Updates on <p_T> fluctuations in $\sqrt{s_{NN}}$ = 3.0 GeV FXT Au+Au

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CF PWG Meeting

Brief Overview

- C_v used to quantify dynamical fluctuations in temperature of the system.
- Effective temperature (T_{eff}).
- Calculated from $<p_T>$ distributions.
- $T_{eff} = T_{kin} + f(\beta_T)$
- T_{kin} obtained from Spectra

$$\frac{1}{C} = \frac{(<T_{kin}^2> - <T_{kin}>^2)}{<T_{kin}>^2} \approx \frac{(<T_{eff}^2> - <T_{eff}>^2)}{<T_{kin}>^2}$$

L. Stodolsky PRL.75.1044

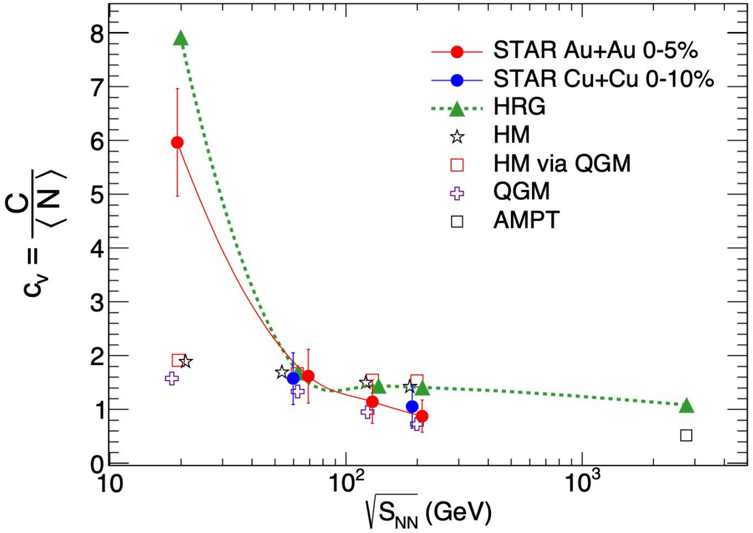
$$C_v = \frac{C}{\Delta}$$

T.K.Nayak et al. PRC.94, 044901 (2016)

- In lattice calculations, $\Delta = VT^3$, although in experiments it's simpler to measure C/N where N is the charged particle multiplicity (N_{ch}).

Brief Overview

- C_v has been calculated with STAR published data at energies 19.6, 62.4, 130 and 200 GeV.
- The experimental values match the prediction from the HRG Model.
- Monotonic increase coming into effect and the analysis at 3 GeV is critical to understand this trend.
- Previous CF talks :
  - https://drupal.star.bnl.gov/STAR/system/files/CF-08_11_22.pdf
  - https://drupal.star.bnl.gov/STAR/system/files/Copy%20of%20CF-09_13_22.pdf
  - https://drupal.star.bnl.gov/STAR/system/files/CF%20-%20Dec822-Rutik.pdf
  - https://drupal.star.bnl.gov/STAR/system/files/Collaboration%20Meeting%20@%20LBNL%20Feb23.pdf



T.K.Nayak et al. PRC.94, 044901 (2016)

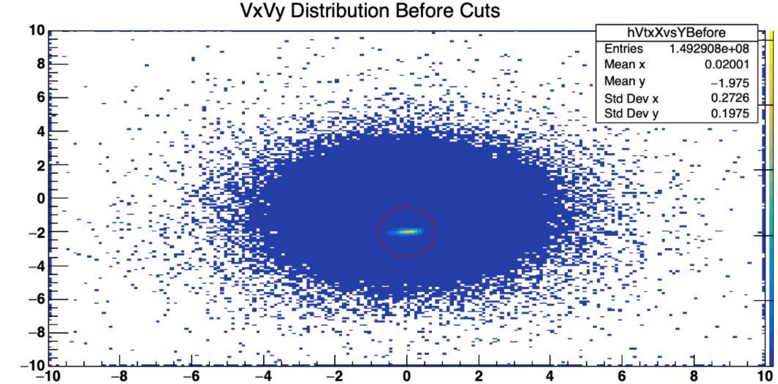
Dataset and Event Cuts

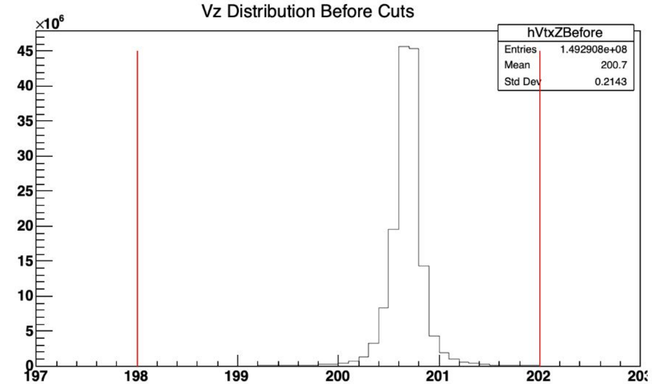
Acceptance Cuts:

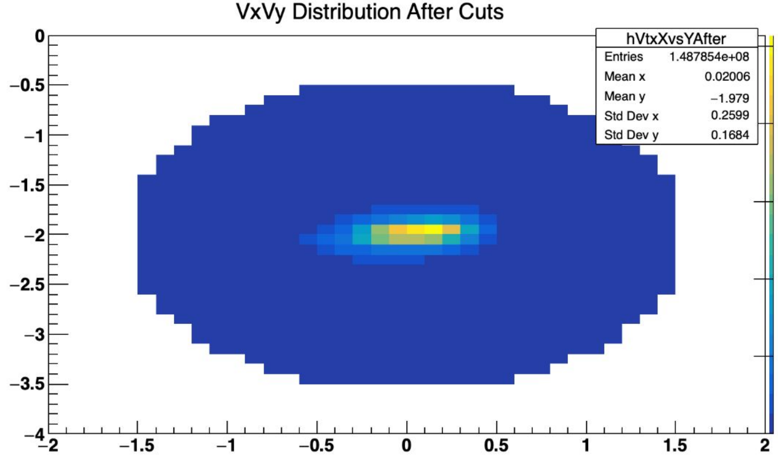
- Fixed Target, run 2018 data production, 3 GeV Au+Au collision, y_c.m. ≈1.05
- Events Cuts:
  - 198 < V_z < 202 cm
  - V_r <1.5 cm about beam spot centered around [0,-2].
  - Trigger ID 620052 and 620053 (Min.Bias)
- Track Cuts:
  - DCA < 3.0 cm
  - NhitsFit/NHitsMax > 0.51
  - NhitsFit > 15

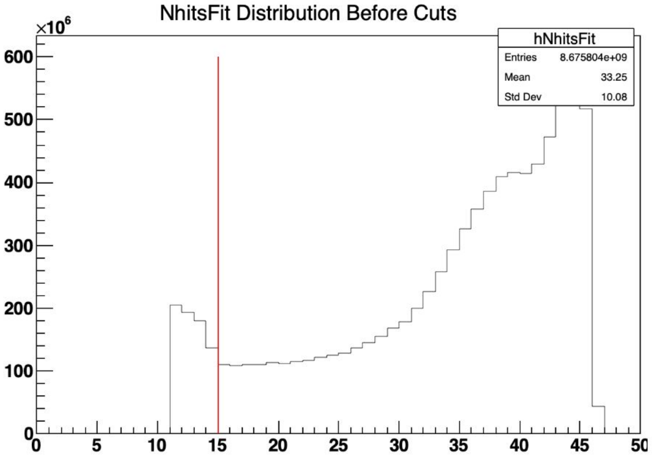
- Good Run List for Fluctuation analyses (149 M HLT Good):
19153029, 19153031, 19153033, 19153034, 19153035, 19153036, 19153037, 19153042,
19153043, 19153044, 19153050, 19153051, 19153052, 19153053, 19153054,19153055,19153056, 19153057, 19153058, 19153059, 19153061, 19153062, 19153063, 19153064,19153066, 19154001, 19154002, 19154005, 19154007, 19154027, 19154028,
19154029,19154030, 19154031, 19154032, 19154036, 19154037, 19154038, 19154039, 19154040,19154041, 19154044, 19154045, 19154046, 19154047, 19154048, 19154049, 19154052,
19154053, 19154054, 19154055, 19154056, 19154057, 19154058, 19154061, 19154063,19154064, 19154065, 19154066, 19154067, 19155001, 19155003, 19155004, 19155005,19155006, 19155008, 19155009, 19155010, 19155011, 19155016, 19155017,
19155018,19155019, 19155020, 19155021, 19155022

QA Plots


VxVy Distribution Before Cuts
hVtxXvsYBefore
Entries 1.492908e+08
Mean x 0.02001
Mean y −1.975
Std Dev x 0.2726
Std Dev y 0.1975


Vz Distribution Before Cuts
hVtxZBefore
Entries 1.492908e+08
Mean 200.7
Std Dev 0.2143

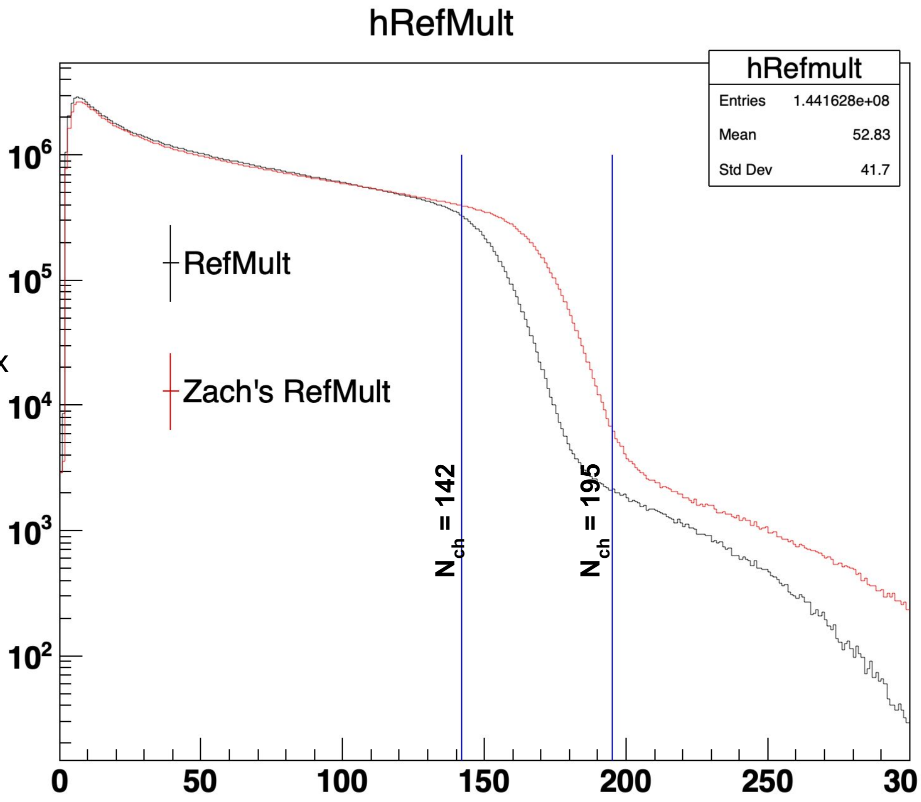

VxVy Distribution After Cuts
hVtxXvsYAfter
Entries 1.487854e+08
Mean x 0.02006
Mean y −1.979
Std Dev x 0.2599
Std Dev y 0.1684


NhitsFit Distribution Before Cuts
hNhitsFit
Entries 8.675804e+09
Mean 33.25
Std Dev 10.08

QA Plots

<u>Zach's RefMult:</u>
- All primary tracks

<u>My RefMult:</u>
- All primary tracks
- DCA <3.0
- NhitsFit/NHitsMax > 0.51



Centrality Low	Centrality High	Number of Events
0	5	1.04E+07
5	10	1.06E+07
10	15	1.01E+07
15	20	9.82E+06
20	25	1.05E+07
25	30	1.02E+07
30	35	9.61E+06
35	40	9.75E+06
40	45	9.85E+06
45	50	9.92E+06
50	55	8.17E+06
55	60	9.51E+06
60	65	9.00E+06
65	70	7.74E+06
70	75	5.42E+06
75	80	4.87E+06

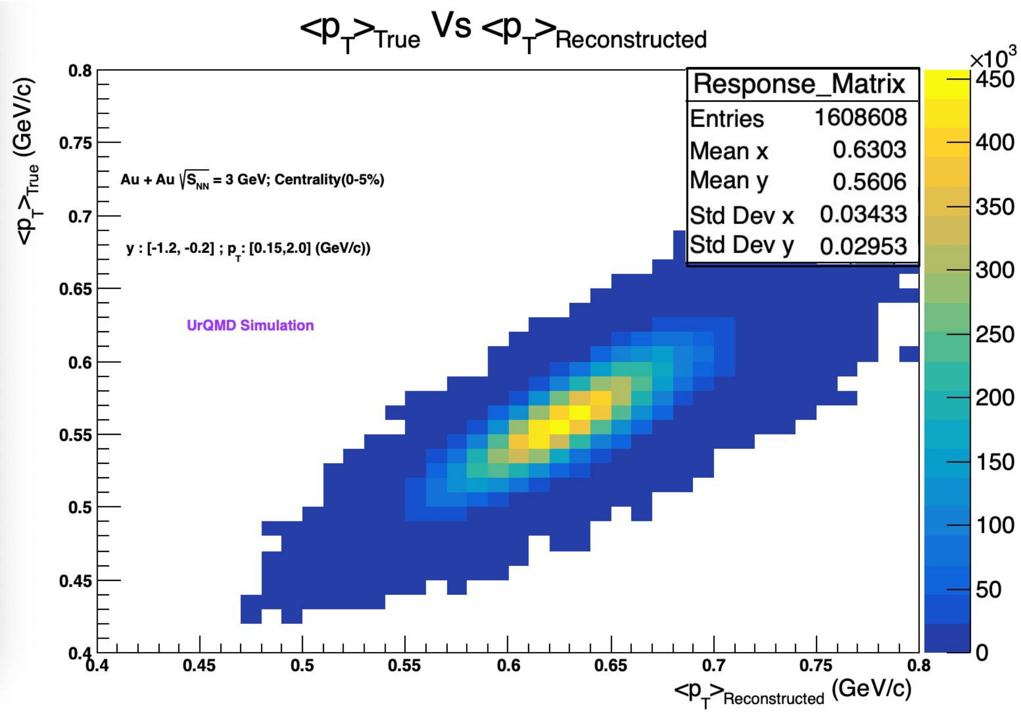
Closure Test for Unfolding Method

- A Closure test was performed on UrQMD Data using Unfolding

- For the Closure test, the detector like events had to be made:

Step 1	Step 2	Step 3	**Detector Like Events from UrQMD**
Calculate efficiency as a function of Pid and p_T, for a track. ($\boldsymbol{\varepsilon}$)	Generate a random number between [0,1]. (r)	Keep the particle if efficiency is greater than the random number. ($r < \boldsymbol{\varepsilon}$)	

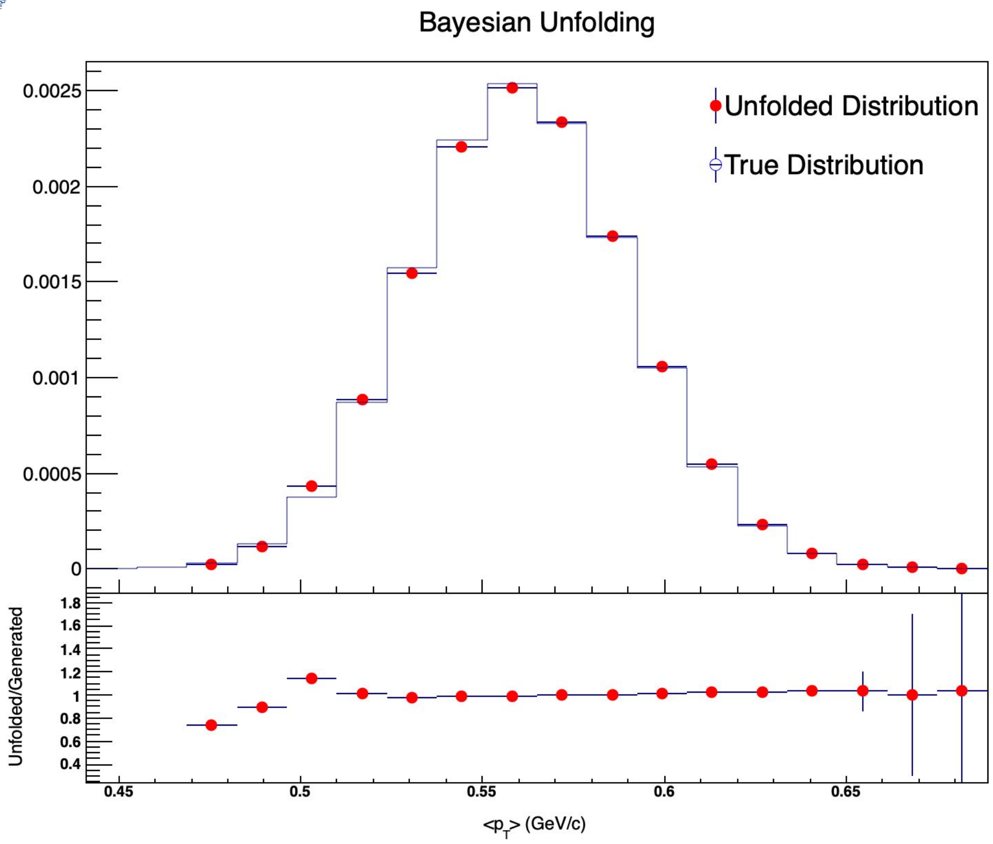
Closure Test for Unfolding Method



The response matrix was calculated from UrQMD at 3 GeV, using the same cuts as the analysis:

- ❖ $0.15 < p_T < 2.0$ (GeV/c)
- ❖ All primary Charged particles.
- ❖ $-1.2 < y < -0.2$
- ❖ 56% of total data (from UrQMD)
- ❖ 40 bins between 0.4-0.8 (GeV/c)
- ❖ With the remaining 44% Closure test was performed.

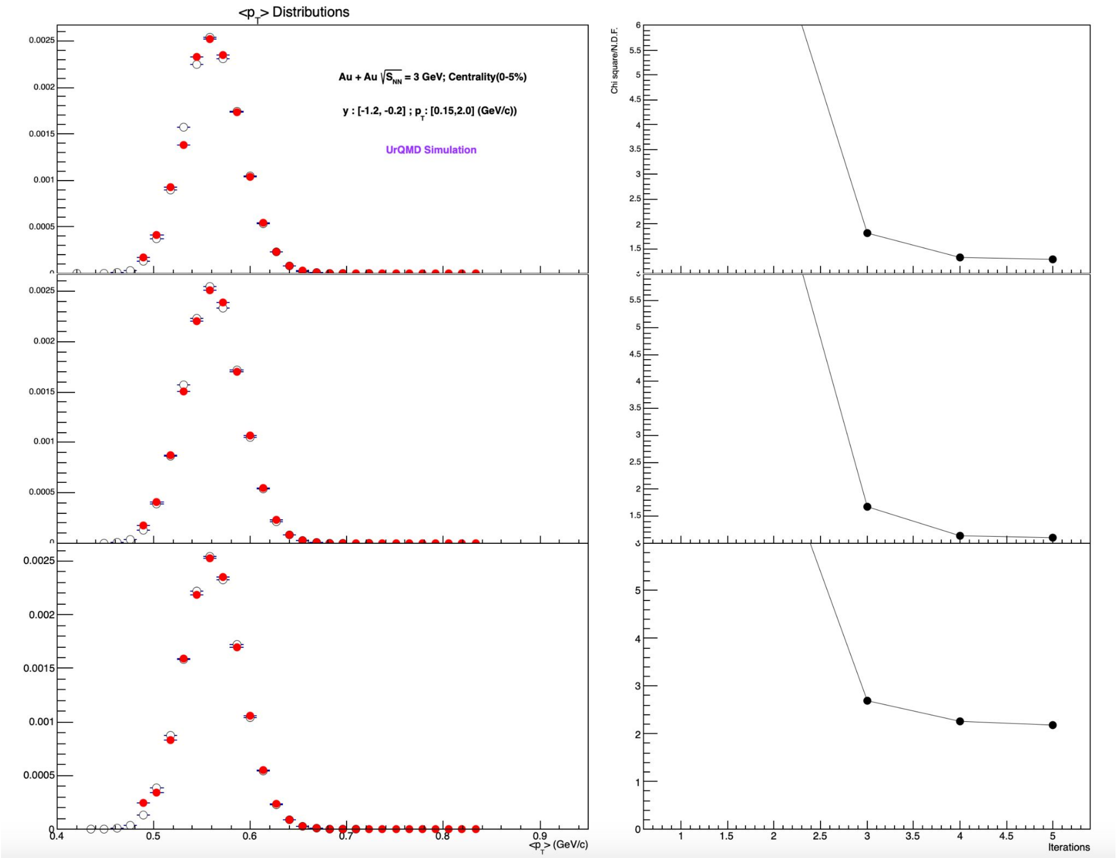
Closure Test for Unfolding Method



Statistical Bootstrap for the Closure Test, divided the testing set into 10 samples.

	Generated	Unfolded
Mean	0.5606 ± 2e-4	0.5608 ± 3e-4
Sigma	0.02949 ± 2e-4	0.02984 ± 3e-4

Closure Test for Unfolding Method

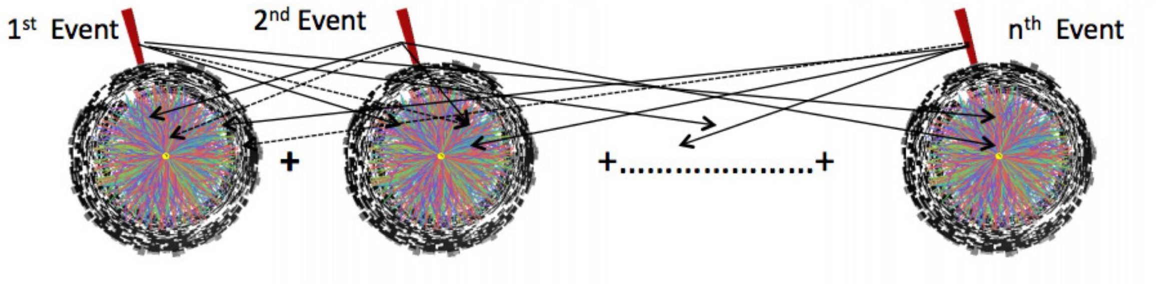


Statistical Bootstrap for the Closure Test, divided the testing set into 10 samples.

	Generated	Unfolded
Mean	0.5606 ± 2e-4	0.5608 ± 3e-4
Sigma	0.02949 ± 2e-4	0.02984 ± 3e-4

Mixed Event Analysis for $\langle p_T \rangle$

- In order to establish whether the observed fluctuations are partly dynamical in nature, we need to disentangle statistical effects i.e. effects due to the finite number of particles in the final state of the collision.
- The Mixed event construction makes synthetic events with tracks from different events to remove any kind of correlations.



The schematic representation of mixed events

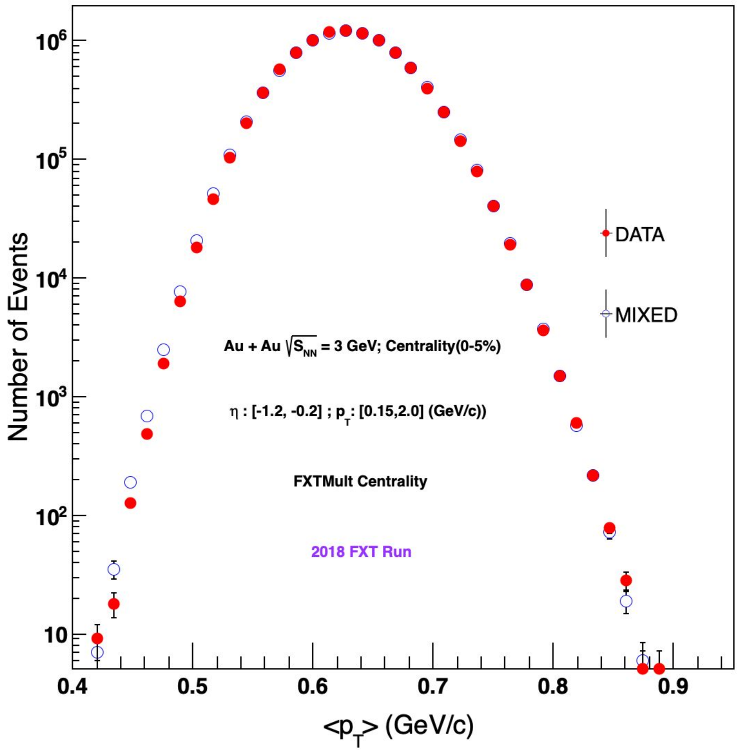
Mixed Event Analysis for $\langle p_T \rangle$

FXTMult $\langle p_T \rangle$ Distributions,

- All primary Charged particles.
- $0.15 < p_T < 2.0$ (GeV/c)
- $-1.2 < \eta < -0.2$

*10 M Events

Reconstructed $\langle p_T \rangle$



Dynamical Fluctuations from $<p_T>$

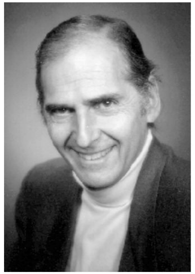
We fit the $<p_T>$ distributions with the gamma function to obtain the mean and sigma

$$f(x) = \frac{x^{\alpha-1} e^{\frac{-x}{\beta}}}{\Gamma(\alpha)\beta^{\alpha}}$$

From the fit parameters α, $\boldsymbol{\beta}$
We can calculate μ and σ:

- $\mu = \alpha\boldsymbol{\beta}$
- $\sigma^2 = \alpha\boldsymbol{\beta}^2$

It's not a Gaussian…it's a Gamma distribution!



$$\sigma_{dyn} = \sqrt{\left(\frac{\sigma_{data}}{\mu_{data}}\right)^2 - \left(\frac{\sigma_{mix}}{\mu_{mix}}\right)^2}$$

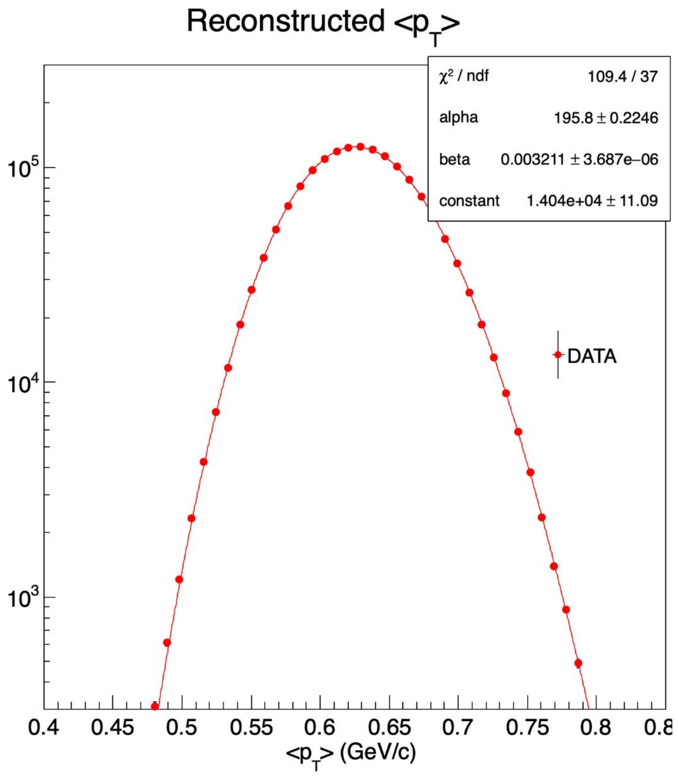
Dynamical Fluctuations from $\langle p_T \rangle$

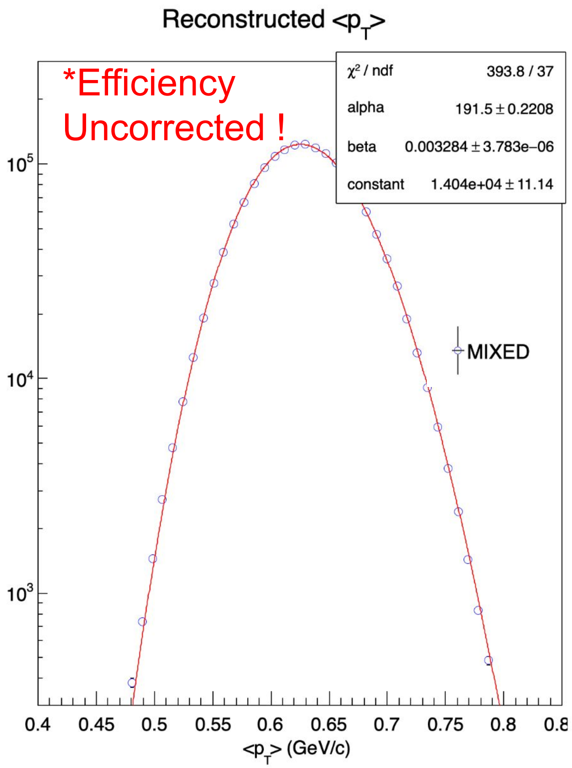
Data_Mean = 0.6289 +/- 0.001
Data_Sigma = 0.0449 +/- 7e-5

Mixed_Mean = 0.6287 +/- 0.001
Mixed_Sigma = 0.0454 +/- 7e-5

FXTMult $\langle p_T \rangle$ Distributions, All charged particles.

- Primary Charged particles.
- $0.15 < p_T < 2.0$ (GeV/c)
- $-1.2 < \eta < -0.2$





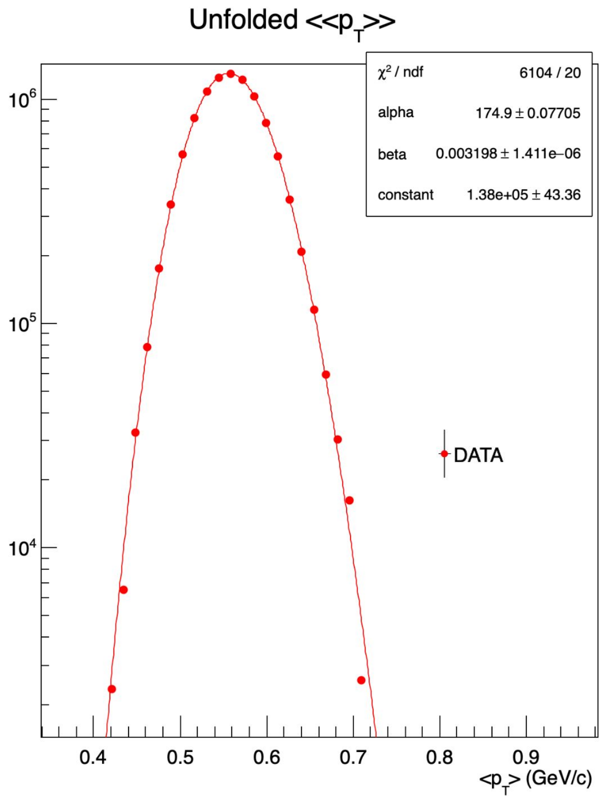
Dynamical Fluctuations from <p_T>

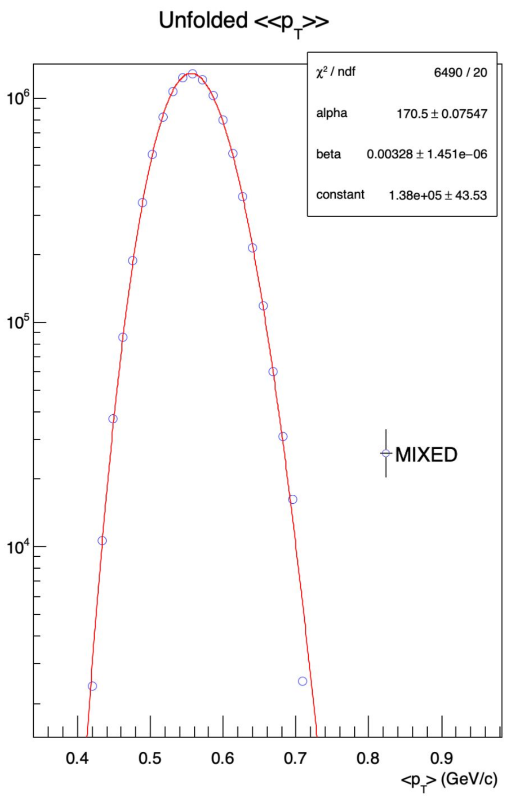
Data_Mean = 0.5593 +/- 0.004
Data_Sigma = 0.0423 +/- 2e-5

Mixed_Mean = 0.5593 +/- 0.004
Mixed_Sigma = 0.0428 +/- 3e-5

FXTMult <p_T> Distributions, All charged particles.

- Primary Charged particles.
- $0.15 < p_T < 2.0$ (GeV/c)
- $-1.2 < \eta < -0.2$

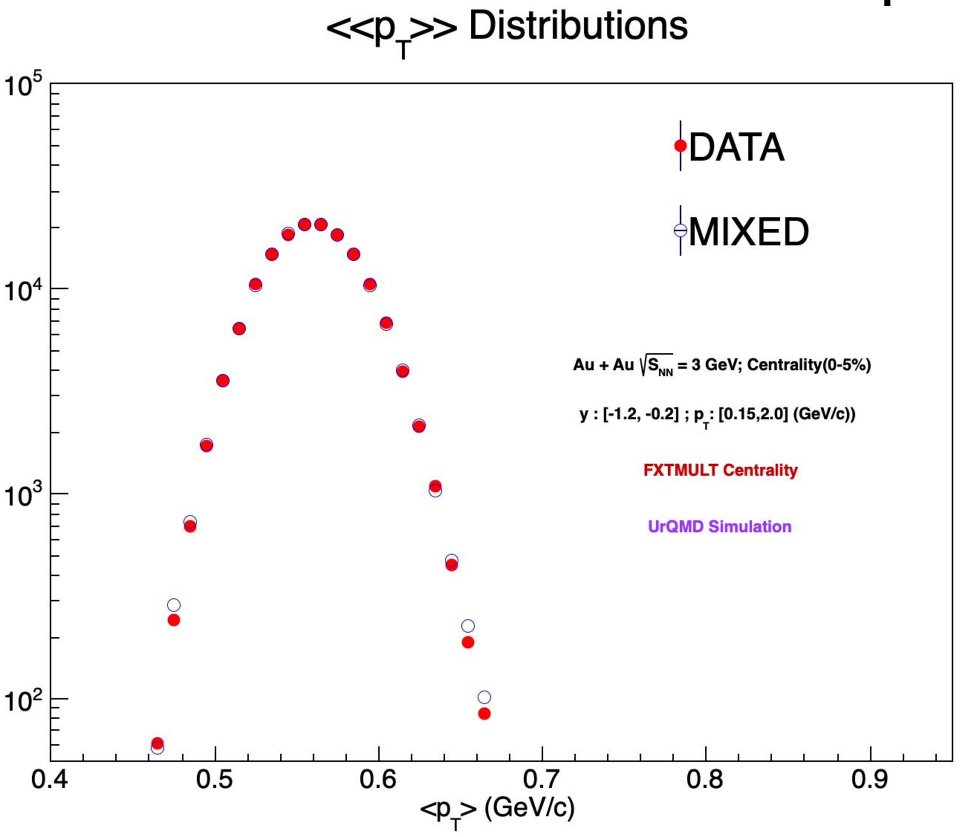




Dynamical Fluctuations from <p_T>

- **UrQMD** Mixing of events, 150K events
- 0-5% -> [0.0,3.45) fm (b)
- No detector effects taken into account

	Data	Mixed
Mean	0.5608	0.5607
Sigma	0.02961	0.02975



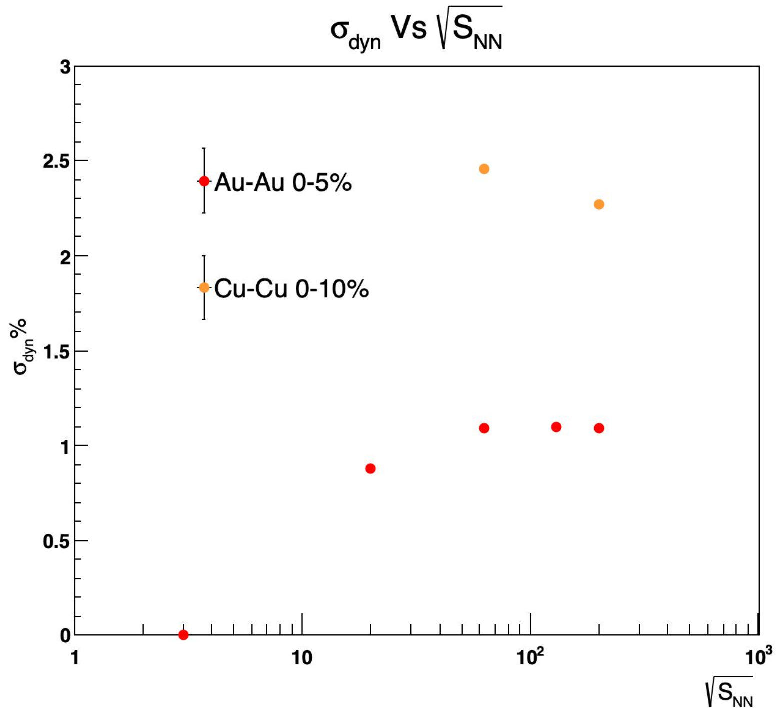
Comparison to Published data

Case	μ	σ
20 GeV, real	0.5228	0.01579
20 GeV, mixed	0.5227	0.01510
62 GeV, real	0.5471	0.01439
62 GeV, mixed	0.5470	0.01310
130 GeV, real	0.5614	0.01423
130 GeV, mixed	0.5612	0.01282
200 GeV, real	0.5799	0.01347
200 GeV, mixed	0.5799	0.01190

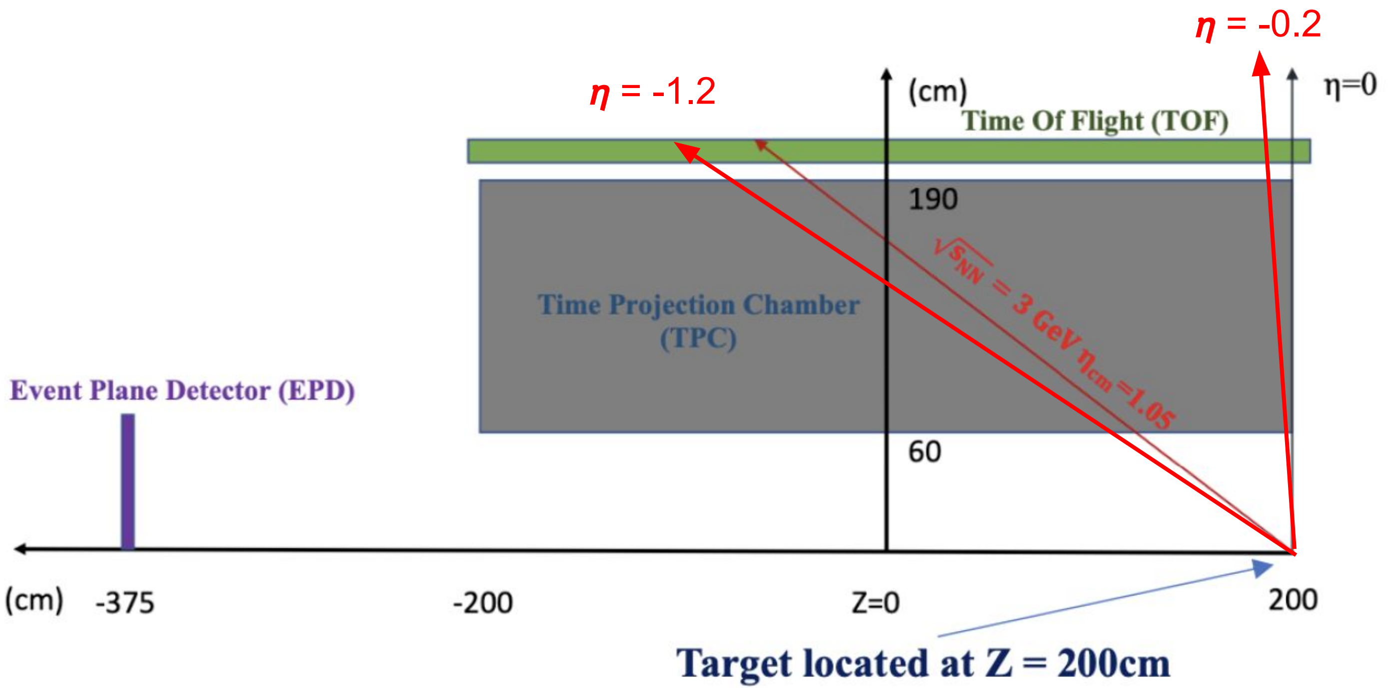
PHYSICAL REVIEW C 72, 044902 (2005)

***This work**

	μ	σ
3 GeV, real	0.5593	0.0423
3 GeV, mixed	0.5593	0.0428



FXT Convention

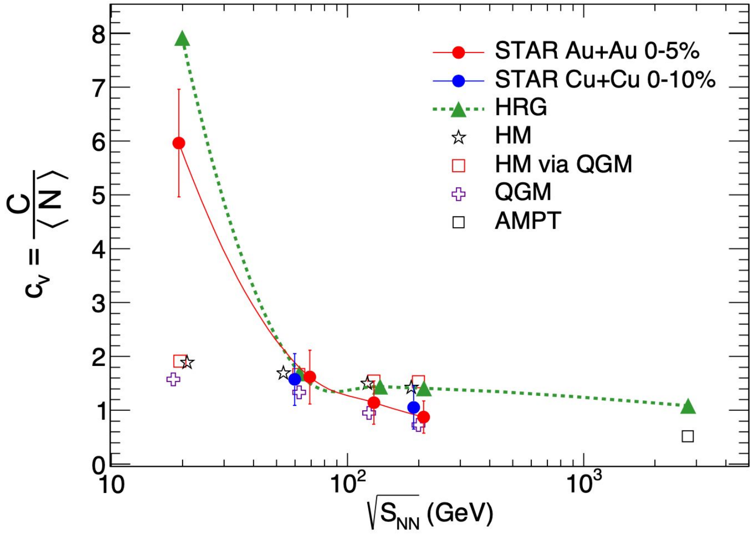


Outlook

1. Study the effect of primordial protons on <p_T> fluctuations.

2. Study the eta window acceptance effect.

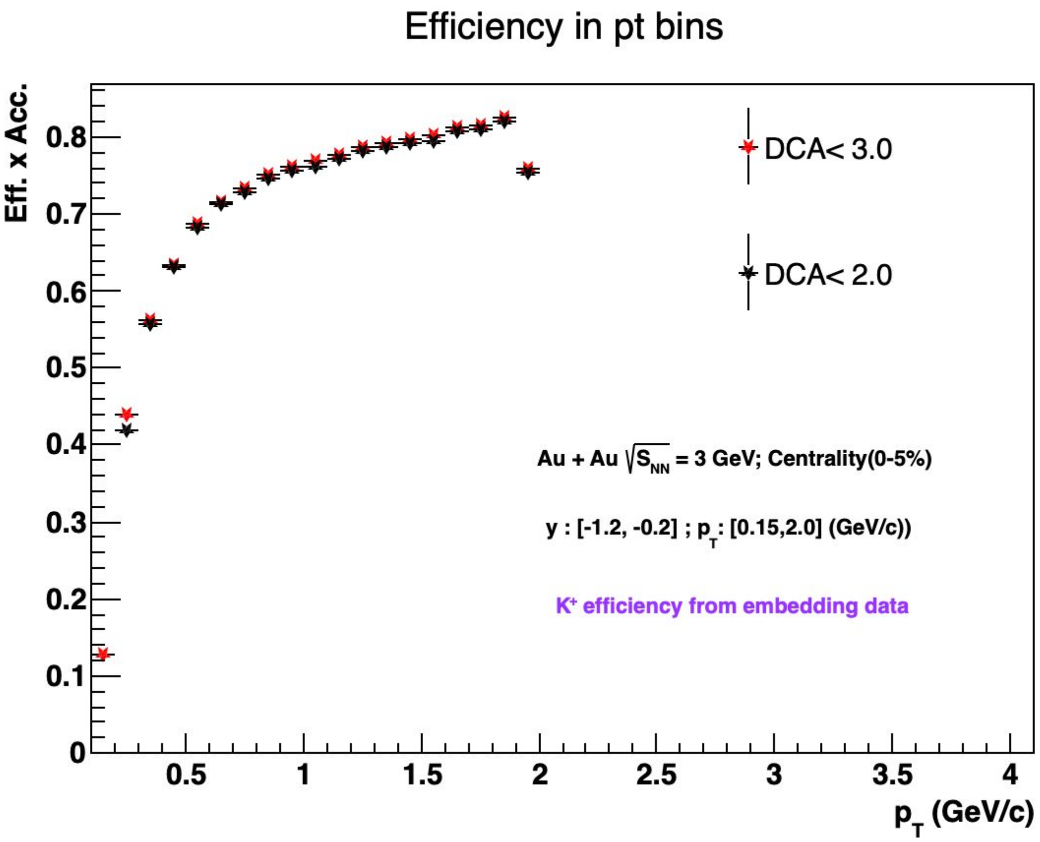
3. Error calculation, systematics



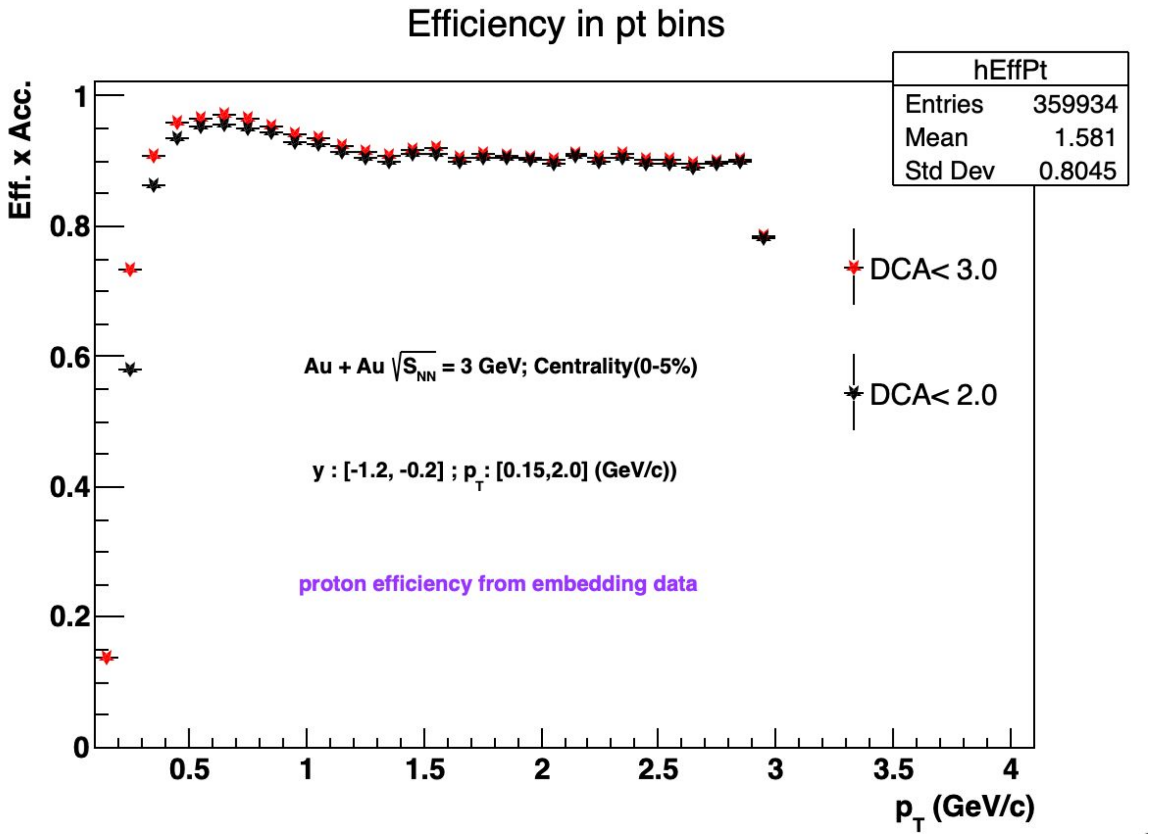
T.K.Nayak et al. PRC.94, 044901 (2016)

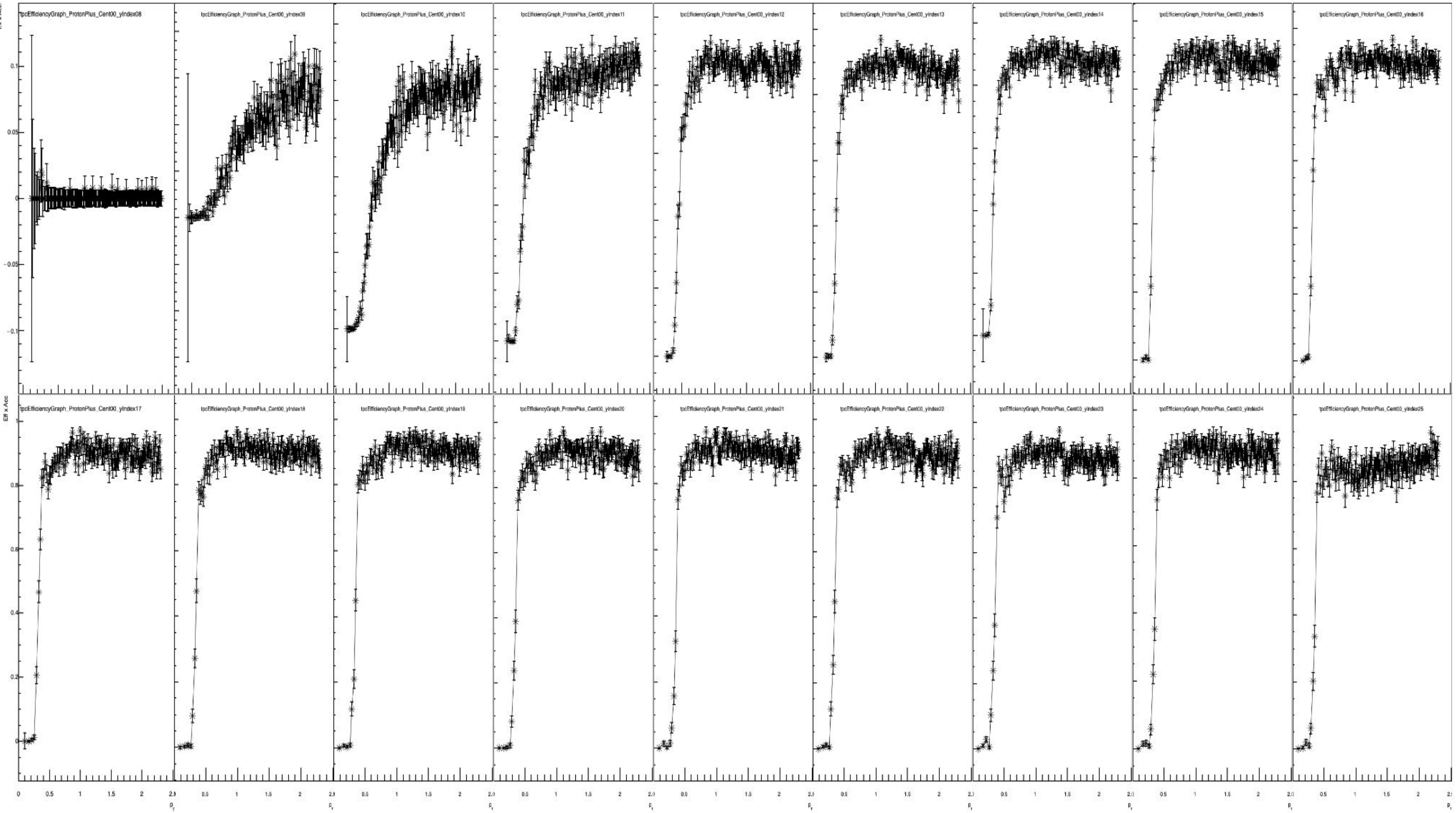
Thank you for your attention

Efficiency plots from embedding



Efficiency plots from embedding





tpcEfficiencyGraph_ProtonPlus_Cent00_yIndex08
tpcEfficiencyGraph_ProtonPlus_Cent00_yIndex09
tpcEfficiencyGraph_ProtonPlus_Cent00_yIndex10
tpcEfficiencyGraph_ProtonPlus_Cent00_yIndex11
tpcEfficiencyGraph_ProtonPlus_Cent00_yIndex12
tpcEfficiencyGraph_ProtonPlus_Cent00_yIndex13
tpcEfficiencyGraph_ProtonPlus_Cent00_yIndex14
tpcEfficiencyGraph_ProtonPlus_Cent00_yIndex15
tpcEfficiencyGraph_ProtonPlus_Cent00_yIndex16
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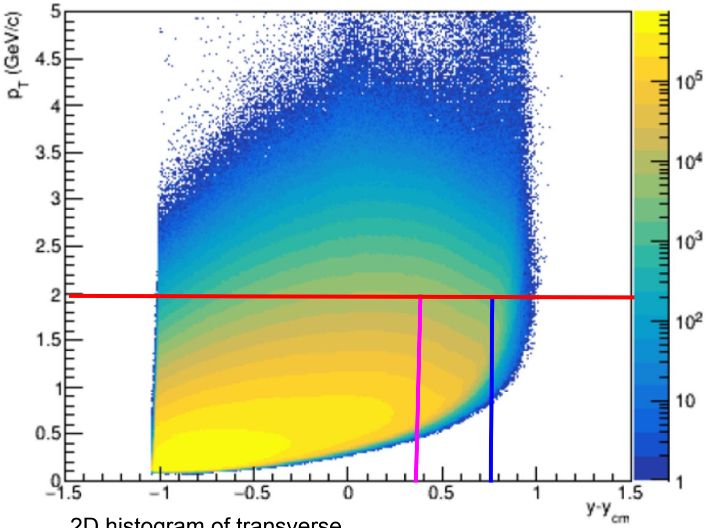
tpcEfficiencyGraph_ProtonPlus_Cent00_yIndex23
tpcEfficiencyGraph_ProtonPlus_Cent00_yIndex24
tpcEfficiencyGraph_ProtonPlus_Cent00_yIndex25
Eff x Acc.
p_T

Eta Study

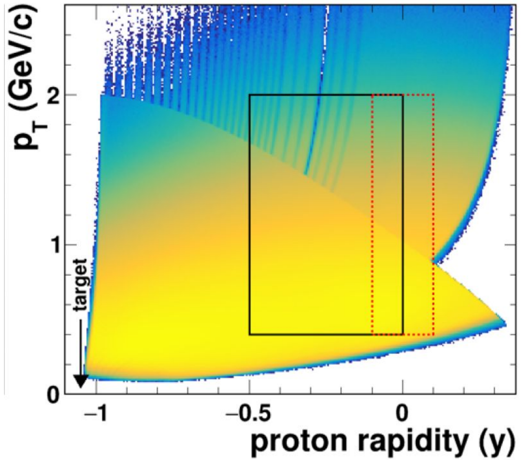
To suppress the spectator protons from entering the analysis, the maximum rapidity range is restricted to $-0.5 < y < 0$.

$y_{cm} = 1.05$

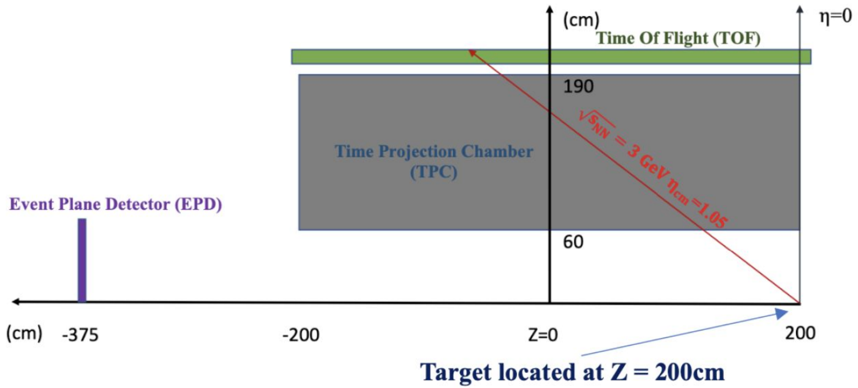
Physical Review Letters 128, 202303 (2022)



2D histogram of transverse momentum vs proton rapidity for proton tracks in the TPC.



Eta Study



Unlike collider mode collisions, the target is located at the edge of TPC, and the midrapidity is not zero in the FXT model collisions in the STAR coordinate system. In order to convert the measured rapidity y in the coordinate system to the rapidity y in the center of mass frame. One need to boost the measured rapidity by beam rapidity.

$$y_{CM} = -(y_{lab} - y_{mid})$$

In our STAR convention, the beam-going direction is the positive direction (the target is located in the negative rapidity direction y_{target} = -1.045).

In order to match the STAR conventions, when calculating rapidity in center of mass frame, in addition to shift by midrapidity, we also need to flip the sign of rapidity.

In the STAR coordinate system,
the target located at Z=200cm the edge of TPC. The EPD located at -375 cm. Red line indicates η_{cm}= 1.05 and it is roughly midrapidity region.

Eta Study

To suppress the spectator protons from entering the analysis, the maximum rapidity range is restricted to −0.5 < y < 0.
The target is located at y = −1.05

Physical Review Letters 128, 202303 (2022)

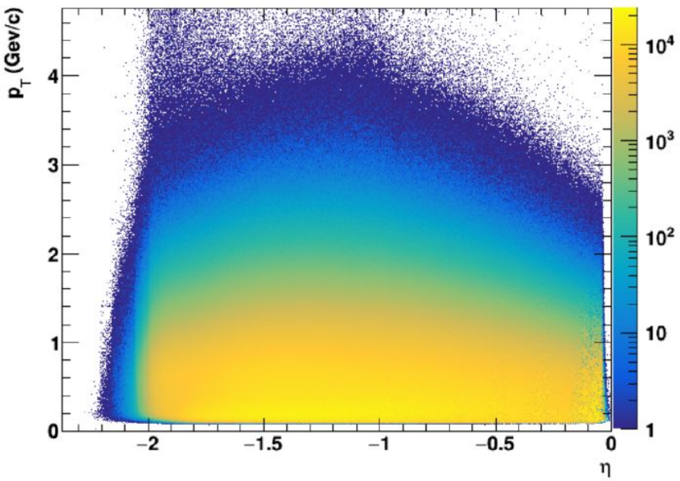
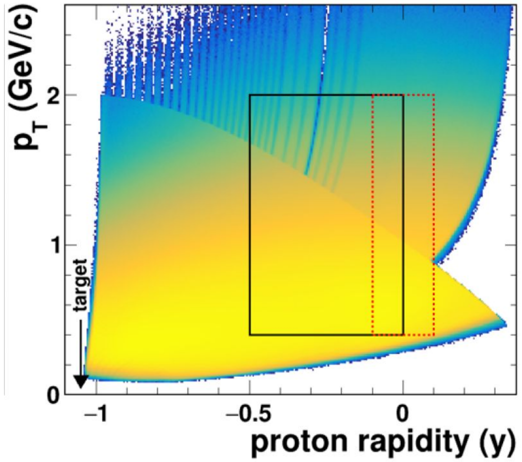


FIG. 1: Pseudorapidity acceptance of the TPC. For the FxtMult definition, primary tracks from $-2 < \eta < 0$ with $NHitsFit/NHitsMax > 0.51$ and tracks within $198 < V_z < 202$ cm are included. FxtMult3 requires an additional cut of $n\sigma Proton < -3$ for positively charged tracks.

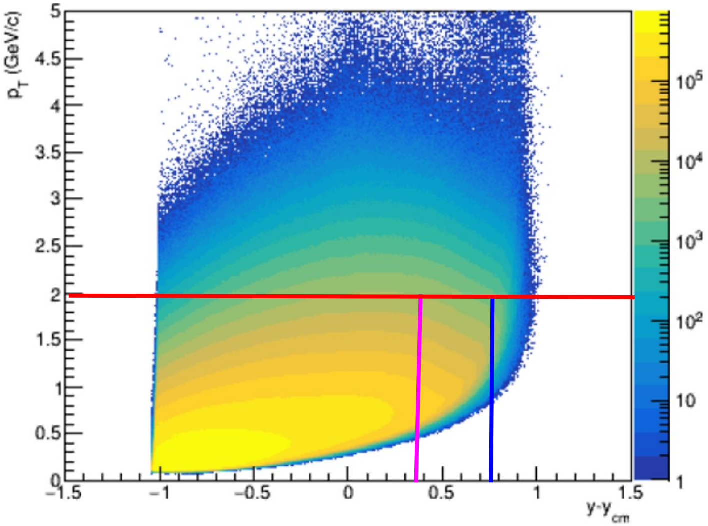


Eta Study

To suppress the spectator protons from entering the analysis, the maximum rapidity range is restricted to −0.5 < y < 0.
The target is located at y = −1.05

Physical Review Letters 128, 202303 (2022)

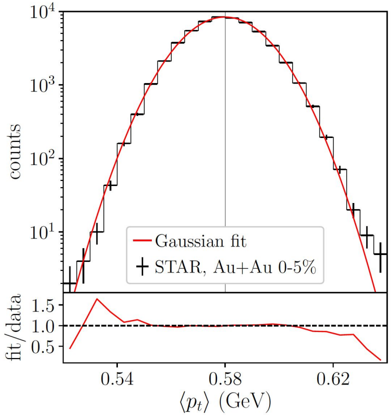
We predict, in particular, that pT fluctuations have positi ve skew, which is significantly larger than if particles were emitted independently. We elucidate the origin of this result by deriving generic formulas relating the fluctuations of pT to the fluctuations of the early-time thermodynamic quantities. We postulate that the large positive skewness of pT fluctuations is a generic prediction of hydrodynamic models.



2D histogram of transverse momentum vs proton rapidity for proton tracks in the TPC.

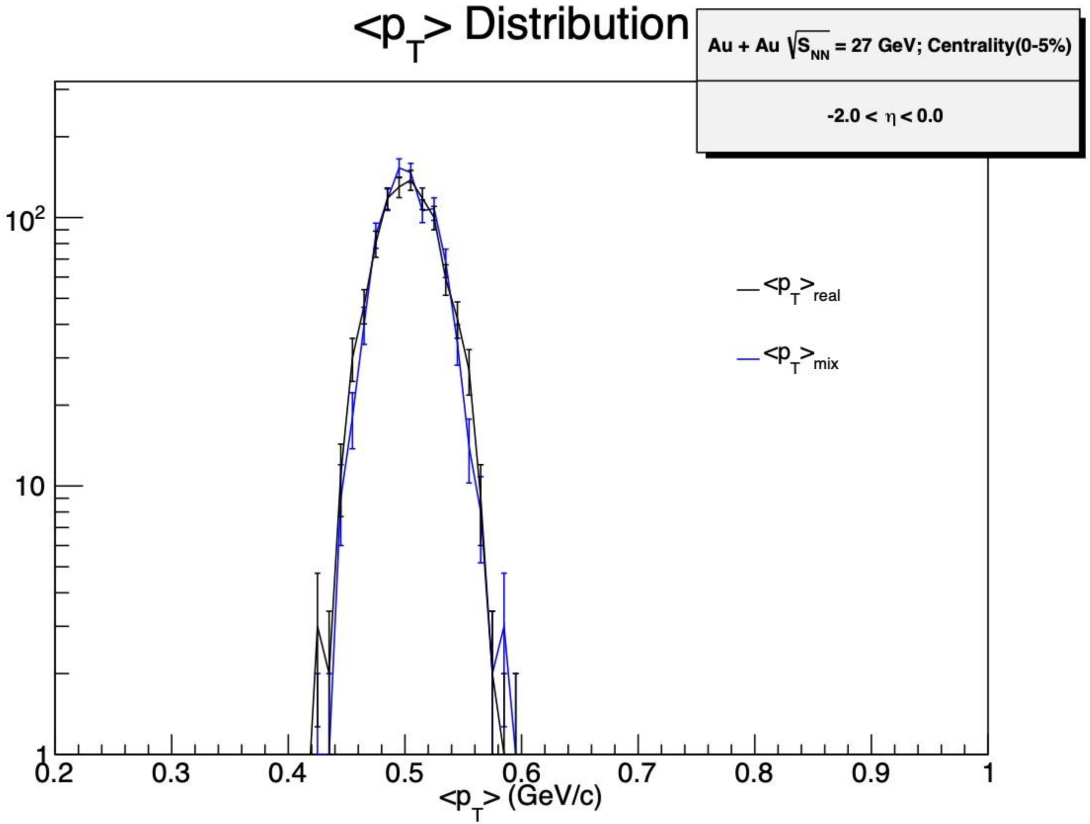
PHYSICAL REVIEW C 103, 024910 (2021)

FIG. 1. Distribution of $\langle p_t \rangle$ for Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV in the 0–5% centrality window. Data from the STAR Collaboration [2] are shown as a histogram. The solid line is a Gaussian fit to these data. The lower panel is the ratio between the Gaussian fit and the data. The data are above the Gaussian to the right and below the Gaussian to the left, which hints at a positive skew.



- A small subset of 27 GeV is taken for analysis.

- The event cuts and track cuts are from Chun-Jian. (https://drupal.star.bnl.gov/STAR/system/files/BES_200_54_27_meanpT_0119.pdf)



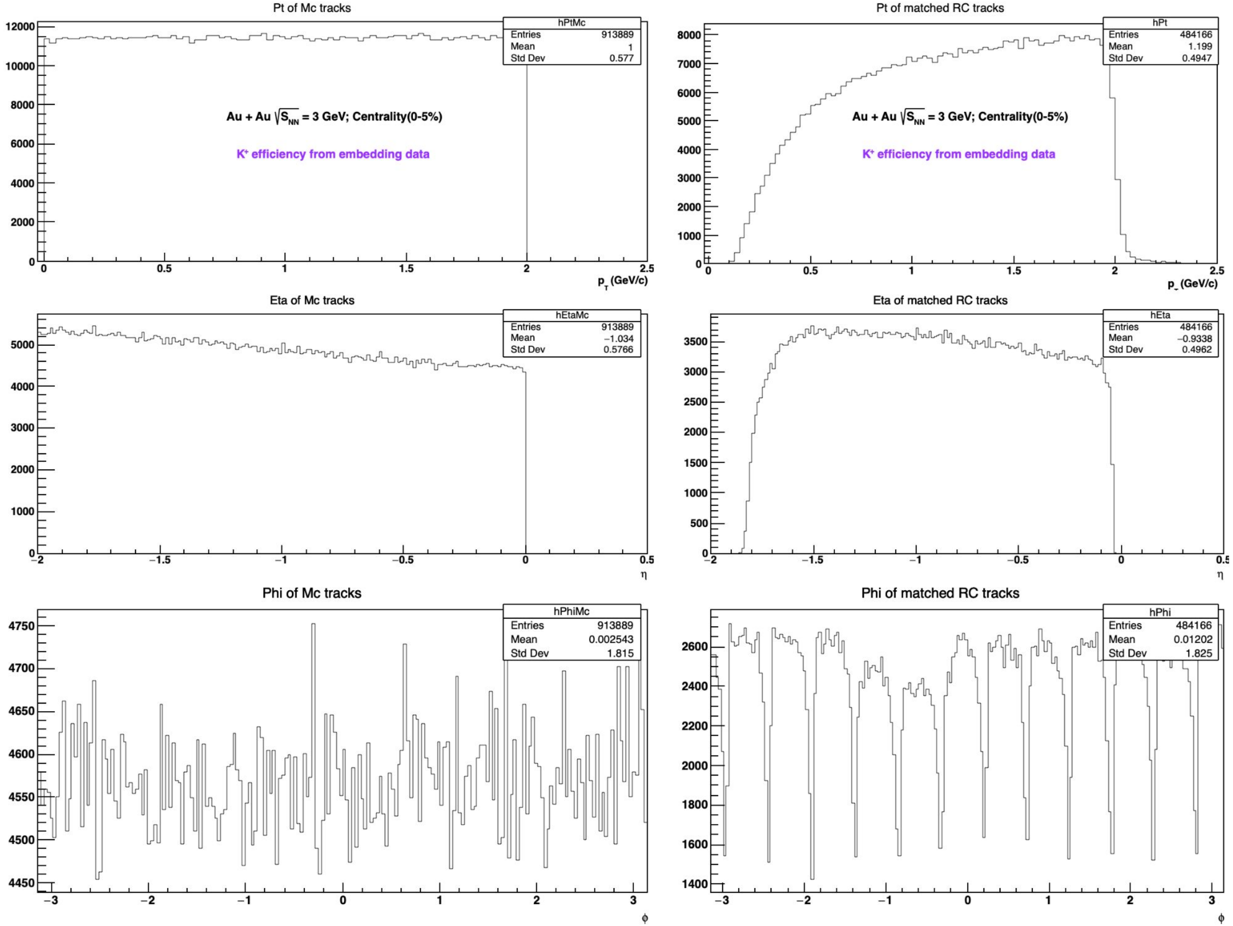
Efficiency plots from embedding

- The changes in systematic cuts affect efficiency, hence have to calculate them for each set of systematic cuts.

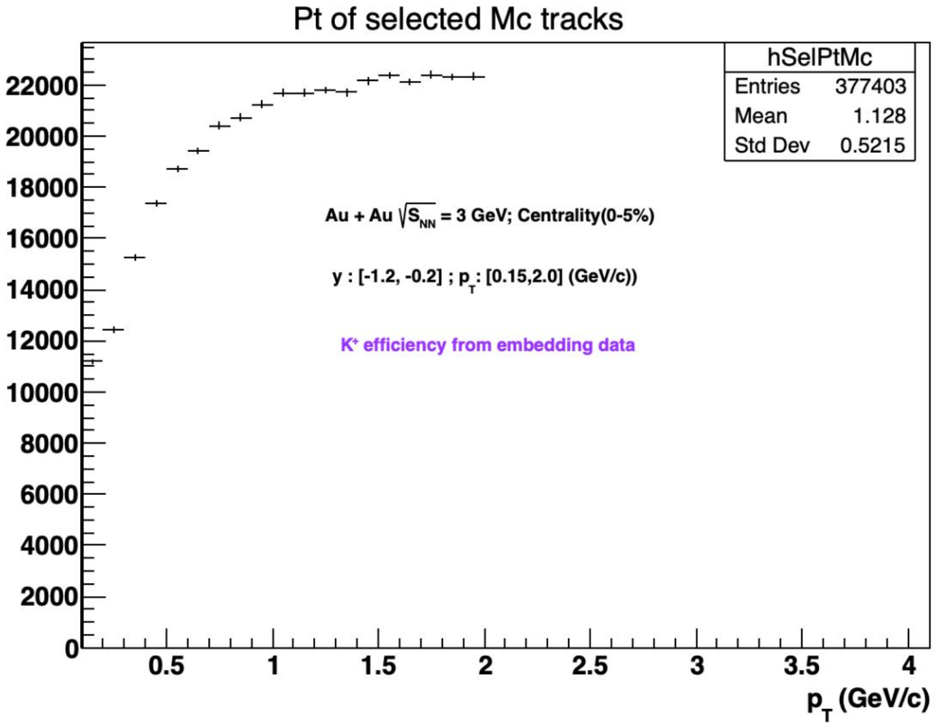
- Embedding data are generally used in STAR experiments for detector acceptance & reconstruction efficiency study. In general, the efficiency depends on running conditions, particle types, particle kinematics, and offline software versions.

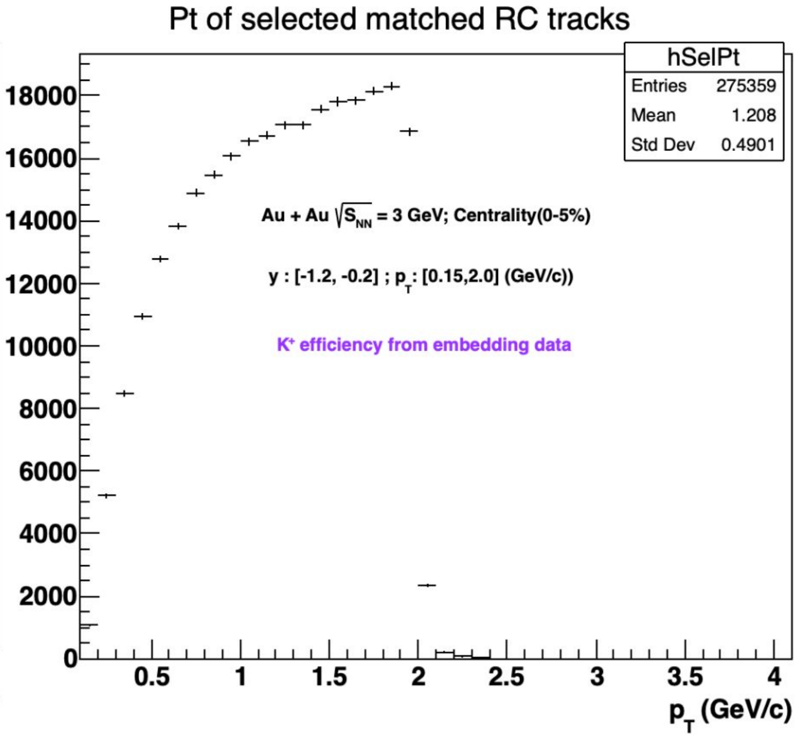
- Particles are generated flat in p_T,eta and phi and then passed through the GEANT 3 simulation of the STAR Detector and then we calculate reconstructed and generated tracks in our acceptance to compute efficiencies.

Efficiency plots from embedding

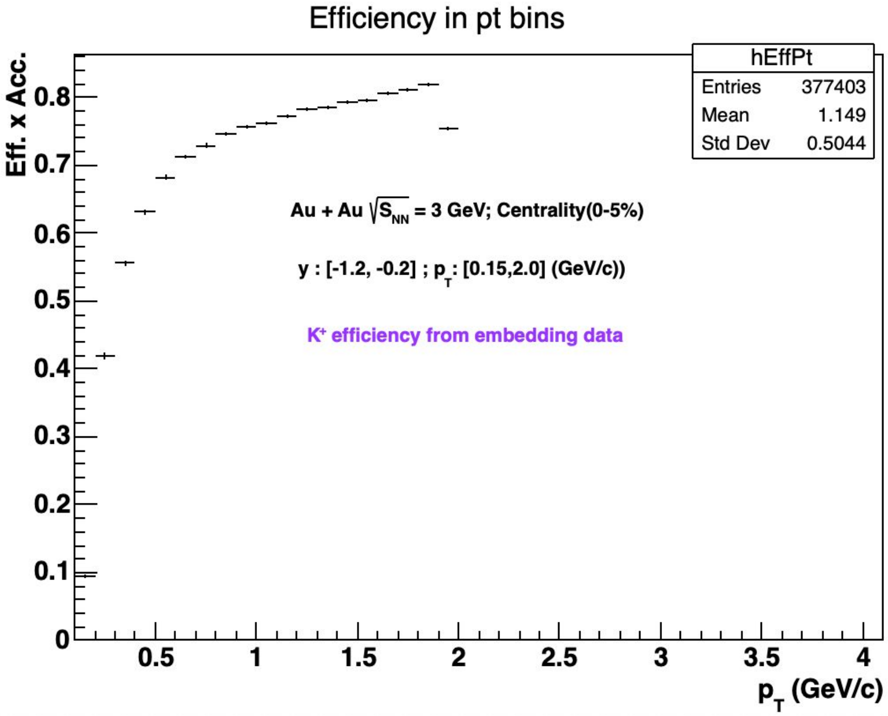


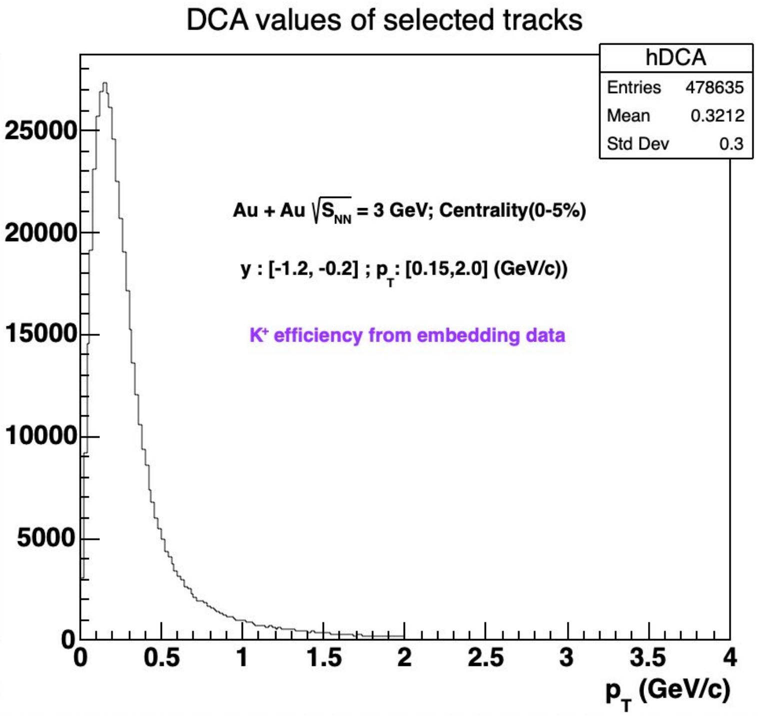
Efficiency plots from embedding



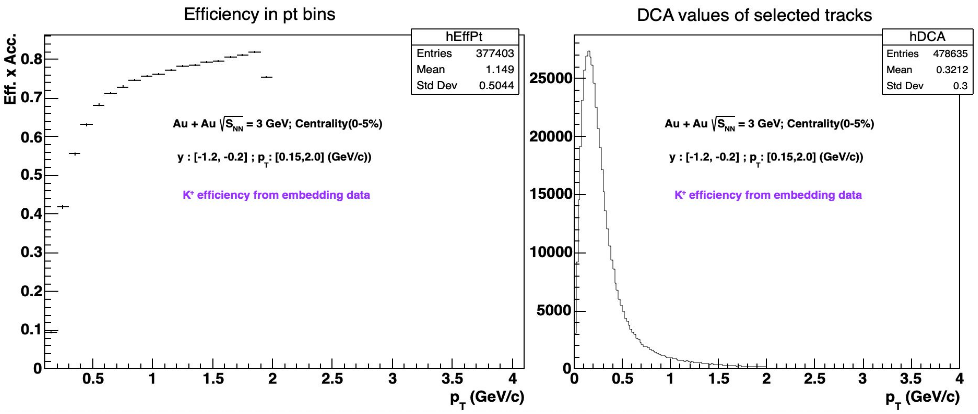


Efficiency plots from embedding

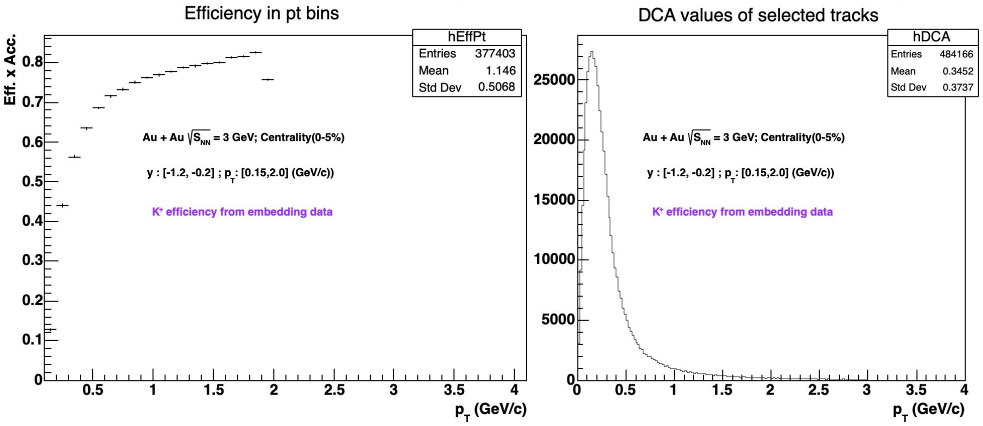




Efficiency plots from embedding

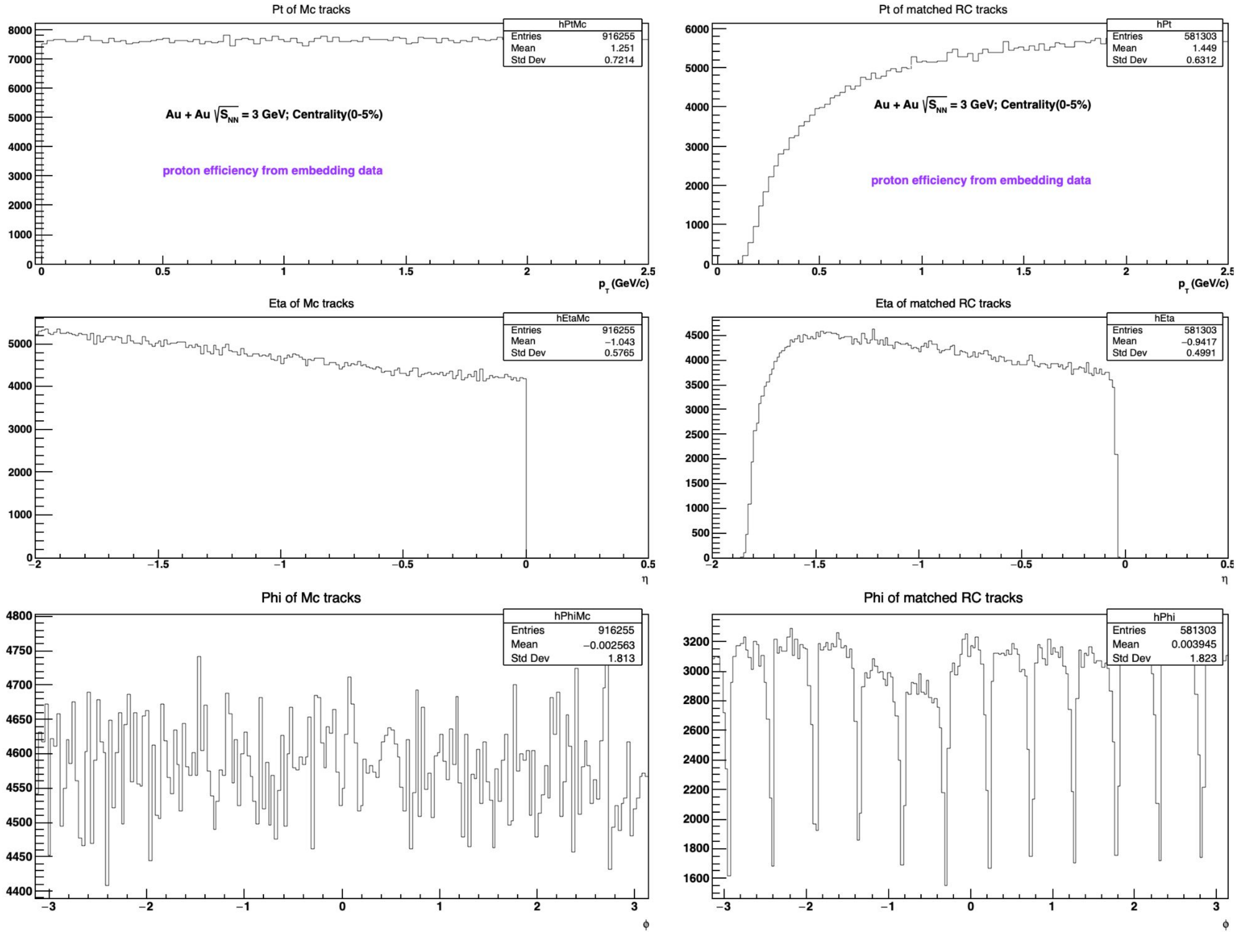


DCA < 2.0



DCA < 3.0

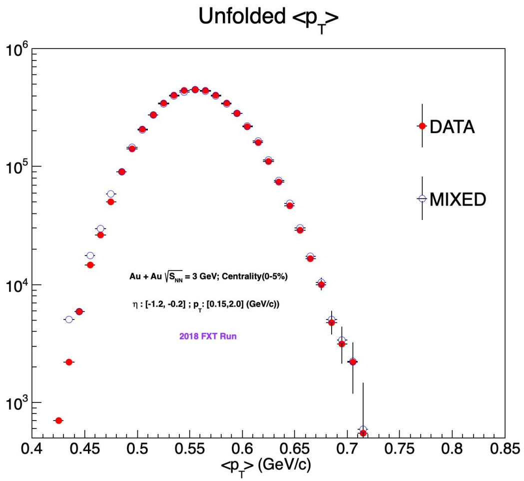
Efficiency plots from embedding

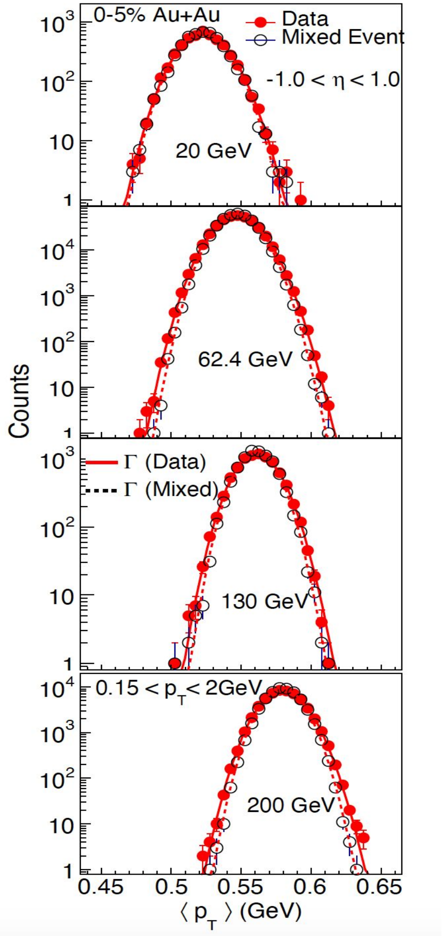


Comparison to Published data

Case	μ	σ
20 GeV, real	0.5228	0.01579
20 GeV, mixed	0.5227	0.01510
62 GeV, real	0.5471	0.01439
62 GeV, mixed	0.5470	0.01310
130 GeV, real	0.5614	0.01423
130 GeV, mixed	0.5612	0.01282
200 GeV, real	0.5799	0.01347
200 GeV, mixed	0.5799	0.01190

PHYSICAL REVIEW C 72, 044902 (2005)

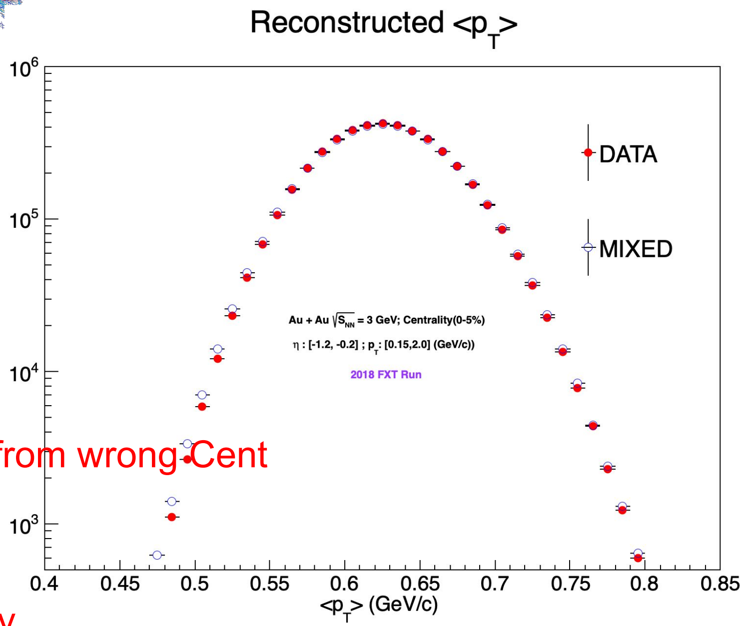


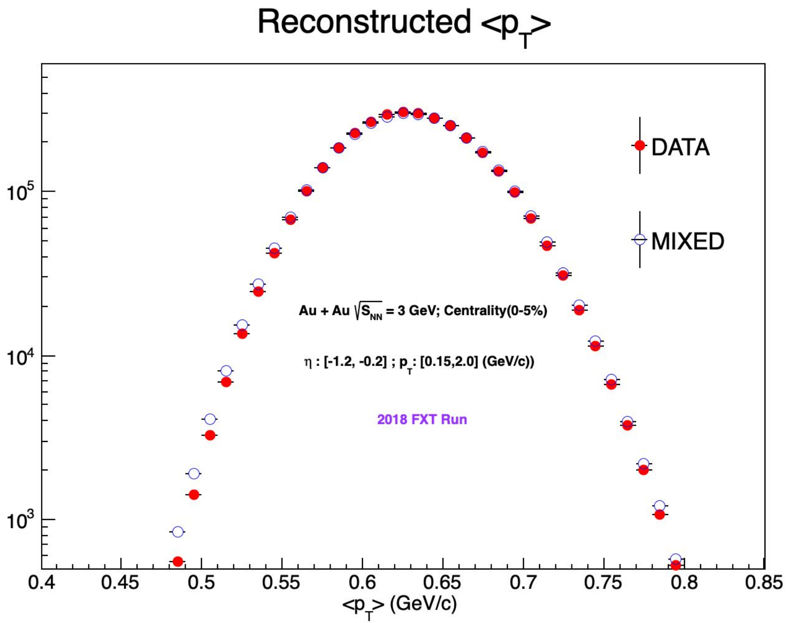


	μ	σ
3 GeV, real	0.5576	0.04038
3 GeV, mixed	0.5575	0.04111

This is from wrong Cent def.

Systematics





This is from wrong Cent def.

*Efficiency Uncorrected !

DCA < 3.0 cm

	Data	Mixed
Mean	0.6271	0.6271
Sigma	0.04338	0.04402

DCA < 2.0 cm

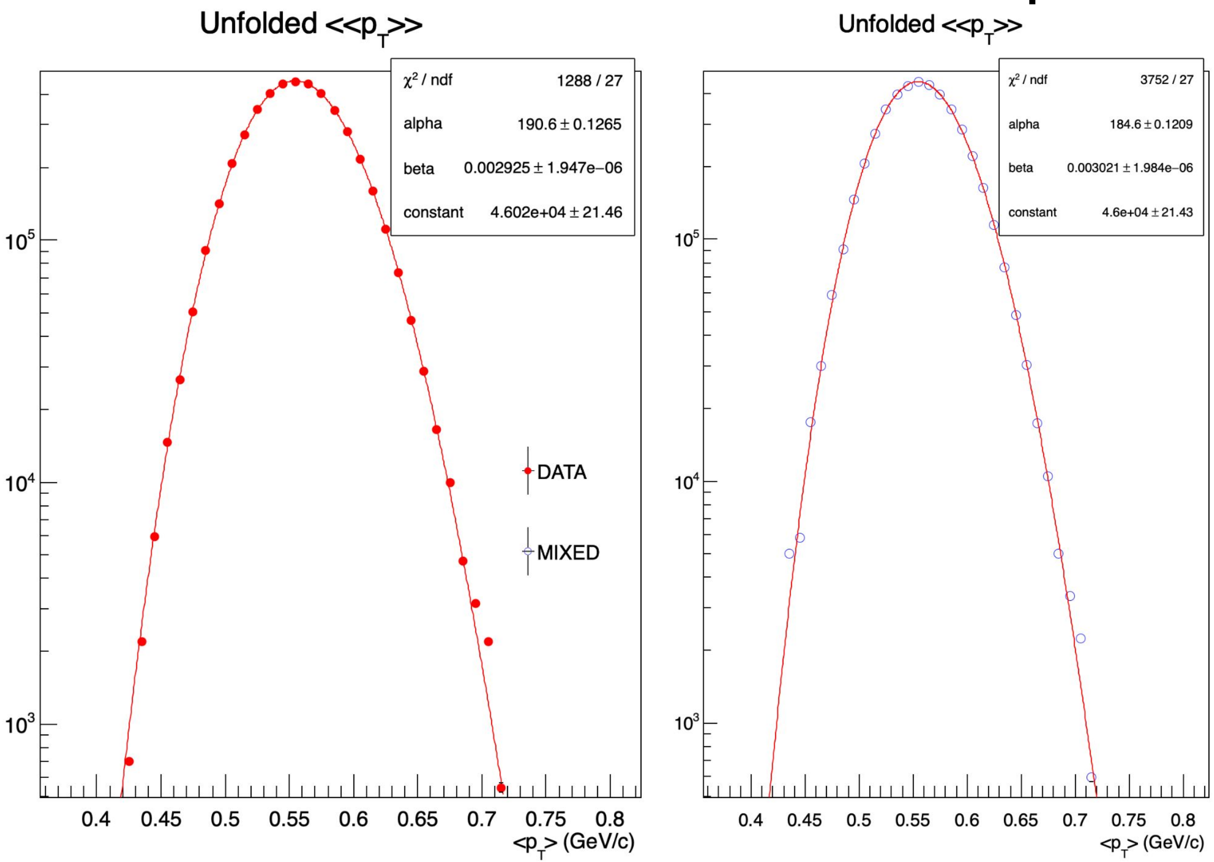
	Data	Mixed
Mean	0.6304	0.6304
Sigma	0.04327	0.04409

Dynamical Fluctuations from $<p_T>$

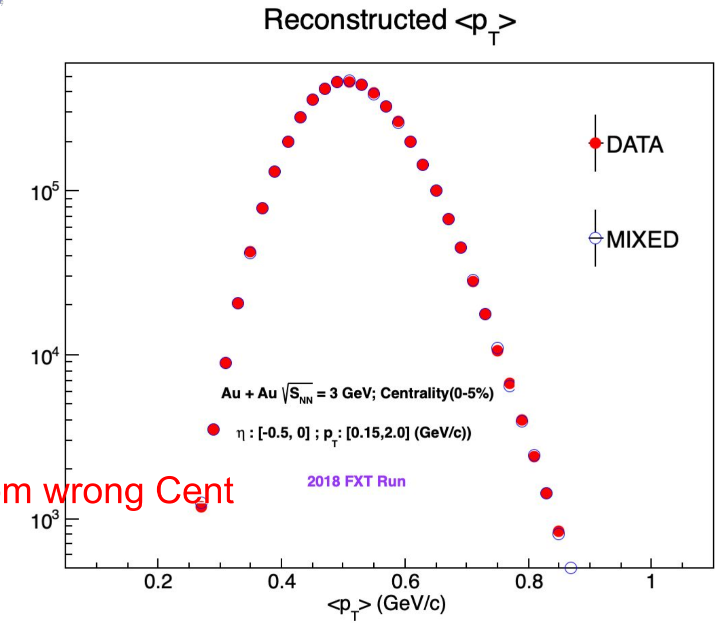
Data_Mean = 0.5576 +/- 0.0007
Data_Sigma = 0.04038 +/- 4e-5

Mixed_Mean = 0.5576 +/- 0.0007
Mixed_Sigma = 0.04105 +/- 4e-5

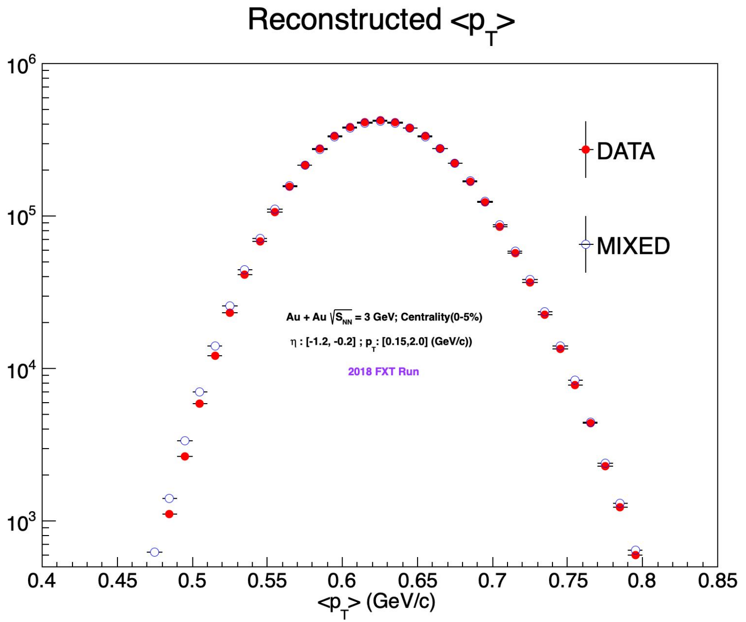
This is from wrong Cent def.



Eta Study



This is from wrong Cent def.



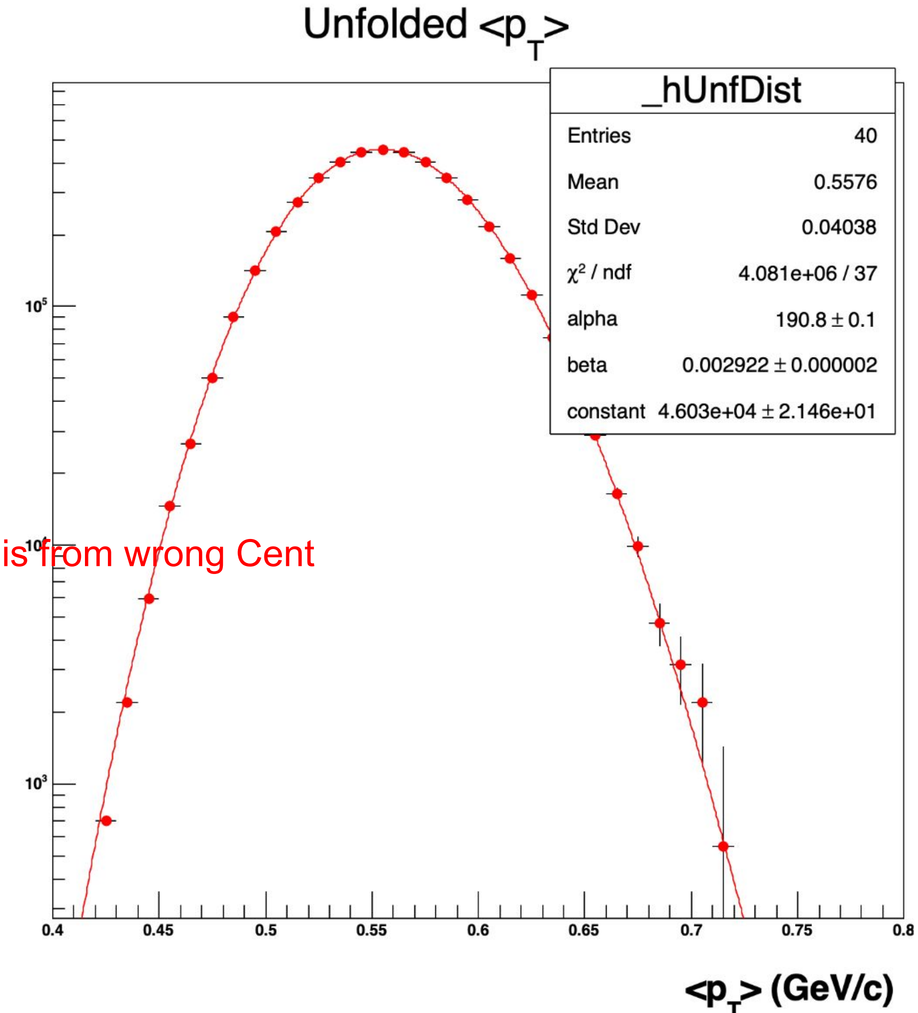
*Efficiency Uncorrected !

$-0.5 < \eta < 0.0$

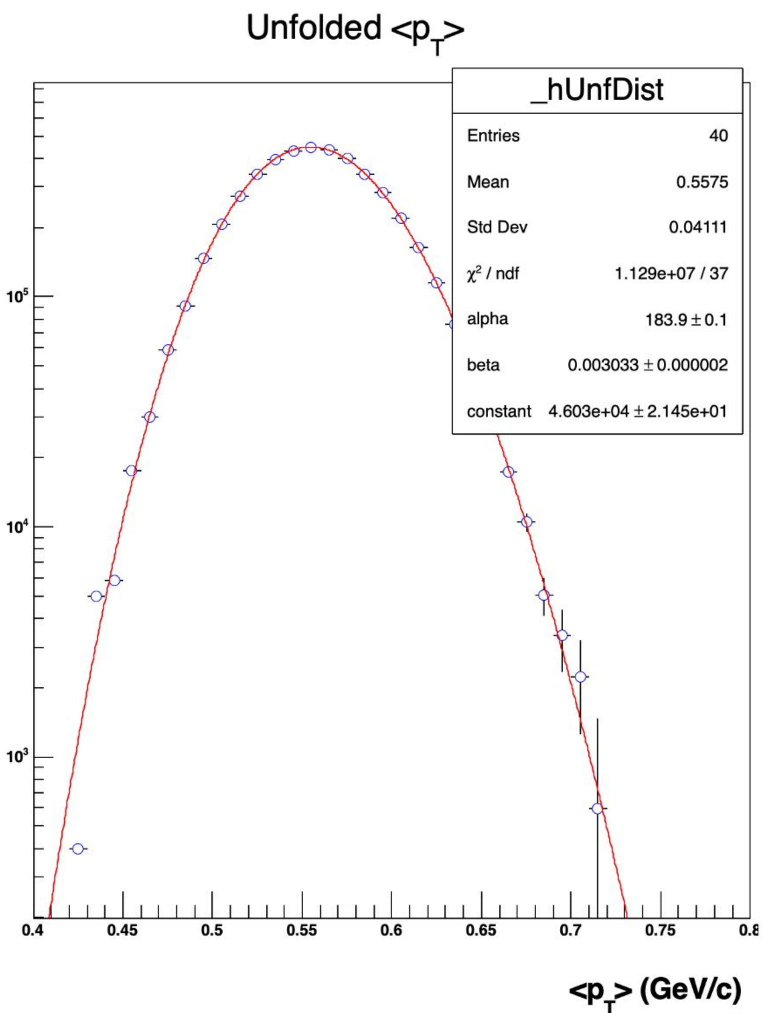
	Data	Mixed
Mean	0.5149	0.5148
Sigma	0.07925	0.07924

$-1.2 < \eta < -0.2$

	Data	Mixed
Mean	0.6271	0.6271
Sigma	0.04338	0.04402

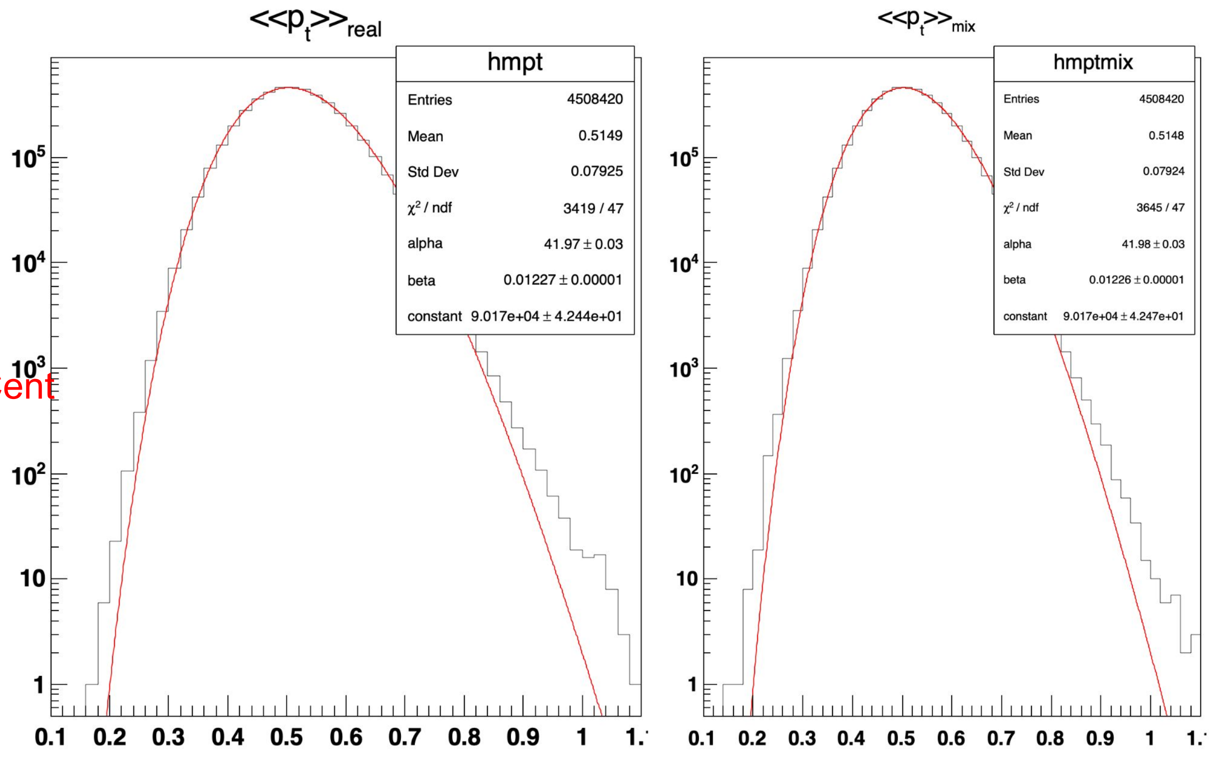


This is from wrong Cent def.



Eta Study

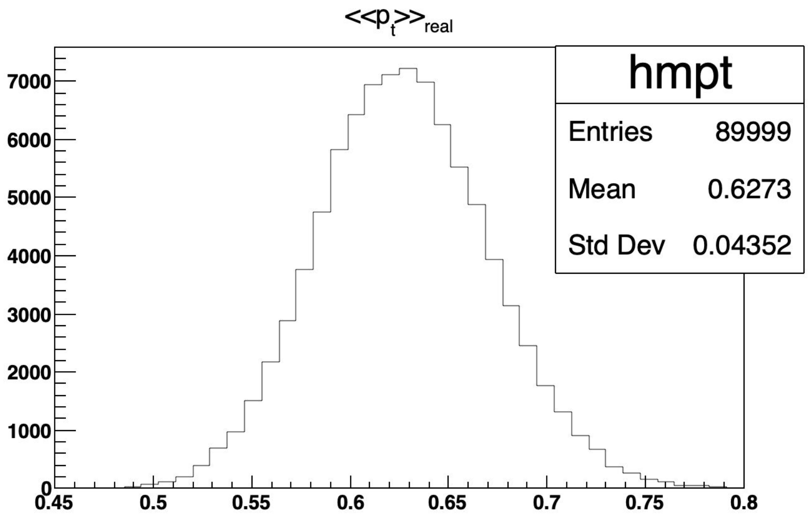
$$\sigma_{dyn} = \sqrt{(\frac{\sigma_{data}}{\mu_{data}})^2 - (\frac{\sigma_{mix}}{\mu_{mix}})^2}$$

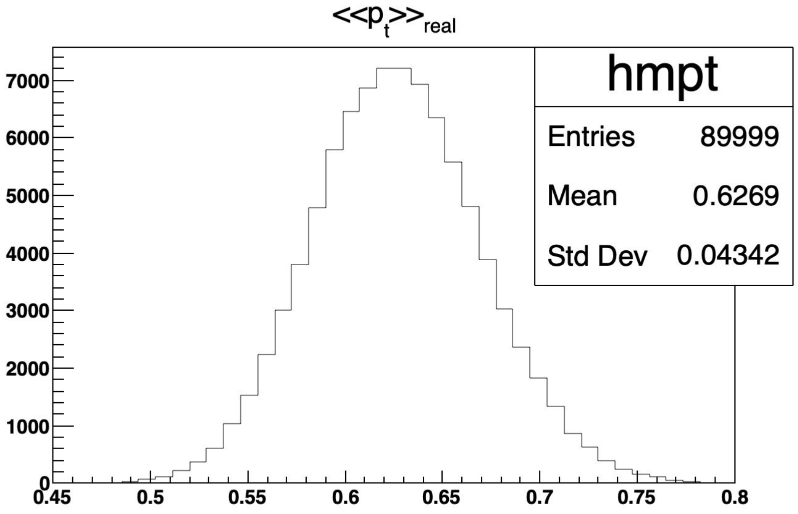


This is from wrong Cent def.

Systematics for <p_T>

For systematic contributions, BES-I analysis included DCA and nHitsFit uncertainties.
Dan Cebra provided a list for Fluctuation analysis. 3.7M (0-5%) out of 140M events

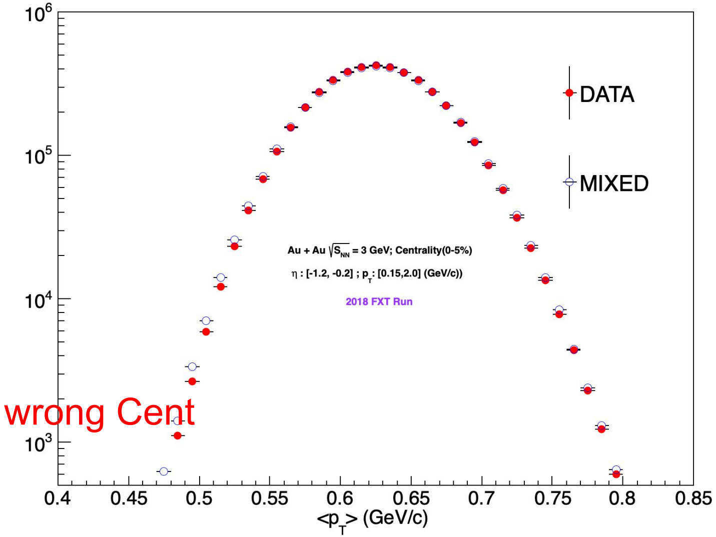




Mixed Event Analysis for <p$_T$>

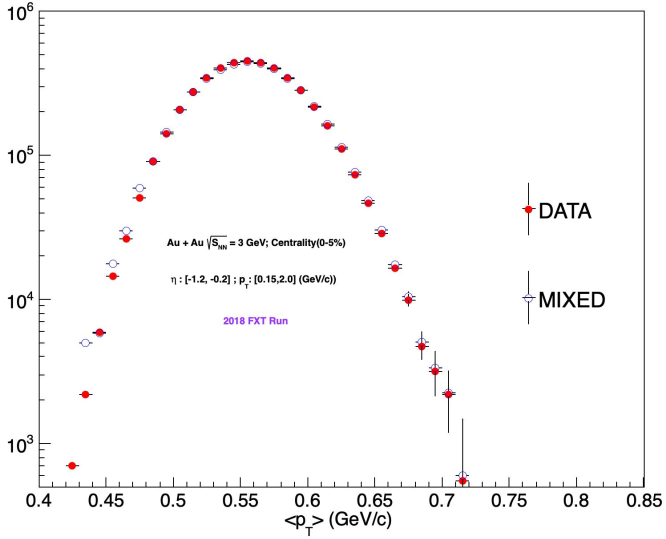
4.6 M*

Reconstructed <p$_T$>



This is from wrong Cent def.

Unfolded <p$_T$>

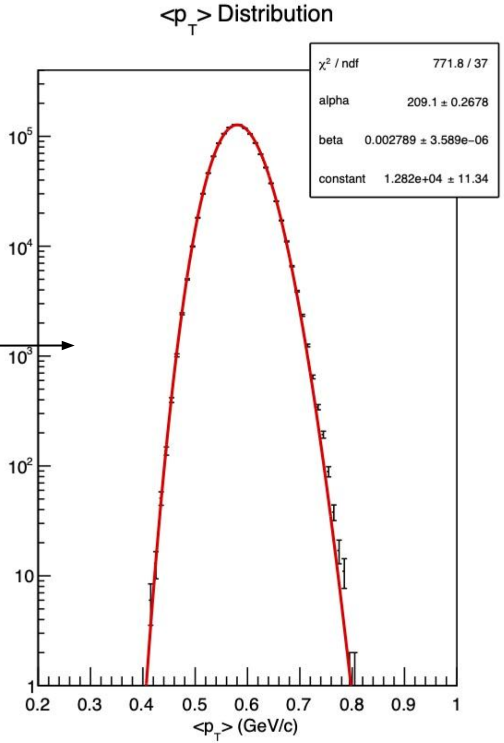


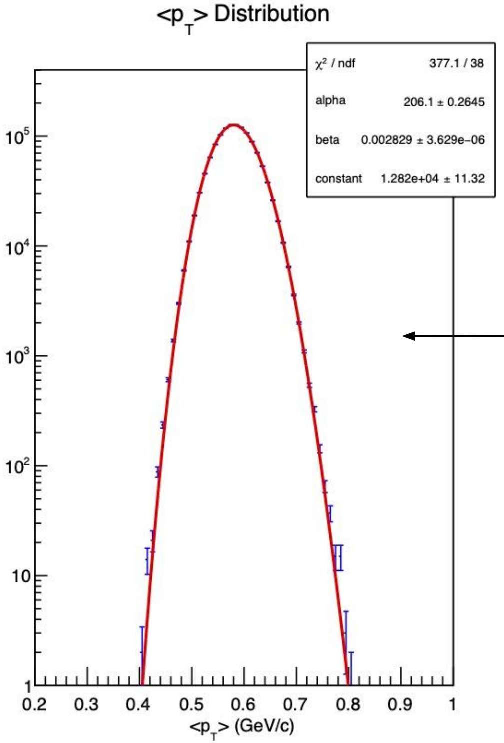
	Data	Mixed
Mean	0.6271	0.6271
Sigma	0.04338	0.04402

	Data	Mixed
Mean	0.5576	0.5575
Sigma	0.04038	0.04111

Backup Slides

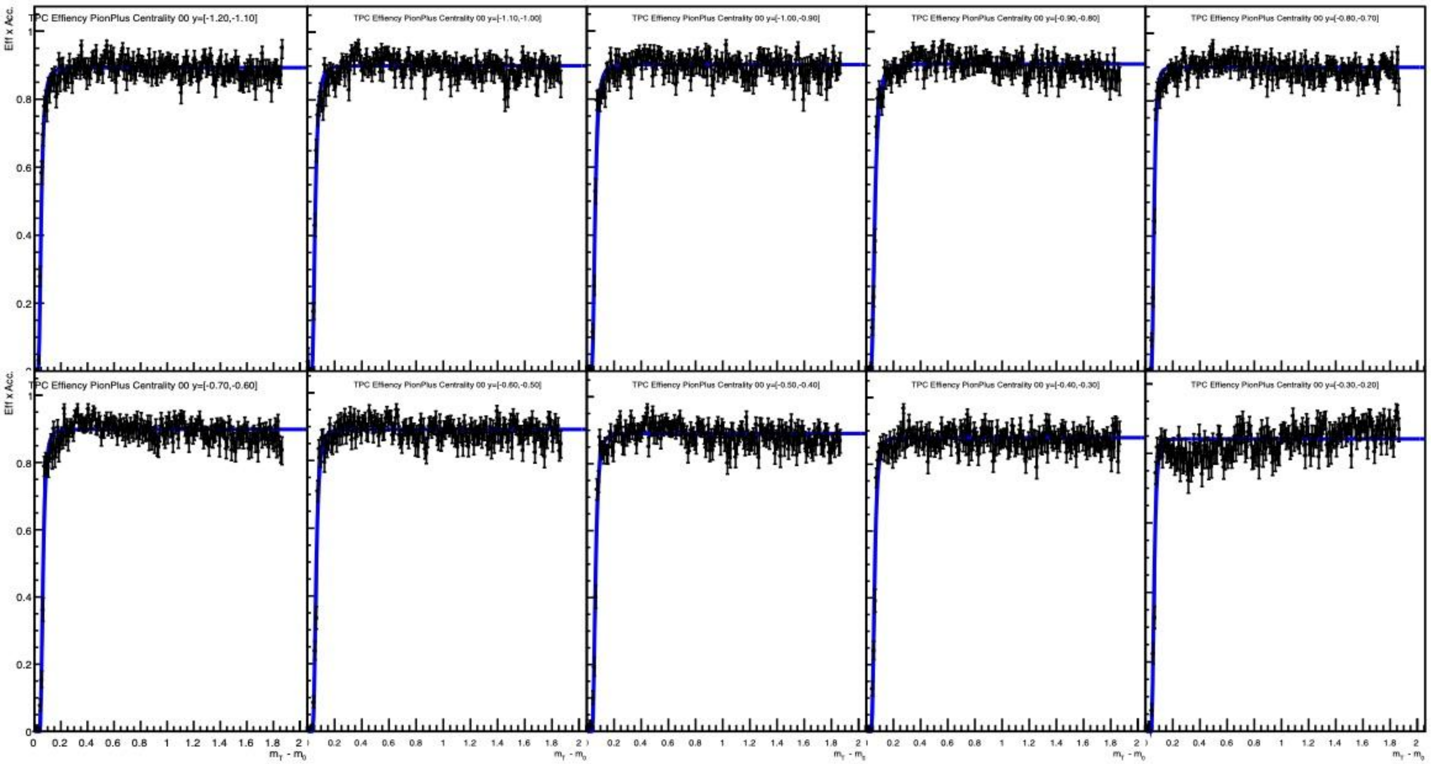
DATA





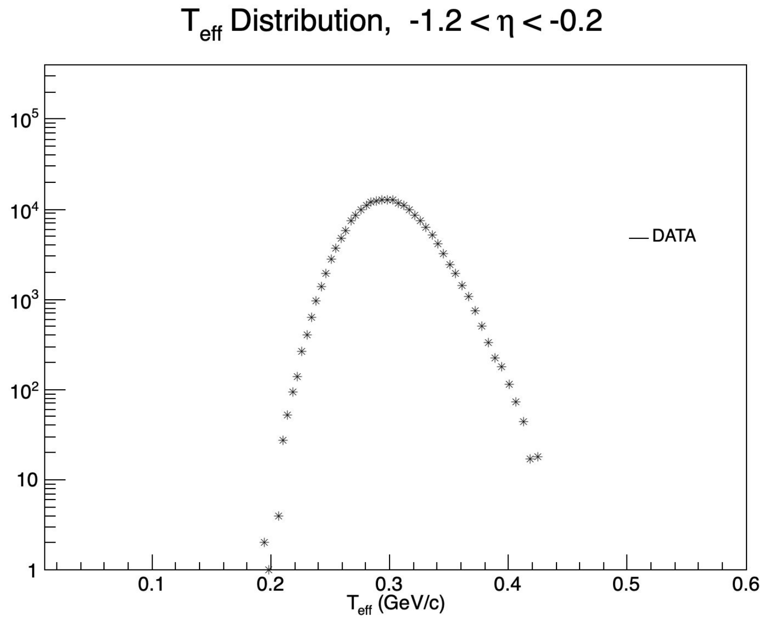
MIXED

- $-1 < \eta < 0$



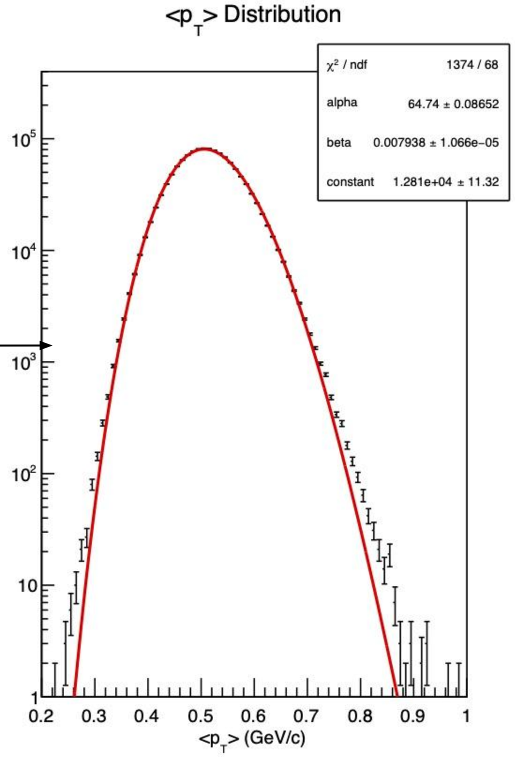
<u>Pion (+) Efficiencies</u>

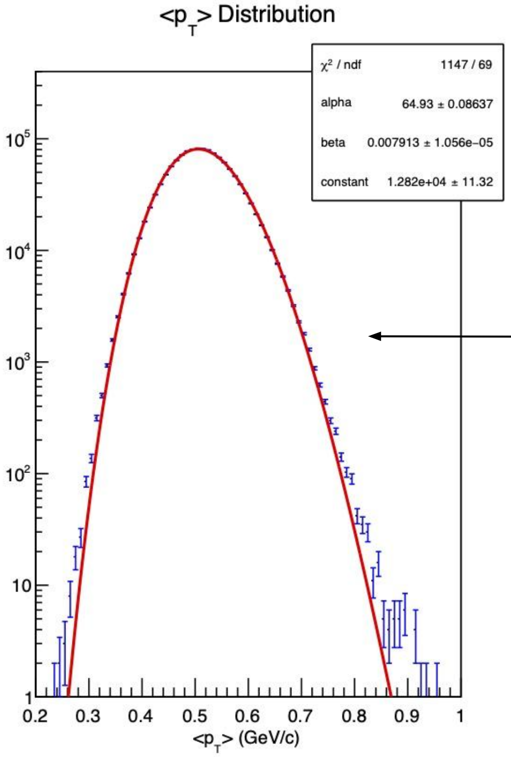
$$< p_T >= 2T_{eff} + \frac{a^2 e^{-a/T_{eff}} - b^2 e^{-b/T_{eff}}}{(a+T_{eff})e^{-a/T_{eff}} - (b+T_{eff})e^{-b/T_{eff}}}$$



Backup Slides

DATA





MIXED

❖ $-0.5 < \eta < 0$

Backup Slides

- A small subset of 27 GeV is taken for analysis.
- The event cuts and track cuts are from Chun-Jian. (https://drupal.star.bnl.gov/STAR/system/files/BES_200_54_27_meanpT_0119.pdf)