The total cross section at the LHC

models and experimental consequences

J.R. Cudell

IFPA, Université de Liège

13th International Conference on
Elastic & Diffractive Scattering, 2009

Papers and collaborators

Based on

- J. R. C. and O. V. Selyugin, “How precisely will the total cross section be measured at the LHC?,” Phys. Rev. Lett. **102** (2009) 032003 [arXiv:0812.1892 [hep-ph]].
- J. R. C., E. Predazzi and O. V. Selyugin, “New analytic unitarisation schemes,” Phys. Rev. D **79** (2009) 034033 [arXiv:0812.0735 [hep-ph]].
- J. R. C. and O. V. Selyugin, “Unitarisation and black-disk limit at the LHC in the presence of a hard pomeron,” Phys. Lett. B **662** (2008) 417 [arXiv:hep-ph/0612046].
- J. R. C., A. Lengyel and E. Martynov, “The Soft and the hard pomerons in hadron elastic scattering at small t,” Phys. Rev. D **73** (2006) 034008 [arXiv:hep-ph/0511073].
- J. R. C., E. Martynov, O. V. Selyugin and A. Lengyel, “The hard pomeron in soft data,” Phys. Lett. B **587** (2004) 78 [arXiv:hep-ph/0310198].
- COMPETE Collaboration, “Benchmarks for the forward observables at RHIC, the Tevatron-run II and the LHC,” Phys. Rev. Lett. **89** (2002) 201801 [arXiv:hep-ph/0206172].
- COMPETE Collaboration, “Hadronic scattering amplitudes: Medium-energy constraints on asymptotic behaviour,” Phys. Rev. D **65** (2002) 074024 [arXiv:hep-ph/0107219].

Outline

No theory

- General principles:
  - analyticity
  - unitarity of partial waves
- several possibilities:
  - simple or multiple poles
  - cuts (eikonal, U matrix, multi-channel eikonal, KMR,...)
- Phenomenological fits and extrapolation

No theory

- General principles:
  - analyticity
  - unitarity of partial waves
- several possibilities:
  - simple or multiple poles
  - cuts (eikonal, U matrix, multi-channel eikonal, KMR,...)
- Phenomenological fits and extrapolation

No theory

- General principles:
  - analyticity
  - unitarity of partial waves
- several possibilities:
  - simple or multiple poles
  - cuts (eikonal, U matrix, multi-channel eikonal, KMR,...)
- Phenomenological fits and extrapolation

Fits to what?

- Total cross sections
  - pp, $\bar{p}p$
  - πp, Kp
  - γp, $\gamma\gamma$
- ρ parameter pp, $\bar{p}p$, Kp, πp
- Elastic cross sections
- COMPETE set http://pdg.lbl.gov/2009/hadronic-xsections/hadron.html
- Elastic dataset at http://www.theo.phys.ulg.ac.be/~cudell/data/ with E. Martynov and A. Lengyel

- problems
  - pp low energy + CDF/E710
  - only low energy
  - extra singularities?
- low quality of data
- odderon, multiple exchanges

Fits to what?

- Total cross sections
  - pp, $\bar{p}p$
  - πp, Kp
  - γp, $\gamma\gamma$
- ρ parameter pp, $\bar{p}p$, Kp, πp
- Elastic cross sections
- COMPETE set http://pdg.lbl.gov/2009/hadronic-xsections/hadron.html
- Elastic dataset at http://www.theo.phys.ulg.ac.be/~cudell/data/ with E. Martynov and A. Lengyel

- problems
  - pp low energy + CDF/E710
  - only low energy
  - extra singularities?
- low quality of data
- odderon, multiple exchanges

Fits to what?

- Total cross sections
  - pp, $\bar{p}p$
  - πp, Kp
  - γp, $\gamma\gamma$
- ρ parameter pp, $\bar{p}p$, Kp, πp
- Elastic cross sections
- problems
  - pp low energy + CDF/E710
  - only low energy
  - extra singularities?
- low quality of data
- odderon, multiple exchanges
- COMPETE set http://pdg.lbl.gov/2009/hadronic-xsections/hadron.html
- Elastic dataset at http://www.theo.phys.ulg.ac.be/~cudell/data/ with E. Martynov and A. Lengyel

Fits to what?

- Total cross sections
  - pp, $\bar{p}p$
  - πp, Kp
  - γp, $\gamma\gamma$
- ρ parameter pp, $\bar{p}p$, Kp, πp
- Elastic cross sections
- COMPETE set http://pdg.lbl.gov/2009/hadronic-xsections/hadron.html
- Elastic dataset at http://www.theo.phys.ulg.ac.be/~cudell/data/ with E. Martynov and A. Lengyel

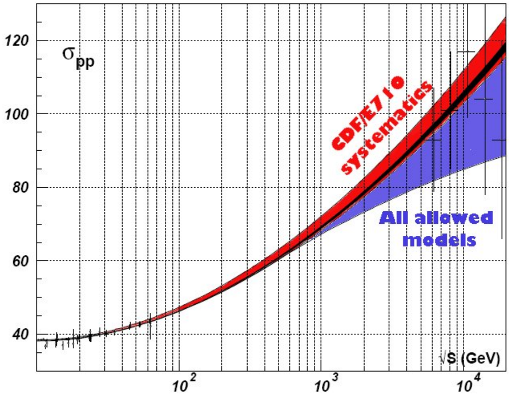
- problems
  - pp low energy + CDF/E710
  - only low energy
  - extra singularities?
- low quality of data
- odderon, multiple exchanges

Fits to what?

- Total cross sections
  - pp, $\bar{p}p$
  - πp, Kp
  - γp, $\gamma\gamma$
- ρ parameter pp, $\bar{p}p$, Kp, πp
- Elastic cross sections
- problems
  - pp low energy + CDF/E710
  - only low energy
  - extra singularities?
- low quality of data
- odderon, multiple exchanges
- COMPETE set http://pdg.lbl.gov/2009/hadronic-xsections/hadron.html
- Elastic dataset at http://www.theo.phys.ulg.ac.be/~cudell/data/ with E. Martynov and A. Lengyel

All σ_{tot} and ρ at $\sqrt{s} > 5$GeV: COMPETE 2002

double poles ($\log(s)$)/ triple poles ($\log^2(s)$)
+ 2 undegenerate lower trajectories



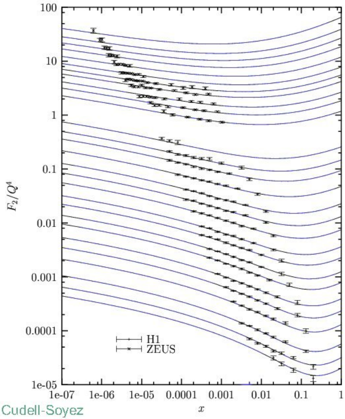
$\sigma^{pp}_{tot}(10\ \text{TeV})$
$84 - 112$ mb
$\sigma^{pp}_{tot}(14\ \text{TeV})$
$90 - 117$ mb

Remarks

- best fit is a “universal” triple-pole but no universality in DIS
- soft pomeron fit gives χ^2/dof of 1.12 but falls in the band
- triple poles fall for $\sqrt{s} < 6$ GeV
- double pole negative for $\sqrt{s} < 9.5$ GeV
- weight of low-energy data

More developments of multipole fits

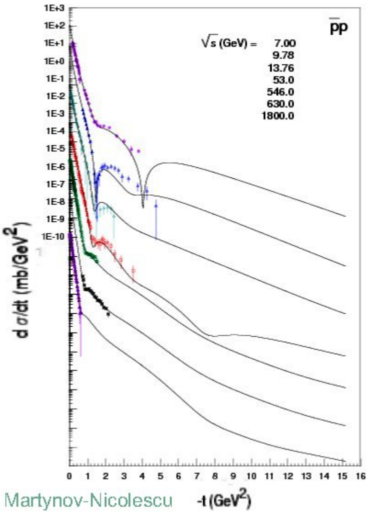
- DIS data
- Elastic scattering



Cudell-Soyez

More developments of multipole fits

- DIS data
- Elastic scattering



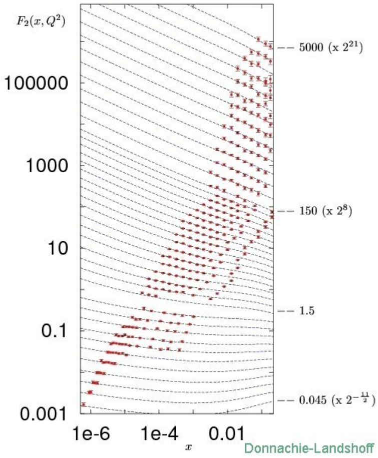
Martynov-Nicolescu

- Multiple-pole fits seem to work, but we do not know where these poles come from
- Is it possible to rescue simple-pole fits?
  - simple phenomenology
  - few parameters
  - exchange of bound states

- Multiple-pole fits seem to work, but we do not know where these poles come from
- Is it possible to rescue simple-pole fits?
  - simple phenomenology
  - few parameters
  - exchange of bound states

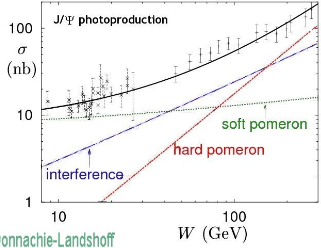
1 hard + 1 soft pomerons

- DIS data
- vector meson production (intercept+slope)
- total cross sections and ρ parameter for $\sqrt{s} < 100$ GeV
- small-t elastic scattering
- The hard pomeron coupling is small in soft data



1 hard + 1 soft pomerons

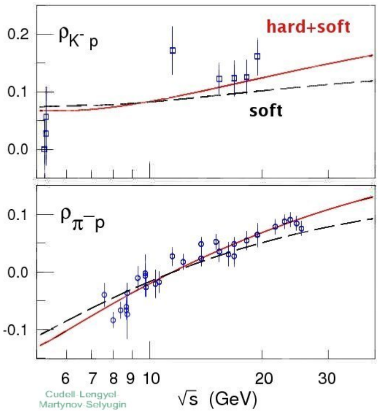
- DIS data
- vector meson production (intercept+slope)
- total cross sections and ρ parameter for $\sqrt{s} < 100$ GeV
- small-t elastic scattering
- The hard pomeron coupling is small in soft data



Donnachie-Landshoff

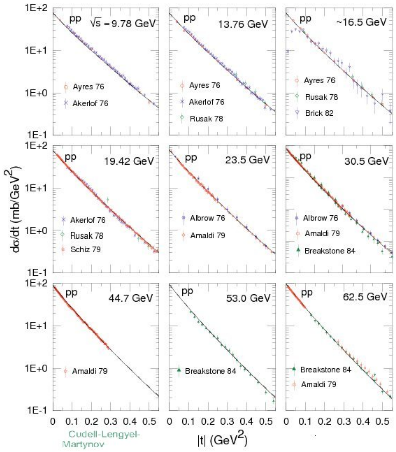
1 hard + 1 soft pomerons

- DIS data
- vector meson production (intercept+slope)
- total cross sections and ρ parameter for $\sqrt{s} < 100$ GeV
- small-t elastic scattering
- The hard pomeron coupling is small in soft data



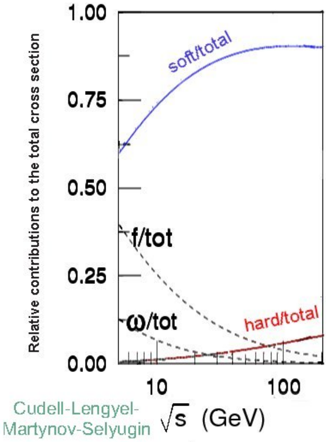
1 hard + 1 soft pomerons

- DIS data
- vector meson production (intercept+slope)
- total cross sections and ρ parameter for $\sqrt{s} < 100$ GeV
- small-t elastic scattering
- The hard pomeron coupling is small in soft data



1 hard + 1 soft pomerons

- DIS data
- vector meson production (intercept+slope)
- total cross sections and ρ parameter for $\sqrt{s} < 100$ GeV
- small-t elastic scattering
- The hard pomeron coupling is small in soft data

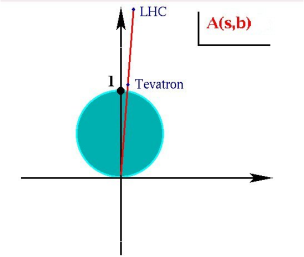


Unitarity

$$\frac{d\sigma}{dt} = \frac{1}{16\pi s^2} |a(s,t)|^2 \quad \overset{Fourier}{\underset{impact\ parameter}{\longrightarrow}}$$

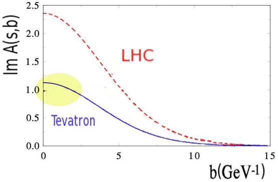
$$partial\ wave \quad A(s,b), \ (\ell = b\sqrt{s})$$

$$|A(s,b)|^2 \leq 2Im\,(A(s,b))$$

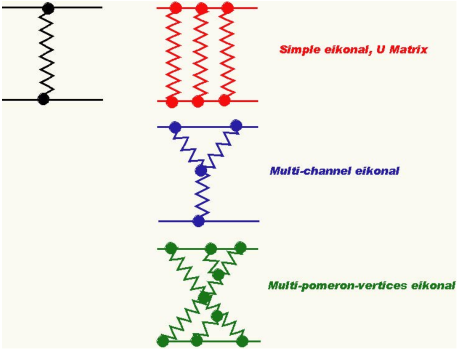


Unitarity problem

Our model with soft+hard pomerons violates unitarity at small b around the Tevatron energy, assuming the t dependence given by $F_1(t)$



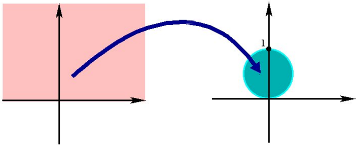
Unitarisation - physics



Even in the simplest case we cannot calculate the resummation

Unitarisation - math

- Map half of the complex plane to the unitarity circle
- Map it to part of the unitarity circle : extended schemes
- Map one given amplitude to the unitarity circle

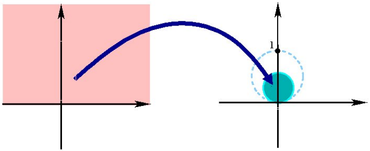


eikonal: $\mathcal{A}(s,b) = i(1 - \exp(iA(s,b))$

U-matrix: $\mathcal{A}(s,b) = \frac{A(s,b)}{1 - iA(s,b)/2}$

Unitarisation - math

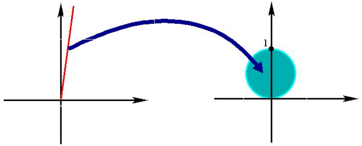
- Map half of the complex plane to the unitarity circle
- Map it to part of the unitarity circle : extended schemes
- Map one given amplitude to the unitarity circle



eikonal
$\mathcal{A}(s,b) = \frac{i}{\omega}(1 - \exp(i\omega A(s,b))$
or U-matrix
$\mathcal{A}(s,b) = \frac{A(s,b)}{1 - i\omega A(s,b)/2}$

Unitarisation - math

- Map half of the complex plane to the unitarity circle
- Map it to part of the unitarity circle : extended schemes
- Map one given amplitude to the unitarity circle



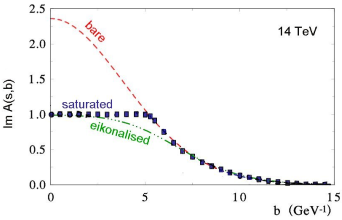
interpolating general scheme:

$$\mathcal{A}(s,b) = \frac{i}{\omega}\left[1 - \frac{1}{(1 - i\omega A(s,b)/\gamma)^{\gamma}}\right]$$

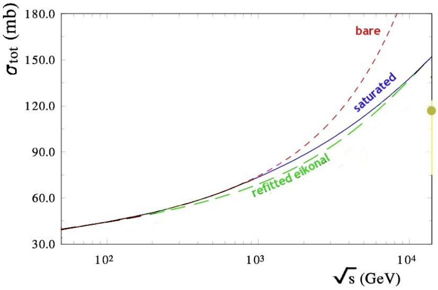
Unitarised hard+soft pomerons

Two simple choices:

- “Saturation”: cut *Im* $A(s,b)$ at 1 and add a smoothing function - in some sense minimal unitarisation
- Use a simple eikonal



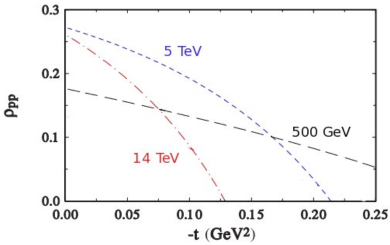
Consequences for σ_{tot}



The total cross section could reach ∼150 mb:

σ_{tot}(10TeV)=132 mb
σ_{tot}(14TeV)=146 mb

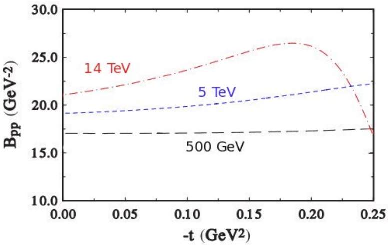
ρ parameter



The ρ parameter could be much larger:

$\rho(0) \geq 0.24$ is possible (at 10 or 14 TeV)

Slope of the elastic cross section



The elastic cross section is not an exponential

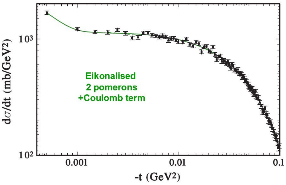
$$\frac{d\sigma}{dt} = A \exp(B(t)t)$$

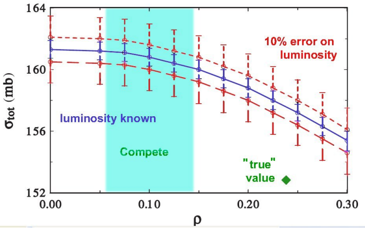
Experimental measurement

The “standard” measurement of σ_{tot} assumes

- B =constant
- ρ small

Simulate data + perform standard analysis





The extracted value of σ_{tot} is off by about 10 mb

Predictions

σ_{tot}(14TeV)	model	physics
$>$ 200 mb	U-matrix	new scattering regime
$\approx$ 150 mb	2-pomeron models	strong saturation
$100 - 115$ mb	triple poles	1-pomeron eikonal, minijets
$<$ 100 mb	double poles	multi-pomeron vertices

Measurements

- New regime $\Rightarrow$
  - ρ will have a strong t dependence
  - $d\sigma/dt \neq N\exp(Bt)$
- necessary to evaluate these dependences to measure the cross section to better than 10%.
- Note that this is the precision of the Tevatron measurements...