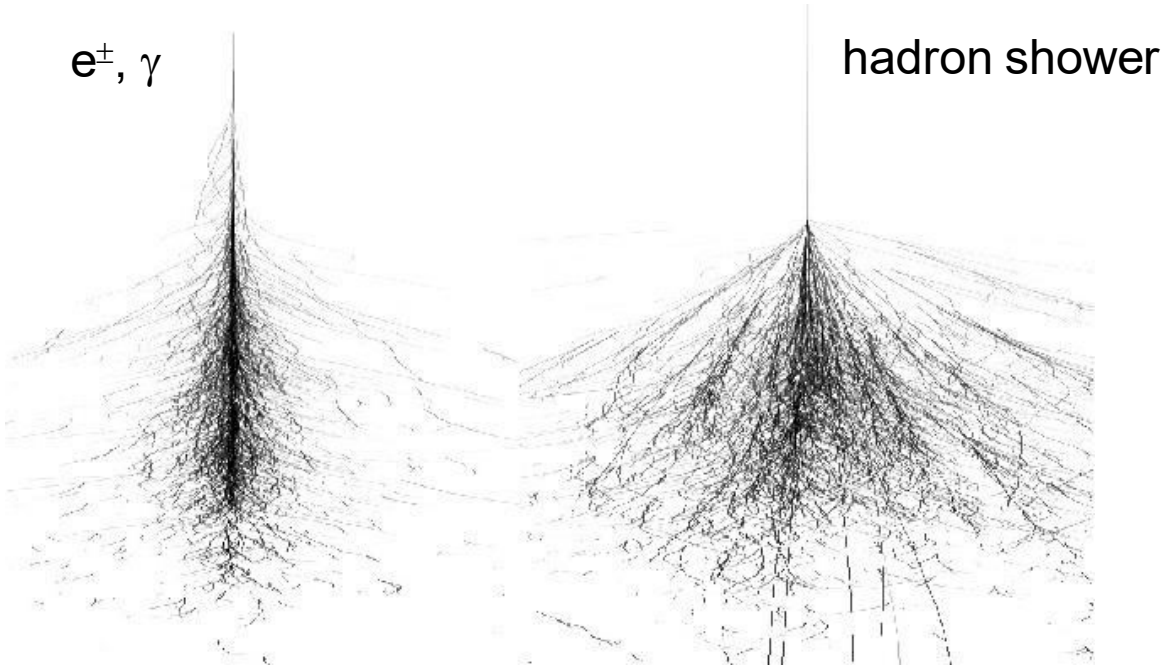
PWG4 summary

V. Riabov



Status & structure

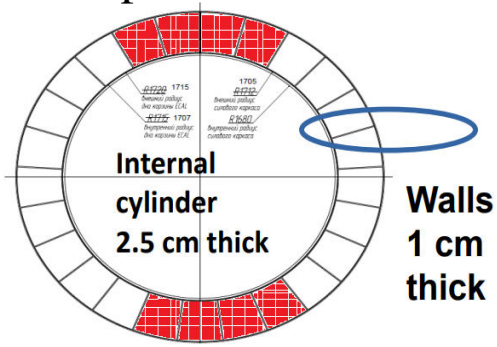
- Regular PWG4 meetings since Feb, 2019
  - ✓ https://mpdforum.jinr.ru/c/electromagnetic-probes
- PWG4 scope - electromagnetic probes:
  - ✓ electromagnetic calorimeter (ECAL) reconstruction software
  - ✓ reconstruction of photons and neutral meson
  - ✓ dielectron continuum and LMR
  - ✓ estimation of direct photon yields and flow
- Conveners: V. Riabov, Chi Yang
- Talk outline: most recent results and activities

ECAL acceptance

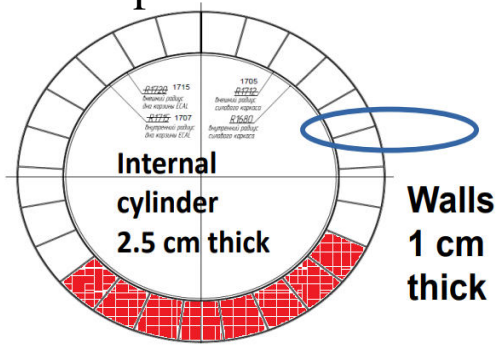
ECAL geometry, today

- Full configuration: (25 sectors in azimuth with full pseudorapidity coverage; 50 half-sectors)
- Most probable acceptance for year-1: 8 sectors → optimization of geometry configuration

Option #1



Option #2



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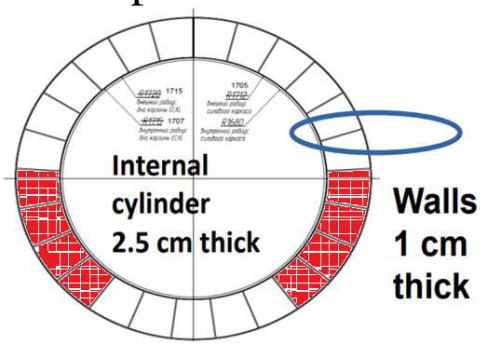

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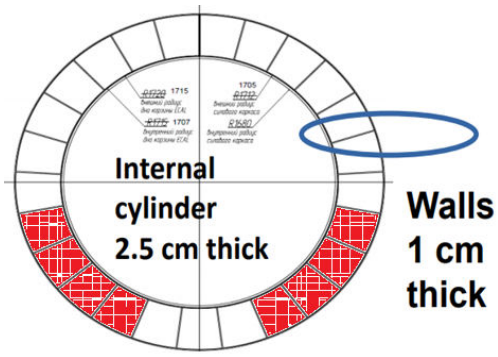

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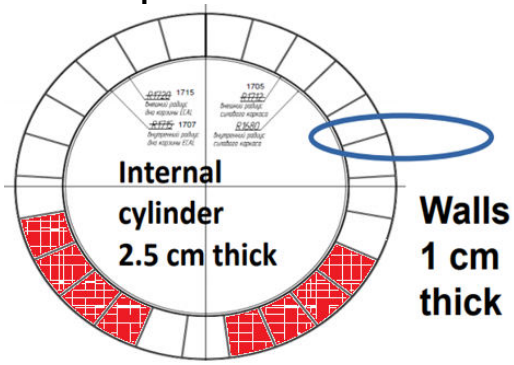

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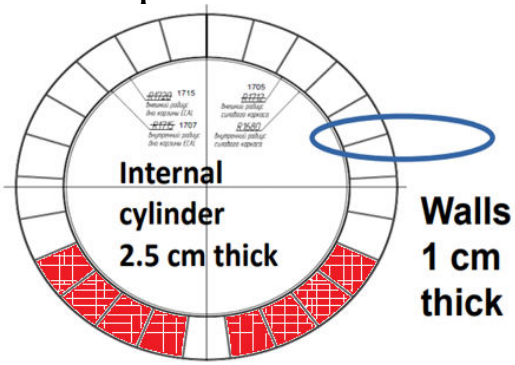
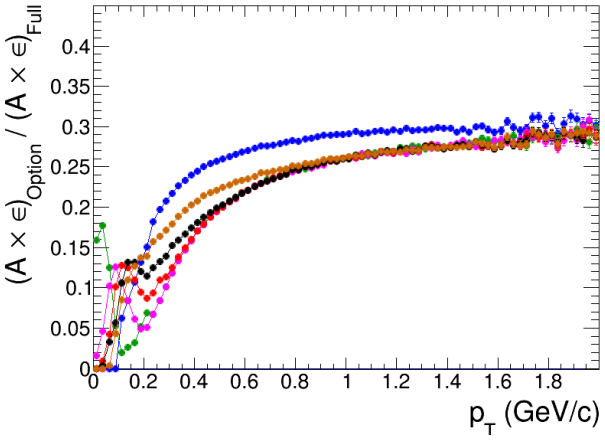
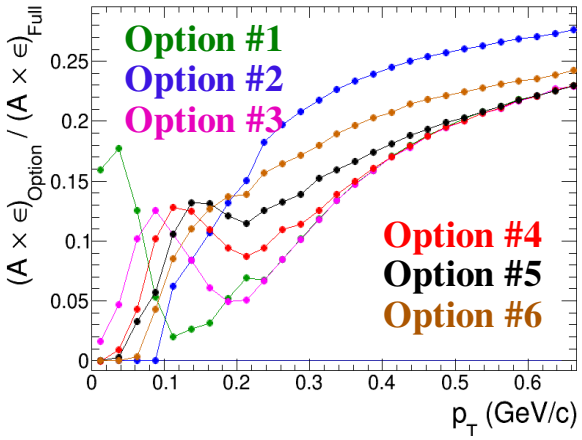
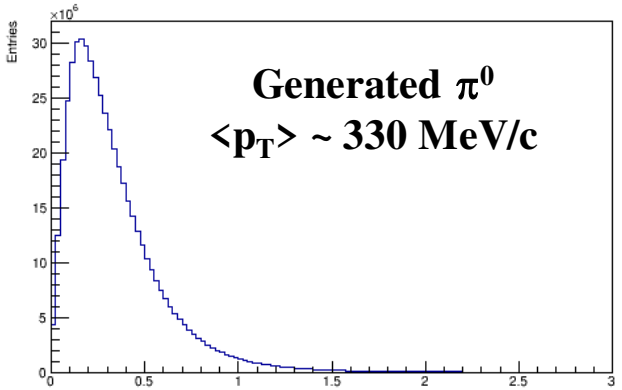


Sampling fraction for π^0 and η

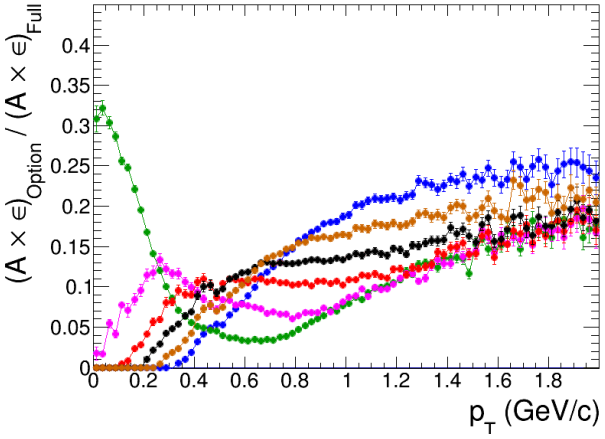
- π^0 fractional efficiencies: UrQMD, BiBi@9.46, realistic vertex distribution

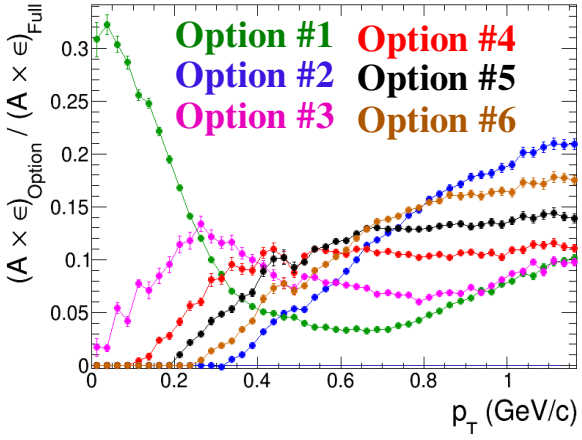


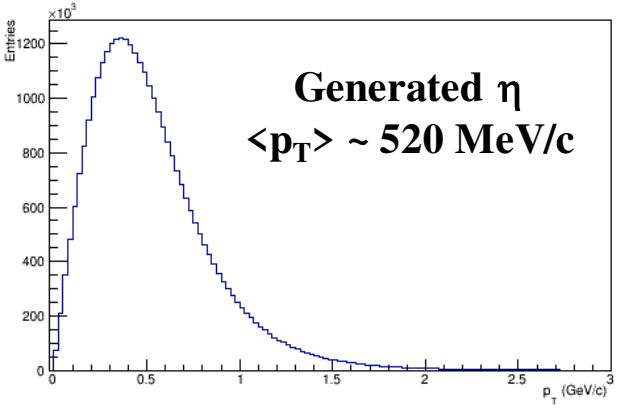




- η fractional efficiencies: BiBi@9.46, realistic vertex distribution





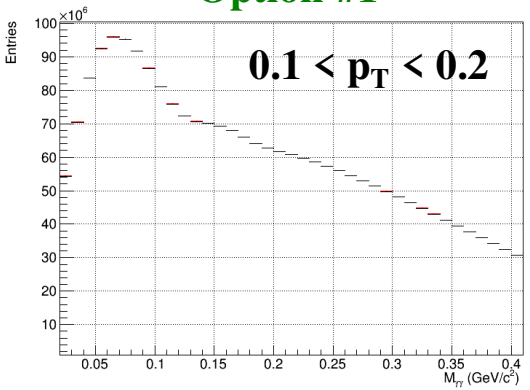


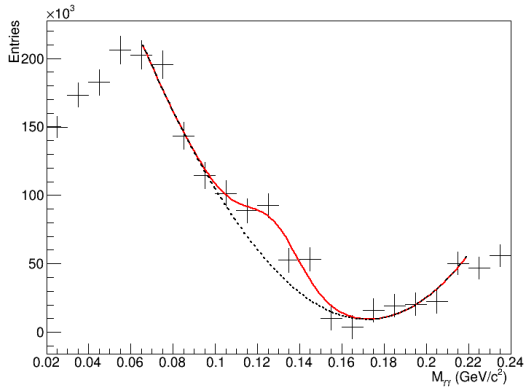
- Loss of efficiency is >> than just a geometrical factor of 0.32, especially at p_T < 1-2 GeV
- Options 4 - 5 are the most balanced for neutral meson measurements:
  - ✓ open up acceptance at low p_T, ~ 50 MeV/c for π^0 and ~150-200 MeV/c for η → sample most of p_T spectrum
  - ✓ moderate efficiency at intermediate p_T

Reconstruction of π^0, low p_T

- UrQMD, 10M minbias BiBi@9.46, realistic vertex distribution
- Same statistics for all options

Option #1





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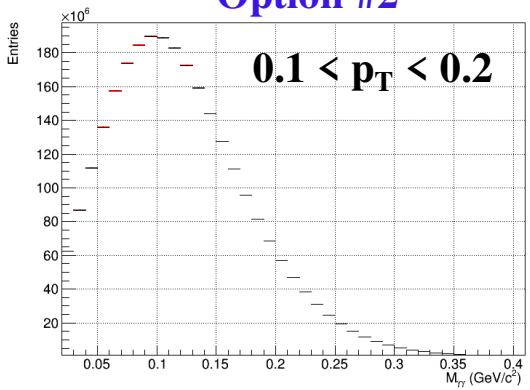

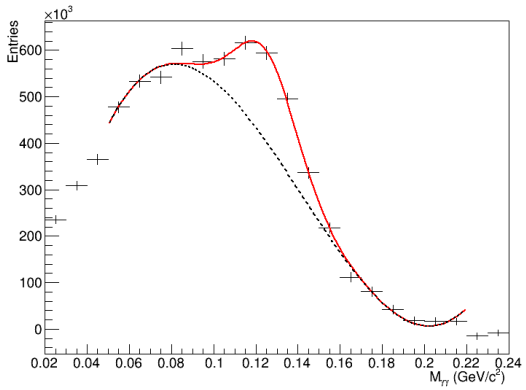

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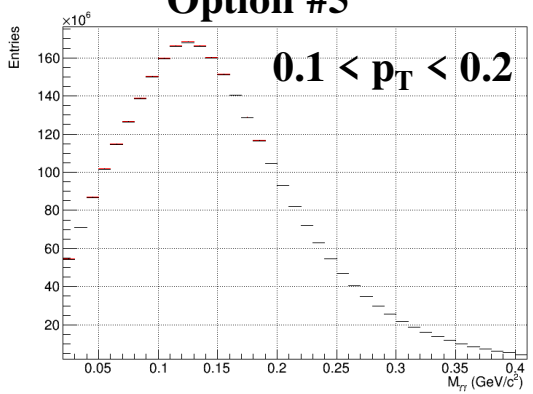
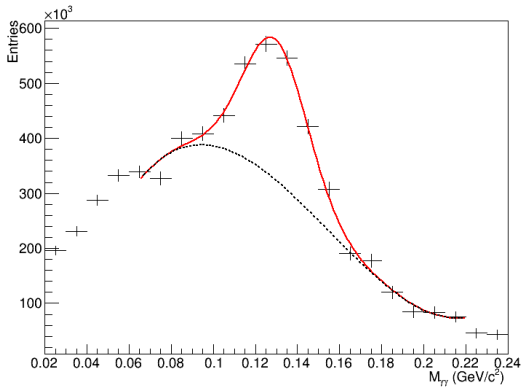
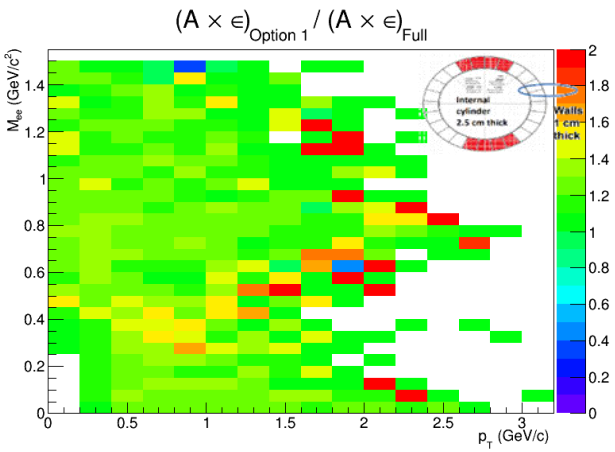


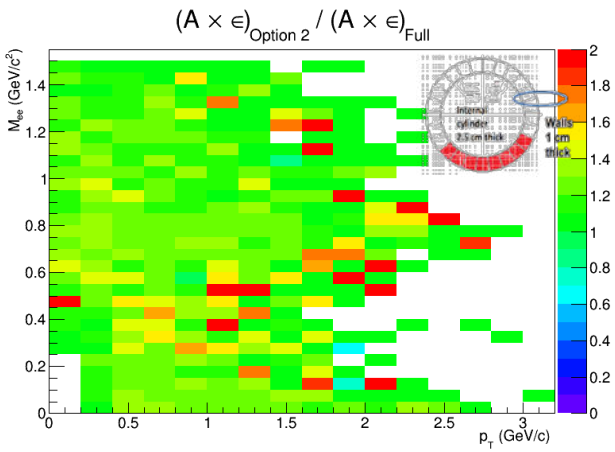


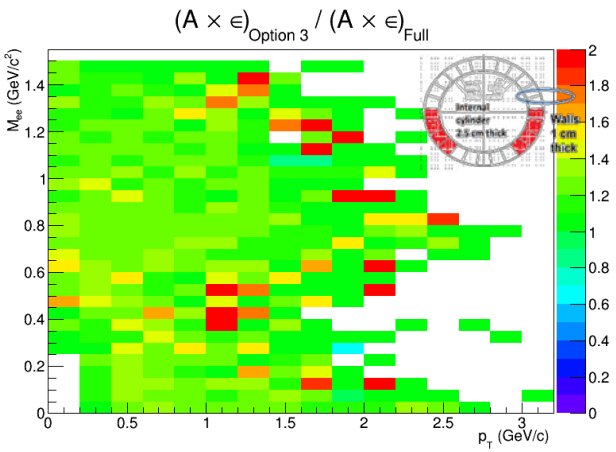
- Options #4 #5 provide better signal significance at p_T ~ 100 MeV/c
- Measurement of neutral meson is possible, but very significant loss of efficiency at low momentum

Acceptance for dielectrons

- ECAL is used to identify tracks that are matched to the ECAL clusters (E/p, time-of-flight)
- ECAL acceptance does not affect the (di)electron efficiency, only purity & efficiency
- Fractional yields: UrQMD, BiBi@9.46, smeared vertex, $p_T^{\text{single } e^{\pm}} > 200$ MeV/c



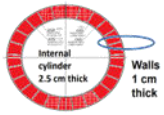


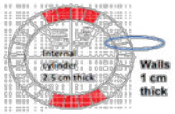


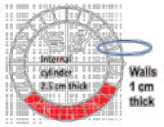
- Fractional efficiencies > 1, ECAL reduces $e^{\pm}$ detection efficiency, but improves purity
- No obvious difference observed for Options #1,2,3 (4-6)

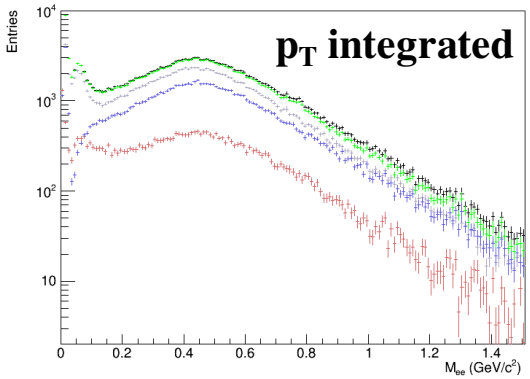
Dielectron M_{inv} spectra

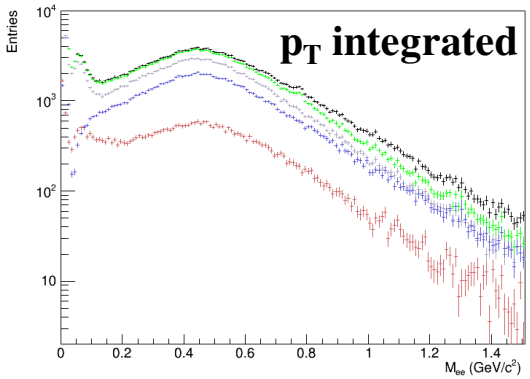
- M_{ee} yields: UrQMD, BiBi@9.46, smeared vertex

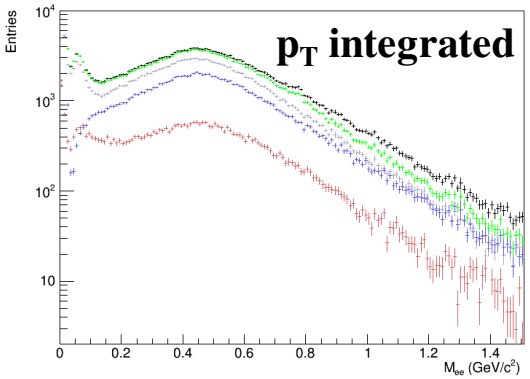


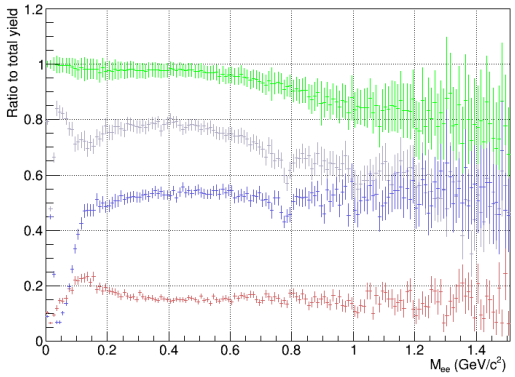


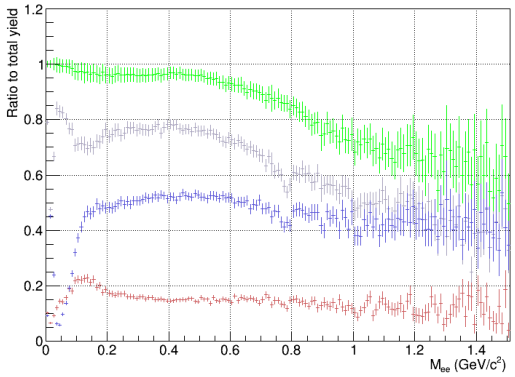


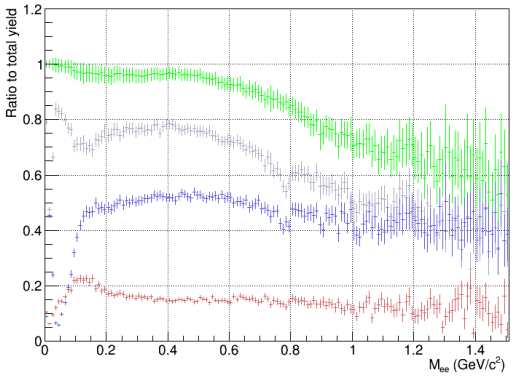












M_{ee} measured/reconstructed with eID in the TPC&TOF&ECAL;
M_{ee} true electrons: among them M_{ee} with π^0 Dalitz, M_{ee} with conversion, M_{ee} with η Dalitz

- No obvious difference between the Options #1,2 (3-6)

Summary

- Acceptance for neutral meson measurements is strongly reduced at low p_T
- Options # 4,5 look most promising for neutral mesons → day-1 measurements
- All options have similar effect for dielectron measurements

Dielectron continuum and LVMs

New Monte Carlo production

- Request11: *PWG4 - dielectrons, 15M minbias BiBi@9.2*
- The production has been finished a few weeks ago
- Aims at dielectron studies but good for most of other analyses
- Features (what's different compared to previous dielectron productions):
  - ✓ latest MpdRoot version with the updated materials, detector response and reconstruction algorithms
  - ✓ realistic dE/dx calculations with Geant-4
  - ✓ dphi, dzed variables for better track-to-TOF matching
  - ✓ most probable first collision system, BiBi@9.2
  - ✓ high statistics, 15 M events
- Output data:
  - ✓ /eos/nica/mpd/sim/data/exp/dst-BiBi-09.2GeV-mp02-21-500ev/BiBi/09.2GeV-mb/UrQMD/BiBi-09.2GeV-mp02-21-500ev/
  - ✓ 30,000 DST files
- Thanks to Andrey Moshkin !!!

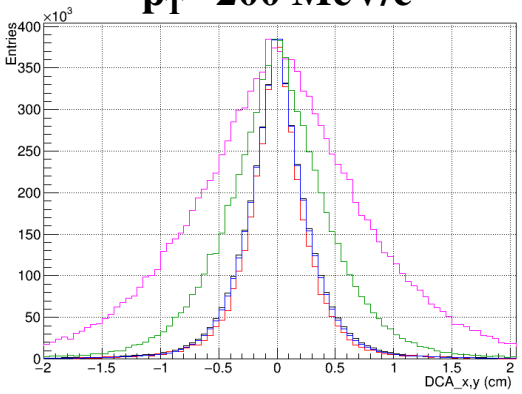
Ongoing studies

- Optimization of track and eID selection cuts:
  - ✓ more differential DCA parameterizations
  - ✓ better control over the track-to-TOF matching
  - ✓ better treatment of eID in the TPC, TOF and ECAL
- Optimization of pair selection cuts:
  - ✓ rejection of conversion track candidates
  - ✓ rejection of Dalitz decay track candidates
- Criteria of optimization:
  - ✓ larger statistical significance of signals → smaller statistical uncertainties
  - ✓ higher S/B ratio → smaller systematic uncertainties from background normalization
- Signals:
  - ✓ LM region 0.2-0.6 GeV/c^2
  - ✓ LVM: Omega, Phi

DCA to primary vertex

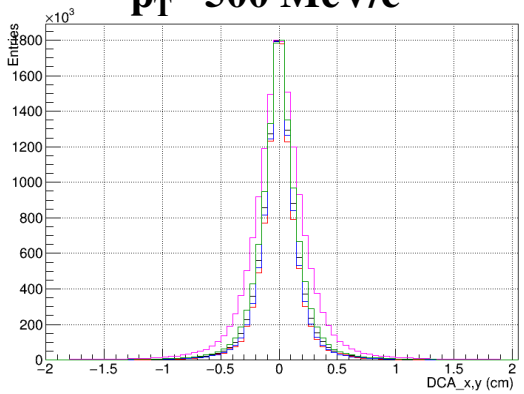
- DCA cuts are used to select primary particles and reject background from secondary and γ - conversion
- Examples of DCAx(y) distributions for charged particles, pions, kaons, protons and electrons, normalized to have the same maximum

p_T ~200 MeV/c



Charged
Pions
Kaons
Protons
Electrons

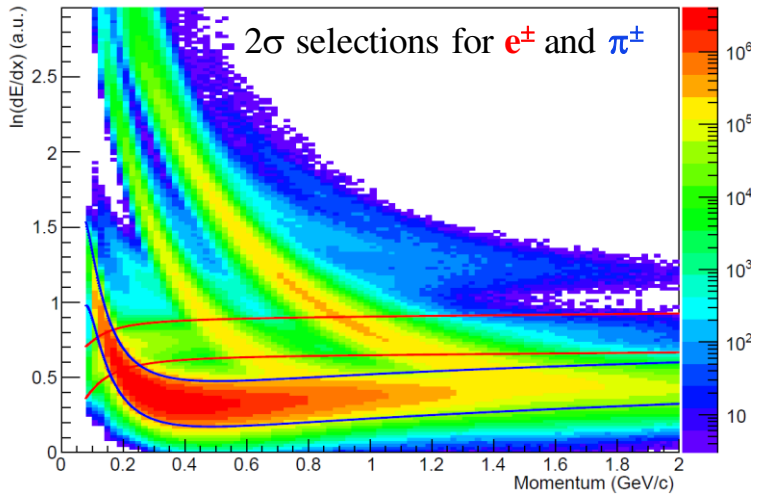
p_T ~500 MeV/c



- DCA distributions show clear p_T, centrality and rapidity dependence
- DCA was parameterized as a function of p_T, centrality and rapidity for inclusive charged particles and then normalized for n-sigma selections
- The width of DCA distributions shows PID dependence at p_T < 400 MeV/c → tighter DCA cuts give preference to electron selection at low p_T (for primary particles)
- The width of DCA selections is optimized for better signal significance and smaller S/B

eID capabilities

- TPC: ln(dE/dx)



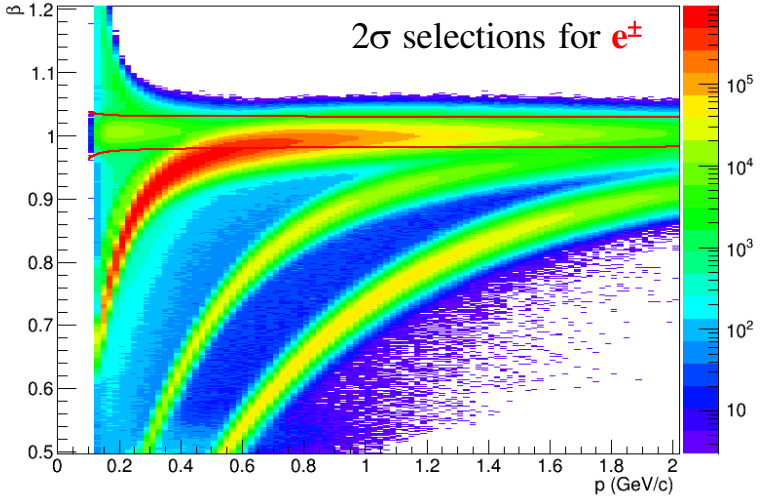
Tracks:

# of hits > 39

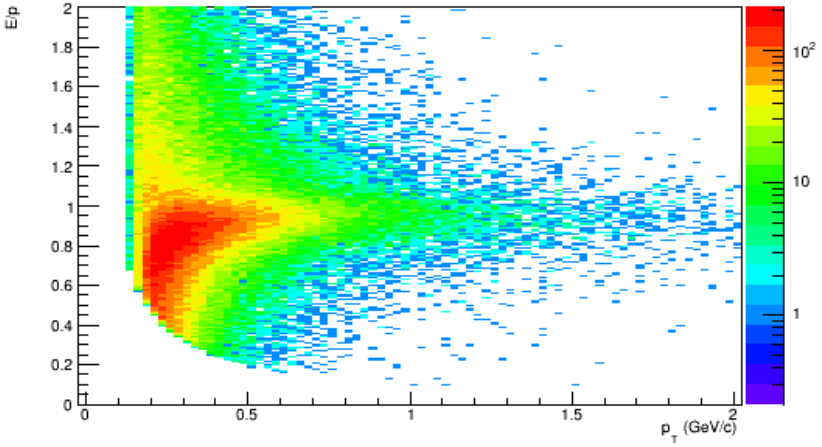
$|\eta| < 1$

$|DCA\_x,y,z| < 3\ \sigma$

- TOF: $\beta = v/c \sim 1$, $p_T > 150$ MeV/c



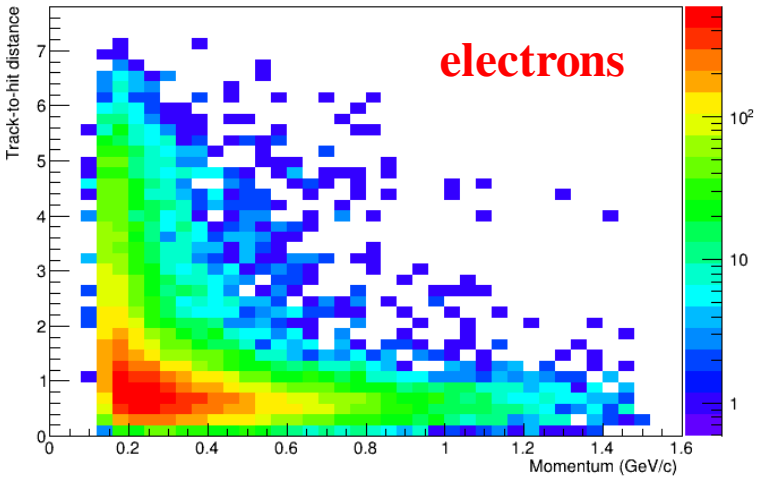
- ECAL: time-of-flight ($\delta \sim 500$ ps) and E/p ~ 1 for 2σ-matched tracks

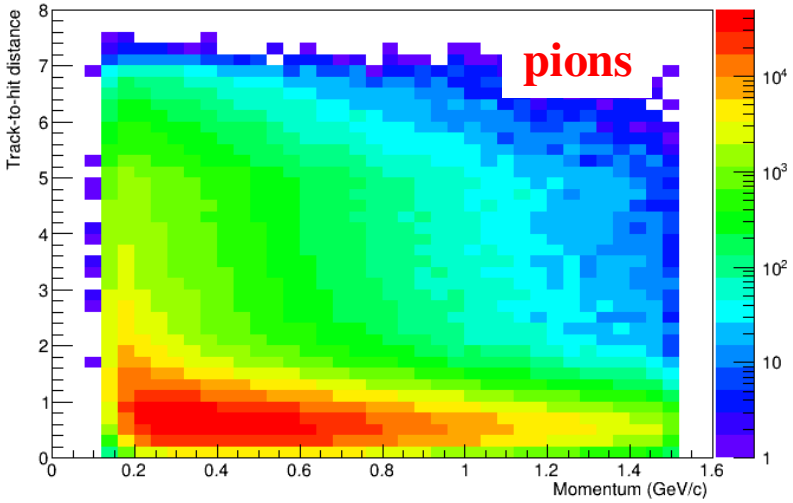


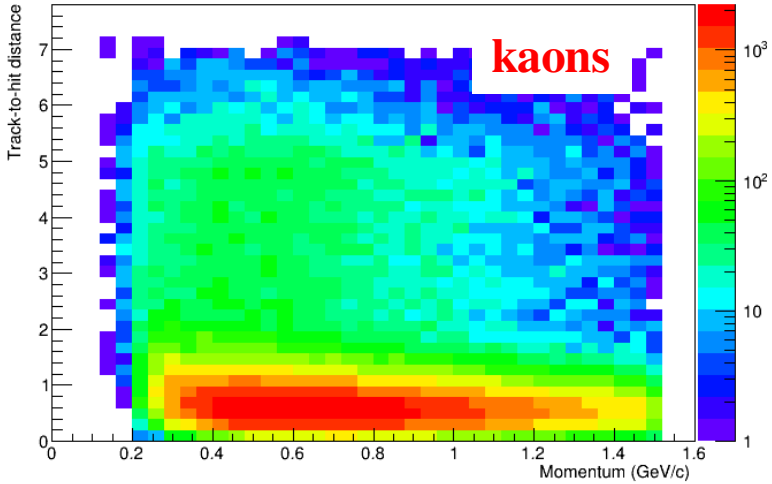
- ✓ turns on at $p_T > 200$ MeV/c
- ✓ TOF ([-3σ,2σ]) & E/P ([-3σ,2σ]) cuts provide high eID efficiency in a wide p_T range

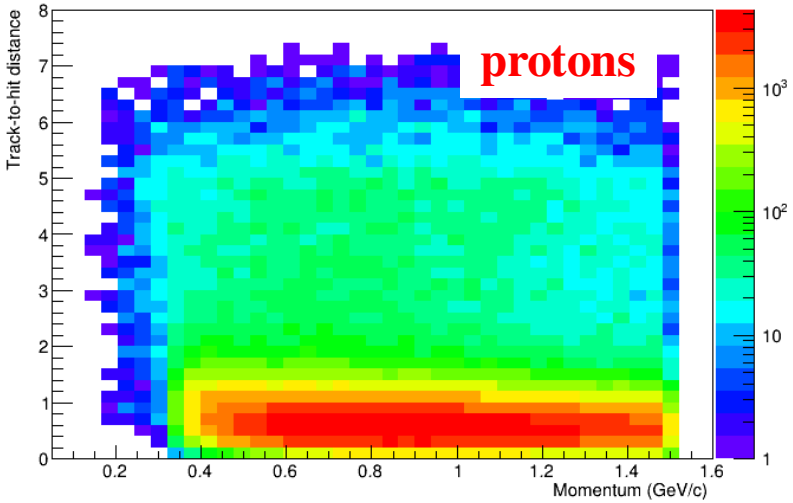
Track-to-TOF matching distributions in TOF vs. p_T

- Track-to-hit distance in the TOF (or *distance* = 1/*weight*) vs. p_T, minbias BiBi@9.46





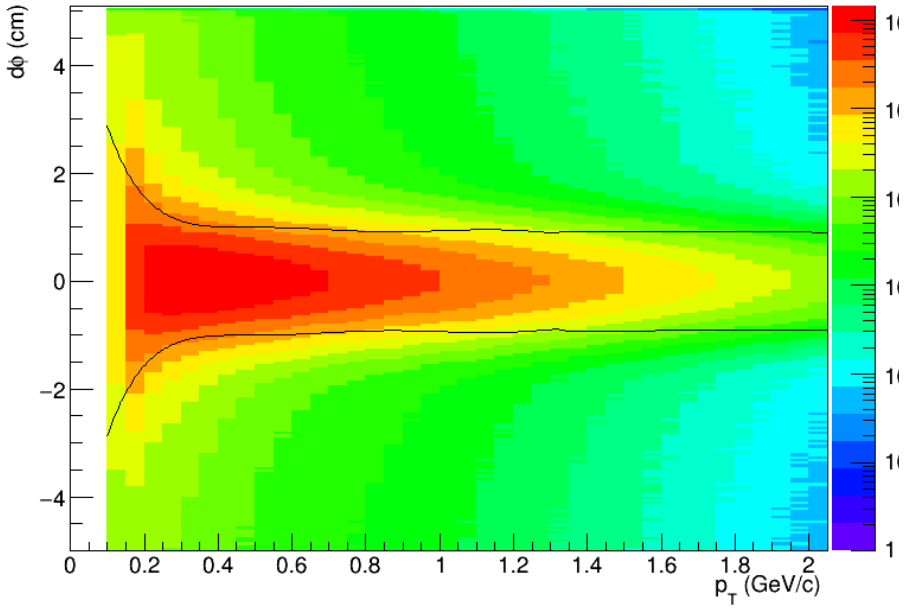


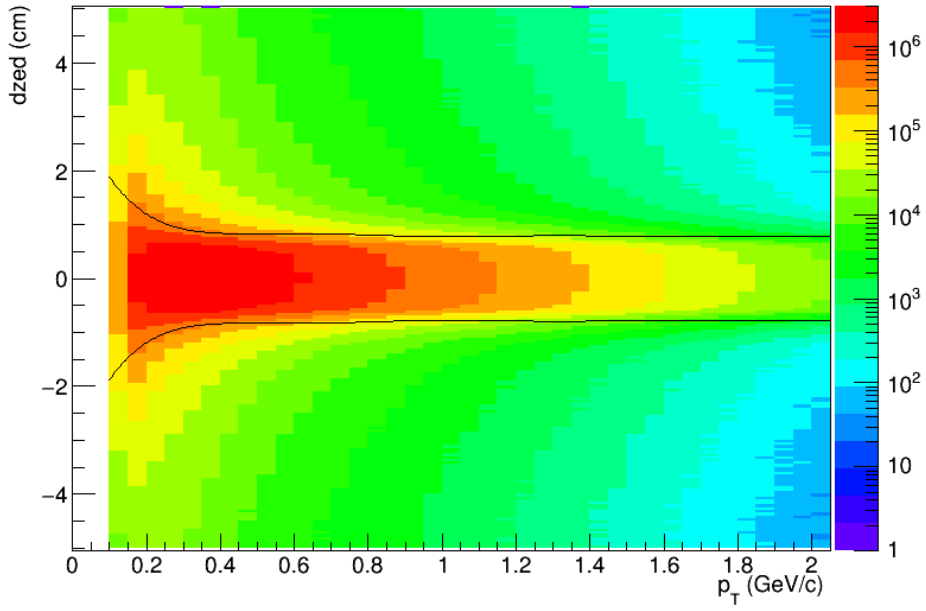


- Matching distributions are very wide

Track-to-TOF matching distributions vs. p_T

- Selected tracks:
  - ✓ hits > 39
  - ✓ |η| < 1
  - ✓ |DCA_x,y,z| < 3 σ
- Default track-to-TOF matching cut is |*distance*| < 7 cm
- Split *distance* to d*phi* and d*zed* and then parameterized matching distributions for all charged tracks vs. p_T

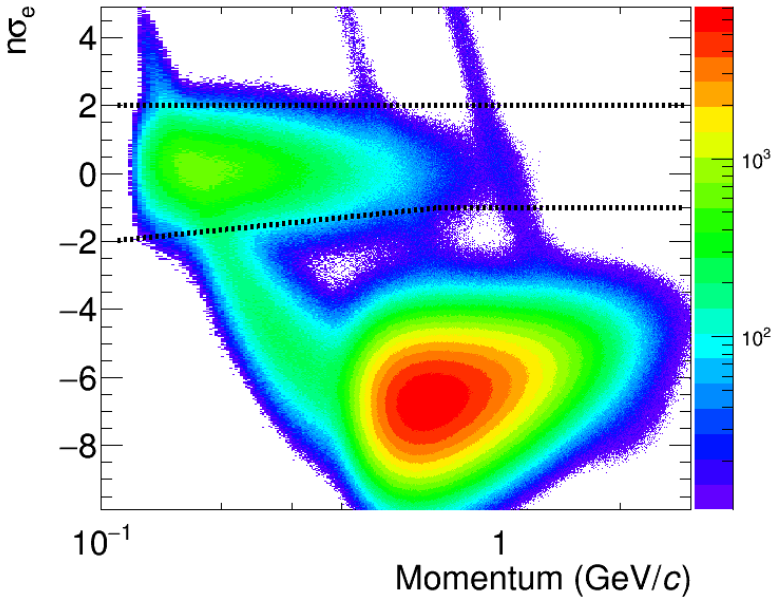




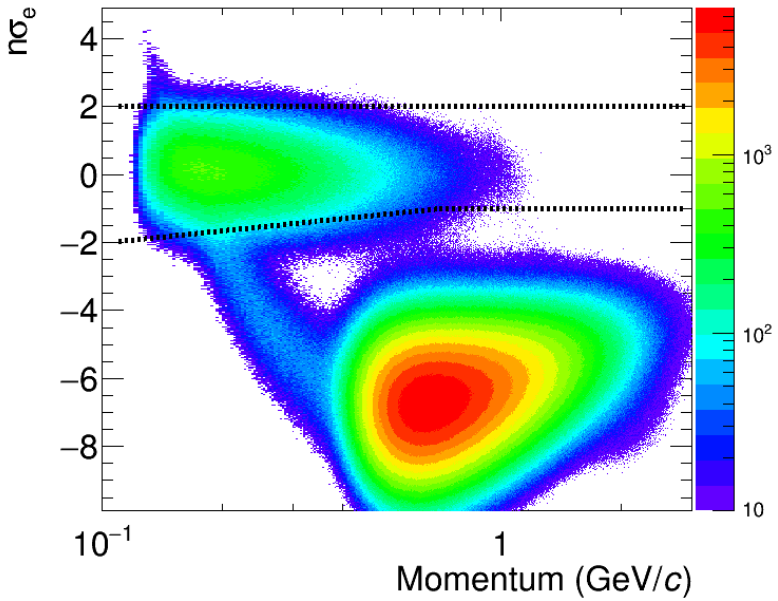
- 2σ bands are shown with black lines
- Do not observed a significant charge dependence of dφ
- Selection of n-sigma matching cuts is analysis dependent

dE/dx with TOF selections

- Selected tracks:
  - ✓ hits > 39
  - ✓ |η| < 1
  - ✓ |DCA_x,y,z| < 3 σ
  - ✓ Default matching to TOF + 2σ TOF-eID



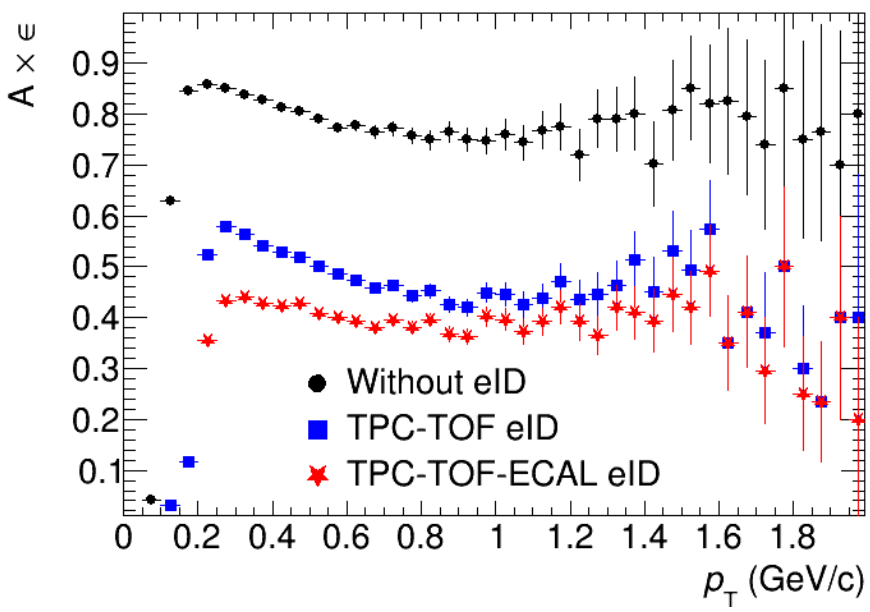
- Selected tracks:
  - ✓ hits > 39
  - ✓ |η| < 1
  - ✓ |DCA_x,y,z| < 3 σ
  - ✓ 2σ matching to TOF + 2σ TOF-eID

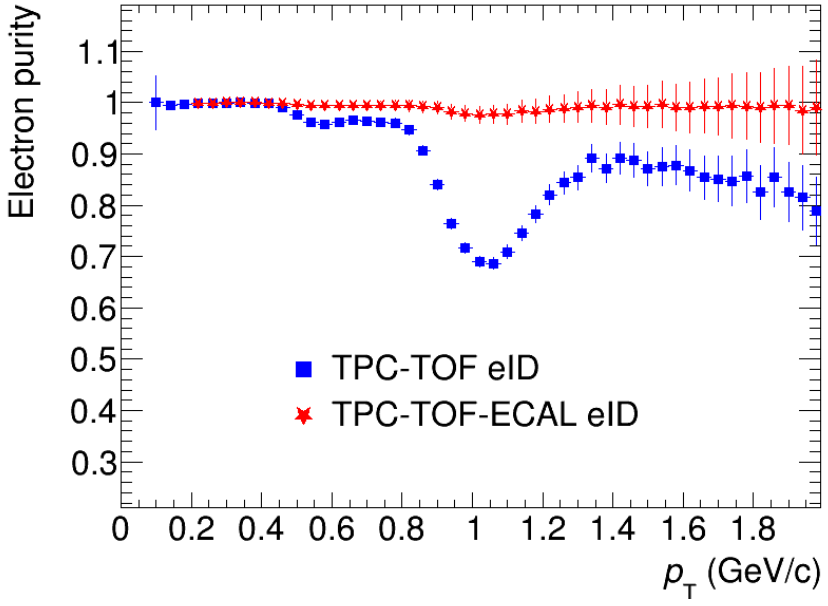


- 2σ matching reduces background from wrong association of tracks and TOF hits
- Background remains anyway, including β > 1 tail
- Dashed lines show the cuts which improve separation of pions and electrons at the expense of lower efficiency

Efficiency and purity

- Selected tracks:
  - ✓ hits > 39
  - ✓ |η| < 1
  - ✓ |DCA_x,y,z| < 3 σ
  - ✓ 2σ matching to TOF
  - ✓ 1-2σ TPC-eID
  - ✓ 2σ TOF-eID



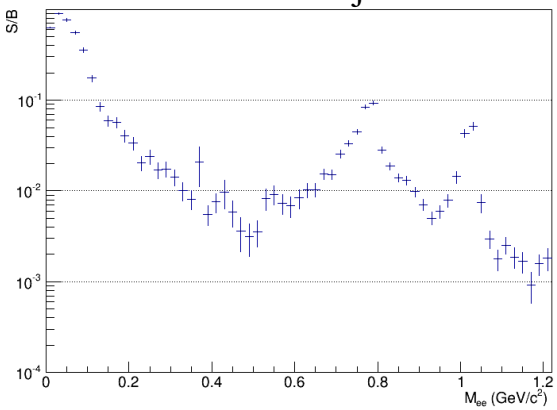


- New production: BiBi@9.2, realistic vertex

Conversion rejection

- Form pairs:
  - ✓ track #1 – passes tight track selection and eID cuts (same as in dielectron analysis)
  - ✓ track #2 – passes loose track selection and e-ID cuts
- Selections for conversion pairs:
  - ✓ Chi2 for the secondary vertex, pointing angle, DCA for $e^{\pm}$, distance to PV, invariant mass
- Once pair is consistent with $\gamma \rightarrow ee$ → both tracks are tagged as a conversion pair candidates and then rejected from the analysis
- minbias BiBi@9.45 events

No conversion rejection



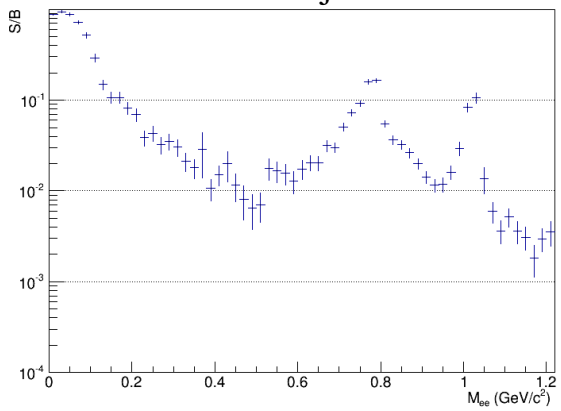
S/B in 0.2-1.5: 0.014

==========

Omega (s/sqrt(b)): 2.23
Phi (s/sqrt(b)): 0.86
LMR (s/sqrt(b)): 0.42

==========

Conversion rejection



S/B in 0.2-1.5: 0.028

==========

Omega (s/sqrt(b)): 2.93
Phi (s/sqrt(b)): 1.17
LMR (s/sqrt(b)): 0.56

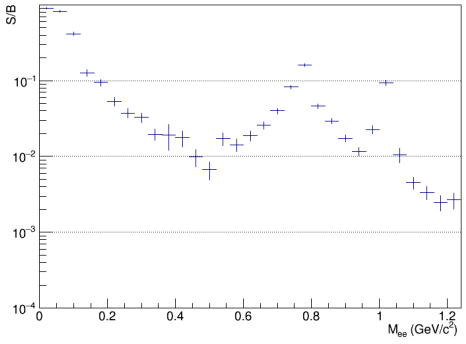
==========

- ✓ Rejection of conversion candidates improves S/B by a factor of 2
- ✓ Signal significance also improves

Dalitz decay rejection

- Pair each electron track candidate with all positron track candidates in the event
- If for any of the pairs $M_{e+e-} < M_{cut}$ → tag electron and positron track candidates for rejection

No cut



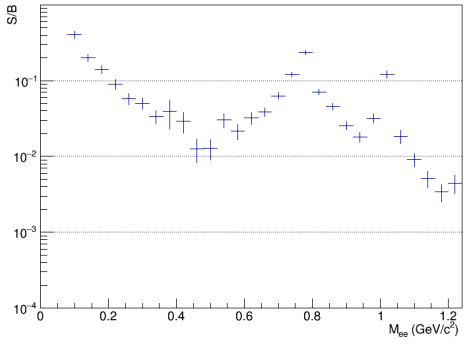
S/B in 0.2-1.5: 0.028

==========

Omega (s/sqrt(b)): 2.93
Phi (s/sqrt(b)): 1.17
LMR (s/sqrt(b)): 0.56

==========

100 MeV/c^2



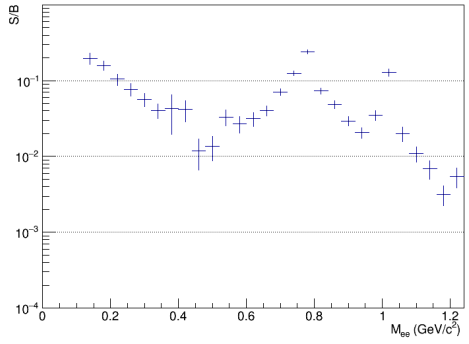
S/B in 0.2-1.5: 0.046

==========

Omega (s/sqrt(b)): 3.13
Phi (s/sqrt(b)): 1.2
LMR (s/sqrt(b)): 0.6

==========

135 MeV/c^2



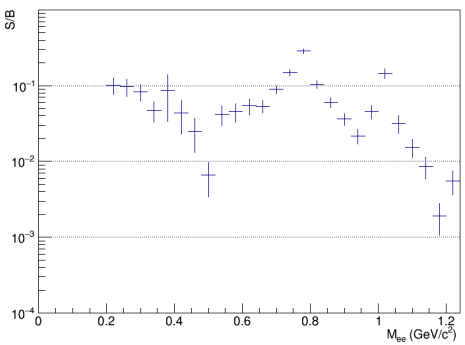
S/B in 0.2-1.5: 0.052

==========

Omega (s/sqrt(b)): 2.89
Phi (s/sqrt(b)): 1.10
LMR (s/sqrt(b)): 0.56

==========

200 MeV/c^2



S/B in 0.2-1.5: 0.069

==========

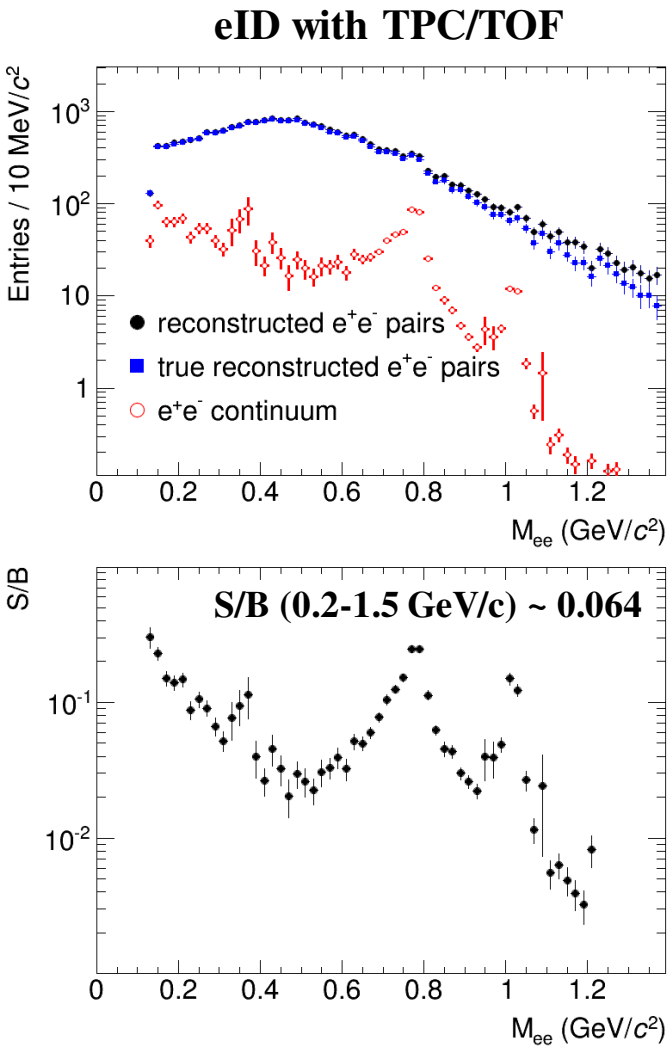
Omega (s/sqrt(b)): 2.62
Phi (s/sqrt(b)): 0.93
LMR (s/sqrt(b)): 0.49

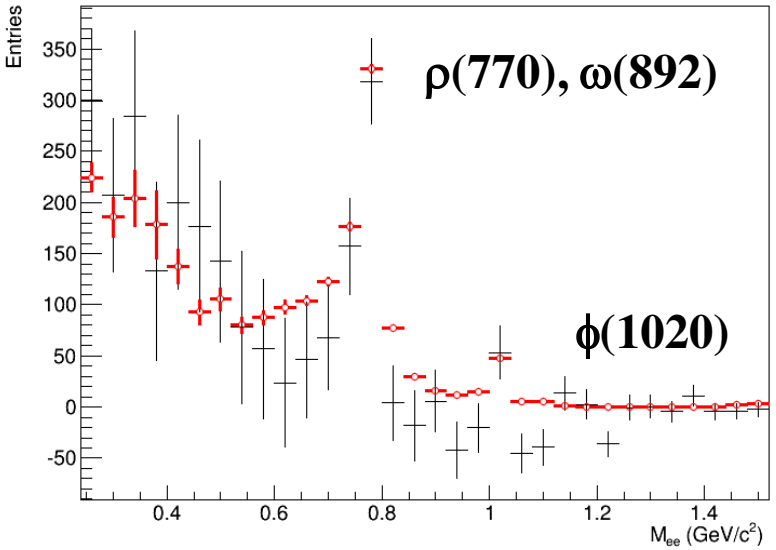
==========

- A cut of M > 100 MeV/c^2 improves the S/B and signal significance
- Further improvements in S/B are at the expense of smaller statistical significance
- The cut is a source of systematic uncertainties, which are difficult to control and evaluate

Examples of dielectron M_{inv} spectra, p_T integrated

- 15 M minbias BiBi@9.2 events





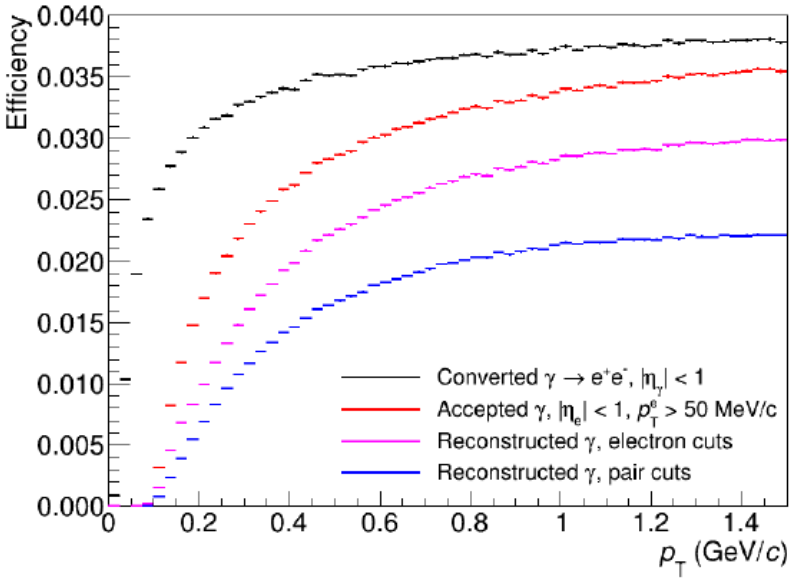
Summary for dielectrons

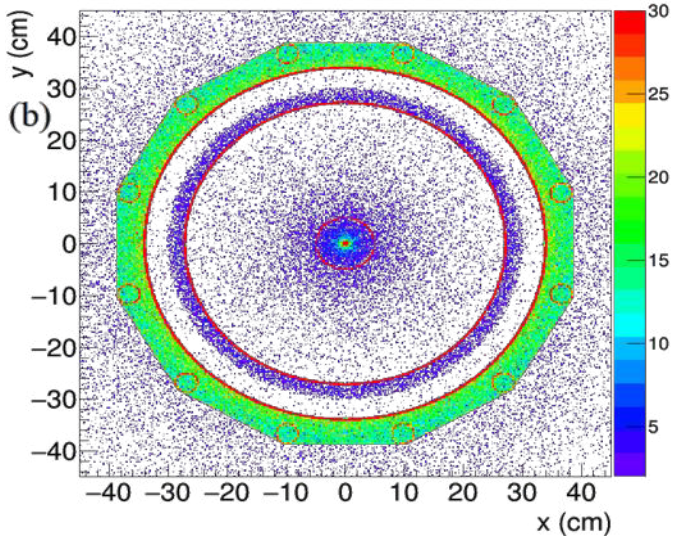
- Optimization of techniques for extraction of dielectron signals is ongoing
- Obtained results look promising
- Meaningful measurements for e^+e^- continuum and LVMs would require ~ 10^8 AuAu/BiBi sampled events, first observations will be possible with ~50 M events

Photon conversion method (PCM)

Reconstruction of photons with PCM, disadvantages

- Photons can be measured in the ECAL or in the tracking system as e^+e^- conversion pairs (PCM):

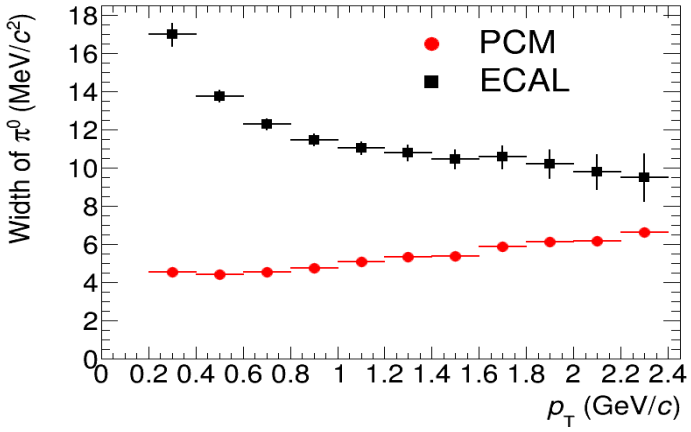


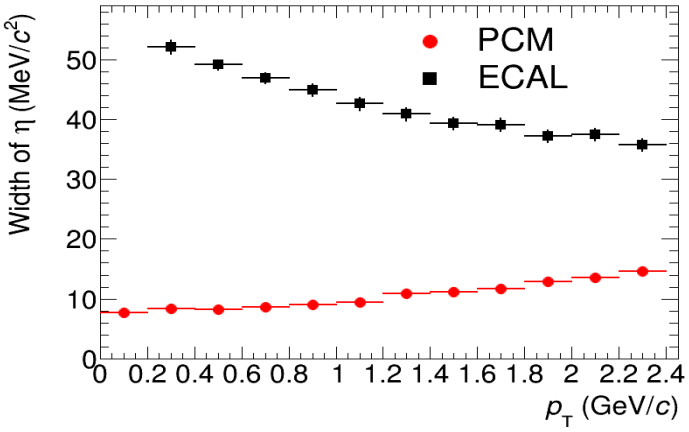


- Only < 4% of photons convert, < 2% of photons is reconstructed
- Efficiencies for neutral mesons are on sub-percent level, ~ $0.15 \cdot 10^{-4}$
- Low statistics is the main disadvantage of the PCM method

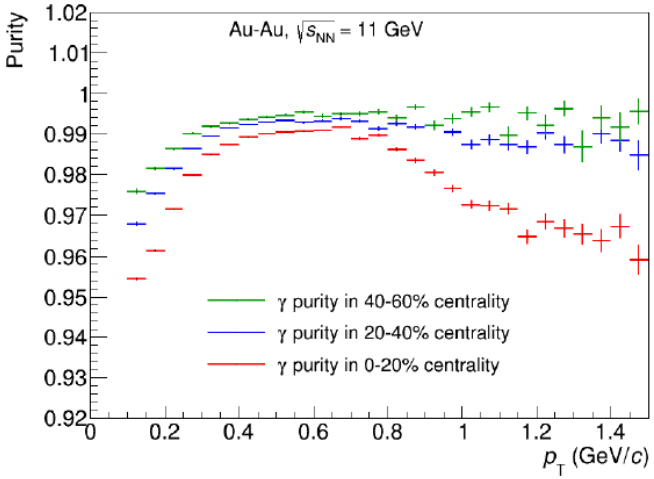
Reconstruction of photons with PCM, advantages

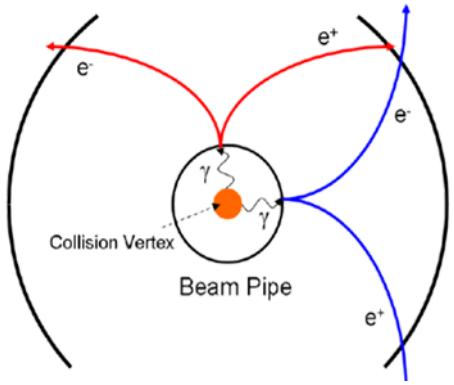
- PCM resolution for photons and neutral mesons is much better compared to the ECAL





- Photon purity is > 95%

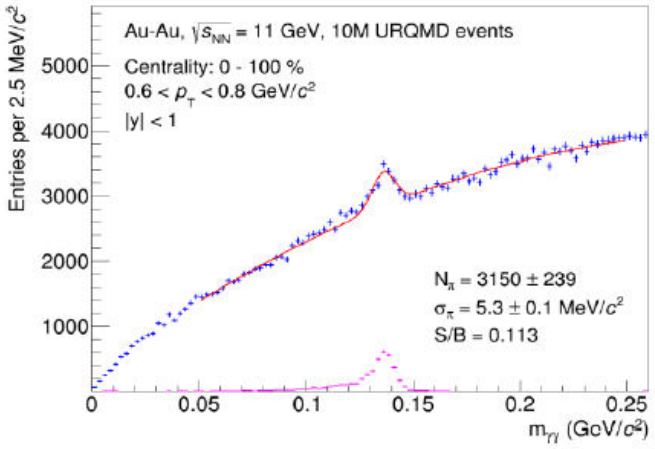


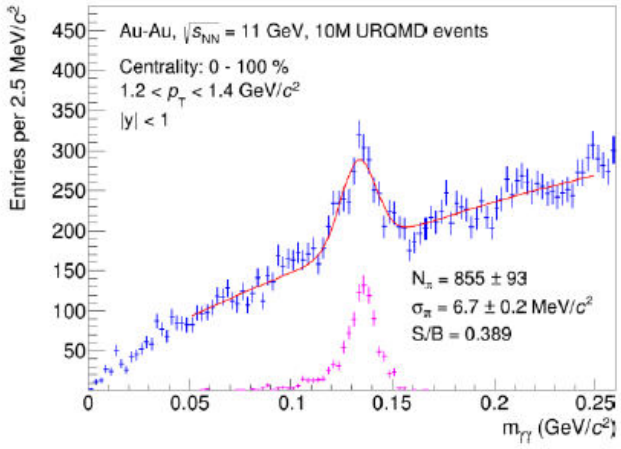


- High energy resolution and photon purity are the main advantages of the PCM method

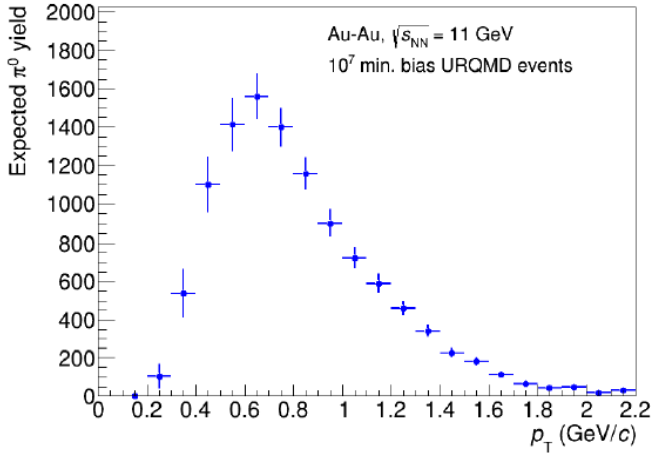
Reconstruction of neutral mesons with PCM

- Pair photons reconstructed with PCM: $\pi^0 \rightarrow \gamma\,(\gamma \rightarrow e^+e^-) + \gamma\,(\gamma \rightarrow e^+e^-)$





- Expected π^0 yields for 10^7 AuAu@11 events

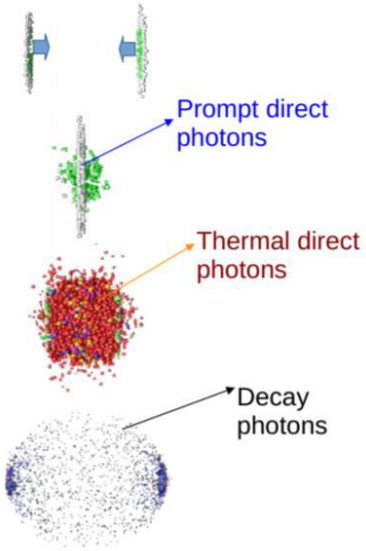


- Statistics hungry analysis
- Provides a good cross check for ECAL measurements
- Hybrid analysis of $\pi^0(\eta) \rightarrow \gamma\,(\gamma \rightarrow e^+e^-) + \gamma$ (ECAL) is possible and looks promising → See talk by D. Peresunko

Direct photons

Sources and estimations

- Direct photons – photons not from hadronic decays.
- Produced throughout the system evolution:
  - ✓ QCD matter is transparent for leptons, once produced they leave the interaction region unaffected preserving their properties
  - ✓ estimation of the 'effective' system temperature at low E
  - ✓ hard scattering probe at high E



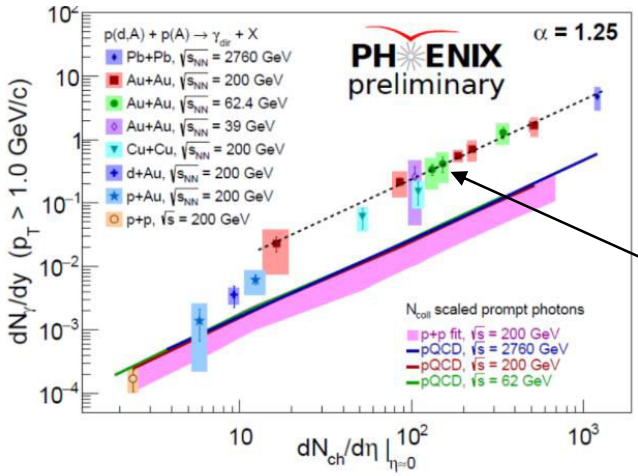
Estimation of the direct photon yields @NICA

model calculations

empirical scaling

See talk by D. Blau

- 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



central AuAu@11

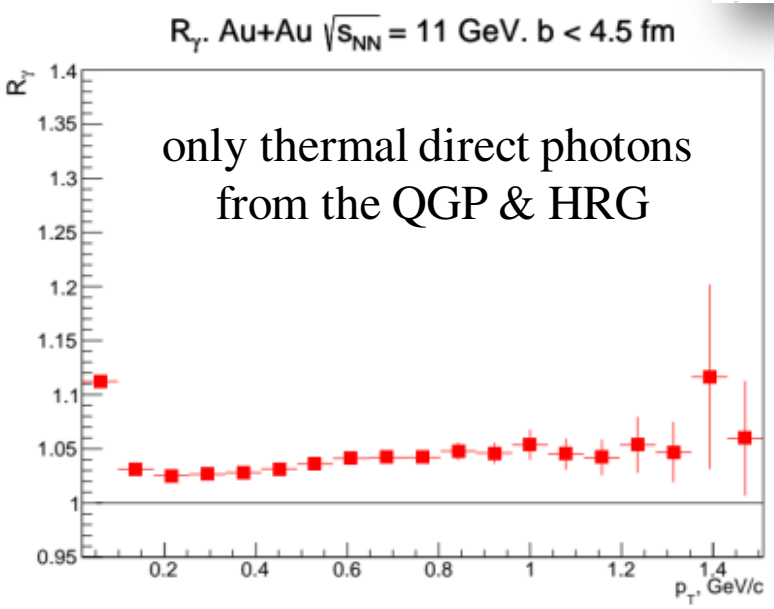
Expected yields of direct photons

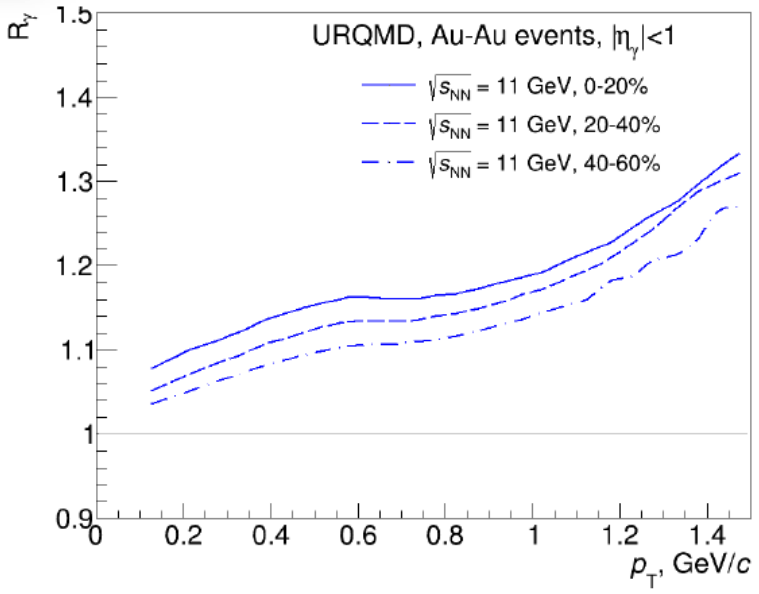
Estimation of the direct photon yields @NICA

model calculations

empirical scaling

$$R_\gamma = \frac{\gamma^{incl}}{\gamma^{hadron}}$$

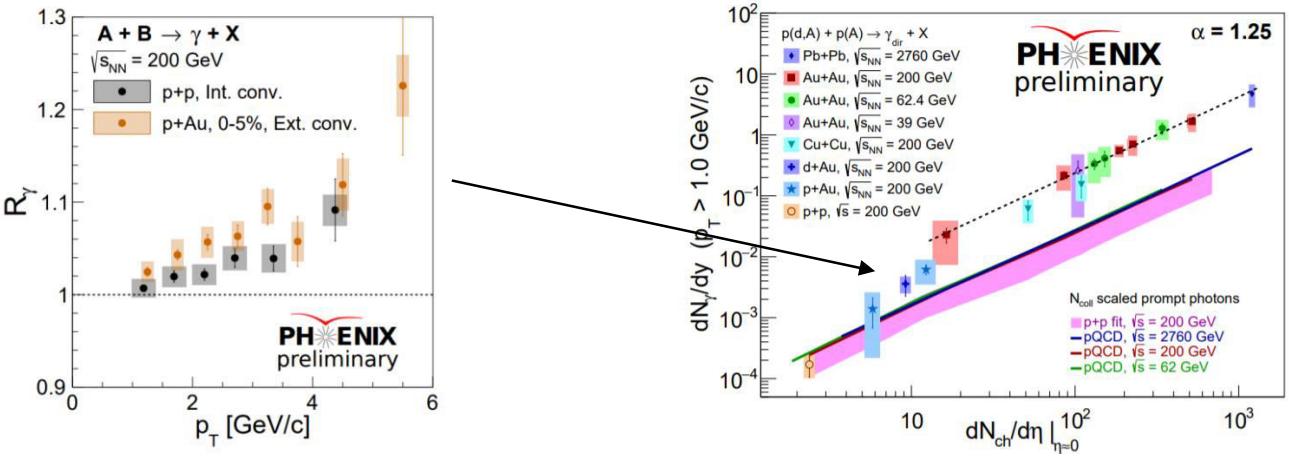




- Rγ estimations vary from 5% to 15% at p_T > 0.5 GeV/c at top NICA energies
- Estimations for direct photon yields and flow vs. centrality and collision energy → See talk by D. Blau

Comparison to RHIC/LHC

- Rγ ~ 1.1-1.2 in heavy-ion collisions at RHIC and the LHC, $\sqrt{s_{NN}}$ = 39-2760 GeV
- Rγ ~ 5% is on the verge of experimental measurability (PHENIX in pp/pA@200, ≥ 3σ)



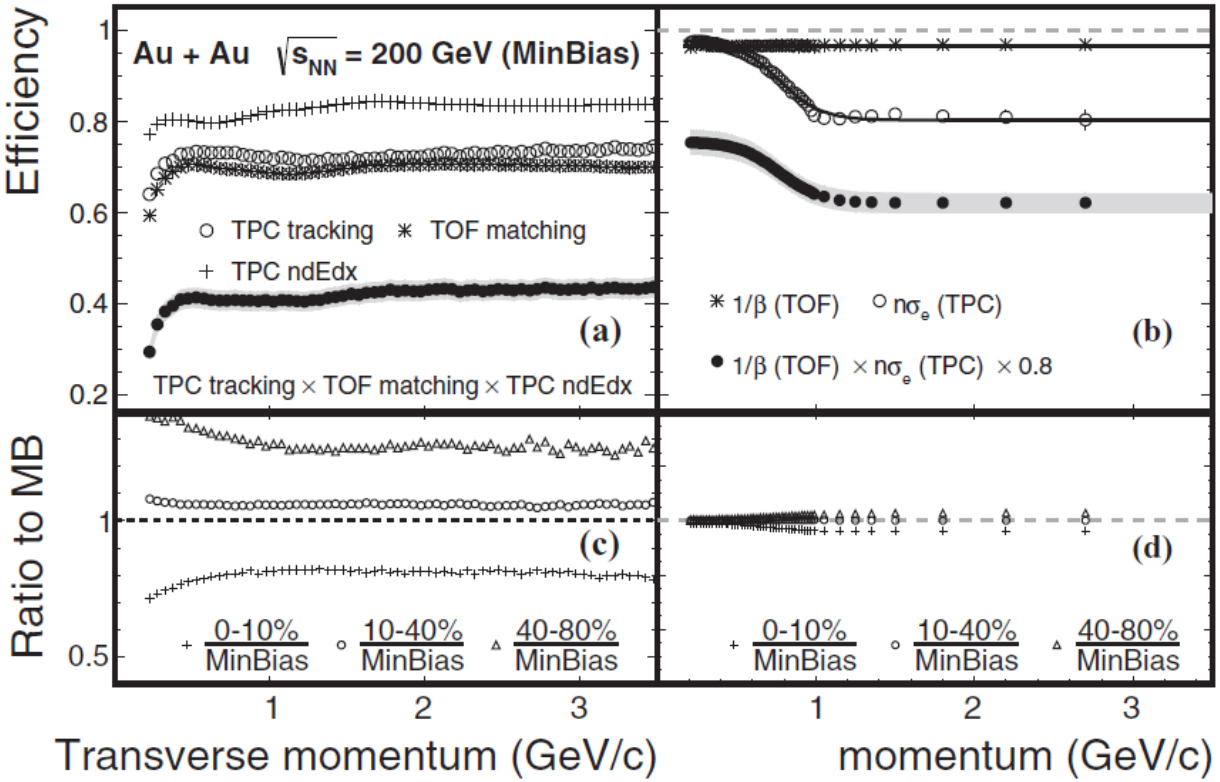
- Experimentally photons can be measured with the ECAL and/or PCM
- Measurements of direct photon yields and flow are going to be challenging but yet possible
- Development of reconstruction techniques and estimation of needed statistics are in progress,

Summary

- PWG4 is active and works to enhance the MPD physical program
- Many studies are in progress
- Many vacant tasks , need extra man power and deeper involvement of the collaboration
- Contact conveners if you wish to join:
  - ✓ Victor Riabov – riabovvg@gmail.com
  - ✓ Chi Yang - chiyang@rcf.rhic.bnl.gov

BACKUP

eID efficiency: STAR

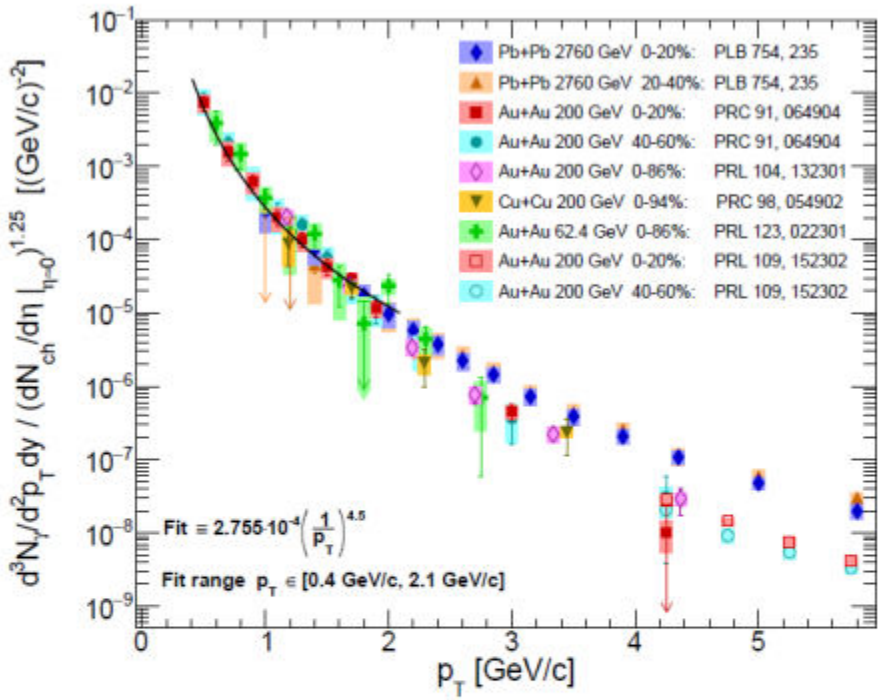


$$\varepsilon_{\mathrm{eID}} = \varepsilon_{\beta} \times \varepsilon_{\mathrm{dEdxPID}}$$

$$\varepsilon_{\mathrm{dEdxPID}} = \varepsilon_{\mathrm{ndEdx}} \times \varepsilon_{\mathrm{n}\sigma_e}$$

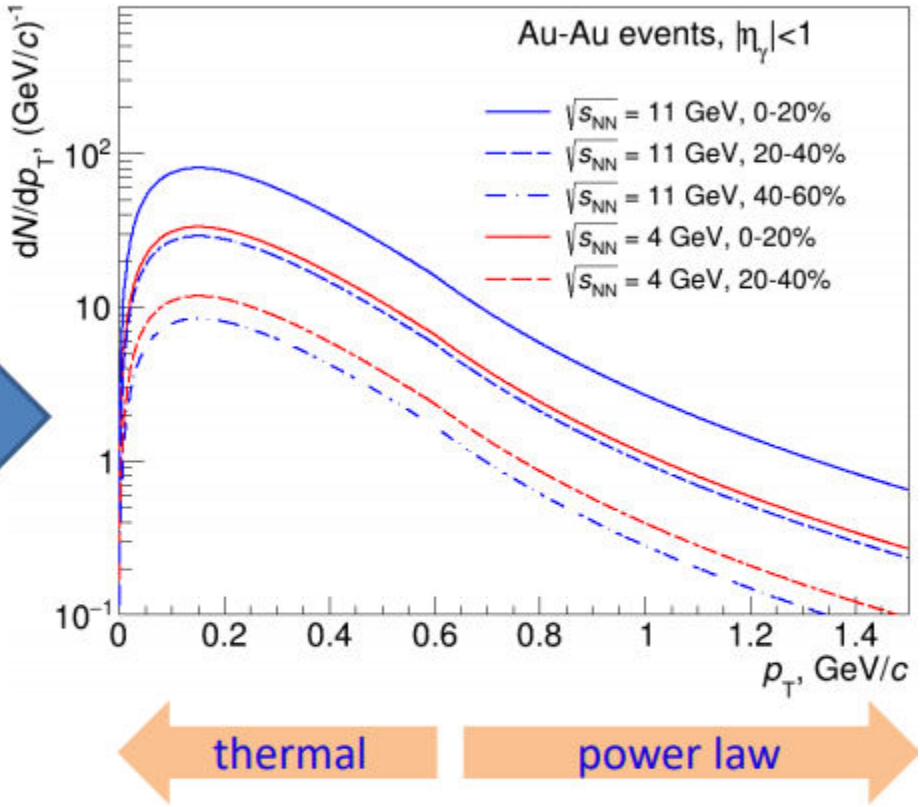
- Single eID efficiency at p_T > 200 MeV/c (STAR): ~ 0.45 · (0.93-0.75) = 30-40%
- The MPD TPC-TOF-ECAL single eID efficiency with tight cuts is comparable

p_T-differential direct photon yields



PHENIX, PRL 123, 022301

Khachatryan, Praszałowicz EPJC 80 (2020) 670

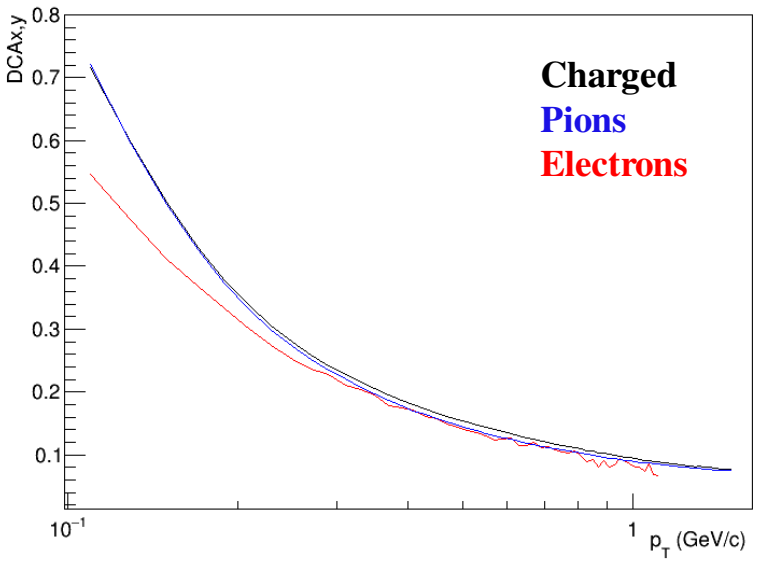


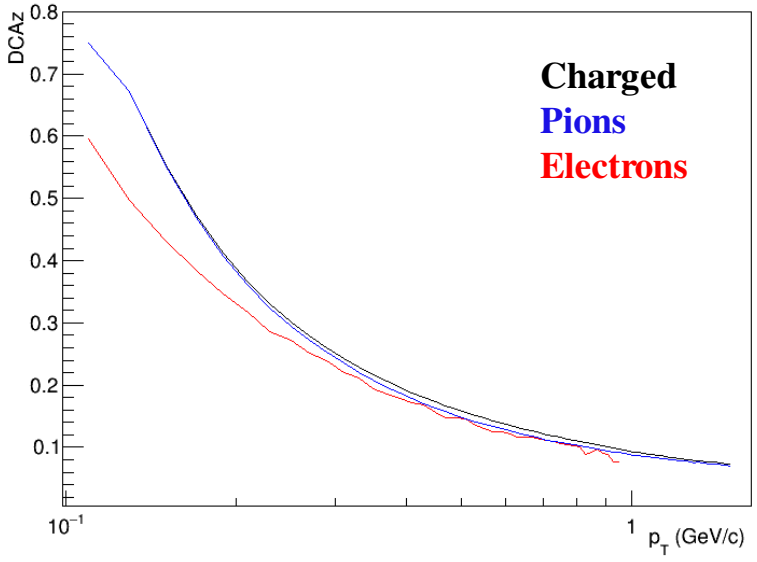
thermal | power law

- 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)

DCA vs. PID, primary particles

- Width of DCA_x,y and DCA_z distributions vs. p_T for charged particles, pions and electrons

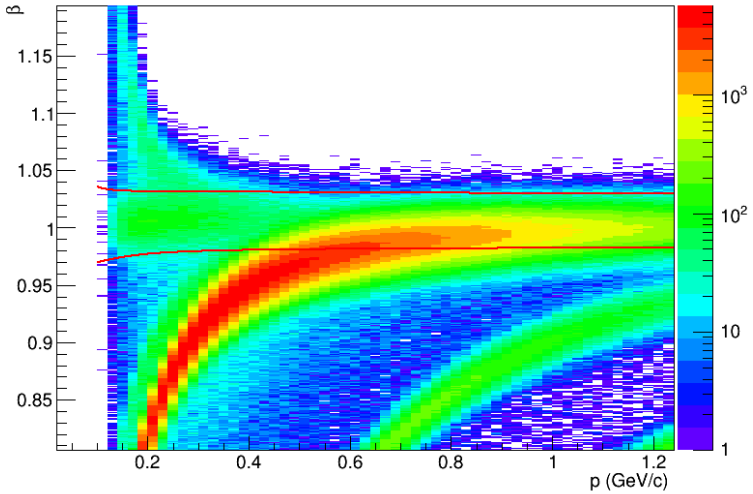


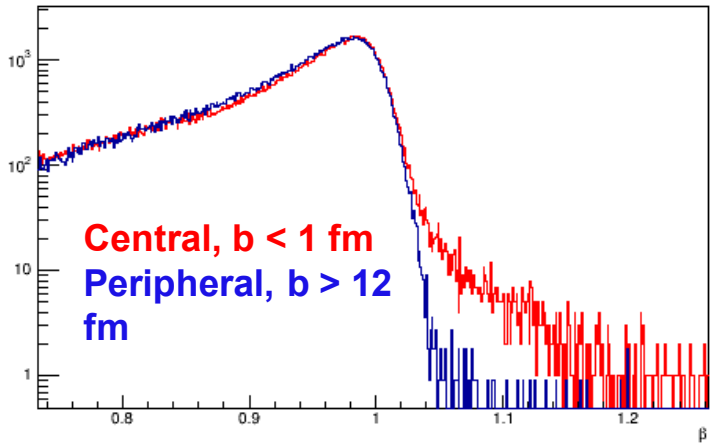


- All the differences between e/π/K/p are at very low momentum (~25%)
- At p_T > 0.4 GeV/c there is no difference between particles (except for protons)
- Tighter DCA cuts give some preference to electron selection at low p_T (for primary particles)

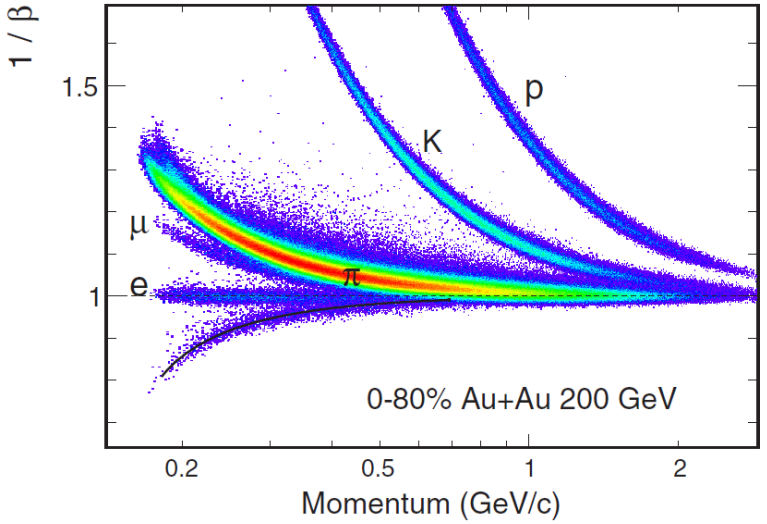
Problem of TOF-TPC track mismatching

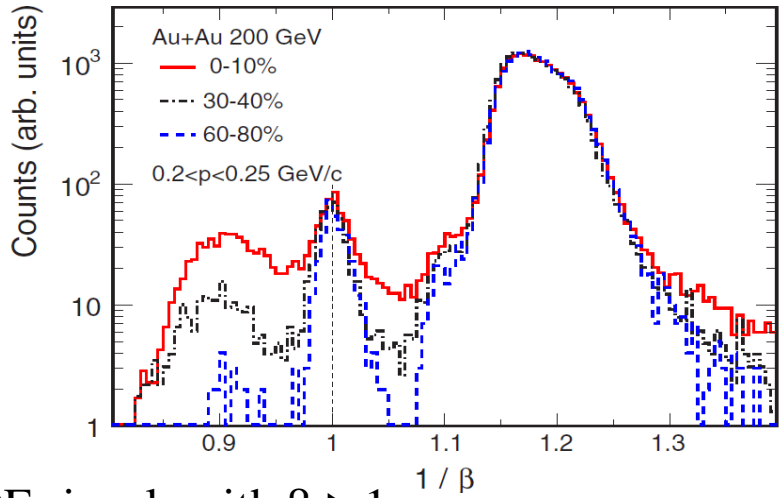
MPD





STAR

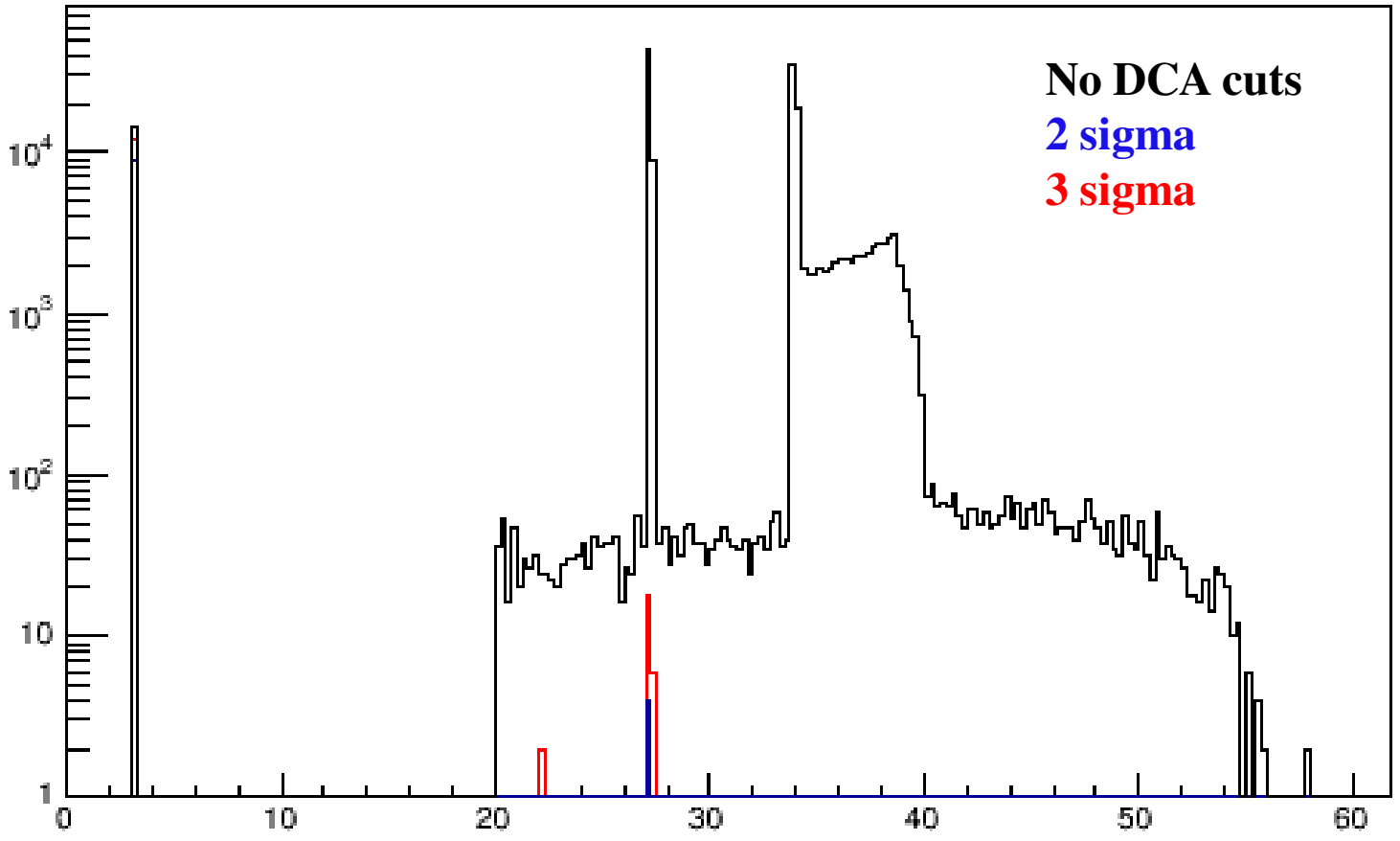




- Both STAR and MPD observe non-physical TOF signals with β > 1,
- Unphysical signals are most prominent in central collisions, diminished in peripheral
- Effect is explained by track mismatching in the TOF

DCA vs. radius, electrons

- Production radius of e^+e^- pairs with different DCA_xyz cuts



- DCA cuts do not reject conversion at beam pipe
- DCA cuts reject most of conversion on the TPC vessels