FLUCTUATIONS AND CORRELATIONS STUDY AT NA61/SHINE

Daria Prokhorova

for the NA61/SHINE Collaboration

St. Petersburg State University

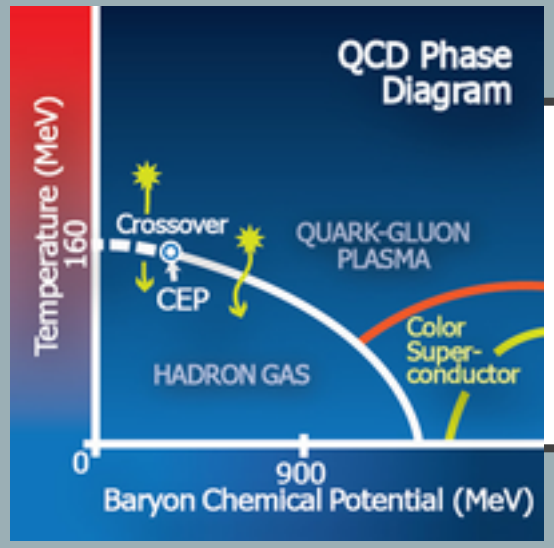
Laboratory of Ultra-High Energy Physics

October 22, III NICA days, Warsaw, Poland

MPD/SHINE Joint Session

OUTLINE

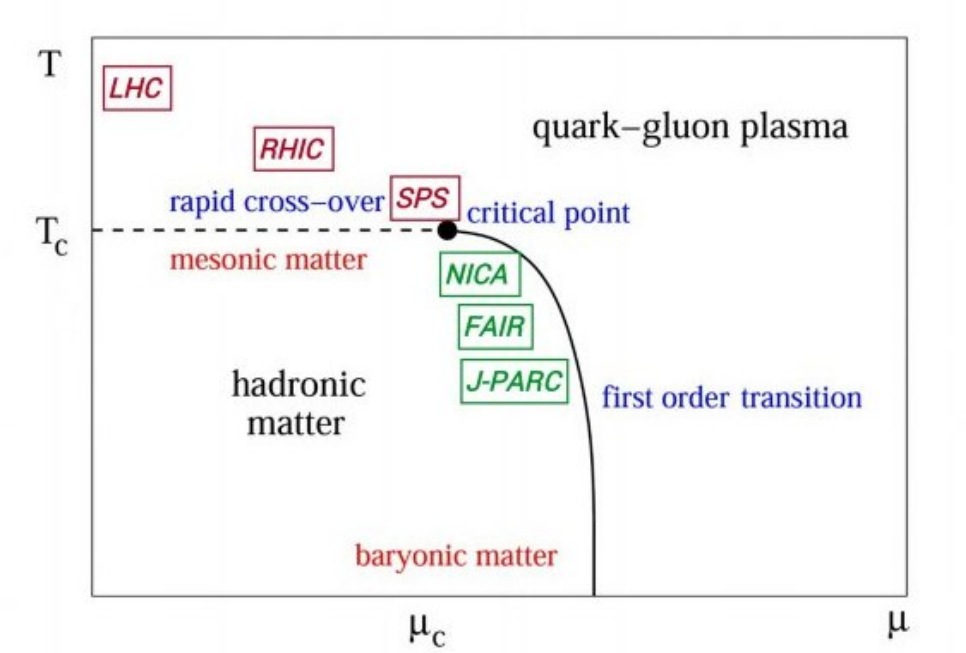
1. Search for the critical point
2. NA61/SHINE experiment
3. Fluctuation measures
4. Results corrections and possible systematic problems
5. Conclusions



SEARCH FOR THE CRITICAL POINT

QCD PHASE DIAGRAM EXPLORATION

The most popular scenario:



[Gazdzicki, M., Seyboth, P. *Acta Phys. Pol. B* **47**, 1201 (2016)]

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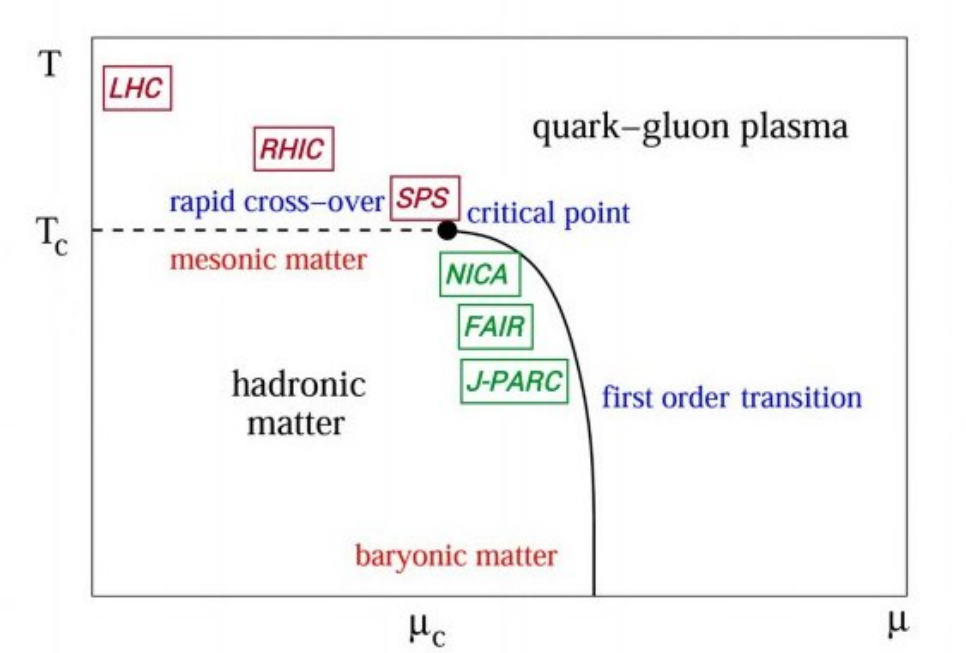

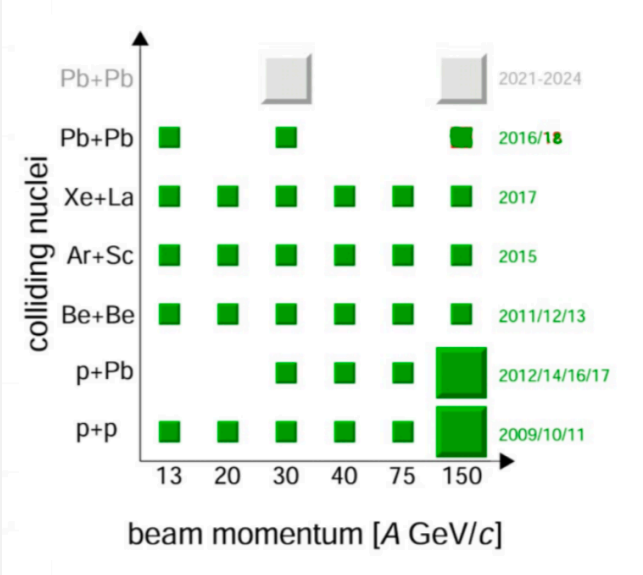

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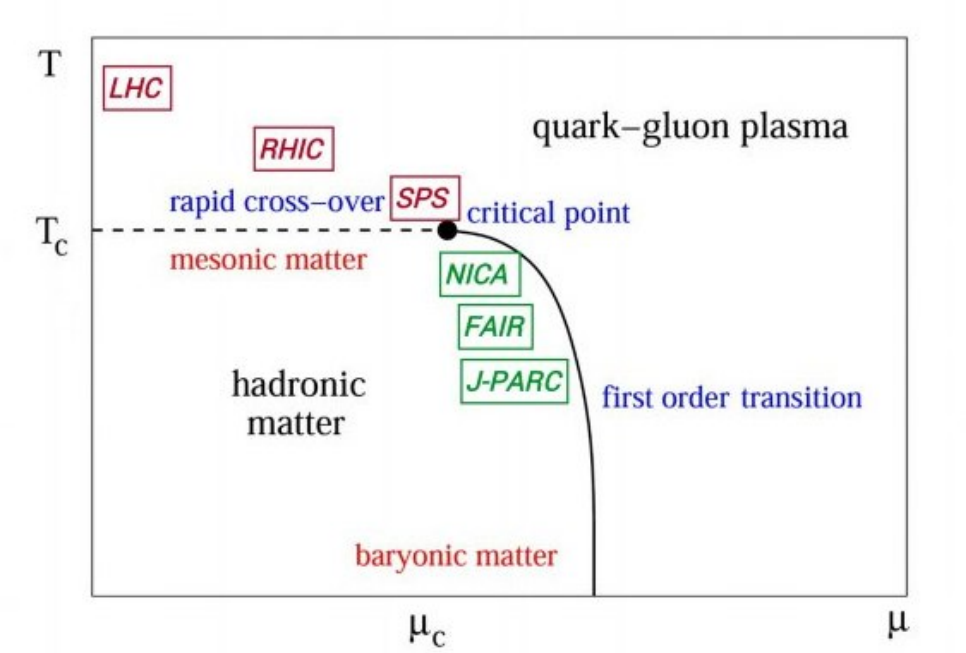
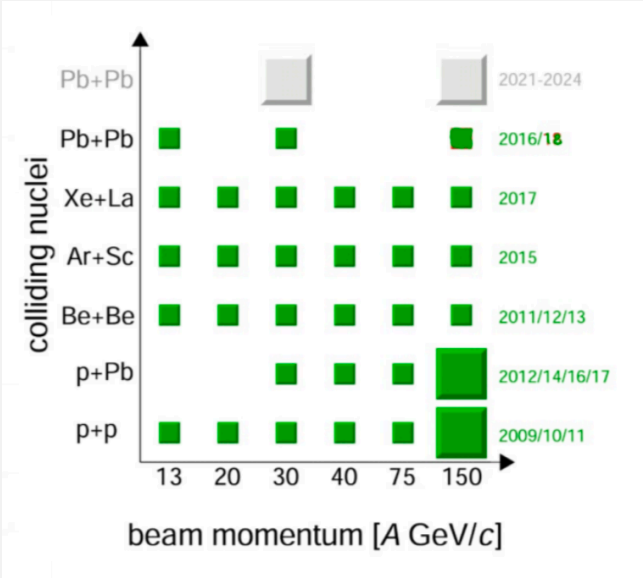
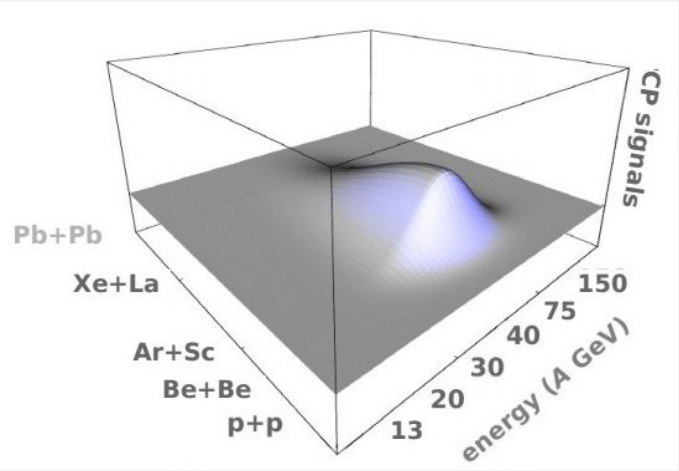




Expected region of enhanced fluctuations



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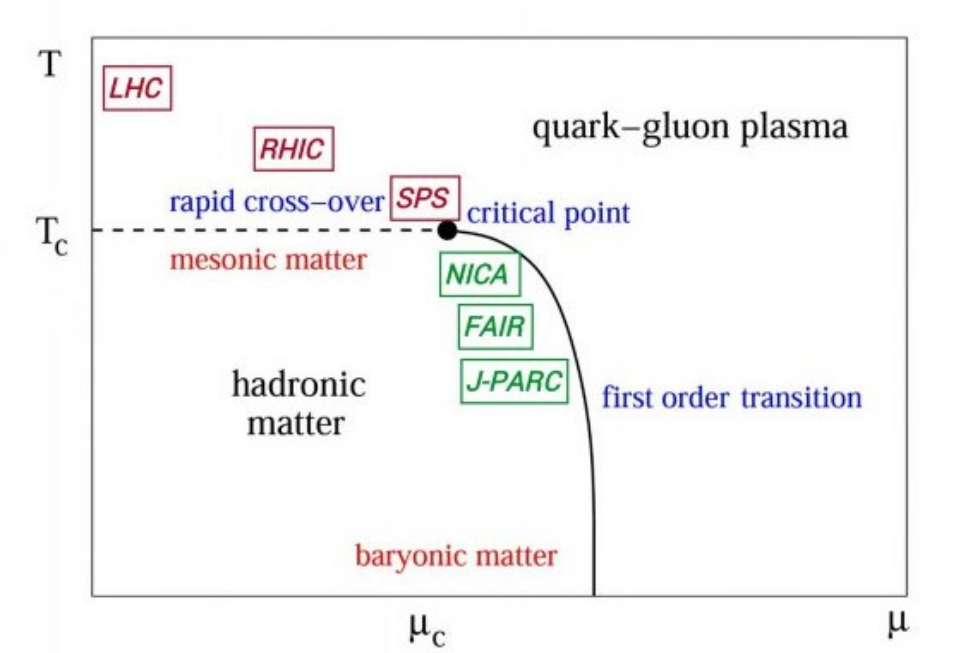

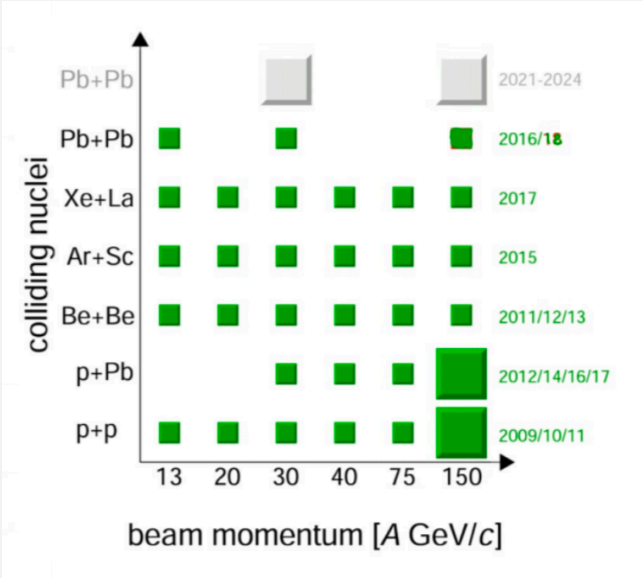

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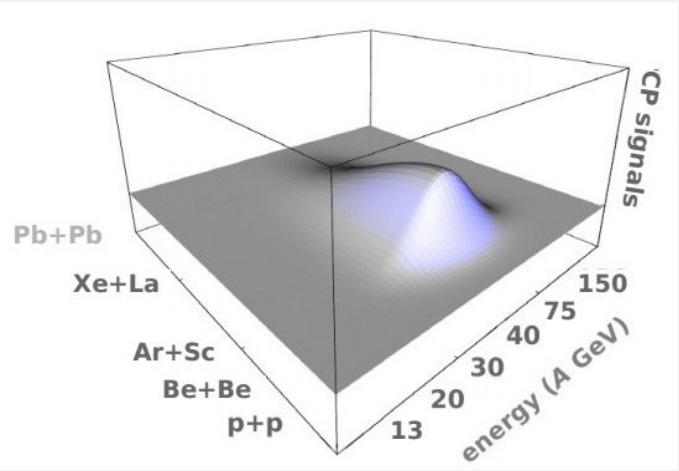

NA61/SHINE strong interactions programme:

- study the properties of the onset of deconfinement
- search for the critical point of strongly interacting matter

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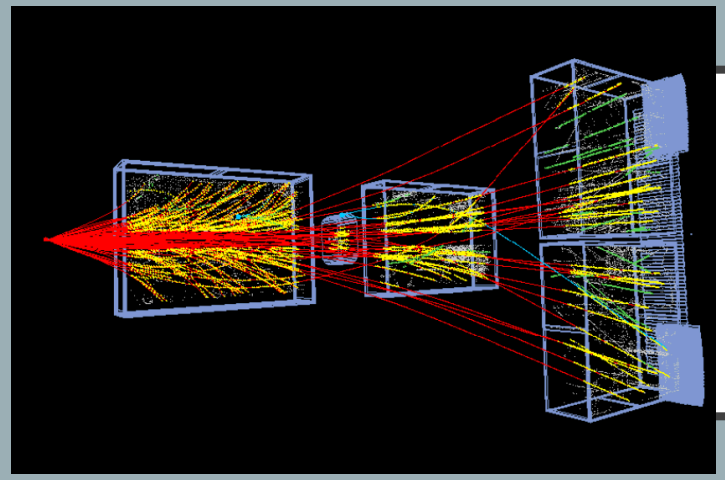
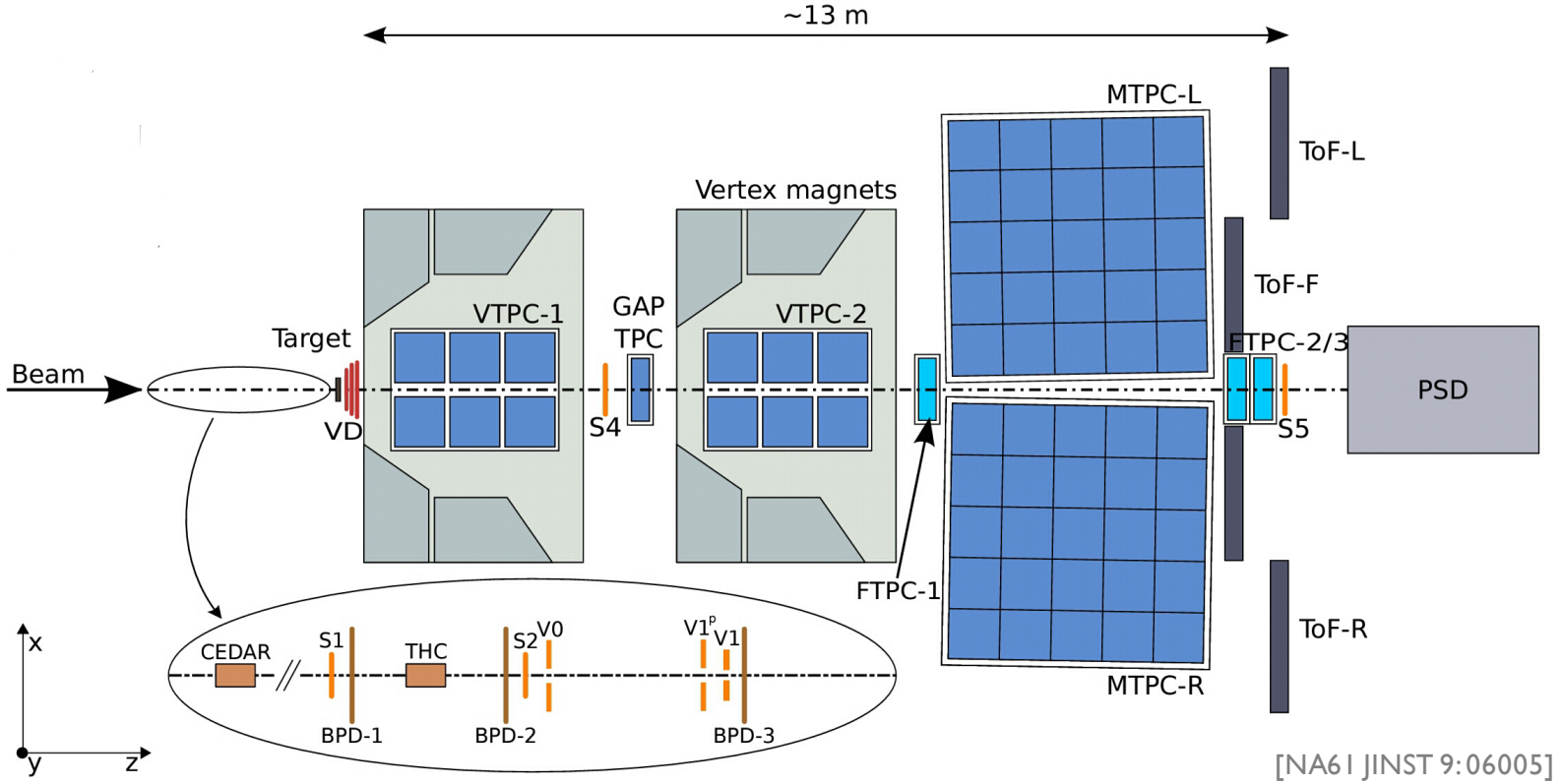


NA61/SHINE EXPERIMENT

NA61/SHINE FACILITY AT CERN SPS

SHINE - **S**PS **H**eavy **I**on and **N**eutrino **E**xperiment



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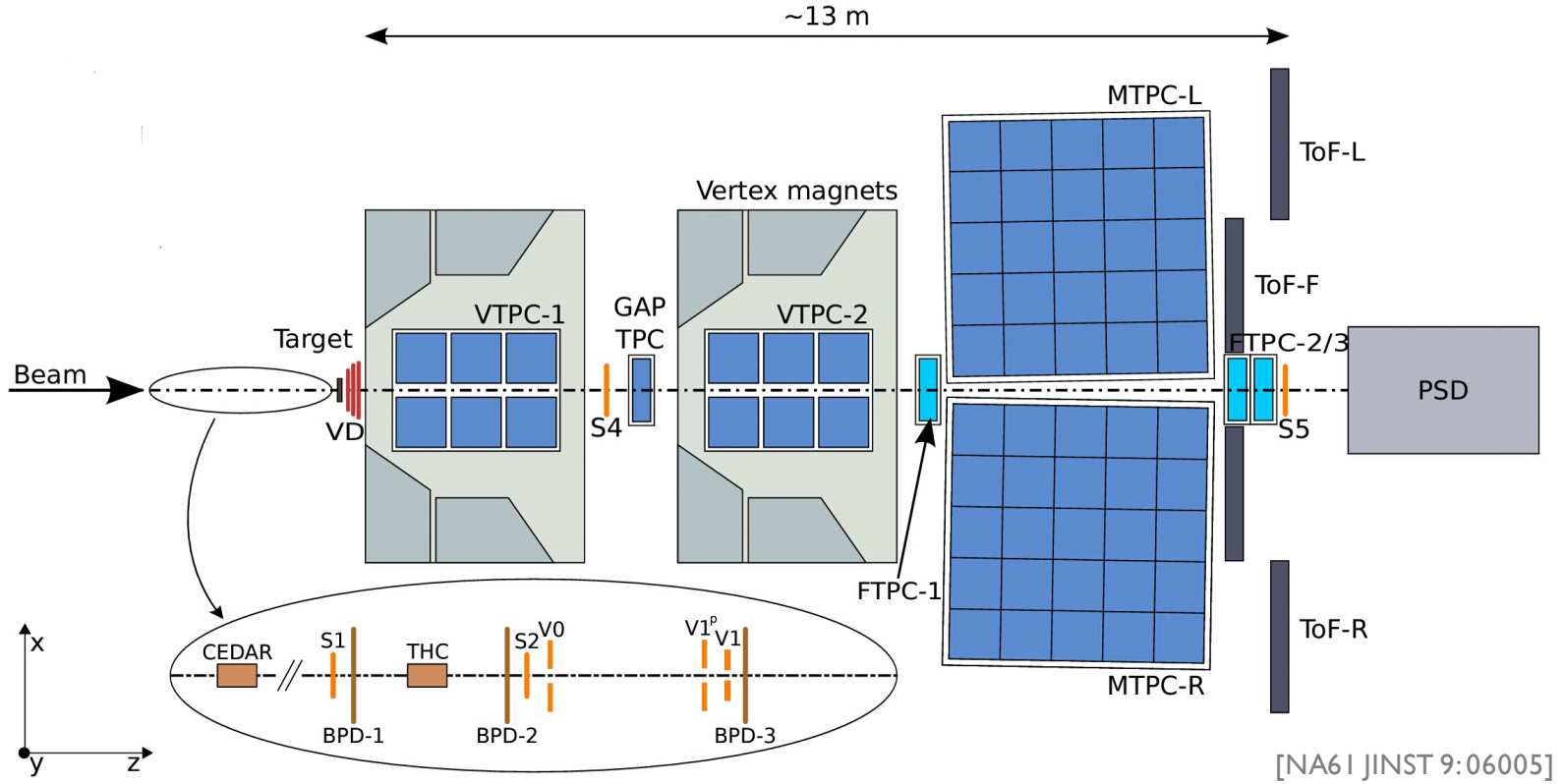

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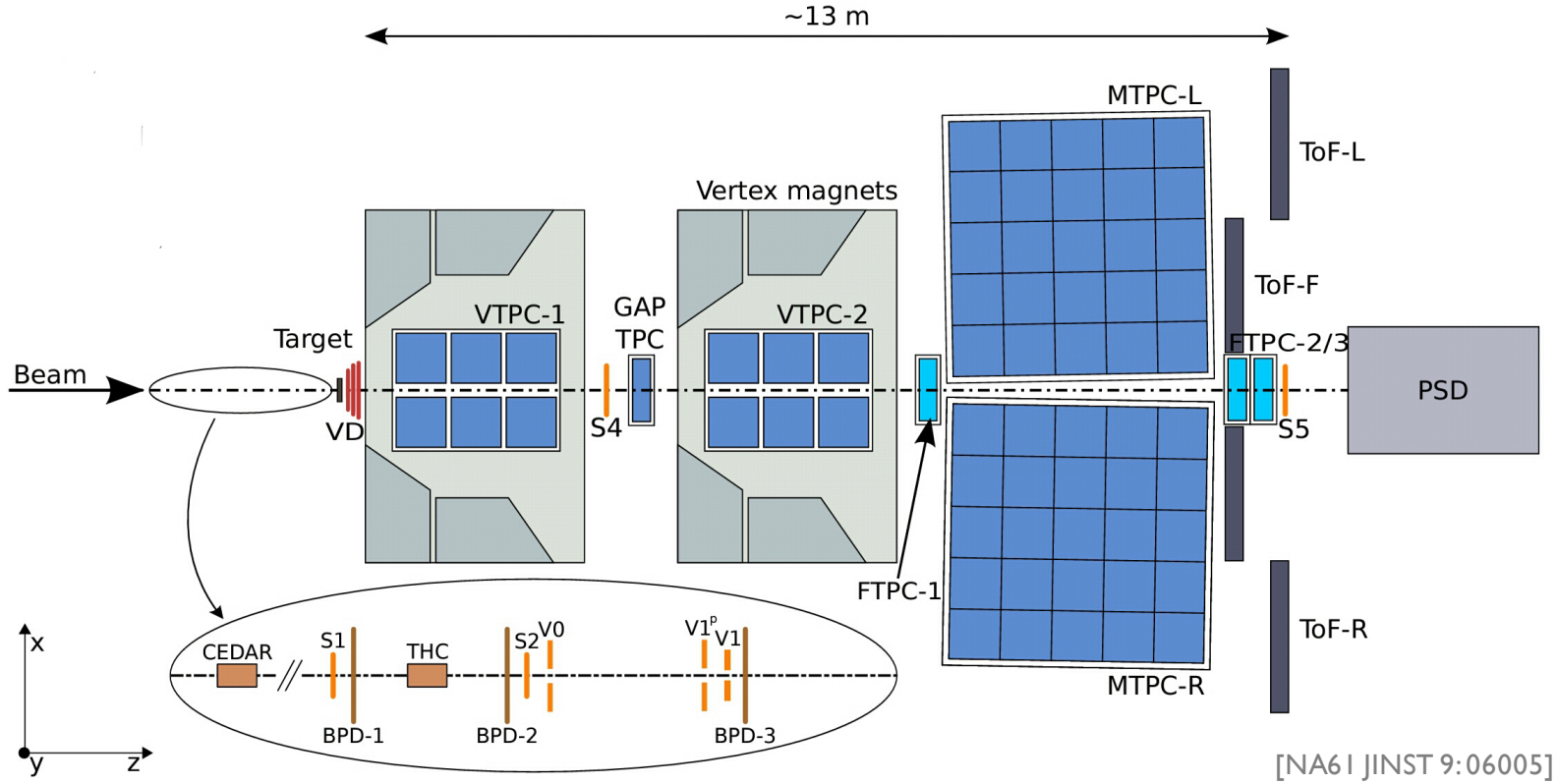

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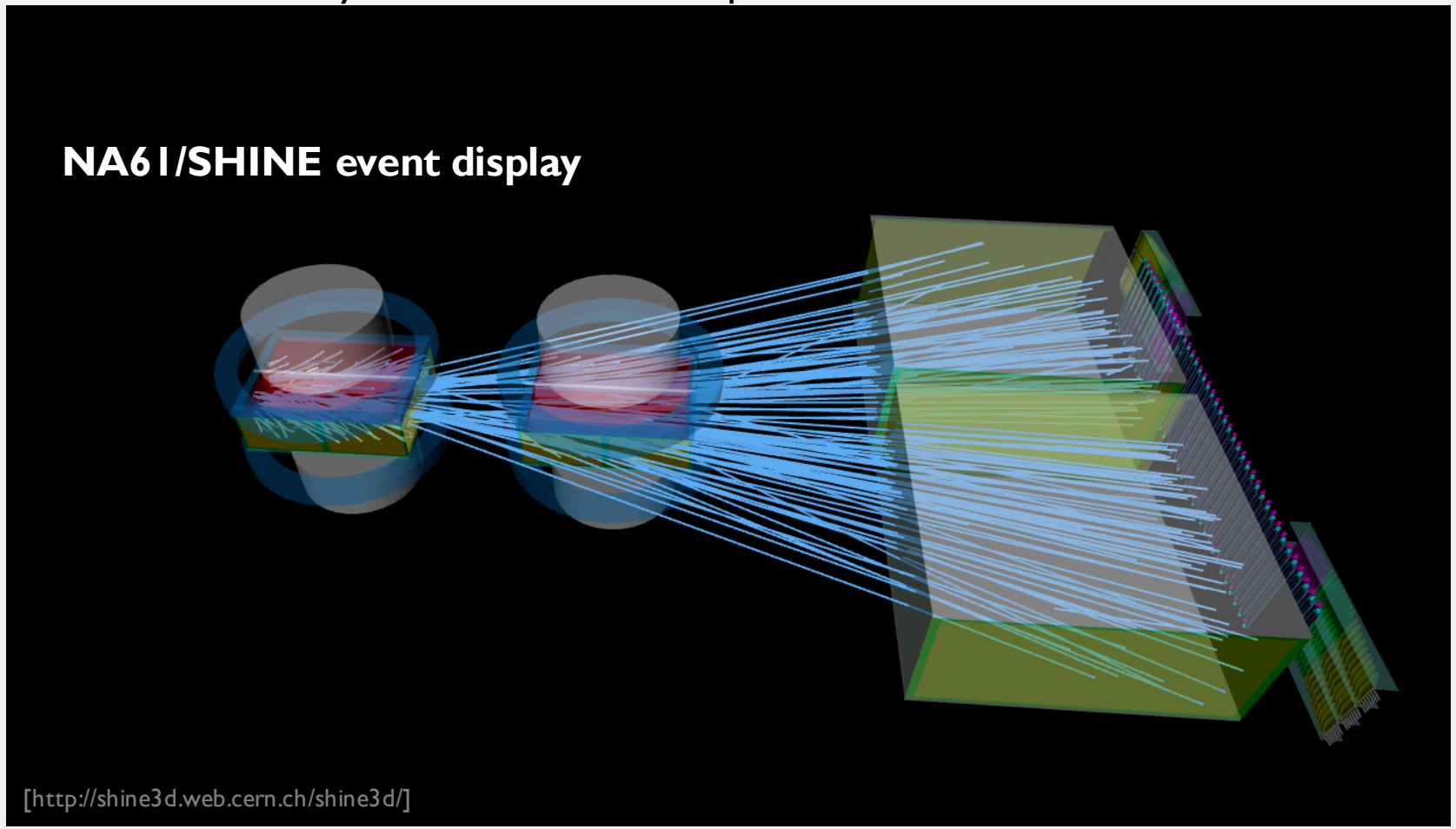

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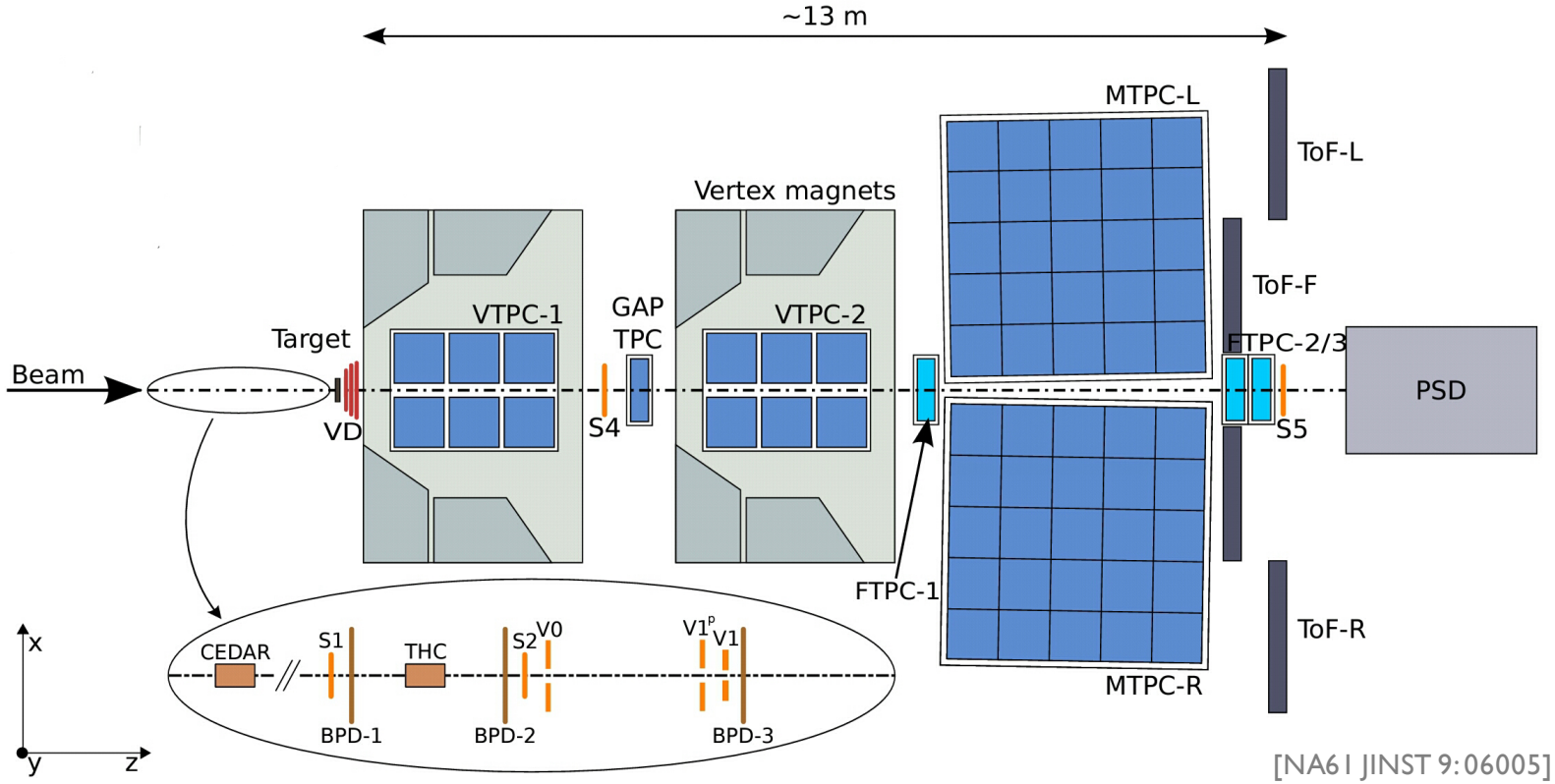

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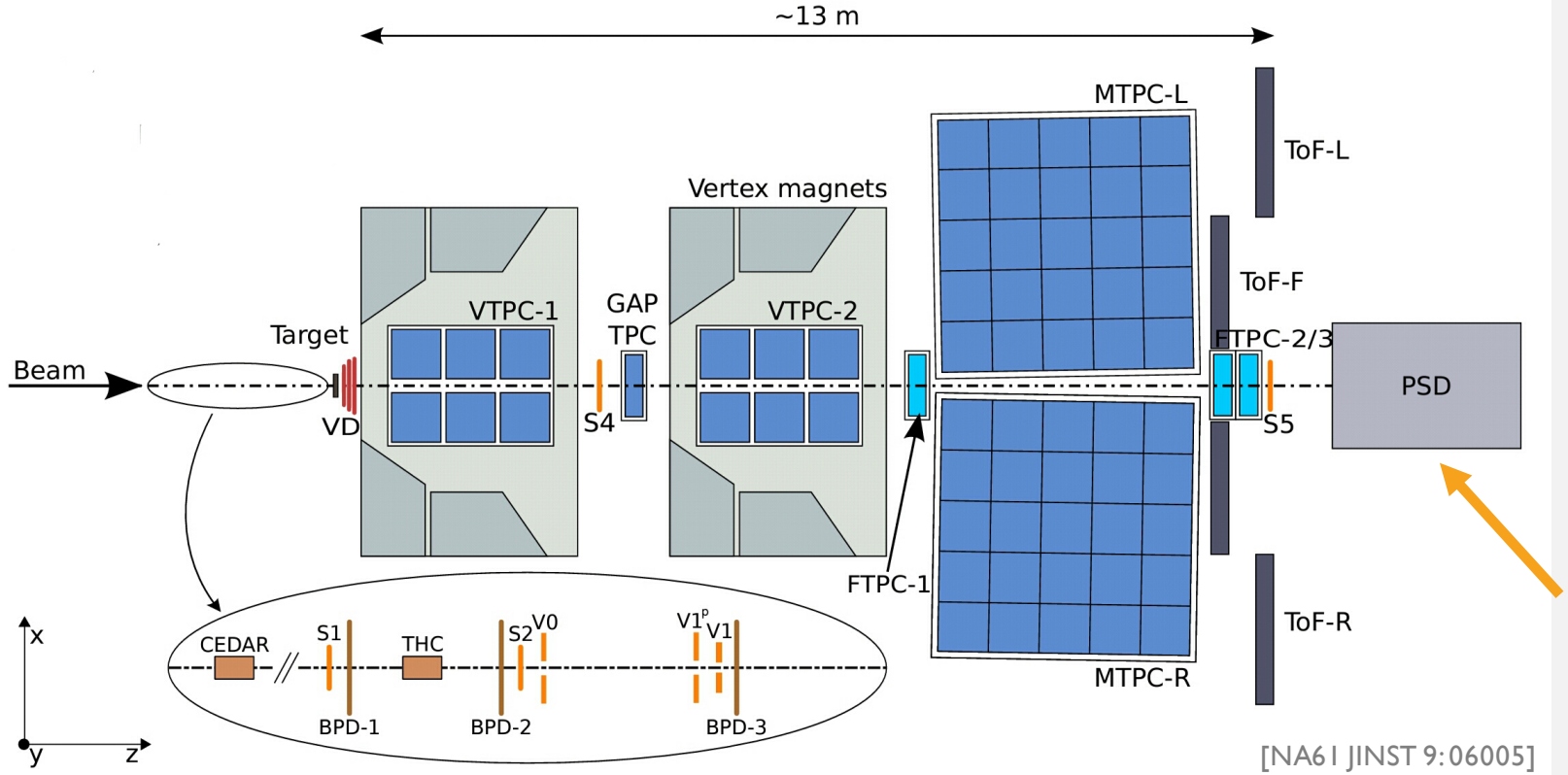

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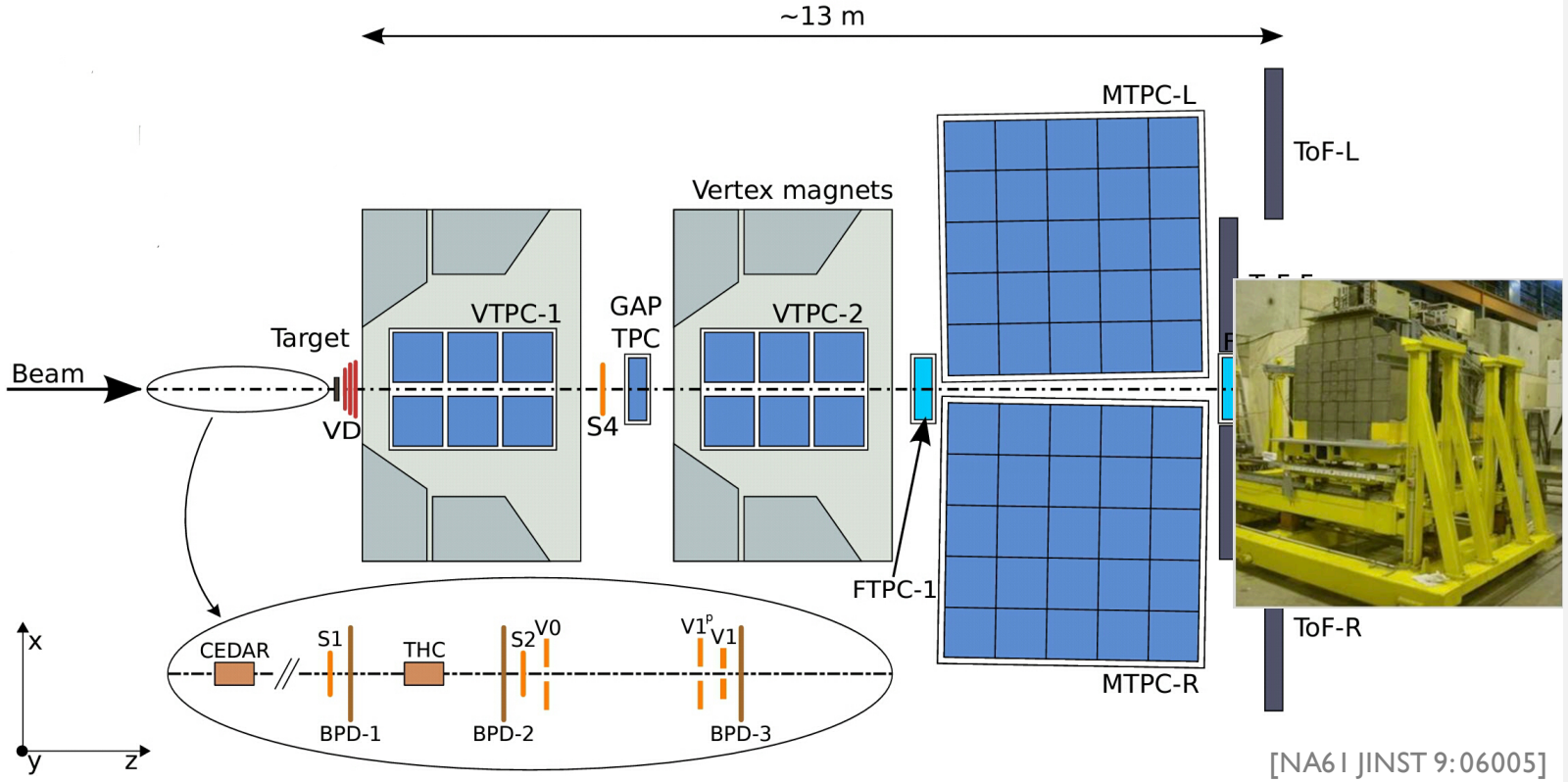

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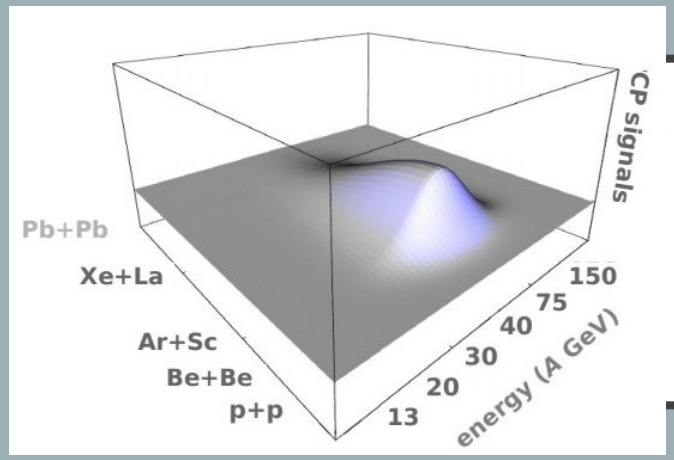

FLUCTUATION MEASURES

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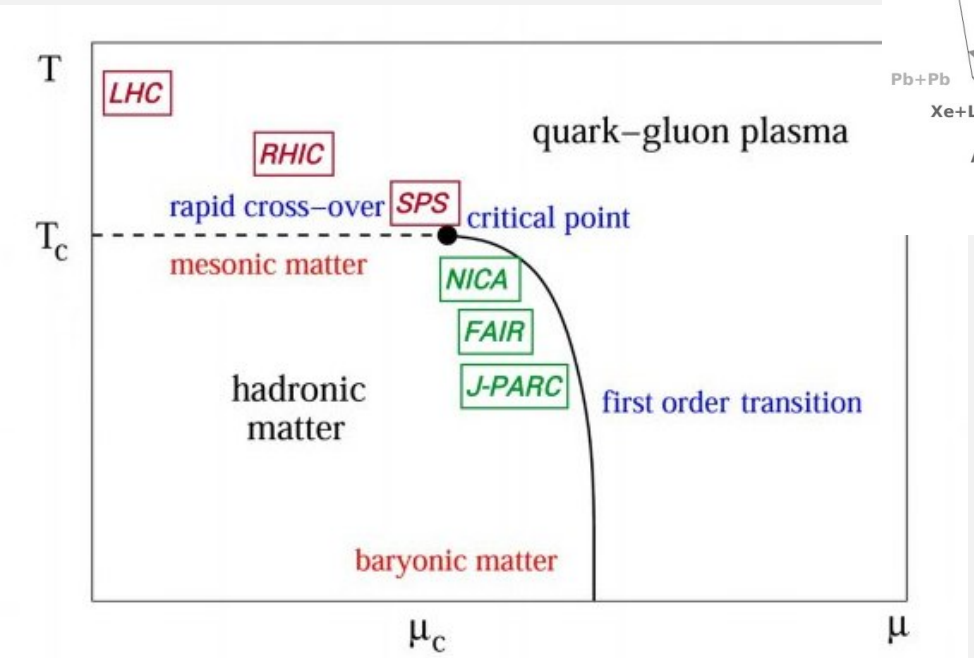

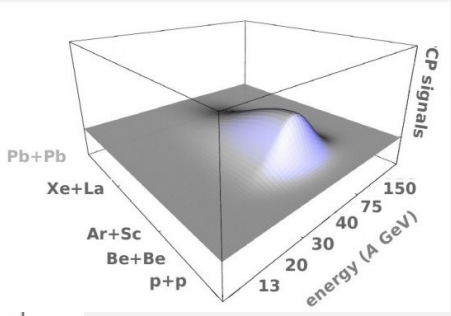

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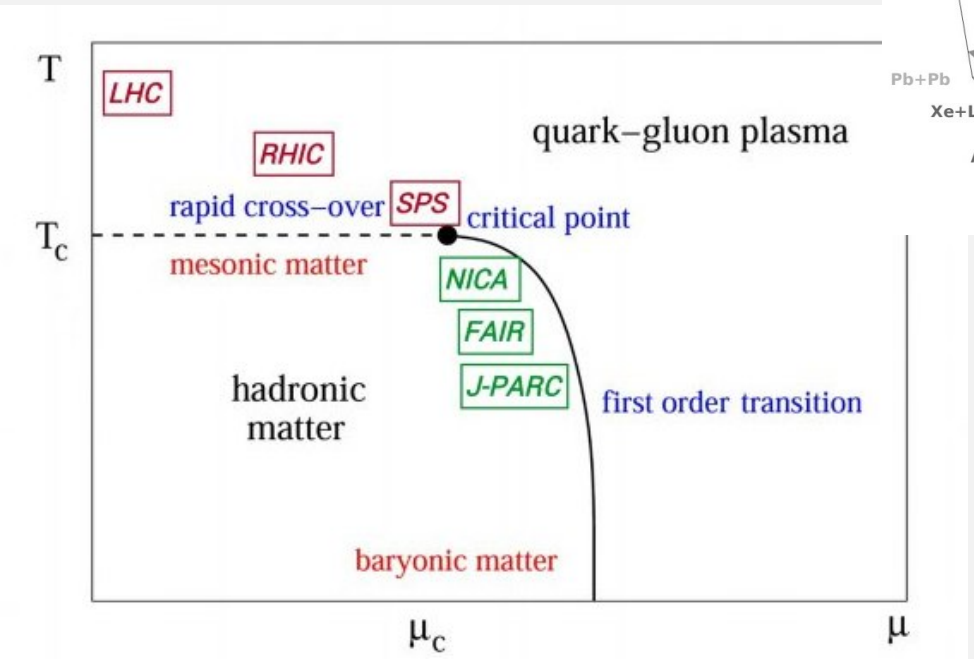

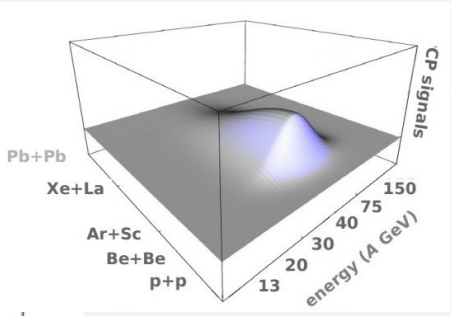

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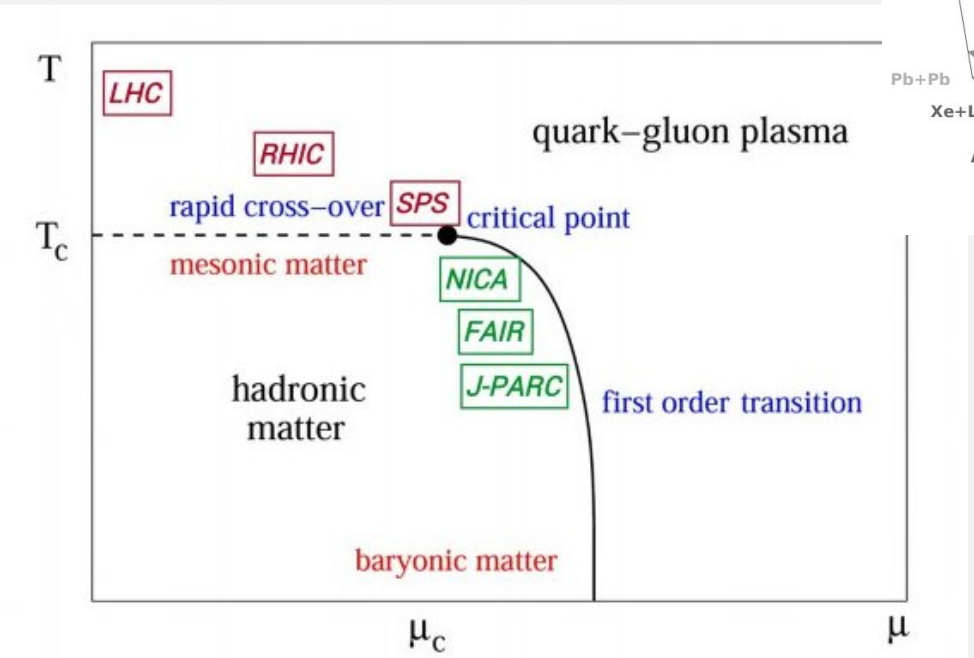

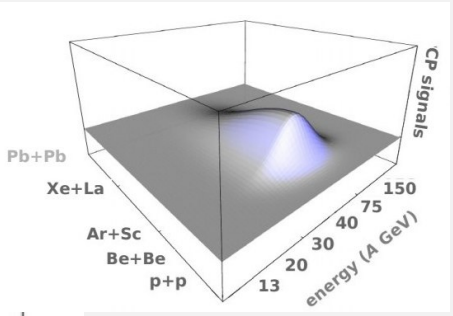

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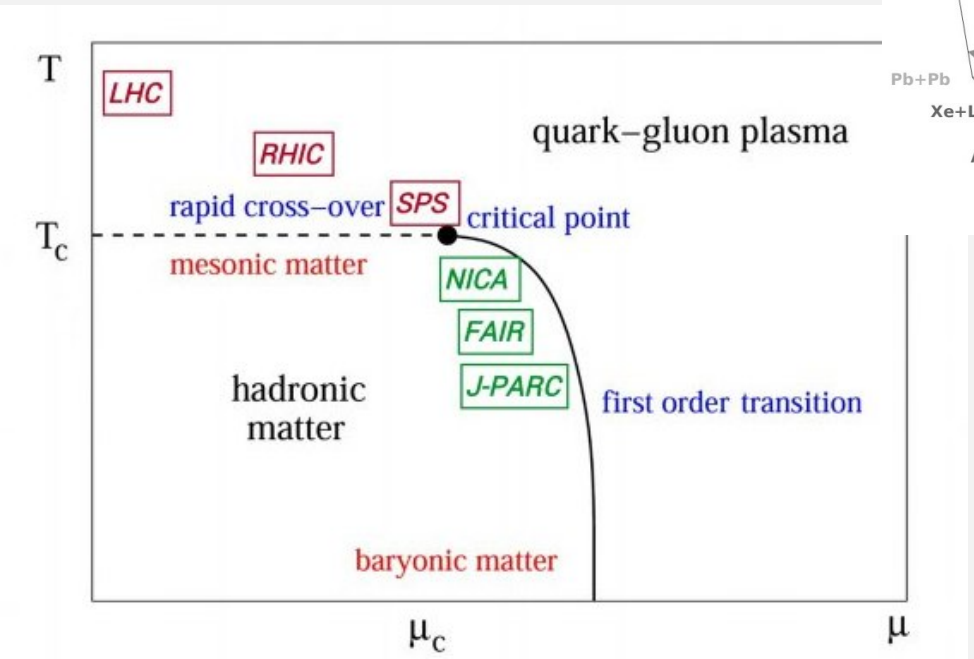

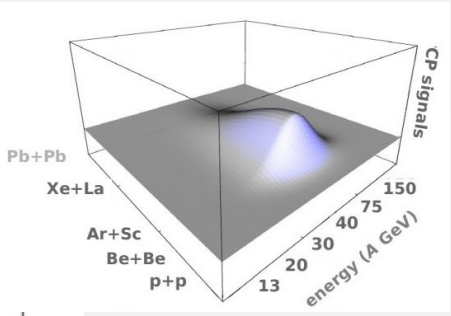

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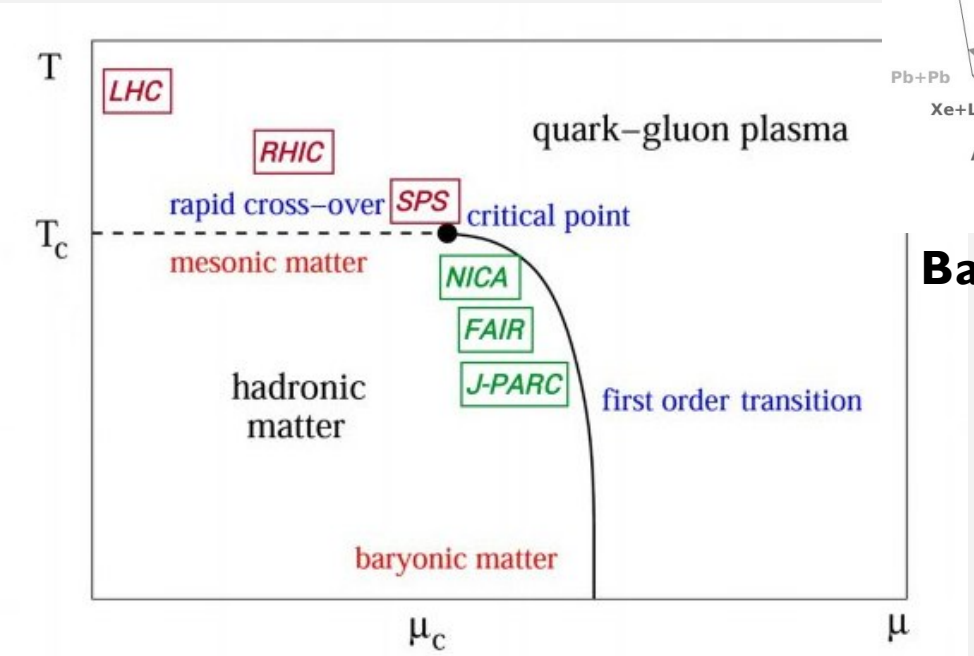

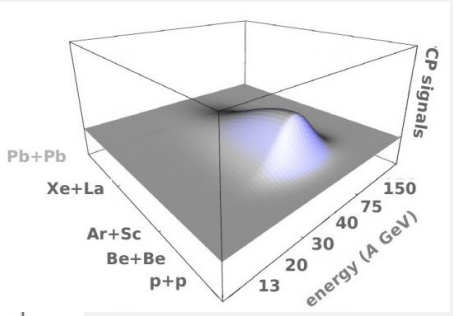

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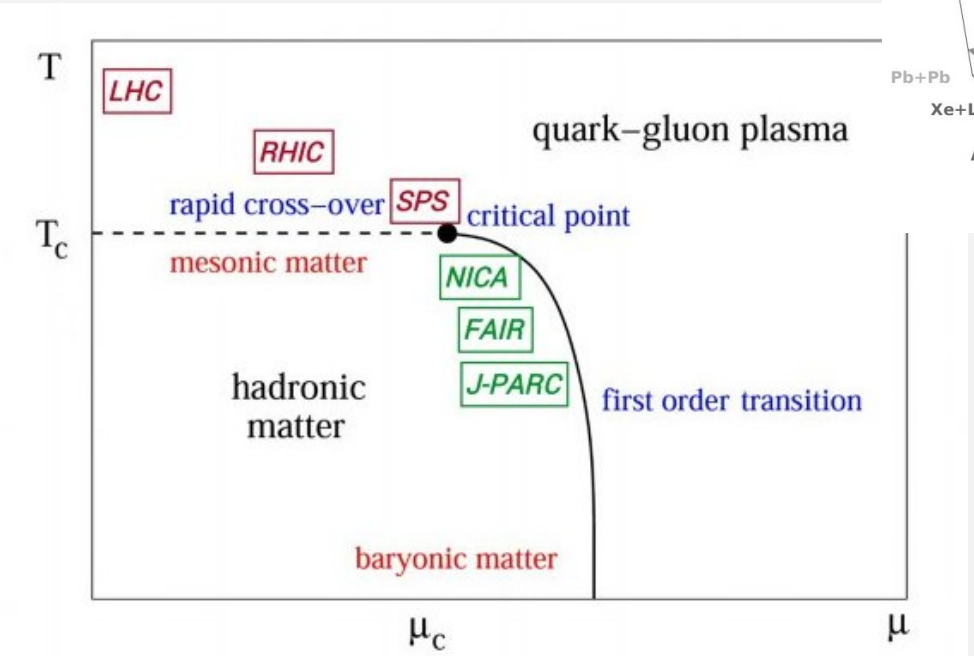

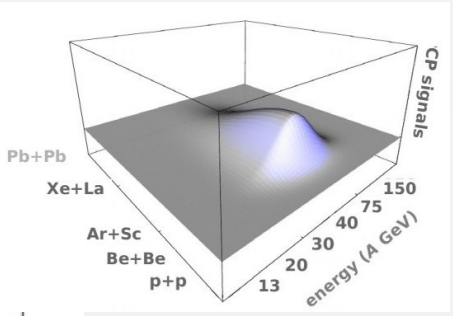

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Intensive fluctuation measure: independent of the number of sources or the system volume

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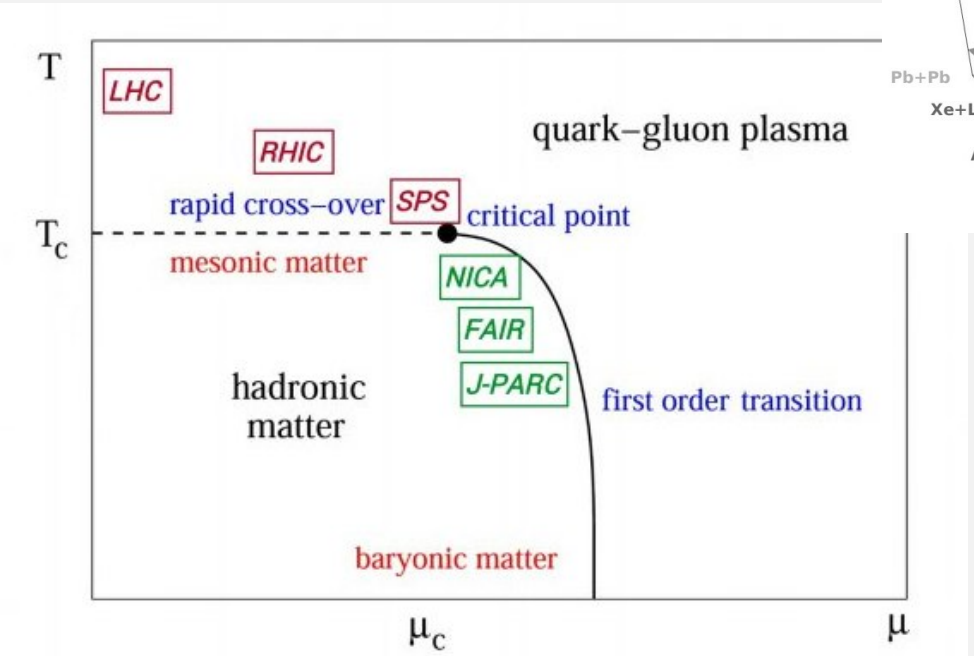

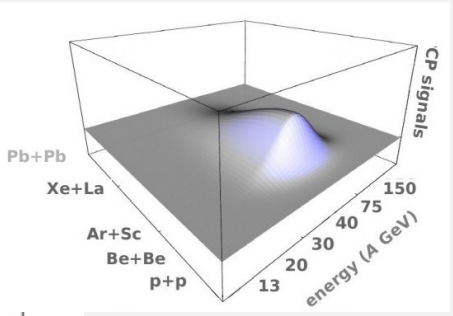

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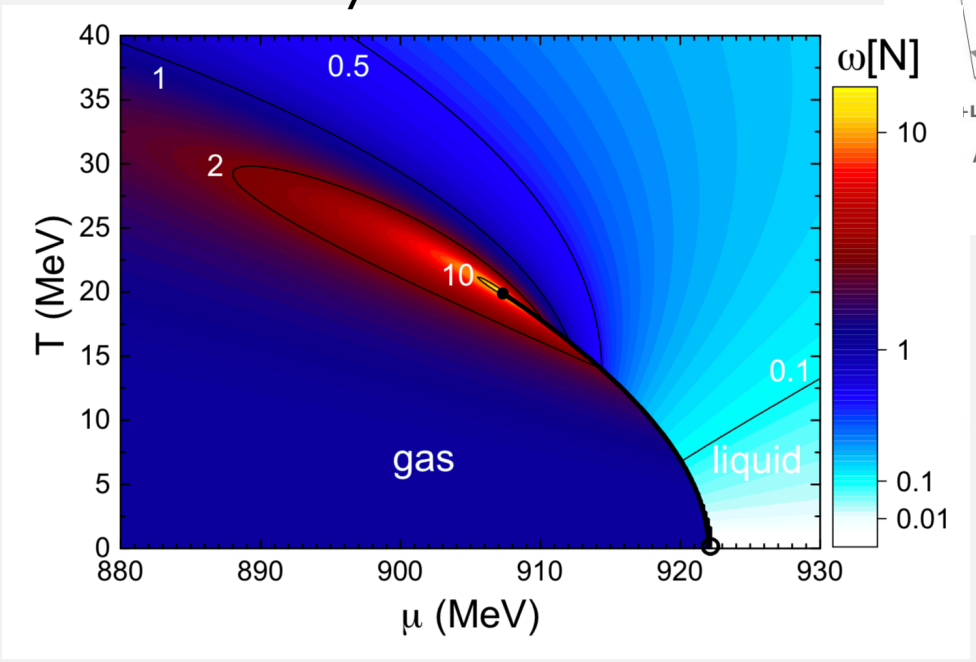
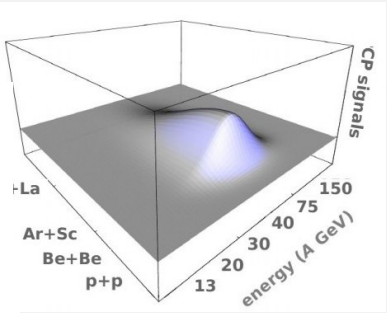
Possible sensitivity:





Nucleon system with van der Waals EOS in GCE formulation in the vicinity of the Critical Point

[Vovchenko, Gorenstein, Stoecker, PRL 118: 182301, Vovchenko, et al., JPA 48: 305001]

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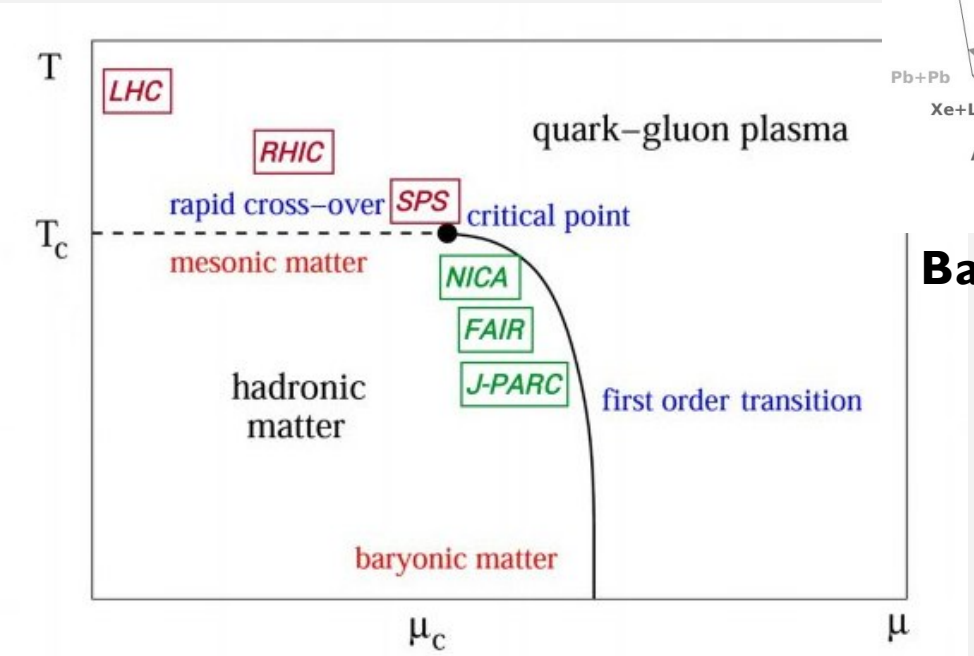

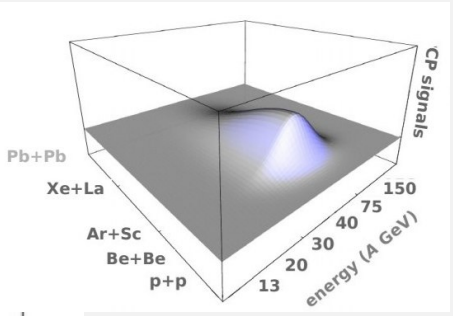

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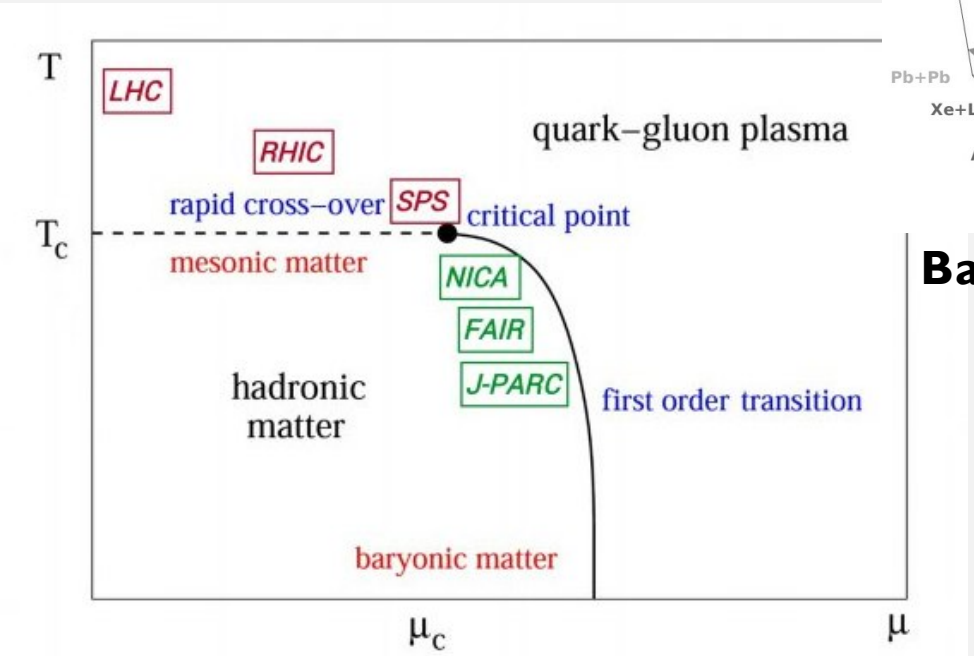

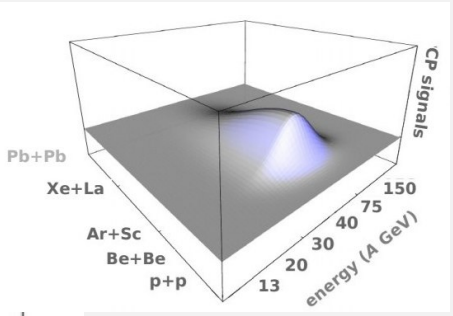

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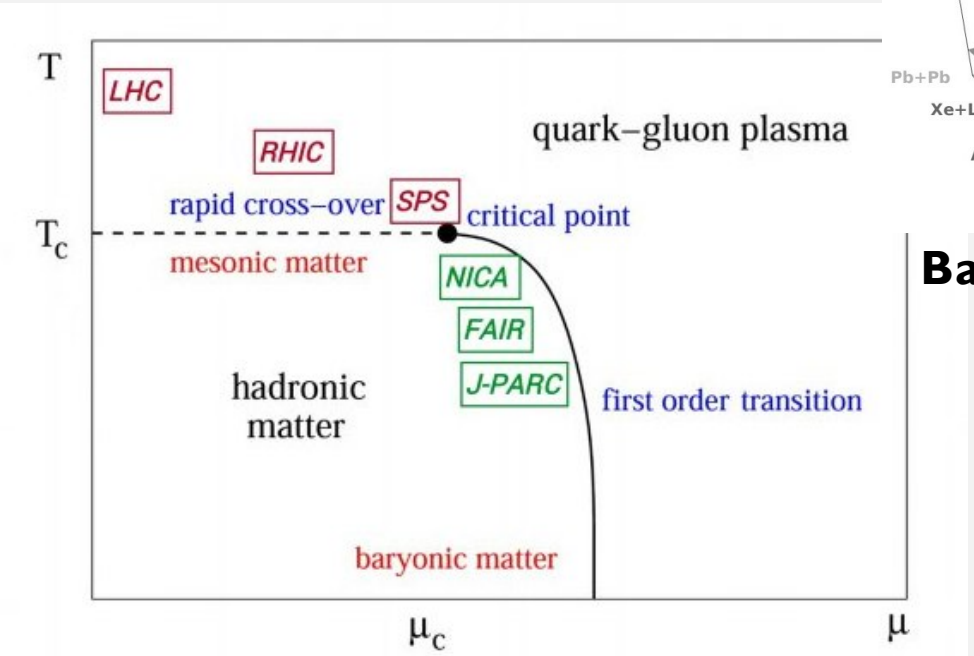

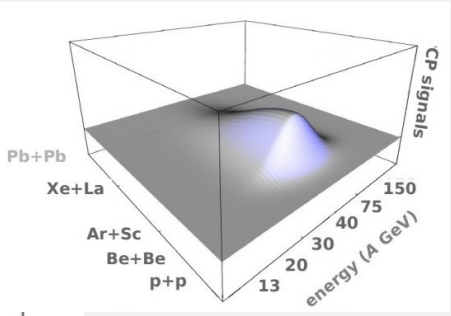

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Higher order moments: **intensive skewness and kurtosis** of conserved quantities distributions are more sensitive to the correlation length divergence

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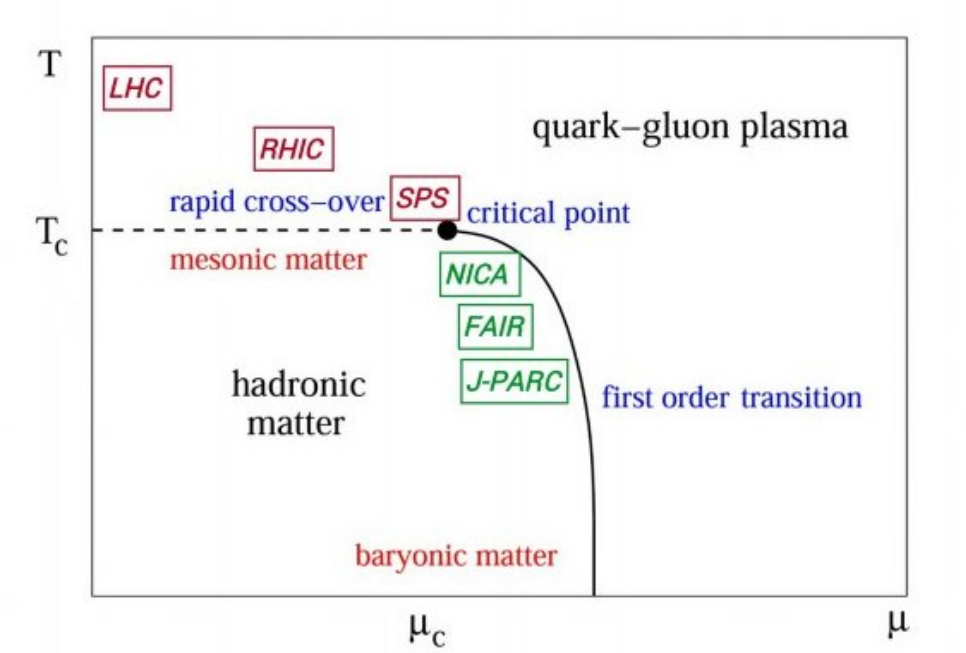


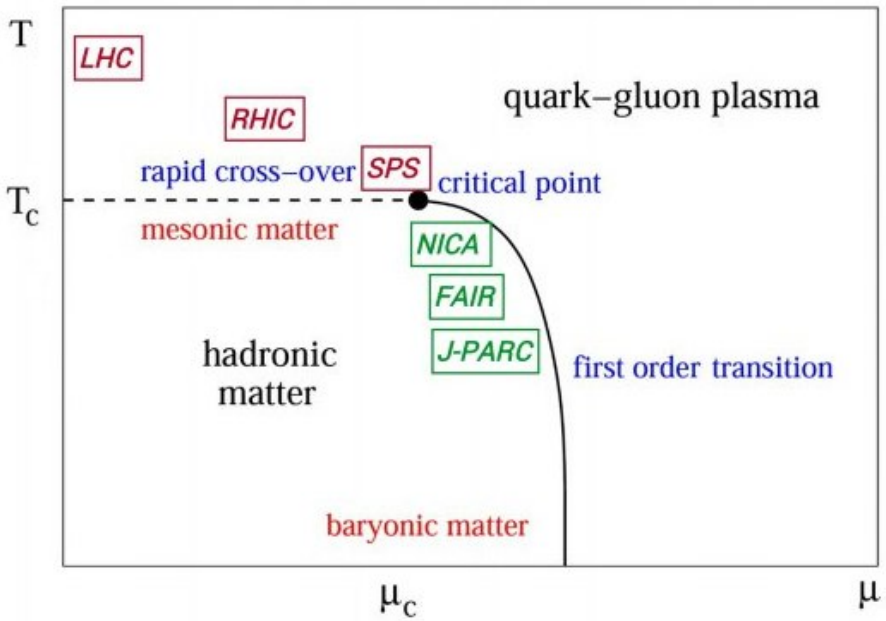
Higher order moments: **intensive skewness and kurtosis** of conserved quantities distributions are more sensitive to the correlation length divergence

FLUCTUATION MEASURES

Scan in system size and beam energy → search for the **critical point**

~ region of enhanced fluctuations

[Gazdzicki, M., Seyboth, P. *Acta Phys. Pol. B* **47**, 1201 (2016)]



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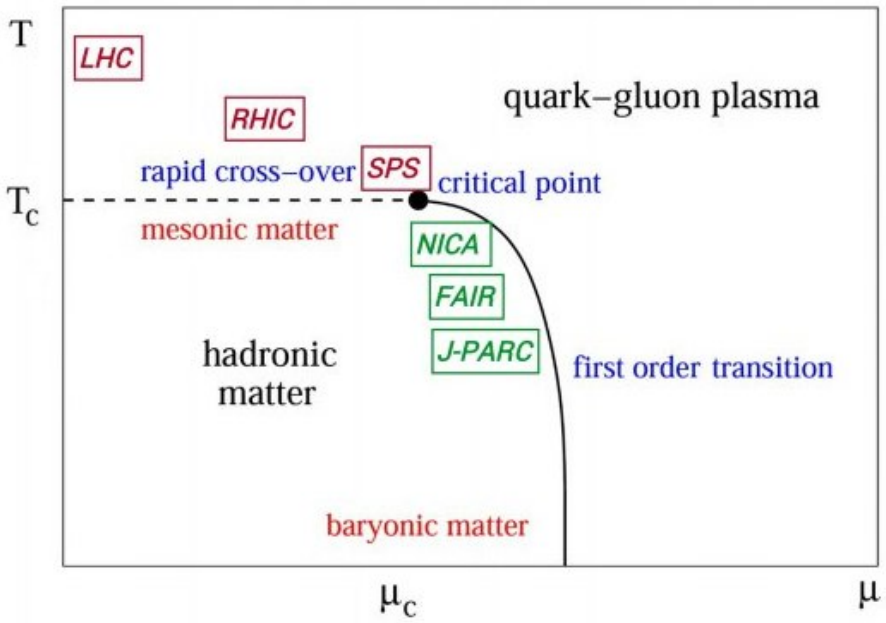

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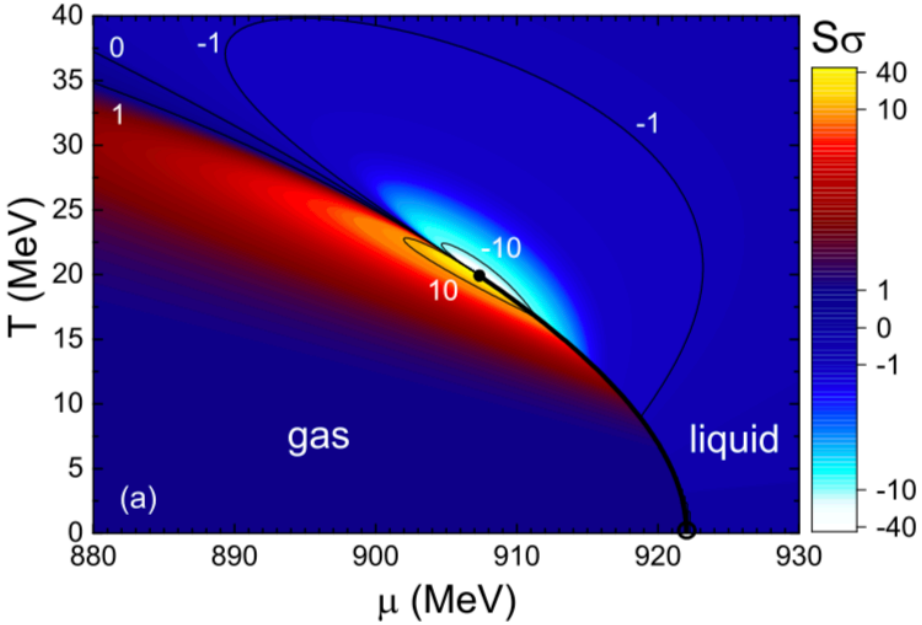

Nucleon system with van der Waals EOS in GCE formulation in the vicinity of the Critical Point

[Vovchenko, Gorenstein, Stoecker, PRL 118: 182301, Vovchenko, et al., JPA 48: 305001]

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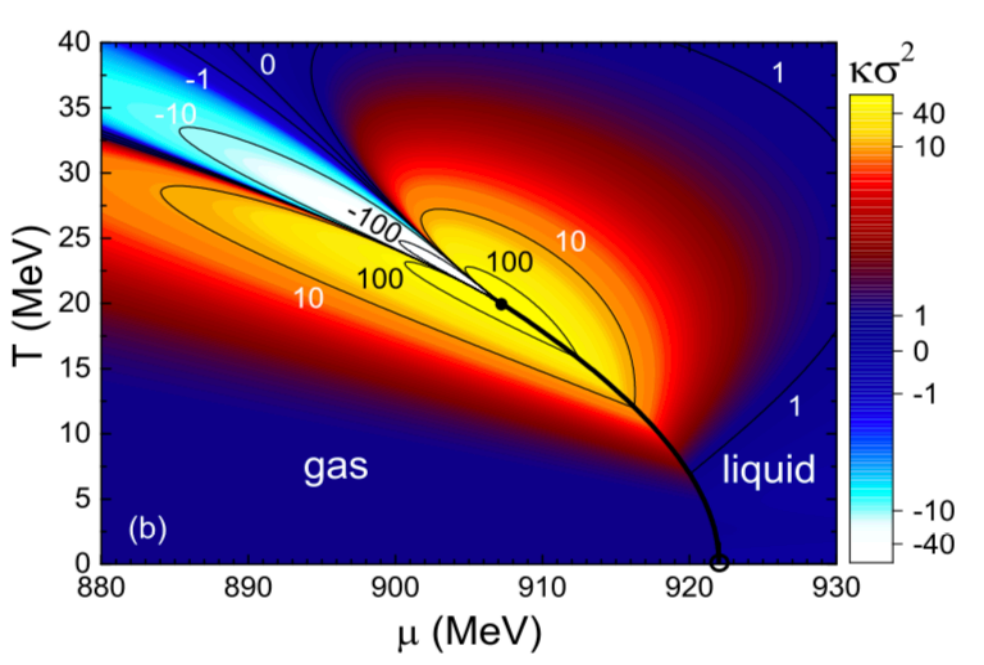

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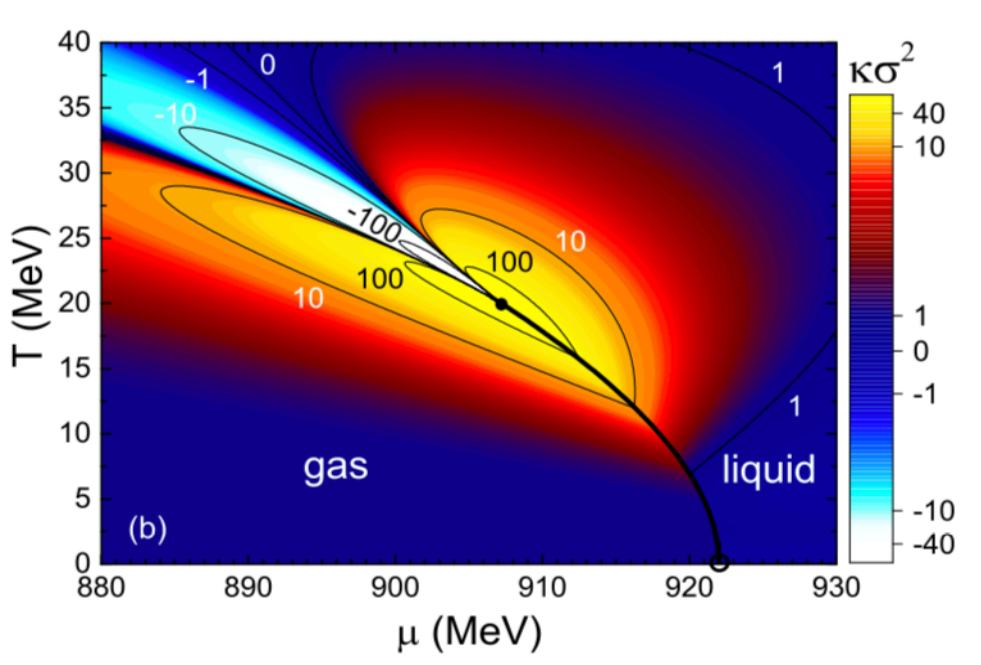

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but the problem is that the dependence on the volume distribution remains

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Scan in system size and beam energy → search for the **critical point**

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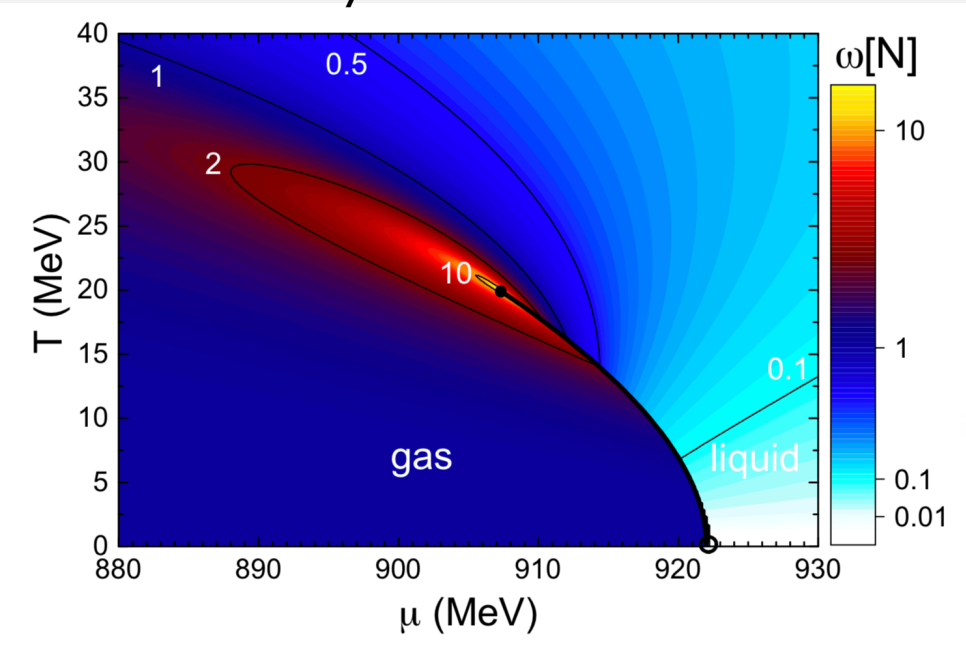

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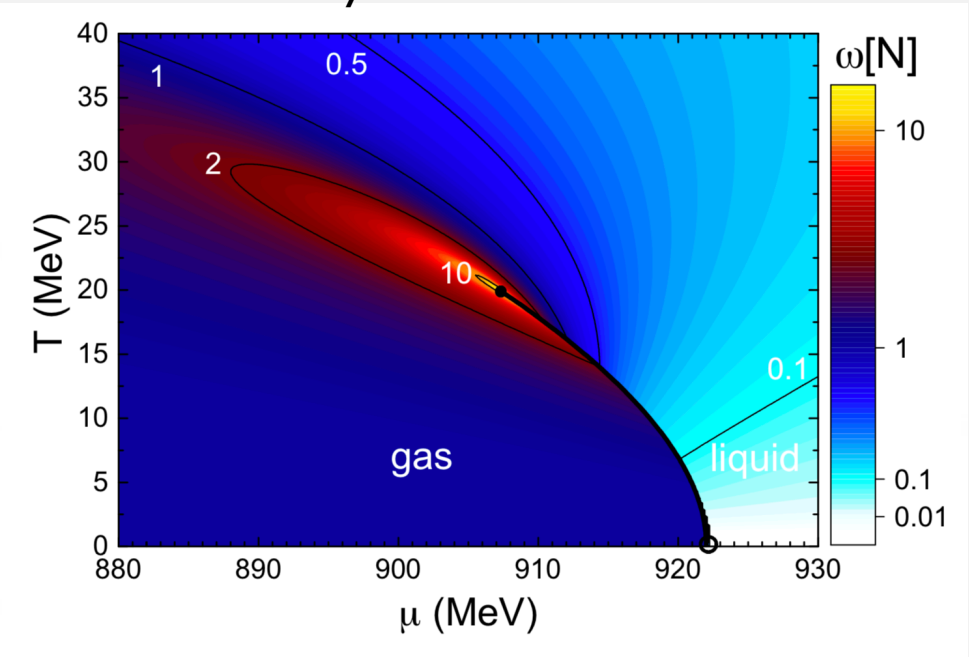

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Scan in system size and beam energy → search for the **critical point**

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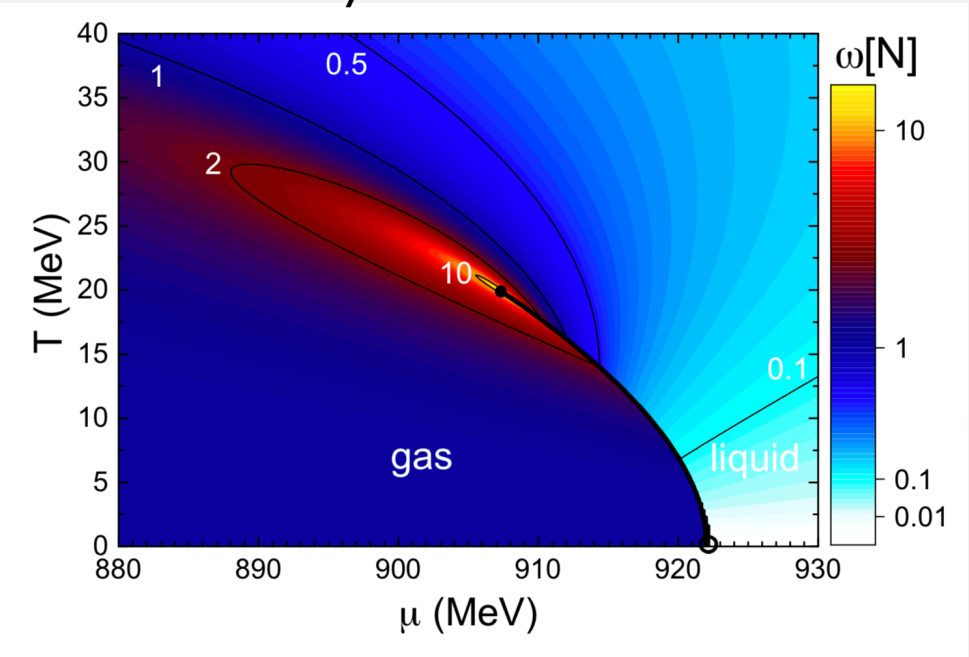

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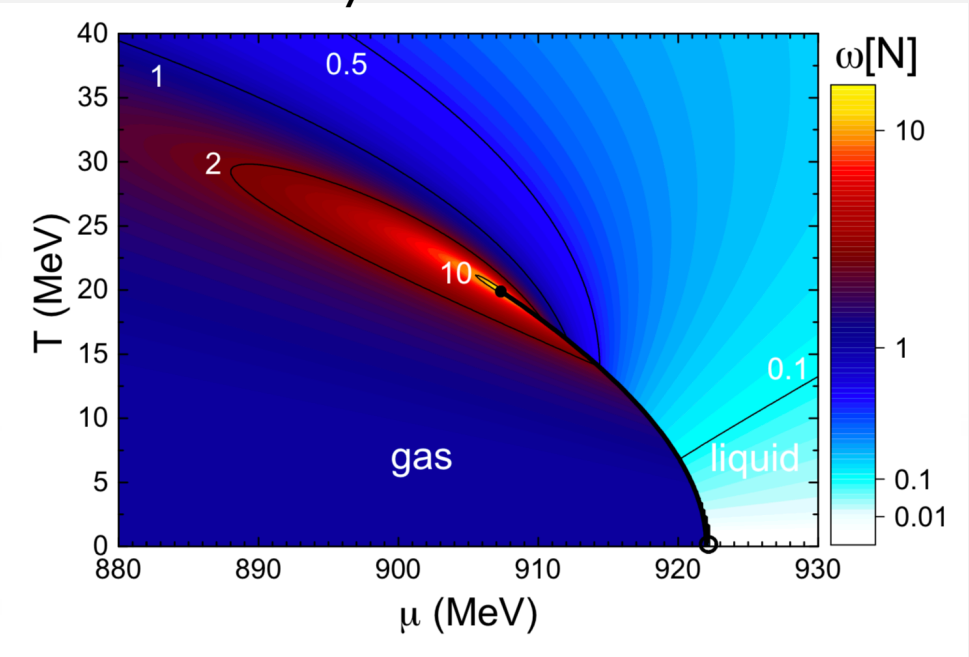

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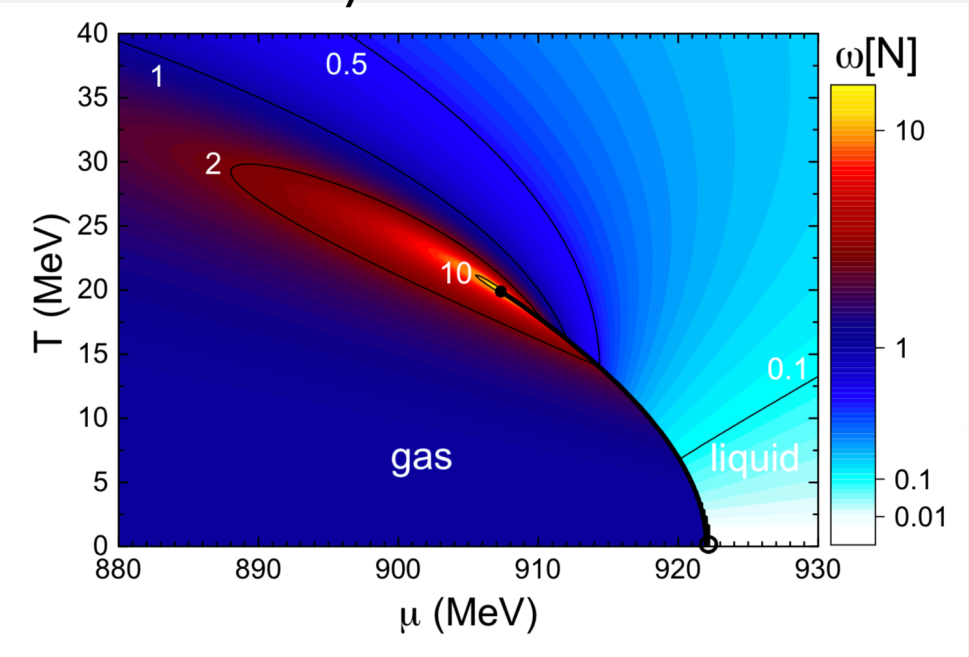

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scaled variance of the quantity A for each source

System volume ↔ scaled variance of the number of sources

FLUCTUATION MEASURES

Scan in system size and beam energy → search for the **critical point**

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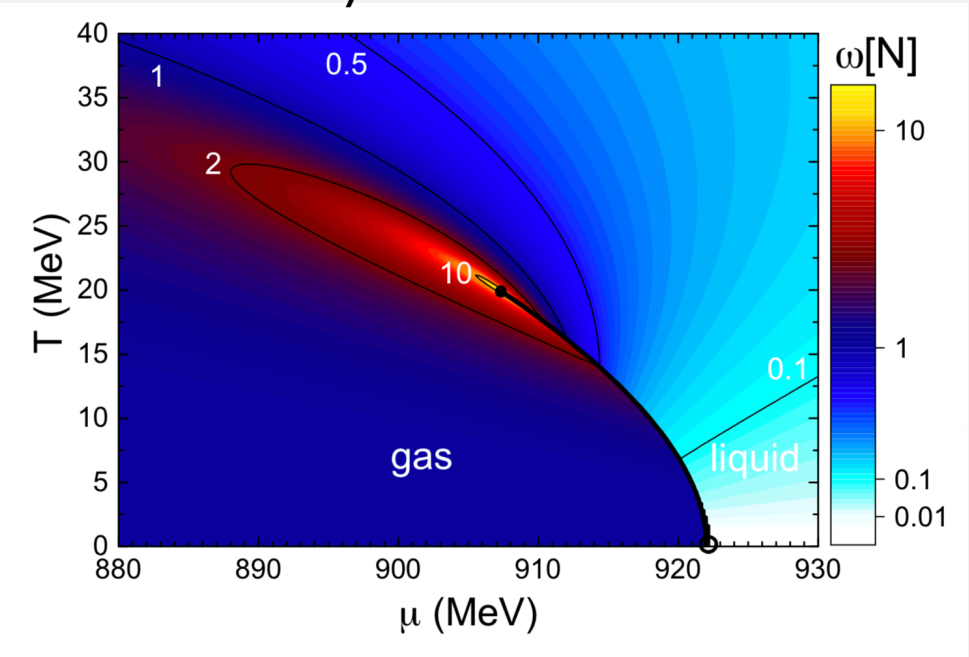

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Intensive fluctuation measure: independent of the number of sources or the system volume, **but still depend on the volume fluctuations**

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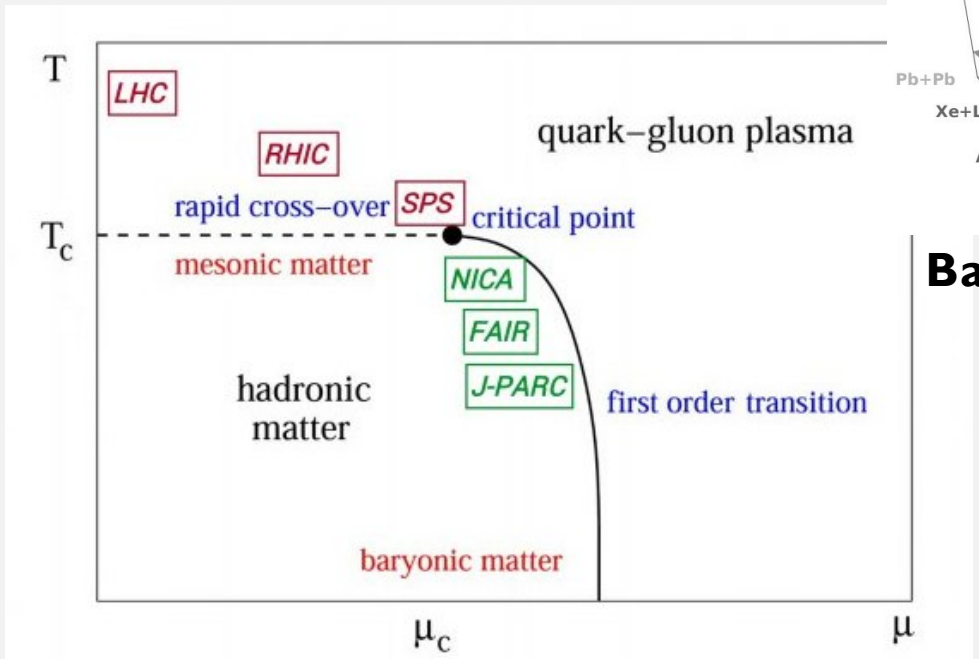

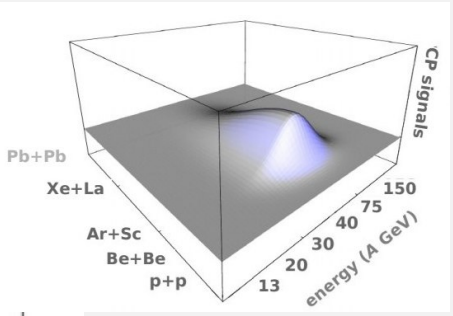

~ region of enhanced fluctuations

What is the CP signal amplitude?
What if it is shadowed by trivial fluctuations?

Proper measures are required

Baseline: construct quantities with the trivial properties in the reference models

+

More sensitivity

FLUCTUATION MEASURES

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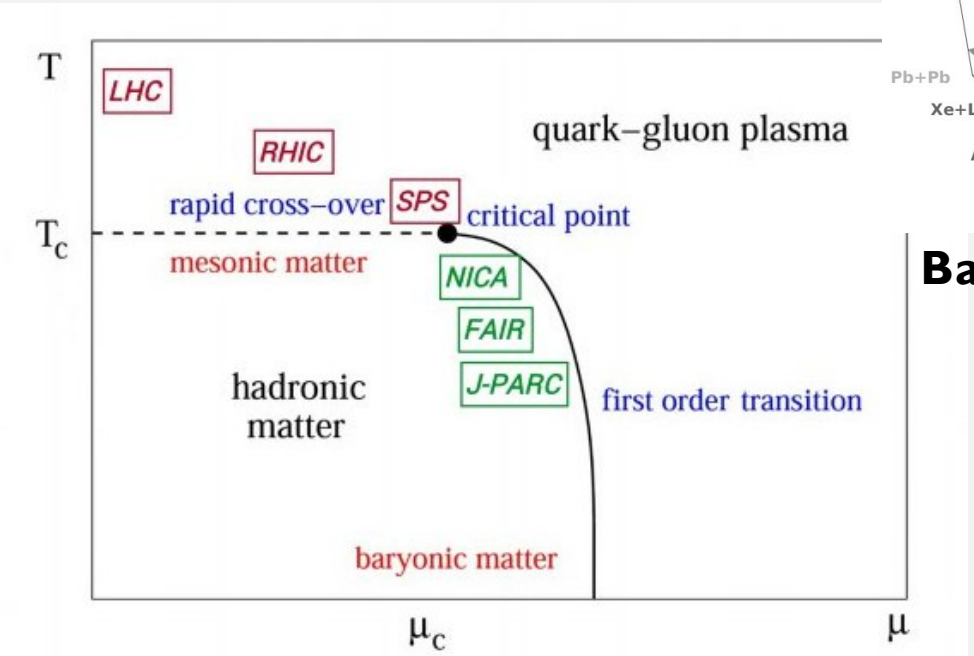

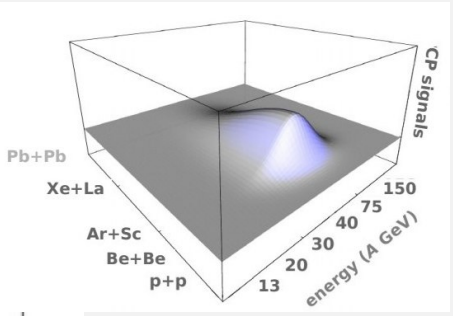

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+

More sensitivity

+

Exclude the impact of trivial (volume) fluctuations

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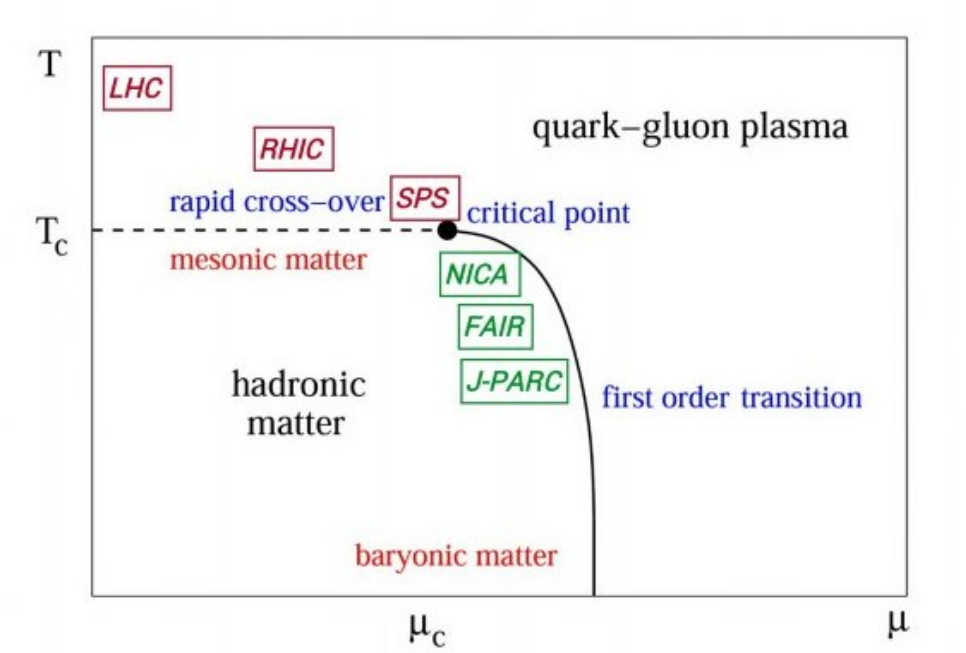

Strongly intensive quantities: are independent both on the volume and the event-by-event fluctuations of the volume in statistical model of the ideal Boltzmann gas in the grand canonical ensemble

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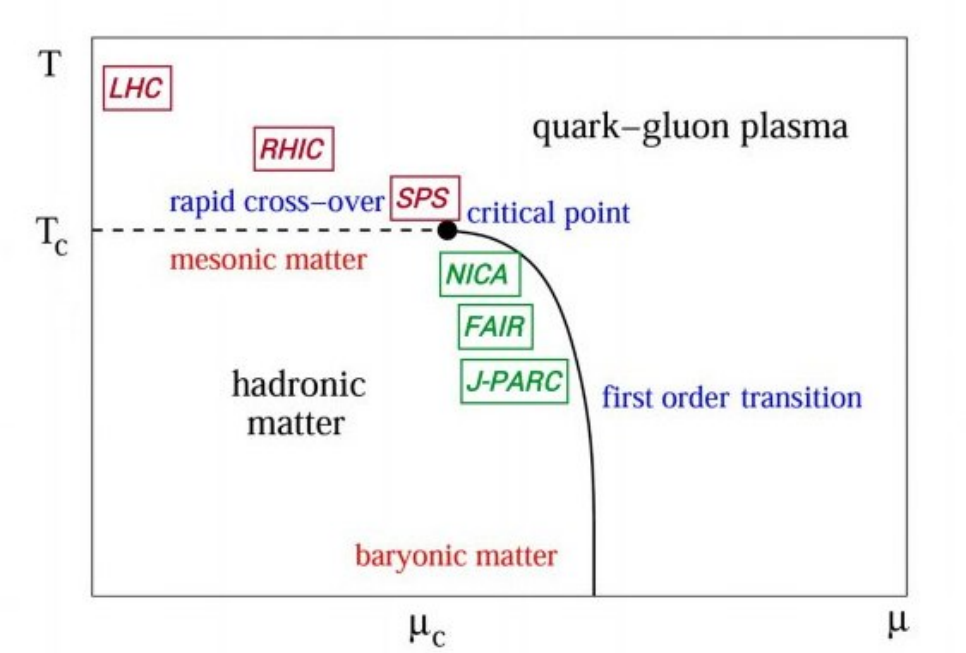

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[Gazdzicki et al. PRC 88:024907]

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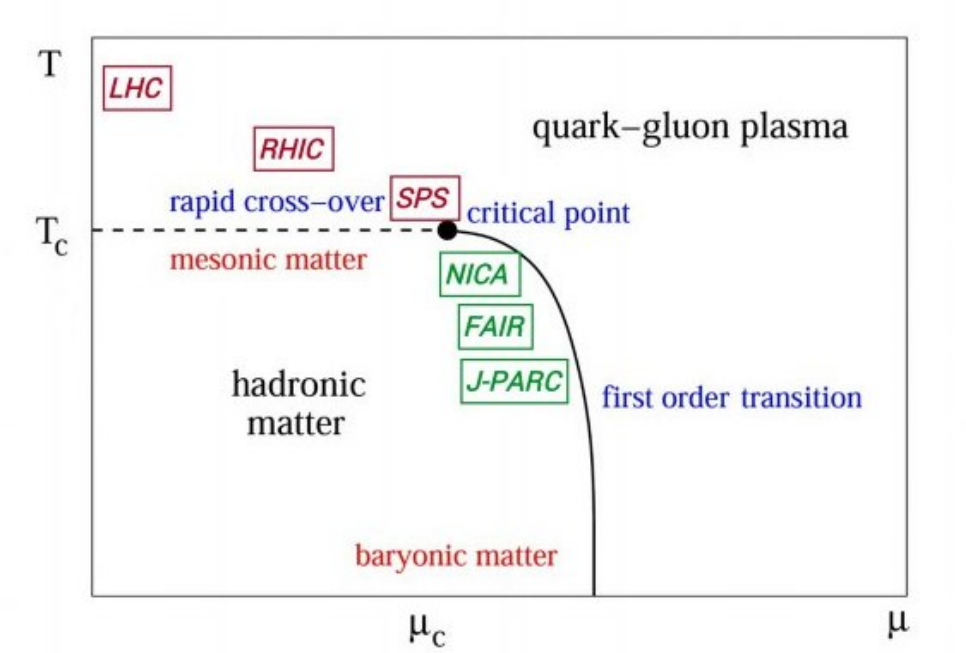

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Scan in system size and beam energy → search for the **critical point**

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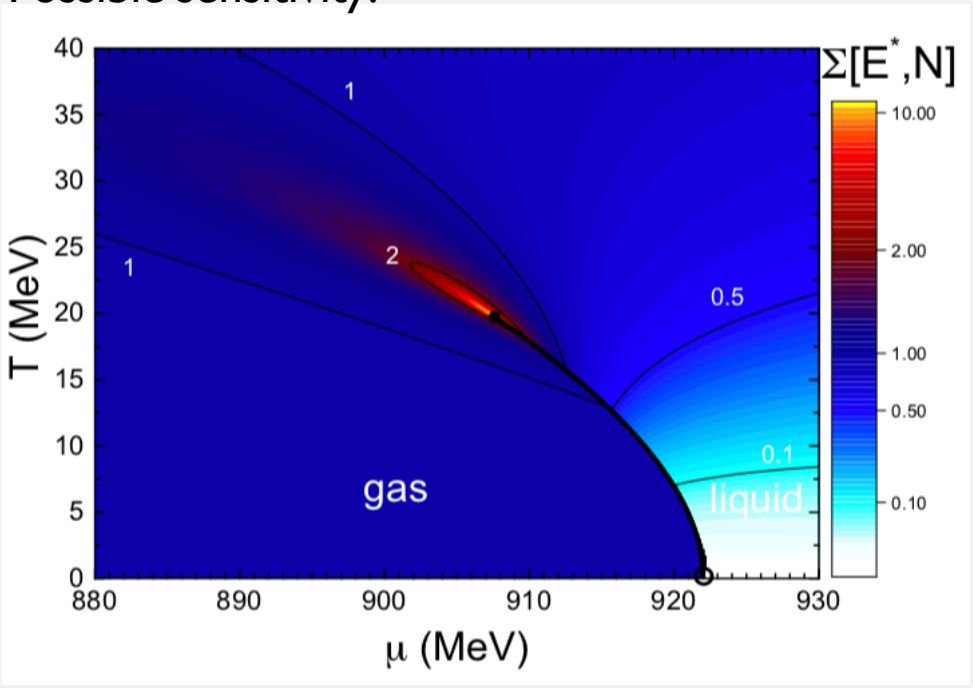

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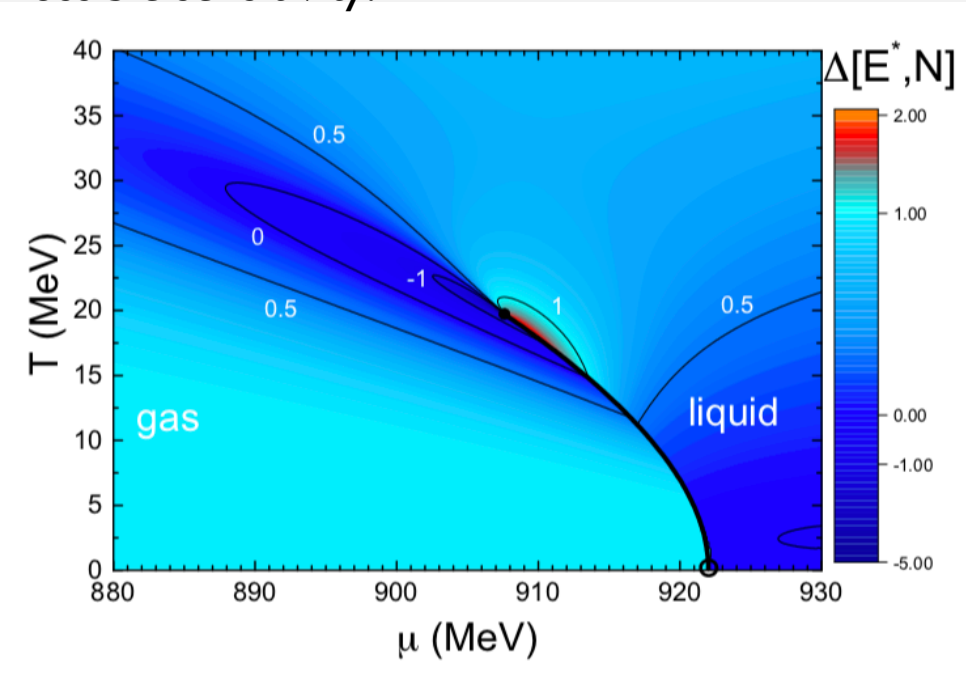

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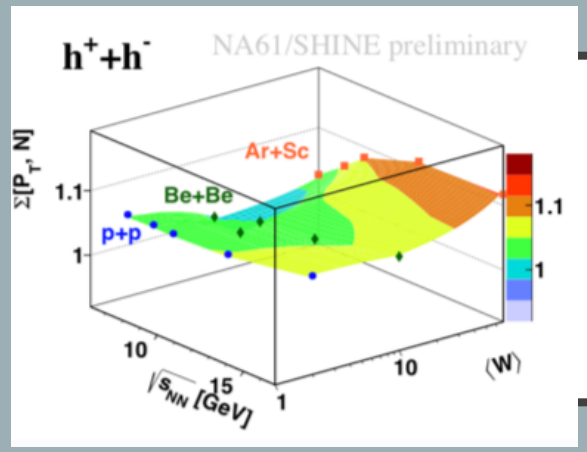

SOME NA61/SHINE RESULTS

REFERENCE VALUES

Moments of **negatively charged hadrons** distribution

ω[h-] = 1
$S\sigma$[h-] = 1
$\kappa\sigma^2$[h-] = 1

ω[h-] = 0
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Moments of **net charge** distribution (h+ - h-)

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Scellam distribution - works if h+ and h– are distributed according to independent Poisson distributions

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Moments of **net charge** distribution (h+ - h-)

Scellam distribution - works if h+ and h– are distributed according to independent Poisson distributions

ω[h+ - h-] = $(\mu_+ + \mu_-)/(\mu_+ - \mu_-)$
$S\sigma$[h+ - h-] = $(\mu_+ - \mu_-)/(\mu_+ + \mu_-)$
$\kappa\sigma^2$[h+ - h-] = 1

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Moments of **negatively charged hadrons** distribution

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simple reference
(a single number)

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Scellam distribution - works if h+ and h– are distributed according to independent Poisson distributions

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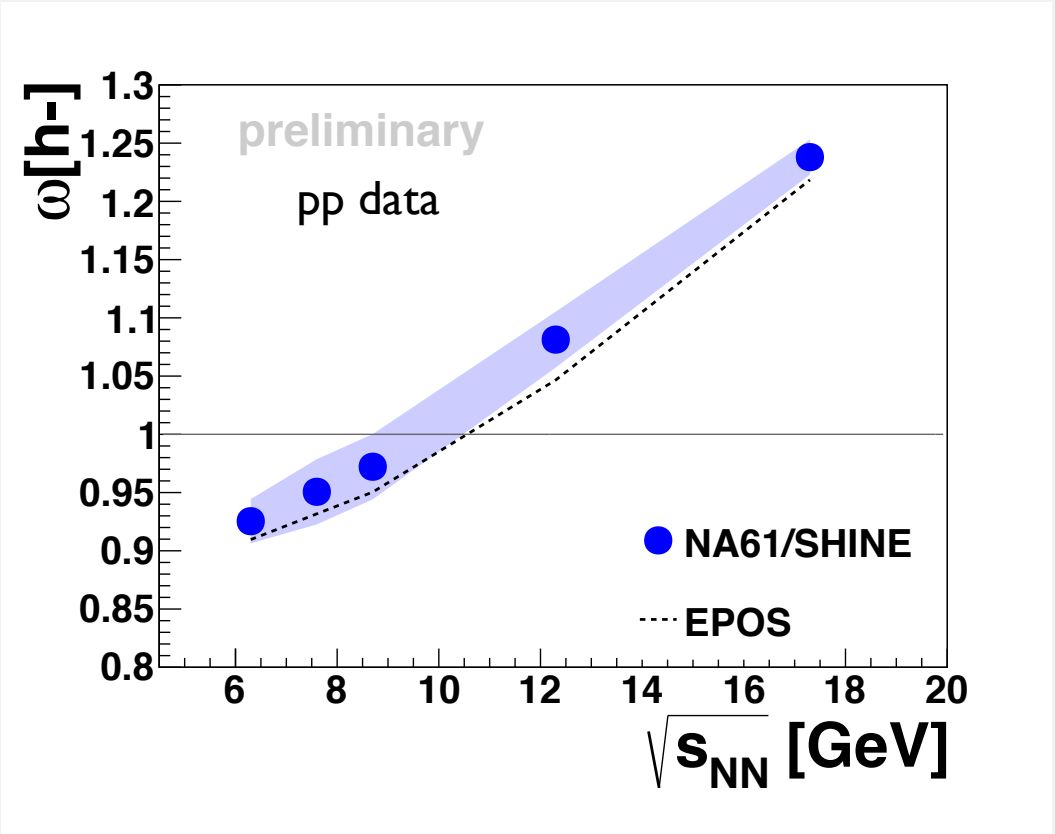
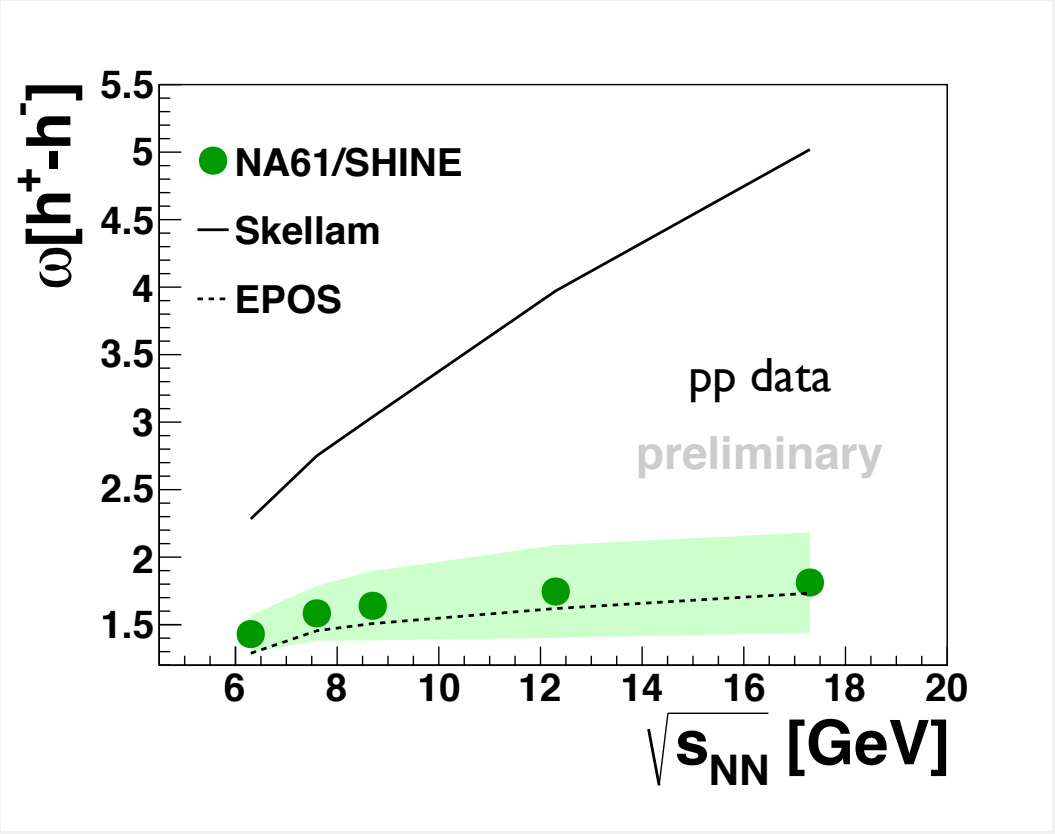
$S\sigma$[h+ - h-] = $(\mu_+ - \mu_-)/(\mu_+ + \mu_-)$
$\kappa\sigma^2$[h+ - h-] = 1

complicated one
(depends on mean values)

SOME NA61/SHINE RESULTS: SCALED VARIANCE





Reference lines:

ω[h-] = 1 for independent particle production (Poisson)
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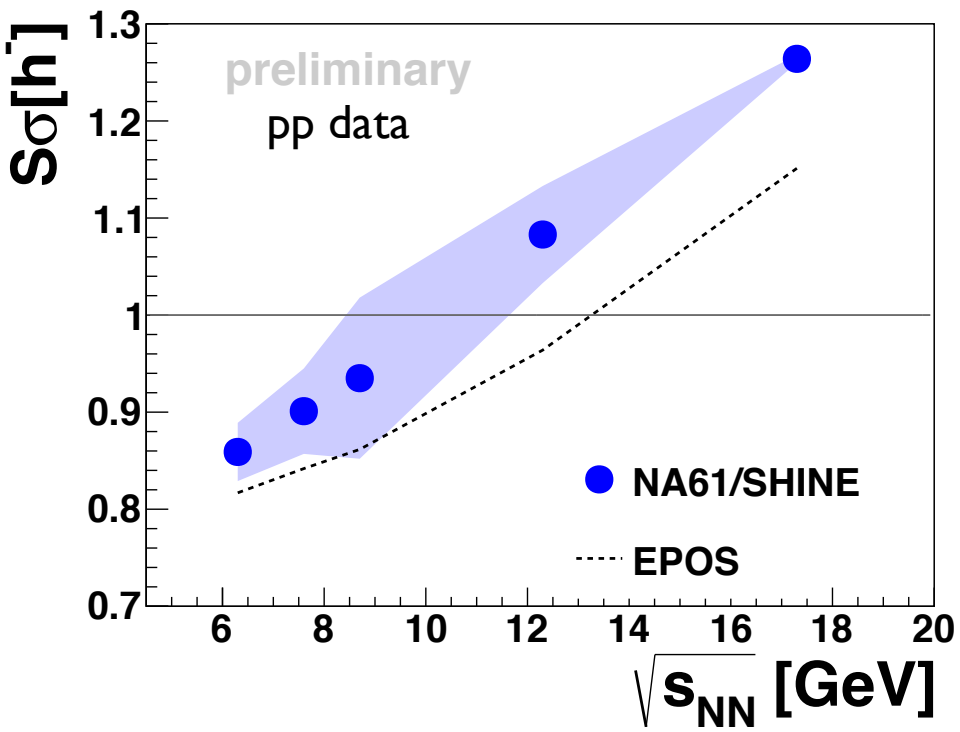
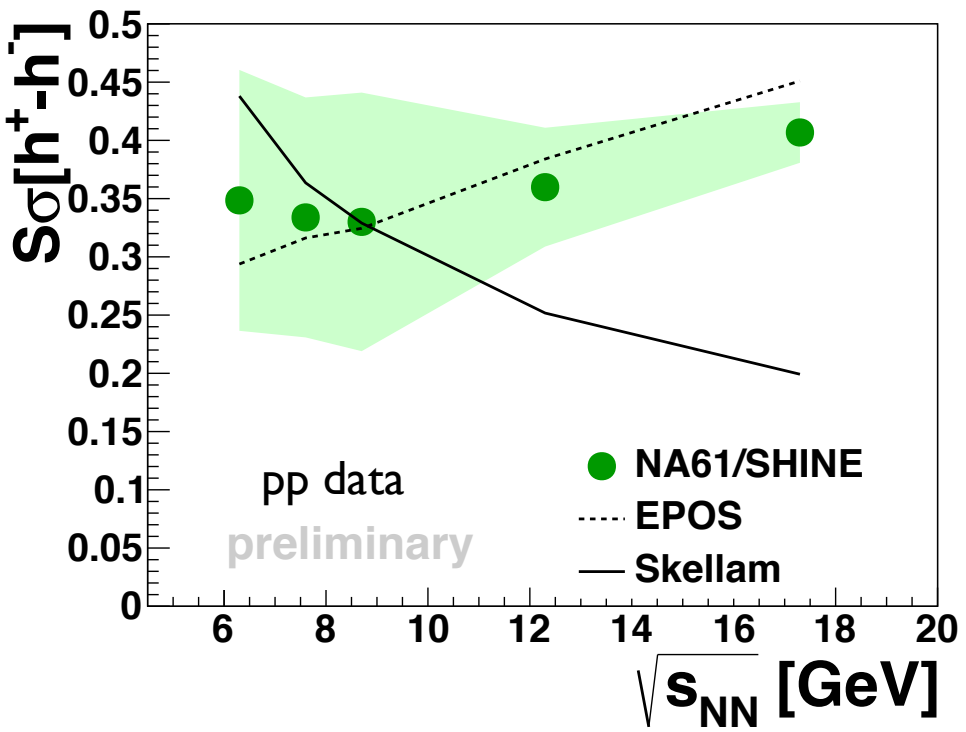
SOME NA61/SHINE RESULTS: SKEWNESS





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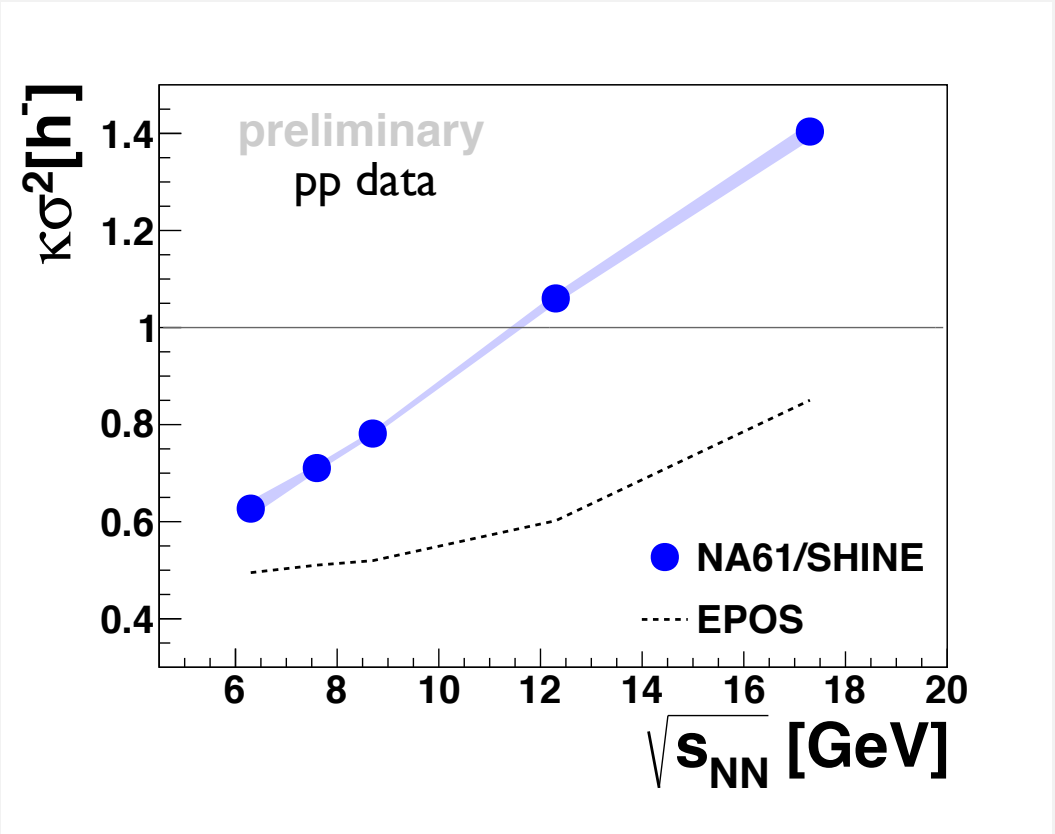
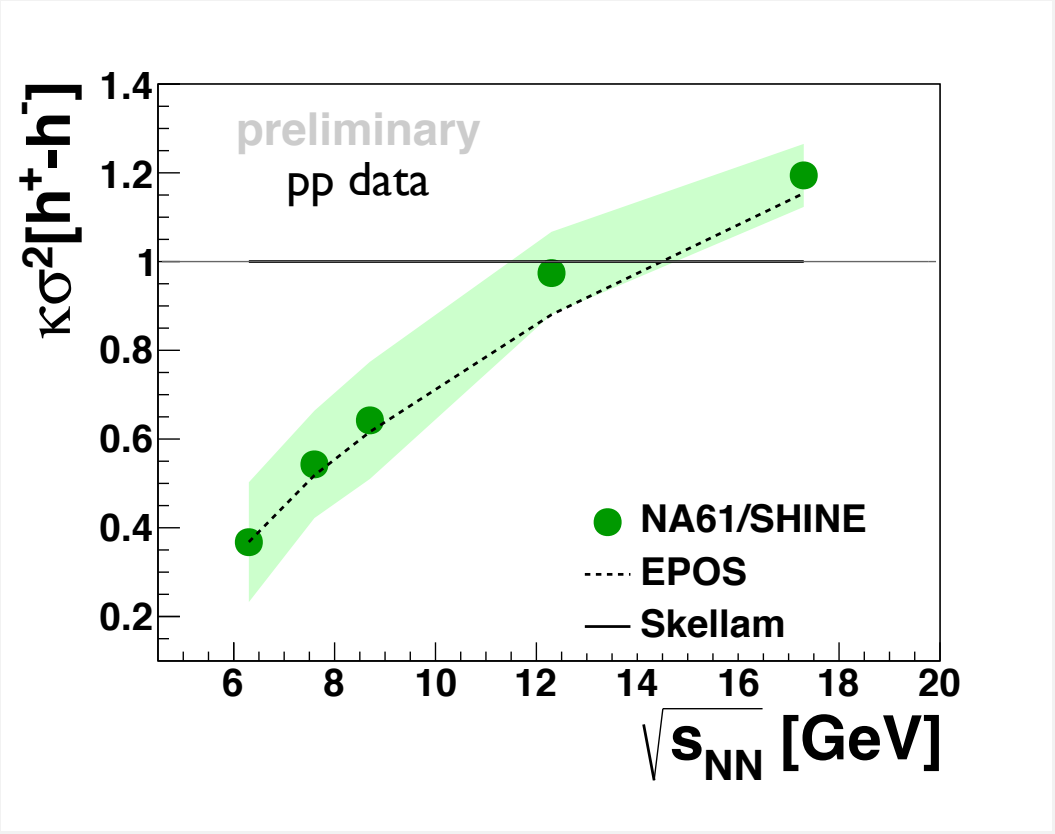
SOME NA61/SHINE RESULTS: KURTOSIS





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SOME NA61/SHINE RESULTS: SIQ

Strongly intensive quantities

$$\Sigma[P_T, N] = \frac{1}{C_\Sigma}\left[\langle N\rangle\omega[P_T] + \langle P_T\rangle\omega[N] - 2\cdot(\langle P_T\cdot N\rangle - \langle P_T\rangle\langle N\rangle)\right]$$

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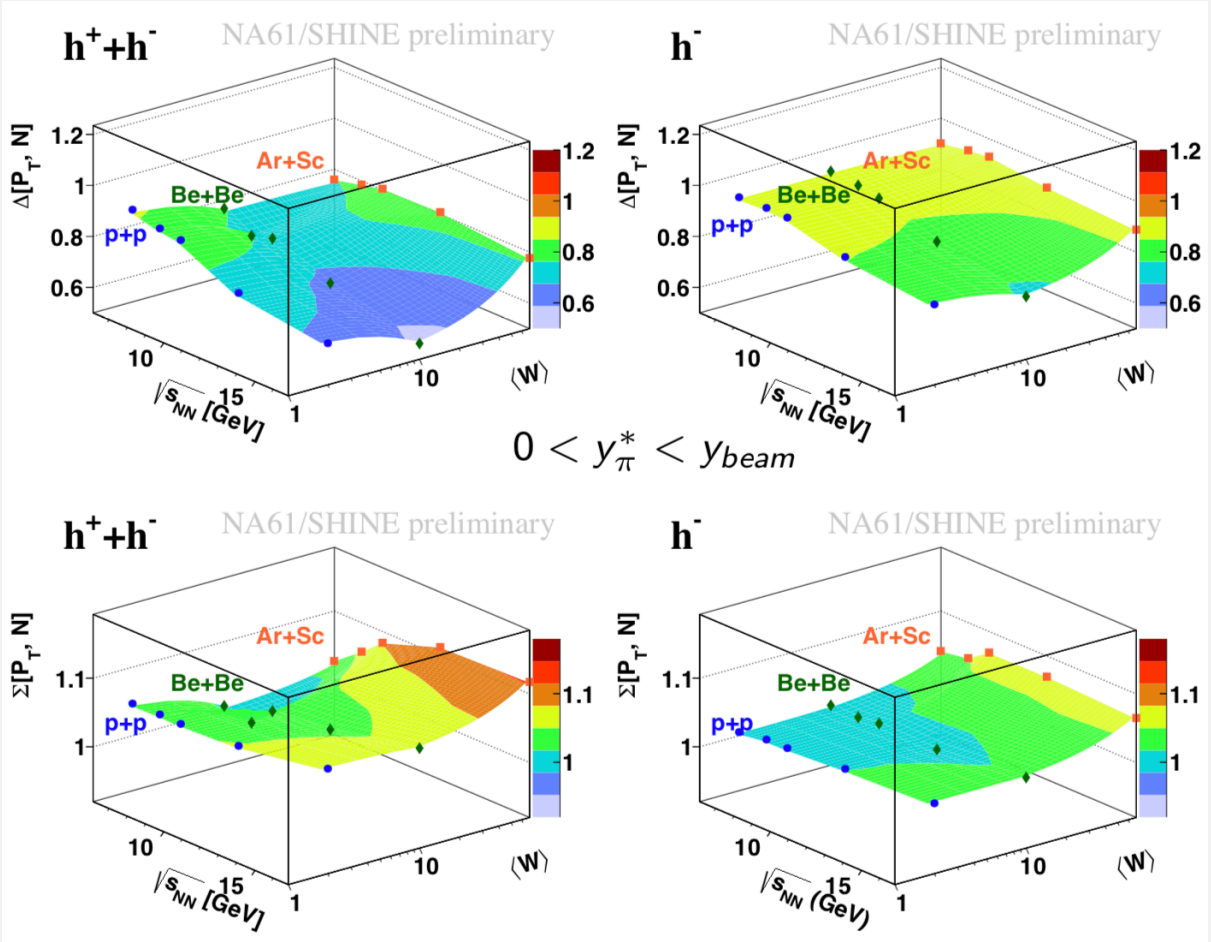

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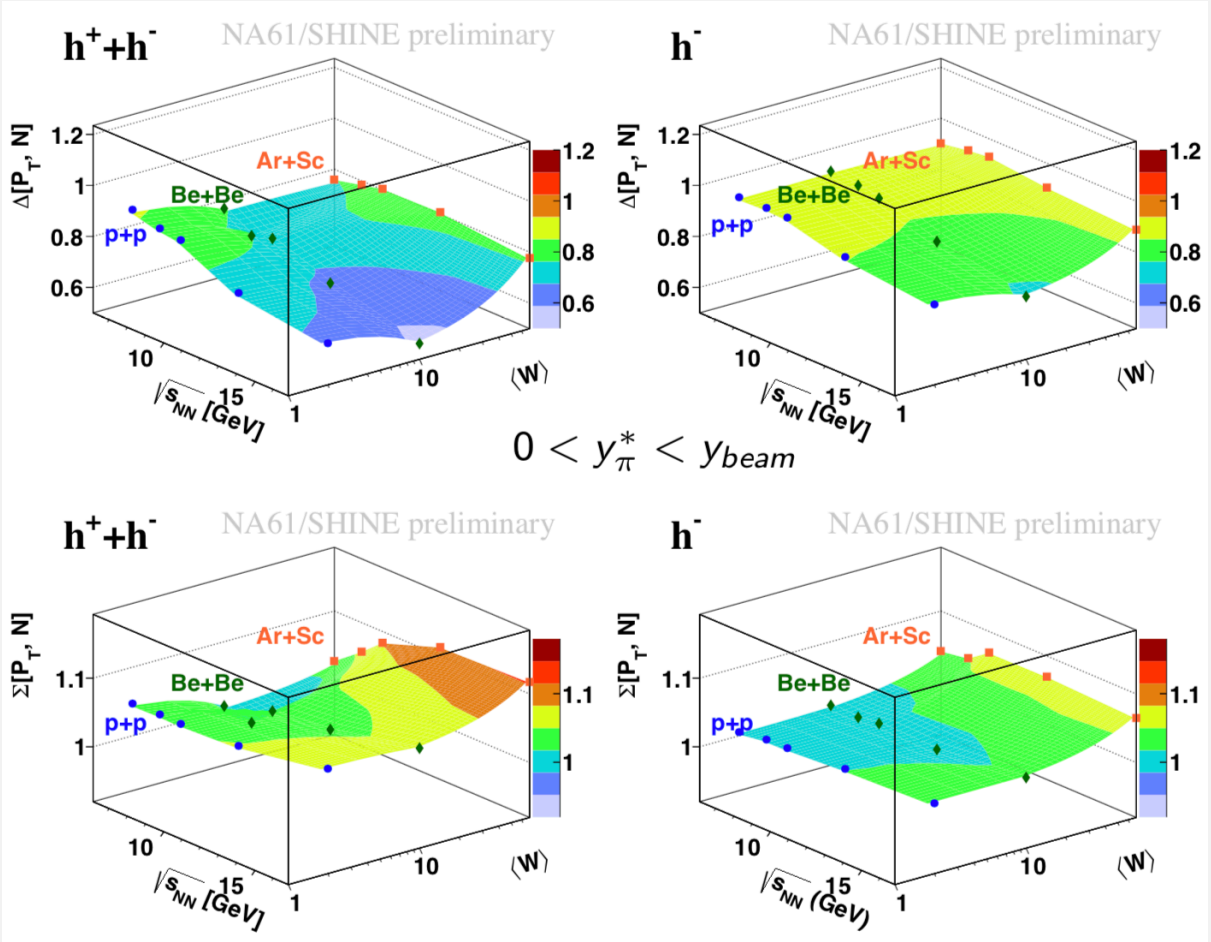

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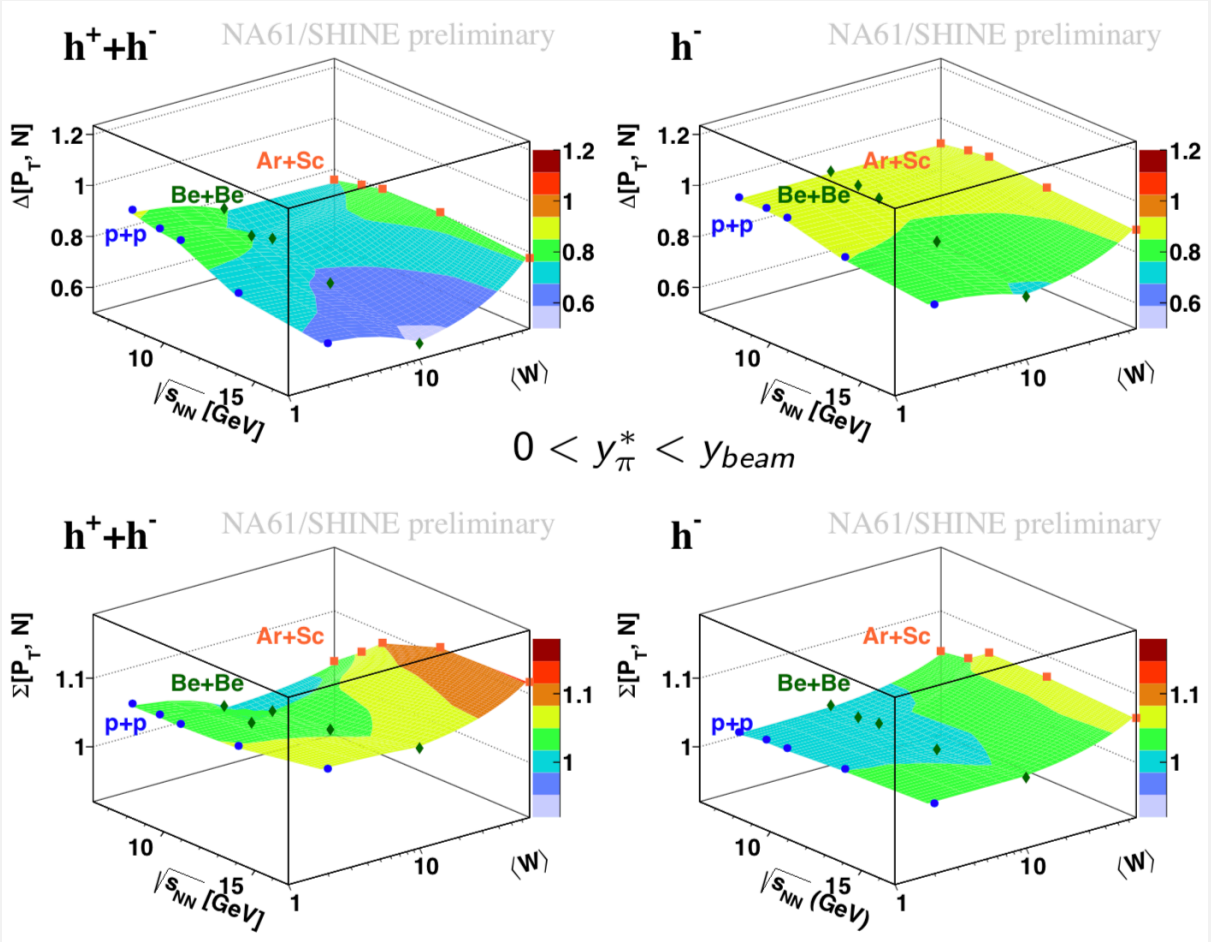

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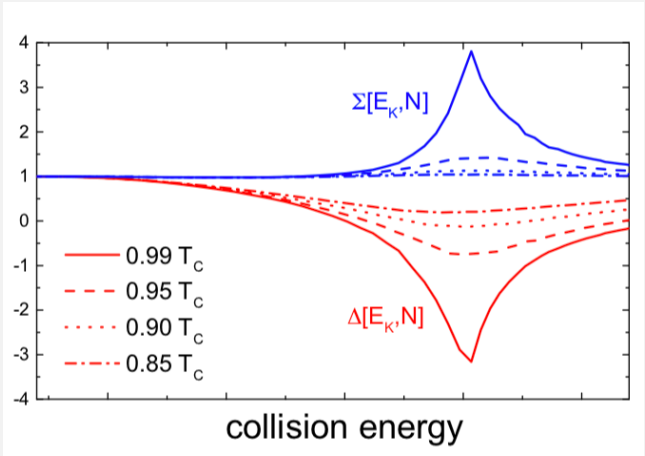

Nucleon system with van der Waals EOS in GCE formulation in the vicinity of the Critical Point

[Vovchenko, Gorenstein, Stoecker, PRL 118: 182301, Vovchenko, et al., JPA 48: 305001]

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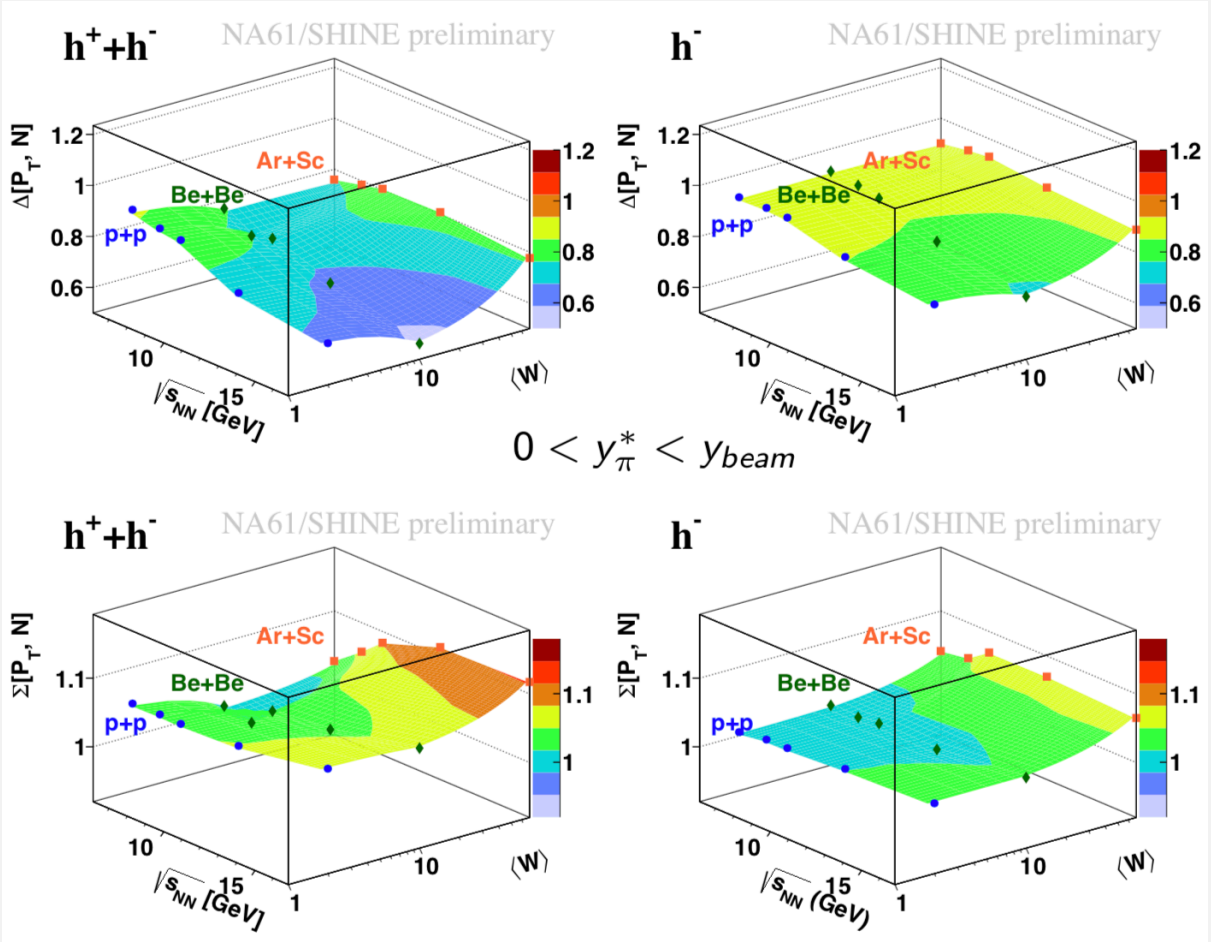

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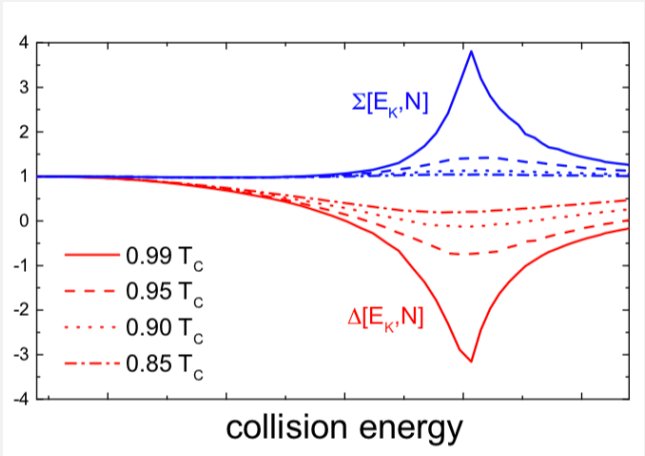

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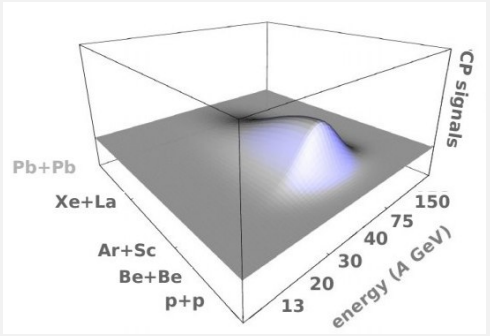

Naive sketch

[Gazdzicki, M., Seyboth, P. *Acta Phys. Pol. B* **47**, 1201 (2016)]

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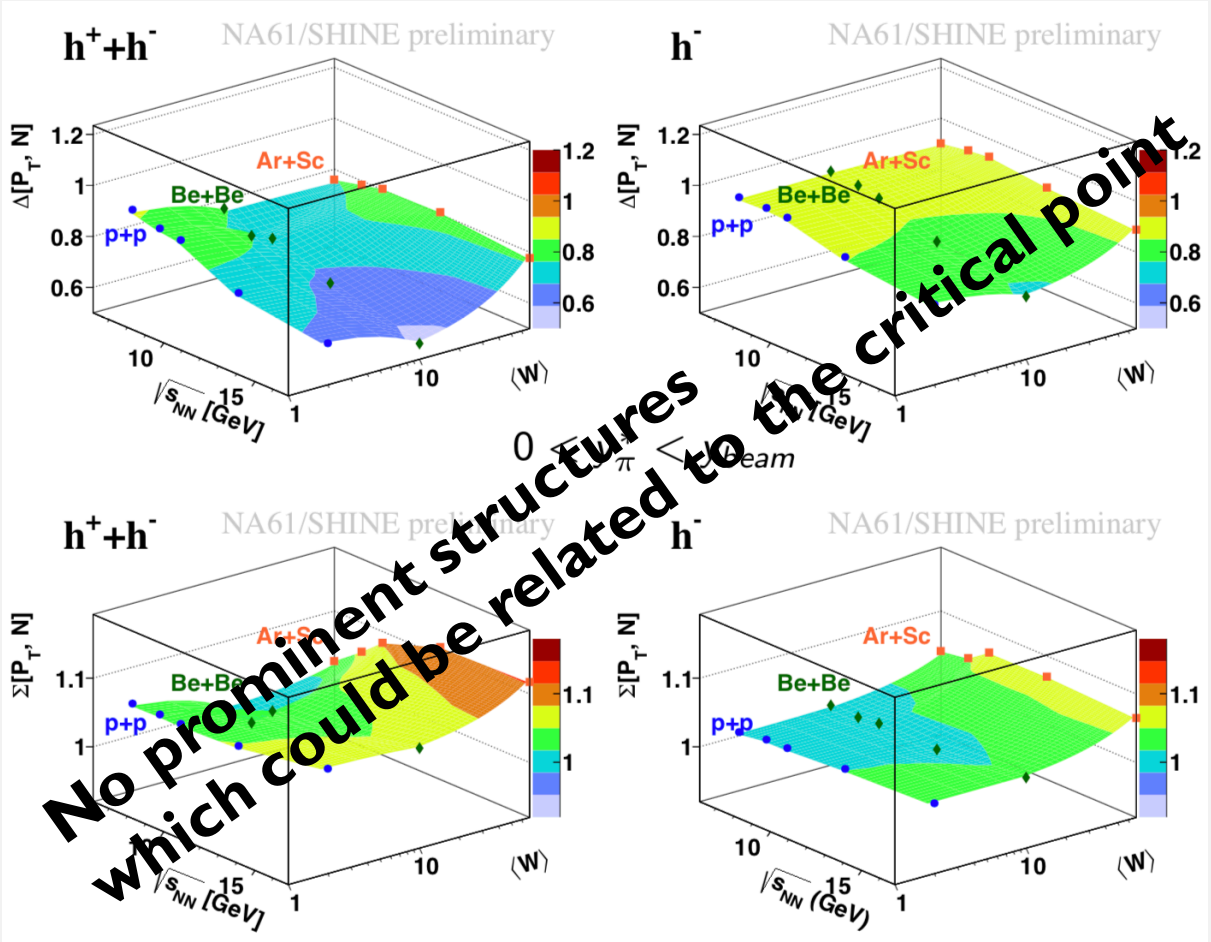

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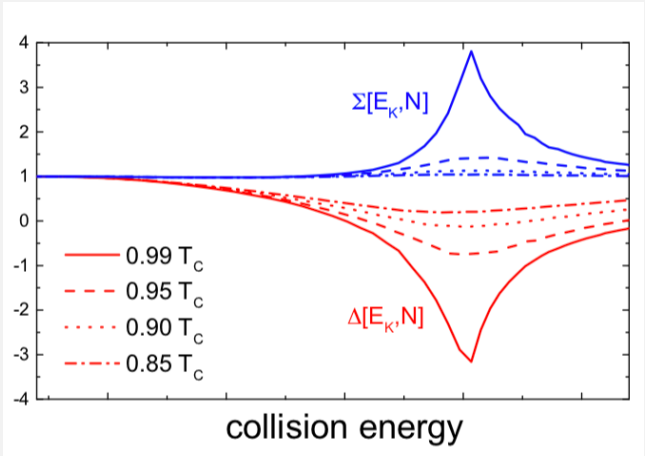

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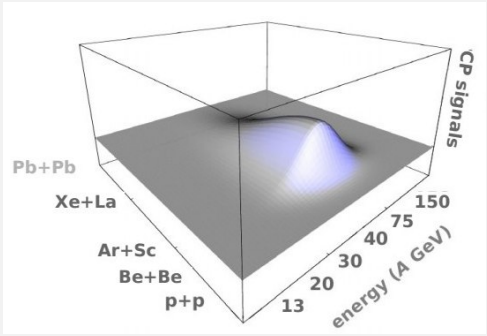

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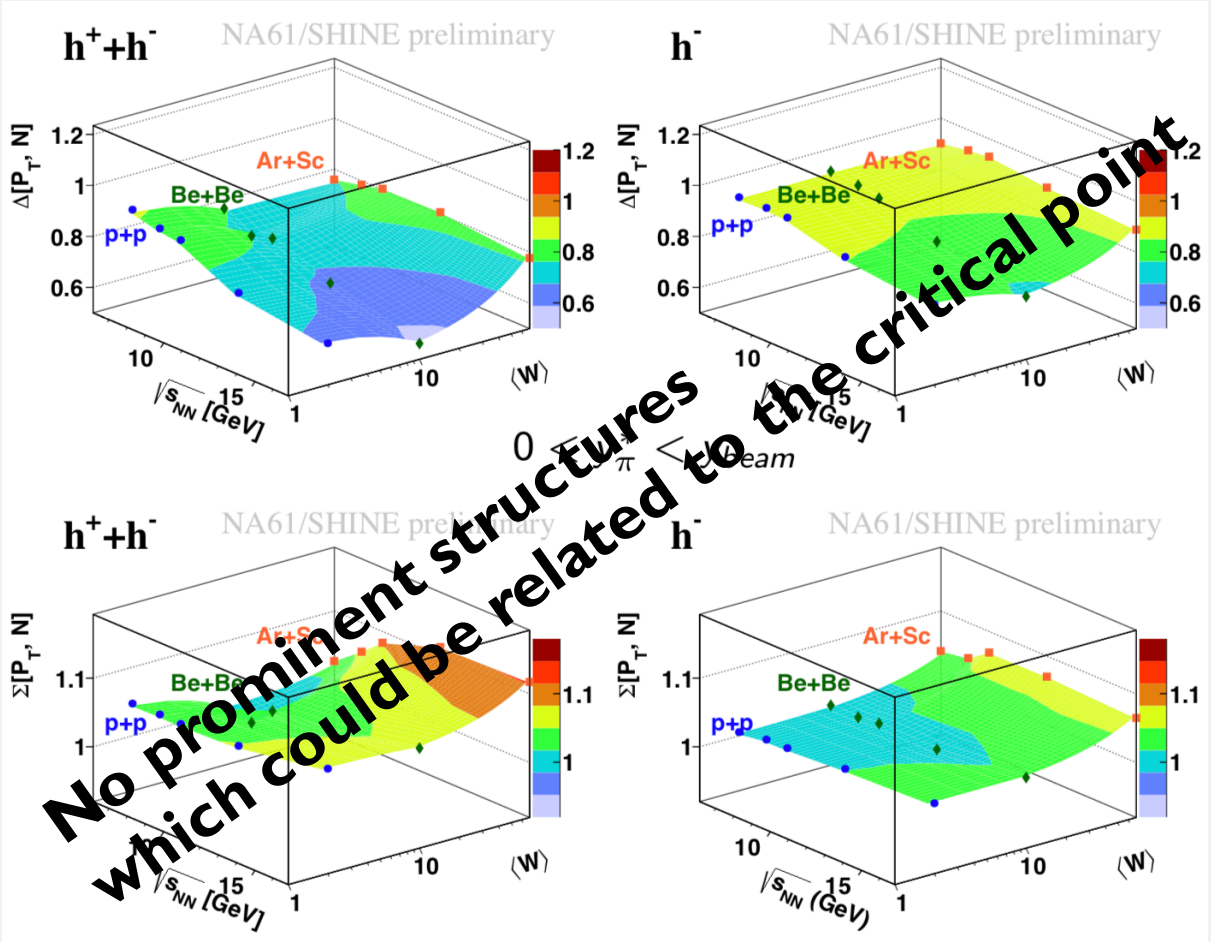

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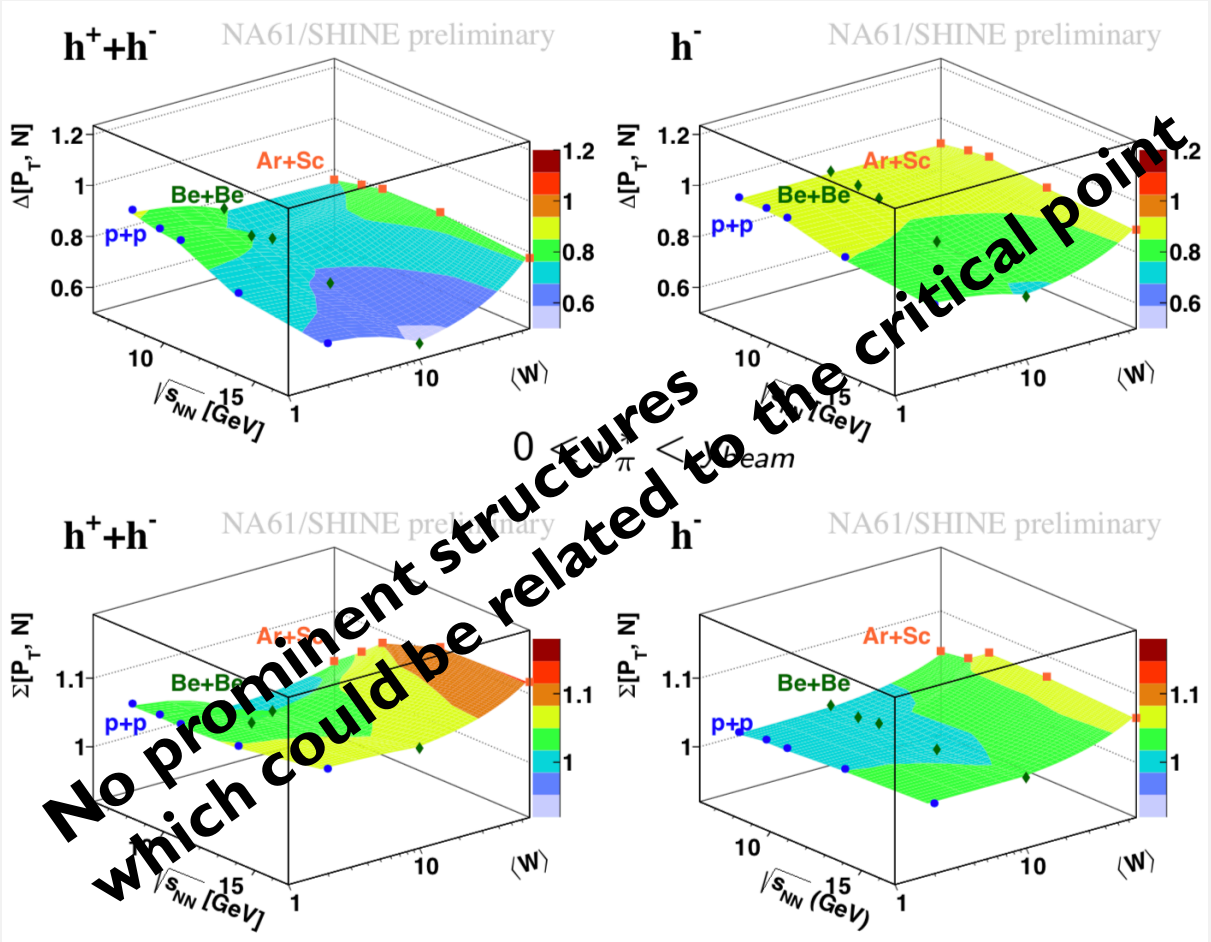

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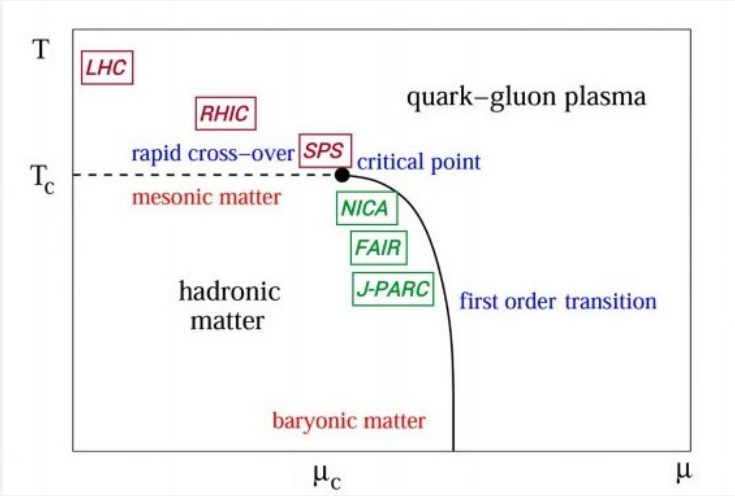
Becattini F, Manninen J and Gazdzicki M PRC 73 044905



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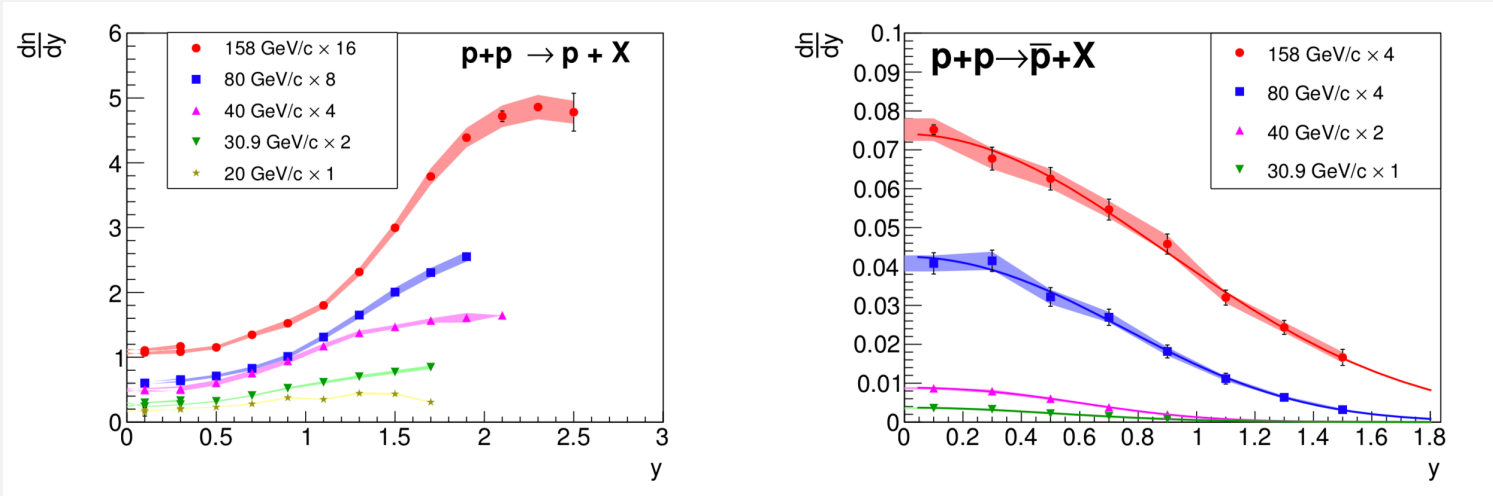

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Moreover, the ratio of p and $\bar{p}$ changes significantly with rapidity in inelastic p + p at the SPS energies

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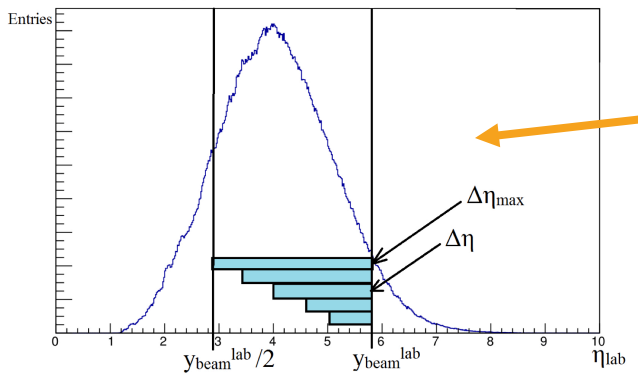
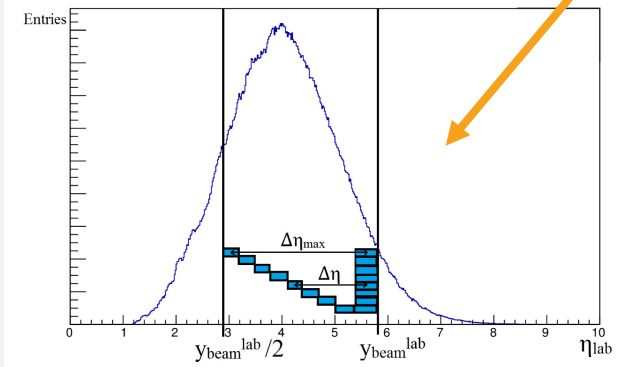


[D. Prokhorova, KnE Energ. Phys. 3 (2018) 217–225]



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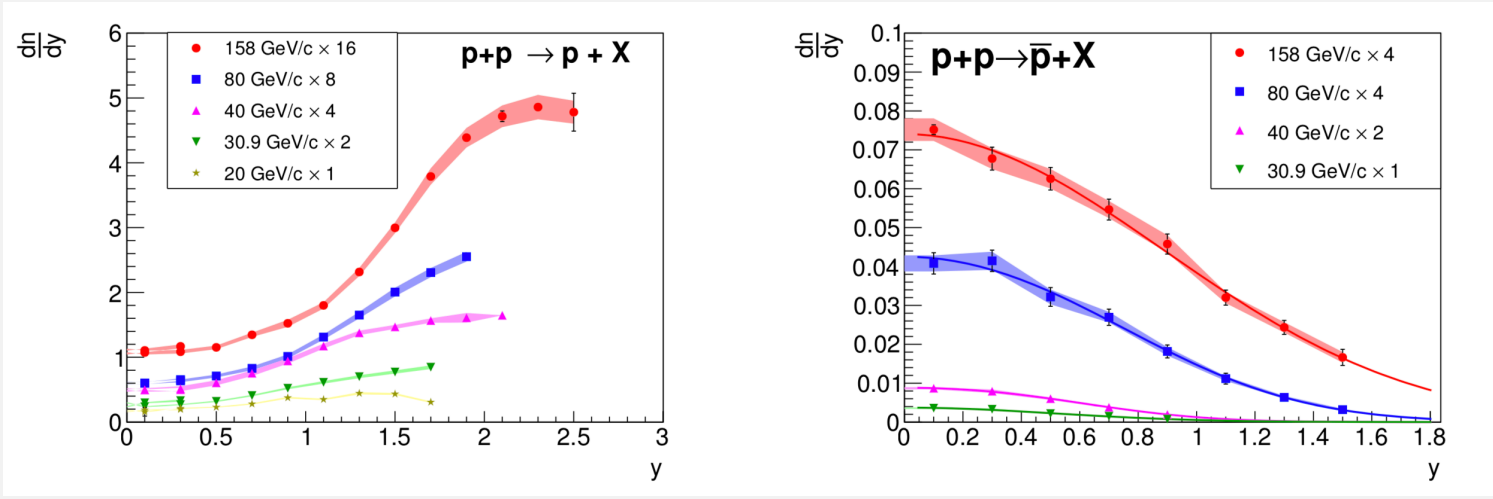

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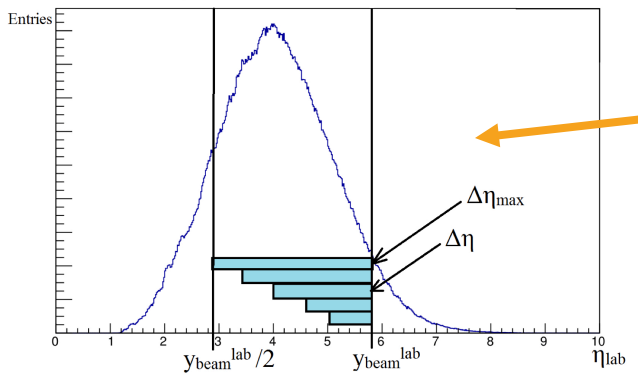

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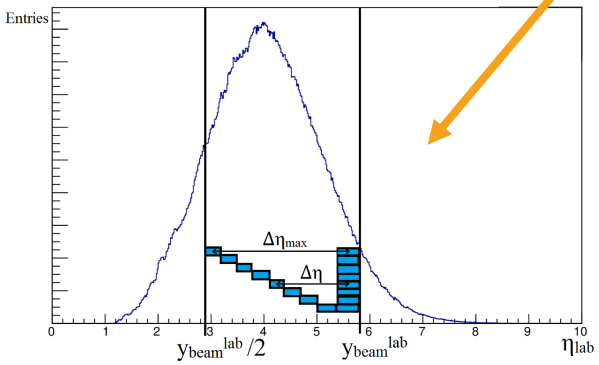

In this case we also probe the short- and long-range correlations and access the information about particle sources

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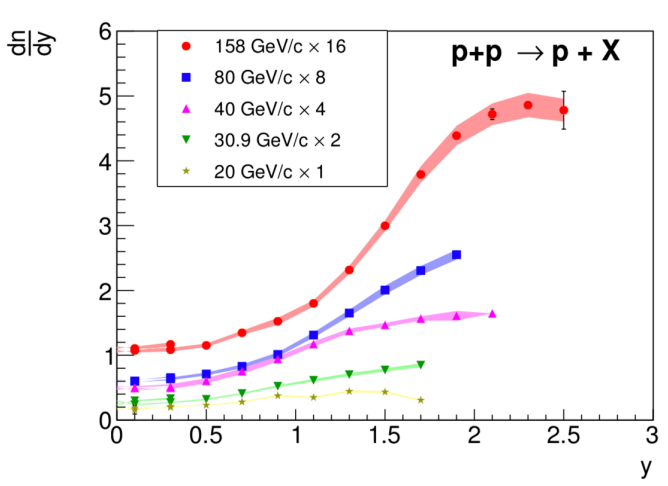

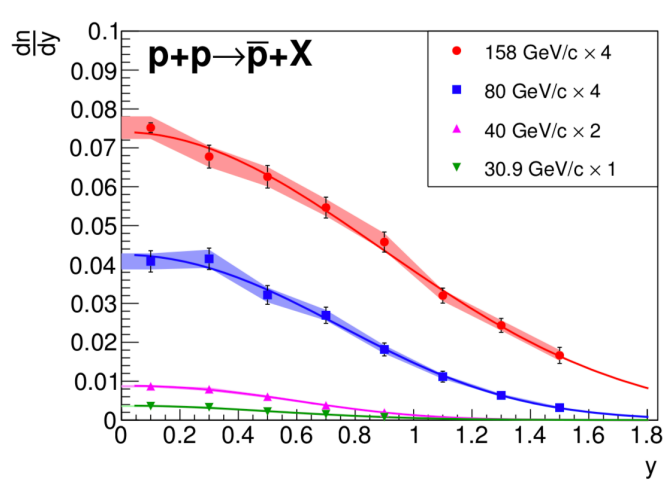

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FLUCTUATION STUDIES WITH PSEUDORAPIDITY

Strongly intensive variables defined in two kinematically separated regions

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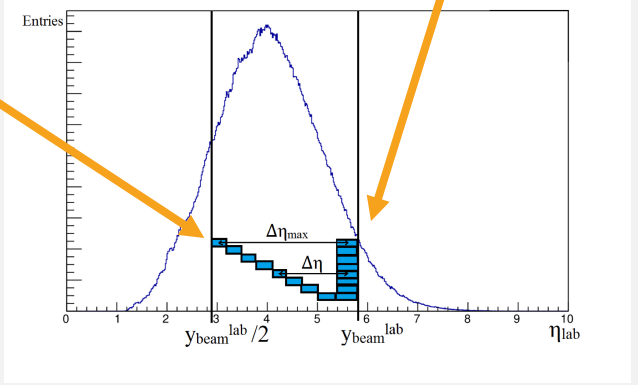
N_F

N_B

[D. Prokhorova, EPJ Web of Conferences **204**, 07013 (2019)]



uncorrected rapidity distribution of all charged hadrons produced in p + p @158 GeV/*c* in NA61/SHINE experimental acceptance

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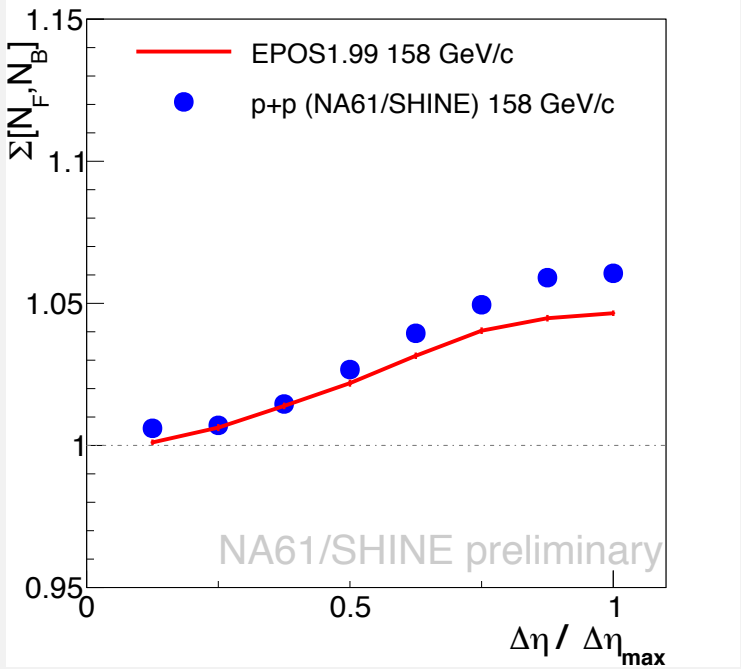

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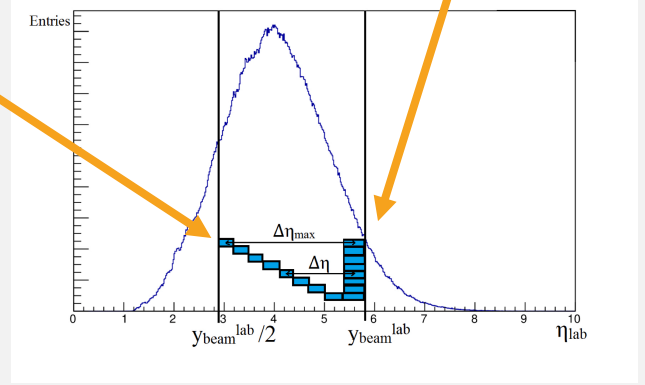

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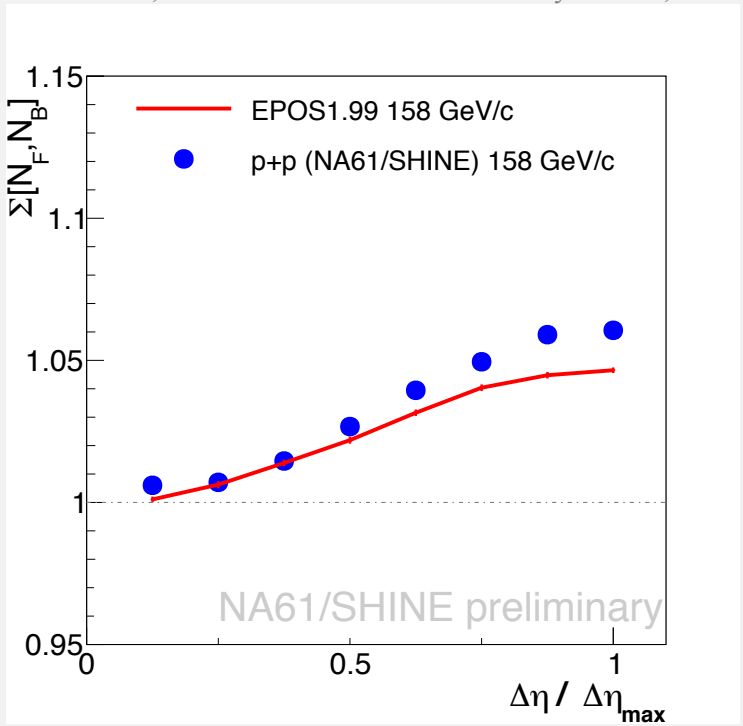

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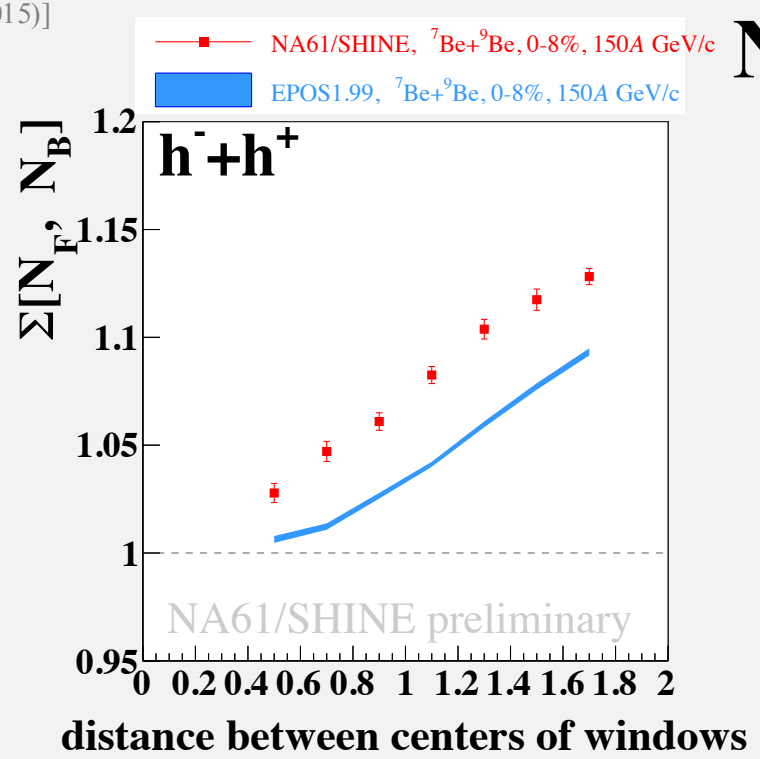

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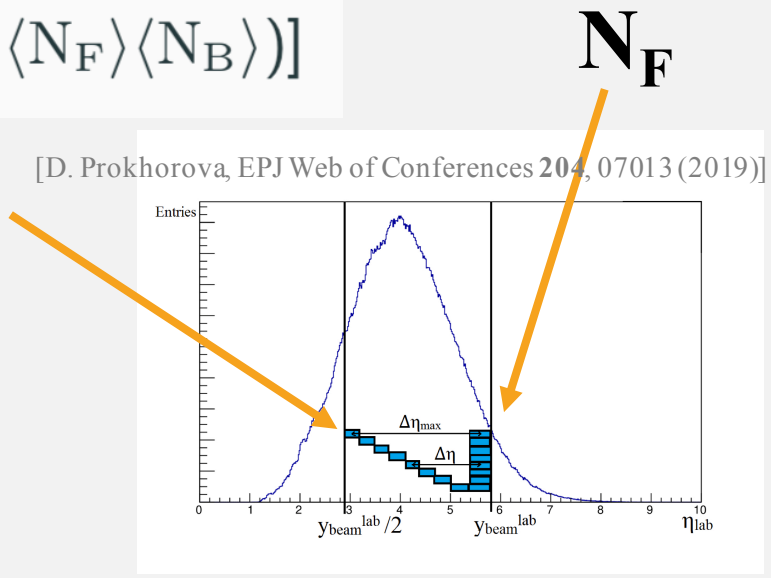

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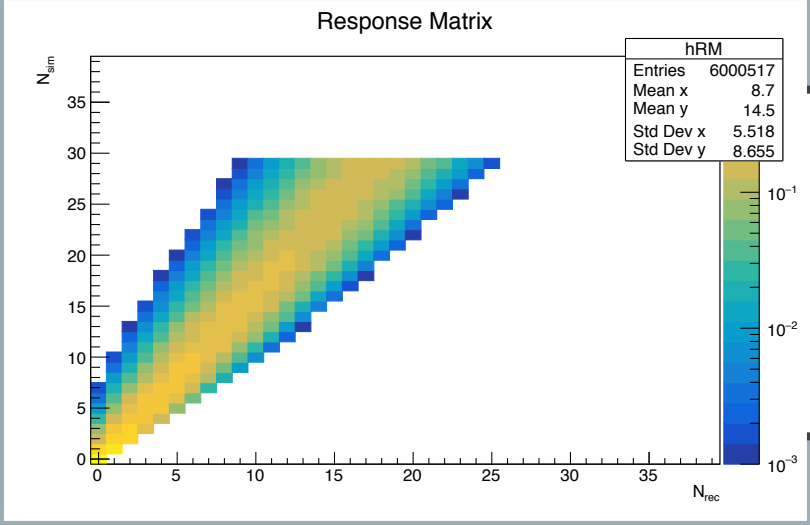

RESULTS CORRECTIONS

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Issues– detector inefficiencies:

1. Loses of events – trigger biases
2. Loses or gains of tracks – event migration in multiplicity histogram

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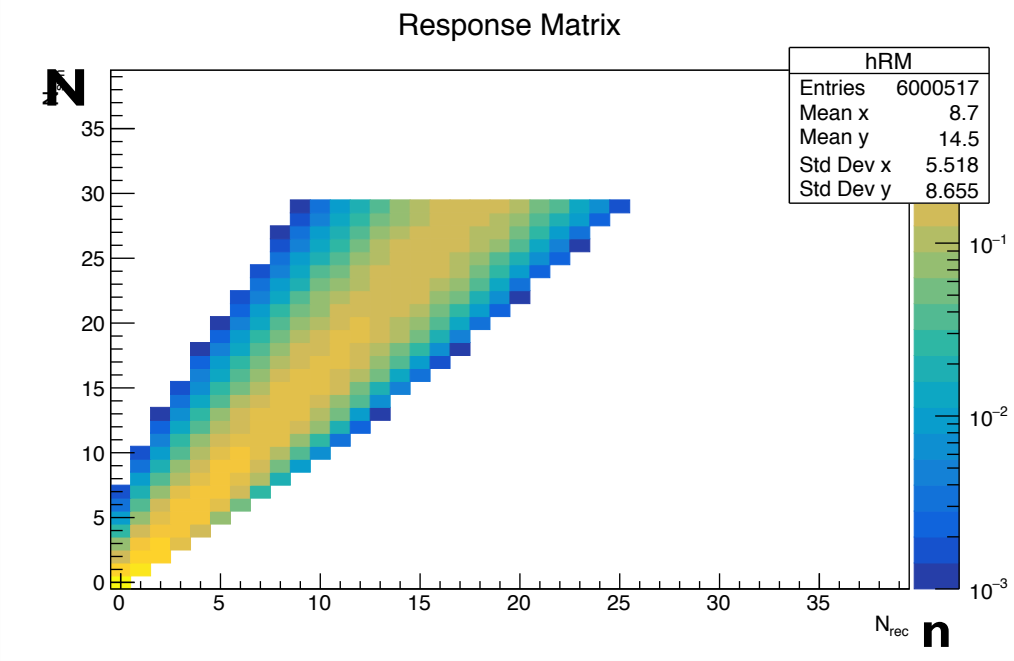

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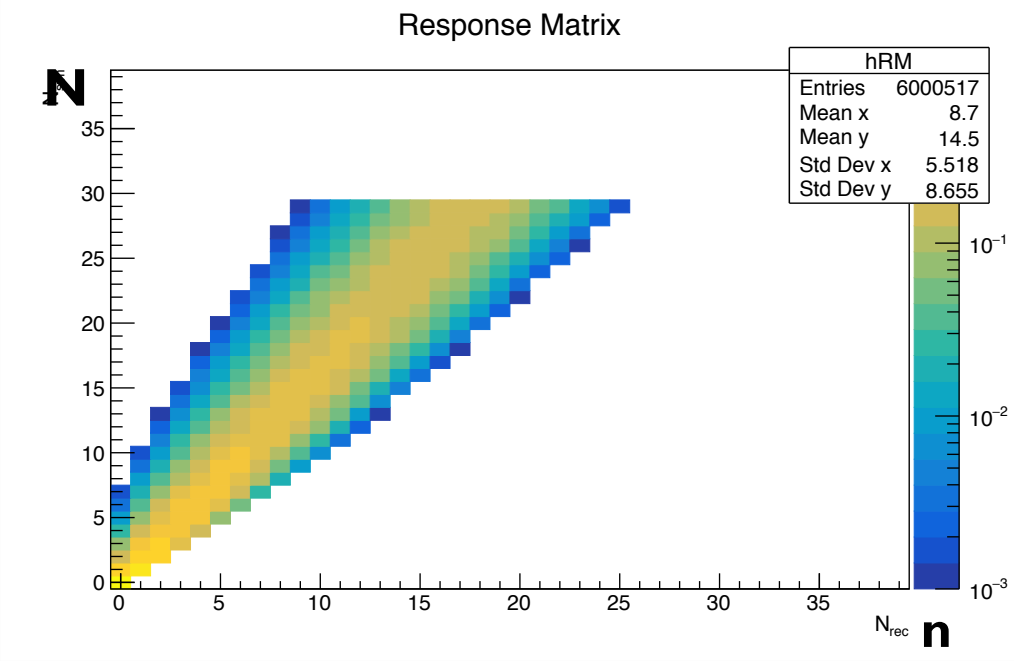
- Response Matrix represents the probability to measure *n* in the event with the real quantity equal to N
- Event loses are considered in the Response Matrix normalization



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Issues– detector inefficiencies:

corrections of the results are needed

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- correction of the **Measured Moments** of Distribution (based on T. Nonaka, M. Kitazawa, S. Esumi, arXiv:1805.00279 (NIMA 906 (2018) 10))

CONCLUSION

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The detailed analysis of the accumulated experimental data is continued. **Stay tuned!**

NA61/SHINE Collaboration Meeting at St. Petersburg, 2018

Have a SHINY day!

THANK YOU FOR YOUR ATTENTION

daria.prokhorova@cern.ch

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