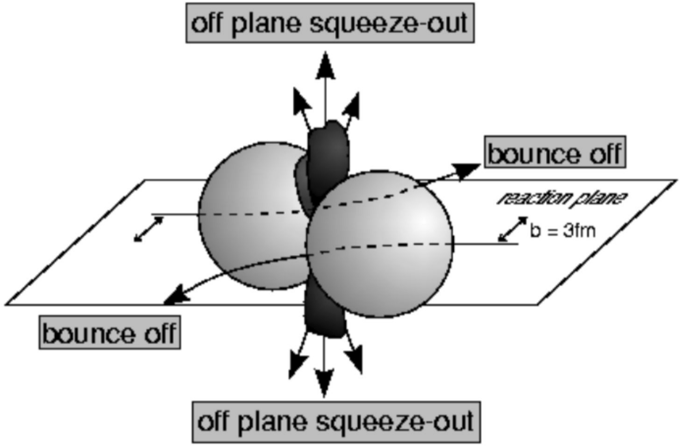
Performance study for the anisotropic flow measurements in MPD-FXT

P. Parfenov, M. Mamaev and A. Taranenko
(NRNU MEPhI, JINR)

Anisotropic flow & spectators



The azimuthal angle distribution is decomposed in a Fourier series relative to reaction plane angle:

$$\rho(\varphi - \Psi_{RP}) = \frac{1}{2\pi}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos n(\varphi - \Psi_{RP})\right)$$

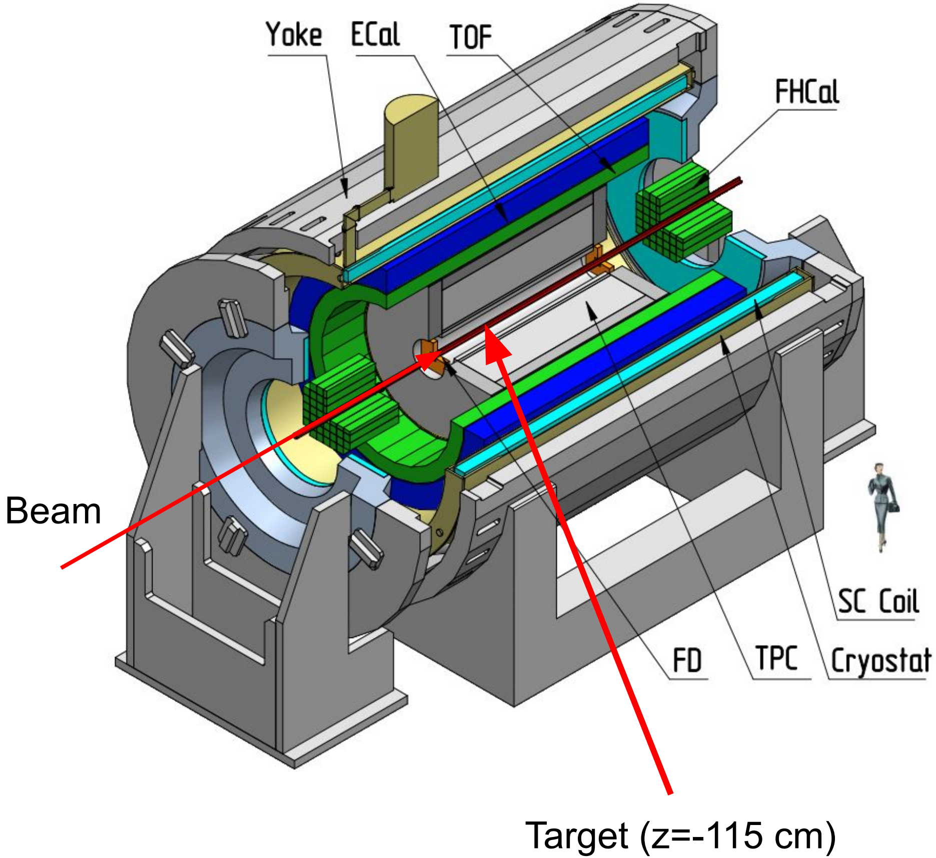
Anisotropic flow:

$$v_n = \langle \cos\left[n(\varphi - \Psi_{RP})\right]\rangle$$

Anisotropic flow is sensitive to:

- Time of the interaction between overlap region and spectators
- Compressibility of the created matter

MPD in Fixed-Target Mode (FXT)



- Model used: UrQMD mean-field
  - Bi+Bi, E_{kin}=1.45 AGeV ($\sqrt{s_{NN}}$ =2.5 GeV)
  - Bi+Bi, E_{kin}=2.92 AGeV ($\sqrt{s_{NN}}$ =3.0 GeV)
  - Bi+Bi, E_{kin}=4.65 AGeV ($\sqrt{s_{NN}}$=3.5 GeV)
- Point-like target
- GEANT4 transport
- Particle species selection via true-PDG code of the associated mc track

Flow vectors

From momentum of each measured particle define a u_n-vector in transverse plane:

$$u_n = e^{in\phi}$$

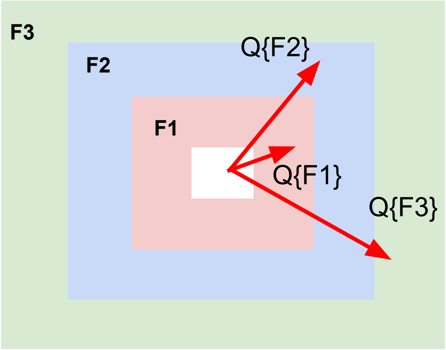
where φ is the azimuthal angle

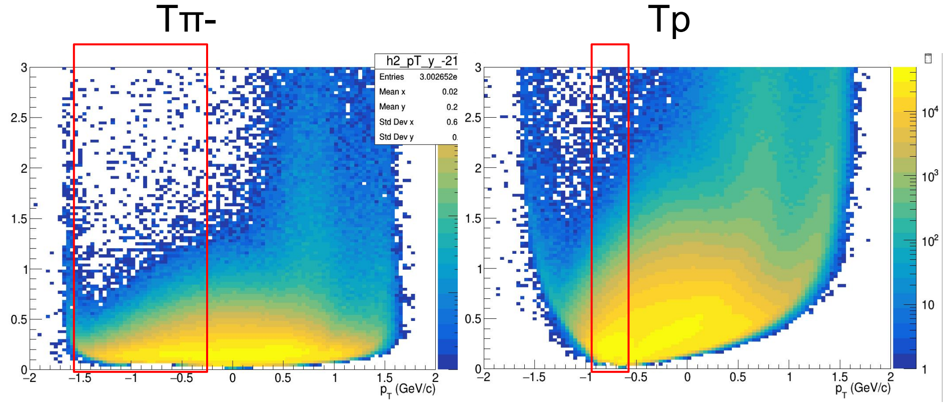
Sum over a group of u_n-vectors in one event forms Q_n-vector:

$$Q_n = \frac{\sum_{k=1}^{N} w_n^k u_n^k}{\sum_{k=1}^{N} w_n^k} = |Q_n| e^{in\Psi_n^{EP}}$$

Ψ_n^{EP} is the event plane angle

Modules of FHCal divided into 3 groups





Additional subevents from tracks not pointing at FHCal:
Tp: p; -1.0<y<-0.6;
Tπ: π-; -1.5<y<-0.2;

Flow methods for v_n calculation

Tested in HADES:

M Mamaev et al 2020 PPNuclei 53, 277–281
M Mamaev et al 2020 J. Phys.: Conf. Ser. 1690 012122

Scalar product (SP) method:

$$v_1 = \frac{\langle u_1 Q_1^{F1} \rangle}{R_1^{F1}} \qquad v_2 = \frac{\langle u_2 Q_1^{F1} Q_1^{F3} \rangle}{R_1^{F1} R_1^{F3}}$$

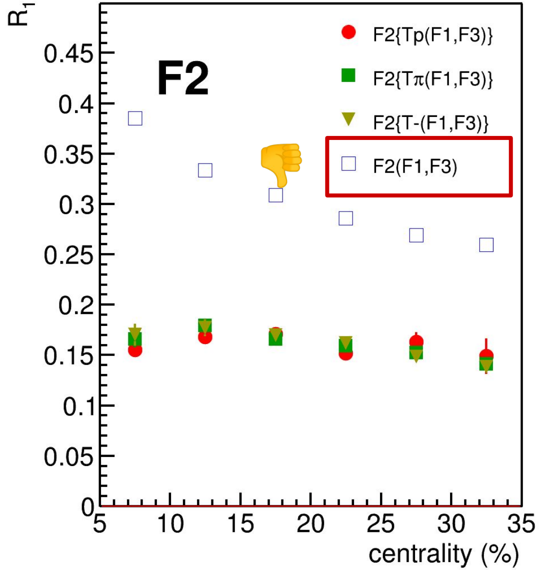
Where R_1 is the resolution correction factor

$$R_1^{F1} = \langle \cos(\Psi_1^{F1} - \Psi_1^{RP}) \rangle$$

Symbol “F2(F1,F3)” means R_1 calculated via (3S resolution):

$$R_1^{F2(F1,F3)} = \frac{\sqrt{\langle Q_1^{F2} Q_1^{F1} \rangle \langle Q_1^{F2} Q_1^{F3} \rangle}}{\sqrt{\langle Q_1^{F1} Q_1^{F3} \rangle}}$$

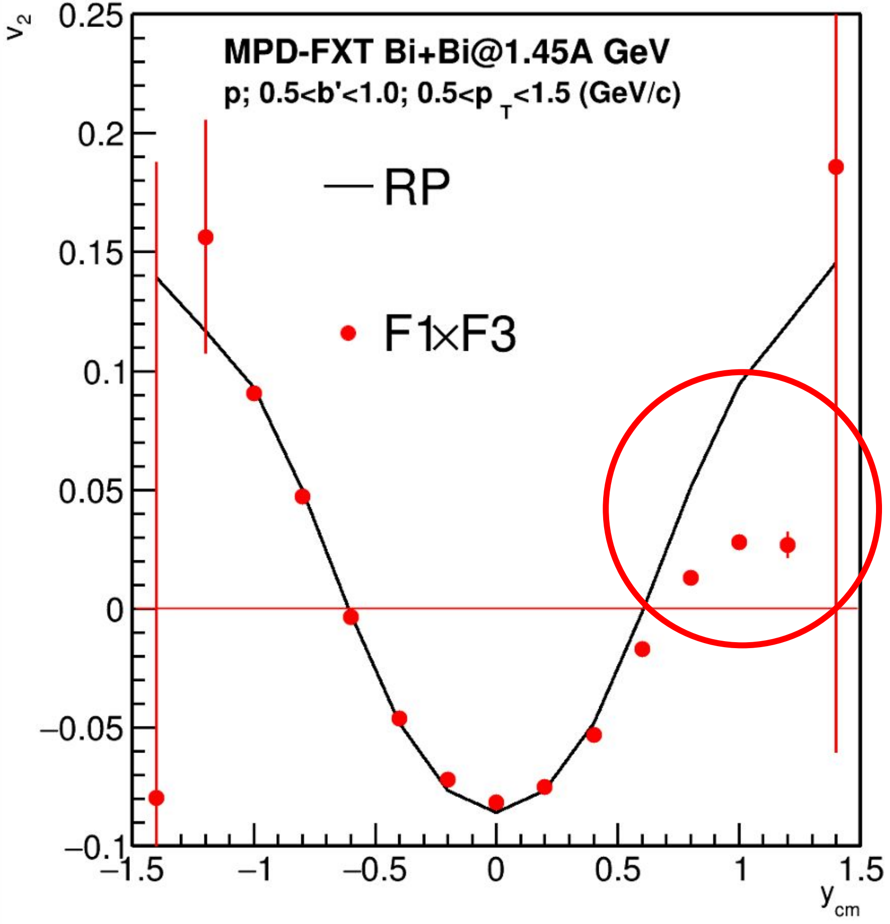
Method helps to eliminate non-flow
Using 2-subevents doesn’t



Symbol “F2{Tp}(F1,F3)” means R_1 calculated via (4S resolution):

$$R_1^{F2\{Tp\}(F1,F3)} = \langle Q_1^{F2} Q_1^{Tp} \rangle \frac{\sqrt{\langle Q_1^{F1} Q_1^{F3} \rangle}}{\sqrt{\langle Q_1^{Tp} Q_1^{F1} \rangle \langle Q_1^{Tp} Q_1^{F3} \rangle}}$$

Previous results: main issue



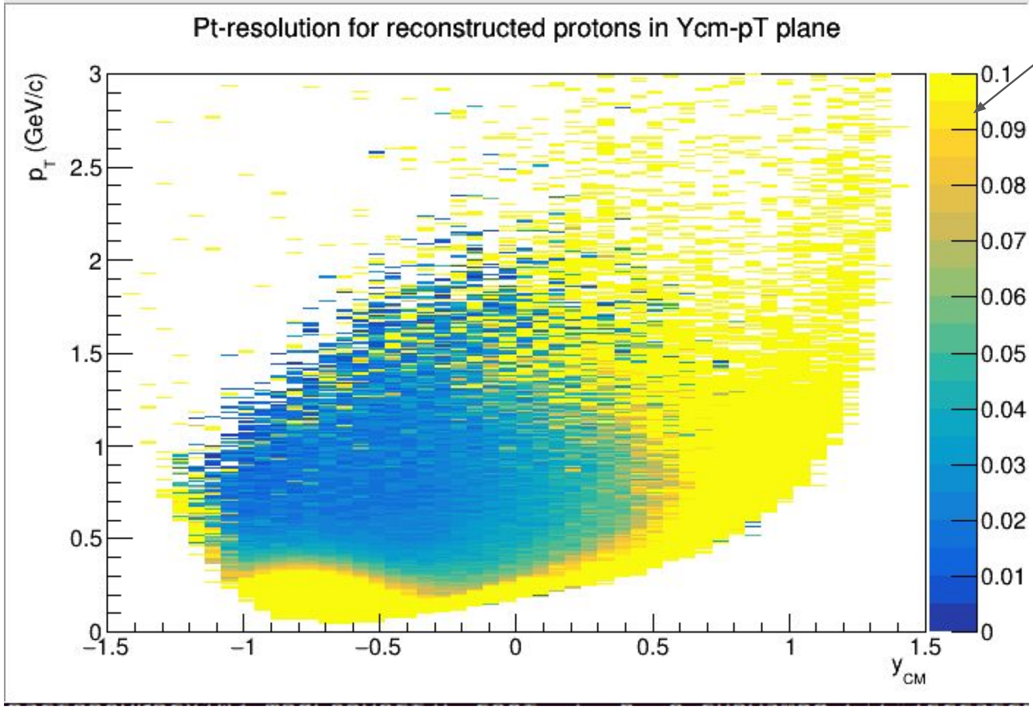
Discrepancy between “reco” and “sim”:

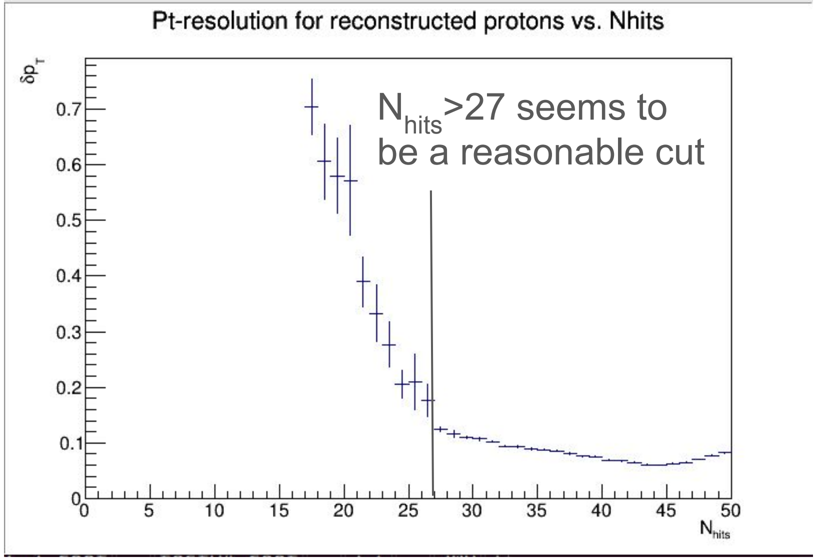
- Efficiency?
- Track quality?

Let’s look at the track quality…

Basic track quality check: p_T

$$\Delta p_T = \frac{|p_T^{\mathrm{reco}} - p_T^{\mathrm{mc}}|}{p_T^{\mathrm{mc}}}$$



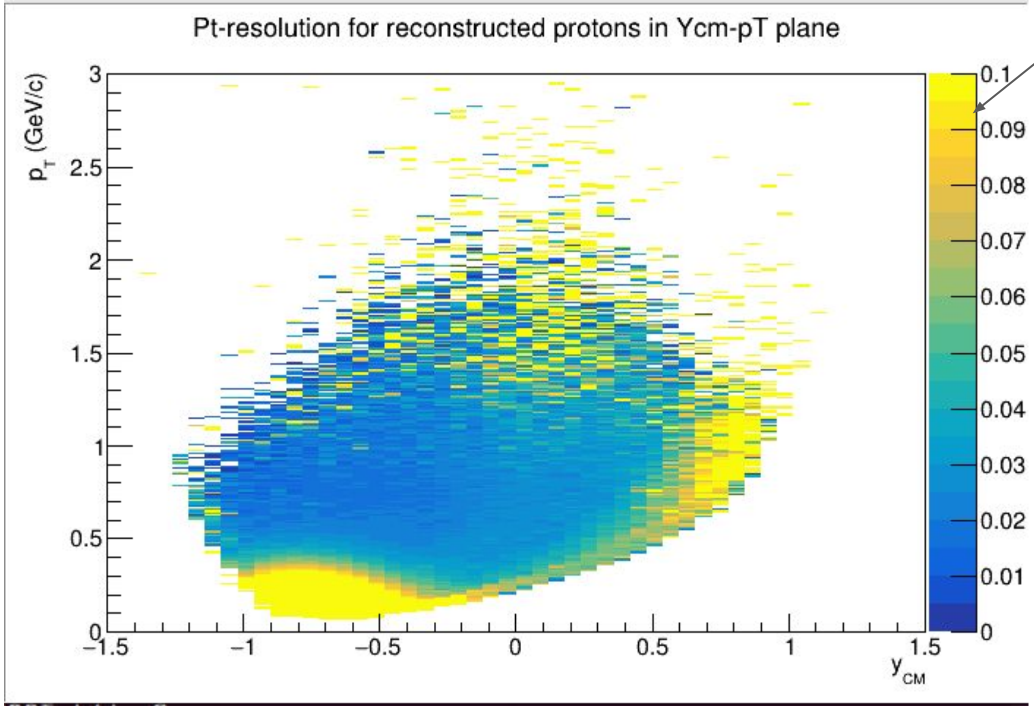


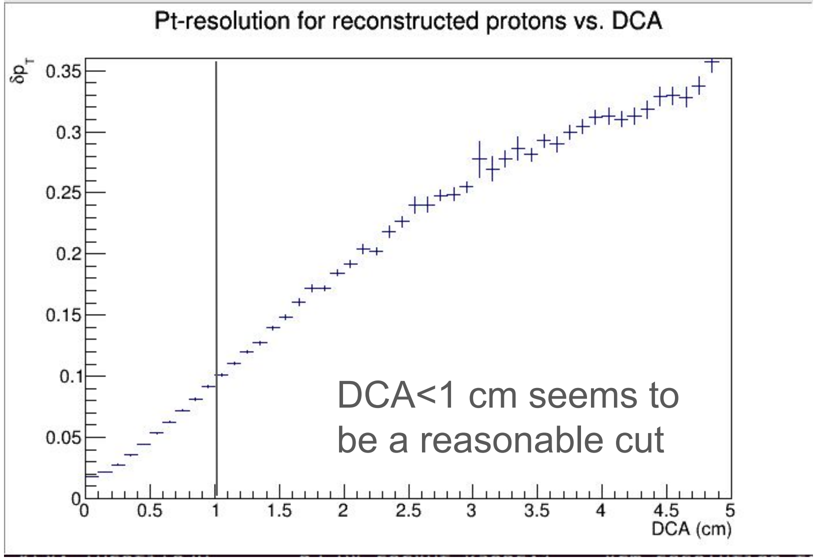
N_{hits}>27 seems to be a reasonable cut

It seems the pt-resolution drops in the forward rapidity region (y_{CM}>0.5)

Basic track quality check: p_T

$$\Delta p_T = \frac{\left|p_T^{\mathrm{reco}} - p_T^{\mathrm{mc}}\right|}{p_T^{\mathrm{mc}}}$$



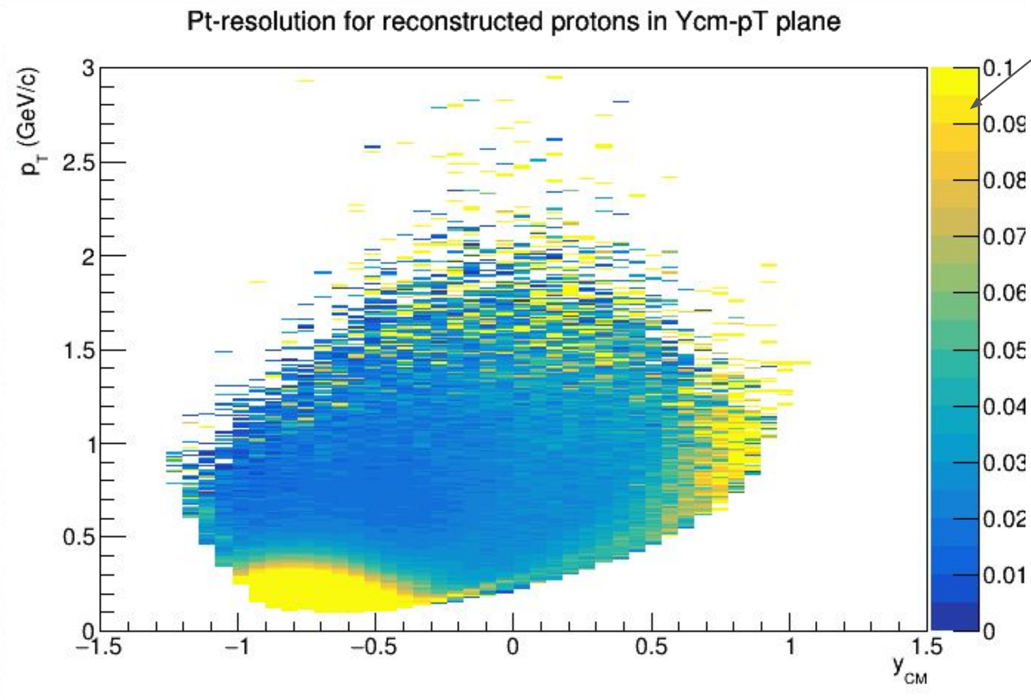


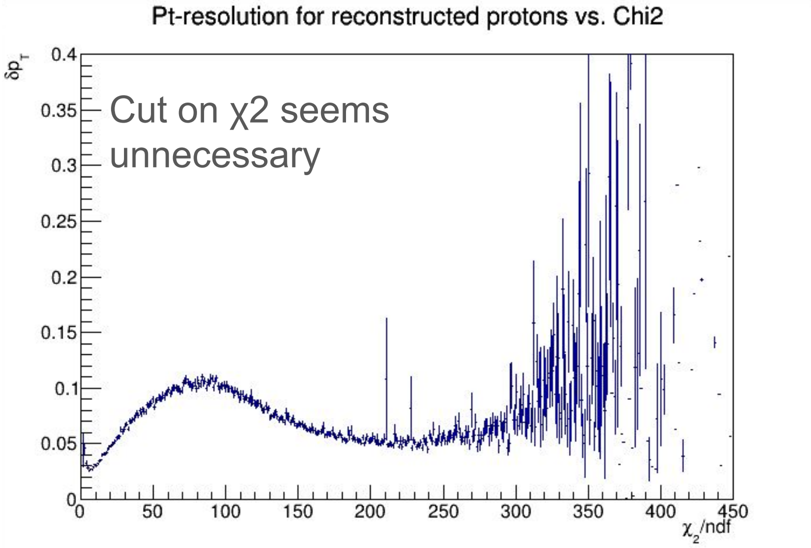
DCA<1 cm seems to be a reasonable cut

Cut N_{hits}>27 seems to improve the situation

Basic track quality check: p_T

$$\Delta p_T = \frac{|p_T^{\mathrm{reco}} - p_T^{\mathrm{mc}}|}{p_T^{\mathrm{mc}}}$$



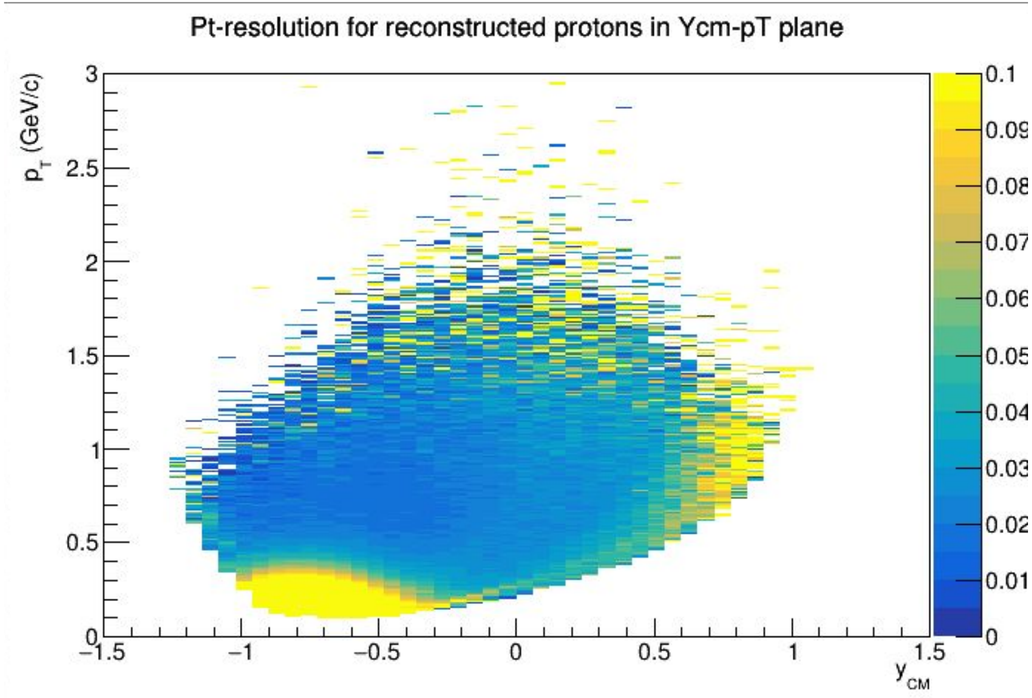


Cut on χ2 seems unnecessary

Cut DCA<1 cm slightly improve the situation

Track cuts based on p_T-resolution check

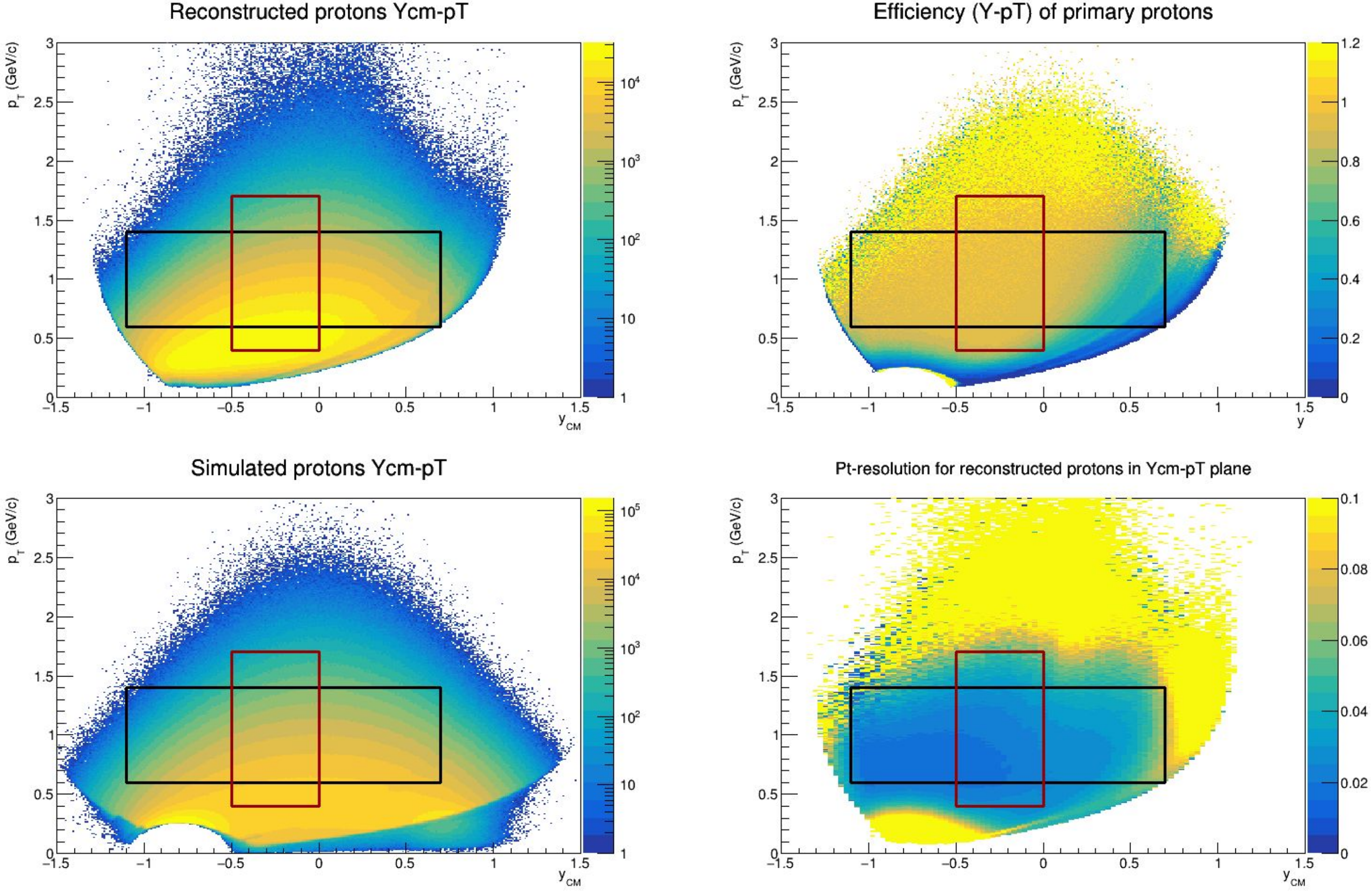
Protons:
- Nhits>27
- DCA<1 cm



Now let’s look at the efficiency plots with the new cuts

(y-pt) distribution, efficiency and δpt (protons)

$$\mathrm{eff} = \frac{\frac{dN}{dydp_T}(\mathrm{reco})}{\frac{dN}{dydp_T}(\mathrm{sim})}$$



Reconstructed protons Ycm-pT

Efficiency (Y-pT) of primary protons

Simulated protons Ycm-pT

Pt-resolution for reconstructed protons in Ycm-pT plane

$$\Delta p_T = \frac{|p_T^{\mathrm{reco}} - p_T^{\mathrm{mc}}|}{p_T^{\mathrm{mc}}}$$

Bi+Bi $\sqrt{s_{NN}}$=2.5 GeV

Cuts for reco tracks:

- Nhits>27
- DCA< 1 cm
- PID (pdg code)
- Primary (motherId)

Cuts for sim particles:

- PID (pdg code)
- Primary (motherId)

Black box: acceptance window for $v_n(y)$

Red box: acceptance window for $v_n(p_T)$

(y-pt) distribution, efficiency and δpt (protons)

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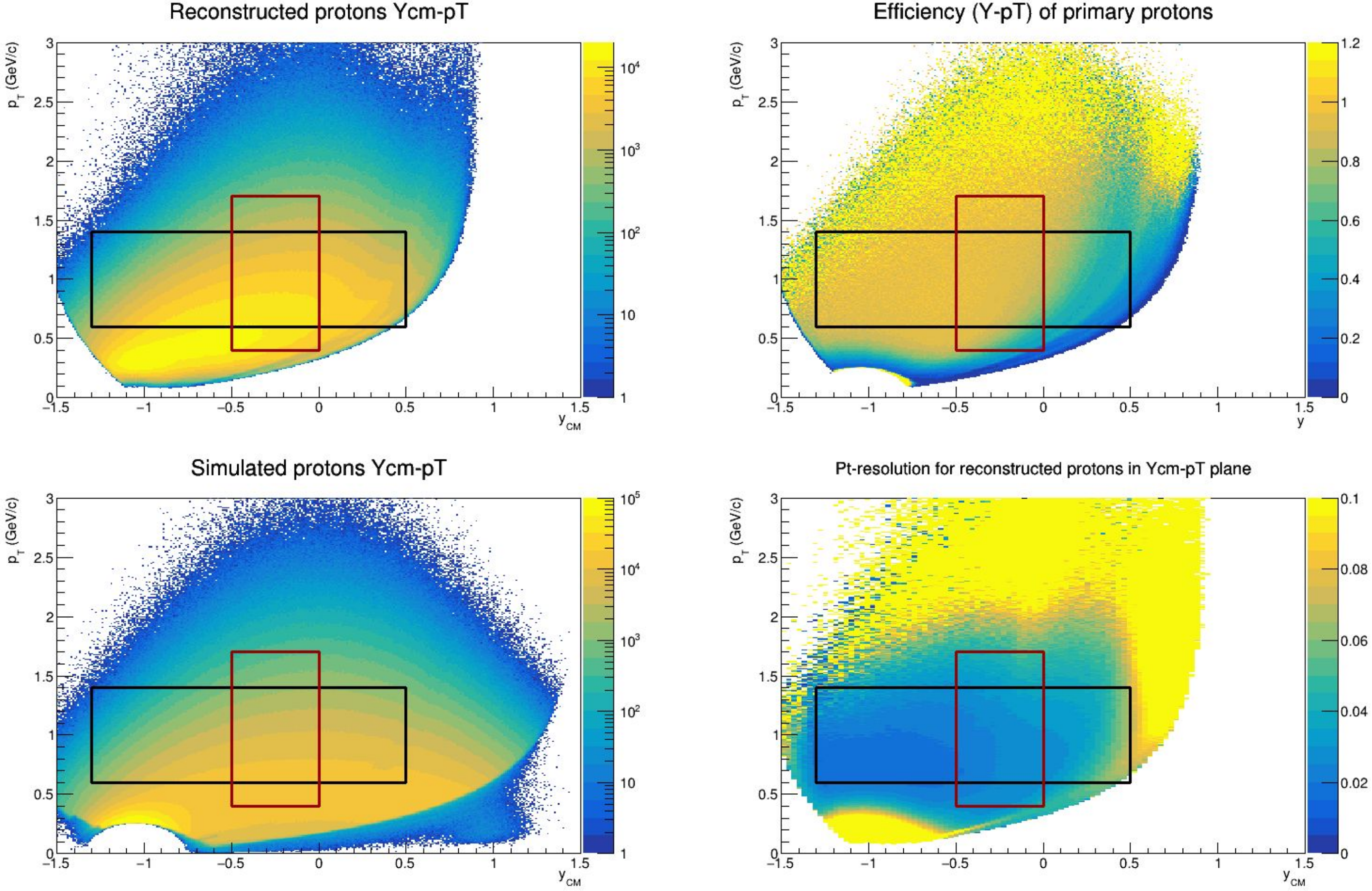
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Pt-resolution for reconstructed protons in Ycm-pT plane

$$\Delta p_T = \frac{\left|p_T^{\mathrm{reco}} - p_T^{\mathrm{mc}}\right|}{p_T^{\mathrm{mc}}}$$

Bi+Bi $\sqrt{s_{NN}}$=3.0 GeV

Cuts for reco tracks:

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- DCA< 1 cm
- PID (pdg code)
- Primary (motherId)

Cuts for sim particles:

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Black box: acceptance window for $v_n(y)$

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(y-pt) distribution, efficiency and δpt (protons)

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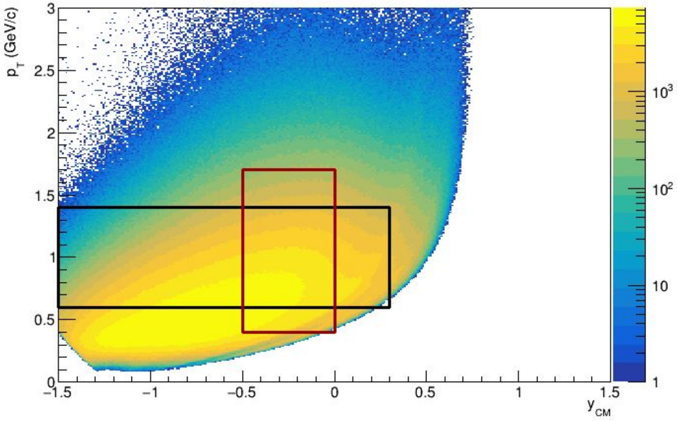
Reconstructed protons Ycm-pT



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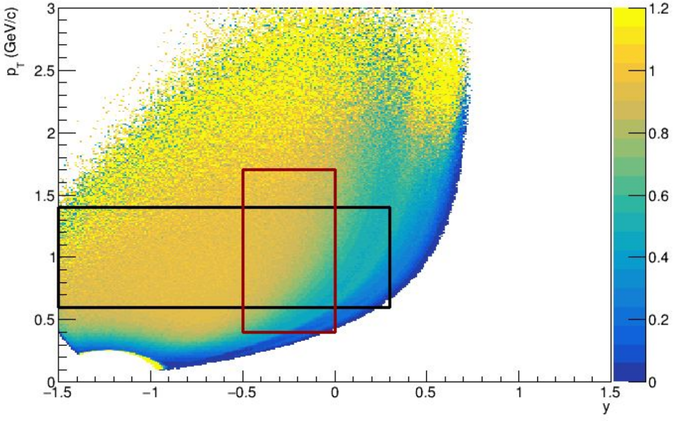
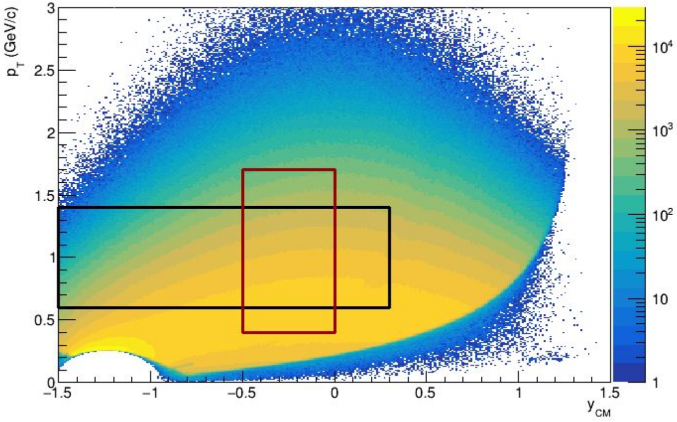
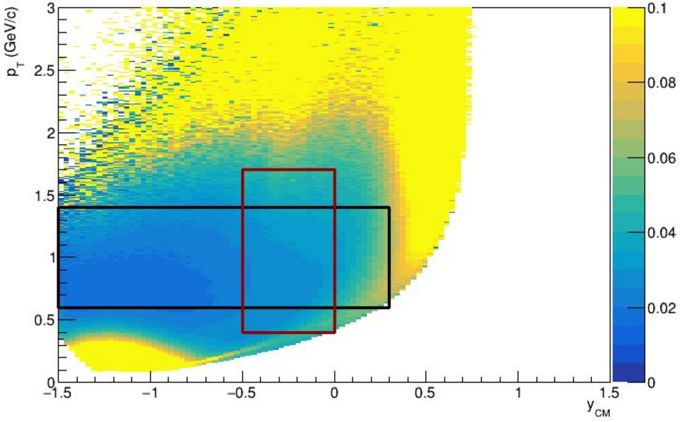


$$\Delta p_T = \frac{\left|p_T^{\mathrm{reco}} - p_T^{\mathrm{mc}}\right|}{p_T^{\mathrm{mc}}}$$

Simulated protons Ycm-pT



Pt-resolution for reconstructed protons in Ycm-pT plane



Bi+Bi $\sqrt{s_{NN}}$=3.5 GeV

Cuts for reco tracks:

- Nhits>27
- DCA< 1 cm
- PID (pdg code)
- Primary (motherId)

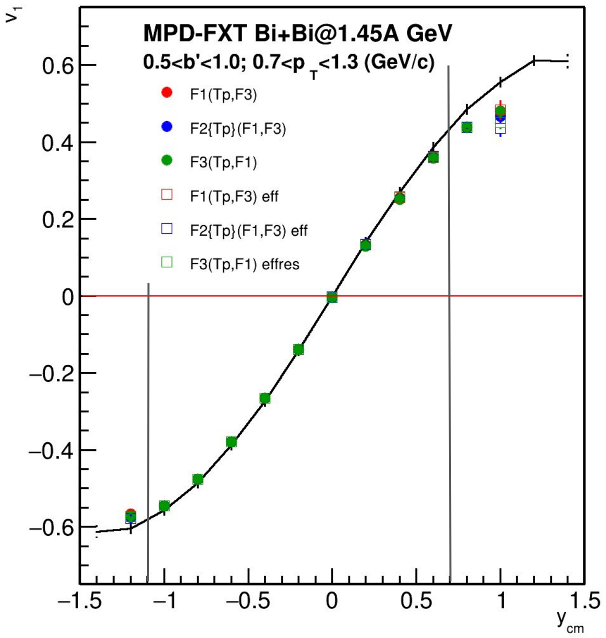
Cuts for sim particles:

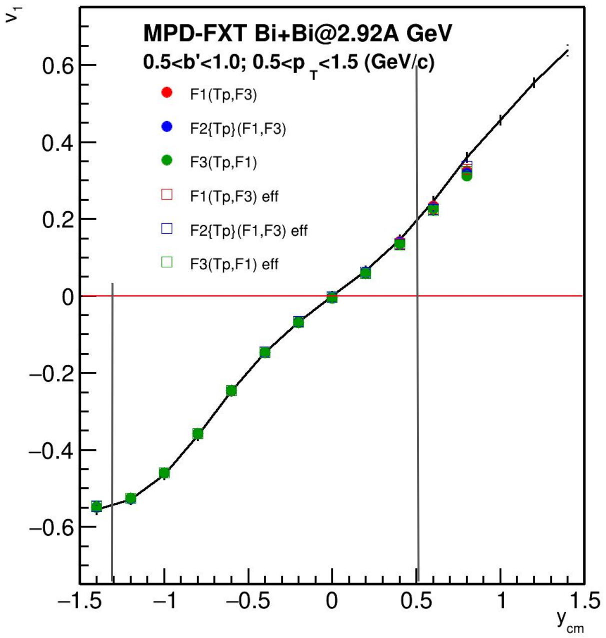
- PID (pdg code)
- Primary (motherId)

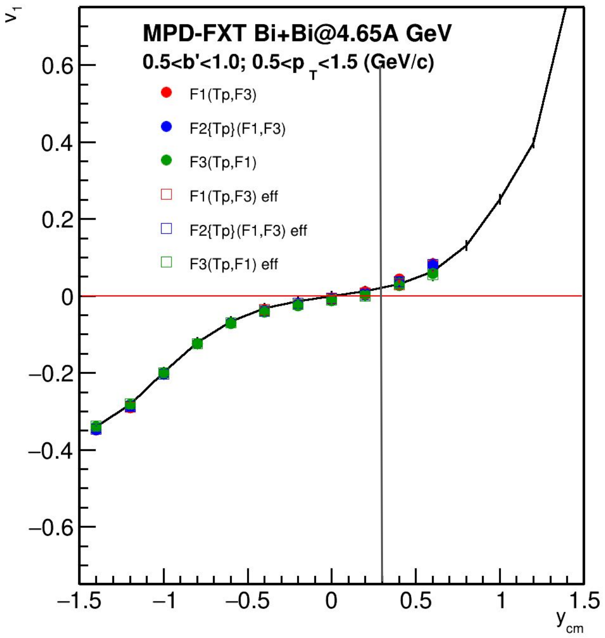
Black box: acceptance window for $v_n(y)$

Red box: acceptance window for $v_n(p_T)$

$v_1(y)$ of protons

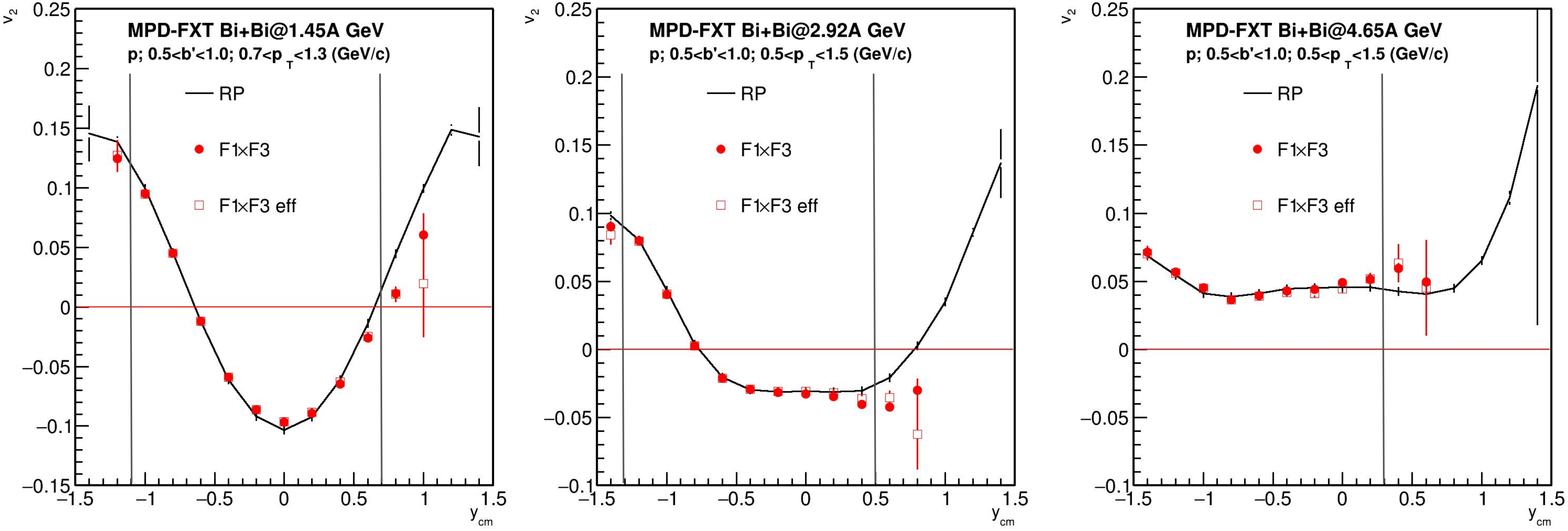






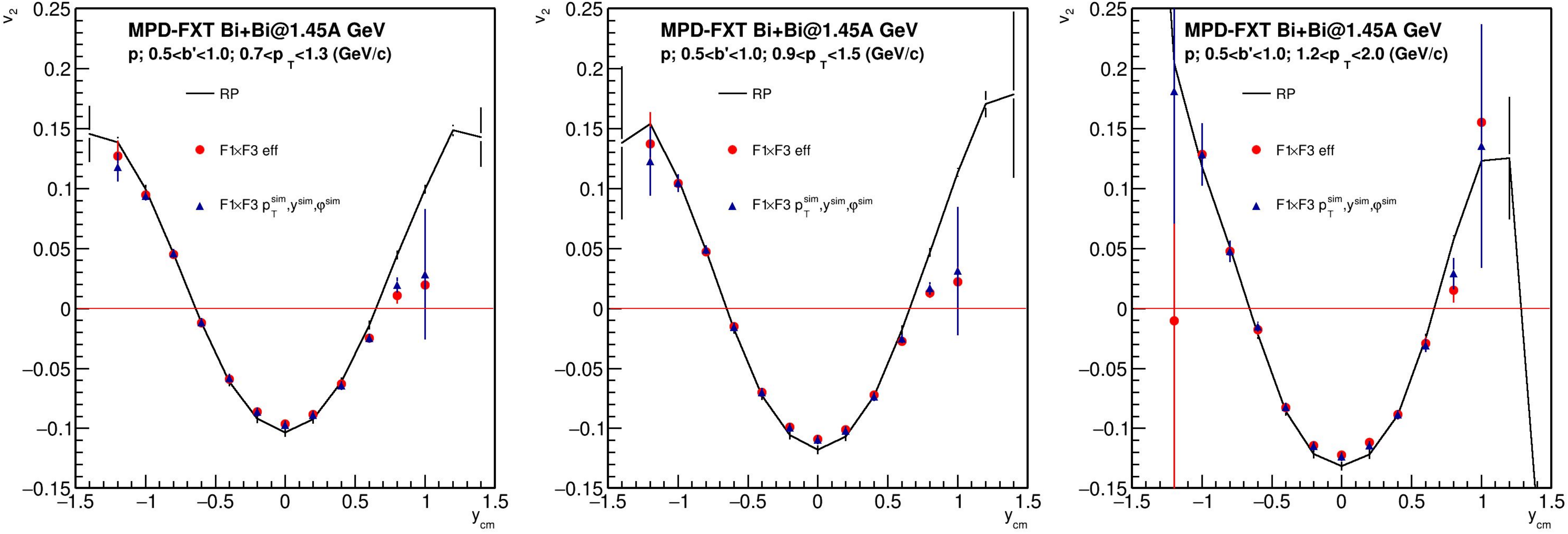
Efficiency corrections have no significant influence

$v_2(y)$ of protons



Efficiency introduces no significant difference

$v_2(y)$ of protons: acceptance vs. resolution

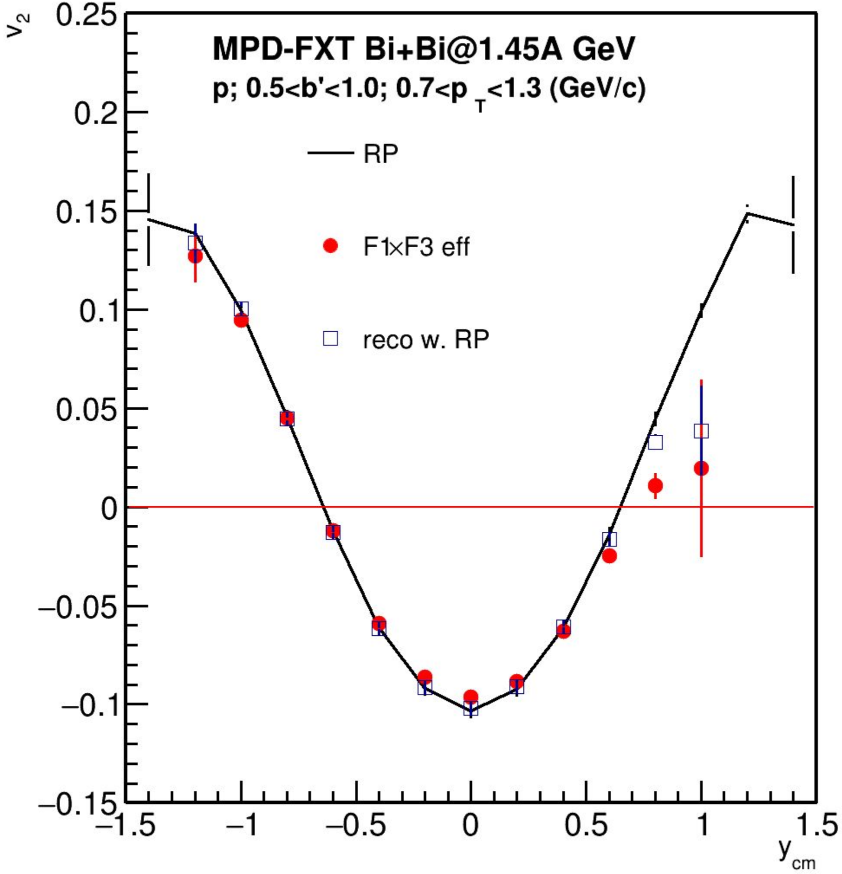


Need more statistics to check

Difference is mostly due to acceptance.

Effects related to the (p_T,y,φ)-resolution are small.

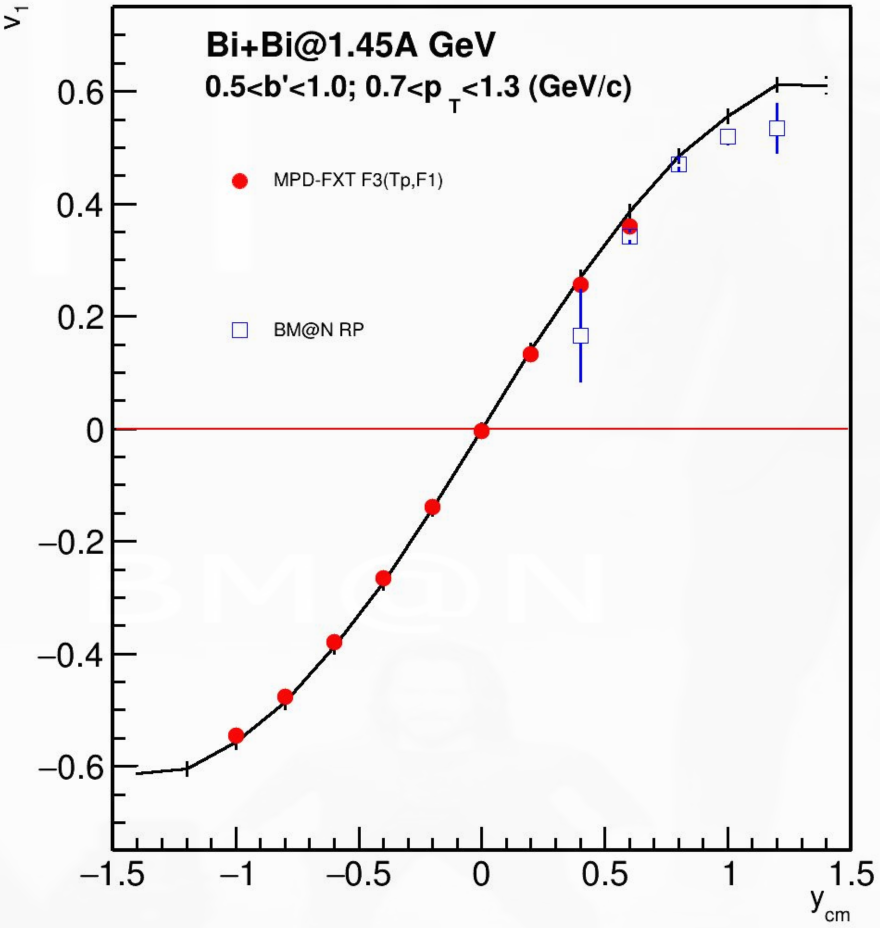
$v_2(y)$ of protons: effect of autocorrelation?



One additional source of the discrepancy might be due to autocorrelation caused by tracks that fall into FHCal: they are both in u- and Q-vectors

Comparison with “reco” results w.r.t. RP suggests that might happen

Comparison with BM@N performance



BM@N TOF system (TOF-400 and TOF-700) has poor midrapidity coverage at $\sqrt{s_{NN}}$ = 2.5 GeV

- One needs to check higher energies ($\sqrt{s_{NN}}$ = 3, 3.5 GeV)
- More statistics are required due to the effects of magnetic field in BM@N:
  - Only “yy” component of <uQ> and <QQ> correlation can be used

Despite the challenges, both MPD-FXT and BM@N can be used in v_n measurements:

- To widen rapidity coverage
- To perform a cross-check in the future

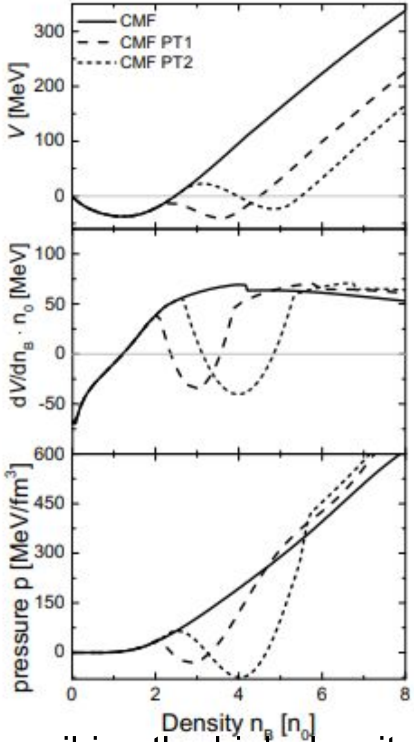
Summary

- Optimal cuts for tracks were provided:
    - Protons
        - Nhits>27
        - DCA<1 cm
- Good agreement between “reco” and “mc” within corresponding acceptance window
- Discrepancy between “reco” and “mc” at forward rapidity:
    - Comparison with associated mc track shows that non-zero (p_T,y,φ)-resolution has small effect on resulted v_n - difference is due to acceptance
    - Possible contribution to the discrepancy from the tracks that fall into FHCal - in progress
- Comparison with BM@N for Bi+Bi at $\sqrt{s_{NN}}$ = 2.5 GeV:
    - BM@N TOF acceptance has poor midrapidity coverage at $\sqrt{s_{NN}}$ = 2.5 GeV
    - Both MPD-FXT and BM@N can be useful for the future flow studies at Nuclotron-NICA

Backup

v_n as a function of collision energy

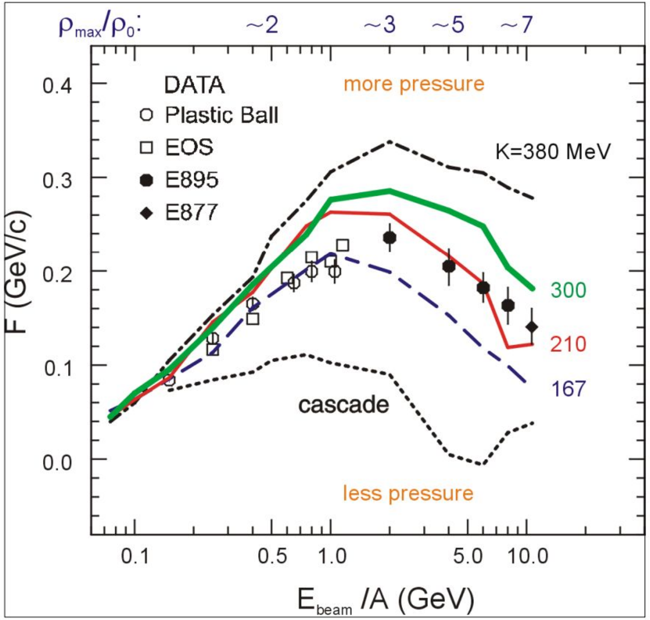
P. DANIELEWICZ, R. LACEY, W. LYNCH
10.1126/science.1078070



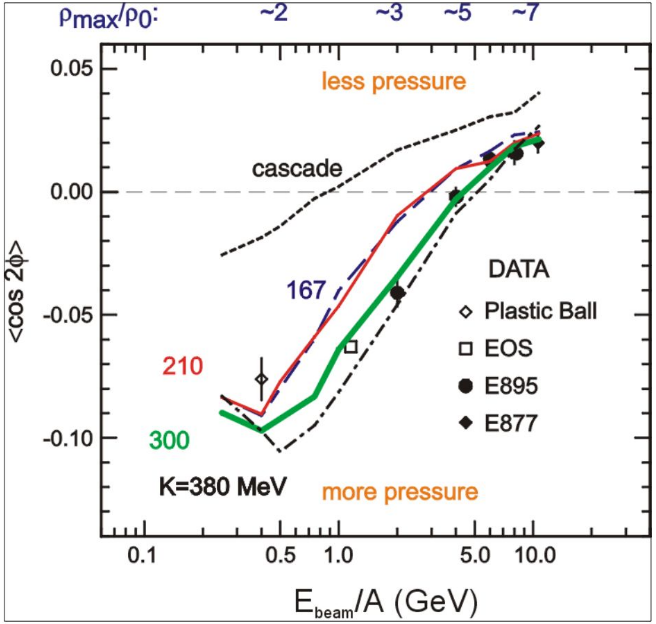
EPJ Web of Conferences 276, 01021 (2023)

Describing the high-density matter using the mean field
Flow measurements constrain the mean field

v_1 suggests softer EOS

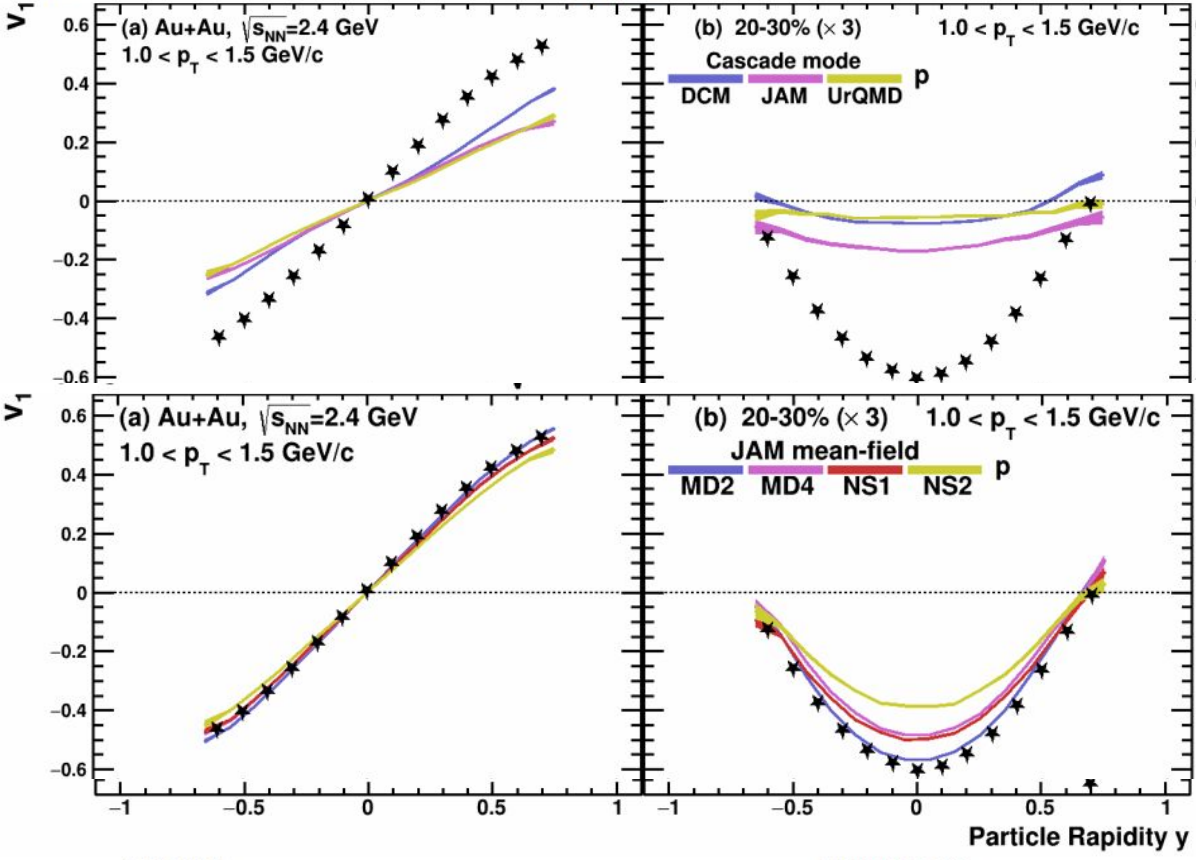


v_2 suggests harder EOS



Discrepancy is probably due to non-flow correlations

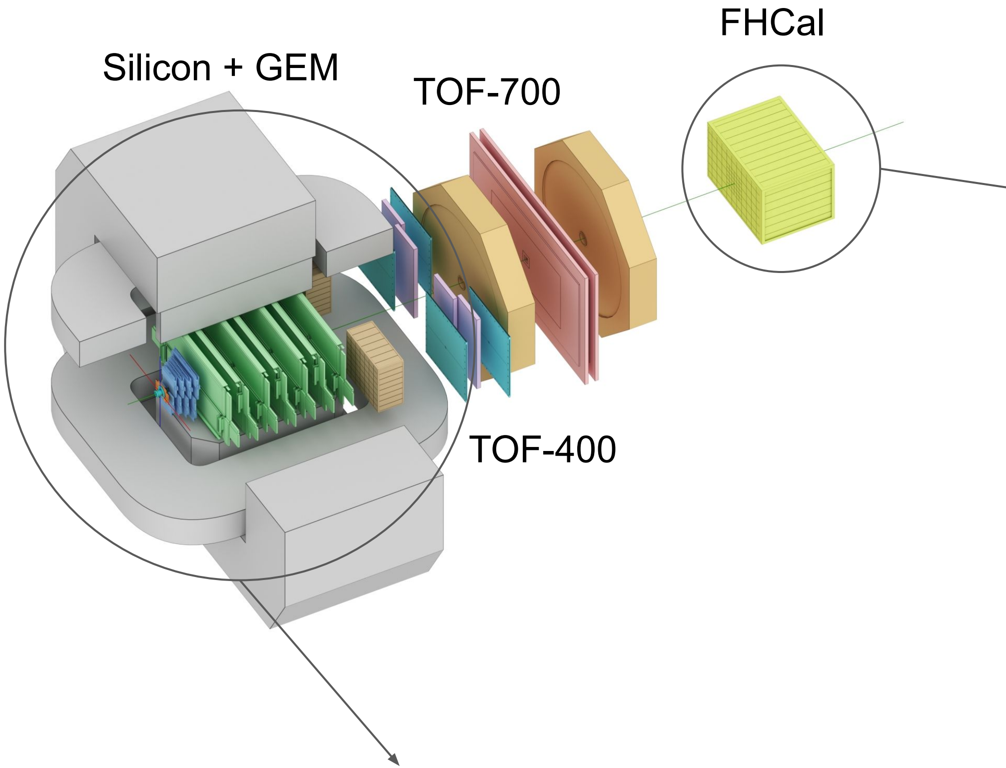
Selecting the model

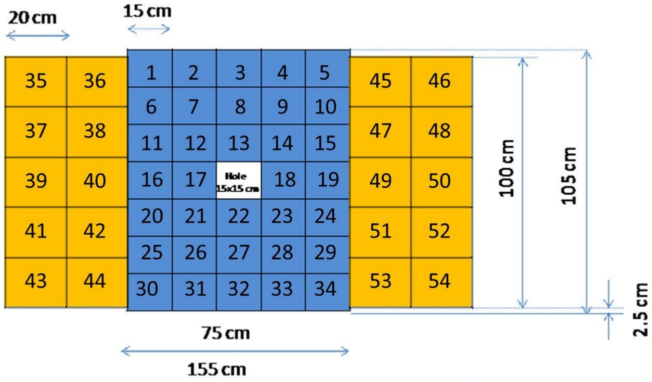

P.Parfenov Particles 5 (2022) 4, 561-579

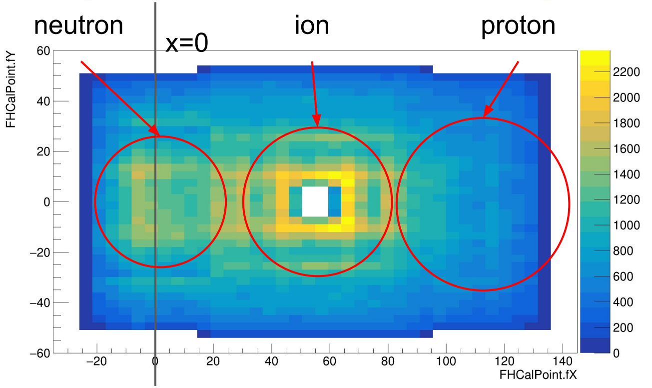
Cascade models fail to reproduce v_n at low-energy heavy-ion collision

Mean field models reproduce the v_n rather well

The BM@N experiment (GEANT4 simulation for RUN8)







Square-like tracking system within the magnetic field deflecting particles along X-axis

Charge splitting on the surface of the FHCal is observed due to magnetic field