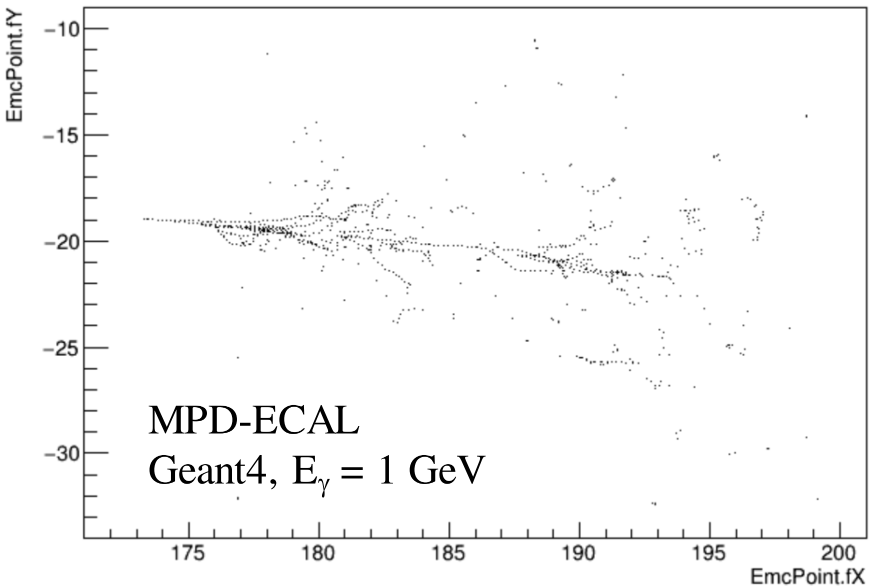
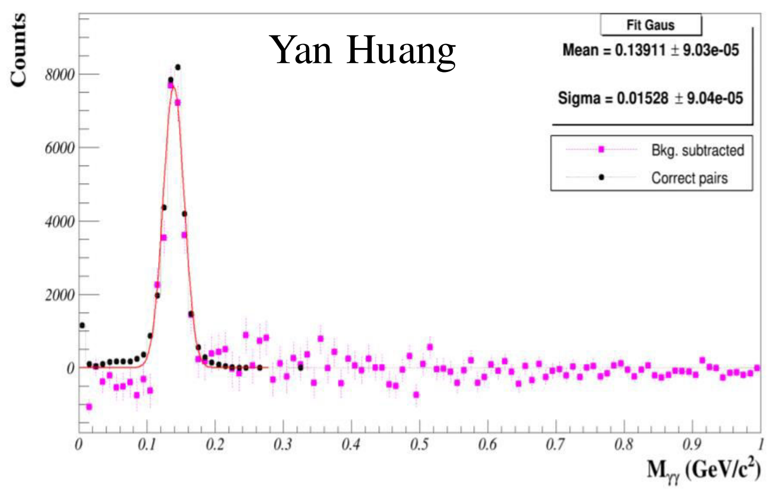
Progress in ECAL simulation

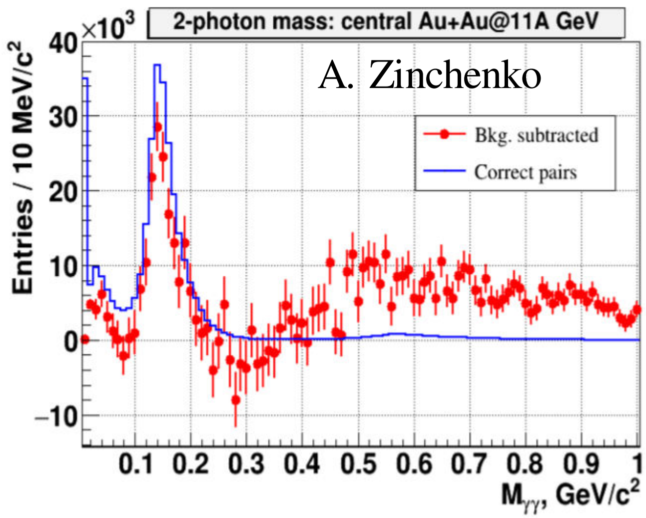
V. Riabov for the MPD-ECAL Group



Status on January, 23

- Projective geometry in Geant v.3,4 (ITEF)
- Two versions of digitizer-clusterizer:
  - ✓ by Maxim Martemyanov (ITEF) → basic study of ECAL performance for single photons, not applicable for high multiplicity events
  - ✓ by Alexander Zinchenko (JINR) → study of ECAL performance in realistic multiplicity environment, reconstruction of π^0 mesons in central AuAu@11 (UrQMD)





- Missing parts:
  - ✓ signal unfolding in high multiplicity events, tuning of signal selection and PID cuts
  - ✓ realistic performance and physics studies

MPD-ECAL program

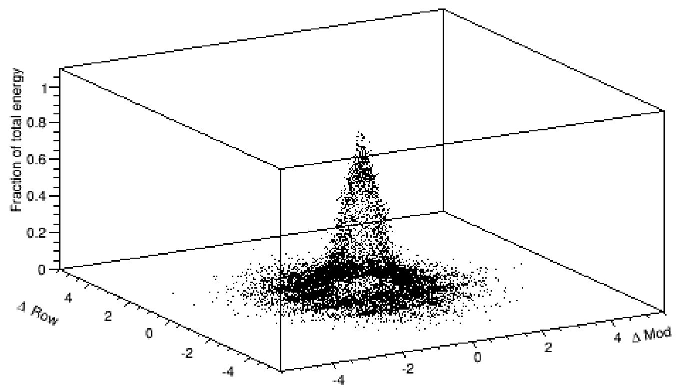
- Photons (yield, flow, HBT):
  - ✓ inclusive
  - ✓ direct
- Neutral mesons (yield, flow):
  - ✓ $\pi^0(\eta) \to \gamma\gamma$
  - ✓ $K_s \to \pi^0\pi^0$, $\omega \to \pi^0\gamma$
- Electron identification, E/p ~ 1:
  - ✓ e^+e^- continuum at low/intermediate mass
  - ✓ LVM (ρ, ω, ϕ) $\to e^+e^-$
  - ✓ e_{HF}
  - ✓ conversion pairs (alternative reconstruction of photons)
  - ✓ charmonia

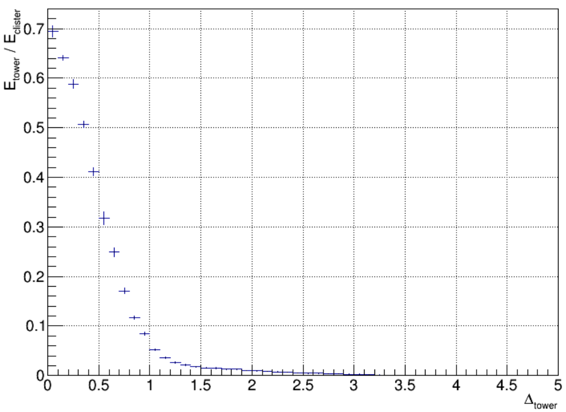
Recent progress

- ECAL Software Group formed in February, 2019:
  - ✓ regular meetings with remote access by Vidyo and public agenda on indico, https://indico.jinr.ru/category/276/
  - ✓ everyone interested is welcome to join (contact me)
- Main tasks:
  - ✓ actual detector geometry
  - ✓ reconstruction and unfolding of electromagnetic clusters
  - ✓ cluster matching to reconstructed charged tracks
  - ✓ association of clusters with Monte Carlo contributors
  - ✓ guidance for prototype tests (feedback)
- Final destination:
  - ✓ fast reconstruction software with friendly interface integrated to ‘mpdroot’
  - ✓ documentation, recommendation and examples of use for easy start
  - ✓ basic physics/feasibility studies (to be advanced by Collaboration/PWGs)

Cluster unfolding

- Based on 'known' shape of electromagnetic clusters in the MPD-ECAL:
  - ✓ simulated for single photons: $E_i/\sum E_i$: ΔMod : ΔRow
  - ✓ shower shape shows weak energy dependence





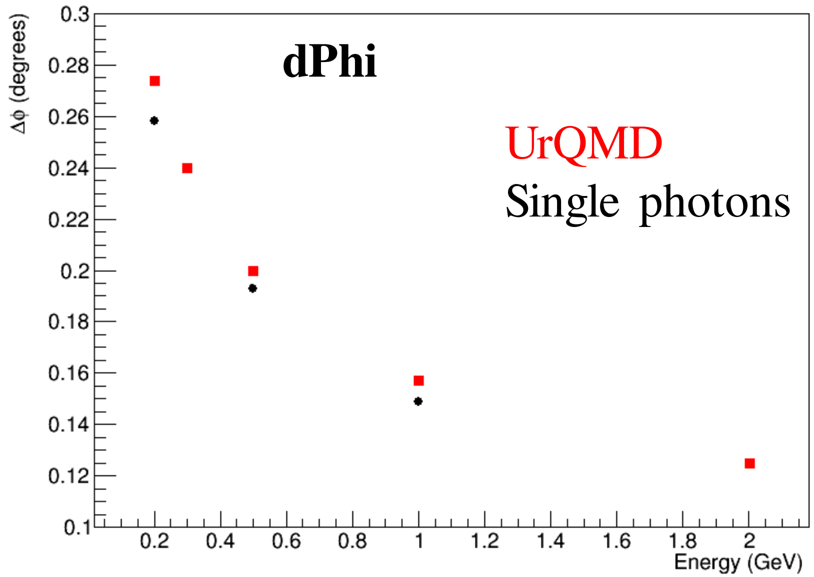
- Provides higher efficiency of cluster reconstruction and better energy/spatial resolution in high multiplicity environment

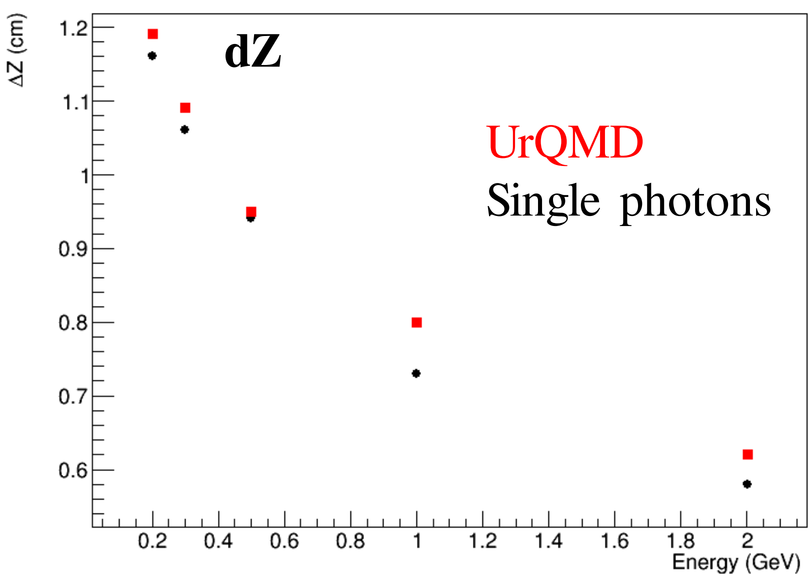
- Same shower shape is used for shower shape analysis ($\gamma/e^{\pm}$ PID)

$$\text{Chi2} = \sum_i \frac{\left(E_i^{measured} - E_i^{expected}\right)^2}{\sigma_i^2} \qquad \sigma_i^2 = 0.008 \cdot E_i^{expected} \cdot \left(1 - \frac{E_i^{expected}}{E}\right)$$

Spatial resolution

- Signal averaging: $w_i = \max\left\{0, \left[w_0 + ln\left(\frac{E_i}{E_T}\right)\right]\right\}$, $w_0 = 3.0$
- Spatial resolution for single photons (black markers)
- Spatial resolution for photons in AuAu@11 simulated by UrQMD (red markers)

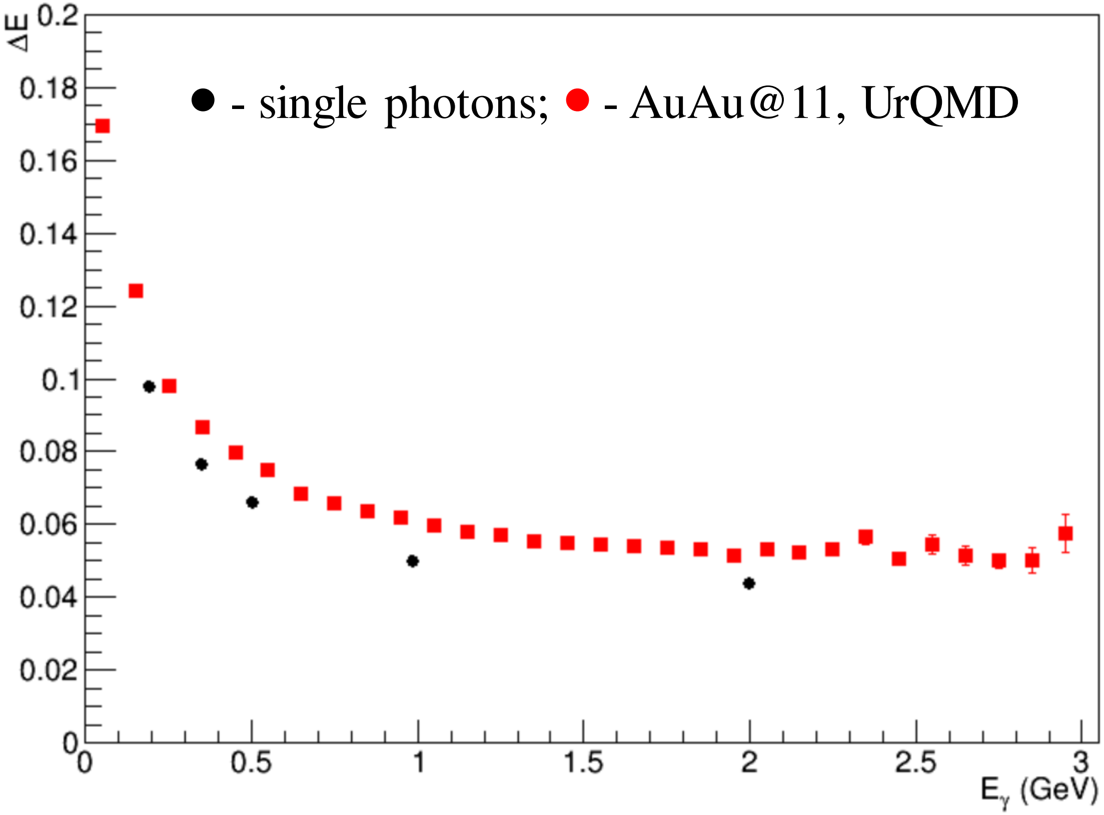




- Spatial resolution shows weak multiplicity dependence

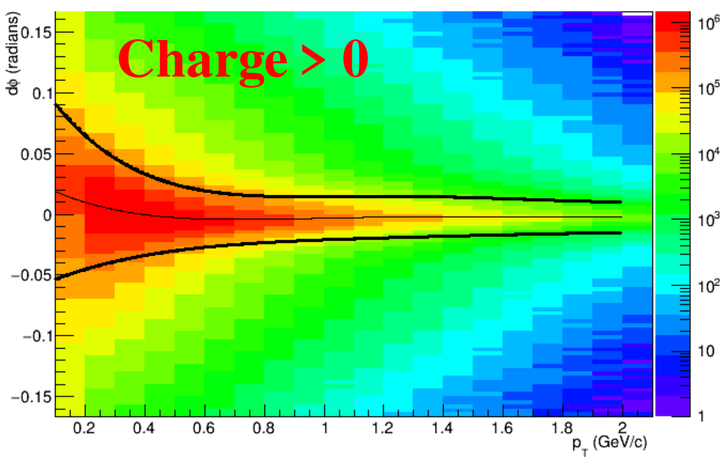
Energy resolution

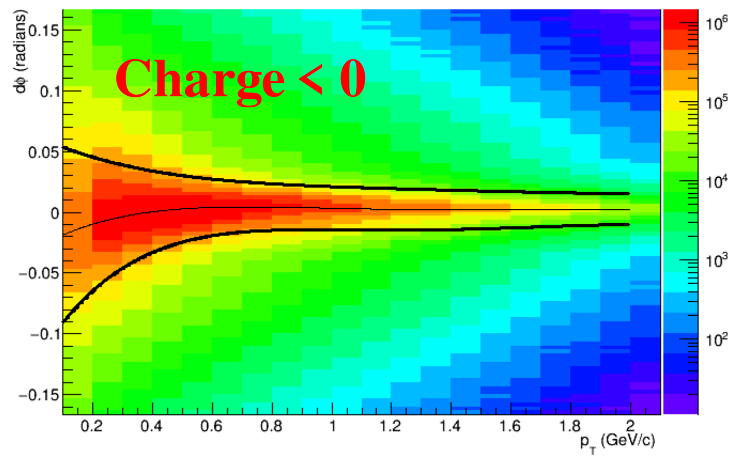
- Energy resolution for single photons and photons in AuAu@11 (UrQMD)
- Energy resolution shows significant multiplicity dependence → underlying event serves as noise for reconstructed electromagnetic clusters



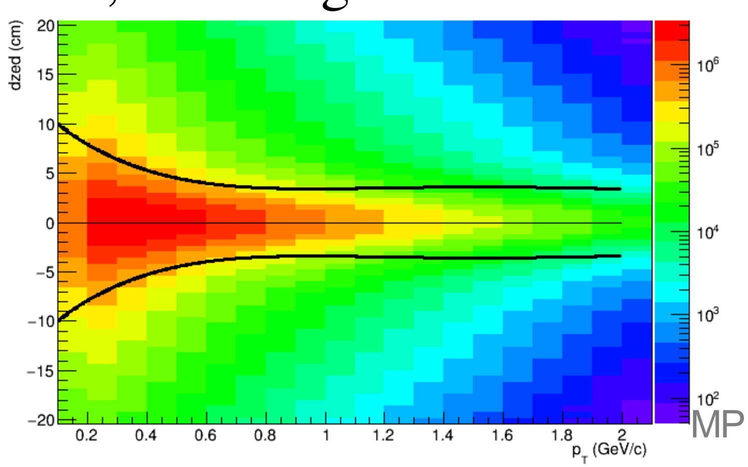
Cluster-to-track matching

- Association of clusters with closest tracks (dPhi, dZ, track index)
- Low-p_T tracks, p_T < 100 MeV/c, hardly reach the ECAL surface
- dPhi shows charge-dependent shift at low p_T (incidence angle, response to hadrons)





- dZ, not charge sensitive



- Note Logz() scale
- Matchings are parametrized as a function of p_T and charge (black lines in plots are $\pm$ 2.0 σ)

Photon ID

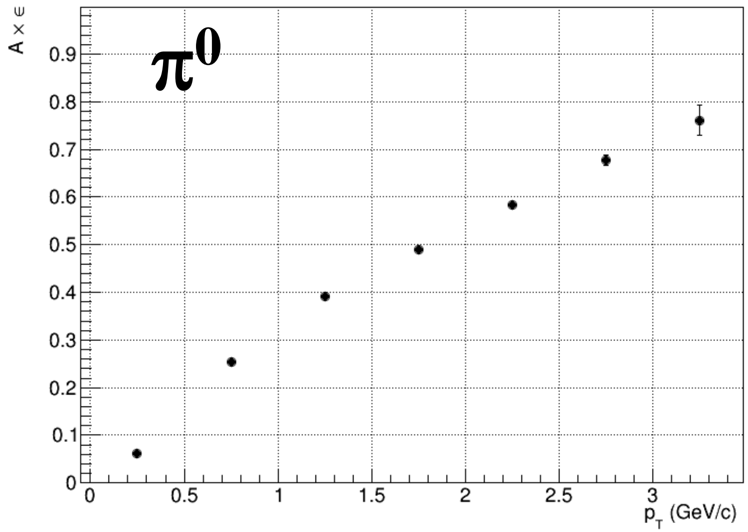
- Identification of photonic signals in the MPD-ECAL:
  - ✓ charged track veto → no tracks in 2-3σ vicinity of a cluster
  - ✓ time-of-flight → TOF – L/c ~ 0 for photons (< 2 ns, conservative cut)
  - ✓ shower shape → electromagnetic shape of clusters, also works for electrons!

- All three methods are well developed and tested for the MPD-ECAL
- Methods proved to be very efficient for selection of electromagnetic signals
- Efficiency and rejection factors of the cuts are comparable
- Methods are not additive (correlated), best combination of PID cuts is to be decided for each physical analysis

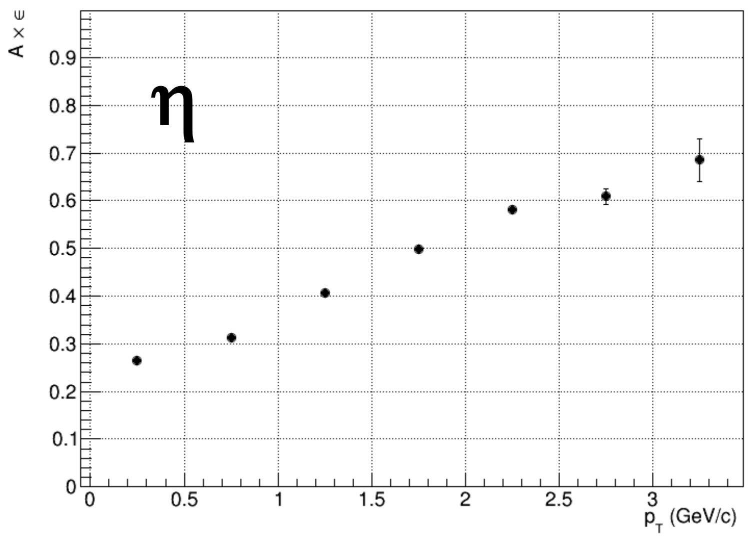
π^0, η reconstruction

- $\pi^0 \rightarrow \gamma\gamma$ (BR ~ 99%)
- $\eta \rightarrow \gamma\gamma$ (BR ~ 39%)
- Event selection:
  - ✓ minbias AuAu@11 by UrQMD3.4
  - ✓ $|Z_{vrtx}|$ < 50 cm
- Photon selection:
  - ✓ clusterizer with unfolding
  - ✓ $E\gamma$ > 0.1 GeV
  - ✓ number of towers > 2
  - ✓ TOF < 2 ns
- Pair cuts:
  - ✓ $|y|$ < 0.5

π^0 reconstruction efficiency ($|y|$<0.5)

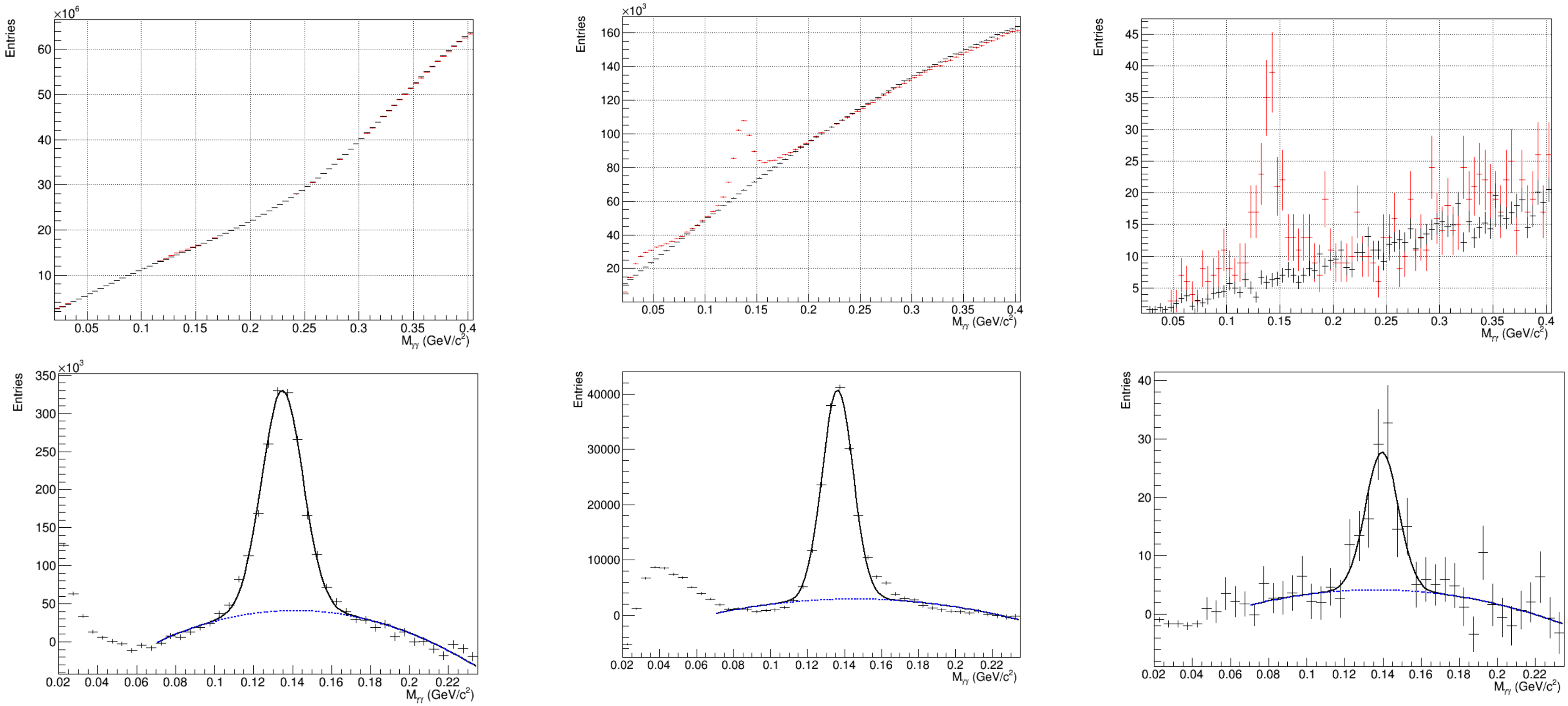


η reconstruction efficiency ($|y|$<0.5)



π^0, reconstructed peaks

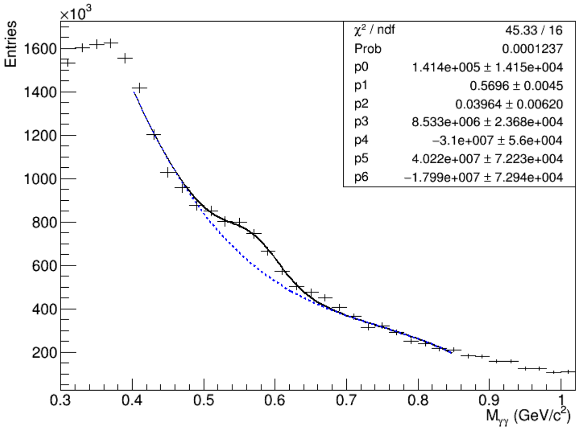
0-0.5 GeV/c | **1.5-2.0 GeV/c** | **4-5 GeV/c**



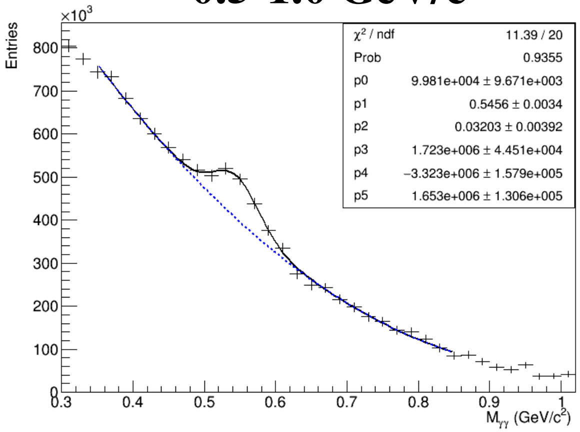
- Combinatorial background is estimated using event mixing
- Signal can be reconstructed from low momentum, ~ 0.25 GeV, at all centralities
- Cluster merging starts at ~ 6 GeV/c

η, reconstructed peaks

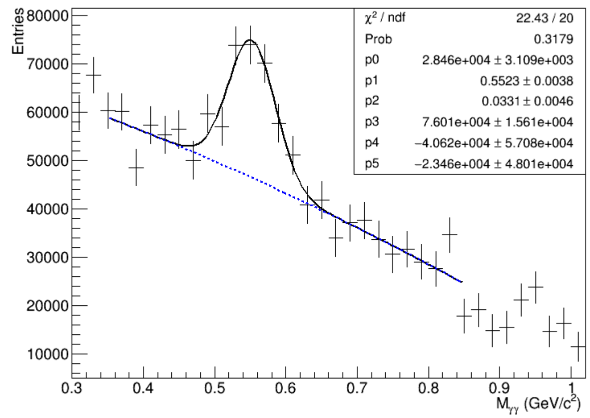
0-0.5 GeV/c



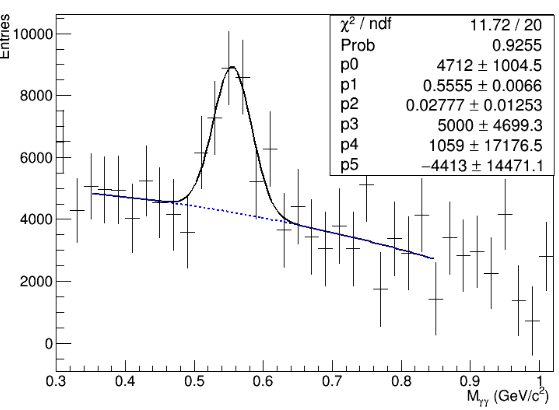
0.5-1.0 GeV/c



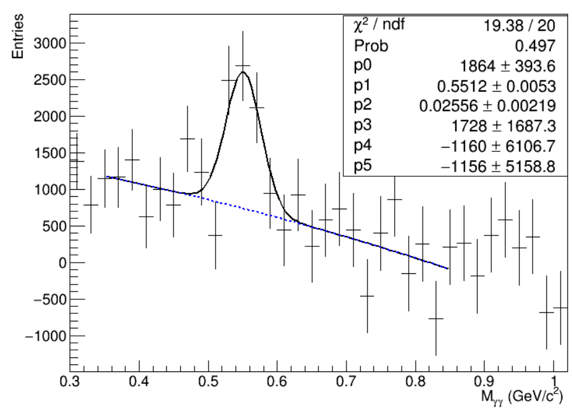
1-1.5 GeV/c



1.5-2 GeV/c



2-3 GeV/c

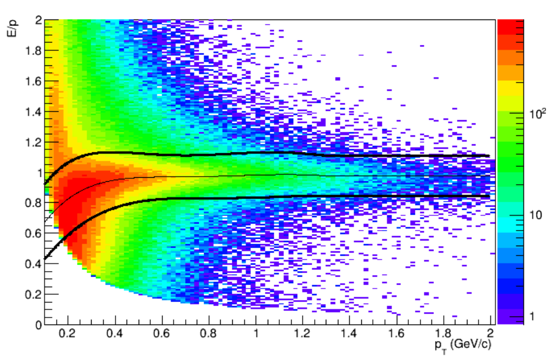


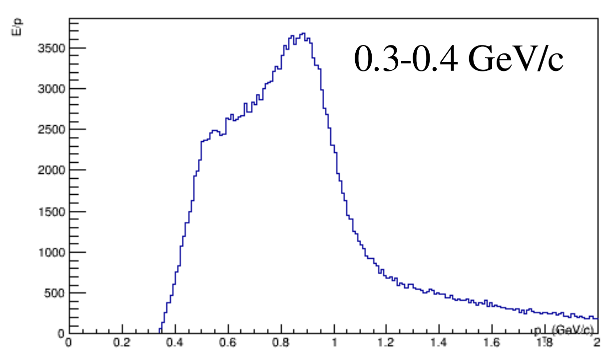
- Mass ~ 0.55 GeV/c^2
- Width ~ 30 MeV/c^2

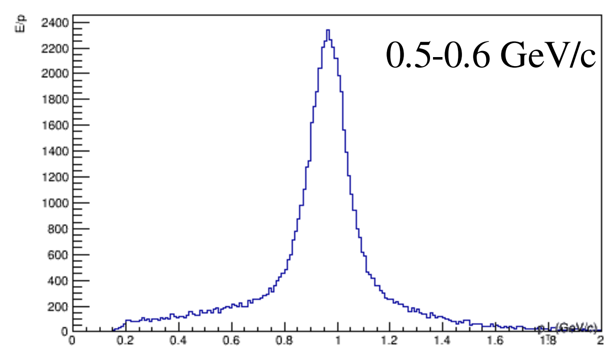
- Combinatorial background is estimated using event mixing
- Signal can be reconstructed from low momentum, ~ 0.25 GeV, at all centralities
- High-p_T reach is limited by available statistics

Electron ID

- Primary e-ID detectors are the TPC and TOF
- MPD-ECAL can help to clean up sample of selected electrons:
  - ✓ tracks matched to ECAl within 2-3σ
  - ✓ E/p ~ 1.0
- Limitations of the MPD-ECAL for e-ID:
  - ✓ low-p_T tracks do not reach ECAL, p_T < 0.1 GeV/c
  - ✓ MIP hadrons leave ~ 0.2 GeV in the ECAL → low-pT hadrons tend to have E/p ~ 1
  - ✓ showers from low-p_T electrons often split up in several sub-clusters and have elongated shape (can not be identified as electromagnetic showers by shape analysis)
- ECAL becomes effective at p_T > 0.2-0.3 GeV/c



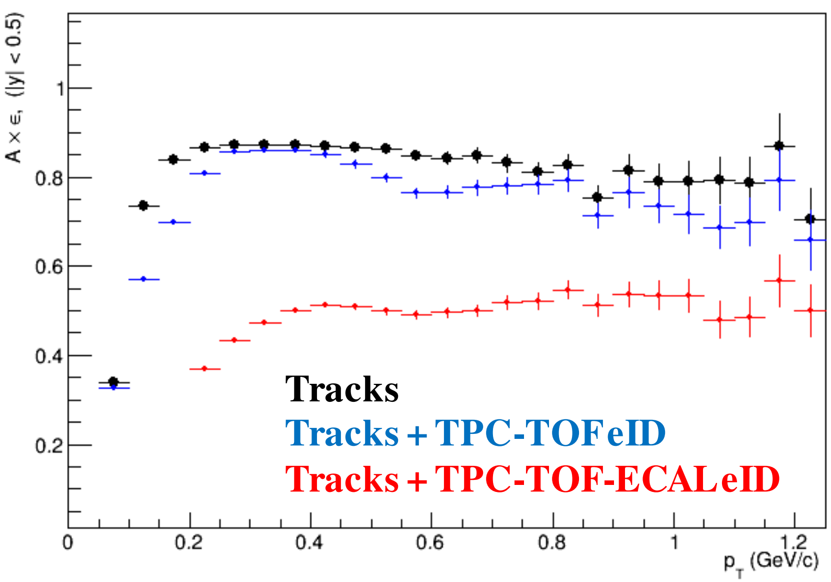




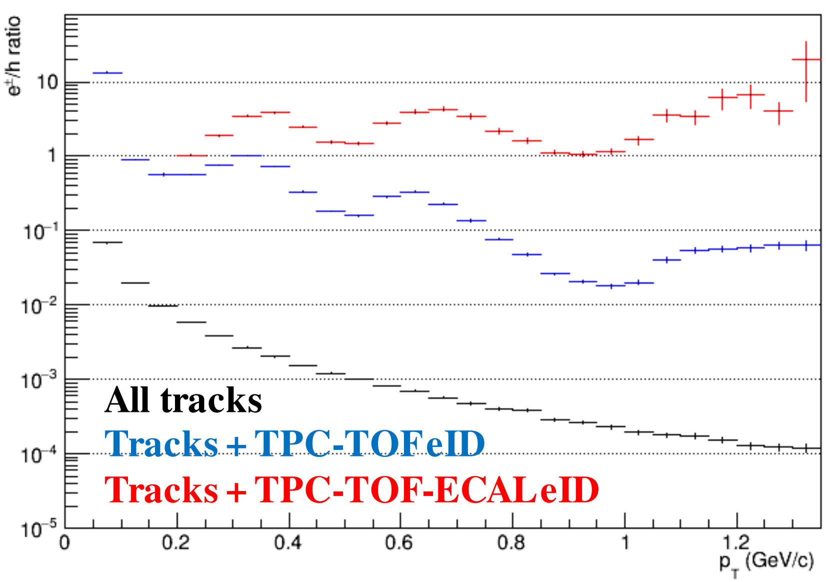
Electron ID, efficiency

- AuAu@11 (UrQMD), realistic vertex distribution
- Track selections and PID cuts:
  - ✓ reconstructed tracks: nTPC_hits > 39, DCA_xyz < 3σ
  - ✓ TPC-TOF eID: eID_probability > 0.75
  - ✓ ECAL eID: tracks matched to ECAl within 3σ + E/p, 3σ cut (Gaussian main peak)

Acceptance x efficiency (|y| < 0.5)



Reconstructed tracks, e/h ratio

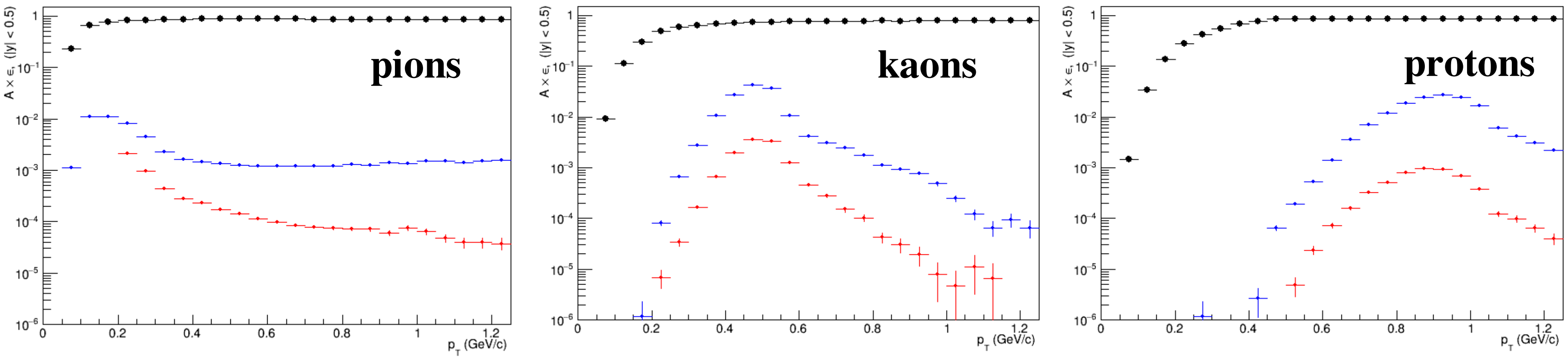


- Efficiency drops by ×0.5 (cluster missassociation, wide E/p ratio)
- With ECAL eID, ratio e/h increases by ×10 at 0.5 GeV/c and by ×100 at 1.2 GeV/c

Electron ID, efficiency for hadrons

- AuAu@11 (UrQMD), realistic vertex distribution
- Track selections and PID cuts: same as in previous slide

Acceptance x efficiency (|y| < 0.5)



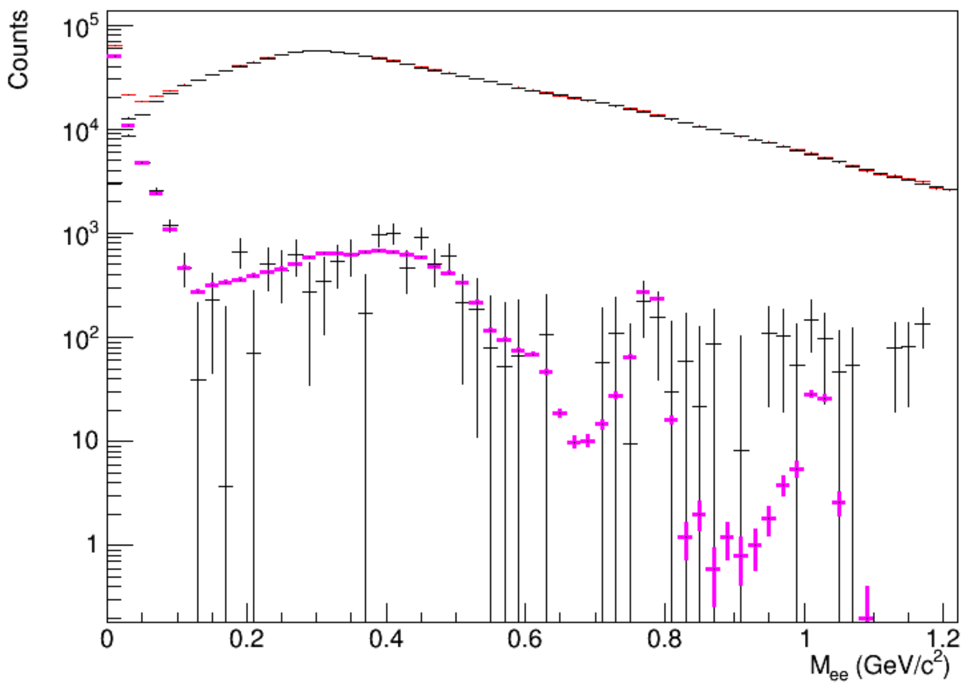
Tracks

Tracks + TPC-TOF eID

Tracks + TPC-TOF-ECAL eID

Di-electron spectrum, first look

- AuAu@11 (UrQMD), realistic vertex distribution, 1.5 M events
- LVM → e^+e^-, vector mesons are weighted to have zero generated width (to be seen)
- Track selections and PID cuts:
  - ✓ reconstructed tracks: nTPC_hits > 39, DCA_xyz < 3σ, pair conversion cuts
  - ✓ TPC-TOF eID: eID_probability > 0.75
  - ✓ ECAL eID: tracks matched to ECAl within 3σ + E/p, 3σ cut (Gaussian main peak)



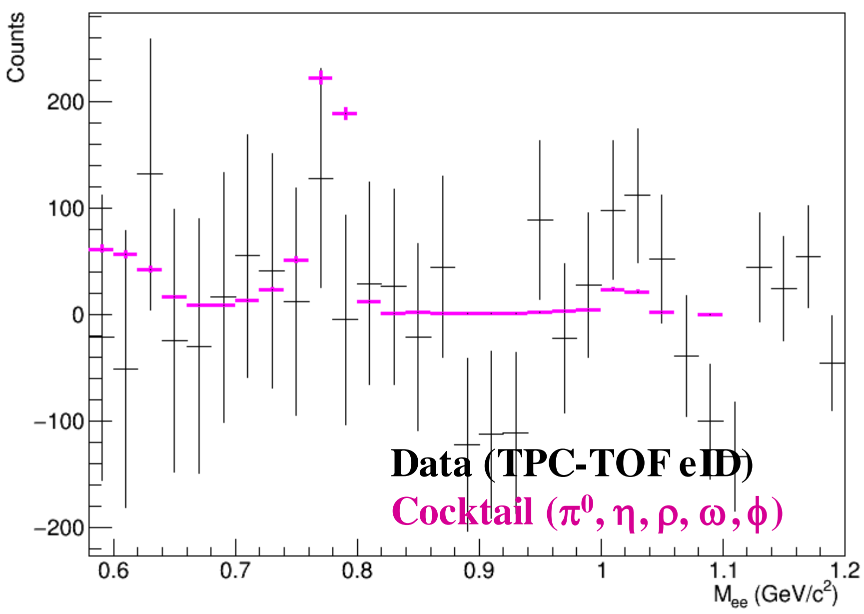
Data (TPC-TOF eID)

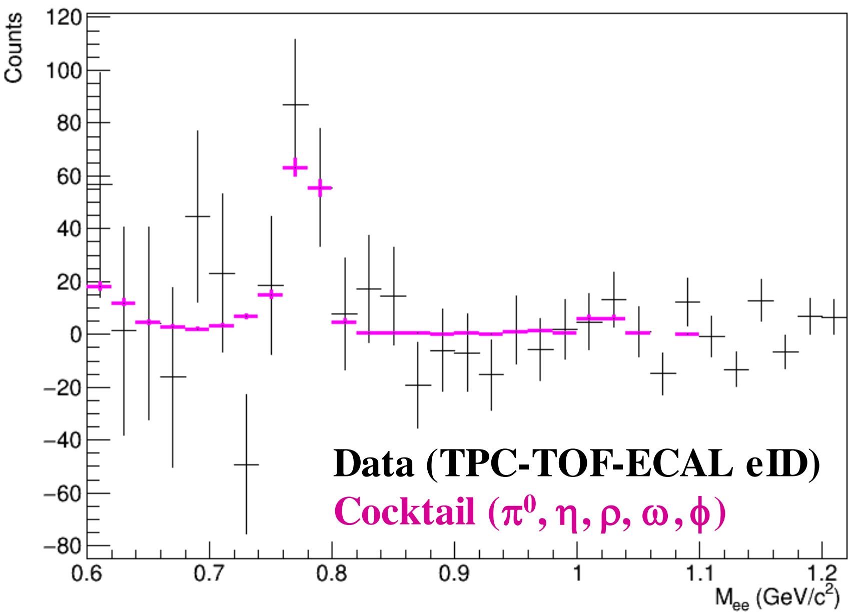
Mixed event background

True cocktail (π^0, η, ρ, ω, ϕ)

Di-electron spectrum, first look

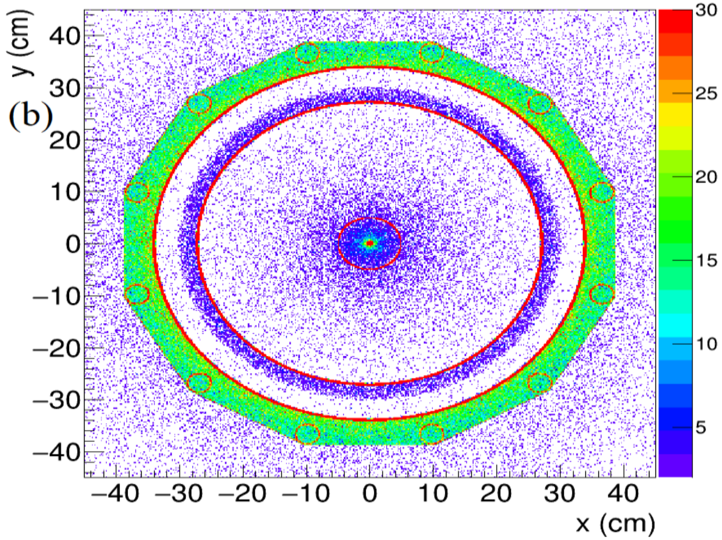
- AuAu@11 (UrQMD), realistic vertex distribution, 1.5 M events
- LVM → e^+e^-, vector mesons are weighted to have zero generated width (to be seen)
- Track selections and PID cuts: same as in previous slide
- ECAL improves S/B ratio for LVM by a factor of 5 for p_T-integrated M_{ee} spectrum
- 10M events is a minimum data sample for detailed study of e^+e^- continuum

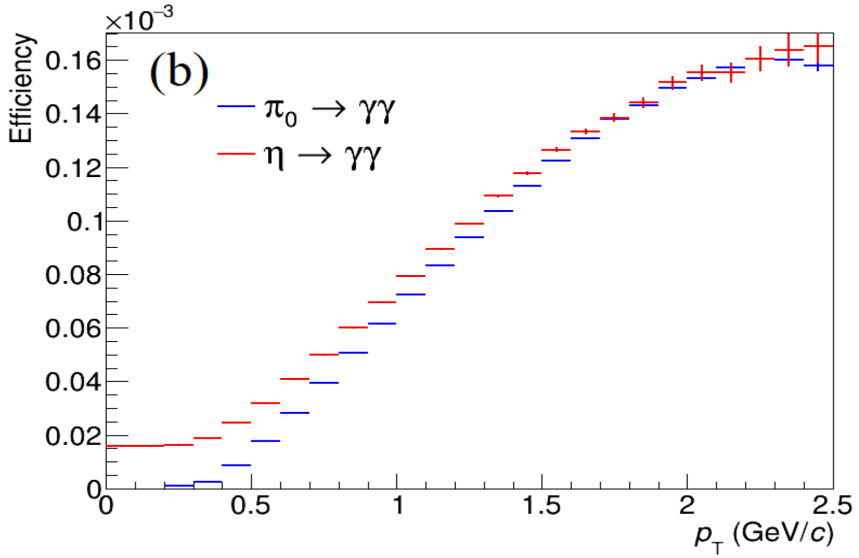




Conversion

- UrQMD, minbias AuAu@11, realistic vertex distribution, 10M events
- Conversions on the beam pipe and inner TPC vessels can be used to collect a clean sample of photons
- Competing method of γ, π^0 and η reconstruction, especially at low momentum
- Performance can be further improved by using ECAL ePID

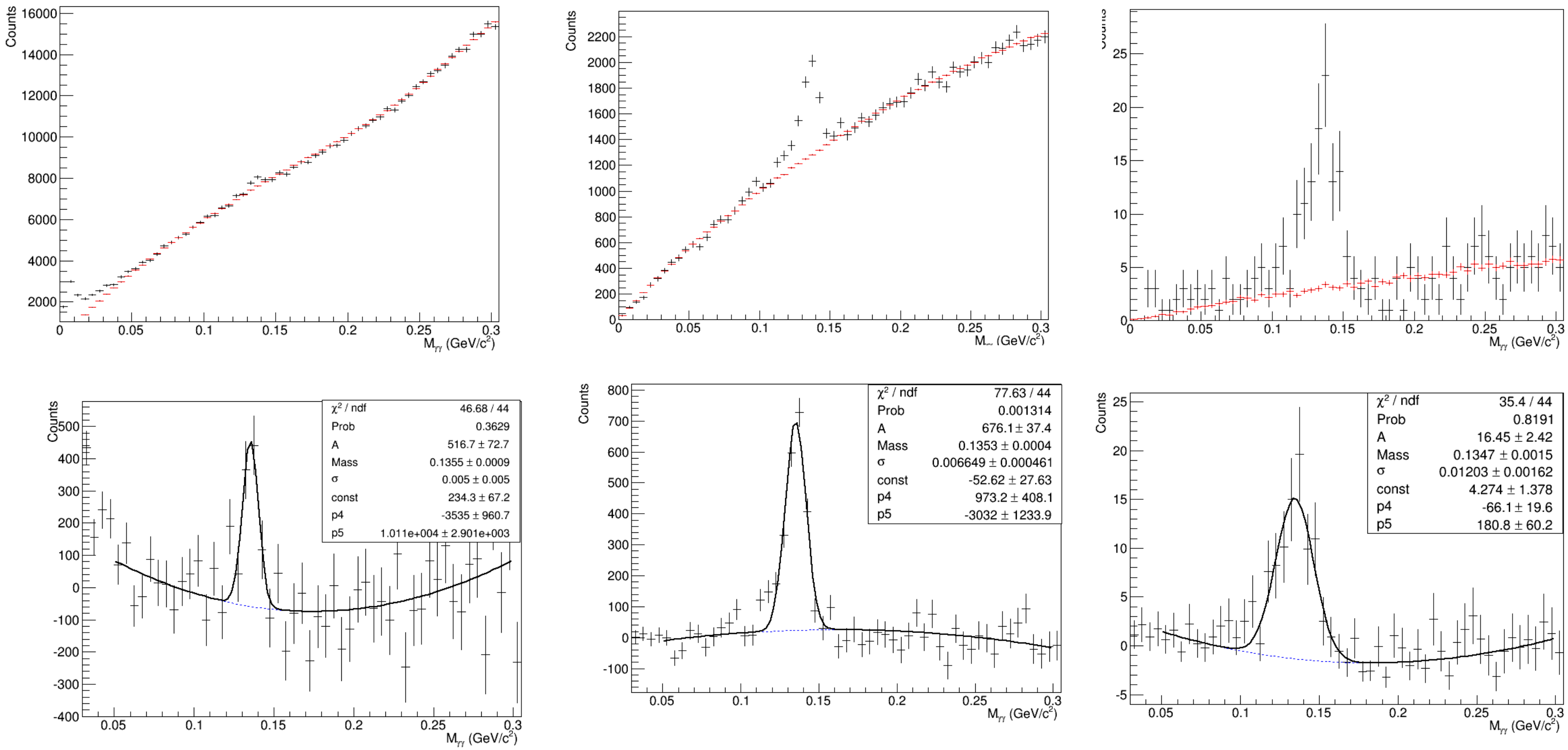




Neutral mesons through conversion, π^0

- minbias AuAu@11, UrQMD; $\pi^0 \rightarrow \gamma\gamma \rightarrow (e^+e^-)(e^+e^-)$
- Smaller peak width (better energy resolution) and S/B at low momentum

0-0.5 GeV/c **1.0-1.5 GeV/c** **2.5-3.0 GeV/c**



Near future

- New and more realistic MPD-ECAL geometry:
  - ✓ new tower shapes based on two milling angles, new geometrical sizes and positions
  - ✓ solid containers for ECAL modules made from carbon composite medium (total number equal to 25)
  - ✓ new power frame to mount ECAL containers
  - ✓ expected in a month

- New geometry will need new digitizer and tuning of the clusterizer

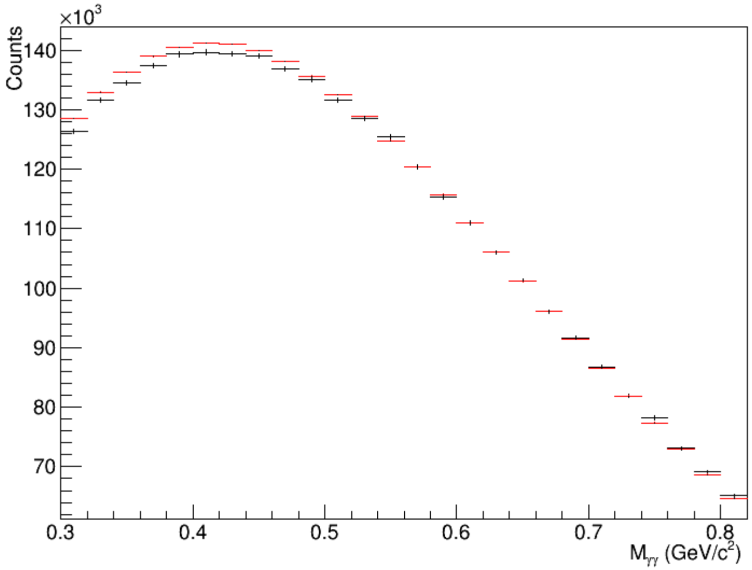
Conclusions

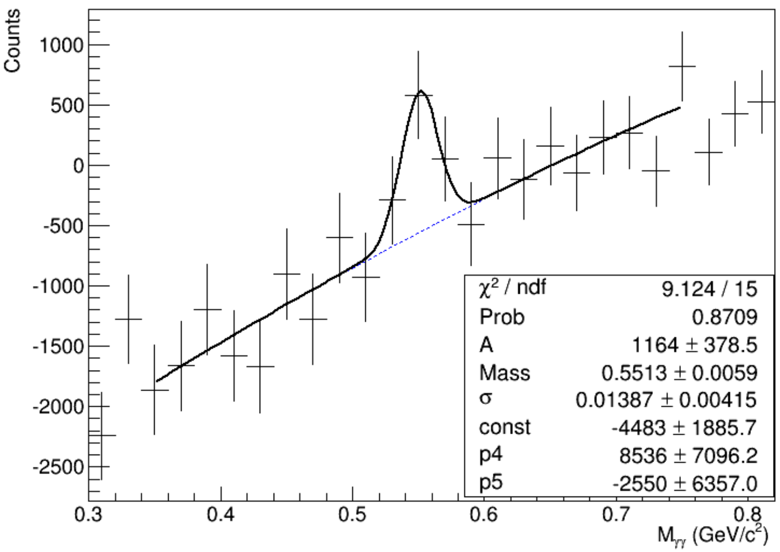
- ECAL enhances physical program of the MPD experiment
- ECAL Software Group is operational and productive
- Basic physical studies will be performed in the Group, others will be advanced by PWGs
- Cross-check of the simulated detector parameters with the beam test results is important

BACKUP

Neutral mesons through conversion, η

- minbias AuAu@11, UrQMD; $\eta \rightarrow \gamma\gamma \rightarrow (e^+e^-)(e^+e^-)$
- first observation of η signal (3σ bump)





π^0, mass and width

- Mass and width are multiplicity dependent
- Cluster merging starts at ~ 6 GeV/c → increasing masses and widths
- Reconstruction efficiency drops to ~ 0 at 15 GeV/c