a multivariate approach to muon ID

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Reminder on muID

1) IsMuon: Hit in FOI around track extrapolation points on each station are searched; FOI are parameterised as a+b*exp(-c*p), with coeff. depending on momentum and region;

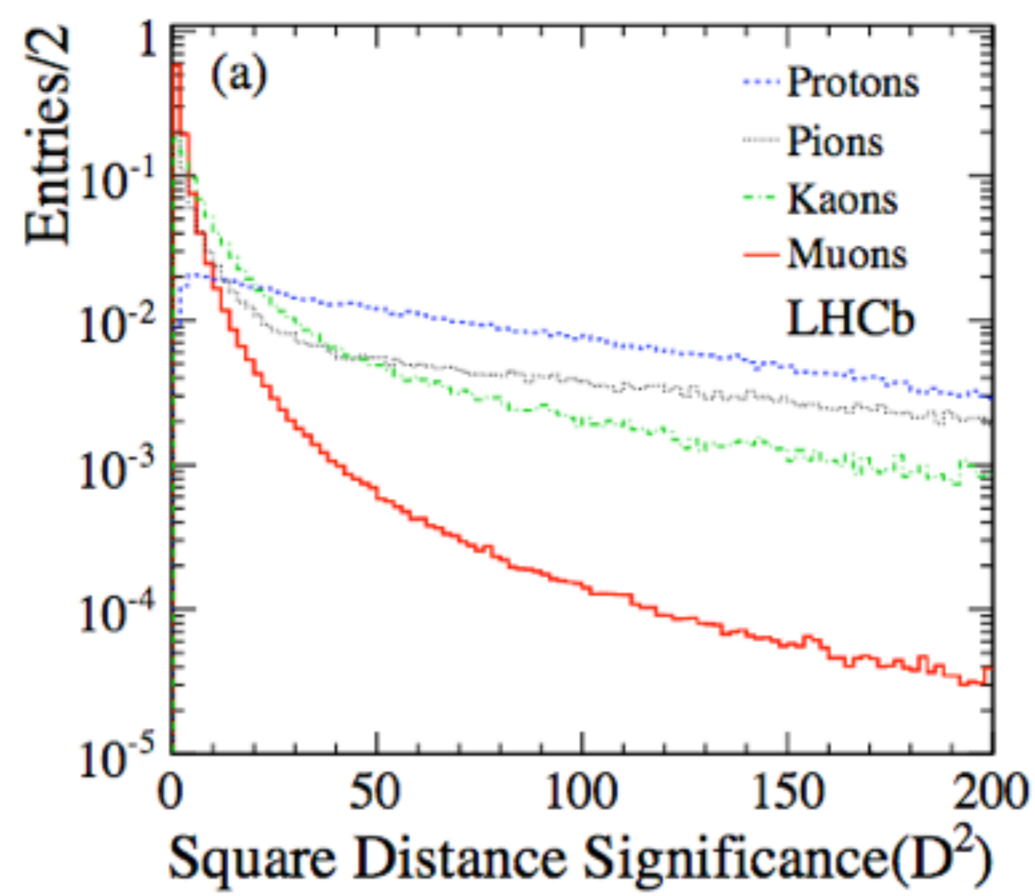
A coincidence of stations is required, as a function of momentum

Momentum range	Muon stations
$3\ \mathrm{GeV}/c < p < 6\ \mathrm{GeV}/c$	M2 and M3
$6\ \mathrm{GeV}/c < p < 10\ \mathrm{GeV}/c$	M2 and M3 and (M4 or M5)
$p > 10\ \mathrm{GeV}/c$	M2 and M3 and M4 and M5

2) Muon likelihood: based on the average squared distance (D^2) of muon hits to the track extrapolation points

$$D^2 = \frac{1}{N}\sum_i \left\{ \left(\frac{x^i_{closest} - x^i_{track}}{pad^i_x} \right)^2 + \left(\frac{y^i_{closest} - y^i_{track}}{pad^i_y} \right)^2 \right\}$$

this info is usually combined in a likelihood with RICH and CALO (combDLL); all analyses use IsMuon + combDLL cuts



Work in progress for a better muonID

1) isMuon:

- We (re)studied the performances of the "isMuonTight" algo, already present in Brunel, which makes use of "crossed" hits only (i.e. requires both X and Y views); in particular, it is interesting to understand if an improvement of the bkg rejection is possible at high luminosity with a reasonable signal loss (see Patrizia's presentation)

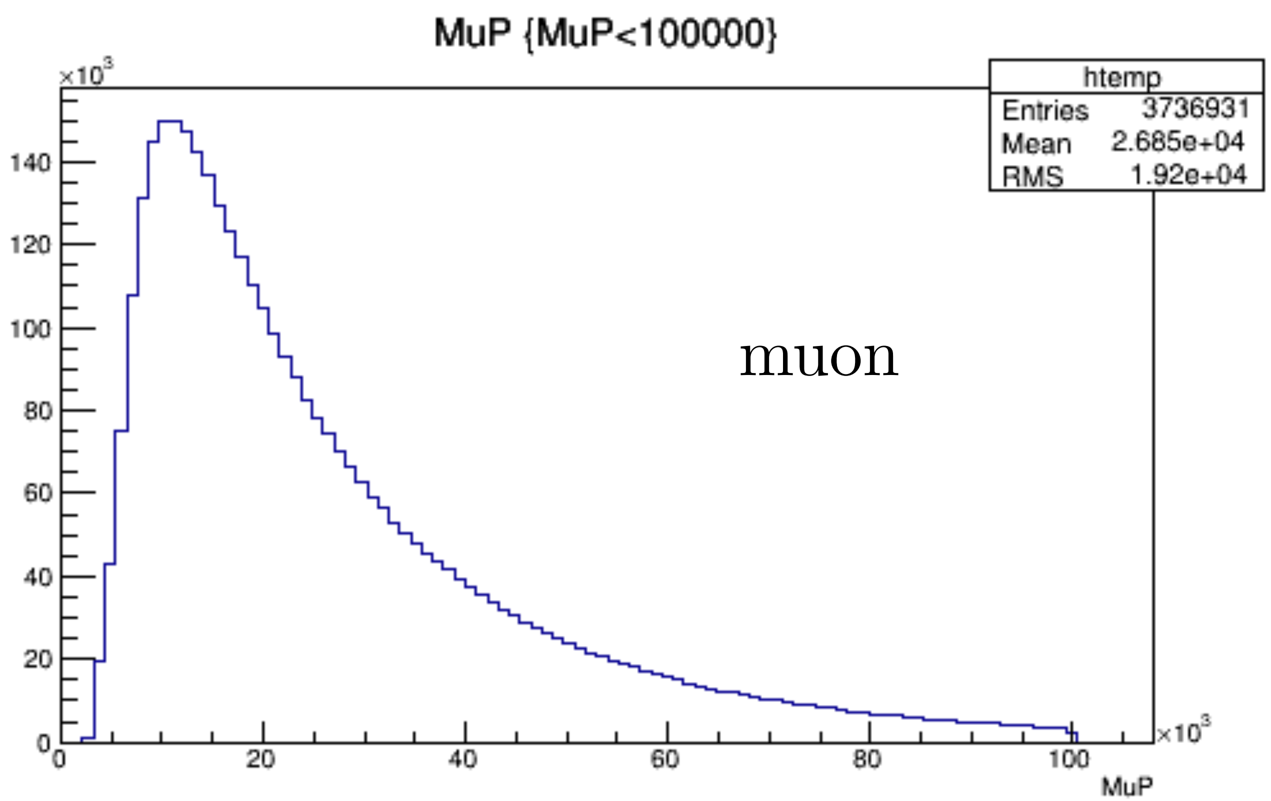
2) Muon classifier after isMuon:

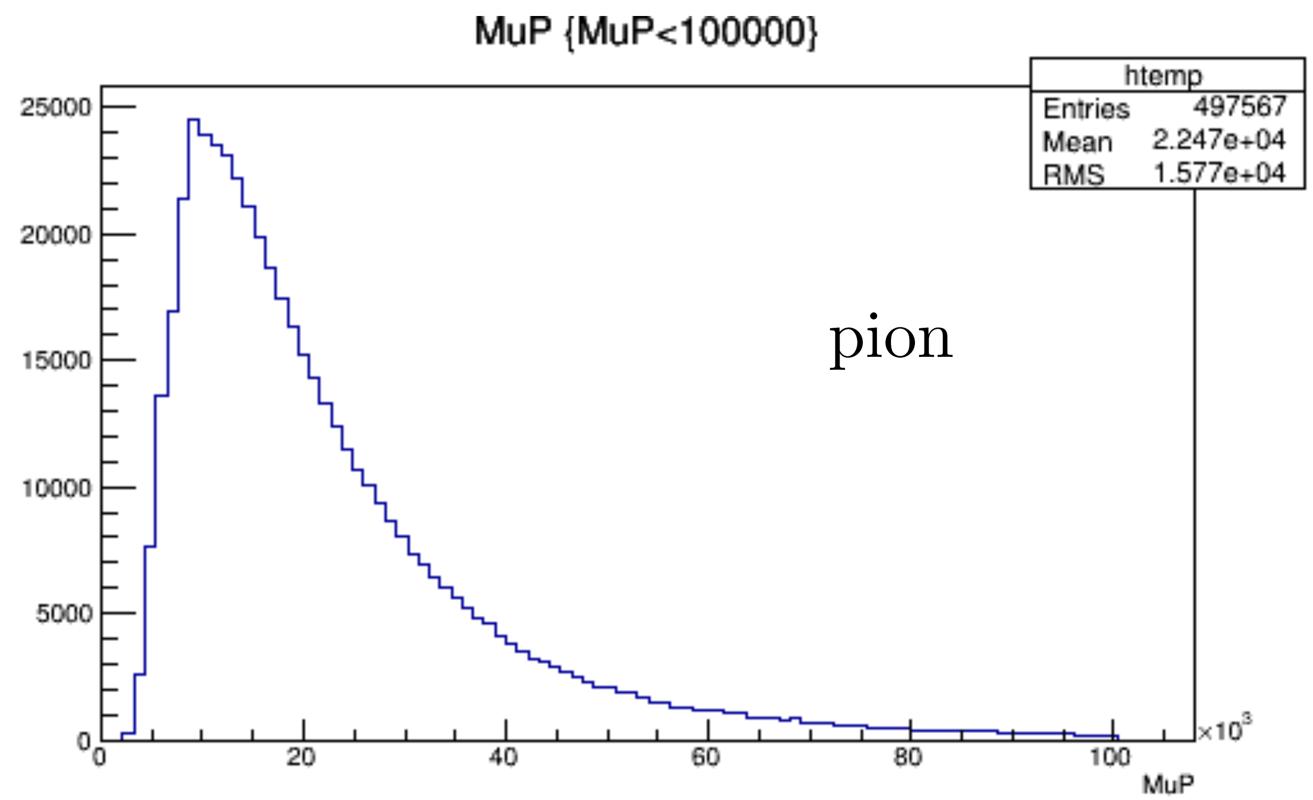
- Use the full information from the muon detector: space residuals, multiple scattering errors, times, isolation (Nshared), multiplicity;
- **Account for correlations (see Violetta's talk)**
- A multivariate approach adopted

BDT

- A Boosted Decision Tree is trained:
  - muon and pion from $J/\psi \to \mu\mu$ and $D^0 \to K\pi$ data control samples have been used to train the algorithms and test the performances. A study using proton as background is ongoing.
  - Useful muon detector variables (space residuals, muon detector hit times, number of shared hits)
- Tight selection cuts (including mass cuts) are used to define the training samples, **isMuonTight is always required**
- A BDT classifier is trained for each detector region
- **No momentum binning performed,** pion and muon have similar momentum spectrum

momentum spectrum





Space residuals

Space residuals of closest muon detector hit wrt track extrapolation point on M2, X coordinate; the estimated error includes also multiple scattering

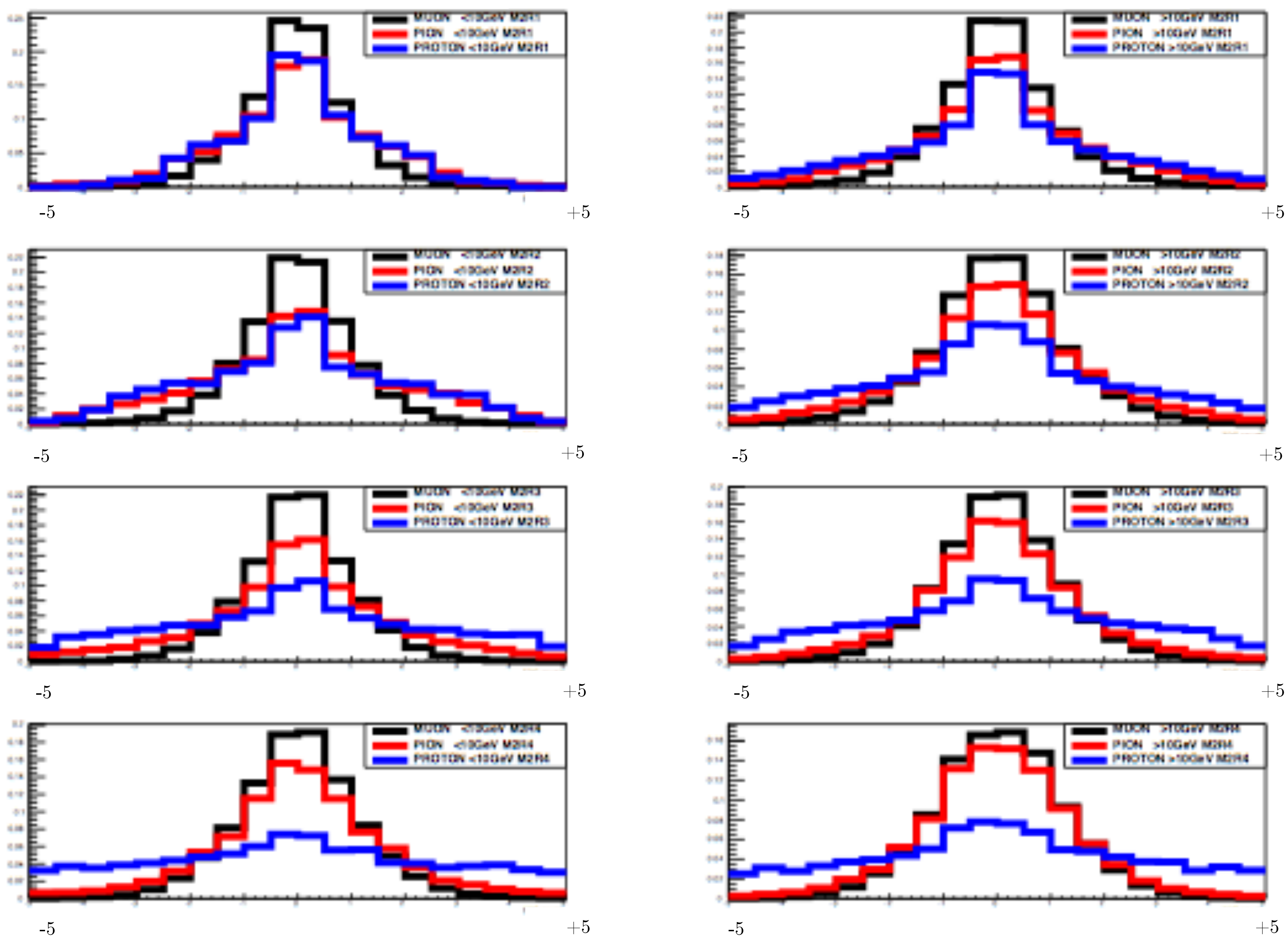
p<10 GeV p>10 GeV

R1

R2

R3

R4



muon
pion
proton

This is the most powerful variable discriminating btw muons and combinatorial background (== protons)

hit time on M2

Hit time for the closest muon detector hit wrt track extrapolation point on M2, X channel;

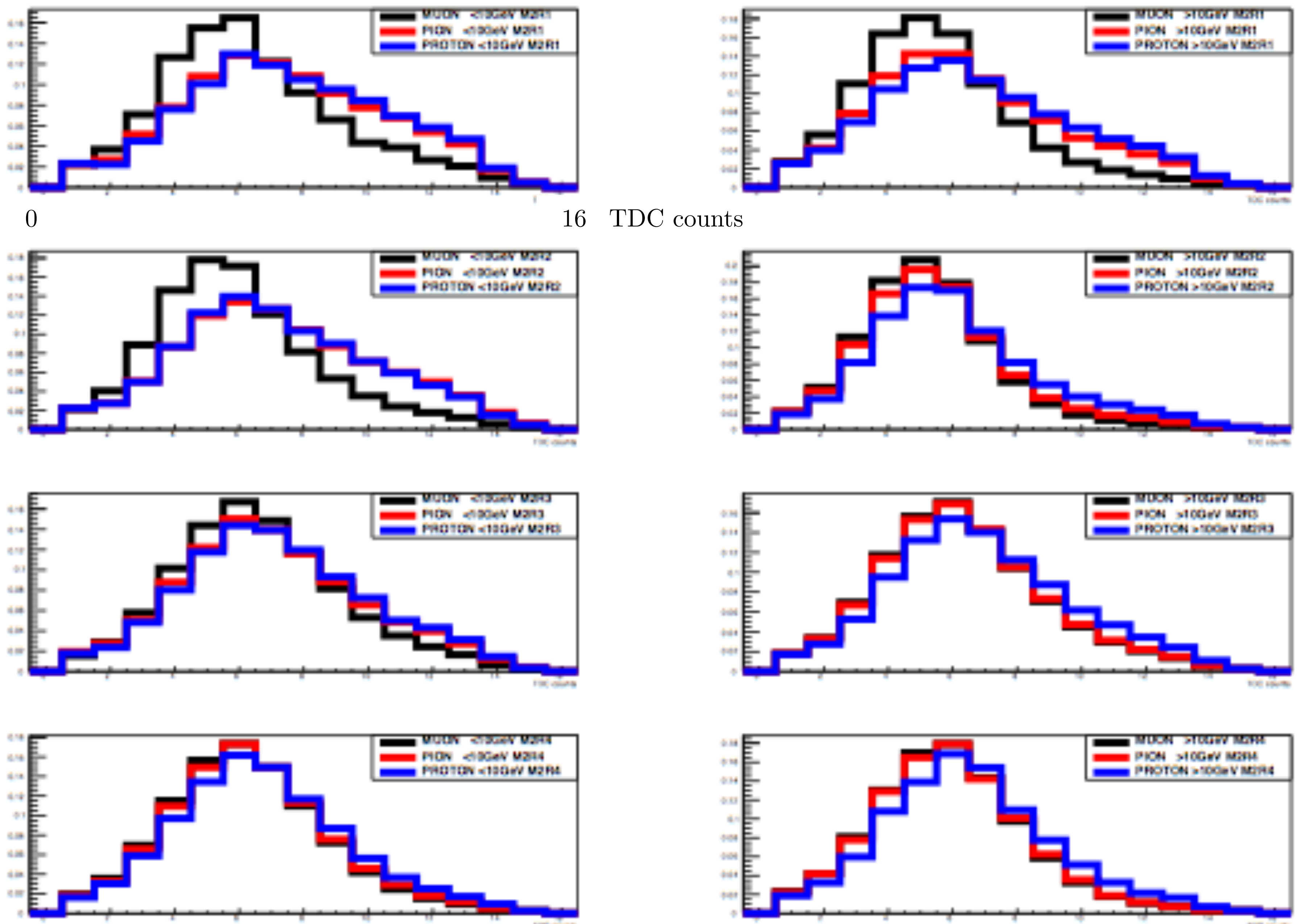
p<10 GeV p>10 GeV

R1

R2

R3

R4



muon
pion
proton

This variable may be useful to increase the bkg rejection power on regions R1 and R2

NShared

NShared, already present in Brunel, counts the number of hits shared among different muon candidates (==0 for an isolated muon)

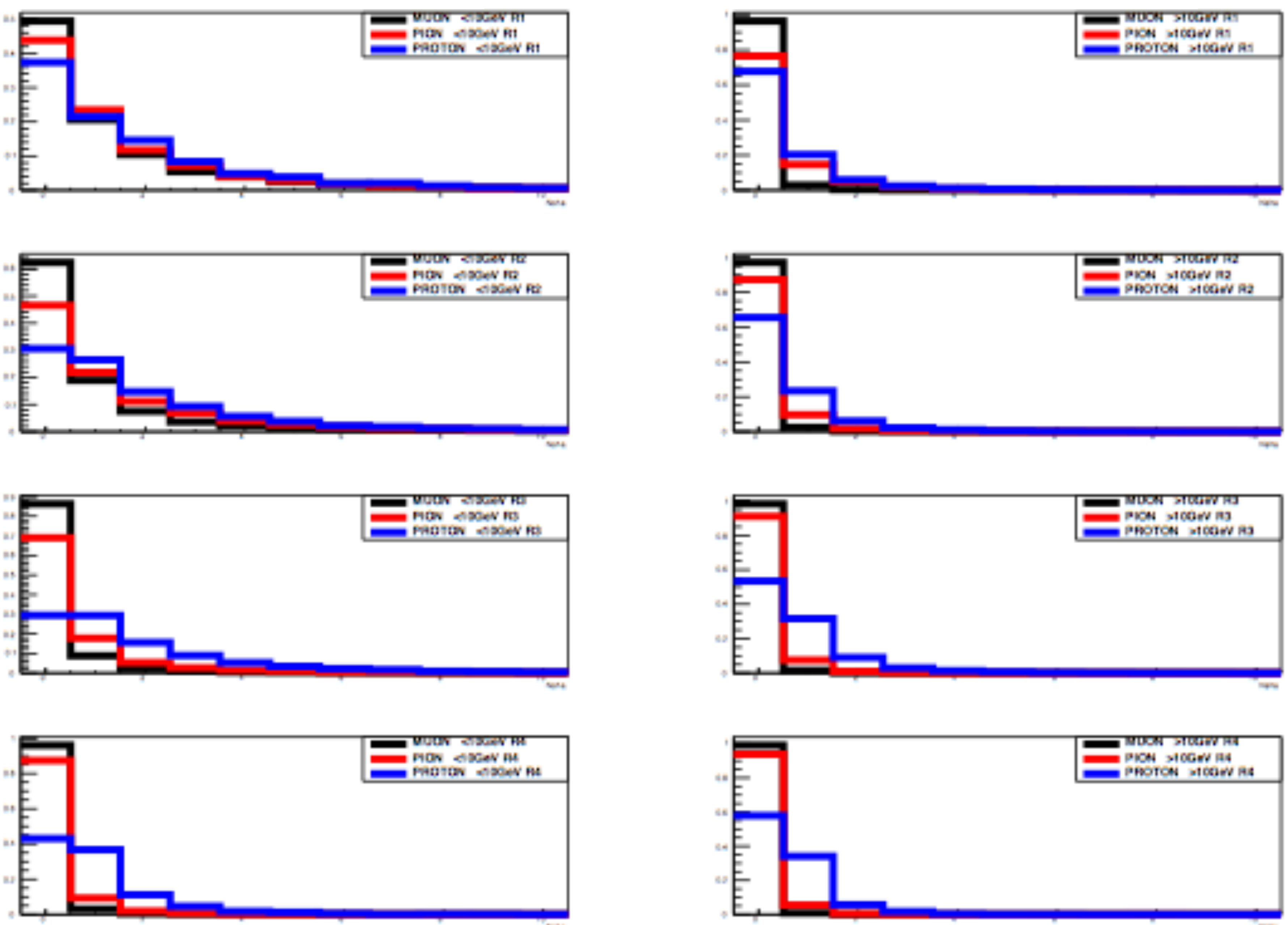
p<10 GeV   p>10 GeV

R1

R2

R3

R4



muon
pion
proton

This variable may be useful especially against protons, which satisfy isMuon thanks to hits from other muons passing nearby (or to accidental hits)

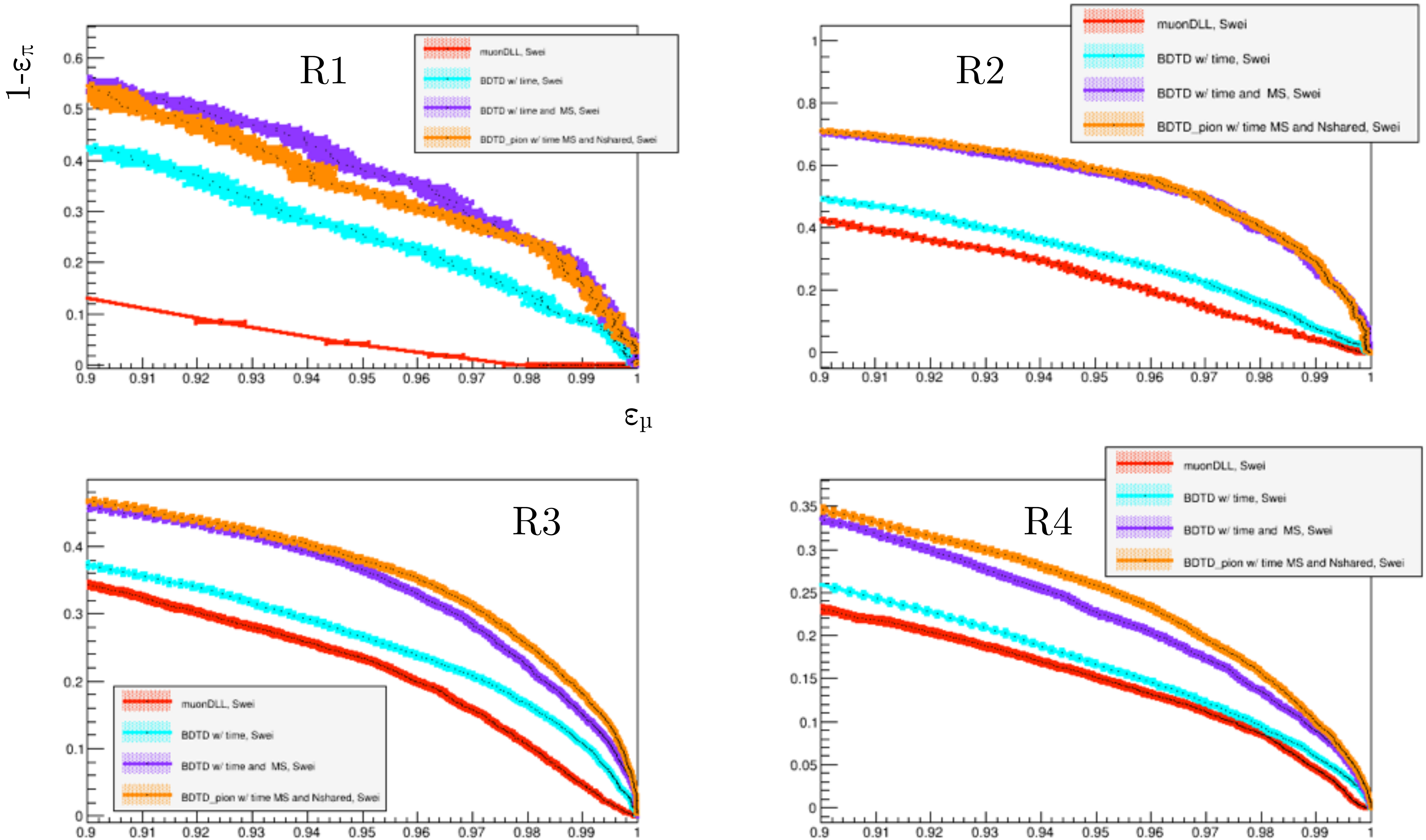
BDT definition

- Several BDTs have been trained using data control samples of muons as signal, and pion as background. Optimisation performed on a small grid of parameters.
- ROC curves for pion rejection vs muon eff (relative to isMuonTight) are shown in the following slides, for different regions and momentum ranges
- When computing the ROCs, residual background is subtracted via sPlot technique

We compare:	input variables
muonDLL*	**space residuals normalized to pad size**
BDT w/ time	**same as muonDLL + times**
BDT w/ time and MS	**include multiple scattering in residual**
BDT w/time MS and Nsha	**include Nshared**

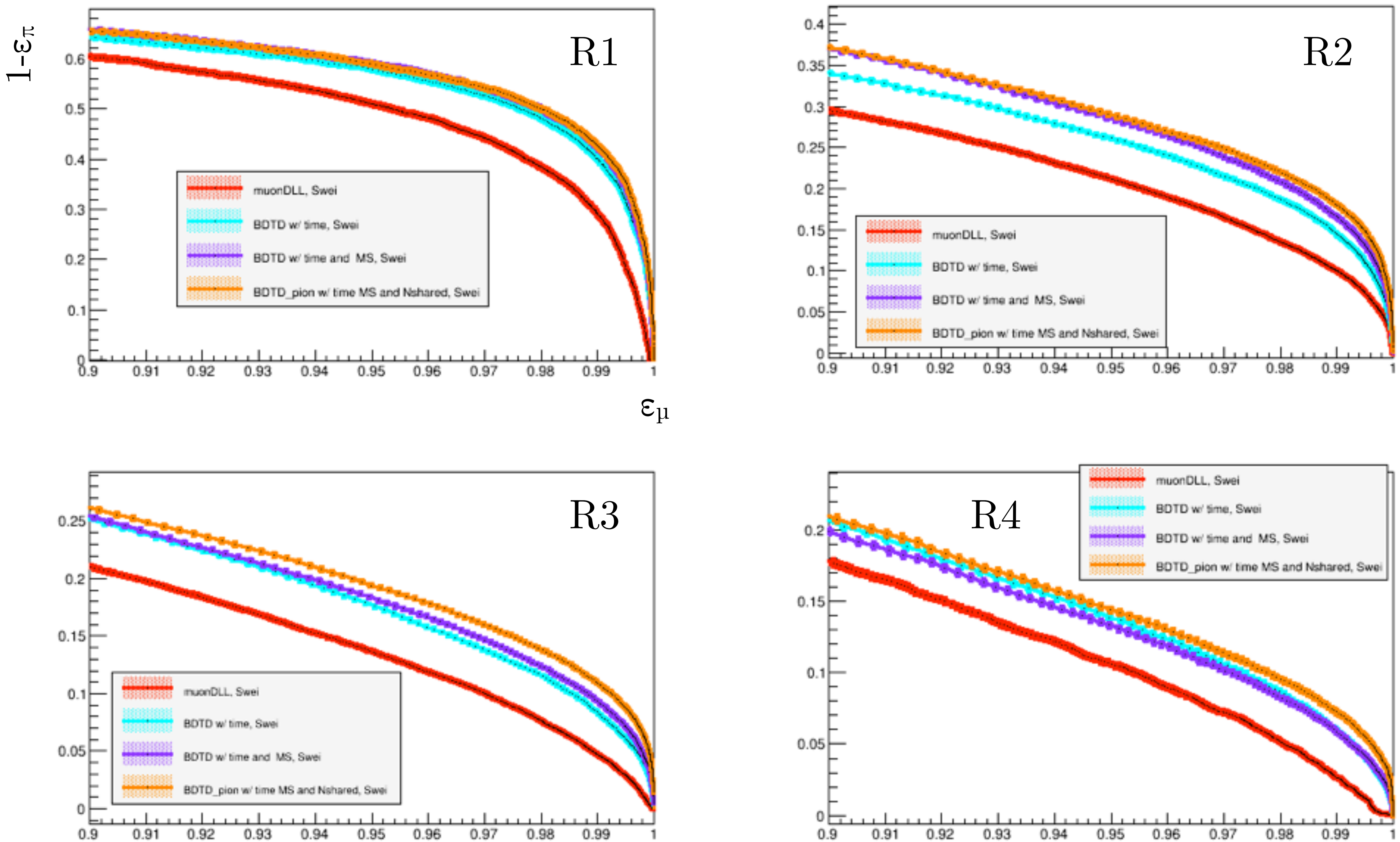
* disclaimer: the muonDLL version is the one presently used in LHCb, a new calibration is being deployed and will be added to this comparison when available

ROCs for pion vs muon, p<10GeV



BDT improves wrt muonDLL, by using additional info and correlations

ROCs for pion vs muon, p>10GeV



BDT improves wrt muonDLL, by using additional info and correlations

MisID performances

- pion MisID evaluated at 95% signal efficiency
- performances at current luminosity:

measured at ⟨nPV⟩~2.3	3<p<6 GeV	6<p<10 GeV	p>10 GeV
isMuon + muonDLL	0.0799±0.0007	0.0315±0.0002	0.00666±0.00003
isMuonTight + muonDLL	0.0469±0.0005	0.0222±0.0002	0.00611±0.00003
isMuonTight + BDT	0.0348±0.0005	0.0173±0.0002	0.00567±0.00003

- factor ~2 of MisID reduction for P<10GeV probably due to a more effective reduction of combinatorics
- most of the improvement seem related to a better use of the spatial residuals: correlations, multiple scattering error (see Violetta's talk)

Still work in progress

- New ingredients used in the training:
  - Used per event Multiple Scattering instead of discrete values binned in P and Pt
  - Transverse momentum Pt and Px measured using the muon stations
- Also in that case muon and pion from $J/\psi \rightarrow \mu\mu$ and $D^0 \rightarrow K\pi$ data samples used in the training/test
- Roc curves evaluated by subtracting residual background with sPlot.

We compare:	input variables
muonDLL	space residuals normalized to pad size
BDTD pion May 2015	include time. discrete MS, Nshared (BDT w/time MS and Nsha)
BDTD pion new	include per event MS and momentum from Muon Detector

New Variables

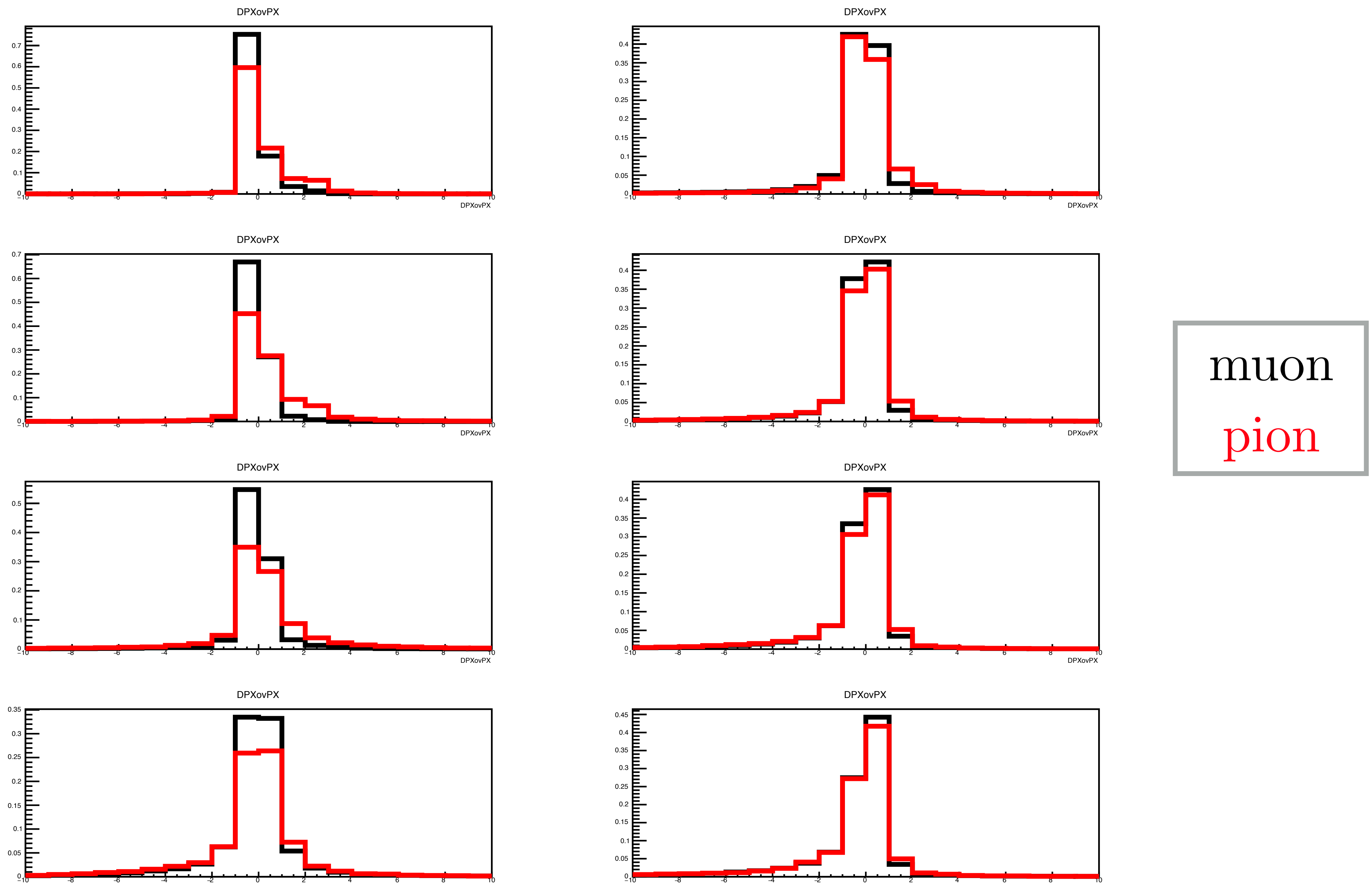
Difference between PX measured with the tracking system and that one obtained with the muon stations

R1

R2

R3

R4



p<10 GeV

p>10 GeV

New Variables

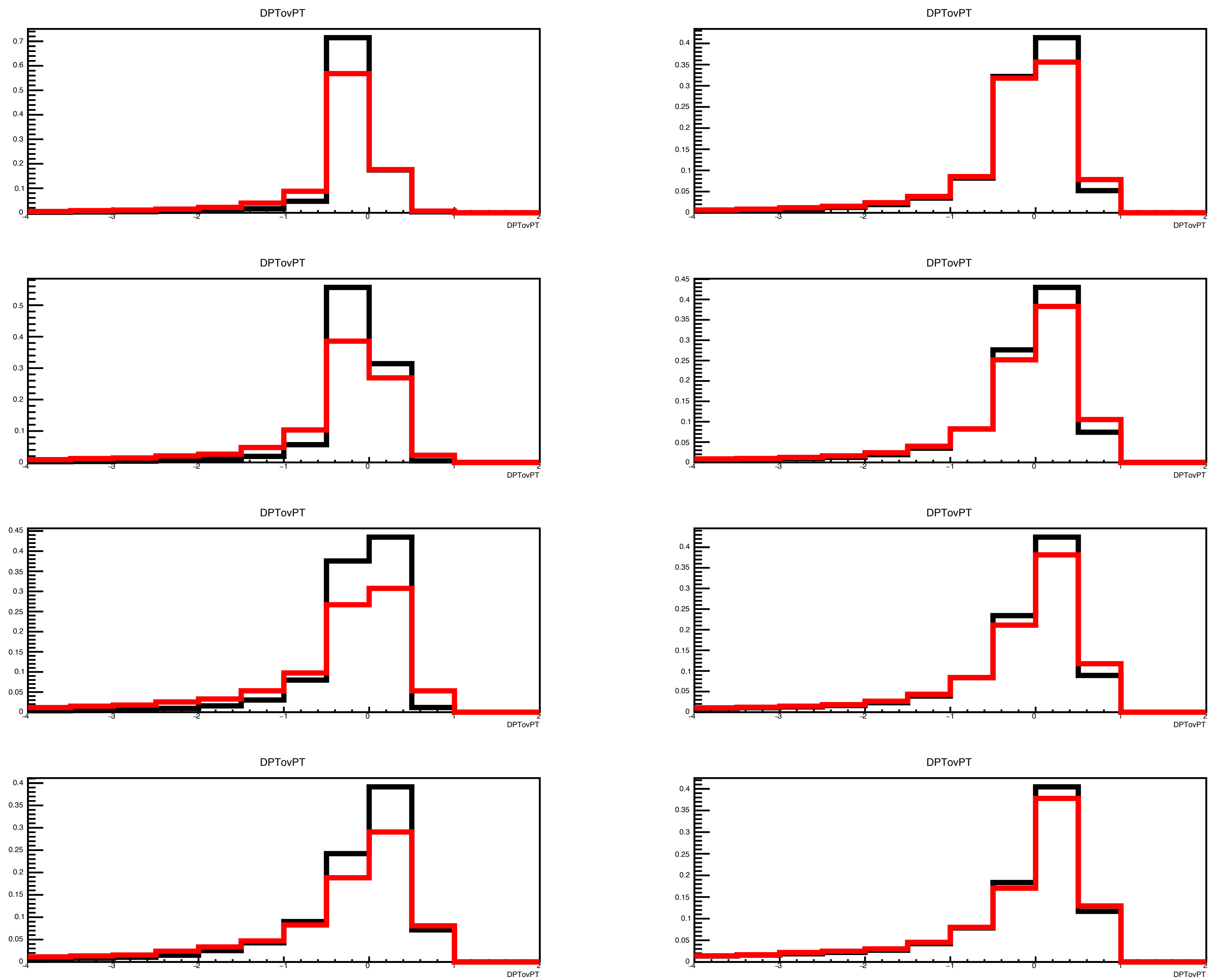
Same as the previous slide but with the transverse momentum

R1

R2

R3

R4



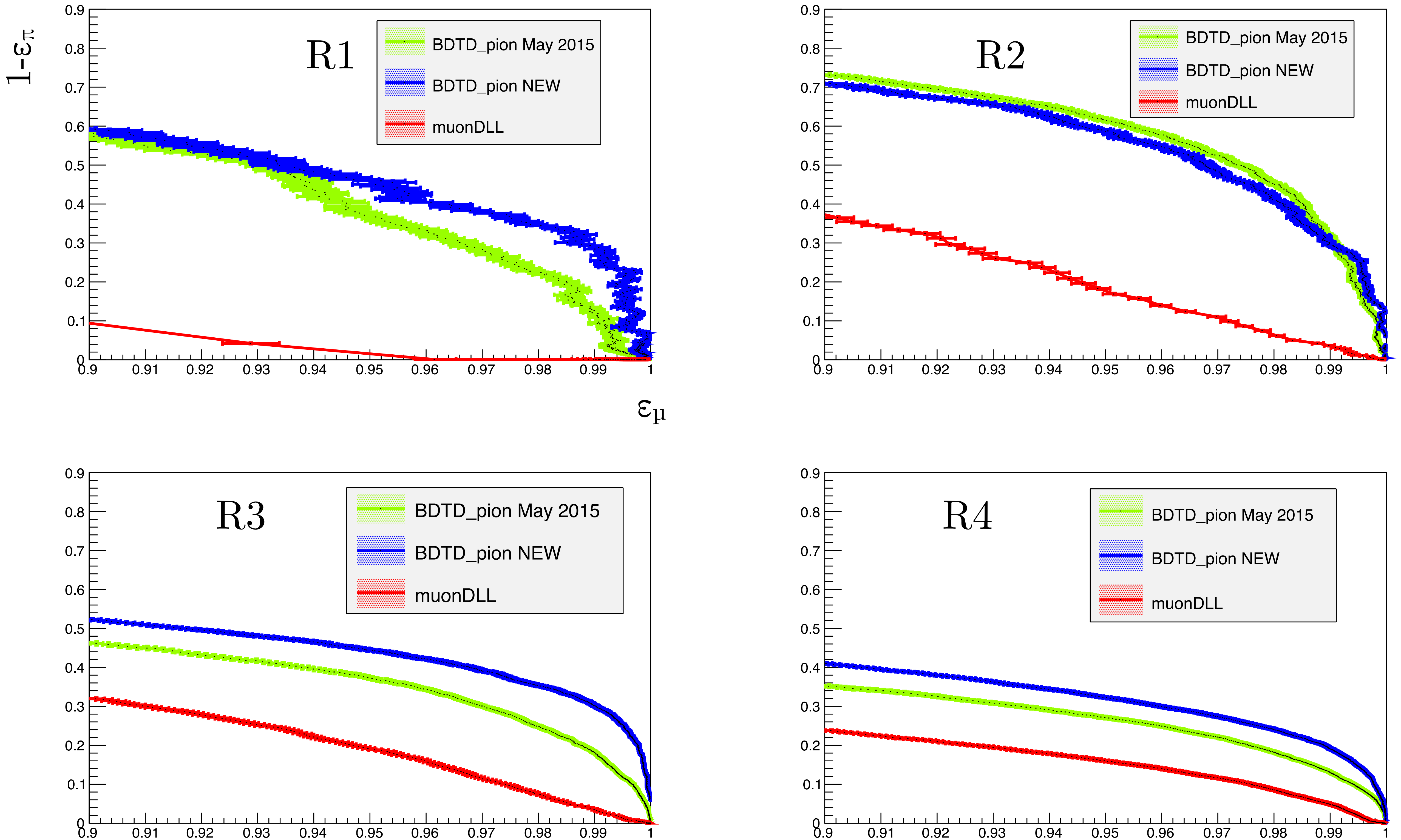
muon

pion

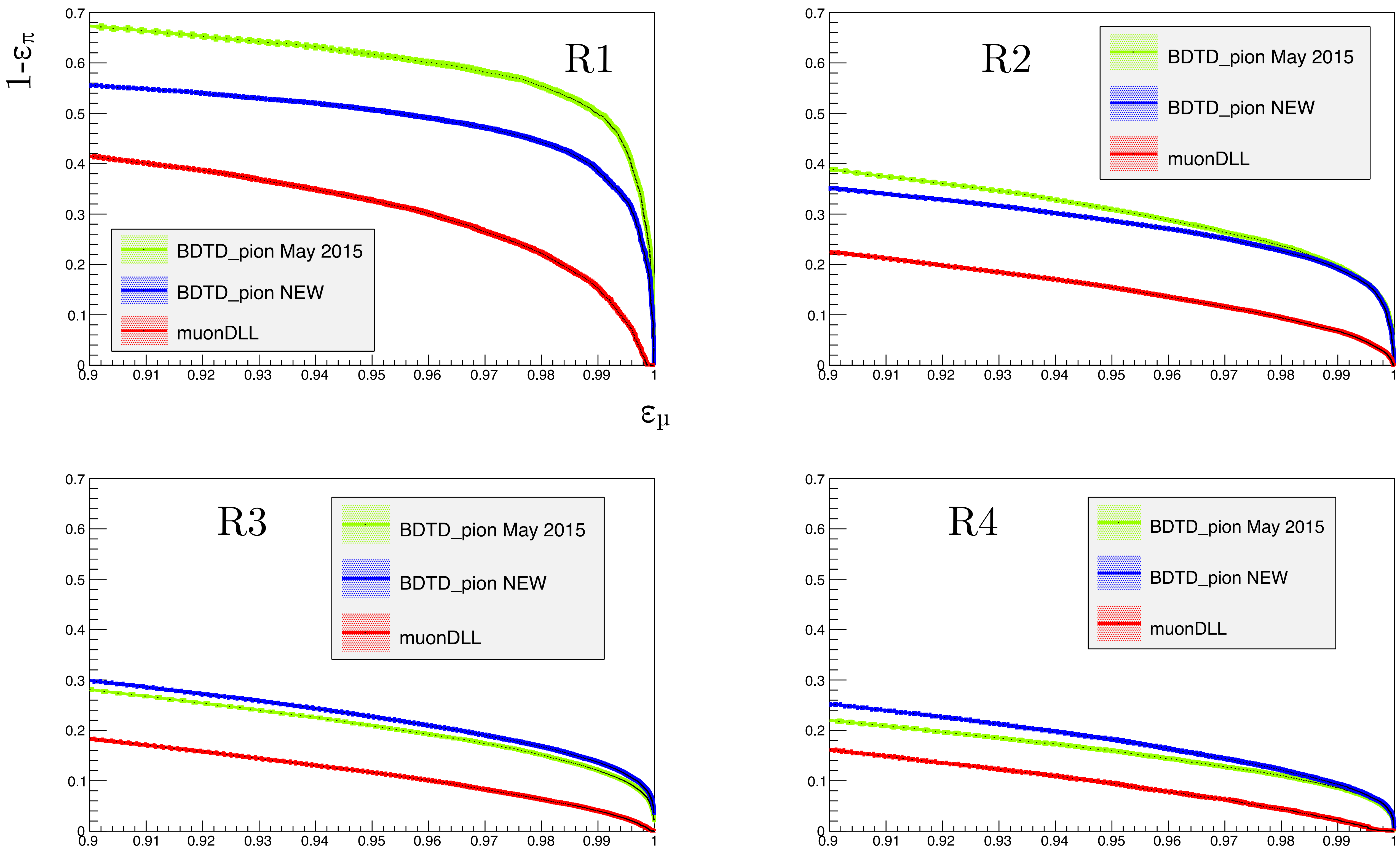
p<10 GeV

p>10 GeV

ROCs for pion vs muon, p<10GeV



ROCs for pion vs muon, p>10GeV



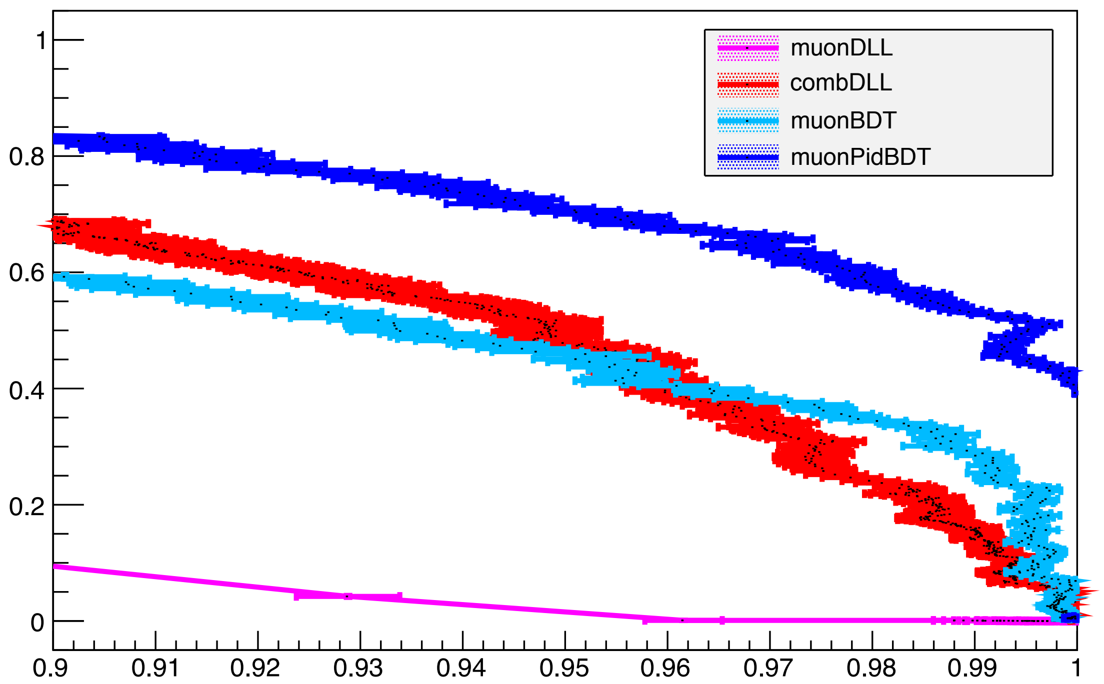
Performances in R1 and R2 to be understood.

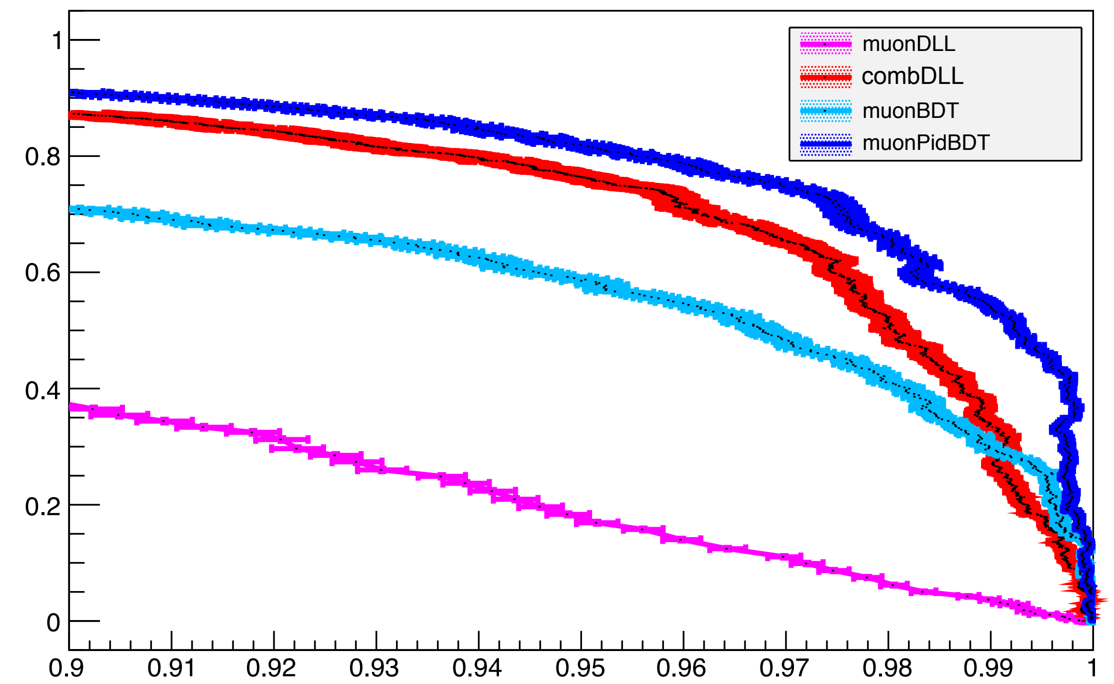
Adding RICH and CALO info

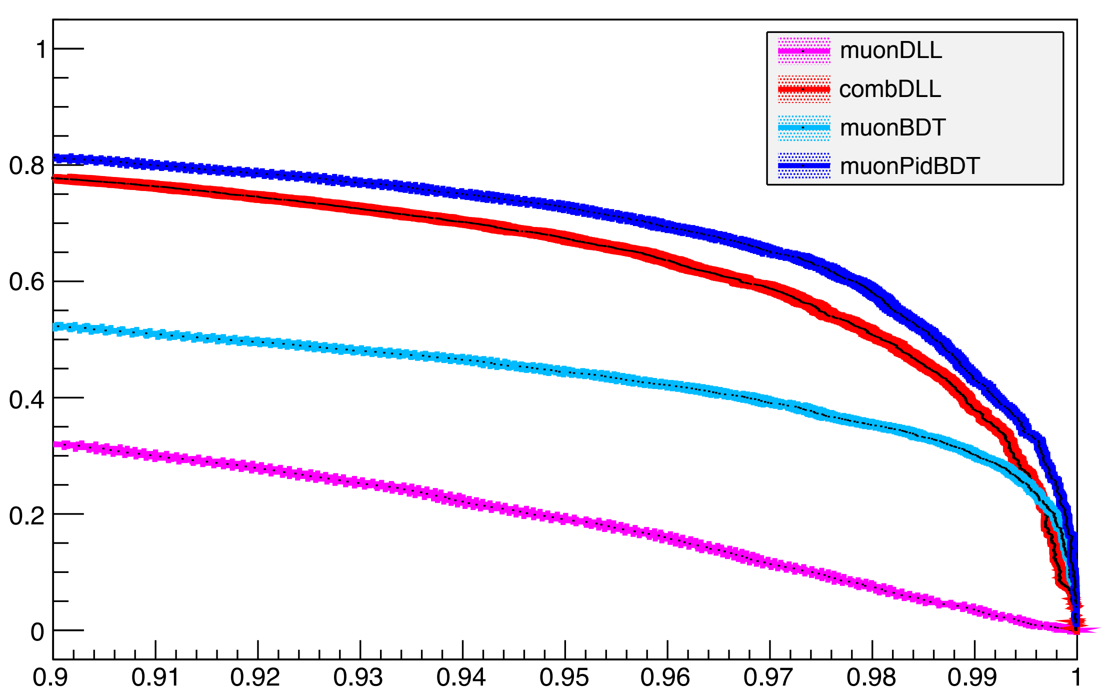
- Combination with RICH and Calorimeter DLLs performed adding the related variables in the BDT training
- This preliminary study is performed with a rough optimisation of the training parameters

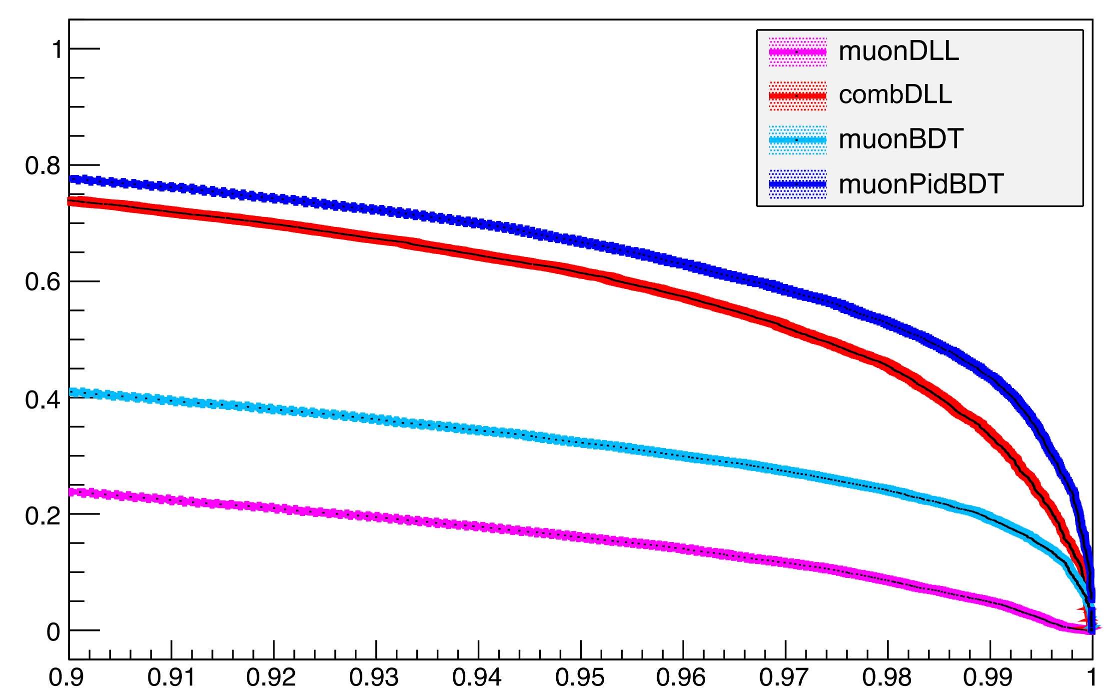
We compare:	input variables
muonDLL	**space residuals normalized to pad size**
combDLL	**muonDLL+richDLL+caloDLL**
muonBDT	**last BDT (not optimised)**
muonPidBDT	**include richDLL and caloDLL as input variables**

ROCs for pion vs muon, p<10GeV

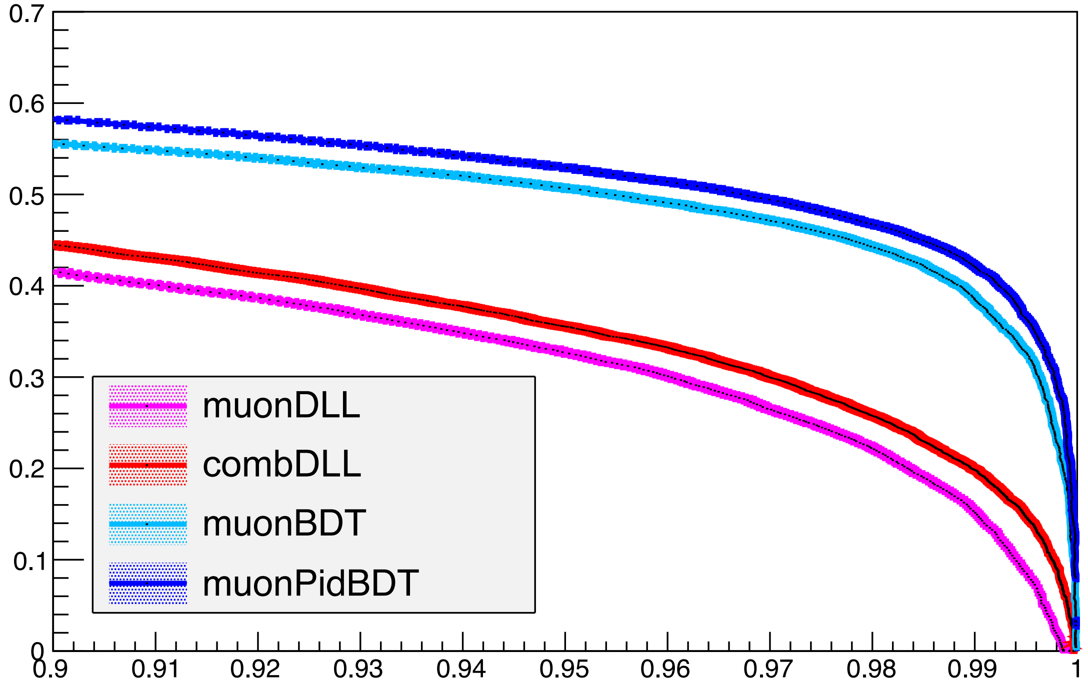


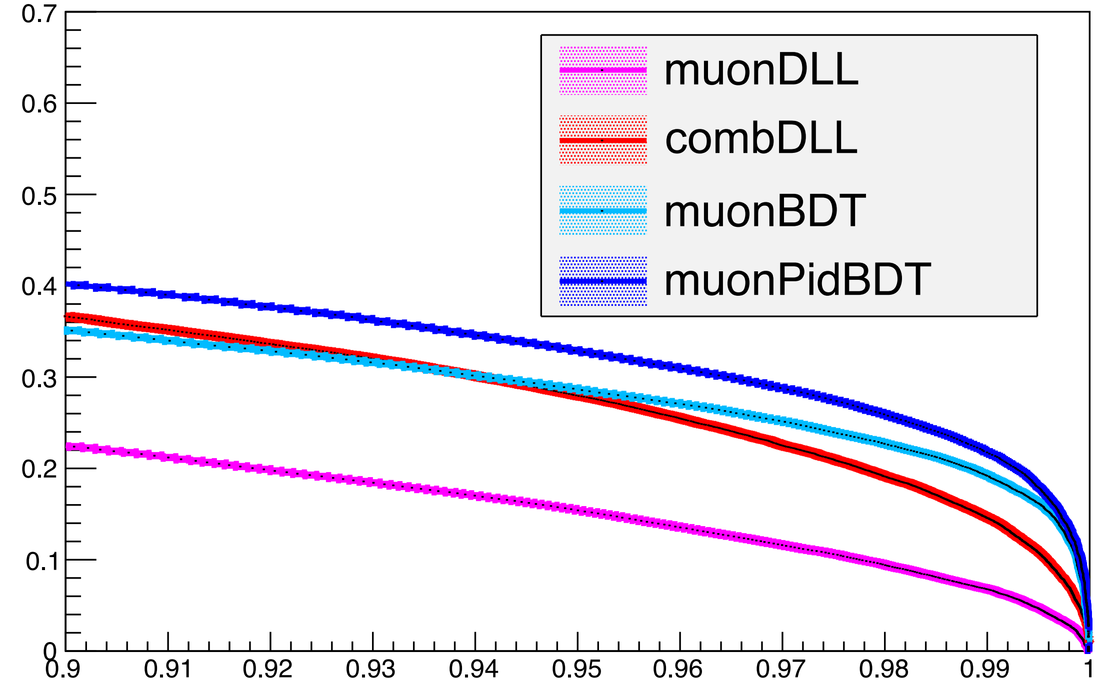


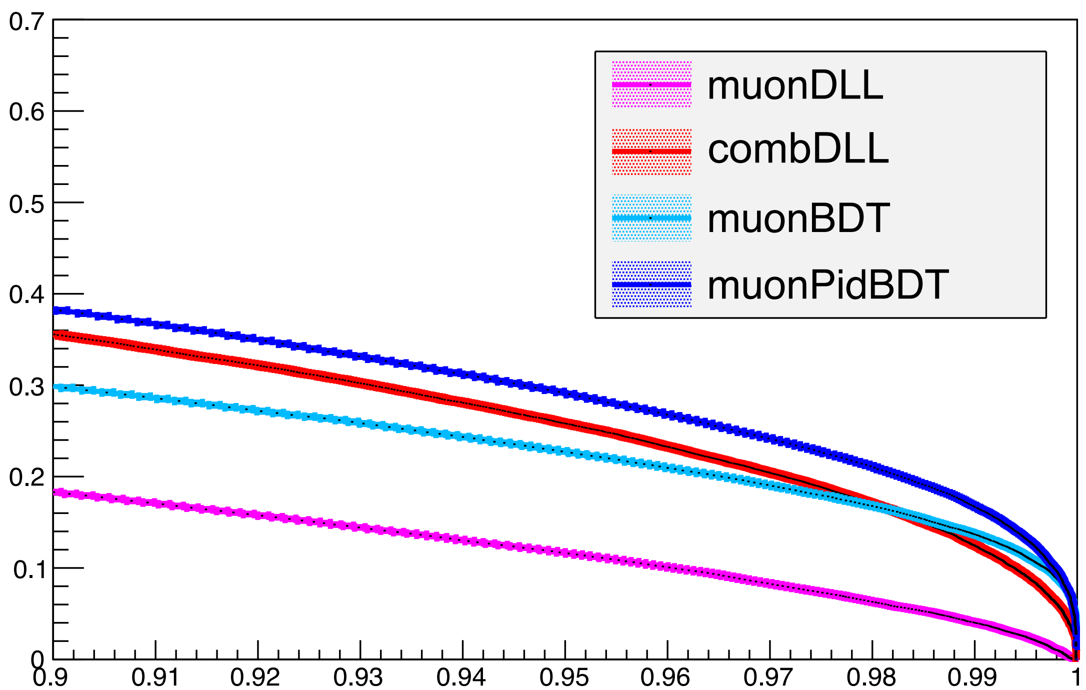


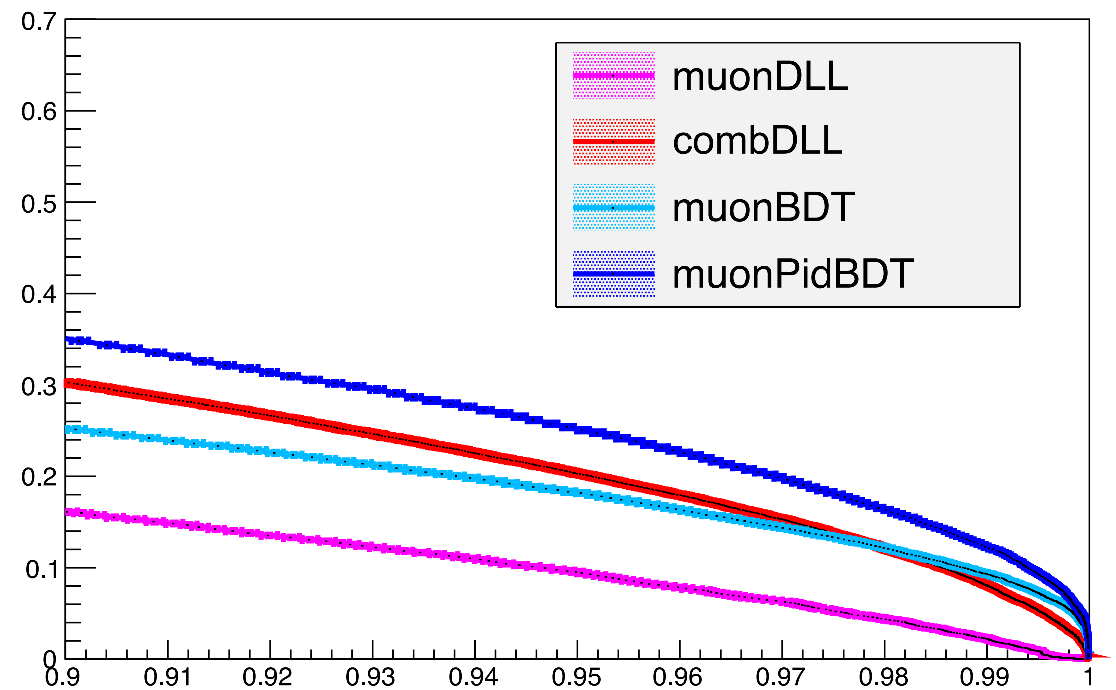


ROCs for pion vs muon, p>10GeV









Conclusions

- we evaluated the performances of a BDT for the 2nd step of muonID, which makes use of spatial residuals (including multiple scattering error), hit times and Nshared: **as a result, we observe a sensitive improvement in background rejection especially for p<10GeV. Any single improvement of the MuonID algorithm is fundamental for stable performances at higher luminosity.**

- results are still preliminary: algorithms still to be optimised, possibly more variables will be used (see Marco's talk)

- preliminary study on a general muon PID that includes also RICH and CALO information looks already very promising.

- As soon as the classifier is finalised a TupleTool will be released