High energy diffraction

M.G. Ryskin (PNPI) 2025

The main properties of high energy diffraction are considered.

Plan

1.Definition

Diffraction = elastic scattering caused by the distortion of incoming wave function

V.N. Gribov – "High energy diffraction may be related to confinement since here we deal with the amplitude of *high energy* particles interaction."

Diffractive events is a good place to search for the *new physics* (glueballs, QCD instanton, etc.) in a good experimental environment (i.e. low secondaries multiplicity)

2. **Pomeron**

(multiperipheral models, QED, BFKL)
Diffractive cone shrinkage

3.**AGK-rules, space-time picture**

U-matrix or eikonal unitarization

4. Weak vs. strong Pomeron-Pomeron interaction

5. TOTEM-ALFA σ_{tot} tension

1. Diffraction is the elastic scattering caused by the distortion of incoming (plane wave) wave function due to other (inelastic) interactions

Not *any* LRGap is diffraction

(Odderon, photon exchange are Not diffracttion)

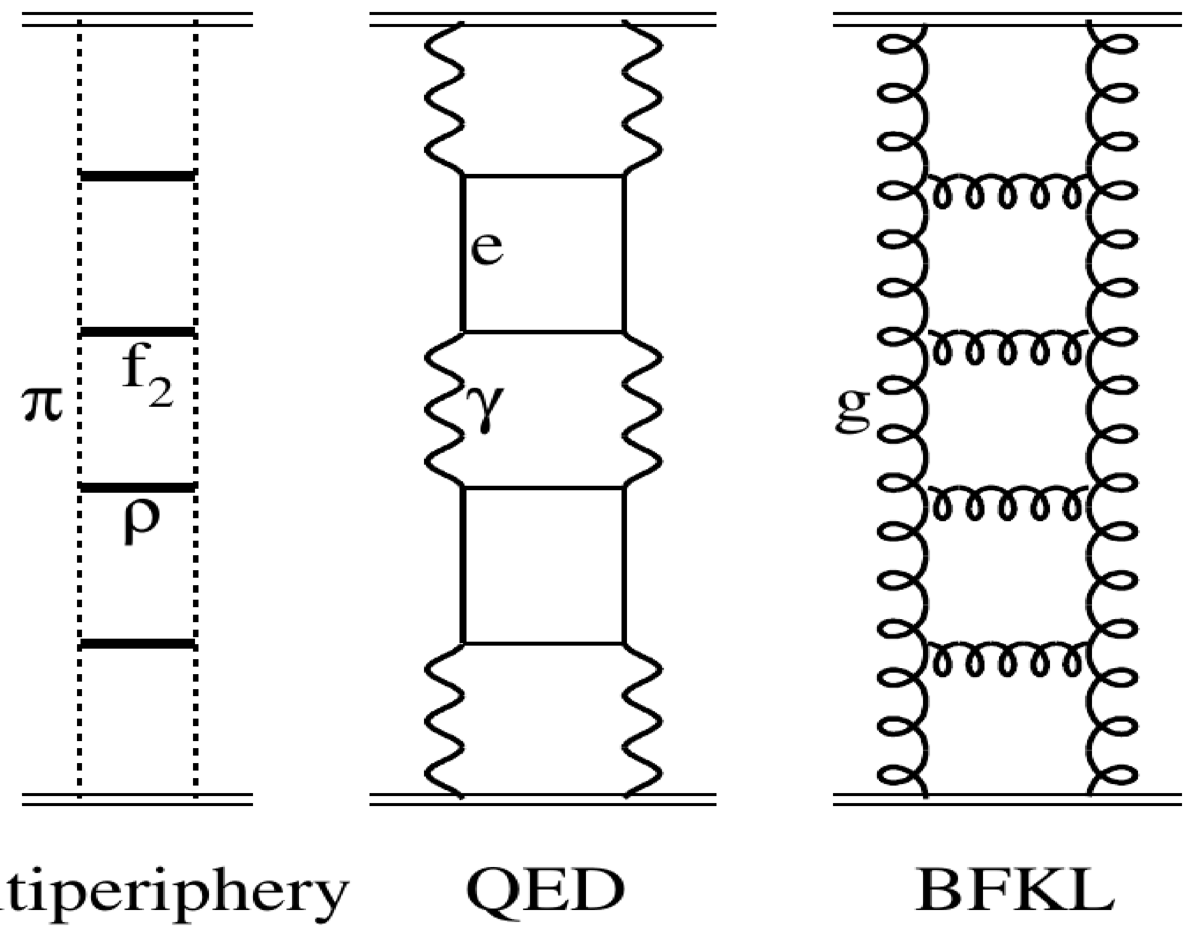
High energy behaviour of diffractive amplitude may be (???) connected with confinement

Low multiplicity of diffractive events (low numbers of Pomerons) makes them attractive for searching a new physics (like glueballs, QCD instantons, etc.) in a good experimental environment.

2. Diffractive amplitudes are described by the **Pomeron** (Pomerons) exchange.

$$A(s,t) = \int_{-i\infty}^{+i\infty} dj\eta(j)F(j,t)(s/s_0)^j$$

Pomeron is the pole in complex angular momentum plane, j



Pomeron is the pole in complex angular momentum plane, j

$$A(s,t) = \int_{-i\infty}^{+i\infty} dj \eta(j) F(j,t)(s/s_0)^j$$

Pomeron pole $F(j,t) = 1/(\alpha_P(t) - j)$

$\alpha_P(t) \neq \text{const}$
($\alpha_P(t) = \text{const}$ contratricts to t unitarity)
For small $|t|$ $\alpha_P(t) = \alpha_P(0) + \alpha'_p t$ that is Diffarctive cone shrinkage

$$A(s,t) = V^2(t) \left(\frac{s}{s_0}\right)^{1+\alpha_P(0)+\alpha'_P t}$$

$$B_{el} = 2\frac{d \ln A(s,t)}{dt} = 4B_V + 2\alpha'_P \ln(s/s_0)$$

Interaction radius (radius of disk) increases as $\alpha'_P \ln s$

multiperiphery – at each step (cell) i transverse momenntum $k_{ti} \sim m_{res} = const$

diffusion in impact parameter plane, b

$\Delta b \sim 1/ < k_t >$ $\qquad R^2 = n_{step}\Delta^2 b \propto \ln s$

$\alpha'_P \sim (dn_i/dy)/k_{ti}^2$

BFKL – diffusion in $\ln k_t$

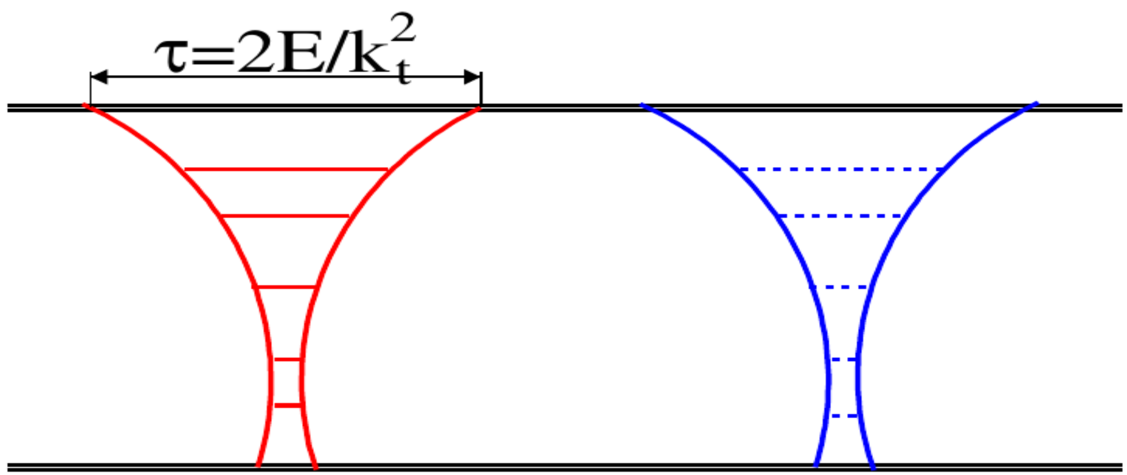
k_t grows with s $\qquad \ln^2 k_t \sim n_{step}$

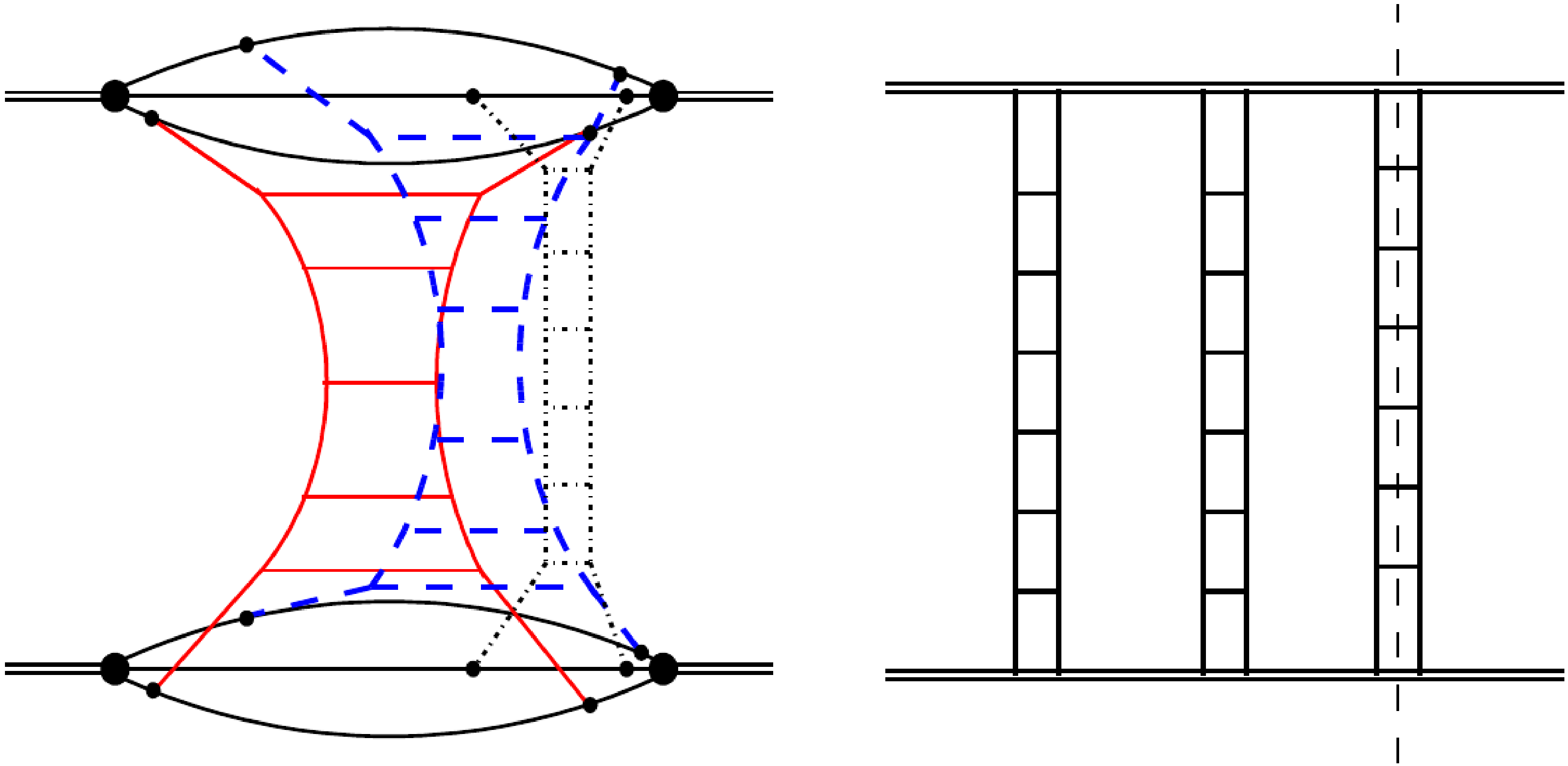
$\alpha'_P(s \to \infty) \to 0$

For $\alpha_P(0) = 1$ ($\sigma_{tot}(s \to \infty) \to const$)
$R^2 \propto \ln s$ while $dN_{wee}/dr^2 \propto 1/\ln s$
(wee parton =
smallest energy parton with Y close to Y_{target})

For $\alpha_P(0) > 1$ wee density $\frac{dN_{wee}}{dr^2}$ increases with s
==> large probability of 'multiparton interactions'
$->$ MultiPomeron exchange

Space-time picture





Eikonal **U-matr.**

In U-matr. case one can cut only one object; it is impossible to cut a few "quasi potentials" (Pomerons) simultaneously.

Eikonal

$$\mathcal{A}(s,b) \;=\; i[1-e^{i\chi(s,b)}] = -i\sum_{n=1}^{\infty}\frac{[i\chi(s,b)]^n}{n!}$$

U-matr.

$$\mathcal{A}(s,b) \;=\; \frac{\hat{\chi}(s,b)}{1-i\hat{\chi}(s,b)/2} = -2i\sum_{n=1}^{\infty}\frac{[i\hat{\chi}(s,b)]^n}{2^n}$$

Note - the first two terms are the SAME

1. Unitarization

$$2\mathrm{Im}\mathcal{A}(s,b) = |\mathcal{A}(s,b)|^2 + G_{inel}(s,b)$$

Two solutions for $\mathrm{Im}\mathcal{A}$:

$$\mathrm{Im}\mathcal{A}(s,b) = \frac{1 \pm \sqrt{1-(1+\rho^2)G_{inel}(s,b)}}{1+\rho^2};$$

$$\rho(s,b) = \mathrm{Re}/\mathrm{Im}$$

$$\mathcal{A}(s,t) = s\int bdbJ_0(bq)\mathcal{A}(s,b)$$

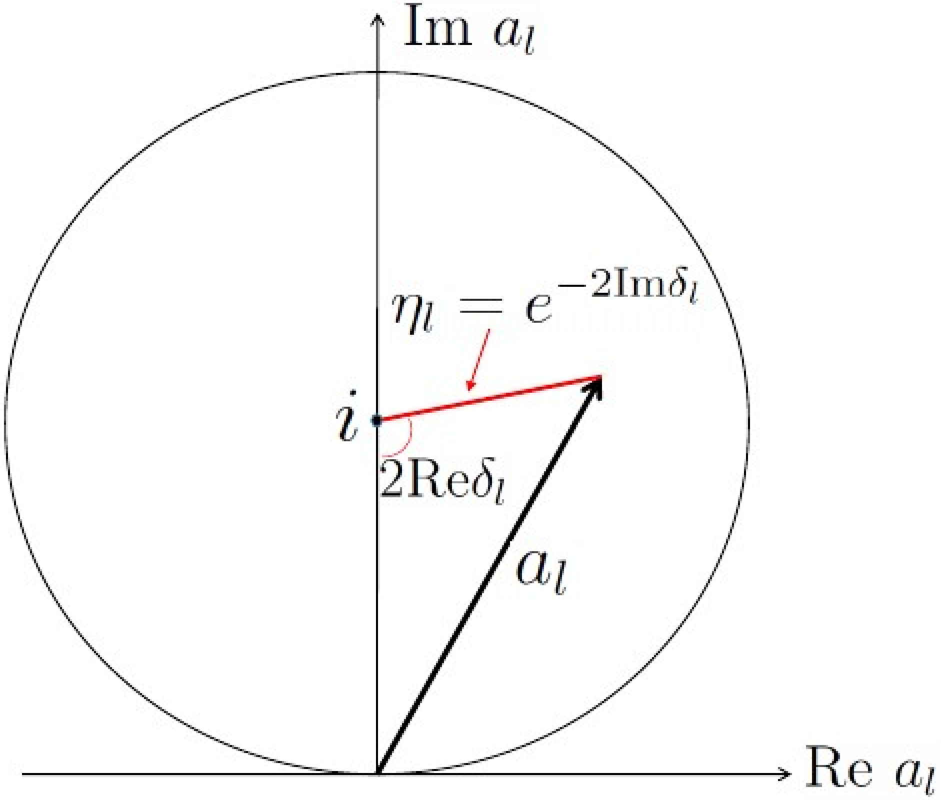
Inelastic contribution:

$$G^{eik}_{inel}(s,b) = 1 - e^{-2\mathrm{Im}\chi(s,b)} \to 1$$

$$G^{U}_{inel}(s,b) = 2\mathrm{Im}\mathcal{A}(s,b) - |\mathcal{A}(s,b)|^2$$

$$= \frac{2\mathrm{Im}\hat{\chi}(s,b)}{(1 - i\hat{\chi}(s,b)/2)(1 + i\hat{\chi}^*(s,b)/2)} \to 0$$

The hole in center at $|\hat{\chi}| \to \infty$



The partial wave amplitude, $a_l \;=\; i(1 - e^{2i\delta_l})$,

2. AGK rules

$$\text{unitarity} - \quad 2\mathrm{Im}\mathcal{A}_{ij} = disc\mathcal{A}_{ij} = \sum_m \mathcal{A}^*_{im}\mathcal{A}_{mj}$$

Im$\mathcal{A}$ is given by the cut of diagr. over state m

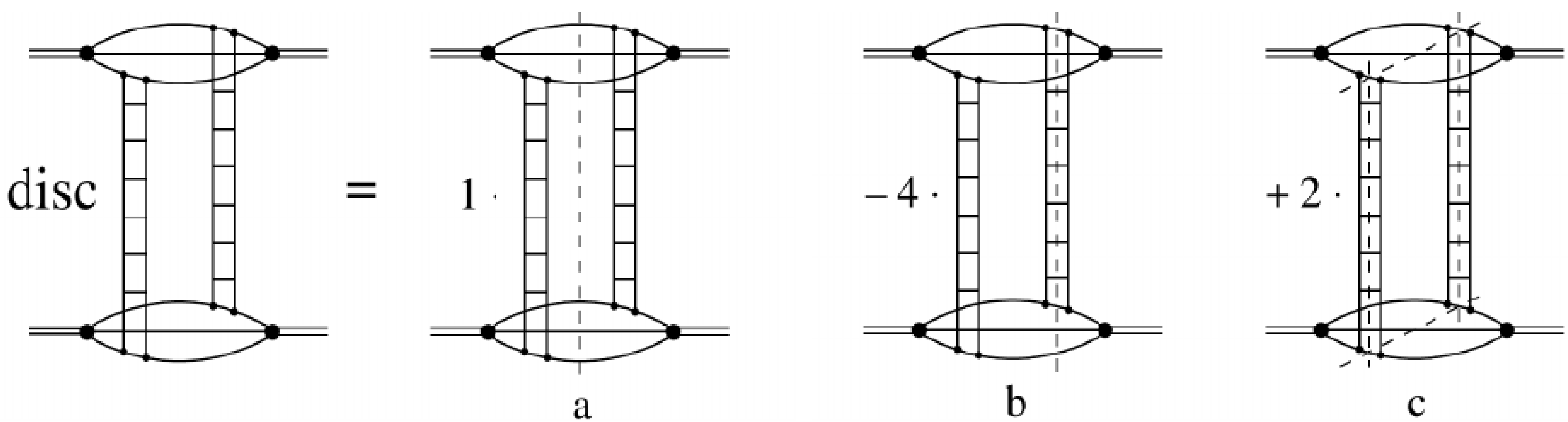


FIG. 1. Two-Pomeron exchange in the t channel expressed as a sum over all intermediate states in the s-channel.

Pomeron exchange gives $\text{Im}\chi = \mathbb{P}/2$

($\mathbb{P}=$ cut Pomeron)

In the cut Pomeron we deal with discontinuity ($disc = 2\text{Im}A$) while the uncut Pomeron can be to the left or the right of the cut (this is the origin of factor 2 in (9)) and this way the real part canceled.

$$\text{Im}\mathcal{A}_{(\text{cut}\,\mathbb{P})}(s, t = 0) = s \sum C_n (-1)^{n-1} \mathbb{P}^n$$

cutting k Pomerons from the term $C_n(-1)^{n-1}\mathbb{P}^n$

$$c_n^{k \neq 0} = (-1)^{n-k} 2^{n-1} \frac{n!}{k!(n-k)!}\ , \qquad (9)$$

$$c_n^{k=0} = (-1)^n (2^{n-1} - 1)$$

$$\sigma^k(s, b) = 2 \sum_n C_n \cdot (-1)^{n-k} 2^{n-1} \frac{n![\mathbb{P}(s, b)]^n}{k!(n-k)!}$$

$$\frac{n!\mathbb{P}^n}{(n-k)!} = \mathbb{P}^k \left(\frac{d}{d\mathbb{P}}\right)^k \mathbb{P}^n$$

$$\sigma^k_{eik}(s) = \int d^2b \, \frac{[\mathrm{Re}\Omega(s,b)]^k}{k!} \exp(-\mathrm{Re}\Omega(s,b))$$

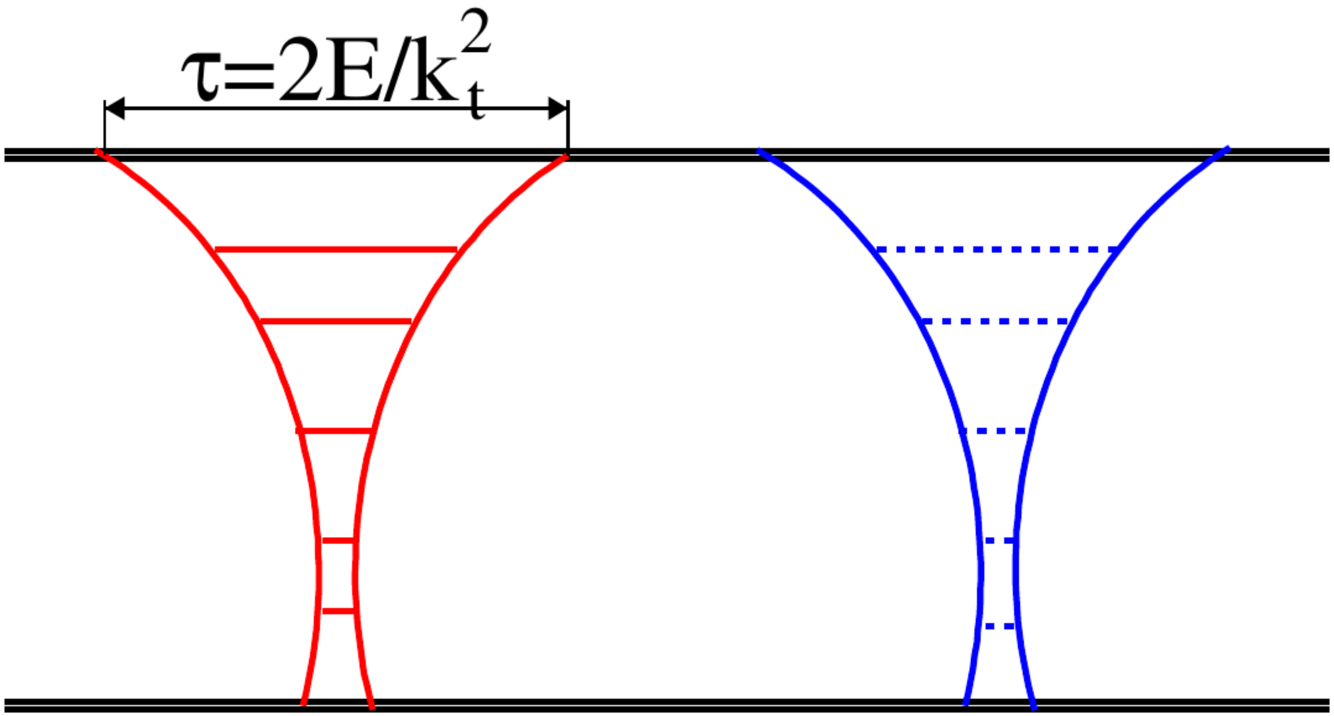
$$\Omega(s,b) \equiv -2i\chi(s,b) \qquad \mathrm{Re}\Omega = \mathbb{P}$$

$$\sigma^k_U(s) = 2\int d^2b \left[\frac{\mathrm{Im}\hat{\chi}(s,b)}{1+\mathrm{Im}\hat{\chi}(s,b)}\right]^k \frac{1}{1+\mathrm{Im}\hat{\chi}(s,b)}$$

$$\text{Problem} - \sum_k \sigma^k_U(s,b) = 2\frac{\mathrm{Im}\hat{\chi}(s,b)}{1+\mathrm{Im}\hat{\chi}(s,b))} \to 2 \neq 0$$

$$2\mathrm{Im}\mathcal{A}(s,b) = |\mathcal{A}(s,b)|^2 + G_{inel}(s,b)$$

U-matr. is inconsistent with AGK -???



$\tau = 2E/k_t^2$

3. Multiplicity distribution

For numerical estimates, we take the parameters of the Pomeron trajectory and the Pomeron-proton coupling from 2402.11385.

We assume that one Pomeron produces the Poisson distribution in $N = N^{\mathbb{P}}_{ch}/C$.

[C accounts for "short range correlations" and denotes the mean charged multiplicity of a cluster (resonance or minijet). Due to electric charge conservation, we expect $C > 2$.]

value of $N^{\mathbb{P}}_{ch}$ is chosen to reproduce the particle density $dN_{ch}/d\eta$

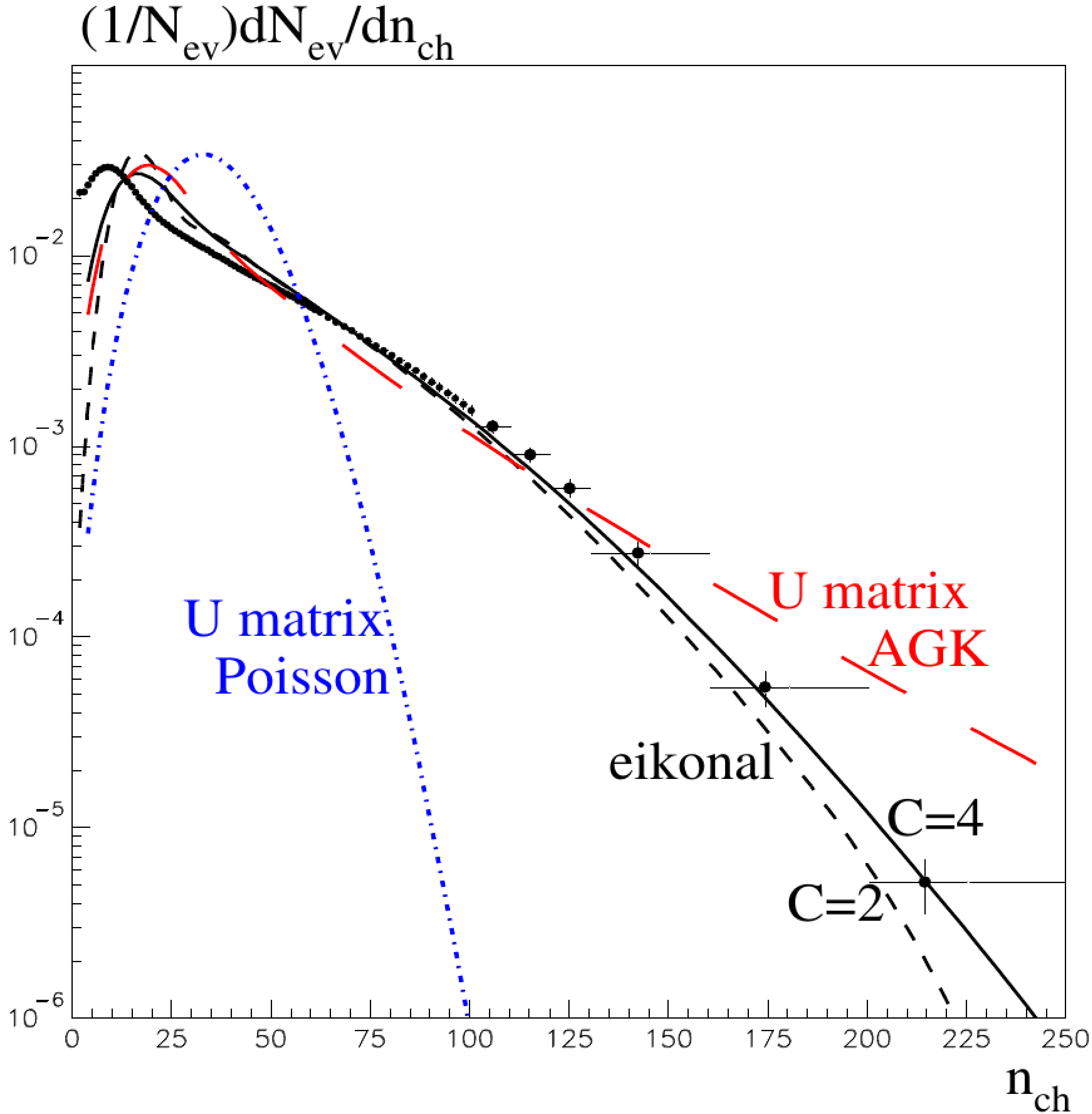
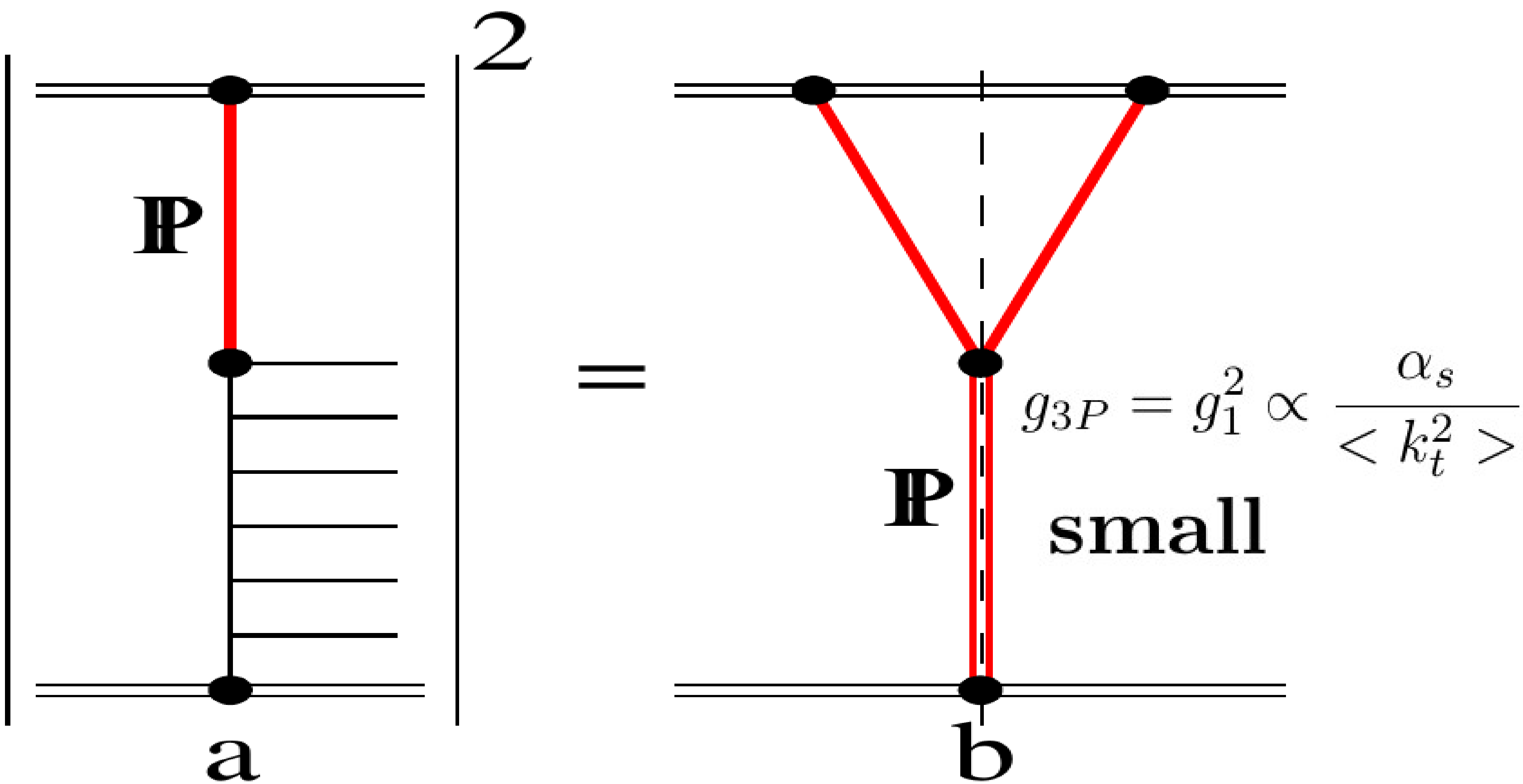
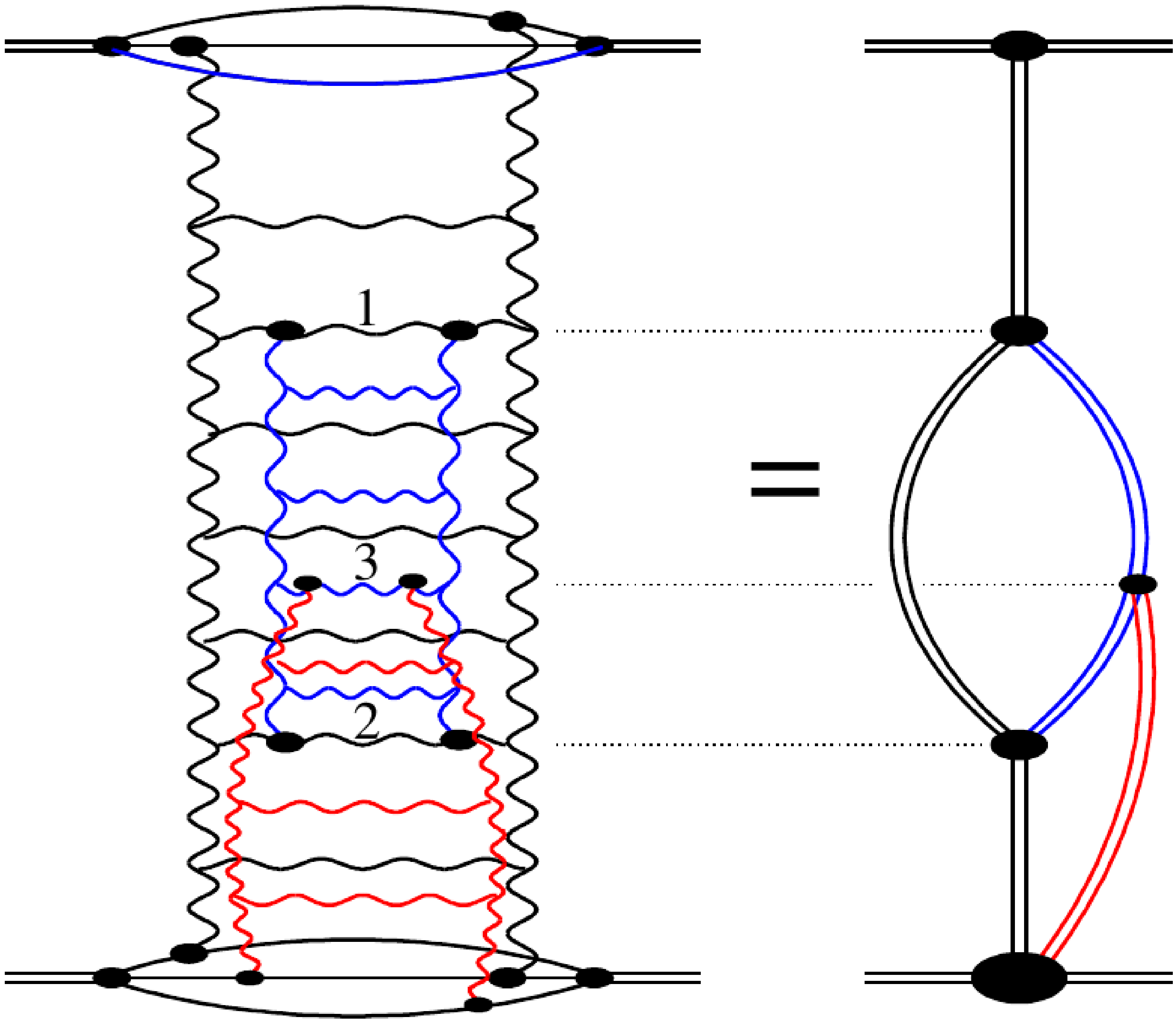


FIG. 3. Charged particle central region ($-2.5 < \eta < 2.5$) multiplicity distribution in the eikonal (black continuous and short dashed curves) and the U-matrix (red long dashed and blue dot-dashed curves; $C = 4$) unitarization schemes. The data are from [13].

Pomeron-Pomeron interactions

Diffraction dissociation –
elastic scattering of intermediate parton




1
3
2
=

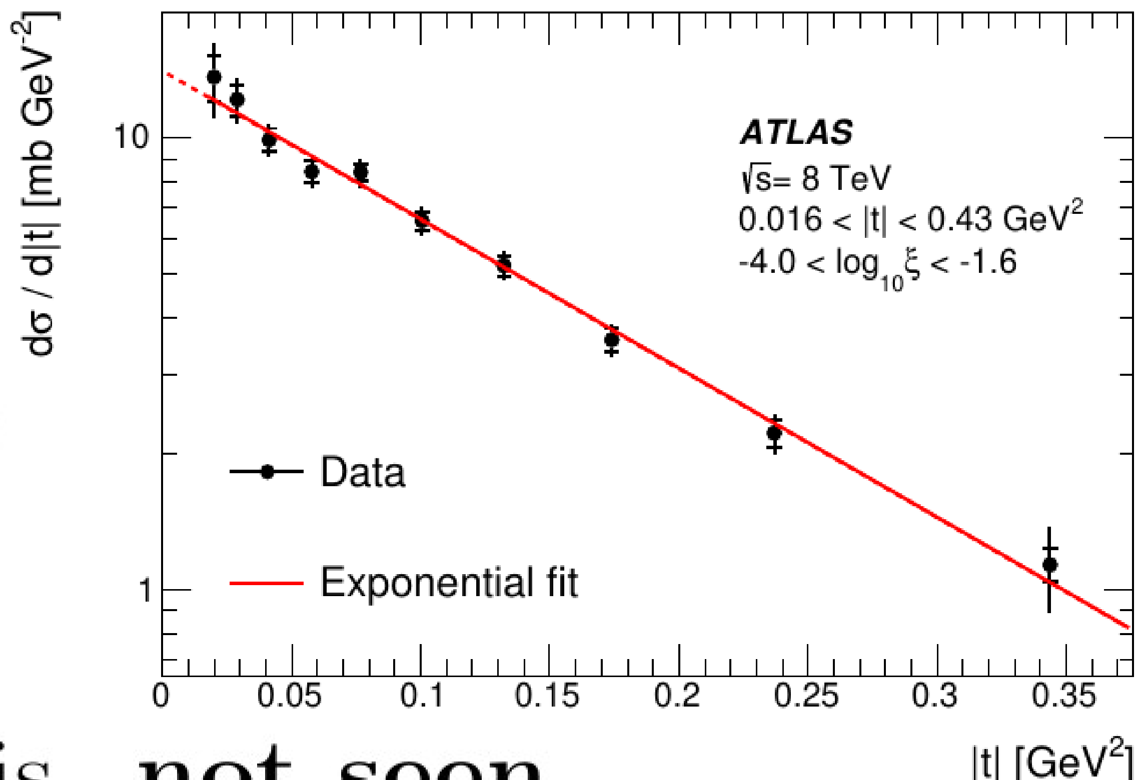
two regimes

weak coupling – $\sigma_{tot} \to const$

$g_{3P} \propto q_t^2$ vanishes at $t \to 0$

strong coupling – $\sigma_{tot} \propto \ln^\eta s$

$B_{el} \propto \ln^\gamma s$



$0 < \eta \leq \gamma \leq 2$

vanish. of g_{3P} is **not seen**

$$\alpha_P(0) = \alpha_{seed}(0) + g_1^1 + (\text{Pom. loop})$$

$|\text{Pom. loop}|$ increases with s for $\alpha_{seed} > 1$

Pom. loop < 0

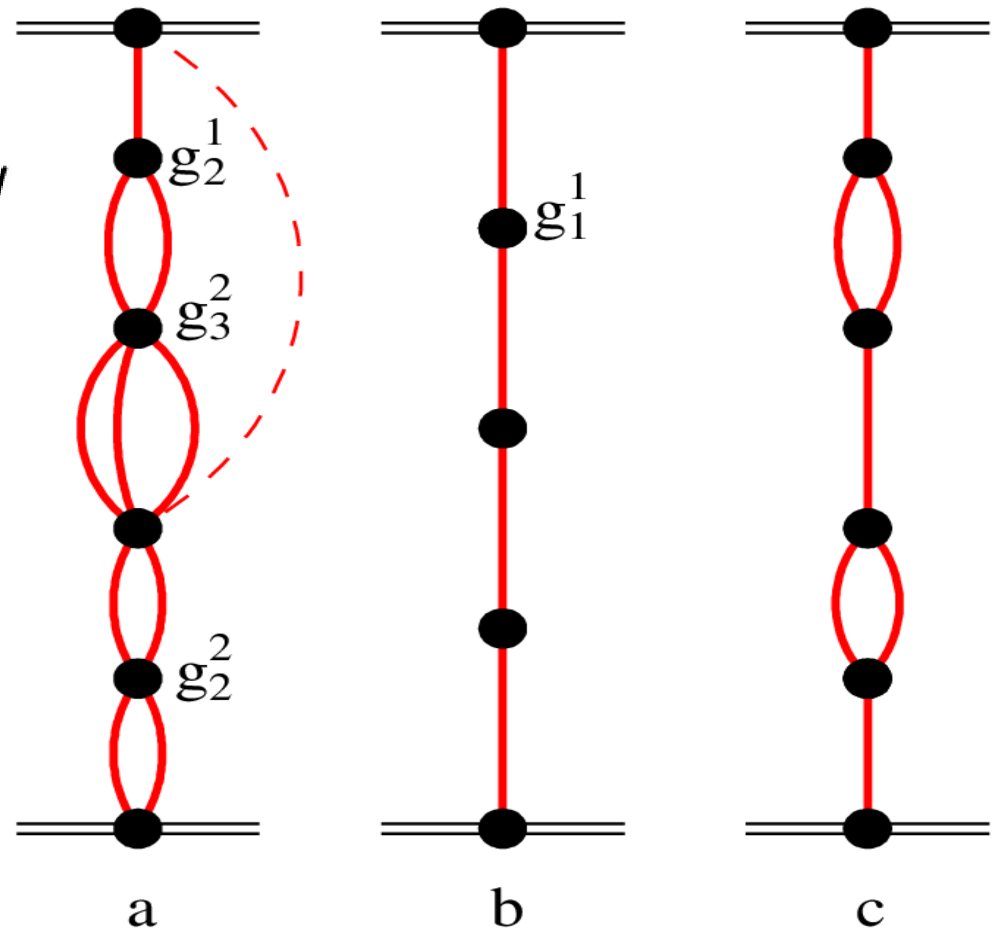
Theory with g_{3P} *only*

gives $\sigma_{tot} \to 0!$

at $s \to \infty$

---

g_m^n are important!



5. TOTEM-ALFA σ_{tot} tension

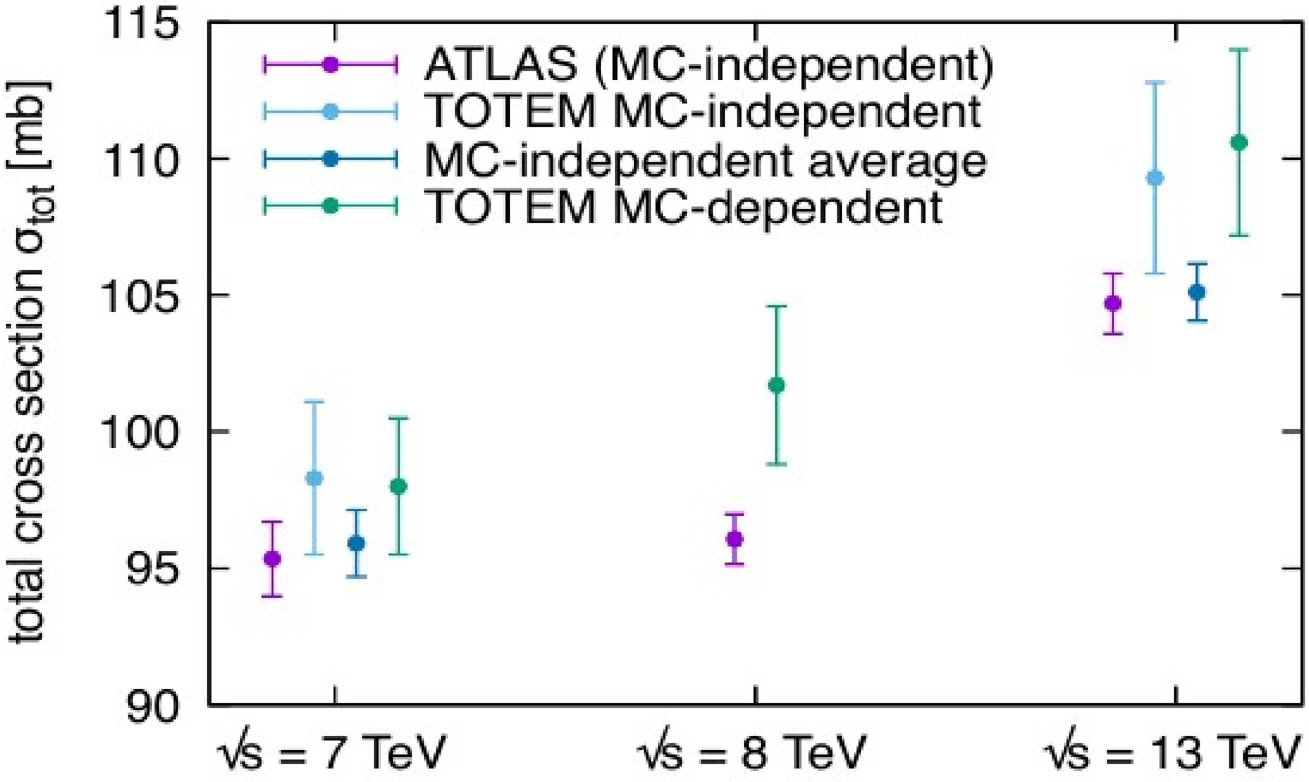


Figure 2: Total pp cross section values measured at LHC.

$$\sigma_{\rm tot}^2 = \frac{16\pi}{1+\rho^2}\frac{1}{L}\frac{{\rm d}N_{\rm el}}{{\rm d}t}\bigg|_{t\to 0}$$ L dependent

Coulomb

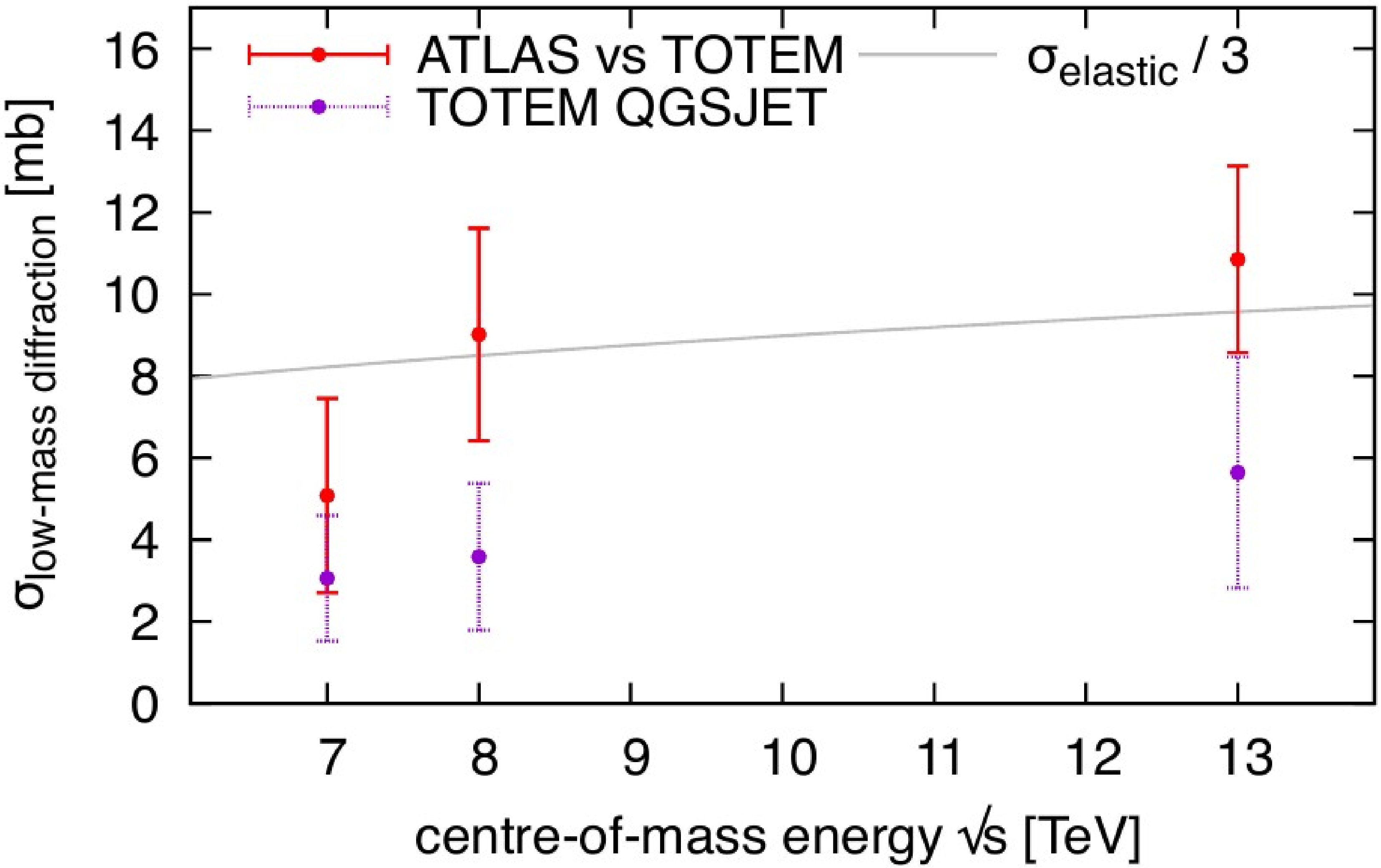
L independent

$$\sigma_{\rm tot} = \frac{16\pi}{1+\rho^2}\frac{1}{N_{\rm el}+N_{\rm inel}}\frac{{\rm d}N_{\rm el}}{{\rm d}t}\bigg|_{t\to 0}$$

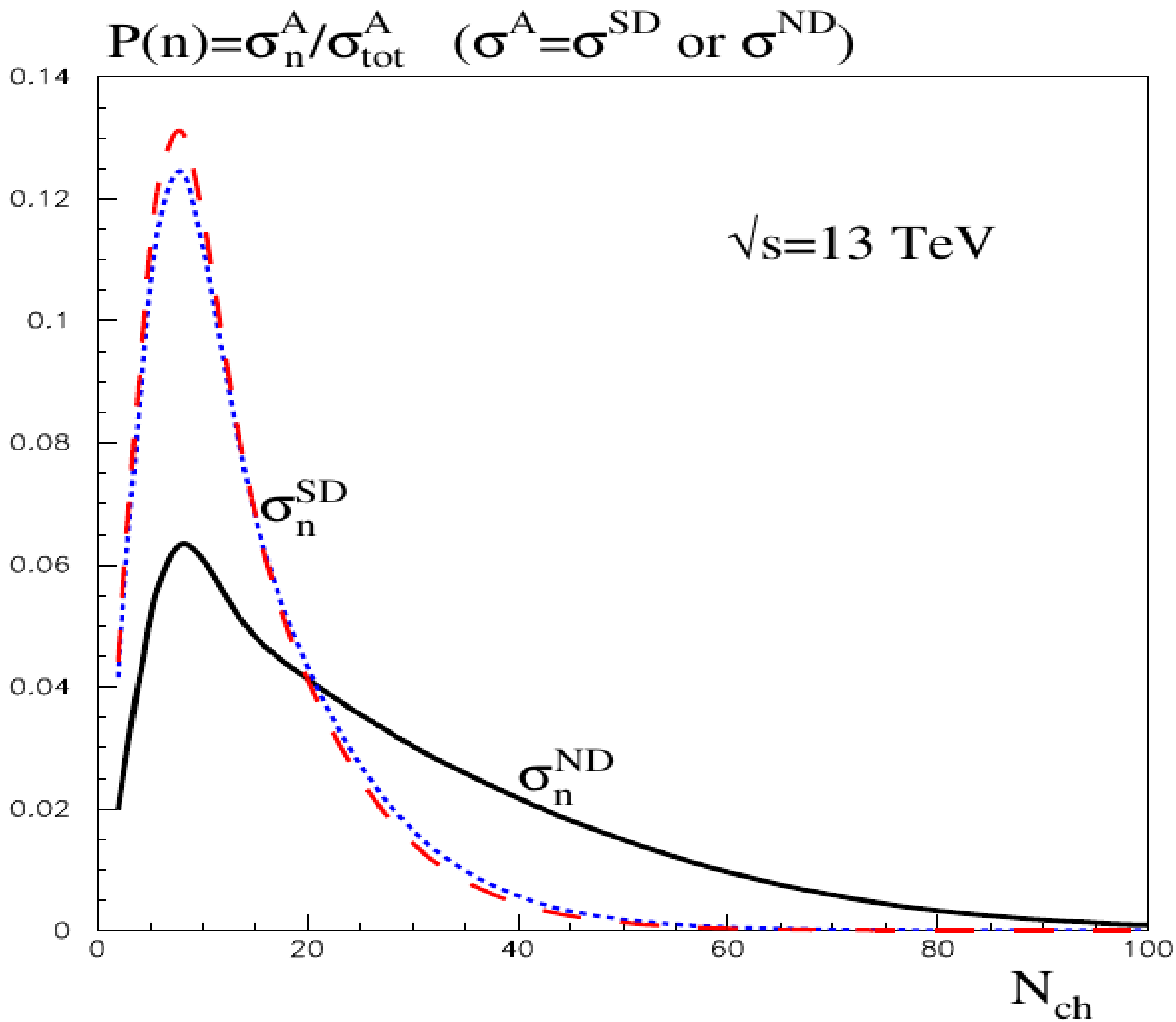
$N_{inel}(|\eta| > 6.5)$ not known !

Per Grafström[1] and Rafał Staszewski[2]

2502.13618



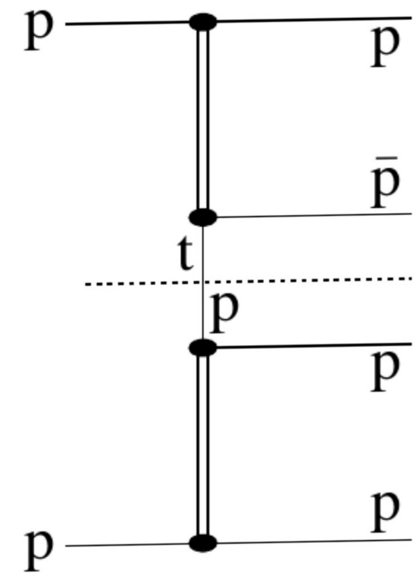
THANK YOU



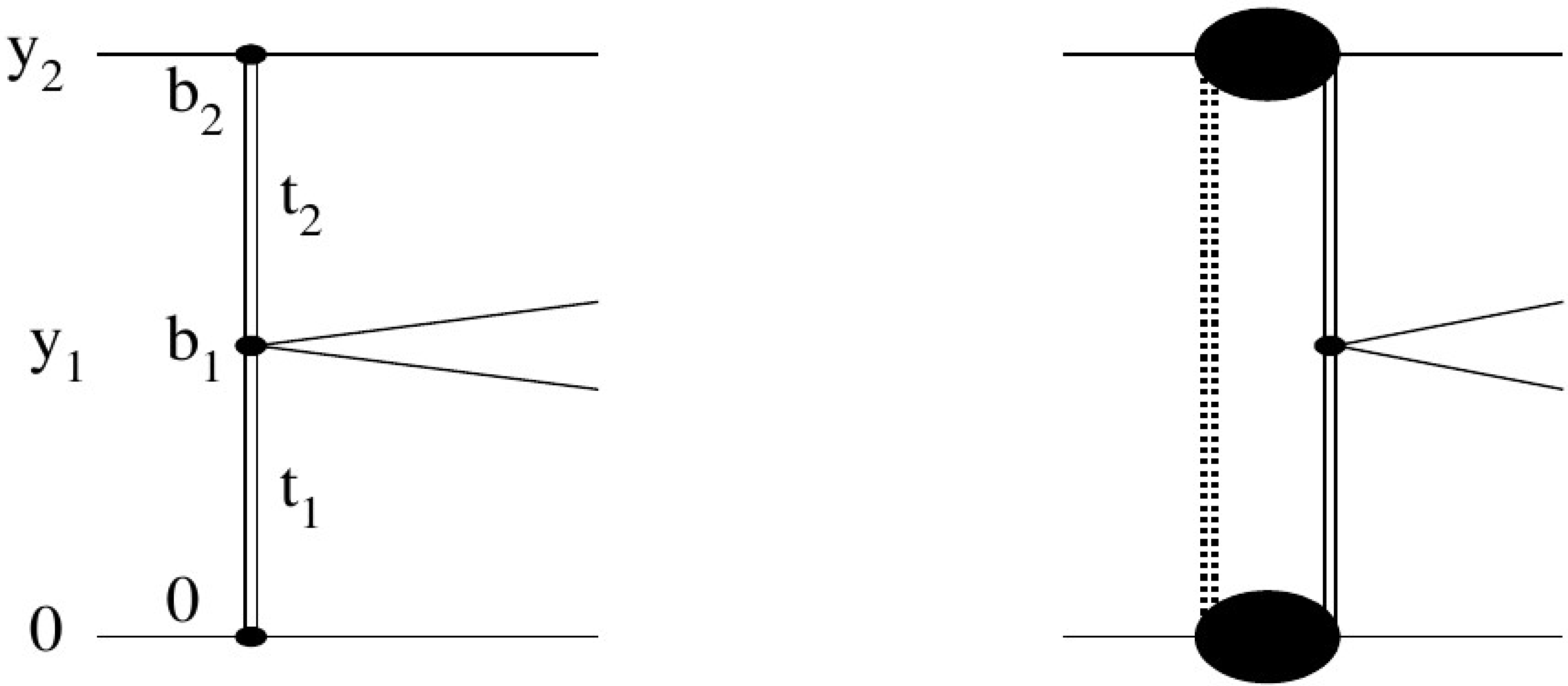
$P(n)=\sigma_n^A/\sigma_{tot}^A \quad (\sigma^A=\sigma^{SD} \text{ or } \sigma^{ND})$
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
$\sqrt{s}$=13 TeV
σ_n^{SD}
σ_n^{ND}
0
20
40
60
80
100
N_{ch}

b) $\sigma(pp \to p + (\bar{p}p) + p) \propto \ln s$

on contrary to $G^U_{inel}(s,b) \to 0$



c) $dN/d\eta \propto s^{0.23}$



y2
b2
t2
y1
b1
t1
0
0

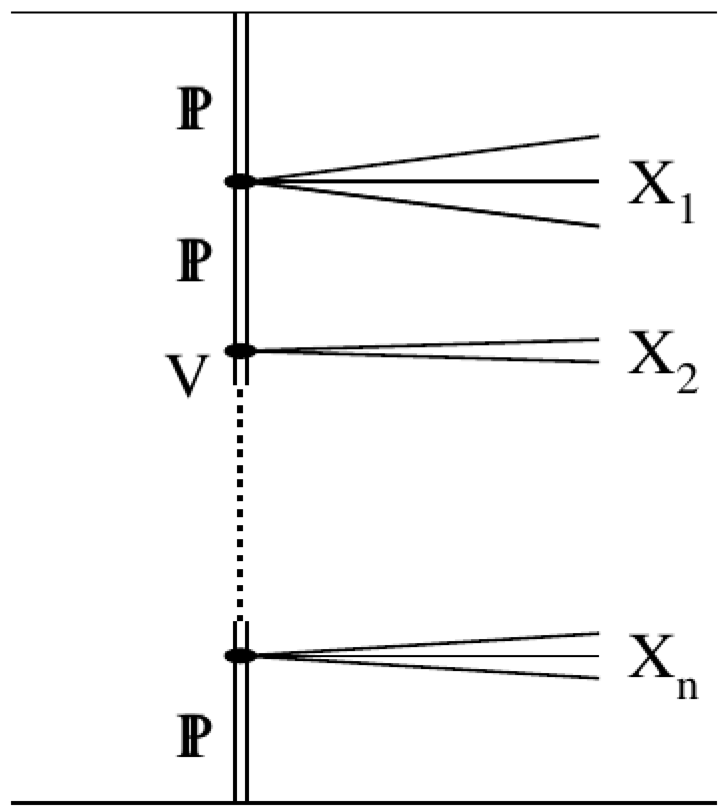


Figure 1: Multi-Reggeon production

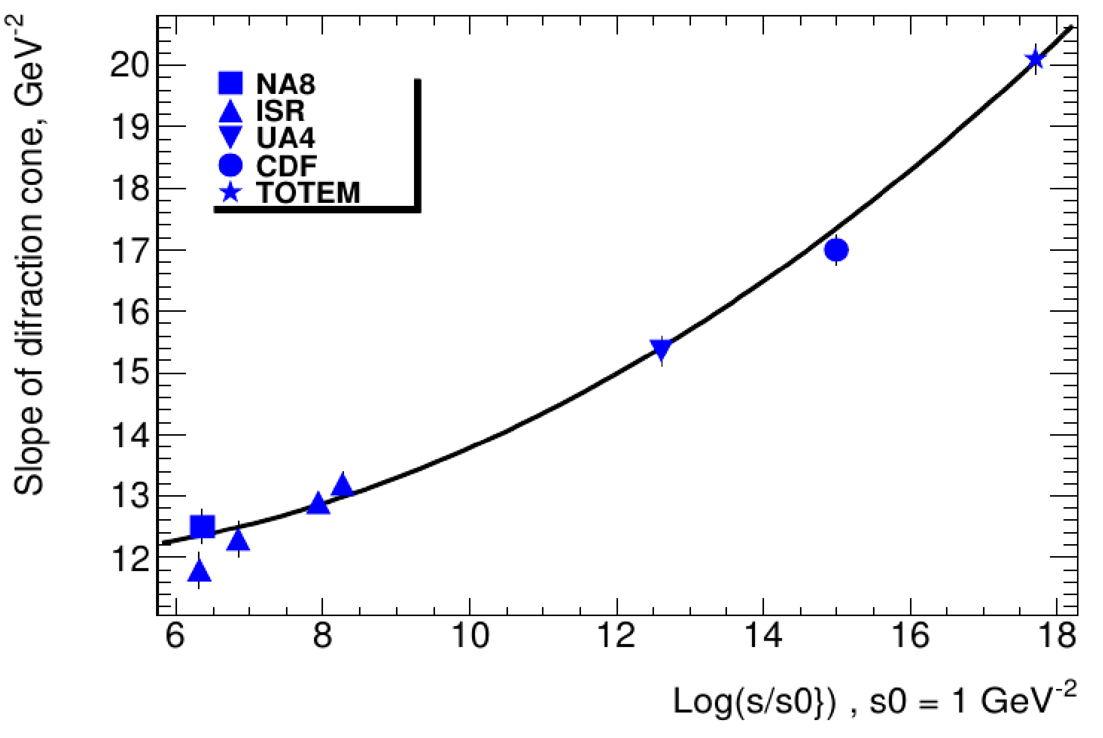
V.A. Schegelsky, M.G. Ryskin .112.3243

$$B_{el} = B_0 + b_1 \ln(s/s_0) + b_2 \ln^2(s/s_0) \qquad b_2 = (.037 \pm .006) GeV^{-2}$$

$$\sigma_{tot} = \sigma_0 + c_1 \ln(s/s_0) + c_2 \ln^2(s/s_)$$

$$c_2 = (0.2817 \pm 0.0064) \text{ mb}$$

$$c_2(B_{el}) = (0.294 \pm 0.005) \text{ mb}$$



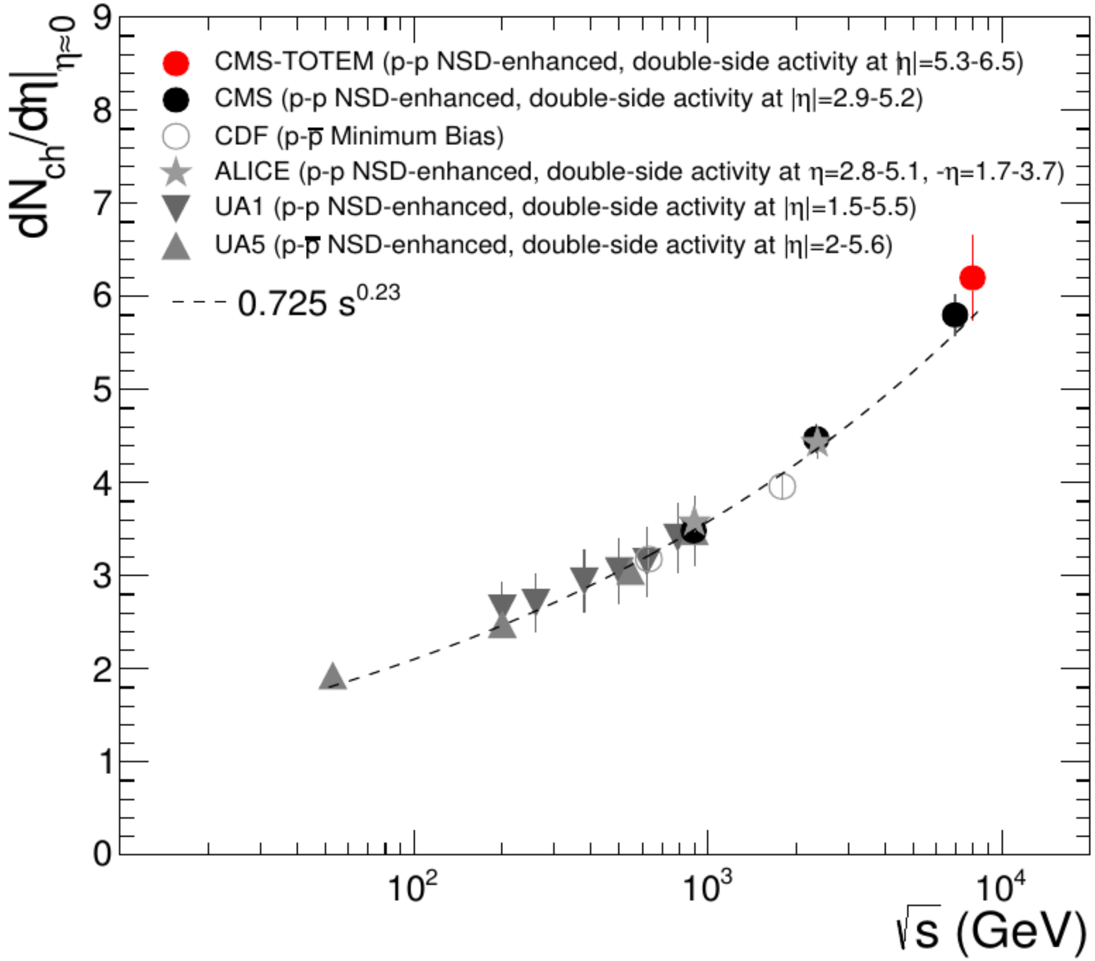


Figure 7: Value of $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ at $\eta \approx 0$ as a function of the centre-of-mass energy in pp and $\mathrm{p\overline{p}}$ collisions. Shown are measurements performed with different NSD event selections from UA1 [12], UA5 [14], CDF [10, 11], ALICE [6], and CMS [4]. The dashed line is a power-law fit to the data.

$$\alpha_P(0) = \alpha_{seed}(0) + g_1^1 + (\text{Pom. loop})$$

$|\text{Pom. loop}|$ increases with s for $\alpha_{seed} > 1$

Pom. loop < 0

Theory with g_{3P} *only*

gives $\sigma_{tot} \to 0$!

at $s \to \infty$

---

g_m^n are important!