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Azimuthal Fluctuation Analysis

- Motivation
- Introduction
- Analysis Techniques
  - Ratio Distribution
  - Pull Distribution
- Summary

APS DNP Fall Meeting 2020

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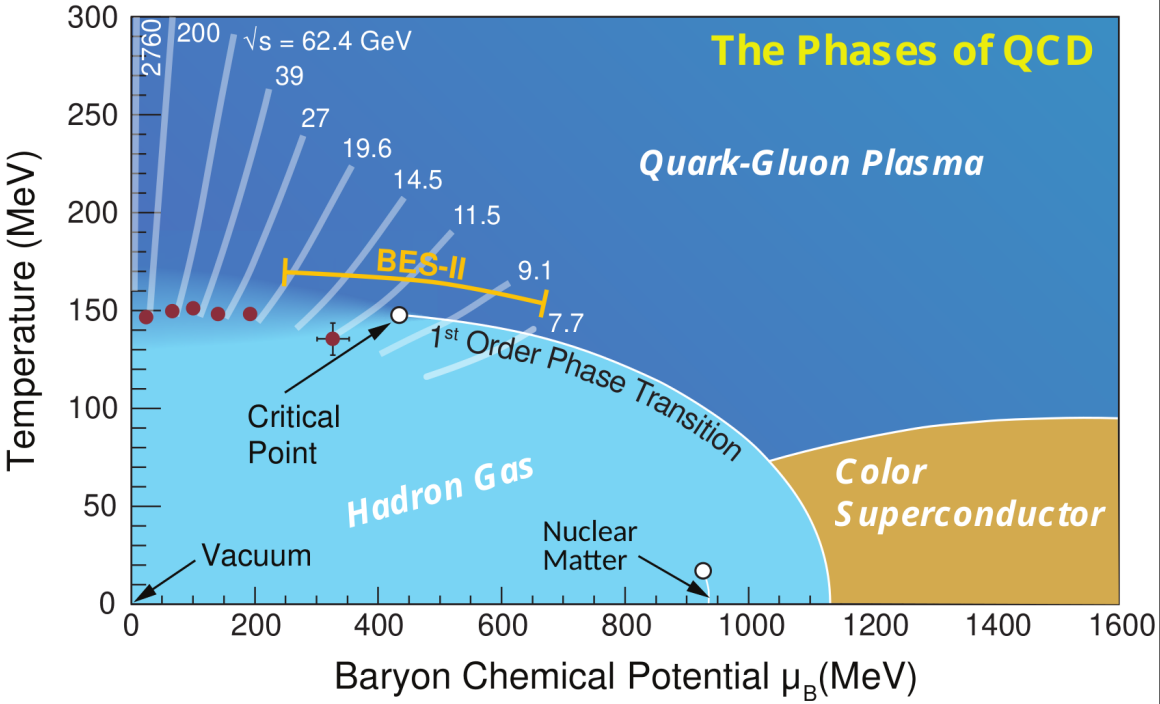
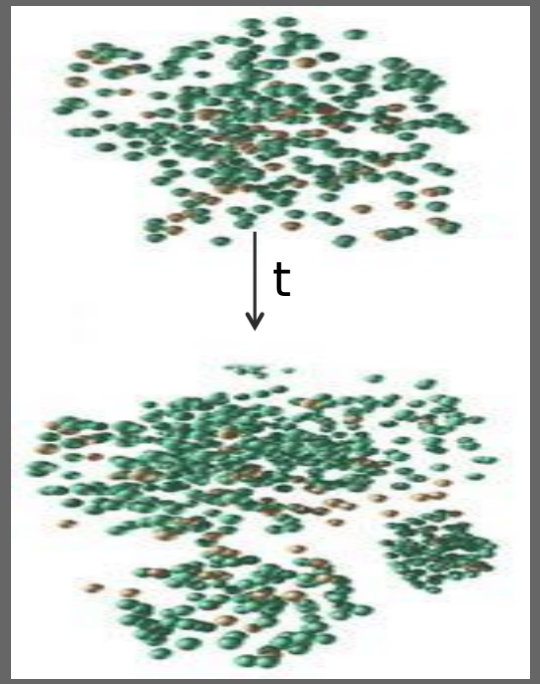
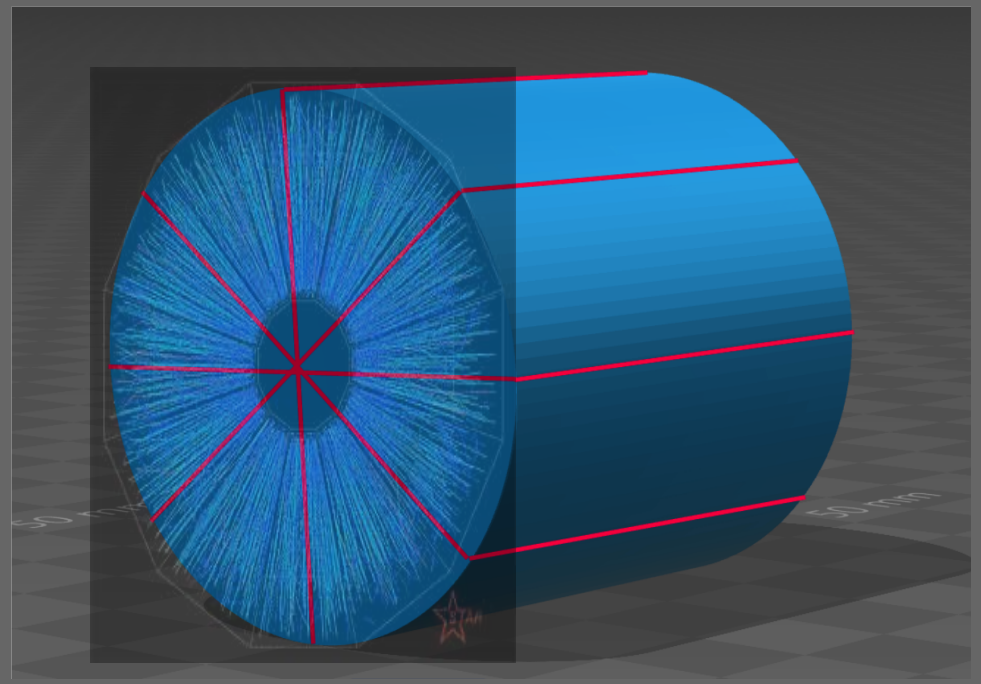
Motivation



- A major experimental goal is to map out the QCD phase diagram
- QGP to hadron gas transition is accessible in heavy ion collisions
- RHIC Beam Energy Scan I and II are intended to probe this transition at various locations

Introduction

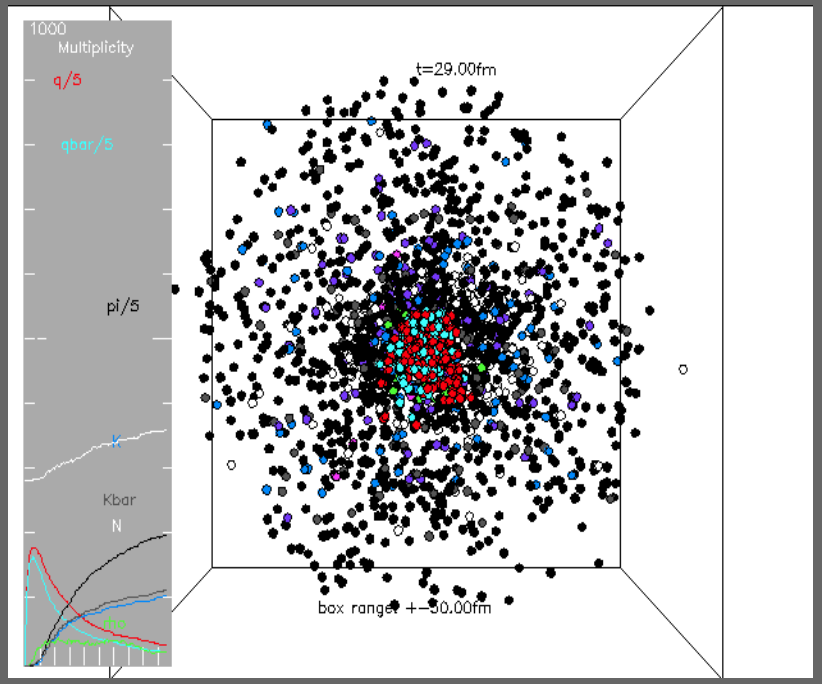




- Baryon clustering predicted in QGP to hadron gas phase transition
- Previous analyses look for multiplicity fluctuations in full STAR acceptance
- In this analysis, we partition the azimuthal momentum distribution and look for multiplicity fluctuations across divisions
- AMPT model used to demonstrate methodology, STAR analysis ongoing

AMPT Model

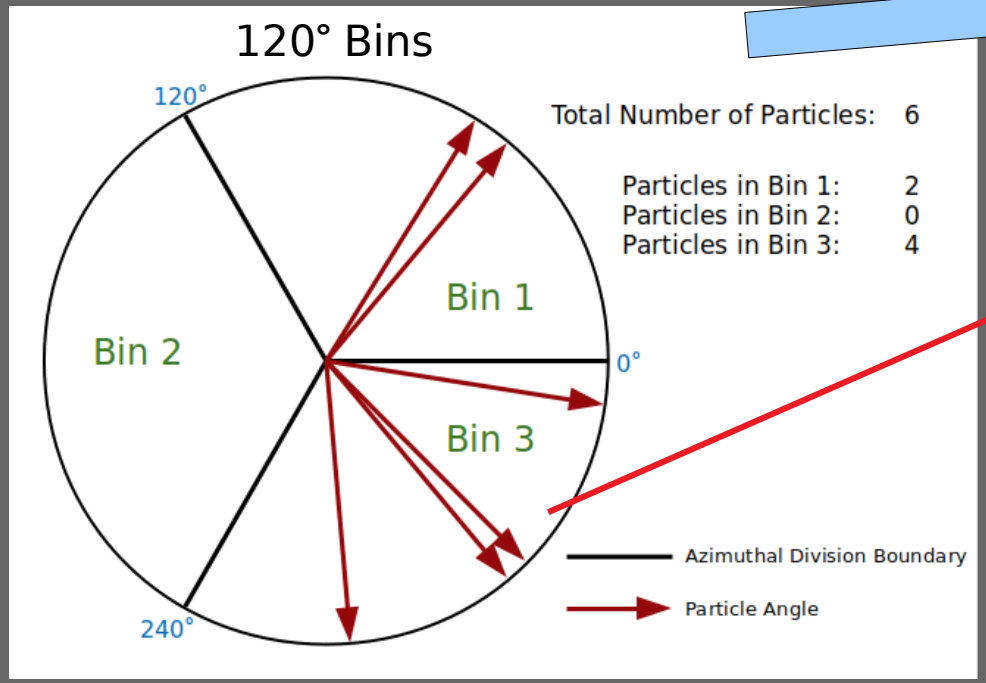
- Data from AMPT Model in *string melting* mode is used to demonstrate the analysis techniques
- Establish baseline to compare with STAR data
- Protons from Au+Au collisions analyzed
  - $|\eta| < 0.5$
  - $|p| < 3.0$ GeV/c
  - 0.4 GeV/c $< p_T < 2.0$ GeV/c



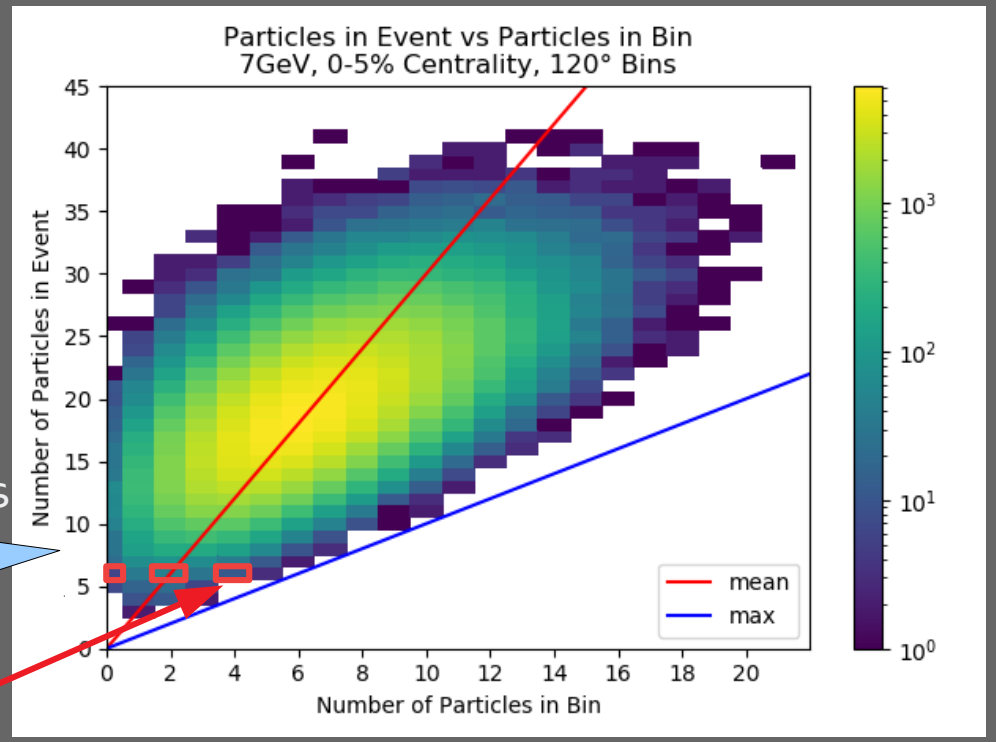
$\sqrt{s_{NN}}$ (GeV)	AMPT Events (x10^6)
7	3.20
11	2.68
19	2.73
27	2.29
39	2.44
62	2.51

Azimuthal Partitioning

Partition the azimuth in each event and histogram particle tracks



Histogram bin contents over many events

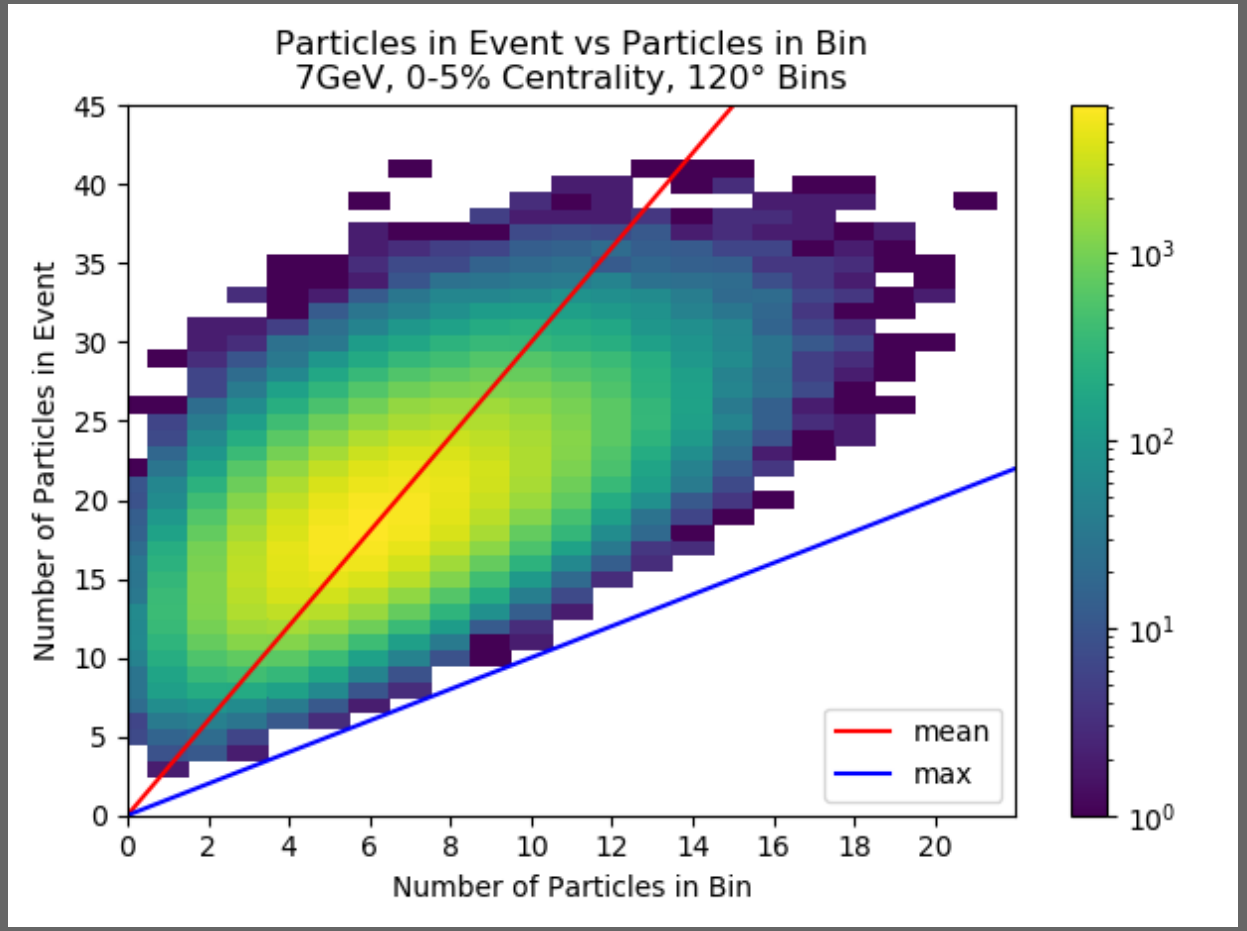


Mixed event sample is generated by randomly selecting N particle tracks from a class of raw events sorted by energy, centrality and event plane angle

Procedure carried out identically for raw data and mixed event data

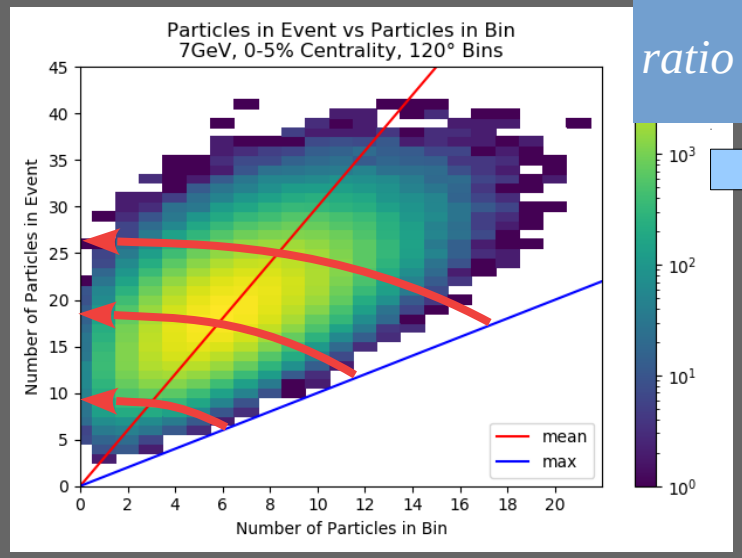
Two Analyses of Distribution

- Ratio Transformation
- Pull Transformation

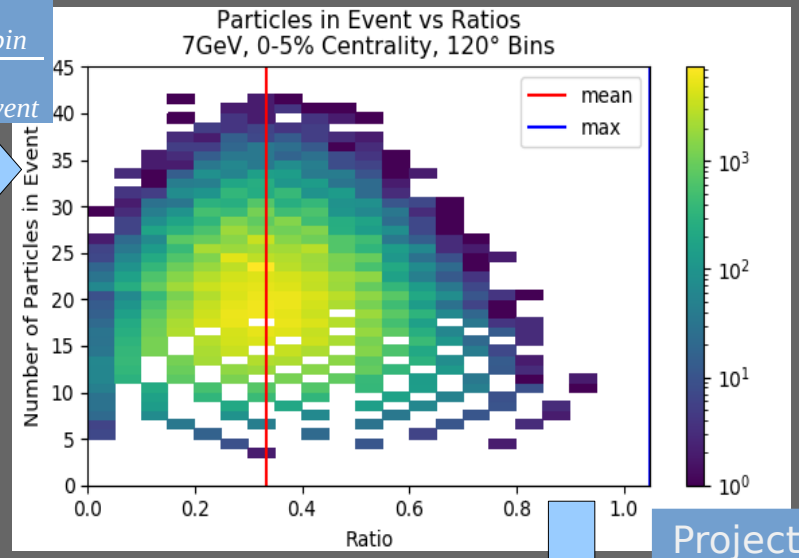


120° azimuthal bins of proton tracks and top 5% most central events presented in these slides

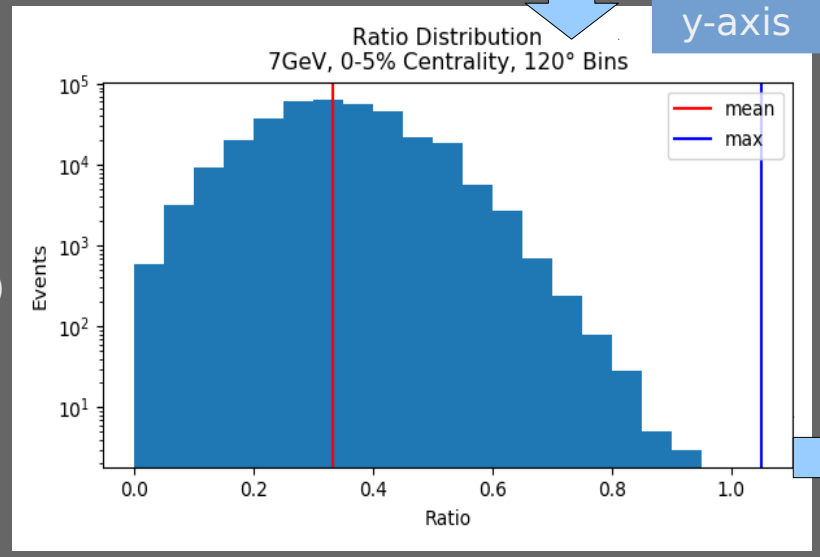
The Ratio Distribution



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



Project down y-axis



Calculate moments of these ratio distributions

Divide by corresponding moments of mixed distributions

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

Kurtosis is typically defined with a minus 3 and is technically "excess kurtosis"

$$\mu_n = \frac{\sum_i (y_i - \bar{y})^n}{\sum_i y_i}$$

n^{th} central moment

Uncertainty on kurtosis calculated via the delta theorem

Luo arXiv:1109.0593v2

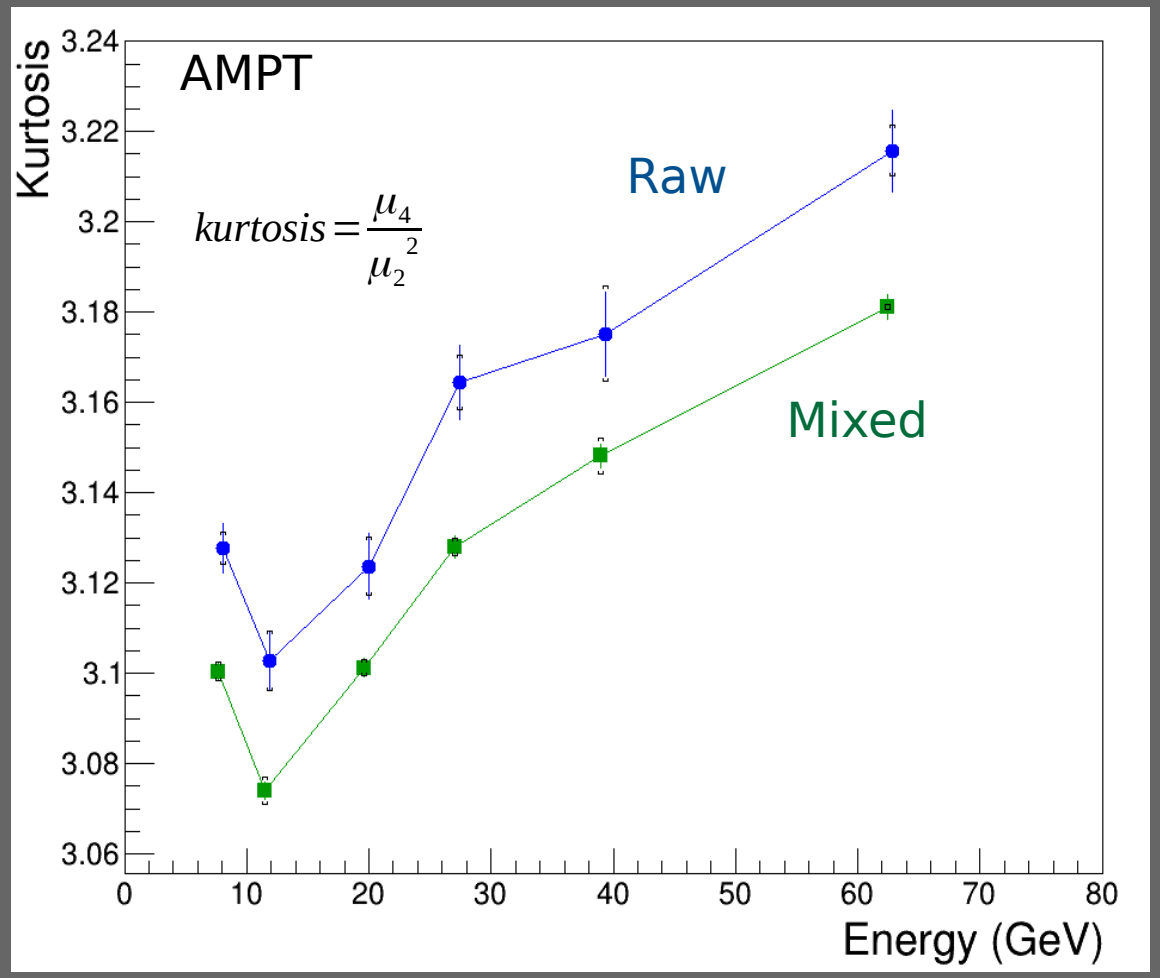
Compress (Divide)

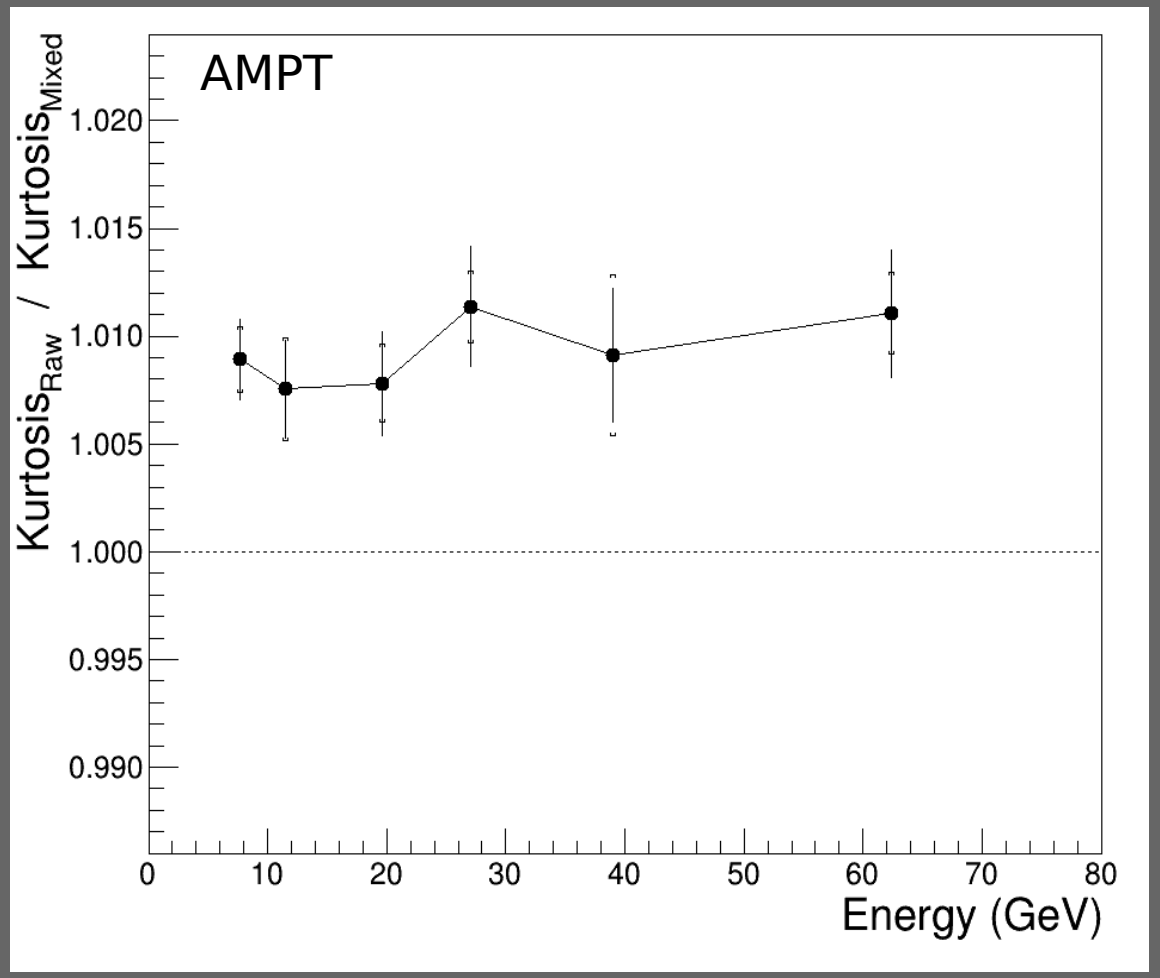
n_{bin} = Number of Particles in Bin (x value)

n_{event} = Number of Particles in Event (y value)

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

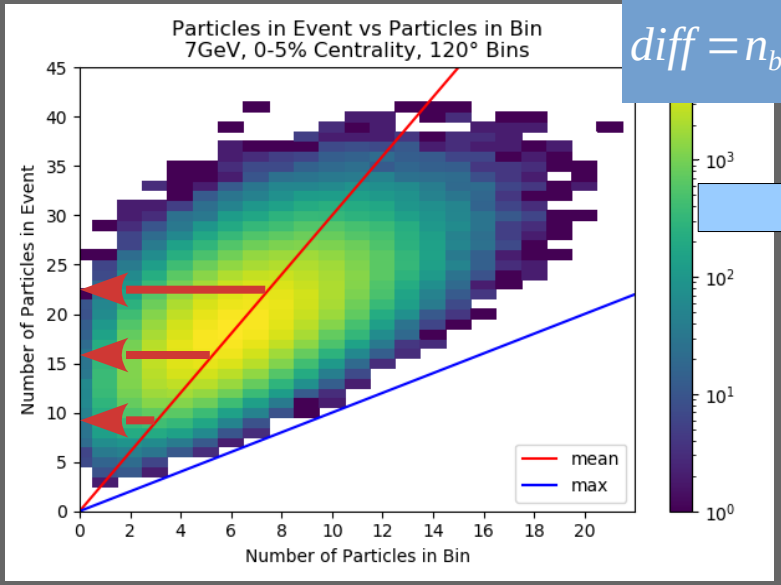
Ratio Distribution: Kurtosis vs Energy



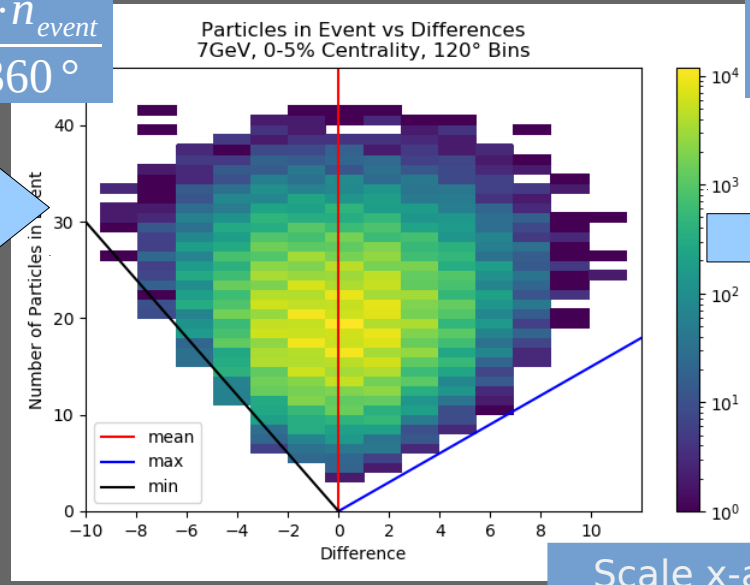


Systematic uncertainties due to random rotation of each event and random mixing of events.

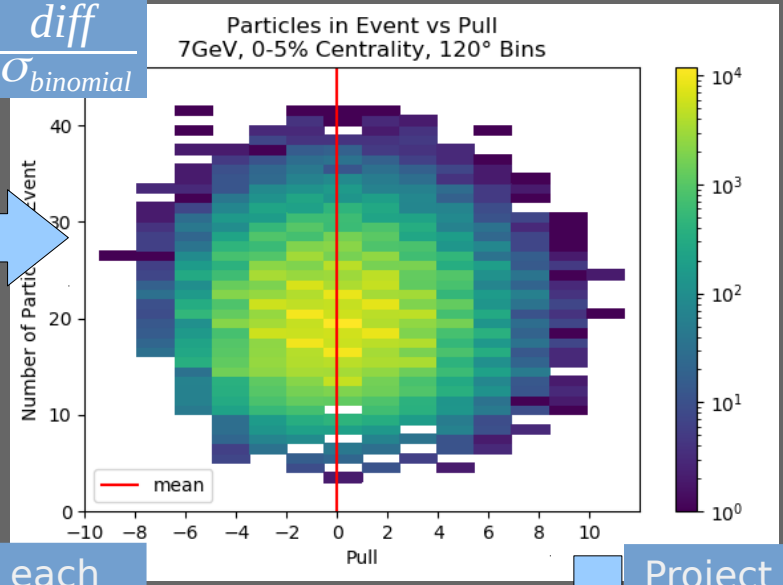
The Pull Distribution



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

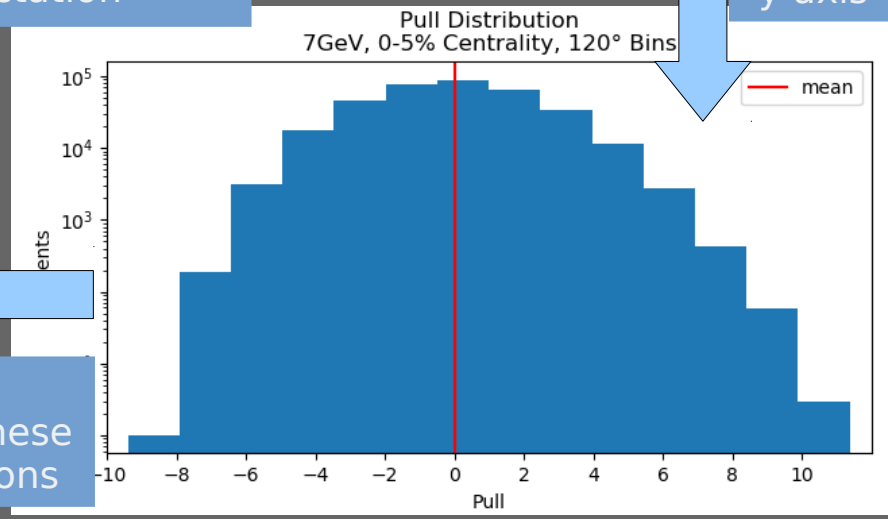


$$pull = \frac{diff}{\sigma_{binomial}}$$



Scale x-axis for each slice by SD of binomial expectation

Project down y-axis



Calculate moments of these pull distributions

Divide by corresponding moments of mixed distributions

Rotate (Subtract)

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

$$\sigma_{binomial} = \sqrt{n_{event}\,pq}$$

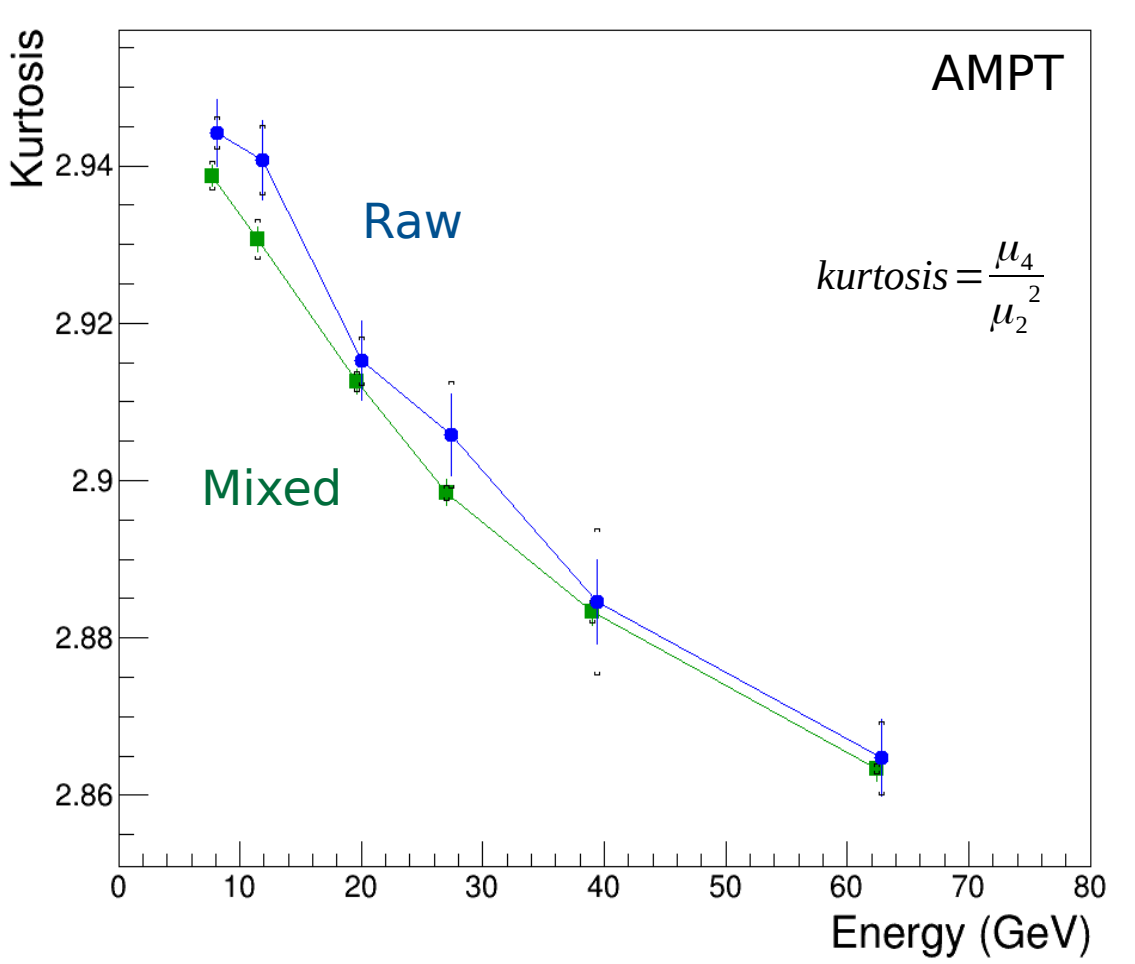
n_{bin} = Number of Particles in Bin (x value)

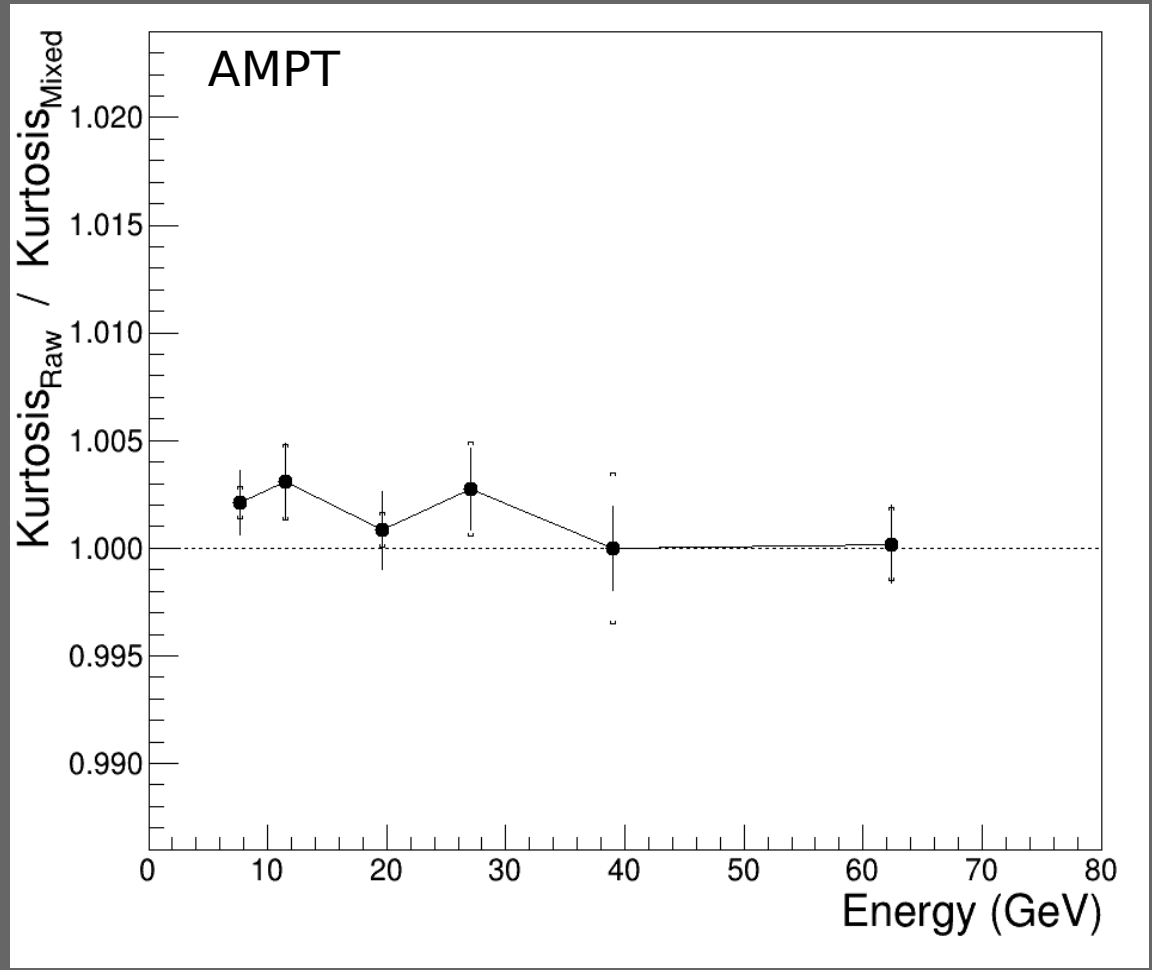
n_{event} = Number of Particles in Event (y value)

w = Bin Width (°)

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

Pull Distribution: Kurtosis vs Energy

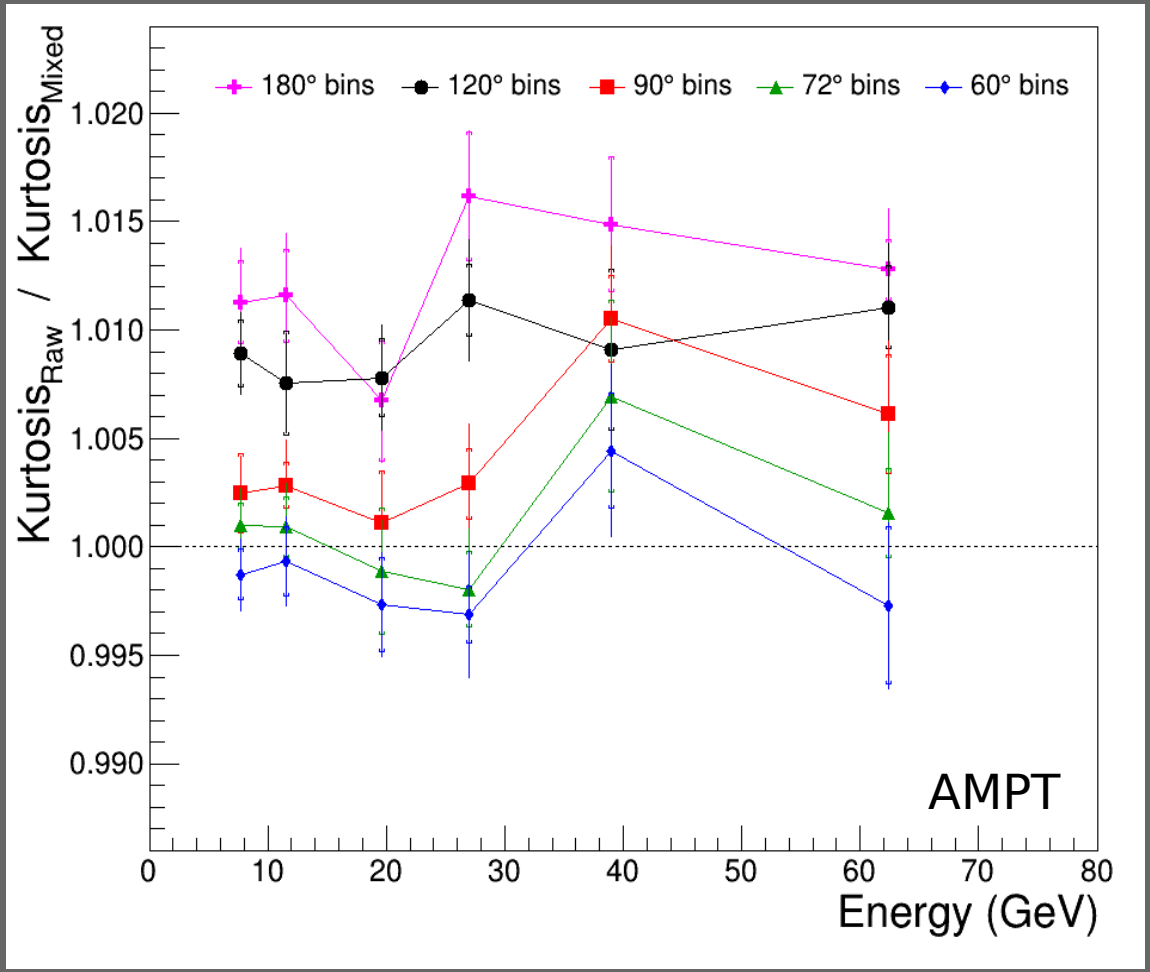




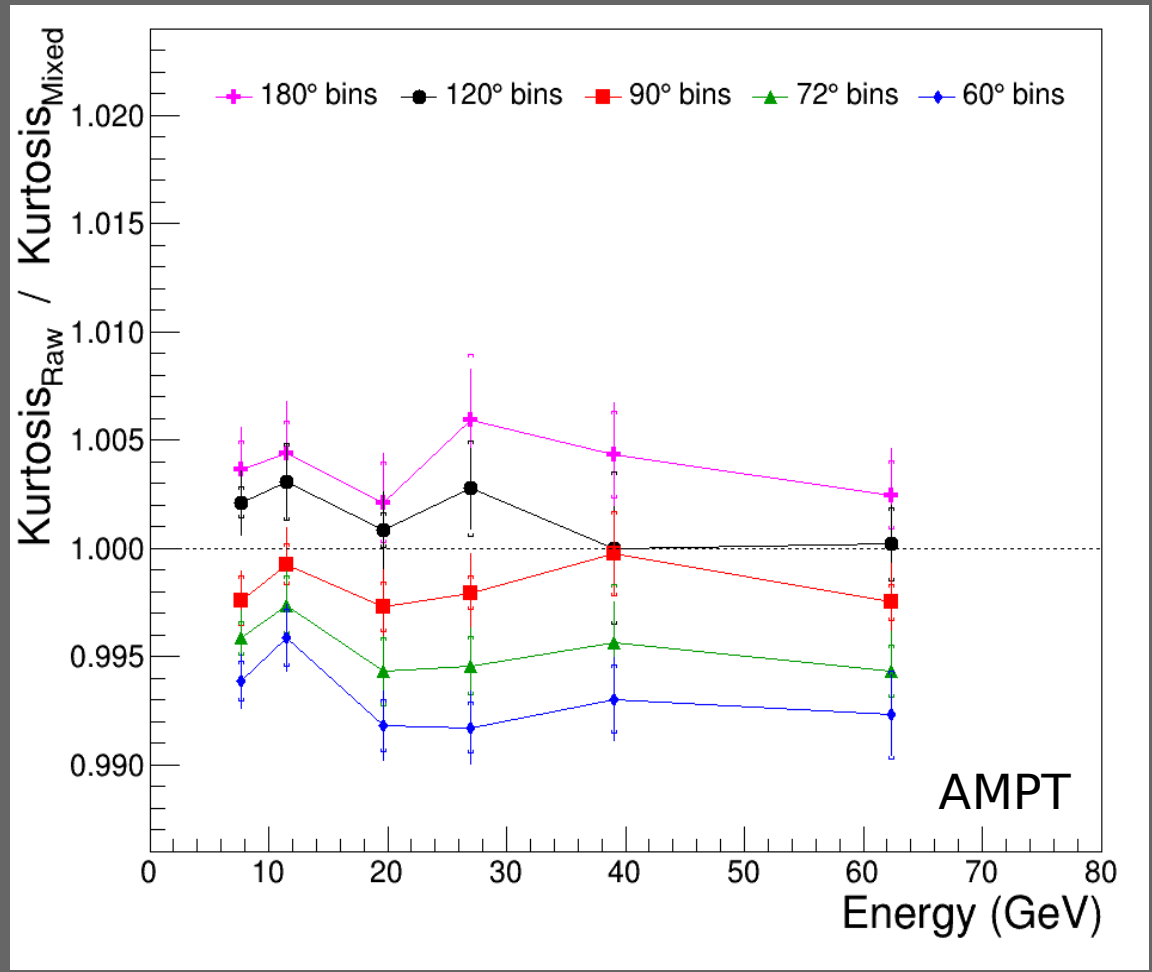
Systematic uncertainties due to random rotation of each event and random mixing of events.

Ratio & Pull Distributions: Bin Width Variation

Ratio Distribution



Pull Distribution



Both transformations of the original 2D distribution give similar trends though different magnitudes

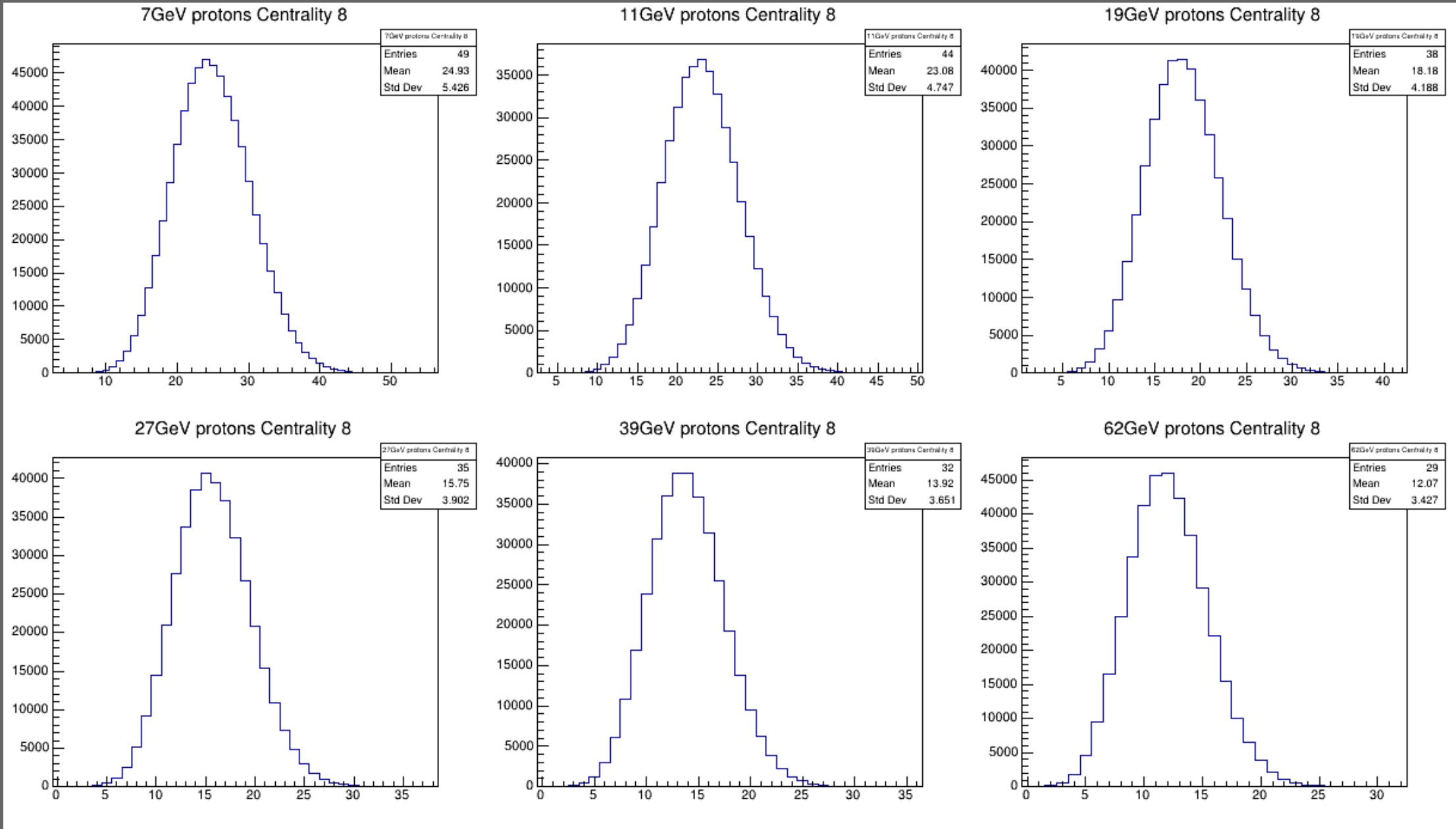
Summary

- Search for baryon density fluctuations with azimuthal partitions
- Two analysis methods using AMPT to establish a baseline
  - Ratio Transformation
  - Pull Transformation
- STAR data analysis ongoing

Thank you!

Backup

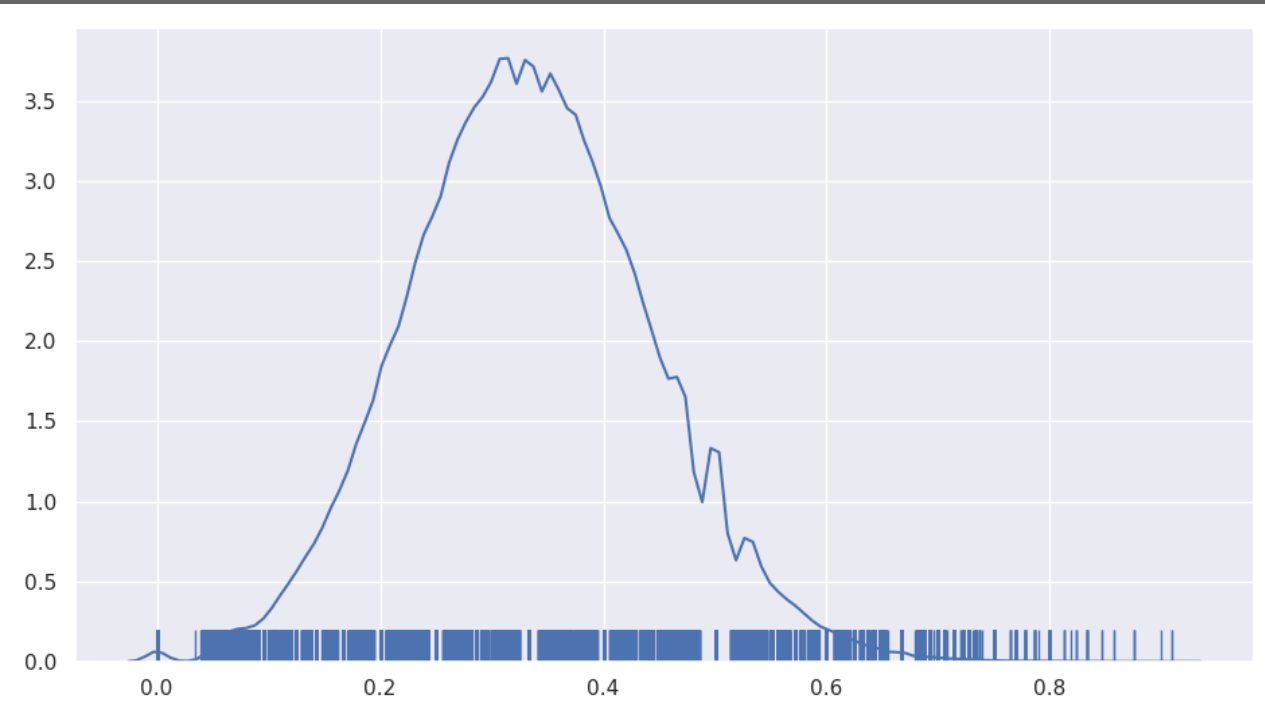
AMPT Proton Distributions



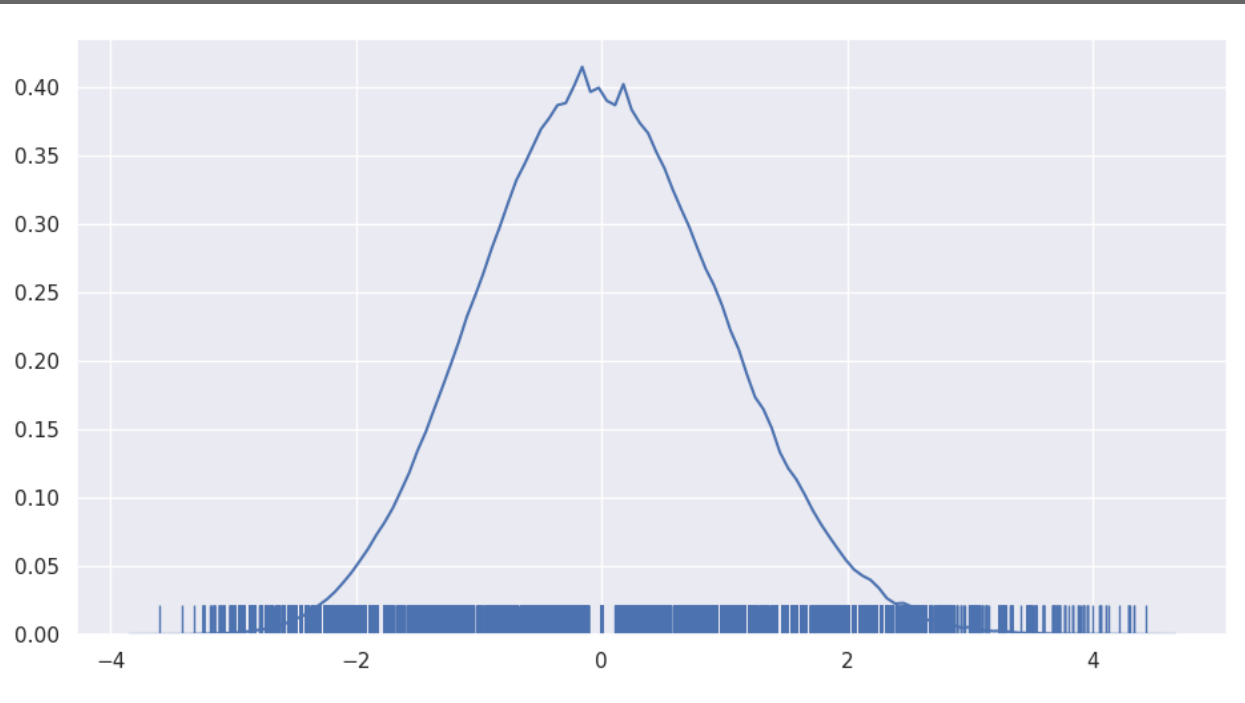
Ratio/Difference KDE

As a consequence of working with integer data, the distributions are rather discretized and not faithfully represented in histograms (large dependence on binning). Kernel density estimation and rug plots are shown below to help visualize the true distributions.

Ratio Distribution

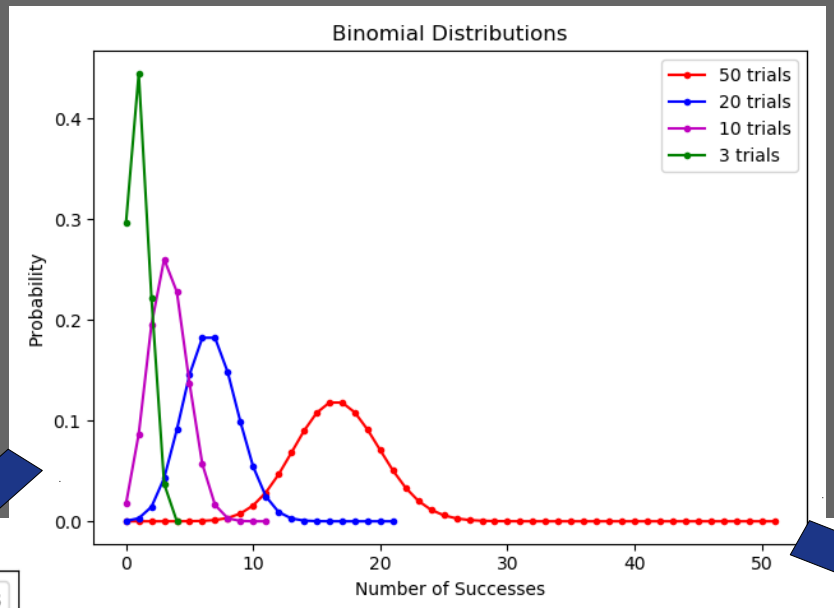


Pull Distribution



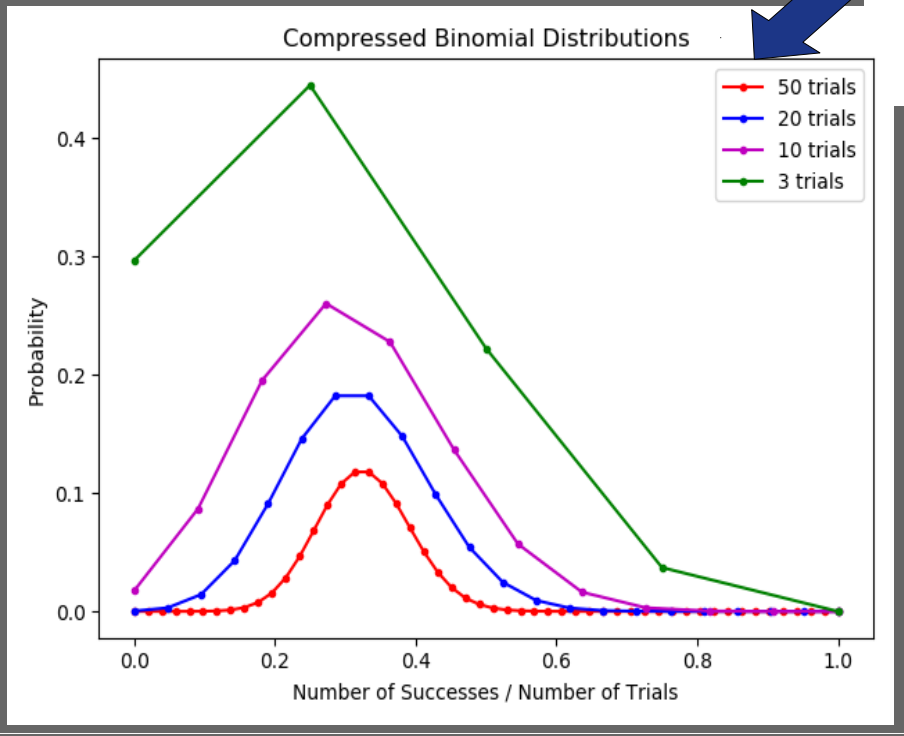
Relating Binomial Slices to Ratio/Pull Distributions

Using the binomial model for slices, the ratio and pull transformations effectively contract these binomial distributions and then superimpose them



Ratio/Difference distribution tails are sensitive to events with low number of total protons

Ratio Distribution



Pull Distribution