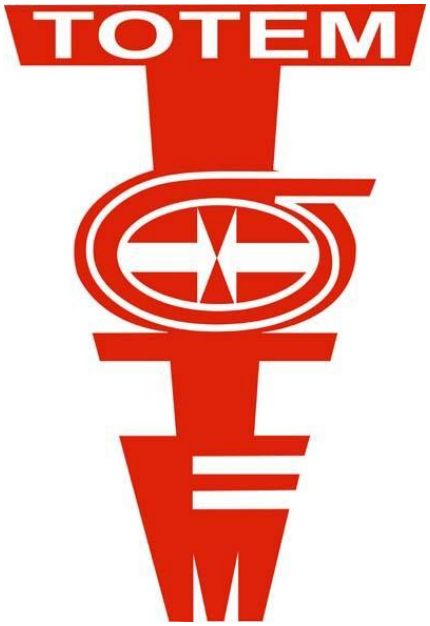
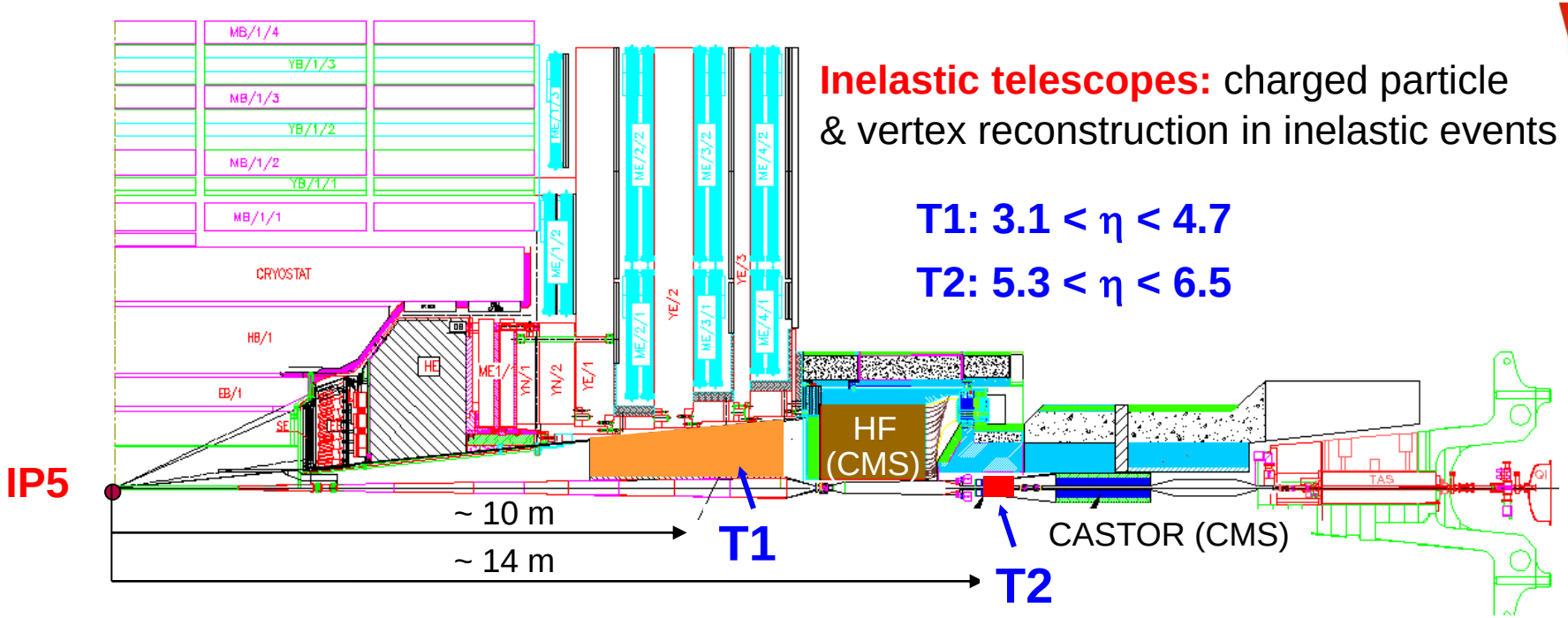
Status and Plans of the TOTEM Experiment



LHCC Open Session
26 September 2012

Mario Deile
on behalf of the TOTEM Collaboration

Experimental Setup @ IP5

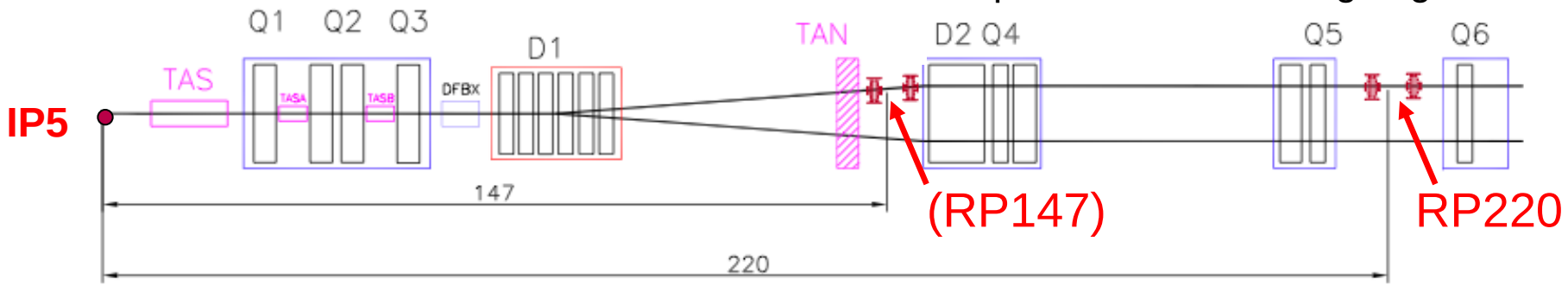


Inelastic telescopes: charged particle & vertex reconstruction in inelastic events

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

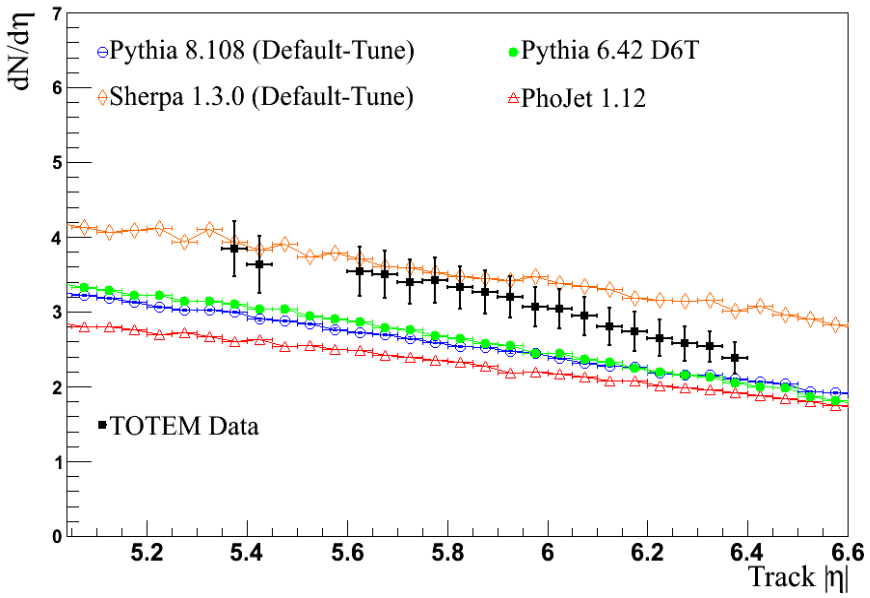
- Measurement of the forward charged particle pseudorapidity density in pp collisions at $\sqrt{s}$ = 7 TeV with the TOTEM experiment
[EPL 98 (2012) 31002]

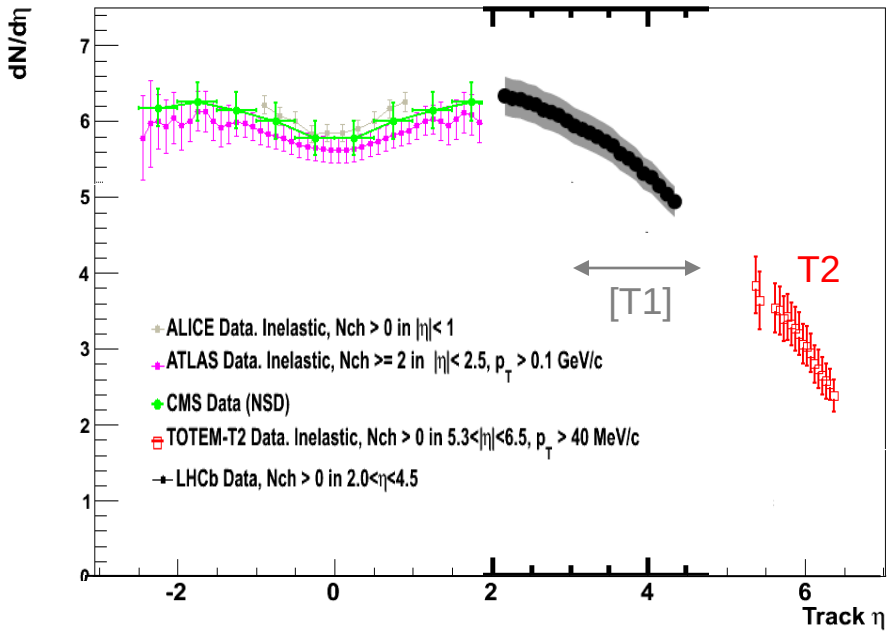
- Measurement of proton-proton elastic scattering and total cross-section at $\sqrt{s}$ = 7 TeV
[CERN-PH-EP-2012-239, to be submitted to journal]

- 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

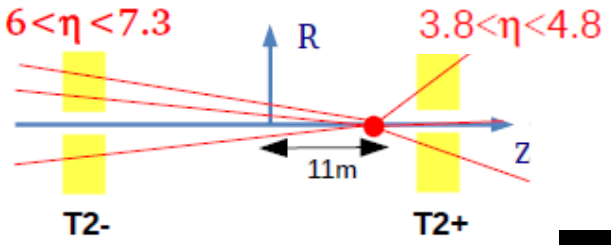




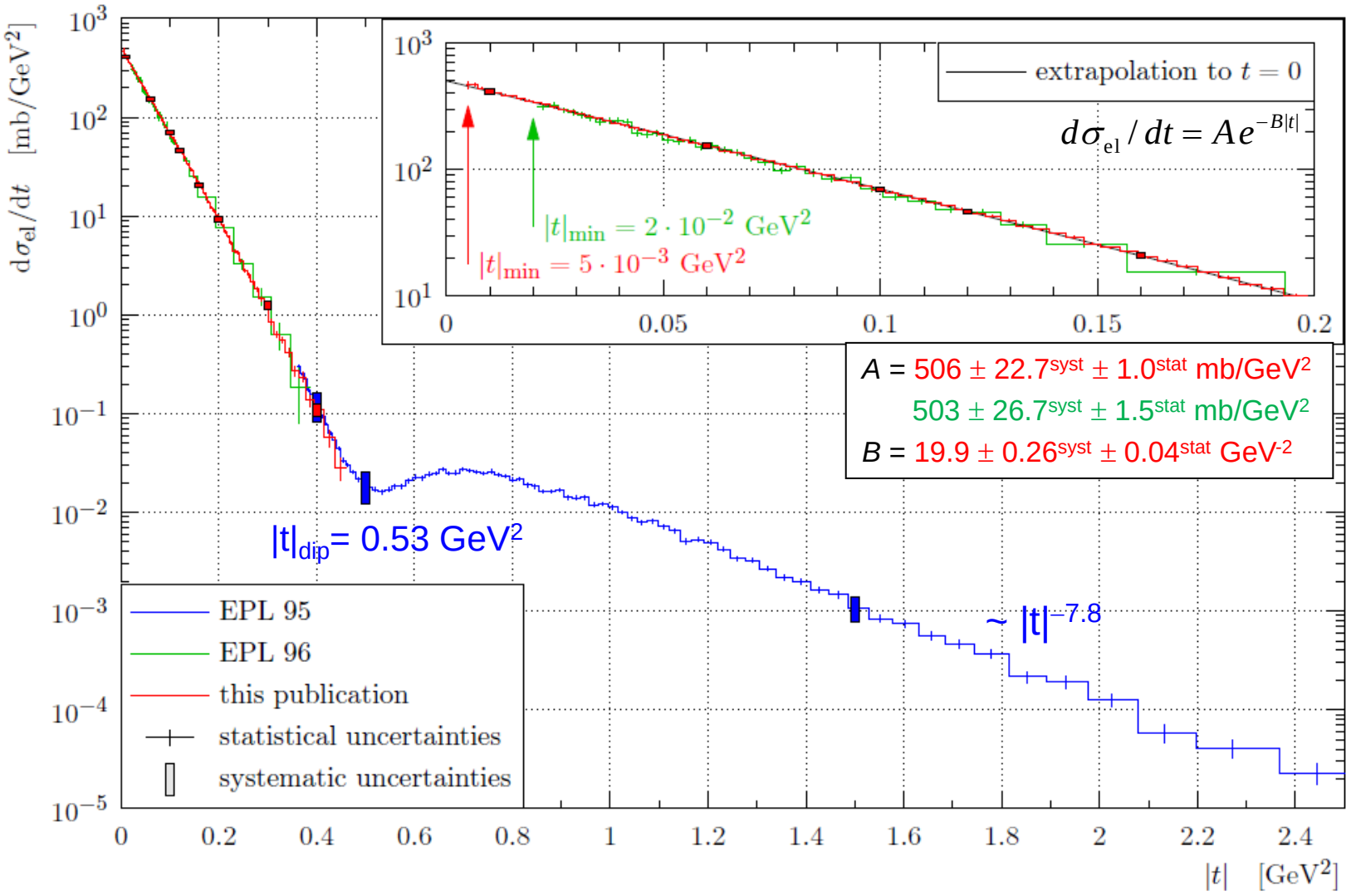
Analyses in progress:

- 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

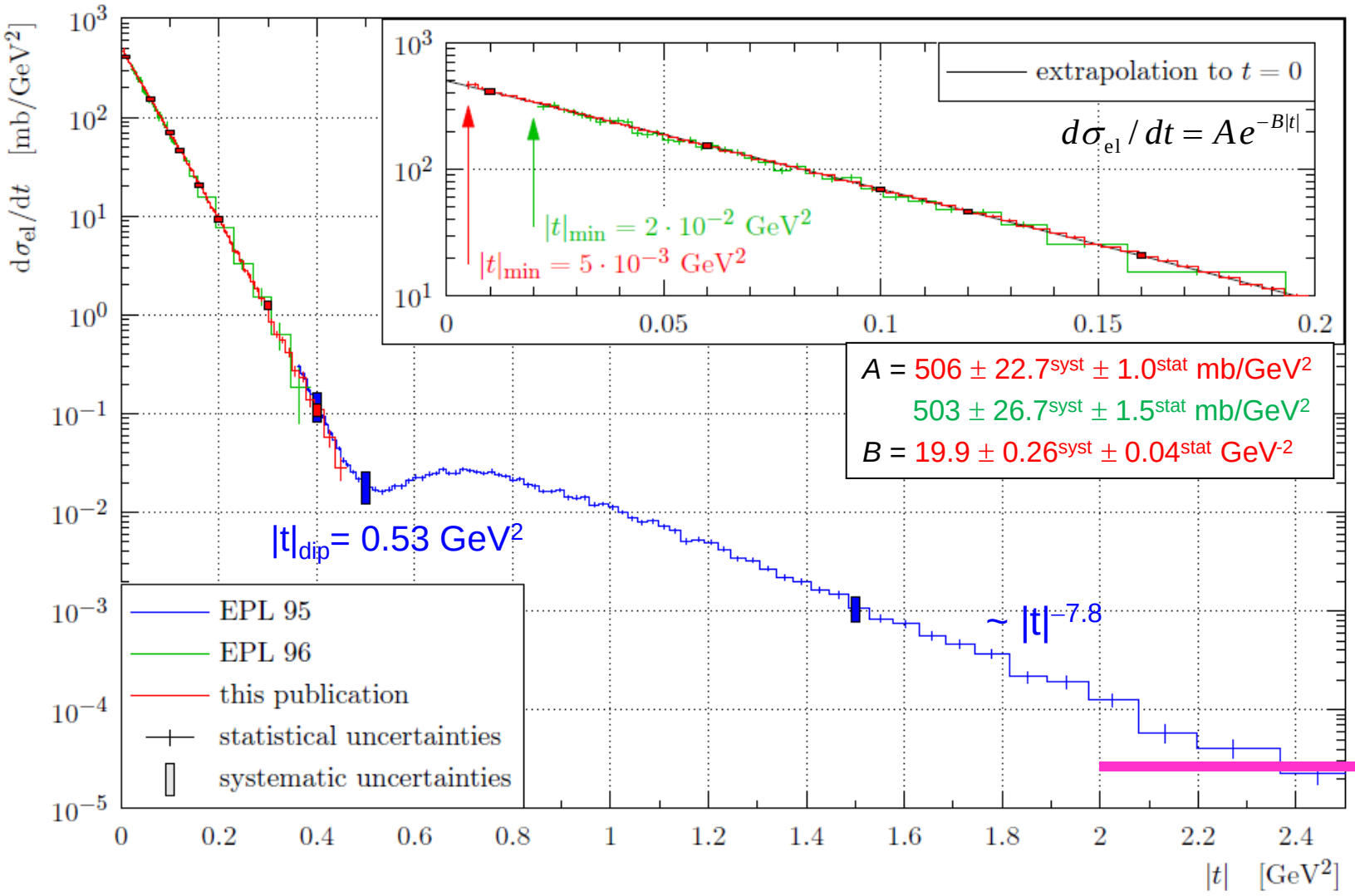


Integrated elastic cross-section:

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)*

Elastic pp Scattering at 7 TeV: Differential Cross-Section



Additional data set under analysis:
2 GeV^2 < |t| < 3.5 GeV^2

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.

Absolute Luminosity Measurement

The "luminosity-independent method" also yields the luminosity:

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

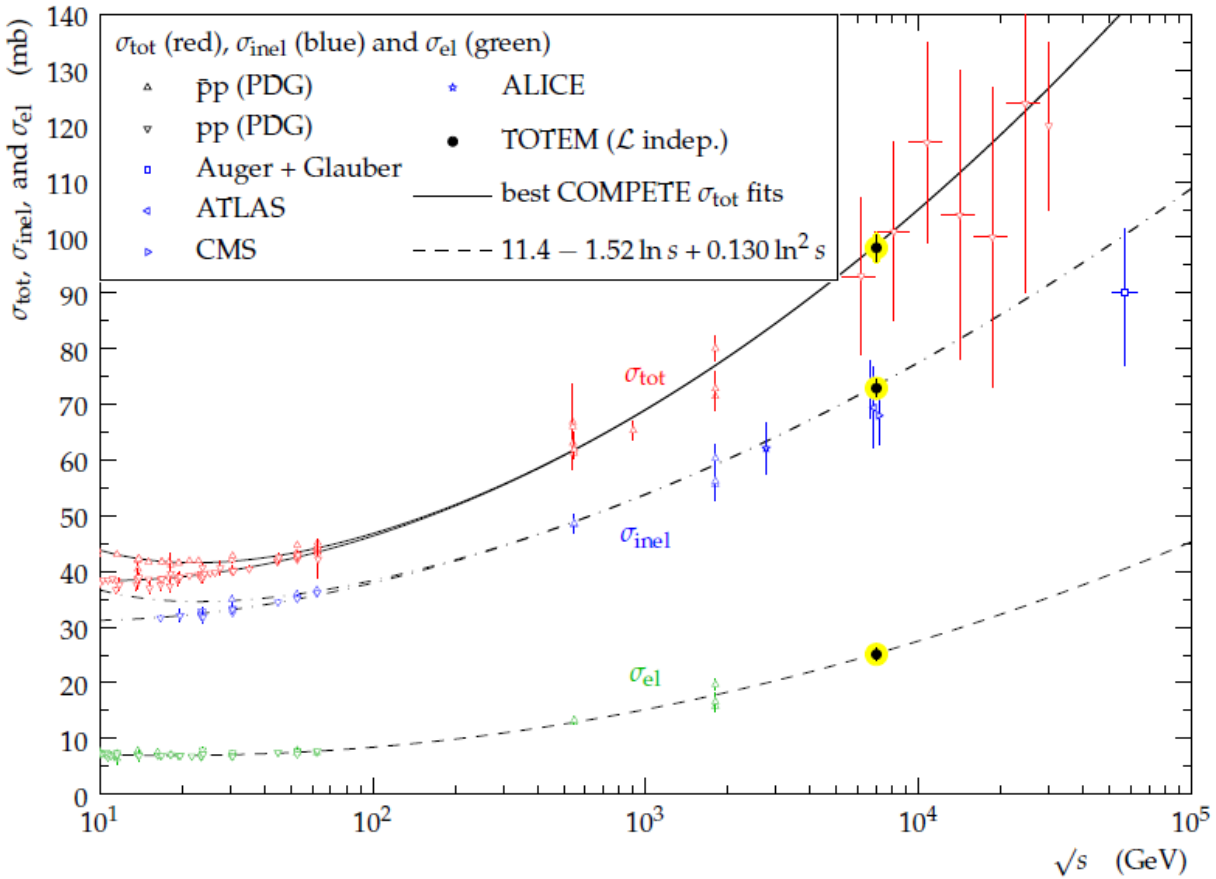
June 2011: $\mathcal{L}_{\text{int}} = (1.65 \pm 0.07)\ \mu\text{b}^{-1}$ [CMS: $(1.65 \pm 0.07)\ \mu\text{b}^{-1}$]

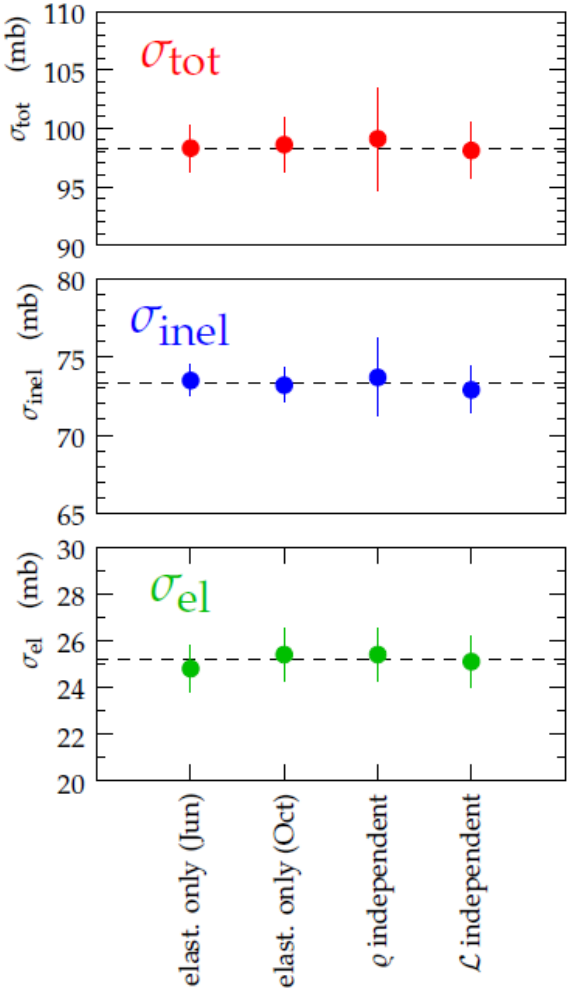
October 2011: $\mathcal{L}_{\text{int}} = (83.7 \pm 3.2)\ \mu\text{b}^{-1}$ [CMS: $(82.0 \pm 3.3)\ \mu\text{b}^{-1}$]

Excellent agreement with CMS luminosity measurement.

Absolute luminosity calibration for T2

Cross-Section Measurements



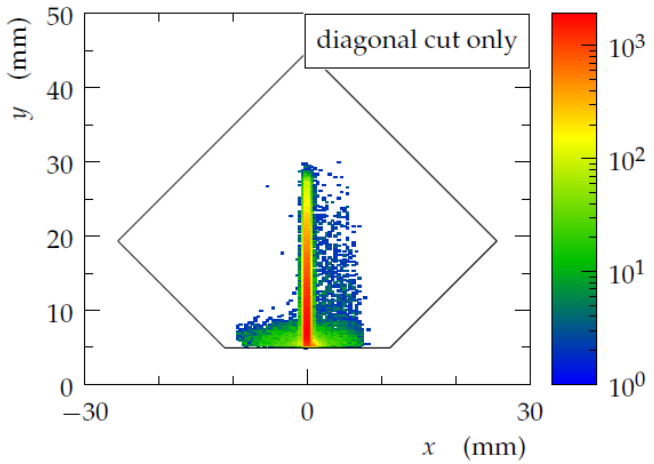


Elastic Scattering and Total Cross-Section at 8 TeV

July 2012: runs at β* = 90 m

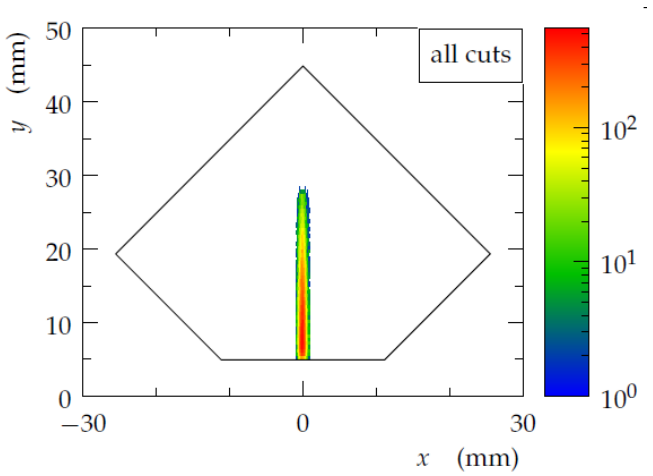
dataset	date	bunches	RPs	$\|t\|_{\min}$ (GeV^2)	$\mathcal{L}$ (mb^{-1})
1	7 July, 1st fill	1	3σ	$4 \cdot 10^{-3}$	–
2	7 July, 2nd fill	1	6σ	$7 \cdot 10^{-3}$	≈ 40
3*a*	12–13 July	1	9.5σ	$15 \cdot 10^{-3}$	≈ 30
3*b*	12–13 July	2 or 3	9.5σ	$15 \cdot 10^{-3}$	≈ 820

only RP alignment, RPs moving



collinearity,
low ξ,
common vertex

cut	quantities
diagonal	4 RP hits
1	ϑ_x^{*R} vs. ϑ_x^{*L}
2	ϑ_y^{*R} vs. ϑ_y^{*L}
3	$\|x^{*R}\|$
4	$\|x^{*L}\|$
5	ϑ_y^{*R} vs. $y^{R,F} - y^{R,N}$
6	ϑ_y^{*L} vs. $y^{L,F} - y^{L,N}$
7	x^{*R} vs. x^{*L}



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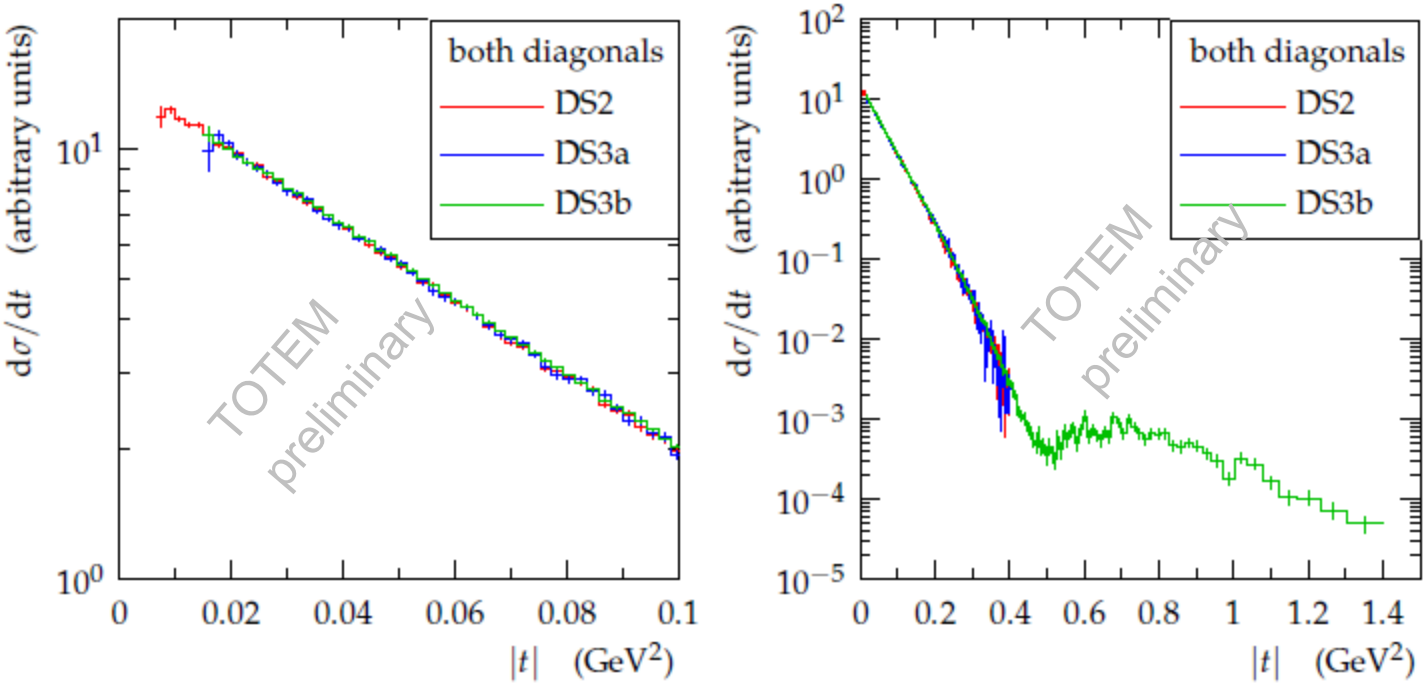
only RP alignment, RPs moving

Preliminary t-distributions (unnormalised)



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

→ total and inelastic pp cross-sections at 8 TeV

Coming Soon

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})
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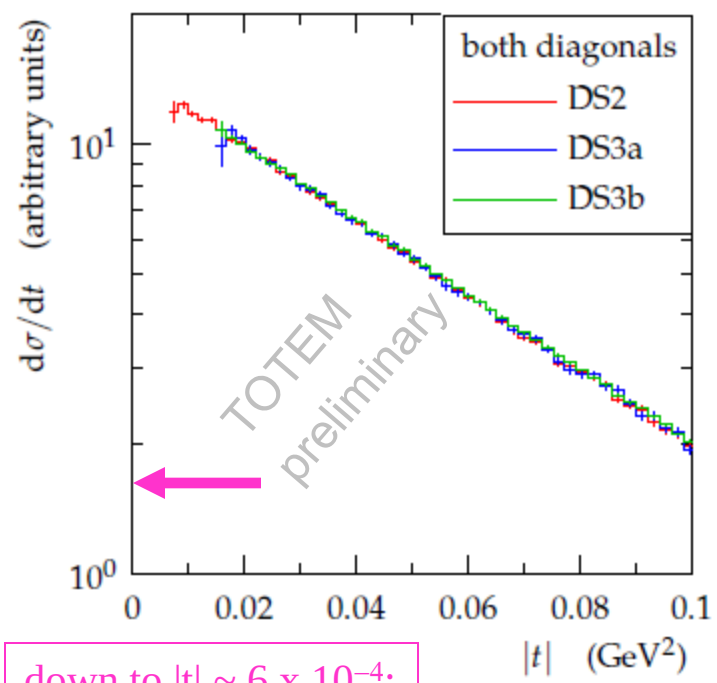
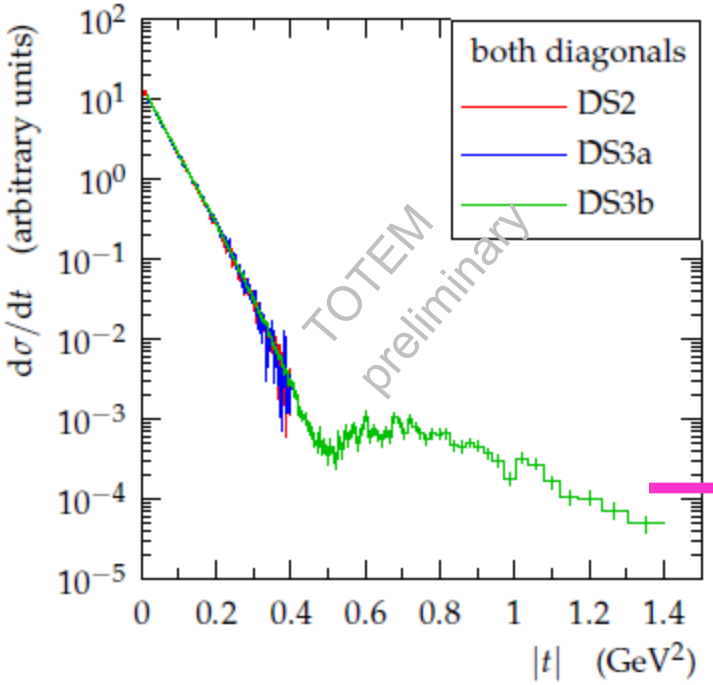




down to |t| ~ 6 x 10^{-4}: foreseen at β* = 1km

larger |t|:
- possible at β*=0.6m
- difficult due to 2xSD and other background

A First, Very Crude ρ Estimate at 7 TeV

$$\rho = \frac{\mathrm{Re}\,T(t=0)}{\mathrm{Im}\,T(t=0)}$$

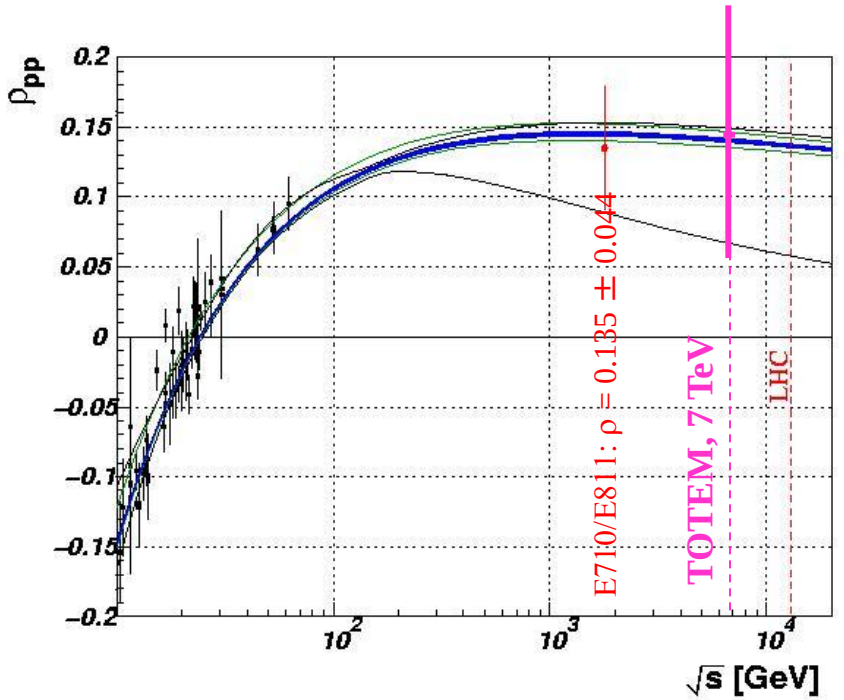
From optical theorem:

$$\rho^2 = 16\pi\,\mathcal{L}_{\mathrm{int}}\,\frac{\left.\frac{\mathrm{d}N_{\mathrm{el}}}{\mathrm{d}t}\right|_{t=0}}{\left(N_{\mathrm{el}}+N_{\mathrm{inel}}\right)^2} - 1 \quad = \quad 0.009 \pm 0.056$$

$\rho < 0.32$ (95% CL),

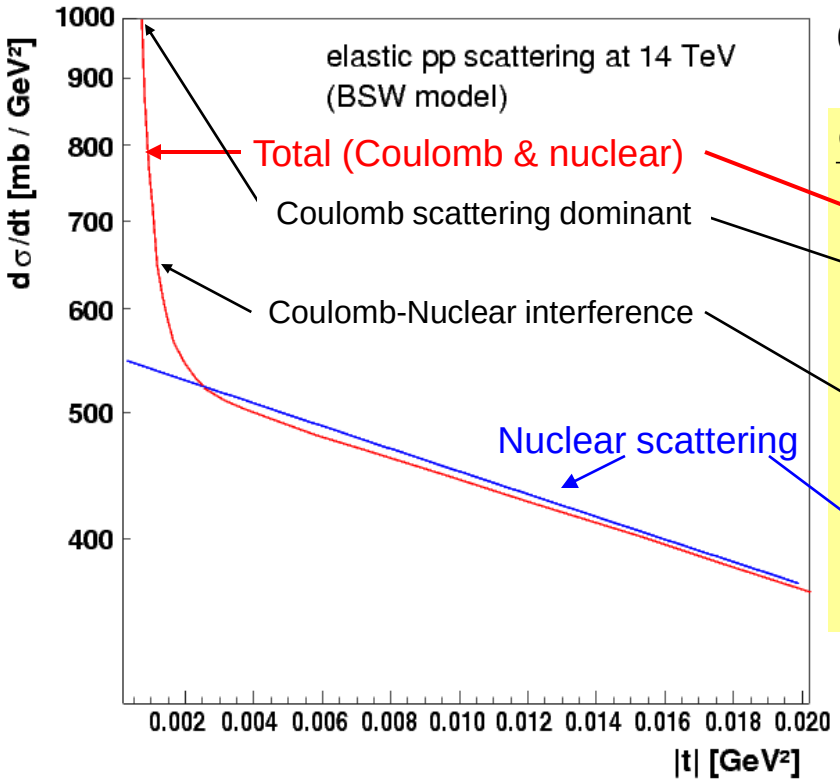
or, using Bayes' approach (with uniform prior $|\rho|$ distribution):

$|\rho| = 0.145 \pm 0.091$ [COMPETE extrapolation: $\rho = 0.141 \pm 0.007$]



Not so exciting, but …

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 = $(1 + |t| / 0.71)^{-2}$

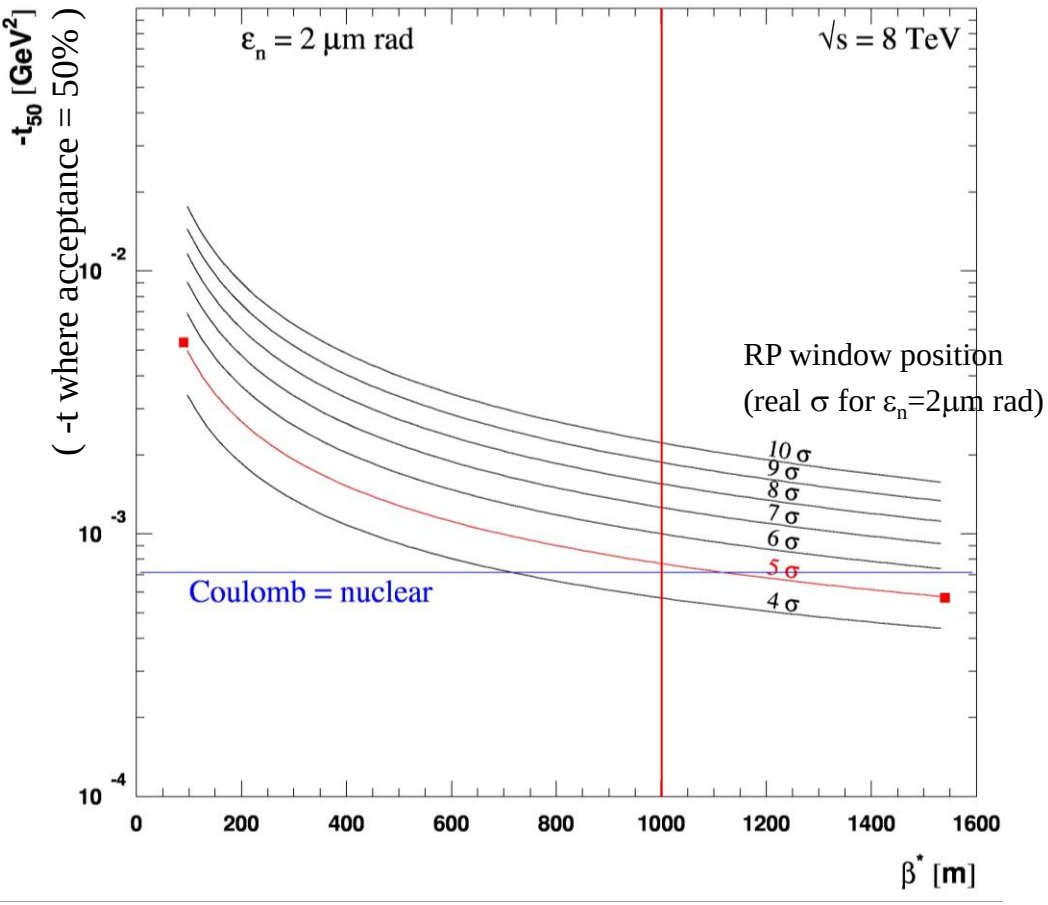
ρ = $\Re$ / $\Im$ [$T_{elastic,nuclear}(t = 0)$]

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 centre to ~ 4σ

How to reach the Coulomb-Nuclear Interference Region ?



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

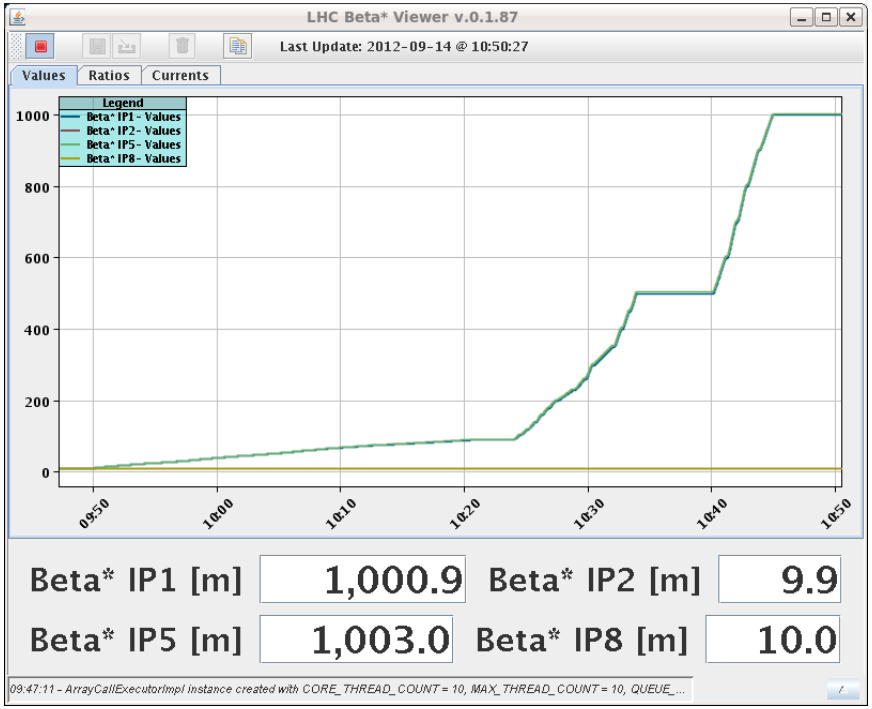
Beam emittance ε_n < 2 μm rad

→ **Challenging but possible**

The β* = 1000 m Optics

MD in June: first unsqueeze to 1km achieved

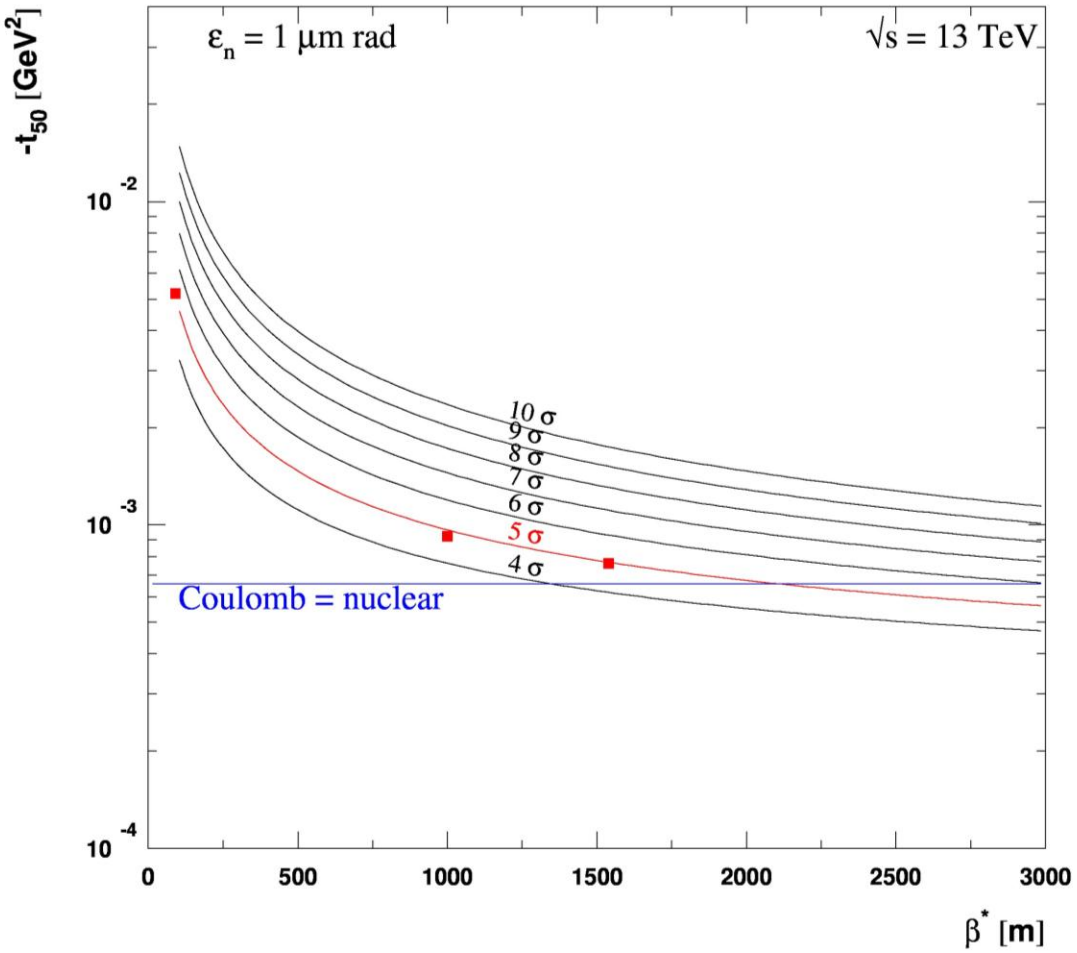
14 September:



- 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

After LS1: Low-|t| Elastic Scattering at 13 TeV



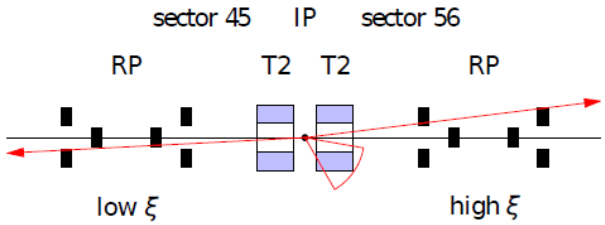
- To reach CNI region, push β* to > 2000 m
- At 13 TeV: good t-resolution needs parallel-to-point focussing in both x and y (phase advance π/2)

→ Additional magnet cables needed. To be installed during LS1.

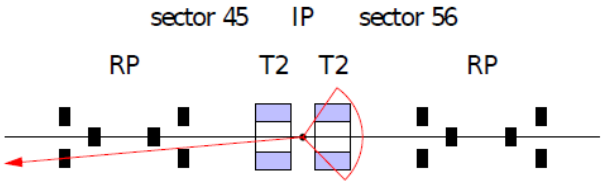
Diffractive Analyses Ongoing

Based on β* = 90 m (7 TeV) run in Oct. 2011 (RP @ 4.8σ – 6.5σ):

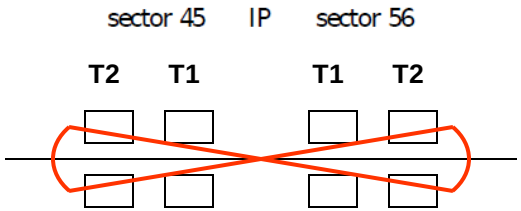
- Central Diffraction
  ($d^2\sigma_{DPE} / dt_1\, dt_2$, σ_{DPE})



- Single Diffraction
  ($d\sigma_{SD}/dt$, $d\sigma_{SD}/d\xi$, σ_{SD})



- Double Diffraction
  Select diff. masses 3.4 GeV < M < 10 GeV
  requiring tracks in both T2s, veto on T1s



→ Extend studies over full η range with CMS (2012 data)

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

Runs Planned for 2012 / 2013

- $\beta^* = 1000$ m: scheduled for 24 October
  → study CNI region, attempt to measure ρ

- RP insertions in normal physics runs ($\beta^* = 0.6$ m)
  - hard diffraction together with CMS (high diffractive masses reachable)
  - study of closest possible approach of the horizontal RPs (i.e. acceptable beam losses)
    → essential for all near-beam detector programmes at high luminosity after LS1

- request a low-pileup run ($\mu \sim 5$ %) with RPs at $\beta^* = 0.6$ m (in May RPs were not aligned)
  → study soft central diffraction final states
  with 2 leading protons defining Pomeron-Pomeron mass $M^2 = \xi_1 \xi_2 s$
  (good ξ resolution at $\beta^* = 0.6$ m → $\sigma(M) \sim 5$ GeV)

- participation in the p-Pb runs with insertions of the RPs on the proton side
  → study diffractive/electromagnetic and quasi-elastic p-Pb scattering
  p-Pb test run in September with CMS was successful (T2 trigger given to CMS)


TOTEM

Backup

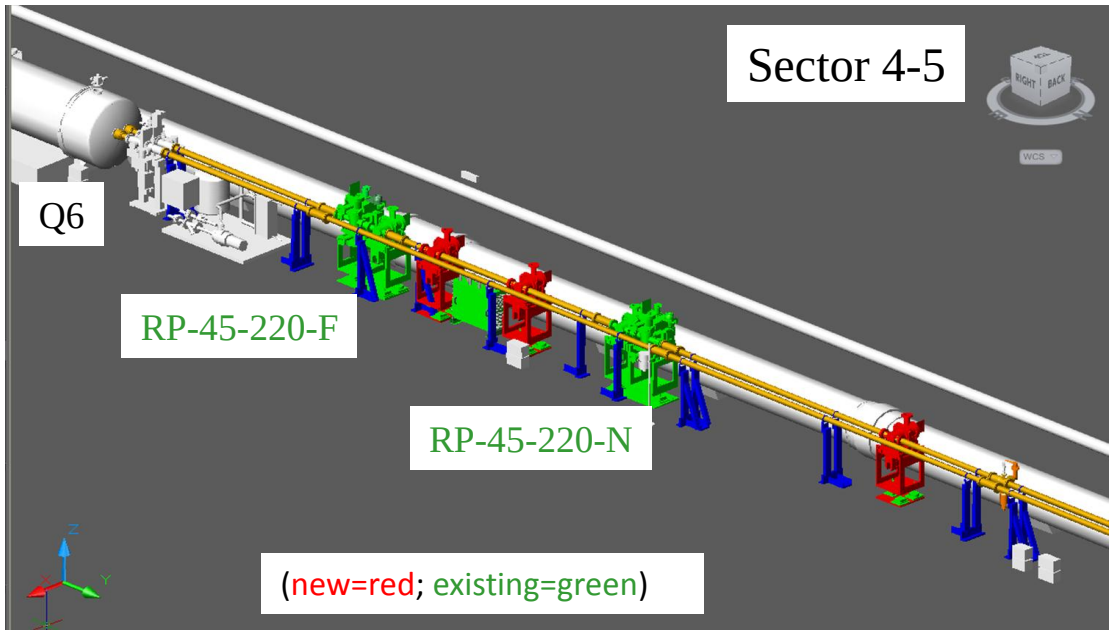
Upgrade of RP detector system at 220 m

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

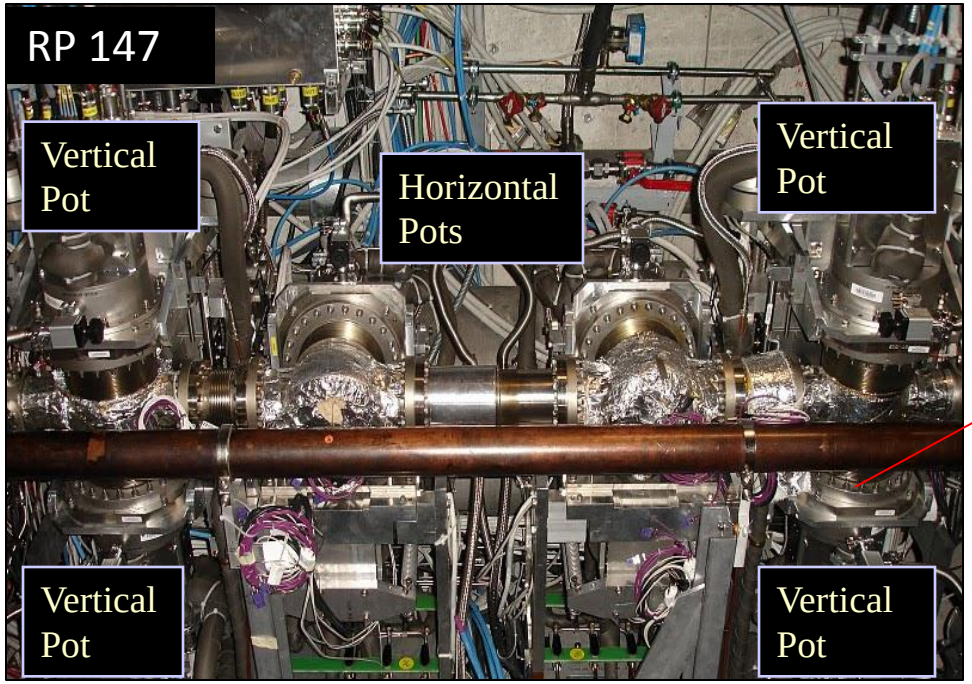
- Installation of additional RPs (horizontal)
- Integration of timing and pixel detectors in horizontal RPs

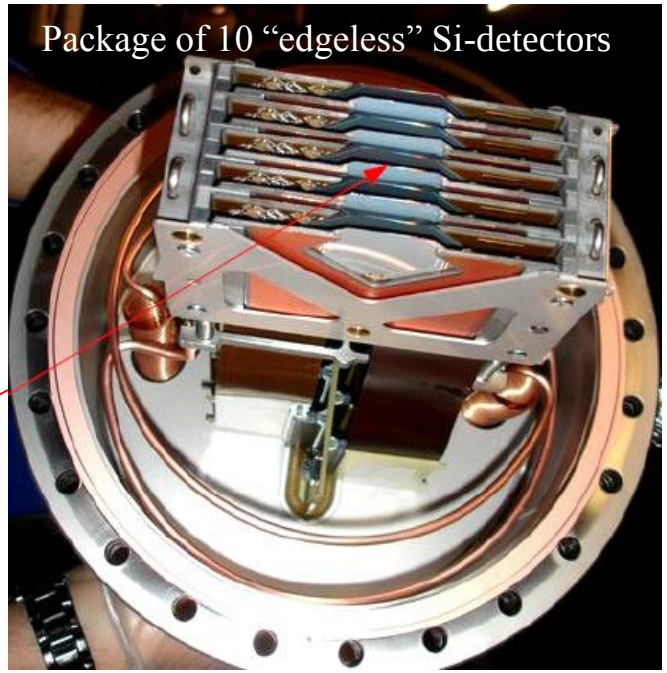
Guideline:

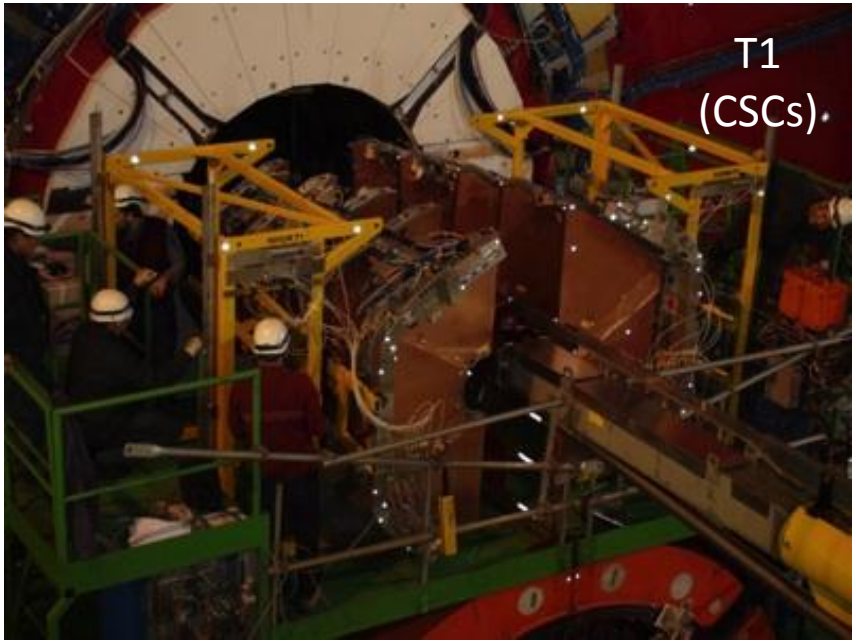
- The present 220m stations must not be affected (touched) by any upgrade activity, until the high beta special runs after LS1 are finished.
- The new horizontal RPs could be installed during LS1 and equipped successively with new tracking & timing detectors.
- Preparation of engineering change request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

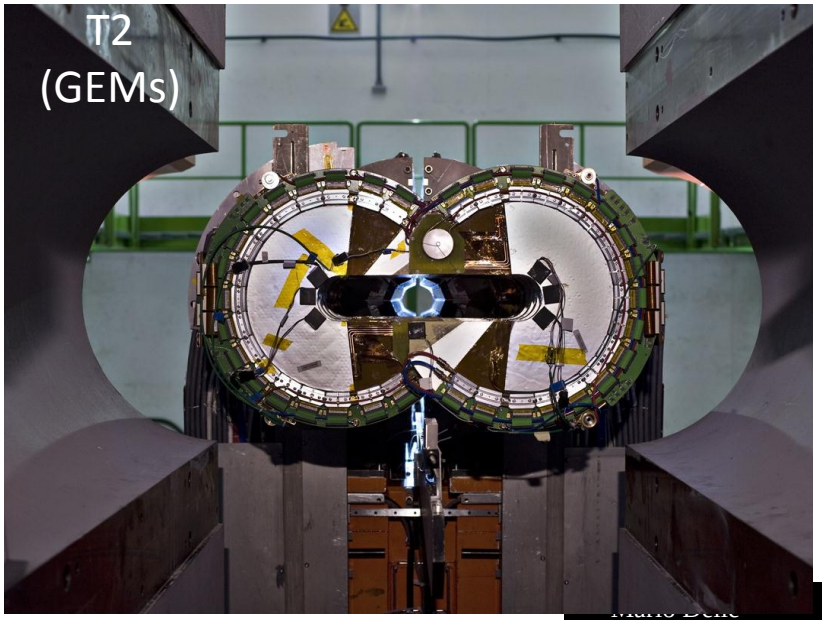


Detectors


RP 147
Vertical Pot
Horizontal Pots
Vertical Pot
Vertical Pot
Vertical Pot

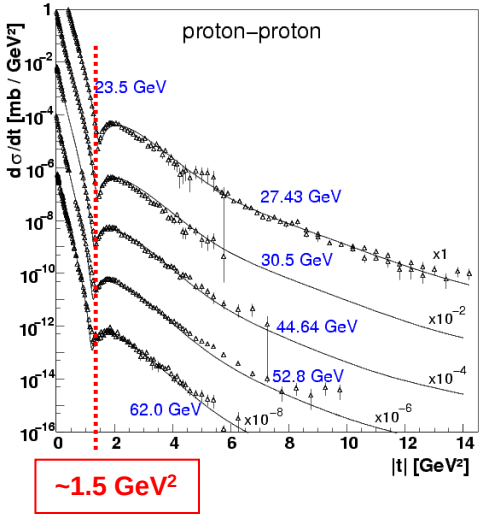

Package of 10 “edgeless” Si-detectors

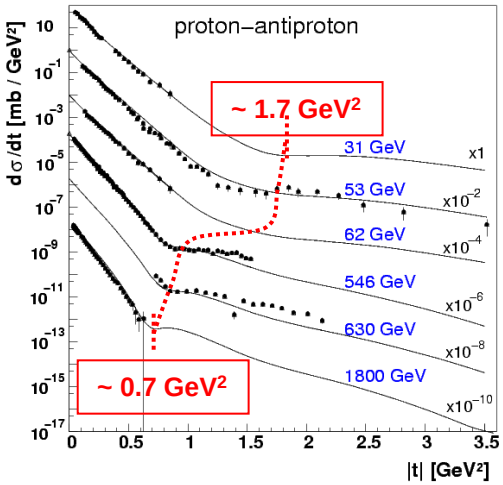

T1
(CSCs)


T2
(GEMs)

After LS1: Elastic Scattering and Total Cross-Section at lower E

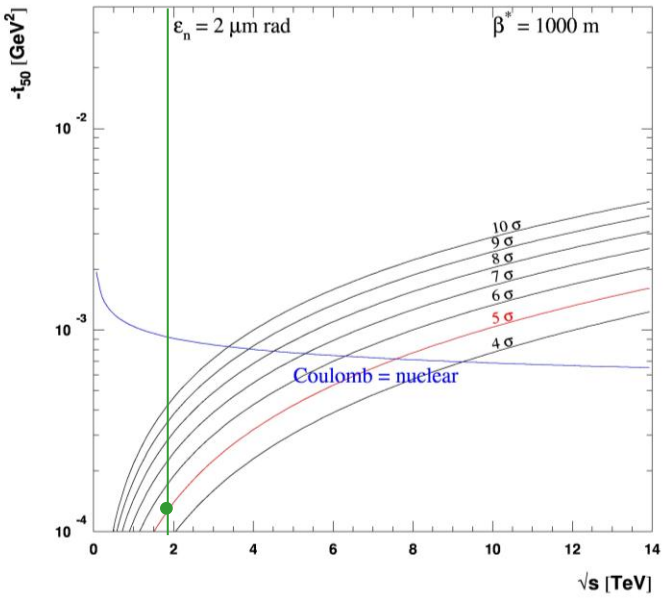
- $\sqrt{s}$ = 900 GeV : compare with $S\bar{p}pS$
- $\sqrt{s}$ = 1.8 TeV : compare with Tevatron, help resolving the σ_{tot} ambiguity
- compare $d\sigma_{elastic}/dt$ for pp and $\bar{p}p$ (dip vs. shoulder)





- ρ measurement more precise

due to access deep into the Coulomb region:



pA Minimum Bias Physics

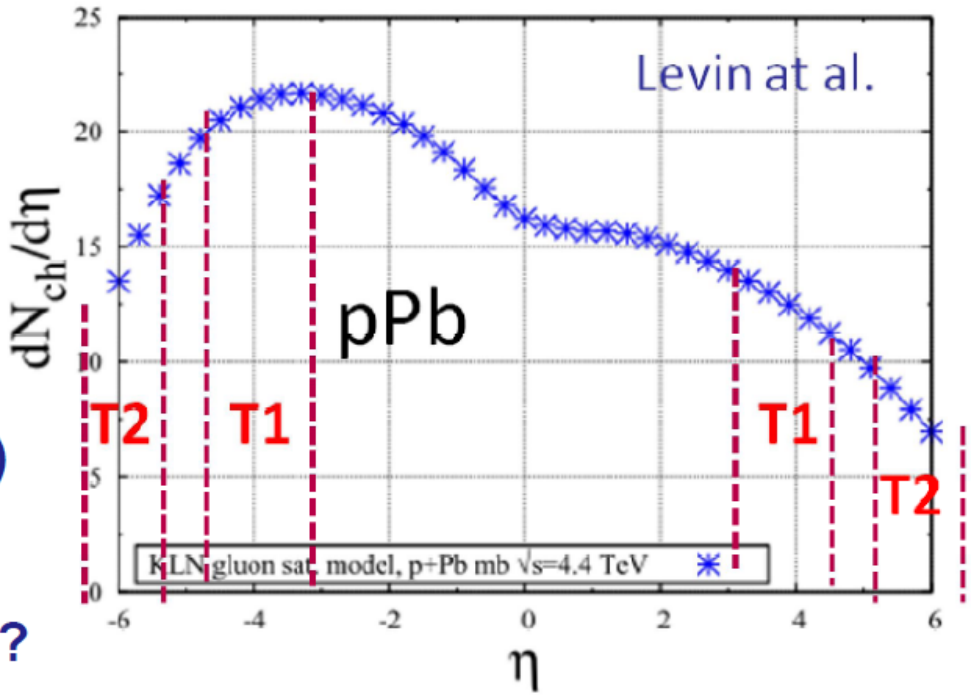
Charged particle acceptance (together with CMS): $|\eta| \leq 6.5$

Trigger: one T2 track(?)

$dN/d\eta_{pPb}$ using T1 & T2 (vs centrality from CMS)

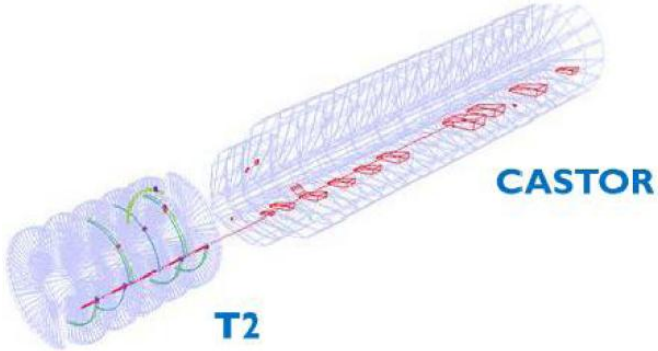
Forward-backward multiplicity correlations?

Central-forward multiplicity correlations?



Pattern recognition at high multiplicity to be optimized

Energy flow & small x: T1+HF, T2+Castor



[K. Oesterberg, pA @ LHC workshop, June 2012]

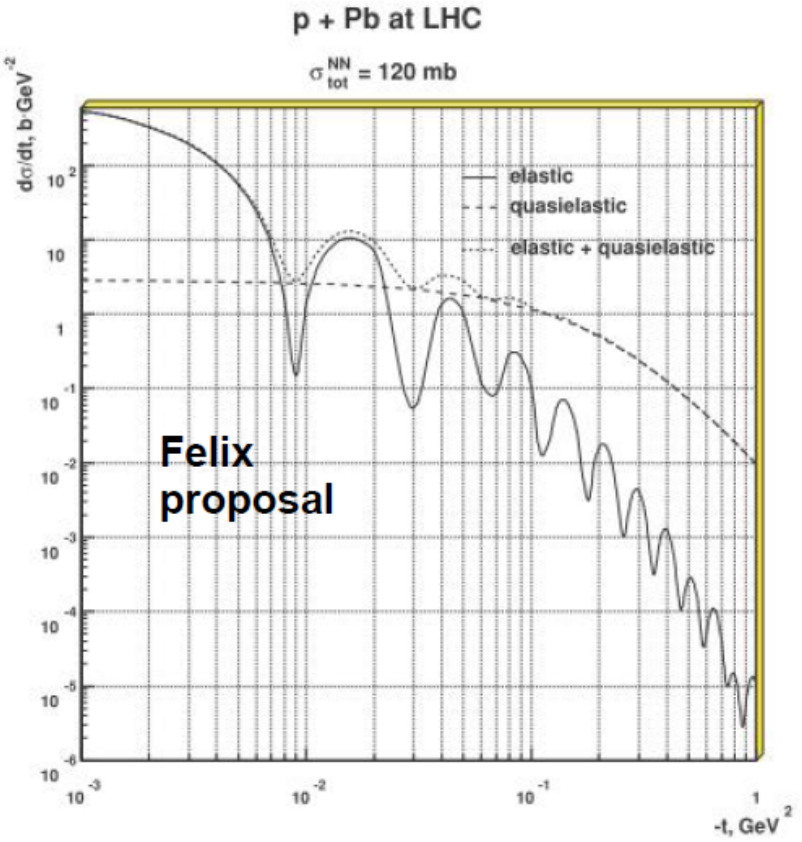
Cross-sections

Test of dynamics:

- **knockout: p Pb → p + d + (A–2)*** $\xi^{p}_{fragment} = (1 - (A/Z)_{fragment} / (A/Z)_{Pb})$
  - measure both p & d (= "p with $\Delta p/p = -0.21$") + veto hadron activity.

Need large t for p or significant $\Delta p/p$. Study $\Delta p/p$ & t dependence.

- **quasielastic: p Pb → p Pb*** dominates at large t
  - measure xi & t of p + only γ on opposite side (veto hadrons)



Diffraction & $\gamma\gamma$

- very large Pomeron & γ fluxes but nothing measured in RP on outgoing Pb side (rate problem?)

p with signficant $\Delta p/p$ (or large t) + central object (jets, J/Ψ, Υ etc..)

[K. Oesterberg, pA @ LHC workshop, June 2012]

pA with Leading Protons

Assumption: $\beta^* = 0.6$ m, $\varepsilon_n = 2.5$ μm rad, x-angle = 142.5 μrad,

$L_{y,RP220} = 13.07$ m, $D_{x,\,RP220} = 0.08$ m

Diffractive protons: $0.026 < \xi < 0.25$ (horizontal RPs @ 14 σ)

Quasi-elastic protons: $|t| > 3.7$ GeV^2 (vertical RPs @ 12 σ)

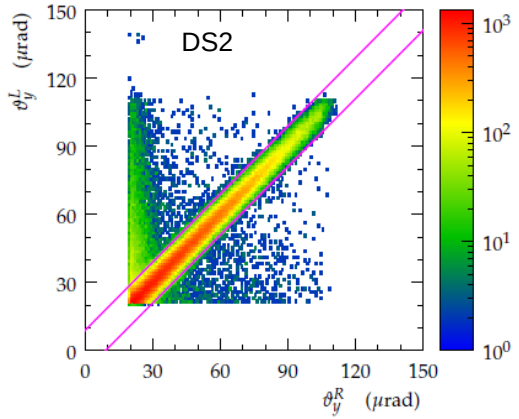
Beam-based alignment for Roman Pots needed.

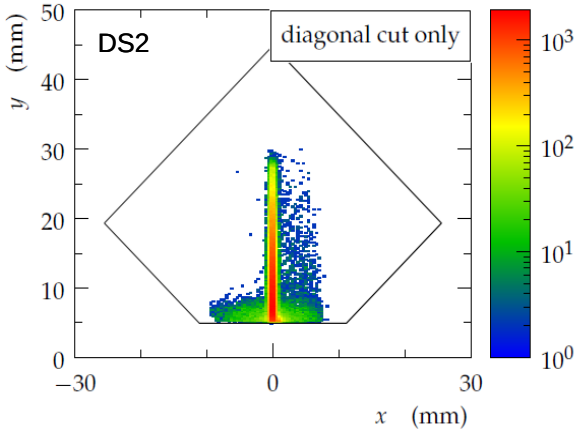
Elastic Scattering @ 8 TeV, β*=90m: Analysis

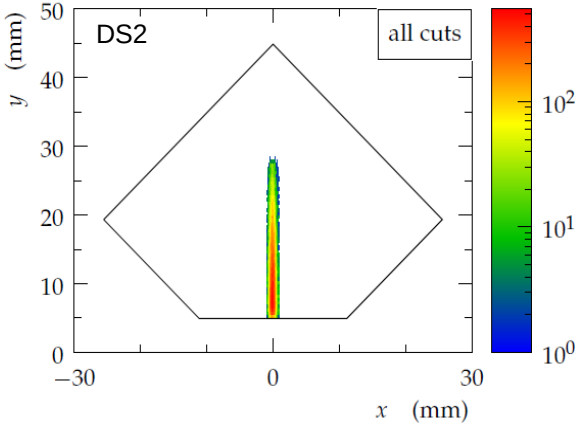
- *Optics @8 TeV basically the same as @7 TeV (in terms of optical functions)*
  ➡ *follow the same analysis steps*

- *Alignment : RPs aligned wrt collimators; tracks-based alignment; alignment with physics tracks*
- *Kinematics reconstruction: $\Theta^*_{x,y}$ and x**
- *Elastic Tagging: collinearity, low ξ, vertex*

cut	quantities
diagonal	4 RP hits
1	ϑ_x^{*R} vs. ϑ_x^{*L}
2	ϑ_y^{*R} vs. ϑ_y^{*L}
3	$\lvert x^{*R}\rvert$
4	$\lvert x^{*L}\rvert$
5	ϑ_y^{*R} vs. $y^{R,F} - y^{R,N}$
6	ϑ_y^{*L} vs. $y^{L,F} - y^{L,N}$
7	x^{*R} vs. x^{*L}







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- *Kinematics reconstruction: $\Theta^*_{x,y}$ and x^**
- *Elastic Tagging: collinearity, low ξ, vertex*
- *Acceptance Correction*
- *Resolution Unfolding*
- *Normalization: Background*
  Efficiency
  Luminosity
- *Systematics uncertainty determination*