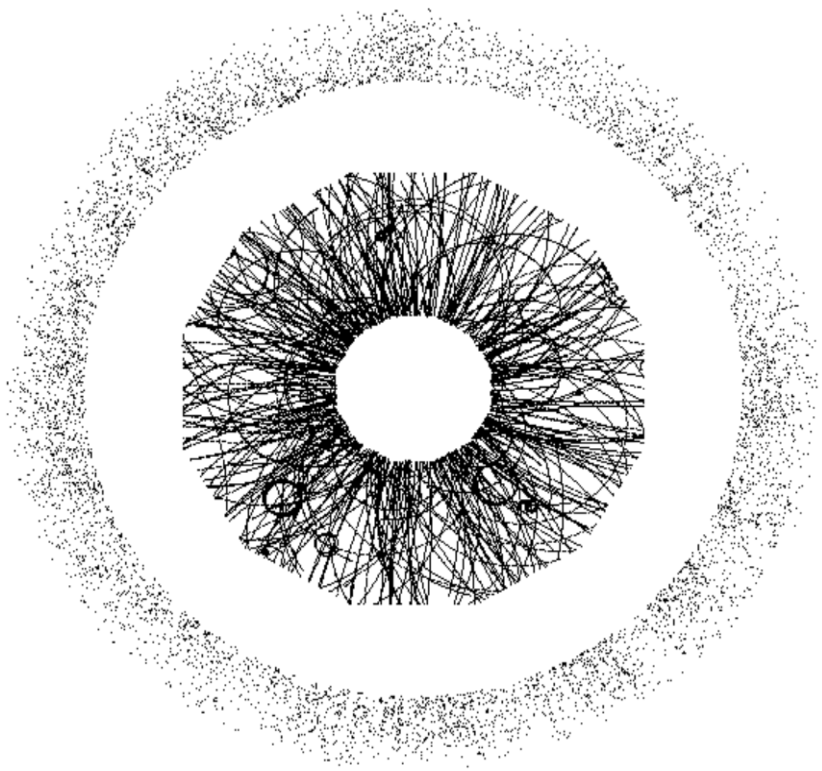
NICA

Nuclotron-based
Ion Collider fAcility

Neutral mesons and dielectrons

V. Riabov for the PWG4

(15 + 5) minutes



Neutral mesons in heavy-ion collisions

- Wide variety of neutral mesons:
  - ✓ π^0 ($\pi^0 \rightarrow \gamma\gamma$)
  - ✓ η ($\eta \rightarrow \gamma\gamma$, $\eta \rightarrow \pi^0 \pi^+ \pi$)
  - ✓ K_s ($K_s \rightarrow \pi^0 \pi^0$)
  - ✓ ω ($\omega \rightarrow \pi^0 \gamma$, $\omega \rightarrow \pi^0 \pi^+ \pi$)
  - ✓ η' (η' $\rightarrow \eta\, \pi^+ \pi$)
  - ✓ etc.

- Neutral mesons are of great interest:
  - ✓ complementary measurements to $\pi^\pm$, $K^\pm$ etc. with different systematics
  - ✓ study of mass and quark content/count dependent effects such as collective flow, recombination, parton energy loss, strangeness production etc.
  - ✓ source of background for many other observables such as direct photons, e_{HF} and di-electrons

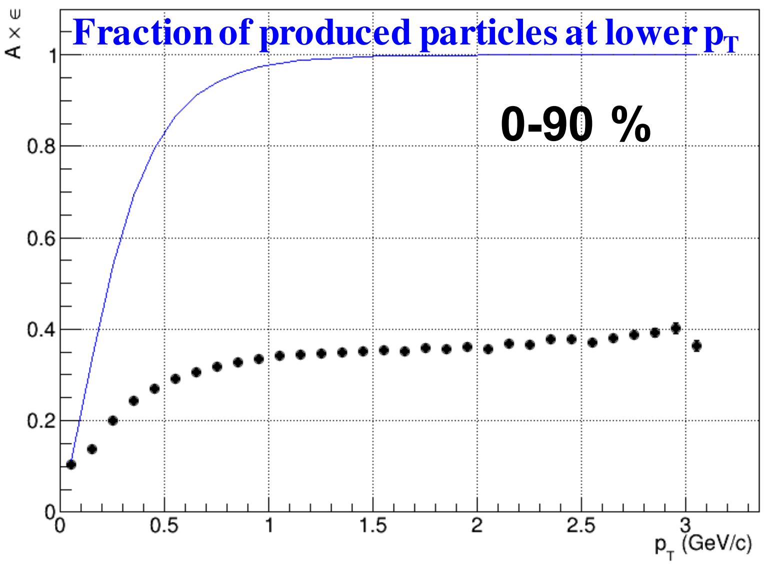
- π^0, η are the most promising signals for day-one measurements

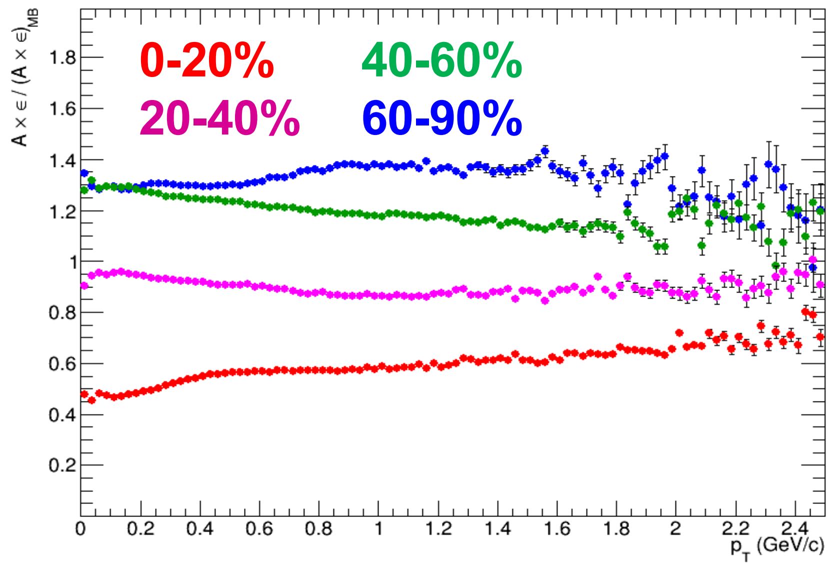
- Reconstruction methods:
  - ✓ ECAL
  - ✓ γ-conversion in detector materials

Reconstruction with the ECAL

π^0 reconstruction in AuAu@11

- Measurement uncertainties at low p_T are driven by systematic uncertainties for the raw yield extraction due to non-Gaussian shape of the reconstructed peaks from cluster merging
- Focus is on optimization of the reconstructed peak shape and less on the reconstruction efficiency
- Optimized selection cuts for higher significance of π^0 and η signals in AuAu@11 (UrQMD, v.3.4):
  - ✓ Photons: $E_{core2\%}$ > 0 GeV, $T_{reduced}$ < 2 ns, charged track veto, Chi2/NDF < 4.0
  - ✓ Pairs: |en1-en2|/(en1+en2) < 0.75, |y| < 0.5
- ~ 15M AuAu@11 events - centralized Monte Carlo production

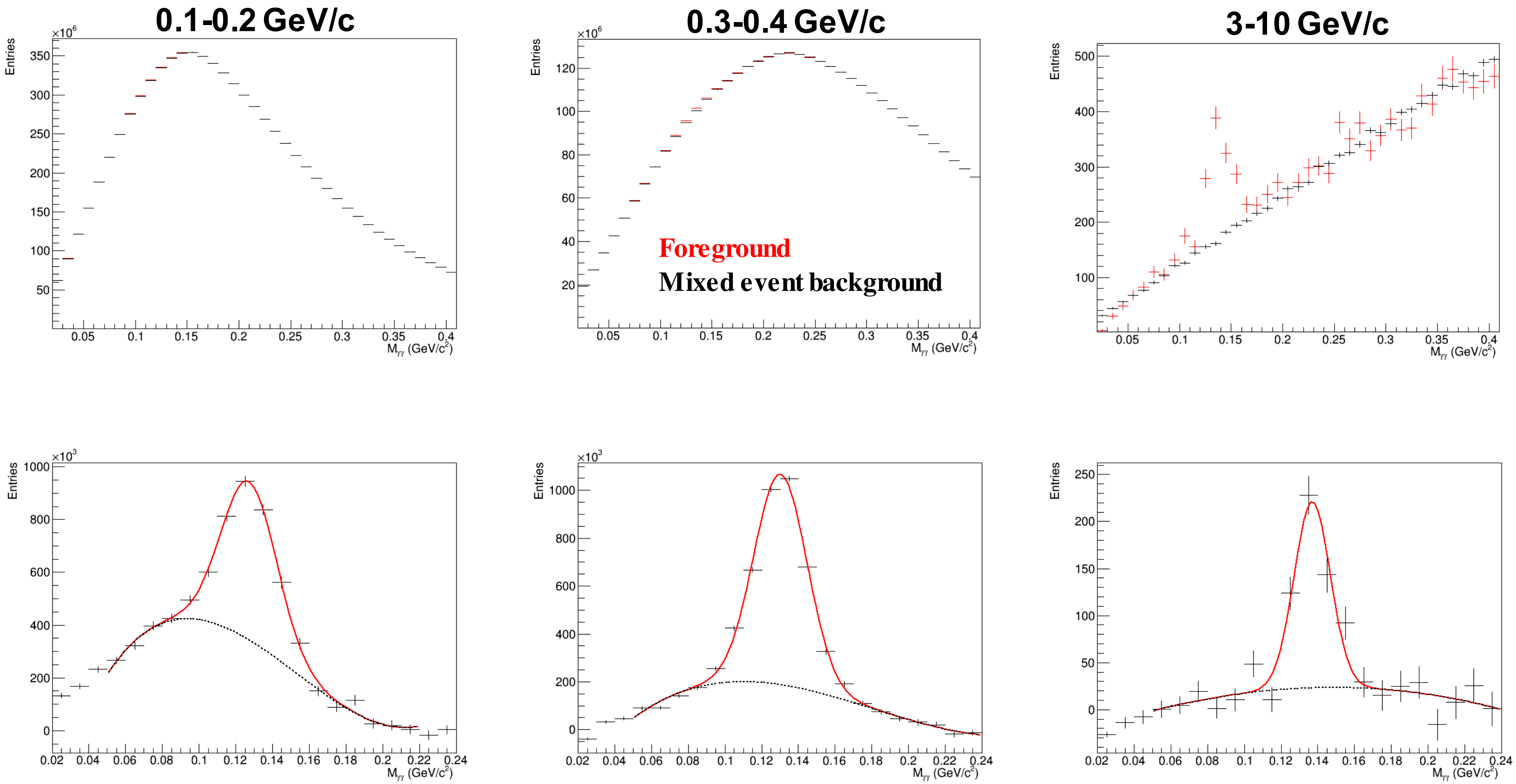




- Efficiency for π^0 is > 10%, increasing with p_T
- Maximum raw yield of π^0 is expected at ~ 300 MeV/c
- Reconstruction efficiency shows strong multiplicity dependence (false veto + shower merging)

π^0 peak examples in AuAu@11

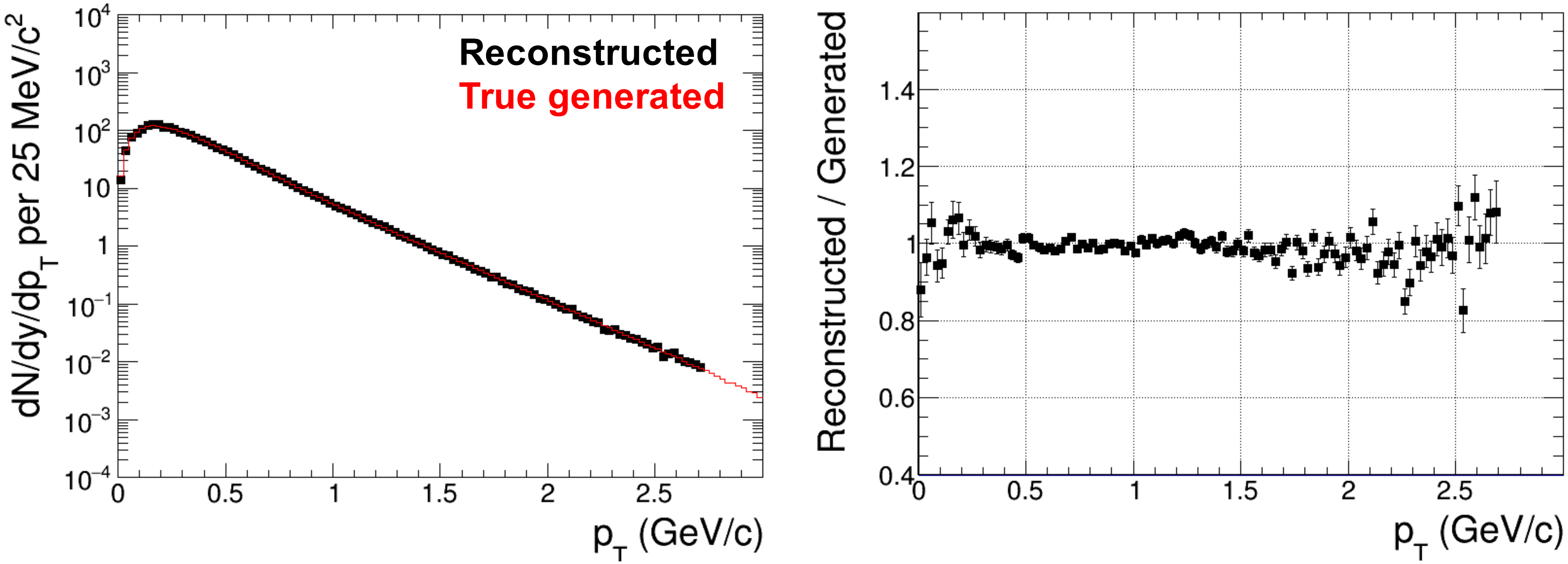
- 15M AuAu@11, realistic vertex distribution



- The peak width decreases with increasing momentum (better energy resolution)
- The S/B improves with increasing momentum

π^0 in AuAu@11: MC closure test

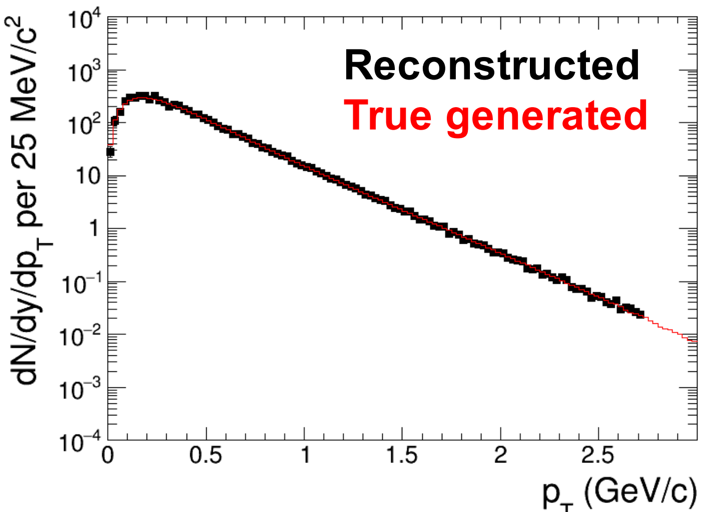
- 15M AuAu@11 events

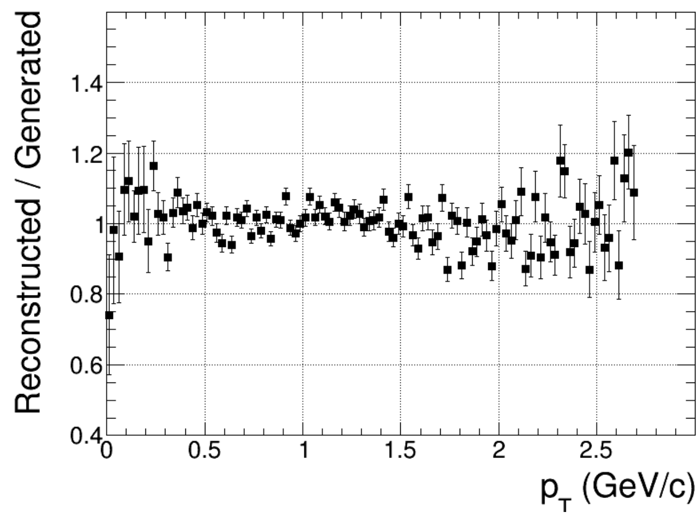


- Reconstructed spectrum matches the generated one within uncertainties
- Reliable raw yield extraction starts at $p_T > 50$ MeV/c
- Signal is present at lower $p_T < 50$ MeV/c but the signal shape is not trivial
- Significant reduction of systematic effects at low momentum with optimized cuts
- Further improvements are possible

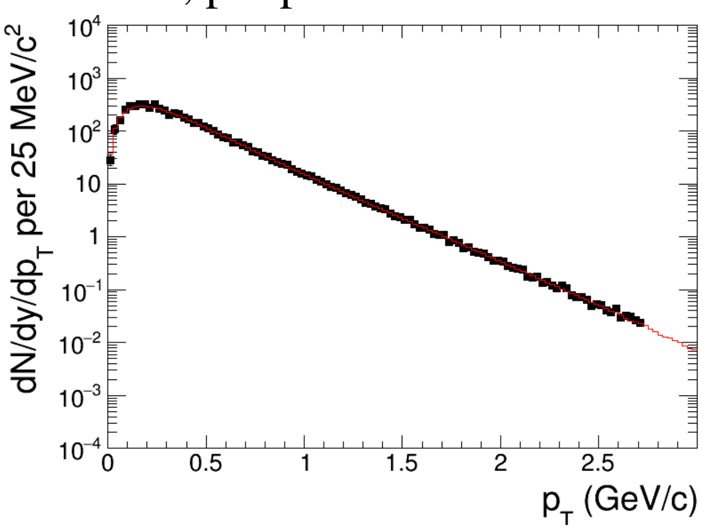
π^0 in 0-20% and 60-90% AuAu@11: MC closure test

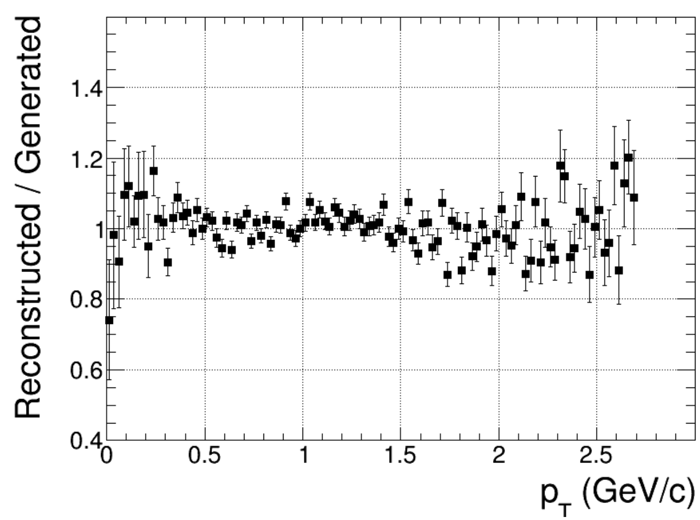
- 0-20%, most central collisions





- 60-90%, peripheral collisions

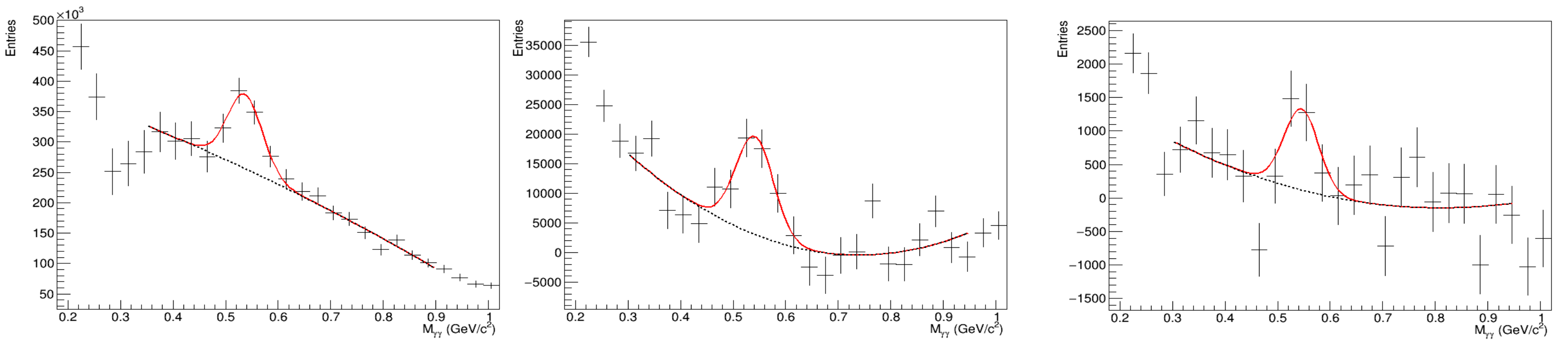




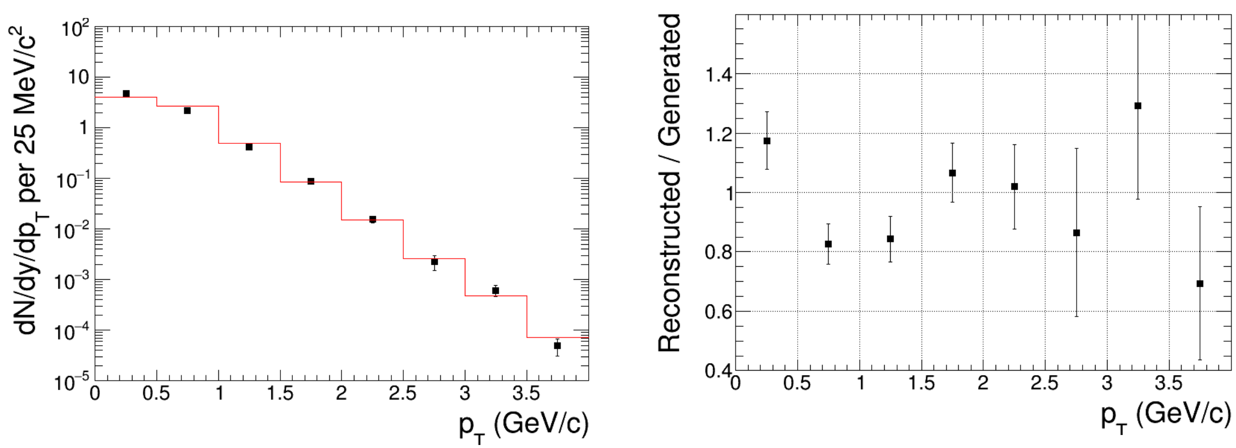
- Reconstructed spectra match the generated ones
- Reliable raw yield extraction starts at $p_T > 50$ MeV/c

η reconstruction in minbias AuAu@11

- Need much larger data sample for observation of the signal:
  - ✓ produced at much lower rate compared to π^0 at low p_T < 2-3 GeV/c, $\eta/\pi \sim 0.5$ at $p_T >> 1$
  - ✓ $\eta \to \gamma\gamma$ results in a much wider reconstructed peak (~40 MeV/c vs. ~10 MeV/c for π^0)
- With 15 M minbias AuAu@11 → only observe signals with rough p_T binning and large uncertainties
- Multiplicity dependent studies are not possible



- MC closure test → reconstructed spectrum matches the generated one in minbias AuAu@11



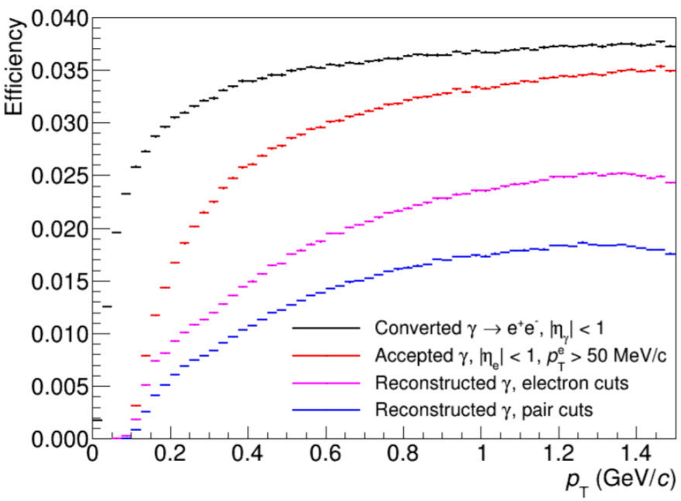
- Possible systematic effects are smeared out by huge statistical fluctuations

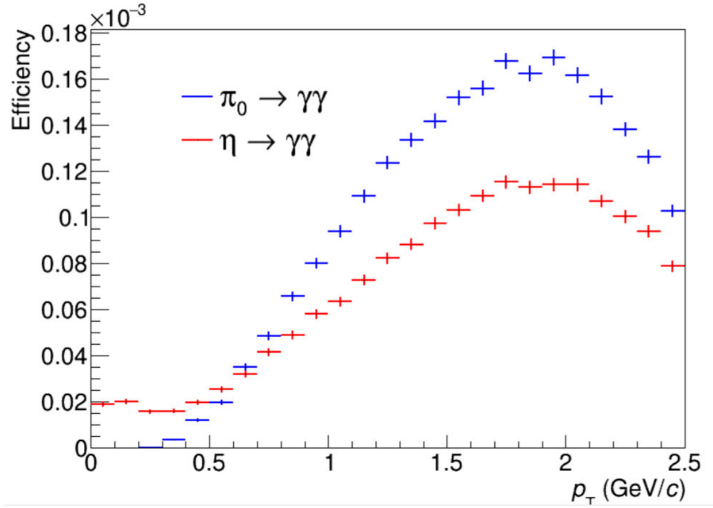
Neutral mesons via external conversion, $\gamma \rightarrow e^+e^-$

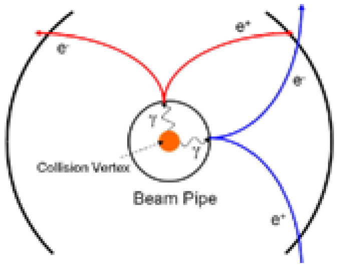
(see talk by E. Kryshen)

Reconstruction of neutral mesons

- Photons can be measured in the tracking system via $\gamma \rightarrow e^+e^-$ (PCM):



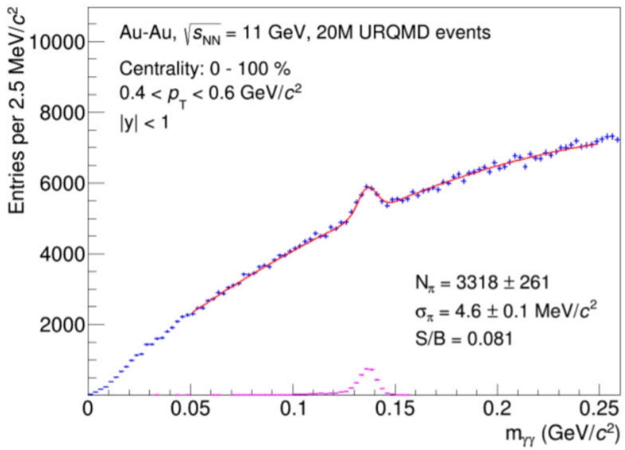


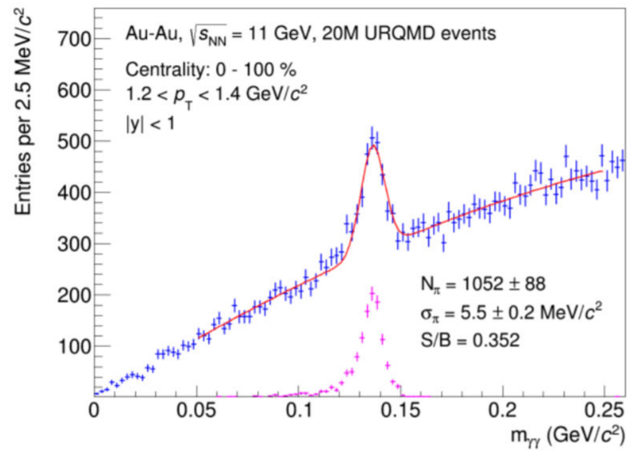


- Conversion e^+e^- pairs are identified by:
  - ✓ charged track + eID in the TPC and TOF
  - ✓ cut on the pointing angle to the primary vertex
  - ✓ cut on the opening angle plane with respect to the magnetic field
- Only ~ 4% of photons convert and only ~ 1.5% of photons is reconstructed with the PCM
- Efficiencies for neutral mesons are on sub-percent level
- The PCM is going to the main method for the measurement of low-E photons, neutral meson reconstruction is also possible at low p_T

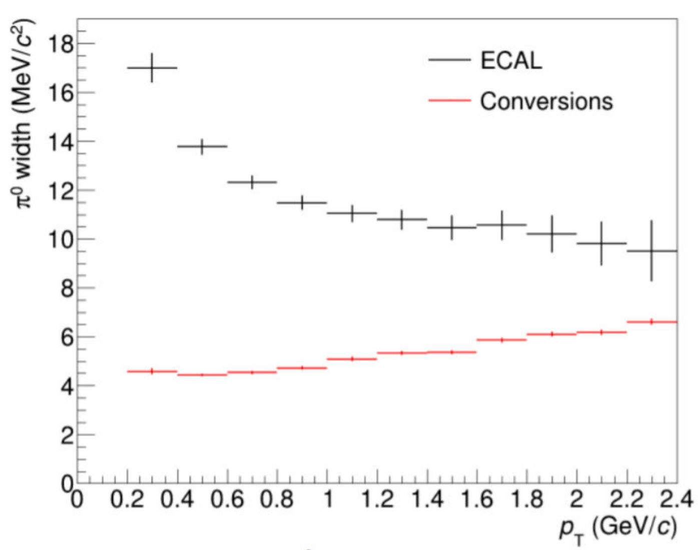
PCM resolution

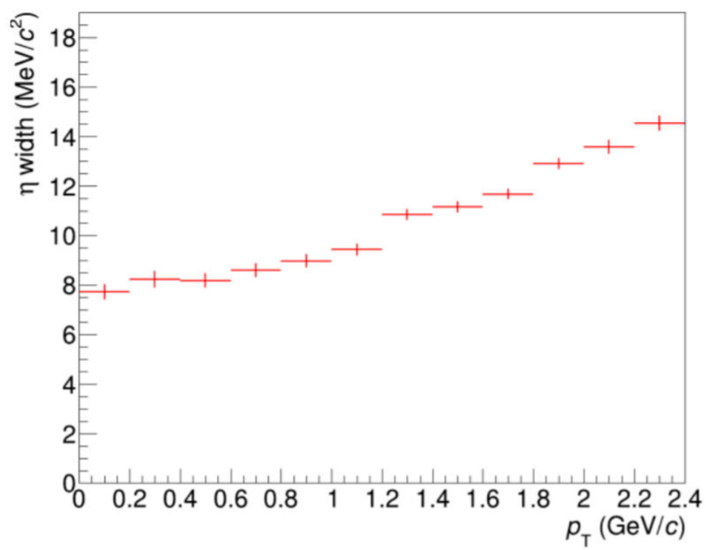
- S/B ratio is high enough, mixed-event subtraction is not required





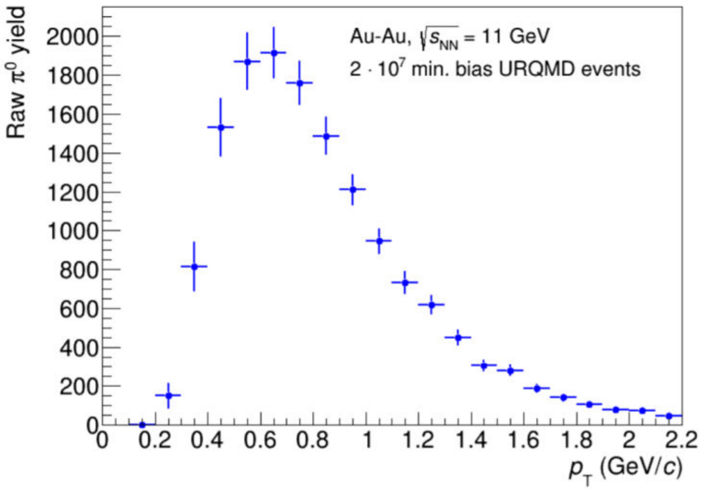
- PCM resolution for photons and neutral mesons is much better at low momenta



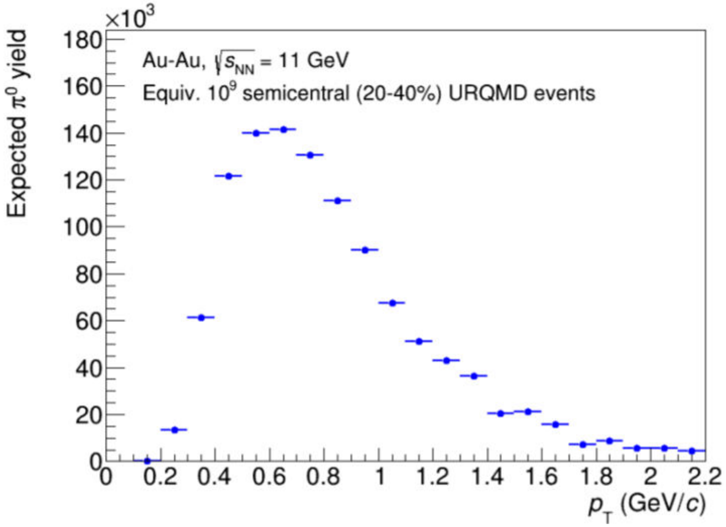


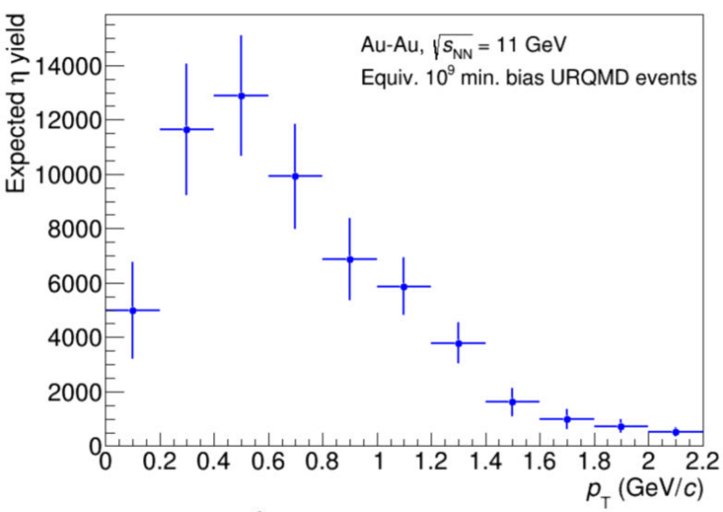
PCM yields for neutral mesons

- π_0 spectrum can be measured with 20 M sampled AuAu@11 events



- About 10^9 AuAu@11 must be sampled for π_0 multiplicity dependent study and flow measurements; for the measurements of η





Summary

- Reconstruction of π^0:
  - ✓ measurements are possible with ~ 10^7 sampled AuAu@11 events → achievable in year-1
  - ✓ range of measurements $p_T > 50$ MeV/c, up to ~ 3-4 GeV/c

- Reconstruction of η:
  - ✓ first rough measurements are possible with ~ 10^7 sampled AuAu@11 events → achievable in year-1
  - ✓ finer binning and/or multiplicity-dependent studies will need > 10^8 events

- Measurements with the ECAl and conversion method are complementary:
  - ✓ ECAL provides higher statistics
  - ✓ conversion method benefit from much better energy resolution at low momentum

Dielectron continuum and LVMs

Dielectron sources and background

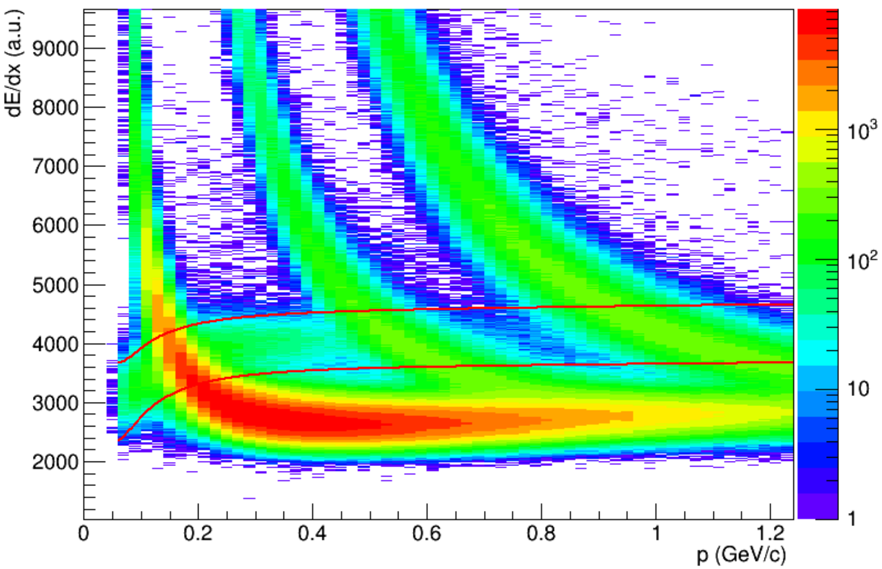
- The main sources of background are Dalitz decays of light hadrons
  - ✓ most of general-purpose event generators predict consistent yields within ±20-30% → acceptable for estimations and feasibility studies
- The main sources of dielectron pairs:

i	Dilepton channels	
1	Dalitz decay of π^0:	$\pi^0 \to \gamma e^+ e^-$
2	Dalitz decay of η:	$\eta \to \gamma l^+ l^-$
3	Dalitz decay of ω:	$\omega \to \pi^0 l^+ l^-$
4	Dalitz decay of Δ:	$\Delta \to N l^+ l^-$
5	Direct decay of ω:	$\omega \to l^+ l^-$
6	Direct decay of ρ:	$\rho \to l^+ l^-$
7	Direct decay of ϕ:	$\phi \to l^+ l^-$
8	Direct decay of J/Ψ:	$J/\Psi \to l^+ l^-$
9	Direct decay of Ψ':	$\Psi' \to l^+ l^-$
10	Dalitz decay of η':	$\eta' \to \gamma l^+ l^-$
11	pn bremsstrahlung:	$pn \to pn l^+ l^-$
12	$\pi^\pm N$ bremsstrahlung:	$\pi^\pm N \to \pi N l^+ l^-$

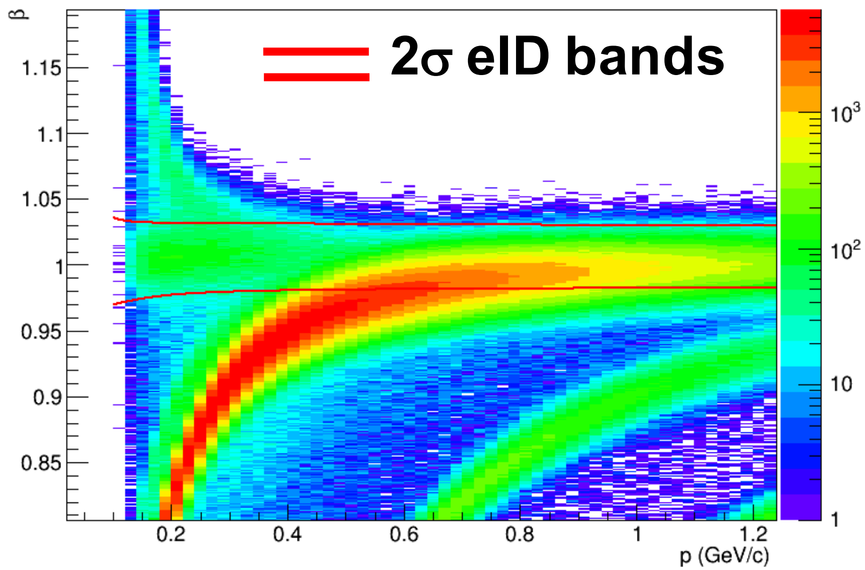
- The simulated yields of resonances show significant model dependence
- UrQMD and PHSD are used for estimations of dielectron signals in heavy-ion collisions at NICA, other inputs are considered …

eID capabilities

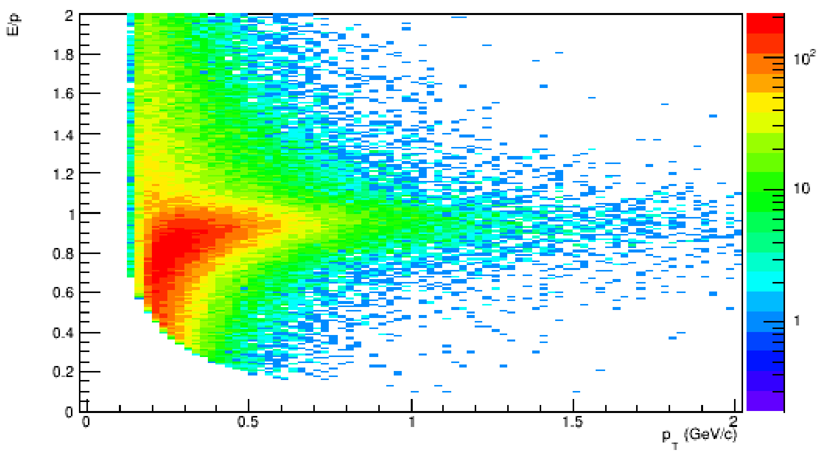
- TPC: dE/dx, for all tracks



- TOF: $\beta = v/c \sim 1$, $p_T > 150$ MeV/c



- ECAL: time-of-flight ($\delta \sim 500$ ps) and E/p ~ 1 for 2σ-matched tracks

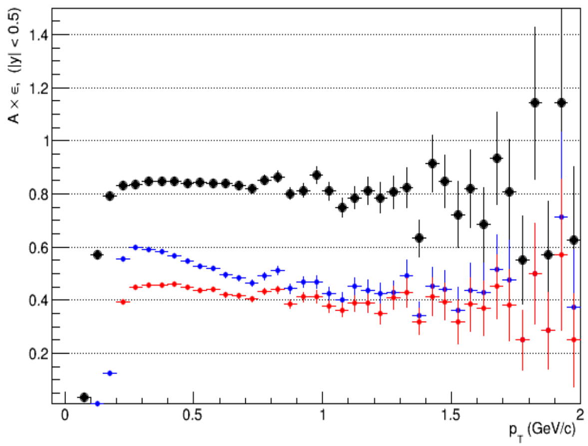


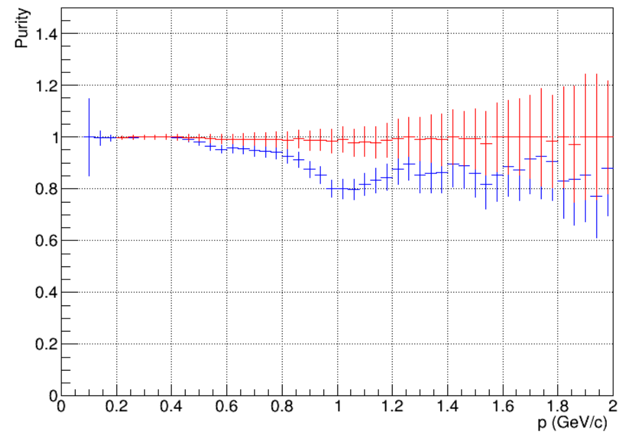
✓ turns on at $p_T > 200$ MeV/c

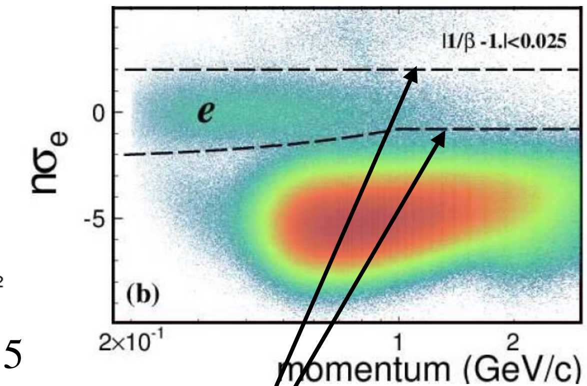
✓ TOF ($[-3\sigma,2\sigma]$) & E/P ($[-3\sigma,2\sigma]$) cuts provide high eID efficiency in a wide p_T range

eID efficiency and purity

- AuAu@11, UrMQD v.3.4
- **noID**, **TPC&TOF** or **TPC&TOF&ECAL** eID (2σ TOF matching, STAR's β cut



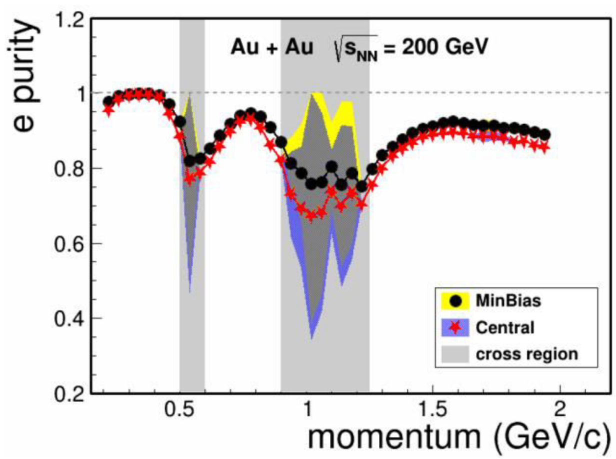




"β cut"

PHYSICAL REVIEW C 92, 024912 (2015

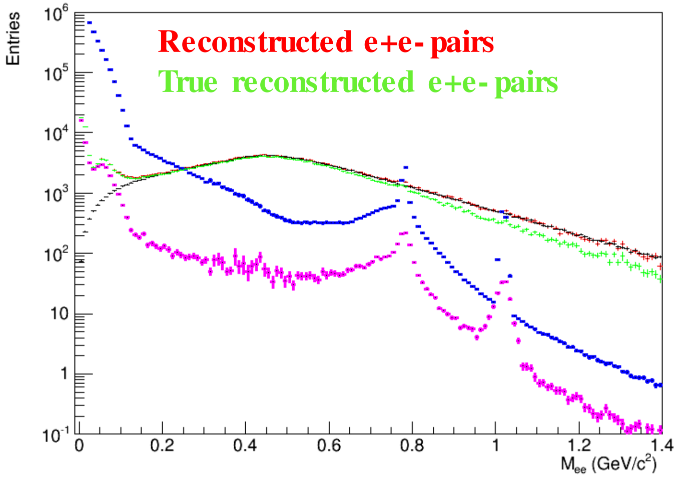
STAR: single electron efficiency at p_T > 200 MeV/c is 30-40%

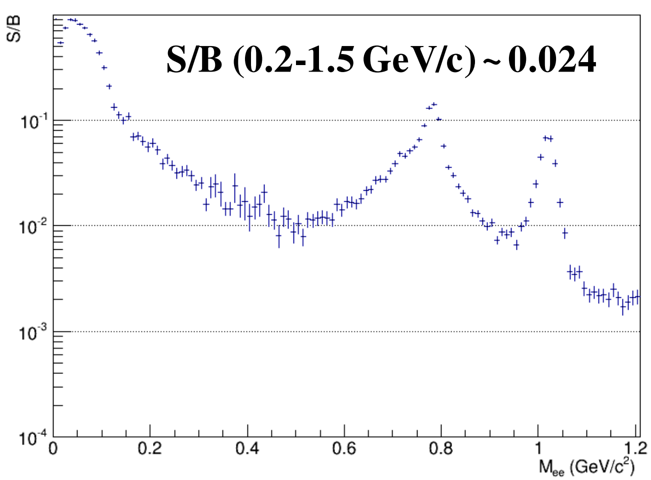


- Achieved purity & efficiency with **TPC&TOF** eID are comparable/better to STAR
- Tight matching cut makes eID by **TPC&TOF** quite sufficient for eID
- Additional **ECAL** eID helps to clean-up the electron sample at high p_T/e^+e^--mass

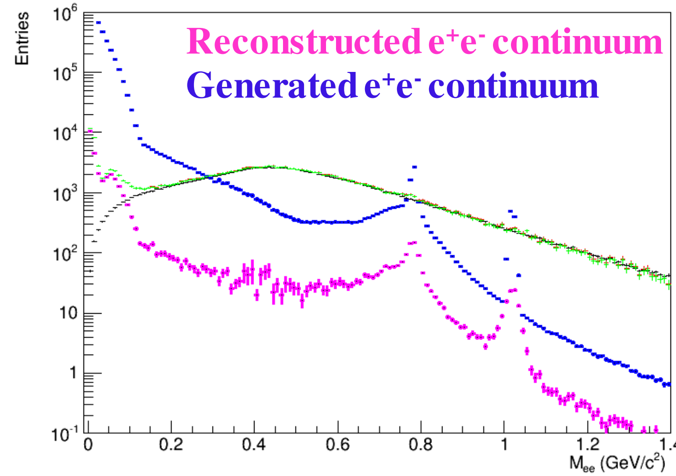
Examples of dielectron M_{inv} spectra, p_T integrated

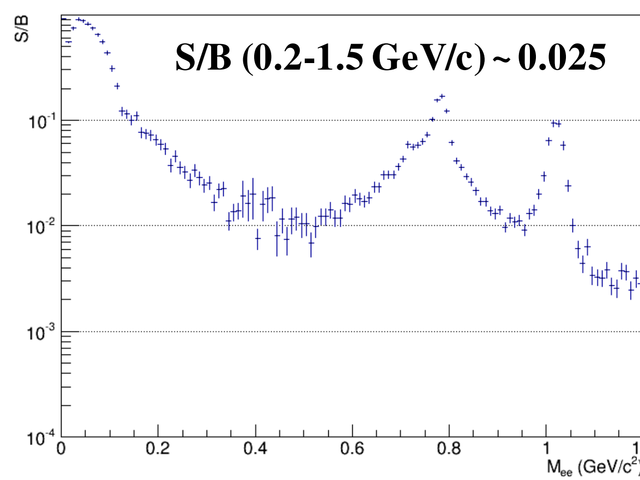
eID with TPC/TOF-eID





eID with TPC/TOF/EMC-eID





- Hadron contamination is reduced at higher masses with an additional ECAL-eID
- The higher the p_T the larger the contribution/importance of the ECAL-eID

Summary

- eID in the TPC&TOF is sufficient for most of the tasks
- Additional eID in the ECAL is important at high e^+e^- masses and high momenta
- Meaningful measurements for e^+e^- continuum and LVMs would require ~ 10^8 AuAu/BiBi events, first observations are possible with 10-30 M events

BACKUP

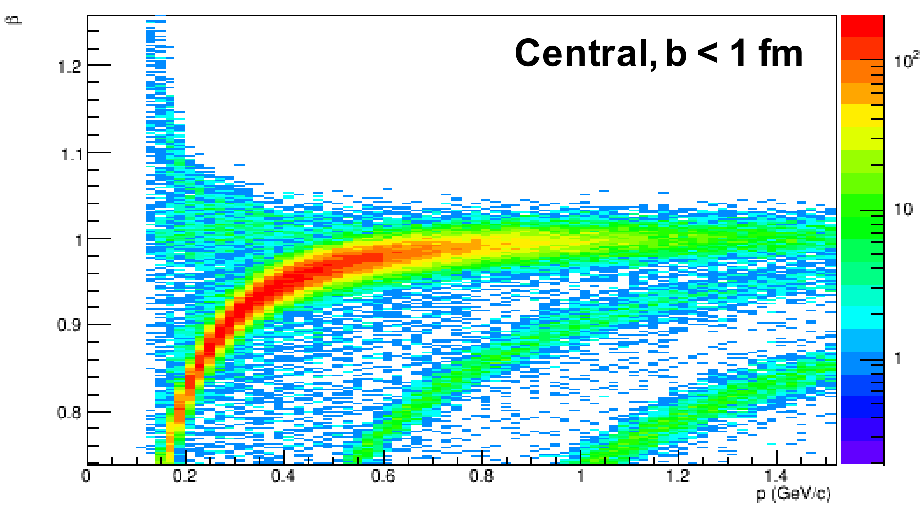
Dielectron continuum studies

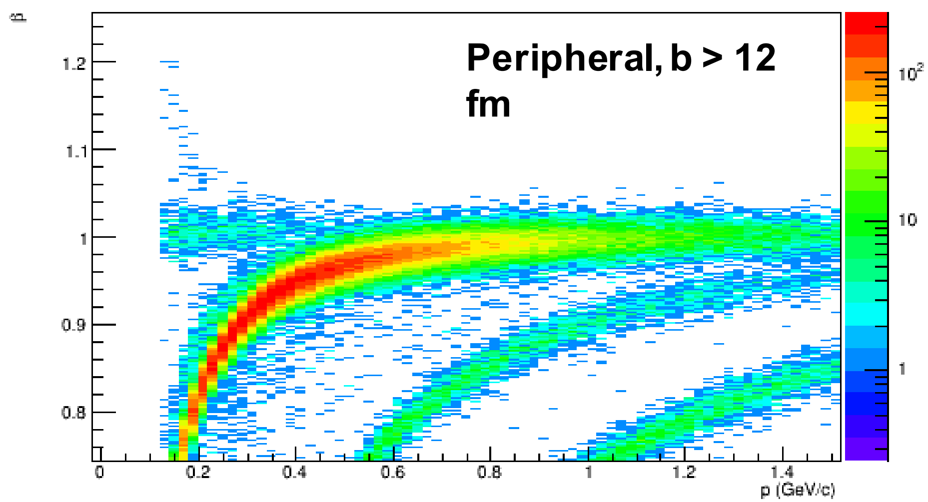
- The QCD matter produced in A-A interactions is transparent for leptons, once produced they leave the interaction region largely unaffected

- Dielectron continuum at low and intermediate mass/p_T carries a wealth of information about reaction dynamics and medium properties:
  - ✓ broadening and mass shift of LVMs $\rightarrow e^+e^-$
  - ✓ resonances in e^+e^- vs. hadronic decay channels
  - ✓ direct photon production via internal conversion
  - ✓ charm production and correlations etc.

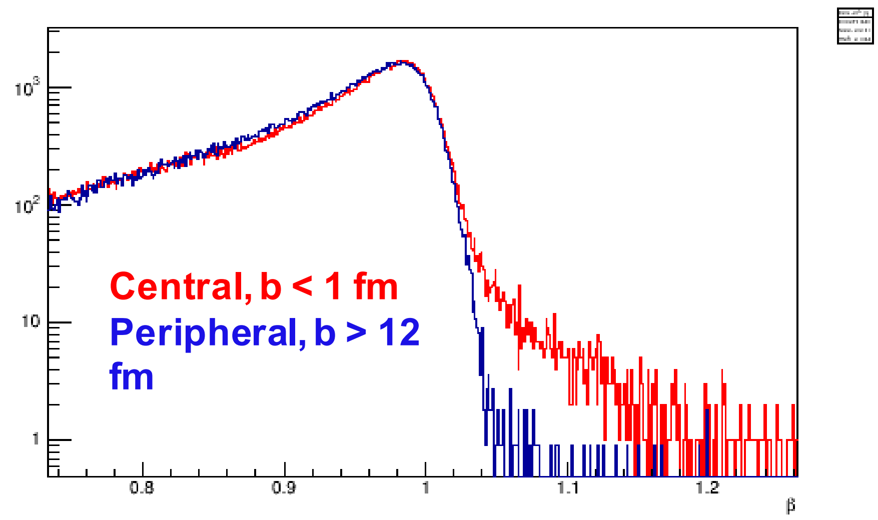
- Feasibility studies for dielectrons consist of two tasks:
  - ✓ evaluation of background and continuum contributions in AuAu@11
  - ✓ development of eID and pair selection cuts to enhance signal significance

Particle identification, TOF: MPD



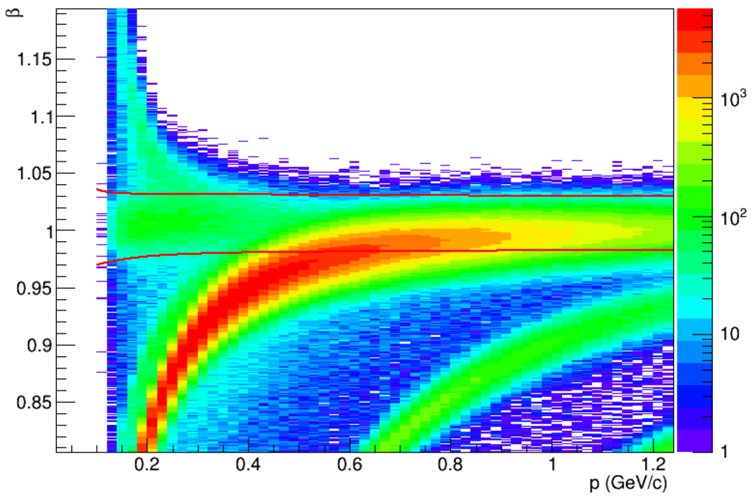


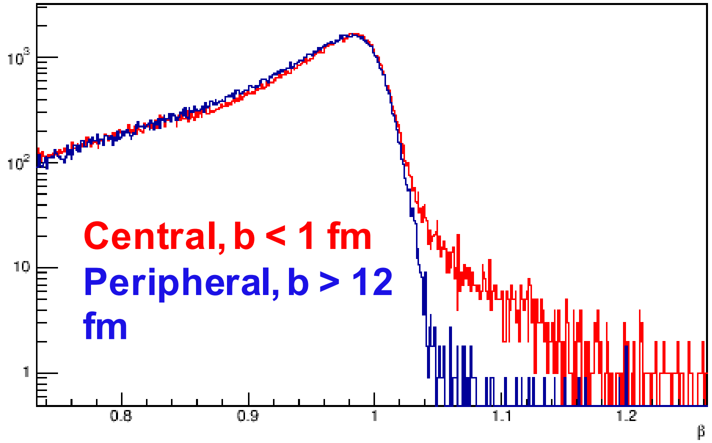
- Observed non-physical tail ($\beta > 1$) in the TOF: much more prominent in high multiplicity events (b < 1 fm); the tail is almost absent in peripheral collisions (b > 12 fm)
- Ascribed the effect to track mismatching in the TOF



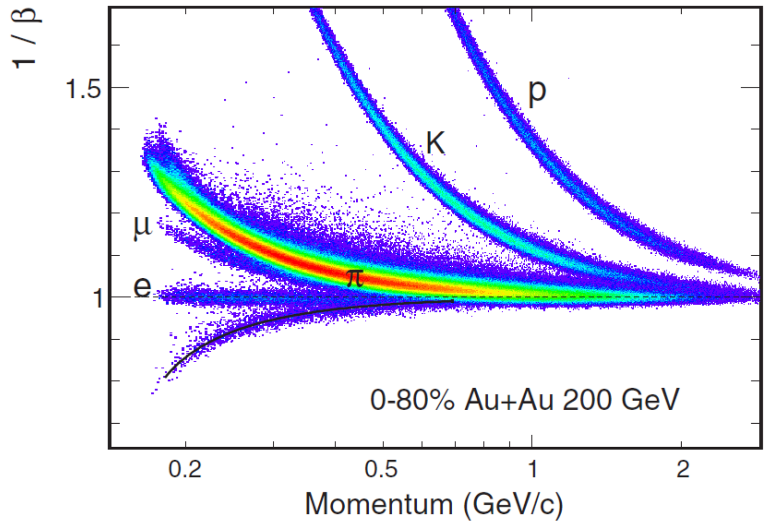
Problem of TOF-TPC track mismatching

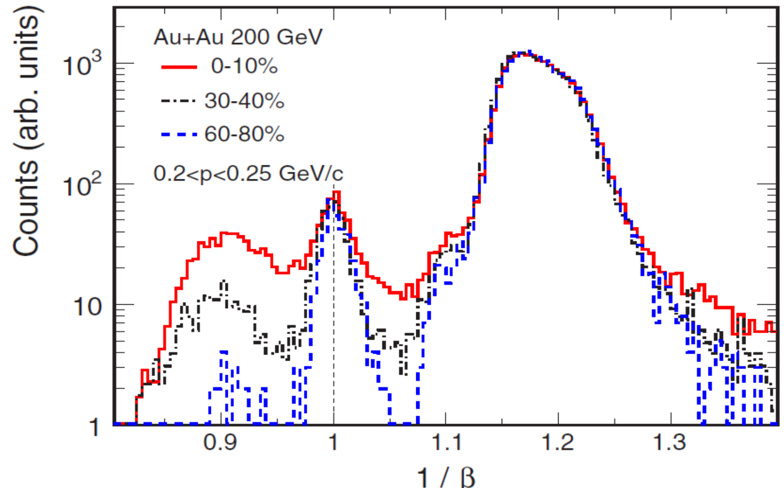
MPD





STAR

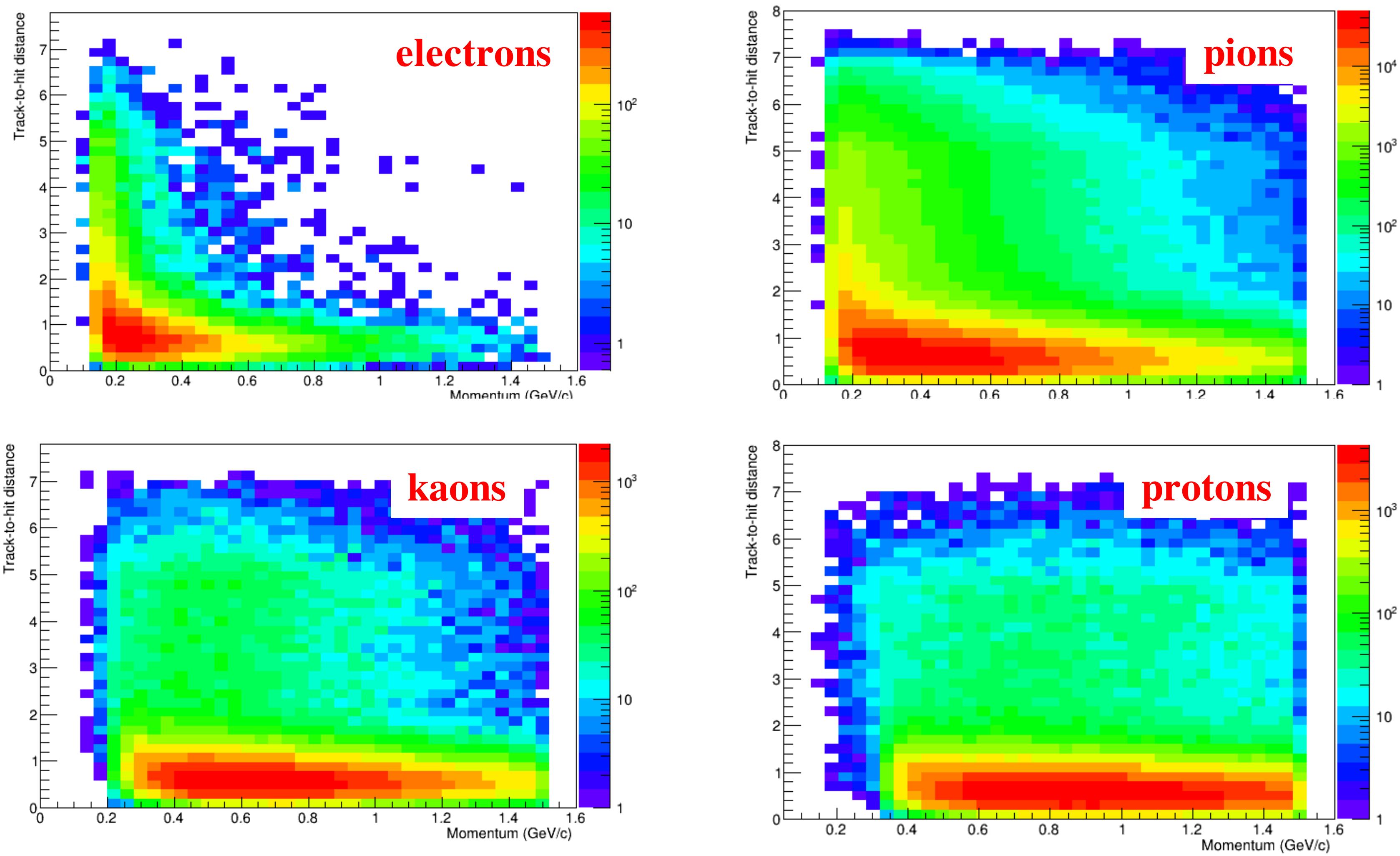




- Both STAR and MPD observe non-physical TOF signals with $\beta > 1$,
- Unphysical signals are most prominent in central collisions, diminished in peripheral
- Effect is explained by track mismatching in the TOF

Matching distributions vs. p_T

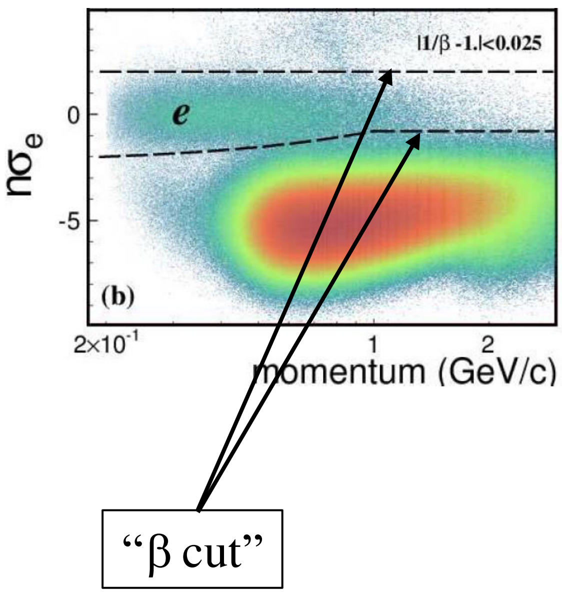
- Track-to-hit distance in the TOF (or 1/weight) vs. p_T, minbias BiBi@9.46



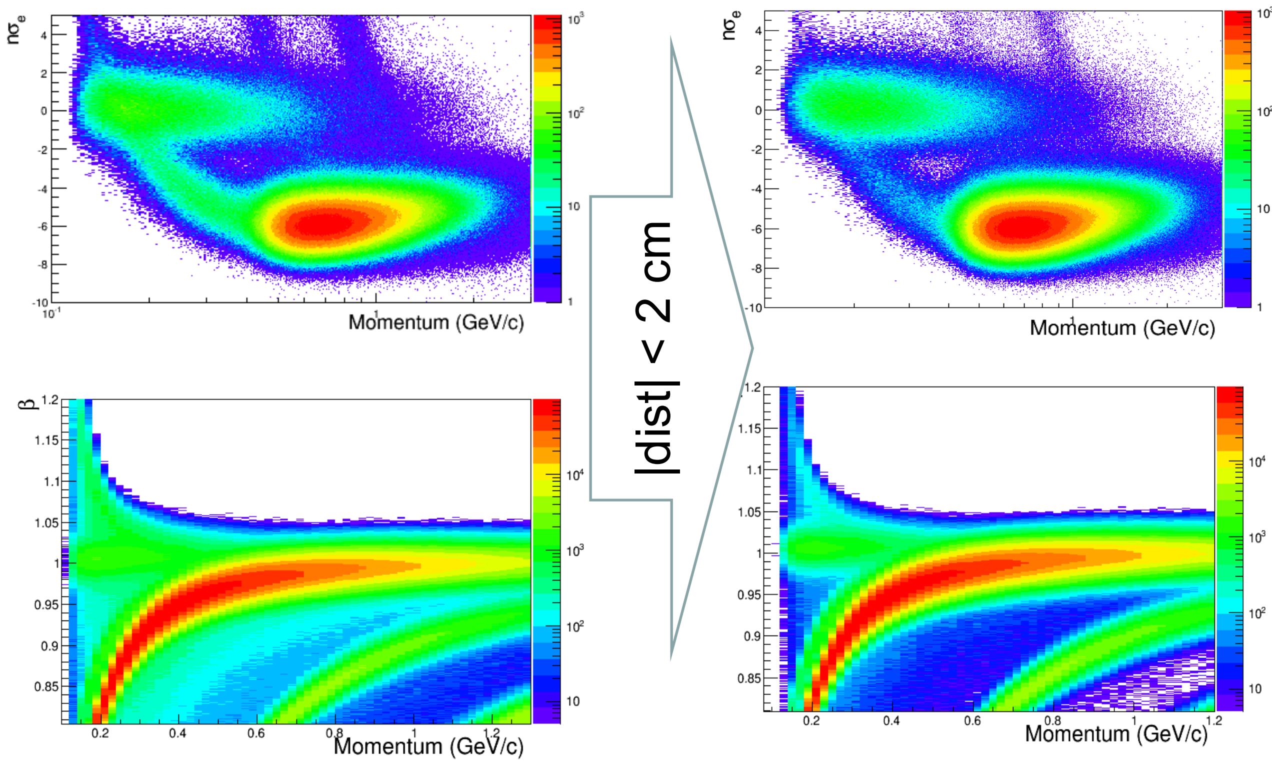
- Matching distributions are quite wide (too wide ???)

dE/dx selections with 2σ eID TOF cut

STAR, AuAu@200

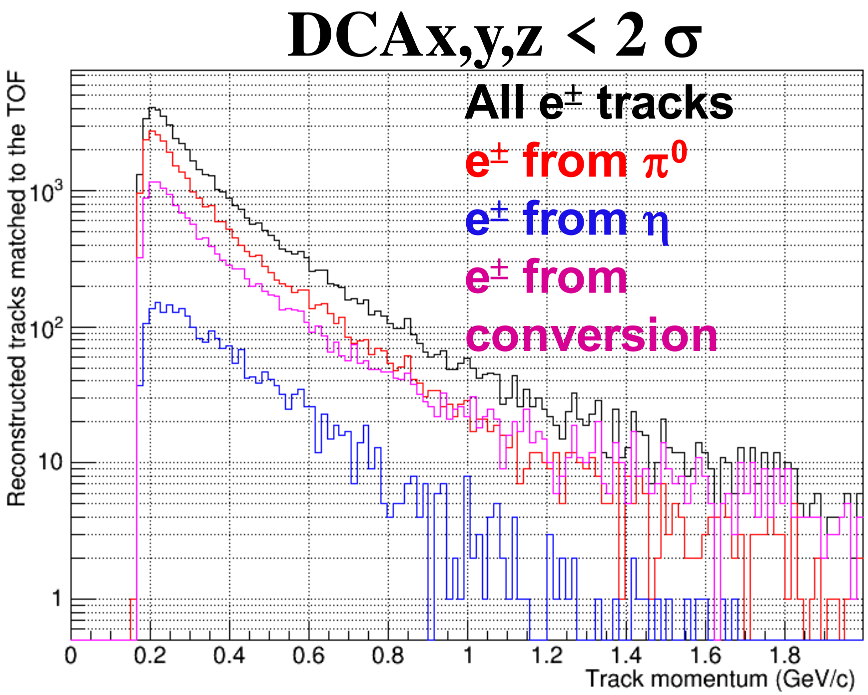


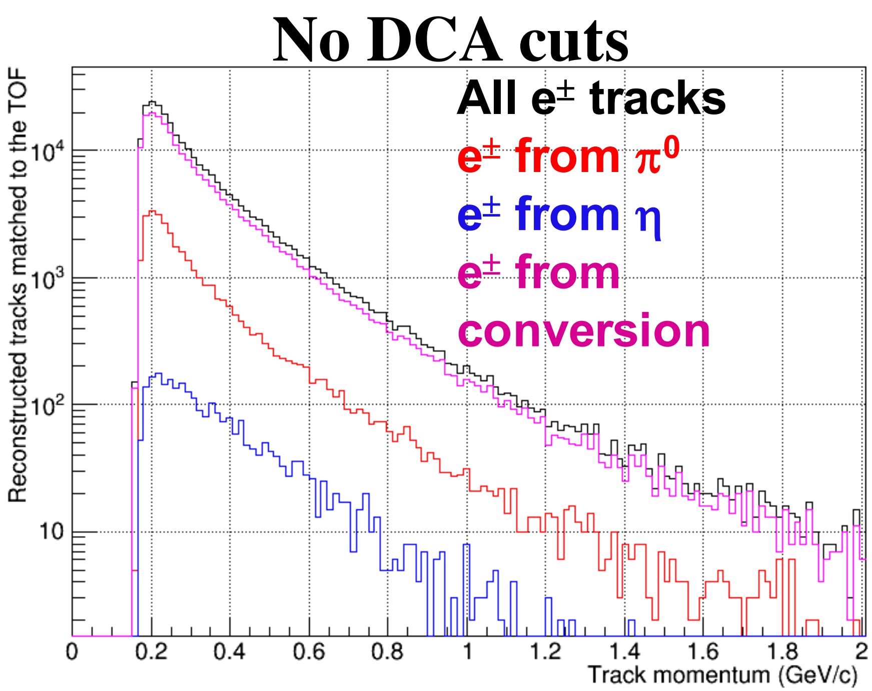
MPD, BiBi@9.46



- Tighter matching (|dist| < 2cm) cut:
  - ✓ suppresses the grass and the β > 1 tail
  - ✓ significantly improves e/π and probably π/K separation

Sources of electrons: MPD



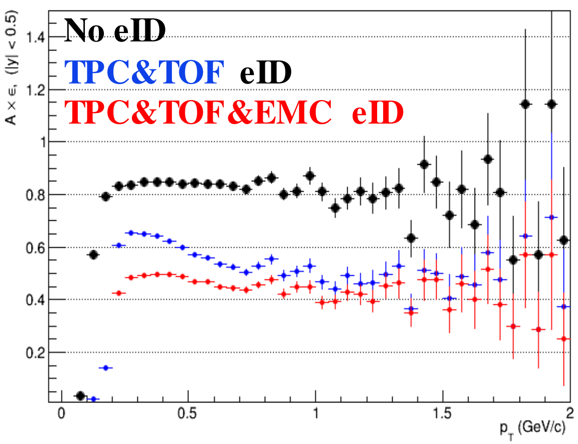


- Minbias AuAu@11 collisions (centralized production #3, AuAu@11 with Geant-3)
- Only TPC $e^{\pm}$ tracks matched to the TOF are selected, the only difference is in DCAx,y,z cuts
- With tight DCAx,y,z cuts the main source of electrons is π^0 (Dalitz decays)
- With no DCAx,y,z selections, the electron spectrum is totally dominated (by an order of magnitude) by conversion electrons while contributions from π^0 and η remain ~ the same

→ Comparison of the electron purities make sense only when contributions of conversion are comparable in the experiments (materials and cuts)

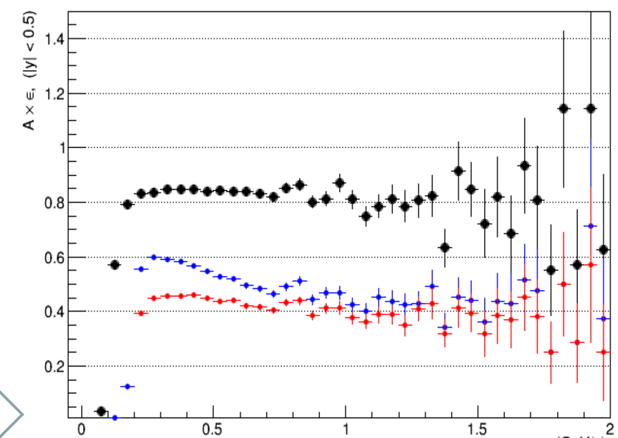
Recent improvement of the TOF eID capabilities

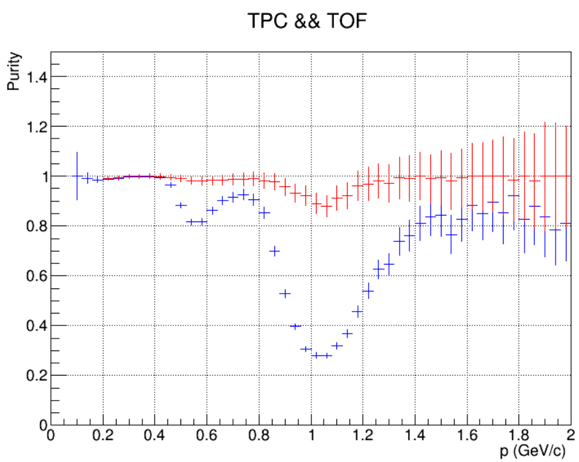
- By default, TOF uses rather loose cuts for track matching → high probability of wrong hit association → multiplicity-dependent contamination of the electron sample and distinct unphysical tail at $\beta > 1$
- Hit-to-track matching distributions were parameterized in *d*φ and *dzed* vs p_T, cut on $2\sigma(p_T)$
- Significant improvement of electron purity at reasonably small reduction of electron selection efficiency



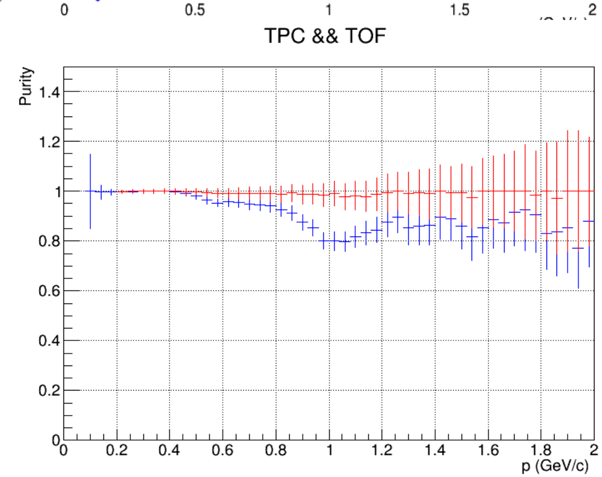
Efficiency

Additional
2σ TOF-matching

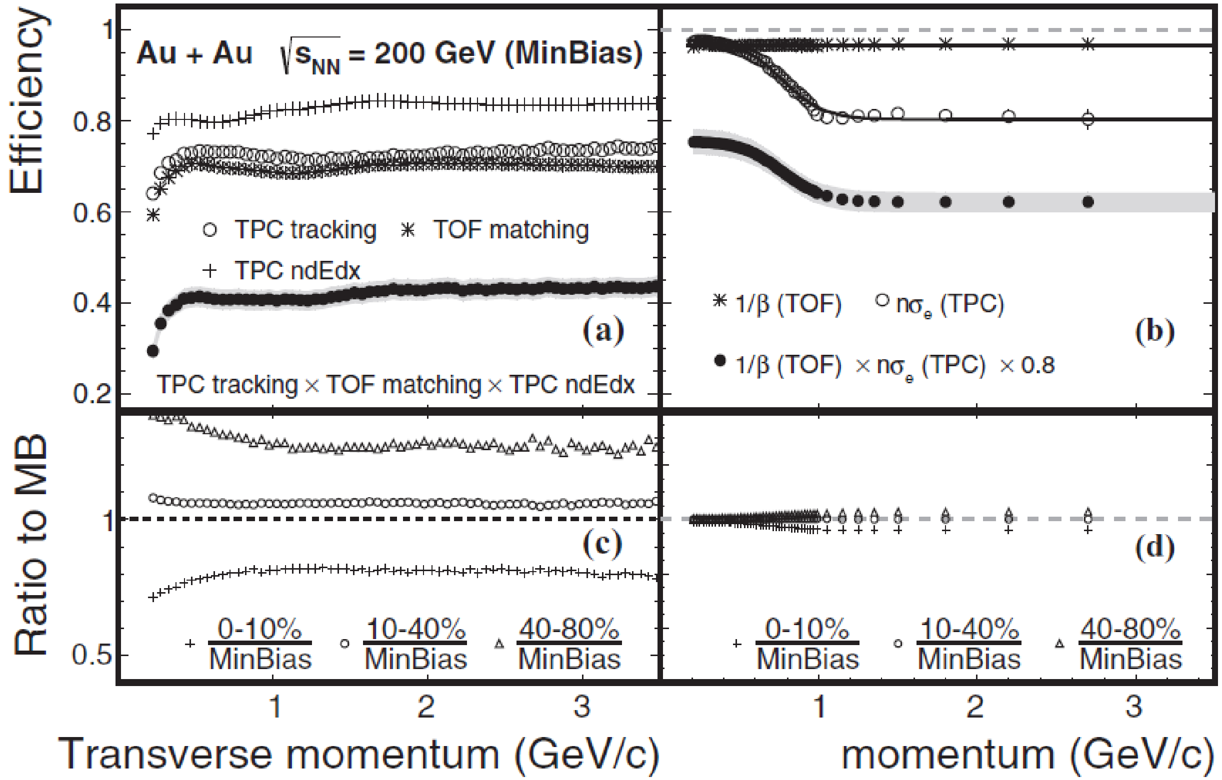




Purity



eID efficiency: STAR

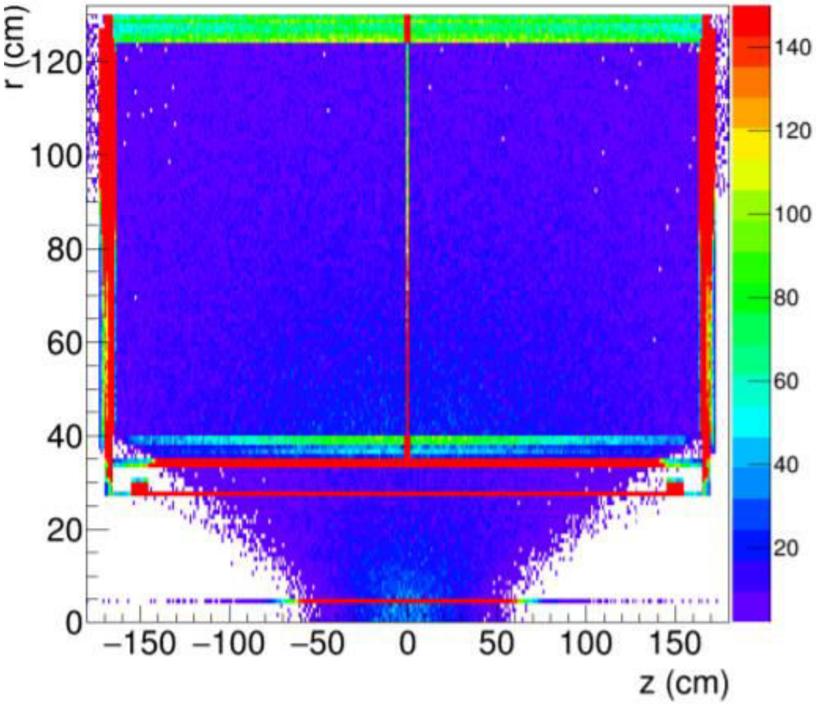


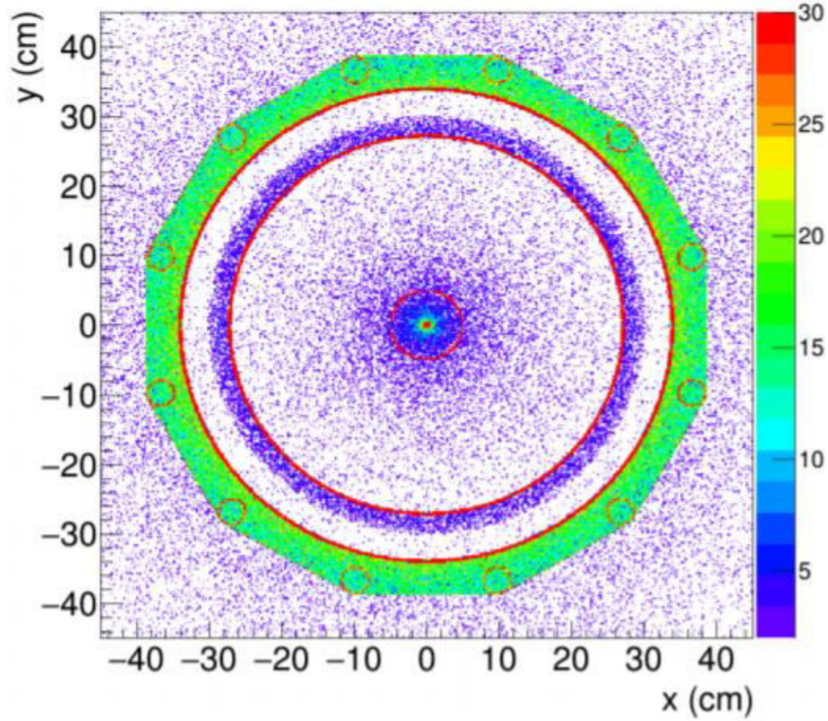
$$\varepsilon_{\text{eID}} = \varepsilon_{\beta} \times \varepsilon_{\text{dEdxPID}}$$

$$\varepsilon_{\text{dEdxPID}} = \varepsilon_{\text{ndEdx}} \times \varepsilon_{\text{n}\sigma_{e}}$$

- Single eID efficiency at p_T > 200 MeV/c (STAR): ~ 0.45 · (0.93-0.75) = 30-40%
- The MPD TPC-TOF-ECAL single eID efficiency with tight cuts is comparable

Photon conversion centers





Main conversion structures in Stage 1:

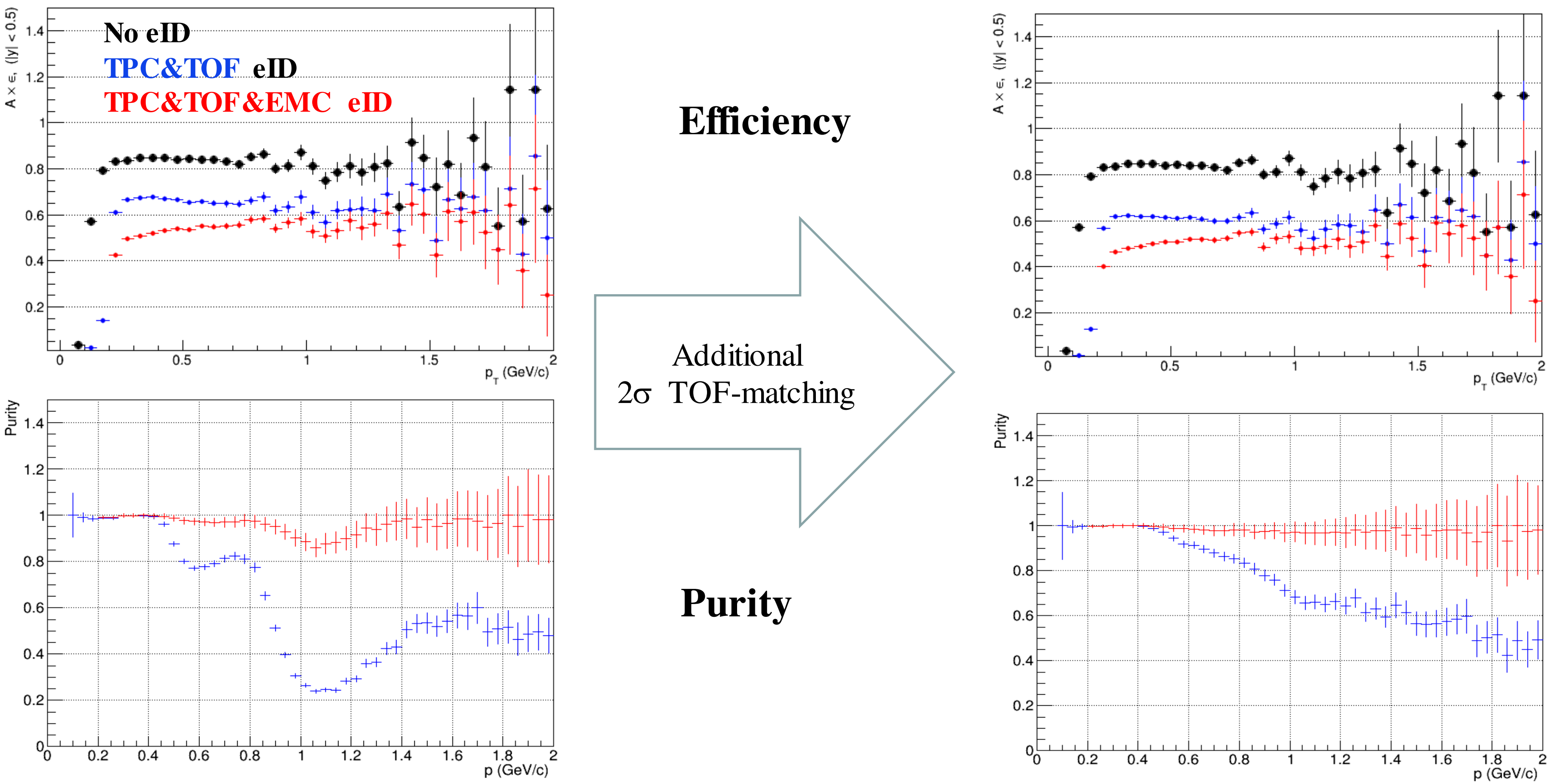
- Beam pipe: 0.3% X_0
- Inner TPC barrel structures: 2.4% X_0

Future:

- Inner tracking system
- Dedicated photon convertor (cylindrical metal pipe) under investigation

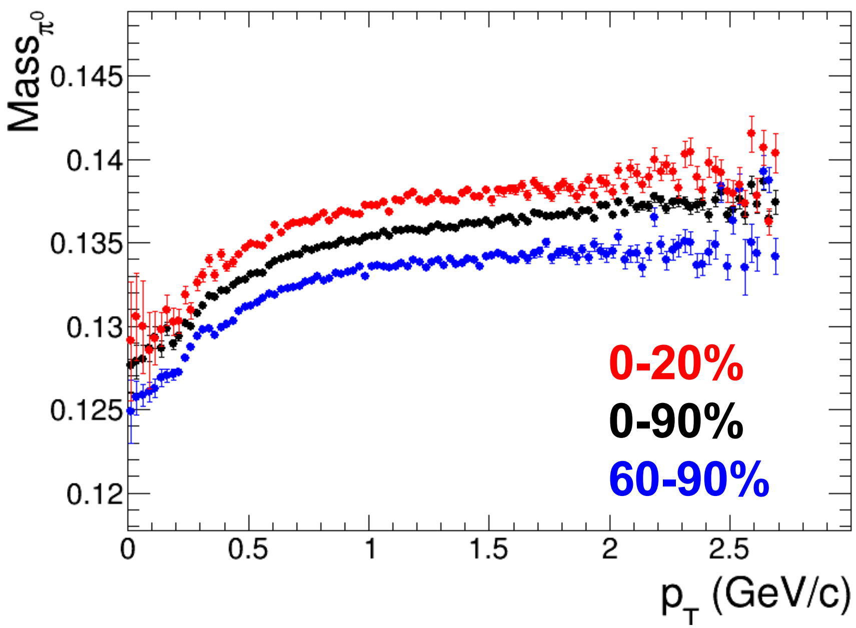
Recent improvement of the TOF-eID

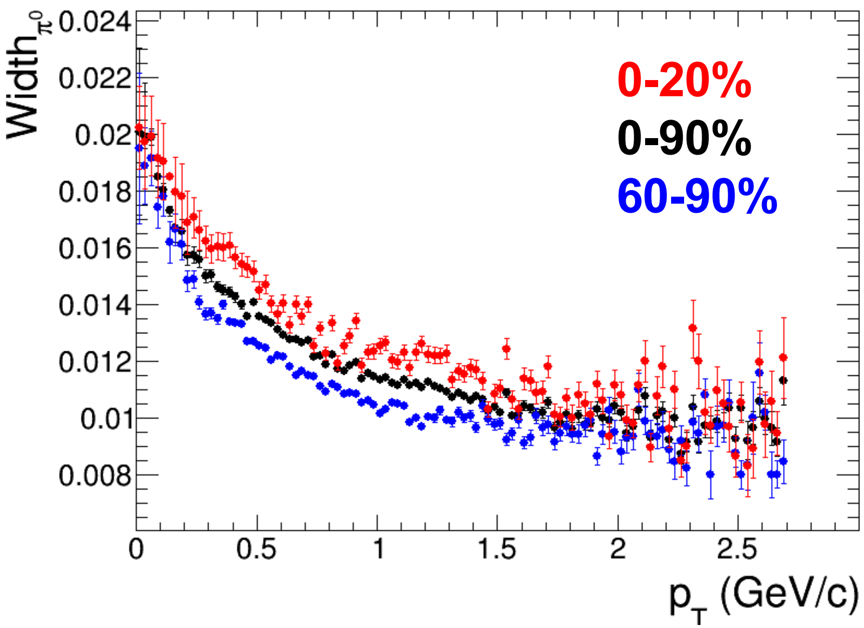
- By default, TOF uses rather loose cuts for track matching → high probability of wrong hit association → multiplicity-dependent contamination of the electron sample and distinct unphysical tail at $\beta > 1$
- Hit-to-track matching distributions were parameterized in $d\varphi$ and *dzed* vs p_T, cut on $2\sigma(p_T)$
- Significant improvement of electron purity at reasonably small reduction of electron selection efficiency



π^0 in AuAu@11: mass and width

- Same cuts and selections for all centralities





- Reconstructed mass increases with multiplicity and p_T:
  - ✓ shower merging at high multiplicity
  - ✓ energy leakage and non-linearity
- Reconstructed width increases with multiplicity and decreases with p_T:
  - ✓ energy resolution is multiplicity dependent
  - ✓ energy resolution improves with increasing energy