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Proton Azimuthal Fluctuation Analysis

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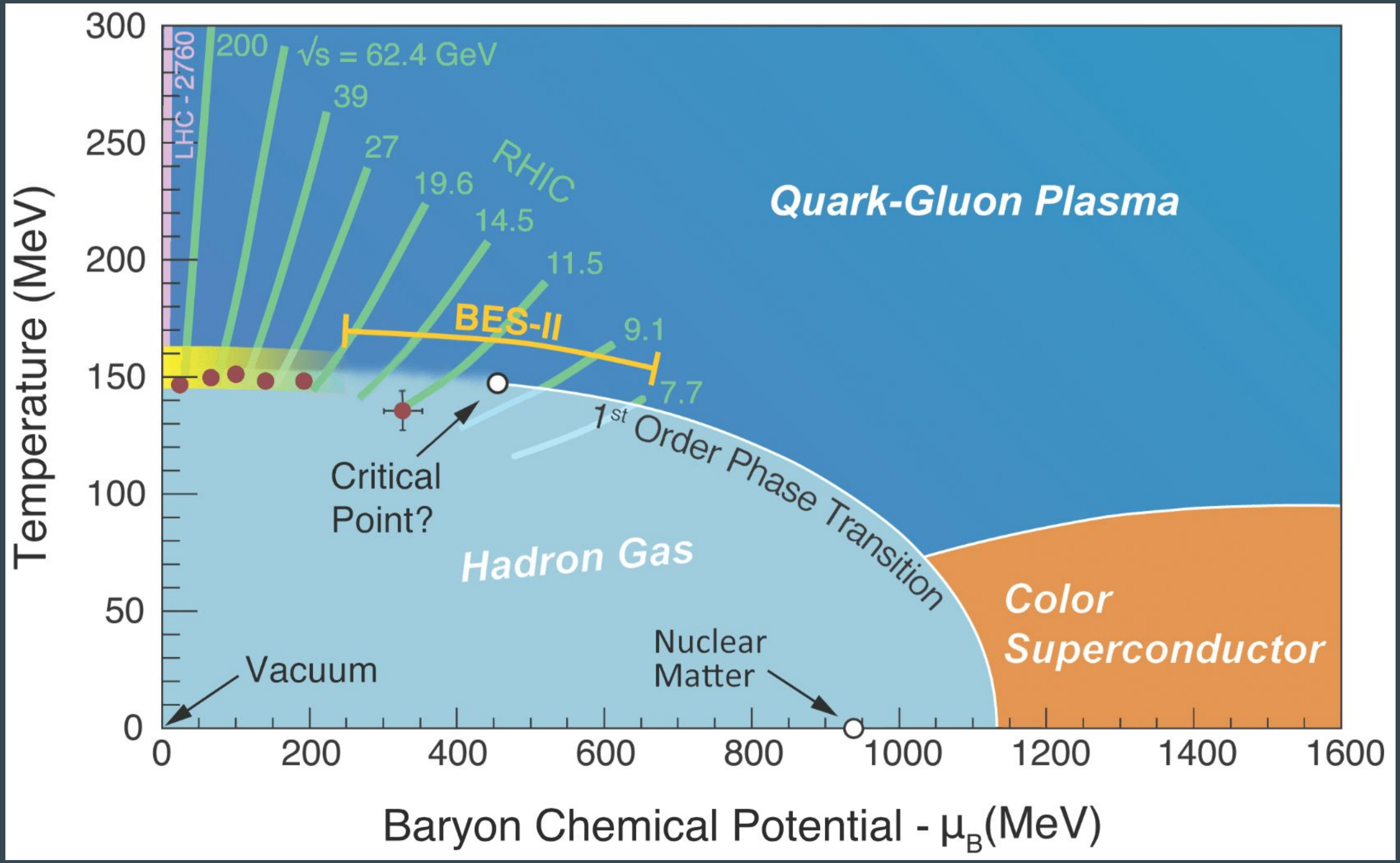
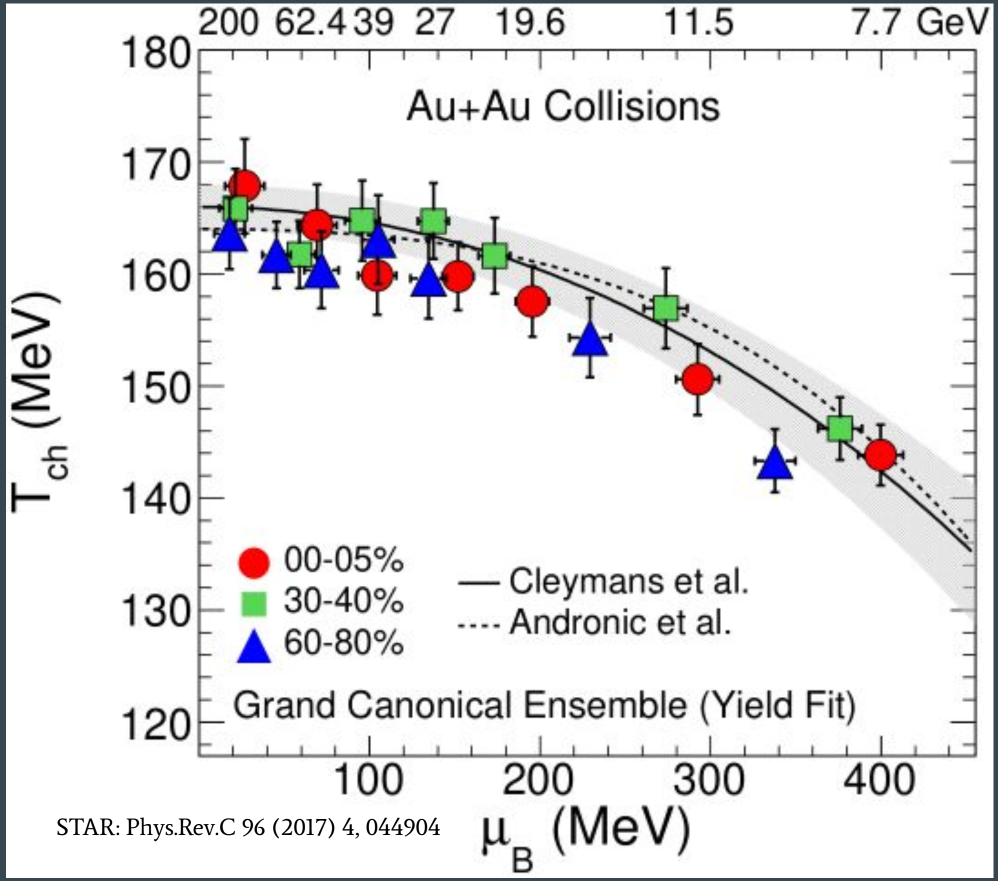
Motivation

- Map out QCD phase diagram via BES, specifically QGP to hadron gas transition
- Search for signal of critical phenomena as a function of energy





Data Set - Au+Au Beam Energy Scan I

$\sqrt{s_{NN}}$ (GeV)	Triggers	Minimum Bias Events (million)	0-5% Central Events (million)	AMPT 0-5% Central Events (million)
7.7	290001, 290004	3.1	0.17	1.61
11.5	310004, 310014	7.4	0.42	1.46
19.6	340001, 340011, 340021	17	0.91	1.42
27	360001	32	1.8	1.60
39	280001	88	5.7	1.56
62.4	270001, 270011, 270021	47	3.0	1.52

Proton Selection

$\|y\| < 0.5$
DCA < 1.0
$\|n\sigma_{proton}\| < 2.0$ 1.0 for 27GeV
$0.4 < p_T < 0.8$ & $p < 1.0$ or $0.8 < p_T < 2.0$ & $p < 3.0$ & $0.6 < m^2 < 1.2$

Systematic Cuts

$DCA_{max} \in (0.8, 1.2)$
$\|n\sigma_{proton}\|_{max} \in (1.8, 2.2)$ (0.9, 1.1) for 27GeV
$m^2_{range} \in (0.2, 0.6)$ centered on 0.9
nHitsFit $\in$ [15, 25]

Centrality Definition: refmult3

Charged particles within $|\eta|$<0.5 excluding protons

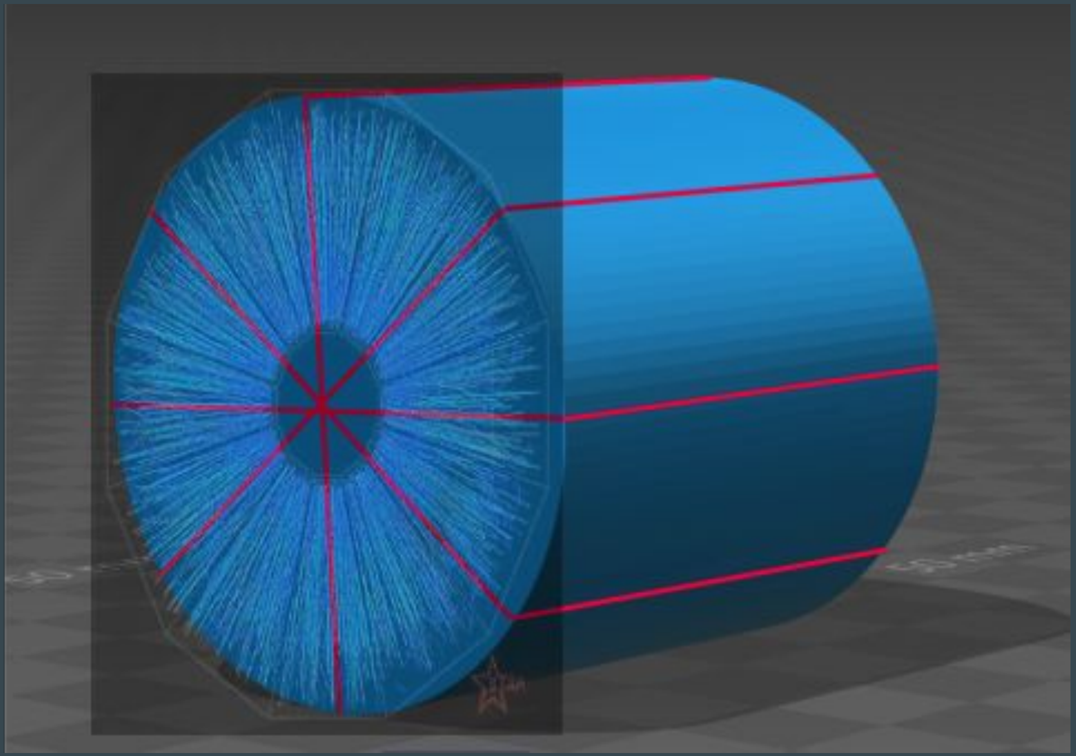
Corrections Implemented:

- Pile-up Rejection
- Dca-xy Bad Events Cut
- Bad Runs Removed

Corrections Not Implemented:

- Efficiency Correction
- Centrality Bin Width Correction

Analysis Introduction

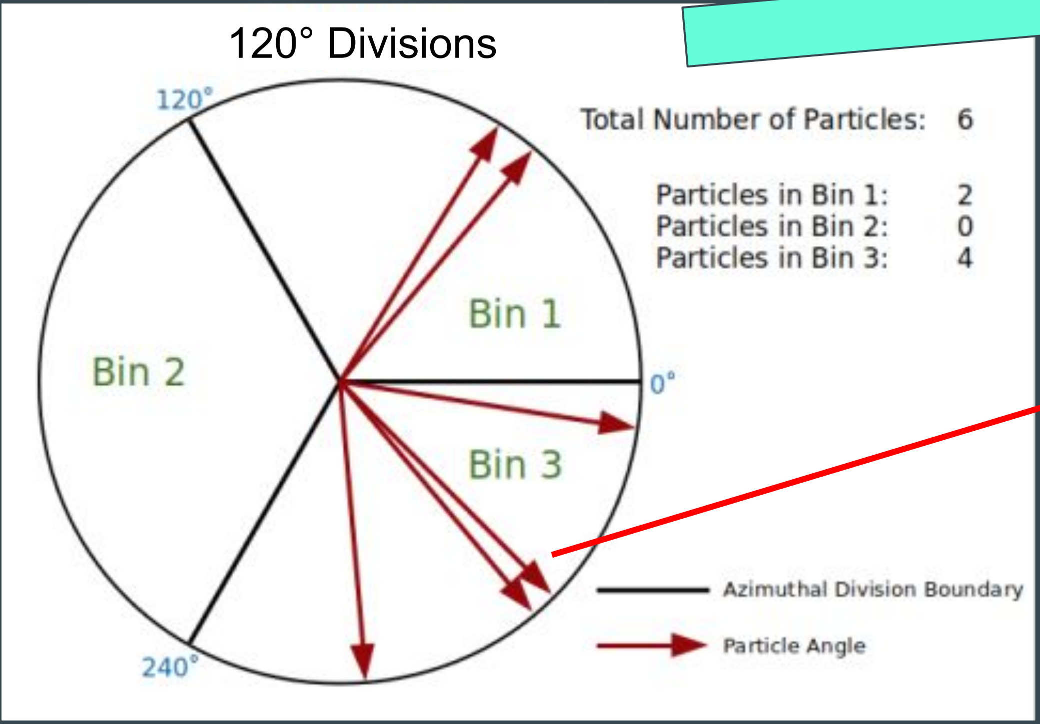


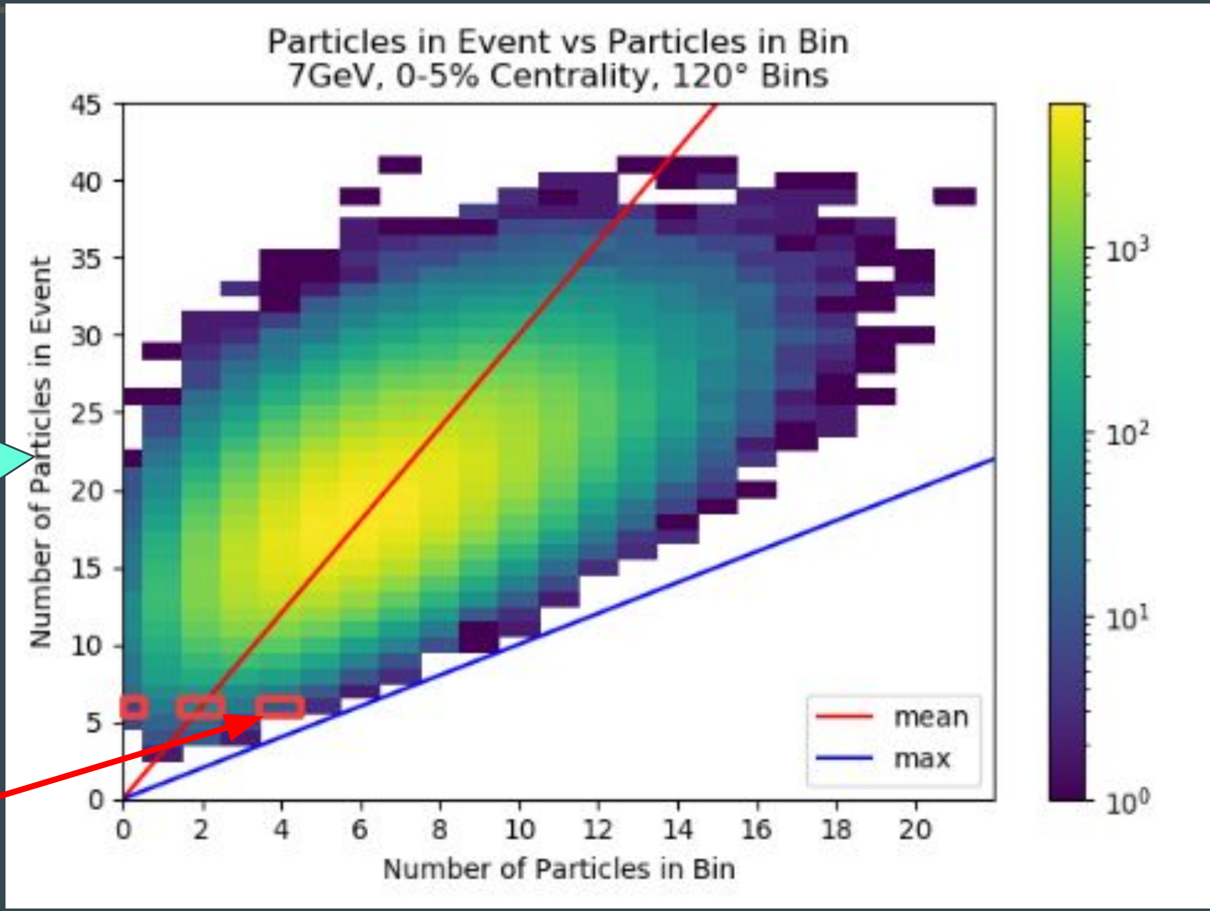
- In each event the azimuthal distribution of protons is partitioned to search for signals of local parton density fluctuations
- Non-monotonic trends of kurtosis with energy after correcting for background effects may indicate critical phenomena
- AMPT used as baseline, deviations may indicate additional physics present
- Different angular widths may be sensitive to different correlation lengths

Azimuthal Partitioning

Partition the azimuth in each event and histogram particle tracks

Histogram bin contents over many events



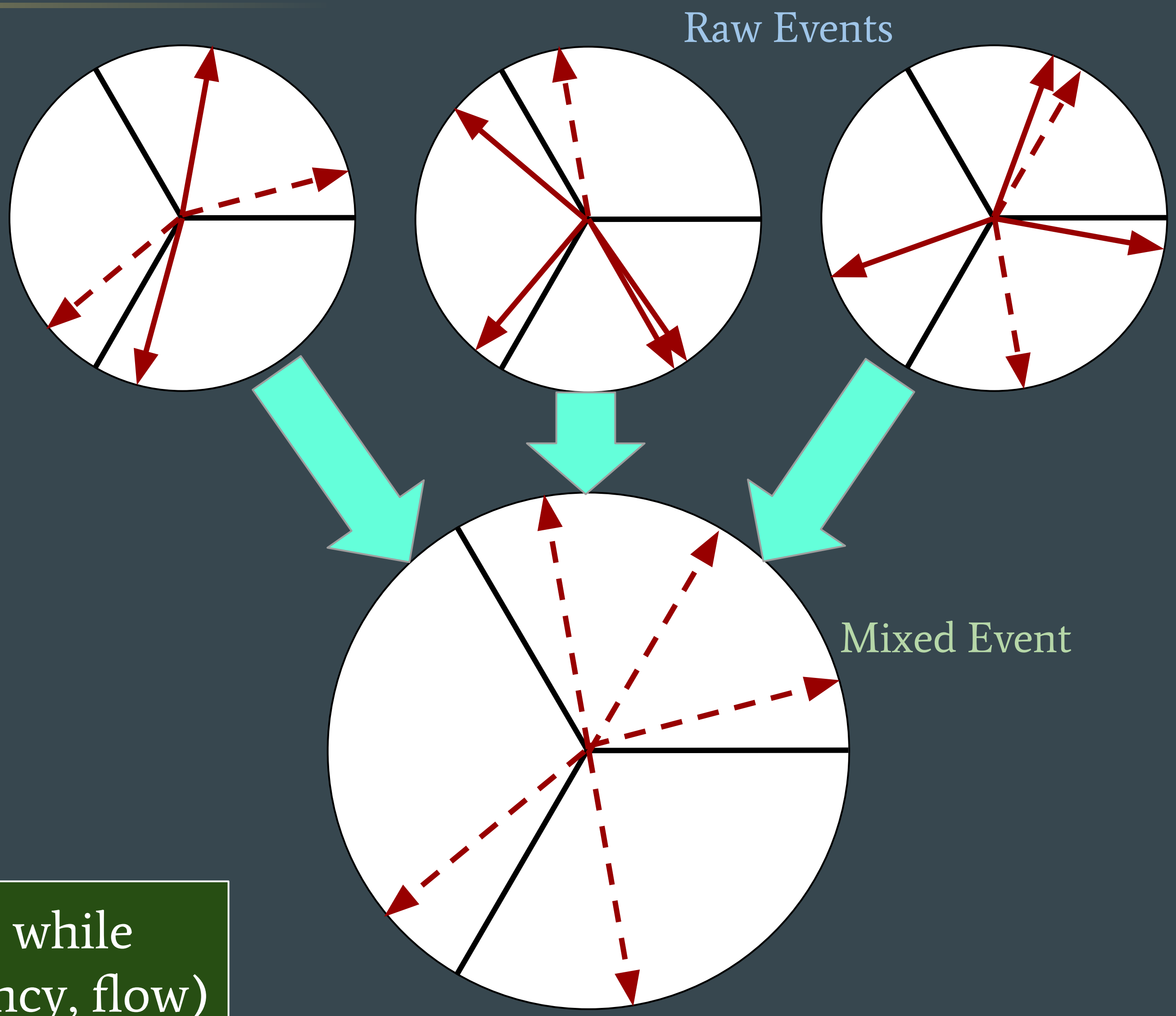


Procedure carried out identically for raw and mixed event data

Mixed Events

Each raw event sorted into a class based on energy, centrality, and event plane angle

Randomly select particle tracks from N (~150) events to generate mixed events

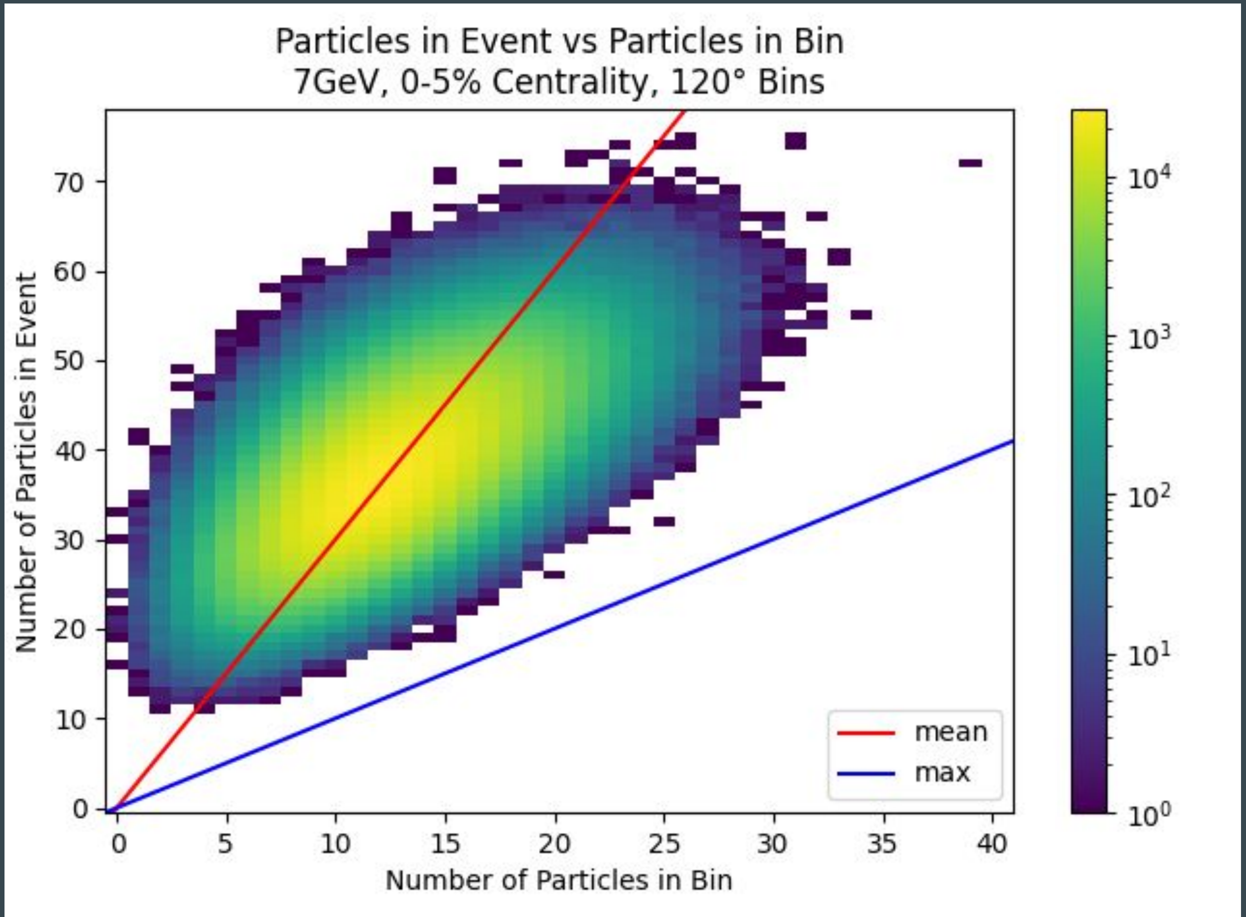


Goal:

Wash out event-by-event effects (fluctuations) while capturing background effects (detector efficiency, flow)

Two Analyses of Distribution

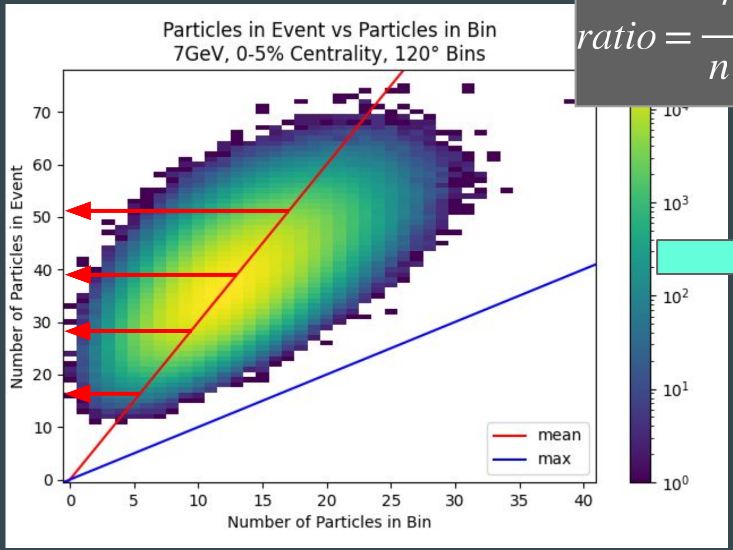
- Ratio Transformation
- Pull Transformation

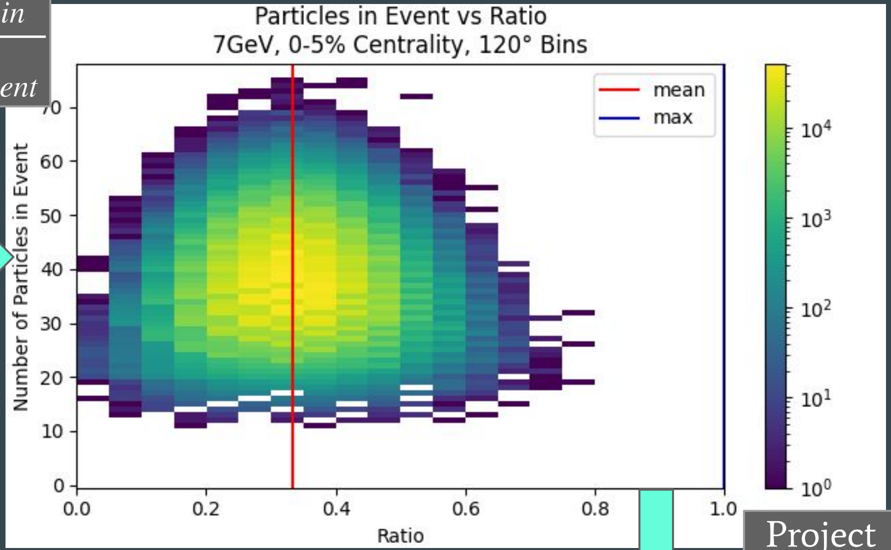


120° azimuthal divisions of proton tracks and top 5% most central events presented in these slides

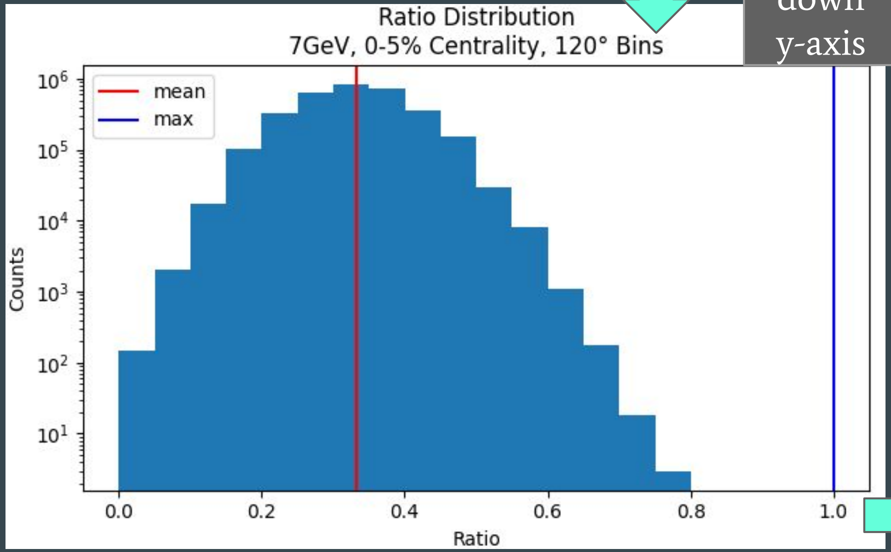
The Ratio Distribution

$$ratio = \frac{n_{bin}}{n_{event}}$$





Project down y-axis



Compress (Divide)

n_{bin} = Number of particle in bin (x axis)

n_{event} = Number of particle in event (y axis)

$$ratio = \frac{n_{bin}}{n_{event}}$$

$$kurtosis = \frac{\mu_4}{\mu_2^{\,2}}$$

Kurtosis is typically defined with a minus 3

$$\mu_n = \frac{\sum_i^N \left(x_i - \bar{x} \right)^n}{N}$$

n^{th} central moment

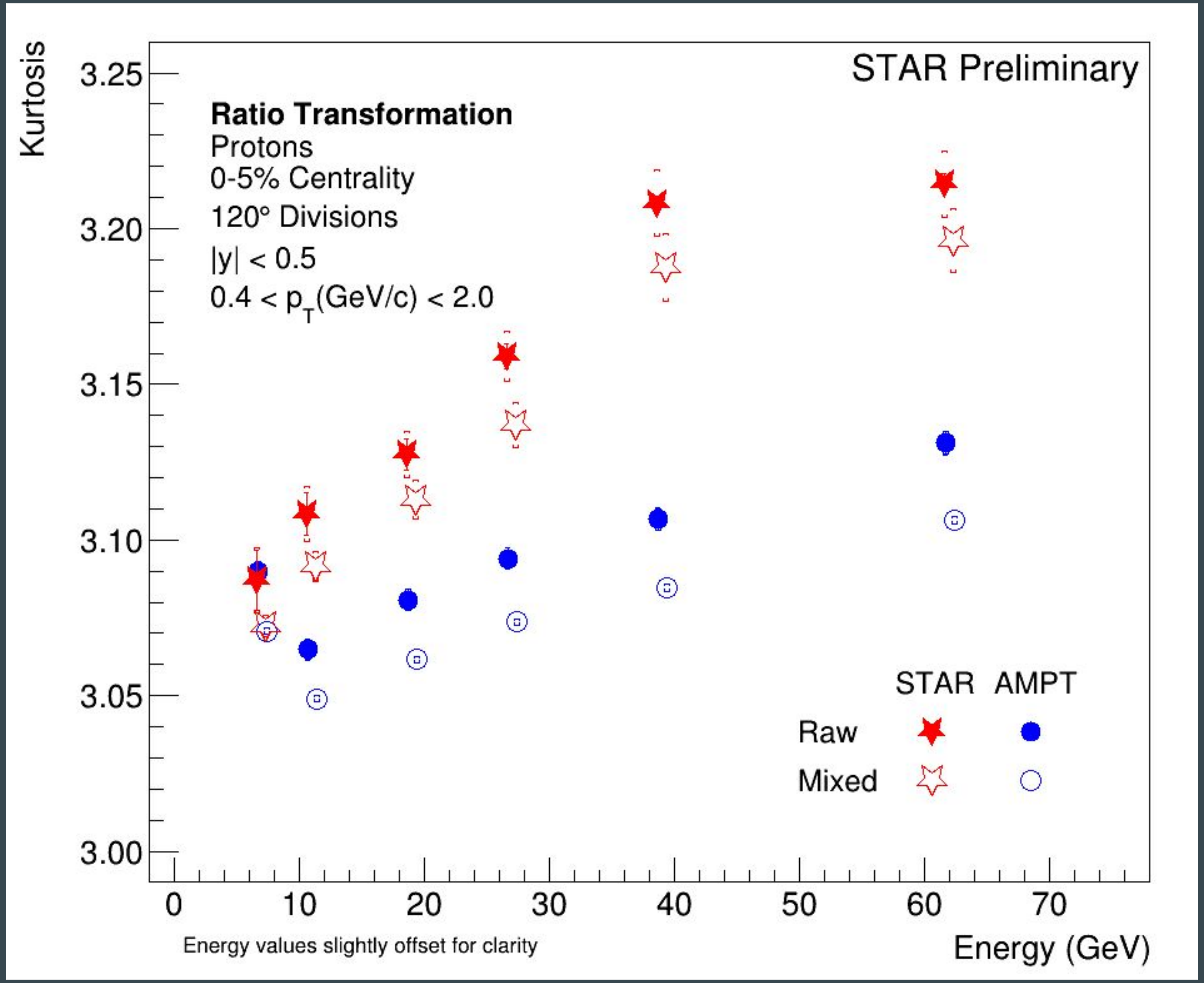
Statistical uncertainty on kurtosis calculated via delta theorem

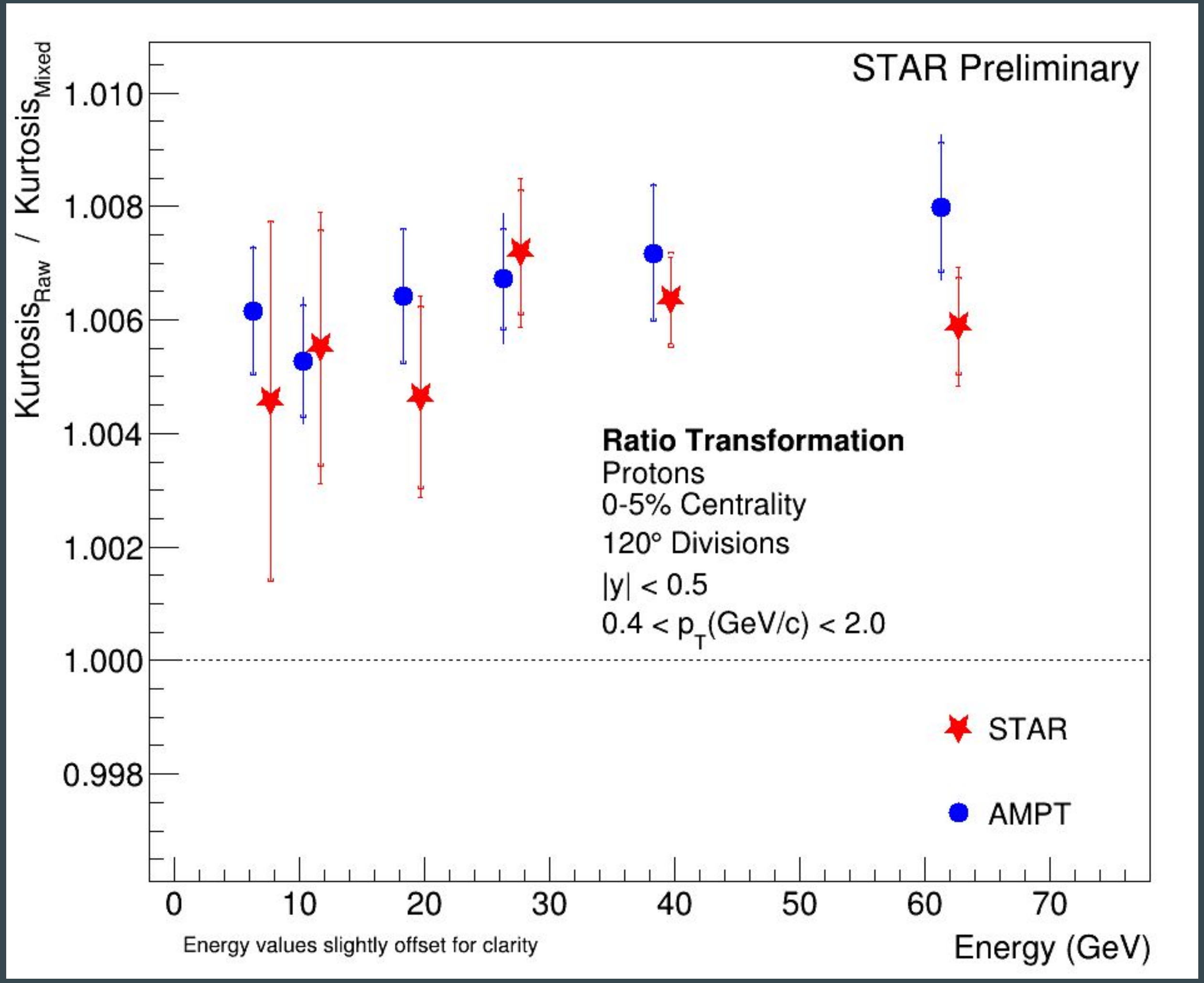
Luo arXiv:1109.0593v2

Calculate moments of these ratio distributions

Divide by corresponding moments of mixed distributions

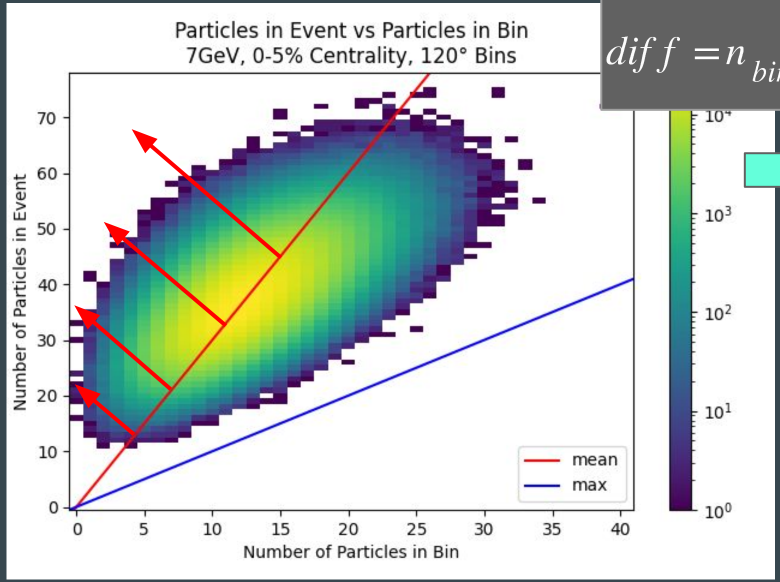
Ratio Distribution : Kurtosis vs Energy



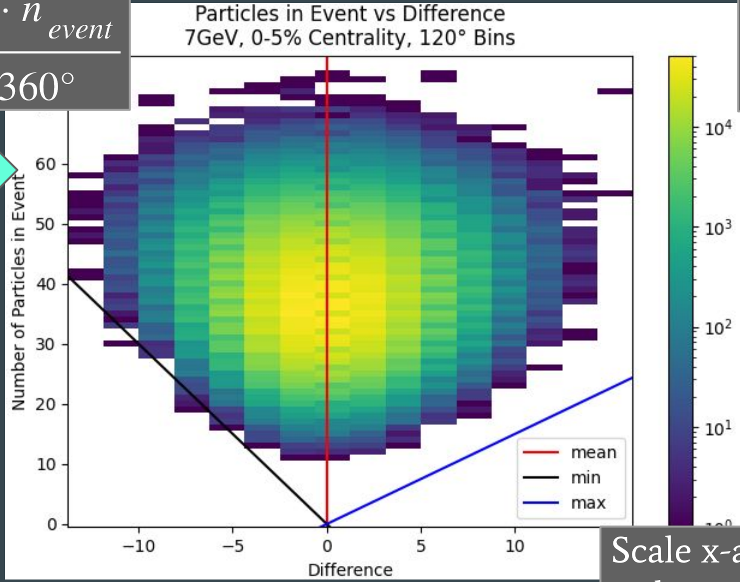


No significant trends with energy or deviations from AMPT observed → no indication of non-monotonicity within statistics

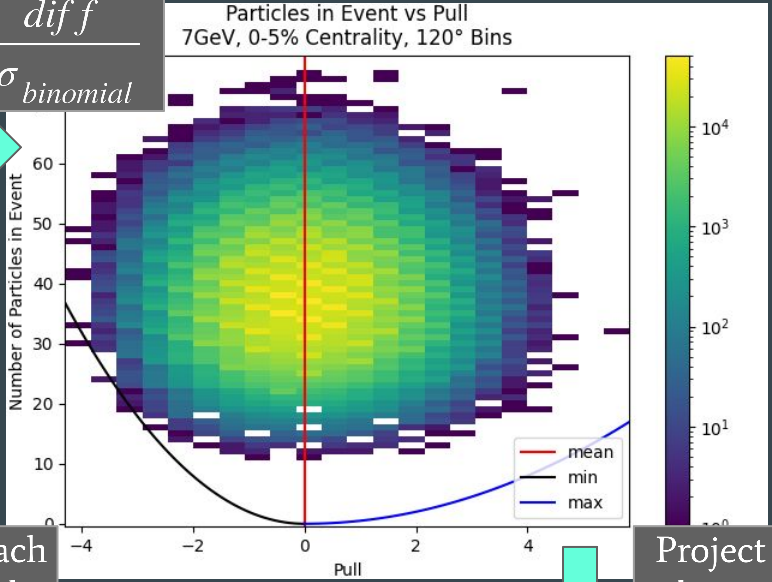
The Pull Distribution



$$diff = n_{bin} - \frac{w \cdot n_{event}}{360°}$$

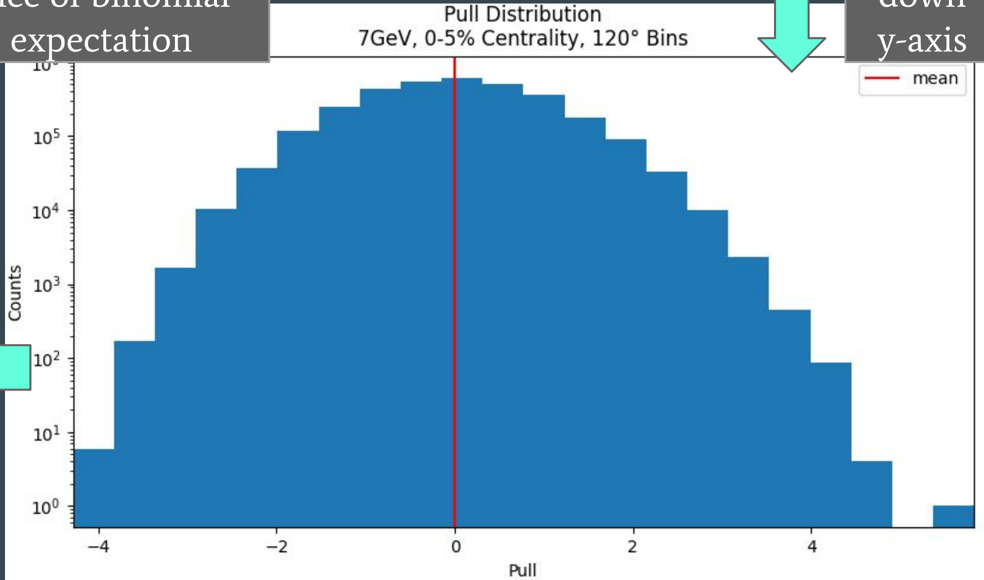


$$pull = \frac{diff}{\sigma_{binomial}}$$



Scale x-axis for each slice of binomial expectation

Project down y-axis



Rotate (Subtract)

n_{bin} = Number of particle in bin (x axis)
n_{event} = Number of particle in event (y axis)
w = Bin Width (°)

$$p = \frac{w}{360°} \quad q = 1 - p$$

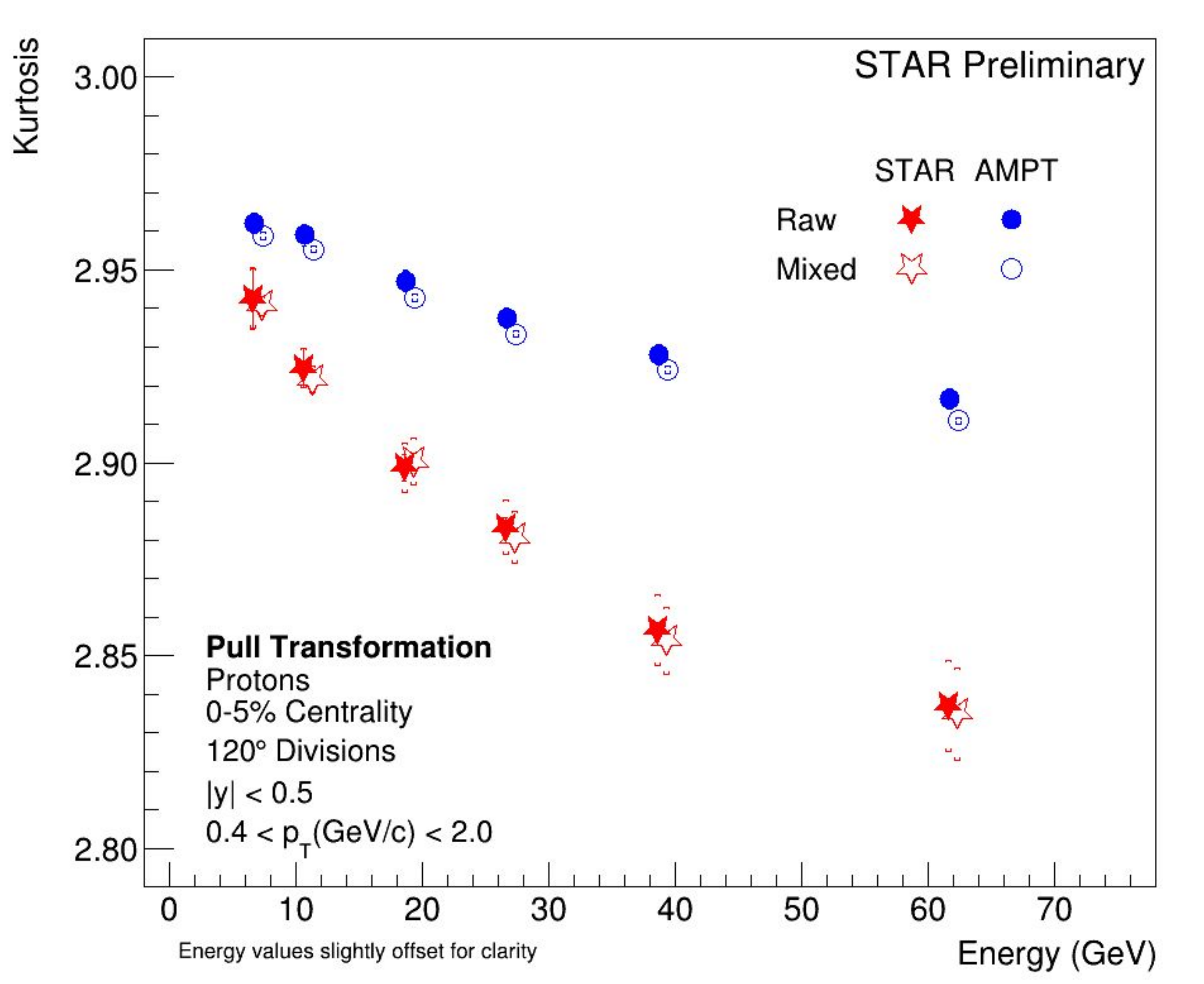
$$\sigma_{binomial} = \sqrt{n_{event} \cdot p \cdot q}$$

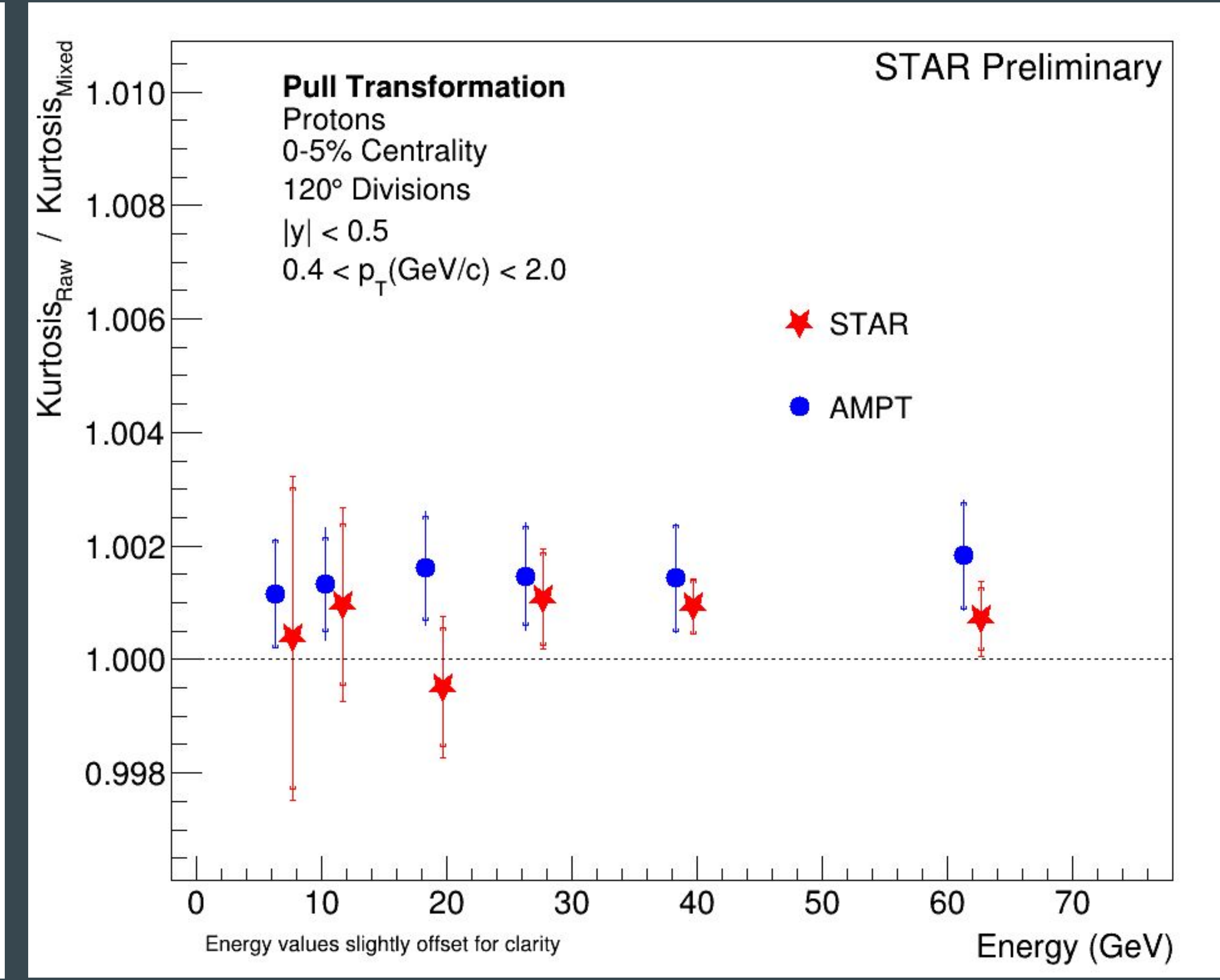
Divide by corresponding moments of mixed distributions

$$pull = \frac{n_{bin} - n_{event} \cdot w / 360°}{\sigma_{binomial}}$$

Calculate moments of these pull distributions

Pull Distribution : Kurtosis vs Energy

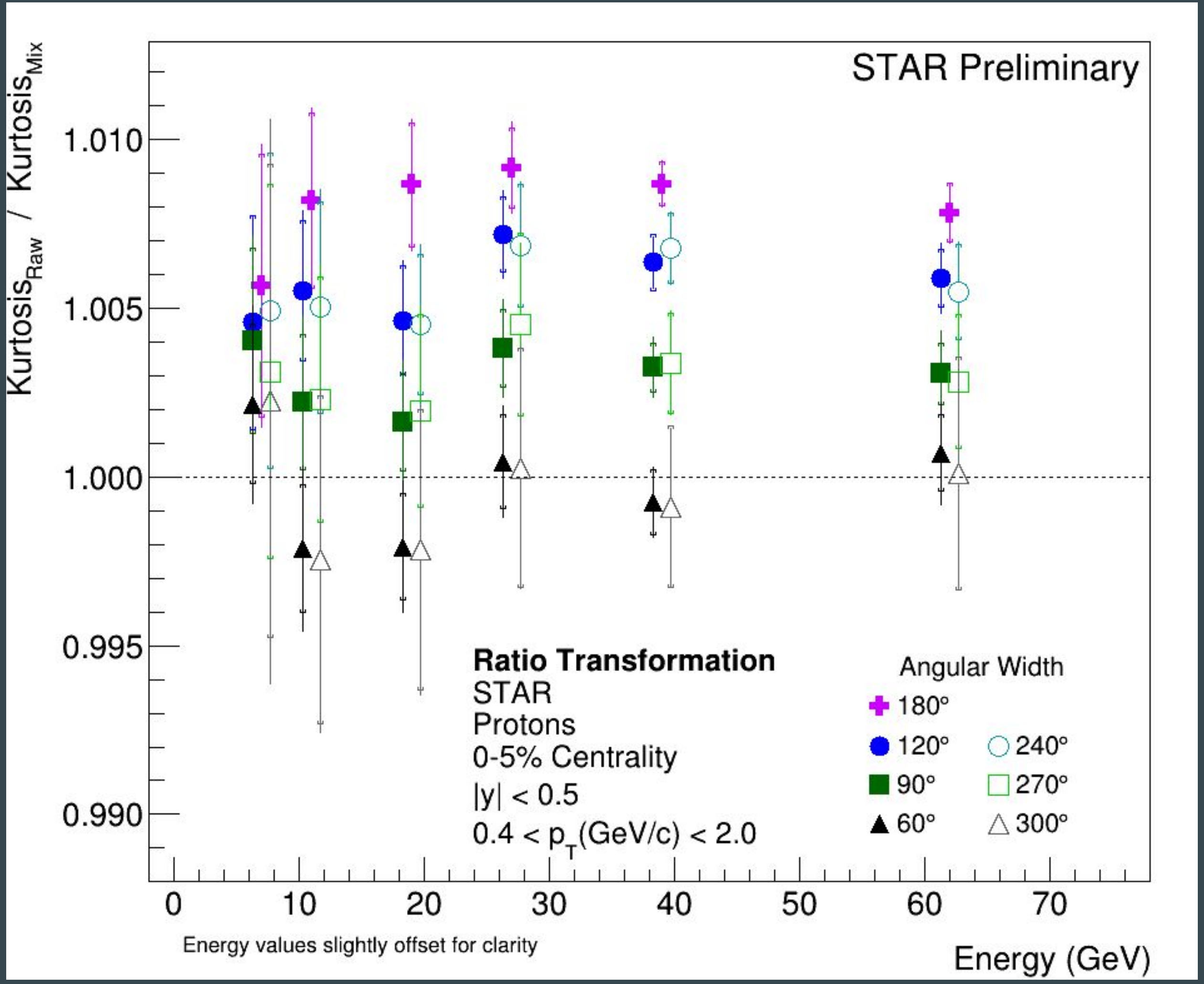




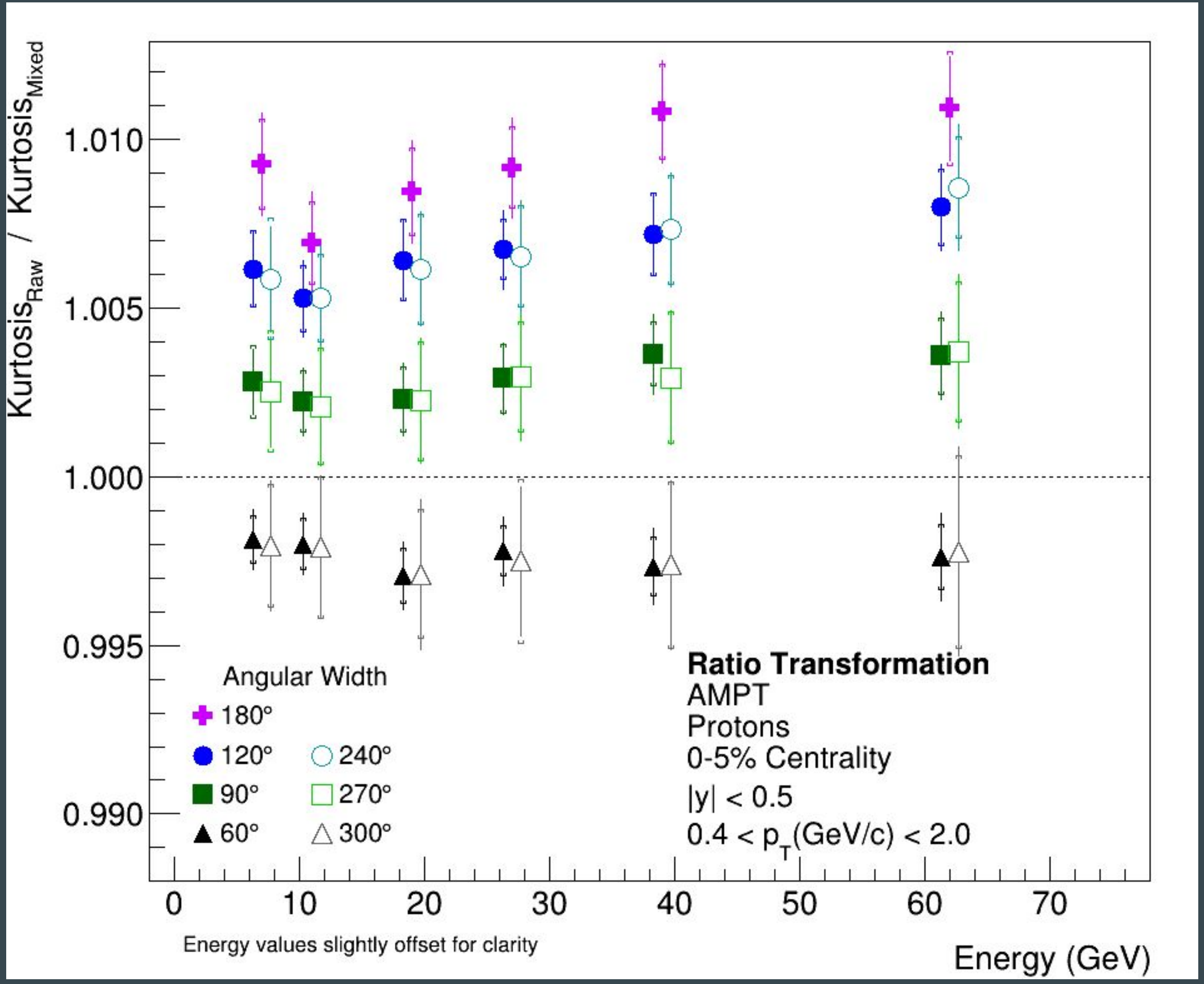
No significant trends with energy or deviations from AMPT observed, very similar to Ratio after normalizing by mixed

Ratio Distribution Angular Width Variation

STAR



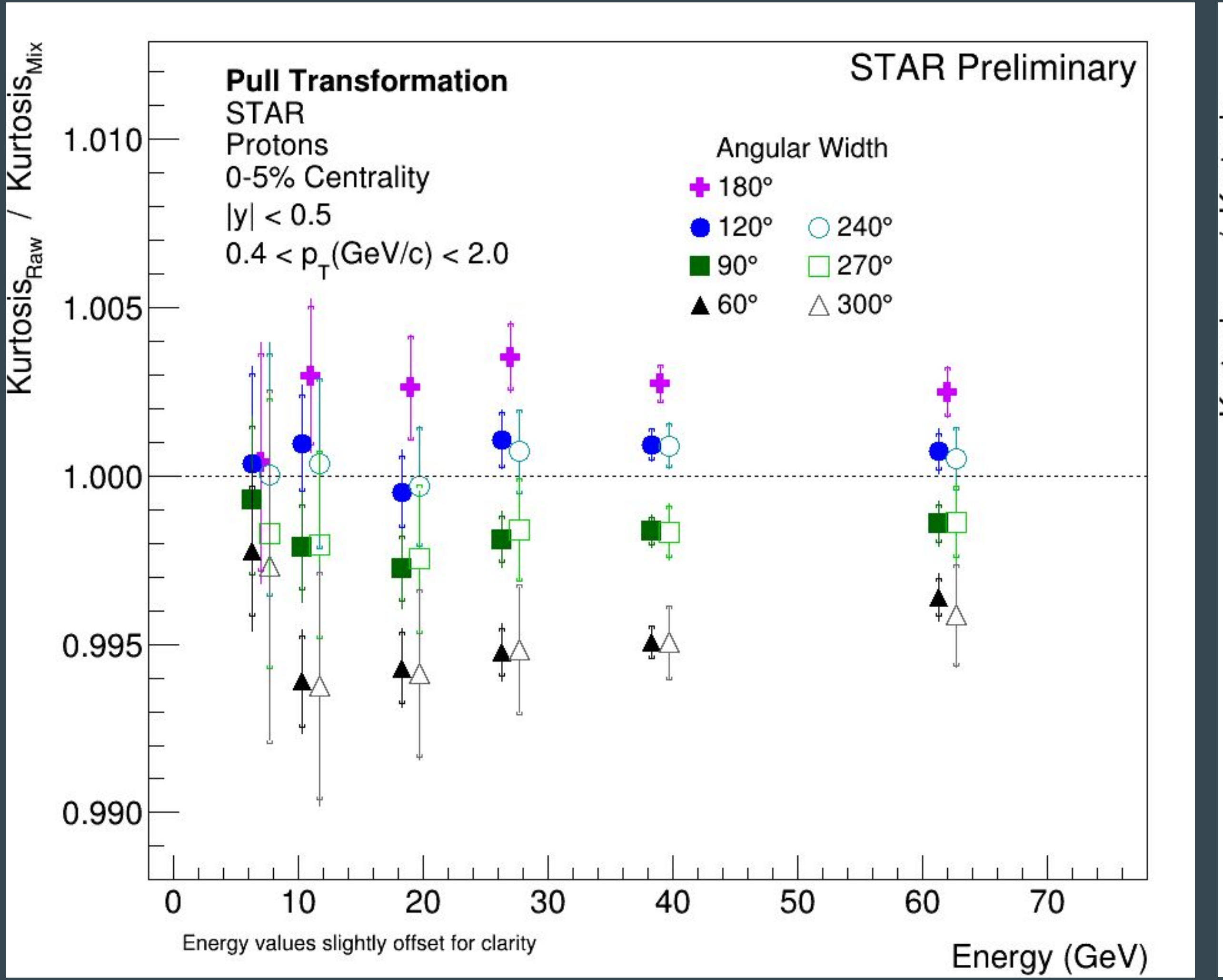
AMPT



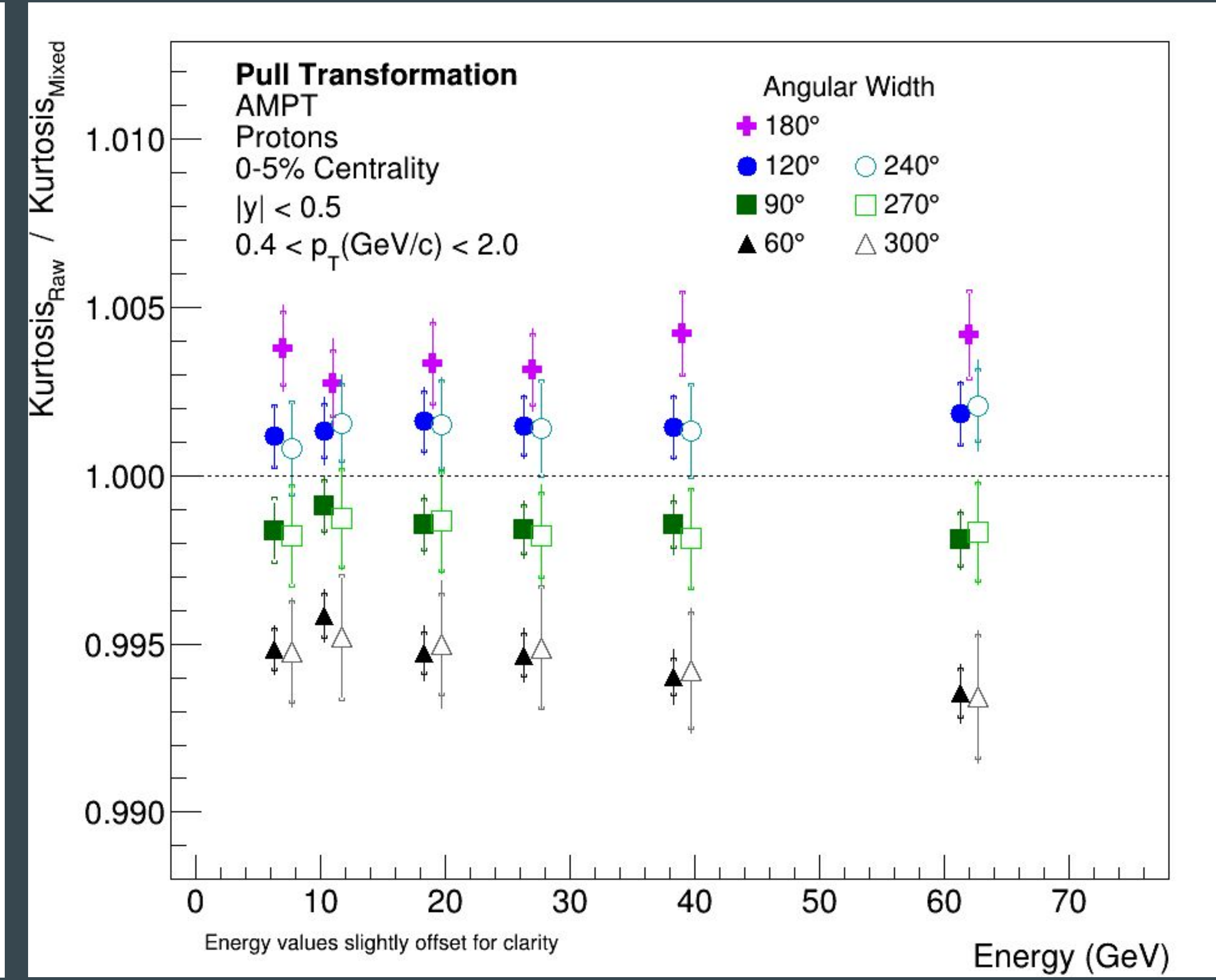
Largest value for 180° divisions, similar values for 180°±x° division pairs. No clear trends for any angular widths

Pull Distribution Angular Width Variation

STAR



AMPT



Largest value for 180° divisions, similar values for 180°±x° division pairs. No clear trends for any angular widths

Summary

- Two analysis methods performed on both STAR and AMPT data
  - Ratio Transformation
  - Pull Transformation

- Uncertainties large due to transformations performed
  - No clear, significant trends with energy
  - No significant deviations from AMPT model
  - 180° bins give largest raw to mixed ratio, decreasing symmetrically for larger or smaller bins

- No significant signal of non-monotonicity within statistical sensitivity
  - Dynamical model of critical behavior needed to make true comparison

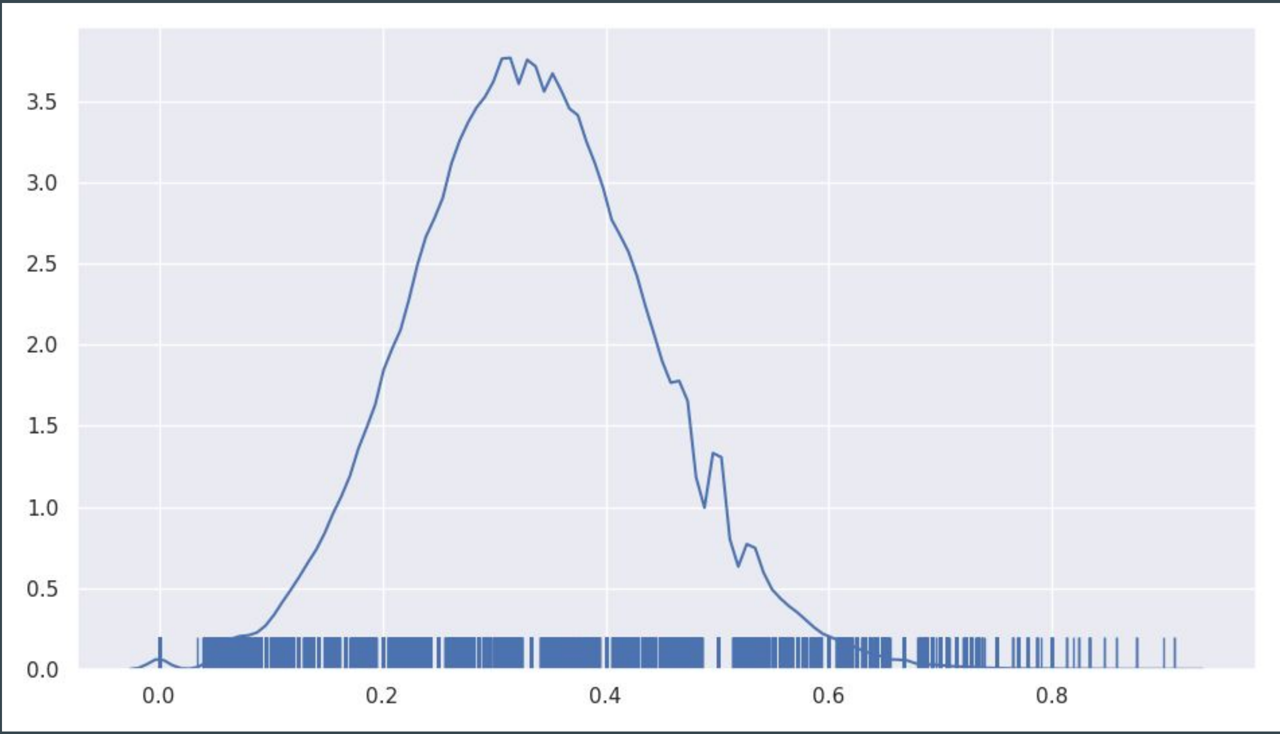
Backup

Systematics

- Default
  - Run analysis 60 times with default parameters and randomization
    - $|y| < 0.5$
    - $dca < 1$ cm
    - $|n\sigma_{proton}| < 2$
    - $m^2 \in (0.6, 1.2)$
  - Default point is medium of these 60 runs, using that run's statistical uncertainty
- Systematics
  - Run analysis 120 times, randomly sample each variable from uniform distribution
    - $0.8 < dca < 1.2$
    - $1.8 < |n\sigma_{proton}| < 2.2$
    - $0.2 < m^2_{range} < 0.6$ (centered around 0.9)
    - $15 <= nHitsFit <= 25$
  - Systematic error bar magnitude corresponds to standard deviation of these 120 values, centered on default point

Ratio/Pull KDEs

Ratio Distribution



Pull Distribution