Centrality determination with the Event Plane Detector for fluctuation measurements from STAR

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STAR ☆

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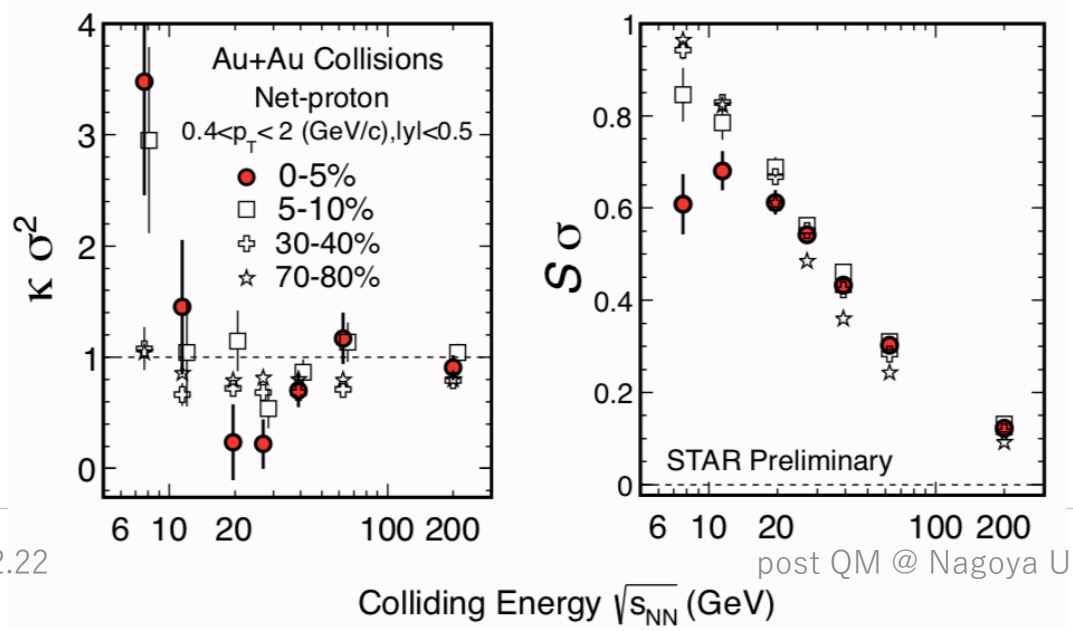
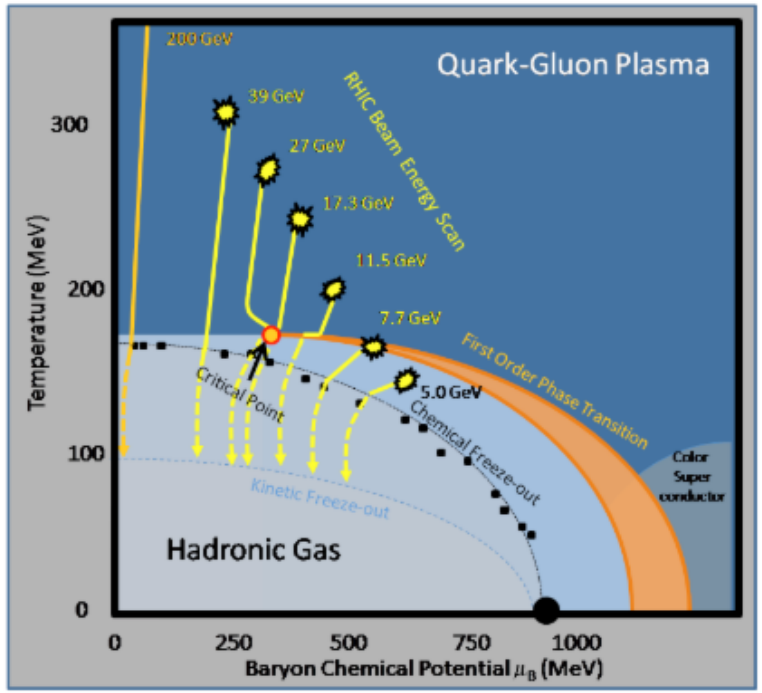
Physics Motivation

- ✓ Lattice QCD calculation has predicted that phase transition around μ_B=0 is "**smooth crossover**".
- ✓ We search for the 1st-order phase transition and the **critical point**.
- ✓ Fluctuations of conserved quantities are considered to be a powerful tool to search for the critical point.

Beam Energy Scan@STAR (~2014, 7.7-200 GeV)

Non-monotonic behavior of net-p $\kappa\sigma^2$ at low energy appeared, which could be a signature of the critical point.





Y.Aoki et al., Nature, 443, 675 (2006)
X.Luo,PoS(CPOD2014)019

Beam Energy Scan II (BES-II)

Beam Energy Scan II (2019~)

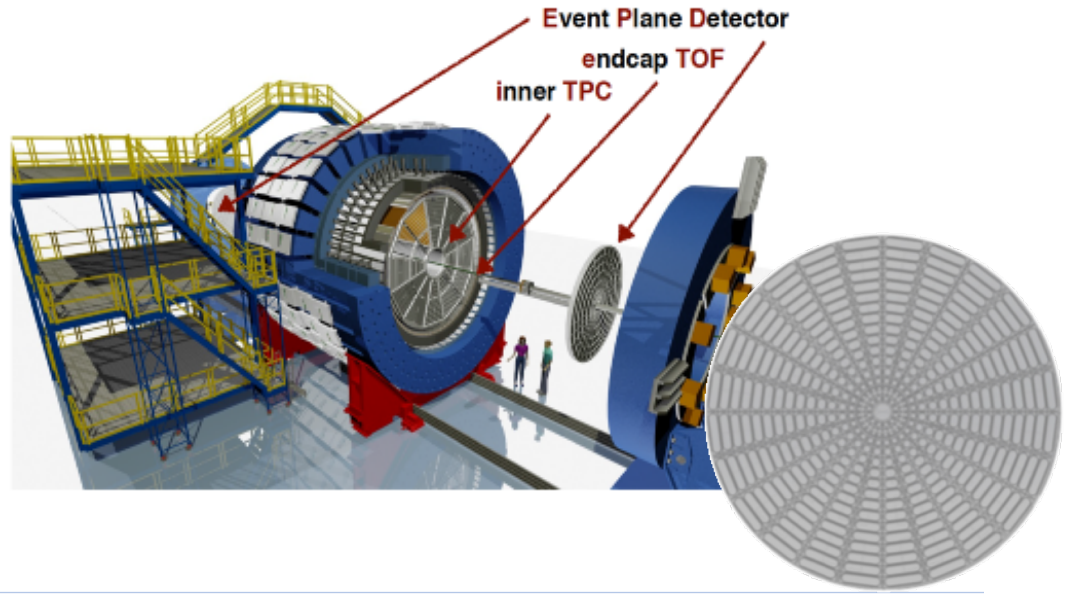
- Lower collision energies (< 20 GeV)
- New detectors (**EPD**, eTOF, iTPC)
- 10-20 times larger statistics than BES-I

Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Run Time	Number Events
9.8	19.6	205	4.5 weeks	400M
7.3	14.5	260	5.5 weeks	300M
5.75	11.5	315	5 weeks	230M
4.55	9.1	370	9.5 weeks	160M
3.85	7.7	420	12 weeks	100M
31.2	7.7 (FXT)	420	2 days	100M
19.5	6.2 (FXT)	487	2 days	100M
13.5	5.2 (FXT)	541	2 days	100M
9.8	4.5 (FXT)	589	2 days	100M
7.3	3.9 (FXT)	633	2 days	100M
5.75	3.5 (FXT)	666	2 days	100M
4.55	3.2 (FXT)	699	2 days	100M
3.85	3.0 (FXT)	721	2 days	100M

Run 19 Run 20 Run 21

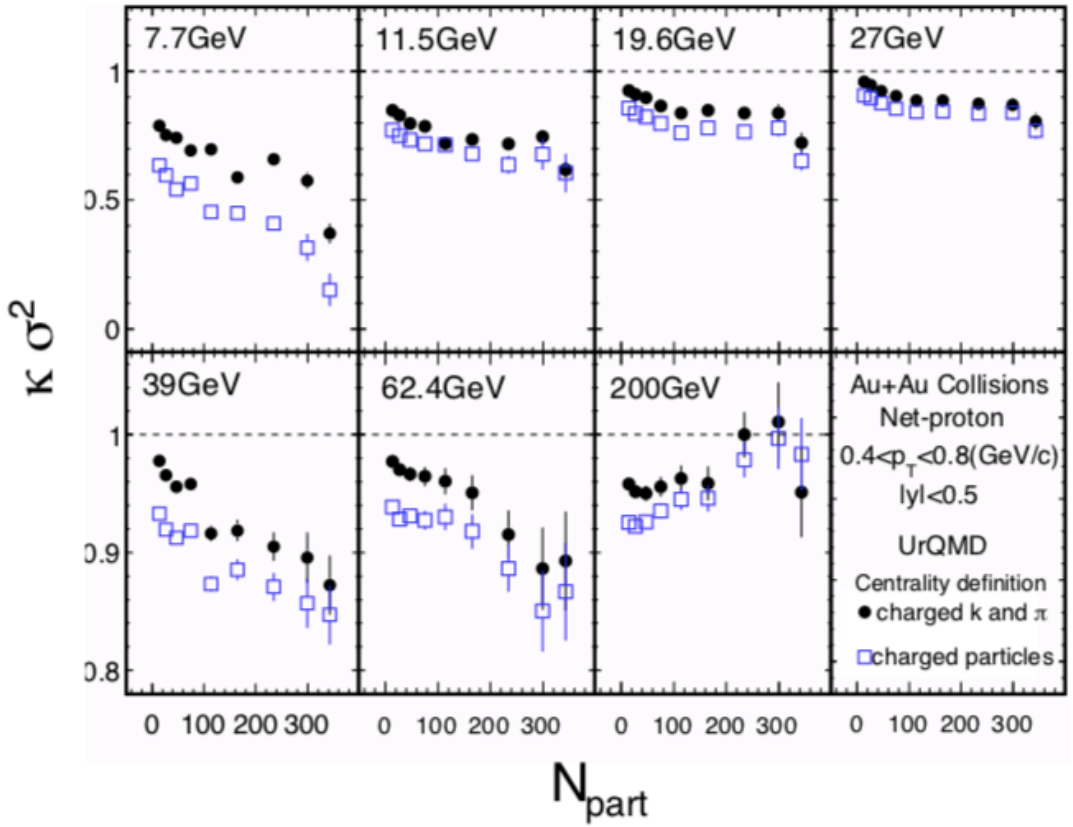
Event Plane Detector (EPD)

- ✓ A new scintillation detector installed in $2.1 < |\eta| < 5.1$
- ✓ Consist of 16 rings x 24 segments in East and West side each
- ✓ Expected to be a centrality detector with less **autocorrelation effect**



Autocorrelation Effect

- ✓ UrQMD studies show autocorrelation effect makes fluctuations smaller.
- ✓ Current centrality determination is based on multiplicity at mid-rapidity, excluding particles of interest.
  - ➢ Current centrality determination maybe biased by the autocorrelation.
- ☐ Important to determine the centrality by reducing autocorrelation effect for fluctuation measurements.



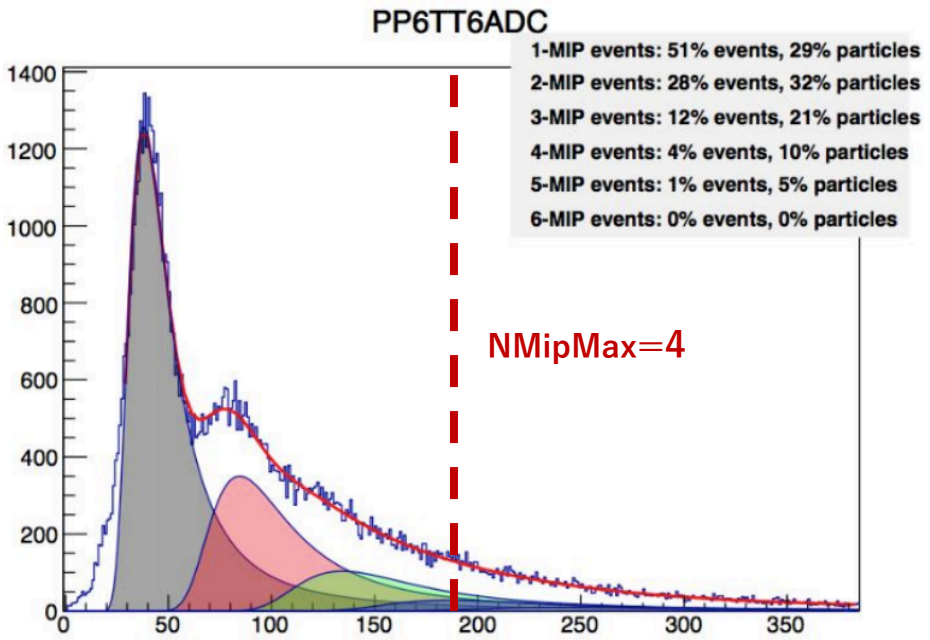
X.Luo et al. , J. Phys. G: Nucl. Part. Phys. 40 105104 (2013)
T.Sugiura et al., arXiv:1903.02314(2019)
A. Chatterjee et al., arXiv:1910.08004

Performance of the EPD

Landau Fluctuation

- ✓ The EPD measures NMip, gain calibrated energy loss in tile, in units of Landau MPV for one MIP.
- ✓ Considered large NMip (>NMipMax) is due to Landau fluctuation effect, and assume the NMip of the tile is NMipMax.

  ⇒ NMipMax=4 : If (NMip>4) NMip=4



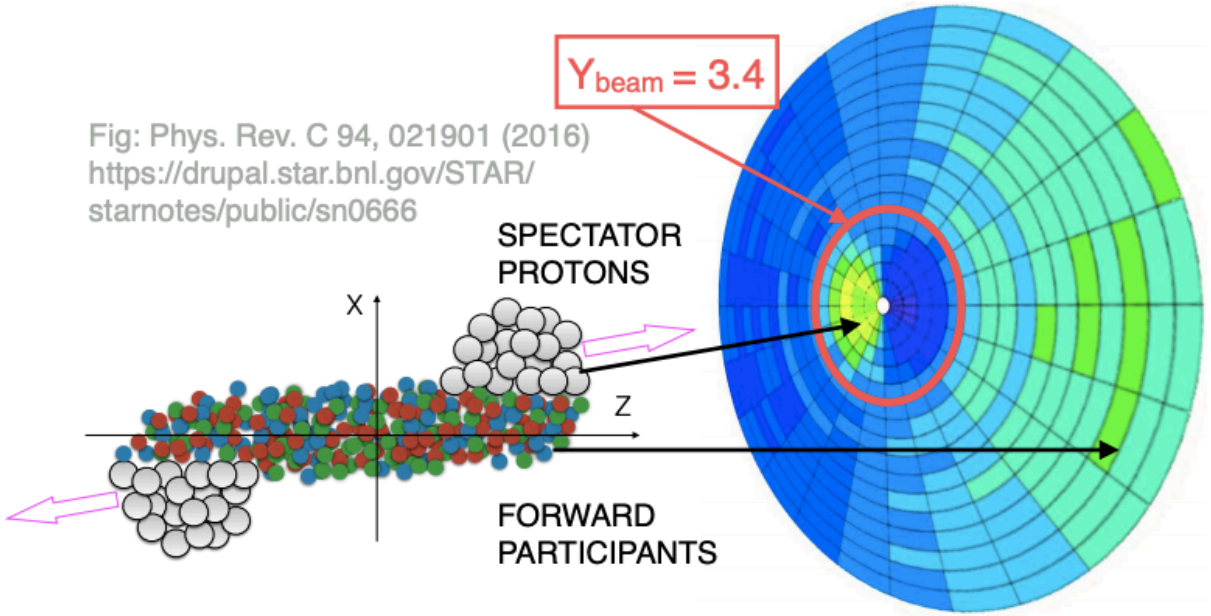


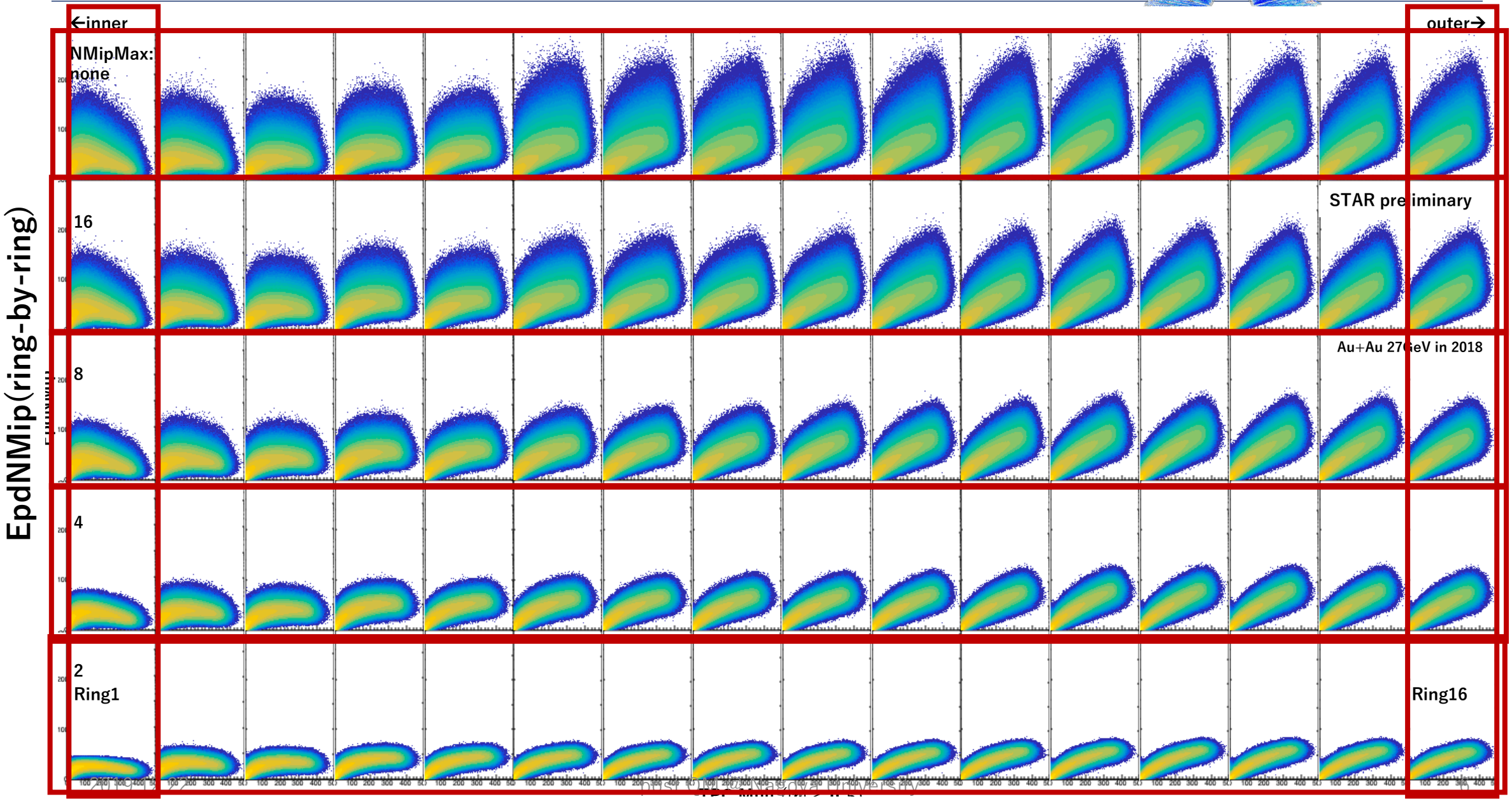
Fig: Phys. Rev. C 94, 021901 (2016)
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0666

From Prithwish's talk

Spectators in the EPD

- ✓ In lower energy collisions, also spectators are measured in the EPD region.
- ✓ Number of spectators increases in peripheral collisions.

EPD-TPC Correlations in Au+Au 27 GeV



Centrality Determination by the EPD

- ✓ Positive correlation between EPD and TPC in outer rings
- ✓ Anticorrelation in inner rings (spectator-participant correlation)
- ✓ **Summing up all rings will make the centrality resolution worse.**
- ✓ Construct a cleaner correlation between EPD and TPC

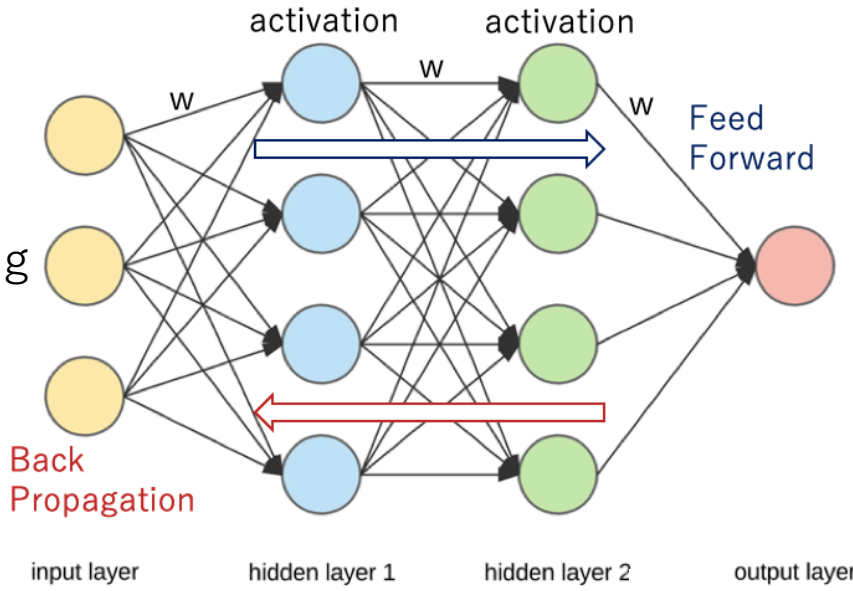
⇨
- ☐ **Using only outer rings of the EPD**
- ☐ **Neural Network approach to recover the linearity**

☐ **Need to search for the best way to use the EPD as a centrality detector!**

Neural Network (N.N.) Approach

Artificial Neural Network is a method of Machine Learning, inspired by biological neural network. It "learns" by updating weights and biases between each neuron.

Epd NMip in each ring

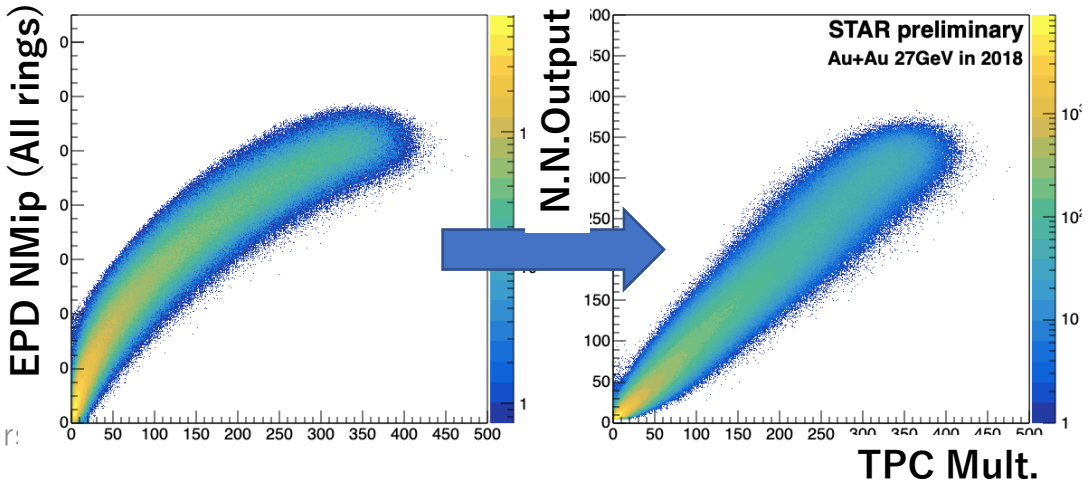


TPC Multiplicity
(previous centrality)

→ (left) non-linear correlation between EPD and TPC because of spectators in inner rings

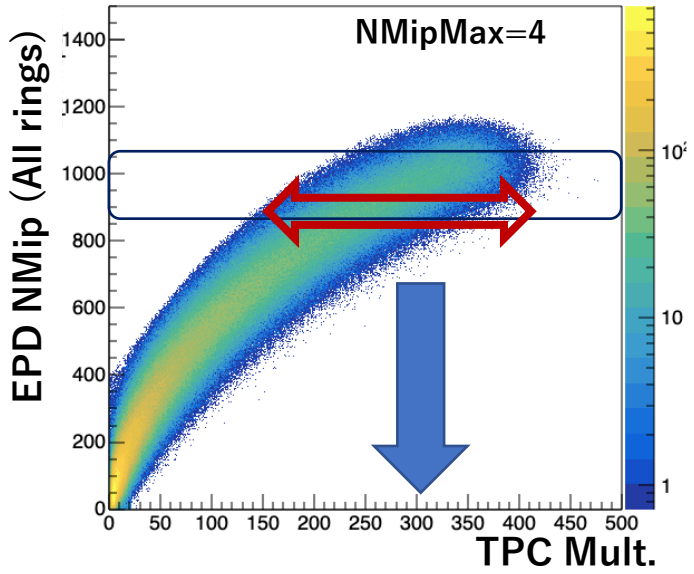
→ (right) linear correlation between N.N. output and TPC multiplicity

➢ **Centrality Resolution can be improved!**



Centrality Resolution of the EPD

- ✓Impact parameter b cannot be measured experimentally.
- ✓Seeing relative width of correlations, centrality resolution by the EPD can be compared.

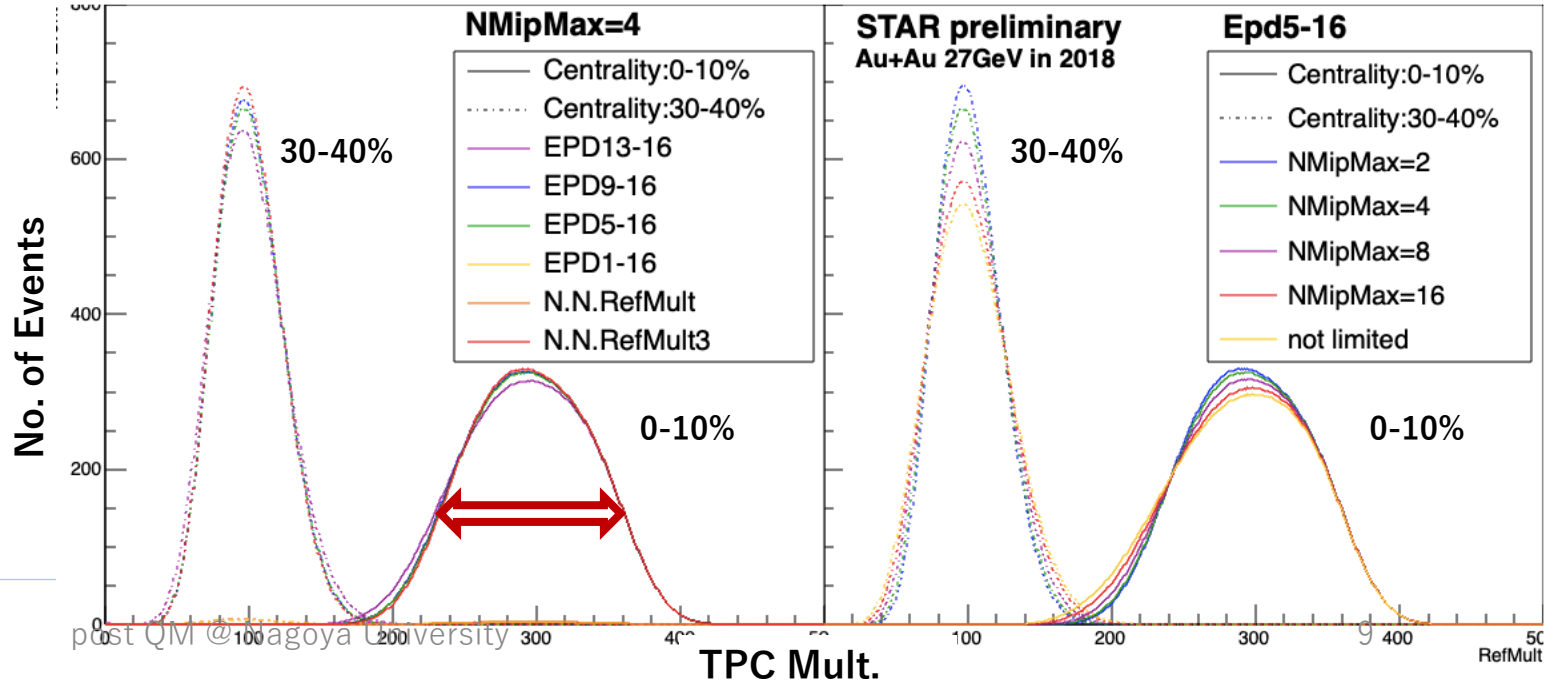


* RefMult : multiplicity in $|\eta|<0.5$, measured by TPC.

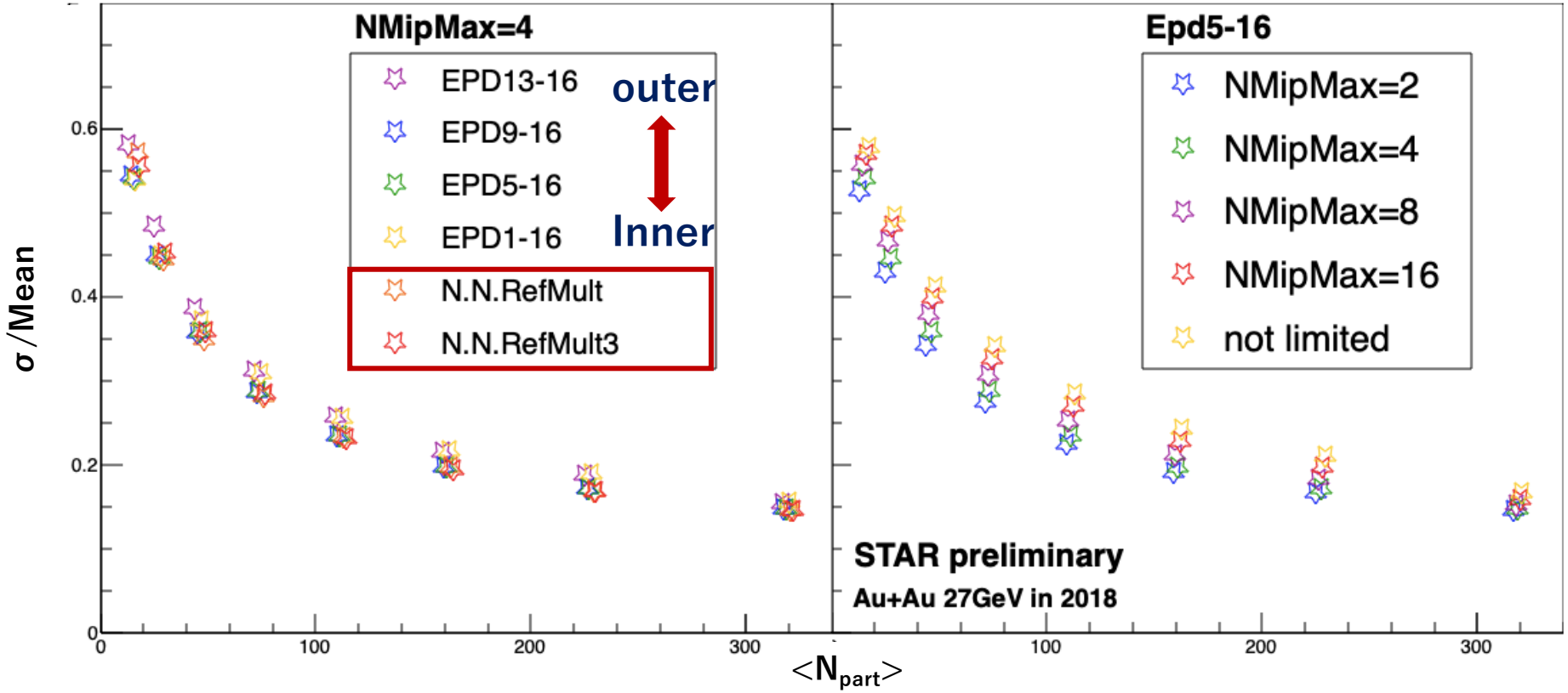
* RefMult3 : multiplicity in $|\eta|<1.0$, measured by TPC, excluding protons

* N.N.RefMult/RefMult3 : Output of N.N. trained to return RefMult/RefMult3

→ TPC Mult. distributions in a centrality class determined by the EPD



Centrality Resolution of the EPD



- ✓"EPD9-16" (outer 8 rings) and "EPD5-16" (outer 12 rings) have better resolution than "EPD13-16" (outer 4 rings).
- ✓"N.N.RefMult" and "N.N.RefMult3" have the best centrality resolution. We can use information by the EPD all rings weighted automatically.
- ✓"NMipMax=2" has the best centrality resolution compared to larger NMip upper limit, because of reduced Landau fluctuation.

Perspective for Fluctuation Measurements

✓ Ways to determine collision centrality with the EPD are discussed.

☐ Need to know how fluctuation results change by ways for centrality selection.

☐ Need to keep in mind that below 2 affect the same direction:
- Worse centrality resolution makes fluctuations larger.
- Less autocorrelation makes fluctuations larger.

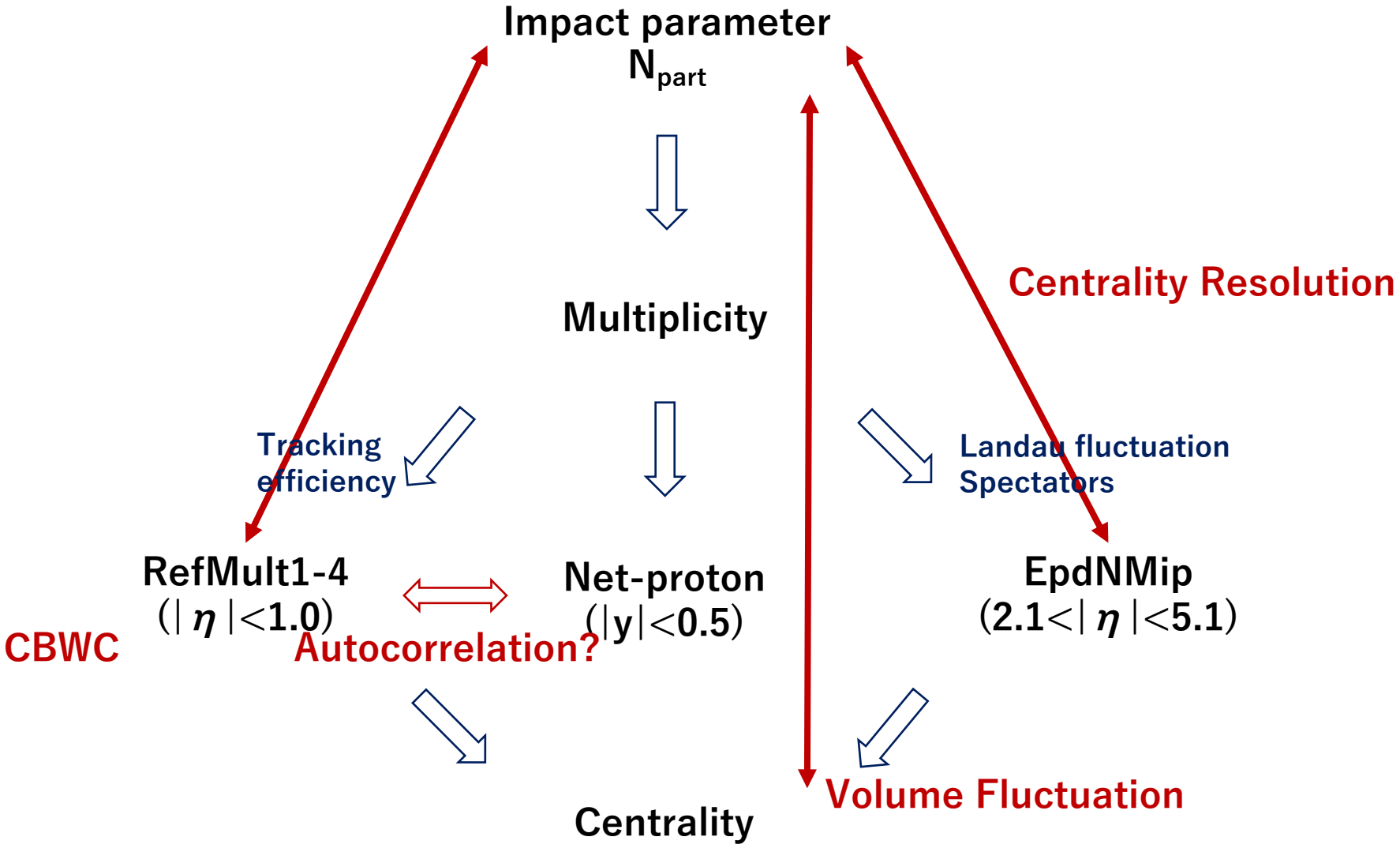
☐ **Autocorrelation of the previous centrality determination really effects on fluctuations?**

References

- X. Luo, PoS (CPOD2014) 019
- Y. Aoki et al., Nature, 443, 675 (2006)
- X. Luo et al., J. Phys. G: Nucl. Part. Phys. 40 105104 (2013)
- T. Sugiura et al., Phys. Rev. C 100, 044904(2019)

Back up

Volume Fluctuation and Autocorrelation

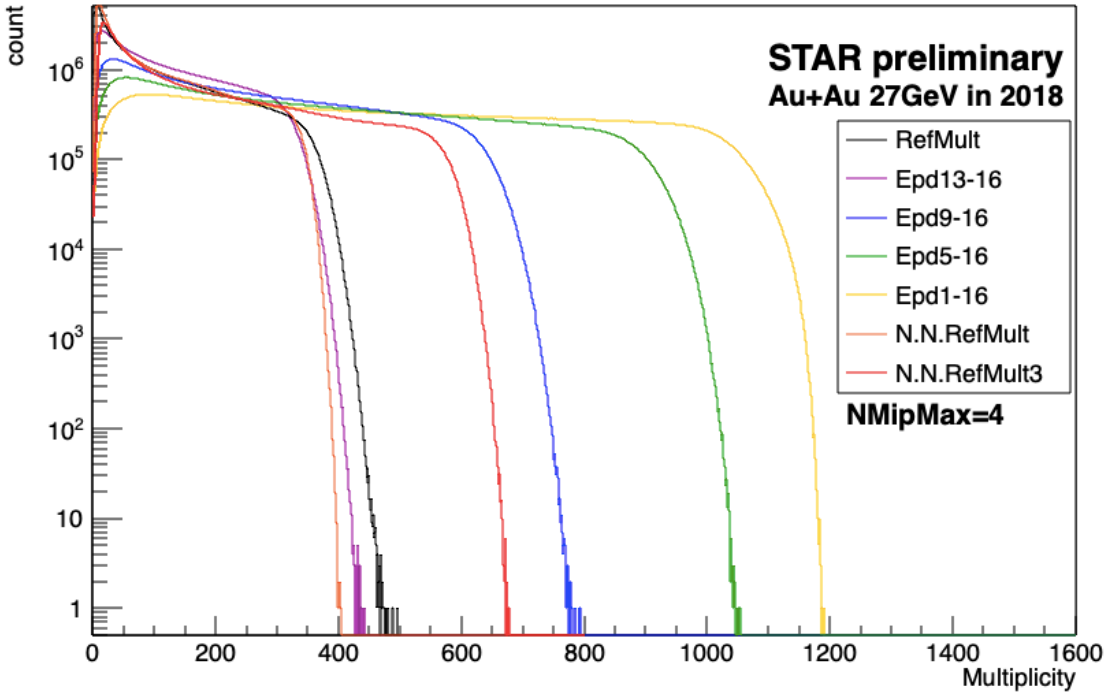


Multiplicity/NMip Distributions

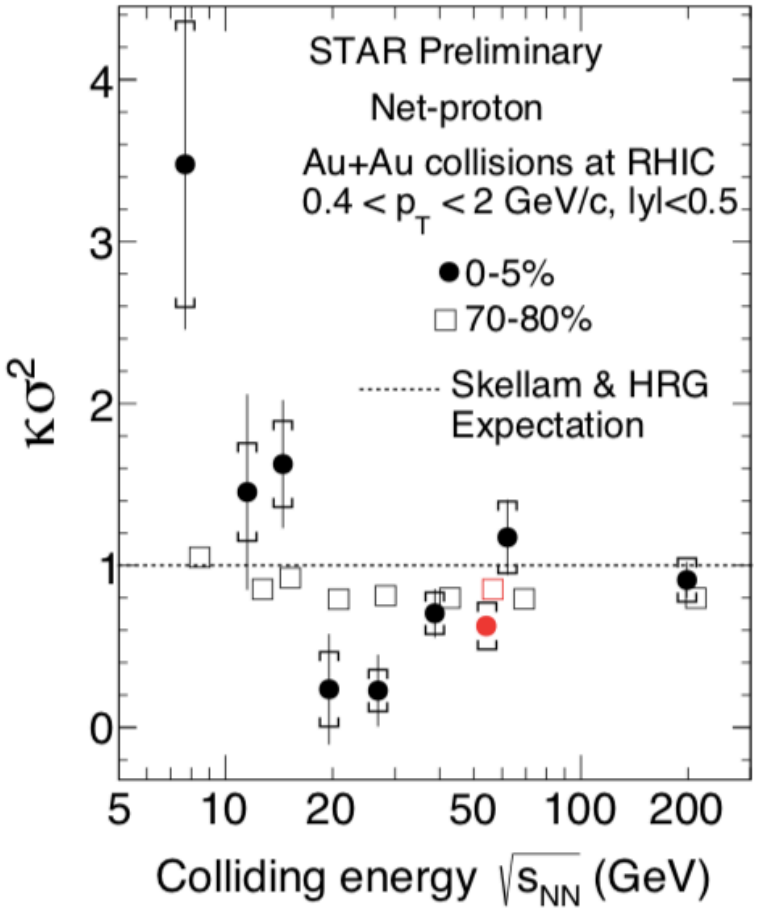
- ✓ NMip distributions measured by the EPD have different shape compared to multiplicity by the TPC due to spectators and Landau fluctuations.

- ✓ Centrality can be determined for each class to have the same number of events based on these distributions.

- ☐ **Need to investigate a model including spectators and Landau fluctuations effects for the EPD centrality ??**



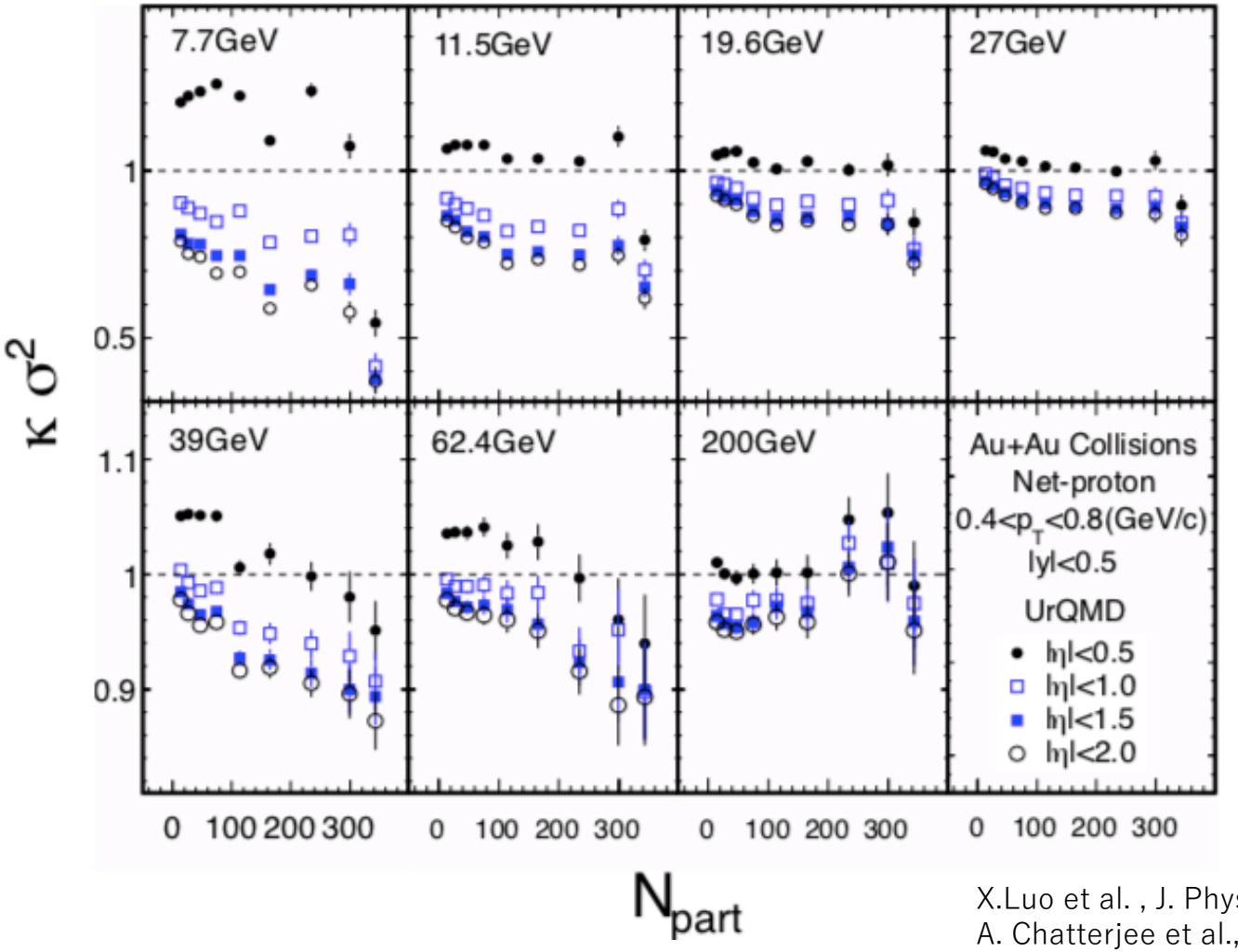
Energy Dependence of $\kappa\sigma^2$



- C_4/C_2 values at 54.4 GeV follows the energy dependence observed in other energies.

Centrality Resolution Effect

- Worse centrality resolution makes fluctuations larger.



X.Luo et al. , J. Phys. G: Nucl. Part. Phys. 40 105104 (2013)
A. Chatterjee et al., arXiv:1910.08004