Performance for centrality determination and anisotropic flow measurement of the Forward Hadron Calorimeter (FHCal) for MPD detector at NICA

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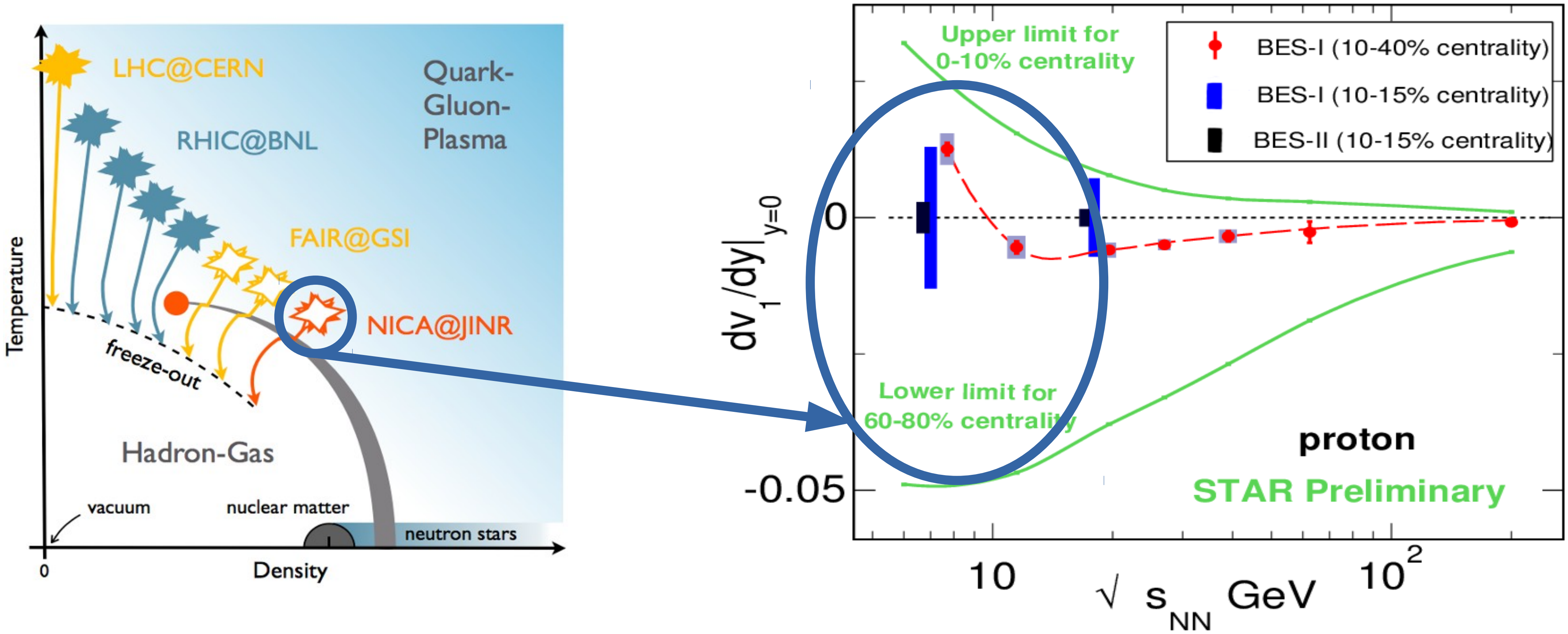
MPD DAC meeting, JINR,
Dubna, Russia
20.06.2018

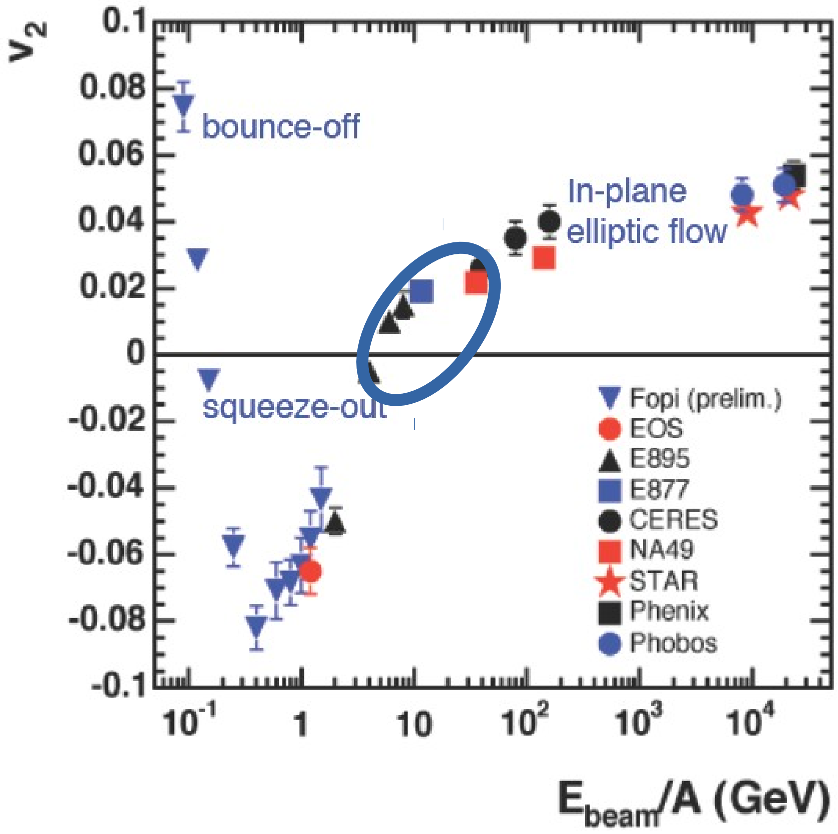
Directed flow at NICA energies

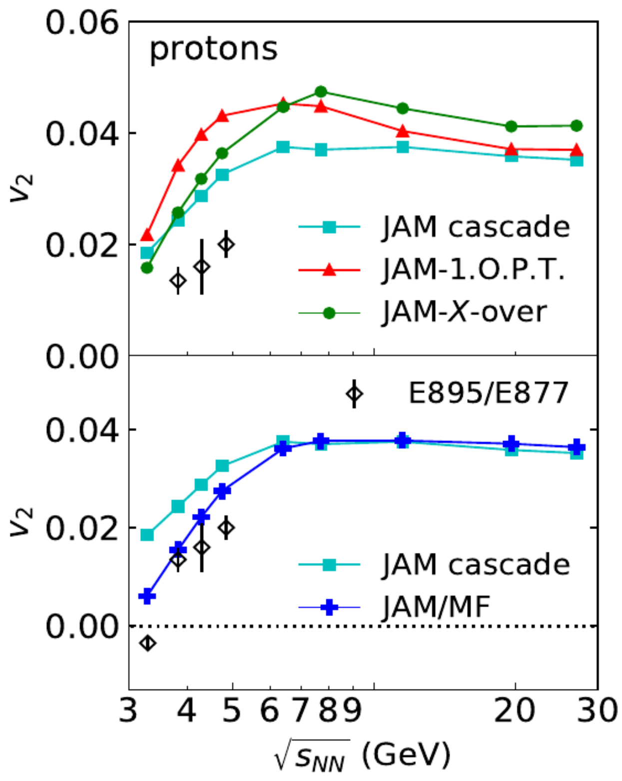


Strong centrality dependence of directed flow of protons is expected at NICA energy range based on STAR preliminary data

Non-monotonic dv_1/dy behavior can signal the phase transition

Elliptic flow at NICA energies

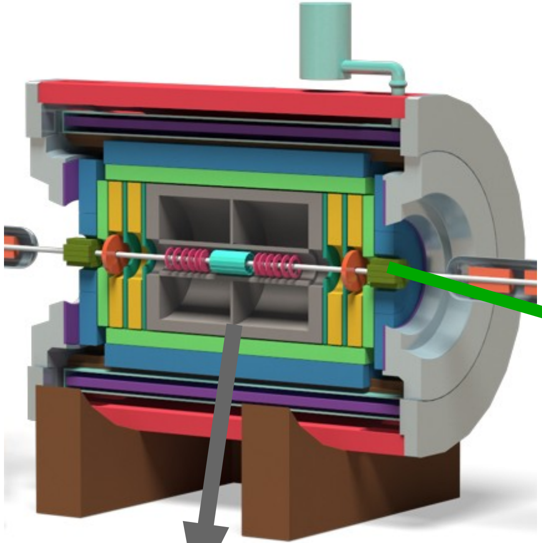




Nara, Yasushi et al. Eur.Phys.J. A54 (2018)

At Nuclotron-NICA energy range elliptic flow as a function of energy changes sign
Both directed and elliptic flow can signal a first order phase transition

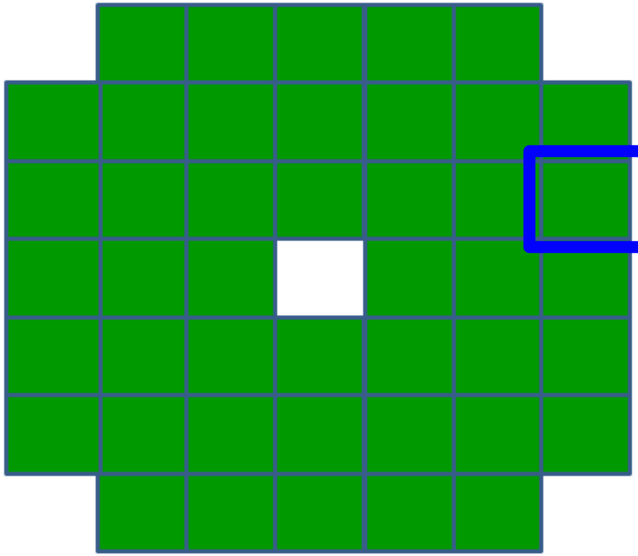
Multi-Purpose Detector (MPD) at NICA



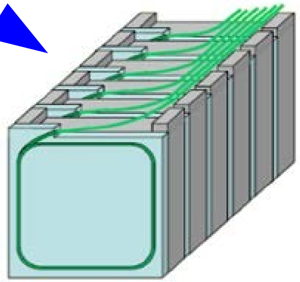
Forward Hadron Calorimeter (FHCal)

2 sub detectors located at z=+3.2 meters from interaction point

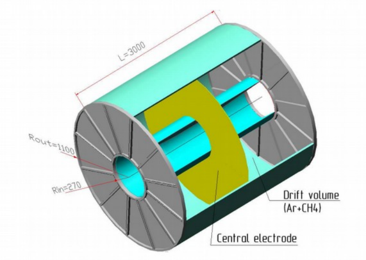
Transverse segmentation:
44 modules



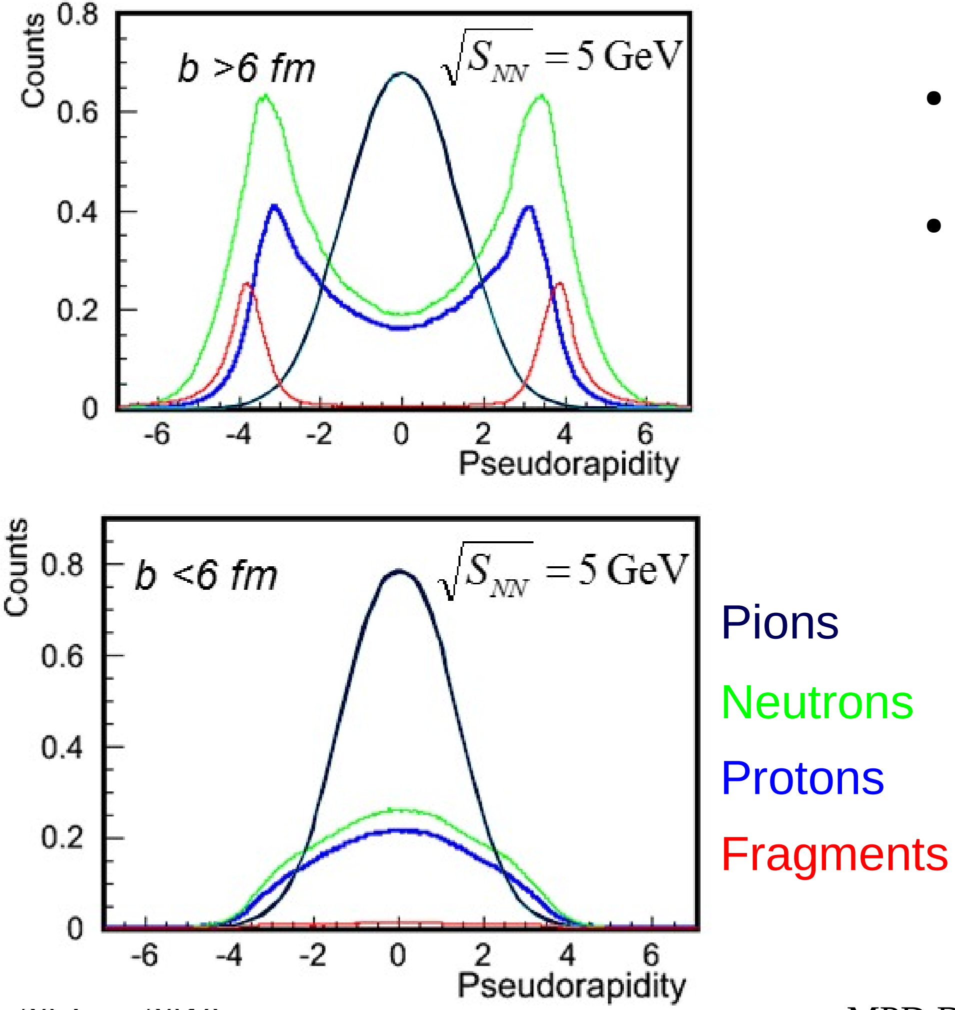
Longitudinal segmentation:
7 sections of lead/scintillator
(15 × 15 x 106 cm)



Time projection chamber (TPC)
Inner radius 27 cm, outer radius 140 cm, length 340 cm.



FHCal and TPC acceptance



- **TPC** - charged particles at midrapidity (participants)
- **FHCal** - hadrons at forward rapidity (spectators + participants)

$-5<\eta<-2$	$-1.2<\eta<1.2$	$2<\eta<5$
FHCal	TPC $0.2<p_T<2$ GeV/c	FHCal

Setup, event and track selection

UrQMD
LA-QGSM

→ GEANT3
GEANT4

→ Reconstruction

→ Flow analysis

- Au+Au, $N_{events} = 4 \cdot 10^6$
- $\sqrt{s_{NN}}$ = 5 GeV
- $\sqrt{s_{NN}}$ =11 GeV

- TPC
- FHCal
- TOF
- ...

Event classification:
- Track multiplicity
- FHCal energy

Track selection:
- Primary tracks (2σ DCA cut)
- $N_{TPC\ hits} > 32$
- $0.2 < p_T < 2$ GeV/c
- $|\eta| < 1.5$
- PID based on TPC+TOF (MpdPid)

MPDRoot, April 2018

http://mpd.jinr.ru/wp-content/uploads/2018/05/MPD_TDR_FHCal_28_05_2018.pdf

Setup, event and track selection

UrQMD
LA-QGSM
→ GEANT3
GEANT4
→ Reconstruction → Flow analysis

- Au+Au, **$N_{events} = 4 \cdot 10^6$**
- $\sqrt{s_{NN}}$ = 5 GeV
- $\sqrt{s_{NN}}$ =11 GeV

- TPC
- FHCal
- TOF
- ...

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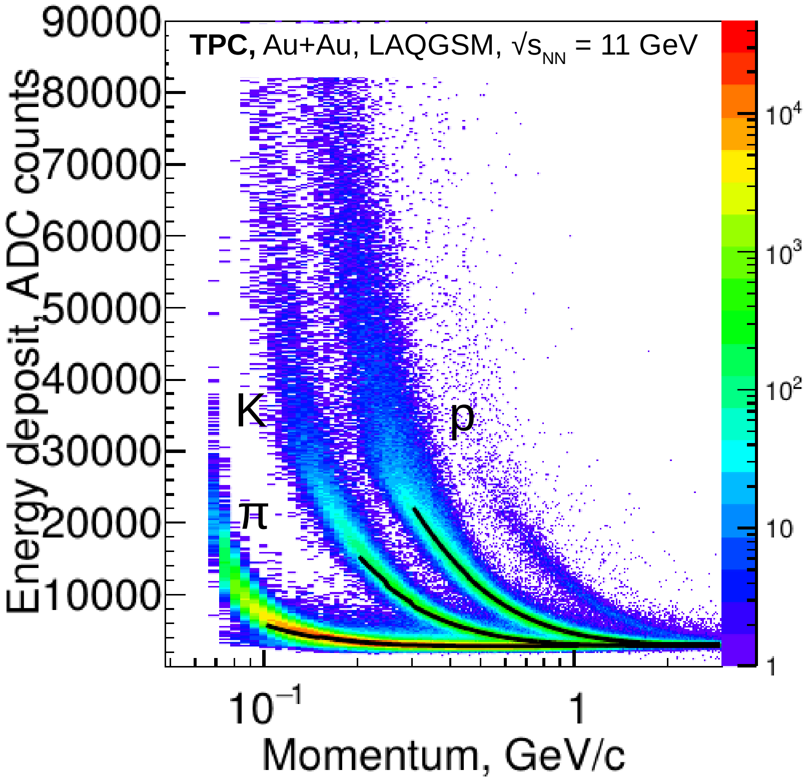
- **PID based on TPC+TOF (MpdPid)**

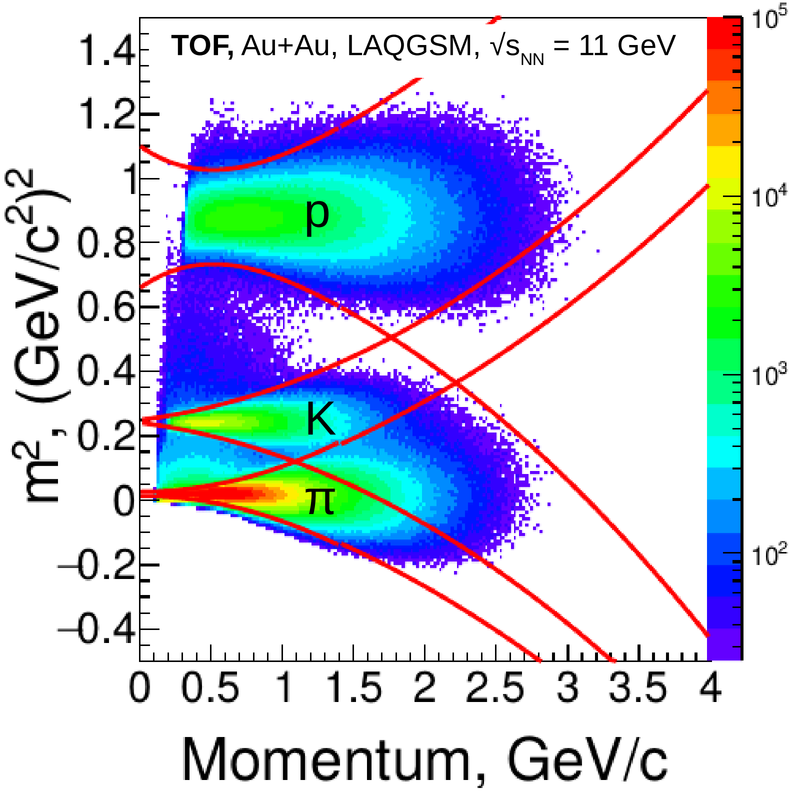
MPDRoot, April 2018

http://mpd.jinr.ru/wp-content/uploads/2018/05/MPD_TDR_FHCal_28_05_2018.pdf

Combined particle identification based on TPC + TOF



Low momentum:
dE/dx from TPC



High momentum:
m^2 estimated from TOF signal

Anisotropic flow performance

Event plane method

- Reaction plane is not known experimentally
- Finite number of detected particles leads to limited resolution of the event plane orientation
- Azimuthal angle of the event plane can be estimated from azimuthal angles of emitted particles:

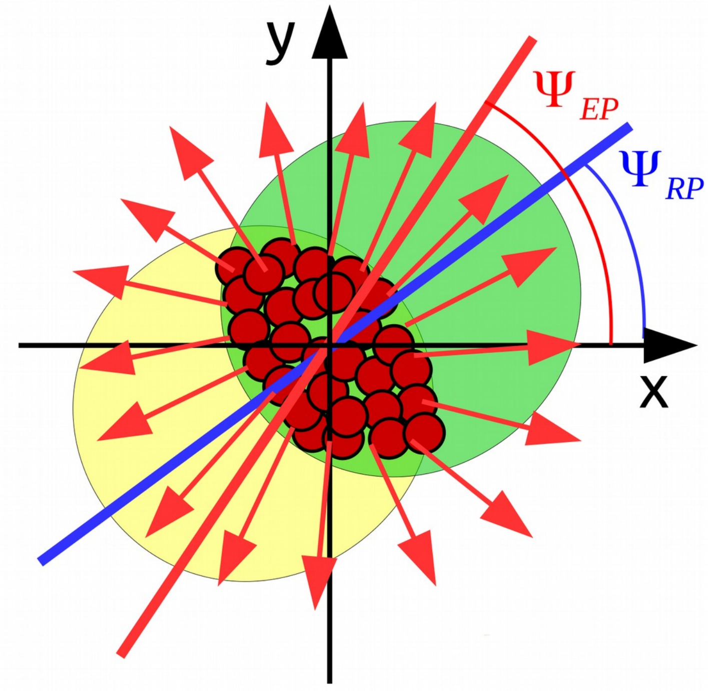
$$\vec{Q}_n = \{Q_{n,X}, Q_{n,Y}\}$$

$$Q_{n,X} = \sum_i \omega_i \cos(n\varphi_i) = |\vec{Q}| \cos(n\Psi_{n,EP})$$

$$Q_{n,Y} = \sum_i \omega_i \sin(n\varphi_i) = |\vec{Q}| \sin(n\Psi_{n,EP})$$

$$i = 0 \ldots N_{particles}$$

$$\Psi_{n,EP} = \frac{1}{n} \tan^{-1}\left(\frac{Q_{n,Y}}{Q_{n,X}}\right)$$



$$v_n = \frac{\langle \cos(n(\varphi - \Psi_{n,EP})) \rangle}{R_{n,EP}}$$

$$R_{n,EP} = \langle \cos(n(\Psi_{n,EP} - \Psi_{RP})) \rangle$$

$R_{n,EP}$ − Resolution correctioin factor

Resolution correction factor

$$v_n = \frac{\langle \cos(n(\varphi - \Psi_{n,EP}))\rangle}{R_{n,EP}}$$

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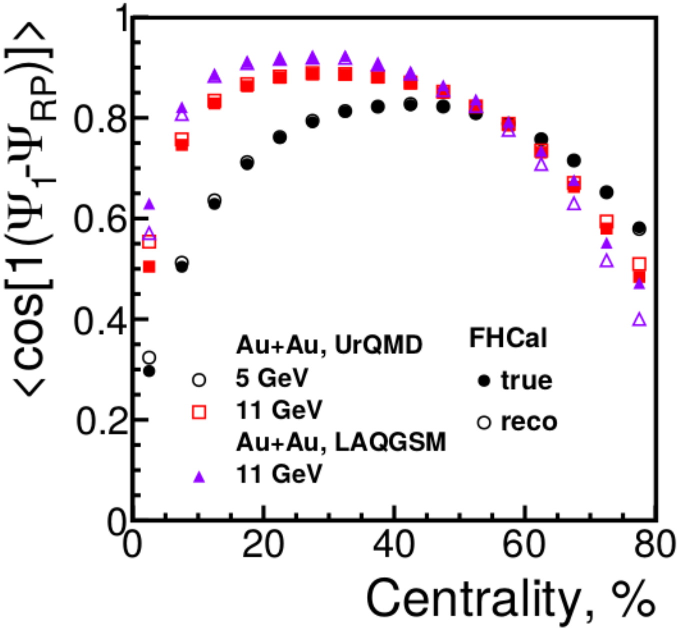
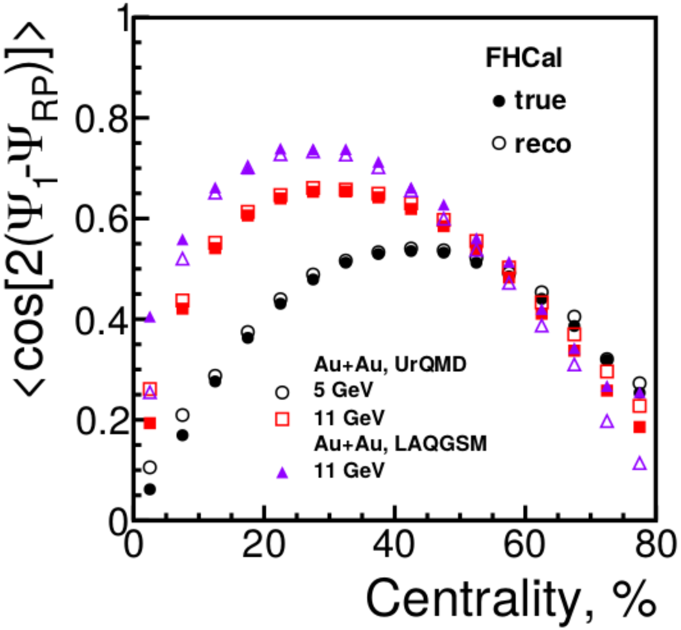
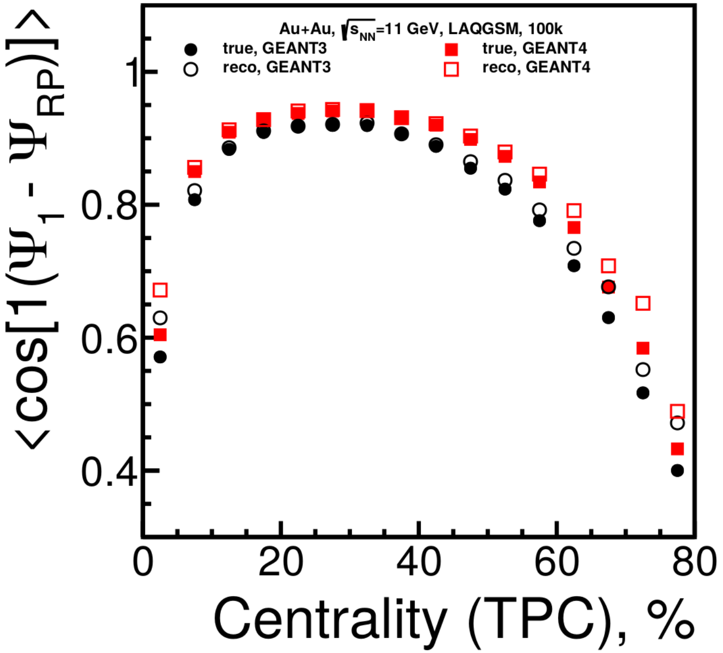
$R_{n,EP}$ – Resolution correctioin factor

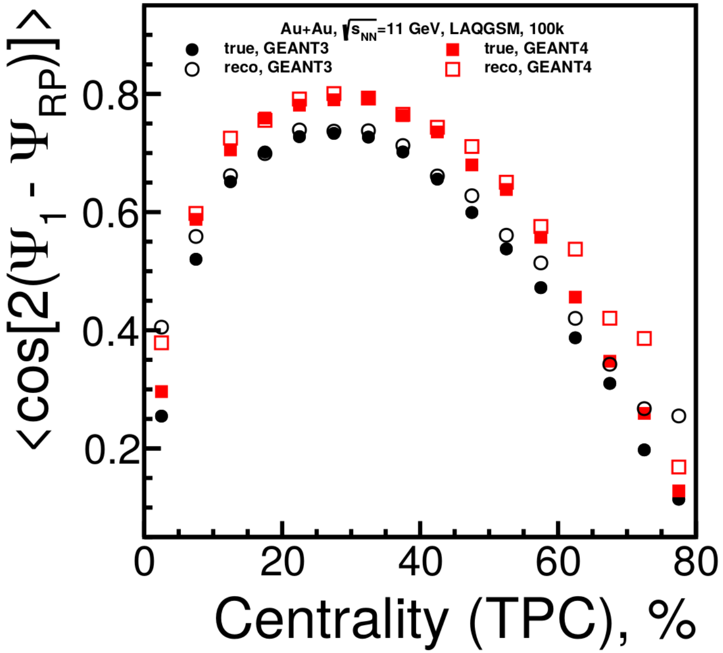




Good performance in the centrality range 0-80% for NICA collision energy range

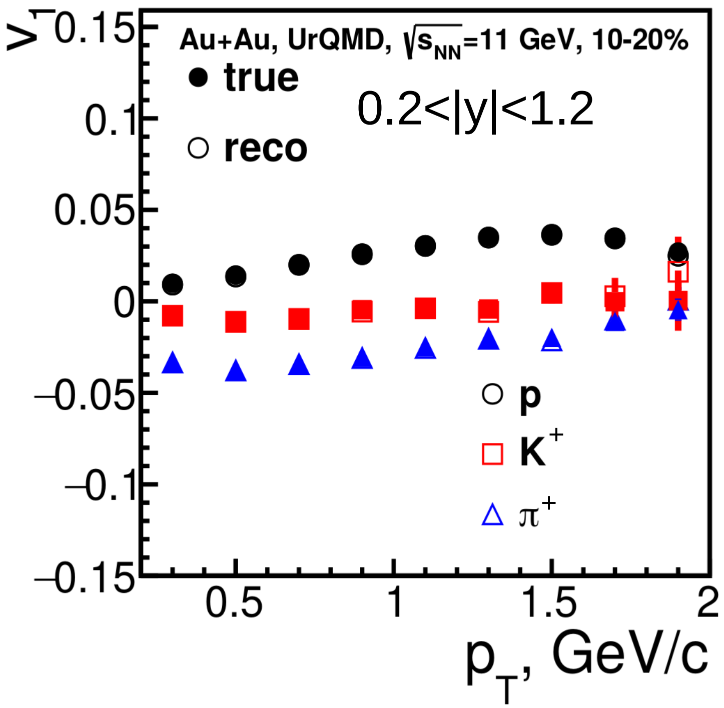
Resolution correction factor: GEANT3 vs GEANT4 comparison

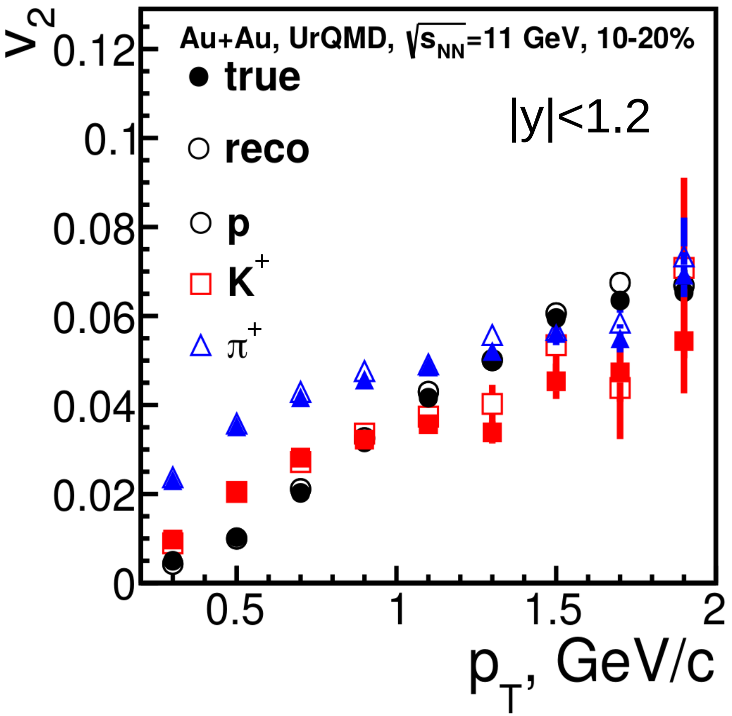




GEANT4 has more realistic hadronic shower simulation

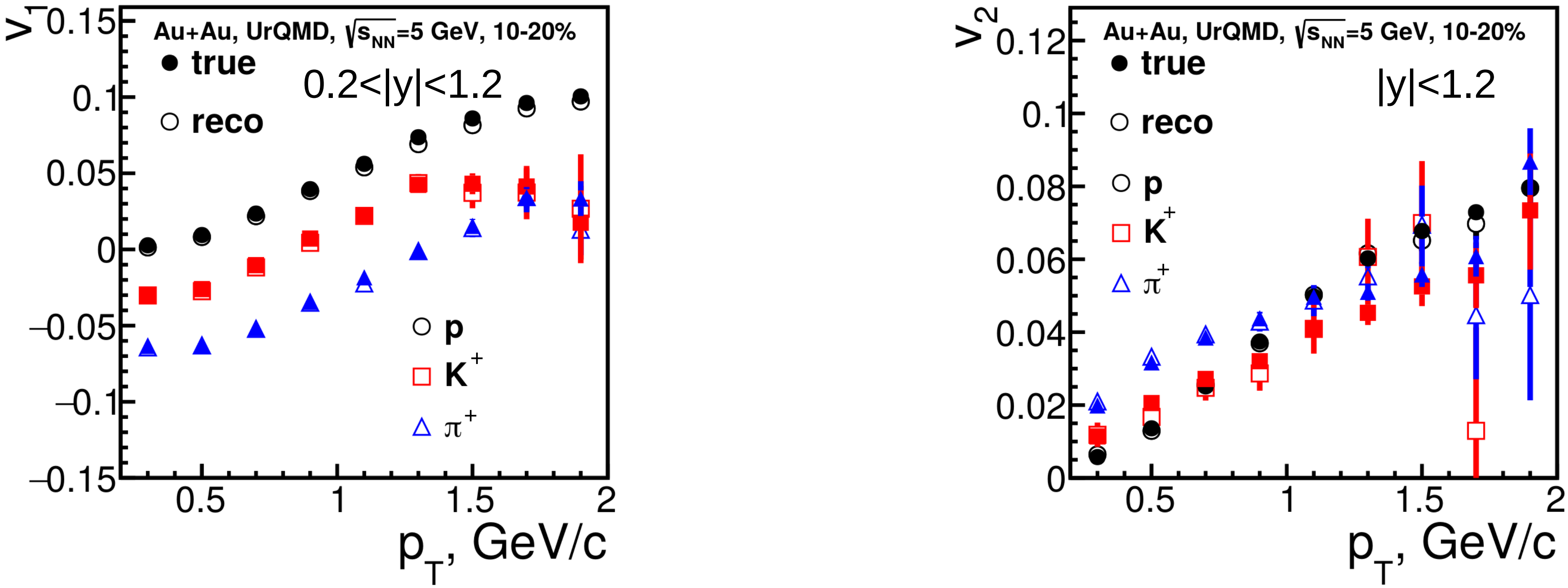
p_T dependence of directed and elliptic flow Au+Au, $\sqrt{s_{NN}}$ = 11 GeV





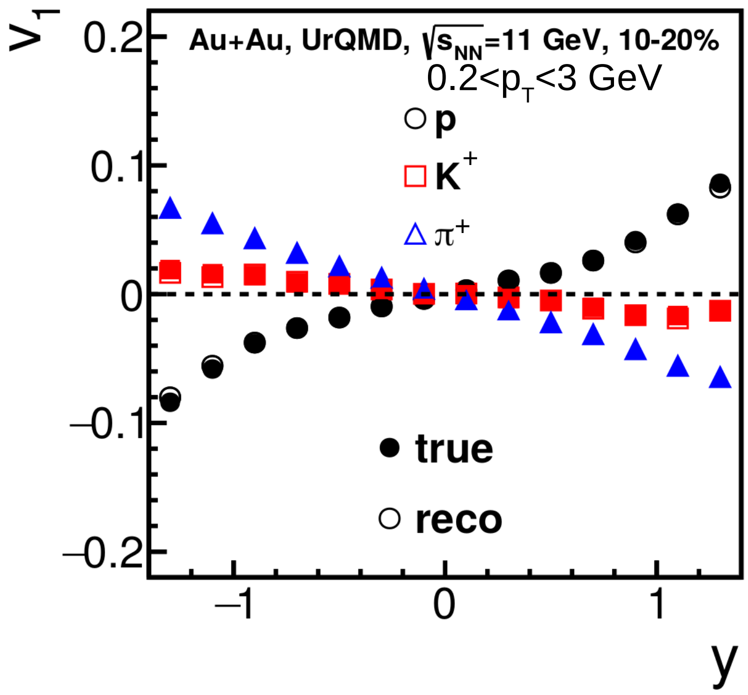
Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

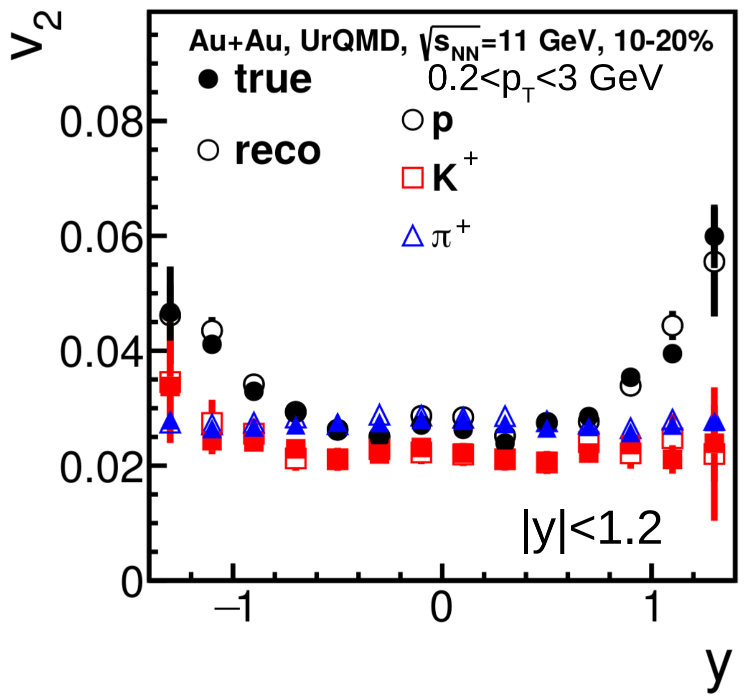
p_T dependence of directed and elliptic flow Au+Au, $\sqrt{s_{NN}}$ = 5 GeV



Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

y dependence of directed and elliptic flow Au+Au, $\sqrt{s_{NN}}$ = 11 GeV





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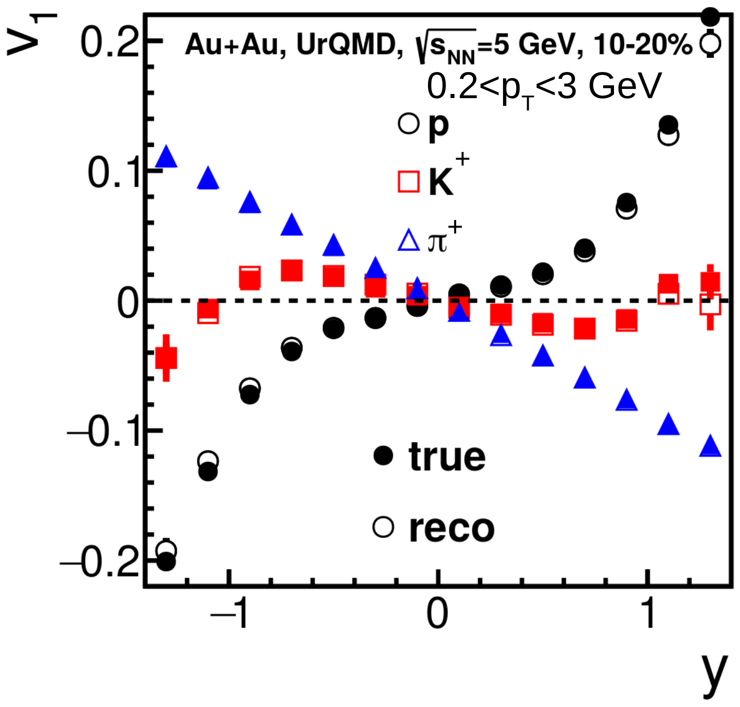
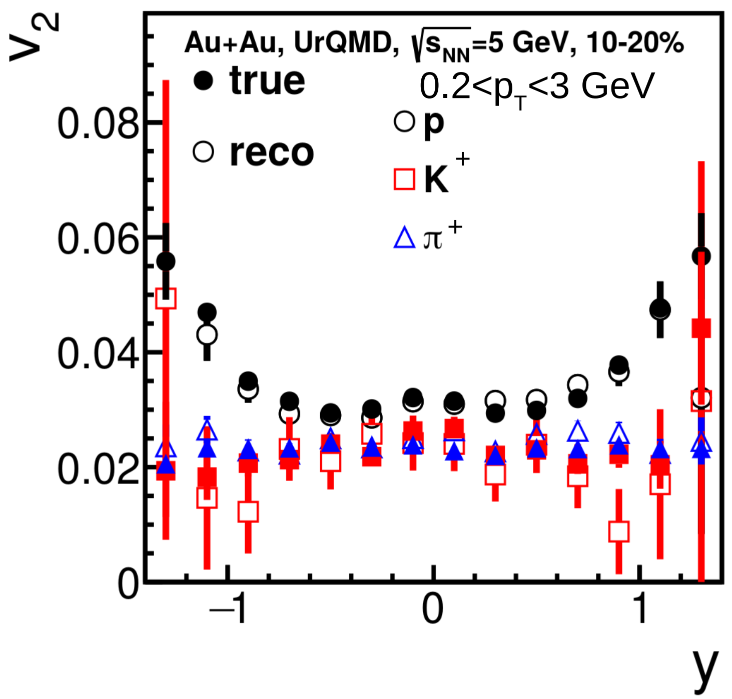




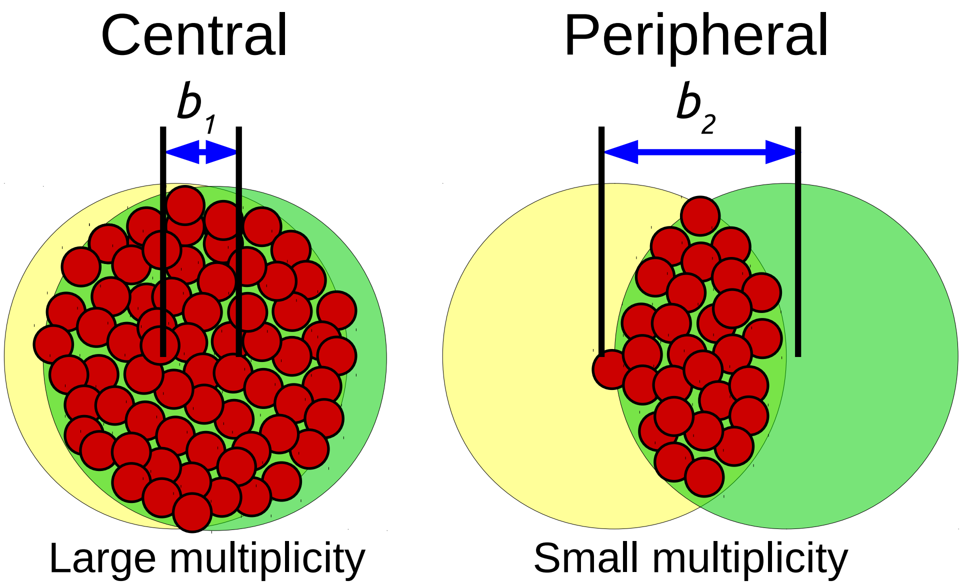
Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation
Results for 40-50% centrality range are stored in the backup slides

Anisotropic flow performance summary

- Full reconstruction chain was implemented:
  - Combined particle identification based on TPC and TOF
  - Full tracking: latest version of cluster finder
  - Realistic hadronic simulation (GEANT4)
- Reconstructed v_1,v_2 are in agreement with MC simulated values

Centrality determination

Centrality determination



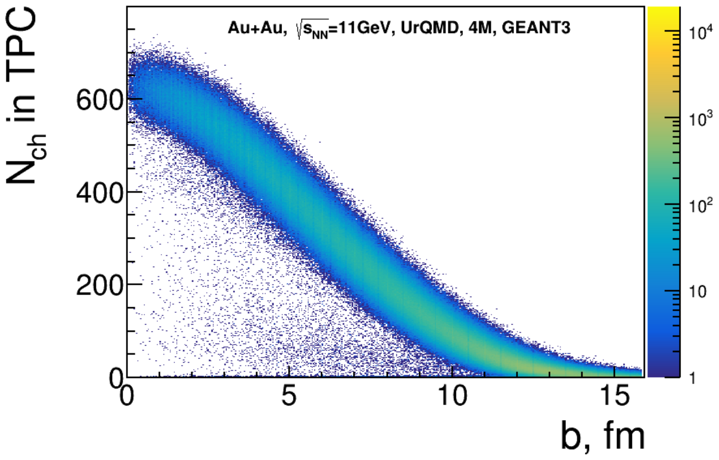
Impact parameter is not known

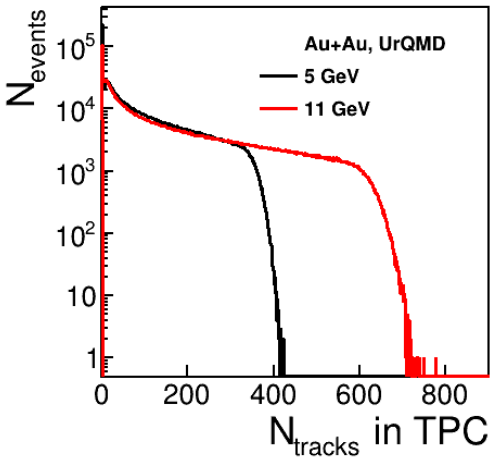
Experimentally:

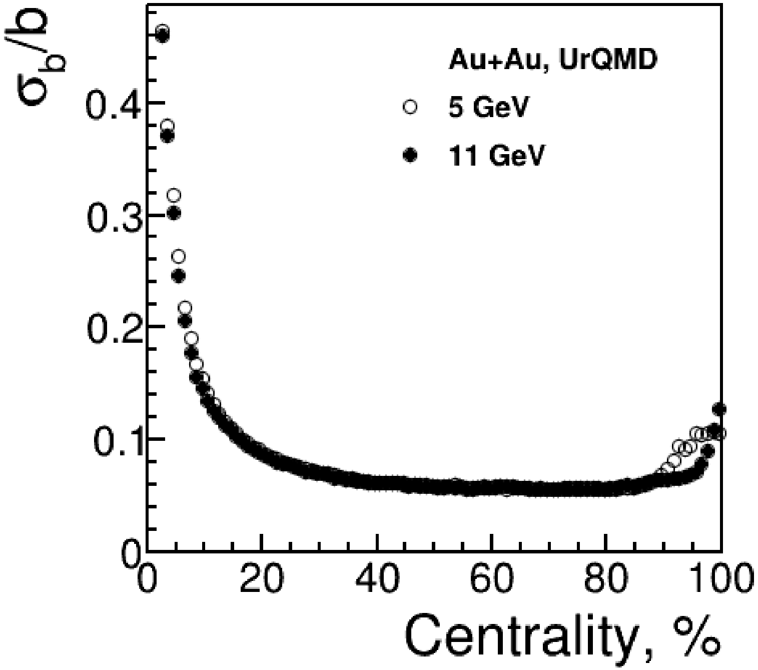
Centrality classes determined based on a fraction of a total number of nucleus-nucleus inelastic collisions

Multiplicity of the produced particles and/or spectator's energy can be used for centrality determination

Centrality estimation using multiplicity distribution in TPC



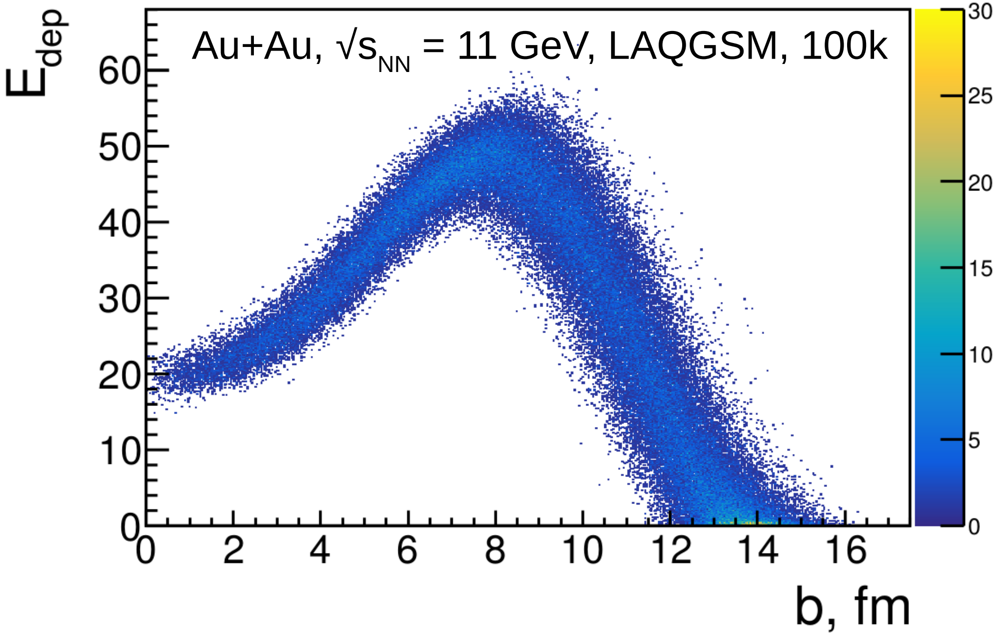


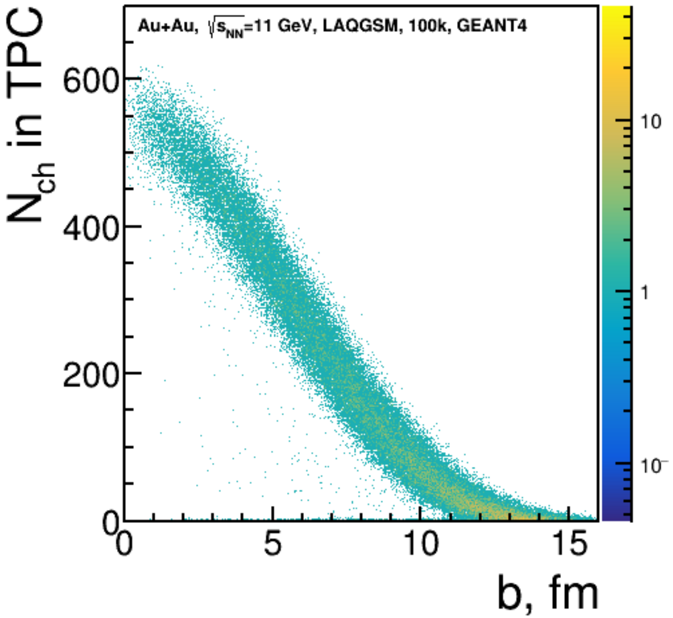


- Good correlation between *b* and TPC Multiplicity
- Events were grouped in centrality classes based on multiplicity distribution

Impact parameter resolution is 5-10% for ~10-80% centrality range

FHCal centrality performance

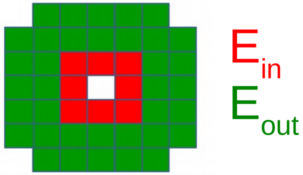




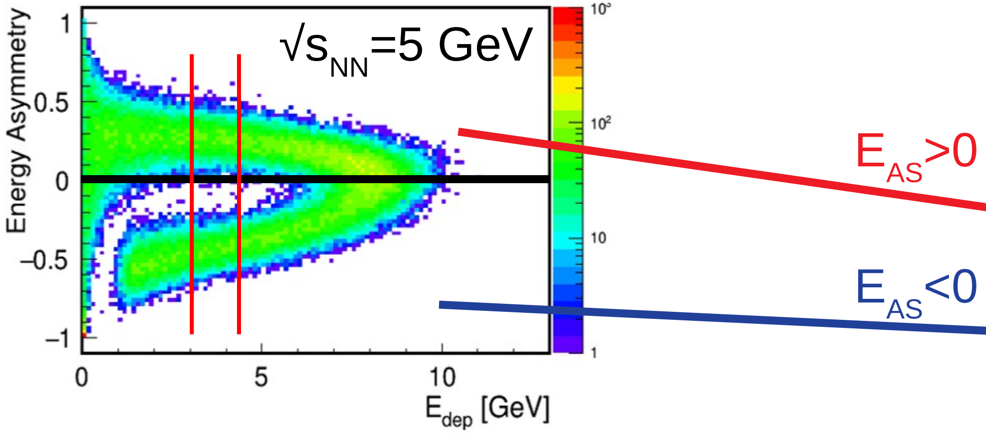
The fragment loss in the central area of the beam pipe limits range of the centrality determination using energy deposition in FHCal

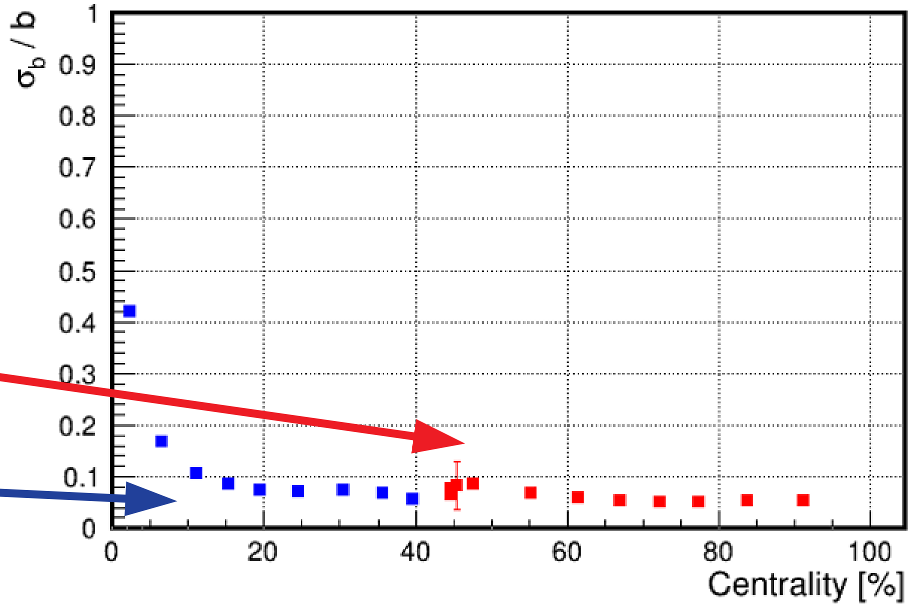
Centrality estimation using FHCal-subevent energy correlation

Energy asymmerty:



M. Golubeva et al. J.Phys.Conf.Ser. 798 (2017) no.1, 012074





Done by INR group

Resolution of FHCal centrality using energy asymmetry is ~6% in mid-central collisions

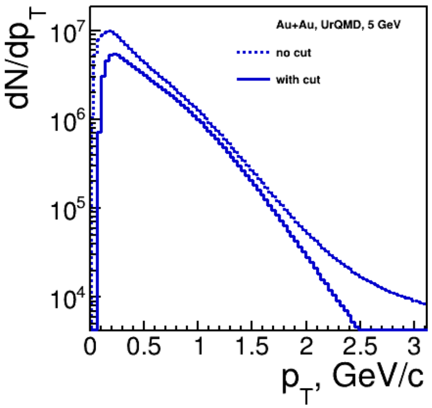
Centrality determination summary

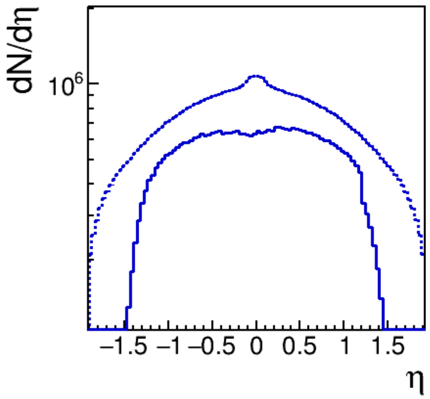
- Procedure for centrality determination using multiplicity from TPC or energy deposition from FHCal is developed:
  - Centrality classification using TPC allows for impact parameter resolution 5-10%
  - Centrality classification using FHCal allows for impact parameter resolution 5-10%
  - Combined centrality estimation based on both TPC and FHCal is under development

Thank you for your attention!

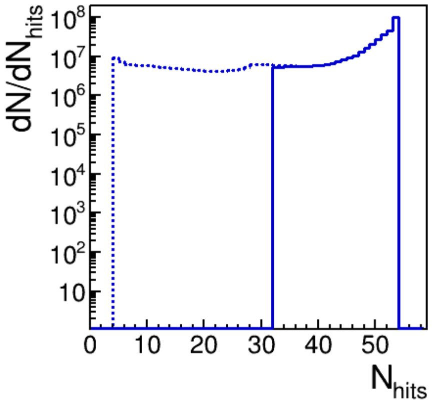
Backup

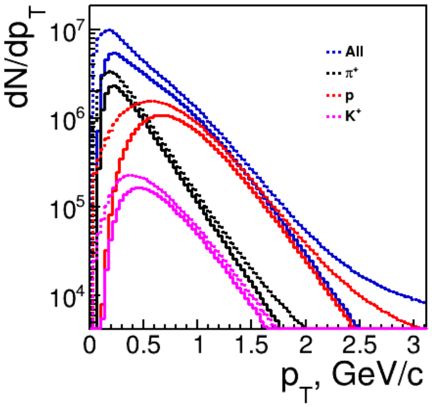
Track selection

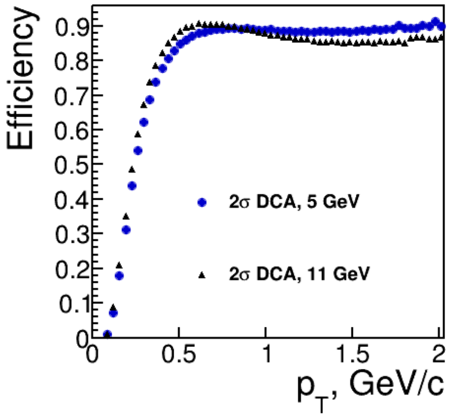




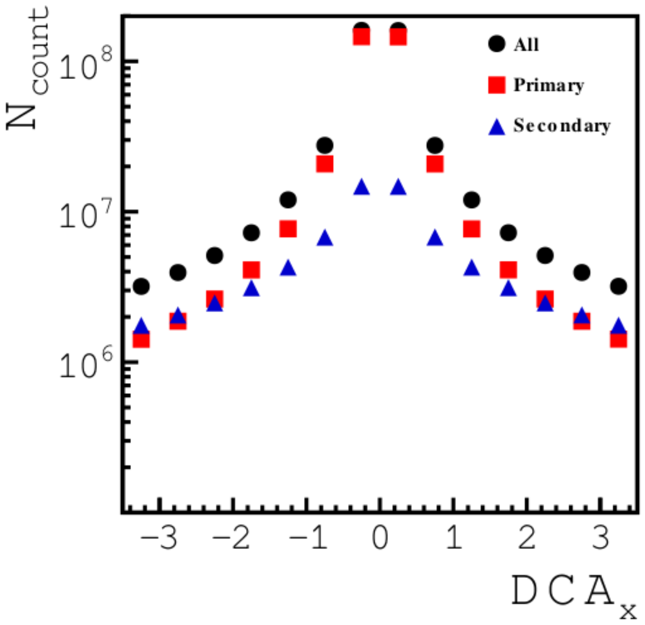
- $N_{\text{TPC hits}} > 32$
- $|p_T| < 3$
- $|\eta| < 1.5$
- PID based on TPC+TOF (MpdPid)

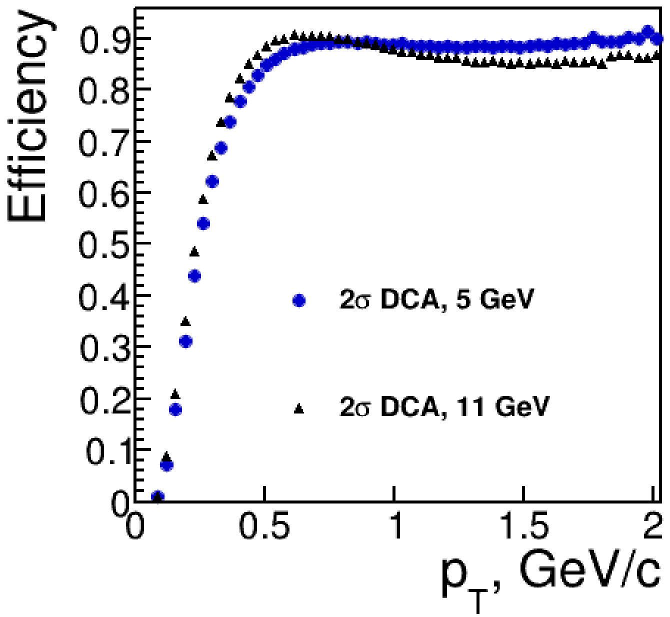






Primary track selection



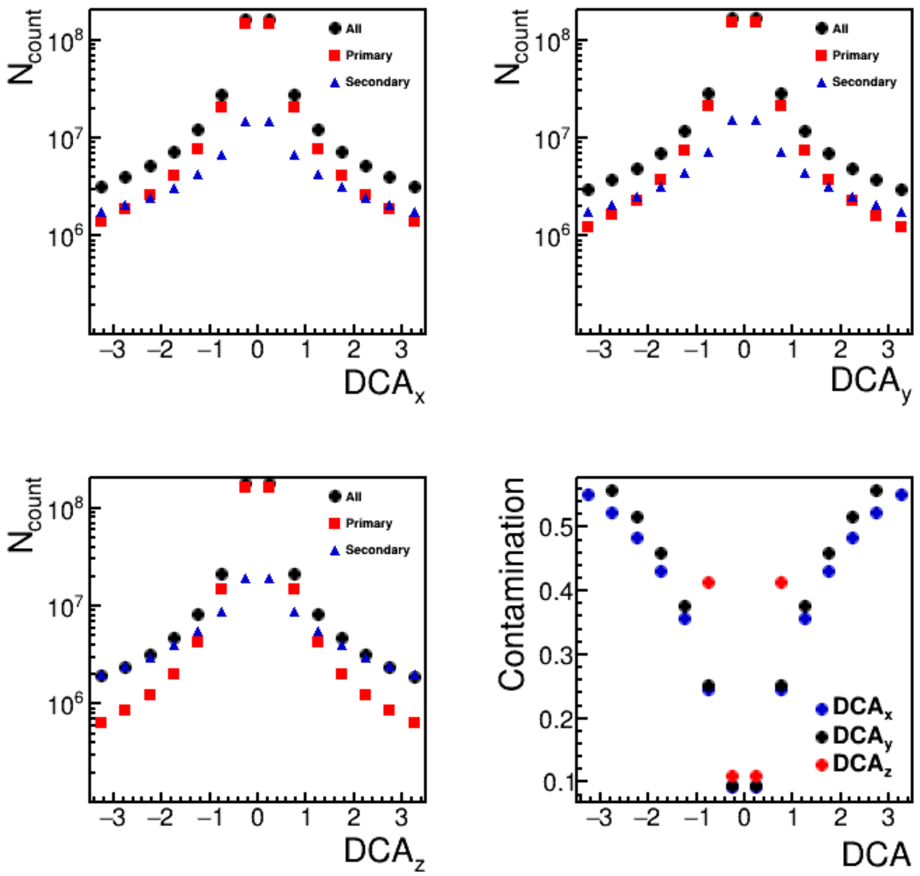


Distance of the closest approach (DCA) between TPC tracks and primary vertex

Tracks from secondary particles distort measured azimuthal flow coefficients

Introduced p_T and η dependent 2σ DCA cut from Gaussian fit with smoothened p_T dependence to second particle contamination

Primary track selection

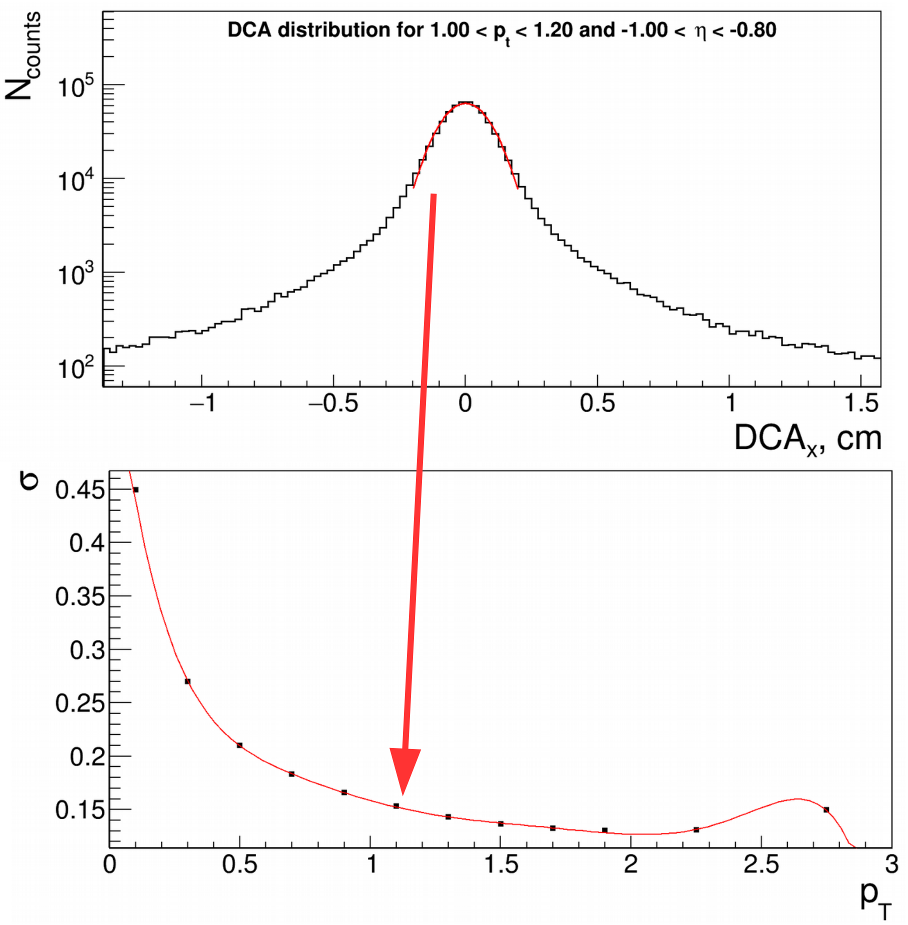


Distance of the closest approach (DCA) between TPC tracks and primary vertex

Tracks from secondary particles distort measured azimuthal flow coefficients

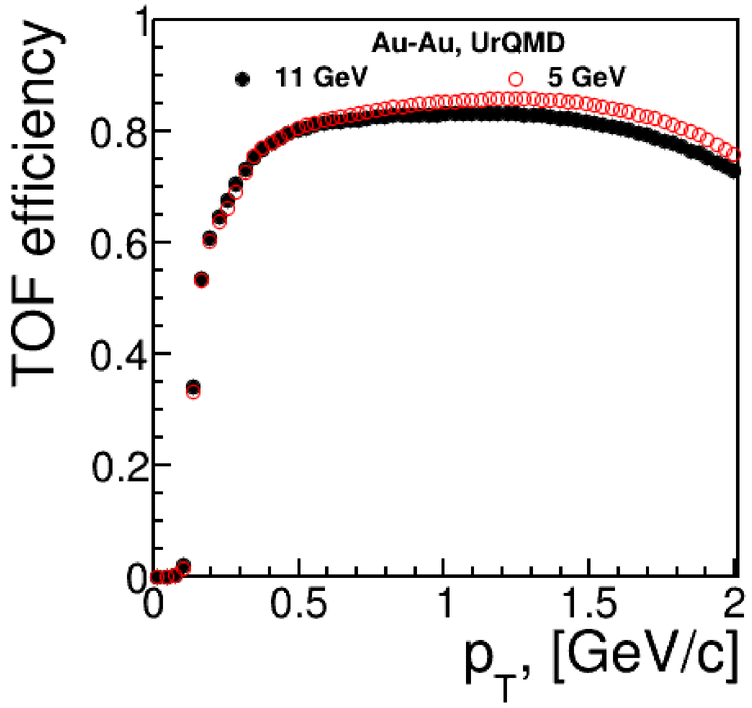
Introduced p T and η dependent 2σ DCA cut from Gaussian fit with smoothened p T dependence to reduce secondary contamination

Primary track selection: 2σ cut



- Peak of the DCA distribution was fitted using gaus fit;
- σ given from that fit as function of p_T was fitted using polynomial fit.
- Fitted polynomial function (*Pol*) was used for primary track selection: $|DCA|<2Pol(p_T)$.

PID implementation in the performance study

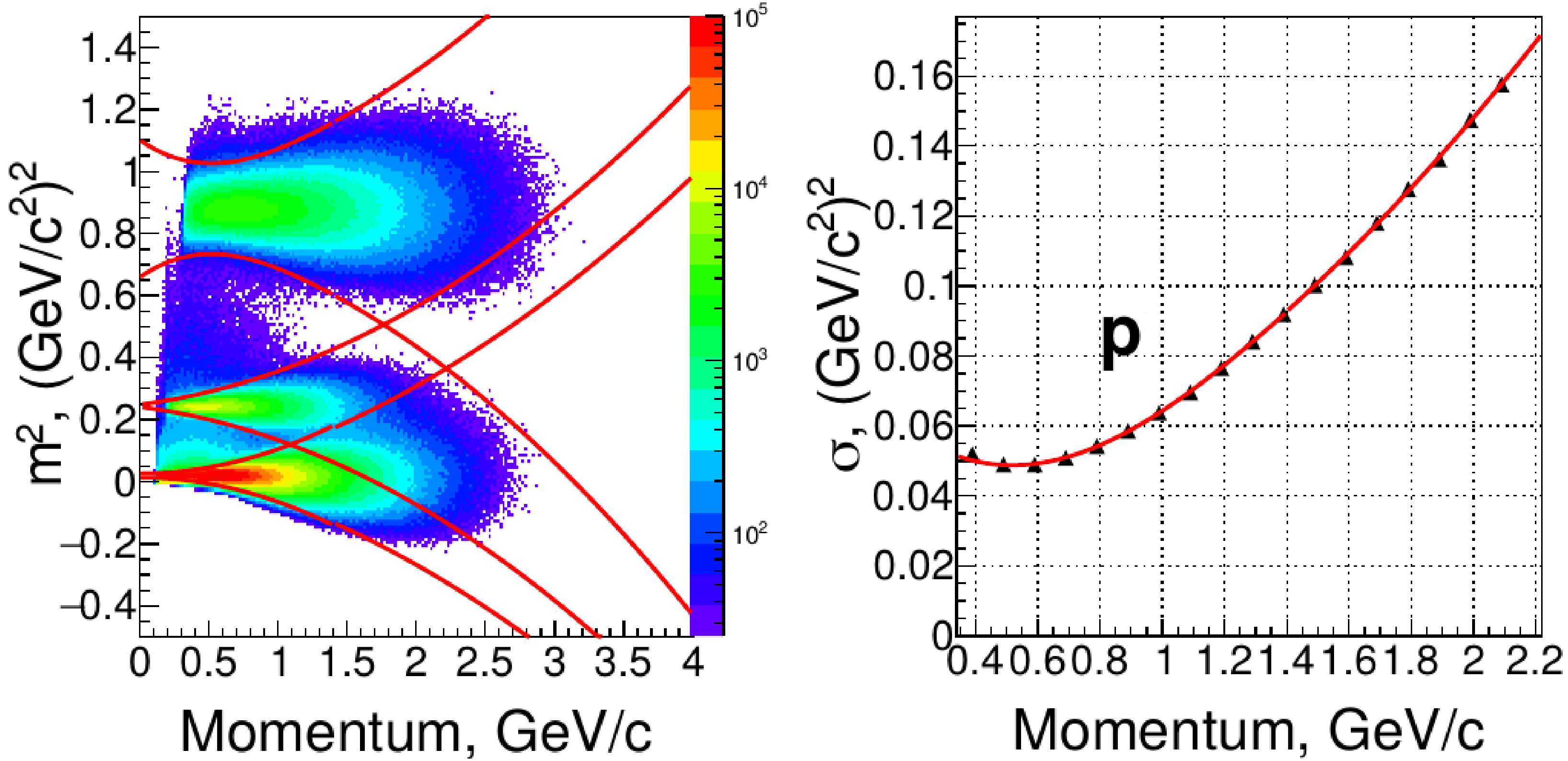


Only tracks with TOF hit were selected

MpdPid method returns probability of the track to be the certain particle species

Only tracks with corresponding particle probability $P_{particle}$>90% were selected

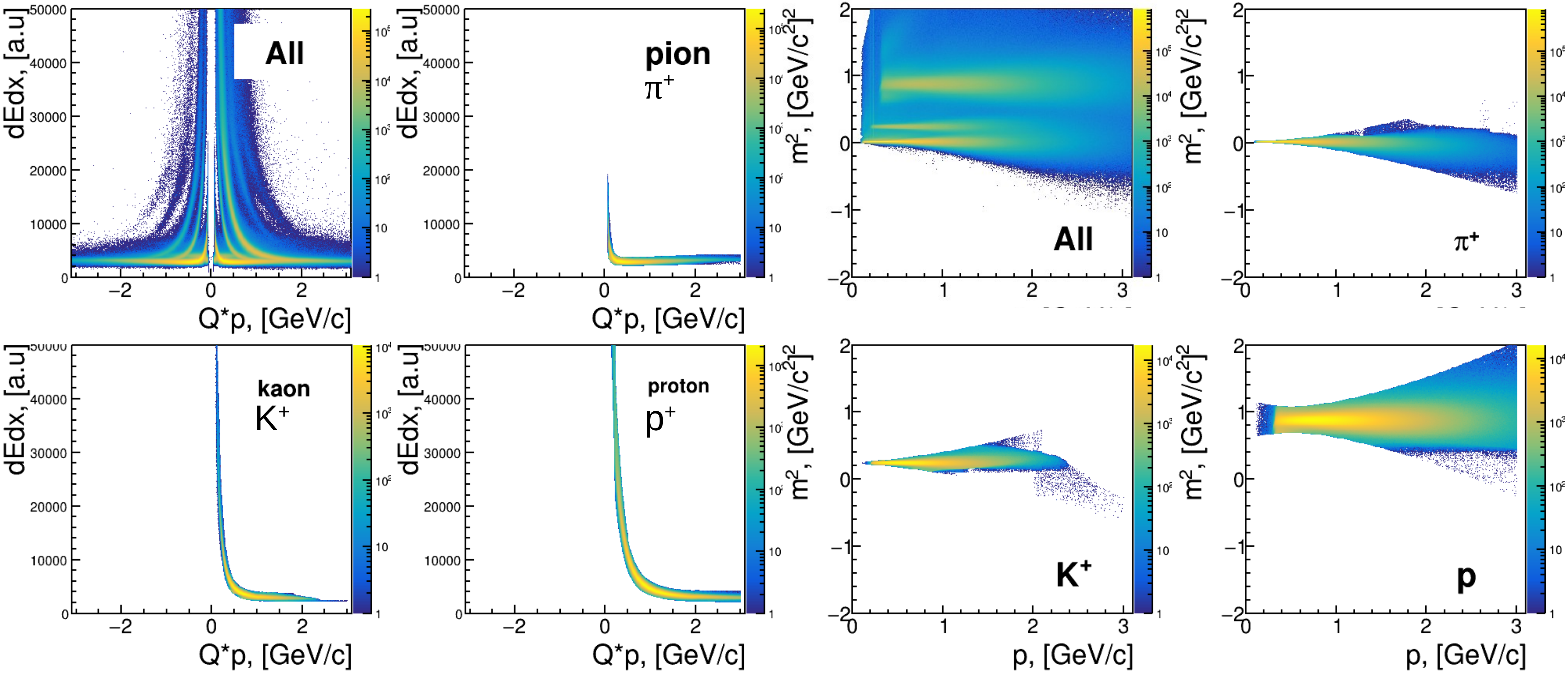
Particle identification using TOF



TOF identification significantly improves PID results in the high momenta region (p>1 GeV/c). It is based on the separation by the m^2 values.

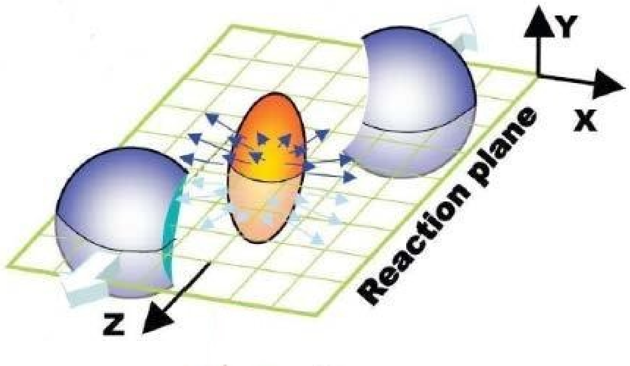
Red lines on this figure show 3σ bands for pions, kaons and protons.

PID implementation in the performance study



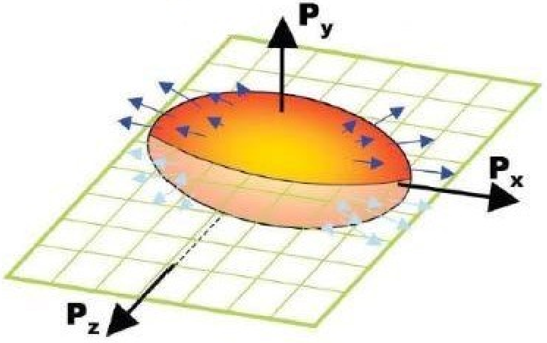
Anisotropic flow in heavy-ion collisions

Spacial anisotropy



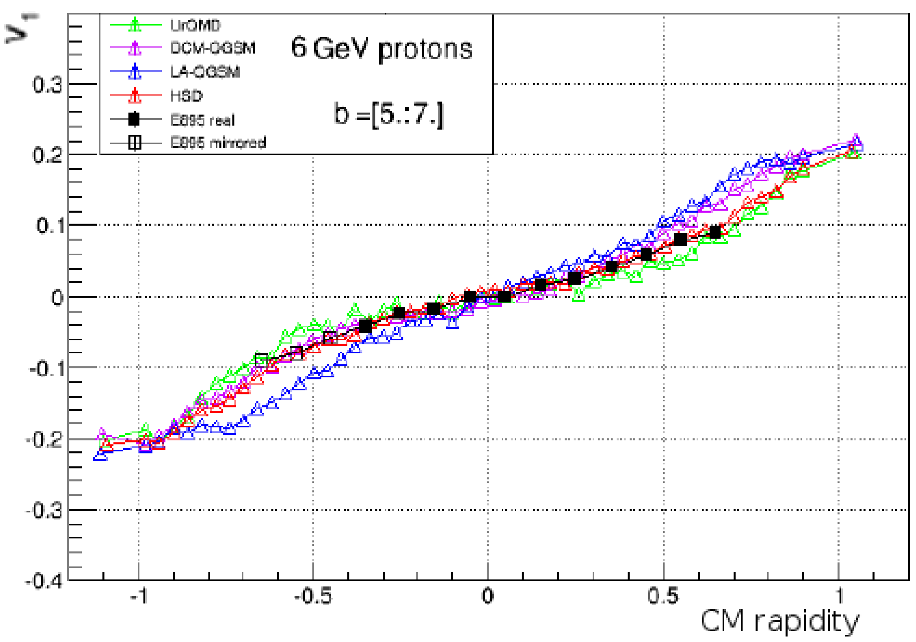
Interaction

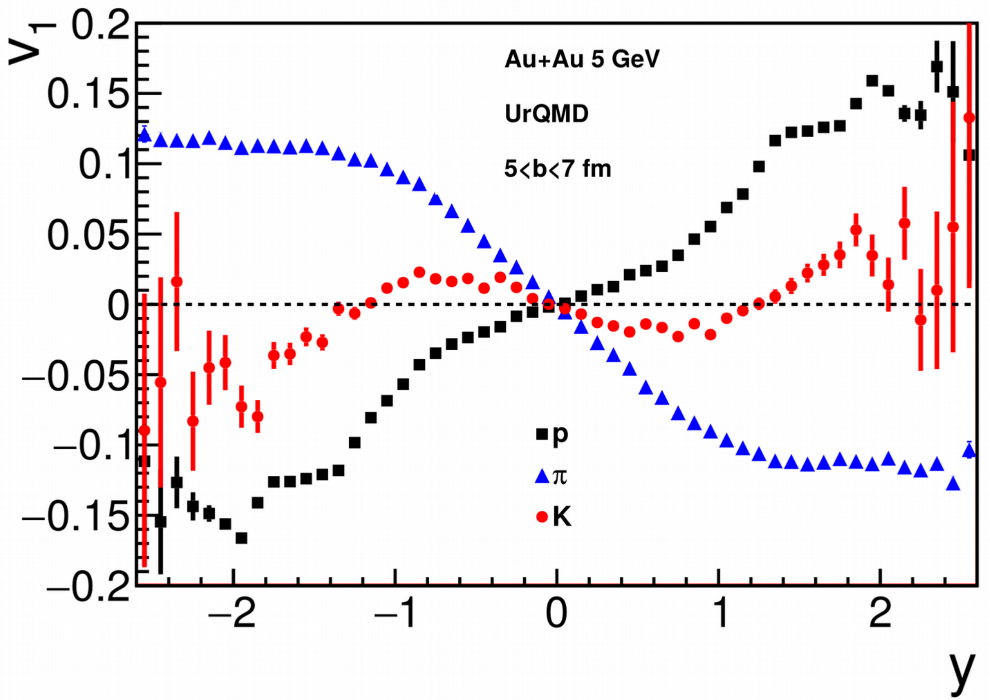
Momentum anisotropy



v_1/v_2 – directed/elliptic flow

Modeling directed flow at NICA energies





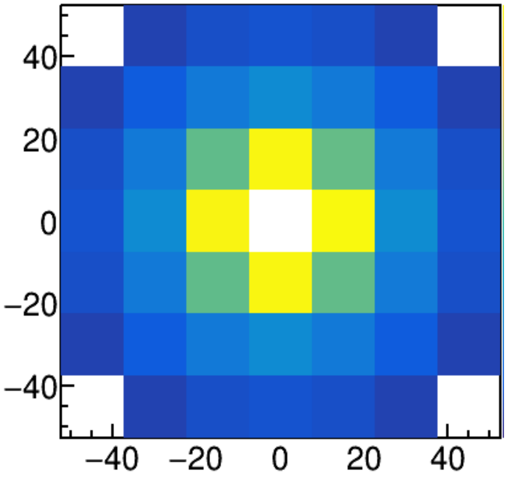
Both UrQMD and LAQGSM are in agreement with experimental measurements. For performance study UrQMD and LAQGSM are used.

EP method implementation

Q-vectors and Ψ_n were calculated both left and right FHCal parts in order to obtain EP resolution for half of the detector and then for full detector:

E_i is the energy deposition in *i-th* FHCal module and φ_i is its azimuthal angle. For *m=1* weights had different signs for backward and forward rapidity.

No gain calibration was used.



Energy distribution in FHCal

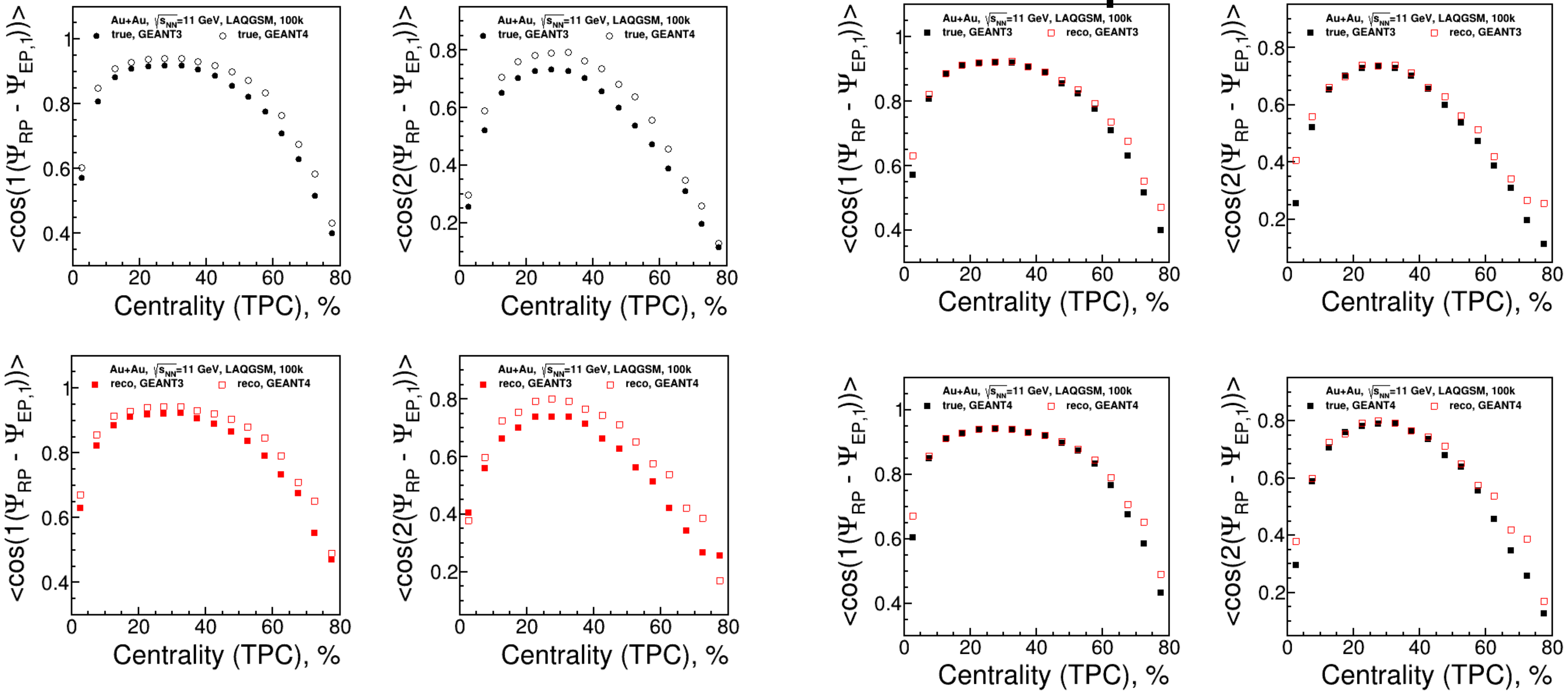
Event plane resolution factor

In order to exclude detector acceptance effects and get v_n one should calculate EP resolution factor first

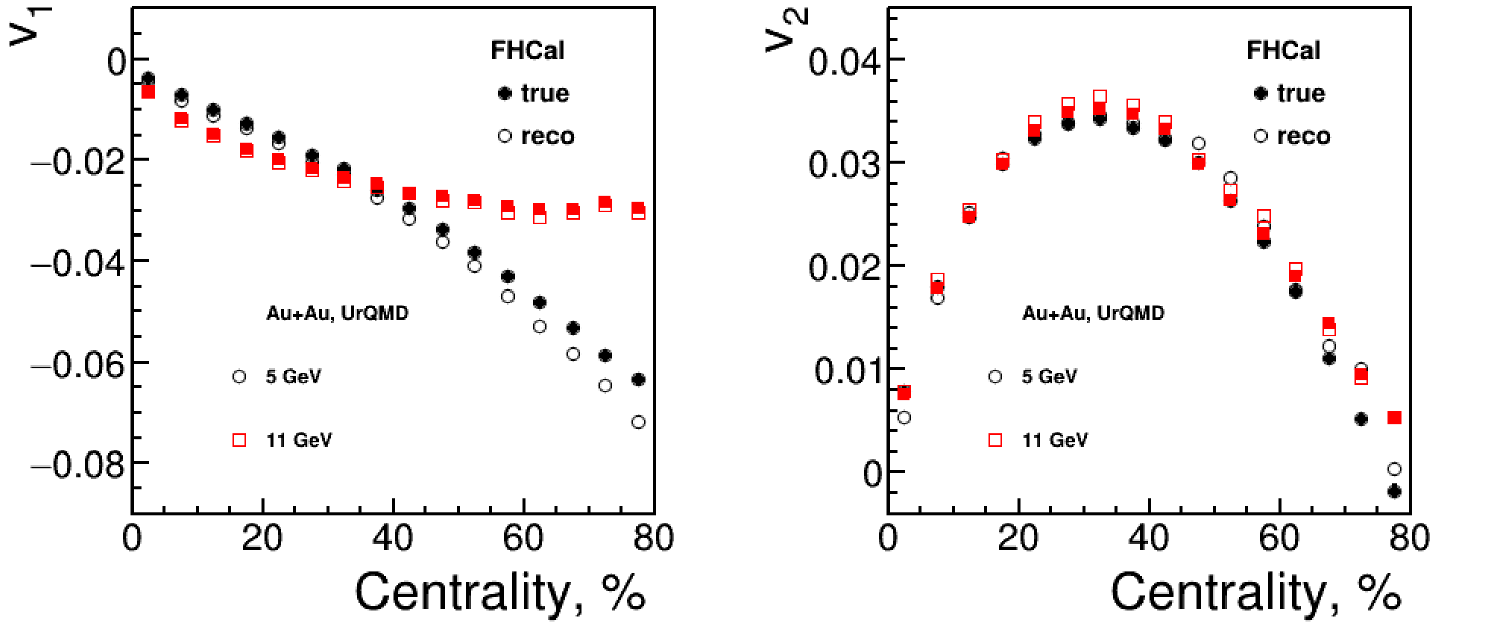
Using 2-subevent method and extrapolation formula we get:

And then v_n will be

Resolution correction factor: GEANT3 vs GEANT4 comparison



Azimuthal flow as function of centrality

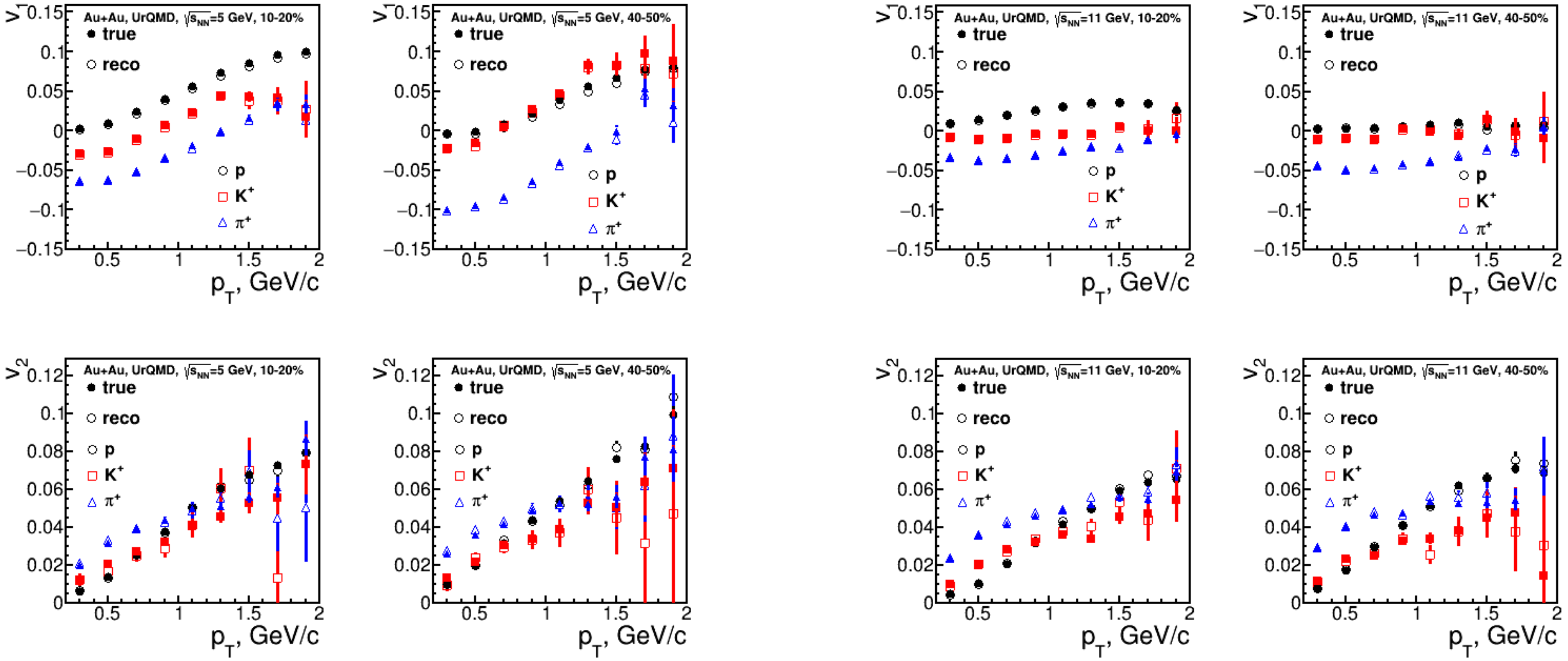


Momentum range: p_T = (0.2-3) GeV/c. Pseudorapidity range: |η|<1.5.

No efficiency correction as a function of p T /η is applied
Should be investigated in the future - not critical for TDR approval

Azimuthal flow as function of p_T

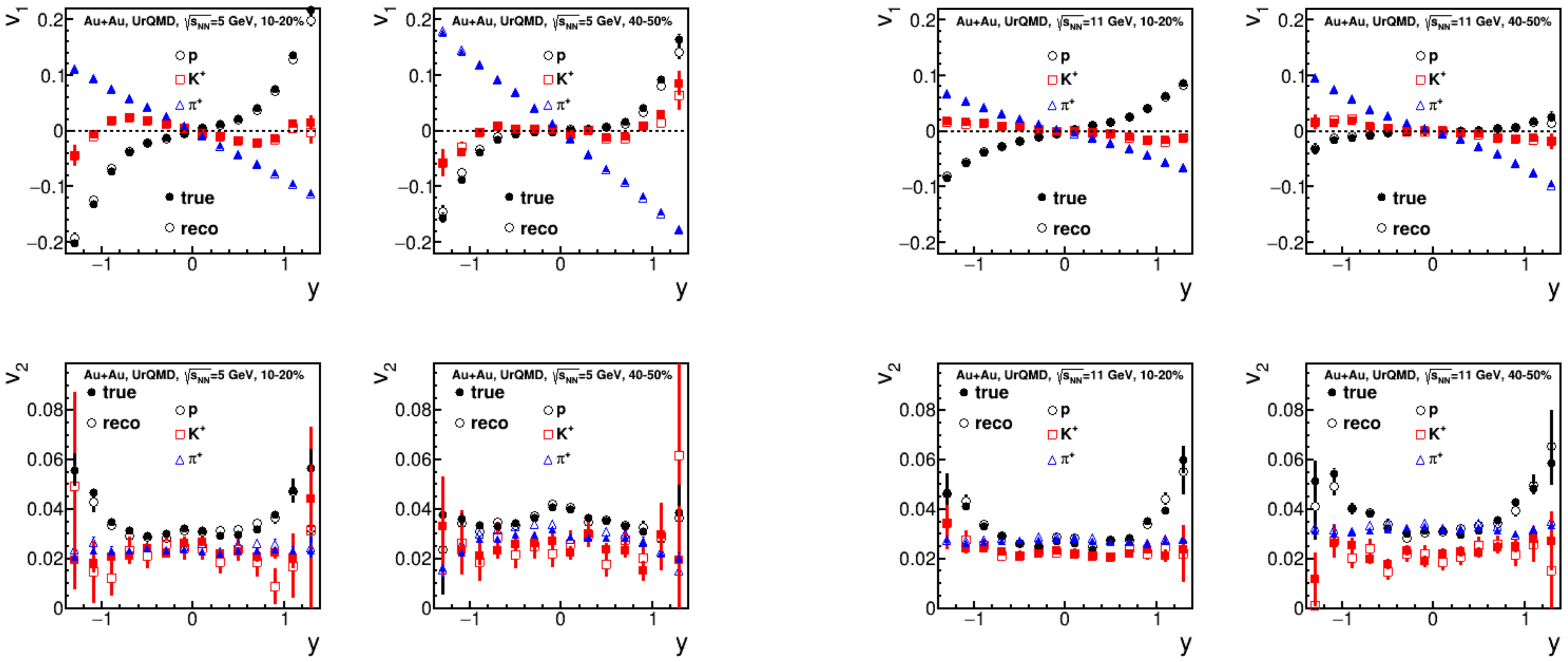
5 GeV 11 GeV



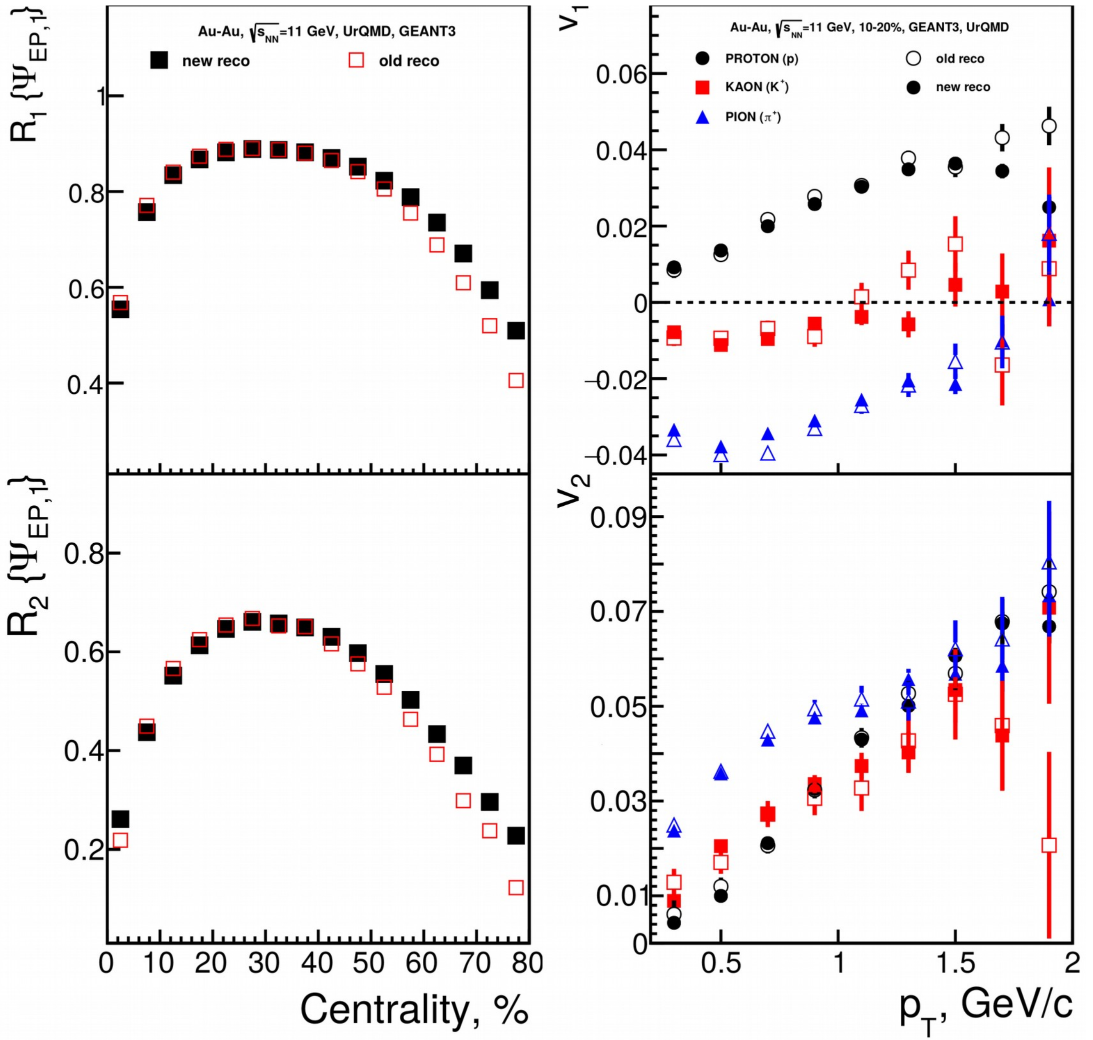
Azimuthal flow as function of y

5 GeV

11 GeV



Comparison with the old results



Old data: 2017 (FHCal TDR version)
New data: 4M generated in 2018

Centrality was estimated using the multiplicity in TPC

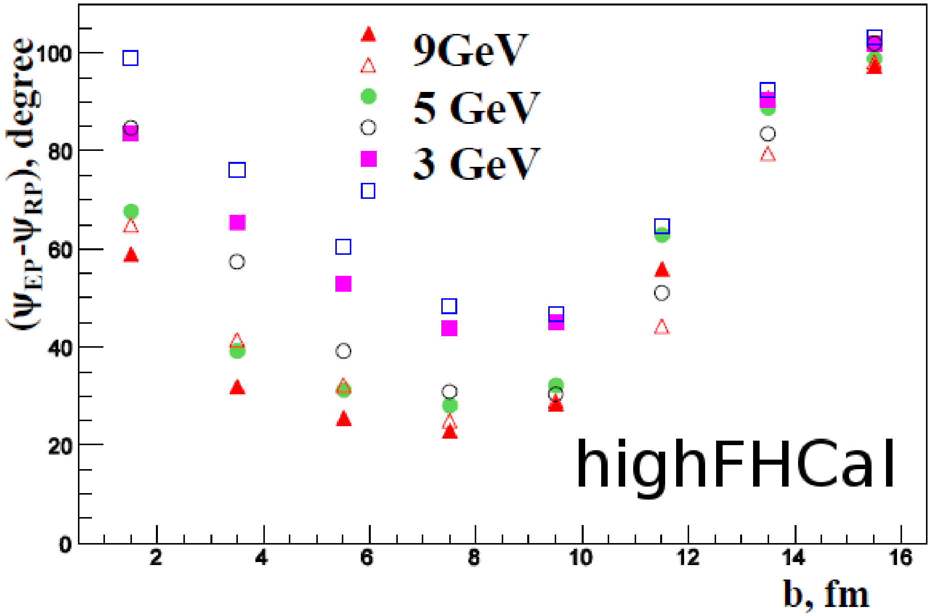
New tracking algorithm was used

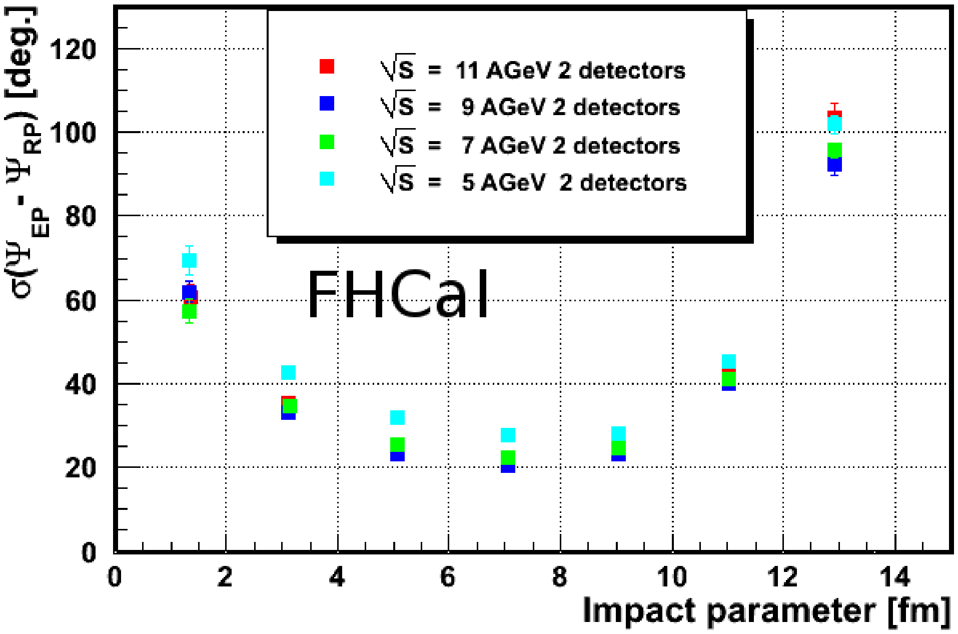
Difference in centrality determination is caused by new tracking

Centrality estimation with FHCAL is in progress

No correction yet for pT/η dependence of the PID efficiency

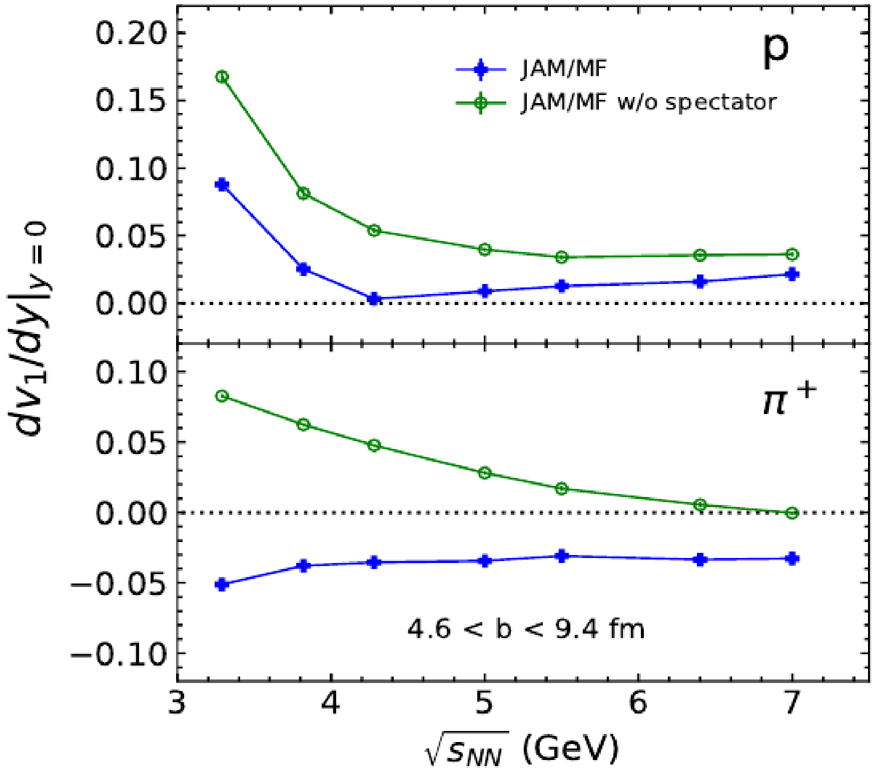
Comparison with other detectors:
high granularity FHCal (highFHCal) and FHCal

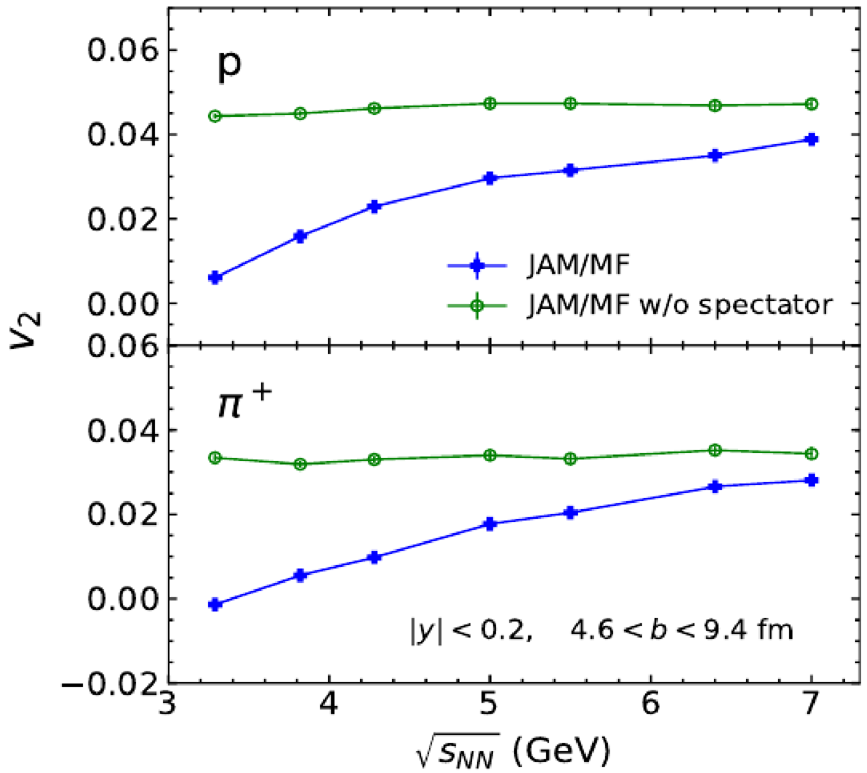




Event plane resolution is comparable to that of FHCal and highFHCal

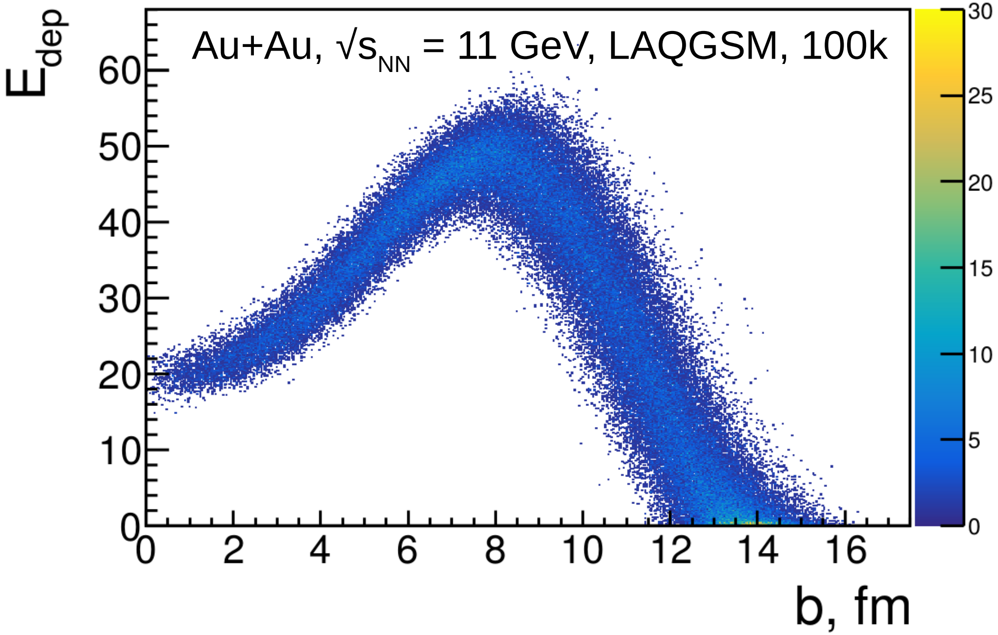
Beam energy dependence of v_1 slope and v_2

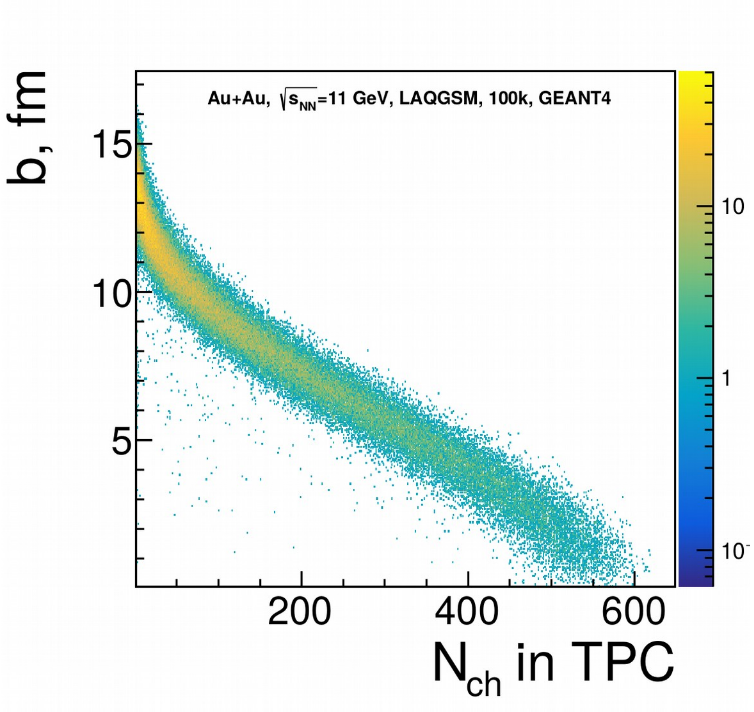




Zhang, Chao et al. arXiv:1803.02053 [nucl-ex]

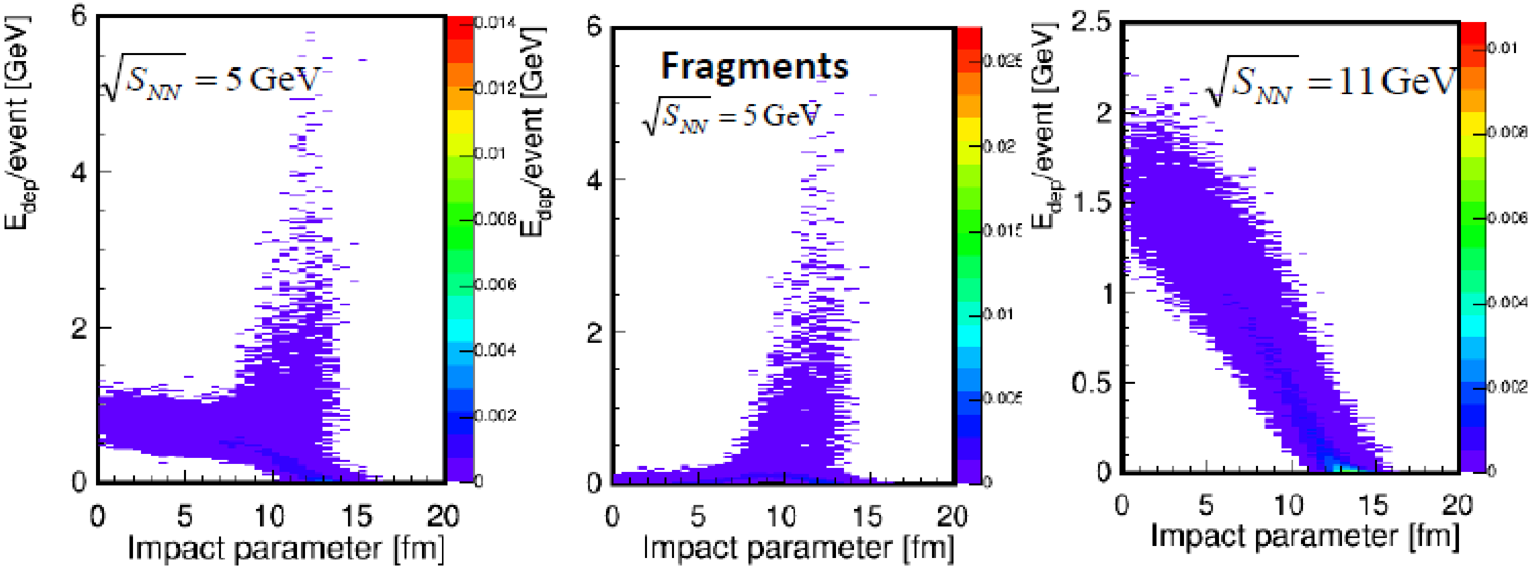
FHCal centrality performance



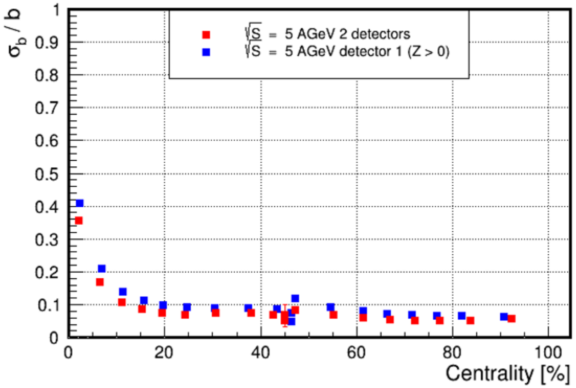


The fragment loss in the central area of the beam pipe limits range of the centrality determination using energy deposition in FHCal

FHCal centrality performance

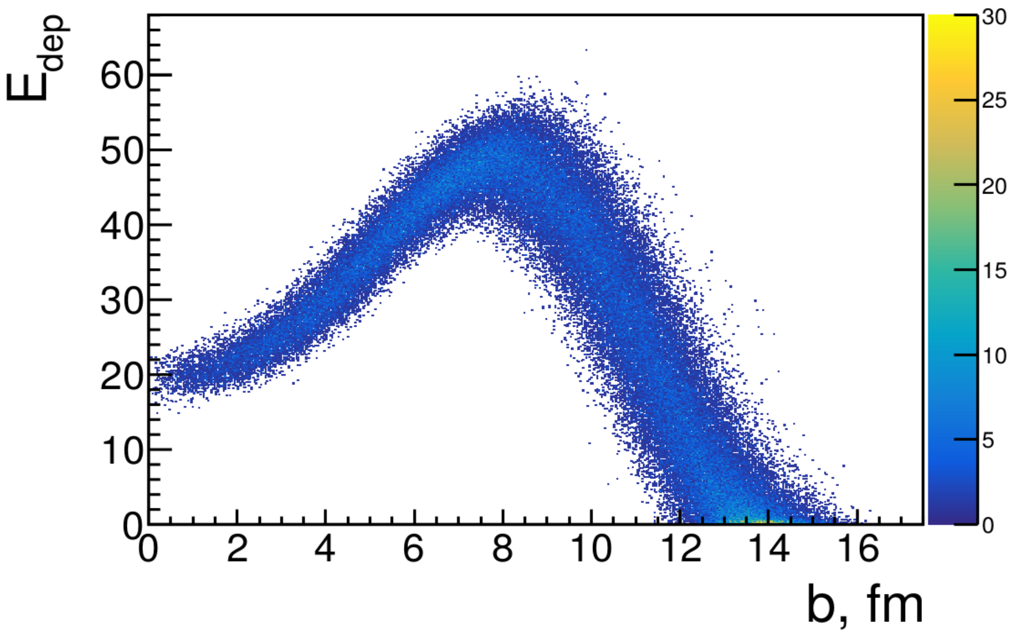


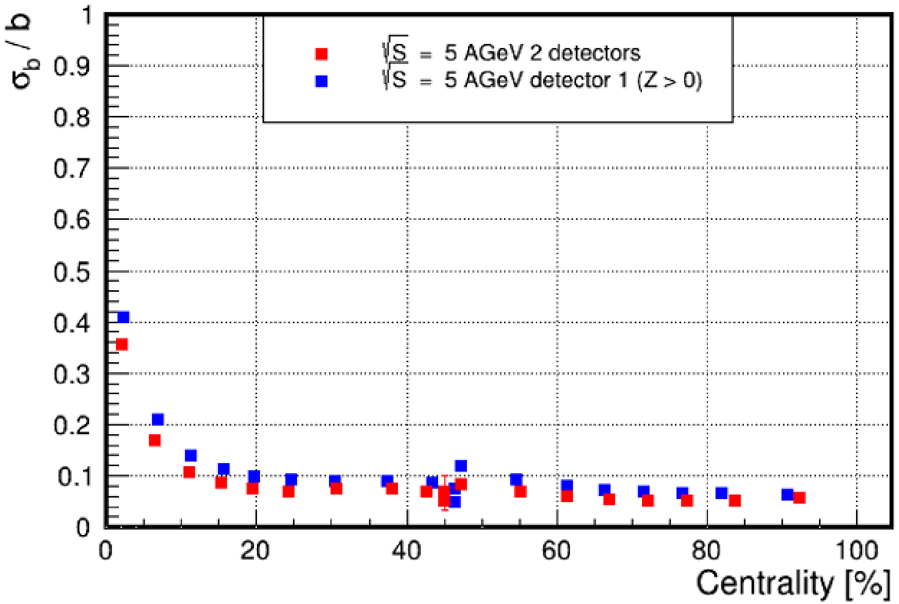
Comparable to TPC and is limited by decorrelation due to fragments losses in forward rapidity. FHCal centrality resolution is ~10% in mid-central collisions



Both TPC track multiplicity and FHCal energy decomposition correlated with TPC track multiplicity can be used for centrality determination

FHCal centrality performance

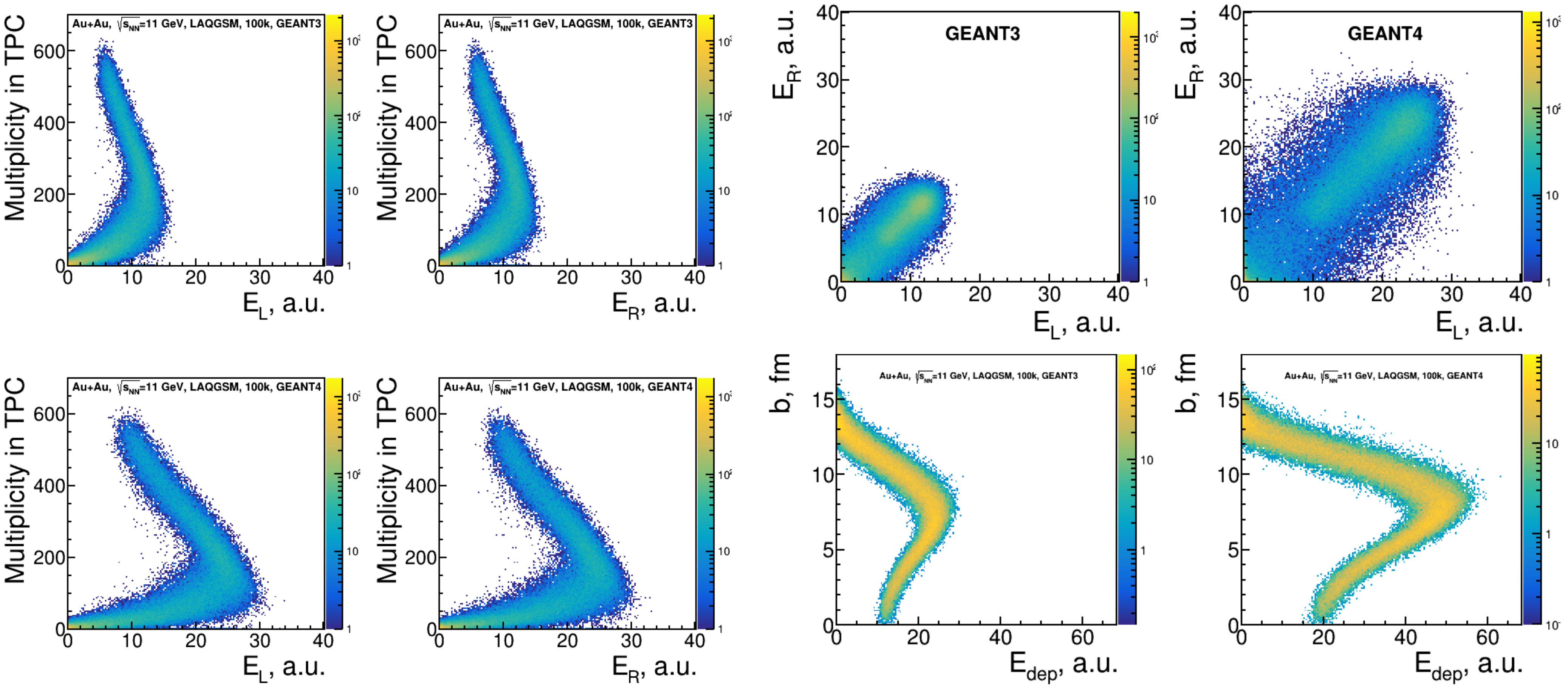




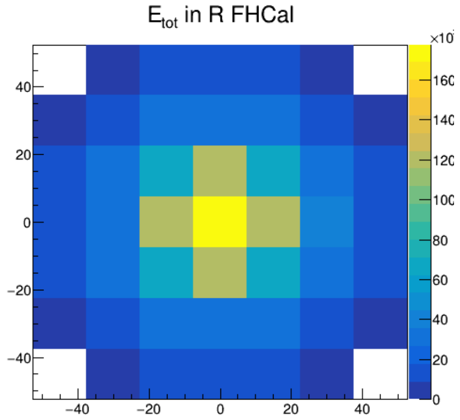
Comparable to TPC and is limited by decorrelation due to fragments losses in forward rapidity.
FHCal centrality resolution is ~10% in mid-central collisions

Both TPC track multiplicity and FHCal energy decomposition correlated with TPC track multiplicity can be used for centrality determination

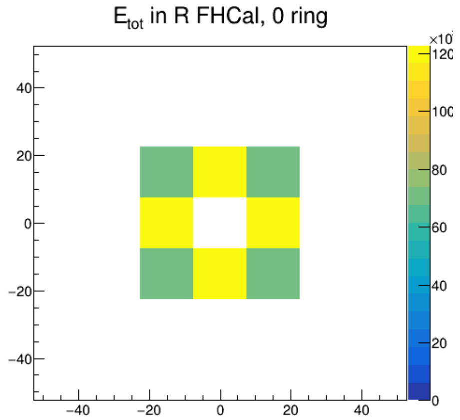
E_{dep}, Multiplicity GEANT3 vs GEANT4



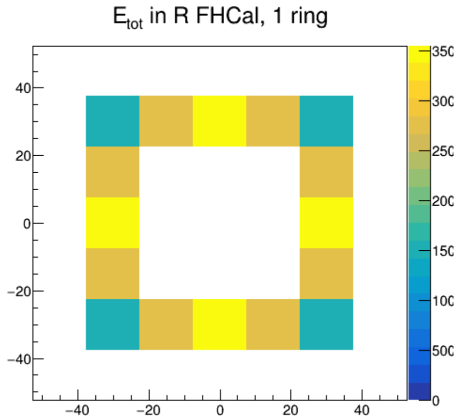
FHCal rings selection



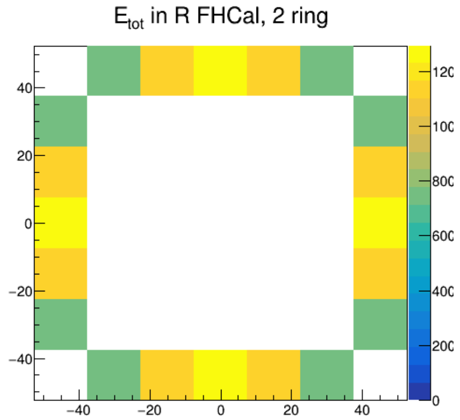
- 2 FHCal detectors:
  - Backward (B) in η<0
  - Forward (F) in η>0
- 3 FHCal modules groups:
  - Inner (0)
  - Middle (1)
  - Outer (2)



Inner (0)

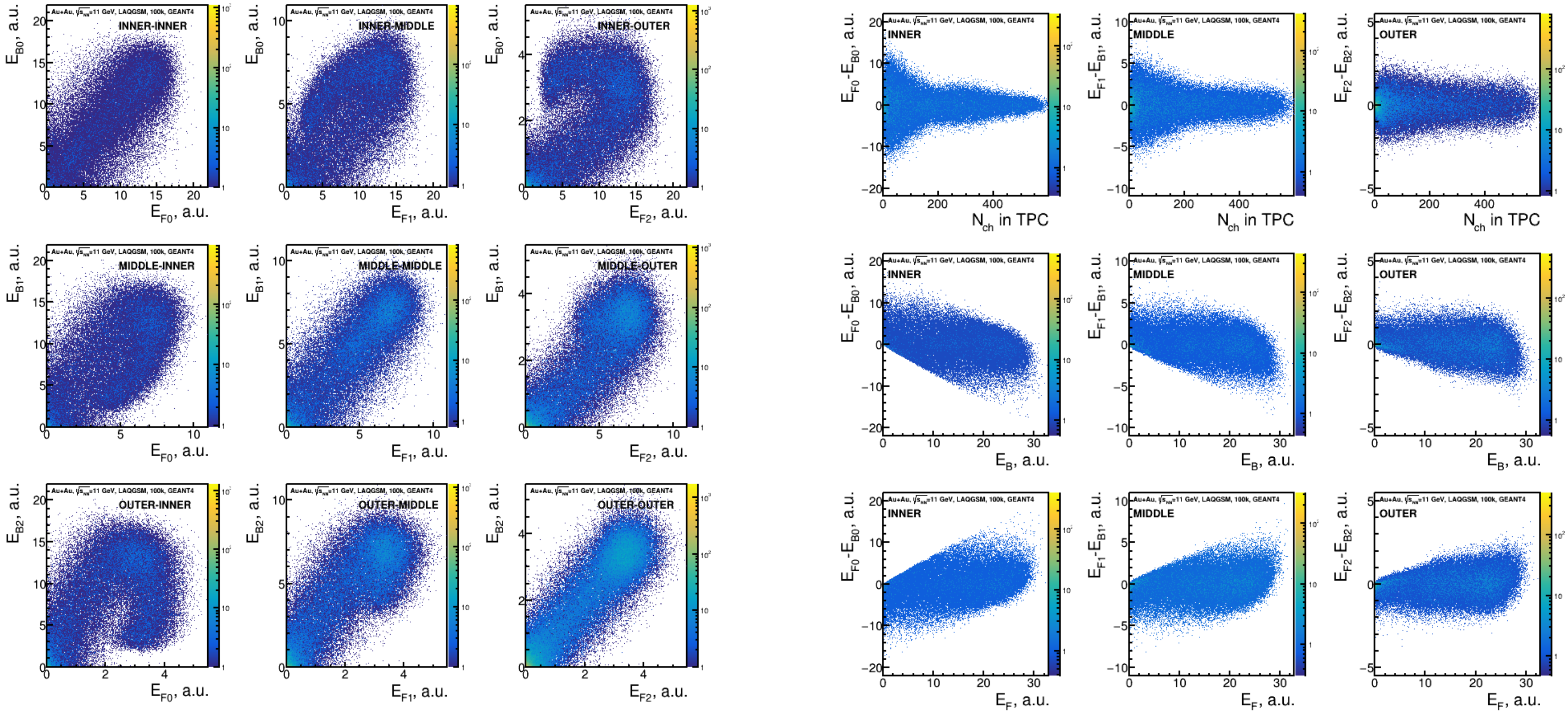


Middle (1)

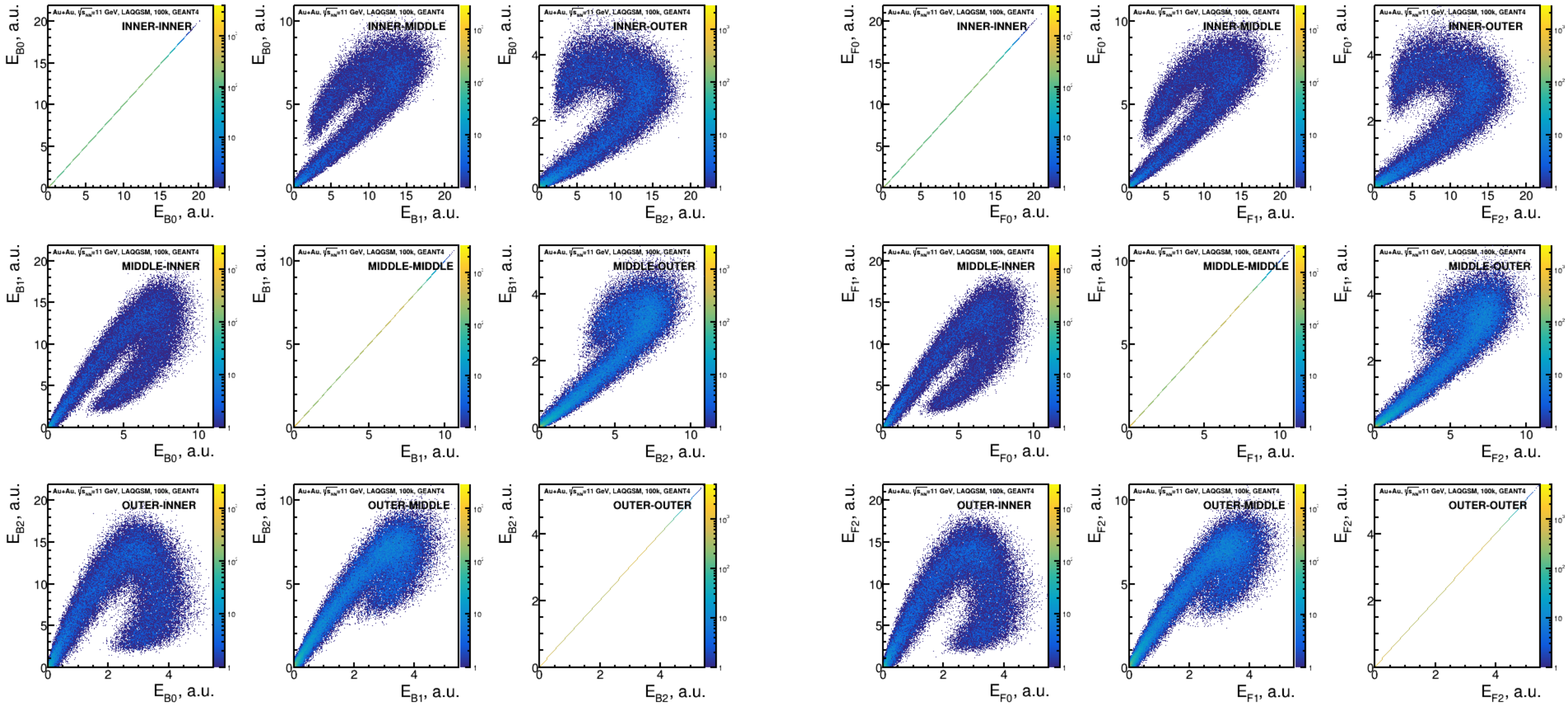


Outer (2)

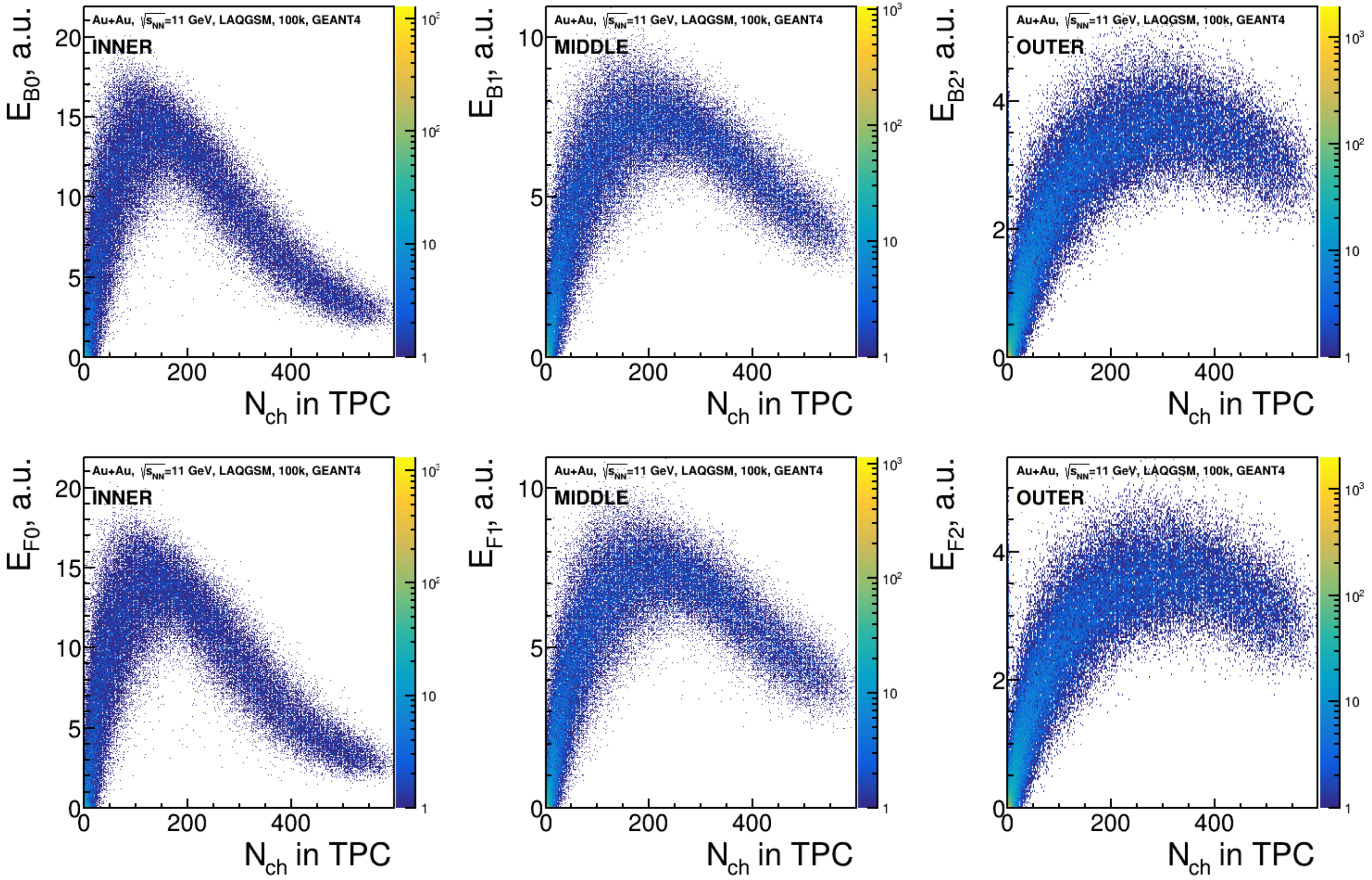
F-B correlations of FHCal modules



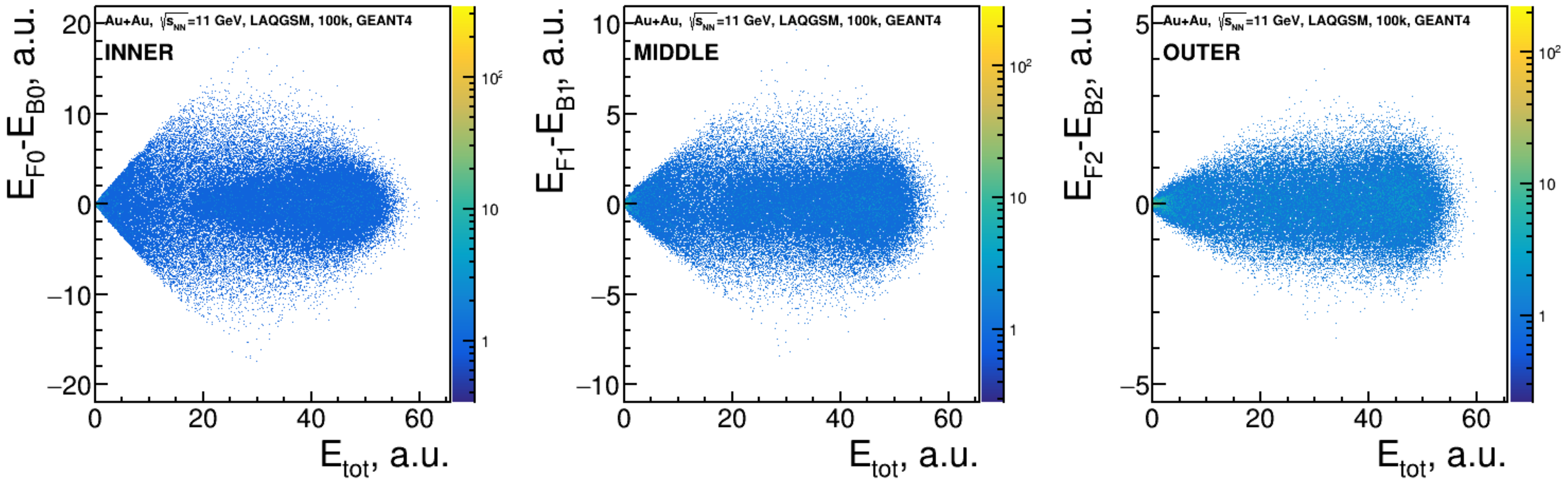
B-B & F-F correlations of FHCal modules



E(ring) vs multiplicity in TPC



E_F-E_B(ring) vs E_{Tot}



Impact parameter vs E,Mult