The TOTEM experiment at LHC for proton-proton cross section measurements.

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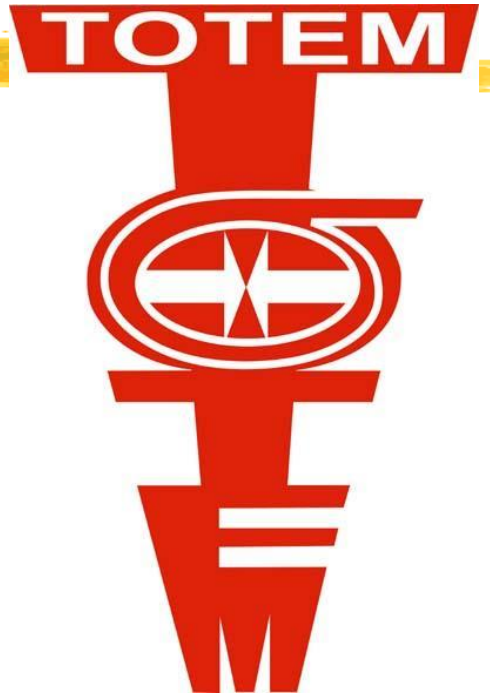
On behalf of TOTEM Collaboration



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TOTEM Physics goals

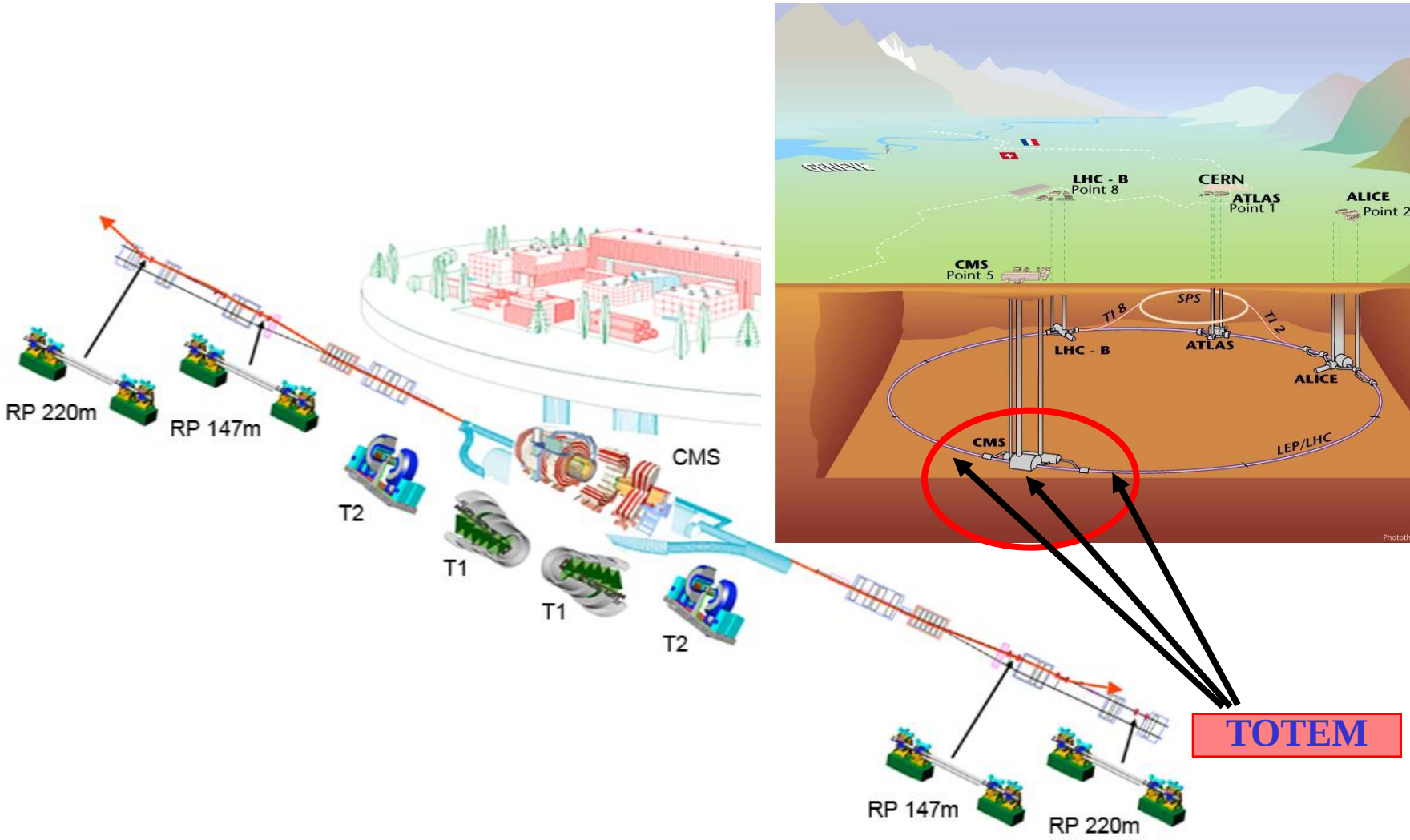
- TOTEM (TOTal cross section, Elastic scattering and diffraction dissociation Measurement at the LHC)
  - σ_{TOT}^{pp} with a precision ~ 1-2%, luminosity independent method (optical theorem) simultaneously measuring:
    - N_{el} down to -t ~10^{-3} GeV^2
    - N_{inel} with losses < 3%

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

$$\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2}\frac{d\sigma_{el}}{dt}|_{t=0}, \quad \sigma_{inel} = \sigma_{tot} - \sigma_{el}.$$

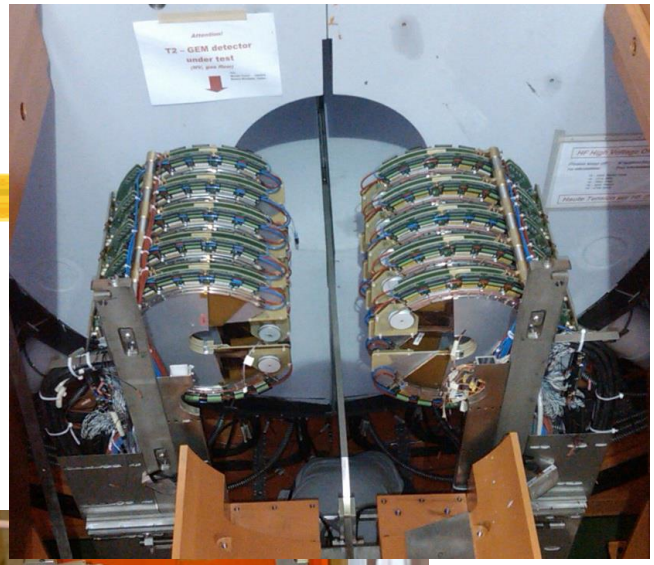
  - Elastic pp scattering in the range $10^{-3} < |t| \sim (p\theta)^2 < 10$ GeV^2
  - Soft diffraction (SD and DPE)
  - Particle flow in the forward region (cosmic ray MC validation/tuning)
- TOTEM & CMS
  - Soft and hard diffraction in SD and DPE (production of jets, bosons, h.f.)
  - Central exclusive particle production
  - Low-x physics
  - Particle and energy flow in the forward region

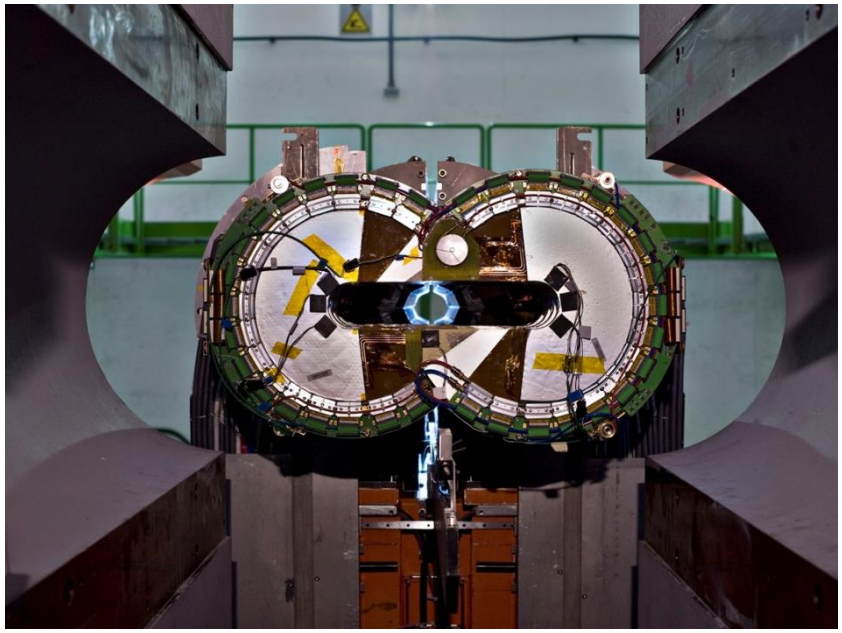
TOTEM Experiment LHC Run I



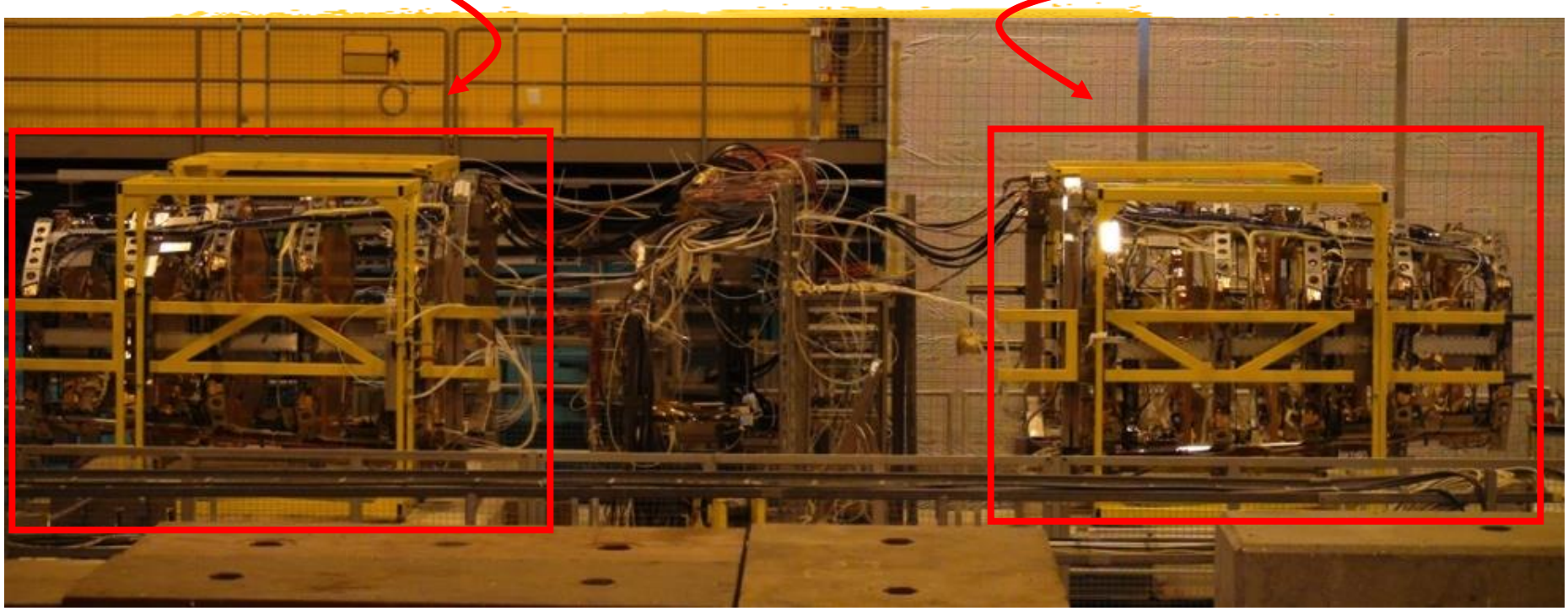
T2 Detector

- T2 telescope is based on GEM chambers.





T1 detector



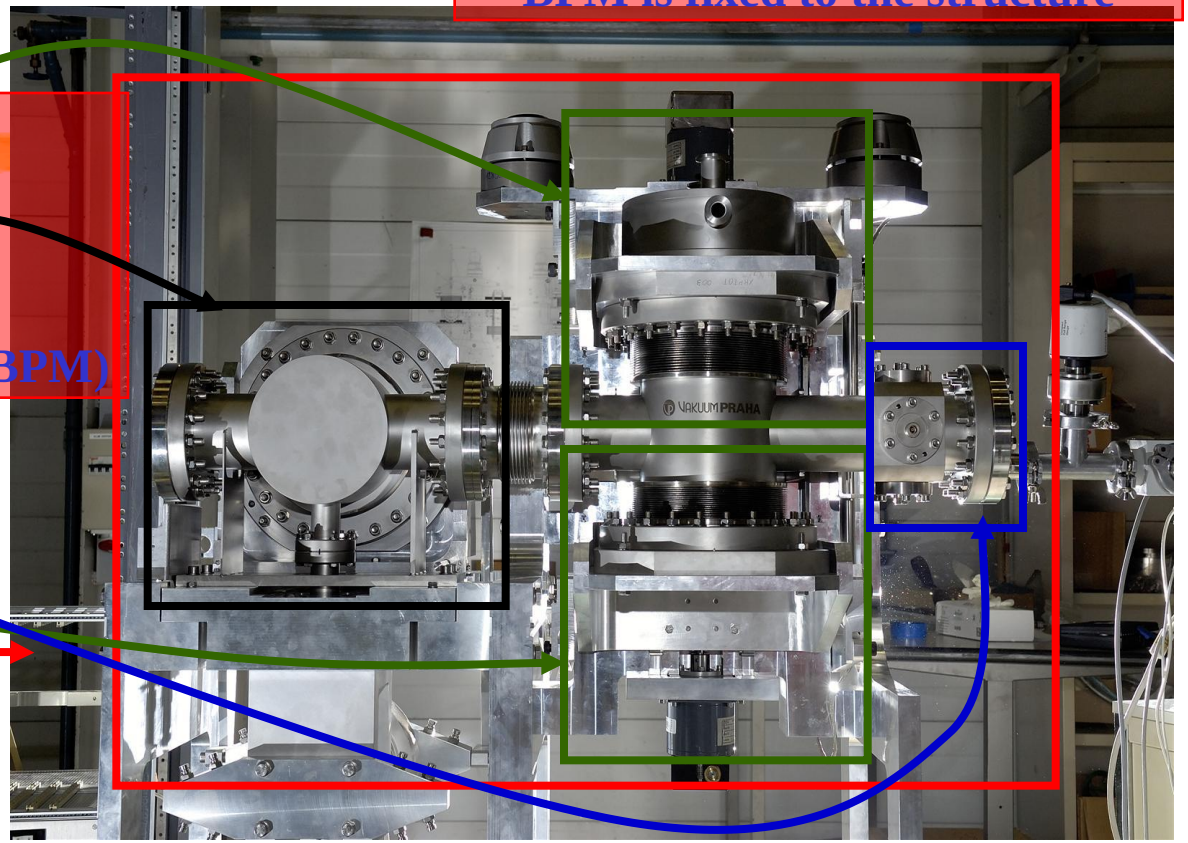
- T1 telescope uses cathode strip chambers (CSC)

Roman pots

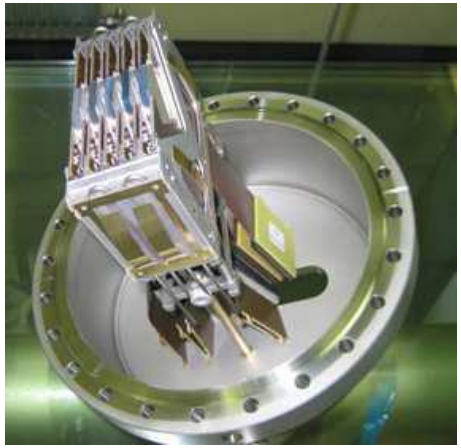
BPM is fixed to the structure

One RP station:
- 2 units

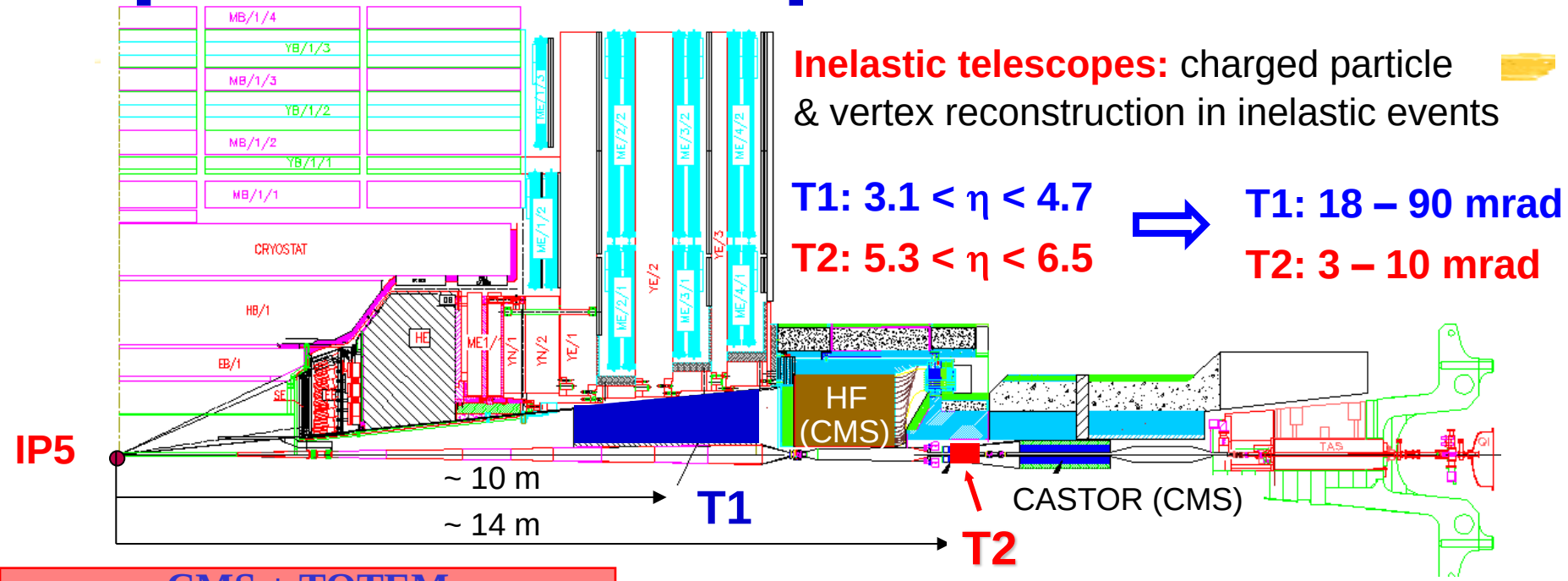
One unit:
- 2 vertical pot
- 1 horizontal pot
- 1 Beam Position Monitor (BPM)



- During LHC RunI, 12 Roman pots, distributed in 4 stations at ±220 and ±147 m.
- Each RP is equipped with a stack of 10 silicon strip detectors, designed with the specific objective of reducing the insensitive area at the edge facing the beam to only a few tens of μm



Experimental Setup @ IP5 LHC Run I



Inelastic telescopes: charged particle & vertex reconstruction in inelastic events

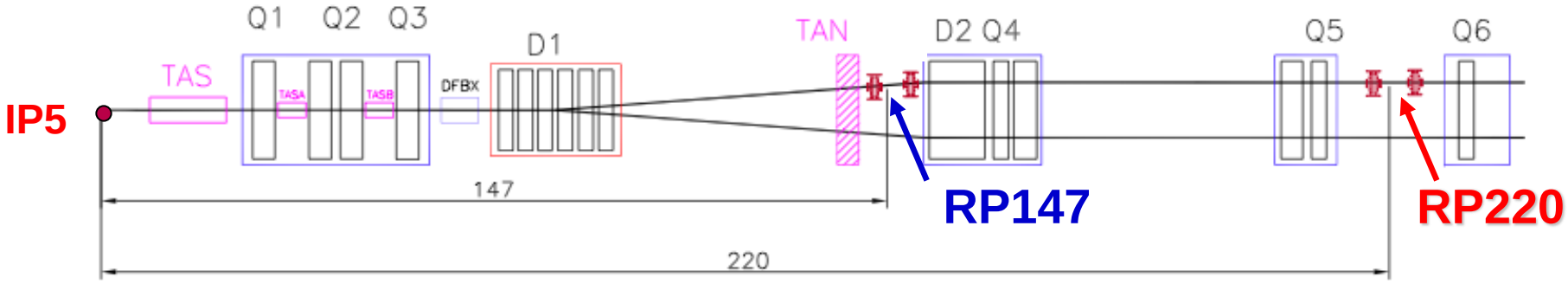
T1: 3.1 < η < 4.7
T2: 5.3 < η < 6.5

⇨

T1: 18 – 90 mrad
T2: 3 – 10 mrad

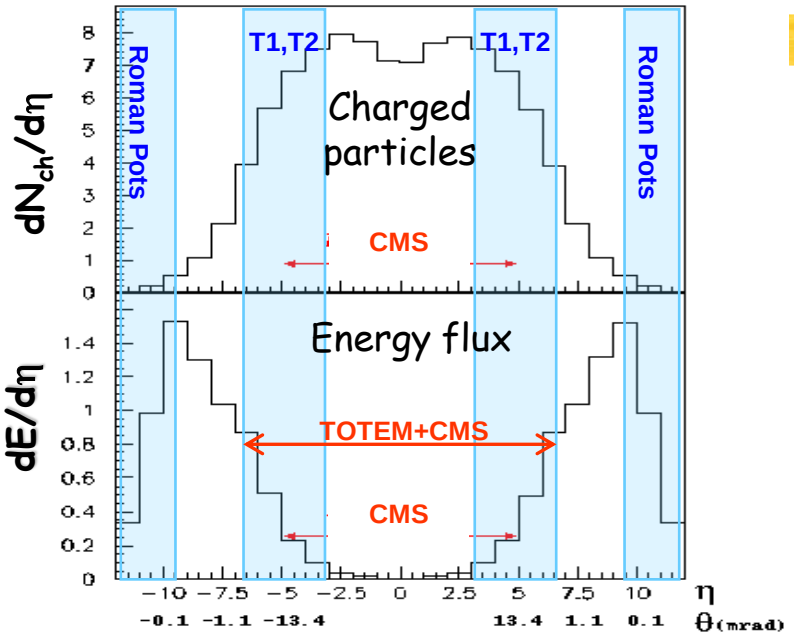
CMS + TOTEM
unprecedented η coverage

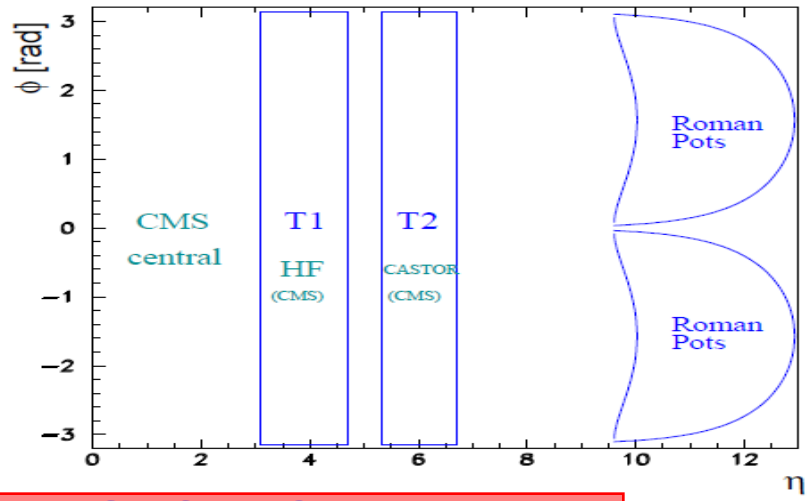
Roman Pots: measure elastic & diffractive protons close to outgoing beam

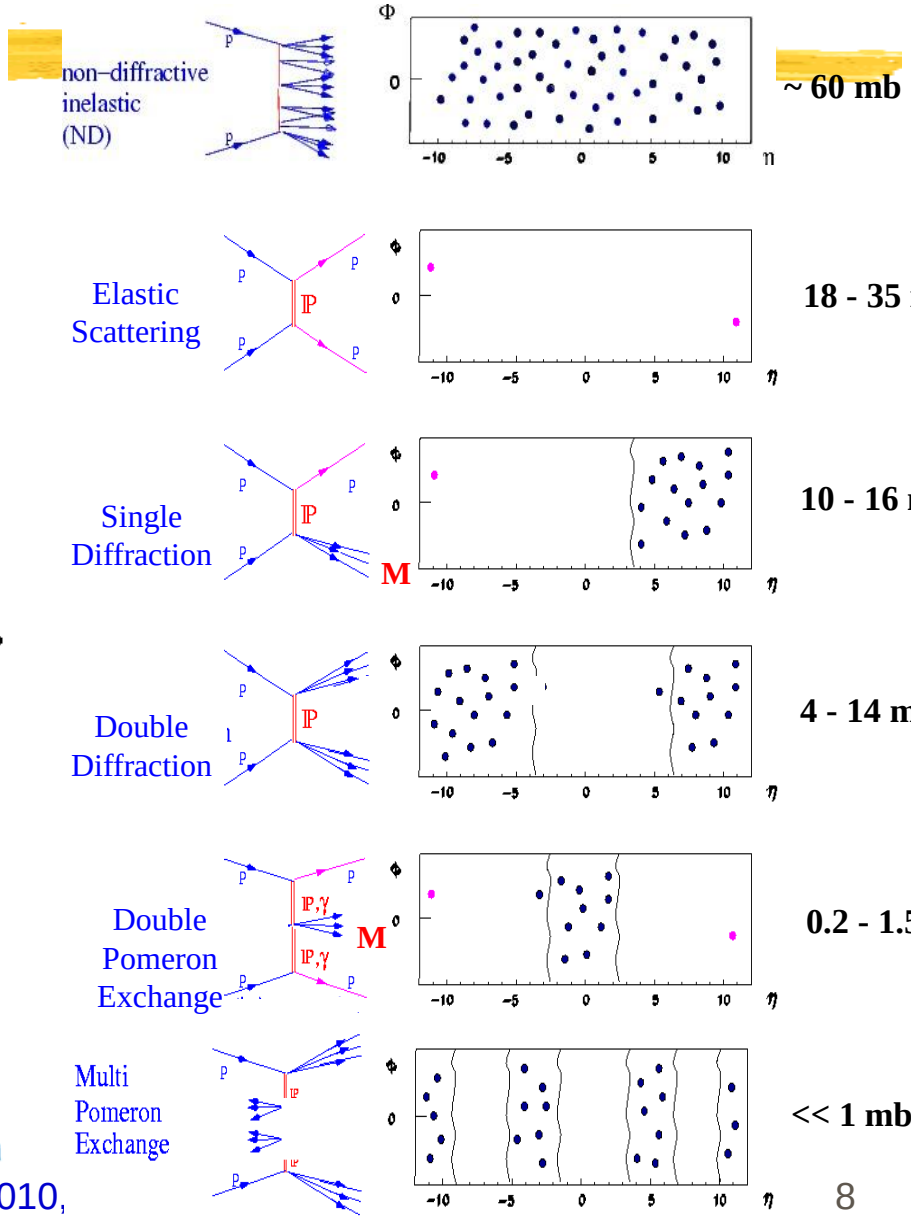


Event Topology & η coverage

LHC, inelastic collisions





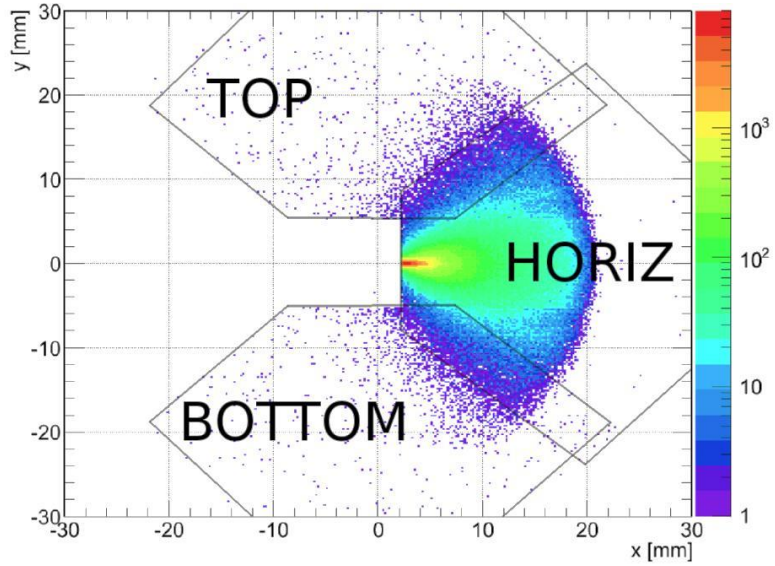


CMS + TOTEM unprecedented η coverage

F.S. Cafagna, ICHEP 2010,

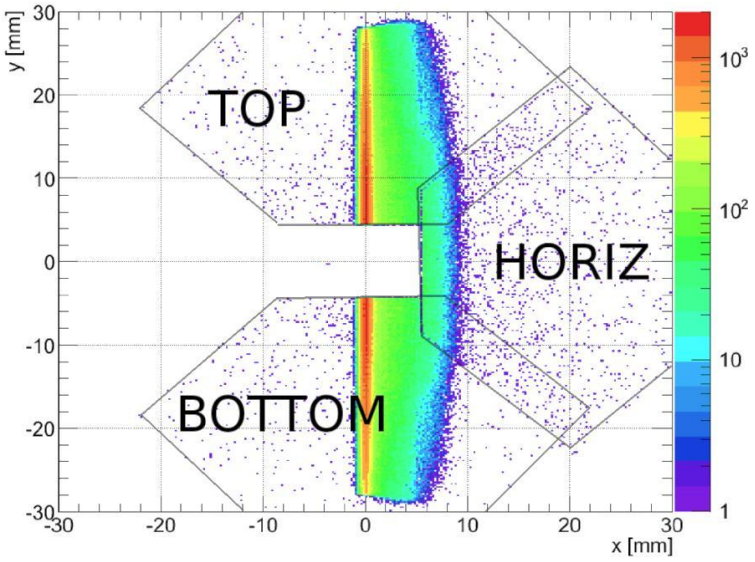
LHC Optics

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



- **Diffractive** protons are mainly in the **horizontal** pot
- **Elastic** protons in the **vertical** pot near X~0

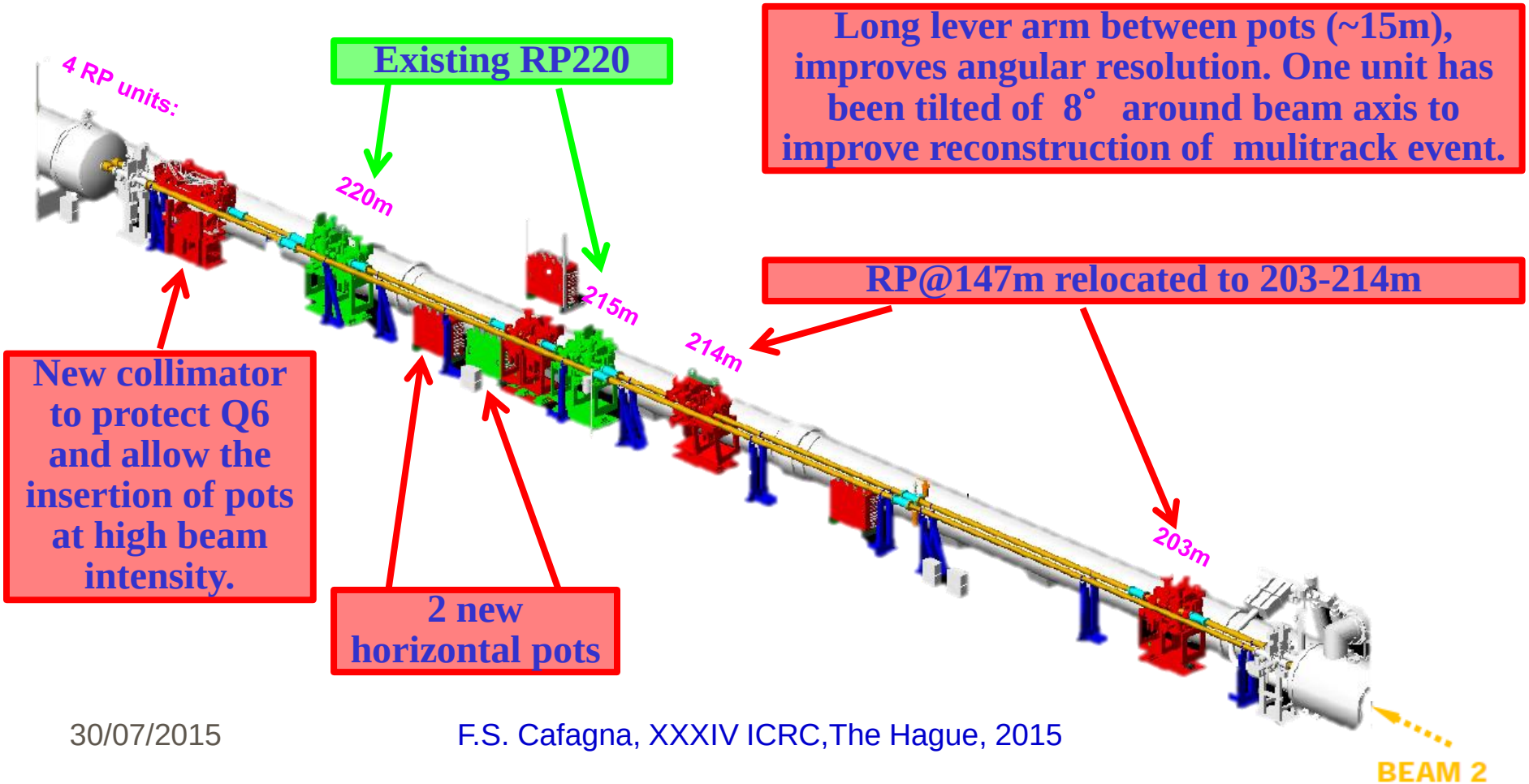
β* = 90 m (special optic for RP runs)



- Diffractive protons are mainly in the vertical pot
- **Elastic** protons in a **narrow band** at X~0

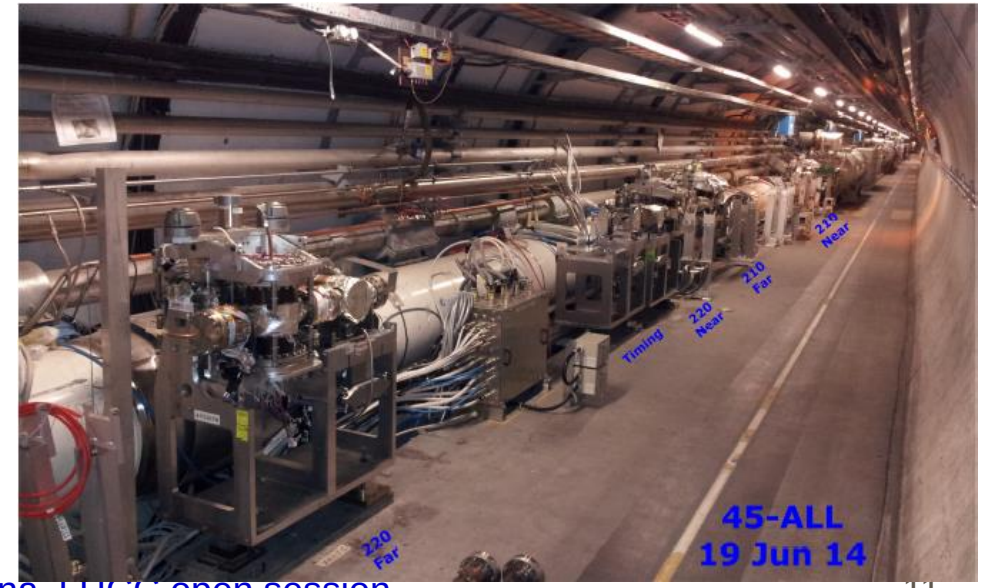
TOTEM Program for RUN II

- **Timing Measurements in the Vertical Roman Pots of the TOTEM Experiment** (CERN-LHCC-2014-020 ; TOTEM-TDR-002; https://cds.cern.ch/record/1753189/);
- **CMS-TOTEM Precision Proton Spectrometer** (CERN-LHCC-2014-021 ; TOTEM-TDR-003 ; CMS-TDR-13; https://cds.cern.ch/record/1753795?ln=en);



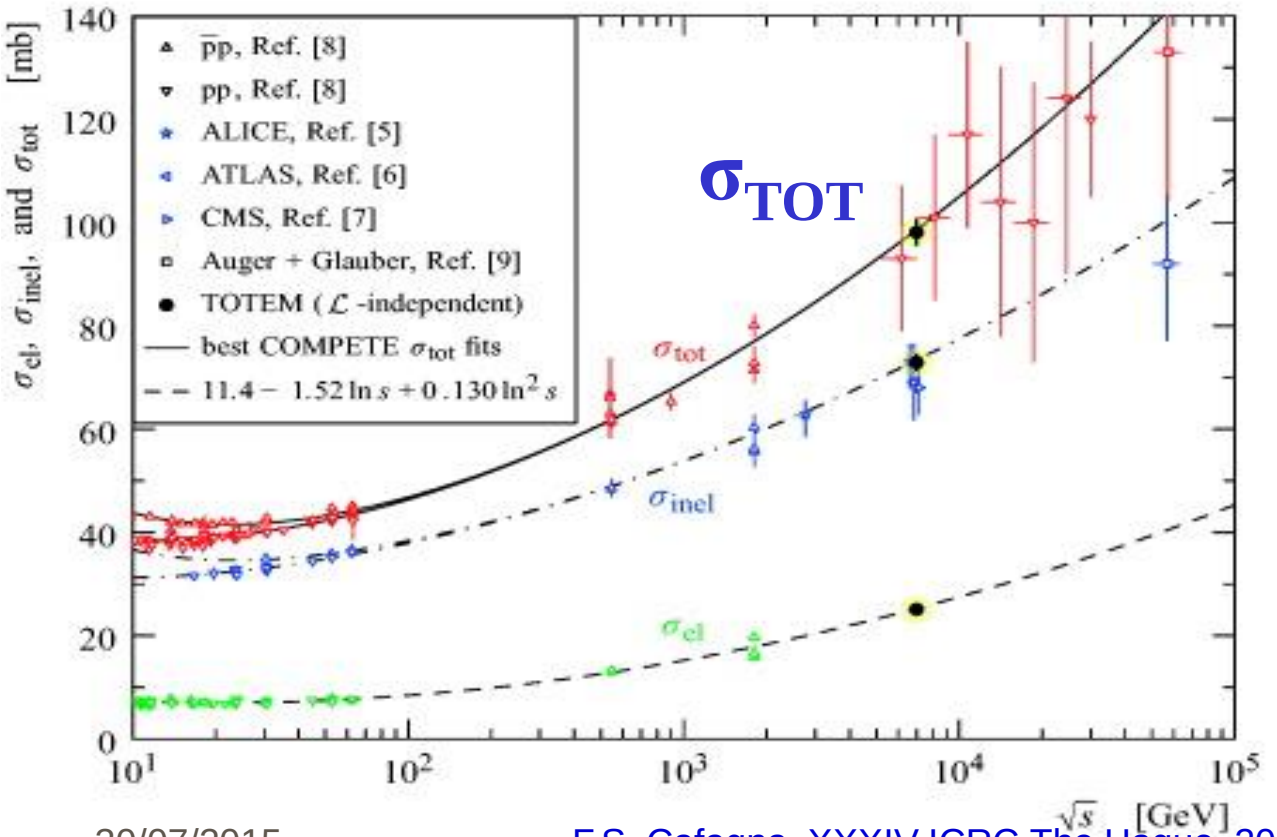
TOTEM Program for RUN II

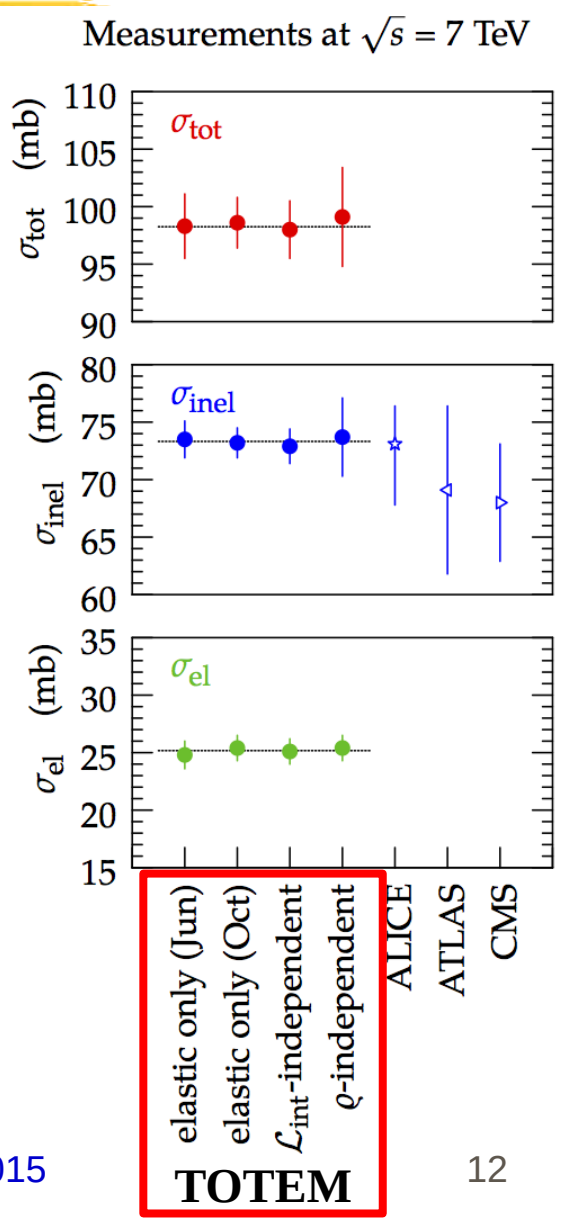
- TOTEM will install new timing detector in relocated vertical RP, to resolve the pileup of multiple events in the same bunch crossing, in the special runs with low luminosity.
- CMS and TOTEM, join proposal called: CMS-TOTEM Precision Proton Spectrometer (CT-PPS), proposes the installation of new tracking detectors in two horizontal RP and a timing detector in one of the new horizontal, to be able to operate the detector at high luminosity, close to the beam.



TOTEM total cross-section

	$\mathcal{L}$ independent at $\sqrt{s} = 7$ TeV, eq. 1.1	$\mathcal{L}$ independent at $\sqrt{s} = 8$ TeV, eq. 1.1
σ_{tot} (mb)	98.0 ± 2.5	101.7 ± 2.9
σ_{inel} (mb)	72.9 ± 1.5	74.7 ± 1.7
σ_{el} (mb)	25.1 ± 1.1	27.1 ± 1.4
	$\sqrt{s} = 7$ TeV, $4.7 < \lvert\eta_{min}\rvert < 6.5$	
σ_{DD} (μb)	116 ± 25	





Ruling out SWY approach

- High-statistics data with β^*=90m at $\sqrt{s}$ = 8 TeV, can be used to compare differential elastic cross-section, with a pure exponential

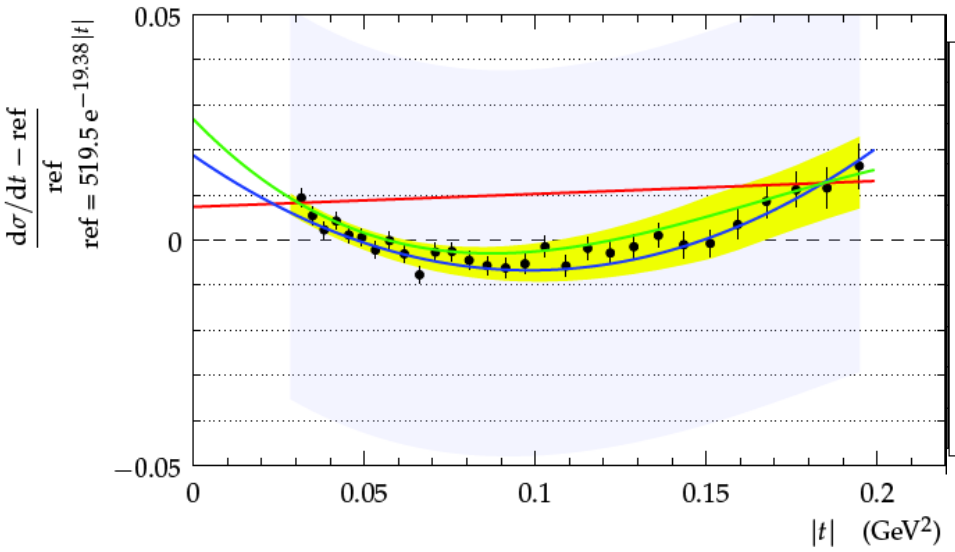
$d\sigma/dt \propto |F^{C+H}|^2$ = Coulomb + hadronic + "interference"

from QED

constrained by measured $e^{-B(t)}$
$B(t) = b_1 t + b_2 t^2 + \ldots$
N_b = # parameters in exp.

***Simplified West-Yennie (SWY)* [1]: often used "standard", only compatible with pure exponential amplitude & constant phase**

- Now exclude Coulomb-hadronic interference with constant phase & constant exponential slope for hadronic amplitude (N_b= 1) at >7σ using same data ⇒ ruling out SWY approach



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

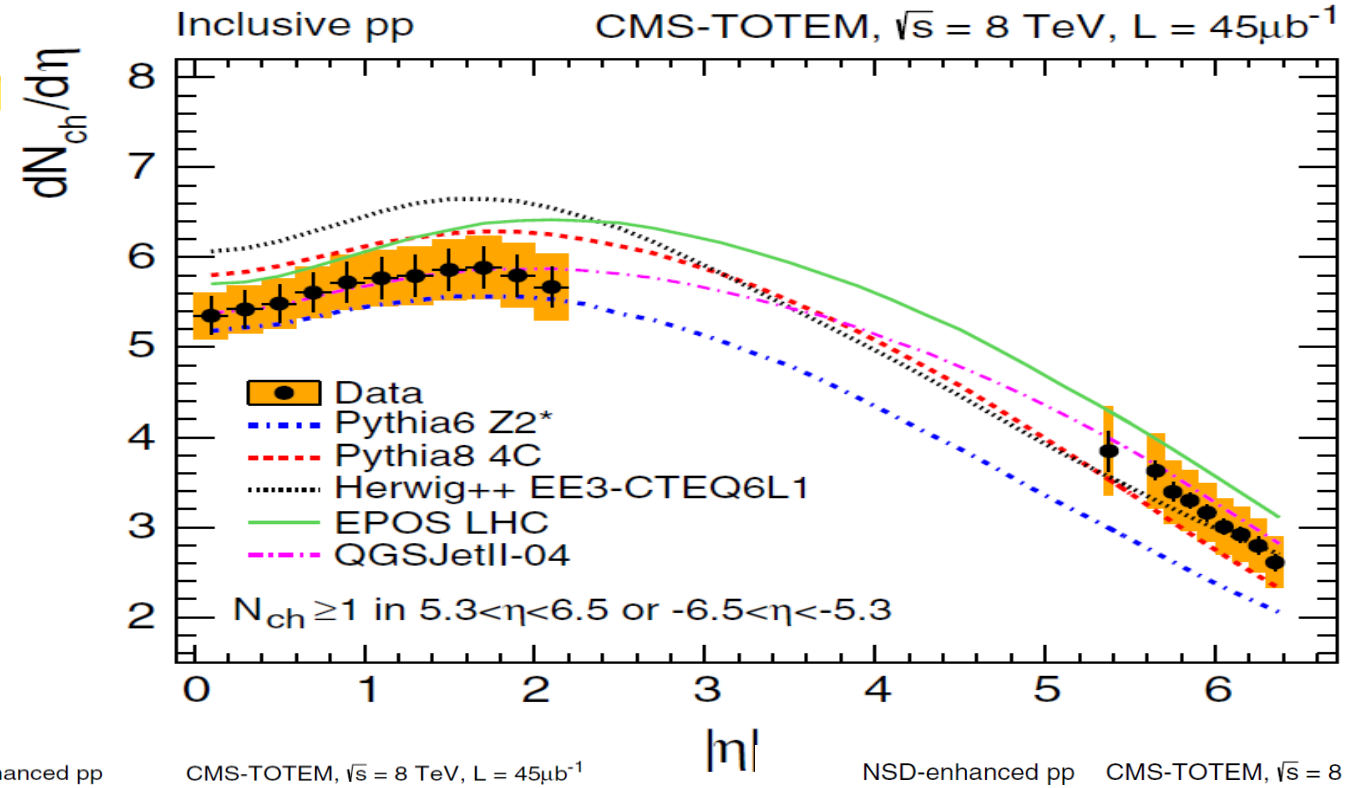
fit parametrisation: $a \exp(\sum_{n=1}^{N_b} b_n t^n)$

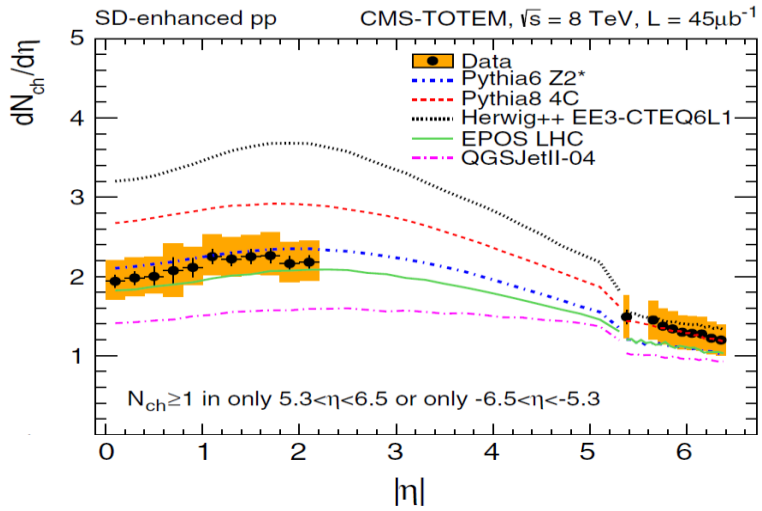
fits with statistical and systematic uncertainties:

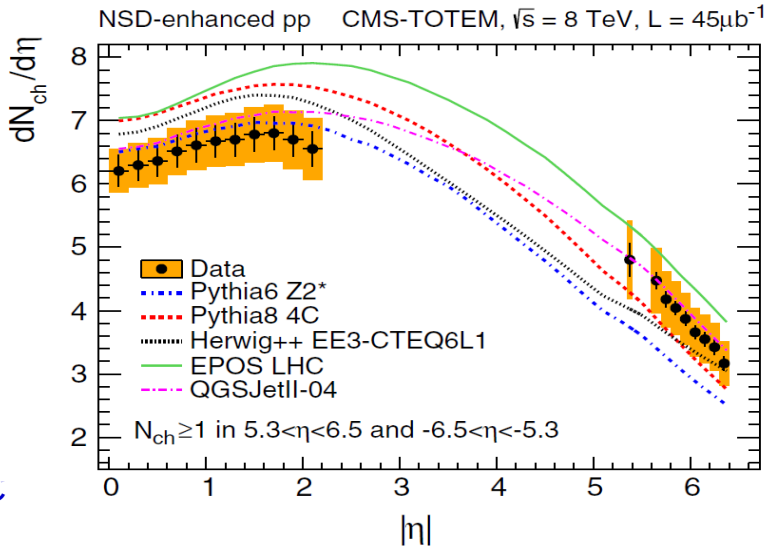
$N_b = 1$: $\chi^2/\text{ndf} = 117.5/28 = 4.198 \Rightarrow$ p-value $= 6.14 \times 10^{-13}$, significance = 7.20 σ
$N_b = 2$: $\chi^2/\text{ndf} = 29.3/27 = 1.085 \Rightarrow$ p-value $= 3.47 \times 10^{-1}$, significance = 0.94 σ
$N_b = 3$: $\chi^2/\text{ndf} = 25.5/26 = 0.980 \Rightarrow$ p-value $= 4.92 \times 10^{-1}$, significance = 0.69 σ

[1] G. B. West and D. R. Yennie, Phys. Rev. 172 (1968) 1413.

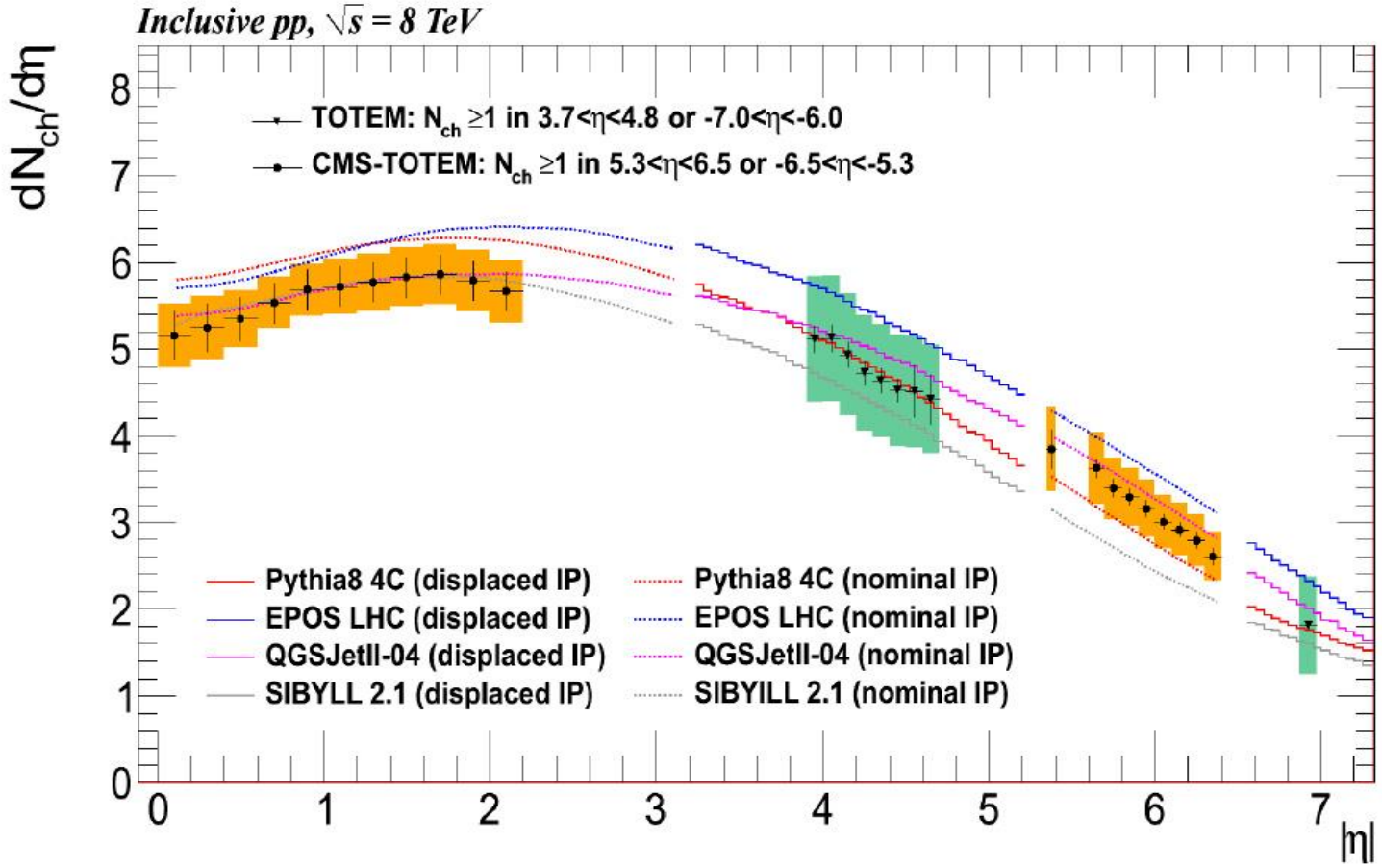
CMS-TOTEM Forward Charged Multiplicity

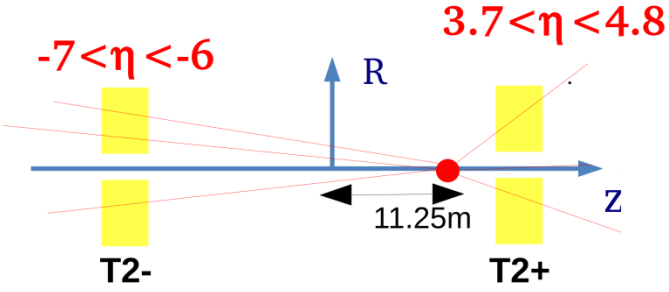






TOTEM Extended Forward Charged Multiplicity





Conclusion

- TOTEM has measured, for the first time at the LHC, the total proton-proton cross section at both $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 8 TeV, using a luminosity independent method. The method was validated comparing the elastic and inelastic cross sections measured in independent ways.
- Furthermore, double diffractive cross section has been measured in an η range where it has never been determined before.
- Quantities that are relevant in cosmic rays studies, like the charge particle pseudorapidity distributions, has been measured in the forward region.
- After the LS1, TOTEM will join forces with CMS, creating a combined apparatus with the largest η coverage and with the most performing two-arm proton spectrometer ever built at a collider.
- Stay tuned for more cross section at $\sqrt{s}$ = 13 TeV.

THANKS!!!

Spares