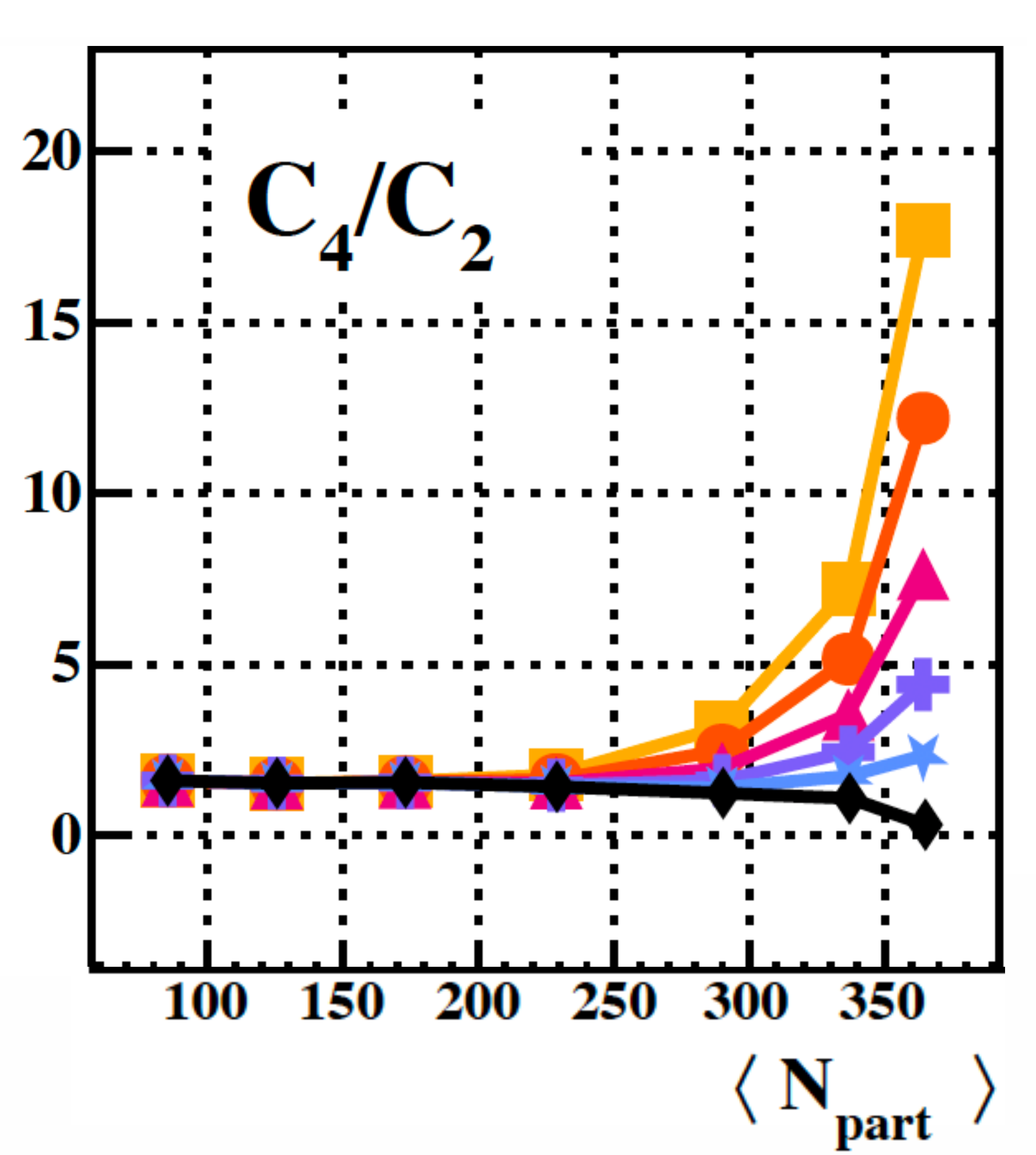


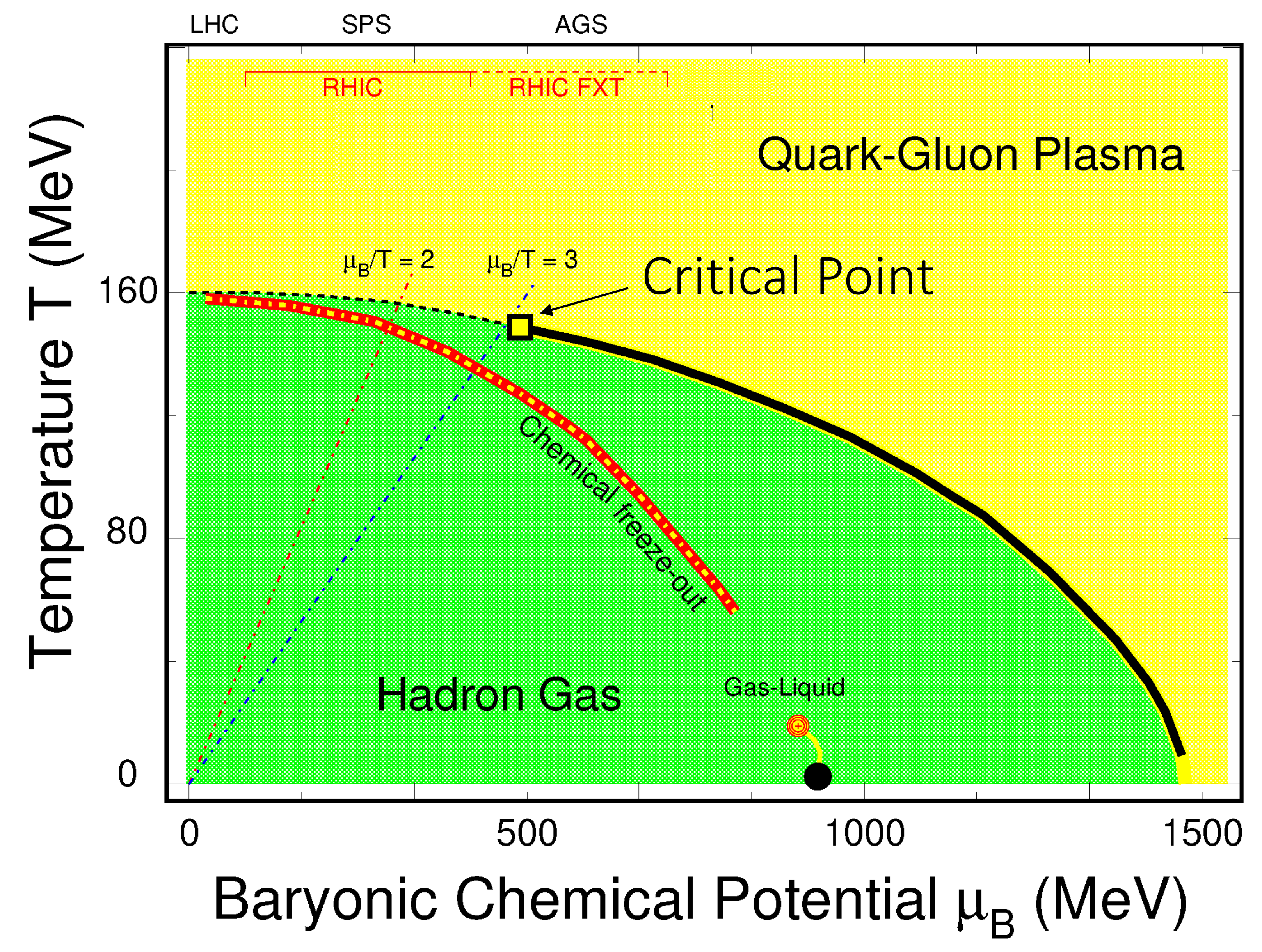
How Not to Measure a False Critical Point

Zachary Sweger
University of California, Davis

Overview

- QCD Critical Fluctuations
- Rare and spontaneous detector failure
- Toy model with UrQMD
- How not to measure a false signal

Phases of QCD Matter



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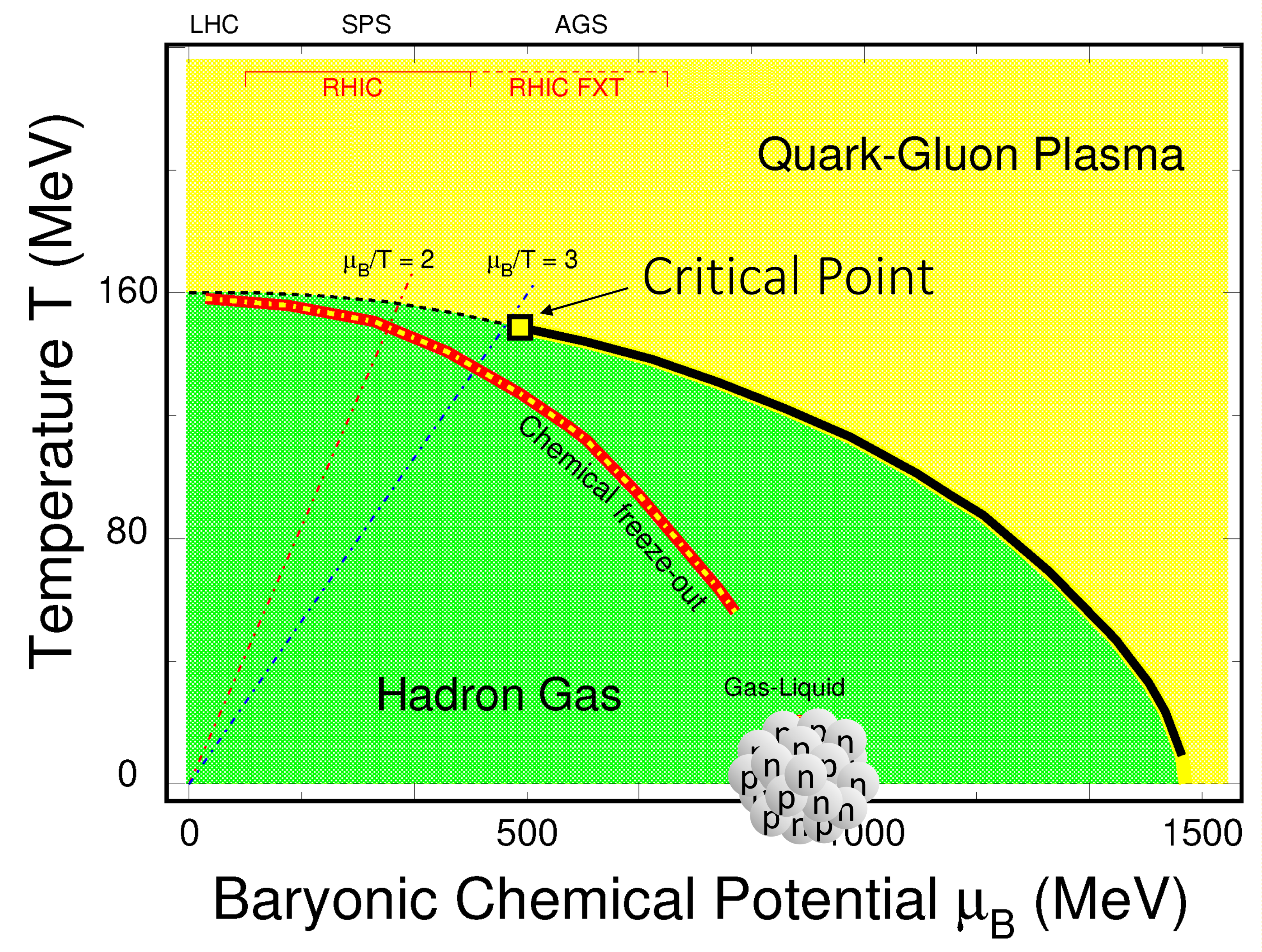

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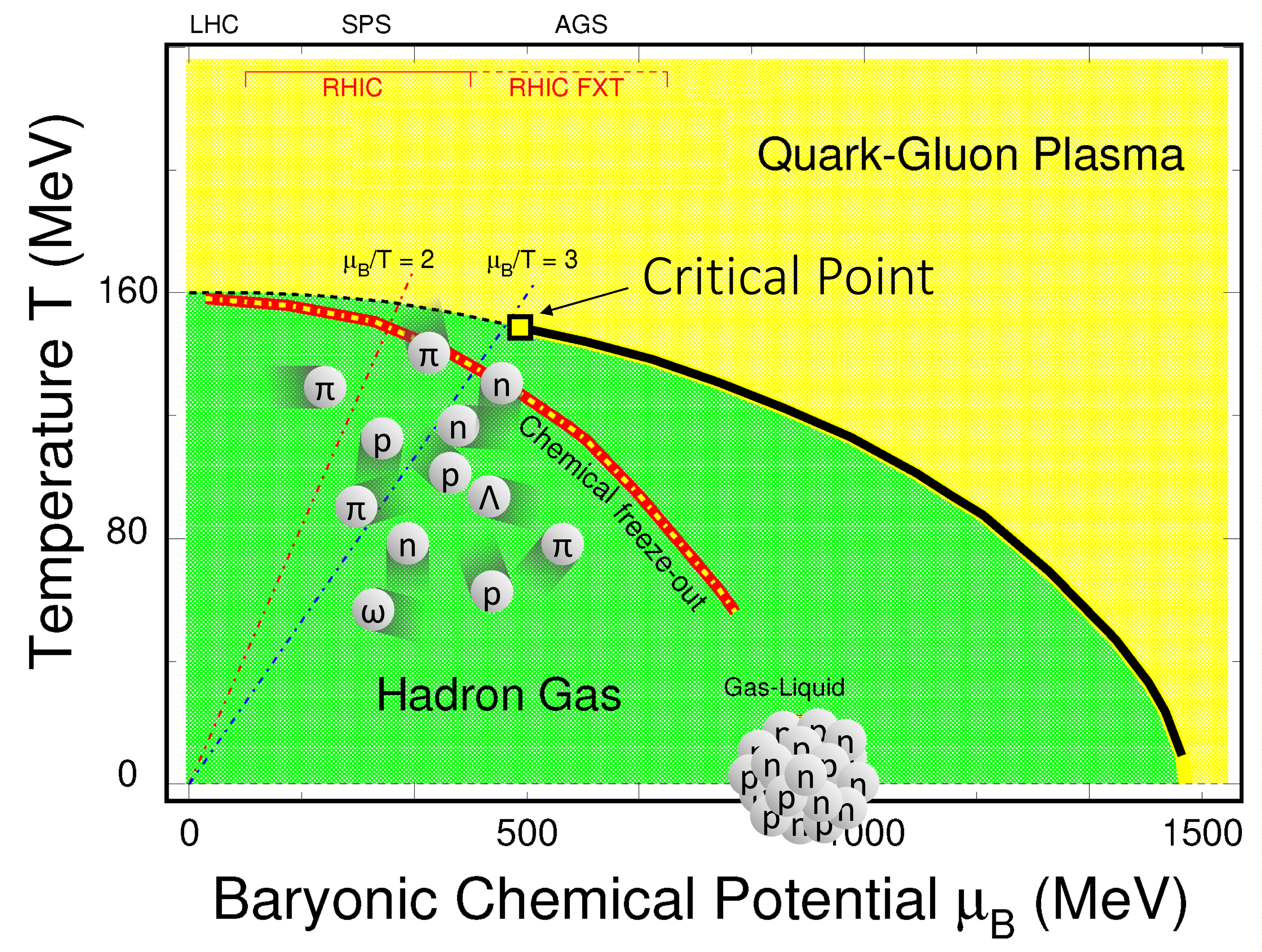

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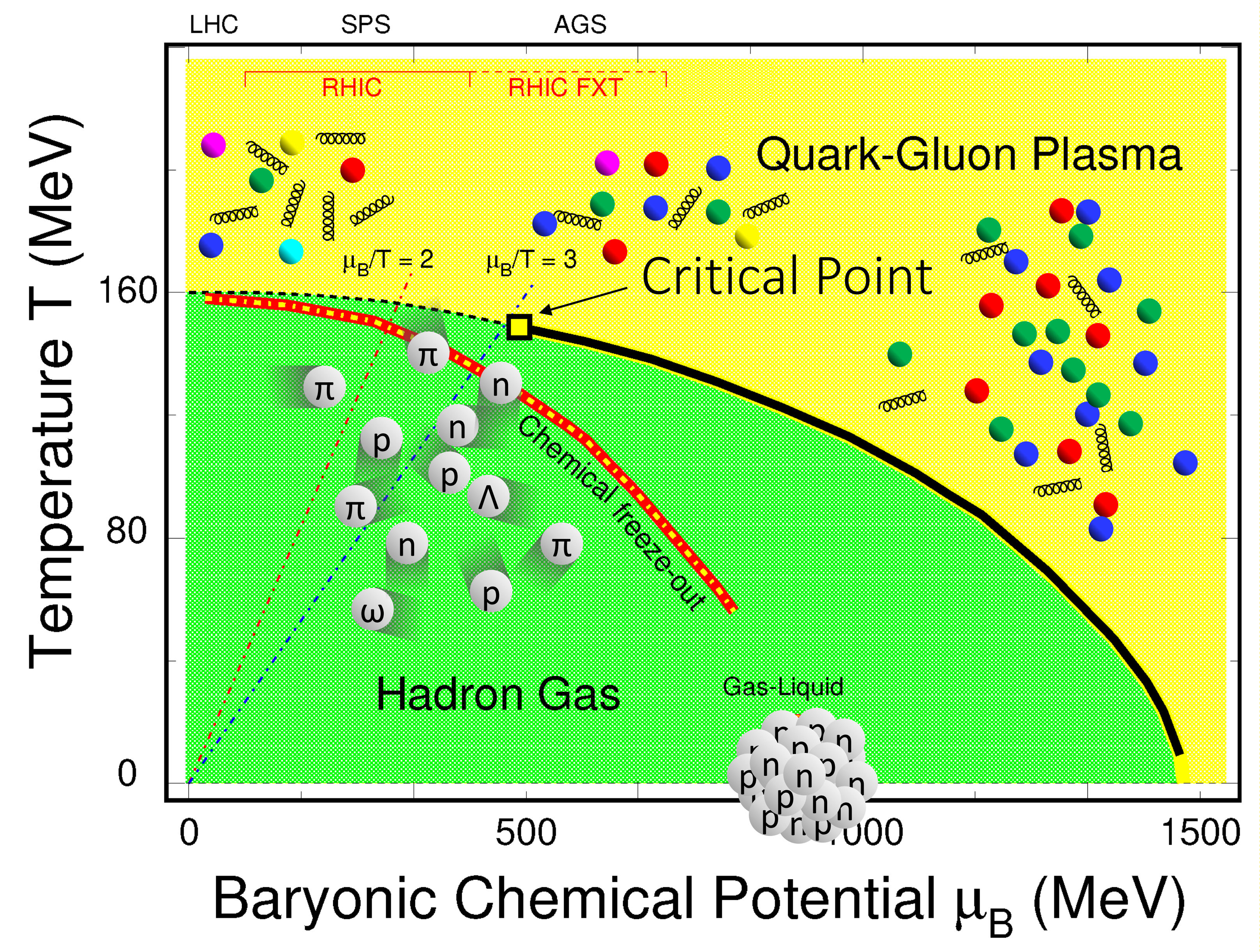

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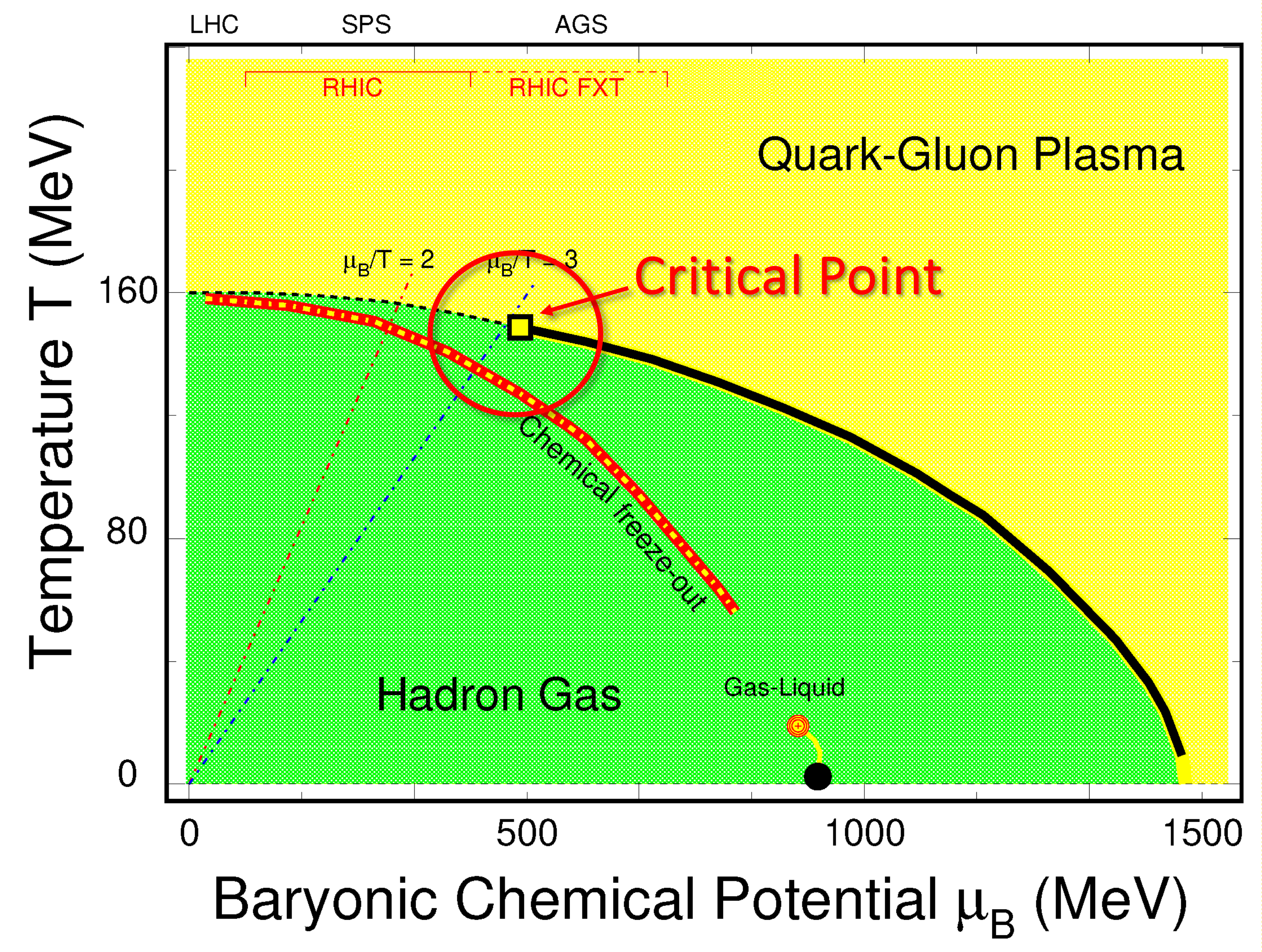

Non-Gaussian fluctuations in baryon number

- Distribution of net-baryon number is expected to fluctuate near a critical point
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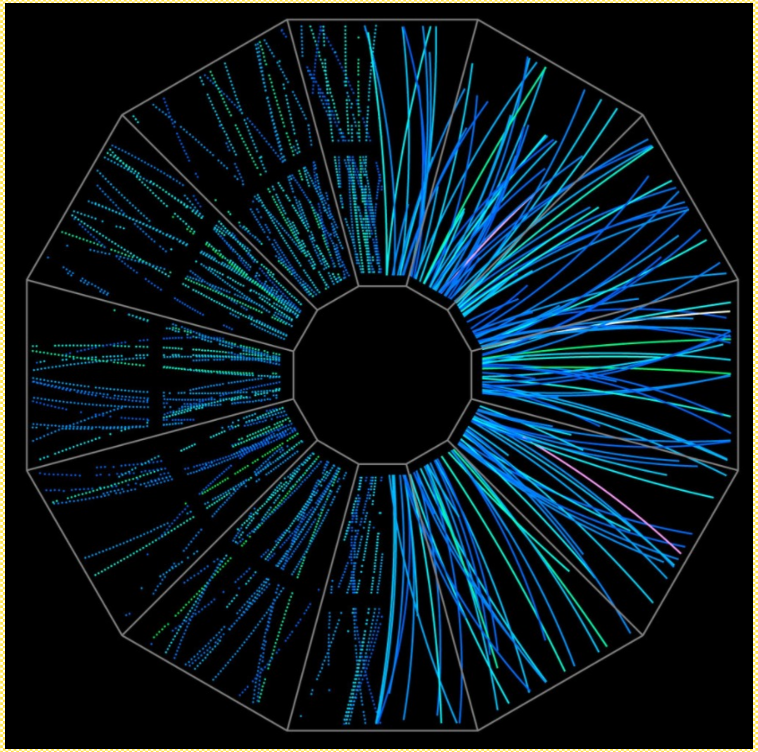

https://www.bnl.gov/newsroom/news.php?a=214492

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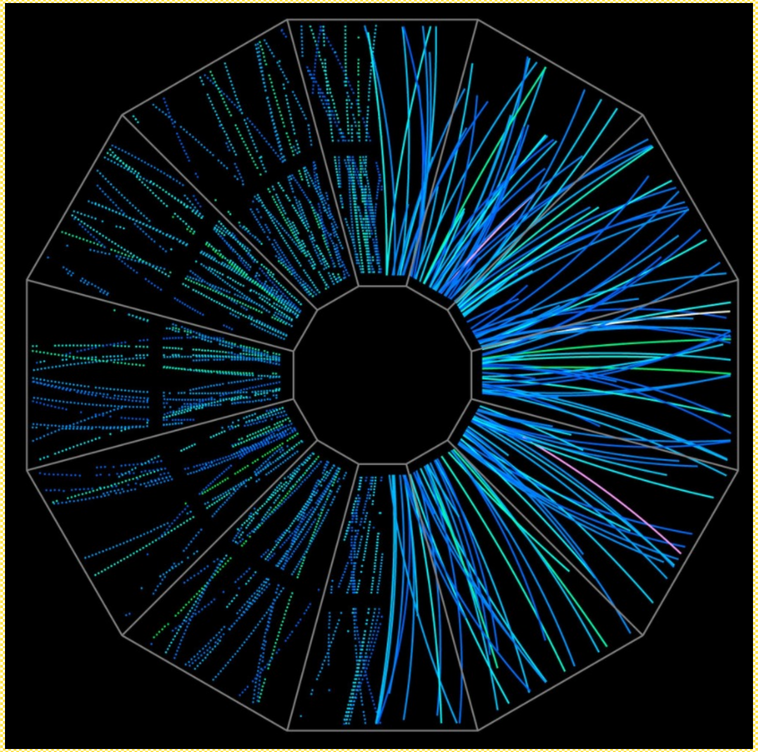

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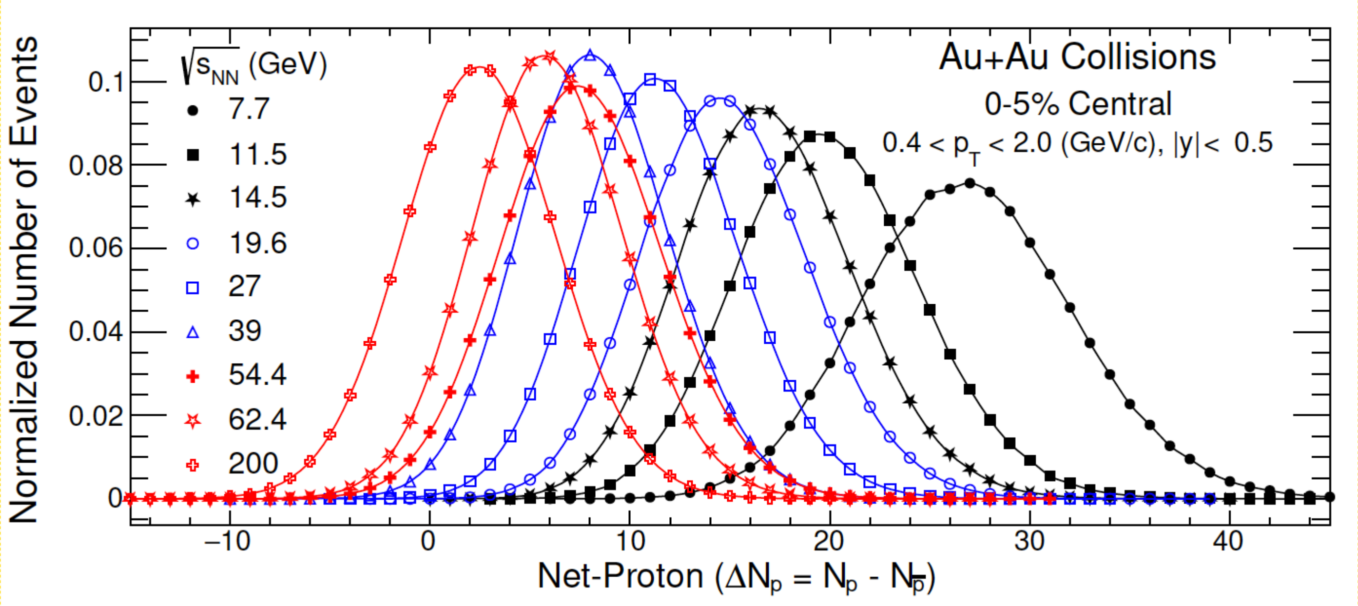

Net-proton distributions at several energies as measured by STAR.
arXiv:2001.02852v2 [nucl-ex] 31 Jul 2020

Non-Gaussian fluctuations in baryon number

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- Measure the mean, variance, skewness, kurtosis…

cumulants

$$C_1 = \langle N \rangle \equiv \mu \text{ [mean]}$$

$$C_2 = \langle (N-\mu)^2 \rangle \equiv \sigma^2 \text{ [variance]}$$

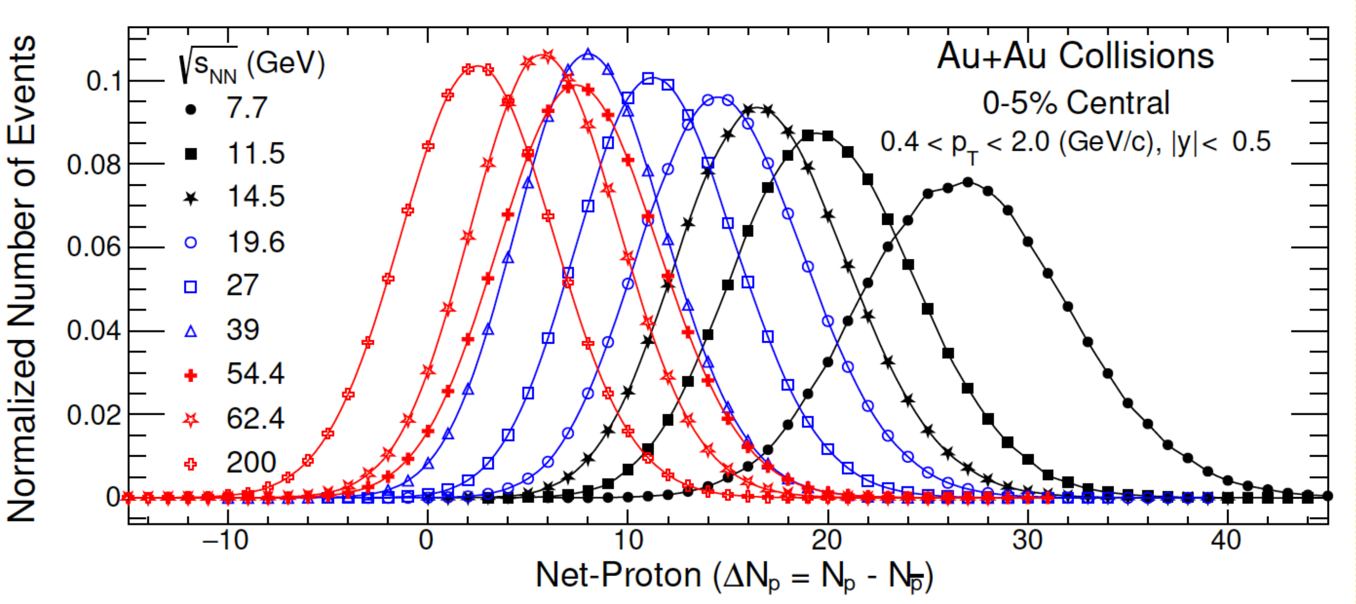
$$C_3 = \langle (N-\mu)^3 \rangle$$

$$C_4 = \langle (N-\mu)^4 \rangle - 3\langle (N-\mu)^2 \rangle^2$$

standardized moments

$$S\sigma = C_3/C_2 \text{ [skewness]}$$

$$\kappa\sigma^2 = C_4/C_2 \text{ [excess kurtosis]}$$



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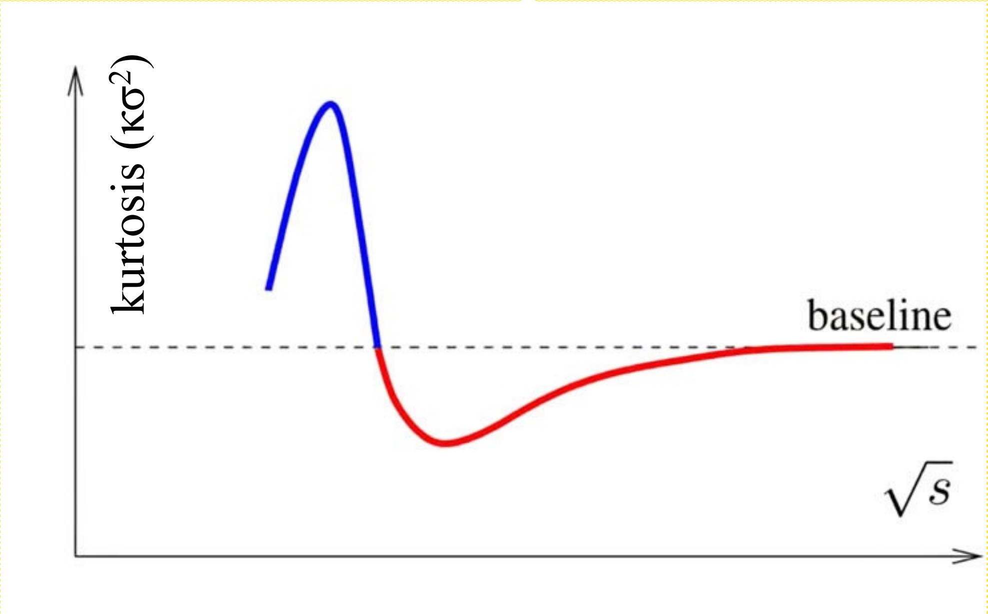
Proximity to Critical Point → Alternately Enhanced and Suppressed Kurtosis

Predicted fluctuation in kurtosis near critical point

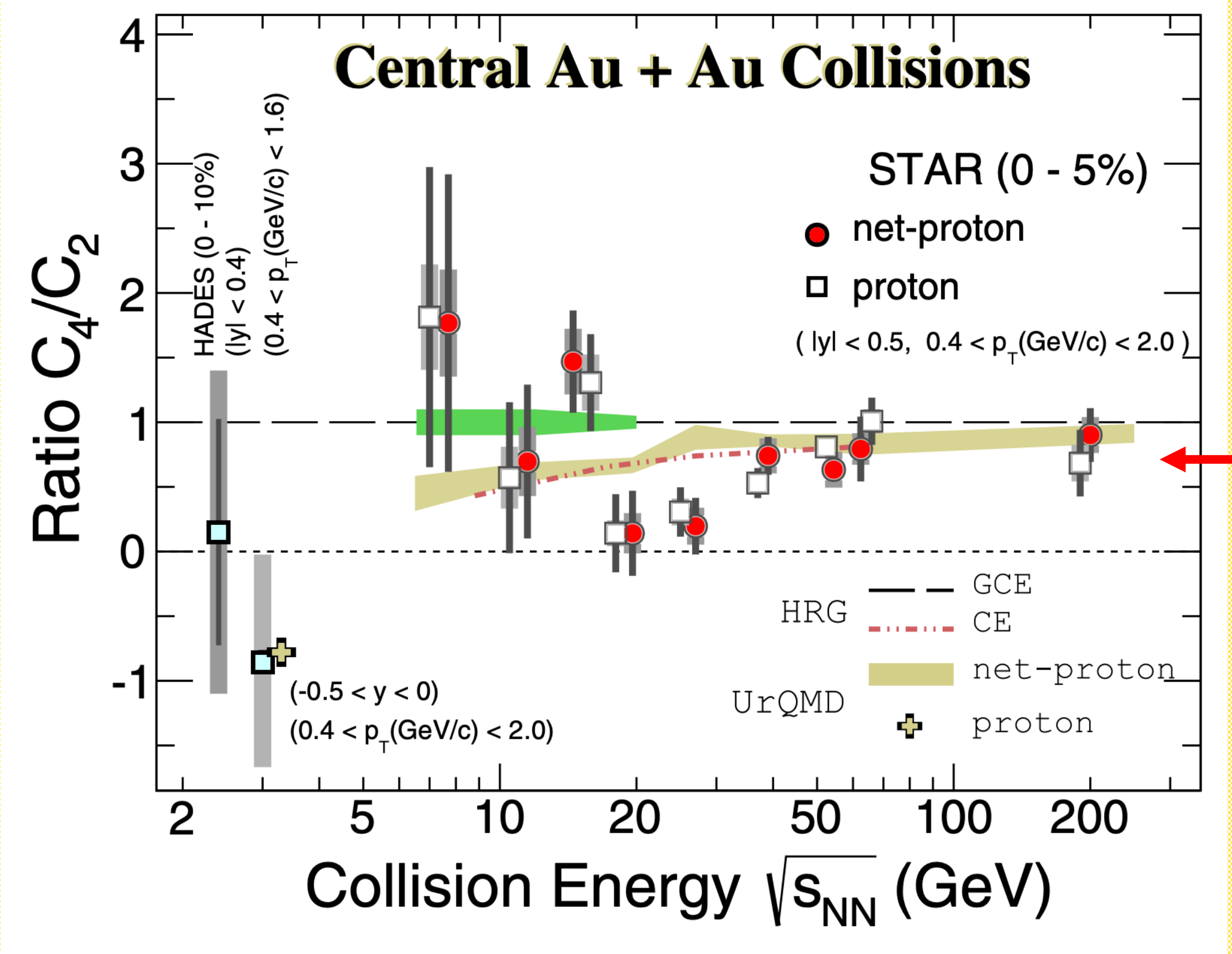
Fluctuation in kurtosis near critical point



M. Stephanov. J. Physics G.: Nucl. Part. Phys. **38** (2011) 124147

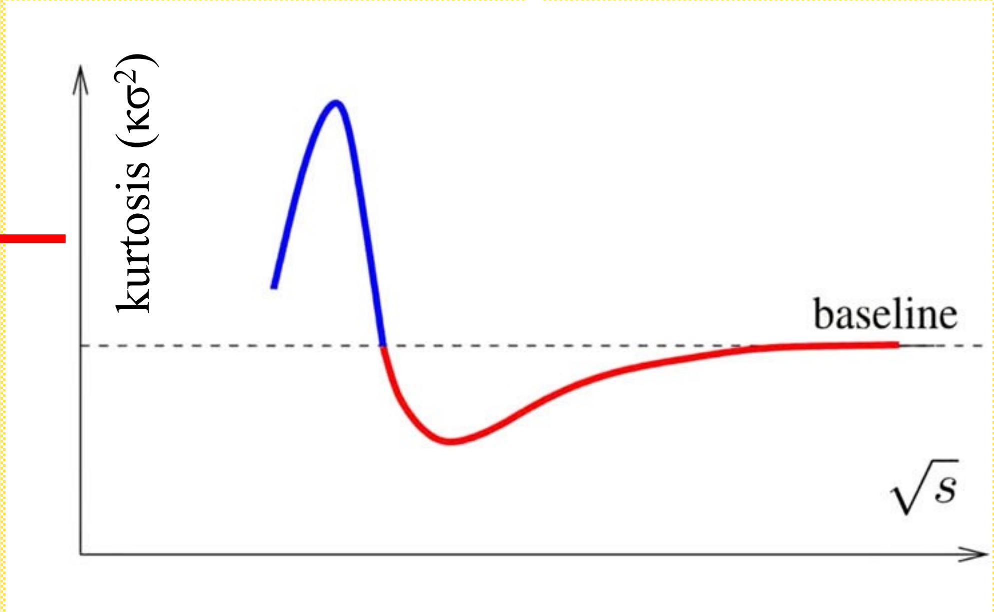
Comparison to Published Beam Energy Scan Results

Published Results



STAR, Phys. Rev. Lett. 128, 202303 (2022); Phys.Rev.C 107.024908 (2023).
Phys. Rev. Lett. 126, 092301 (2021); Phys. Rev. C 104, 024902 (2021)

Fluctuation in kurtosis near critical point



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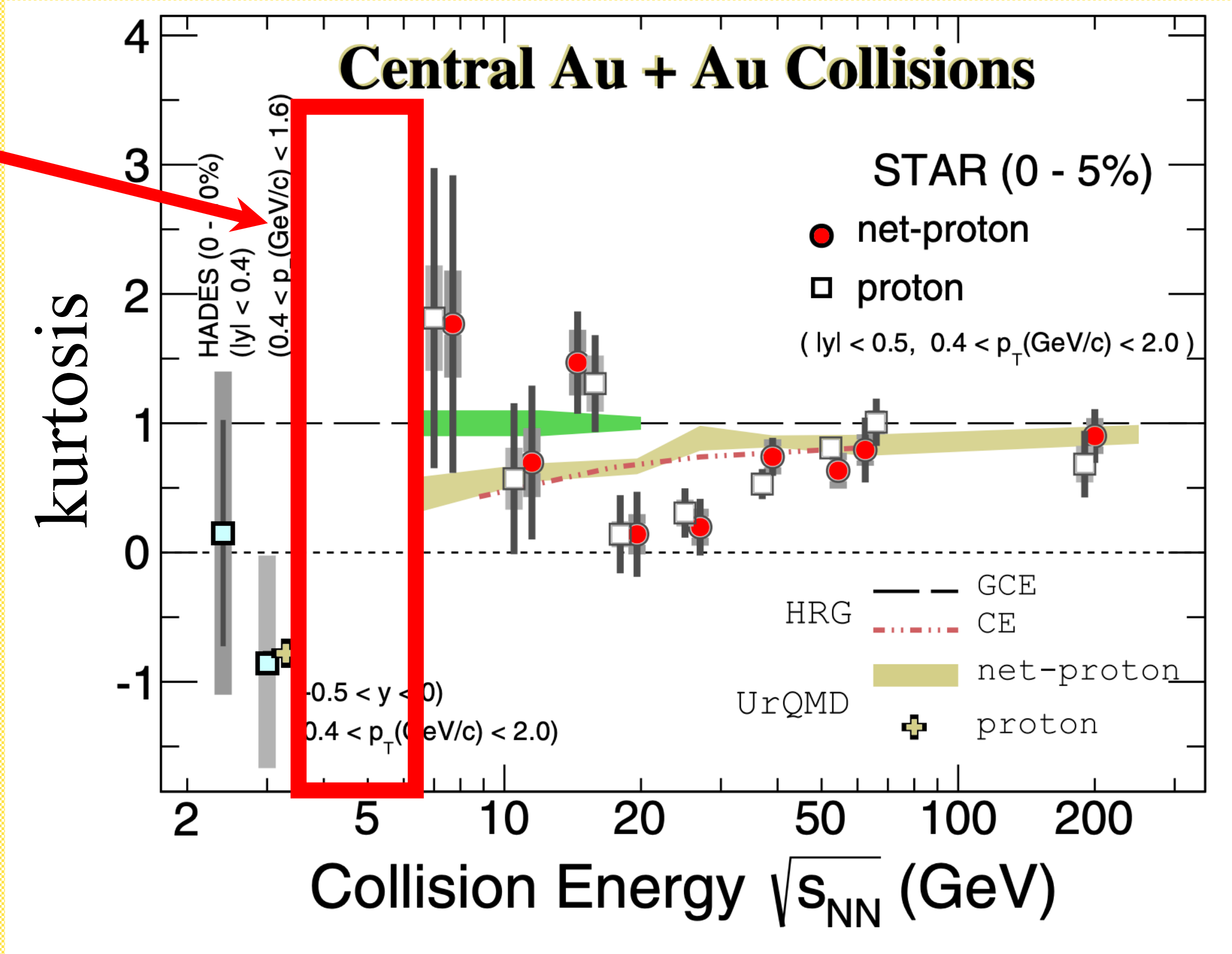
Remaining Results

- The remaining fixed-target datasets will cover much of the gap

Published Results



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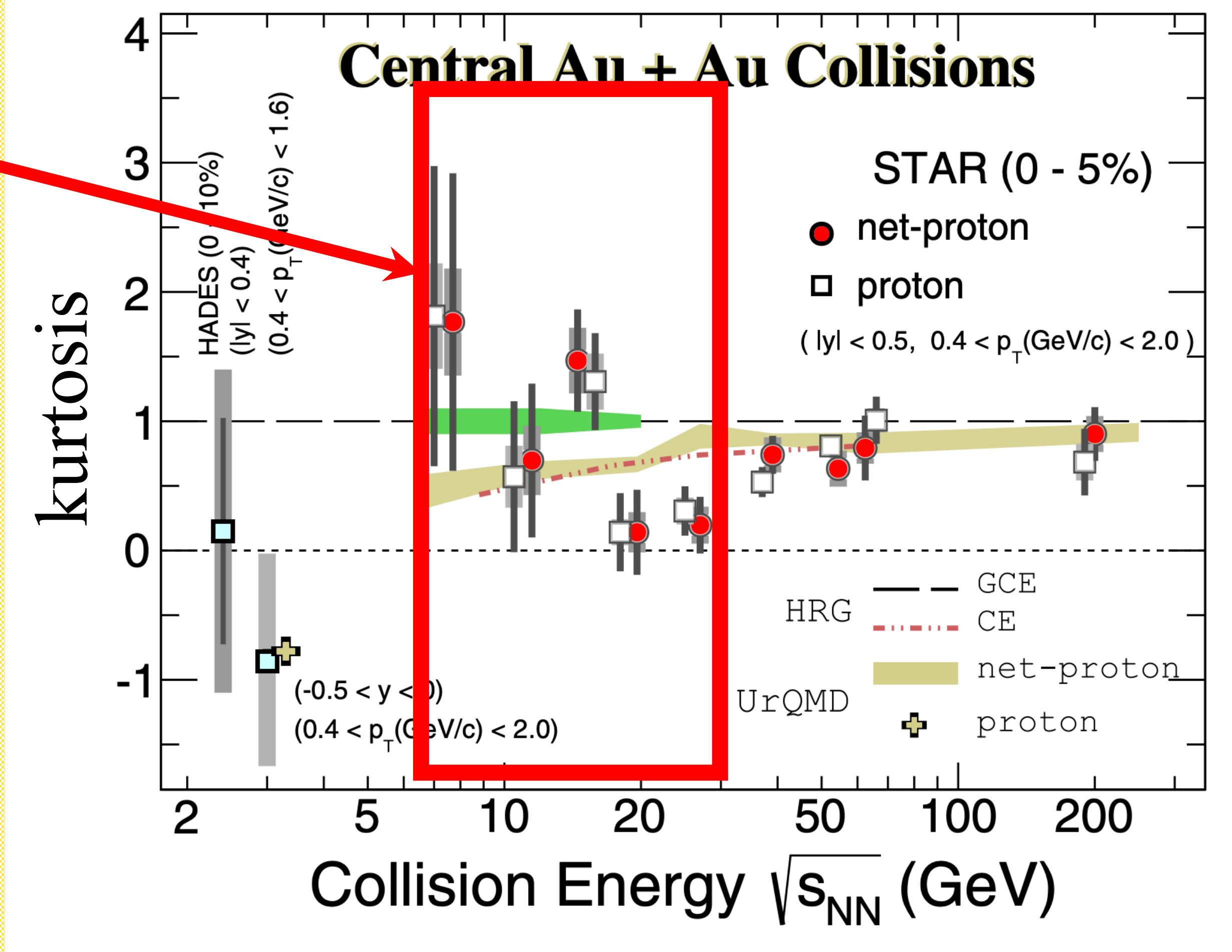
Remaining Results

- The remaining fixed-target datasets will cover much of the gap
- High-statistics data re-collected below 27 GeV (BES-II)
  - ➢ High precision new results shown in Bappaditya Mondal's poster!
  - ➢ Waiting for publication

Published Results



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Proton Number and Multiplicity Correlations

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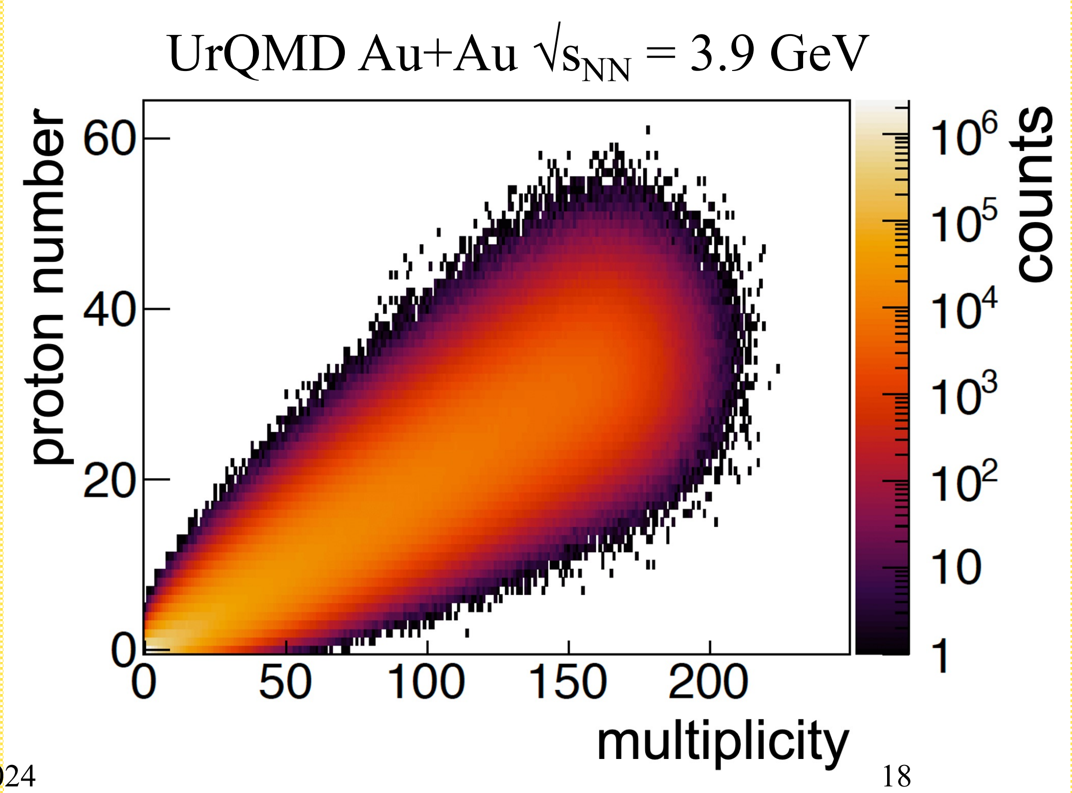
The takeaway: the correlation between proton number and multiplicity is our *entire* measurement



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- Large kurtosis means large tails
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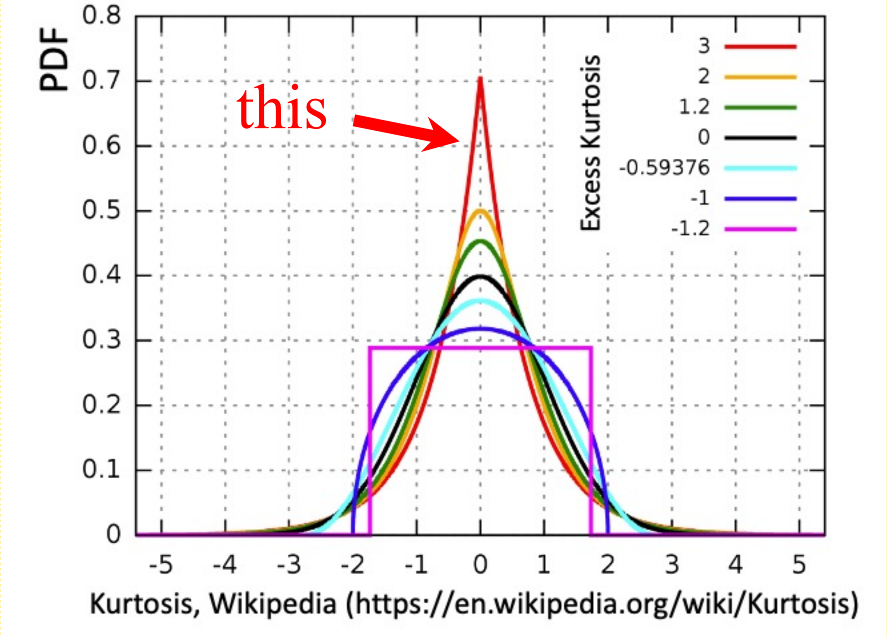
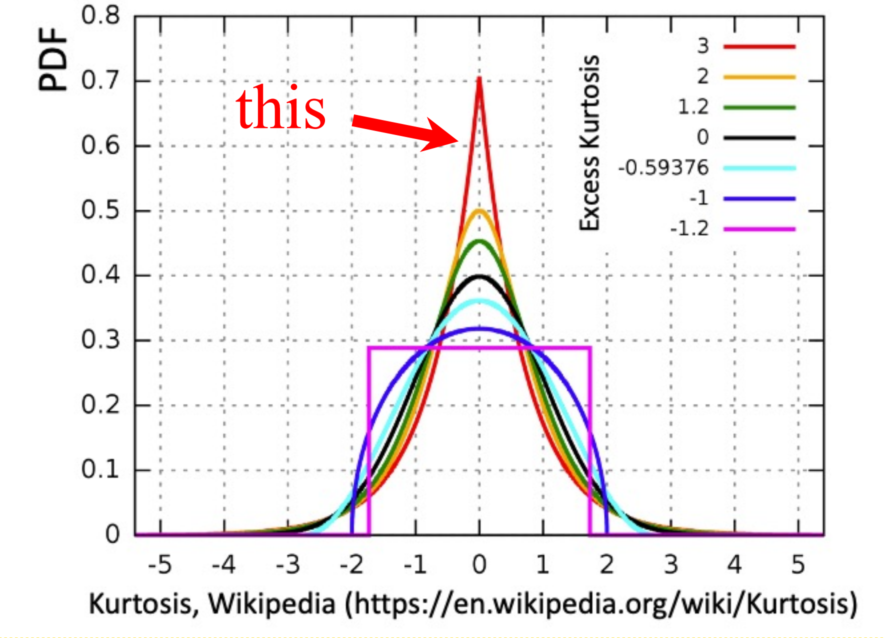
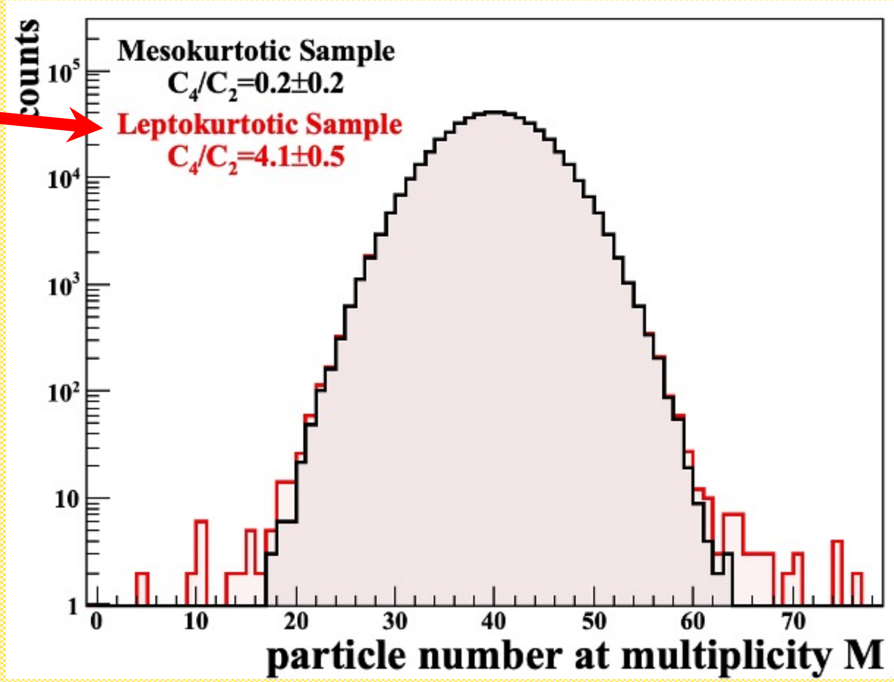


What does large kurtosis mean?

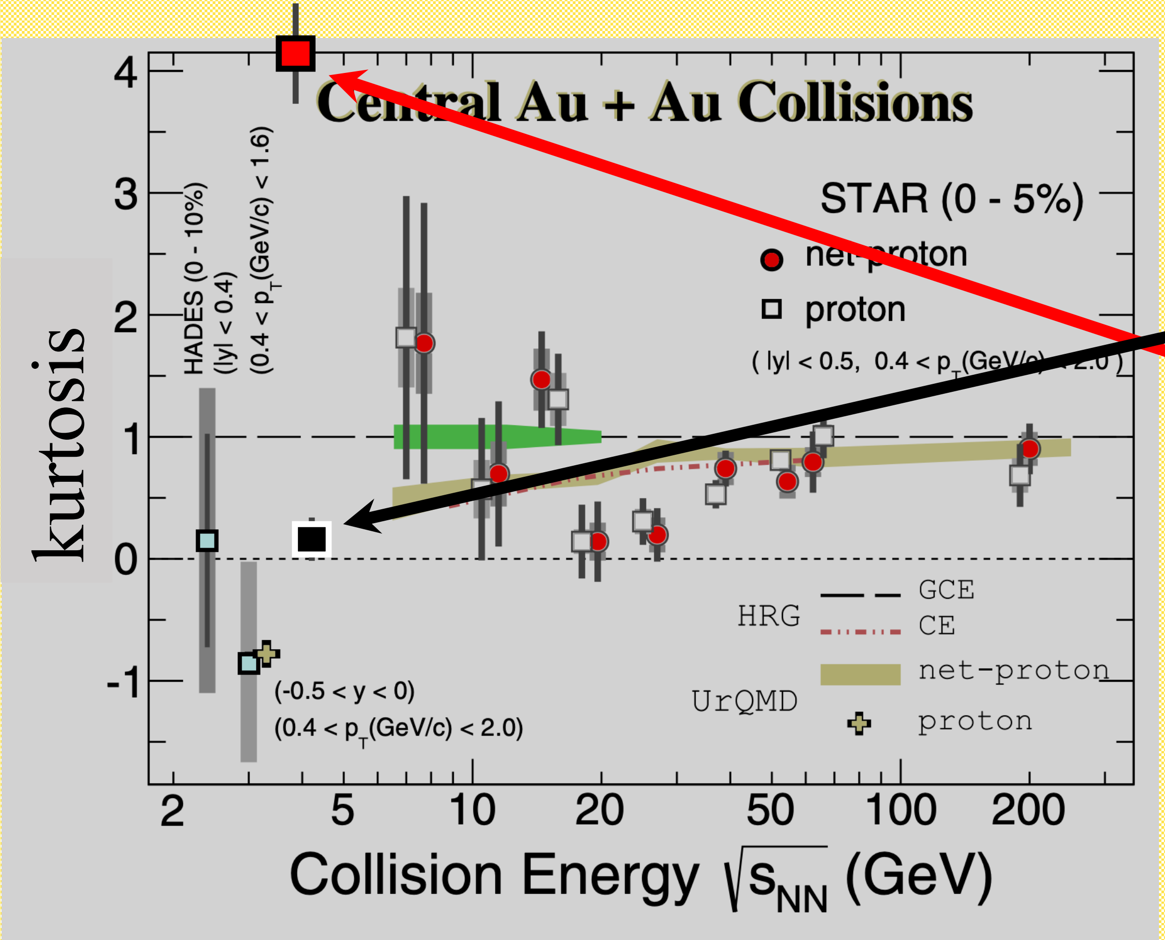
- Large kurtosis means large tails
- We use this figure which shows a highly-tailed distribution with a large kurtosis
- Long tails *many* decades down cause large kurtosis too!
- The black is a Gaussian. The red is the same Gaussian, but one in 10000 samples is from a Gaussian with twice the width

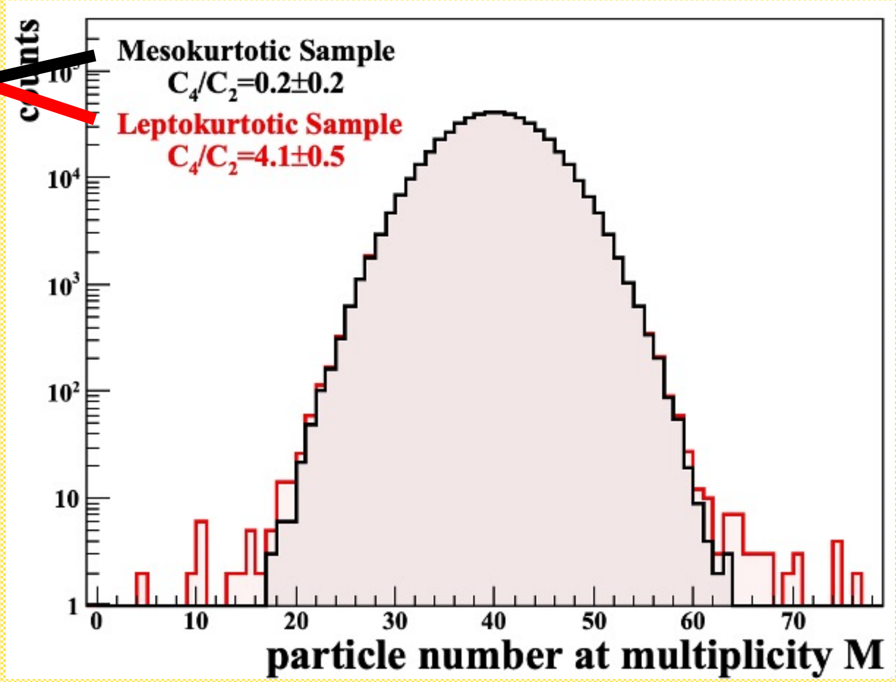




What does large kurtosis mean?

- This gives an idea of the scale of fluctuations





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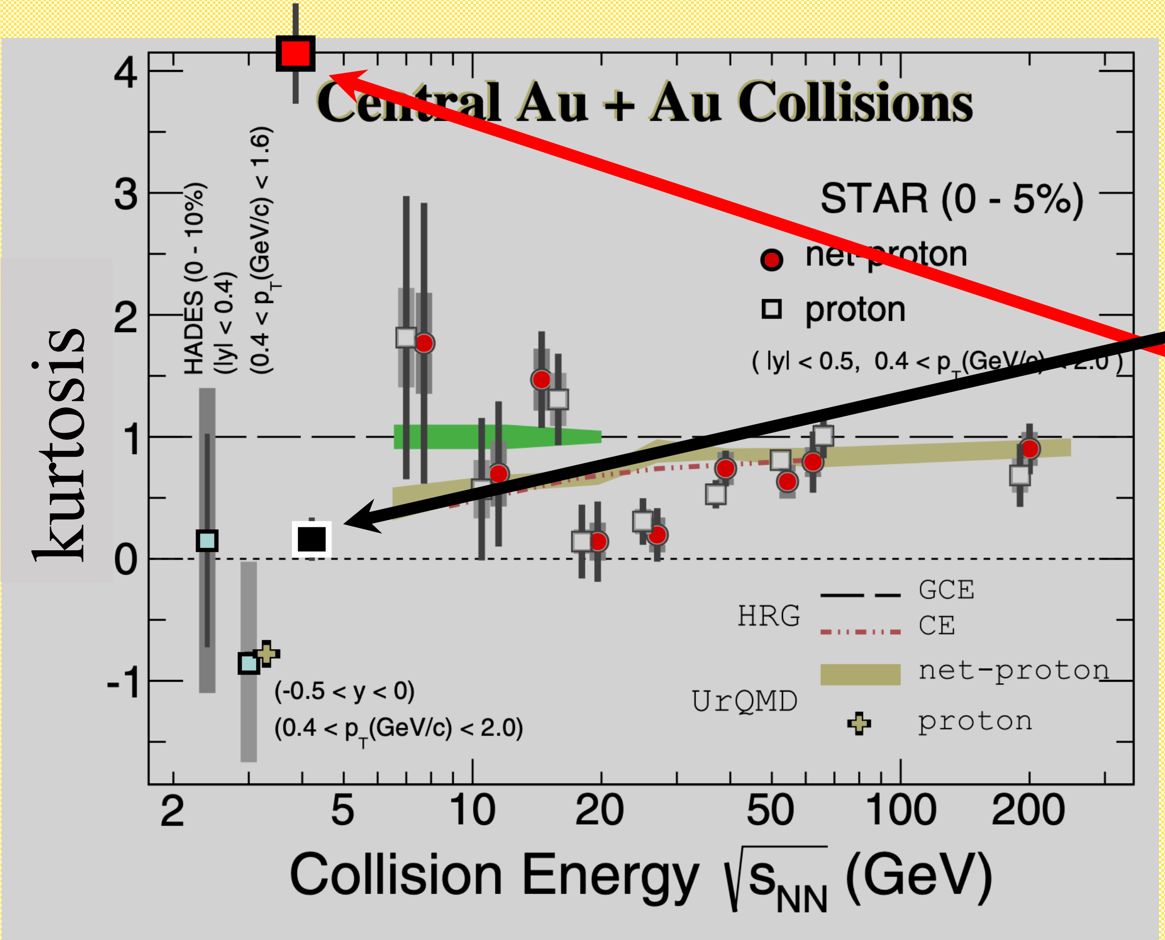
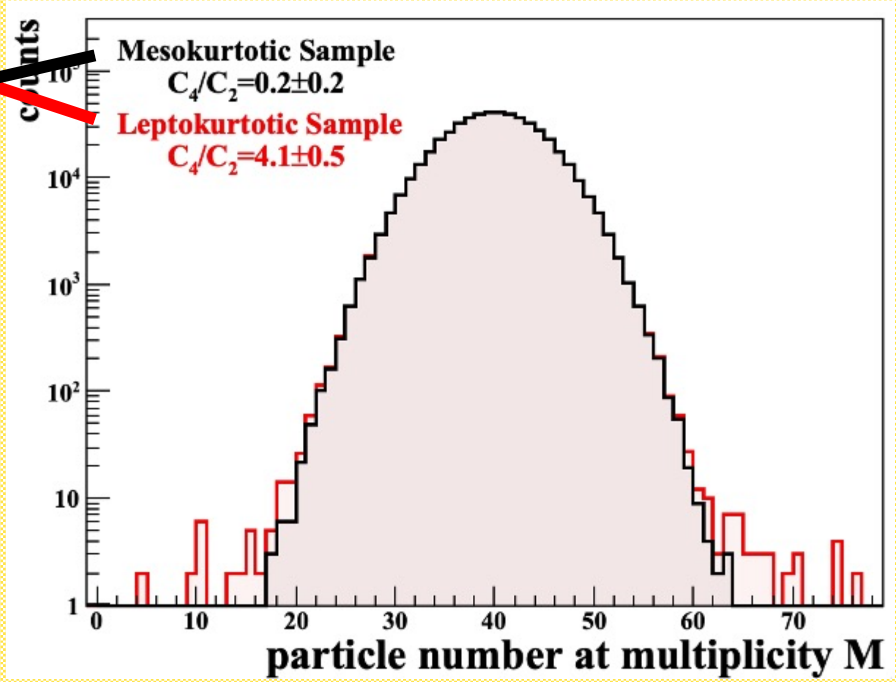
What does large kurtosis mean?

- This gives an idea of the scale of fluctuations
- We need to understand all low-statistics outliers!





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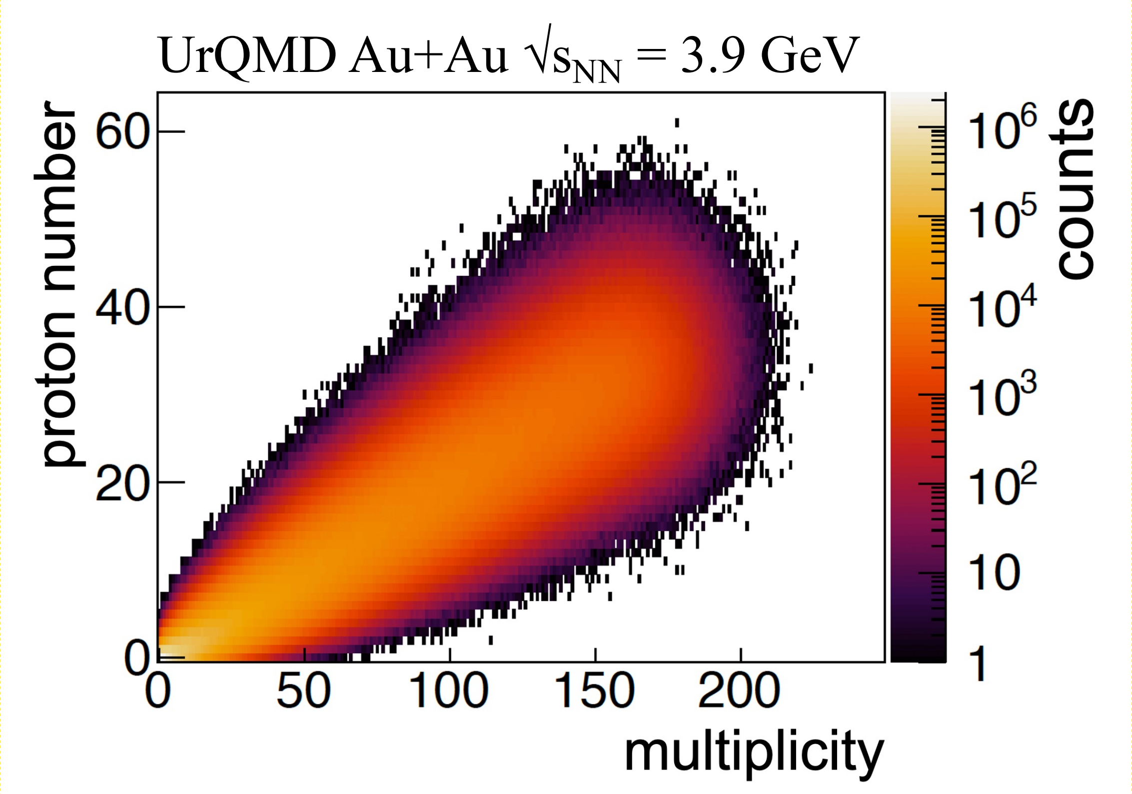
Rare and Spontaneous Detector Failure

- We often use different detectors to measure proton number and multiplicity
- This makes us vulnerable to the rare and spontaneous failure of either detector



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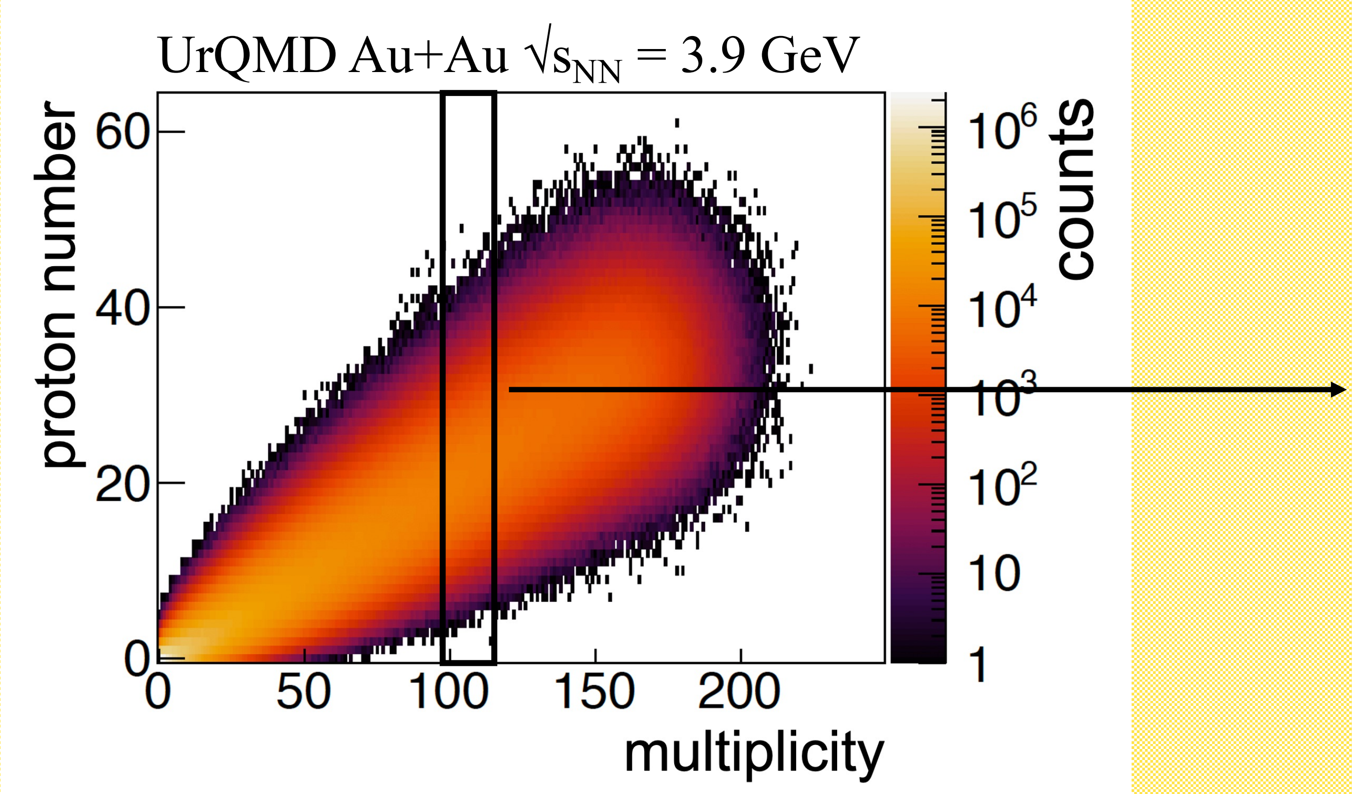

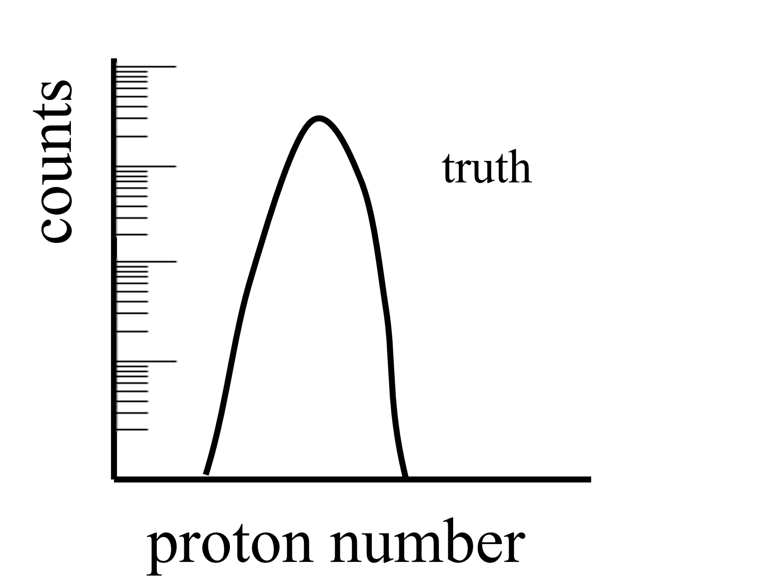

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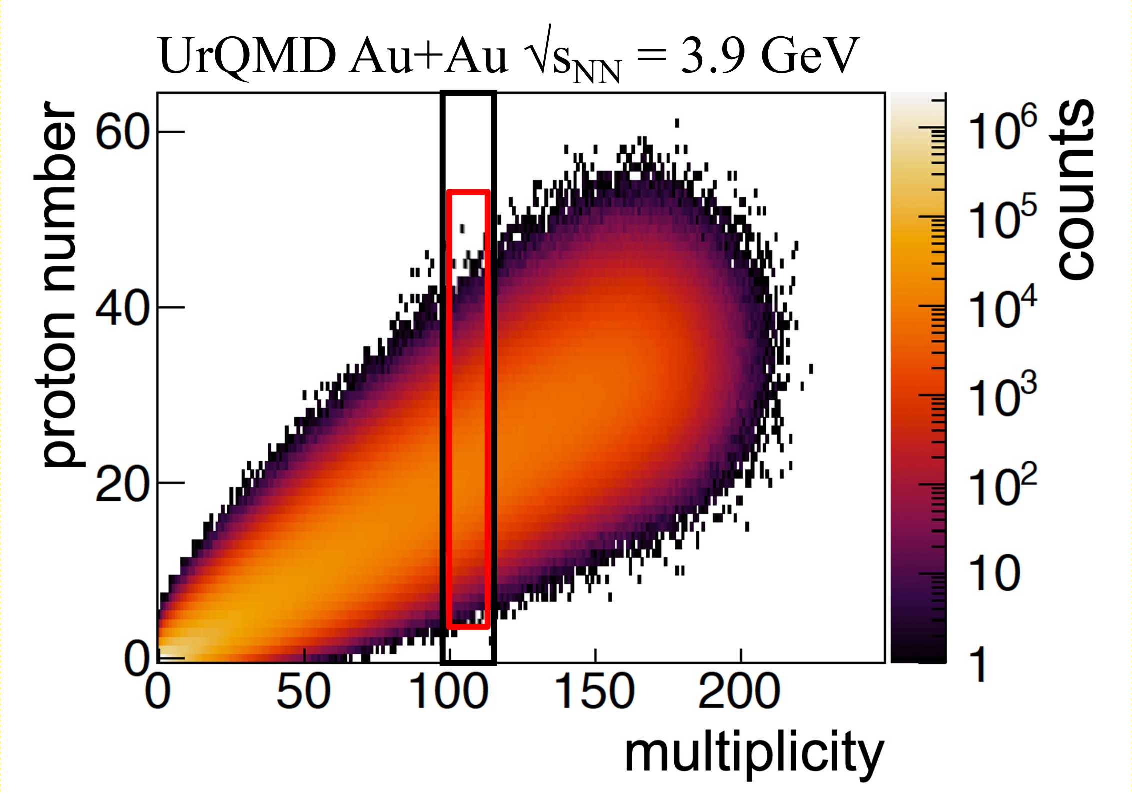
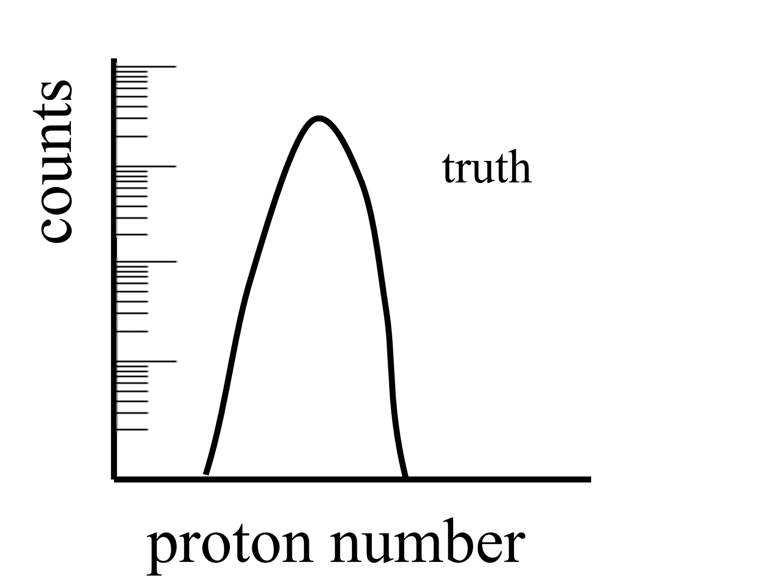
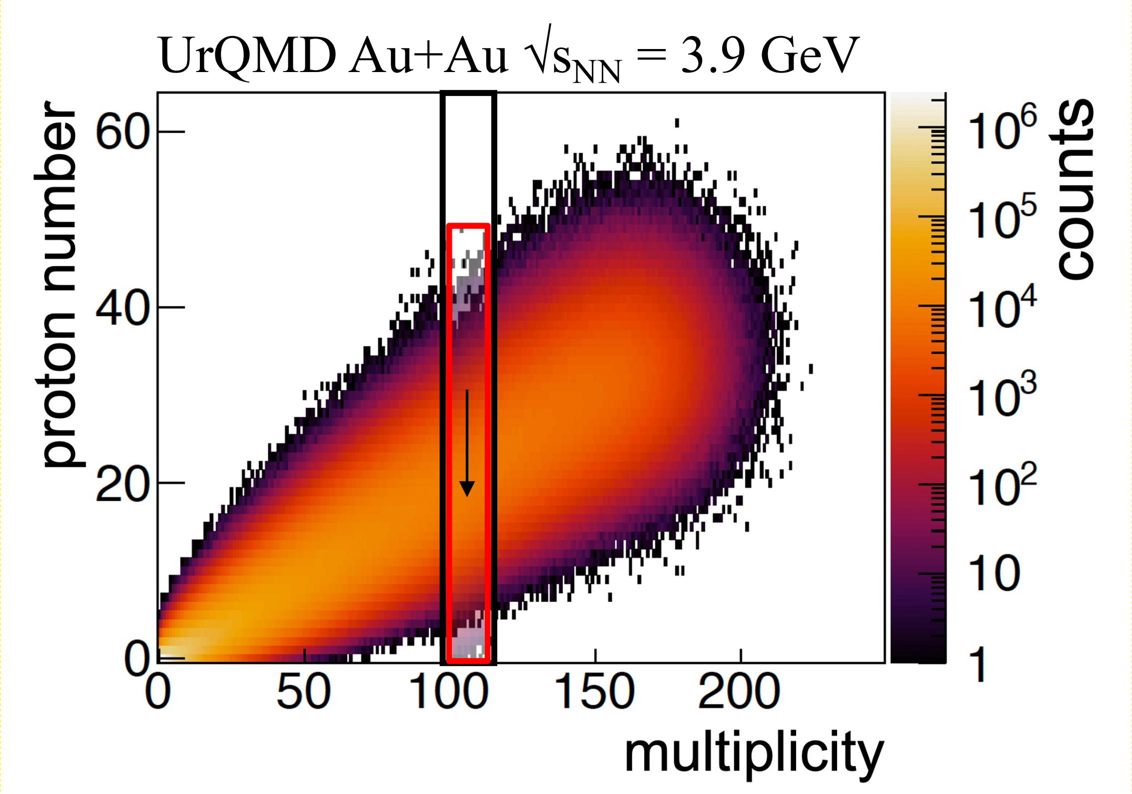
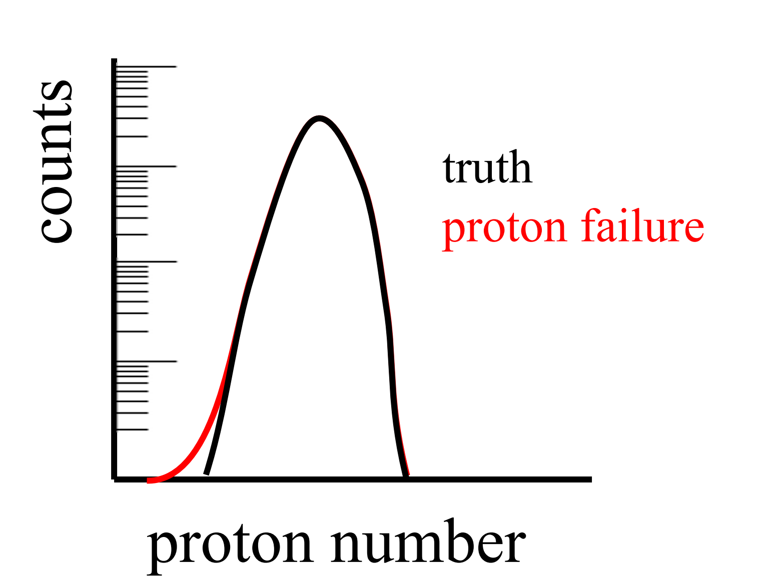




Rare and Spontaneous Detector Failure

- We often use different detectors to measure proton number and multiplicity
- This makes us vulnerable to the rare and spontaneous failure of either detector
- Consider a vertical slice in our correlation plot
  - ❑ If the proton detector ever fails, we get a sudden vertical shift adding to low tails





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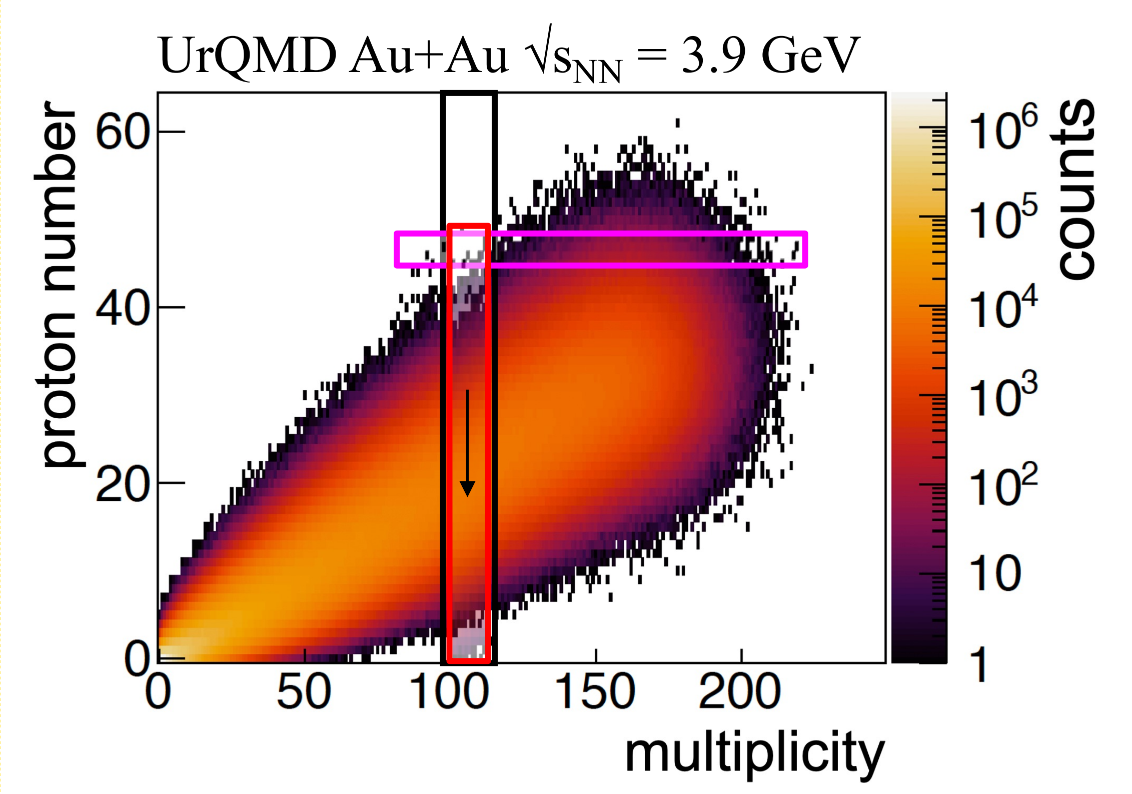

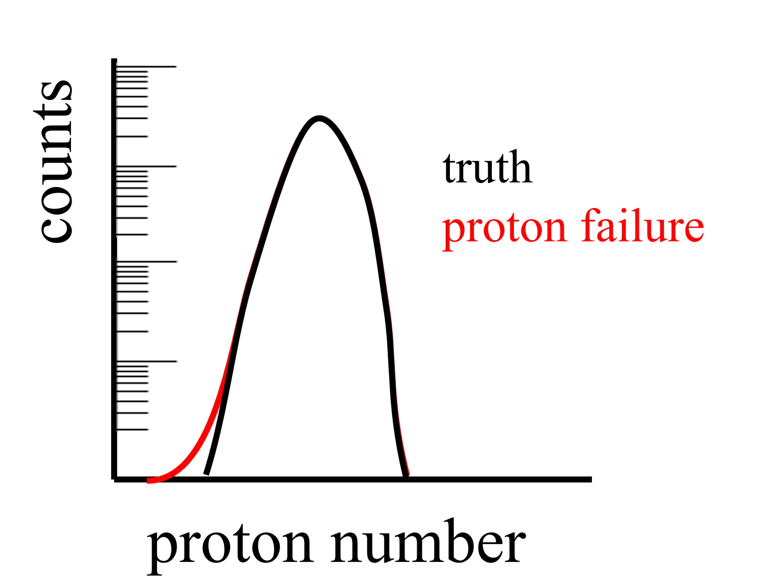

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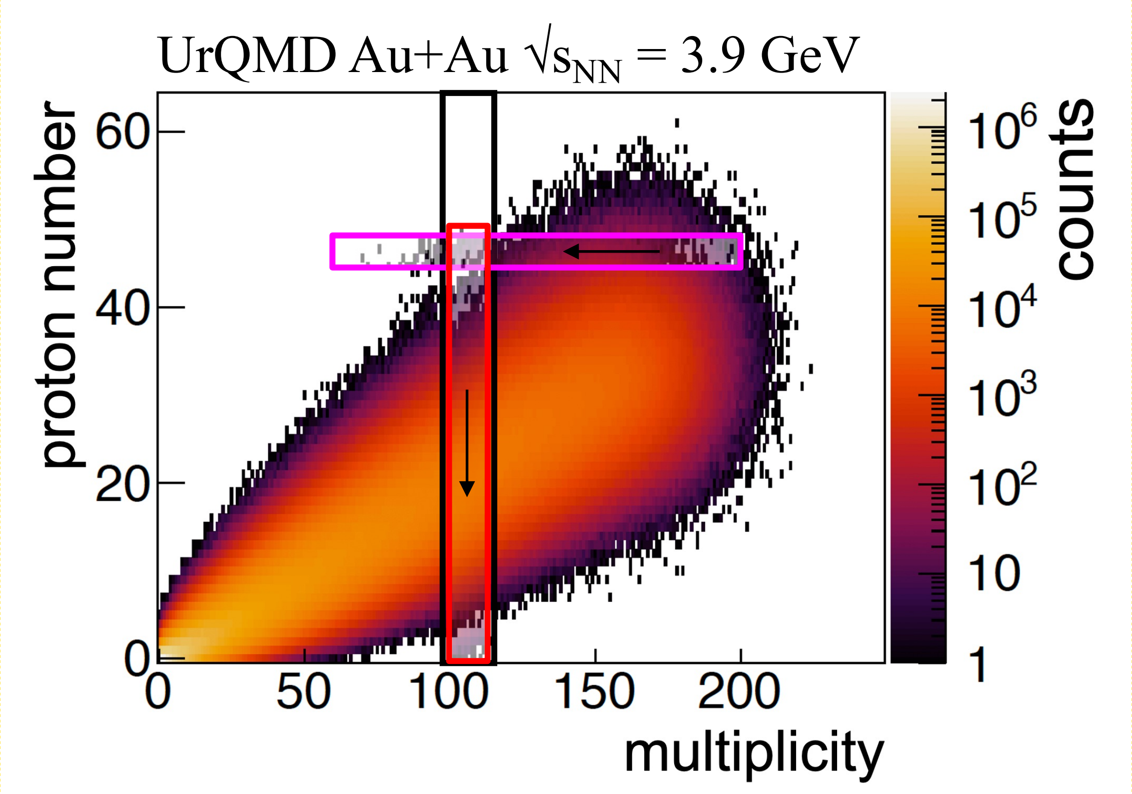
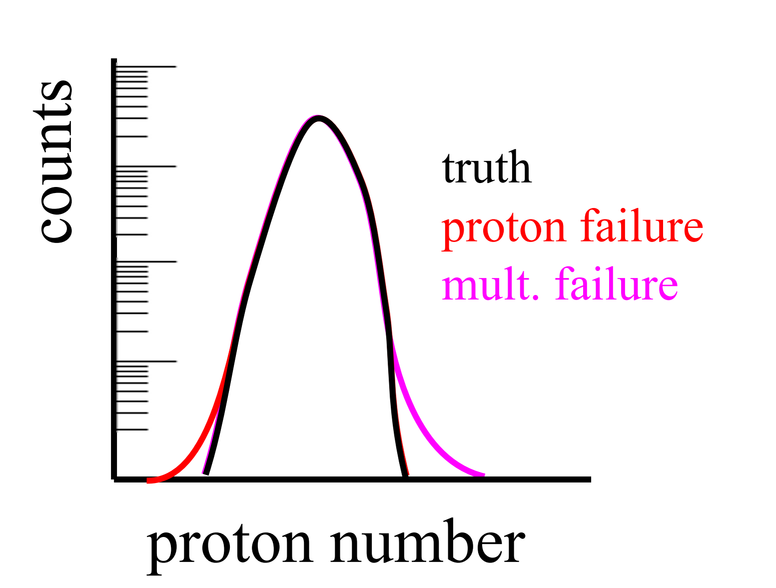
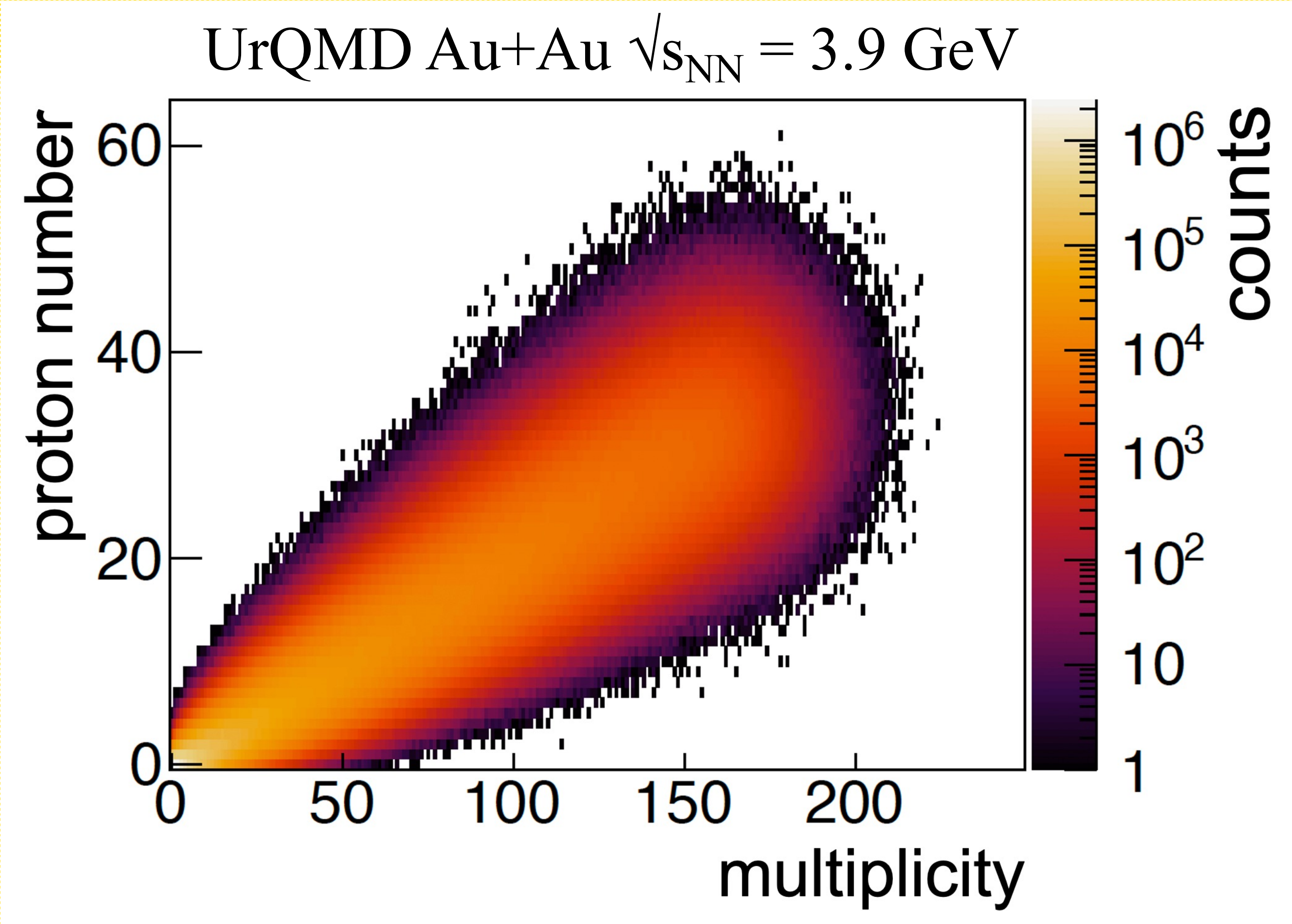
  - ❑ If the multiplicity detection ever fails, sudden horizontal shift adds to high tails





Rare and Spontaneous Detector Failure

- There are many potential sources of detector failure
- Proton detector:



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- There are many potential sources of detector failure
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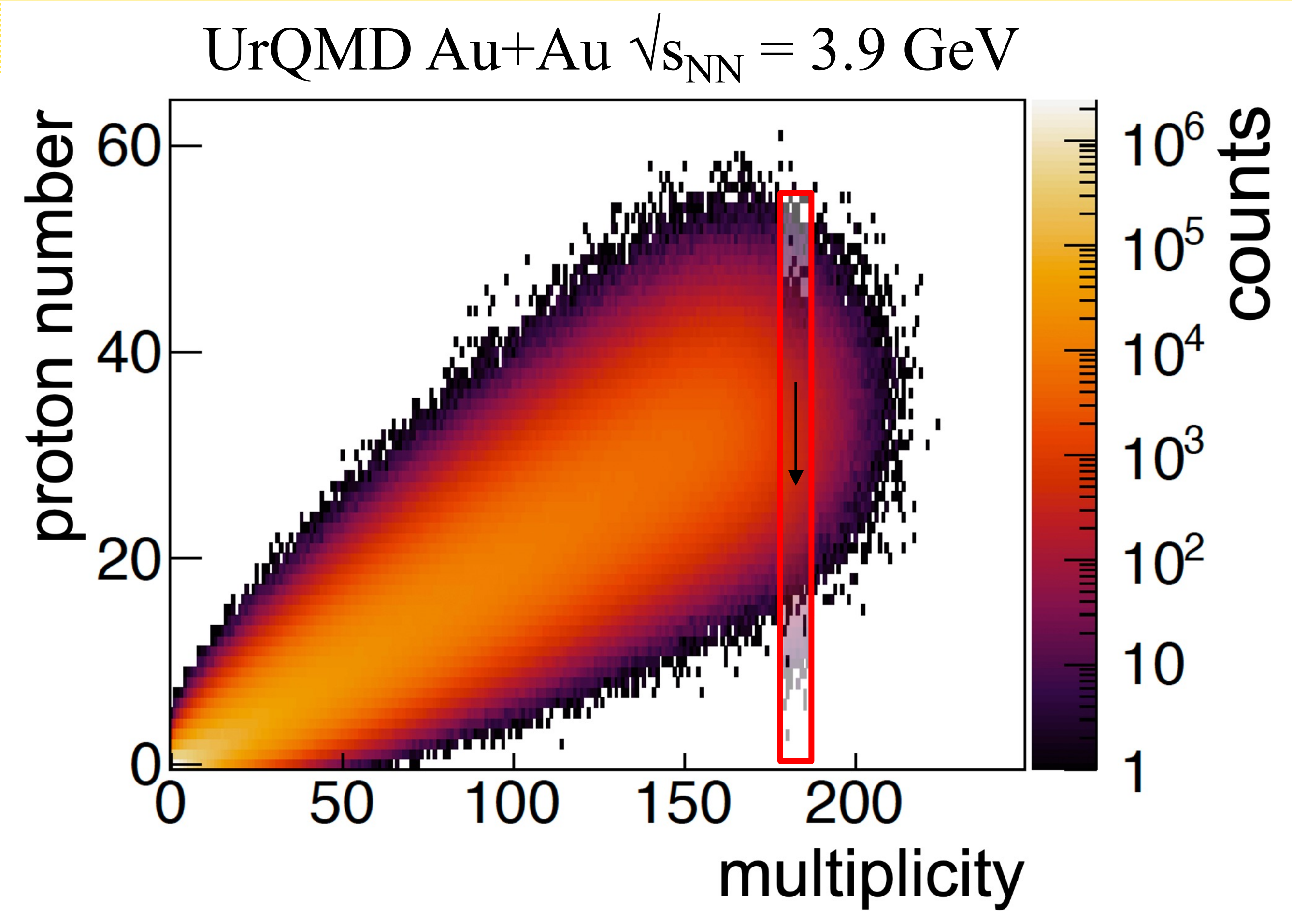

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- There are many potential sources of detector failure
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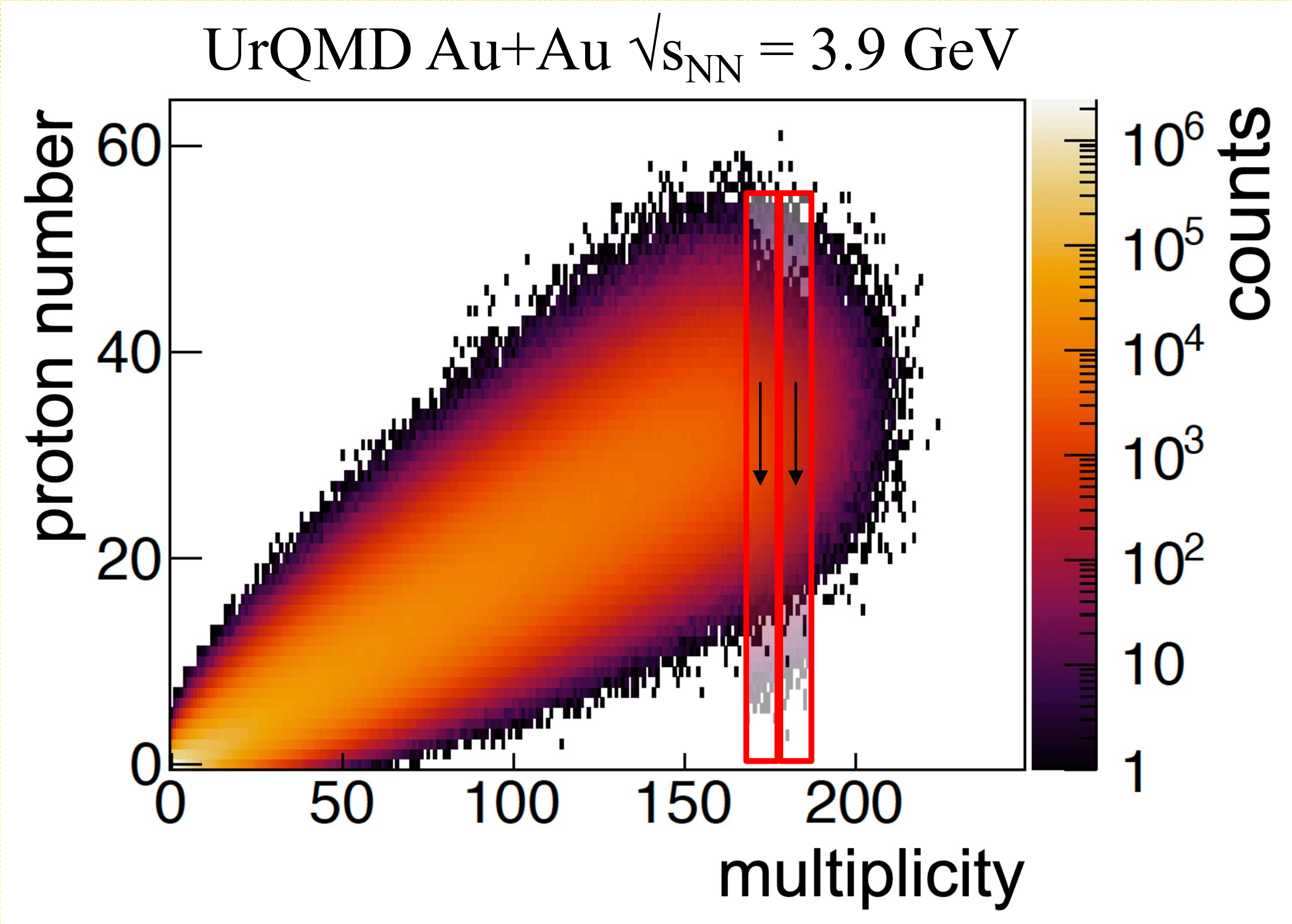

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- There are many potential sources of detector failure
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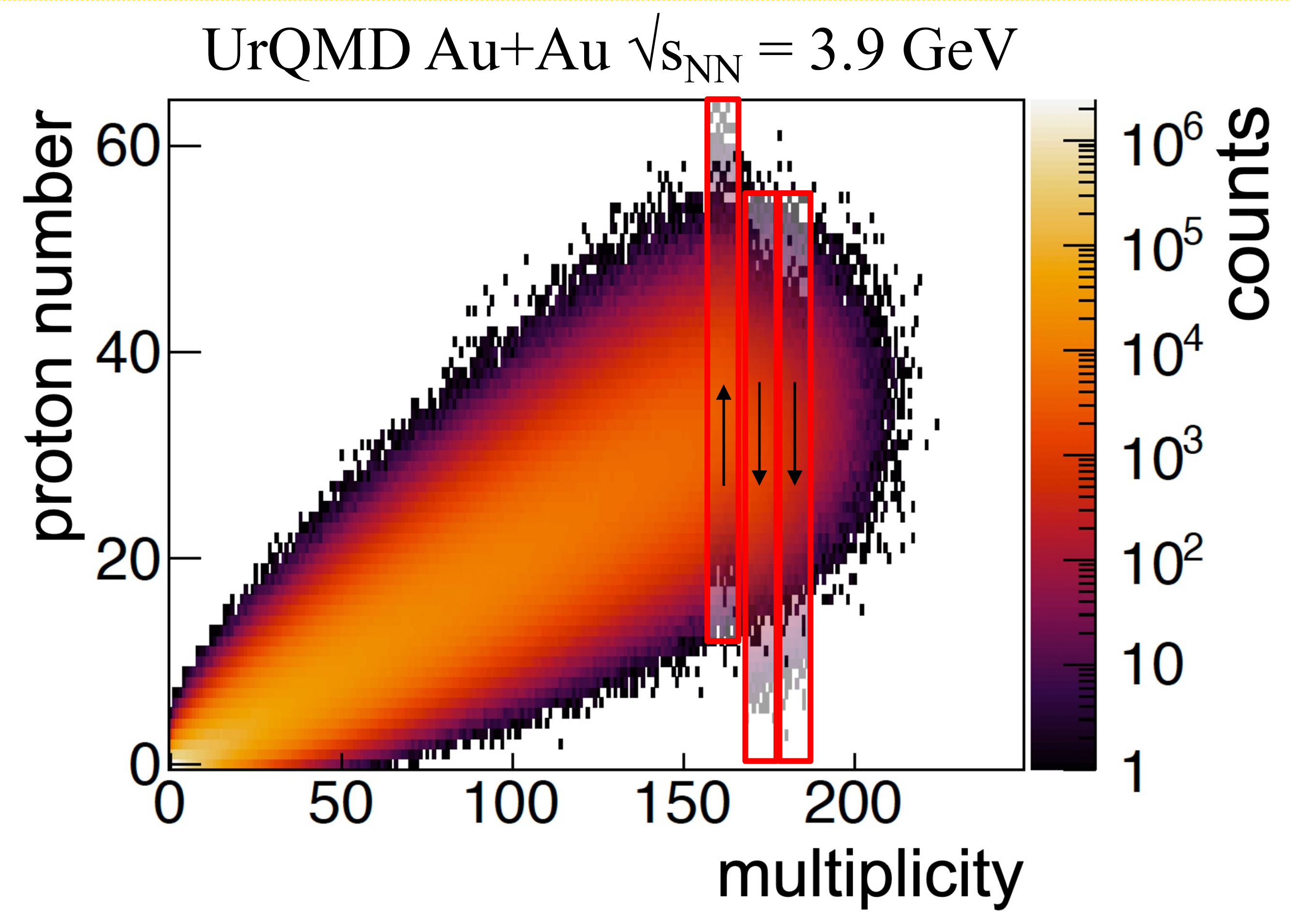

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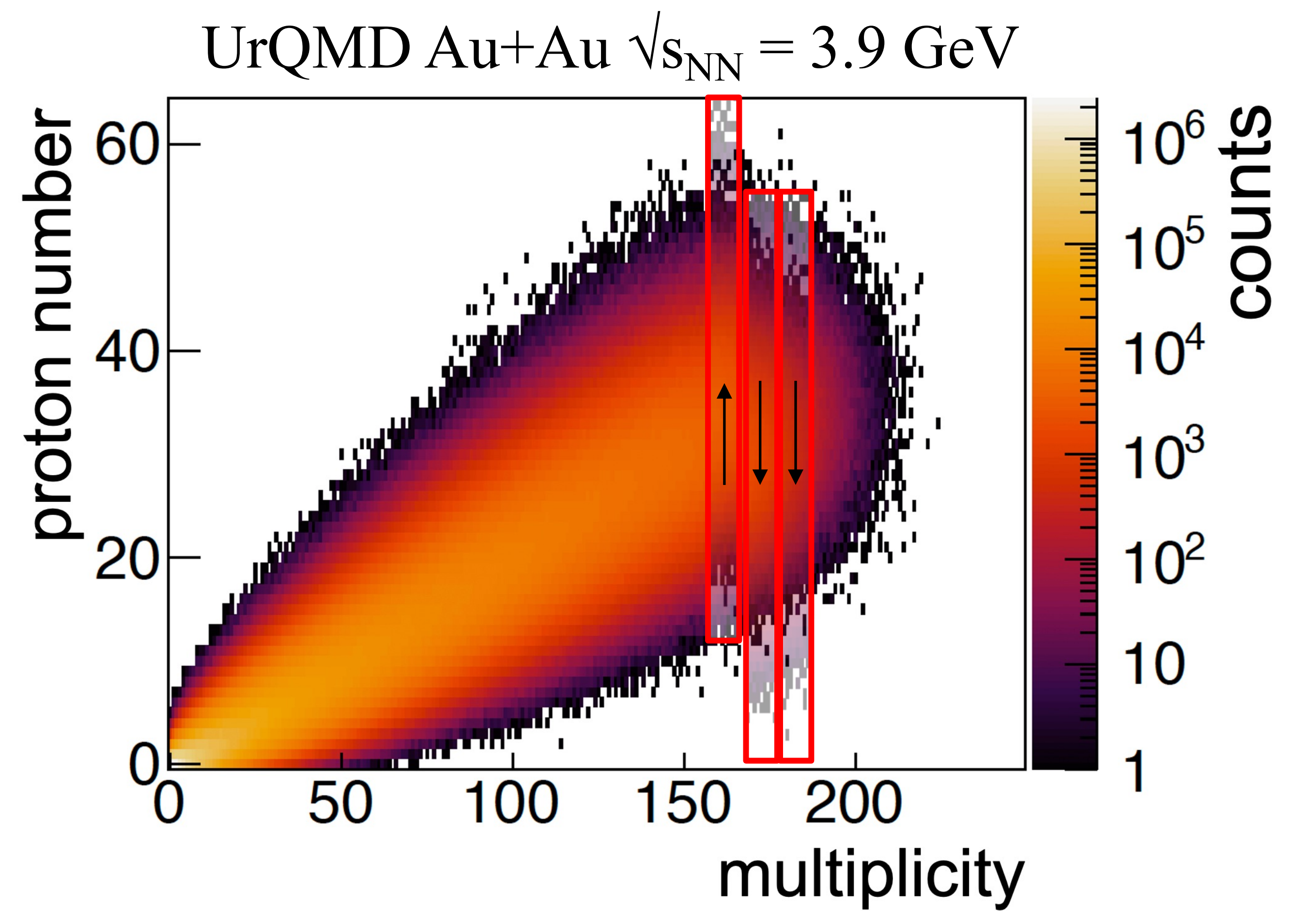

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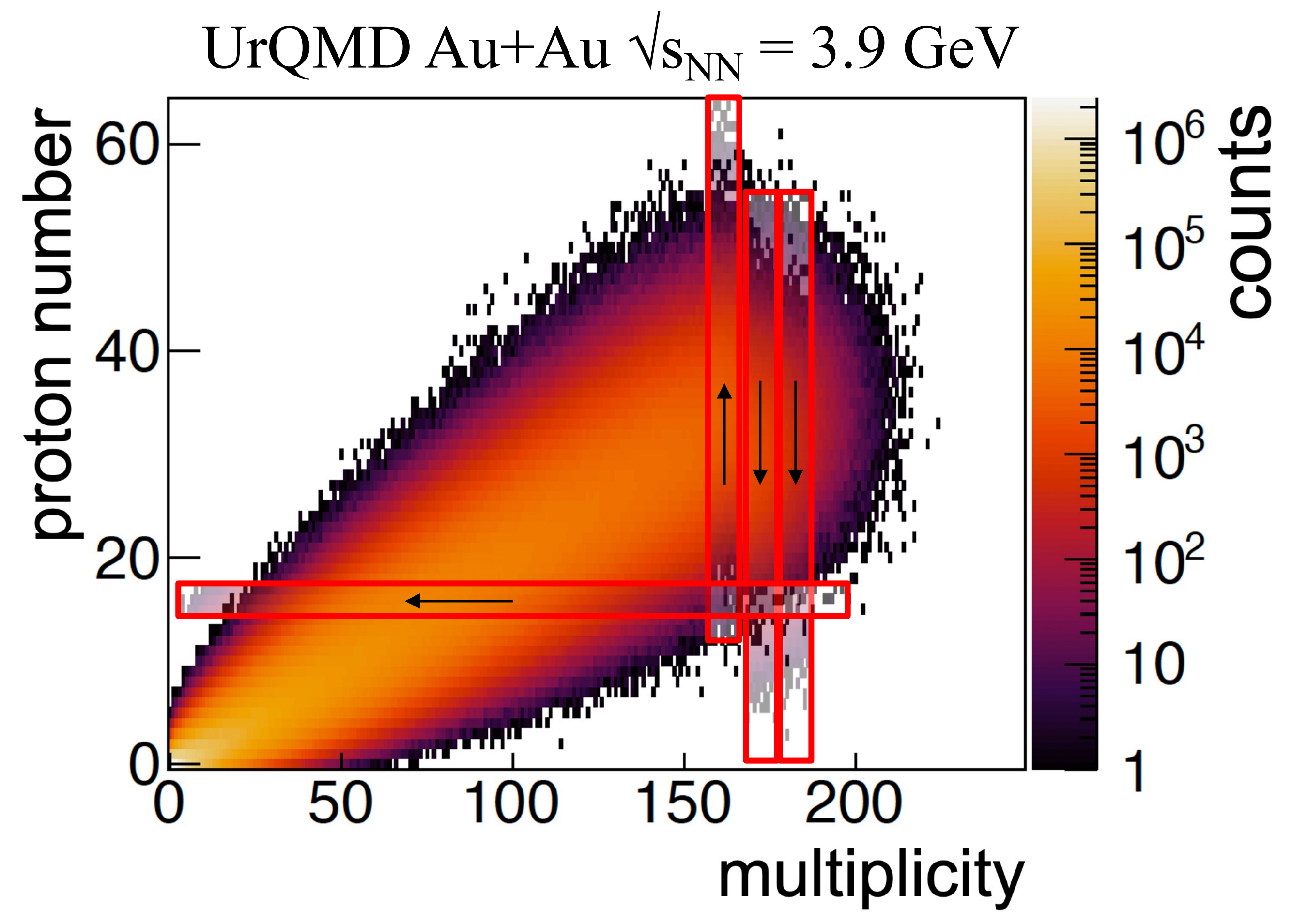

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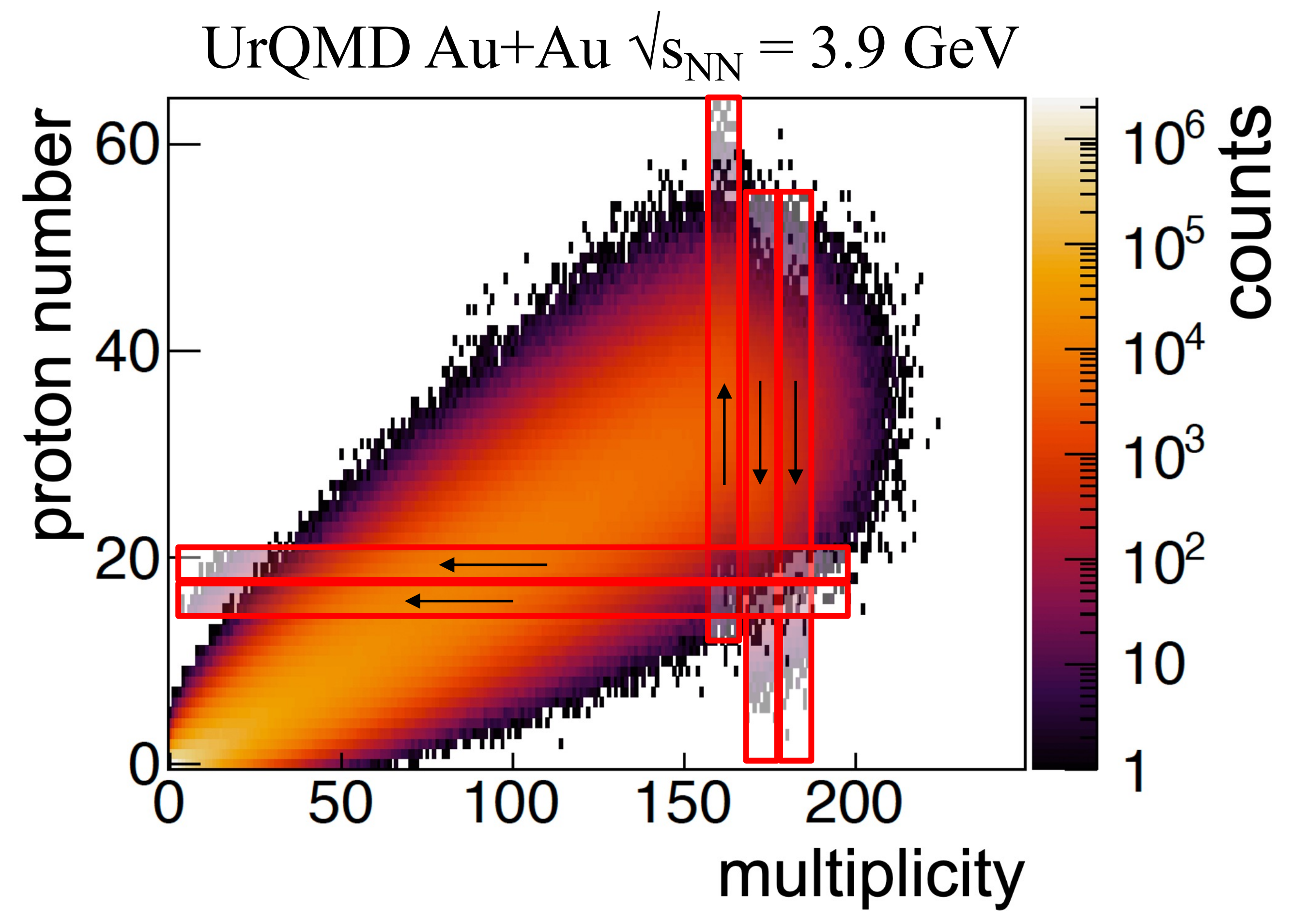

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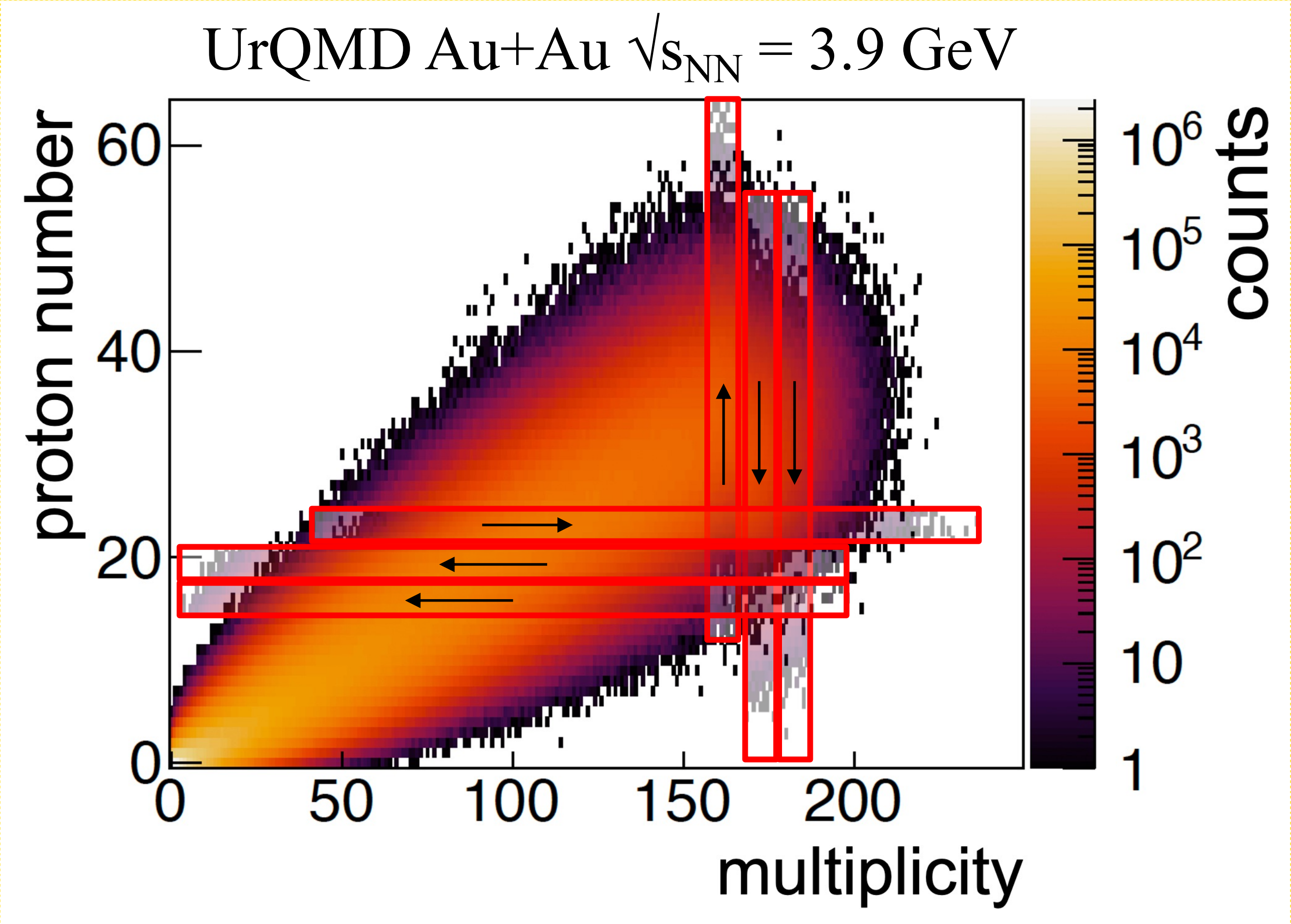

Toy Model at $\sqrt{s_{NN}} = 3.9$ GeV

The Toy Model

- UrQMD in cascade mode
- $\sqrt{s_{NN}} = 3.9$ GeV
- Analysis window: $0.4 < p_T < 2$ GeV/c, $-0.5 < y-y_{CM} < 0$
- Out-of-time pileup: double collisions at 0.01% rate

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- Out-of-time pileup: double collisions at 0.01% rate
- TPC toy model:
  - ➢ 100% efficiency for single collisions
  - ➢ 100% pileup efficiency (slow detector)
- TOF toy model:
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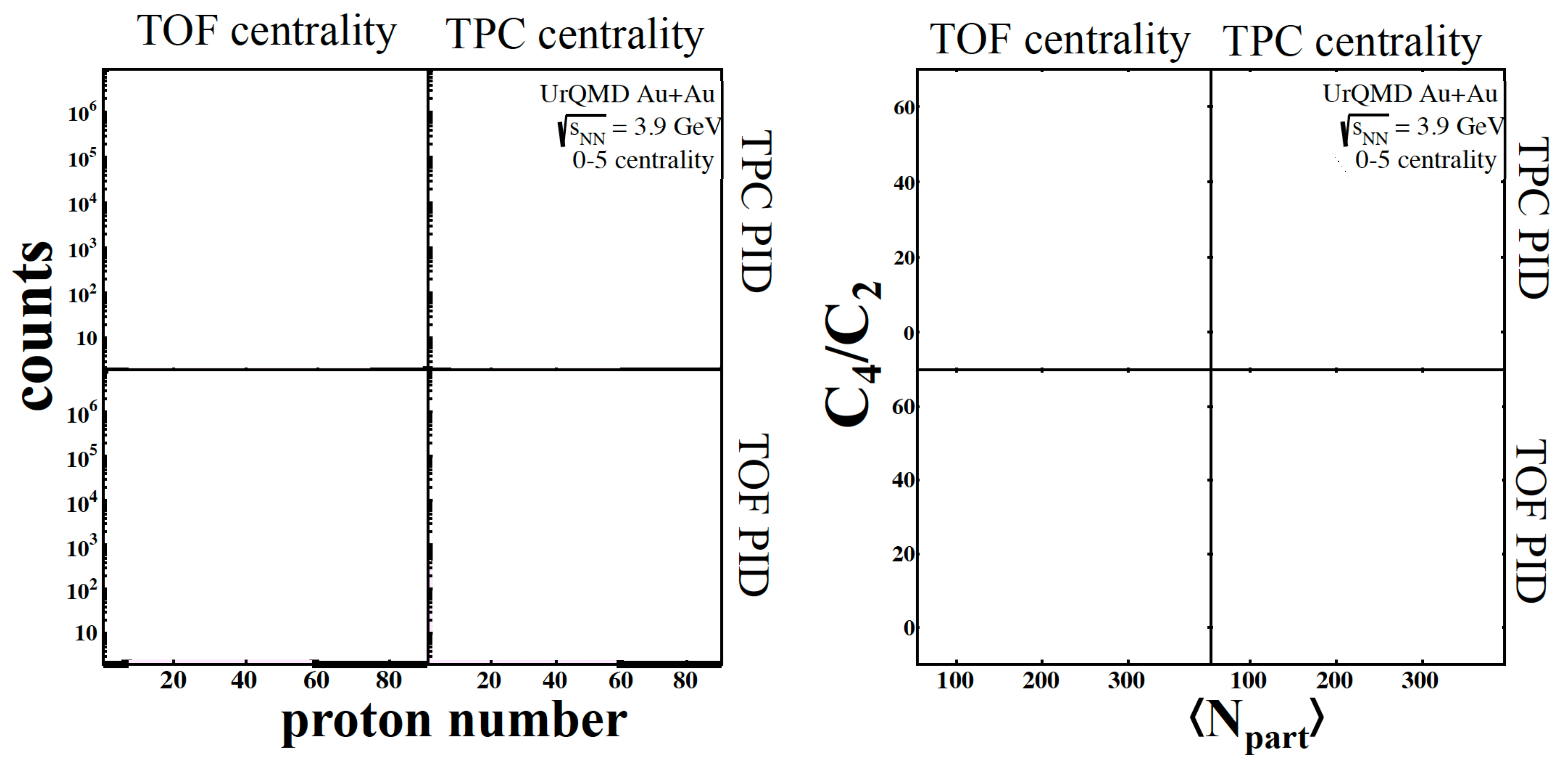
  - ➢ 0% pileup efficiency (fast detector)

Pileup in the Toy Model



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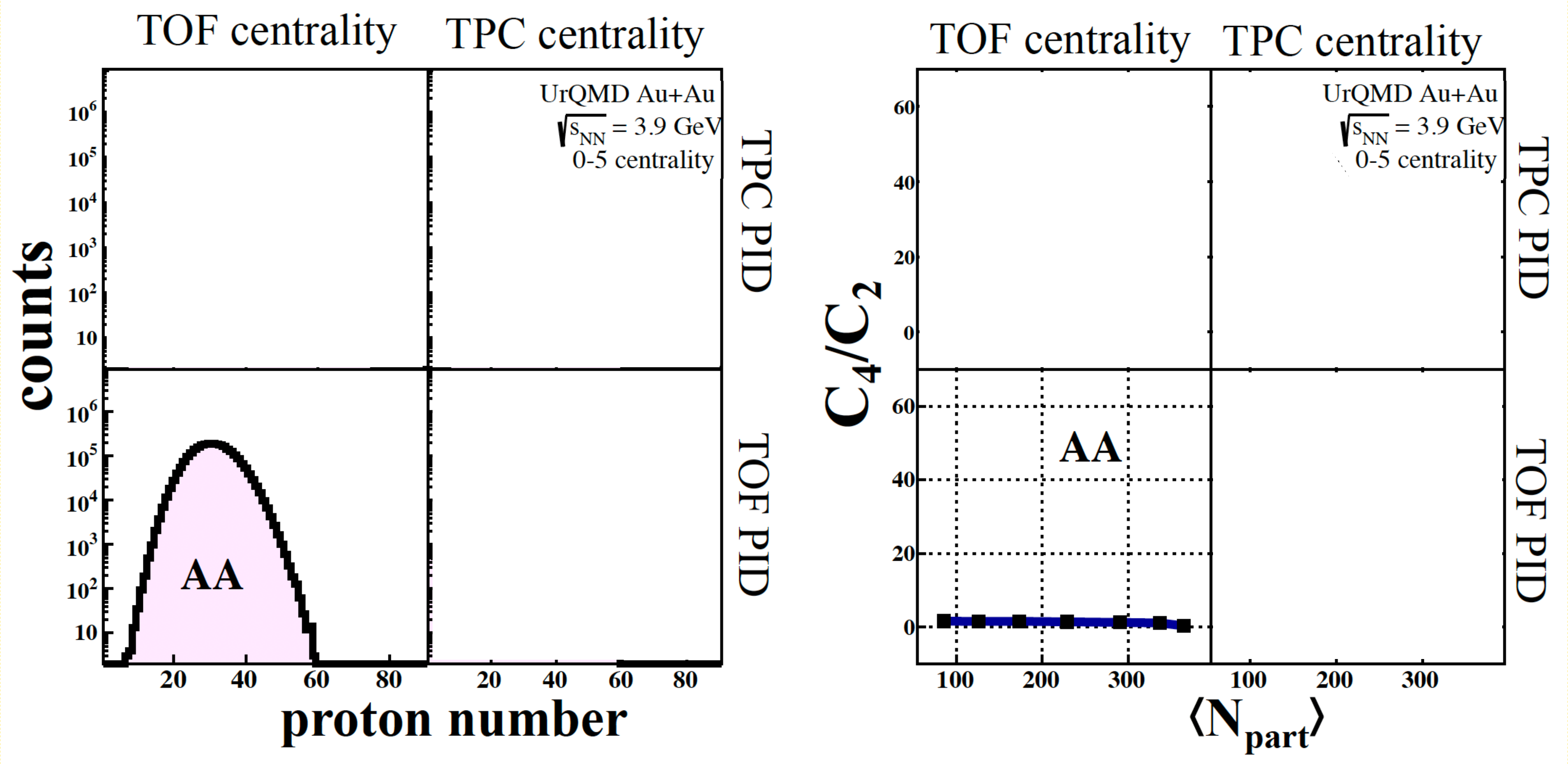

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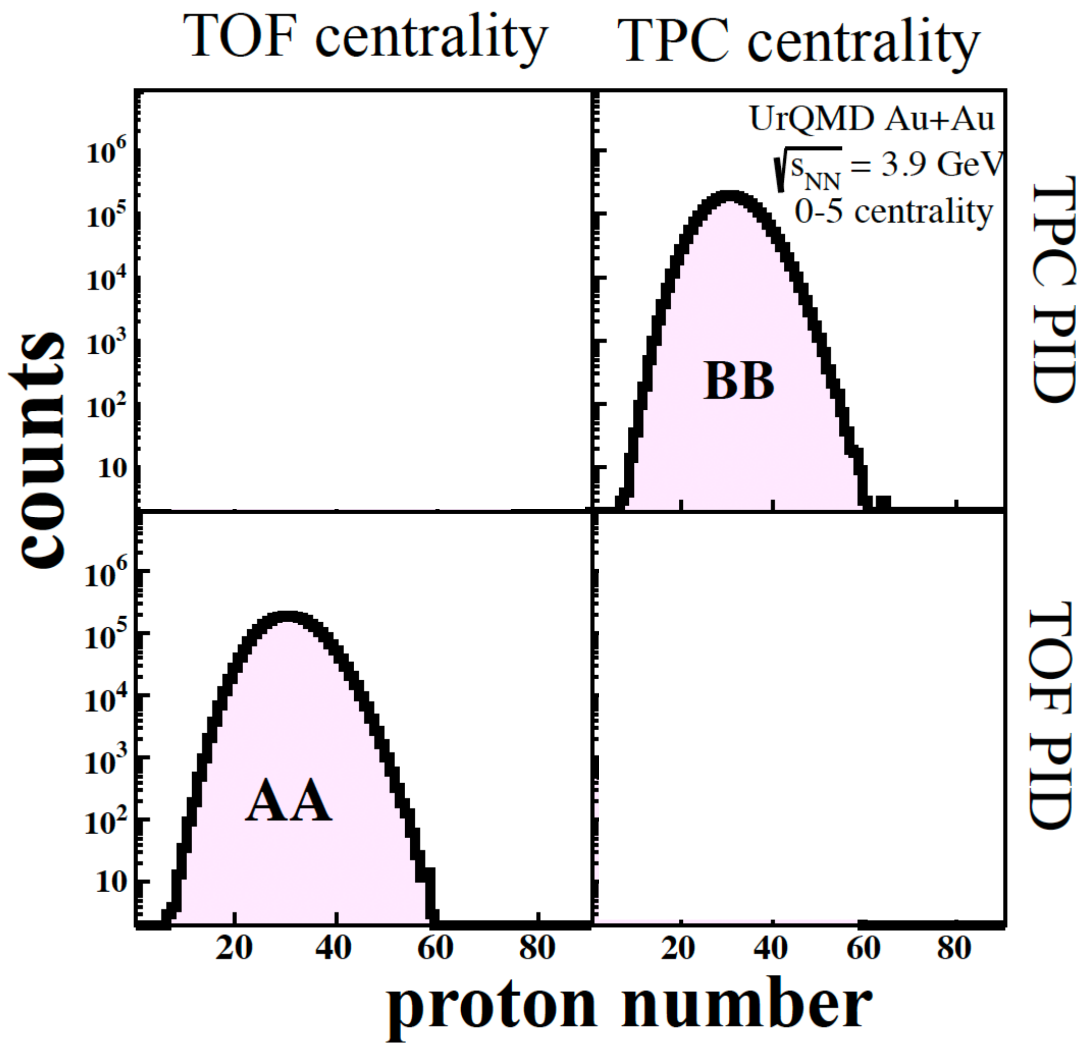

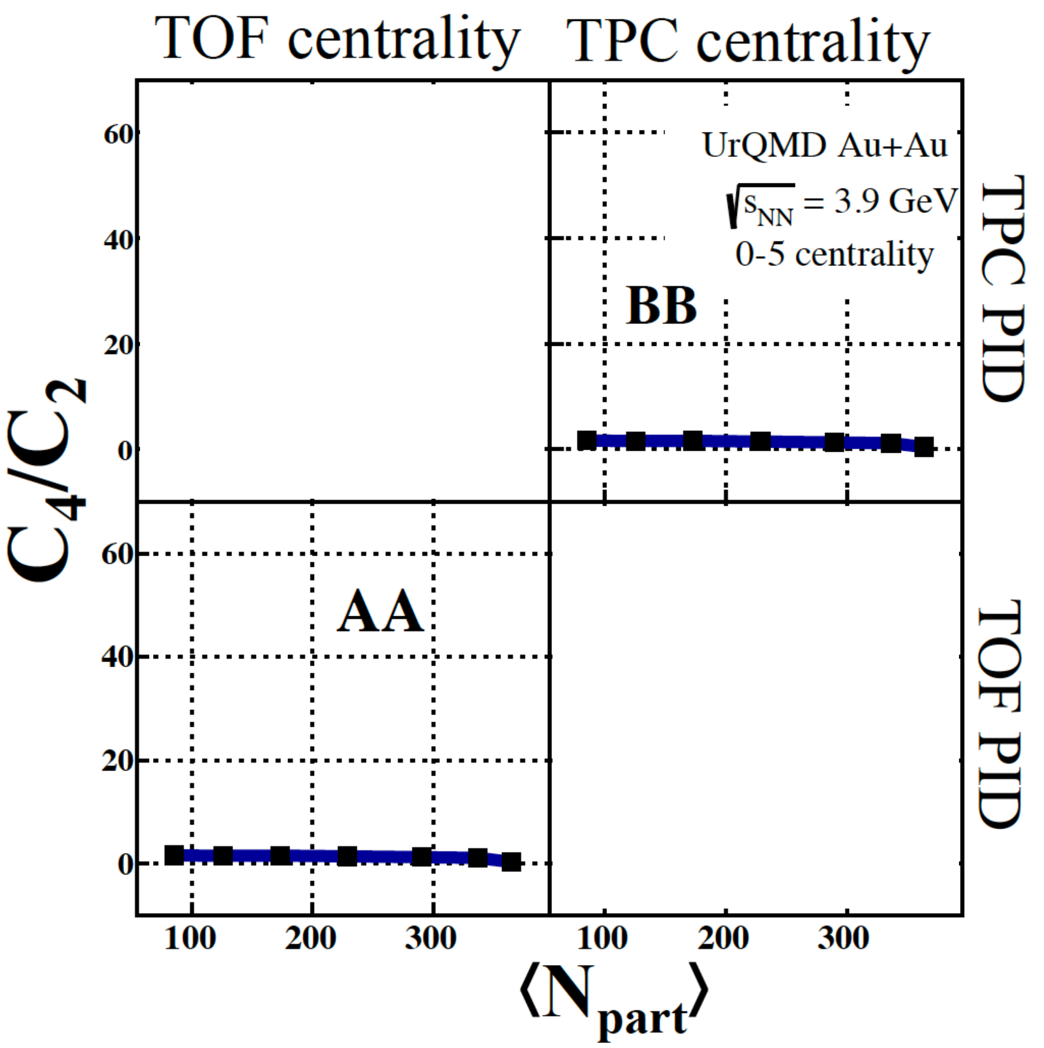

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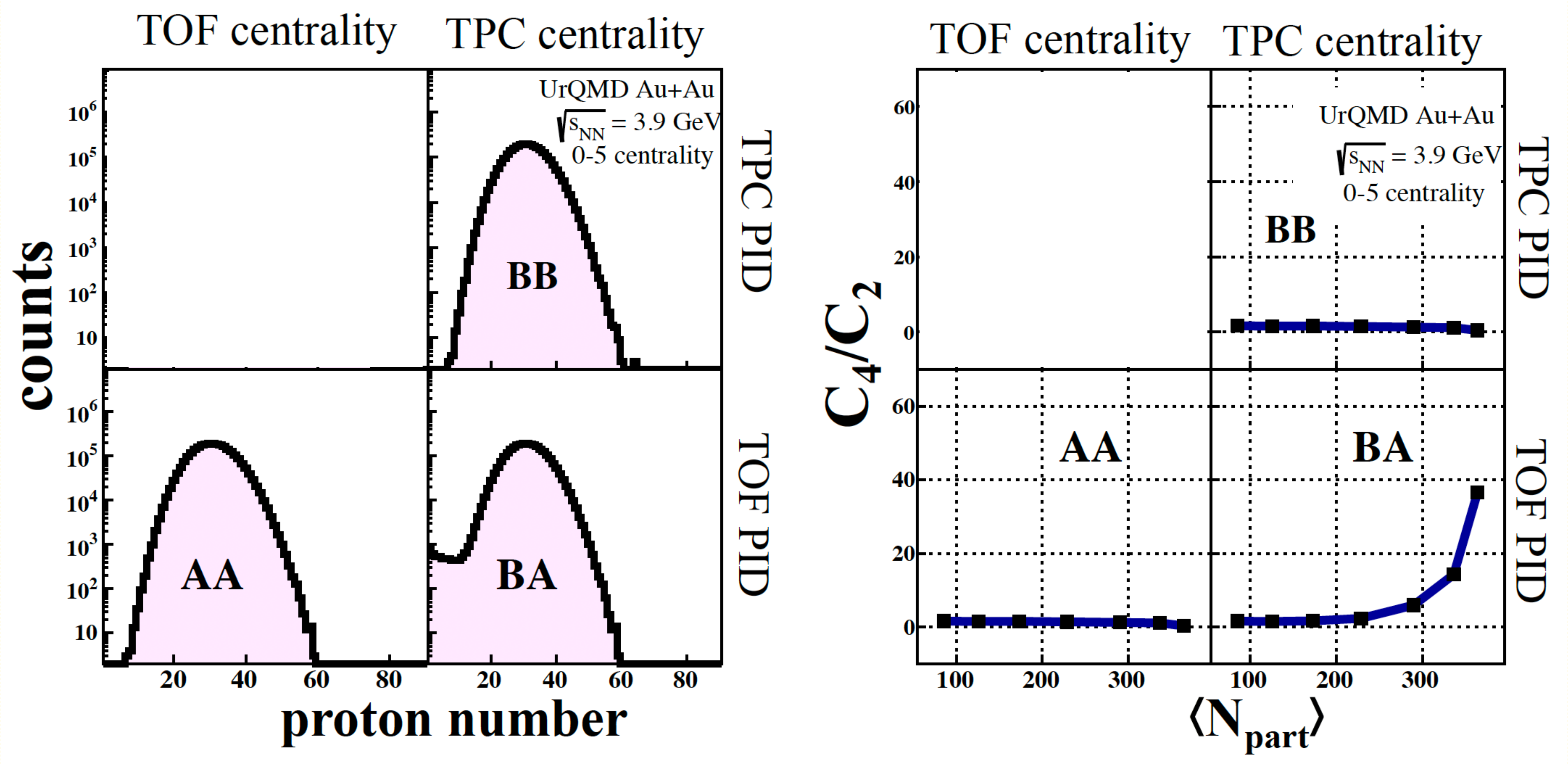

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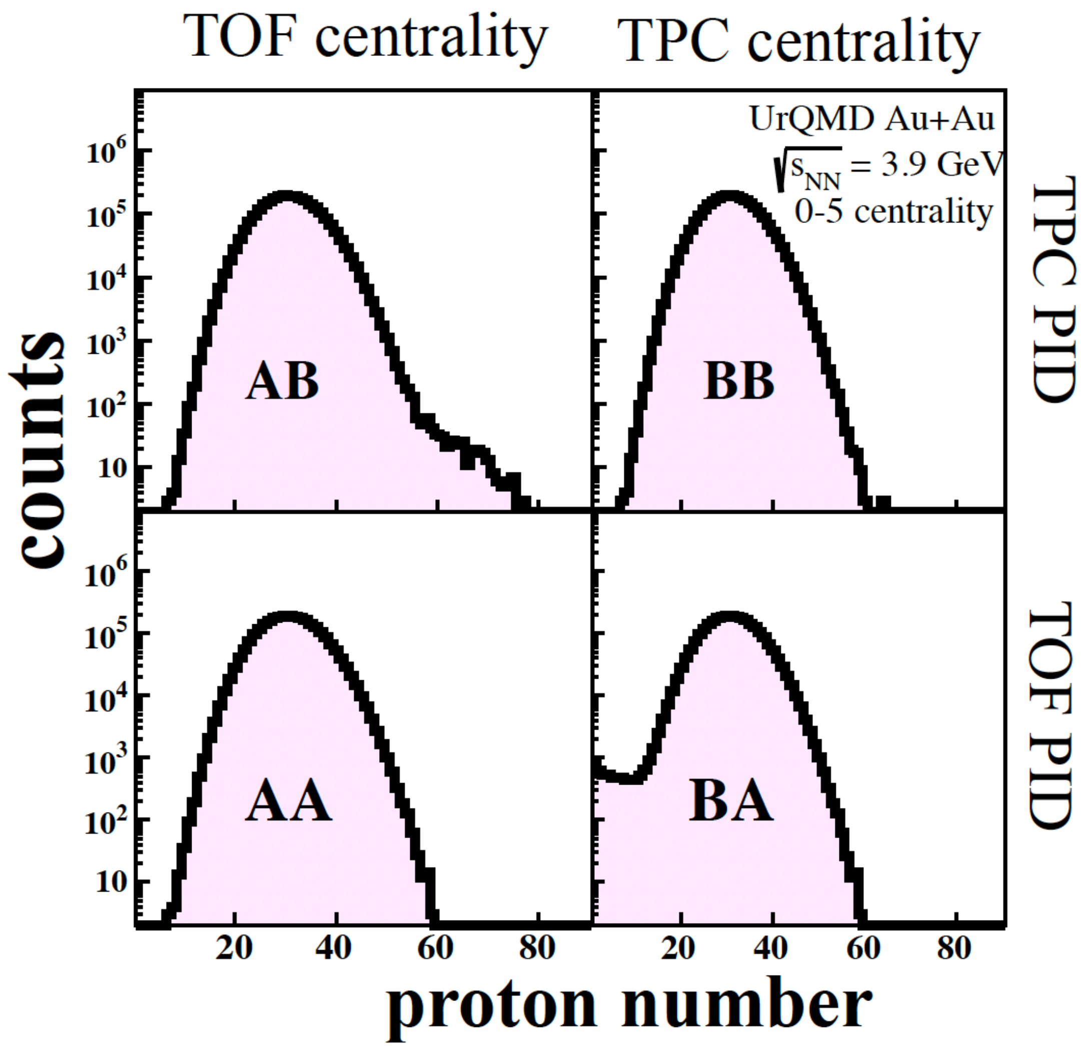
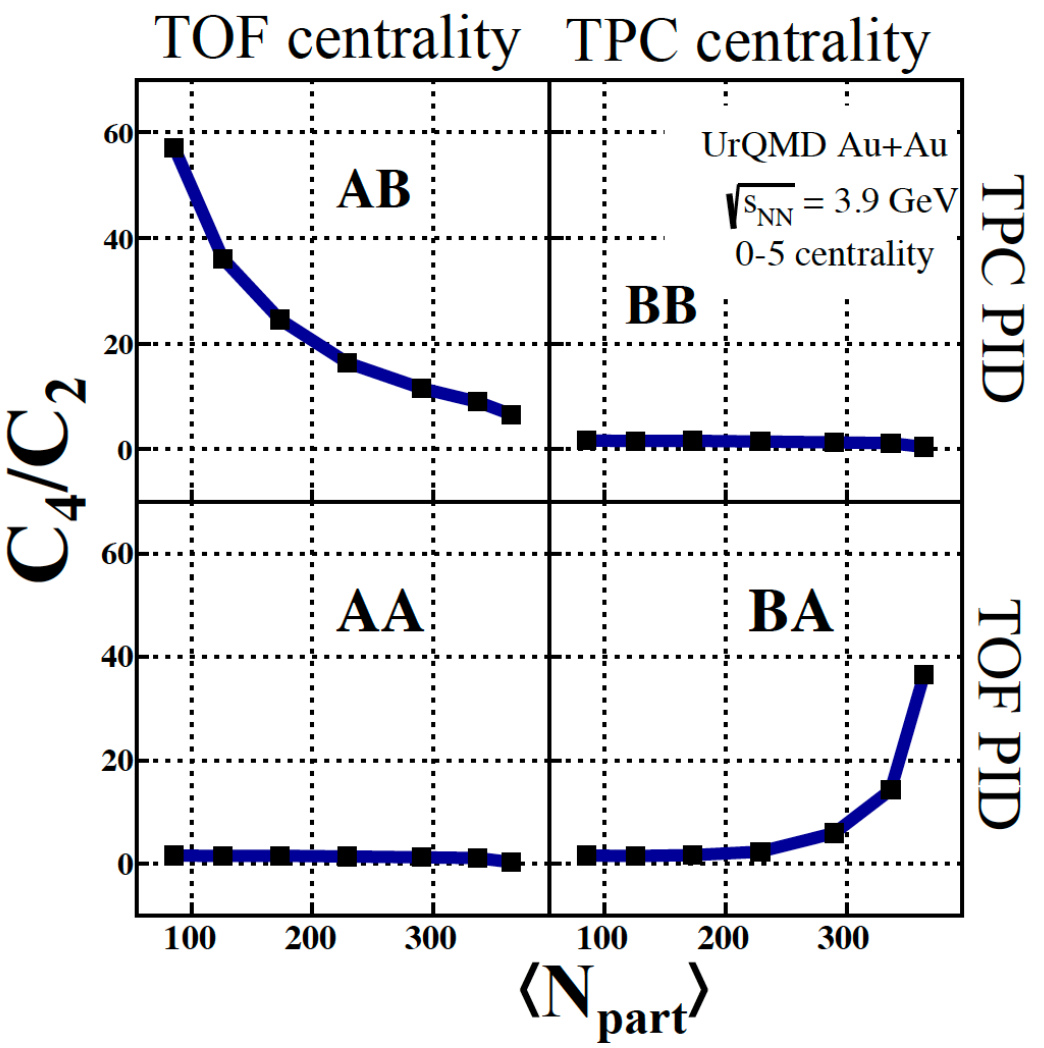
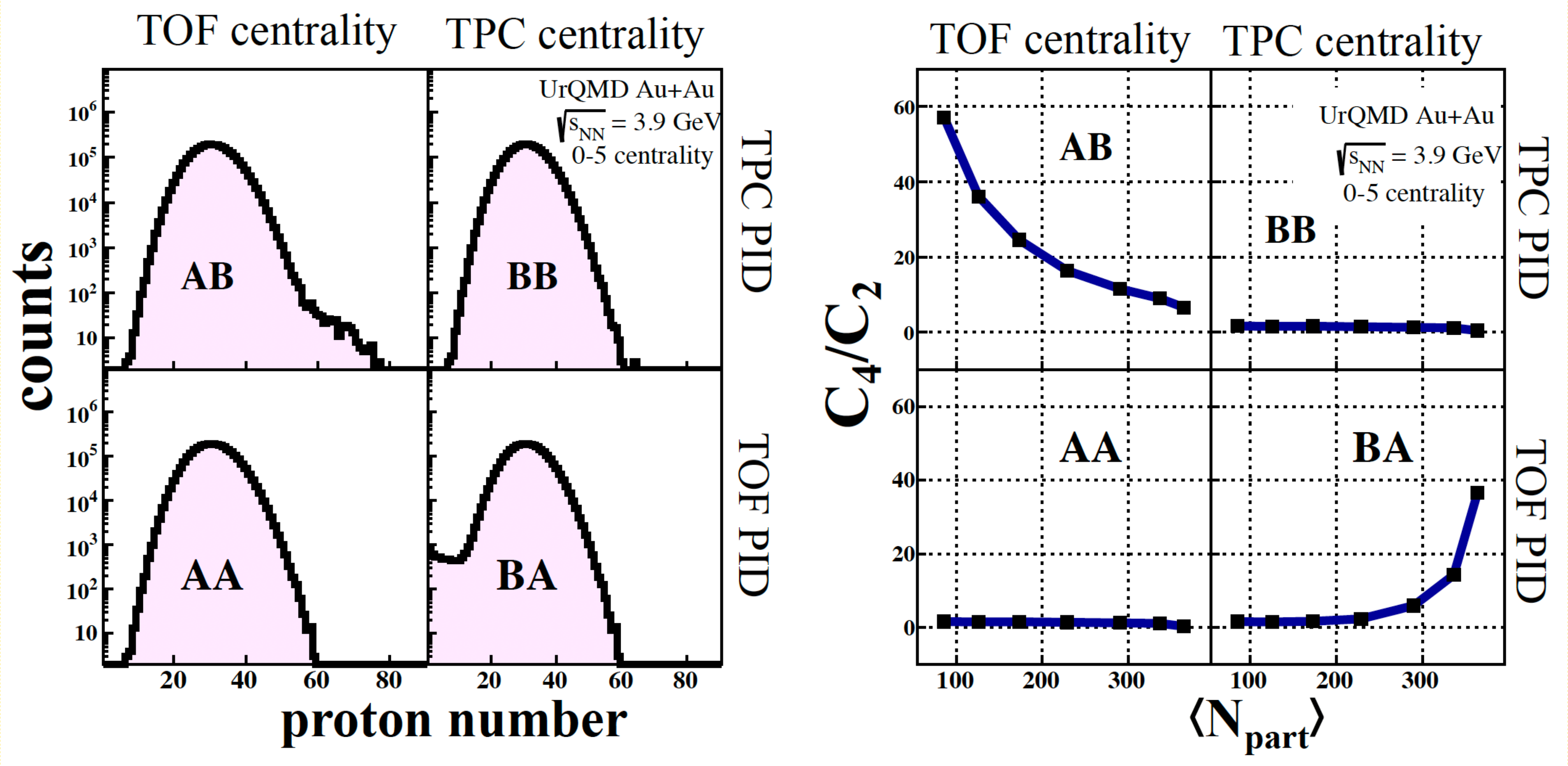




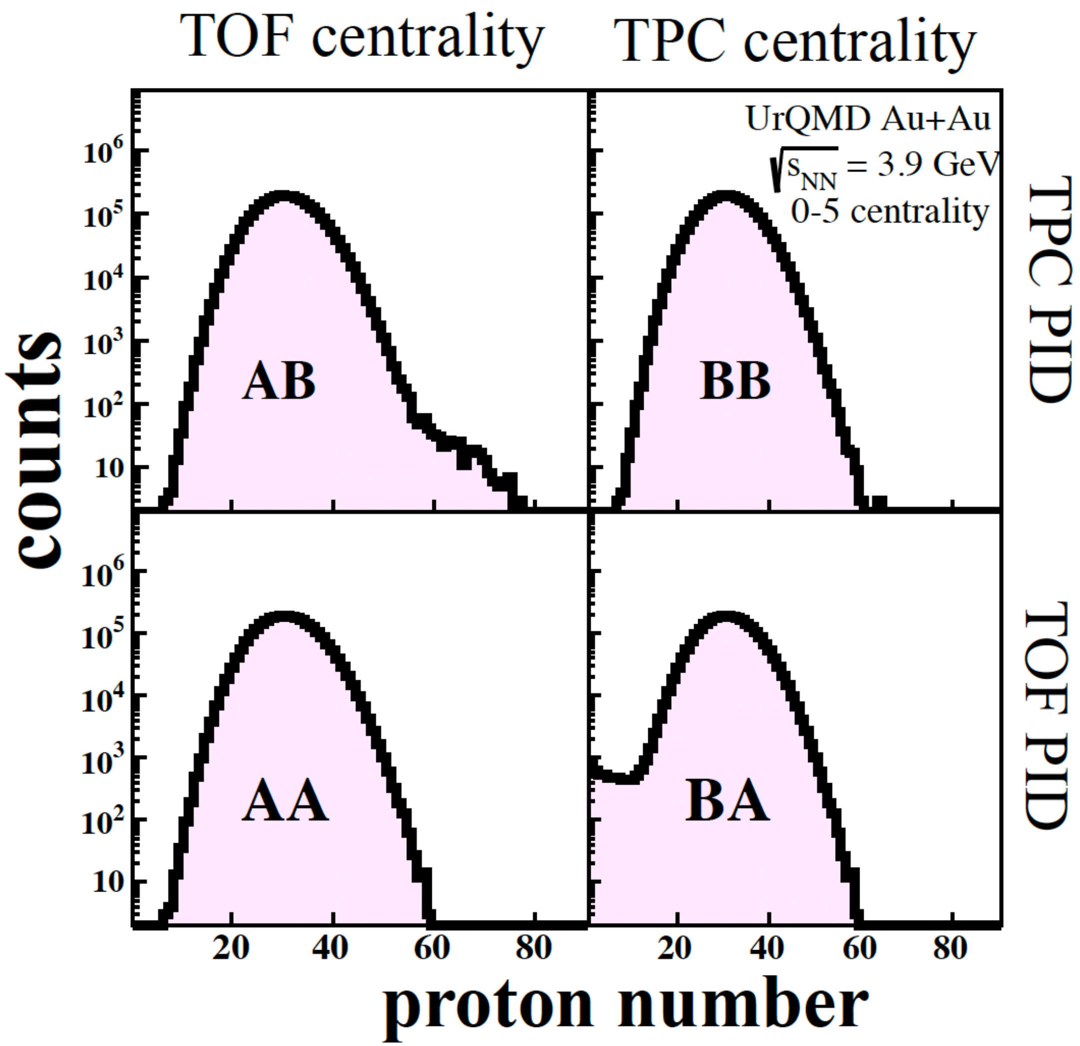
Pileup in the Toy Model

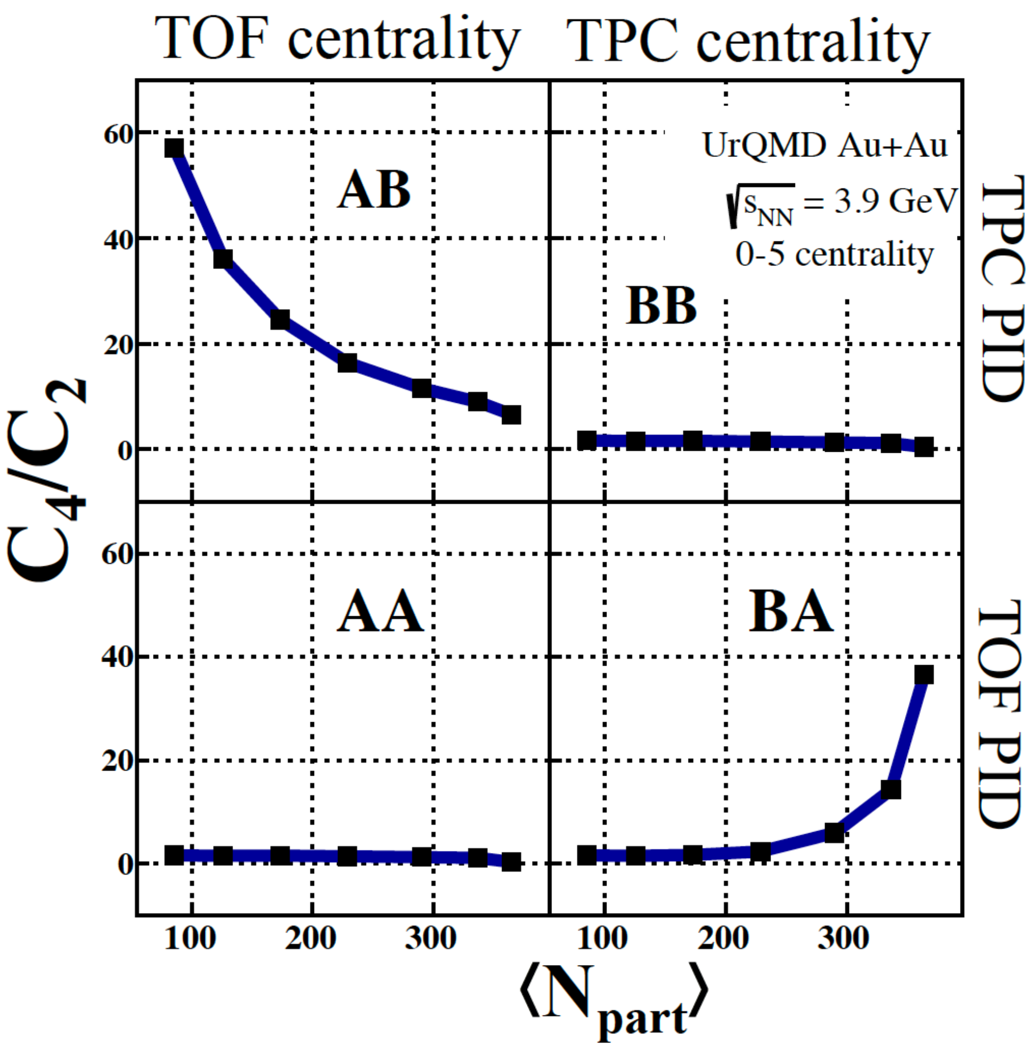
- When identical detectors are used tails are suppressed



Pileup in the Toy Model

- When identical detectors are used tails are suppressed
- Pileup only causes large signal when we mix detectors





A More Realistic Toy Model

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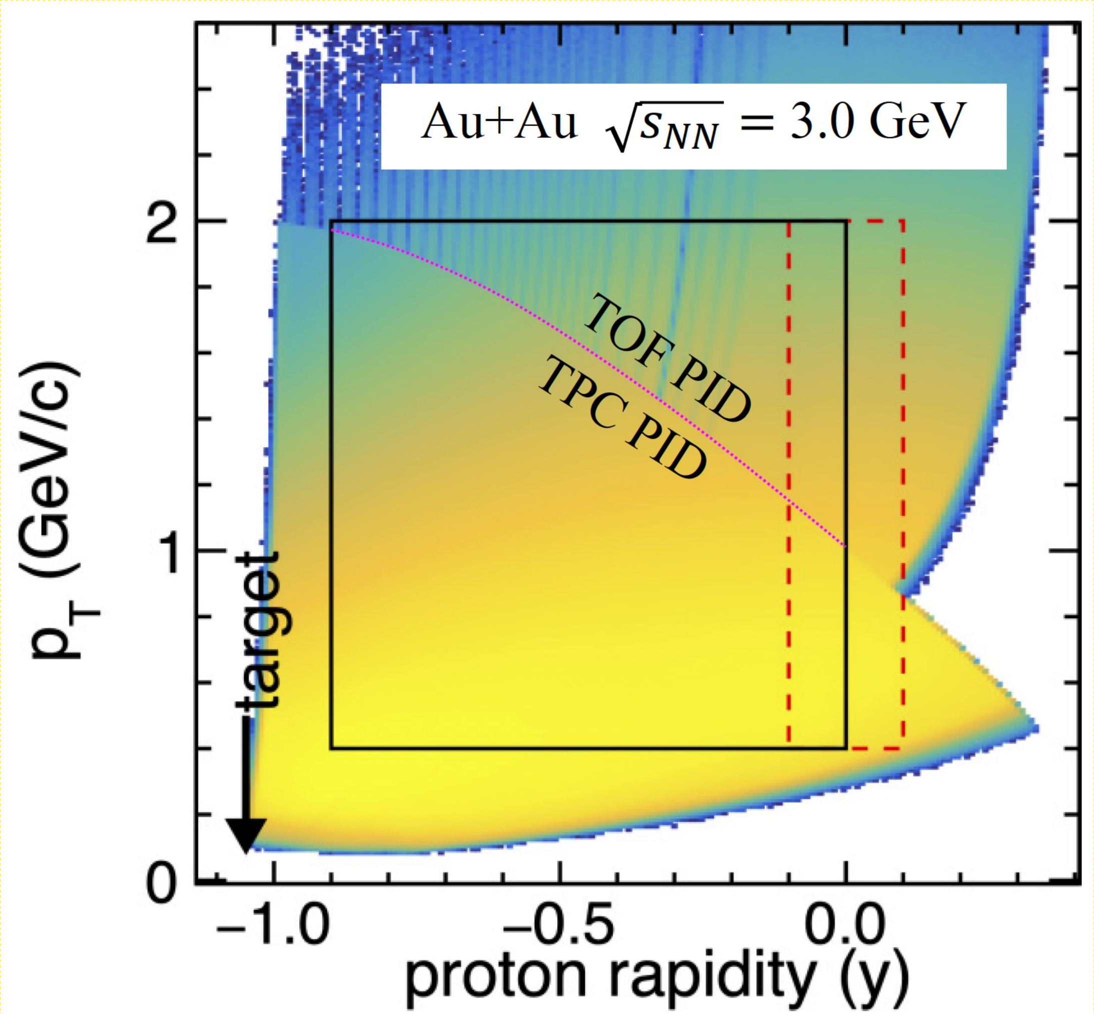
- Like at 3 GeV, we often don't use one detector to identify protons
- At some momentum, we switch from using the TPC to additionally requiring TOF



STAR, Phys. Rev. Lett. 128, 202303 (2022); Phys.Rev.C 107.024908 (2023).

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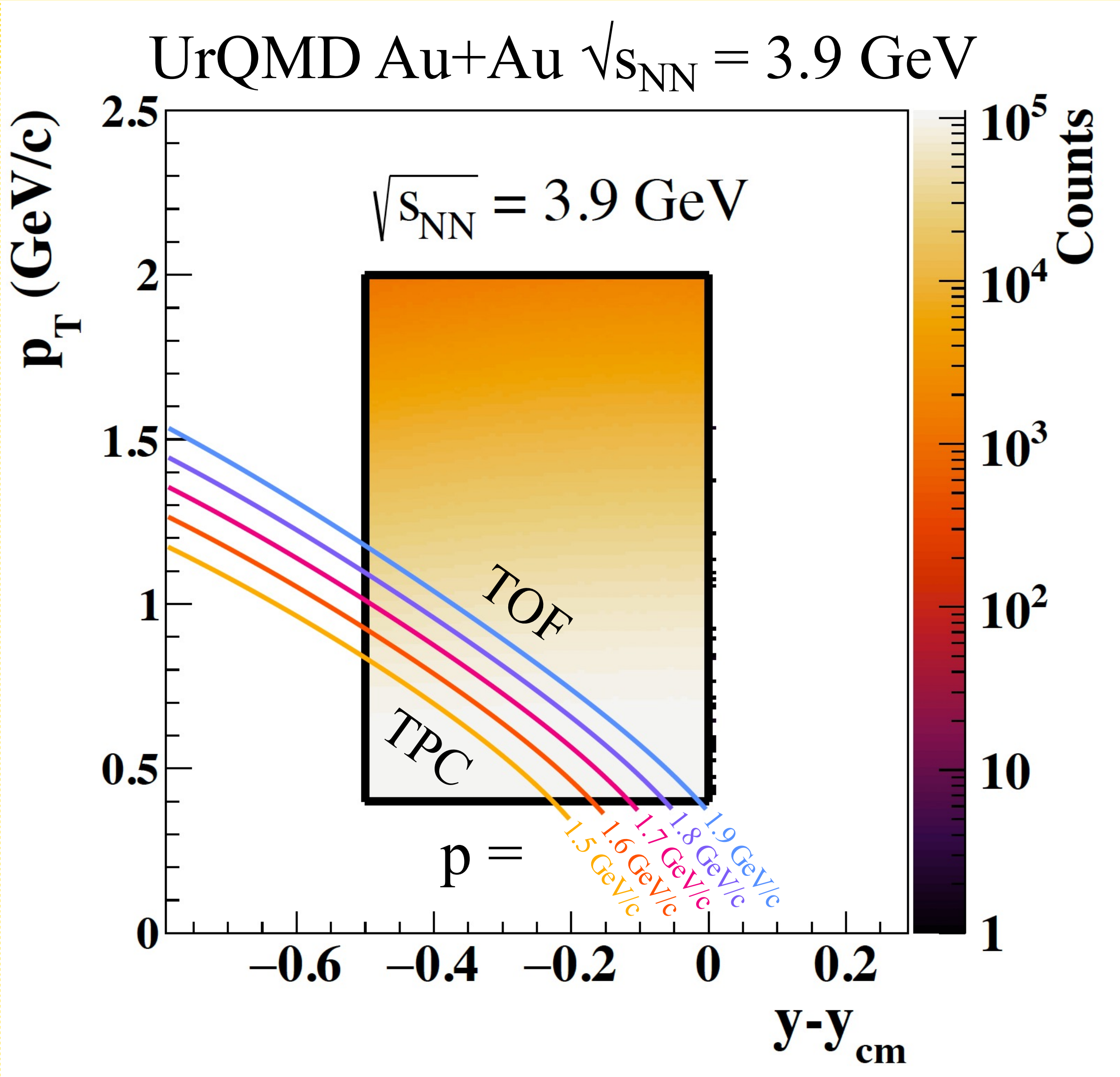

A More Realistic Toy Model

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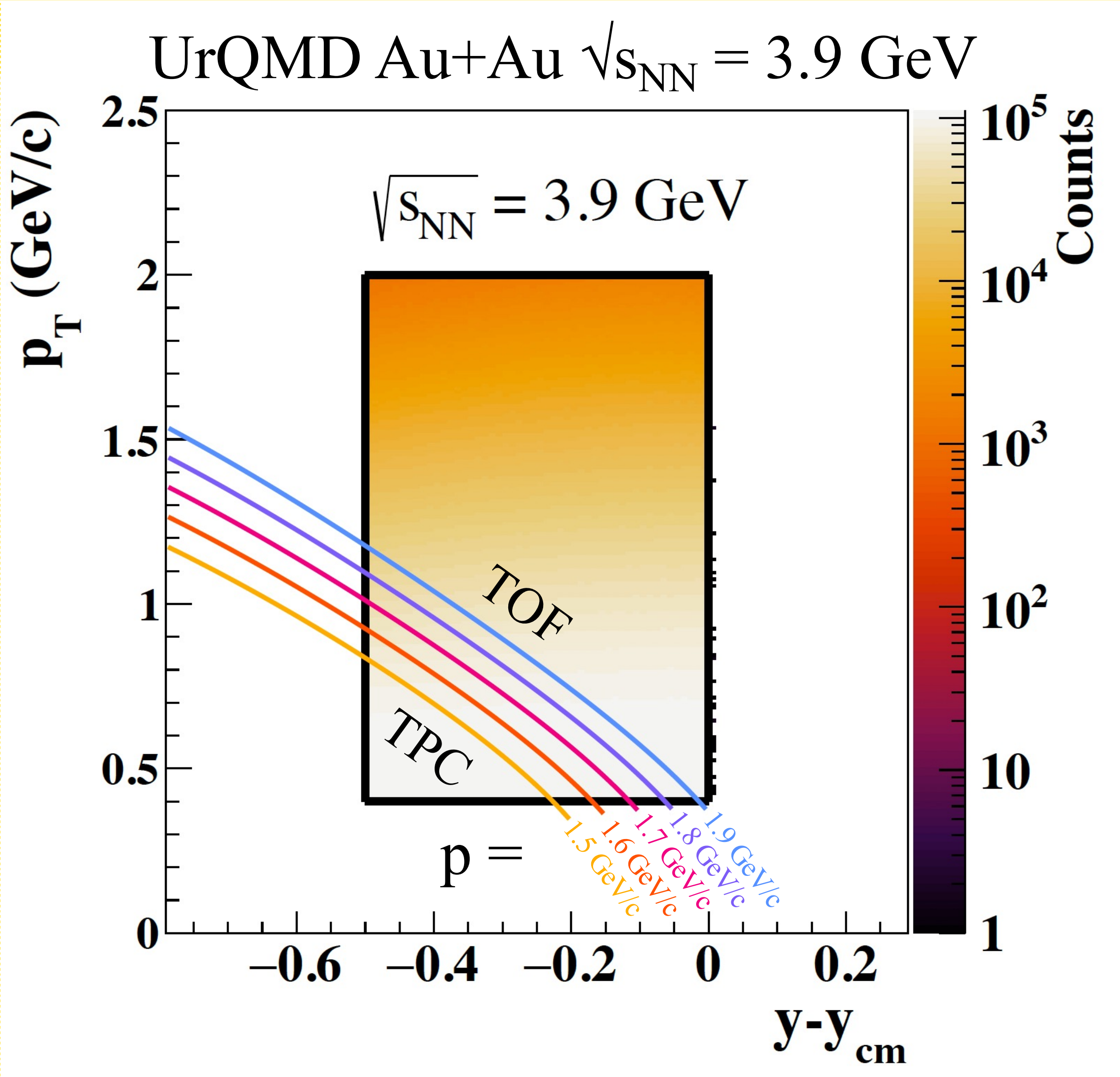
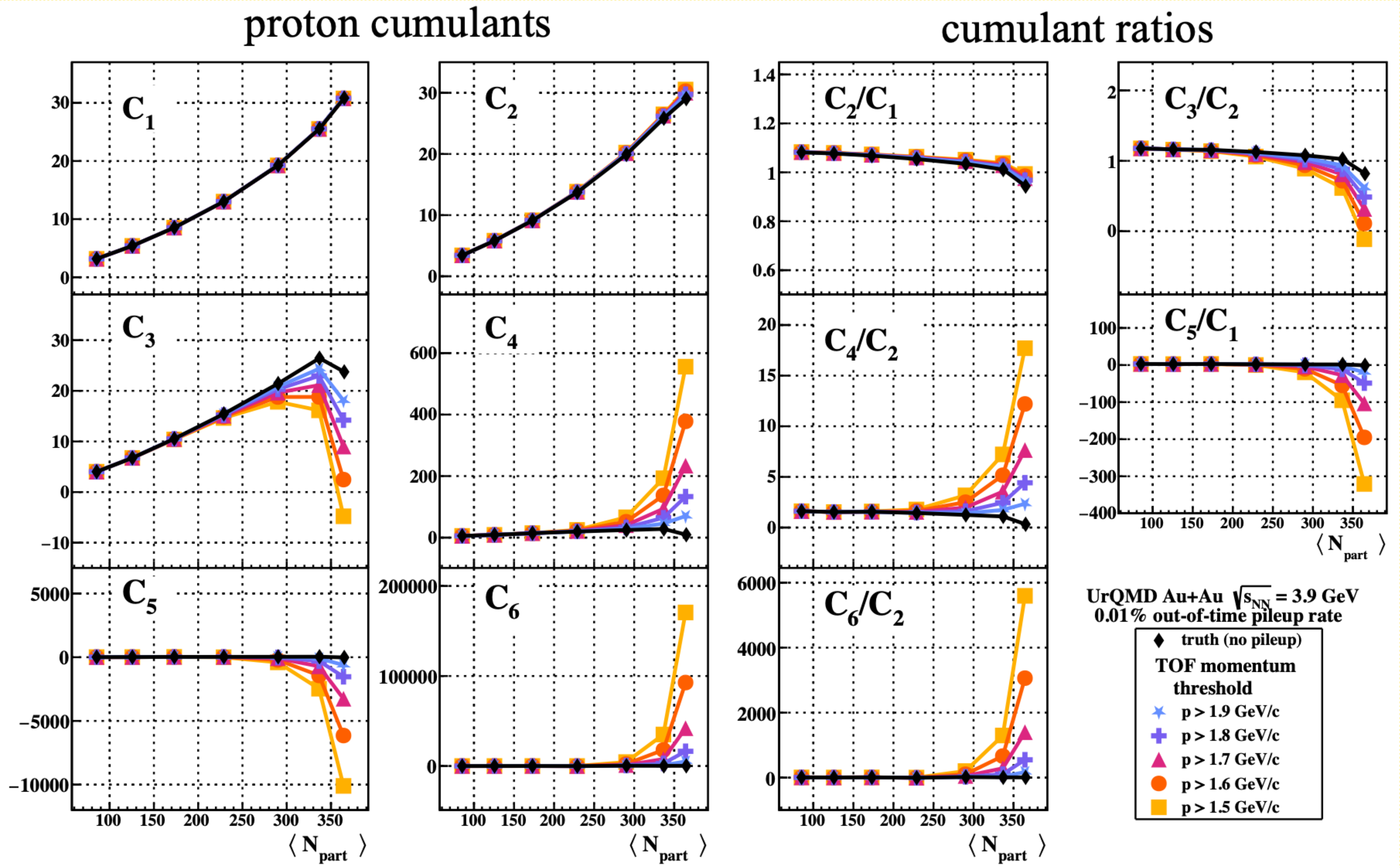
- At some momentum, we switch from using the TPC to additionally requiring TOF
- In toy model, we can similarly set a momentum above which we require TOF
- We can test effect of various momentum cutoffs
- Strategy:
  - ❑ toy TPC measures multiplicity
  - ❑ toy TPC measures protons beneath momentum cutoff. Above cutoff, use toy TOF (no pileup)



Cumulant Instability in the Toy Model



How to Measure a False Critical Point

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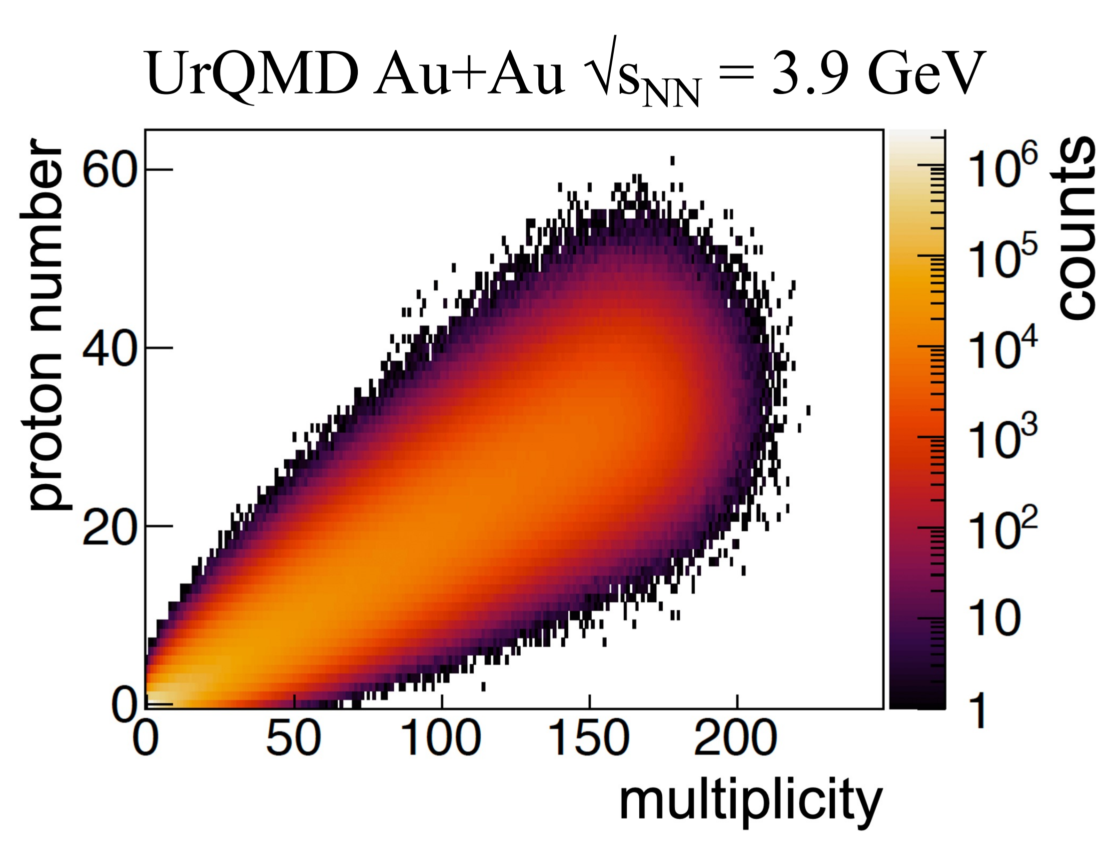

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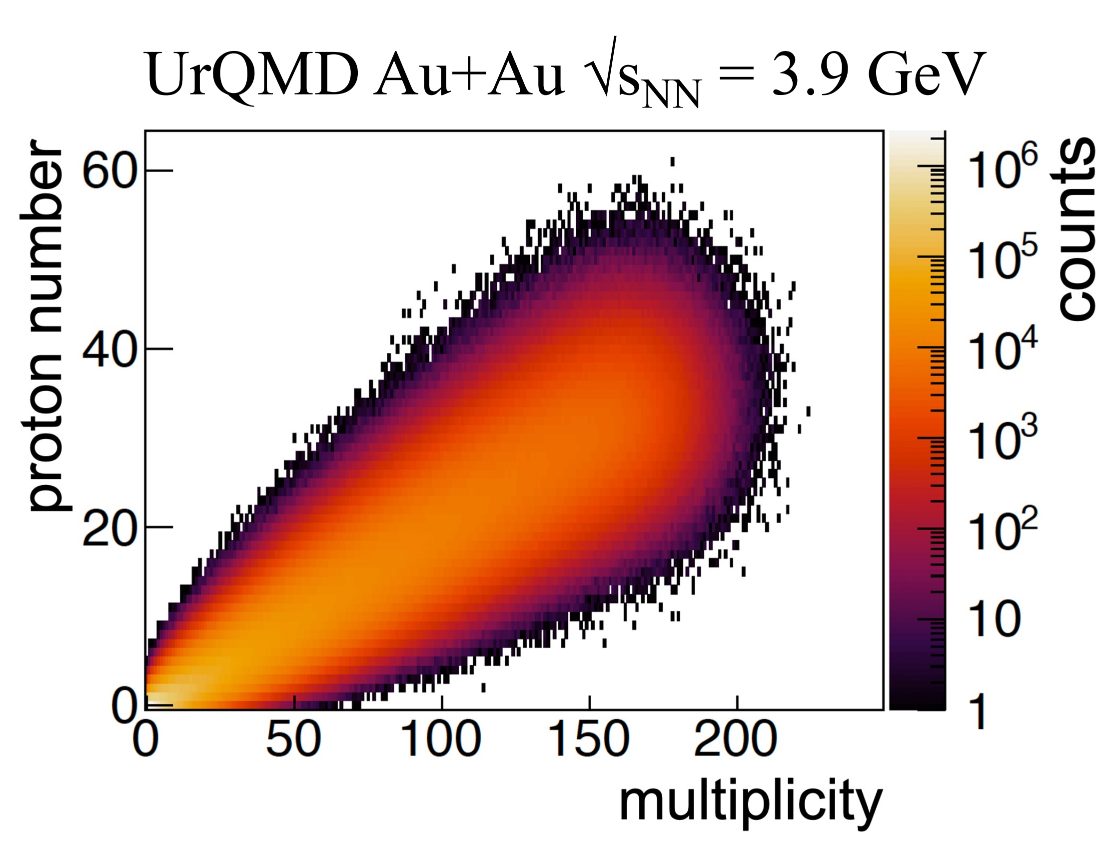

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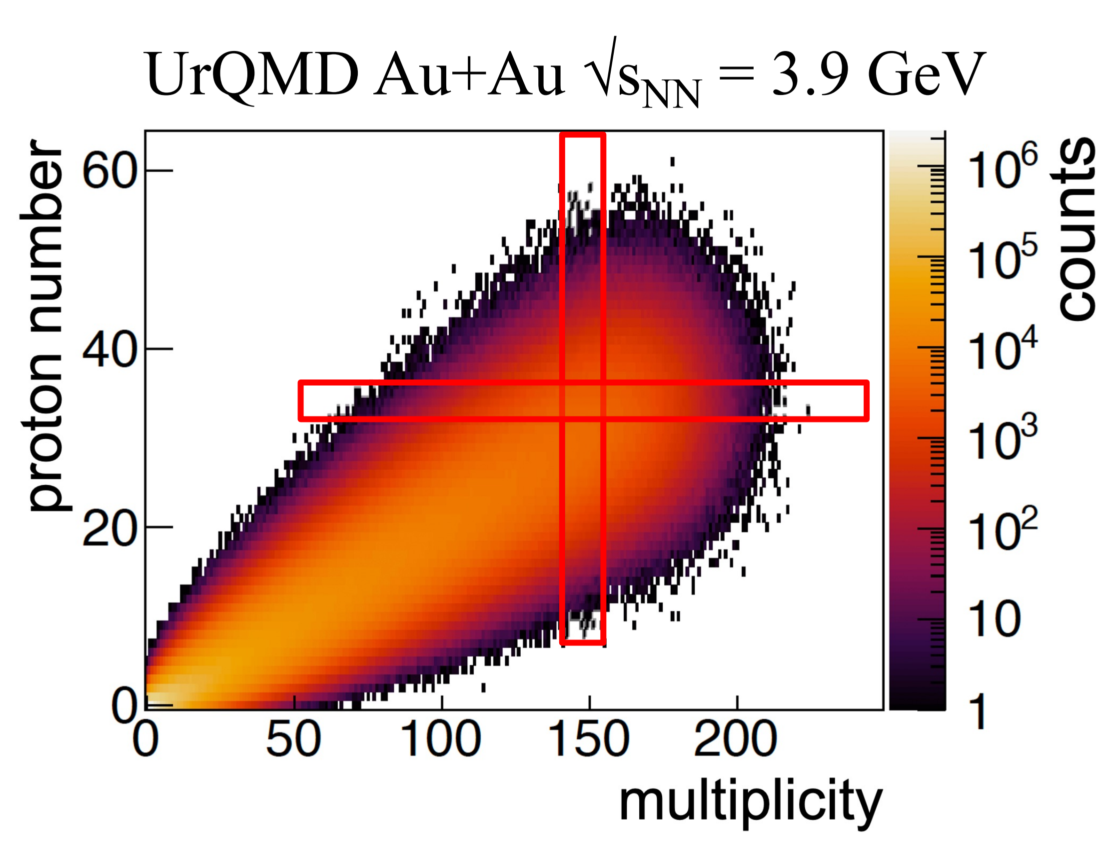

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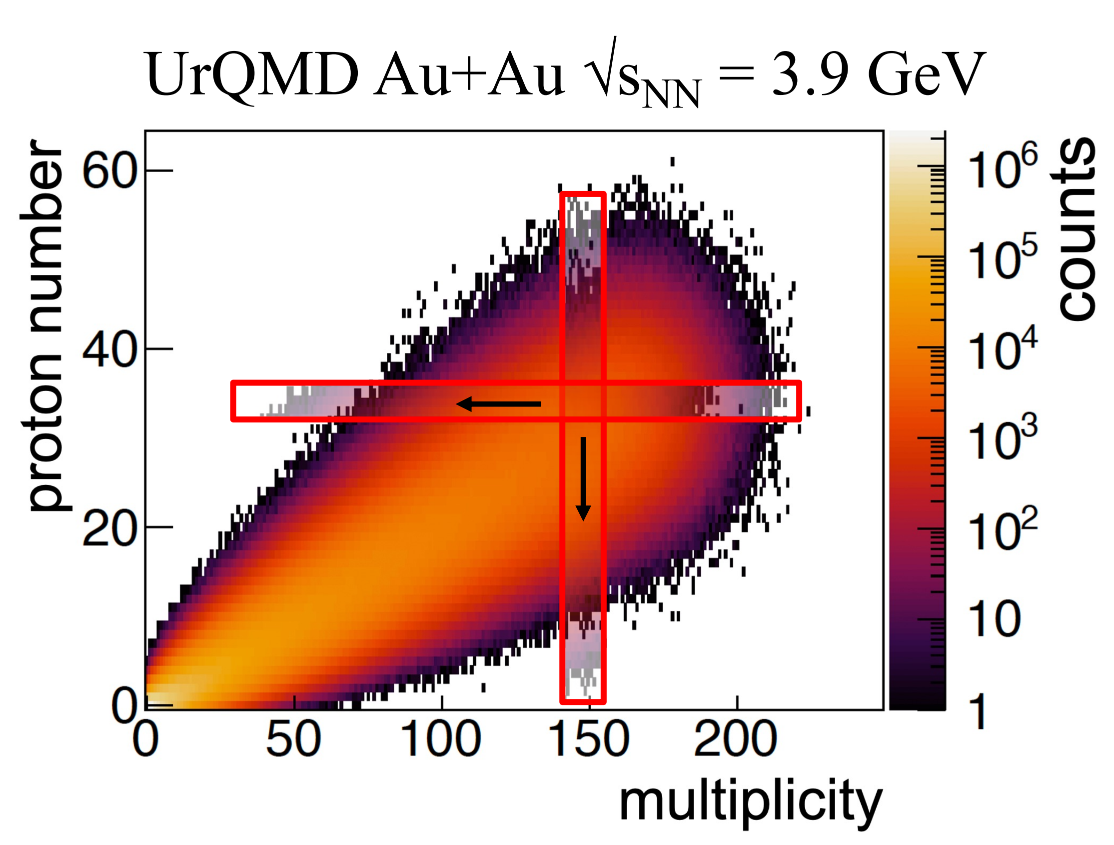
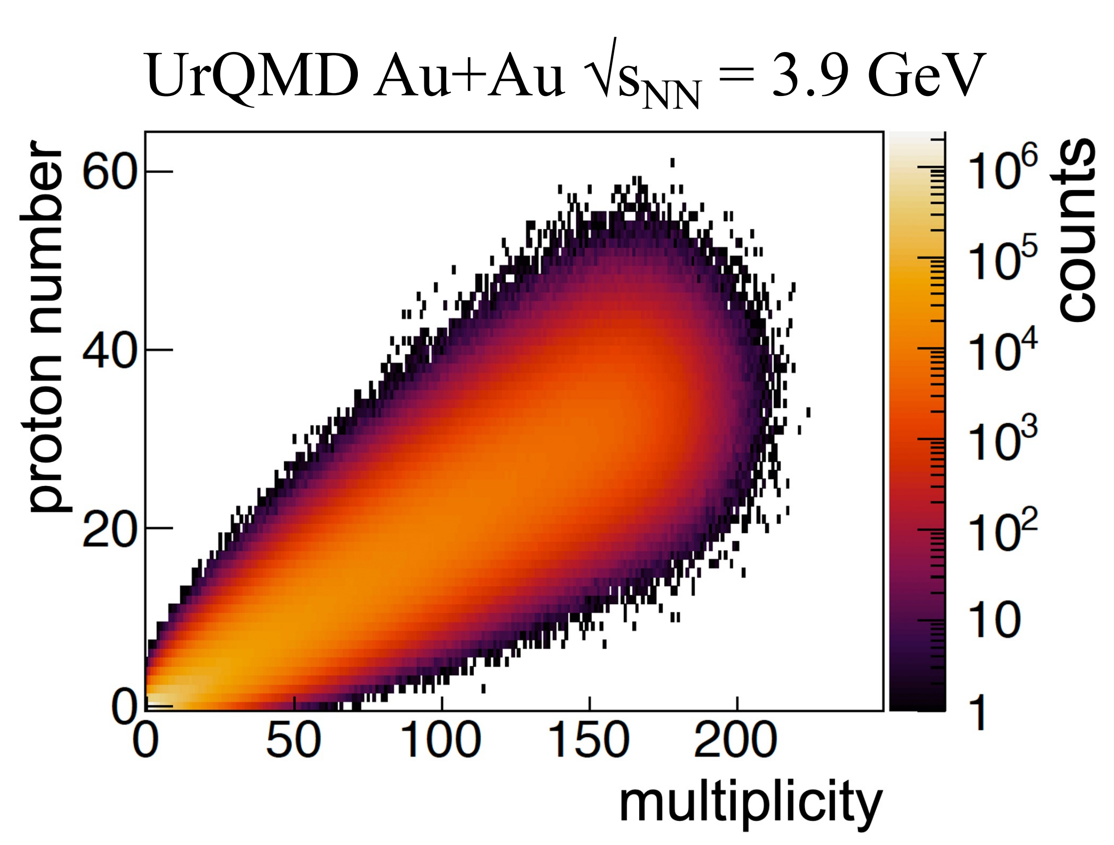
  1. Measure multiplicity and proton number with two different detectors/methods
  2. Ensure that a small fraction of the time, the methods become uncorrelated

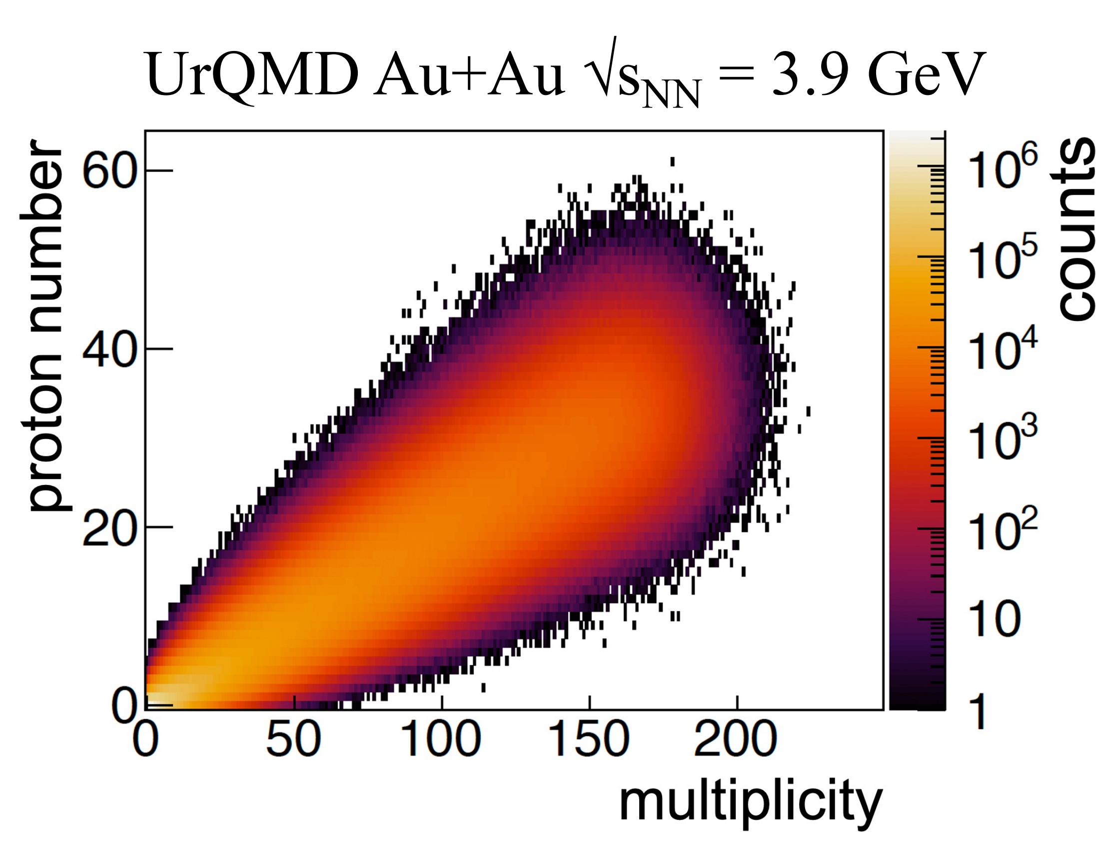


How *NOT* to Measure a False Critical Point



How *NOT* to Measure a False Critical Point

- To make a robust signal



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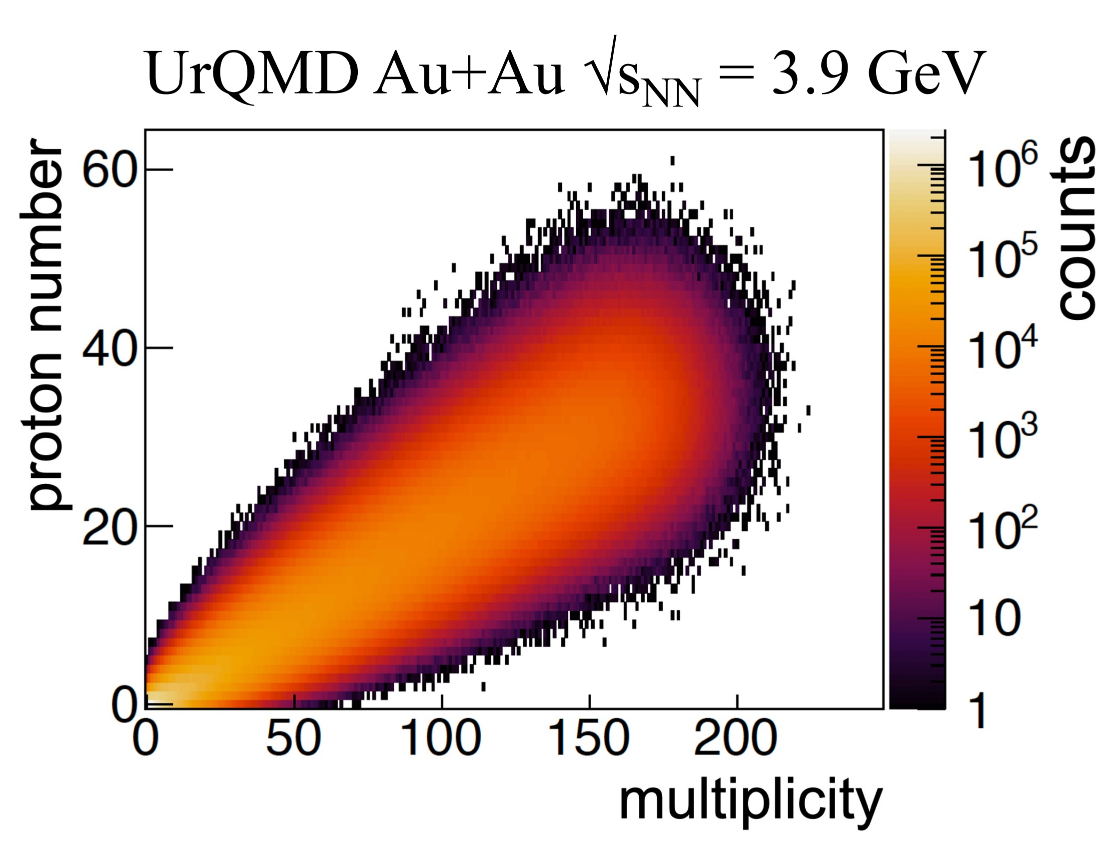

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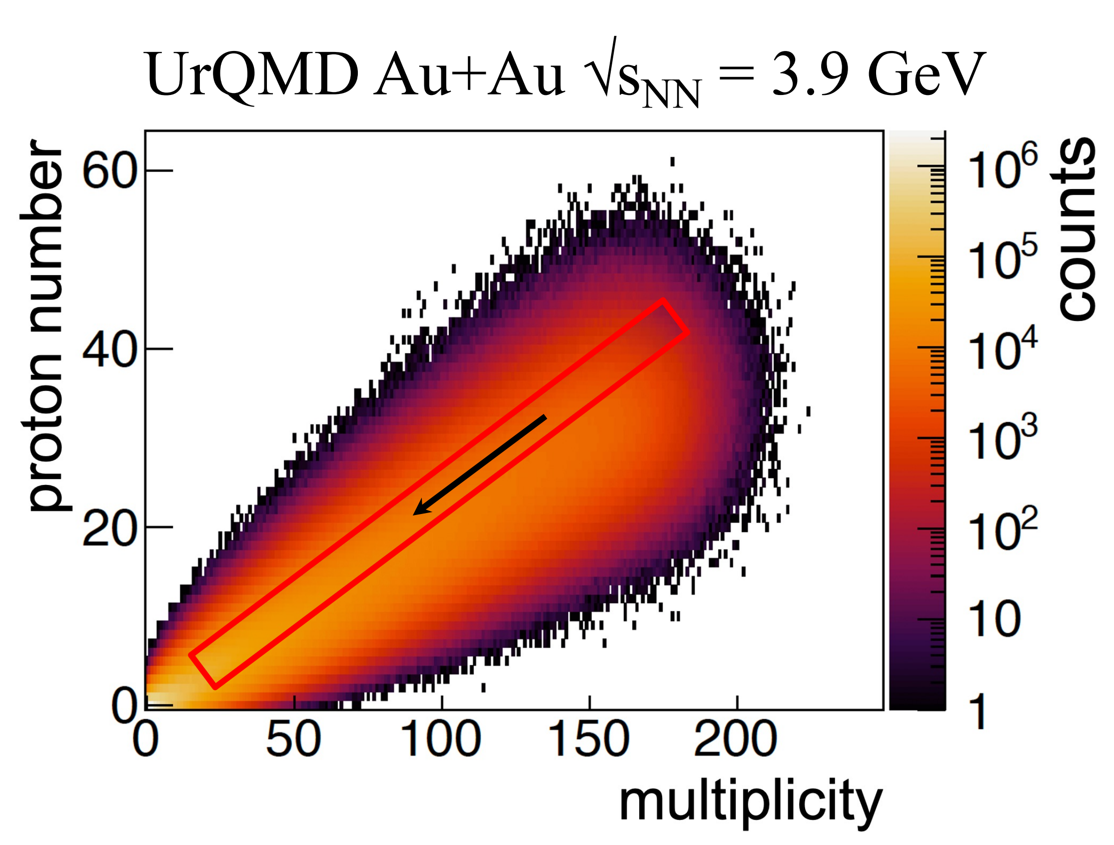

How *NOT* to Measure a False Critical Point

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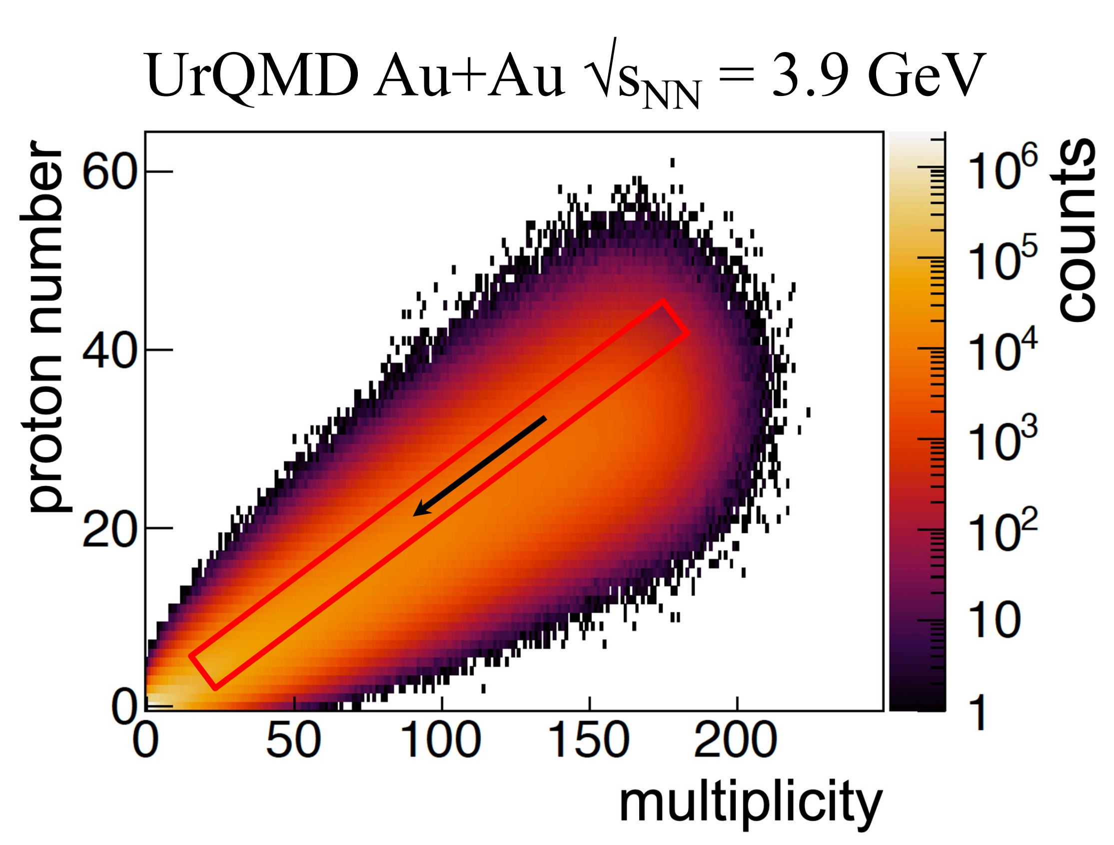
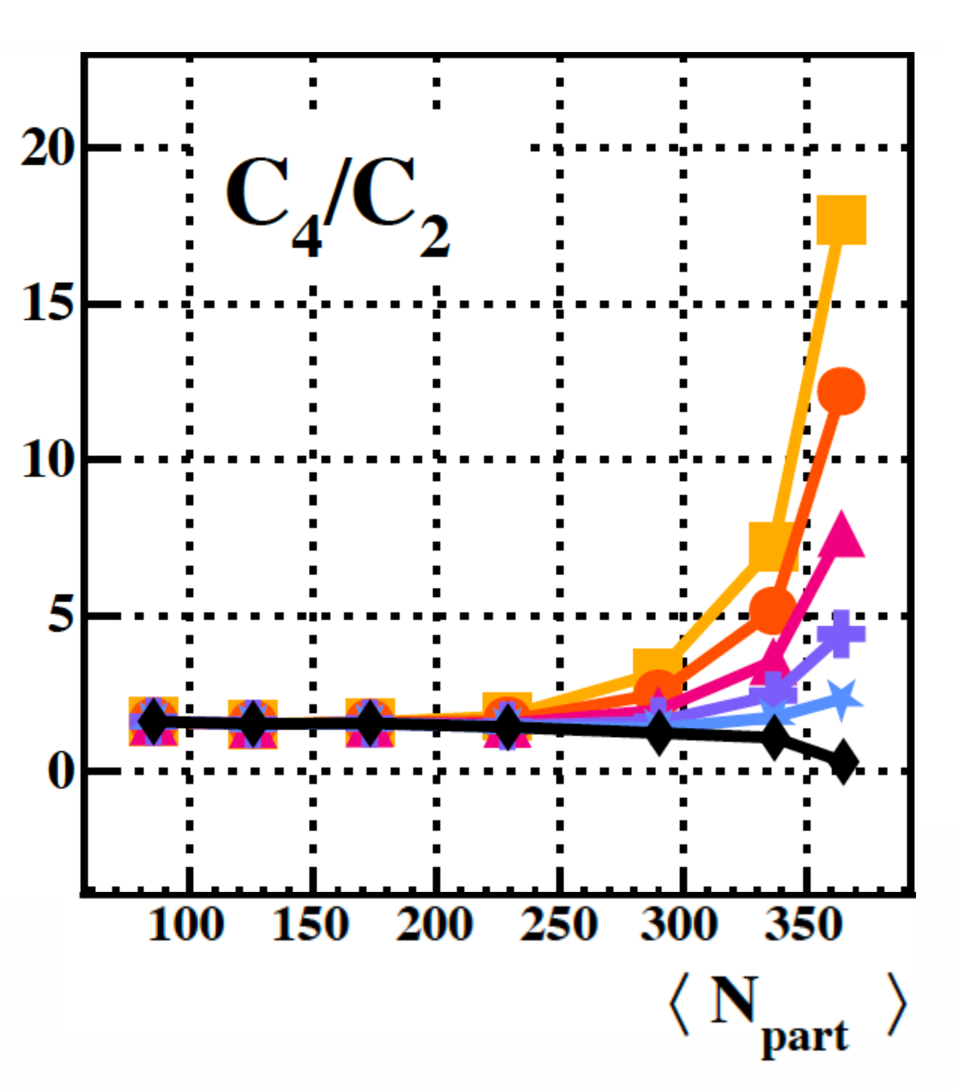
- If both measurements fail, they fail in the same way
- Nearly all non-physics fluctuations are suppressed!



Conclusions



Conclusions

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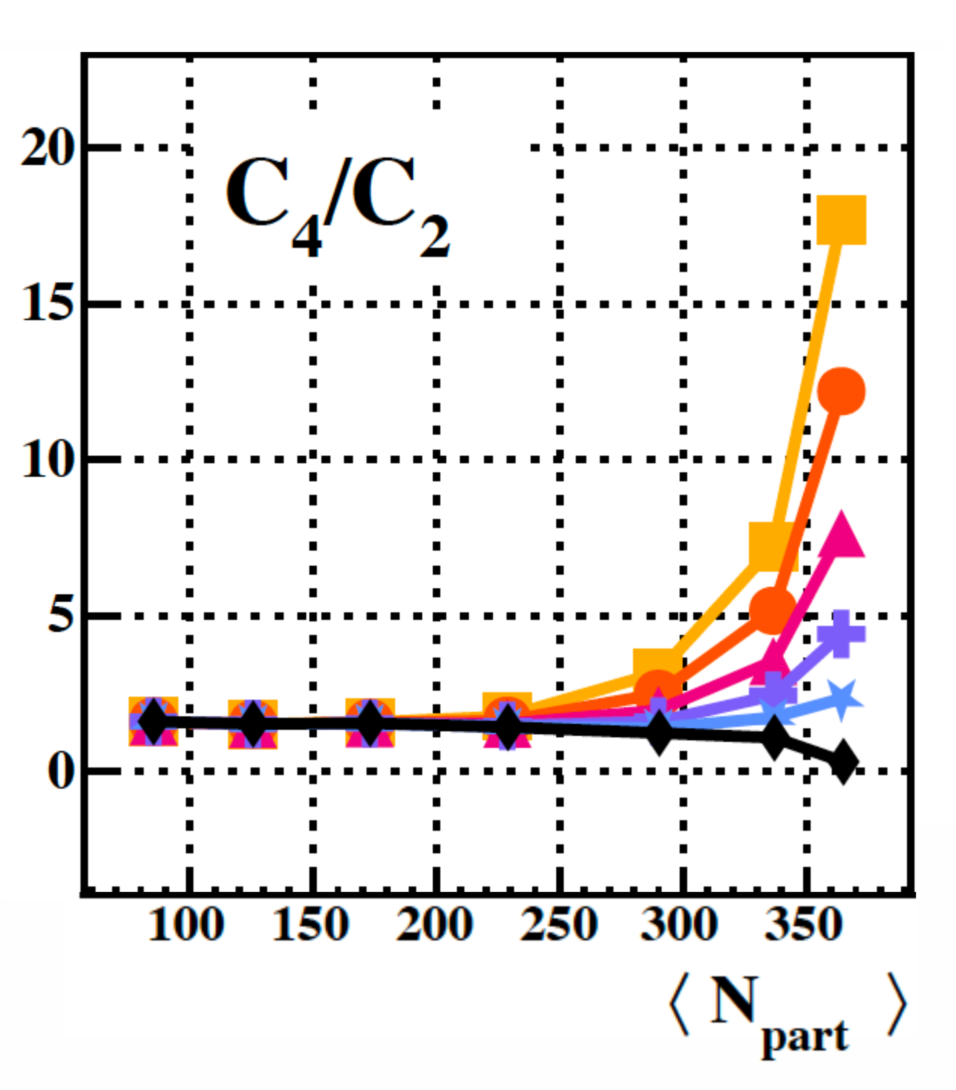

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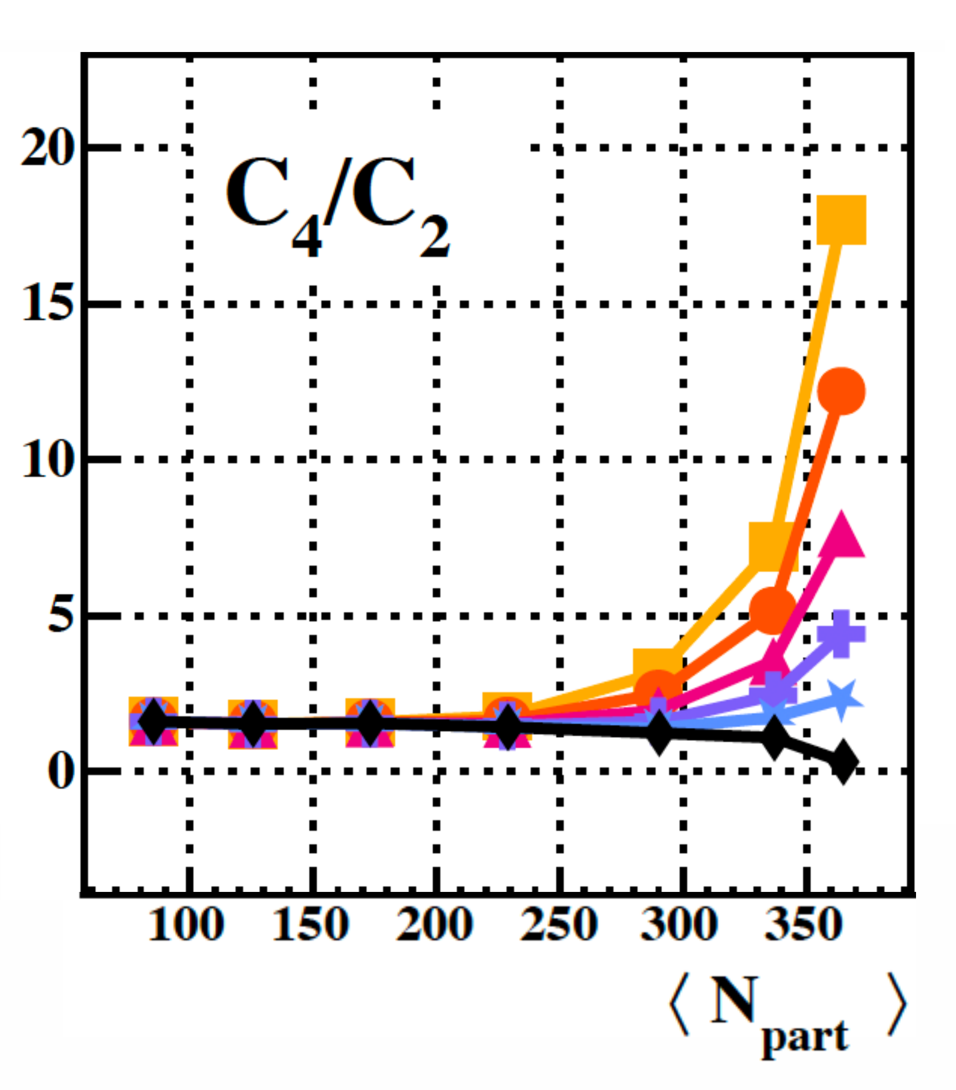

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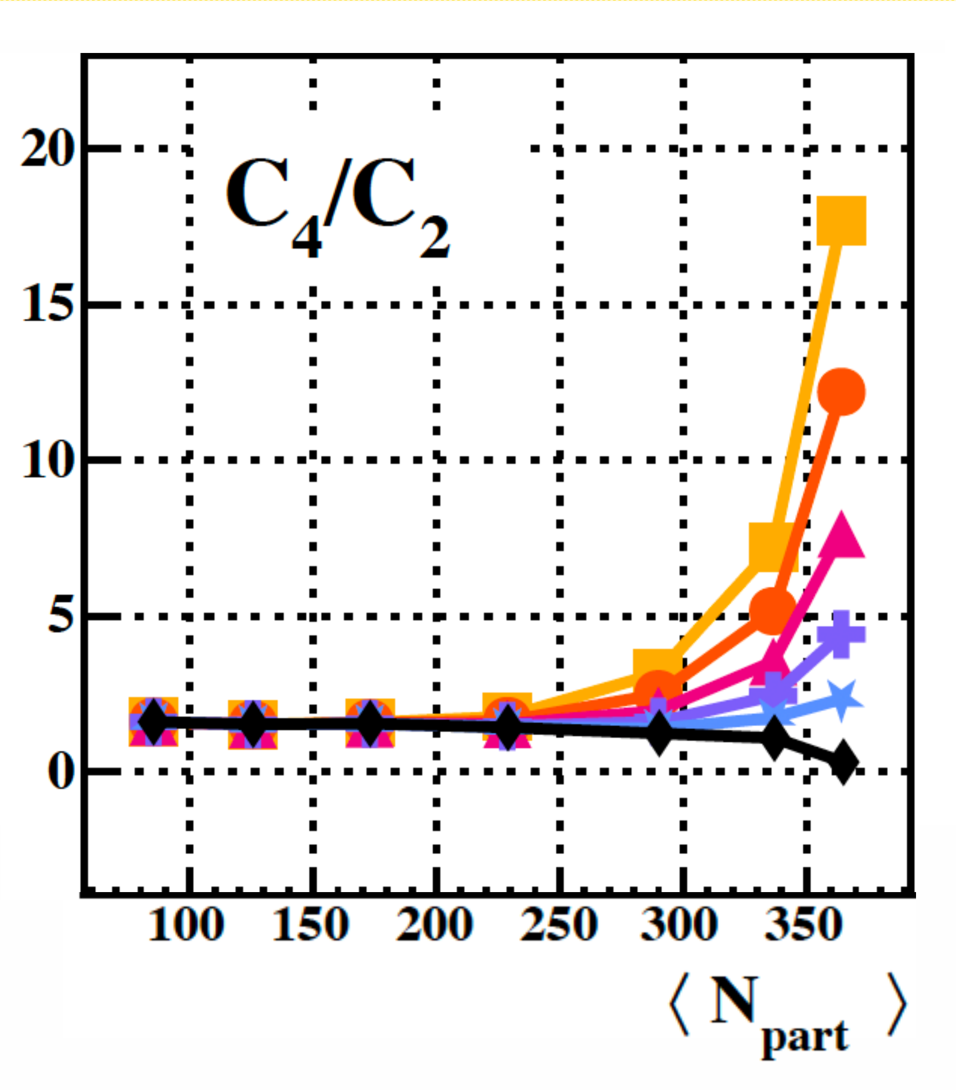

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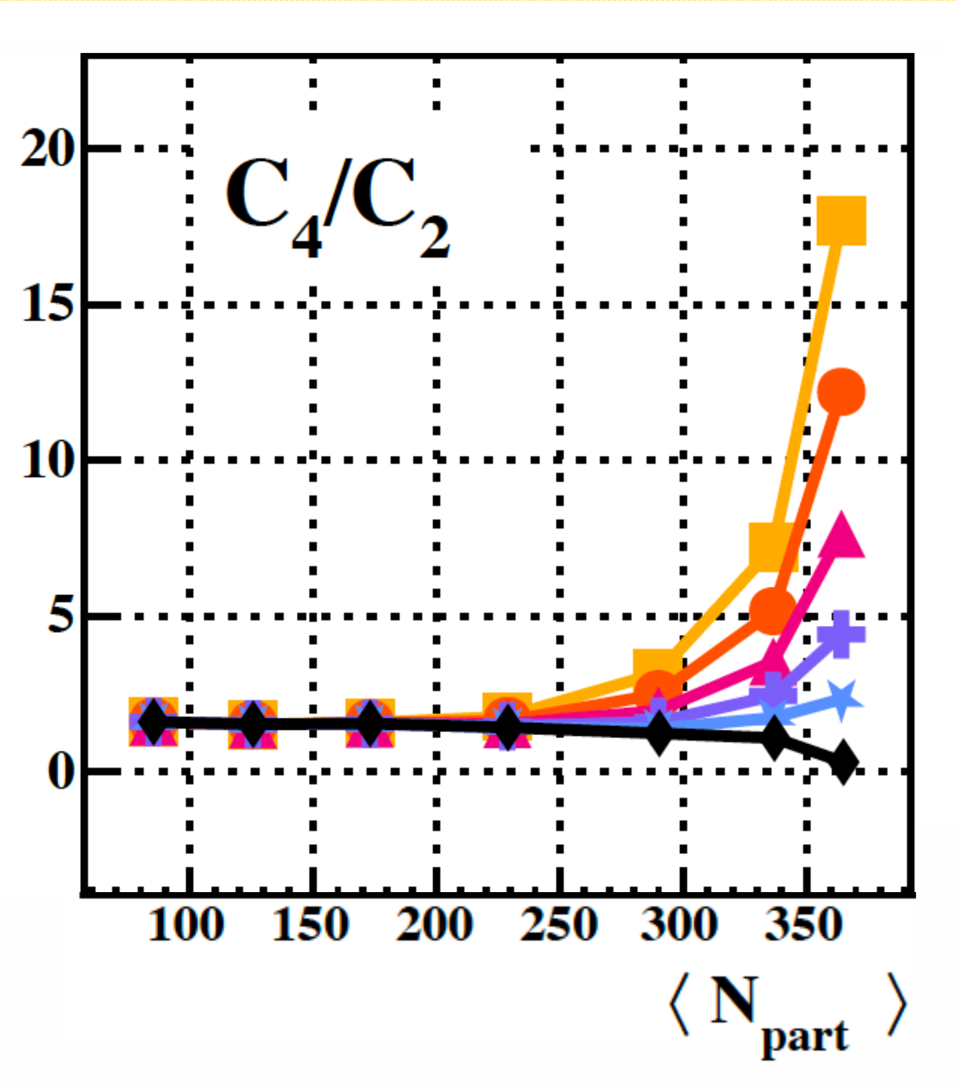

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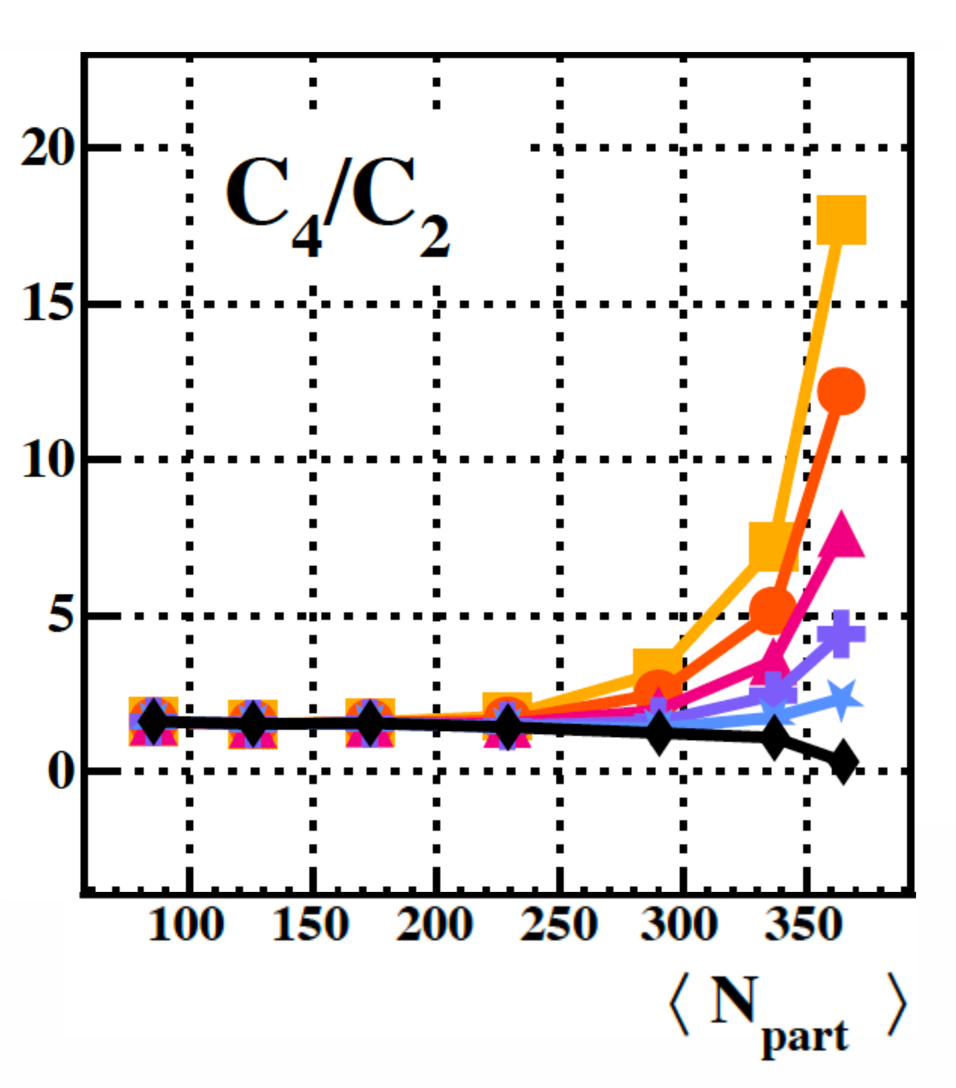

Conclusions

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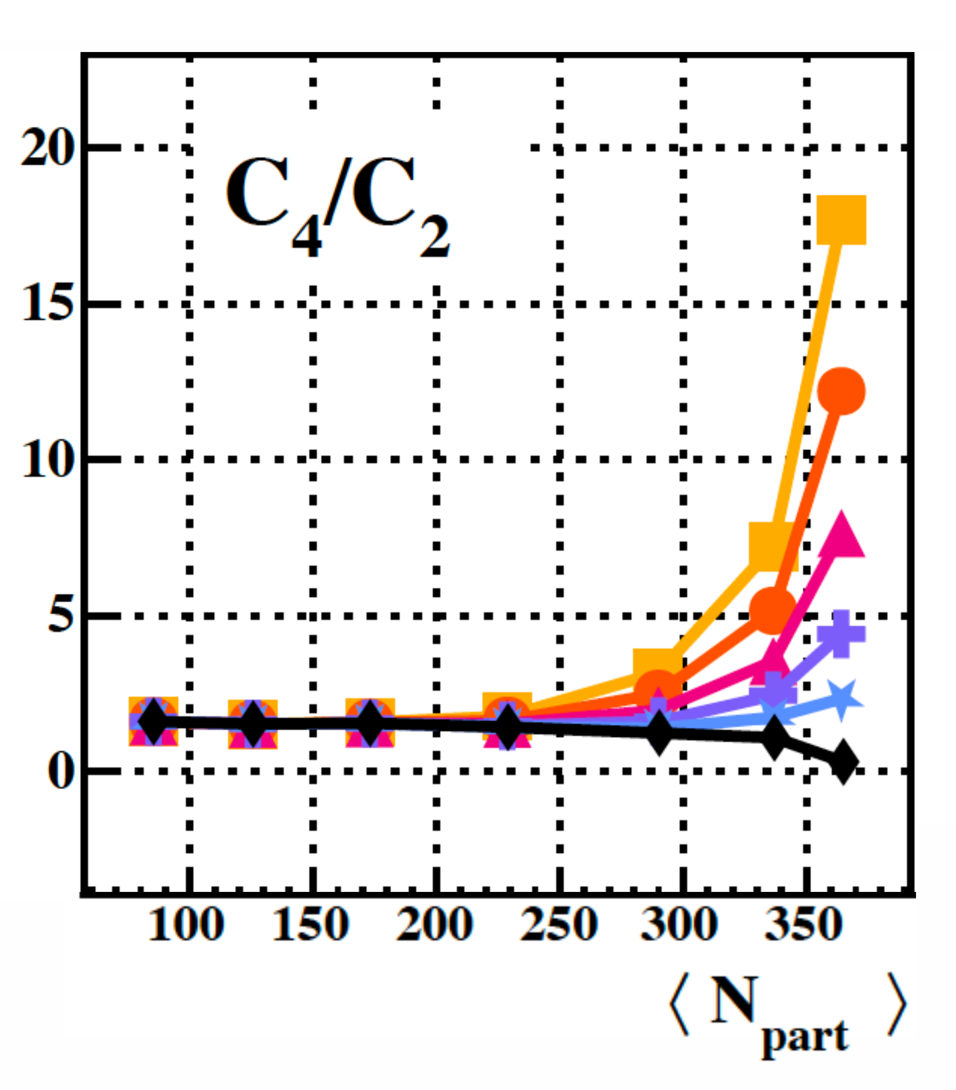
  - ✓ pileup
- These can be suppressed by maximizing similarities between proton number and multiplicity measurements



Thank you!