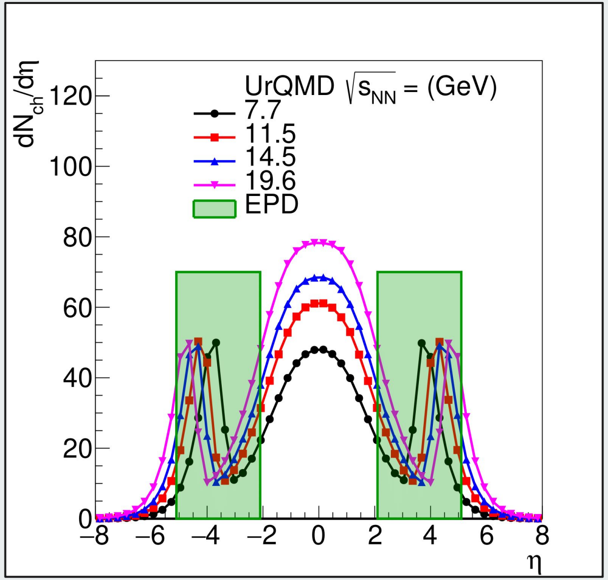
Supported in part by

Centrality determination with a forward detector in the RHIC Beam Energy Scan

DNP, 2021

Skipper Kagamaster, for the **STAR Collaboration**,
Lehigh University

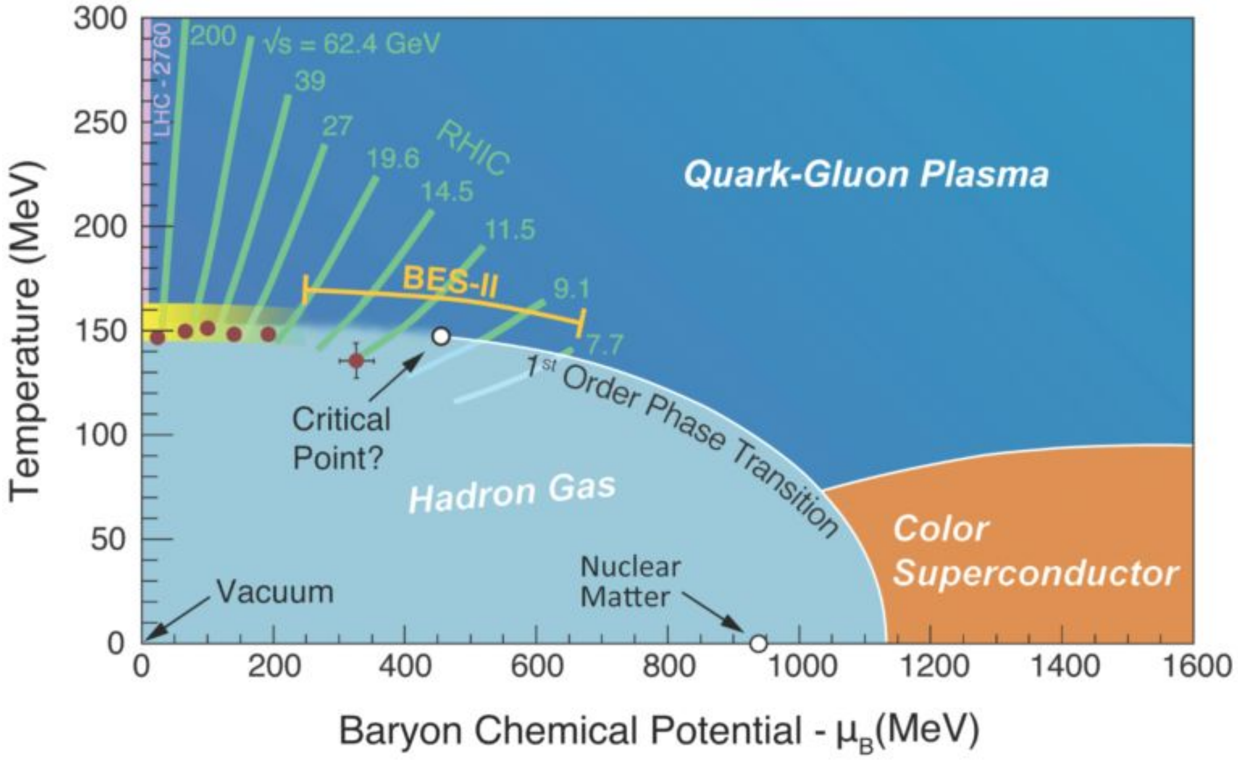


QCD Matter

The image to the right is the proposed **phase diagram** for **QCD matter**.

Higher moments of multiplicity distributions (such as **net-proton kurtosis, κ**) are current candidates for markers of the **QCD** critical point (**CP**).

NuclPhysA 2017.05.116



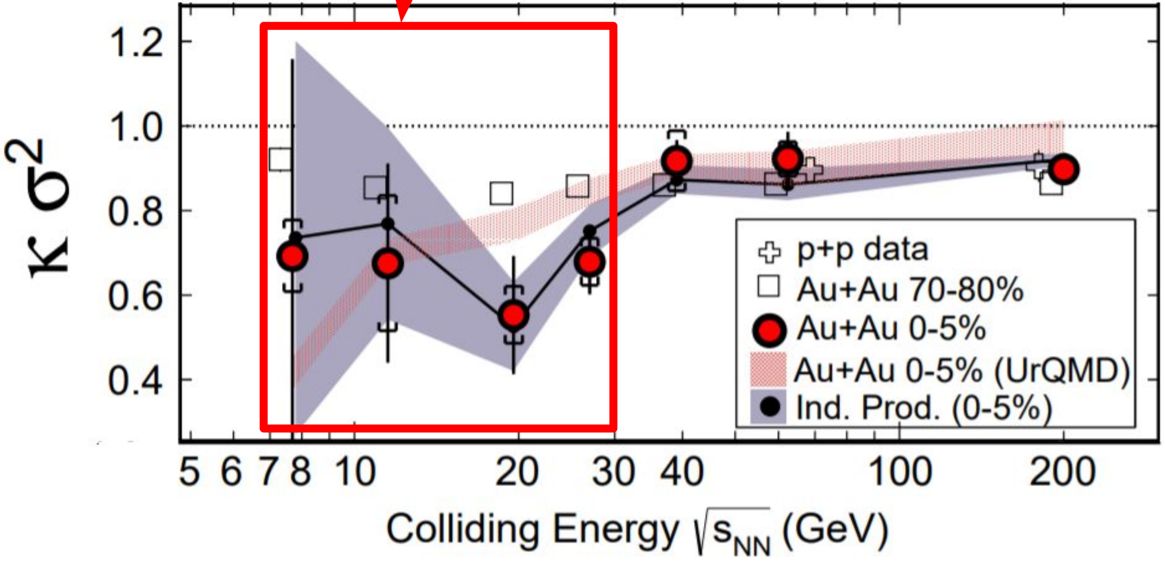
Net-Proton Kurtosis

In an **event**, **baryon number** is **conserved**. As a **proxy** for all **baryons**, we often use **net-protons** (which is **protons - antiprotons**).

UrQMD is a **simulation** with no **CP** dynamics. It is expected that **κ** behaves **monotonically** in the absence of a **CP**, thus **non-monotonic** behaviour in **κ** is a **marker** for the **QCD CP**.

STAR Beam Energy Scan (**BES**) range for **QCD critical point** search

Phys. Rev. Lett. **112**.032302

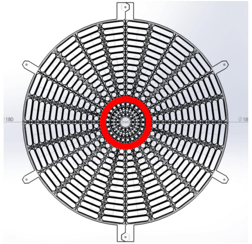


Autocorrelation Effect (ACE)

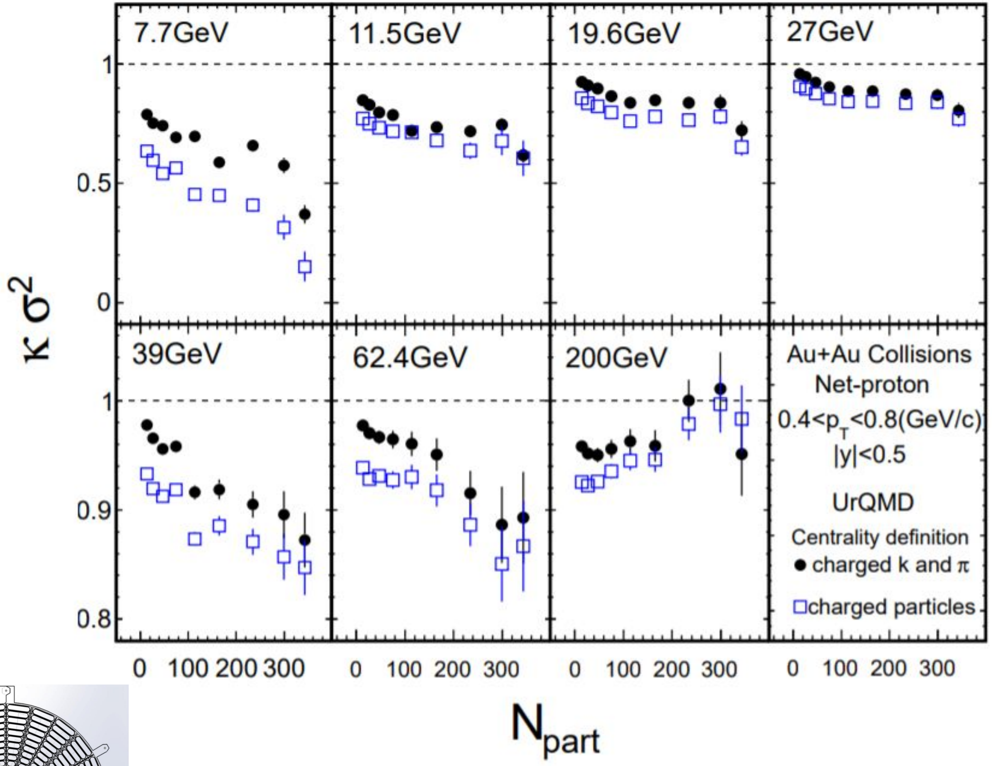
The image shows **ACE** using **UrQMD** with both **κ** and **centrality** determined at **mid-η**. (Note: **UrQMD** does not have **critical phenomenon** built in).

ACE will **suppress** cumulant **magnitudes**.

Using a forward **η** detector, such as the **STAR Event Plane Detector (EPD)**, would avoid the **ACE**.

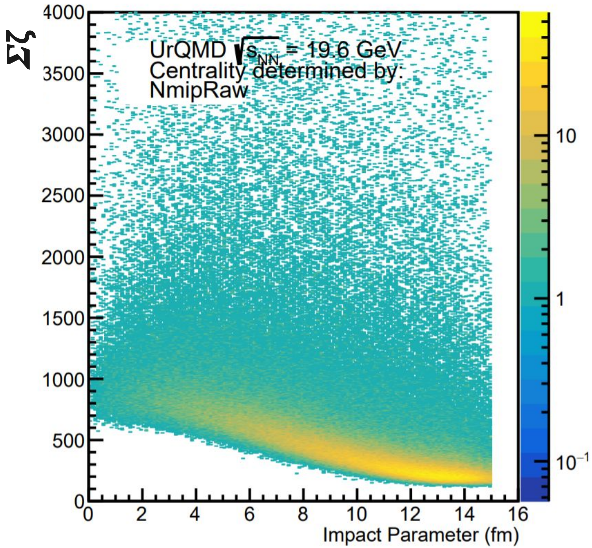


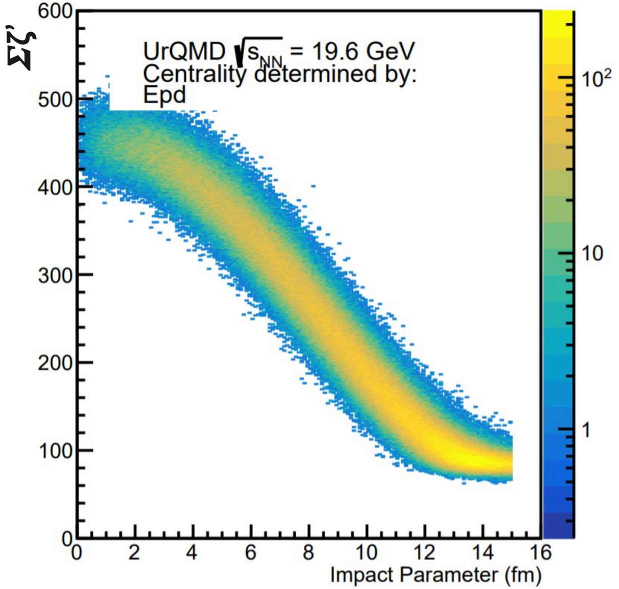
Nucl. Part. Phys. **40.**105104



Truncated nMIP

PRC103.044902





EPD measures **nMIP (ζ)**, which is subject to **Landau fluctuations** (UrQMD ζ generated via convoluted Landau distributions; see *Rachael Botsford's* talk for a more detailed discussion of ζ).

Using **truncated nMIP (ζ')**, smooths out the distribution.

$\zeta < 0.3 \rightarrow \zeta' = 0$*, $\zeta > 2.0 \rightarrow \zeta' = 2.0$

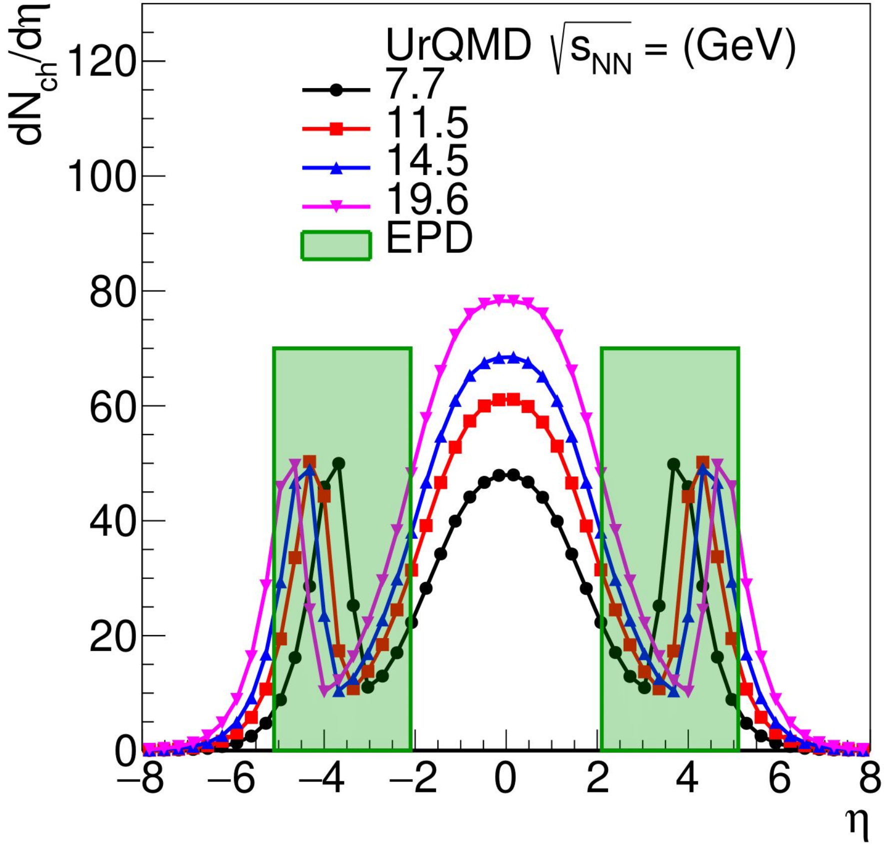
*For data; not necessary in UrQMD

Spectator Protons

PRC103.044902

Spectator protons, not seen in the η range of the **EPD** at $\sqrt{s_{NN}}$ = 200 GeV, enter the **η** range of the **EPD** at lower $\sqrt{s_{NN}}$ (such as those of **STAR BES**).

As can be seen, **spectator proton**s do not intrude into acceptances for midrapidity centrality metrics such as **STAR RefMult3** (charged ***K*** and ***π*** at |***η***| < 1).



EPD Linear Weights

ζ' is fit to a global observable G_i (**b**, in our case) via **linear weighting** (W_r) of each ring (C_r).

$$X = \sum_{r=1}^{16} W_r C_r + W_{bias}$$

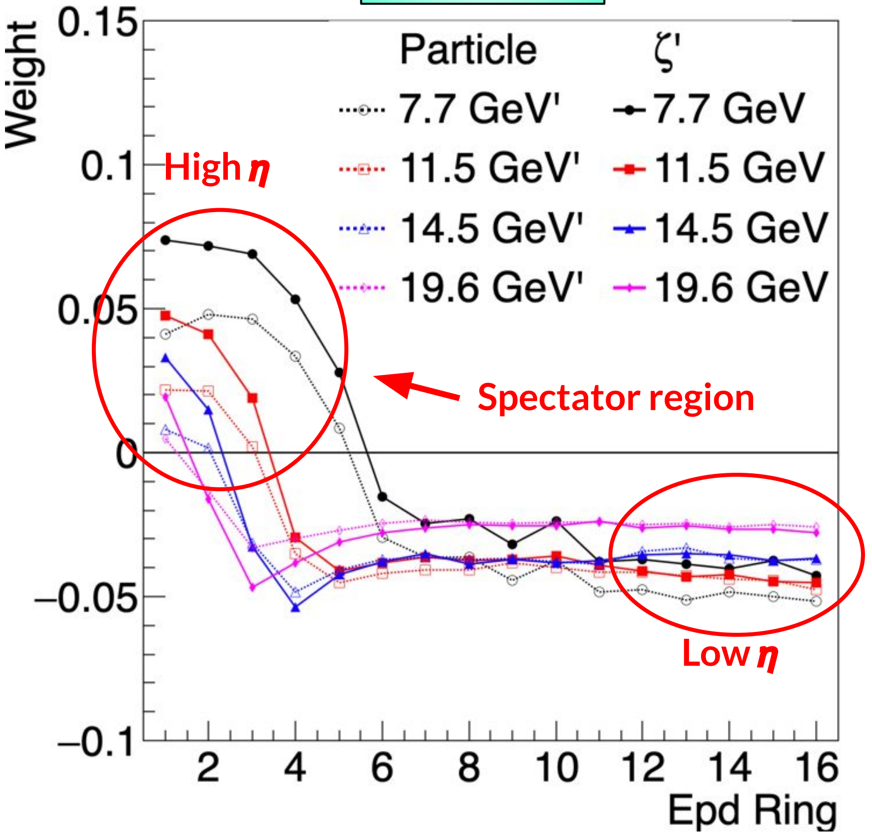
$$\chi^2 = \sum_{i=1}^{N} \left(\sum_{r=1}^{16} C_{ri} W_r + W_{bias} - G_i \right)^2$$

$$A_{q,r} W_r = B_q$$

$$A_{q,r} \equiv \sum_i^N C_{r,i} C_{q,i} \quad , \quad B_q \equiv \sum_i^N G_i C_{q,i}$$

UrQMD

PRC103.044902



Weighting Schemes for EPD Centrality

Weights for **EPD rings** are:

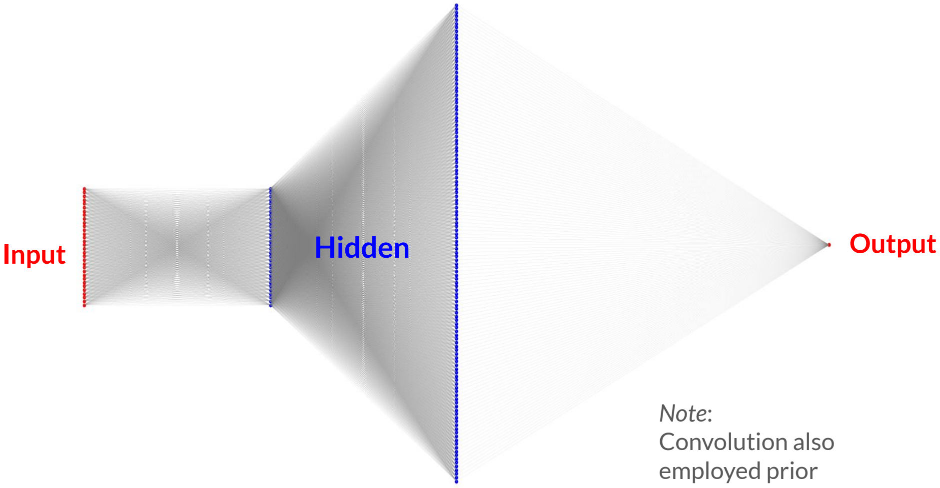
- **Cannot be determined** by theory
  - No **robust model** exists with complete **spectator/participant** physics in forward region at **BES** energies
  - **UrQMD** does not match **data** in the forward region at lower **BES** energies
- **Linear weighting** is a method, but we could use:
  - Outer **EPD** ring sums with **Glauber Monte Carlo (GMC)** fit
  - Logarithmic weights
  - Etc.

We simply need robust **variability**. Thus we are turning to **Machine Learning**.

- Very good at **varying weights**
- Can leverage ring weights **dynamically**
- Easy to **implement** and **optimise**

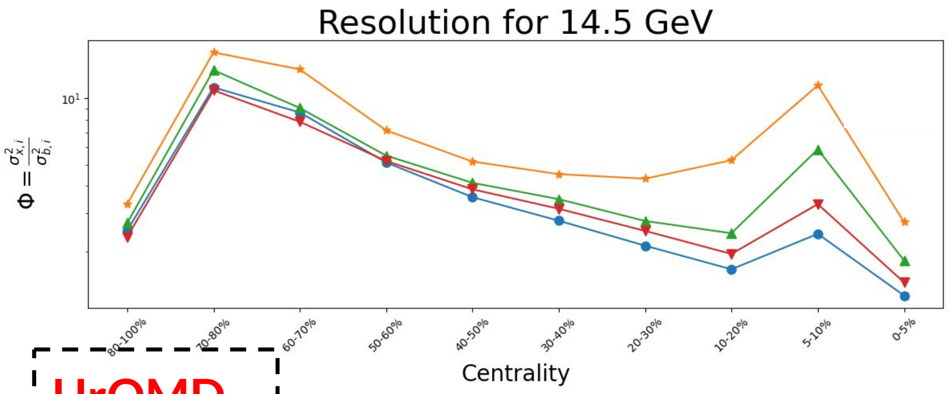
Multi-layer Perceptron Model (MLP)

- **Input** layer -> **hidden** layers -> **output** layer
- Each layer hands off its data to every **perceptron** (neuron) in the next layer
- Layers add **weights** and **biases**
- 32 inputs (rings) -> **32** perceptrons -> **128** perceptrons -> **1** output

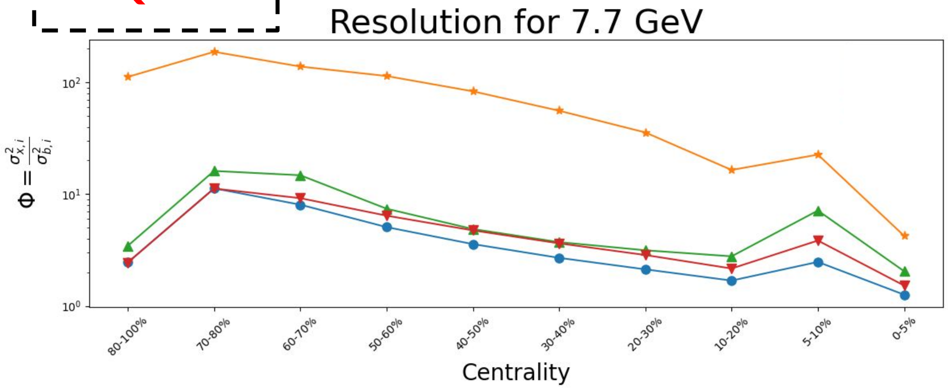


Note:
Convolution also employed prior to first hidden layer.

Centrality Resolution in Lower BES Energy



UrQMD



X trained on global observable: b

Resolution is determined by dividing the **variance of the b distribution** from a **centrality metric X** in a certain **bin i** by the **variance of the b distribution** in the same bin as determined by b itself.

- RefMult3
- EPD Sum
- EPD Lin Weight
- EPD ML

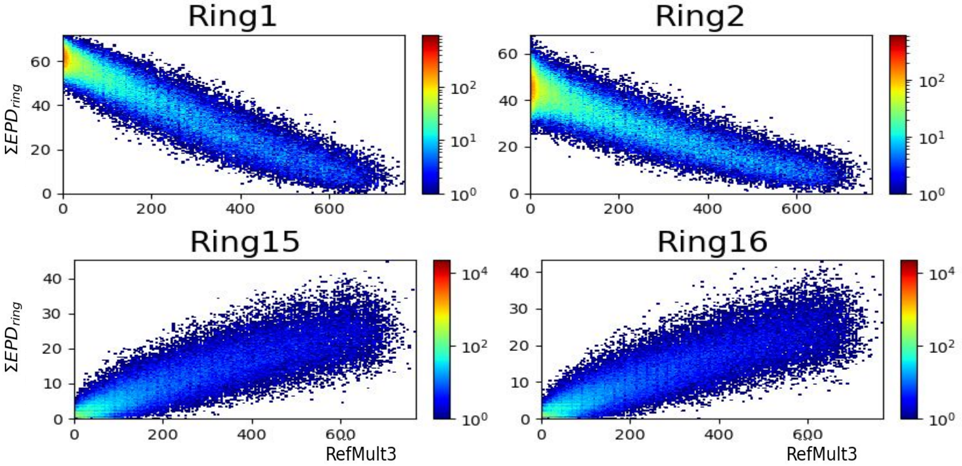
$$\Phi = \frac{\sigma^2_{X,i}}{\sigma^2_{b,i}}$$

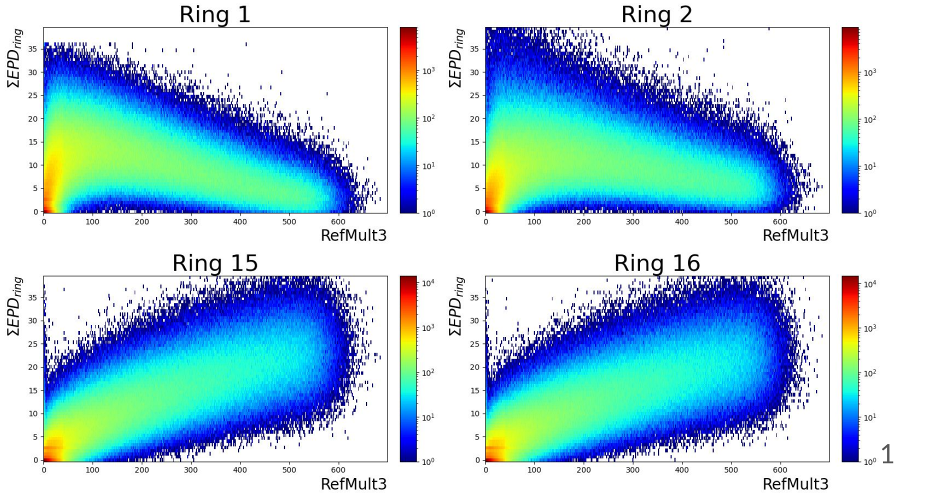
Kagamaster

STAR Data

UrQMD
$\sqrt{s_{NN}}$=14.5 GeV

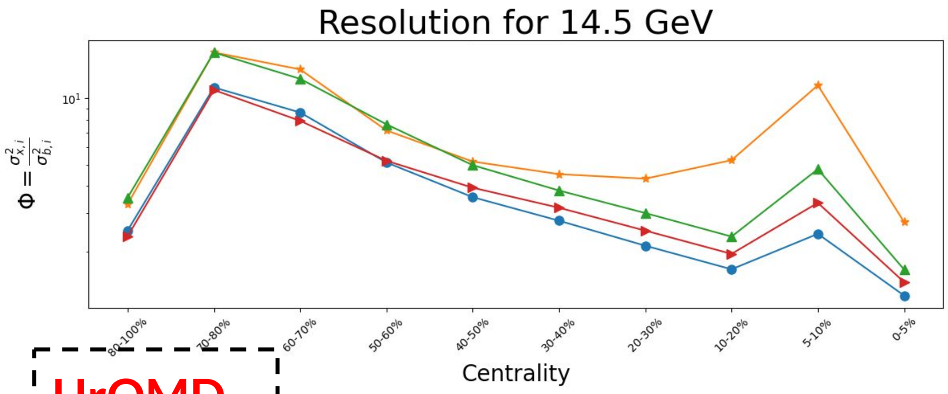
- No access to b in data
  - Another **global observable** must be used
  - **RefMult3** selected as **global observable**
    - Charged particles (less protons/antiprotons) in range $|\eta|<=1.0$
- **Spectator protons** affect correlations; data mirrors **UrQMD**, but not exactly.
  - **UrQMD** has no **critical phenomenon**
  - The model used was a **non GEANT** model (not all factors simulated)
  - An **exact correlation** between **simulation** and **data** should **not** be **expected**



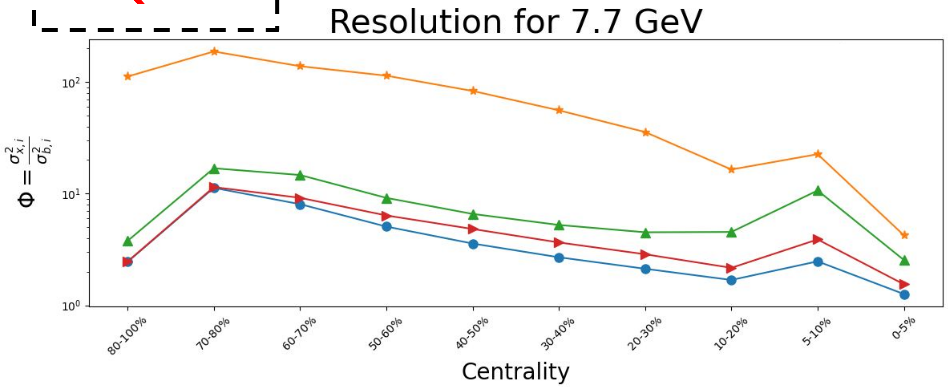


☆STAR☆
$\sqrt{s_{NN}}$ = 14.5 GeV

Centrality Resolution in Lower BES Energy



UrQMD



X trained on global observable: RefMult3

Resolution is determined by dividing the **variance of the b distribution** from a **centrality metric X** in a certain **bin i** by the **variance of the b distribution** in the same bin as determined by b itself.

$$\Phi = \frac{\sigma^2_{X,i}}{\sigma^2_{b,i}}$$

Summary

- A **simple sum** of the particles in the **EPD acceptance** range at **low energies** nets a **poor centrality resolution** due to the **spectator protons**.
- This **resolution**, however, can be **recovered** by a nuanced, **differential analysis**.
- Study is **ongoing** performing **EPD ring scaling** on **STAR** data. Possible methods:

Use outer EPD and map to GMC

Pro:

- **Well tested** methodology

Con:

- Loss of resolution from using **~½ of the detector**

Map EPD to RefMult3

Pro:

- RefMult3 is robust and well understood

Con:

- Further removed from **b** (**EPD -> RefMult3 -> b**)
- High level mapping may **reintroduce ACE**

*Open to new ideas for a **self-referential centrality** from **EPD**:*

- Unsupervised clustering or ... ?

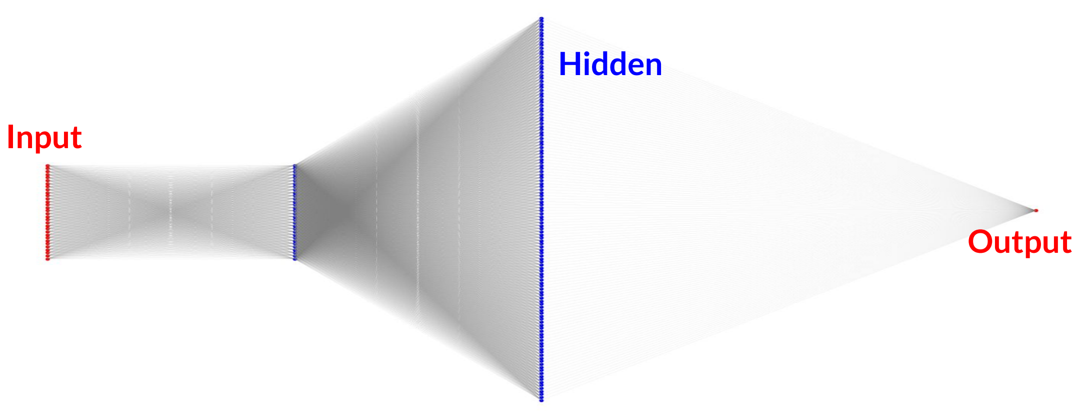
Special Thanks

National Science Foundation grant 1945296.

Department of Energy grant DE-SC0020651.

The Lee Fellowship.

Thank you for your attention!
Questions?



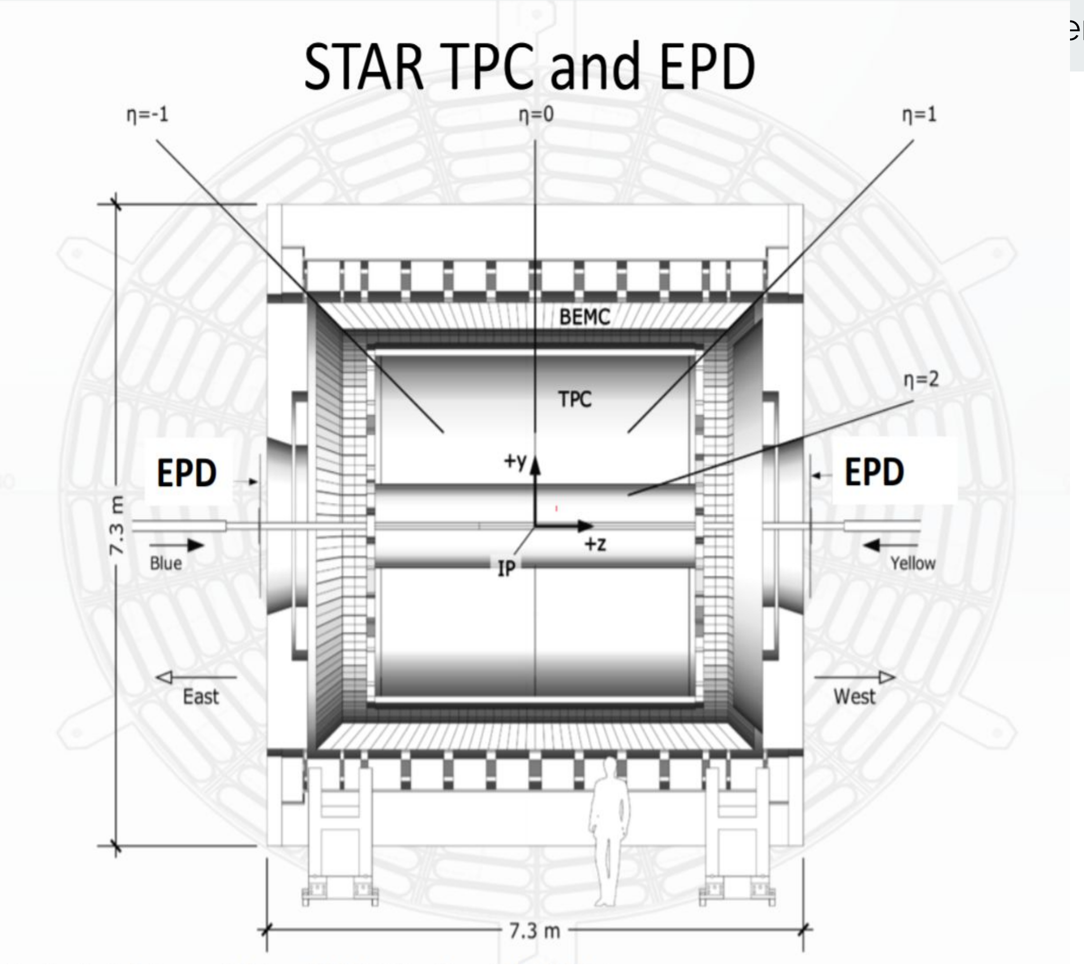
Backup Slides

Pseudorapidity (η)

In the **STAR** detector, the **Time Projection Chamber** (**TPC**) is at **$|\eta| \leq 1$** and the **Event Plane Detector** (**EPD**) is at **$2.1 \leq |\eta| \leq 5.1$**.

TPC range will be called **mid-rapidity** and **EPD** range **forward rapidity**.

$$\eta = -\ln\left(\tan\frac{\theta}{2}\right)$$



Annika Ewigleben, APS Meeting, April 2017

EPD: Charged Particles

The **EPD** is a forward detector made of **scintillator** with tiles of **wavelength shifting fibers** which capture emitted **photons** from **charged particles**.

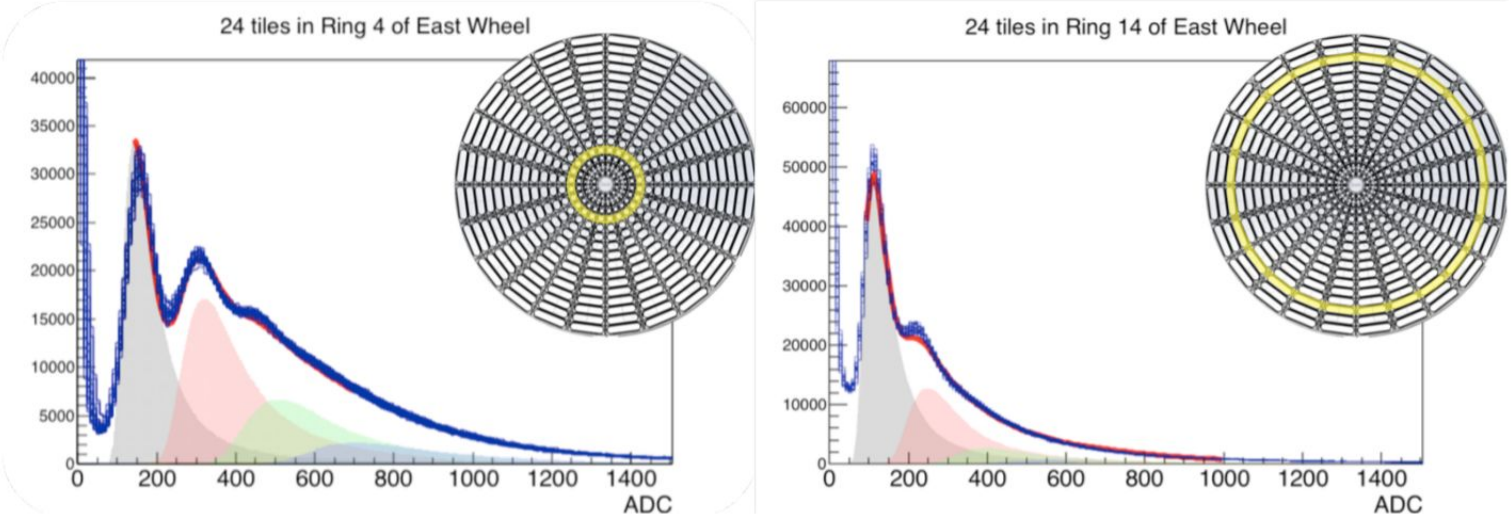
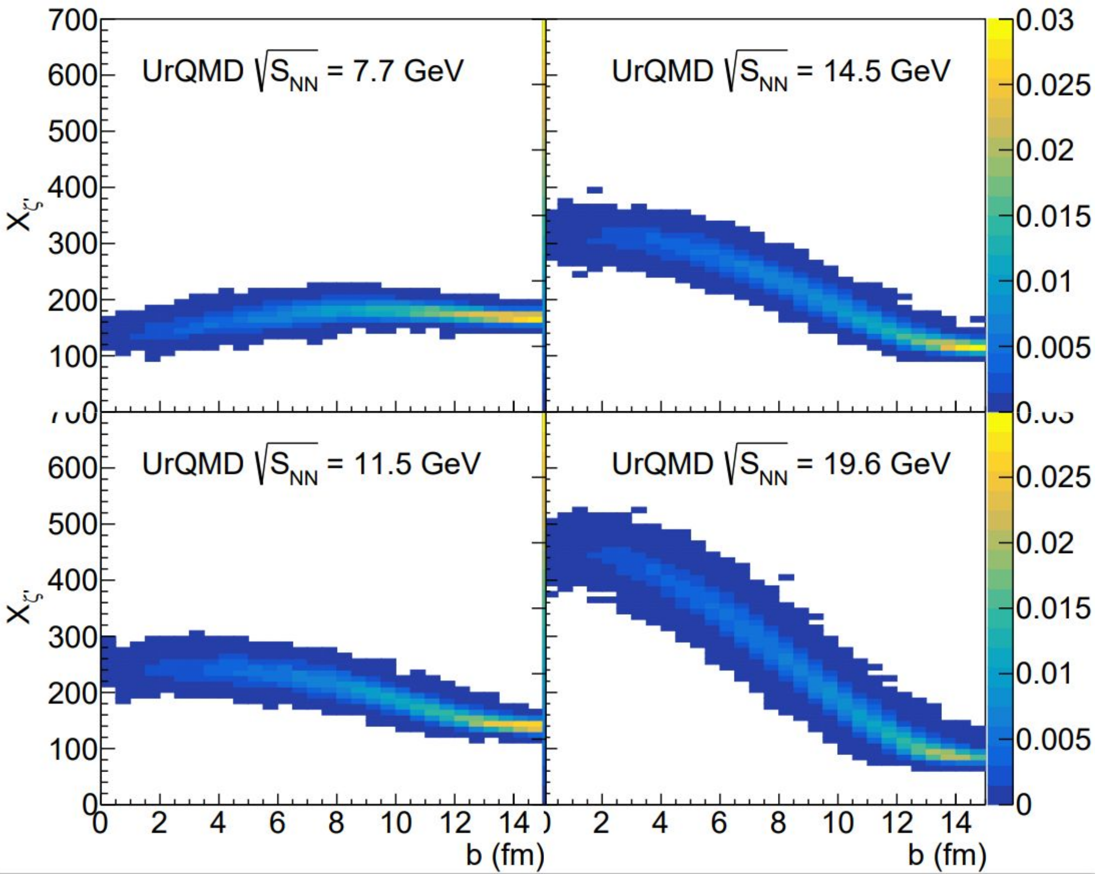


Image: J. Adams, A. Ewigleben, S. Garrett, W. He, T. Huang, P. M. Jacobs, X. Ju, M. A. Lisa, M. Lomnitz, R. Pak, et al., “The star event plane detector,” Nuclear Instru-ments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, (2020)

Findings

We can see $X_{\zeta'}$ has a **flat correlation** with **b** in **7.7** and **11.5 GeV.**

14.5 and **19.6 GeV** are a little better, but a **simple sum** is clearly a **poor metric** given the **spectator protons**.



Linear Weights

$X_{\zeta' LW}$ must be changed for **data** as there is no access to **b**.

- **Data** is **14.5 GeV STAR** data
  - ~1400 runs
  - ~5M events
- Global observable: **RefMult3**
- **Weights** are necessary because of **spectators**
- Any **global observable** is admissible (not just **b** or **RefMult3**)

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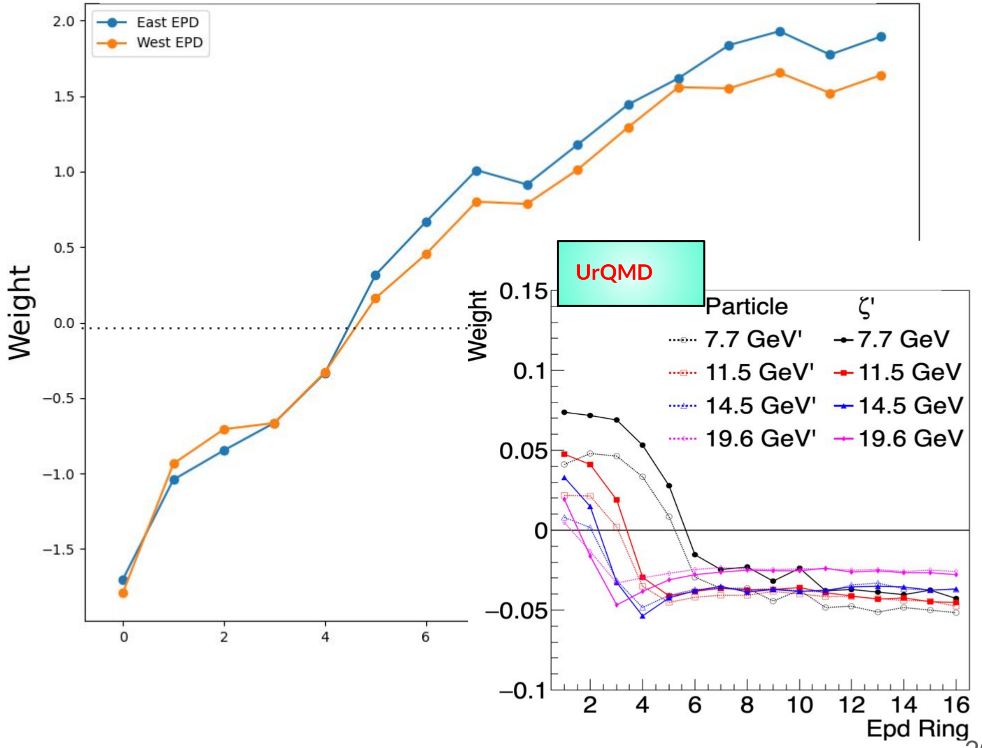
$\sqrt{s_{NN}}$ = 14.5 GeV

EPD Ring Weights



Activation Functions

Rectified Linear Unit (ReLU)

$$f(x) = \begin{cases} x, & x \geq 0 \\ 0, & x < 0 \end{cases}$$

Swish

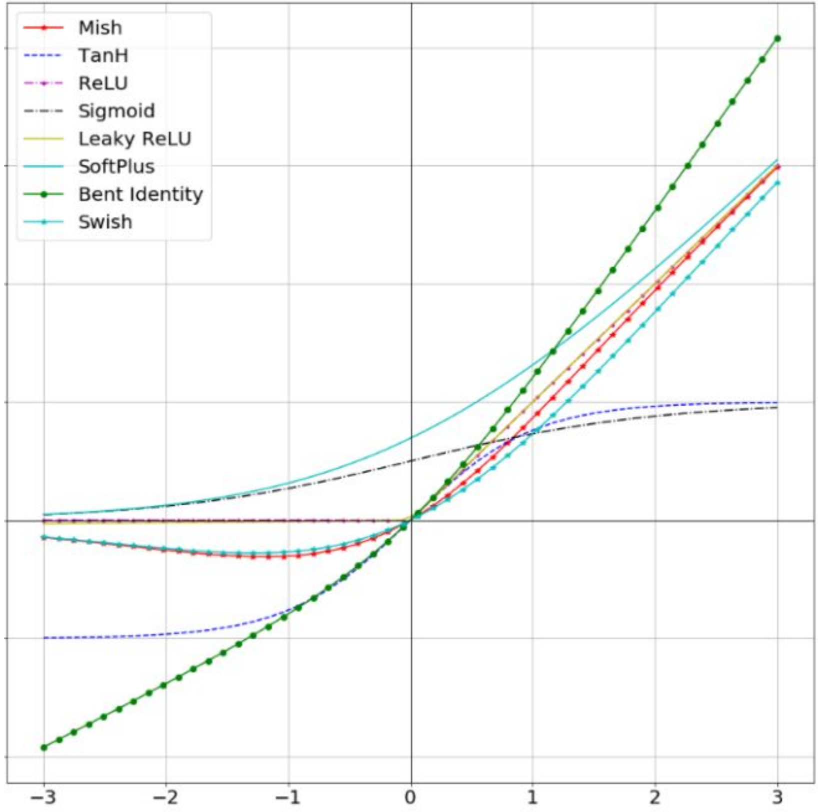
$$f(x) = x \cdot \sigma(x)$$

$$\sigma(x) = \left(1 + e^{-x}\right)^{-1}$$

Mish

$$f(x) = x \cdot tanh(\zeta(x))$$

$$\zeta(x) = log(1 + e^{x})$$



https://arxiv.org/vc/arxiv/papers/1908/1908.08681v1.pdf

Correlation with RefMult3

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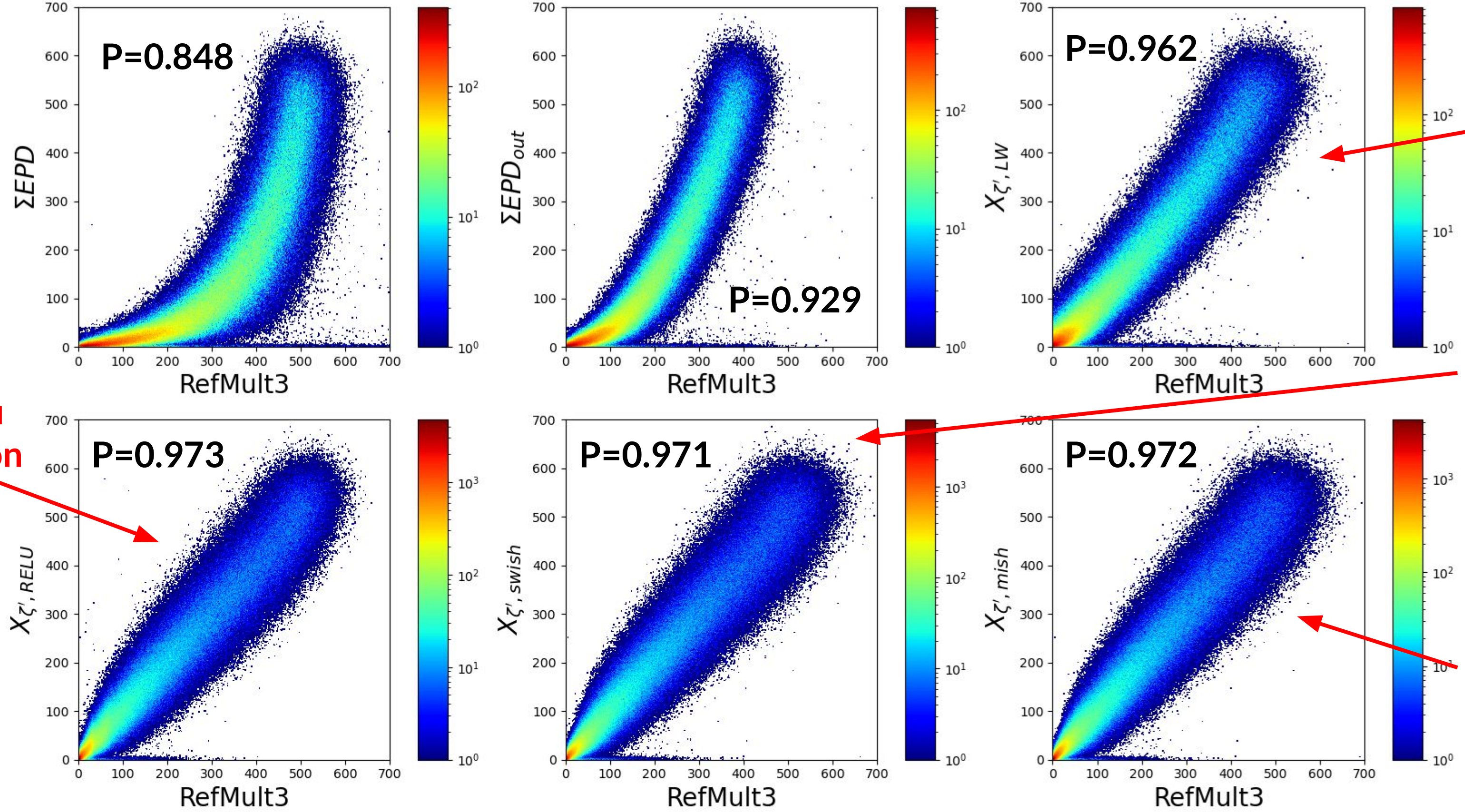
$\sqrt{s_{NN}}$ = 14.5 GeV



Linear Weight Method

ML, Swish Activation

ML, ReLu Activation

ML, Mish Activation

Distributions