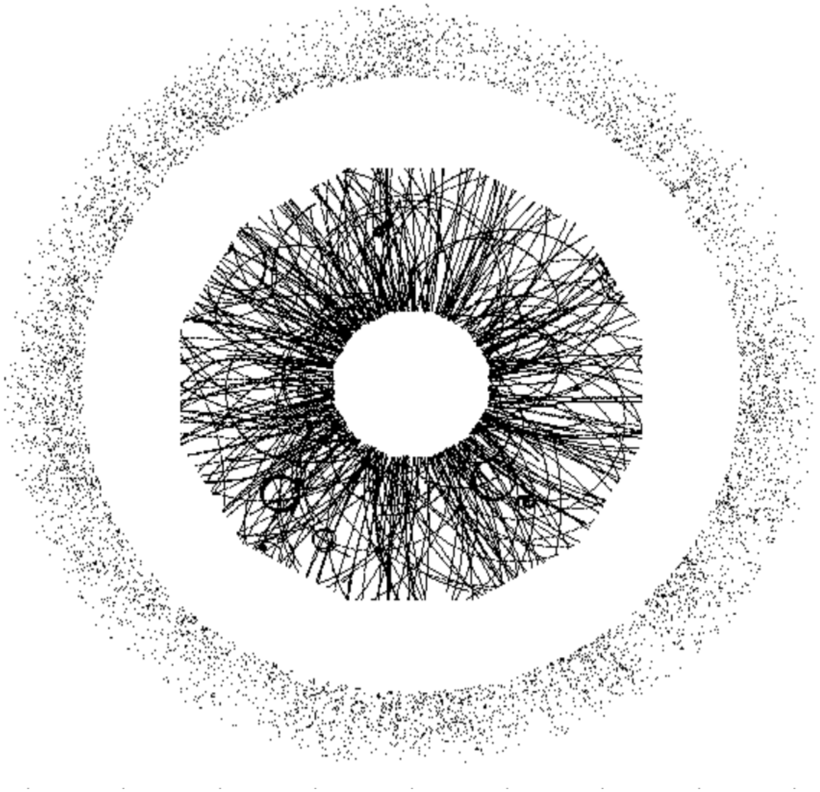
NICA

Nuclotron-based
Ion Collider fAcility

PWG4 summary

V. Riabov for the PWG4



PWG4

- Conveners: V. Riabov, Chi Yang
- PWG4 website: https://mpdforum.jinr.ru/c/electromagnetic-probes
- PWG4 scope - electromagnetic probes:
  - ✓ Electromagnetic calorimeter (ECAL) reconstruction
  - ✓ Photons and neutral mesons in ECAL and central barrel
  - ✓ Dielectron continuum
  - ✓ LVM, spectral shape and yield in-medium modifications, comparison to hadronic channels

Status of the PWG4

- Regular meetings since Feb, 2019; ~ 30 reports:
  - ✓ Development of ECAL reconstruction software
  - ✓ Reconstruction of neutral mesons
  - ✓ Measurement of LVMs and dielectron continuum
  - ✓ Estimation of the direct photon yields → **see report by D. Blau today**

- Relatively wide attendance, meetings in person and by Vidyo
- Materials on the web: https://indico.jinr.ru/category/371/

- Physics cases and tasks are well defined
- Focus is on solution of practical problems (estimation of expected signals, development of algorithms/software for signal reconstruction) and development of analysis technics, estimation of detector sensitivity to signals, needed statistics etc.

- Many vacant tasks → please contact conveners if you would like to join

Outline

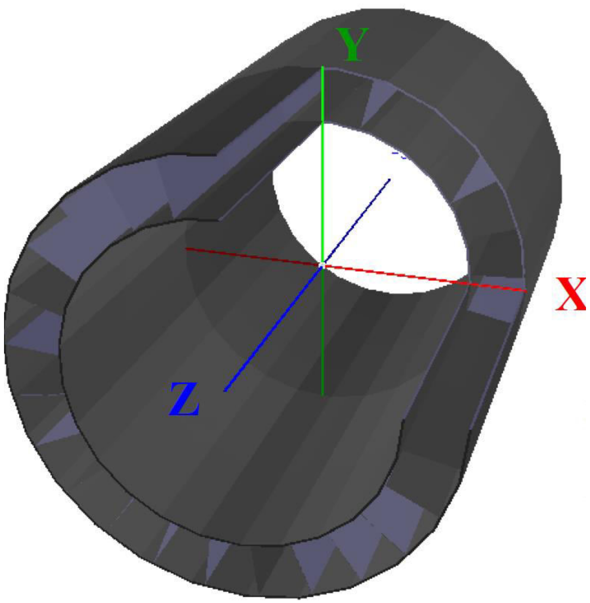
- PWG4 results for electromagnetic probes which are new or significantly updated since the last Collaboration meeting in Poland (Nica days -2019)

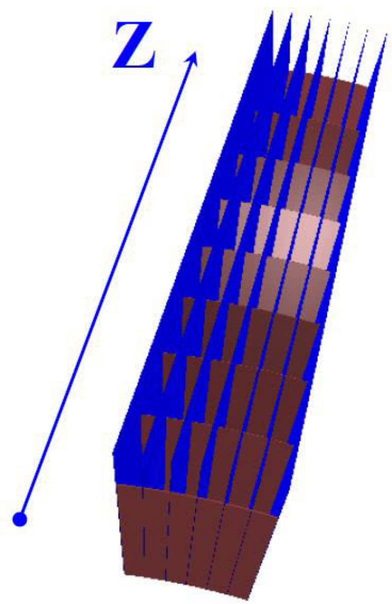
ECAL reconstruction software

ECAL is one of the main detectors for the measurement of electromagnetic signals

New ECAL geometry, v.3

- A new ECAL geometry was introduced at the last Collaboration meeting (JINR)
- The new geometry was introduced in Geant (IHEP)
  - ✓ Non-homogeneous acceptance, towers are intervened with carbon fiber support structures of different width (up to a few centimeters) → irregular structure → variance of the absolute scale
  - ✓ Addition of 2.1 cm of paint in each tower, smaller number of tiles
  - ✓ Support structure of 12.7% X_0 in front of the towers (carbon fiber cylinder)





- Worse energy resolution and smaller efficiency due to smaller light collection, smearing of the absolute scale and higher photon conversion probability

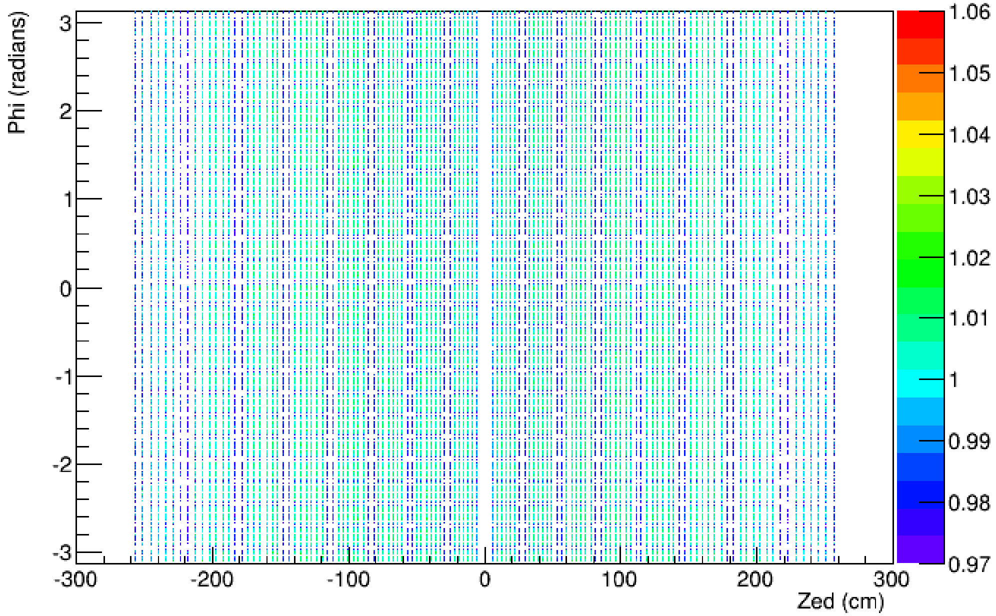
New digitizer-clusterizer

- A new digitizer-clusterizer was committed into Git (NRC KI)
  - ✓ Unfolds merged signals in high-multiplicity events → best performance
  - ✓ Fast and efficient
  - ✓ Disk space friendly
  - ✓ Flexible and easy to tune to beam test results
  - ✓ Ready to work with real data
  - ✓ The code is in public use
  - ✓ Further optimizations (better calibrations, more advanced PID selections etc.) will continue

- Need results of the full-scale ECAL prototype tests for comparison to tune the simulated light collection, noise level, linearity etc …

ECAL simulations

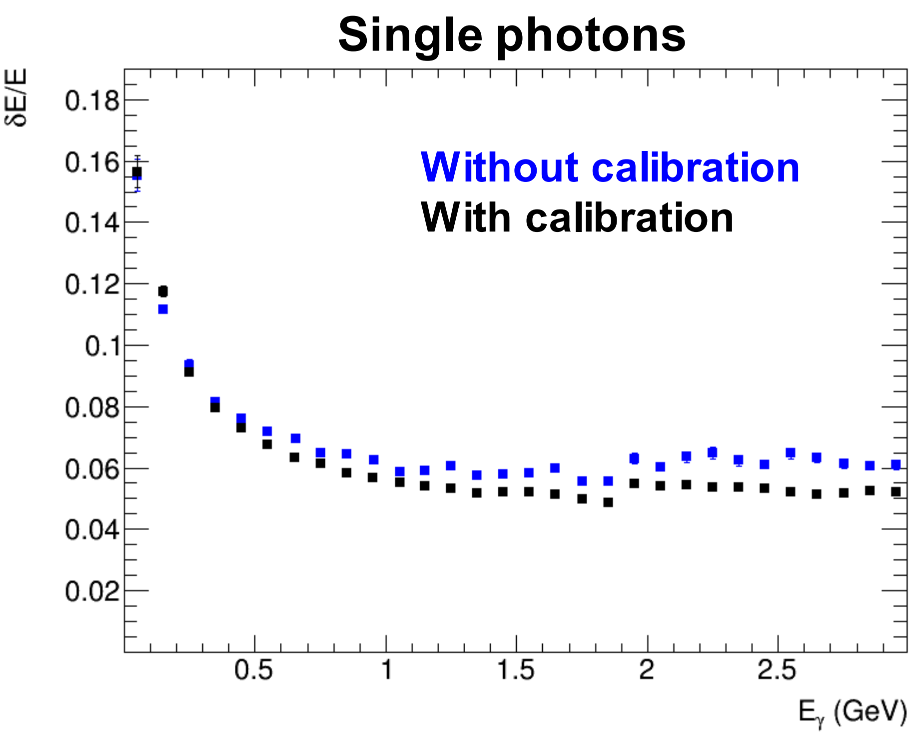
- The first centralized large MC production was produced by the PWG4 request (~15M events)
- The simulation is based on the latest MpdRoot version and includes the simulation of the ECAL with improved tower-by-tower calibration to compensate the detector non-homogenity

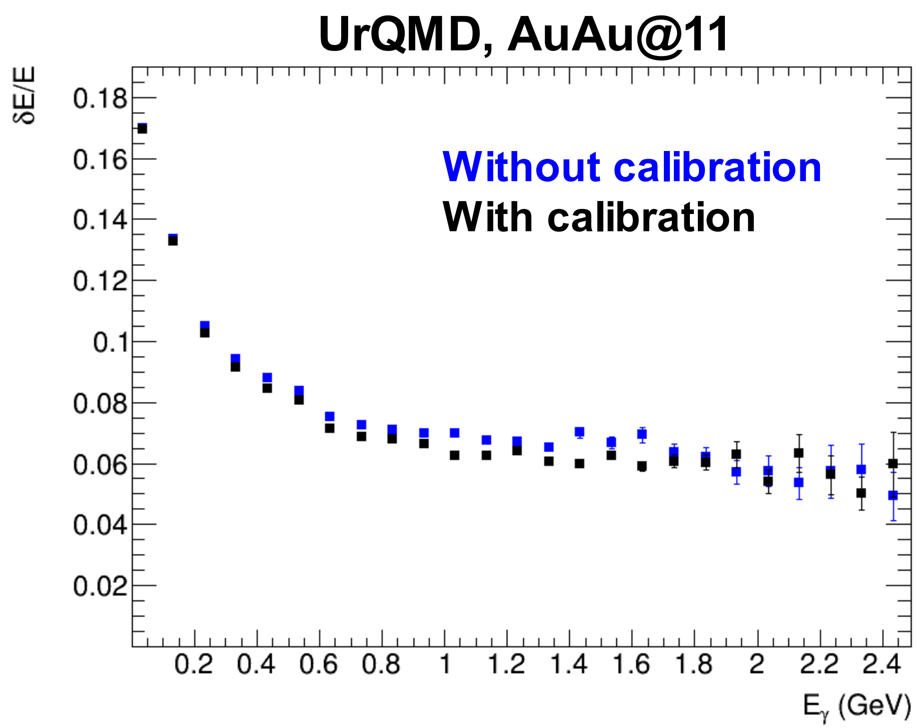


- The ECAL simulation output is a list of all reconstructed showers/clusters:
  - ✓ Full and truncated energy
  - ✓ Coordinates of the shower center of gravity: x, y, z, R, phi, theta
  - ✓ List of top-five MC contributors (index, energy deposition)
  - ✓ PID variables: Chi2/NDF, dispersion
  - ✓ time of flight, track matching in dphi/dz, list of associated towers (for recalibration and debugging)

ECAL performance: energy resolution

- Energy resolution is significantly affected by detector geometry and multiplicity
- Fine tower-by-tower calibration improves the resolution (reduces the constant term)

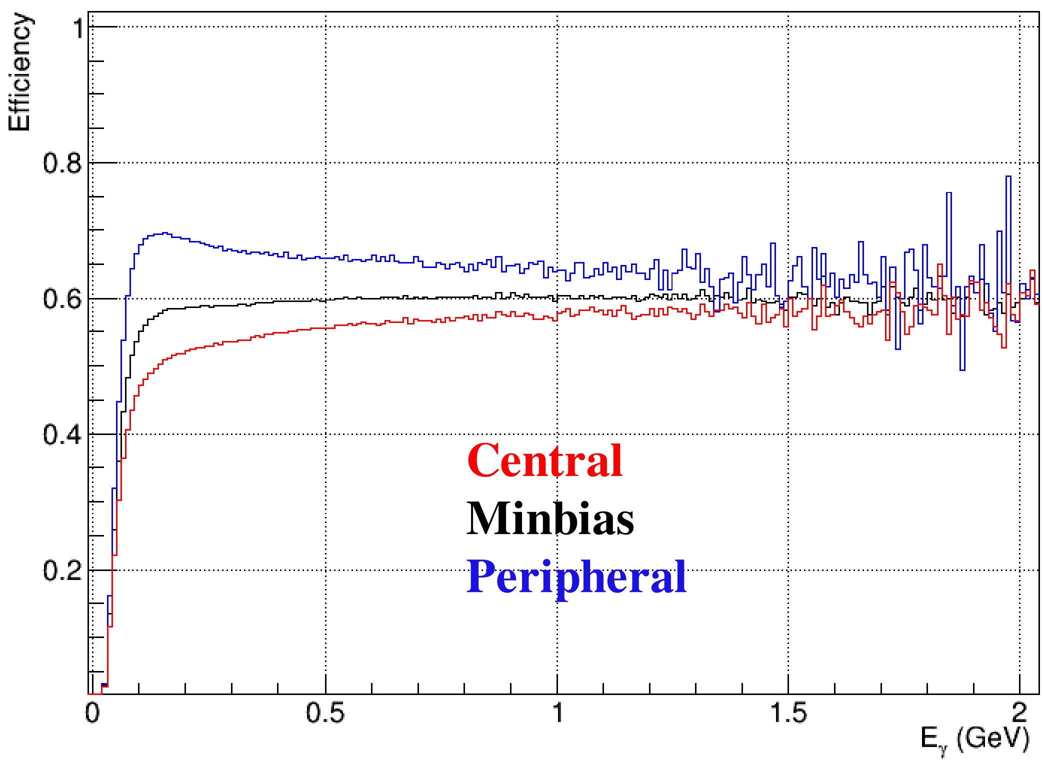


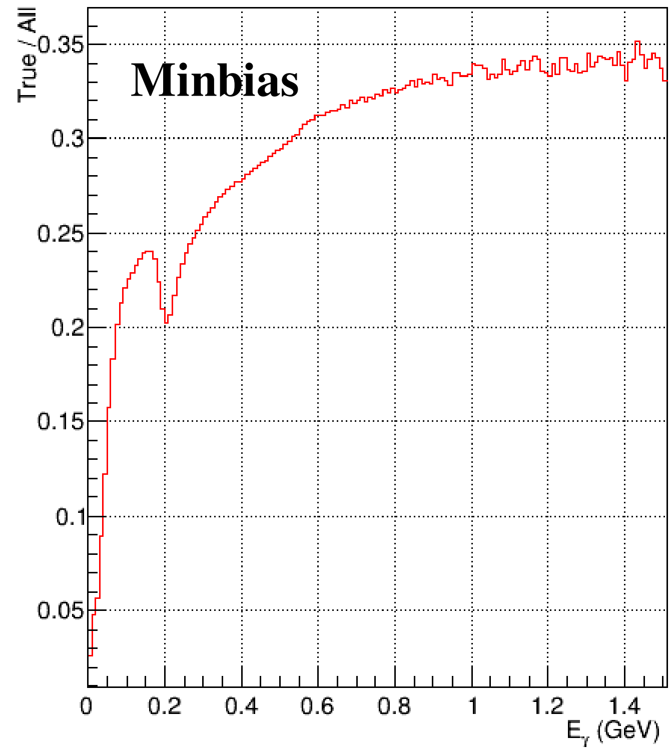


- The real detector energy resolution will be noticeably worse than the commonly quoted ~5%/√E, which is simulated and measured for <u>single photons</u> under condition of <u>full light collection</u> in <u>ideal geometry (v.2)</u>

ECAL performance: γ efficiency & purity

- UrQMD. Minbias AuAu@11; realistic vertex distribution





- Only ~ 60% of primary photons reach the ECAL surface, others convert (TOF + carbon fiber)
- Efficiency drop in central collisions is caused by overlap of the showers
- The real efficiency is higher because some of e^+e^- conversion pairs are reconstructed as a single cluster; such clusters differ by shape though
- Measurements at low energy suffer from large backgrounds

Neutral mesons in ECAL

Neutral mesons (π_0, η) are the day-one measurements for the MPD

Neutral mesons in heavy-ion collisions

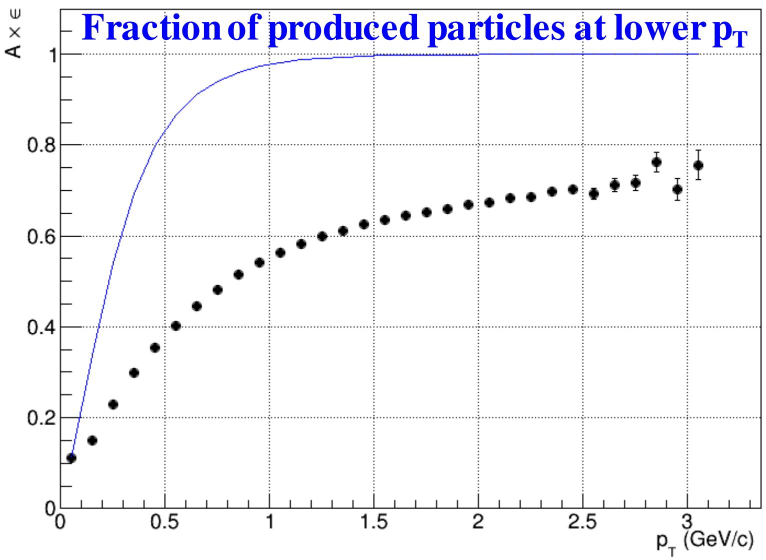
- Wide variety of neutral mesons:
  - ✓ **π^0 ($\pi^0 \to \gamma\gamma$)**
  - ✓ **η ($\eta \to \gamma\gamma, \eta \to \pi^0 \pi^+ \pi$)**
  - ✓ K_s ($K_s \to \pi^0 \pi^0$)
  - ✓ **ω ($\omega \to \pi^0\gamma, \omega \to \pi^0 \pi^+ \pi$)**
  - ✓ η' ($\eta' \to \eta\ \pi^+ \pi$)
  - ✓ etc.

- 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
  - ✓ …

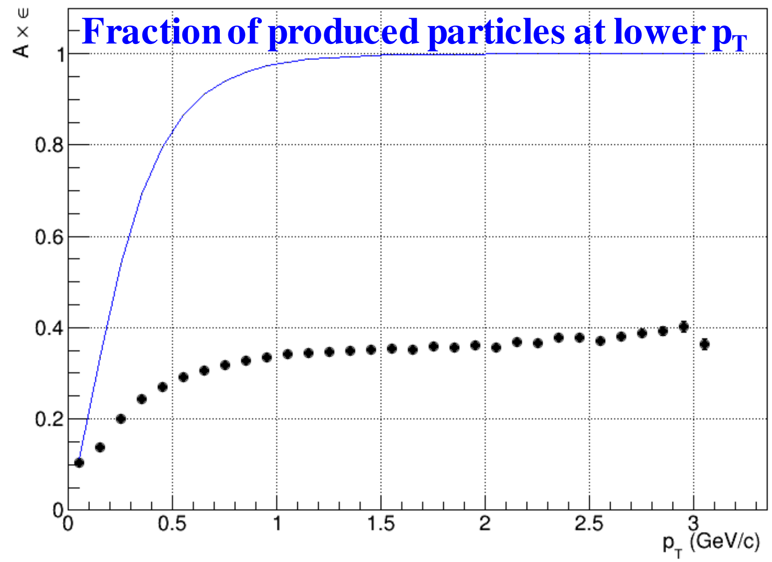
- π^0, η are the most promising signals for day-one measurements

π^0 reconstruction in AuAu@11

- Minimum cuts for observation of signals:
  - ✓ Events: UrQMD, |z-vertex| < 50 cm
  - ✓ Photons: E > 0 GeV, $T_{reduced}$ < 2 ns
  - ✓ Pairs: |y| < 0.5



- Optimized cuts for better significance:
  - ✓ Events: UrQMD, |z-vertex| < 50 cm
  - ✓ Photons: E > 0 GeV, $T_{reduced}$ < 2 ns,
  - ✓ PID: charged track veto, Chi2/NDF < 4.0
  - ✓ Pairs: |y| < 0.5

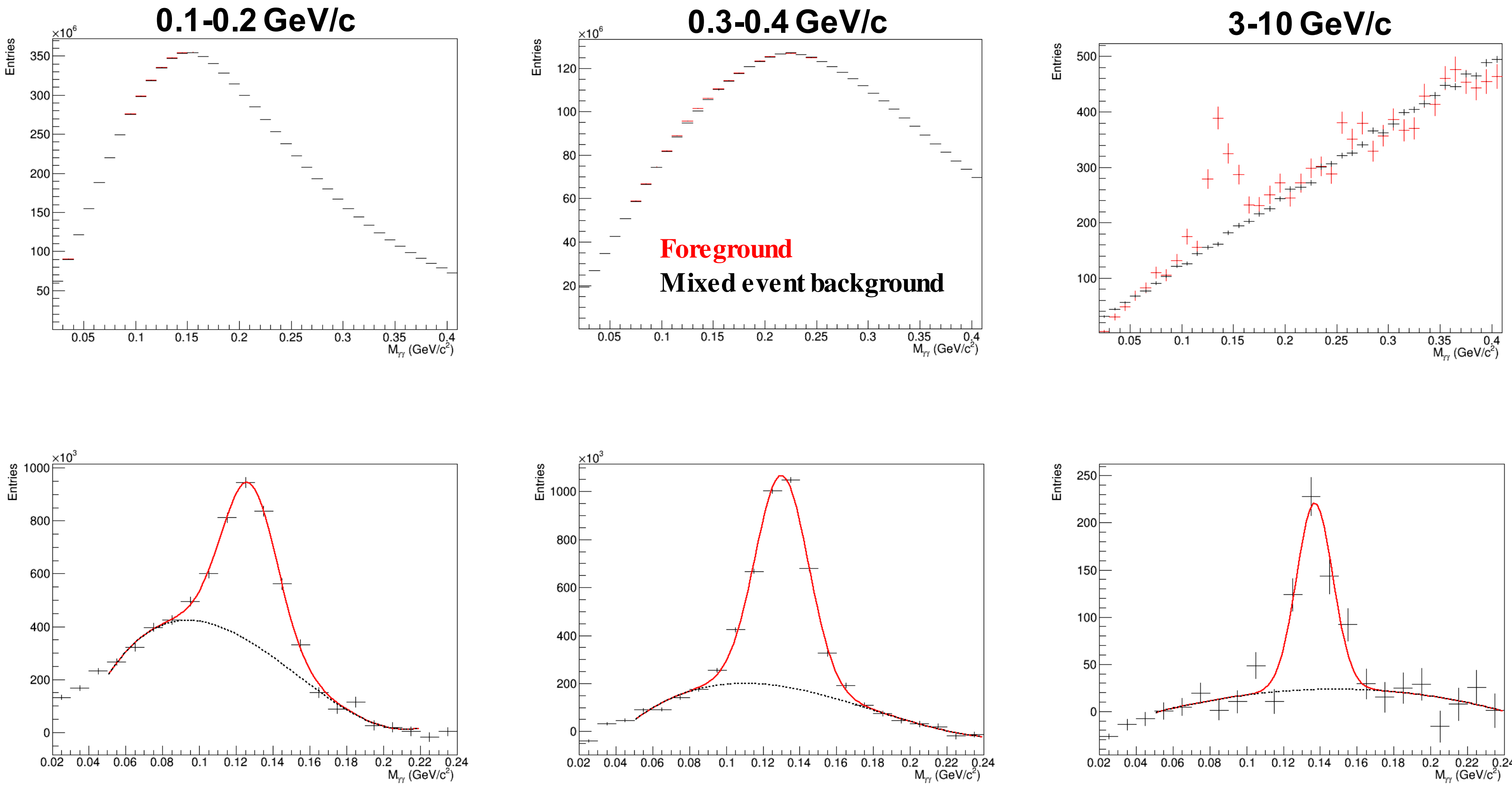


- Efficiency for π^0 is > 10% at p_T > 50-100 MeV
- Signal is measurable starting from ~ 25 MeV/c
- Maximum raw yield of π^0 is expected at ~ 300 MeV/c

- With ~ 10M sampled AuAu@11 events the measurement uncertainties will be driven by systematic uncertainties for the raw yield extraction → focus is on better control of the extracted raw yields

π^0 peak examples in AuAu@11

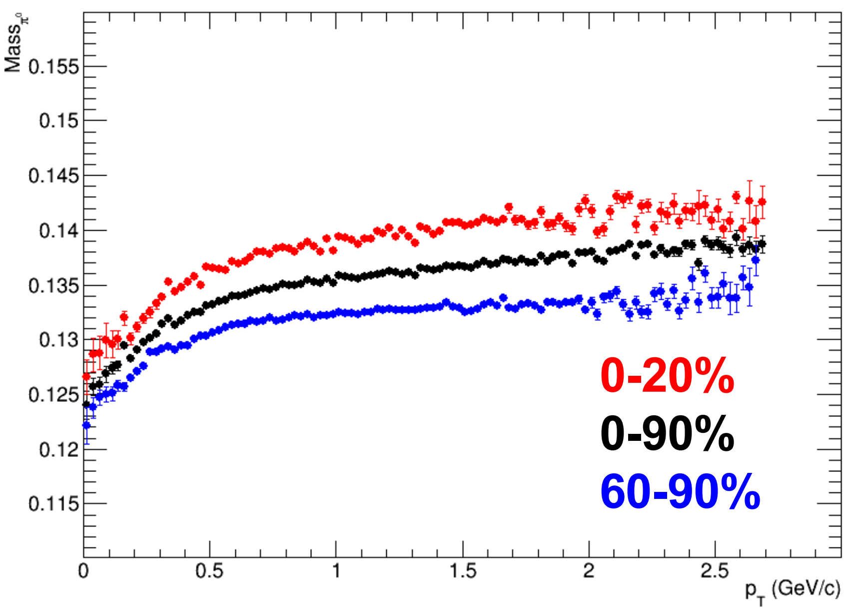
- UrQMD. Minbias AuAu@11, realistic vertex distribution

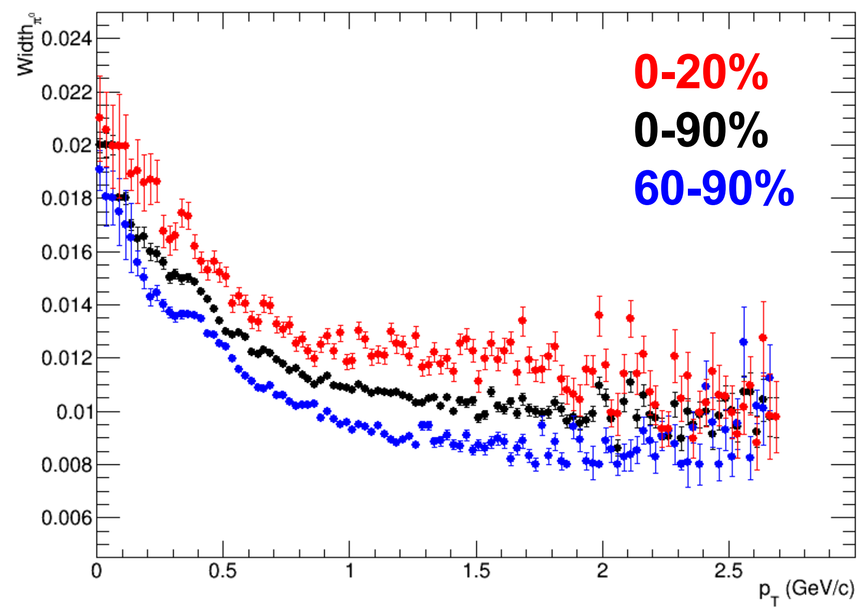


- The peak width decreases with increasing momentum (better energy resolution)
- The S/B improves with increasing momentum

π^0 in AuAu@11: mass and width

- Optimized cuts for better significance:
  - ✓ Events: UrQMD, |z-vertex| < 50 cm
  - ✓ Photons: E > 0 GeV, $T_{reduced}$ < 2 ns,
  - ✓ PID: charged track veto, Chi2/NDF < 4.0
  - ✓ Pairs: |y| < 0.5

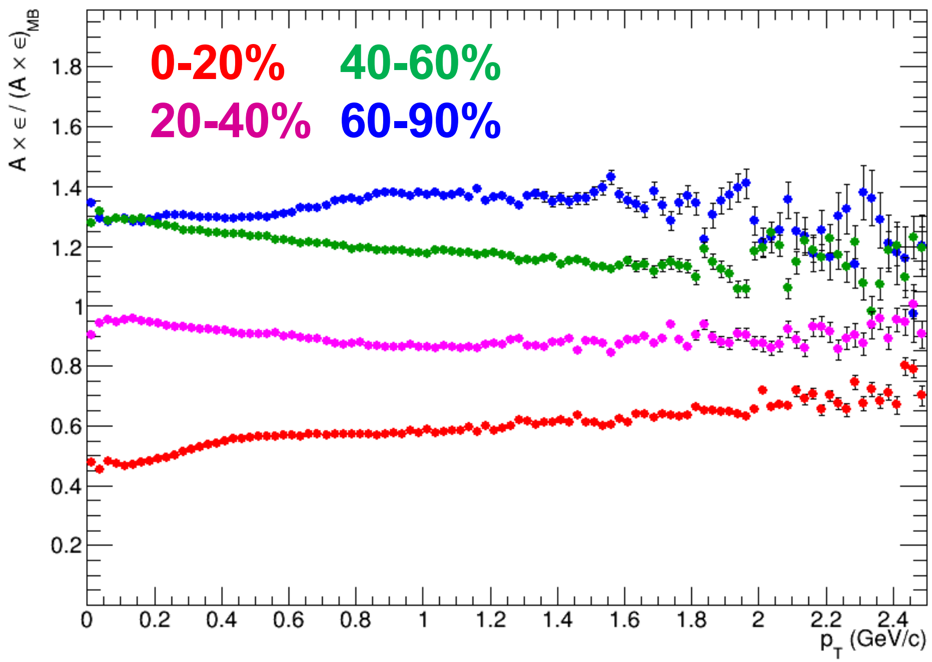




- Reconstructed mass increases with multiplicity and p_T:
  - ✓ Shower merging at high multiplicity
  - ✓ Energy leakage and non-linearity
- Reconstructed width increases with multiplicity and decreases with p_T:
  - ✓ Energy resolution is multiplicity dependent
  - ✓ Energy resolution improves with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

π^0 in AuAu@11: reconstruction efficiecny

- Optimized cuts for better significance:
  - ✓ Events: UrQMD, |z-vertex| < 50 cm
  - ✓ Photons: E > 0 GeV, $T_{reduced}$ < 2 ns,
  - ✓ PID: charged track veto, Chi2/NDF < 4.0
  - ✓ Pairs: |y| < 0.5

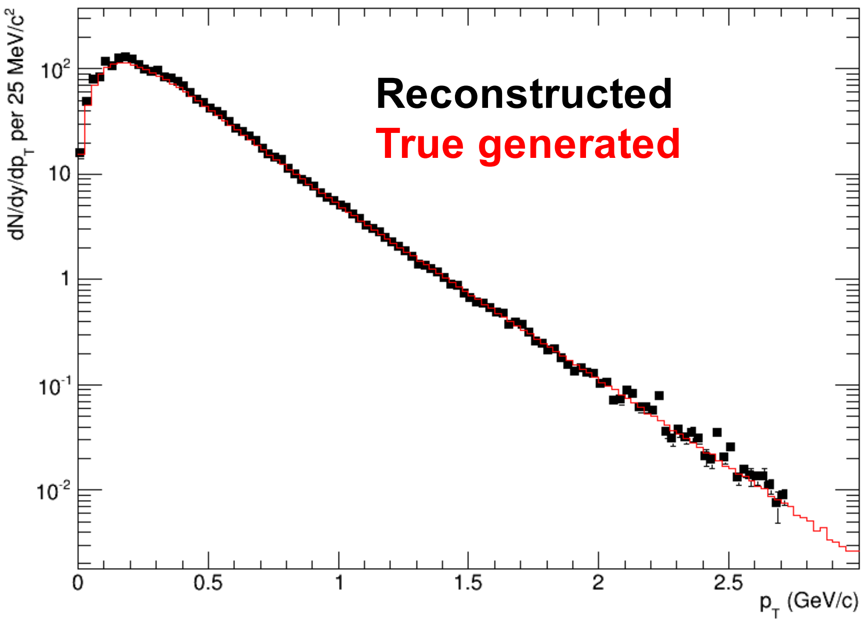


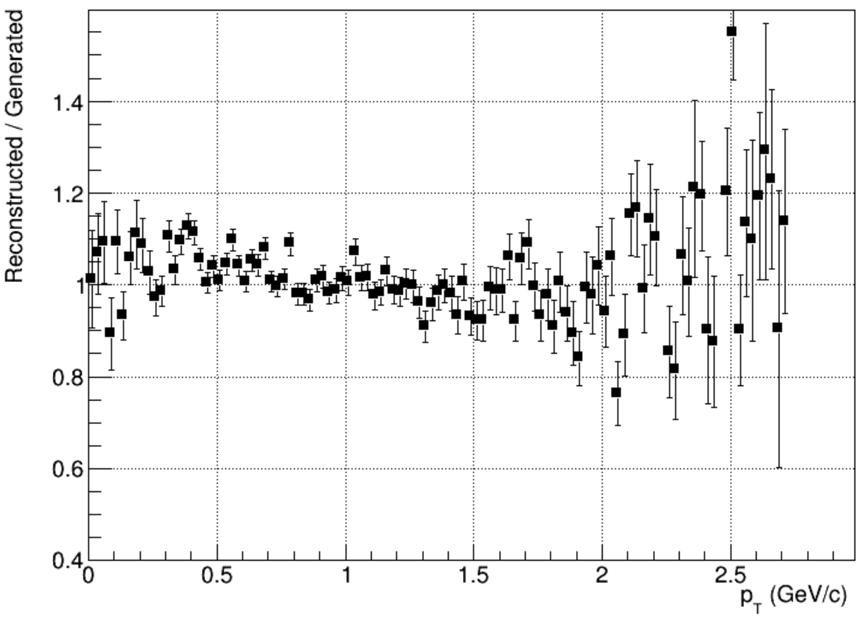
- Reconstruction efficiency shows strong multiplicity dependence:
  - ✓ Multiplicity dependence of false track matching (false veto)
  - ✓ Larger fraction of merged clusters with non-EM shower shapes at high multiplicity
- Statistical uncertainties in central collisions are smaller because of larger particle yields per event

π^0 in AuAu@11: MC closure test

- Optimized cuts for better significance:
- 4M events AuAu@11

✓ Events: UrQMD, |z-vertex| < 50 cm
✓ Photons: E > 0 GeV, $T_{reduced}$ < 2 ns,
✓ PID: charged track veto, Chi2/NDF < 4.0
✓ Pairs: |y| < 0.5

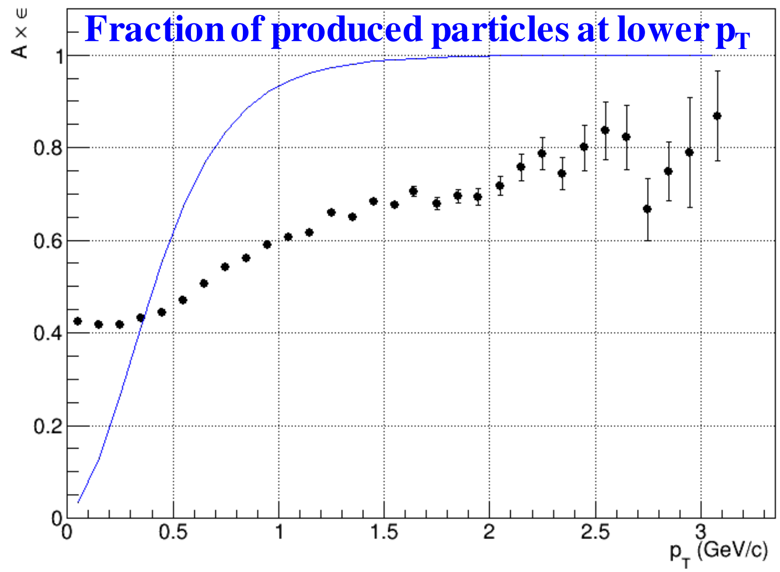




- Very encouraging results !!!
- The fully corrected reconstructed spectrum matches the generated one within uncertainties
- Measurements are possible from ~ 25 MeV/c momentum, too good to be true in real life ???
- The main measurement uncertainties at low momentum are from non-Gaussian peak shapes → ignore lower efficiencies and tune cuts to gain better control of the peak shapes

η reconstruction in AuAu@11

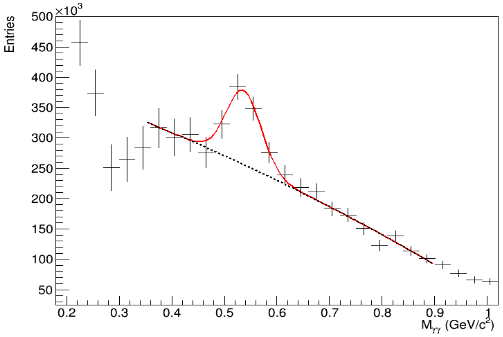
- Optimized cuts for better significance:
  - ✓ Events: UrQMD, |z-vertex| < 50 cm
  - ✓ Photons: E > 0.1 GeV, $T_{reduced}$ < 2 ns,
  - ✓ PID: charged track veto
  - ✓ Pairs: |y| < 0.5

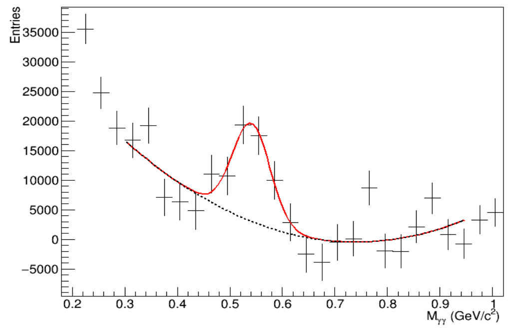


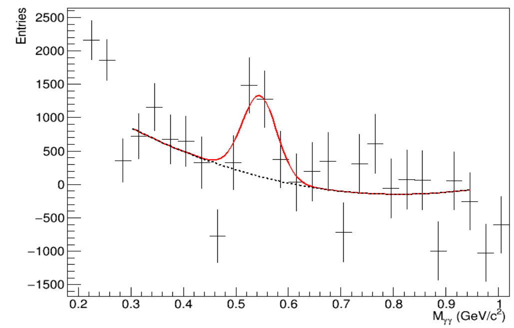
- Efficiency for η is > 40% at p_T > 100 MeV, higher than that for π^0
- Maximum raw yield of η is expected at ~ 300 MeV/c

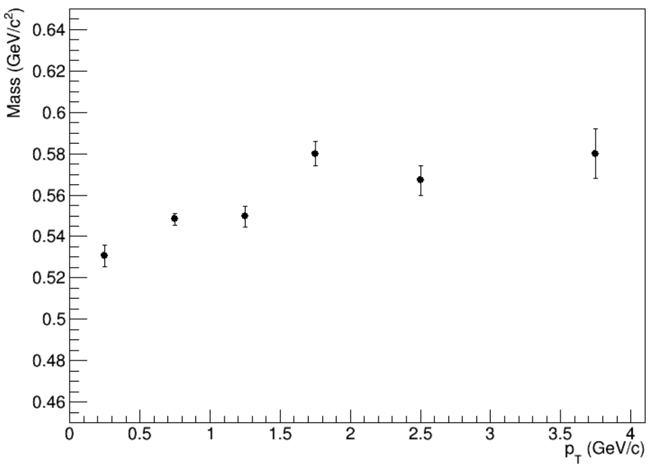
η peak examples in AuAu@11, mass & width

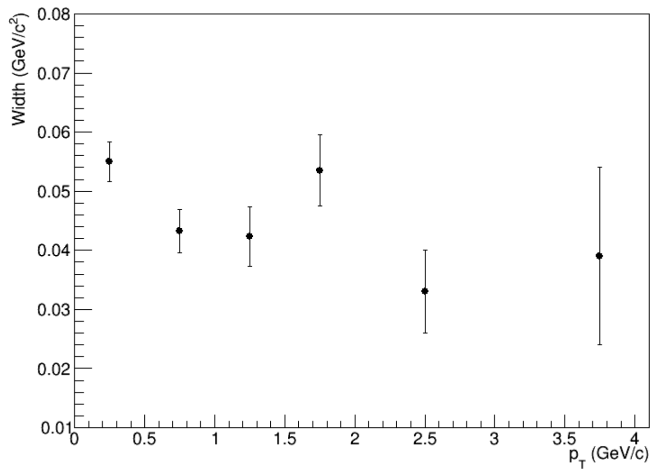
- 15 M events AuAu@11











- η is produced at much lower rate compared to π^0; $\eta \to \gamma\gamma$ is a much wider peak
  → need larger statistics for observation and measurements
- Signal is observed with 15M sampled AuAu@11 events
- MC closure test is in progress
- Multiplicity dependent study needs higher statistics (embedded simulations)

Dielectron continuum and LVMs

Search for in-medium modifications are statistics hungry

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.

- Any feasibility studies for dielectrons can be subdivided in wo major sub-tasks:

  ✓ Evaluation of background and continuum contributions in AuAu@11
  ✓ Development of eID and pair selection cuts to enhance signal significance

Dielectron sources and background

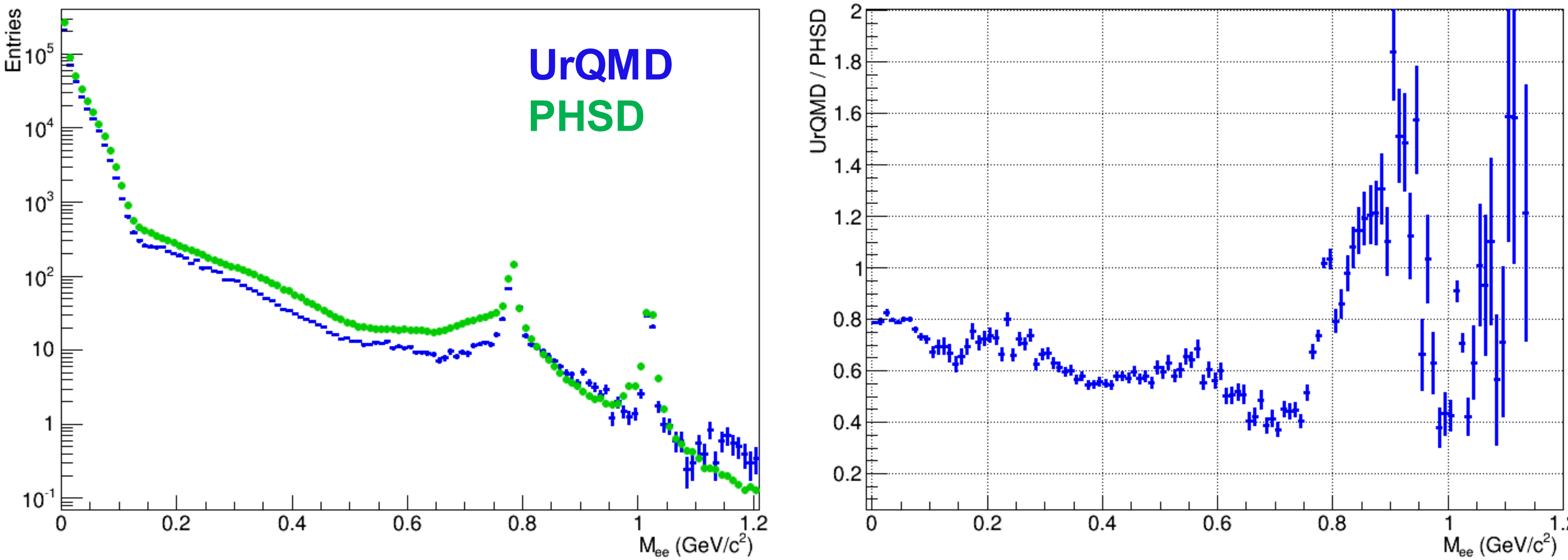
- The main sources of background are charged π/K/p misidentified as electrons
  - ✓ most of general-purpose event generators correctly reproduce π/K/p yields within ±20-30% → acceptable for estimations and feasibility studies
- The main sources of dielectron pairs are hadronic decays of: π^0, η, ρ, ω, ϕ, η'

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
- Only a few event generators can simulate the dielectron continuum or resonance yields in e^+e^- channels → evaluation of the dielectron continuum/signal is one of the live and important tasks !!!

Simulated dielectron continuum: UrQMD vs. PHSD

- AuAu@11, UrQMD estimation is from the centralized MC production, 15M events (slide 8)

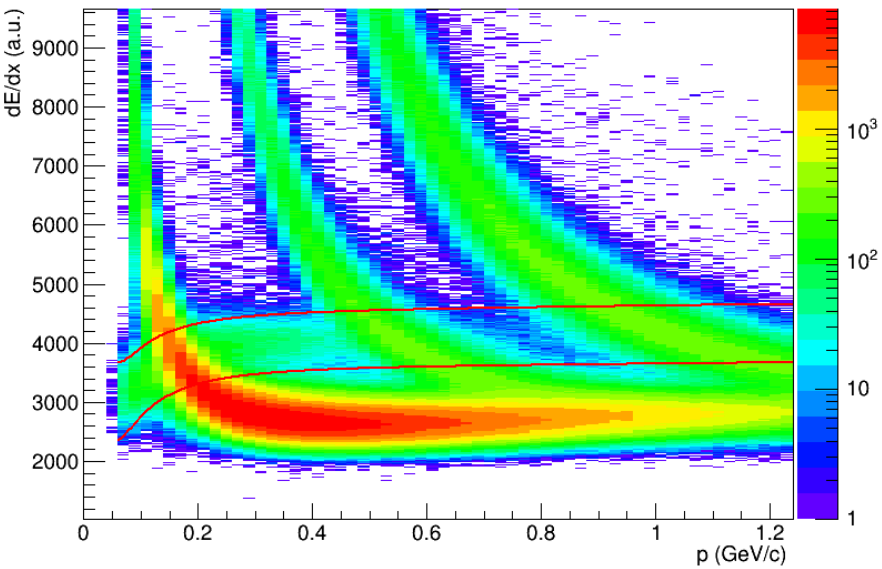


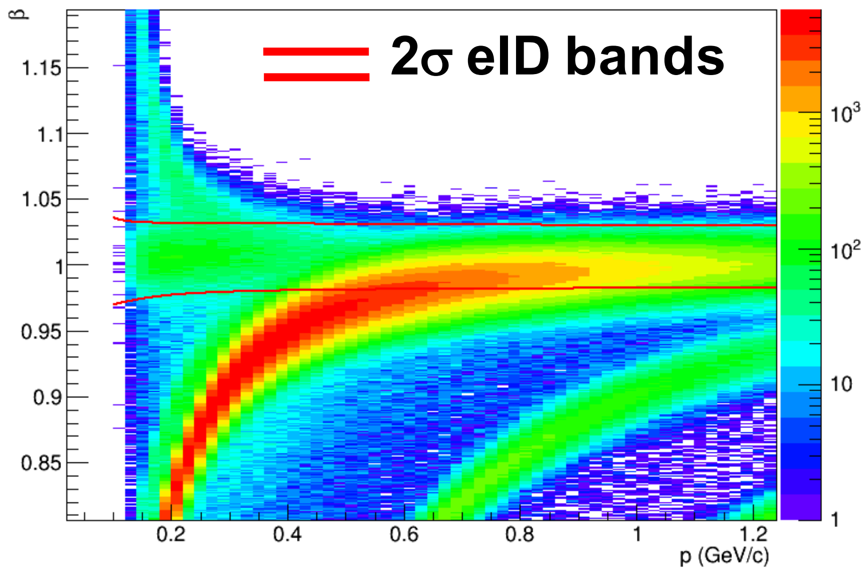
- UrQMD and PHSD give consistent predictions for the background
- Dielectron continuum predictions differ by up to 50%

→ need more input on the input (PLUTO, …, ???) … your ideas are welcome

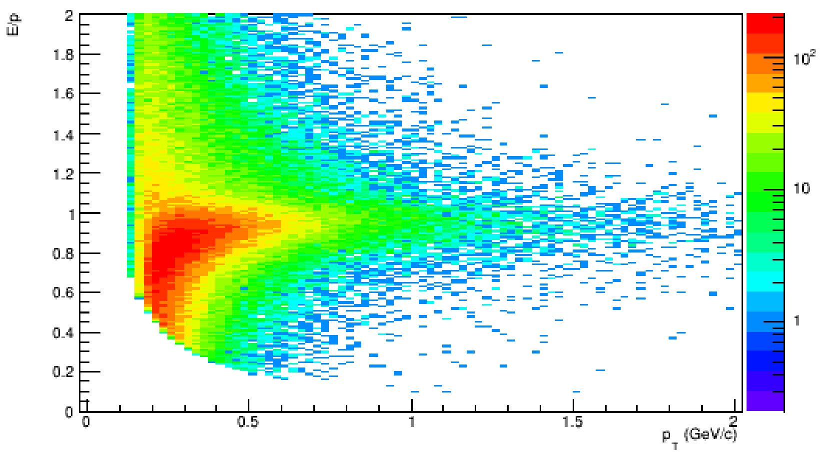
eID capabilities

- TPC: dE/dx ; TOF: $\beta = v/c$





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



→ TOF:

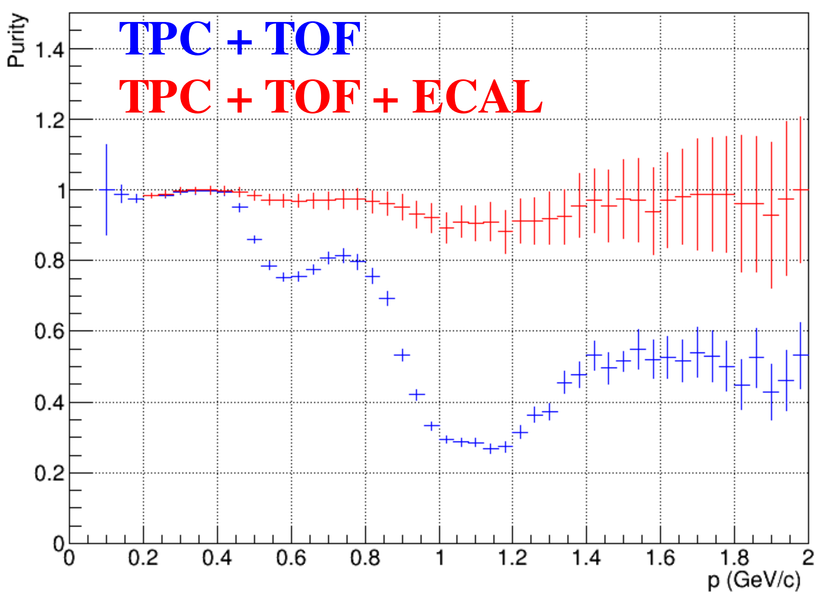
- ➢ turns on only at p_T > 150 MeV/c
- ➢ significant probability of track mismatching at high multiplicity → wrong ID → need extra study by experts

→ ECAL:

- ➢ turns on only at p_T > 200 MeV/c
- ➢ loose TOF & E/P cuts provide high eID efficiency in a wide p_T range

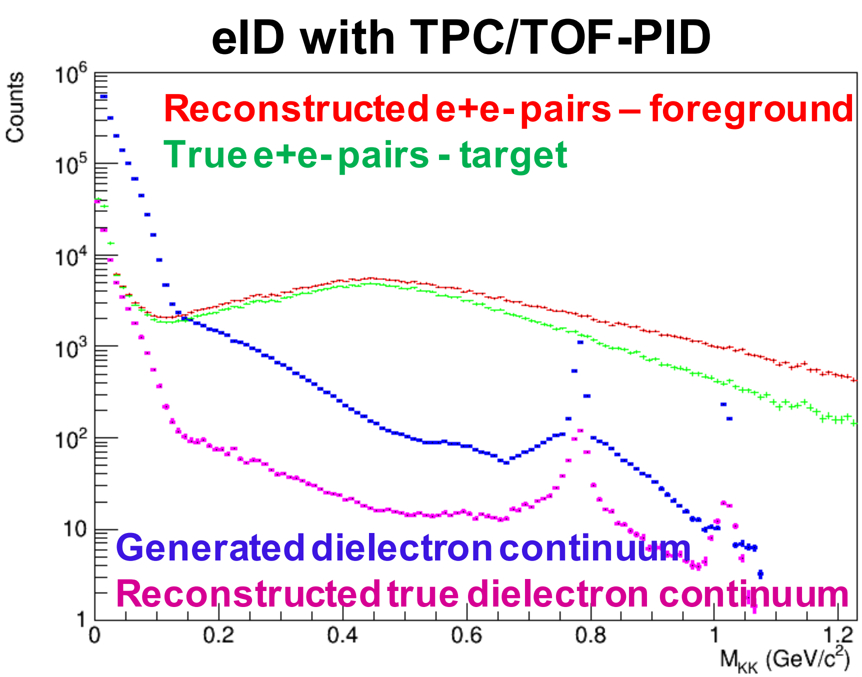
Electron purity and efficiecny

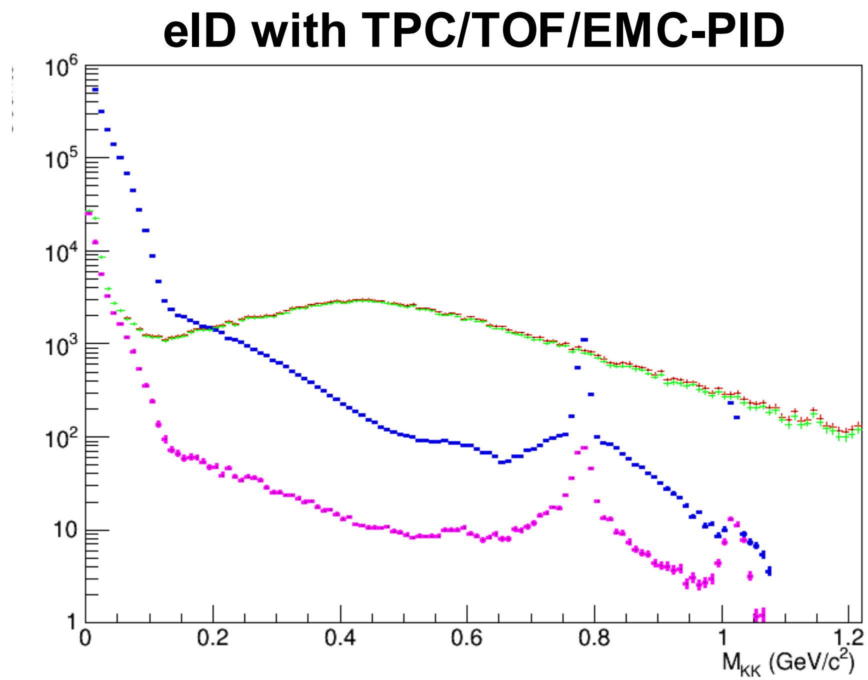
- Electron purity > 95 % can only be achieved by using rather tight eID cuts:
  - ✓ 2σ eID in TPC (by dE/dx)
  - ✓ 1σ πID veto in TPC (by dE/dx)
  - ✓ 2σ eID in TOF (by β)
  - ✓ [-3σ,2σ] time-of-flight + [-3σ,2σ] E/P in ECAL
- The tight eID cuts correspond to ~ 55% electron reconstruction efficiency at p_T > 200 MeV/c, the efficiency rapidly drops to zero at p_T ~ 100 MeV/c



- The TPC & TOF alone can not provide clean electron sample at p_T > 400 MeV/c
- The ECAL is a vital detector for eID at high p_T

Dielectron M_{inv} spectra

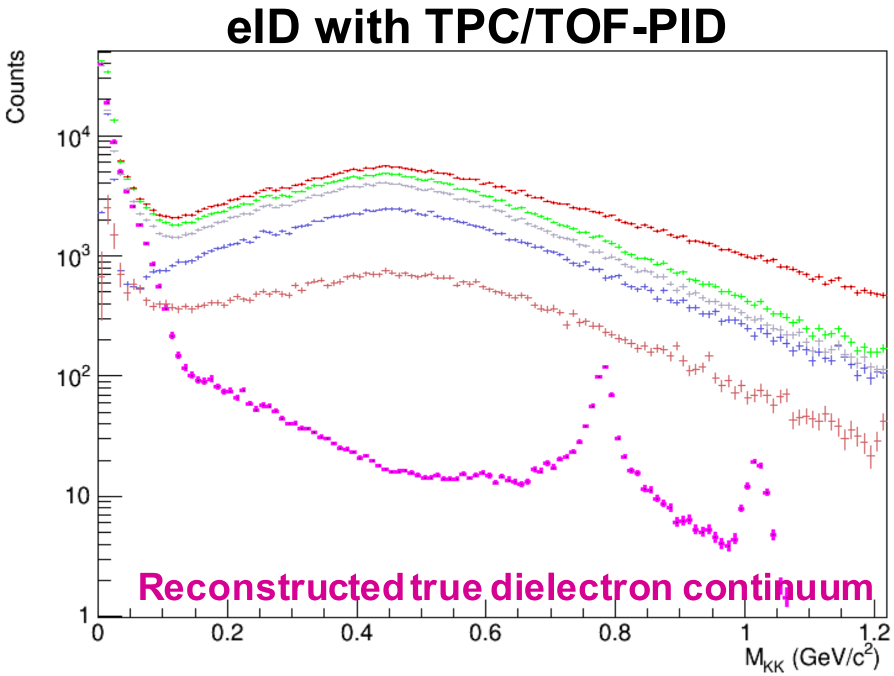


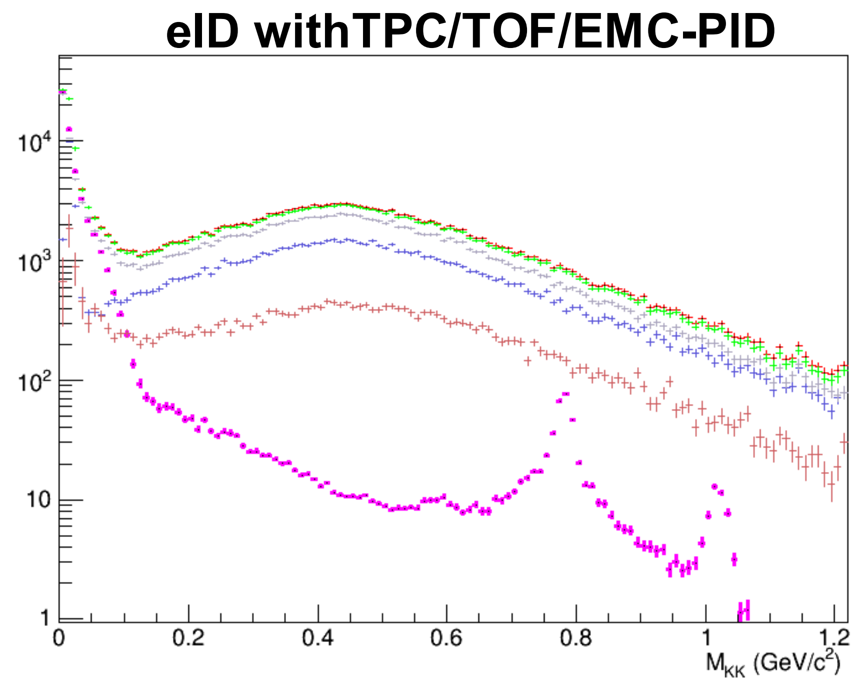


- Hadron contamination at low mass is largely suppressed with tight eID cuts
- Effective hadron suppression at high mass/p_T is possible only with the EMC-ePID
- With the achieved electron purity (> 95%) most of the measured signals are true e^+e^- pairs from different sources

Rec. eff. = Reconstructed true dielectron continuum / Generated dielectron continuum

Dielectron M_{inv} spectra, sources of pairs





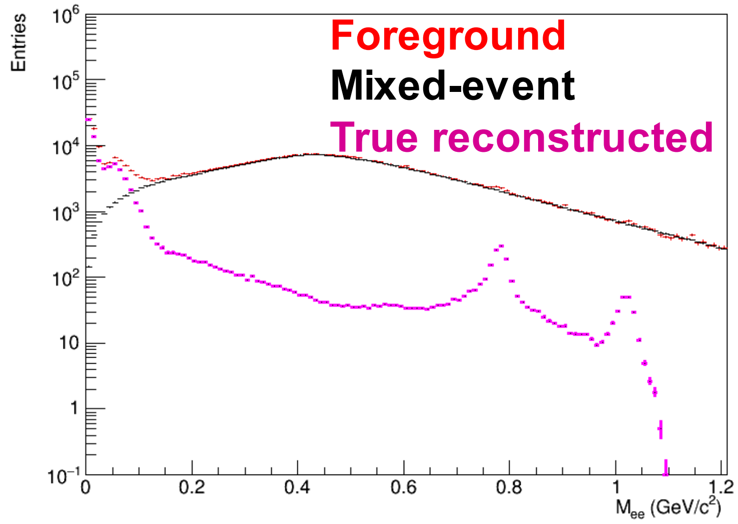
Reconstructed e+e- pairs – foreground
True e+e- pairs – target
Pairs with at least one π^0 Dalitz electron
Pairs with at least one conversion electron
Pairs with at least one η Dalitz electron

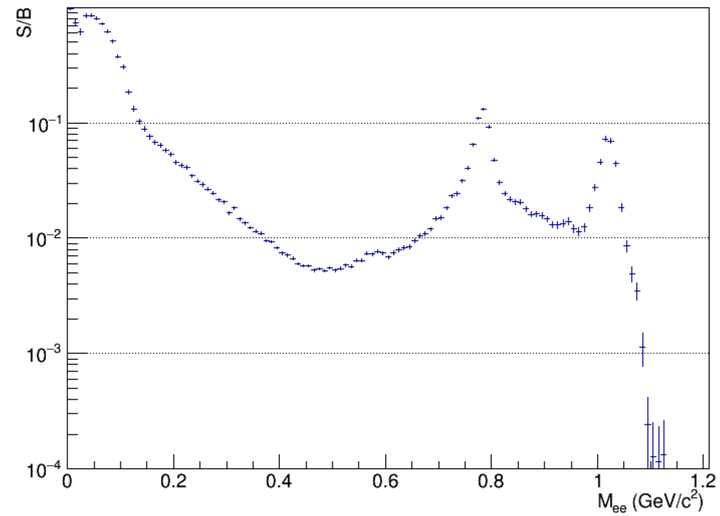
- The dominant source of dielectron pairs – Dalitz decays of π^0 → irreducible
- The second most significant source of pairs – conversion electrons → the contribution can be reduced by optimizing the analysis cuts (work in progress)
- The third main source of pairs – Dalitz decays of η → irreducible

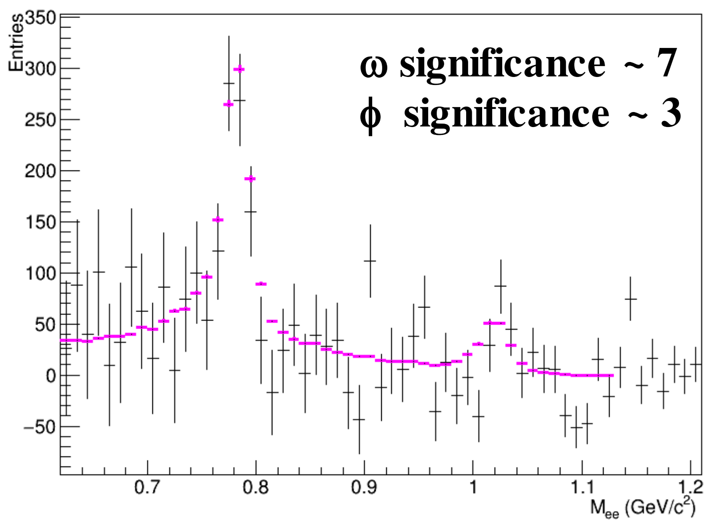
→ The dominant source of correlated combinatorial background is irreducible

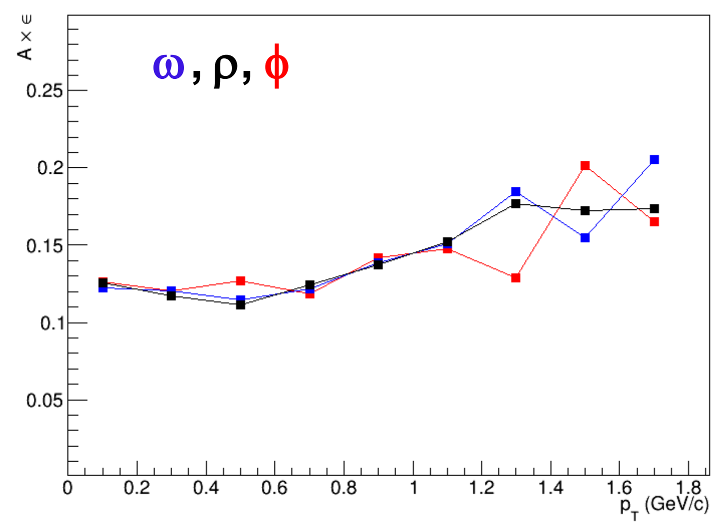
Reconstruction of dielectron continuum and LVMs

- ~ 15M events AuAu@11 events, full statistics of the large MC production









- The dielectron analysis is statistics hungry
- First results for LVM would need ~ 100M sampled AuAu@11 events

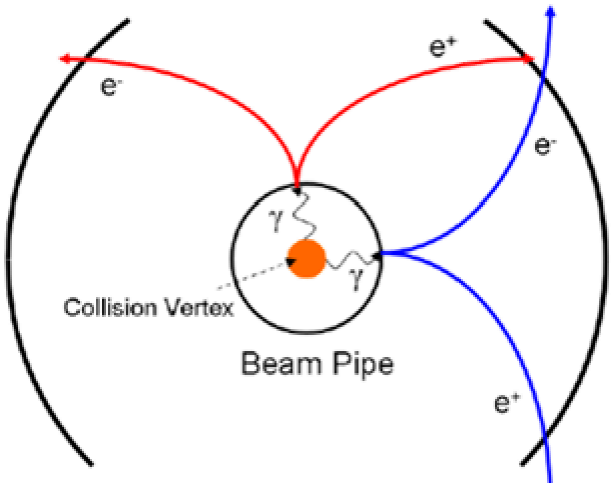
Photons and neutral meson:

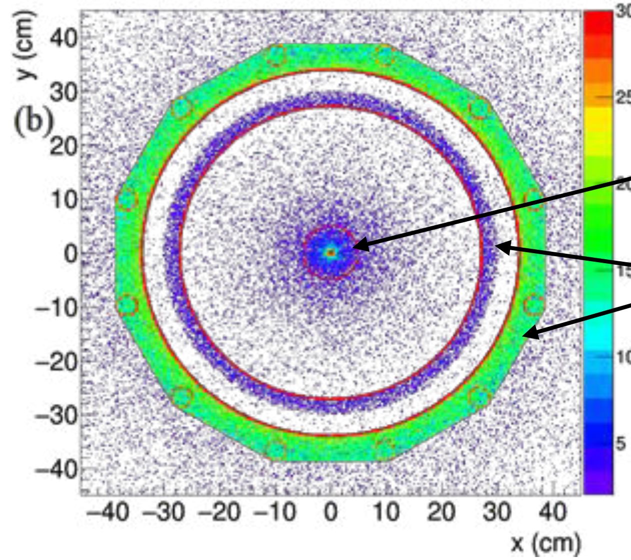
reconstruction via external conversion, $\gamma \rightarrow e^{+}e^{-}$

Neutral mesons (π_0, η) and inclusive photons are the day-one measurements for the MPD

Reconstruction of neutral mesons

- Photons can be measured in the tracking system via e^+e^- conversion pairs (PCM):
  - ✓ Advantage: high energy resolution at low momenta
  - ✓ Disadvantage: low efficiency due to low conversion probability



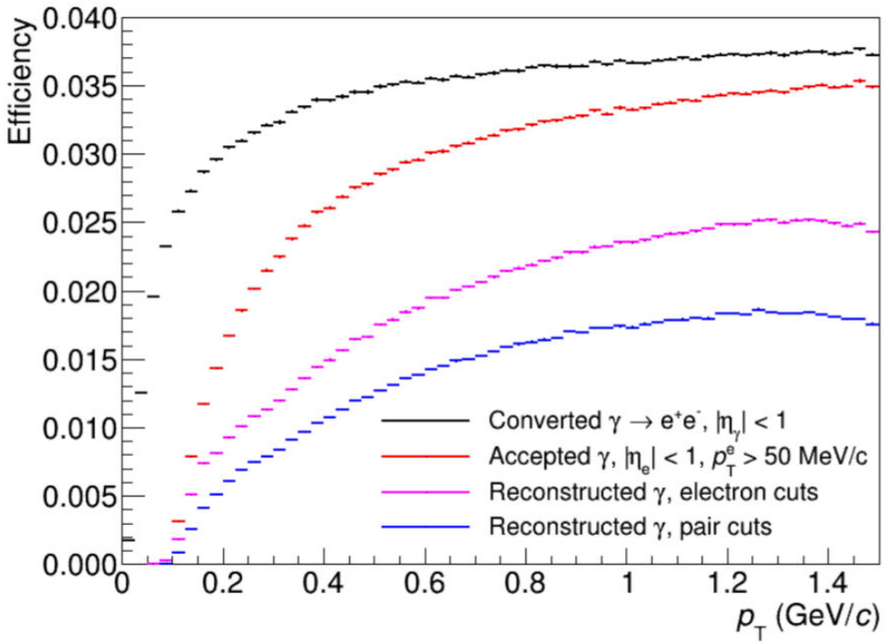


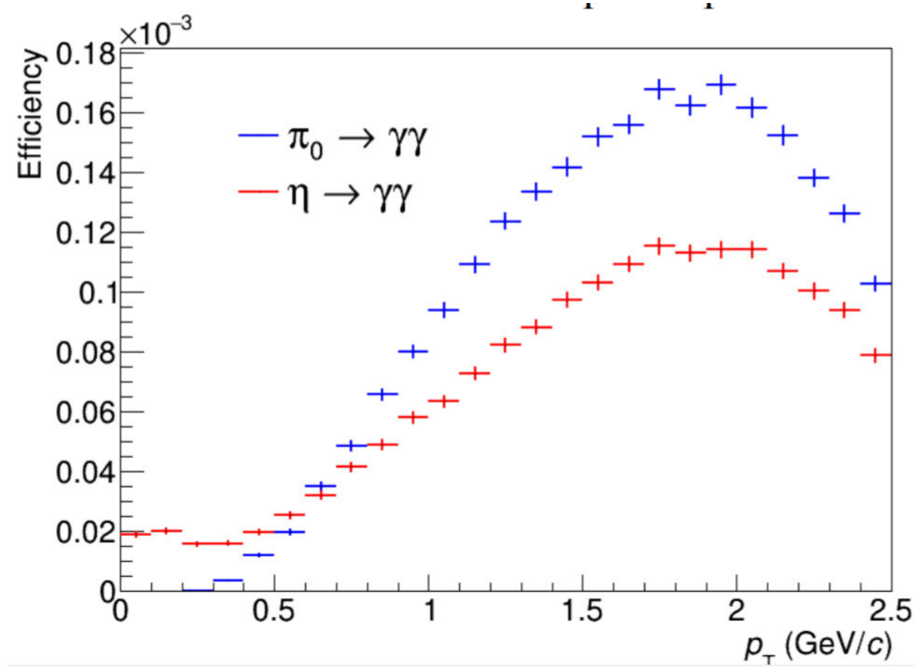
beam pipe ($0.3\%\ X_0$)

inner TPC vessels ($2.4\%\ X_0$)

- The PCM is going to the main method for the measurement of low-E photons, including direct photons
- See talk by D. Blau for evaluation of direct photon yields in A-A collisions at NICA
- The PCM can also be used to measure the neutral mesons at low p_T → a powerful cross check for the measurements in the ECAL

PCM efficiency

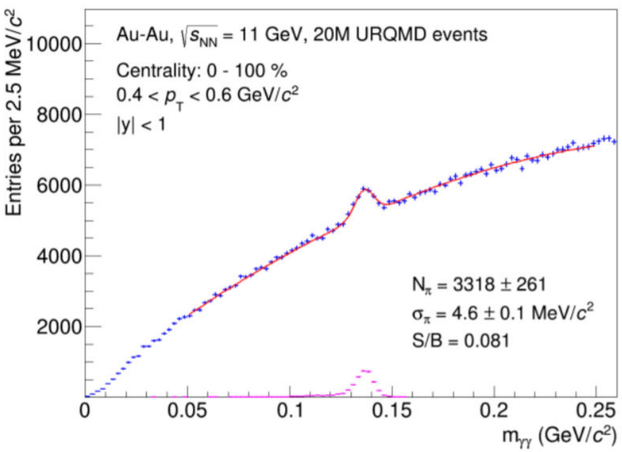


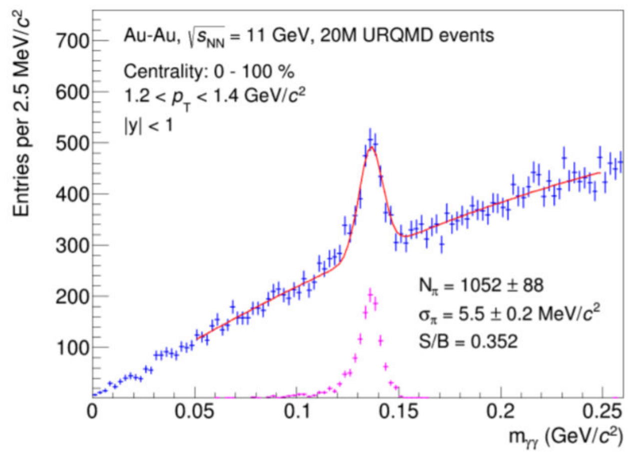


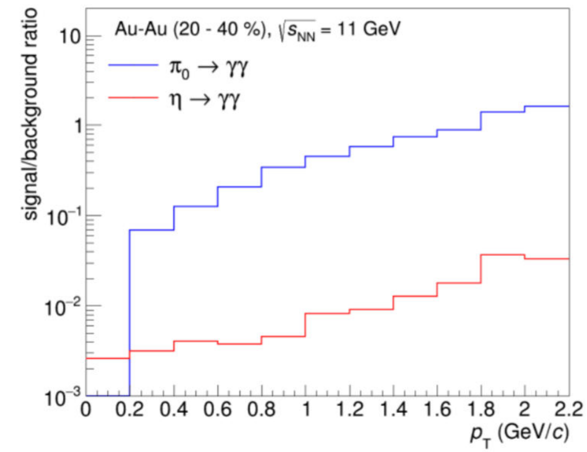
- Conversion e^+e^- pairs are identified by:
  - ✓ charged track eIDed in the TPC and TOF
  - ✓ cut on the pointing angle to the primary vertex
  - ✓ cut on the opening angle plane with respect to the magnetic field
- Only ~ 4.5% of photons convert and only ~ 1.5% of photons is reconstructed with the PCM
- Efficiencies for neutral mesons are on sub-percent level

PCM resolution

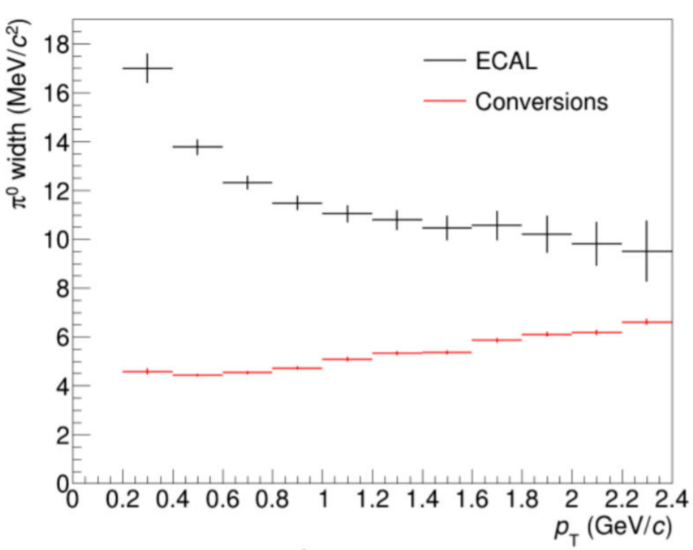
- S/B ratio is high enough, mixed-event subtraction is not required

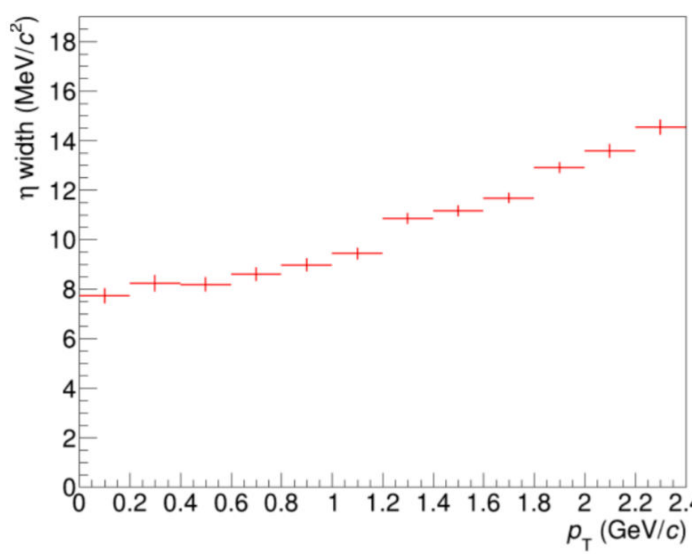






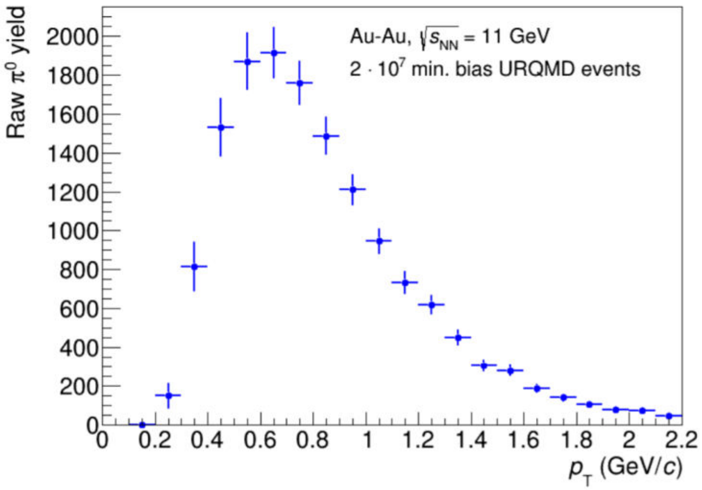
- PCM resolution for photons and neutral mesons is much better compared to the ECAL !!!



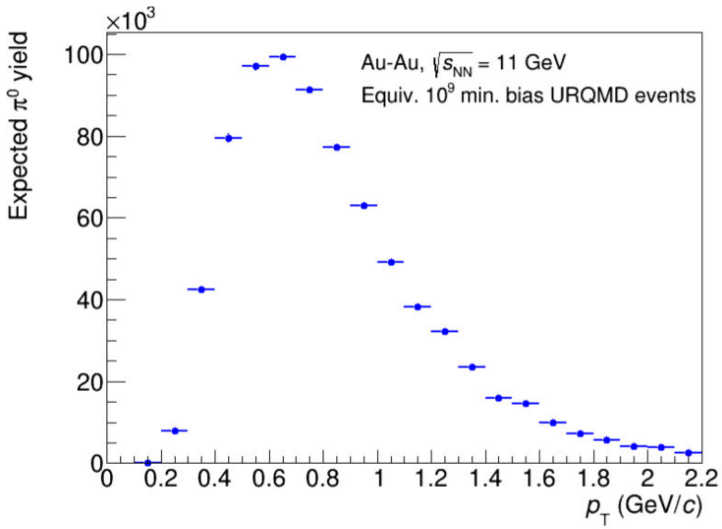


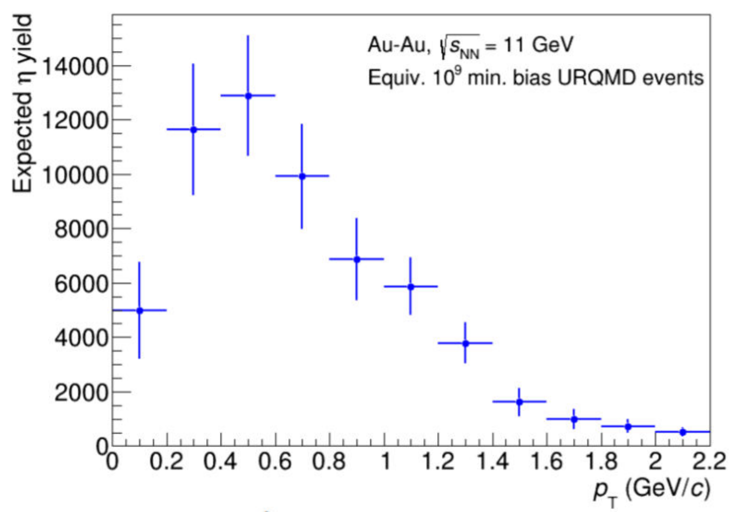
PCM yields for neutral mesons

- π_0 spectrum can be measured with 10 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



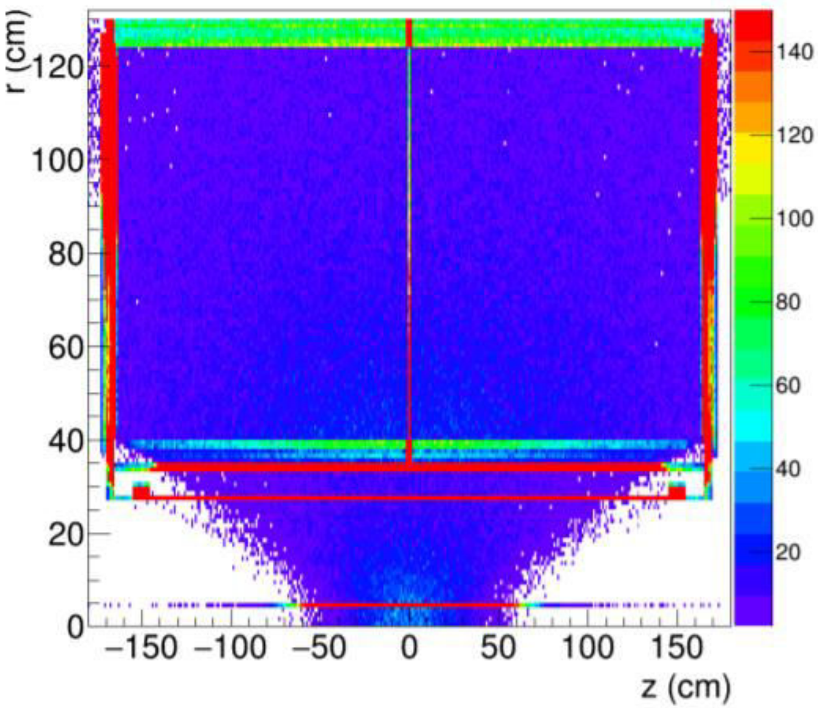


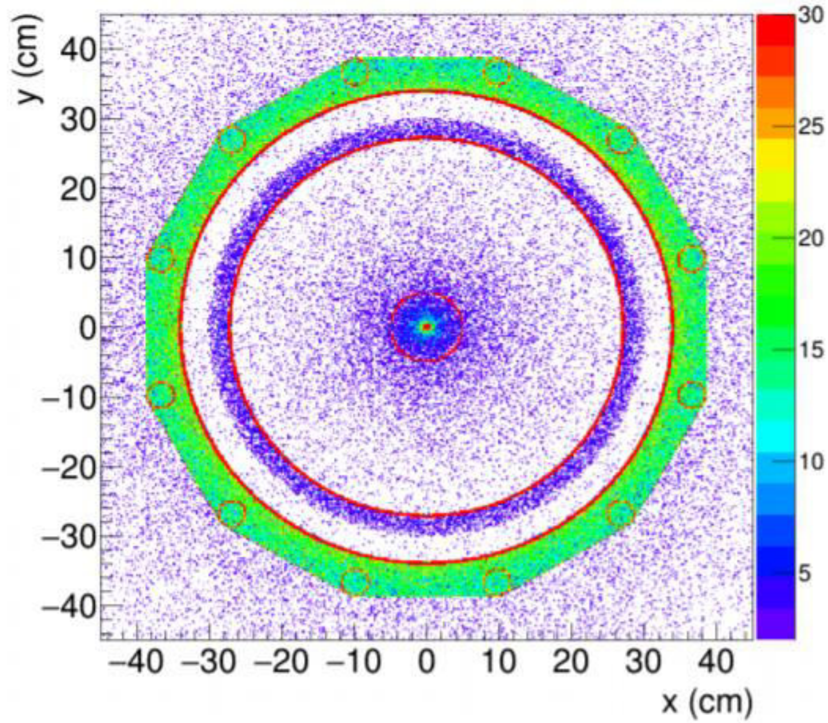
Summary

- PWG4 is active and works to enhance the MPD physical program
- Some of the results are expected to be available in the first year of detector operation with A-A beams, others would need larger statistics
- Many studies are in progress, need extra man power and deeper involvement of the collaboration members
- Many vacant tasks
- Contact conveners if you wish to join:
  - ✓ Victor Riabov – riabovvg@gmail.com
  - ✓ Chi Yang - chiyang@rcf.rhic.bnl.gov

BACKUP

Photon conversion centers





Main conversion structures in Stage 1:

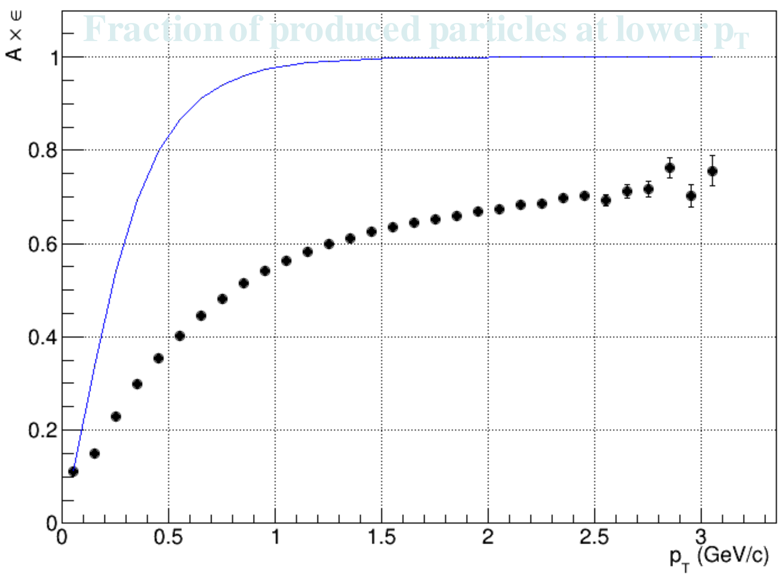
- Beam pipe: 0.3% X_0
- Inner TPC barrel structures: 2.4% X_0

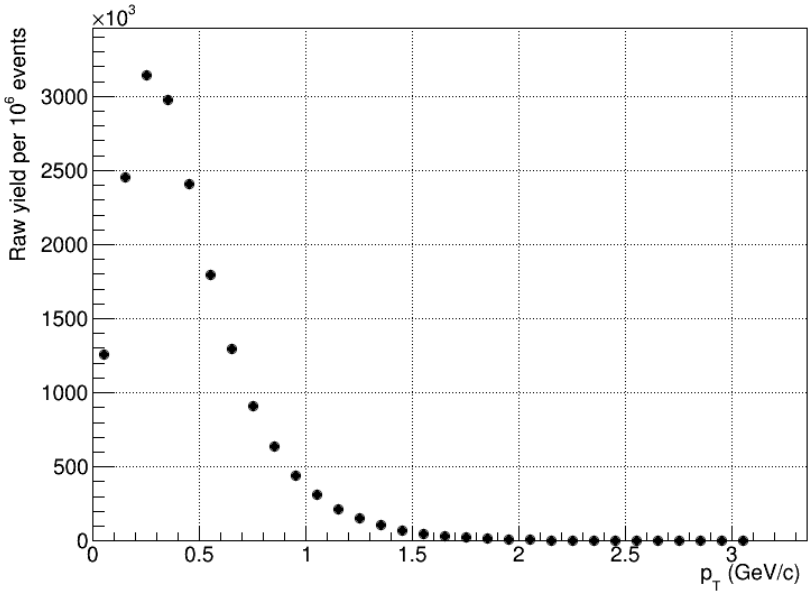
Future:

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

π^0 reconstruction, minimum cuts

- Minimum cuts for observation of signals:
  - ✓ Events: UrQMD, |z-vertex| < 50 cm
  - ✓ Photons: E > 0 GeV, $T_{reduced}$ < 2 ns
  - ✓ Pairs: |y| < 0.5





- Efficiency for π^0 is > 10% at p_T > 100 MeV
- Signal is measurable starting from ~ 100 MeV/c → ~ 90% of the total yield
- Maximum raw yield of π^0 is expected at ~ 300 MeV/c