Holographic description of total hadronic cross sections at high energies

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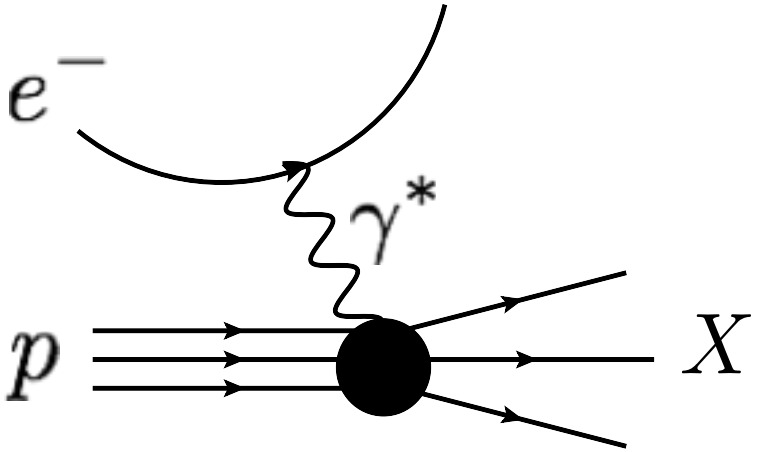
Outline

1. Introduction of previous analysis on DIS at small *x* in holographic QCD
2. Motivation
3. Analysis on total hadronic cross sections
4. Summary

DIS structure functions

$$\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[\left\{1+(1-y)^2\right\}F_2\left(x,Q^2\right) - y^2 F_L\left(x,Q^2\right)\right]$$



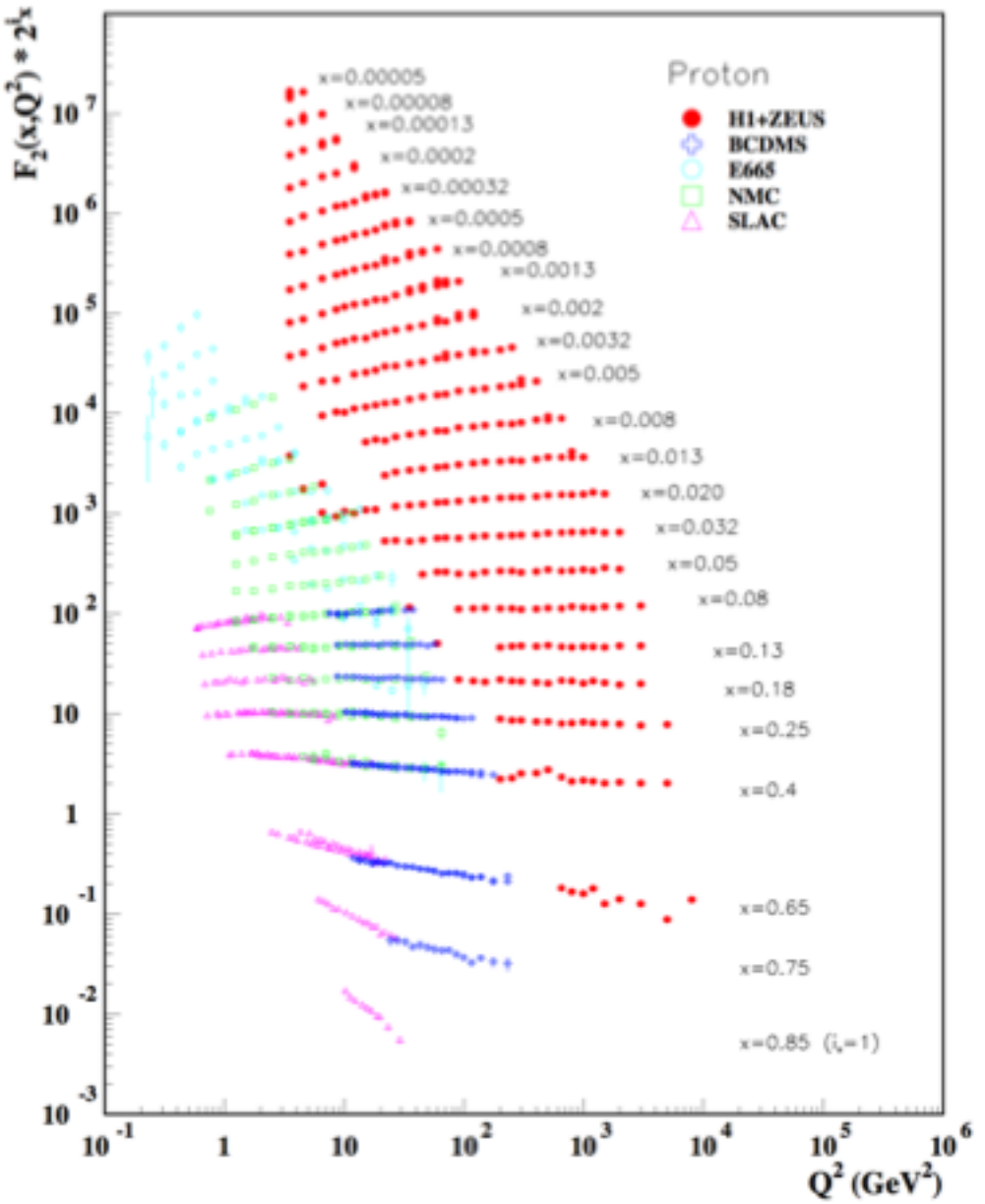
$$F_2\left(x,Q^2\right) = \frac{Q^2}{4\pi^2\alpha}\sigma_{tot}\left(x,Q^2\right)$$

$$F_L\left(x,Q^2\right) = \frac{Q^2}{4\pi^2\alpha}\sigma_L\left(x,Q^2\right)$$

- Structure functions are physical quantities which have information on the internal structure of hadrons.
- They depend on two kinematic variables, Bjorken-*x* and photon 4-momentum squared Q^2.

F_2 structure function of proton

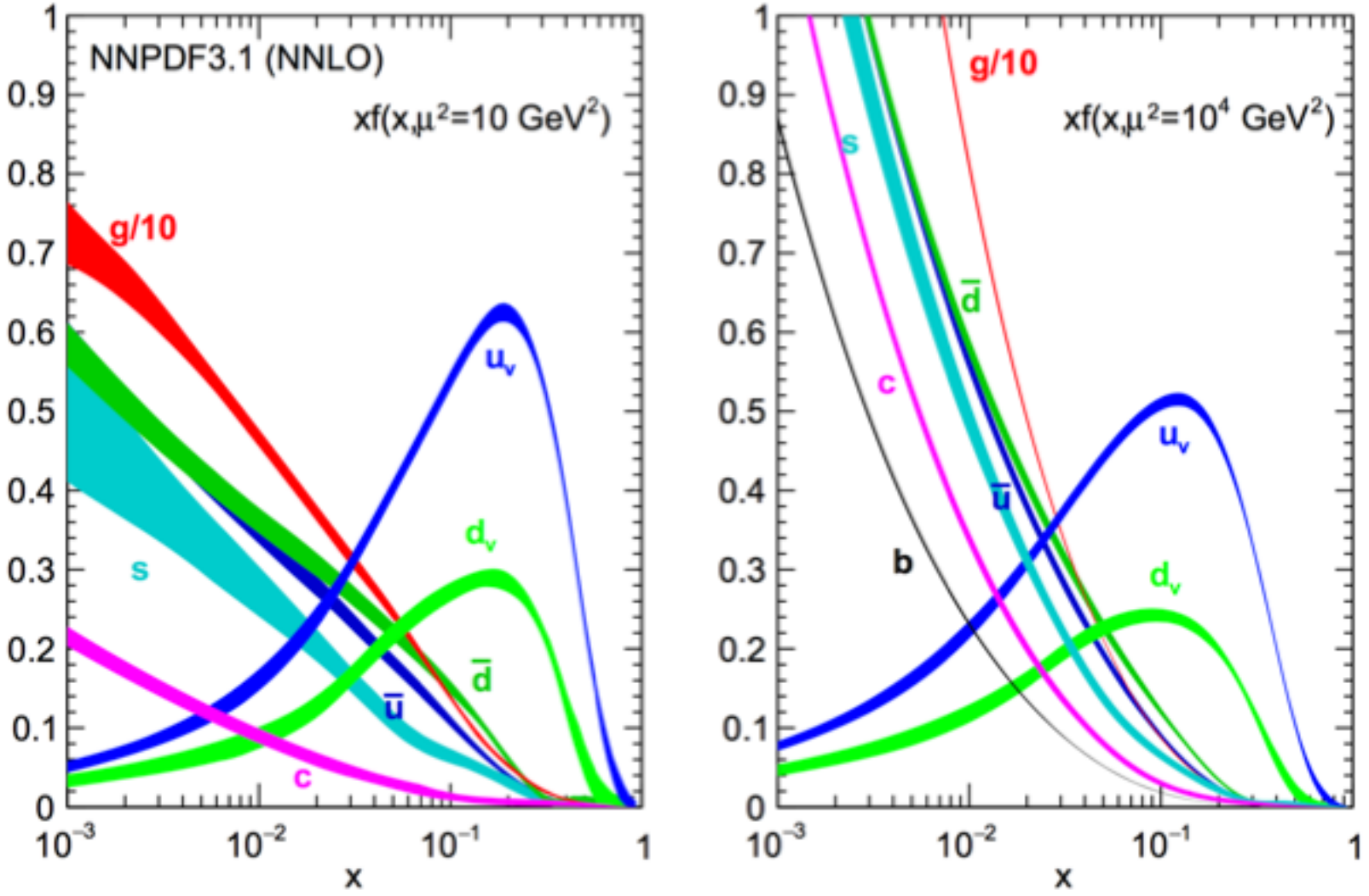
PDG (2016)



- Proton F_2 has been measured in the very wide kinematic range so far.
- Structure functions are basically nonperturbative physical quantities.

Proton parton distribution functions (PDFs)

NNPDF Collaboration (2017)

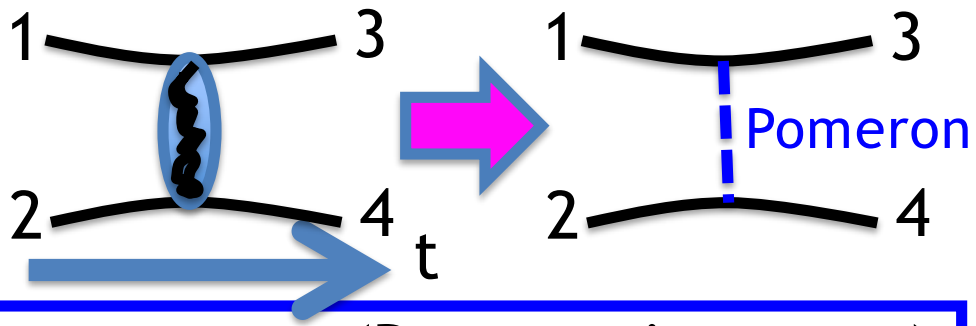


Pomeron exchange picture

- A description of high energy scattering before QCD
- Pomeron: a color singlet gluonic object
- Total cross sections for high energy two-to-two scattering can be well reproduced by this picture

$$s = (p_1 + p_2)^2 = (p_3 + p_4)^2$$

$$\sigma_{tot}(s) \sim s^{\alpha_0 - 1}$$



can be expressed by a single parameter (Pomeron intercept)

Therefore, F_2 structure function can be written as

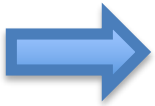
$$F_2(x, Q^2) \sim x^{1-\alpha_0}$$

(this is effective only in the small *x* region)

Holographic description of structure functions

- **Polchinski-Strassler (2003)**
- **Brower-Polchinski-Strassler-Tan (2007)**
- **Brower-Djuric-Sarcevic-Tan (2010)**

derived Pomeron exchange kernel



studied nucleon structure functions

$$\mathcal{A}(s,t) = 2is\int d^2b e^{iq\cdot b}\int dzdz' P_{13}(z)P_{24}(z')\left\{1-e^{i\chi(s,b,z,z')}\right\}$$

$$F_2\left(x,Q^2\right) = \frac{Q^2}{2\pi^2}\int dzdz' P_{13}\left(z,Q^2\right)P_{24}\left(z',Q'^2\right)\mathrm{Im}\left[\chi\left(s,z,z'\right)\right]$$

z and z' : 5th coordinate

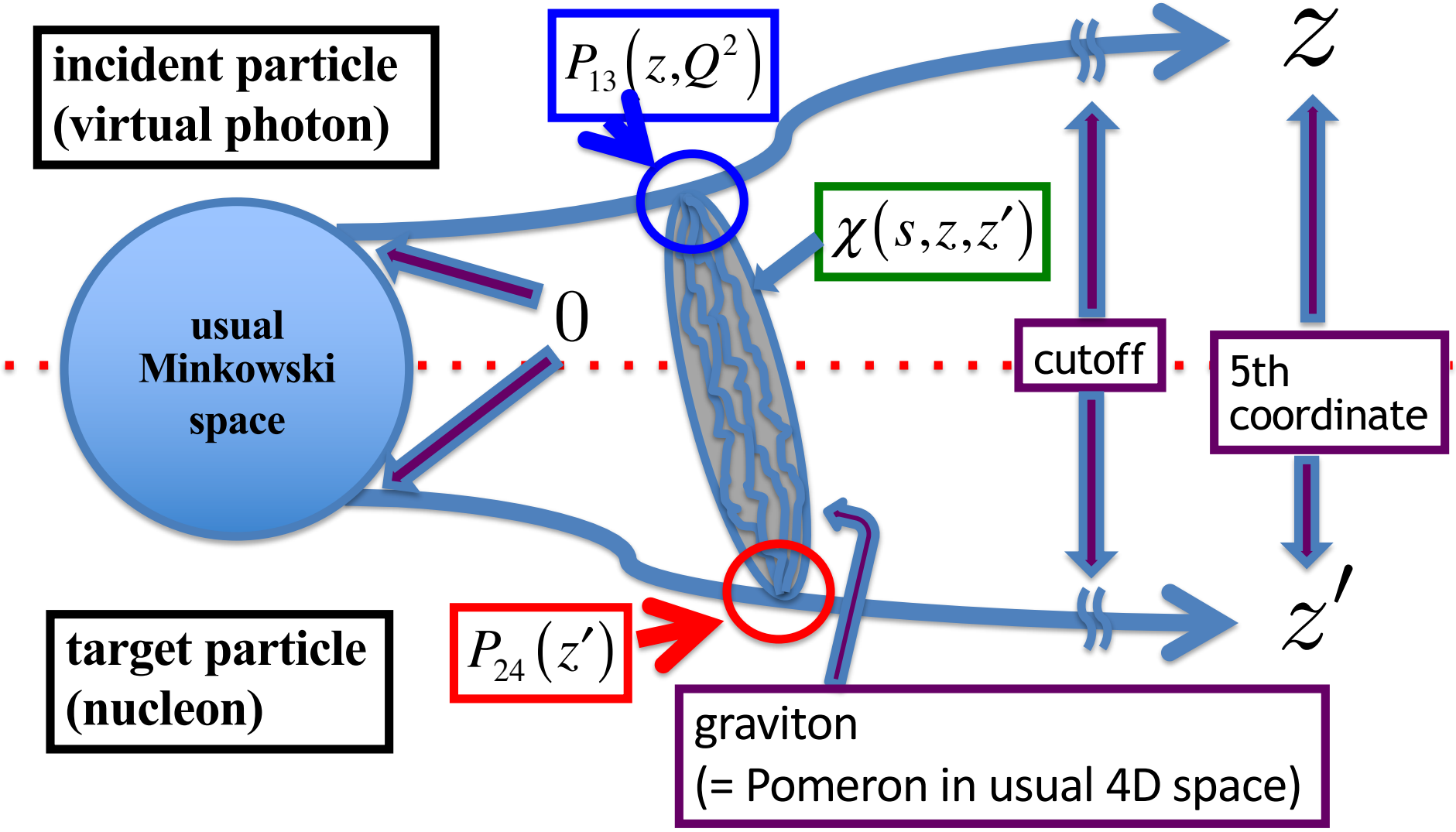
χ : Pomeron exchange kernel in the AdS space

$P_{13}(z,Q^2)$: incident particle (Q: 4-momentum)

$P_{24}(z',Q'^2)$: target particle

overlap functions (density distributions in the AdS space)

5D background spacetime (AdS_5)



Pomeron exchange kernel

Brower-Polchinski-Strassler-Tan (2007)
Brower-Strassler-Tan (2009)

$$F_i\left(x,Q^2\right)=\frac{g_0^2\rho^{3/2}Q^2}{32\pi^{5/2}}\int dz\,dz'P_{13}^{(i)}\left(z,Q^2\right)P_{24}\left(z',Q'^2\right)(zz')\mathrm{Im}\left[\chi\left(s,z,z'\right)\right]$$

$i=2$ or L

$$\mathrm{Im}\left[\chi_c\left(s,z,z'\right)\right]\equiv e^{(1-\rho)\tau}e^{-\frac{\log^2 z/z'}{\rho\tau}}/\tau^{1/2}$$

$$\tau=\log\left(\rho zz's/2\right)$$

mimicking confinement effect

$$\mathrm{Im}\left[\chi_{\mathrm{mod}}\left(s,z,z'\right)\right]\equiv\mathrm{Im}\left[\chi_c\left(s,z,z'\right)\right]+\mathcal{F}\left(z,z',\tau\right)\mathrm{Im}\left[\chi_c\left(s,z,z_0^2/z'\right)\right]$$

$$\mathcal{F}\left(z,z',\tau\right)=1-2\sqrt{\rho\pi\tau}e^{\eta^2}\mathrm{erfc}\left(\eta\right)$$

$$\eta=\left(-\log\frac{zz'}{z_0^2}+\rho\tau\right)/\sqrt{\rho\tau}$$

energy dependence

magnitude

strength of confinement effect

3 adjustable parameters : ρ, g_0^2, z_0

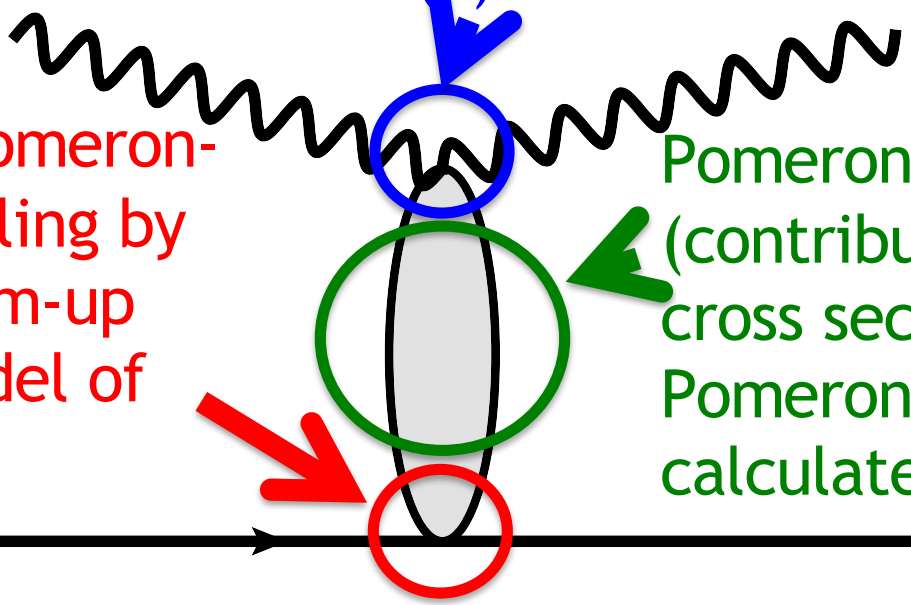
Model setup

$$F_i\left(x,Q^2\right)=\frac{g_0^2\rho^{3/2}Q^2}{32\pi^{5/2}}\int dz\,dz' P_{13}^{(i)}\left(z,Q^2\right)P_{24}\left(z',Q'^2\right)(zz')\mathrm{Im}\left[\chi\left(s,z,z'\right)\right]$$

$i=2$ or L

using wave function of the 5D U(1) vector field

virtual photon



calculating Pomeron-nucleon coupling by using a bottom-up AdS/QCD model of nucleon

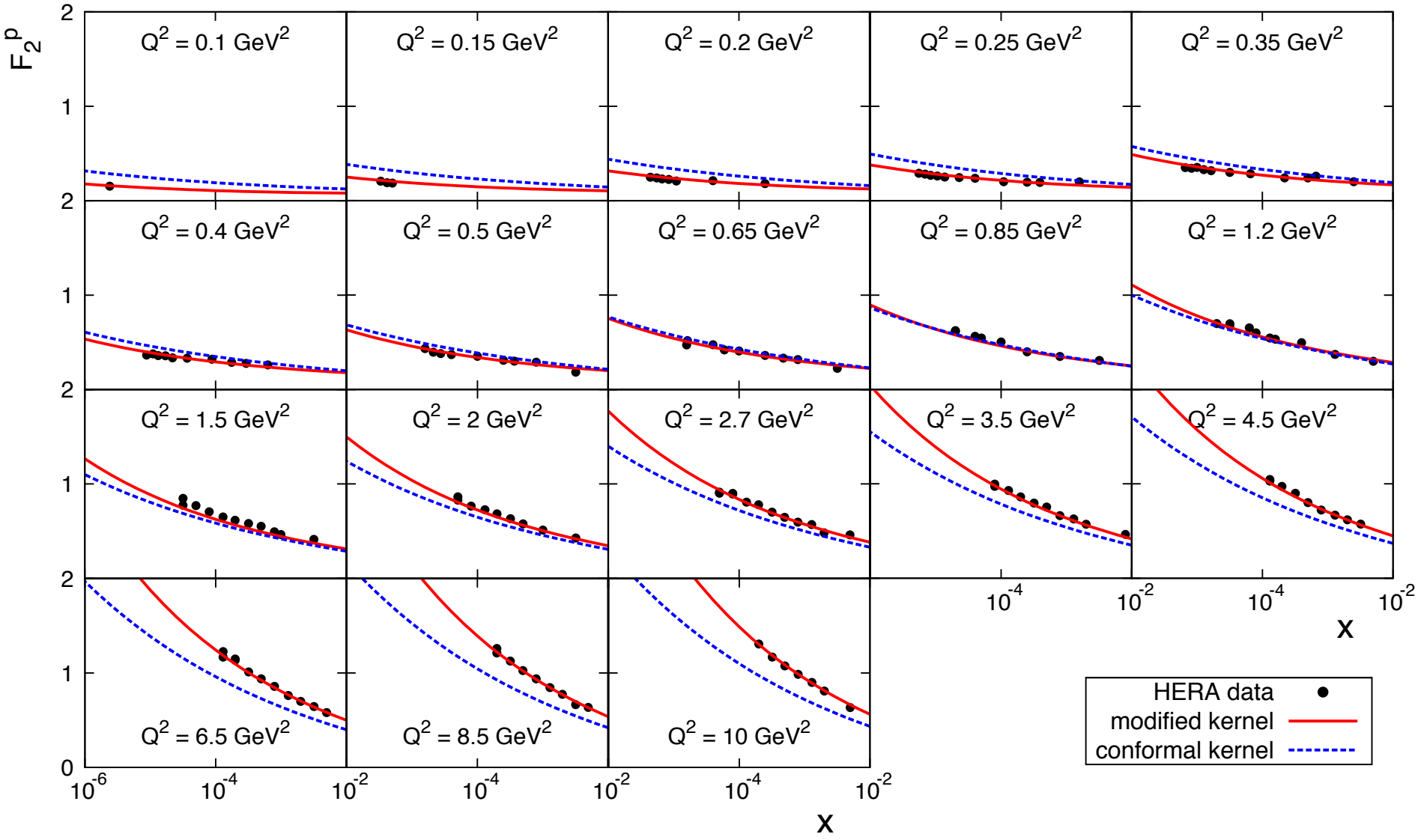
Pomeron exchange kernel (contribution to the total cross section for the Pomeron exchange, calculated by AdS/CFT)

nucleon

This framework can be applied to other hadrons' SFs, longitudinal SFs, and hadron-hadron scattering.

Proton structure function

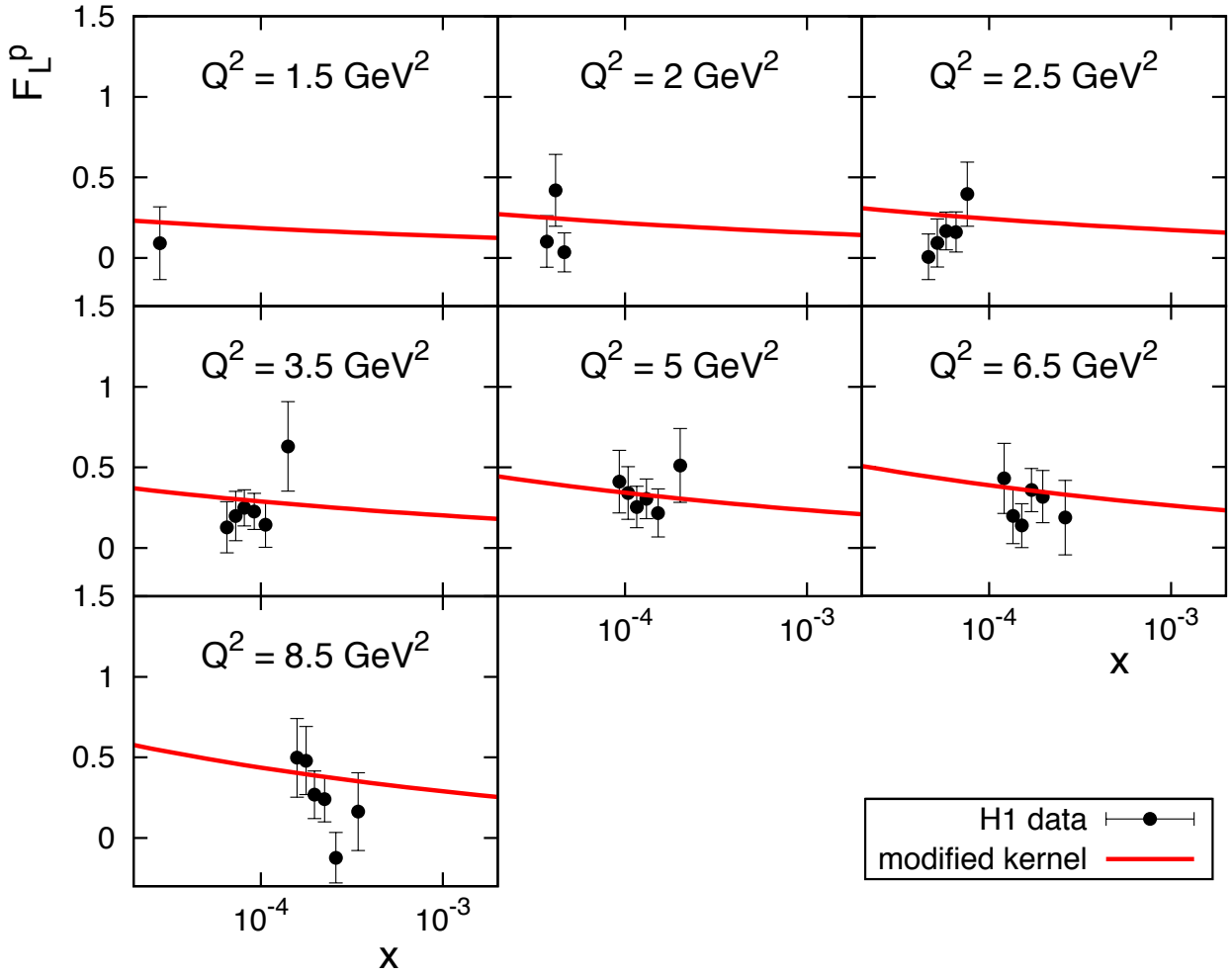
AW-Suzuki (2014)



Proton longitudinal structure function

- Replacing the density distribution of the probe photon with its longitudinal component

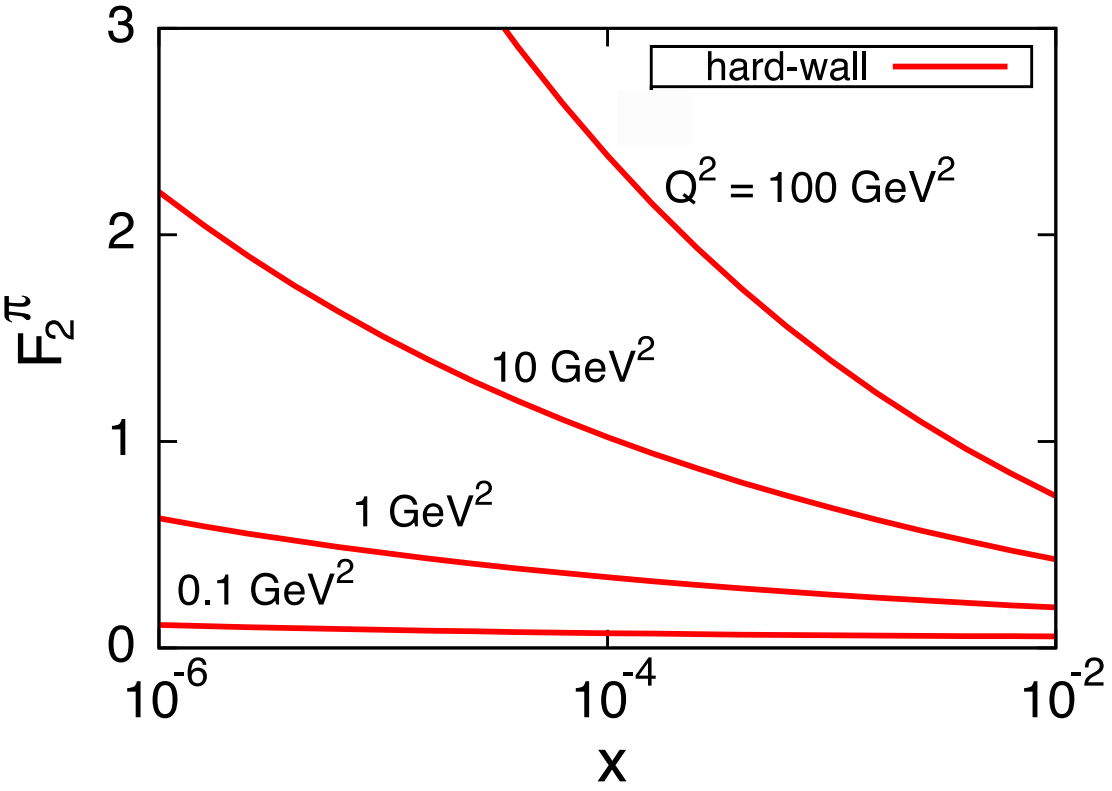
AW-Suzuki (2014)



Pion structure function

- Replacing the density distribution for target hadron with pion's, which can be calculated by using a bottom-up AdS/QCD model of mesons

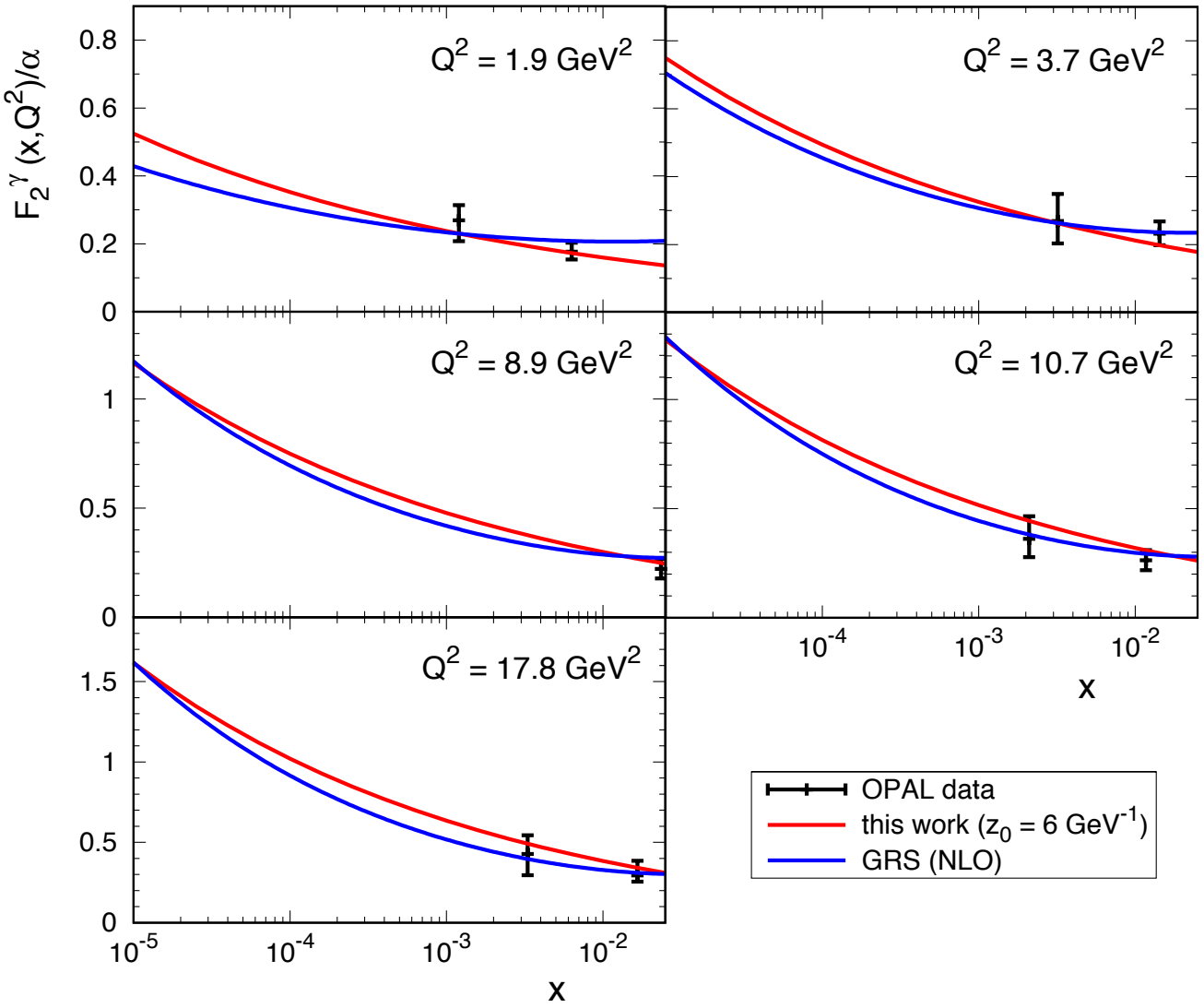
AW-Suzuki (2012)



- There is no experimental data

Photon structure function

AW-Li (2015)

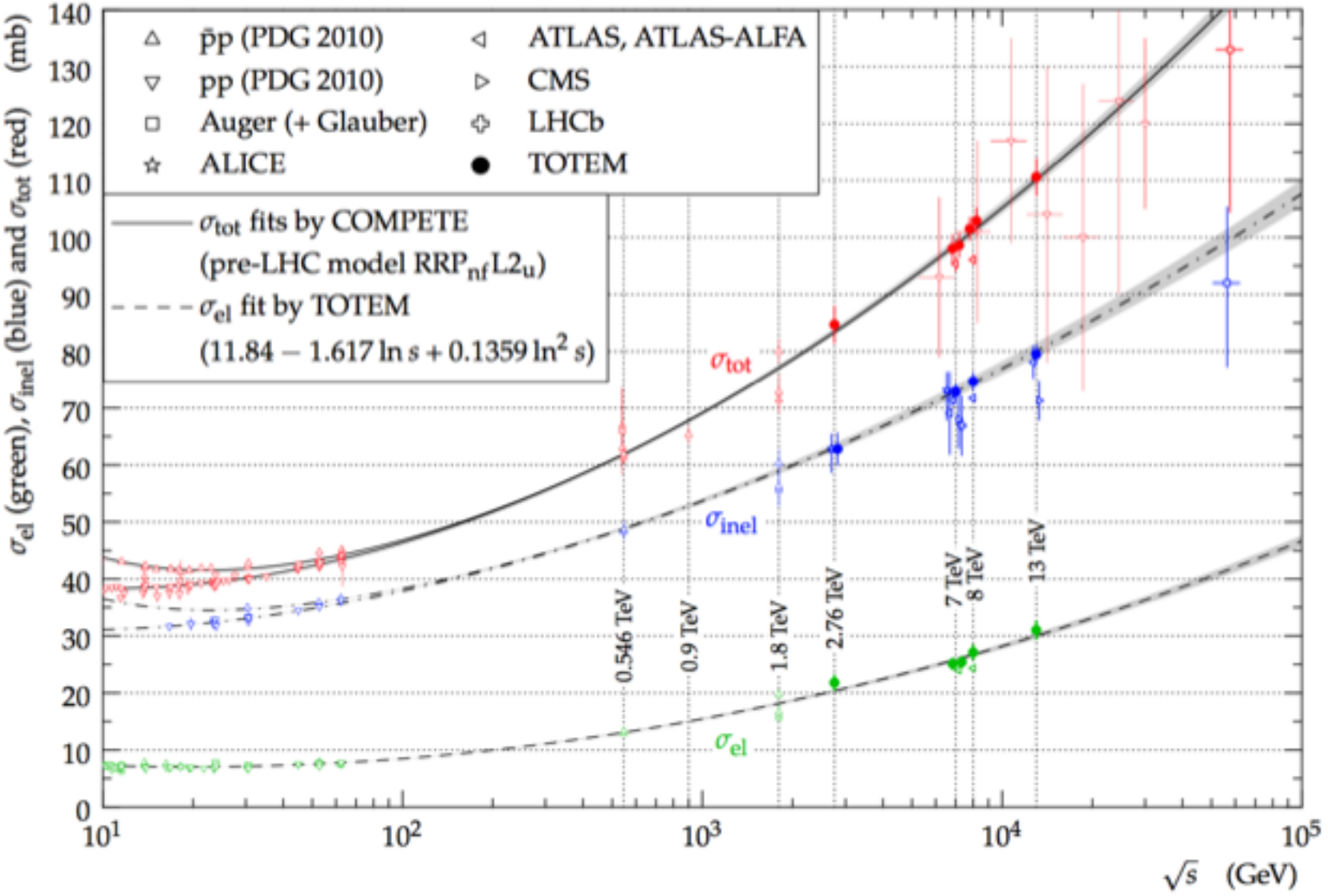


Motivation (why total cross section?)

- TOTEM 13TeV data have recently come out!
- 13TeV corresponds to x~10^(-8) which is much smaller than that at HERA (x > 10^(-6)).
- In such a very small x region, is the (single) Pomeron exchange still working well?
- How about the holographic (BPST) Pomeron?
- Via the analysis, we might obtain some information about the applicable limit of the model.

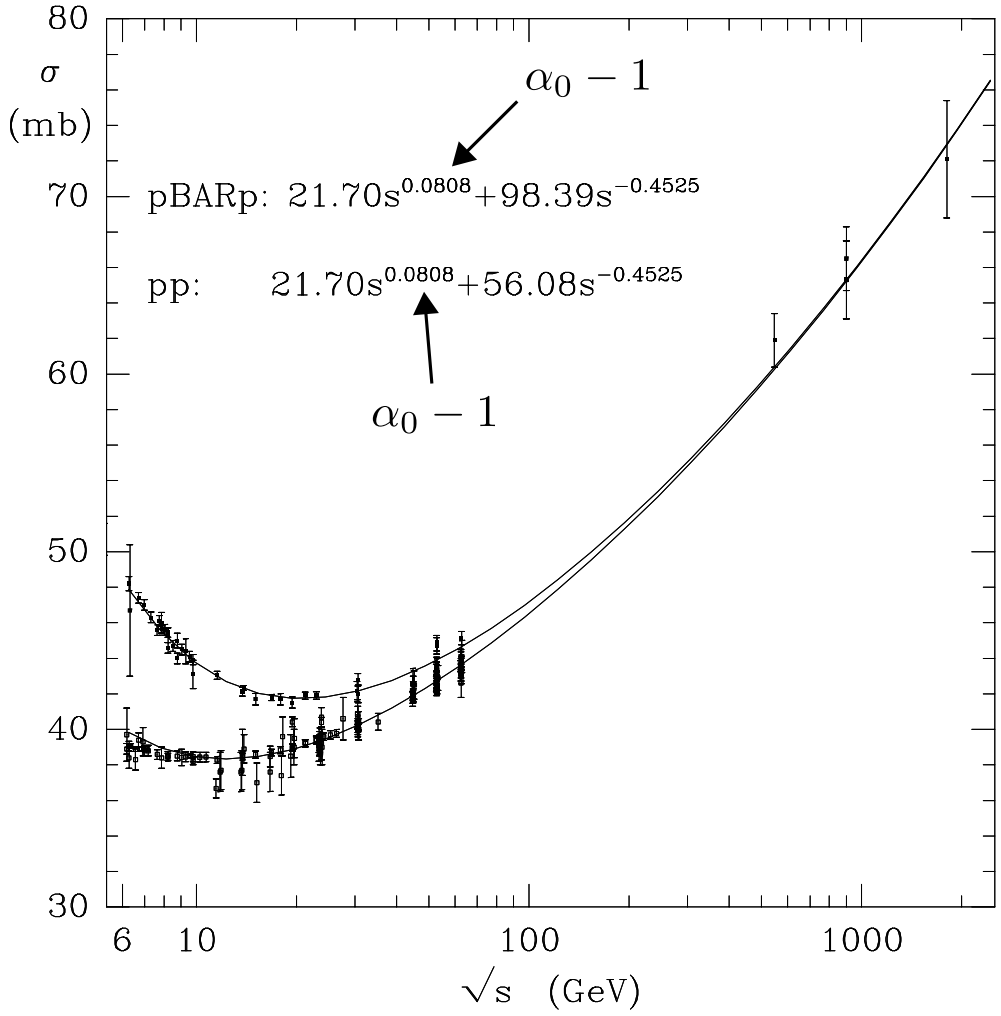
13TeV data from TOTEM

TOTEM Collaboration (2017)



Total cross sections via Pomeron exchange

proton-(anti)proton total cross section



Donnachie-Landshoff (1992)

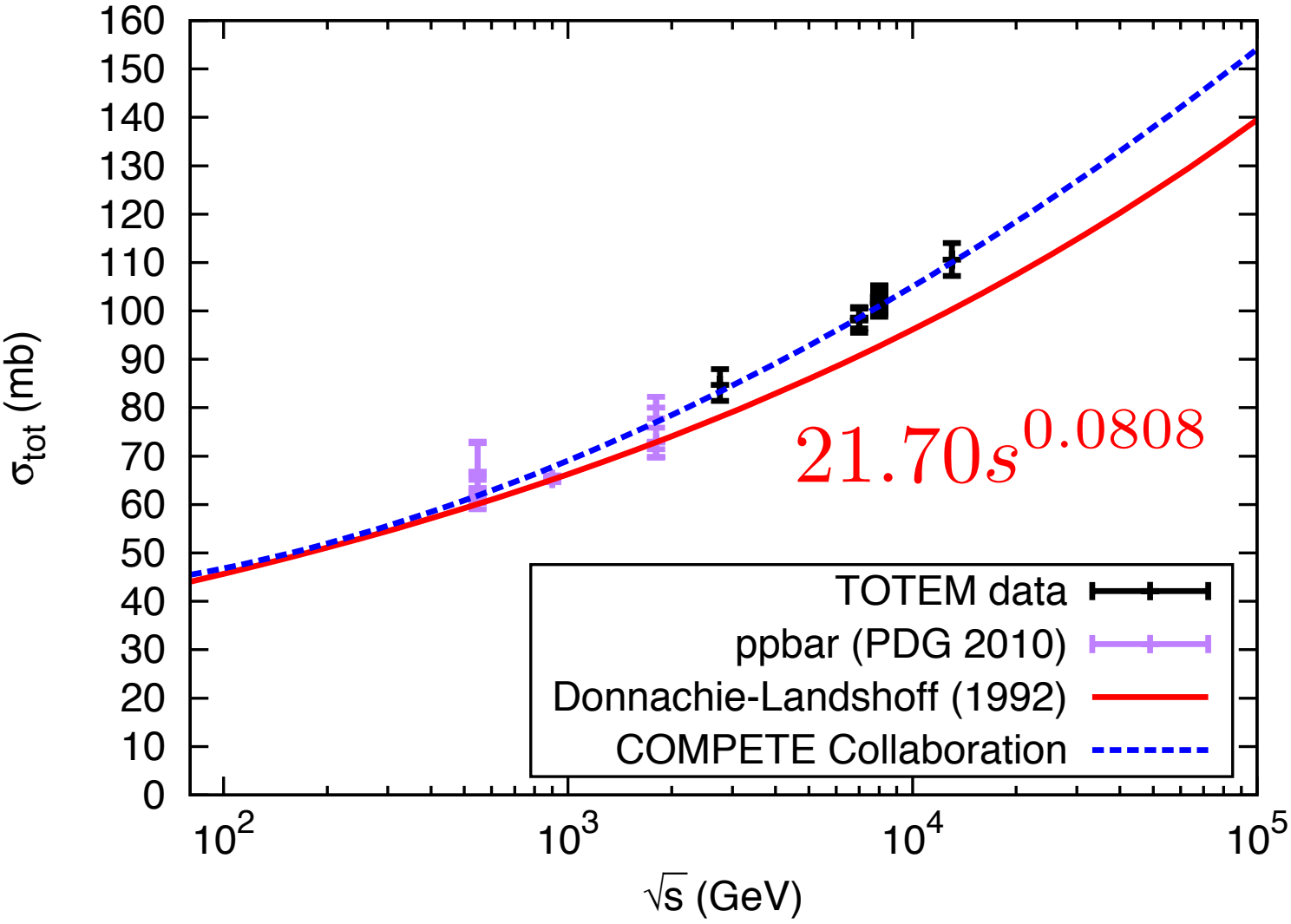
$$\sigma_{tot}(s) \sim s^{\alpha_0 - 1}$$

$$\alpha_0 = 1.0808$$

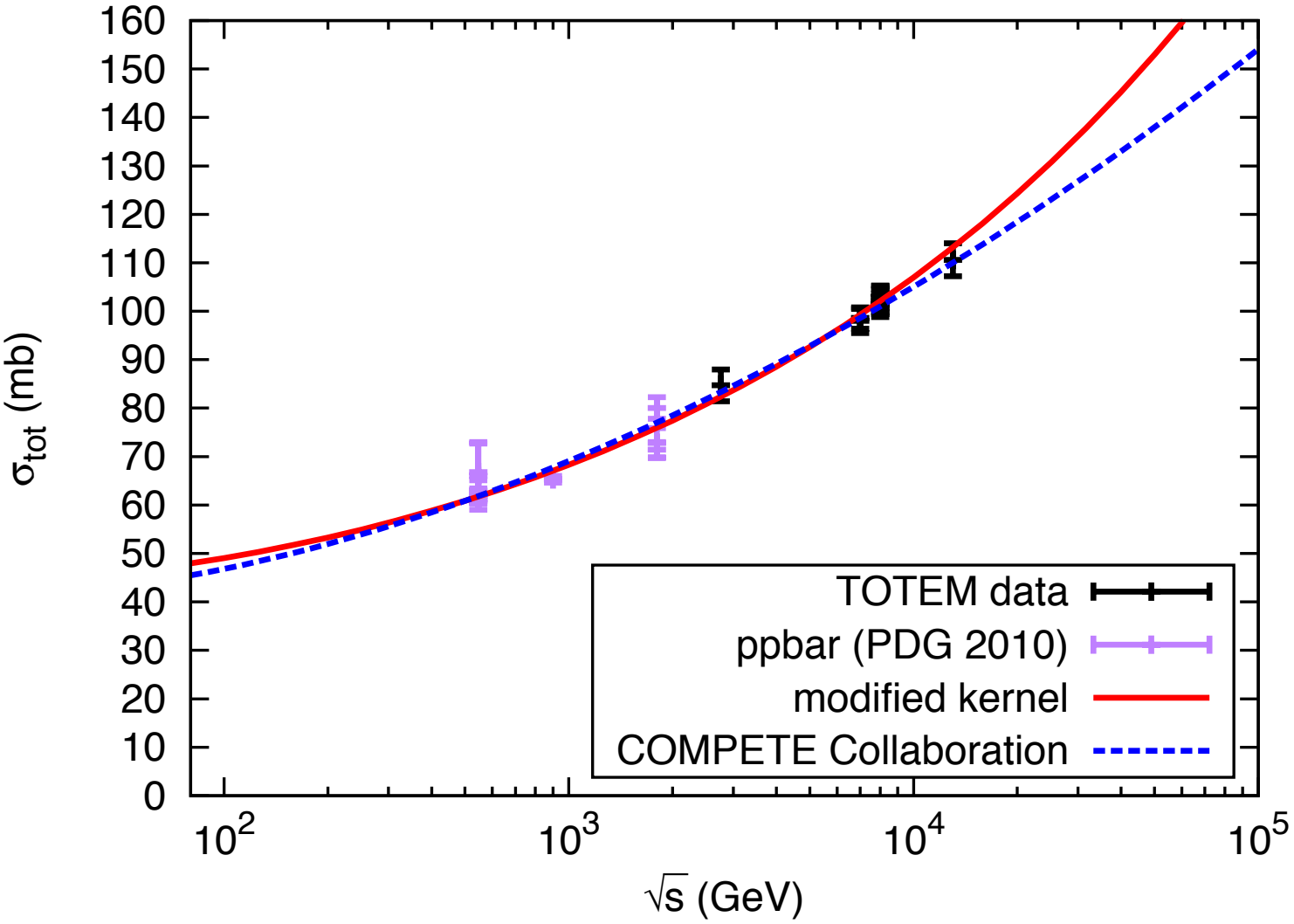
(soft Pomeron intercept)

well describing the experimental data

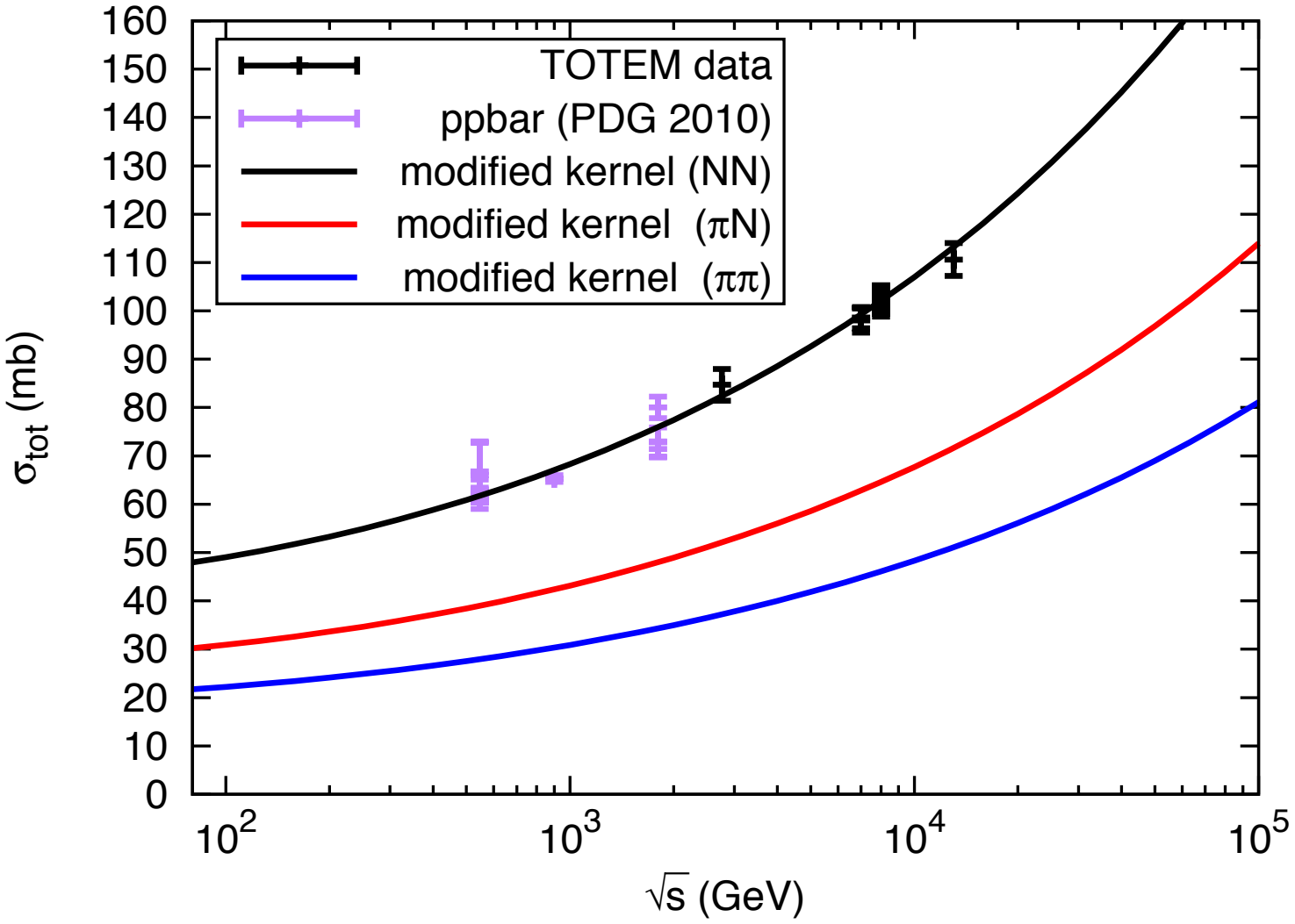
Can the soft Pomeron reproduce the data?



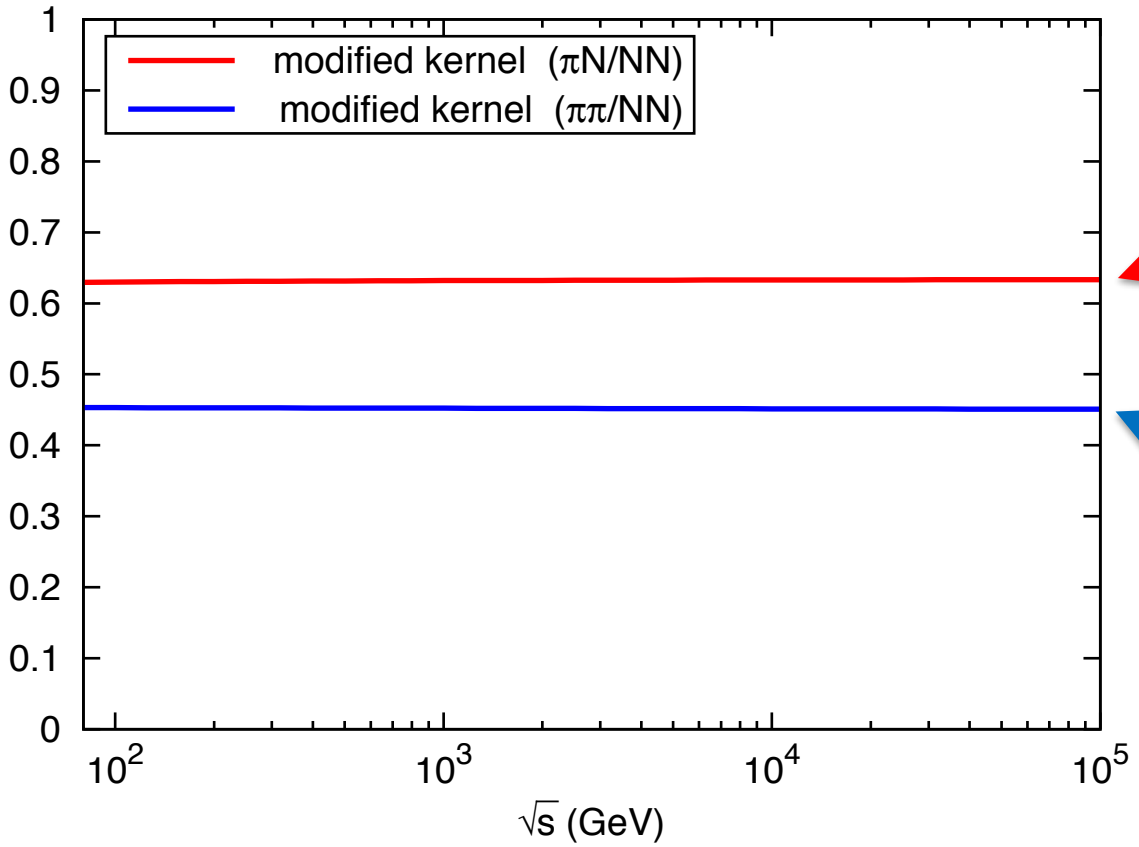
How about the holographic (BPST) Pomeron?



π-N and π-π scattering



Total cross section ratios



PREDICTIONS:

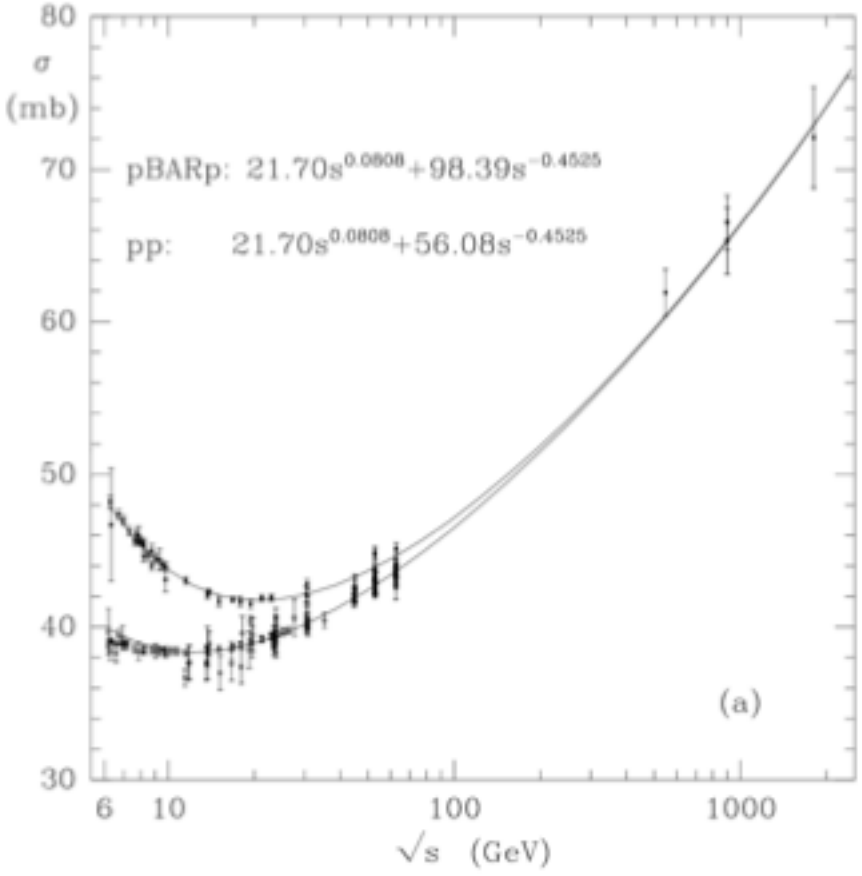
$$\left(\frac{\sigma_{tot}^{\pi N}}{\sigma_{tot}^{NN}}\right) \approx 0.63$$

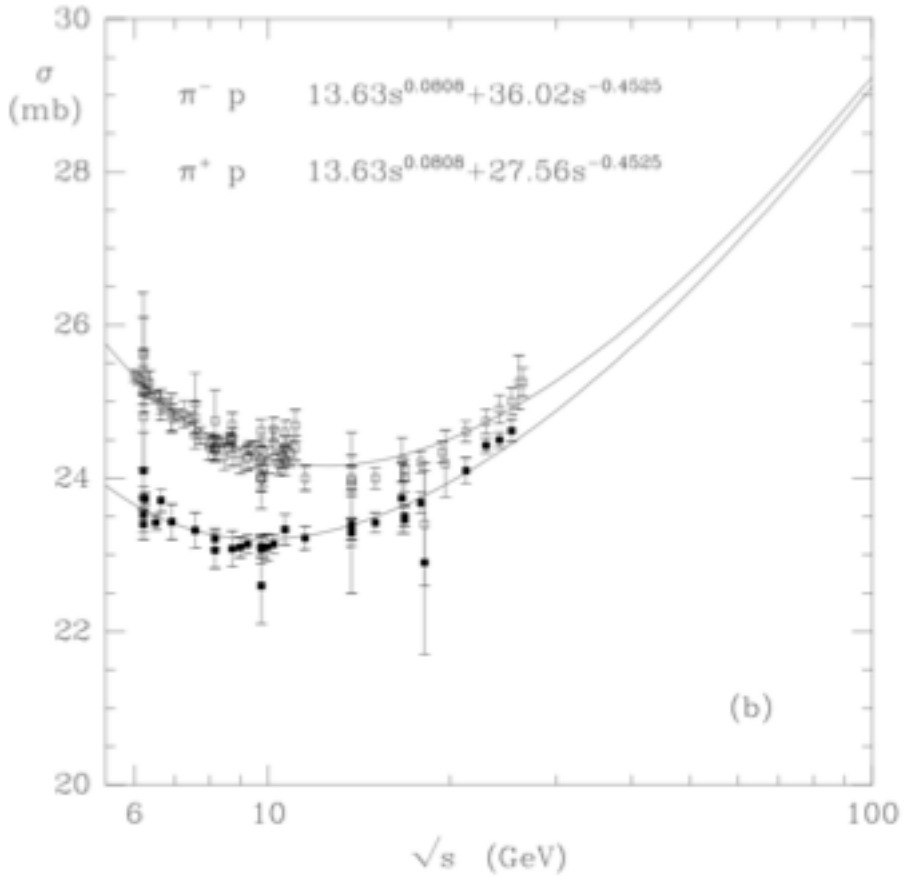
$$\left(\frac{\sigma_{tot}^{\pi\pi}}{\sigma_{tot}^{NN}}\right) \approx 0.45$$

N.B. we do NOT need any additional parameter to calculate the pion involved cross sections!

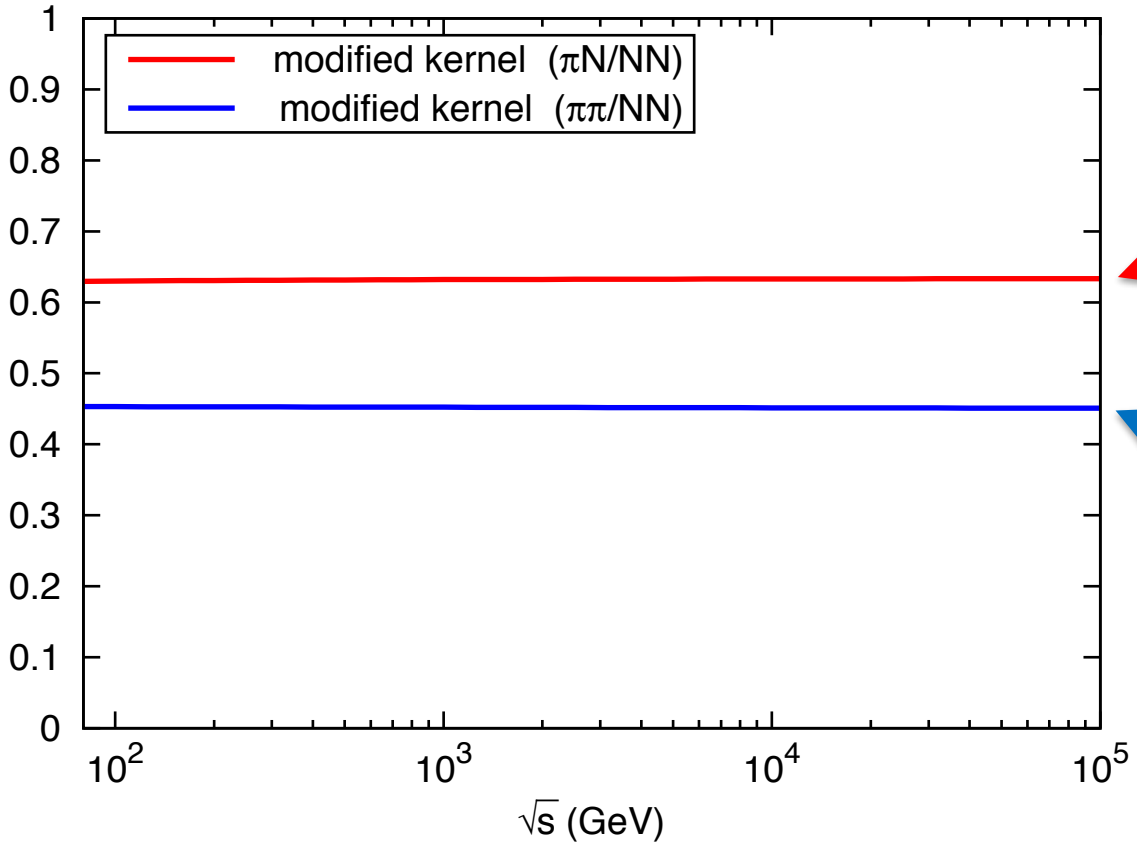
p-p and π-p scattering by Donnachie-Landshoff

Donnachie-Landshoff (1992)





Total cross section ratios



PREDICTIONS:

$$\left(\frac{\sigma_{tot}^{\pi N}}{\sigma_{tot}^{NN}}\right) \approx 0.63$$

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$$\left(\frac{\sigma_{tot}^{\pi^{\pm}p}}{\sigma_{tot}^{pp}}\right)_{DL(1992)} \approx 0.63$$

N.B. we do NOT need any additional parameter to calculate the pion involved cross sections!

Summary

- We have studied total hadronic cross sections at high energies in the framework of holographic QCD.
- We have shown that all the TOTEM data, including the recent one at 13TeV, can be well reproduced with the model.
- A substantial deviation between our calculation and the empirical fit has been observed in the very large s region, where sqrt(s) > 10TeV.
- Realization of the saturation effect within the model may be important.