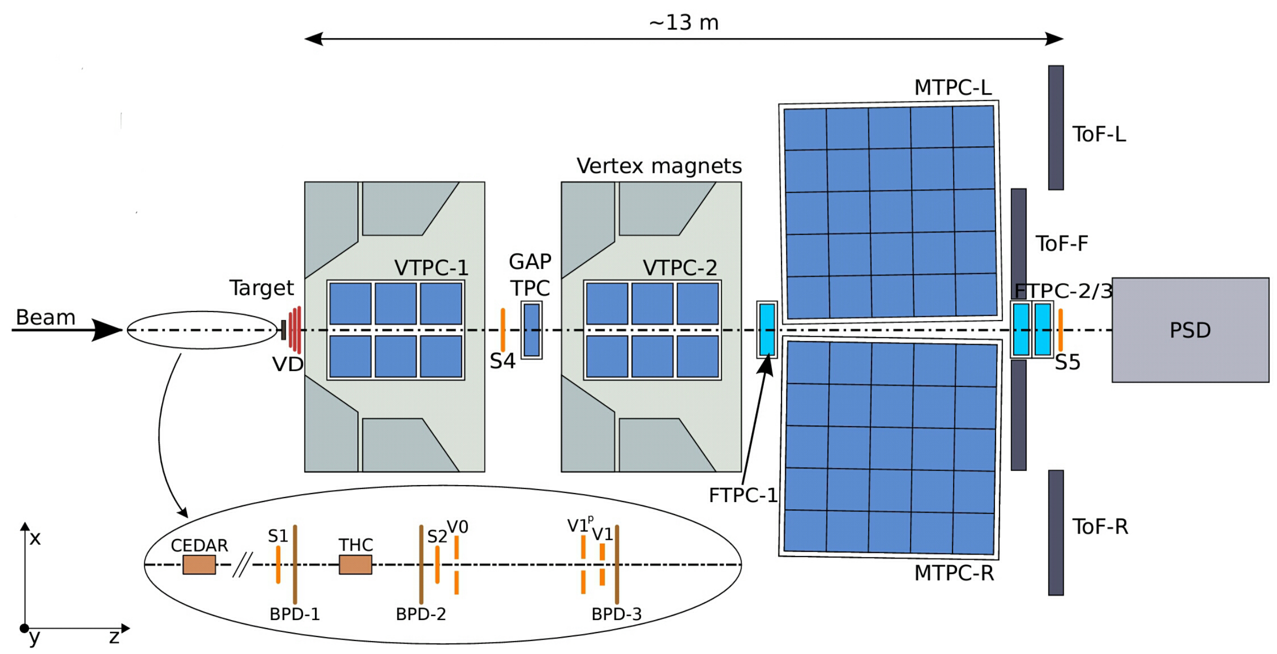
New results from the NA61/SHINE: fluctuations in p+p interactions

Daria Prokhorova, Agnieszka Borucka

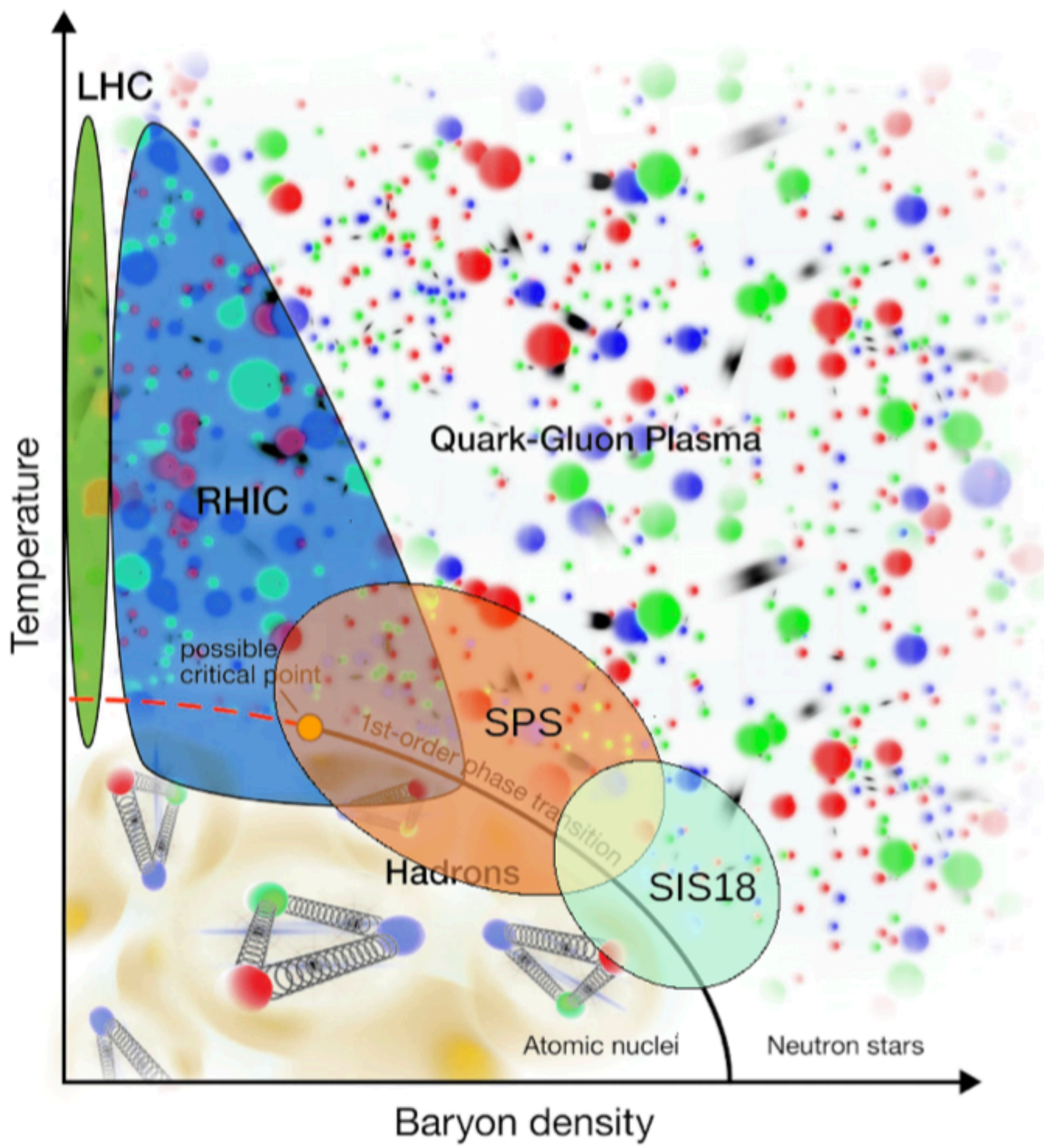
05/02/2021



Outline of my talk

1. Brief introduction to the study of fluctuations in NA61/SHINE
2. Quantities of interest
3. Study of rapidity/pseudorapidity dependence of fluctuations in p+p
4. Energy dependence of fluctuations in p+p

Study the phase diagram of QCD



Strong interactions program of NA61/SHINE:

- study the properties of the onset of deconfinement
- search for the Critical Point of strongly interacting matter

We measure fluctuations of primary hadrons in inelastic events

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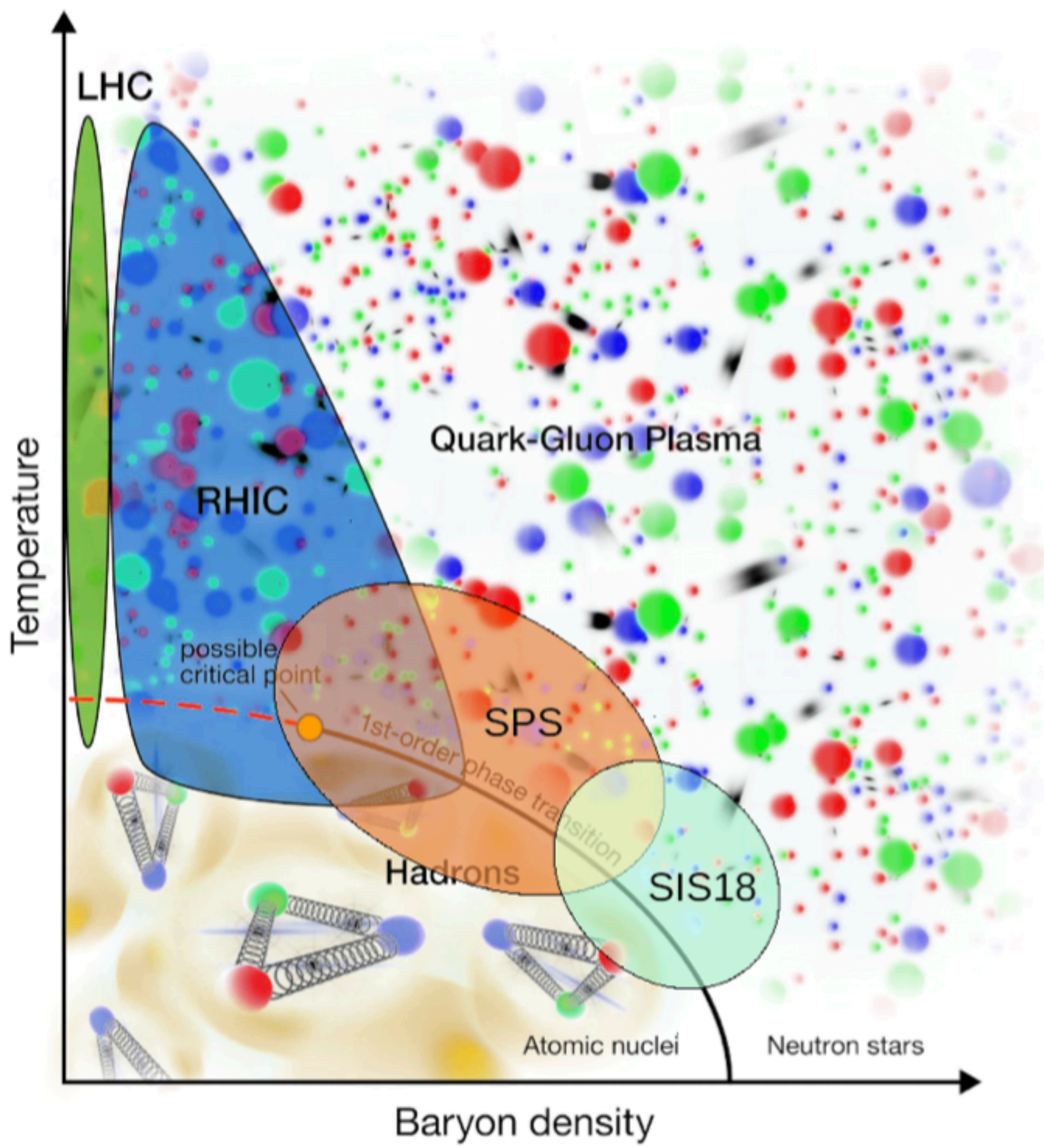
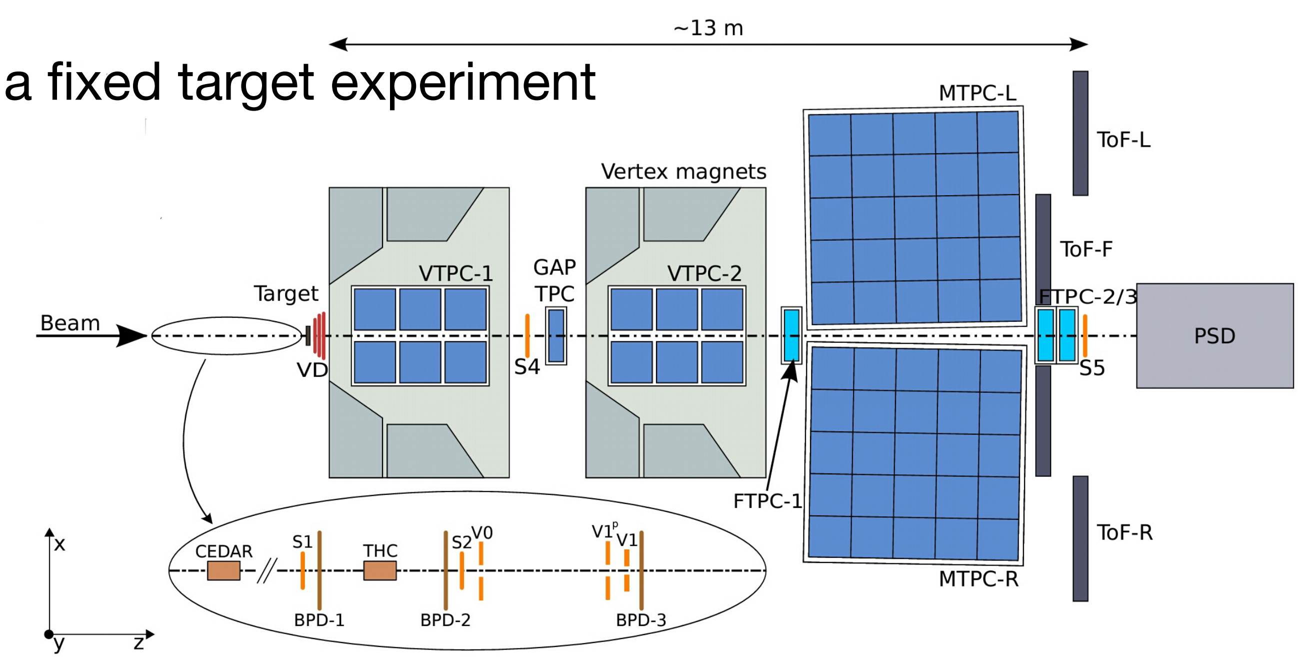


We are a fixed target experiment



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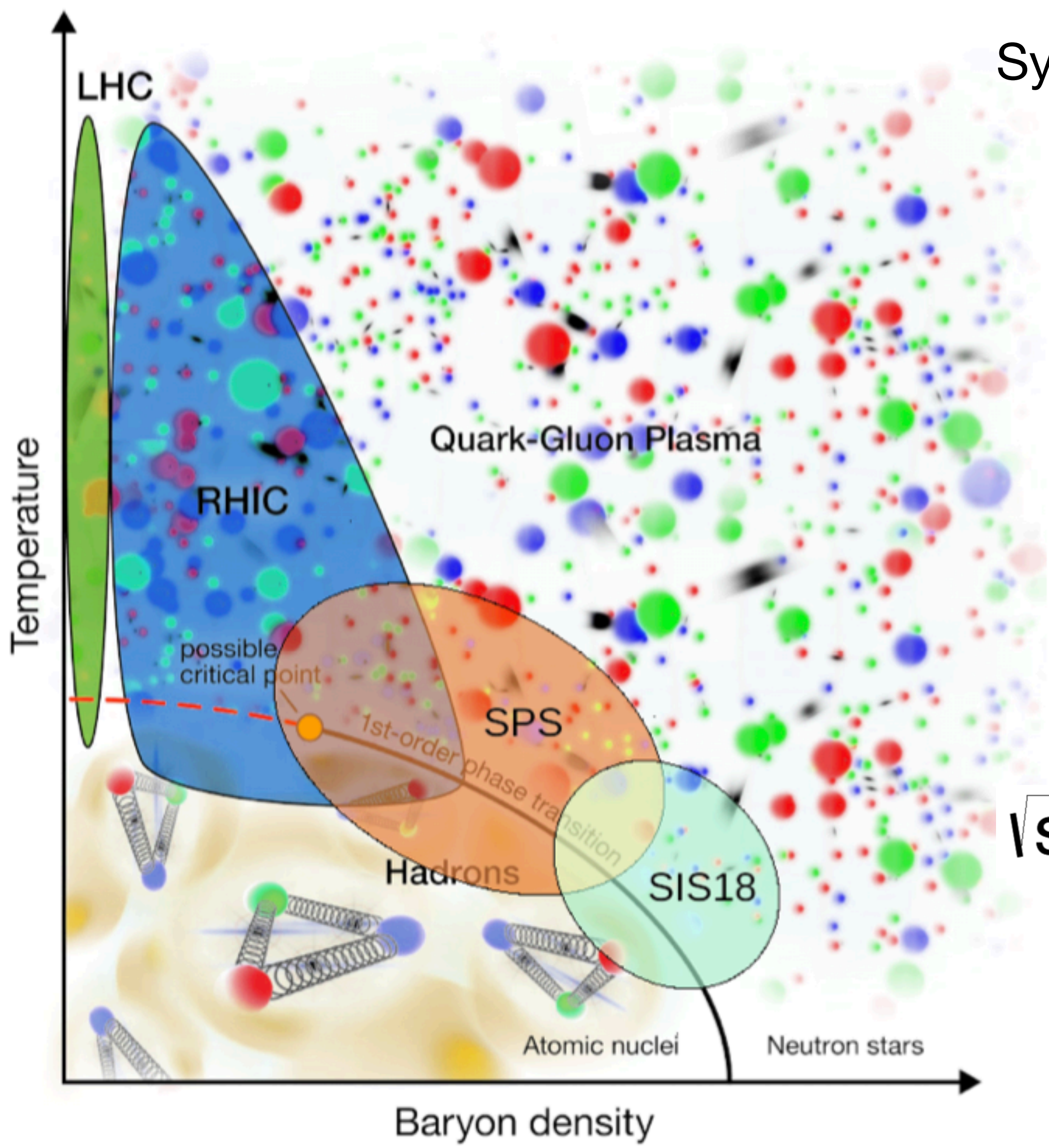
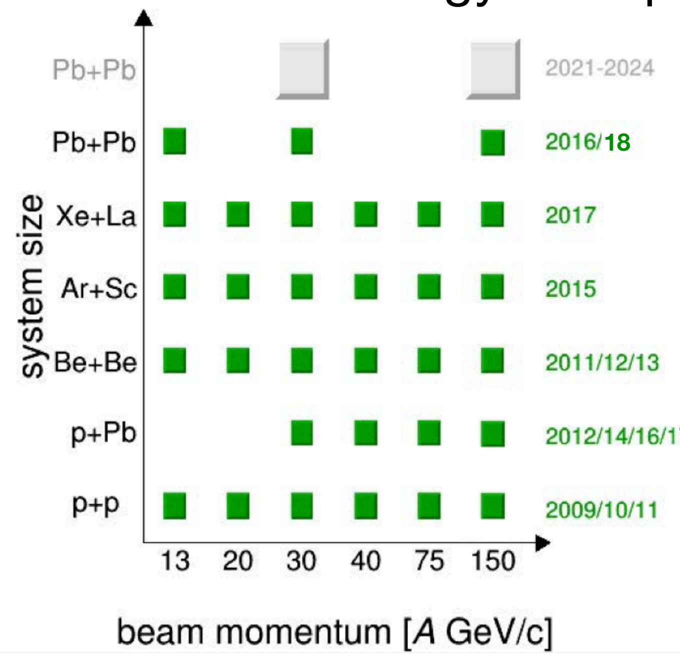
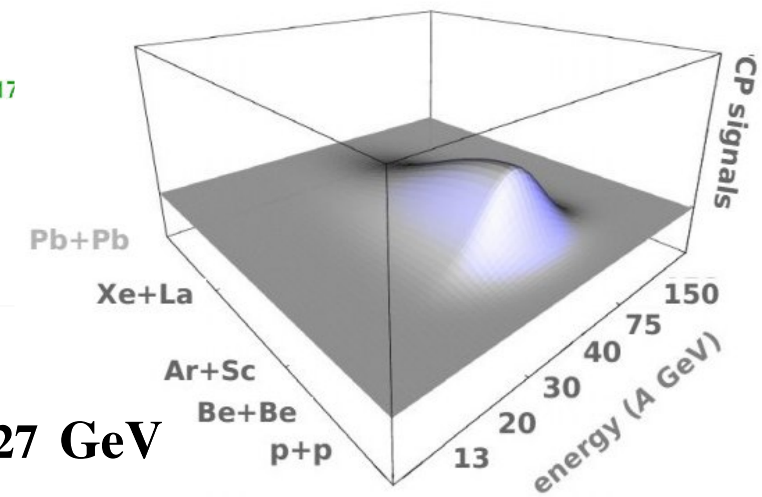


System size-beam energy scan program



Sketch of the possible critical behavior



$\sqrt{s}$ = 5.11 6.27 7.62 8.73 12.32 17.27 GeV

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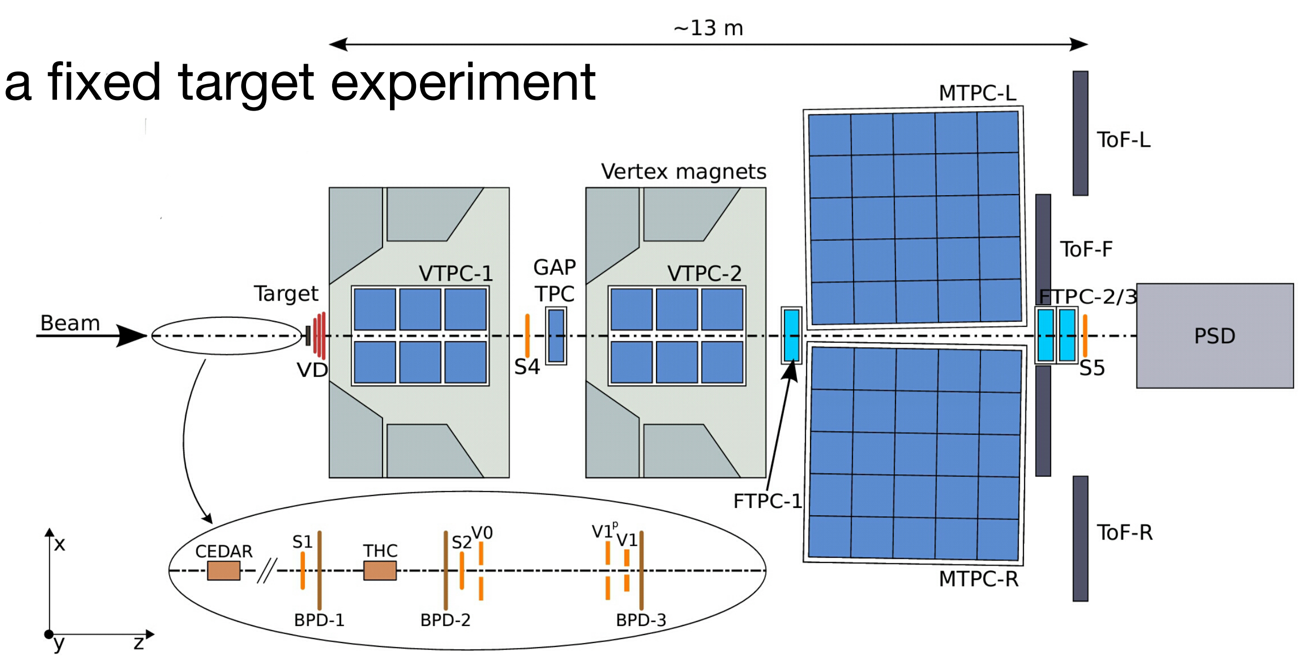

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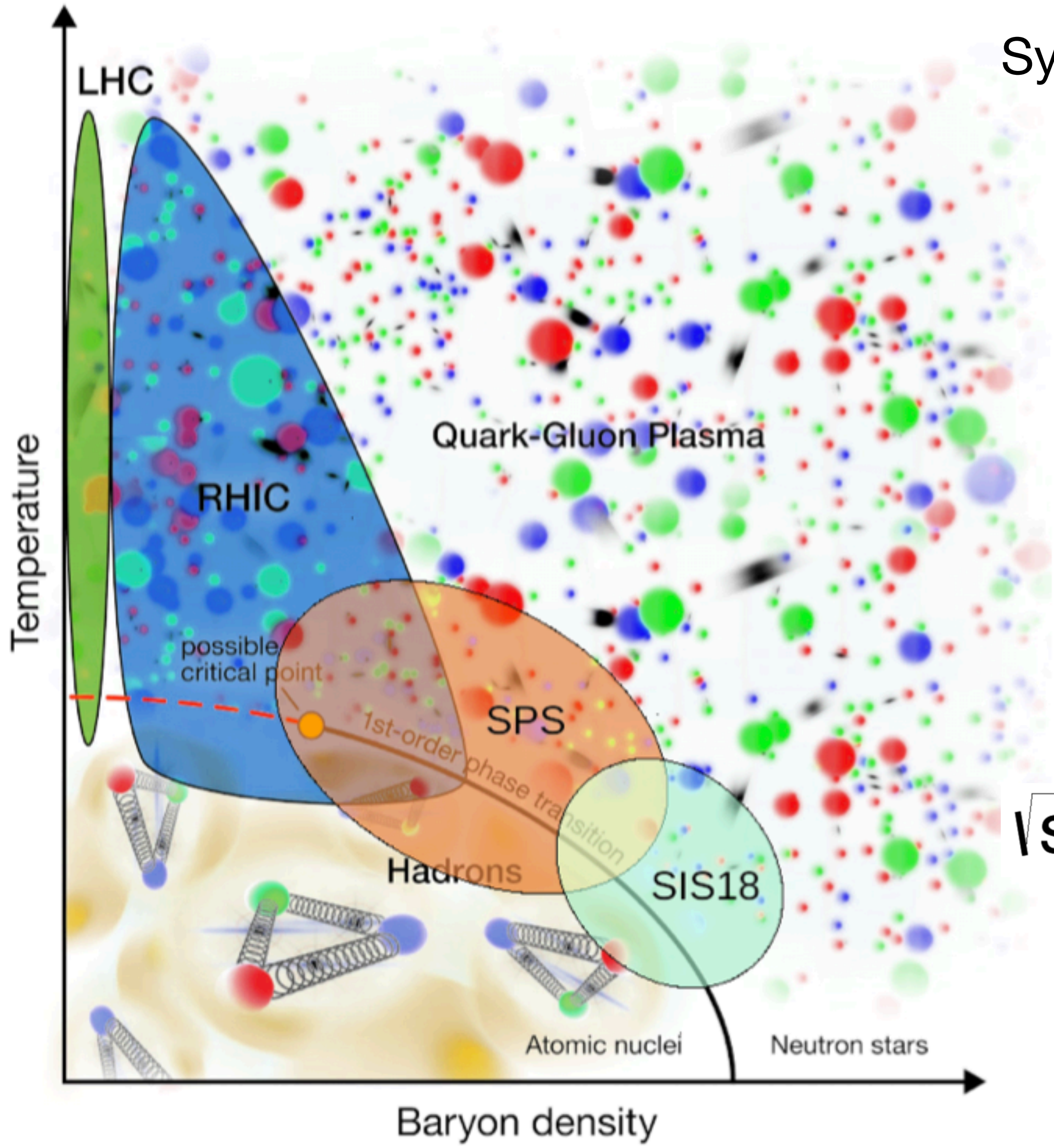

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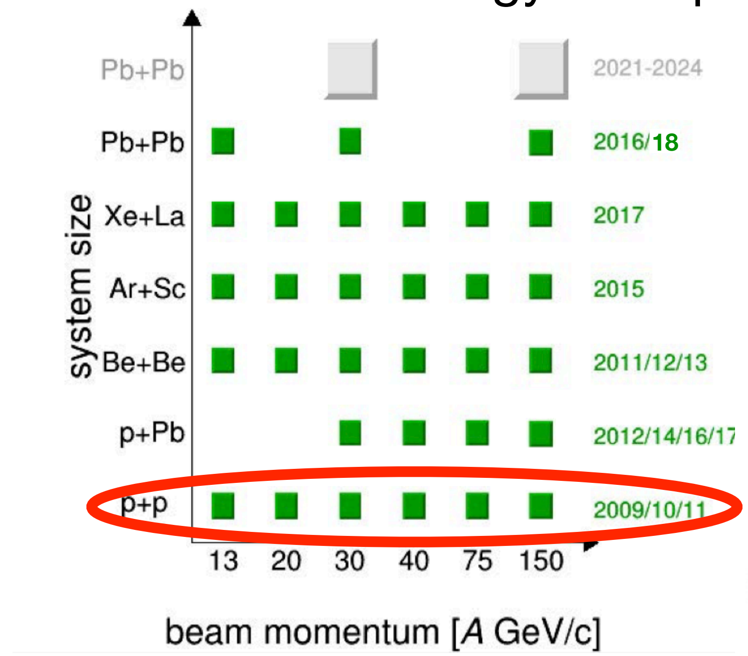

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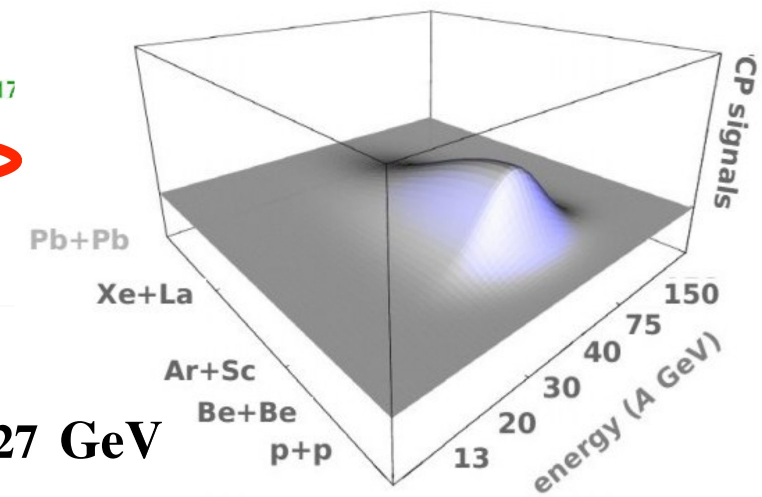

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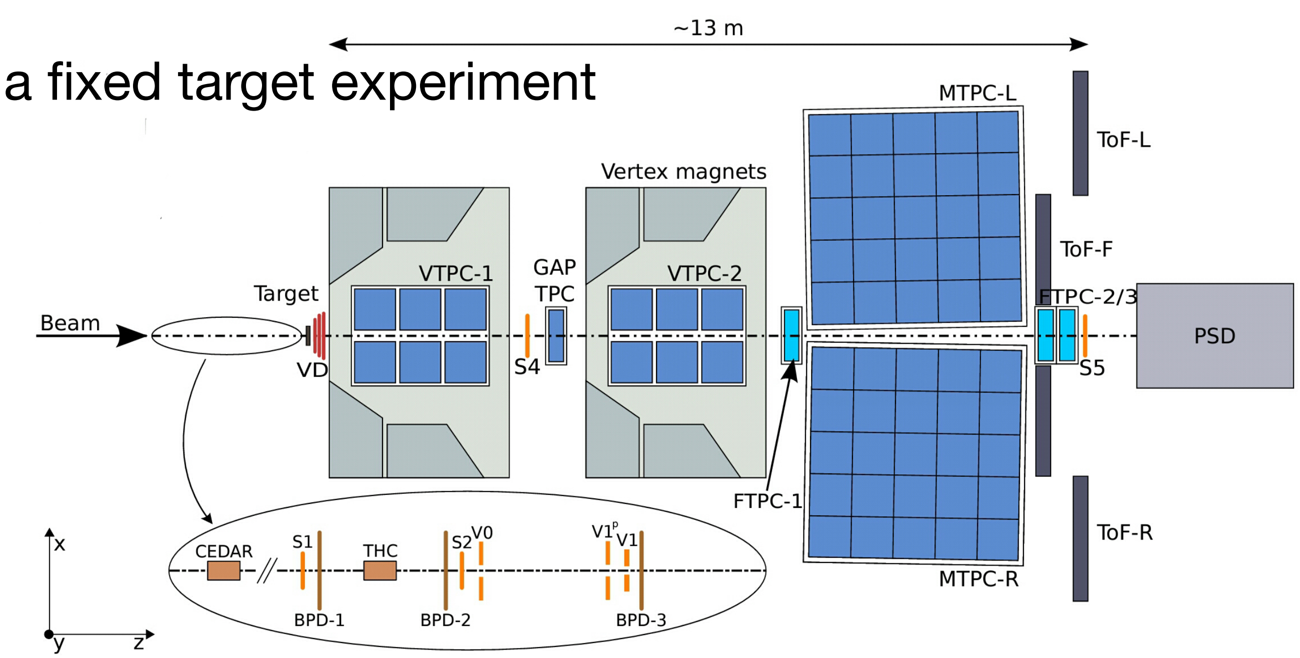

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Quantities of interest

1. Intensive quantities

$$\omega[N] = \frac{\langle N^2\rangle - \langle N\rangle^2}{\langle N\rangle}$$

$$S\sigma = \frac{\langle(\Delta N)^3\rangle}{\langle(\Delta N)^2\rangle}, \quad \Delta N = N - \bar{N}$$

$$\kappa\sigma^2 = \frac{\langle(\Delta N)^4\rangle - 3\langle(\Delta N)^2\rangle^2}{\langle(\Delta N)^2\rangle}$$

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$$\Delta[P_T, N] = \frac{1}{C_\Delta}\left[\langle N\rangle\omega[P_T] - \langle P_T\rangle\omega[N]\right],$$

Gorenstein M and Gazdzicki M 2011 *Phys. Rev. C* 84 014904

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

$$C_\Delta = C_\Sigma = \langle N\rangle\omega(p_T), \qquad \omega(p_T) = \frac{\overline{p_T^2} - \overline{p_T}^2}{\overline{p_T}} \qquad \omega[P_T] = \frac{\langle P_T^2\rangle - \langle P_T\rangle^2}{\langle P_T\rangle}, \qquad \langle P_T\rangle = \frac{\sum_{k=1}^{M} P_T^{(k)}}{M}$$

Gazdzicki M, Gorenstein M, and Mackowiak-Pawlowska M 2013 *Phys. Rev. C* 88 024907

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3. Strongly intensive quantities defined for two separated regions of the phase space

$$\Sigma[N_F, N_B] = \frac{1}{\langle N_B \rangle + \langle N_F \rangle}\left[\langle N_B \rangle \omega[N_F] + \langle N_F \rangle \omega[N_B] - 2(\langle N_F N_B \rangle - \langle N_F \rangle \langle N_B \rangle)\right]$$

some results were published: NA61/SHINE Collaboration, Eur.Phys.J.C 76 (2016) 11, 635; e-Print: 1510.00163 [hep-ex]

Choice of the phase space: in rapidity

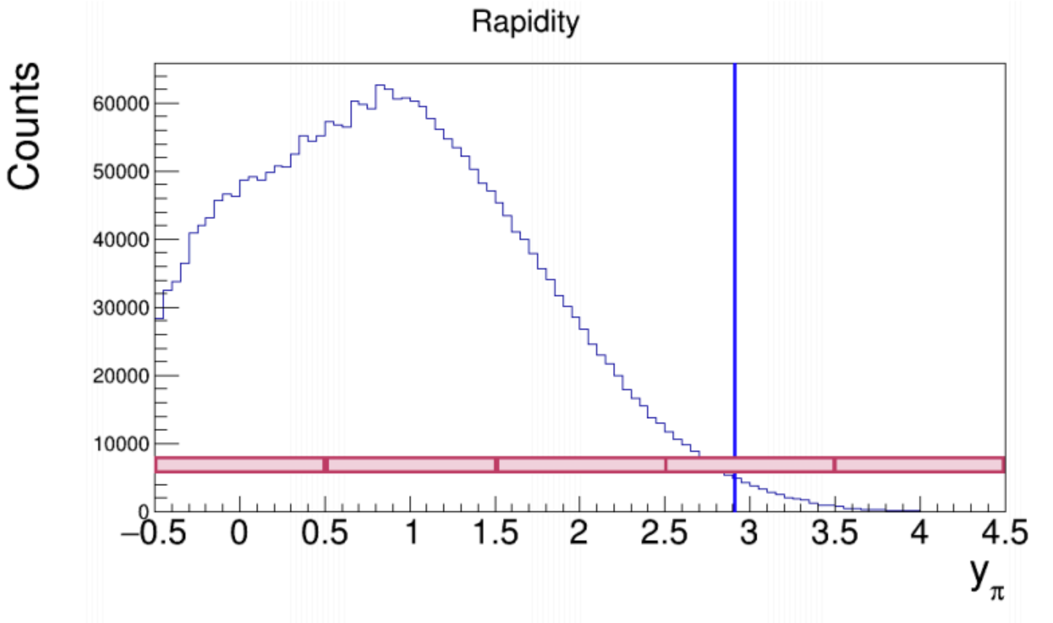

Figure: Constant width of bin

$$\Delta y = 1$$

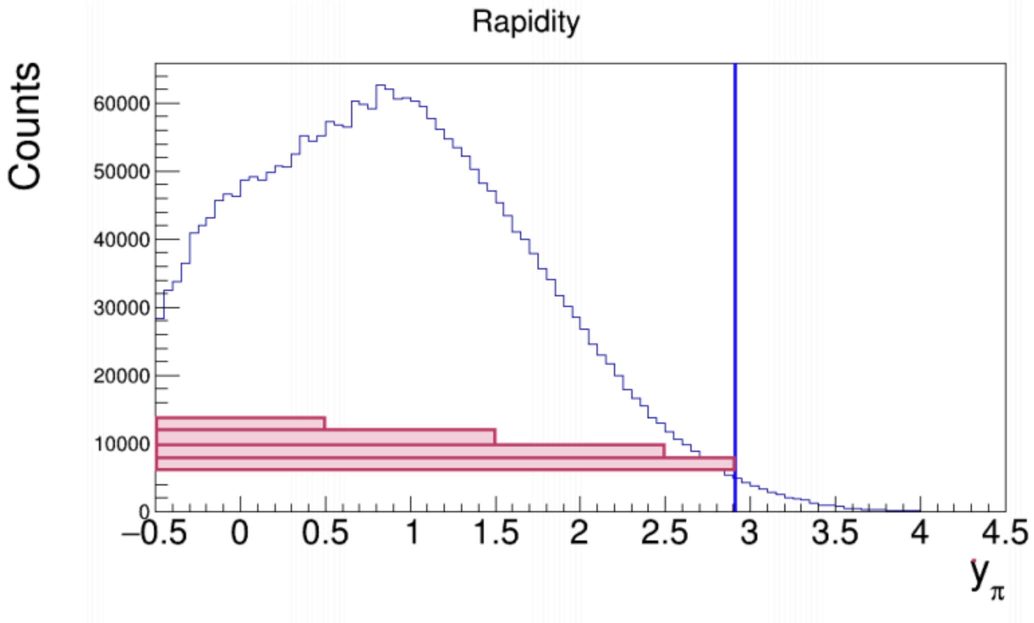

Figure: Expanding bins

$$\Delta y \in (1; 3.5)$$

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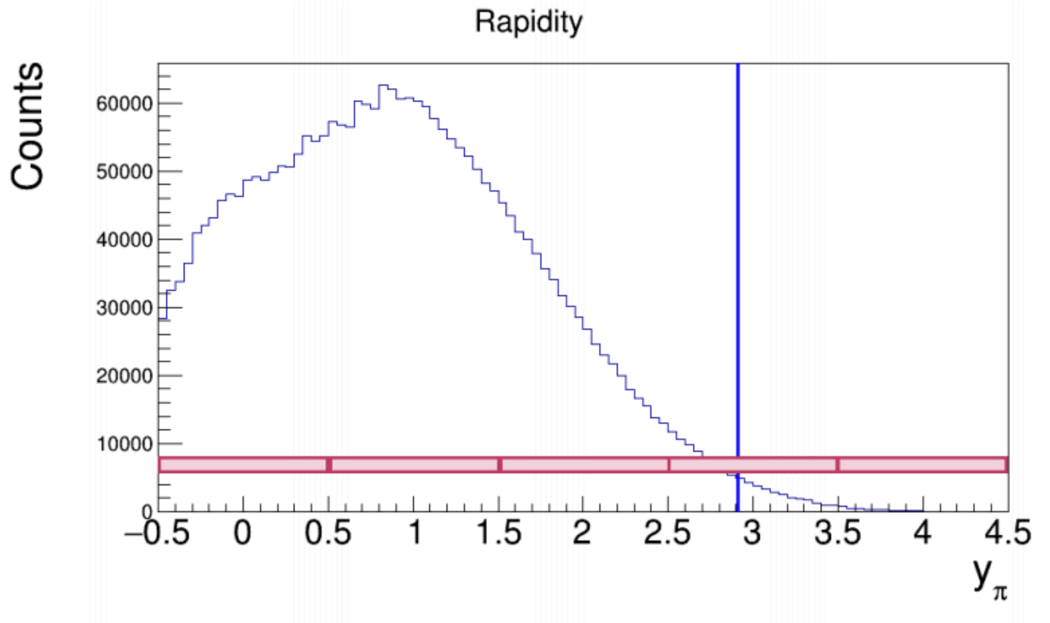

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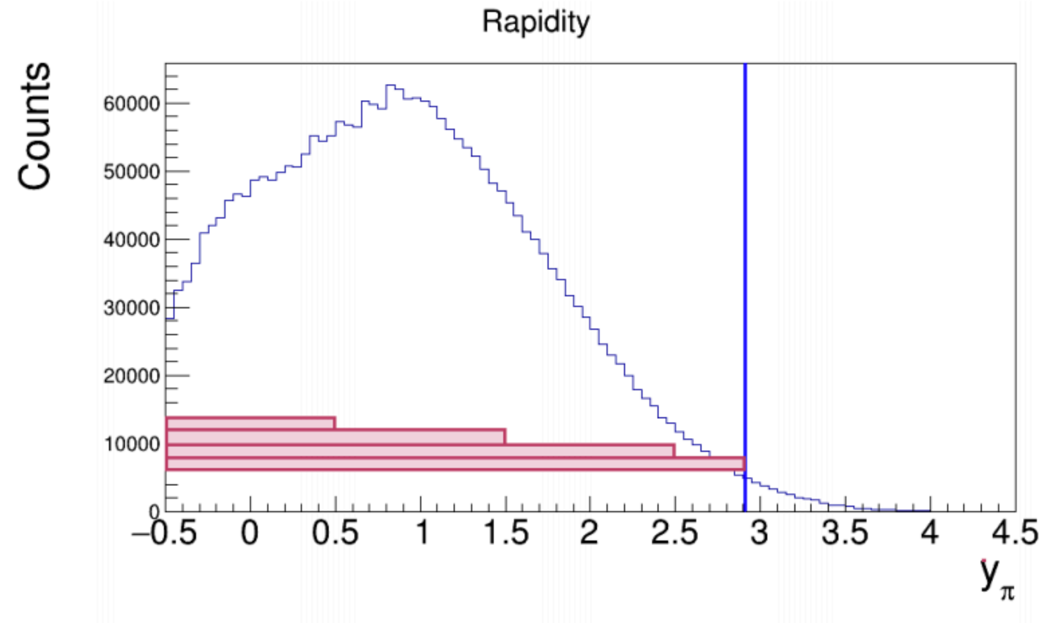


Figure: Expanding bins

$$\Delta y \in (1; 3.5)$$

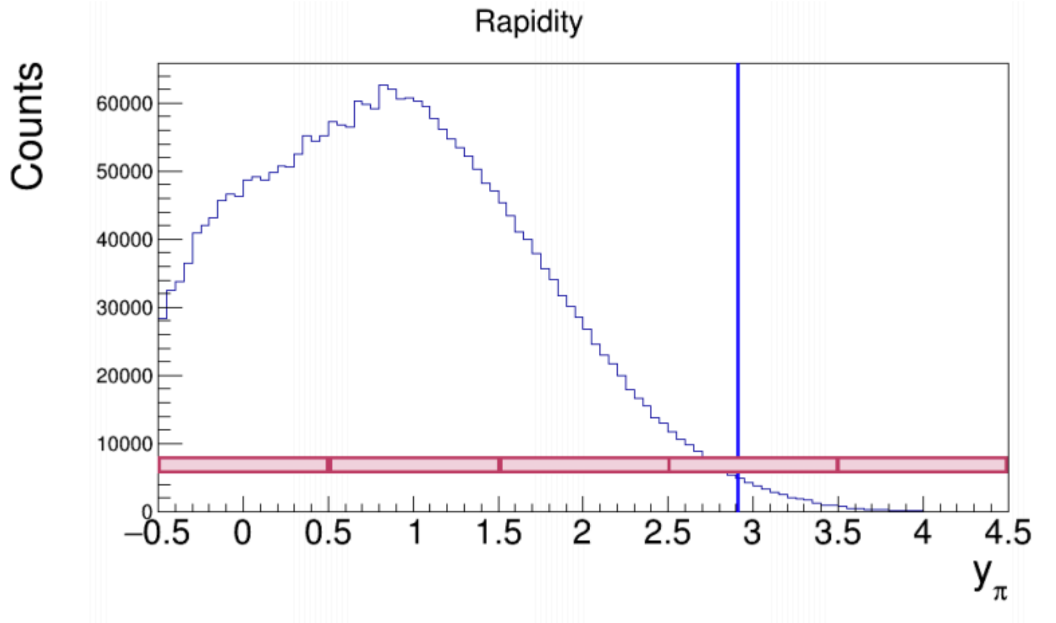
According to https://arxiv.org/pdf/1911.03426.pdf **we estimate x as:**

$$x_i = \frac{\int_{-\Delta y/2}^{\Delta y/2} dy \, \frac{dN_i}{dy}}{\int_{-\infty}^{\infty} dy \, \frac{dN_i}{dy}} \equiv \frac{\langle n_i \rangle}{\langle N_i \rangle}$$

the value for the 4pi acceptance was taken from:

A. Aduszkiewicz et al., [NA61/SHINE Collab.] Eur. Phys. J. C77 no. 10, (2017) 671.

Choice of the phase space: in rapidity



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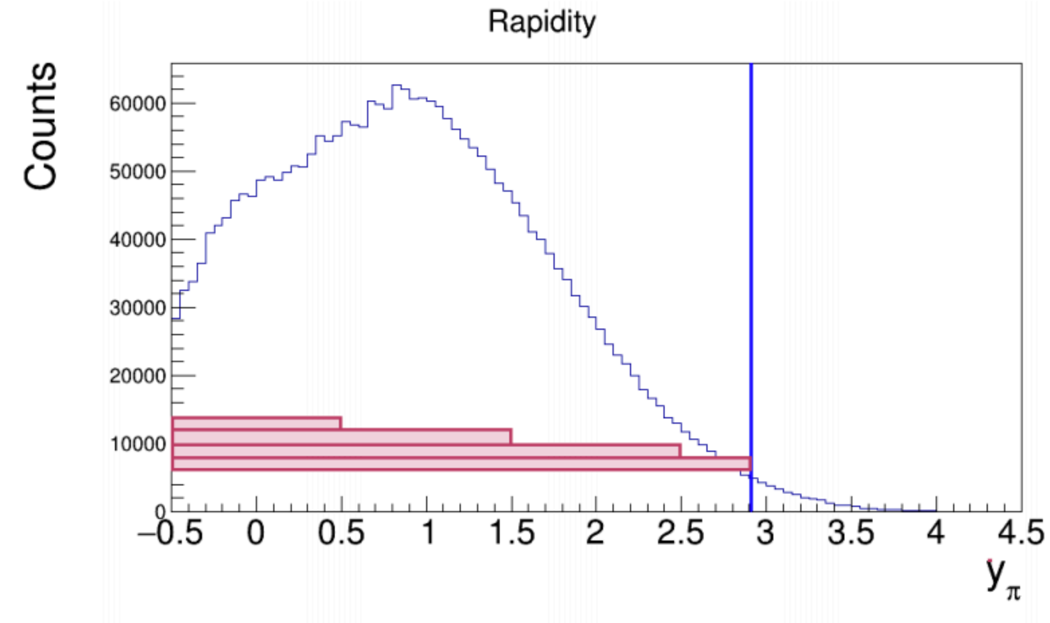

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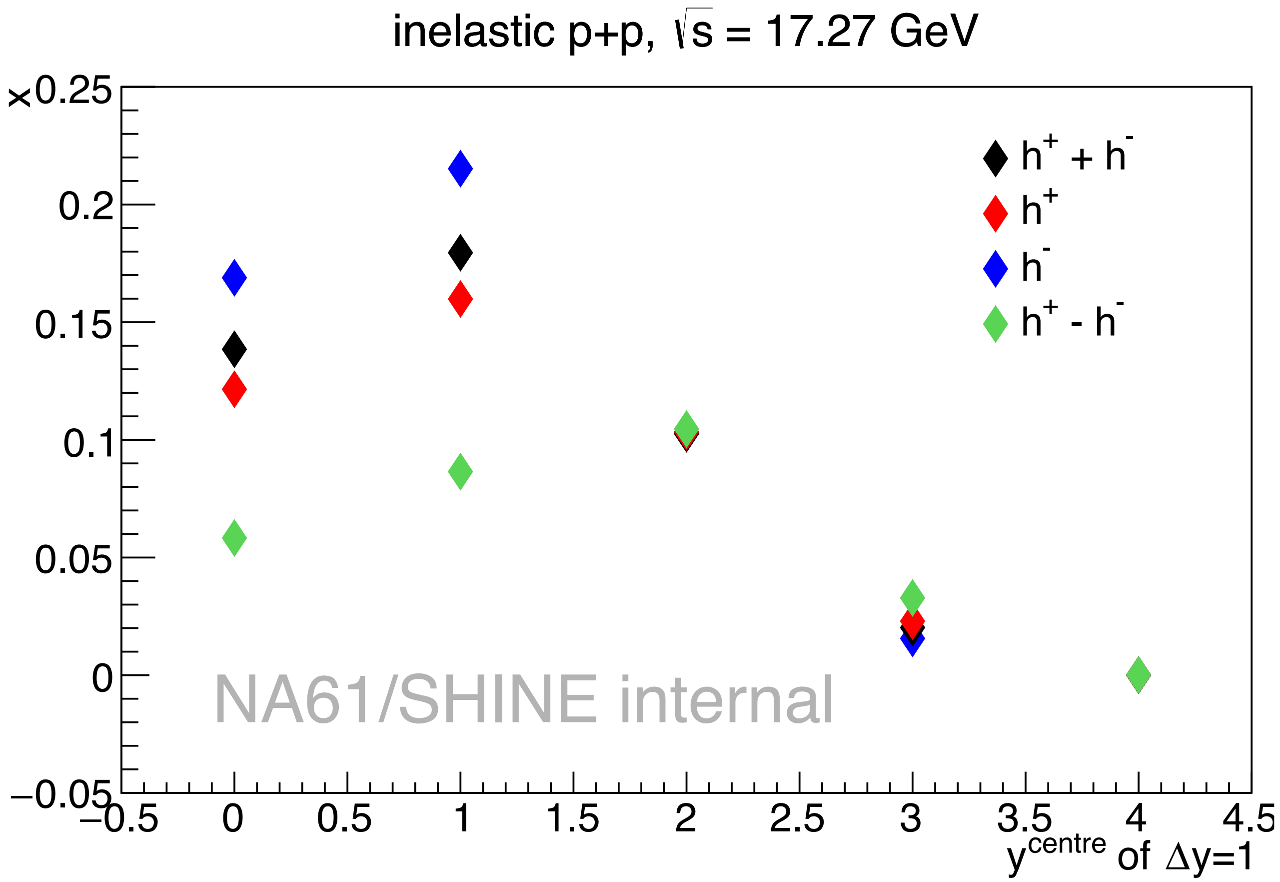
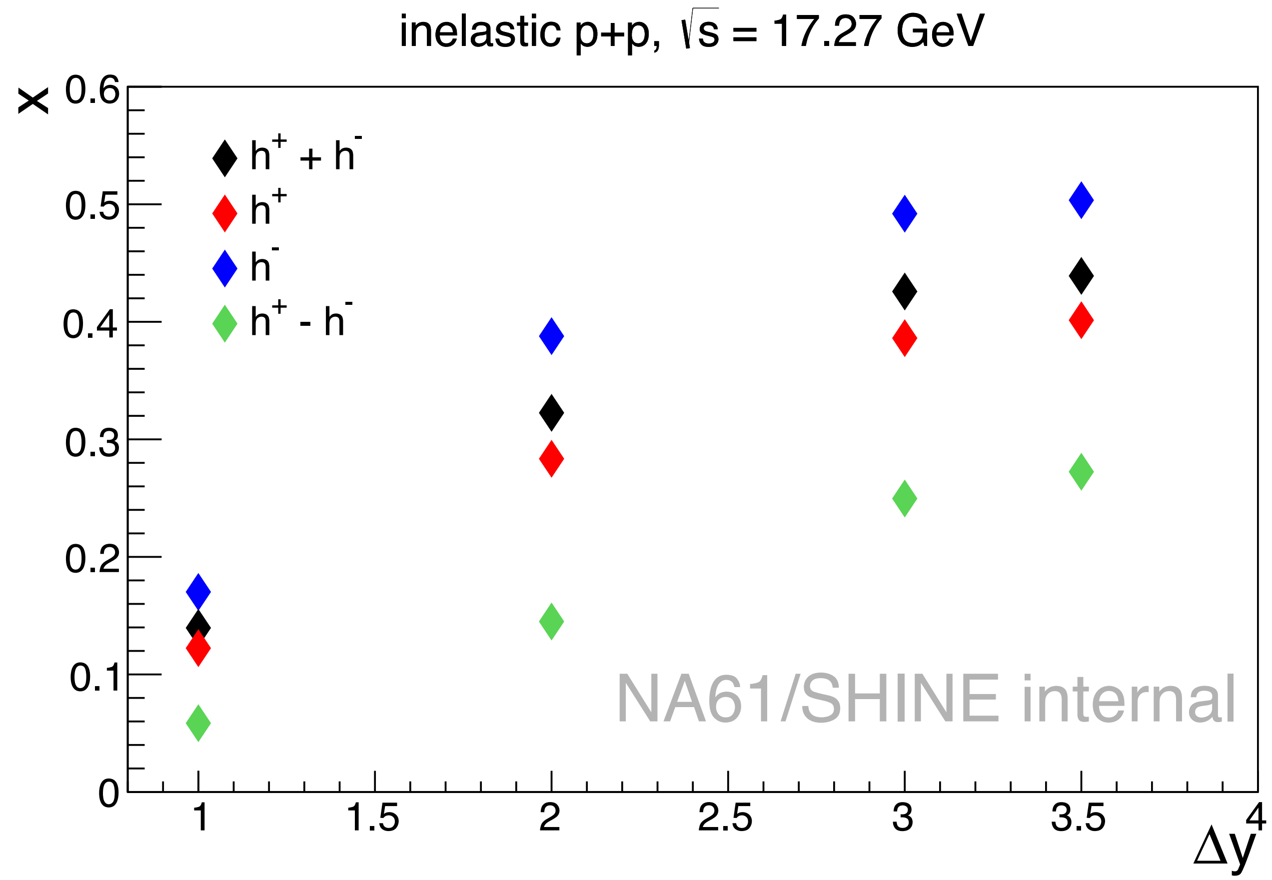
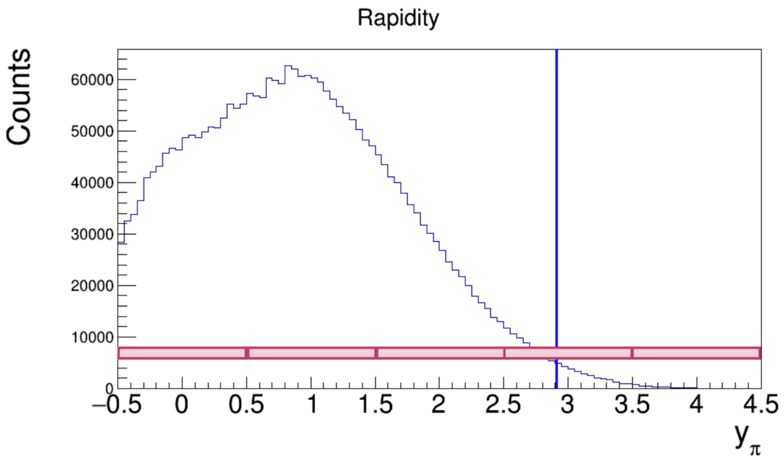
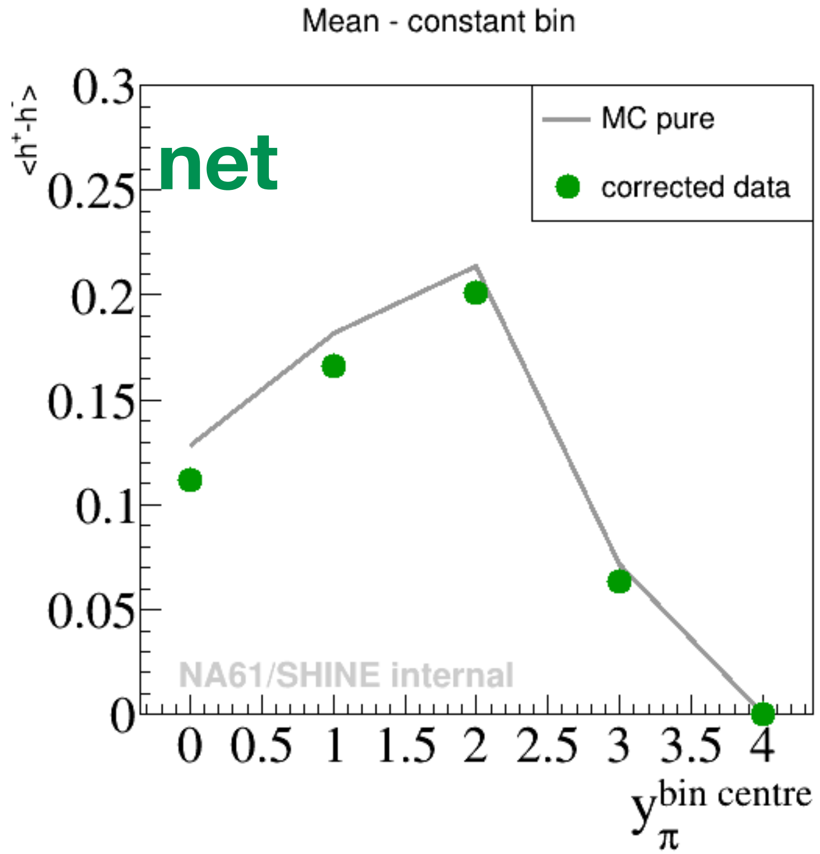




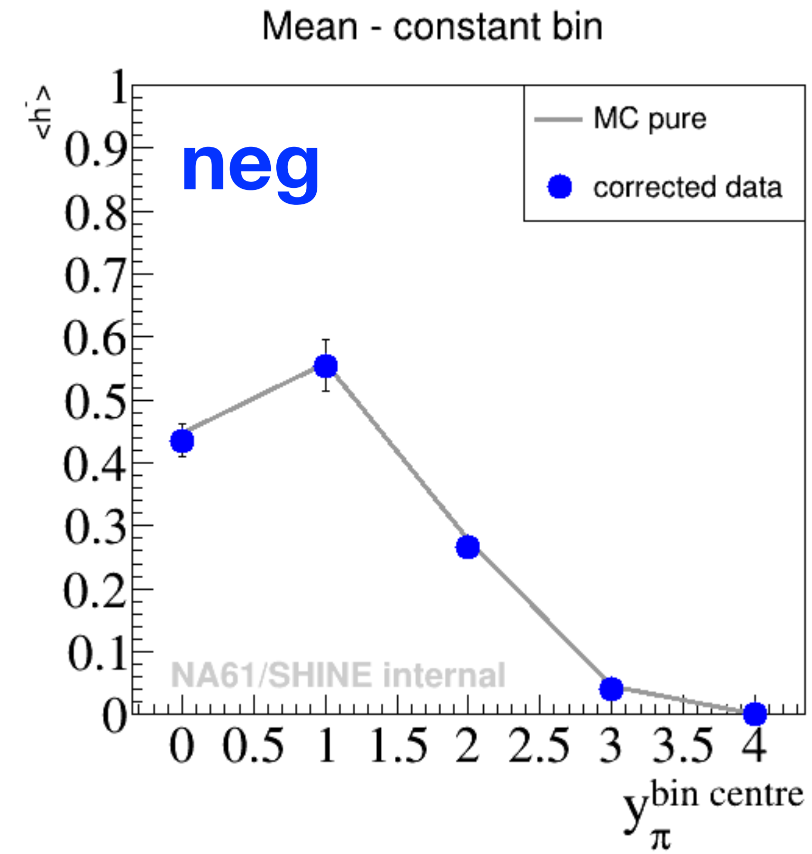
p+p@158GeV/c

√s = 17.27 GeV





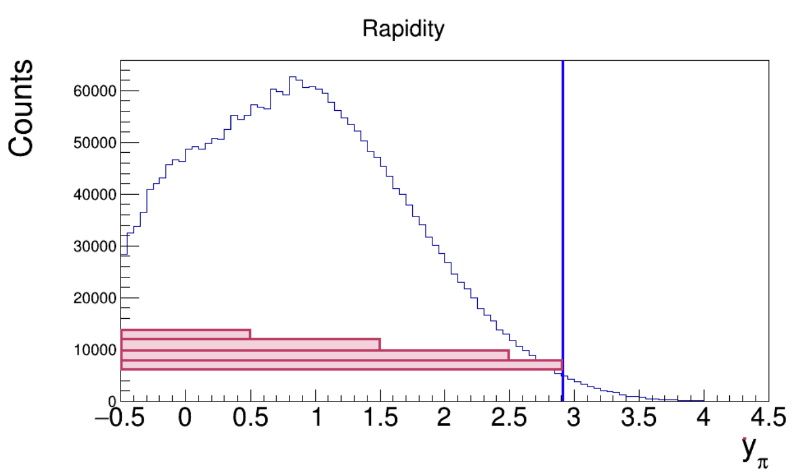
x= 0.06 0.09 0.10 0.03 0.0001

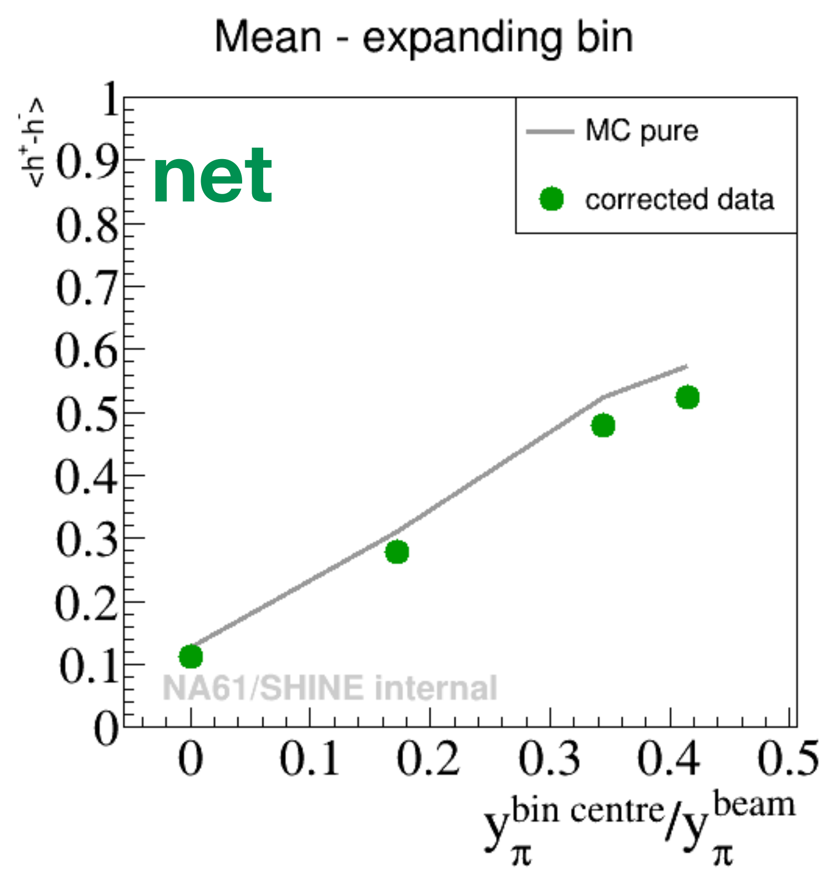


x= 0.17 0.22 0.10 0.02 0.00002

<Ni>

*MC pure (EPOS1.99) is calculated in the NA61/SHINE acceptance





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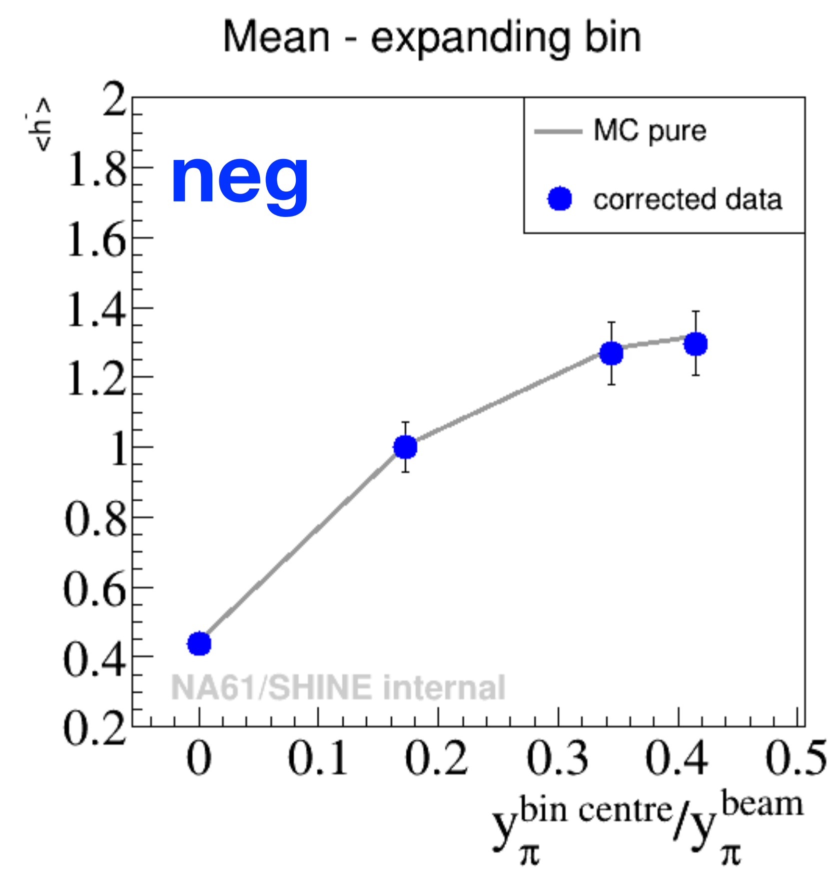

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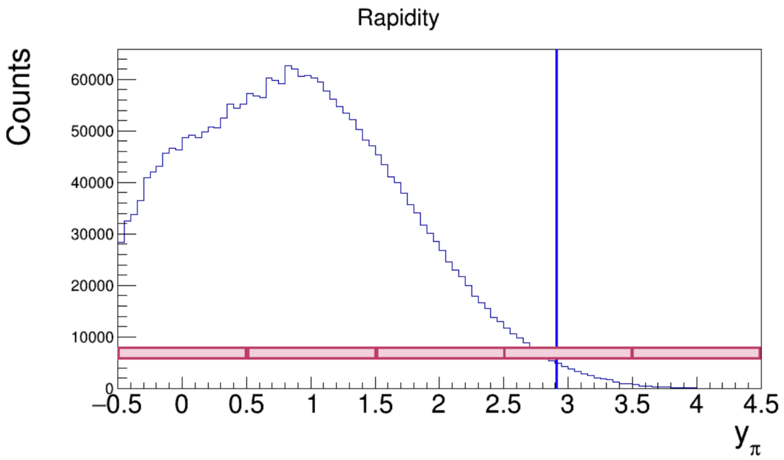

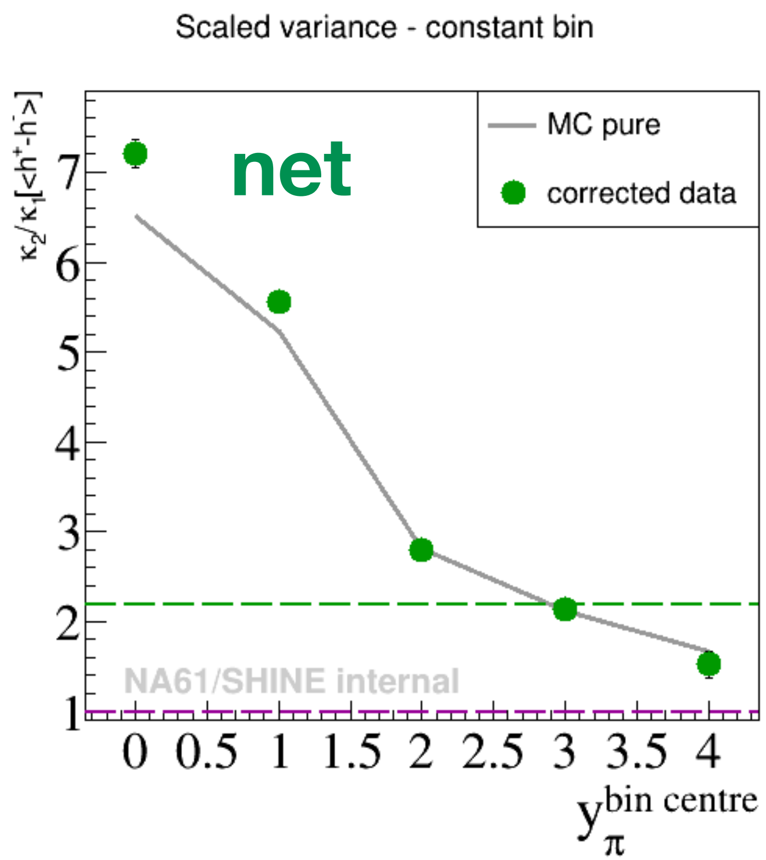

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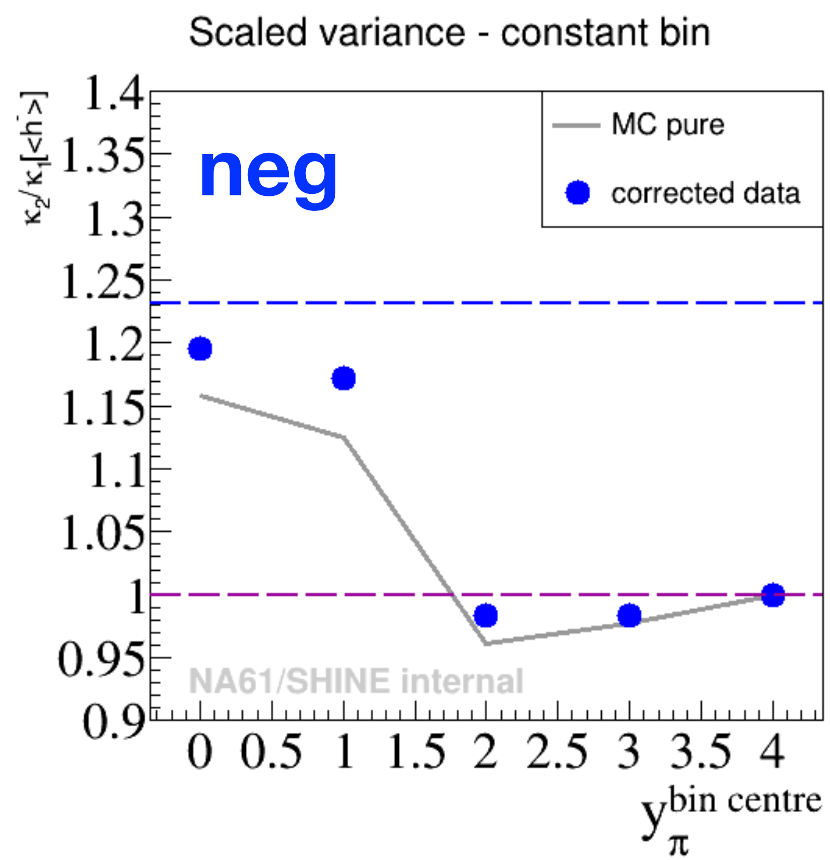

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ω[Ni]

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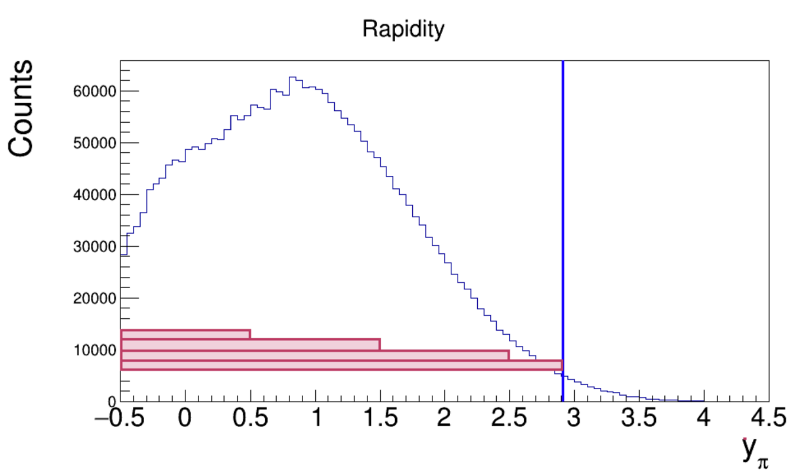

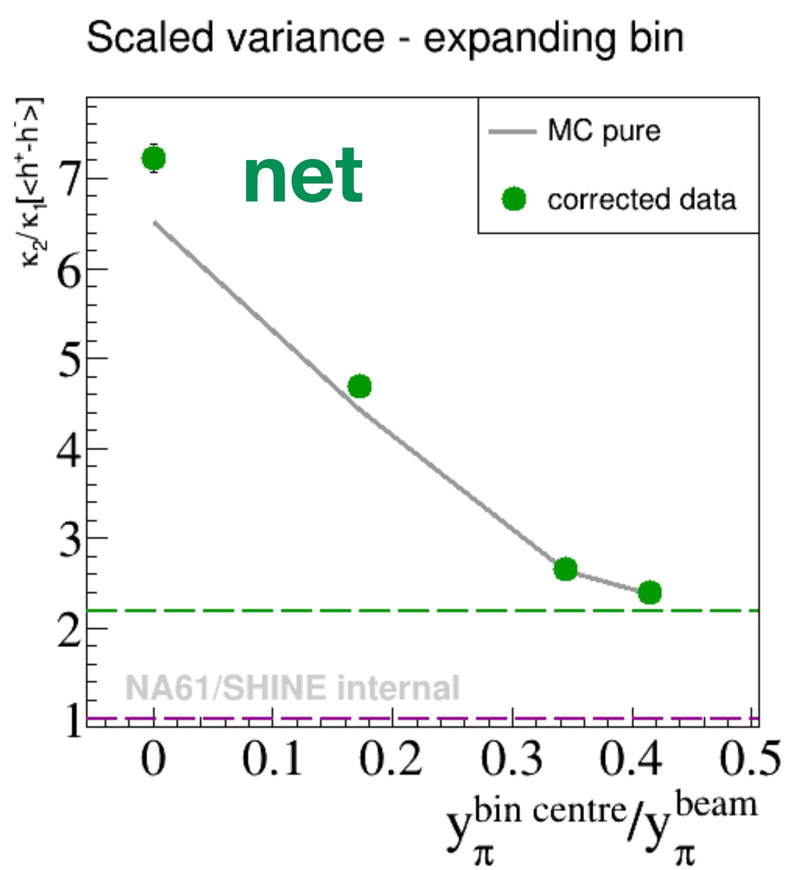

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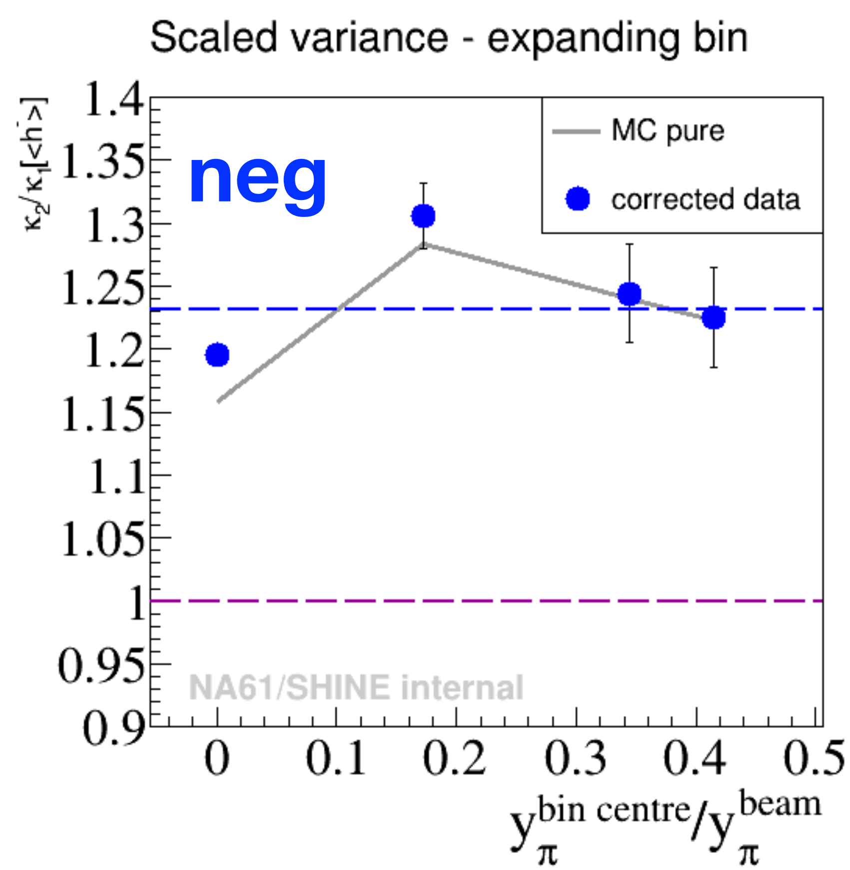

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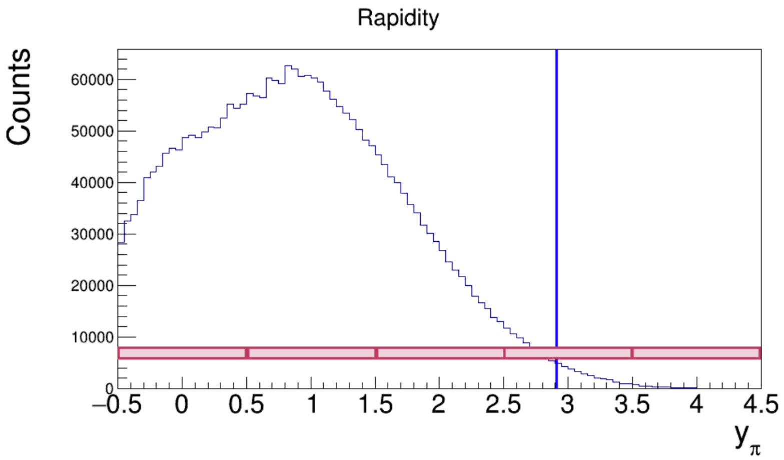

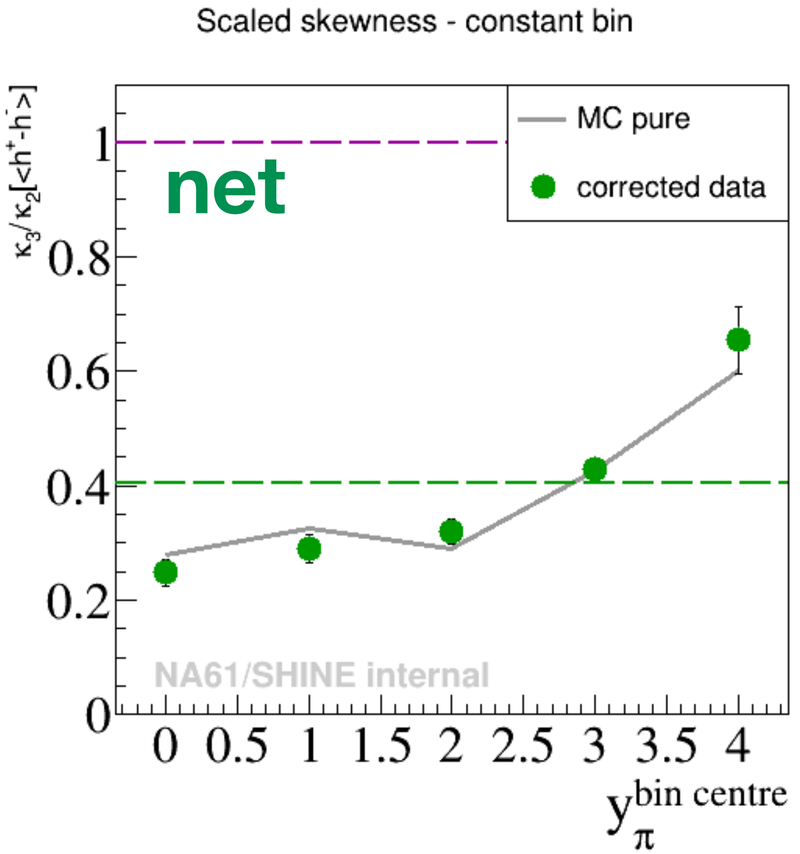

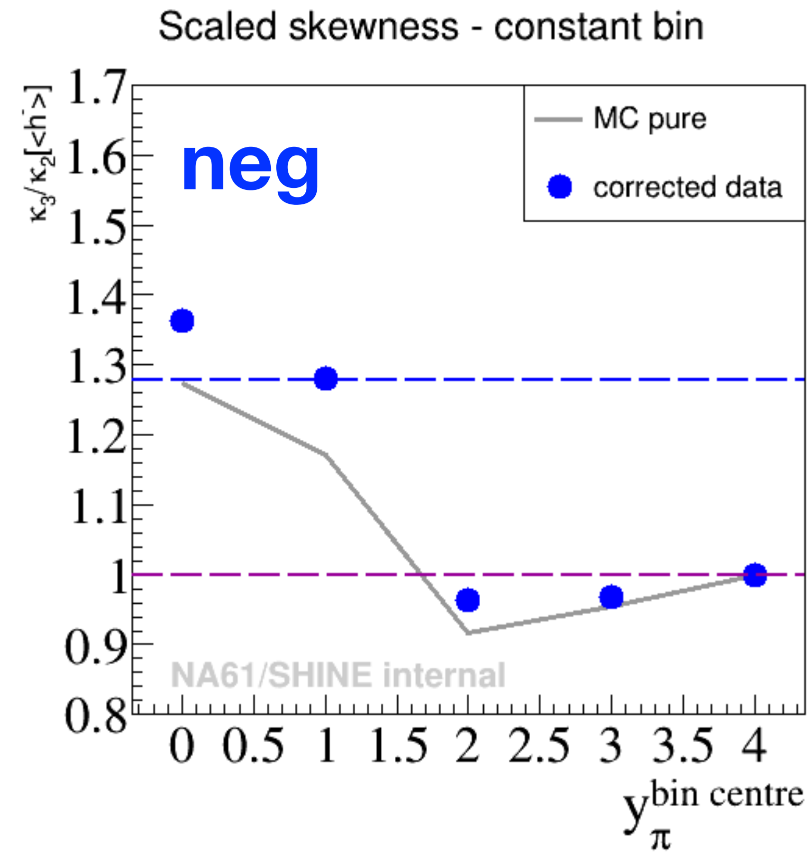

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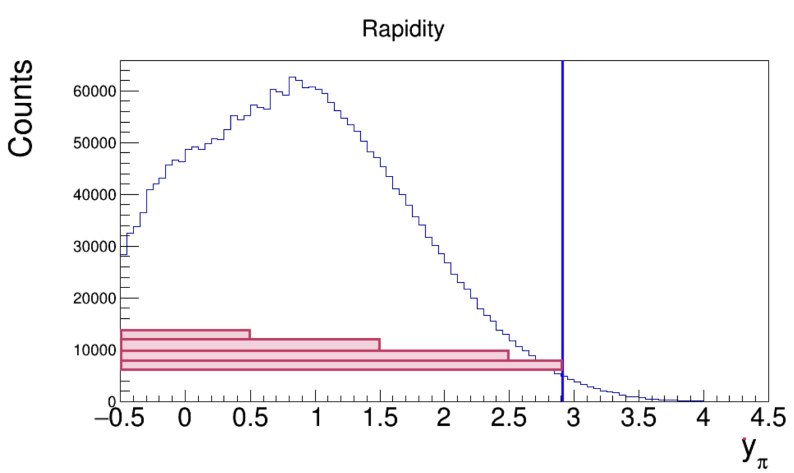

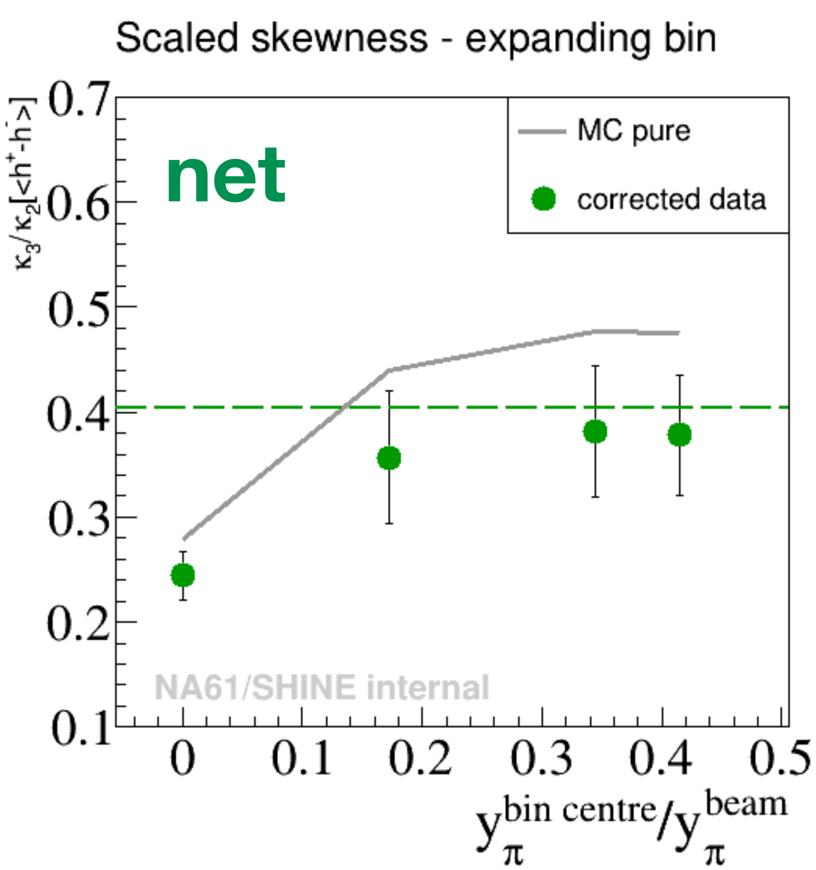

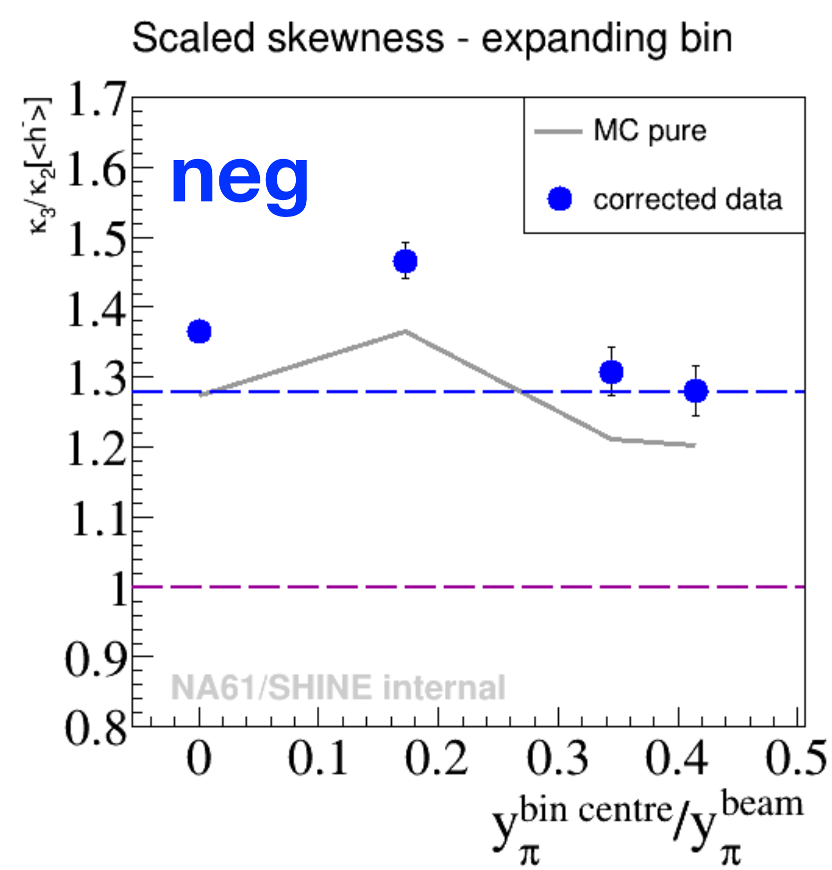

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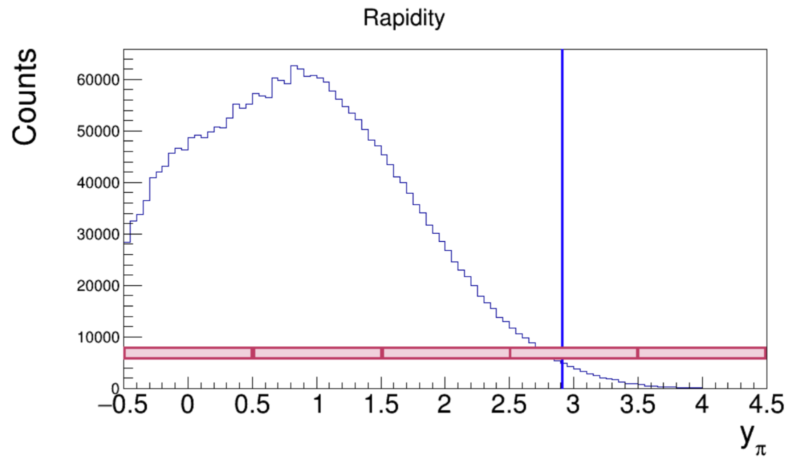

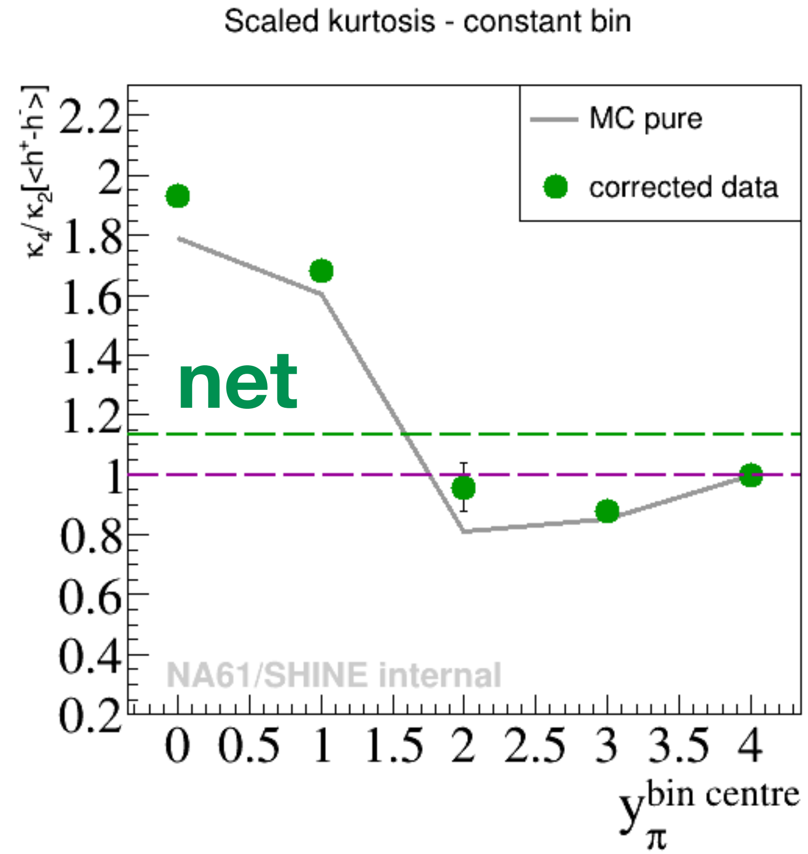

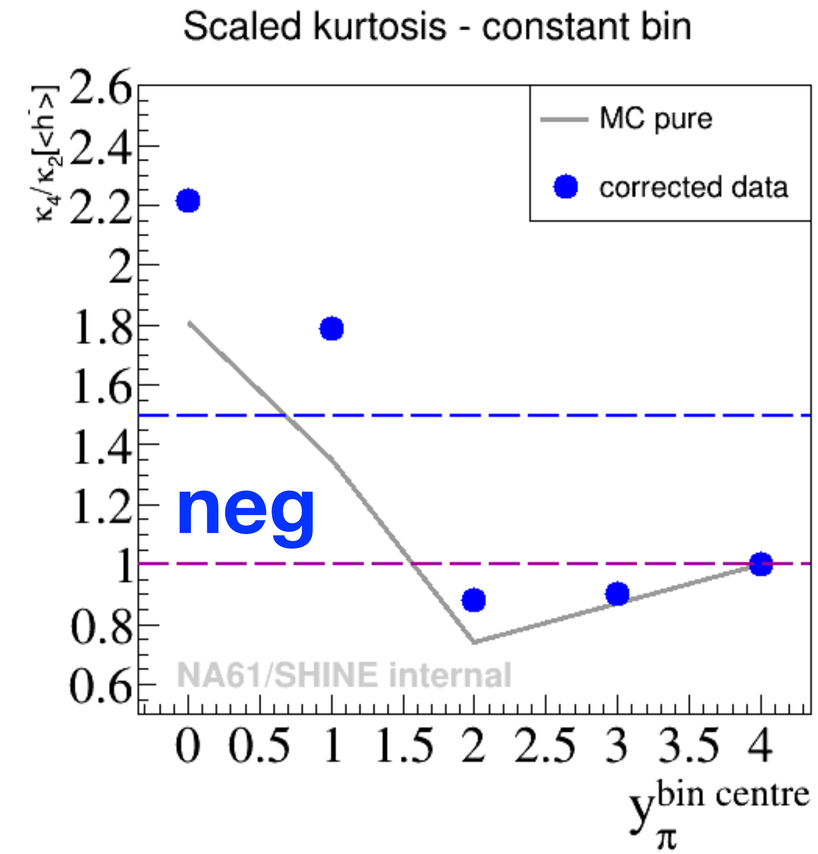

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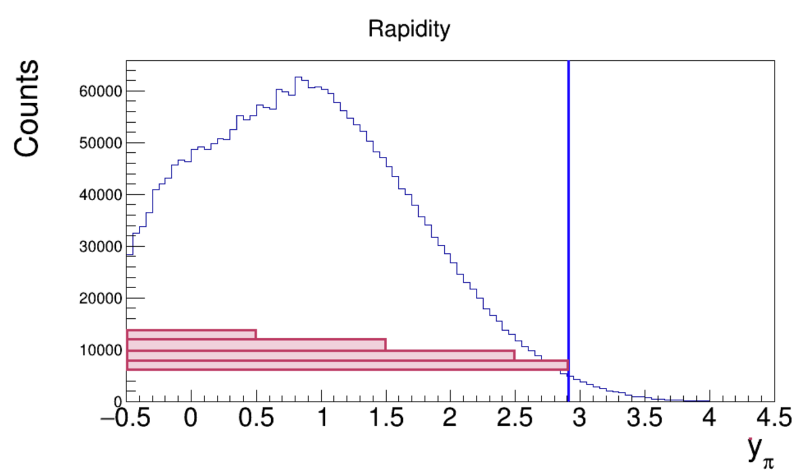

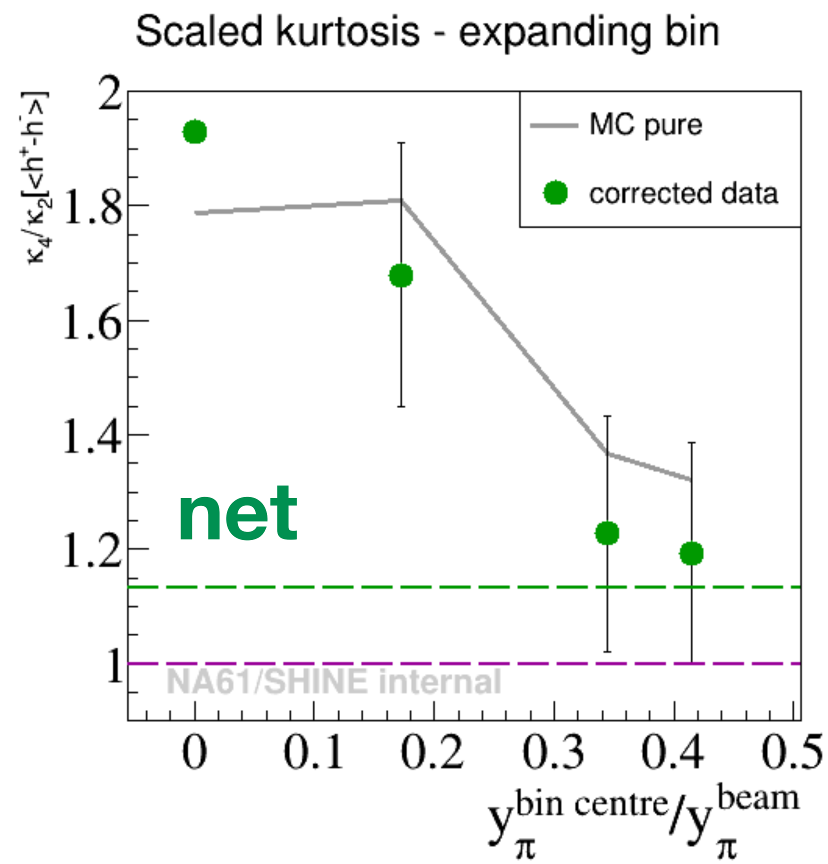

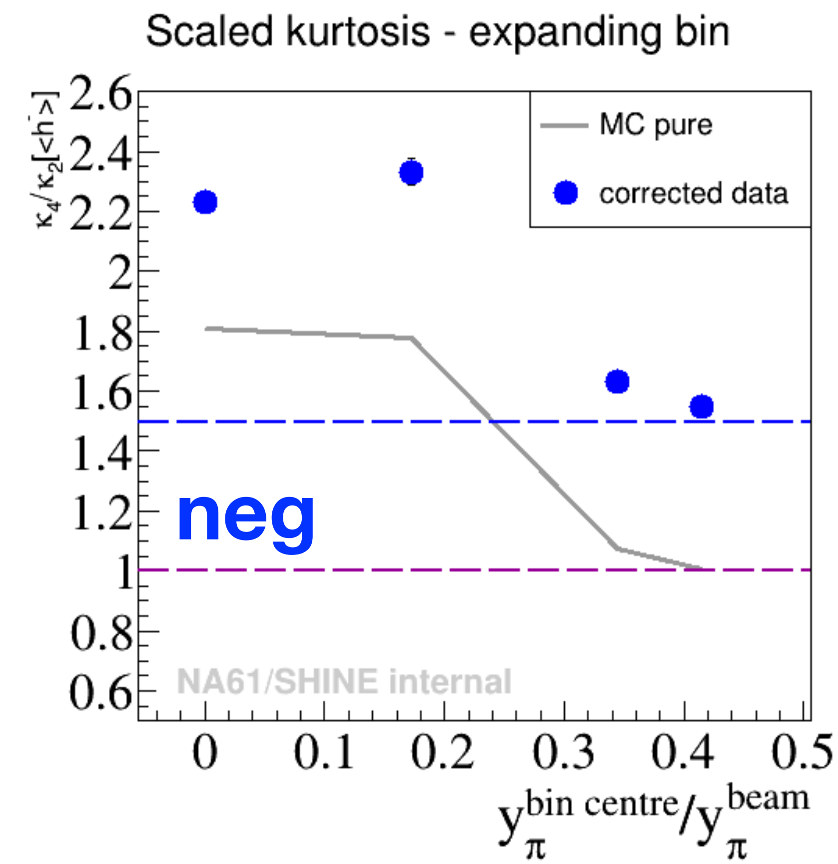

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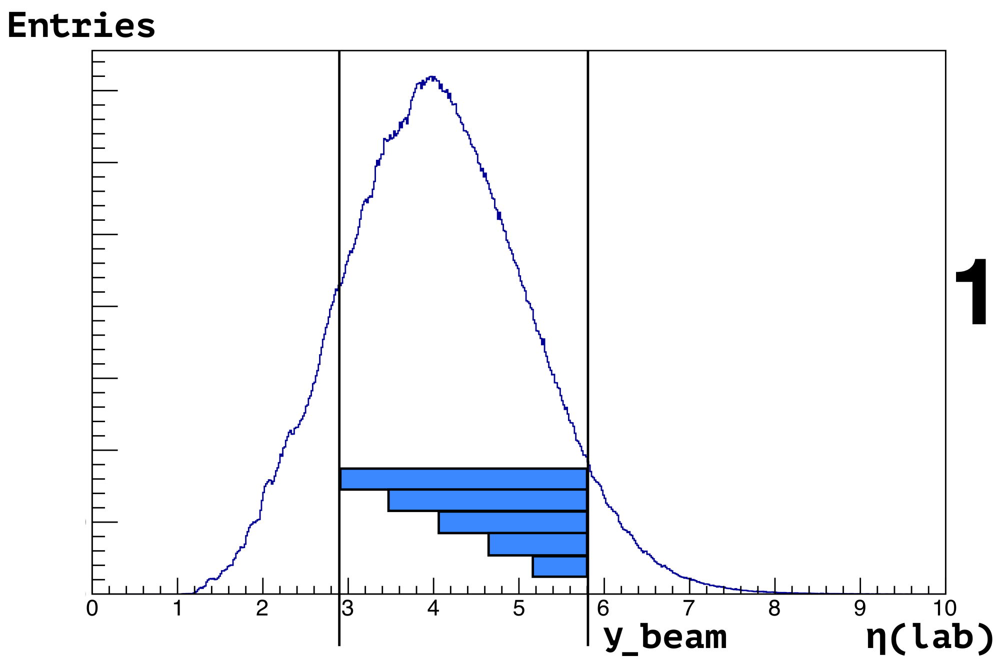
Choice of the phase space: in pseudorapidity

The same x definition from https://arxiv.org/pdf/1911.03426.pdf



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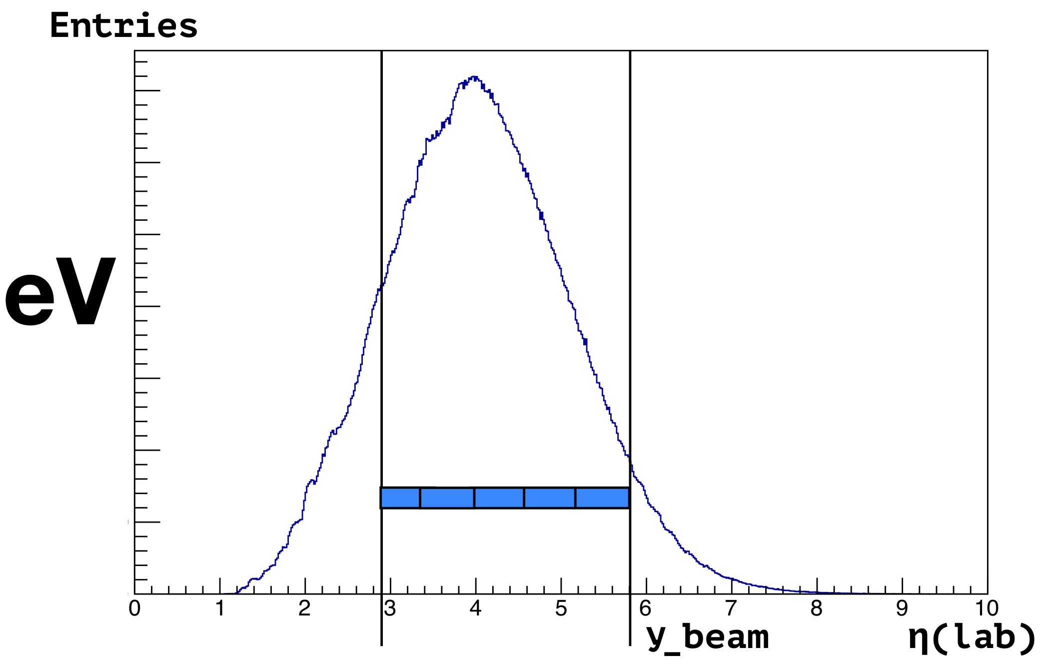

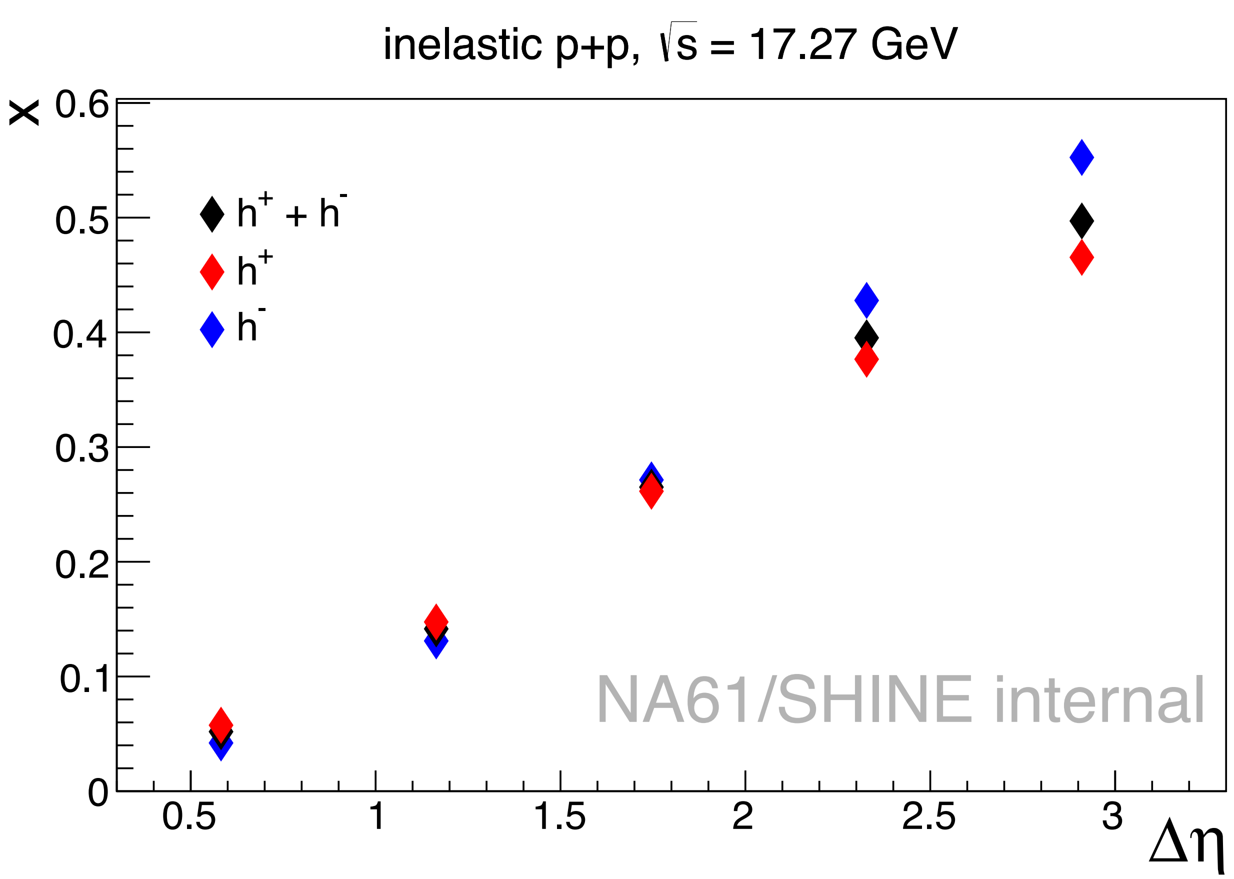

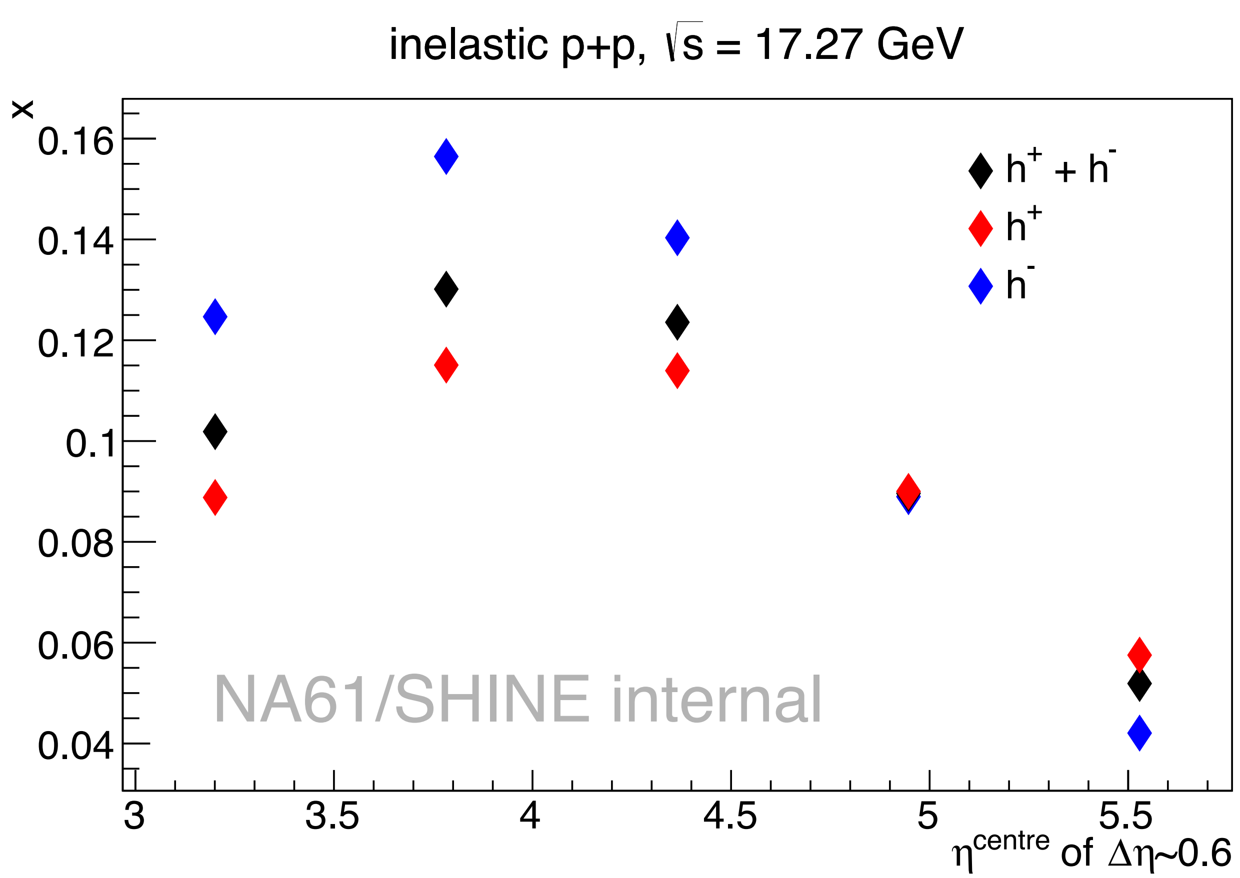

***numerator in x is not corrected**

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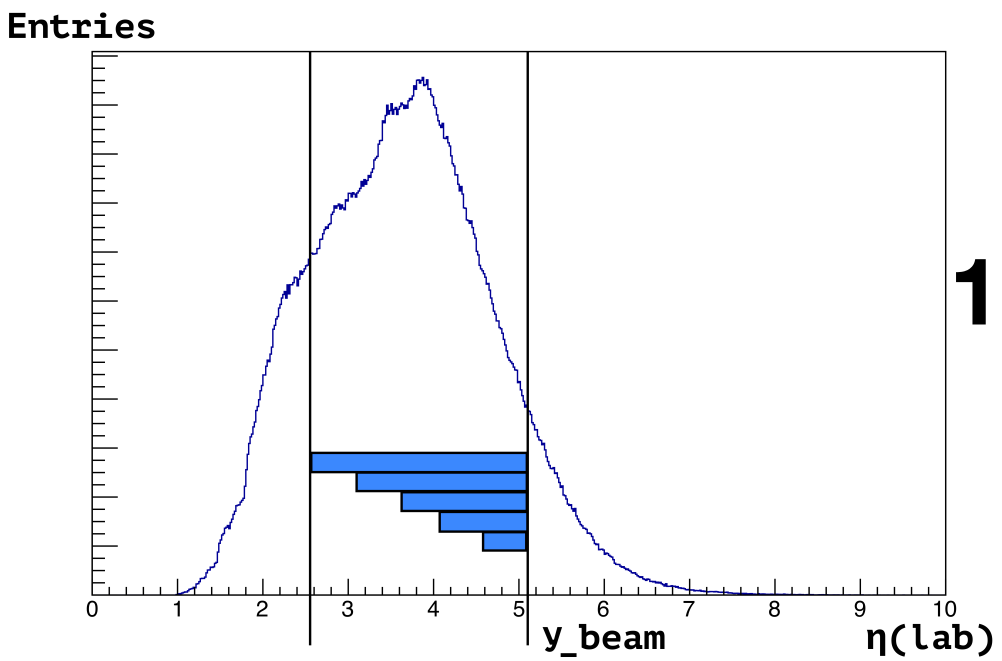
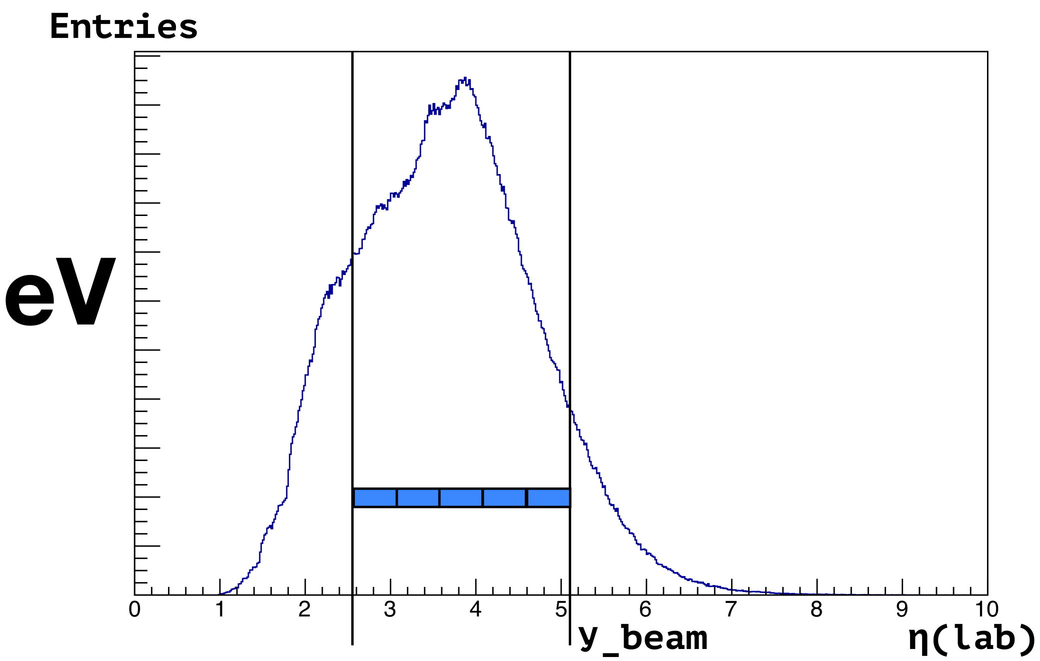
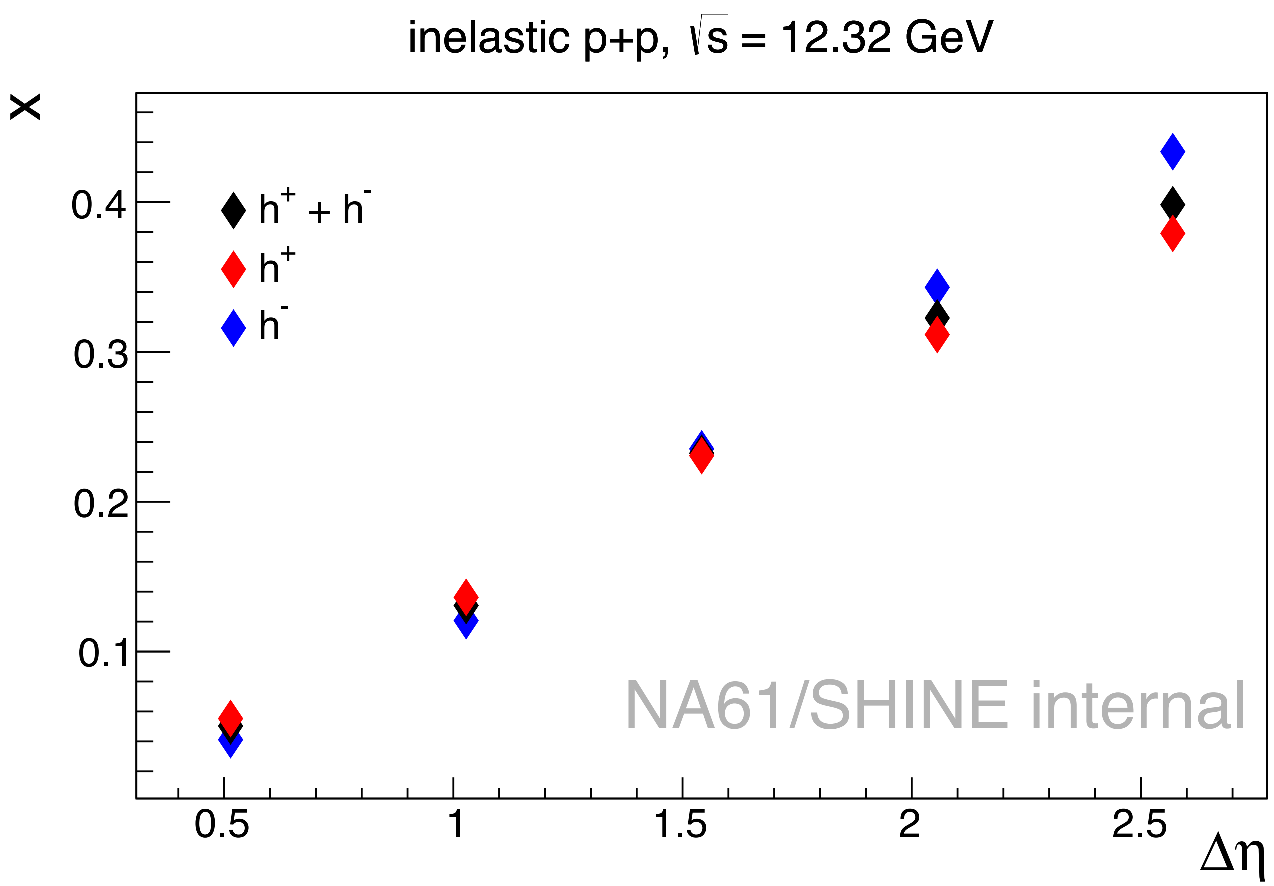
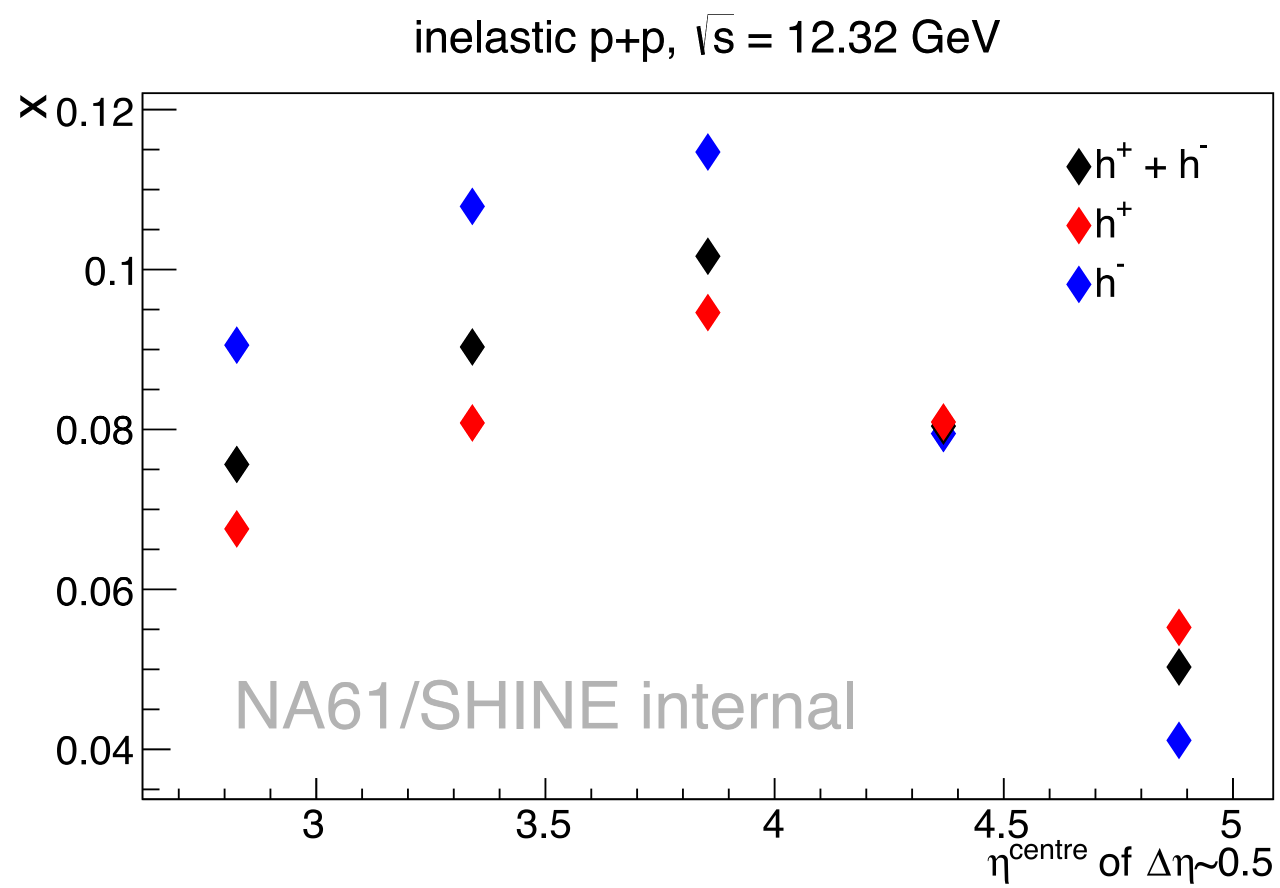


12.32 GeV







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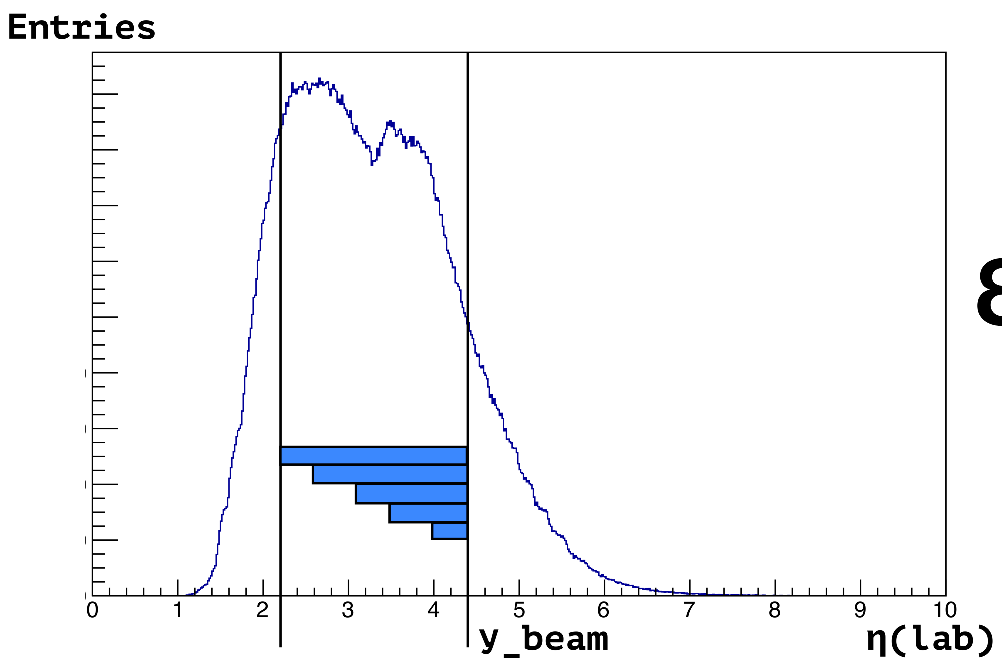
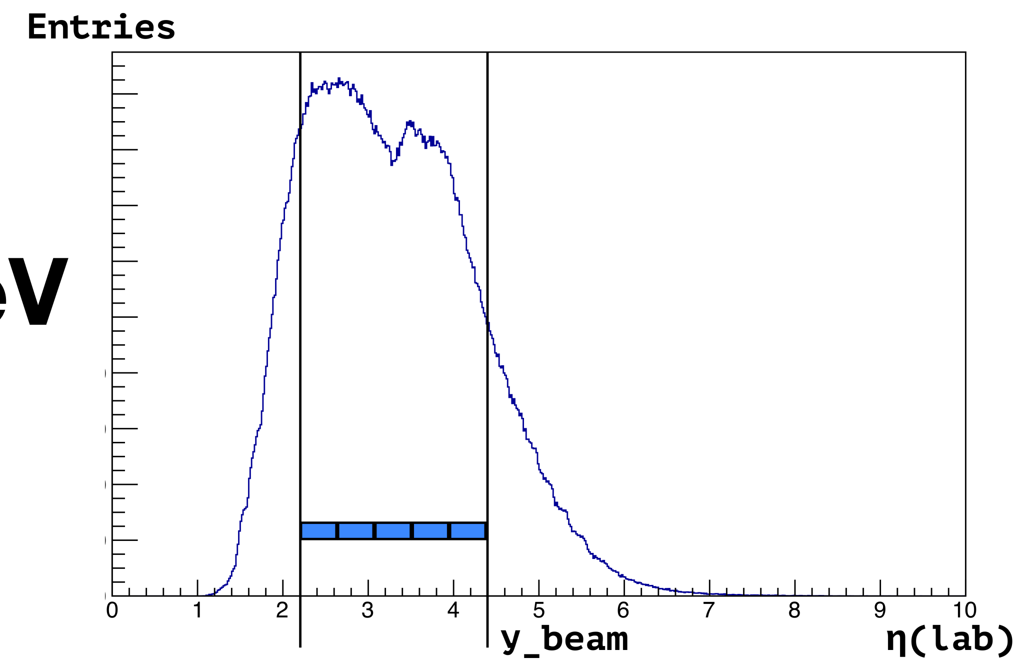
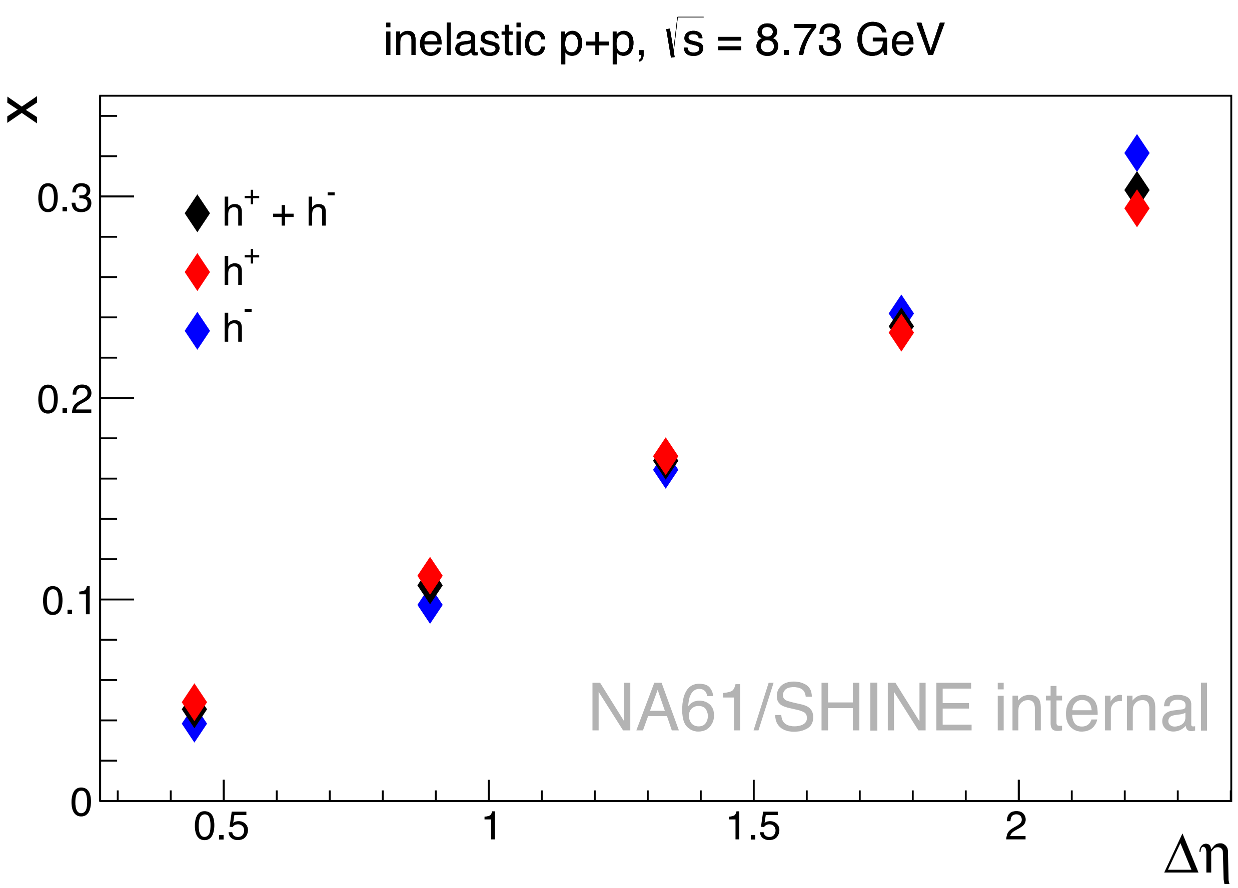
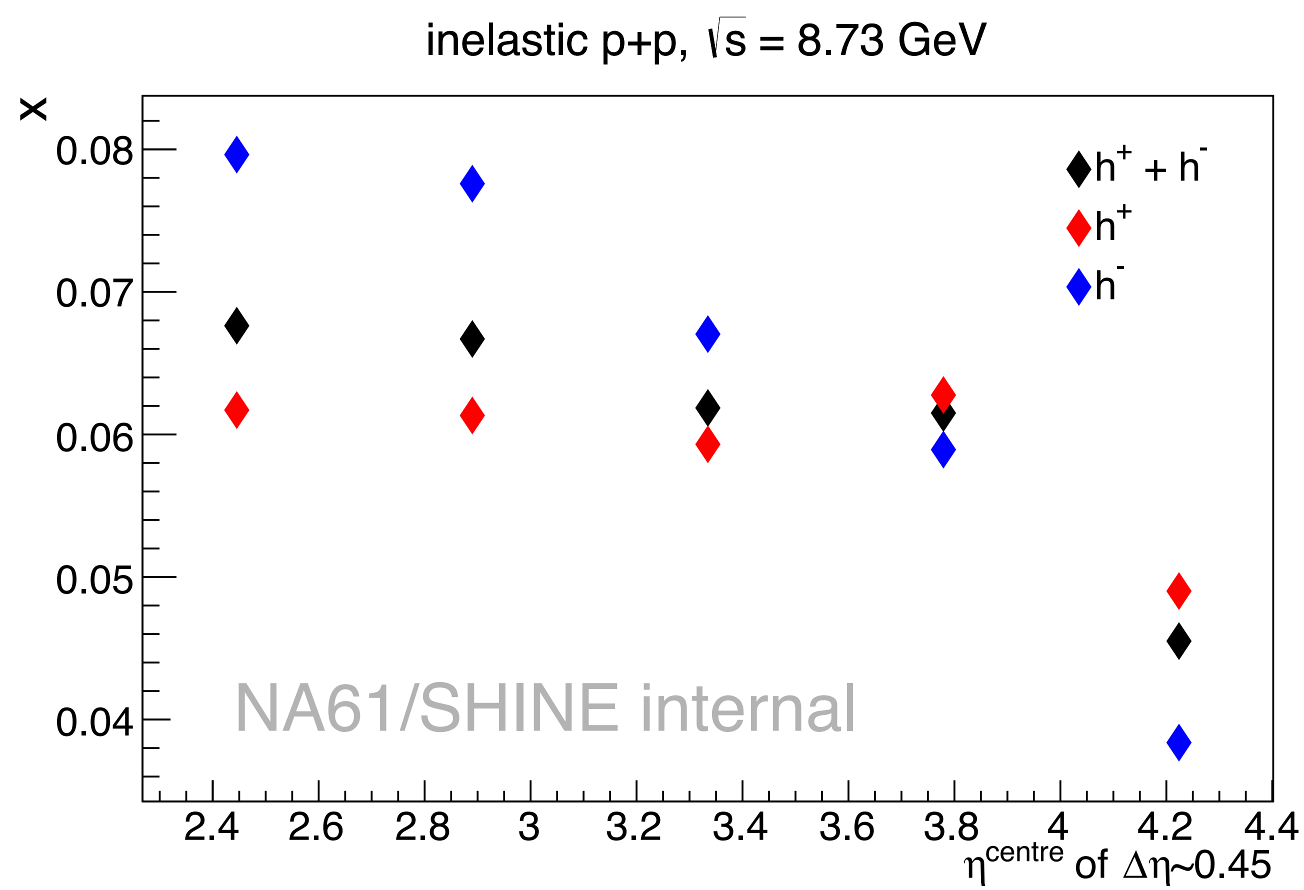
The same x definition from https://arxiv.org/pdf/1911.03426.pdf



8.73 GeV



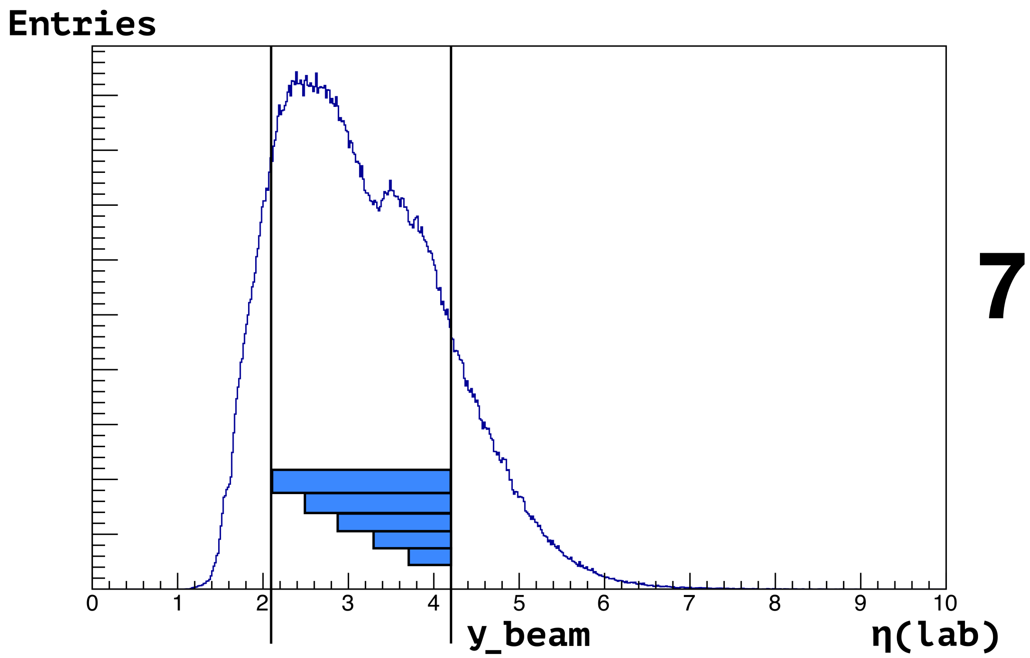




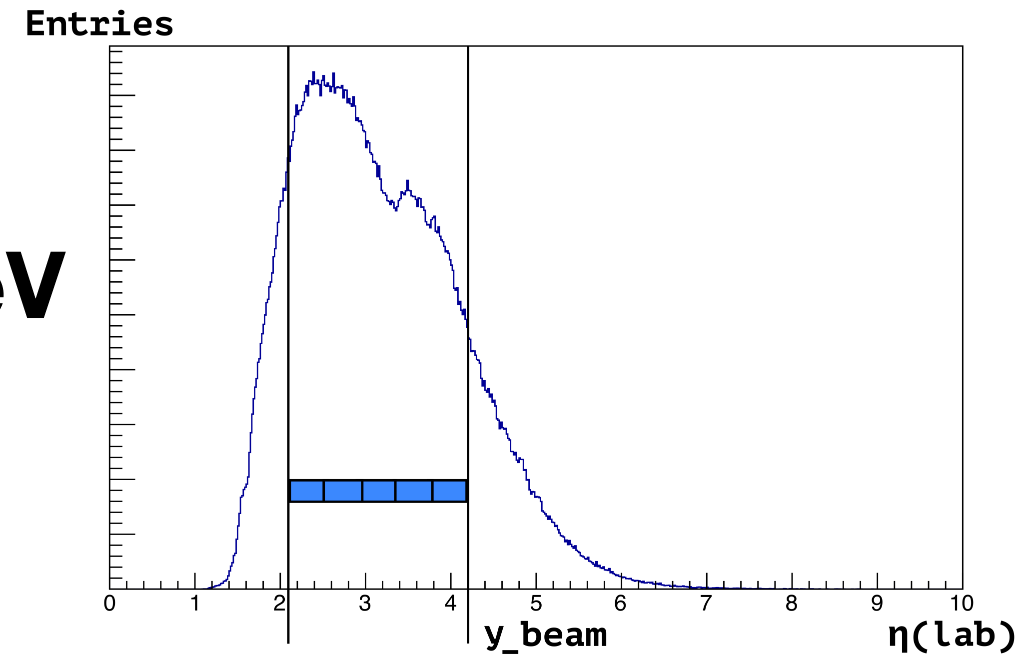
***numerator in x is not corrected**

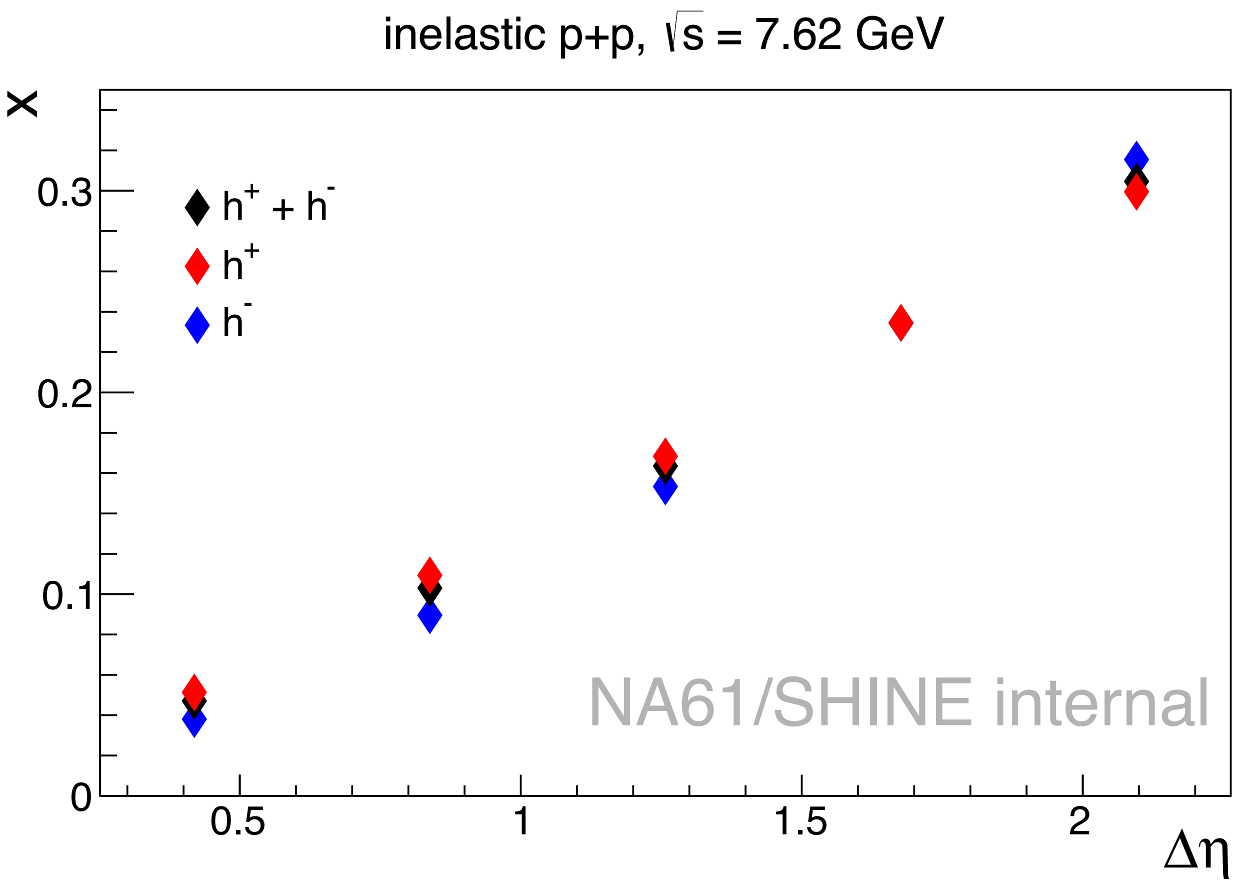
Choice of the phase space: in pseudorapidity

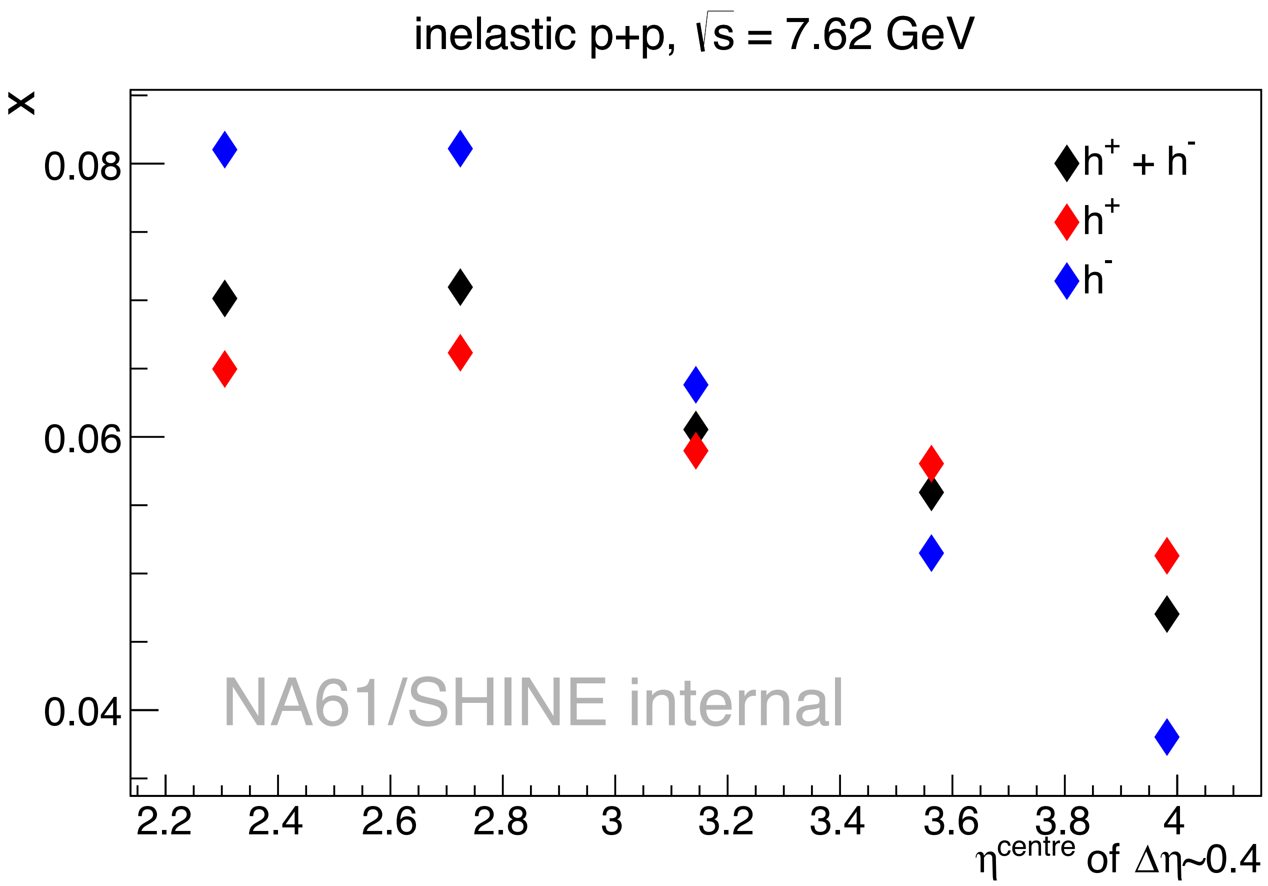
The same x definition from https://arxiv.org/pdf/1911.03426.pdf



7.62 GeV



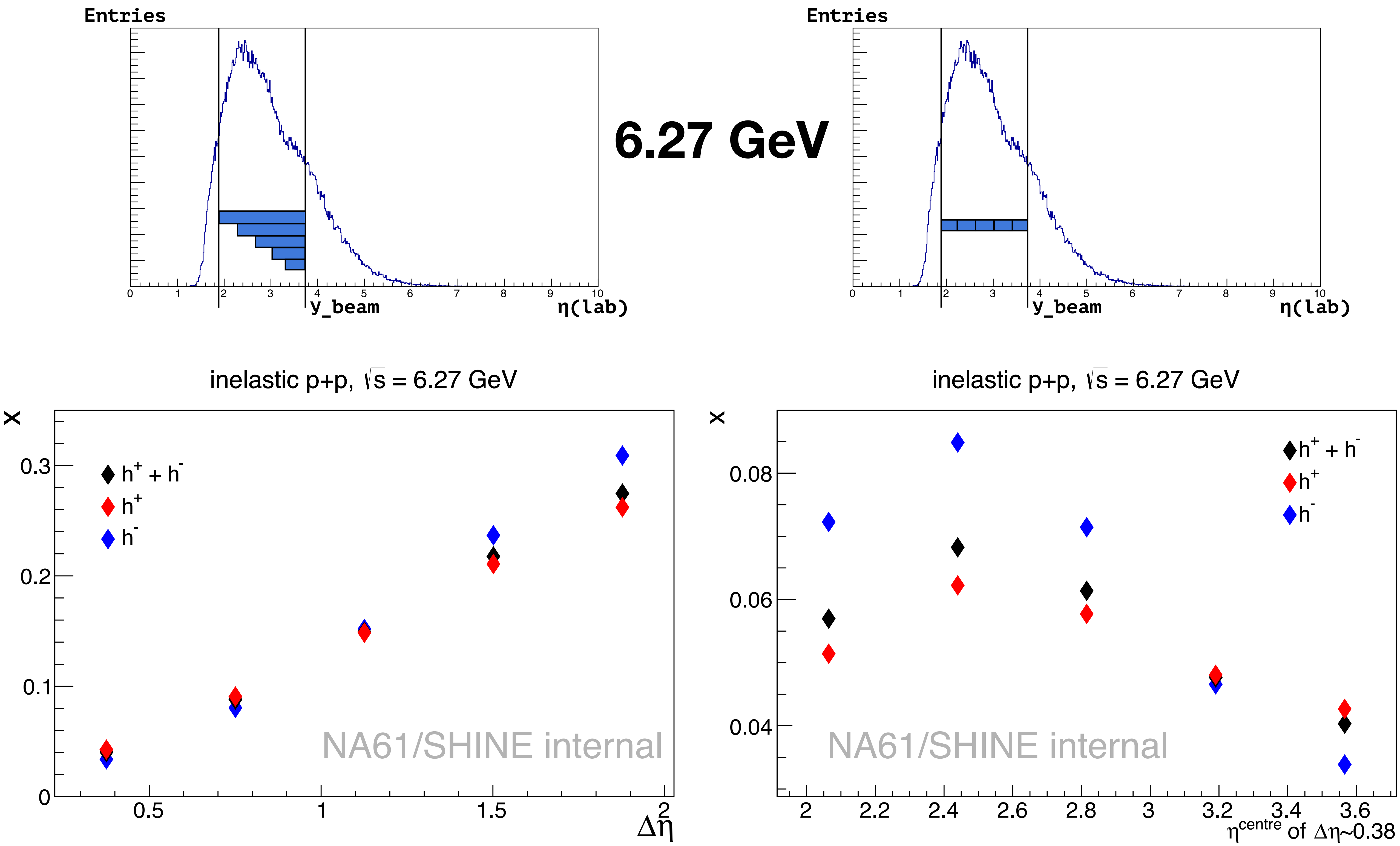




***numerator in x is not corrected**

Choice of the phase space: in pseudorapidity

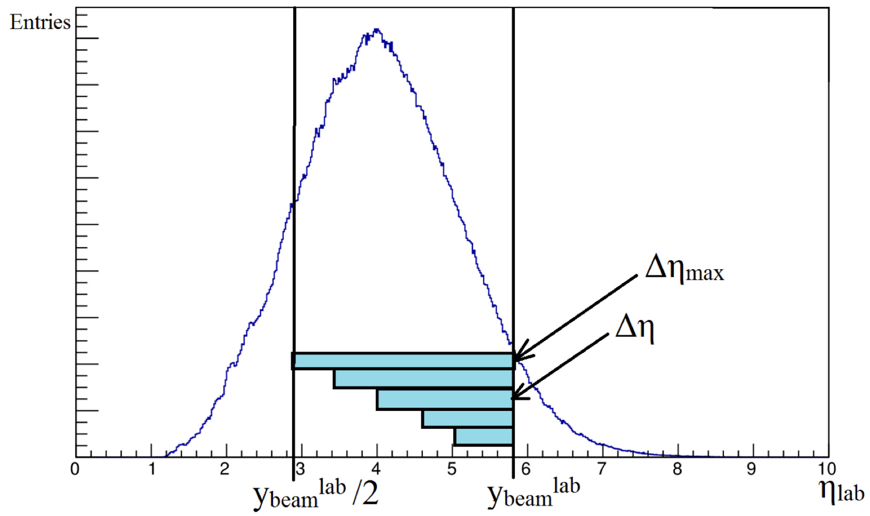
The same x definition from https://arxiv.org/pdf/1911.03426.pdf



***numerator in x is not corrected**

Pseudorapidity dependence vs beam energy

The same x definition from https://arxiv.org/pdf/1911.03426.pdf



$$\Delta[P_T, N] = \frac{1}{C_\Delta}\left[\langle N\rangle\omega[P_T] - \langle P_T\rangle\omega[N]\right],$$

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

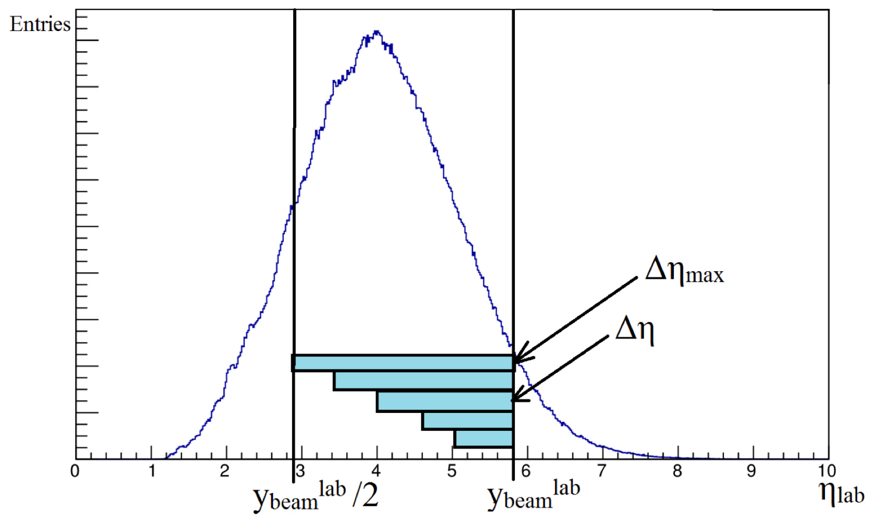
All charged:

√s = 17.27 GeV	**x =**	0.05	0.1	0.3	0.4	0.5
√s = 12.32 GeV	**x =**	0.05	0.1	0.2	0.3	0.4
√s = 8.73 GeV	**x =**	0.05	0.1	0.17	0.24	0.3
√s = 7.62 GeV	**x =**	0.05	0.1	0.16	0.23	0.3
√s = 6.27 GeV	**x =**	0.04	0.09	0.15	0.22	0.27

***numerator in x is not corrected**

Pseudorapidity dependence vs beam energy

The same x definition from https://arxiv.org/pdf/1911.03426.pdf



$$\Delta[P_T, N] = \frac{1}{C_\Delta}\left[\langle N\rangle\omega[P_T] - \langle P_T\rangle\omega[N]\right],$$

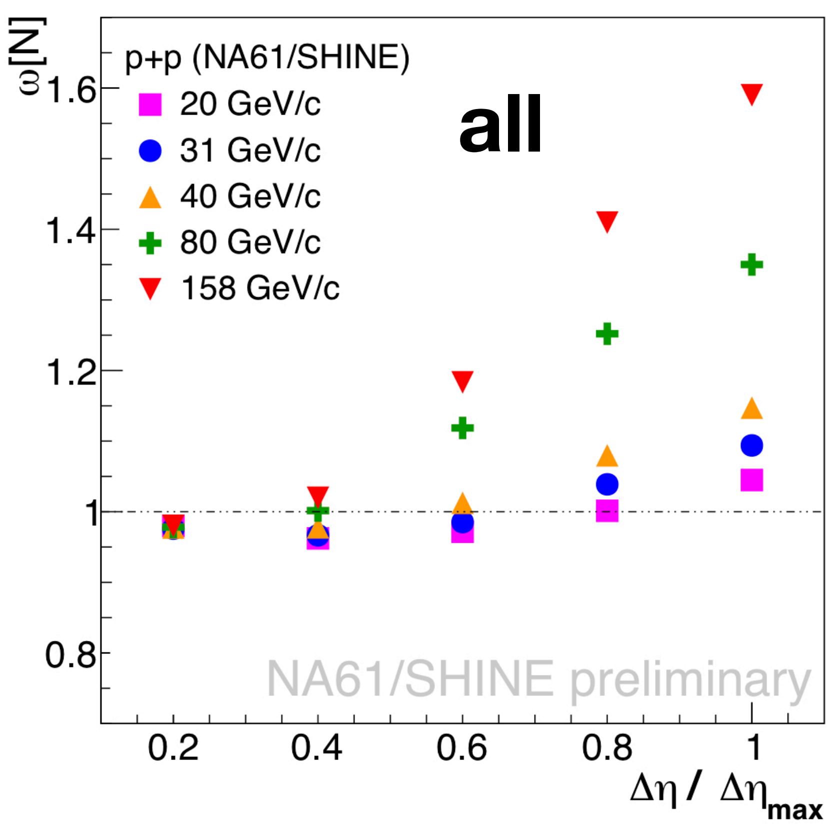
$$\Sigma[P_T, N] = \frac{1}{C_\Sigma}\left[\langle N\rangle\omega[P_T] + \langle P_T\rangle\omega[N] - 2(\langle P_T\cdot N\rangle - \langle P_T\rangle\langle N\rangle)\right]$$

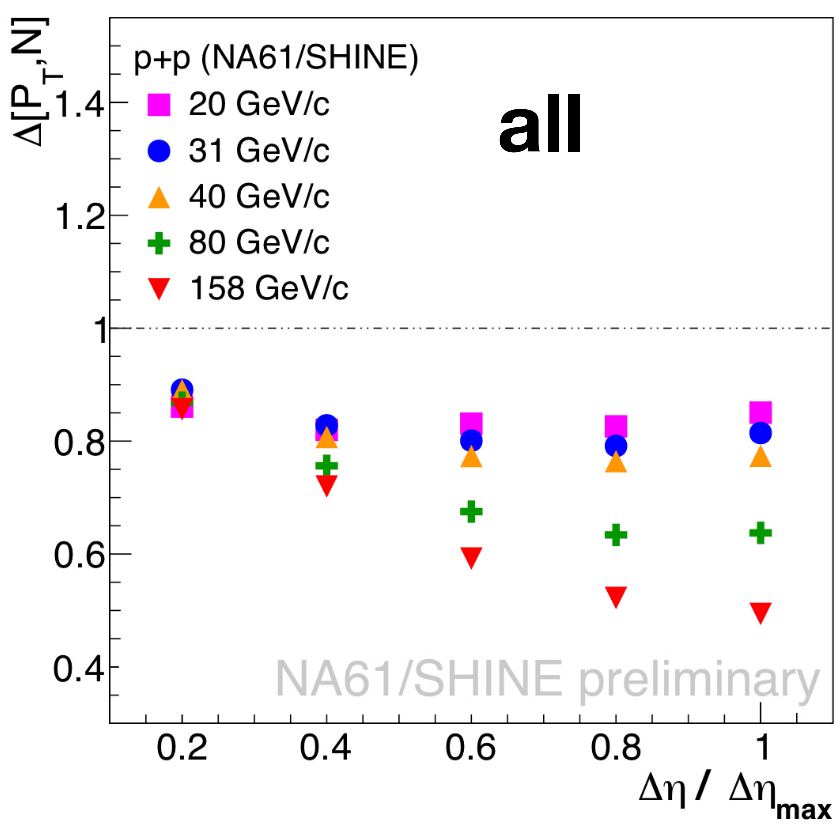
All charged:

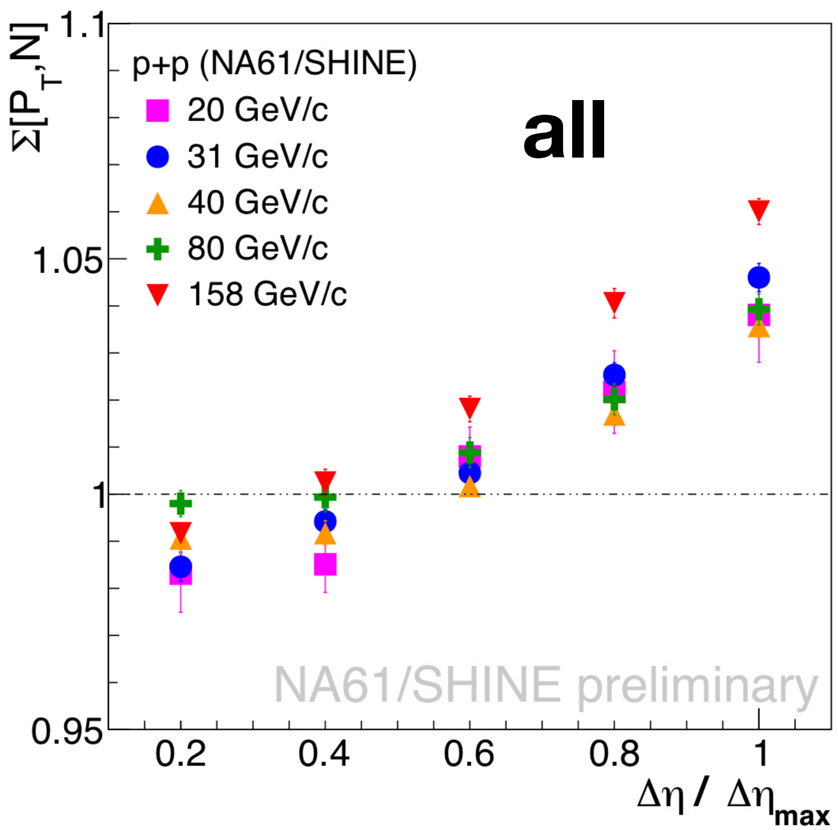
$\sqrt{s}$ = 17.27 GeV	x =	0.05	0.1	0.3	0.4	0.5
$\sqrt{s}$ = 12.32 GeV	x =	0.05	0.1	0.2	0.3	0.4
$\sqrt{s}$ = 8.73 GeV	x =	0.05	0.1	0.17	0.24	0.3
$\sqrt{s}$ = 7.62 GeV	x =	0.05	0.1	0.16	0.23	0.3
$\sqrt{s}$ = 6.27 GeV	x =	0.04	0.09	0.15	0.22	0.27

***numerator in x is not corrected**

Czopowicz T, Acceptance map: https://edms.cern.ch/document/1549298/1



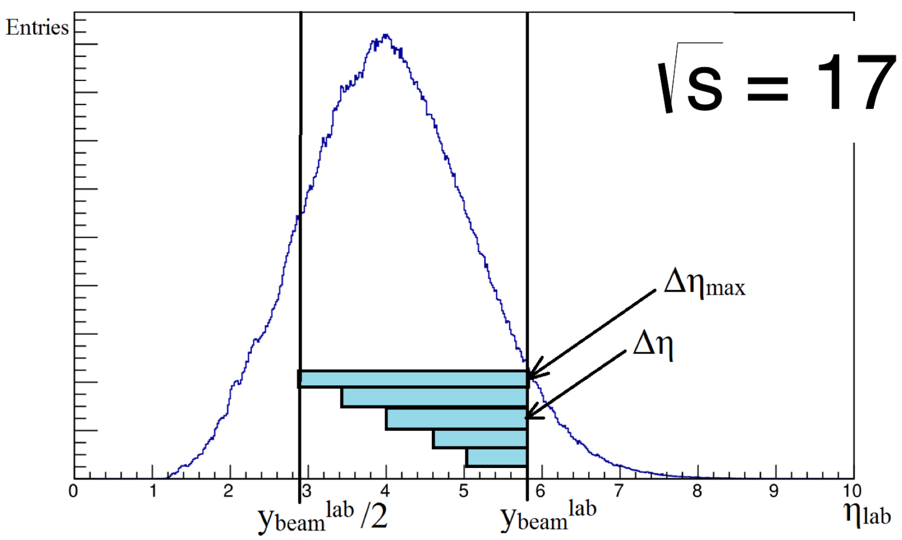




Prokhorova, D. for NA61/SHINE Col., KnE Energy, Vol. 3, p 217 (2018) https://doi.org/10.18502/ken.v3i1.1747

Comparison with EPOS1.99 in the NA61/SHINE acceptance

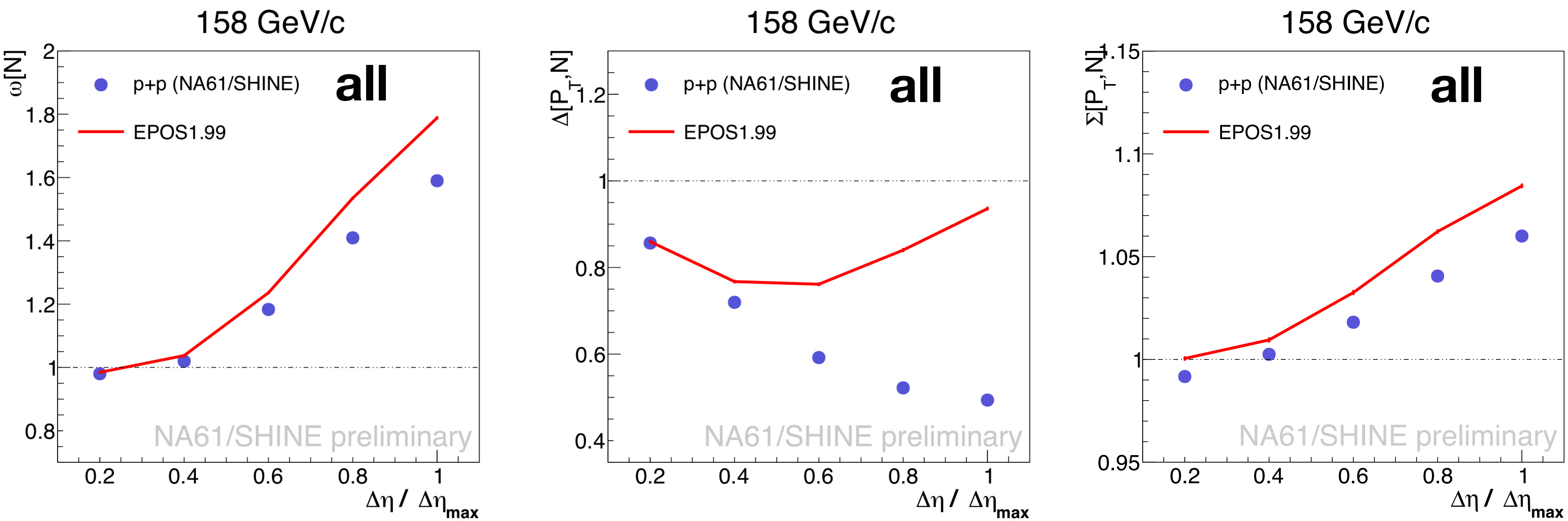
Czopowicz T, Acceptance map: https://edms.cern.ch/document/1549298/1



$$\omega[N] = \frac{\langle N^2\rangle - \langle N\rangle^2}{\langle N\rangle}$$

$$\Delta[P_T, N] = \frac{1}{C_\Delta}\left[\langle N\rangle\omega[P_T] - \langle P_T\rangle\omega[N]\right],$$

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



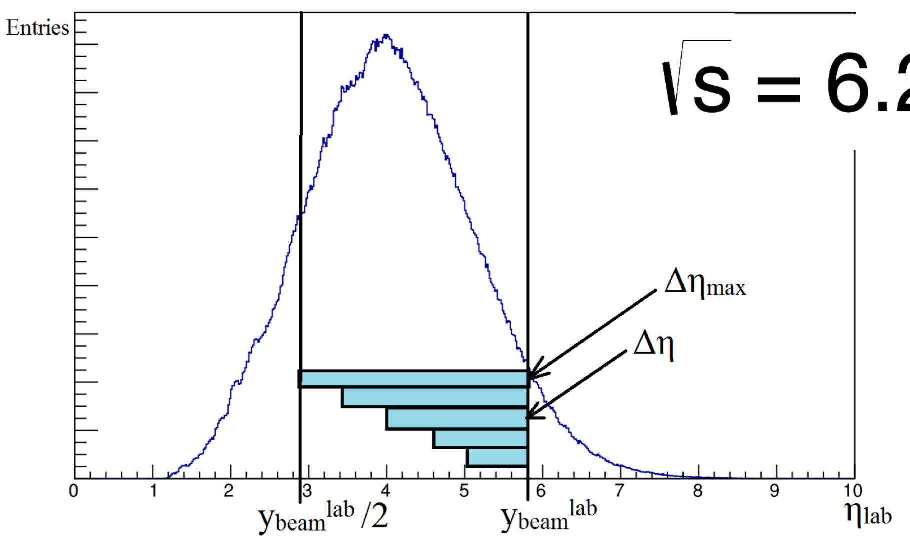
Prokhorova, D. for NA61/SHINE Col., KnE Energy, Vol. 3, p 217 (2018) https://doi.org/10.18502/ken.v3i1.1747

x = 0.05 0.1 0.3 0.4 0.5

***numerator in x is not corrected**

Comparison with EPOS1.99 in the NA61/SHINE acceptance

Czopowicz T, Acceptance map: https://edms.cern.ch/document/1549298/1

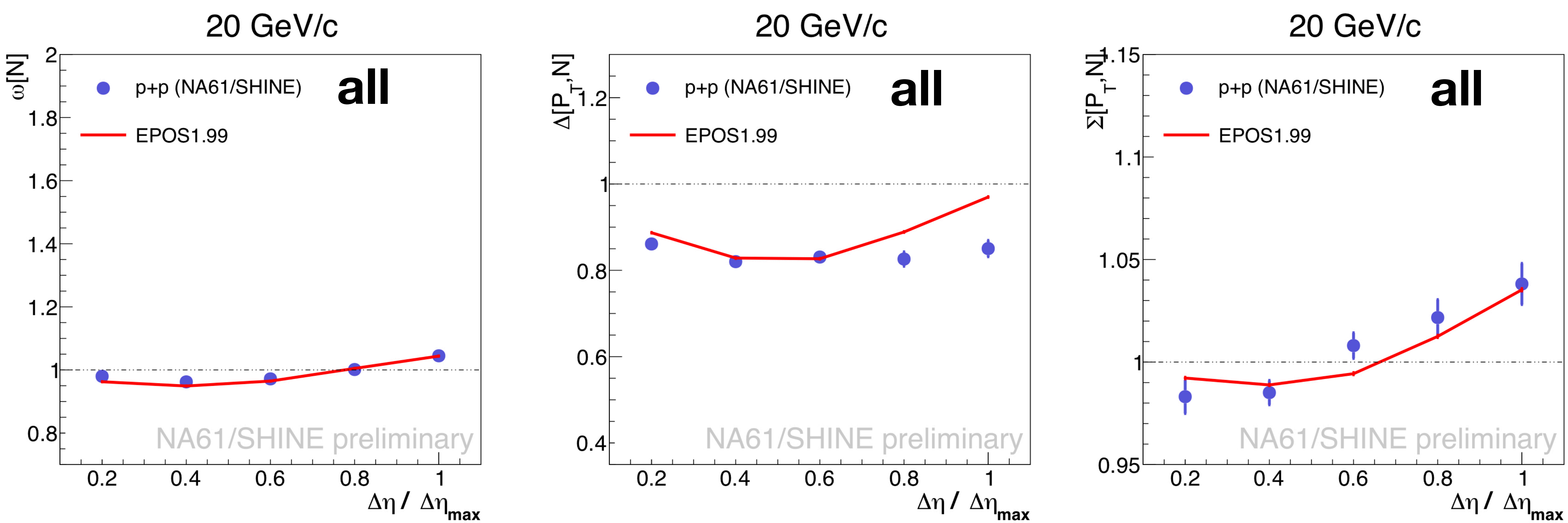


$\sqrt{s}$ = 6.27 GeV

$$\omega[N] = \frac{\langle N^2\rangle - \langle N\rangle^2}{\langle N\rangle}$$

$$\Delta[P_T, N] = \frac{1}{C_\Delta}\left[\langle N\rangle\omega[P_T] - \langle P_T\rangle\omega[N]\right],$$

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



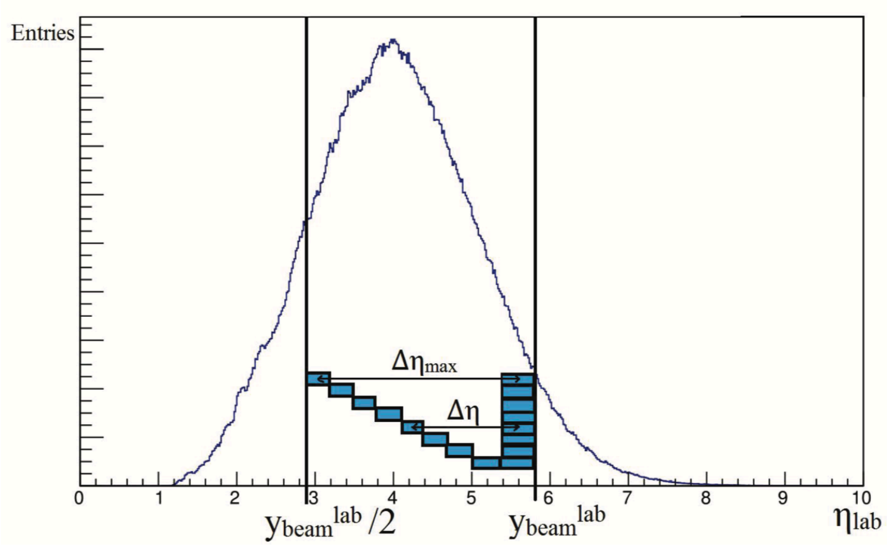
Prokhorova, D. for NA61/SHINE Col., KnE Energy, Vol. 3, p 217 (2018) https://doi.org/10.18502/ken.v3i1.1747

x = 0.04 0.09 0.15 0.22 0.27

***numerator in x is not corrected**

Choice of the phase space: separated pseudorapidity regions

Czopowicz T, Acceptance map: https://edms.cern.ch/document/1549298/1

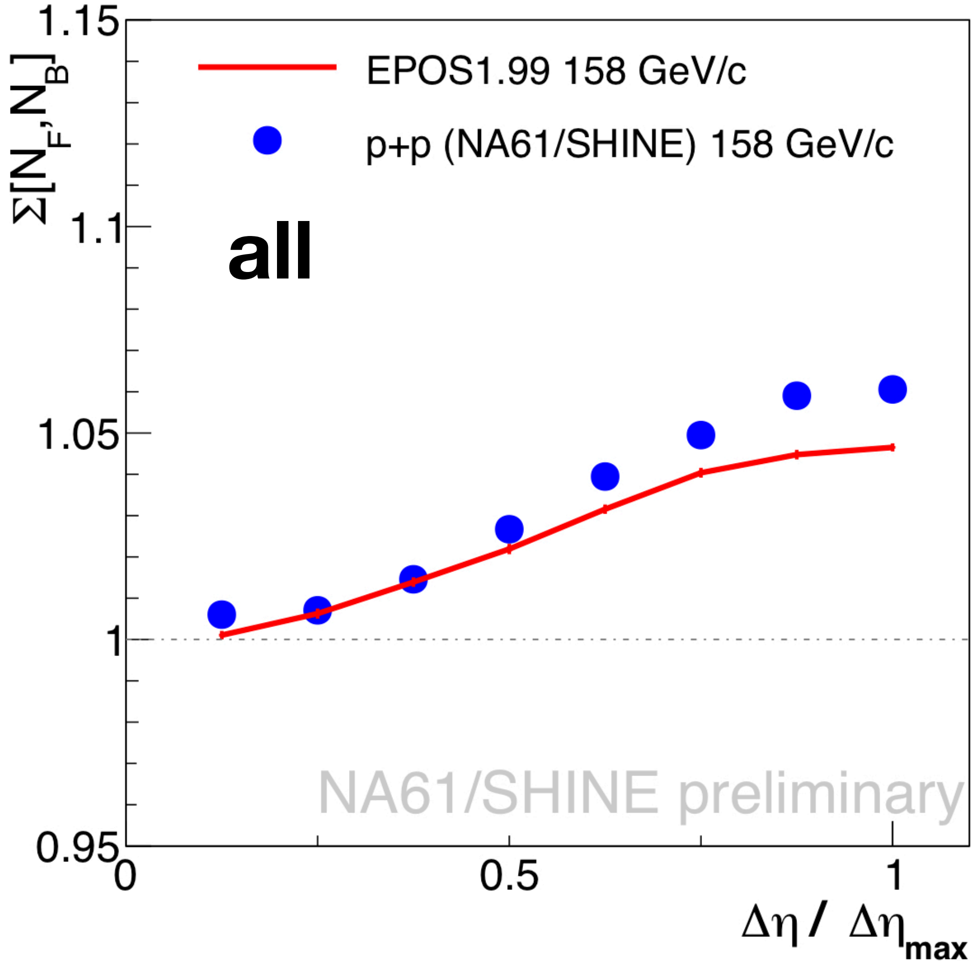


$$\Sigma[N_F, N_B] = \frac{1}{\langle N_B \rangle + \langle N_F \rangle} \left[\langle N_B \rangle \omega[N_F] + \langle N_F \rangle \omega[N_B] - 2(\langle N_F N_B \rangle - \langle N_F \rangle \langle N_B \rangle) \right]$$

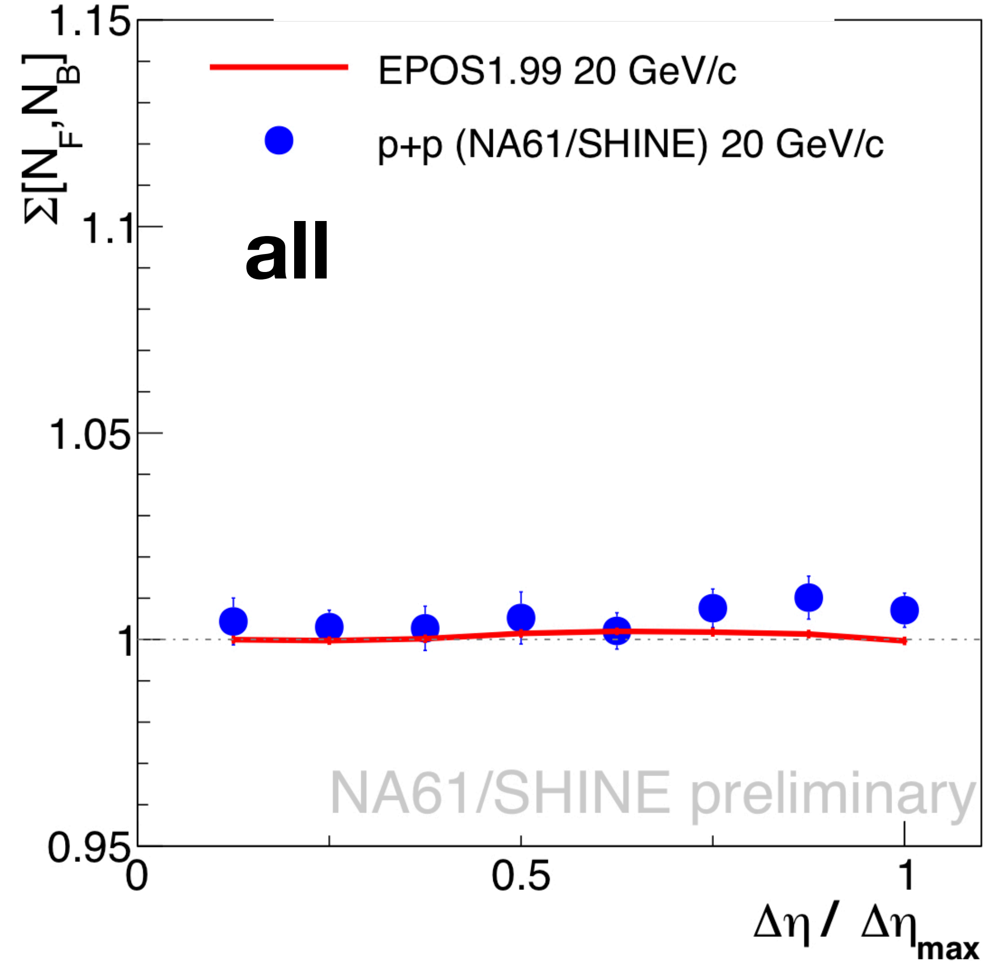
1. E. Andronov and V. Vechernin, “Strongly intensive observable between multiplicities in two acceptance windows in a string model,” Eur. Phys. J. A 55, 14 (2019), https://doi.org/10.1140/epja/i2019-12681-x

2. D.S. Prokhorova, V.N. Kovalenko, «Pseudorapidity dependence of multiplicity fluctuations in the model of interacting quark-gluon strings of finite rapidity length», Bull. Russ. Acad. Sci. Phys. 84, p. 1261–1265 (2020), https://doi.org/10.3103/S1062873820100202

$\sqrt{s}$ = 17.27 GeV



$\sqrt{s}$ = 6.27 GeV

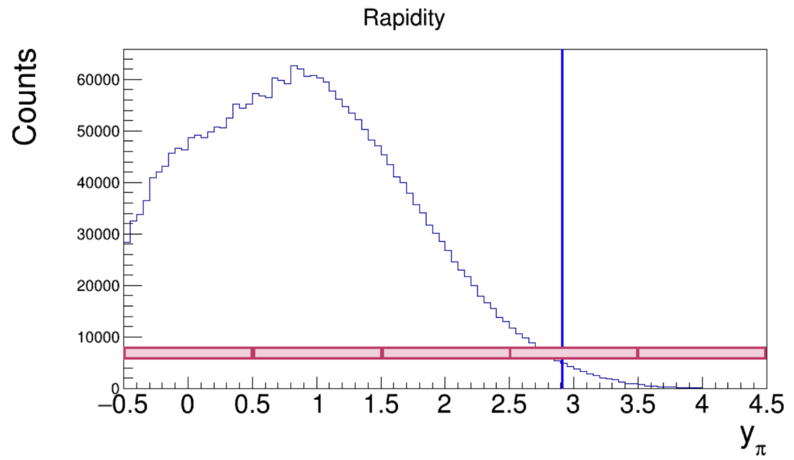


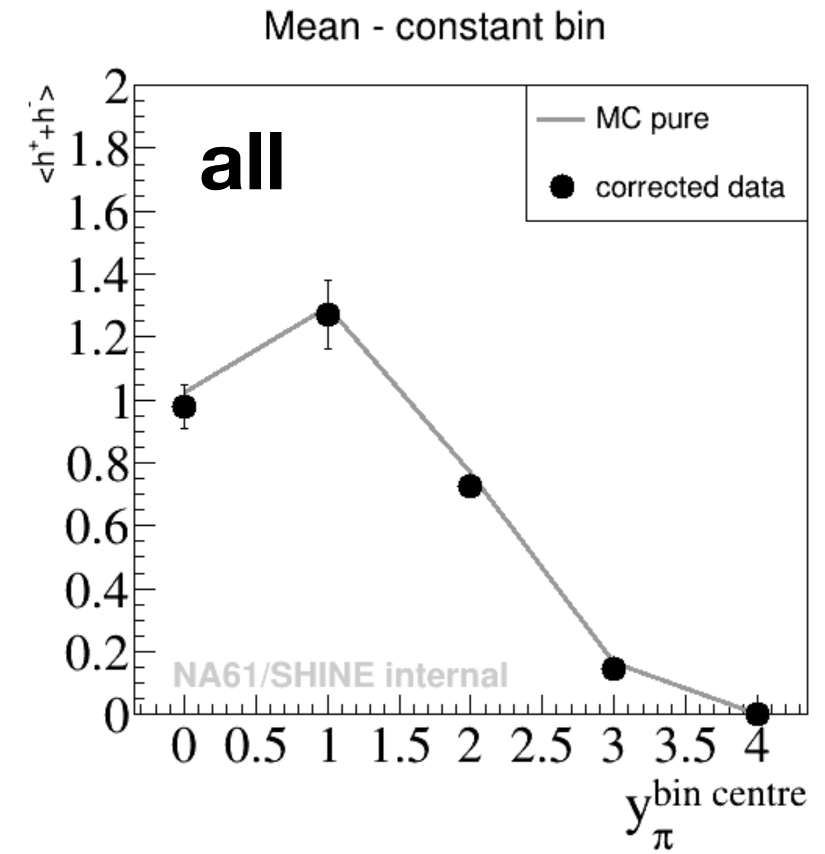
Prokhorova, D. for NA61/SHINE Col., KnE Energy, Vol. 3, p 217 (2018) https://doi.org/10.18502/ken.v3i1.1747

Ideas for the future analysis:

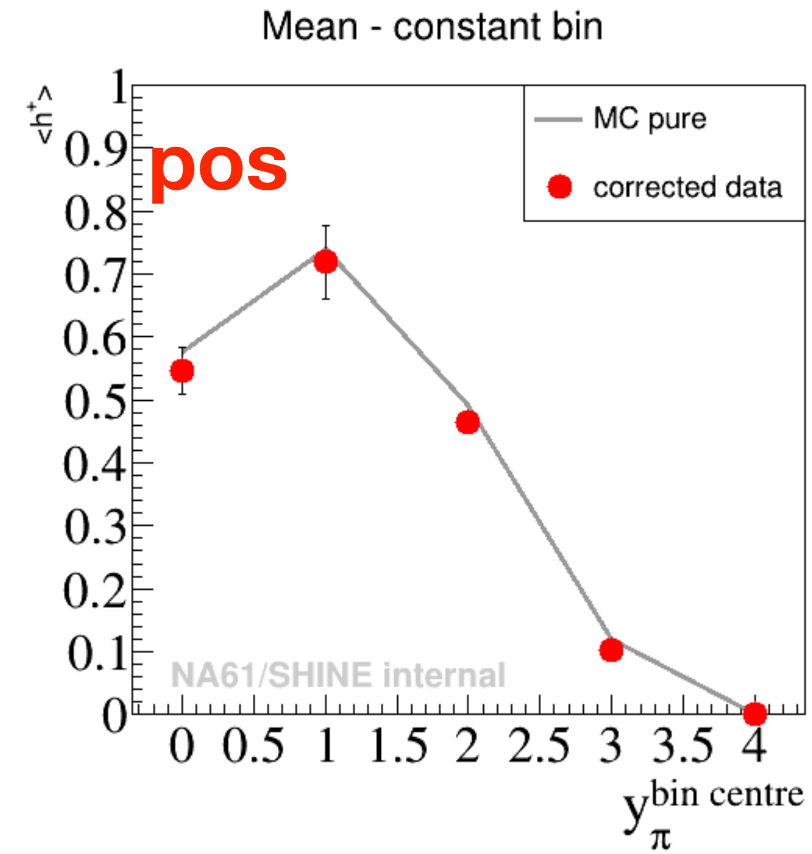
- selection of the intervals with equal multiplicities
- …

Back-up





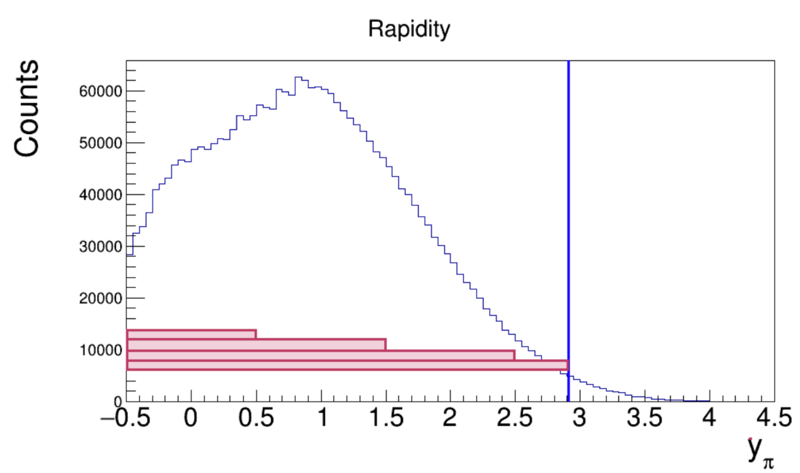
x= 0.14 0.18 0.10 0.02 0.00005

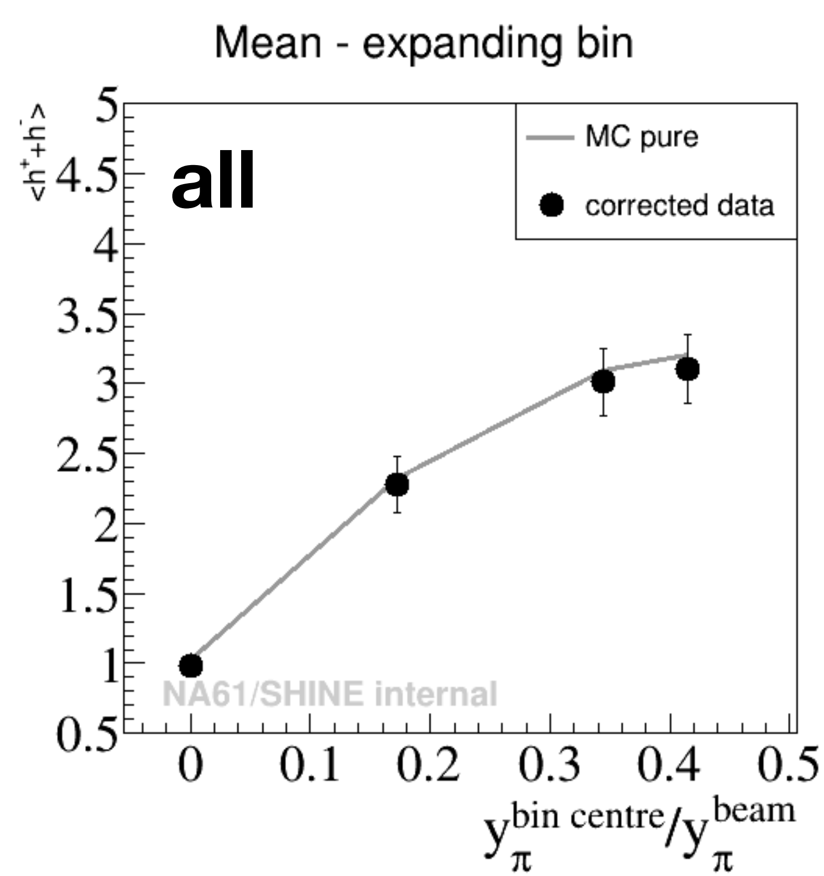


x= 0.12 0.16 0.10 0.02 0.00006

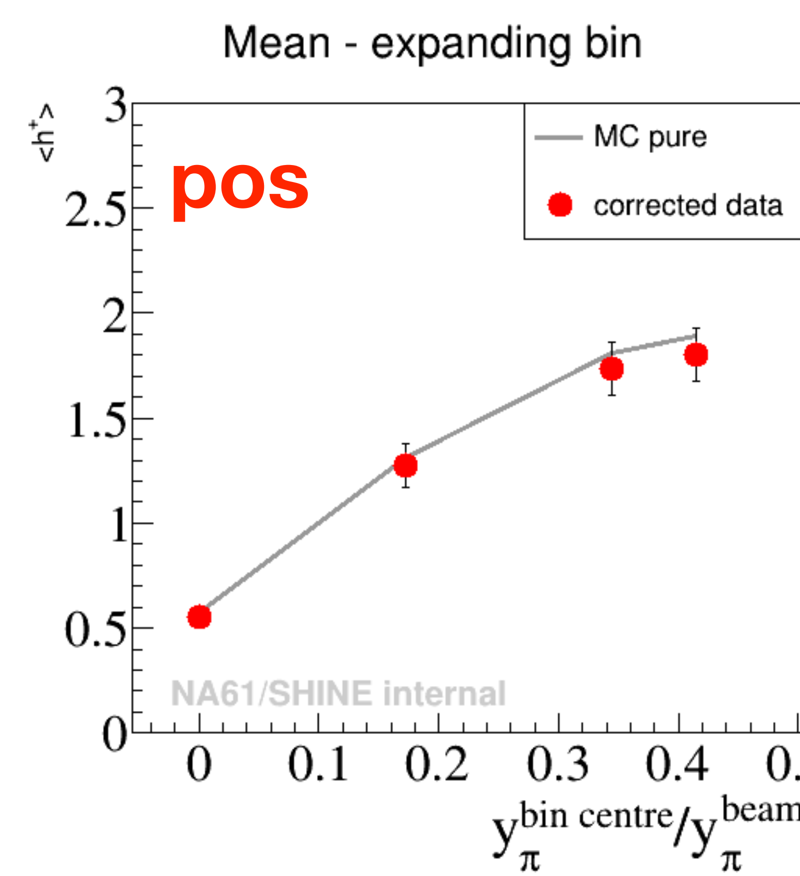
<Ni>

*MC pure is calculated in the NA61/SHINE acceptance

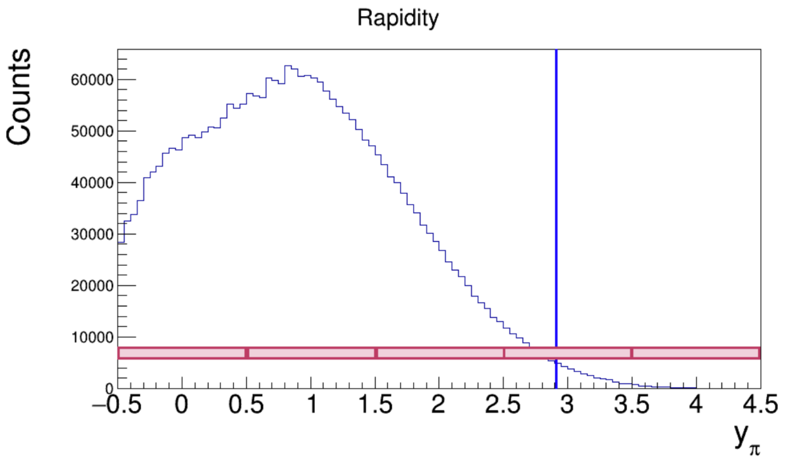


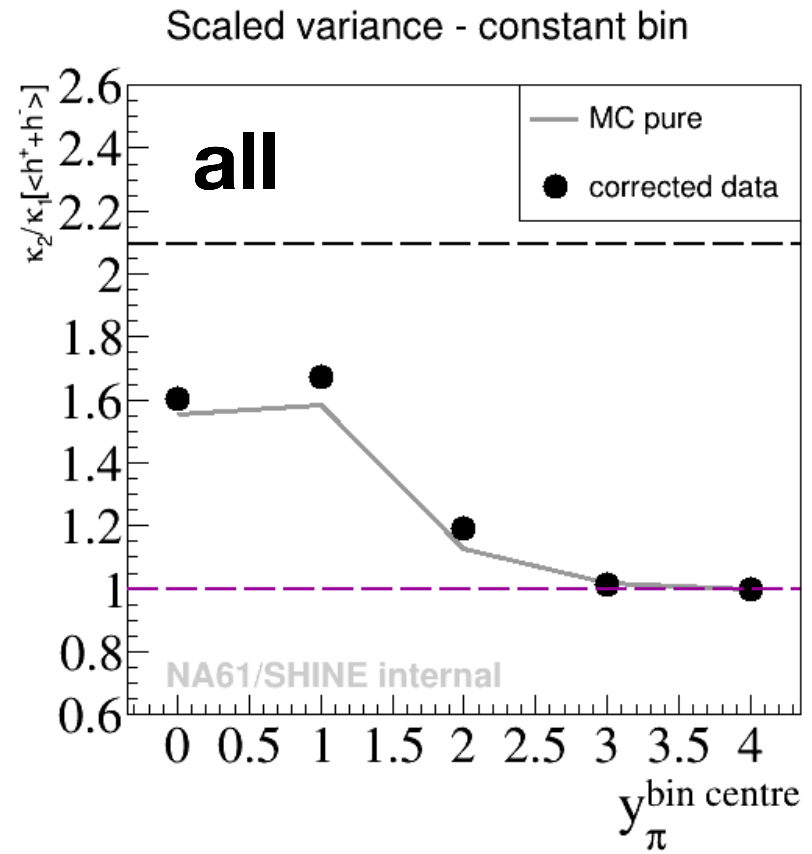


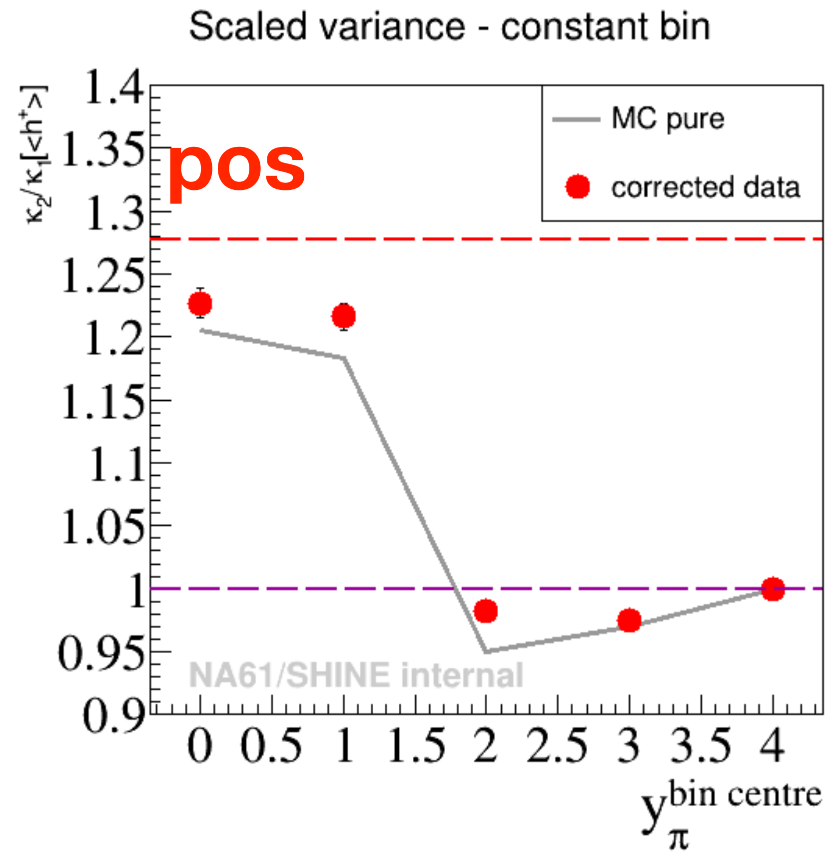
x= 0.14 0.32 0.43 0.44



x= 0.12 0.28 0.38 0.40





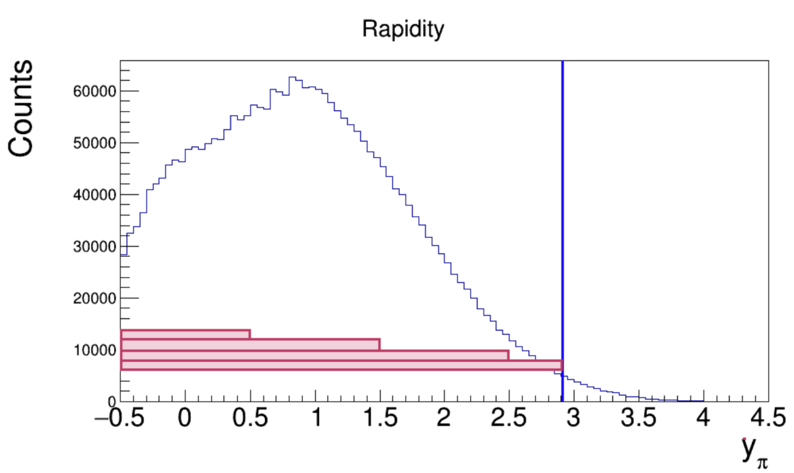


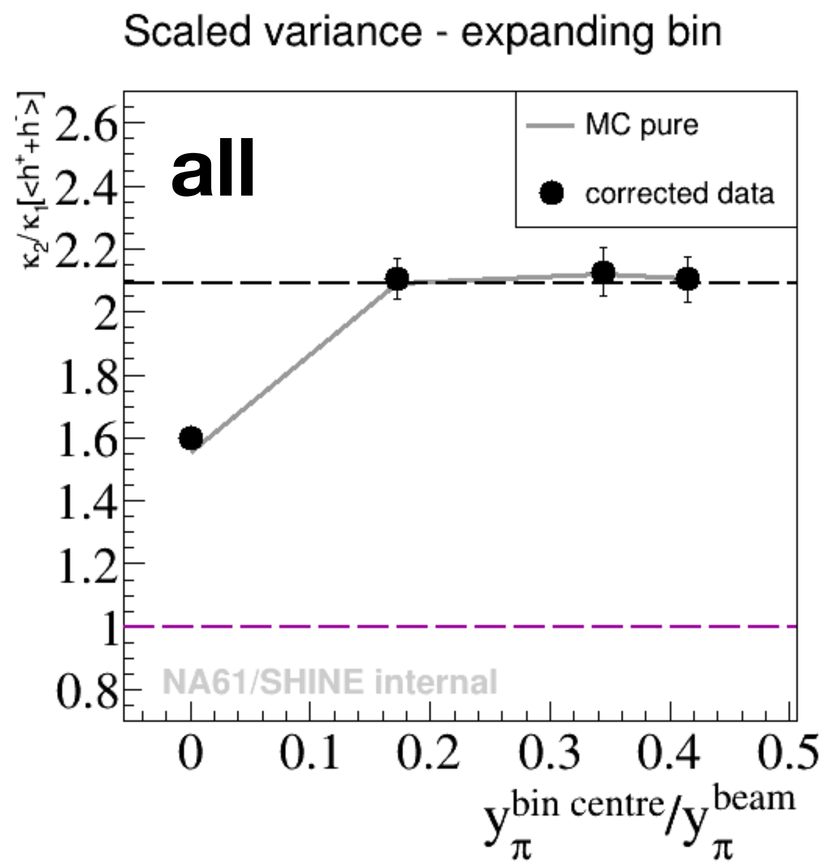
x= 0.14 0.18 0.10 0.02 0.00005

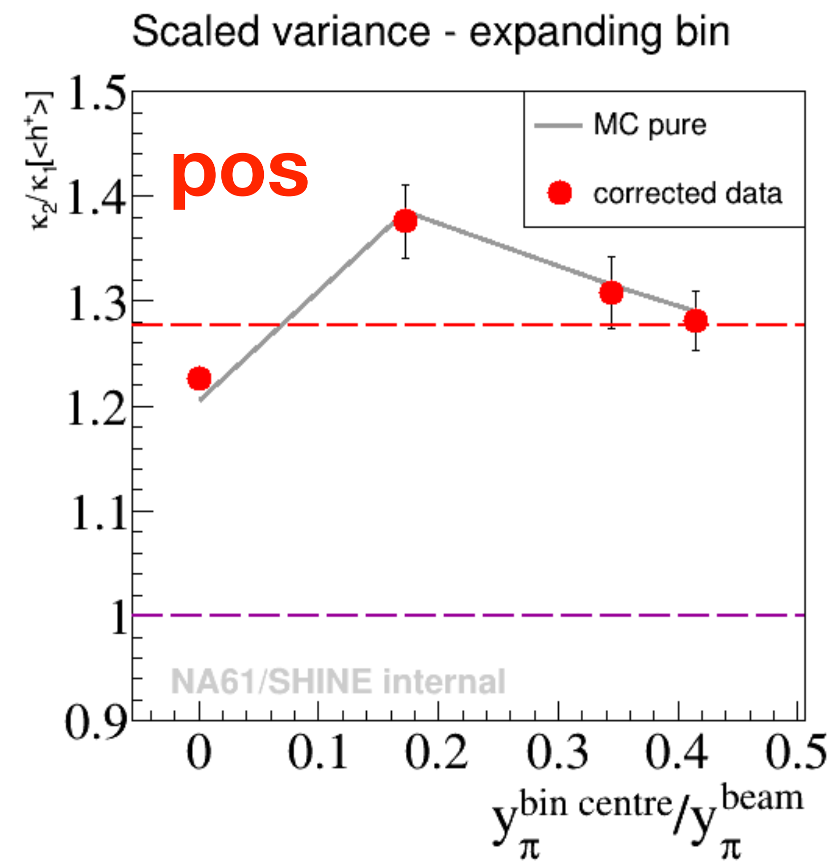
x= 0.12 0.16 0.10 0.02 0.00006

ω[Ni]

*MC pure is calculated in the NA61/SHINE acceptance

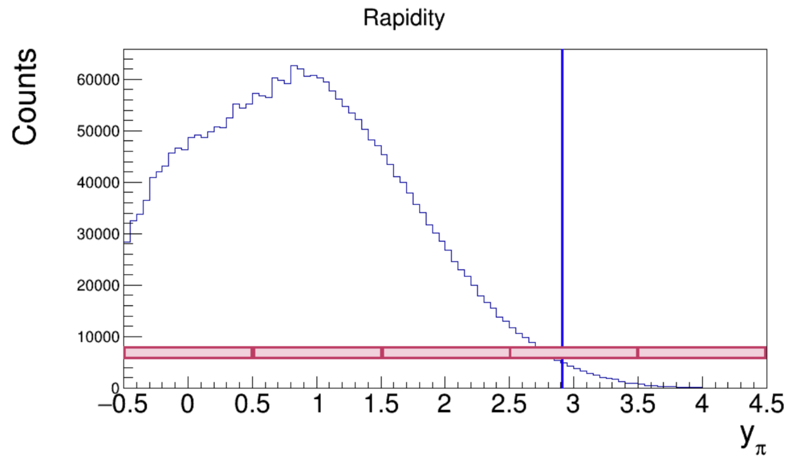


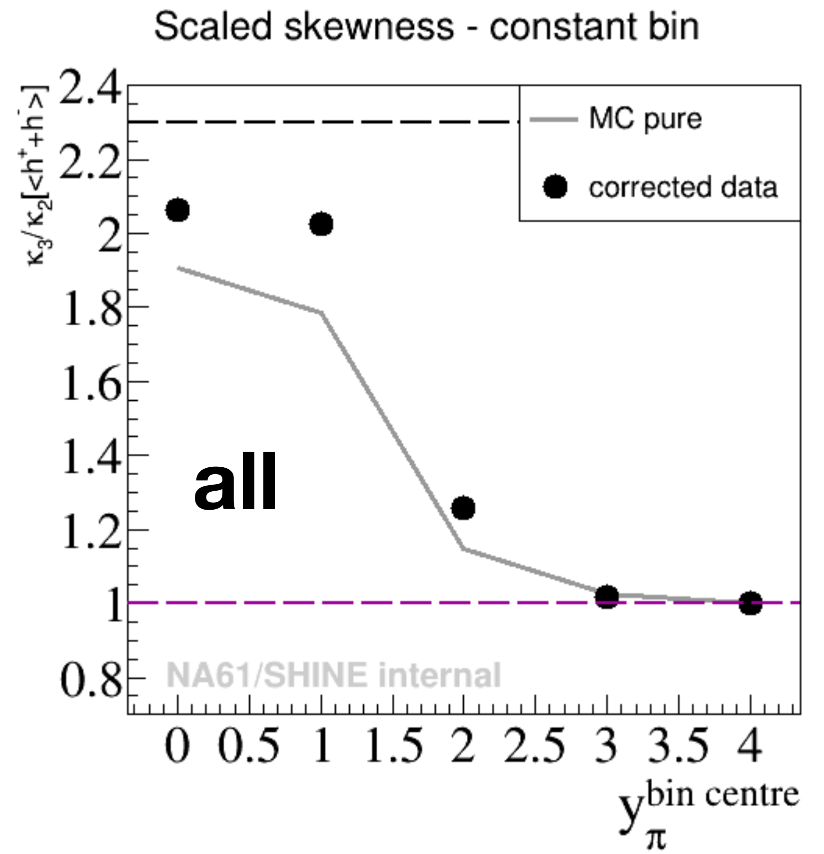




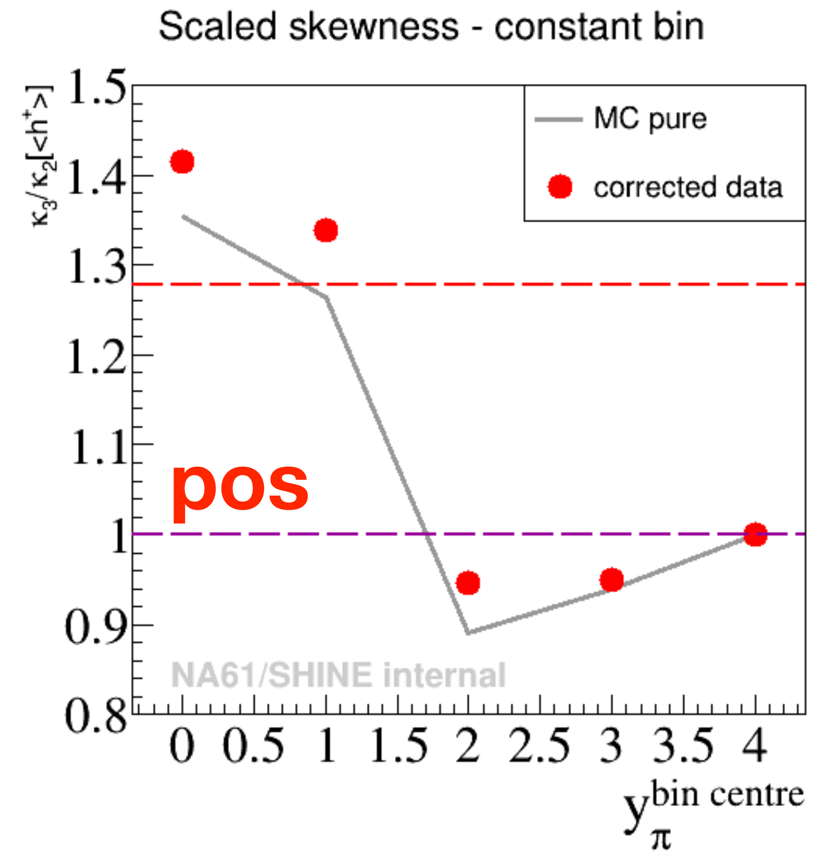
x= 0.14 0.32 0.43 0.44

x= 0.12 0.28 0.38 0.40





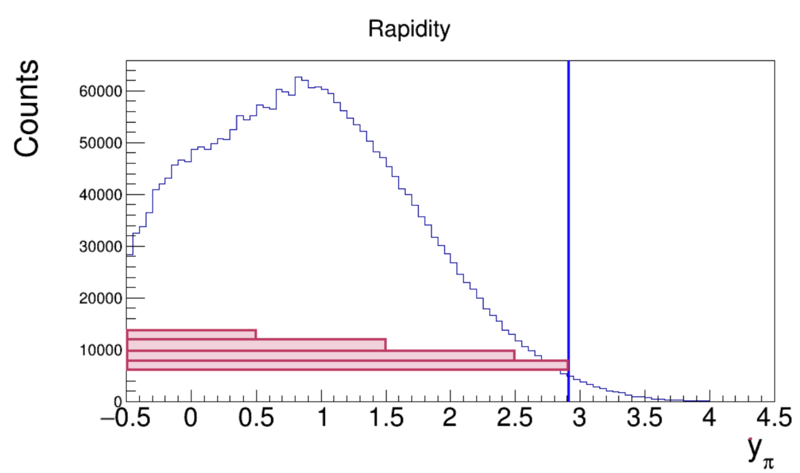
x= 0.14 0.18 0.10 0.02 0.00005

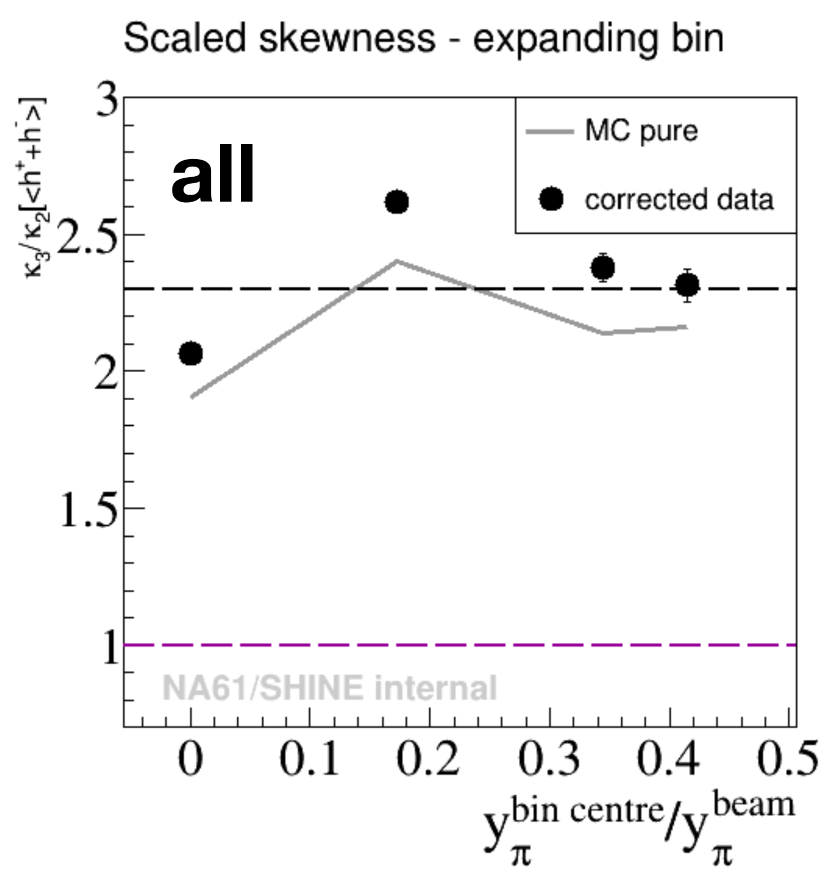


x= 0.12 0.16 0.10 0.02 0.00006

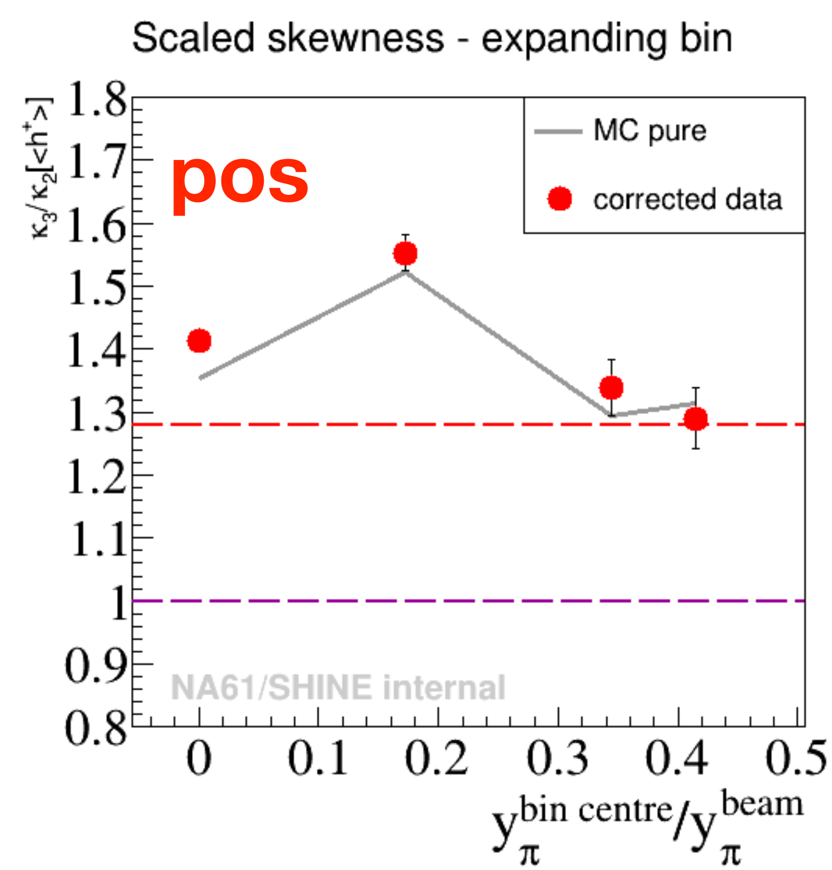
Sσ

*MC pure is calculated in the NA61/SHINE acceptance

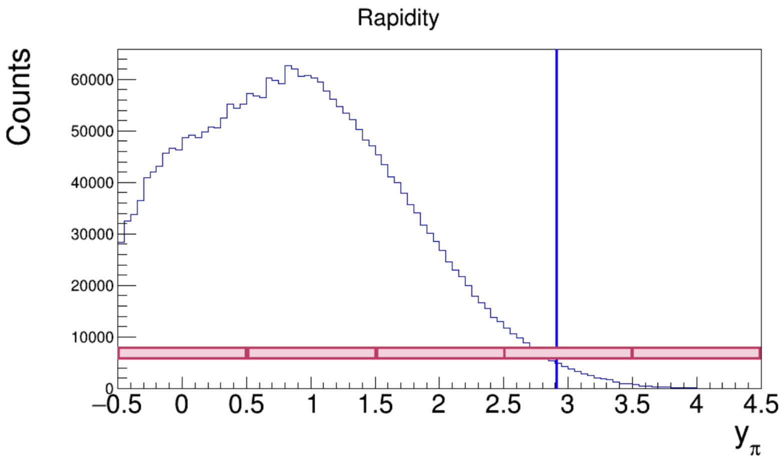




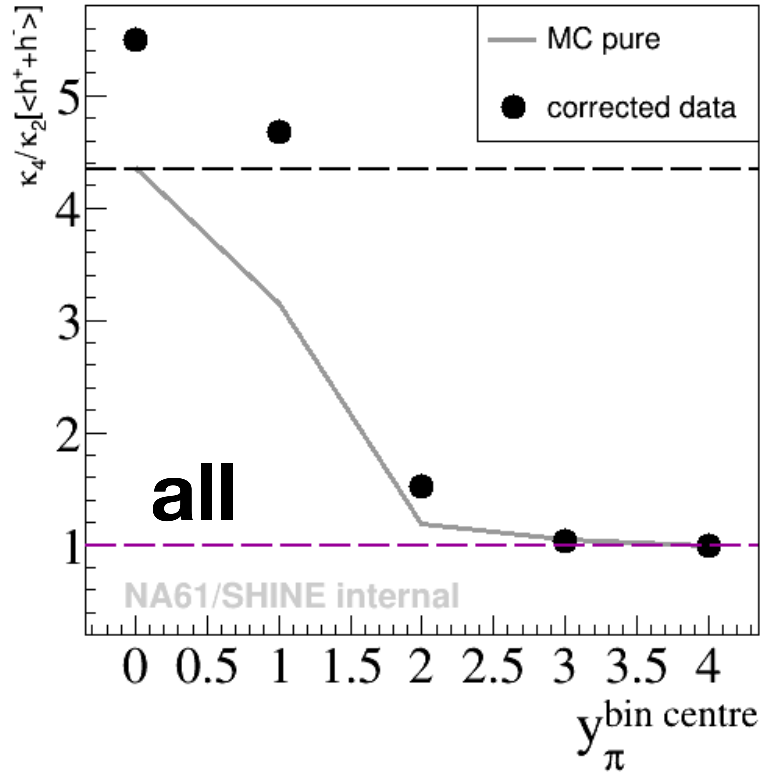
x= 0.14 0.32 0.43 0.44



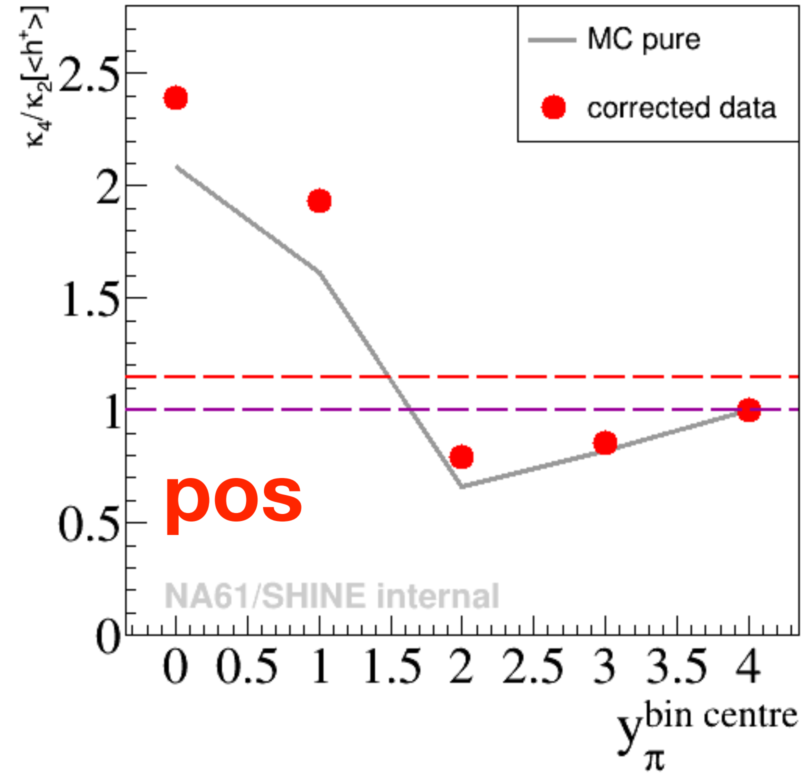
x= 0.12 0.28 0.38 0.40



Scaled kurtosis - constant bin



Scaled kurtosis - constant bin

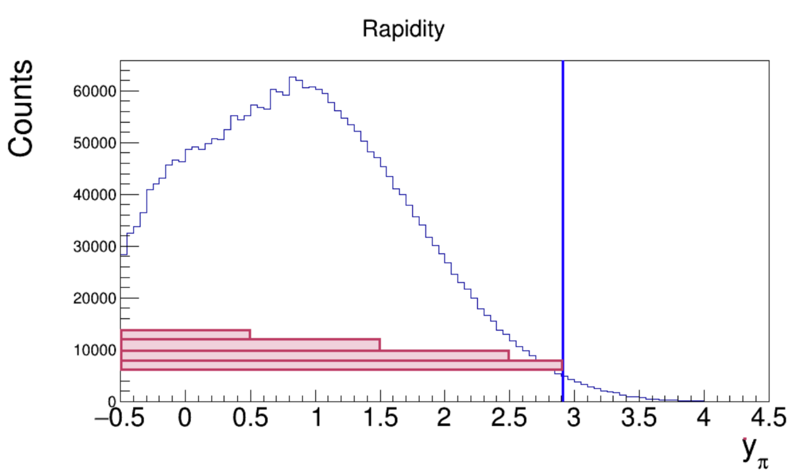


x= 0.14 0.18 0.10 0.02 0.00005

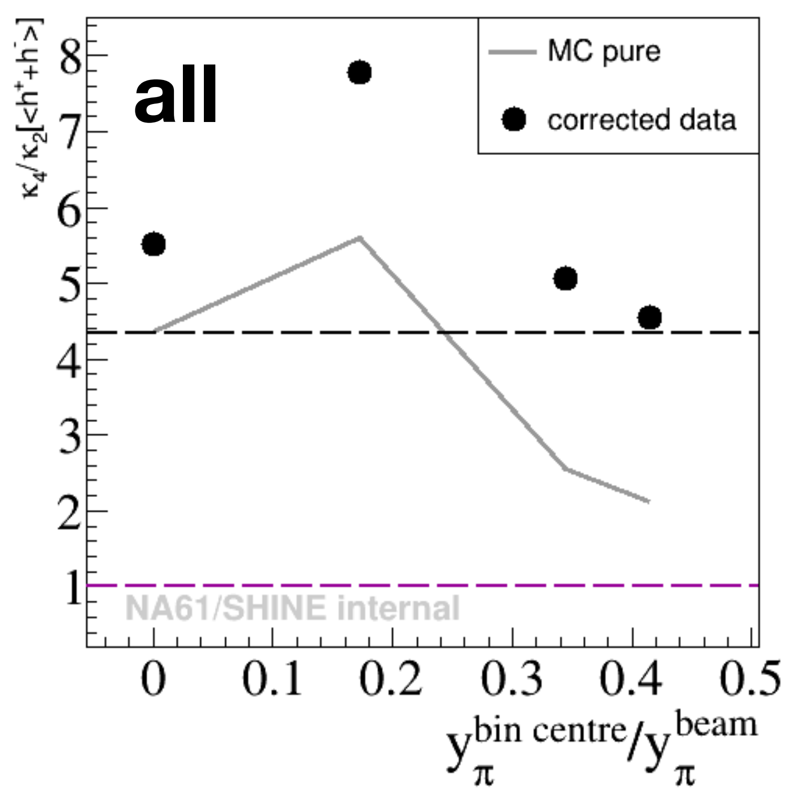
x= 0.12 0.16 0.10 0.02 0.00006

ϰσ^2

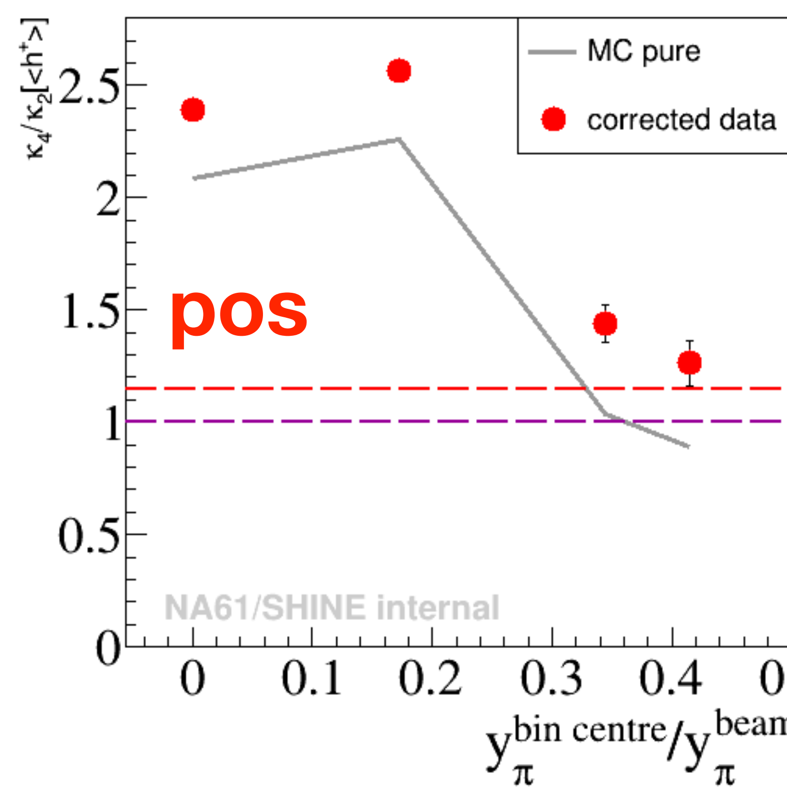
*MC pure is calculated in the NA61/SHINE acceptance



Scaled kurtosis - expanding bin



Scaled kurtosis - expanding bin



x= 0.14 0.32 0.43 0.44

x= 0.12 0.28 0.38 0.40