Preparation for $D^+ \to K\pi\pi$ analysis

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based on E. Bruna PhD thesis

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$D^+ \rightarrow K^- \pi^+ \pi^+$: motivation

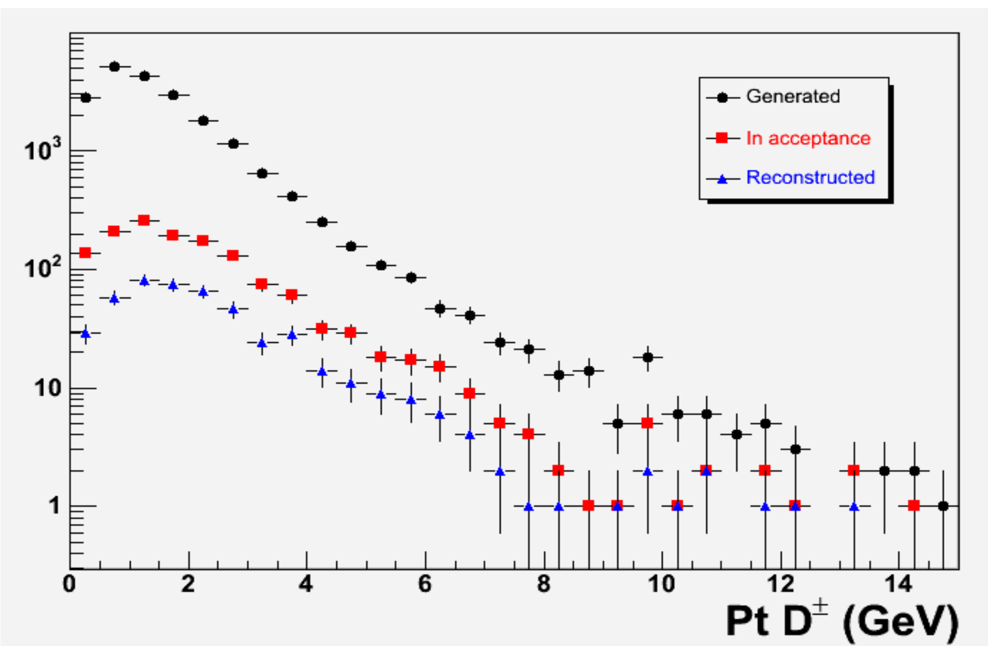
- Accurate determination of charm production cross section by measuring as many charmed hadrons as possible

- Ratios like D^0/D^+ , D_s/D^+ bring information about the hadronization mechanism

- Different systematics w.r.t. the benchmark study $D^0 \rightarrow K\pi$
  - D^+ fully reconstructable from a 3-charged body decay instead of the 2 body decay $D^0 \rightarrow K\pi$
    - ✓ ***Larger combinatorial background***
    - ✓ ***Softer decay products ($\langle p_T \rangle$ ~ 0.7 GeV/c compared to ~ 1 GeV/c of D^0 daughters)***
  - D^+ has a "longer" mean proper length ($c\tau$ ~312μm compared to ~123 μm of the D^0)
  - Possibility to exploit the resonant decay through Kbar0* to enhance the S/B ratio

$D^{\pm}$ statistics in PbPb

b_{min}-b_{max} (fm)	σ (%)	N_{cc} / ev.	$D^{\pm}$ yield/ev.
0-3	3.6	118	45.8
3-6	11	82	31.8
6-9	18	42	16.3
9-12	25.4	12.5	4.85
12-18	42	1.2	0.47



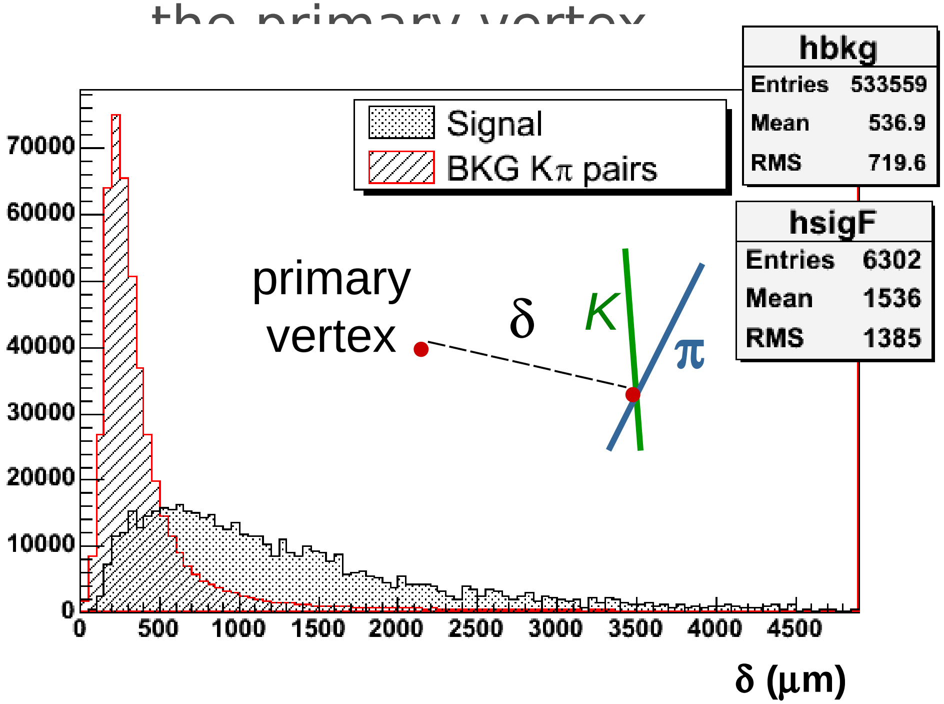
- N_{cc} = number of c-cbar pairs
  - MNR cross-section calculation
  - Includes shadowing (EKS98)
  - Shadowing centrality dependence from Emelyakov et al., PRC 61, 044904
- $D^{\pm}$ yield calculated from N_{cc}
  - Fraction $N_{D^{\pm}}/N_{cc}$ (≈0.38) from PYTHIA fragmentation
  - D^{+} less abundant than D^{0} by about a factor 3
- Geometrical acceptance and reconstruction efficiency
  - Extracted from 1 event with 20000 $D^{\pm}$ in full phase space
- B. R. $D^{\pm} \rightarrow K\pi\pi$ = 9.2 %
  - Larger than the B.R. $D^{0} \rightarrow K\pi$ (=3.8%)

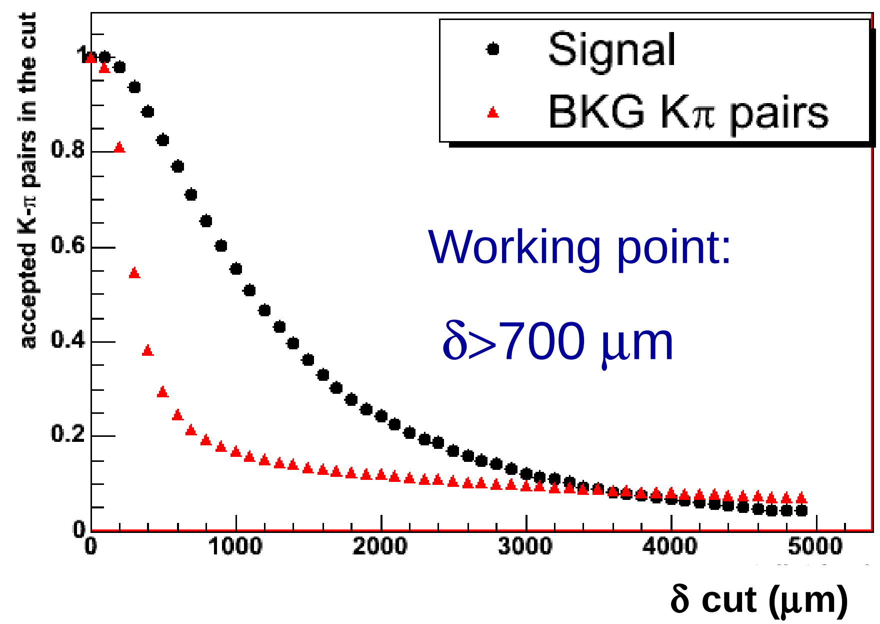
Simulation and analysis strategy

- Pb-Pb events generated in 2005 on the italian grid
  - SIGNAL: 5000 events with ≈9000 $D^{\pm} \rightarrow K\pi\pi$ (PYTHIA)
  - BACKGROUND: 20000 central Hijing events
- Starting points for Pb-Pb analysis:
  - Huge combinatorial background: 10^9 triplets in central Hijing event
  - Three studies with different PID information:
    - ✓ ***Perfect PID - No PID - Combined Bayesian PID (ITS+TPC+TRD+TOF+HMPID)***
- pp events with parametrized TPC response generated in 2006 on the italian grid (PWG3 production)
  - Statistics = Physics run of 5.4 10^6 events
  - Extra events with charmed mesons forced to decay hadronically to increase the signal statistics
- Starting points for pp analysis
  - Much smaller combinatorial background (on average 100 triplets/event)
  - Much worser resolution on primary vertex position
  - For each candidate triplet, primary vertex must be recalculated removing the candidate secondary tracks
  - PID information not used

Pre-selection steps

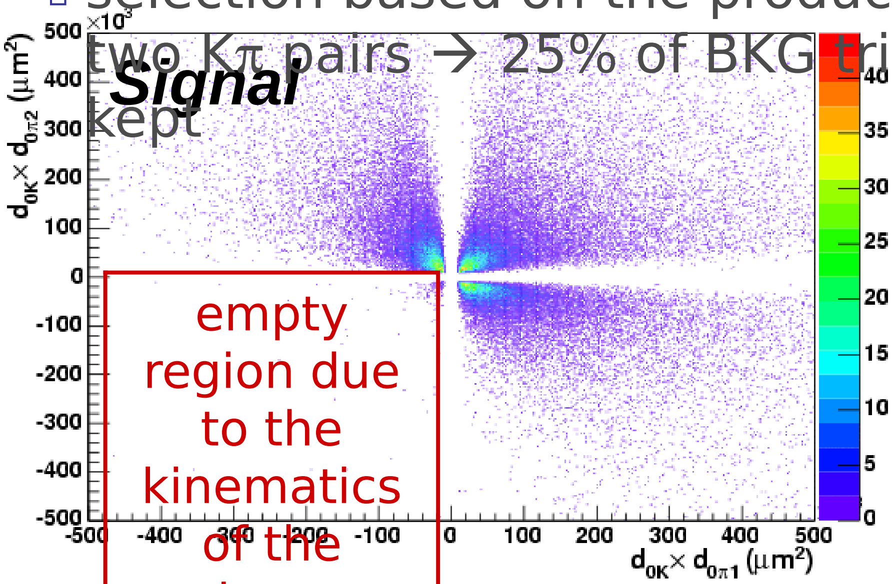
- Cuts on single tracks (p_T, $d_0^{r\phi}$)
  - In Pb-Pb reduce the combinatorial background from 10^9 to 10^6 triplets per event keeping ≈10% of the signal
  - p_T cut different for K and π (identified by the charge sign)
- Cuts on Kπ candidate pairs
  - K and π have opposite charge sign
  - Cut on the distance δ between the vertex of the 2 tracks and the primary vertex



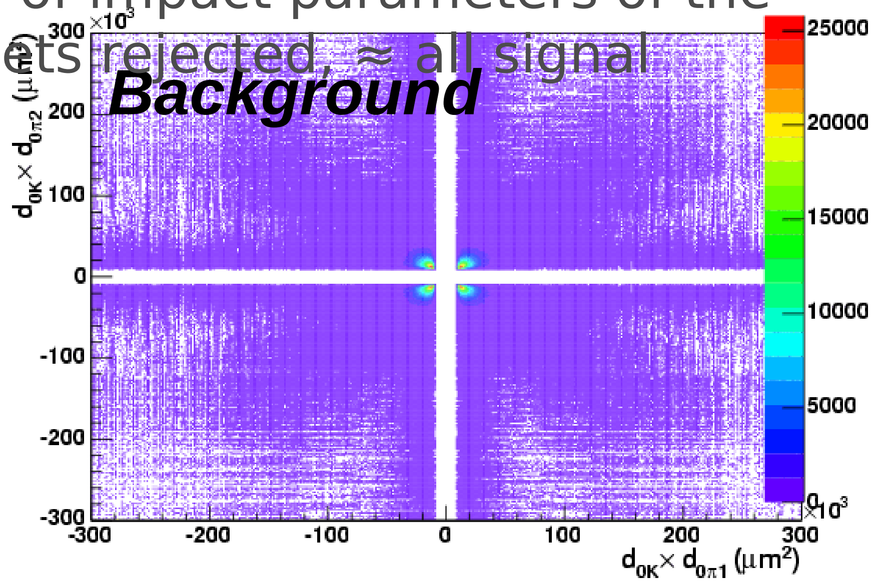


Pre-selection steps

- Cuts on single tracks (p_T, $d_0^{r\phi}$)
- Cuts on Kπ candidate pairs
  - distance δ between the 2 track vertex and the primary vertex
- Build the triplets starting from two selected Kπ pairs
  - both Kπ pairs with vertex displaced from the primary vertex
- Cuts on Kππ candidate triplets of tracks
  - selection based on the products of impact parameters of the two Kπ pairs → 25% of BKG triplets rejected, ≈ all signal kept



empty region due to the kinematics of the

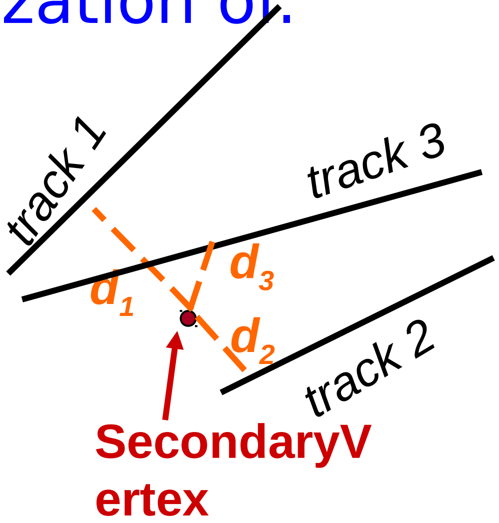


Decay vertex reconstruction

(AliVertexerTracks::VertexForSelectedTracks)

- Tracks (helices) approximated with Straight Lines
- Vertex coordinates (x_0,y_0,z_0) from minimization of:

$$D^2 = d_1^2 + d_2^2 + d_3^2$$



with

$$d_k^2 = \left(\frac{x_k - x_0}{\sigma_x}\right)^2 + \left(\frac{y_k - y_0}{\sigma_y}\right)^2 + \left(\frac{z_k - z_0}{\sigma_z}\right)^2$$

  - σ_{xi}, σ_{yi}, σ_{zi} are the errors on the track parameters

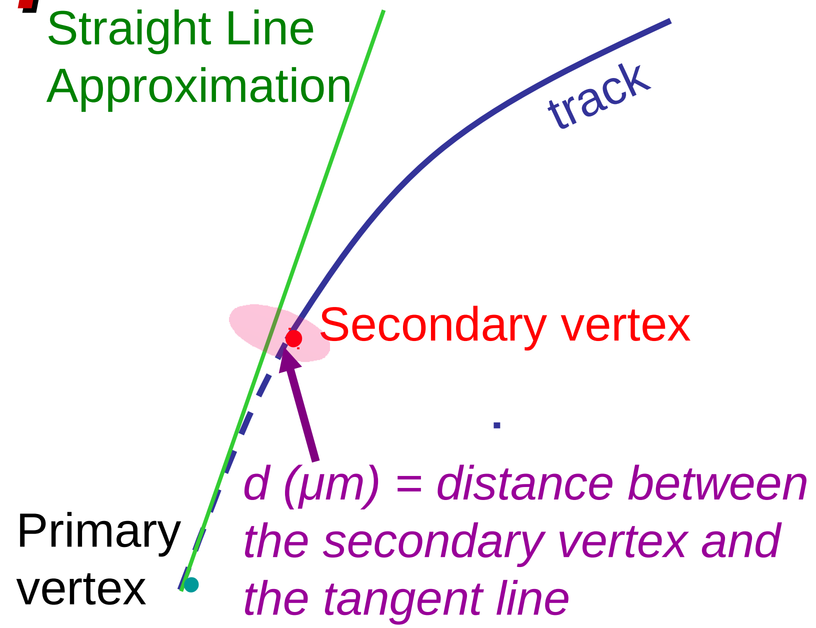
- Calculate track dispersion around the found vertex:

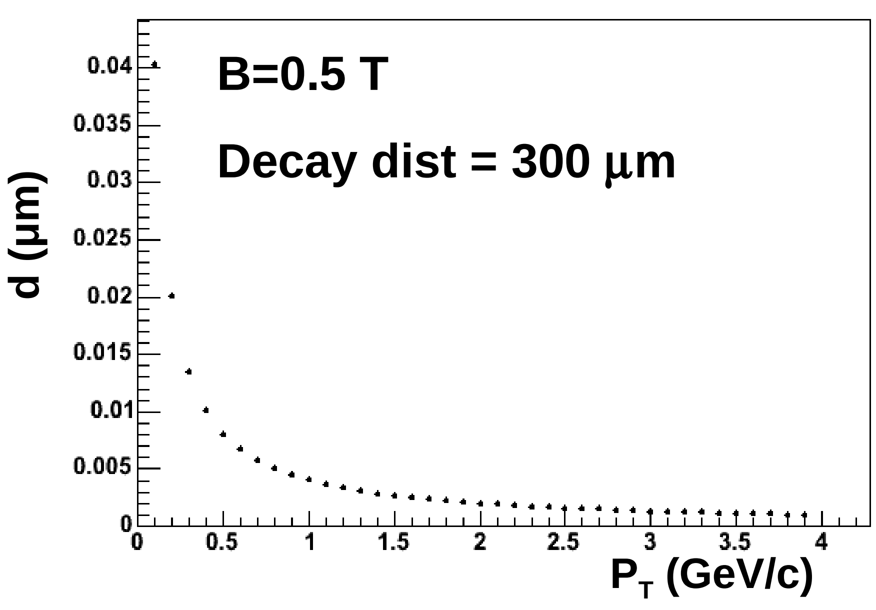
$$\sigma^2 = \sum_{k=1}^{3} \left[(x_k - x_o)^2 + (y_k - y_o)^2 + (z_k - z_o)^2 \right]$$

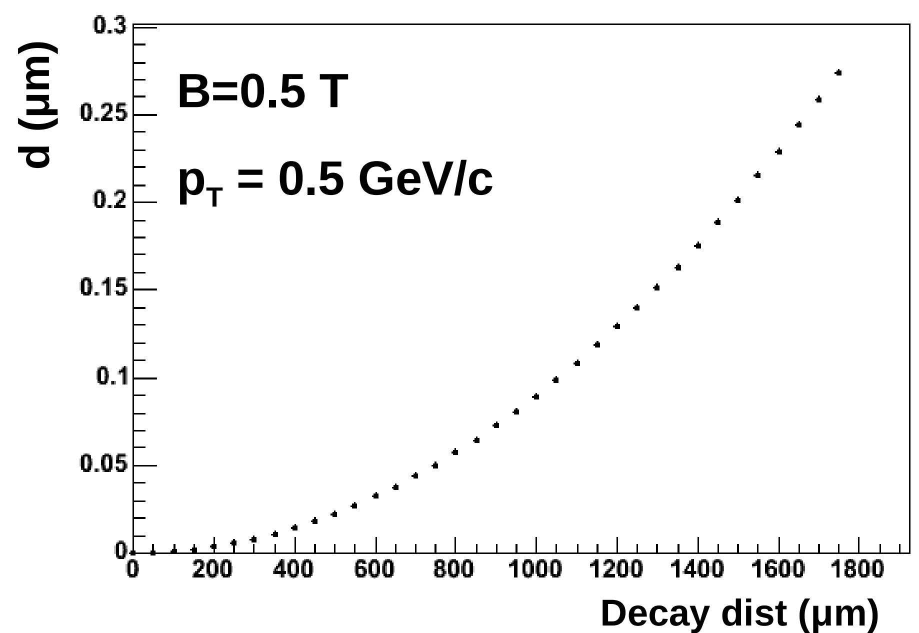
  - used to select good vertices

Straight Line Approximation

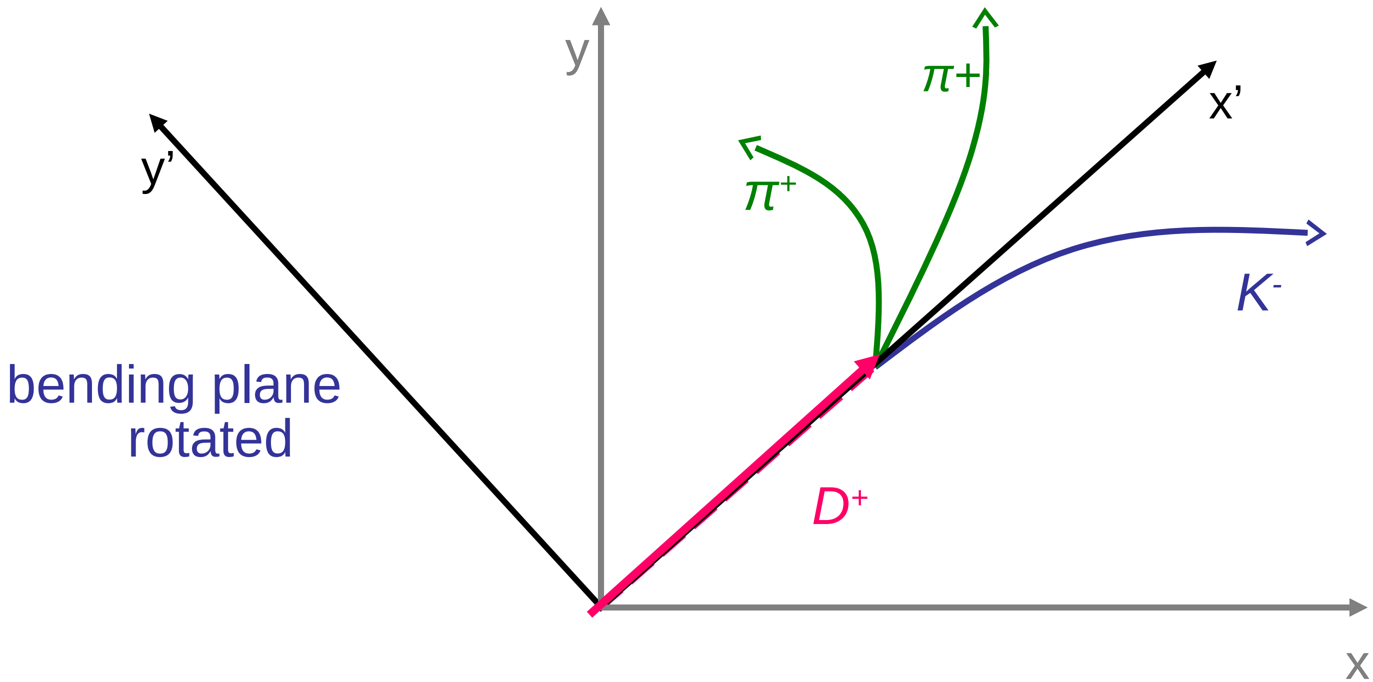
- Geometrical calculation of the "error" introduced by approximating the track (helix) with a straight line close to the primary vertex.
  - Good approximation: error is negligible w.r.t. tracks $r\phi$ d_0 resolution ($\approx$ 100 μm for 0.5 GeV/c tracks)

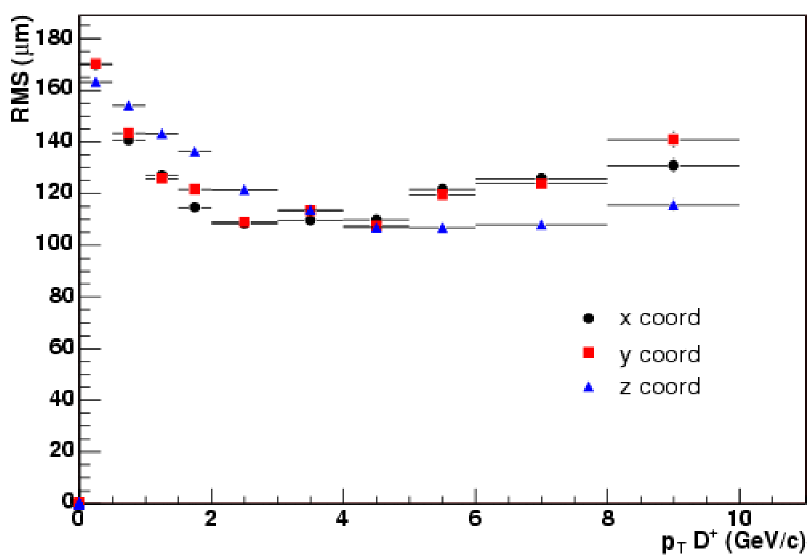


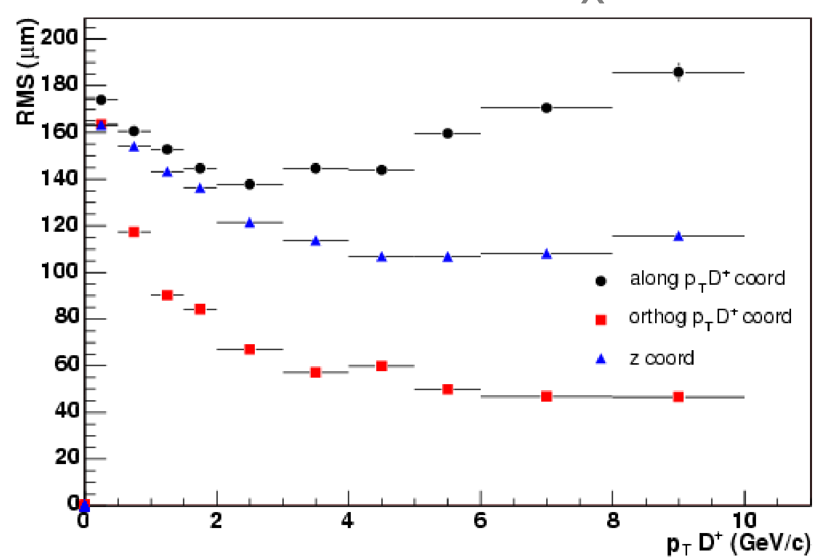




Vertex finder: $D^+ \to K\pi\pi$

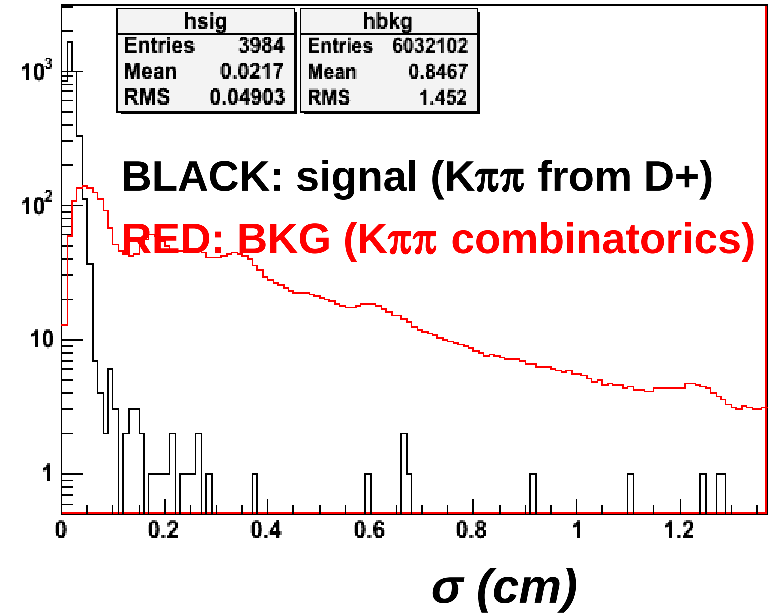


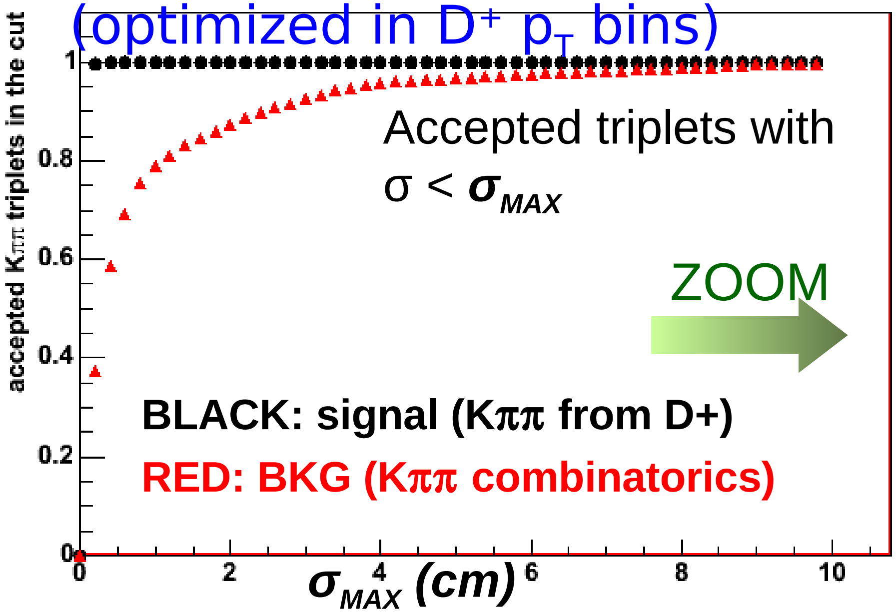


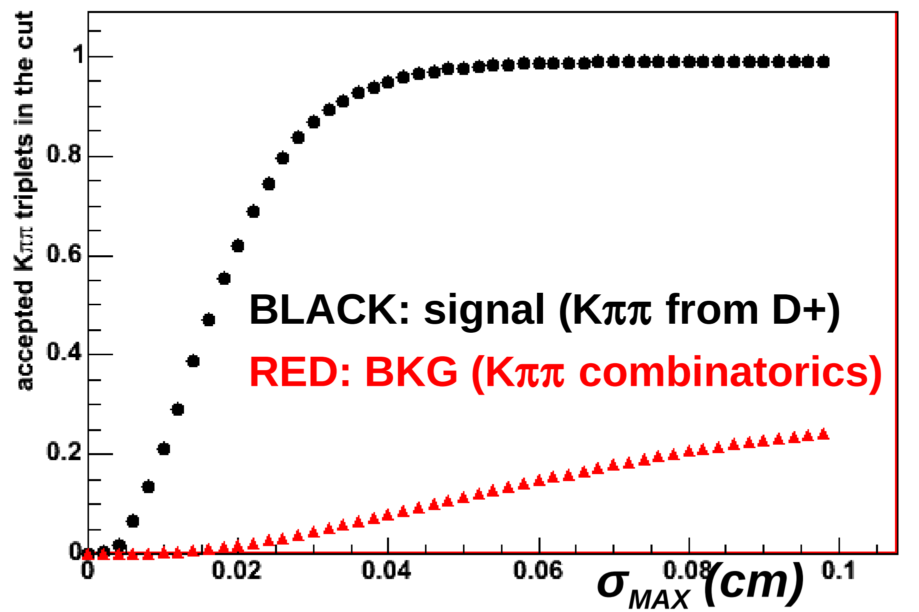


Vertex selection: $D^+ \to K\pi\pi$

- Vertex quality selection based on track dispersion σ around the found vertex
  - Distribution of σ for signal and background Kππ triplets
  - Fraction of selected signal and background triplets as a function of the cut on track dispersion (σ_{MAX}).
- Working point: σ < 200 μm (optimized in D^+ p_T bins)

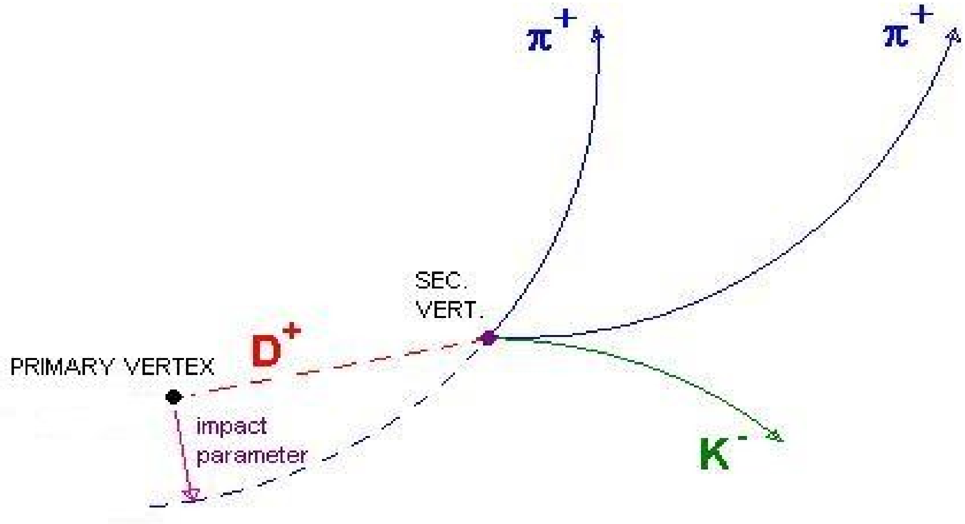




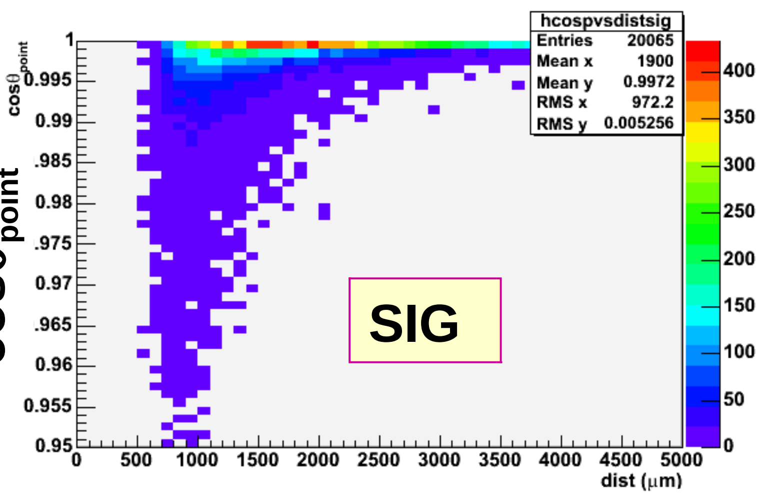


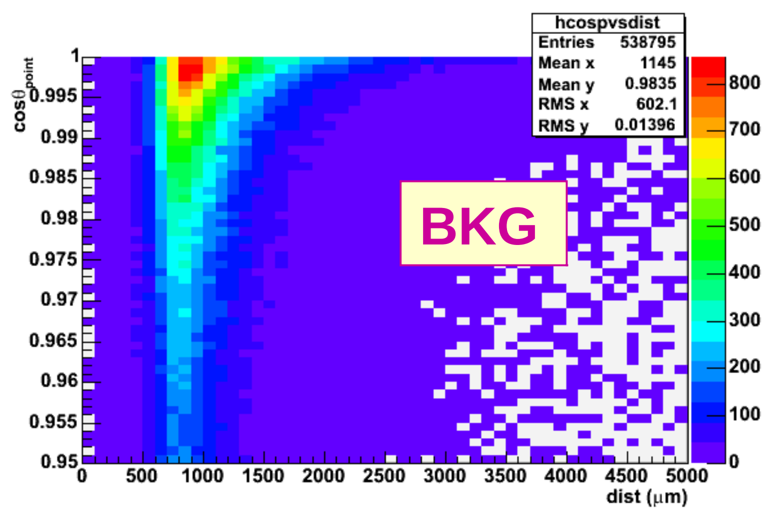
D^+ final selection steps (I)

- Four selection variables:
  - Distance between primary and secondary vertex (d_{PS})
  - $\cos\theta_{point}$
  - Sum of squared impact parameters $s = d_{01}^2+d_{02}^2+d_{03}^2$
  - Max. p_T among the 3 tracks $p_M=\mathrm{Max}\{p_{T1},p_{T2},p_{T3}\}$



$\cos\theta_{point}$





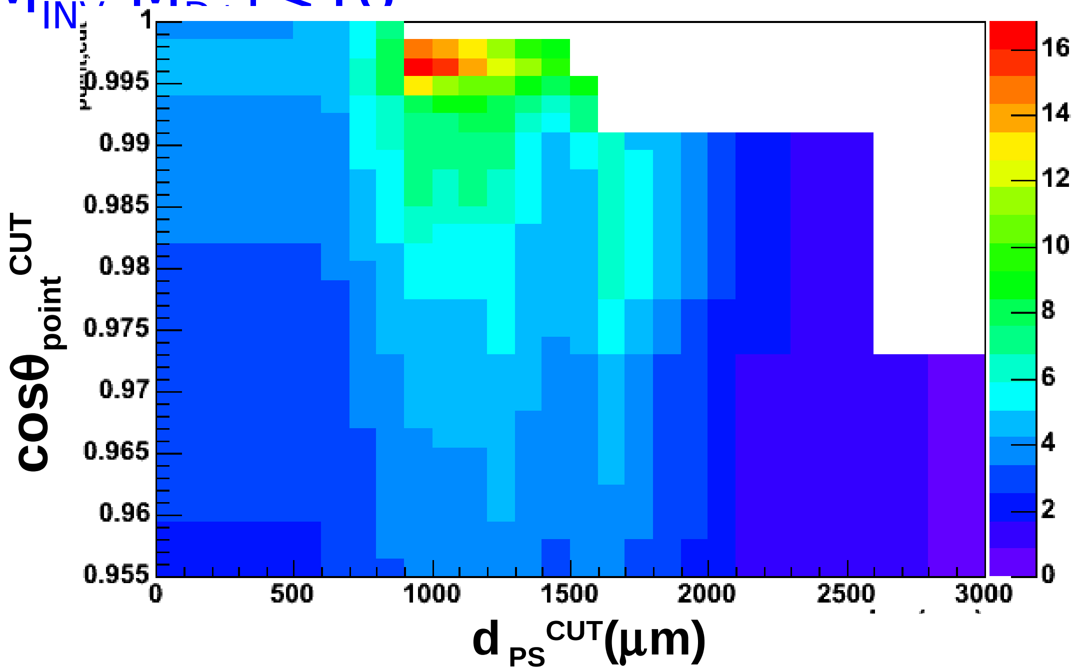
$d_{PS}(\mu m)$

D^+ final selection steps (II)

- Fill matrices S^{ijkl} and B^{ijkl}
  - each matrix cell contains the number of signal and background triplets passing the set of cuts

$$d_{PS} > c^i \,,\ \cos\theta_{point} > c^j \,,\ s > c^k \,,\ p_M > c^l$$

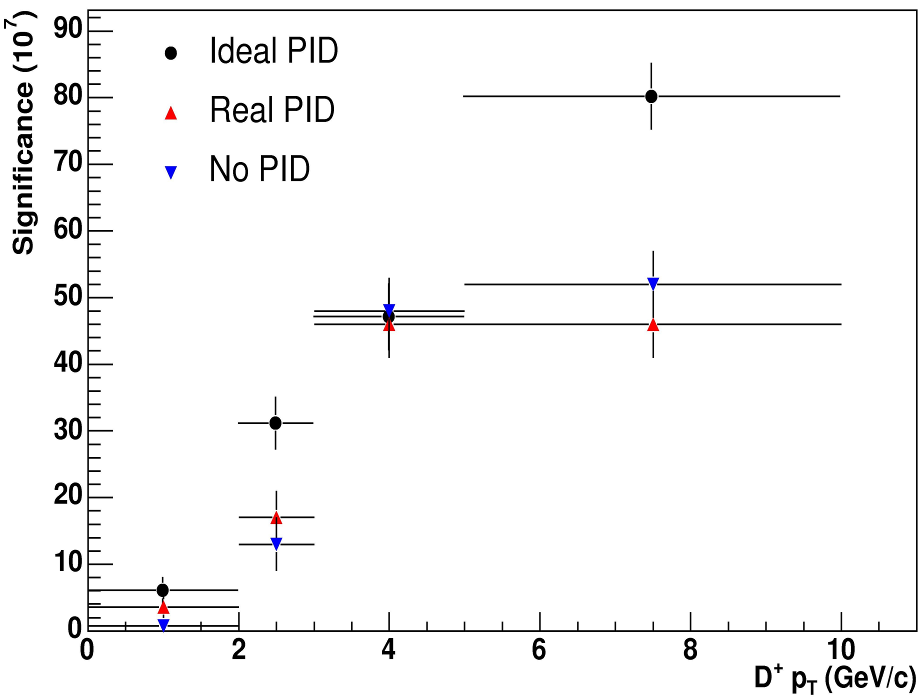
- Select the set of cuts (i.e. the matrix cell) which maximizes the significance ($S/\sqrt{(S+B)}$) in the mass range $|M_{INV}-M_{D^+}|<1\sigma$

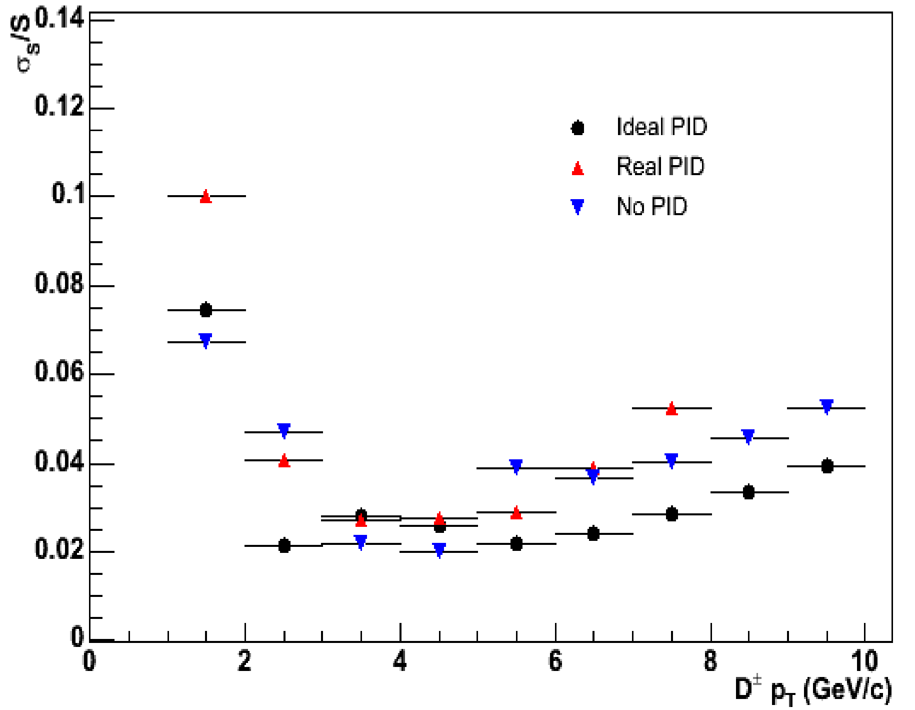


Significance $S/\sqrt{(S+B)}$ for $2<p_T<3$ (normalized to 10^7 PbPb events)

Results: PbPb (I)

- Significance and relative statistical error vs. D^+ p_T
  - S/ev~10^{-3} , B/ev ~10^{-4}
  - Significance and relative statistical error (=1/√S) normalized to 10^7 central PbPb events



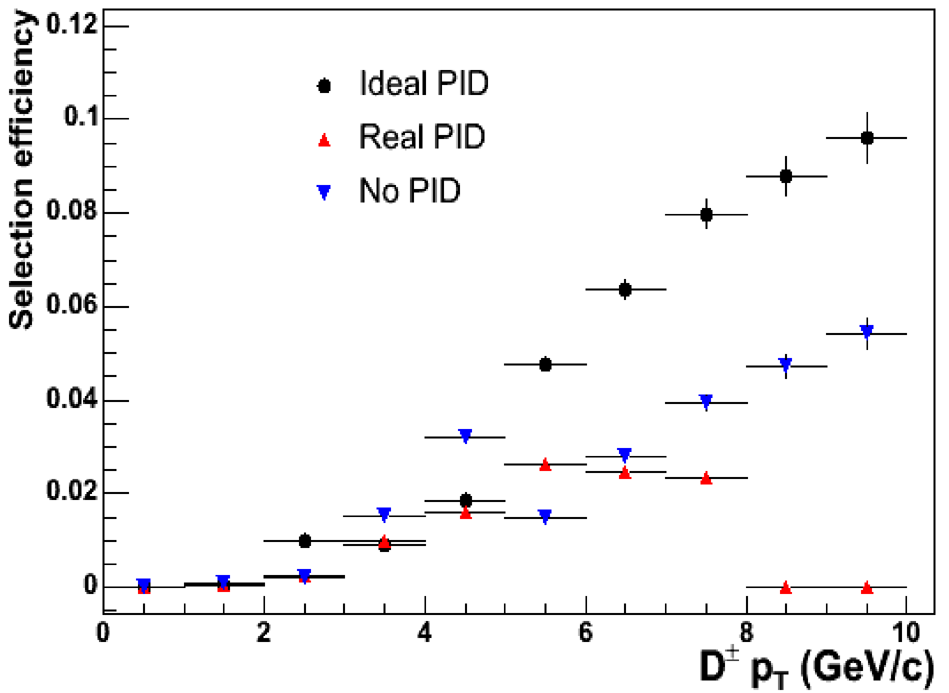


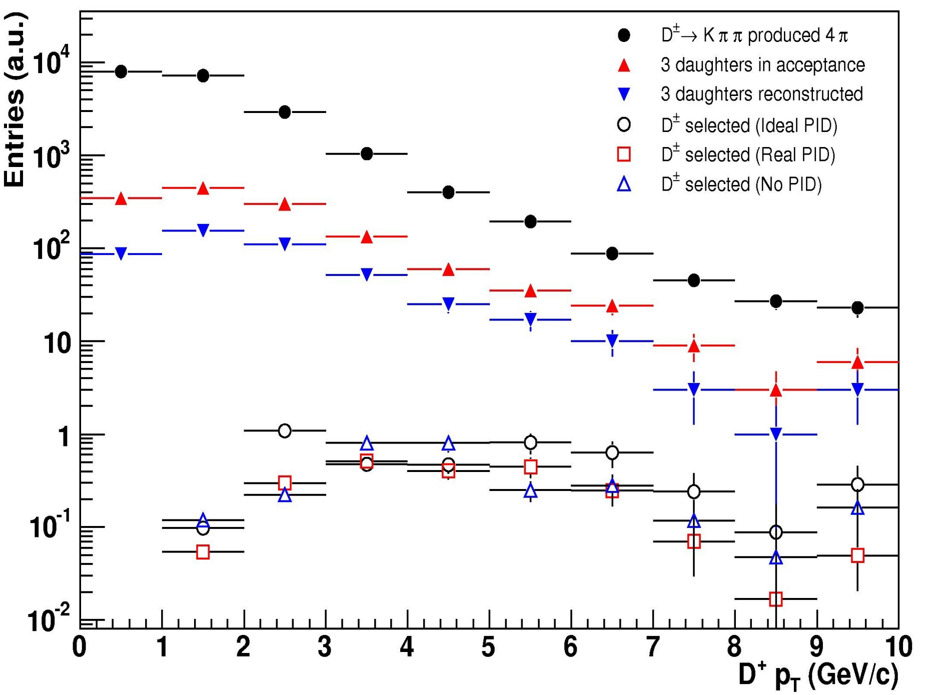
Results: PbPb (II)

- Fraction of selected signal triplets and p_T spectra

$$\varepsilon = \frac{selected\ \ D^{+}}{D^{+}\ with\ 3\ reconstructed\ \ daughters}$$

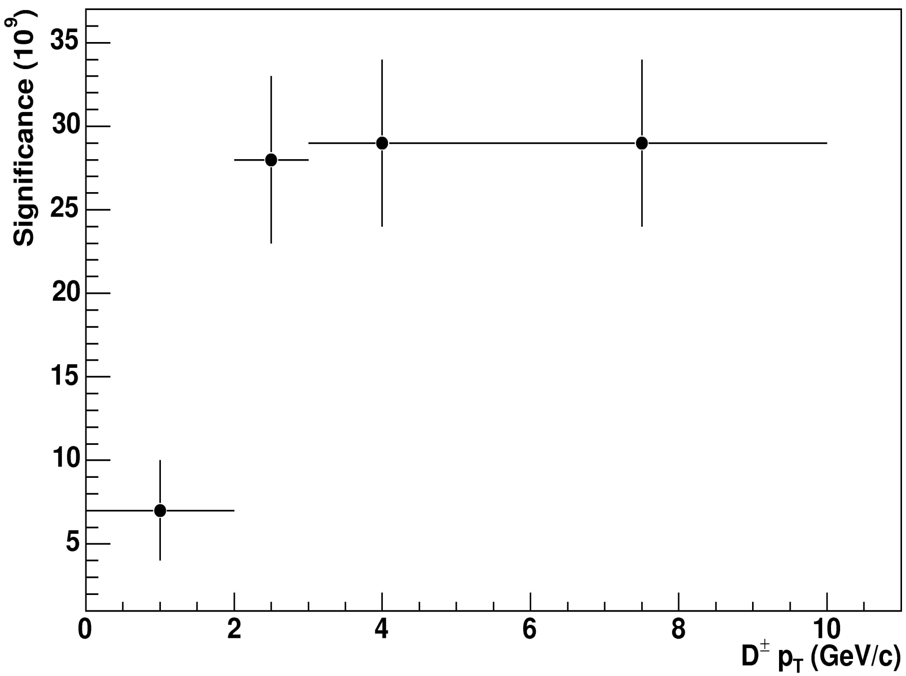
  - p_T integrated fraction of selected $D^+ \approx 1.5\%$ (Ideal PID), 0.6% (Real PID), 1% (no PID)

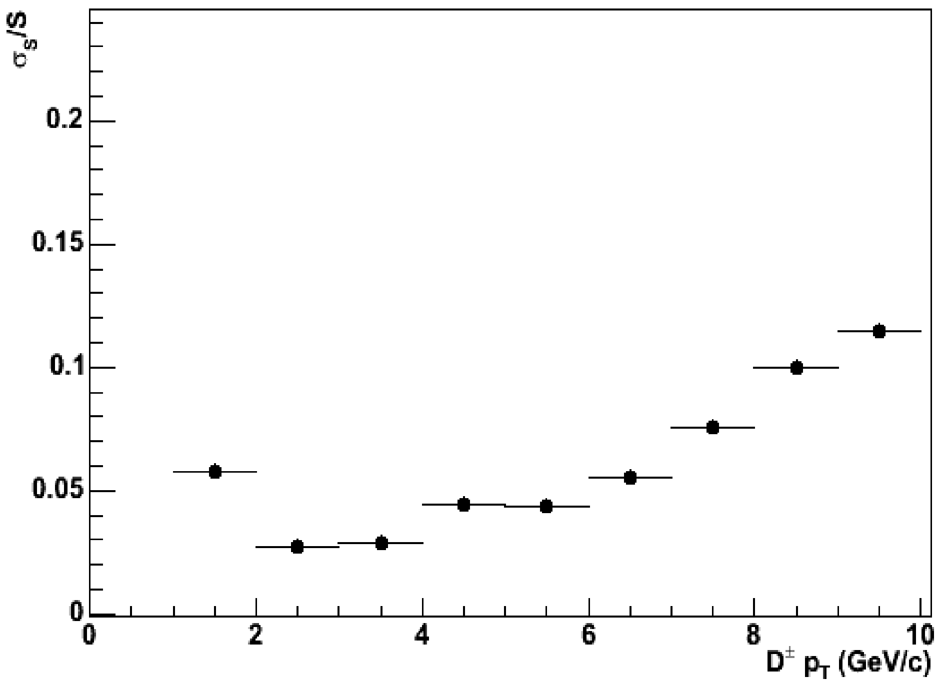




Results: pp (I)

- Significance and relative statistical error vs. D^+ p_T
  - S/ev~5 10^{-6} , B/ev ~5 10^{-6}
  - Significance and relative statistical error (=1/√S) normalized to 10^9 pp Minimum Bias events



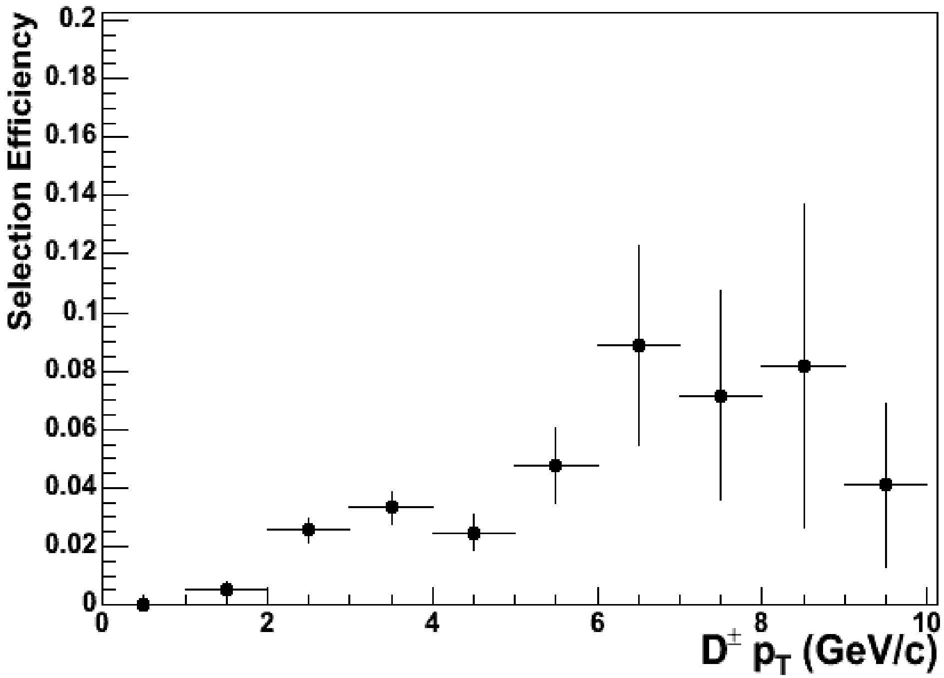


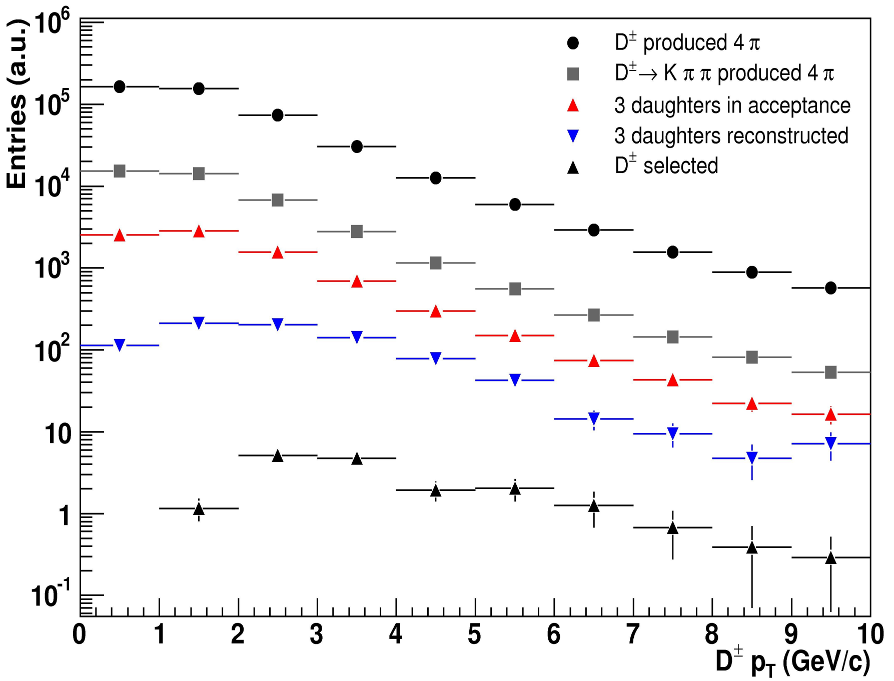
Results: pp (II)

- Fraction of selected signal triplets and p_T spectra

$$\varepsilon = \frac{selected\ \ D^{+}}{D^{+}\ with\ 3\ reconstructed\ \ daughters}$$

  - p_T integrated fraction of selected D+ ≈ 4% (only NO PID case studied)





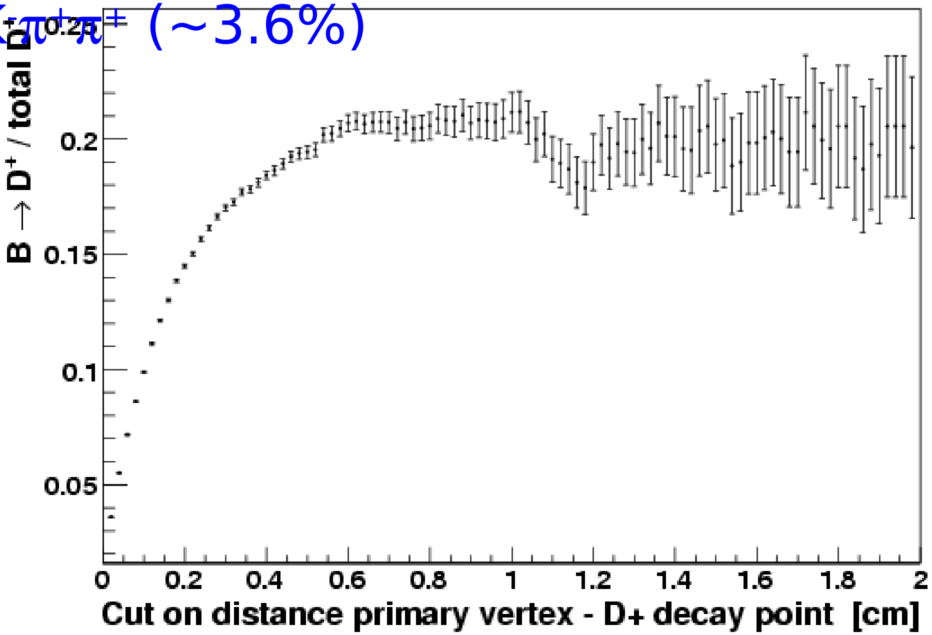
Systematic uncertainties

- Acceptance, reconstruction and PID efficiencies (~10%)
- Centrality selection (~7%)
- Nucleon-nucleon inelastic cross section (~5%)
- Parameters of the Woods-Saxon profile and nuclear density (~5%)
- Error on branching Ratio $D^+ \to K\pi^+\pi^+$ (~3.6%)
- Feed-down from beauty:

  $\mathbf{N_{c\to D\pm} = N_{D\pm} - N_{b\to B \to D\pm}}$

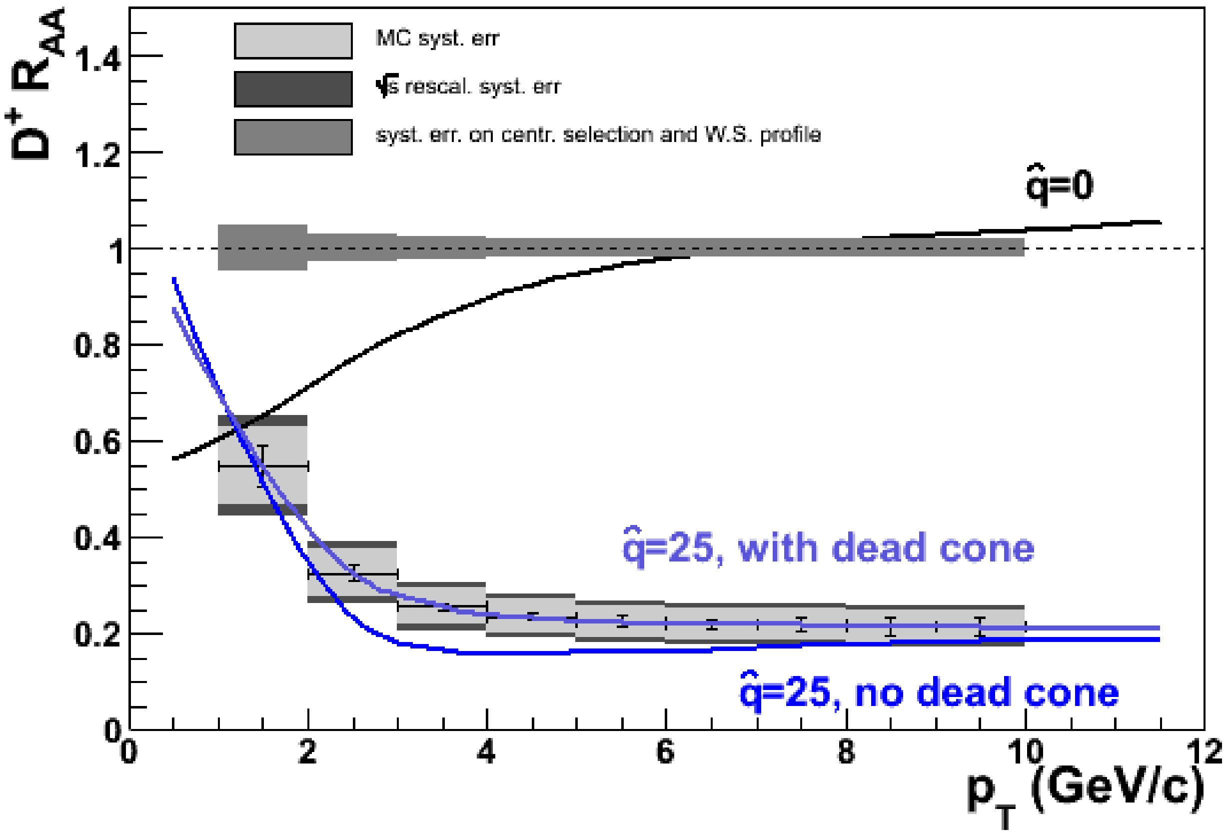
  - Contamination (from MNR c.s. for c and b and B.R. for B→ D±)

    K= $\mathbf{N_{b\to B \to D\pm} / N_{c\to D\pm}}$ **=4%**
  - D+ from B are more displaced
    - ✓ ***The cut on distance between primary to secondary vertex increases the fraction of selected D^+ coming from B decay***



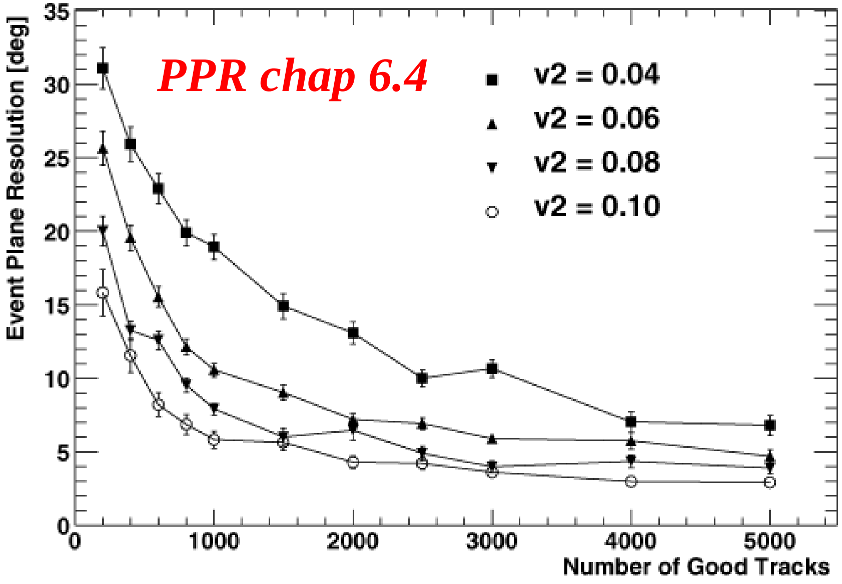
Perspectives for D^+ R_{AA}

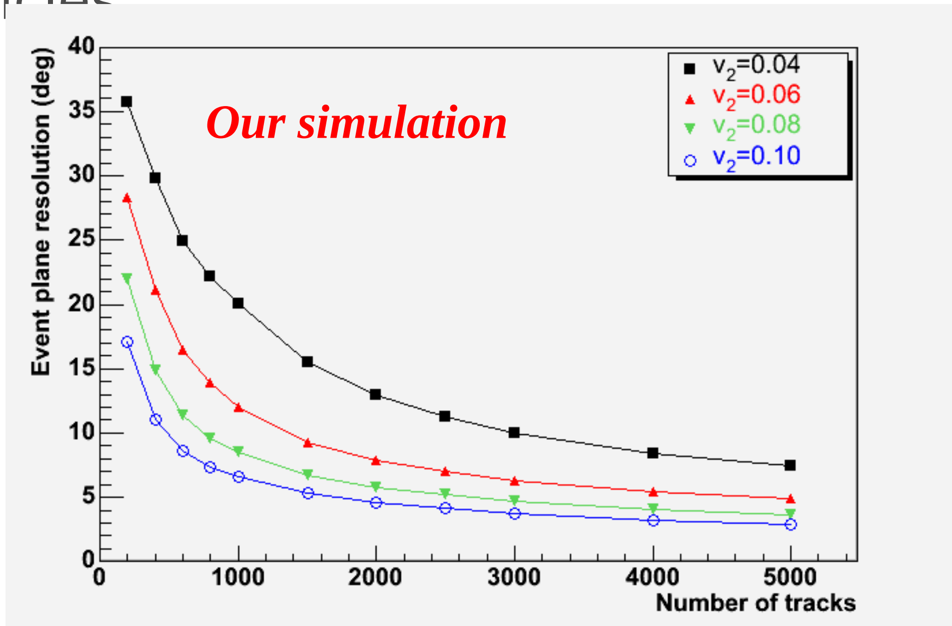
- Statistical error bars from 10^9 pp Min. Bias events and 10^7 central PbPb events (1 year of data taking)
  - Statistical error smaller than the syst. errors up to 10 GeV/c



Perspectives for D^+ v_2 (I)

- GOAL: evaluate statistical error bars on the measurement of $v_2(p_T)$ of D mesons
- TOOL: fast simulation (ROOT+3 classes +1 macro)
- Ingredients for event plane resolution
  - Multiplicity of charged particles





Perspectives for D^+ v_2 (II)

- Simulations performed for centrality class 6<b (fm)<9
  - To compare with model calculations at b=8 fm (see next slide)
- Multiplicity (Armesto, Salgado, Wiedemann hep/ph 0407018)

$$\frac{1}{N_{part}}\frac{dN_{ch}^{AA}}{d\eta}\Big|_{\eta\sim 0} = N_0 \sqrt{s}^{\lambda} N_{part}^{\frac{1-\delta}{3\delta}}$$

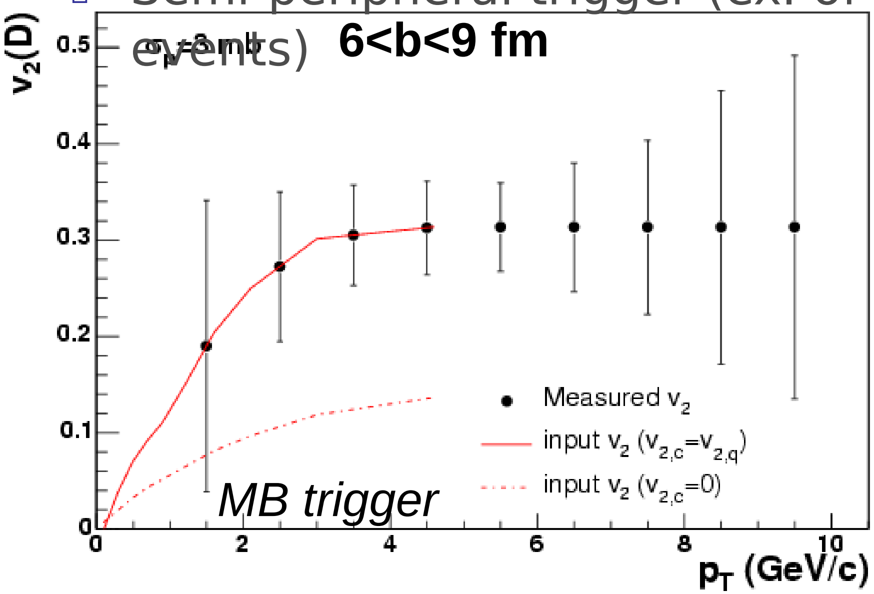
  - From Glauber in 6<b<9 : <Npart> =175 → $N_{ch}(|y|<1)$ = 1570
- v_2 of charged hadrons = 0.125
  - From (Low Density Limit) extrapolation of v_2/ε vs. 1/S dN/dy (see E. Simili)
- D^+ azimuthal angle resolution from the PbPb sample of simulated signal
- D^+ statistics in 6<b<9 centrality class:
  - Number of D^+ per event from analysis in central events rescaled with the number of N_{cc} per event in the 2 centrality classes (=42/118)
  - Number of events in 6<b (fm)<9 (normalized to $2\ 10^7$ Min. Bias events)
    - ✓ *=18% (from 14% to 32%) of total inelastic cross section*

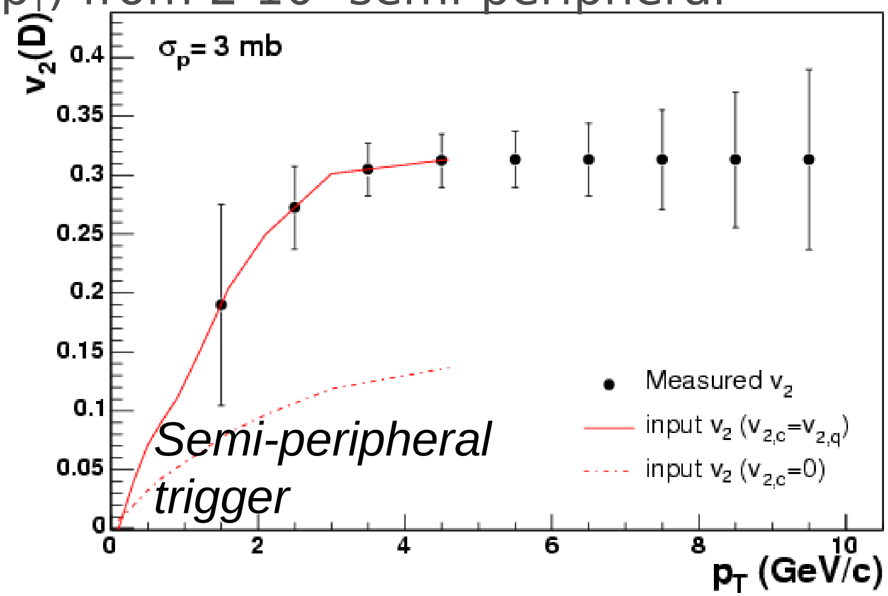
Perspectives for D+ v_2 (III)

- Model calculations:
  - $v_2(c)$ at the LHC for b=8fm (Ko,Chen,Zhang Braz. J. phys. To be publ.)
  - Hadronization vi h similar velocities

$$v_2^D(p_\perp) \approx v_2^c(\tfrac{5p_\perp}{6}) + v_2^q(\tfrac{p_\perp}{6})$$

- Statistical error bars quite large
  - Sum $D^0 \rightarrow K\pi$ and $D^\pm \rightarrow K\pi\pi$
    - ✓ ***Number of events roughly ×2 → error bars on v_2 roughly /√2***
  - Semi-peripheral trigger (ex. of $v_2(p_T)$ from $2 \cdot 10^7$ semi-peripheral events)





Conclusions

- Monte Carlo studies on $D^+ \rightarrow K^-\pi^+\pi^+$ show that the analysis is feasible with a pretty good significance down to $p_T \approx 0.5$-1 GeV/c both in PbPb and pp collisions by means of:
  - Selection strategy based on pre-selection cuts, vertex finding and maximization of the significance based on multi-dimensional matrices
  - Vertex Finding algorithm for secondary vertices (AliVertexerTracks::VertexForSelectedTracks)
- Analysis tools:
  - AliAODRecoDecayHF3prong class will be soon prototyped
    - ✓ ***Selection strategy and cut variables are defined***
- Perspectives for observables R_{AA} and v_2
  - Background "subtraction" method(s) for v_2 analysis still to be defined
    - ✓ ***Need for large statistics of reconstructed PbPb events with elliptic flow***

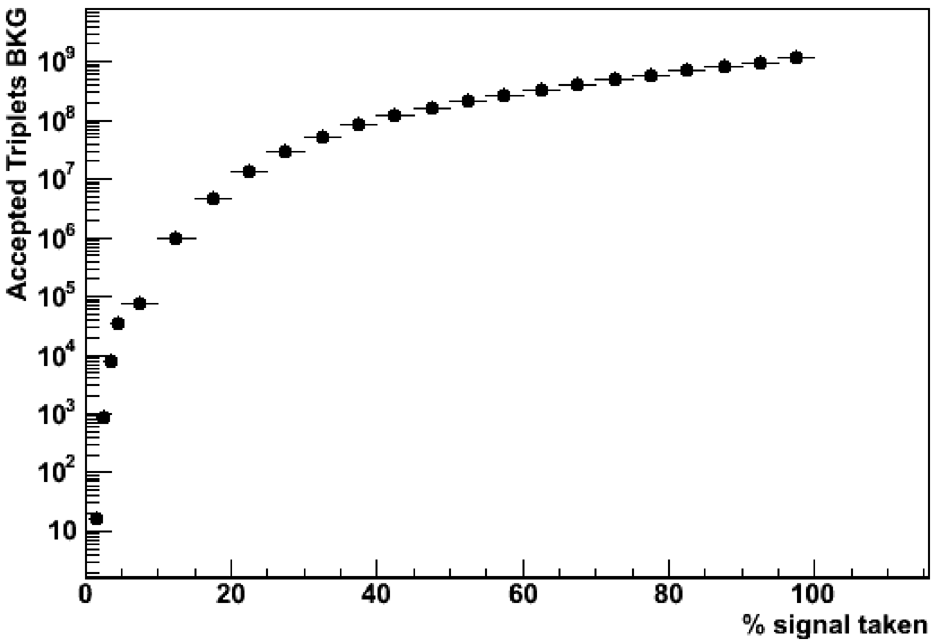
Backup slides

Results scaled to a lower multiplicity scenario for Pb-Pb

- Results presented so far for Pb-Pb based on $dN_{ch}/dy=6'000$
  - $N_{tracks}=7000$
  - BKG/ev=N(N-1)(N-2)/3! ~ $6x10^{10}$
- Extrapolations from RHIC results seem to favour a lower multiplicity scenario, $dN_{ch}/dy=2'000$
  - N_{tracks}~7000/3 ~2300
  - BKG/ev ~ $2x10^{9}$
- Let's consider the D^{+} p_T interval: $0<p_T<2$ GeV/c:
  - The results in the highest multiplicity scenario ($dN_{ch}/dy=6'000$) are not satisfactory
  - BKG/ev is downscaled by a factor ~30;
  - SIG/ev not rescaled
  - S/√S+B (normalized to 10^{7} ev.) ~ 10 in case of Real PID: it is possible the study of the low-p_T spectra

1^{st} step: single track cuts

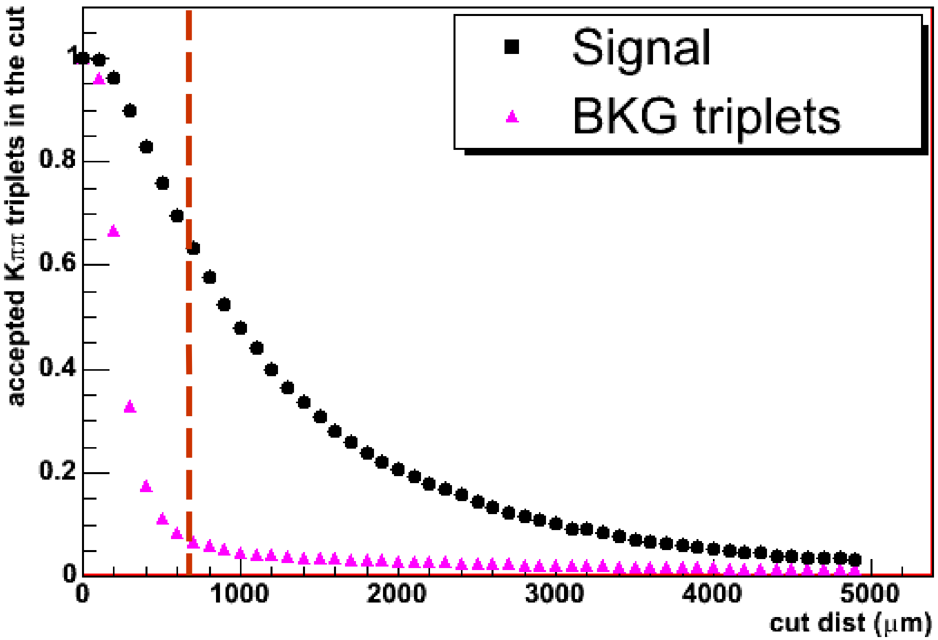
- Cuts on p_T and d_0 of all tracks
- If PID information is used
  - Reject p, e and μ
  - Different p_T cut for π and K



Selection	SIG/event	Selected SIG	BKG/event	Selected BKG	S/B
No cuts	0.1	100%	10^9	100%	10^{-10}
P_T π >0.5 GeV/c **P_T K >0.7 GeV/c** **d_0 = 95 μm**	0.008	8%	10^6	0.1%	10^{-8}

Combining $K\pi\pi$ triplets

- Build the triplets starting from two selected $K\pi$ pairs
  - both $K\pi$ pairs with vertex displaced from the primary vertex

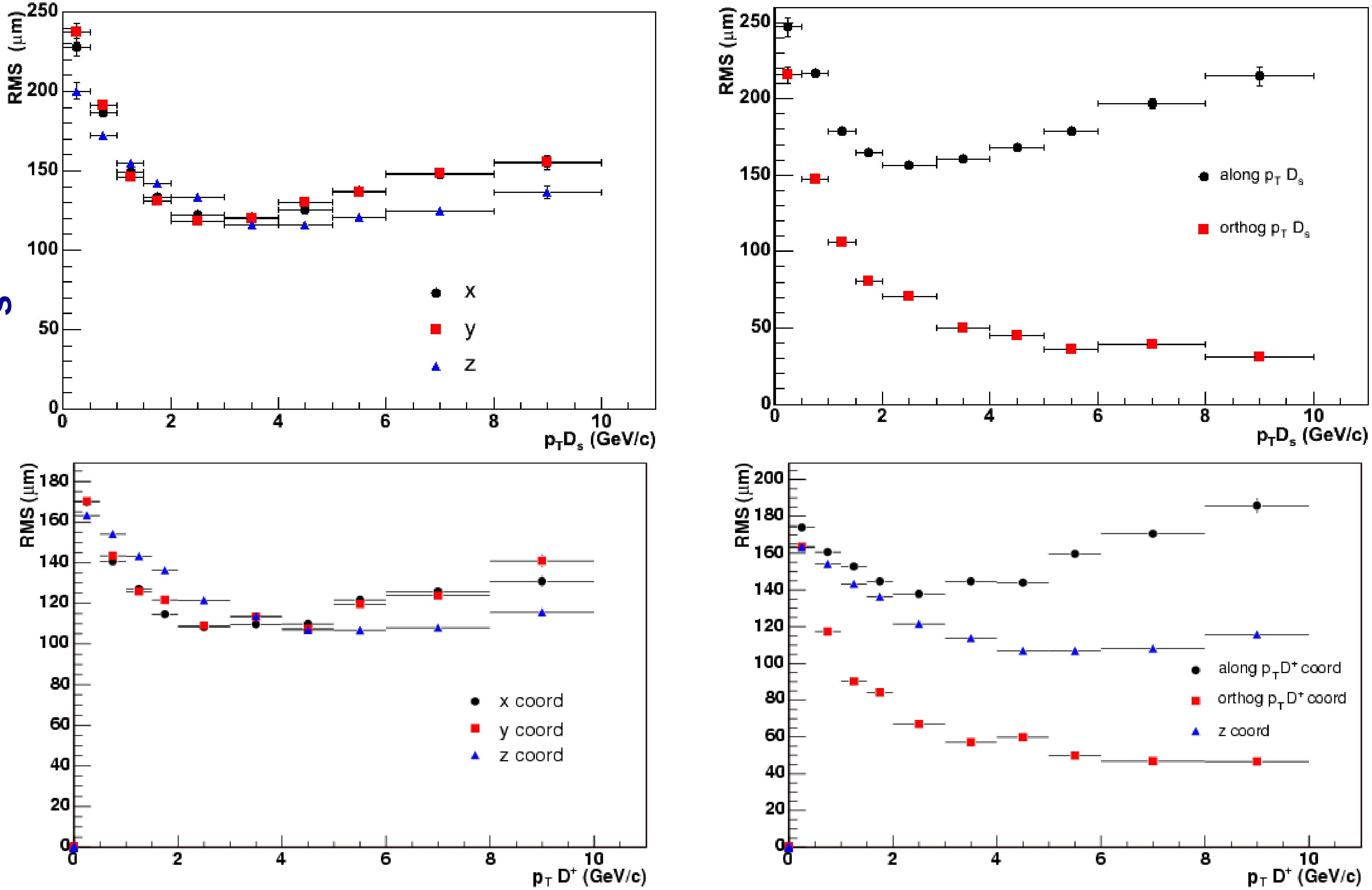


Vertex finder: $D_s \rightarrow KK\pi$

R. Silvestri, E. Bruna

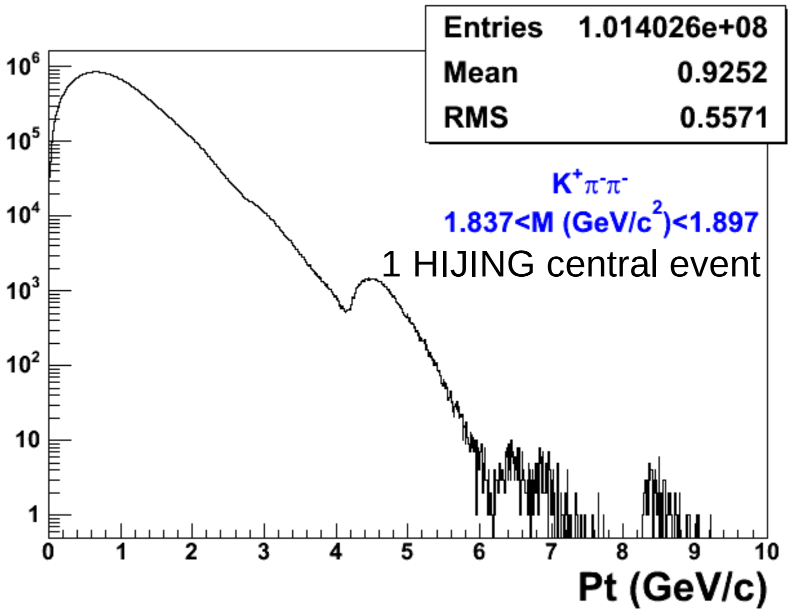
$D_s \rightarrow KK\pi$

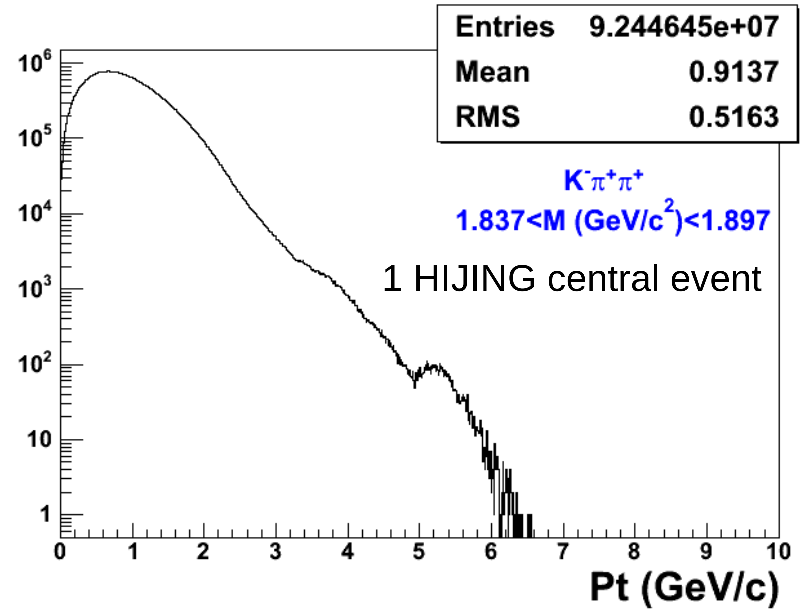
$D^+ \rightarrow K\pi\pi$



- Better resolution for D+ due to larger average momentum of daughter tracks

Combinatorial background



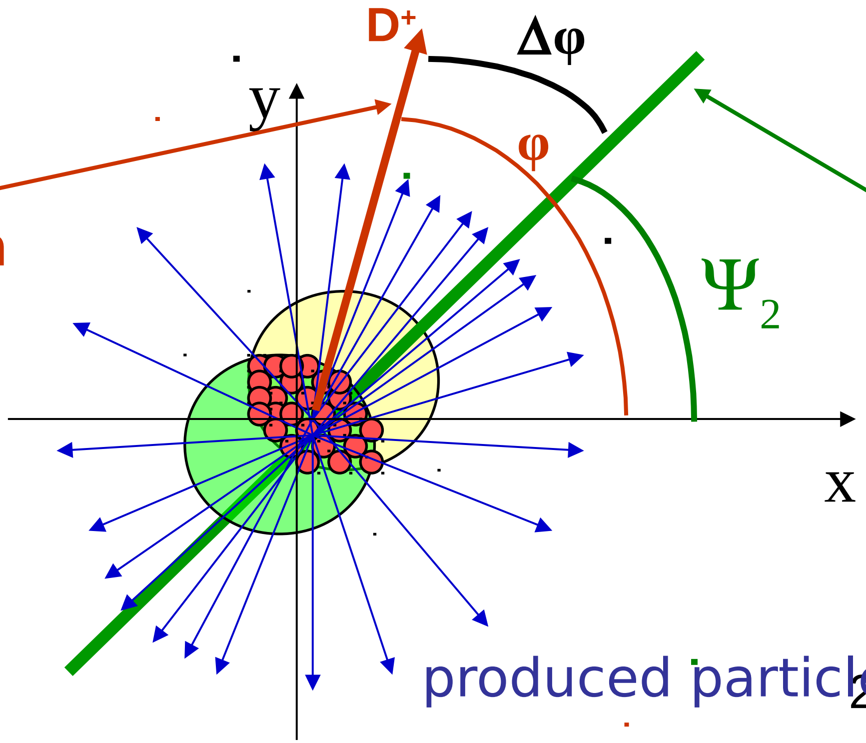


- Huge number ($\approx 10^{10}$ without PID) of combinatorial $K\pi\pi$ triplets in a HIJING central event
  - $\approx 10^8$ triplets in mass range 1.84<M<1.90 GeV/c^2 ($D^\pm$ peak $\pm$ 3σ)
    - ✓ ***Final selection cuts not yet defined***
  - Signal almost free from background only for p_T > 6 GeV/c
  - At lower p_T need to separate signal from background in v_2 calculation

First ideas for background

- Sample candidate $K\pi\pi$ triplets in bins of azimuthal angle relative to the event plane ($\Delta\varphi = \varphi - \Psi_2$)
  - Build invariant mass spectra of $K\pi\pi$ triplets in $\Delta\varphi$ bins
  - Extract number of $D^{\pm}$ in $\Delta\varphi$ bins from an invariant mass analysis
- Quantify the anisotropy from numbers of $D^{\pm}$ in the $\Delta\varphi$ bins

D meson momentum as reconstructed from the $K\pi\pi$ triplet

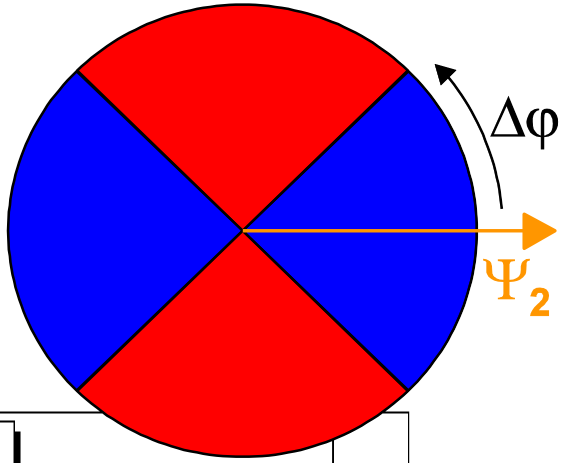


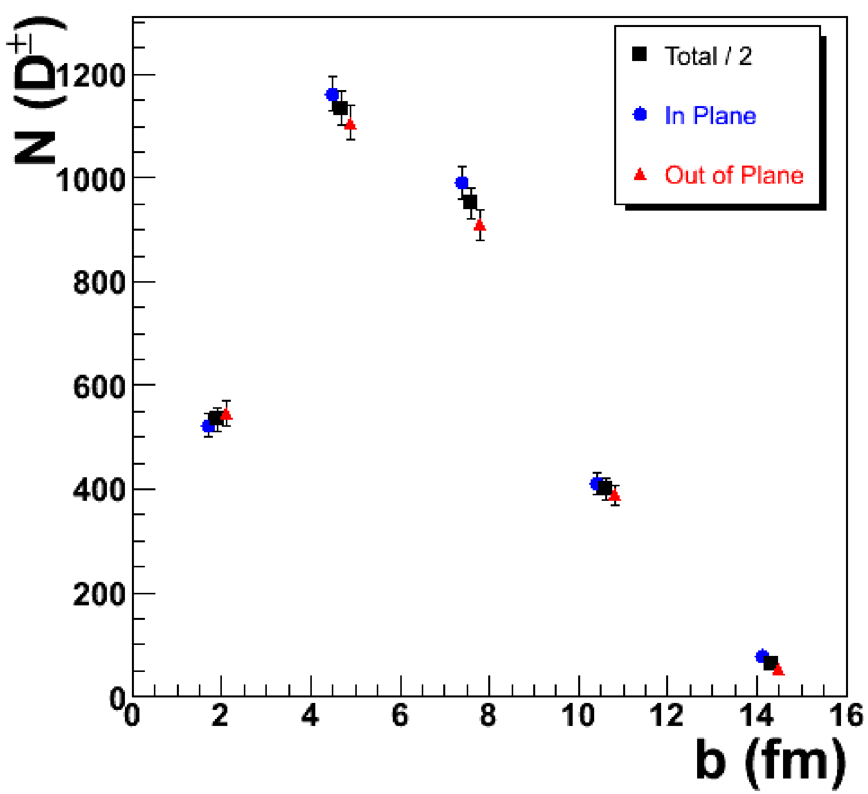
Event plane (estimator of the unknown reaction plane)

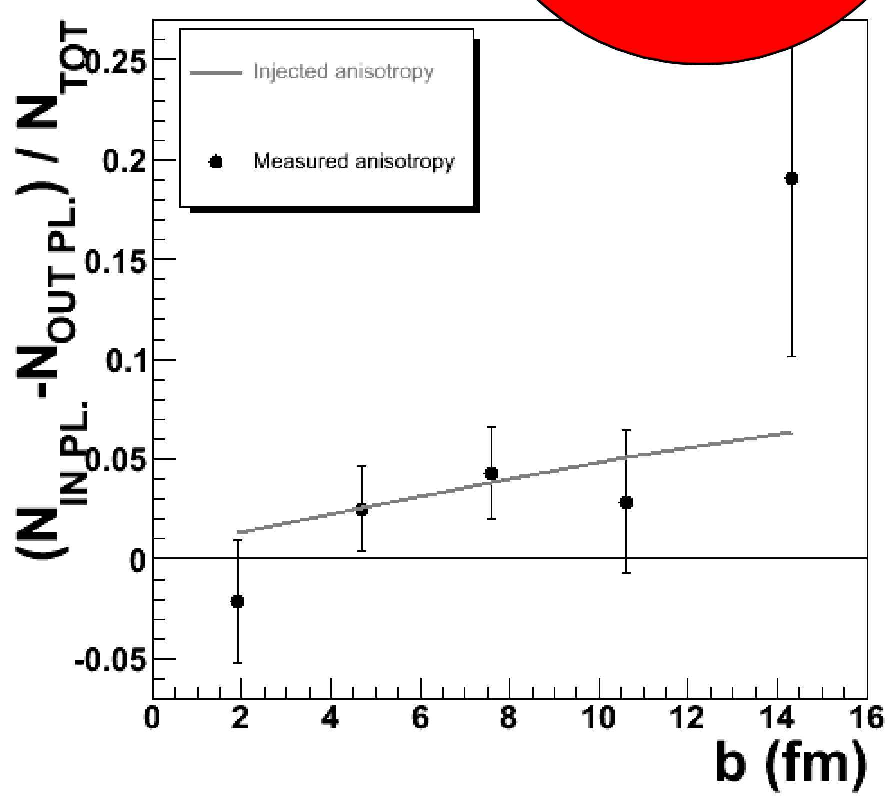
produced particles (mostly pions)

Analysis in 2 bins of Δφ

- Non-zero v_2 difference between numbers of D ± in-plane and out-of-plane
- Extract number of D± in 90º “cones”:
  - in-plane (-45<Δφ<45 U 135<Δφ<225)
  - out-of-plane (45<Δφ<135 U 225<Δφ<315)

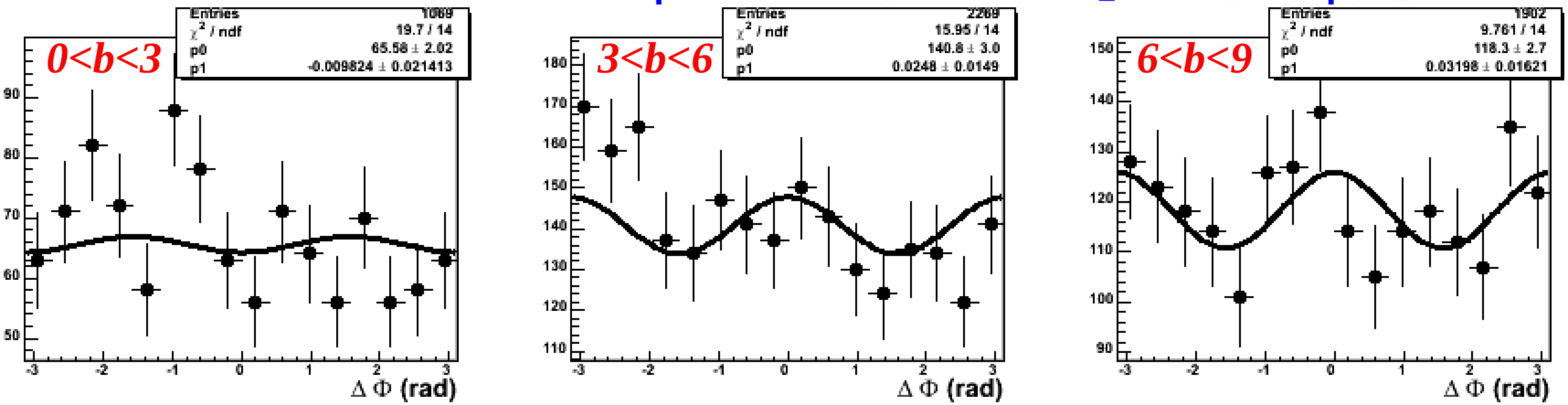


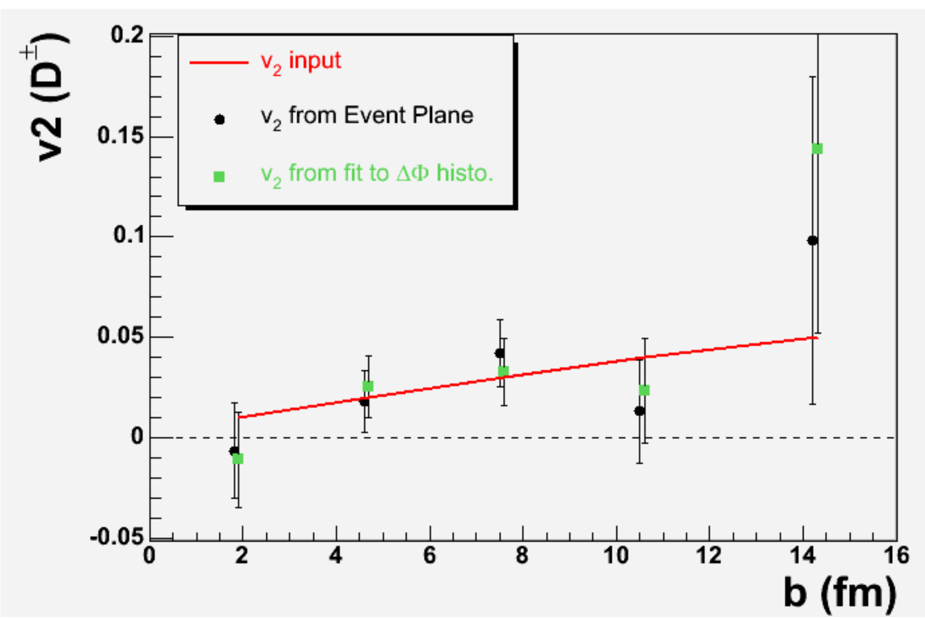




Analysis in more bins of Δφ

- 16 Δφ bins
- Fit number of D± vs. Δφ with $K[1 + 2v_2\cos(2\Delta\varphi)]$





v_2 values and error bars compatible with the ones obtained from <cos(2Δφ)>

Other ideas for background

Different analysis methods to provide:

1. Cross checks
2. Evaluation of systematics

- Apply the analysis method devised for Λs by Borghini and Ollitrault [PRC 70 (2004) 064905]

$$N_{\text{pairs}}(M) = N_b(M) + N_\Lambda(M). \longrightarrow \begin{array}{l} N_{\text{pairs}}(M) v_{c,n}(M) = N_b(M) v_{c,n}^{(b)}(M) + N_\Lambda(M) v_{c,n}^{\Lambda}, \\ N_{\text{pairs}}(M) v_{s,n}(M) = N_b(M) v_{s,n}^{(b)}(M) + N_\Lambda(M) v_{s,n}^{\Lambda}. \end{array}$$

  - Used by STAR for Λs
  - To be extended from pairs (2 decay products) to triplets (3 decay products)

- Extract the $\cos[2(\varphi-\Psi_{RP})]$ distribution of combinatorial $K\pi\pi$ triplets from:
  - Invariant mass side-bands
  - Different sign combinations (e.g. $K^+\pi^+\pi^+$ and $K^-\pi^-\pi^-$)