On the difference between pp and ppbar cross sections

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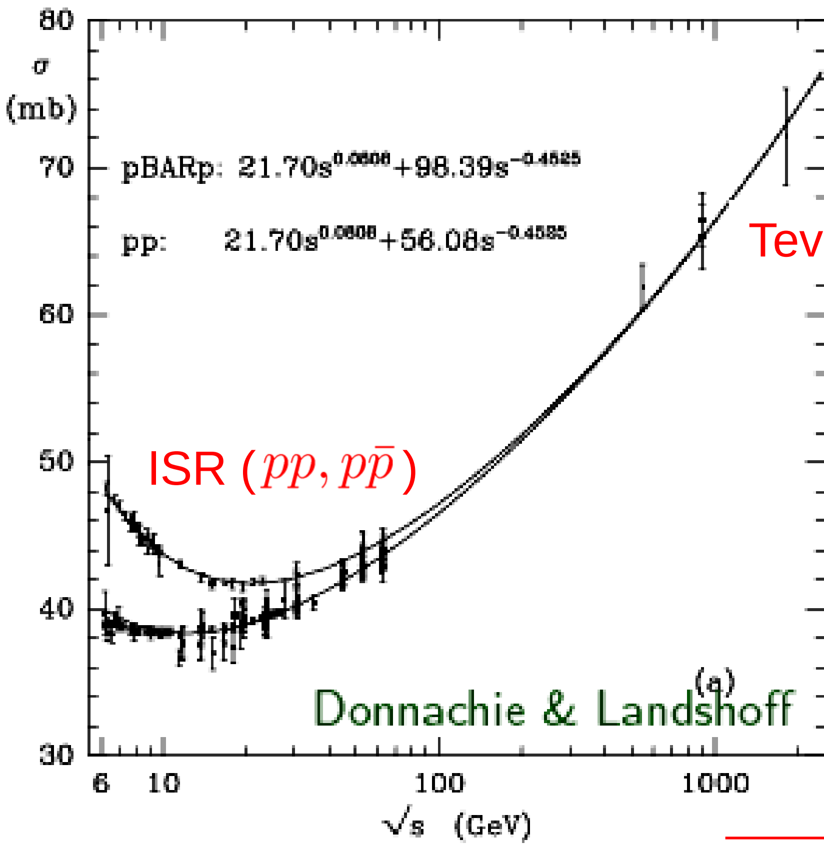
JHEP 1003:037 (2010); 0912.3806 [hep-th]

with Emil Avsar and Toshihiro Matsuo

The total cross section difference

Consider the difference $\Delta\sigma \equiv \sigma_{tot}^{p\bar{p}} - \sigma_{tot}^{pp}$



Tevatron ($p\bar{p}$)

LHC(pp), cosmic rays

What's the fate of $\Delta\sigma$ as $s \rightarrow \infty$?

Up to the ISR energy, $(\sqrt{s} = 53\mathrm{GeV})$

$$\Delta\sigma \sim s^{-0.5} > 0$$

First data from LHC

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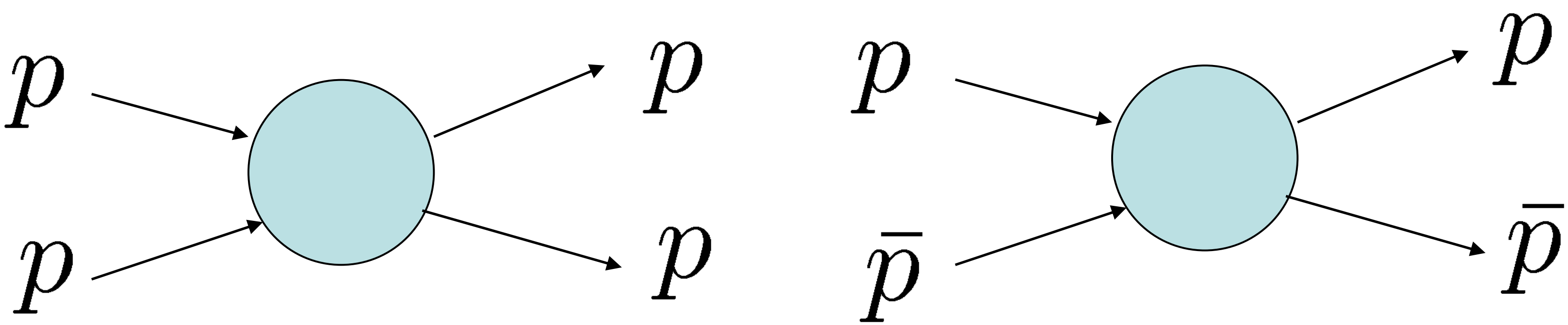
Charged-particle multiplicities in pp interactions at $\sqrt{s} = 900$ GeV measured with the ATLAS detector at the LHC ☆,☆☆

A B S T R A C T

The first measurements from proton–proton collisions recorded with the ATLAS detector at the LHC are presented. Data were collected in December 2009 using a minimum-bias trigger during collisions at a centre-of-mass energy of 900 GeV. The charged-particle multiplicity, its dependence on transverse momentum and pseudorapidity, and the relationship between mean transverse momentum and charged-particle multiplicity are measured for events with at least one charged particle in the kinematic range $|\eta| < 2.5$ and $p_T > 500$ MeV. The measurements are compared to Monte Carlo models of proton–proton collisions and to results from other experiments at the same centre-of-mass energy. The charged-particle multiplicity per event and unit of pseudorapidity at $\eta = 0$ is measured to be $1.333 \pm 0.003(\text{stat.}) \pm 0.040(\text{syst.})$, which is 5–15% higher than the Monte Carlo models predict.

Discrepancy between the data and MC tuned to Tevatron and CERN $p\bar{p}$ data

Odderon and Reggeon



The difference $\Delta\mathcal{A} \equiv \mathcal{A}_{pp\to pp}(s,t) - \mathcal{A}_{p\bar{p}\to p\bar{p}}(s,t)$

is odd under crossing, generated by the exchange of C-odd objects in QCD

→ Reggeon (vector mesons)
  Odderon (C-odd glueballs) Lukaszuk, Nicolescu (1973)

$$\Delta\sigma(s) = \frac{1}{s}\,\mathrm{Im}\Delta\mathcal{A}(s,t=0) \sim s^{-0.5}$$

Attributed to the Reggeon exchange. Any room for the Odderon?

The AdS/CFT correspondence

Maldacena (1997)

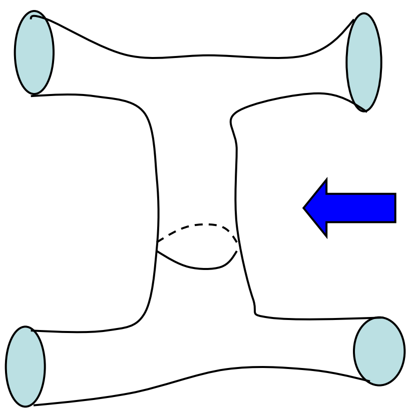
Conjecture: N=4 SYM at strong coupling is dual to type IIB at weak coupling on $AdS_5 \times S^5$

$$ds^2 = R^2 \frac{\overbrace{-dx^\mu dx_\mu}^{\text{our universe}} + \overbrace{dz^2}^{\text{extra dimensions}}}{z^2} + R^2 d\Omega_5^2$$

N=4 SYM		string
(anomalous) dimension	⟷	mass
`t Hooft parameter λ	⟷	curvature radius R^4/α'^2
number of colors $1/N_C$	⟷	string coupling constant g_s

High energy scattering in AdS

Regge trajectory in string theory $m^2 = \frac{4n}{\alpha'} = \frac{2(j-2)}{\alpha'}$



$g_{\mu\nu},\ \phi,\ A_\mu\ B_{\mu\nu},\cdots$

graviton, dilaton, SO(6) gauge boson, B-field….

Total cross section → Reggeized graviton = Pomeron

Total cross section difference → Reggeized B-field = Odderon

Brower, Djuric, Tan (2009)

The antisymmetric B-field

10D B-field B_{MN}

compactify on S^5

B_{mn}

"diagonal"

$B_{m\alpha}$

"off-diagonal"

dual

$\mathrm{tr}\left(F^{+}_{\mu\nu}F^{2}_{-}\phi^{k}\right)$

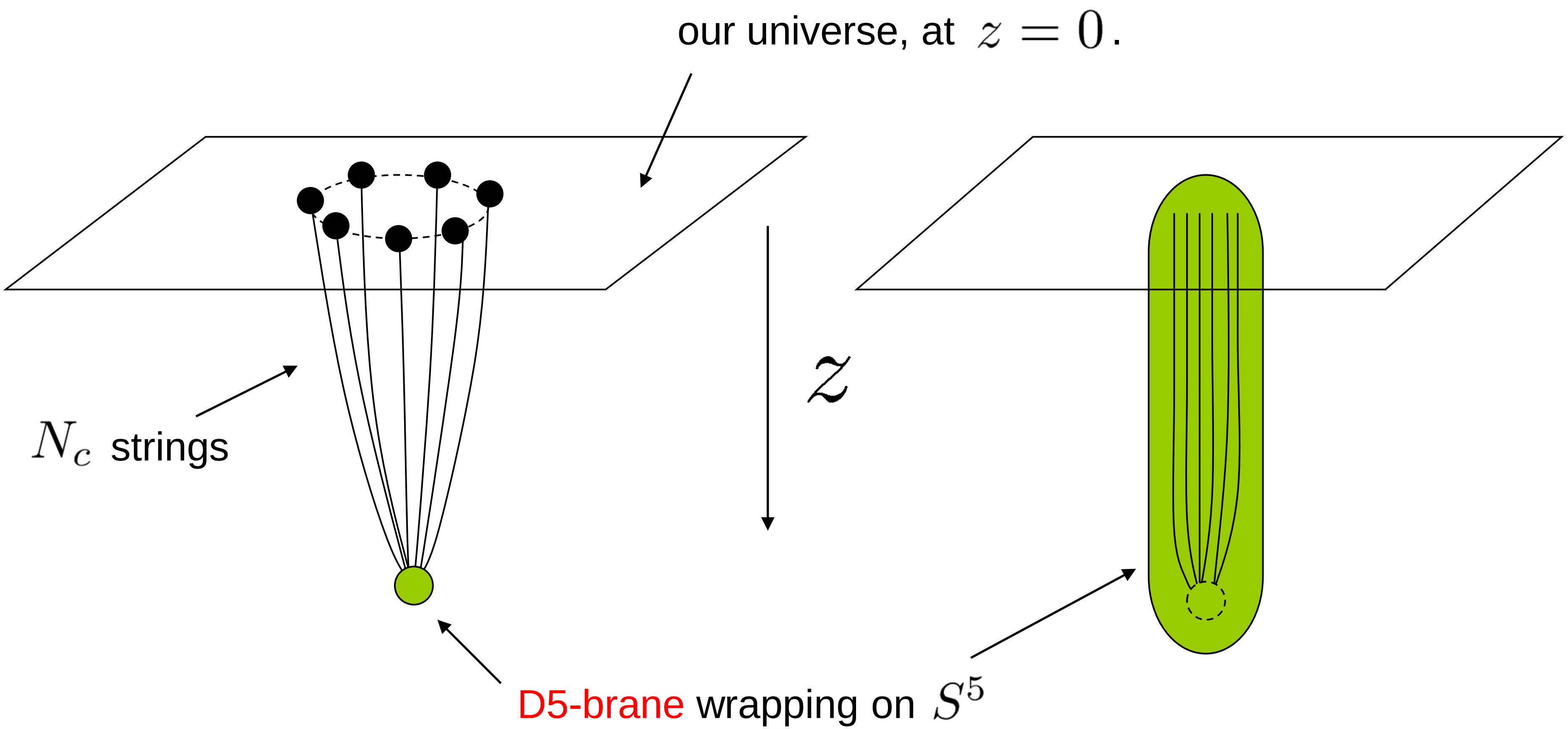
"Odderon"

$\mathrm{tr}\left(F^{+}_{\mu\nu}\bar{\psi}_{A}\bar{\sigma}^{\nu}\psi_{B}\phi^{k-1}\right)$

"Reggeon"

Odderon and Reggeon unified in 10 dimensions

Baryons in AdS/CFT



Witten (1998)

Imamura (1999)
Callan, Guijosa, Savvidy (1999)

Baryon-Odderon coupling

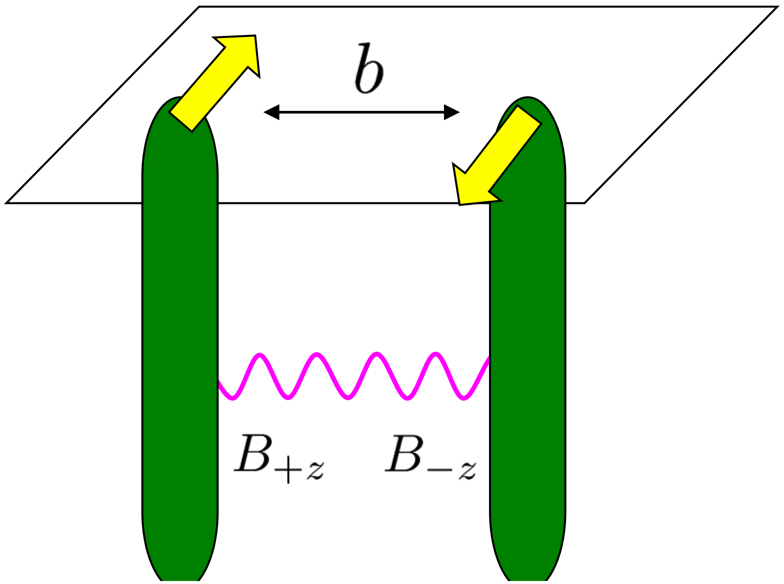
Born-Infeld and Chern-Simons action

$$S = T_5 \int d^6\xi \left\{ -\sqrt{-\det(\tilde{G} + \tilde{B} + 2\pi\alpha' F)} + 2\pi\alpha' F \wedge c_{(4)} \right\}$$

$$= \frac{1}{\mathrm{Vol}_{S^4}} \int dx^+ d\theta d\Omega_4 \frac{\partial \mathcal{L}}{\partial F_{+\theta}} \frac{\tilde{B}_{+\theta}}{2\pi\alpha'}$$

$$= \frac{\pm N_c}{2\pi\alpha' \mathrm{Vol}_{S^4}} \int dx^+ d\theta d\Omega_4 \left(B_{+\theta} + \frac{\partial z}{\partial \theta} B_{+z} \right)$$

Reggeon (decouple) Odderon



Odderon amplitude, fixed impact parameter

$$i\mathcal{A}^{\pm}(s,b) = \pm i^2 \left(\frac{N_c}{2\pi\alpha' \mathrm{Vol}_{S^4}} \right)^2 \sum_k \int dx^+ dz d\Omega_4 Y^{(k)}(\Omega)$$

$$\times \int dx'^- dz' d\Omega_4' Y^{(k)}(\Omega') \langle B^{(k)}_{+z}(x^+, 0, b, z) B^{(k)}_{-z'}(0, x'^-, 0, z') \rangle$$

B-field propagator

Bena, Nastase, Vaman (2001)

$$\langle B_{mn} B_{m'n'} \rangle = T^1_{mnm'n'} D(u) - \partial_m V_{n,m'n'} + \partial_n V_{m,m'n'} + T^3_{mn,m'n'} K(u)$$

$$\begin{cases} T^1_{mn,m'n'} = R^4 (\partial_m \partial_{m'} u \partial_n \partial_{n'} u - \partial_m \partial_{n'} u \partial_n \partial_{m'} u) \\ u = \dfrac{(z - z')^2 + (x_\perp - x'_\perp)^2 - 2(x^+ - x'^+)(x^- - x'^-)}{2zz'} \\ D(u) \sim \dfrac{1}{z^2 \partial_z^2 - z\partial_z + 1 - M^2} \end{cases}$$

"chordal distance"

Up to this point, the amplitude is purely real.

Analytic continuation in spin

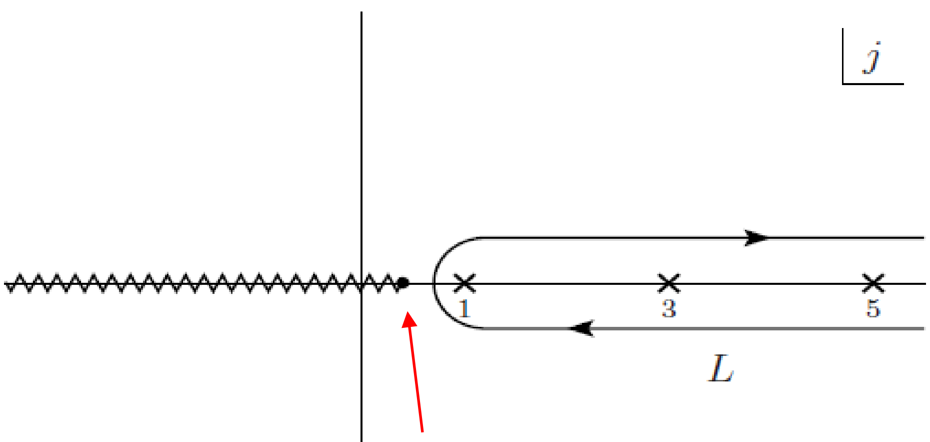
Include higher spin string excited states.

Analytically continue the B-field propagator to $j \neq 1$ and sum over j

$$D(u) \sim \frac{1}{z^2\partial_z^2 - z\partial_z + 1 - M^2}$$

$$\Rightarrow \frac{1}{z^2\partial_z^2 - z\partial_z + 1 - M_j^2}$$

$$M_j^2 = M^2 + 2\sqrt{\lambda}(j-1)$$



A cut beginning at $j_O = 1 - \frac{M^2}{2\sqrt{\lambda}}$

Total cross section difference

$$\Delta\sigma = \sigma^{BB} - \sigma^{BB} = 2\int d^2b\, Im\, \mathcal{A}^-(s,b) - 2\int d^2b\, Im\, \mathcal{A}^+(s,b)$$

$$= -\frac{\pi\sqrt{\lambda}}{4(\mathrm{Vol}_{S^4})^2}\sum_{I,k}\frac{M_I + \frac{1}{M_I}}{k+2}\int dz d\Omega_4 Y^{(k)}(\Omega_5)\int dz' d\Omega'_4 Y^{(k)}(\Omega'_5)\left(\frac{zz's}{4\sqrt{\lambda}}\right)^{\alpha_O(0)-1} .$$

Odderon intercept

$$\alpha_O = j_O + \frac{1}{2\sqrt{\lambda}}$$

Note that $\Delta\sigma$ is negative !

…in conflict with the ISR data…

How can $\Delta\sigma$ be negative?

sign of $\Delta\sigma$ → sign of $\mathrm{Im}\mathcal{A}$ → sign of the interaction

exchange of the B-field → repulsion → $\Delta\sigma > 0$??

However, this may not be true in a curved space !
Look at the tensor part of the B-field propagator

$$T^1_{+z,-'z'} = \underbrace{(-\partial_+\partial_{-'}u)}_{\eta_{+-}}\underbrace{(-\partial_z\partial_{z'}u)} - \cdots$$

positive if the derivatives act on the numerator
negative if the derivatives act on the denominator

$$u = \frac{(z-z')^2 + b^2 + \eta_{+-}(x^+ - x'^+)(x^- - x'^-)}{zz'}$$

Sign flip from the warp factor

$$T^{1}_{+z,-'z'} \sim \eta_{+-}\left(\underbrace{-1 - v}_{\text{negative}} + \underbrace{\frac{z}{z'} + \frac{z'}{z}}_{\text{positive (expected)}}\right) \qquad v = \frac{(z-z')^2 + b^2}{2zz'}$$

negative   positive (expected)

The negative contribution is enhanced after integrating over b ,

dominates over the positive contribution when $\ln s \gg \sqrt{\lambda}$

Attraction between like charges and repulsion between opposite charges !

$\Delta\sigma < 0$ due to the curvature of AdS.

A scenario ("prediction")

Reggeon gives a positive contribution $\Delta\sigma \sim s^{\alpha_R - 1} > 0$

$$\alpha_R(0) = 1 - \frac{9}{2\sqrt{\lambda}},\ \ 1 - \frac{16}{2\sqrt{\lambda}}, \cdots ,$$

Odderon gives a negative contribution $\Delta\sigma \sim s^{\alpha_O - 1} < 0$

when $\ln s \gg \sqrt{\lambda}$

$$\alpha_O(0) = 1,\ \ 1 - \frac{3}{2\sqrt{\lambda}},\ \ 1 - \frac{8}{2\sqrt{\lambda}},\ \ 1 - \frac{15}{2\sqrt{\lambda}}, \cdots .$$

At the ISR energies, the Reggeon dominates. But the Odderon eventually flips the sign of $\Delta\sigma$, possibly at the LHC!

A recent prediction

Extrapolate the low-energy phenomenological fit to high energies.

Avila, Gauron, Nicolescu (2007)

LHC is also a good place to discover the Odderon. We predict

$$\sigma_T^{pp}(\sqrt{s} = 14\ \text{TeV}) = 123.32\ \text{mb}\ ,$$

$$\Delta\sigma(\sqrt{s} = 14\ \text{TeV}) = -3.92\ \text{mb}\ ,$$

Negative !

An old prediction

A Possible Interpretation of pp Rising Total Cross-Sections.

L. Łukaszuk (*) and B. Nicolescu

Division de Physique Théorique (**), Institut de Physique Nucléaire (***) and Laboratoire de Physique Théorique et Hautes Energies (***) - Paris

In the very first paper in 1973, they have predicted

$$\Delta\sigma < 0 \quad !!$$

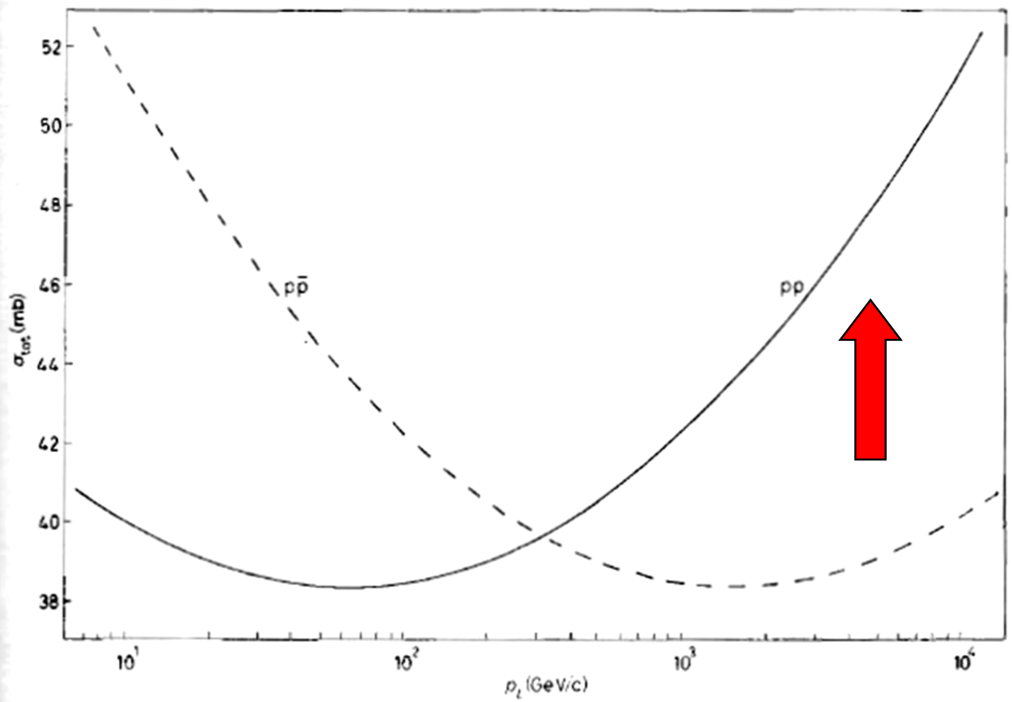


Fig. 3. – Comparison between the predictions of σ_T^{pp} and $\sigma_T^{p\bar{p}}$.

A hint from LHC?

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ABSTRACT

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Need to produce more particles in pp !

Conclusion

- Single-odderon exchange between “baryons” calculated from AdS/CFT
- Analytical expression of the total cross section difference.
- The pp cross section becomes larger than the ppbar cross section at very high energies, possibly at the LHC.