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# Are the proton-proton and proton-antiproton interactions different at very high energies?

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# Are the proton-proton and proton-antiproton interactions different at very high energies?

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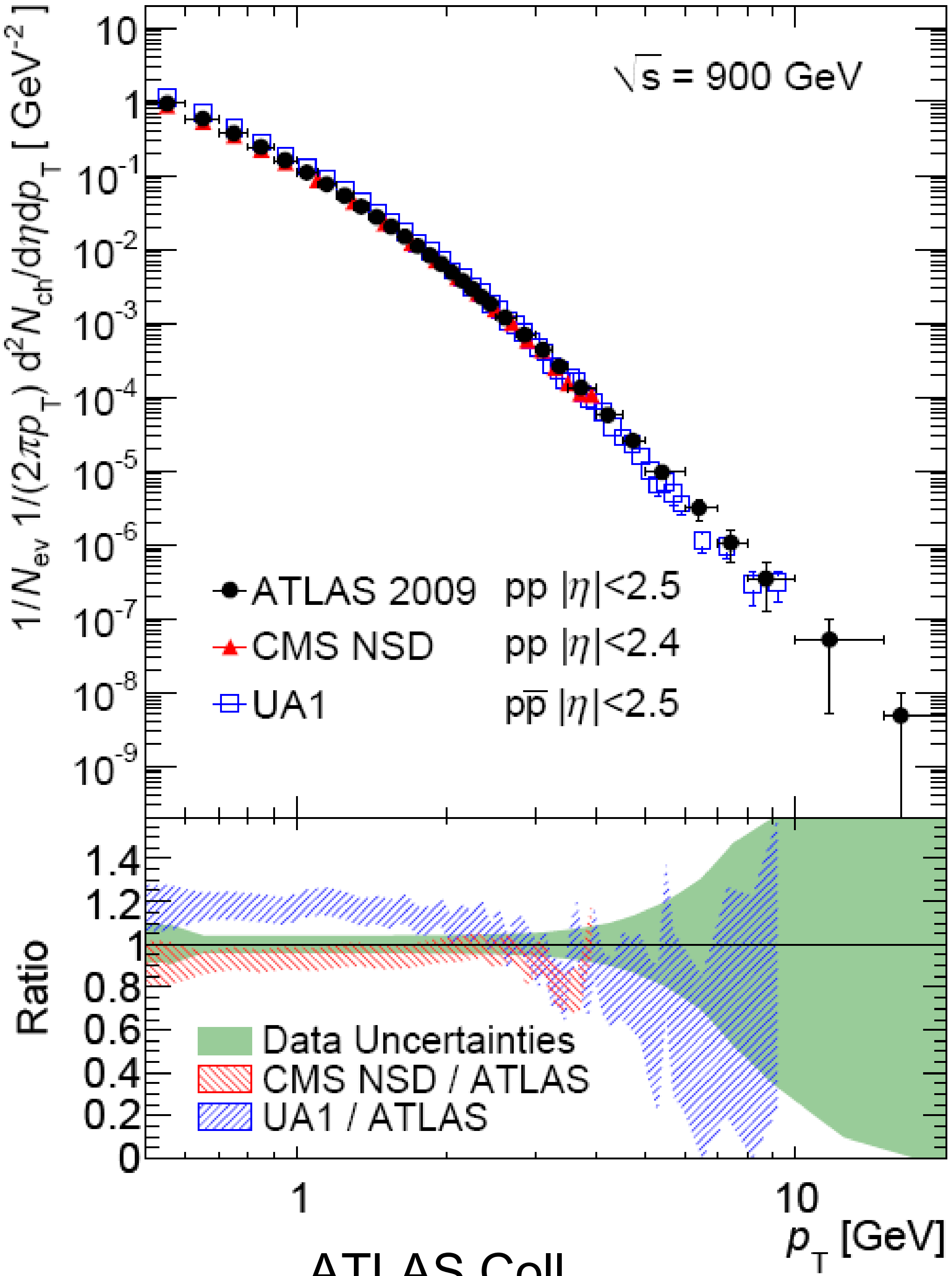



ATLAS Coll.
arXiv:1003.3124v1

# New effect?

$$p\bar{p}/pp \approx 1.2$$

contribution from single-diffractive component estimated from Pythia gives only about 10%

# Low Constituents Number Model

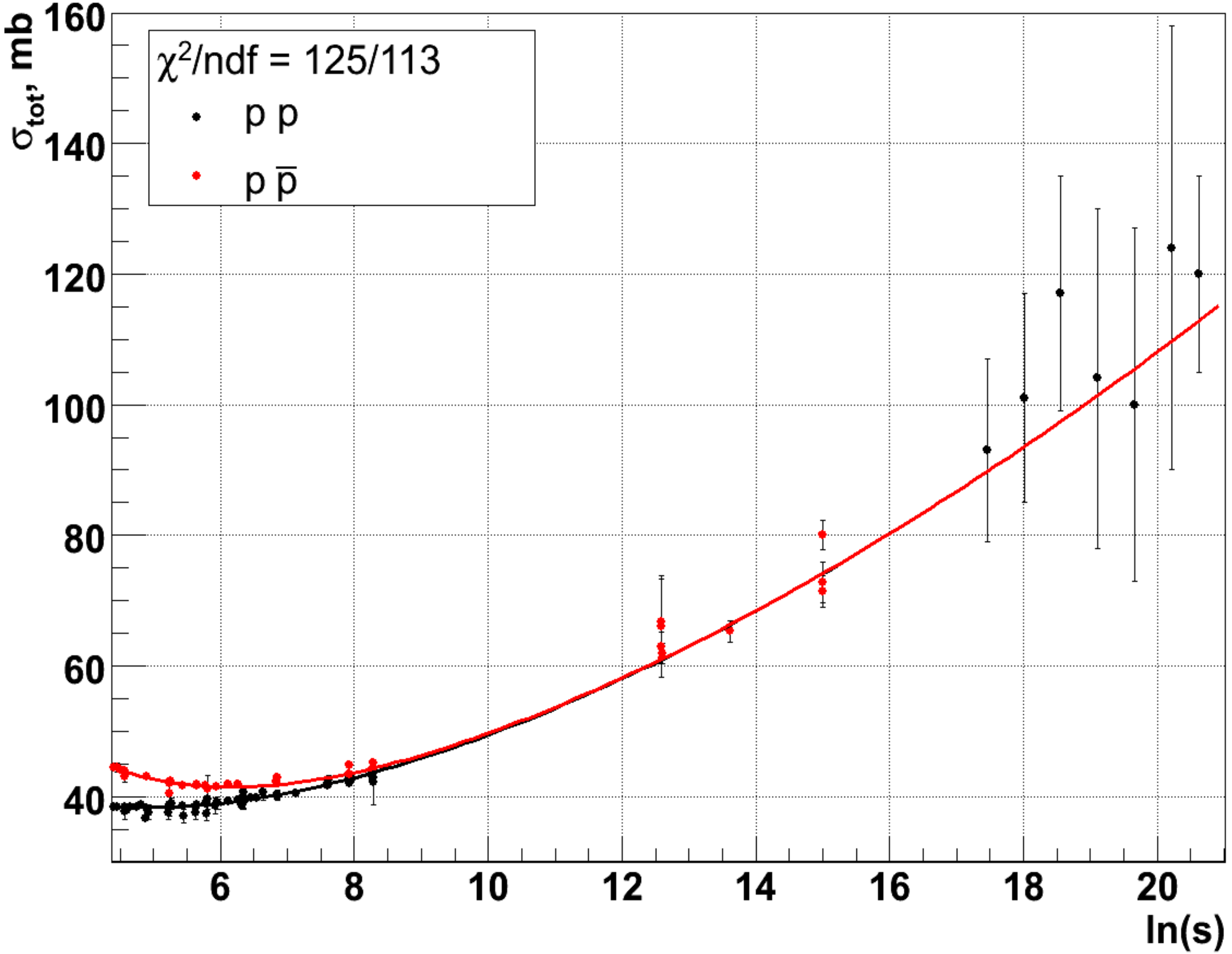
1) On the first step before the collision there is small number of constituents in hadrons. They are  valence quarks and few gluons which fill in the whole spectrum in rapidity space.

2) On the second step the hadrons interaction is carried out by gluon exchange between the valence quarks and initial gluons and the hadrons gain the color charge.

3) On the third step after interaction the colored hadrons move apart and when the distance between them becomes larger than the confinement radius, the lines of color electric field gather into the string. This string breaks out into secondary hadrons.

LCNM gives good description of various experimental data at different energies (total and elastic cross sections, multiplicity distributions, etc.).

$$\sigma_{tot}^{p(\bar{p})p} = 63.52 s^{-0.358} \mp 35.43 s^{-0.56} + \sigma_0^{pp} + \sigma_1^{pp} \ln s + \sigma_2^{pp} (\ln s)^2$$

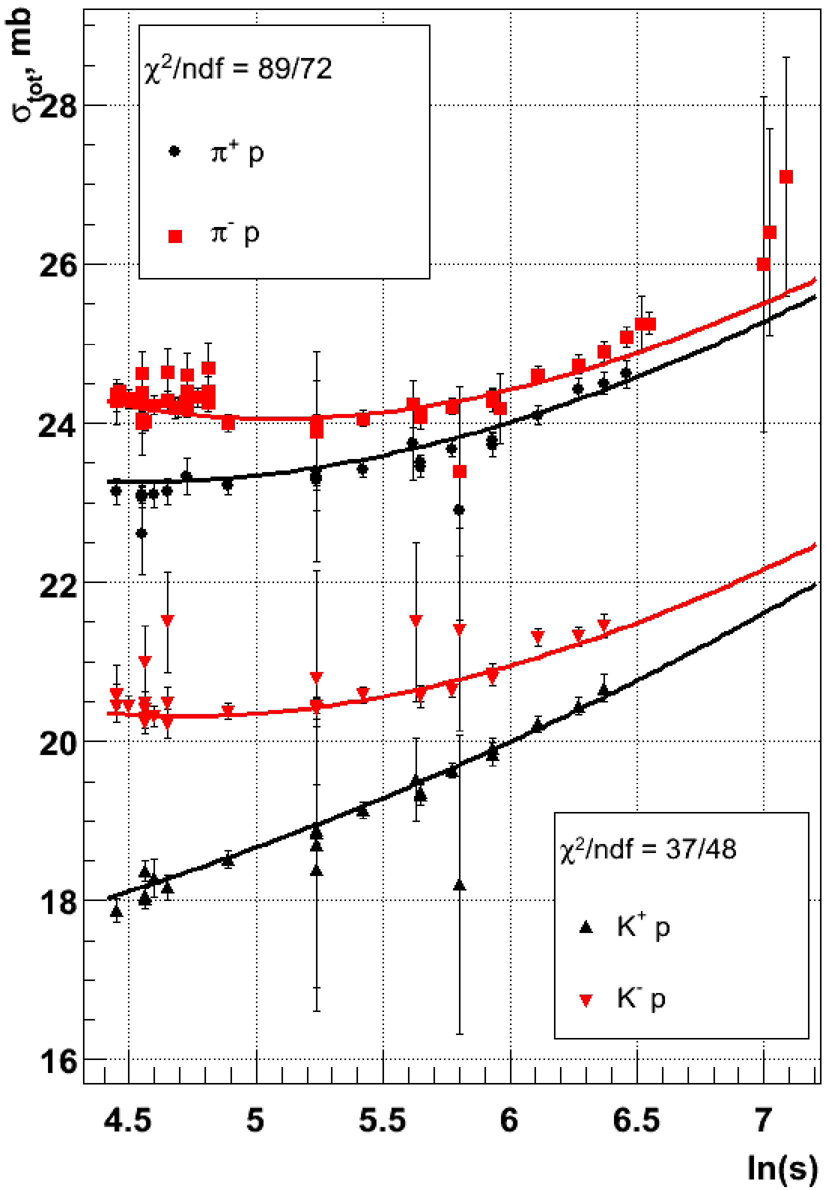


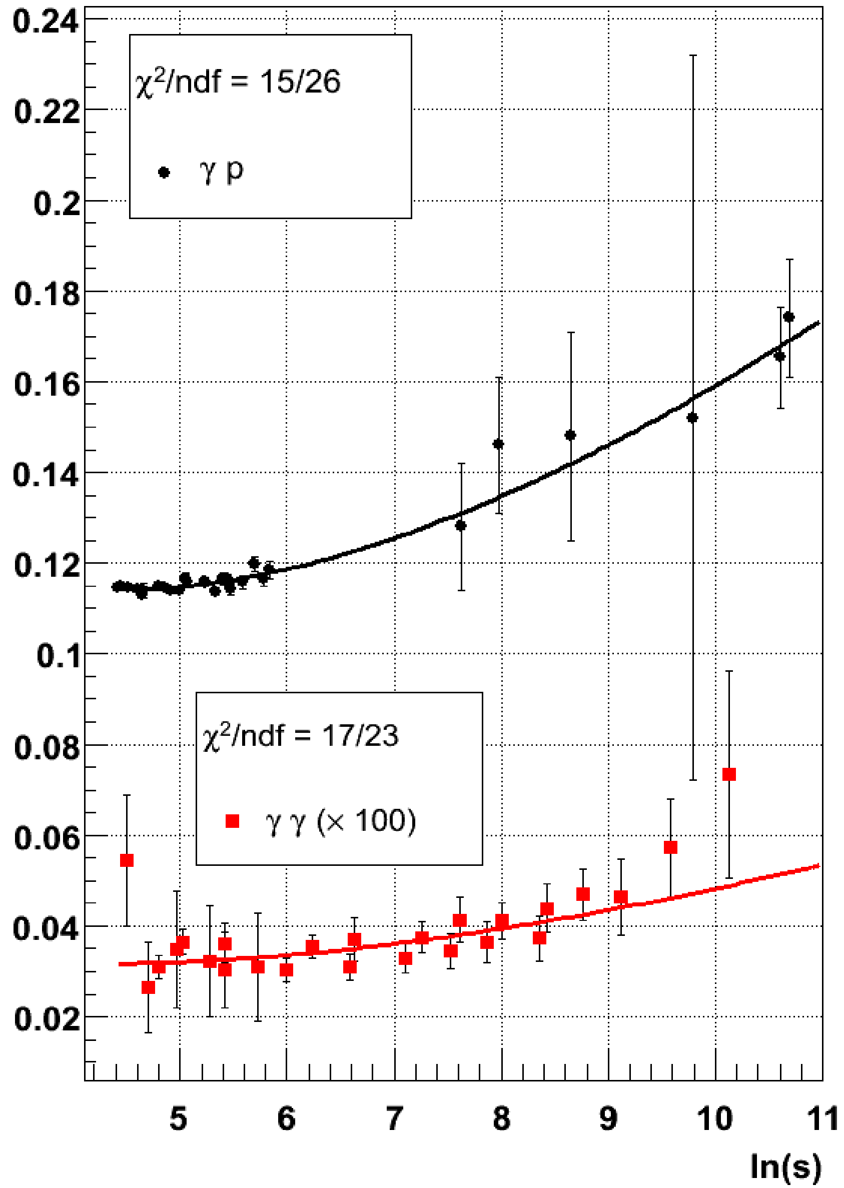

$$\sigma_0^{pp} = 20.08 \pm 0.42$$

$$\sigma_1^{pp} = 1.14 \pm 0.13$$

$$\sigma_2^{pp} = 0.16 \pm 0.01$$

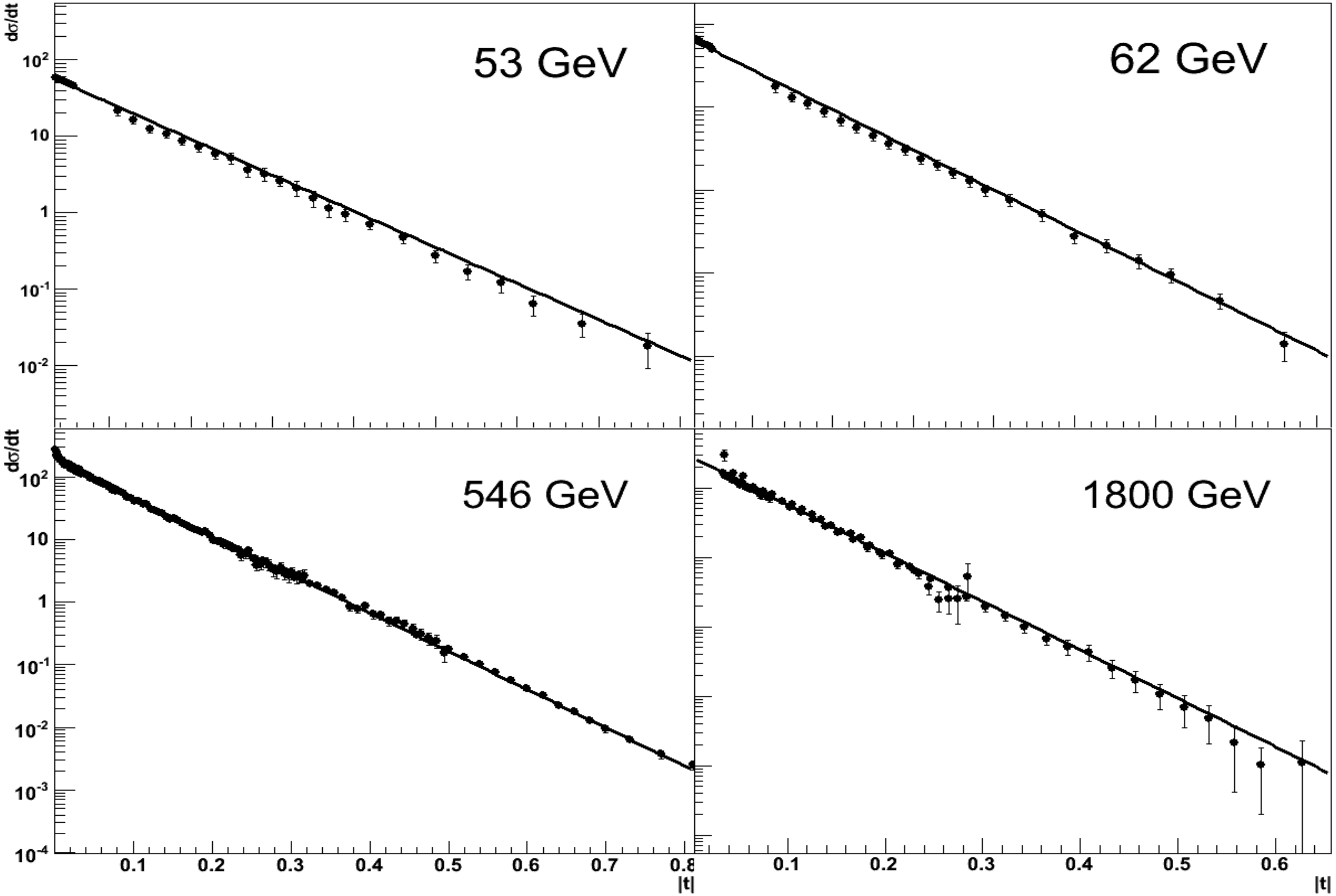
only two gluons in initial state!




$$\sigma_0^{\pi^{\pm}p}/\sigma_0^{pp} = 0.62 \pm 0.01 \qquad \sigma_0^{pp} \simeq \left(\sigma_0^{\gamma p}\right)^2/\sigma_0^{\gamma\gamma} = 24.82 \pm 3.42 \text{ mb}$$

$$\sigma_0^{K^{\pm}p}/\sigma_0^{pp} = 0.55 \pm 0.01$$

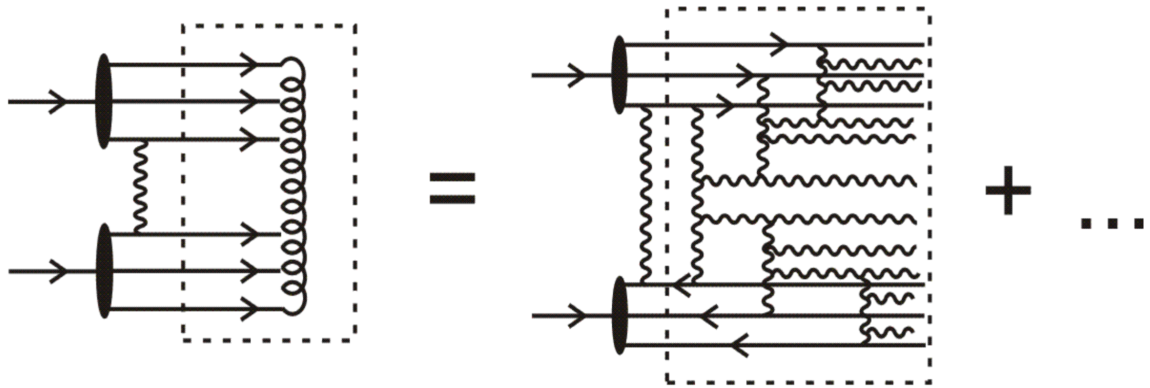



$$\frac{d\sigma^{el}}{dt} = \frac{1}{16\pi}\left[\sigma_0 + \sigma_1 \ln s + \sigma_2 (\ln s)^2\right]^2 \left(1+\rho^2\right) \exp\{-B(s)|t|\}$$

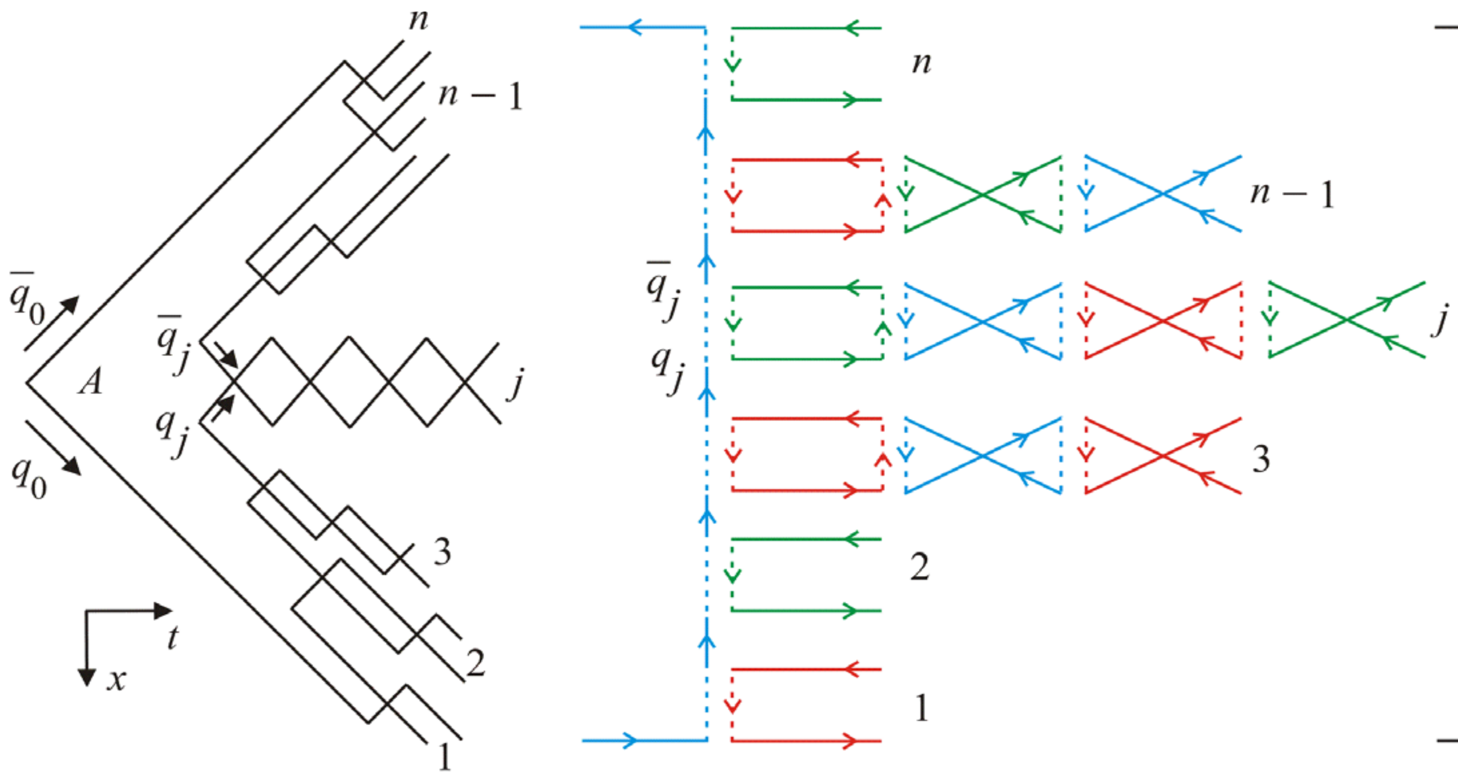
$$B = 7.12 + 0.34 \ln s + 0.02 \ln^2 s$$

# Gluon string

There are no other characteristic sizes for configuration with only valence quarks but hadrons sizes. Large number of gluons is produced in gluon string because of running constant $\alpha_s$ large value. There is no suppression on energy because exchange is of vector type. All these diagrams have the same order of magnitude in given order of coupling constant and every one of them corresponds to definite final hadrons state. Number of these diagrams is infinite in principle. Hence hadrons multiplicity in final state as random variable has to obey normal distribution because of central limit theorem of probability theory.



# Quark string



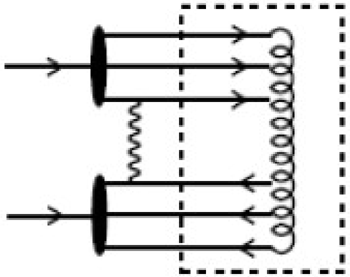

a) b) c)

Quark pairs produced in string field are virtual and they come out on mass shell by tunneling. Momenta of these quarks appearing at mass shell are equal to zero in center-of-mass system of moving apart quarks. Color and spin correlations are essential. So hadrons multiplicity distribution will vary from Poisson and normal distributions. We suppose that it is negative binomial distribution.

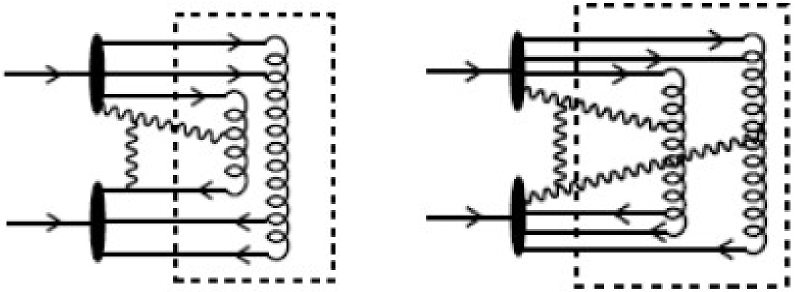
# Types of inelastic processes in *pp* and *p$\bar{p}$* collisions

## proton-antiproton

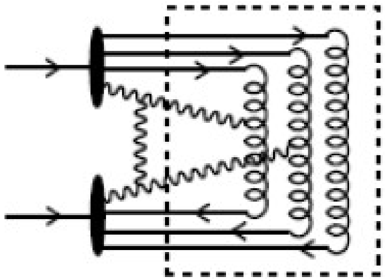
1)



2)

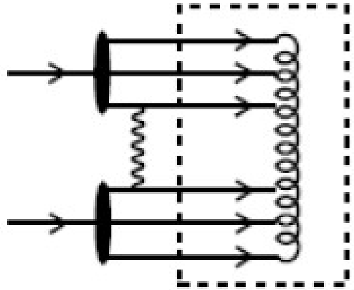


3)

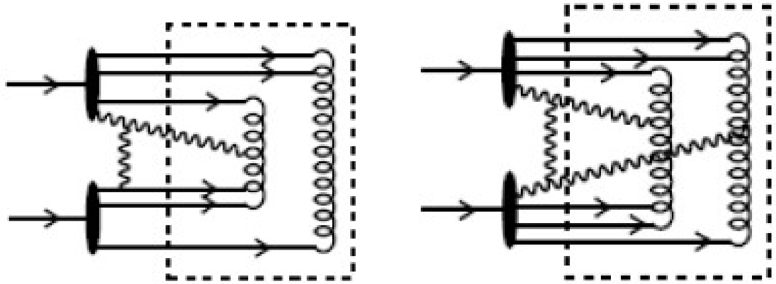


## proton-proton

1)

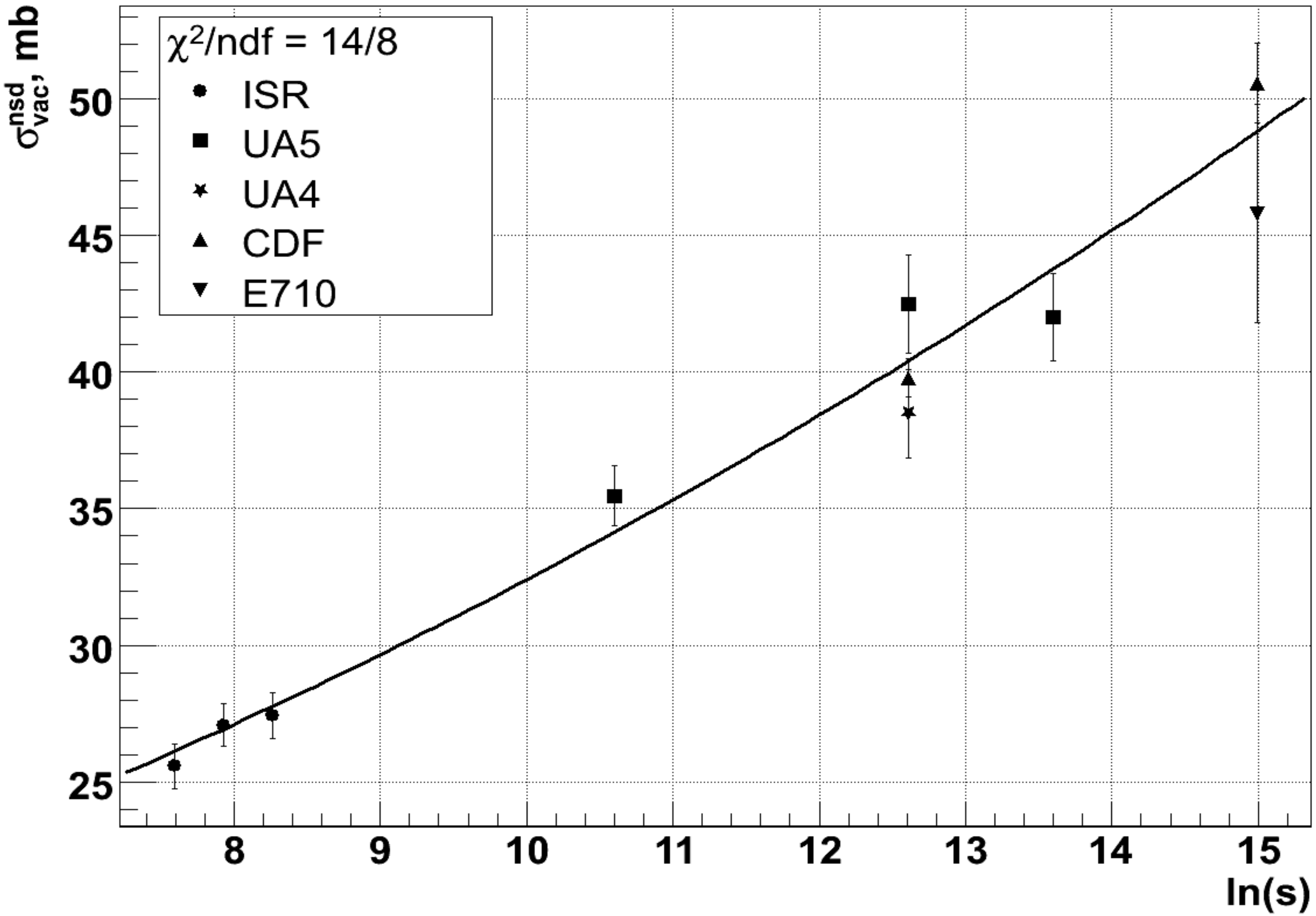


2)



The experimental multiplicity distributions are normalized by non single diffraction cross sections $\sigma_{nsd} = \sigma_{tot} - \sigma_{el} - \sigma_{sd}$.
Pomeron contributions are the same as for total cross sections

$$\sigma_{vac}^{nsd} = \sigma_0^{nsd}(1 + \delta_1^{nsd} \ln s + \delta_2^{nsd} \ln^2 s) \, .$$




$$\sigma_0^{nsd} \simeq 13.3$$

$$\delta_1^{nsd} = 0.075 \pm 0.011$$

$$\delta_2^{nsd} = 0.007 \pm 0.001$$

# Weights of distributions

proton-antiproton

proton-proton

Normal distribution

$$\frac{1}{1+\delta_1^{nsd}\ln s+\delta_2^{nsd}(\ln s)^2}$$

$$\frac{1}{1+\delta_1^{nsd}\ln s+\delta_2^{nsd}(\ln s)^2}$$

Double NBD

$$\frac{\delta_1^{nsd}\ln s+(1-c)\,\delta_2^{nsd}(\ln s)^2}{1+\delta_1^{nsd}\ln s+\delta_2^{nsd}(\ln s)^2}$$

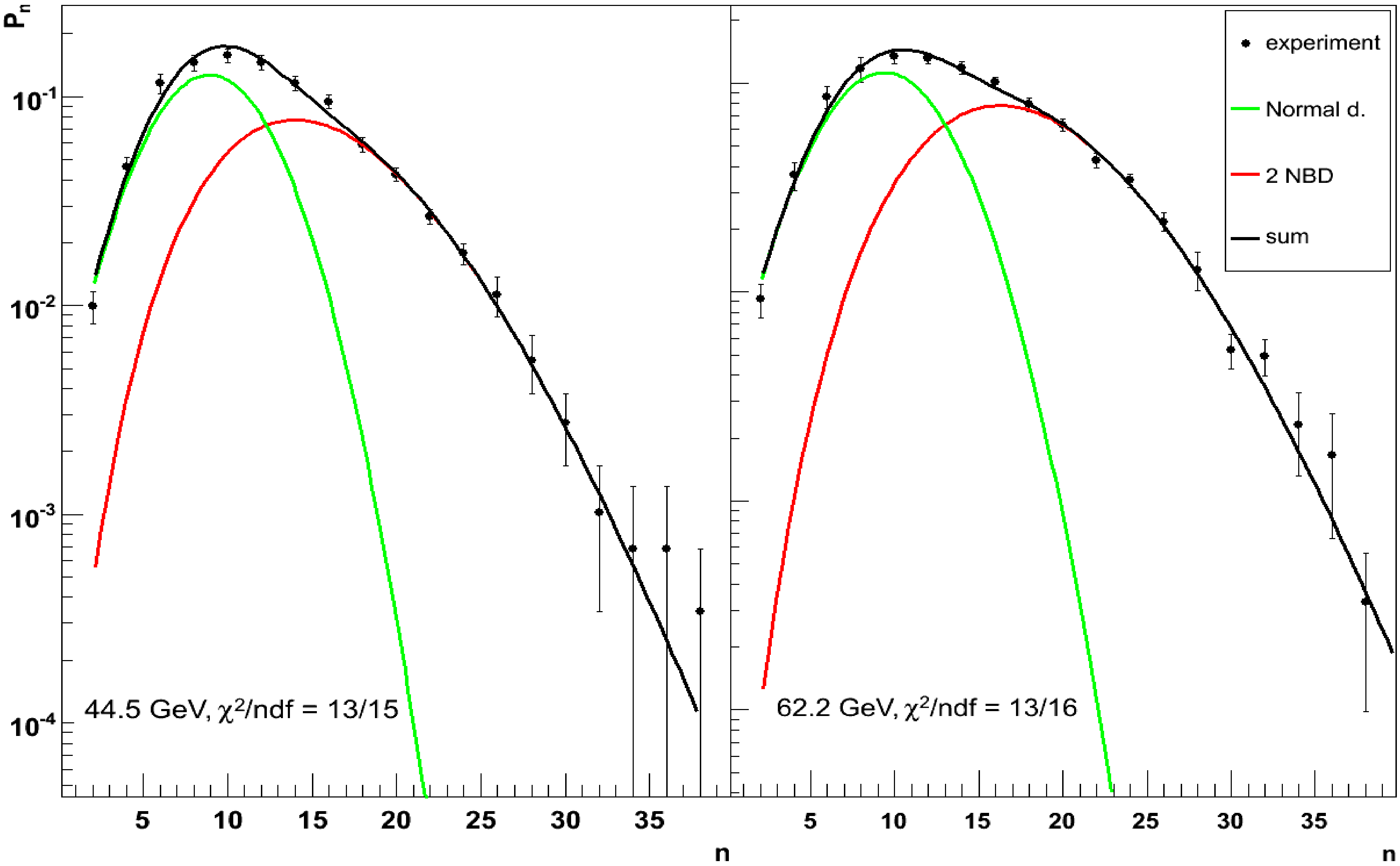
$$\frac{\delta_1^{nsd}\ln s+\delta_2^{nsd}(\ln s)^2}{1+\delta_1^{nsd}\ln s+\delta_2^{nsd}(\ln s)^2}$$

Triple NBD

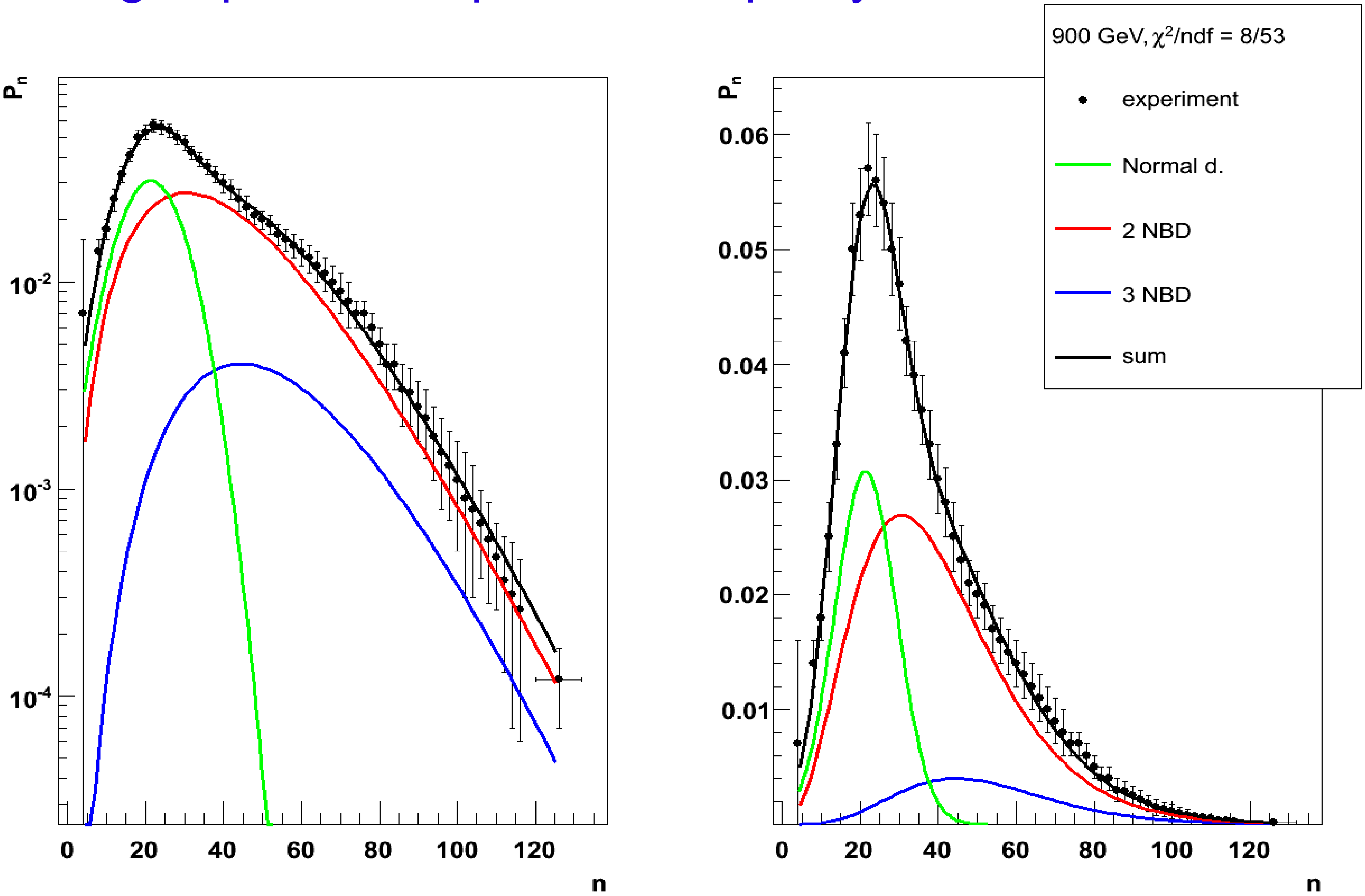
$$\frac{c\,\delta_2^{nsd}(\ln s)^2}{1+\delta_1^{nsd}\ln s+\delta_2^{nsd}(\ln s)^2}$$

c=0.25

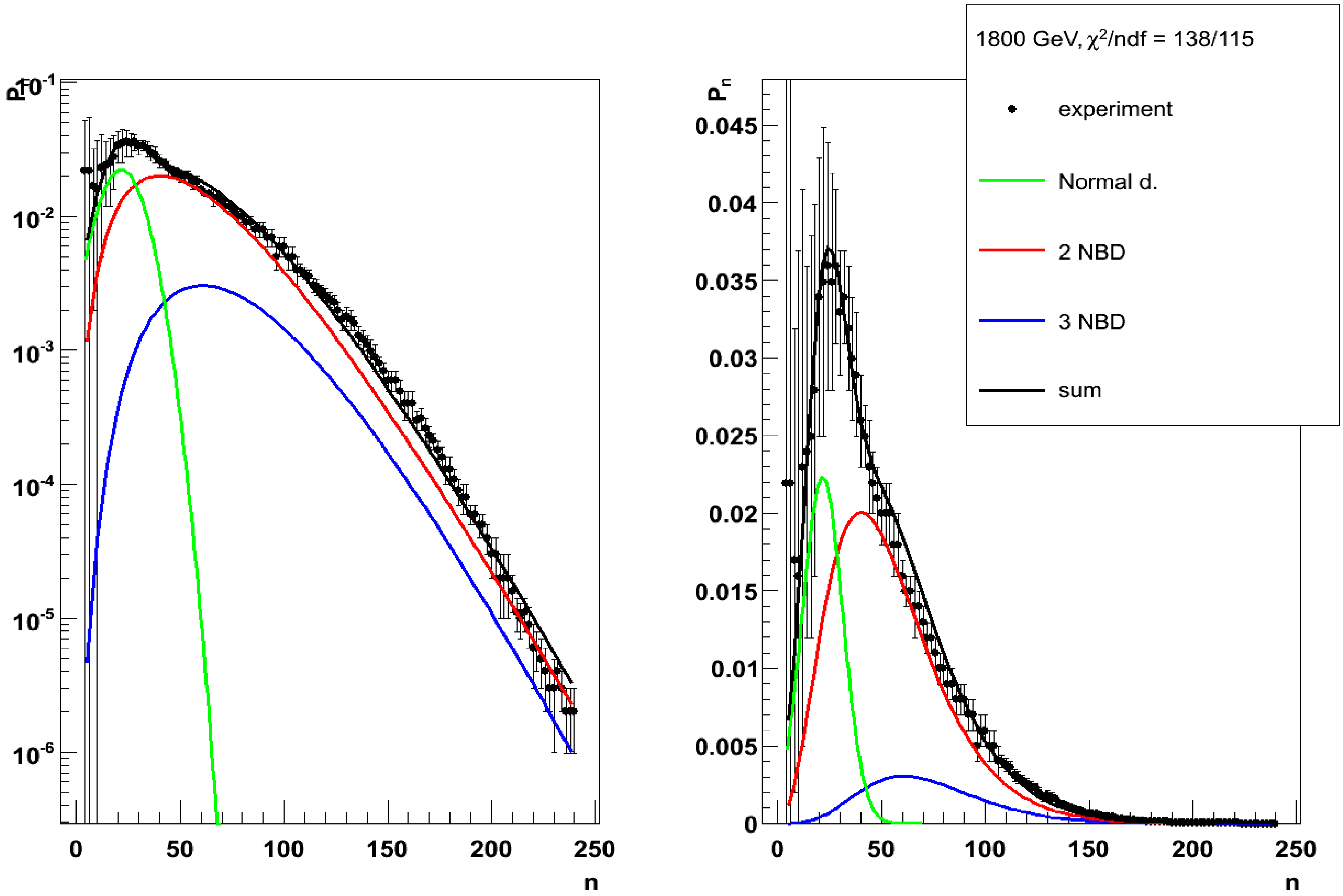
# Fitting of proton-proton multiplicity distributions



# Fitting of proton-antiproton multiplicity distributions



# Fitting of proton-antiproton multiplicity distributions



## Inclusive pseudorapidity distributions in *pp* and *p anti-p* interactions

Invariant inclusive cross section of production of one charged particle in event with *n* charged particles

$$(2\pi)^3 2E_1 \frac{d^3\sigma_n^{incl}}{d^3p_1} = \frac{1}{(n-1)!}\sum_{m=0}^{\infty}\frac{1}{m!}\int d\tau_{n-1+m}\left|A_{2\to n+m}\left(\vec{p}_1;\vec{p}_2,\ldots,\vec{p}_n,\vec{q}_{n+1},\ldots,\vec{q}_{n+m}\right)\right|^2$$

Invariant inclusive cross section

$$(2\pi)^3 2E_1 \frac{d^3\sigma^{incl}}{d^3p_1} = \sum_{n=1}^{\infty}(2\pi)^3 2E_1 \frac{d^3\sigma_n^{incl}}{d^3p_1}$$

Inclusive cross section is normalized by mean multiplicity of corresponding cross section of inelastic process, here we use non single diffraction cross section

$$\int d\eta \frac{d\sigma^{incl}}{d\eta} = \langle n\rangle\,\sigma^{nsd}$$

At the same time cross section $d^3\sigma_n^{incl}/d^3p_1$ is normalized by

$$\int d\eta \frac{d\sigma_n^{incl}}{d\eta} = n\,\sigma_n$$

We think that inclusive cross sections are the most informative. UA5 Coll. (Z. Phys. C33 (1986) 1) gave data on inclusive cross sections in nine bins depending on number of charged particles $2 \leqslant n \leqslant 10,\ 12 \leqslant n \leqslant 20,\ \ldots,\ n \geqslant 82$. We define the following notations:

$$\sigma^{(1)} = \sum_{n=2}^{10} \sigma_n, \quad \sigma^{(2)} = \sum_{n=12}^{20} \sigma_n, \quad \ldots \quad \sigma^{(9)} = \sum_{n=82}^{\infty} \sigma_n$$

$$\frac{\mathrm{d}\sigma^{(1)incl}}{\mathrm{d}\eta} = \sum_{n=2}^{10} \frac{\mathrm{d}\sigma_n^{incl}}{\mathrm{d}\eta}, \quad \ldots \quad \frac{\mathrm{d}\sigma^{(9)incl}}{\mathrm{d}\eta} = \sum_{n=82}^{\infty} \frac{\mathrm{d}\sigma_n^{incl}}{\mathrm{d}\eta}$$

$$\sum_{i=1}^{9} \frac{\mathrm{d}\sigma^{(i)incl}}{\mathrm{d}\eta} = \frac{\mathrm{d}\sigma^{incl}}{\mathrm{d}\eta}$$

Data of UA5 are given in format $\frac{1}{\sigma^{(i)}} \frac{\mathrm{d}\sigma^{(i)incl}}{\mathrm{d}\eta}$

We integrated the expression $\frac{1}{\sigma^{nsd}}\frac{\mathrm{d}\sigma^{(i)incl}}{\mathrm{d}\eta}$ over pseudorapidity space

$$\frac{1}{\sigma^{nsd}}\int \mathrm{d}\eta \frac{\mathrm{d}\sigma^{(i)incl}}{\mathrm{d}\eta} = \frac{1}{\sigma^{nsd}}\sum_{n \text{ in bin}}\int \mathrm{d}\eta \frac{\mathrm{d}\sigma_n^{incl}}{\mathrm{d}\eta} = \sum_{n \text{ in bin}} n\,\frac{\sigma_n}{\sigma^{nsd}} = \sum_{n \text{ in bin}} n\,P_n = \bar{n}^{(i)}$$

$$\bar{n}^{(1)} = \sum_{n=2}^{10} n\,P_n, \quad \bar{n}^{(2)} = \sum_{n=12}^{20} n\,P_n, \;\ldots\; \bar{n}^{(9)} = \sum_{n=82}^{\infty} n\,P_n$$

Non single diffraction cross sections are the same for *pp* and *p anti-p* interactions because of Pomeranchuk theorem. But shapes of multiplicity distribution curves are different for *pp* and *p anti-p* since underlying elementary subprocesses are different. Therefore values of $\bar{n}^{(i)}$ are different for *pp* and *p anti-p*, we denote them $\bar{n}^{(i)}_{pp}$ and $\bar{n}^{(i)}_{p\bar{p}}$ correspondingly.

$$\int \mathrm{d}\eta \frac{\mathrm{d}\sigma^{(i)incl}_{pp}}{\mathrm{d}\eta} \Big/ \int \mathrm{d}\eta \frac{\mathrm{d}\sigma^{(i)incl}_{p\bar{p}}}{\mathrm{d}\eta} = \frac{\bar{n}^{(i)}_{pp}}{\bar{n}^{(i)}_{p\bar{p}}} \quad (1)$$

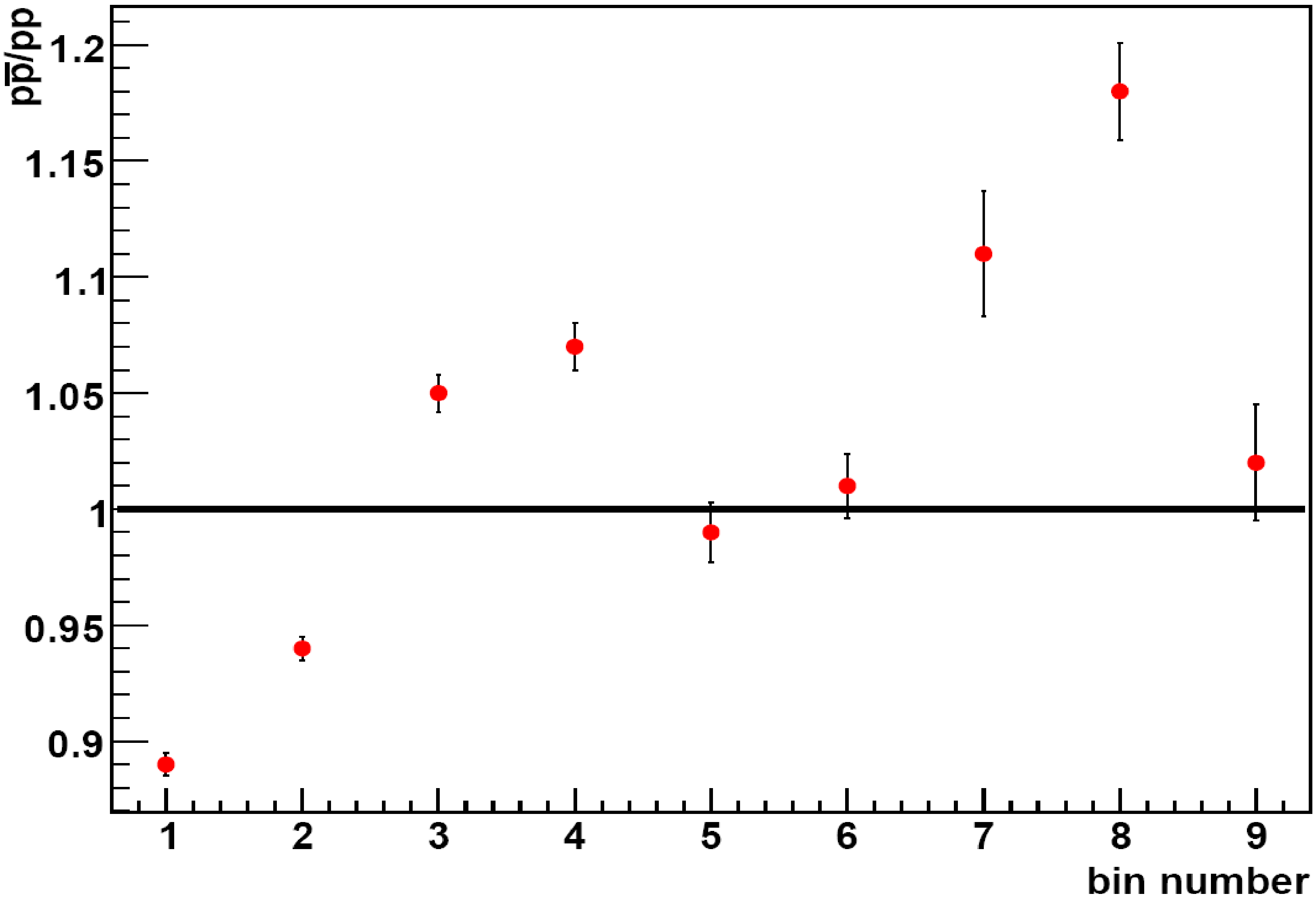
The expression $\bar{n}_{pp}^{(i)}/\bar{n}_{p\bar{p}}^{(i)}$ does not depend on pseudorapidity.
Besides, number of charged particles in each bin can be taken arbitrary but relation (1) is kept strictly. Therefore we have for inclusive cross sections

$$\frac{\mathrm{d}\sigma_{pp}^{(i)incl}}{\mathrm{d}\eta} = \frac{\bar{n}_{pp}^{(i)}}{\bar{n}_{p\bar{p}}^{(i)}} \frac{\mathrm{d}\sigma_{p\bar{p}}^{(i)incl}}{\mathrm{d}\eta}$$

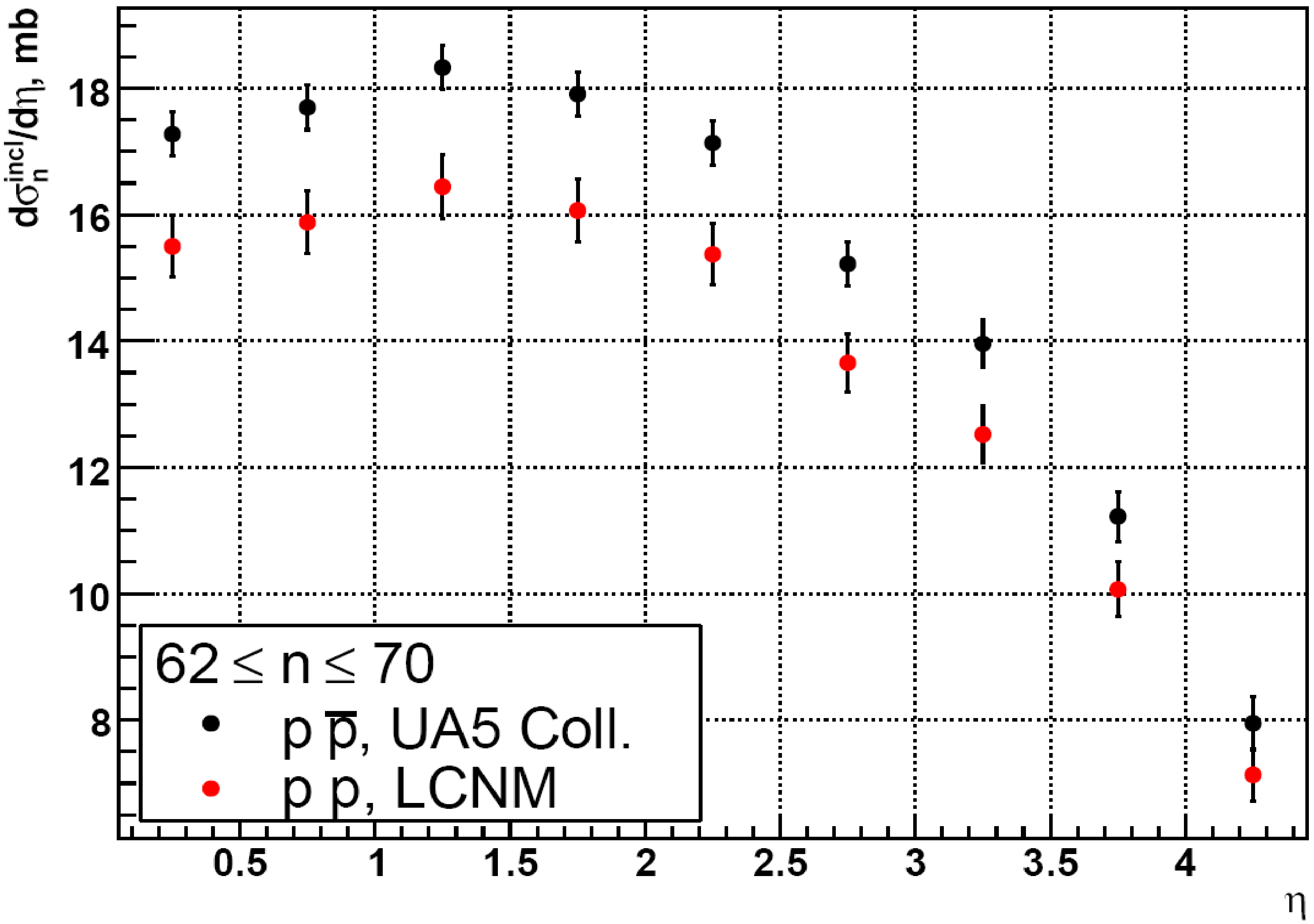
From LCNM and fitting of multiplicity distributions for *pp* and *p anti-p* at different energies we obtained prediction for multiplicity distribution in *pp* scattering at 900 GeV.

We calculated the values of coefficients $\bar{n}_{pp}^{(i)}/\bar{n}_{p\bar{p}}^{(i)}$ for nine bins of multiplicity to estimate the difference in inclusive cross sections for *pp* and *p anti-p*.

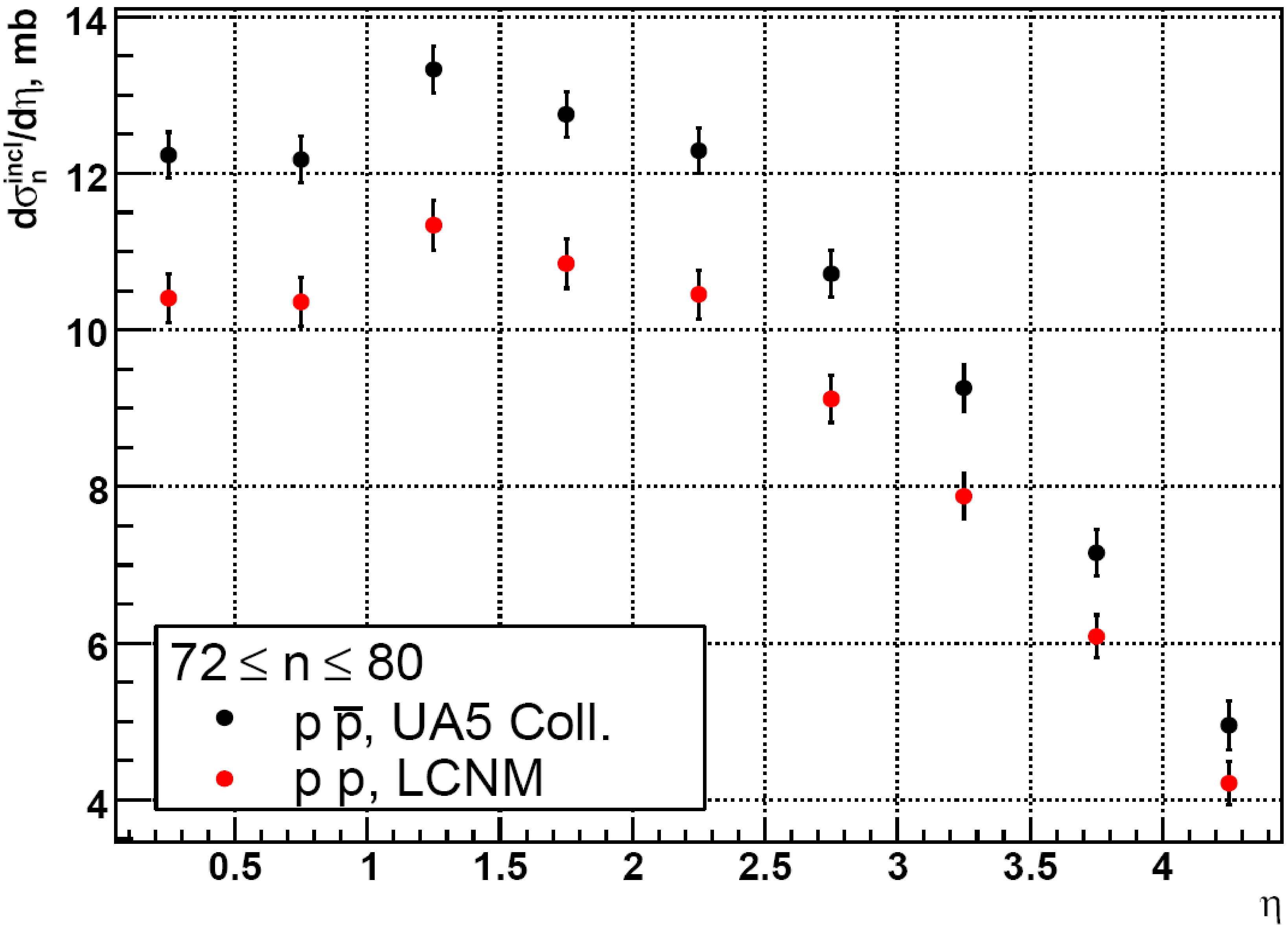
# Ratio of *p anti-p* to *pp* for pseudorapidity density in different multiplicity bins



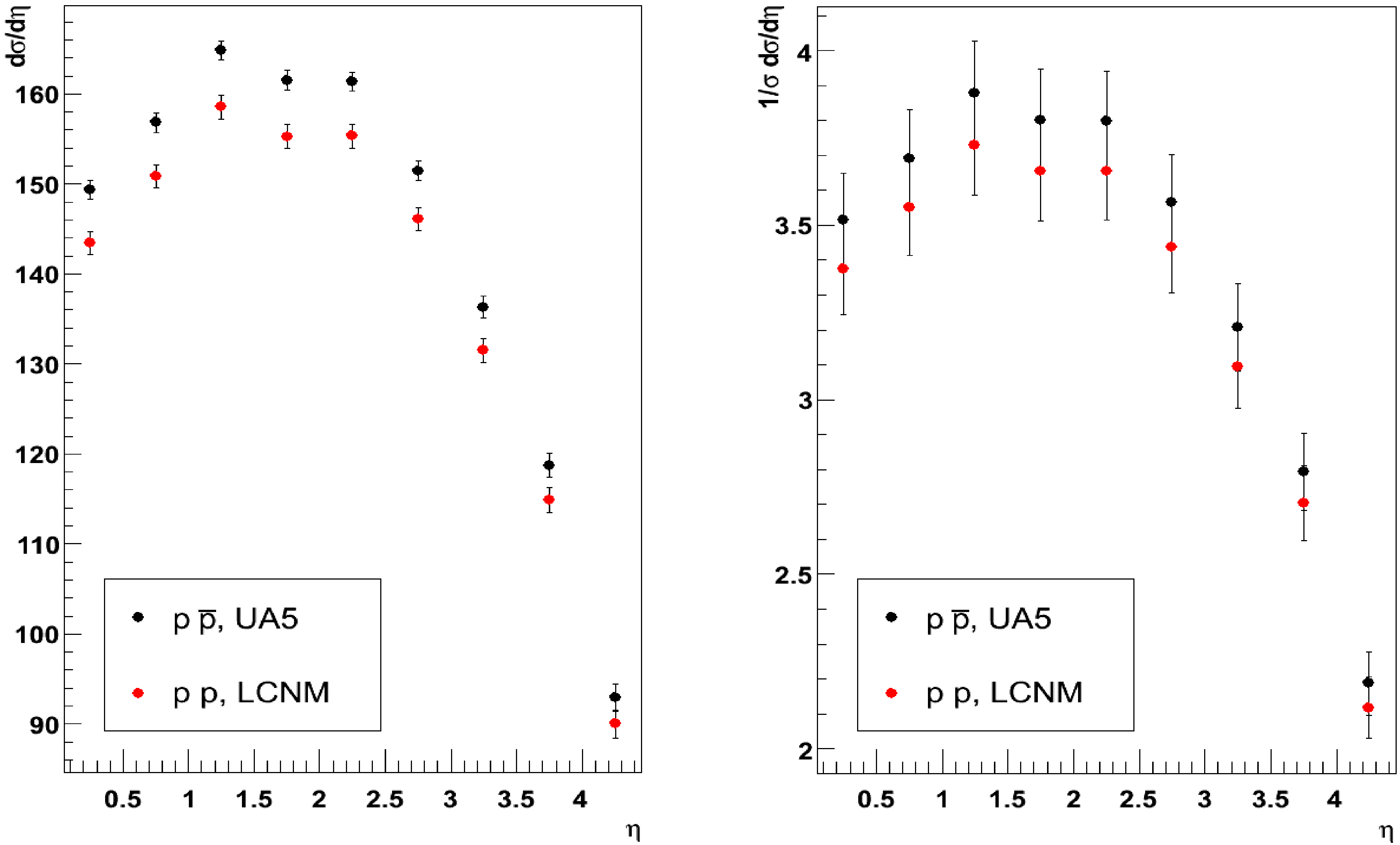
# Pseudorapidity density in multiplicity bin number 7



# Pseudorapidity density in multiplicity bin number 8

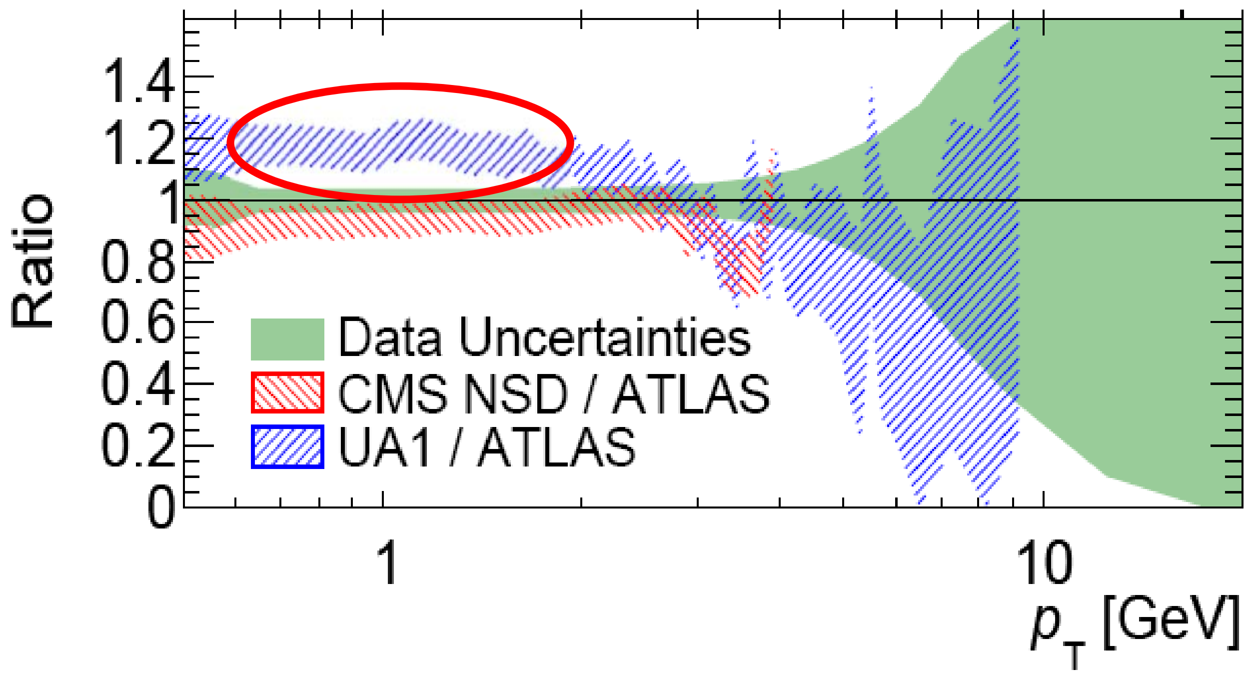


# Effect of normalization for total pseudorapidity density



# Conclusion

We suppose that ATLAS Coll. discovered new effect of difference in multiplicity production in proton-proton and proton-atiproton collisions. Further analysis of unnormalized inclusive distributions is very essential.



Thank you for attention!