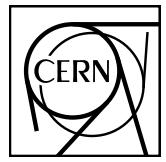


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D-hadron correlations in p-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$

F. Colamaria, S. Kumar, M. Mazzilli

Abstract

In this note, we present the analysis of azimuthal correlations of D mesons and primary charged π, K, p, e, μ performed in the ALICE central barrel in p-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$, from 2016 data taking. The analysis is performed in an extended p_T range and with additional observables with respect to p-Pb 2013 data analysis. After a description of the analysis strategy, corrections and systematic uncertainties, the results obtained for prompt D^0 , D^{*+} and D^+ mesons in different ranges of transverse momentum of the D meson and of the associated particles are presented. The results are then compared to Monte Carlo models and also with published 2013 p-Pb analysis results for the common p_T ranges.

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32 1 Introduction and Motivation

33 The study of the azimuthal correlations of heavy-flavour particles and charged particles at the LHC
 34 energies provides a way to characterize charm production and fragmentation processes in pp collisions.
 35 The measurement also provide a way to probe our understanding of QCD in the perturbative regime,
 36 accessible in a large kinematic range given the large mass of heavy quarks. Flavour conservation in
 37 QCD implies that charm quarks are always produced as pairs of quarks and anti-quarks. The azimuthal
 38 correlations obtained using a meson carrying a heavy quark as trigger particle with the other charged
 39 particles in the same event give the possibility to study the underlying charm production mechanism in
 40 detail. In particular, prompt charm quark-antiquark pair production is back to back in azimuth at first
 41 order in leading-order perturbative-QCD (pQCD). If an hadron from the quark hadronization is taken as
 42 trigger particle, a near-side (at $\Delta\phi = 0$) and an away-side (at $\Delta\phi = \pi$) peak would appear in the azimuthal
 43 correlation distributions, coming from the fragmentation of the quark pair. Heavy quarks produced from
 44 the splitting of a massless gluon can be rather collimated and may generate sprays of hadrons at small
 45 $\Delta\phi$. Finally, for hard-scattering topologies classified as “flavour-excitation”, a charm quark undergoes a
 46 hard interaction from an initial splitting ($g \rightarrow c\bar{c}$), leading to a big separation in rapidity of the hadrons
 47 originating from the antiquark (quark) with respect to the trigger D meson and contribute to a rather flat
 48 term to the $\Delta\phi$ -correlation distribution.

49 Heavy-flavour correlation studies in more complex collision systems, like Pb-Pb, play a crucial role in
 50 studying the modification of the fragmentation of charmed jets due to in-medium (or cold nuclear matter,
 51 in case of p-Pb collisions) effects, in a similar way as it was done for di-hadron correlation studies in
 52 heavy-ion collisions (see for example [5]). Furthermore, the recent observation of long range correlations
 53 in p-Pb for light flavour hadrons ([3], [4]) and for heavy-flavour decay electrons (ALICE preliminary re-
 54 sults) points to possible collective effects or effects originating from gluon saturation in the initial state.
 55 More information could be extracted by the eventual observation of the same effect with D mesons.

56

57 In the following note, we first describe the analysis strategy for the p-Pb 2016 data sample in all its steps,
 58 followed by the list of analysis corrections and the estimation of systematic uncertainties. Finally the
 59 results of $\Delta\phi$ correlations, and quantitative observable extracted to fits to those distributions, obtained for
 60 prompt D^0 , D^+ and D^{*+} in different ranges of transverse momentum for the D-meson (trigger particle)
 61 and the associated particles are presented.

62 The extension of the momentum ranges (both for D mesons and associated particles) with respect to the
 63 2013 p-Pb dataset, as well as the improved precision in the common ranges allow a more thorough inves-
 64 tigation of the charm quark fragmentation properties (multiplicity of tracks as a function of momentum,
 65 geometrical profile of charm jets, p_T distribution of the tracks inside the jet). This can also allow us to
 66 put better constraints on the description of charm fragmentation and charm jet properties provided by
 67 models. The possibility of spotting cold nuclear matter effects affecting the charm fragmentation in p-Pb
 68 was severely limited, in the published paper, by the uncertainties on both pp and p-Pb samples. This will
 69 no longer be the case with the new p-Pb data sample, as soon as a pp sample with equivalent precision
 70 is collected (the pp reference run expected by the end of this year could be of help in this sense). In
 71 addition, the new measurements can be used as solid and precise references in view of an analysis on
 72 a Pb-Pb sample at the same energy (hopefully already in 2018 data taking, otherwise after the ALICE
 73 upgrade).

74 2 Data/Monte Carlo samples and event selection

75 The data samples used for the analyses were the FAST and CENT_woSDD samples from periods LHC16q
 76 and LHC16t (AOD samples). The reason of choosing different types of data samples is explained later
 77 on, in this section. It was verified, by looking at D-meson and associated charged track η and φ distribu-
 78 tions, and at the mixed-event correlation distributions for each subsamples, that no visible differences is
 79 present for the four periods, hence it was possible to perform the analysis directly on the merged samples
 80 without any bias.

81 The Monte Carlo productions adopted for this study were:

- 82 1. LHC17d2a_fast_new, a HIJING production with enrichment of heavy quarks (charm and beauty)
 83 and their decay products in each of the event, performed by PYTHIA6 with Perugia2011 tune,
 84 and with forced hadronic decays of the charmed hadrons. This production was used for D-meson
 85 efficiency evaluation, purity estimation and Monte Carlo closure test.
- 86 2. LHC17f2b_cent_woSDD and LHC17f2b_fast, minimum-bias samples produced with DPMJET
 87 generator, are used for the evaluation of the tracking efficiencies.

88 Table 1 shows the list of runs used for the analysis, for each of the data taking periods, and of the Monte
 89 Carlo productions used to evaluate the corrections:

90 The trigger mask request for the event selection is kINT7. Only events with a reconstructed primary
 91 vertex within 10 cm from the centre of the detector along the beam line are considered. This choice max-
 92 imises the detector coverage of the selected events, considering the longitudinal size of the interaction
 93 region, and the detector pseudorapidity acceptances. In the analysis, the center-of-mass reference frame
 94 of the nucleon-nucleon collision is shifted in rapidity by $y_{NN} = 0.465$ in the proton direction with re-
 95 spect to the laboratory frame, due to the different per-nucleon energies of the proton and the lead beams.
 96 Beam-gas events are removed by offline selections based on the timing information provided by the V0
 97 and the Zero Degree Calorimeters, and the correlation between the number of hits and track segments in
 98 the SPD detector. This is automatically performed in the Physic Selection, a positive outcome of which
 99 is required during our event selection. The pile-up cuts for out-of-bunch pile-up protection are also in-
 100 volved when calling the Physics Selection task. The minimum-bias trigger efficiency is 100% for events
 101 with D mesons with $p_T > 1 \text{ GeV}/c$. For the analyzed data samples, the probability of pile-up from col-
 102 lisions in the same bunch crossing is below 2% per triggered event (in most of the runs, well below 1%).
 103 Events in which more than one primary interaction vertex is reconstructed with the SPD detector (with
 104 minimum of 5 contributors, and a z distance greater than 0.8 cm) are rejected, which effectively removes
 105 the impact of in-bunch pile-up events on the analysis. Out-of-bunch tracks are effectively rejected by the
 106 Physics Selection pile-up cuts, and also by the request of at least one point in the SPD, which has a very
 107 limited time acquisition window (300 ns). Indeed, though the default associated track selection requires
 108 a minimum of 2 points in the ITS, as it will be shown later on full compatibility of the corrected results
 109 with 2 and 3 minimum ITS clusters are obtained. For FAST and CENT_woSDD samples, the latter case
 110 indirectly forces the presence of a point in the SPD.

111 Since data collected during p-Pb 2016 data taking are distinguished into two categories - one including
 112 SDD detector (CENT_wSDD sample) and the second one without the SDD in the reconstruction, or
 113 in the acquisition (CENT_woSDD and FAST samples, respectively), a study of performance of the D-
 114 hadron correlation analysis with respect to the data samples employed has been carried out for D^{*+} and
 115 D^+ mesons (more sensitive to the presence of the SDD w.r.t. the D^0 , due to their reconstruction from
 116 three decay tracks).

117 For this reason, the D-hadron correlation distribution has been compared on LHC16q_pass1_CENT_wSDD
 118 and LHC16q_pass1_CENT_woSDD and the relative statistical uncertainty has been estimated in order to

Type	Production	Run list	nEvents
Monte-Carlo	LHC17d2a_fast_new (c/b enriched), LHC17f2b_fast (MB), LHC17f2b_cent_woSDD (MB)	267166, 267165, 267164, 267163, 265525, 265521, 265501, 265500, 265499, 265435, 265427, 265426, 265425, 265424, 265422, 265421, 265420, 265419, 265388, 265387, 265385, 265384, 265383, 265381, 265378, 265377, 265344, 265343, 265342, 265339, 265338, 265336, 265335, 265334, 265332, 265309 = [36 runs]	50M
Data	LHC16q, pass1_CENT_woSDD	265525, 265521, 265501, 265500, 265499, 265435, 265427, 265426, 265425, 265424, 265422, 265421, 265420, 265419, 265388, 265387, 265385, 265384, 265383, 265381, 265378, 265377, 265344, 265343, 265342, 265339, 265338, 265336, 265335, 265334, 265332, 265309 = [32 runs]	261M total
	LHC16q, pass1_FAST	265525, 265521, 265501, 265500, 265499, 265435, 265427, 265426, 265425, 265424, 265422, 265421, 265420, 265419, 265388, 265387, 265385, 265384, 265383, 265381, 265378, 265377, 265344, 265343, 265342, 265339, 265338, 265336, 265335, 265334, 265332, 265309 = [32 runs]	260M
	LHC16t, pass1_CENT_woSDD	267166, 267165, 267164, 267163 = [4 runs]	40M
	LHC16t, pass1_FAST	267166, 267165, 267164, 267163 = [4 runs]	41M

Table 1: Data Set and Run list

understand if it was better to perform the analysis separately on the two data sample, applying in this case different corrections, or not. In particular, it was crucial for the correlation analysis involving the D^{*+} meson because the track reconstruction efficiency of the soft pion is $\approx 10\%$ higher employing also the SDD information. Figure 1 shows the normalized azimuthal correlation distribution for low, mid and high p_T for D^{*+} meson. Blue points are referred to the woSDD sample while red points represents wSDD data. Figure 2 shows the relative statistical uncertainty extracted from the azimuthal correlation distributions for the D^{*+} in different kinematic ranges.

It can be observed that the data sample that includes the SDD information is characterized by $\approx 10 - 15\%$ more statistics in each p_T ranges analyzed. This difference is related to the larger efficiency in track reconstruction with the wSDD sample - a larger number of tracks survives to the selection request of 3 points in the ITS, which is part of the selection requests applied on the previous D-h analysis.

As a result, the wSDD sample is also affected by a slightly lower relative statistical uncertainty (about 12-15%) due to several reasons: the larger tracking efficiency, the larger number of signal entries in the invariant mass distributions (again an effect of the larger tracking efficiency) and a slight increase of S/B, which reflects in a slight decrease of uncertainty from the sideband subtraction. It has also to be considered that, on the full sample including also the FAST cluster, the increase in performance would be further reduced. The overall statistical uncertainty difference resulting from the comparison is not

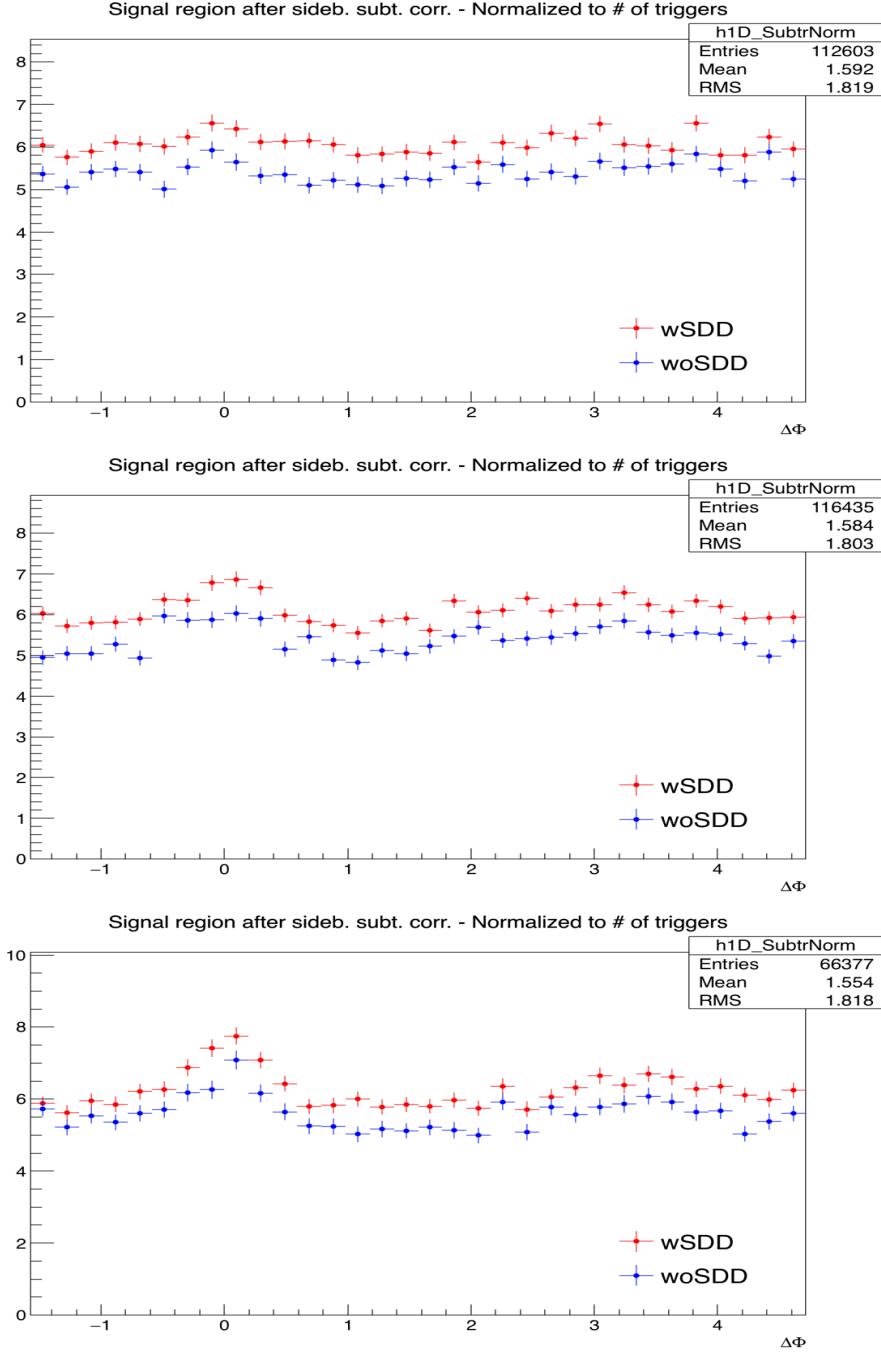


Figure 1: Normalized azimuthal correlation distribution of D^{*+} for low p_T ($3 < p_T(D^{*+}) < 5 \text{ GeV}/c$) on the top panel, mid p_T ($5 < p_T(D^{*+}) < 8 \text{ GeV}/c$) on the middle panel and high p_T ($8 < p_T(D^{*+}) < 16 \text{ GeV}/c$) on the bottom panel with a p_T threshold for associated tracks of $p_T(\text{assoc}) > 0.3 \text{ GeV}/c$. Blue points are referred to the woSDD sample while red points represent wSDD data.

136 enough to justify the implementation of two different analysis and two subsequent different corrections
 137 either for D^{*+} and D^+ .

138 In order to, to cope with the lower tracking efficiency w.r.t. 2013 data sample, after this study, it was
 139 decided to reduce the ITS request for the associated tracks from 3 (used on 2013 data) to 2 ITS clusters
 140 as default selection criterion.

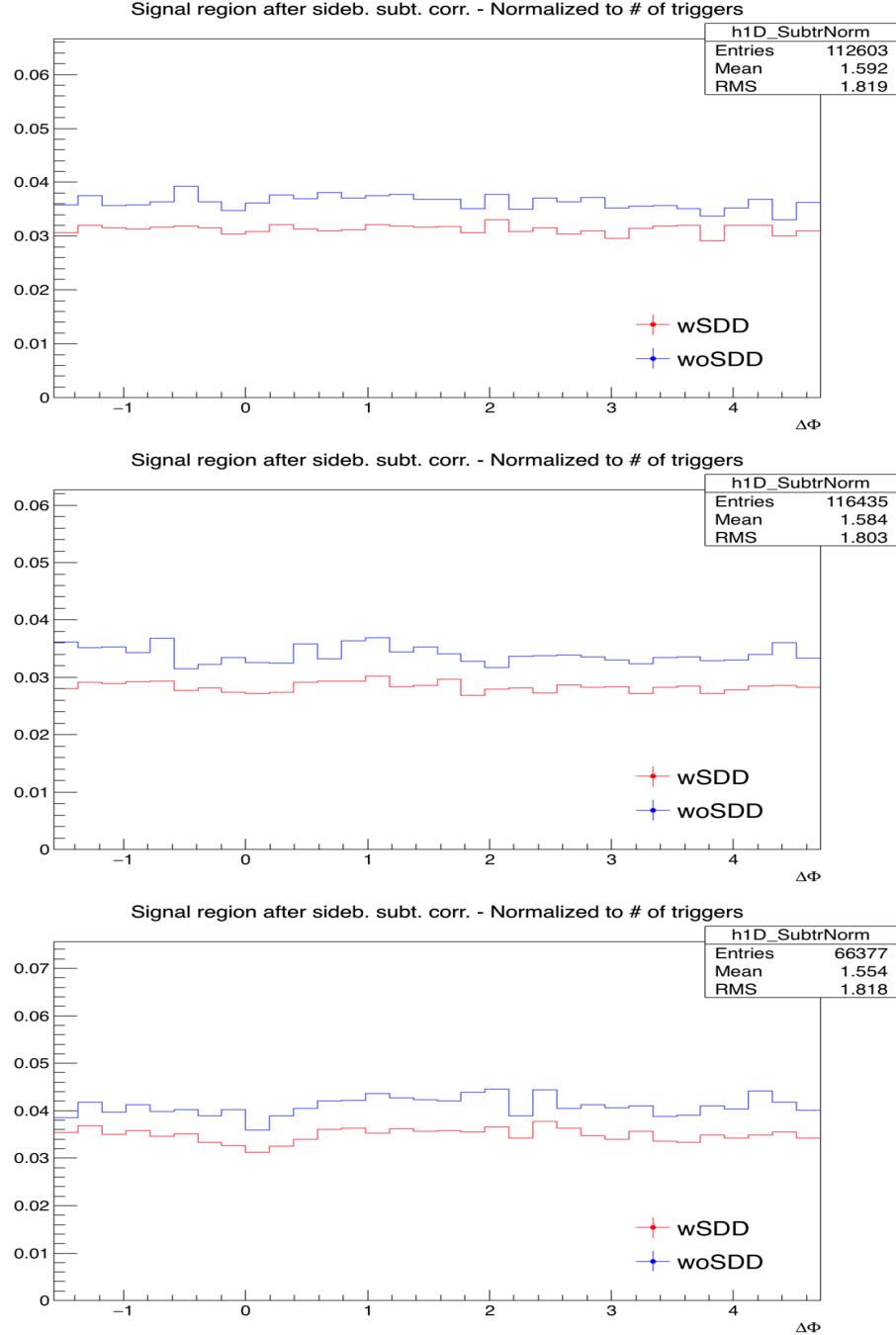


Figure 2: Statistical uncertainty extracted from the azimuthal correlation distribution of D^{*+} with associated charged particles. Top panel: $3 < p_T(D^{*+}) < 5 \text{ GeV}/c$. Mid panel: $5 < p_T(D^{*+}) < 8 \text{ GeV}/c$. Bottom panel: $8 < p_T(D^{*+}) < 16 \text{ GeV}/c$. Blue line is referred to the woSDD sample while the red line represents wSDD data.

141 3 Analysis strategy

142 The analysis follows the same strategy one used in 2013 p-Pb data sample (see published paper [2])
 143 and analysis notes [7], [6]). Correlation pairs are formed by trigger particles (D mesons) reconstructed
 144 and selected in the following p_T^{trig} ranges: $3 < p_T^{\text{trig}} < 5 \text{ GeV}/c$, $5 < p_T^{\text{trig}} < 8 \text{ GeV}/c$, $8 < p_T^{\text{trig}} < 16$
 145 GeV/c , $16 < p_T^{\text{trig}} < 24 \text{ GeV}/c$, and associated particles (charged tracks) for the following p_T^{assoc} re-
 146 gions: $p_T^{\text{assoc}} > 0.3 \text{ GeV}/c$, $0.3 < p_T^{\text{assoc}} < 1 \text{ GeV}/c$, $1 < p_T^{\text{assoc}} < 2 \text{ GeV}/c$, $2 < p_T^{\text{assoc}} < 3 \text{ GeV}/c$,
 147 $p_T^{\text{assoc}} > 3 \text{ GeV}/c$ (with the addition of $p_T^{\text{assoc}} > 1 \text{ GeV}/c$ for comparison with p-Pb 2013 results). In this

analysis, the particle identification defines the trigger particle rather than a momentum cut and therefore the momentum range of the associated particles is not constrained by that of the trigger particle. Our definition of associated particle includes primary particles of the following species: pion, kaon, proton, electron, muon. The primary particle definition comprises particle coming from the primary vertex of interaction, including those coming from strong and electromagnetic decay of unstable particles, and particles deriving from the decay of hadrons with charm or beauty. We therefore include any charged π, K, p, e, μ except those coming from weak decays of strange particles and particles produced in the interaction with the detector material. This definition corresponds to that used in the method AliAODM-CParticle::IsPyphysicalPrimary(). All associated particles surviving the selection cuts and not matching the adopted criterion are considered as a contamination whose contribution has to be corrected for.

158

159 The analysis is performed through the following steps:

- 160 1. **D meson selection and signal extraction.** For each single event, “trigger” particles are defined
161 as the selected D meson candidates (D^0 , D^+ and D^{*+}) within a given p_T^{trig} range. The detection
162 strategy for D mesons at central rapidity is the same performed for the analyses of the D-meson
163 production at central rapidity [1], and also applied for the D-h analysis on 2010 pp and 2013 p-Pb
164 samples [2]. It is based on the reconstruction of decay vertices displayed from the primary vertex
165 by a few hundred μm and on the identification of the decay-particle species. The identification
166 of the charged kaon and pion in the TPC and TOF detectors is also used, to further reduce the
167 background at low p_T . An invariant-mass analysis is then used to extract the raw signal yield,
168 using the same fit functions described in [2]. The D mesons are selected in the rapidity range
169 varying from $|y| < 0.5$ at low p_T to $|y| < 0.8$ for $p_T > 5 \text{ GeV}/c$.
- 170 2. **Correlation of D candidates with associated tracks.** Particle pairs are formed by correlating each
171 trigger particle with the charged primary particles passing the track selection (excluding those
172 coming from the decay of the D-meson candidate) in a specified p_T^{assoc} interval (which can overlap
173 with the p_T^{trig} range) and in the pseudo-rapidity range $|\eta| < 0.8$. For the D^0 meson, also the low-
174 momentum pion tracks from feed-down of D^{*+} mesons are removed via 3σ invariant mass cut on
175 the $M(K\pi\pi) - M(K\pi)$ difference. This because these soft pion are not related to the charm quark
176 fragmentation chain. For D meson candidates in the invariant mass signal region, defined by a \pm
177 2σ interval around the D meson mass peak, the azimuthal angle difference $\varphi^{\text{assoc}} - \varphi^{\text{trigg}} \equiv \Delta\varphi$ and
178 the pseudorapidity difference $\eta^{\text{assoc}} - \eta^{\text{trig}} \equiv \Delta\eta$ are evaluated and stored to build two-dimensional
179 correlation distribution.
- 180 3. **Correction for limited acceptance and detector inhomogeneities with Event Mixing** The angular
181 correlation distribution may be affected, even for uncorrelated pair of particles, by structures
182 not due to physical effects, but originating from the limited detector acceptance, as well as from
183 angular inhomogeneities in the trigger and track reconstruction efficiencies as a function of $\Delta\varphi$
184 and $\Delta\eta$. Effects of this kind are removed using the Event Mixing technique. In this technique, the
185 analysis is executed on the same data sample of the standard one (called “same event” analysis,
186 SE), but the trigger particles found in each event are correlated to charged particles reconstructed
187 in different events (“Mixed Events” analysis, ME) with similar characteristic, in particular con-
188 cerning the event multiplicity and z position of the primary vertex (see Section 3.3.1).

189

190 The differential yield of associated particles per trigger particle is obtained by

$$\frac{1}{N_{\text{trig}}} \frac{d^2 N^{\text{pair}}}{d\Delta\eta d\Delta\varphi} = B_{\text{ME}}(0,0) \times \frac{S(\Delta\eta, \Delta\varphi)}{B_{\text{ME}}(\Delta\eta, \Delta\varphi)}, \quad (1)$$

191 where N^{pair} is the total number of correlated D-hadron pairs. The functions $S(\Delta\eta, \Delta\phi)$ and $B_{ME}(\Delta\eta, \Delta\phi)$
 192 are the signal and the mixed event background distributions, respectively. The later is normalized
 193 to its value in $(\Delta\eta, \Delta\phi) = (0, 0)$, i.e. $(B(0, 0))$. Further details on the mixed-event correction are
 194 provided in the next section.

195 **4. Subtraction of background correlation from signal distribution.** The invariant mass signal re-
 196 gion also includes background D-meson candidates. Their contribution to the raw correlation
 197 distribution is subtracted as follows. For each p_T bin, the mean and the sigma of the invariant mass
 198 spectrum are extracted. For D^0 and D^+ , a “background” region is defined in the sidebands of the
 199 mass distribution as the interval $4 \text{ GeV}/c^2 < |m - m^{\text{pdg}}| < 8 \text{ GeV}/c^2$ (for the D^{*+} meson, only
 200 the right sideband is used). The angular correlation distribution for background candidates in this
 201 region is extracted and normalized with respect to the background in the signal region estimated
 202 from the mass fit. This normalized background correlation distribution is then subtracted from
 203 the raw signal one to obtain the signal correlation distribution. The normalization factor is the
 204 ratio of the number of background candidates under the signal peak (obtained by integrating the
 205 background of the fit function within the signal region) over the number of background candidates
 206 in the sidebands (obtained via bin-counting in the sideband region). An example of the signal re-
 207 gion, sideband and sideband-subtracted 1D correlation distributions (along $\Delta\phi$) is shown in figure
 208 3, together with the comparison of the three distributions after the normalization to the number of
 209 triggers.

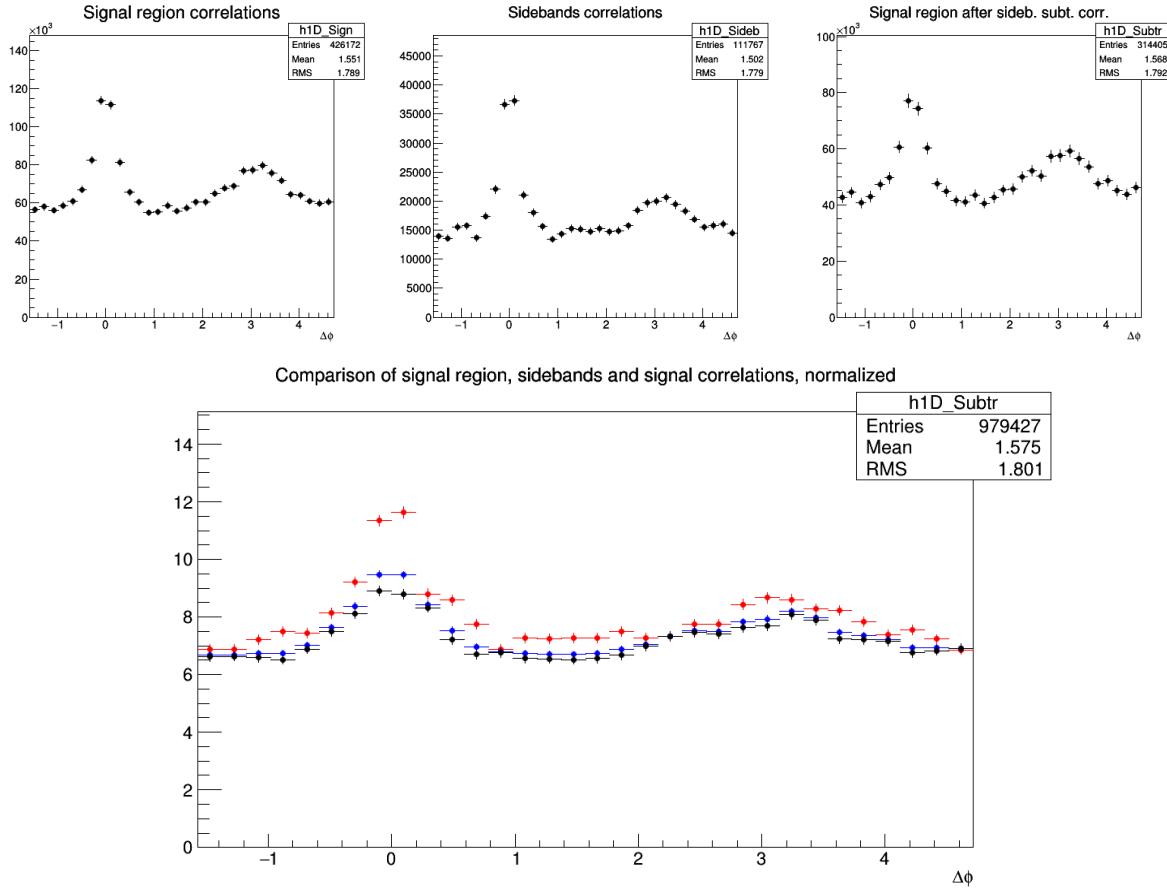


Figure 3: Top: Example of D^0 -h signal region (left), sideband (middle), and signal minus sideband (right) correlation distributions. Bottom: signal region per-trigger normalized correlation distribution (blue), sideband region per-trigger normalized correlation distribution (red), background-subtracted per-trigger normalized correlation distribution (black).

- 210 5. **Correction for D meson efficiency and associated track efficiency.** After filling the signal and
 211 background correlation distributions, it is necessary to take into account also for the correlations
 212 with tracks, those are not reconstructed, or not passing the quality selection due to poor recon-
 213 struction. In the same way, the loss of D-mesons which are not reconstructed, or do not pass the
 214 selection, impacts the correlation distribution shape. Hence, each pair is weighted by the inverse
 215 of the product of the associated track and D meson reconstruction efficiency, ϵ_{trk} and ϵ_{trig} . Further
 216 details are provided later on in this section.
- 217 6. **Projection in $\Delta\varphi$.** The limited statistics available does not allow to study the two dimensional
 218 $(\Delta\eta, \Delta\varphi)$ distribution, which is therefore projected to the $\Delta\varphi$ axis by integrating on $|\Delta\eta| < 1$.
 219 Despite, in principle, our maximum $\Delta\eta$ acceptance is of $|\Delta\eta| < 1.6$, removing the large $|\Delta\eta|$
 220 regions allow us to reject angular regions with very low statistics, where fluctuations would be
 221 amplified by a large mixed-event correction, and avoid the so-called wings effect.
 222 As the difference in the azimuthal angle is periodic ($\Delta\varphi = 0 = 2\pi$), the $\Delta\varphi$ -range is limited to the
 223 essential range of 2π . The $\Delta\varphi$ -limits are chosen to be $[-\pi/2, 3\pi/2]$ in order to provide a good
 224 visibility of the correlation pattern, which peaks around 0 and π .
- 225 7. **Correction for the contamination of secondary particles** The DCA to primary vertex cut, ap-
 226 plied during the associated track selection, has the role of removing the secondary particles from
 227 the associated track sample. Secondary particles are indeed produced either from long-lived
 228 strange hadrons or from interaction of particles with the detector material. A residual contamina-
 229 tion from secondary tracks is hence expected in the correlation distributions. This contamination
 230 is estimated from Monte Carlo simulation based on Pythia as described more in detail in the next
 231 section. The background-subtracted event-mixing corrected correlations are multiplied by a purity
 232 factor to encounter this contribution.
- 233 8. **Correction for bias on B to D decay topologies** The presence of the topological cuts for the D-
 234 meson selection indirectly induce a bias on the topology of the B to D decay topologies, favouring
 235 cases with a small opening angle between the D-meson and the other tracks from the B decay.
 236 This affects the feed-down component of the data correlation distributions. This effect is corrected
 237 for with a procedure described in the subsection 3.3.3. Note that this correction is a novelty
 238 with respect to the previous analyses, where only a quite conservative systematic uncertainty was
 239 applied to take into account this effect.
- 240 9. **Correction for feed-down of D meson from b-hadron decay** The selection strategy employed
 241 for the D meson candidates selection enhances the fraction of reconstructed D mesons coming
 242 from the decay of a b-hadron. Typical values, with the cuts used for the D-meson selection, are of
 243 the order of 10% or less. The correlation distribution of these secondary D mesons will be sensi-
 244 tive to the properties of beauty jets and beauty hadron decay, which in general differ from those
 245 relative to charm jets and hadrons. The procedure used to subtract this contribution is described in
 246 the next paragraphs of this section.
- 247 10. **Study of correlation properties.** The properties of the azimuthal correlation distribution are quan-
 248 tified by fitting the distribution with a function composed of two Gaussian functions, modelling
 249 the near and the away side peaks, and a constant term describing the baseline. The mean of the
 250 Gaussian are fixed at $\Delta\varphi = 0$ and $\Delta\varphi = \pi$. To accomplish the 2π periodicity of the $\Delta\varphi$ variable, the
 251 Gaussian functions are “duplicated” with mean at $\Delta\varphi = 2\pi$ and $\Delta\varphi = -\pi$. The fitting procedure
 252 is described in details in Section 5.

253 3.1 Mass plots and cut optimization

254 The invariant mass distributions of D^0 , D^{*+} and D^+ in the various pt ranges are shown in Figure 4, 5
 255 and 6 respectively. Note that the distributions are weighted by the D-meson selection and reconstruction

efficiency, to allow a correct normalization of the correlation distributions, which have also these weights.

For D^{*+} , the standard D2H p-Pb cuts (for the 2013 cross section analysis, [8]) were used. The same holds for the D^+ , but with the addition of cuts on the normalized decay length in xy plane and of the normalized difference between measured and expected daughter track impact parameters (topomatic cut). A particular cut optimization was instead performed for the D^0 meson. Twelve cut sets were tried, with the goal of increasing the S/B factor, in order to reduce fluctuations induced by the sideband subtraction (the limiting factor for the analysis performance). In Figure 7 the D^0 -h correlation distributions are shown for the different cut sets, in exemplary kinematic regions (left column), together with the bin-by-bin relative statistical uncertainty on the data points (right column). The best cut set (option G) was defined from the standard cuts used for the p-Pb 2013 cross section analysis, with a tightened selection on the cosine of the pointing angle, and with the addition of a cut on the normalized decay length in xy plane and of a selection on the normalized difference between measured and expected daughter track impact parameters (topomatic cut).

3.2 Code used for the analysis

The code used for D meson-hadron correlation analysis is fully committed in AliPhysics. The analysis classes can be found in `$ALICE_ROOT/PWGHF/correlationHF/`. The D meson specific classes where the aforementioned steps are carried out are `AliAnalysisTaskDStarCorrelations`, `AliAnalysisTaskSEDOCorrelations` and `AliAnalysisTaskDplusCorrelations`. The classes which are common to the D meson specific analysis which includes the associated particle cuts and the correlation observables are `AliHFAssociatedTrackCuts`, `AliHFCorrelator`, `AliHFOfflineCorrelator`, `AliReducedParticle` and `AliDhCorrelationExtraction`. Several additional classes and macros in the same folder deal with the correction steps.

The final results presented here are extracted are the HFCJ pPb (n. 88) train runs 254-257 (for D^0 and D^+) and 268-271 (for D^{*+}).

3.3 Further details on corrections

3.3.1 Event Mixing

The event-mixing technique is used for correcting the raw correlation distribution for effects arising from the detector limited acceptance in rapidity and detector spatial inhomogeneities. The calculation of the Event Mixing correlation distribution is performed online. An event pool is created, where events preceding the one containing a D candidate are stored based on their properties (position of the vertex along the z axis and multiplicity). Each time a D meson candidate is found in an event, only the events contained in the same pool as the event under analysis is used to evaluate the correlations for the event mixing correction.

For D^0 and D^+ , an offline approach for the mixed-event correction has been developed. In this approach, D-meson triggers and associated tracks from every analyzed event are stored in dedicated TTree, together with the needed kinematic information to build correlation distributions, and with identifiers of the events to which they belong. In this way, it is possible to correlate each D meson with all the tracks belonging to the same pool over the full event sample, and not being limited to the same subjob as for the online analysis. This allows to increase the statistics of the mixed-event correlation distributions. It was verified that online and offline approaches are fully compatible within the statistical uncertainties.

The multiplicity and z vertex position bins for the pools used in the p-Pb analysis (for both approaches) are the following:

- Multiplicity bins: $(0, 35); (35, 55); (55, +\infty)$

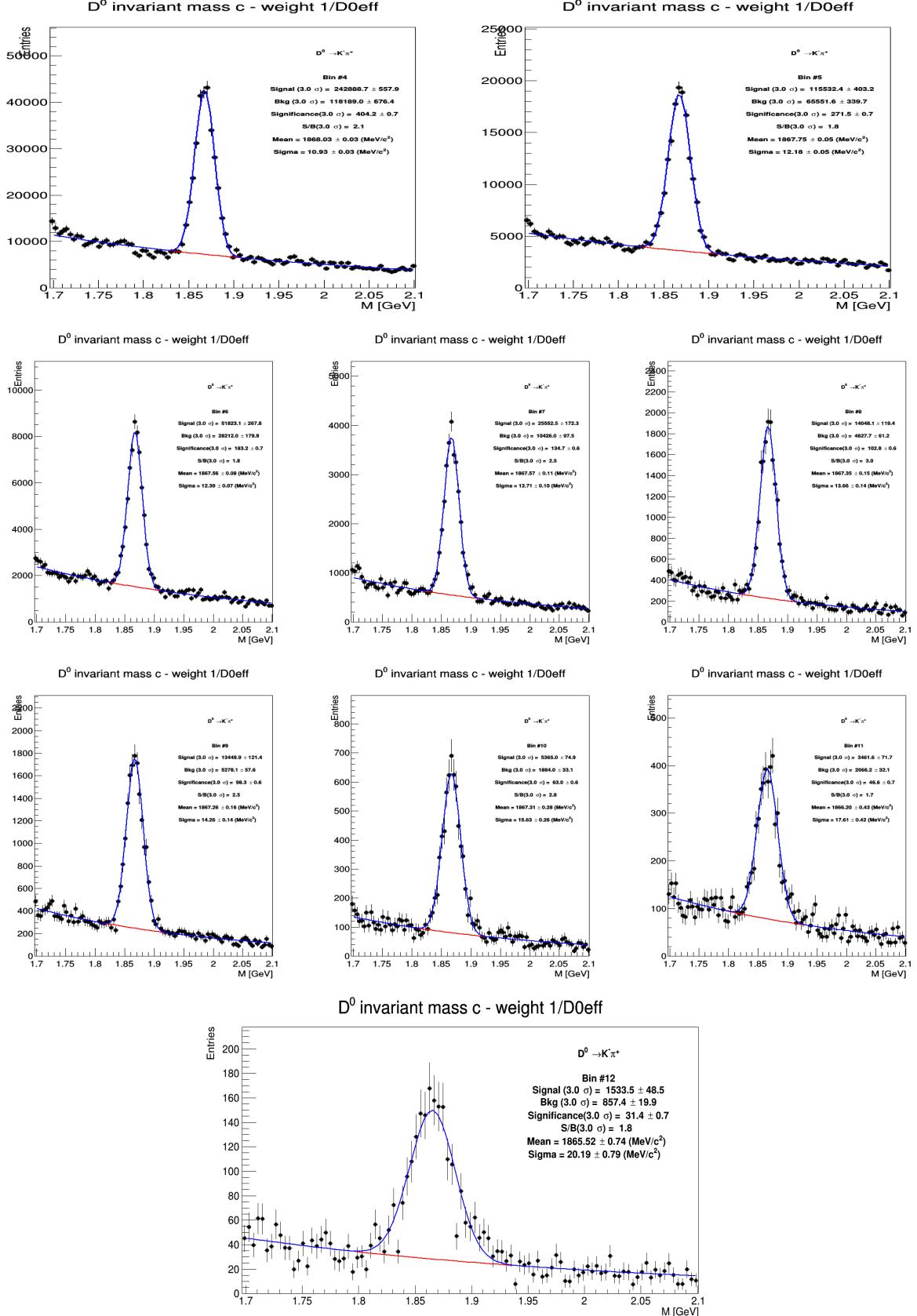


Figure 4: Invariant mass distributions of D^0 corrected with efficiency in different p_T regions. Top: $3 < p_T^D < 4$ GeV/c (left), $4 < p_T^D < 5$ GeV/c (right), Mid 1: $5 < p_T^D < 6$ GeV/c (left), $6 < p_T^D < 7$ GeV/c (middle), $7 < p_T^D < 8$ GeV/c (right); Mid2: $8 < p_T^D < 10$ GeV/c, $10 < p_T^D < 12$ GeV/c (middle), $12 < p_T^D < 16$ GeV/c (right) and Bottom: $16 < p_T^D < 24$ GeV/c.

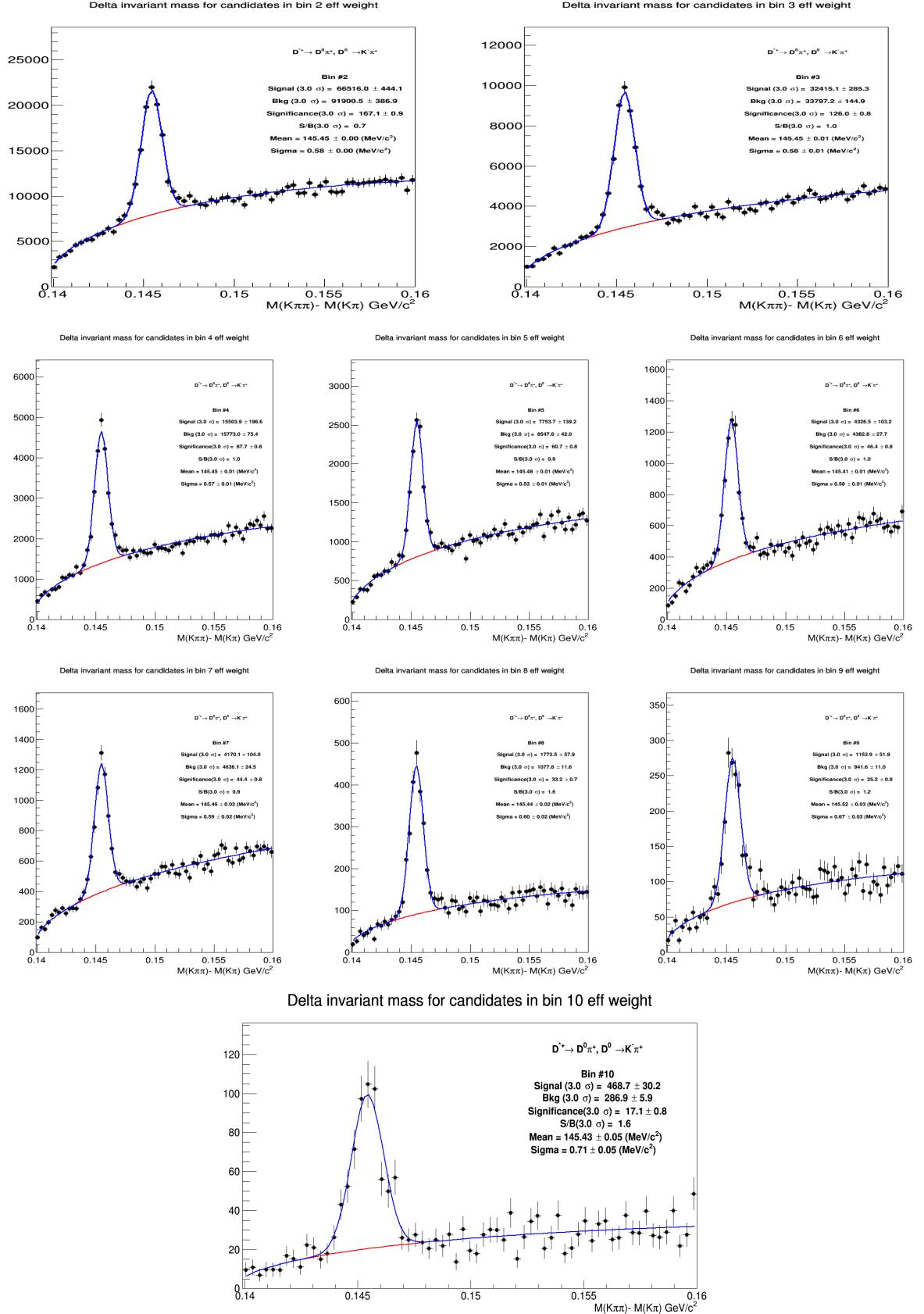


Figure 5: Invariant mass distributions of D^{*+} corrected with efficiency in different p_T regions. Top: $3 < p_T^D < 4$ GeV/c (left), $4 < p_T^D < 5$ GeV/c (right), Mid 1: $5 < p_T^D < 6$ GeV/c (left), $6 < p_T^D < 7$ GeV/c (middle), $7 < p_T^D < 8$ GeV/c (right); Mid2: $8 < p_T^D < 10$ GeV/c, $10 < p_T^D < 12$ GeV/c (middle), $12 < p_T^D < 16$ GeV/c (right) and Bottom: $16 < p_T^D < 24$ GeV/c .

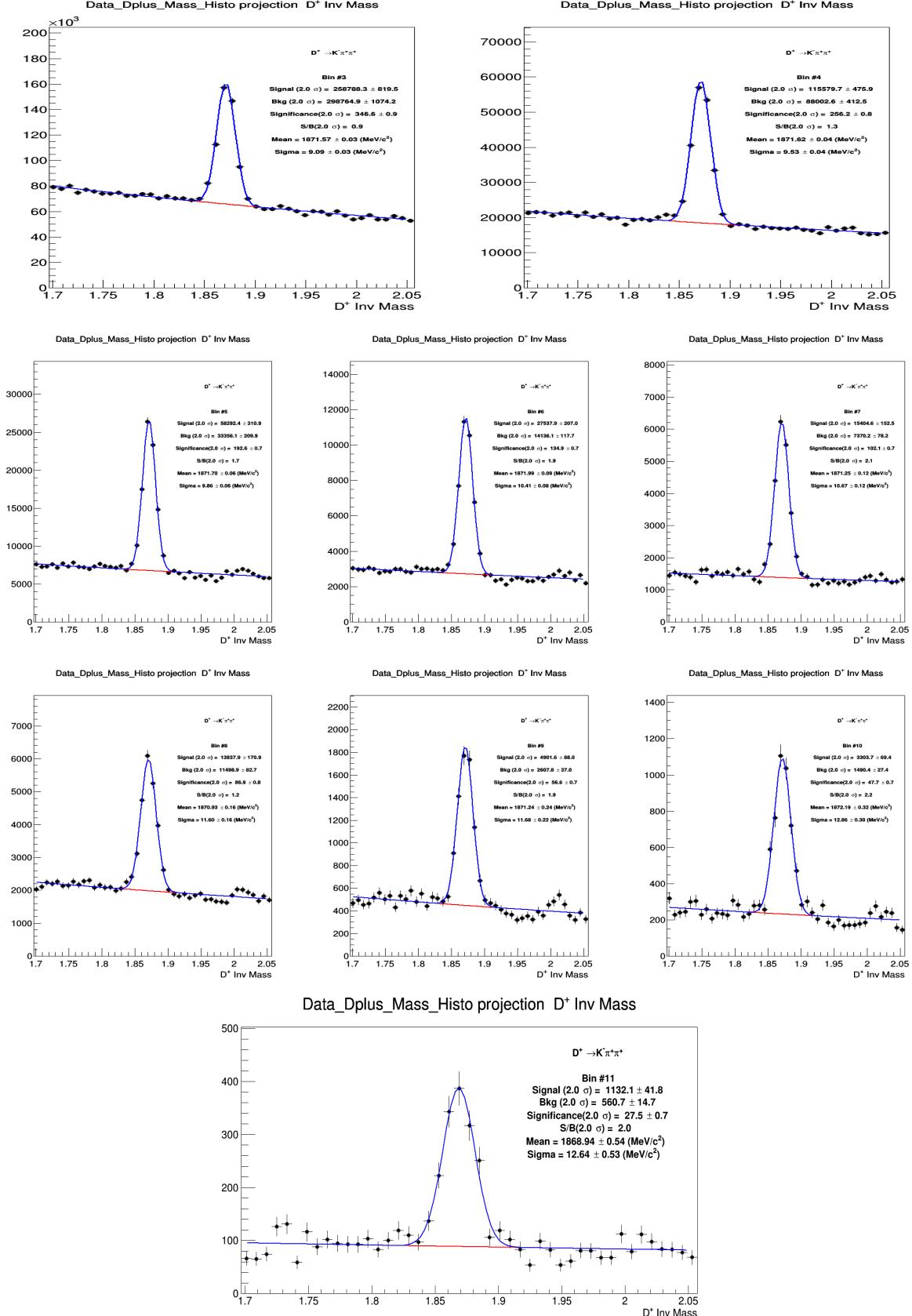


Figure 6: Invariant mass distribution of D⁺ corrected with efficiency in different p_T regions. Top: 3 < p_T^D < 4 GeV/c (left), 4 < p_T^D < 5 GeV/c (right), Mid 1: 5 < p_T^D < 6 GeV/c (left), 6 < p_T^D < 7 GeV/c (middle), 7 < p_T^D < 8 GeV/c (right); Mid2: 8 < p_T^D < 10 GeV/c, 10 < p_T^D < 12 GeV/c (middle), 12 < p_T^D < 16 GeV/c (right) and Bottom: 16 < p_T^D < 24 GeV/c .

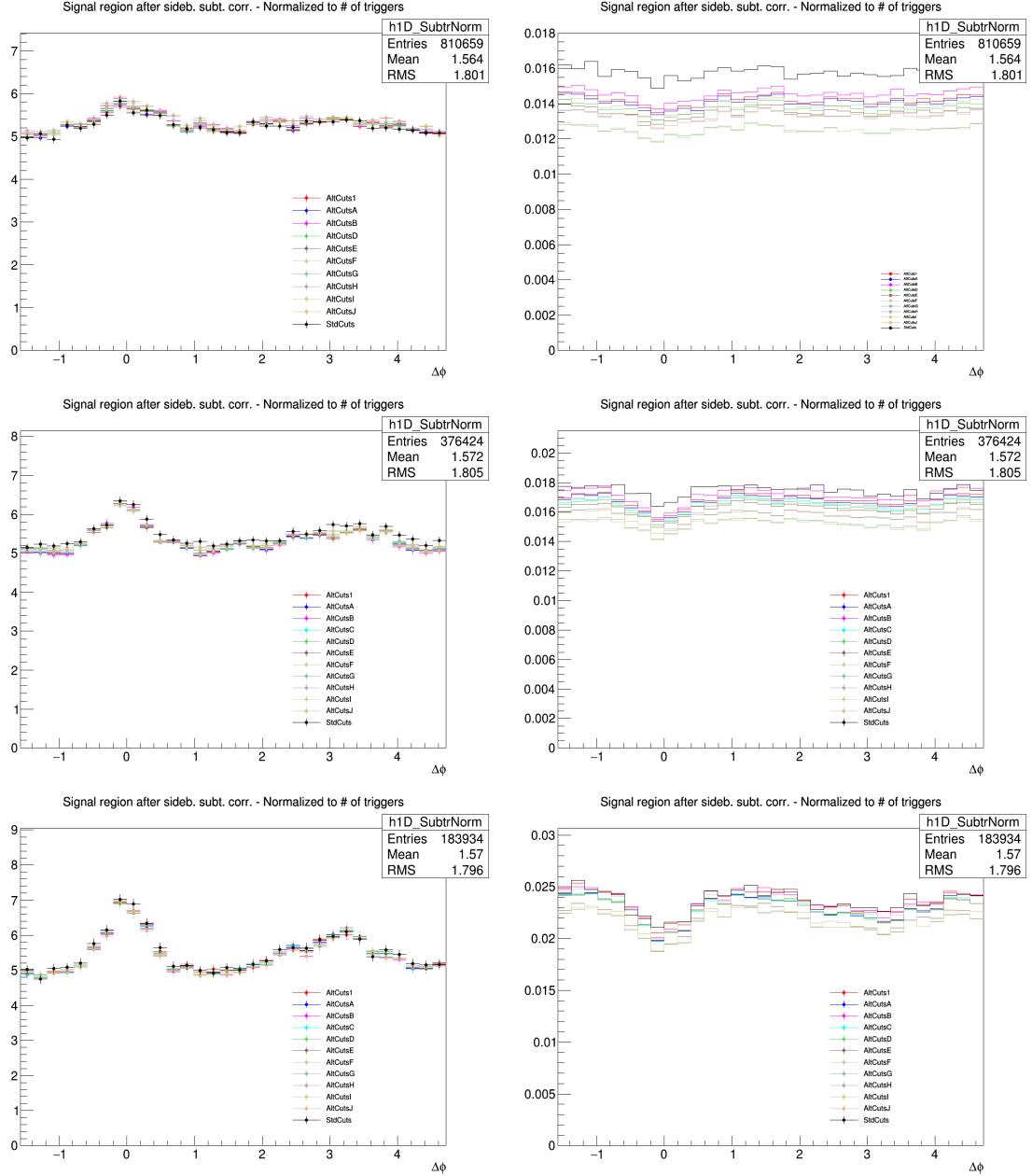


Figure 7: D^0 - h correlation distributions with different cut options (left) and point-by-point relative statistical uncertainty (right) for $3 < p_T^D < 5 \text{ GeV}/c$ (top), $5 < p_T^D < 8 \text{ GeV}/c$ (middle), $8 < p_T^D < 16 \text{ GeV}/c$ (bottom), in all cases with associated track $p_T > 0.3 \text{ GeV}/c$.

299 – Vertex z (cm) = (-10, -1.5); (-1.5, 3.5); (3.5, 10)

300 In an ideal case, the mixed event distribution is expected to have a constant flat distribution as function
 301 of $\Delta\varphi$ and a triangular shaped distribution in $\Delta\eta$ deriving from the limited η acceptance of the detector.
 302 In case, instead of detector inefficient regions, or holes, in the same angular position for D meson and
 303 associated tracks, these structures produce an excess of correlations at $\Delta\varphi = 0$ in the $\Delta\varphi$ distribution. The
 304 obtained distribution is used as a weight in each correlation bin, i.e, the corrected correlation distribution
 305 is calculated as follows:

$$\frac{dN^{corr}(\Delta\varphi\Delta\eta)}{d\Delta\varphi d\Delta\eta} = \frac{\frac{dN^{SE}(\Delta\varphi\Delta\eta)}{d\Delta\varphi d\Delta\eta}}{\frac{dN^{ME}(\Delta\varphi\Delta\eta)}{d\Delta\varphi d\Delta\eta}} \frac{dN^{ME}(0,0)}{d\Delta\varphi d\Delta\eta} \quad (2)$$

306 In Eq.2, the last term stands for the average of the bins in the region $-0.2 < \Delta\eta < 0.2$, $-0.2 < \Delta\varphi < 0.2$
 307 (multiple bins are used to minimize the effect of statistical fluctuations on the normalization of the mixed-
 308 event plots). This kind of normalization, adopted in the analysis of hadron-hadron correlations, relies
 309 on the fact that at $(\Delta\eta, \Delta\varphi) = (0,0)$ the trigger and associated particle experience the same detector
 310 effects. In the D meson case this is true only on average and not at very low p_T , since D mesons are
 311 reconstructed from particles that can go in different detector region. However, $(\Delta\eta, \Delta\varphi) = (0,0)$ is in
 312 any case the region with maximum efficiency for the pairs (both correlated and uncorrelated). Thus the
 313 same convention was adopted.

314 The mixed-event correlation distributions are built in both D meson signal and sideband regions. Both
 315 are corrected with the relative distributions. An example of the mixed-event distributions, and of the
 316 outcome of the mixed-event correction, is provided in Figures 8 and 9. The expected triangular shape
 317 in $\Delta\eta$, for the mixed-event distributions, addresses the effect of the limited detector pseudo-rapidity
 318 acceptance. Note that the mixed-event distribution is limited to the interval $|\Delta\eta| < 1$: the decision to
 319 limit the mixed-event correction, and thus the whole analysis, to this range was taken in order to avoid
 320 the so-called “wing effect”, i.e. the wing-like structures arising in the correlation distribution at large $\Delta\eta$
 321 due to the limited filling of the correlation bins in that region.

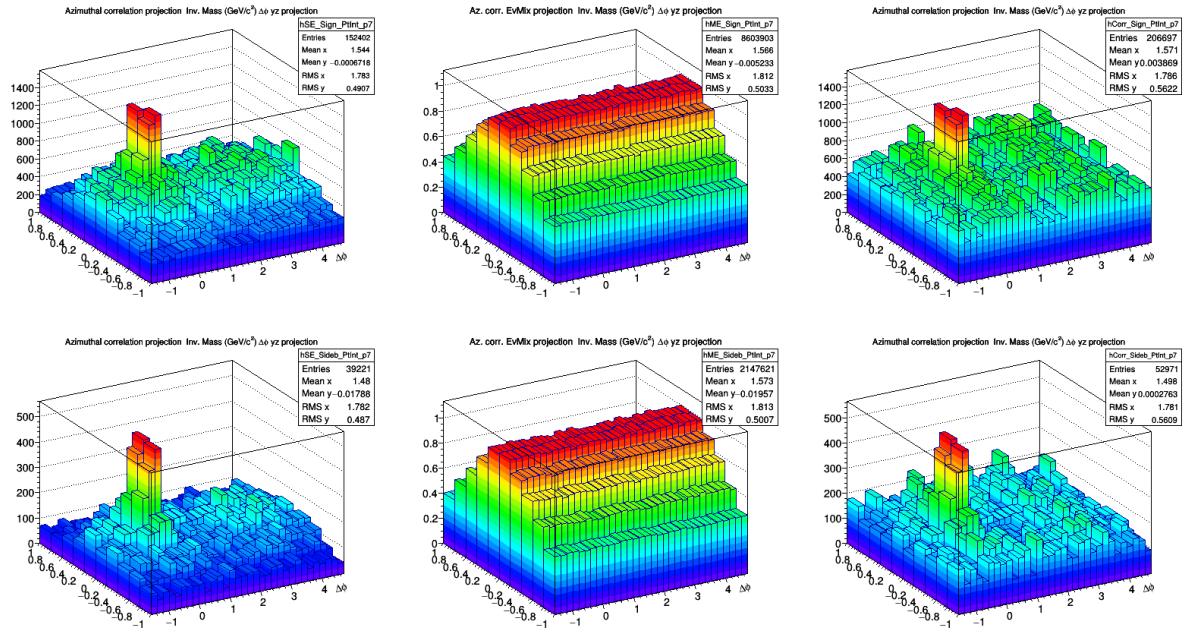


Figure 8: D^0 meson ($\Delta\phi$, $\Delta\eta$) correlation for in the signal region (top row) and sidebands (bottom row) from Single Event (left) and Mixed Event analysis (center) for high p_T : $8 < p_T < 16 \text{ GeV}/c$ with associated $p_T > 0.3 \text{ GeV}/c$. The right column shows the SE/ME corrected distributions.

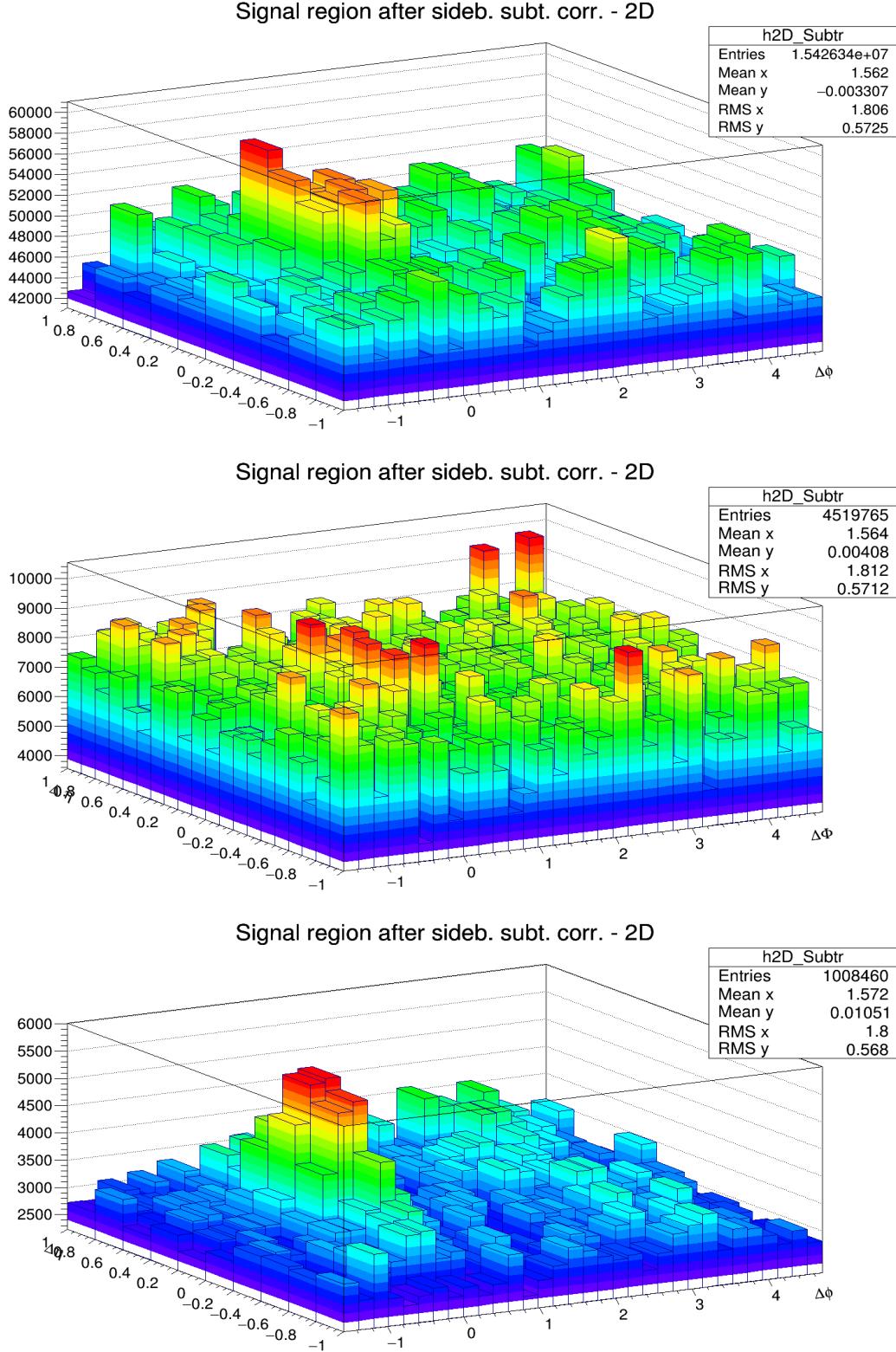


Figure 9: Top: $(\Delta\phi, \Delta\eta)$ correlation distribution of D^0 -h with $3 < p_T < 5$ GeV/c and associated track kinematic range: $0.3 < p_T < 1.0$ GeV/c Mid: $(\Delta\phi, \Delta\eta)$ correlation distribution of D^{*+} -h with $3 < p_T < 5$ GeV/c and associated track p_T Threshold: $p_T > 0.3$ GeV/c Bottom: $(\Delta\phi, \Delta\eta)$ correlation distribution of D^+ -h with $8 < p_T < 16$ GeV/c and associated track p_T threshold: $p_T > 0.3$ GeV/c. All the plots are shown after the mixed-event correction and the sideband subtraction.

322 **3.3.2 Tracking and D-meson trigger efficiency**

323 **(i) Tracking efficiency** - The tracking efficiency was calculated by obtaining the ratio between the yield
324 at the reconstructed level and generated level, for a defined “type” of particles (in our case non-identified
325 particles) and it is estimated differentially in p_T , η , and z_{vtx} of the charged particles.

326

327 Tracking efficiency maps were produced as TH3D histograms (p_T , η , z_{vtx}) obtained from MC analysis
328 on the minimum-bias samples LHC17f2b_fast and LHC17f2b_cent_woSDD, considering only primary
329 pions, kaons, protons, electrons and muons, and applying at reconstructed level the track selections
330 (summarized in Table. 2). These efficiency maps were used in the analysis tasks to extract single track
331 efficiencies; each correlation pairs found in the data analysis was inserted in correlation plots with a
332 weight of **1/efficiency value**. As a cross-check, the tracking efficiency was evaluated, with the same
333 criteria, also on the LHC17f2a_fast and LHC17f2a_cent_woSDD samples, which were produced with
334 EPOS-LHC generator instead of SPMJET. Compatibility within 1% between the efficiency values on the
335 two samples was found. The 1D (p_T dependence) tracking efficiency, evaluated on f2b samples (blue)
336 and on f2a samples (red) are shown in Fig. 10, as well as the ratio of f2b over f2a efficiencies.

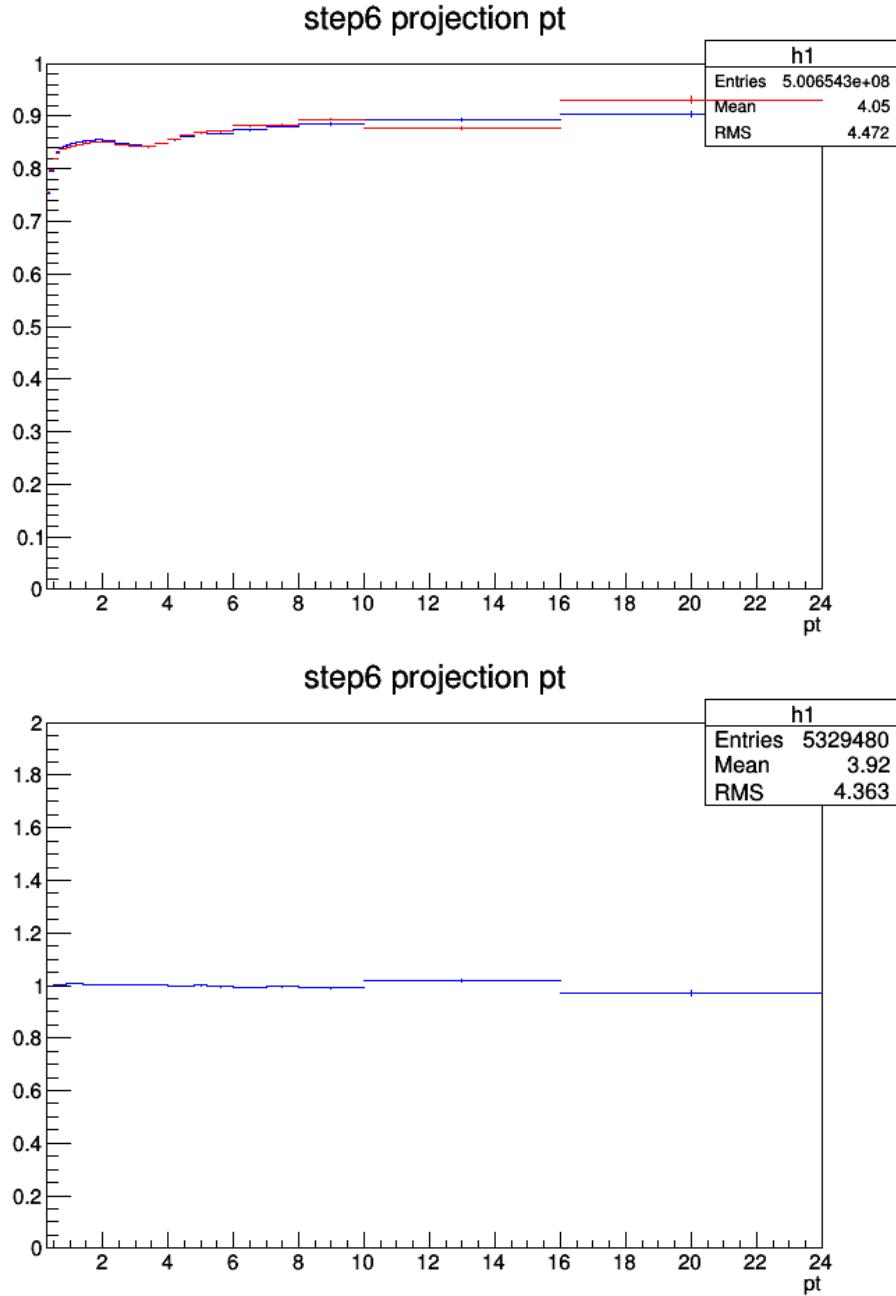


Figure 10: 1D (vs p_T) tracking efficiency map for standard track selection, evaluated on f2b samples (blue) and f2a samples (red) on top panel, and their ratios on bottom panel.

337 Details of cuts at event level and particle/track selection at different steps are listed in Table 2 .
 338

339 **(ii) D meson efficiency** - Due to limited statistics, the correlation analysis is performed in quite wide p_T
 340 bins and in each of them the reconstruction and selection efficiency of D mesons is not flat, in particular
 341 in the lower p_T region. We correct for the p_T dependence of the trigger efficiency within each p_T -bin.

342 This correction is applied online, by using a map of D meson efficiency as a function of p_T and event
 343 multiplicity (in terms of SPD tracklets in $|\eta| < 1$) extracted from the enriched Monte Carlo sample
 344 LHC17d2a_fast_new. The η dependence was neglected due to the statistics of the available Monte Carlo
 345 sample, which rule out the possibility of performing a 3D study.

MC Generated	
Stages	Cuts
1. MC Part with Generated Cuts	After Event Selection Charge PDG Code Physical Primary Kinematics Cuts $-0.8 < \eta < 0.8$ $p_T > 0.3 \text{ (GeV}/c)$
2. MC Part with Kine Cuts	
MC Reconstructed	
4. Reco tracks	After Event Selection Physical Primary Kinematics Cuts $-0.8 < \eta < 0.8$ $p_T > 0.3 \text{ (GeV}/c)$
5. Reco tracks with Kine Cuts	Quality Cuts SetRequireSigmaToVertex(kFALSE) SetDCAToVertex2D(kFALSE) SetMinNCrossedRowsTPC(70) SetMinRatioCrossedRowsOverFindableClustersTPC(0.8) SetMinNClustersITS(2) SetMaxChi2PerClusterTPC(4) SetMaxDCAToVertexZ(1) SetMaxDCAToVertexXY(1) SetRequireTPCRefit(TRUE) SetRequireITSRefit(FALSE)
6. MC true with Quality Cuts	Same as step 6
7. Reco tracks with Quality Cuts	

Table 2: The list of event and particle/track selection cuts used in the estimation of single track efficiency

346 To properly count the number of trigger particles used to normalize the correlation distributions, N_{trig} ,
 347 each D meson is weighted with the inverse of its efficiency in the invariant mass distribution. The main
 348 role of the correction for the D meson efficiency is to account for the p_T dependence of the correlation
 349 distribution within a given D meson p_T interval. Indeed, only the p_T shape of the D meson efficiency
 350 within the correlation p_T^{trig} ranges is relevant while the average value in the p_T range is simplified due to
 351 the normalization of the correlation distribution to the number of trigger particles.

352 Efficiency plots for D^0 , D^+ and D^{*+} mesons are shown in Figs. 11 and 12.

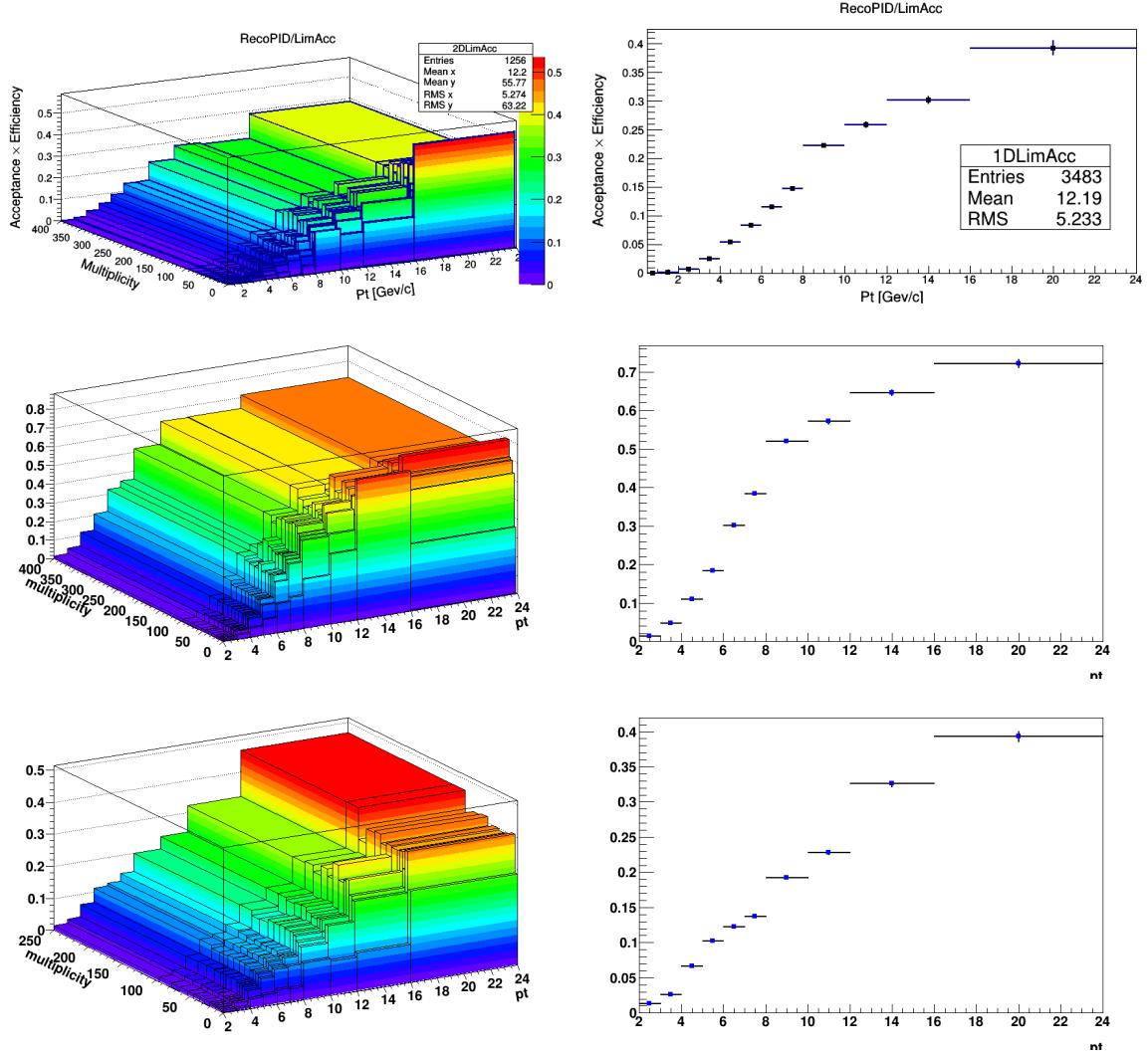


Figure 11: Top panel: (p_T , multiplicity) dependence (left) and p_T dependence (right) of prompt D^+ meson efficiency. Mid panel: (p_T , multiplicity) dependence (left) and p_T dependence (right) of prompt D^{*+} meson efficiency. Bottom panel: (p_T , multiplicity) dependence (left) and p_T dependence (right) of prompt D^0 meson efficiency.

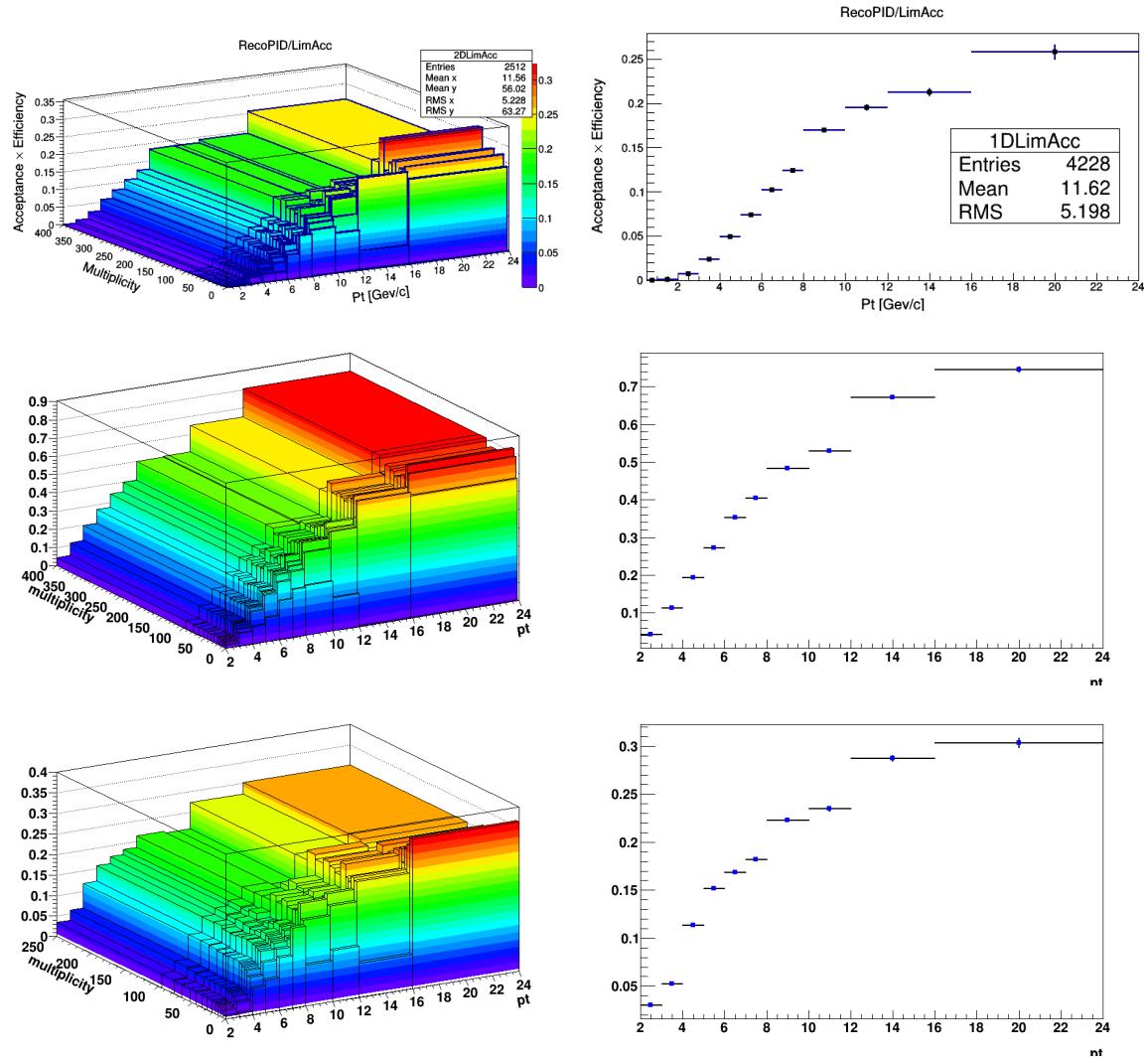


Figure 12: Top panel: (p_T , multiplicity) dependence (left) and p_T dependence (right) of feed-down D^+ meson efficiency. Mid panel: (p_T , multiplicity) dependence (left) and p_T dependence (right) of feed-down D^{*+} meson efficiency. Bottom panel: (p_T , multiplicity) dependence (left) and p_T dependence (right) of feed-down D^0 meson efficiency.

353 It was observed that multiplicity dependence of the efficiency does not bias the extraction of the signal
 354 yield from the invariant mass distributions (which, as anticipated, are also weighted in the same manner).
 355 In addition, the multiplicity dependence of the efficiencies (shown for the D^0 , in integrated p_T range, in
 356 Fig. 13) is rather flat in the range 20-80 tracklets, where about 90% of the reconstructed D -mesons are
 found, which explains why it has a negligible effect on the correlation distributions on this data sample.

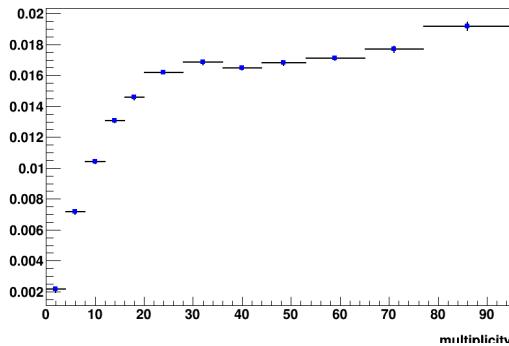


Figure 13: Prompt D^0 meson efficiency as a function of multiplicity (SPD tracklet in $|\eta| < 1$.

357

358 3.3.3 Correction for bias on B to D decay topologies

To verify the consistency of the analysis chain and of the corrections applied to the correlation distributions extracted from data, a Monte Carlo closure test was setup and tried on the D⁰-h analysis.

361 On the Monte Carlo enriched with charm and beauty quarks (LHC17d2a_fast_new), the correlation analy-
 362 sis was performed both at kinematic level and at reconstructed level. At kinematic level, only acceptance
 363 cuts were applied on the D mesons and the associated particles, using the Monte Carlo information for
 364 the identification of the D mesons and the hadrons in the event and rejecting the non-primary particles.
 365 At reconstructed level, the analysis was performed as if it were executed on data, applying the event se-
 366 lection, the acceptance cuts for D mesons and the associated particles, selecting the D meson candidates
 367 with filtering cuts on their daughters, topological cuts and PID selection, and then keeping only the true
 368 D mesons by matching with the Monte Carlo truth; non-primary particles were rejected by means of
 369 the DCA selection. Event mixing correction was applied both at reconstructed and at kinematic level,
 370 where it takes into account just the effects of the acceptance cuts. In addition, at reconstructed level, the
 371 efficiency corrections for D mesons and associated tracks were also applied.

372 Examples of correlation plots at both steps are shown in Figures 14 and 15, separating the correlation
373 contribution of associated tracks and D mesons from different origins, as described in the legend of the
374 plots.

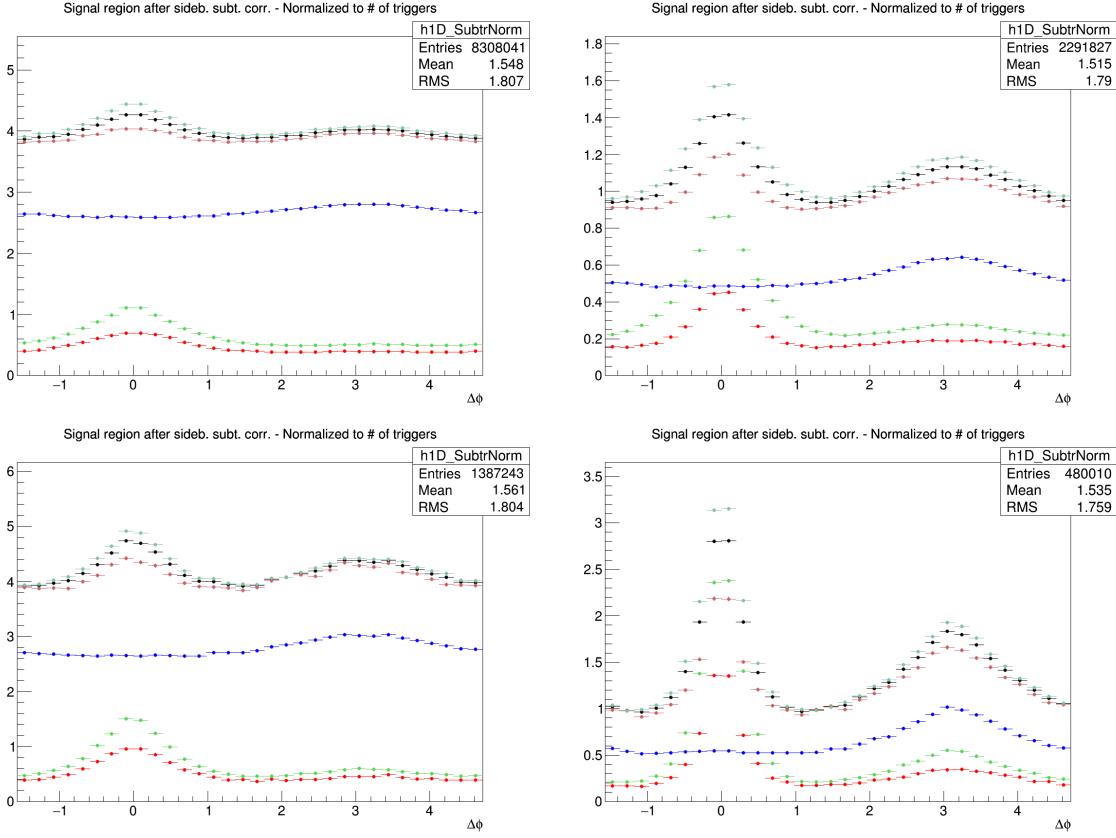


Figure 14: D^0 -hadrons azimuthal correlation distribution obtained from Monte Carlo, at kinematic step. Black points: All D^0 -all hadrons, normalized by all D^0 triggers; light red points: D^0 from c-hadrons from c, normalized by c- D^0 triggers; dark red points: D^0 from c-all hadrons, normalized by c- D^0 triggers; light green points: D^0 from b-hadrons from b, normalized by b- D^0 triggers; dark green points: D^0 from b-all hadrons, normalized by b- D^0 triggers; blue points: All D^0 -hadrons from light quarks, normalized by all D^0 triggers. The panels show the ranges: $3 < p_T(D) < 5 \text{ GeV}/c$, $0.3 < p_T(\text{assoc}) < 1 \text{ GeV}/c$ (top-left); $3 < p_T(D) < 5 \text{ GeV}/c$, $p_T(\text{assoc}) > 1 \text{ GeV}/c$ (top-right); $8 < p_T(D) < 16 \text{ GeV}/c$, $0.3 < p_T(\text{assoc}) < 1 \text{ GeV}/c$ (bottom-left); $8 < p_T(D) < 16 \text{ GeV}/c$, $p_T(\text{assoc}) > 1 \text{ GeV}/c$ (bottom-right).

375 The consistency check was performed to verify whether, after having applied all the corrections to the
 376 azimuthal correlation plots at reconstructed level, the results were compatible with the ones at kinematic
 377 level. Hence, the ratios of fully corrected reconstructed plots over kinematic plots were evaluated in all
 378 the D^0 p_T bins and for the various p_T thresholds for the associated tracks, separating the contributions for
 379 the different origins of particles and triggers. The ratios, shown in Figure 16, denote a good compatibility
 380 with 1, within the uncertainties, with the only exception being due to some structures in the near side
 381 region for the beauty origin case. These structures were already found in the pp 2010 and p-Pb 2013
 382 analysis, and it was verified that they are induced by our topological selection for the D mesons. Indeed,
 383 in cases in which the D meson triggers come from B hadrons, applying the topological cuts (especially
 384 the cosine of the pointing angle) tends to favour cases with a small angular opening between the products
 385 of the B hadron decay (i.e. the D meson trigger itself and other particles), with respect to cases where
 386 the B decay particles are less collinear.

387 In the Monte Carlo closure test, this situation is reflected in the correlation distributions at reconstructed
 388 level, where the topological selection is applied, while it does not occur at kinematic level. Hence, in
 389 the reconstructed/kinematic ratio, the distribution would show an excess for $\Delta\phi = 0$ (due to the favoured
 390 decays with small opening angle), which is then compensated by a depletion for larger values of $\Delta\phi = 0$

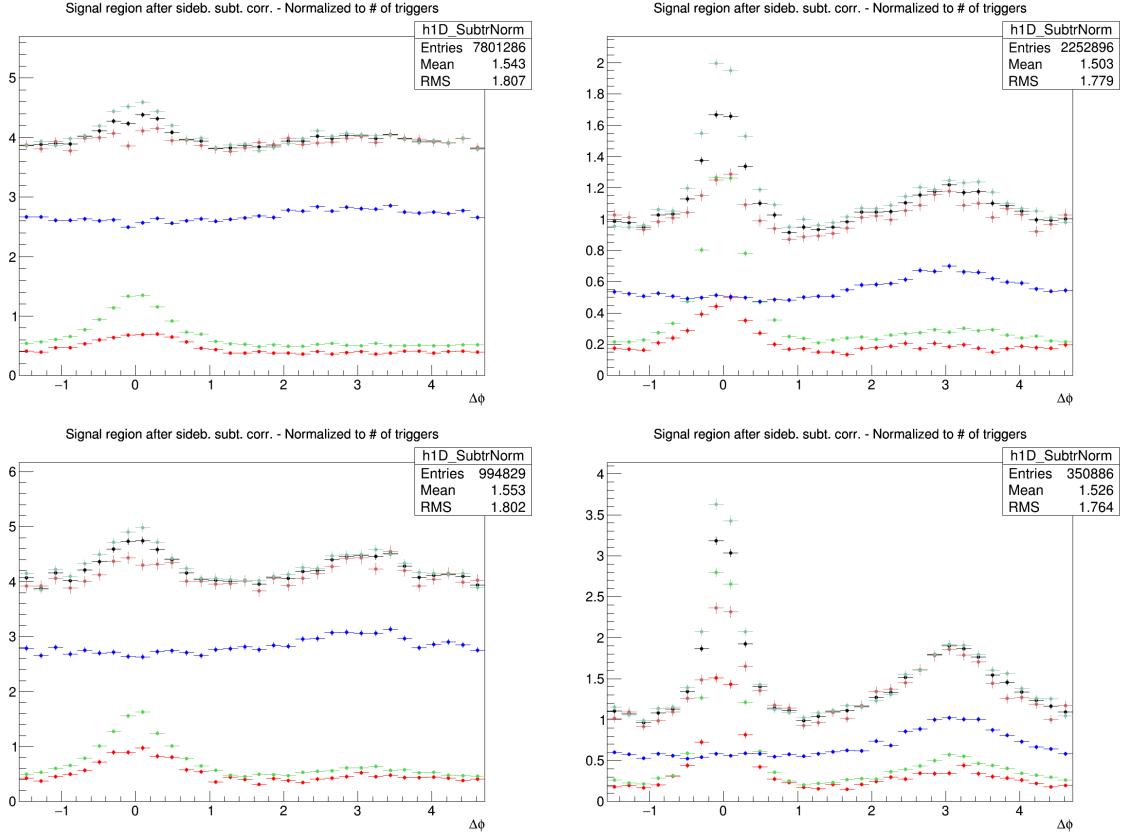


Figure 15: D^0 -hadrons azimuthal correlation distribution obtained from Monte Carlo, at reconstructed step. Black points: All D^0 -all hadrons, normalized by all D^0 triggers; light red points: D^0 from c-hadrons from c, normalized by c- D^0 triggers; dark red points: D^0 from c-all hadrons, normalized by c- D^0 triggers; light green points: D^0 from b-hadrons from b, normalized by b- D^0 triggers; dark green points: D^0 from b-all hadrons, normalized by b- D^0 triggers; blue points: All D^0 -hadrons from light quarks, normalized by all D^0 triggers. The panels show the ranges: $3 < p_T(D) < 5 \text{ GeV}/c$, $0.3 < p_T(\text{assoc}) < 1 \text{ GeV}/c$ (top-left); $3 < p_T(D) < 5 \text{ GeV}/c$, $p_T(\text{assoc}) > 1 \text{ GeV}/c$ (top-right); $8 < p_T(D) < 16 \text{ GeV}/c$, $0.3 < p_T(\text{assoc}) < 1 \text{ GeV}/c$ (bottom-left); $8 < p_T(D) < 16 \text{ GeV}/c$, $p_T(\text{assoc}) > 1 \text{ GeV}/c$ (bottom-right).

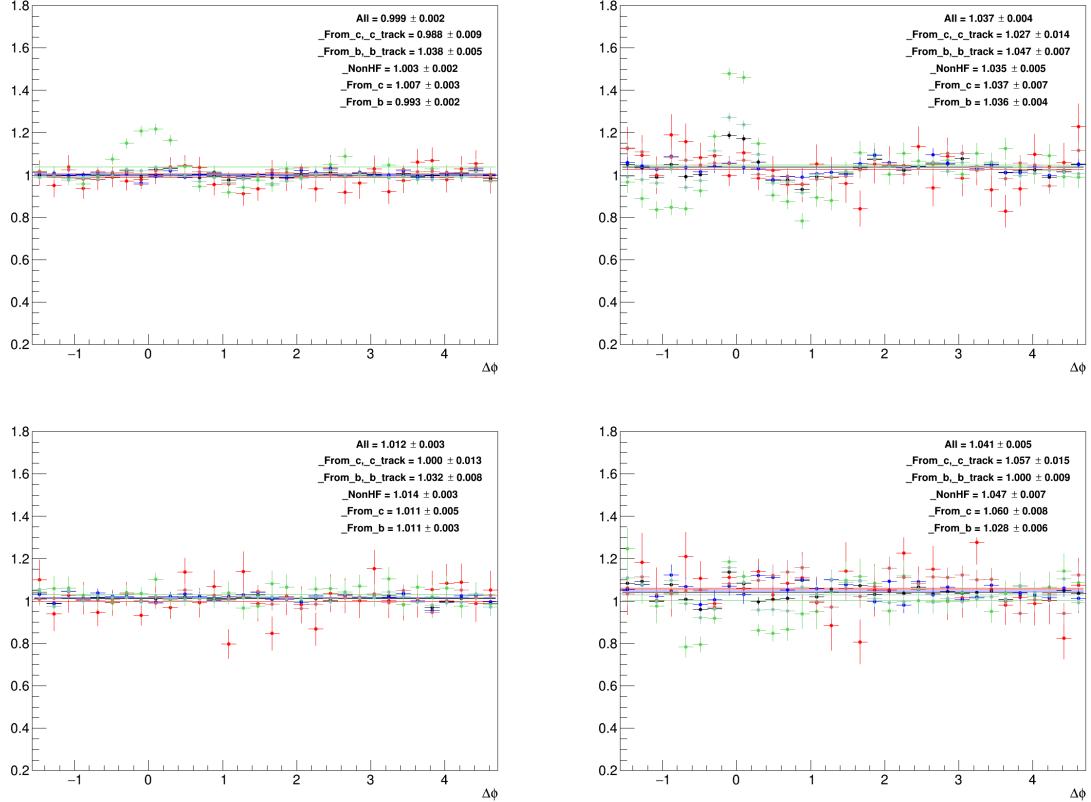


Figure 16: Ratios of fully corrected azimuthal correlation plots at reconstructed level over azimuthal correlation plots at kinematic level, in the two D^0 p_T bins, for the different associated p_T ranges. Black points: All D^0 -all hadrons, normalized by all D^0 triggers; light red points: D^0 from c-hadrons from c, normalized by c- D^0 triggers; dark red points: D^0 from c-all hadrons, normalized by c- D^0 triggers; light green points: D^0 from b-hadrons from b, normalized by b- D^0 triggers; dark green points: D^0 from b-all hadrons, normalized by b- D^0 triggers; blue points: All D^0 -hadrons from light quarks, normalized by all D^0 triggers. The panels show the ranges: $3 < p_T(D) < 5 \text{ GeV}/c$, $0.3 < p_T(\text{assoc}) < 1 \text{ GeV}/c$ (top-left); $3 < p_T(D) < 5 \text{ GeV}/c$, $p_T(\text{assoc}) > 1 \text{ GeV}/c$ (top-right); $8 < p_T(D) < 16 \text{ GeV}/c$, $0.3 < p_T(\text{assoc}) < 1 \text{ GeV}/c$ (bottom-left); $8 < p_T(D) < 16 \text{ GeV}/c$, $p_T(\text{assoc}) > 1 \text{ GeV}/c$ (bottom-right).

(corresponding to B decays with larger angles, which are disfavoured). These structures are prominent at low $D^0 p_T$, where the topological cuts are tighter, and tend to disappear at higher p_T , where the selections are released. They are also larger in the higher associated track p_T ranges, where the fraction of B-hadron decay tracks dominate the overall correlation distributions.

The data correlation distribution need to be corrected for this bias, and in particular for the enhancement of b-origin correlation pairs at the centre of the near side region, which would influence the near-side peak features. In order to do this, the amount of the b-origin excess is evaluated from the Reco/Kine ratio, by considering the b- D^0 -all tracks case (dark green points). The excess at Reco level (affecting data) is quantified as a $\Delta\varphi$ modulation **modul** for the five points an each side of the $\Delta\varphi = 0$ value (or, equivalently, on the first five points of the reflected distributions, which start from $\Delta\varphi = 0$). This is done separately in each p_T range. Then, the correction is done by applying this modulation to the data correlation distributions, but taking into account that only the correlation entries from $B \rightarrow D$ are affected, while the $c \rightarrow D$ correlations need to be left unaltered. In particular, it has to be considered that:

- On data, the $B \rightarrow D$ correlation pairs are only a fraction ($1-f_{\text{prompt}}$) of the total.
- The amplitude of $B \rightarrow D|_{\text{amplit}}$ correlation pattern is different (greater) than the amplitude of the $c \rightarrow D|_{\text{amplit}}$ correlation pattern:

Thus, the following equation is applied to get the corrected $C(\Delta\varphi)_{\text{corr}}$ data points starting from the raw ones, $C(\Delta\varphi)_{\text{raw}}$:

$$C(\Delta\varphi)_{\text{corr}} = C(\Delta\varphi)_{\text{raw}} \cdot \left[\frac{c \rightarrow D|_{\text{amplit}}}{(B+c) \rightarrow D|_{\text{amplit}}} \cdot f_{\text{prompt}} + \frac{B \rightarrow D|_{\text{amplit}}}{(B+c) \rightarrow D|_{\text{amplit}}} \cdot (1 - f_{\text{prompt}}) \cdot \frac{1}{\mathbf{modul}} \right] \quad (3)$$

where $(B+c) \rightarrow D|_{\text{amplit}} = c \rightarrow D|_{\text{amplit}} \cdot f_{\text{prompt}} + B \rightarrow D|_{\text{amplit}} \cdot (1 - f_{\text{prompt}})$, and where the two amplitudes are evaluated from the Monte Carlo distributions of Figure 15 at reconstructed level (so, including the bias), and f_{prompt} with the procedure described in 3.3.5. Applying the **modul** factor to the beauty part of the data correlation distributions brings its value back to the generated level case, effectively removing the bias. The effect of the correction is a shift of the data points in the near-side region (in general, downward in the first and second points, the upward in the others). The maximum value of the shift is of about 5%, at the centre of the near-side peak, for the lowest D-meson p_T range ($3 < p_T < 5 \text{ GeV}/c$) and the highest associated track p_T range ($p_T > 3 \text{ GeV}/c$). The typical values are instead of a couple of percentage points. The correction is zero in the highest D-meson p_T range. To take into account for possible inaccuracies in the definition of the modulations, or in their rescaling, a systematic uncertainty is applied on the corrected data points, with value $|C(\Delta\varphi)_{\text{corr}} - C(\Delta\varphi)_{\text{raw}}|/\sqrt{12}$, on each side of the data points affected by the bias (symmetric uncertainty).

421 **3.3.4 Secondary track contamination**

422 The secondary tracks inside the associated track sample, due to interaction of primary track with the de-
 423 tector material or to decays of strange hadrons, are mostly removed by the DCA cuts applied during the
 424 cut selection phase ($DCA(xy) < 1 \text{ cm}$, $DCA(z) < 1 \text{ cm}$). Anyway, a small fraction of secondary tracks
 425 survives this cut, and the data correlation distributions have to be corrected for this residual contami-
 426 nation. The fraction of surviving secondary tracks is evaluated via a study on the LHC17d2a_fast_new
 427 sample, by counting the number of tracks accepted by the selection whose corresponding generated-
 428 level track doesn't satisfy the `IsPhysicalPrimary()` call, and dividing this number by the total number
 429 of accepted tracks. The outcome of the check is reported in Figure 17. As it's visible, no more than
 430 5% secondary tracks pass the selection. Moreover, the fraction of residual secondary tracks is flat along
 431 the $\Delta\varphi$ axis, as shown, for exemplary p_T regions, in Figure 18, where the inhomogeneities are always
 432 below 1%. For this reason, it is possible to directly scale the data correlation distributions by their purity
 433 fraction (i.e. 1 - secondary contamination). This is done with an associated p_T dependence, due to the
 434 increase of the purity with the track p_T , while the purity fraction is taken flat versus the D-meson p_T .
 435 The purity values that were chosen are the following:

- 436 – $p_T(\text{assoc}) > 0.3 \text{ GeV}/c : 0.958$
- 437 – $p_T(\text{assoc}) > 1 \text{ GeV}/c : 0.973$
- 438 – $0.3 < p_T(\text{assoc}) < 1 \text{ GeV}/c : 0.953$
- 439 – $1 < p_T(\text{assoc}) < 2 \text{ GeV}/c : 0.969$
- 440 – $2 < p_T(\text{assoc}) < 3 \text{ GeV}/c : 0.982$
- 441 – $p_T(\text{assoc}) > 3 \text{ GeV}/c : 0.990$

442 It was also verified with the same Monte Carlo study that applying the DCA selection rejects less than
 443 0.2% primary tracks (tagged as false positives) from the associated track sample, again with a flat az-
 444 imuthal distribution, inducing hence a fully negligible bias on the data correlation distributions. This is
 445 shown in Figure 19. This was also verified for specific charm-origin and beauty-origin tracks, due to
 446 their larger DCA with respect to primary tracks from light quarks. In this case, the fraction of rejected
 447 charm and beauty tracks stays below 1% in all the kinematic ranges apart from the associated track p_T
 448 regions 0.3-1 and $> 0.3 \text{ GeV}/c$, where the rejection can be as high as 2%. In these kinematic ranges,
 449 though, the data correlation distributions are dominated by non-heavy-flavour tracks, as it was verified
 450 from the simulations, hence the overall bias is still contained below 1%, thus negligible.

451 These studies were performed on an enriched Monte Carlo sample, which could not fully reproduce
 452 the relative abundancies of the species. Anyway, for events with a reconstructed D-meson, this bias is
 453 expected to be minor, and only these events are used in the data analysis. In any case, the percentages
 454 obtained from the study were found to be consistent within 1% with the outcome of the studies for the
 455 p-Pb 2013 analysis, which reassures us on the full validity of these results.

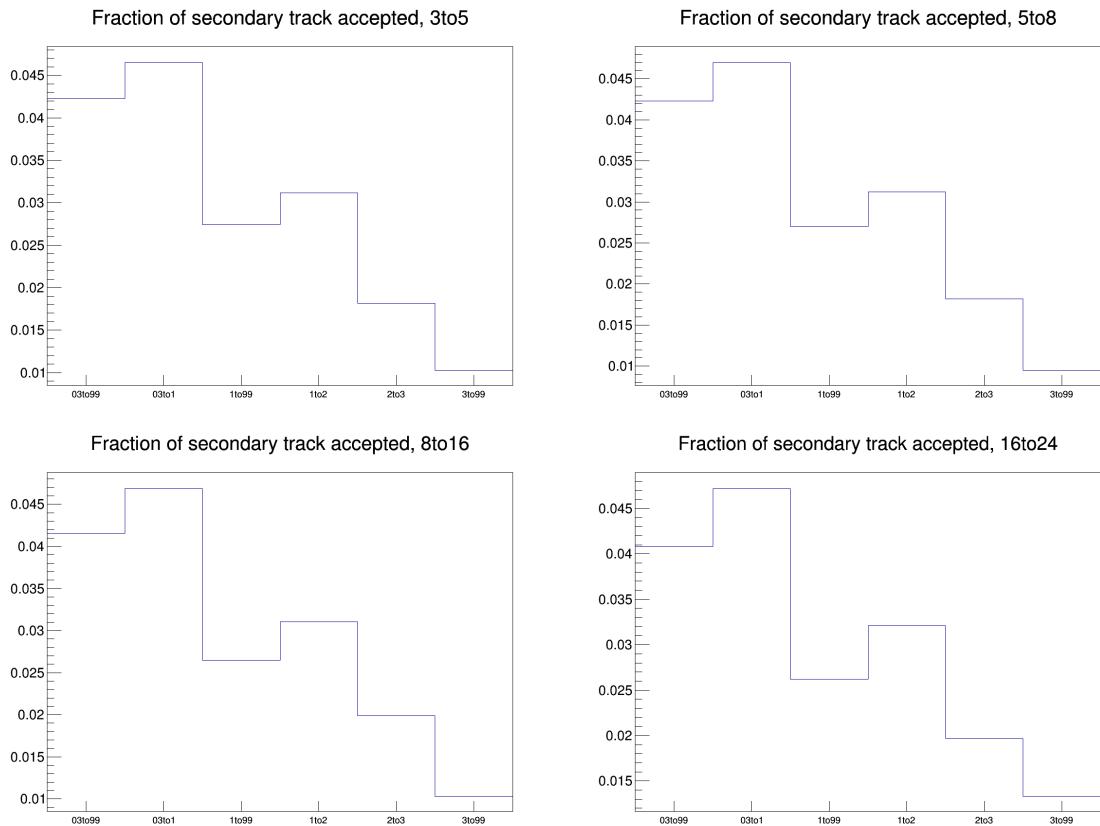


Figure 17: Fraction of secondary tracks over total amount of tracks which pass the DCA selection. The four panel show the fractions for the D-meson p_T ranges: 3-5, 5-8, 8-16, 16-24, respectively. Inside each panel, the associated track p_T ranges are shown on the x -axis.

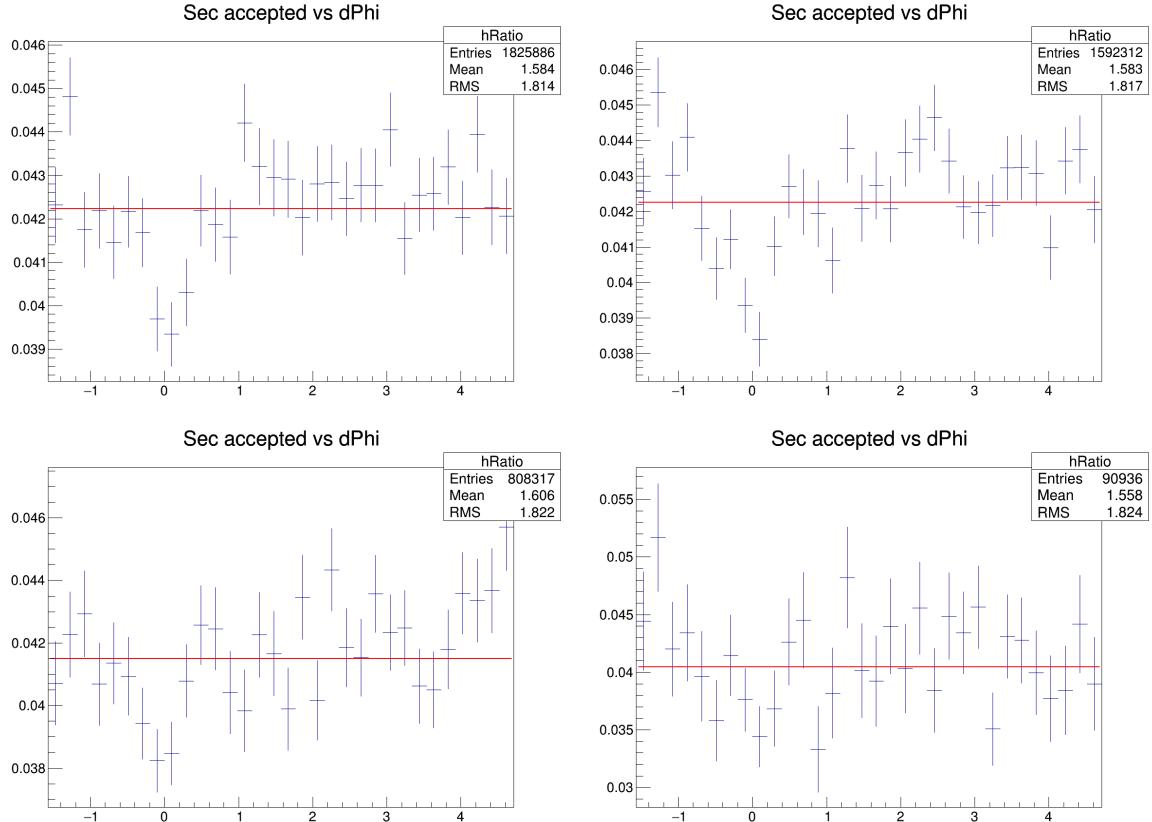


Figure 18: $\Delta\phi$ dependence of the fraction of secondary tracks in the D^0 - h correlation distributions. The four panel show the fractions for the D -meson p_T ranges: 3-5, 5-8, 8-16, 16-24, respectively. The associated track p_T ranges are the integrated one, i.e. $p_T > 0.3 \text{ GeV}/c$.

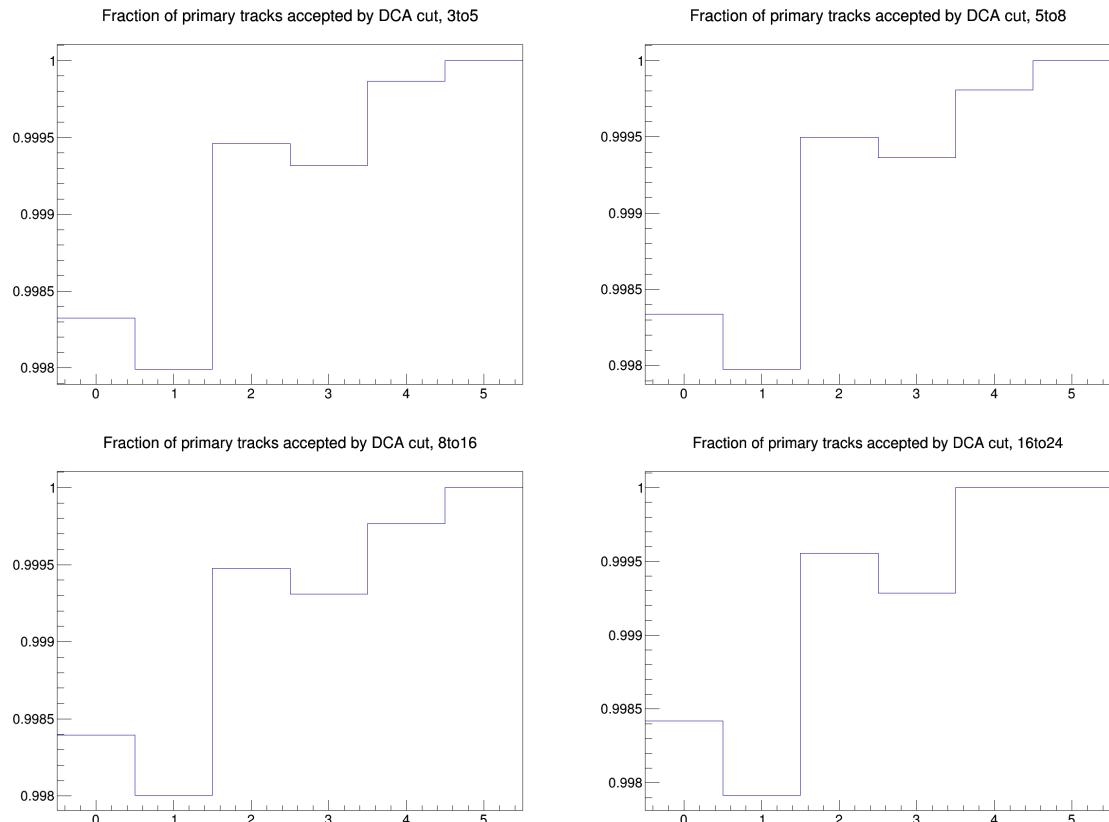


Figure 19: Fraction of primary tracks rejected by the DCA selection. The four panel show the fractions for the D-meson p_T ranges: 3-5, 5-8, 8-16, 16-24, respectively. Inside each panel, the associated track p_T ranges are shown on the x -axis.

456 **3.3.5 Beauty feed-down**

457 The contribution of correlations of D meson from b-hadron decay is subtracted from the data correlation
 458 distributions as:

$$\tilde{C}_{\text{prompt D}}(\Delta\phi) = \frac{1}{f_{\text{prompt}}} \left(\tilde{C}_{\text{inclusive}}(\Delta\phi) - (1 - f_{\text{prompt}}) \tilde{C}_{\text{feed-down}}^{\text{MC templ}}(\Delta\phi) \right). \quad (4)$$

459 In the above equation, $\tilde{C}_{\text{inclusive}}(\Delta\phi)$ and $\tilde{C}_{\text{prompt D}}(\Delta\phi)$ are per-trigger azimuthal correlation distribu-
 460 tions before and after feed-down contribution subtraction, f_{prompt} is the fraction of prompt D meson
 461 and $\tilde{C}_{\text{feed-down}}^{\text{MC templ}}$ is a template of the azimuthal correlation distribution for the feed-down component ob-
 462 tained from home-made Monte Carlo simulation at generated level, using PYTHIA6 with Perugia2011
 463 tune. In order to avoid biases related to the different event multiplicity in real and simulated events,
 464 the correlation distribution was shifted to have its minimum coinciding with the baseline of the data
 465 azimuthal-correlation distribution before feed-down subtraction.

466 The value of f_{prompt} (Figure 20), which depends on D-meson species and varies as a function of the p_T ,
 467 is estimated on the basis of FONLL predictions for the production of feed-down D mesons at central
 468 rapidity, in pp collisions at $\sqrt{(s)} = 5$ TeV, and using the reconstruction efficiency of prompt and feed-
 469 down D mesons, following the so-called N_b approach defined in [1]. Typical values are about 8-10%
 470 for the D^0 , about 4-7% for the D^+ and about 5-8% for the D^{*+} . The procedure adopted is the same
 471 as what done in the past analysis [7]: however, in p-Pb, in order to consider a possible non-zero v_2 -
 472 like modulation of the baseline, a range of $0 < v_2 < 0.2$ values for tracks and for secondary D mesons
 473 is considered for the systematic uncertainty evaluation (using an hypothesis of no modulation for both
 474 cases for central values).

475 Examples of the PYTHIA templates used for the feed-down contribution subtraction are shown in Figures
 476 21 (Figure 22 shows the same templates but for prompt D mesons).

477 The feed-down subtraction was performed after rescaling the data correlation distributions for the purity
 478 fraction, and correcting them by the near-side modulation induced by the bias on the B decay topology.

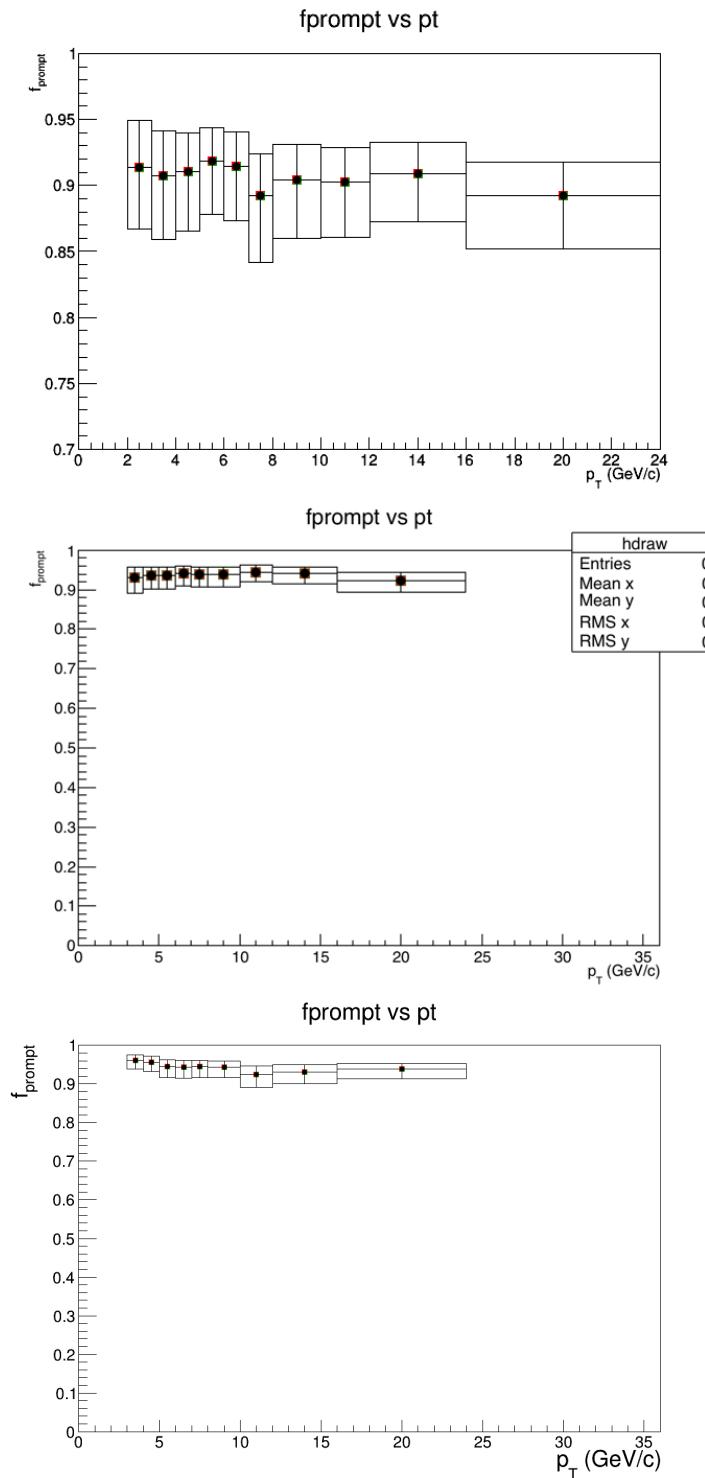


Figure 20: f_{prompt} as a function of the p_T for D^0 (top), D^{*+} (mid) and D^+ (bottom) estimated on the basis of FONLL predictions

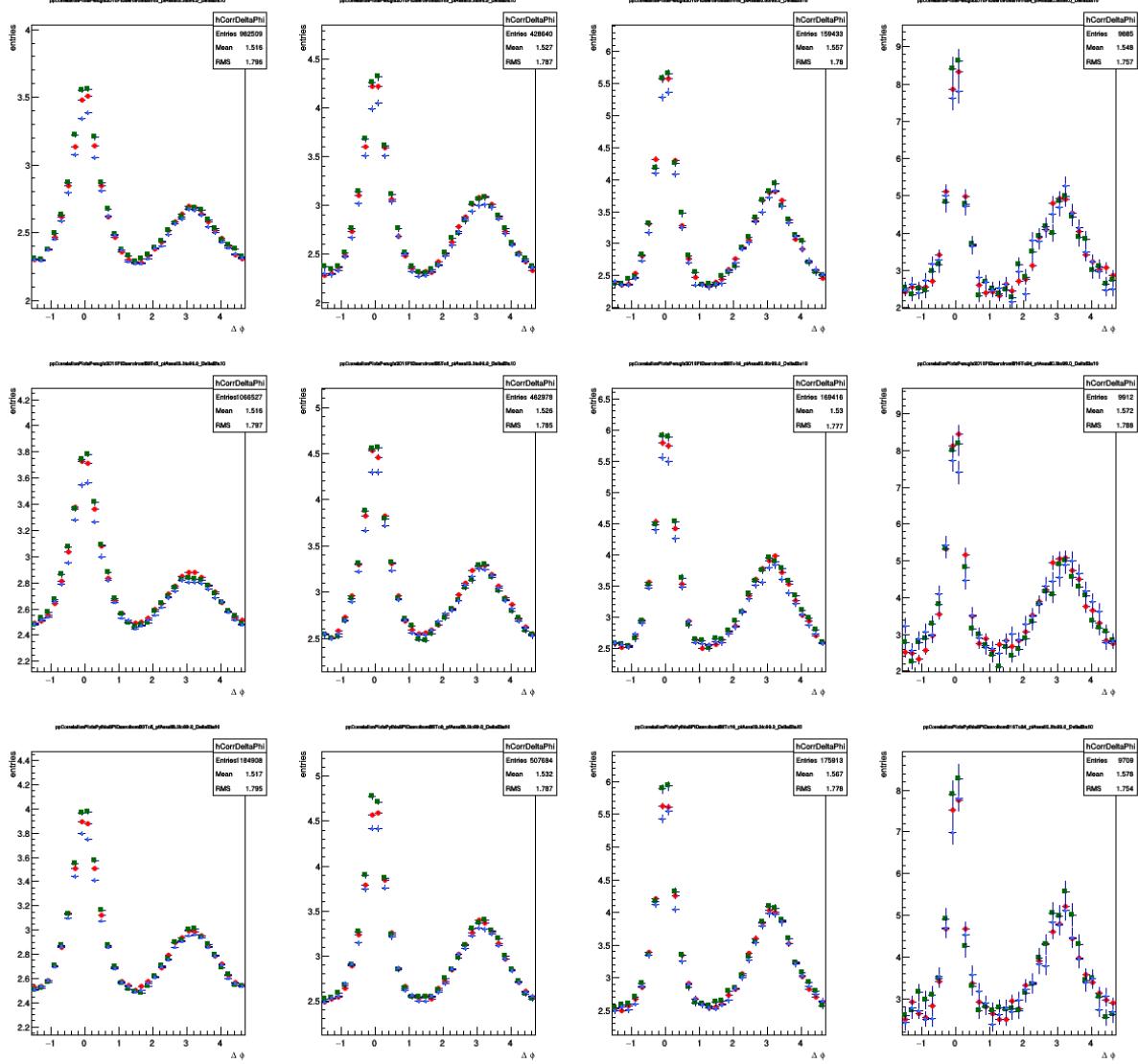


Figure 21: Azimuthal correlation distribution between D meson from b-hadron decay and charged particles obtained from Monte Carlo simulations based on Pythia-Perugia2010 tune (row1), Pythia-Perugia2011 tune (row2), Pythia8 tune 4C (row3) for associated track $p_T > 0.3 \text{ GeV}/c$ and D-meson p_T ranges: 3-5, 5-8, 8-16, 16-24 GeV/c . D⁰ in blue, D⁺ in green, D^{*} in red.

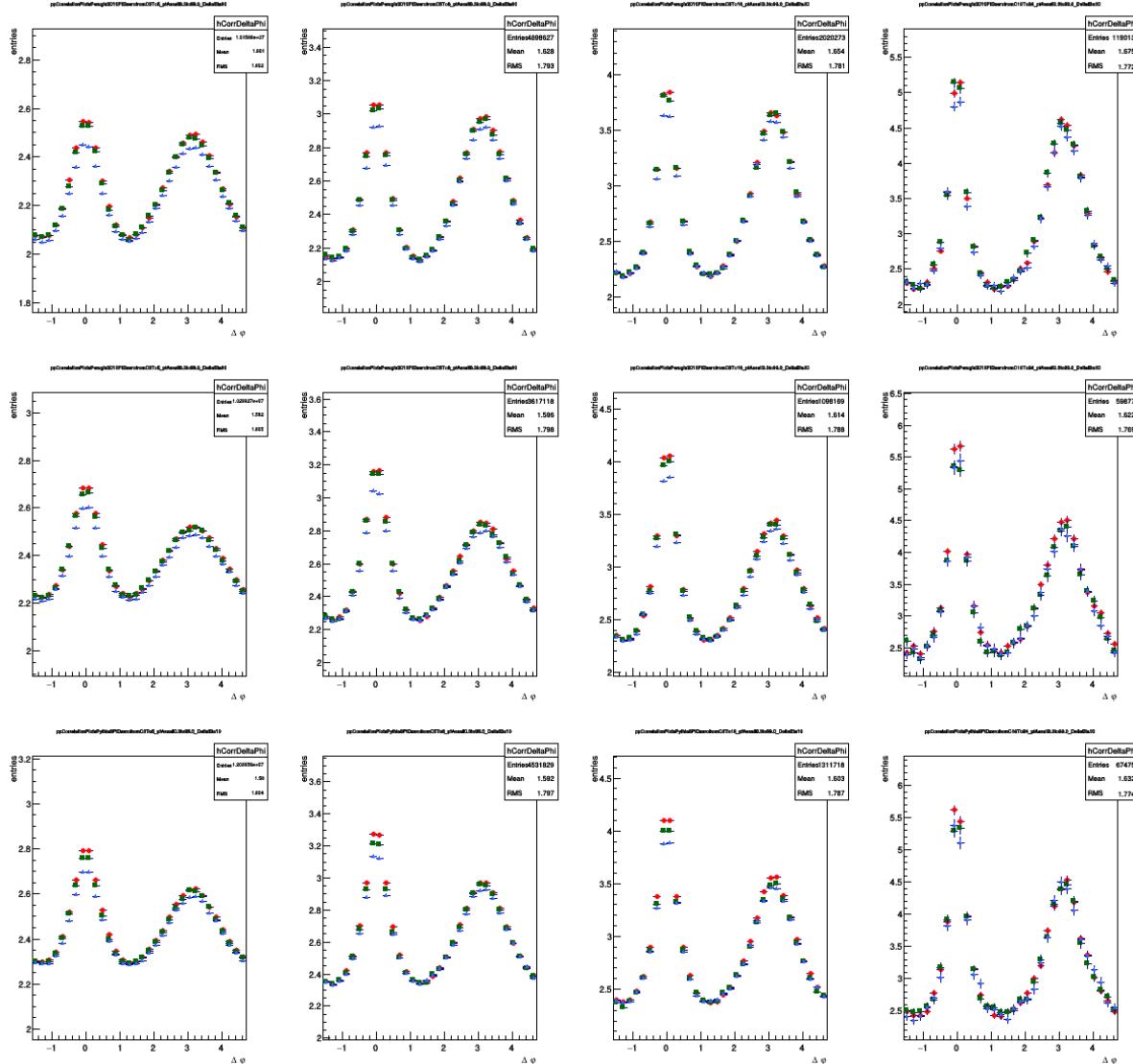


Figure 22: Azimuthal correlation distribution between prompt D meson and charged particles obtained from Monte Carlo simulations based on Pythia-Perugia2010 tune (row1), Pythia-Perugia2011 tune (row2), Pythia8 tune 4C (row3) for associated track $p_T > 0.3 \text{ GeV}/c$ and D-meson p_T ranges: 3-5, 5-8, 8-16, 16-24 GeV/c . D^0 in blue, D^+ in green, D^{*+} in red.

4 Systematic uncertainties on $\Delta\phi$ correlation distributions

4.1 Uncertainty on S and B extraction

The systematic uncertainty for the D meson yield extraction was determined separately for the three mesons. It was obtained by evaluating the value of the signal candidate from the invariant mass spectra with the following differences with respect to the standard approach:

- Changing the background fit function, for D^0 and D^+ (tried with polynomials of 1st and 2nd order) and for D^{*+} (tried with polynomials of 2nd order and a power function);
- Changing the range in which the signal is extracted from the Gaussian fit;
- Reducing the range of invariant mass axis in which the signal region is defined (and S and B are extracted);
- Rebinning the invariant mass distributions before the fit for D^0 and D^+
- Extracting S and B via integral of the fit functions or B via bin counting and S via integral of the Gaussian function.

Both the value of the yield and the sidebands correlations normalization factor are affected by changing the yield extraction approach, while the rest of the procedure to extract the azimuthal correlation distribution is the same as in the standard analysis. The fully corrected azimuthal correlation plots were evaluated, for each of these approaches, in all D meson p_T bins and for each value of associated tracks p_T threshold. The ratios of the correlation distributions obtained with the standard yield extraction procedure and by differentiating the approach were evaluated. From the average of these ratios, which are found to be flat versus $\Delta\phi$, a systematic uncertainty can be extracted, which was taken of 1% for $3 < p_T(D) < 16 \text{ GeV}/c$ and of 2% in $16 < p_T(D) < 24 \text{ GeV}/c$ (3% for D^0). No dependence versus the associated track p_T was assumed, since from a physics point of view we don't expect a modification of the signal and sideband values to have a dependence of this kind. Figures 23, show the ratios obtained by the above mentioned procedure for exemplary p_T ranges, which anyway span over the full kinematic ranges analyzed, for D^0 -h correlations. Figures 24 and 25 show the same ratios for D^{*+} -h, D^+ -h as well.

4.2 Uncertainty on background correlation shape

The systematic uncertainty for the subtraction of the background correlations includes the effects due to a potentially biased description of the background correlation shape, which is evaluated from of the sidebands correlations. In particular, the background correlation shape could present some hidden invariant mass dependence. To estimate this uncertainty, the invariant mass range of the sidebands definitions was varied with respect to the default values. For the D^0 meson, the usual range of the sidebands is 4 to 8 σ from the centre of the peak of the Gaussian fit and it was modified, for both sidebands to:

- inner half (4 to 6 σ from the centre of the peak);
- outer half (6 to 8 σ from the centre of the peak)
- extended to 4 to 10 σ (in case this is possible without exceeding the fitting range of the mass plots)

Slightly different variations, but with the same reasoning, were considered for the D^+ meson.

For the D^{*+} meson, the usual range of sideband in invariant mass spectra is 5 to 10 σ (only on the right side) from the centre of the peak of the Gaussian fit of the invariant mass spectra, and it was modified to:

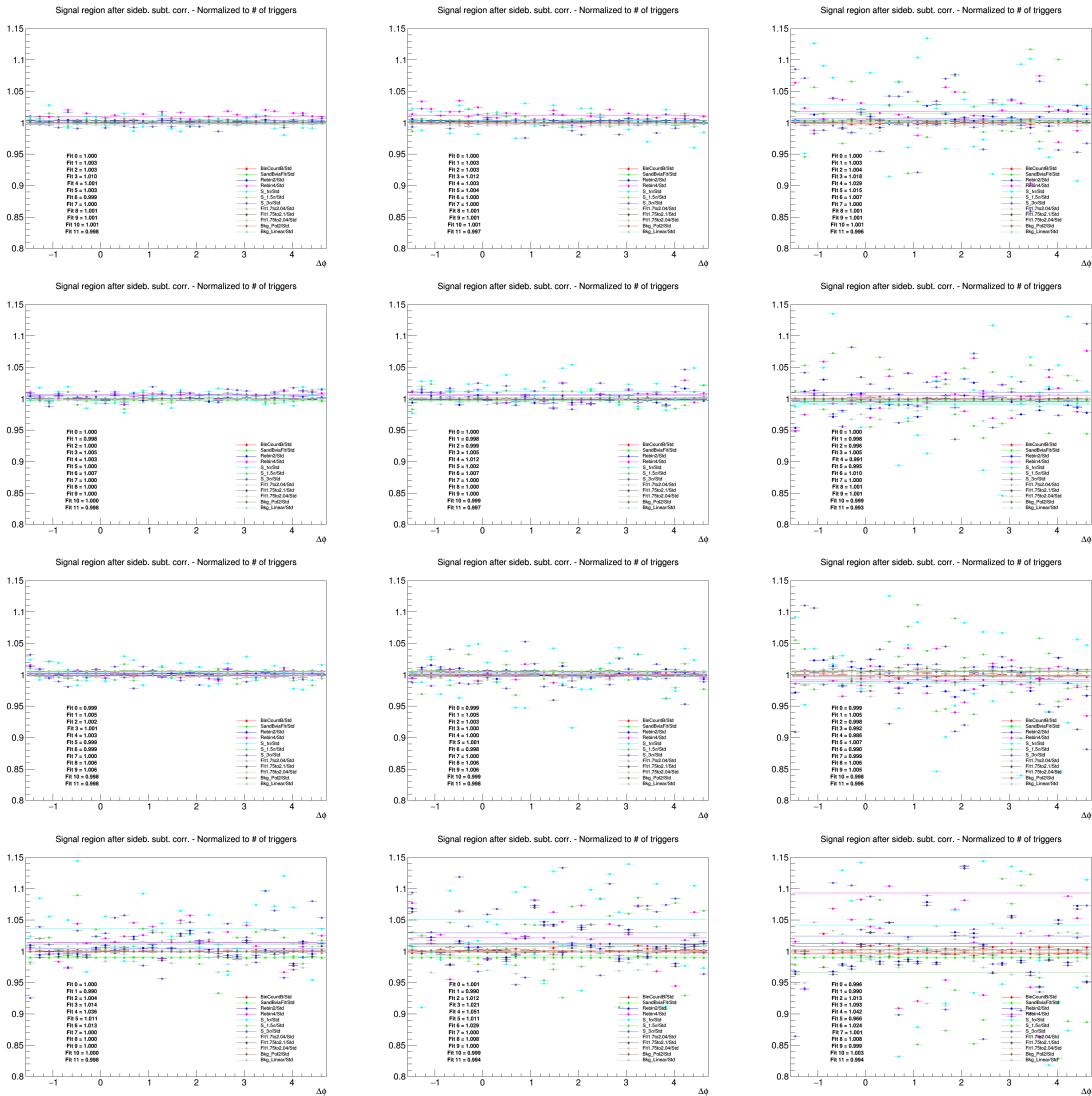


Figure 23: Ratios of D^0 - h correlation plots obtained changing S and B extraction procedure over those obtained with standard yield extraction procedure. Rows: $p_T(D^0)$ 3-5, 5-8, 8-16, 16-24 GeV/c . In each row, the panels show the associated track p_T ranges 0.3-1, 1-2, $>3 \text{ GeV}/c$, respectively.

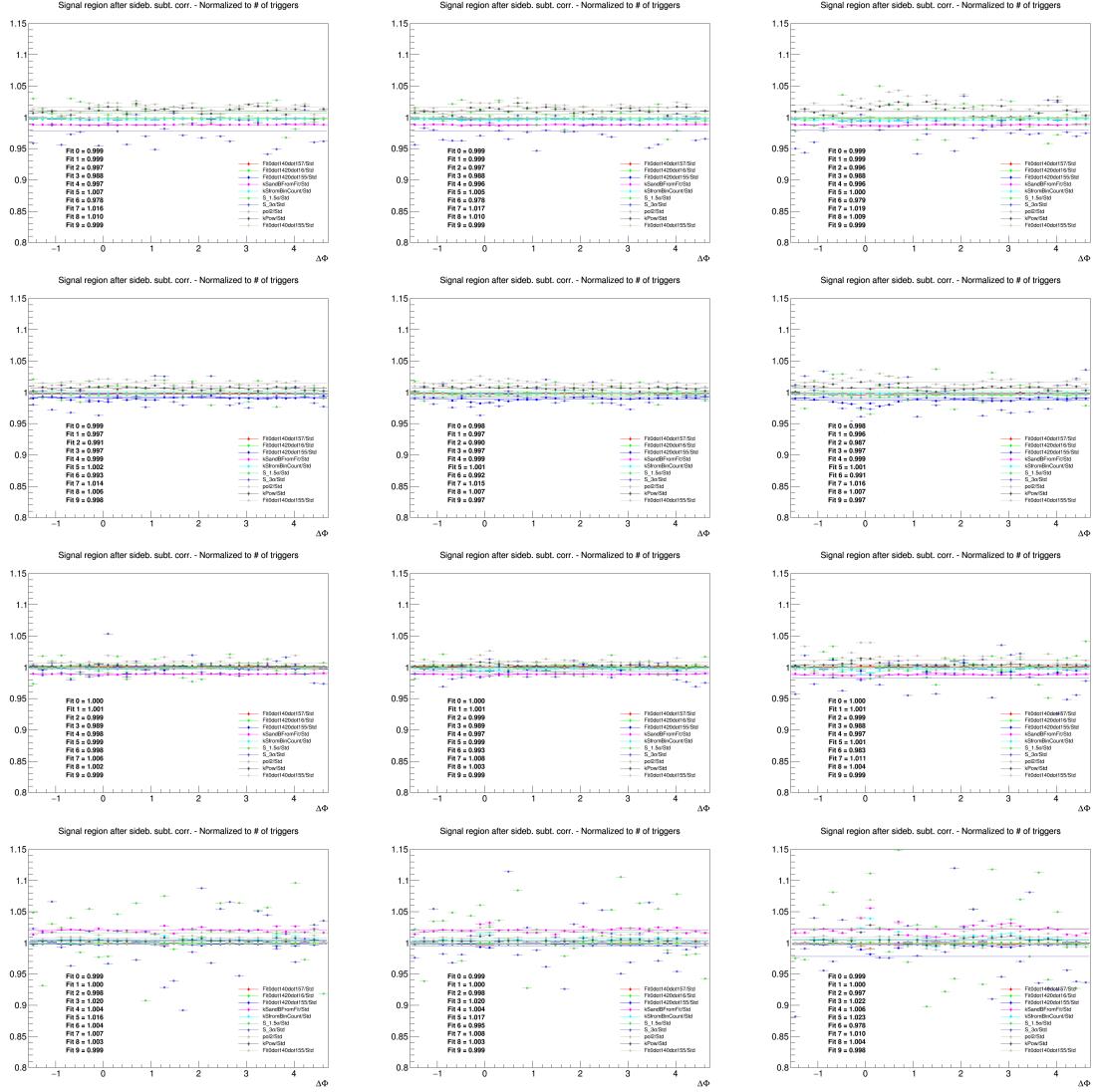


Figure 24: Ratios of $D^*+ - h$ correlation plots obtained changing S and B extraction procedure over those obtained with standard yield extraction procedure. Rows: $p_T(D^*)$ 3-5, 5-8, 8-16, 16-24 GeV/ c . In each row, the panels show the associated track p_T ranges >0.3 GeV/ c , 0.3-1 GeV/ c and >1 GeV/ c , respectively.

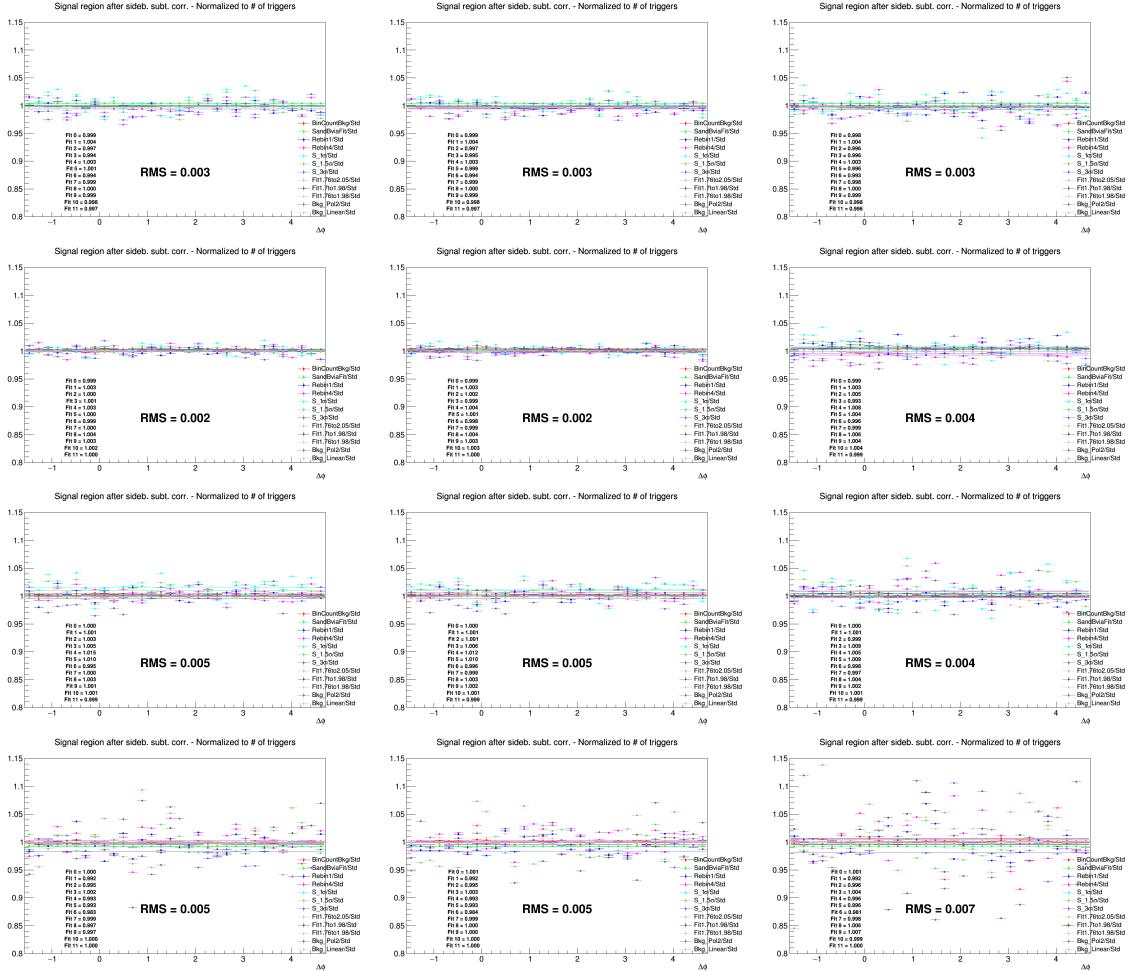


Figure 25: Ratios of D⁺-h correlation plots obtained changing S and B extraction procedure over those obtained with standard yield extraction procedure. Rows: $p_T(D^+)$ 3-5, 5-8, 8-16, 16-24 GeV/c. In each row, the panels show the associated track p_T ranges 0.3-1 GeV/c, >0.3 GeV/c, and >1 GeV/c, respectively.

- inner half (5 to 8 σ from the centre of the peak);
- outer half (8 to 13 σ from the centre of the peak);
- extended to 5 to 13 σ from the centre of the peak;
- extended to 6 to 16 σ from the centre of the peak.

The rest of the procedure for the azimuthal correlations distribution was unchanged, and the ratios of the fully corrected azimuthal correlation plots obtained with the standard sidebands range and the correlation plots extracted with different sidebands definitions, were evaluated for each D-meson p_T bin and associated tracks p_T threshold. Results of this check are shown in Figures 26, 27 and 28 for D^0 , D^{*+} , D^+ respectively, for exemplary p_T ranges, spanning over the full kinematic regions analysis. From the values of the ratios extracted from the checks, which do not show any azimuthal dependence a systematic uncertainty for the background subtraction can be evaluated. Also no dependence versus the associated track p_T was assumed also in this case. The uncertainty was hence taken of 1% for $3 < p_T(D) < 16$ GeV/ c and 3% for $16 < p_T(D) < 24$ GeV/ c for the three D mesons.

4.3 Uncertainty on D-meson cut stability

To study the systematics due to the topological selections on the D meson, the cut variation approach was used. For each D-meson, alternate sets of released and tightened selection cuts were applied to extract the correlation distribution, varying in particular the cosine of the pointing angle, the maximum DCA among the daughter tracks and the product of the daughter track impact parameters. For each set of cuts new 2D (p_T vs multiplicity), D meson efficiency map was computed. In Figures 29, 30, 31 (for D^0 , D^{*+} and D^+ , respectively) the ratio of the different 1D efficiencies with the alternate cuts with respect to the default cut selection is chosen, to highlight how the different selections effectively varied the efficiency values, especially at low p_T , where cuts are more effective.

Figure 32, 33, 34 show the ratio of the correlation distributions with alternate cut sets over those with the standard approach, for exemplary p_T ranges covering the full kinematic region of interest for the analyses. The ratios are reasonably flat in $\Delta\phi$, hence a flat systematic was evaluated as systematic uncertainty from D-meson the cut variations. For the D^0 , the uncertainty was considered of 2% for all the p_T ranges of trigger and tracks analyzed. For the D^{*+} , the uncertainty was considered of 1.5% for $3 < p_T(D) < 8$ GeV/ c and of 1% for $8 < p_T(D) < 24$ GeV/ c . For the D^+ , the uncertainty was considered of 1% for $3 < p_T(D) < 16$ GeV/ c and of 3% for $16 < p_T(D) < 24$ GeV/ c .

4.4 Uncertainty on tracking efficiency evaluation

The systematic uncertainty for the tracking efficiency includes the effects related to the set of filtering cuts defined for the associated tracks selection (mainly requests on the quality of reconstructed tracks for the TPC and ITS detectors). This uncertainty was determined by repeating the full analysis using different selections for the cuts on the associated tracks with respect to the usual selection (TPC only tracks with at least 2 points in the ITS). The alternative selections were: pure TPConly selection, meaning TPC tracks with no requests on the number of hits in the ITS, and TPC+ITS selection, which requires filterbit 4 with, in addition, at least 3 points in the ITS, ITS refit and a hit in at least an SPD layer. The ratios of the azimuthal correlation distributions with different sets of tracks selection over distributions with standard selection were evaluated, and are shown in Figures 35 and 36 for D^0 -h correlations. Their values were used to determine a systematic uncertainty, which as the previous ones could be assigned flat in $\Delta\phi$, and which was estimated of 3% in all the ranges of p_T analyzed.

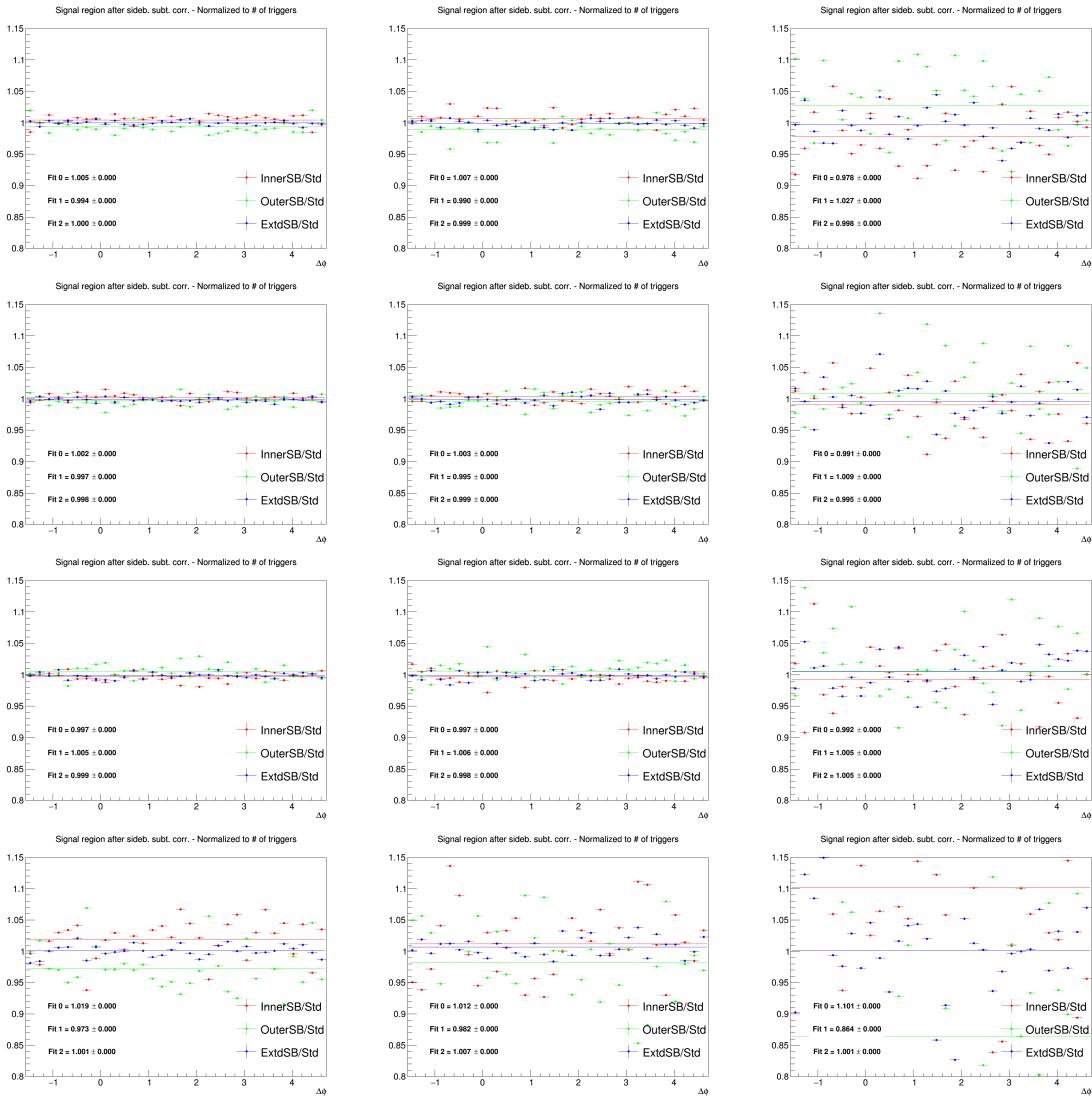


Figure 26: Ratios of D^0 - h correlation plots obtained by changing the sideband ranges over those obtained with standard sideband ranges. Rows: $p_T(D^0)$ 3-5, 5-8, 8-16, 16-24 GeV/ c . In each row, the panels show the associated track p_T ranges 0.3-1, 1-2, >3 GeV/ c , respectively.

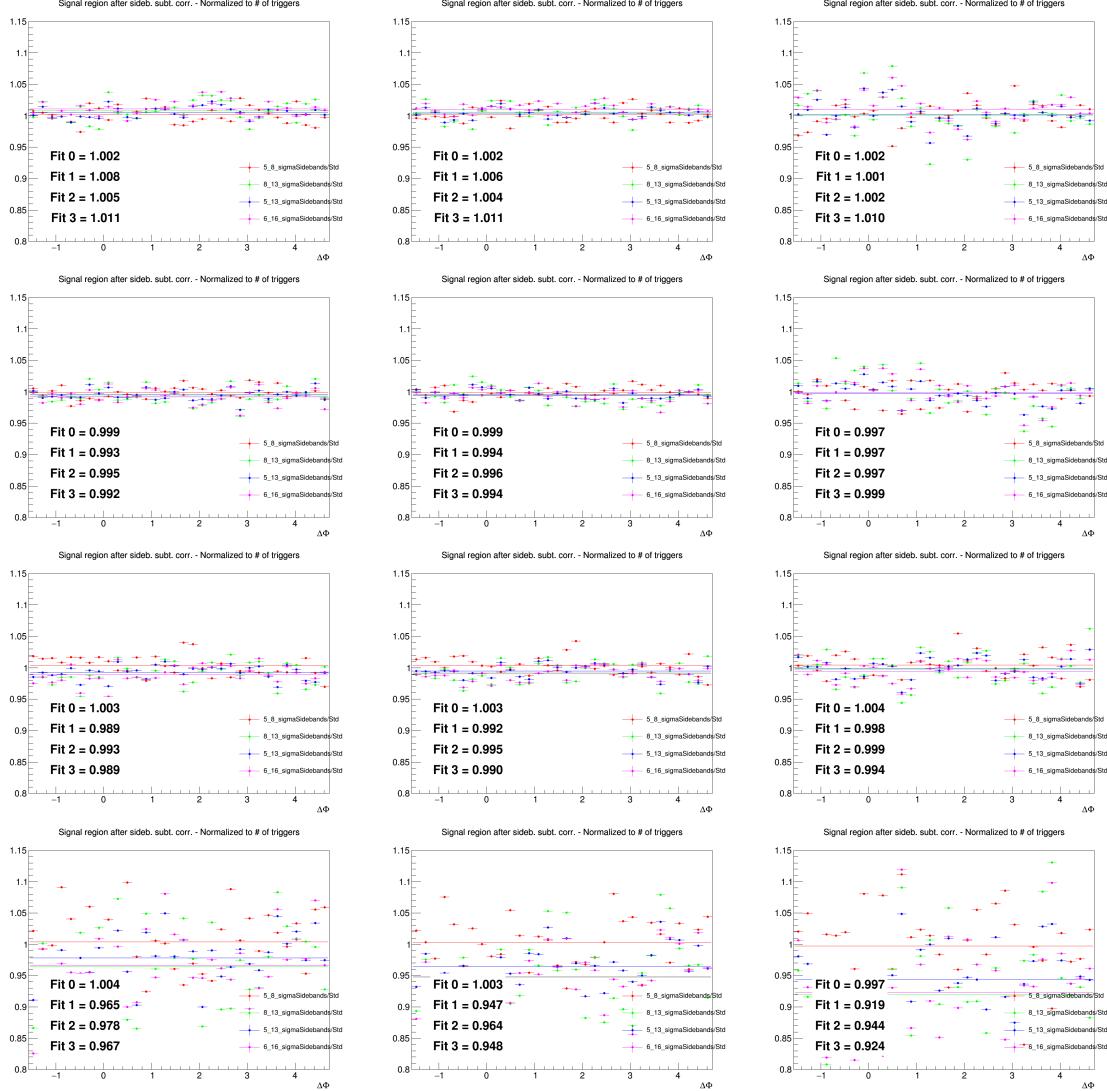


Figure 27: Ratios of $D^*+ - h$ correlation plots obtained by changing the sideband ranges over those obtained with standard sideband ranges. Rows: $p_T(D^*)$ 3-5, 5-8, 8-16, 16-24 GeV/ c . In each row, the panels show the associated track p_T ranges 0.3-1, >0.3 GeV/ c and >1 GeV/ c , respectively.

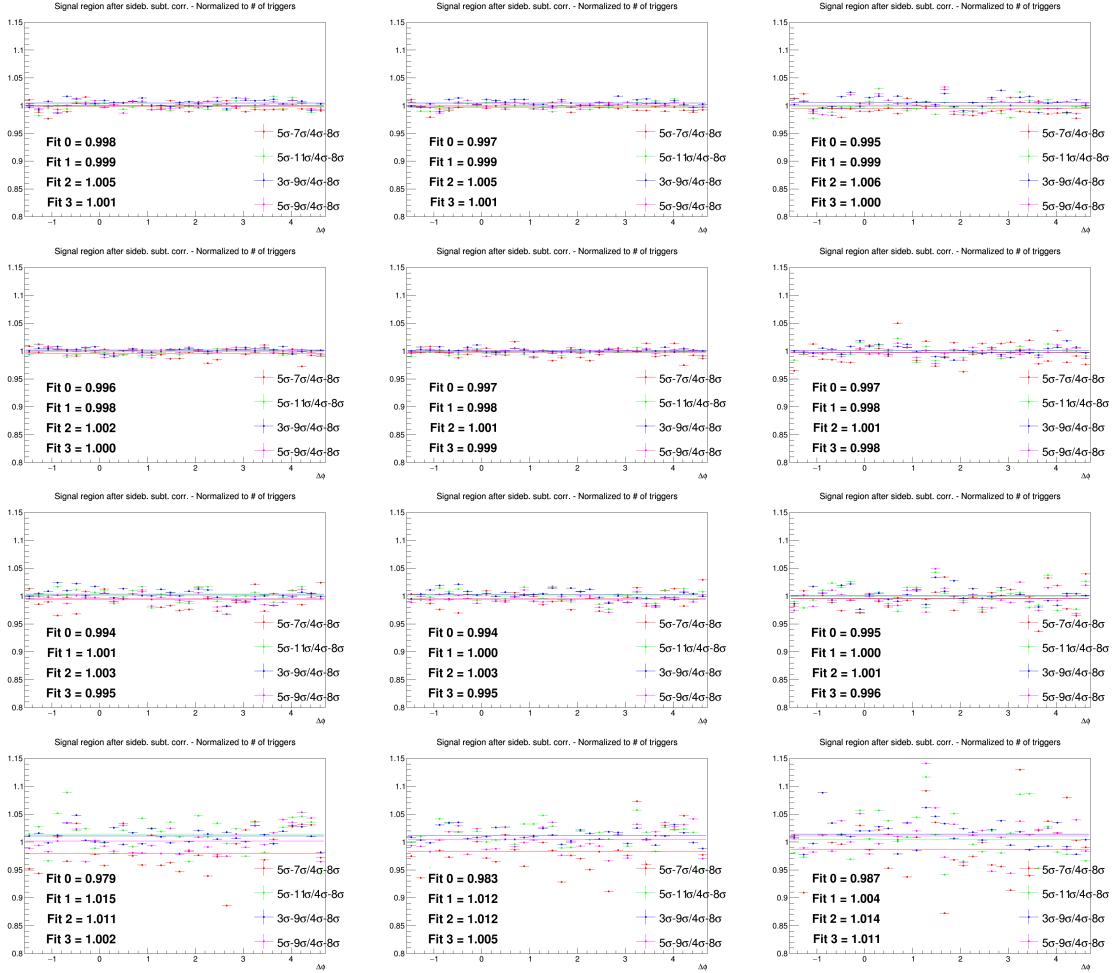


Figure 28: Ratios of $D^+ - h$ correlation plots obtained by changing the sideband ranges over those obtained with standard sideband ranges. Rows: $p_T(D^+)$ 3-5, 5-8, 8-16, 16-24 GeV/ c . In each row, the panels show the associated track p_T ranges 0.3-1, >0.3 GeV/ c and >1 GeV/ c , respectively.

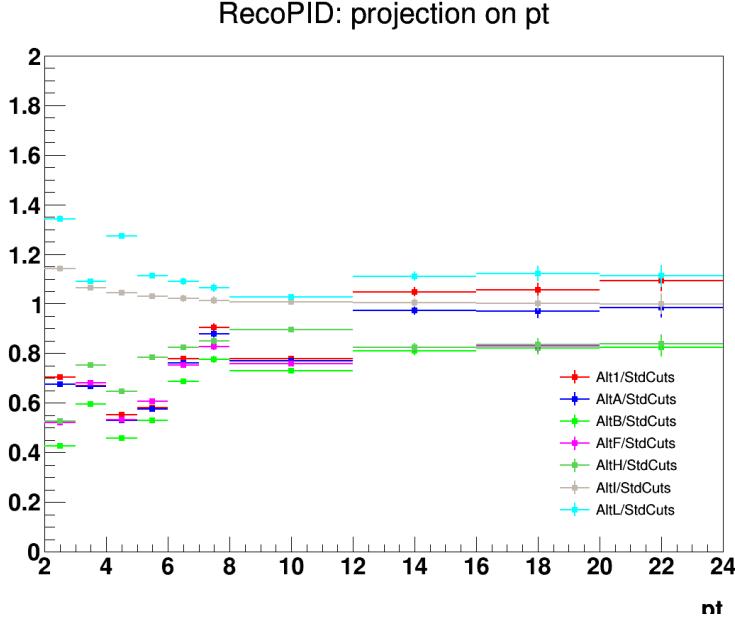


Figure 29: Ratio of D^0 efficiencies with alternate cut variations w.r.t. the standard cut used for the analysis.

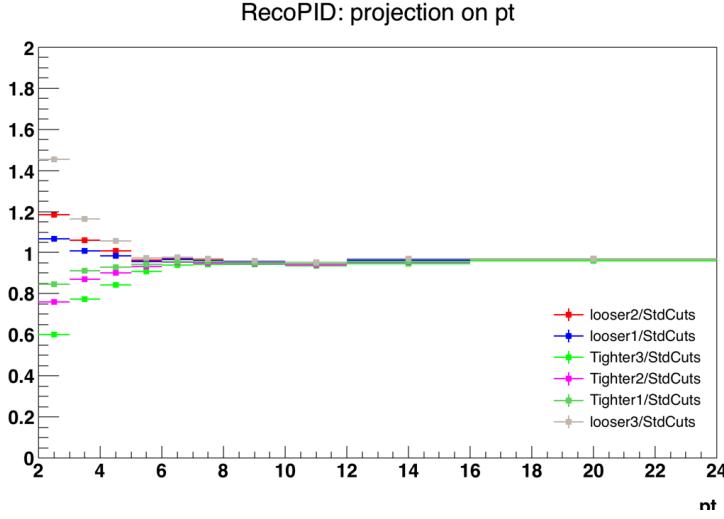


Figure 30: Ratio of D^{*+} efficiencies with alternate cut variations w.r.t. the standard cut used for the analysis.

558 4.5 Uncertainty on secondary particle contamination

559 Secondary particles, i.e. particles coming from strange hadrons decays or particles produced in interactions with the material, are expected to be tagged and removed by means of a distance of closest approach (DCA) from primary vertex cut. The uncertainty arising from the residual contamination of 560 secondary tracks can be estimated from a Monte Carlo study, at reconstructed level. The number of 561 primary/secondary tracks which are accepted/rejected from the DCA cut was determined for different 562 values of the DCA selection, and the correlation distributions for the various cases were evaluated. The 563 variations were done in the xy direction, where the DCA resolution is better, and the following cases 564 were tried (in addition to the default 1 cm cut): 0.1 cm, 0.25 cm, 0.5 cm, filtering DCA cut (i.e. 2.4 cm). 565

566 Figure 37 shows the amount of secondary tracks which are accepted by the DCA cut, over the total 567 number of tracks (primary and secondary) accepted by the selection, for the various DCA selections that 568 were tried. This is shown for the exemplary case of $5 < p_T < 8 \text{ GeV}/c$ (there's no $p_T(D)$ dependence) and 569 as a function of the associated track p_T ranges. Hence, this quantity represents the residual contamination 570

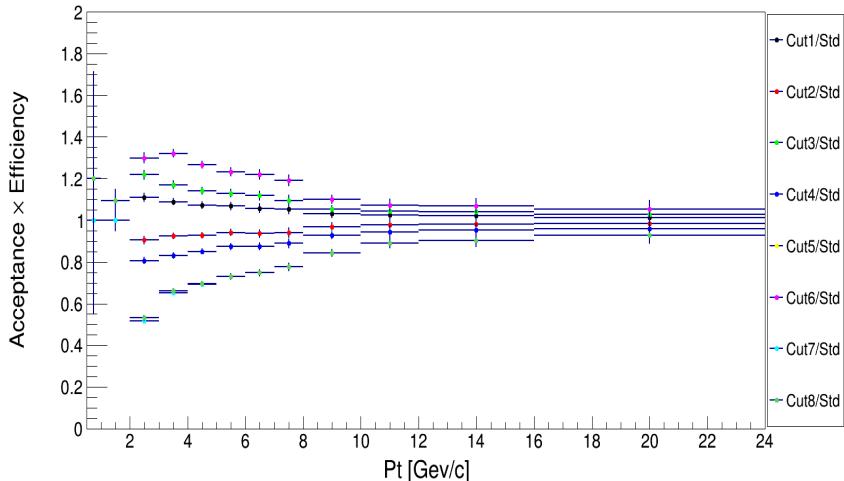


Figure 31: Ratio of D^+ efficiencies with alternate cut variations w.r.t. the standard cut used for the analysis.

of secondary tracks in our reconstructed track sample. From these values, the corresponding primary track purities (1-contamination) were extracted, in each of the momentum ranges. It was also verified that, for all the cut selections, the $\Delta\varphi$ distributions of the residual contaminations were flat within 1%.

As a second step of the procedure to verify the DCA cut stability, the D^0 -h data analysis was performed with all the different DCA selection (each time with the proper tracking efficiency map). After having extracted the correlation distributions, these were rescaled for the corresponding purities and compared with the purity-corrected correlation distributions obtained with the standard DCA selection. The ratios of the alternate selections over the standard selection, after the purity correction of both, are shown in Figures 38 and 39.

The ratios show a flat trend along the $\Delta\varphi$ axis and, in general, a discrepancy from the value of 1 of no more than 3% (the worst case being the 0.3-1 GeV/c range for the associated track). Hence, a flat and symmetric 3% systematical uncertainty on the evaluation of the secondary contamination was assigned on the base of this check in 0.3-1 GeV/c, reduced to 2.5% in > 0.3 GeV/c and to 1.5% for the other ranges. This amount also covers possible biases in the estimation of the purity (the $\Delta\varphi$ distribution of the residual contamination is always contained inside 1%, as previously said).

4.6 Uncertainty on feed-down subtraction

As described in the 3.3.5 section, the feed-down subtraction from the data distributions is performed by means of simulation templates of $B \rightarrow D$ -h correlation distributions from PYTHIA6 generator, with Perugia2011 tune, and considering the central value of f_{prompt} to extract the feed-down D-meson contribution. In order to evaluate a systematic uncertainty on this procedure, the feed-down subtraction procedure was repeated considering, together with PYTHIA6+Perugia2011 templates, also PYTHIA6+Perugia2010 and PYTHIA8 simulations. In each case, not only the central value of the measured f_{prompt} was considered to rescale the distributions, but also the maximum and minimum values of its total uncertainty.

Then, the envelope of nine the different cases obtained by varying the templates and the f_{prompt} assumption was considered, and a value of the systematics defined as the envelope spread divided by $\sqrt{3}$ was taken as systematic uncertainty. This uncertainty was assumed uncorrelated among the different $\Delta\varphi$ points.

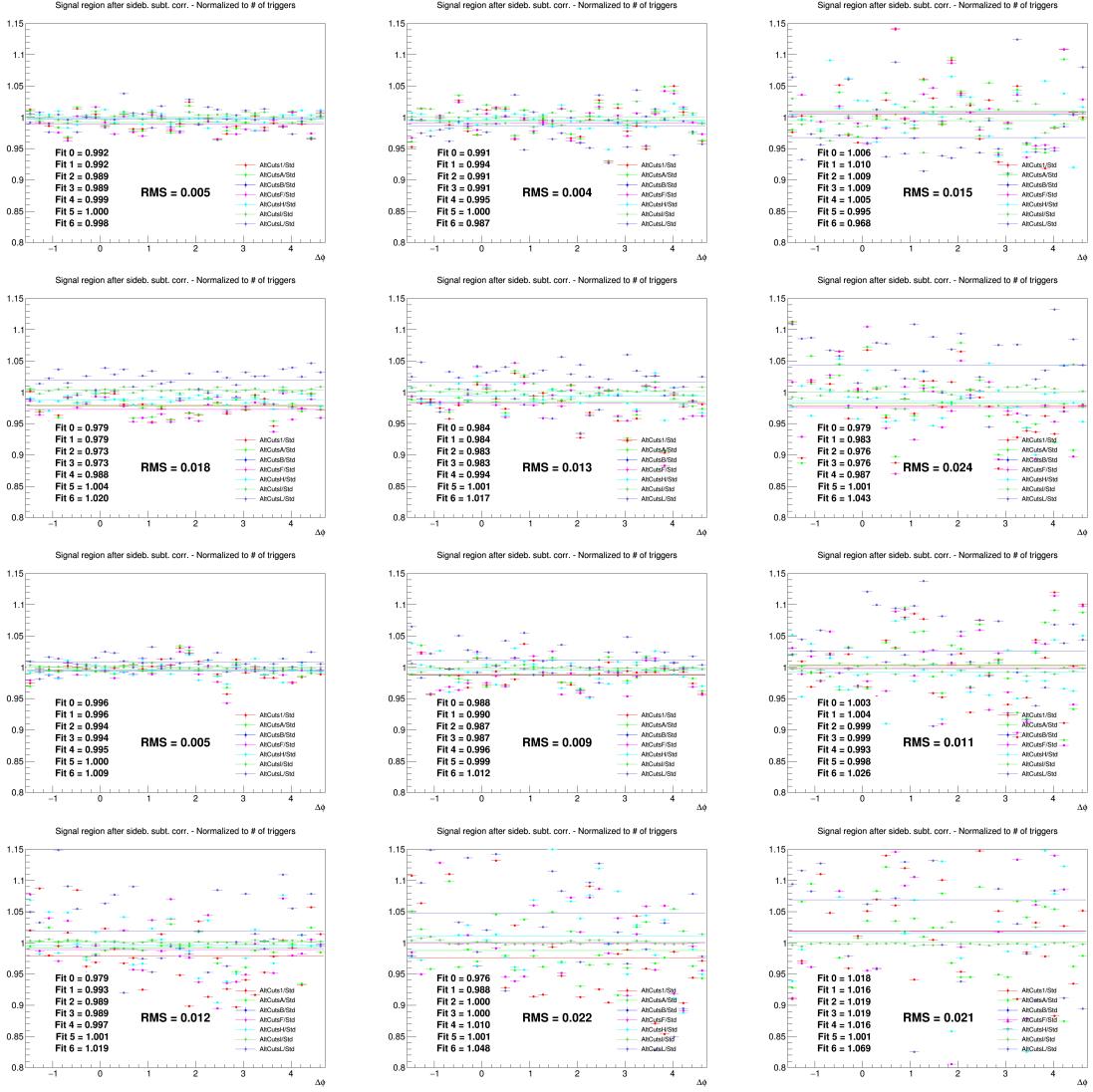


Figure 32: Ratios of D⁰-h correlation plots obtained with alternate D-meson cut sets over those obtained with standard selection. Rows: $p_T(D^0)$ 3-5, 5-8, 8-16, 16-24 GeV/c. In each row, the panels show the associated track p_T ranges 0.3-1, 1-2, 2-3 GeV/c, respectively.

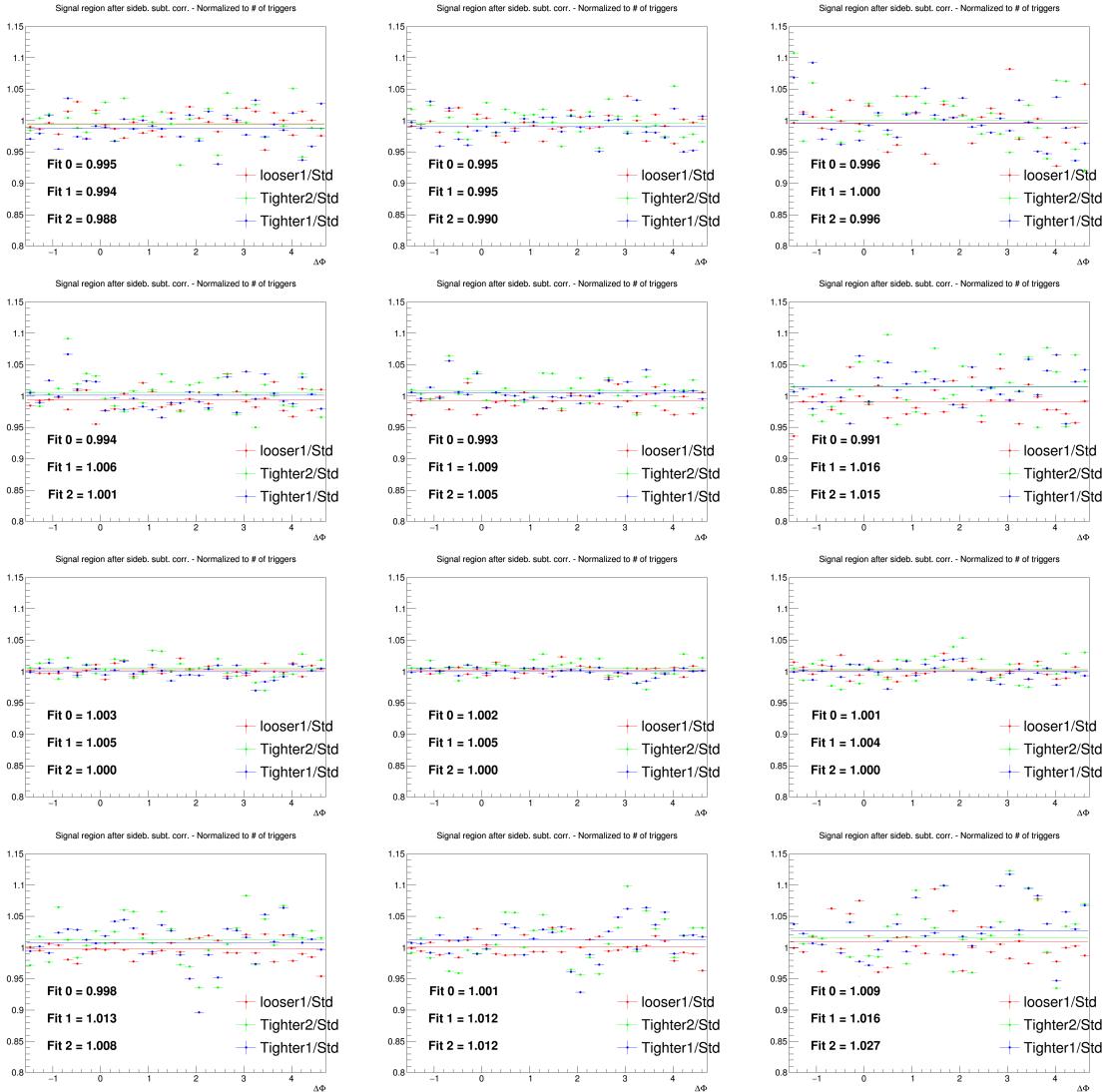


Figure 33: Ratios of $D^{*+} - h$ correlation plots obtained with alternate D-meson cut sets over those obtained with standard selection. Rows: $p_T(D^{*+})$ 3-5, 5-8, 8-16, 16-24 GeV/ c . In each row, the panels show the associated track p_T ranges 0.3-1, >0.3 GeV/ c , >1 GeV/ c , respectively.

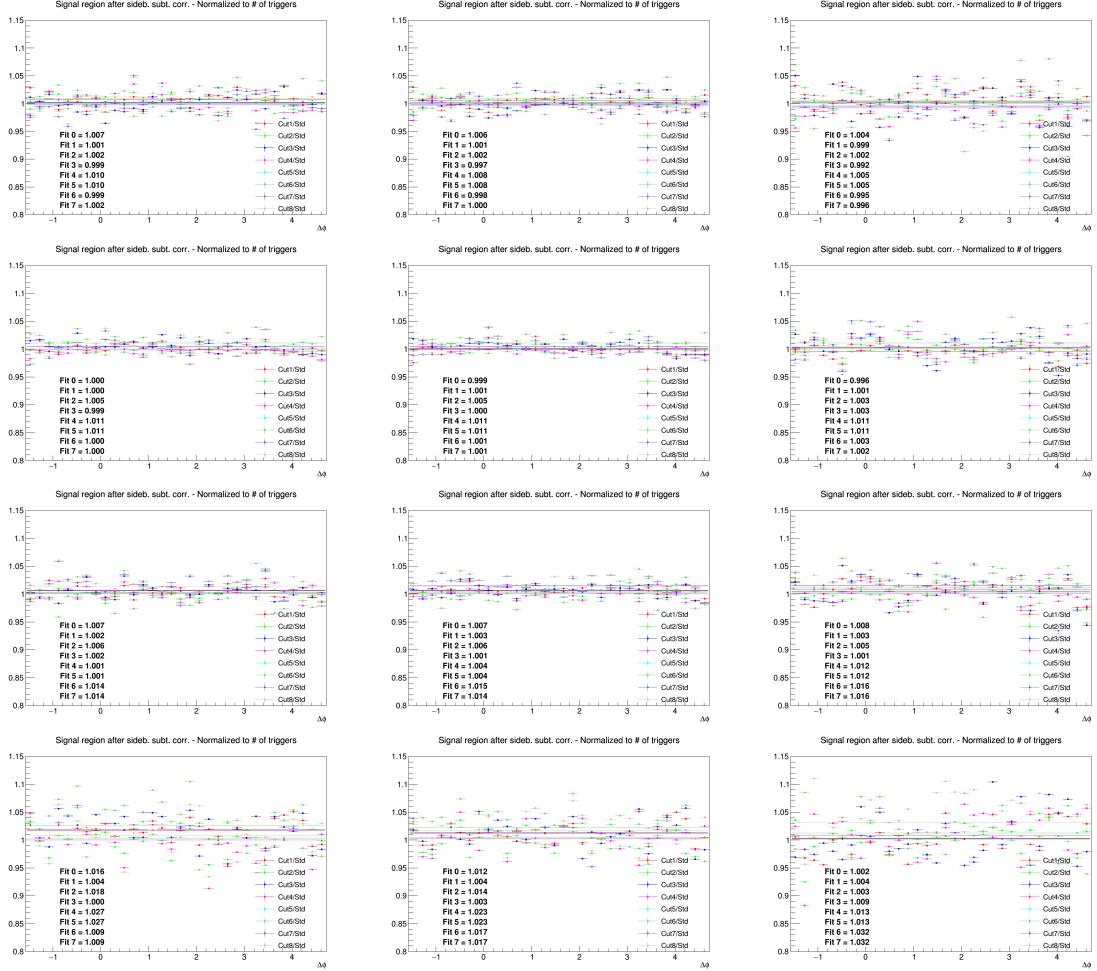


Figure 34: Ratios of D⁺ - h correlation plots obtained with alternate D-meson cut sets over those obtained with standard selection. Rows: p_T(D⁺) 3-5, 5-8, 8-16, 16-24 GeV/c. In each row, the panels show the associated track p_T ranges 0.3-1, >0.3 GeV/c, >1 GeV/c, respectively.

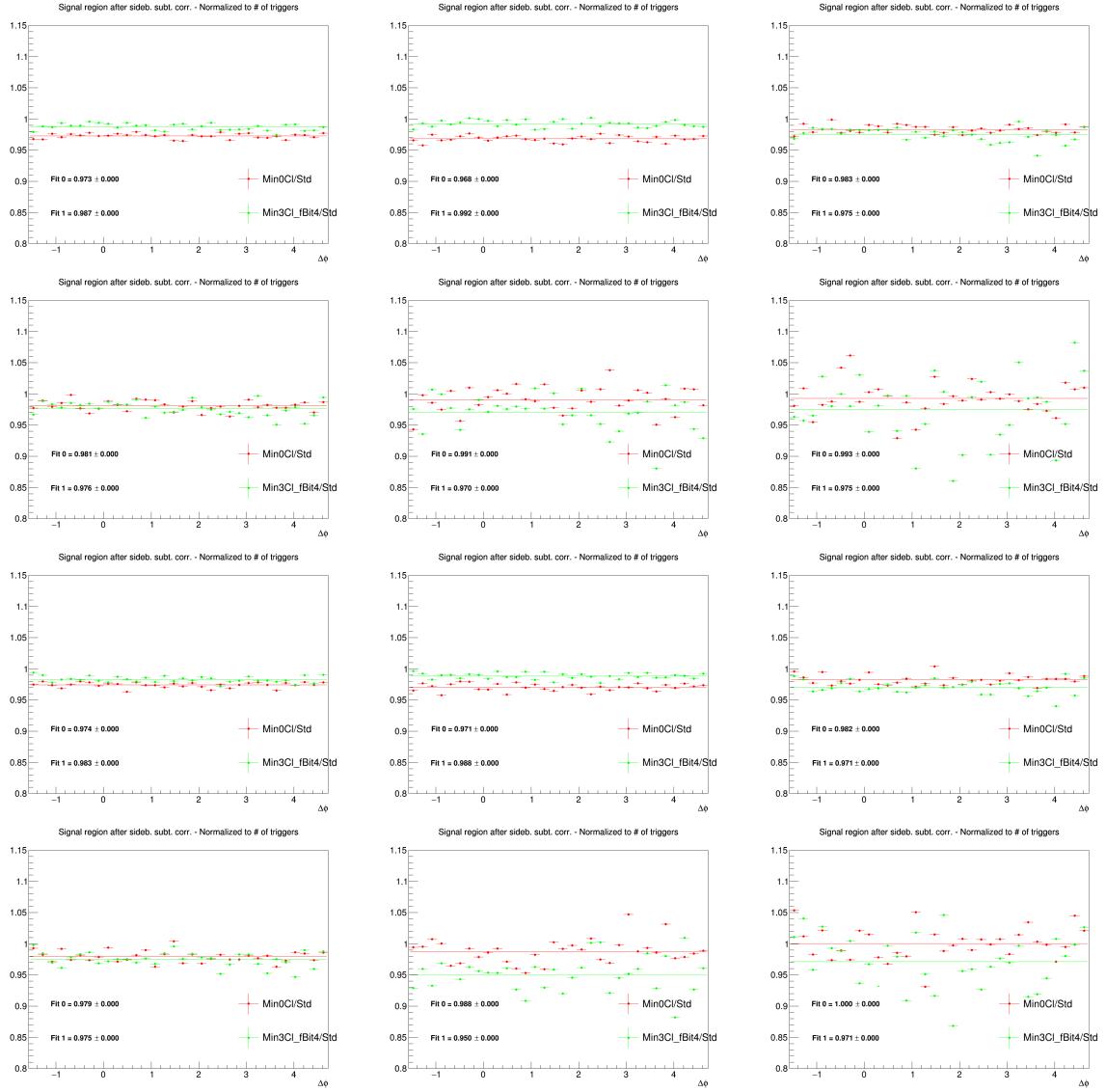


Figure 35: Ratios of D^0 - h correlation plots obtained with different associated tracks filtering selections. First 6 plots: $p_T(D)$ 3-5 GeV/ c , next 6 plots: $p_T(D)$ 5-8 GeV/ c . Each bunch of 6 plots has $p_T(\text{assoc})$ of >0.3 , 0.3-1, >1 , 1-2, 2-3, <3 GeV/ c , respectively.

598 4.7 Uncertainty on correction for the bias on B to D decay topologies

599 The evaluation of this systematic uncertainty was already explained in Section 3.3.3. For each of the
600 five data points close to the center of the near-side peak, which are affected by the bias, a bilateral and
601 symmetric uncertainty of amplitude $|C(\Delta\phi)_{\text{corr}} - C(\Delta\phi)_{\text{raw}}|/\sqrt{12}$ was assigned.

602 This because the uncorrected data points are expected to be the extreme (with the current D -meson
603 selection, the bias is always upwards at the centre of the peak, and always upwards on its sides). We
604 then assume that, if the correction is properly evaluated, the corrected data points are at the centre of the
605 possible spread of the true unbiased results. In this case, the span of the possible true results (in case
606 of underestimation/overestimation of the bias) goes from the uncorrected data points to its symmetric
607 value, with respect to the corrected data point, on the other direction. If this distribution is uniform,
608 and constrained by these two values, the 1σ confidence region for the position of the is in a bilateral
609 $|C(\Delta\phi)_{\text{corr}} - C(\Delta\phi)_{\text{raw}}|/\sqrt{12}$ window, centered on the $C(\Delta\phi)_{\text{corr}}$ points.



Figure 36: Ratios of D^0 - h correlation plots obtained with different associated tracks filtering selections. First 6 plots: $p_T(D) 8\text{-}16 \text{ GeV}/c$, next 6 plots: $p_T(D) 16\text{-}24 \text{ GeV}/c$. Each bunch of 6 plots has $p_T(\text{assoc})$ of >0.3 , $0.3\text{-}1$, >1 , $1\text{-}2$, $2\text{-}3$, $<3 \text{ GeV}/c$, respectively.

610 This source of uncertainty was assumed uncorrelated among the $\Delta\phi$ points.

611 4.8 Summary table

612 A summary of the $\Delta\phi$ -correlated uncertainties affecting the correlation distributions is show in Figure
613 40. They are the S and B extraction uncertainty, the background shape uncertainty, the cut variation
614 uncertainty, the tracking efficiency uncertainty and the secondary particle contamination uncertainty.

615 The overall amount of $\Delta\phi$ -correlated uncertainties is about 5-6% (depending on the p_T bin) for the single
616 D-meson cases; when evaluating the averages of the distributions (see next section), this uncertainty
617 shrinks to 4-5%. This uncertainty is a global scale factor of the distributions, and is quoted as a label in
618 the plots.

619 The systematics uncertainties from feed-down subtraction and $B\rightarrow D$ decay topology bias, instead are
620 $\Delta\phi$ dependent, and are hence reported as uncorrelated boxes in the plots. They do not amount to more
621 than 4%, in every bin of all the kinematic ranges studied.

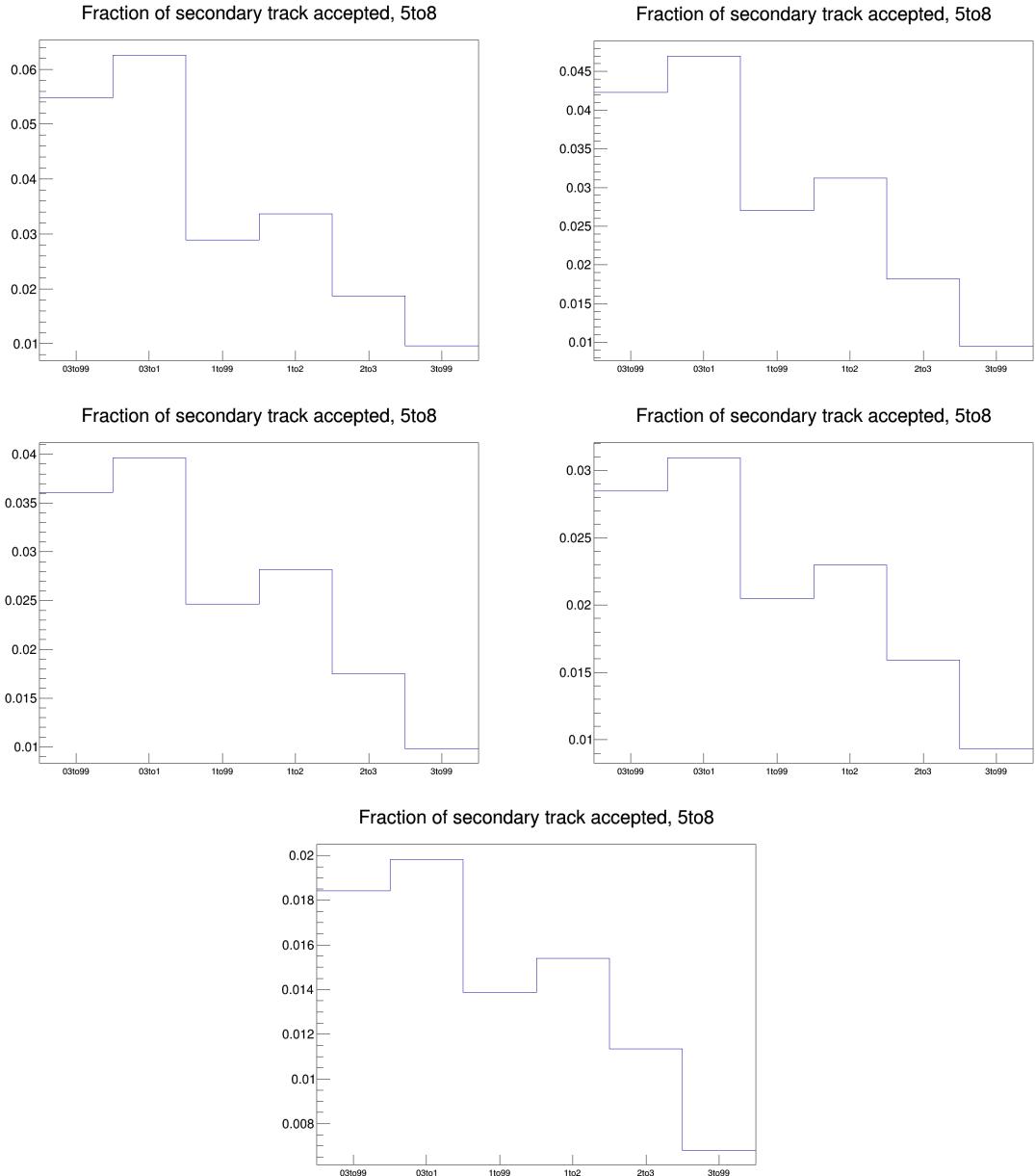


Figure 37: Secondary track contamination as a function of the associated track p_T , for the various DCA selections tried. The plots are ordered from the loosest to the tightest selection, i.e.: $DCA(xy) < 2.4 \text{ cm}$, $< 1 \text{ cm}$, $< 0.5 \text{ cm}$, $< 0.25 \text{ cm}$, $< 0.1 \text{ cm}$.

622 5 Results

623 5.1 Comparing the three D meson correlation distributions

624 To check the compatibility of three D meson analyses, Figure 41 shows the corrected azimuthal corre-
 625 lation distributions (except for the feed-down subtraction and the secondary contamination removal) for
 626 $D^0\text{-}h$, $D^{*+}\text{-}h$ and $D^+\text{-}h$, in each column, on the data sample used in the analysis. Results are shown for
 627 $3 < D p_T < 5 \text{ GeV}/c$, $5 < D p_T < 8 \text{ GeV}/c$, $8 < D p_T < 16 \text{ GeV}/c$ and $16 < D p_T < 24 \text{ GeV}/c$ with
 628 associated tracks $p_T > 0.3$, $p_T > 1$, $0.3 < p_T < 1 \text{ GeV}/c$, $1 < p_T < 2 \text{ GeV}/c$, $2 < p_T < 3 \text{ GeV}/c$ and
 629 $p_T > 3 \text{ GeV}/c$.

630 Figures 42, 43, 44, 45 show the superimposed correlation distributions from the single-meson analyses

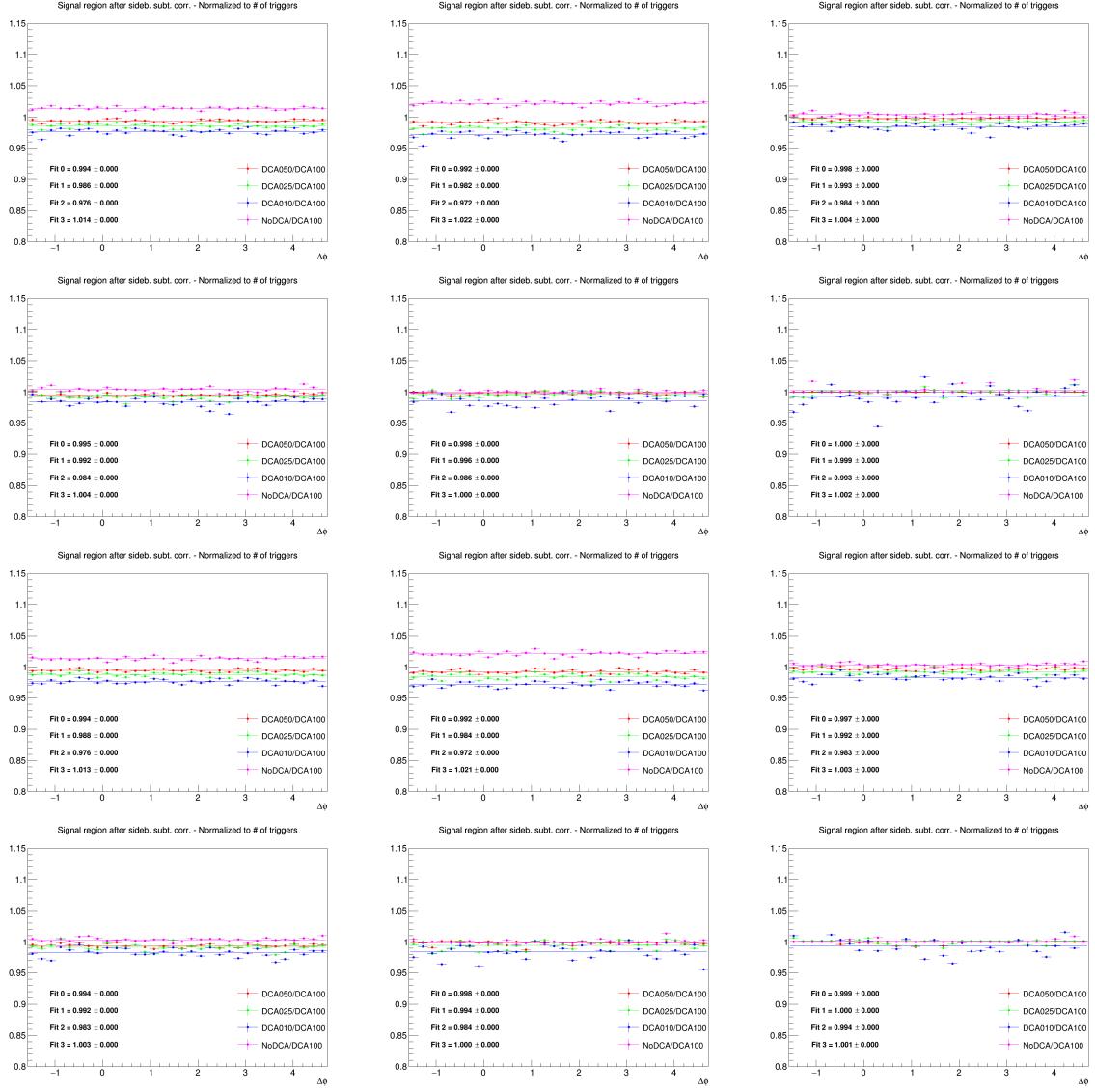


Figure 38: Ratios of correlation plots (with D^0 as trigger meson) obtained with different associated DCA selections, after purity correction. First 6 plots: $p_T(D)$ 3-5 GeV/ c , next 6 plots: $p_T(D)$ 5-8 GeV/ c . Each bunch of 6 plots has $p_T(\text{assoc})$ of >0.3, 0.3-1, >1, 1-2, 2-3, <3 GeV/ c , respectively.

631 (same plots as previous figure) for better visualize the agreement among the different D-meson species
632 results.

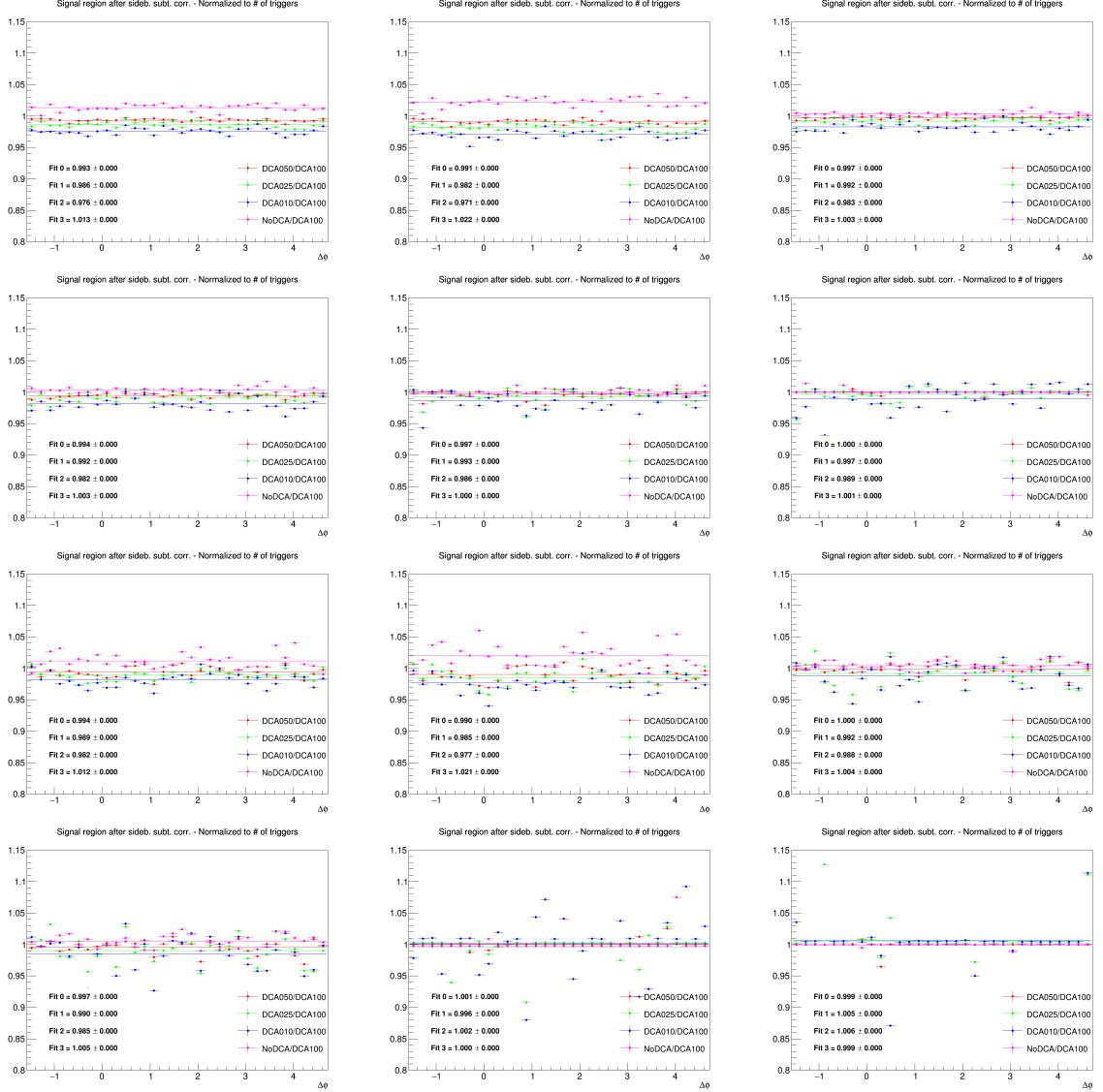


Figure 39: Ratios of correlation plots (with D^0 as trigger meson) obtained with different associated DCA selections, after purity correction. First 6 plots: $p_T(D)$ 8-16 GeV/ c , next 6 plots: $p_T(D)$ 16-24 GeV/ c . Each bunch of 6 plots has $p_T(\text{assoc})$ of >0.3 , 0.3-1, >1 , 1-2, 2-3, <3 GeV/ c , respectively.

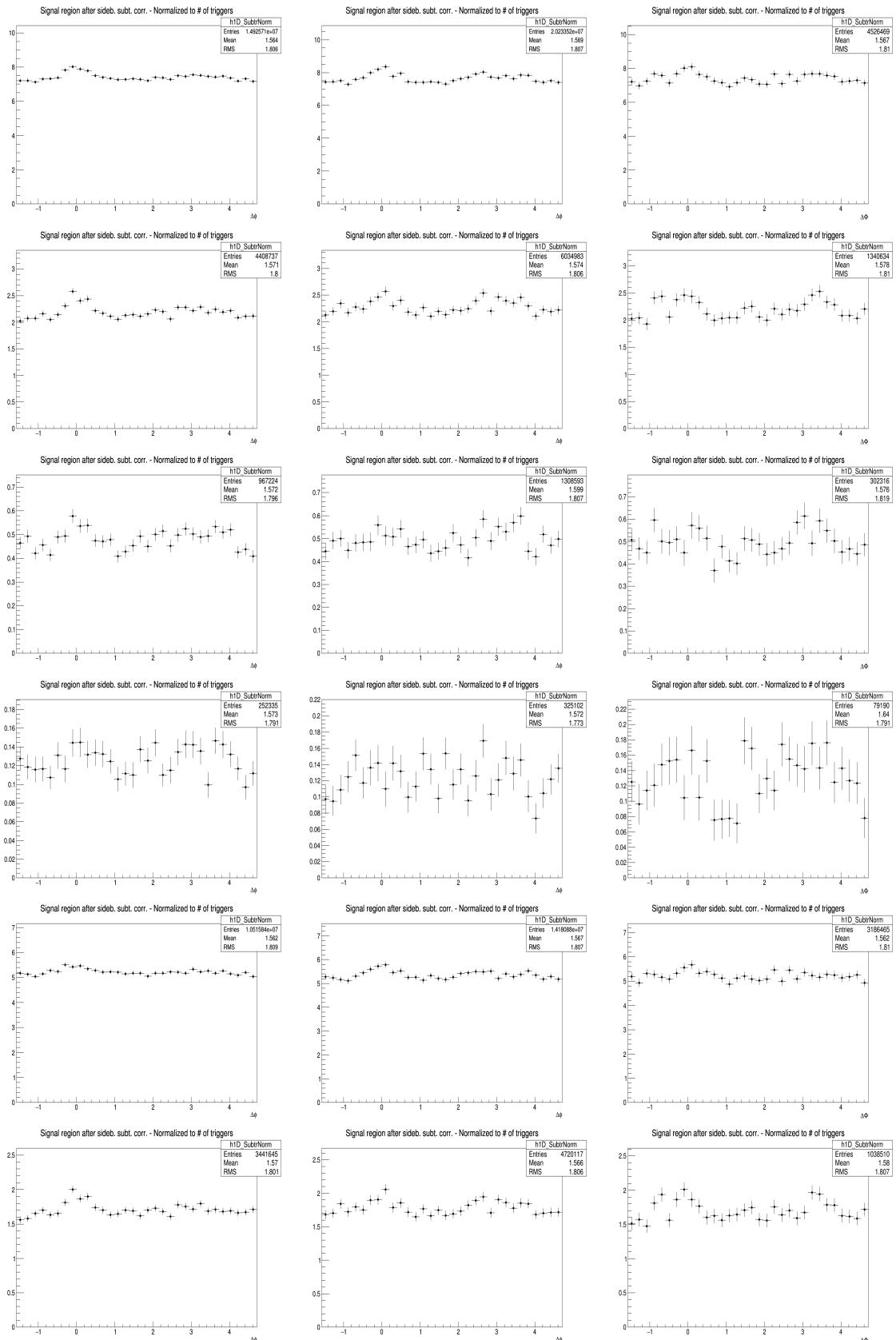
pPb Sample	D^0				D^*				D^+			
D Pt Range (GeV/c)	3-5	5-8	8-16	16-24	3-5	5-8	8-16	16-24	3-5	5-8	8-16	16-24
S and B Extraction	1%	1%	1%	3%	1%	1%	1%	2%	1%	1%	1%	2%
Background Correlation Shape	1%	1%	1%	3%	1%	1%	1%	3%	1%	1%	1%	3%
D meson Cut Variation	2%	2%	2%	2%	1.5%	1.5%	1%	1%	1%	1%	1%	3%

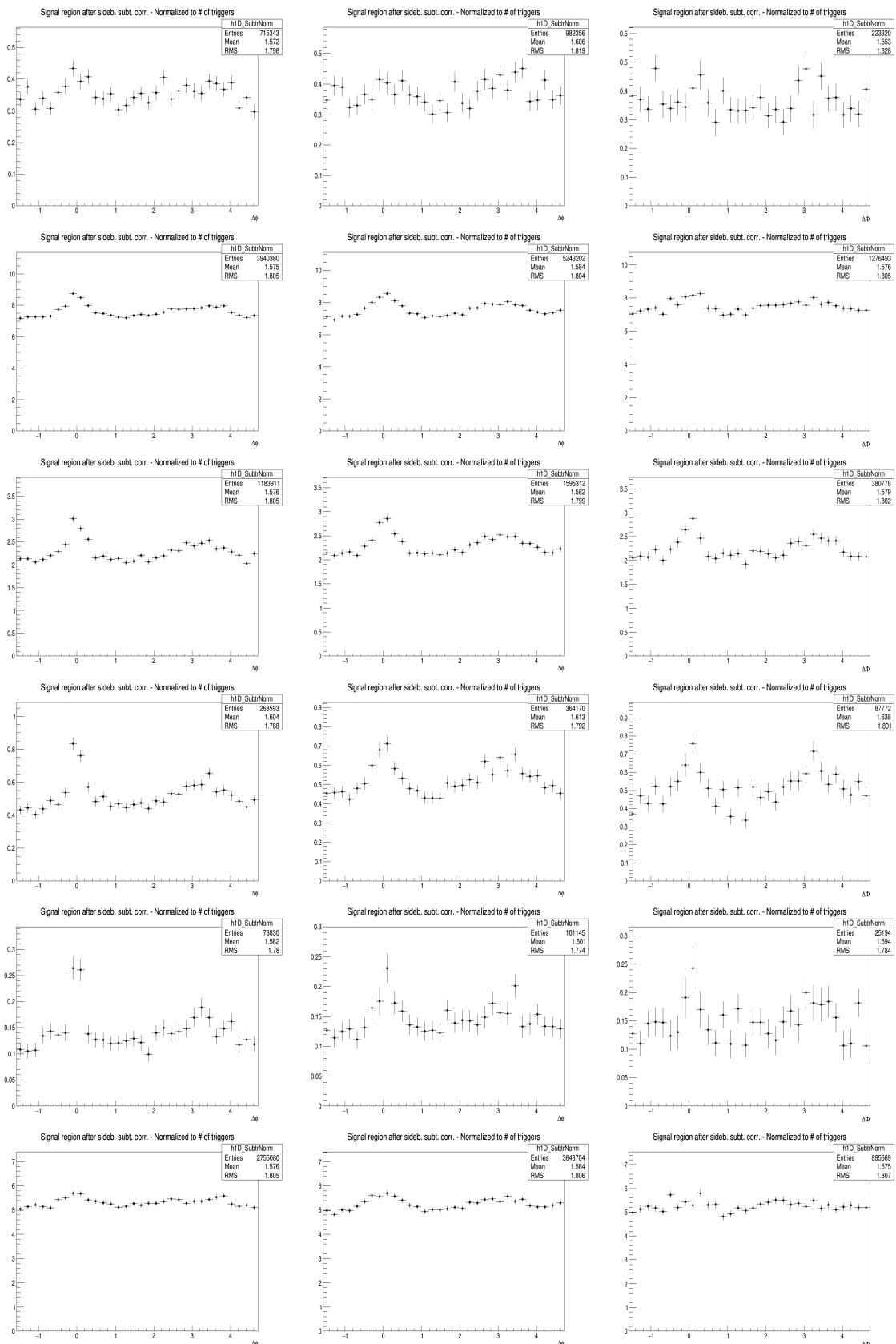
pPb Sample	D^0, D^* and D^+ (common for all the $p_T(D)$ ranges)						
Assoc (p_T) Ranges (GeV/c)	> 0.3	> 1.0	> 2.0	> 3.0	0.3-1.0	1.0-2.0	2.0-3.0
Track Efficiency	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%
Purity	2.5%	1.5%	1.5%	1.5%	3%	1.5%	1.5%

Figure 40: Summary of the $\Delta\phi$ -correlated uncertainties associated to the correlation distributions, for three D-mesons, in the different kinematic ranges of D meson and hadrons.

5.1 Comparing the three D meson correlation distributions

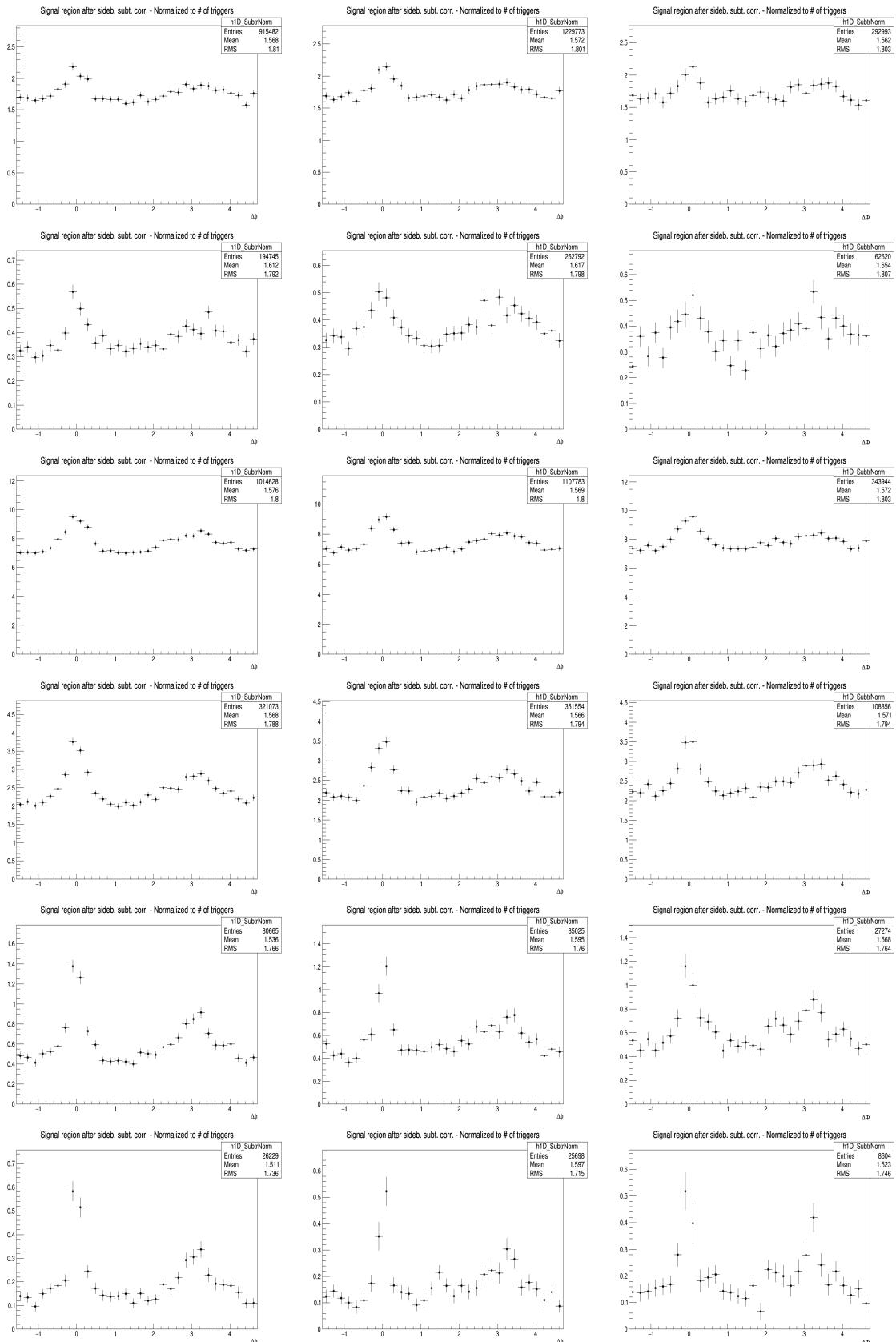
57

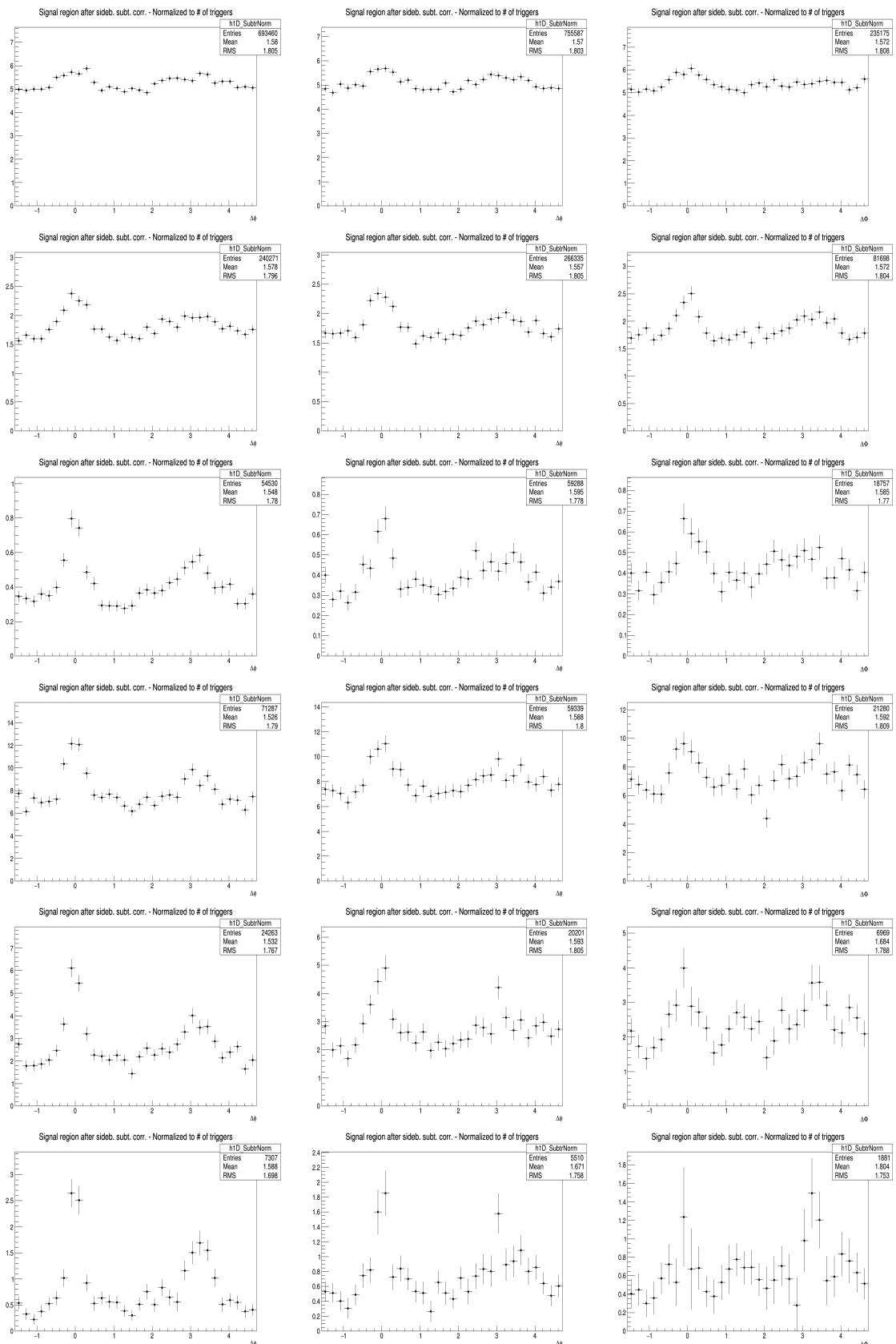




5.1 Comparing the three D meson correlation distributions

59





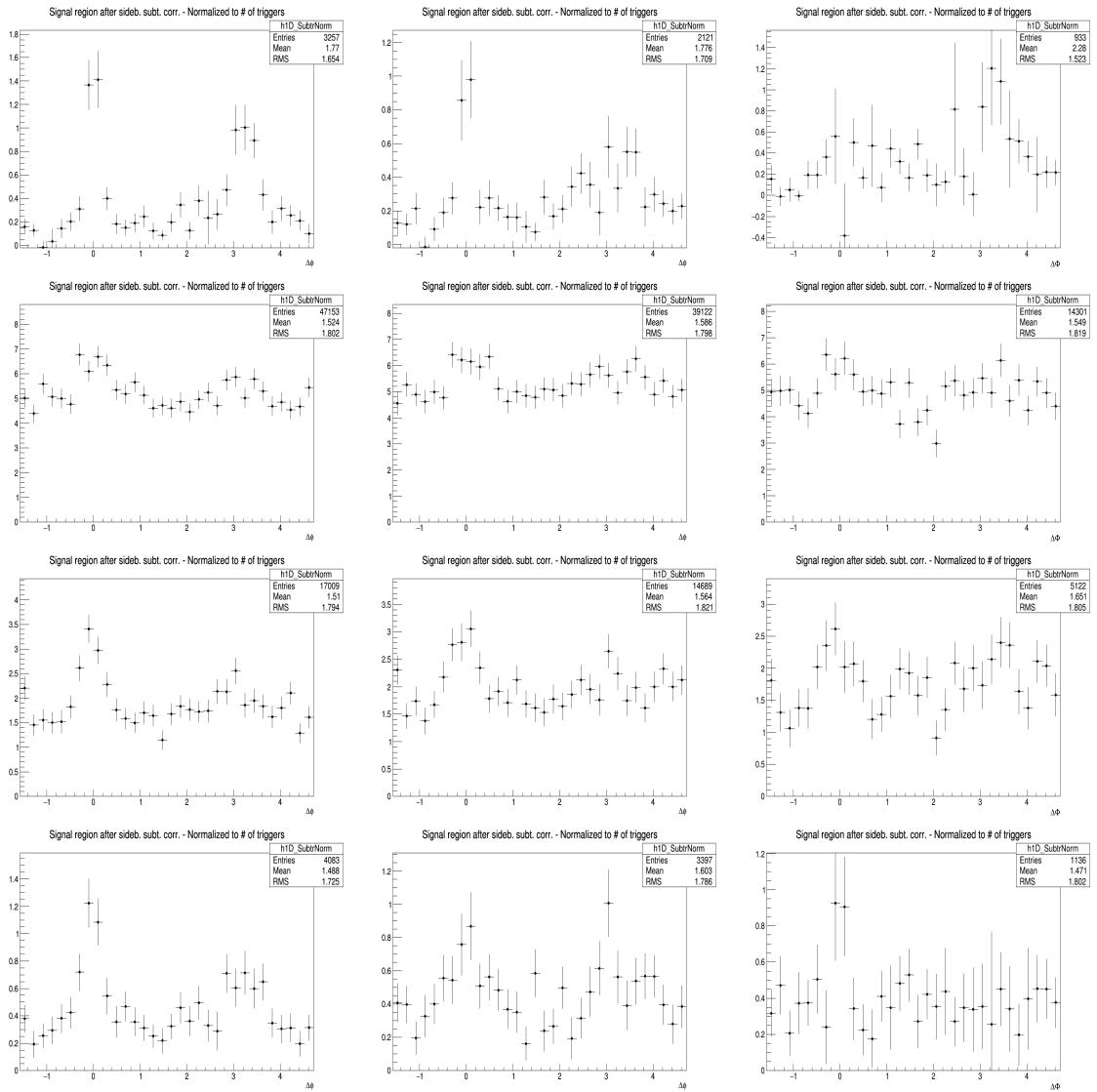


Figure 41: Corrected distribution of D-hadrons azimuthal correlations for the three species (apart from feed-down and purity), from analysis on the data sample, for the analyzed D-meson (**Column-Left:** D^0 , **Column-Middle:** D^+ and **Column-Right:** D^{*+}) and different associated tracks p_T ranges (**Row 1-7:** $3 < Dp_T < 5 \text{ GeV}/c$, $p_T (\text{Assoc}) > 0.3, > 1.0, > 2.0, > 3.0, 0.3-1.0, 1.0-2.0$ and $2.0-3.0 \text{ GeV}/c$ respectively), (**Row 8-14:** $5 < Dp_T < 8 \text{ GeV}/c$, $p_T (\text{Assoc}) > 0.3, > 1.0, > 2.0, > 3.0, 0.3-1.0, 1.0-2.0$ and $2.0-3.0 \text{ GeV}/c$ respectively), (**Row 15-21:** $8 < Dp_T < 16 \text{ GeV}/c$, $p_T (\text{Assoc}) > 0.3, > 1.0, > 2.0, > 3.0, 0.3-1.0, 1.0-2.0$ and $2.0-3.0 \text{ GeV}/c$ respectively) and (**Row 22-28:** $16 < Dp_T < 24 \text{ GeV}/c$, $p_T (\text{Assoc}) > 0.3, > 1.0, > 2.0, > 3.0, 0.3-1.0, 1.0-2.0$ and $2.0-3.0 \text{ GeV}/c$ respectively)

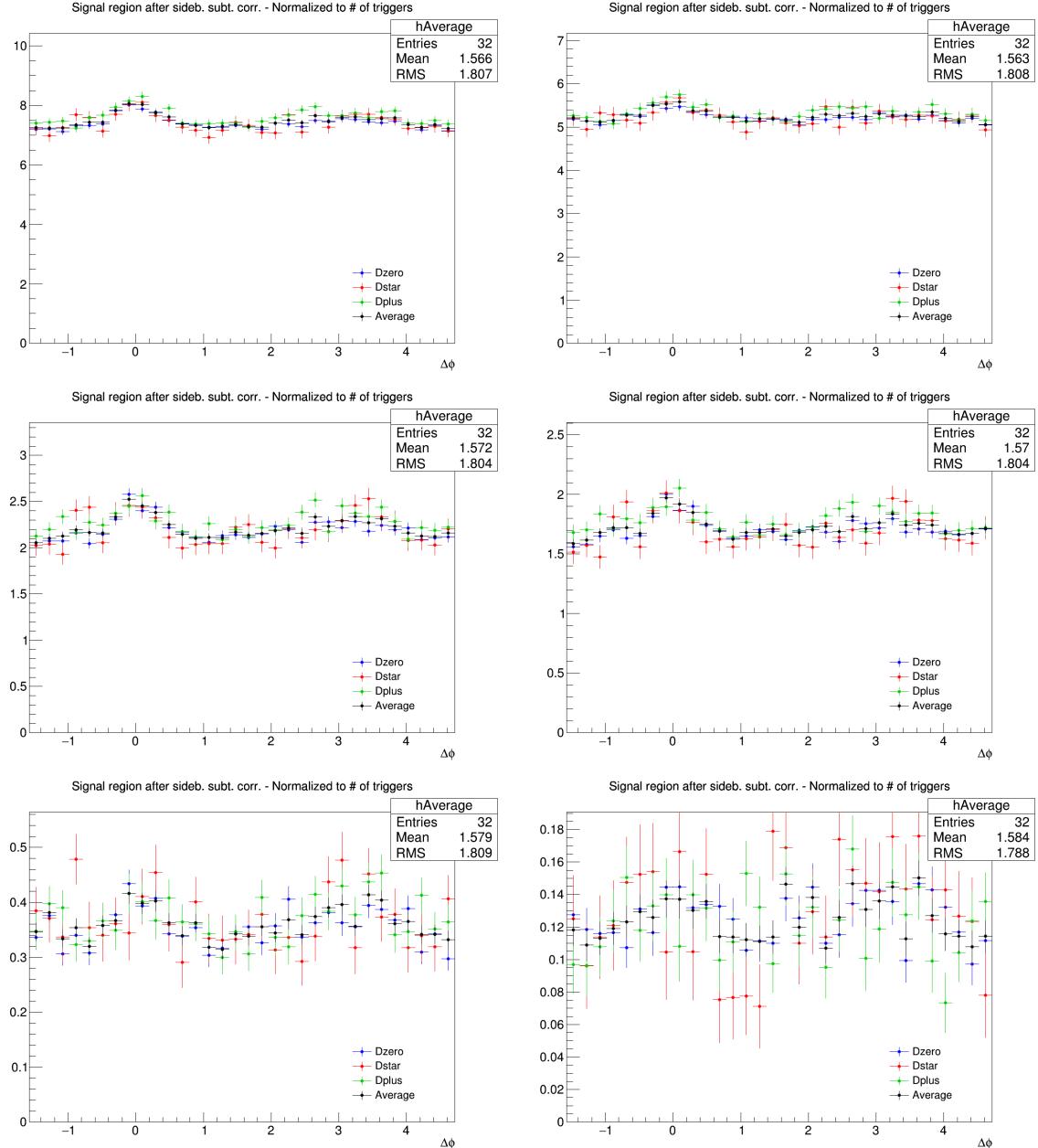


Figure 42: Superimposition of the corrected distribution of D-hadrons azimuthal correlations for the three species (apart from feed-down and purity), from analysis on the data sample, for the analyzed D-meson and different associated track p_T ranges, and D-meson p_T ranges (3-5 GeV/c on this page). **Panels from 1 to 6 of each page:** p_T (Assoc) > 0.3, 0.3-1.0, >1.0, 1.0-2.0, 2.0-3.0 and >3.0 GeV/c

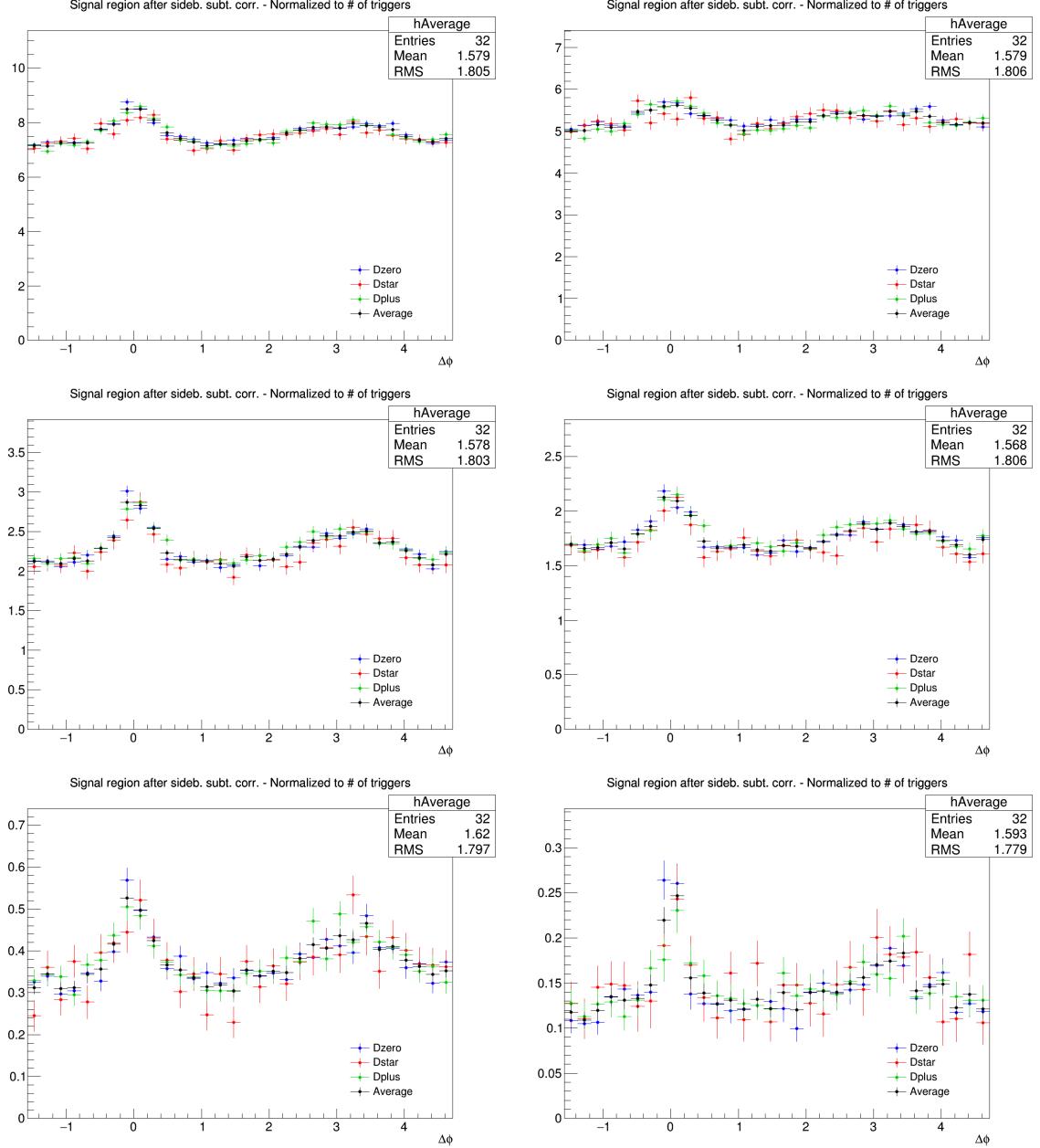


Figure 43: Superimposition of the corrected distribution of D-hadrons azimuthal correlations for the three species (apart from feed-down and purity), from analysis on the data sample, for the analyzed D-meson and different associated track p_T ranges, and D-meson p_T ranges (5-8 GeV/c on this page). **Panels from 1 to 6 of each page:** $p_T(\text{Assoc}) > 0.3, 0.3-1.0, >1.0, 1.0-2.0, 2.0-3.0 and $>3.0 \text{ GeV}/c$$

633 An agreement of the distributions from the three mesons within the uncertainties is found in all the
 634 kinematic ranges.

635 Despite being evaluated in the full 2π range, the range of final results was then reduced to $[0, \pi]$ radians,
 636 reflecting the points outside that range over the value of 0. This allowed to reduce the impact of statistical
 637 fluctuations on the data points (supposing equal statistics for a pair of symmetric bins, after the reflection
 638 the relative statistical uncertainty for the resulting bin is reduced by a factor $1/\sqrt{2}$).

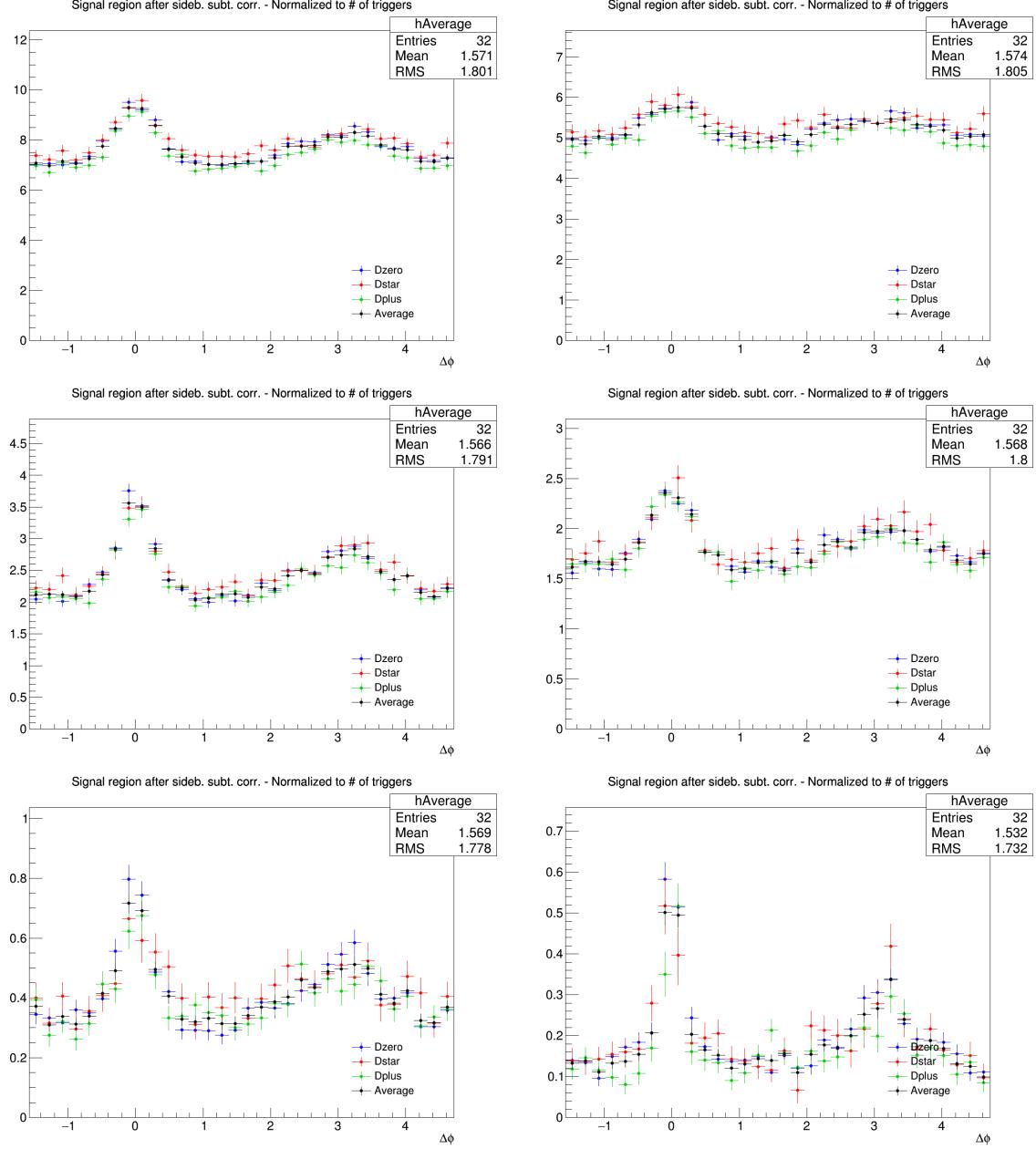


Figure 44: Superimposition of the corrected distribution of D-hadrons azimuthal correlations for the three species (apart from feed-down and purity), from analysis on the data sample, for the analyzed D-meson and different associated track p_T ranges, and D-meson p_T ranges (8-16 GeV/c on this page). **Panels from 1 to 6 of each page:** p_T (Assoc) > 0.3, 0.3-1.0, >1.0, 1.0-2.0, 2.0-3.0 and >3.0 GeV/c

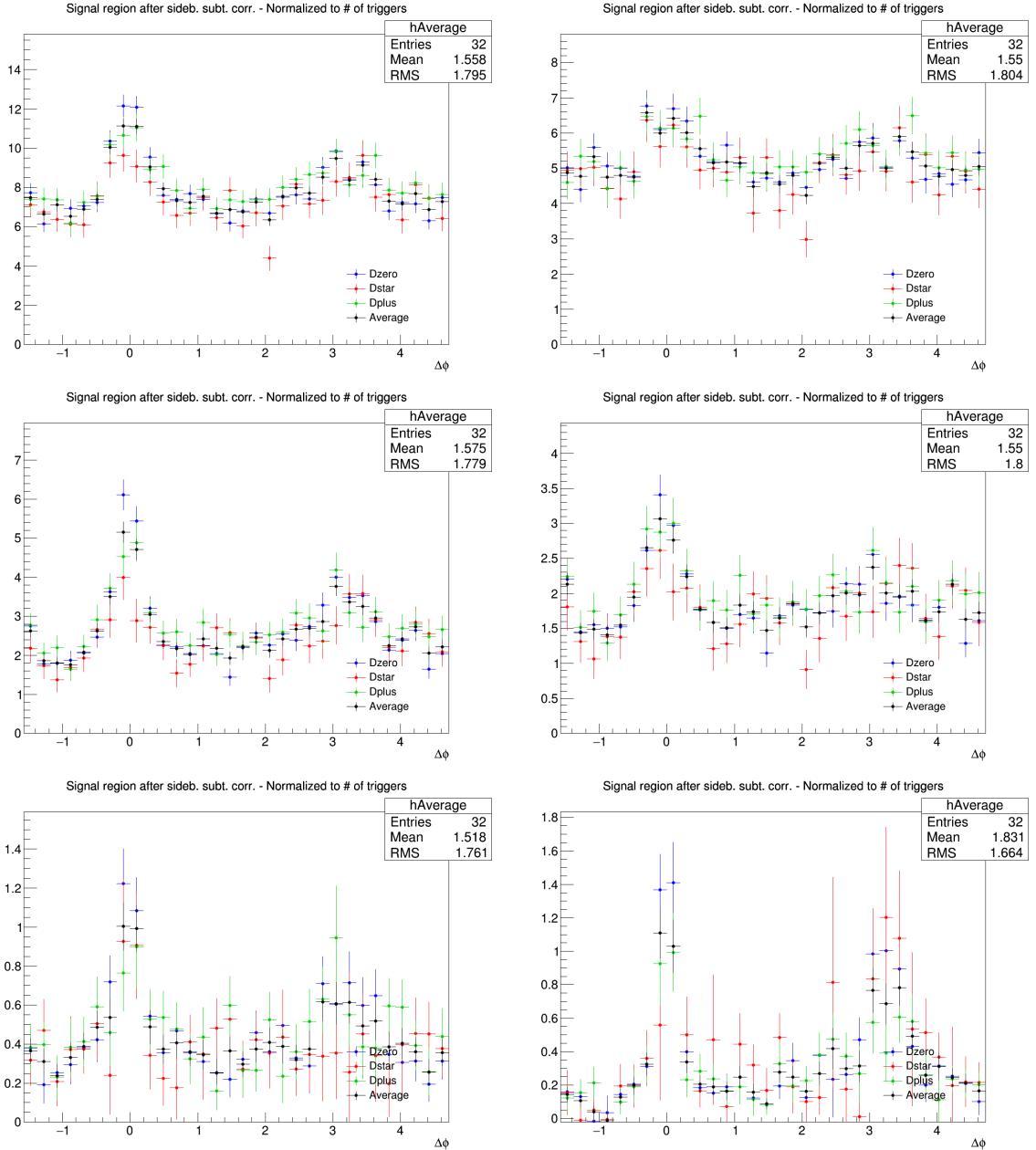


Figure 45: Superimposition of the corrected distribution of D-hadrons azimuthal correlations for the three species (apart from feed-down and purity), from analysis on the data sample, for the analyzed D-meson and different associated track p_T ranges, and D-meson p_T ranges (16-24 GeV/c on this page). **Panels from 1 to 6 of each page:** $p_T(\text{Assoc}) > 0.3, 0.3-1.0, >1.0, 1.0-2.0, 2.0-3.0 and $>3.0 \text{ GeV}/c$$

639 **5.2 Average of D⁰, D⁺ and D^{*+} results**

640 Given the compatibility within the uncertainties among the D⁰, D⁺ and D^{*+} azimuthal correlations, and
 641 since no large differences are visible in the correlation distributions observed in Monte Carlo simulations
 642 based on Pythia with Perugia0, 2010 and 2011 tunes¹, it was possible to perform a weighted average
 643 (eq. 5) of the azimuthal correlation distributions of D⁰, D⁺ and D^{*+}, in order to reduce the overall
 644 uncertainties. Although some correlation between the mesons could be present (about the 30% of the
 645 D⁰, and also part of the D⁺, come from D^{*+} decays), the three selected D-meson samples can be treated
 646 as uncorrelated. The sum of the statistical uncertainties; the systematics uncertainty on S and B extraction
 647 and on background shape, are added in quadrature and the inverse of this sum was used as weight, w_i .

$$\left\langle \frac{1}{N_D} \frac{dN_{\text{assoc}}}{dp_T} \right\rangle_{D\text{mesons}} = \frac{\sum_{i=\text{meson}} w_i \frac{1}{N_D} \frac{dN_i^{\text{assoc}}}{d\Delta\phi}}{\sum_{i=\text{meson}} w_i}, w_i = \frac{1}{\sigma_{i,\text{stat}}^2 + \sigma_{i,\text{uncorr.syst}}^2} \quad (5)$$

648 The statistical uncertainty and the uncertainties on S and B extraction and on background shape (those
 649 used for the weights) on the average were then recalculated using the following formula:

$$\sigma^2 = \frac{1}{n_D} \frac{\sum_{i=\text{meson}} w_i \sigma_i^2}{\sum_{i=\text{meson}} w_i} \quad (6)$$

650 where n_D is the number of mesons considered in the average. It can be observed that for $\sigma_i^2 = 1/w_i$ the
 651 formula coincides with the standard one giving the uncertainty on a weighted average. The contribution
 652 to the average systematic uncertainty for those uncertainty sources not included in the weight definition,
 653 was evaluated via error propagation on the formula of the weighted average (5), resulting in equation
 654 (7) and (8) for sources considered uncorrelated and correlated among the mesons. In particular, the
 655 uncertainties on the associated track reconstruction efficiency, on the contamination from secondary, on
 656 the feed-down subtraction, and that resulting from the Monte Carlo closure test were considered fully
 657 correlated among the mesons, while those deriving from the yield extraction (included in the weight
 658 definition) and on the D meson reconstruction and selection efficiency were treated as uncorrelated.

$$\sigma^2 = \frac{\sum_{i=\text{meson}} w_i^2 \sigma_i^2}{(\sum_{i=\text{meson}} w_i)^2} \quad (7)$$

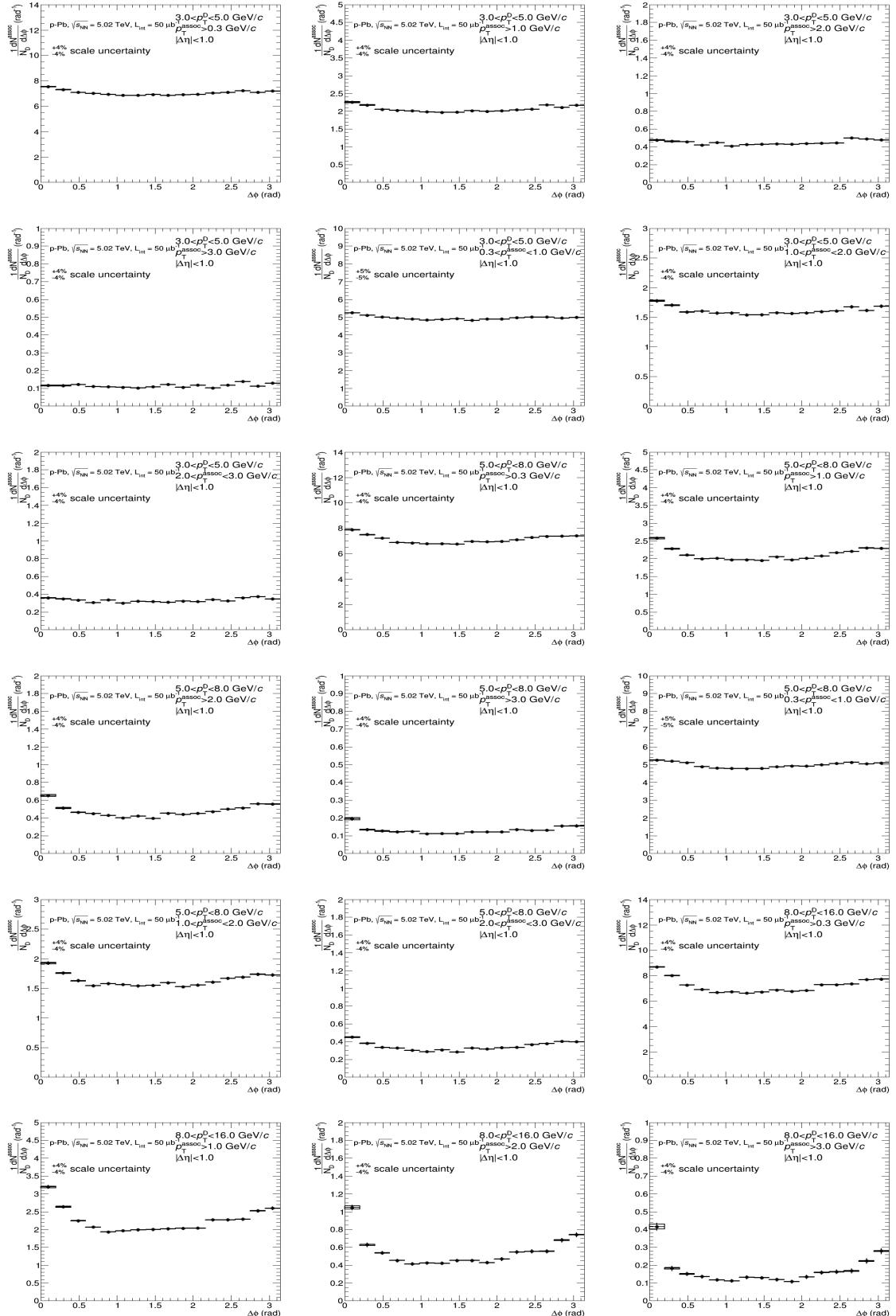
$$\sigma = \frac{\sum_{i=\text{meson}} w_i \sigma_i}{\sum_{i=\text{meson}} w_i} \quad (8)$$

659 Figure 46 shows the averages of the azimuthal correlation distributions of D⁰, D⁺ and D^{*+} and charged
 660 particles with $p_T > 0.3$ GeV/c, $0.3 < p_T < 1$ GeV/c, $p_T > 1$ GeV/c, $1 < p_T < 2$ GeV/c, $2 < p_T <$
 661 3 GeV/c, $p_T < 3$ GeV/c in the D meson p_T ranges $3 < p_T < 5$ GeV/c, $5 < p_T < 8$ GeV/c, $8 < p_T <$
 662 16 GeV/c and $16 < p_T < 24$ GeV/c. As expected, a rising trend of the height of the near-side peak
 663 with increasing D-meson p_T is observed, together with a decrease of the baseline level with increasing
 664 p_T of the associated tracks. To further increase the statistical precision on the averaged correlation
 665 distributions, given the symmetry around 0 on the azimuthal axis, the distributions were reflected and
 666 shown in the range $[0, \pi]$. This reduces the statistical uncertainty on the points by, approximately, a factor
 667 of $1/\sqrt{2}$.

¹A slight near side hierarchy is present among the three meson results, with D^{*+} meson having a lower peak amplitude than D⁰ and D⁺. It was verified that this is induced by the presence of D⁰ and D⁺ mesons coming from D^{*+}, the latter having on average a larger p_T and coming, hence, on average, from a larger p_T quark parton, which fragments in slightly more tracks in the near-side.

5.2 Average of D^0 , D^+ and D^{*+} results

67



668 The usage of weighted average requires, as an underlying assumption, identical results expected for
 669 different species (or, at least, compatible within the uncertainties). Anyway, it was also verified that the
 670 usage of the arithmetic average instead of the weighted average increases the uncertainties on the points,

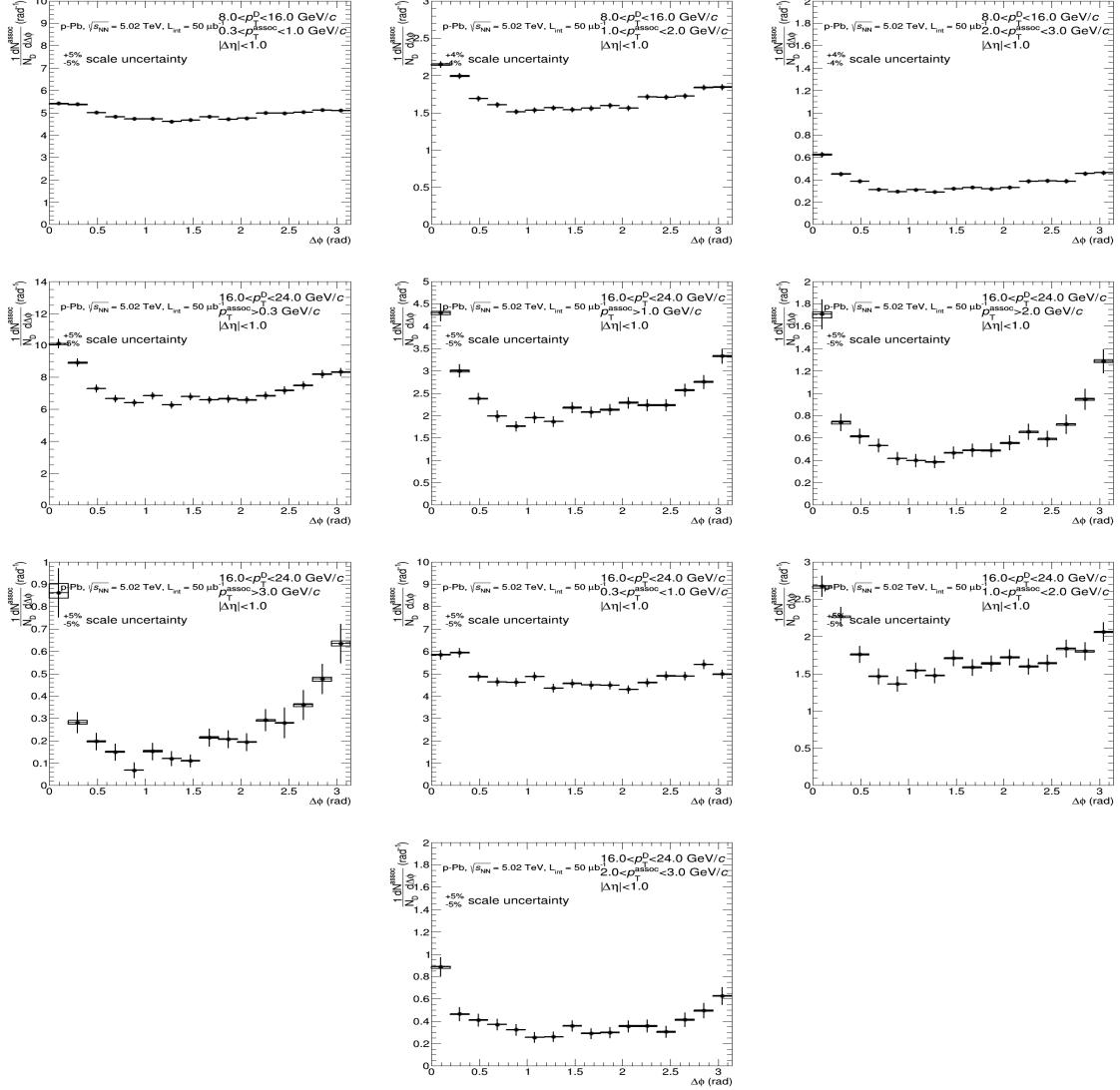


Figure 46: Average of D^0 , D^+ and D^{*+} azimuthal correlation distributions, in the D meson p_T ranges $3 < p_T < 5$ GeV/c, $5 < p_T < 8$ GeV/c, $8 < p_T < 16$ GeV/c and $16 < p_T < 24$ GeV/c, with associated tracks with $p_T > 0.3$ GeV/c, $p_T > 1$ GeV/c and $0.3 < p_T < 1$ GeV/c.

671 but produces a negligible shift of their central values.

672 5.3 Fit observable p_T trends and uncertainties

673 In order to extract quantitative and physical information from the data correlation patterns, the averaged
 674 D-h correlation distributions are fitted with two Gaussian functions (with means fixed at $\Delta\varphi=0$ and $\Delta\varphi=\pi$
 675 values), plus a constant term (baseline). A periodicity condition is also applied to the fit function to obtain
 676 the same value at the bounds of 2π range. The expression of the fit function is reported below (equation
 677 9):

$$f(\Delta\varphi) = c + \frac{Y_{NS}}{\sqrt{2\pi}\sigma_{NS}} e^{-\frac{(\Delta\varphi-\mu_{NS})^2}{2\sigma_{NS}^2}} + \frac{Y_{AS}}{\sqrt{2\pi}\sigma_{AS}} e^{-\frac{(\Delta\varphi-\mu_{AS})^2}{2\sigma_{AS}^2}} \quad (9)$$

678 where baseline is calculated as the weighted average of the points lying in the so-called "transverse
 679 region", i.e. the interval $\frac{\pi}{4} < |\Delta\varphi| < \frac{\pi}{2}$.

680 An example of the results from the fit is shown in Figure 47

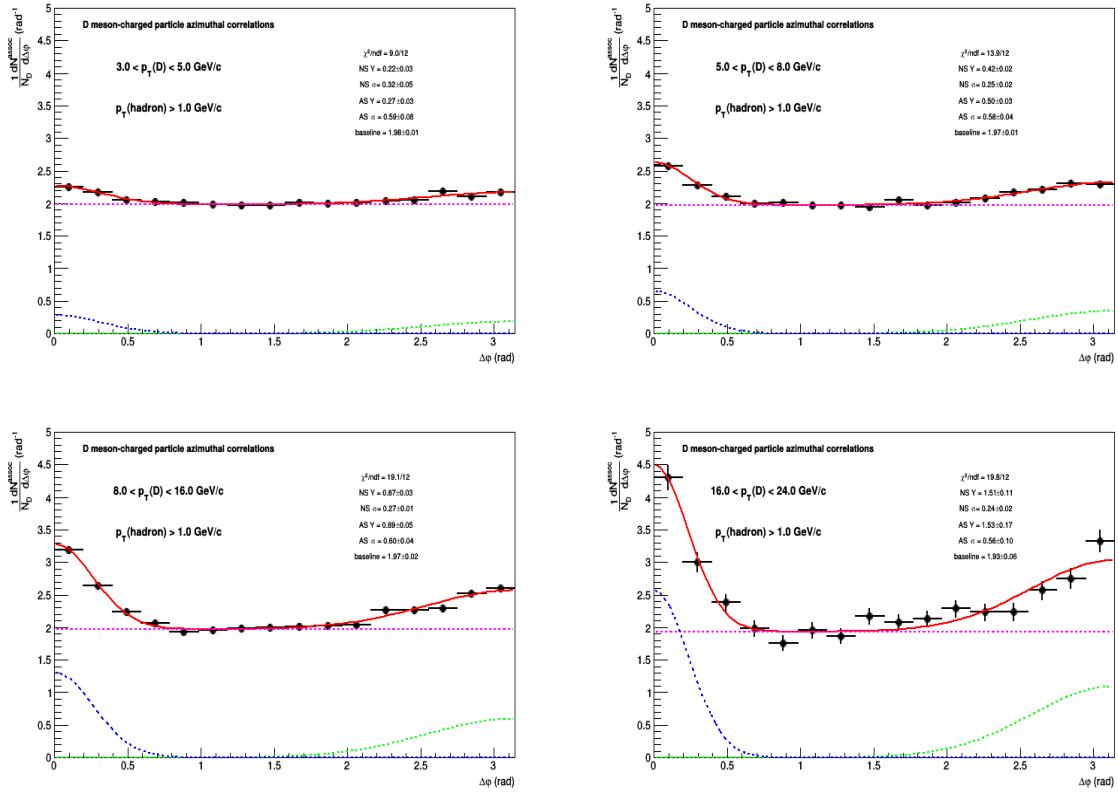


Figure 47: Example of fit to azimuthal correlation distributions and baseline estimation.

681 From the fit outcome, it is possible to retrieve the near-side and away-side yield and widths (integral
 682 and sigma of the Gaussian functions, respectively), as well as the baseline height of the correlation
 683 distribution. The near-side observables give information on the multiplicity and angular spread of the
 684 tracks from the fragmentation of the charm jet which gave birth to the D-meson trigger. At first order,
 685 instead, the away-side observables are related to the hadronization of the charm parton produced in the
 686 opposite direction (though the presence of NLO processes for charm production breaks the full validity
 687 of this assumption). The baseline value is a rough indicator of the underlying event multiplicity, though

below the baseline level also charm and beauty-related pairs are contained (especially in cases of NLO production for the heavy quarks).

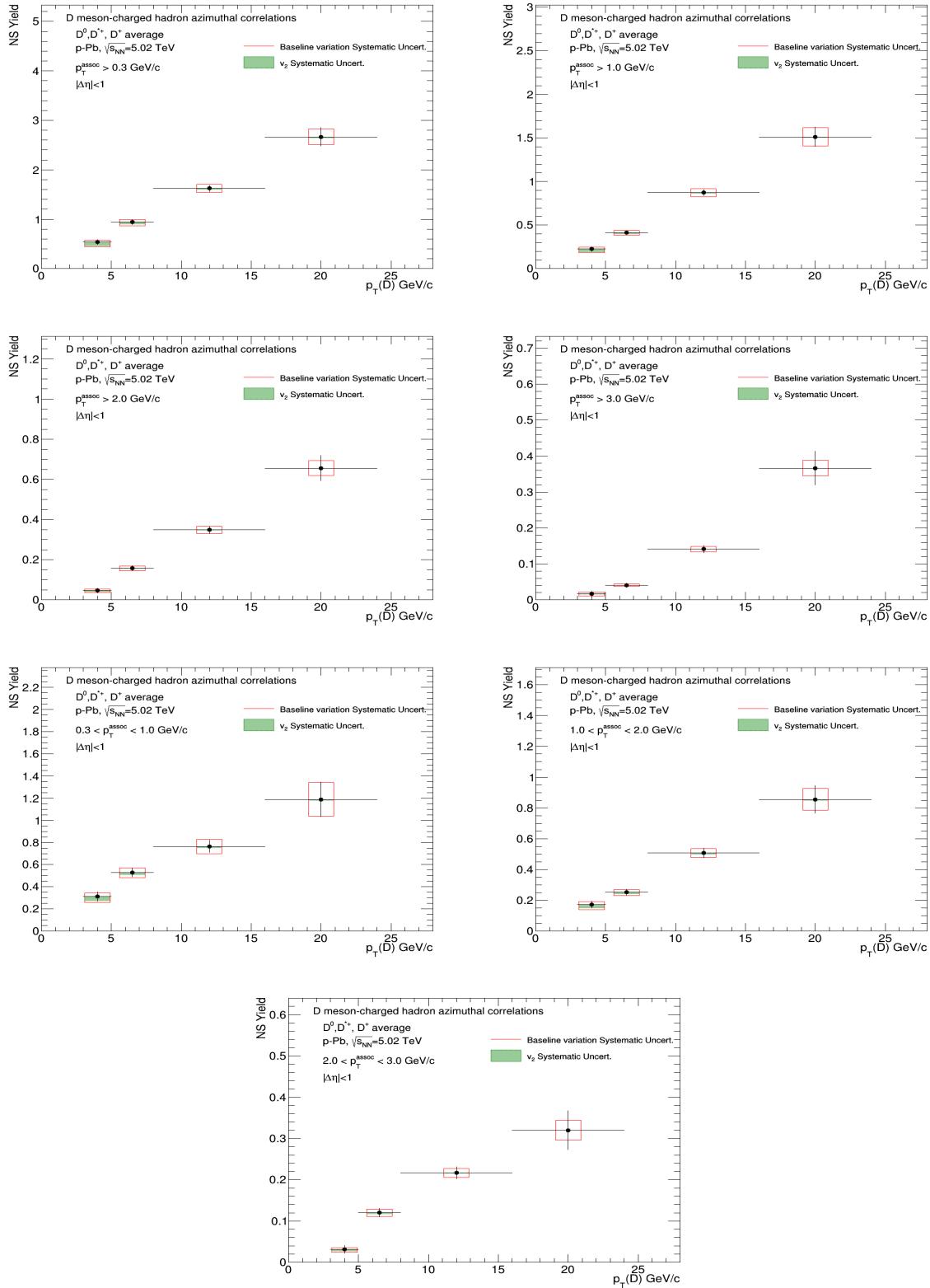
The evaluation of the systematic uncertainties on the observables obtained from the fits is performed as follows:

- The fits are repeated by changing the range of the transverse region in which the baseline is evaluated. Alternate definitions of $\frac{\pi}{4} < |\Delta\phi| < \frac{3\pi}{8}$, $\frac{3\pi}{8} < |\Delta\phi| < \frac{\pi}{2}$ and $\frac{\pi}{4} < |\Delta\phi| < \frac{5\pi}{8}$ are considered.
- In addition, $\Delta\phi$ correlation points are shifted to the upper and lower bounds of their uncorrelated systematic boxes, and refitted.
- The maximum variation of the parameters between the fit outcomes defined in the previous points is considered as systematic uncertainty for the near-side and away-side widths.
- For the estimation of the baseline and of the near-side and away-side yields, the previous value is added in quadrature with the $\Delta\phi$ -correlated systematics in the correlation distributions, since these values are affected by a change in the global normalization of the distributions.
- In addition, for all the fit observables, another fit variation is performed assuming, instead of a flat baseline, a $v_{2\Delta}$ -like modulation, with the following v_2 values for the associated tracks (assuming $v_{2\Delta} = v_2(h) \cdot v_2(D)$): 0.04 (0.3-1 GeV/c), 0.06 (>0.3 GeV/c), 0.08 (1-2 GeV/c), 0.09 (>1 GeV/c, 2-3 GeV/c), 0.1 (>3 GeV/c), on the basis of ATLAS preliminary results for heavy-flavour muons at 8 TeV; for the D-meson triggers the following v_2 values were instead assumed: 0.05 (3-5 GeV/c), 0.03 (5-8 GeV/c), 0.02 (8-24 GeV/c), on the basis of previous ALICE measurements in p-Pb collisions at 5 TeV [3]. The difference of the fit observables with respect to the standard fits is taken as uncertainty. Due to its peculiarity, this systematic uncertainty is summed in quadrature with the others to obtain the total uncertainty, but is also shown separately in the figures.

$$\sigma^{syst} = \sqrt{(Max(\Delta par^{ped.mode}, \Delta par^{\Delta\phi point}))^2 + (\sigma_{Syst}^{corr})^2} \quad (10)$$

5.3.1 Results for near-side yield and width, away-side yield and width, and baseline

Figures 48, 49, 50, 51 and 52 show the near-side associated yield, width (the sigma of the Gaussian part of the fit functions), away-side associated yield, width and the height of the baseline, for the average correlation distributions, in the kinematic ranges studied in the analysis, together with their statistical and systematic uncertainties. For each kinematic range, the correspondent plot showing the systematic uncertainty of the considered observable from the variation of the fit procedure is reported as well (which is the full systematic uncertainty for the widths). Figures 53, 54, 55, 56 and 57 show the full systematic uncertainties for near side yield and width, away side yield and width, and baseline, with the breakdown of fit variation, $v_{2\Delta}$ and $\Delta\phi$ correlated systematic uncertainties.



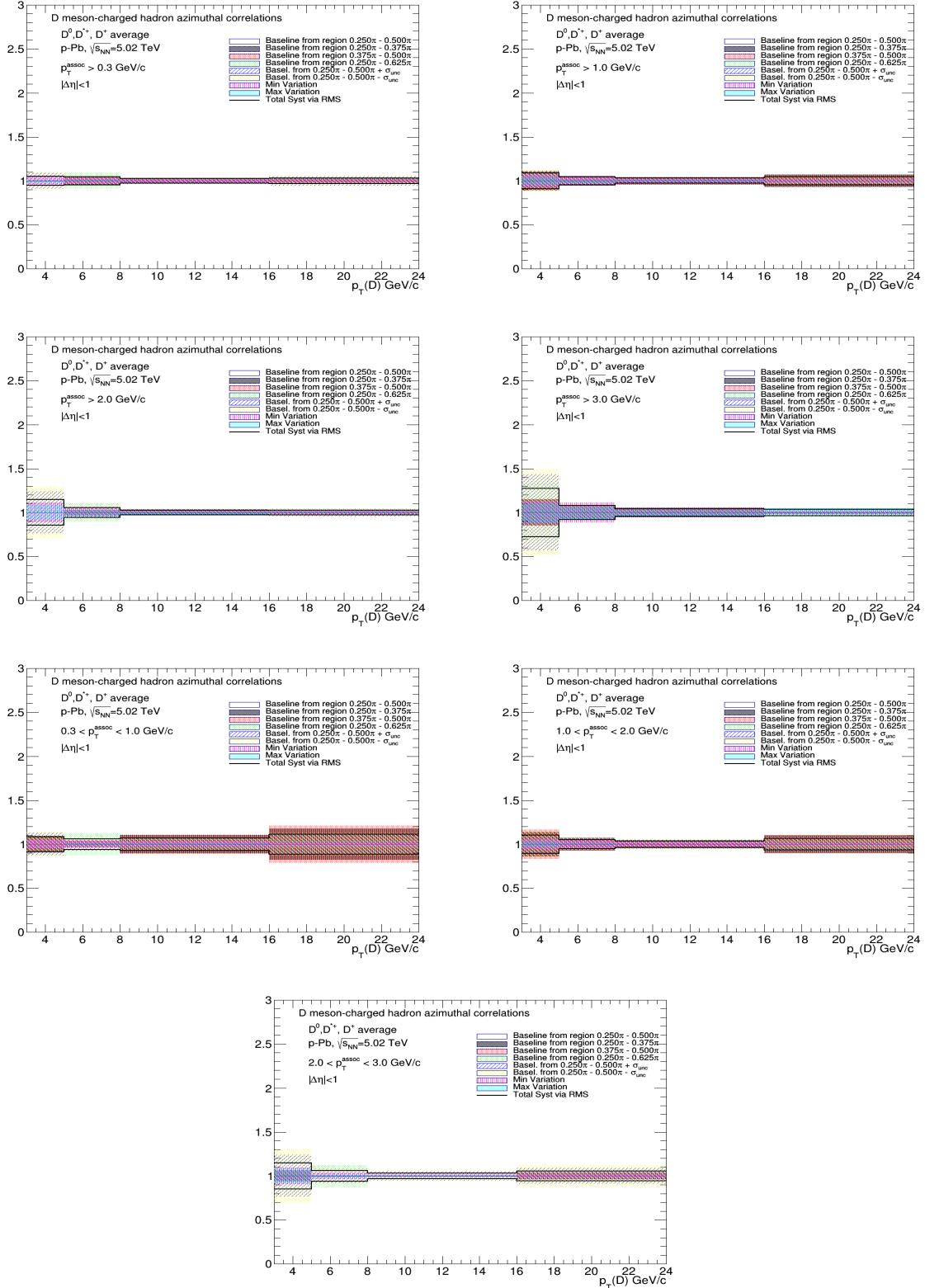
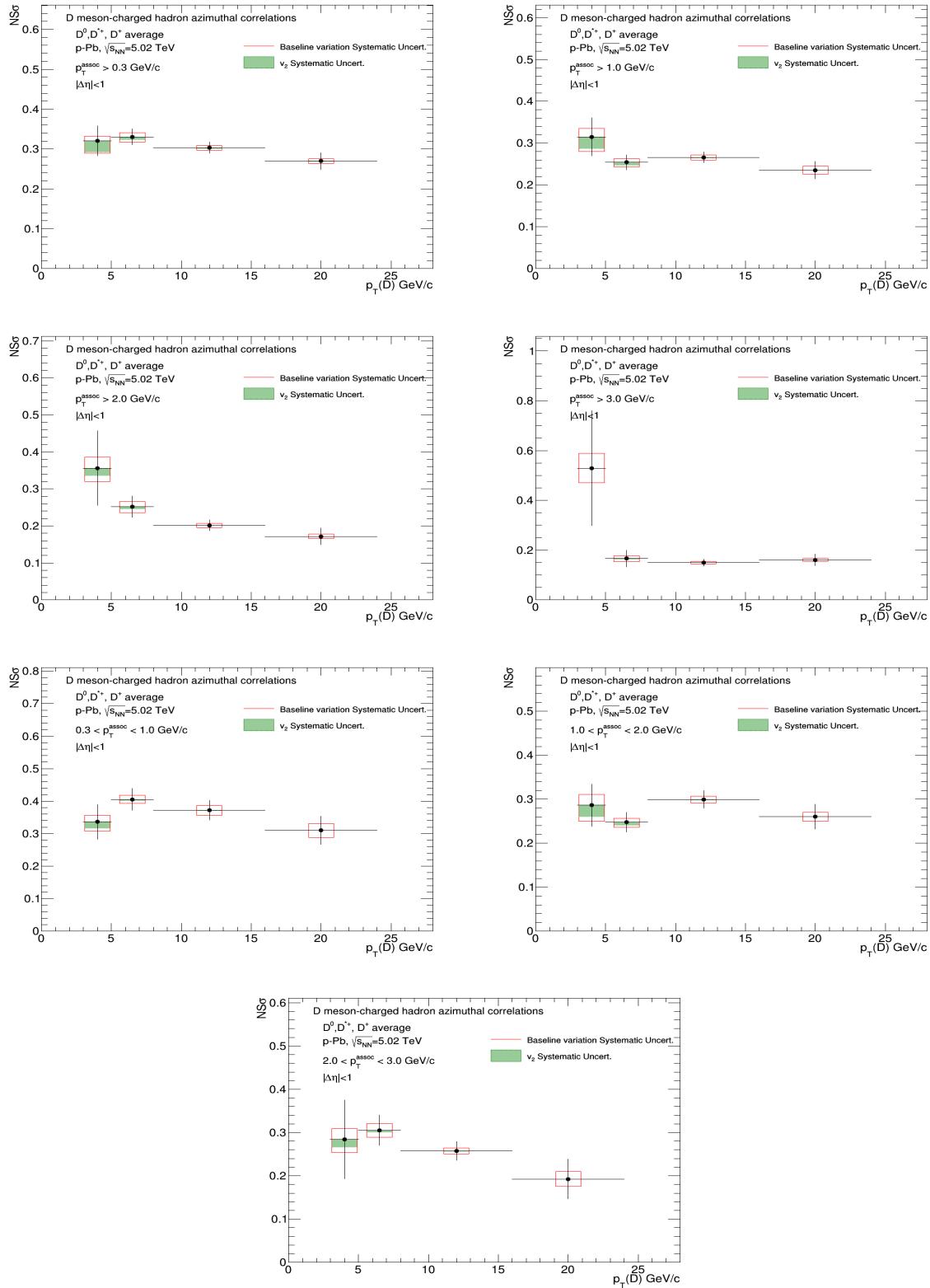


Figure 48: Top panels: near side yield $p_T(D)$ trend for the D-meson average, extracted from fit to the azimuthal correlation distributions, for all the analyzed kinematic ranges of associated track p_T . Bottom panels: for each kinematic region the systematic uncertainties coming from the variation of the fit procedure are shown.



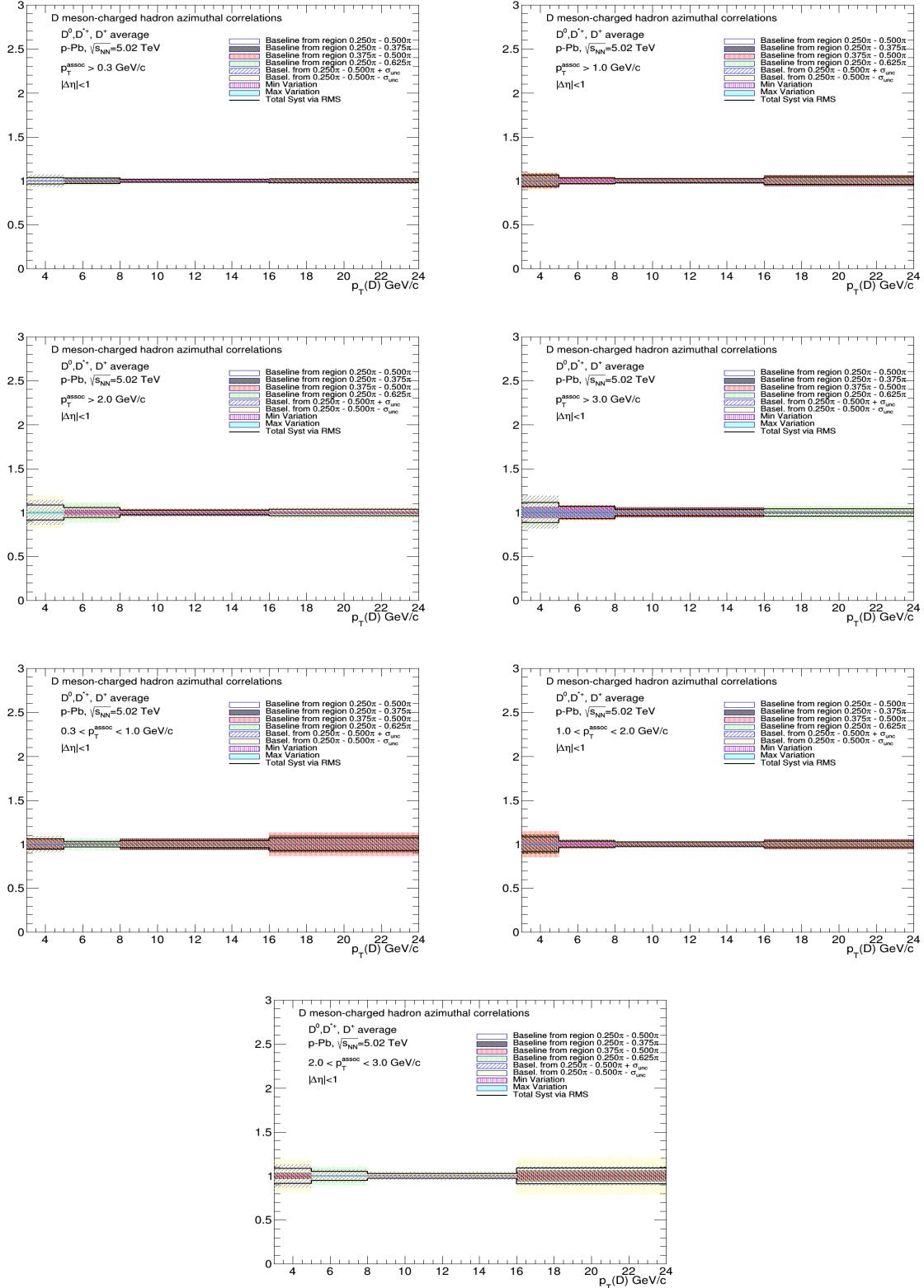
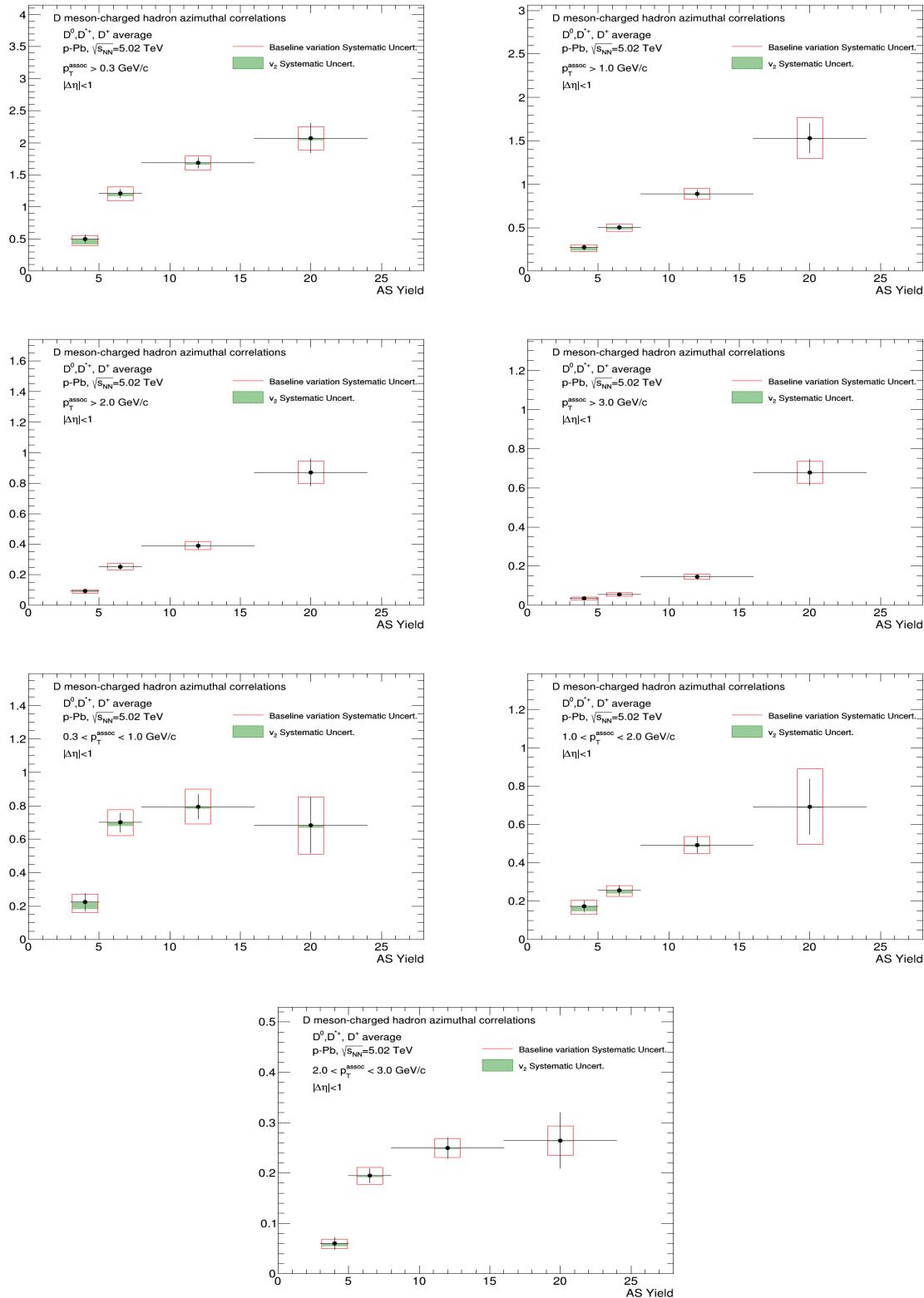


Figure 49: Top panels: near side width $p_T(D)$ trend for the D-meson average, extracted from fit to the azimuthal correlation distributions, for all the analyzed kinematic ranges of associated track p_T . Bottom panels: for each kinematic region the systematic uncertainties coming from the variation of the fit procedure are shown.



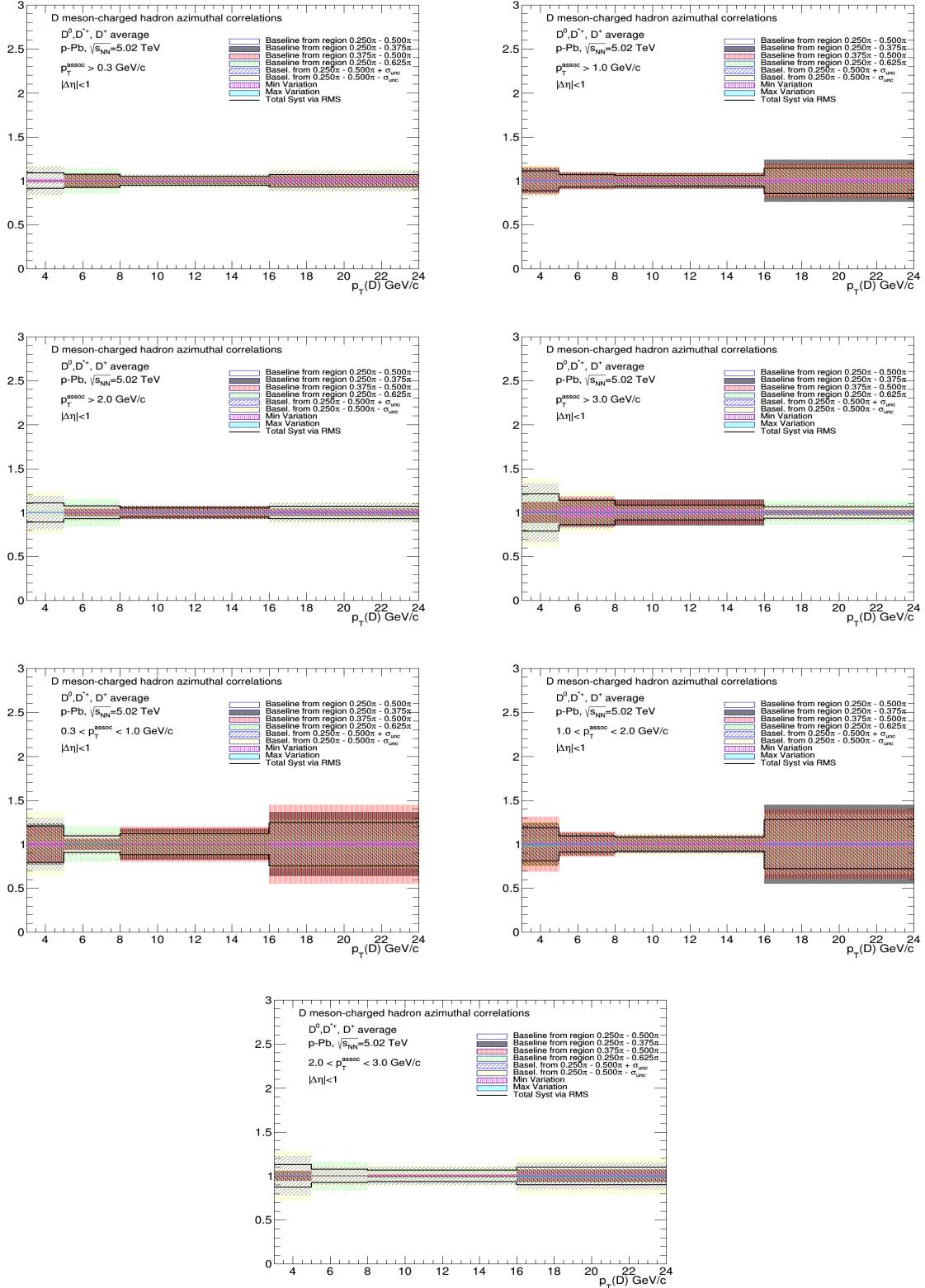
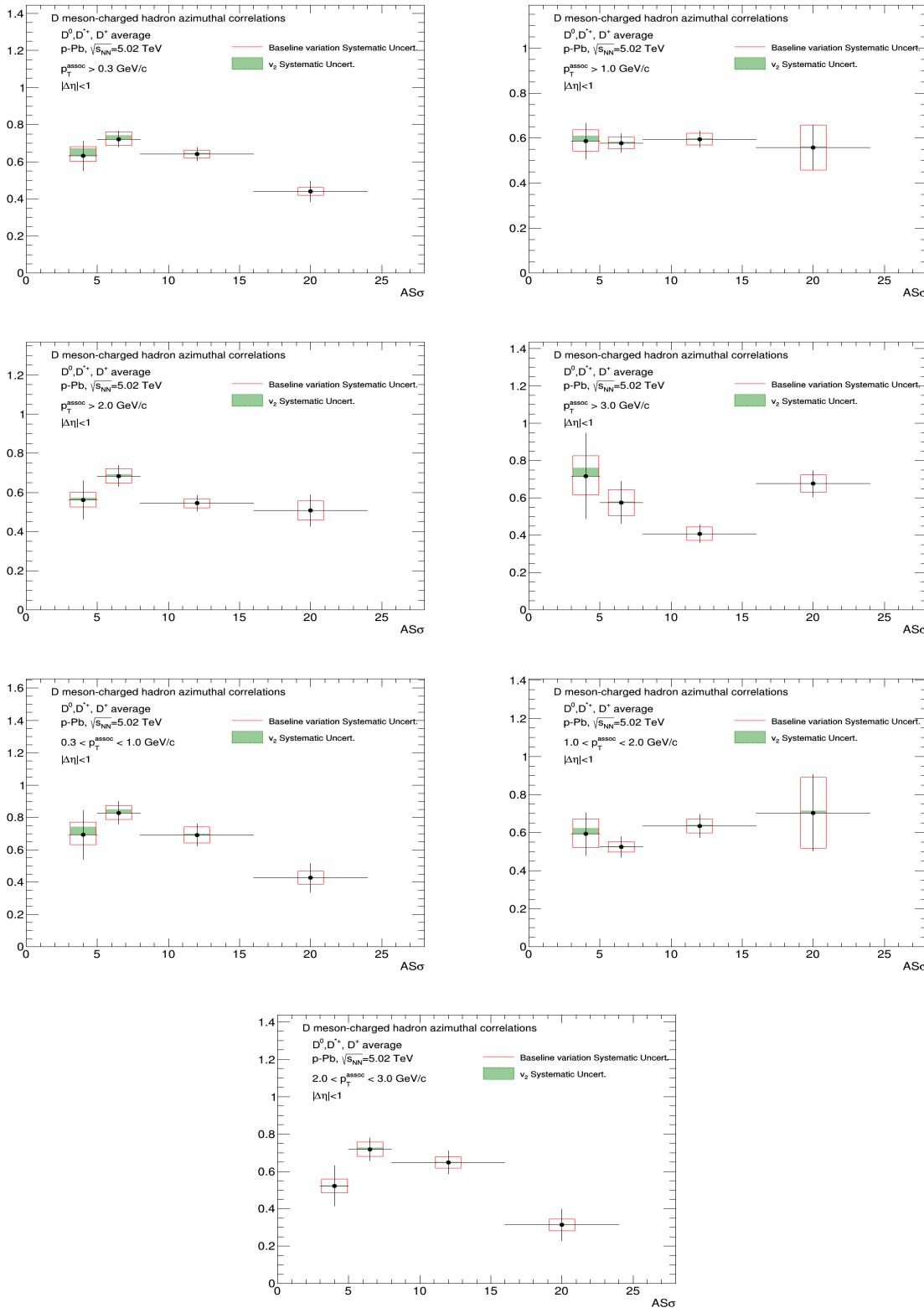


Figure 50: Top panels: away side yield $p_T(D)$ trend for the D-meson average, extracted from fit to the azimuthal correlation distributions, for all the analyzed kinematic ranges of associated track p_T . Bottom panels: for each kinematic region the systematic uncertainties coming from the variation of the fit procedure are shown.



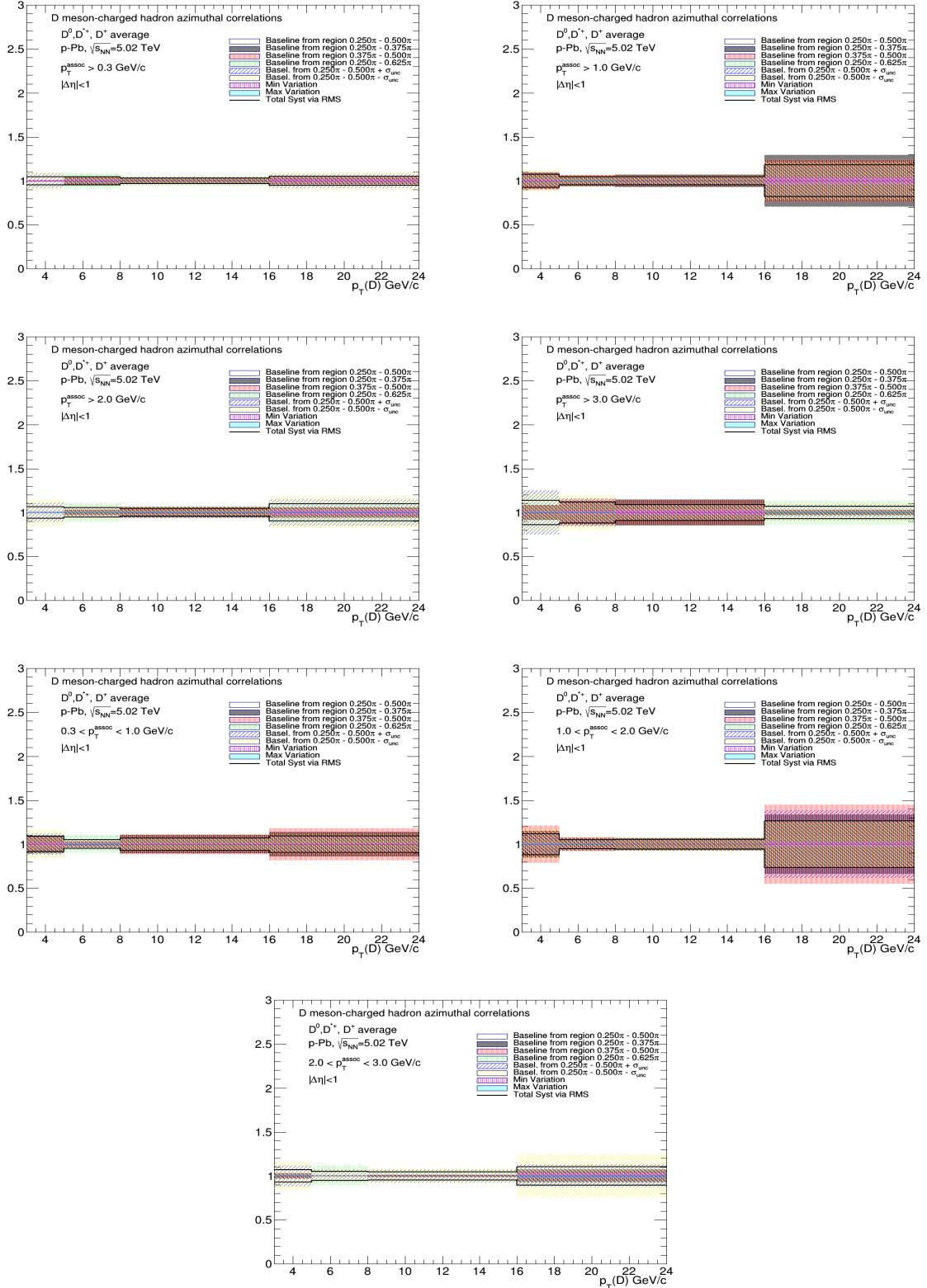
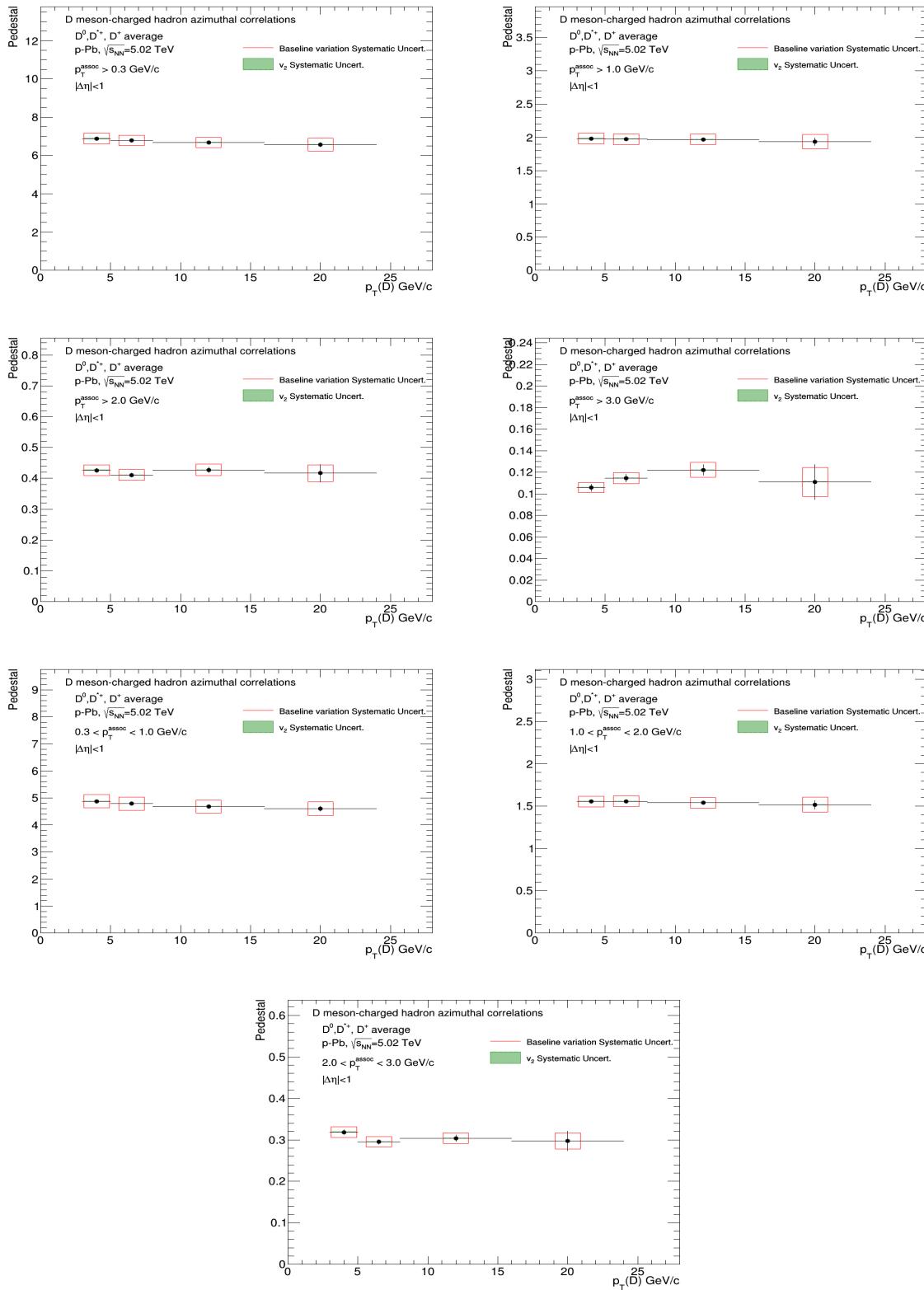


Figure 51: Top panels: away side width $p_T(D)$ trend for the D-meson average, extracted from fit to the azimuthal correlation distributions, for all the analyzed kinematic ranges of associated track p_T . Bottom panels: for each kinematic region the systematic uncertainties coming from the variation of the fit procedure are shown.



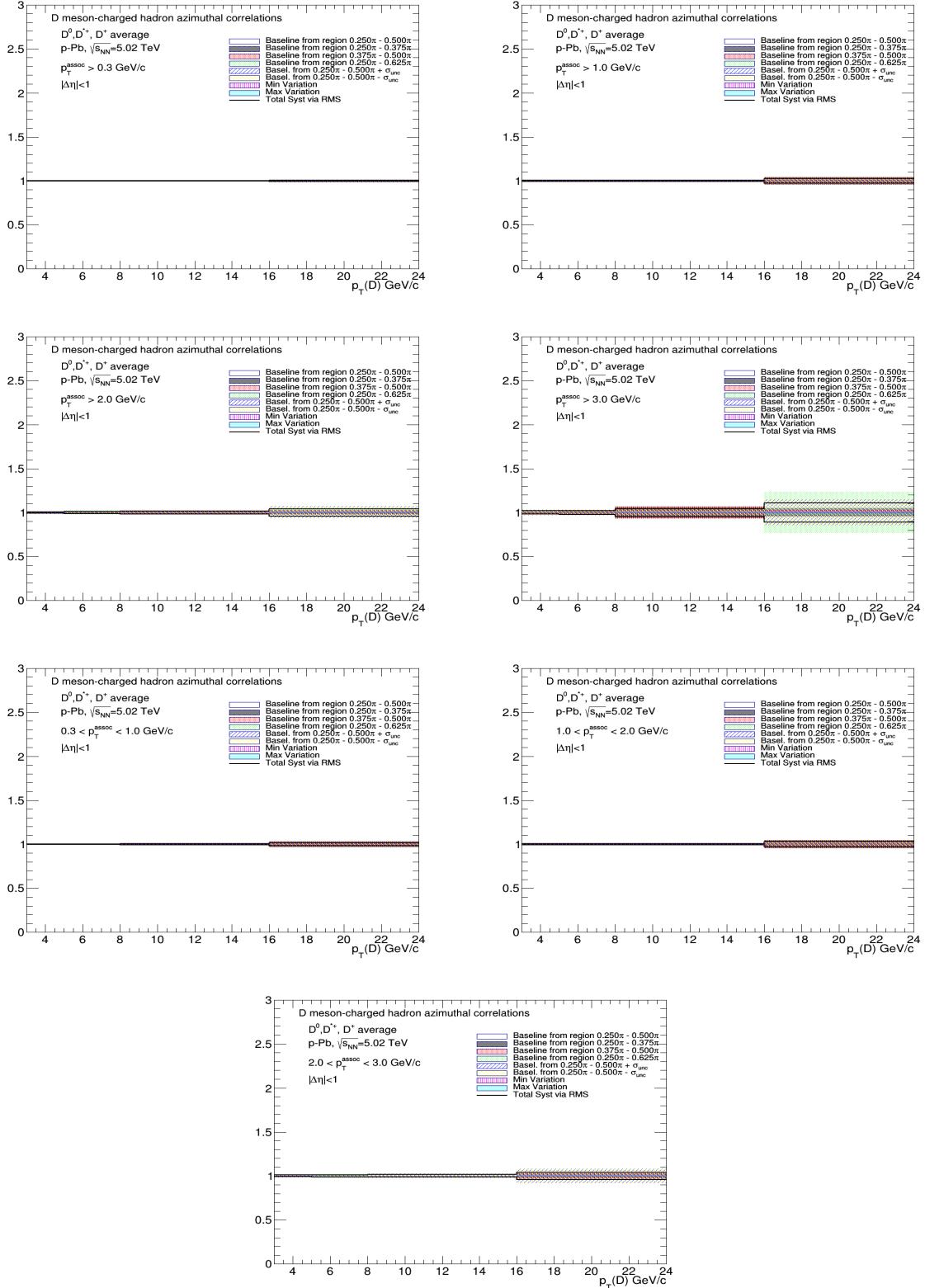


Figure 52: Top panels: baseline height trend for the D-meson average, extracted from fit to the azimuthal correlation distributions, for all the analyzed kinematic ranges of associated track p_T . Bottom panels: for each kinematic region the systematic uncertainties coming from the variation of the fit procedure are shown.

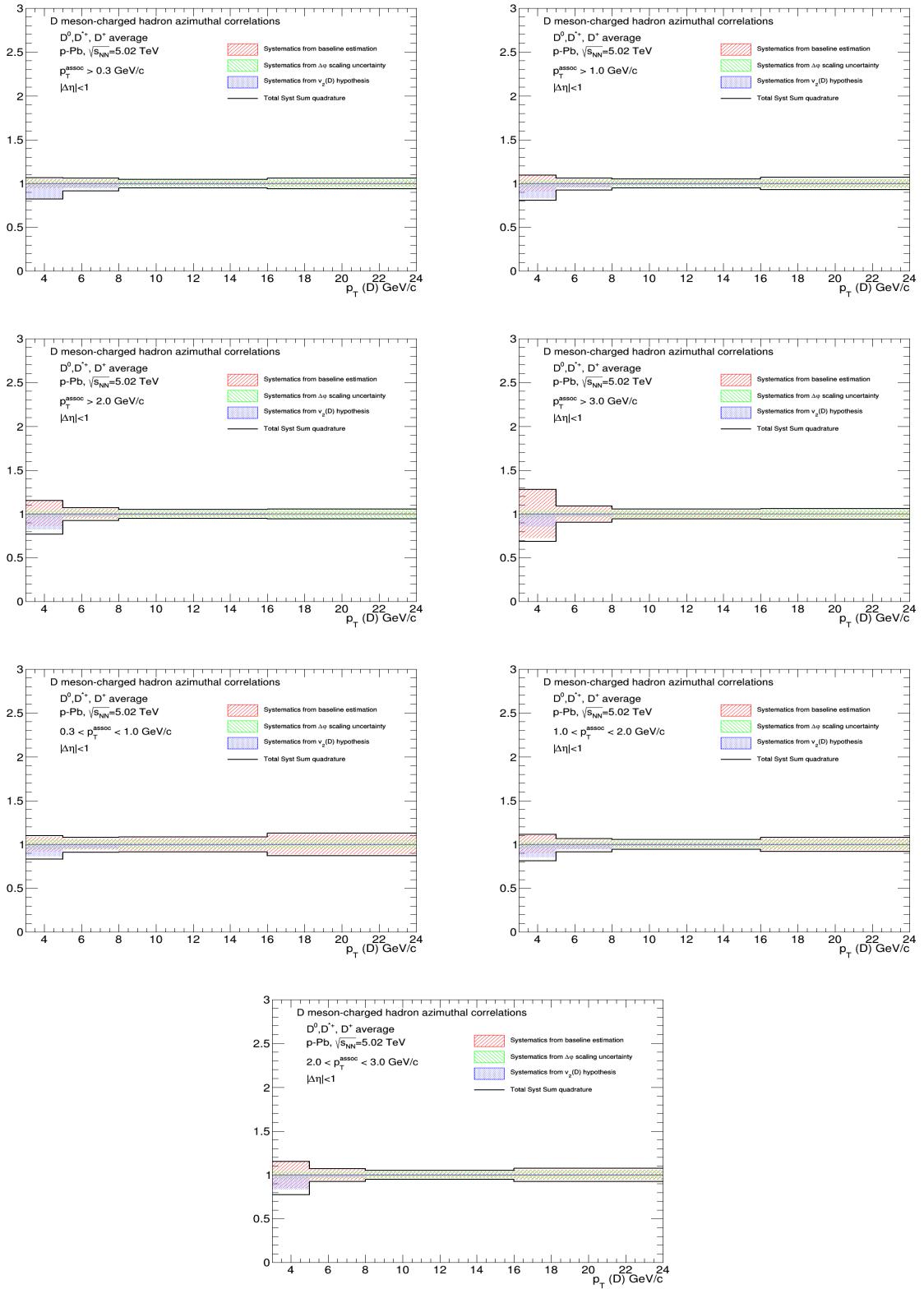


Figure 53: Total systematic uncertainty, and its components, for near-side yields in the different kinematic ranges analyzed

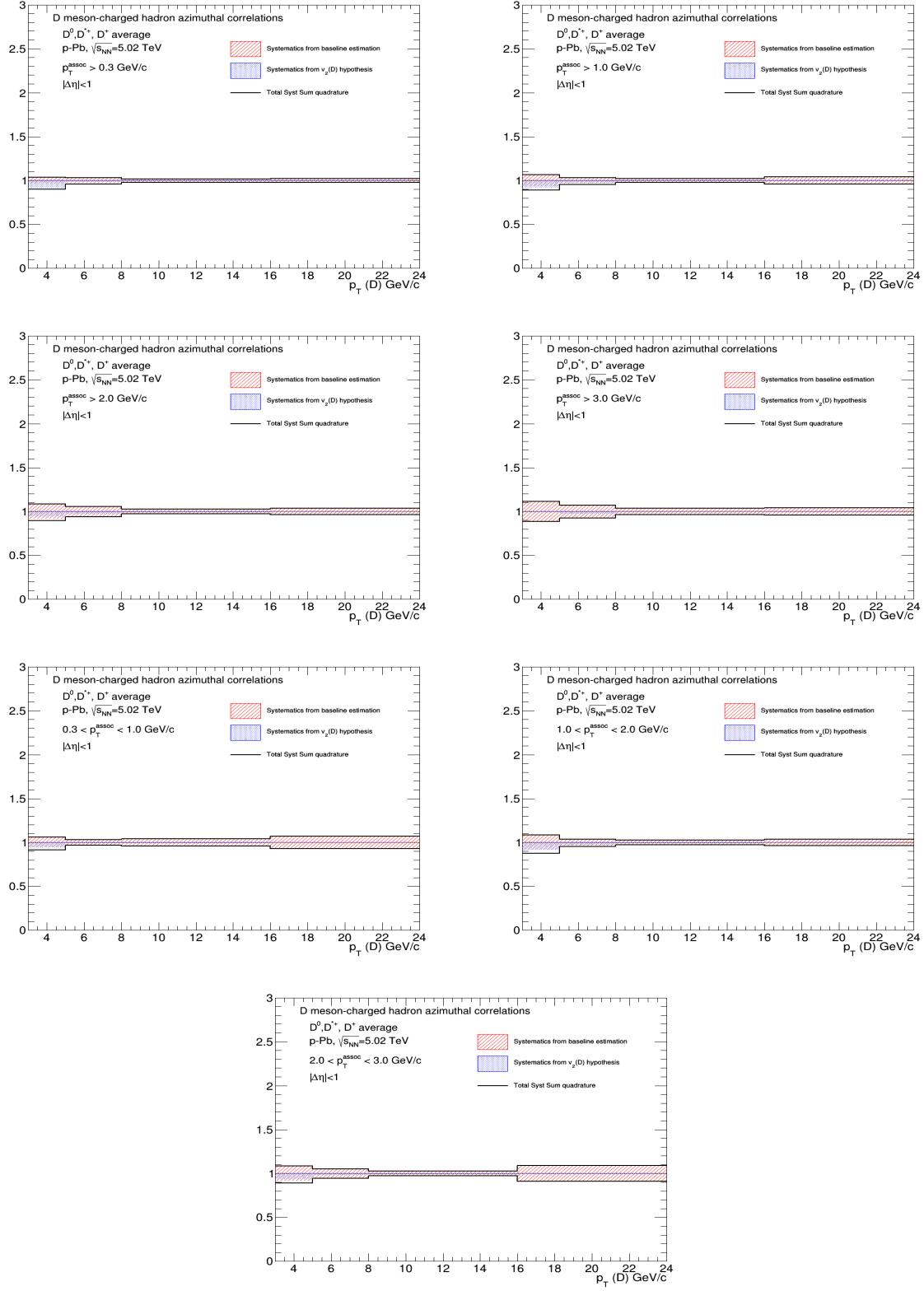


Figure 54: Total systematic uncertainty, and its components, for near-side sigma in the different kinematic ranges analyzed

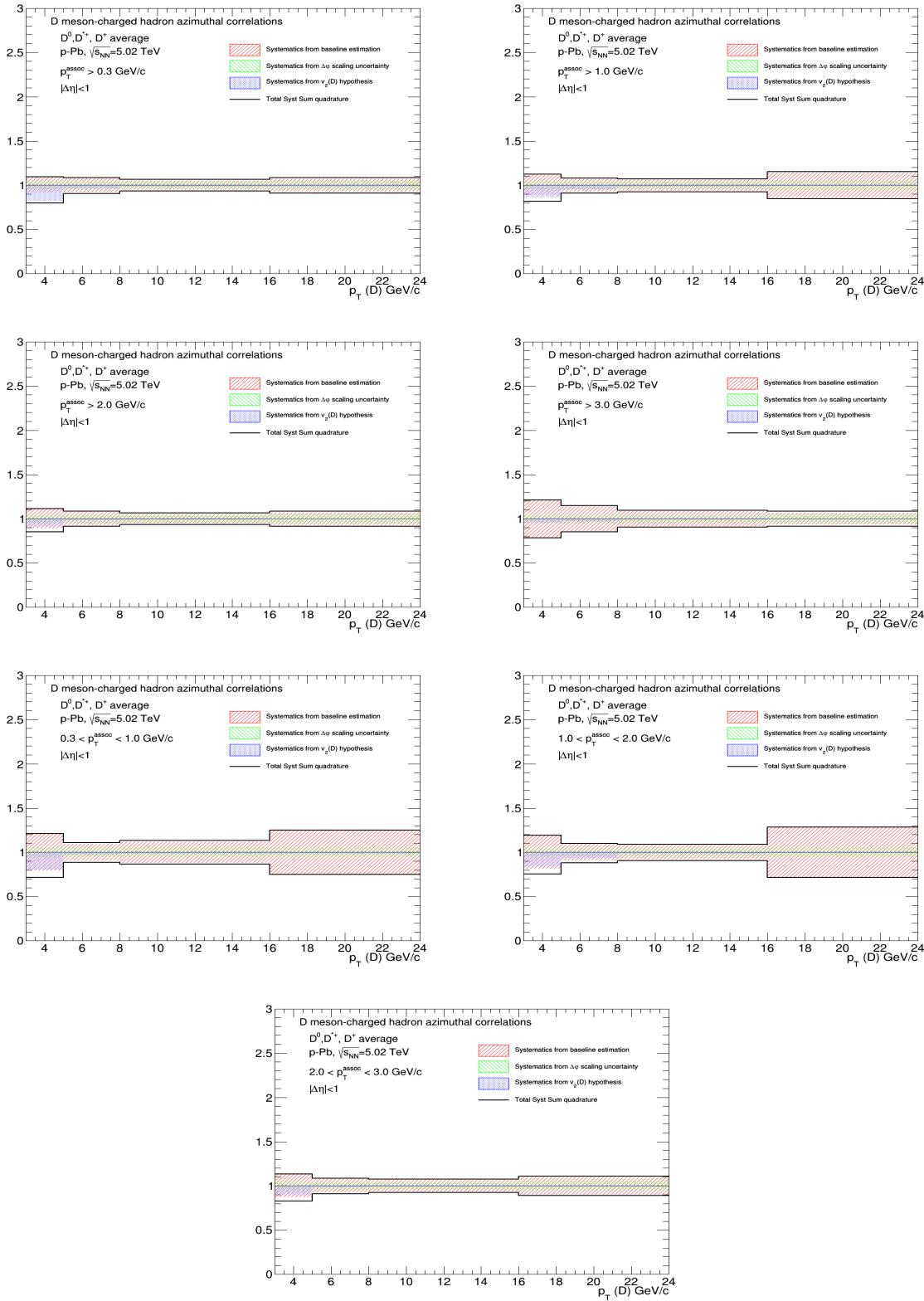


Figure 55: Total systematic uncertainty, and its components, for away-side yields in the different kinematic ranges analyzed

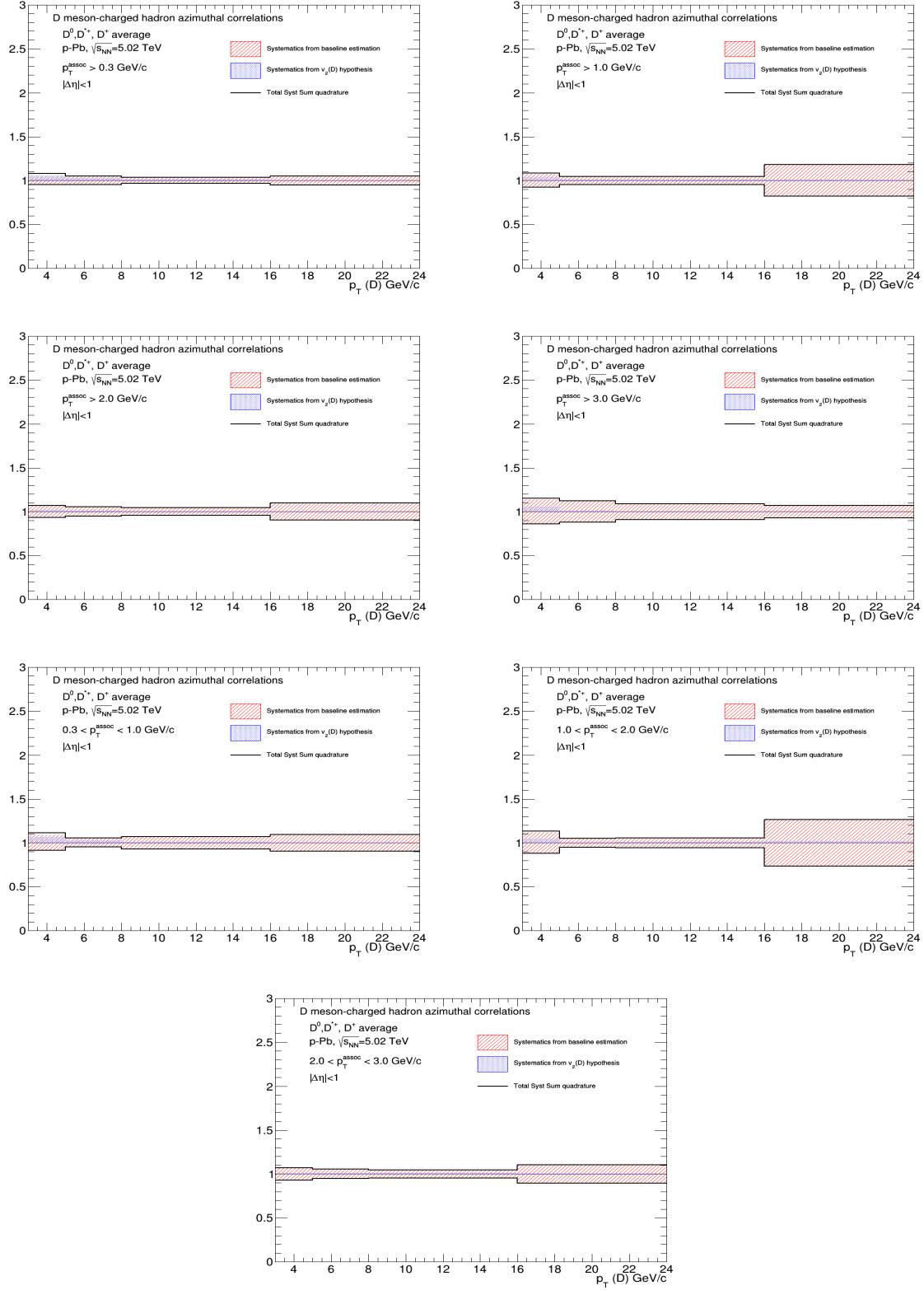


Figure 56: Total systematic uncertainty, and its components, for away-side sigma in the different kinematic ranges analyzed

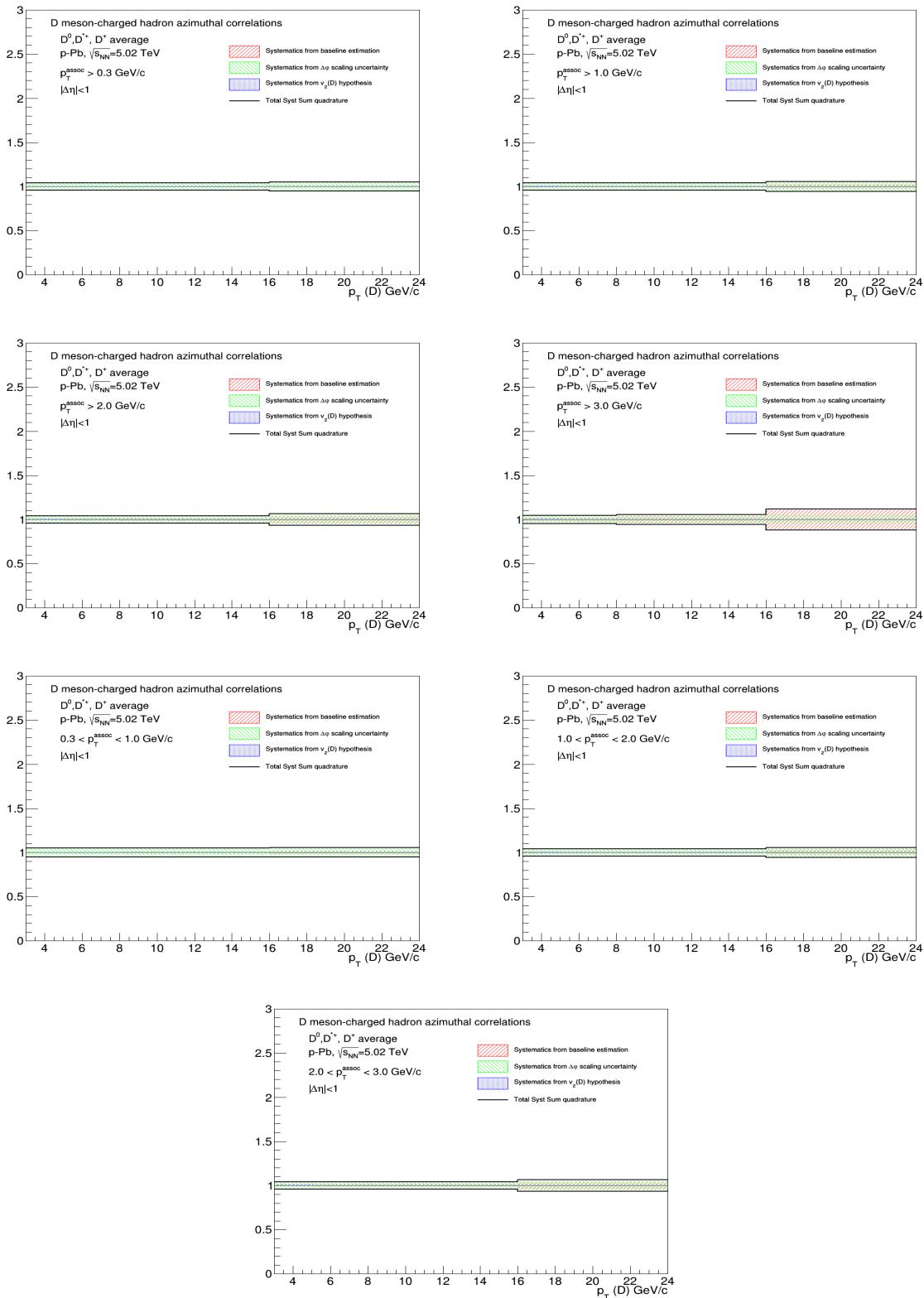


Figure 57: Total systematic uncertainty, and its components, for baseline heights in the different kinematic ranges analyzed.

719 5.4 Comparison of 2016 p-Pb and 2013 p-Pb results

720 In Figure 58, the average correlation distributions from the published analysis in p-Pb 2013 sample
 721 (black points) and the new p-Pb 2016 sample (red points), both at 5 TeV, are compared. As it's evident,
 722 the statistical and systematic uncertainties are largely reduced in the new data sample. The feature of
 723 the correlation distributions are the same in both systems, and an overall compatibility of the shapes is
 724 observed. The only tension concerns the level of the pedestal, especially in the $5 < p_T < 8 \text{ GeV}/c$ range,
 725 but well within the scaling uncertainties (10% in p-Pb 2013, 4% in p-Pb 2016, fully independent). Note
 726 that the plots are zoomed on the y-axis, which doesn't start from zero.

727 Figure 59 shows the same comparison for the fit observables. Also in this case the uncertainties are
 728 largely reduced for the 2016 analysis. The near-side widths are on top of each other; for the near-side
 729 yields a slight decrease of the 2016 results is observed in some p_T ranges with respect to 2013 results,
 730 though well within the uncertainty. The pedestal values are slightly higher for 2016 results, as already
 731 observed from the correlation distributions, but within the uncertainties. The sensitivity to away-side
 732 observables was very poor for 2013 results, hence a comparison with 2016 data is difficult, anyway,
 733 within the large uncertainties, also the away-side observables are compatible between the two datasets.

734 5.5 Comparison of 2016 p-Pb and 2010 pp results

735 Figure 60 shows the comparison of the average D-h correlation distributions in pp 2010 data sample at
 736 $\sqrt{s} = 7 \text{ TeV}$ (published in [2]) and in the new p-Pb 2016 sample at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$. The results are
 737 shown after the subtraction of the baseline. The precision of the new p-Pb results is much better than that
 738 of pp results; the correlation distributions show very similar features in the two collision systems.

739 In Figure 61 the comparison is performed for the near-side peak observables, again in the common
 740 kinematic ranges, where the same consideration about the uncertainties holds. The similarity of the
 741 correlation distributions is reflected also in the near-side yield and width values, which do not seem to
 742 differ within the uncertainties, pointing to the absence of strong effects from cold-nuclear matter effects
 743 on the correlation distributions.

744 It has to be said that, on the base of a study performed with Pythia6-Perugia2011 simulations, a scaling
 745 factor of about 0.93 is expected when passing from a center-of-mass energy of $\sqrt{s} = 7 \text{ TeV}$ to $\sqrt{s} = 5$
 746 TeV, difficult to be appreciated with the current uncertainties, especially the pp ones.

747 5.6 Comparison of 2016 p-Pb and model expectations

748 A comparison of the average D-h correlation distributions on the new p-Pb data samples with expec-
 749 tations from Monte Carlo simulations (currently Pythia6-Perugia2011, Pythia6-Perugia2010, Pythia6-
 750 Perugia0, PYTHIA8; POWHEG+PYTHIA and EPOS 3 will be added if they come in time) is shown in
 751 Figure 62, after the baseline subtraction (which differs strongly between data and simulations, due to he
 752 very different underlying event). The simulations, though being for pp, include the boost of the center-
 753 of-mass along the beam axis present in p-Pb collisions and nuclear PDF. The shape of the correlation
 754 distributions is well reproduced by all the models, together with their p_T trend and with the evolution of
 755 the correlation peaks.

756 Figures 63 and 64 show the same comparison for the fit observables (peak yields and widths for near-side
 757 and away-side, respectively), for all the addressed p_T ranges.

758 5.7 Planned results for SQM approvals

759 We are planning to approve the following results, all shown in the previous figures (the final graphical
 760 style of the plots is still to be finalized):

- 761 – Average D-h correlation distributions, in exemplary p_T range

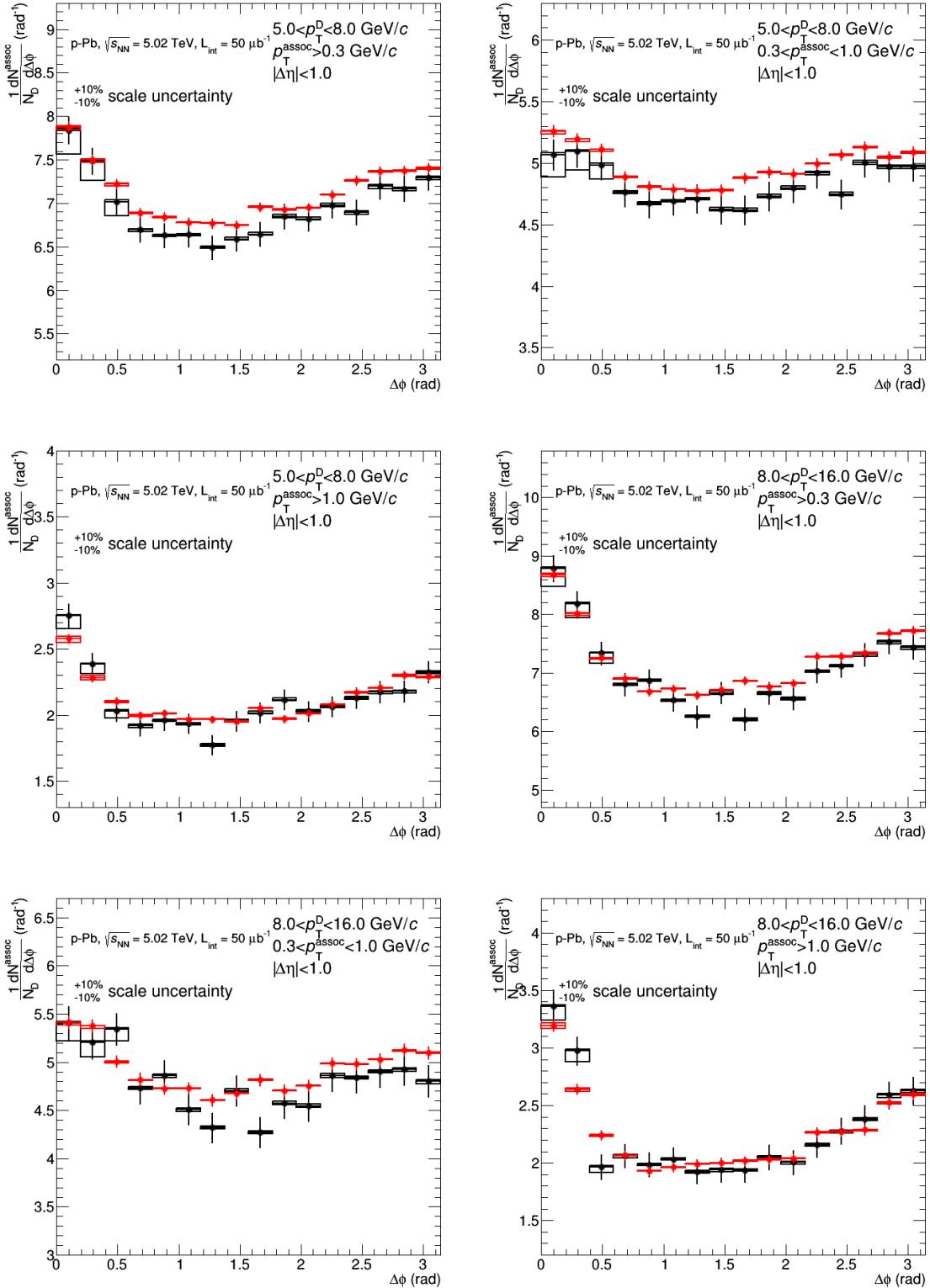


Figure 58: Comparison of 2016 (red) and 2013 (black) results for azimuthal correlation distributions, for the common p_T ranges.

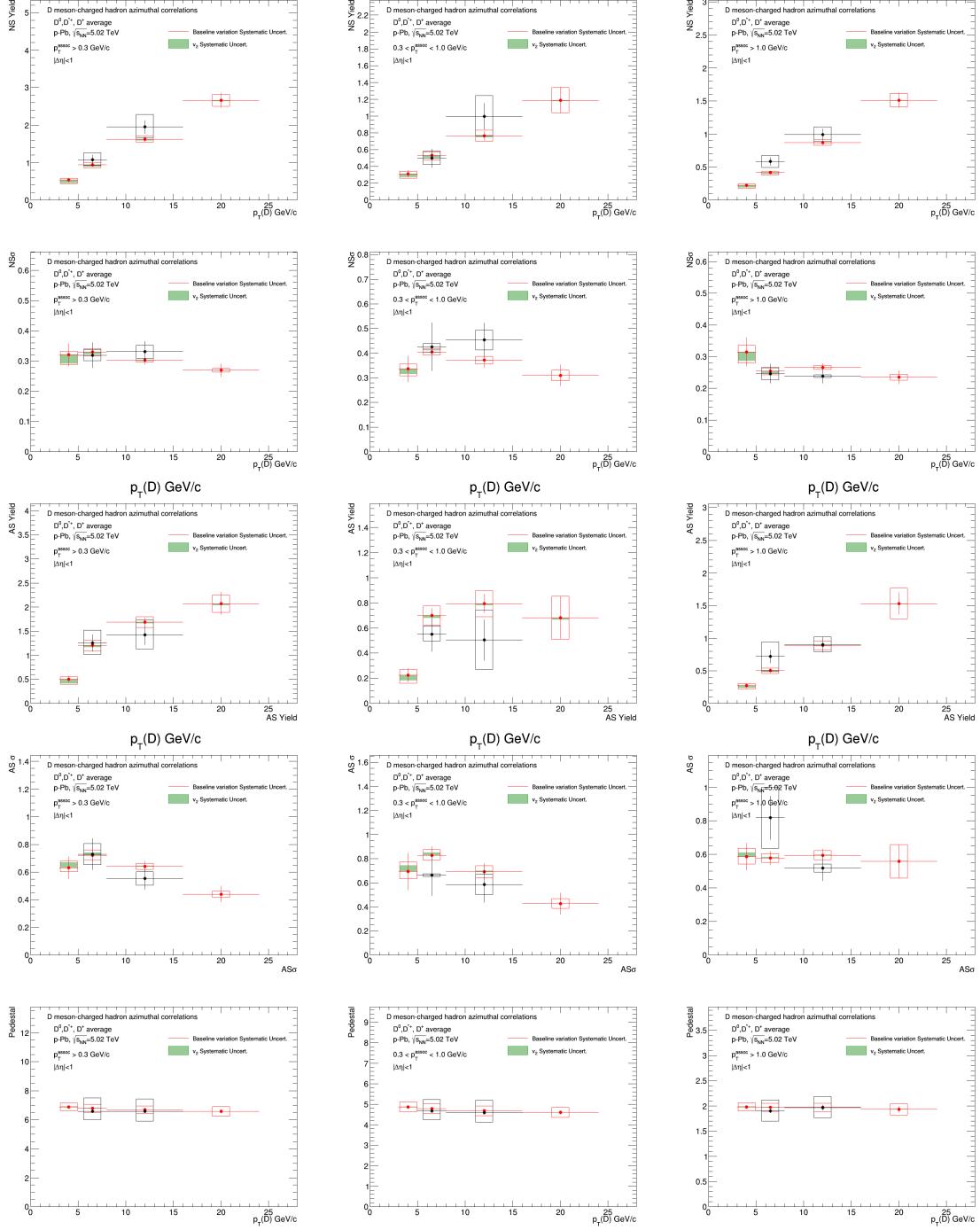


Figure 59: Comparison of the average D-h azimuthal correlation properties between 2016 p-Pb (red) and 2013 p-Pb (black) data analysis, for the common p_T ranges of D meson and associated particles.

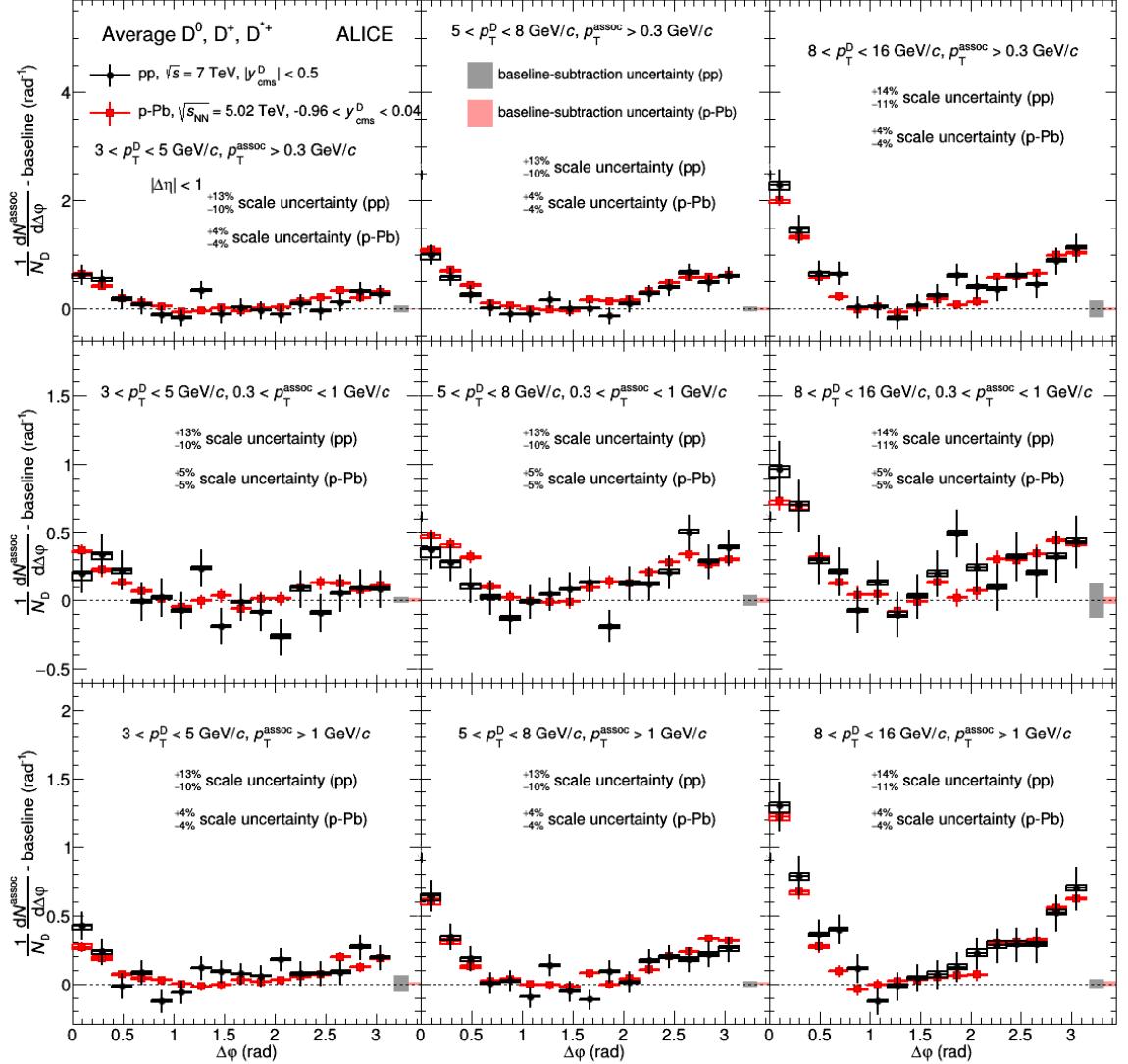


Figure 60: Comparison of pp 2010 (black) and p-Pb 2016 (red) average D-h azimuthal correlation distributions, for the common p_T ranges.

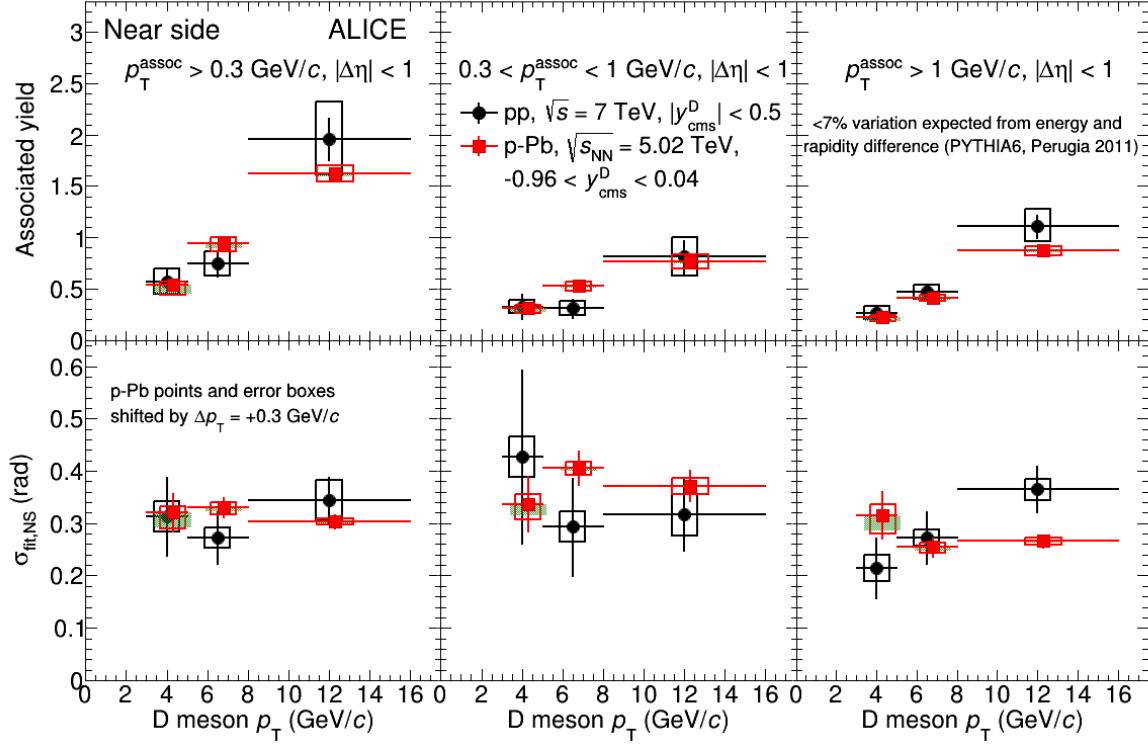
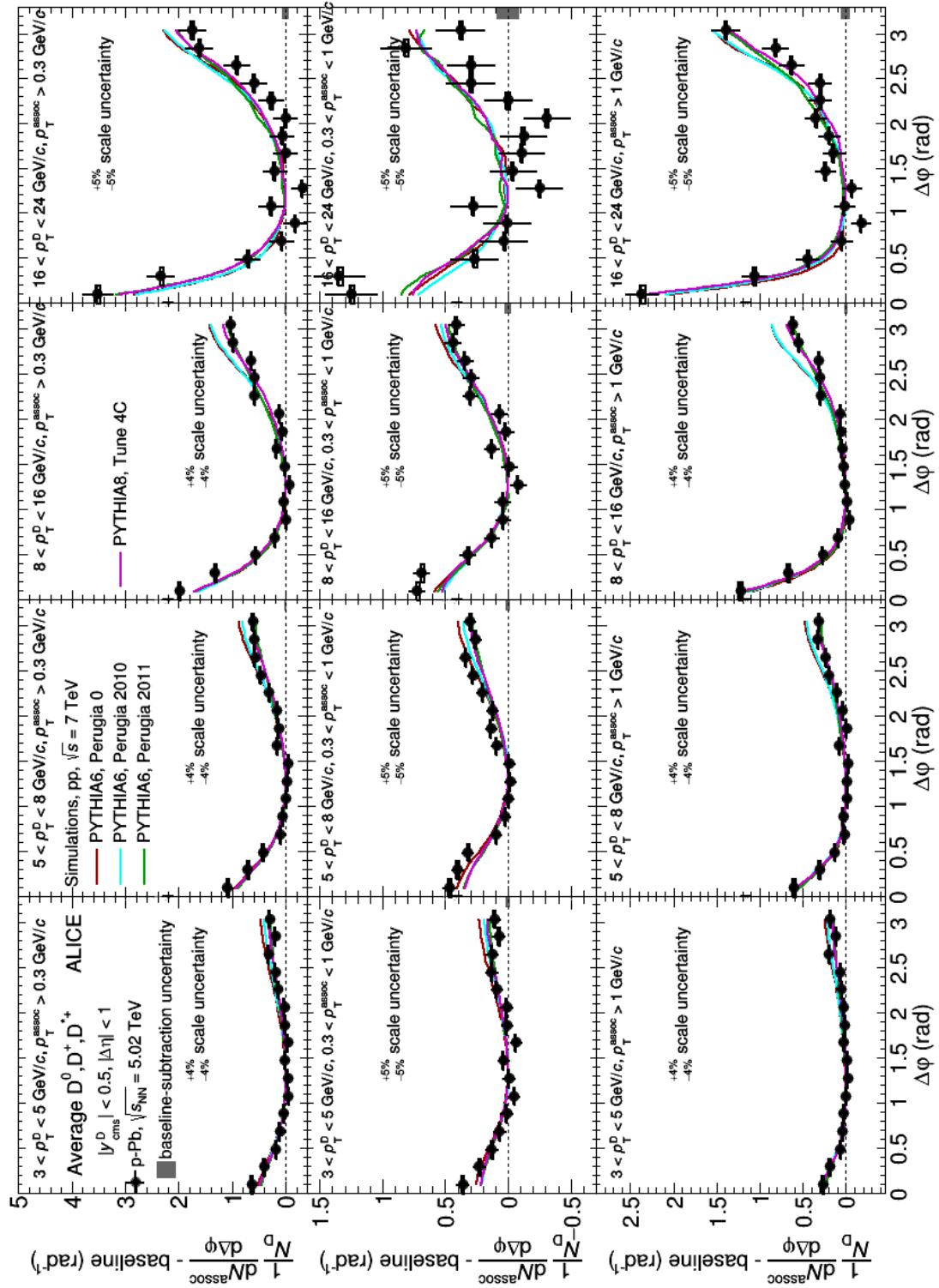


Figure 61: Comparison of pp 2010 (black) and p-Pb 2016 (red) near-side peak yields and widths, for the common p_T ranges.

- 762 – Fit of D-h correlation distributions, in exemplary pT range
- 763 – $p_T(D)$, $p_T(\text{assoc})$ trend of NS yield, NS width, AS yield, AS sigma
- 764 – Comparison of correlation distributions with expectations from models (PYTHIA6, PYTHIA8, if
765 in time POWHEG, EPOS)
- 766 – Comparison of fit observables with expectations from models (PYTHIA6, PYTHIA8, if in time
767 POWHEG, EPOS)
- 768 – Comparison of correlation distributions with pp 2010 results
- 769 – Comparison of fit observables with pp 2010 results



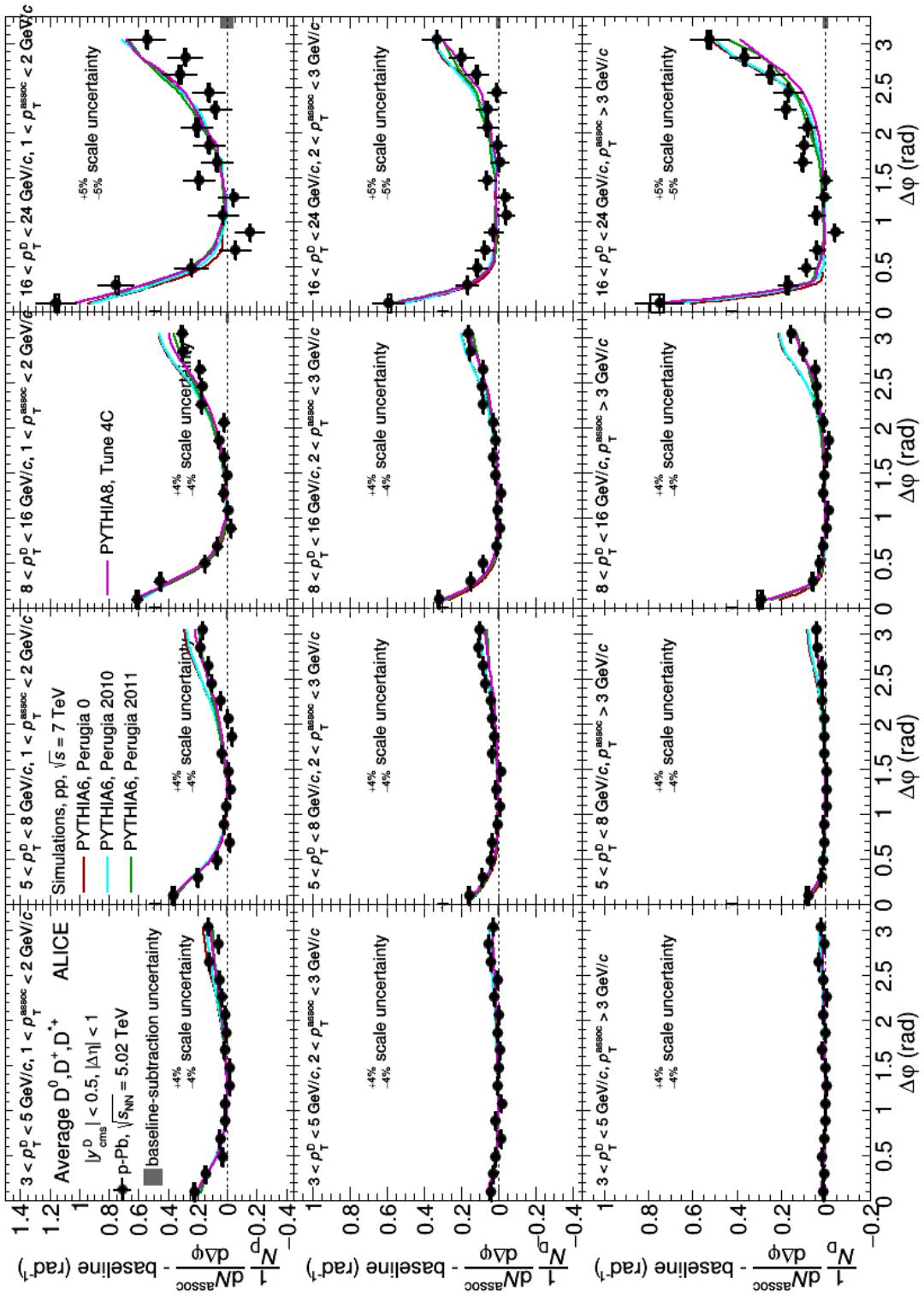
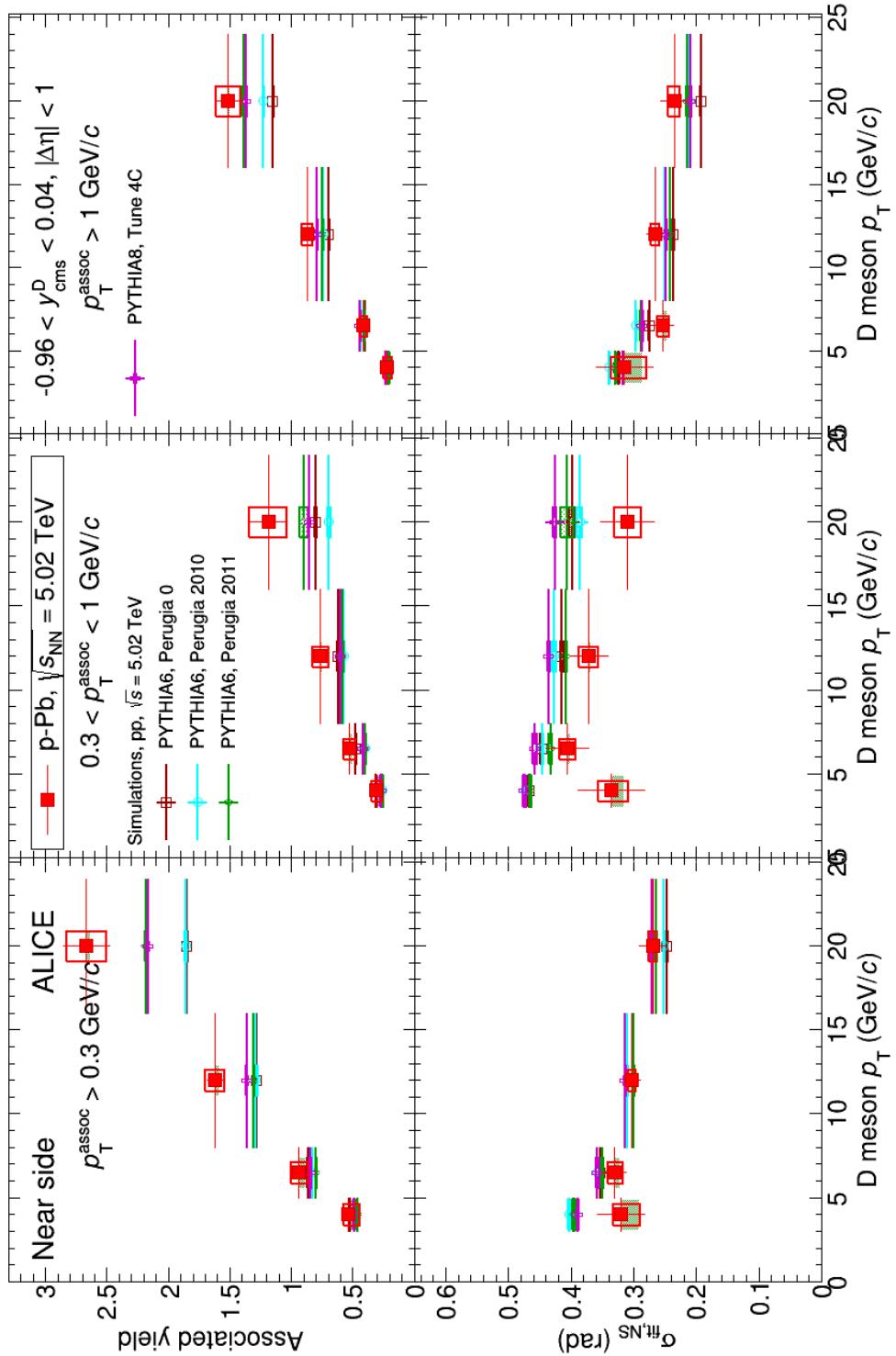


Figure 62: Comparison of p-Pb 2016 average D-h correlation distributions and model expectations, for all the studied kinematic ranges.



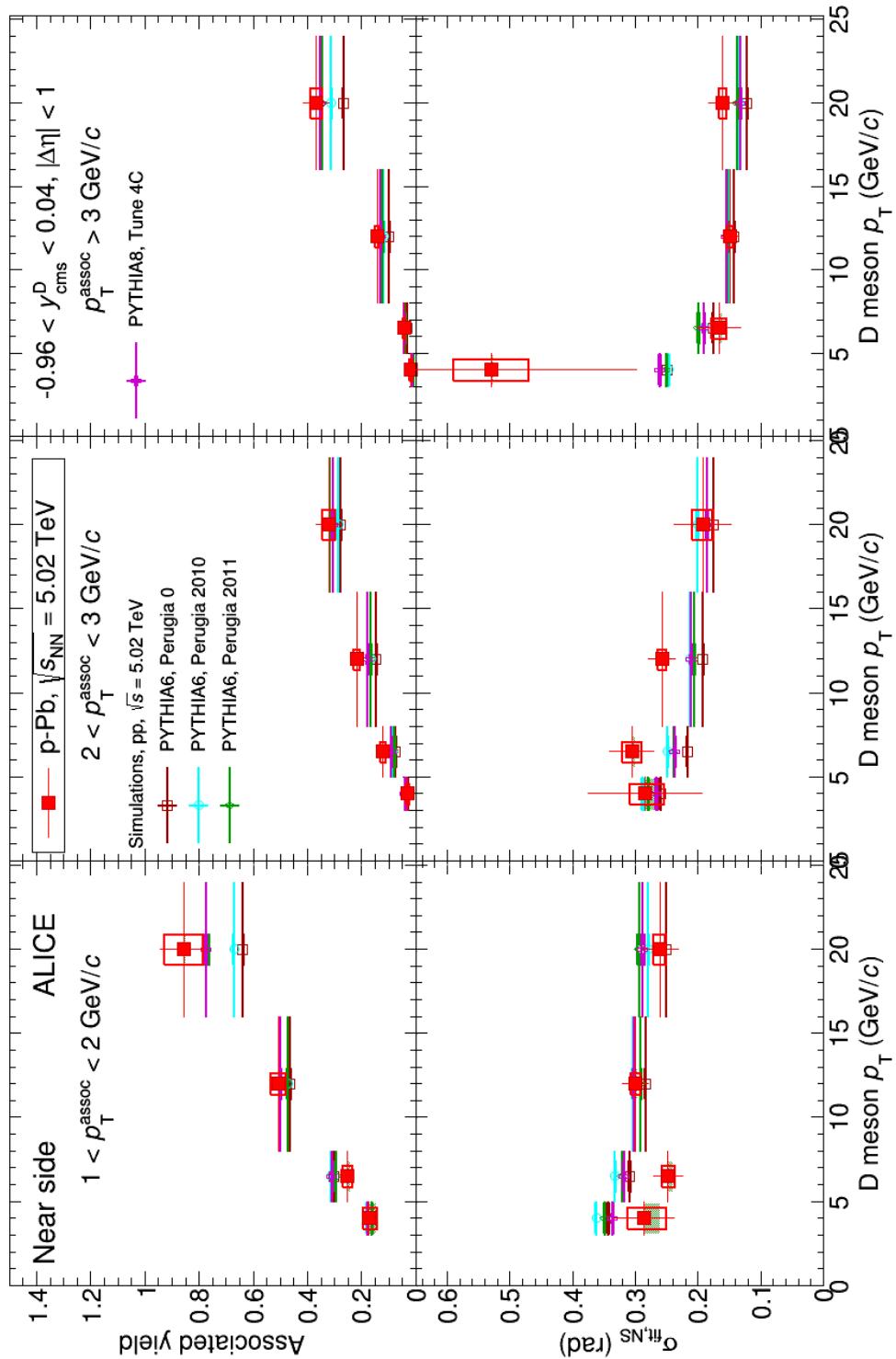
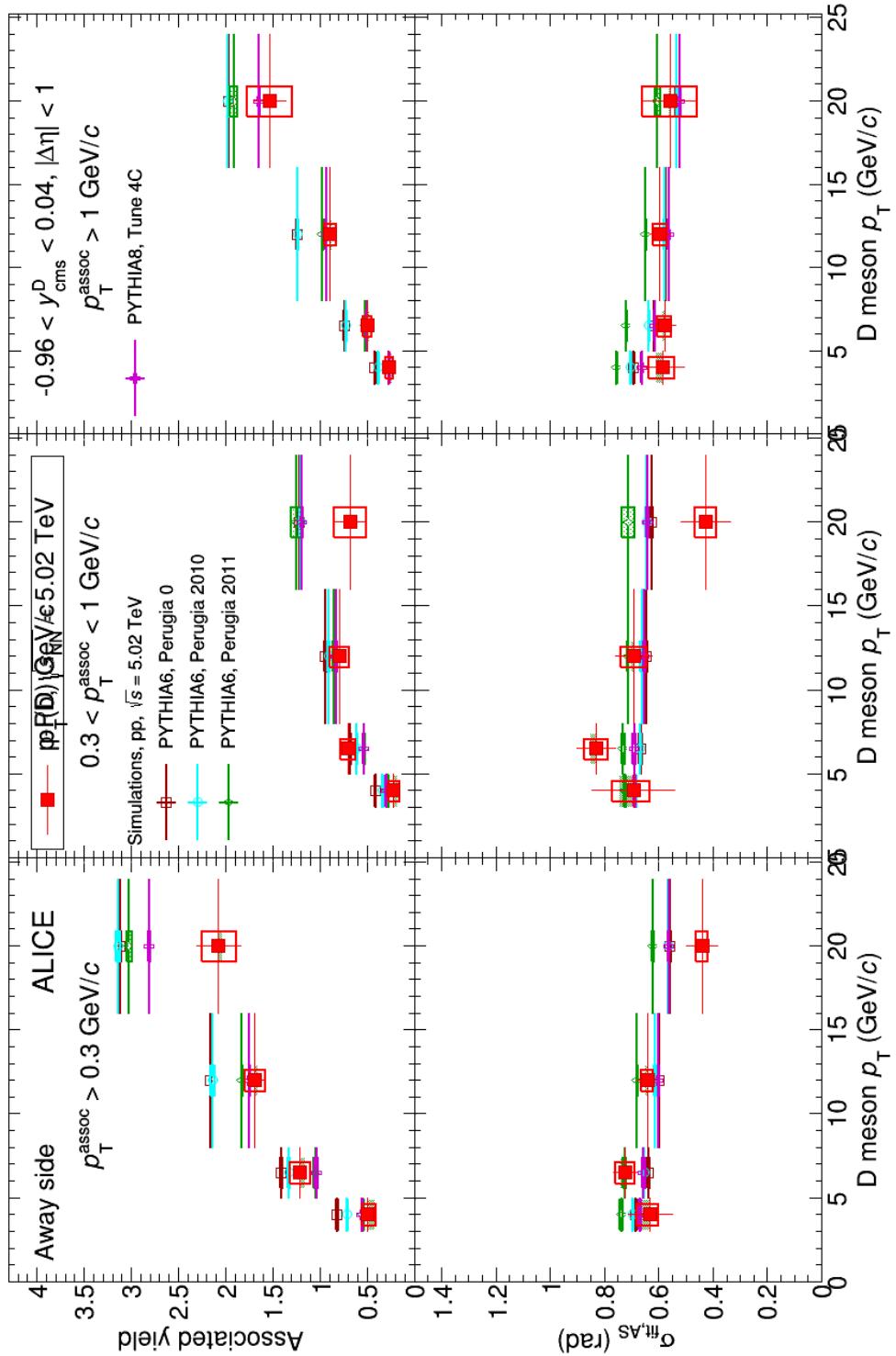


Figure 63: Comparison of near-side peak yields and widths from p-Pb 2016 results and model expectations, for all the studied kinematic ranges.



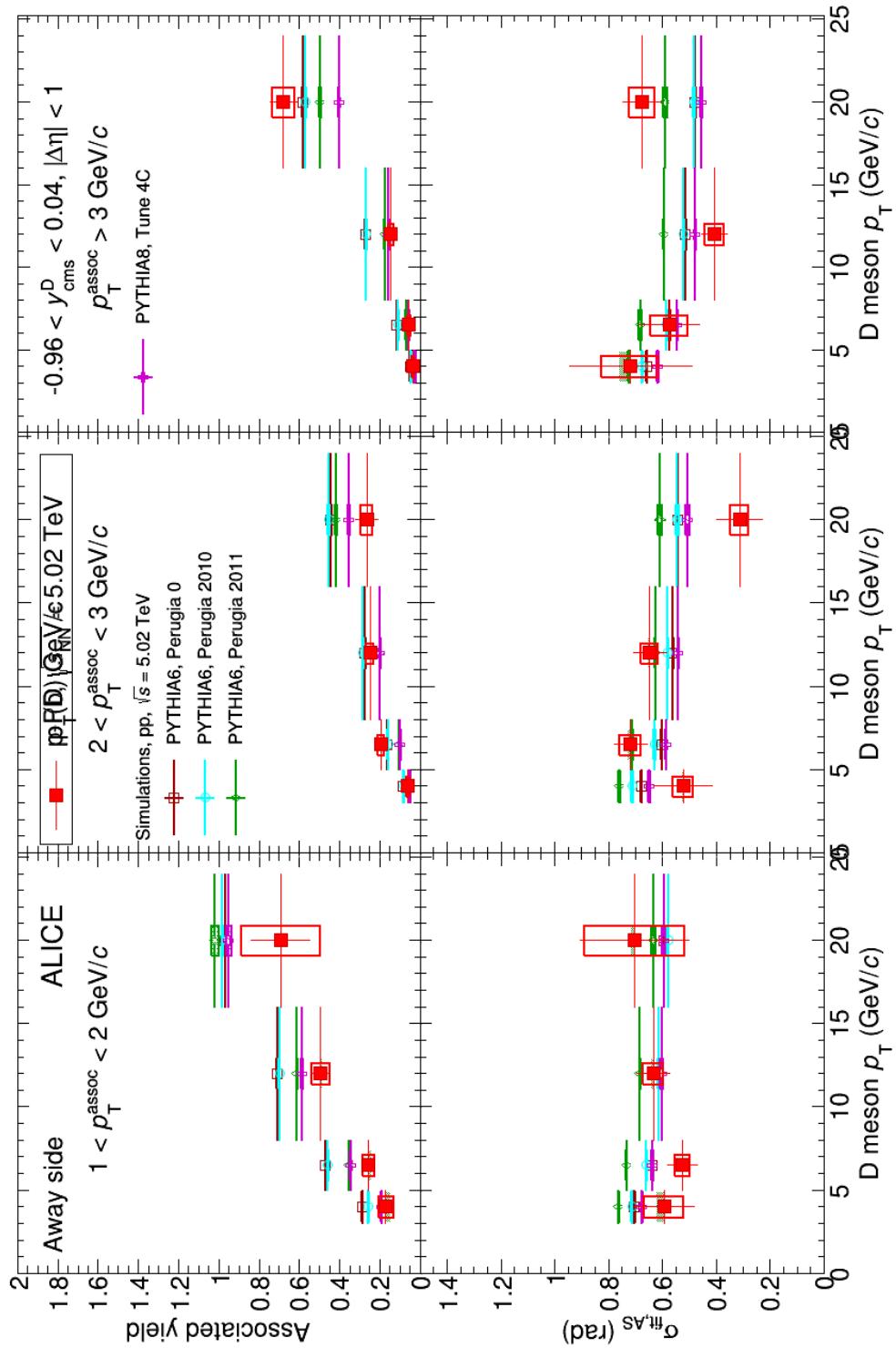


Figure 64: Comparison of away-side peak yields and widths from p-Pb 2016 results and model expectations, for all the studied kinematic ranges.

770 **6 Bibliography**

771 **References**

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