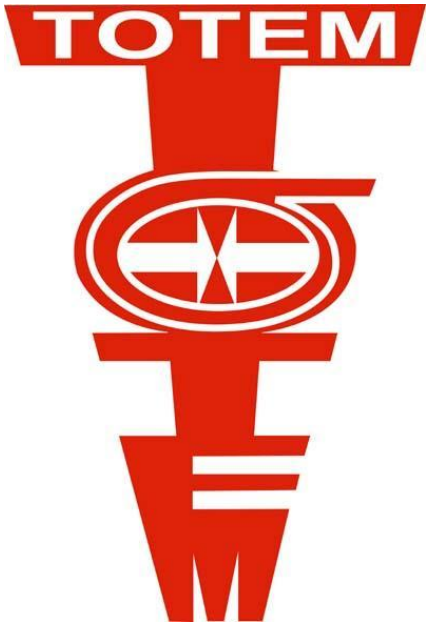
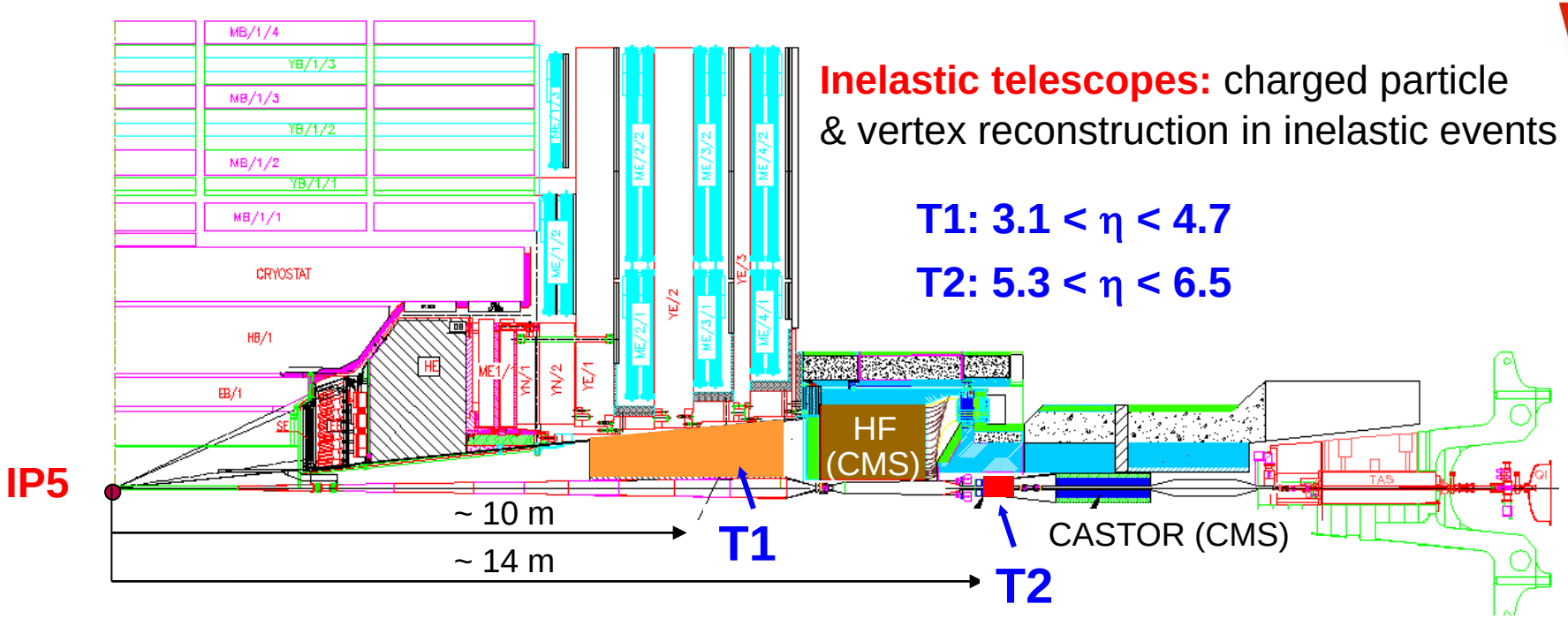
Status of the Experiment



RRB - TOTEM
30 October 2012

S.Giani - CERN
on behalf of the TOTEM Collaboration

Experimental Setup @ IP5

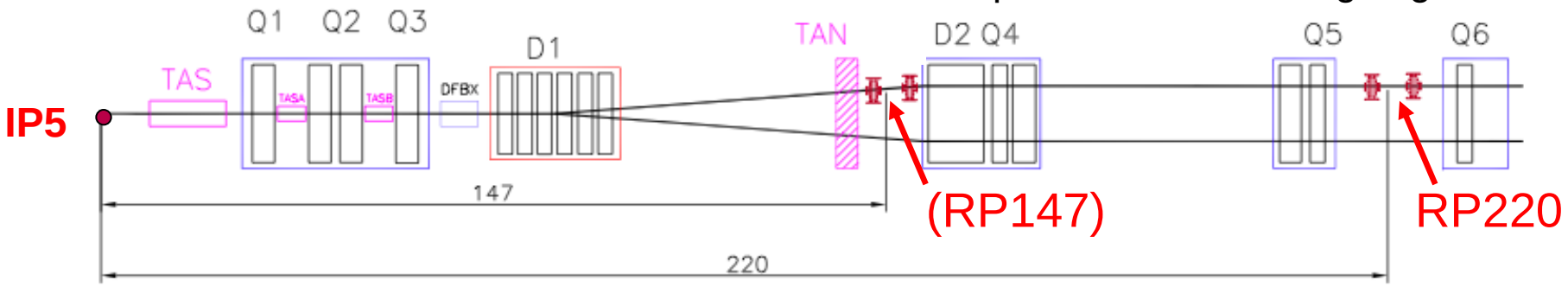


Inelastic telescopes: charged particle & vertex reconstruction in inelastic events

T1: 3.1 < η < 4.7

T2: 5.3 < η < 6.5

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



Recent and Upcoming Publications

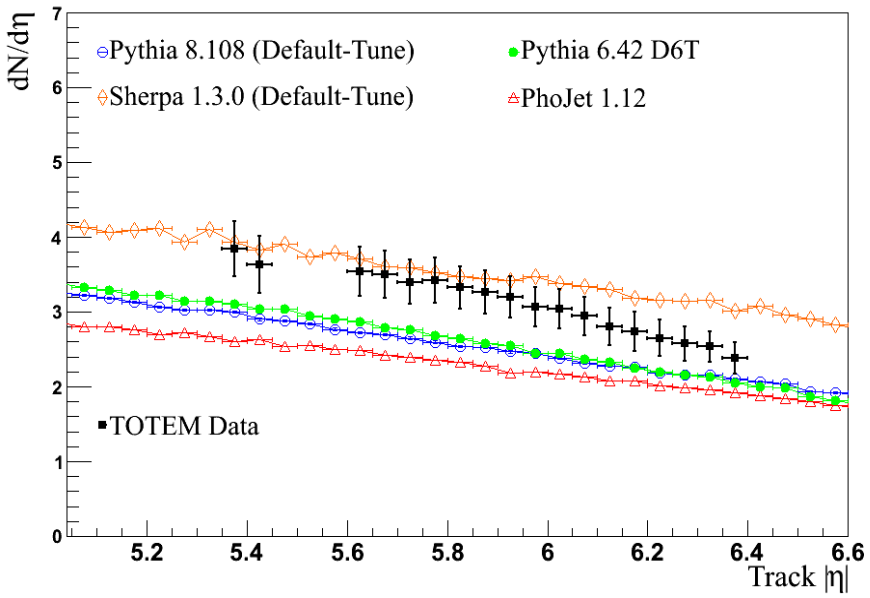
- Measurement of the forward charged particle pseudo-rapidity density in pp collisions at $\sqrt{s}$ = 7 TeV with the TOTEM experiment
[EPL 98 (2012) 31002]

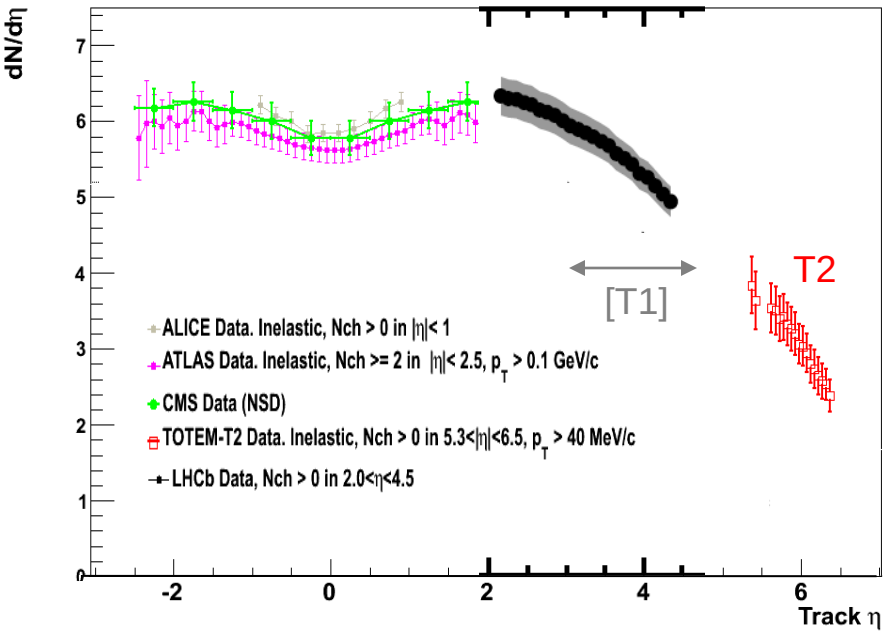
- Measurement of proton-proton elastic scattering and total cross-section at $\sqrt{s}$ = 7 TeV
[CERN-PH-EP-2012-239, to be submitted to journal]

- Measurement of proton-proton inelastic scattering cross-section at $\sqrt{s}$ = 7 TeV
[final draft, to be submitted to journal]

- Luminosity independent measurements of total, elastic and inelastic cross-sections at $\sqrt{s}$ = 7 TeV
[draft in progress, to be submitted to journal]

Charged Particle Pseudorapidity Density dN / dη

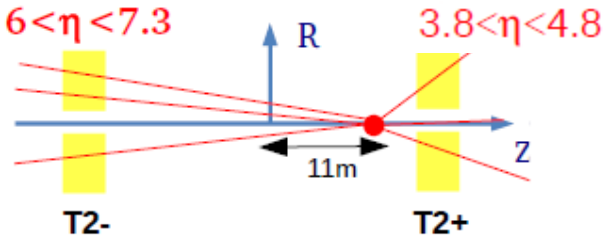




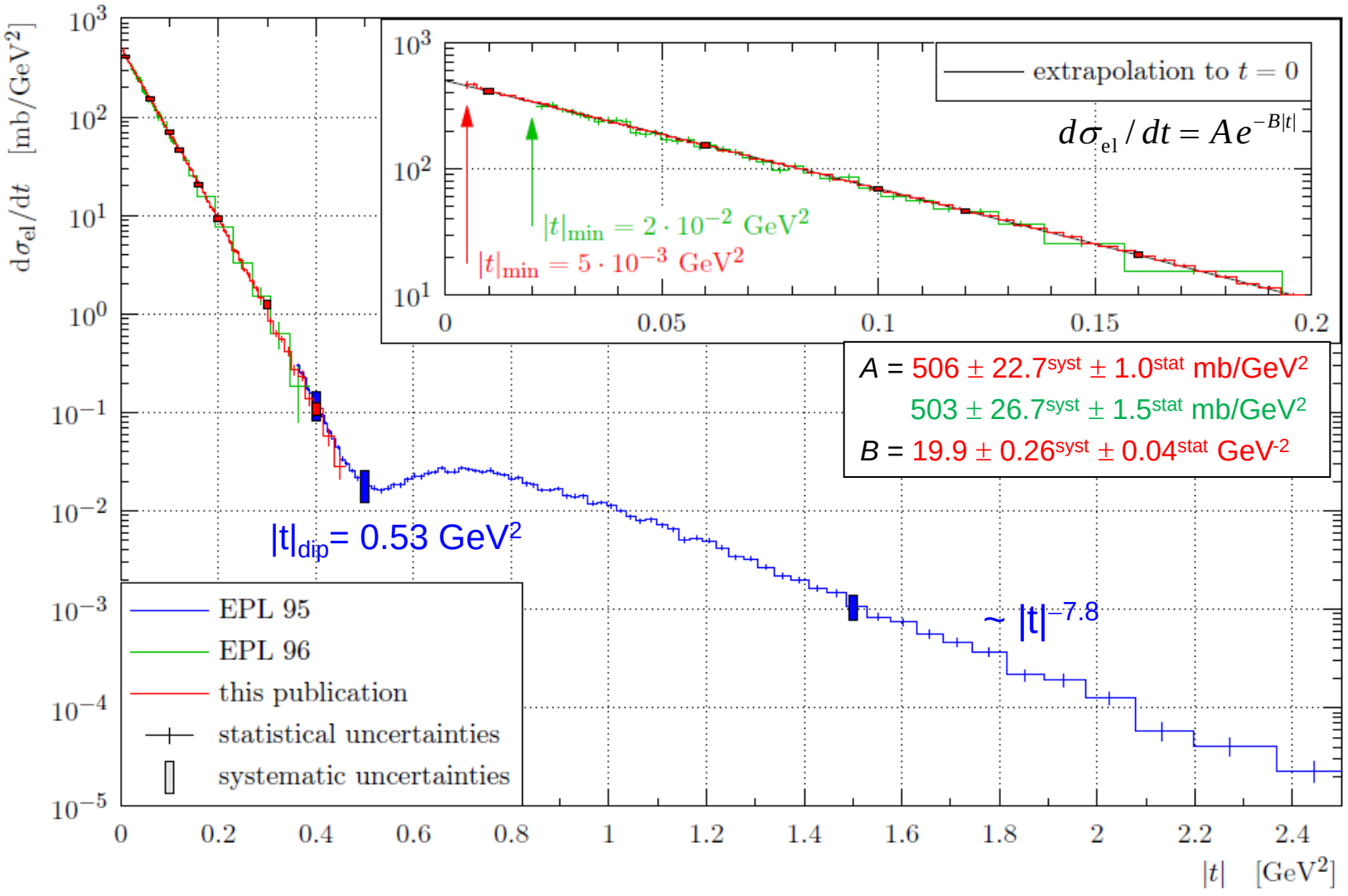
Analyses in progress:

- T1 measurement at 7 TeV ($3.1 < |\eta| < 4.7$)
- **NEW**: combined analysis CMS + TOTEM ($0 < |\eta| < 6.5$) on low-pileup run of 1st May 2012 (8 TeV):
  common trigger (T2, bunch crossings), both experiments read out

- **NEW**: parasitical collision at $\beta^* = 90$ m (7 July 2012)
  → vertex at ~11m → shifted η acceptance:



Elastic pp Scattering at 7 TeV: Differential Cross-Section



Integrated elastic cross-section:

25.4 ± 1.0^{lumi} ± 0.3^{syst} ± 0.03^{stat} mb *(90% measured)*

24.8 ± 1.0^{lumi} ± 0.2^{syst} ± 0.2^{stat} mb *(50% measured)*

3 Ways to the Total Cross-Section

elastic observables only:

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

(ρ=0.14 [COMPETE])

June 2011 (EPL96): σ_{tot} = (98.3 ±2.8) mb

Oct. 2011 (PH pre.): σ_{tot} = (98.6 ±2.2) mb

different bunch intensities !

σ_{tot}

ϱ independent:

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

σ_{tot} = (99.1 ± 4.3) mb

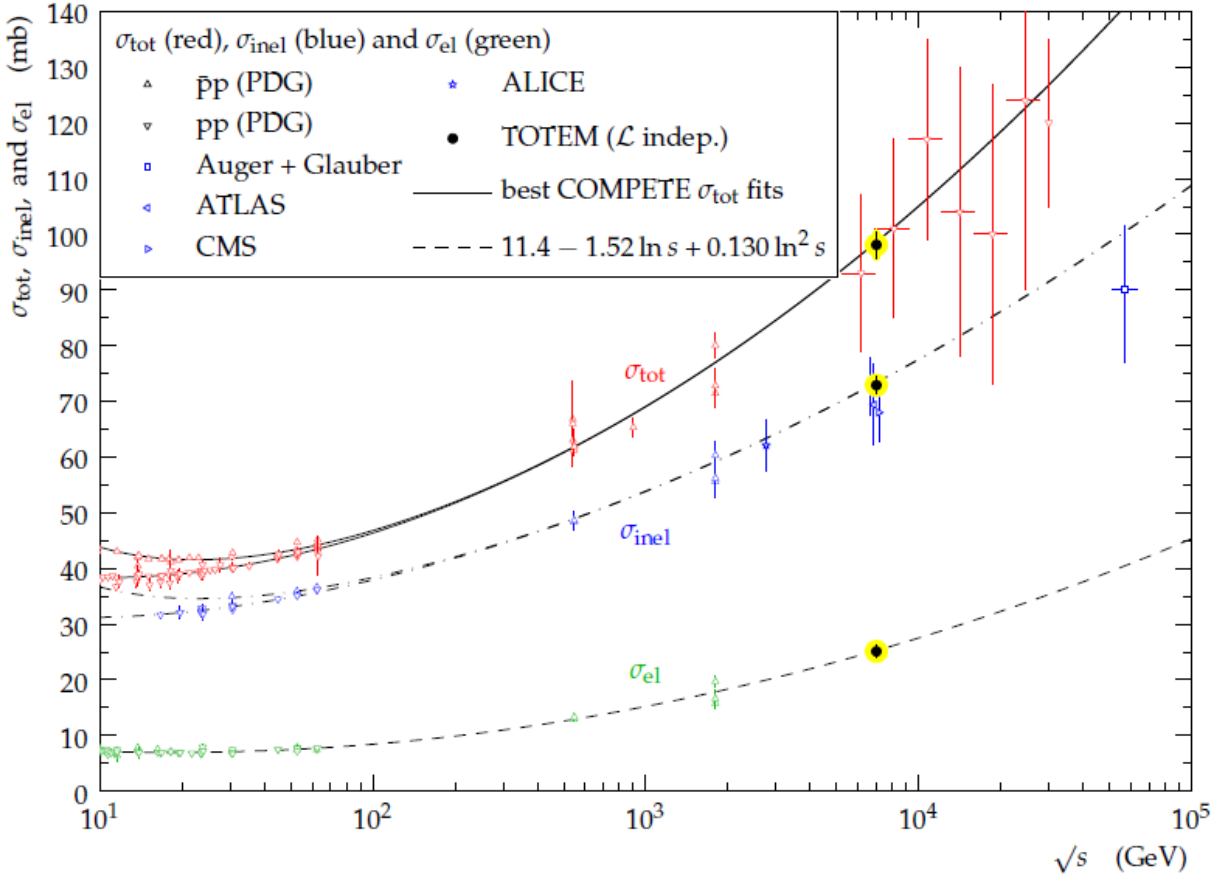
luminosity independent:

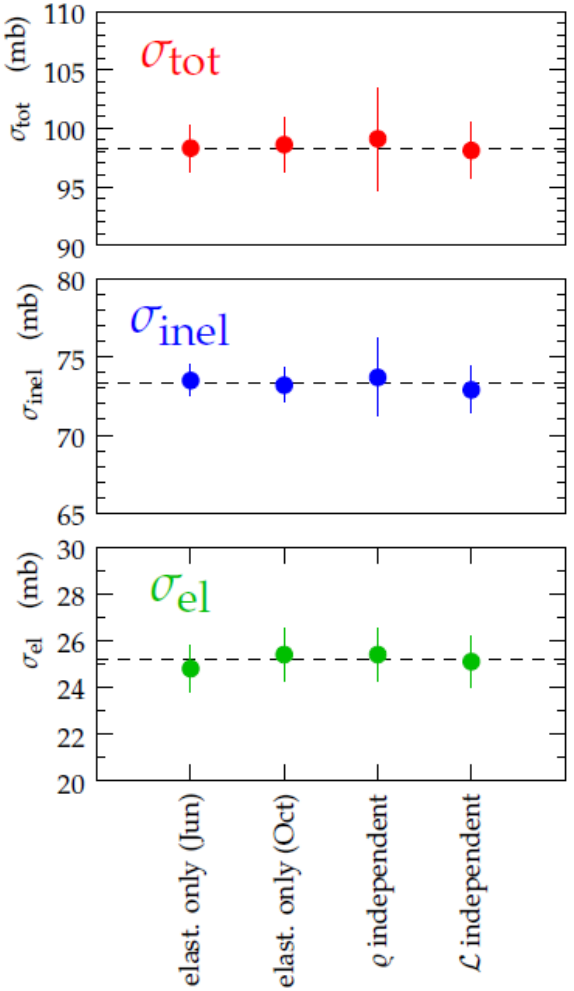
$$\sigma_{\text{tot}} = \frac{16\pi}{1+\varrho^2}\,\frac{dN_{\text{el}}/dt|_0}{N_{\text{el}} + N_{\text{inel}}}$$

σ_{tot} = (98.0 ± 2.5) mb

Excellent agreement between cross-section measurements at 7 TeV using
- runs with different bunch intensities,
- different methods.

Cross-Section Measurements





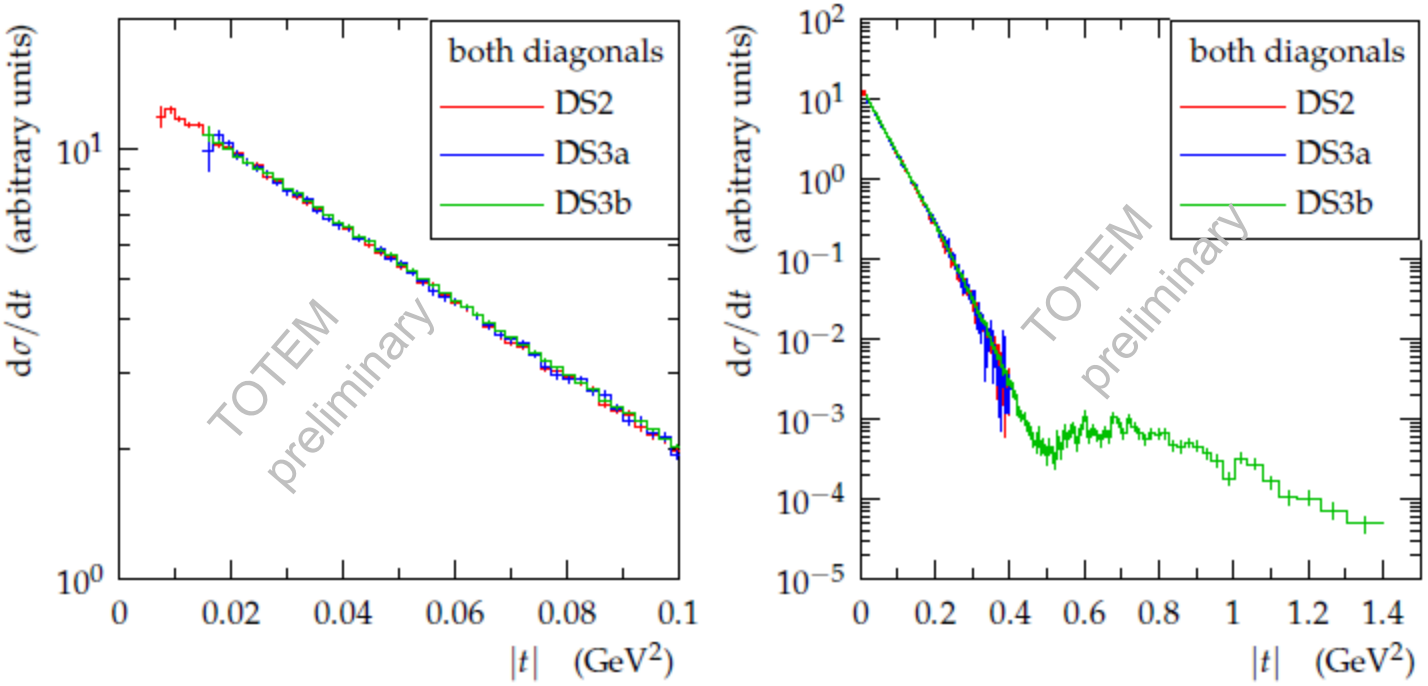
Elastic Scattering and Total Cross-Section at 8 TeV

July 2012: runs at β* = 90 m

dataset	date	bunches	RPs	$\|t\|_{min}$ (GeV^2)	$\mathcal{L}$ (mb^{-1})
1	7 July, 1st fill	1	3σ	$4 \cdot 10^{-3}$	–
2	7 July, 2nd fill	1	6σ	$7 \cdot 10^{-3}$	≈ 40
3*a*	12–13 July	1	9.5σ	$15 \cdot 10^{-3}$	≈ 30
3*b*	12–13 July	2 or 3	9.5σ	$15 \cdot 10^{-3}$	≈ 820

only RP alignment, RPs moving

Preliminary t-distributions (unnormalised)



to be normalised via: CMS, T2, "luminosity-independent method"

→ total and inelastic pp cross-sections at 8 TeV

Coming Soon…

[LHCC Sept'12]

… [RRB Oct'12]

$\sqrt{s} = 8$ TeV

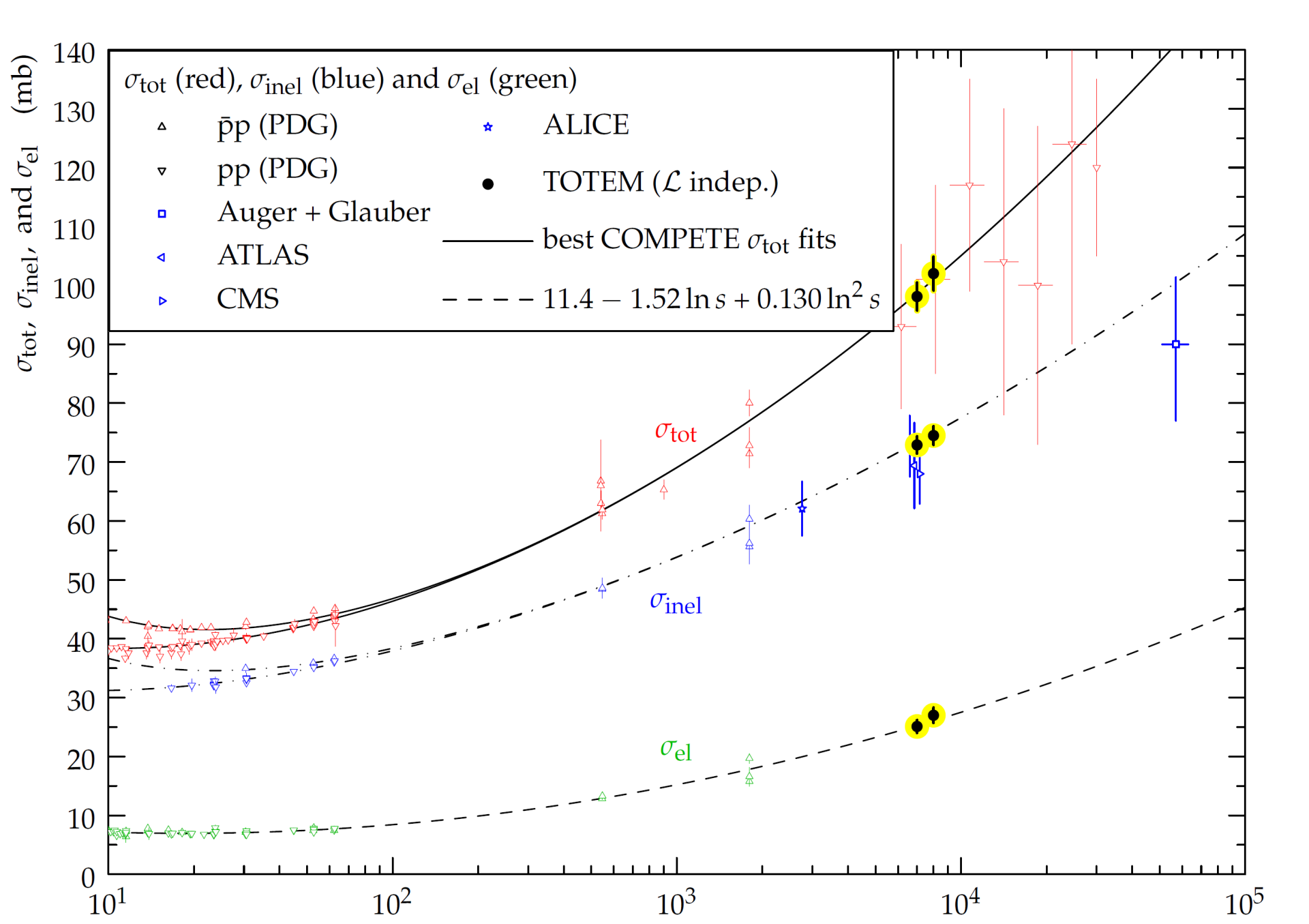
Two data samples triggered by TOTEM RPs pp coincidences

Luminosity-independent Elastic, Inelastic, Total Cross-Sections:

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

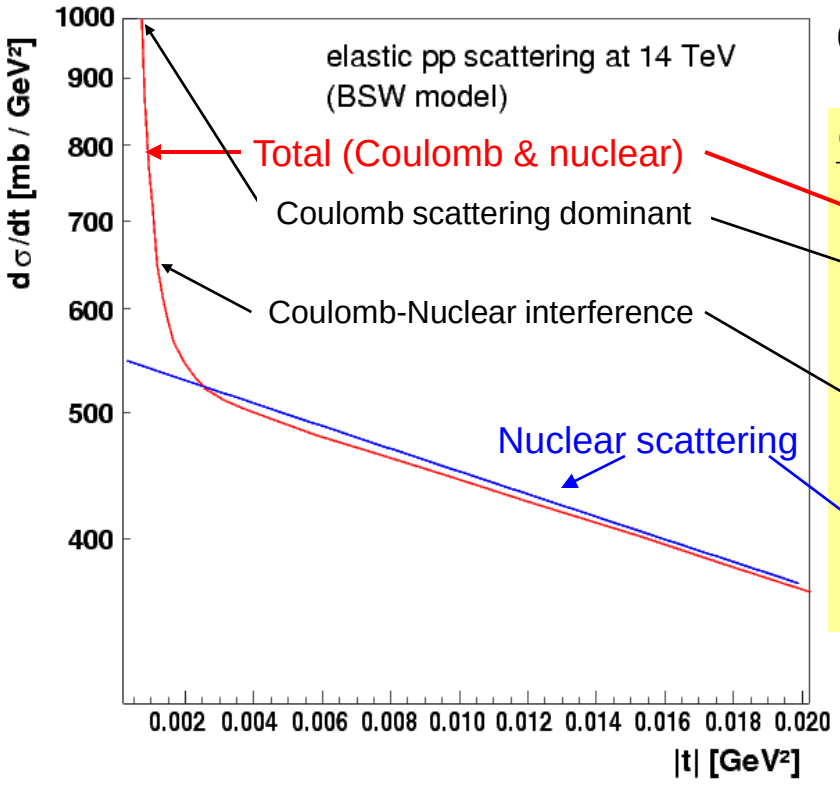
Internal refereeing completed

Editorial Process started [***preprint upcoming***]


σ_{tot} (red), σ_{inel} (blue) and σ_{el} (green)
$\bar{p}p$ (PDG)
pp (PDG)
Auger + Glauber
ATLAS
CMS
ALICE
TOTEM ($\mathcal{L}$ indep.)
best COMPETE σ_{tot} fits
$11.4 - 1.52 \ln s + 0.130 \ln^2 s$
σ_{tot}, σ_{inel}, and σ_{el} (mb)
σ_{tot}
σ_{inel}
σ_{el}
$\sqrt{s}$ (GeV)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
10^1
10^2
10^3
10^4
10^5

… [RRB Oct'12]

ρ Measurement: Elastic Scattering at Low |t|



Optical Theorem: $\sigma_{tot} = \frac{4\pi}{s}\Im\left(T_{elastic,nuclear}(t=0)\right)$

$$\frac{d\sigma}{dt} = \frac{4\pi\alpha^2(\hbar c)^2 G^4(t)}{|t|^2} + \frac{\alpha(\rho-\alpha\phi)\sigma_{tot}G^2(t)}{|t|}e^{-B|t|/2} + \frac{\sigma_{tot}^2(1+\rho^2)}{16\pi(\hbar c)^2}e^{-B|t|}$$

α = fine structure constant

ϕ = relative Coulomb-nuclear phase

G(t) = nucleon el.-mag. form factor = $(1 + |t| / 0.71)^{-2}$

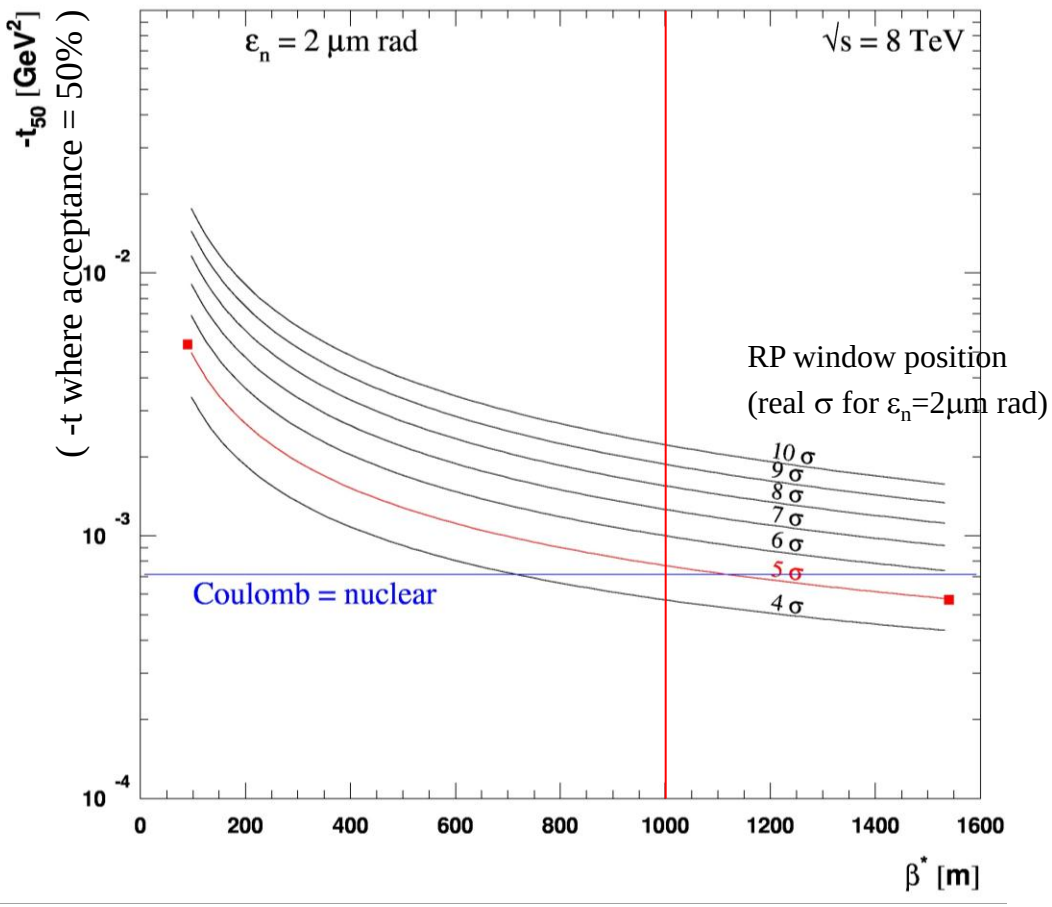
ρ = $\Re$ / $\Im$ [$T_{elastic,nuclear}(t = 0)$]

Measurement of ρ by studying the Coulomb – Nuclear interference region down to

$|t| \sim 6 \times 10^{-4}$ GeV²

Reachable with β* ~ 1000 m still in 2012 if RPs can approach beam center to ~ 4σ

How to reach the Coulomb-Nuclear Interference Region ?



The pots have to approach the beam to a distance ~ 4 σ

Beam emittance ε_n < 2 μm rad

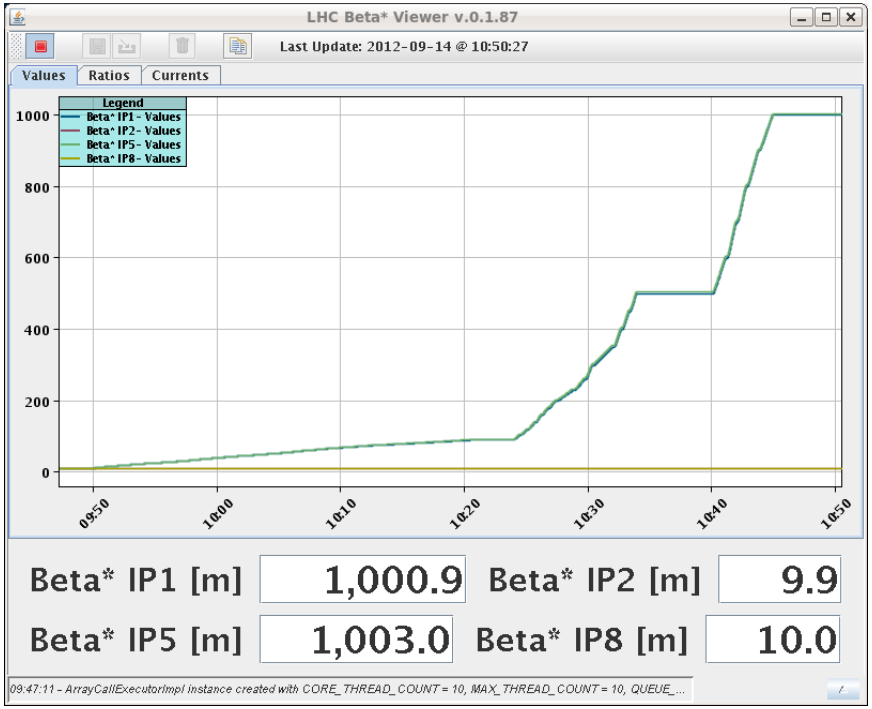
→ **Challenging but possible**

[LHCC Sept'12]…

The β* = 1000 m Optics

MD in June: first unsqueeze to 1km achieved

14 September:



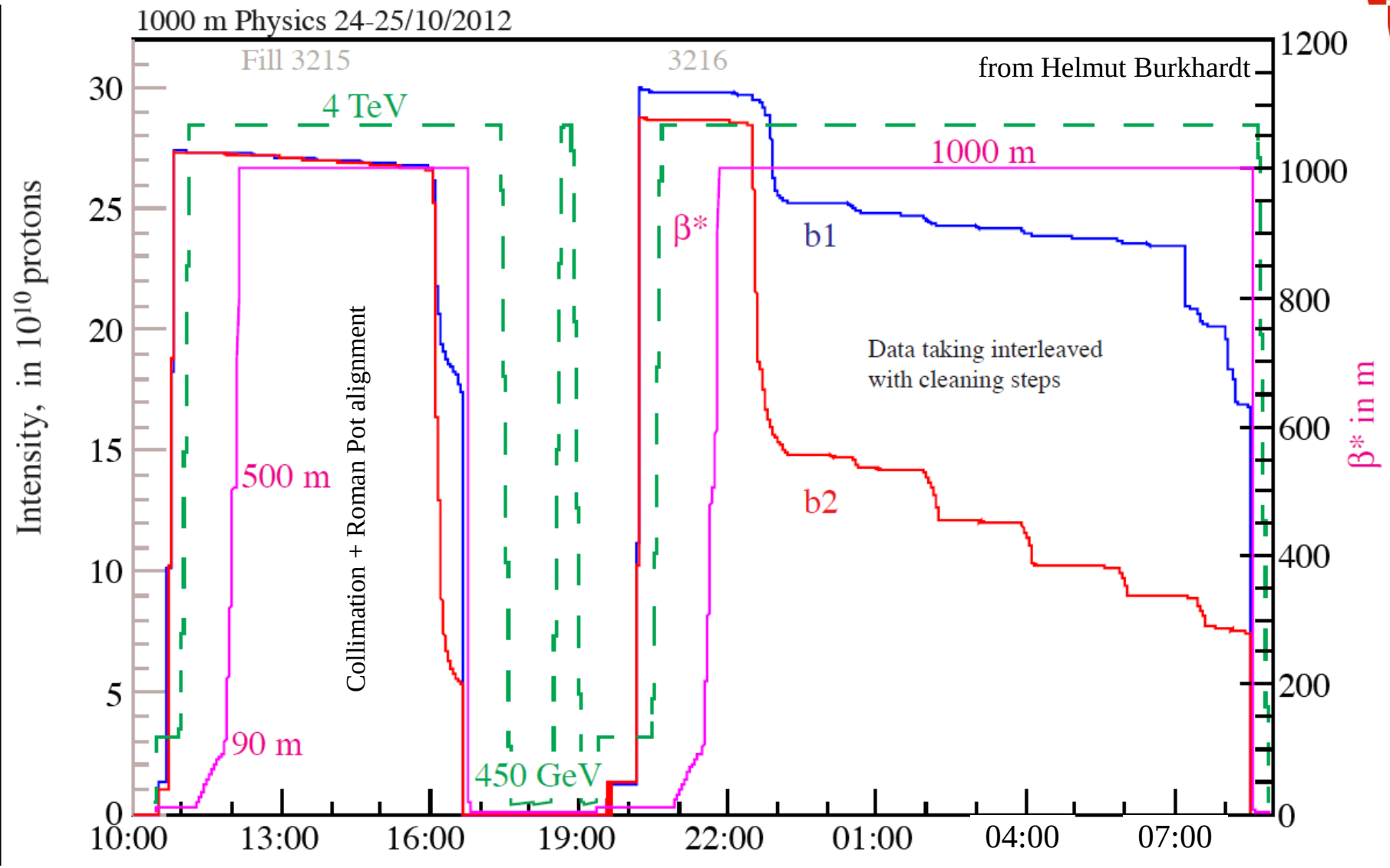
- special beam optics with β* = 1000 m fully commissioned
- collisions in IP1 and IP5 found
- vertical emittances $\varepsilon_n \sim 2$ μm rad
- 4 vertical TOTEM RPs (out of 8) aligned at ~4 σ
- time slot ended → no physics data taken yet, diagnostic data on **halo background** being analysed

Physics run scheduled for October 2012

[LHCC Sept'12]…

The Run at β* = 1 km: Overview

2 fills with 3 bunches of ~10^{11} p (2 colliding, 1 non-colliding)



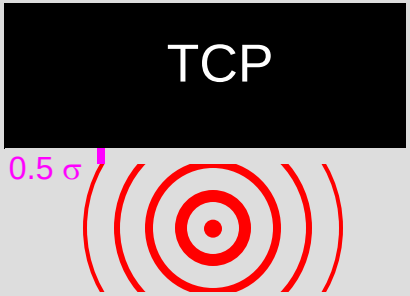
All RPs aligned in < 2 hours (record)

Beam Cleaning with TCPs in IP7

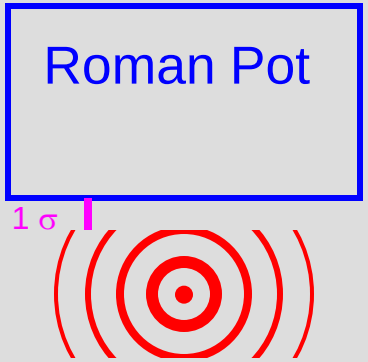
Idea first explored in the MD of 11 October.

1. Scrape the beam with TCP at 2 σ

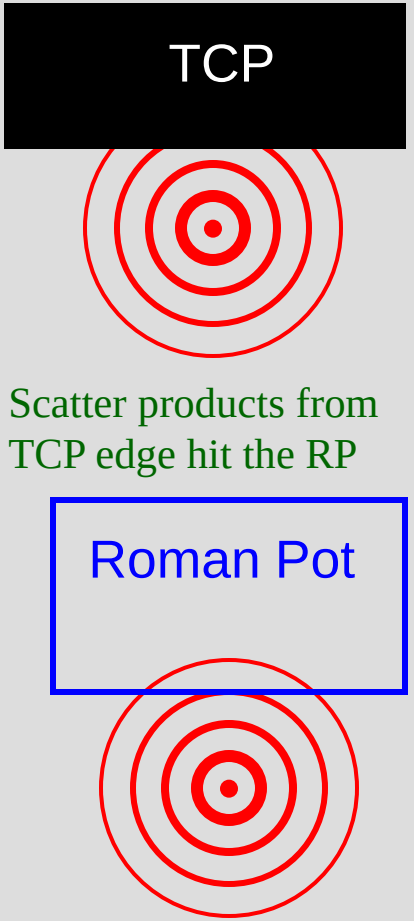
2. Retract TCP from 2 σ to 2.5 σ → gap of 0.5 σ



RP at 3 σ is protected by the gap



3. Gap refills within ~ 1h



Scatter products from TCP edge hit the RP

Data Collected

Very rough estimates:

$\mathcal{L} \sim R_{T2} / 70$ mb

$R_{elastic} \sim 25$ mb x $\mathcal{L}$

Period	Δt [s]	⟨T2 Rate⟩ [Hz]	⟨$\mathcal{L}$⟩ [mb^{-1} s^{-1}]	∫$\mathcal{L}$ dt [mb^{-1}]	N(elastic) per diagonal
1	3960	122	1.74	6890	86 k
2	4320	108	1.54	6652	83 k
3	4860	78	1.11	5370	67 k
4	5760	60	0.86	4937	62 k
5	3960	46	0.66	2613	32 k
6	1440	32	0.46	662	8 k
Total	24300			27124	338 k

1 diagonal at 3 σ → Coulomb interference region: ~338 k

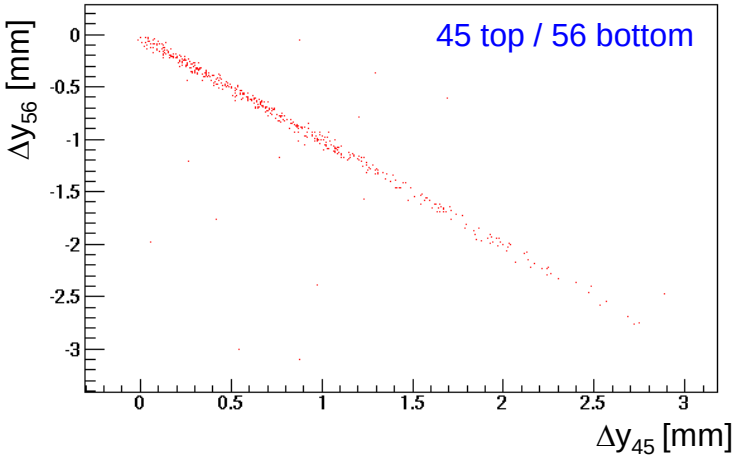
1 diagonal at 10 σ → Control sample: ~338 k

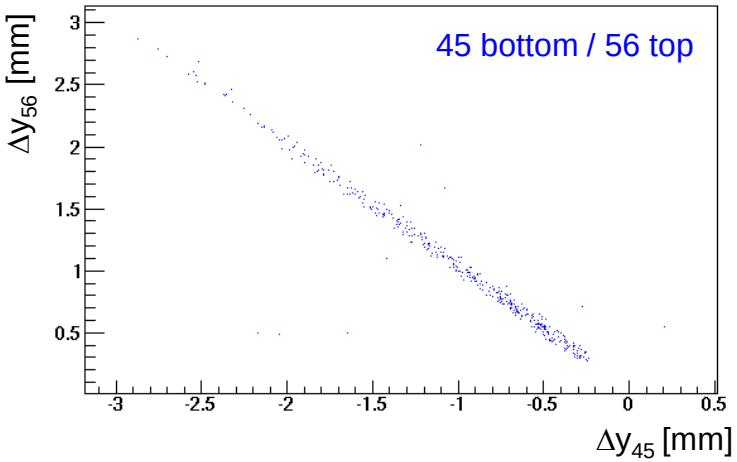
Total: 776 k

… [RRB Oct'12]

Raw Elastic Correlation Plots

Local track slopes in sector 56 (along beam 1) vs sector 45 (along beam 2) (without alignment):



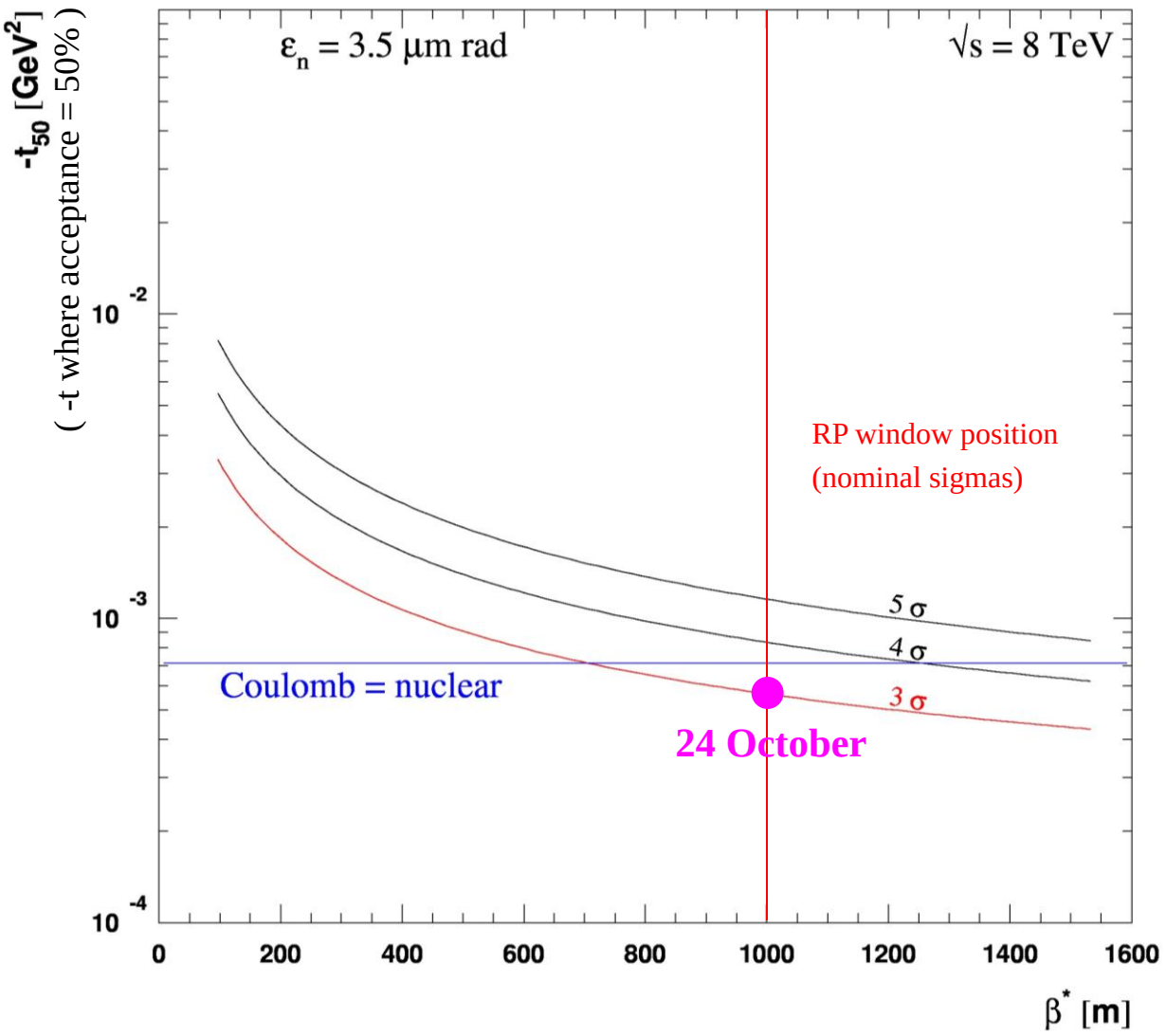


$$\Delta y_{56} = y_{56,\mathrm{far}} - y_{56,\mathrm{near}}$$
$$\Delta y_{45} = y_{45,\mathrm{far}} - y_{45,\mathrm{near}}$$

$$\left.\begin{aligned}\Delta y_{56} &= \Delta L_{56}\theta_y^* + \Delta y_{56,\mathrm{misalign}} \\ \Delta y_{45} &= \Delta L_{45}\theta_y^* + \Delta y_{45,\mathrm{misalign}}\end{aligned}\right\} \Rightarrow \frac{\Delta y_{56} - \Delta y_{56,\mathrm{misalign}}}{\Delta y_{45} - \Delta y_{45,\mathrm{misalign}}} = \frac{\Delta L_{56}}{\Delta L_{45}}$$

… [RRB Oct'12]

Did we reach the Coulomb-Nuclear Interference Region ?



… [RRB Oct'12]

Many Thanks to ...

... the many people involved in the preparation of the 1km optics and the realisation of the run, in particular

- Helmut with his optics team,
- Stefano with the collimation group,
- the operations group,
- the coordinators.

Joint Data Taking with CMS

Realisation of common running much earlier than ever anticipated

1. Hardware: electrical from RP220 to CMS → trigger within CMS latency
2. Trigger: bi-directional level-1 exchange → same events taken
3. Synchronisation: orbit number and bunch number in data streams
4. Offline:
   - common repository for independently reconstructed data
   - merging procedure → common n-tuples

Joint Data Taking with CMS

May 2012: low pileup run: $\beta^* = 0.6$ m, $\sqrt{s} = 8$ TeV, T1 & T2 & CMS read out

Date	Trigger	Inelastic events	
May 1	T2 ‖ BX	~5 M	no RP

dN/dη,
correlations,
underlying event

July 2012: $\beta^* = 90$ m, $\sqrt{s} = 8$ TeV, RP & T1 & T2 & CMS read out

Date, Set	Trigger	Inelastic events	RP position
July 7, DS 2	T2 ‖ RP_{2arms} ‖ BX	~2 M	6 σ
July 12-13, DS 3a	T2 ‖ RP_{2arms} ‖ BX	~10 M	9.5 σ V, 11σ H
July 12-13, DS 3b	T2 ‖ RP_{2arms} ‖ CMS (CMS = 2 jets @ $p^T > 20$GeV, 2 μ, 2 central e/γ)	~3.5 M	9.5 σ V, 11σ H

σ_{tot}, σ_{inel} with CMS,
soft & semi-hard diffraction,
correlations

Abundant material for analysis activities throughout LS1

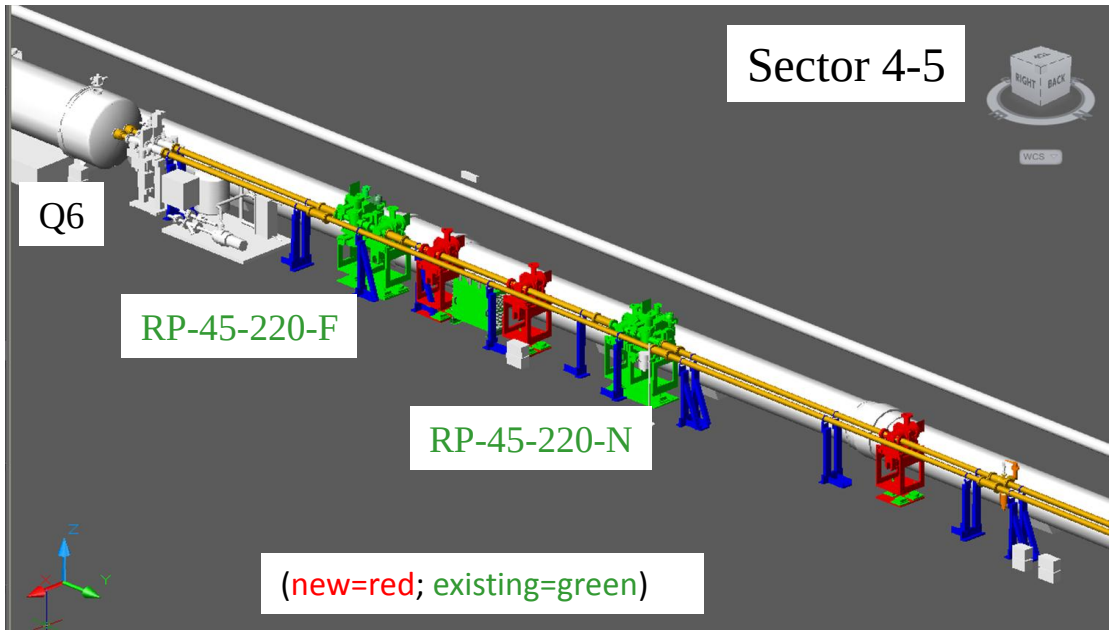
Analyses starting:

- hard diffraction: p + dijets (90m runs)
- combined $dN_{ch}/d\eta$ and multiplicity correlations

Upgrade of RP detector system at 220 m

For diffractive physics at high-luminosity (high pileup):

- Installation of additional RPs (horizontal)
- Integration of timing and pixel detectors in horizontal RPs

Guideline:

- The present 220m stations must not be affected (touched) by any upgrade activity, until the high beta special runs after LS1 are finished.
- The new horizontal RPs could be installed during LS1 and equipped successively with new tracking & timing detectors.
- Preparation of engineering change request for TCL6 collimator installation started (CMS+TOTEM)