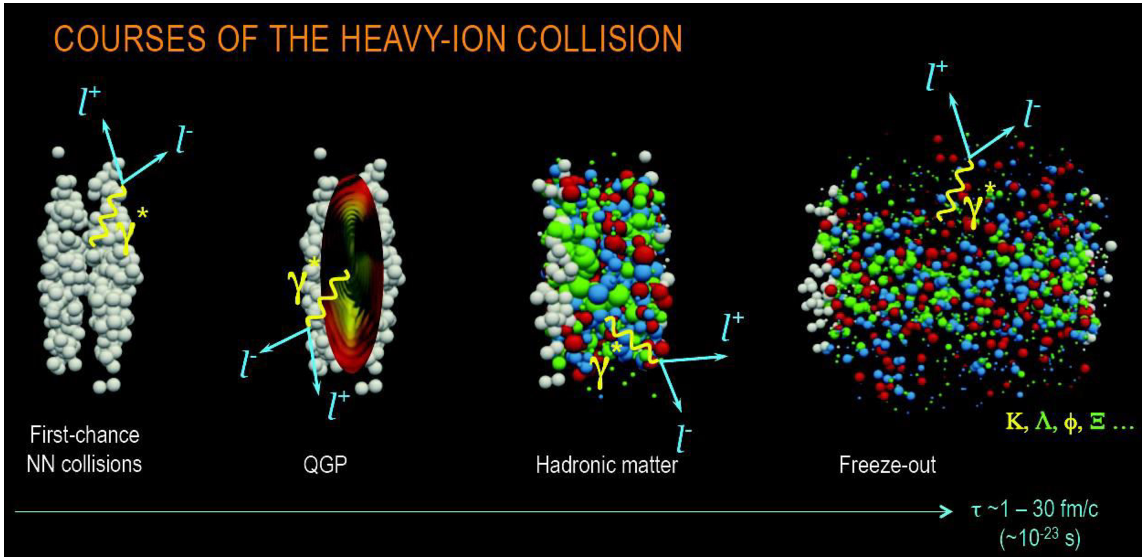
Nuclotron-based
Ion Collider fAcility

PWG4 summary

V. Riabov for the PWG4



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

eID in mass productions

Latest Monte Carlo productions

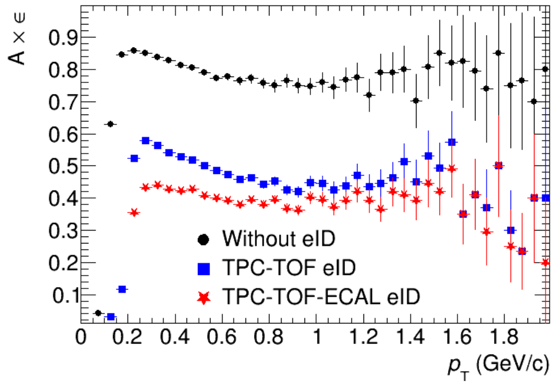
- **Request11**: *PWG4 - dielectrons, 15M minbias BiBi@9.2*
- Geant-4 based simulation
- Aims at dielectron studies but good for most of other analyses:
  - ✓ enhanced dielectron BRs for vector mesons (x20)
  - ✓ updated materials, detector response and reconstruction algorithms
  - ✓ dphi, dzed variables for better track-to-TOF matching
  - ✓ most probable first collision system, BiBi@9.2
  - ✓ high statistics, 15 M events
- Output:
  - ✓ /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 files

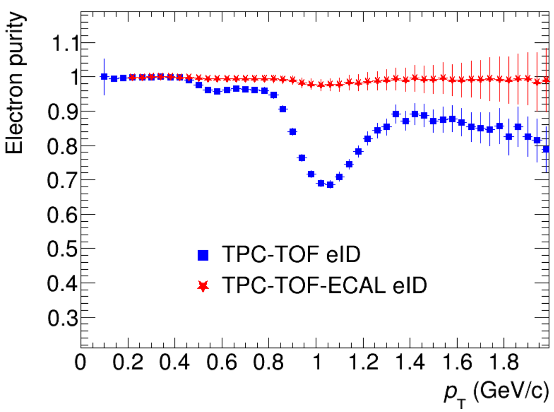
- **Request13**: *PWG4 - dielectrons, 15M minbias BiBi@9.2*
- Same as Request 11 but with a different simulation of dE/dx in the TPC
  - ✓ new dE/dx parameterization
  - ✓ new TPC digitizer (MpdTpcDigitizerAZlt vs. MpdTpcDigitizerAZ)

Efficiency and purity

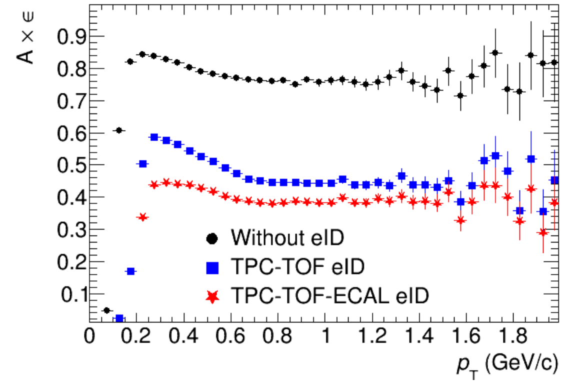
- Selected tracks:
  - ✓ hits > 39
  - ✓ |η| < 1
  - ✓ |DCA_x,y,z| < 2.5 σ
- eID selections:
  - ✓ 2σ matching to TOF
  - ✓ 1-2σ TPC-eID
  - ✓ 2σ TOF-eID

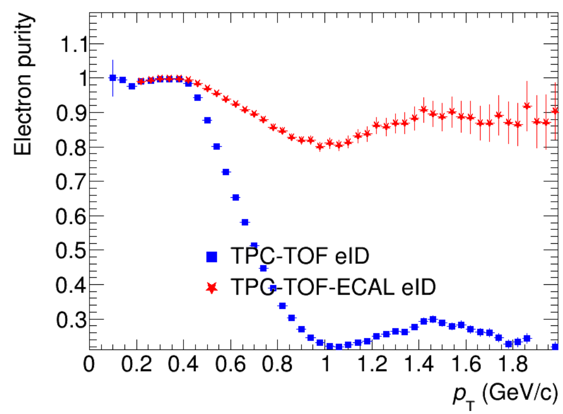
Request 11





Request 13



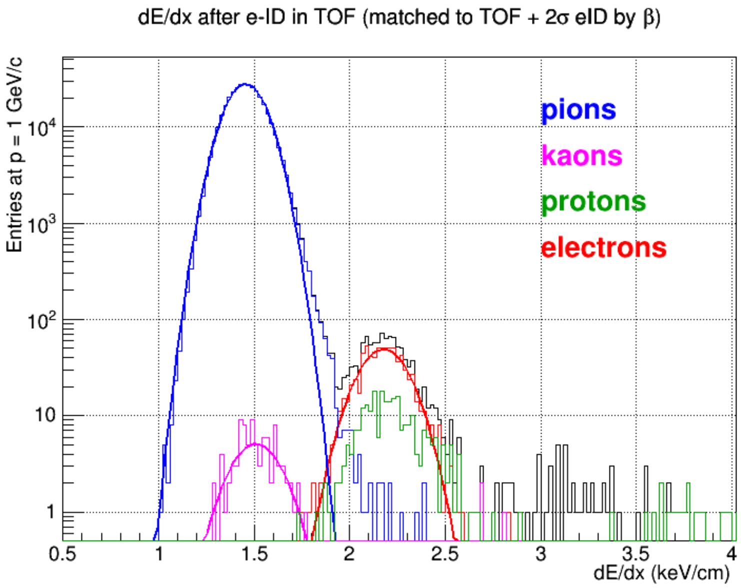


- Similar reconstruction efficiencies with different electron selection/PID cuts
- Observe problems with electron purity for **Request13** production

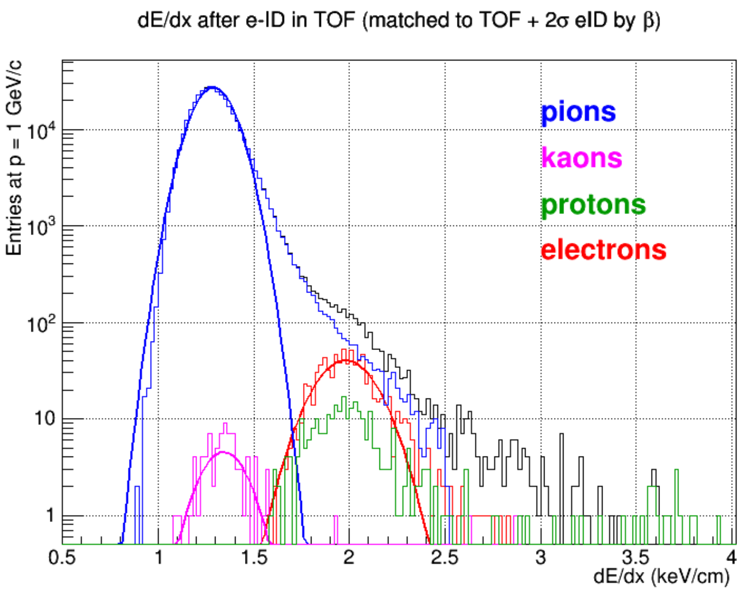
Closer look at dE/dx distributions + TOF e-ID

- Selected tracks:
  - ✓ hits > 39
  - ✓ |η| < 1
  - ✓ |DCA_x,y,z| < 2.5 σ
  - ✓ p_T = 1 GeV/c
- eID selections:
  - ✓ 2σ matching to TOF
  - ✓ 2σ TOF-eID

Request 11



Request 13

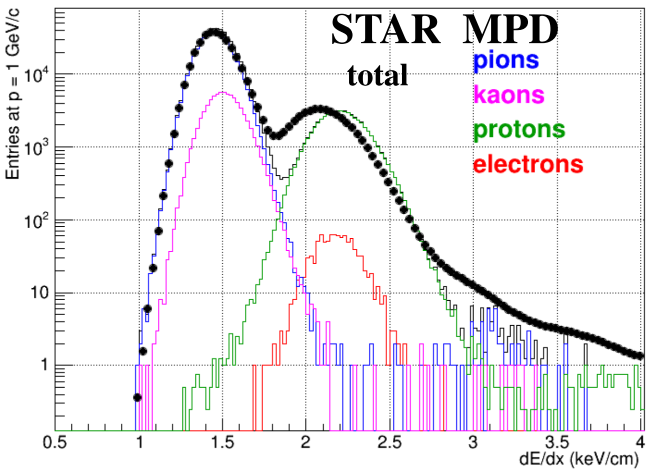


- The problem of electron purity is traced to long non-Gaussian tails of dE/dx distributions for hadrons in **Request 13** production, electrons can not be distinguished from the pion tail
- Kaon and proton contributions are comparable after TOF e-PID

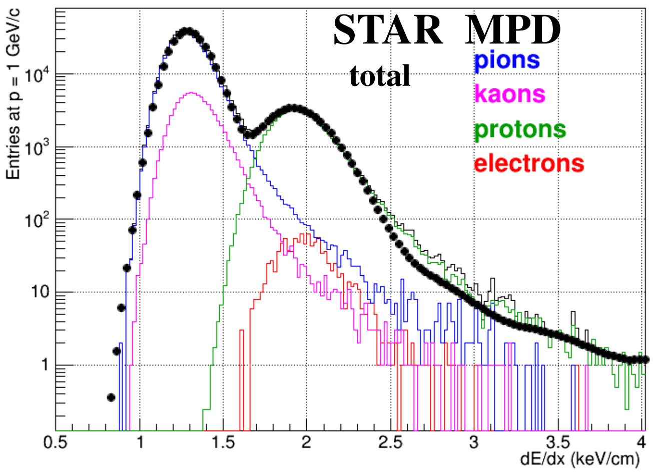
Comparison to dE/dx from STAR - I

- STAR dE/dx distribution was provided by Chi Yang (for internal checks only) :
  - ✓ minbias AuAu@54 GeV
  - ✓ basic event and track quality cuts (|η| < 1.0, |DCA| < 1 cm), p_T ~ 1 GeV/c
- For comparison:
  - ✓ dE/dx of STAR is scaled to reproduce the pion peak (arbitrary calibration)
  - ✓ MPD proton peak is scaled to reproduce the second peak (different K/π and p/ π ratios)

Request 11

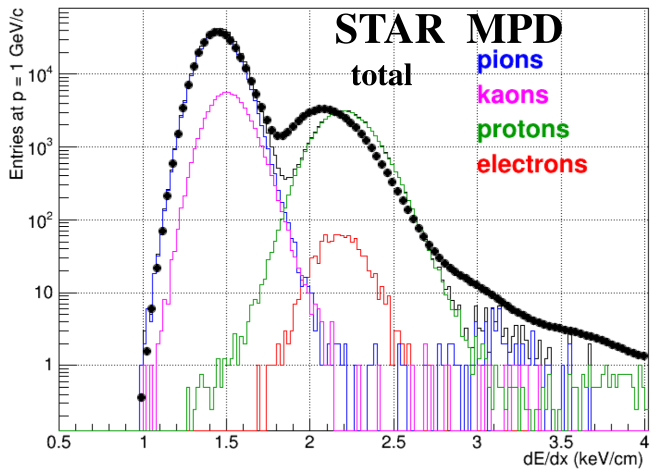


Request 13

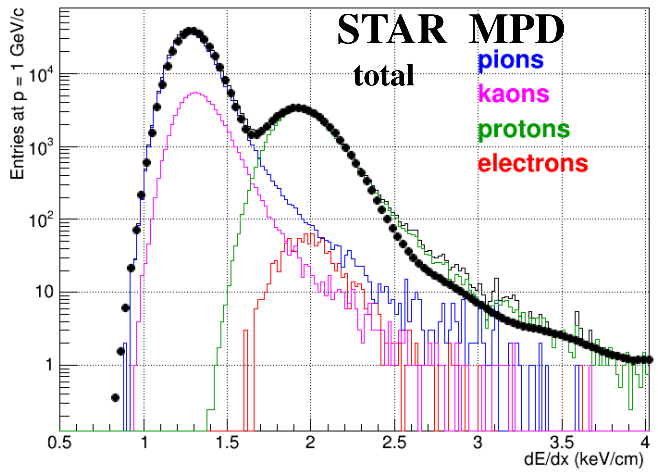


Comparison to dE/dx from STAR - II

Request 11



Request 13



- Mean values of dE/dx are better reproduced in **Request 13** production.
- Tails of dE/dx distributions get overestimated in **Request 13** → the MPD total distribution is above that of STAR at dE/dx > 2 keV/cm even though STAR additionally includes signals from deuterons:

→ new dE/dx (used in Request 13) are better tuned to STAR data (relative peak position)

→ new TPC digitizer (used in Request 13) results in excessive tails of dE/dx distributions

Conclusions (productions)

- The latest TPC digitizer does not quite reproduce the expected shape of dE/dx distributions for hadrons
- There is no production with new dE/dx and old TPC digitizer
- So far, we stick to **Request 11** production for dielectron studies

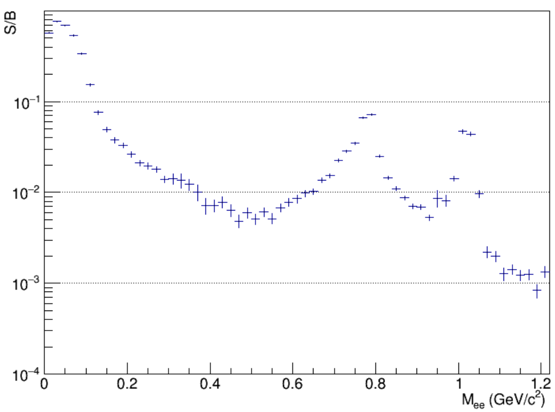
Dielectrons

Background rejection: conversion candidates

- Background rejection based on pair cuts.
- Conversion rejection:
  - ✓ tightly identified e-tracks are paired with loosely identified e-tracks in the event to be tested against conversion hypothesis based on: Chi2 for the secondary vertex (SV), distance between the tracks in SV, PV-SV distance, invariant mass → variables are correlated, 2D cuts are used
  - ✓ if a pair is consistent with a conversion pair hypothesis then both tracks are tagged and rejected

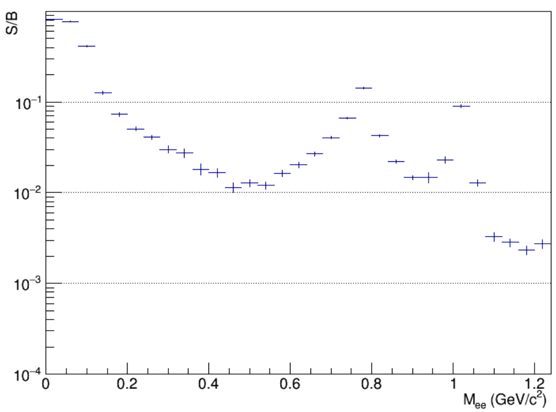
- Highly selective cuts → high multiplicity in central BiBi@9.2 collisions does not result in significant false rejection of electrons due to high combinatorics

No conversion rejection



S/B in 0.2-1.5: 0.012
======================
Omega (s/sqrt(b)): 3.7
Phi (s/sqrt(b)): 1.7
LMR (s/sqrt(b)): 0.9
======================

Conversion rejection



S/B in 0.2-1.5: 0.026
======================
Omega (s/sqrt(b)): 5.0
Phi (s/sqrt(b)): 2.3
LMR (s/sqrt(b)): 1.2
======================

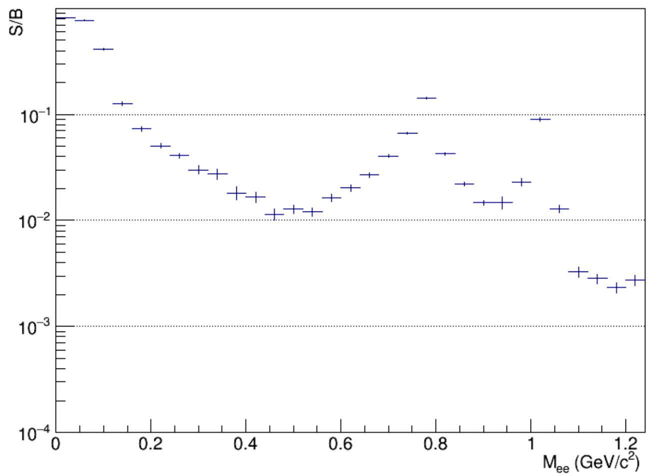
Rejection of conversion improves S/B by a factor of two

Signal significance also improves

Background rejection: Dalitz candidates

- Dalitz rejection, M_{cut}:
  - ✓ e-tracks are paired, if a pair's invariant mass $M_{inv} < M_{cut}$ then both e-tracks are rejected as Dalitz candidates

No cut



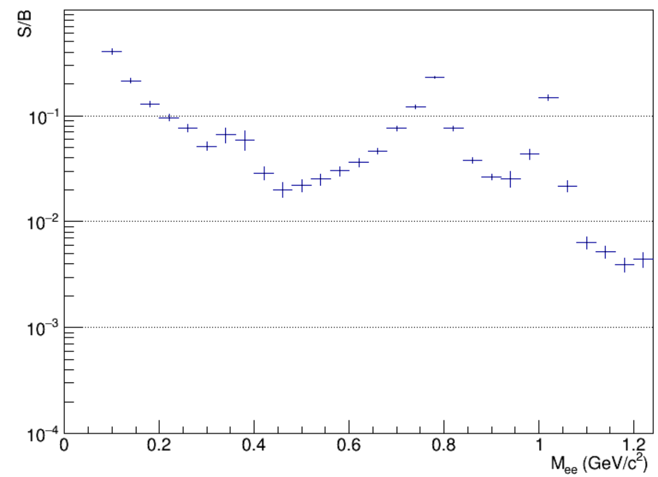
S/B in 0.2-1.5: 0.026

======================

Omega (s/sqrt(b)): 5.0
Phi (s/sqrt(b)): 2.3
LMR (s/sqrt(b)): 1.2

======================

M_{cut} = 100 MeV/c^2



S/B in 0.2-1.5: 0.053

======================

Omega (s/sqrt(b)): 5.2
Phi (s/sqrt(b)): 2.3
Rho (s/sqrt(b)): 1.2

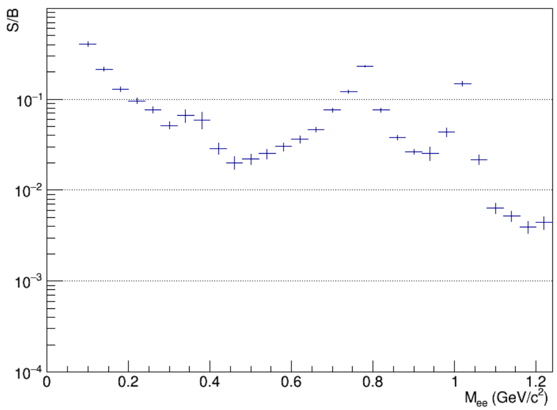
======================

- A cut of M_{cut} = 100 MeV/c^2 improves the S/B by a factor and preserves the signal significance
- Further improvements in S/B with tighter M_{cut} cuts are possible but in the expense of smaller statistical significance of the measured signals
- The cut is a potential source of systematic uncertainties

Dalitz candidates, loosening the cuts

- Dalitz rejection, M_{cut} = 100 MeV/c^2:
  - ✓ e-tracks are paired, if a pair's invariant mass $M_{inv} < M_{cut}$ then both e-tracks are rejected as Dalitz candidates
- Varied the pair selection cuts:
  - ✓ tight selection cuts for a primary electron in the pair (same cuts as for e+e- continuum)
  - ✓ loosen selection cuts for a partner in search for conversion/Dalitz candidates

tight cuts for a partner → **nhits > 10** → **nhits > 10 && dca < 3.5σ**

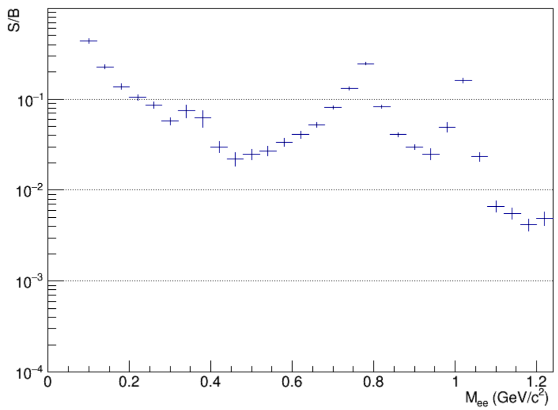


S/B in 0.2-1.5: 0.053

======================

Omega (s/sqrt(b)): 5.2
Phi (s/sqrt(b)): 2.3
Rho (s/sqrt(b)): 1.2

======================

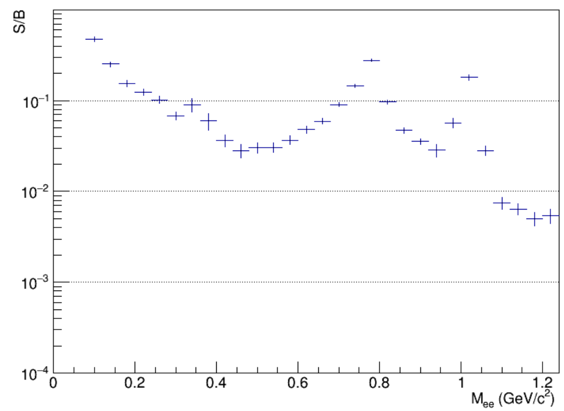


S/B in 0.2-1.5: 0.059

======================

Omega (s/sqrt(b)): 5.3
Phi (s/sqrt(b)): 2.4
LMR (s/sqrt(b)): 1.3

======================



S/B in 0.2-1.5: 0.068

======================

Omega (s/sqrt(b)): 5.4
Phi (s/sqrt(b)): 2.4
LMR (s/sqrt(b)): 1.3

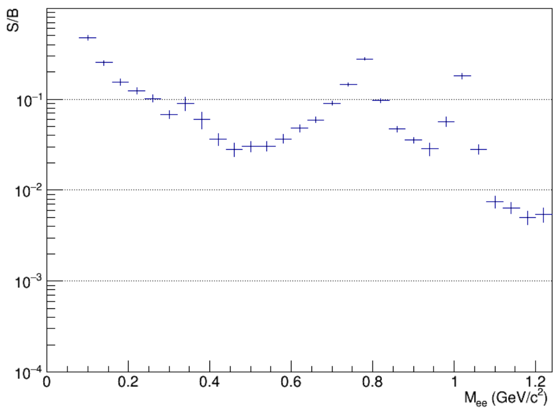
======================

- By loosening the cuts for a partner (to some limit) we increase efficiency of background rejection

Pair cuts, limiting acceptance for a primary e

- Idea was to limit acceptance for a primary electron → easier to find a **reconstructed** conversion or Dalitz partner for rejection

|η| < 1 → |η| < 0.75 → |η| < 0.5

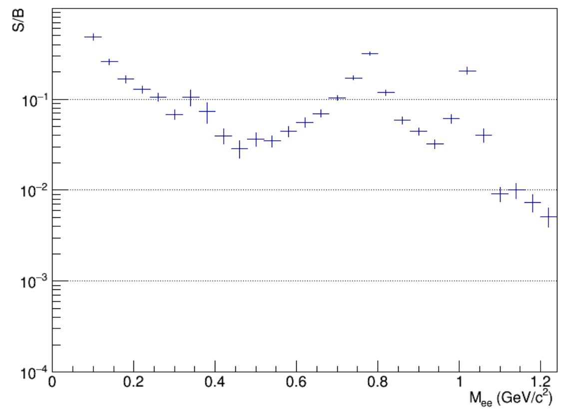


S/B in 0.2-1.5: 0.068

========================

Omega (s/sqrt(b)): 5.4
Phi (s/sqrt(b)): 2.4
LMR (s/sqrt(b)): 1.3

=========================

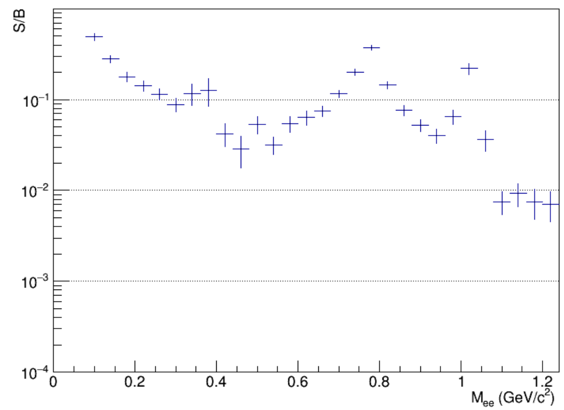


S/B in 0.2-1.5: 0.077

========================

Omega (s/sqrt(b)): 4.6
Phi (s/sqrt(b)): 2.0
Rho (s/sqrt(b)): 1.2

========================



S/B in 0.2-1.5: 0.092

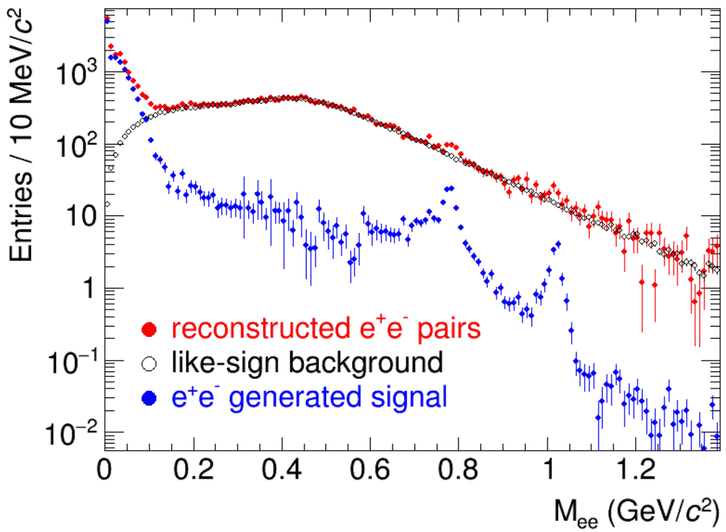
========================

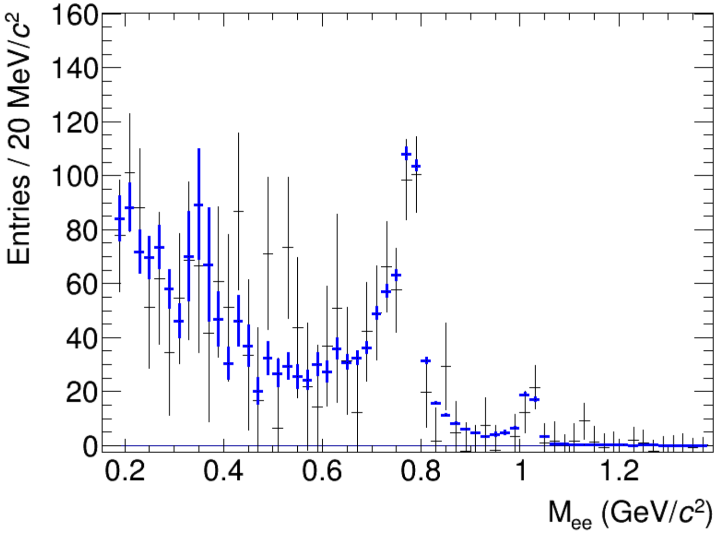
Omega (s/sqrt(b)): 3.3
Phi (s/sqrt(b)): 1.4
Rho (s/sqrt(b)): 0.9

=========================

- By limiting acceptance for a primary electron, we indeed improve S/B ratio but loose statistical significance of the signals due to smaller reconstruction efficiecny

Summary for dielectrons



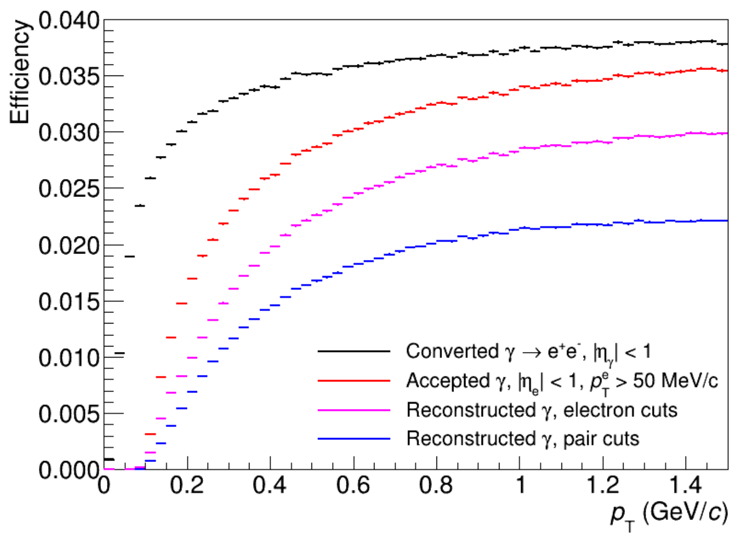


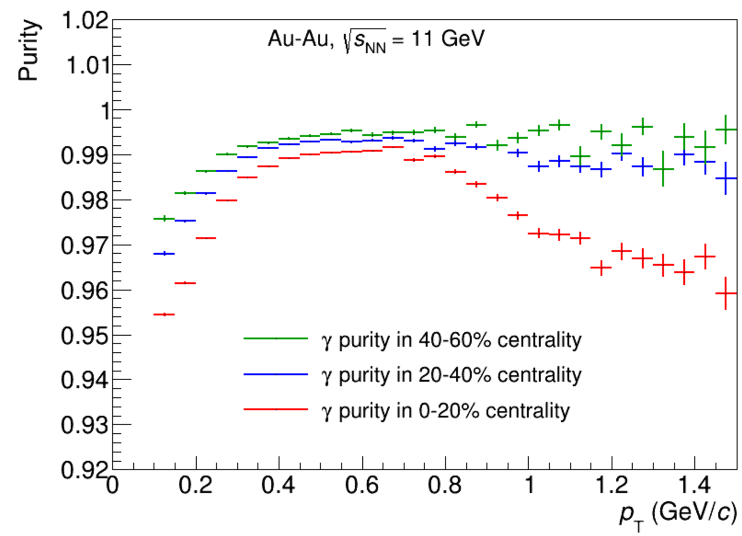
- S/B (integrated in 0.2-1.5 GeV/c2) ~ 5-10%
- Methods to improve S/B ratio with a minimal penalty for pair reconstruction are being developed and matured
- Meaningful measurements for e^+e^- continuum and LVMs would require ~ 10^8 AuAu/BiBi sampled events, first observations will be possible with ~50 M events

Photon conversion

Photon efficiency and purity

- Studied with MpdRoot for Stage-1 detector
- MpdParticle to build secondary vertices, cuts optimized to maximize signal significance
- Typical cuts on electrons:
  - ✓ $|\eta|<1$, $p_T > 50$ MeV/c, ≥ 20 hits in TPC, $\pm 4\sigma$ electron PID selections in the TPC/TOF
- Typical cuts on pairs:
  - ✓ 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-pair plane orientation wrt B: $\Psi_{pair} < 0.1$ rad

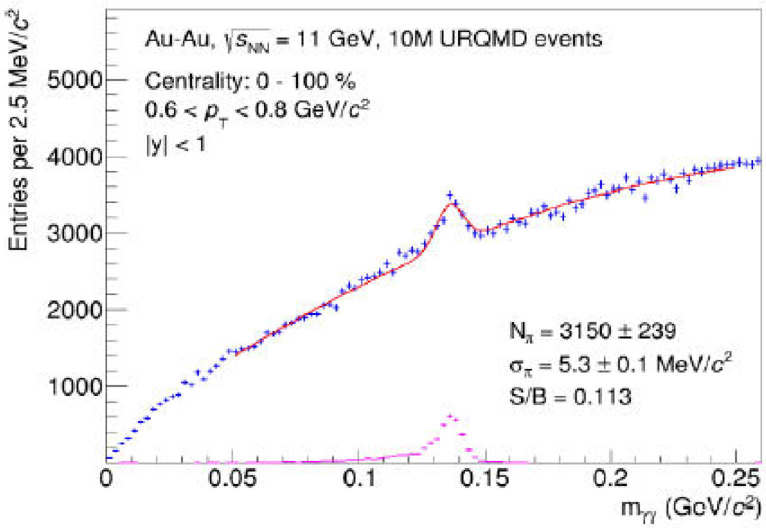


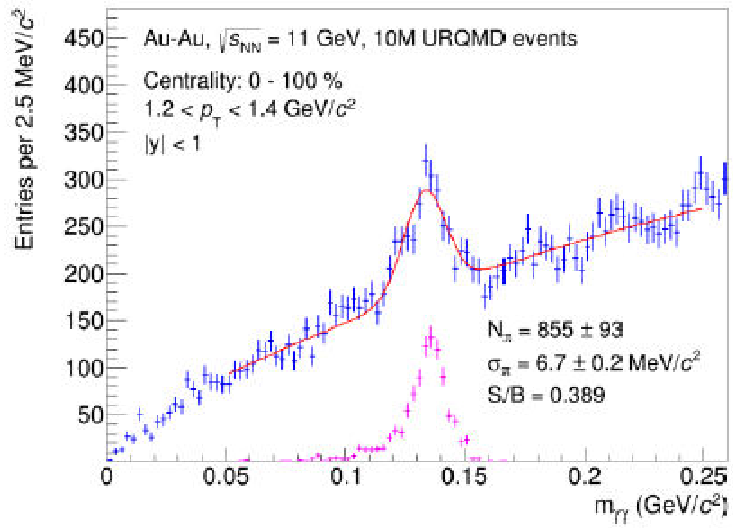


- Photon reconstruction efficiency of $\leq 2\%$ with purity $> 95\%$

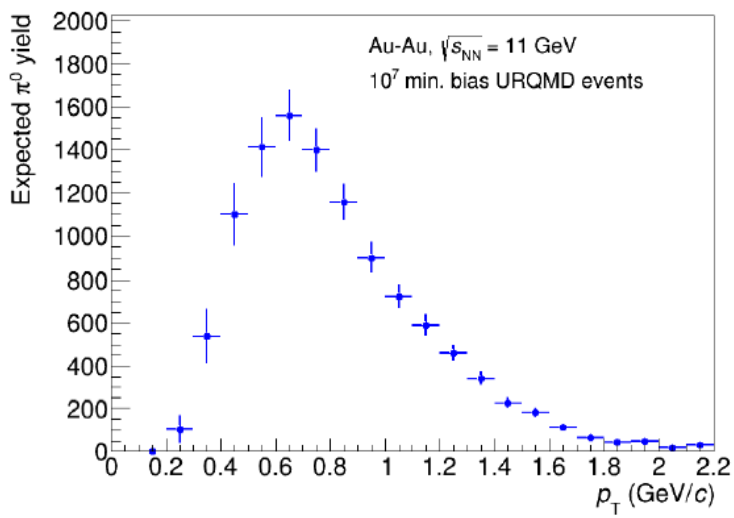
Neutral mesons

- 10M minimum bias AuAu@11 URQMD events

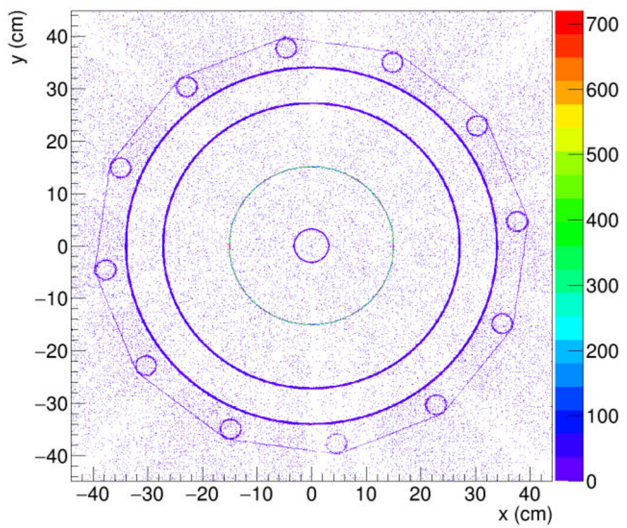


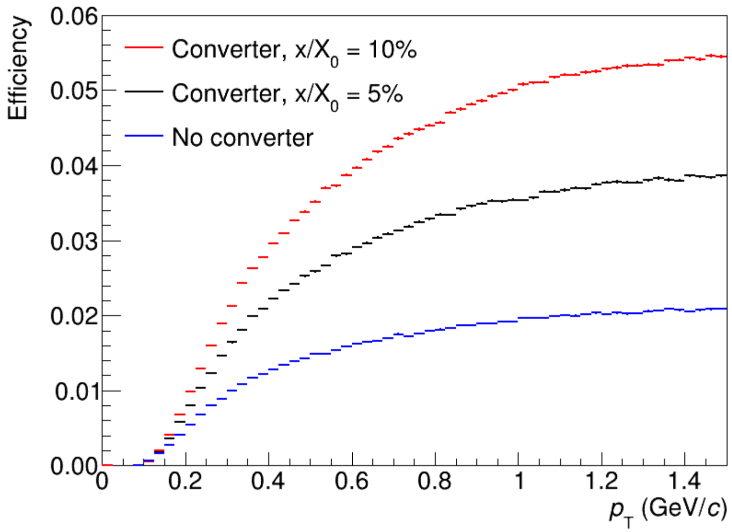


- Due to high photon reconstruction purity the mixed-event background subtraction is not needed
- Pion signal is clearly visible in a wide p_T range → day-1 measurements
- First measurements of η would require a factor of ~ 10 larger data sample
- Hybrid measurements (EMCAL + PCM) are being developed



Dedicated photon converter - I

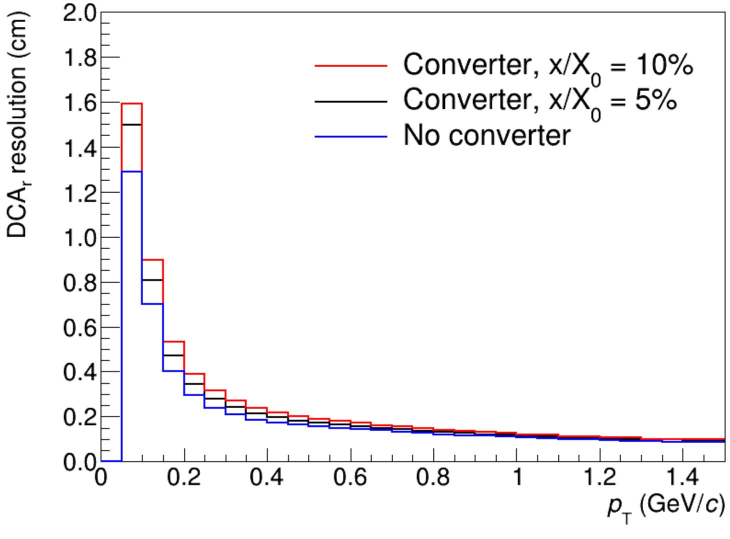


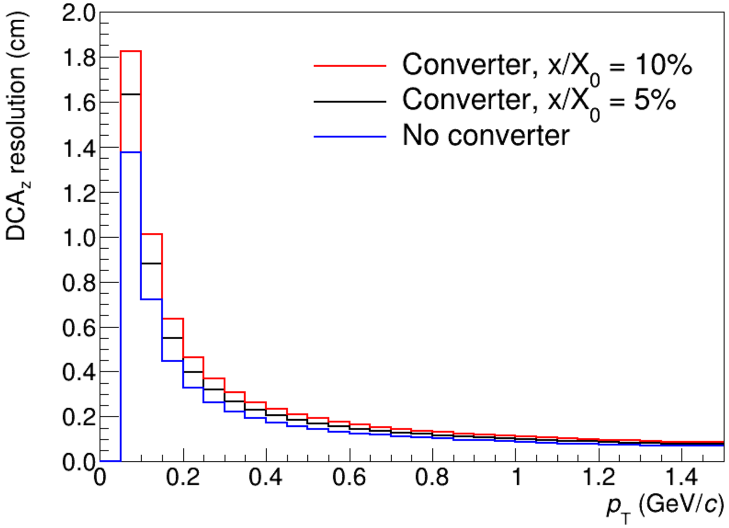


- A dedicated conversion layer under investigation:
  - ✓ cylindrical copper pipe with radius of 15 cm
  - ✓ radiation length: 5% and 10% (0.7 and 1.4 mm)
- Advantages:
  - ✓ photon reconstruction efficiency can be increased by a factor ~3, neutral mesons ~ 10
  - ✓ minimization of systematic uncertainties due to well known material budget
- Disadvantages:
  - ✓ ruins single electron and dielectron measurements
  - ✓ deteriorates hadron measurements ???

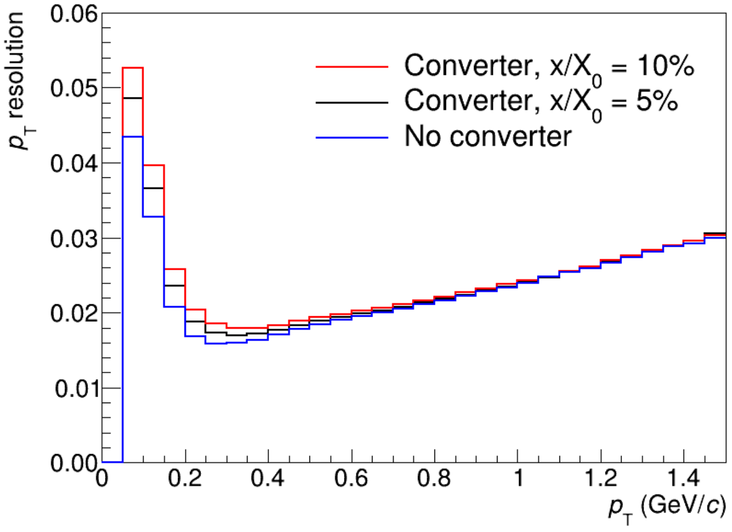
Dedicated photon converter - II

- DCAr and DCAz distributions:





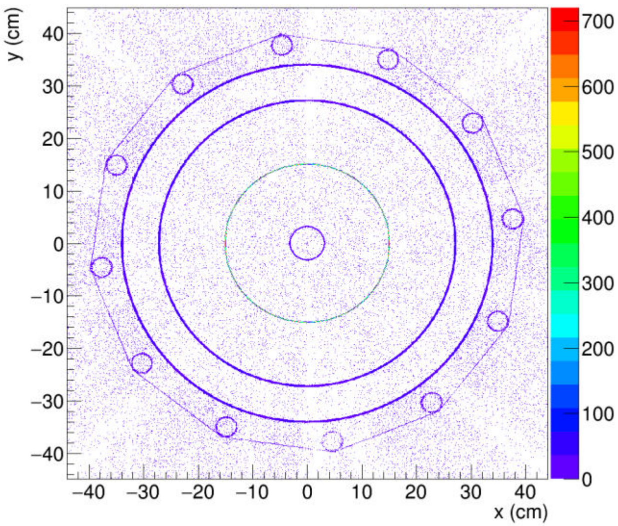
- Momentum resolution:



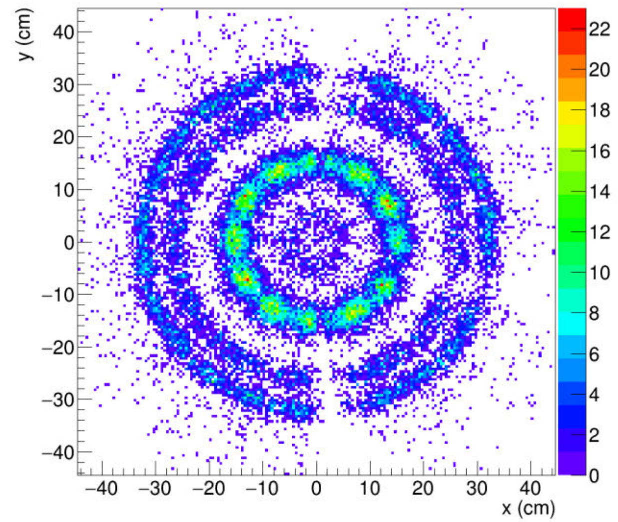
- Marginal decrease in the reconstruction quality of charged particles
- The decrease is noticeable only at low p_T < 0.5 GeV/c

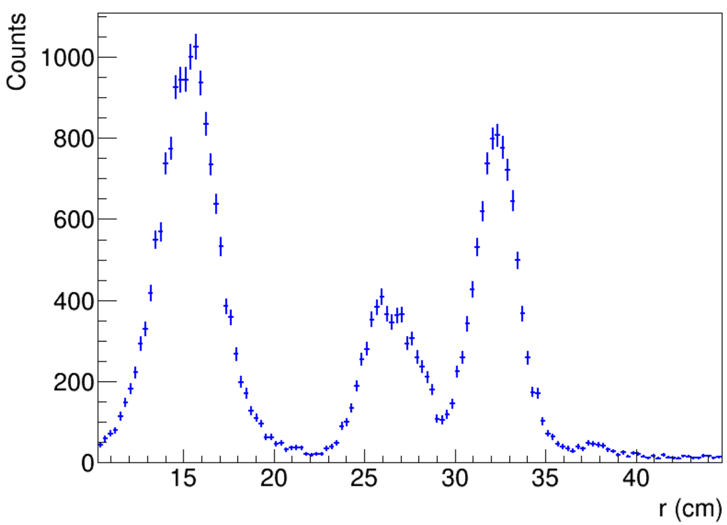
Probing material budget

Real detector geometry



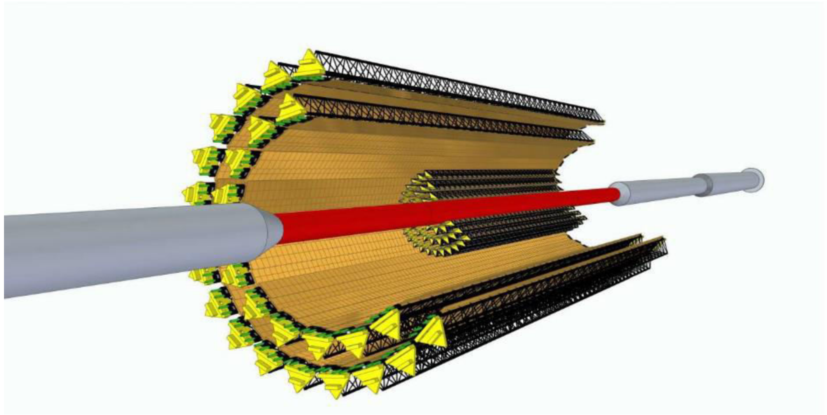
Reconstructed conversion centers

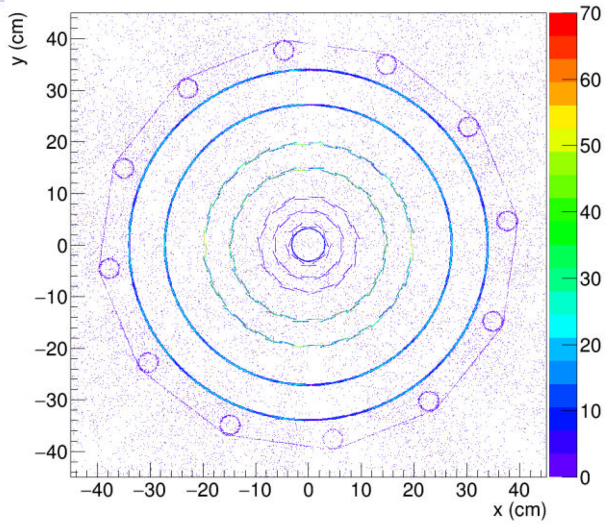




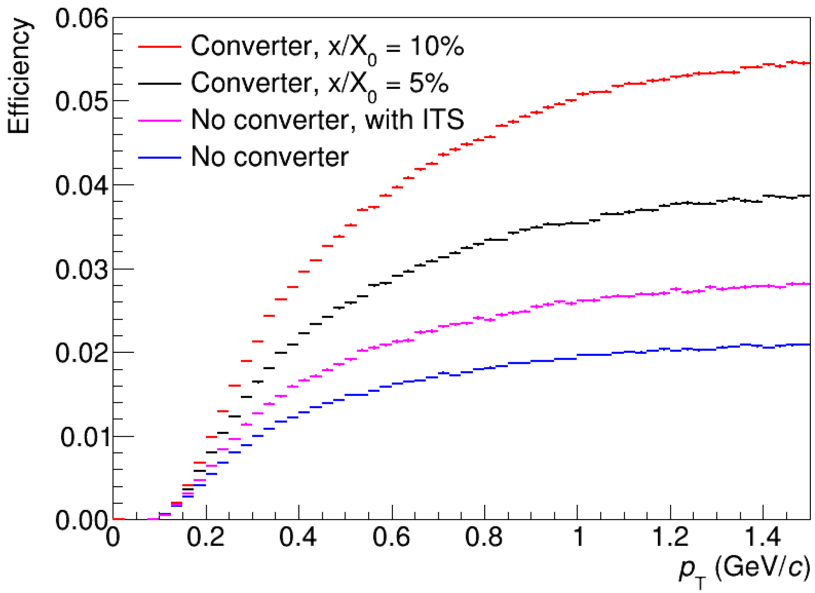
- Reconstructed ee-pairs can be used for detector alignment and estimation of the material budget
- Radiation length of the converter is known with high precision and can be used as a reference
- Spatial resolution needs to be improved

Photon conversion in Stage-2





- ITS in Stage-2:
  - ✓ five layers of Monolitic Active Pixel Sensors
  - ✓ ~ 0.4% X_0 in current design
  - ✓ Photon reconstruction efficiency slightly improves compared to Stage-1 setup



- Photon reconstruction efficiency slightly improves compared to Stage-1 setup

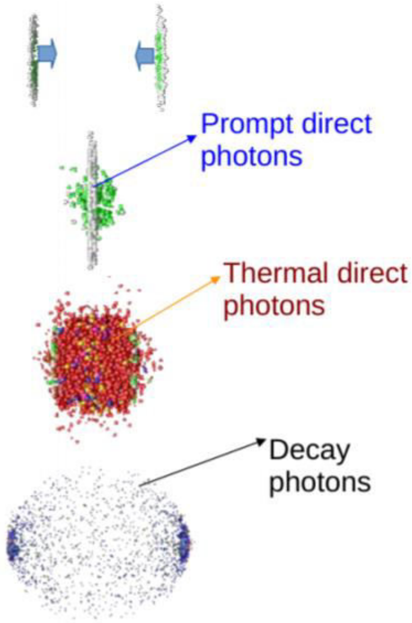
Conclusions (conversion)

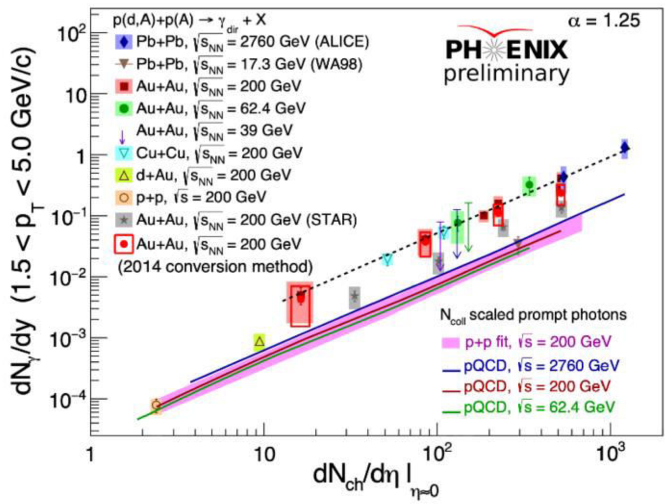
- Photon conversion method is a powerful tool to measure photons and neutral mesons
- Feasibility studies on the dedicated converter and Stage-2 setup show promising results
- Further developments: conversion for precise detector alignment and for estimation of the detector material budget

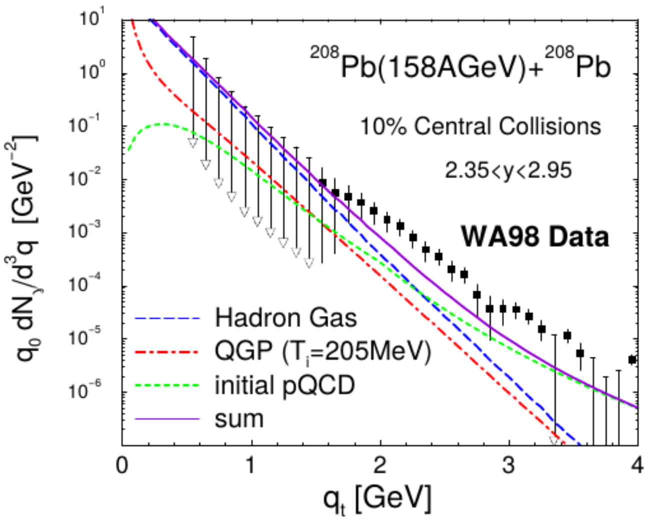
Direct photons

Motivation

- Direct photons – photons not from hadronic decays.
- Produced throughout the system evolution:
  - ✓ QCD matter is transparent for photons, once produced they leave the interaction region unaffected preserving their properties
  - ✓ estimation of the effective system temperature at low energy
  - ✓ hard scattering probe at high energy
- Experimental measurements in A+A collisions are available from the LHC (2.76 TeV), RHIC (62-200 GeV) and WA98 (17.2 GeV)
- No measurements at NICA energies, interested in the measurement of direct photon yields and flow vs. p_T and centrality







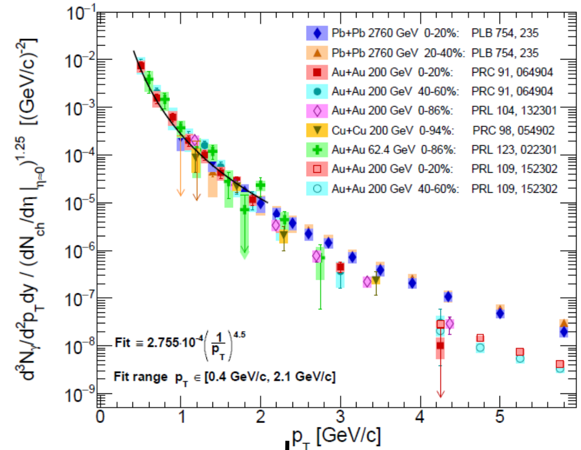
Direct photon yields at NICA

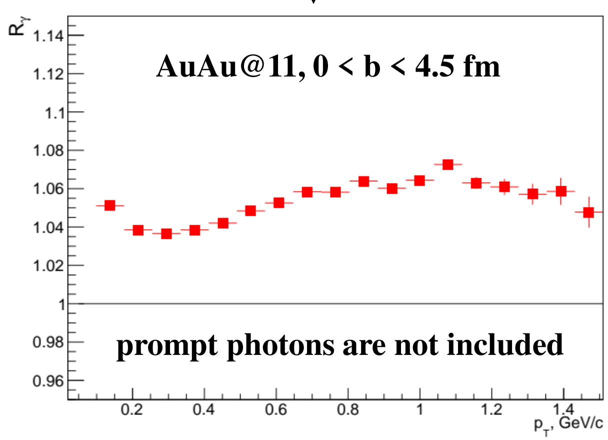
Estimation of the direct photon yields @NICA

model calculations

empirical scaling

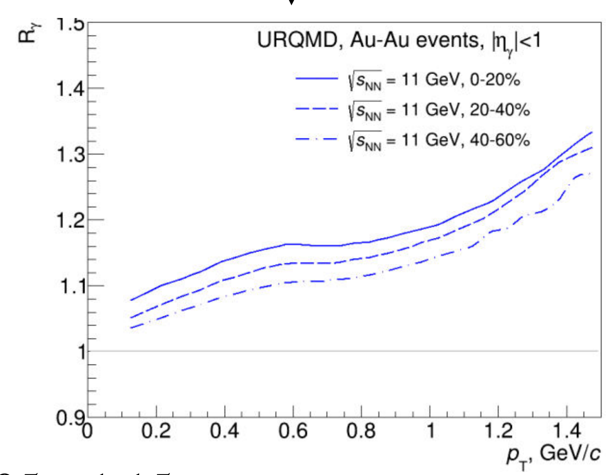
- ○ UrQMD v3.4 with hybrid model (3+1D hydro, bag model EoS, hadronic rescattering and resonances within UrQMD)
- ○ Each cell have Ti, Ei, μbi:
  - T is high – QGP phase (Peter Arnold, Guy D. Moore, Laurence G. Yaffe, JHEP 0112:009 2001)
  - T is low – HG phase (Simon Turbide, Ralf Rapp, Charles Gale, 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





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

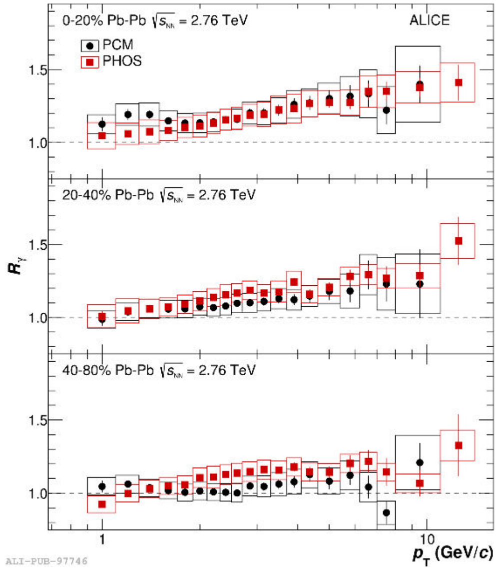
$$\gamma_{\rm direct} = \left(1 - \frac{1}{R_\gamma}\right) \cdot \gamma_{\rm inc}$$

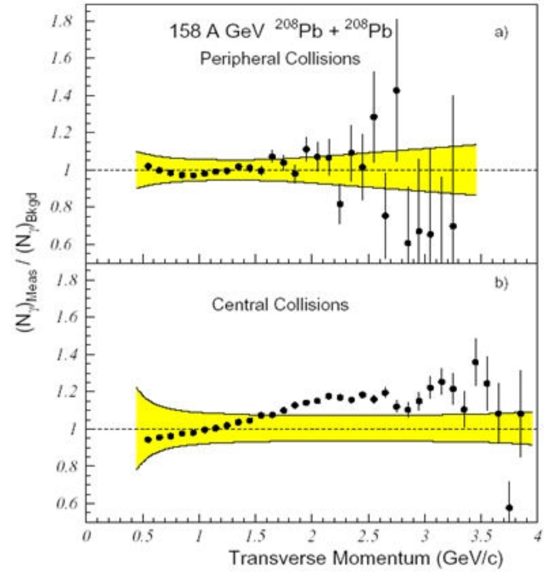


- Non-zero direct photon yields are predicted, Rγ ~ 1.05 – 1.15

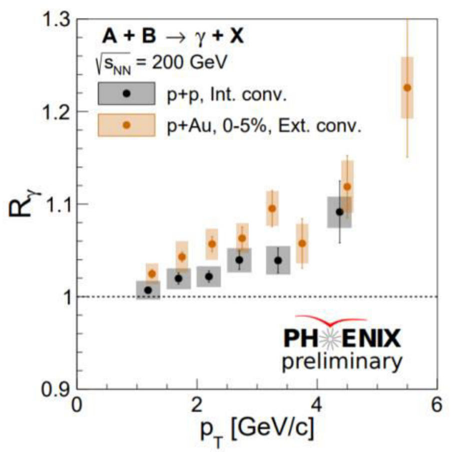
Comparison to higher energies

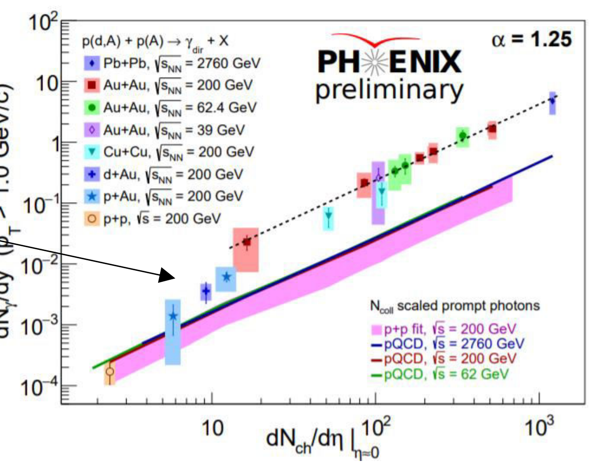
- Rγ ~ 1.05-1.2 in heavy-ion collisions at SPS/RHIC/LHC, $\sqrt{s_{NN}}$ = 17.2-2760 GeV





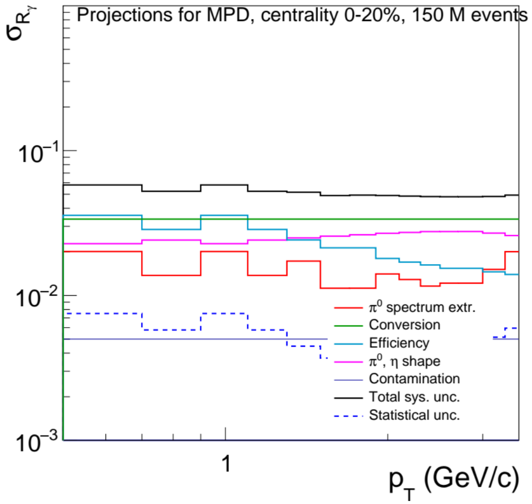
- Rγ ~ 5% is on the verge of experimental measurability (PHENIX in pp/pA@200, ≥ 2σ)





Prospects for measurements in the MPD

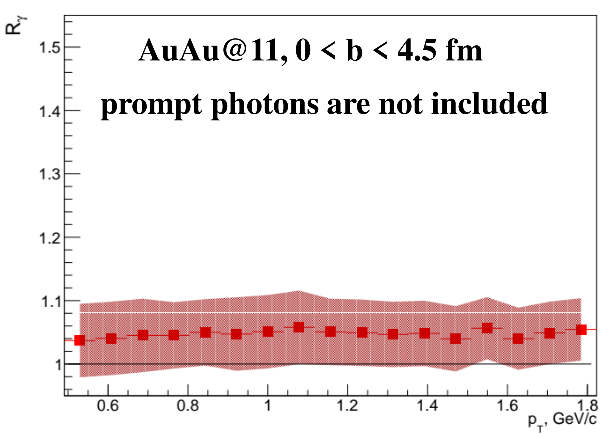
- Estimated measurement uncertainties for Rγ to be 4-6 %:



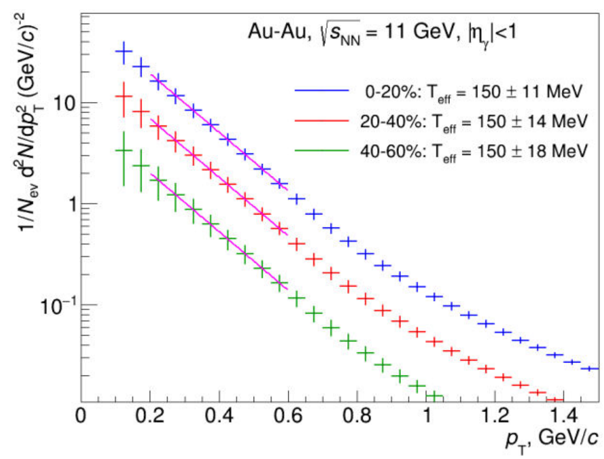
The main sources of uncertainties:

- ✓ detector material budget → conversion probability
- ✓ π^0 reconstruction efficiency
- ✓ p_T-shapes of π^0 and η production spectra

- With Rγ ~ 5% the measurements are problematic:



- With Rγ ~ 1.1% and δRγ/Rγ ~ 3% the T_{eff} can be measured with ~ 10% uncertainty



Conclusions (direct photons)

- $R\gamma$ is predicted to be 1.05-1.15 in central A-A collisions at top NICA energies
- Measurements of direct photon yields and flow are going to be challenging but yet possible
- Experimentally photons can be measured with the ECAL and/or PCM
- Development of reconstruction techniques and estimation of needed statistics are in progress

ECAL calibration and alighnment

(with physical signals)

What/Why should be calibrated

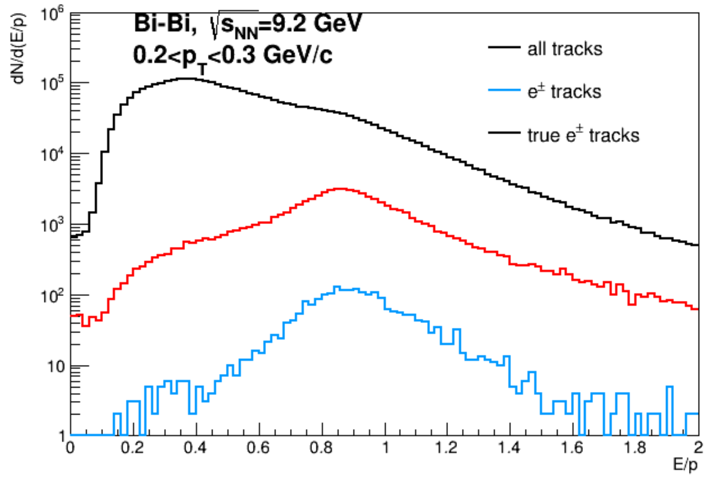
- Energy calibration:
  - ✓ absolute energy scale and alignment of the detector elements (half-sectors)
  - ✓ relative tower-by-tower calibration
- Time calibration

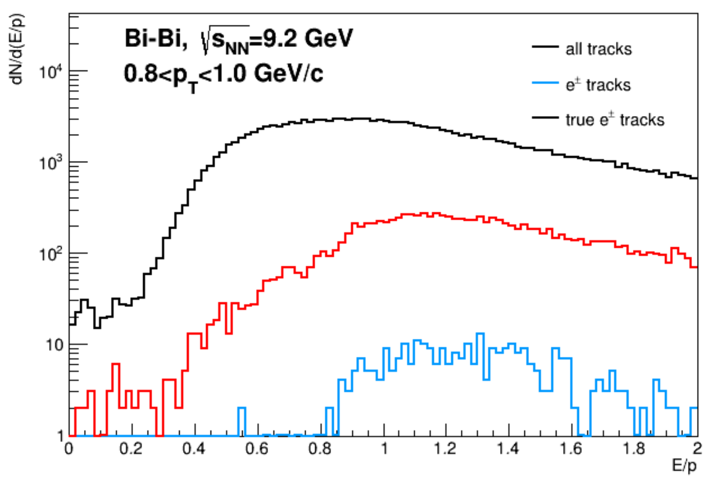
- First approximation:
  - ✓ preliminary calibration of the ECAL with cosmic muons at the stage of construction
    → the calibration should be good enough to make measurements of physical signals possible
  - ✓ photogrammetry and optical survey of the baskets in the frame
    → true geometry should be known within a few centimeters

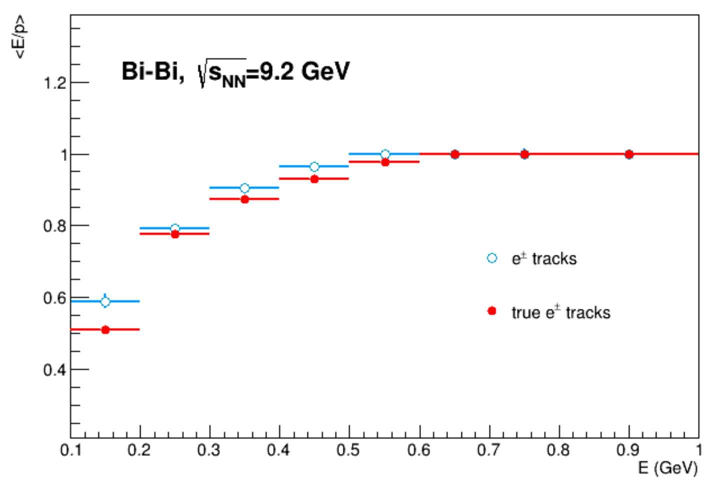
- Fine tuning (topic of interest):
  - ✓ energy calibration using slopes of the measured energy spectra, E/p ratios for electrons, reconstructed mass of π^0, etc.
  - ✓ alignment using charged particle tracks

Electron E/p ratio

- Calculated E/p ratio for **all TPC tracks**, for **tracks identified as electrons in the TPC** and for **true electron tracks** for two different p_T bins
- Quality of E/p can be improved by tuning the TPC track selections (nhits, η, DCA, etc.) and e-ID (TOF)





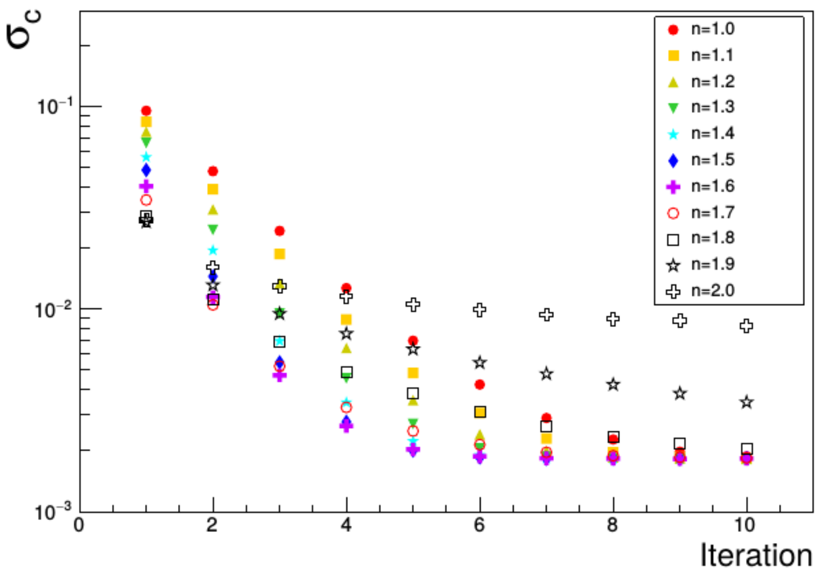


- Number of electron tracks is not sufficient to calibrate each tower → use E/p measurements for absolute energy scale in larger detector elements
- Electrons are sensitive to material budget and the E/p calibration includes uncertainties in description of material budget in front of calorimeter

Calibration with π^0

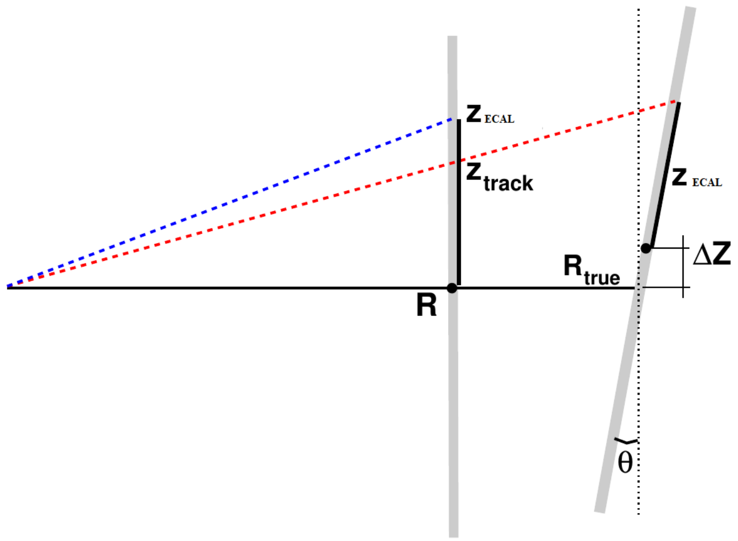
- For each tower in the ECAL fill $M\gamma\gamma$ distribution, where one of the photons is in the cell
- Find π^0 peak position in the distribution and calculate correction for calibration:
  $c_i = (m_\pi^{measured\ in\ tower\ i} / < m_\pi >)^n$
- Re-clusterize (repeat reconstruction with new calibration coefficients) and repeat iterations until no improvement is observed in the next iteration
- What is optimal value of n in the calibration correction?

σ_c – average deviation of the calibration constants for towers from true values



- The best convergence rate and better resolution is achieved with n = 1.6-1.7 and five iterations

ECAL alignment with tracks



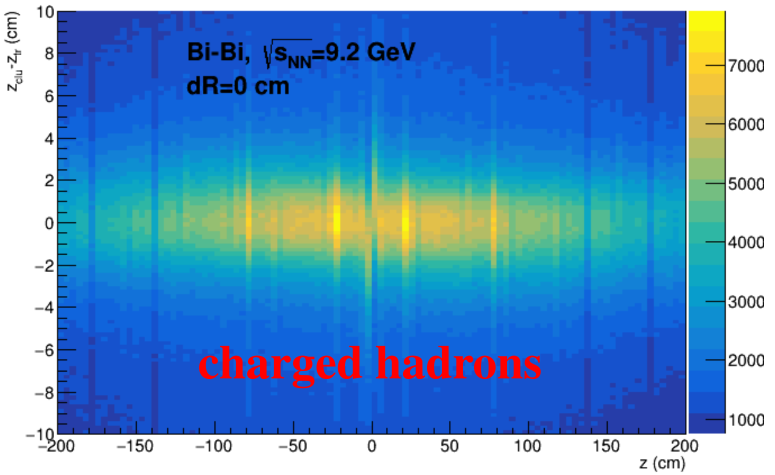
- If description of ECAL geometry in MpdRoot is wrong, then putting π^0 mass peak in proper position may result in wrong absolute energy calibration:

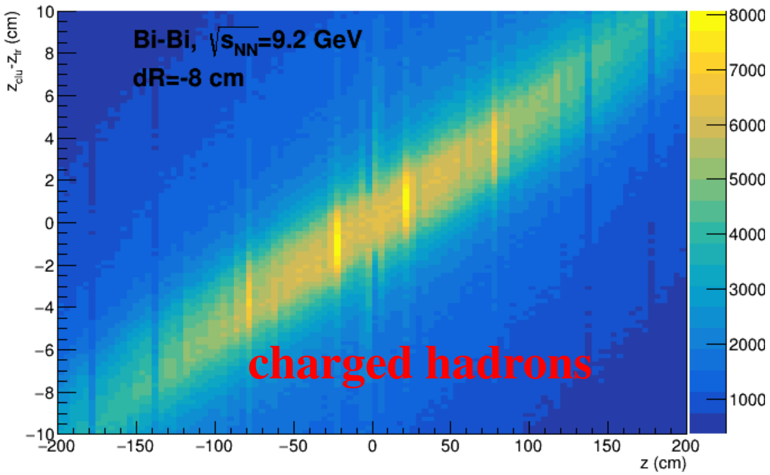
$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\theta_{12})} = 2\sqrt{E_1E_2}|\sin(\theta/2)| \approx \sqrt{E_1E_2}\frac{L_{12}}{R}$$

- The most dangerous is shift in radial direction
- Can be checked by studying the systematic dzed(zed) shift between the (electron) tracks and corresponding (matched) ECAL clusters

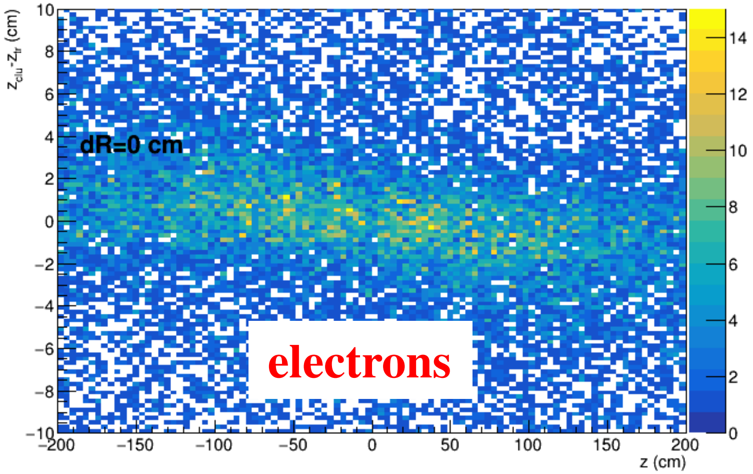
dzed vs. zed

- Dependence dz(z) is sensitive enough to find mis-alignment in radial direction of ~ 1 cm





- The measurements are PID dependent, because the depth of electron and hadron shower
- slightly differ → should be accounted



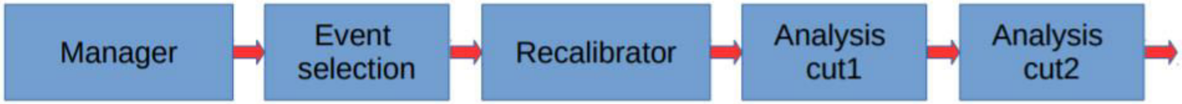
Conclusions (calibration)

- Physical signals and charged particle tracks can be used for fine energy calibration and alignment of the ECAL
- The procedure is not all-mighty and the preliminary energy calibration must be known within a few percent and the detector geometry must be known within a few centimeters at maximum
- Geometry and energy scale are correlated for physical signals

Analysis framework

Centralized analysis framework

- Analysis manager reads event into memory
- Calls wagons to analyze (modify) data:



Class **MpdAnalysisManager** requires list of input files, list of branches to be used for analysis and list of tasks to process these files. Finally MpdAnalysisManager takes care of writing output objects for each task with special list.

Taks which will be called by MpdAnalysisManager should be derived from **MpdAnalysisTask** and have several methods implemented:

void UserInit(); // Users should prepare objects to fill (histograms, trees etc)

void ProcessEvent(MpdAnalysisEvent &event) ; // method is called for each event and event data are provided by container MpdAnalysisEvent

void Finish() ; //method is called when scan in finished but class data are not written yet.

Class **MpdAnalysisEvent** contains references to all branched containing data for this event. MpdAnalysisManager can be configured to read only few branches reaslly necessary for analysis.

Code committed into MPD/physics dir:

https://git.jinr.ru/nica/mpdroot/-/tree/dev/physics

Physics Forum soon !!!

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