ECT*
EUROPEAN CENTRE FOR THEORETICAL STUDIES
IN NUCLEAR PHYSICS AND RELATED AREAS

Physics program of the ALFA detector

Per Grafström
University of Bologna and CERN

On behalf of the
ATLAS collaboration

QCD at LHC
Forward physics and UPC collisions of heavy ions

Trento, Italy, from Monday, September 26, 2016 to Friday, September 30, 2016.

ALFA Physics in a Nutshell

- ***Basic measurement with ALFA standalone-$d\sigma_{el}/dt$ at small t***

Derived quantities:

- σ_{tot} using optical theorem σ_{el} by integration
- σ_{el} /σ_{tot} by division
- σ_{inel} by subtraction
- the slope parameter B
- ρ = Re f_{el} / Im f_{el}

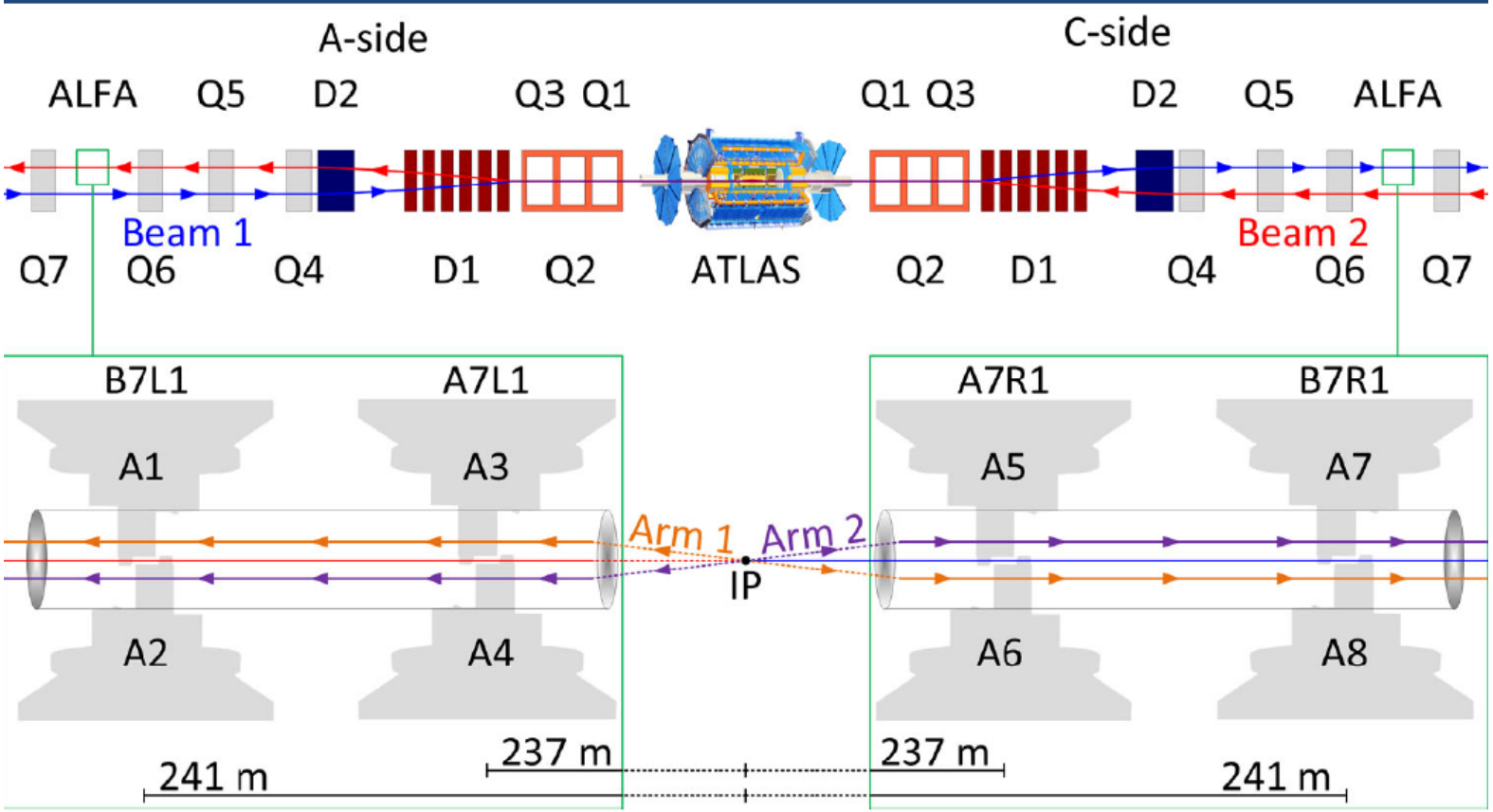
Global quantities characterizing the interaction and $\sqrt{s}$ evolution always to be measured.

- ***Measurement with central ATLAS detector and proton tagging with ALFA***
  - Single diffraction
  - Exclusive Production
  - Comparison of particle distribution for non-diffractive proton-proton interaction with diffractive interactions

- ***Proton tagging with LHCf***

What is ALFA ?

ALFA setup

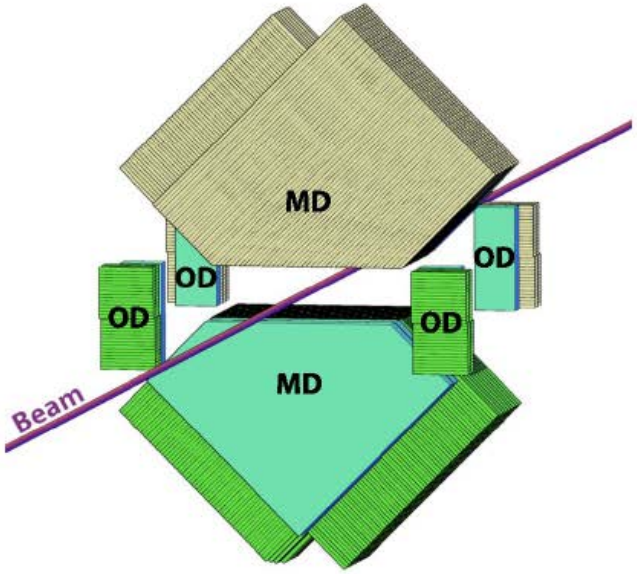


4 stations with 8 detectors at both sides of ATLAS provide 2 independent “elastic” arms.

What is ALFA ?

ALFA tracking detectors

Design principle



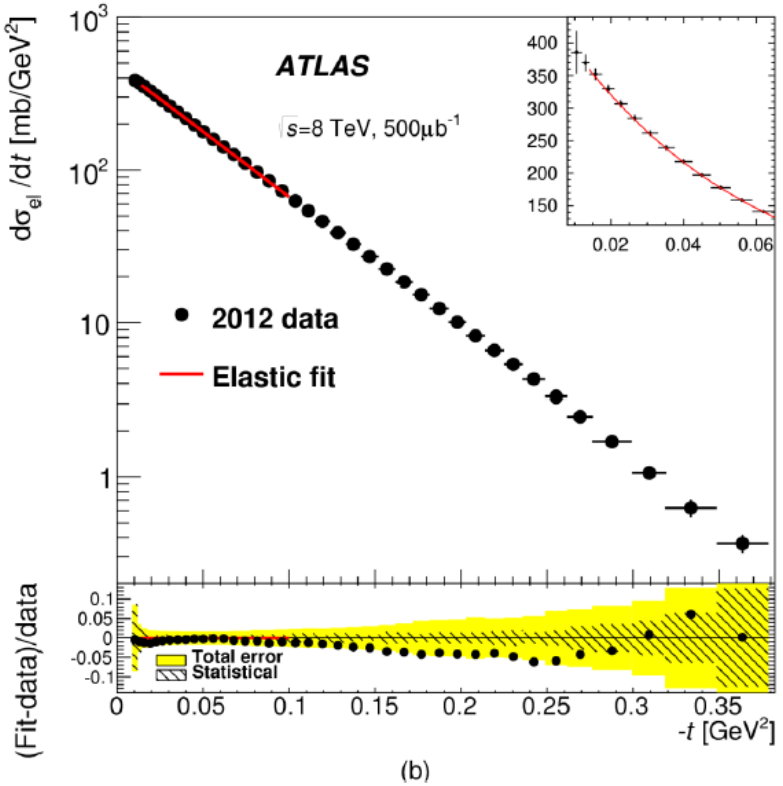
Real detector

- Main detectors (MD): 2 x 10 layers of 0.5 x 0.5 mm^2 square fibers.
- Read out by MAPMTs with 64 channels.
- Light yield 4 -5 photo-electrons per fiber.
- Measured resolution ~ 35 µm.
- Special overlap detectors (OD) to measure the distance.

Basic measurement: $d\sigma_{el}/dt$

New results from ATLAS at 8 TeV
Physics Letters B 761 (2016) 158–178
arXiv:1607.06605

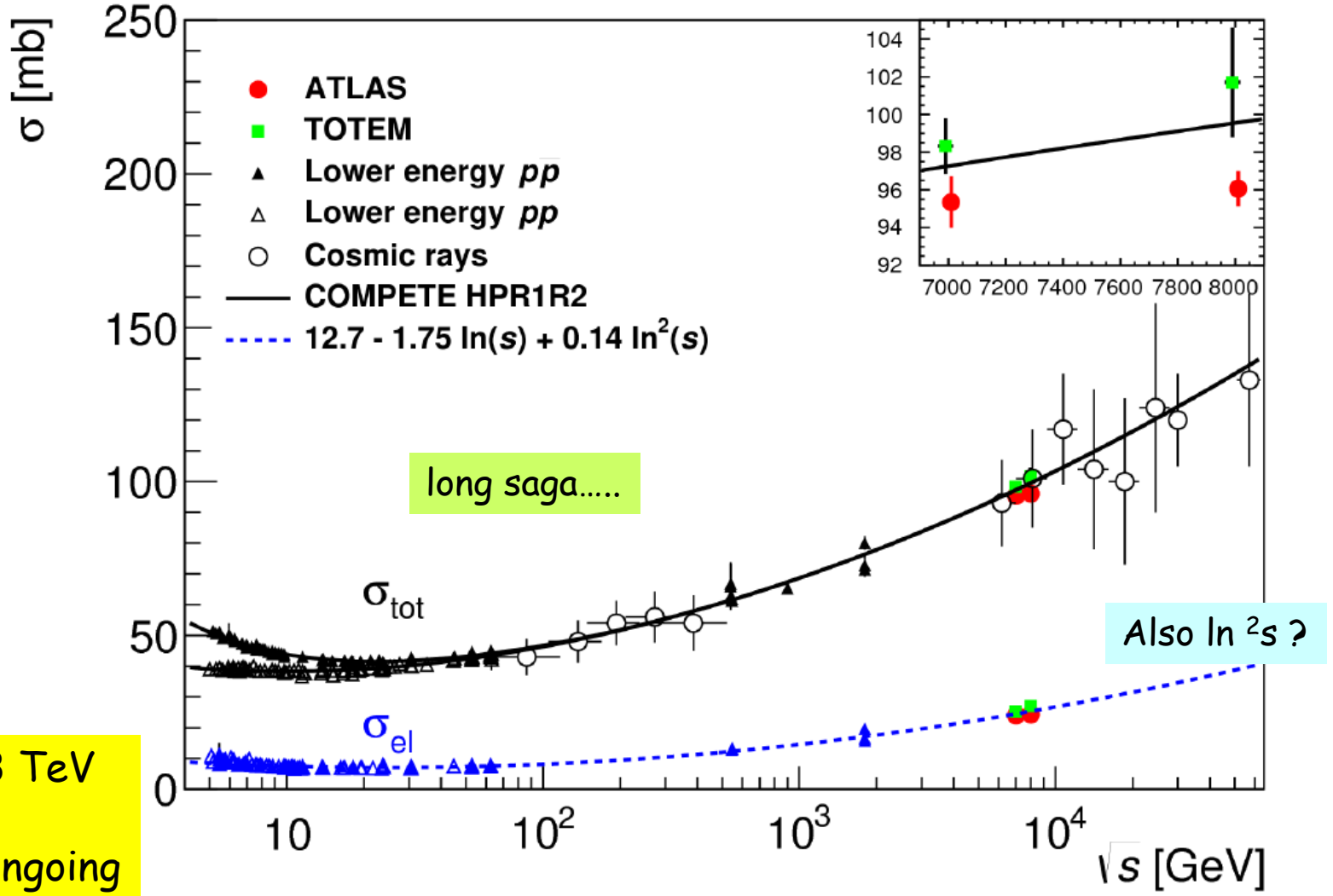
- Fit theoretical prediction to data.
- Nuclear term dominates, but Coulomb and interference terms included.
- Fit range: 0.014 GeV^2 < t < 0.1 GeV^2 (lower bound defined by acceptance, upper to ensure single exponential).
- Dominant errors:
  - Luminosity uncertainty 1.5%
  - Beam energy 0.65%
  - Extrapolation to t = 0 (various models).



Results:

$$\sigma_{\text{tot}} = 96.07 \pm 0.18\ (\text{stat.}) \pm 0.85\ (\text{exp.}) \pm 0.31\ (\text{extr.})\ \text{mb}\ ,$$
$$B = 19.74 \pm 0.05\ (\text{stat.}) \pm 0.16\ (\text{exp.}) \pm 0.15\ (\text{extr.})\ \text{GeV}^{-2}$$

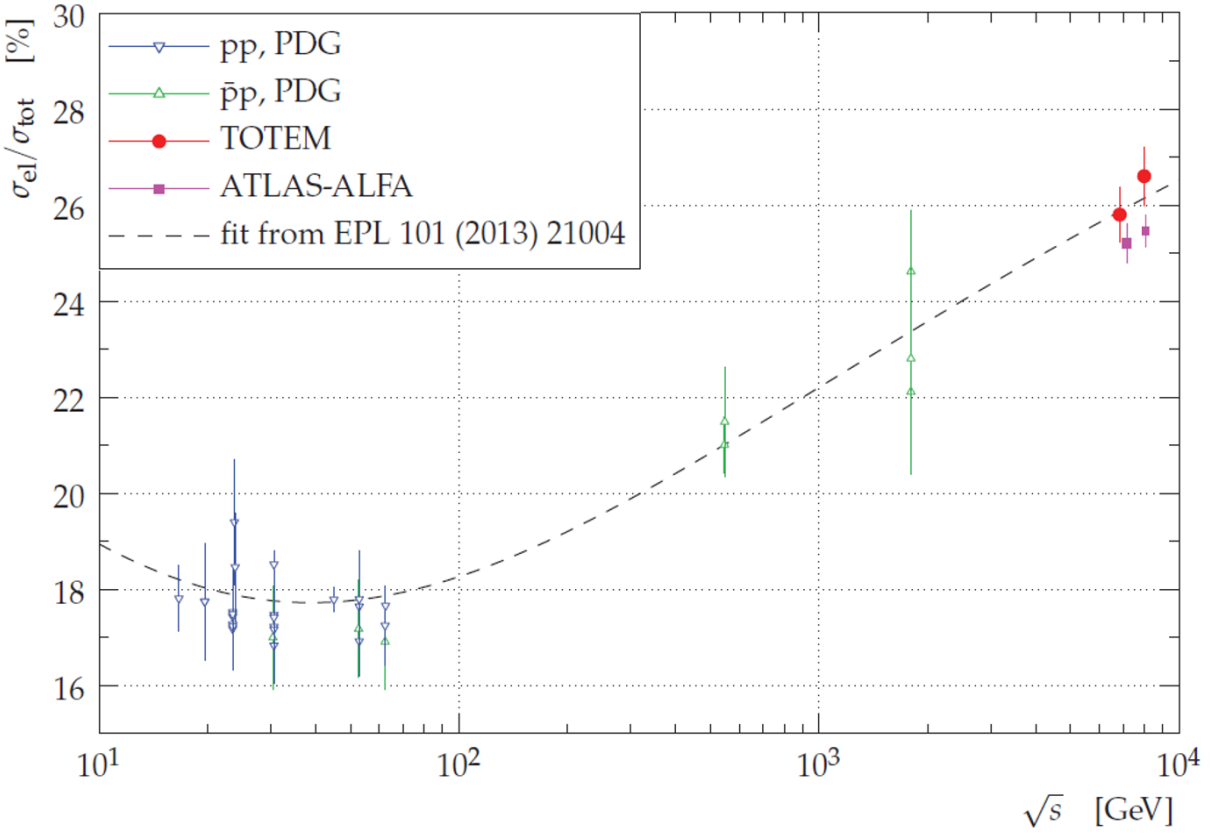
σ_{tot} and σ_{el} evolution with $\sqrt{s}$



ATLAS 13 TeV
β* =90 m
Analysis ongoing

ATLAS 7 TeV Nuclear Physics, Section B (2014), pp. 486-548
ATLAS 8 TeV arXiv: 1607.06605 to be published in PLB

σ_{el}/σ_{tot}



$\sigma_{el}/\sigma_{tot} \approx 1/4$ at 7-8 GeV

Still far away from black disc limit of 1/2…..seem to be a slow approach

M.M Block et al. arXive:1409.3196

Black disc + energy independent edge ~1fm
The black disc grows with R ~ ln s

Based upon the fact σ_{el} also grows like $\ln^2 s$ but with half of the corresponding coefficient for σ_{tot}.

Crossover from edge dominance to disc dominance around 10 TeV

More Speculations: I.M.Dremin arXiv:1605.0821

1/4 represent special value

Transition from saturation for central collision to Torus like configuration.

May be some hint with …13 GeV data….?

….a bit more about speculations…..

Dremin uses the impact parameter representation and determines G(s,b) i.e. the "overlap" function

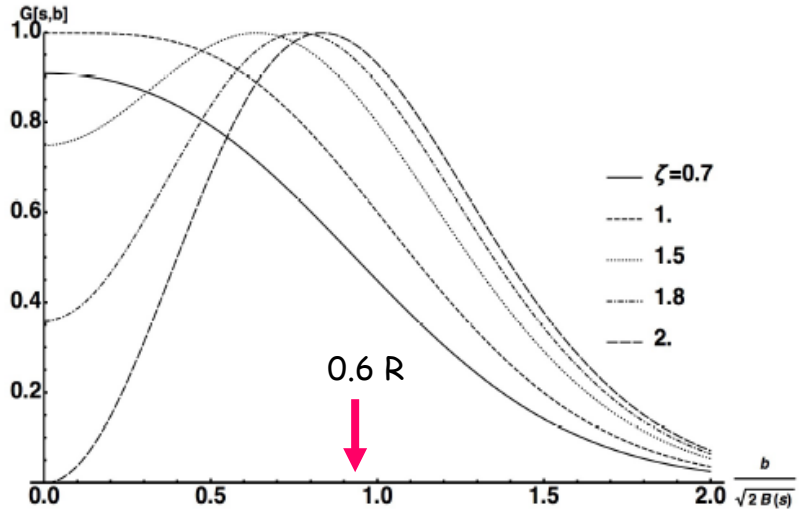
G(s,b) = the impact parameter profile of inelastic proton interactions
(G(s,b) can also be expressed in terms of opacity Ω(s,b) : $G(s,b)= 1 - e^{-\Omega(s,b)}$ (eikonal phase)

G(s,b) is determined using only information from elastic scattering at small t and unitarity.

Dremin defines $\xi= \sigma_{tot} /4B \approx 4\sigma_{el}/\sigma_{tot}$

(approx. valid if the Re part of scattering amplitude= 0 and σ_{el} determined by the diffractive cone)

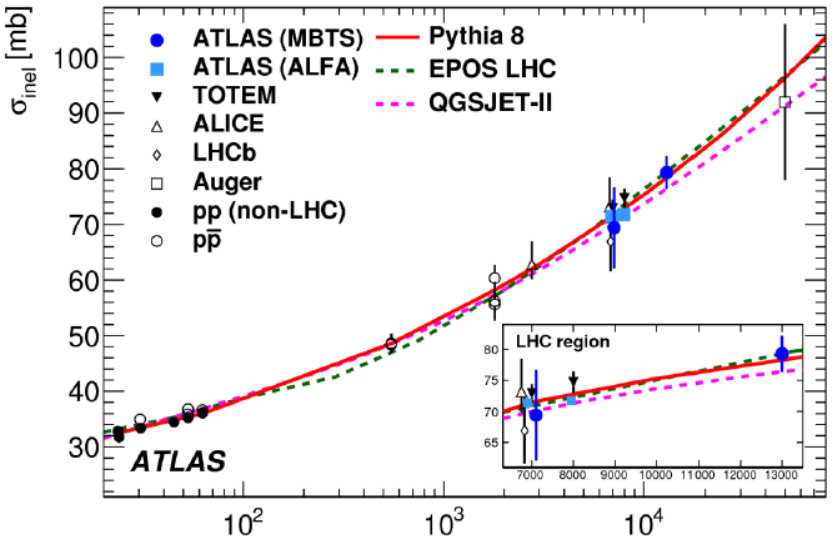
$\xi \approx 1$ at 7-8 TeV and $\xi = 2$ at the black disc limit



Dremin argues that the Black Disc terminology should be replaced by a Black Torus

σ_{inel} evolution with $\sqrt{s}$

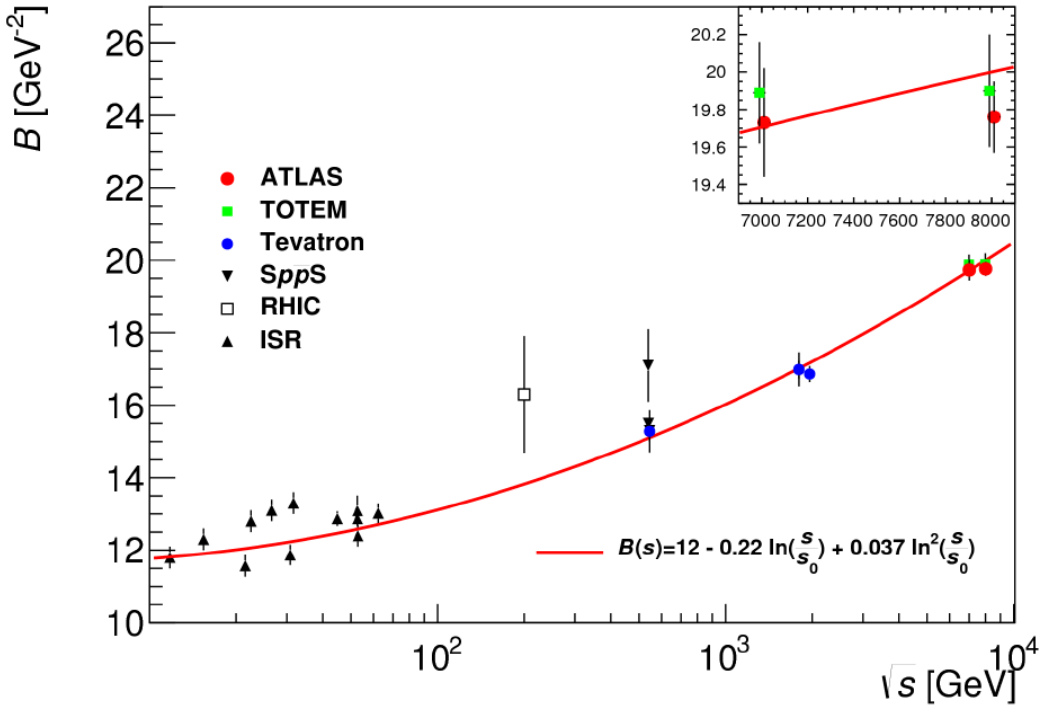
	7 TeV	8 TeV	13 TeV	Comments
MBTS	69.1 $\pm$ 7.3 mb		79.3 $\pm$ 2.9 mb	Main error contribution extrapolation
ALFA	71.3 $\pm$ 0.9 mb	71.7 $\pm$0.7mb		Small errors due to precise lumin.
TOTEM	72.9 $\pm$ 1.5 mb	74.7$\pm$ 1.7 mb		Based on elastic & inelastic rates
CMS			71.3 $\pm$ 3.5 mb	Preliminary, based on HF calorimeters



- In general increase with $\sqrt{s}$ visible as expected.
- Values at 7 TeV and 8 TeV agree within errors.
- At 13 TeV some discrepancy, but large errors.

More precise measurements with ALFA and TOTEM at 13 TeV are soon coming

B-slope evolution with √s



"Standard" parametrization of B with s

$B=B_0 + 2\alpha_p'^{eff} \ln(s/s_0)$

$\alpha_p'^{eff}$ = slope of the Pomeron trajectory

$\alpha_p'^{eff}$ = 0.25 GeV^{-2} normally taken from Donnachie-Landshoff

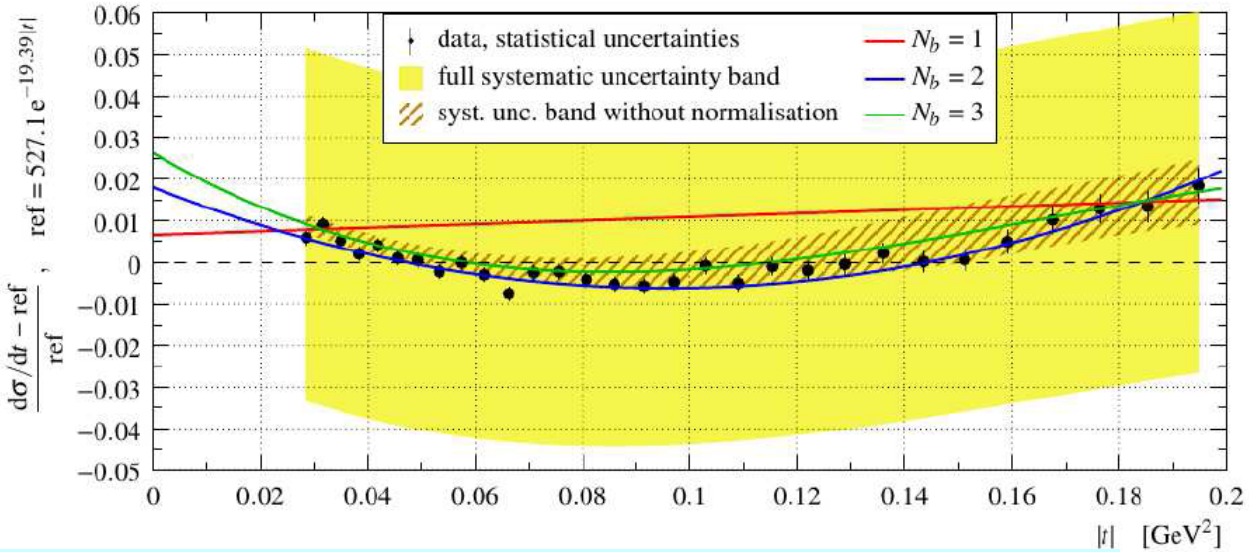
ATLAS/TOTEM at 7 TeV and 8 TeV indicates that $\alpha_p'^{eff}$ increases with energy (need $\ln^2(s/s_0)$ term)

Schegelsky and Ryskin
Phys. Rev. D **85**, 094024 (2012)

Soon confirmation of rise of effective $\alpha_p'^{eff}$ at 13 TeV ?

Non-exponential $d\sigma_{el}/dt$

By now well-known TOTEM result at 8TeV



ATLAS t-dependent systematic uncertainties too large at 8TeV to see this effect.

It would be nice to also have confirmation from ATLAS at 13 TeV

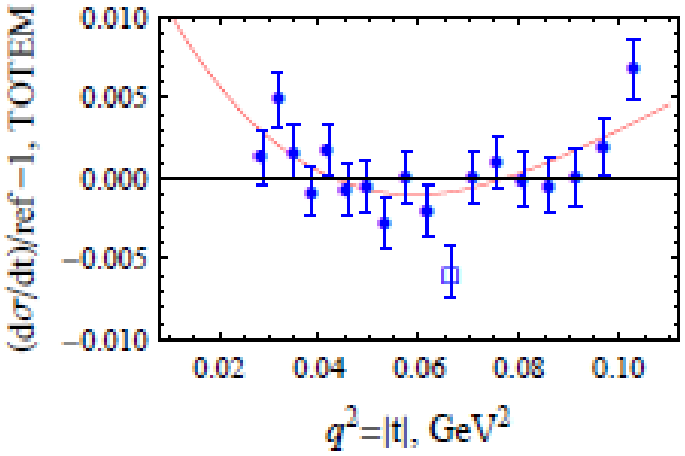
One important uncertainty comes from the beam momentum uncertainty.
ATLAS uses a beam momentum uncertainty of 0.65%
whereas TOTEM uses an uncertainty of only 0.1%.
Expect to converge on this soon.

Recent paper Bloch & Halzen et al.

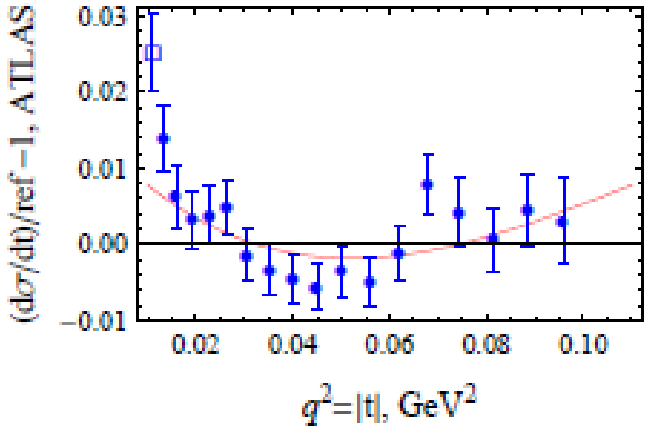
"The slope, curvature, and higher parameters in proton and antiproton p scattering, and the extrapolation of measurements of d(s, t)/dt to t = 0"

"We study the effects of curvature in the expansion of the logarithm of the differential elastic scattering cross section near t = 0 as $d(s, t)/dt = d(s, 0)/dt \times \exp(Bt + Ct^2 + Dt^3 \cdots)$ in an eikonal model…"

TOTEM 8 TeV

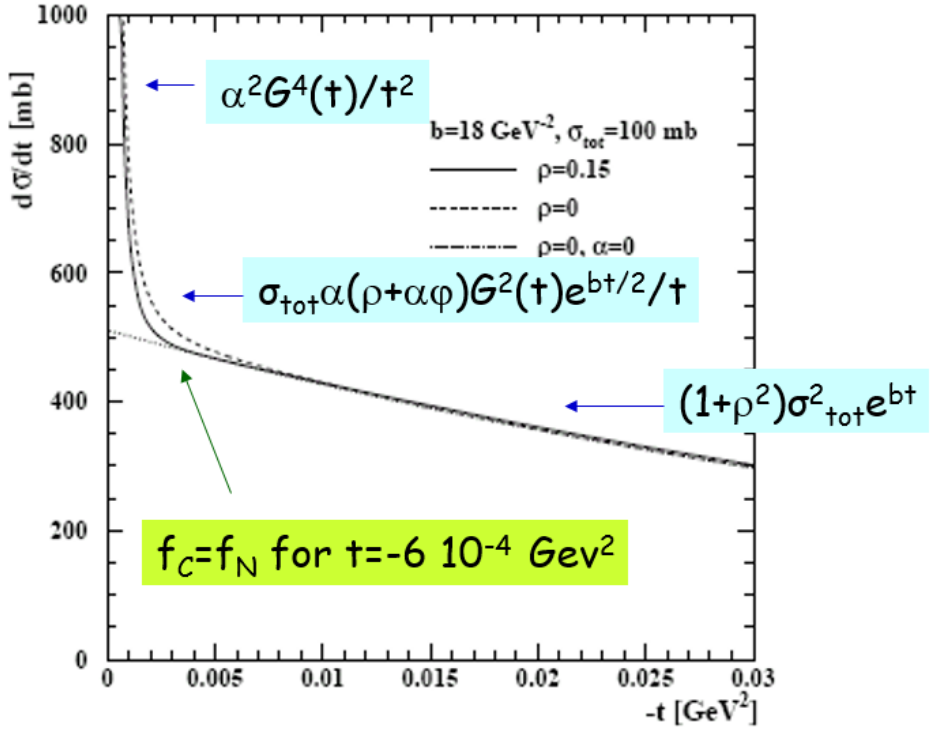


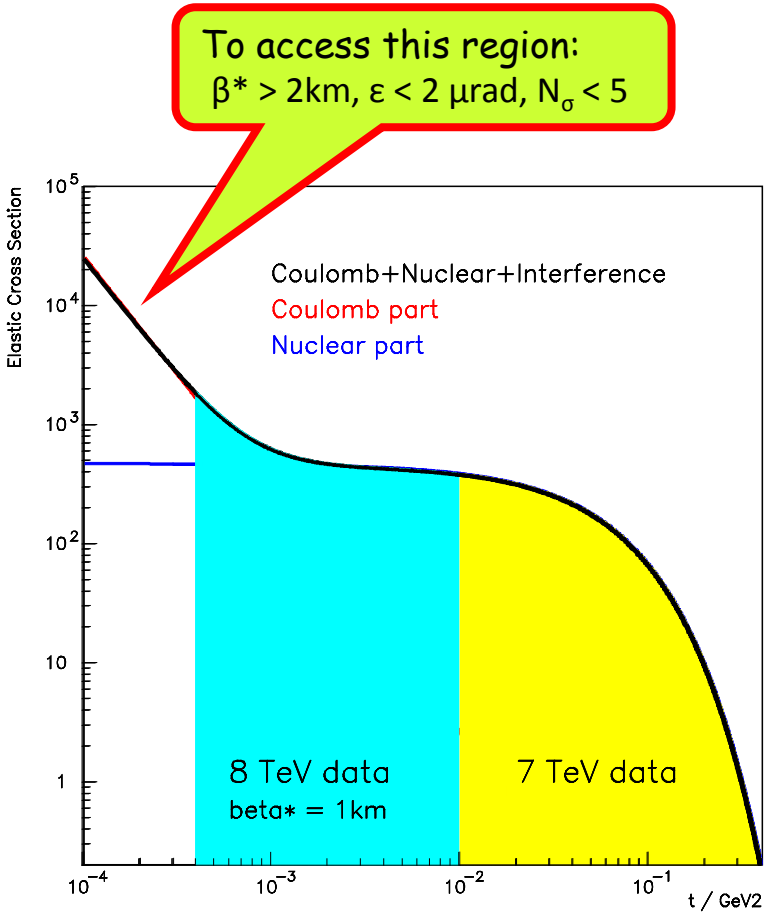
ATLAS 7 TeV



Measuring the phase of the strong amplitude
ρ = Re f_{el}/Im f_{el}

$f_{el}=f_c+f_n$





8 TeV β^* = 1km measurement being analyzed

13 TeV β^* = 2.5 km will be measured now i.e. end of September 2016.

Why measure ρ ?

- Numerical predictions based upon dispersion relations are quite accurate

$$\mathrm{Re}\, f_+(E) = C + \frac{E}{4\pi^2} \int_m^\infty dE' p' \left(\frac{\sigma_+(E')}{E'(E'-E)} - \frac{\sigma_-(E')}{E'(E'+E)} \right) \tag{6}$$

- No violation of dispersion relations seen at low energies

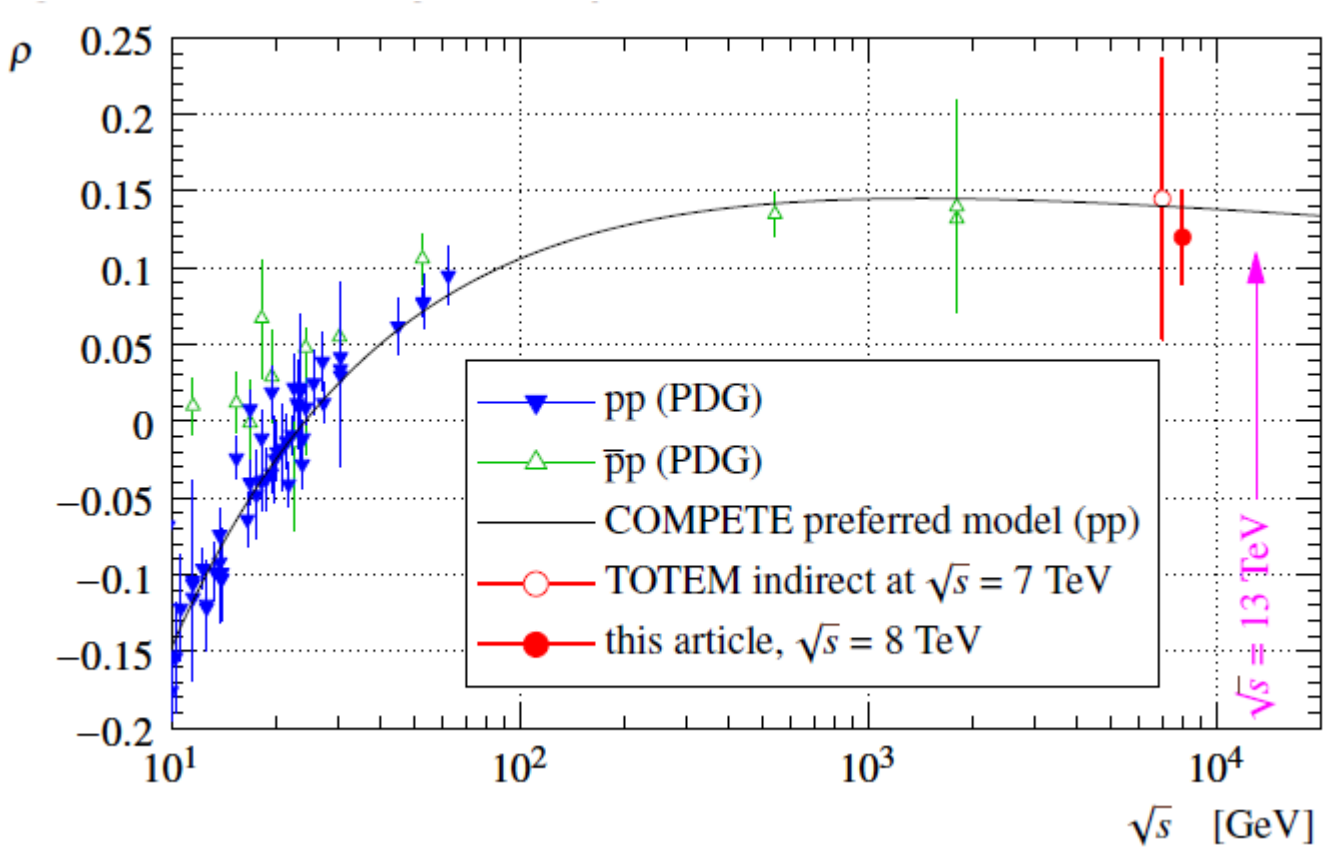
How to interpret a significant deviation of a measured ρ-value from predicted value?

Two possibilities:

σ_{tot} beyond LHC energies behave significantly different from present prejudices ($\ln^2 s$)

Dispersion relations do not hold at high energies

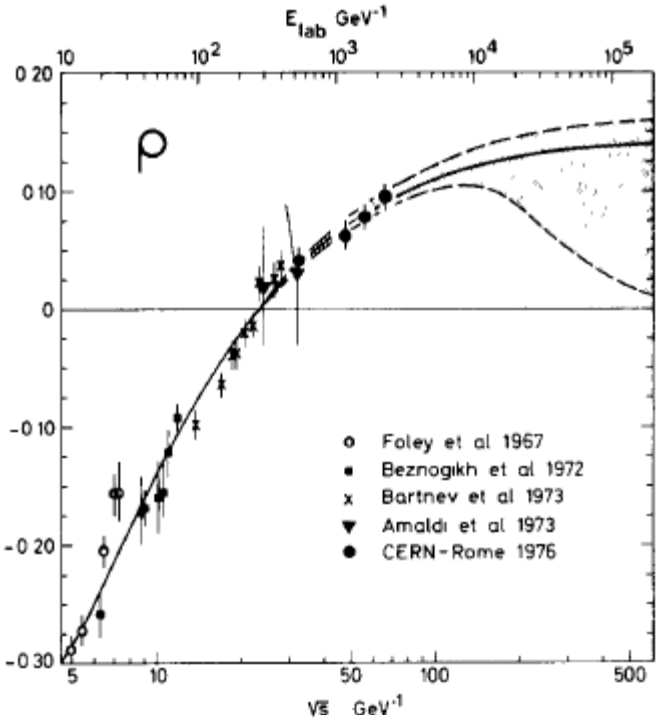
Both interesting…….

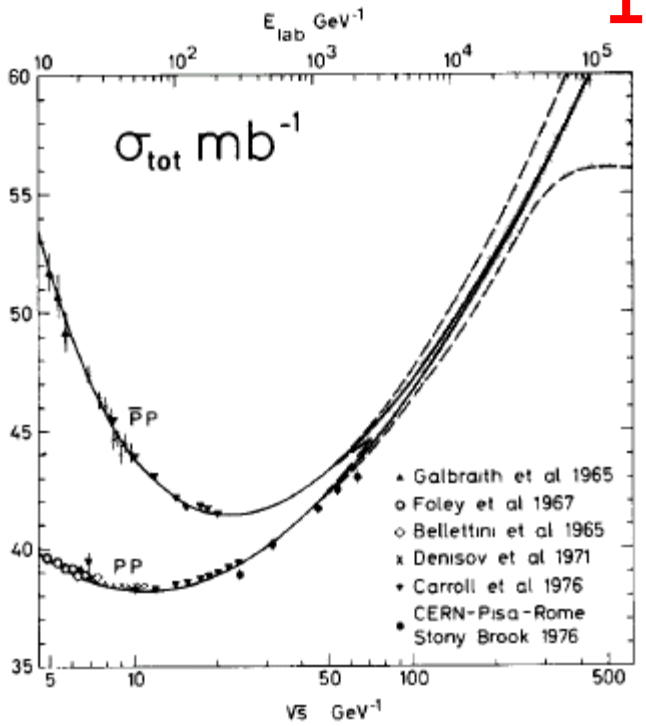


TOTEM measurements- from Jan Kaspar LHC workinggroup 15 March 2016

Use ρ to predict σ_{total}
Predictions from ISR measurements

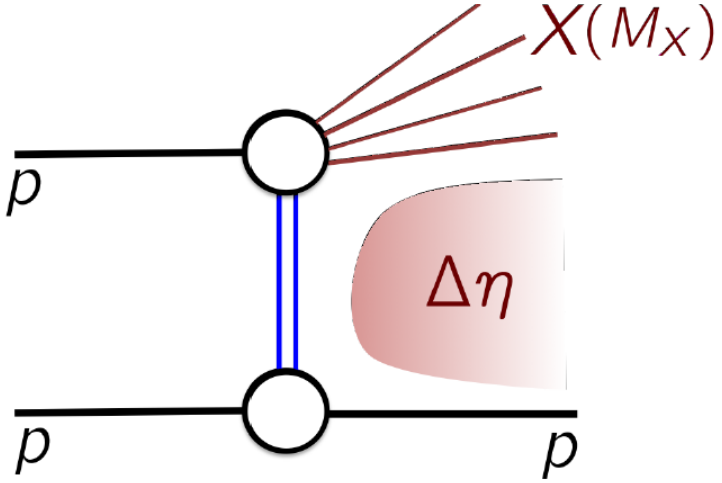
SPS collider





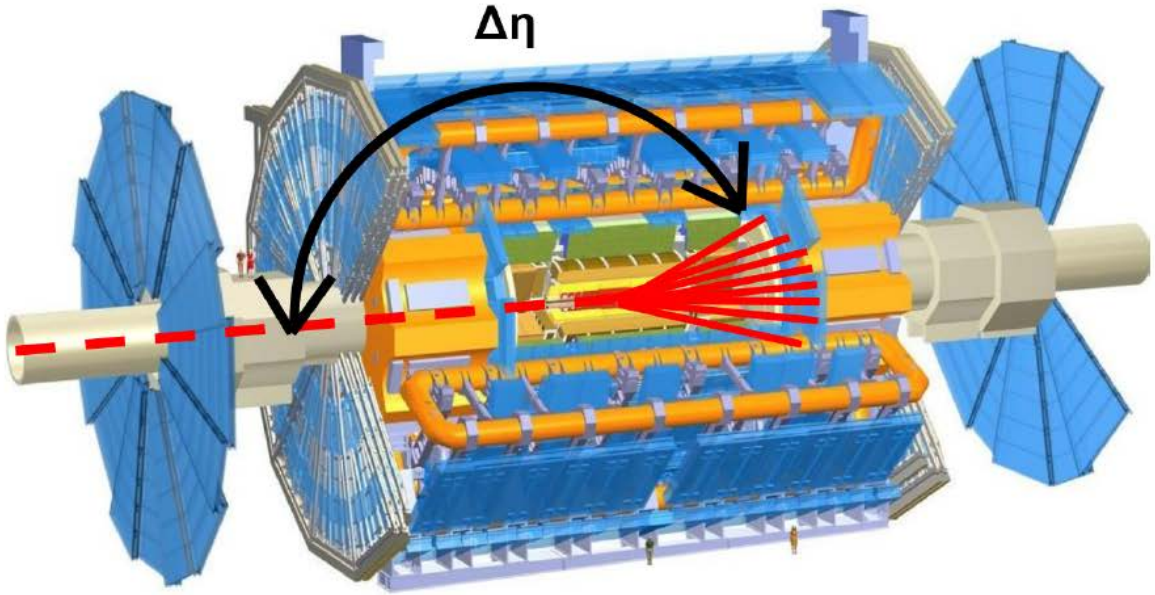
$$\mathrm{Re}\, f_+(E) = C + \frac{E}{4\pi^2} \int_m^\infty dE' p' \left(\frac{\sigma_+(E')}{E'(E'-E)} - \frac{\sigma_-(E')}{E'(E'+E)} \right) \quad (6)$$

Single diffraction



- Cross section is large (but still not well constrained)
- No ATLAS measurement as a function of kinematic variables:
  - proton energy loss (ξ)
  - proton momentum transfer (t)
- Improvement of the published rapidity gap cross section by tagging the final-state proton

Proton tagging will allow to better unfold ND and DD from SD



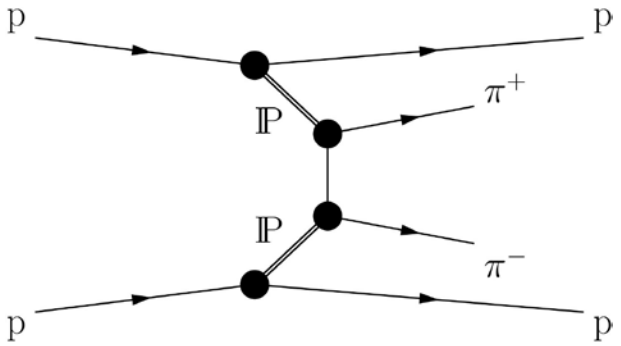
- ALFA and opposite side MBTS trigger
- proton measured in ALFA
- MBTS inner ring veto on the proton side ensures rapidity gap
- dissociated system tagged with MBTS inner ring signal
- t reconstructed using proton measured in ALFA

$$\xi = \frac{M_X^2}{s} \qquad \xi_{EPz}^{\pm} = \frac{\sum_i (E_i \pm p_{z,i})}{\sqrt{s}}$$

- in the studied kinematic region ξ_{EPz} approximation is good

Central Exclusive Production of low mass states

Double Pomeron Exchange (DPE) dominates at high energy



- ππ state interesting in itself
- constrain gap survival probability for di jets, di boson, Higgs….

Advantage of proton tagging
- No background from proton dissociation
- All final state measured i.e. momentum balanced can be used for background reduction)
- Quantum number filter

Low mass state (< 2 GeV) ⟹ proton relative energy loss $\xi \approx 2\times10^{-4}$

⟹ proton with almost beam energy ⟹ follow elastic analysis

Central Exclusive Production of low mass states (cont.)

Analysis ongoing for 7 and 8 TeV for ππ pairs
..for 13 TeV also 4π states and KK

Use dE/dx in pixel to identify ππ final state

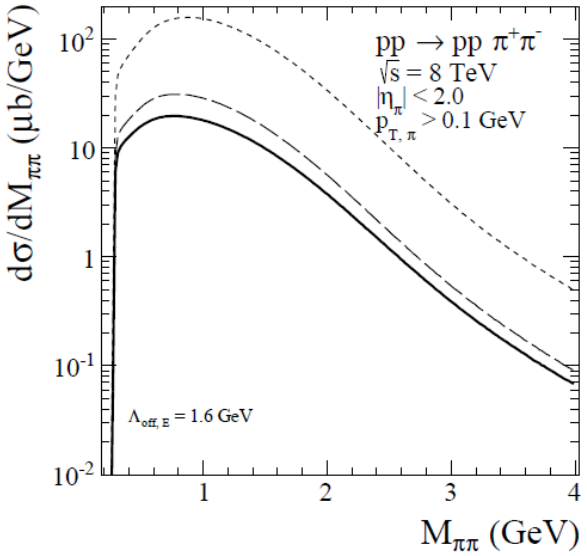
Selection
- 1 primary vertex . 2 primary tracks
- $P^{\pi}_{t} > 100$ GeV, $\eta < 2.5$
- Missing $p_t < 3.5\ \sigma$
- MBTS counter as veto

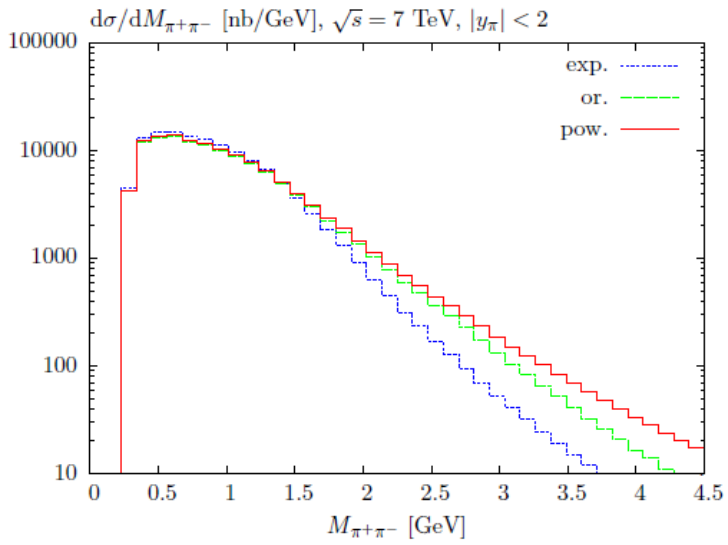
Goal: to extract $m_{\pi\pi}$ and t-distributions

Model predictions

P. Lebiedowicz and A.Szczurek arXiv:1504.07560

L.A. Harland-Lang, V.A. Khoze and M.G. Ryskin arXiv:1312.4553





Large theory errors
Model parameters to be tuned to data

Compare identified particle spectra

- Analysis on going at 13 TeV
- Study of identified particle spectra (π, K and p) in diffractive events- compare with non-diffractive measurements.
  Wealth of data for non-diffractive measurement but not for diffractive.
- Information about differences in proton-proton interactions relative Pomeron-Pomeron interactions.
- Again use pixel for dE/dx identification of particles.

Proton tagging with LHCf

- Very low mass proton excitation to N* resonances decaying to proton and pi0
- Study of classical and diffractive bremssthrahlung of pi0 (photon)

Conclusions

- The differential elastic cross section has been measured using the ALFA detector at 7 and 8 TeV for small t-values.
- A number of derived quantities has been extracted: σ_{tot} , σ_{el} σ_{inel} and the slope parameter B.
- Analysis of 8 TeV, $\beta^* = 1$ km (very small t) ongoing.
  Goal: extract ρ (and luminosity)
- Analysis of 13 TeV, $\beta^* = 90$ m ongoing.
  Goal: extract: σ_{tot} , σ_{el} σ_{inel} and the slope parameter B.
- Analysis of Single Diffraction and Central diffraction data at 7,8 and 13 TeV
  is ongoing.
- Data taking at 13TeV, $\beta^* = 2.5$ km coming up NOW
  Goal: extract ρ (and luminosity).
- Future plans: Continue measurements up to maximum LHC energy