Review diffractive and electromagnetic processes in TOTEM

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Diffractive and electromagnetic processes at high energies

Bad Honnef, August 17 - 21, 2015

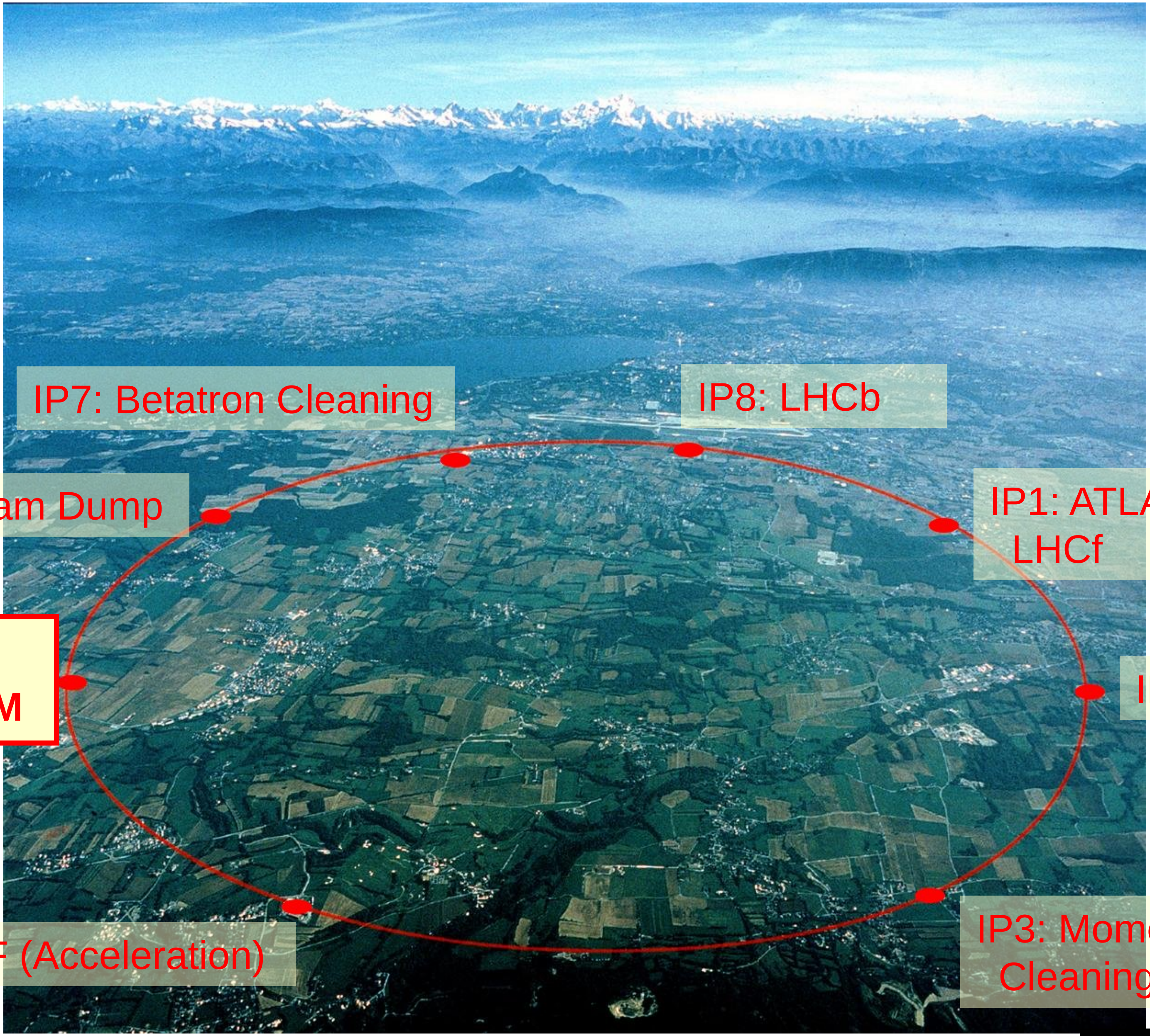
Outline

1. The TOTEM Experiment at the LHC:
   Physics objectives and detector apparatus

2. Some Results from LHC Run 1:
   a. Elastic pp Scattering
   b. Diffraction

3. Detector Upgrade and Physics Plans for Run 2

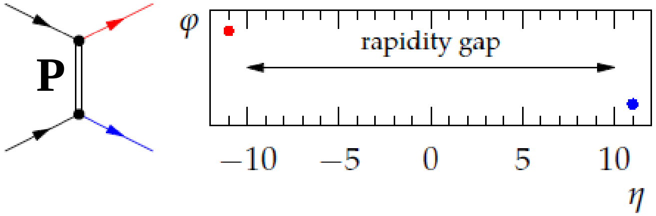
The TOTEM Experiment at the LHC



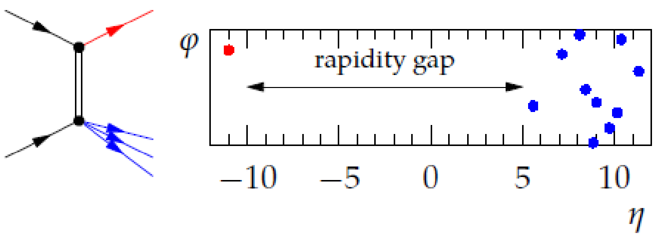
Diffractive and Electromagnetic Processes

Diffractive

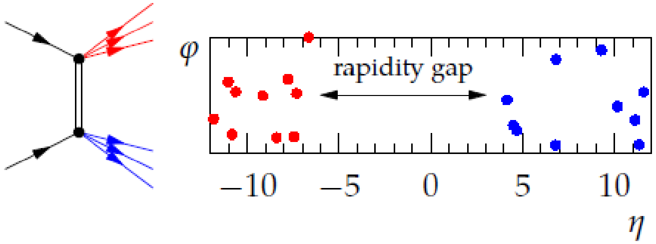
Elastic Scattering (ES), ≈ 25 mb



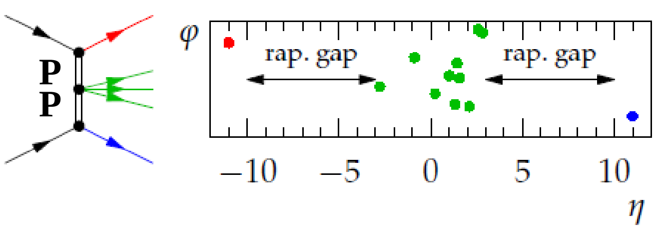
Single Diffraction (SD), ≈ 10 mb



Double Diffraction (DD), ≈ 5 mb



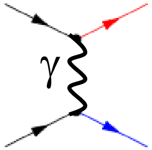
Central Diffraction (CD), ≈ 1 mb



Electromagnetic

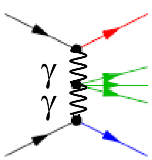
very low momentum transfers

$|t| \sim O(10^{-4}\ \mathrm{GeV}^2)$

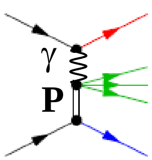


Coulomb scattering

pure QED



Photoproduction



Experimental Setup at IP5

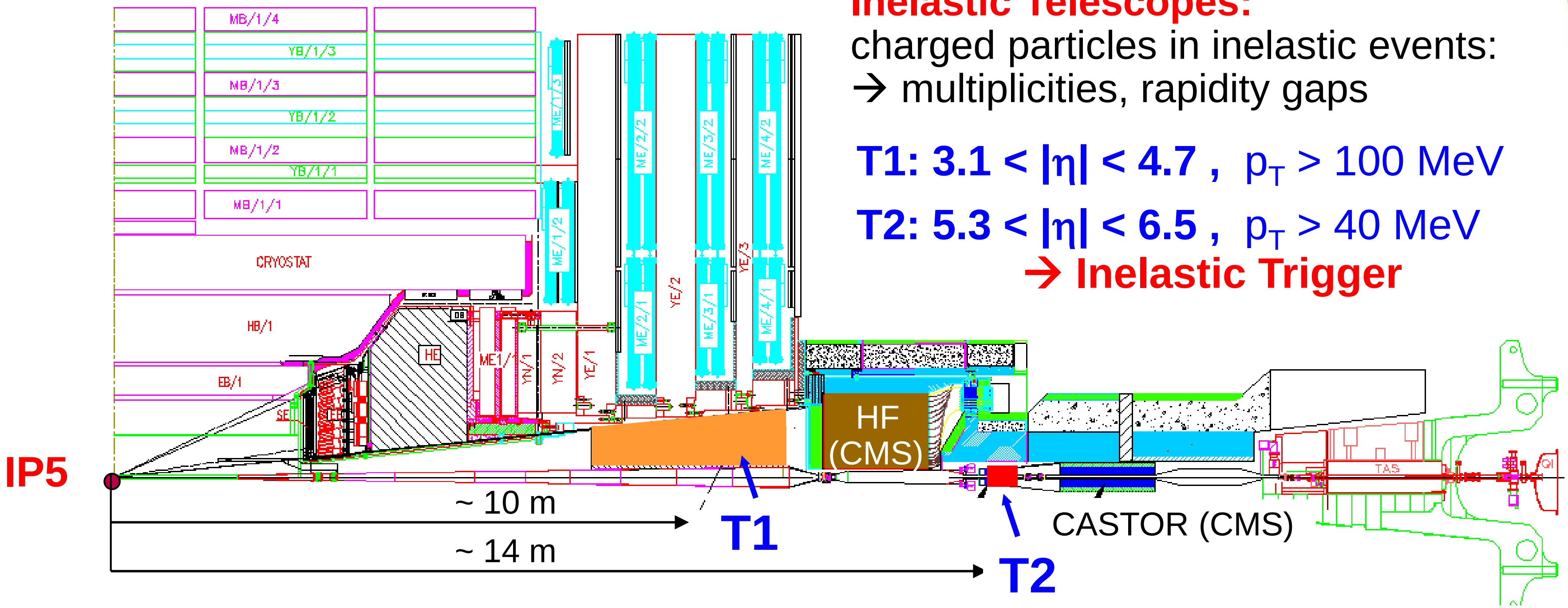
[Ref.: JINST 3 (2008) S08007]

Inelastic Telescopes:
charged particles in inelastic events:
→ multiplicities, rapidity gaps

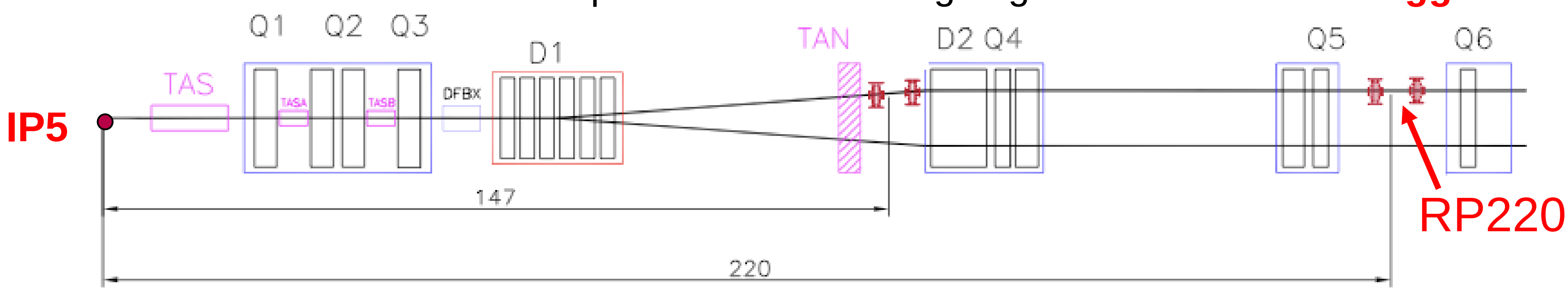
T1: $3.1 < |\eta| < 4.7$, $p_T > 100$ MeV

T2: $5.3 < |\eta| < 6.5$, $p_T > 40$ MeV

→ **Inelastic Trigger**



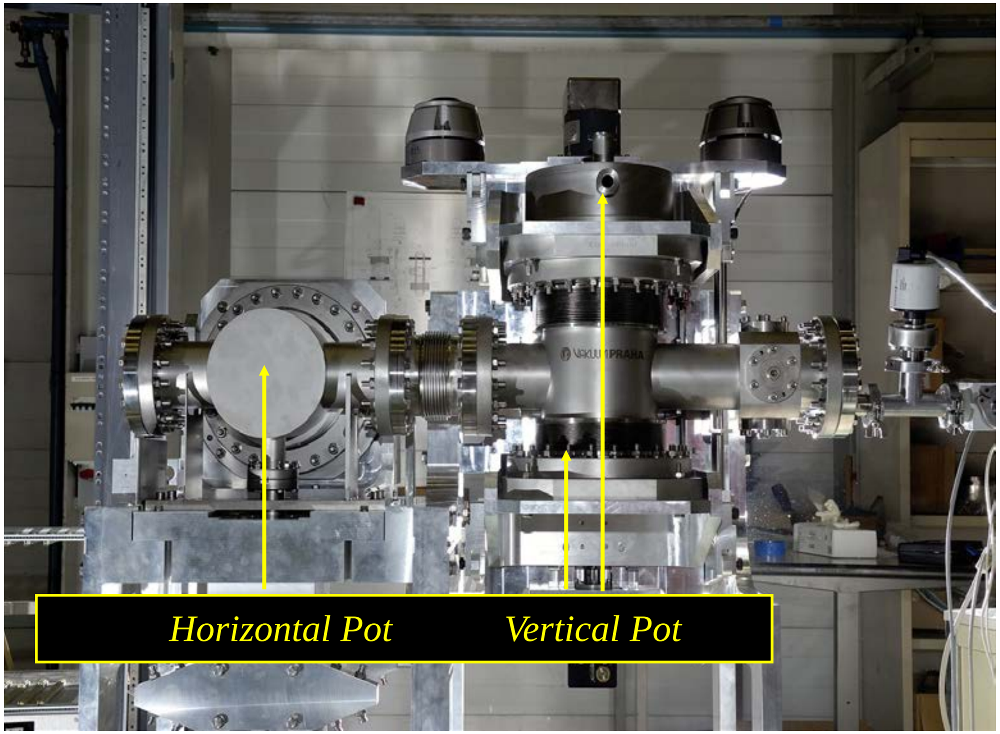
Roman Pots: elastic & diffractive protons close to outgoing beams → **Proton Trigger**

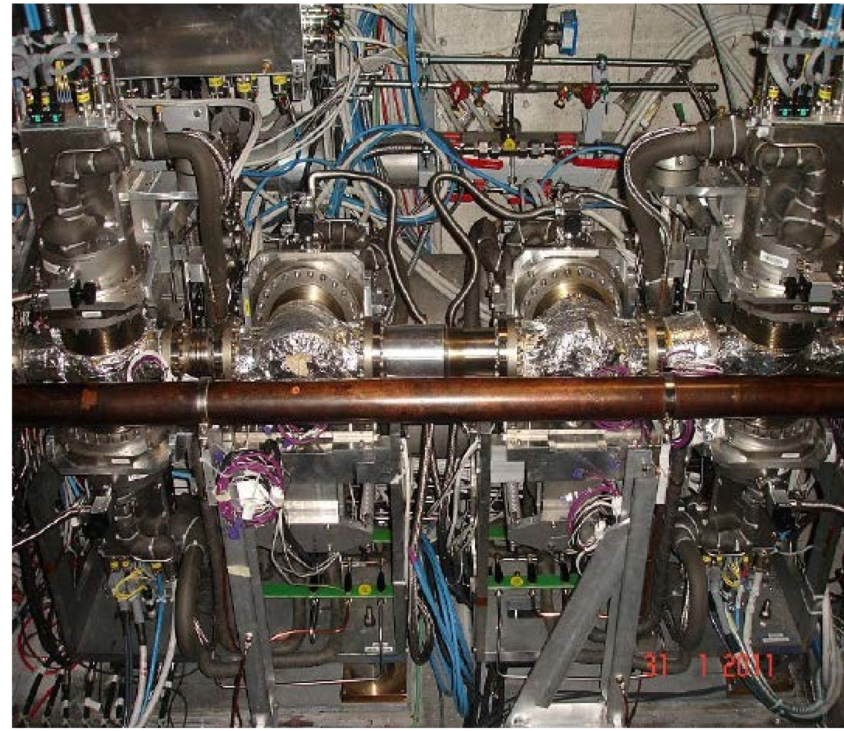


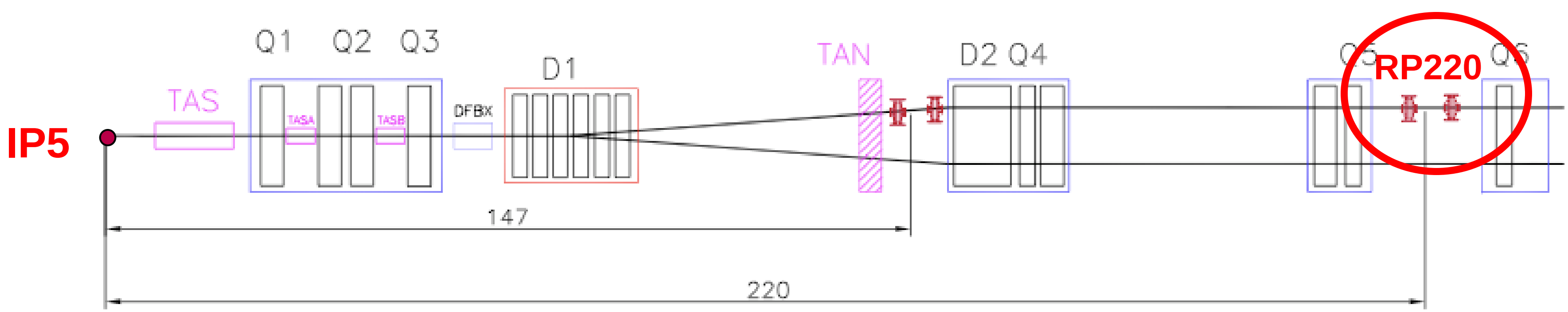
Roman Pots

Roman Pot = movable box inside the beam pipe, housing silicon detectors.

Detectors can approach the beam centre to < 1mm when the beams are stable.

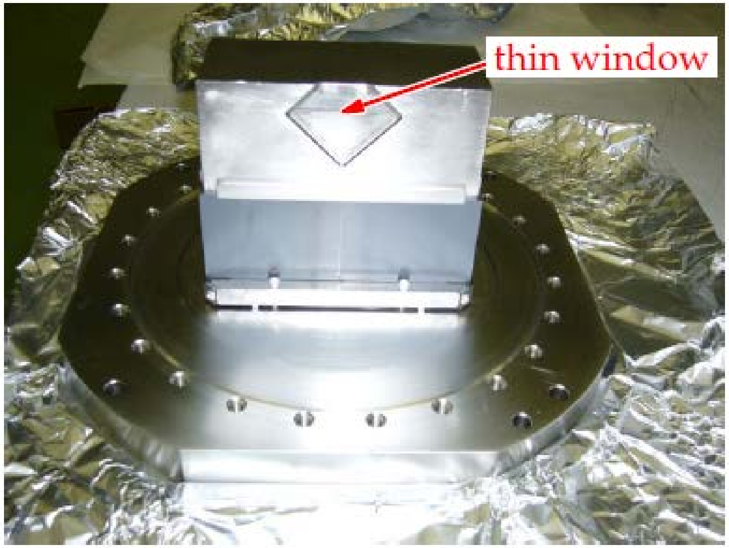




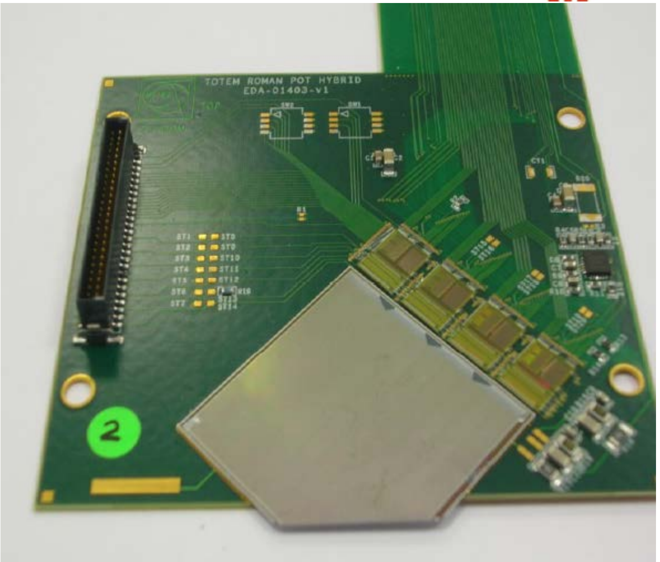


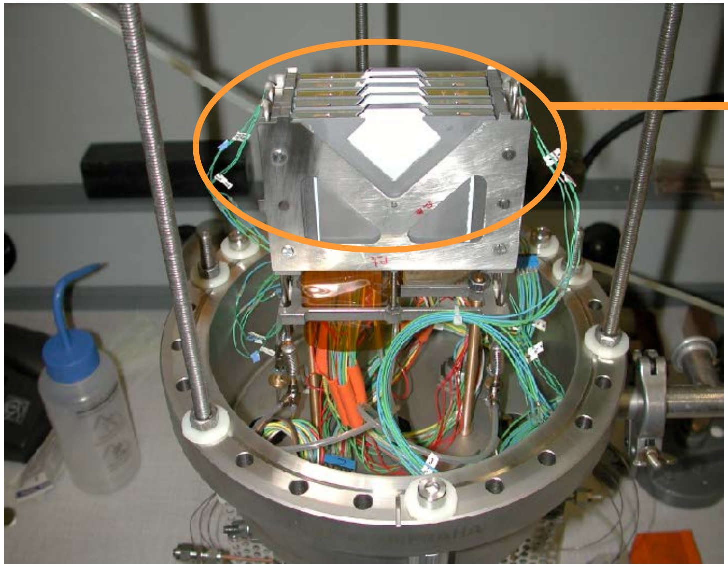
Roman Pot Detector Packages

Detector housing



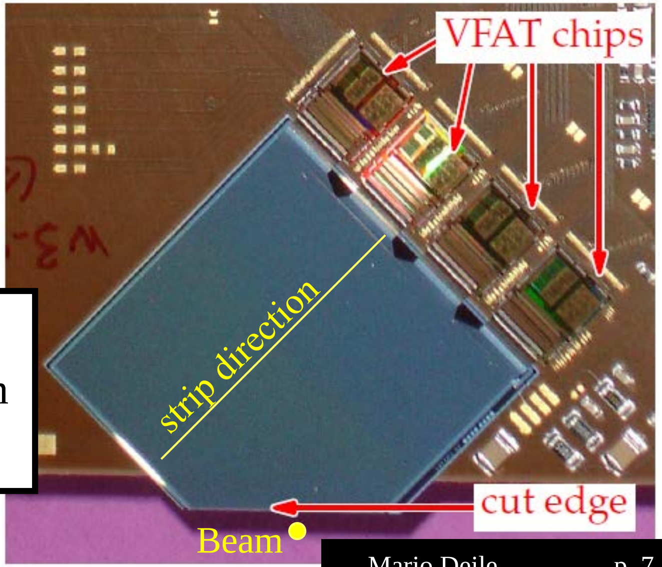
Hybrid board with silicon detector and read-out chips



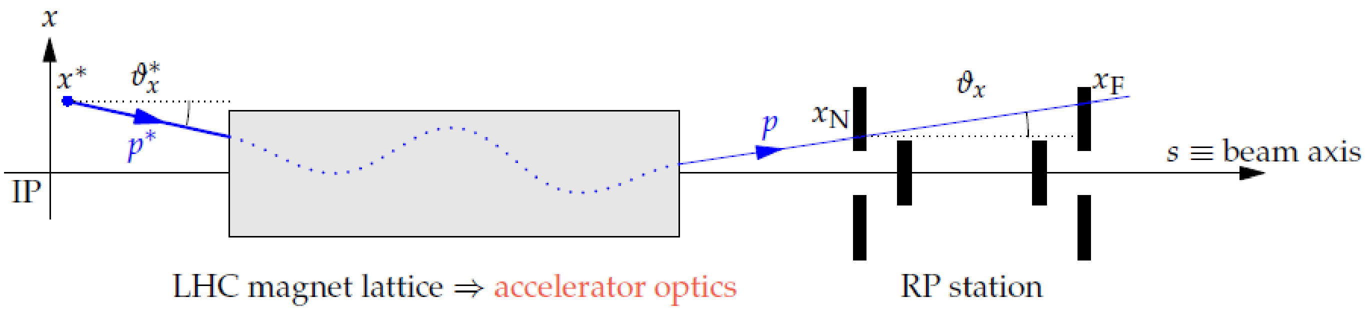


Stack of 10 silicon strip detectors (5 pairs back to back)

"edgeless" silicon sensor (full efficiency at ~ 50 μm from cut edge)



Proton Transport and Reconstruction via Beam Optics



(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

Excellent beam optics understanding needed.

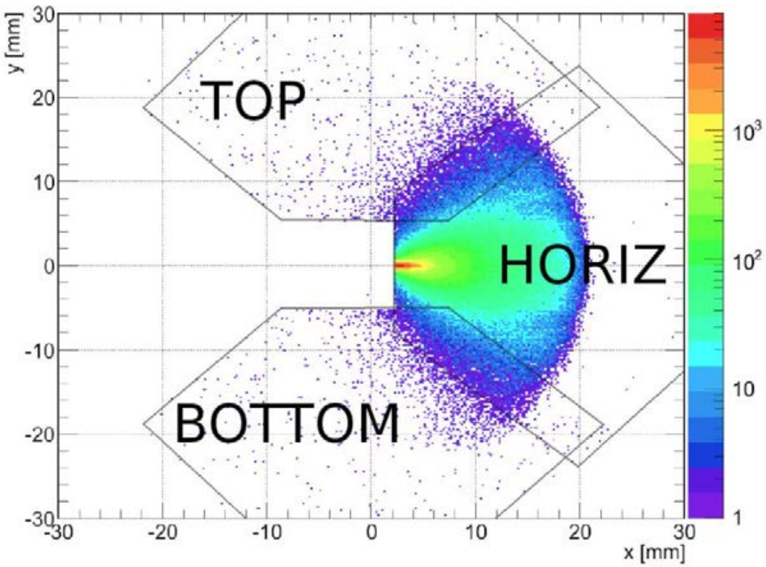
TOTEM method: optics calibration using proton tracks [New J. Phys. 16 (2014) 103041]

Different LHC Optics

Hit maps of simulated diffractive events for 2 optics configurations

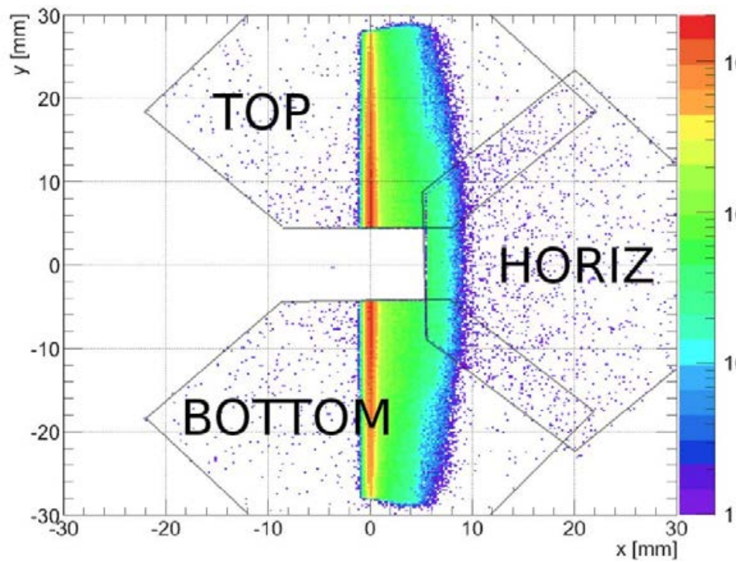
(labelled by β* = betatron function at the interaction point)

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



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

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



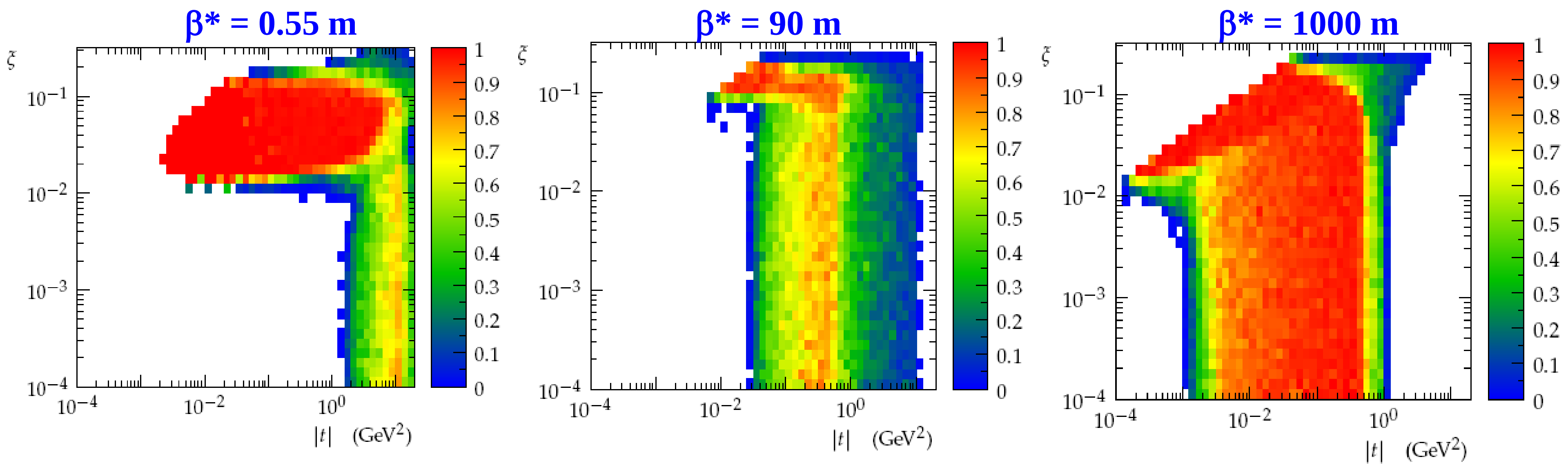
L_x = 0, L_y = 260 m, v_y = 0, D_x = 4 cm

LHC Optics and TOTEM Running Scenario

Acceptance for diffractive protons:

$t \approx -p^2\,\Theta^{*\,2}$: four-momentum transfer squared; $\xi = \Delta p/p$: fractional momentum loss

elastic scattering: special case for $\xi = 0$



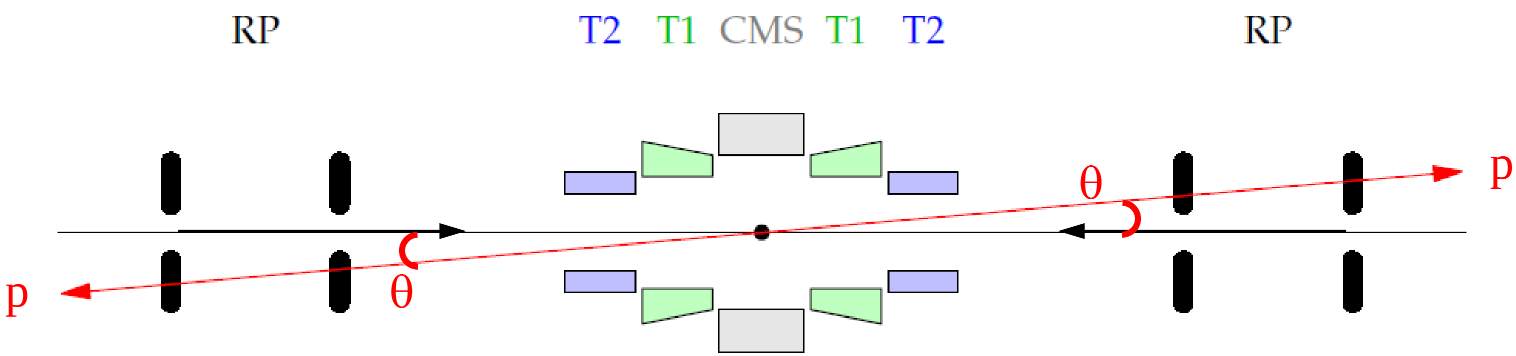
> 10^{33} cm^{-2} s^{-1} ⟵ $\mathcal{L} \propto \dfrac{1}{\beta^*}$ — ~10^{27} cm^{-2} s^{-1}

Diffraction:
ξ > ~0.01
low cross-section processes
(hard diffraction)
Elastic scattering: large |t|

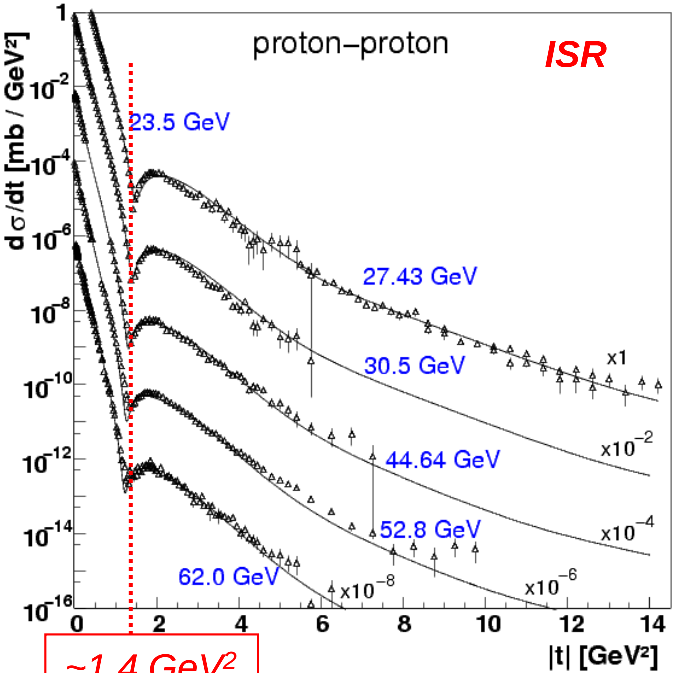
Diffraction:
all ξ if |t| > ~10^{-2} GeV^2
Elastic scattering: low to mid |t|

Elastic scattering: very low |t|
Coulomb-Nuclear Interference

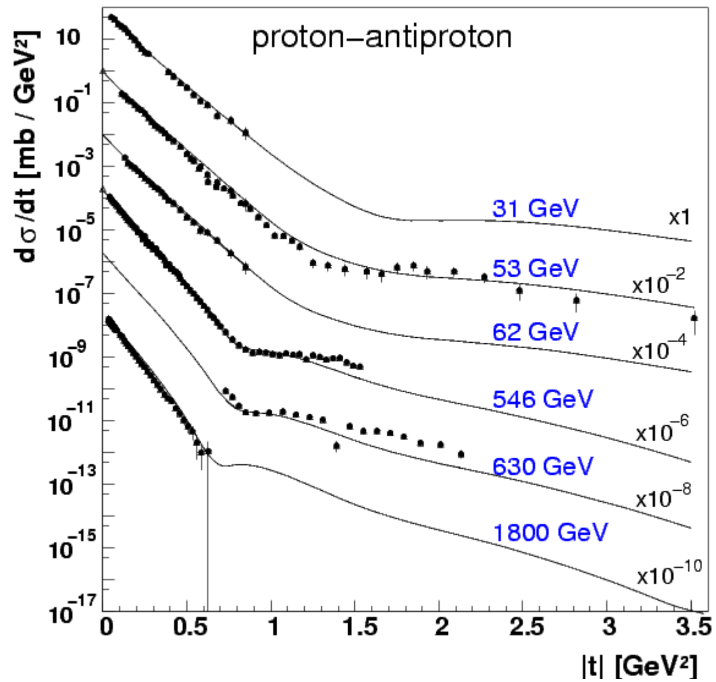
pp Elastic Scattering
7 TeV
8 TeV



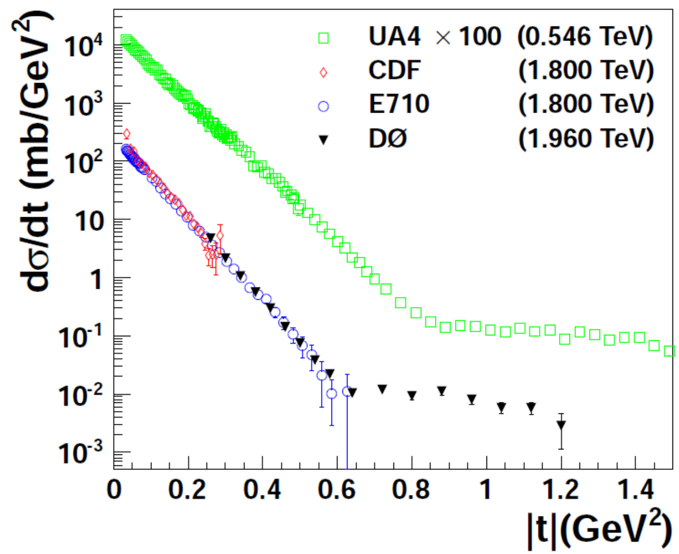
Elastic scattering – from ISR to Tevatron



~1.4 GeV²



$|t| \approx p^2\ \theta^2$

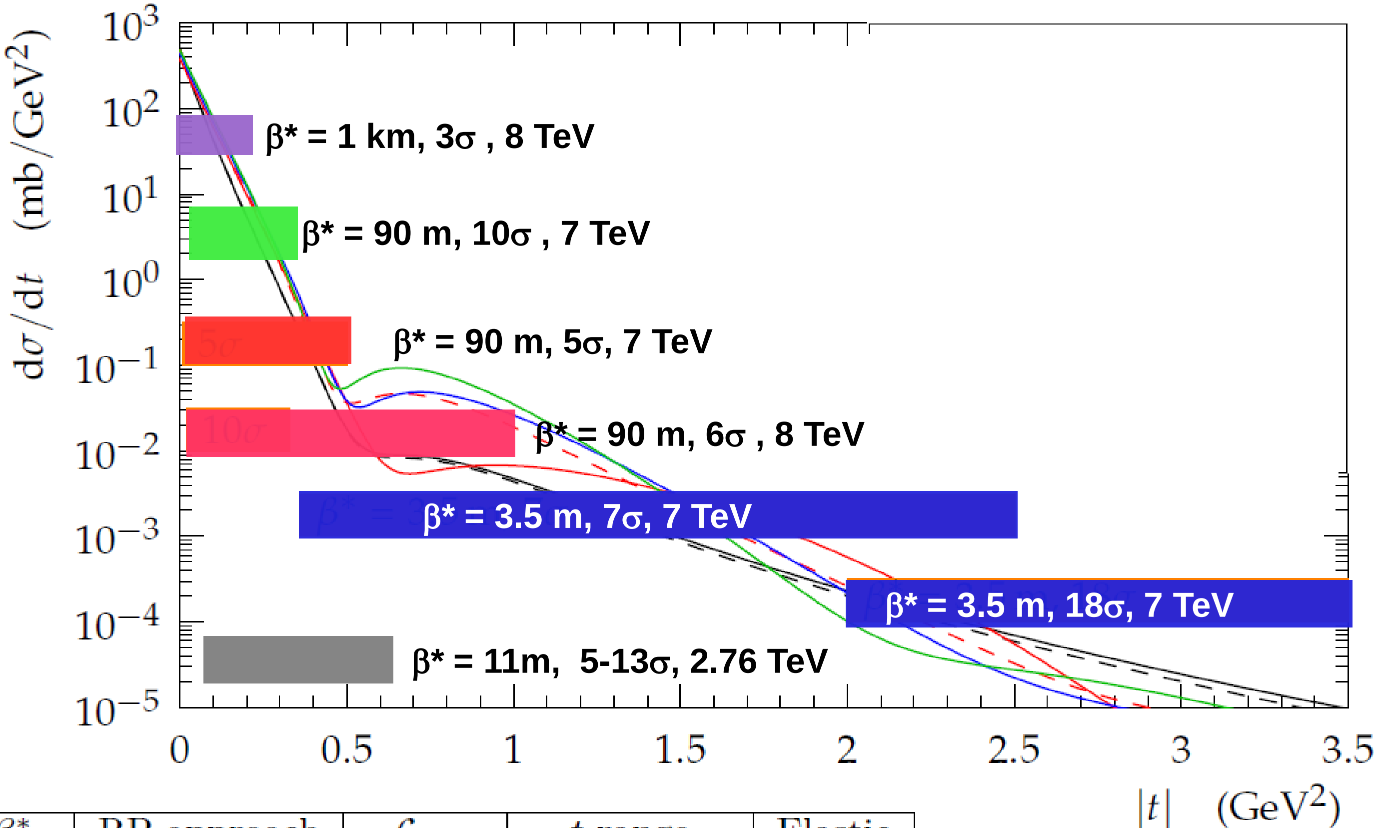


- *Minimum in pp, shoulder in p̄p*
  → different mix of processes

- *Minimum / shoulder moves to lower |t| with increasing s*
  → interaction region grows (as also seen from σ_{tot})

Elastic Scattering: TOTEM Data Collection

Several data sets at different conditions to cover wide |t| range and 3 energies



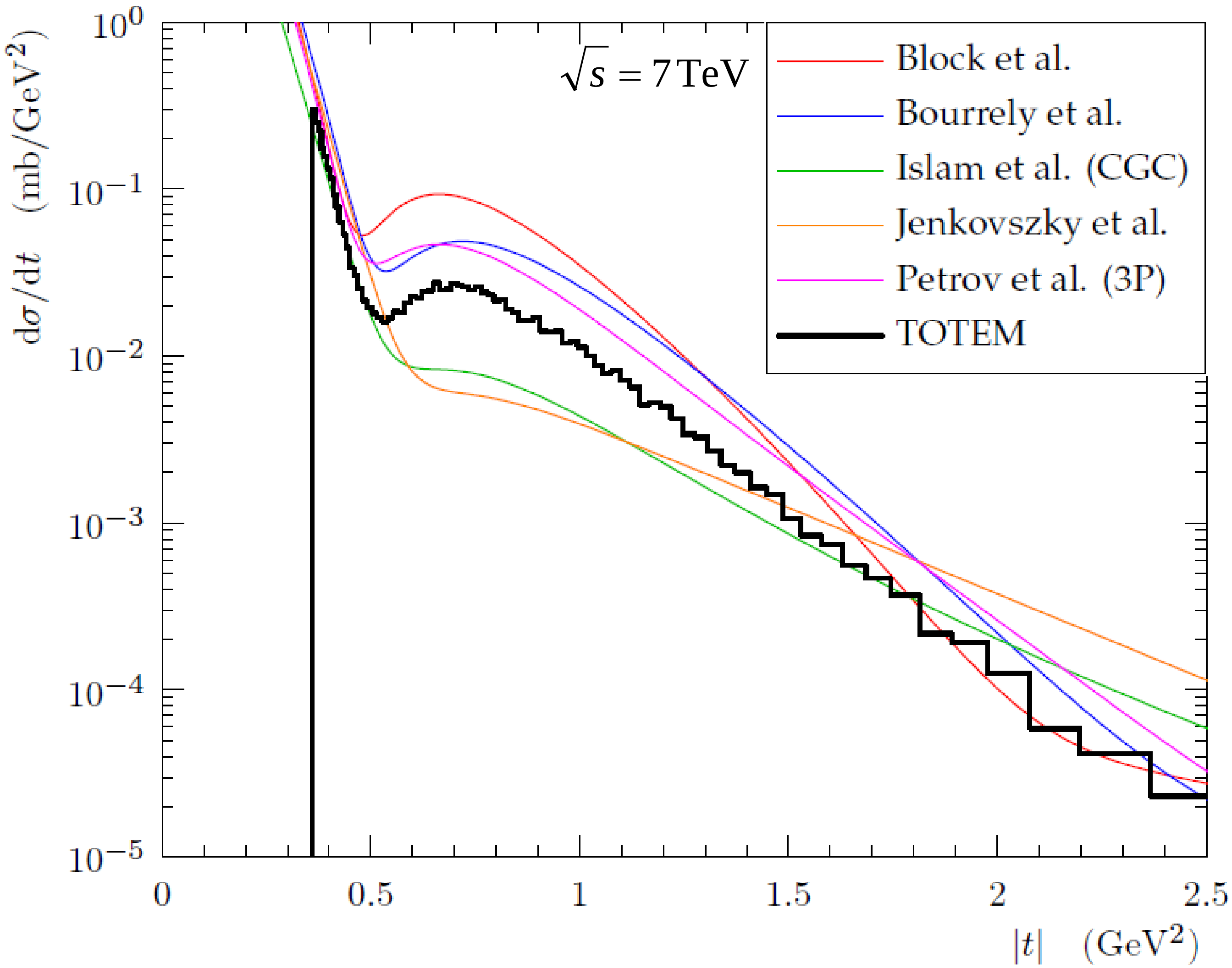
E (TeV)	β^* (m)	RP approach	$\mathcal{L}_{int}$ (μb^{-1})	t range (GeV^2)	Elastic events
7	90	4.8-6.5σ	83	$7{\cdot}10^{-3}$ - 0.5	1M
	90	10σ	1.7	0.02 - 0.4	14k
	3.5	7σ	0.07	0.36 - 3	66k
	3.5	18σ	2.3	2 - 3.5	10k
8	90	6-9σ	60	0.01 - 1	7M
	1000	3σ	20	$6{\cdot}10^{-4}$ - 0.2	0.4M
2.76	11	5-13σ		0.05-0.6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

[EPL 101 (2013) 21002]
[EPL 96 (2011) 21002]
[EPL 95 (2011) 41001]

New

arXiv:1503.08111, accepted by Nucl. Phys. B

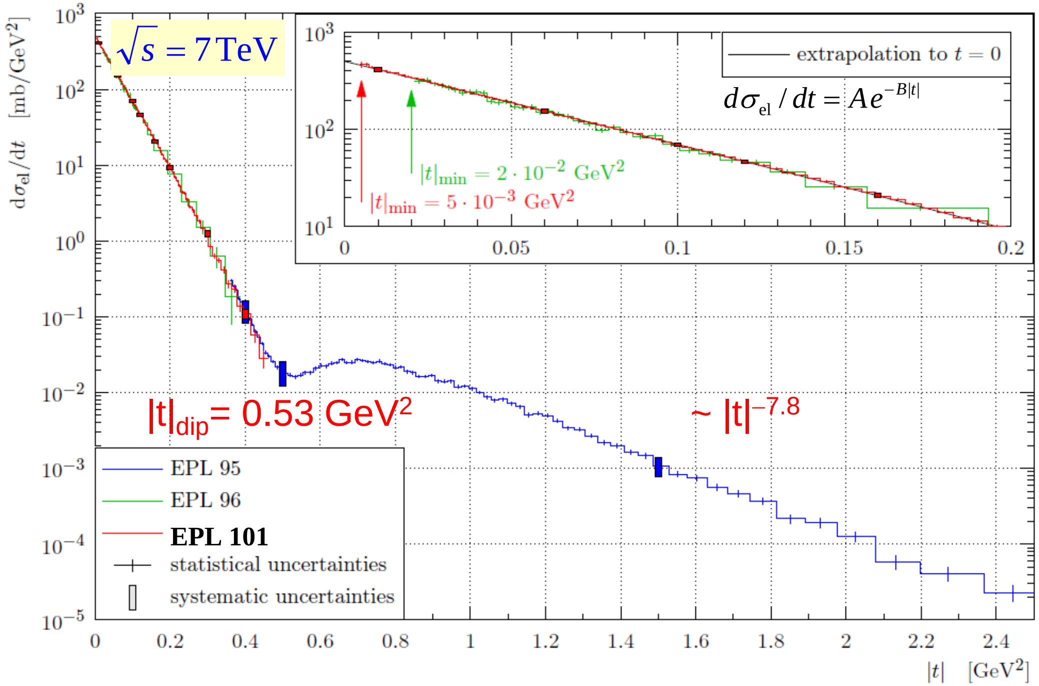
Model Comparisons

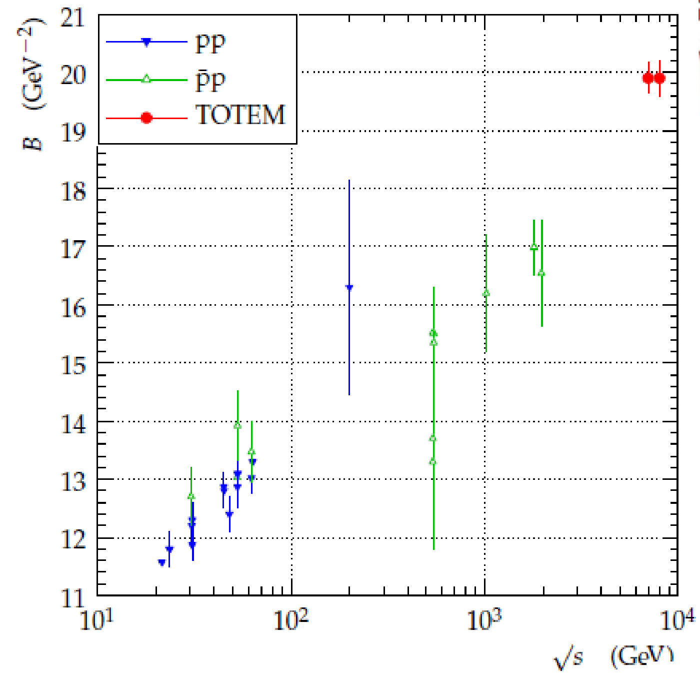


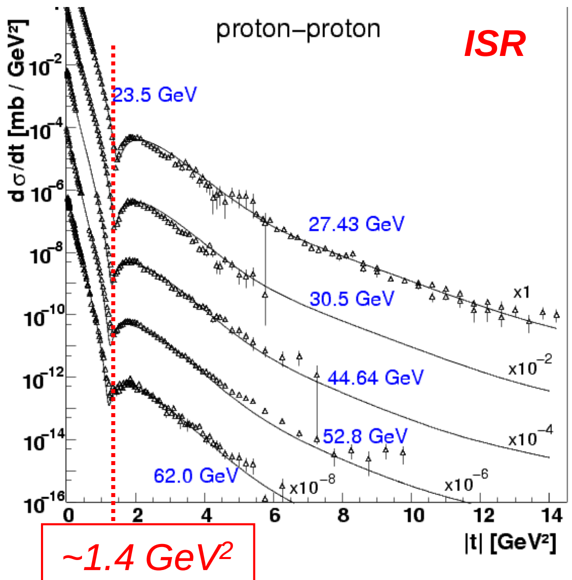
At the time of the TOTEM publication:

No theoretical / phenomenological model described the TOTEM data completely.

Some Lessons on Hadronic Elastic pp Scattering







At low |t|: nearly exponential decrease:

B_{7TeV} = (19.89 ± 0.27) GeV⁻²

B_{8TeV} = (19.90 ± 0.30) GeV⁻²

Extrapolation to t=0 → σ_{tot} via optical theorem:

$$\sigma^2_{tot} = \frac{16\pi}{1+\rho^2}\left.\frac{d\sigma_{el}}{dt}\right|_{t=0}$$

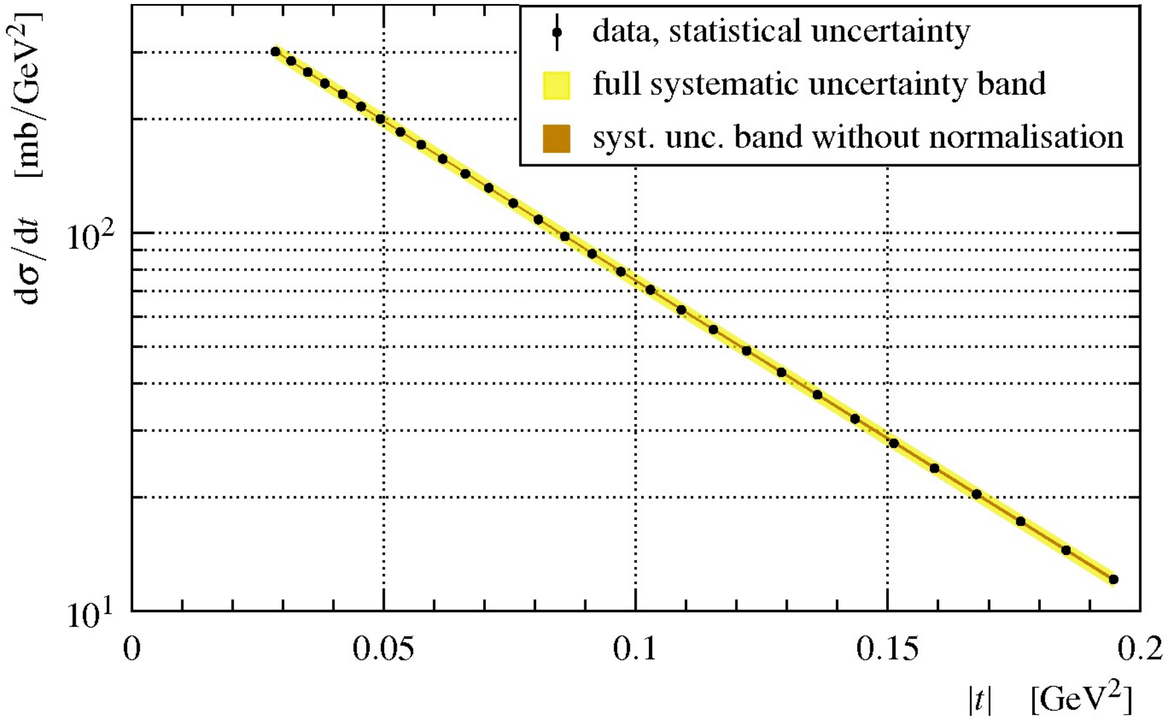
Old trends for increasing s are confirmed:

- "shrinkage of the forward peak": minimum moves to lower |t|
- forward exponential slope B increases

Non-Exponential Elastic pp Differential Cross-Section

High statistics data set (β^*=90m, 2012): 7 M elastic events

0.027 GeV^2 < |t| < 0.2 GeV^2 , i.e. Coulomb effects negligible

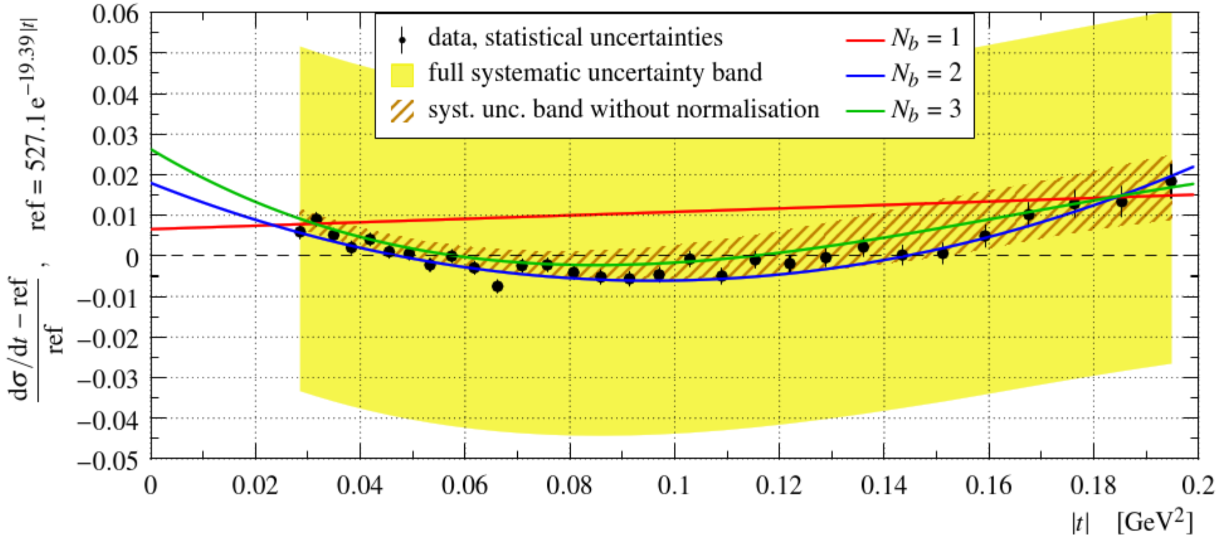


Quite exponential at the first glance, but a closer look reveals …

Non-Exponential Elastic pp Differential Cross-Section

Plotting relative deviation from exponential and fitting

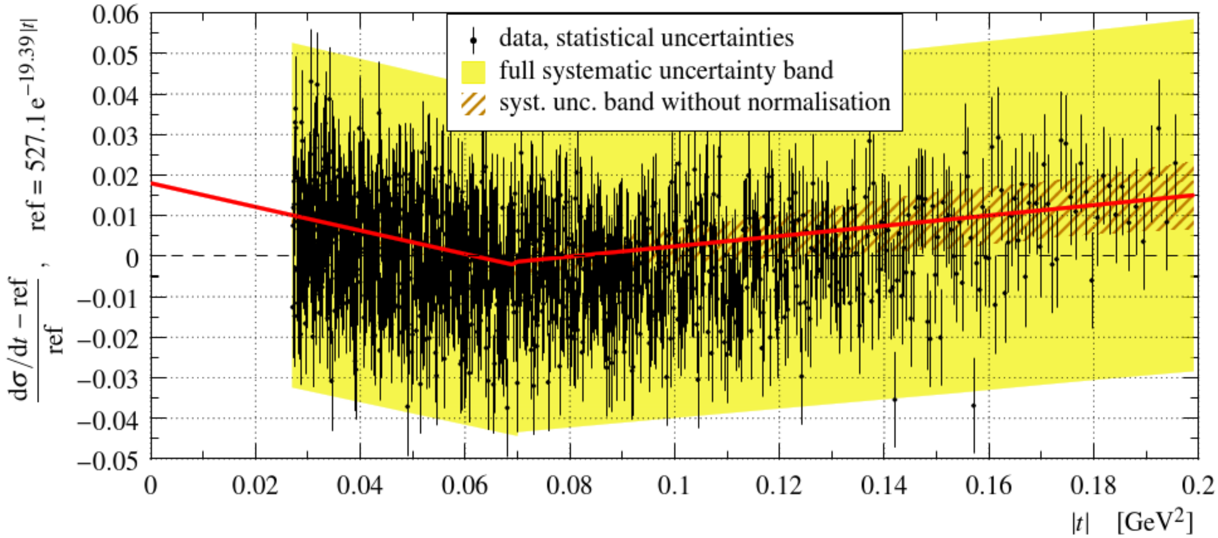
$d\sigma/dt = A\, e^{-B(t)\,|t|}$, with $B(t) = b_0$ or $B(t) = b_0 + b_1\, t$ or $B(t) = b_0 + b_1\, t + b_2\, t^2$



N_b	χ^2/ndf	p-value	significance
1	$117.5/28 = 4.20$	$6.1 \cdot 10^{-13}$	$7.2\,\sigma$
2	$29.3/27 = 1.09$	0.35	$0.94\,\sigma$
3	$25.5/26 = 0.98$	0.49	$0.69\,\sigma$

Pure exponential form ($N_b = 1$) excluded at 7.2 σ significance.

Or: fit simple exponentials in 2 subranges:

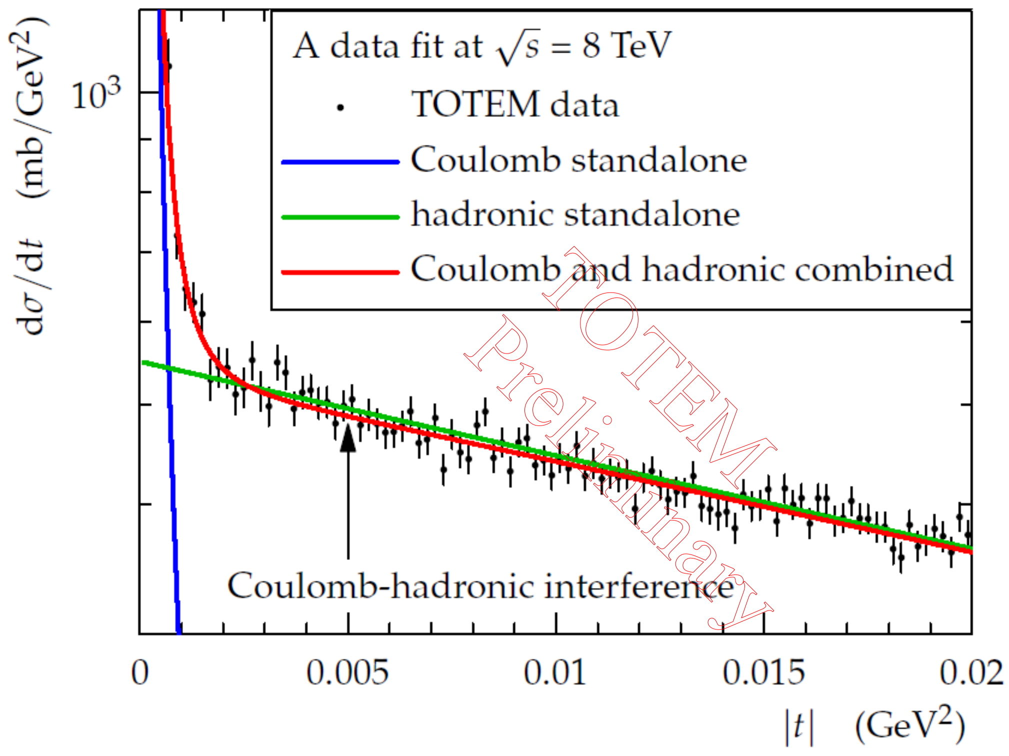


Exponential slopes of subranges inconsistent at 7.8 σ significance.

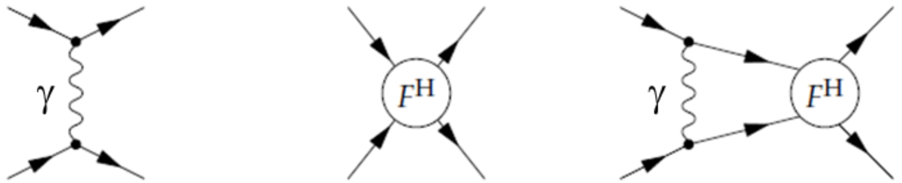
Elastic Scattering in the Coulomb-Nuclear Interference Region

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

- β^* = 1000 m optics: specially developed for measurements at very low |t|
- RP approach to 3 σ from the beam centre



Elastic Scattering in the Coulomb-Nuclear Interference Region



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

$$F^C = \frac{\alpha s}{t} \mathcal{F}^2(t)$$

- Modulus constrained by measurement in nucl. region: $d\sigma/dt \cong A\, e^{-B(t)\,|t|}$
  $B(t) = b_0 + b_1 t + \ldots$
- Phase $\arg(F^H)$: very little guidance by data

Simplified West-Yennie (SWY) formula (standard in the past):

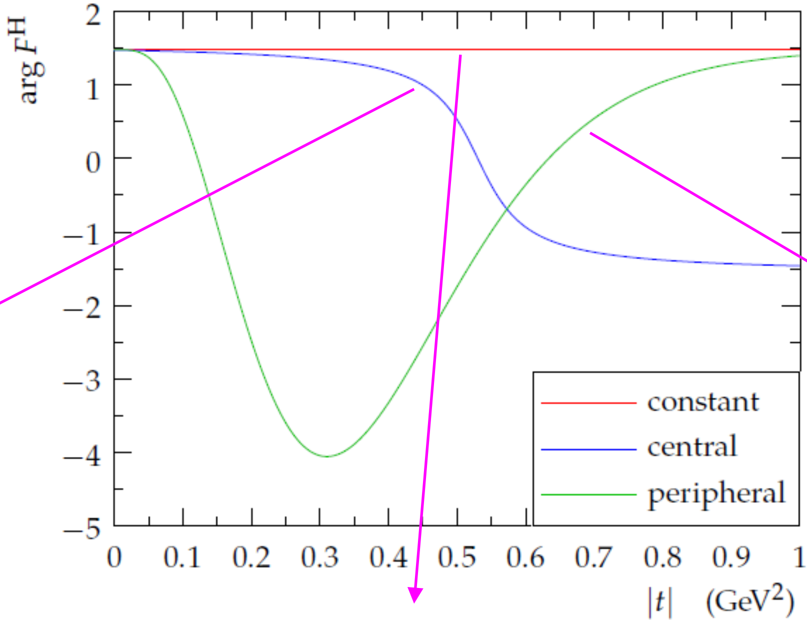
- constant slope $B(t) = b_0$ → already excluded by 90m data at higher |t| → SWY incompatible with data !
- constant hadronic phase $\arg(F^H) = p_0$
- $\Psi(t)$ acts as real interference phase

Kundrát-Lokajíček (KL) formula:

- any slope $B(t)$
- any hadronic phase $\arg(F^H)$
- complex $\Psi(t)$!

Elastic Scattering in the Coulomb-Nuclear Interference Region

Different options for the unknown nuclear phase:



"central phase":
profile function in impact parameter picture:
Elastic scattering preferentially central

$$\arg F(t) = \frac{\pi}{2} - \operatorname{atan}\frac{\cot p_0}{1 - \frac{t}{t_d}}$$

constant phase:
also central behaviour

$$\arg F(t) = p_0$$

"peripheral phase":
profile function in impact parameter picture:
Elastic scattering preferentially peripheral

$$\arg F(t) = p_0 + \zeta_1 \left|\frac{t}{t_0}\right|^{\kappa} \exp(\nu t), \quad t_0 = 1\,\mathrm{GeV}^2$$

Result for $\rho = \frac{\Re F^H(0)}{\Im F^H(0)} = \cot \arg F^H(0) = \cot p_0$ is model dependent

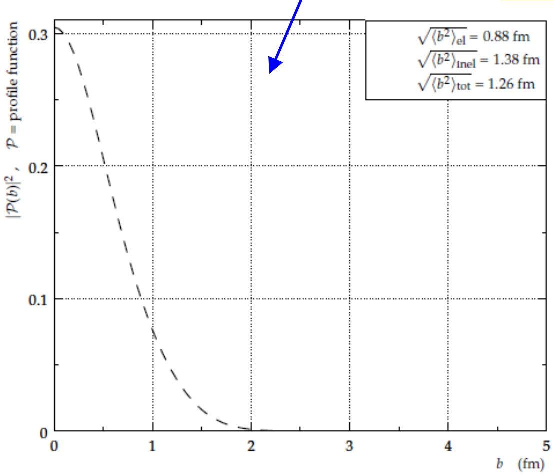
New: Joint analysis of data at very low |t| (β*=1000m) and higher |t| (β*=90m) scrutinising the effects of the choices for B(t) and phase model.

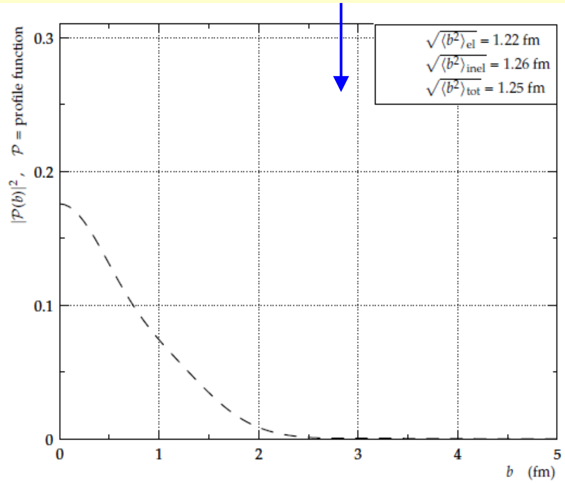
Analysis of the CNI Region

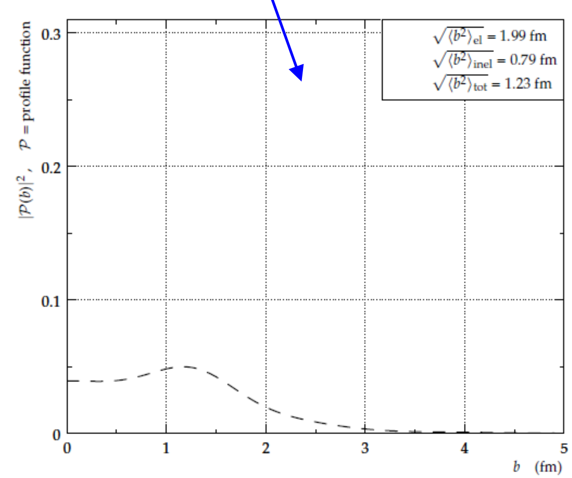
Fit models retained for final analysis:

Hadronic Slope	Constant Phase (representative for all central phases)	Peripheral Phase with bounded shape parameters (KL model $\pm$ 3σ) $\zeta_1 = 800$ $\kappa = 2.311 \pm 0.399$ $\nu = 8.161 \pm 0.390$	Peripheral Phase with fixed shape parameters (KL model) $\zeta_1 = 800$ $\kappa = 2.311$ $\nu = 8.161$ GeV^{-2}
$N_B = 1$ (pure exponential)	excluded	disfavoured	disfavoured
$N_B = 3$ (parabolic exp. slope)	possible	possible	possible

Impact parameter picture: profile functions







Analysis of the CNI Region

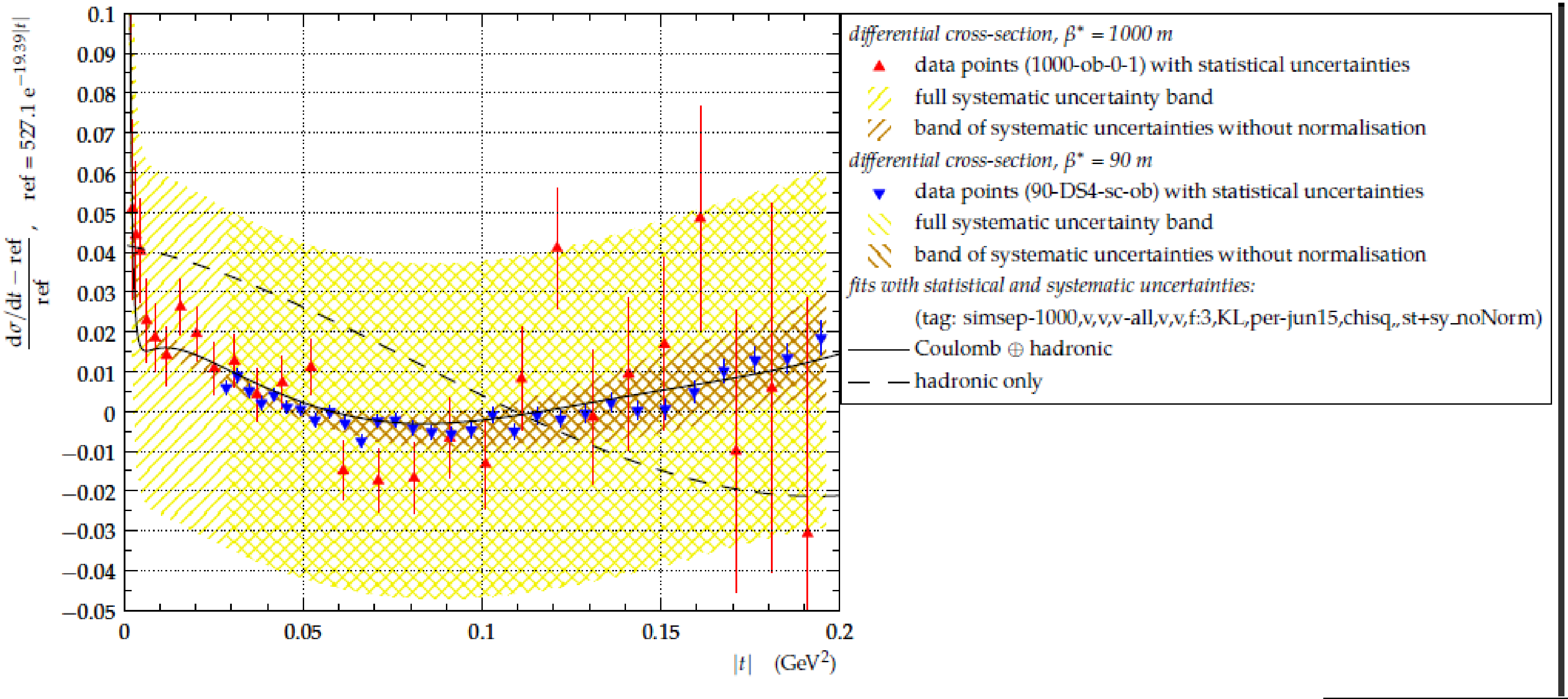
Best fit method retained: 2-stage fit:

Fit 1: only β*=1000m data (very low |t|): all parameters free → determines ρ

Fit 2: combined β*=1000m and 90m data with fixed ρ

Results coming soon

Example: Parabolic exp. slope, peripheral phase with fixed shape



Skipped:

Inelastic and Total pp Cross-Section Measurements

7 TeV

8 TeV

First measurements of the total proton-proton cross section at the LHC energy of $\sqrt{s}$ = 7TeV
[EPL 96 (2011) 21002]

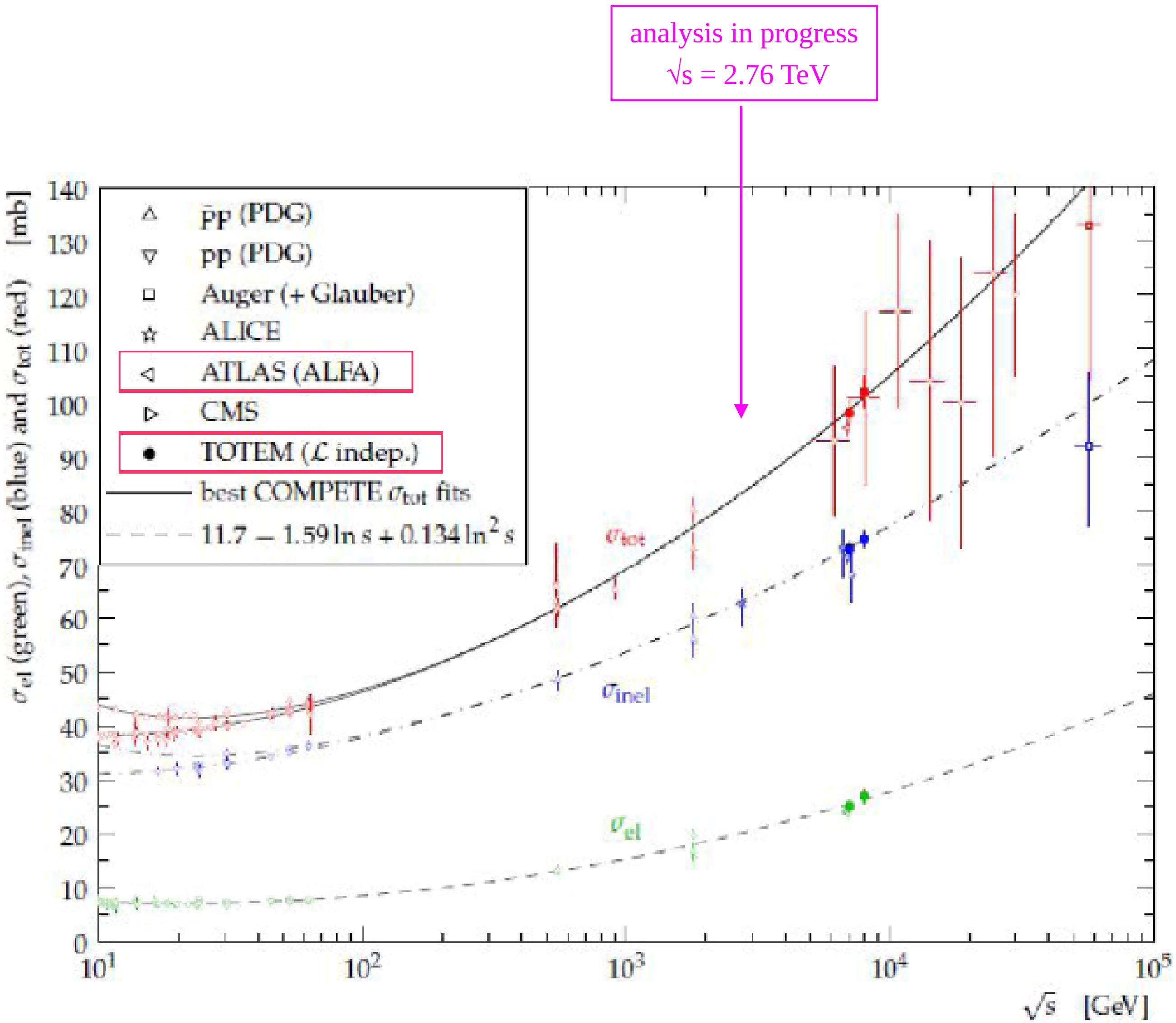
Measurement of proton-proton elastic scattering and total cross-section at $\sqrt{s}$ = 7 TeV
[EPL 101 (2013) 21002]

Measurement of proton-proton inelastic scattering cross-section at $\sqrt{s}$ = 7 TeV
[EPL 101 (2013) 21003]

Luminosity-independent measurements of total, elastic and inelastic cross-sections at $\sqrt{s}$ = 7 TeV
[EPL 101 (2013) 21004]

A luminosity-independent measurement of the proton-proton total cross-section at $\sqrt{s}$ = 8 TeV
[Phys. Rev. Lett. 111, 012001 (2013)]

pp Cross-Section Measurements

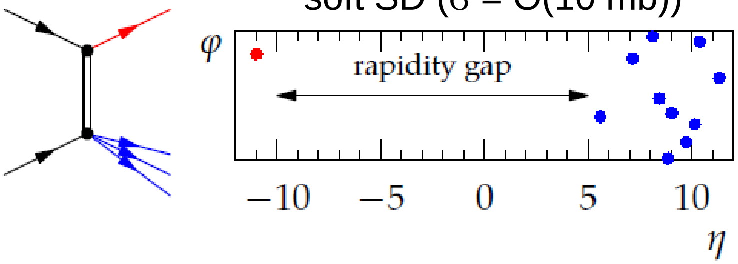


Diffractive Processes:
Standalone and Common Runs with CMS

- Overview -

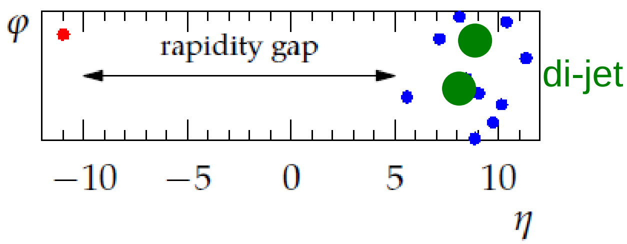
Single Diffraction

soft SD (σ = O(10 mb))



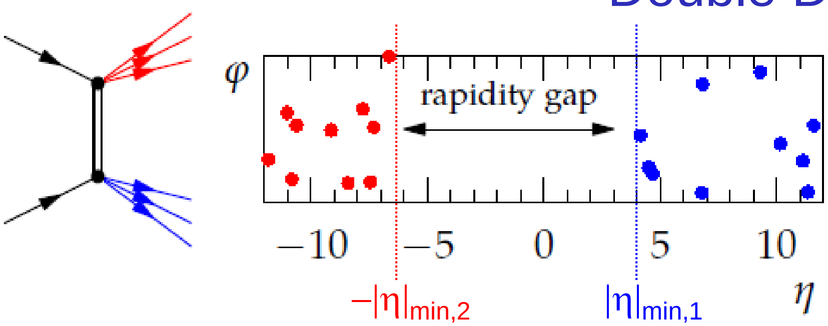
analysis in progress (7 and 8 TeV)

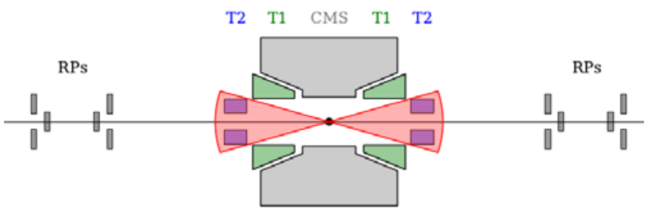
hard SD (e.g. dijet: σ ~ O(10 nb))



analysis in progress with CMS
(also SD J/Ψ production)

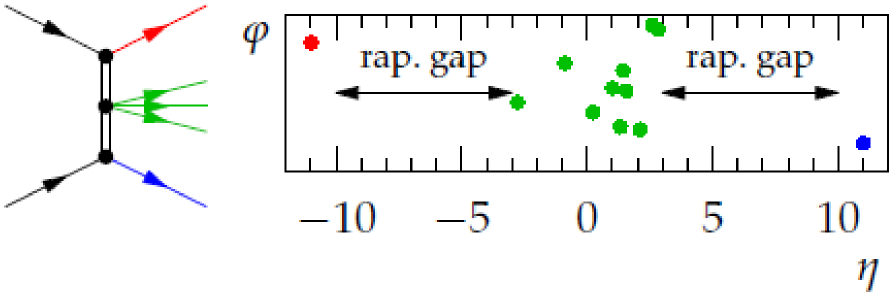
Double Diffraction





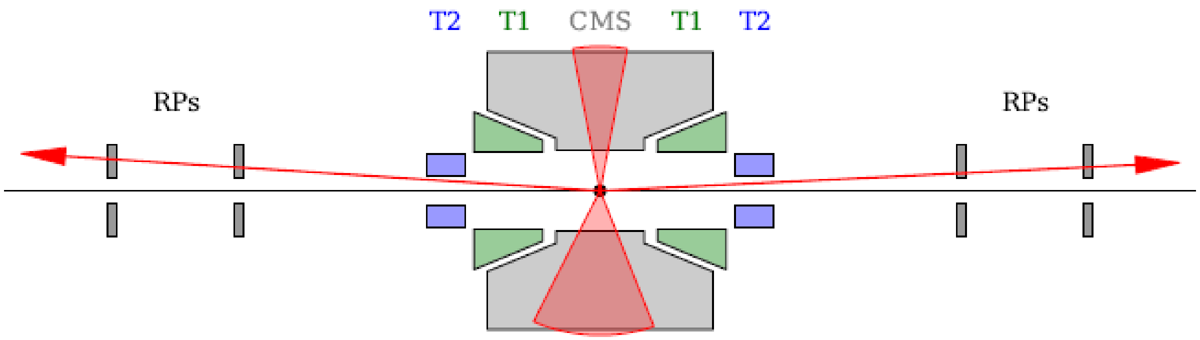
[Phys. Rev. Lett. 111 (2013) 262001]

Central Diffraction ("Double Pomeron Exchange")



- both protons survive with momentum losses ξ_1, ξ_2
- diffractive mass M in the centre
- 2 rapidity gaps $\Delta\eta_1$, $\Delta\eta_2$

soft (inclusive) CD: σ ~1 mb



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

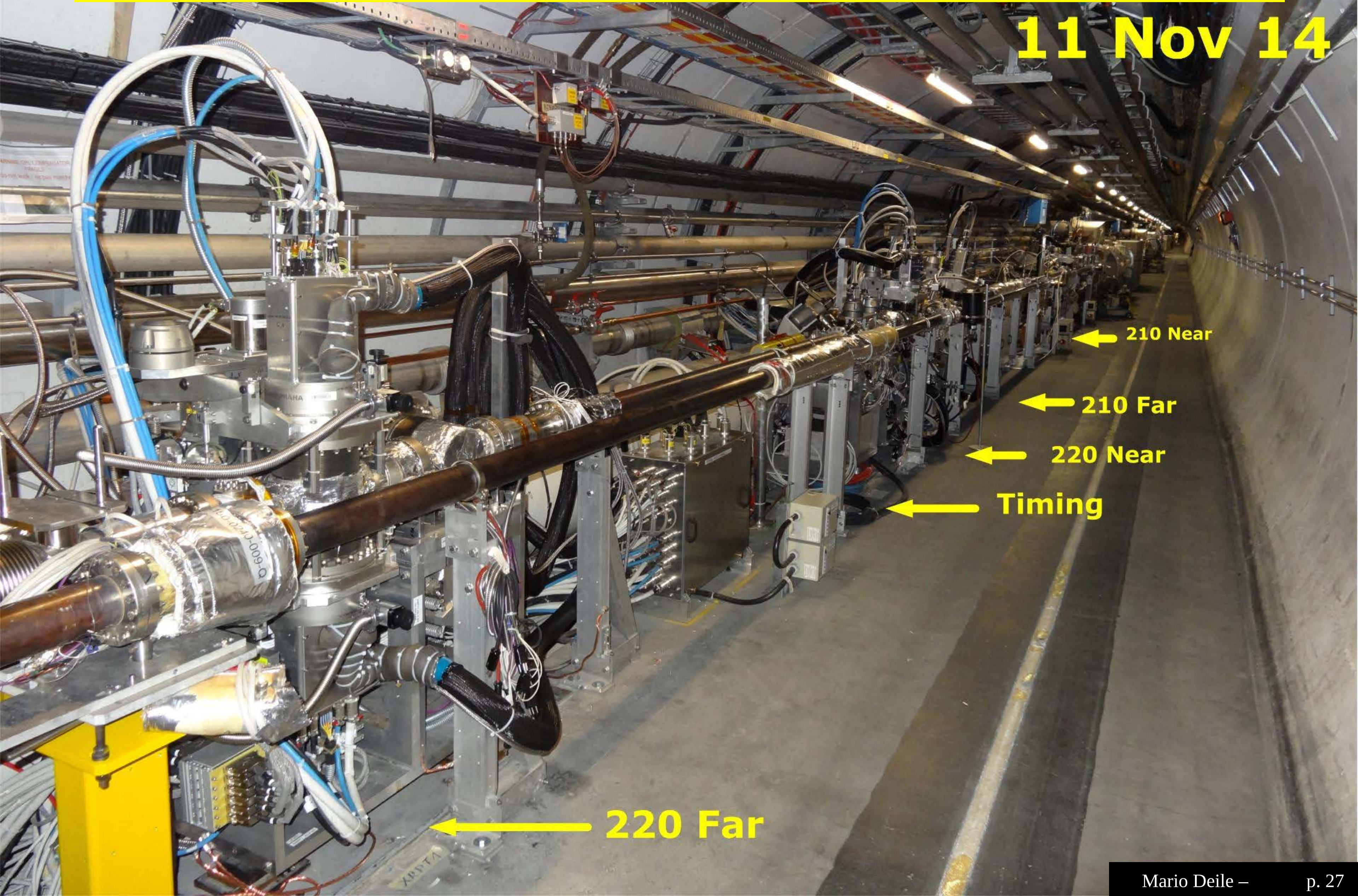
↓

Joint data taking CMS + TOTEM:

kinematic redundancy between protons and central diffractive system

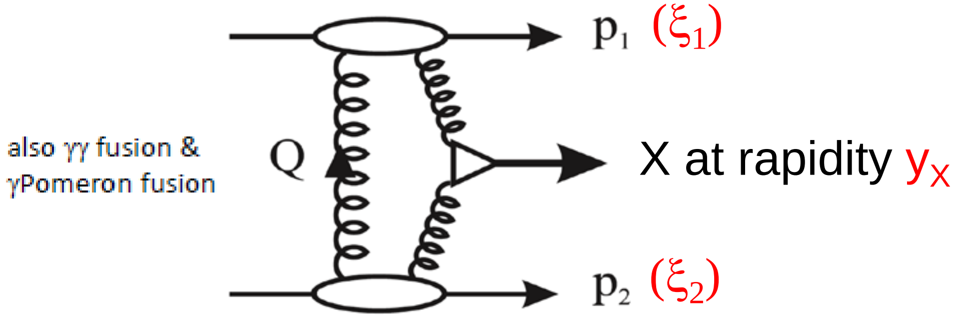
$M_{CMS} = M_{TOTEM}(pp)$?

Perspectives for Run 2



Central Production (with CMS)

Central Exclusive Particle or Dijet Production:



$M_X^2 = \xi_1 \xi_2 s$

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

- Exchange of colour singlets with vacuum quantum numbers
  → selection rules for system X: $J^{PC} = 0^{++}, 2^{++}, \ldots$

- Tagging with double-arm proton detection:
  mass reach and luminosity depending on optics

- Event selection via comparison of central system with proton kinematics:
  M(pp) =? M(central), $p_{T,z}$(pp) =? $p_{T,z}$(central), vertex(pp) =? vertex(central)

- Prediction of rapidity gap from proton ξ: $\Delta\eta_{1,2} = -\ln \xi_{1,2}$

Examples:

- Exclusive dijets: mainly gg (CMS+TOTEM selection, $p^T > 30$GeV: $\sigma_{gg} \sim 100$ pb)
- Studies of glueball candidates
- Exclusive $\chi_{c1,2,3}$ and J/Ψ production: O(10 pb – 10 nb)
- Search for missing mass signals of O(pb) → SUSY searches

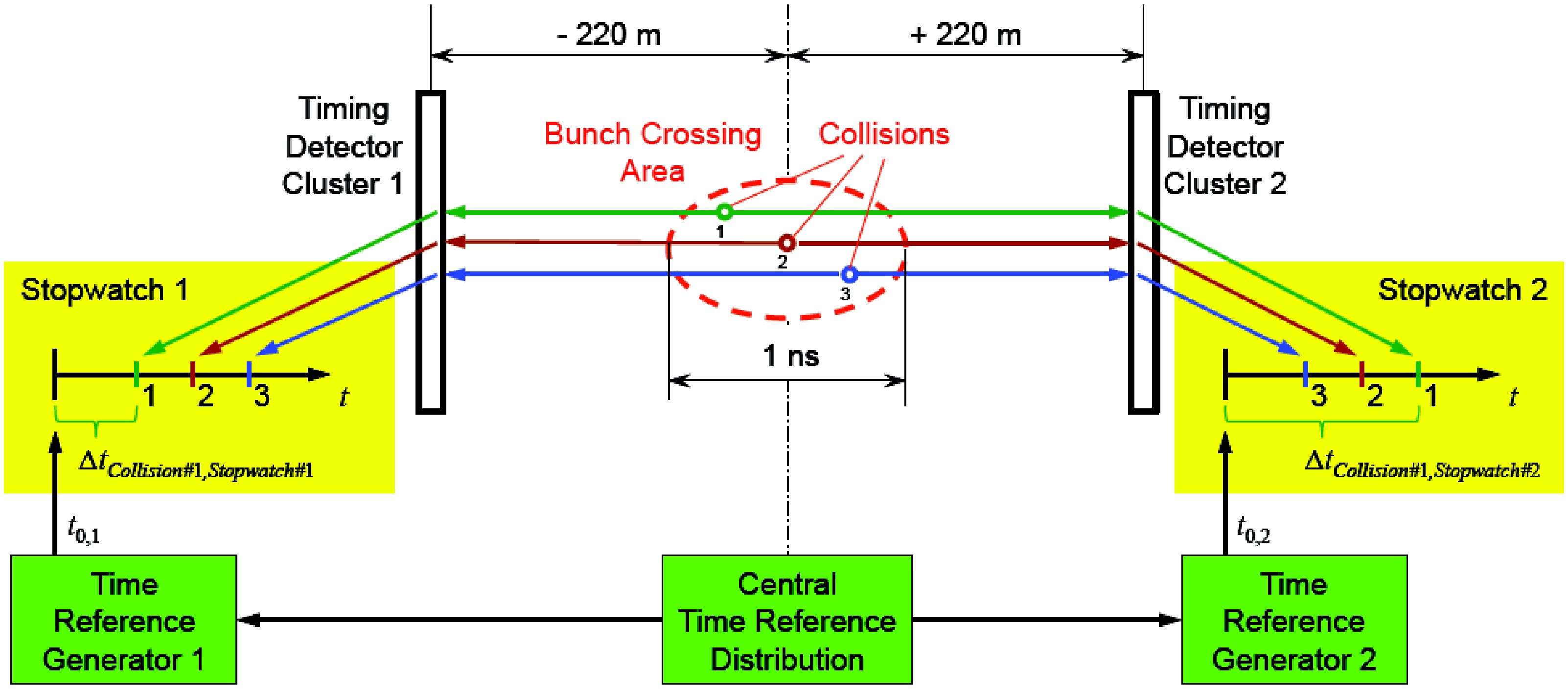
Longitudinal Vertex Reconstruction by Time Measurement

Pileup problem:

High luminosity → multiple events in 1 bunch collision !

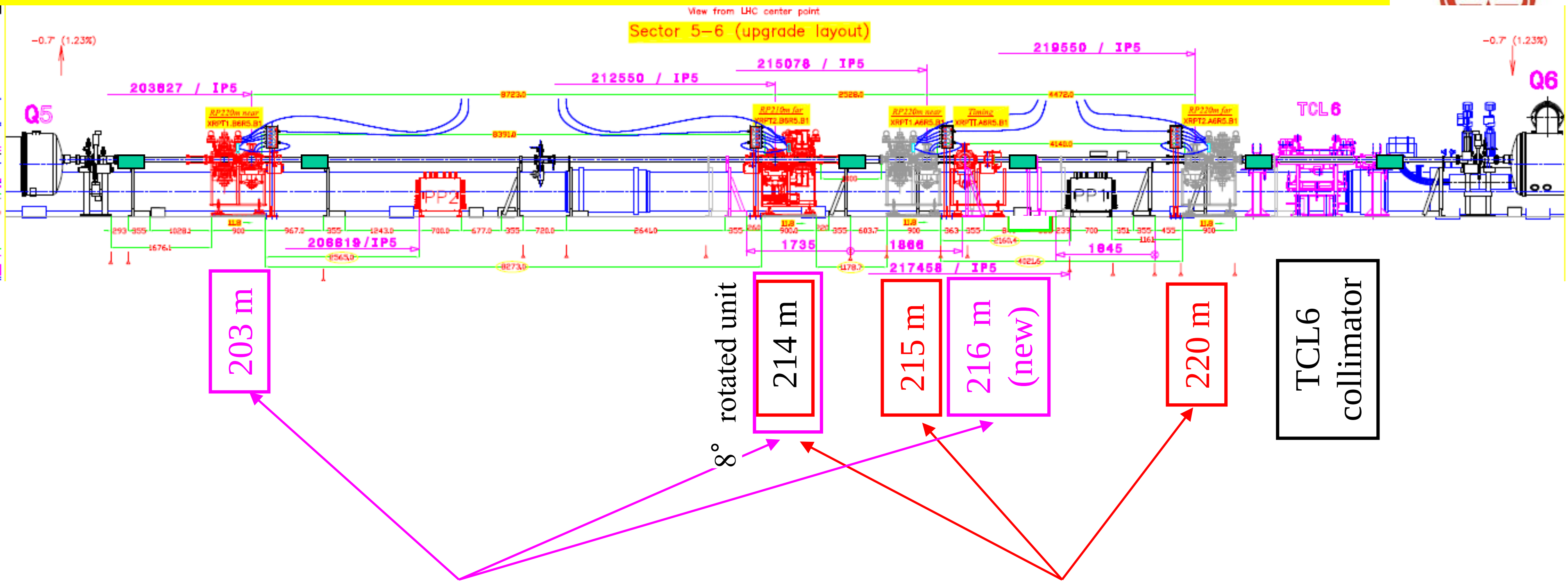
- CMS tracker can separate multiple vertices longitudinally,
- leading proton tracks have angles in μrad range → insufficient vertex precision

→ for double-arm events (CD) reconstruct vertex from time-of-flight difference



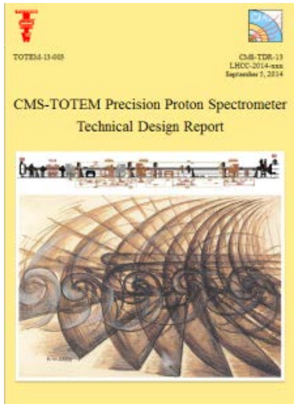
$$\text{Position of Collision 1} \sim \Delta t_{Collision\#1,Stopwatch\#1} - \Delta t_{Collision\#1,Stopwatch\#2}$$

Two Upgrade Projects



Operation at low β* (< 1 m),
high luminosity (fb^{-1}/day), standard runs
diffractive masses > 250 GeV

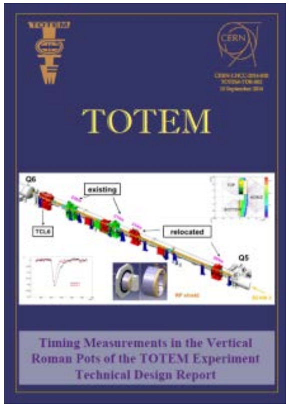
Operation at high β* (19 m, 90 m, > 1 km),
Low - medium lumi. (< 6 pb^{-1}/day), special runs
all diffractive masses



CMS-TOTEM Precision Proton Spectrometer (CT-PPS)

separate project, not covered here

Cherenkov timing detectors in new horizontal Roman Pots



Timing Measurements in the Vertical Roman Pots of the TOTEM Experiment

Thin diamond timing det. in old vertical Roman Pots

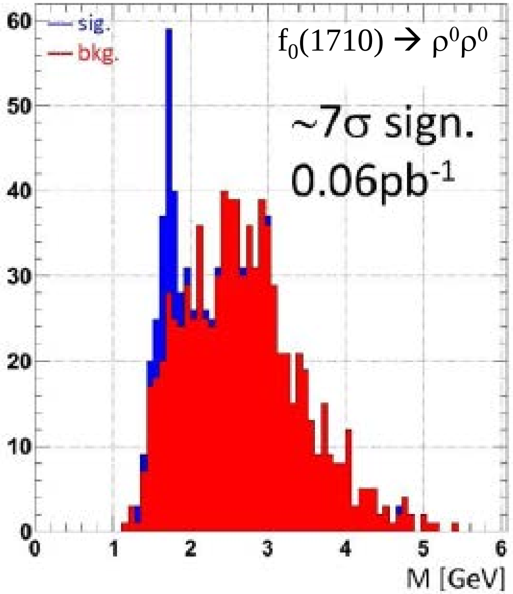
Glueball Studies at $\beta^* = 90$m

Pomeron ~ colourless gluon pair/ladder → Pomeron fusion likely to produce glueballs
CD: $x \sim 10^{-3}$ – 10^{-4} gluons → pure gluon pair gives $M_X \sim 1 – 4$ GeV
Candidates for 0^{++} glueball: $f_0(1500)$ or $f_0(1710)$: the other one belongs to the $1\,^3P_0$ meson nonett

Decays and branching ratios of $f_0(1710)$ poorly explored (unlike $f_0(1500)$)
→ Goal: characterise $f_0(1710)$ and compare with known $f_0(1500)$

CMS+TOTEM data from 2012: ($\mathcal{L} = 3\ \text{nb}^{-1}$ of double arm RP trigger) may show sensitivity to
$f_0(1710) \to \rho^0\rho^0 \to 4\pi$ (channel not yet reported in PDG)
using CMS particle ID (dE/dx) and $\sigma(M) \sim 20 – 30$ MeV
[common analysis note in progress]

Simulation of signal and non-resonant $\rho^0\rho^0$ background [DIME MC] with CMS tracker performance:



No candidate for $f_0(1710) \to K^+K^-$ in available data
→ allow for factor 10 in range of branching ratios
→ need 0.6 pb^{-1} for decay characterisation

Glueball Studies at $\beta^* = 90$m

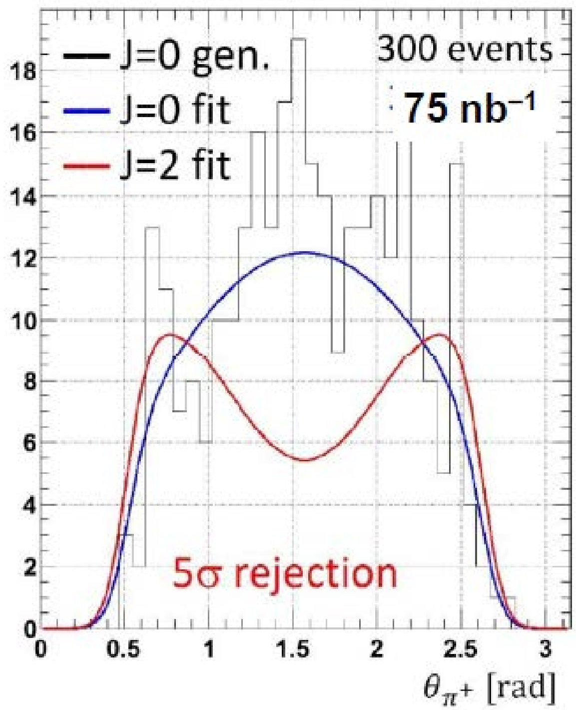
Spin analysis of $f_0(1710) \rightarrow \rho^0\rho^0 \rightarrow 4\pi$ to determine J=0 or 2:

- Angular correlations between leading protons
- Distribution of polar angles $\theta_{\pi+}$ of $\pi^+\pi^-$ pairs
- Distribution of polar and azimuthal angle differences between the 2 $\pi^+\pi^-$ pairs

Example:

polar angle $\theta_{\pi+}$ of the $\pi^+\pi^-$ pair with the ρ candidate at $\eta > 0$ (signal only)

$f_0(1710) \rightarrow \rho^0\rho^0$



Distinction from neighbouring resonances and non-resonant background:
spin analysis in mass bins < 40 MeV → needs ~ 5 pb^{-1}

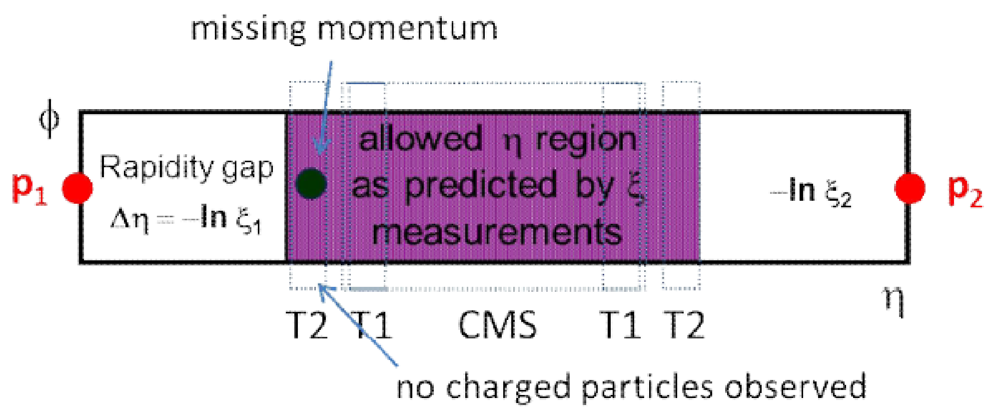
Missing mass & momentum events

new physics that escaped standard searches

(e.g. due to special Pomeron coupling)?

preliminary search for such events performed on existing data samples (0.05 pb^{-1}):

- several topologies investigated for violations of predicted rapidity gap (no signal found)



with $p_{central}$ (particle flow) ≠ p_{pp} & $M_{central}$ (particle flow + $p_{missing}$) ≤ M_{pp} events with $p_{missing}$ in the instrumented region (& requiring $|\eta| > 6.5$ to be forbidden by $\xi_{1,2}$ measurements)

- search for missing mass in $150 < M_{missing} < 600$ GeV at 13 TeV

  some candidates with missing mass up to 400 GeV found but

  limited statistics doesn't allow accurate modeling of background

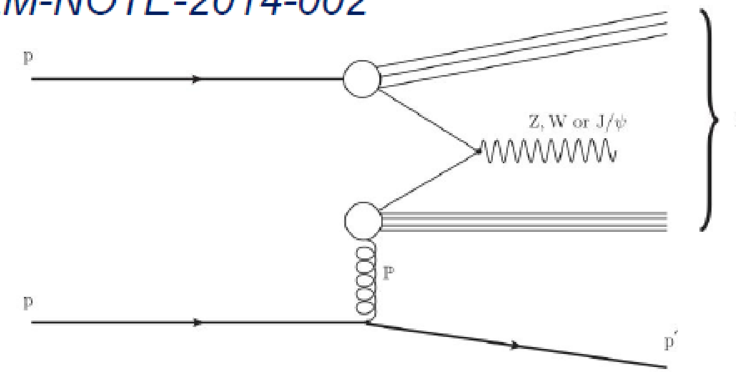
SD processes

Single diffractive processes: study rapidity gap survival probability

Triggered using CMS lepton & jet triggers

Visible σ estimate at $\sqrt{s}$ = 13 TeV (both proton + central object)

CMS PAS FSQ-14-001, TOTEM-NOTE-2014-002



- J/ψ production (POMPYT): $\mu^+\mu^-$
  $3.05 < M_{\mu\mu} < 3.15$ GeV,

5 pb^{-1}: 1540±45 events

- W production (POMWIG): $\mu^\pm/e^\pm$
  (p_T > 20 GeV), 60 < M_T < 110 GeV

5 pb^{-1}: 170±5 events

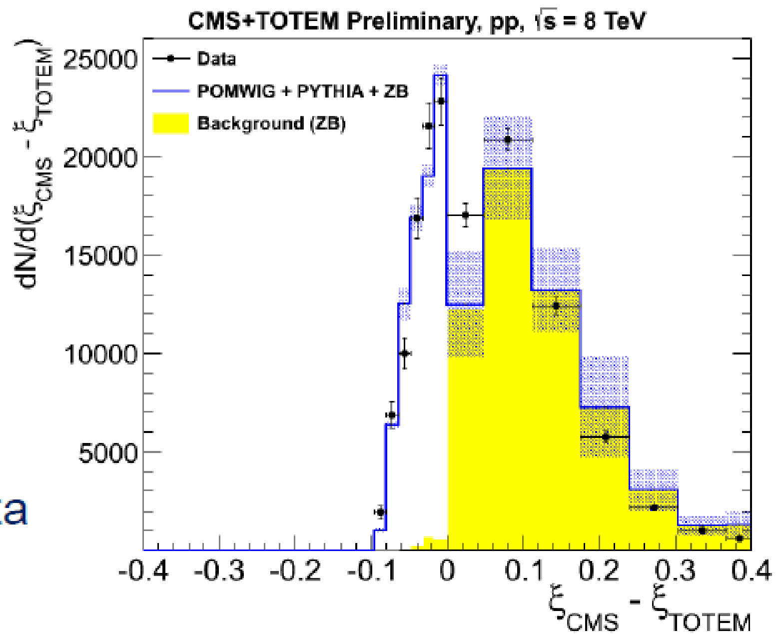
- Z production (POMWIG): $\mu^+\mu^-$ /e^+e^-,
  (p_T > 20 GeV), 60 < M_{ll} < 110 GeV

5 pb^{-1}: 15±1 events

- SD jet production: $p_{T,jet}$ > 30 GeV

5 pb^{-1}: O(100k) events

Background removal demonstrated on common CMS+TOTEM β* = 90 m data at $\sqrt{s}$ = 8 TeV (SD dijets)



Outlook

2015:

•Next week: Van der Meer run (β^*=19 m): medium pileup (μ = 0.4)
→ large |t| elastic, jets in single diff. and central diff.

•Dedicated run (~2 days) at β^*=90 m :
~1 pb^{-1} of data for low-mass central diffractive spectroscopy,
elastic and total cross-section at $\sqrt{s}$ = 13 TeV

•Ongoing: RP test insertions in normal low β^* fills for CT-PPS high-lumi operation

•Finalisation and installation of timing detectors:
- Diamond for timing in vertical pots (β^*=90 m)
- Quartz Cherenkov for timing in horizontal pots for CT-PPS (low β^*)

2016:

•Runs at β^*=90m and low β^* (CT-PPS project) for diffraction with timing detectors

•Runs at β^*~2500m for more studies of Coulomb-nuclear interference

The End

Appendix on Run 2

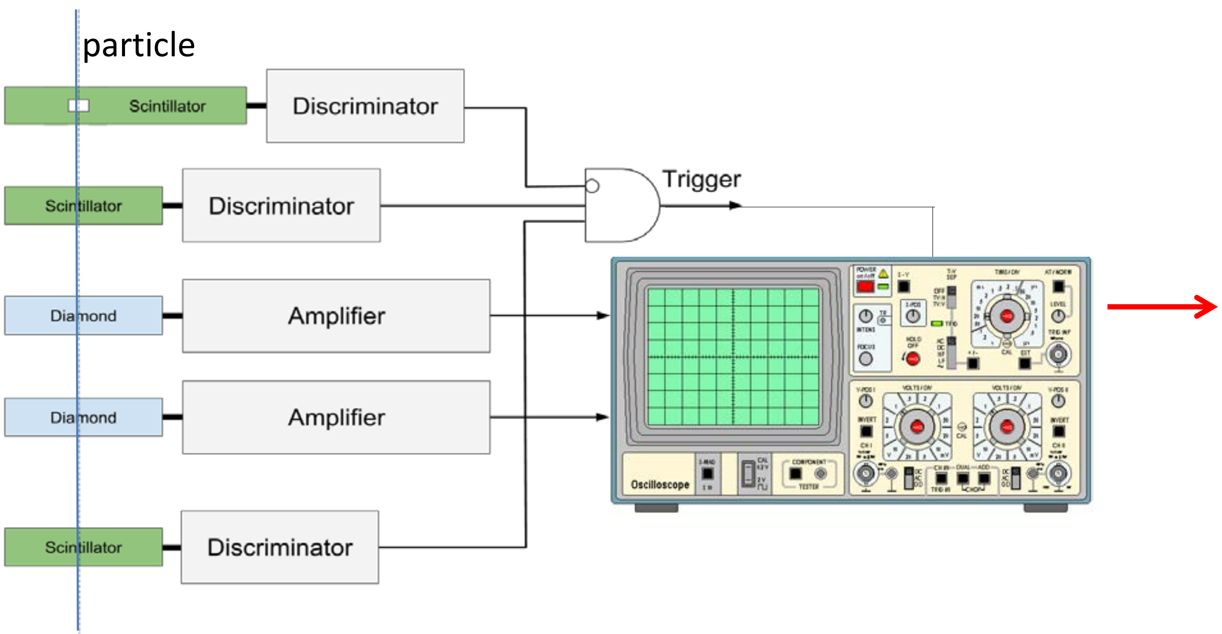
Timing Detector Development for Medium Pileup
(β^* = 90 m Runs)

Objective:

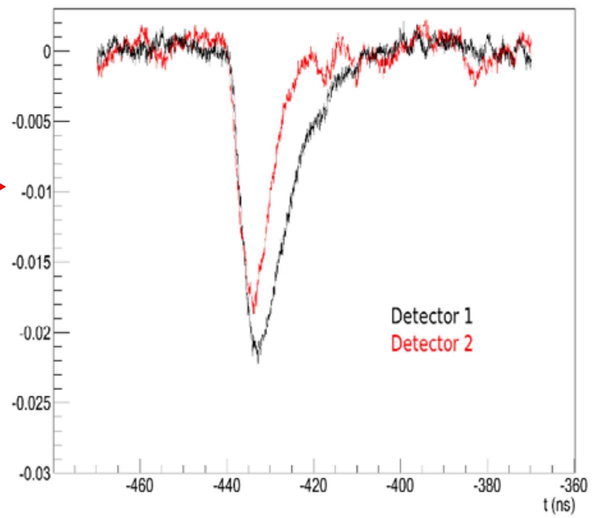
- 4 timing detectors per arm in vertical RPs
- Detector installation foreseen later in 2015
- 50 ps resolution per arm (100 ps per detector) enough since at 90m the pileup $\mu < 0.6$

Development of Diamond Detectors:

Test beams to characterise different detector and front-end configurations: at PS, SPS, DESY

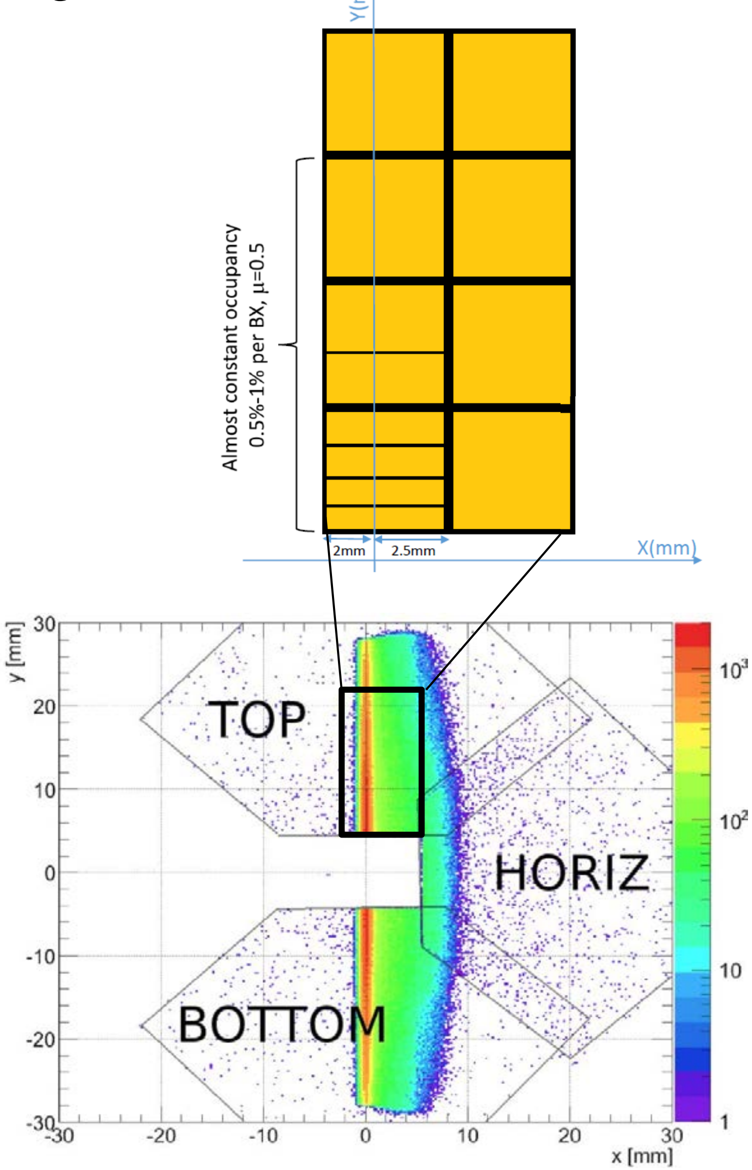


Offline waveform analysis



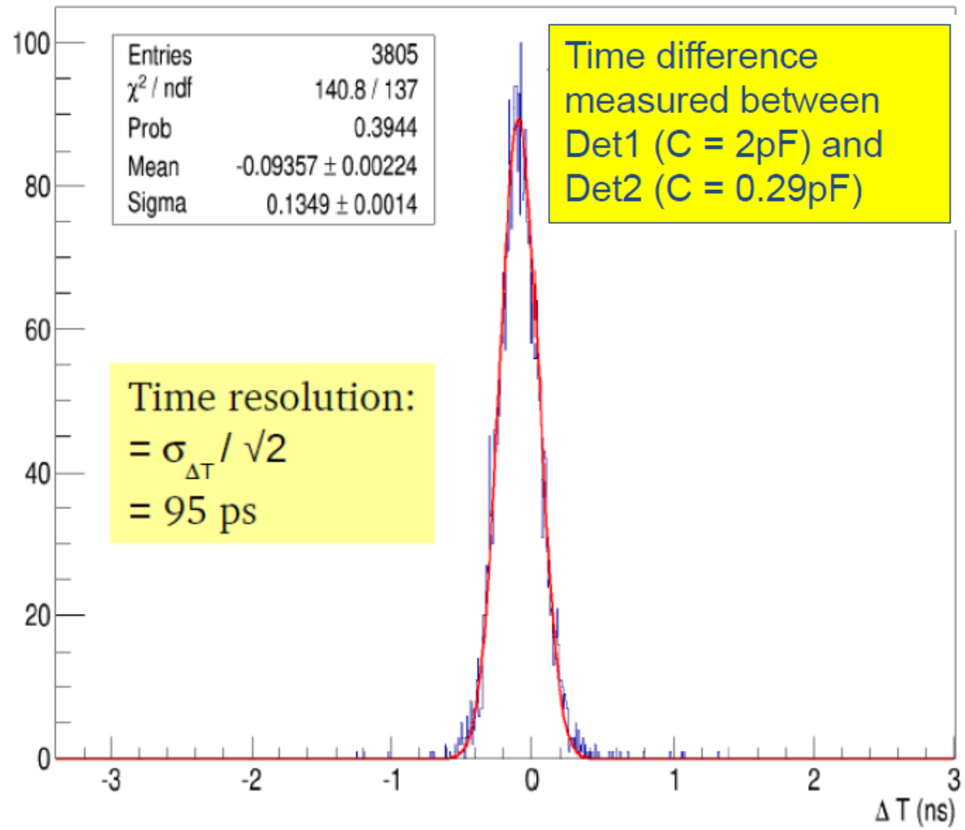
Diamond Detector Layout and Prototype Time Resolution

Segmentation follows the diffractive hit distribution.



Test Hybrid 1: 1 large pixel (C = 2 pF)

Test Hybrid 2: 4 small strip pixels (C = 0.29 – 0.6 pF)



Efficiency measured > 98%

Exclusive jet production

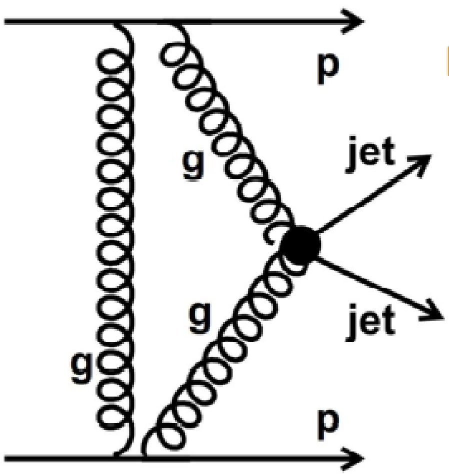
- $J_z = 0$ selection rule: $gg \rightarrow q\bar{q}, b\bar{b}$ suppressed by a factor 10^2-10^3
- unique possibility to observe enhanced gluon jets at LHC

  $\Rightarrow$ 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 & 3-jet topologies

  Durham model: $gg \rightarrow gq\bar{q}$ (more Mercedes-like) & $gg \rightarrow ggg$ (more "back-to-back").



Durham model predictions for CMS-TOTEM selection:

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

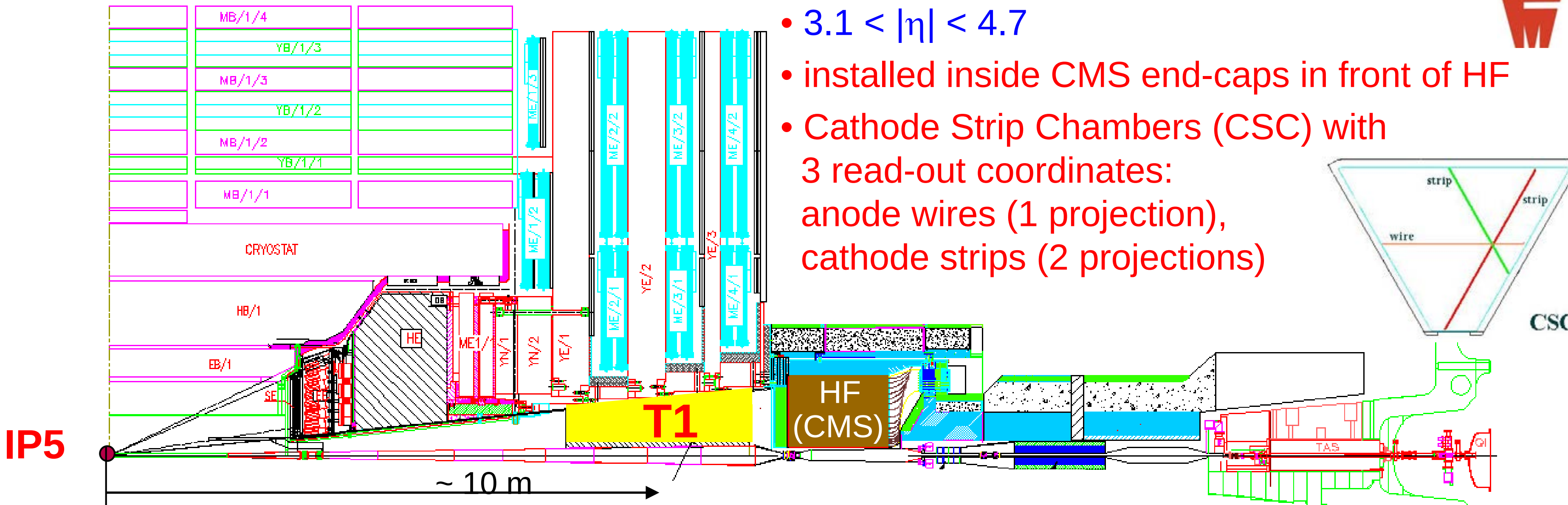
L.Harland-Lang at LHC Working Group on Forward Physics and Diffraction, Trento'14

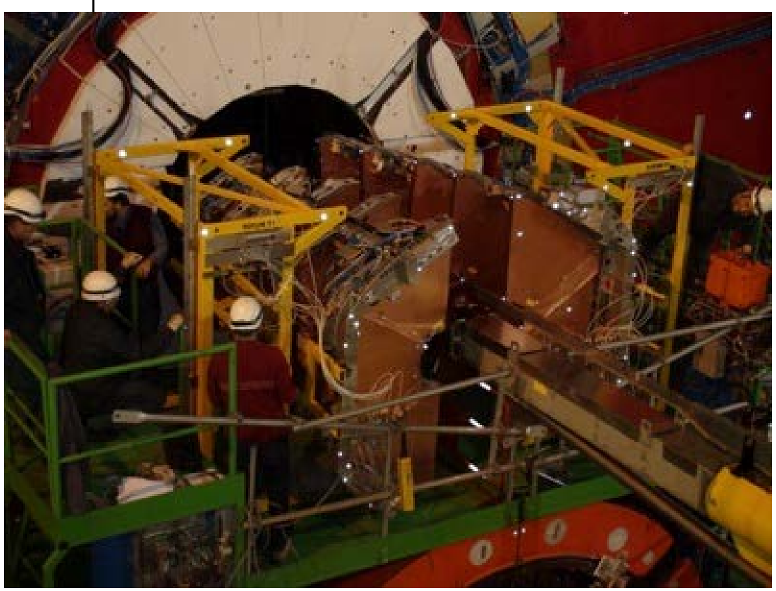
Key: jet trigger threshold & cleaness

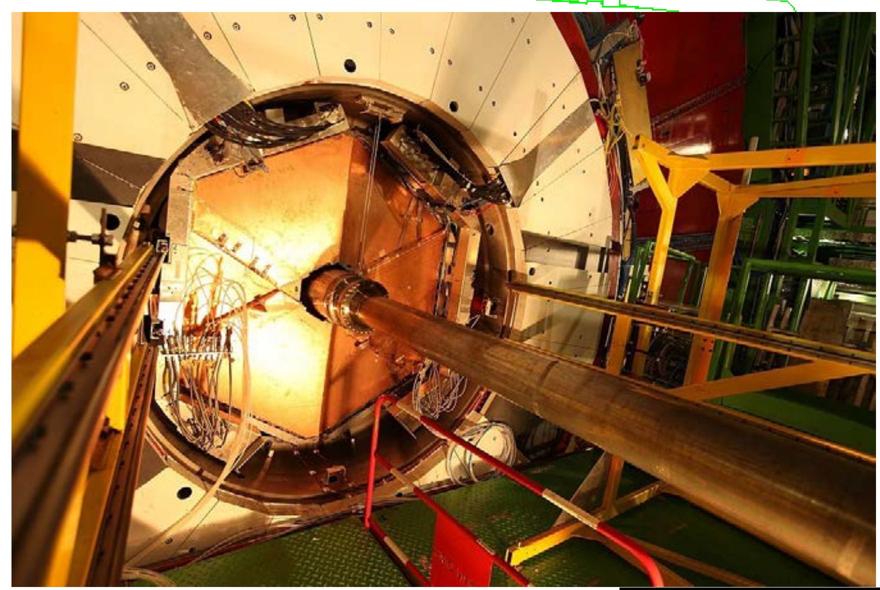
Backup

Experimental Setup: T1

- telescope of 5 planes on each side of IP5
- 3.1 < |η| < 4.7
- installed inside CMS end-caps in front of HF
- Cathode Strip Chambers (CSC) with 3 read-out coordinates: anode wires (1 projection), cathode strips (2 projections)

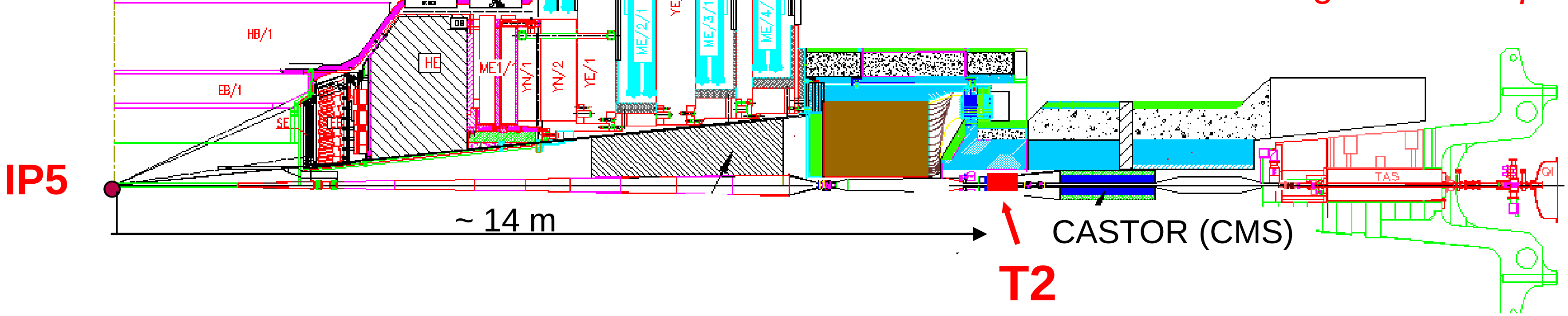


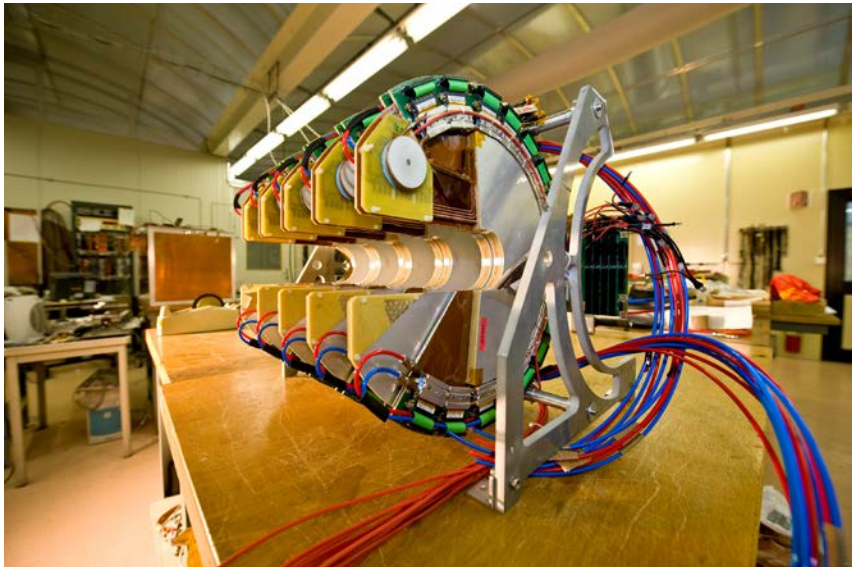


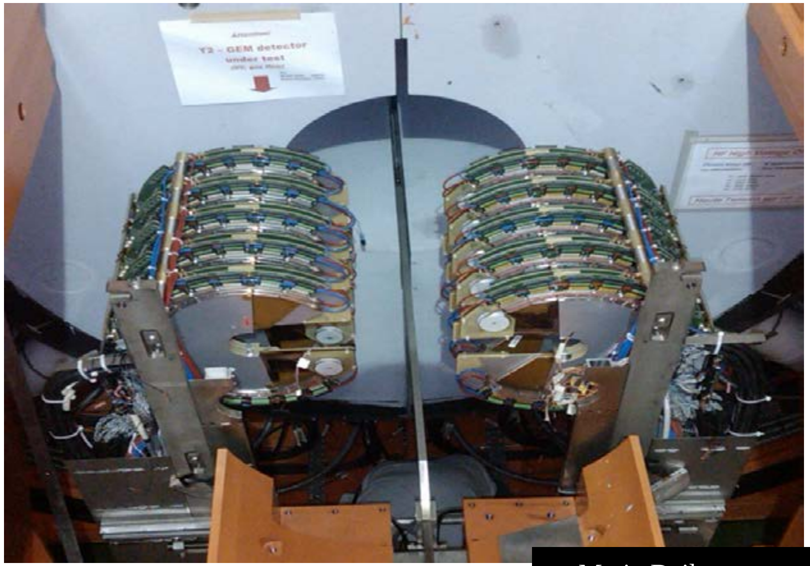


Experimental Setup: T2

- telescope of 10 planes on each side of IP5
- 5.3 < |η| < 6.5
- installed inside CMS shield between HF & Castor
- Gas Electron Multipliers (GEM):
  radial segmentation: *concentric strips*
  coarse radial & azimuthal segmentation: *pads*







From the Elastic to the Total Cross-Section

Optical Theorem: $\sigma_{tot}^2 \propto \left[\Im F_{el,\,had}(t=0)\right]^2 = \frac{1}{1+\rho^2}\left|F_{el,\,had}(t=0)\right|^2$ with $\rho = \left.\frac{\Re F_{el,\,had}}{\Im F_{el,\,had}}\right|_{t=0}$

$$\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2}\left.\frac{d\sigma_{el}}{dt}\right|_{t=0}$$

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.])

June 2011 (EPL96): $\sigma_{tot} = (98.3 \pm 2.8)$ mb

Oct. 2011 (EPL101): $\sigma_{tot} = (98.6 \pm 2.2)$ mb

different beam intensities !

σ_{tot}

ρ independent:

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

$\sigma_{tot} = (99.1 \pm 4.3)$ mb

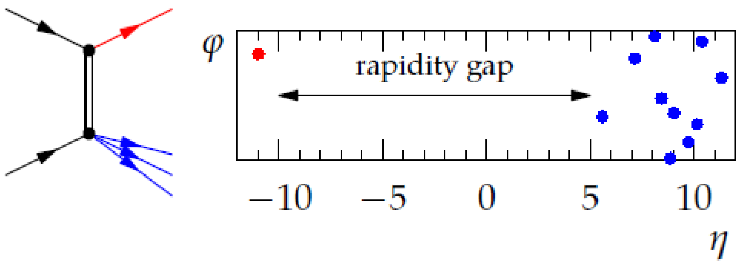
luminosity independent:

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

$\sigma_{tot} = (98.0 \pm 2.5)$ mb

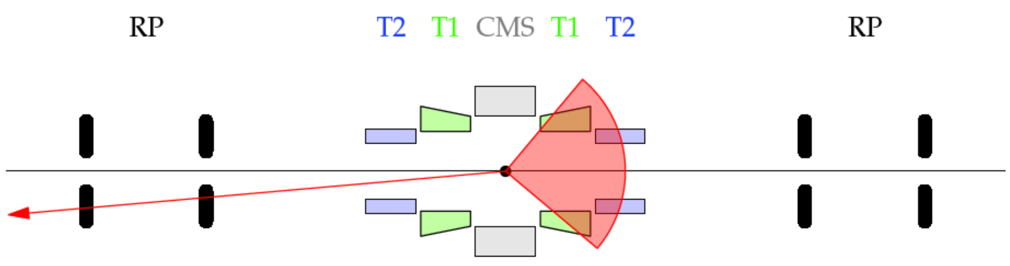
Excellent agreement between cross-section measurements at 7 TeV using
- runs with different beam intensities,
- different methods with different external inputs.

Soft Single Diffraction (SD)



- 1 proton breaks up → diffractive mass M
- 1 proton survives with momentum loss ξ
- rapidity gap $\Delta\eta$ between proton and M

$$\Delta\eta = -\ln\xi, \quad M^2 = \xi s$$



Trigger on T2, require 1 proton

2 ways for measuring ξ:

1. via the proton trajectory (RP): $x_{RP} = L_x \Theta_x^* + v_x x^* + D_x \xi$

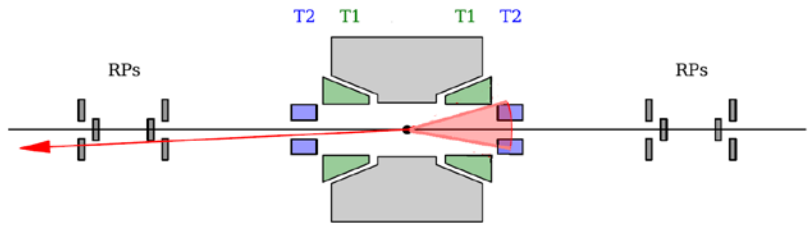
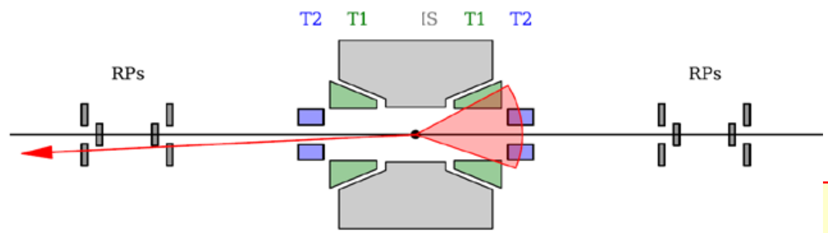
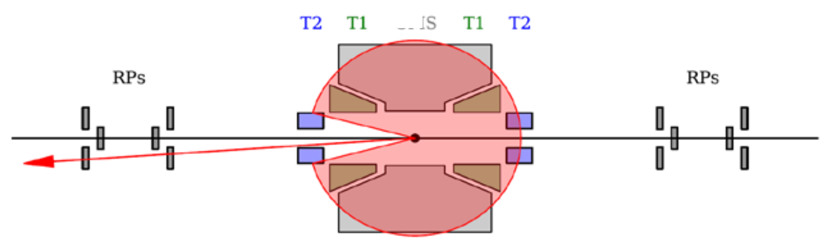
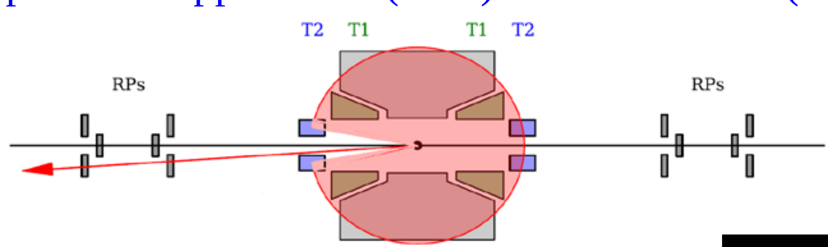
resolution at β^*=90m:
$\delta\xi \sim 0.004 - 0.01$
(dependent on t, ξ)

2. via the rapidity gap (T1, T2)
Note: $\eta_{max,T2} = 6.5 \quad \Leftrightarrow \quad M_{min} = 3.4$ GeV

$\delta\xi \sim \xi$

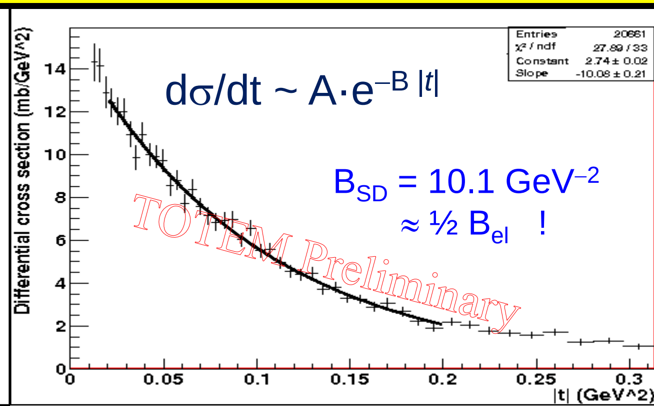
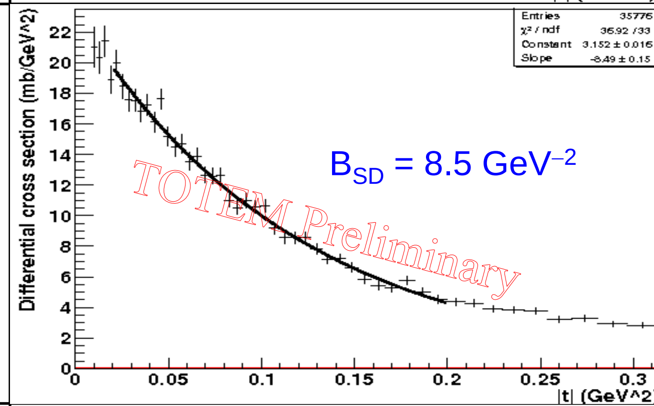
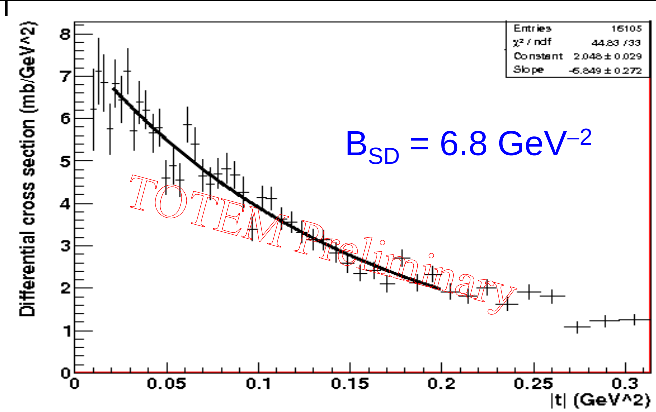
Full differential cross-section: $$\frac{d^2\sigma}{d\xi\, dt}$$

SD Topologies for Different Mass Ranges

M = 3.4 – 7 GeV	$2 \times 10^{-7} < \xi < 1 \times 10^{-6}$	proton & opposite T2 
M = 7 – 350 GeV	$1 \times 10^{-6} < \xi < 2.5 \times 10^{-3}$	proton & opposite T1 + T2 
M = 0.35 – 1.1 TeV	$2.5 \times 10^{-3} < \xi < 2.5 \times 10^{-2}$	proton & opposite T2 (+ T1) & same side T1 
M > 1.1 TeV	$\xi > 2.5 \times 10^{-2}$	proton & opposite T2 (+ T1) & same side T2 (+ T1) 

$$\Delta\eta = -\ln\frac{M^2}{s}$$

SD for Different Mass Ranges (7 TeV Data)

<table>
<tr><td>M =
3.4 – 7 GeV</td><td>$2 \times 10^{-7} < \xi < 1 \times 10^{-6}$</td><td>
</td></tr>
<tr><td>M =
7 – 350 GeV</td><td>$1 \times 10^{-6} < \xi < 2.5 \times 10^{-3}$</td><td>
</td></tr>
<tr><td>M =
0.35 – 1.1 TeV</td><td>$2.5 \times 10^{-3} < \xi < 2.5 \times 10^{-2}$</td><td>
</td></tr>
<tr><td>M > 1.1 TeV</td><td>$\xi > 2.5 \times 10^{-2}$</td><td>in progress</td></tr>
</table>

Work in progress !
Some corrections
still missing !

estimated uncertainty:
$\delta B/B \sim 15\ \%$