Feasibility of thermal photon measurements in heavy ion collisions at NICA energies

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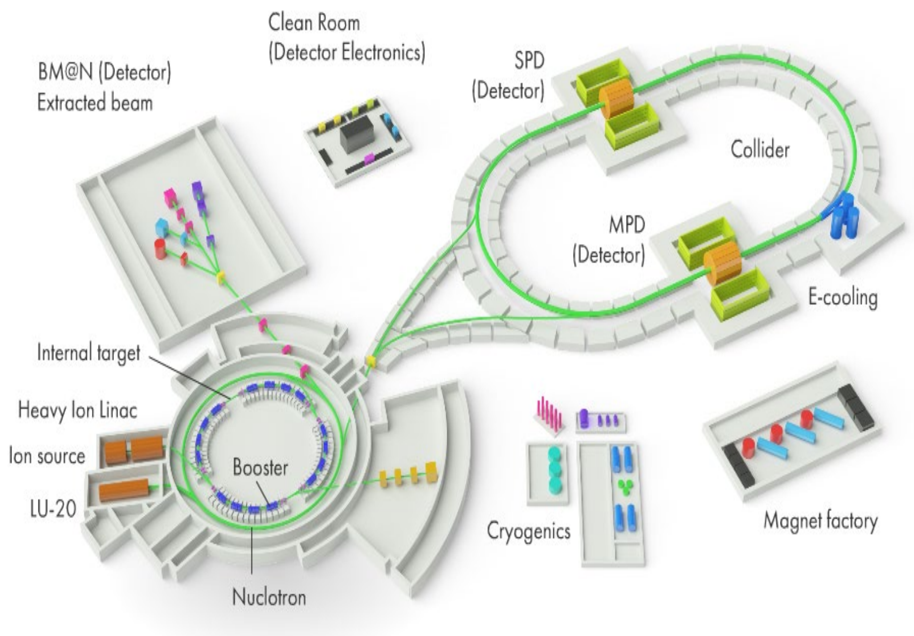
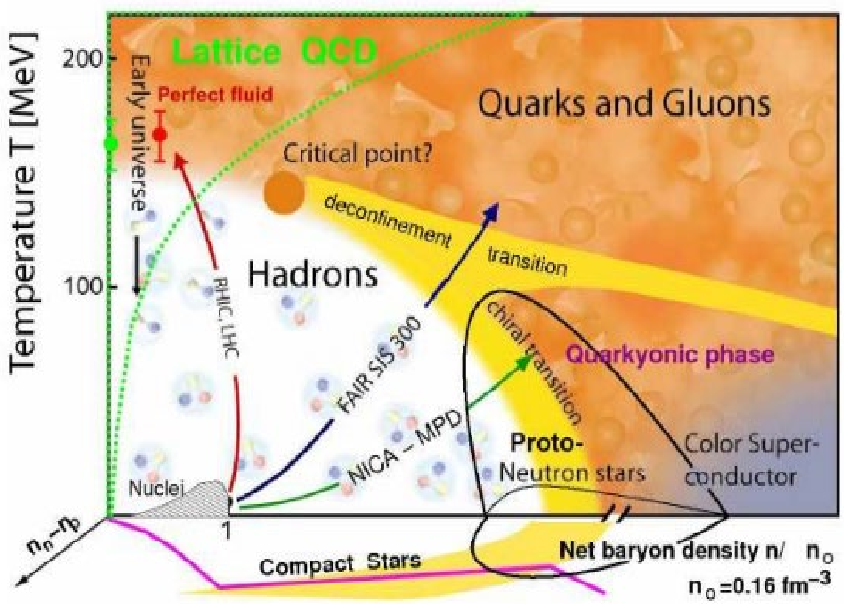
Outline

- Heavy ion collisions at NICA
- Motivation for thermal photons study in heavy-ion collisions
- Photon conversion method
- Feasibility studies for thermal photons measurement in the MPD
- Conclusions and outlook

Heavy ion collisions at NICA

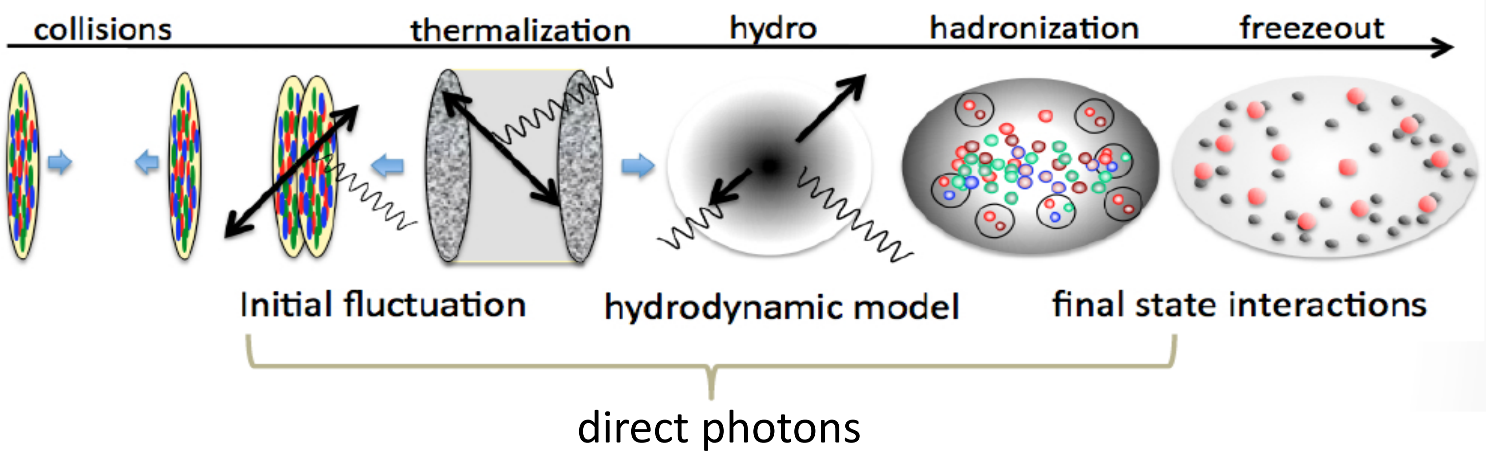


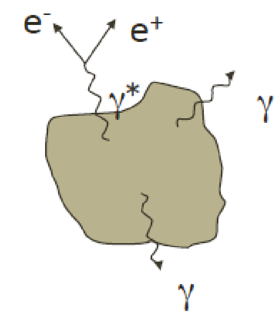


- A mega-science project NICA, Dubna, JINR
- Modernization of existing Nuclotron facility
- Parameters:
  - ✓ relativistic ions up to Au, $\sqrt{s_{NN}} = 4\text{-}11$ GeV
  - ✓ polarized p and d, $\sqrt{s_{NN}} = 27$ GeV (for p)
  - ✓ luminosity 10^{27} cm^{-2}s^{-1}
- Working experiment: BM@N (fixed target)
- Experiments under construction: MPD, SPD (collider)

- Study of the phase diagram in the region of high baryonic density and intermediate temperatures
- Extension of modern heavy-ion programs at RHIC and the LHC to lower energies

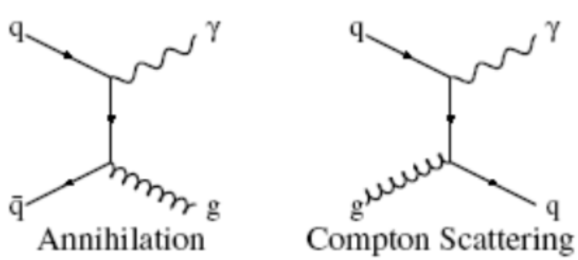
Thermal radiation in heavy ion collisions



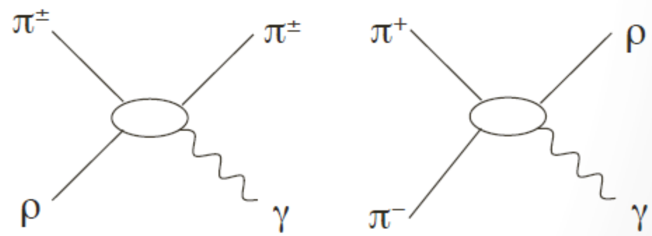


- Photons leave the medium without interaction
- Black body radiation: inverse slope proportional to T_{eff}

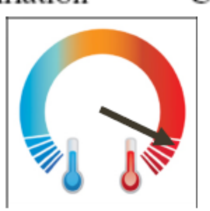
Thermal photons from QGP



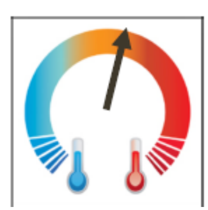
Thermal photons from hadron gas



Naïve:

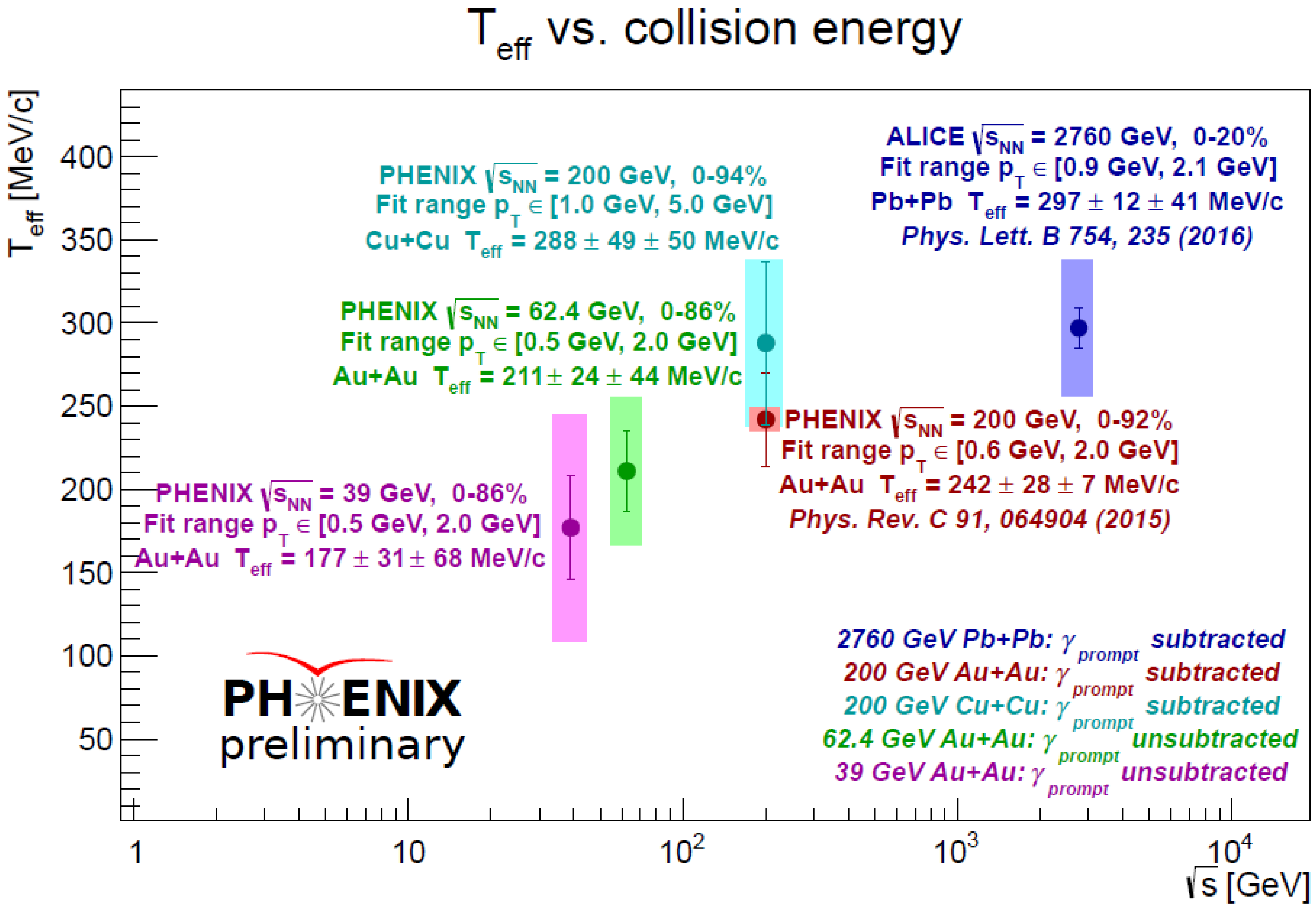


Hot medium
Large yield



Warm medium
Moderate yield

Effective temperature vs energy

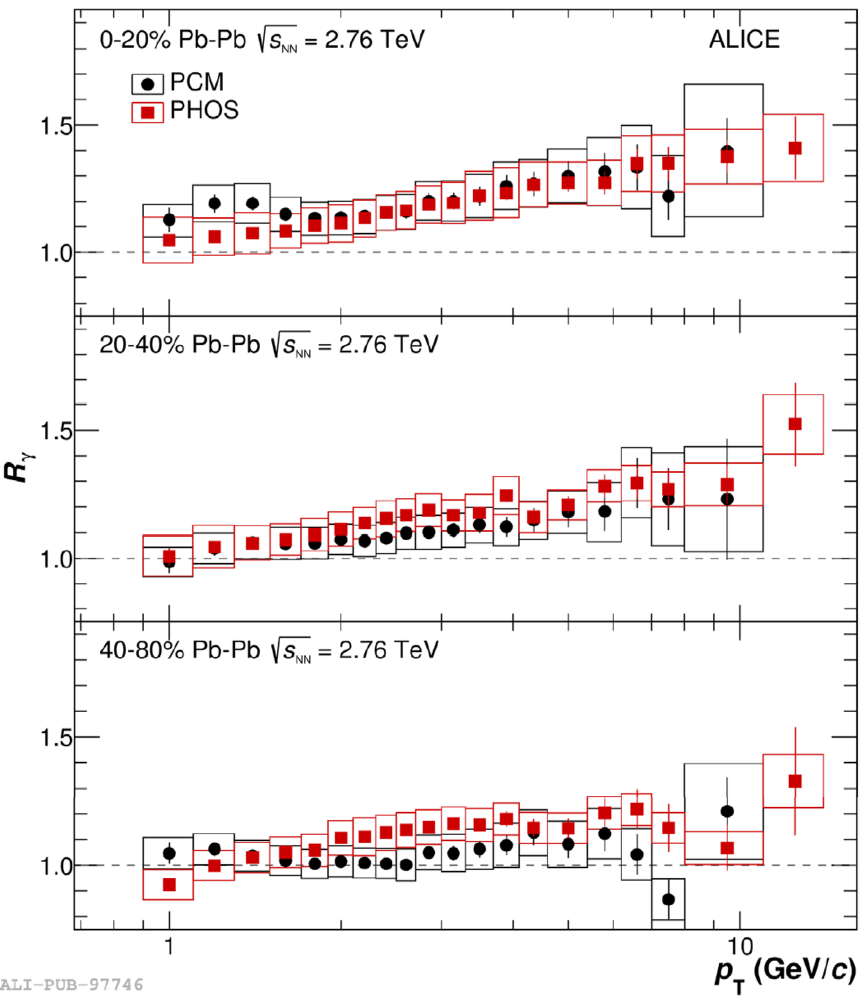


J. Phys.: Conf. Ser. 1070 (2018) 012012

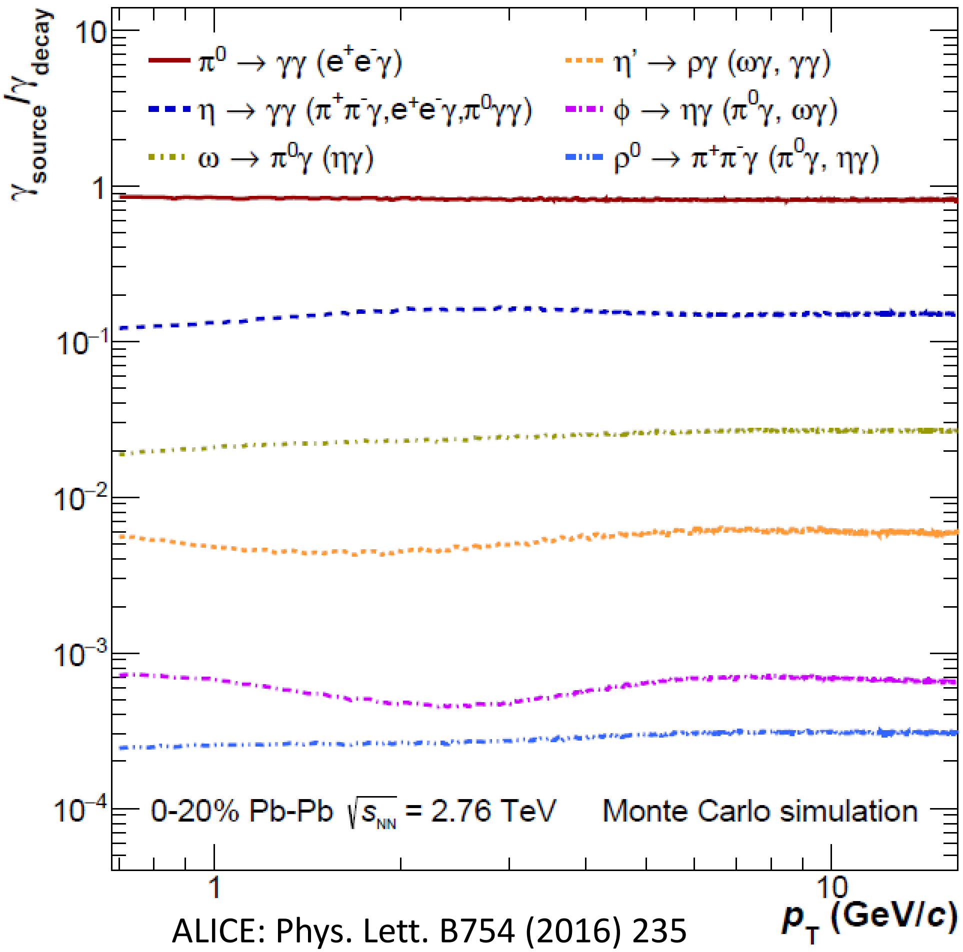
Challenge: decay photons

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

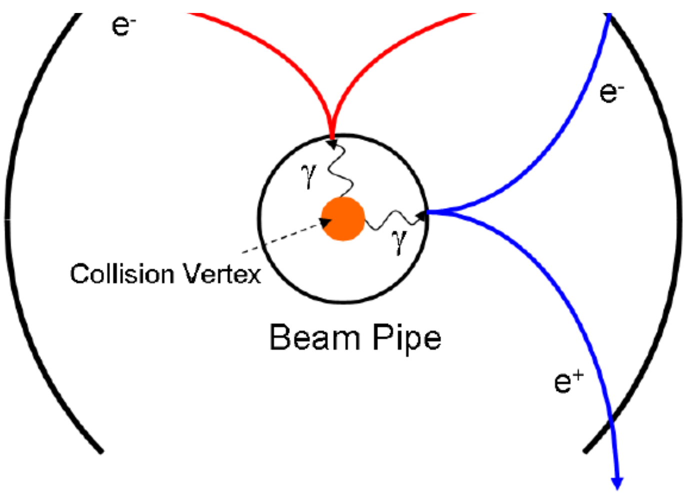


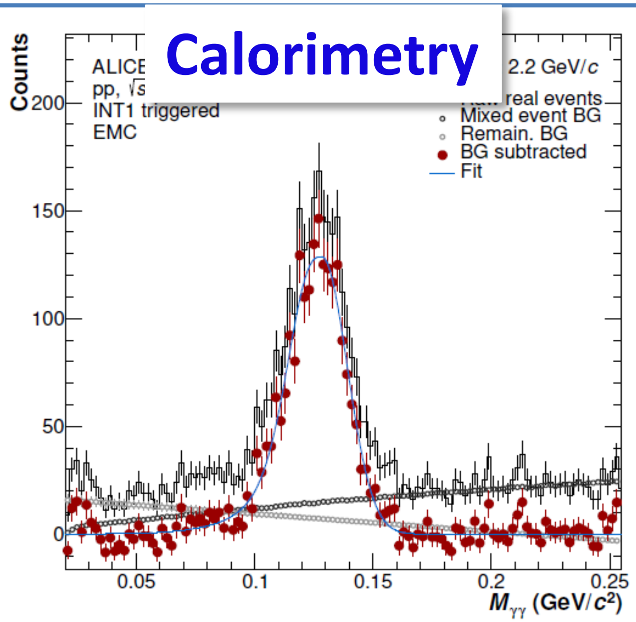
ALICE: Phys. Lett. B754 (2016) 235

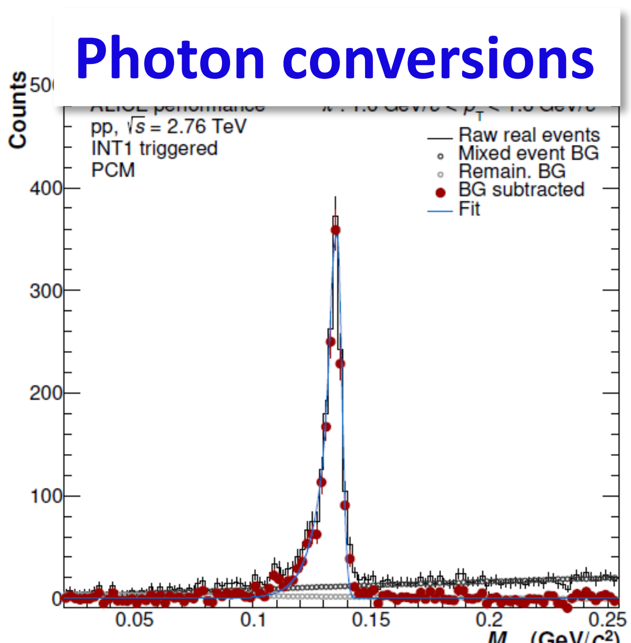
Photon reconstruction: two methods

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

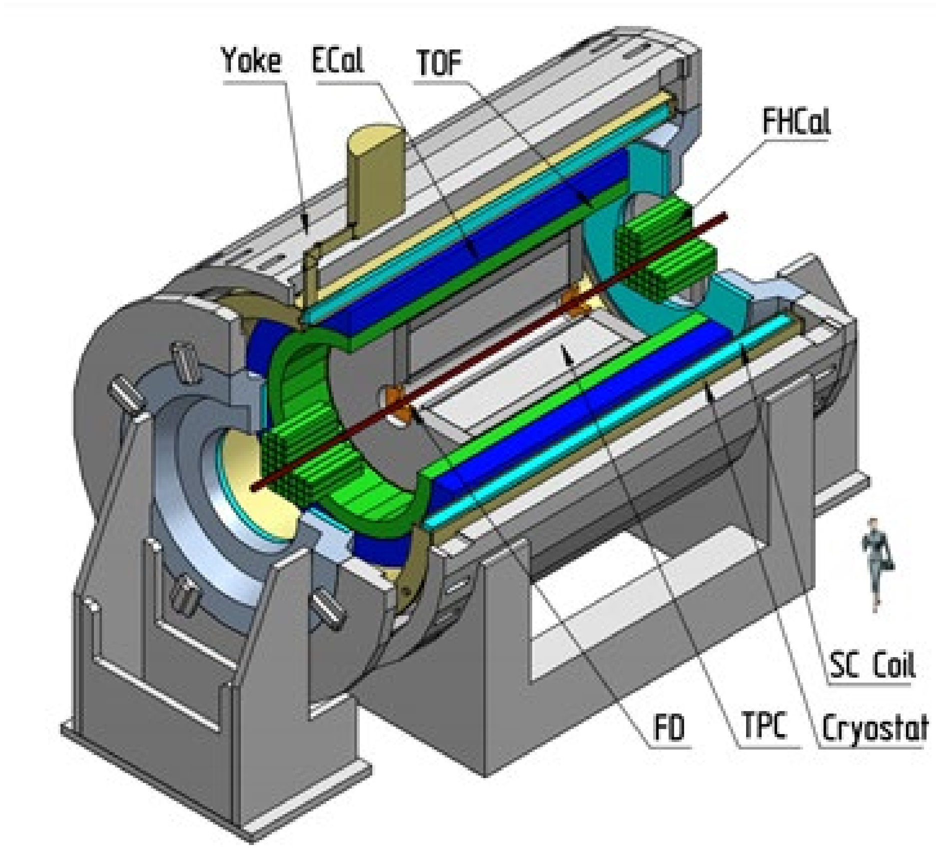
- Photon conversion $\gamma \rightarrow e^+e^-$ in the material
  - $P = 1 - \exp(-7/9\ x/X_0)$
  - Efficient at $0.5 < p_T < 4$ GeV/c
  - Much better resolution at low p_T







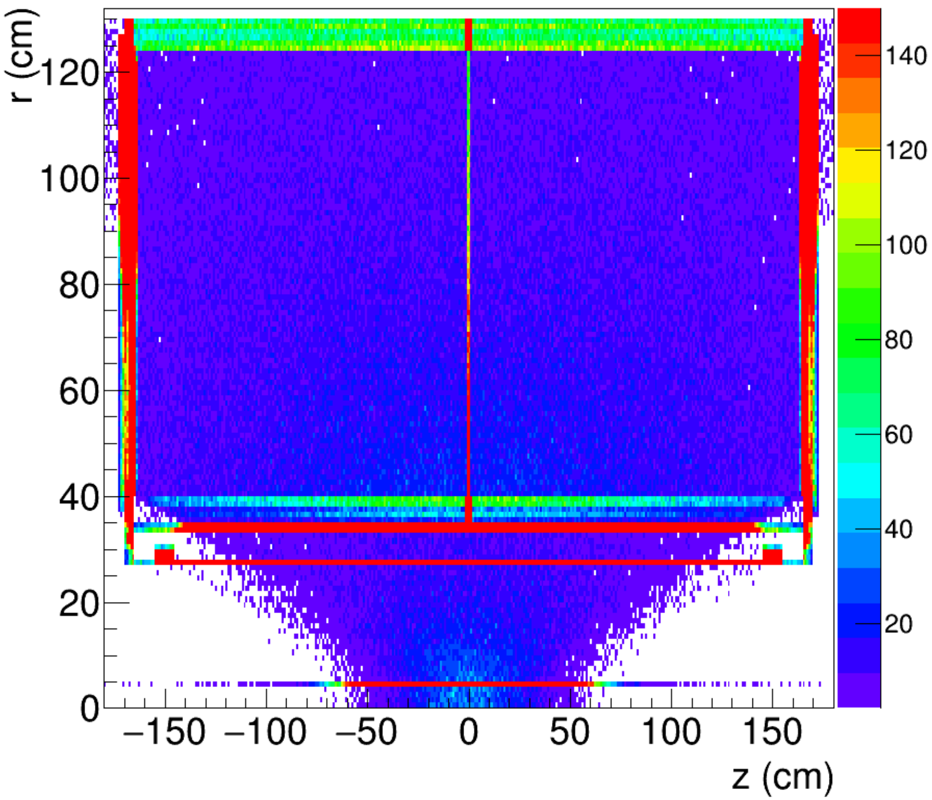
MPD experiment at NICA

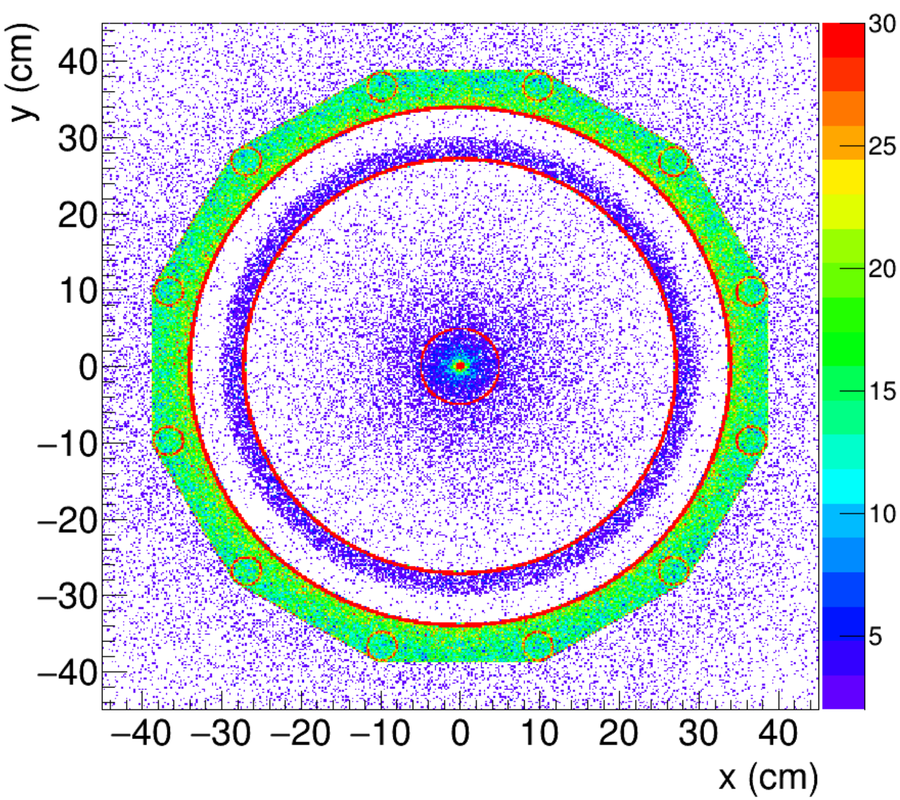


- CMS Energy: 4-11 GeV
- Design luminosity: 10^{27} cm^{-1} s^{-1}
- Stage 1: TPC, TOF, ECAL, FHCal, FFD
- Stage 2: + ITS + EndCap

MPD: NIM A 628 (2011) 99-102

Photon conversion centers





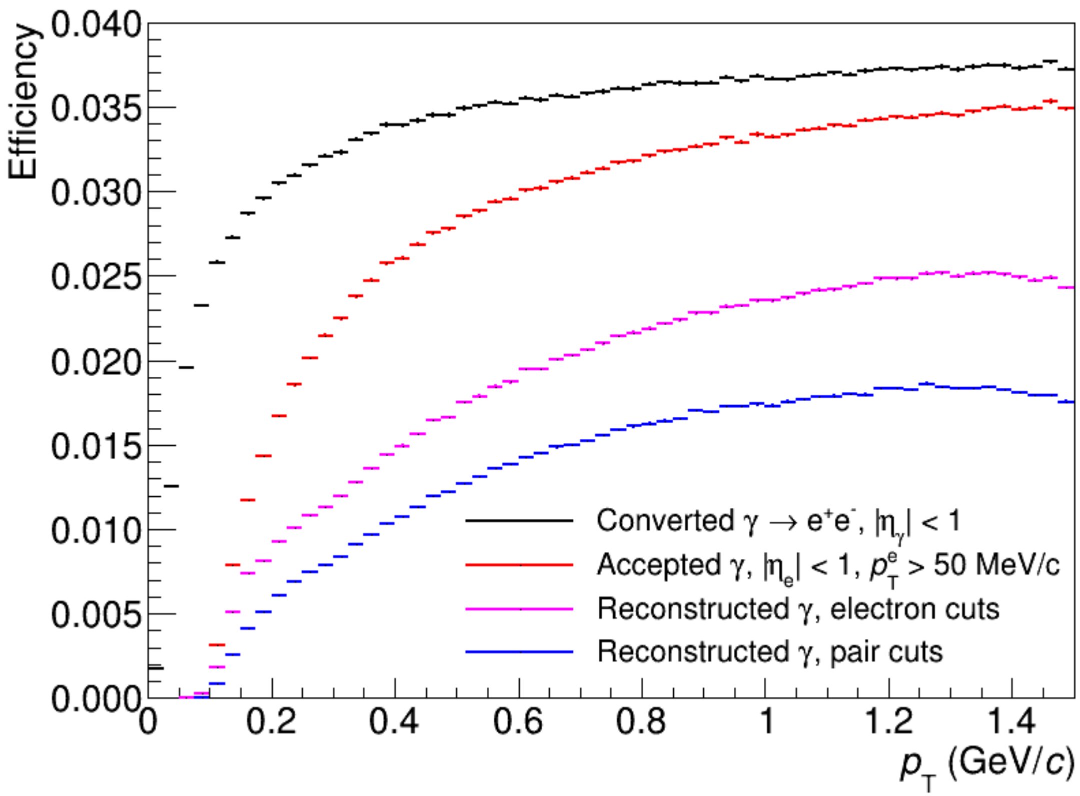
Main conversion structures in Stage 1:

- 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



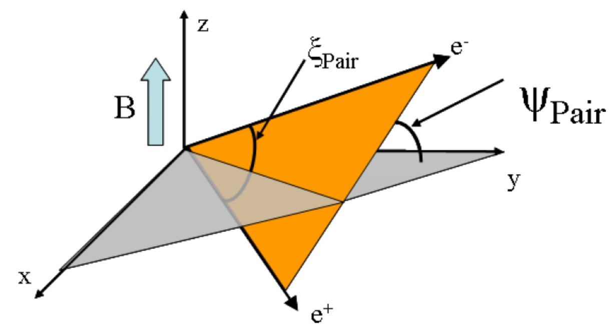
Typical cuts on electrons:

- $|\eta|<1$
- $p_T > 50$ MeV/c
- at least 20 hits in TPC
- +/-4σ electron PID in TPC/TOF

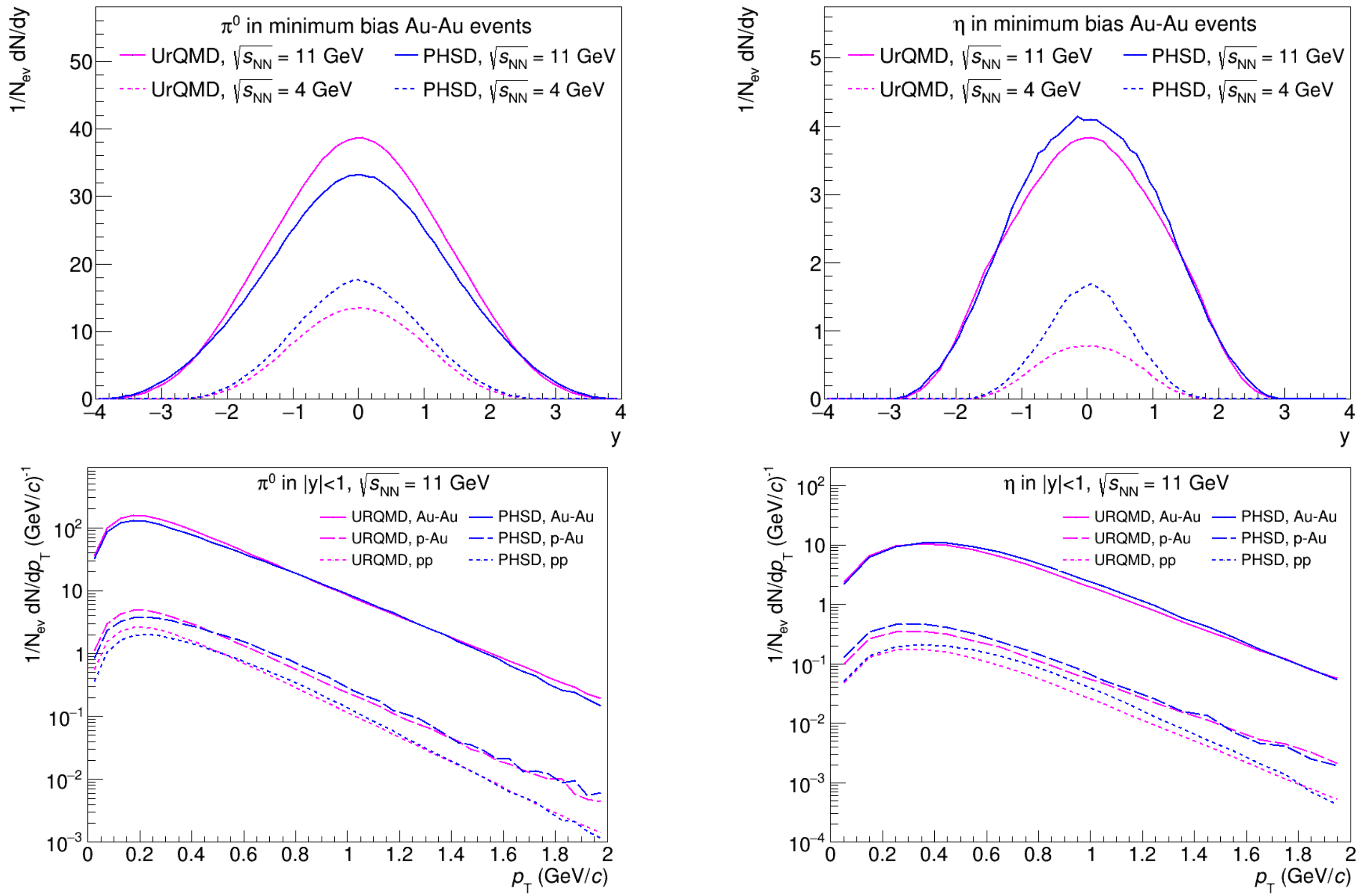
Typical cuts on ee pair:

- Small DCA ($\chi^2 < 10$)
- Vertex R > 10 cm
- Direction to vertex:
  $\theta < \exp(-2.777-2.798 * p_T) + 0.0175$
- $m_{ee} < 22.6 + 17.4 * p_T$
- ee plane orientation wrt B:
  $\Psi_{Pair} < 0.1$ rad

- Studied with MPDROOT Stage 1 setup
- Using MpdParticle to build secondary vertices
- Cuts optimized to maximize signal significance
- Contribution of (non-gamma) background < 10-20%
  - can be further improved with tighter cuts

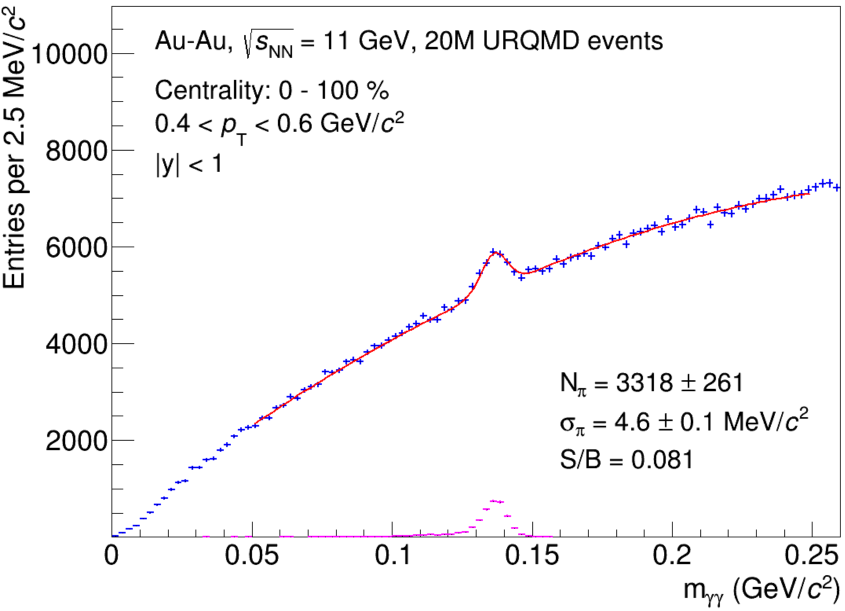


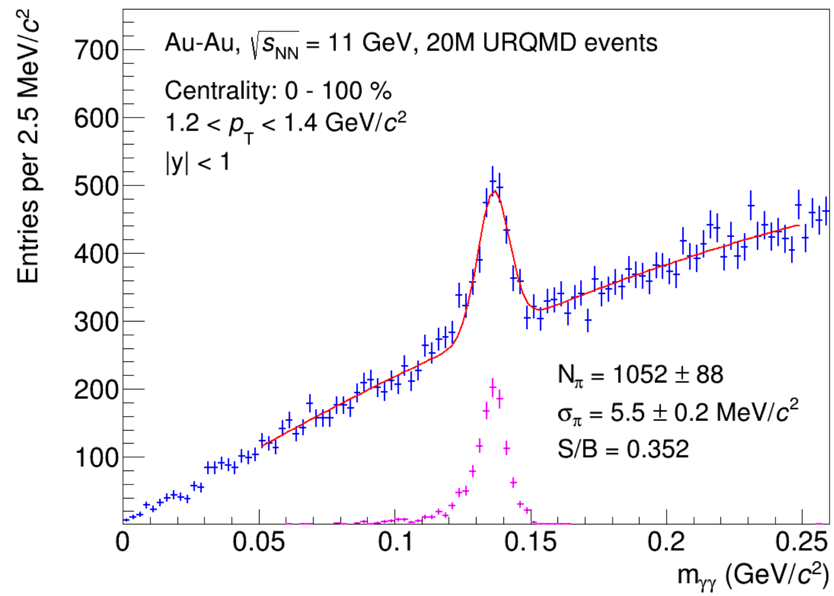
UrQMD and PHSD predictions at NICA energies



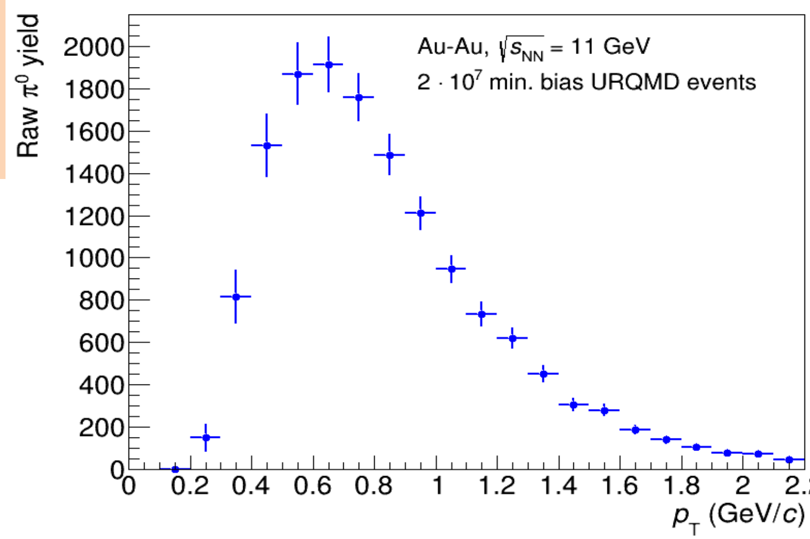
- UrQMD and PHSD generators: good agreement in neutral meson cross sections

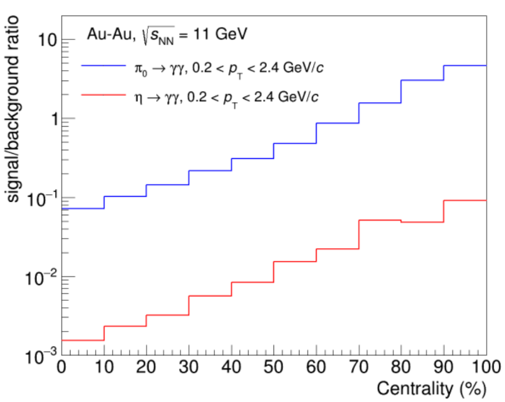
Neutral meson reconstruction

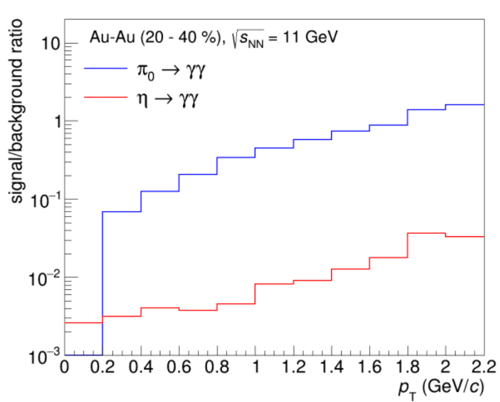




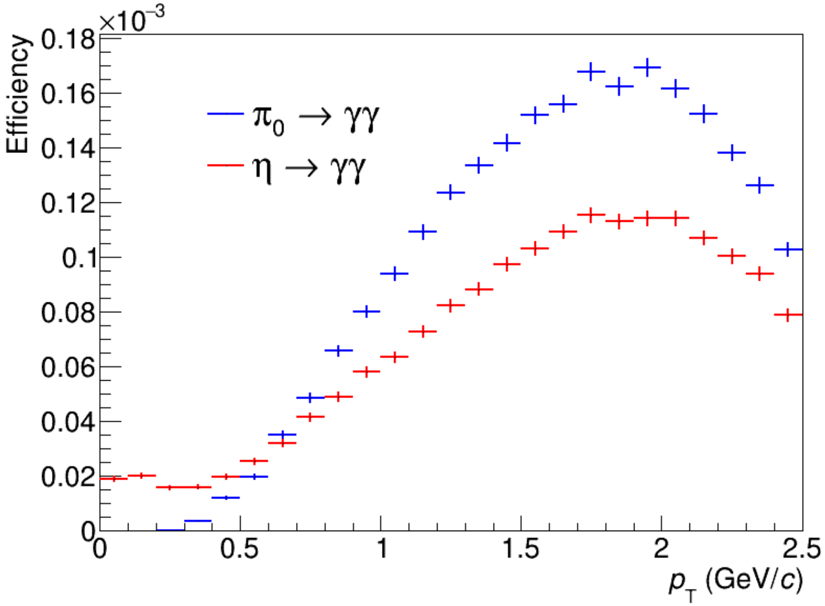
- Using 20M minimum bias URQMD events
- Pion signal is clearly visible in a wide p_T range
- Statistics not enough to study eta reconstruction



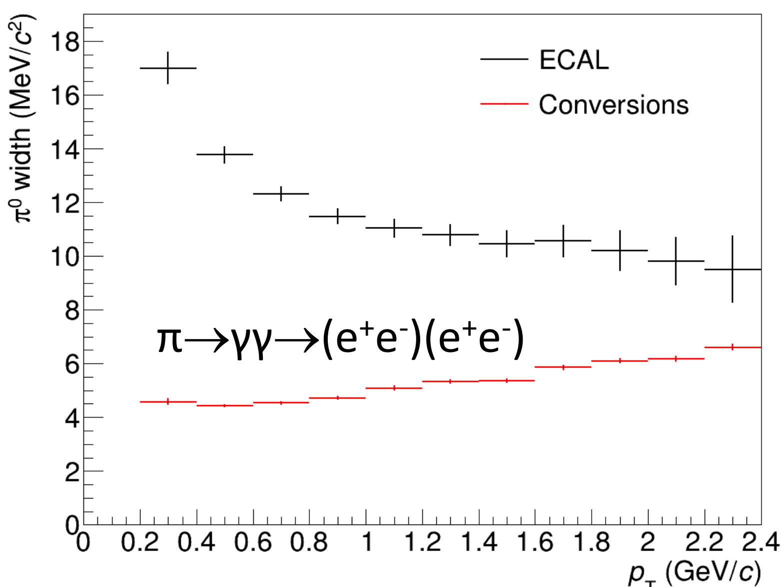


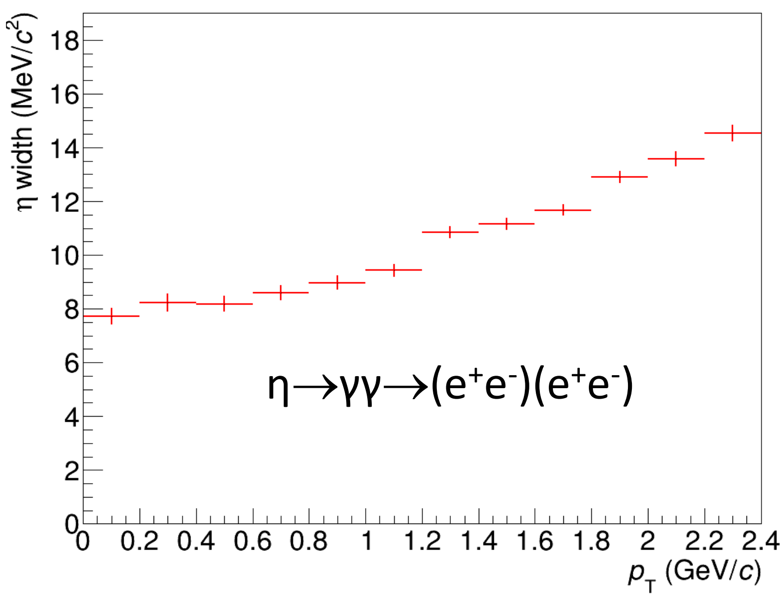


Neutral meson reconstruction efficiency

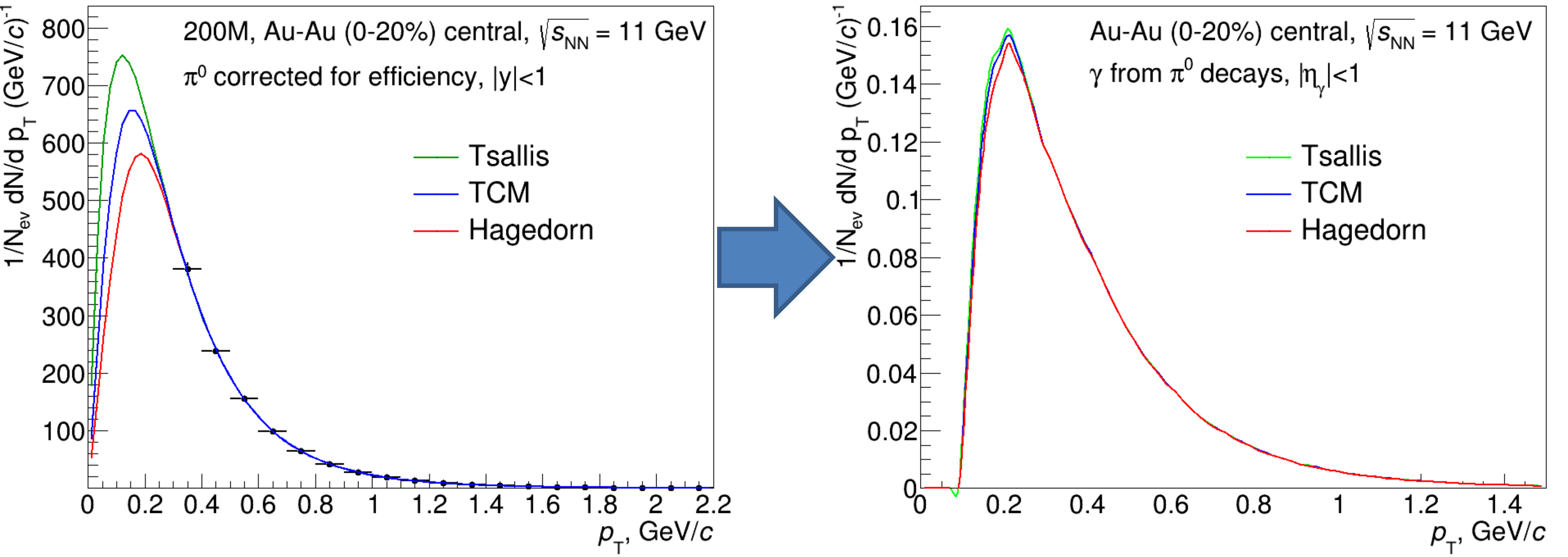


- Embedding technique used to study reconstruction efficiency vs p_T
- 700 000 min. bias UrQMD events @ 11 GeV
- 500 π^0 + 500 η embedded with flat p_T distribution
- Neutral meson reconstruction efficiency ~ 10^{-4}
- π^0 peak is significantly narrower with conversion method compared to ECAL





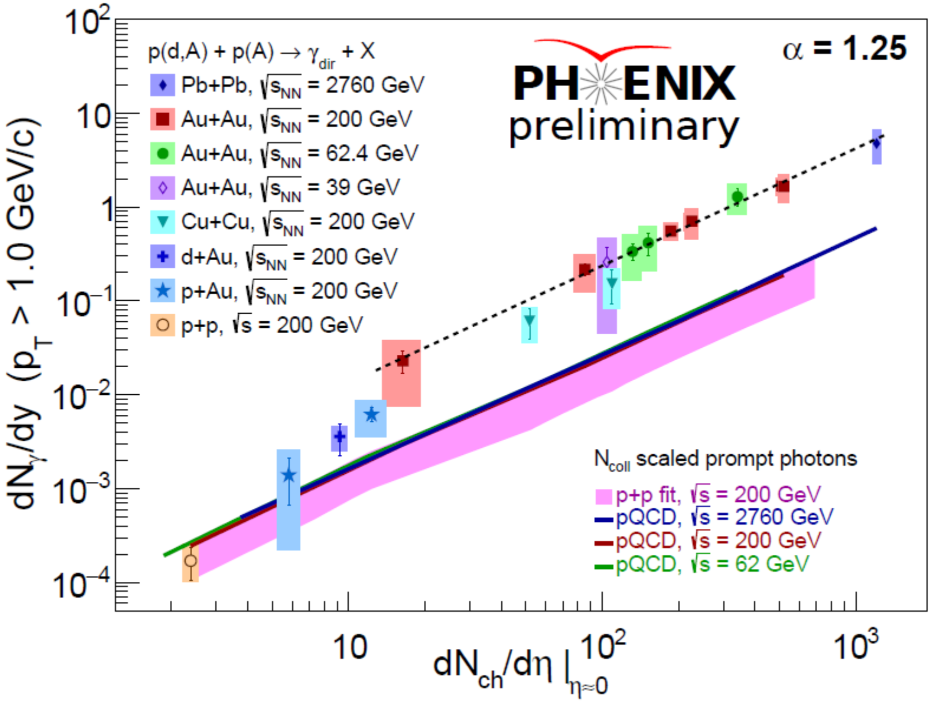
Corrected π^0 spectra



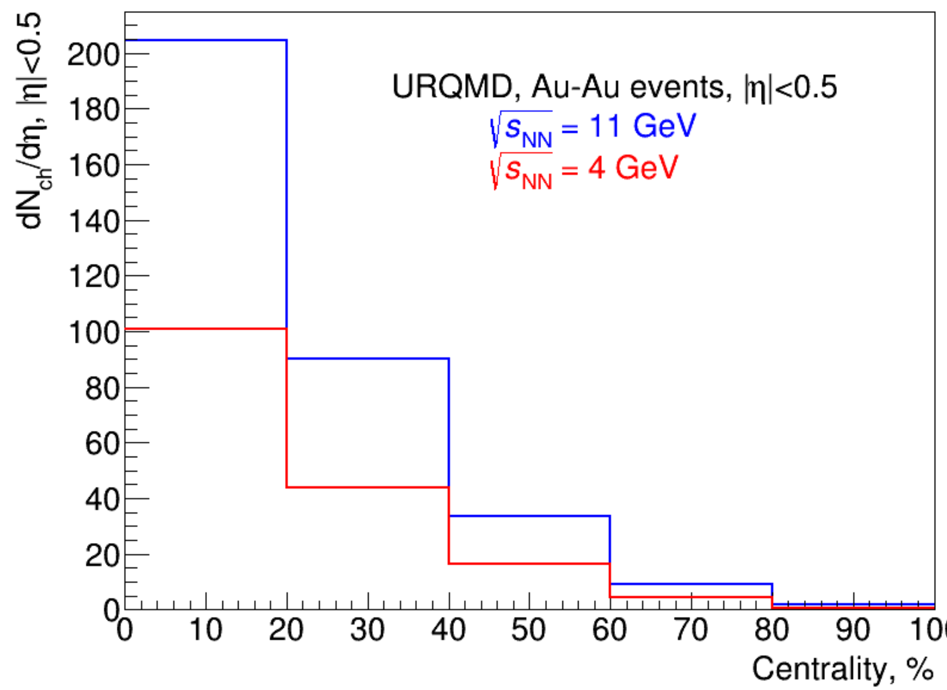
- Efficiency-corrected spectra are extrapolated down to 0 p_T:
  - Tsallis function
  - Two-component model (Bylinkin, Rostovtsev)
  - Hagedorn function
- The obtained fits cab be used to calculate photon spectra from π^0 decays
- Extrapolation uncertainties are significant only at low photon $p_T < 0.3$ GeV/c

Integrated direct photon yield

No reliable predictions for photons in UrQMD/PHSD -> using data driven method



Phys. Rev. Lett. 123, 022301



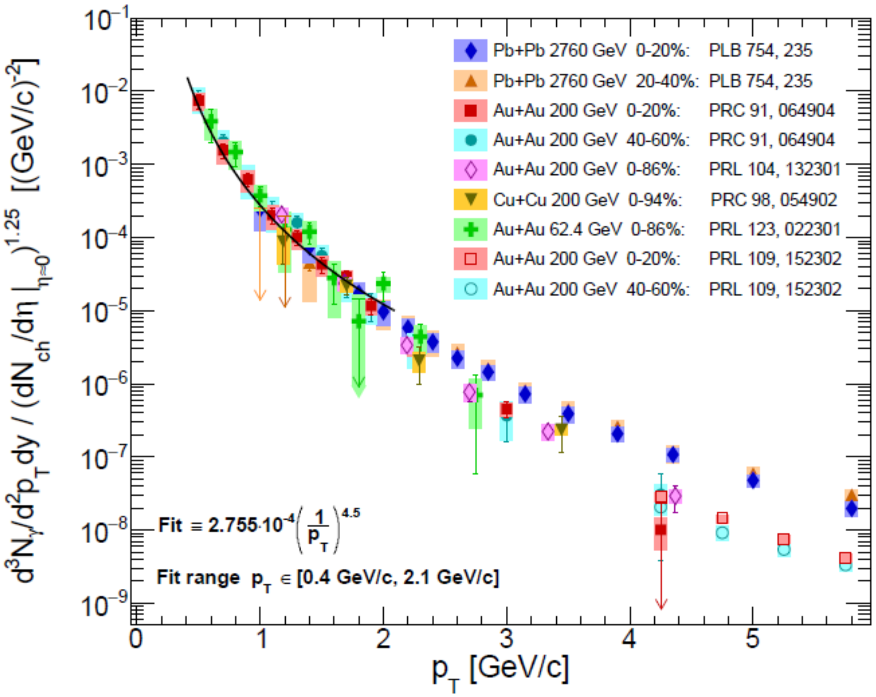
The integrated direct photon yield:

- scales as $(dN_{ch}/d\eta)^{1.25}$ in a wide range of multiplicities/collision energies
- the scaling is violated in small collision systems / small multiplicities ($dN_{ch}/d\eta < 20$)
- AA yield is a factor of ~10 larger than the N_{coll}-scaled yield in pp

Assuming this scaling still holds at lower energies, we can expect universal multiplicity scaling for

- (0-60)% centralities at 11 GeV
- (0-40)% centralities at 4 GeV

p_T-differential direct photon yields



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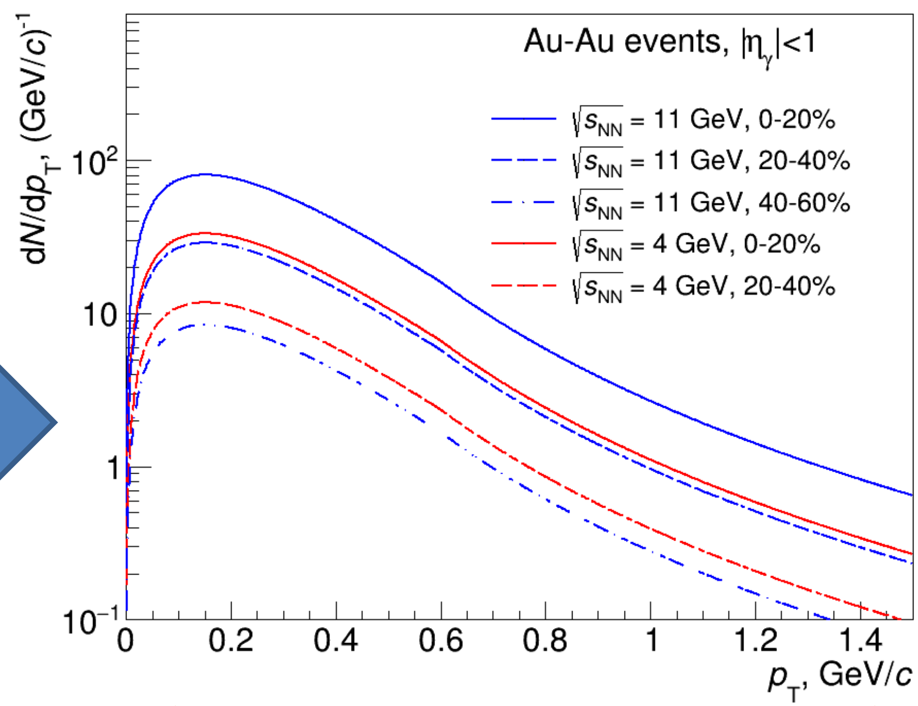
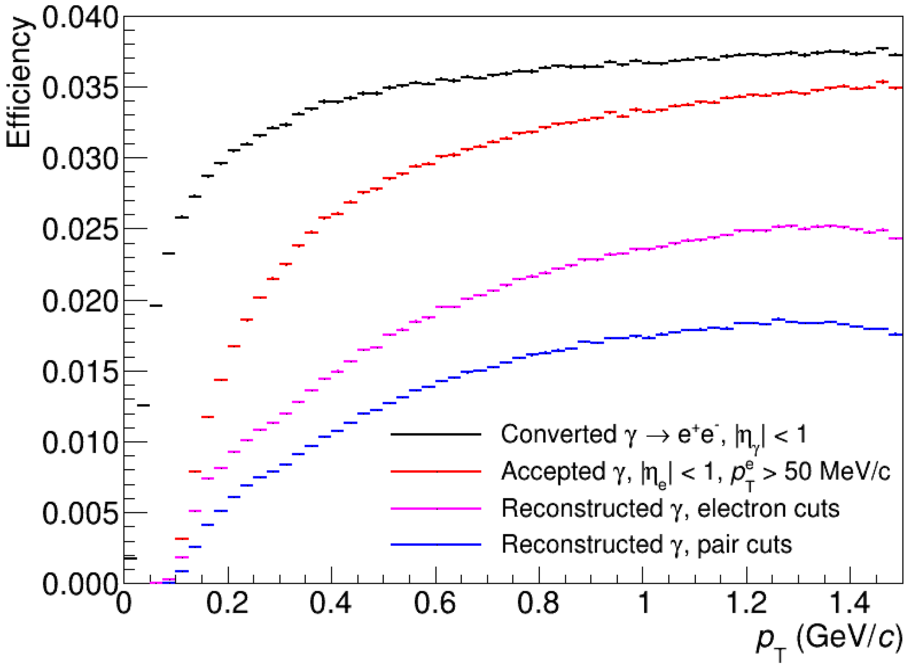
Khachatryan, Praszałowicz EPJC 80 (2020) 670

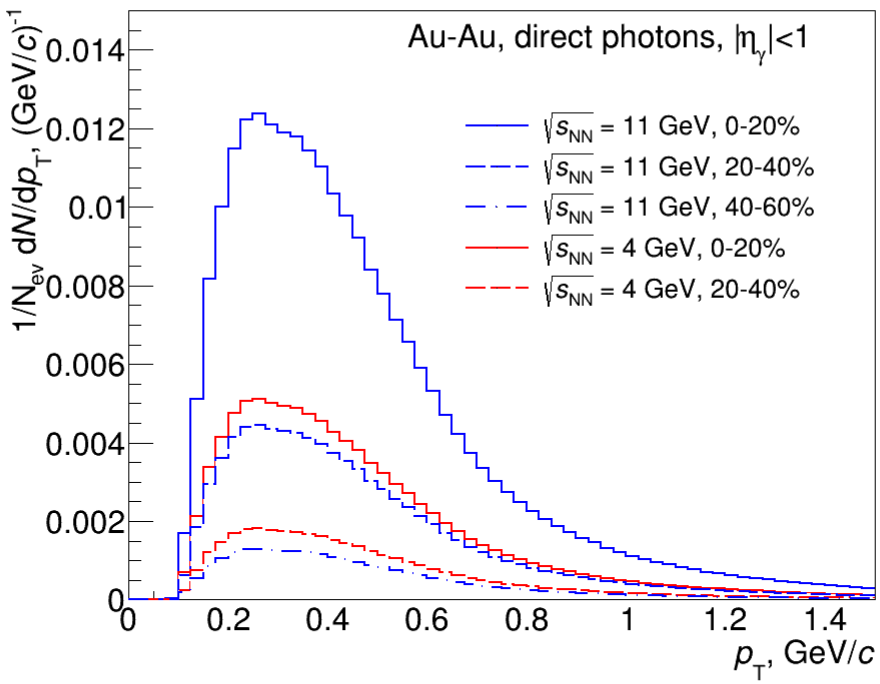


thermal power law

- Universal scaling of p_T-differential direct photon yields at moderate p_T is observed at RHIC/LHC
- It can be used to predict p_T spectra of direct photons at NICA energies for p_T > 0.6 GeV/c
- Switch to thermal spectrum at p_T < 0.6 GeV/c: $dN/dp_T \sim p_T \exp(-p_T/T)$
- Using conservative effective temperature T = 150 MeV (see e.g. *PRC* 93 (2016) 054901)

Reconstructed direct photons





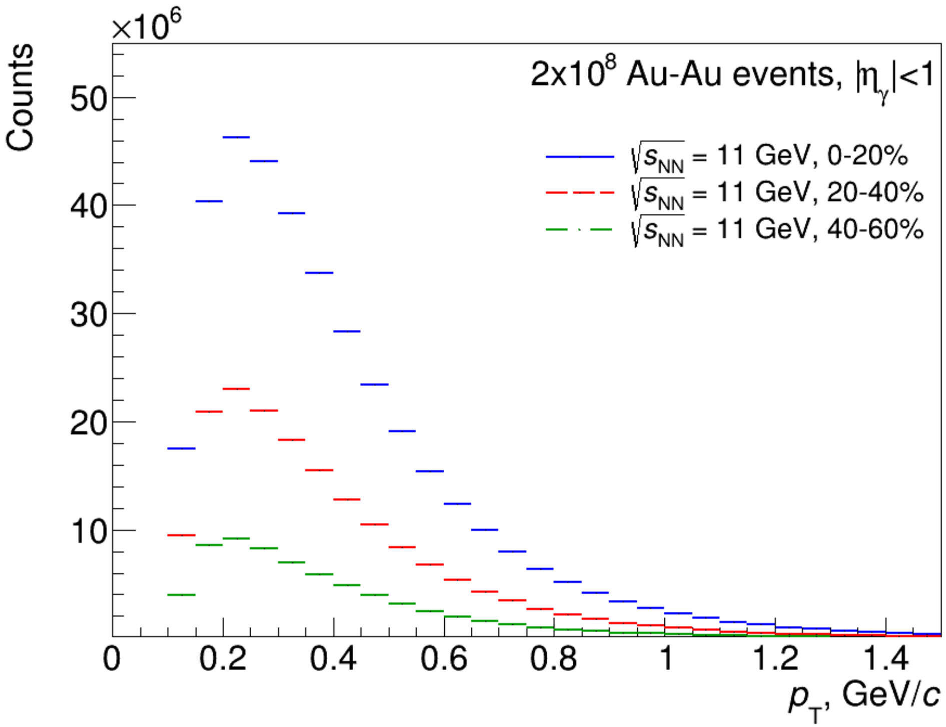
- Reconstructed direct photon spectra can be obtained from predicted direct photon yields multiplied by the photon reconstruction efficiency

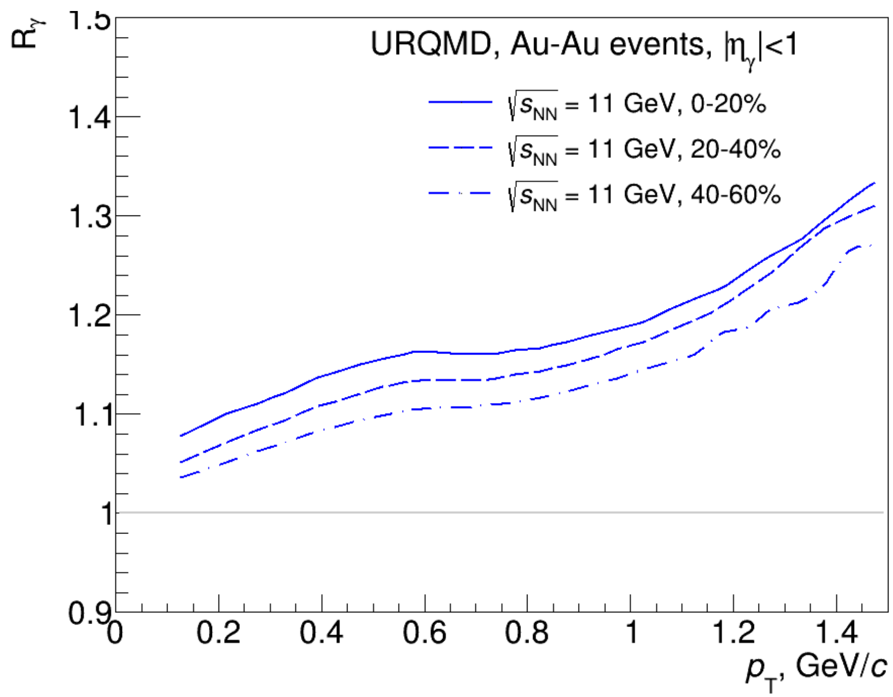
Inclusive photon spectra and R_γ ratio

$$R_\gamma = \frac{\gamma_{\rm inc}}{\gamma_{\rm decay}} = \frac{\gamma_{\rm inc}/\pi^0}{\gamma_{\rm decay}/\pi^0_{\rm param}}$$

Inclusive photon spectrum was simulated as a sum of direct and decay photon spectra

Excess over 1 shows the fraction of direct photons





- Systematic uncertainties on R_γ can be reduced to ~5%
- Conclusion: direct photon yields can be extracted with good accuracy down to low p_T

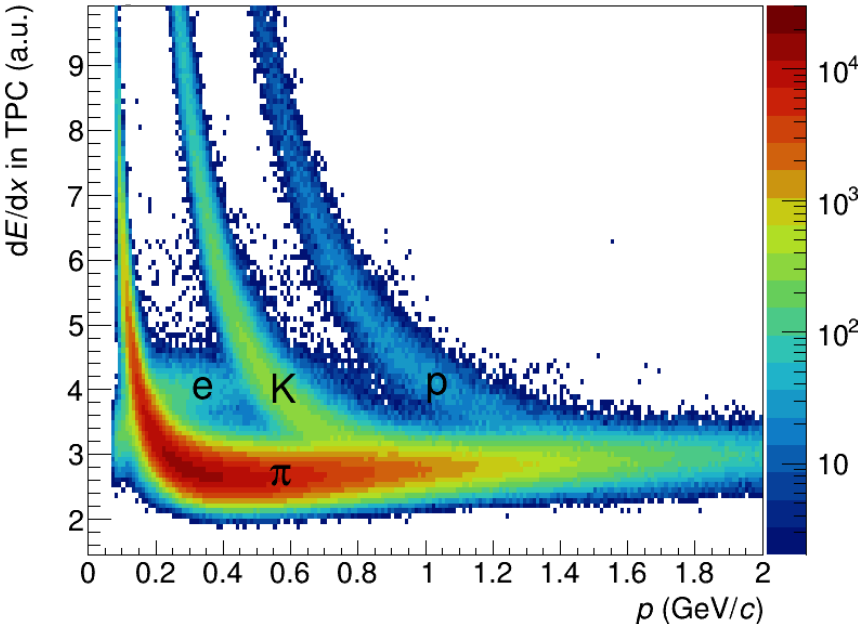
$$\gamma_{\rm direct} = \left(1 - \frac{1}{R_\gamma}\right) \cdot \gamma_{\rm inc}$$

Conclusions and outlook

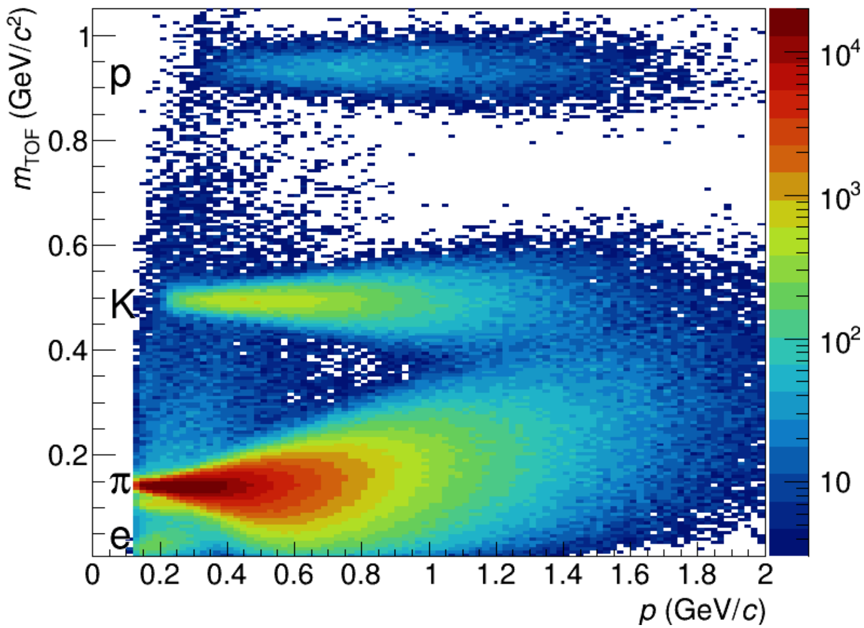
- Photons are valuable probes of dense hadronic matter produced in heavy ion collisions
- Photon conversion method is a powerful tool to measure photon and neutral meson spectra
- Reconstruction of thermal photon yields looks promising at MPD
- Next:
  - Evaluate perspectives of thermal photon flow measurements
  - Feasibility studies on the dedicated convertor and Stage 2 setup

BACKUP

Electron PID

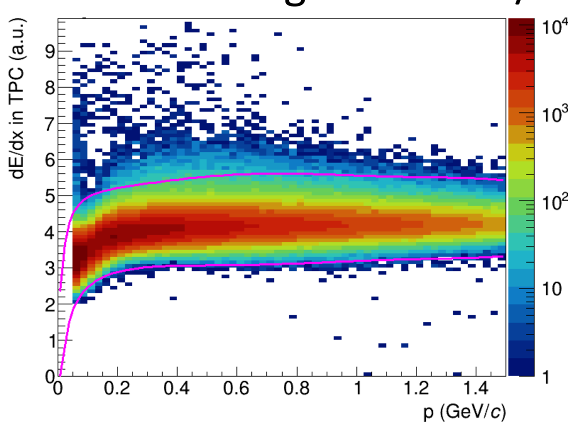


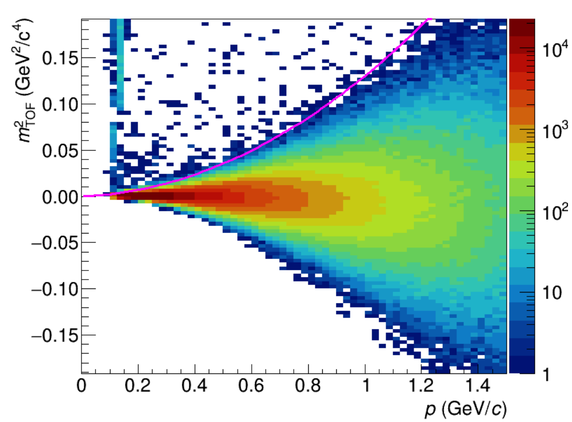
TPC dE/dx: 0.2 - 0.5 GeV/*c*



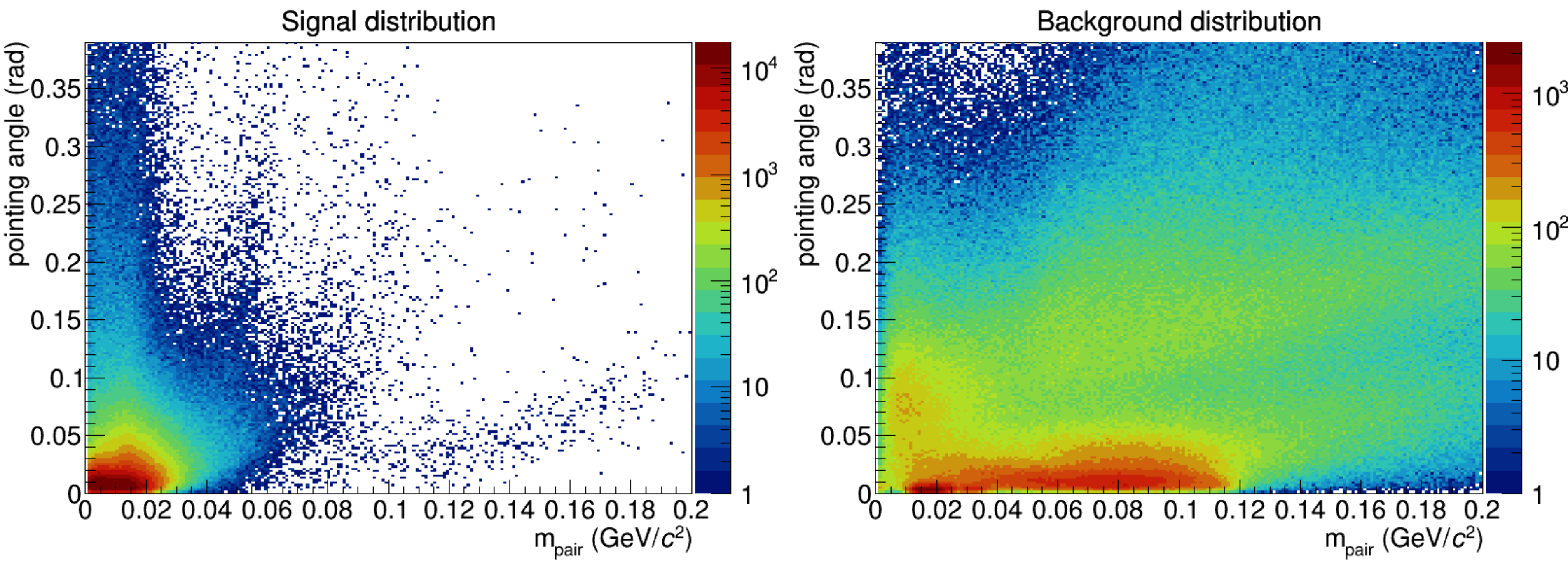
TOF: p_T < 0.3 GeV/*c*

Selecting tracks in +/-4σ around the mean value:

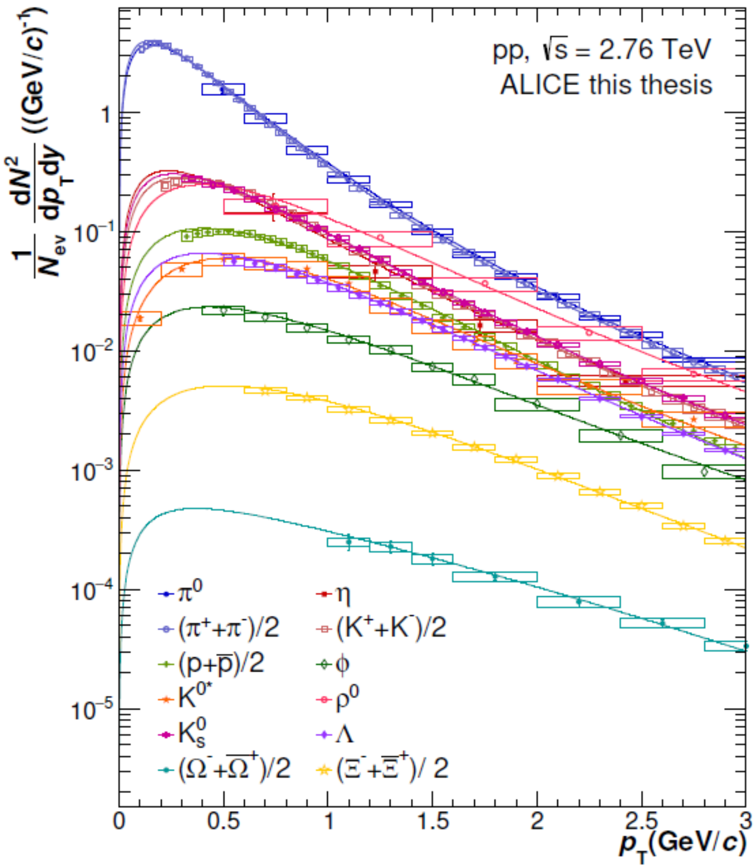




Optimization of electron pair selection cuts



Fit functions for pt distributions



- Two-component model (Bylinkin, Rostovtsev):

$$E\frac{\mathrm{d}^3\sigma}{\mathrm{d}p^3} = A_{\mathrm{e}}\exp\frac{(M-\sqrt{p_{\mathrm{T}}^2+M^2})}{T_{\mathrm{e}}} + A\left(1+\frac{p_{\mathrm{T}}^2}{n_{\mathrm{br}}T^2}\right)^{-n_{br}}$$

- Hagedorn fit:

$$\frac{dN}{dydp_{\mathrm{T}}} = p_{\mathrm{T}}\ A\ \left(\exp\left(-a*p_{\mathrm{T}}-|b|p_{\mathrm{T}}^2\right)+\frac{p_{\mathrm{T}}}{p_0}\right)^{-n}$$

- Tsallis fit:

$$E\frac{d^3\sigma}{dp^3} = \frac{1}{2\pi}\frac{d\sigma}{dy}\frac{(n-1)(n-2)}{(nT)^2}\left(1+\frac{m_T}{nT}\right)^{-n}$$