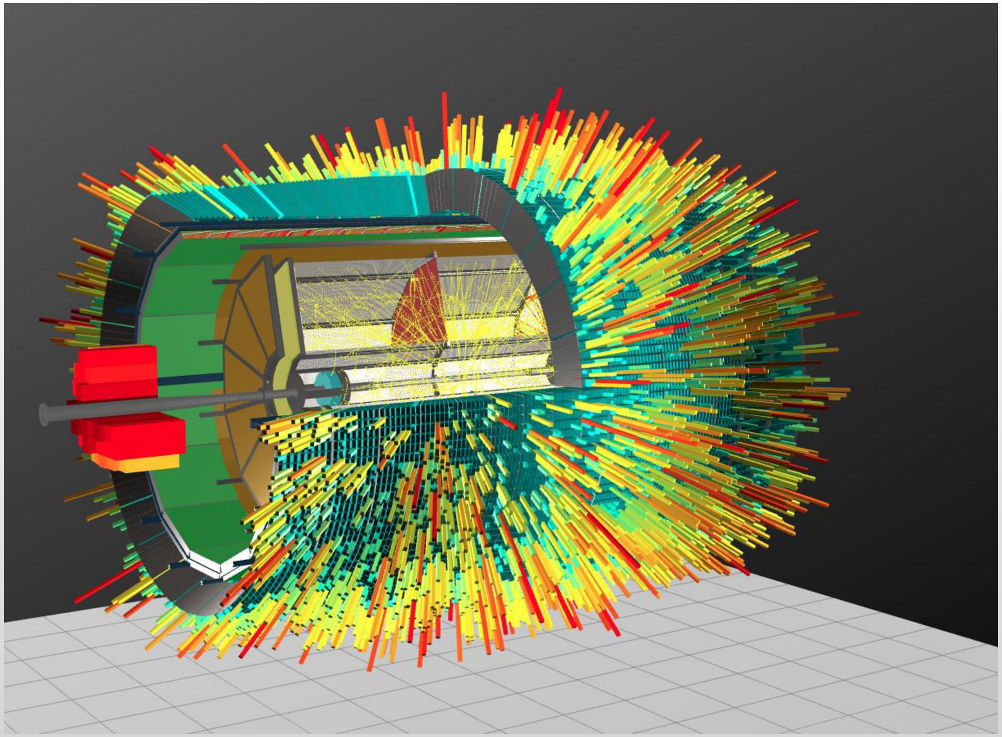
NICA

Nuclotron-based
Ion Collider fAcility

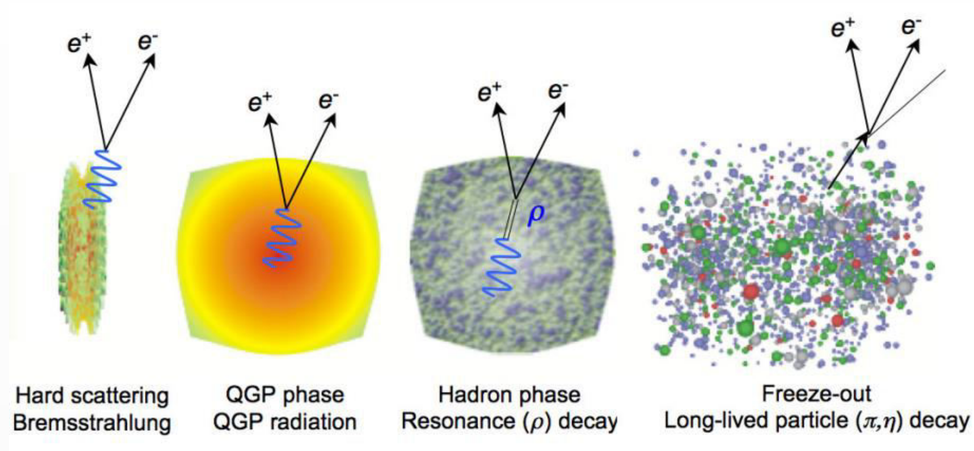
Prospects for the measurement of electromagnetic probes in heavy-ion collisions at NICA energies

V. Riabov for the MPD Collaboration



Electromagnetic probes

- Photons and electrons emitted from different stages of heavy-ion collisions
- Photons and electrons do not participate in strong interactions → produced strongly interacting system (QGP) is transparent → penetrating probes
- Provide undistorted information about the system at the production time

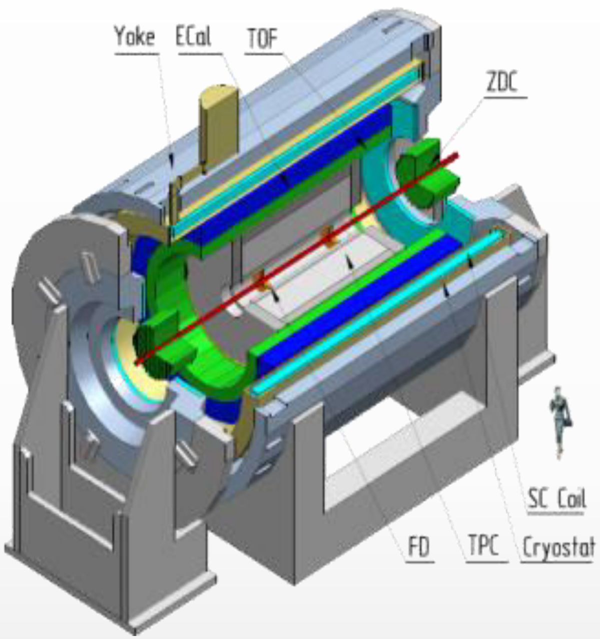


- Problems:
  - ✓ low emission rate
  - ✓ overlapping signals from different stages of heavy-ion collisions
  - ✓ huge background from decays of neutral mesons → precise measurement of the neutral meson production is a needed

- Photons and electrons are promising signals of the phase transition and chiral symmetry restoration
- Interpretation of results requires theoretical models that would describe the dynamics of heavy-ion collisions during the whole system evolution

Multi-Purpose Detector

Stage- I



Length	340 cm
Vessel outer radius	140 cm
Vessel inner radius	27 cm
Default magnetic field	0.5 T
Drift gas mixture	90% Ar+10% CH_4
Maximum event rate	7 kHz ($L = 10^{27}$ $cm^{-2}s^{-1}$)

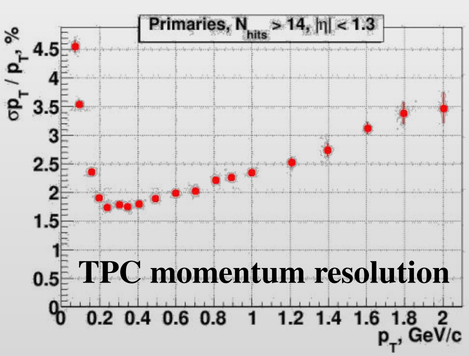
TPC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.6$

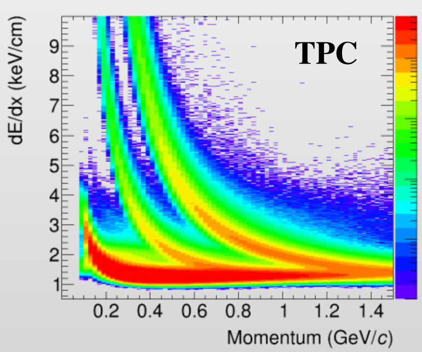
TOF, EMC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$

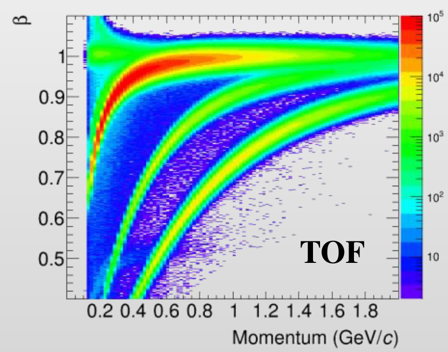
FFD: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$

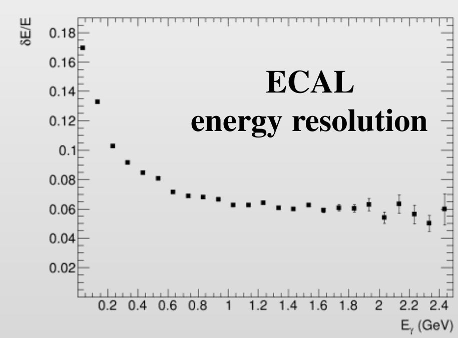
FHCAL: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

Au+Au @ 11 GeV (UrQMD + full chain reconstruction)



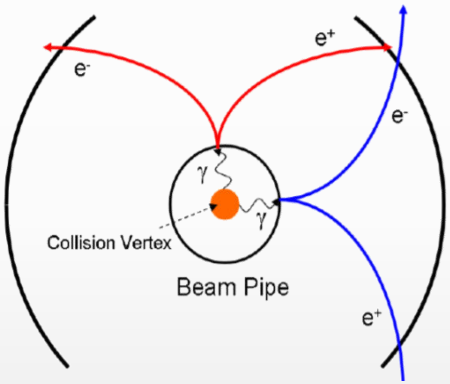


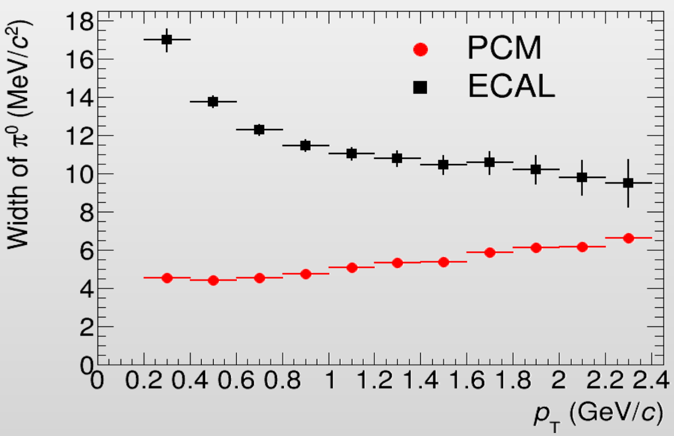


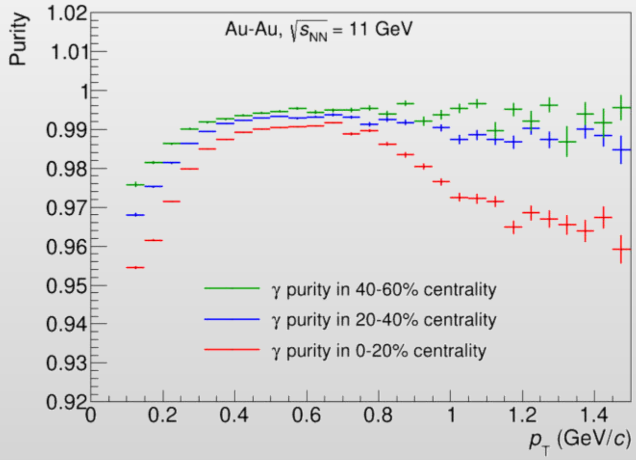


Reconstruction of photons

- Electromagnetic calorimeter ECAL:
  - ✓ dedicated detector to measure electromagnetic signals like $\gamma/e^{\pm}$ (energy, position, time of flight)
  - ✓ energy resolution ~ $1/\sqrt{E}$, better suited for high-E signals
  - ✓ suffer from large hadronic background at low energies
  - ✓ shower shape and time-of-flight selections for identification of photons
- Photon conversion method (PCM) :
  - ✓ photons are identified as e^+e^- pairs with small invariant mass after some second vertex topology, single track and pair selection cuts optimized for better S/B ratio
  - ✓ energy resolution ~ E, better suited for low-E
  - ✓ typically provides very high photon purity
  - ✓ suffer from small γ conversion probability

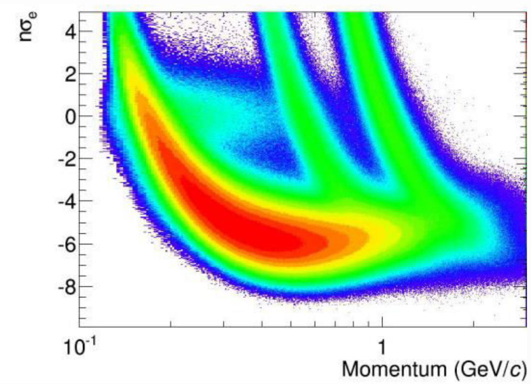


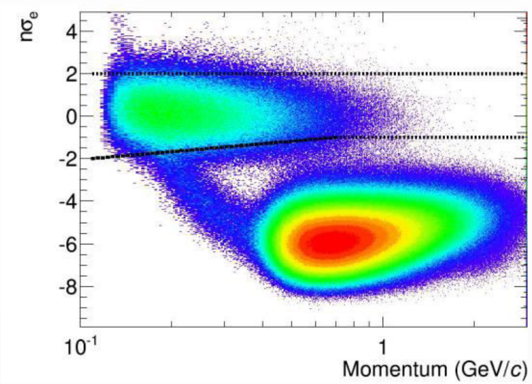


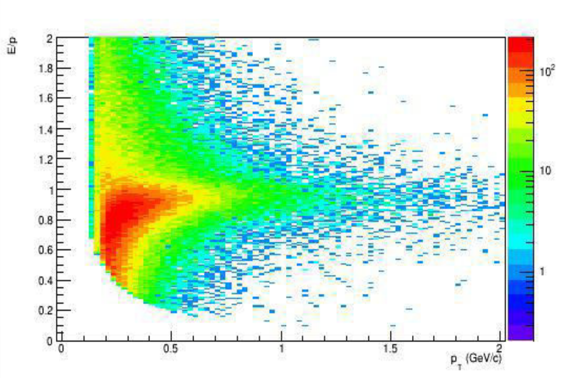


Reconstruction of electrons

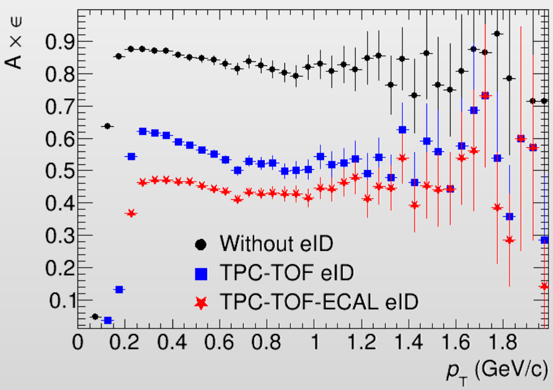
- Charged particle tracks are reconstructed in the TPC
- Particles are identified in the TPC (<dE/dx>), TOF ($v/c \sim 1$) and ECAL ($E/p \sim 1$)

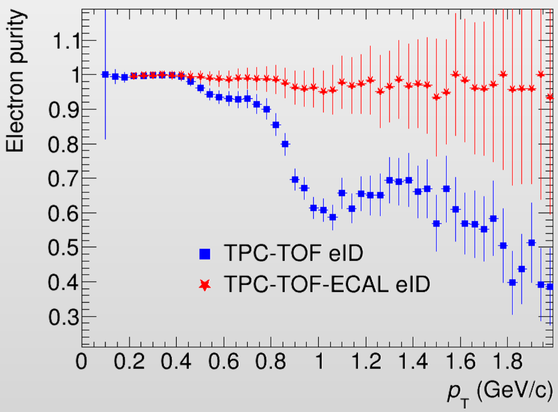






- Reasonable electron track reconstruction efficiency and electron purity after multiparametric optimization of selections

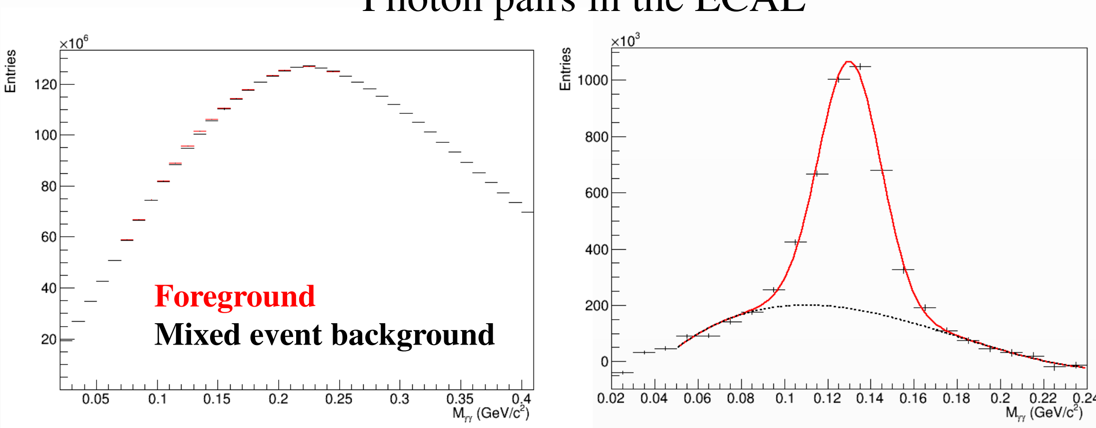




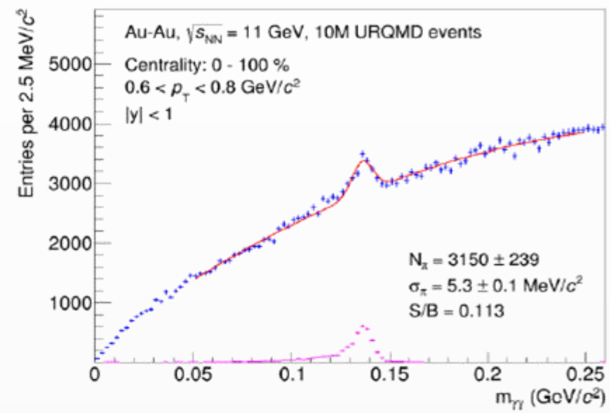
Neutral mesons

- Neutral mesons are the main source of background for direct photon and (di)electron measurements
- 15M AuAu@11 (UrQMD v.3.4) events, realistic vertex distribution

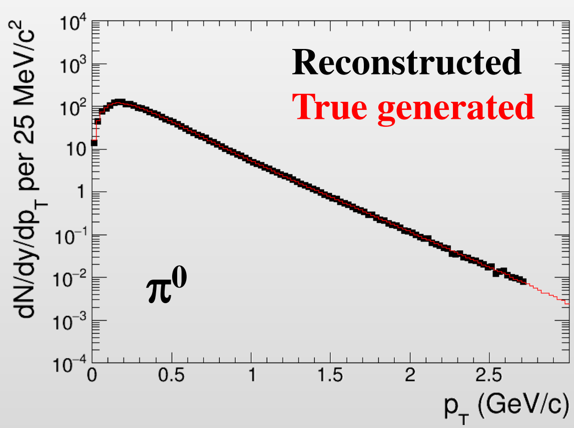
Photon pairs in the ECAL

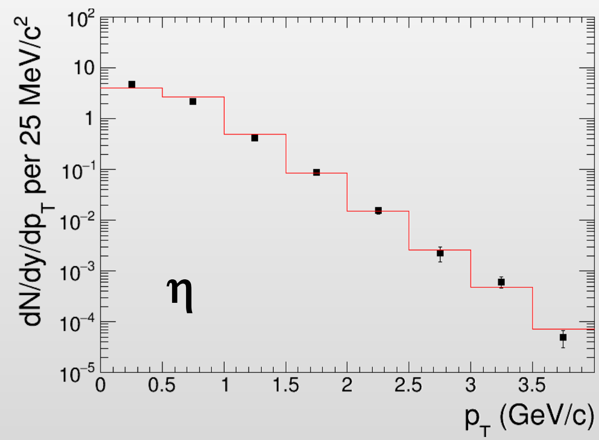


Photon pairs with PCM



- Reconstructed π^0 and η spectra match the generated ones within statistical uncertainties

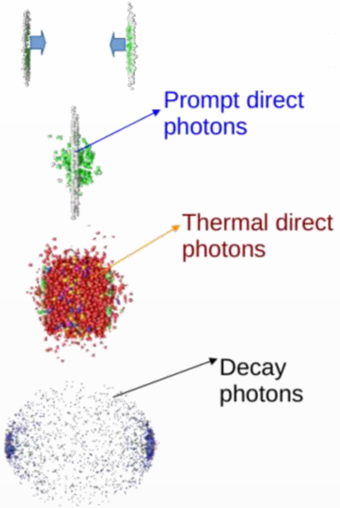




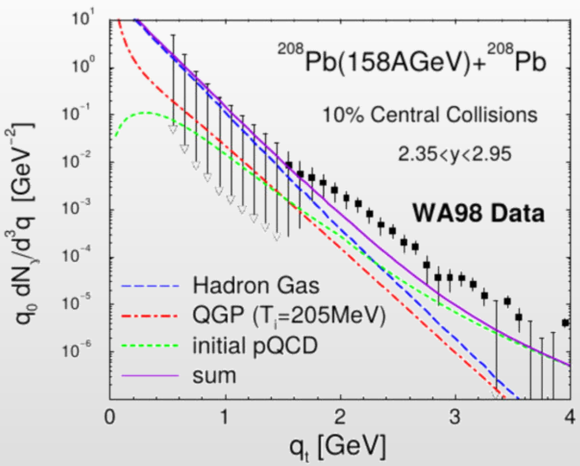
- Measurements of neutral mesons will be possible with ~ 10M sampled heavy-ion collisions

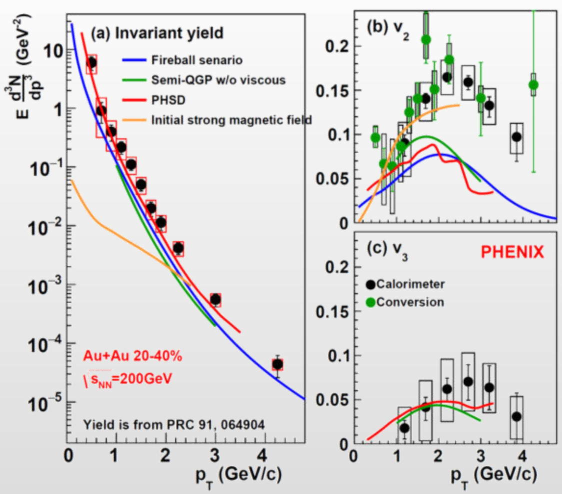
Direct photons

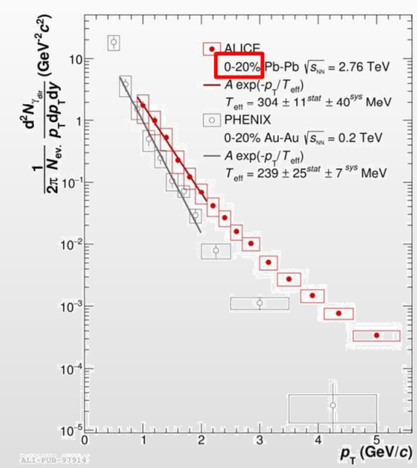
- Direct photons – photons not from hadronic decays.
- Produced throughout the system evolution (thermal + prompt) :
  - ✓ penetrating probe
  - ✓ low-E - most direct estimation of the effective system temperature
  - ✓ high-E - hard scattering probe
- Direct photons in A-A collisions:
  - ✓ LHC, PbPb @ 2.76 and 5 TeV
  - ✓ RHIC, Au-Au(CuCu) @ 62-200 GeV
  - ✓ SPS, PbPb @ 17.2 GeV
- No measurements at NICA energies: yields and flow vs. p_T and centrality



Phys.Rev. C94 (2016) no.6, 064901







Simultaneous description of the large photon yields and flow is a challenge for theoretical models at RHIC and the LHC → “direct photon puzzle”

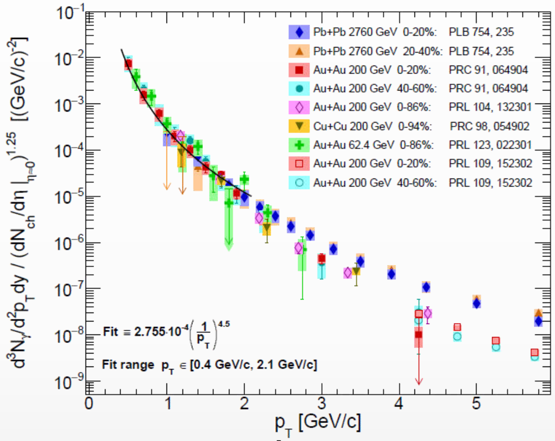
Direct photon yields at NICA

Estimation of the direct photon yields @NICA

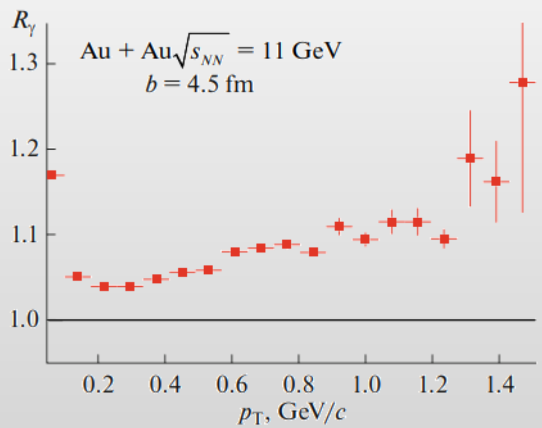
model calculations

empirical scaling

- ✓ UrQMD v3.4 with hybrid model (3+1D hydro, bag model EoS, hadronic rescattering and resonances within UrQMD)
- ✓ each cell have Ti, Ei, μbi:
  - T is high – QGP phase (Peter Arnold, Guy D. Moore, Laurence G. Yaffe, JHEP 0112:009 2001)
  - T is low – HG phase (Simon Turbide, Ralf Rapp, Charles Gale, Phys.Rev.C69:014903,2004)
  - T is intermediate – mixed phase
- ✓ integrate over all cells and all time steps
- ✓ calculations reproduce hydro calculations for the SPS

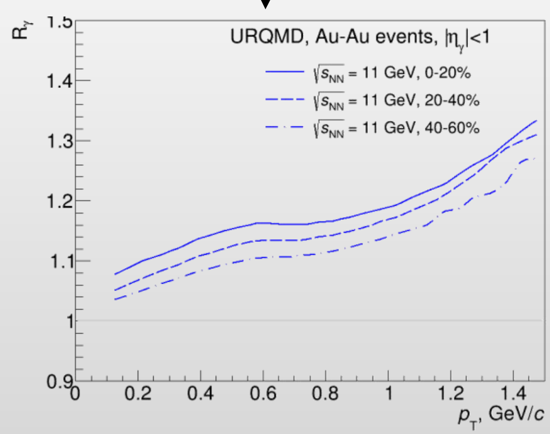


Physics of Particles and Nuclei, 2021, Vol. 52, No. 4, pp. 681–685



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

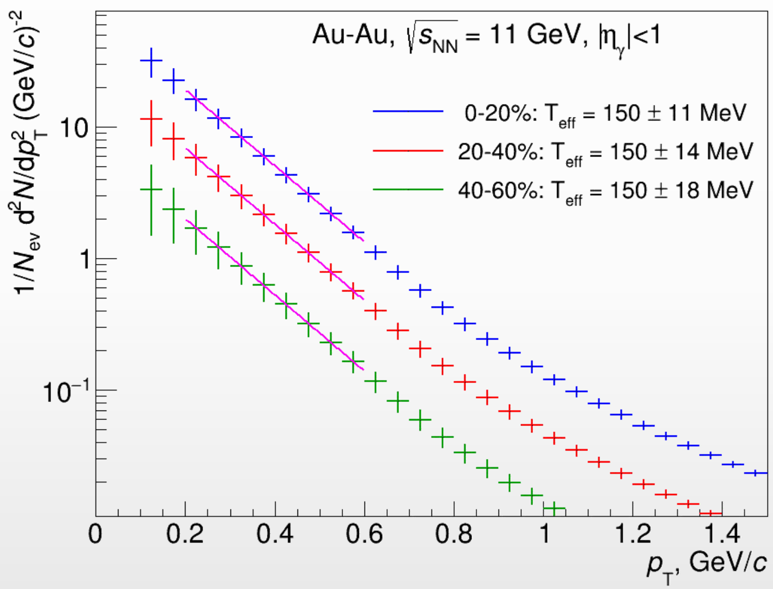
$$\gamma_{direct} = \left(1 - \frac{1}{R_\gamma}\right) \cdot \gamma_{inc}$$



❖ Non-zero direct photon yields are predicted with Rγ ~ 1.05 – 1.15 and v2 ~ 0.5% at top NICA energy

Prospects for the MPD

- Photons can be measured in the ECAL or in the tracking system as e^+e^- conversion pairs (PCM)
- Main sources of systematic uncertainties for direct photons:
  - ✓ detector material budget → conversion probability
  - ✓ π^0 reconstruction efficiency
  - ✓ p_T-shapes of π^0 and η production spectra

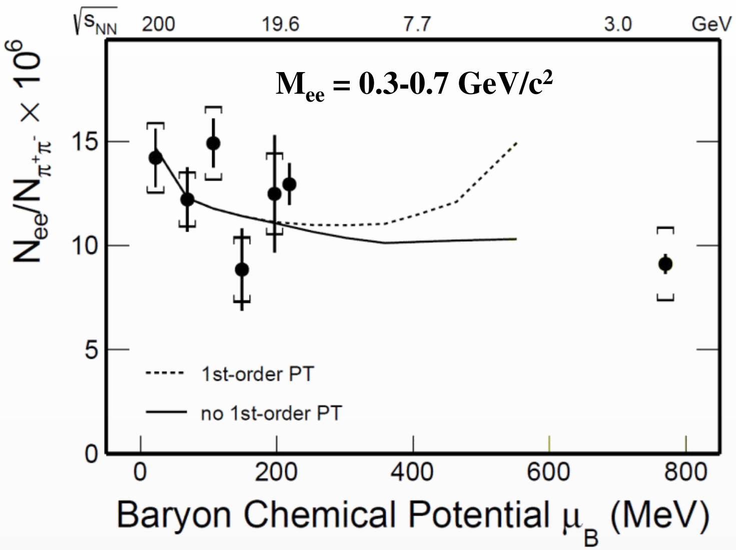


- ECAL and PCM for photon reconstruction and measurement of neutral mesons (background)
- With Rγ ~ 1.1 and δRγ/Rγ ~ 3% → uncertainty of T_{eff} ~ 10%
- Development of reconstruction techniques and estimation of needed statistics are in progress

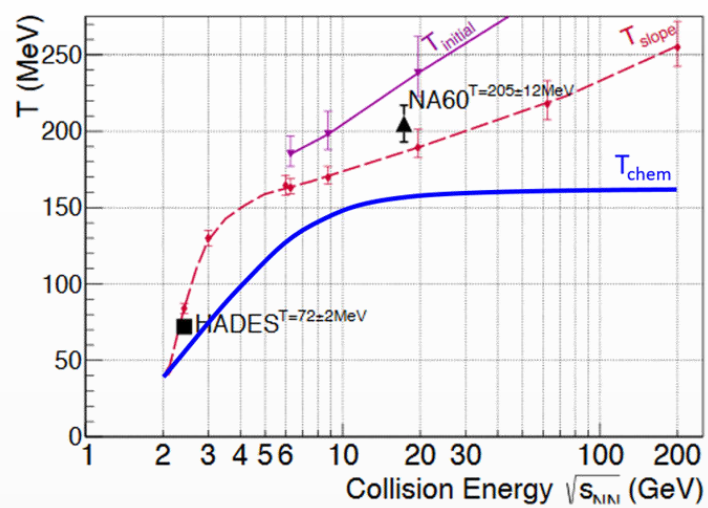
→ MPD can provide unique measurements for direct photon production @ NICA energies

Dielectrons

arXiv:2010.04614 [nucl-th].



T. Galatyuk et al., Eur. Phys. J. A 52 (2016) 131; R. Rapp and H. v. Hess, PLB 753 (2016) 586
J.Cleymans et al. 2006 Phys. Rev. C73, 034905
NA60: H. Specht, AIP Conf. Proc. 1322 (2010) 160; HADES: Nature Physics 15 (2019) 1040



❖ Low Mass Region:

- ✓ excess in dilepton yields: broadening of the ρ meson spectral function → restoration of chiral symmetry
- ✓ sum of QGP and hadronic contributions proportional to fireball lifetime → "chronometer" for heavy-ion collisions
- ✓ yield of dielectron pairs is sensitive to nature of the phase transition

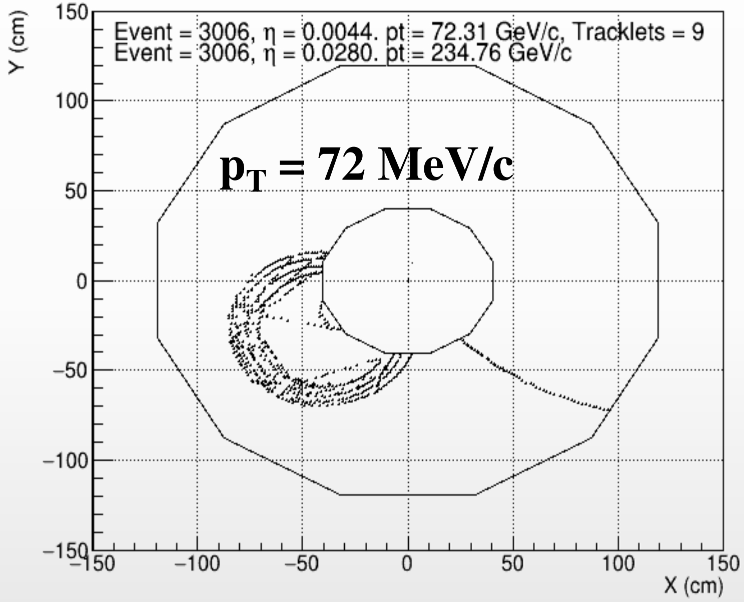
❖ Intermediate Mass Region:

- ✓ excitation function of the inverse-slope parameter, T ($M = 1.5 - 2.5$ GeV/c^2) is closely related to the initial temperature of the fireball → "thermometer" for the heavy-ion collisions

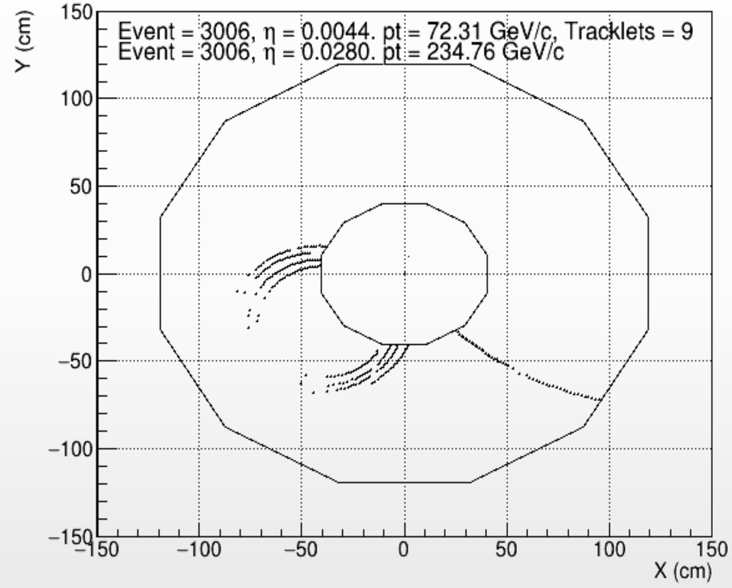
Experimental challenges

- MPD provides high efficiency of electron track reconstruction and identification
- Dielectron measurements suffer from huge combinatorial background, pairs with electrons from Dalitz decays of neutral mesons (π^0, η)

Reconstructed hits



Reconstructed tracks

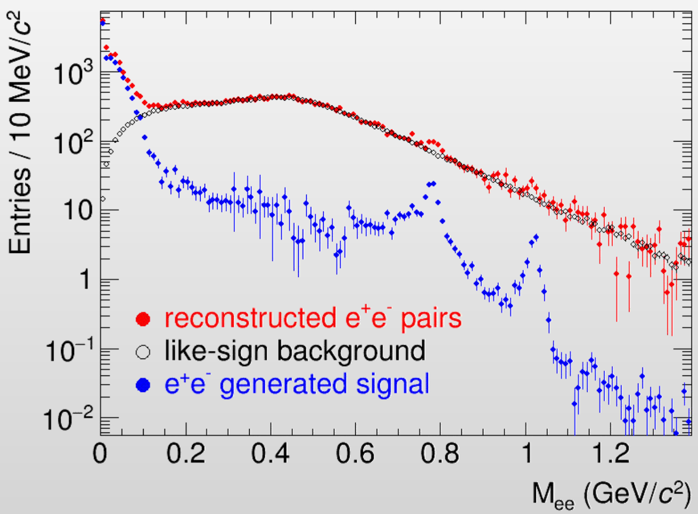


- With the existing track reconstruction algorithms, low p_T tracks are not reconstructed properly even though full hit information is available in the detector for tracks with $p_T > 30$ MeV/c
- Tracks with $p_T < 100$ MeV do not cross the TPC (lower identification probability)

Possible solutions

- Improved reconstruction of low-p_T electron tracks (optimized DCA and track quality selections)
- Tagging and rejection of electrons from conversion → test e^+e^- pairs for consistency with being a conversion pair based on pair topology, mass, pointing angle, DCA, etc.
- Tagging and rejection of electrons from Dalitz decays of $\pi^0 \to \gamma e^+e^-$ → test e^+e^- pairs for consistency with being a pair from the Dalitz decay by mass (M_{ee} < 100-150 MeV/c^2)
- Increase efficiency of tagging by selecting electrons in a limited rapidity acceptance ($|y| < 0.5$) and pairing them with electrons reconstructed in the whole detector acceptance with looser e-ID selections
- Multiparametric analysis to optimize signals statistical significance (smaller statistical uncertainties) and increase S/B ratio (decrease systematic uncertainties)

BiBi@9.2 GeV (UrQMD+PHSD), 10 M events→ full event/detector simulation and reconstruction



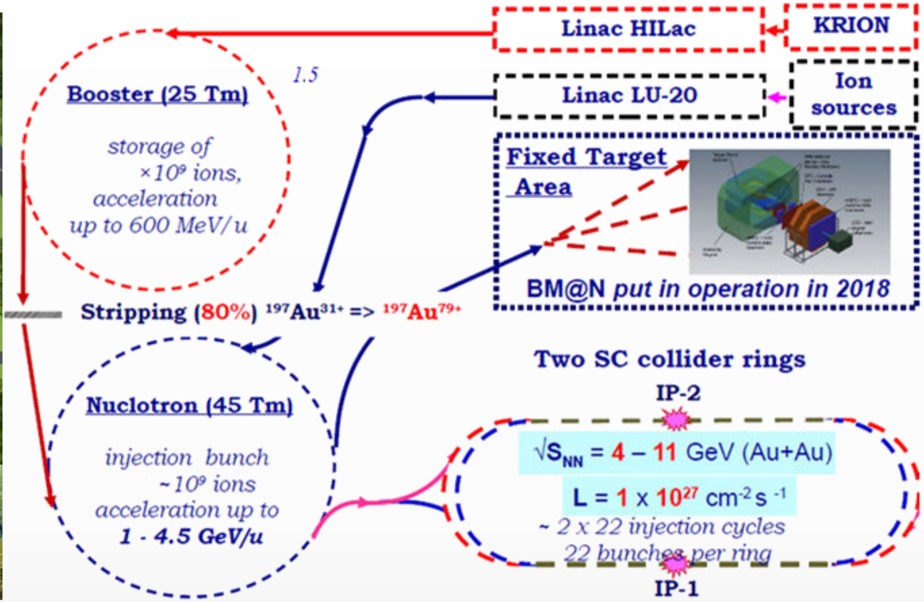
- S/B (integrated in 0.2-1.5 GeV/c^2) ~ 5-10%
- Methods to improve S/B ratio with a minimal penalty for pair reconstruction are being matured
- Meaningful measurements for e^+e^- continuum and LVMs would require ~ 100M events, first observations will be possible with ~ 50M events

Summary

- ✓ Measurements of electromagnetic probes such as the direct photons and dielectron continuum significantly extend the physics program of the MPD experiment
- ✓ Measurements of neutral mesons will be available with the first collected data sets
- ✓ MPD can provide unique measurements for direct photons at NICA energies
- ✓ MPD has very good potential for dielectron measurements, statistics hungry analysis

BACKUP

NICA Project



- The first megascience project in Russia, which is approaching its full commissioning:
  - ✓ already running in the fixed-target mode – BM@N
  - ✓ start of operation in collider mode in 2023-2024 – MPD and later SPD
- Expected beam configuration in Stage-I:
  - ✓ not-optimal beam optics with wide z-vertex distribution, $\sigma_z \sim 50$ cm
  - ✓ reduced luminosity ($\sim 10^{25}$) $\rightarrow$ collision rate ~ 50 Hz
  - ✓ collision system available with the current sources: C (A=12), N (A=14), Ar (A=40), Fe (A=56), Kr (A=78-86), Xe (A=124-134), Bi (A=209) $\rightarrow$ start with Bi+Bi @ 9.2 GeV in 2023-2024