Feasibility of thermal photon measurements in the future MPD experiment at NICA

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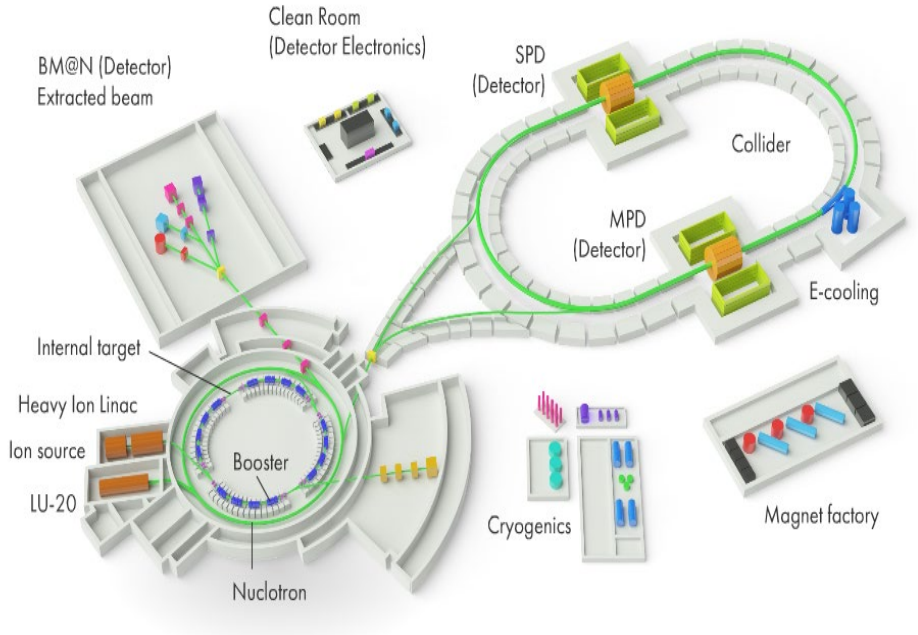
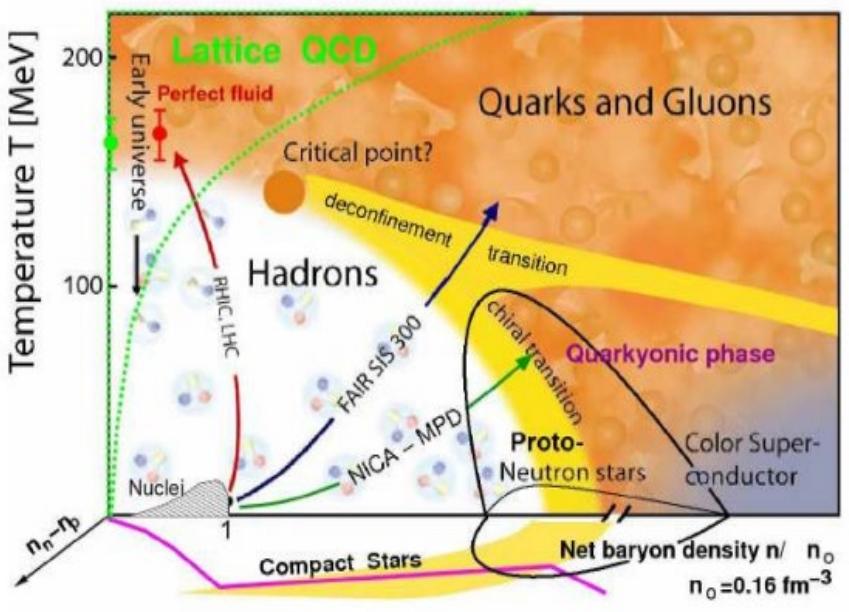
TWENTIETH LOMONOSOV
CONFERENCE August, 19-25, 2021
ON ELEMENTARY PARTICLE PHYSICS
MOSCOW STATE UNIVERSITY

This work was supported by RFBR according to the research project № 18-02-40045

Heavy ion collisions at NICA

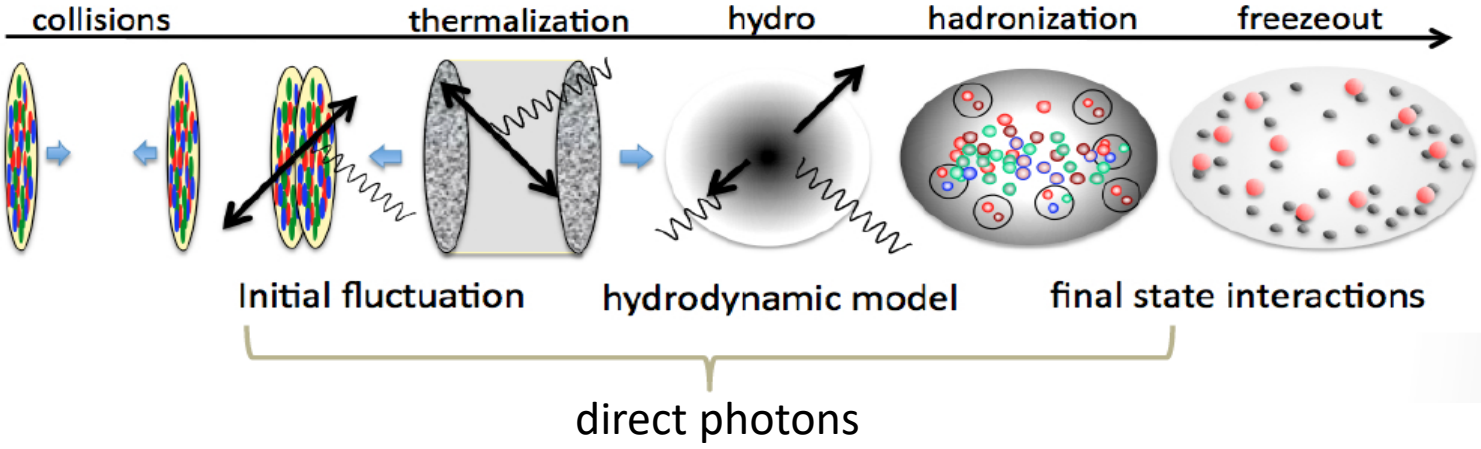


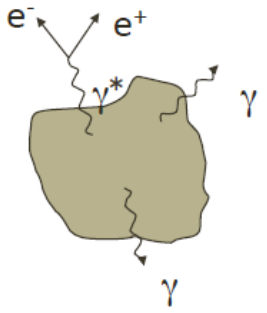


- A mega-science project NICA, Dubna, JINR
- Modernization of existing Nuclotron facility
- Parameters:
  - ✓ relativistic ions up to Au, $\sqrt{s_{NN}}$ = 4-11 GeV
  - ✓ polarized p and d, $\sqrt{s_{NN}}$ = 27 GeV (for p)
  - ✓ luminosity 10^{27} cm^{-2}s^{-1}
- Working experiment: BM@N (fixed target)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

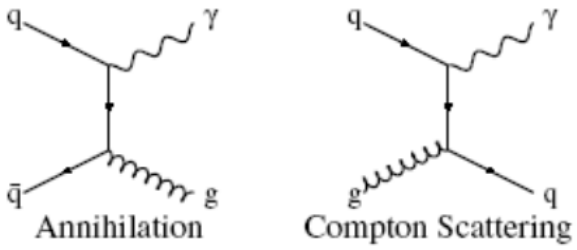
Thermal radiation in heavy ion collisions



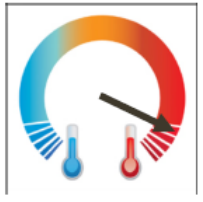


- Photons leave the medium without interaction
- Black body radiation: inverse slope proportional to T_{eff}

Thermal photons from QGP

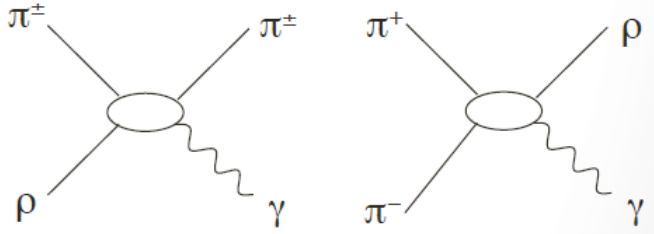


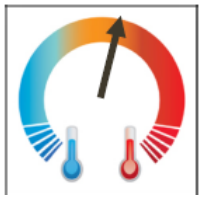
Naïve:



Hot medium
Large yield

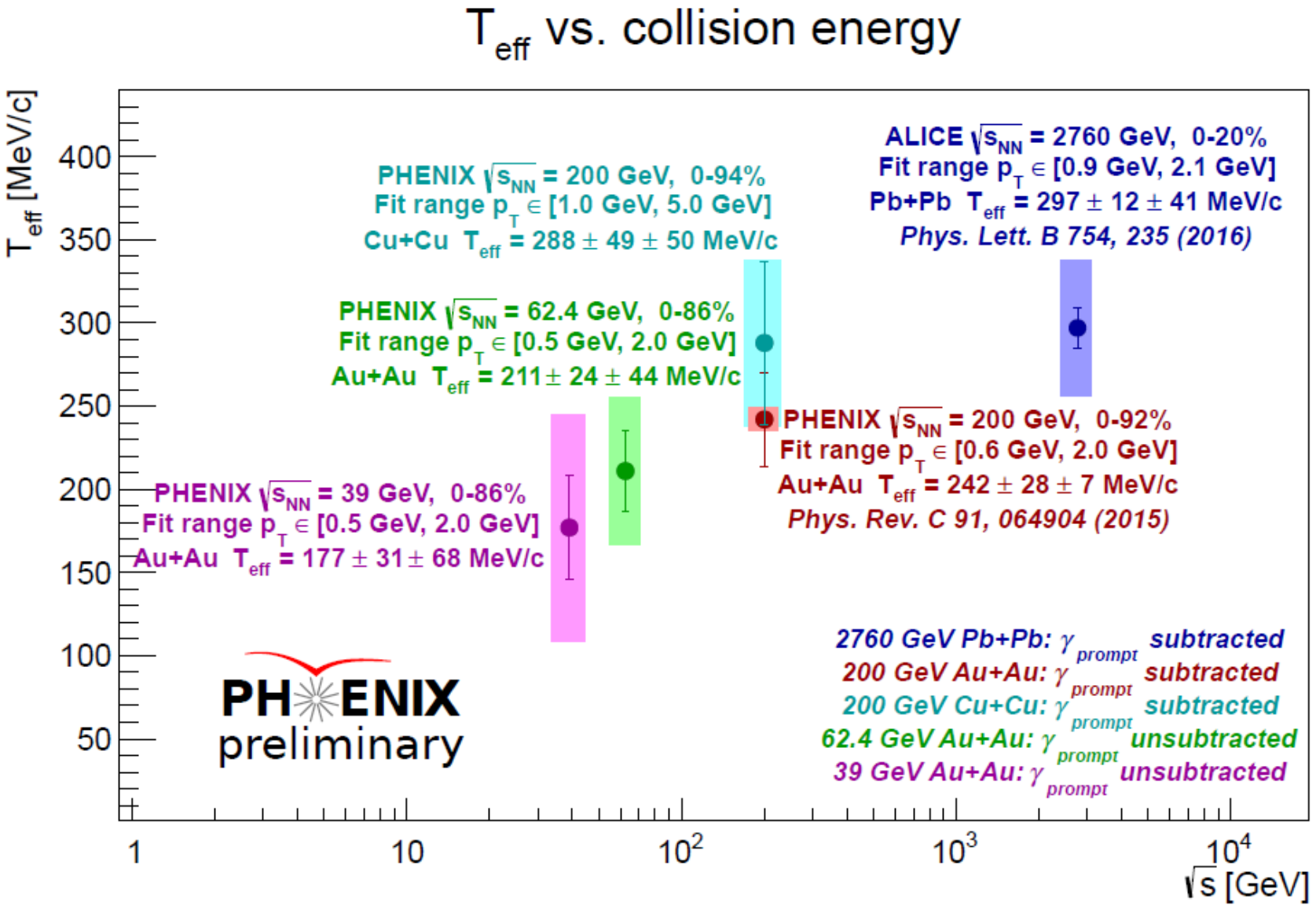
Thermal photons from hadron gas





Warm medium
Moderate yield

Effective temperature vs energy

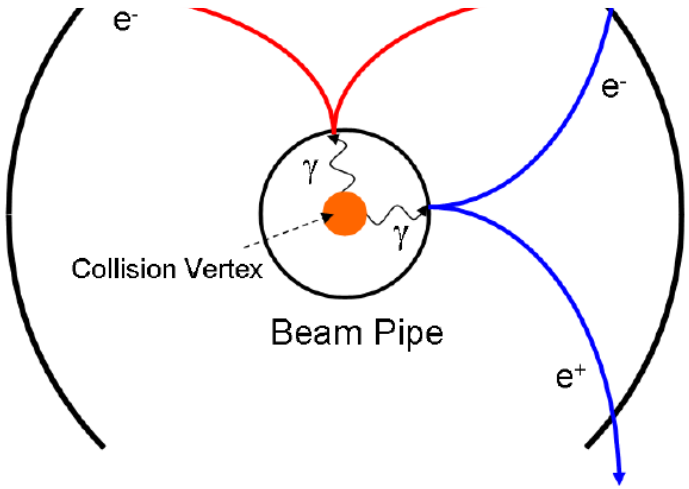


J. Phys.: Conf. Ser. 1070 (2018) 012012

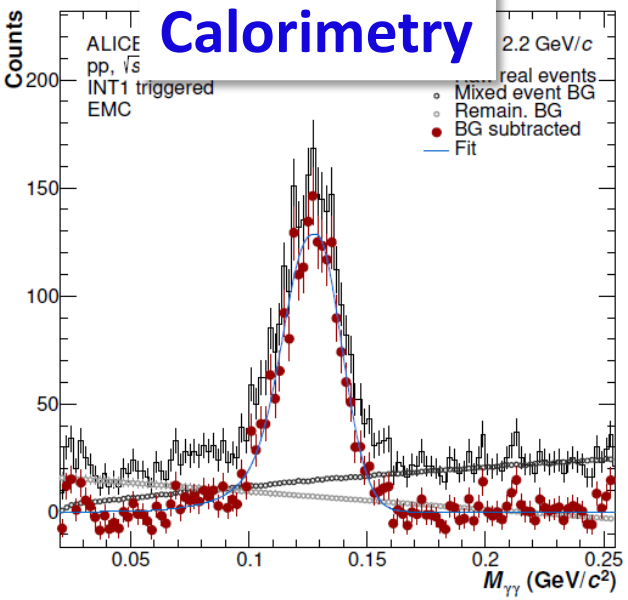
Photon reconstruction: two methods

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

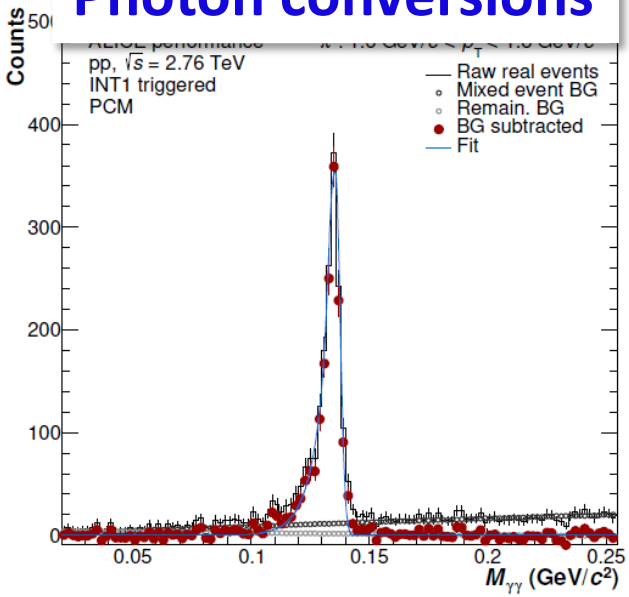
- Photon conversion $\gamma \rightarrow e^+e^-$ in the material
  - $P = 1 - \exp(-7/9\ x/X_0)$
  - Efficient at $0.5 < p_T < 4$ GeV/c
  - Much better resolution at low p_T



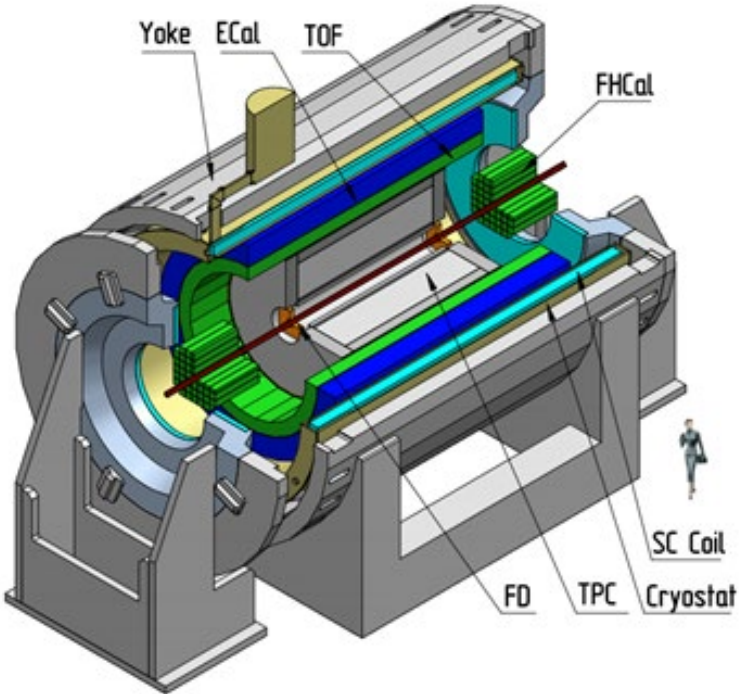
Calorimetry

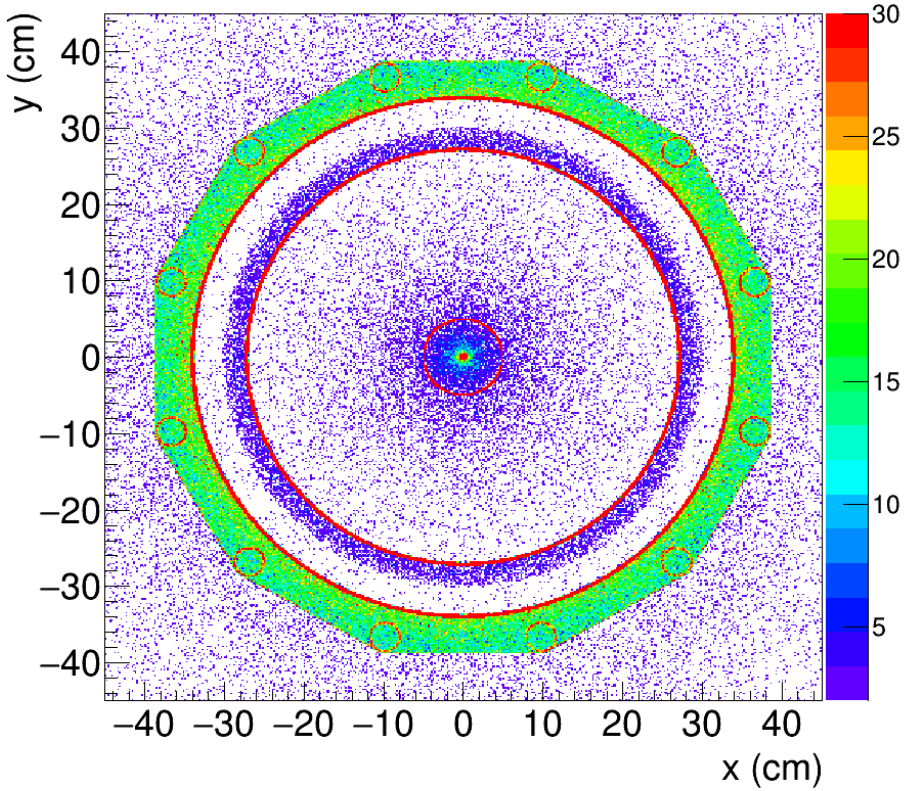


Photon conversions



Conversions at MPD





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

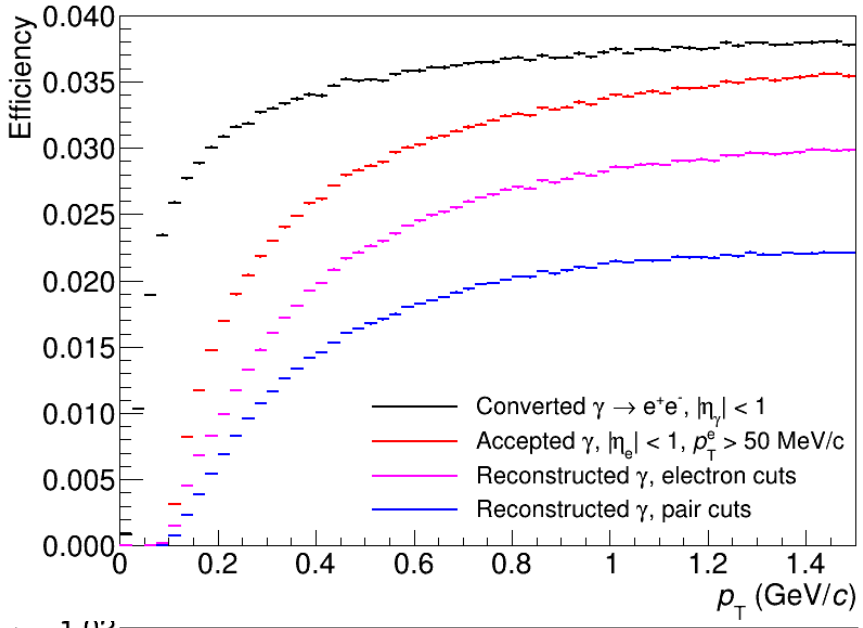
Main conversion structures in Stage 1:

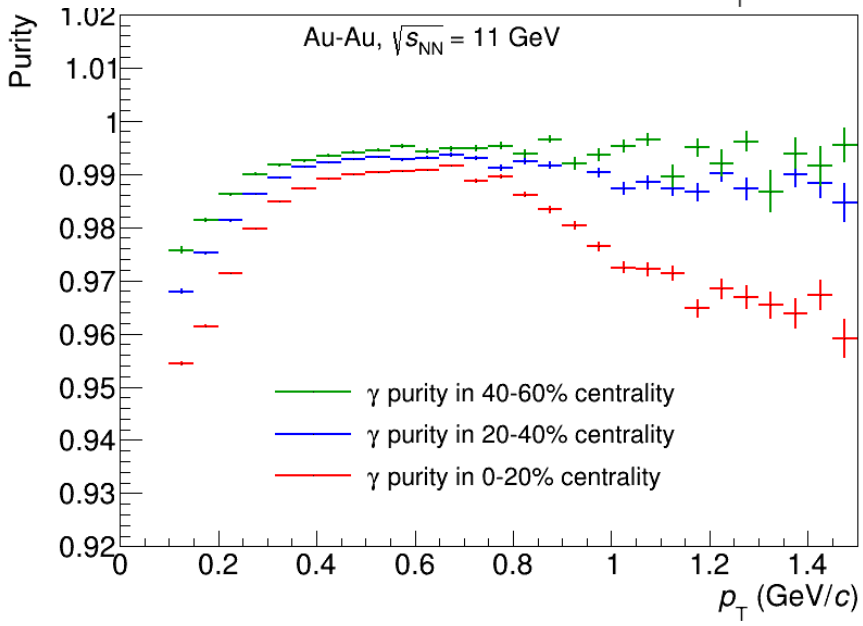
- Beam pipe: 0.3% X_0
- Inner TPC barrel structures: 2.4% X_0

Future:

- Inner tracking system

Conversion reconstruction efficiency





- Studied with MPDROOT Stage 1 setup
- Using MpdParticle to build secondary vertices
- Cuts optimized to maximize signal significance
- Contribution of (non-gamma) background < 5%

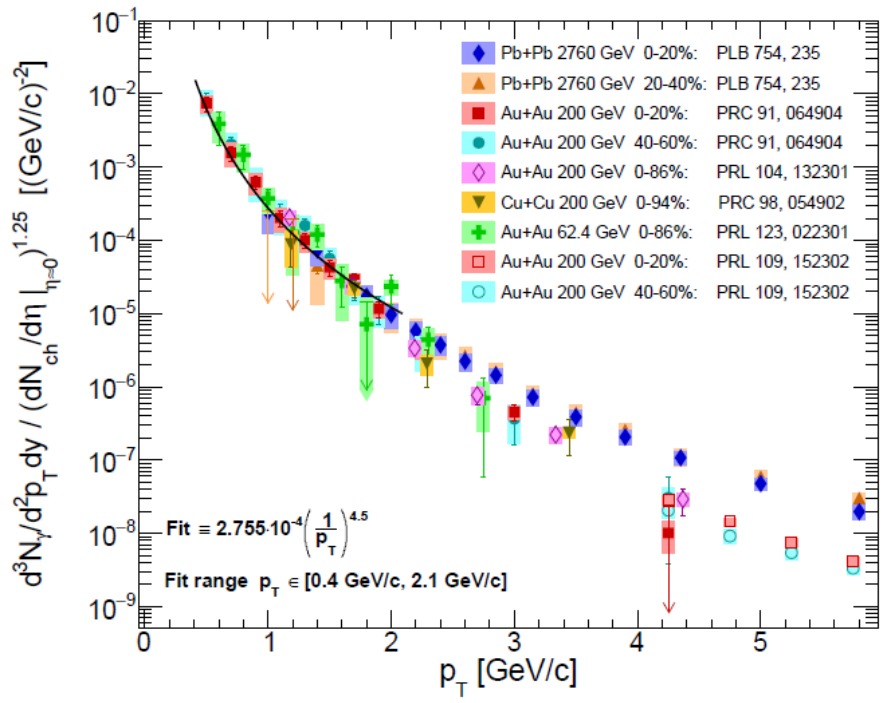
Typical cuts on electrons:

- $|\eta|<1$
- $p_T > 50$ 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:
  $\theta < \exp(-2.777-2.798* p_T) + 0.0175$
- $m_{ee} < 0.022 + 0.017* p_T$ [GeV]
- ee plane orientation wrt B:
  $\Psi_{Pair} < 0.1$ rad

p_T-differential direct photon yields



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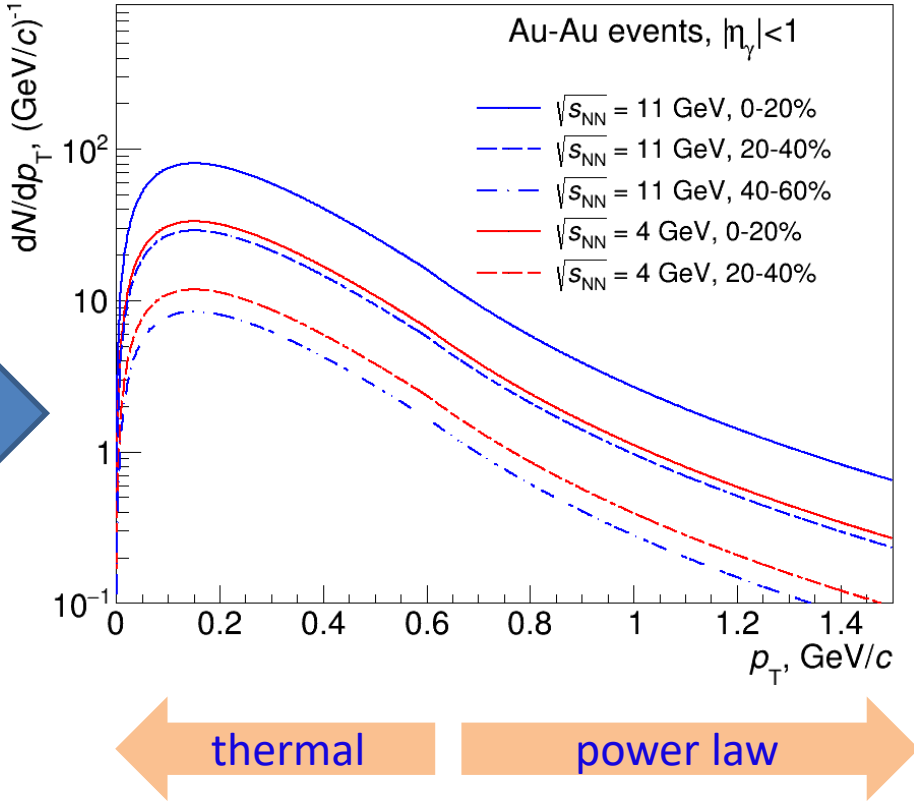
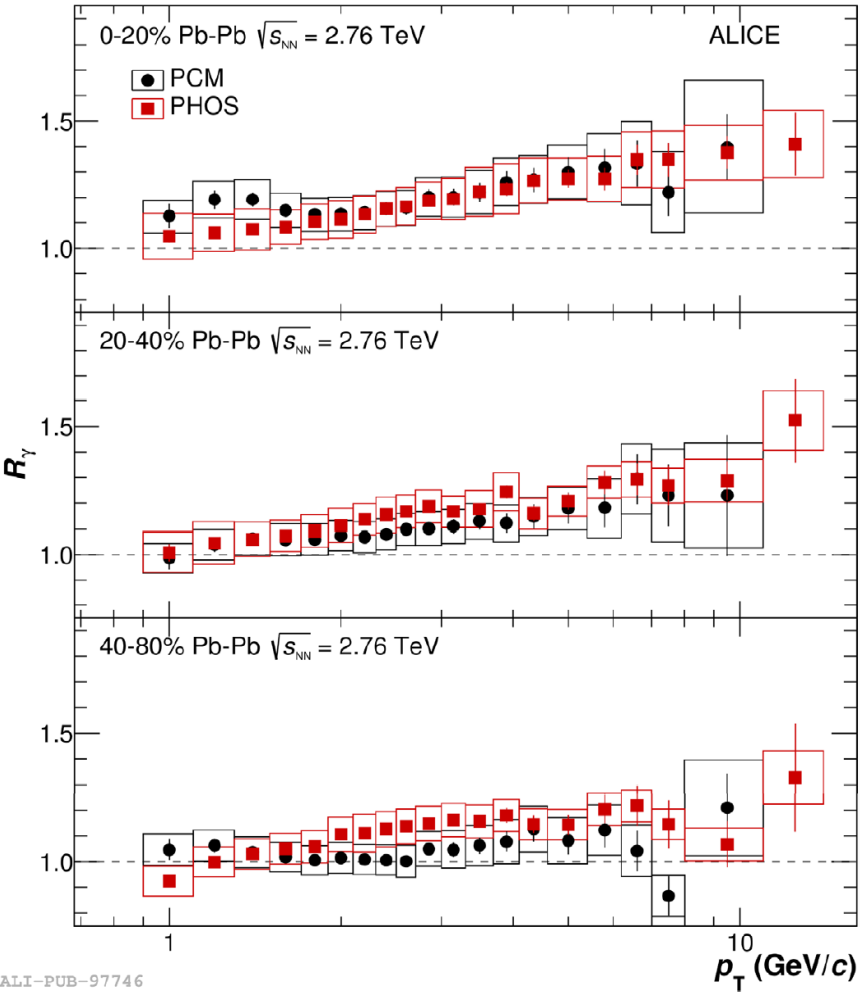


- Universal scaling of p_T-differential direct photon yields at moderate p_T is observed at RHIC/LHC
- It can be used to predict p_T spectra of direct photons at NICA energies for $p_T > 0.6$ GeV/c
- Switch to thermal spectrum at $p_T < 0.6$ GeV/c: $dN/dp_T \sim p_T \exp(-p_T/T)$
- Using conservative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

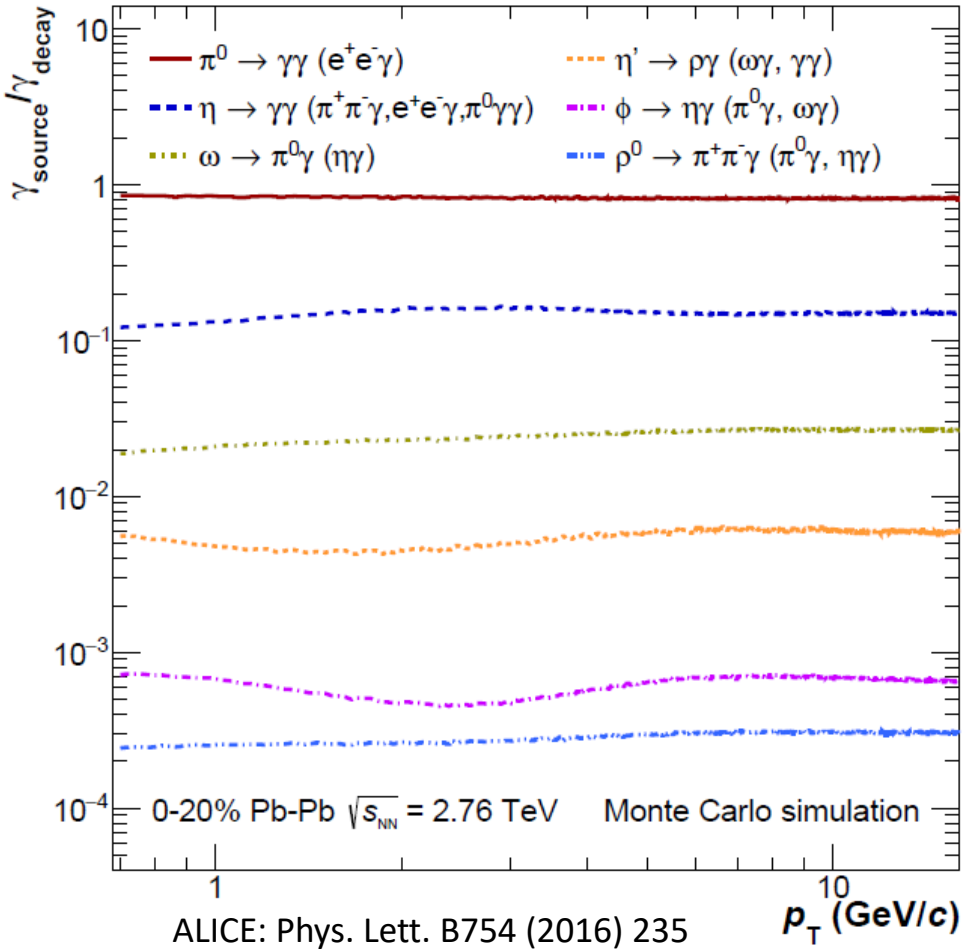
Challenge: decay photons

Inclusive photon spectra are dominated by decay photons

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



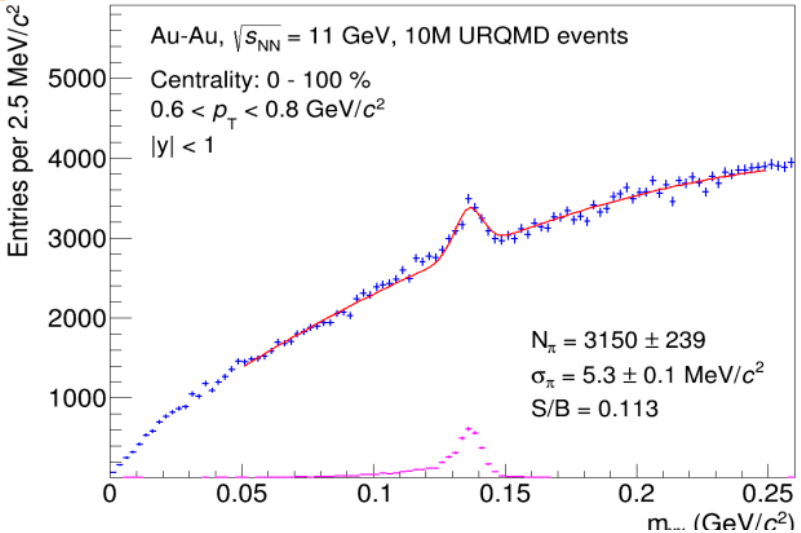
Relative contributions of different hadrons to the total decay photon spectrum as a function of the decay photon transverse momentum

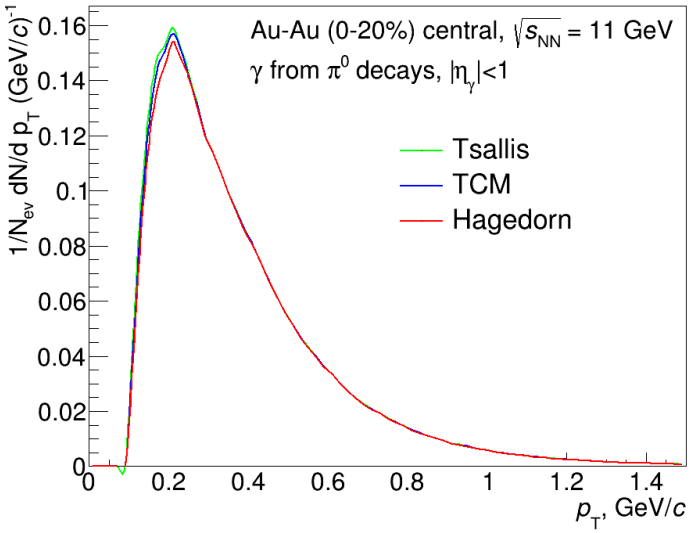


ALICE: Phys. Lett. B754 (2016) 235

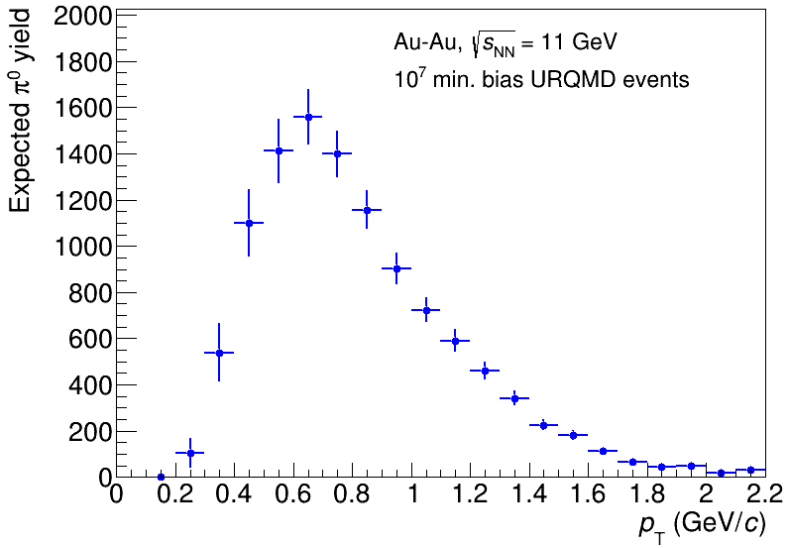
Neutral meson reconstruction

- Using 10M minimum bias URQMD events
- Pion signal is clearly visible in a wide p_T range

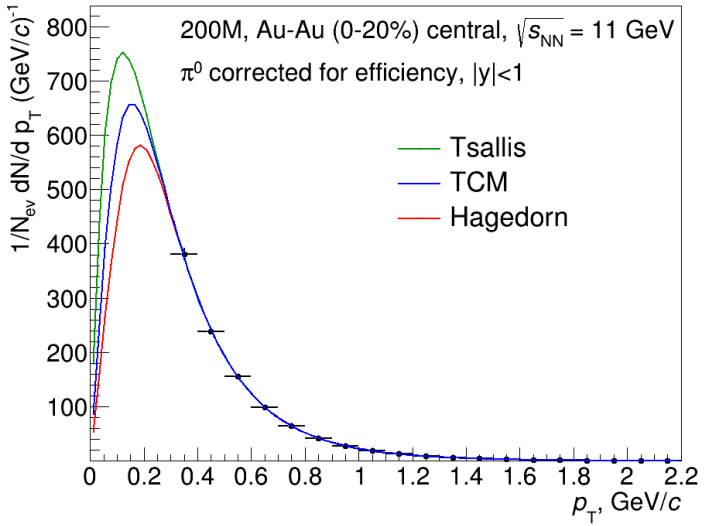




The obtained fits used to calculate photon spectra from π^0 decays



Efficiency-corrected spectra are extrapolated down to 0 p_T

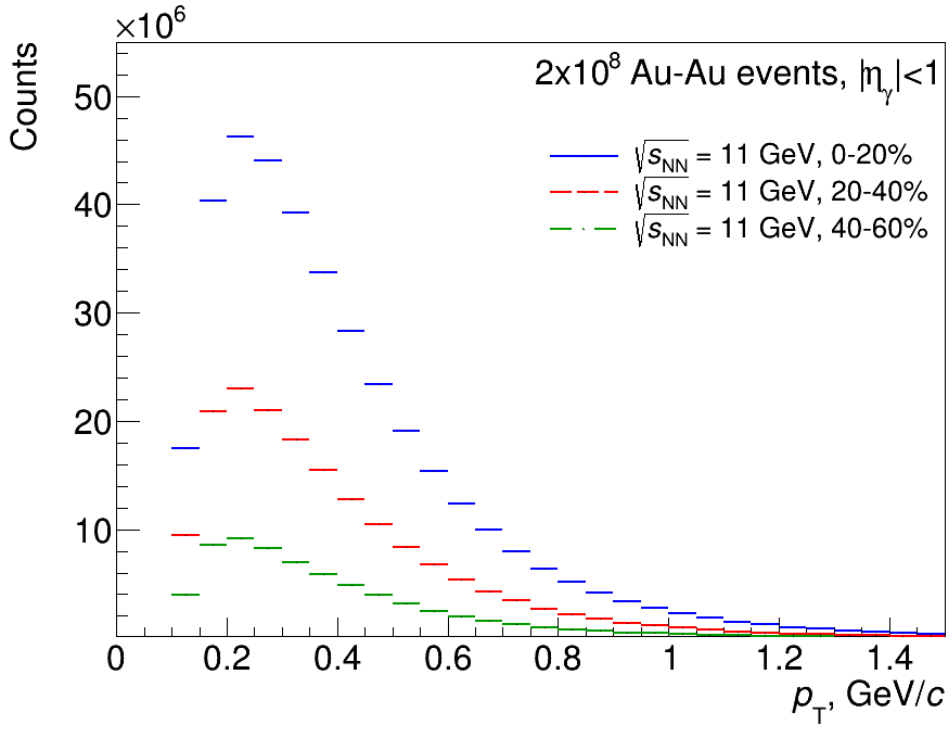


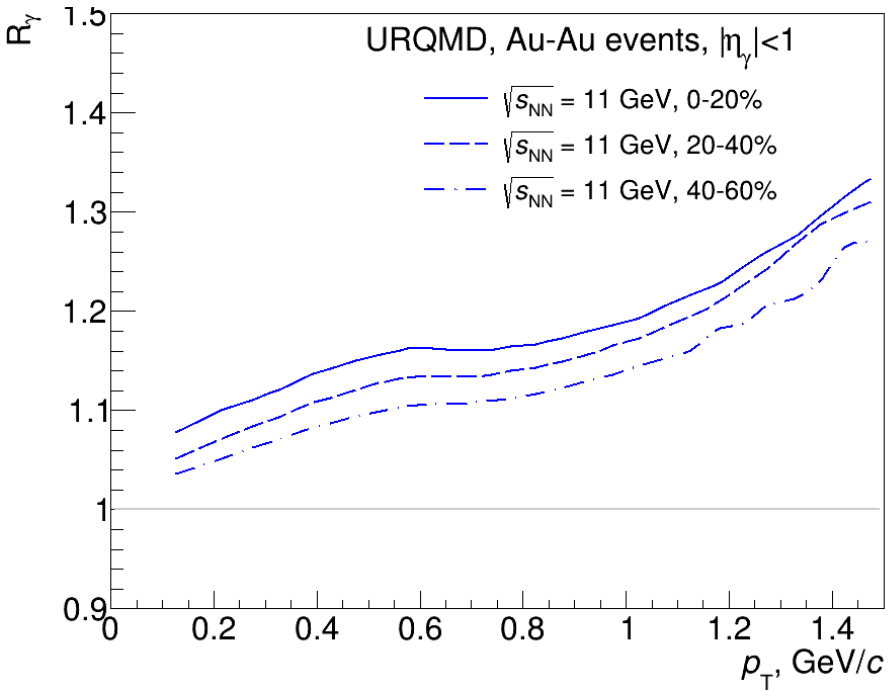
Inclusive photon spectra and R_γ ratio

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

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

Excess over 1 shows the fraction of direct photons

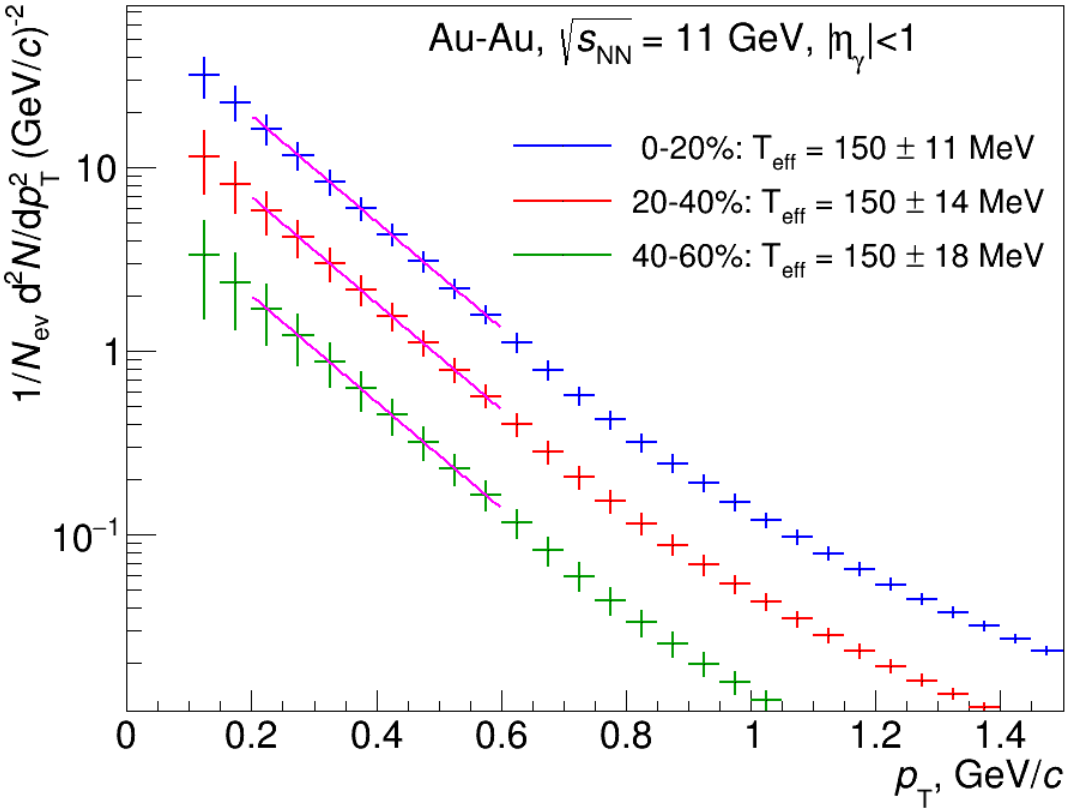




- Systematic uncertainties on R_γ can be reduced to ~2-5%
- Conclusion: direct photon yields can be extracted with good accuracy down to low p_T

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

R_γ and Temperature uncertainties

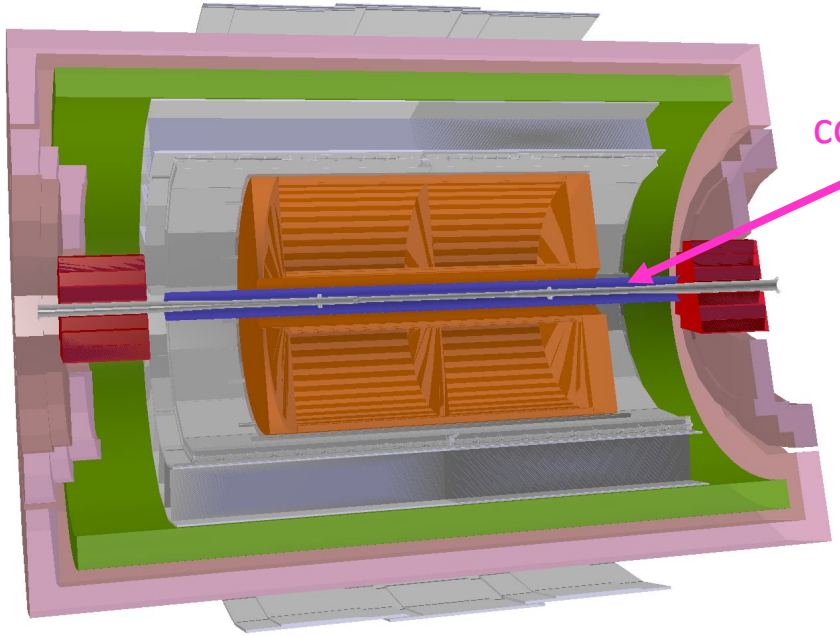


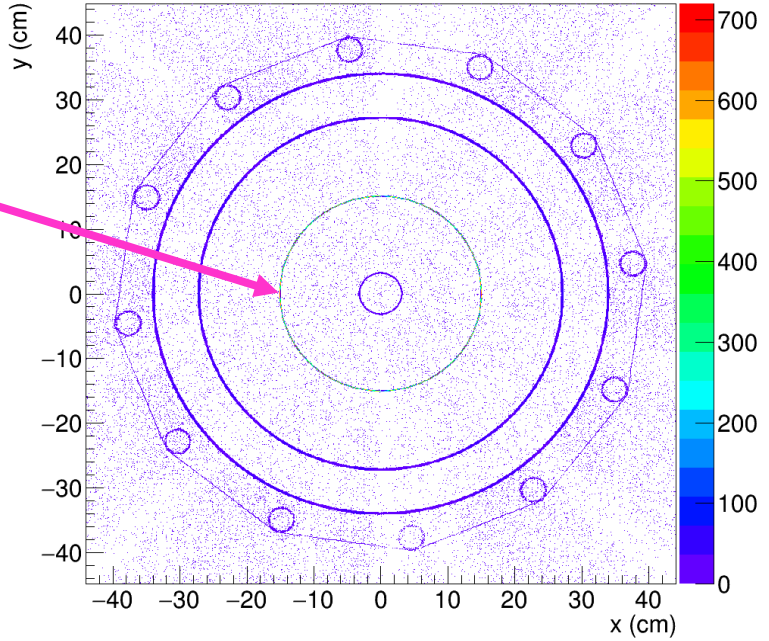
- Direct photon spectra with R_γ systematic uncertainty 2%

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

- Thermal spectrum at p_T < 0.6 GeV/c: $dN/dp_T \sim p_T \exp(-p_T/T)$
- T_{eff} uncertainty ~ 10%
- Decrease in R_γ increase T_{eff} uncertainty

Dedicated photon converter?



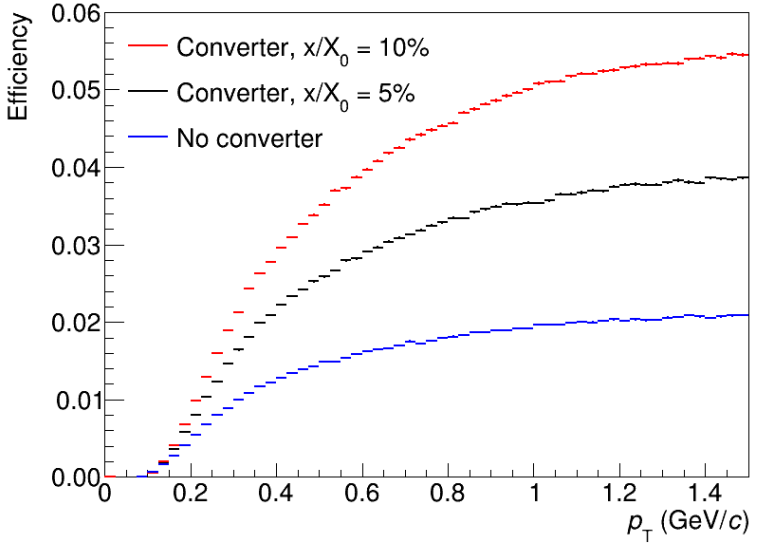


A dedicated conversion layer under investigation:

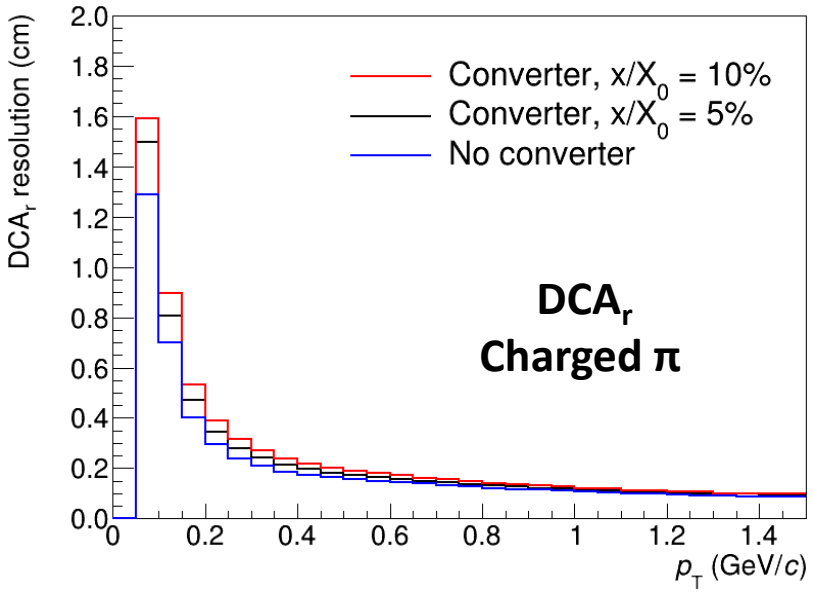
- Cylindrical copper pipe
- Radius – 15 cm
- Radiation length: 5% and 10% (0.7 and 1.4 mm)

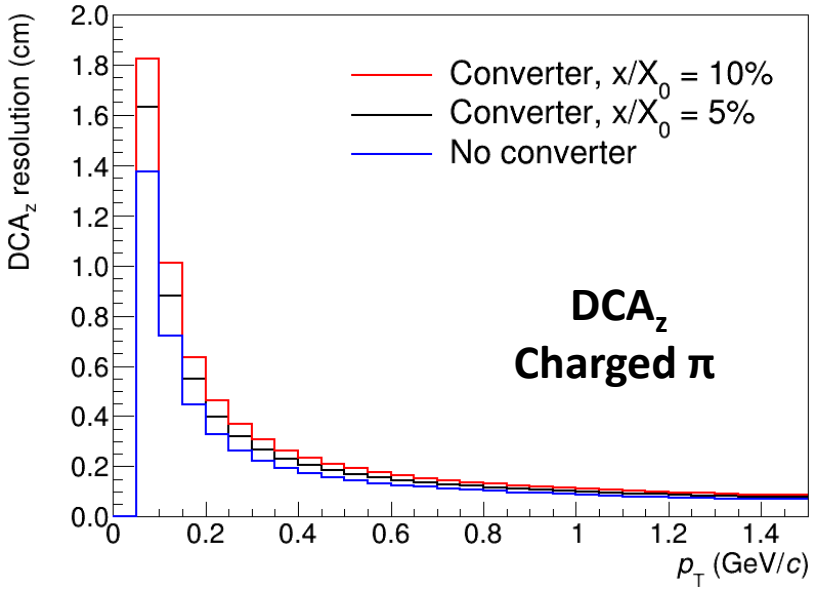
Advantages:

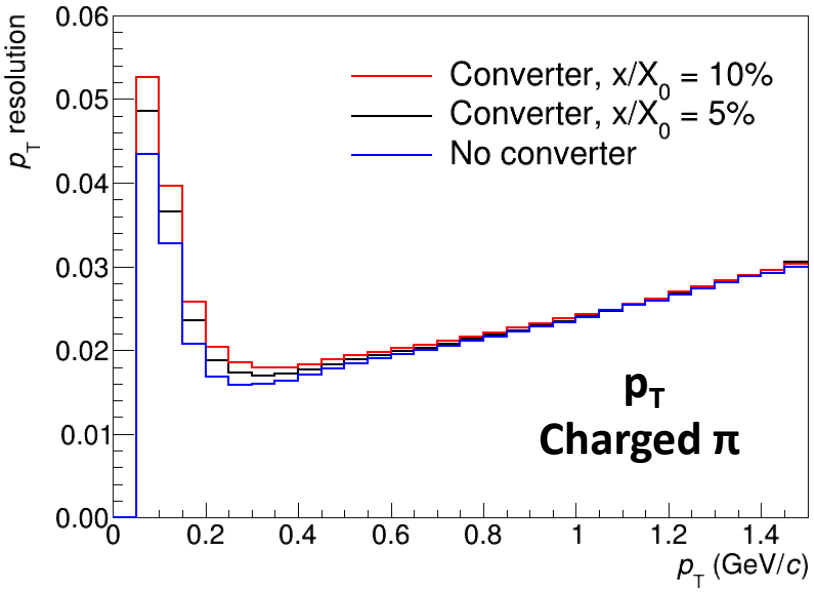
- Photon reconstruction efficiency can be improved by factor ~3
- Minimization of systematic uncertainties due to well known material budget



Resolution of track parameters

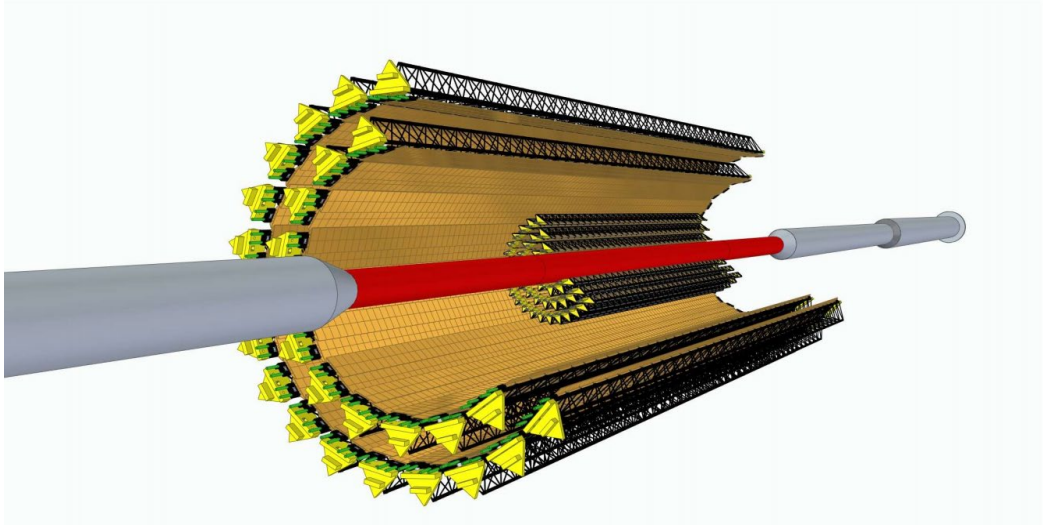


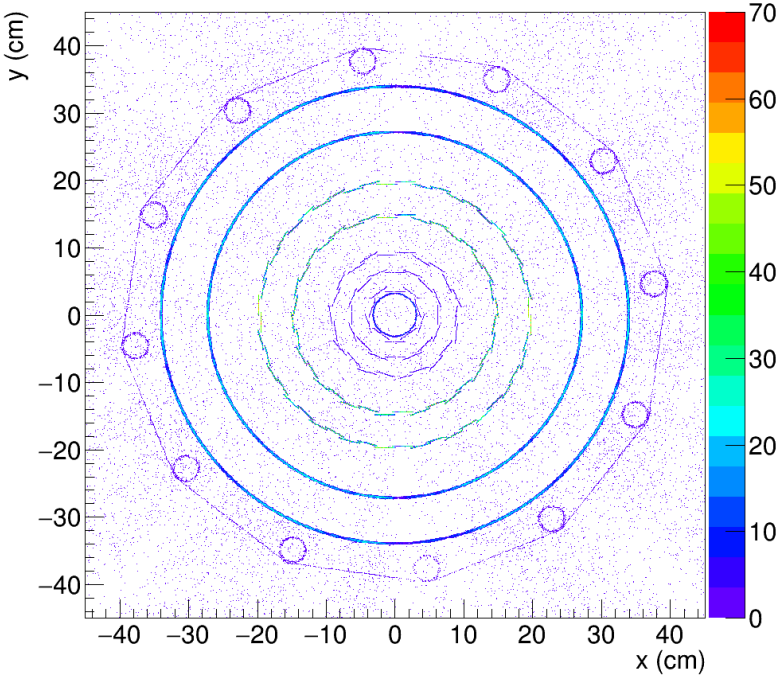




- Marginal decrease in reconstruction quality of charged particles
- The decrease noticeable only at low $p_T < 0.5$ GeV/c

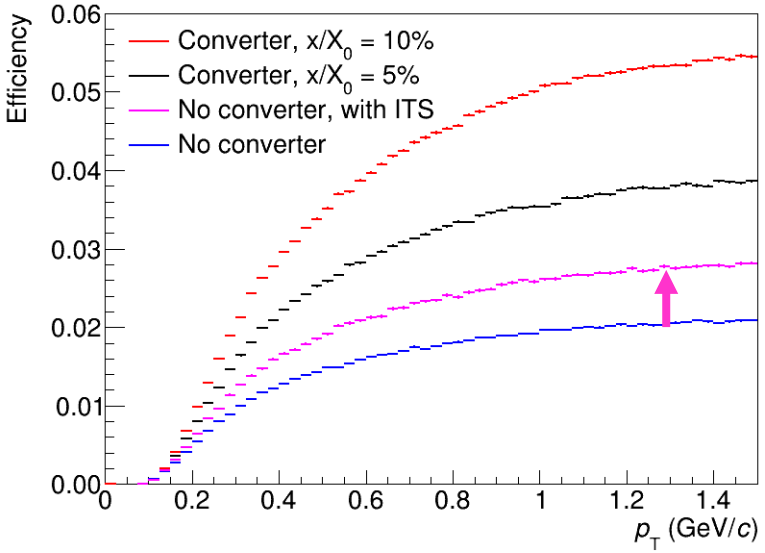
Conversions in Stage 2





Inner tracking system in Stage 2

- 5 layers of Monolithic Active Pixel Sensors
- ~0.4% X_0 in current design
- Photon reconstruction efficiency slightly improves compared to stage 1 setup



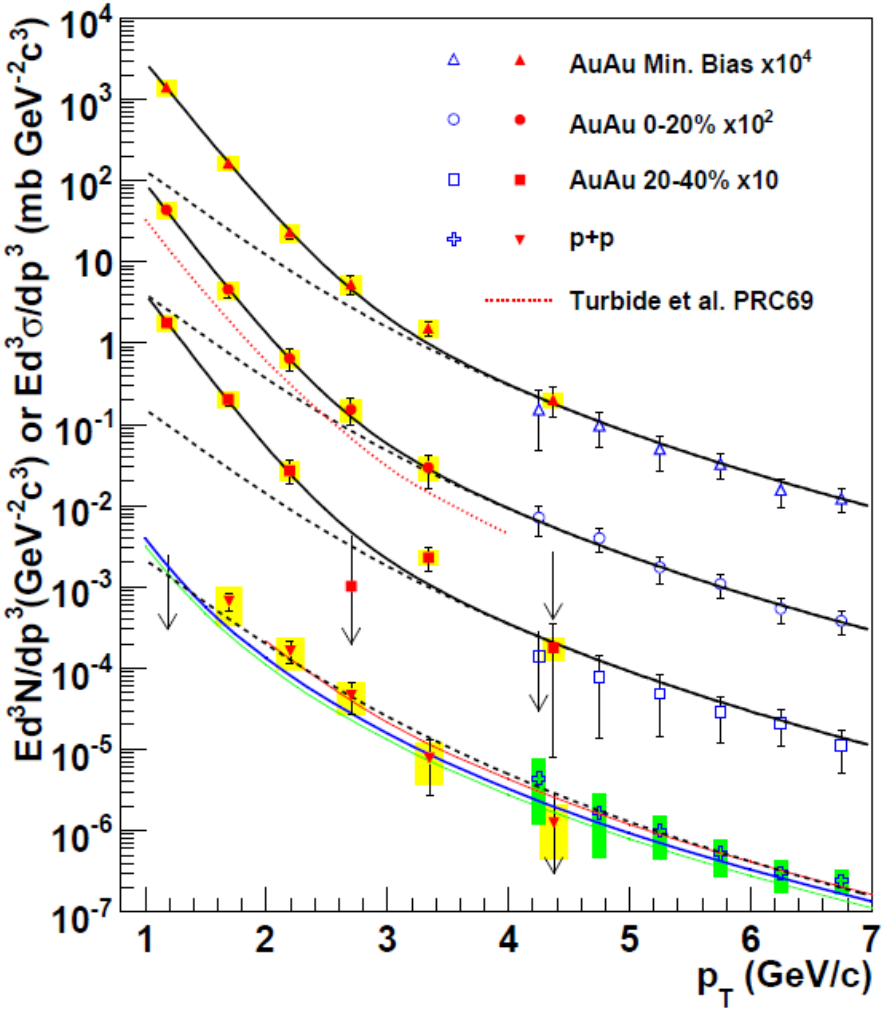
Conclusions and outlook

- 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
- Feasibility studies on the dedicated converter and Stage 2 setup show promising results

BACKUP

Photon spectra at RHIC and LHC

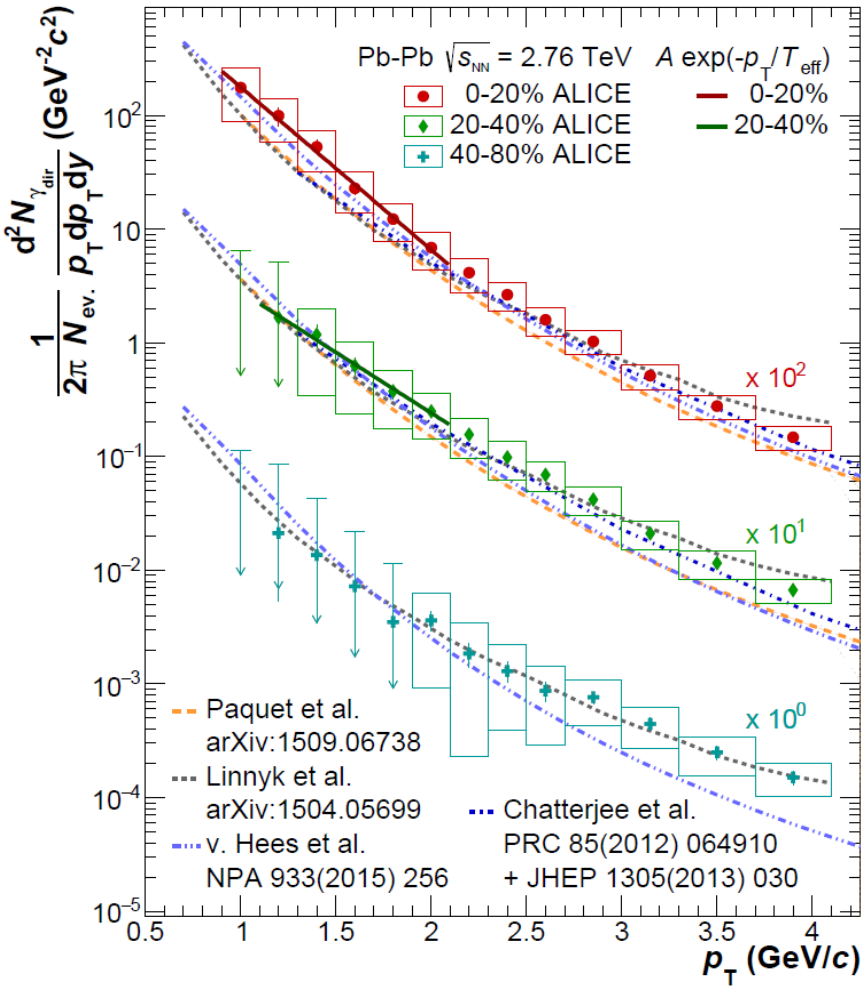
PHENIX (AuAu @ 200 GeV)



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

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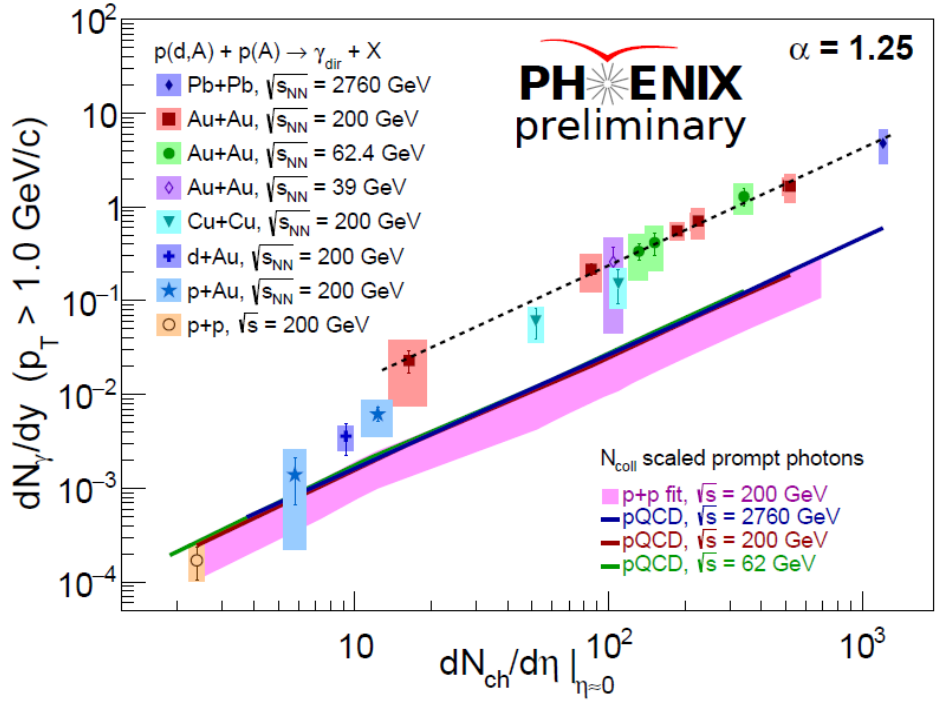
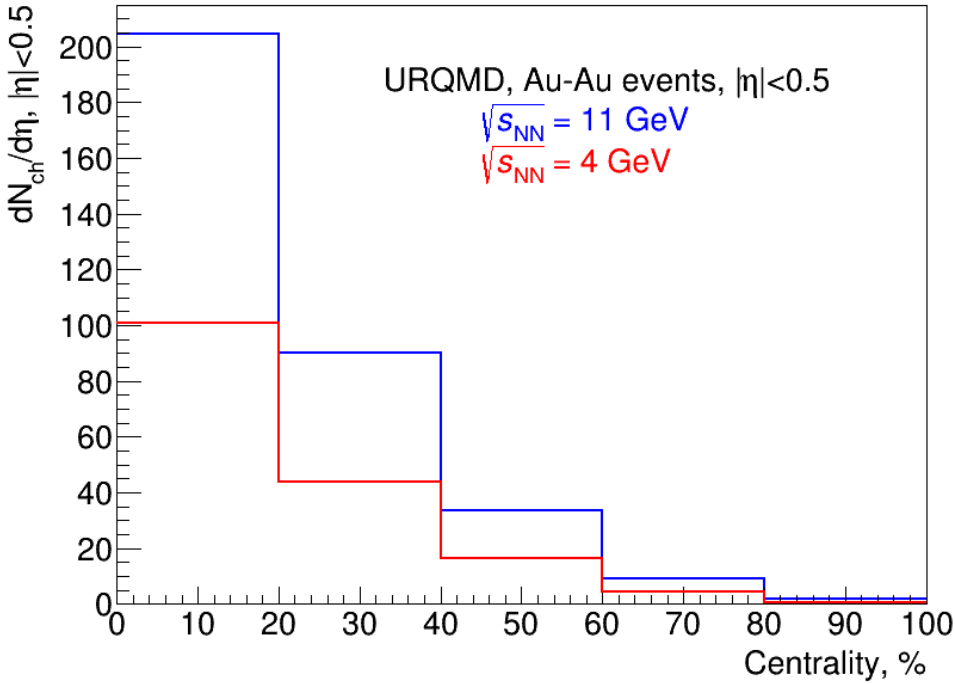
Integrated direct photon yield

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





Phys. Rev. Lett. 123, 022301

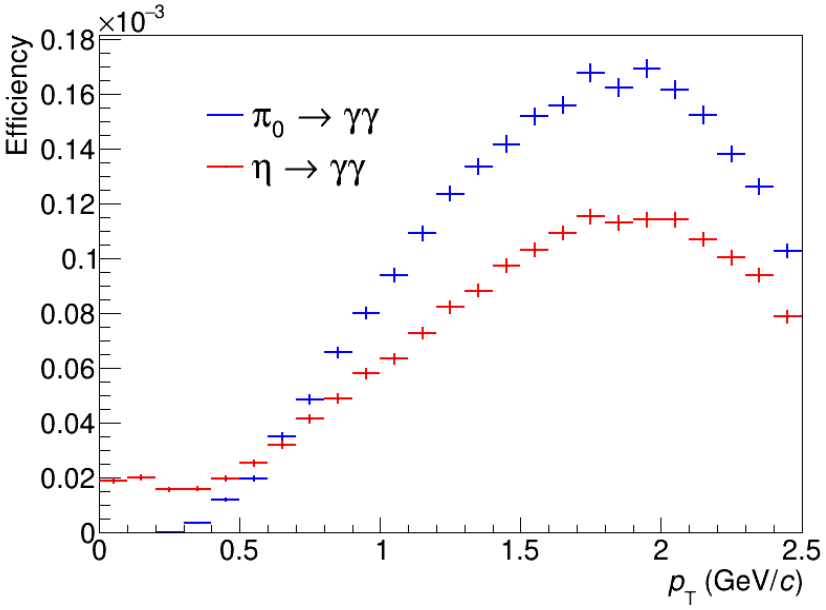
The integrated direct photon yield:

- 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

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