Status of the Simulation work on MpdRoot

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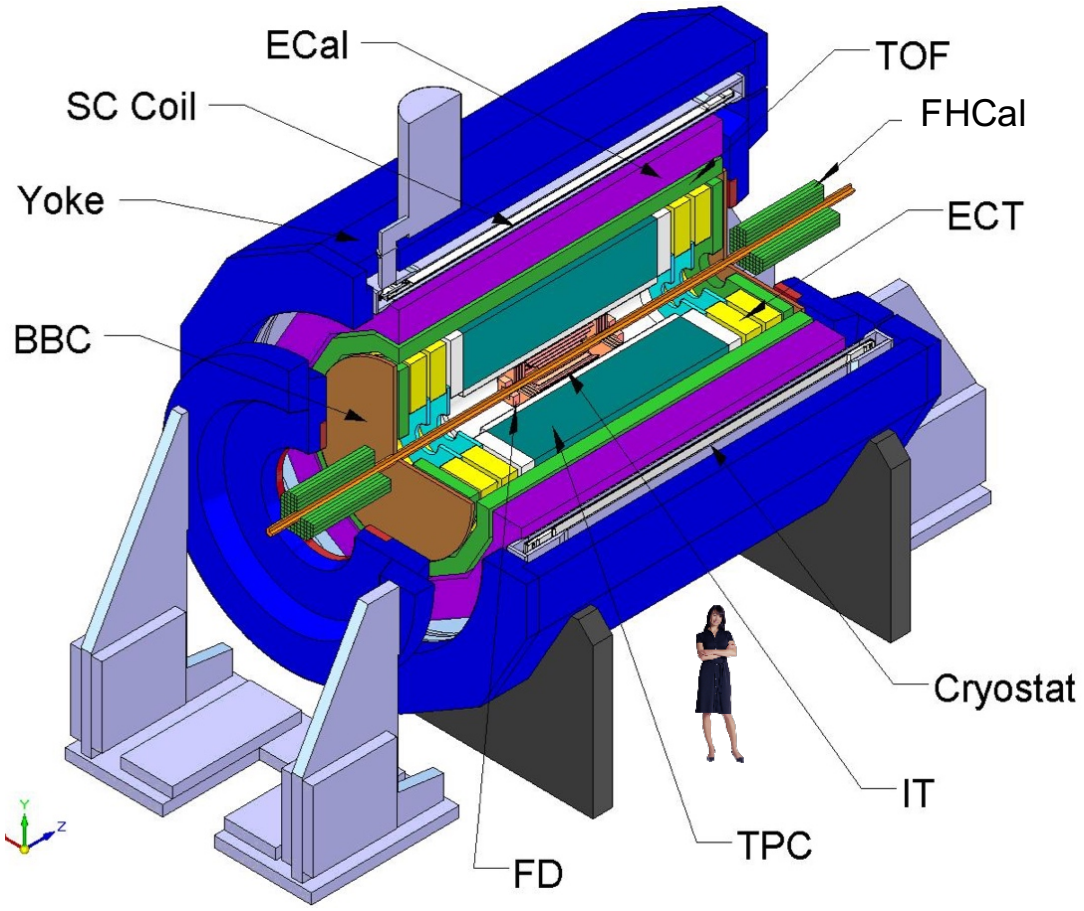
Co-advisor: Yi Wang (王义)

MPD/ECal collaboration

Outline

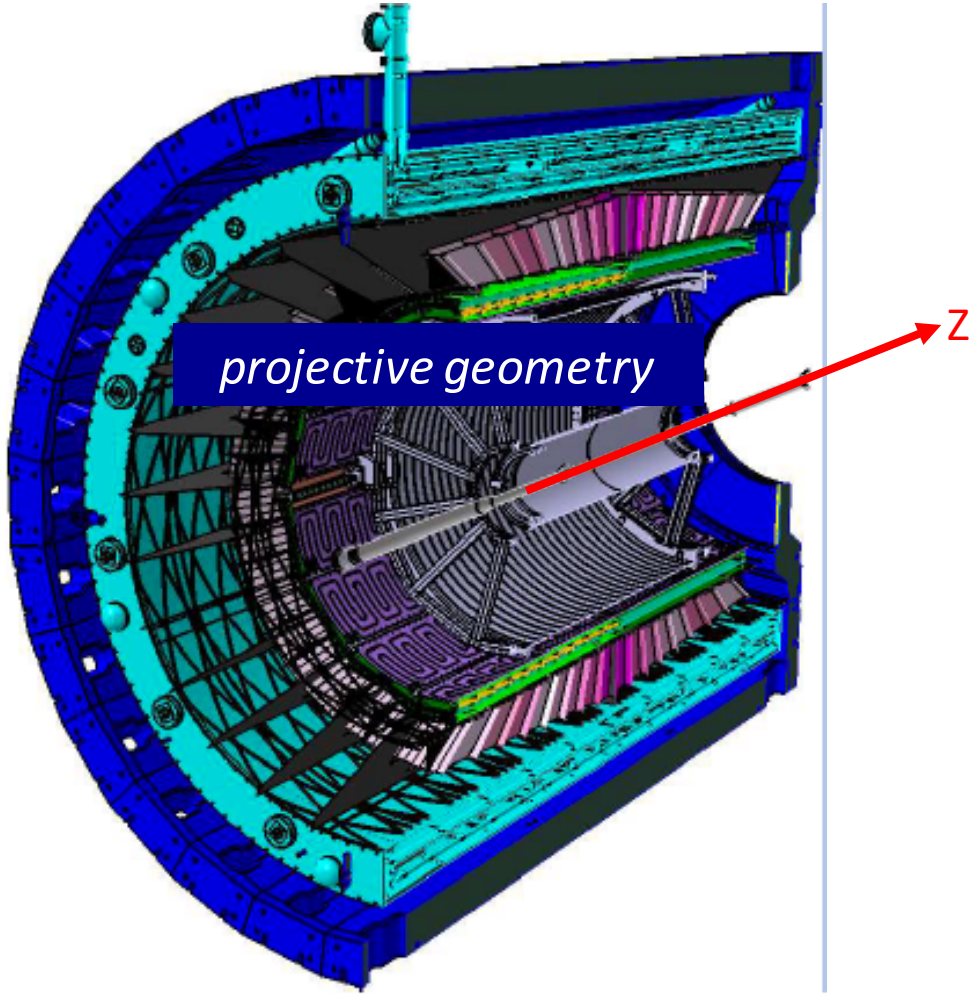
- Introduction
- Performance of ECal in the Simulation
- Ongoing topics
- Summary

Introduction



Concept of the **M**ulti**P**urpose **D**etector(**MPD**)

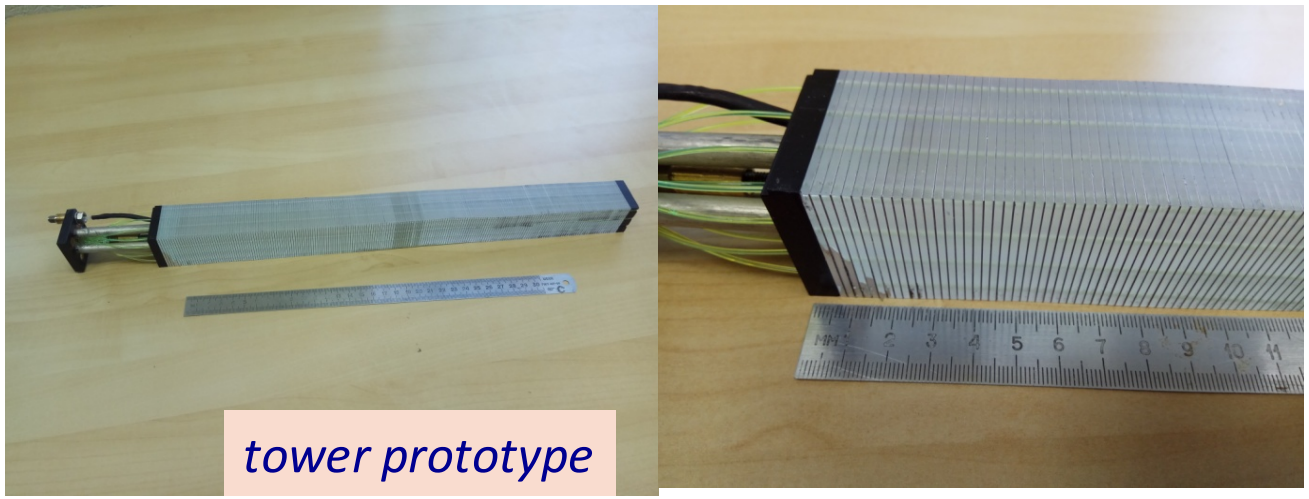
Barrel ECAL ~ 38 400 towers (cells)

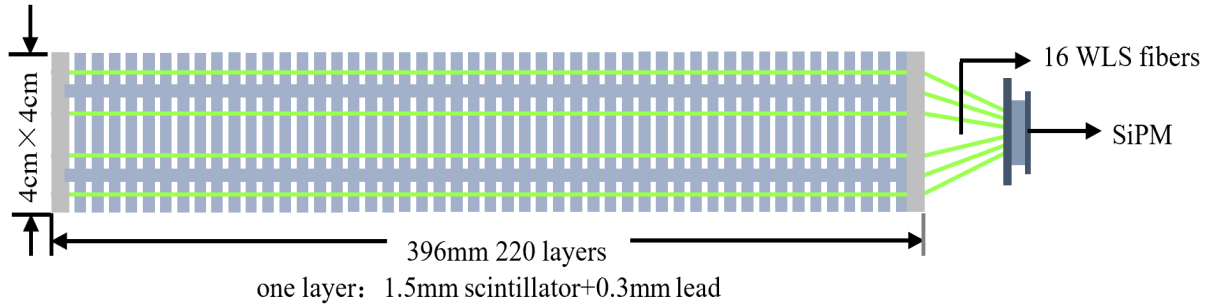


Schematic view of the Electromagnetic Calorimeter

Structure of ECal tower

- *Pb(0.3mm)+Sc(1.5mm) "Shashlyk"*
- *read-out: WLS fibers + MAPD*
- *L ~35 cm (~ 14 X_0)*
- *Segmentation (4x4 cm^2),*
- *$\sigma(E)$ better than 5% @ 1 GeV;*
- *time resolution ~500 ps*





The main goals of ECAL:

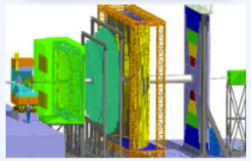
- Participate in particle identification
- Measurement of the photon flux
- Reconstruction of some decays with participation of photons or electrons

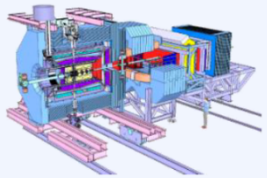
FairRoot Family

Start testing the VMC concept for CBM

2004

First Release of CbmRoot



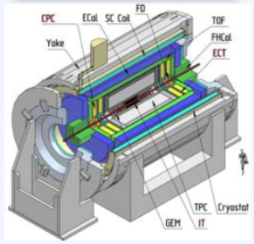


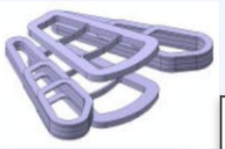
Panda decided to join → oct.

FairRoot: base package for experiments

2006

MPD@NICA started with FairRoot

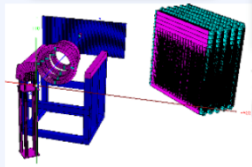


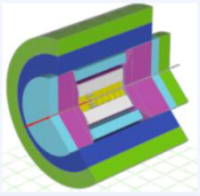


R3B joined

2010

ASYEOS joined

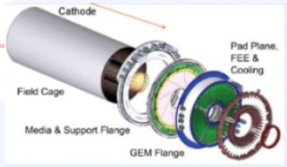


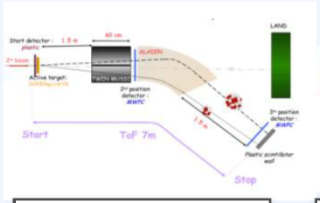


EIC (Electron Ion Collider BNL)

2011

GEM-TPC seperated from PANDA branch





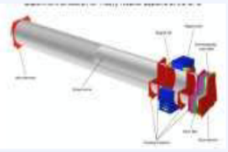
SOFIA (Studies On Fission with Aladin)

2012

ENSAR-ROOT

Collection of modules used by structural nuclear phsyics exp.

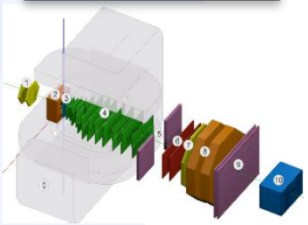
2013

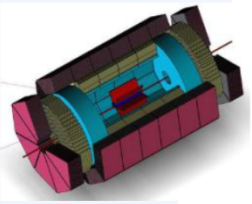


SHIP (Search for Hidden Particles)

2014

BM@N@NICA started with FairRoot



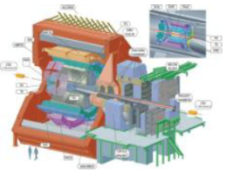


SPD@NICA joined

2015

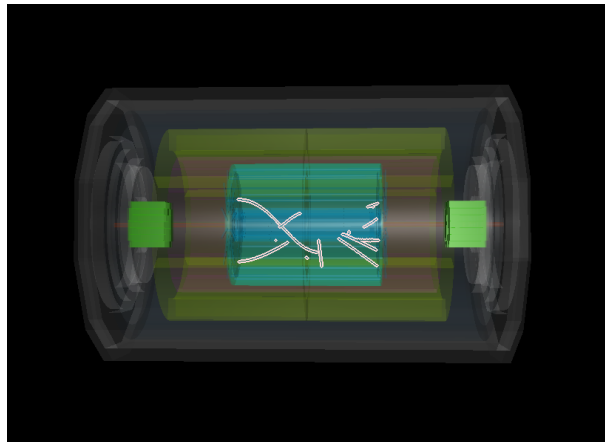
ALICE

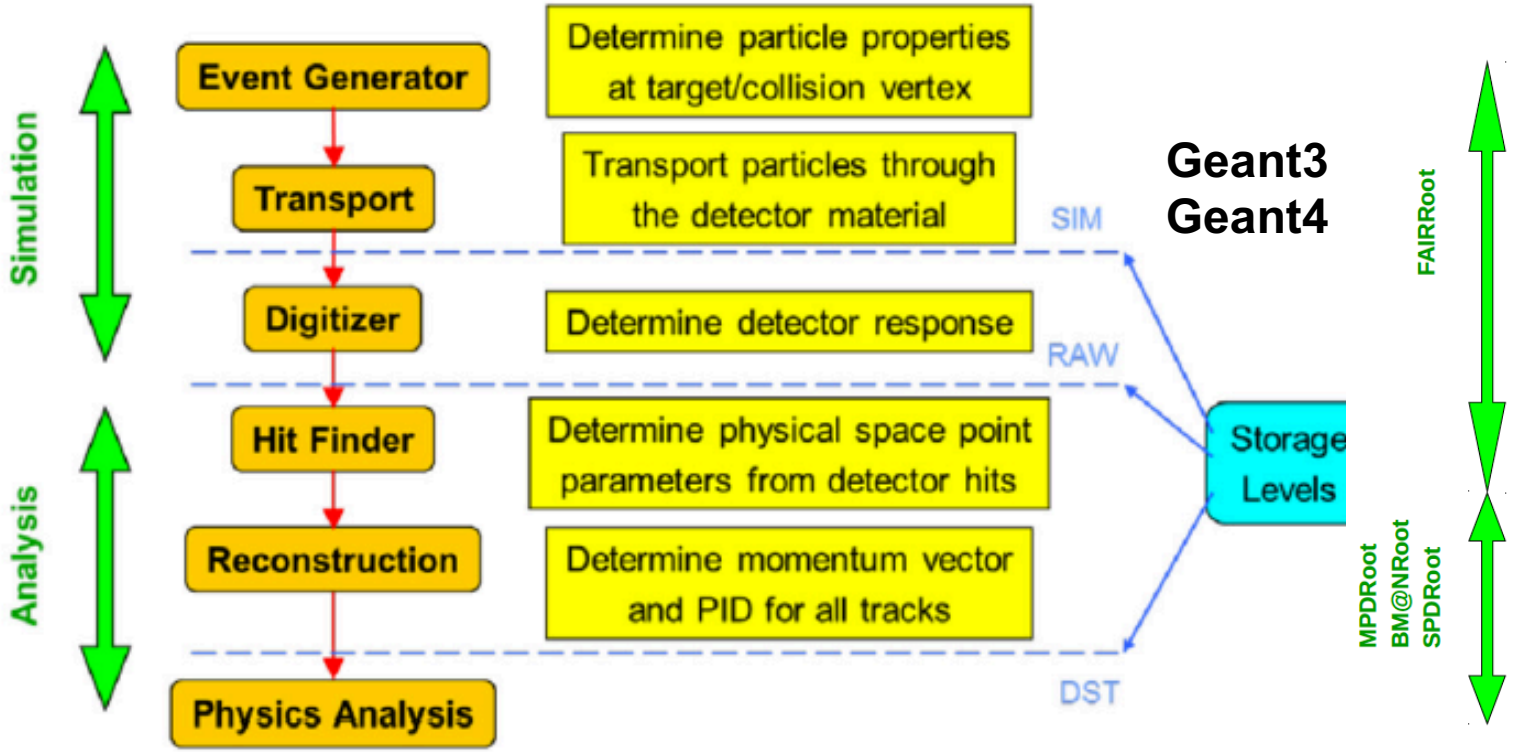
FAIR

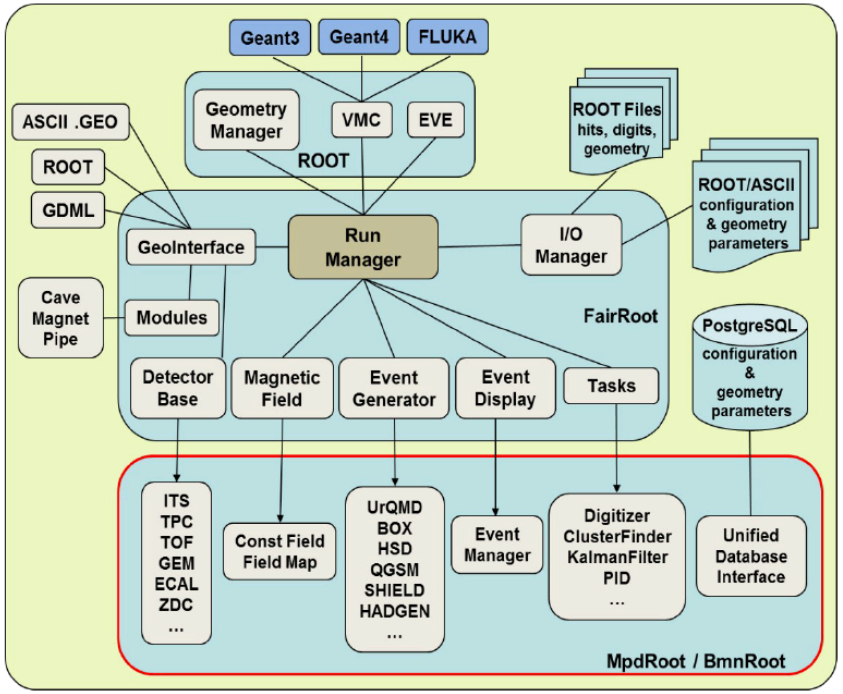


Data flow

UrQmd, LAQGSM, Pythia….

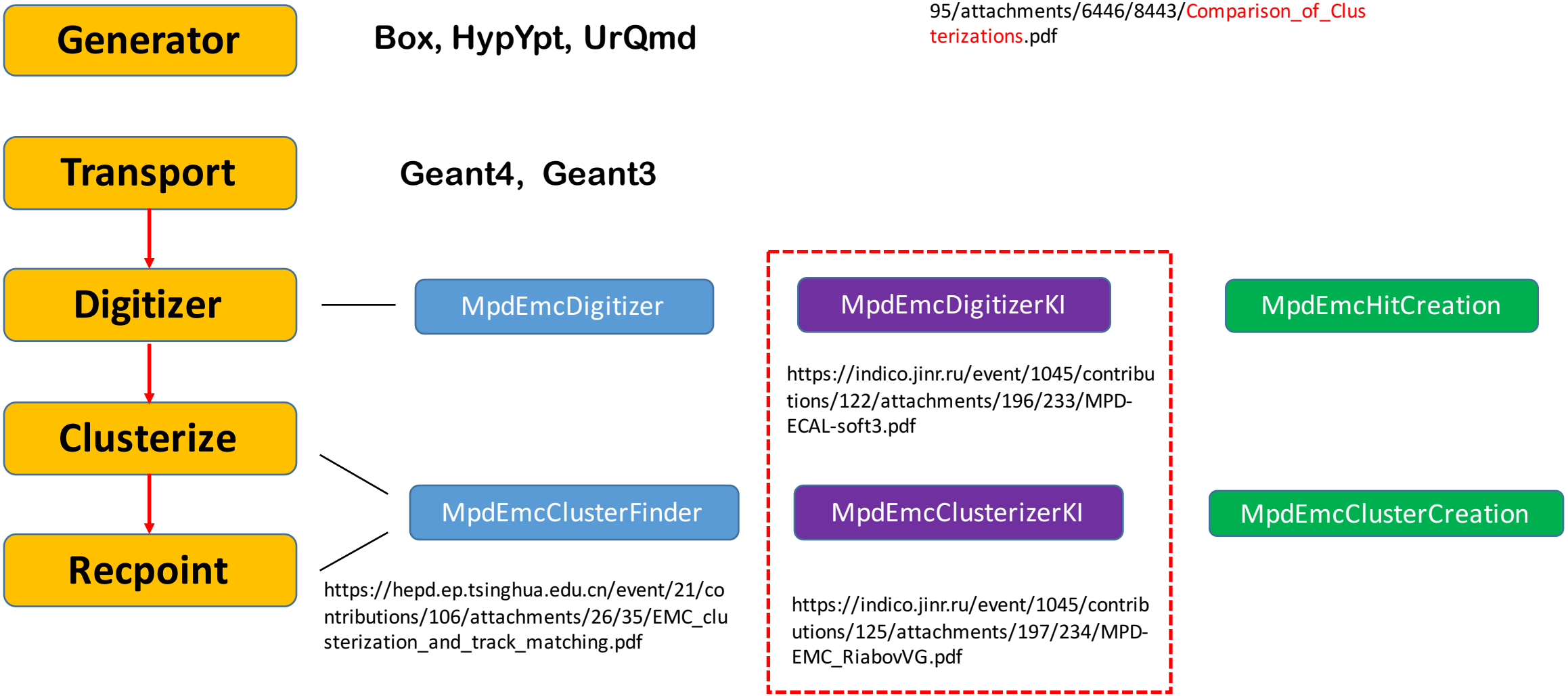






MpdRoot design

EMC Clusterization development



https://indico.jinr.ru/event/984/contributions/8195/attachments/6446/8443/Comparison_of_Clusterizations.pdf

Tutorials notes

- How to install MpdRoot: https://zhuanlan.zhihu.com/p/267332844
- How to use MpdRoot: https://zhuanlan.zhihu.com/p/269122180
- How to create an account on NICA Cluster: https://zhuanlan.zhihu.com/p/263334611

- **Large productions:** https://mpdforum.jinr.ru/t/

  It`s PWG4 request for MPD/ECal group, e.g. *Request5: PWG4 - dielectrons, 10M minbias BiBi@9.46*

Please Email to: h-y12@tsinghua.org.cn if there is any problems.

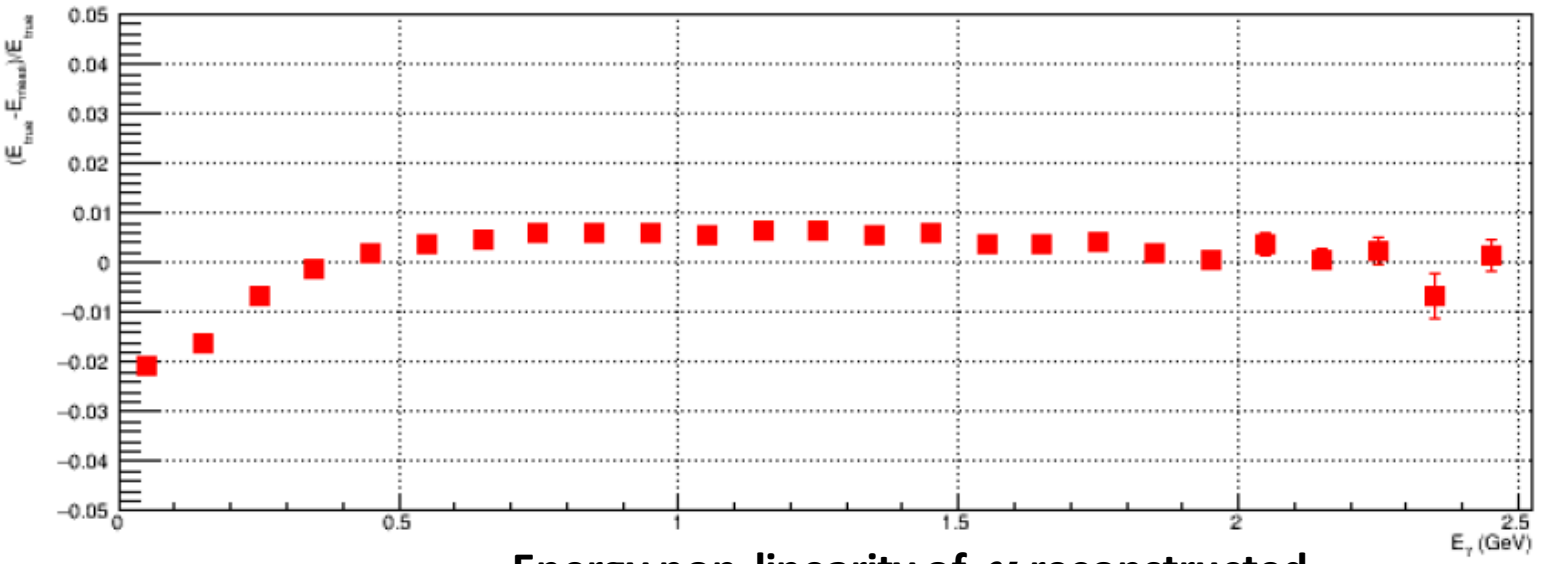
清華大學 Tsinghua University

JOINT INSTITUTE FOR NUCLEAR RESEARCH

- Introduction
- **Performance of ECal in the Simulation**
  - ✓ Reconstruction of γ
  - ✓ Time information and PID
- Ongoing topics
- Summary

Energy resolution for γ

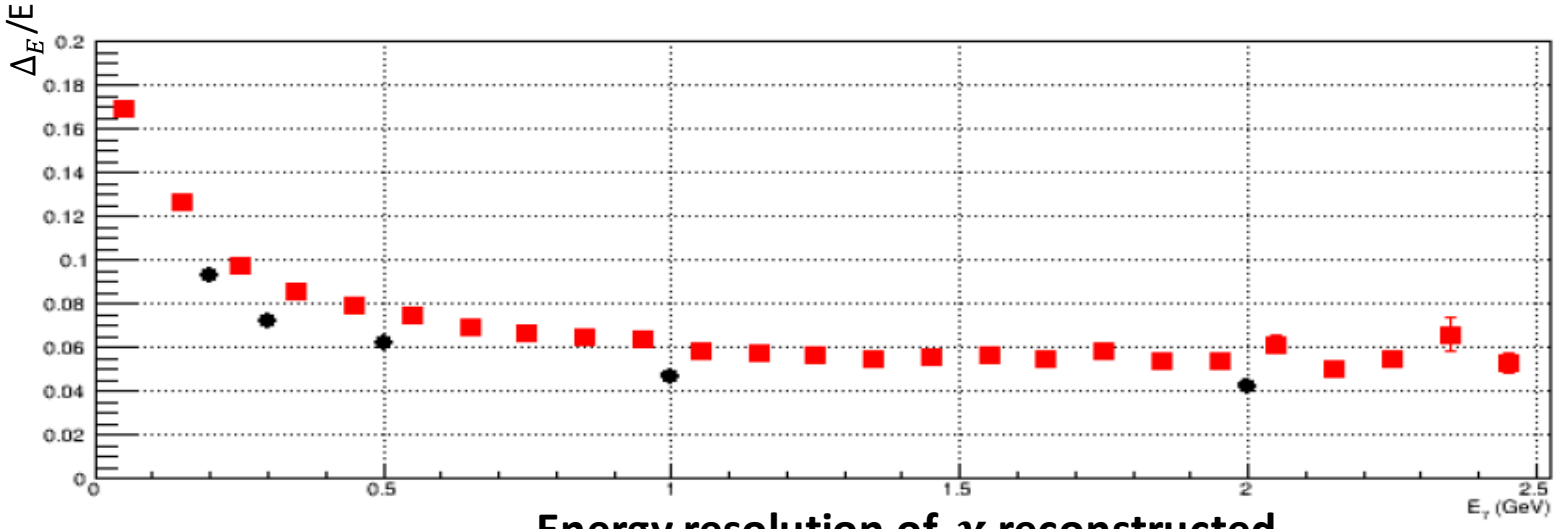
Black dot: Single γ



Energy non-linearity of γ reconstructed

- **UrQmd** $Au + Au$
- $\sqrt{s} = 11GeV$, **b<3fm**

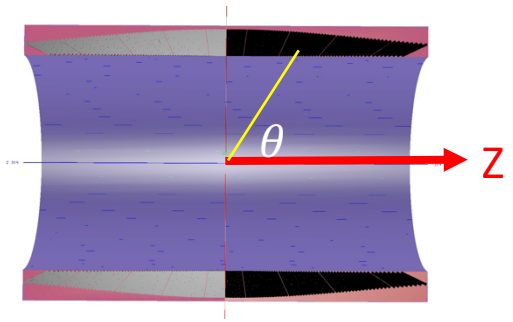
- Energy non-linearity is smaller than 2%.



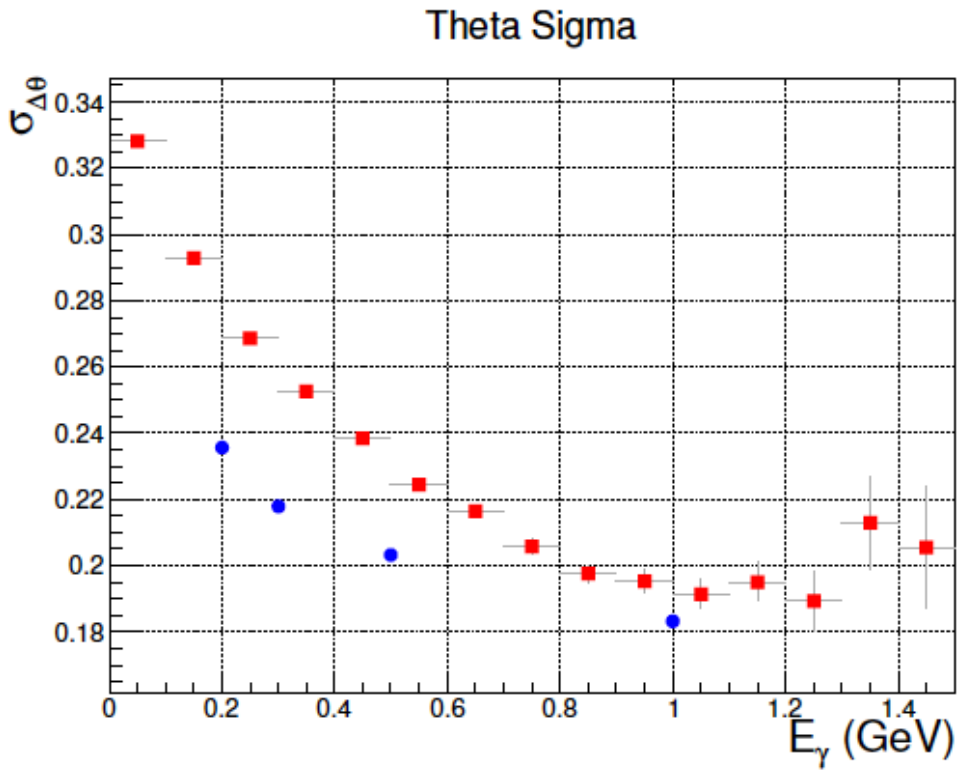
Energy resolution of γ reconstructed

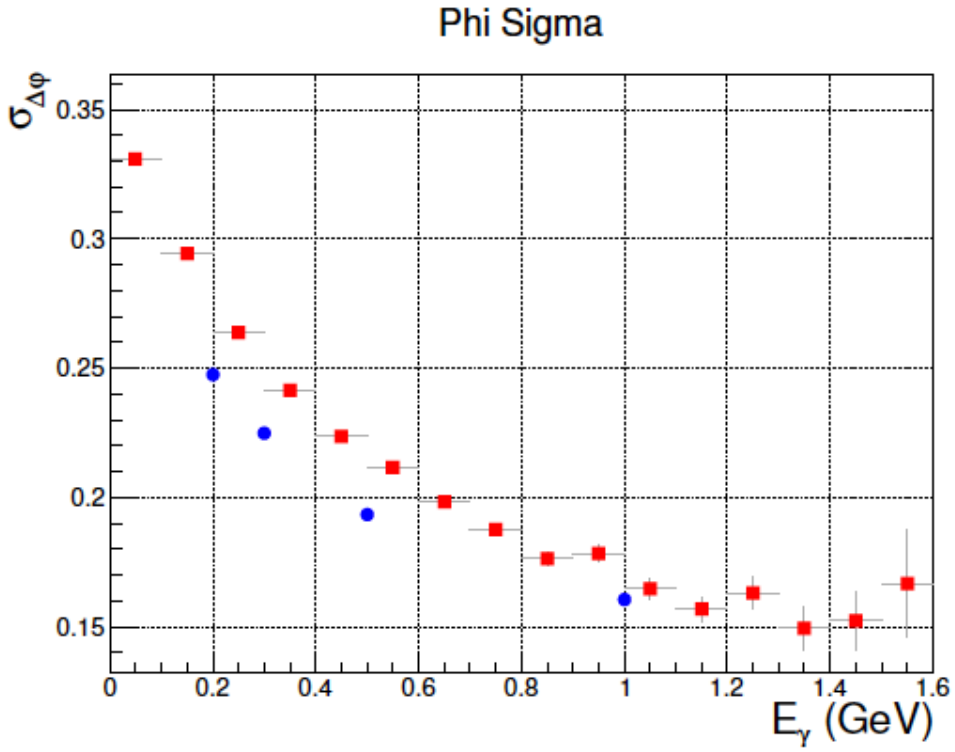
- Energy resolution is about 5% at 1GeV.

Angular resolution for γ



- Angular non-linearity is about 1%.
- Angular resolution is about $0.16°$ at 1GeV, corresponding to 4.8mm.

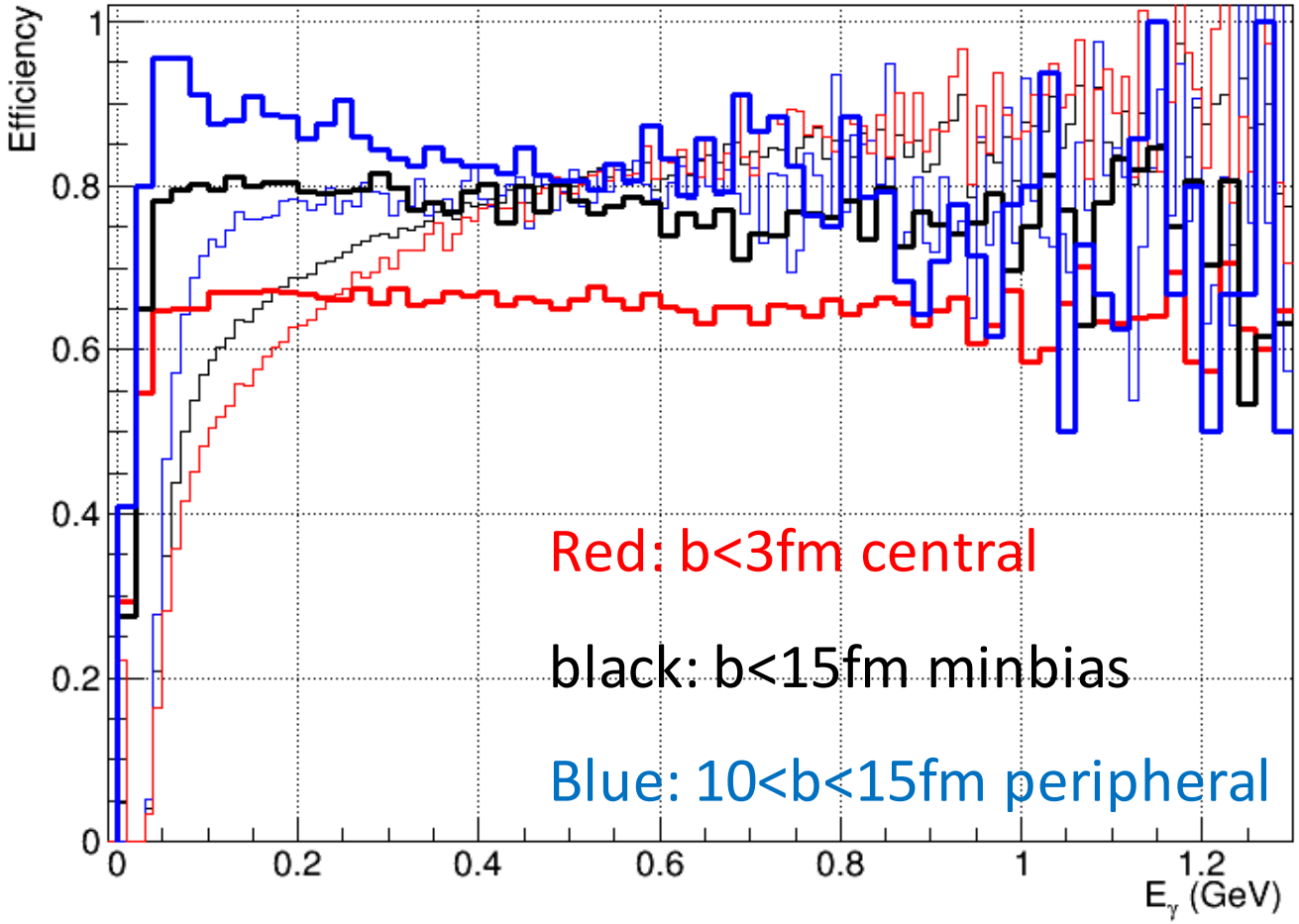




Blue circle: Single γ

Efficiency for γ

- Efficiency with basic cuts:
  - ✓ Events: UrQMD, |z-vertex| < 20 cm
  - ✓ Photons: |y| < 0.5, T < 2 ns, $N_{towers} \geq 2$ (the latter two have marginal effect on efficiency)



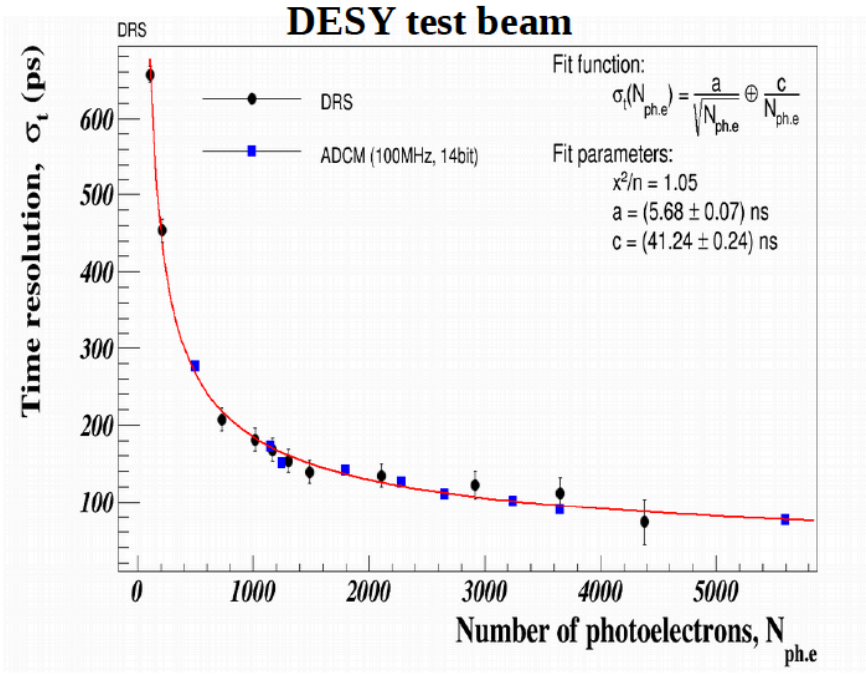
Time information of the Barrel Ecal

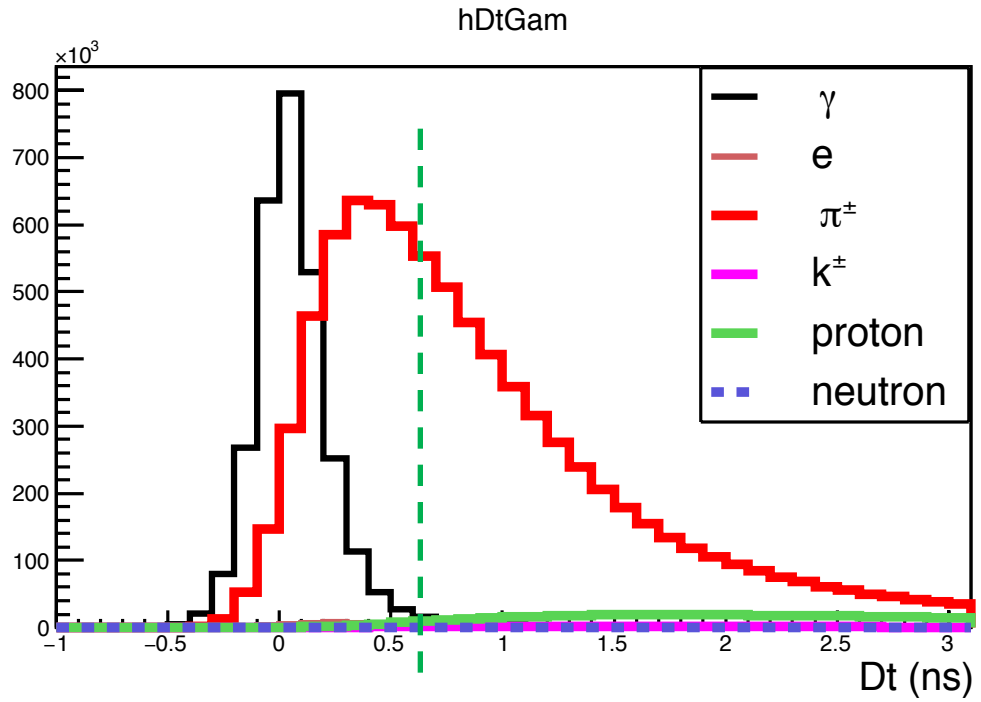
- **Urqmd Gen**
- $Au + Au \quad \sqrt{s} = 11GeV$ **central**
- **Time cut: 15ns; Energy cut: 100MeV**

$$Dt = t_{point} - \frac{L}{c}$$

L: distance from the point to the vertex point generated

c: velocity of light





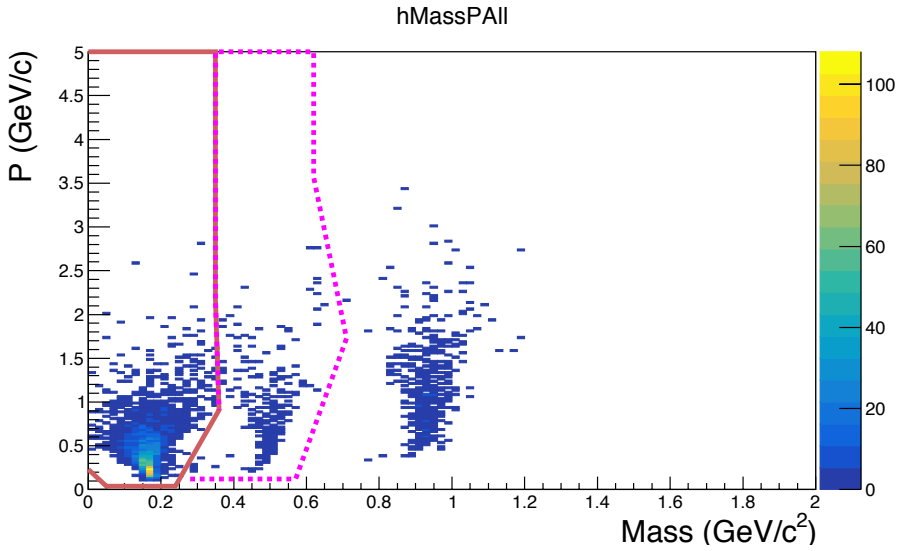
$\delta_t = 150ps$ for charged particles

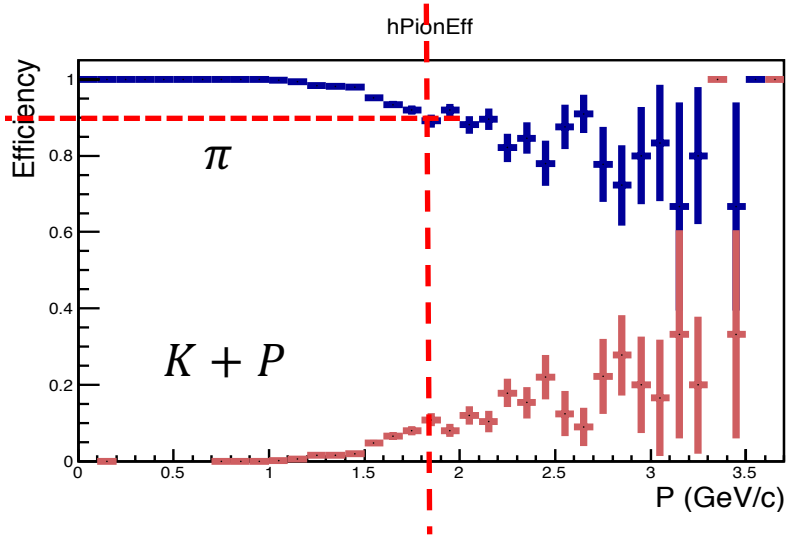
$\delta_t = 80ps$ for neutral particles with energy larger than 700MeV

$N_{ph.e} = 7761.0 \times E(GeV)$

Distribution of Dt after δ_t applied

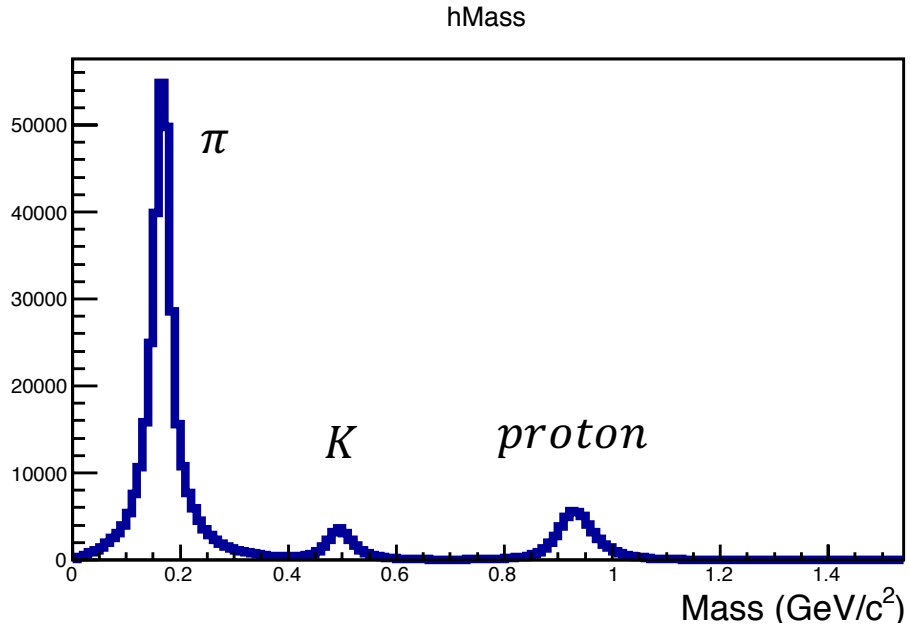
PID for the Barrel Ecal

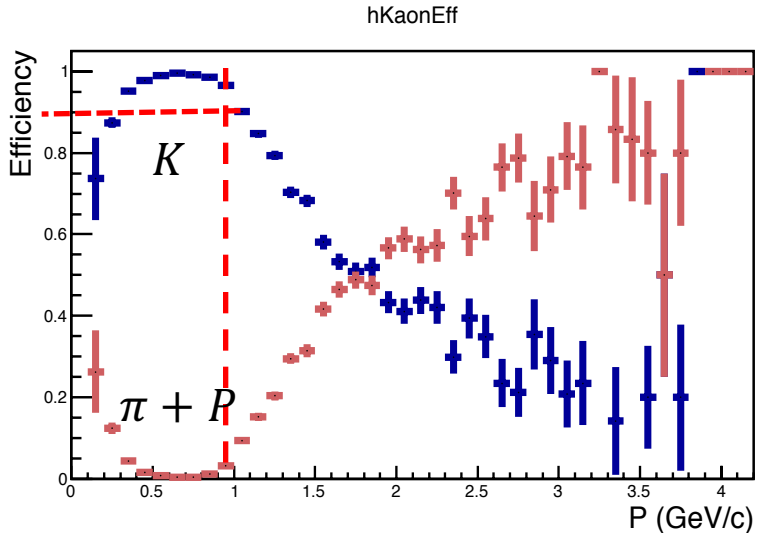




π can be separated from K and p for $P < 1.9 Gev/c$ with efficiency higher than 90% .

Efficiency of separation pions from kaons and proton





K: $P < 1.1 Gev/c$

Efficiency of separation kaons from pions and proton

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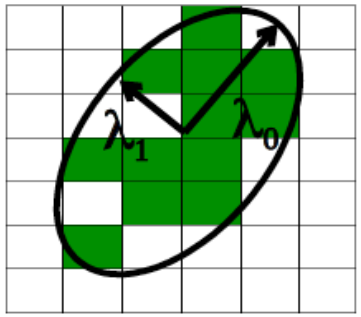
- **Ongoing topics**
  - ✓ **γPID and neutral meson reconstruction**
  - ✓ **Direct photon production**
  - ✓ **ePID and dielectron reconstruction**
- Summary

γPID and neutral meson reconstruction ECal

1) Time of flight
2) Shower shape
3) Charged track matching



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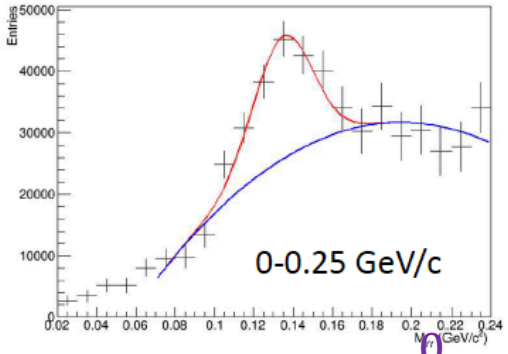
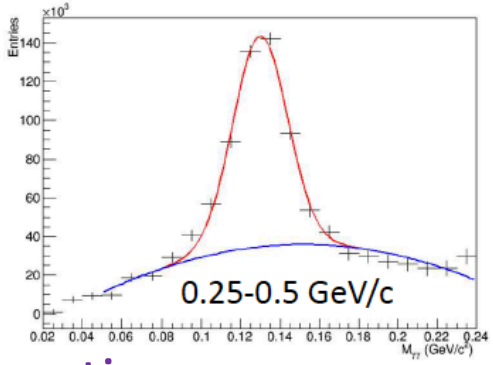
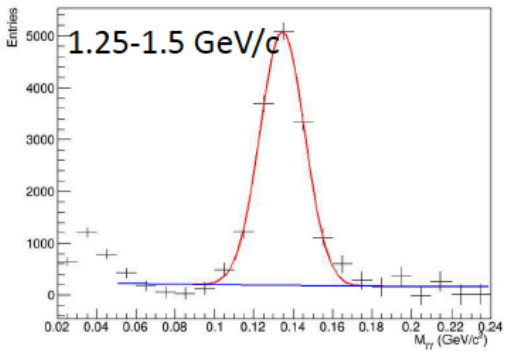
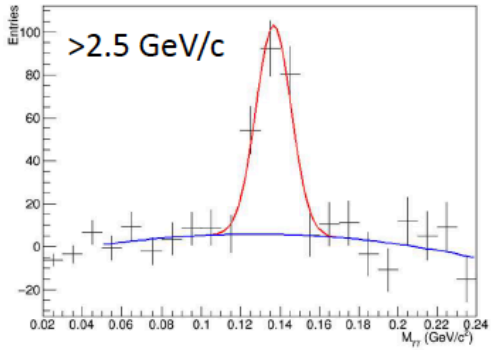


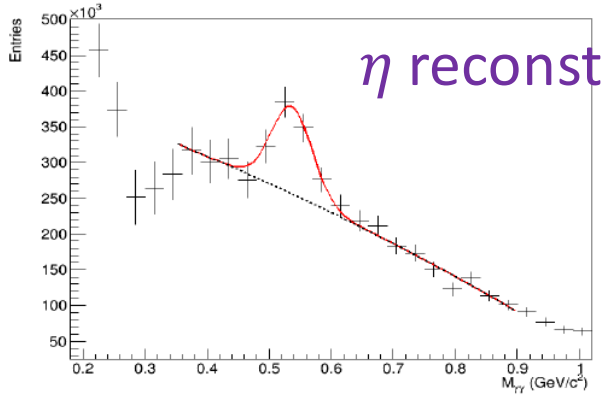


π^0 reconstruction

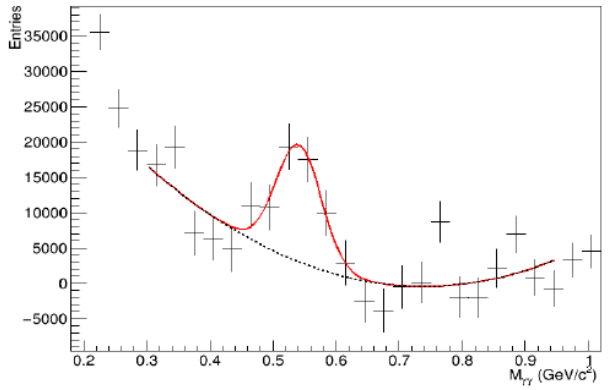




Invariant mass of two photons with different Pt

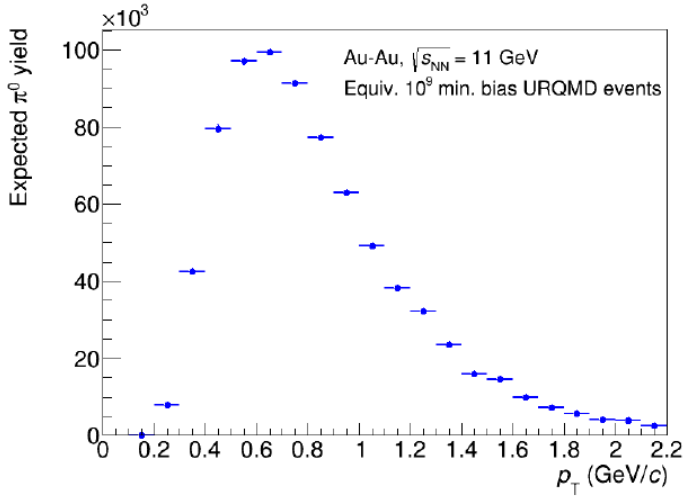


η reconstruction

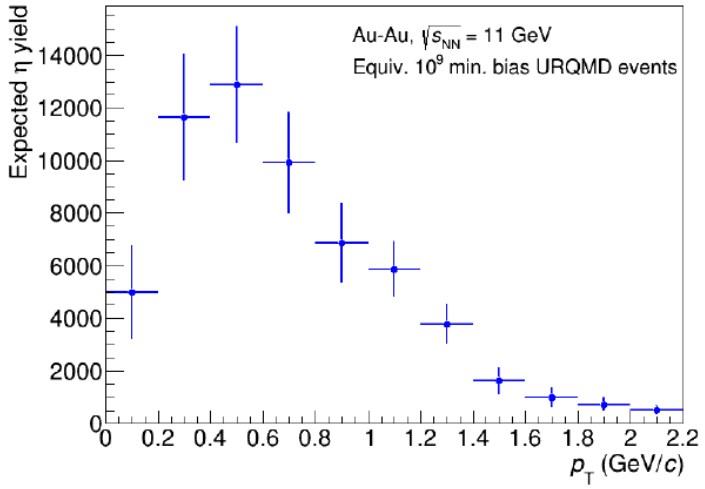


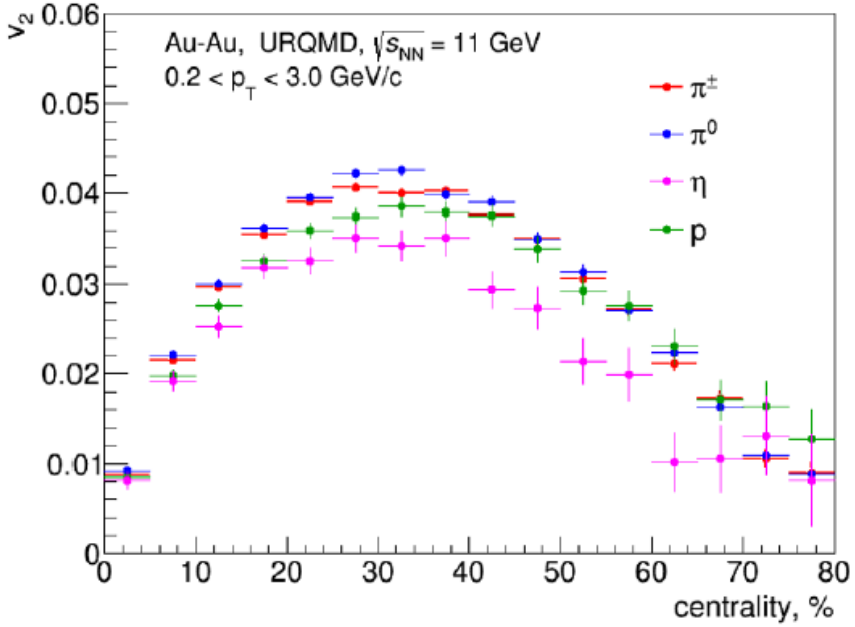
Neutral meson reconstruction Photon conversion

$\pi \to \gamma\gamma \to (e^+e^-)(e^+e^-)$



$\eta \to \gamma\gamma \to (e^+e^-)(e^+e^-)$





$$\frac{dN}{d\varphi} \sim 1 + 2\sum_n v_n \cos n(\varphi - \Psi_{RP})$$

https://indico.jinr.ru/event/1586/contributions/10174/attachments/7979/11740/2020-10-01-kryshen-photons.pdf

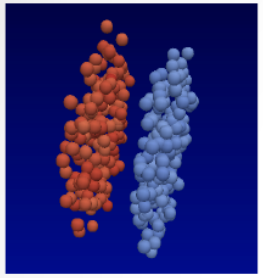
- π^0 spectrum can be measured with 20 M sampled AuAu@11 events
- About 10^9 AuAu@11 must be sampled for π^0 multiplicity dependent study and flow measurements; and for the measurements of η

conversion method benefit from much better energy resolution at low momentum

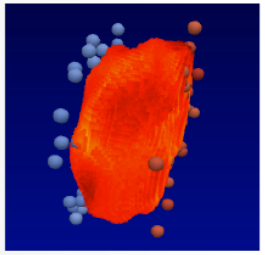
Direct photon production study

We use UrQMD with hydro evolution ("hybrid approach") in order to calculate direct photon yields

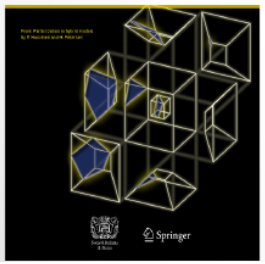
Hybrid model



- Initial State:
  - Initialization of two nuclei
  - Non-equilibrium hadron-string dynamics
  - Initial state fluctuations are included naturally

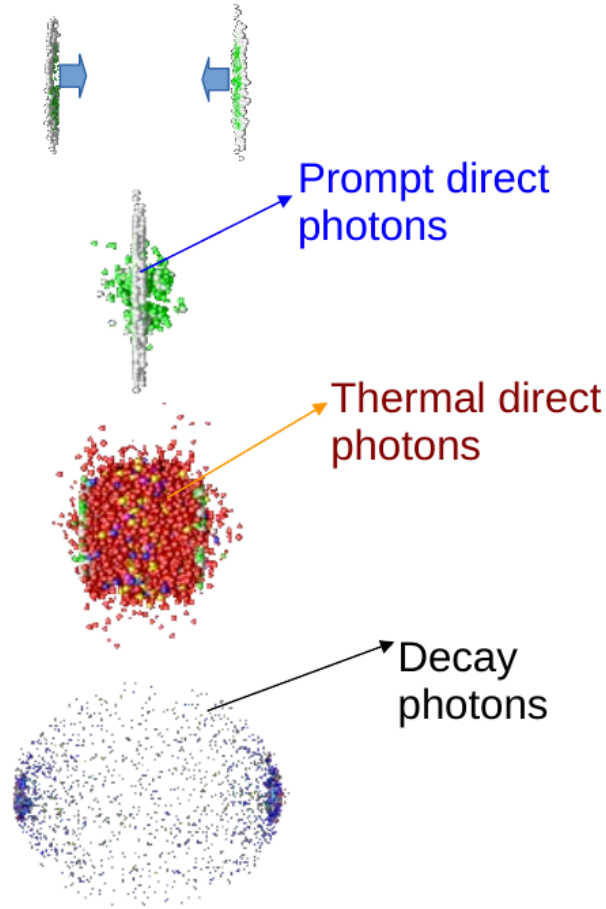


- 3+1d Hydro +EoS:
  - **SHASTA** ideal relativistic fluid dynamics
  - Net baryon density is explicitly propagated
  - Equation of state at finit μ_B



- Final State:
  - Hypersurface at constant energy density
  - Hadronic rescattering and resonance decays within UrQMD

H.Petersen, et al, PRC78 (2008) 044901
P. Huovinen, H. P. EPJ A48 (2012) 171



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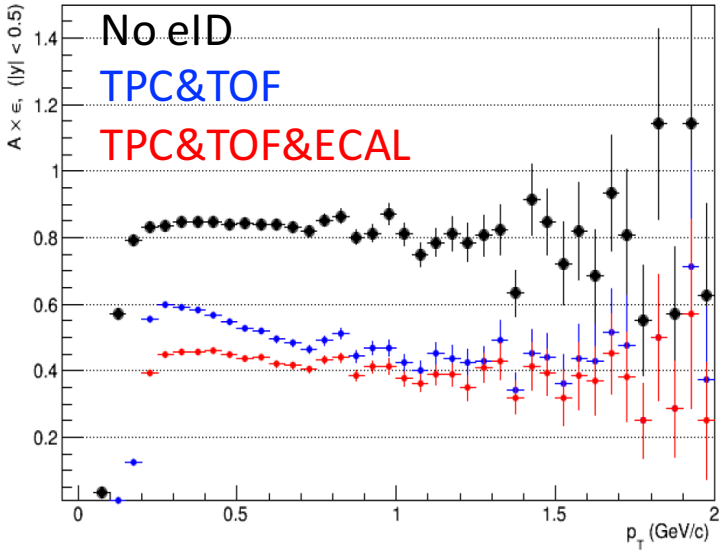
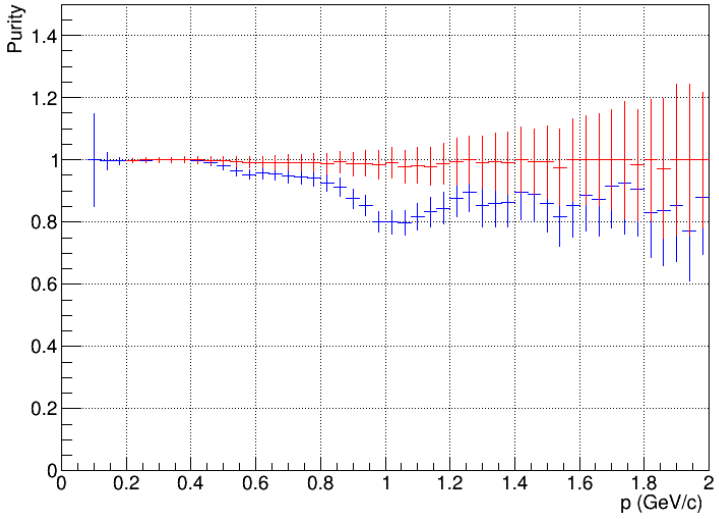
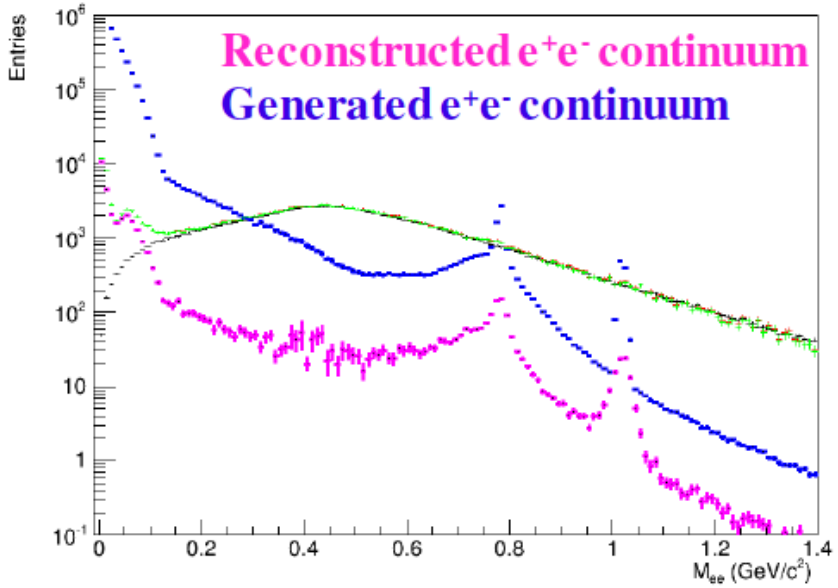
ePID and dielectron reconstruction





- Additional ECAL eID helps to clean-up the electron sample at high pT e^+e^- mass

https://indico.jinr.ru/event/1586/contributions/10173/attachments/7982/11745/RufElectronPID.pdf



- UrQMD & PHSD
- Meaningful measurements for e^+e^- continuum and LVMs would require ~ 10^8 AuAu/BiBi events, first observations are possible with 10-30 M events

https://indico.jinr.ru/event/1460/contributions/9711/attachments/7685/11163/MPD-EMC_RiabovVG.pdf

Summary

1. The performance of MPD/ECal is simulated and π^0 is reconstructed, PID performance of ECal are studied

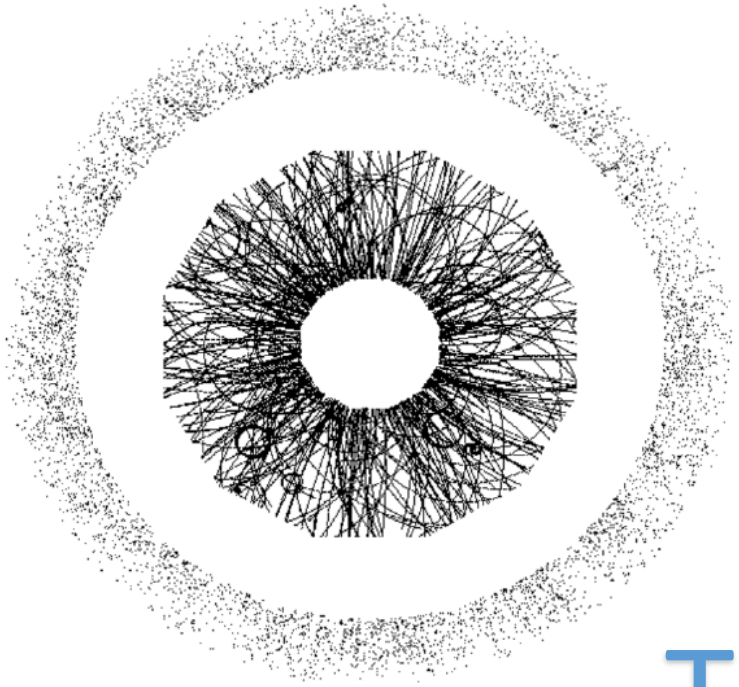
- Energy resolution for γ is about 5% at 1GeV
- Spatial resolution for γ is $\sim$4.8mm.

2. γPID is studied and neutral mesons are reconstructed in two complementary method

- Photon conversion method provides better energy resolution at low P_t
- π^0 spectrum can be measured with 20 M sampled AuAu@11 events

3.ePID is studied and dielectron is reconstructed with UrQmd and PHSD

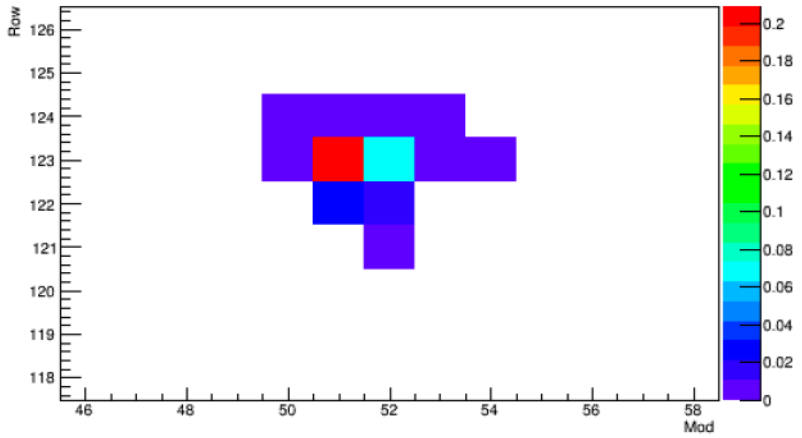
- Additional ECAL eID helps to clean-up the electron sample at high P_t
- First observations for e+e- continuum and LVMs are possible with 10-30 M events



Thanks for your attention!

Backup

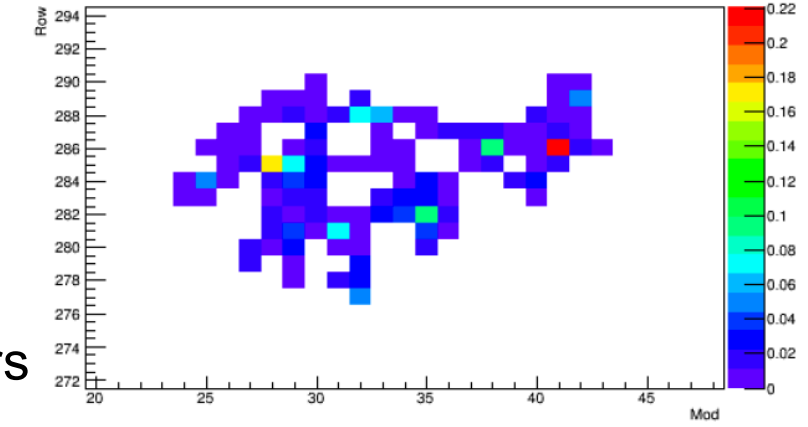
Comparison of clusterization



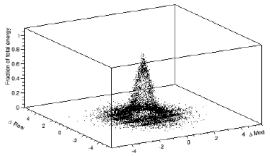
Clusters for one hit

Original clusterization:

- Find the local maximal energy
- Merge hits into cluster
- No common hits in different clusters



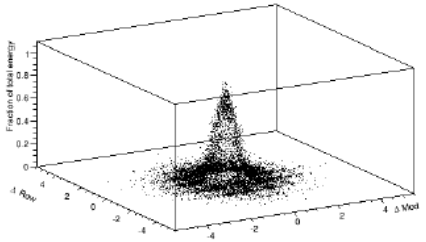
Clusters for multiple hits

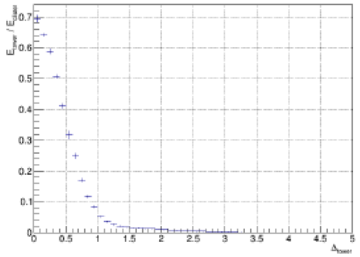


Improved clusterization:

- Find the local maximal energy
- Pre-cluster formation around local maximal
- Separate energy of each module between pre-clusters

- Based on 'known' shape of electromagnetic clusters in the MPD-ECAL:
  - ✓ simulated for single photons: $E_i/\sum E_i : \Delta\text{Mod} : \Delta\text{Row}$
  - ✓ shower shape shows weak energy dependence

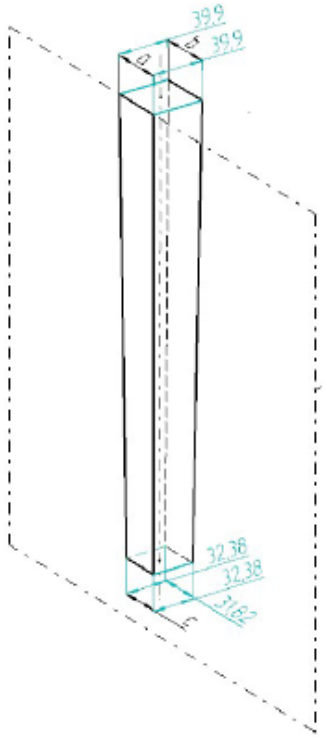


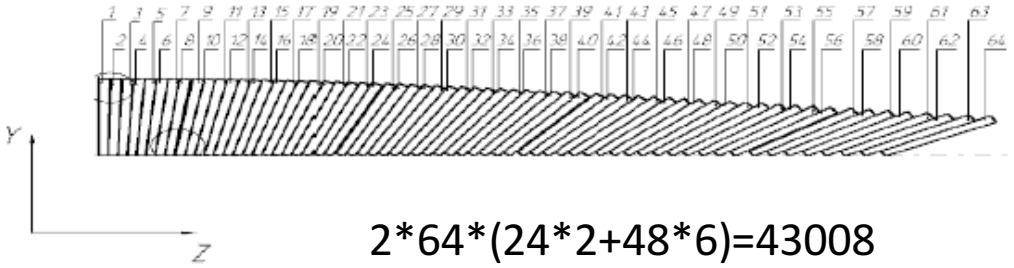


- Provides higher efficiency of cluster reconstruction and better energy/spatial resolution in high multiplicity environment
- Same shower shape is used for shower shape analysis ($\gamma/e^{\pm}$ PID)

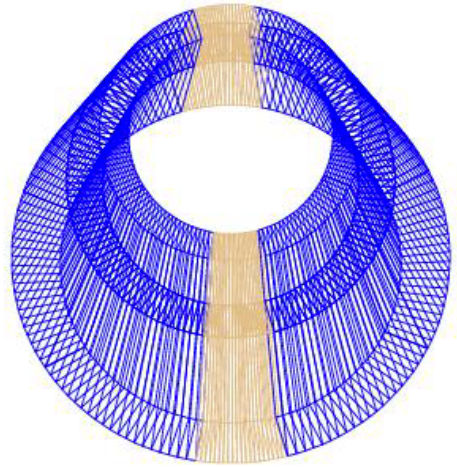
$$\text{Chi2} = \sum_i \frac{\left(E_i^{measured} - E_i^{expected}\right)^2}{\sigma_i^2} \qquad \sigma_i^2 = 0.008 \cdot E_i^{expected} \cdot \left(1 - \frac{E_i^{expected}}{E}\right)$$

Structure of ECal system

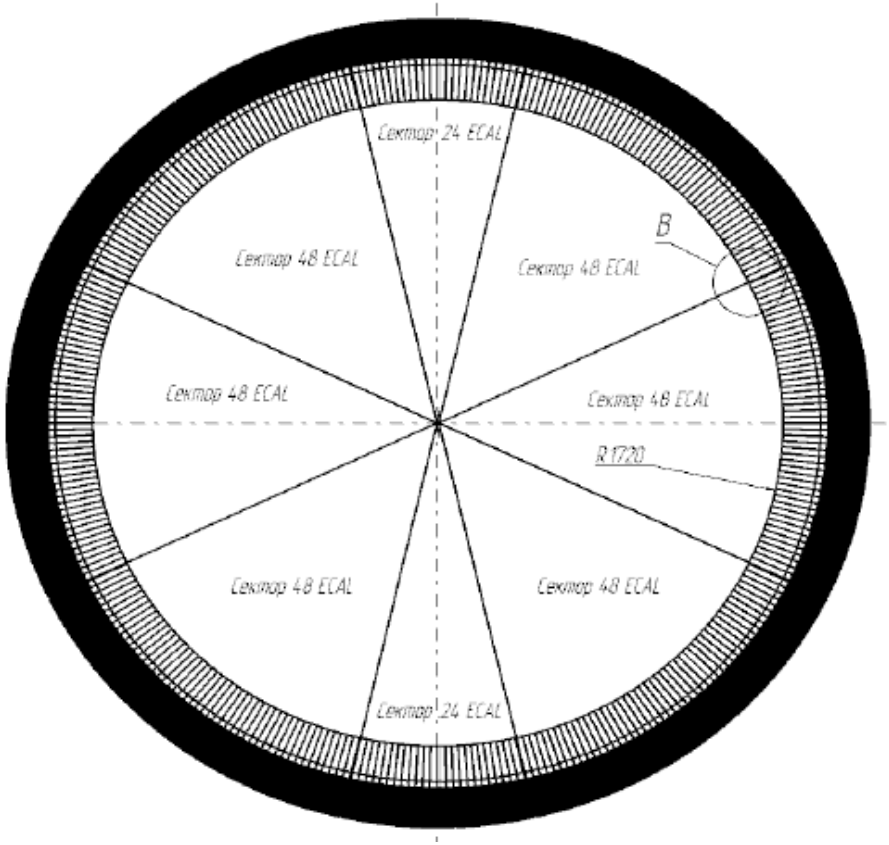


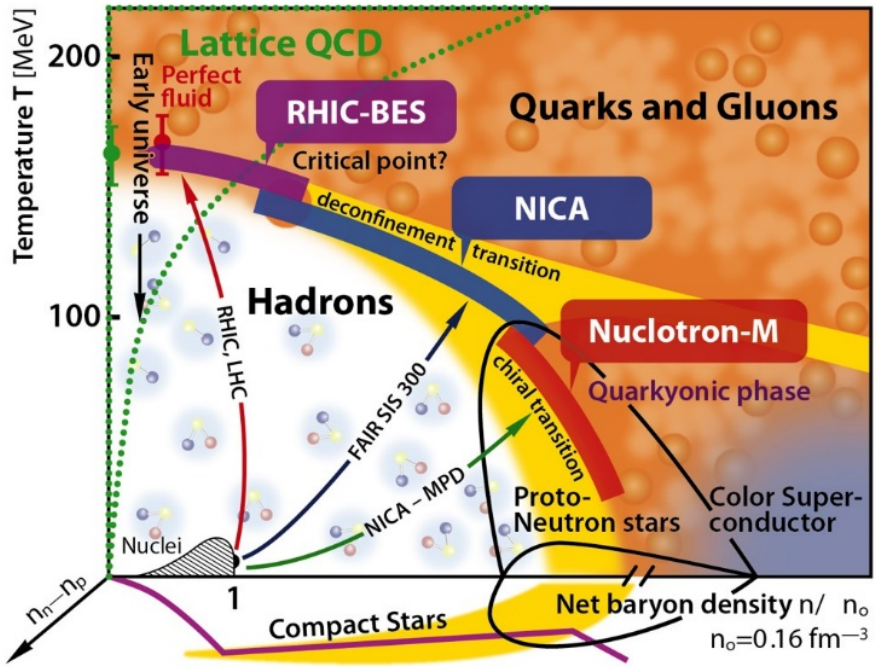


2*64*(24*2+48*6)=43008



The barrel part will be consist of two Chambers. Each of them will be consist eight sectors:
- two of them - 24 modules in Phi plane;
- six of them - 48 modules in Phi plane;
Every row in sector will composed with 64 modules in Theta plane.
Tha ECal Barrel part will be have 43008 modules (channels).

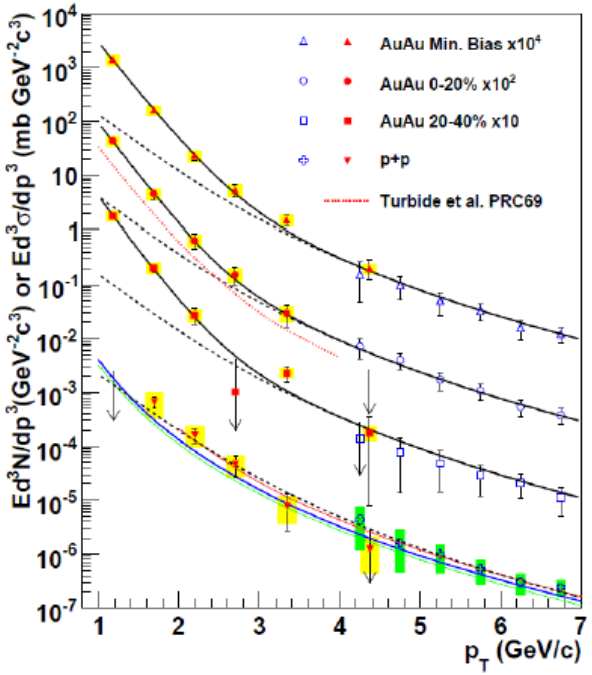




- L ~5 x 10^{25} cm^{-1} s^{-1}
- 10 weeks
- 50% duty factor
- => 10^9 minimum bias events
- Background and signal distributions scaled to 10^9 min. bias events
- Statistical uncertainties estimated as sqrt(S+B)

Photon spectra at RHIC and LHC

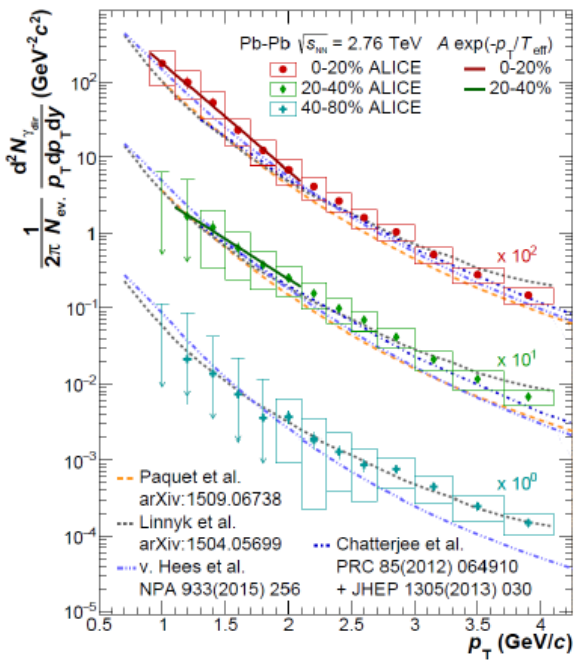
PHENIX (AuAu @ 200 GeV)



T_{eff} = 239 ± 25 (stat) ± 7 (syst) MeV

PHENIX: Phys. Rev. Lett. 104 (2010) 132301

ALICE (PbPb @ 2760 GeV)

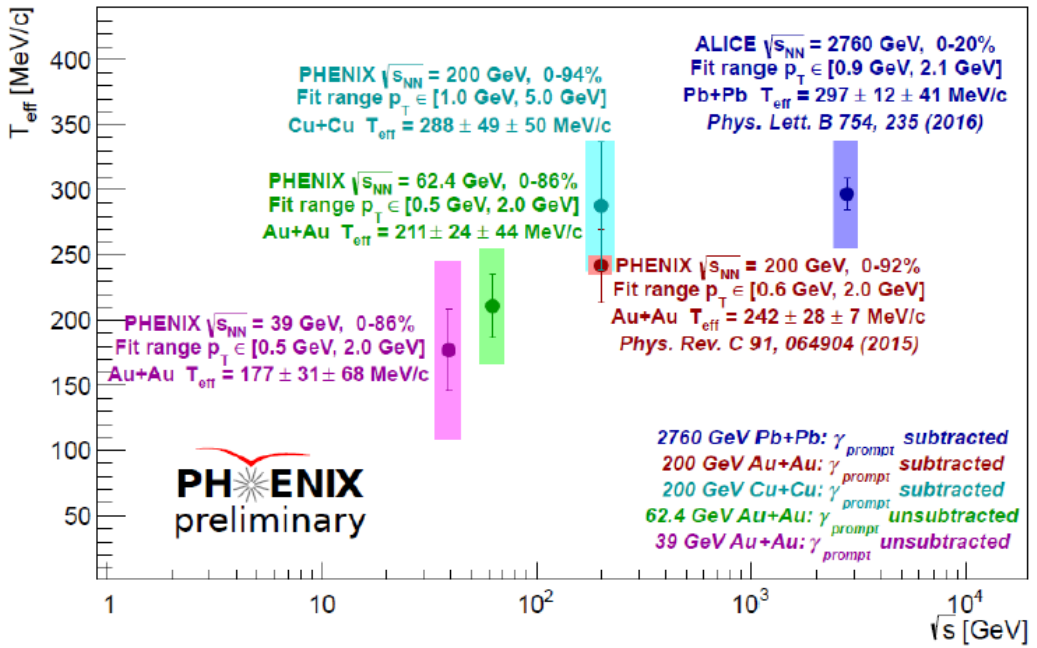


T_{eff} = 297 ± 12 (stat) ± 41 (syst) MeV

ALICE: Phys. Lett. B754 (2016) 235

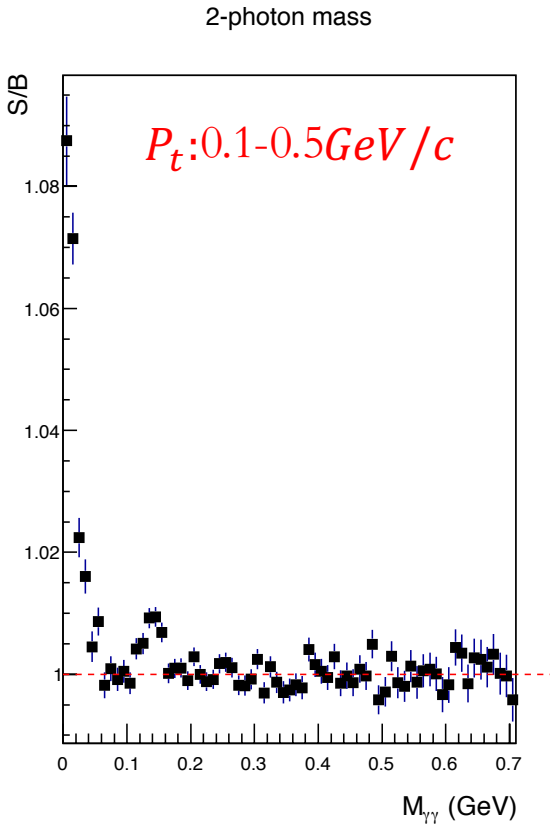
Effective temperature vs energy

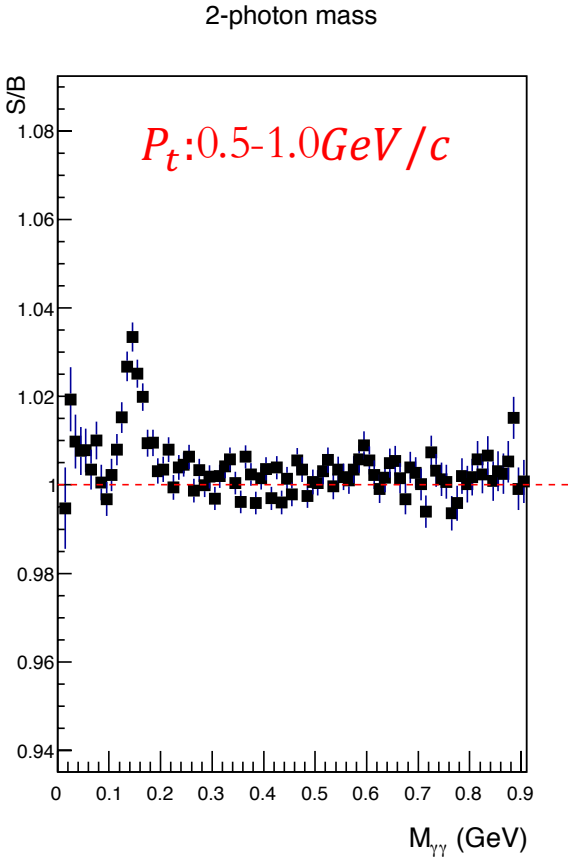
T_{eff} vs. collision energy

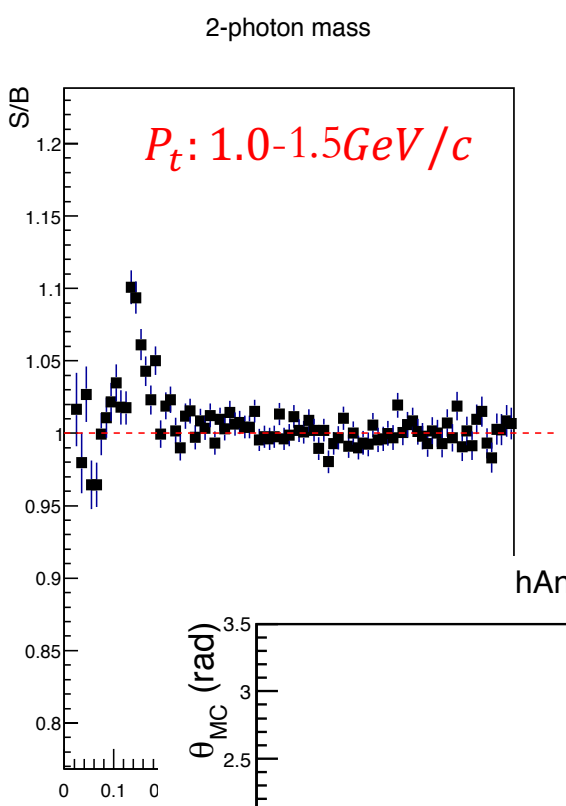


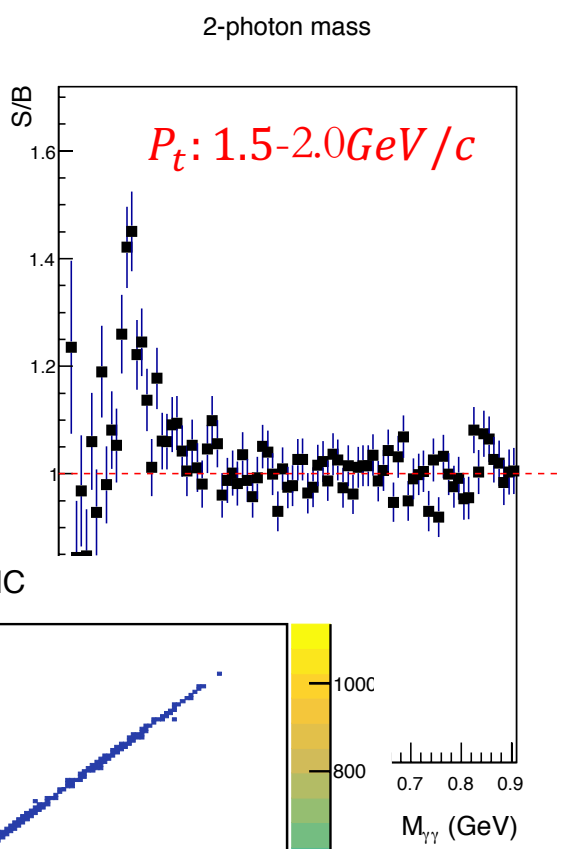
J. Phys.: Conf. Ser. 1070 (2018) 012012

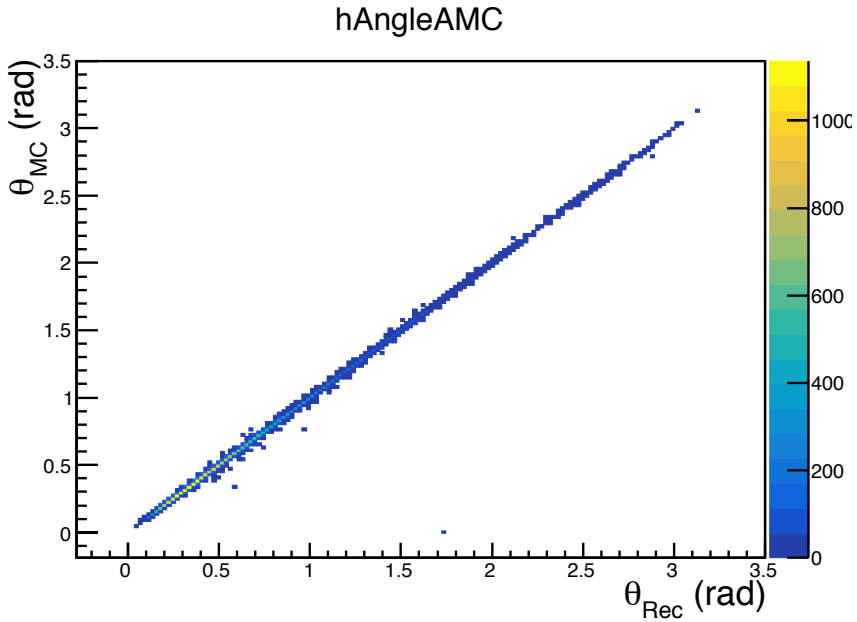
- **UrQmd** $Au + Au$
- $\sqrt{s} = 11GeV$, b_{max}=-3







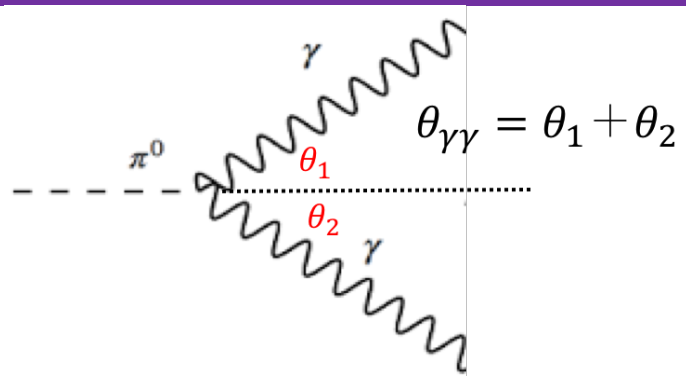




- Yield of π_0 get larger with P_t increases
- The background is large for low $M_{\gamma\gamma}$, especially for low P_t

π^0 Reconstruction

- **UrQmd** $Au + Au$
- $\sqrt{s} = 11GeV$, **b<3fm**



$\theta_{\gamma\gamma} = \theta_1 + \theta_2$

Photon selection

$E_\gamma > 40MeV$

$\chi^2 \leq 15.0$ E/p ≤ 0.8

Invariant mass reconstruction

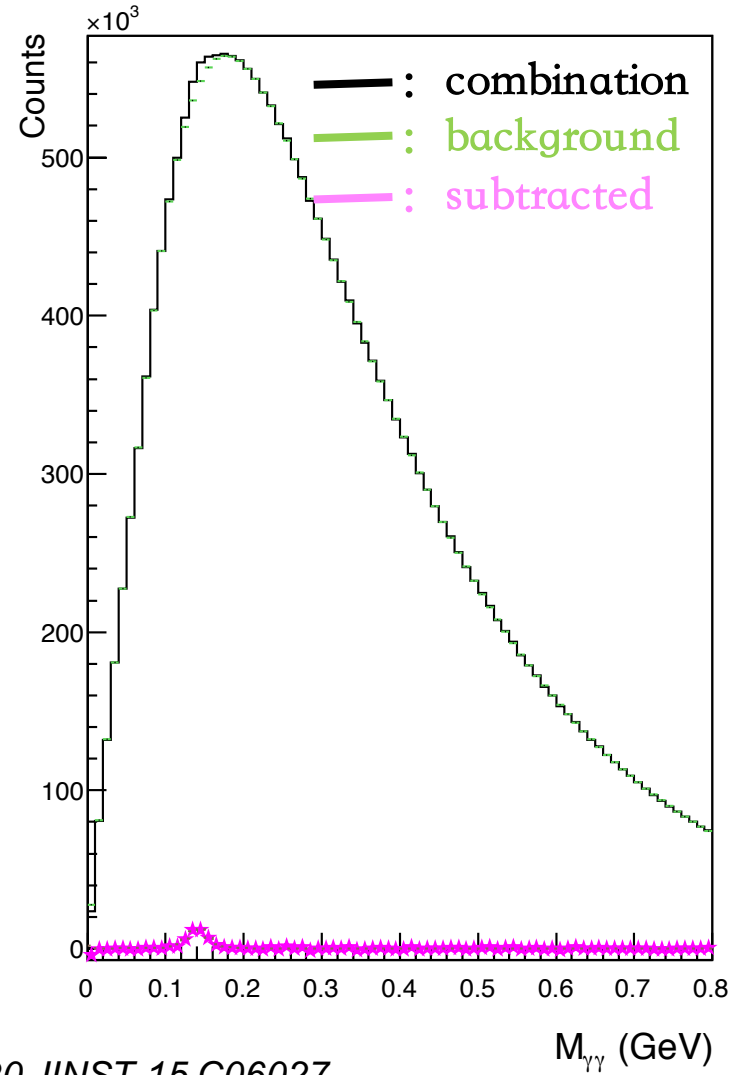
$$M_{\gamma\gamma} = \sqrt{2E_{\gamma 1}E_{\gamma 2}(1 - \cos(\theta_{12}))}$$

Subtract the Background

Event mixed method and scaling

The method of pi0 reconstruction

2-photon mass



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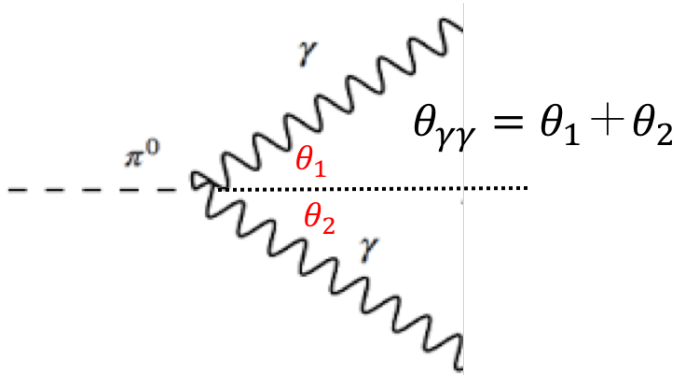
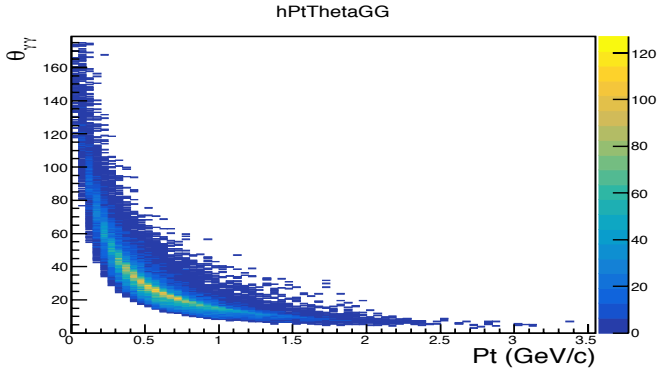
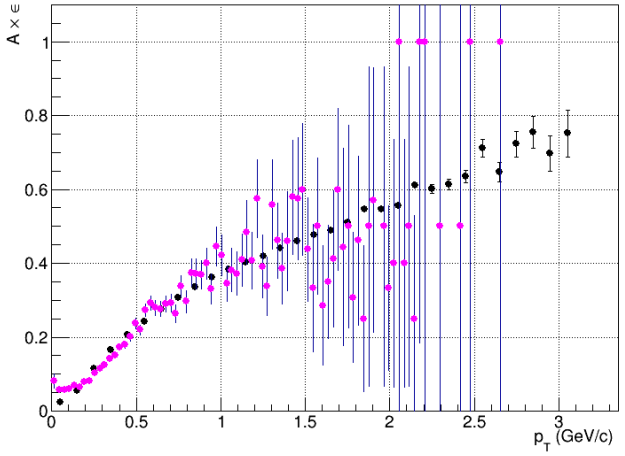
π^0 Reconstruction

- **UrQmd** $Au + Au$
- $\sqrt{s} = 11GeV$, **b<3fm**

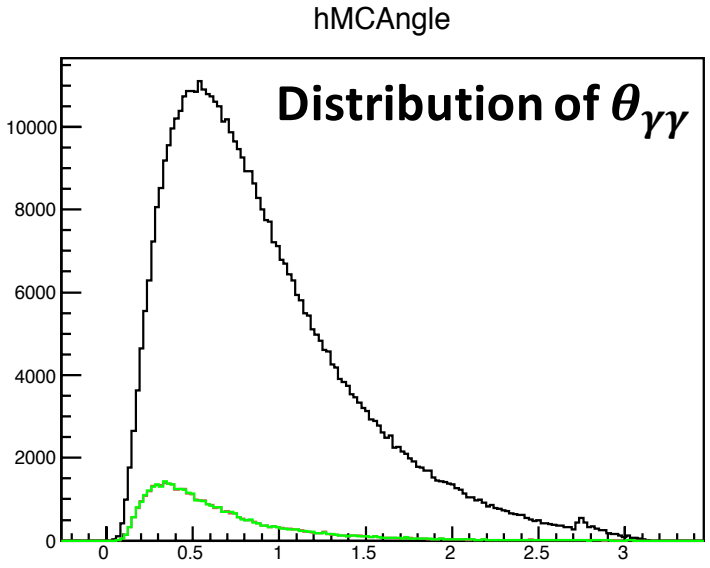


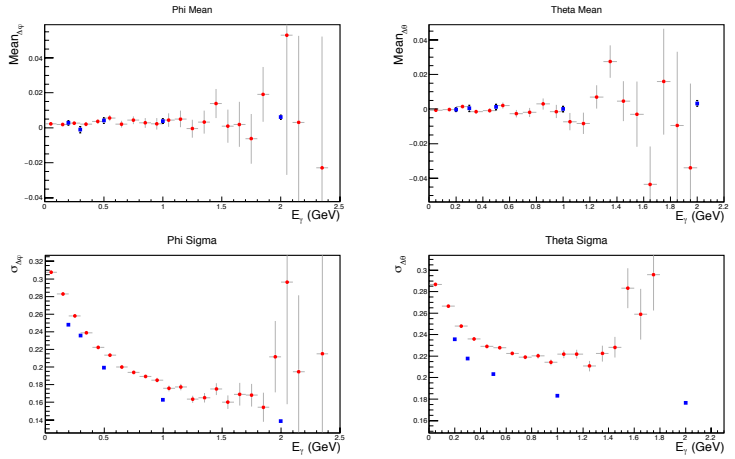
- The angle of two photons $\theta_{\gamma\gamma}$ decreases with higher Pt
- $\theta_{\gamma\gamma}$ distributed at a peak of about 30°





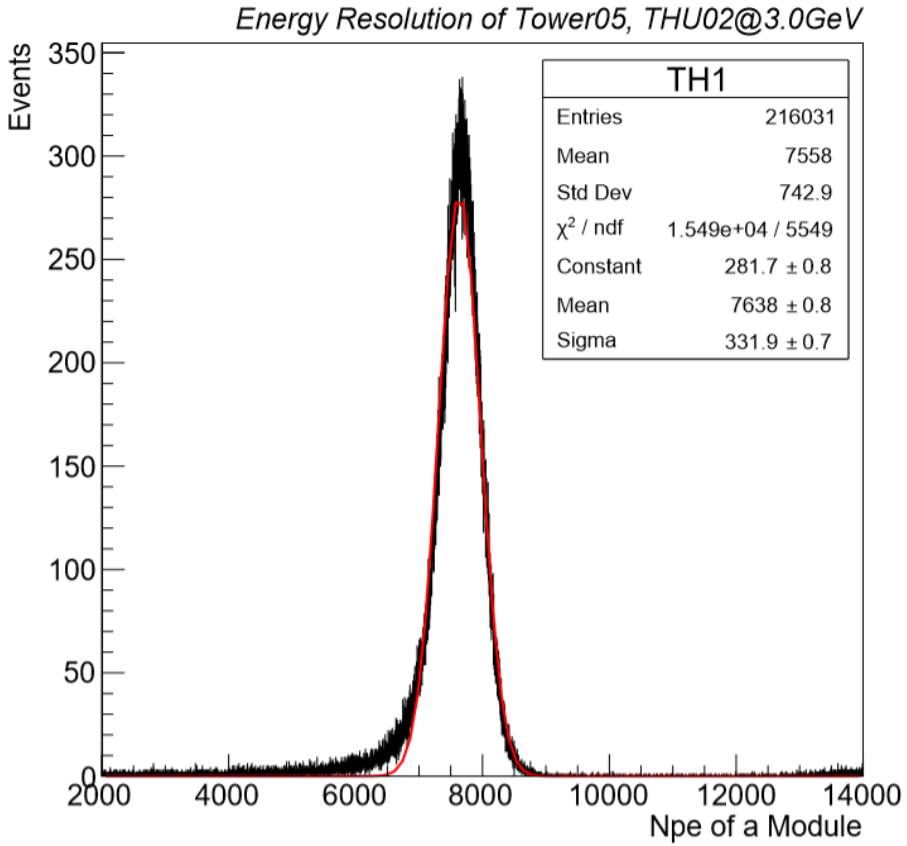
Distribution of $\theta_{\gamma\gamma}$ with Pt





Energy Resolution

- **Obtained from the peak through Gaussian fit.**
- **Got the *sigma* for different energy.**



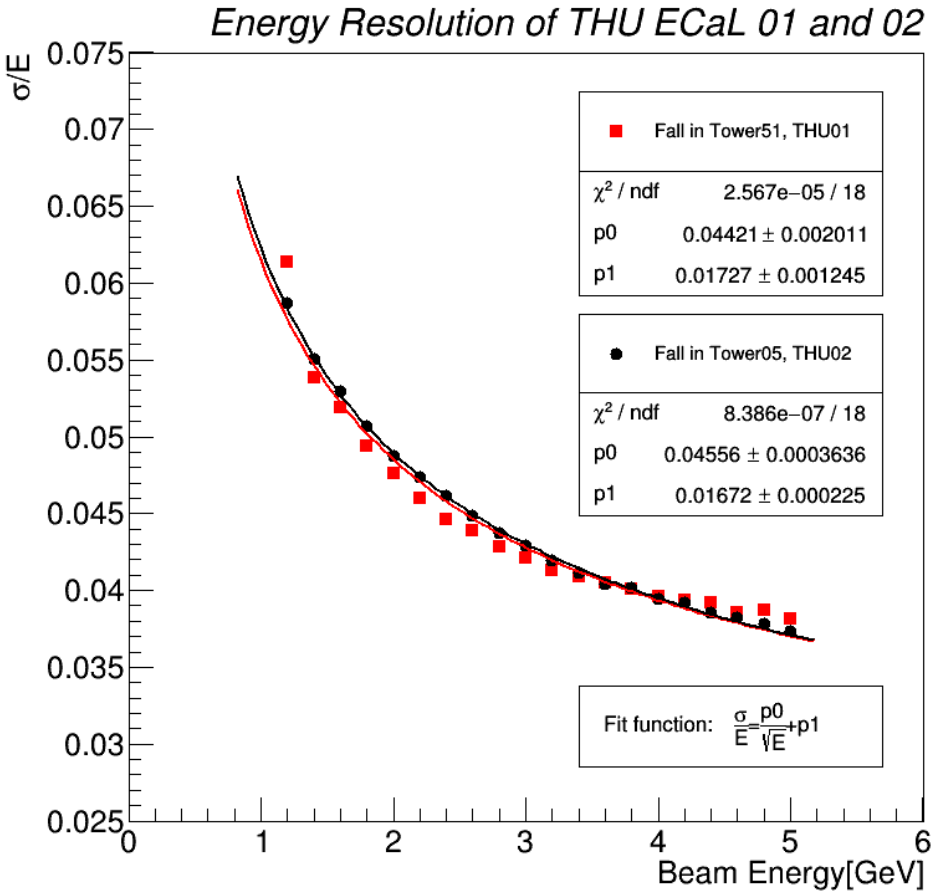
$$\frac{Sigma}{E} = \frac{p_0}{\sqrt{E}} \oplus p_1$$

4.42% < 5%

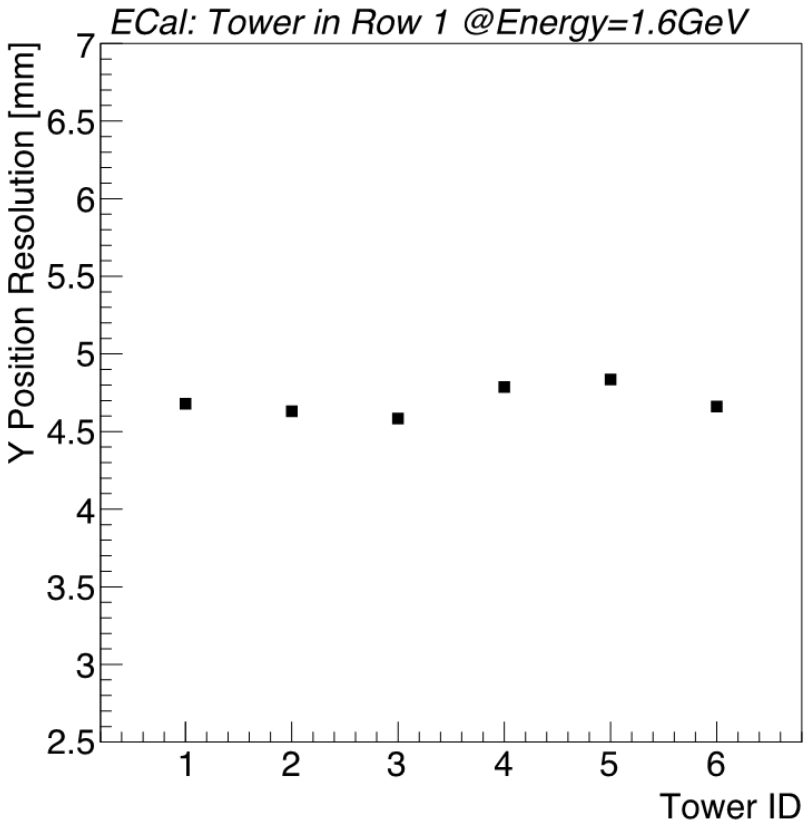
4.56% < 5%

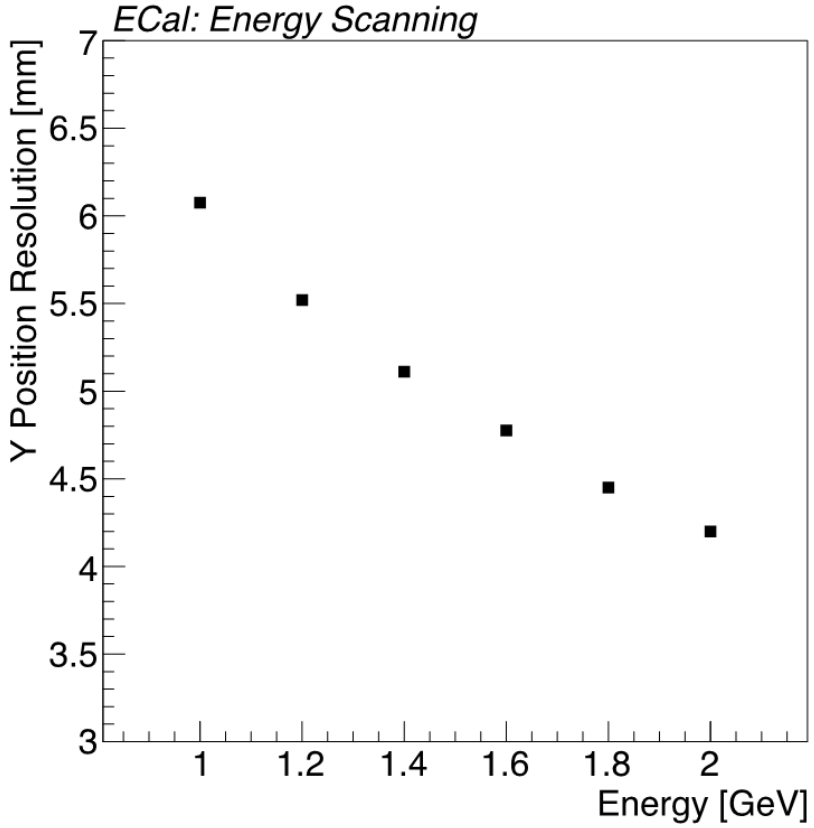
@1GeV

- **Energy resolution is 4.4% and 4.6%.**
- **Show good consistency and fitting.**



Spatial Resolution



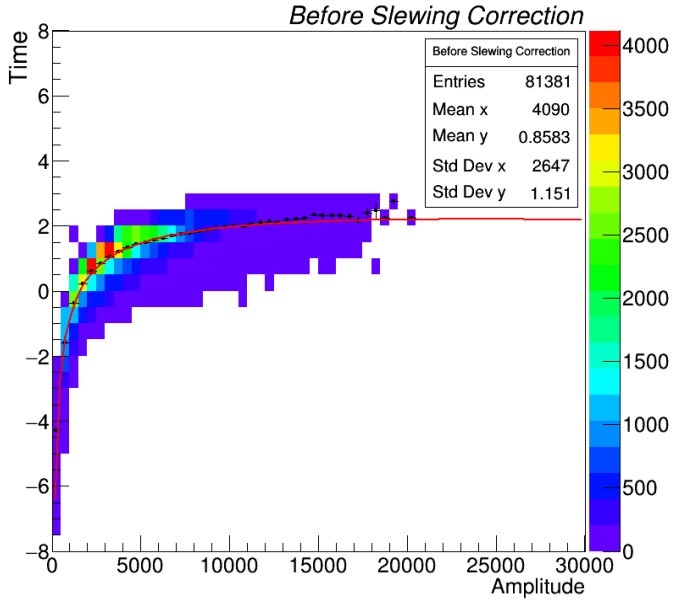


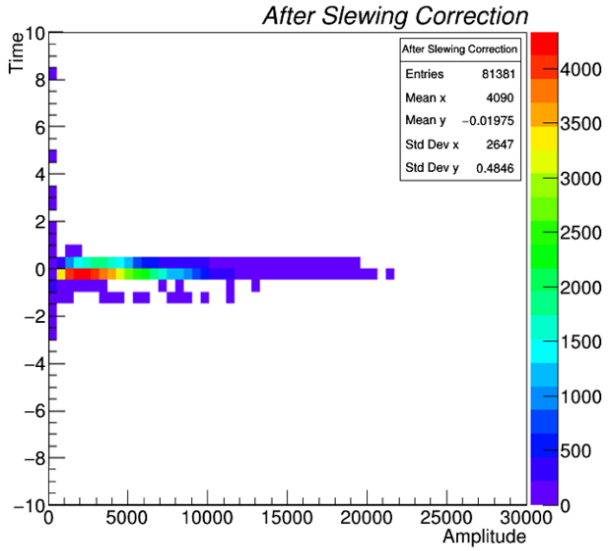
- The spatial resolution is around 4.6 mm @1.6GeV
- The resolution gets improved with energy.

More details can be found here: https://arxiv.org/abs/1902.03629

By using Center of Gravity (COG) algorithm

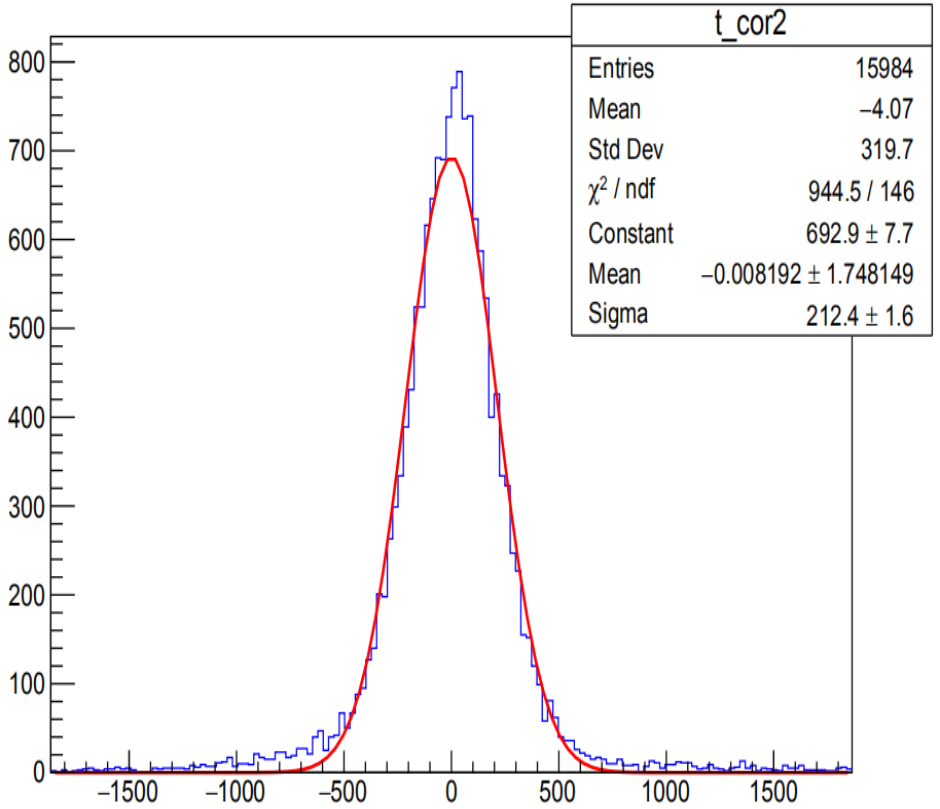
Time Resolution





$$t = a + \frac{p_1}{\sqrt{a}} + \frac{p_2}{a} + p_3 a$$

Correction function



- After the slewing correction, the final time resolution: 212.4ps.

212.4ps < 500ps