Total, elastic and inelastic p-p cross sections at the LHC

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on behalf of the

ATLAS, CMS, LHCb and TOTEM collaborations

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outline

- total cross section σ_{tot} of proton-proton interaction
- rising σ_{tot}, Regge model, pomeron
- measurements of σ_{tot} by
  - ATLAS ALFA – **A**bsolute **L**uminosity **F**or **A**TLAS, new arXiv:1607.06605, submitted to Phys. Lett. B

  and
  - TOTEM - **TOT**al cross-section, **E**lastic scattering and diffraction dissociation **M**easurement the LHC; dedicated experiment

  and their comparison
- inelastic cross section σ_{inel} at LHC including measurements at 13 TeV by
  - ATLAS new arXiv:1606.02625, submitted to Phys. Rev. Lett.

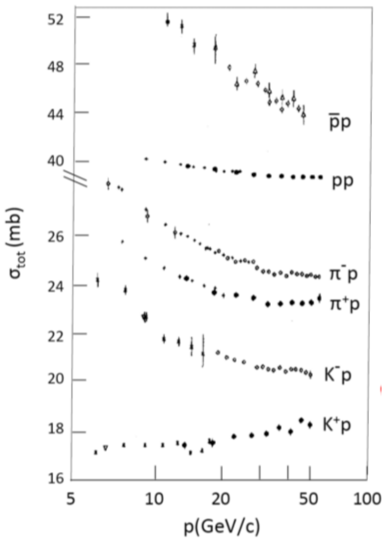
  and
  - CMS

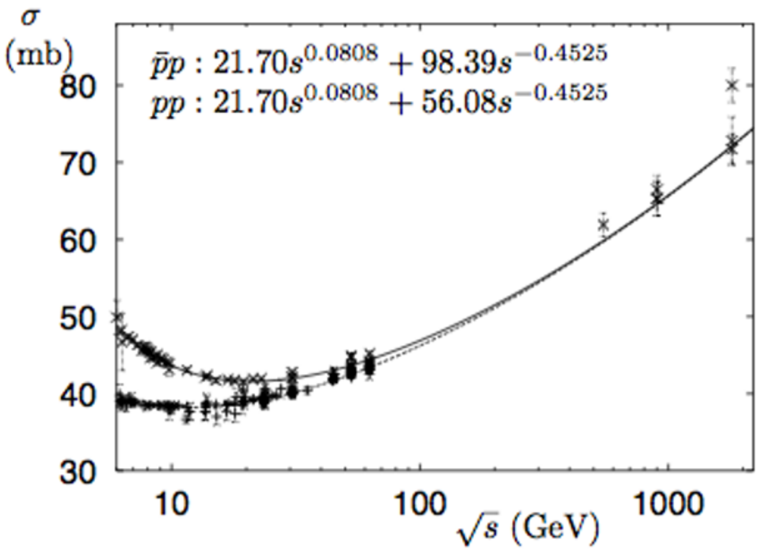
  and their comparison with results of ALICE, LHCb and TOTEM
- outlook

total cross section σ_{tot} of proton-proton interaction

- σ_{tot} of p-p interaction is a fundamental quantity giving the upper bound on probability (cross section) of any process in p-p collisions

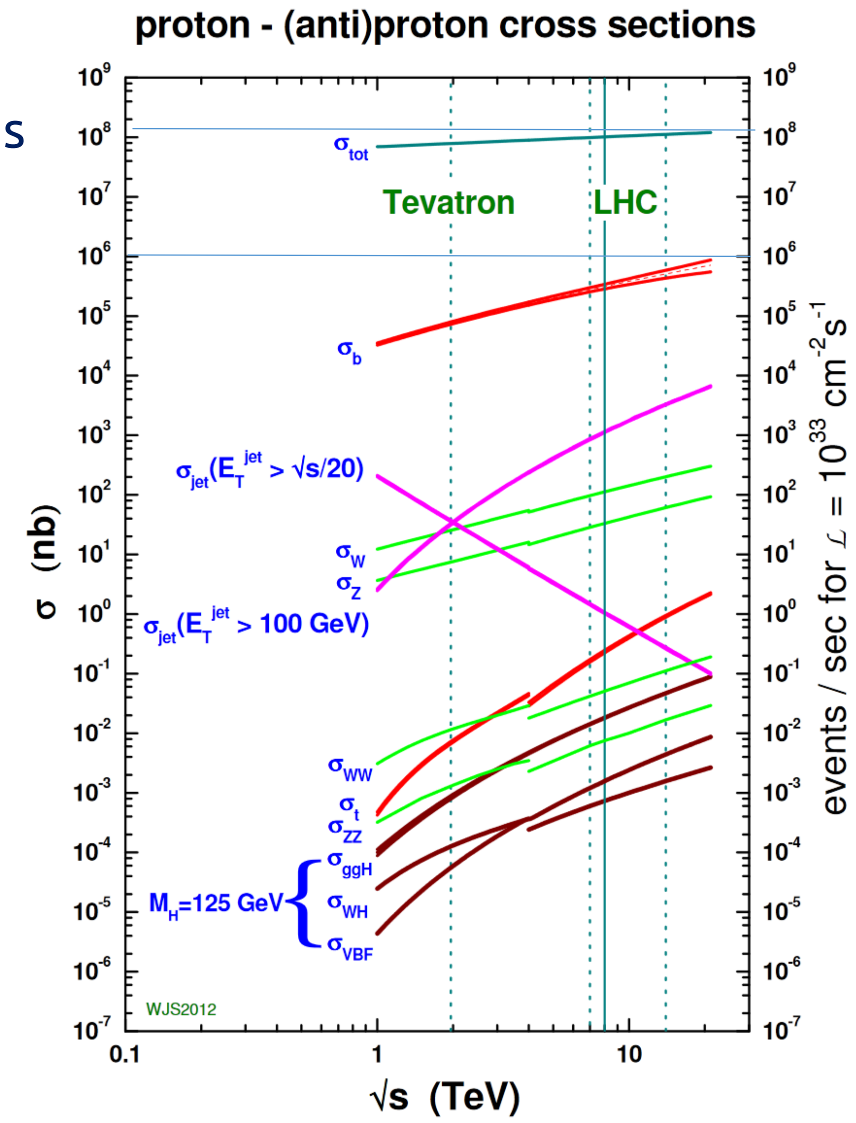
- 1973 – Intersection Storage Rings (ISR): rising of σ_{tot} value





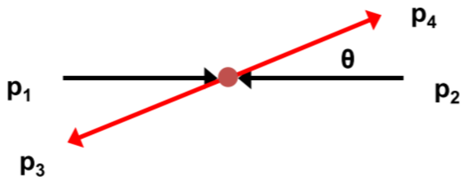
- measurement of σ_{tot} at LHC energies – TOTEM and ALFA

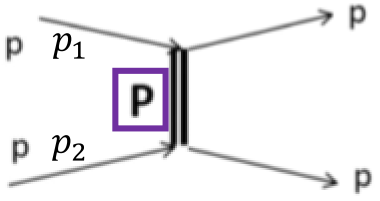
- at higher energies (57 TeV) – cosmic showers, Auger experiment



rising σ_{tot}, Regge model, pomeron

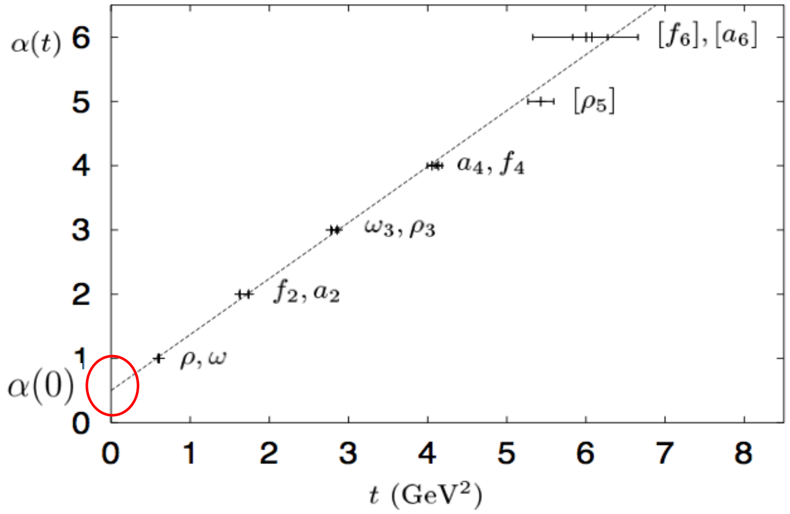
- using optical theorem and Regge theory we can write for a process





$$\sigma_{tot} \approx s^{\alpha(0)-1} \qquad s = (p_1 + p_2)^2$$

$$\frac{d\sigma_{el}}{dt} \approx s^{2(\alpha(0)-1)} e^{-B|t|} \qquad B = B_0 + 2\alpha' \ln s$$



where $\alpha(0)$ is so-called intercept of a Regge trajectory

$$\alpha(t) = \alpha(0) + \alpha' t \qquad t = (p_1 - p_2)^2 \underset{\text{elastic}}{\cong} -(p_0\theta)^2,\ |p_1| = |p_2| = p_0$$

- if $\alpha(0) > 1$, σ_{tot} will rise with rise of s

- trajectory with $\alpha(0) > 1$ has only one "particle" – pomeron **P**

- σ_{tot} is not calculable in the framework of the perturbative QCD; Regge model is used in HEP generators to describe kinematic area where the QCD cannot be applied

measurement of total cross section σ_{tot}

ways of measurement of σ_{tot}

- direct (ρ-independent) measurement of $\sigma_{tot} = N_{tot}/L$, where N_{tot} is total number of events with interaction, L is luminosity, is nontrivial (due to limited acceptance, model dependence)

$\sigma_{tot} = \sigma_{el} + \sigma_{inel}$

$\sigma_{inel} = \sigma_{inel\ diffractive}\ (\sigma_{SD} + \sigma_{DD} + \ldots) + \sigma_{non\ diffractive}$

- traditional way (ISR) of σ_{tot} measurement – via elastic cross section measurement and the use of optical theorem

$$\sigma_{tot} = 4\pi\, \mathrm{Im}[f_{el}(t=0)]$$

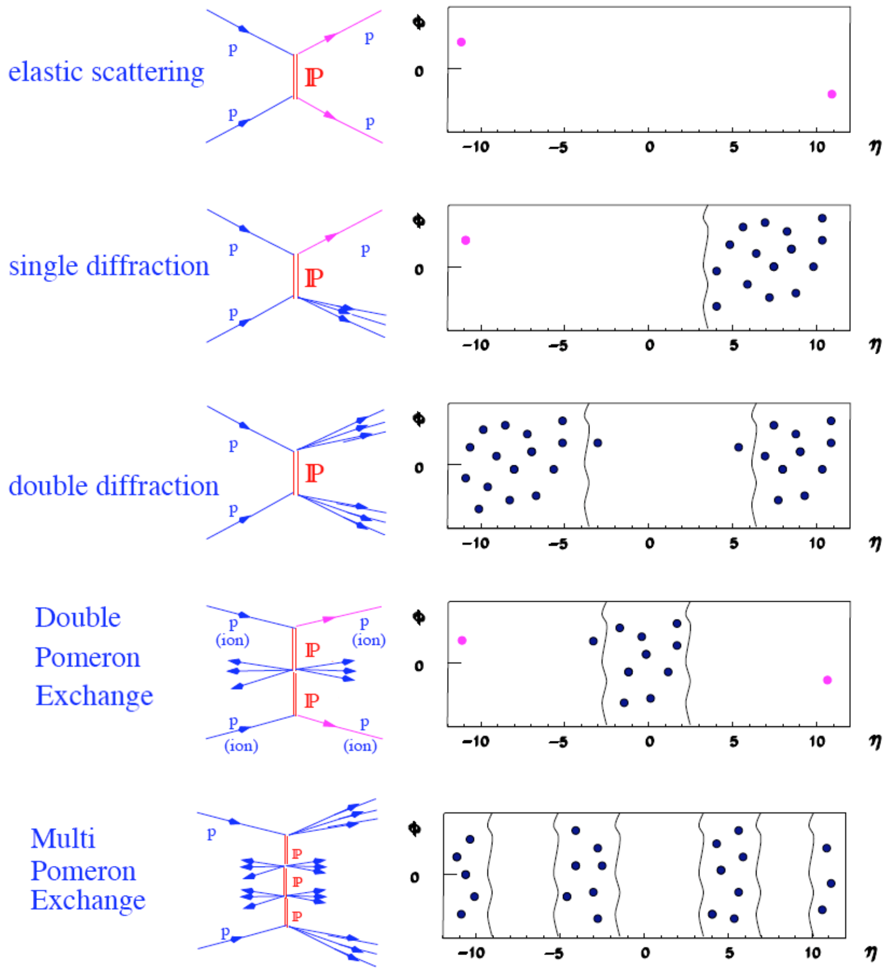
where f_{el} is elastic amplitude

$$\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2}\frac{1}{L}\left(\frac{dN_{el}}{dt}\right)_{t=0} \qquad \rho = \frac{\mathrm{Re}\, f(0)}{\mathrm{Im}\, f(0)}$$

luminosity dependent measurement,
N_X - number of events of X∈(el, tot, inel, …) type

$$\sigma_{tot} = \frac{16\pi}{1+\rho^2}\frac{(dN_{el}/dt)_{t=0}}{N_{tot}}$$

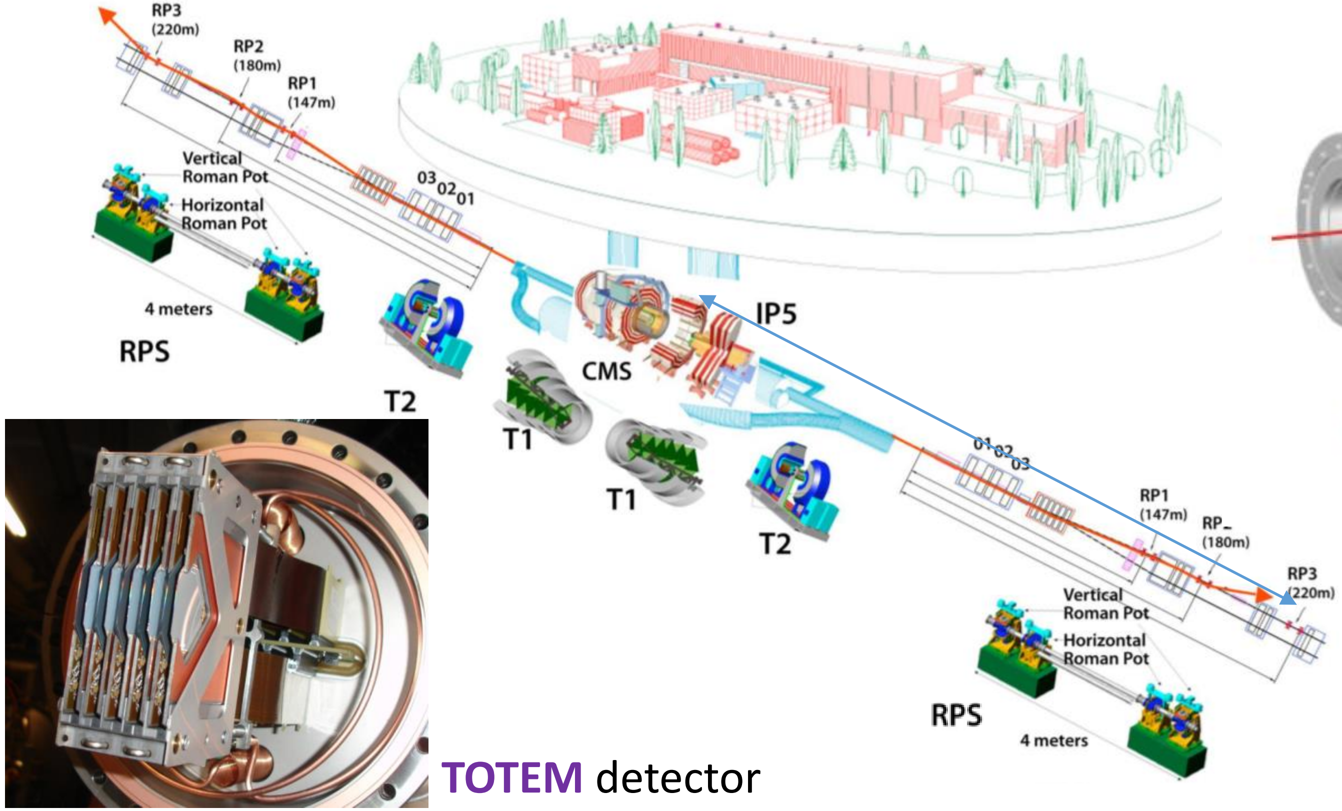
luminosity independent measurement



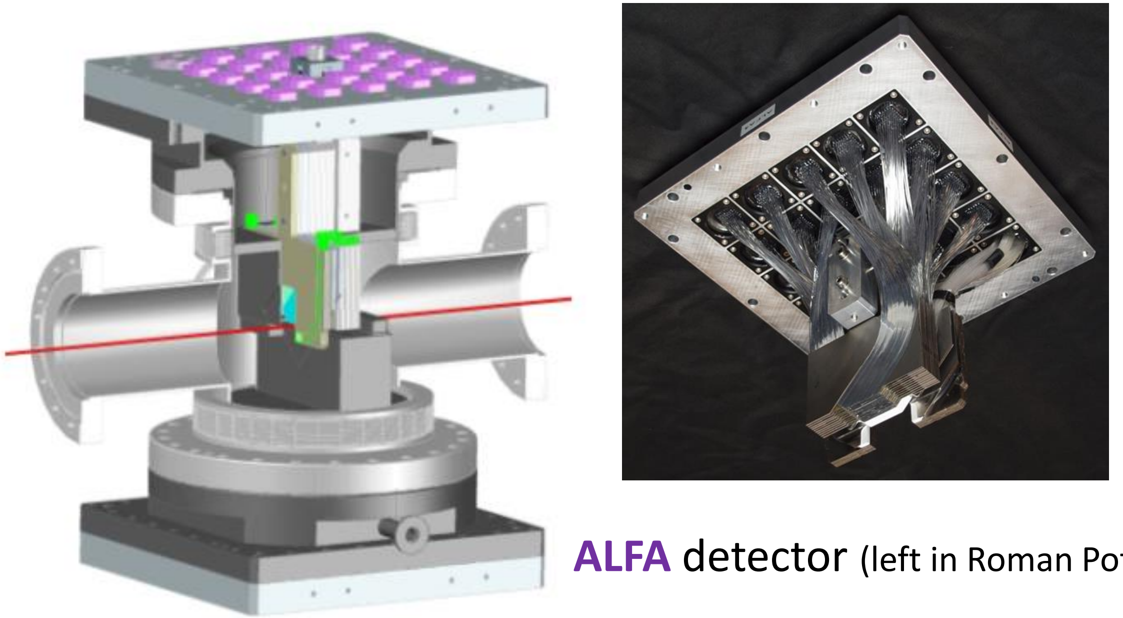
elastic events are the subset of diffractive events; diffractive pattern was observed in elastic collisions

elastic differential rate

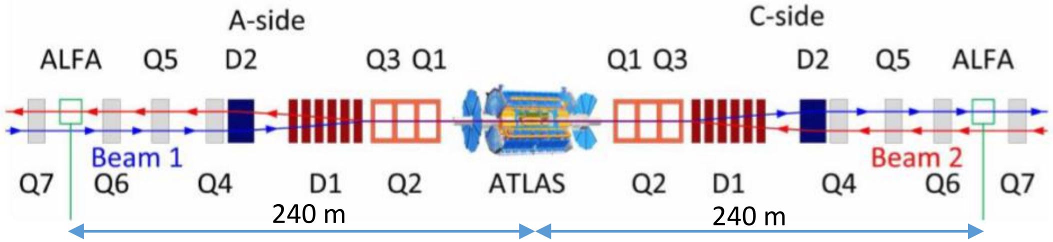
- to establish $\left(\frac{dN_{\text{el}}}{dt}\right)_{t=0}$ we need to measure distribution covering very small angles
- appropriate accelerator optics: separation of elastically scattered protons from beam & beam halo, a small divergence of the beams at interaction point, monoenergetic beam, knowledge of the optics, knowledge of luminosity, …



TOTEM detector



ALFA detector (left in Roman Pot)



fit

ATLAS ALFA method

$$\frac{d\sigma_{el}}{dt} = \frac{1}{16\pi}\left|f_N(t) + f_C(t)e^{i\alpha\phi(t)}\right|^2$$

coulomb amplitude

$$f_C(t) = -8\pi\alpha\hbar c\frac{G^2(t)}{|t|}$$

nuclear amplitude

$$f_N(t) = (\rho + i)\frac{\sigma_{tot}}{\hbar c}e^{-B|t|/2}$$

phase

$$\phi(t) = -\ln\frac{B|t|}{2} - \phi_C$$

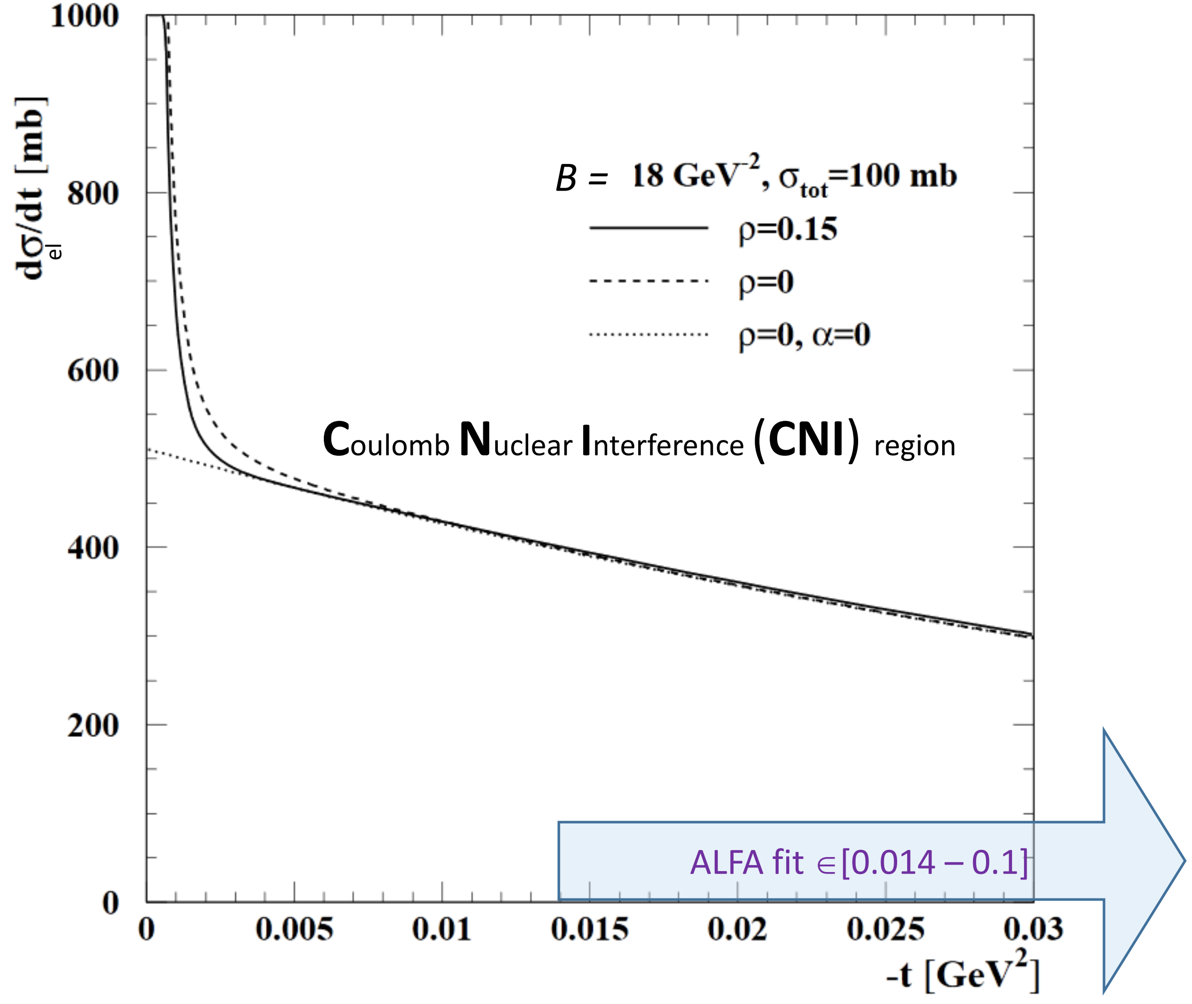
proton form factor

$$G(t) = \left(\frac{\Lambda}{\Lambda + |t|}\right)^2$$

Pythia 8 - values

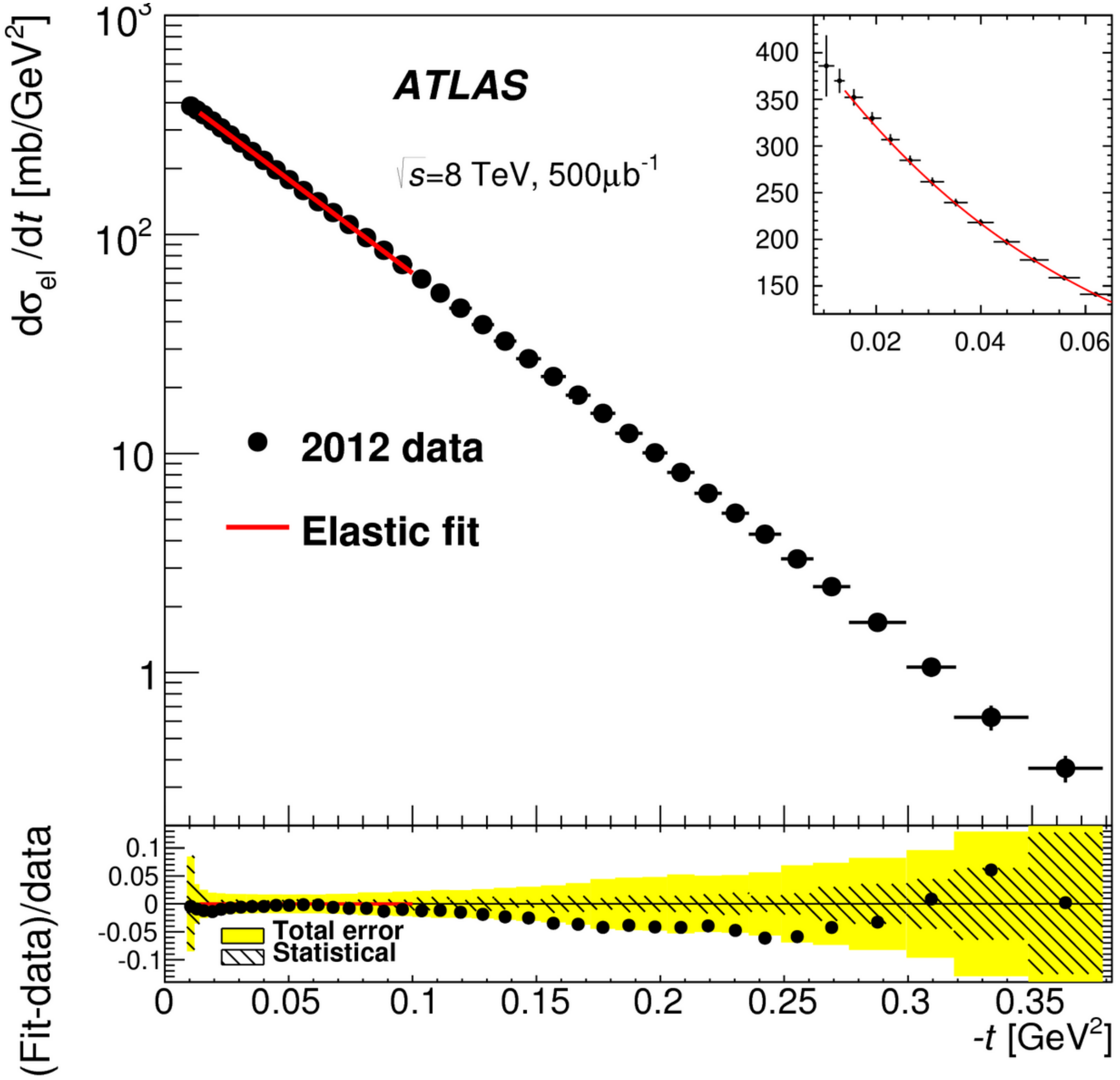
ρ	0.14
Λ	0.71 GeV^2
ϕ_C	0.577

for an illustration, from ATLAS ALFA TDR, CERN/LHCC 2008-04



arXiv:1607.06605

ALFA fit result, 8 TeV, β* = 90 m



	σ_{tot} [mb]			
	Subtraction	Local angle	Lattice	Local subtraction
Total cross section	96.07	96.52	96.56	96.58
Statistical error	0.18	0.15	0.16	0.15
Experimental error	0.85	0.94	0.88	0.89
Extrapolation error	0.31	0.42	0.23	0.23
Total error	0.92	0.98	0.93	0.93

$$\sigma_{tot} = 96.07 \pm 0.18\ (\text{stat.}) \pm 0.85\ (\text{exp.}) \pm 0.31\ (\text{extr.})\ \text{mb}$$

$$\sigma_{el} = 24.33 \pm 0.04\ (\text{stat.}) \pm 0.39\ (\text{syst.})\ \text{mb}$$

both - nuclear part

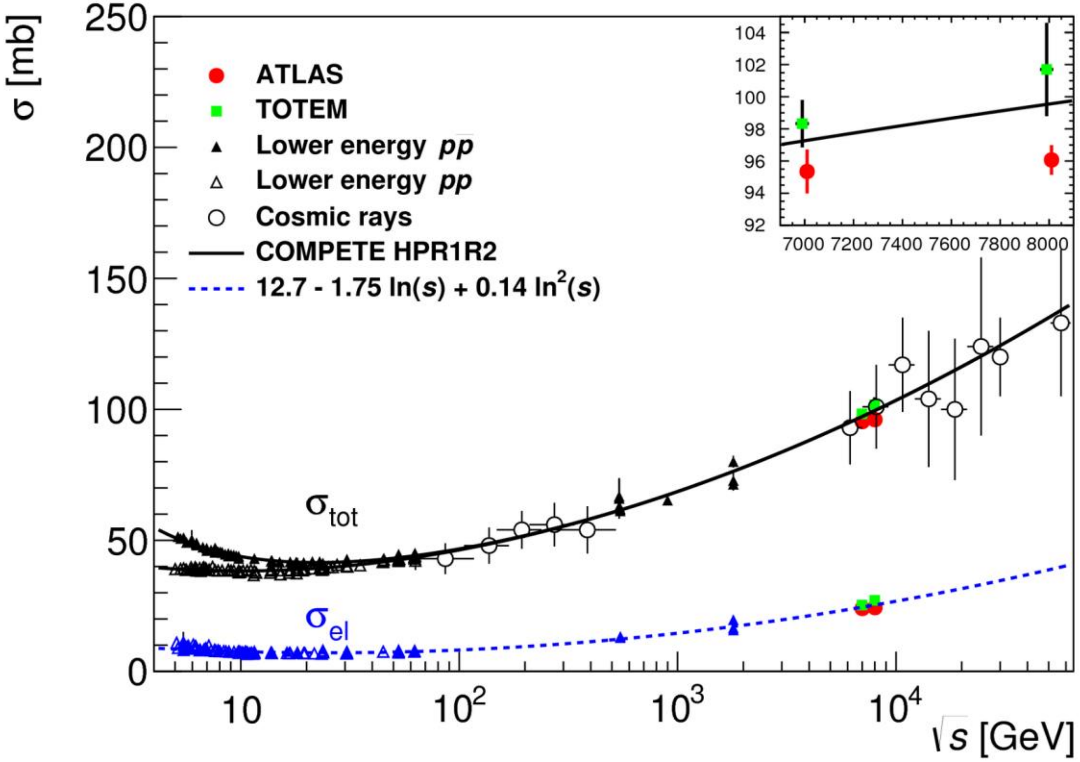
final result based on subtraction method

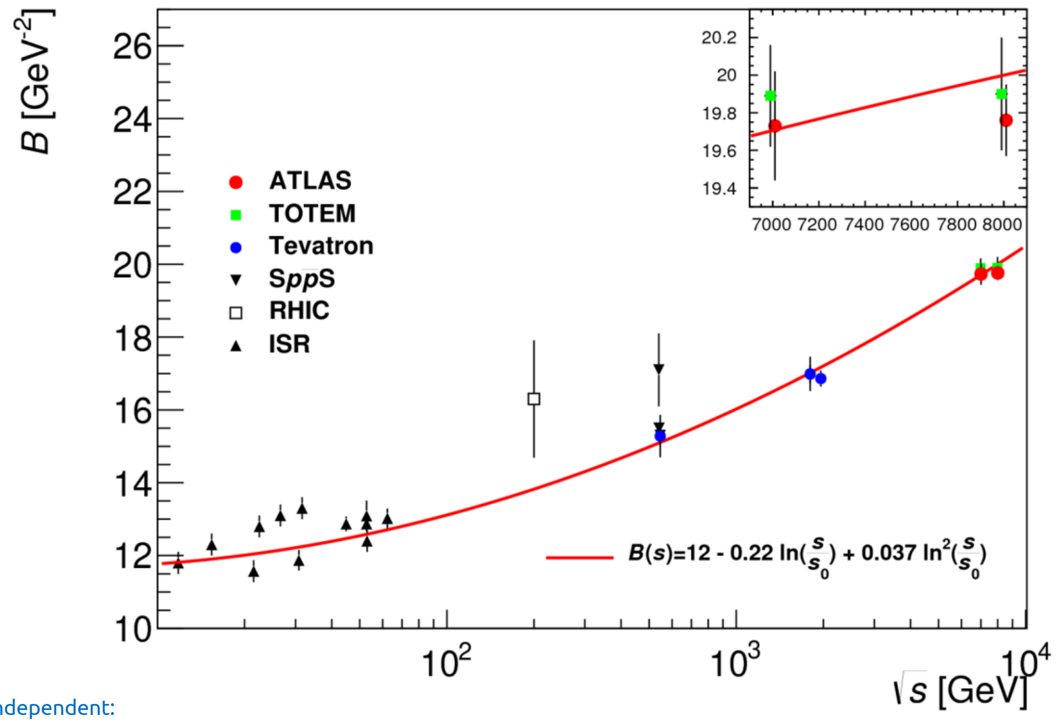
	B [GeV^{-2}]			
	Subtraction	Local angle	Lattice	Local subtraction
Nuclear slope	19.74	19.83	19.87	19.88
Statistical error	0.05	0.05	0.05	0.04
Experimental error	0.16	0.18	0.16	0.17
Extrapolation error	0.15	0.17	0.14	0.15
Total error	0.23	0.26	0.22	0.23

$$B = 19.74 \pm 0.05\ (\text{stat.}) \pm 0.23\ (\text{syst.})\ \text{GeV}^{-2}$$

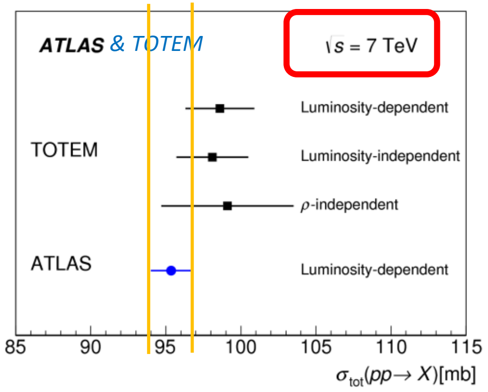
Fit range set to 0.014-0.1 GeV2 where acceptance > 10% and non-exponential terms expected to be negligible (<0.1)

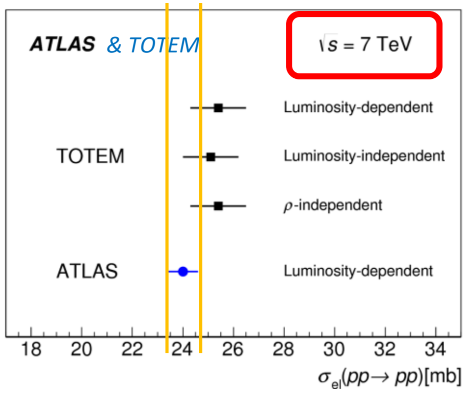
ATLAS ALFA vs earlier measurements





8 TeV
TOTEM lumi independent:
Phys. Rev. Lett. 111, 012001 (2013)
σ_{tot} = (101.7±2.9) mb
σ_{el} = (27.1±1.4) mb



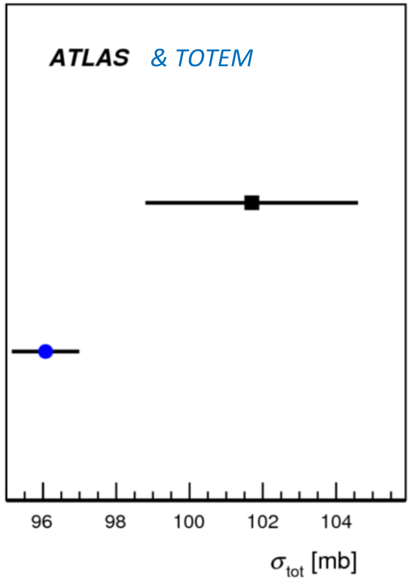


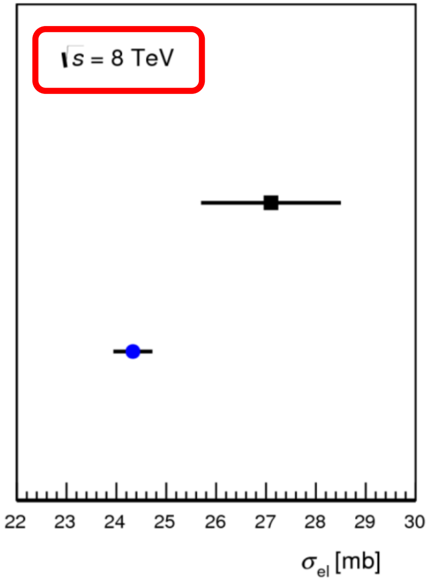
7 TeV
TOTEM lumi dependent:
σ_{tot} = (98.3 ± 2.8) mb EPL 96 (2011) 21002
σ_{tot} = (98.6 ± 2.2) mb EPL 101 (2011) 21002

TOTEM lumi independent
σ_{tot} = (98.0 ± 2.5) mb EPL 101(2013) 21004

TOTEM ρ independent:
σ_{tot} = (99.1 ± 4.3) mb EPL 101(2013) 21004

ATLAS lumi dependent:
Nuclear Physics, B (2014) 889
σ_{tot} = (95.35 ± 1.36) mb
σ_{el} = (95.35 ± 0.6) mb





TOTEM
sl. 12 more measurements

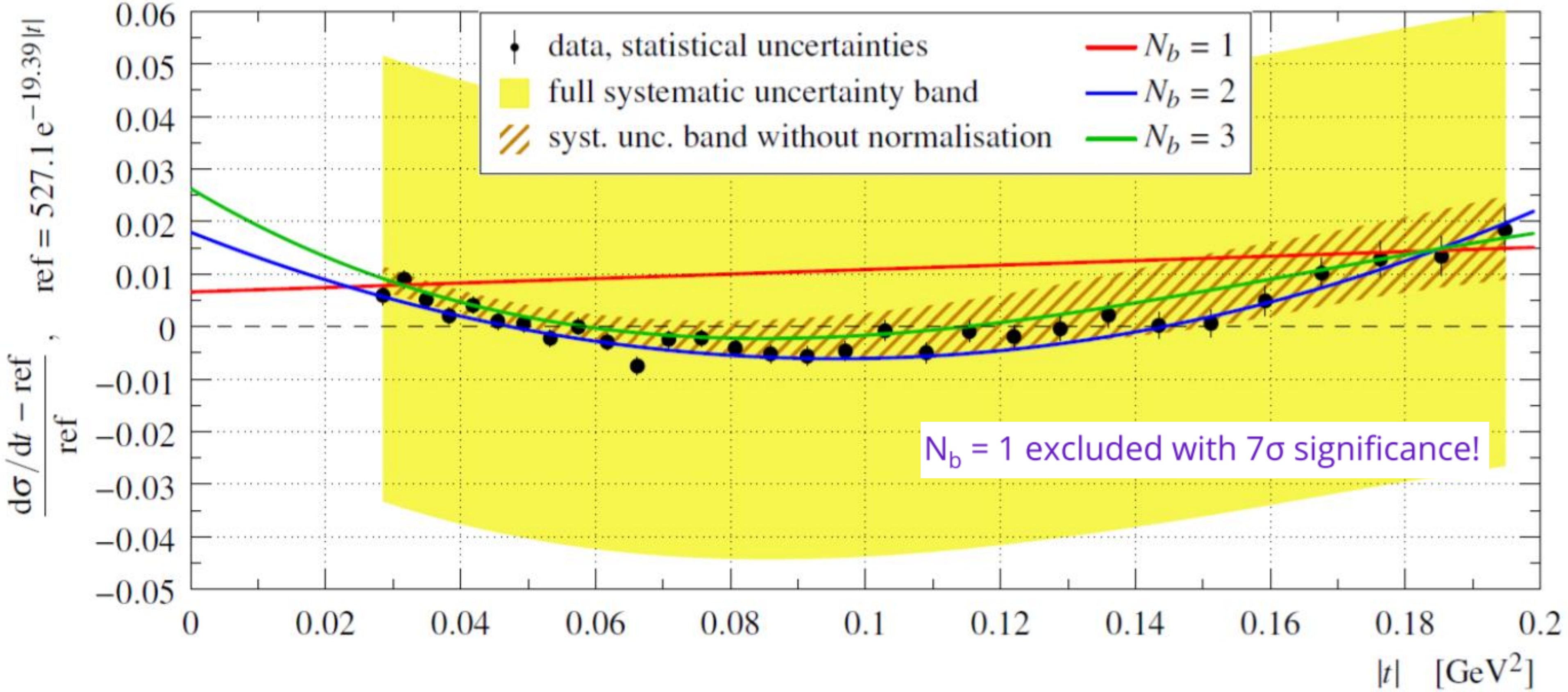
ATLAS

fitting ATLAS ALFA data with other models

	σ_{tot} [mb]	Model
Nominal	96.07 ± 0.86	$f_{\text{N}}(t) = (\rho + i)\,\frac{\sigma_{\text{tot}}}{\hbar c} e^{-Bt/2}$
Ct^2	96.16 ± 0.80	$f_{\text{N}}(t) = (\rho + i)\,\frac{\sigma_{\text{tot}}}{\hbar c} e^{-Bt/2 - Ct^2/2}$
$c\sqrt{-t}$	96.40 ± 0.80	$f_{\text{N}}(t) = (\rho + i)\,\frac{\sigma_{\text{tot}}}{\hbar c} e^{-Bt/2 - c/2(\sqrt{4\mu^2 - t} - 2\mu)}$, $\mu = m_\pi$
SVM	96.16 ± 0.80	$f_{\text{N}}(t) = \rho \frac{\sigma_{\text{tot}}}{\hbar c} e^{-B_R t/2} + i \frac{\sigma_{\text{tot}}}{\hbar c} e^{-B_I t/2}$
BP	96.81 ± 0.95	$f_{\text{el}}(t) = i \left[G^2(t) \sqrt{A} e^{-Bt/2} + e^{i\phi} \sqrt{C} e^{-Dt/2} \right]$
BSW	96.67 ± 0.99	$\text{Re} f_{\text{el}}(t) = c_1 (t_1 + t) e^{-b_1 t/2}$, $\text{Im} f_{\text{el}}(t) = c_2 (t_2 + t) e^{-b_1 t/2}$

RMS of models 0.28 mb, simple model 0.31 mb -> all looks mutually consistent

TOTEM – simple exponential model excluded



$$\frac{d\sigma}{dt}(t) = \frac{d\sigma}{dt}\Big|_{t=0} \exp\left(\sum_{i=1}^{N_b} b_i\, t^i\right)$$

non exp. fit for elastic differential cross section

8 TeV, β*= 90 m

$N_b = 2 : \sigma_{tot} = (101.5 \pm 2.1)$ mb
$N_b = 3 : \sigma_{tot} = (101.9 \pm 2.1)$ mb

Nuclear Physics B 899 (2015) 527–546

non exp. fit for elastic differential cross section & CNI effect

8 TeV, β*= 1 km

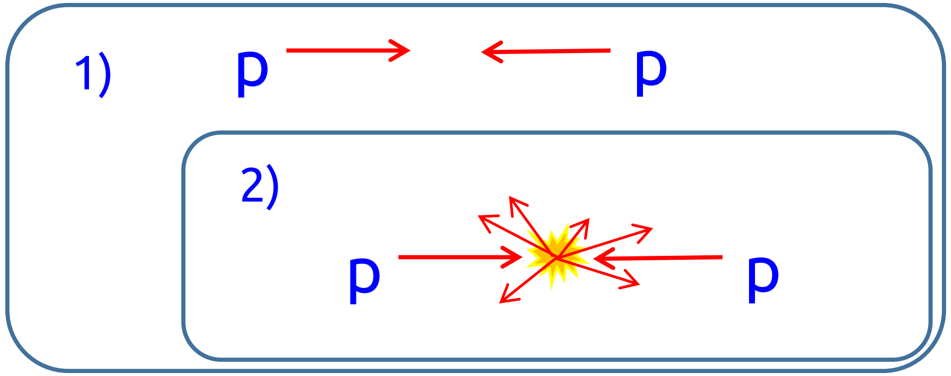
N_b= 3 (central) : $\sigma_{tot} = (102.9 \pm 2.3)$ mb
N_b= 3 (peripheral) : $\sigma_{tot} = (103.0 \pm 2.3)$ mb

central, peripheral – profile function shape in impact parameter space, depending on used nuclear phase model

CERN-PH-EP-2015-325, submitted to EPJC

measurement of inelastic cross section σ_{inel}

analysis technique – common steps



1) establish integrated luminosity $\int L\,dt$

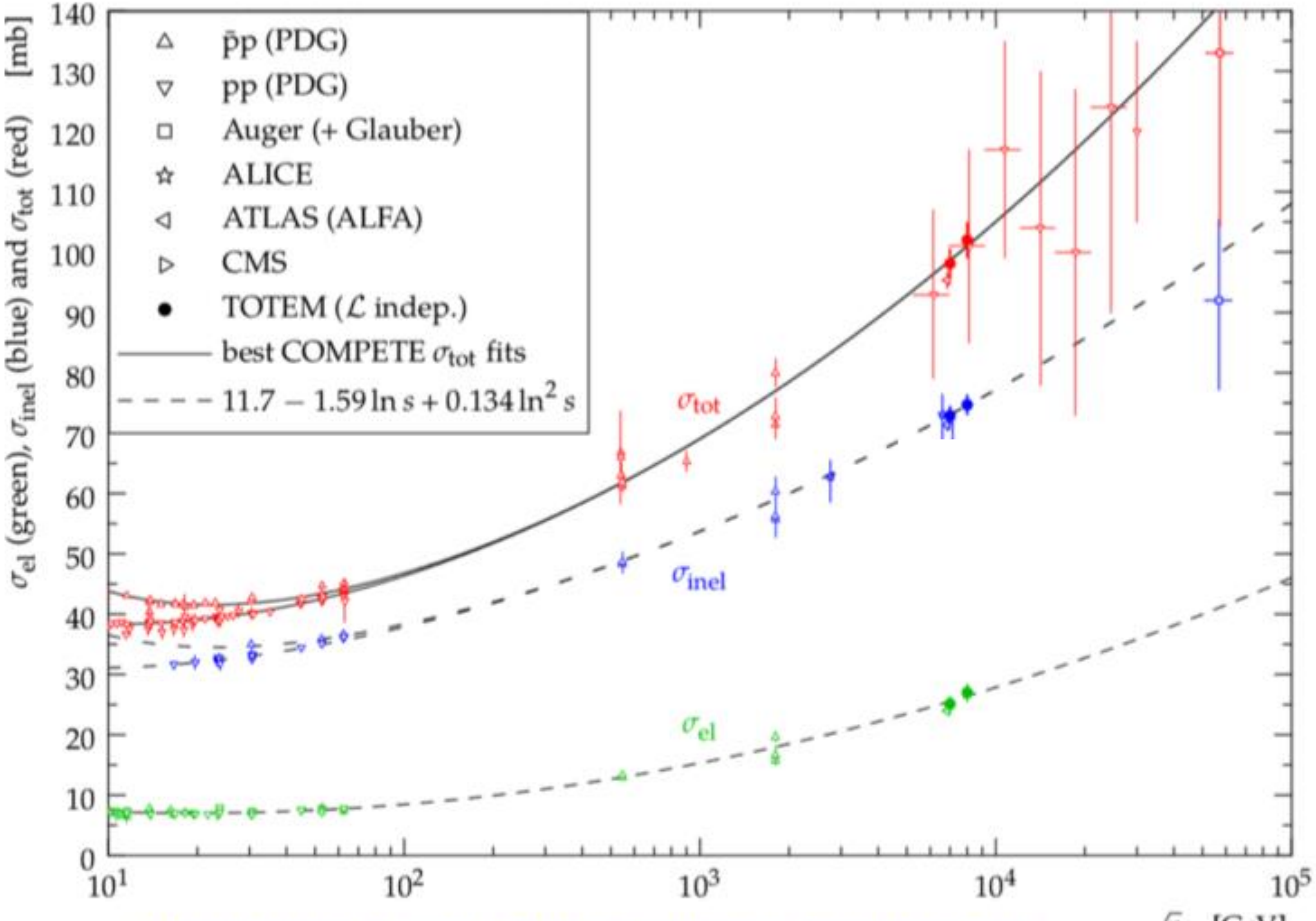
2) in the same period measure a number of interactions N, e.g. via measuring a minimum energy deposition in a detector (**M**inimum **B**ias **T**rigger **S**cintillator for ATLAS, **H**adron **F**orward **CAL**orimeter & **C**entauro **A**nd **ST**range **O**bject **R**esearch for CMS)

3) correct for detection efficiency – ε

4) correct for the possibility of having more than one interaction per bunch crossing, i.e. pileup, F_{pu}

$$\sigma_{\mathrm{inel}} = \frac{N\,F_{\mathrm{pu}}}{\varepsilon \int L\,dt}$$

situation before 13 TeV measurements

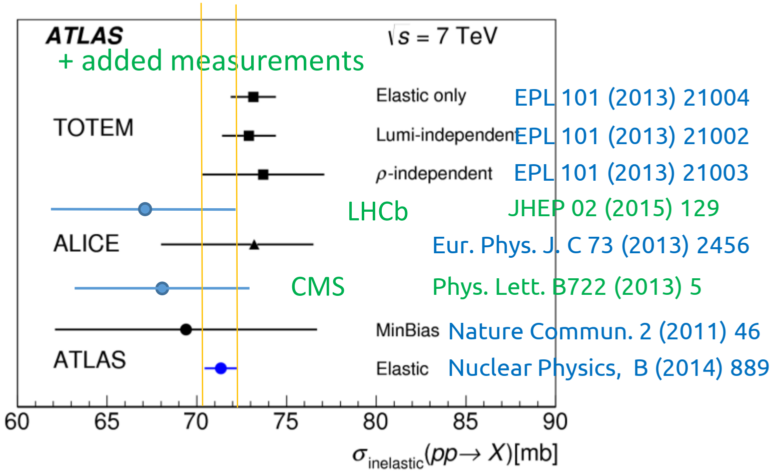


Dependences of total, inelastic and elastic cross-sections on the scattering energy √s

EPL 101 (2013) 21004
Phys. Rev. Lett. 111, 012001 (2013)

$\sqrt{s} = 7$ TeV

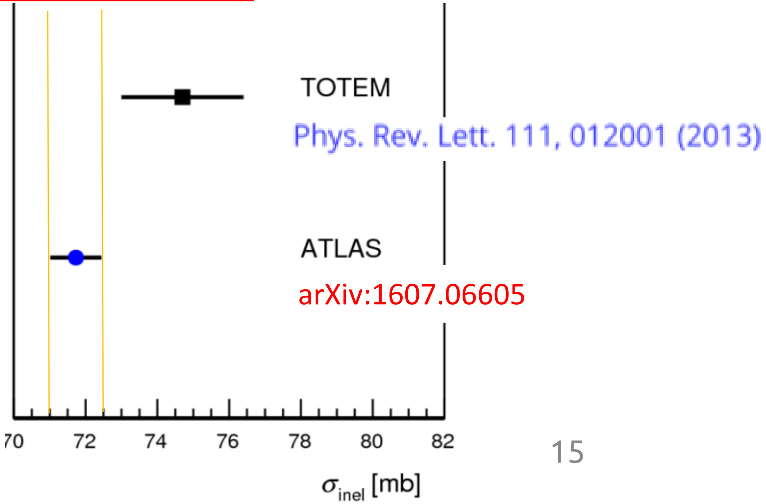
$\sigma_{inel} = 66.9 - 73.7$ mb



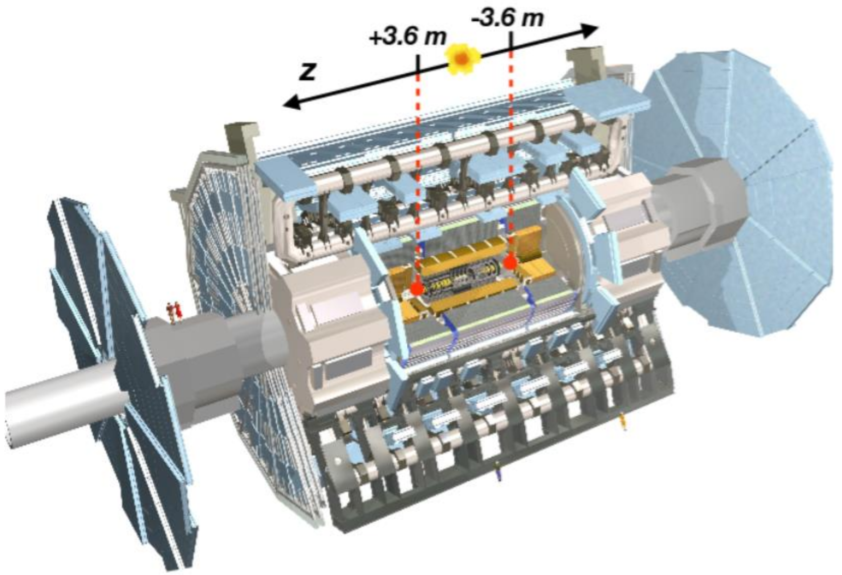
$\sqrt{s} = 8$ TeV

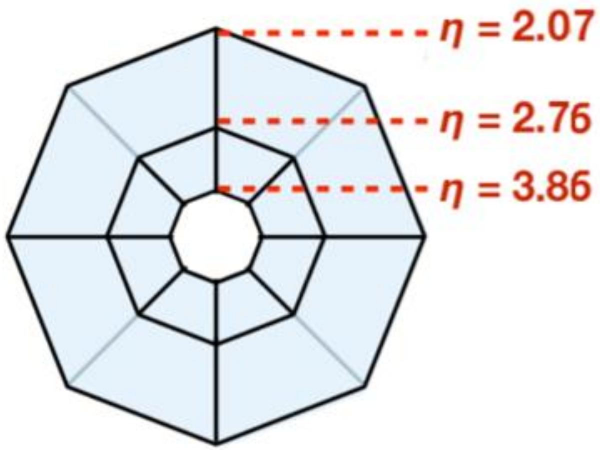
$\sigma_{inel} = 74.7 \pm 1.7$ mb TOTEM

$\sigma_{inel} = 71.78 \pm 0.71$ mb ATLAS ALFA



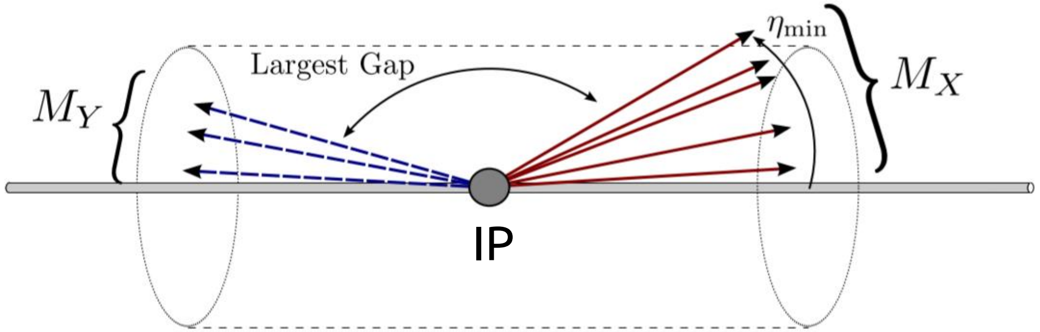
ATLAS – σ_{inel} at 13 TeV arXiv:1606.02625





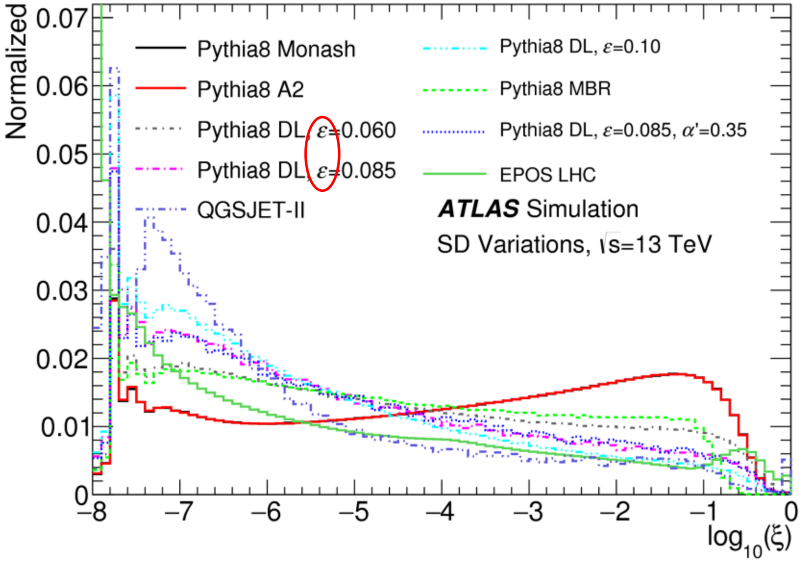
- MBTS – significantly upgraded for LHC RUN II
- 2 cm thick discs in front of forward calorimeters, made of highly efficient polystyrene scintillator
- trigger requires signal at least in one MBTS counter
- inclusive selection - at least 2 of 24 MBTS counters have to collect charge above the threshold

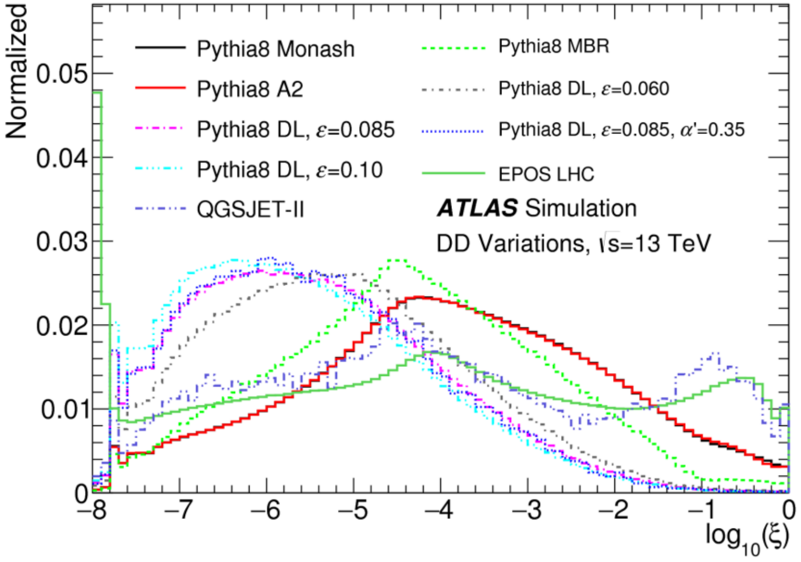
ATLAS – fiducial cut & diffractive enhancement



MBTS acceptance depends on M_X, required acceptance > 50% -> M_X > 13 GeV & $\xi_{M_X} = M_X^2/s > 10^{-6}$

uncertainty on extrapolation to full cross-section given by variations of model ξ-dependencies





try to minimize the impact of physics mismodeling within the fiducial range of the measurement by constraining the fraction of diffractive events

we get diffractive-enhanced sample by requiring hits in only one side of MBTS

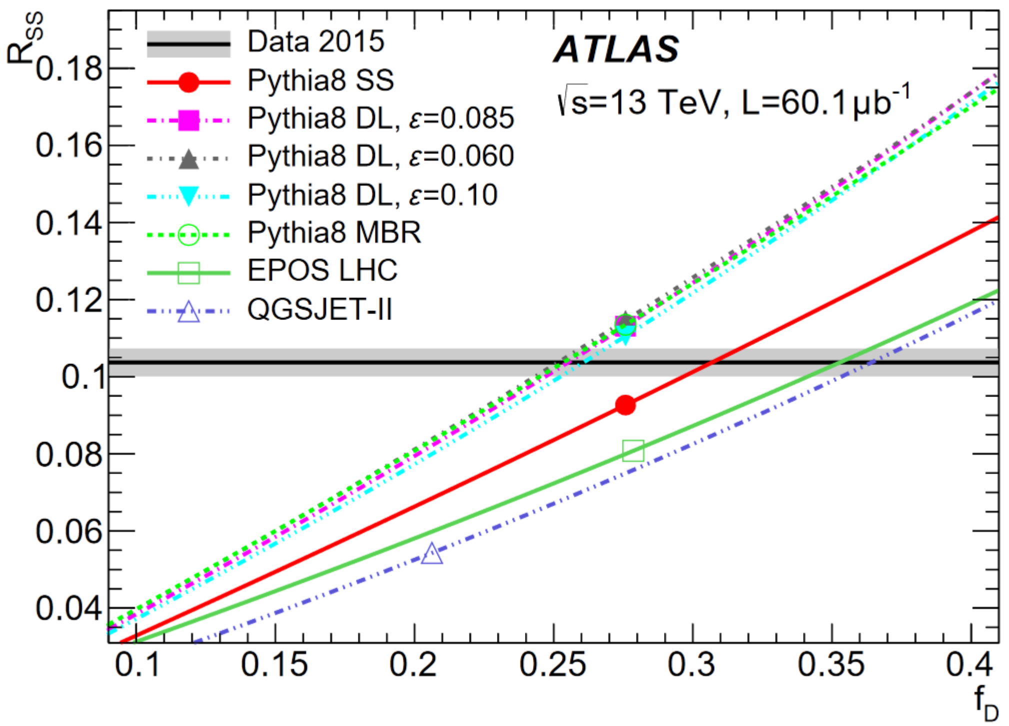
$$\alpha(t) = 1 + \varepsilon + \alpha' t$$

Regge trajectory

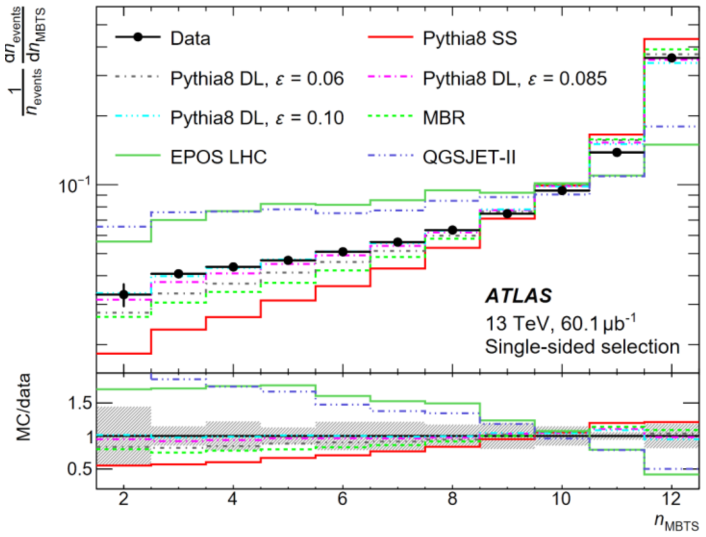
ATLAS – mc tuning and fiducial σ_{inel}

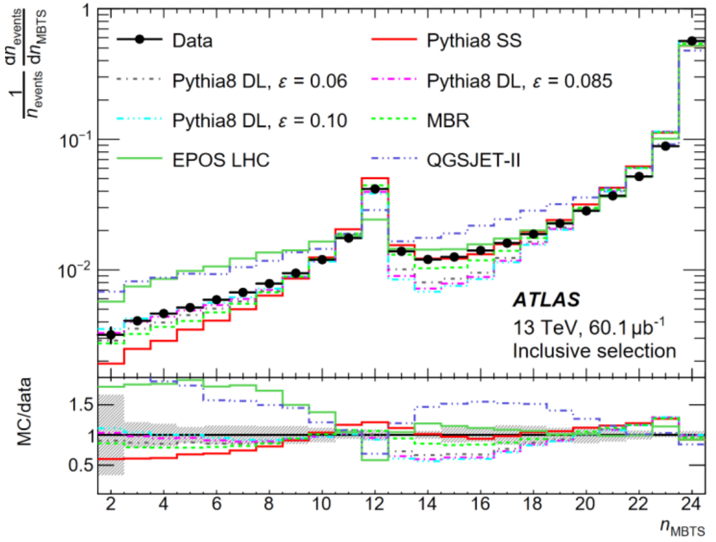
$$R_{SS} \equiv \frac{\text{Number of events in single-sided sample}}{\text{Number of events in inclusive sample}}$$

- R_{SS} depends on diffractive fraction $f_D \equiv (\sigma_{SD}+\sigma_{DD})/\sigma_{inel}$
- R_{SS} in data = 10.4 ± 0.5%
- for each generator/tune, f_D tuned to match R_{SS} measured in data
  e.g f_D(Pythia DL) = 25%



after the tuning



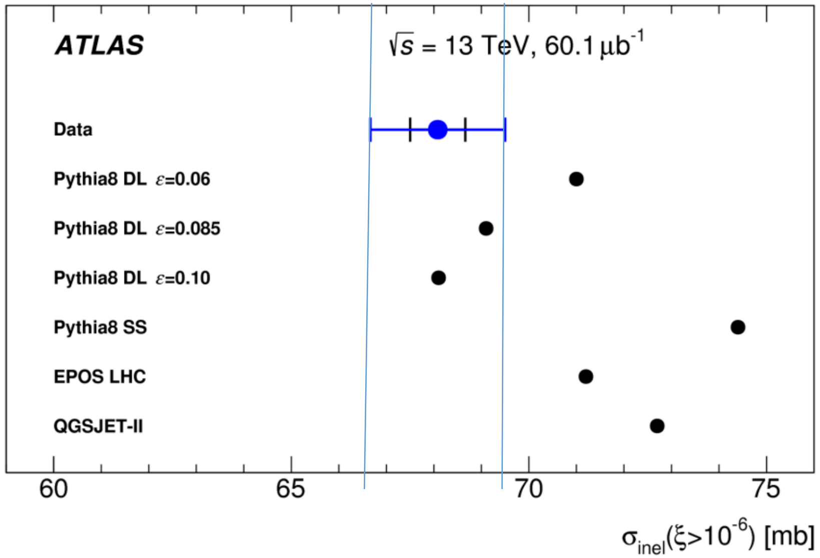


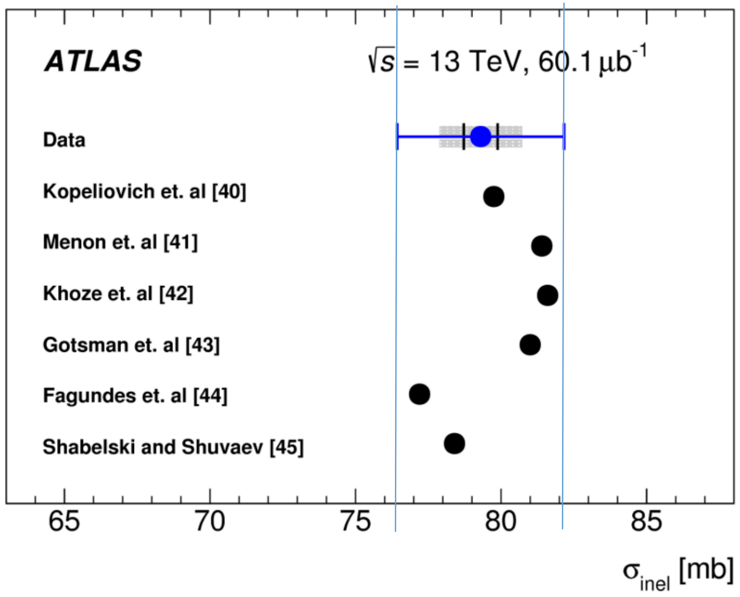
Factor	Value	Rel. uncertainty
Number of events passing the inclusive selection (N)	4159074	–
Number of background events (N_{BG})	51187	±50%
Integrated luminosity [μb^{-1}] ($\mathcal{L}$)	60.1	±1.9%
Trigger efficiency (ϵ_{trig})	99.7%	±0.3%
MC correction factor (C_{MC})	99.3%	±0.5%

$$\sigma_{inel}^{fid}\left(\xi > 10^{-6}\right) = \frac{N - N_{BG}}{\epsilon_{trig} \times \mathcal{L}} \times \frac{1 - f_{\xi<10^{-6}}}{\epsilon_{sel}},$$

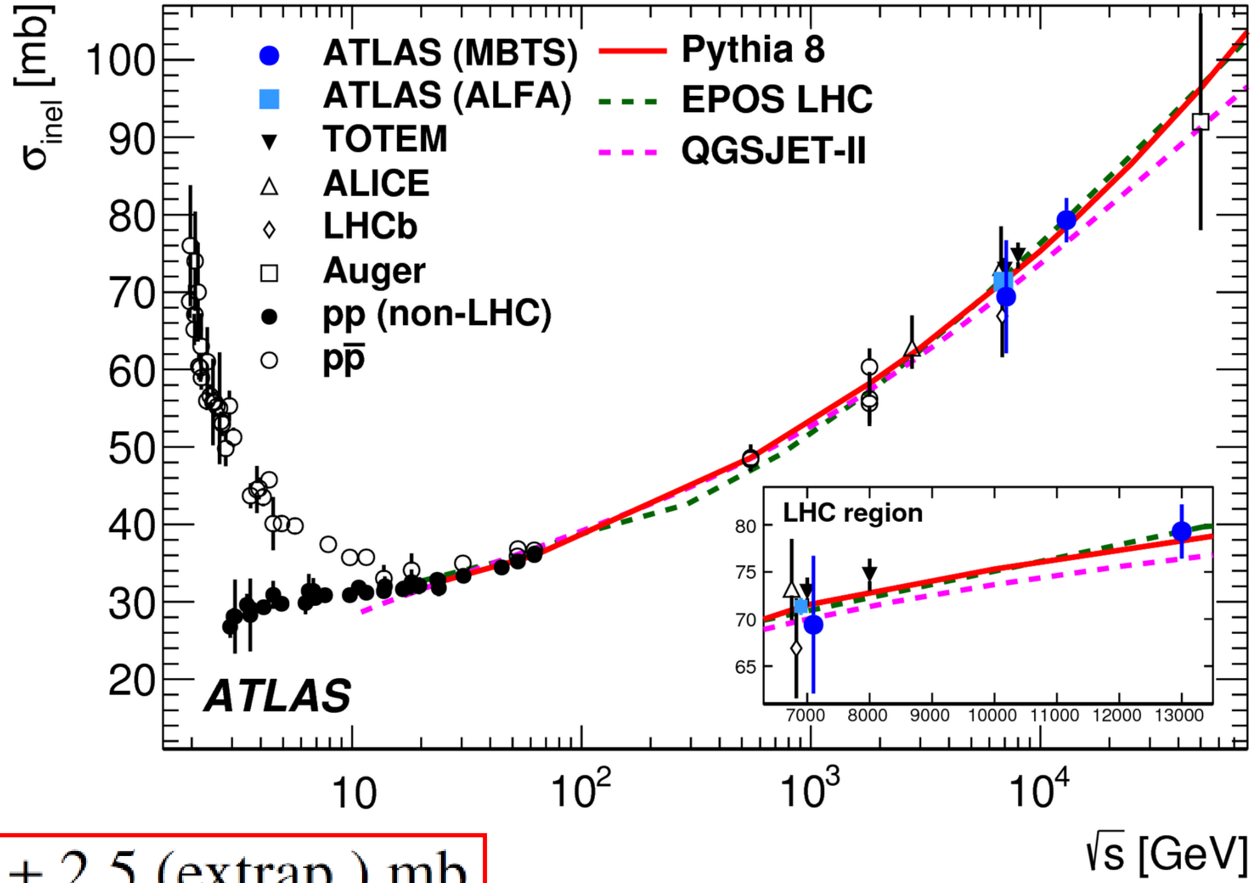
$$\sigma_{inel}^{fid} = 68.1 \pm 0.6\ (\text{exp.})\ \pm 1.3\ (\text{lum.})\ \text{mb}$$

ATLAS – extrapolated σ_{inel}





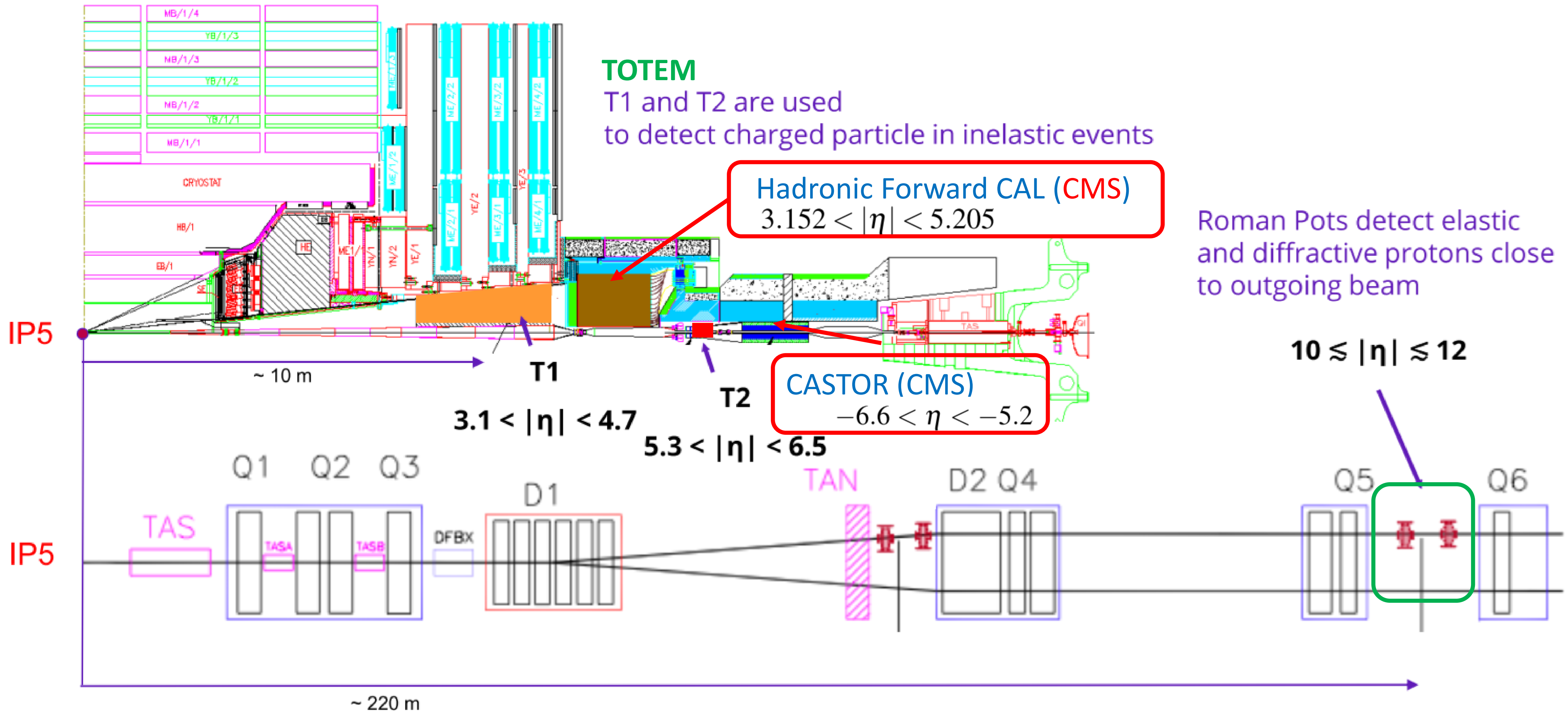
$$\sigma_{inel} = \sigma_{inel}^{fid} + \sigma^{7\,TeV}(\xi < 5\times10^{-6}) \times \frac{\sigma^{MC}(\xi < 10^{-6})}{\sigma^{7\,TeV,\,MC}(\xi < 5\times10^{-6})}$$



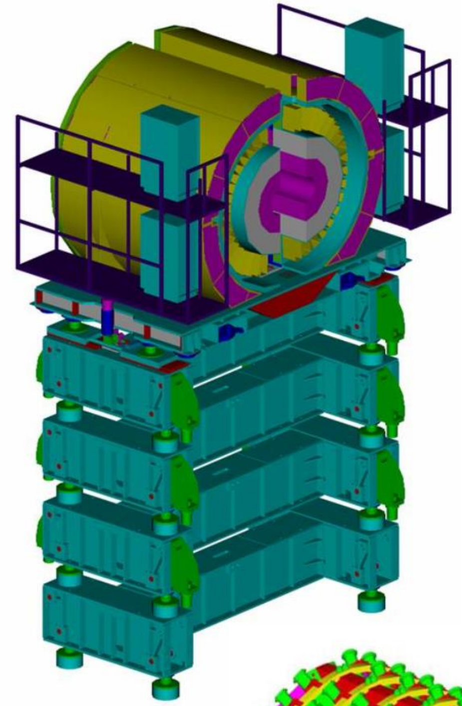
$$\sigma_{inel} = 79.3 \pm 0.6\,(\text{exp.}) \;\pm 1.3\,(\text{lum.}) \;\pm 2.5\,(\text{extrap.})\text{ mb}$$

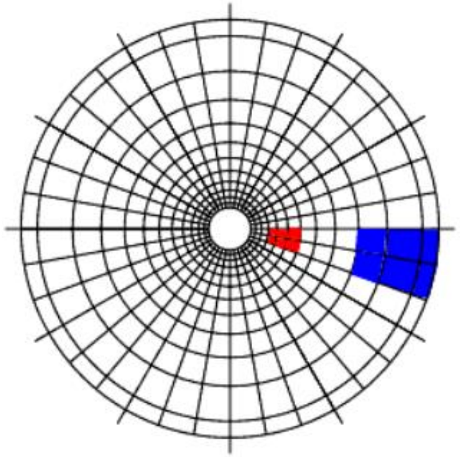
CMS – forward detectors and σ_{inel} at 13 TeV

CMS-PAS-FSQ-15-005



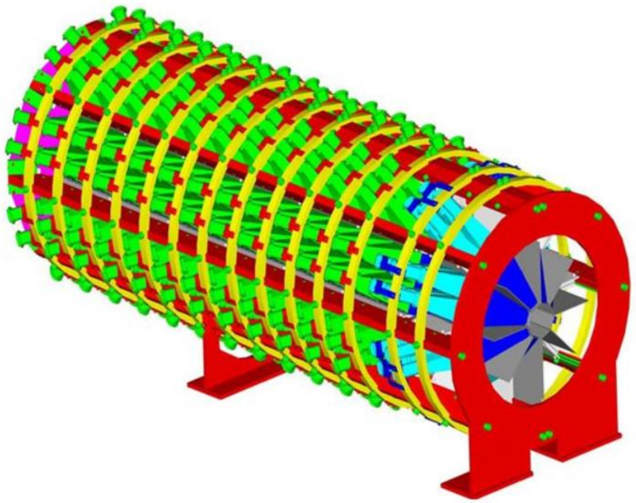
CMS HFCAL and CASTOR





HFCAL

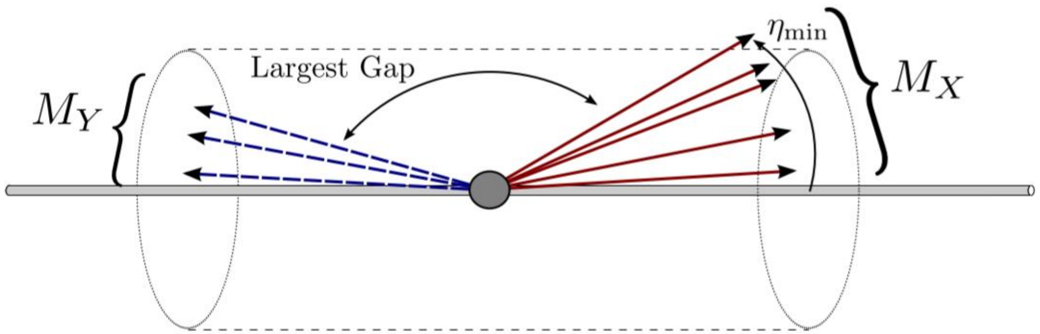
- 18 iron azimuthal wedges, with embedded quartz fibers running along the beam direction
- each wedge is subdivided into 13 pseudorapidity segments (towers)



CASTOR

- tungsten and quartz layers, 14.385 m from IP
- segmented in 16-sectors and 14 *z*-modules, in total 224 cells.
- CASTOR was only partially included in the detector setup during the run periods considered in this analysis

CMS – runs conditions and systematics



$$\xi_X = \frac{M_X^2}{s}, \qquad \xi_Y = \frac{M_Y^2}{s} \qquad \xi = \max(\xi_X, \xi_Y)$$

$B = 3.8$ T

Run	Purity (%)	Pileup (%)	Particle level cross section (mb) $\xi > 10^{-6}$
254989	98.54	52.29	65.60 ± 0.05
255019	99.18	53.72	65.89 ± 0.04
255029	99.25	53.95	65.74 ± 0.04

$B = 0$ T

Run	Purity (%)	Pileup (%)	Particle level cross section (mb) $\xi_X > 10^{-7}$ or $\xi_Y > 10^{-6}$
247324	98.53	5.14	67.08 ± 0.46
247920	98.85	34.18	66.84 ± 0.07
247934	98.78	31.99	66.84 ± 0.09

systematics

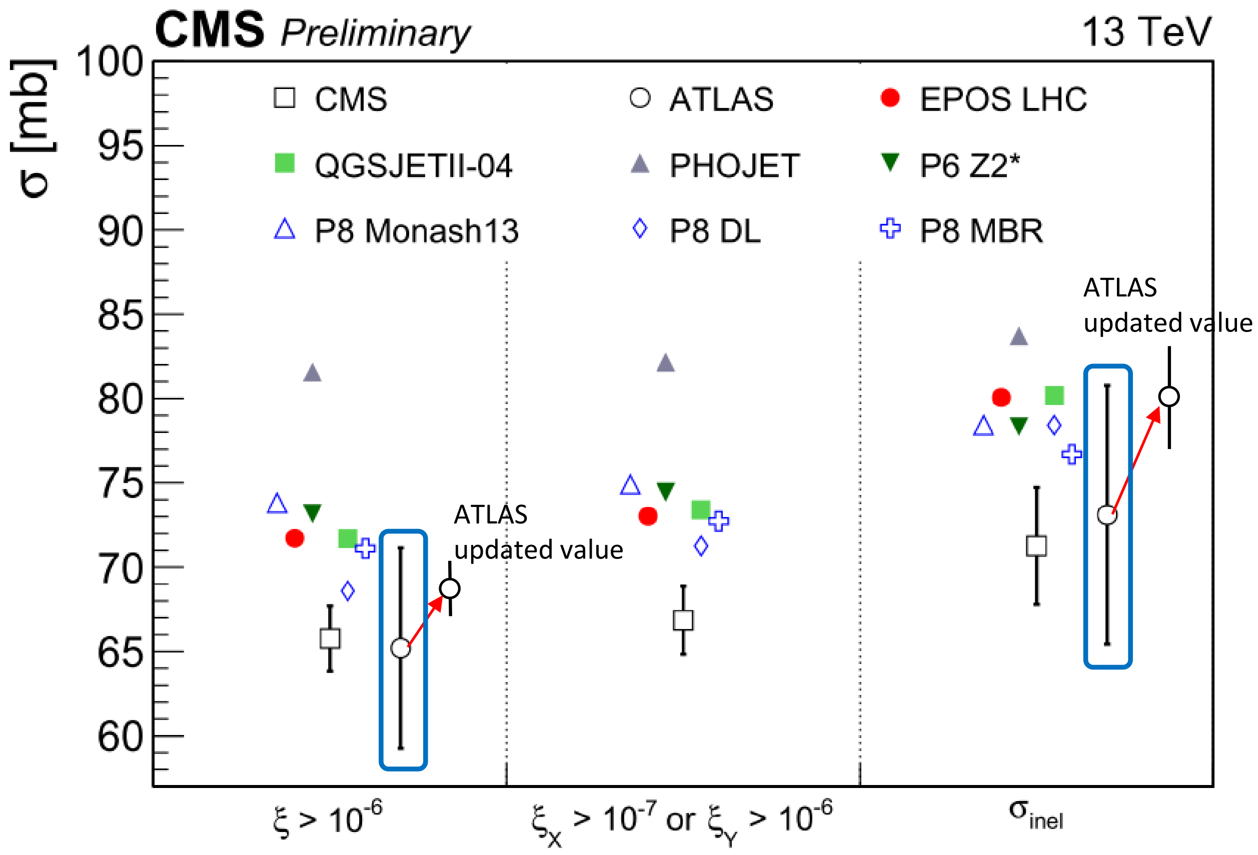
	$\sigma(\xi > 10^{-6})$ (mb)	$\sigma(\xi_X > 10^{-7}$ or $\xi_Y > 10^{-6})$ (mb)
Model dependence	0.66	0.38
HF energy scale uncertainty	0.34	0.13
CASTOR energy scale uncertainty	-	0.04
CASTOR alignment	-	0.03
Run-to-run variation	0.15	0.14
Total	0.76	0.44
Luminosity	1.78	1.96

$$\sigma = \frac{N_{\text{int}}(1 - b_\xi)}{\epsilon_\xi \int \mathcal{L}\, dt}$$

ϵ_ξ – fraction of selected stable-particle level events that fulfill the detector-level offline selection criteria

b_ξ – the contamination – fraction of detector-level offline selected events that are not part of the considered stable-particle level phase space domain

CMS – σ_{inel} at 13 TeV



$$\sigma\left(\xi > 10^{-6}\right) = 65.8 \pm 0.8\ (\text{exp.}) \pm 1.8\ (\text{lum.})\ \text{mb}$$

$$\sigma\left(\xi_X > 10^{-7}\ \text{or}\ \xi_Y > 10^{-6}\right) = 66.9 \pm 0.4\ (\text{exp.}) \pm 2.0\ (\text{lum.})\ \text{mb}$$

$$\sigma_{\text{inel}} = 71.3 \pm 0.5\ (\text{exp.}) \pm 2.1\ (\text{lum.}) \pm 2.7\ (\text{ext.})\ \text{mb}$$

measured cross section is significantly lower than predicted by models for hadronic scattering and ATLAS

outlook

ATLAS ALFA

- ongoing analysis of 8 TeV data for $\beta^* = 1$ km – cross sections, B and rho parameters
- measurement covering CNI region for $\beta^* = 2500$ m at 13 TeV, fall of 2016 – planned 1 week of data taking

TOTEM

- ongoing cross sections analyses at 2.76 TeV for $\beta^* = 11$m and at 13 TeV for $\beta^* = 90$ m
- a new publication in preparation for $\beta^* = 1$ km, confirming the previously obtained results by TOTEM
- measurement covering CNI region for $\beta^* = 2500$ m at 13 TeV – cross sections, rho measurement, common week with ALFA
- search for oderon

LHCb

- inelastic cross section at 13 TeV, end of 2016

outlook

- understanding of differences: ALFA vs TOTEM, ATLAS vs CMS…
  and

- measurements at 14 TeV

backup

optics

- no sextupoles between IP and RPs -> movement in x and y planes independent
- elastic proton (no dispersion), deflected in the IP from a vertex position x, under an angle θ_x arrives to detector

$$\begin{pmatrix} x \\ \theta_x \end{pmatrix}_{\mathrm{RP}} = \mathrm{M}_{\mathrm{IP}\to\mathrm{RP}} \begin{pmatrix} x \\ \theta_x \end{pmatrix}_{\mathrm{IP}}, \quad \mathrm{M}_{\mathrm{IP}\to\mathrm{RP}} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix}$$

- in case of parallel to point optics

$$x_{\mathrm{RP}} = L_x^{\mathrm{eff}}\, \theta_{x\,\mathrm{IP}}$$

i.e. the scattering angle

$$\theta_{\mathrm{IP}} = \sqrt{\theta_{x\mathrm{IP}}^2 + \theta_{y\mathrm{IP}}^2}$$

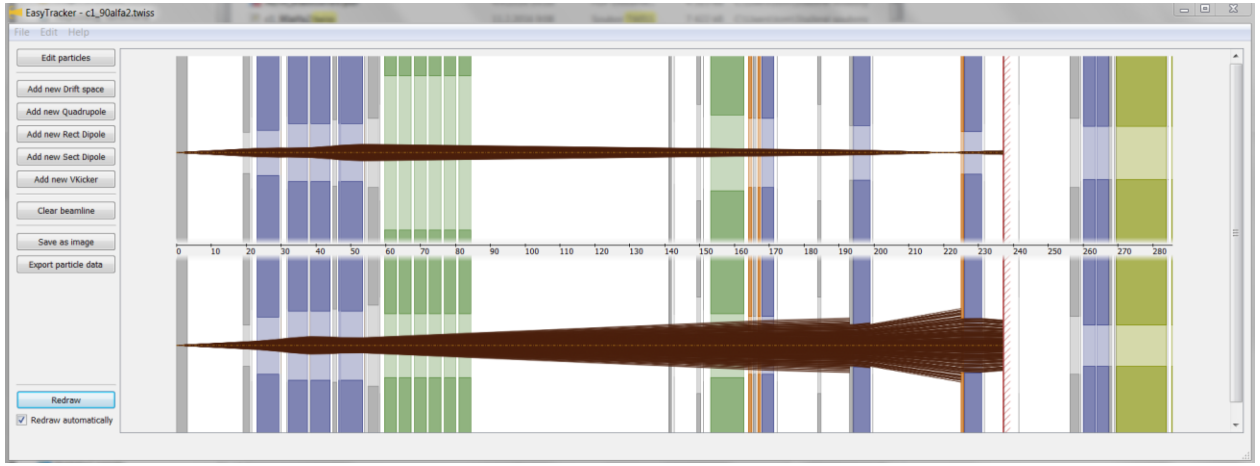
and

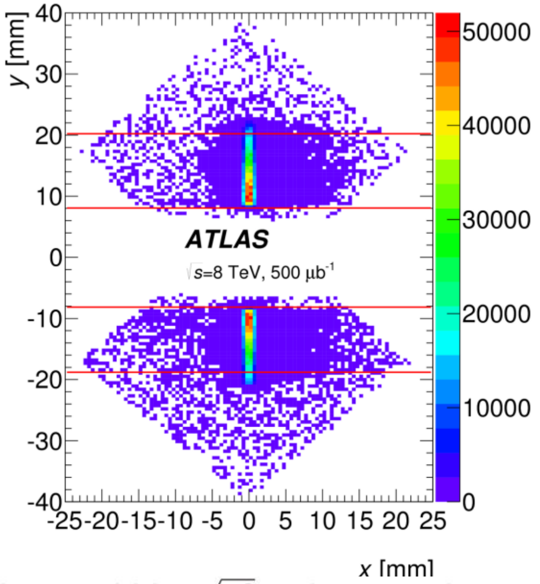
$$t = -p_0^2 \theta_{\mathrm{IP}}^2$$

can be directly written as function of x_{RP}

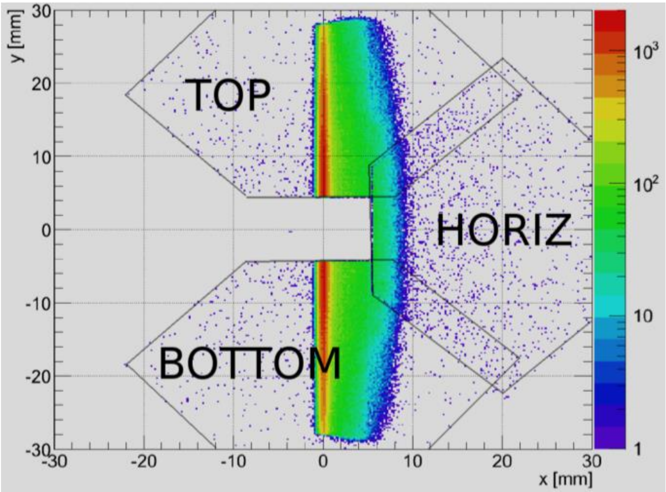
Easy Tracker – beam 1

T. Komárek





- beam width: $\sqrt{\varepsilon\beta}$, ε: beam emittance
- beam angular divergence: $\sqrt{\varepsilon/\beta}$!
- luminosity $\propto$ (beam width at IP)$^{-2}$ $\propto 1/\beta^*$



$\beta^* = 90$ m (special for TOTEM)

$L_x \approx 0$, $L_y \approx 260$ m, $D_x \approx 4$ cm

diffractive protons in *vertical RPs*

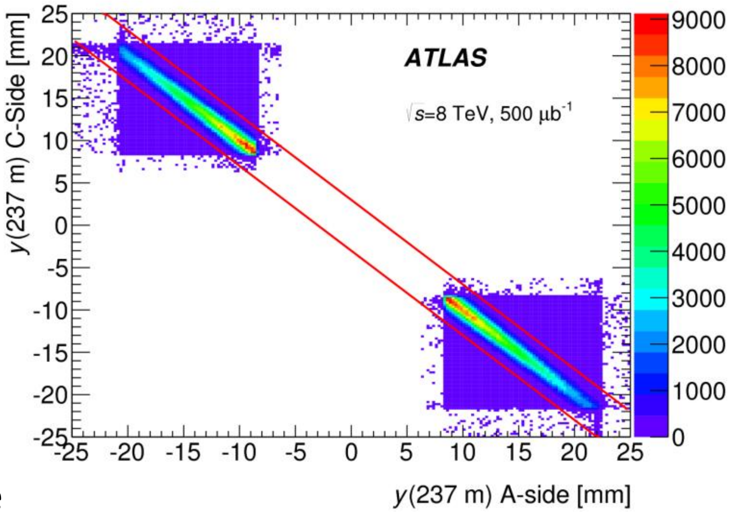
J. Kašpar, QCD at Cosmic Energies – VII., 2016

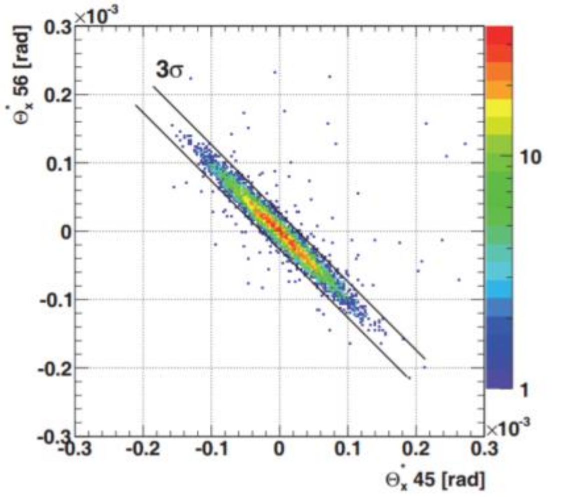
event selection

both TOTEM and ALFA have the same event selection logic although technically differently realized

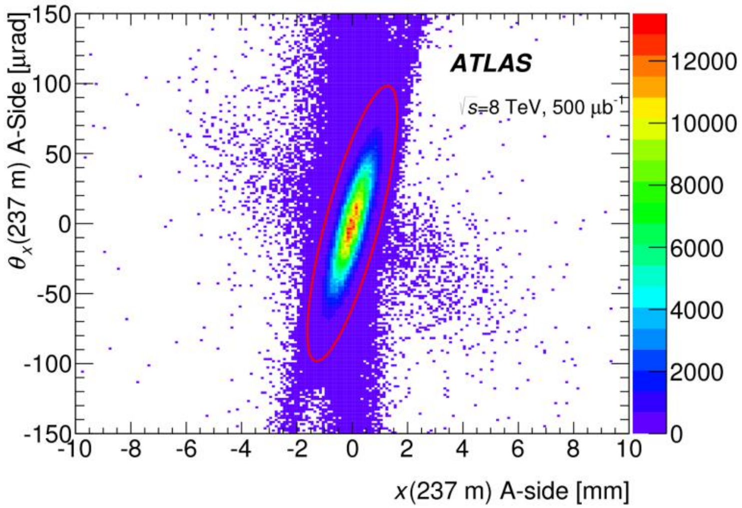
ALFA

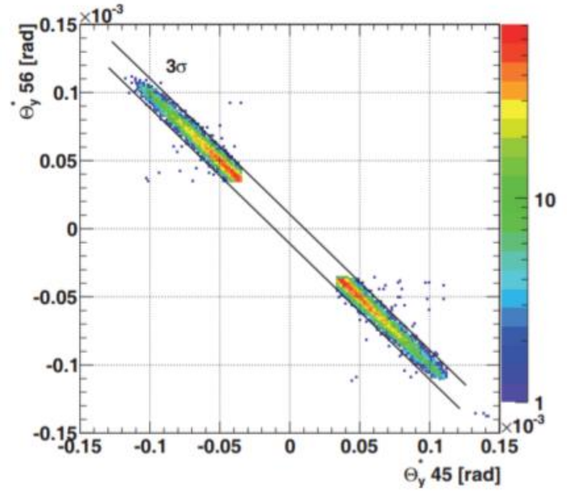
- Lvl1 elastic trigger
- good LBs based on data quality
- geometrical cuts
- elastics selections





e



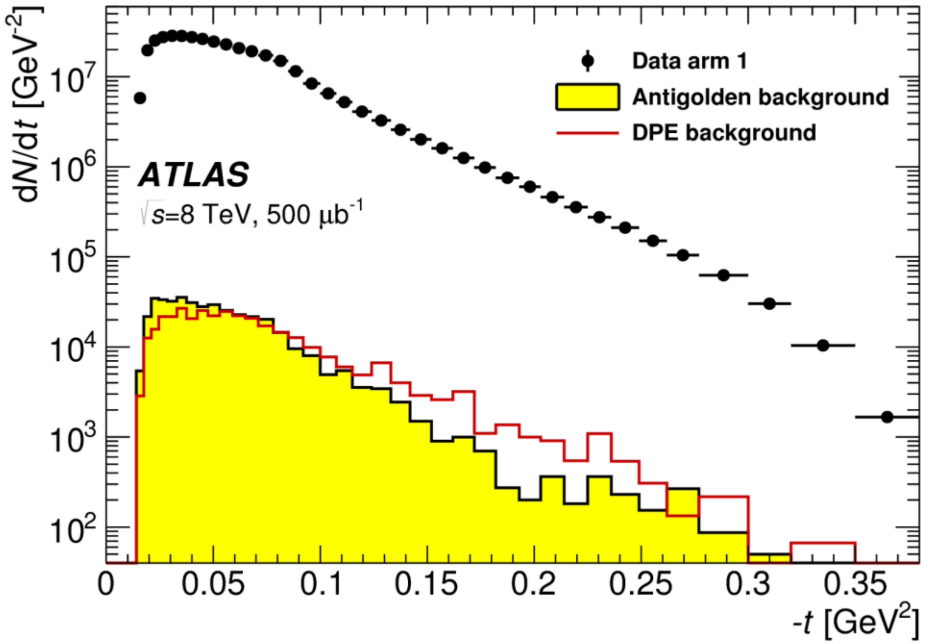


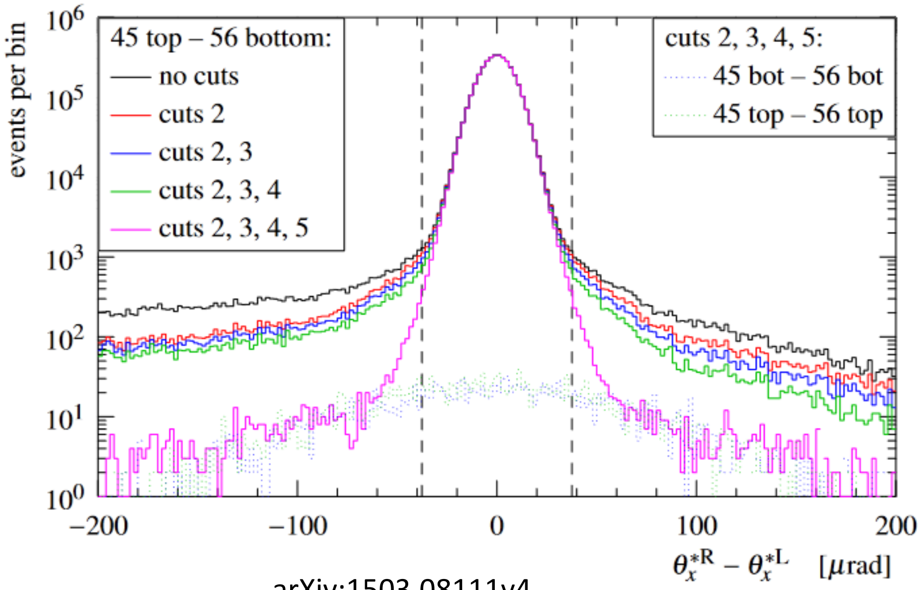
7 TeV, EPL 96 (2011) 21002

background

ways to estimate the irreducible background under the elastic peak:

- counting events in the anti-golden configuration, can also be used to get a *t*-spectrum for background events for subtraction – nominal method for ALFA
- reconstructing the vertex distribution in x through the lattice, where background appears in non Gaussian tails, fraction estimated with background templates obtained from data – nominal for systematics ALFA, nominal TOTEM)
- TOTEM uses the non-colliding bunches to estimate the level of beam-gas background for the measurement of the inelastic rate



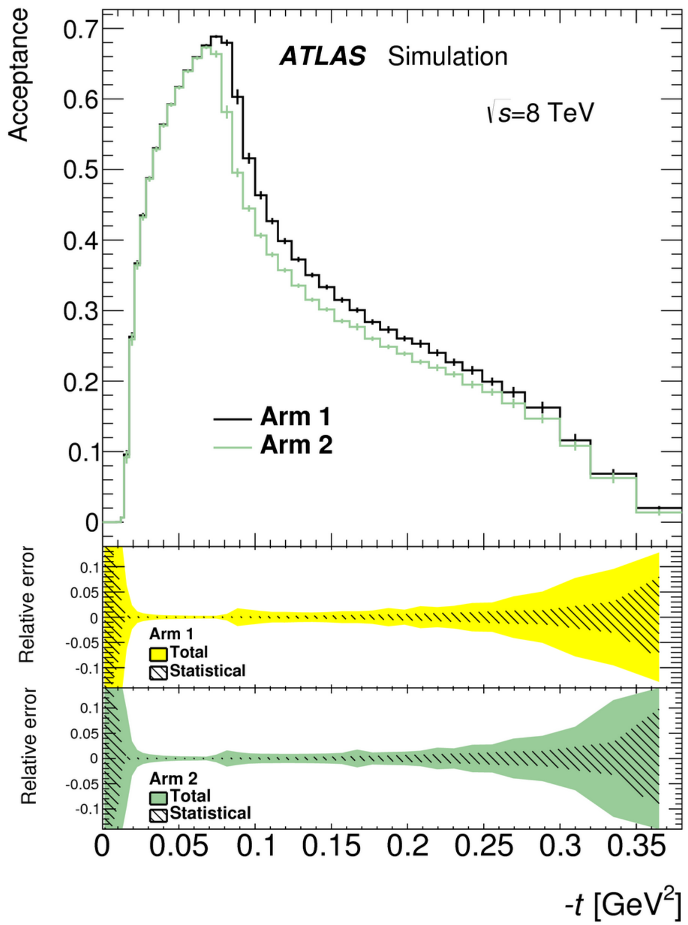


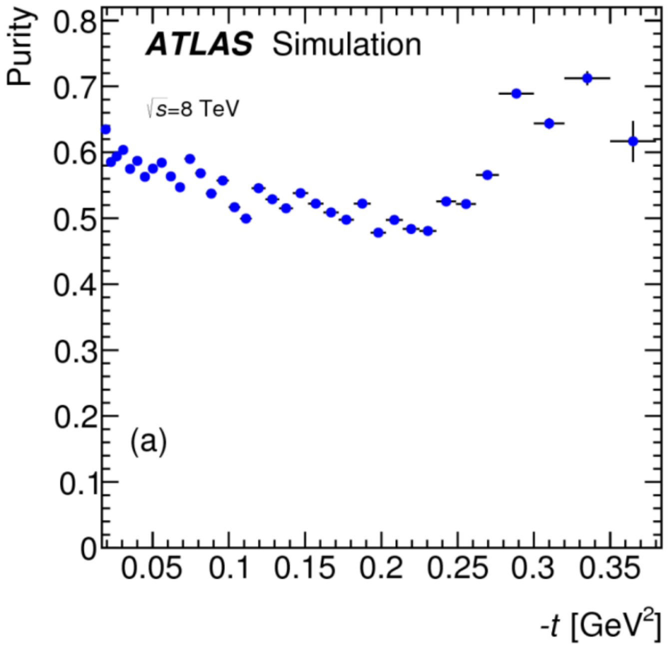
arXiv:1503.08111v4

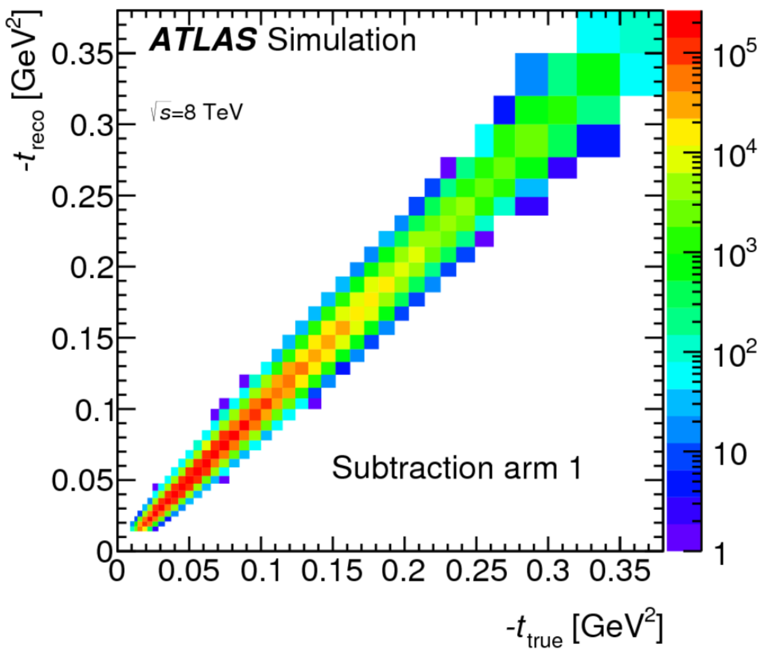
acceptance, purity & migration

$$\frac{d\sigma_{el}}{dt_i} = \frac{1}{\Delta t_i} \times \frac{\mathcal{M}^{-1}[N_i - B_i]}{A_i \times \epsilon^{reco} \times \epsilon^{trig} \times \epsilon^{DAQ} \times L_{int}}$$

where Δt_i is width of the i-th bin, M^{-1} represents the unfolding procedure applied to the background-subtracted number of events $N_i - B_i$, A_i is the acceptance, ϵ^{reco} is the event reconstruction efficiency, ϵ^{trig} is the trigger efficiency, ϵ^{DAQ} is the dead-time correction and L_{int} is the integrated luminosity

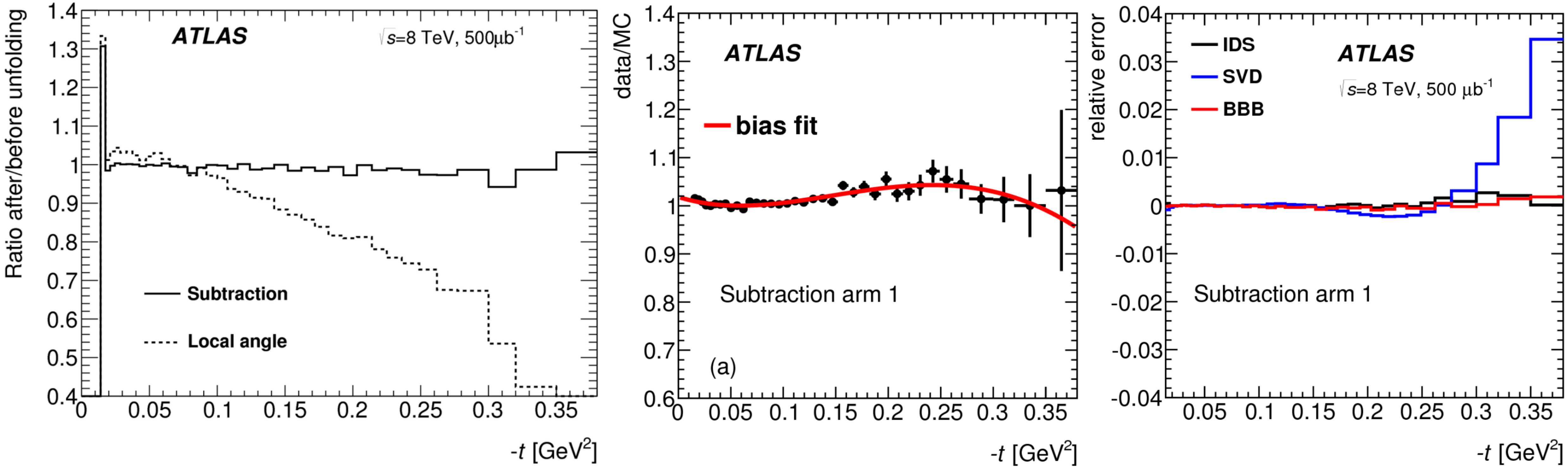






unfolding

Iterative dynamically stabilized unfolding used, cross-checked with bin-by-bin and singular value decomposition methods, unfolding impact for subtraction method is very small



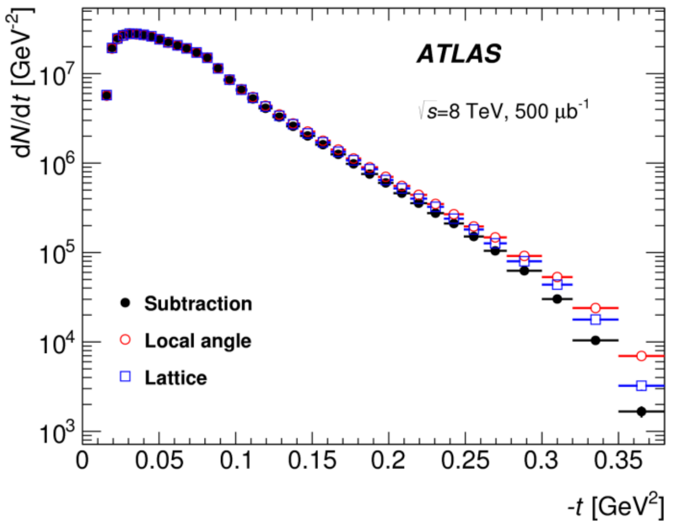
Data/MC ratio at reconstruction level is parametrized to re-weight the simulation. The data-driven closure test consists of the comparison of the unfolded modified reconstruction level spectrum with the modified particle level spectrum.

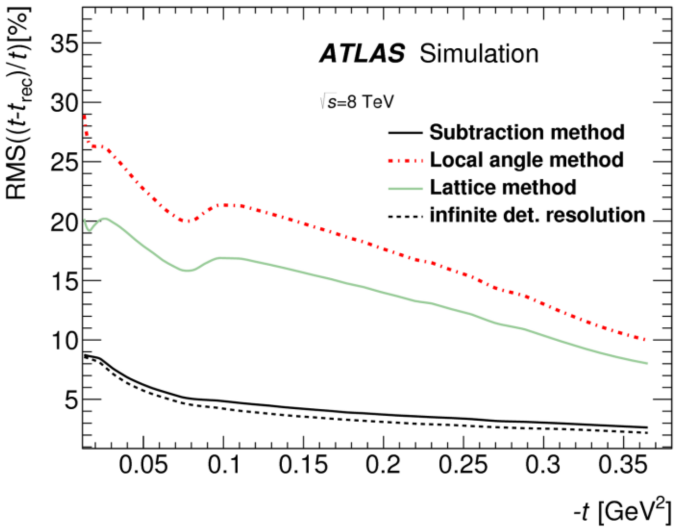
reconstruction & reco efficiency

$$\theta^\star_w = \frac{w_A - w_C}{M_{12,A} + M_{12,C}}$$ subtraction

$$\theta^\star_w = \frac{\theta_{w,A} - \theta_{w,C}}{M_{22,A} + M_{22,C}}$$ local angle

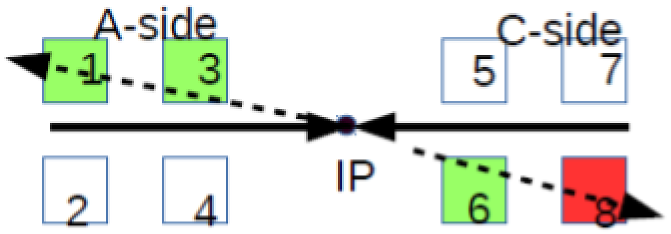
$$\theta^\star_w = M_{12}^{-1} \times w + M_{22}^{-1} \times \theta_w$$ lattice





reco eff: fully data-driven method, using a tag-and-probe approach exploiting elastic back-to-back topology and high trigger efficiency

$N_{3/4}$

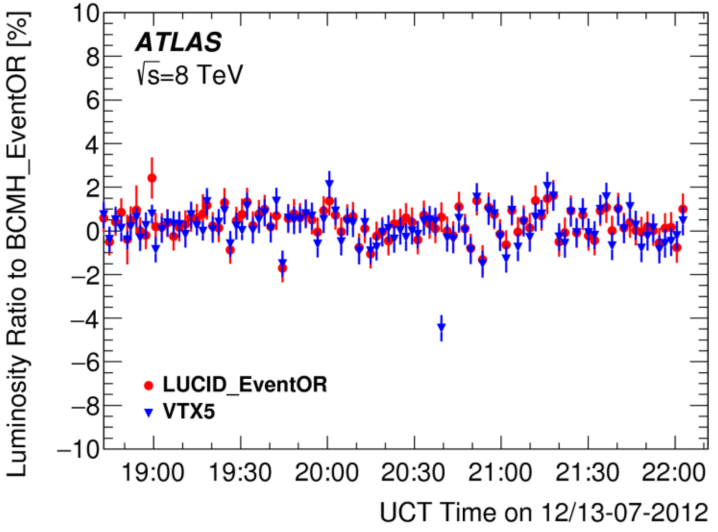


$$\varepsilon_{rec} = \frac{N_{reco}}{N_{reco} + N_{fail}} = \frac{N_{4/4}}{N_{4/4} + N_{3/4} + N_{2/4} + N_{(1+1)/4} + N_{1/4} + N_{0/4}}$$

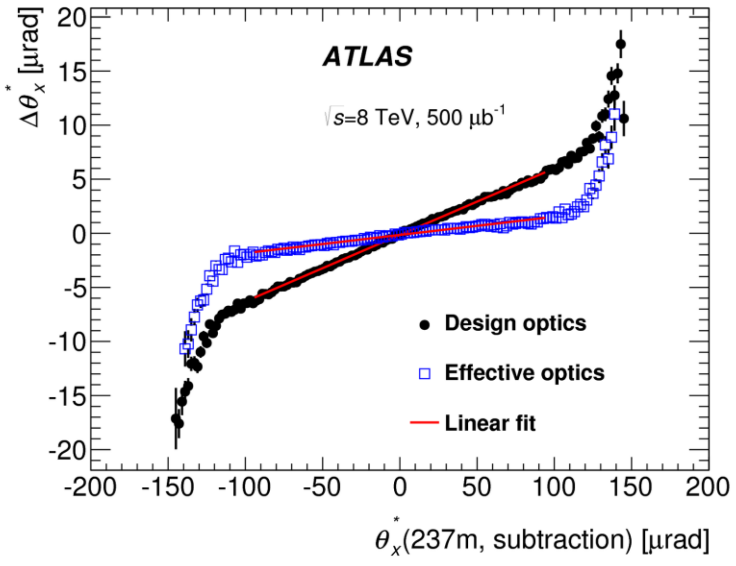
$$\varepsilon_{arm1} = 0.9050 \pm 0.0003_{stat} \pm 0.0034_{syst}$$
$$\varepsilon_{arm2} = 0.8883 \pm 0.0003_{stat} \pm 0.0045_{syst}$$

luminosity and beam optics

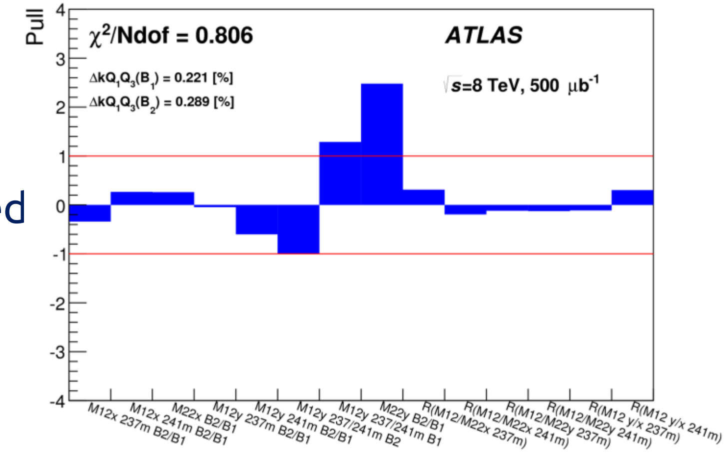
$$L_{int} = 496.3 \pm 0.3_{stat} \pm 7.3_{sys}\ \mu b^{-1}$$



	high β^* run
Source	*value*(%)
Calibration	1.20
Time stability	0.80
Afterglow Background	0.05
Beam-Gas Background	0.30
Calibration Transfer	-
Run-to-Run consistency	-
Total	1.47

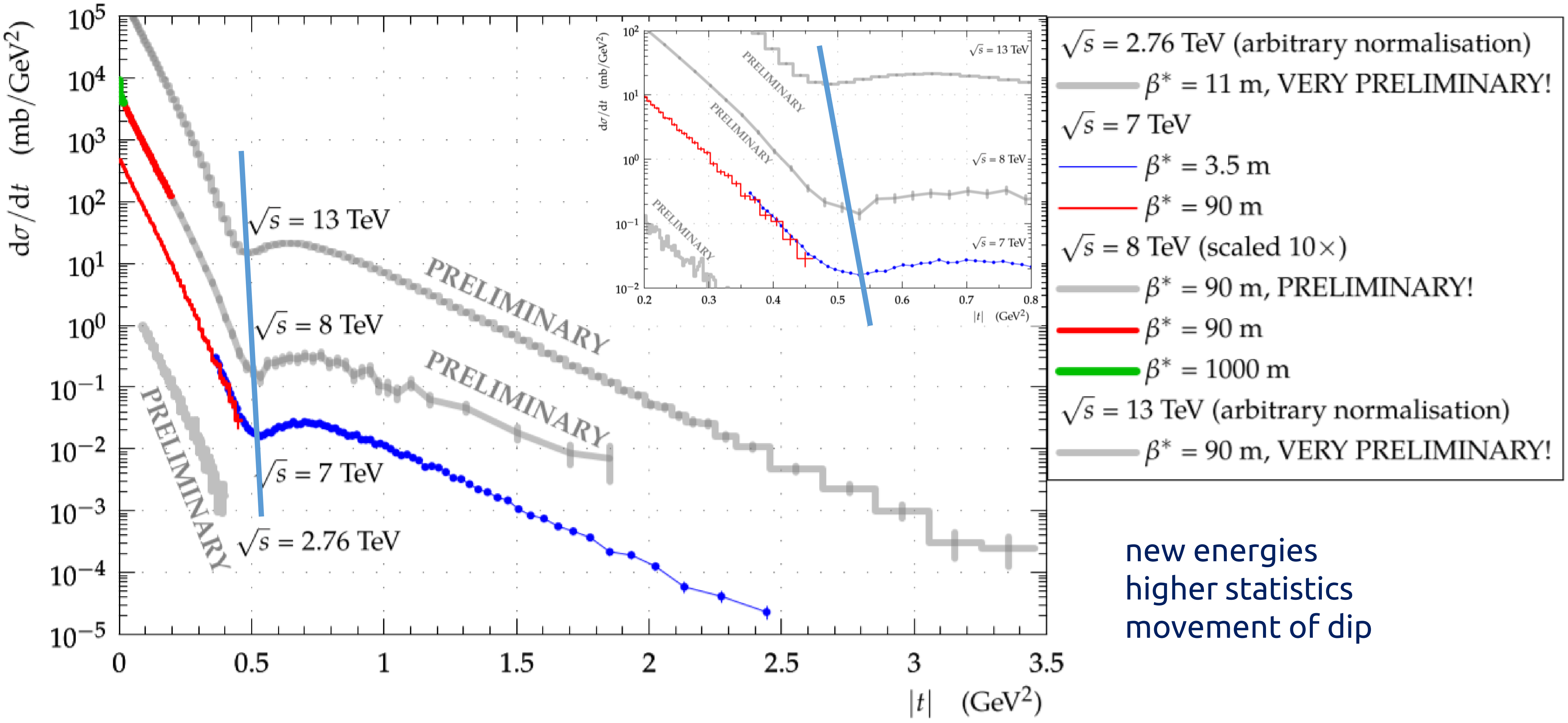


- several constraints were recorded to fine-tune the transport matrix elements
- they are obtained from correlations in the positions/angles or by comparing the reconstructed scattering angle from different methods based on different transport matrix elements



the difference in reconstructed scattering angle in horizontal plane between subtraction and local angle method vs Θ^*_x from subtraction -> scaling factor R(M12/M22)

TOTEM further (preliminary) measurements



new energies
higher statistics
movement of dip