Perspectives of thermal photon measurements in heavy ion collisions at NICA

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QFTHEP, Sochi
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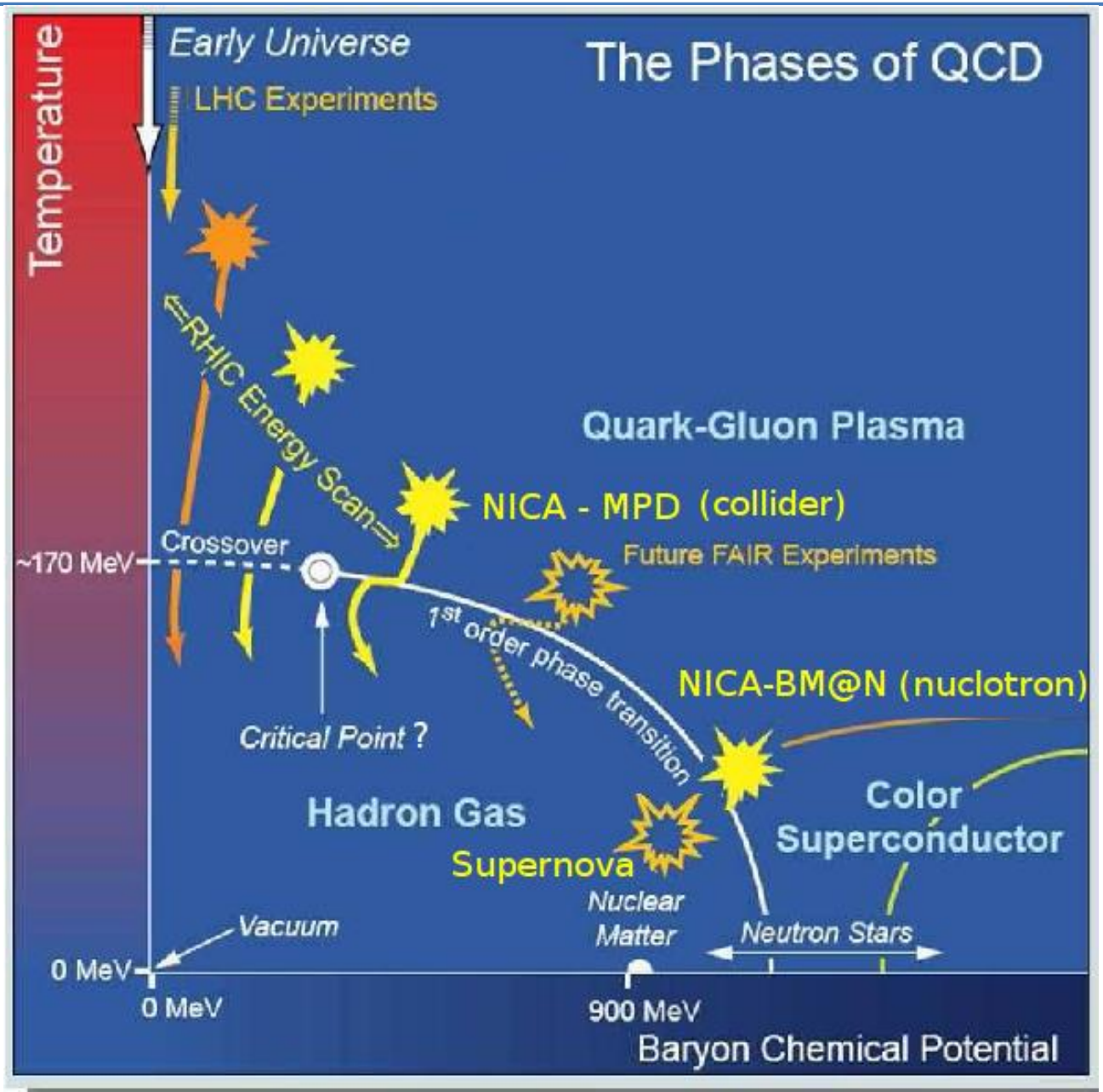
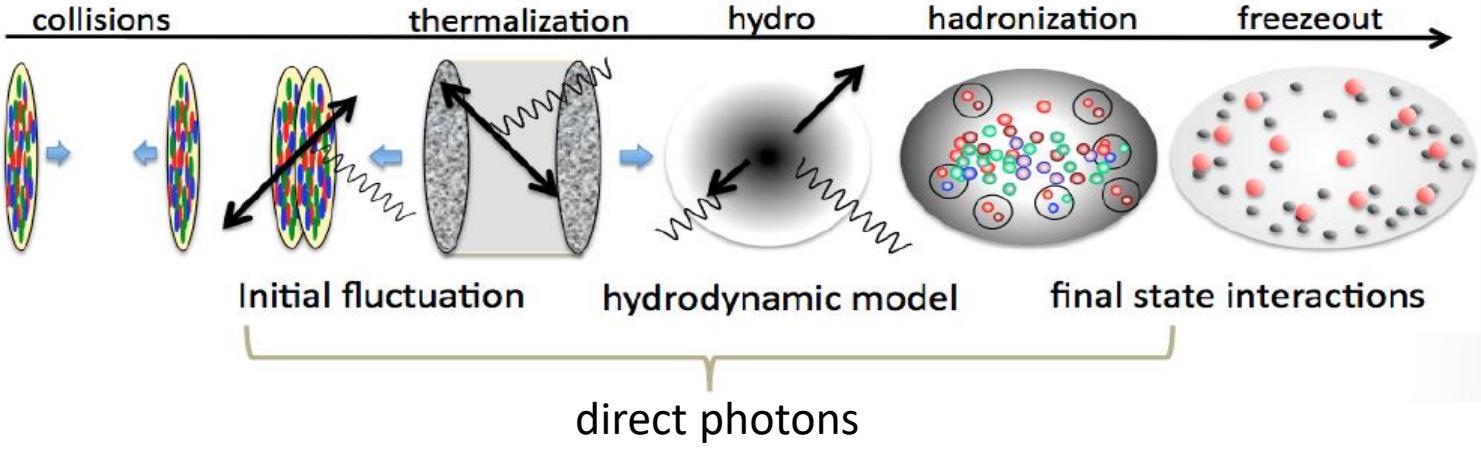
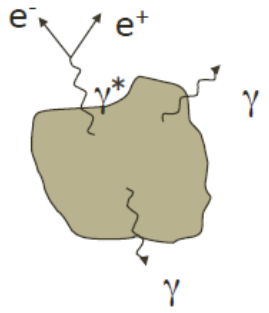
Phase diagram of nuclear matter



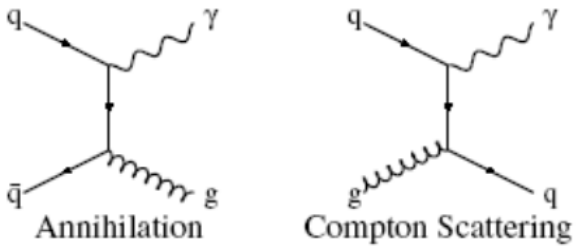
Thermal radiation in heavy ion collisions



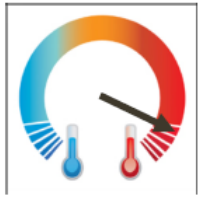


- Black body radiation
  - Real or virtual photons
  - Inverse slope proportional to T_{eff}
  - Photons leave the medium without interaction

Thermal photons from QGP

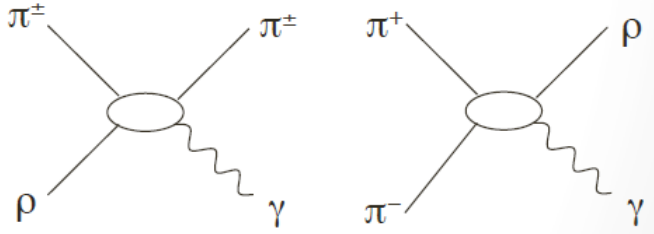


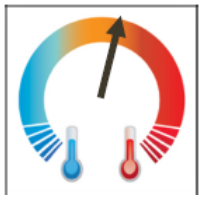
Naïve:



Hot medium
Large yield

Thermal photons from hadron gas

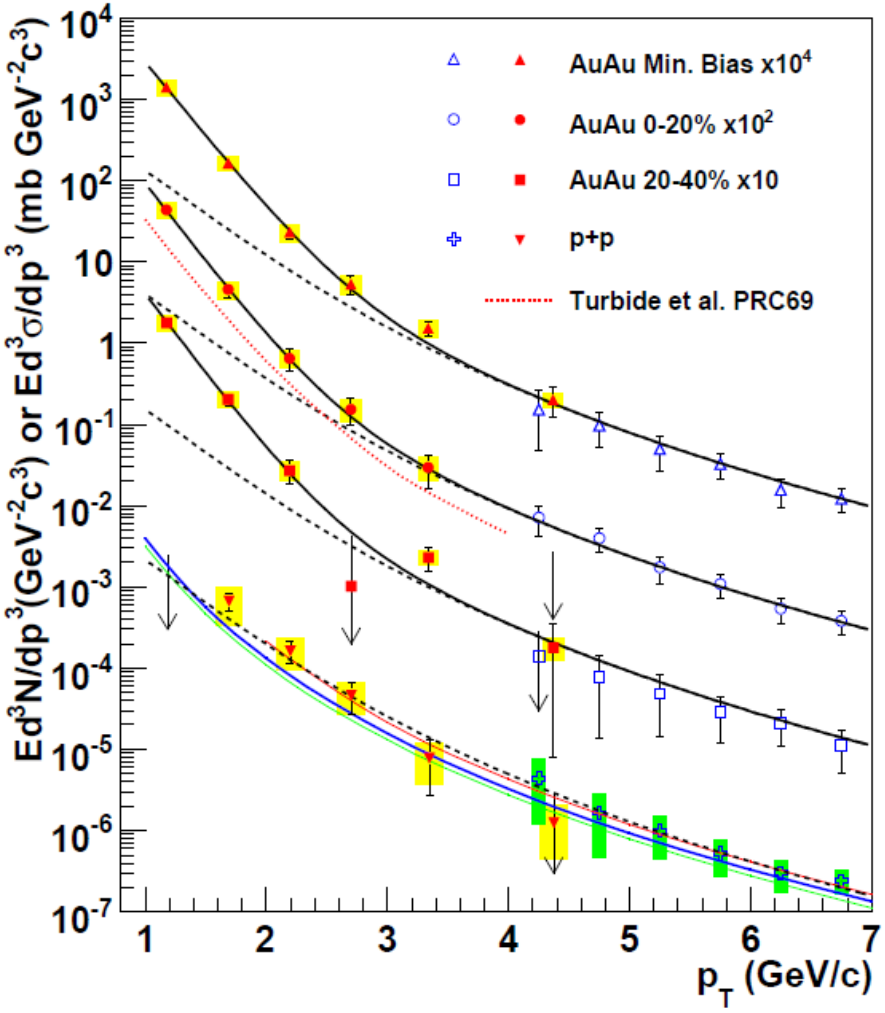




Warm medium
Moderate yield

Photon spectra at RHIC and LHC

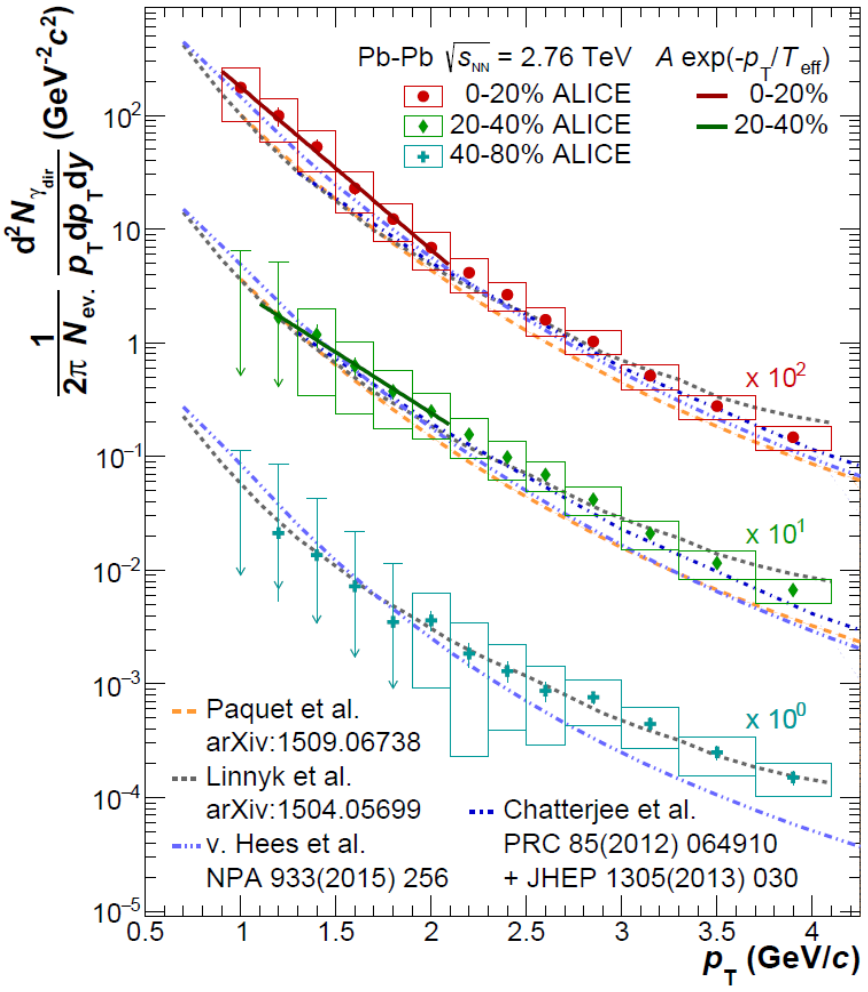
PHENIX (AuAu @ 200 GeV)



T_{eff} = 239 ± 25 (stat) ± 7 (syst) MeV

PHENIX: Phys. Rev. Lett. 104 (2010) 132301

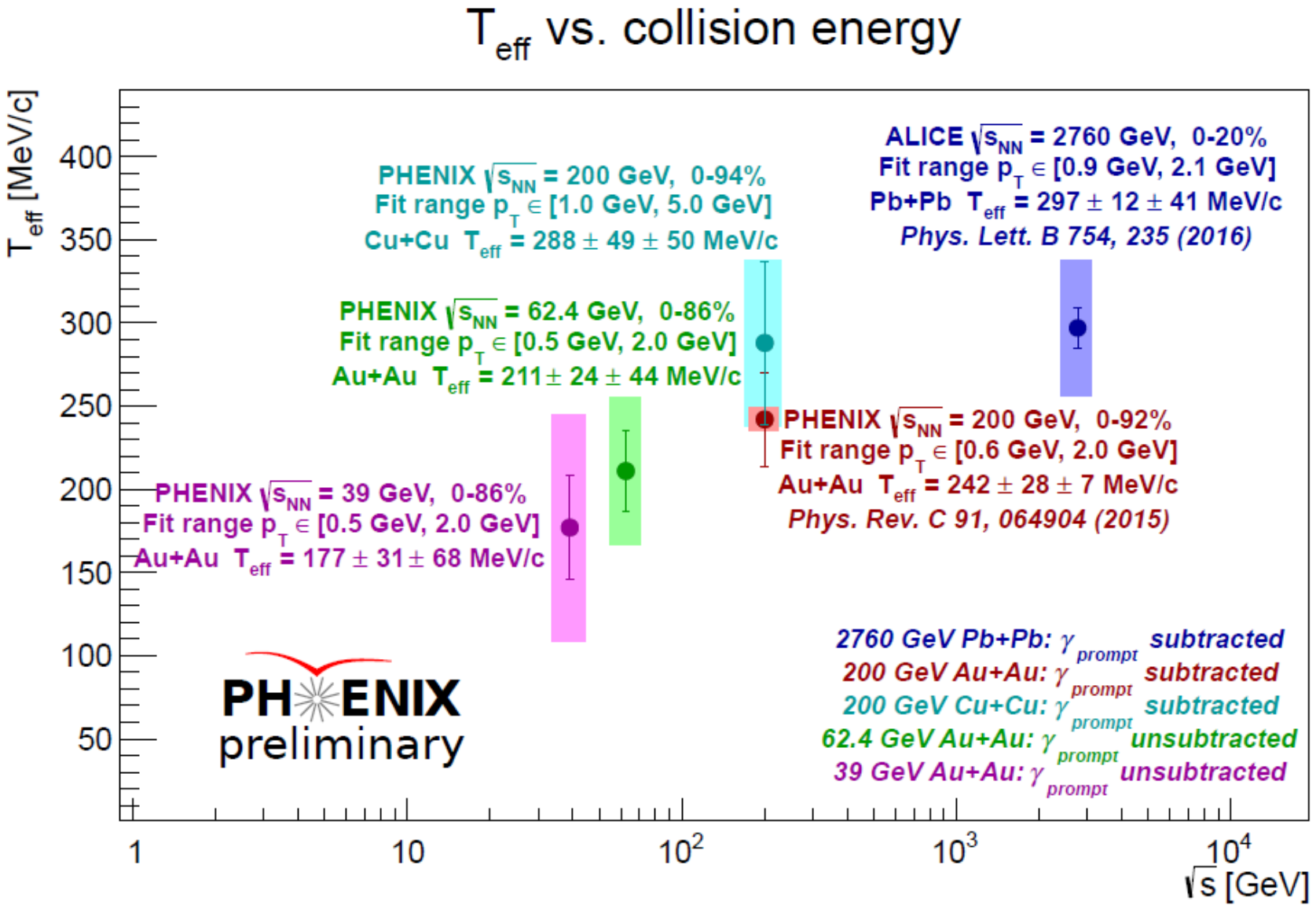
ALICE (PbPb @ 2760 GeV)



T_{eff} = 297 ± 12 (stat) ± 41 (syst) MeV

ALICE: Phys. Lett. B754 (2016) 235

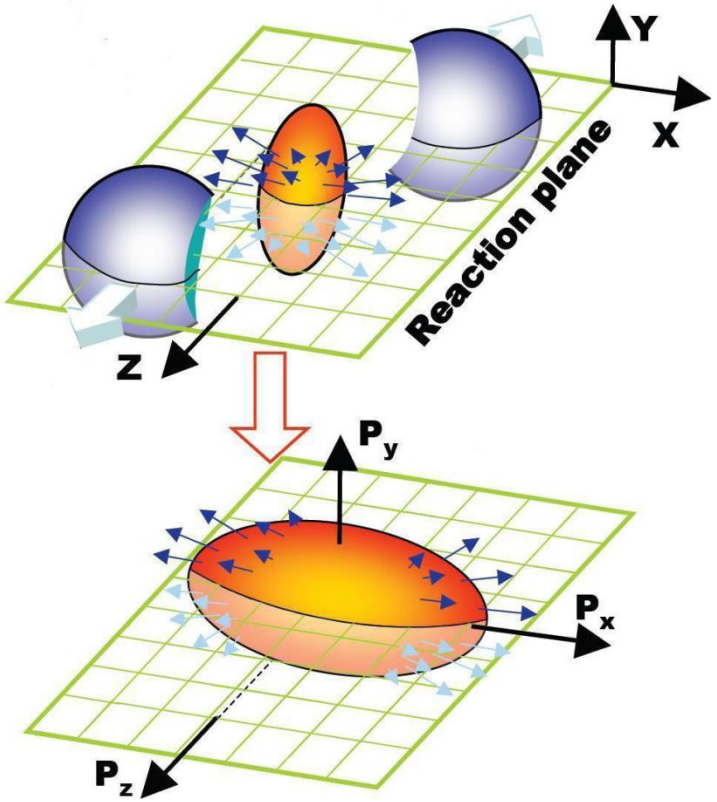
Effective temperature vs energy



J. Phys.: Conf. Ser. 1070 (2018) 012012

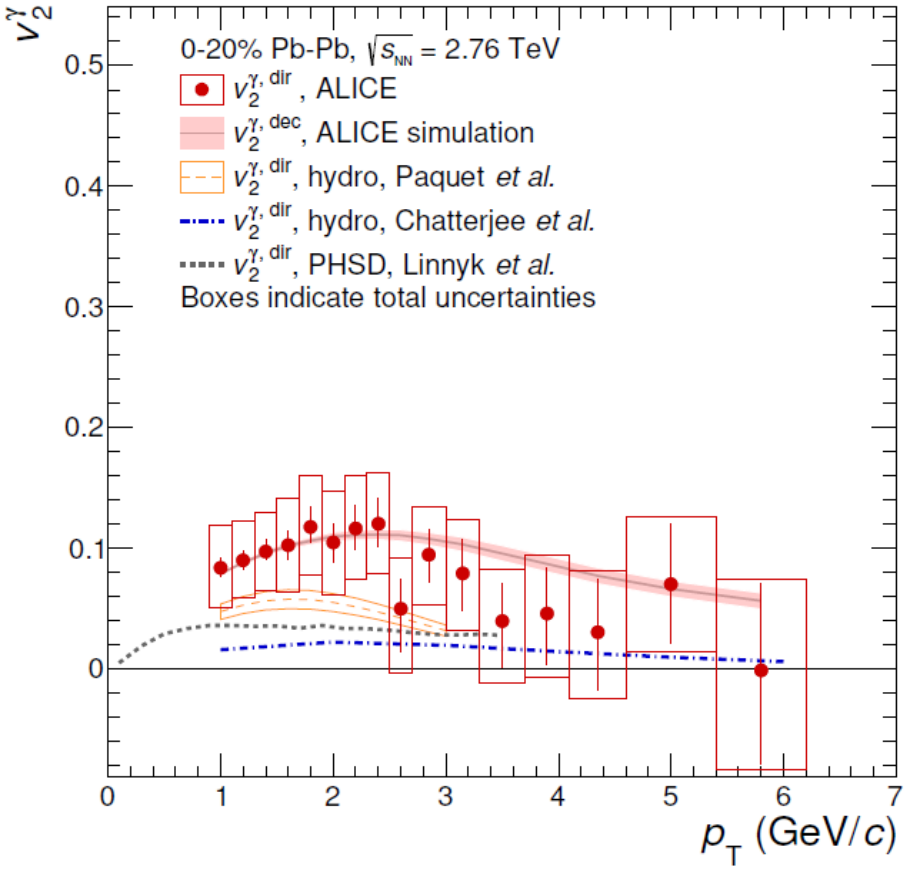
Flow of direct photons

Spatial asymmetry of the initial state translates into the momentum asymmetry



$$\frac{dN}{d\varphi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)]$$

Elliptic flow of direct photons

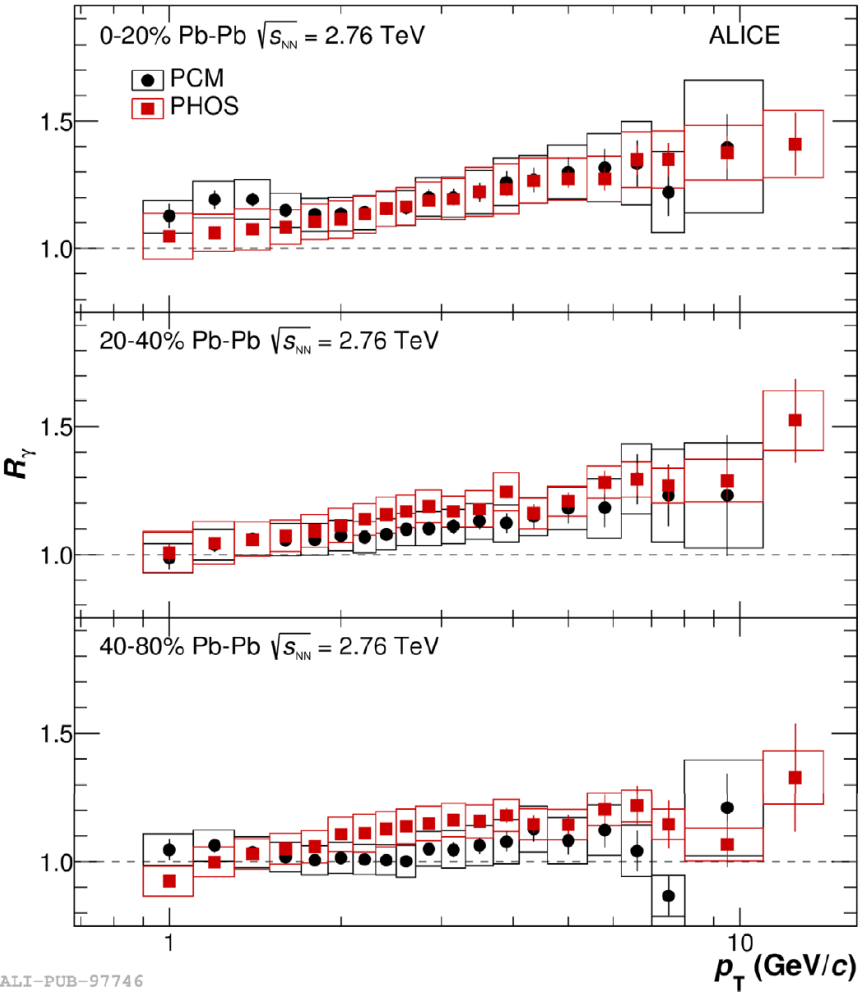


ALICE: Phys. Lett. B 789 (2019) 308

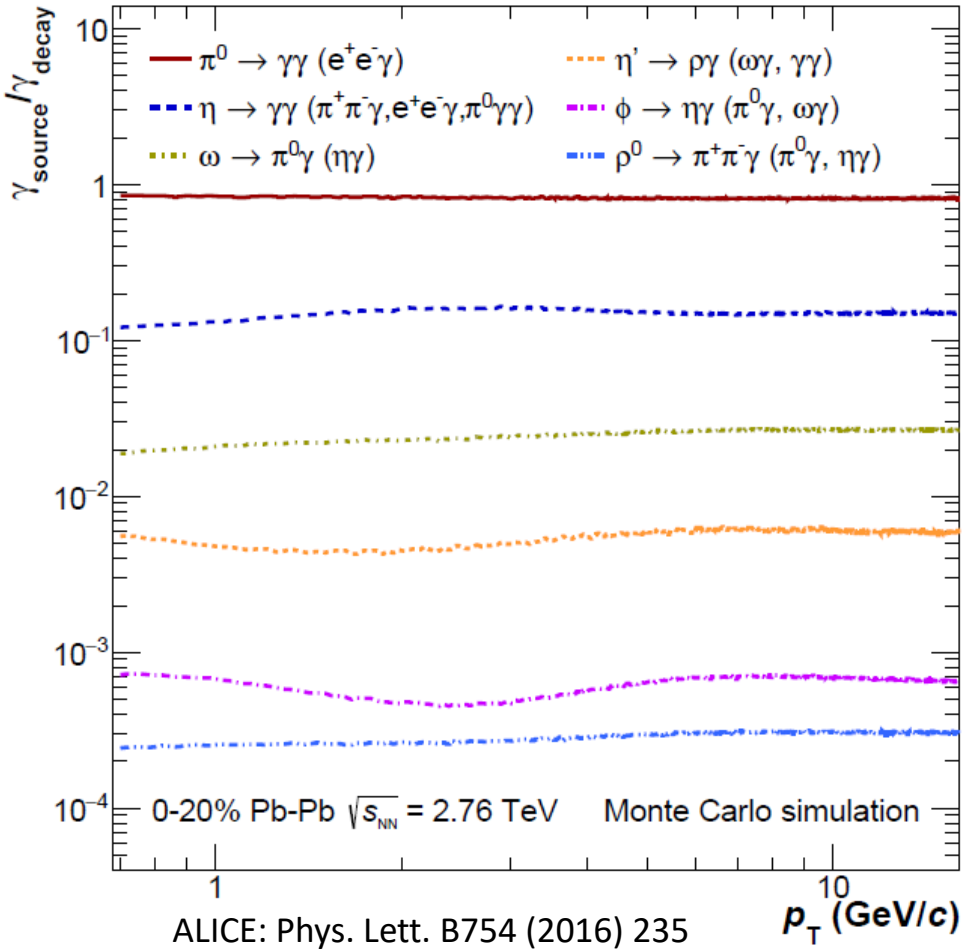
Challenge: decay photons

Inclusive photon spectra are dominated by decay photons

$$R_\gamma = \gamma_{\text{inc}} / \gamma_{\text{decay}}$$

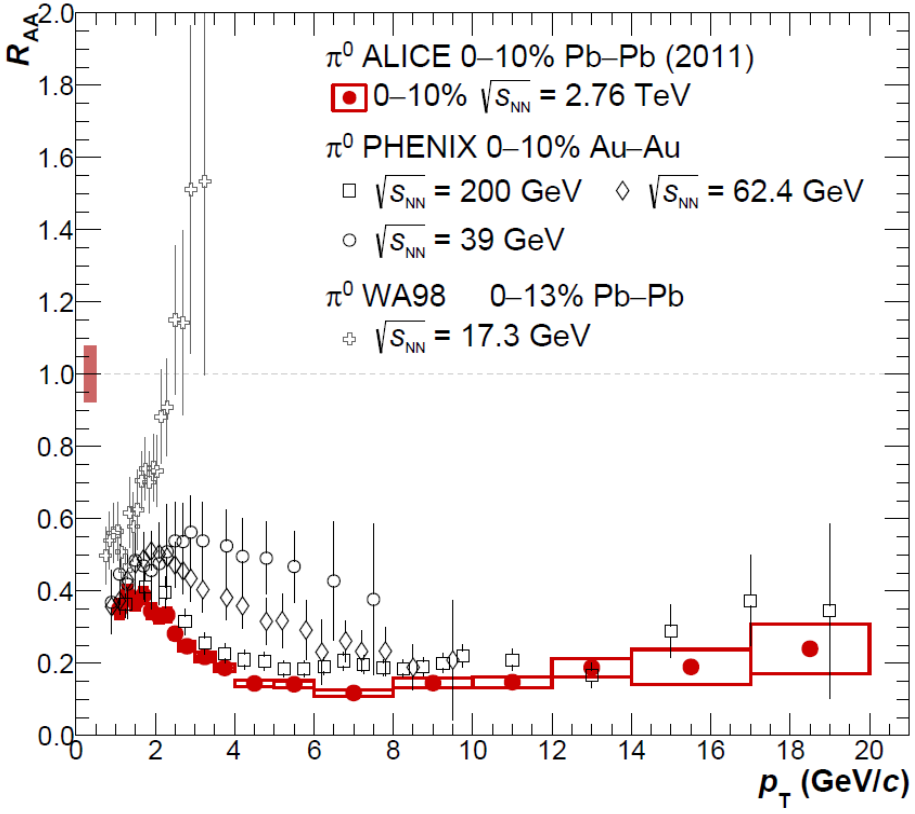


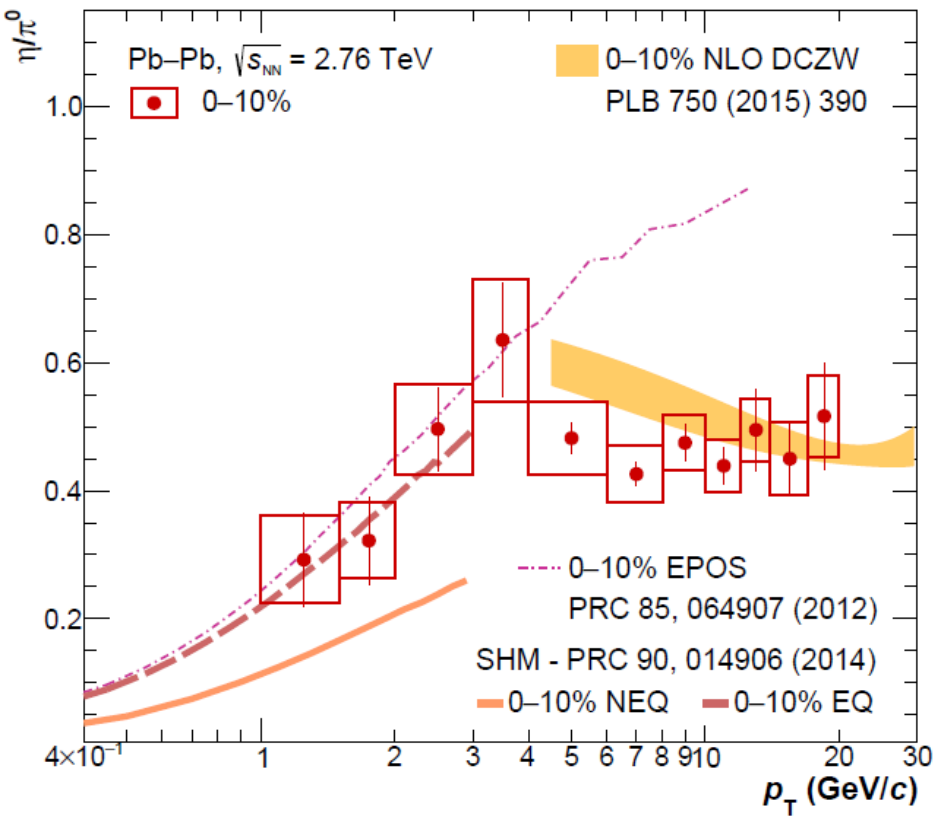
Relative contributions of different hadrons to the total decay photon spectrum as a function of the decay photon transverse momentum



ALICE: Phys. Lett. B754 (2016) 235

Neutral meson spectra

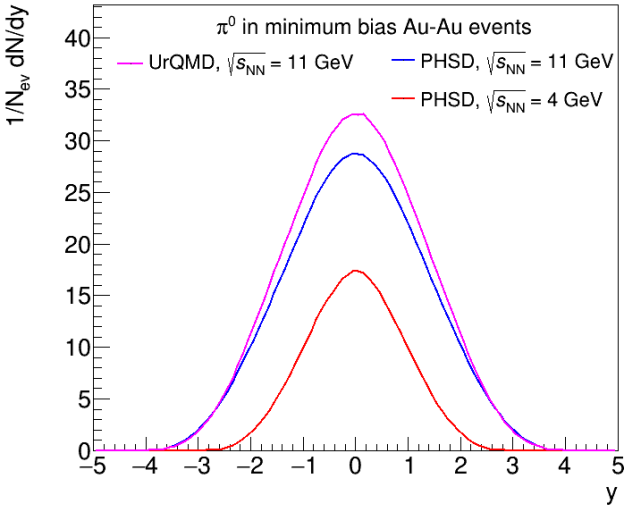


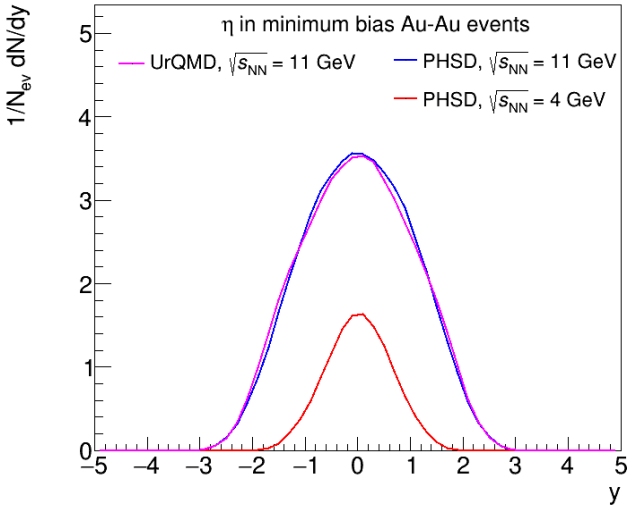


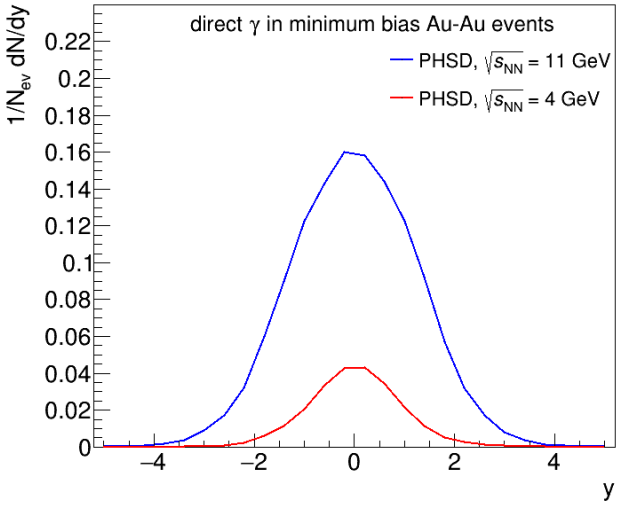
ALICE: Phys.Rev. C98 (2018) 044901

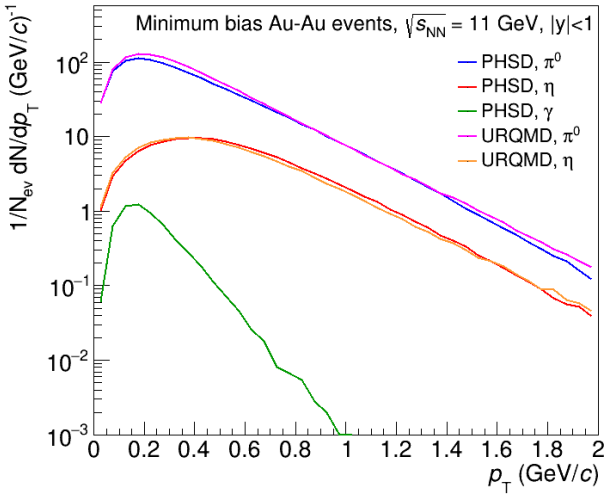
$$R_{\mathrm{AA}} = \frac{N_{\mathrm{AA}}^{J/\psi}}{\langle N_{\mathrm{coll}} \rangle \, N_{\mathrm{pp}}^{J/\psi}} \quad \begin{array}{ll} = 1 \rightarrow & \text{No medium effect} \\ < 1 \rightarrow & \text{Suppression} \\ > 1 \rightarrow & \text{Enhancement} \end{array}$$

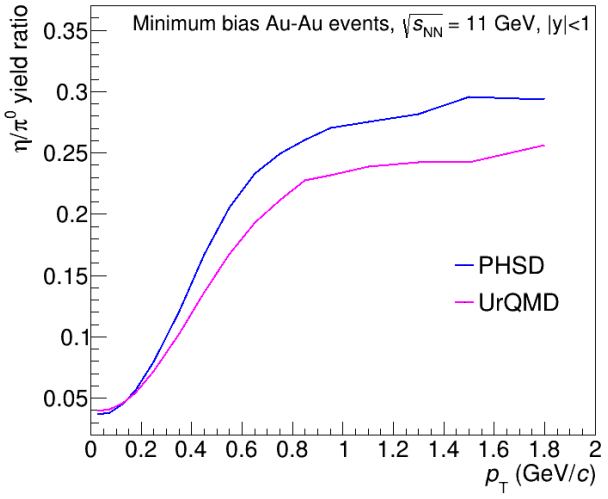
UrQMD and PHSD predictions at NICA energies









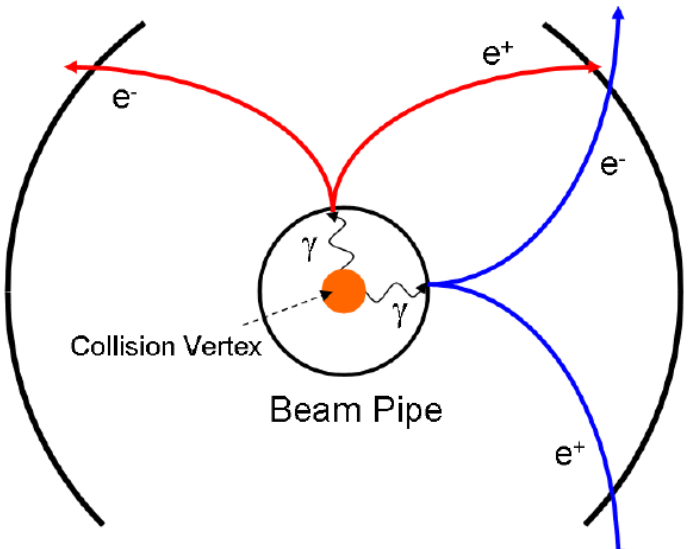


- UrQMD and PHSD generators: good agreement in neutral meson cross sections

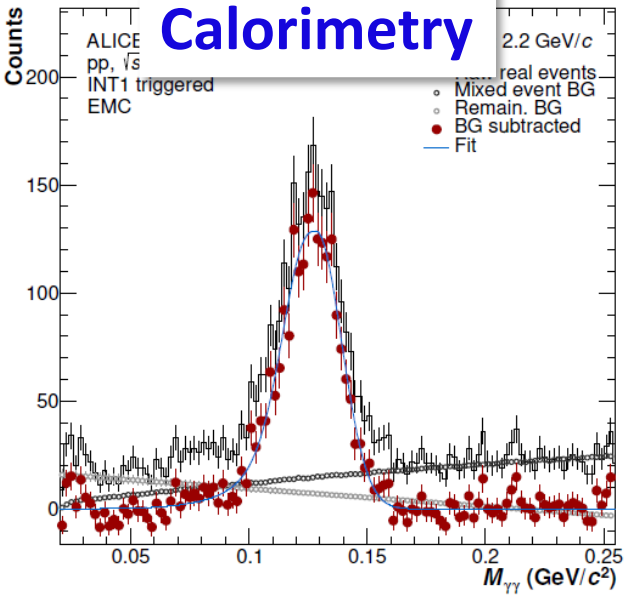
Photon reconstruction: two methods

- Electromagnetic calorimeters
  - Efficient at $p_T > 2$ GeV/c
  - Hardware trigger capabilities

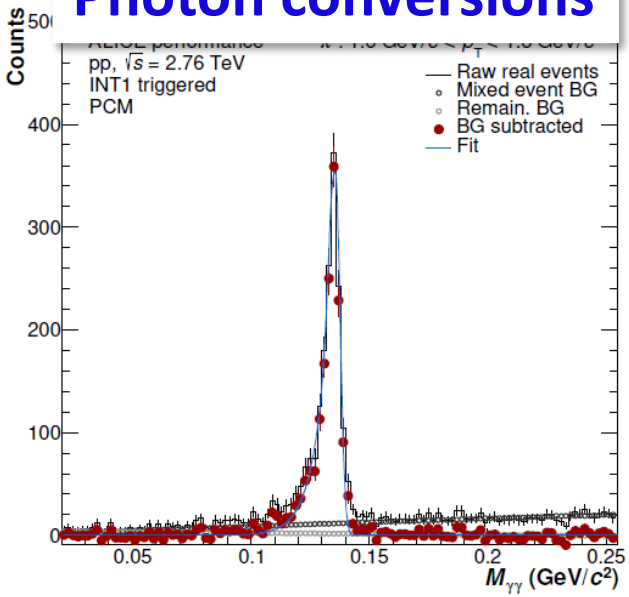
- Photon conversion $\gamma \rightarrow e^+e^-$ in the material
  - $P = 1 - \exp(-7/9\ x/X_0)$
  - Efficient at $0.5 < p_T < 4$ GeV/c
  - Much better resolution at low p_T



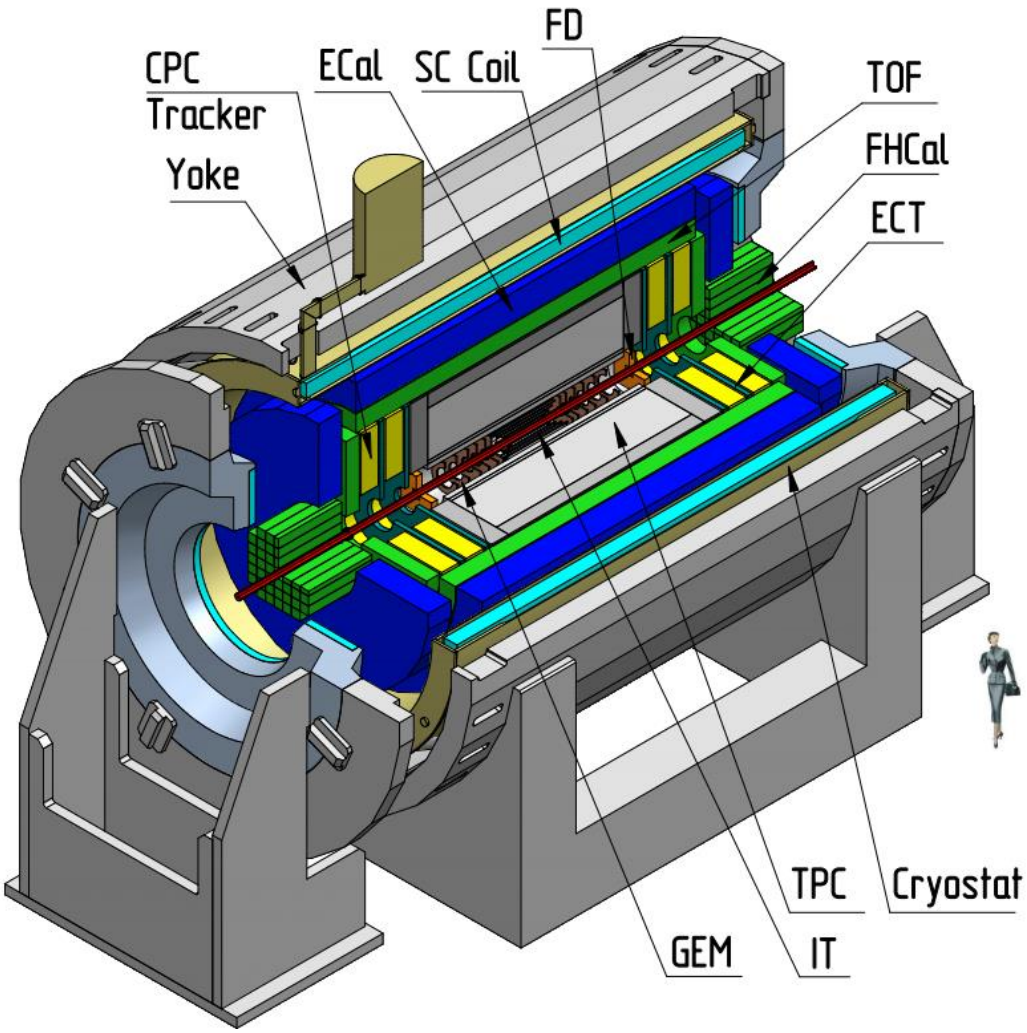
Calorimetry



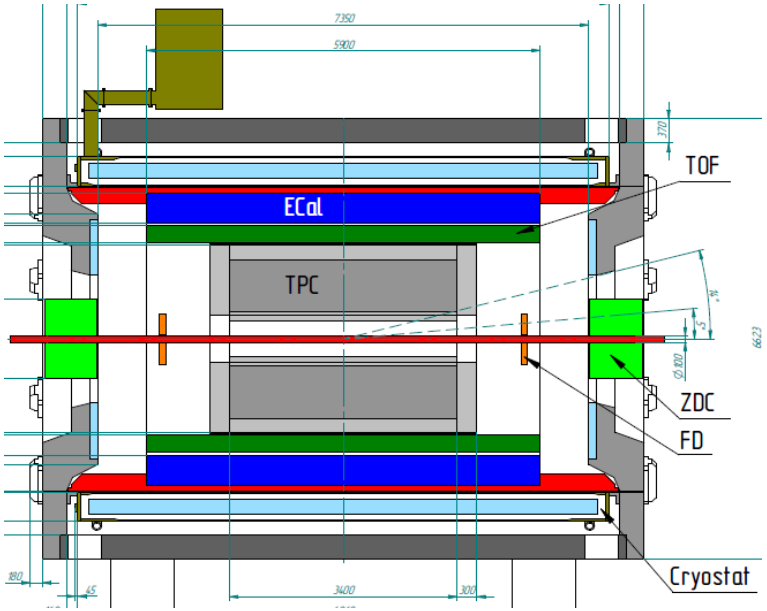
Photon conversions



MPD experiment at NICA

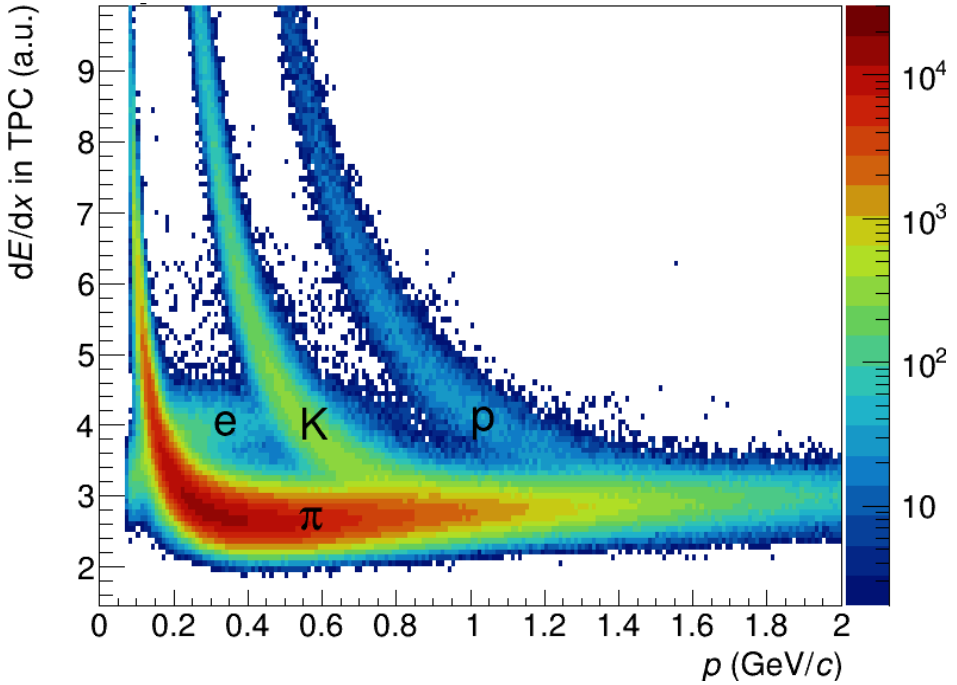


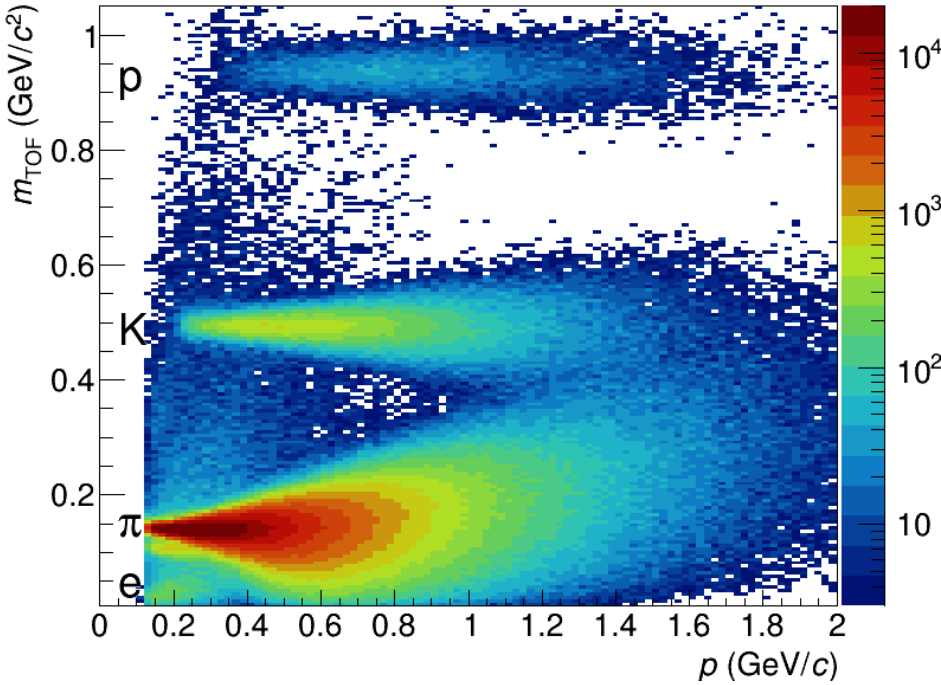
- CMS Energy: 4-11 GeV
- Design luminosity: 10^{27} cm^{-1} s^{-1}
- Stage 1 (2021-2022):
  TPC, TOF, ECAL, FHCal, FFD
- Stage 2 (>2023):
  ITS + EndCap

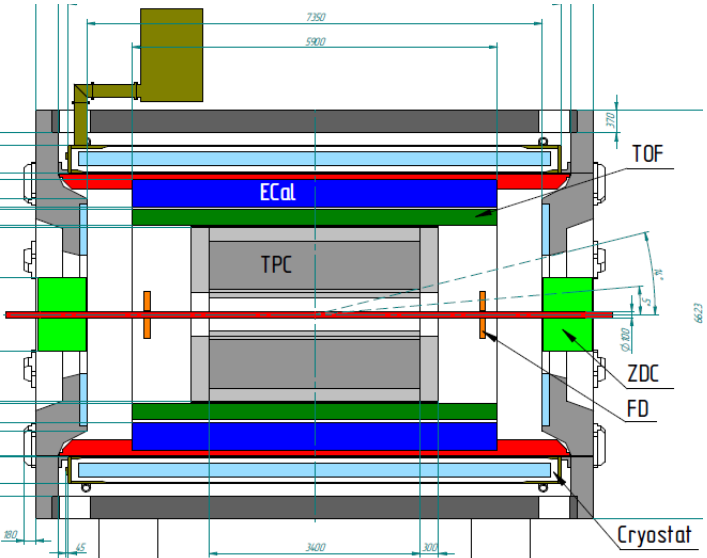


MPD: NIM A 628 (2011) 99-102

Electron PID

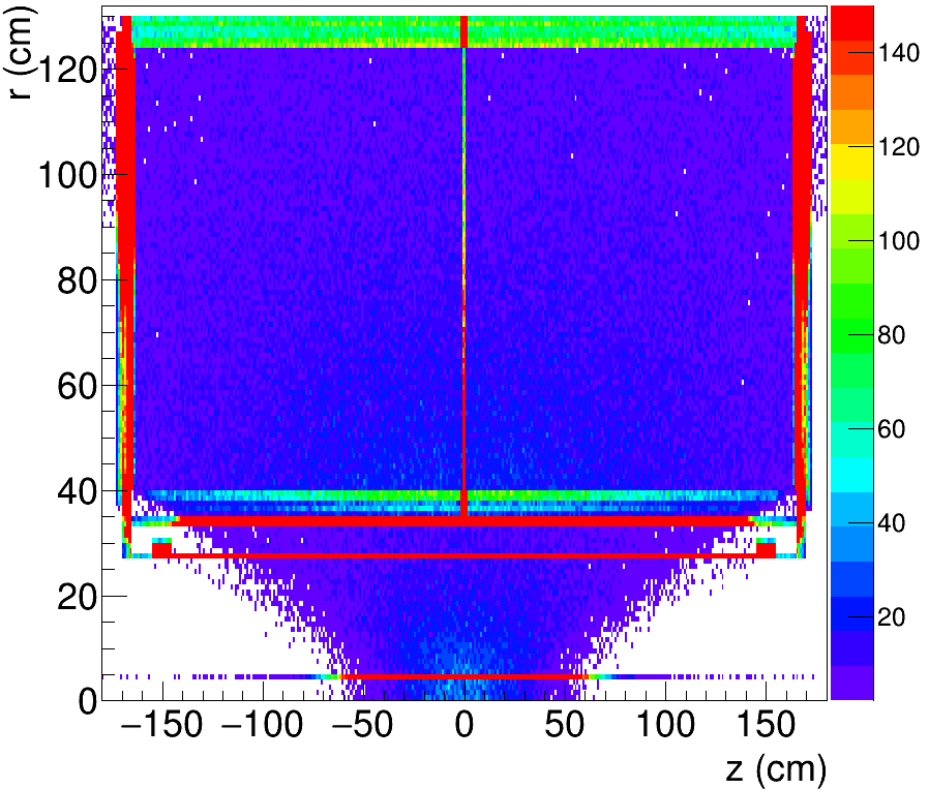


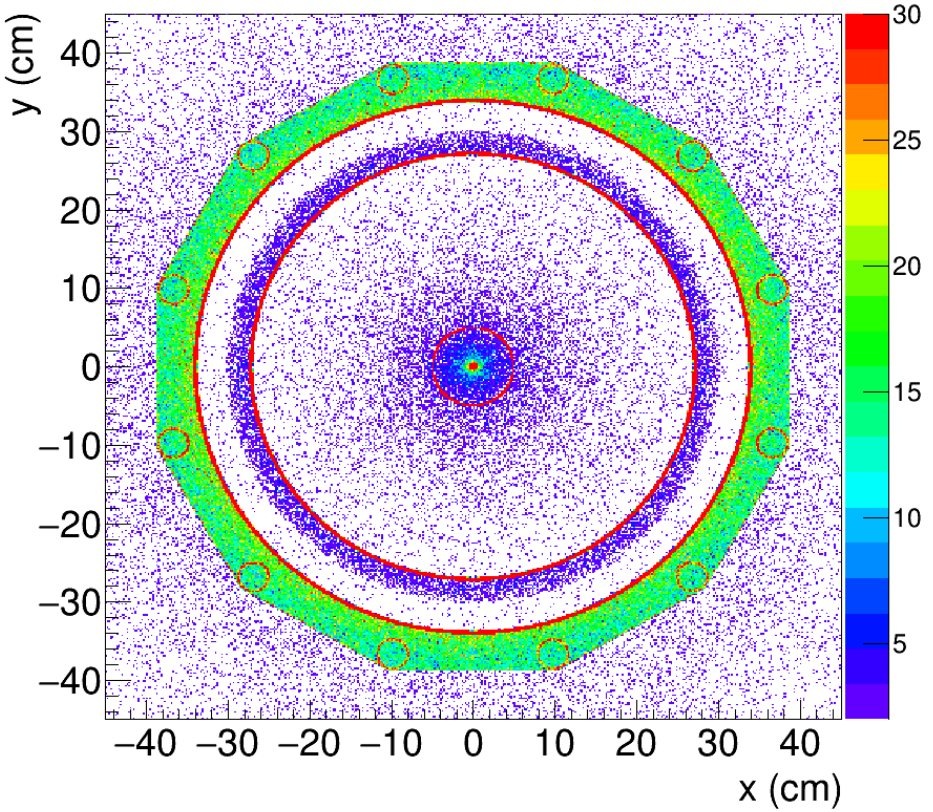




- TPC dE/dx: 0.2 - 0.5 GeV/*c*
- TOF: p_T < 0.3 GeV/*c*
- Possibility to use EMCal at higher p_T under investigation.

Photon conversion centers





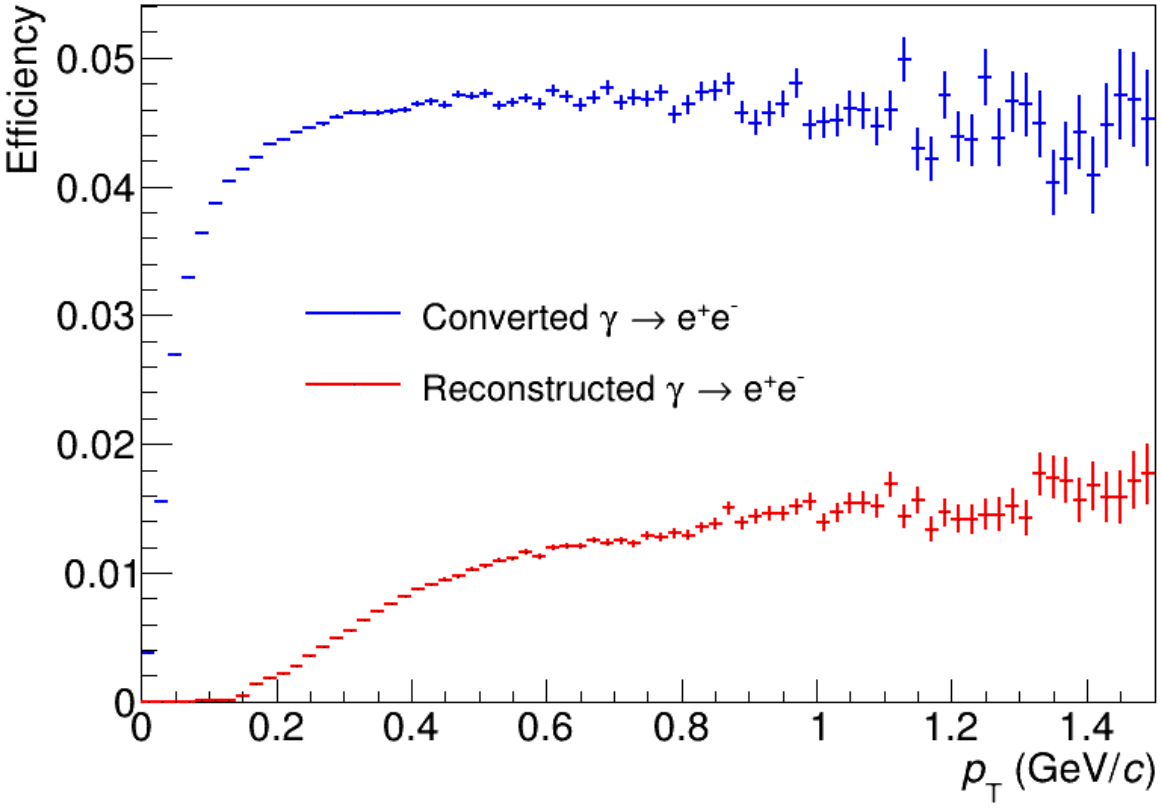
Main conversion structures in Stage 1:

- 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

Conversion reconstruction efficiency

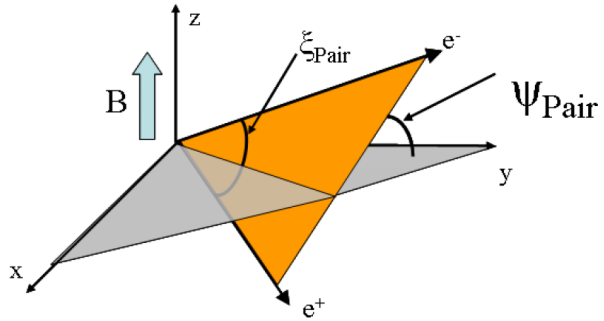


Typical cuts on electrons:

- $p_T > 50$ MeV/c
- at least 10 hits in TPC
- Electron PID probability: >75%

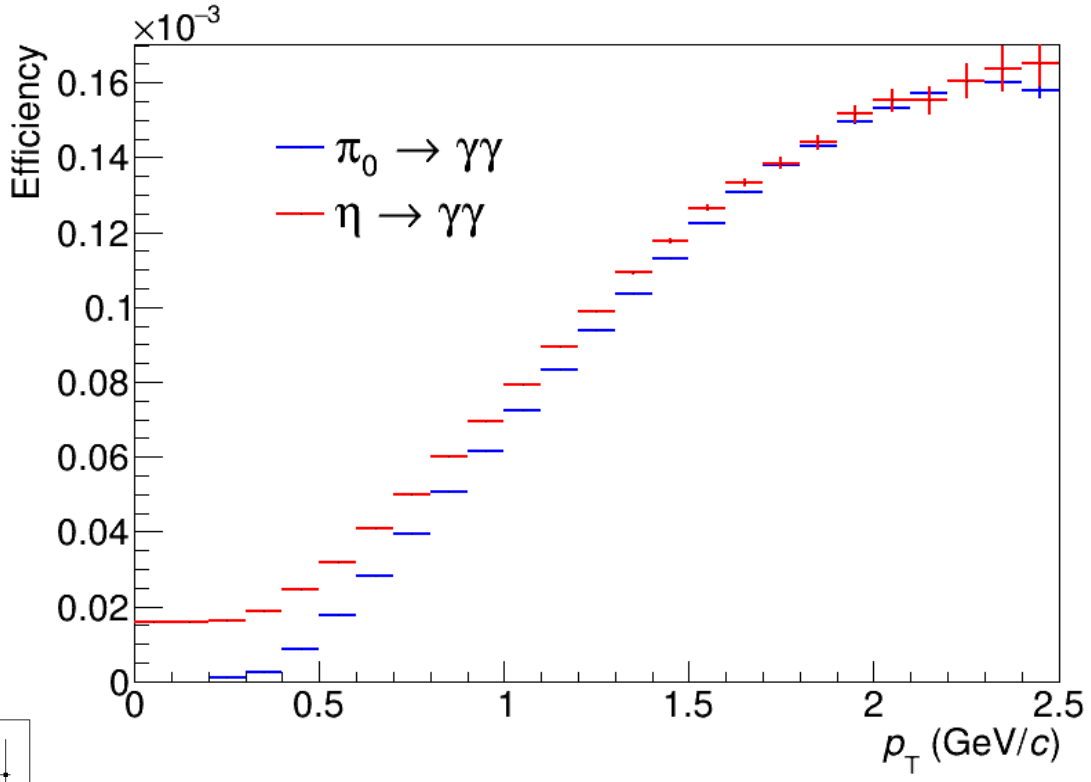
Typical cuts on ee pair:

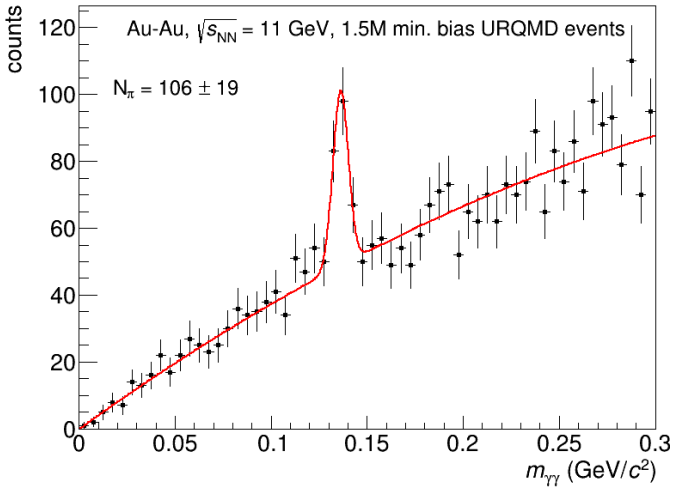
- Small DCA ($\chi^2 < 2$)
- Vertex R > 1 cm
- Direction to vertex: $\sin(\theta)<0.1$
- $m_{ee}<100$ MeV/c^2
- ee plane orientation wrt B: $\Psi_{Pair} < 0.2$ rad



- Studied with UrQMD generator + MPDROOT Stage 1 setup
- Ongoing efforts to increase photon reconstruction efficiency

Neutral meson reconstruction efficiency



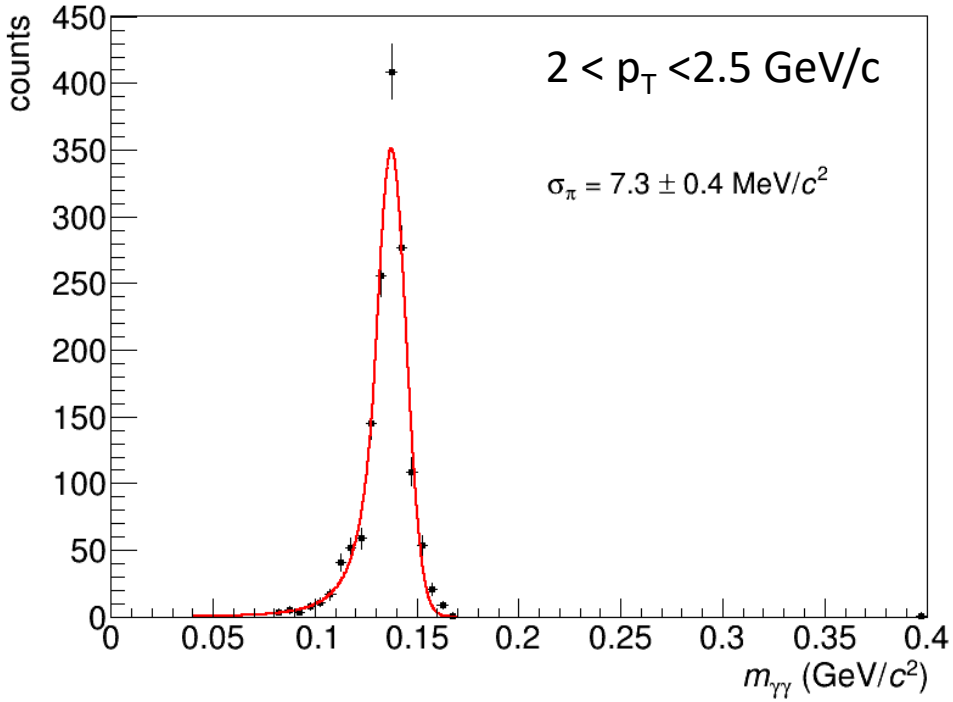


- Neutral meson reconstruction efficiency ~ 10^{-4}

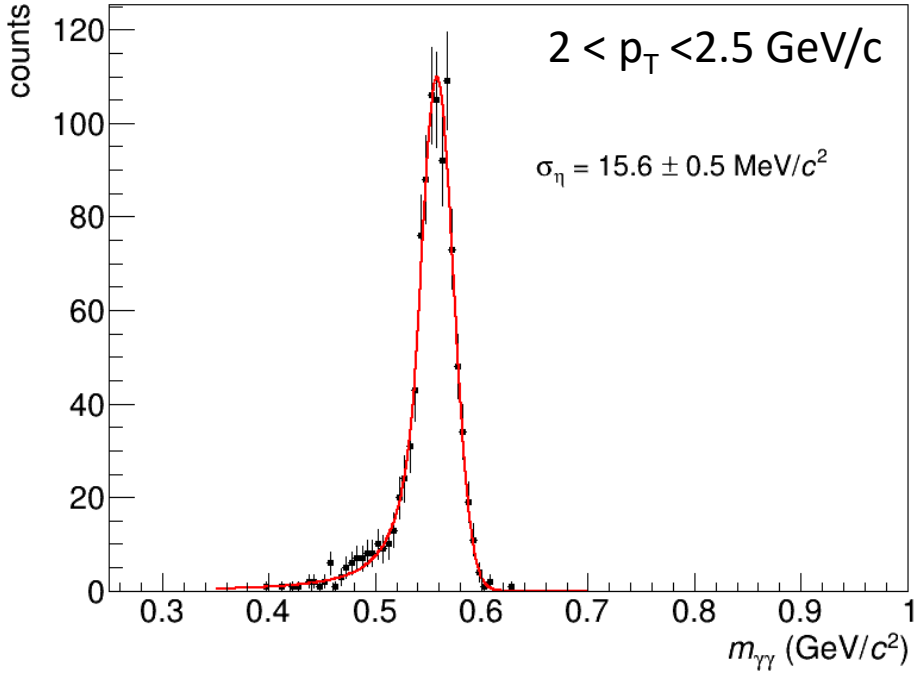
Embedded signal simulations

- Embedding technique used to study reconstruction efficiency vs p_T
- 400 000 min. bias UrQMD events @ 11 GeV
- 500 π^0 + 500 η embedded with flat p_T distribution
- Example: 2 < p_T <2.5 GeV/c

$\pi \rightarrow \gamma\gamma \rightarrow (e^+e^-)(e^+e^-)$



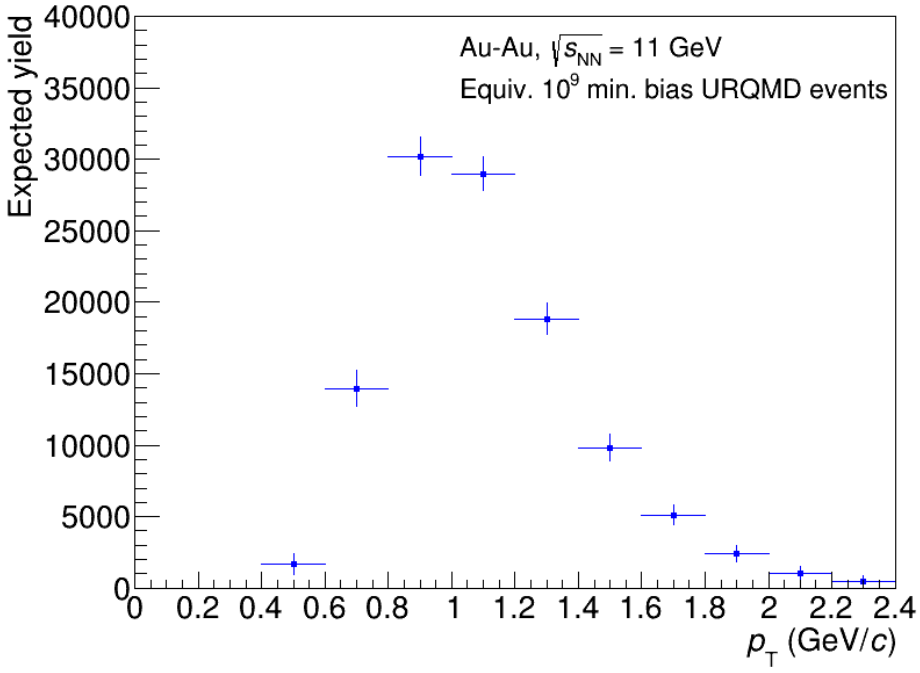
$\eta \rightarrow \gamma\gamma \rightarrow (e^+e^-)(e^+e^-)$



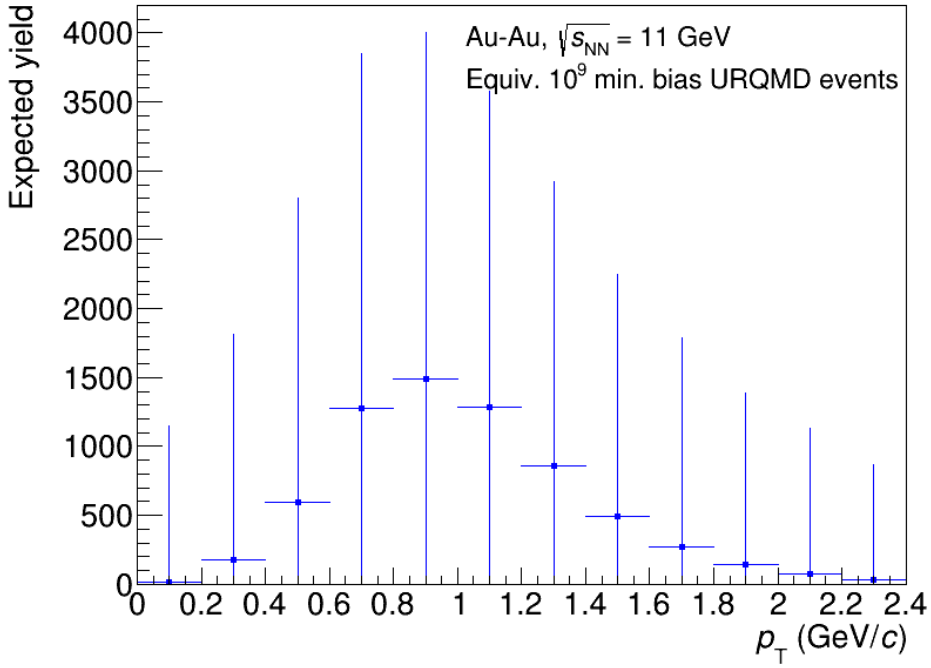
First-year projections

- L ~5 x 10^{25} cm^{-1} s^{-1}
- 10 weeks
- 50% duty factor
- => 10^9 minimum bias events
- Background and signal distributions scaled to 10^9 min. bias events
- Statistical uncertainties estimated as sqrt(S+B)

$\pi \rightarrow \gamma\gamma \rightarrow (e^+e^-)(e^+e^-)$



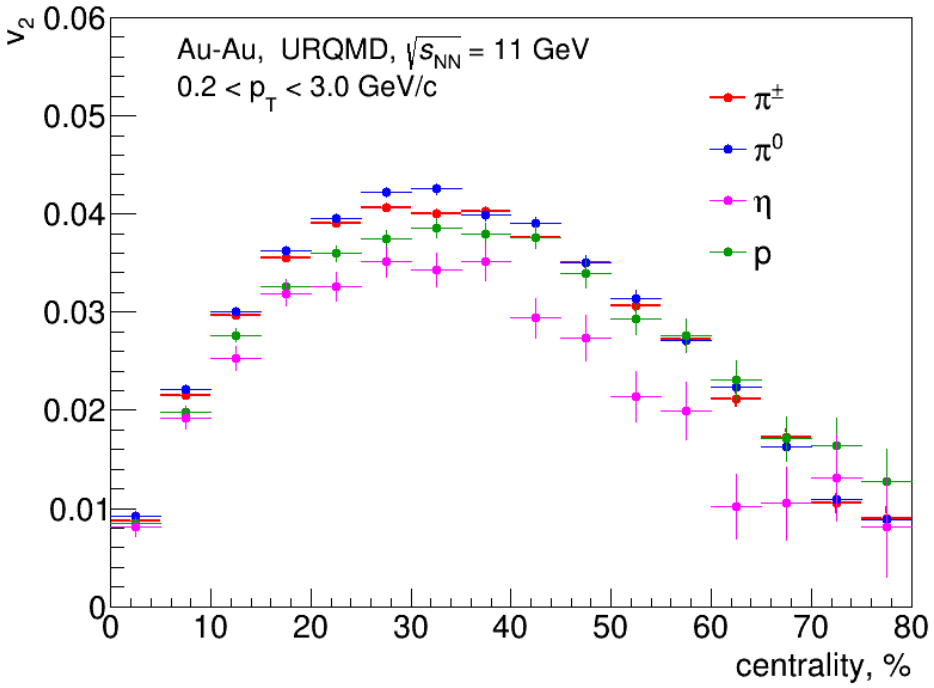
$\eta \rightarrow \gamma\gamma \rightarrow (e^+e^-)(e^+e^-)$

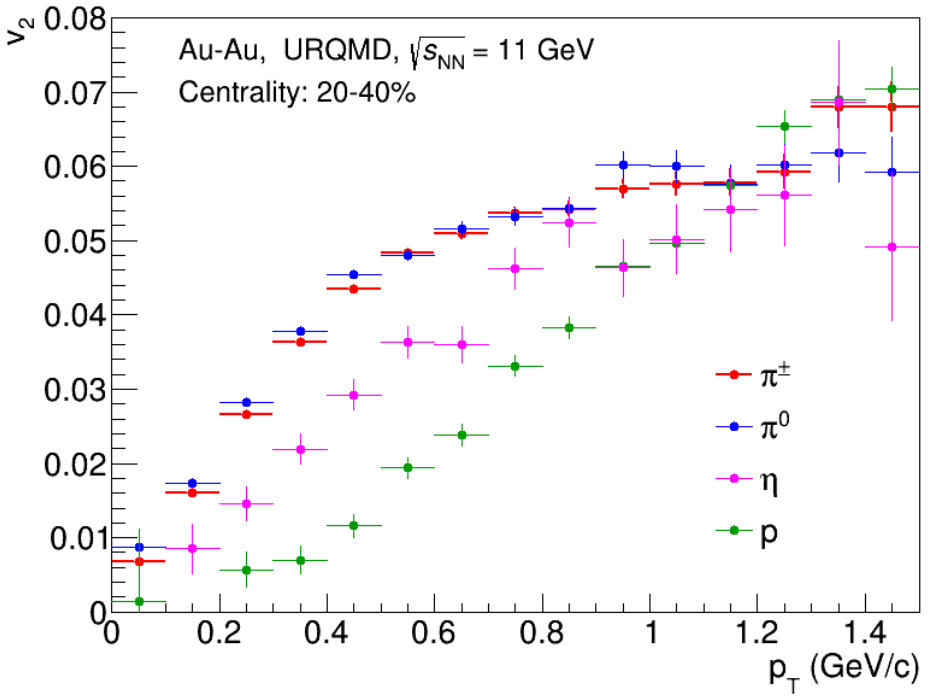


Elliptic flow of neutral mesons

Generator-level studies using true reaction plane

$$\frac{dN}{d\varphi} \sim 1 + 2\sum_n v_n \cos n(\varphi - \Psi_{RP})$$





- Significant v_2 values predicted for all particle species
- As expected, elliptic flow of $\pi^{\pm}$ and π^0 mesons is very similar
- There is a clear mass ordering of v_2 as function of p_T:
  eta meson v_2 (intermediate mass range) is between proton and pion v_2
- First estimates: need O(10^9) semi-central (20-40%) events to measure neutral pion v_2 with ~10% precision in 0.8 < p_T < 2 GeV/c

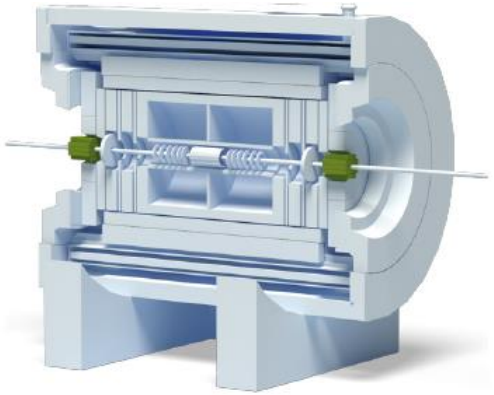
Conclusions and outlook

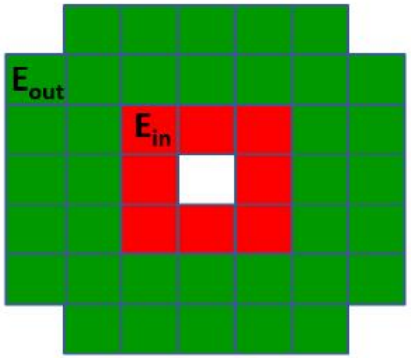
- Photons and neutral mesons - valuable probes of dense hadronic matter produced in heavy ion collisions
- Photon conversion method is a powerful tool to measure photon and neutral meson spectra
- Standard MPD configuration allows one to reconstruct π^0 mesons via conversions already with the first year data taking
- Ongoing efforts to optimize neutral meson reconstruction efficiency
- Next:
  - Feasibility of thermal photon reconstruction
  - Azimuthal flow of photons and neutral mesons
  - Feasibility studies on the dedicated convertor

BACKUP

Event plane determination with FHCal

2 <|η| < 5





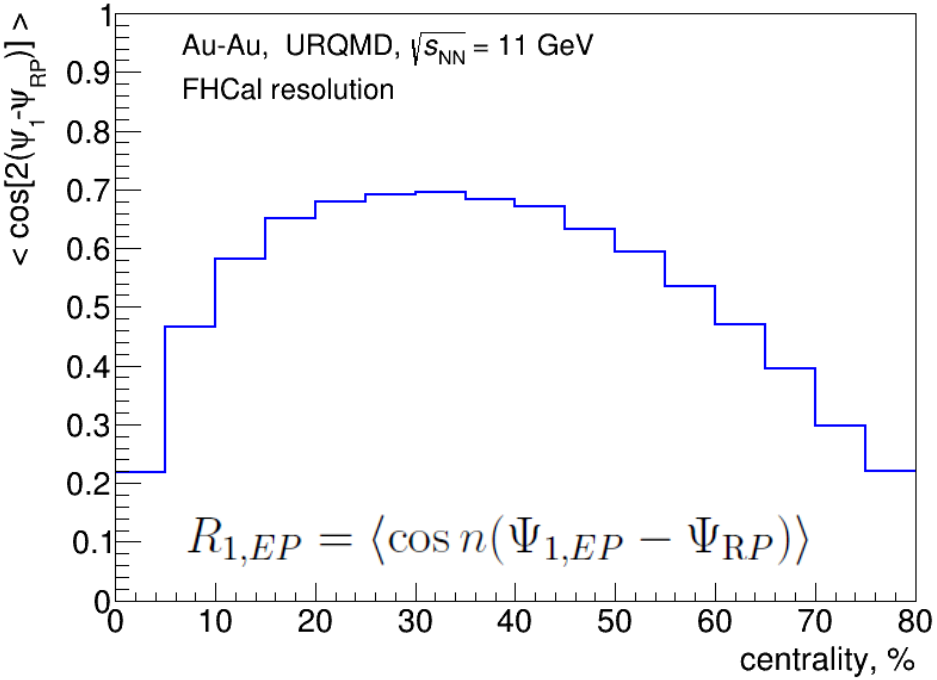
- Event plane:

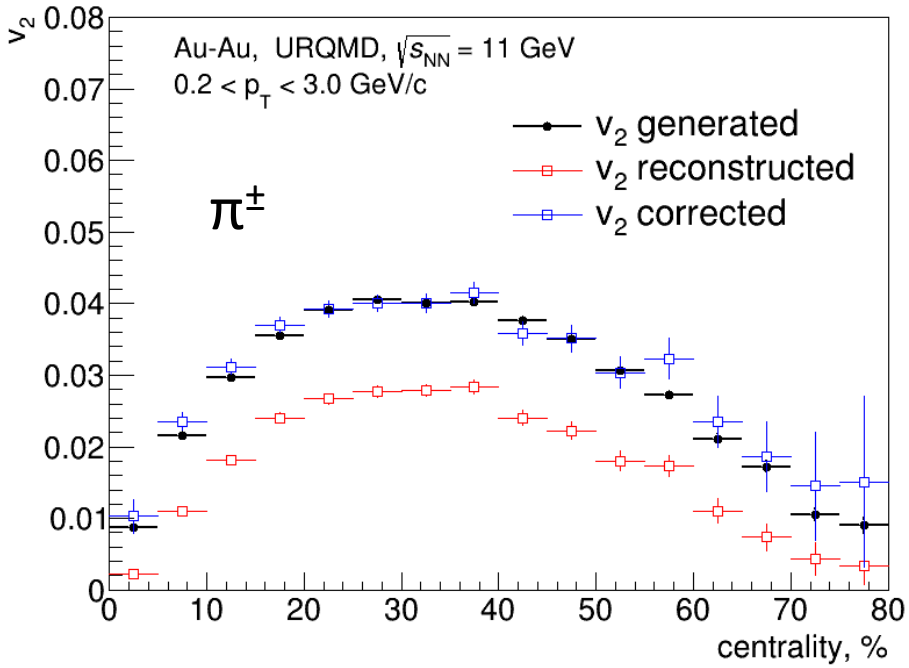
$$\Psi_{1,EP}^{L(R)} = \arctan\left(\frac{\sum E_i \sin\varphi_i}{\sum E_i \cos\varphi_i}\right)$$

- v_n corrected for event plane resolution effects:

$$v_n\{\Psi_{1,EP}\} = \frac{\langle \cos n(\varphi - \Psi_{1,EP})\rangle}{R_{1,EP}}$$

Resolution correction factor





PHSD predictions vs SPS data