Total and Elastic cross-sections

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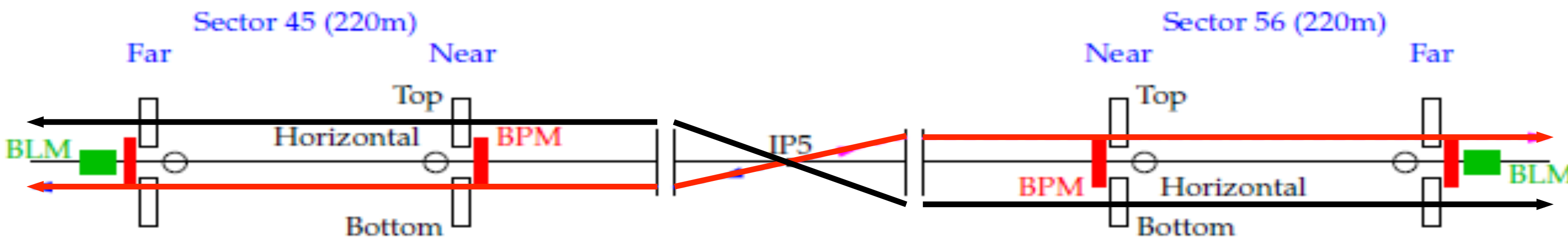
outline

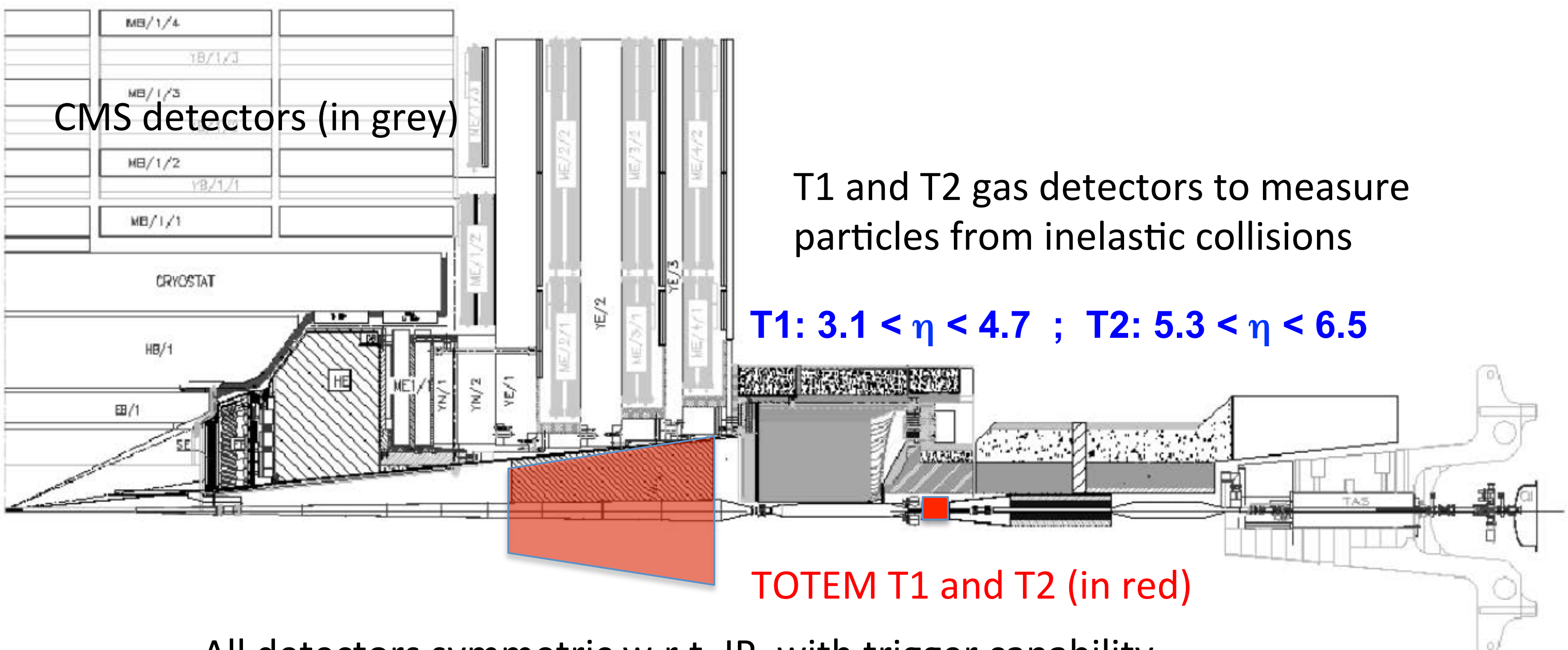
- Experimental technique
- Results
  - Elastic scattering
  - Total cross-section
  - Interference region
- A short overview on future measurements
  - Upgraded detectors
  - Measurement programme
- Conclusions

TOTEM detectors



Silicon detectors in Roman Pots to tag elastic and diffractive protons

CMS detectors (in grey)



T1 and T2 gas detectors to measure particles from inelastic collisions

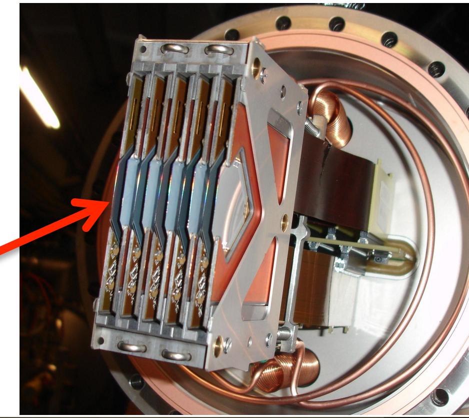
T1: 3.1 < η < 4.7 ; T2: 5.3 < η < 6.5

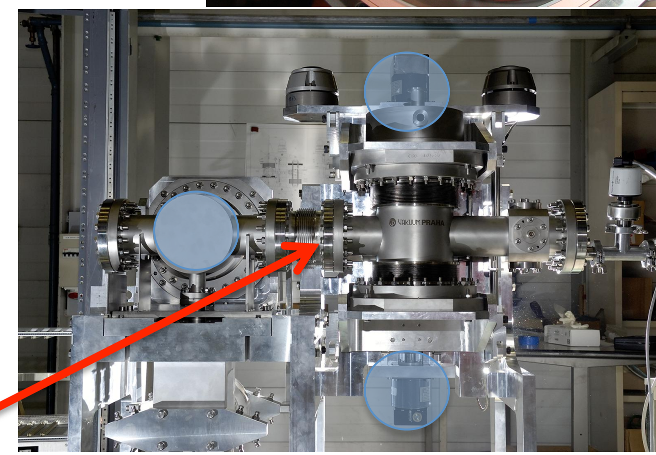
TOTEM T1 and T2 (in red)

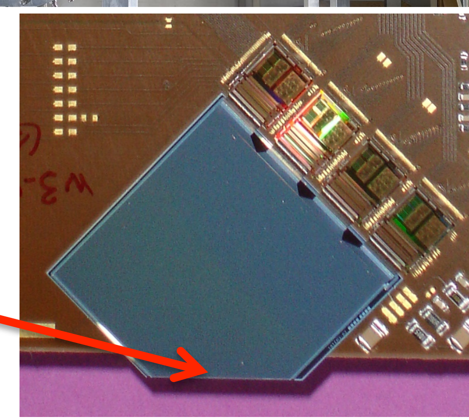
All detectors symmetric w.r.t. IP, with trigger capability

TOTEM Roman Pot detectors

- a RP is a movable beam-pipe insertion device equipped with particle detectors
  - contains 5x2 back-to-back silicon strip detectors
  - retracted when beam unstable or unsuitable (or not in use)
  - close to beam for data taking
- each “station” = near+far units, 3 RPs per unit
  - top+bottom+horizontal in each unit
- edge-less silicon sensors
  - insensitive edge reduced to 50μm
  - 66μm pitch at 45° w.r.t. edge

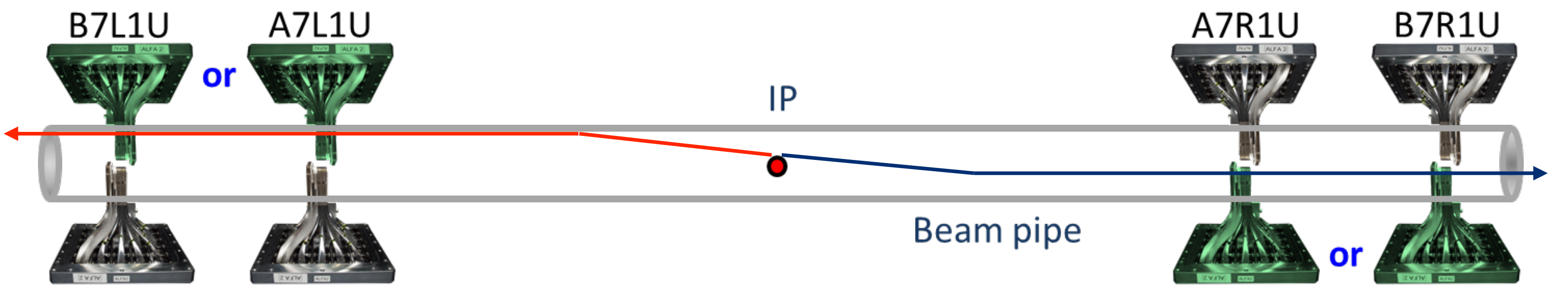






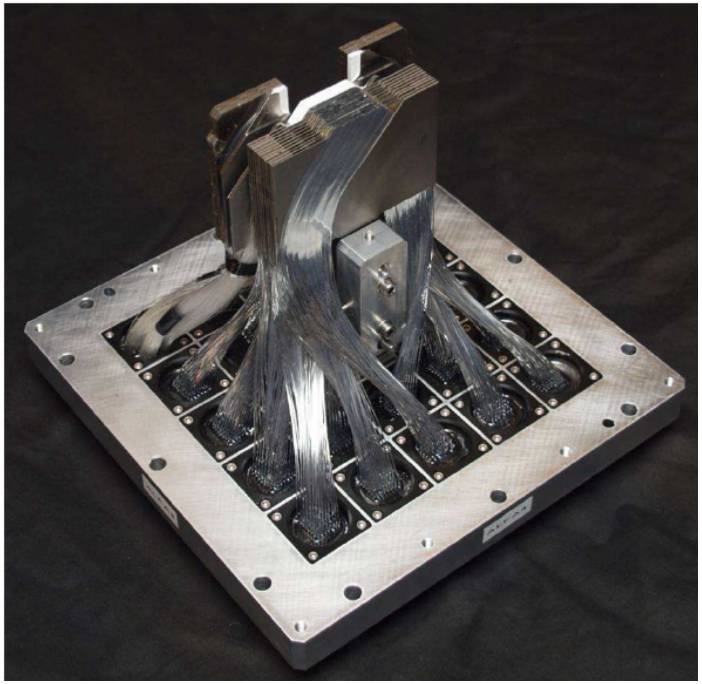
Elastic scattering with ATLAS-ALFA

Roman Pot detectors at 240m from IP1 approaching the beam during special runs at high β^*.



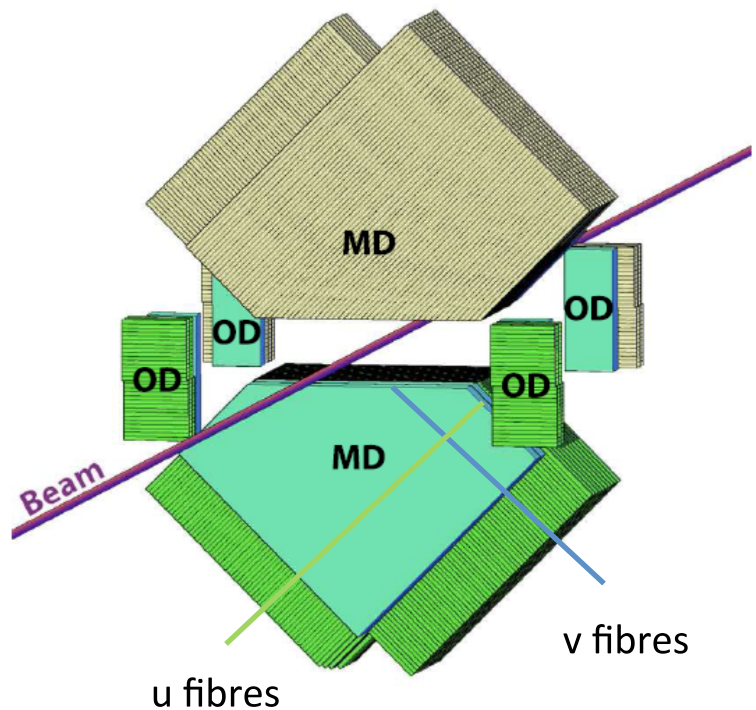
In October 2011 ALFA had the special run 191373 with β^*=90m and recorded 800k good selected elastic events used for the analysis of the total cross section and the nuclear slope B.

The ALFA detector in a nutshell



ALFA is a scintillating fibre tracker, 10 double-sided modules with 64 fibres in uv-geometry. Resolution ~30µm.

Special overlap detectors to measure the distance between upper and lower detectors → alignment



relation between elastic, inelastic, total

elastic observables only:

$$\sigma_{\rm tot}^2 = \frac{16\pi}{1+\varrho^2}\,\frac{1}{\mathcal{L}}\,\frac{dN_{\rm el}}{dt}\bigg|_0$$

↓

$$\sigma_{\rm tot}$$

ϱ independent:

$$\sigma_{\rm tot} = \frac{1}{\mathcal{L}}\left(N_{\rm el} + N_{\rm inel}\right)$$

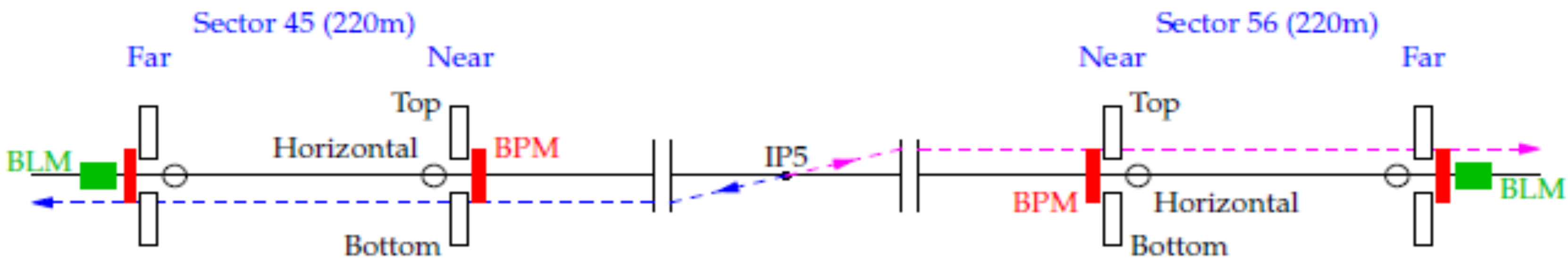
luminosity independent:

$$\sigma_{\rm tot} = \frac{16\pi}{1+\varrho^2}\,\frac{dN_{\rm el}/dt|_0}{N_{\rm el}+N_{\rm inel}}$$

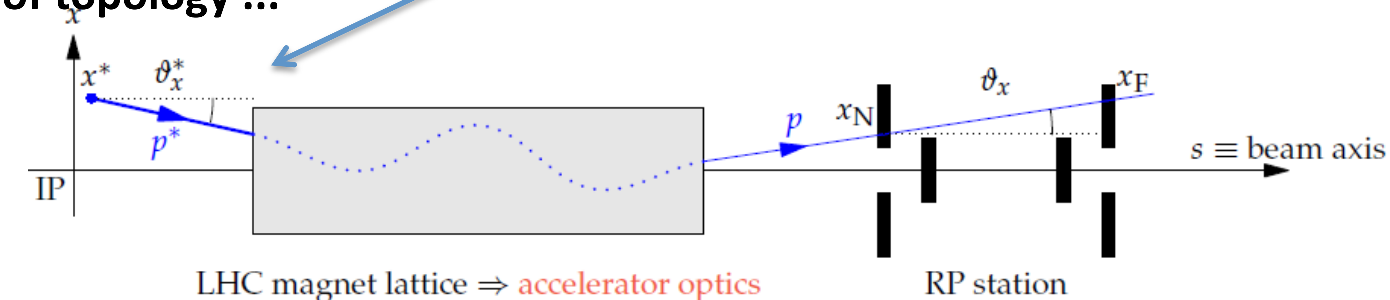
$$\mathcal{L} = \frac{1+\varrho^2}{16\pi}\,\frac{(N_{\rm el}+N_{\rm inel})^2}{dN_{\rm el}/dt|_0}$$

N_{el} from RP; N_{inel} from inel detectors; Lumi from ATL or CMS; ρ from data or COMPETE

measurement principle



from selection of topology ...



... to understanding of transport properties ...

$$\begin{pmatrix} x \\ \Theta_x \\ y \\ \Theta_y \\ \Delta p/p \end{pmatrix}_{RP} = \begin{pmatrix} v_x & L_x & 0 & 0 & D_x \\ v'_x & L'_x & 0 & 0 & D'_x \\ 0 & 0 & v_y & L_y & 0 \\ 0 & 0 & v'_y & L'_y & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x^* \\ \Theta^*_x \\ y^* \\ \Theta^*_y \\ \Delta p/p \end{pmatrix}_{IP5}$$

... to extraction of kinematical variables

x(RP) = (effective length L_x) · (scattering angle ϑ^*_x) + (magnification v_x) · (vertex x^*) + (dispersion Dx) · (rel. momentum loss dp/p)

optics

Optics is a product of lattice elements $\mathbf{T}_i$ and imperfections $\Delta\mathbf{T}_i$:

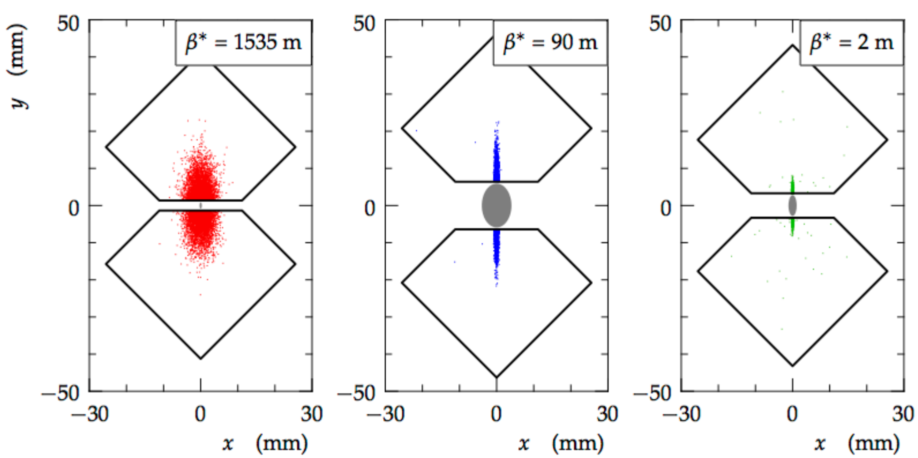
$$\mathbf{T}_{IP5\rightarrow RP220} = \prod_{i=M}^{1}\left[\mathbf{T}_i(k_i) + \Delta\mathbf{T}_i\right]$$

Imperfections $\Delta\mathbf{T}_i$

- Beam momentum offset ($\Delta p/p = 10^{-3}$)
- Magnet transfer function error, I→B, ($\Delta B/B = 10^{-3}$)
- Magnet rotations and displacements ($\Delta\psi < 1$mrad, Δx, $\Delta y < 0.5$mm)
- Power converter errors, k→I, ($\Delta I/I < 10^{-4}$)
- Magnet harmonics ($\Delta B/B = O(10^{-4})$)

Elastic scattering kinematics helps in constraining several parameters

Optics carefully optimized for special runs: hi β*, low luminosity

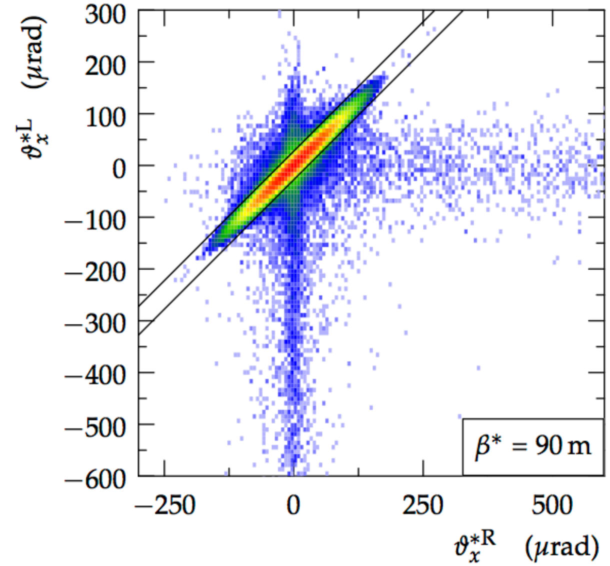


Optics understanding is essential ←→ measurements improve knowledge of optics

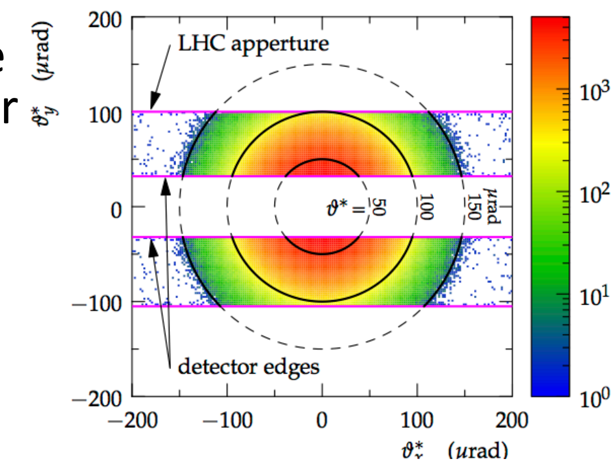
elastic scattering selection and analysis - I

- Alignment – I
  - beam scraping (collimator-like alignment)
- First selection: two diagonals, symmetric w.r.t. IP
- Alignment - II
  - residuals-based (relative between RPs) + absolute by exploiting the elastic scattering topology
- Reconstruction of kinematics
  - by using beam transport formulae
  - → minimize systematics by refining knowledge of optics by using actual data
- Tagging
  - Vertex and angles identical left/righ (n.b. tolerance set by beam divergence → higher β^* means cleaner sample)
  - proton $dp/p \approx 0$
- Bkg subtraction (typically needed for low-β^* optics)
- Acceptance corrections
  - finite RP detector acceptance & finite LHC aperture

θ_x^* *collinearity*



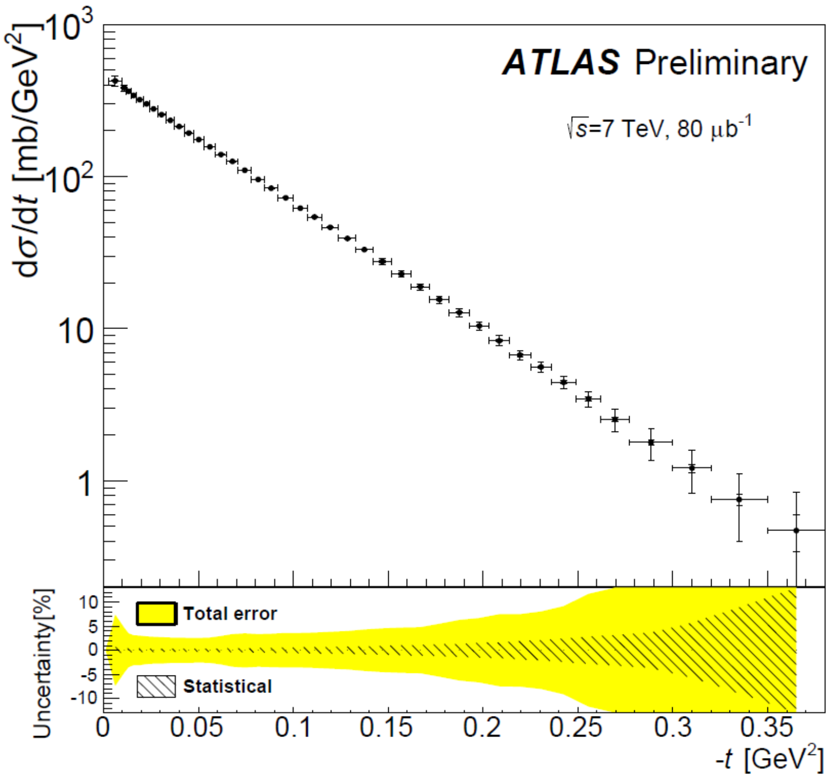
acceptance correction



elastic scattering selection and analysis - II

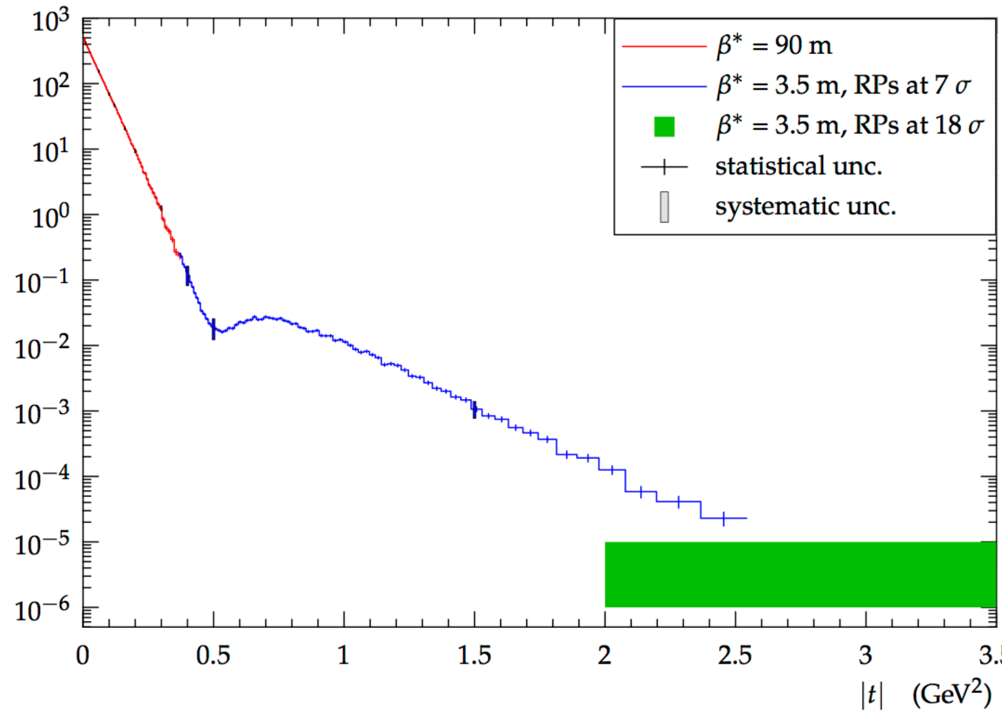
- Resolution studies
  - angular resolution: comparison left-right
  - unfolding with Monte Carlo calculation
- Correct for inefficiencies
  - uncorrelated (per single pot)
  - correlated (due to showers within a group of RPs)
  - pile-up (elastic event + additional tracks)
- Inject luminosity info
  - from ATLAS or CMS
  - calculated from data
- Final dσ/dt, systematic uncertainties and $\mathbf{N_{el}}$

elastic scattering results : √s = 7 TeV



ATLAS-ALPHA
β*=90m

TOTEM
β*=3.5m & 90m



available data from TOTEM @ 7-8 TeV

E (TeV)	β^* (m)	RP approach	$\mathcal{L}_{int}$ (μb^{-1})	t range (GeV^2)	Elastic events
7	90	4.8-6.5σ	83	$7\cdot10^{-3}$ - 0.5	1M
	90	10σ	1.7	0.02 - 0.4	14k
	3.5	7σ	0.07	0.36 - 3	66k
	3.5	18σ	2.3	2 - 3.5	10k
8	90	6-9σ	60	0.01 - 1	0.6M
	1000	3σ	20	$6\cdot10^{-4}$ - 0.2	0.4M
2.76	11	5-13σ		0.05-0.6	45k

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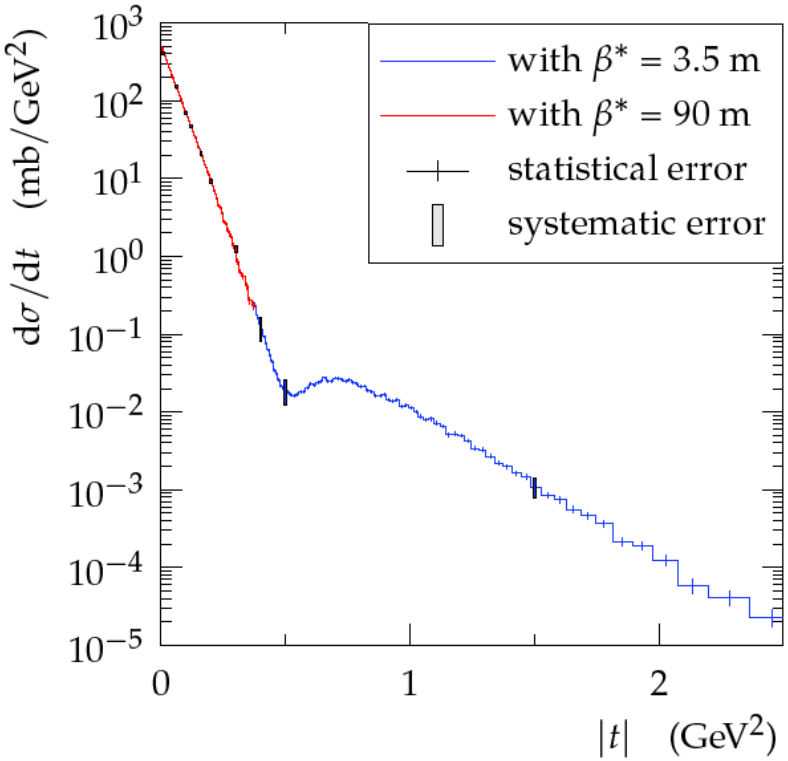
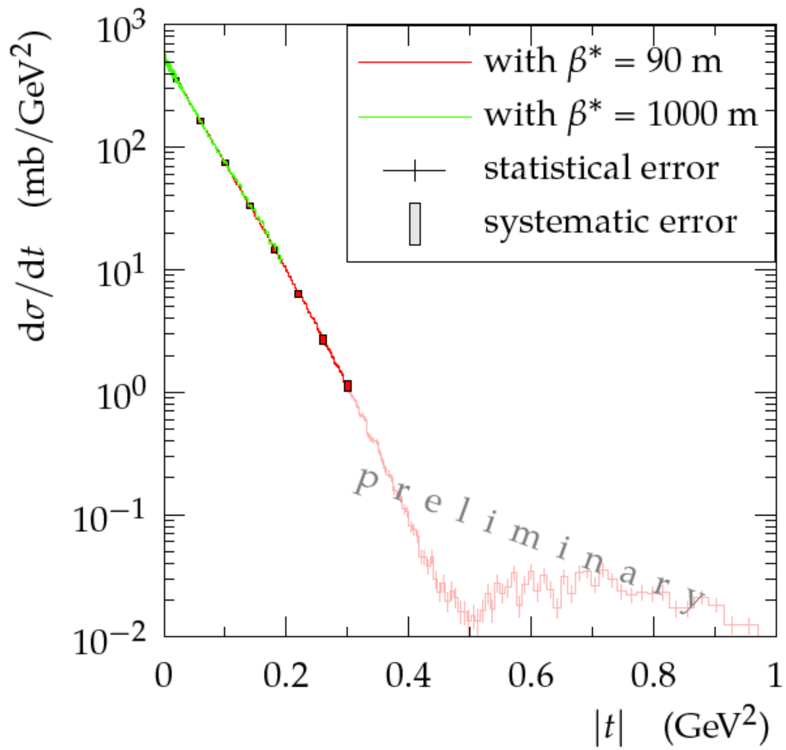
[EPL 95 (2011) 41001]

[PRL 111, 012001]



7 TeV



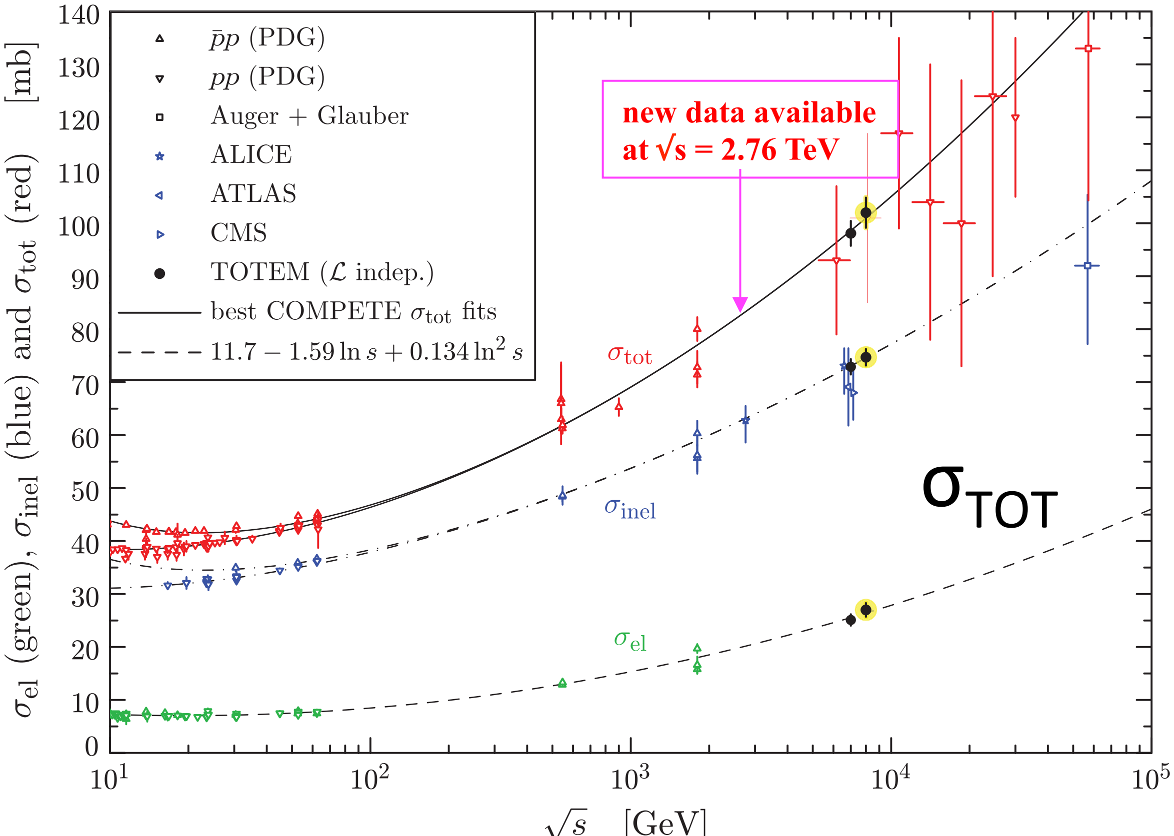
8TeV

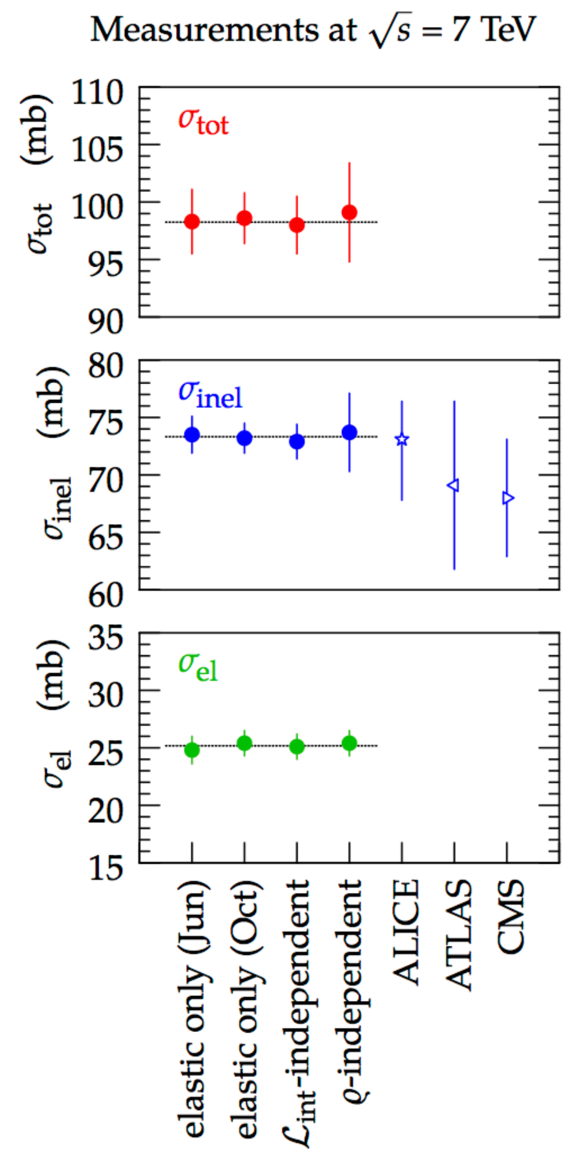
inelastic cross-section

- Raw rate: event counting in inelastic detectors
  - corrections: trigger and detection efficiencies, beam-gas events, pile-up
- Visible rate
  - in TOTEM, cross-check T1 vs. T2 for recovery of events with no tracks in T2 (gap over T2, low-mass diffraction, ...)
- Physics rate: true rate $\mathbf{N_{inel}}$ of inelastic events
- Note: only one relevant Monte Carlo correction (low mass diffraction)
  - it can be constrained from data ($\sigma^{RP}_{tot} - \sigma^{RP}_{el} - \sigma^{T2}_{visible}$)

TOTEM total cross-section

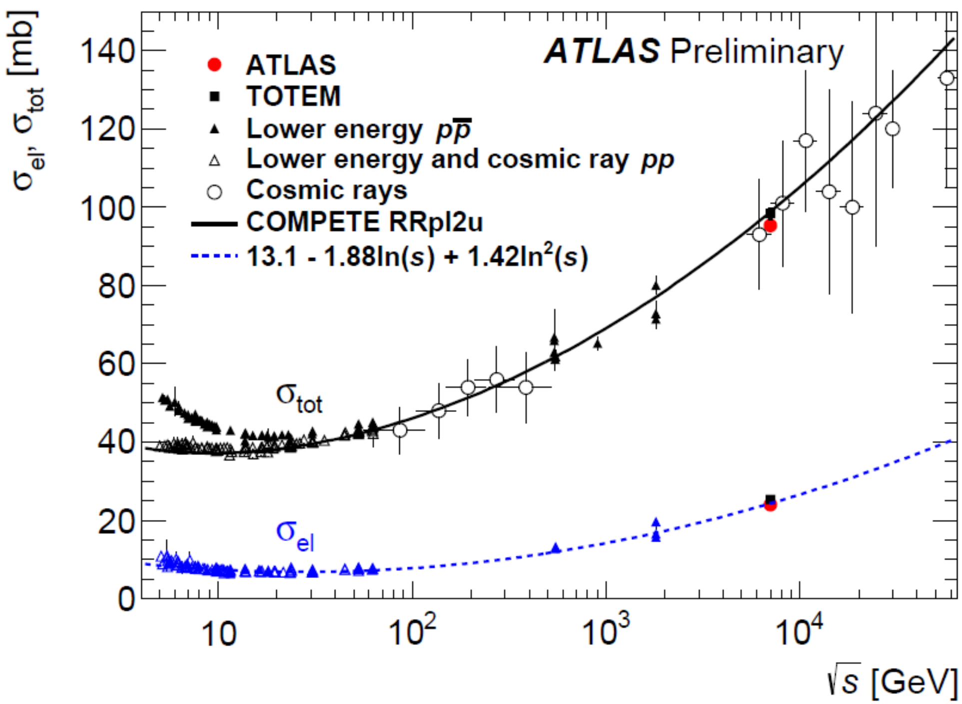
√S [TeV]	method	value
7	elastic only	98.6±2.3 mb
7	ρ independent	99.1±4.4 mb
7	lumi independent	98.1±2.4 mb
8	lumi independent	101.7±2.9 mb

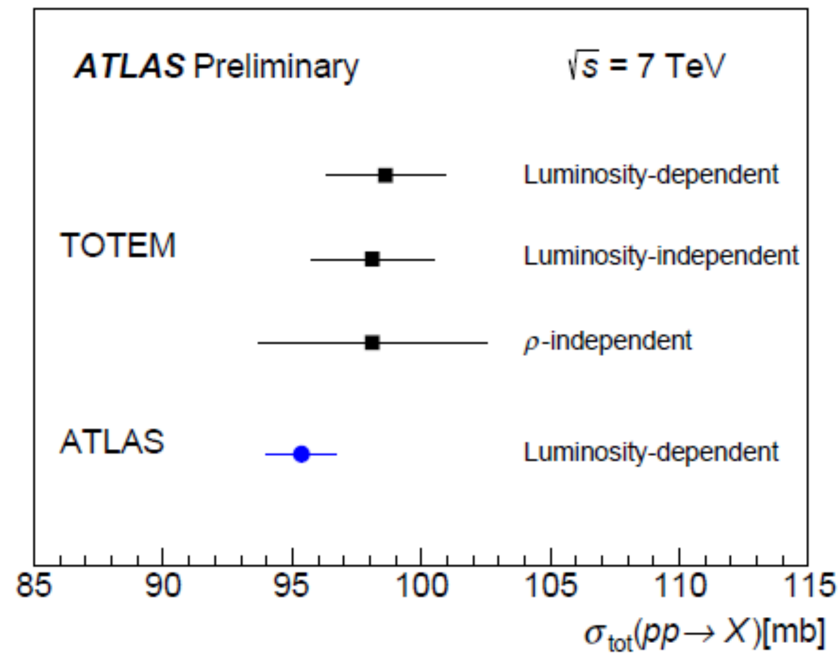




σ_{TOT}

ATLAS total cross-section 7 TeV



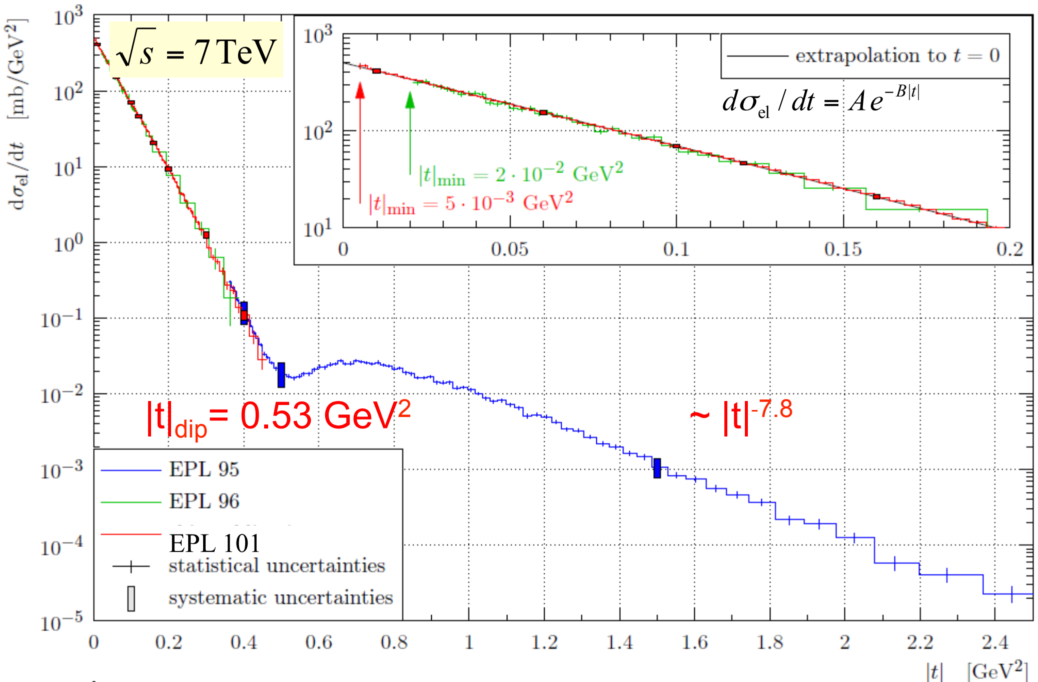


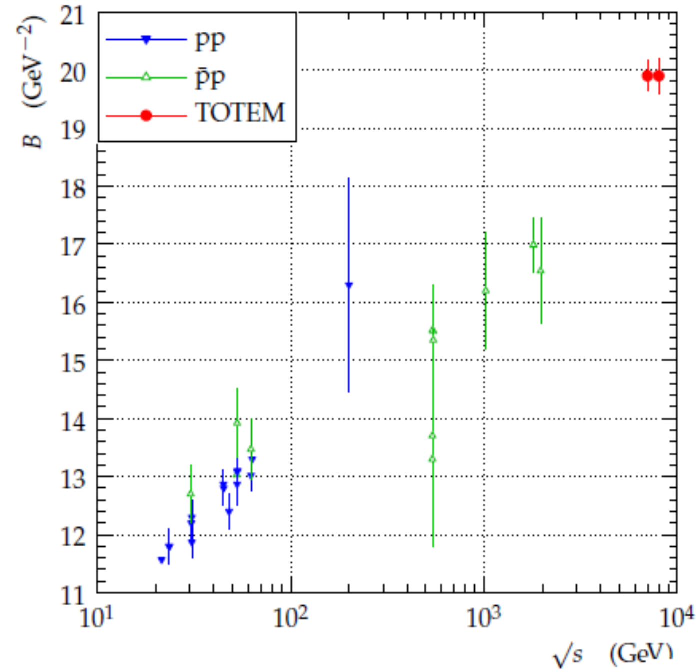
Energy evolution of σ_{tot} and σ_{el}

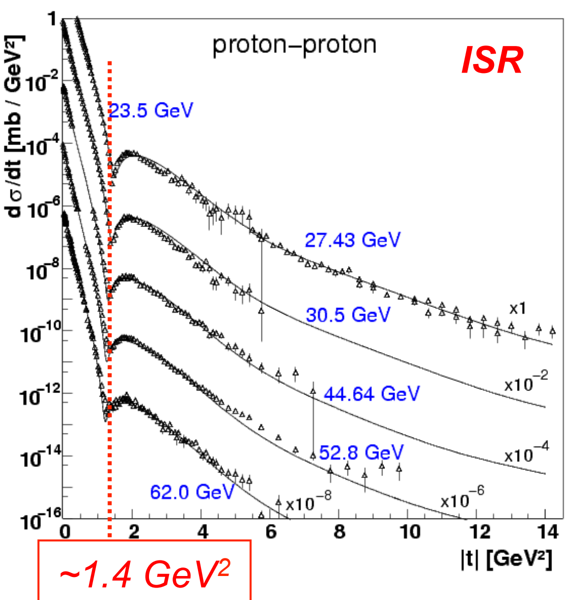
The ATLAS measurement is 3.2 mb lower than TOTEM, the difference corresponds to 1.3 σ, assuming uncorrelated uncertainties.

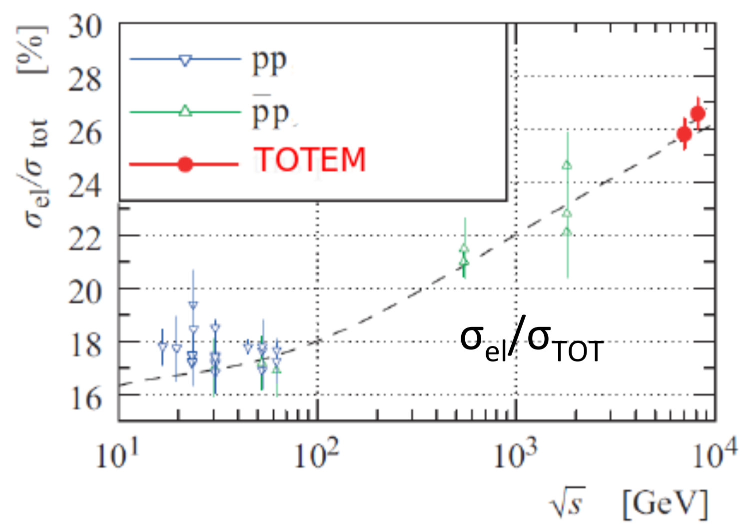
ATLAS	σ_{tot} = 95.4±1.4 mb	B = 19.7 ± 0.3 GeV^{-2}
TOTEM	σ_{tot} = 98.6±2.2 mb	B = 19.9 ± 0.3 GeV^{-2}

general observations





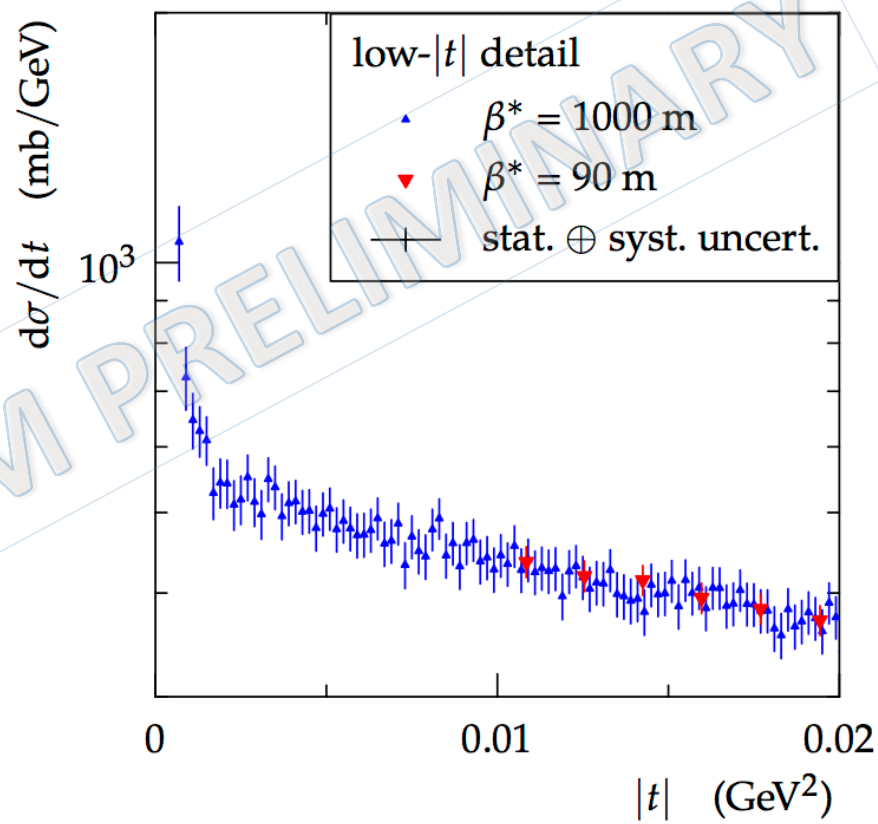




low-t elastic scattering

β*	approach σ	|t| range GeV²	el events	pub
1000m	3 or 10	0.0006 -> 0.2	352k	
90m	6 -> 9.5	0.01 -> 0.3	0.68M	PRL 111 (2013)
90m	9.5	0.02 ->1.4	7.2M	

- overlapping |t| region between β^*=90m and β^*=1000m
- access to very low |t| region and high statistics coverage of |t|> 0.01



reaching the interference region

$$F^{C+H} = F^C + F^H e^{i\alpha\Psi}$$

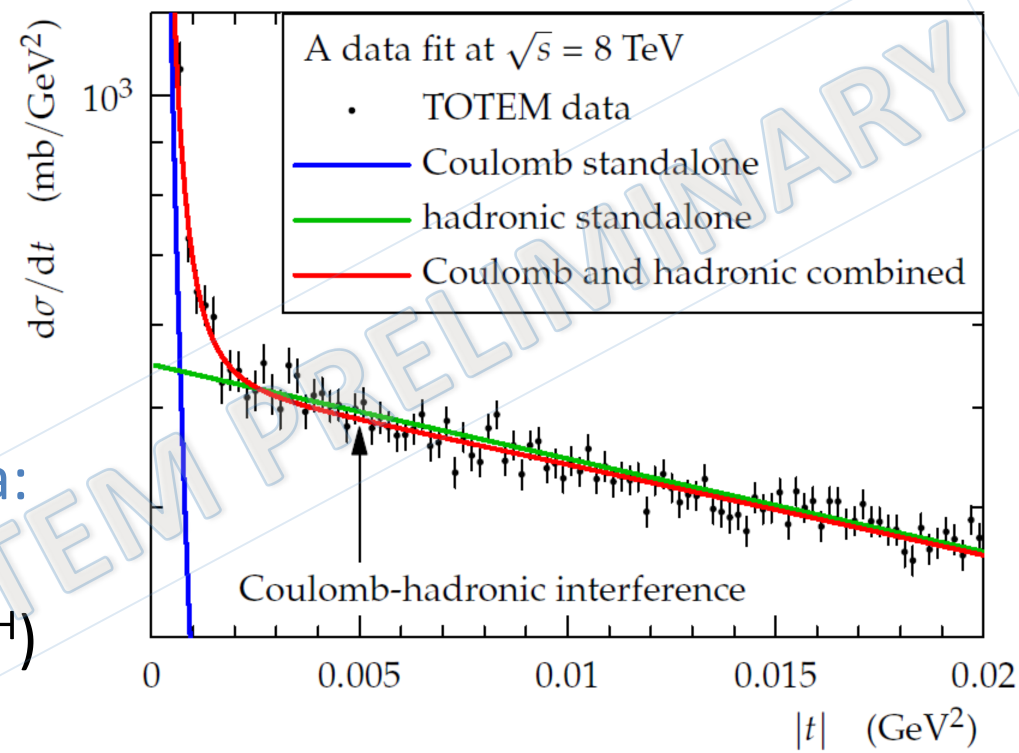
- Modulus constrained by measurement: ds/dt ≅ A $e^{-B(t)\,|t|}$
  - $B(t) = b_0 + b_1 t + \ldots$
- Phase arg(F^H): guidance by data is difficult

Simplified West-Yennie (SWY):

- constant slope $B(t) = b_0$
- constant hadronic phase arg(F^H) = p_0
- ψ(t) acts as real interference phase:

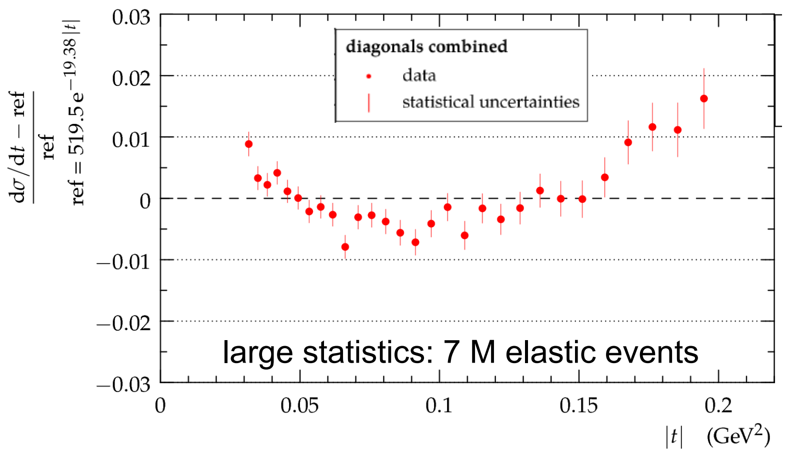
Kundrát-Lokajíček (KL) formula:

- any slope B(t)
- any hadronic phase arg(F^H)
- complex ψ(t):



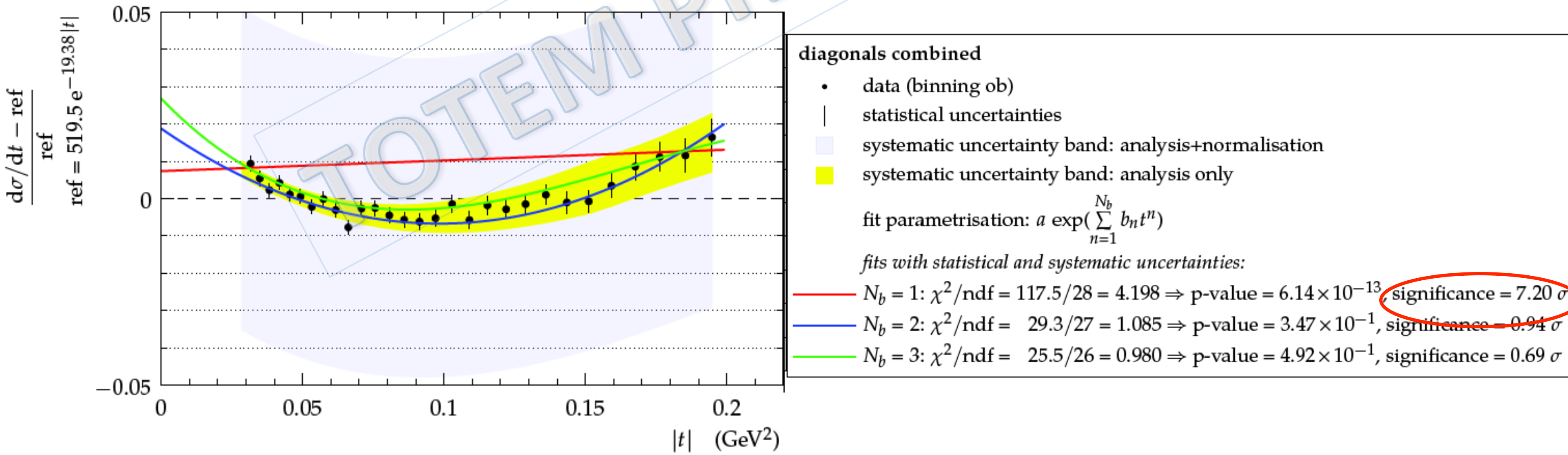
$d\sigma / dt \propto |F^{C+h}|^2$ = Coulomb + interference + hadronic

preliminary indications



- high-statistics β^*=90m data can be used to compare dσ/dt with a pure exponential form
- Present data exclude a simple exponential at ~7σ significance
- → SWY model is ruled out

Fit $d\sigma/dt = A\, e^{-B(t)\,|t|}$, with $B(t) = b_0$ **or** $B(t) = b_0 + b_1 t$ **or** $B(t) = b_0 + b_1 t + b_2 t$



status

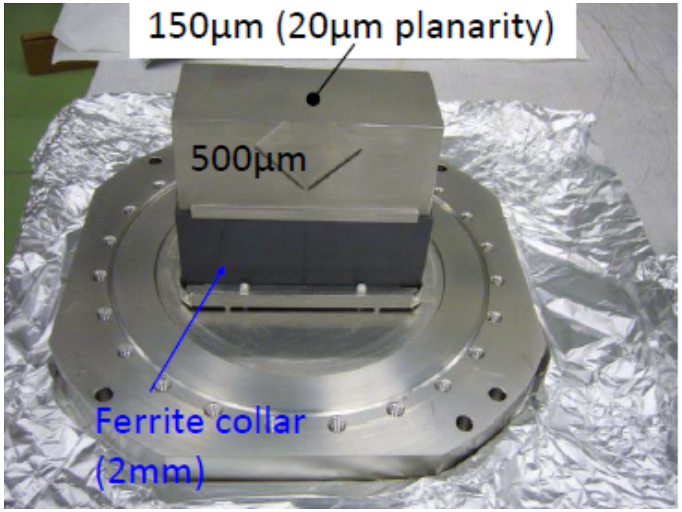
Coll energy	beta*	dataset	el X-sec	total X-sec	C-N interf
7 TeV	90m		published		
	3.5m	medium |t|	published		
	3.5m	high |t|	in progress		
8 TeV	90m	low stat	published		
	90m	high stat		in progress	
	1000m				
2.76 TeV	11m		in progress		

- Future data sets:
  - repeat same
    - with improved detectors
    - with higher precision CNI
  - exploring the widest possible |t| range

consolidation work towards RUN II

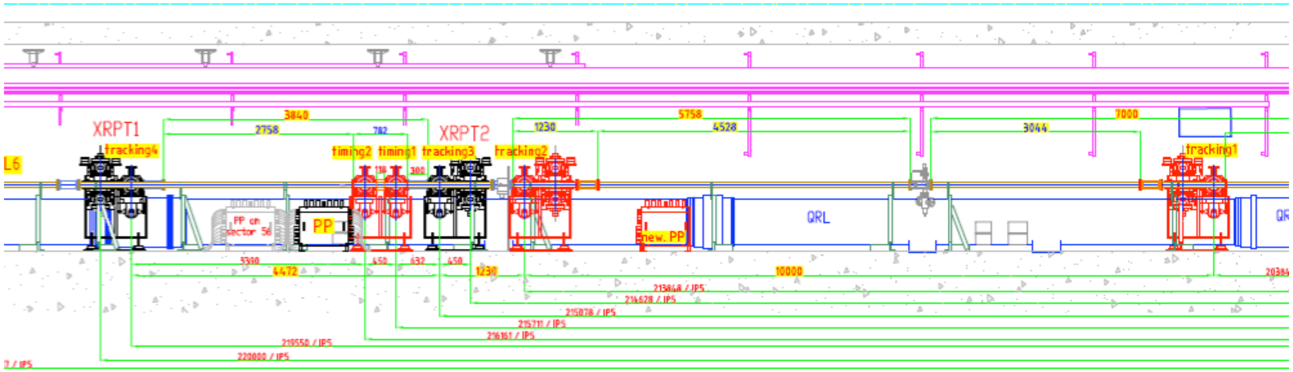
new ferrites for ALL RPs. Much higher:

- bake-out temperature: 1000 °C
- and Curie temperature: 375 °C



Rotated TOTEM RPs to add stereo angles

optimized placement of ATLAS RPs; relocation of TOTEM's 147m RPs in 220m region → additional lever arm and bkg rejection



future data taking

- Running scenarios under discussion for RUN II include a wide range of β^* values

  ≥ 1000m for high-precision low-t elastic scattering analysis

  = 90m with extended runs for high-statistics elastic & total cross-section studies

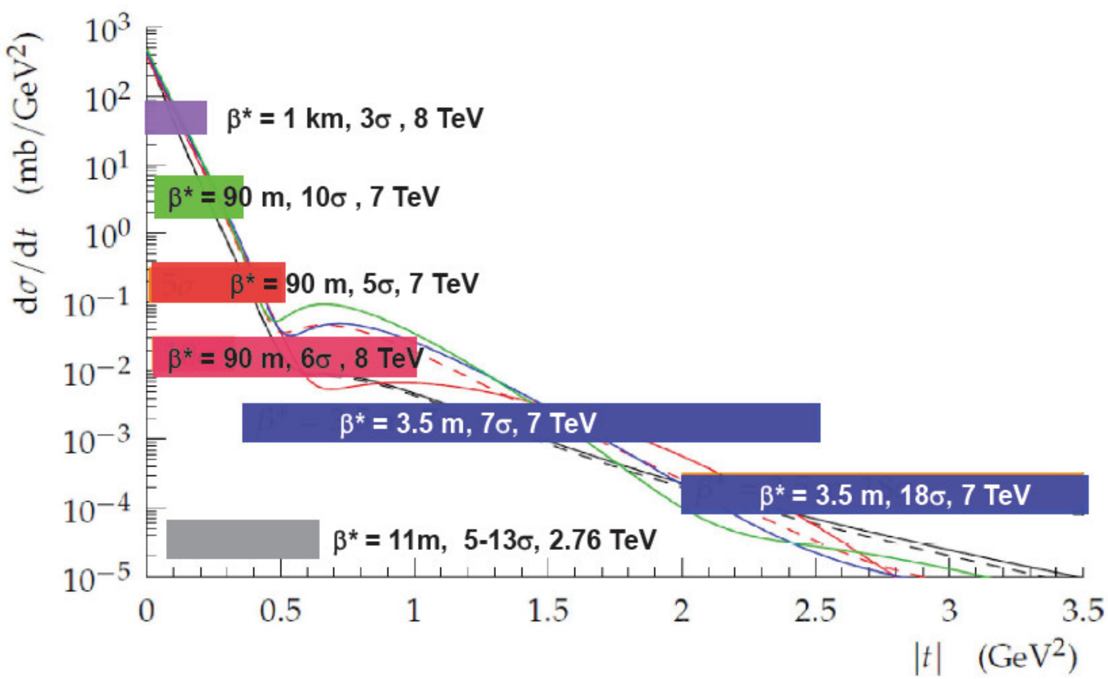
- Proton tagging will also allow additional physics output at medium (90m) and low (0.5m) β^*
  - wide range of masses in central diffraction
  - forward particle production
  - soft and hard diffraction

conclusions

- During Run I the total, elastic and inelastic cross-sections have been measured at $\sqrt{S}$=7 and 8 TeV
- The elastic scattering has been studied in a wide t range.
  - Measurements at very low t excluded a purely exponential behavior of the forward peak and allow first studies of the Coulomb-Nuclear interference region.
- An extensive consolidation and upgrade activity is being finalized to ensure a rich physics programme during RUN II.

backup

TOTEM operations



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2.76	11	5-13σ		0.05-0.6	45k

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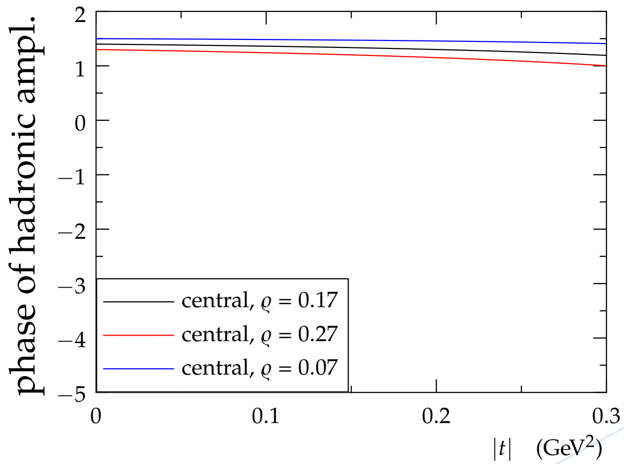
effect of CNI (explorative simulations)

Low |t|: sensitivity to ρ



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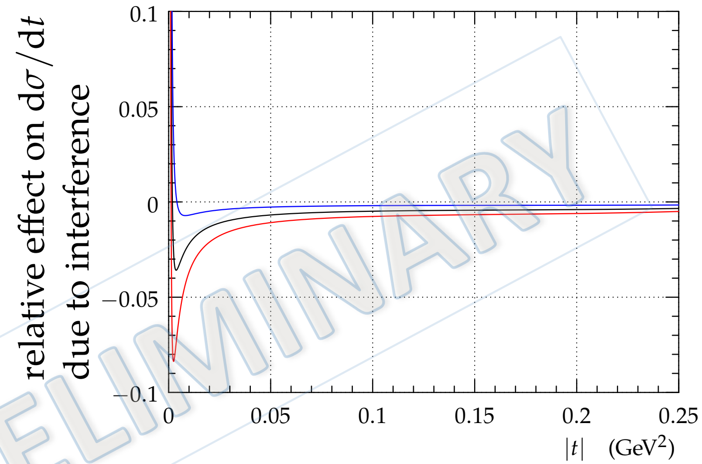
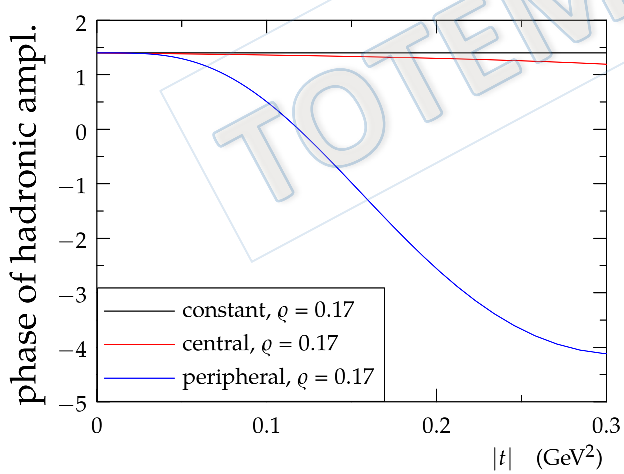


Higher |t|: sensitivity to |t| behaviour of nuclear phases



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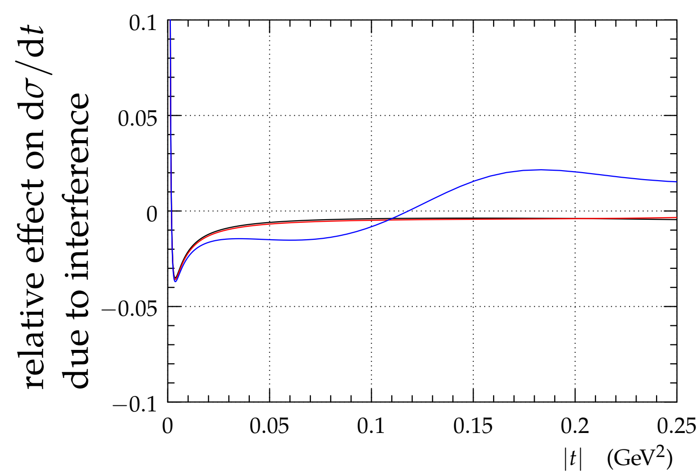
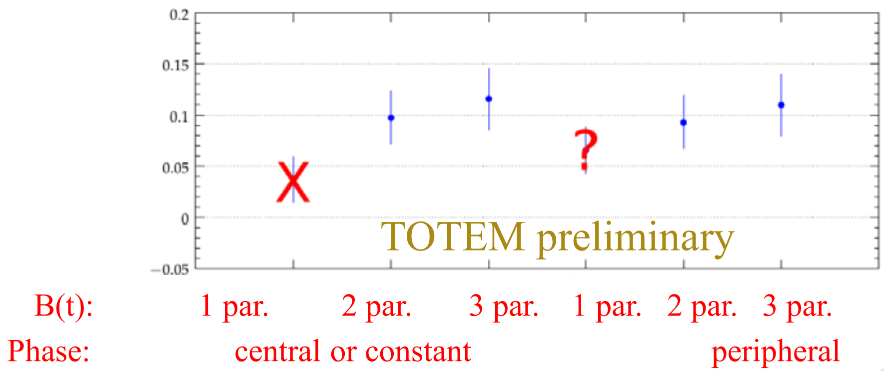
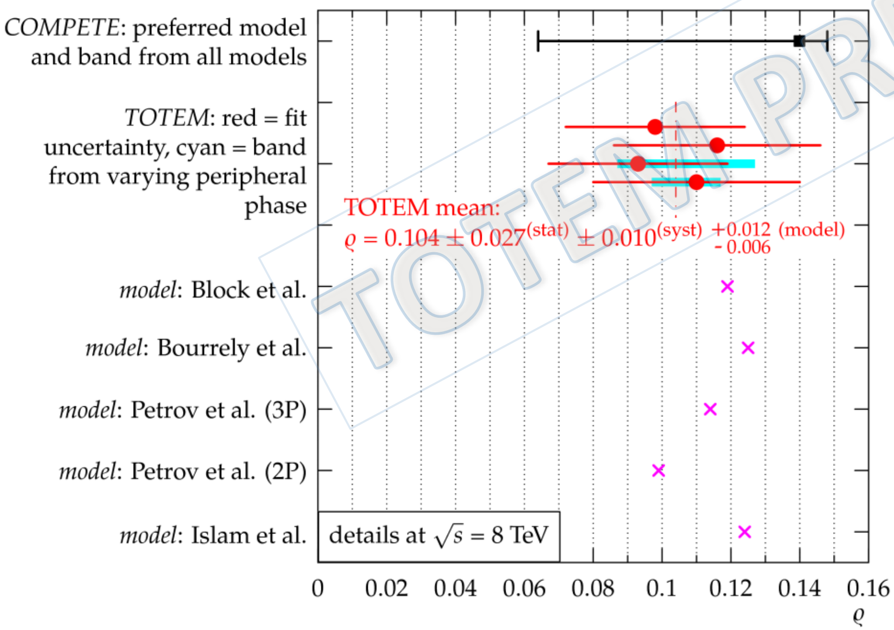
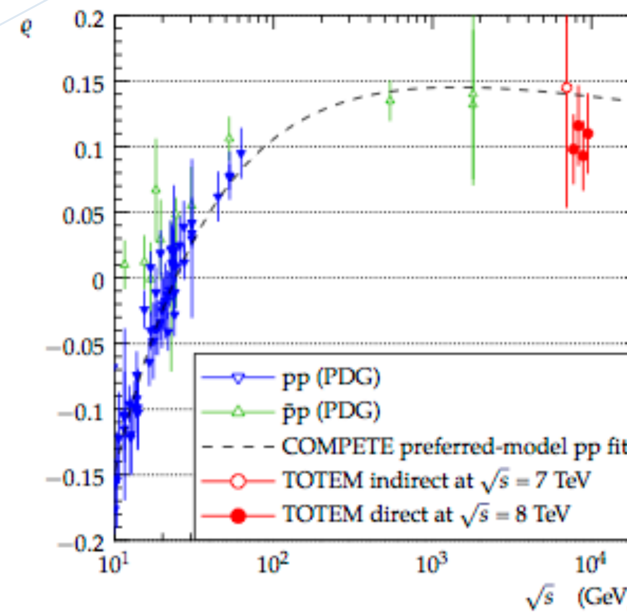


determination of ρ

ρ from fits with different B(t) and Phase(t)







possible running conditions

β^* [m]	cr. angle [μrad]	ε_N [μm rad]	N [10^{11} p/b.]	k bunches	μ	Luminosity [$\mathrm{cm^{-2}\,s^{-1}}$]	
2500	0	2	$0.7 \div 1.5$	2	$0.004 \div 0.02$	$(1.2 \div 5.6) \times 10^{27}$	$= (0.1 \div 0.5)\,\mathrm{nb}^{-1}/24\mathrm{h}$
90	0	2	$0.5 \div 1.5$	156	$0.06 \div 0.5$	$(1.3 \div 12) \times 10^{30}$	$= (0.1 \div 1)\,\mathrm{pb}^{-1}/24\mathrm{h}$
90	100	2	$0.5 \div 1.5$	1000	$0.06 \div 0.5$	$(0.9 \div 7.7) \times 10^{31}$	$= (0.8 \div 7)\,\mathrm{pb}^{-1}/24\mathrm{h}$
0.5	$310 \div 390$	$1.9 \div 3.75$	1.15	$2520 \div 2760$ ($\Delta t = 25\,\mathrm{ns}$)	$19 \div 34$	$(0.8 \div 1.3) \times 10^{34}$	$= (0.7 \div 1.1)\,\mathrm{fb}^{-1}/24\mathrm{h}$