Overview of TOTEM results on total cross-section, elastic scattering and diffraction at LHC

WPCF

25/08/2014

S.Giani

CERN-CH

on behalf of the TOTEM Collaboration

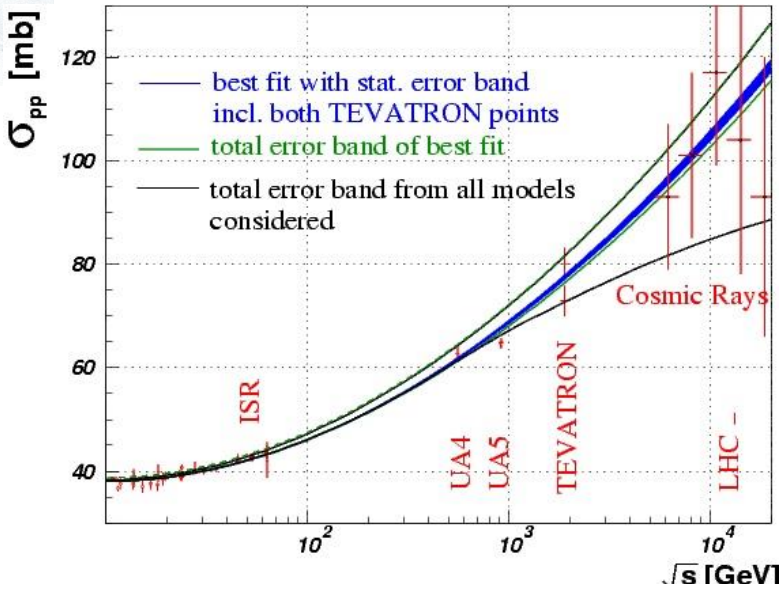
Outlook & Contents

- TOTEM EXPERIMENT
- TOTEM PHYSICS LHC RUN I
- TOTEM DETECTORS LS1 CONSOLIDATION
- TOTEM PHYSICS LHC RUN II
- TOTEM – CMS UPGRADE PROGRAMME

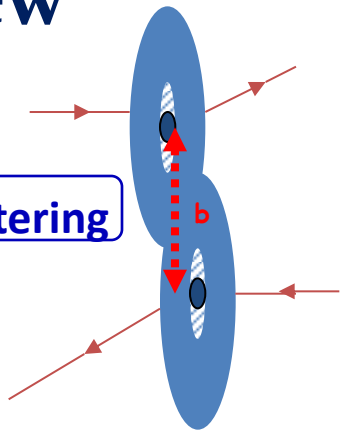
TOTEM EXPERIMENT

TOTEM Physics Overview

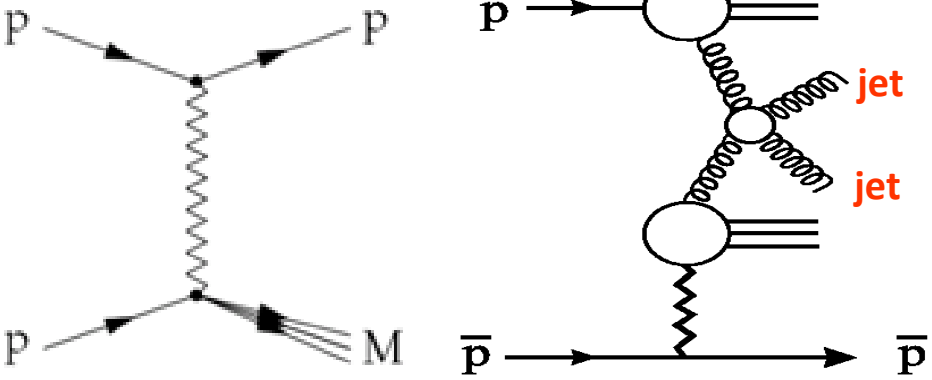
Total cross-section



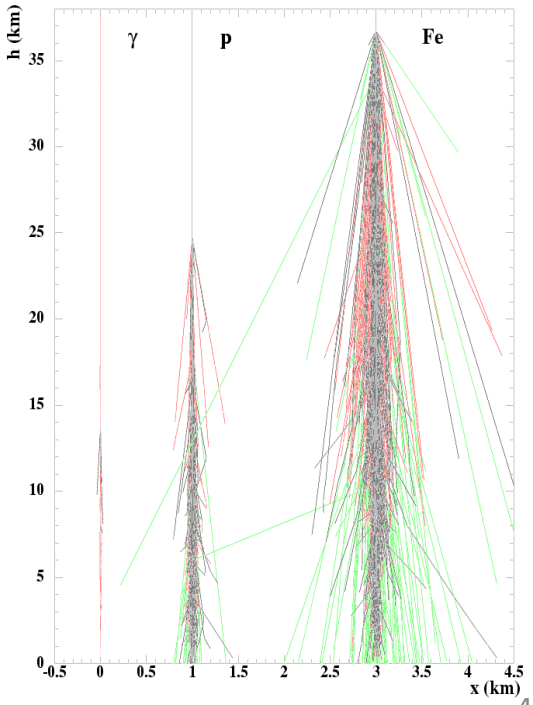
Elastic Scattering



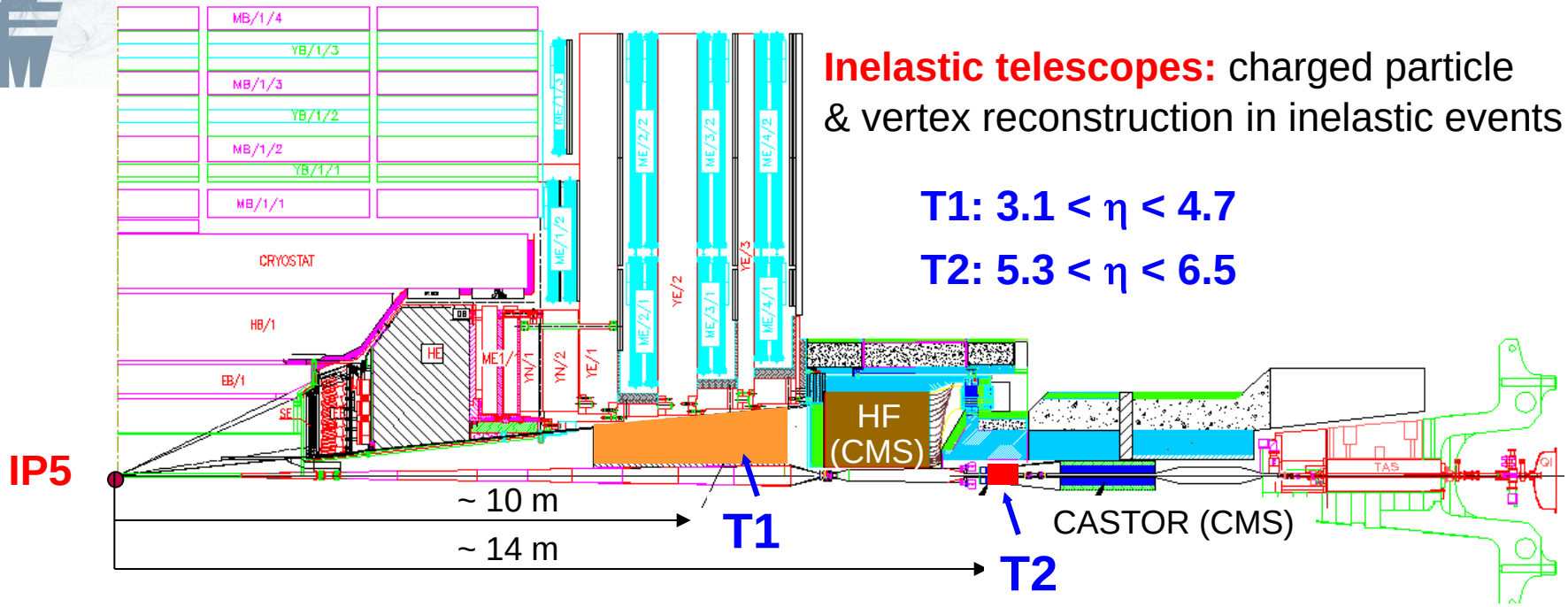
Diffraction: soft (and hard with CMS)



Forward physics



Experimental Setup @ IP5

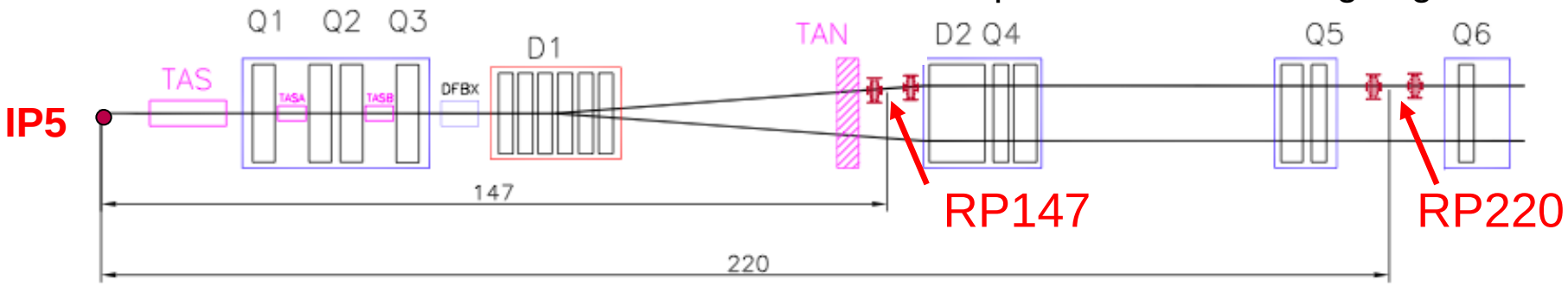


Inelastic telescopes: charged particle & vertex reconstruction in inelastic events

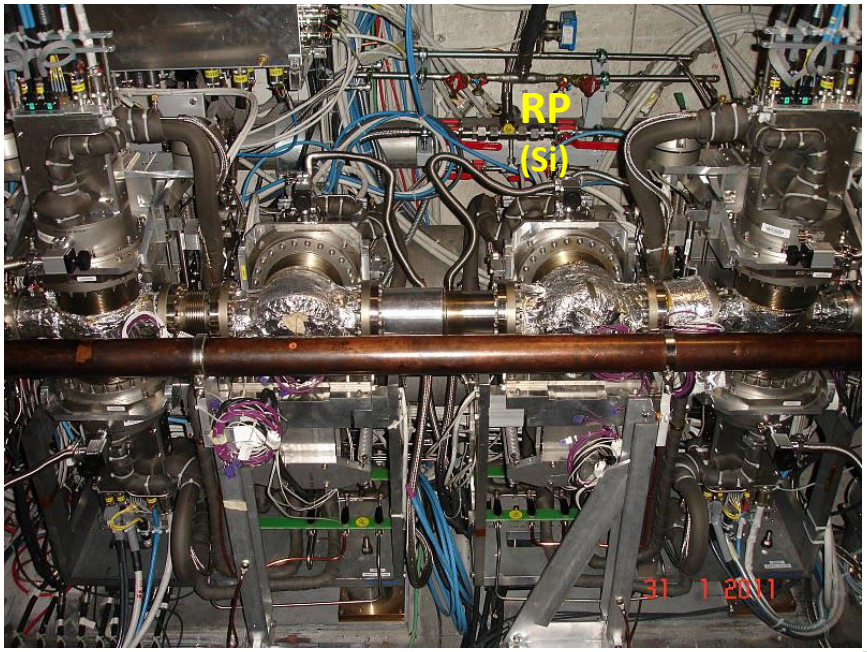
T1: 3.1 < η < 4.7

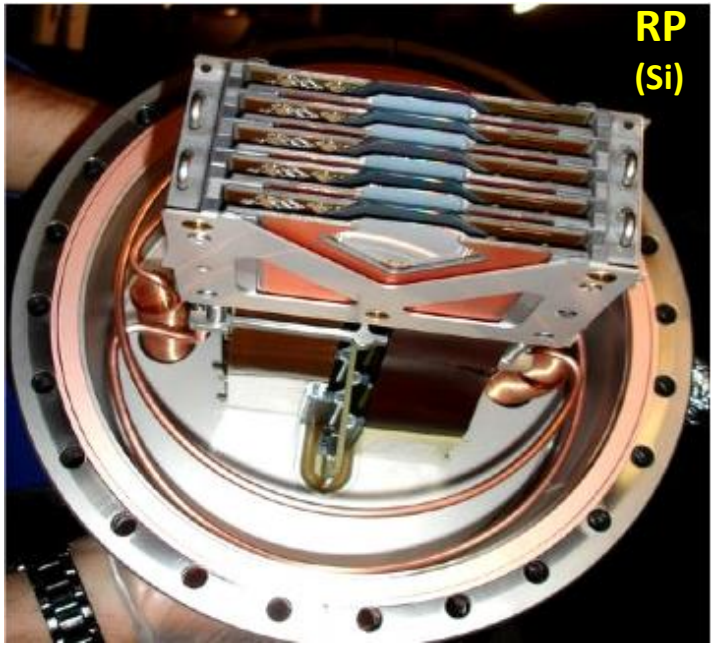
T2: 5.3 < η < 6.5

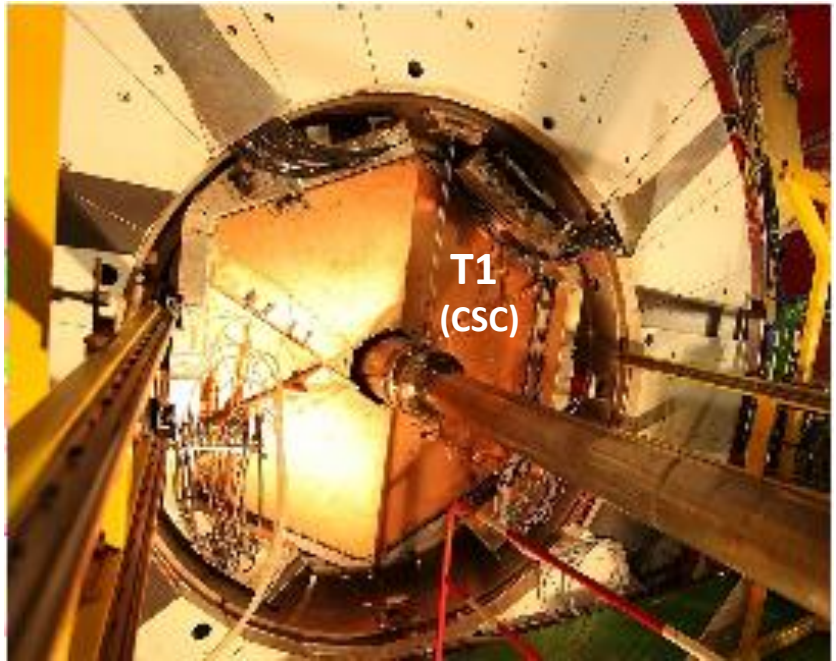
Roman Pots: measure elastic & diffractive protons close to outgoing beam

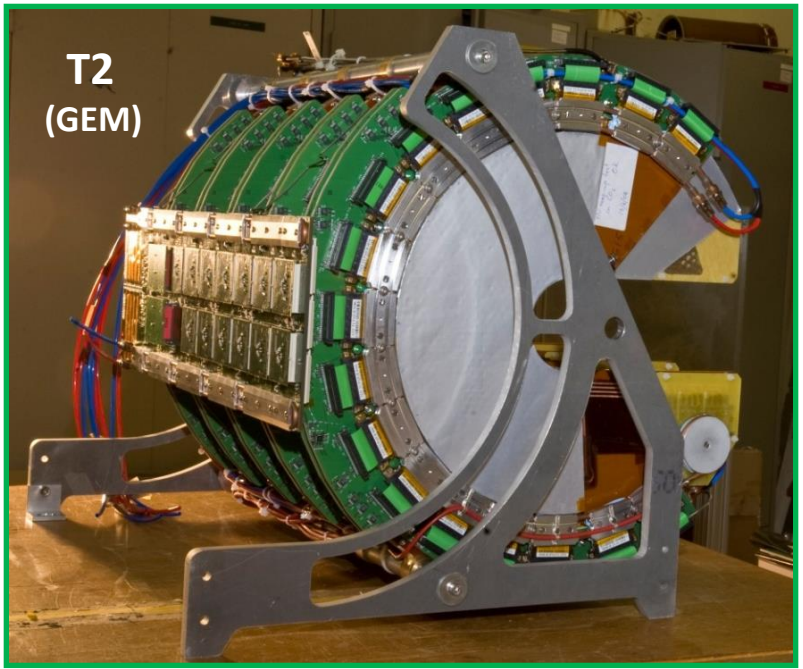


TOTEM Detectors

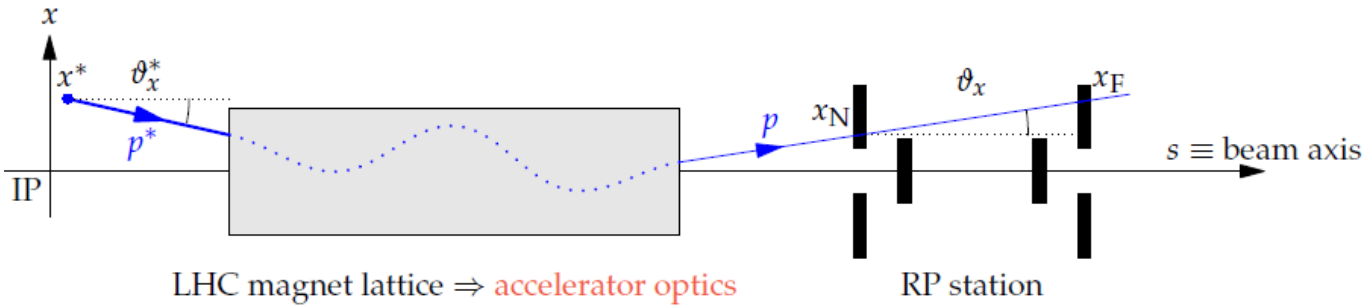








Proton Reconstruction @ LHC



(x^*, y^*): vertex position

(θ_x^*, θ_y^*): emission angle: $t \approx -p^2 (\theta_x^{*2} + \theta_y^{*2})$

$\xi = \Delta p/p$: momentum loss (elastic case: $\xi = 0$)

Measured in RP

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

Values at IP5 to be reconstructed

Product of all lattice element matrices

$$x_{RP} = L_x \Theta_x^* + v_x x^* + D_x \xi$$

$$y_{RP} = L_y \Theta_y^* + v_y y^*$$

L_x, L_y: effective lengths (sensitivity to scattering angle)

v_x, v_y: magnifications (sensitivity to vertex position)

D_x: dispersion (sensitivity to momentum loss); $D_y \sim 0$

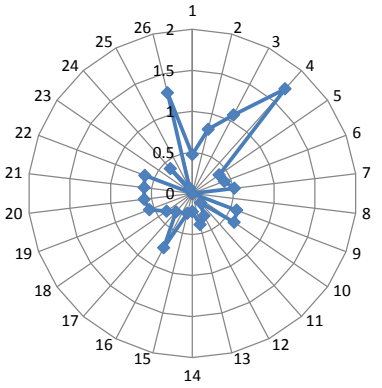
Reconstruction of proton kinematics = "inversion" of transport equation

Transport matrix elements depend on ξ ➔ non-linear problem (except in elastic case!)

Excellent optics understanding needed: CERN-PH-EP-2014-066

LHC Optics: RP sensitivity

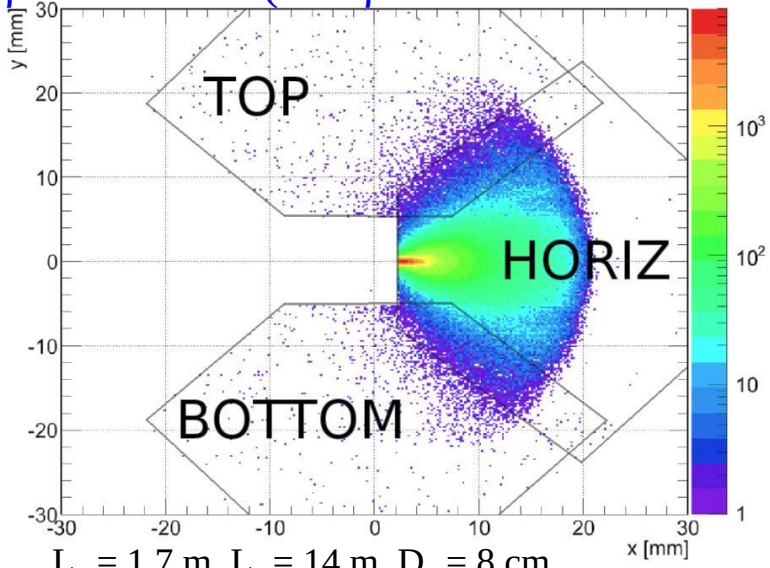
Optics parameters: data full non-linear fit, harmonics, displacements,…



Hit maps of simulated diffractive events for 2 optics configurations

(β* = betatron function at the interaction point)

β* = 0.55 m (low β* = standard at LHC)

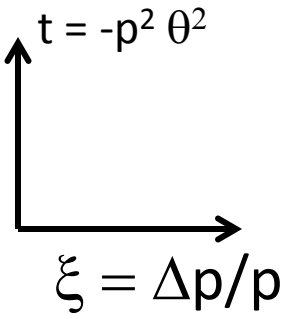


L_x = 1.7 m, L_y = 14 m, D_x = 8 cm

diffractive protons: mainly in **horizontal** RP

elastic protons: in vertical RP near x ~ 0

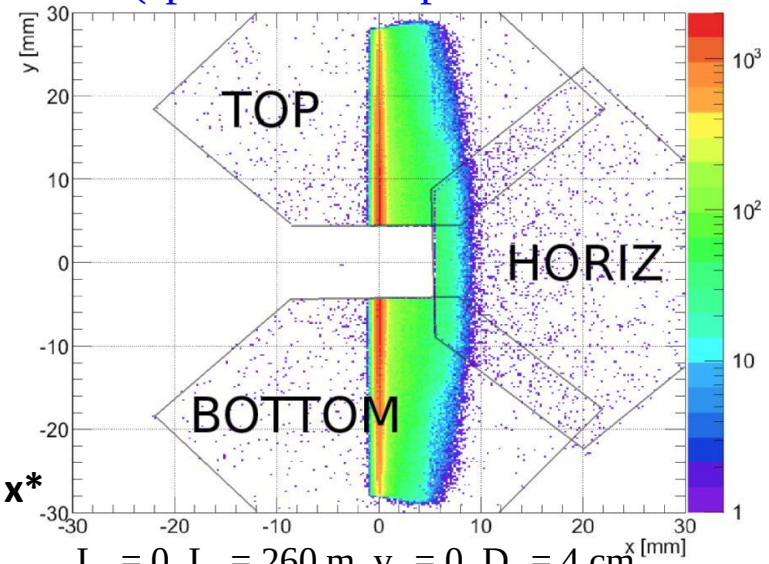
sensitivity only for large scattering angles



$y = L_y \Theta_y + v_y y^*$

$x = L_x \Theta_x + \xi D + v_x x^*$

β* = 90 m (special development for RP runs)



L_x = 0, L_y = 260 m, v_y = 0, D_x = 4 cm

diffractive protons: mainly in **vertical** RP

elastic protons: in narrow band at x ≅ 0,

sensitivity for small vertical scattering angles

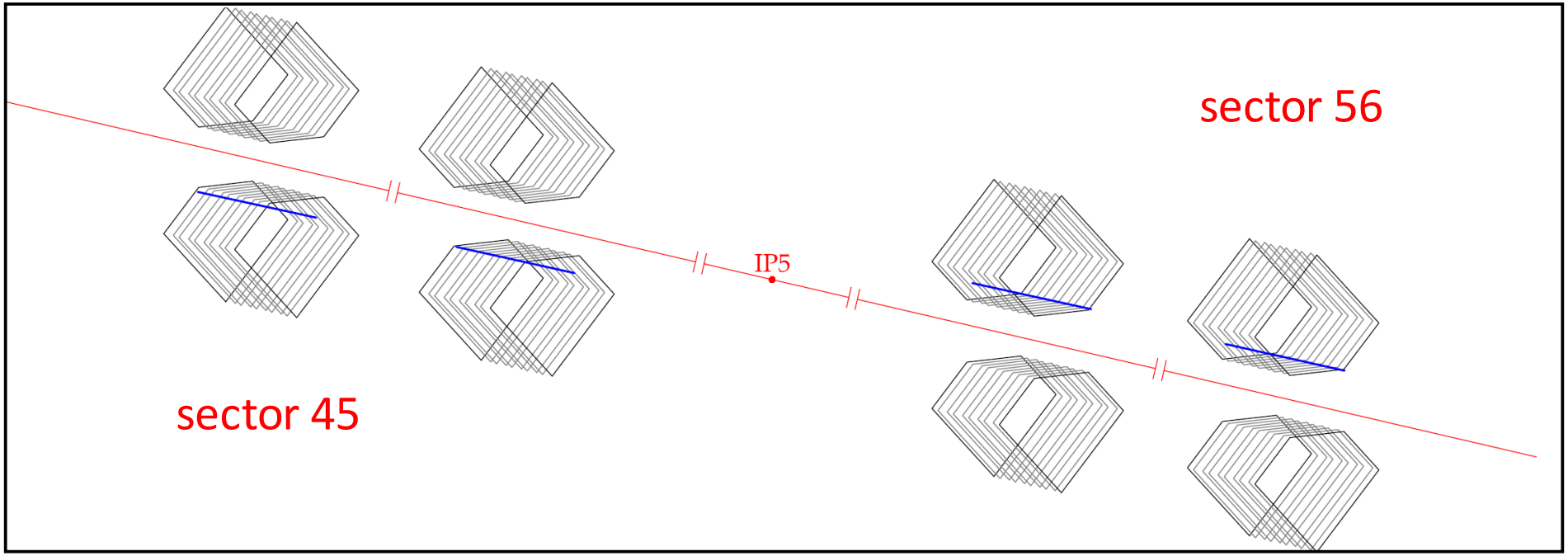
	Beam width @ vertex	Angular beam divergence	Min. reachable |t|
β* ~ 0.5–3.5 m	$\sigma^*_{x,y} = \sqrt{\frac{\varepsilon_n \beta^*}{\gamma}}$ small	$\sigma(\Theta^*_{x,y}) = \sqrt{\frac{\varepsilon_n}{\beta^* \gamma}}$ large	$\lvert t_{\min}\rvert = \frac{n_\sigma^2 p \varepsilon_n m_p}{\beta^*}$ ~ 0.3–1 GeV²
β* = 90 m	large	small	~ 10^{-2} GeV²

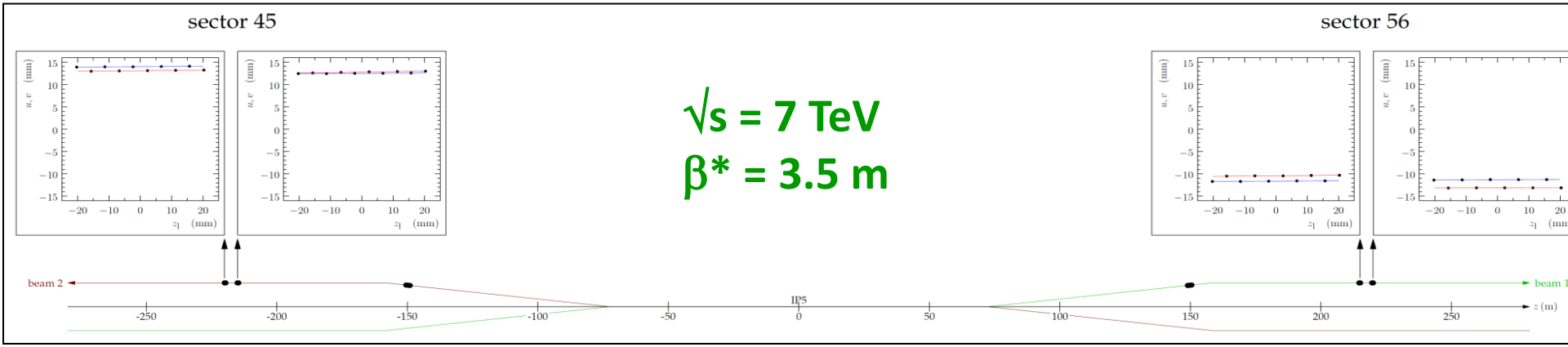
TOTEM Collaboration

- Countries: 8
- Institutes: 16
- Collaborators: ~ 100
- Authors: ~ 80
- Construction: ~ 7 MCHF
- M&O: ~ 0.5 MCHF/y

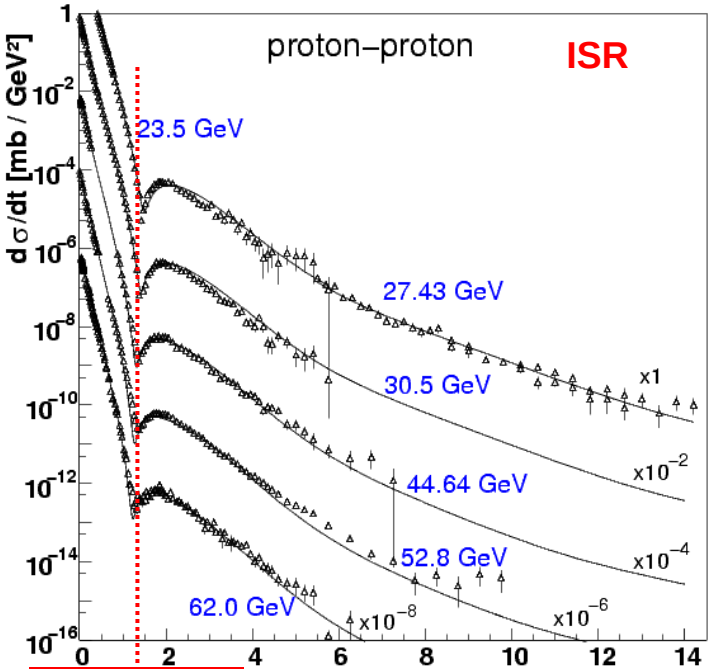
TOTEM PHYSICS LHC RUN I

2010 Data First p-p Elastic Scattering Events

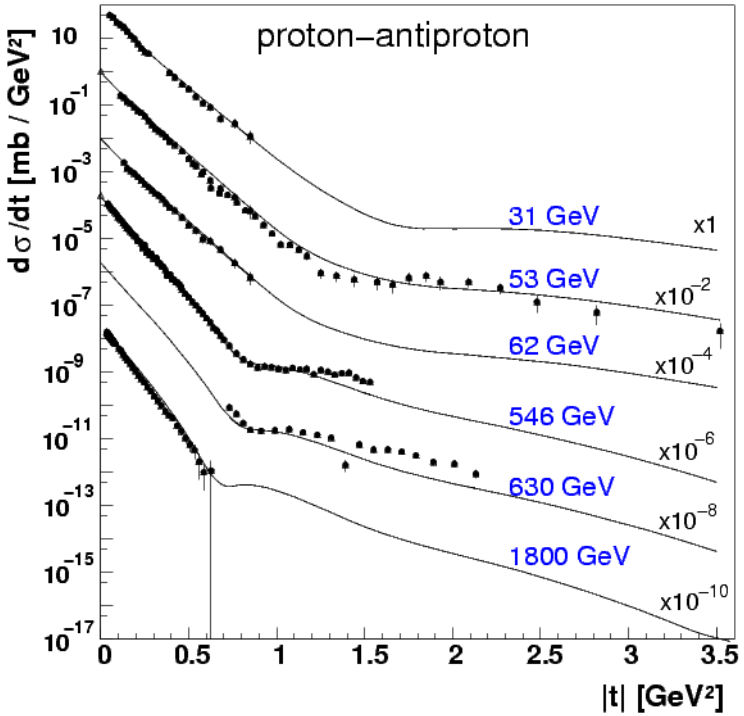




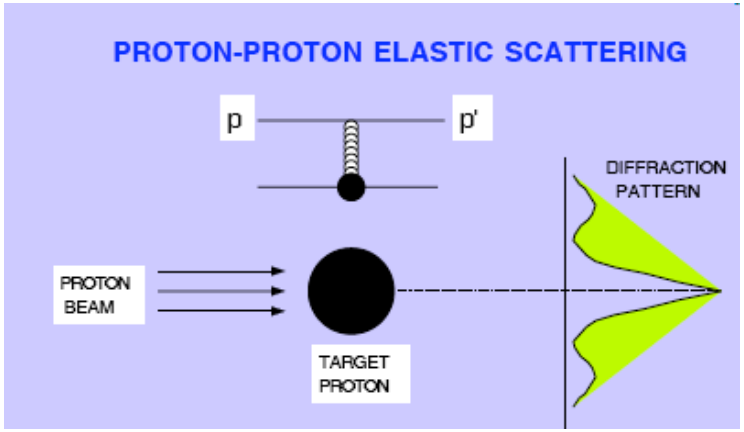
Elastic Scattering – from ISR to Tevatron



~1.4 GeV²



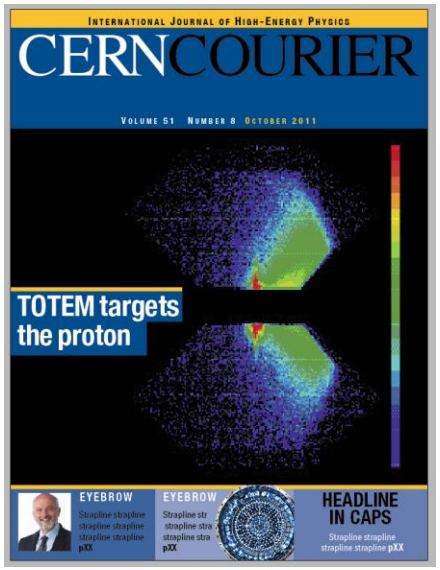
Diffractive minimum: analogous to Fraunhofer diffraction: $|t| \sim p^2 \theta^2$

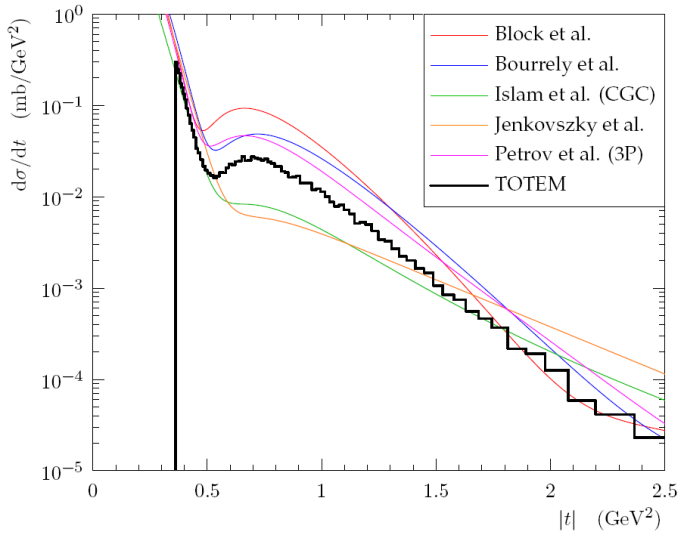


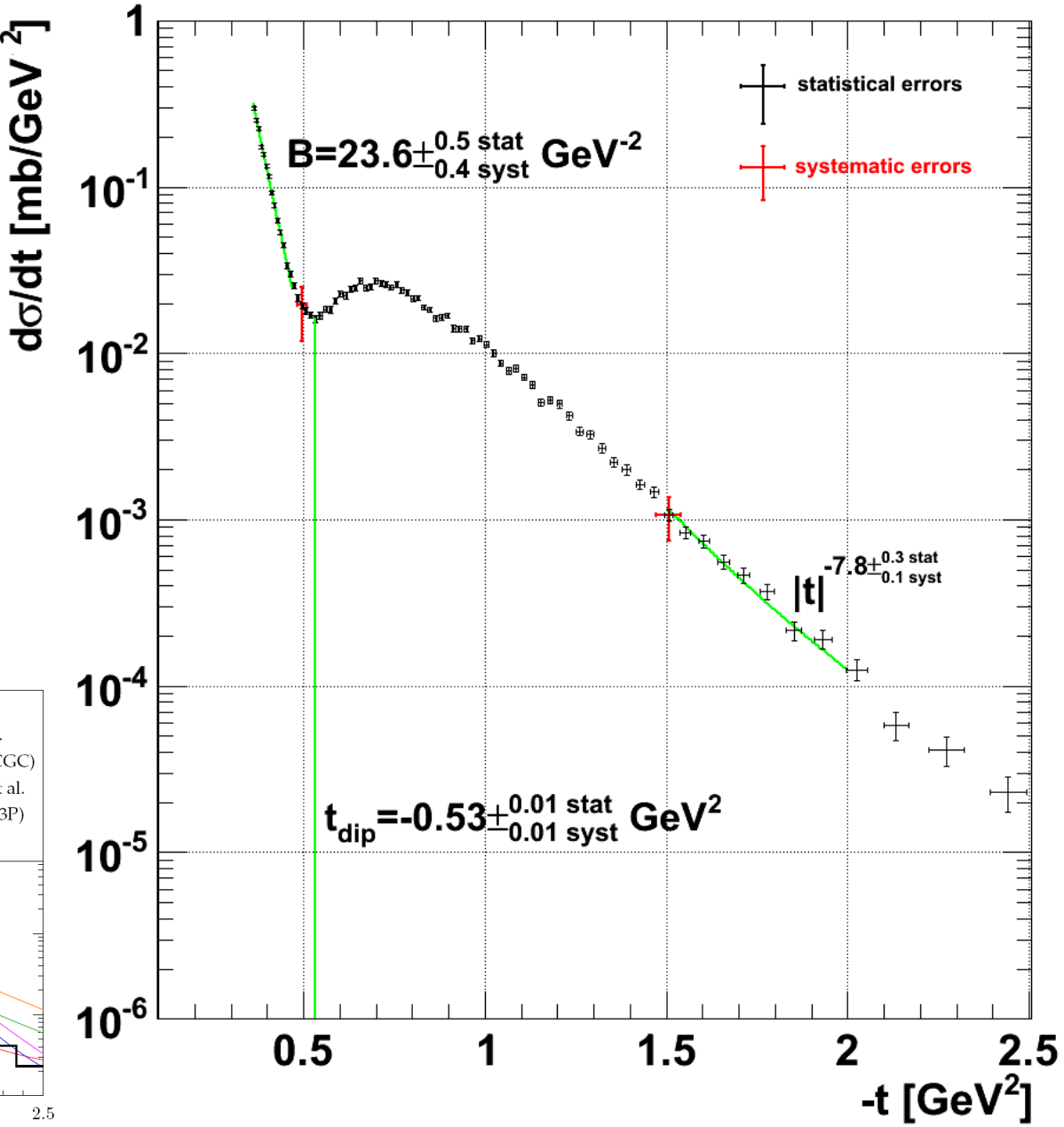
- exponential slope B at low |t| increases
- minimum moves to lower |t| with increasing s
  → interaction region grows (as also seen from σ_{tot})
- depth of minimum changes
  → shape of proton profile changes
- depth of minimum differs between p-p, p-pbar
  → different mix of processes

TOTEM Elastic Differential Cross-Section

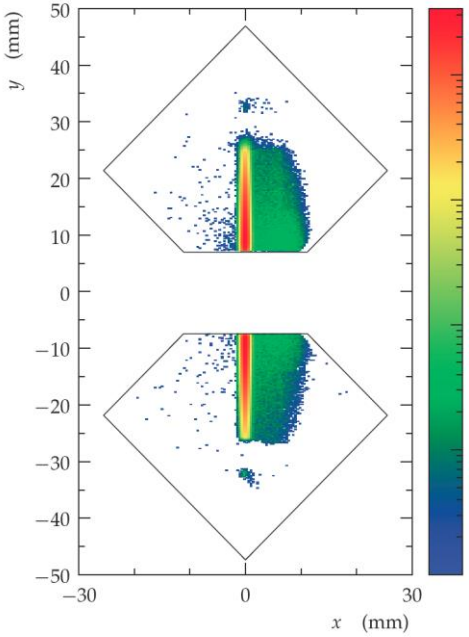
$\sqrt{s} = 7$ TeV

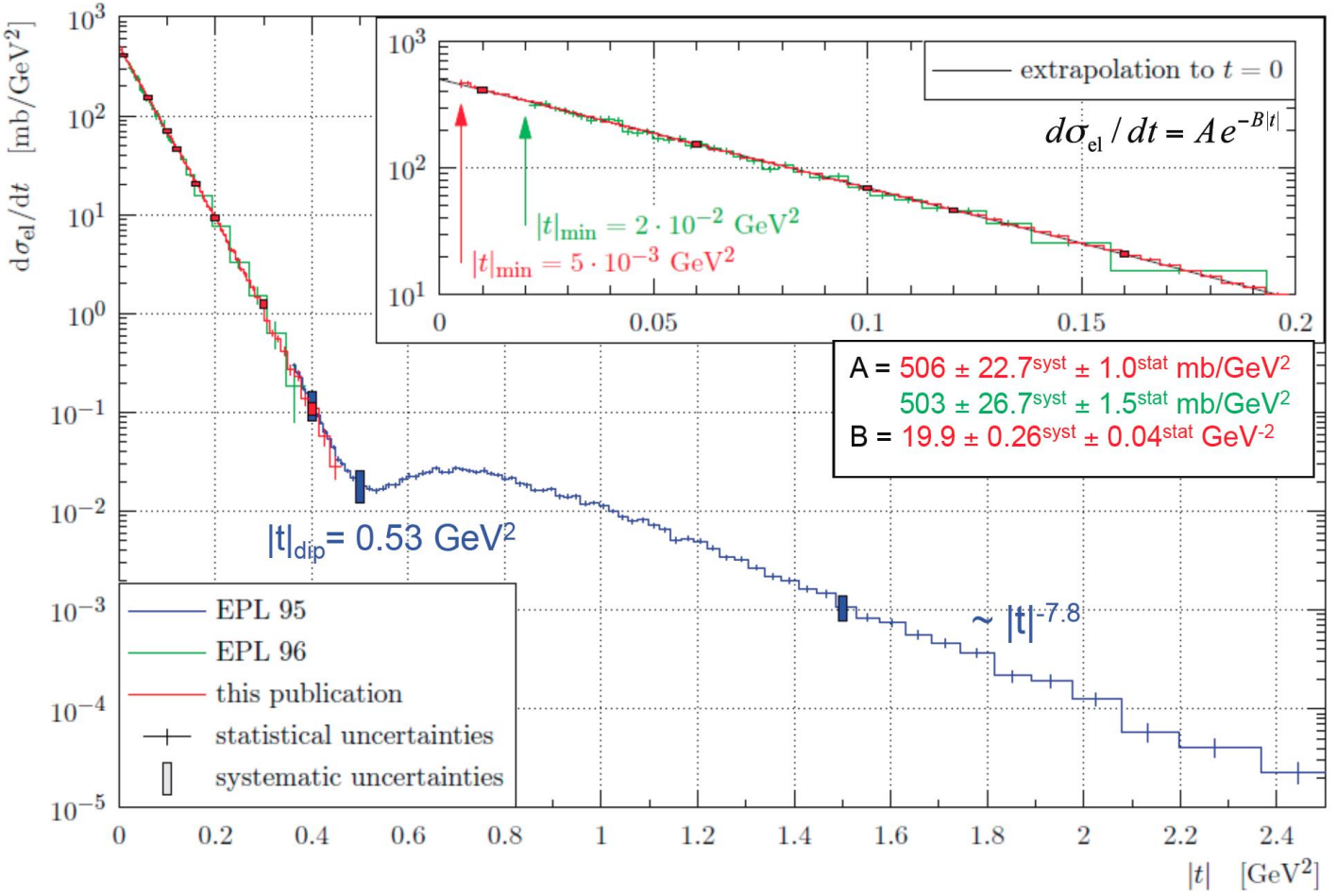






Measurement of low-t Elastic Scattering





Data with β* 90m optics

Extrapolation to t = 0 and integration of elastic cross section:

25.4 ± 1.1 mb (> 90% of cross-section visible, <10% extrapolated)

Total Cross-Section

Optical Theorem: $$\sigma_{TOT}^2 = \frac{16\pi(\hbar c)^2}{1+\rho^2} \cdot \left.\frac{d\sigma_{EL}}{dt}\right|_{t=0}$$

luminosity from CMS

$$\frac{d\sigma_{EL}}{dt} = \frac{1}{L} \cdot \frac{dN_{EL}}{dt}$$

ρ from COMPETE fit:

$$\rho = 0.14^{+0.01}_{-0.08}$$

$$\sigma_{TOT} = \sqrt{19.20\,\text{mb GeV}^2 \cdot \left.\frac{d\sigma_{EL}}{dt}\right|_{t=0}}$$

$$\sigma_{TOT} = \sigma_{EL} + \sigma_{INEL}$$

TOTEM Total Cross-Section [7TeV]

A Letters Journal Exploring the Frontiers of Physics

OFFPRINT

First measurement of the total proton-proton cross-section at the LHC energy of $\sqrt{s} = 7$ TeV

The TOTEM Collaboration (G. Antchev *et al.*)

EPL, **96** (2011) 21002

TOTEM Total Cross-Section Measurements

7 TeV

elastic observables only:

$$\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2}\,\frac{1}{\mathcal{L}}\,\left.\frac{dN_{el}}{dt}\right|_0$$

(ρ=0.14 [COMPETE extrapol.])

[EPL96]: σ_{tot} = (98.3 ±2.8) mb

[EPL101]: σ_{tot} = (98.6 ±2.2) mb

(different beam intensities)

test validity of optical theorem at ~3.5 % level

σ_{tot}

ρ independent:

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

[EPL101]: σ_{tot} = (99.1 ± 4.3) mb

luminosity independent:

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

[EPL101]: σ_{tot} = (98.0 ± 2.5) mb

TOTEM Inelastic Cross-Section

T1 and T2 direct measurement

Inelastic events in T2: classification

tracks in both hemispheres

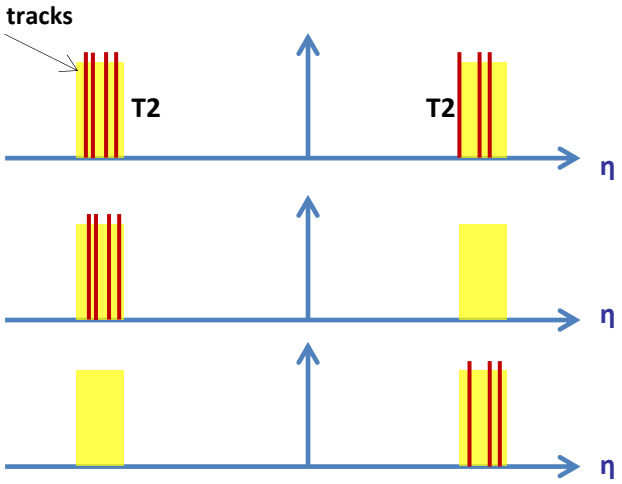
non-diffractive minimum bias

double diffraction

tracks in a single hemisphere

mainly single diffraction

$M_X > 3.4\ GeV/c^2$



Corrections to the T1, T2 visible events (eff., μ)

$\sigma_{inel,\ |\eta| < 6.5} = 70.5 \pm 2.9$ mb

Corrections for acceptance, gaps, DPE (MC/data)

➔ $\sigma_{inel} = 73.7 \pm 0.1^{stat} \pm 1.7^{syst} \pm 2.9^{lumi}$ mb

Inclusive measurement based on Optical Theorem

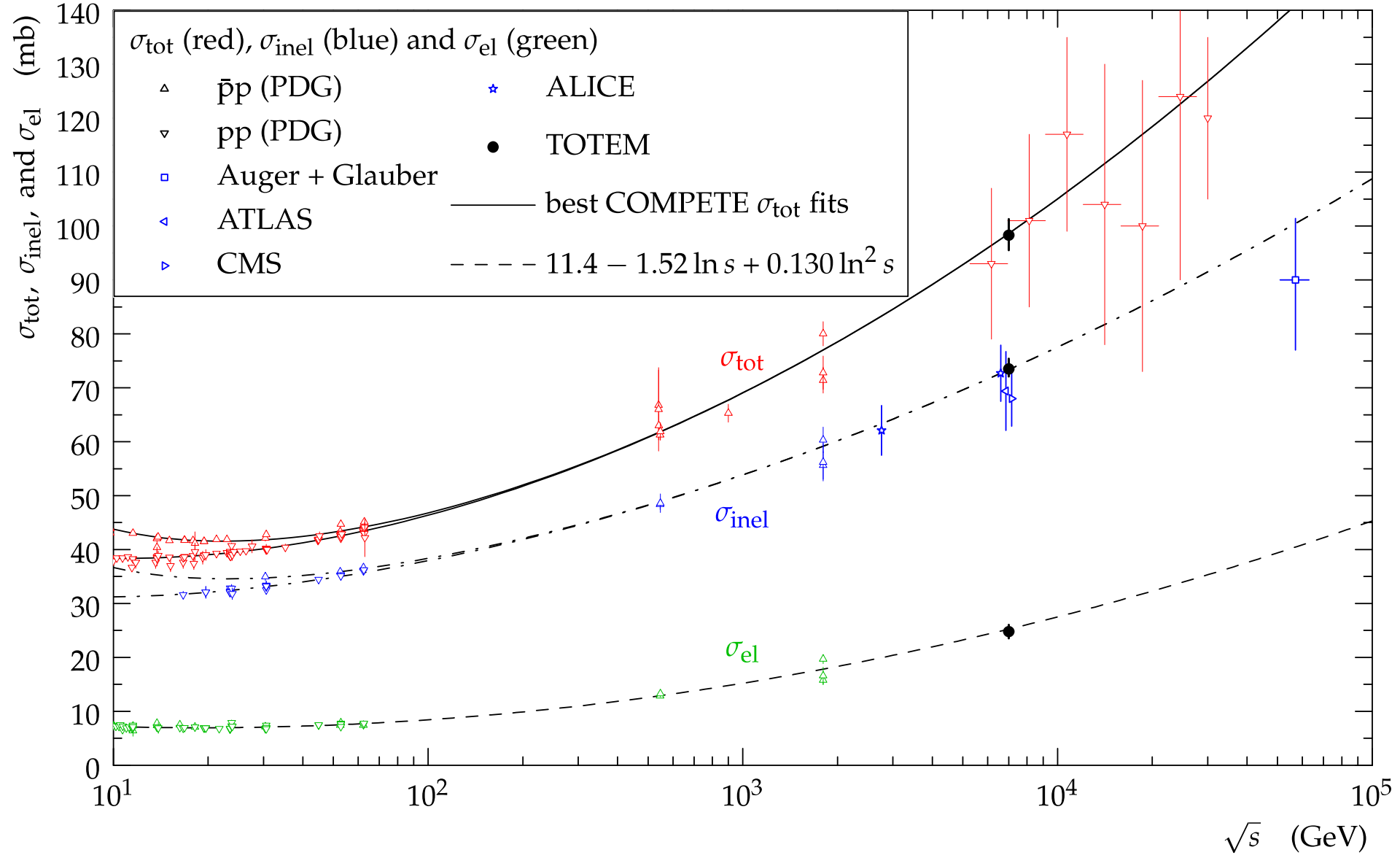
➔ $\sigma_{inel} = \sigma_{tot} - \sigma_{el} = 73.1 \pm 1.3$ mb

$\sigma_{inel,\ |\eta| < 6.5} = 70.5 \pm 2.9$ mb

$\sigma_{inel,\ |\eta| > 6.5} = 2.6 \pm 2.2$ mb

< 6.3 mb (95% CL)

Elastic, Inelastic, Total Cross-Sections [7TeV]



Luminosity-independent Cross-Section [8TeV]

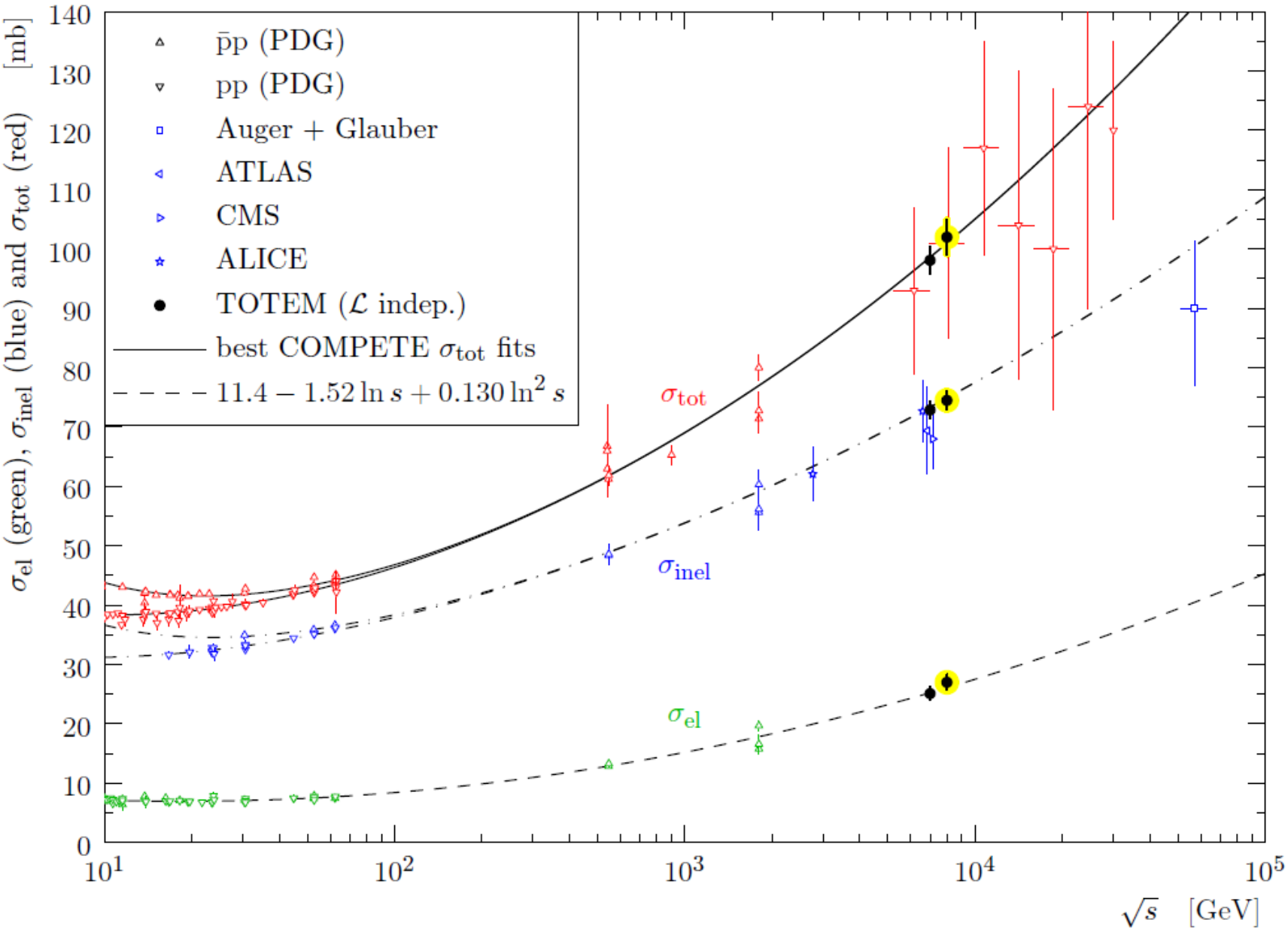
Elastic, Inelastic, Total cross-sections
all measured "luminosity-independent"

July 2012 $\sqrt{s}$ = 8 TeV β^* = 90m

DS	σ_{tot} (mb)	σ_{el} (mb)	σ_{inel} (mb)
2	102 ± 2.8	27.1 ± 1.3	74.9 ± 1.6
3	101 ± 2.8	26.9 ± 1.3	74.2 ± 1.6

Published Physics Review Letters **PRL 111 (2013)**

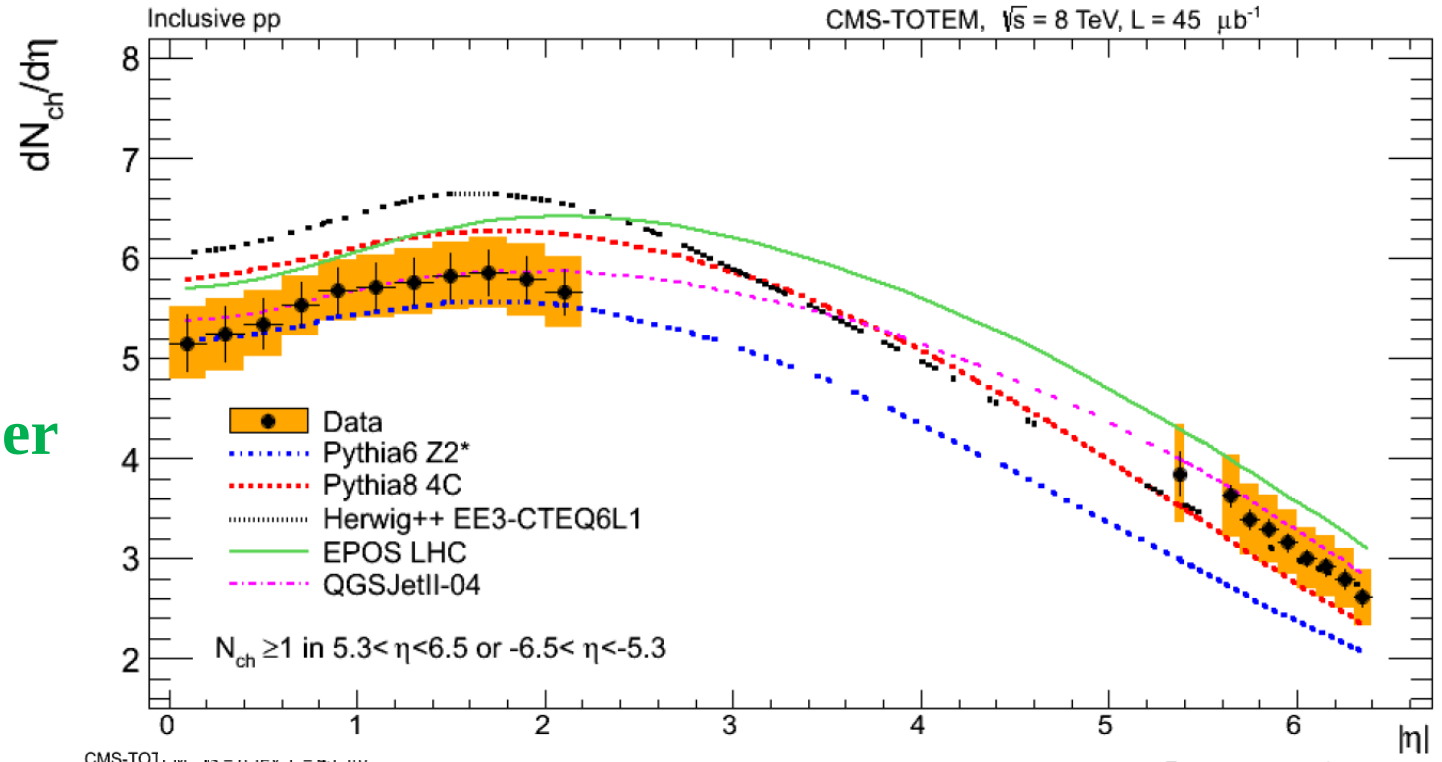
Elastic, Inelastic, Total Cross-Sections [8TeV]

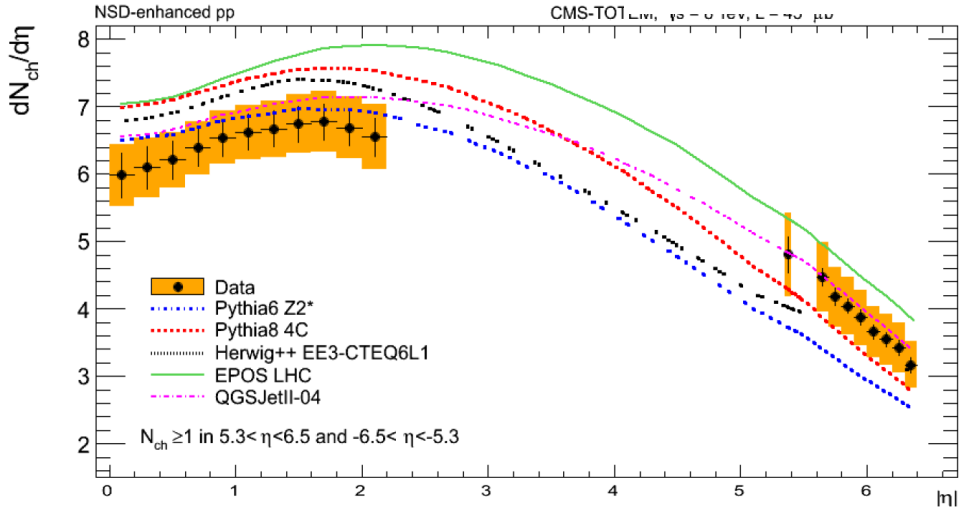


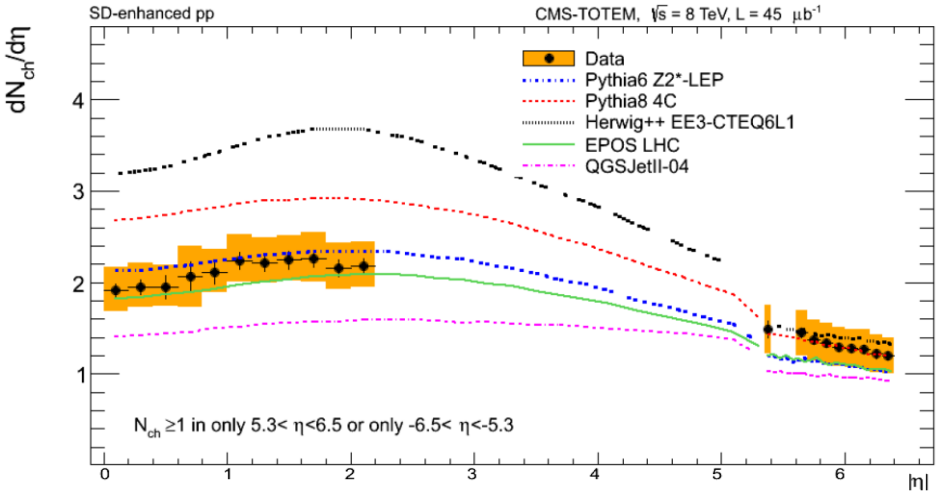
CMS-TOTEM Forward Charged Multiplicity

Joint CMS-TOTEM data taking / trigger

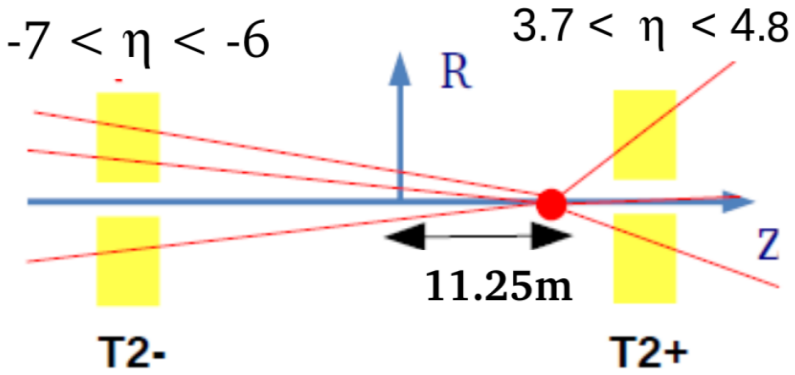
1st common paper CMS-TOTEM [EPJ]

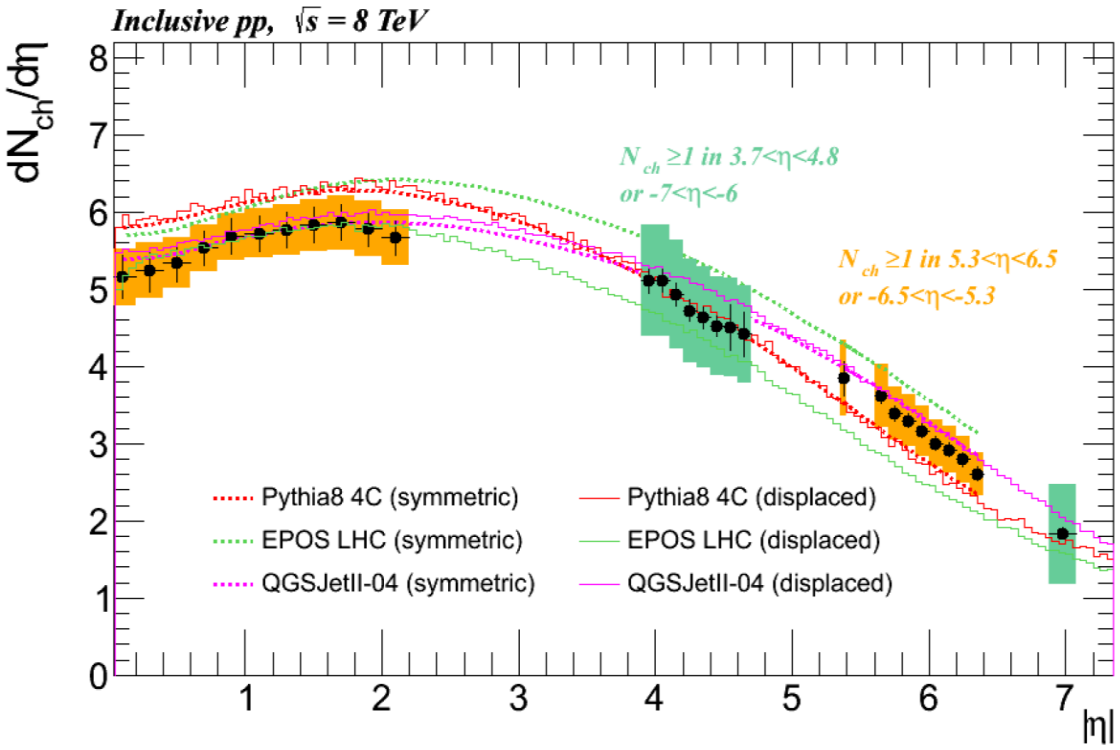






Extended-η Forward Charged Multiplicity



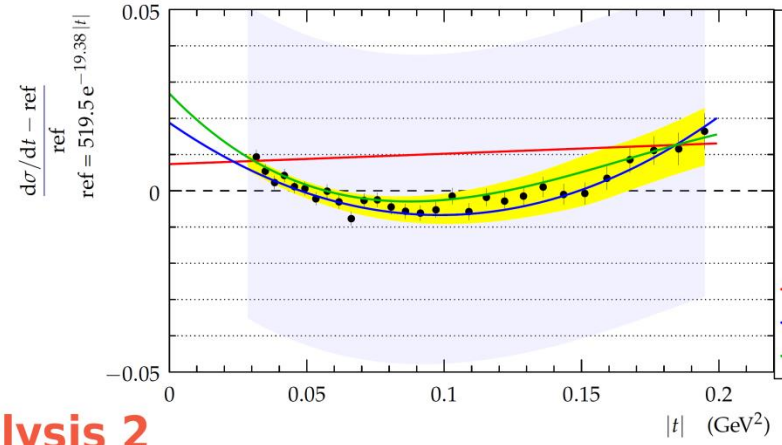


Non-perturbative QCD of Elastic Scattering

From Pomerons to diquark-quark models to coherent amplitudes of gluon exchange between fermionic lines

Analysis 1: fits $A\exp(b_1 t + b_2 t^2 + \ldots)$, N_b parameters in exponent

DS4



diagonals combined

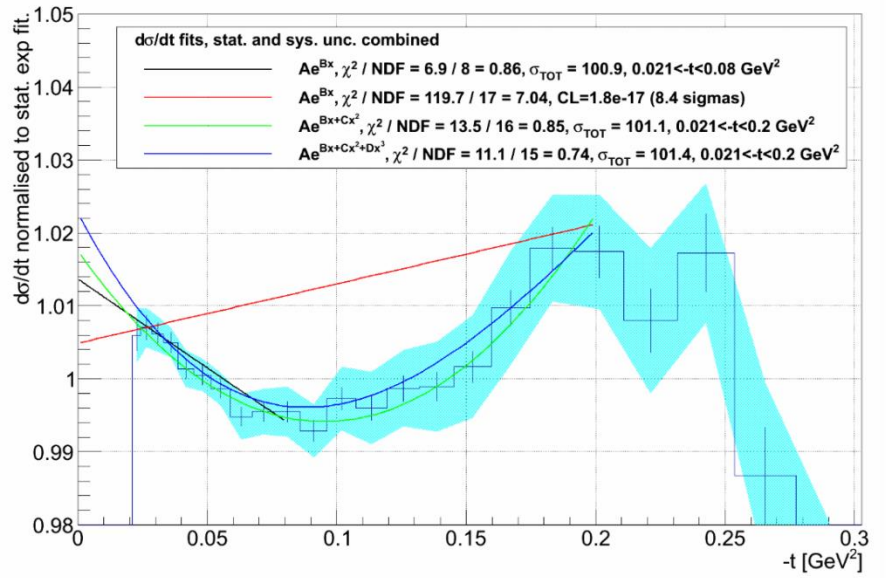
- data (binning ob)
- statistical uncertainties
- systematic uncertainty band: analysis+normalisation
- systematic uncertainty band: analysis only

fit parametrisation: $a\exp(\sum_{n=1}^{N_b} b_n t^n)$

fits with statistical and systematic uncertainties:

- $N_b = 1$: $\chi^2/\text{ndf} = 117.5/28 = 4.198 \Rightarrow$ p-value $= 6.14\times10^{-13}$, significance $= 7.20\,\sigma$
- $N_b = 2$: $\chi^2/\text{ndf} = 29.3/27 = 1.085 \Rightarrow$ p-value $= 3.47\times10^{-1}$, significance $= 0.94\,\sigma$
- $N_b = 3$: $\chi^2/\text{ndf} = 25.5/26 = 0.980 \Rightarrow$ p-value $= 4.92\times10^{-1}$, significance $= 0.69\,\sigma$

Analysis 2



⇓

purely exponential fit excluded at more than 7σ significance

new determination
σ_{tot} = (101.4± 2.0) mb

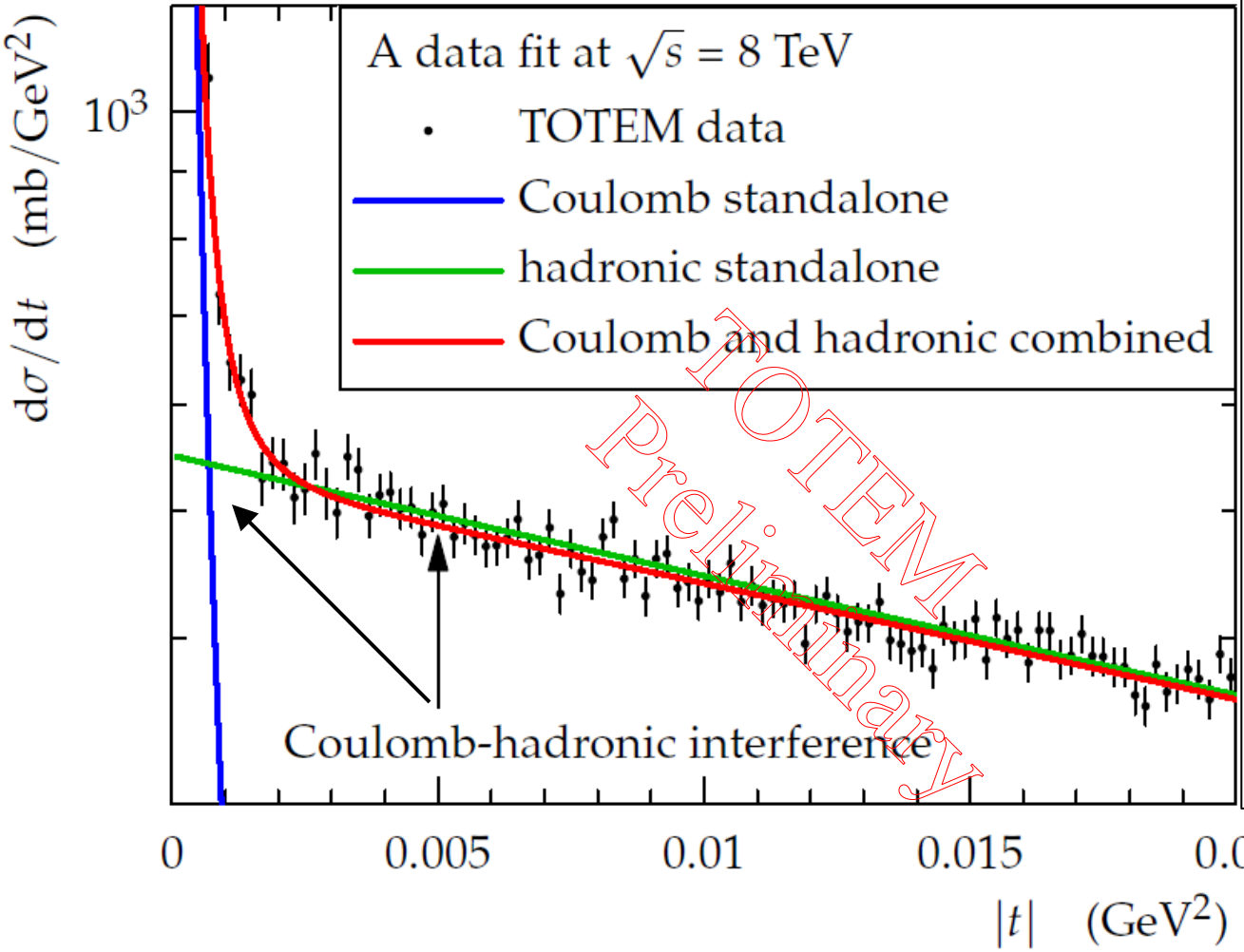
study amplitudes and central vs peripheral phase of nuclear elastic scattering

Coulomb-Nuclear Interference

Measure elastic scattering at **|t|** as low as **6 x 10^{-4} GeV^2**:

- β* = 1000 m optics
- RP approach to 3 σ from the beam centre

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



Preliminary Results:

- First observation of not constant hadronic slope B in pp elastic scattering
- Simplified West-Yennie (SWY) interference formula ruled out by data
- Evidence of Coulomb-hadronic interference at $\sqrt{s}$ = 8 TeV
- TOTEM data exclude centrality of elastic scattering in the form it was derived via SWY formalism

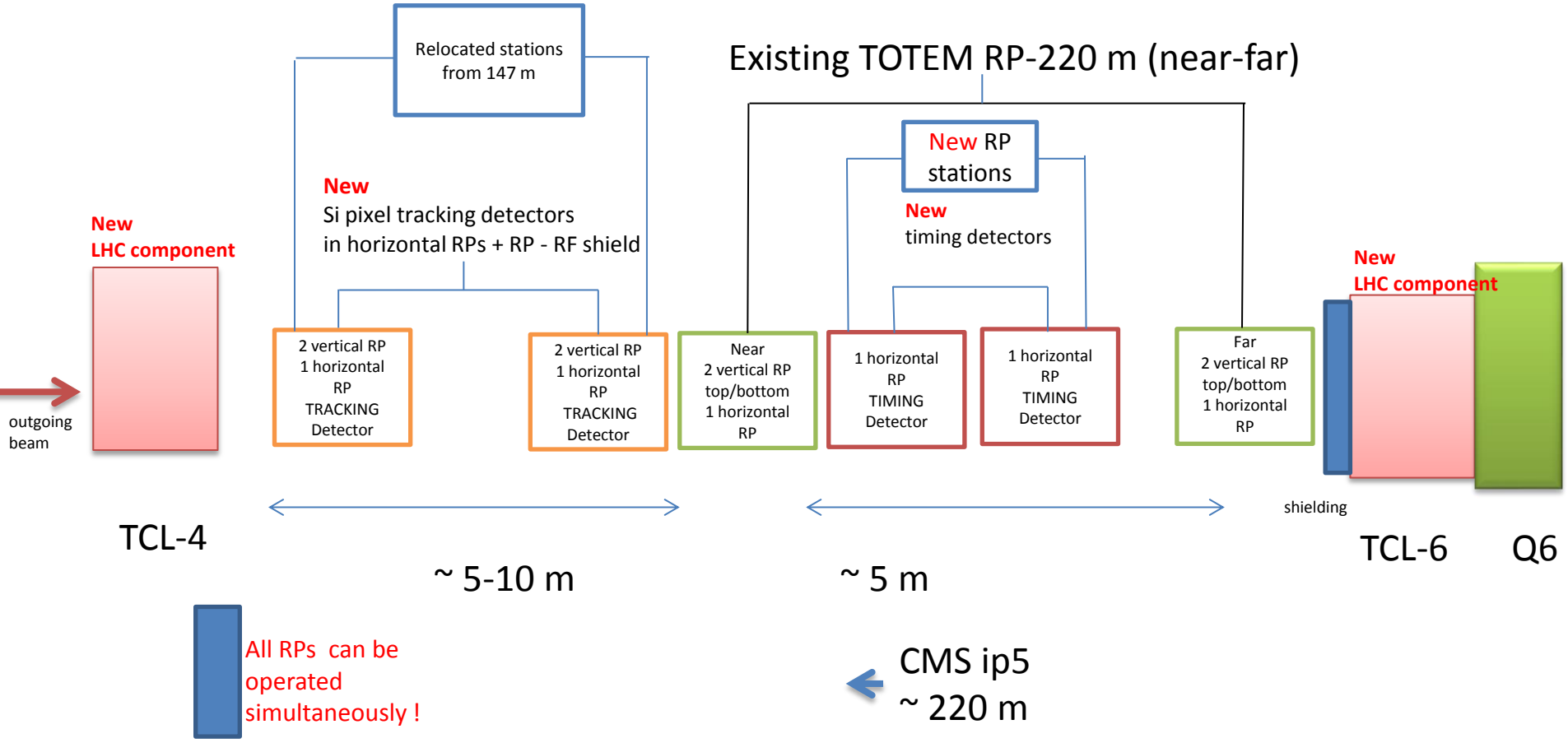
TOTEM Publications

- Proton-proton elastic scattering at the LHC energy of √s = 7 TeV , **EPL 95 (2011) 41001**
- First measurement of the total proton-proton cross section at the LHC energy of √s = 7 TeV **EPL 96 (2011) 21002**
- Measurement of the forward charged particle pseudorapidity density in pp collisions at √s = 7 TeV with the TOTEM experiment, **EPL 98 (2012) 31002**
- Measurement of proton-proton elastic scattering and total cross-section at √s = 7 TeV, **EPL 101 (2013) 21002**
- Measurement of proton-proton inelastic scattering cross-section at √s = 7 TeV, **EPL 101 (2013) 21003**
- Luminosity-independent measurements of total, elastic and inelastic cross-sections at √s = 7 TeV, **EPL 101 (2013) 21004**
- A luminosity-independent measurement of the proton-proton total cross-section at √s = 8 TeV, **Phys. Rev. Lett. 111, 012001 (2013)**
- Double diffractive cross-section measurement in the forward region at LHC, **Phys. Rev. Lett. 111 (2013) 262001** .
- Measurement of pseudorapidity distributions of charged particles in proton-proton collisions at √s = 8 TeV by the CMS and TOTEM experiments CERN-PH-EP-2014-063, submitted to **EPJ**
- The TOTEM Experiment at the CERN Large Hadron Collider **JINST 3 (2008) S08007**
- Performance of the Totem Detectors at the LHC, **Int. J. Mod. Phys. A**
- LHC optics determination with proton tracks measured in the Roman Pots detectors of the TOTEM experiment CERN-PH-EP-TOTEM-2014-002, submitted to **New J. Phys**

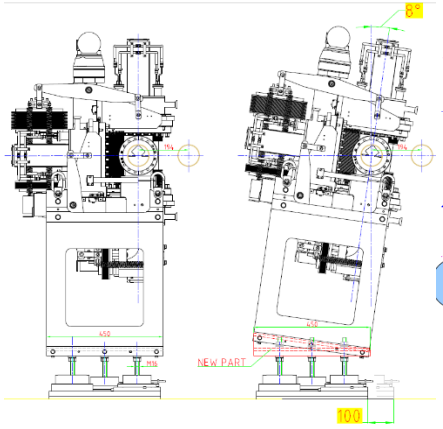
TOTEM DETECTORS
LS1 CONSOLIDATION

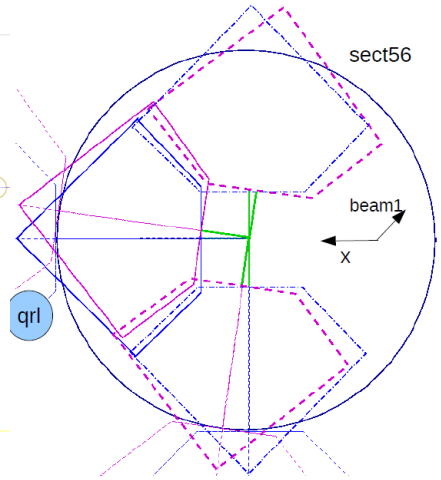
RPs Consolidation & Upgrade – LS1

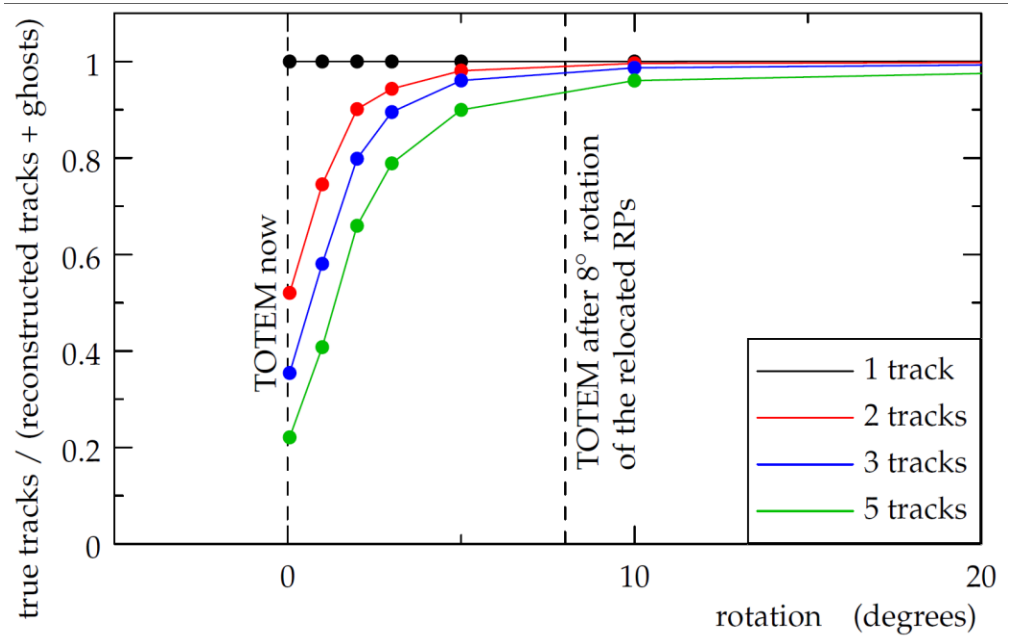
overview (schematic)



RPs Performance

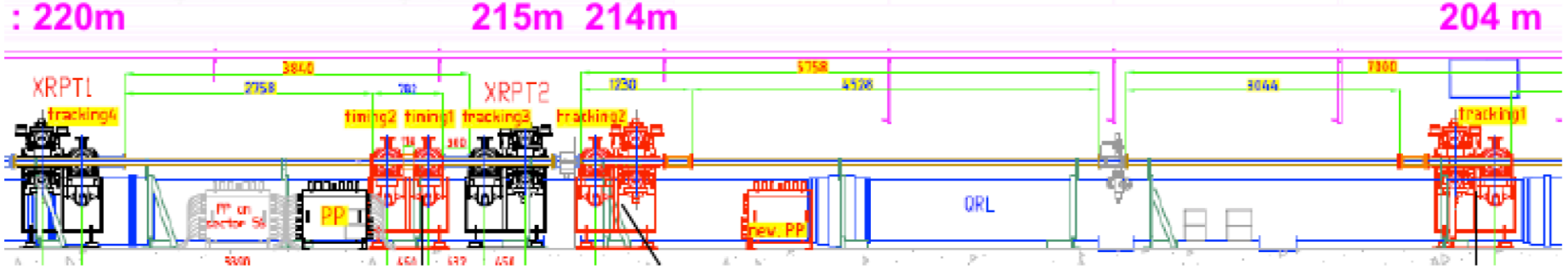






new layout:

- 147 m station relocated to 204 and 214 m (increased lever arm ⇒ better angular resolution)
- RPs at 214 m rotated by 8° ⇒ multi-track capability
- ≈ 216 m new two horizontal RPs for timing detectors (improved proton left–right correlation)



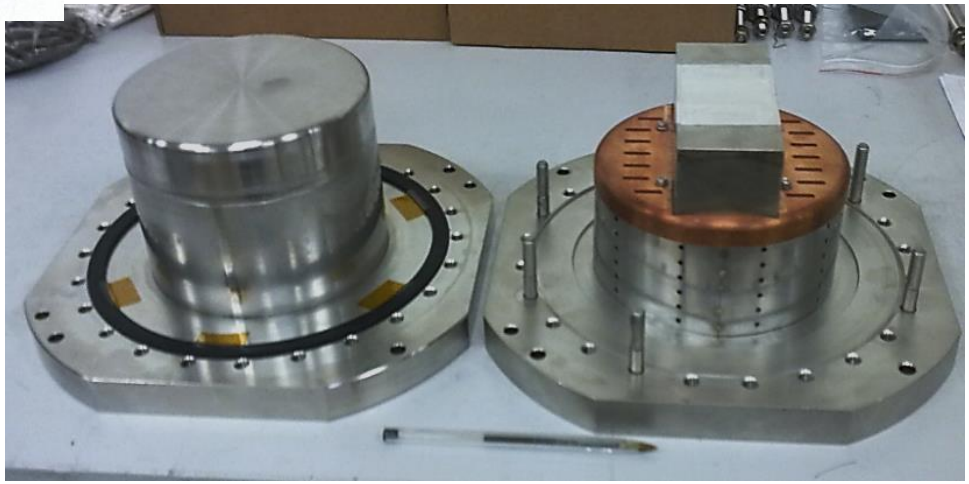
RPs Safety

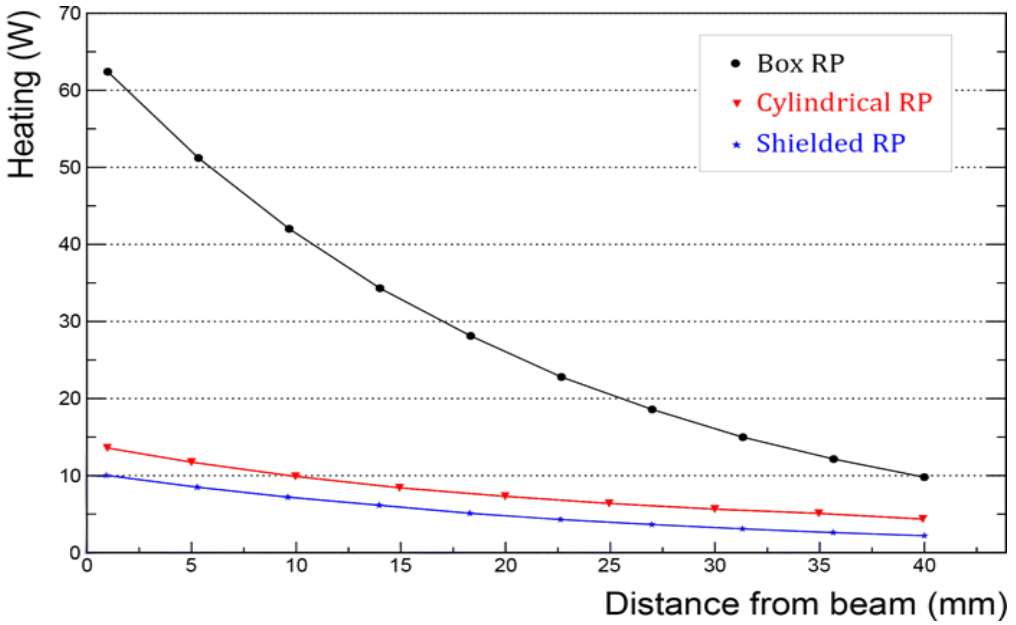
RF studies (impact on machine),

RF shield for square pots of Run I,

New ferrites to control induced RF,

New Pots cylindrical with thin window



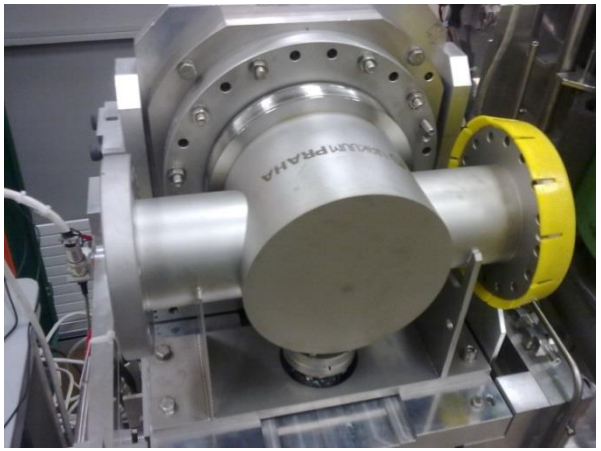


50 ns

I_B=0.6 A

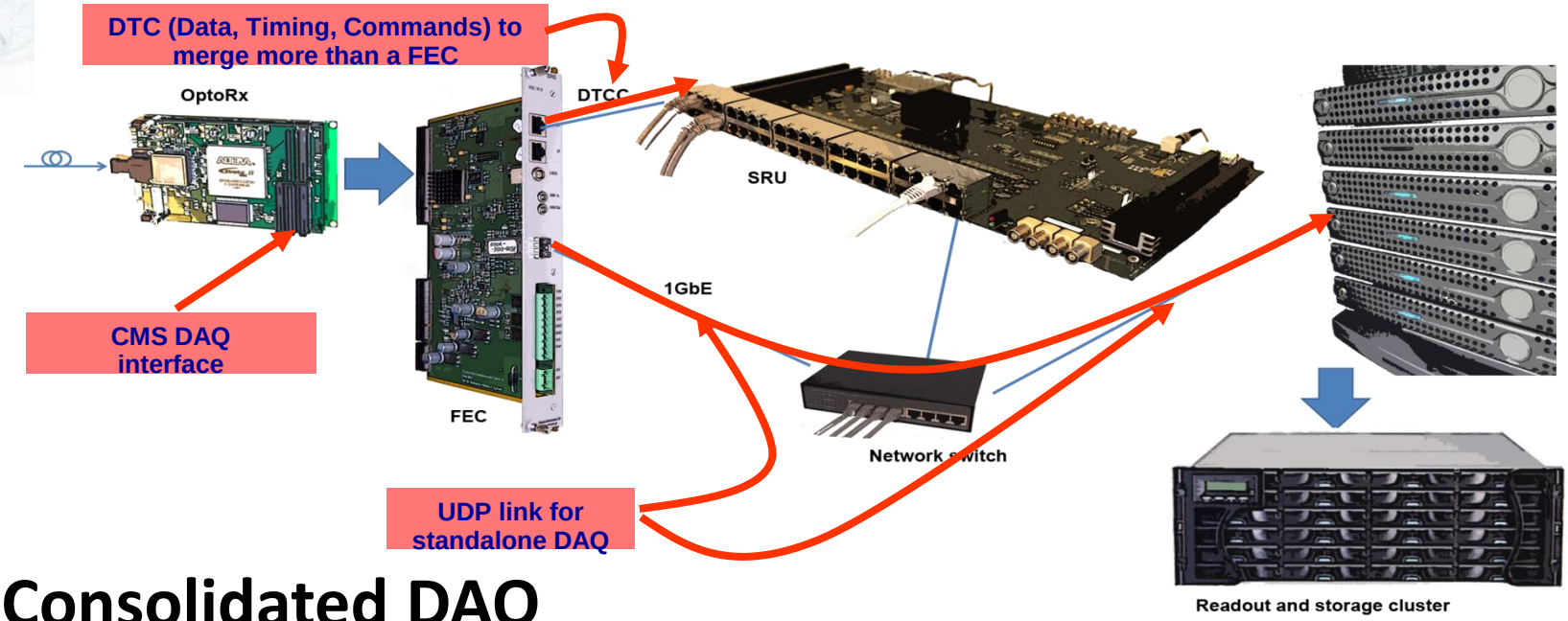
Technical Coordination - Progress

- Location of new horizontal RP confirmed by LHC integration, vacuum and impedance groups.
- 6 horizontal vacuum chambers have been produced and installed in LHC:
  technology OK, all tests passed.
- New ferrites (ring) simulated, designed, produced, tested and integrated into RP.
- RF shields (Faraday cage) produced;
  mechanical and integration tests passed.



- Four 220m RP stations refurbished (new ferrites and anti-collision switches), tested and already installed in the LHC tunnel.
- Four 210m RP stations have been refurbished (new ferrites, RF shield, anti-collision switches), tested,
  - under bakeout
  - will be installed in the LHC in June (next weeks)
  - within LHC schedule

DAQ & Trigger



Consolidated DAQ

- Full compatibility with CMS DAQ [goal integration to exploit CMS HLT online]
- Full compatibility with LHC Trigger Timing and Control (TTC)
- Higher L1 trigger rate (20kHz trigger rate, ~20x w.r.t. previous DAQ system)
  - measured on 1 FEC with 1 OptoRx through a standard PC.
- Replacement of the VME back-end with Ethernet 1Gb links
- Full TTC commands set, L1A and TTC clock distribution integrated in the system.
- Hardware resources (FPGA) at different level enables real-time data filtering.

TOTEM PHYSICS LHC RUN II

pp Interactions

Non-diffractive

Colour exchange

dN / d Δη = exp (-Δη)

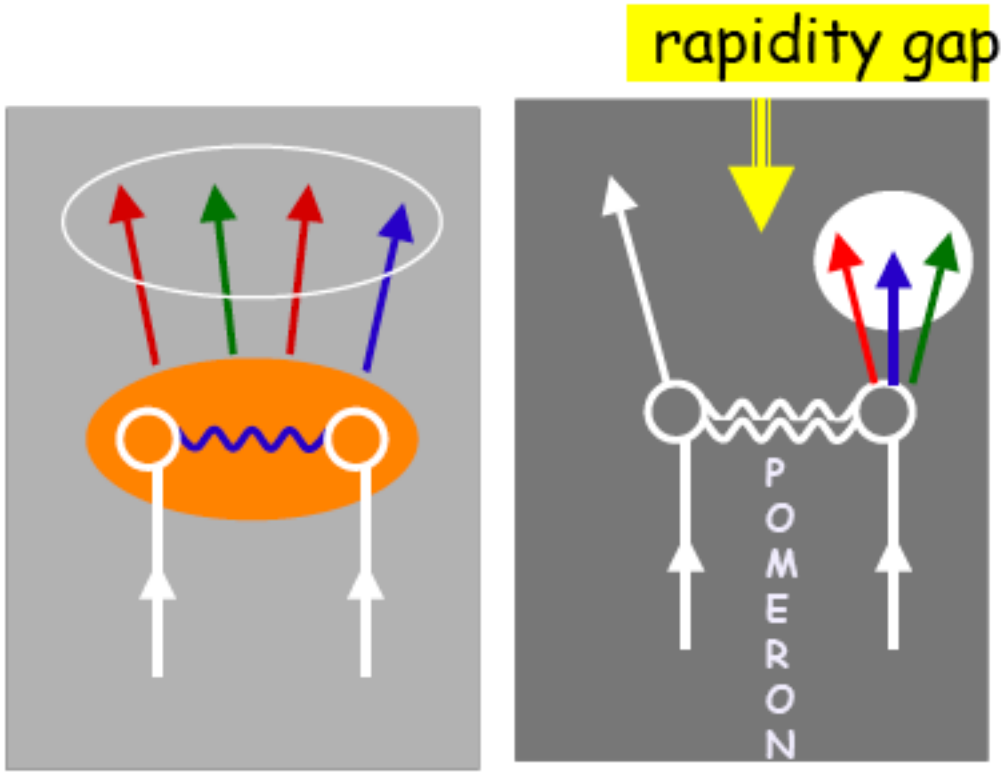
Diffractive

Colourless exchange with vacuum quantum numbers

dN / d Δη = const

(η = -ln tg θ/2)

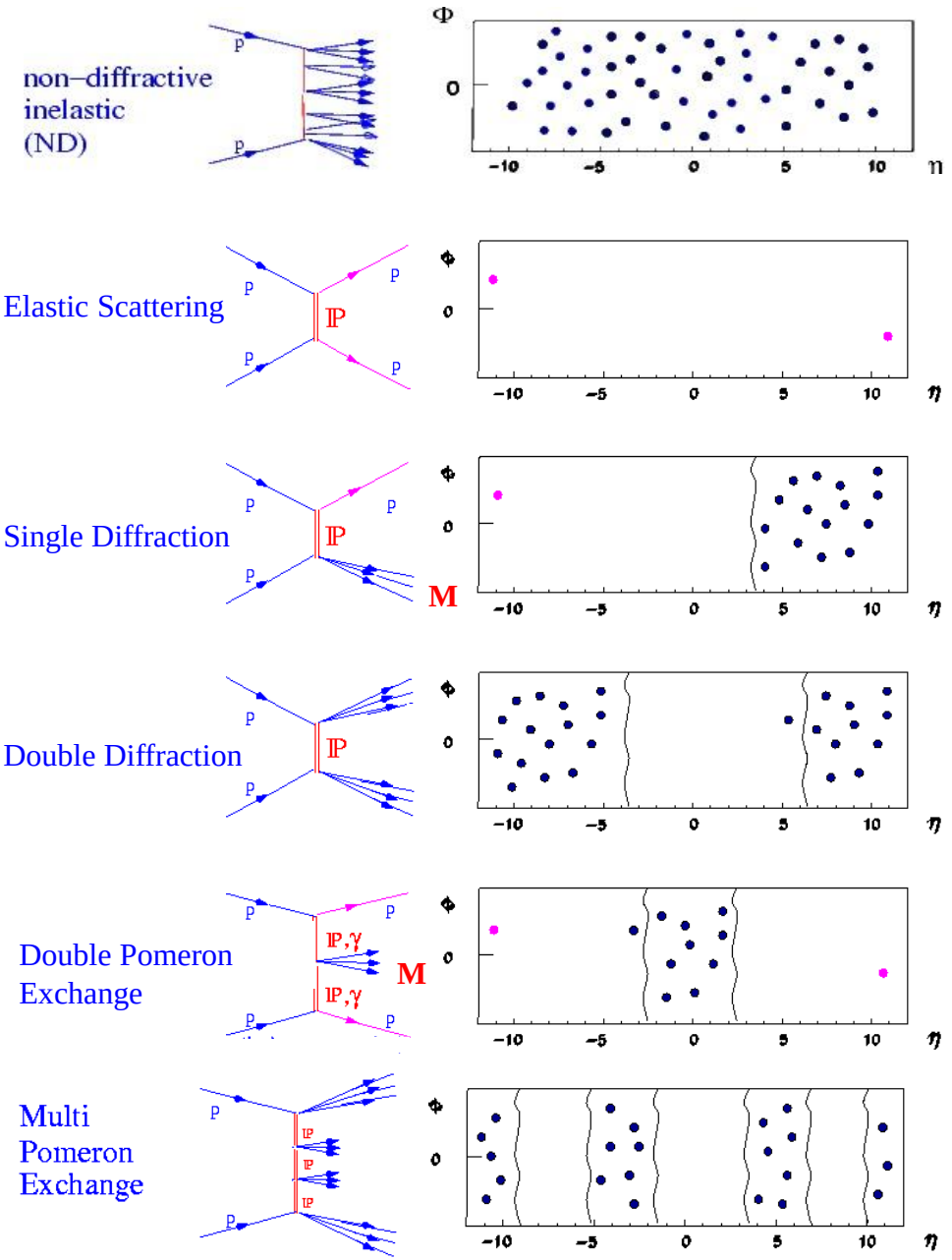
Incident hadrons acquire colour and break apart



Incident hadrons retain their quantum numbers remaining colourless

GOAL: understand the QCD nature of the diffractive exchange

Inelastic and Diffractive Processes



~60 mb

~25 mb

~10 mb

~5 mb

~1 mb

<< 1 mb

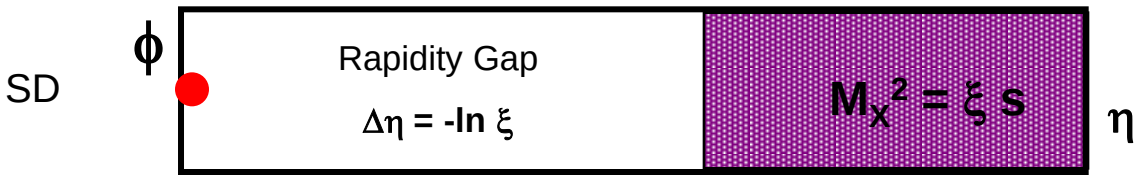
All the drawings show soft interactions.
In case of hard interactions there should be jets which fall in the same rapidity intervals.

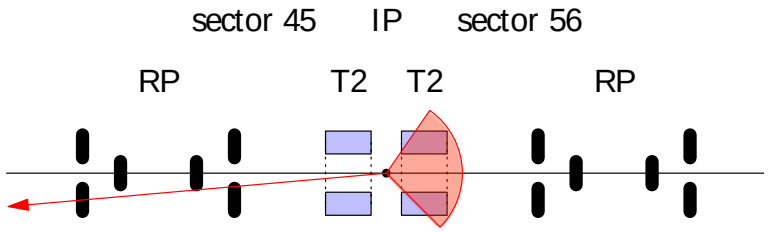
Measure σ (M,ξ,t)

Diffractive scattering is a unique laboratory of confinement & QCD:
A hard scale + hadrons which remain intact in the scattering process.

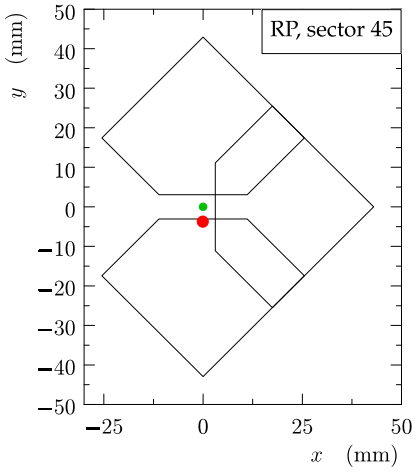
Single Diffraction low ξ

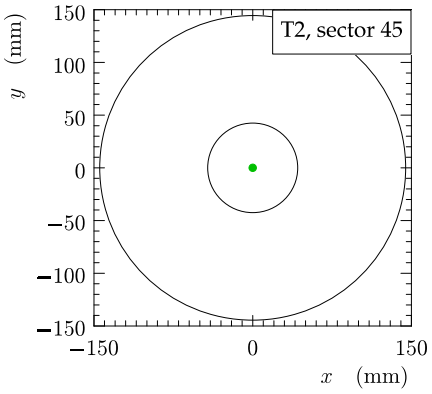
Correlation between leading proton and forward detector T2

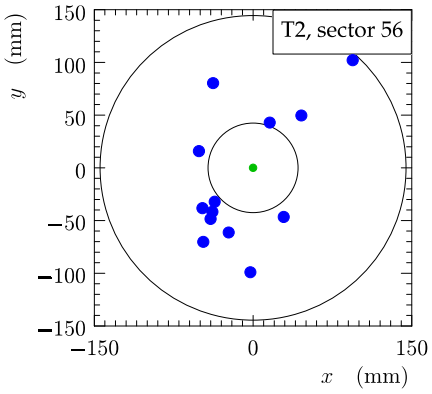


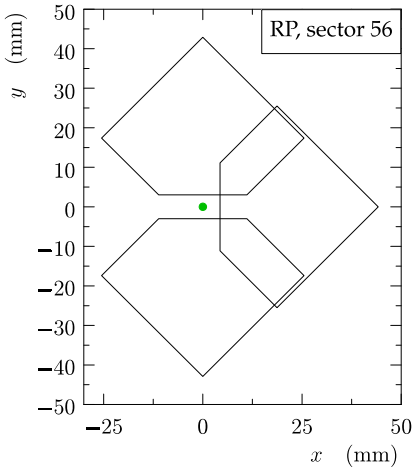


run: 37280003, event: 3000





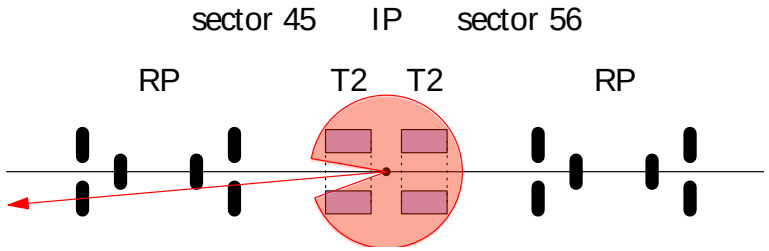




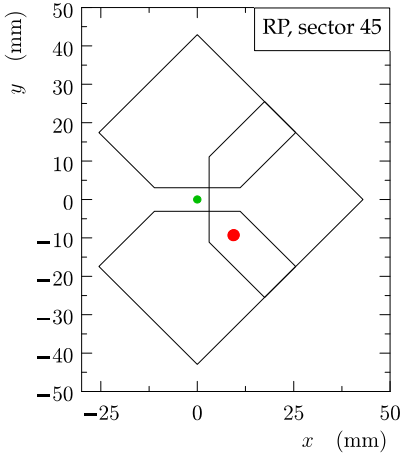
* Ongoing analysis on data of LHC Run I

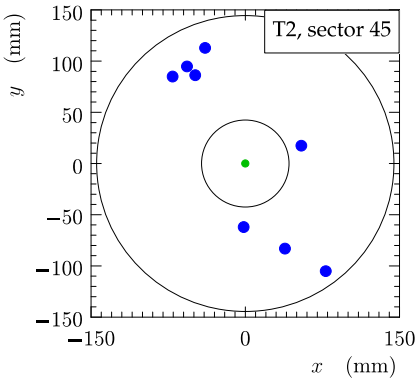
Single Diffraction large ξ

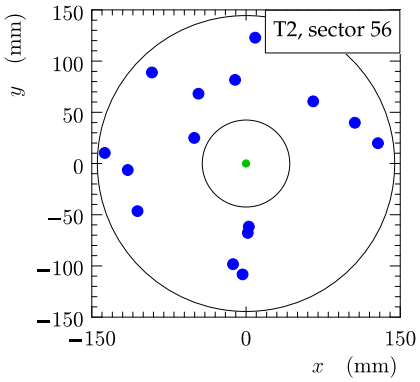
Correlation between leading proton and forward detector T2

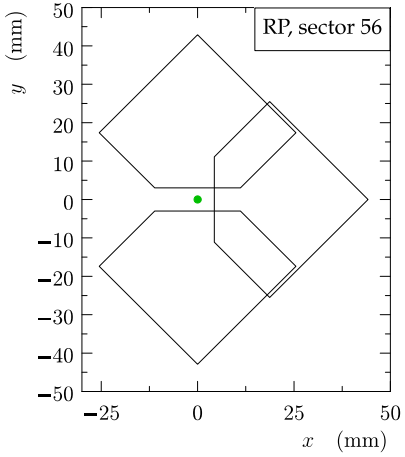


run: 37280006, event: 9522



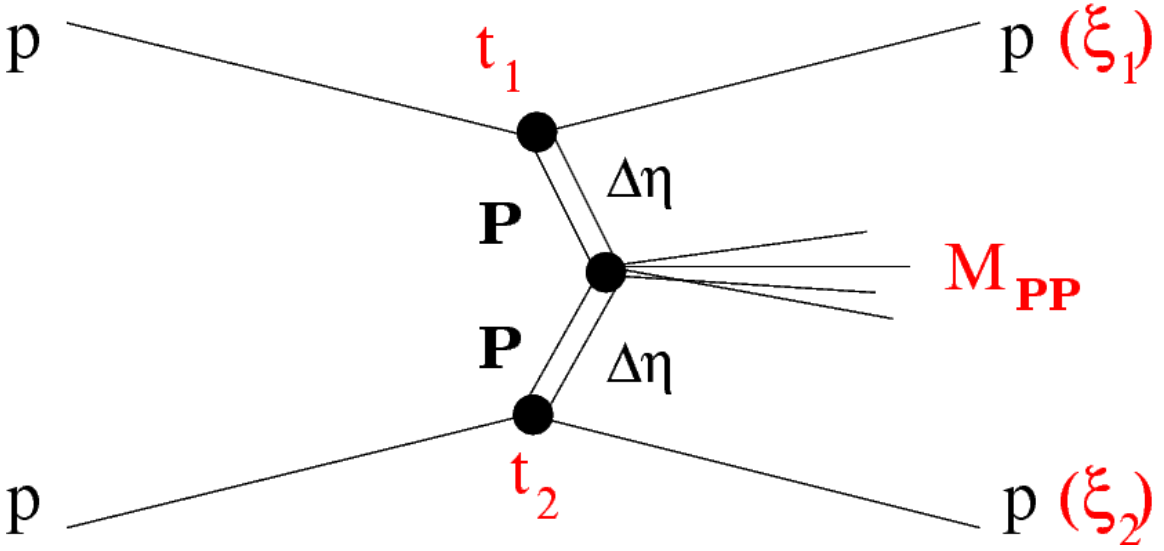


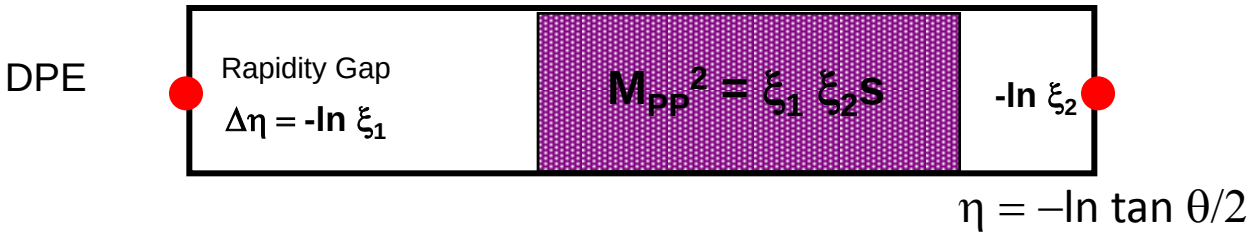




* Ongoing joint CMS-TOTEM jets analysis on data of LHC Run I

Double Pomeron Exchange



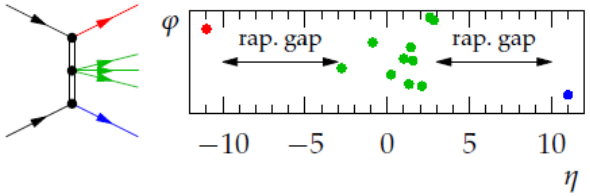


Use the LHC as a Pomeron-Pomeron (gluon - gluon) collider

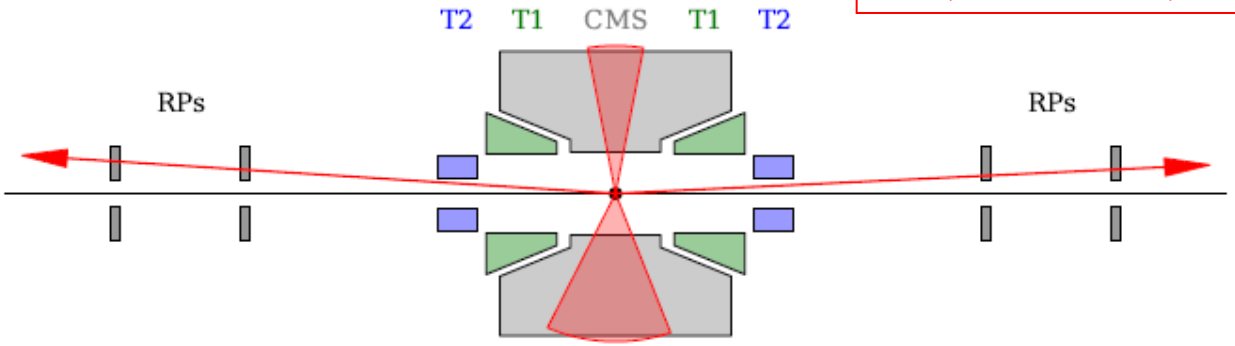
*Central Diffraction **Central Exclusive Production

Diffractive Physics Program LHC Run II

- TOTEM: standard measurement of elastic scattering
  (from the largest to the smallest *t*)
  and of the total and inelastic cross section at the new LHC energy
- TOTEM+CMS: physics search on low mass spectroscopy (1-3GeV)
  - gluonic states and glueball searches
  - diffractive χ_c production
- TOTEM+CMS: central-diffractive jet production
- TOTEM+CMS: missing/escaping mass

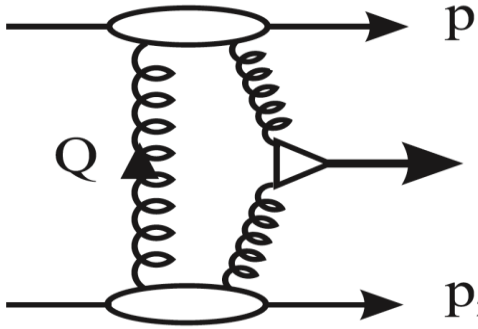


$$\Delta\eta_{1,2} = -\ln \xi_{1,2}, \quad M^2 = \xi_1 \xi_2 s$$



Preliminary investigation of some physics channels in progress with the analysis of data from joint CMS-TOTEM high β^* run (90m) , 8 TeV , July 2012

Central Exclusive Production (CEP)



$M^2 = \xi_1 \xi_2 s$

gg collider

$$y_x = \frac{1}{2} \ln \frac{\xi_1}{\xi_2}$$

also $\gamma\gamma$ fusion & photoproduction

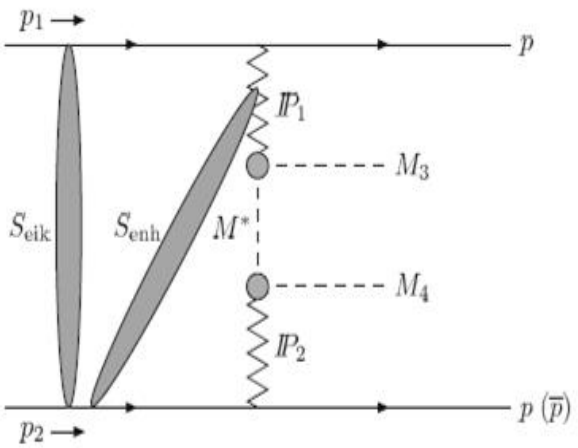
- exchange of colour singlets with vacuum quantum numbers
  $\Rightarrow$ selection rules for system X: $J^{PC} = 0^{++}, 2^{++}, \ldots$ resonances, jets,?....
- <u>With double-arm proton detection:</u>
  β^* = 90m runs: all M(pp), $\mu \sim 0.05 - 0.5 \Rightarrow O(0.1\text{-}10\ pb^{-1}/day)$
  low β^* runs: M(pp) > ~ 350 GeV, μ ~ 30 - 50 $\Rightarrow O(1\ fb^{-1}/day)$
- Comparison/prediction from forward to central system:
- M(pp) =? M(central), $p_{T,z}$(pp) =? $p_{T,z}$(central), vertex(pp) =? vertex(central)
- Prediction of central particle flow topology from proton ξ's (rapidity gaps): $\Delta\eta_{1,2} = -\ln\xi_{1,2}$

- CMS & TOTEM common runs: access to O(pb) production cross-sections

CEP low-Mass States & Glueballs

LHC: a unique lab to study CEP low M states

1 resonance / meson pair
($\pi\pi$, KK, $\rho\rho$, $\eta\eta$)



- small p_T's of final state mesons
  $\Rightarrow$ **CMS tracking** $\Delta M \sim 10$ MeV ($<<$ ISR, RHIC, Tevatron)
- $\pi/K/p$ separation using CMS tracker dE/dx
- proton tagging in β^* = 90m runs $\Rightarrow$ $p_T \sim 40$ MeV
- **RP proton tagging** $\Rightarrow$ no need to invoke rapidity gaps
- large η coverage & protons $\Rightarrow$ exclusivity ensured with excellent S/B
- spin determination from decay angles & proton azimuthal correlations

Small ξ **~10^{-3} 10^{-4} at LHC** from RP vertices $\Rightarrow$ pure gluon pair $\Rightarrow$ masses ~ 1-3 GeV

Pomeron $\approx$ colourless gluon pair/ladder

$\Rightarrow$ Pomeron fusion likely to produce glueballs

- Past luminosity: ~ 0.003 pb^{-1} $\Rightarrow$ need $\times$ 300 (~ 1 pb^{-1}) to produce resonances
- Study of glueballs & χ_c in hadronic modes require $\times$ 3000 (~ 10 pb^{-1})
- Increase in integrated luminosity in high β runs may be obtained :
  - > Increasing bunch number (requires crossing angle for high β runs)
  - > Increasing running time

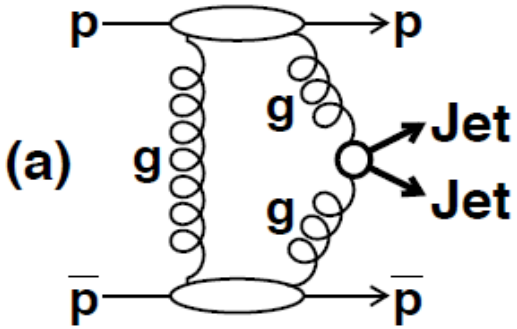
CEP Jets

$$pp \rightarrow p + \text{dijet} + p$$

- $J_z = 0$ selection rule: $gg \rightarrow q\bar{q}, b\bar{b}$ suppressed by a factor 10^2-10^3
- CEP dijets: unique possibility to observe enhanced gluon jets at LHC
  $\Rightarrow$ clean probe of properties of gluon jets (multiplicity, particle correlations...).
- cross-sections extremely sensitive to important & subtle QCD effects:
  - generalized gluon PDFs, rapidity gap survival probabilities, "Sudakov" factors.

- test model predictions:
  study proton azimuthal correlations & CEP 3-jet topologies
  Durham model: $gg \rightarrow gq\bar{q}$ (more Mercedes-like) & $gg \rightarrow ggg$ ("more back-to-back").

Durham group (KHARYS MC)



Predictions for CMS-TOTEM selection:

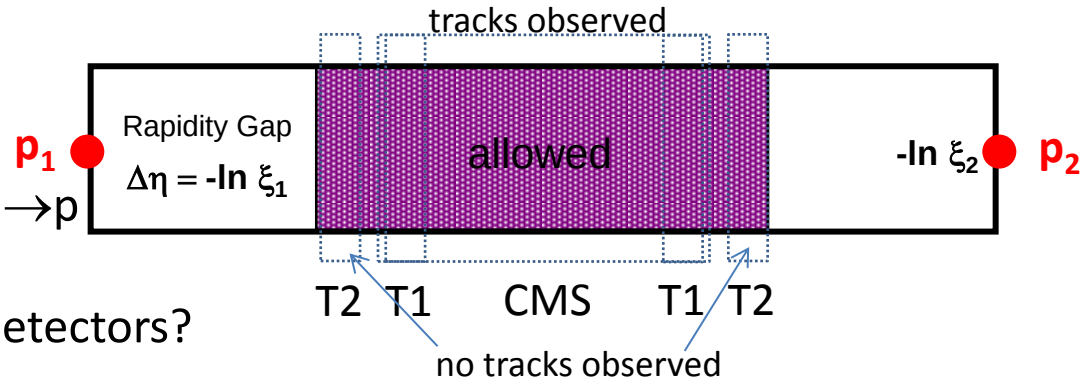
Central: $|\eta_j| < 4.4$, $|p_\perp^j| > 30$ GeV (jets)
Protons: $|p_\perp^y| > 0.1$ GeV, $p_{1\perp}^y * p_{2\perp}^y > 0$
$\Rightarrow \sigma(gg) \approx 100$ pb

Past luminosity: ~ 0.1 pb^{-1} $\Rightarrow$ need $\times$ 1000 (~ 100 pb^{-1}) for sufficient statistics (~ 10k)

Central Diffraction Missing Mass Searches

- Check escaping-mass candidates
- Pile-up protection
- p_{CMS}(Particle Flow) $\neq$ p_{TOTEM}(pp)
  M_{CMS}(Particle Flow + missing momentum) $\leq$ M_{TOTEM}(pp)
  $\rightarrow$ existence of tracks undetected by CMS

- No tracks observed in forward detectors 'allowed' by rapidity gaps
- More forward regions excluded by rapidity gaps $\rightarrow$ 'allowed' = 'required' ?

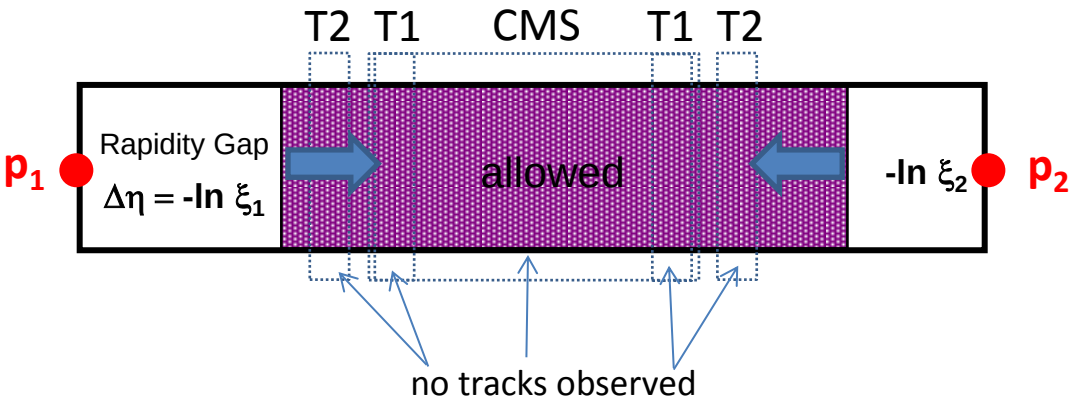


- energetic gammas in T2, N*$\rightarrow$p
- detectors' 'inefficiency'?
- acceptance gaps between detectors?
- high energy neutrinos?
- neutral particle flow in T2 (under simulation)?
- real escaping energy?

These depend on amount of missing energy

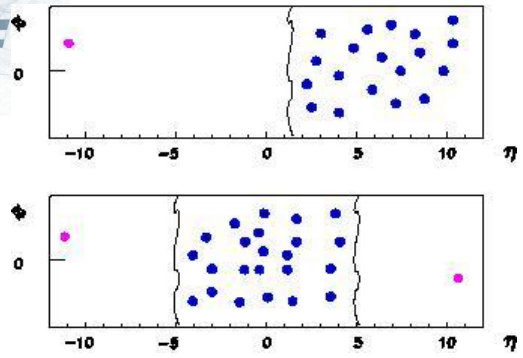
Exclusive Missing Mass Searches

DPE pp candidates in Roman Pots. CMS, T1, T2 empty.



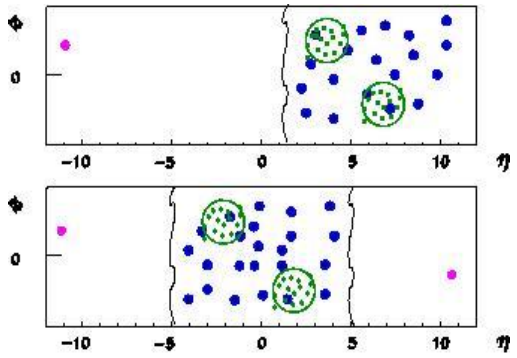
If ξ ~1% logic applies to CMS tracker allowed & everything else forbidden (then it could work also if pile-up).

TOTEM + CMS Running Scenarios



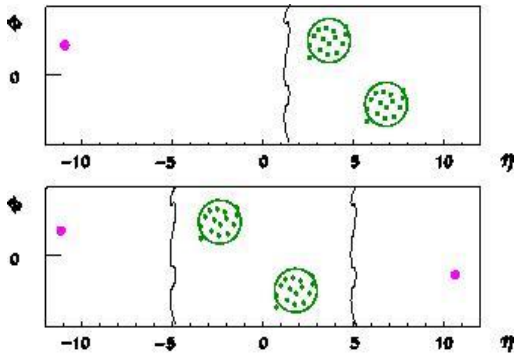
pp->pX
pp->pXp

soft diffraction



pp->pjjX
pp->pjjXp

(semi)-hard diffraction



pp->pjj (bosons, heavy
pp->pjjp quarks,Higgs...)

hard diffraction

Cross section ← → Luminosity

β (m)	1540	90	2	0.5
L (cm^{-2} s^{-1})	10^{29}	10^{30}	10^{32}	10^{34}
	TOTEM LHC runs			Standard LHC runs

TOTEM + CMS Special Runs β* 90m

2015

***** Low-mass diffractive spectroscopy *****		
Past Luminosity:	$\sim 0.003\,\mathrm{pb}^{-1}$	~ 3 bunches, $\mu = 5\%$, ~ 1 physics-day
Requirement:	factor $\sim 300 \rightarrow \mathbf{1\,pb^{-1}}$	
Solution:	~ 1000 bunches, ~ 1 physics-day	or ~ 100 bunches, ~ 10 physics-days
Notes: do-able even without crossing-angle if problems.		
***** Glueball searches and χ_c CEP *****		
Past Luminosity:	$\sim 0.003\,\mathrm{pb}^{-1}$	~ 3 bunches, $\mu = 5\%$, ~ 1 physics-day
Requirement:	factor $\sim 3000 \rightarrow \mathbf{10\,pb^{-1}}$	
Solution:	~ 1000 bunches, ~ 10 physics-days	
Notes: needed $\mu \sim 10\%$ (timing detectors already useful if available).		

2016

***** Missing mass searches, gluonic states BR/couplings, *** CEP di-jets, hard-diffraction**		
Past Luminosity:	$\sim 0.1\,\mathrm{pb}^{-1}$	~ 100bunches, $\mu = 5\%$, ~ 1 physics-day
Requirement:	factor $\sim 1000 \rightarrow \mathbf{100\,pb^{-1}}$	
Solution:	~ 1000 bunches, ~ 10 physics-days,	$\mu \sim 50\%$
Notes: needed timing detectors in vertical RPs.		

TOTEM – CMS UPGRADE PROGRAMME

Timing Measurements in Vertical RPs

Integrated luminosity of 100 pb^{-1} is necessary to probe O(pb) cross-sections for the study of :

- High statistics hard diffractive processes in CD (jet physics)
- Study of BR and quantum numbers of gluonic states candidates
- Missing mass candidates with inclusive production cross section of O(pb)

Such integrated luminosity becomes reasonable for high β runs if a pile up μ ~ 0.5 is generated by increasing bunch population

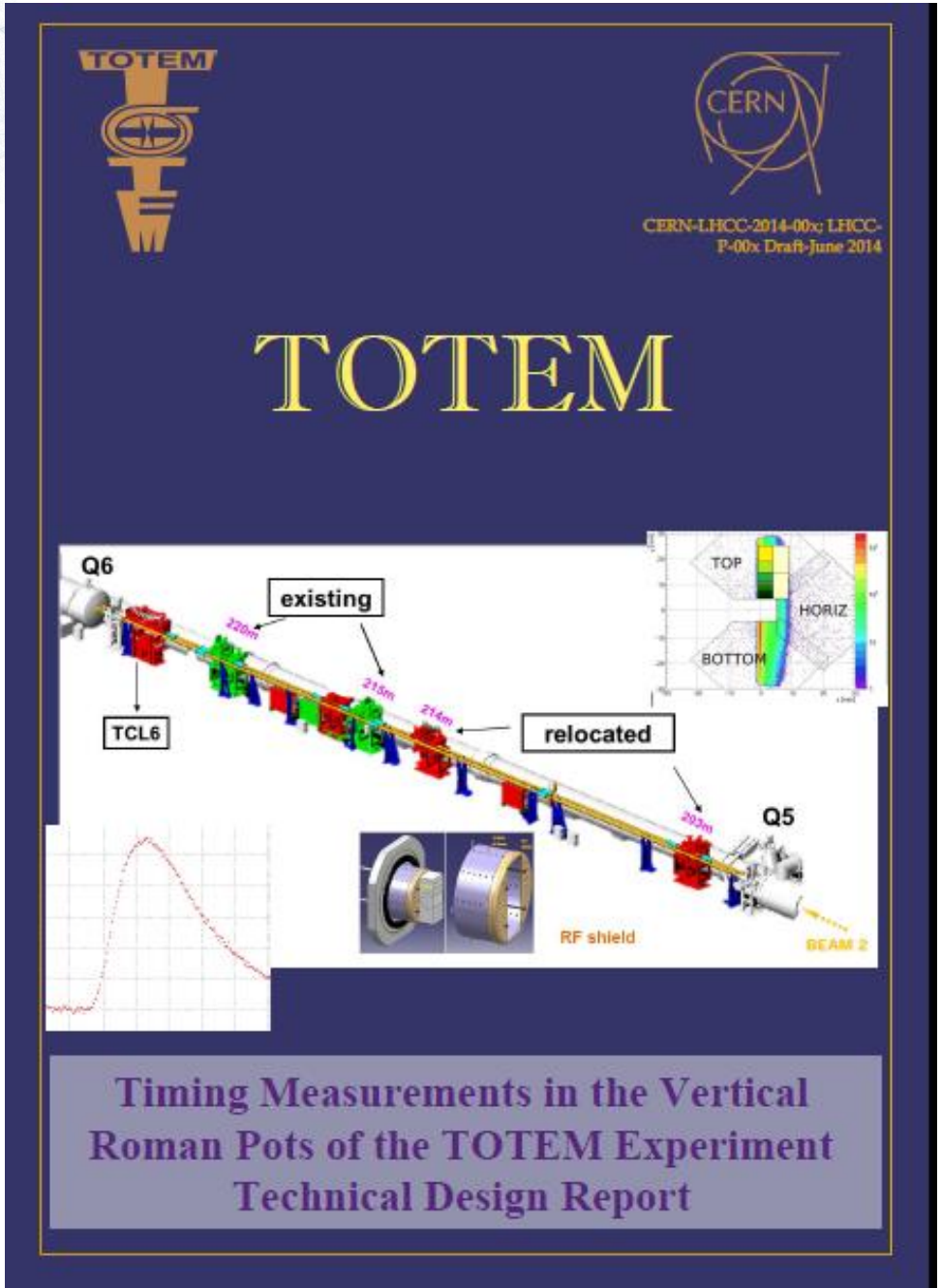
$\Rightarrow$

Advanced forward physics in special runs with vertical pots requires presence of timing to identify the collision vertex

- Signal and background scale with intensity

Remark: timing improves background reduction also in low pileup runs

TDR – Timing Vertical RP Project



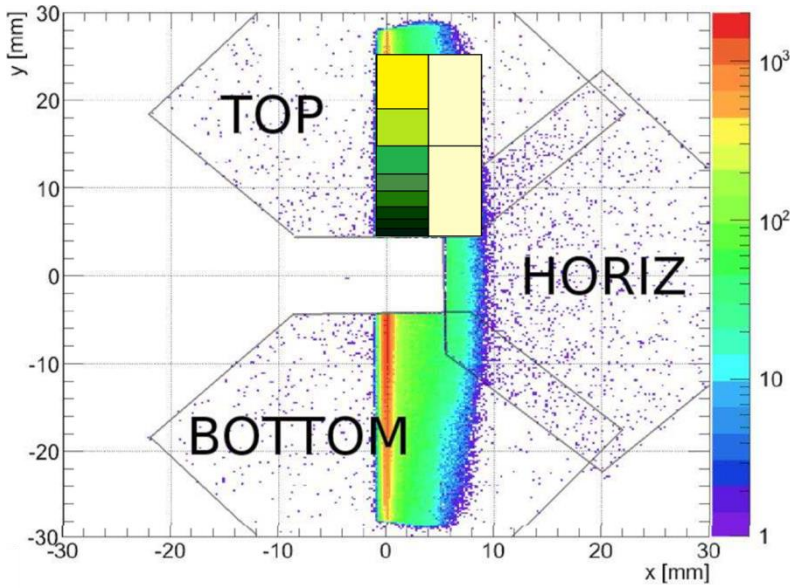
- Goal to use production technologies to implement it by end 2015
- Status and progress on TDR preparation
- Test beam campaigns during summer (PSI, PS, SPS)
- Delivery of TDR to LHCC in September 2014

Vertical RPs Timing Detectors

Optimization driven by physics and technical choices

- Minimize number of channels without compromising the physics program
  - Map plane with different size pads with same occupancy
  - Minimum number optimized with simulation

- Detector
  - Dimensions: 10mm X 20mm
  - 10 pixels with dimensions adapted to track density
  - A stack of 4 Planes improves the single plane timing resolution (1/2)
  - Available on the market is 5X10 mm and 10X10 mm, 500 μm thick
  - Diamond or Silicon



- Timing Specifications
  - Measure time of arrival of proton with a resolution better than 50ps

MoU

CMS-TOTEM : full diffractive physics programme and related new physics searches O(fb) at standard high LHC luminosity.

CMS-TOTEM joint-upgrade MoU signed

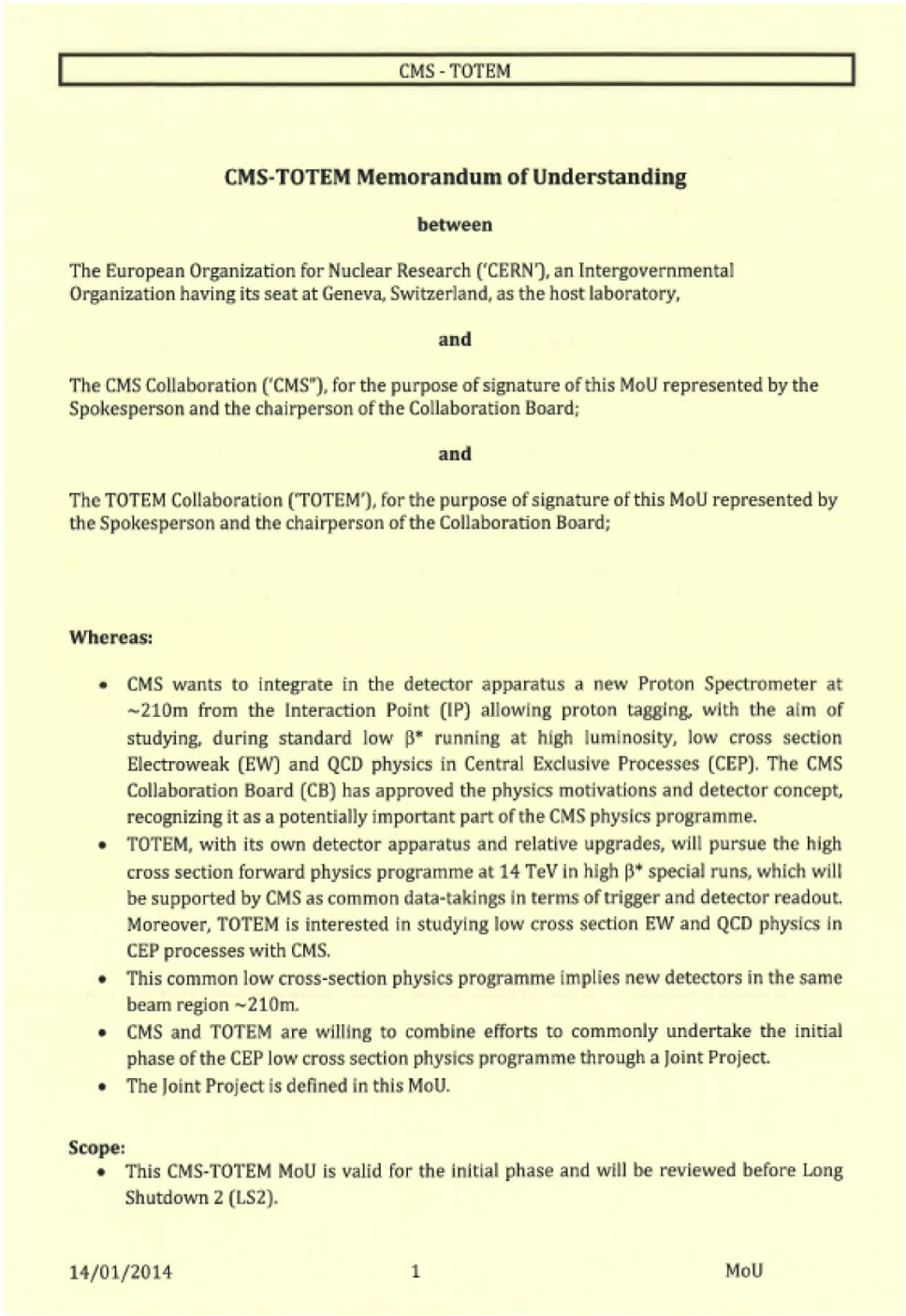
Institution Board & Management Team

Tracking detectors Si pixels in RPs

Timing detectors in new horizontal RPs

10 ps requirement for high pile-up LHC

TDR



CMS - TOTEM

CMS-TOTEM Memorandum of Understanding

between

The European Organization for Nuclear Research ('CERN'), an Intergovernmental Organization having its seat at Geneva, Switzerland, as the host laboratory,

and

The CMS Collaboration ('CMS"), for the purpose of signature of this MoU represented by the Spokesperson and the chairperson of the Collaboration Board;

and

The TOTEM Collaboration ('TOTEM'), for the purpose of signature of this MoU represented by the Spokesperson and the chairperson of the Collaboration Board;

Whereas:

- CMS wants to integrate in the detector apparatus a new Proton Spectrometer at ~210m from the Interaction Point (IP) allowing proton tagging, with the aim of studying, during standard low β* running at high luminosity, low cross section Electroweak (EW) and QCD physics in Central Exclusive Processes (CEP). The CMS Collaboration Board (CB) has approved the physics motivations and detector concept, recognizing it as a potentially important part of the CMS physics programme.
- TOTEM, with its own detector apparatus and relative upgrades, will pursue the high cross section forward physics programme at 14 TeV in high β* special runs, which will be supported by CMS as common data-takings in terms of trigger and detector readout. Moreover, TOTEM is interested in studying low cross section EW and QCD physics in CEP processes with CMS.
- This common low cross-section physics programme implies new detectors in the same beam region ~210m.
- CMS and TOTEM are willing to combine efforts to commonly undertake the initial phase of the CEP low cross section physics programme through a Joint Project.
- The Joint Project is defined in this MoU.

Scope:

- This CMS-TOTEM MoU is valid for the initial phase and will be reviewed before Long Shutdown 2 (LS2).

14/01/2014 1 MoU

TDR – CTPPS Project

June 2, 2014

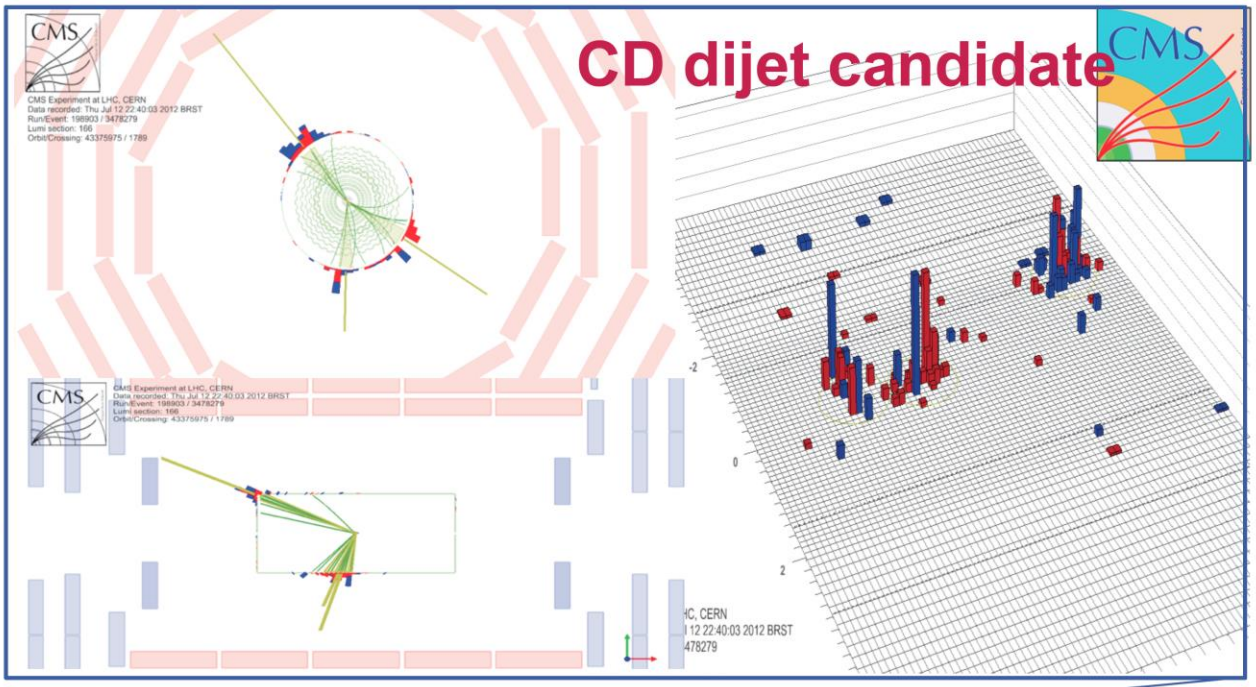
DRAFT

CMS-TOTEM Precision Proton Spectrometer
Technical Design Report

Abstract

Section	Editor
Overview	Joao Varela
Physics with the CMS-TOTEM Precision Proton Spectrometers	Mike Albrow, Ken Osterberg, Michele Arneodo
Strategy and Running Scenarios	Joachim Baechler, Mario Deile
Detector and physics performance	Michele Gallinaro, Valentina Avati
Moving Beam-Pipe	Jonathan Hollar
Roman Pots	Joachim Baechler
Silicon Sensors	Nicolo Cartiglia
Silicon Readout and Mechanical	Maurizio Lo Vetere
Fast Timing Cherenkov Detectors	Mike Albrow
Fast Timing Silicon Detectors	Nicola Turini
Fast Timing Electronics	Joao Varela
Reference Timing System	Doug Wright, Nicola Turini
Trigger Strategy	Nicola Turini
Organization, Cost, Schedule	Doug Wright, Joachim Baechler

CMS-TOTEM di-Jets Analysis



CMS + TOTEM 90m β*
Run/Event 198903/3478279
Jets E_T = 65,45,27 GeV
ξ+ :
MM(pp) = 244 GeV; M(CMS) = 219 GeV
Σp_T(CMS) = 3.4 GeV
FSC empty both sides

M(pp) = 244 GeV ≈ M(central)
ξ_1 = 0.1 ξ_2= 0.01