TOTEM status report

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(on behalf of the TOTEM Collaboration)

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LHCC open session

Outline:

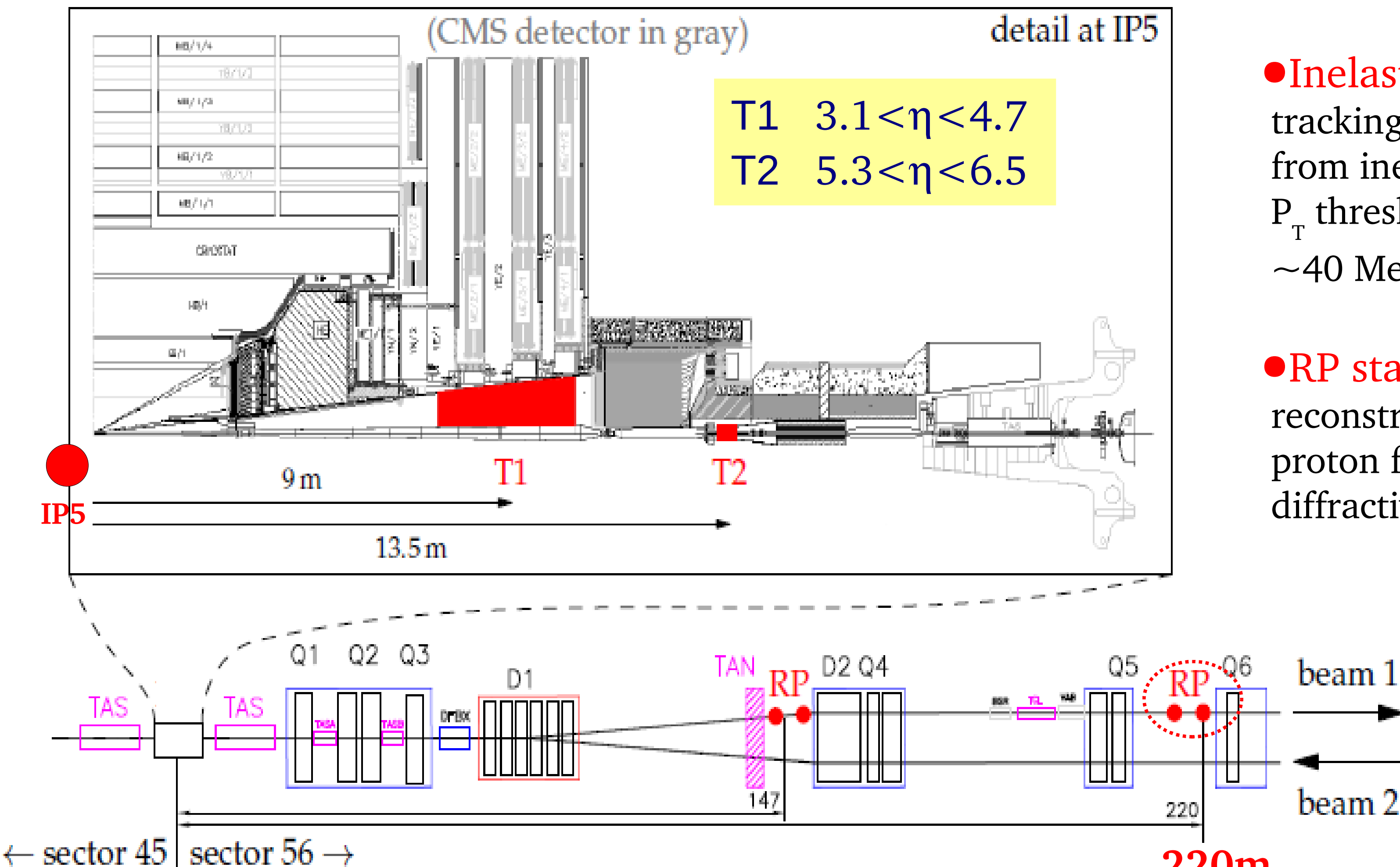
- The TOTEM experiment
- Results on Hadronic-Coulomb interference
- Single diffractive and double diffractive pp cross sections
- Very forward pp $dN_{CH}/d\eta$
- TOTEM consolidation and upgrade programme

The TOTEM experiment

Physics programme:

- Measure the total pp cross section with a precision of about 1÷2 %.
- Study the elastic pp cross section over a wide range of the pp 4-momentum transfer $|t|$.
- Studies on diffractive processes, partially in cooperation with the CMS experiment.

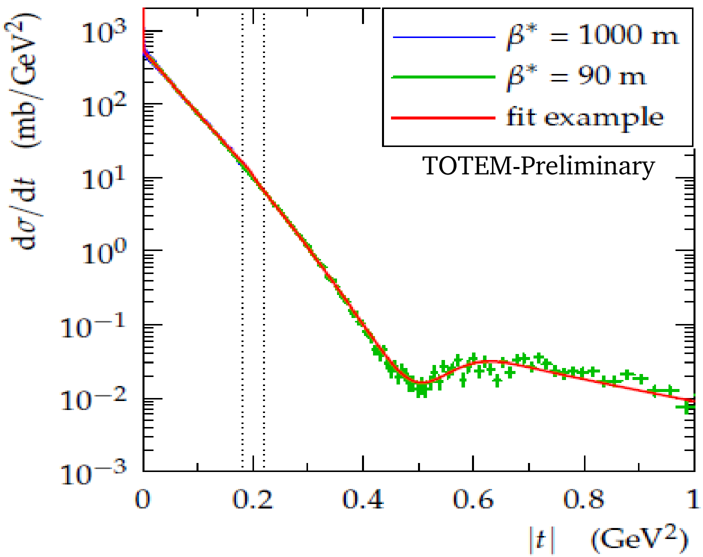
Experimental layout before LS1 (symmetrically placed with respect to IP5):

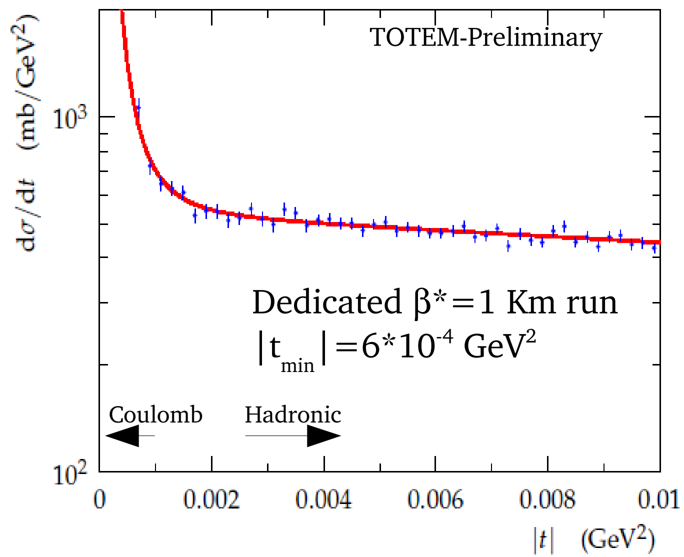


- **Inelastic telescopes T1,T2:** tracking of charged particles from inelastic collision. P_T thresholds: ~100 MeV (T1), ~40 MeV (T2).
- **RP stations at 220m:** reconstruction of the leading proton from elastic and diffractive interaction.

Probing the Hadronic-Coulomb interference at 8 TeV (1):

Proton-proton elastic scattering:





Analysis aim:

1. **Measure $d\sigma_{EL}/dt$ at the smallest possible proton-$|t|$ (where the Coulomb interaction can be probed).**
2. **Fit the data with many theoretical models: evaluate the agreement, extract physics parameters (ρ from argF^H), further improve the σ_{TOT} measurement.**

$$\frac{d\sigma_{EL}}{dt} \propto \left|F^{C+H}\right|^2 \quad , \qquad F^{C+H} = \text{Interference Formula}(F^C, F^H)$$

Models used for the hadronic amplitude:

$$|F^H| = A\exp(b_0) \quad \text{“1”}$$
$$|F^H| = A\exp(b_0 + b_1 t) \quad \text{“2”}$$
$$|F^H| = A\exp(b_0 + b_1 t + b_2 t^2) \quad \text{“3”}$$

$$\arg F^H \simeq p_0 \text{ (“central” phase)}$$
$$\arg F^H = \arg F^H(p_0, \ldots, t) \text{ (“peripheral” phase)}$$

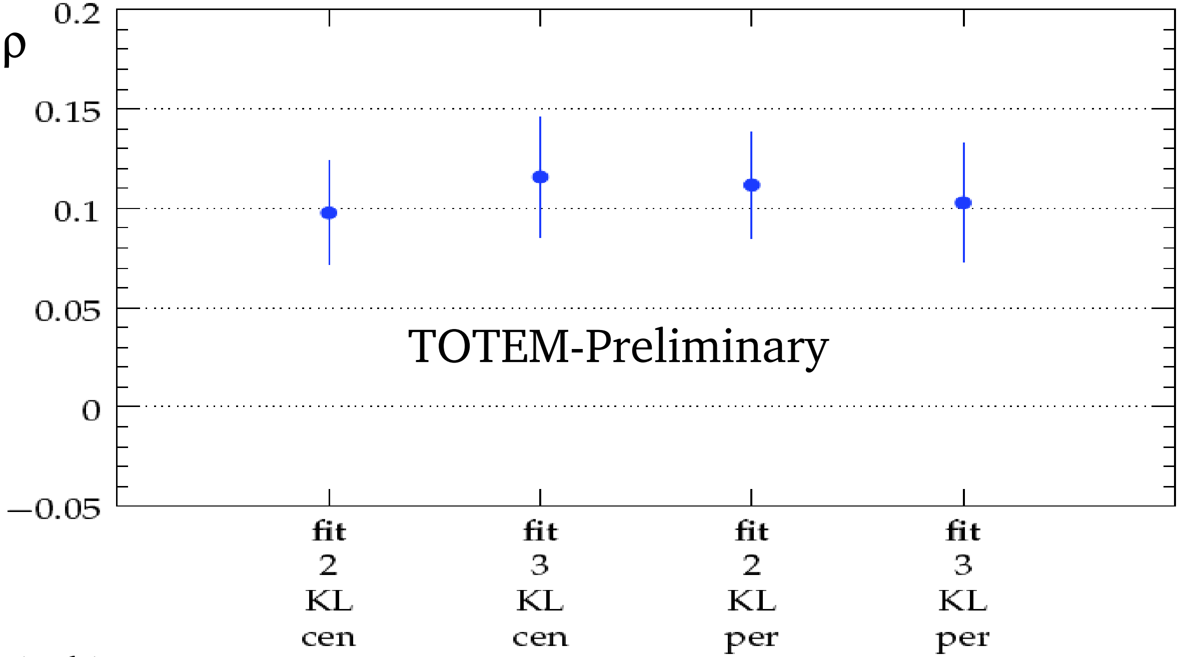
[Z. Phys. C 63, 619–629]

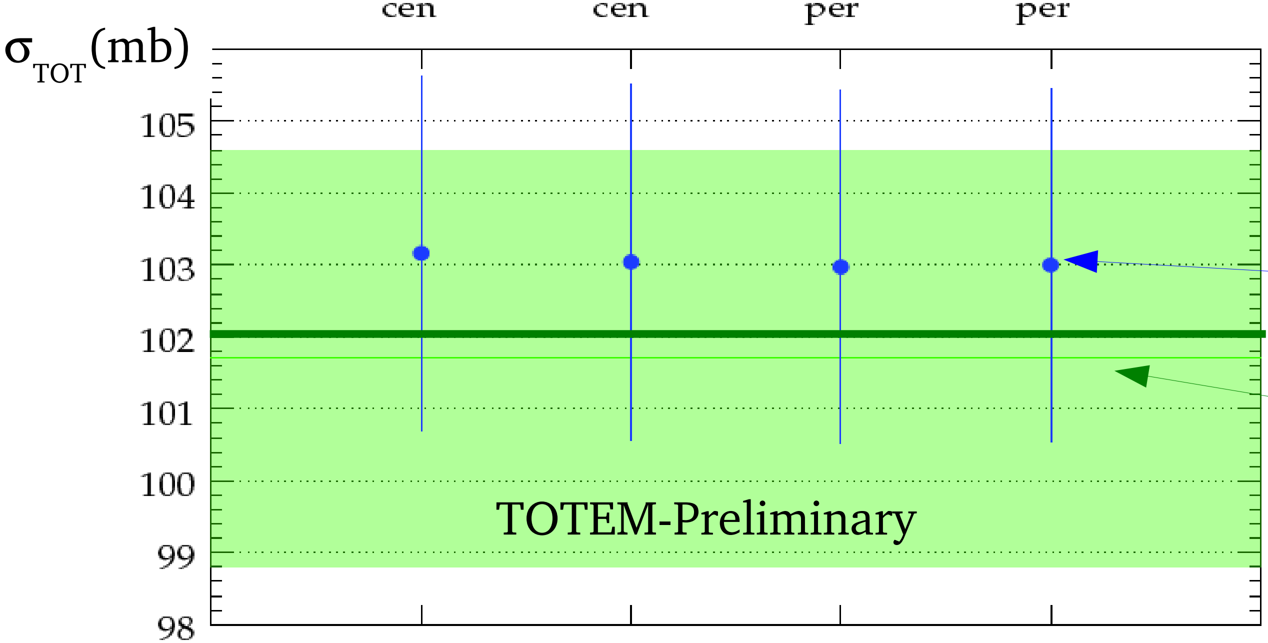
Models used for the interference formula:

Simplified West-Yennie formula (SWY) [Phys. Rev., 1968, vol. 172, p. 1413-1422]
Kundrát-Lokajícek formula (KL) [Z. Phys., 1994, vol. C63, p. 619-630]

Probing the Hadronic-Coulomb interference at 8 TeV (2):

Extraction of ρ and σ_{TOT} by fitting the Hadronic-Coulomb interference region.





- Fit procedure tested with several MC phenomenological models, using realistic statistics. Hadronic modulus can be fitted using at least 2 parameters.

- Error bars include:
  - Fit statistical uncertainty
  - The effect induced on the fit by the relevant experimental uncertainties (misalignment, normalization,..)

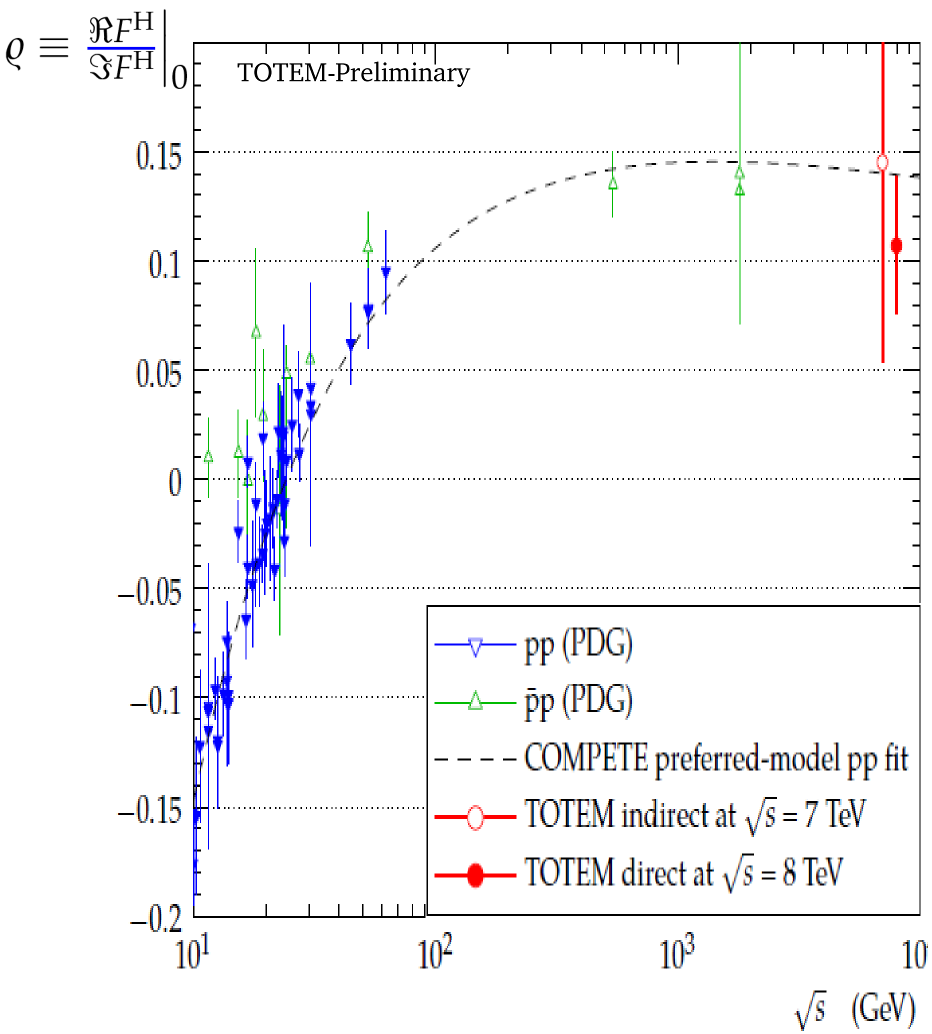
$$\sigma_{tot}^2 = \frac{16\pi}{(1+\rho^2)} \frac{1}{\mathcal{L}} \left(\frac{dN_{el}}{dt} \right)_{t=0}$$

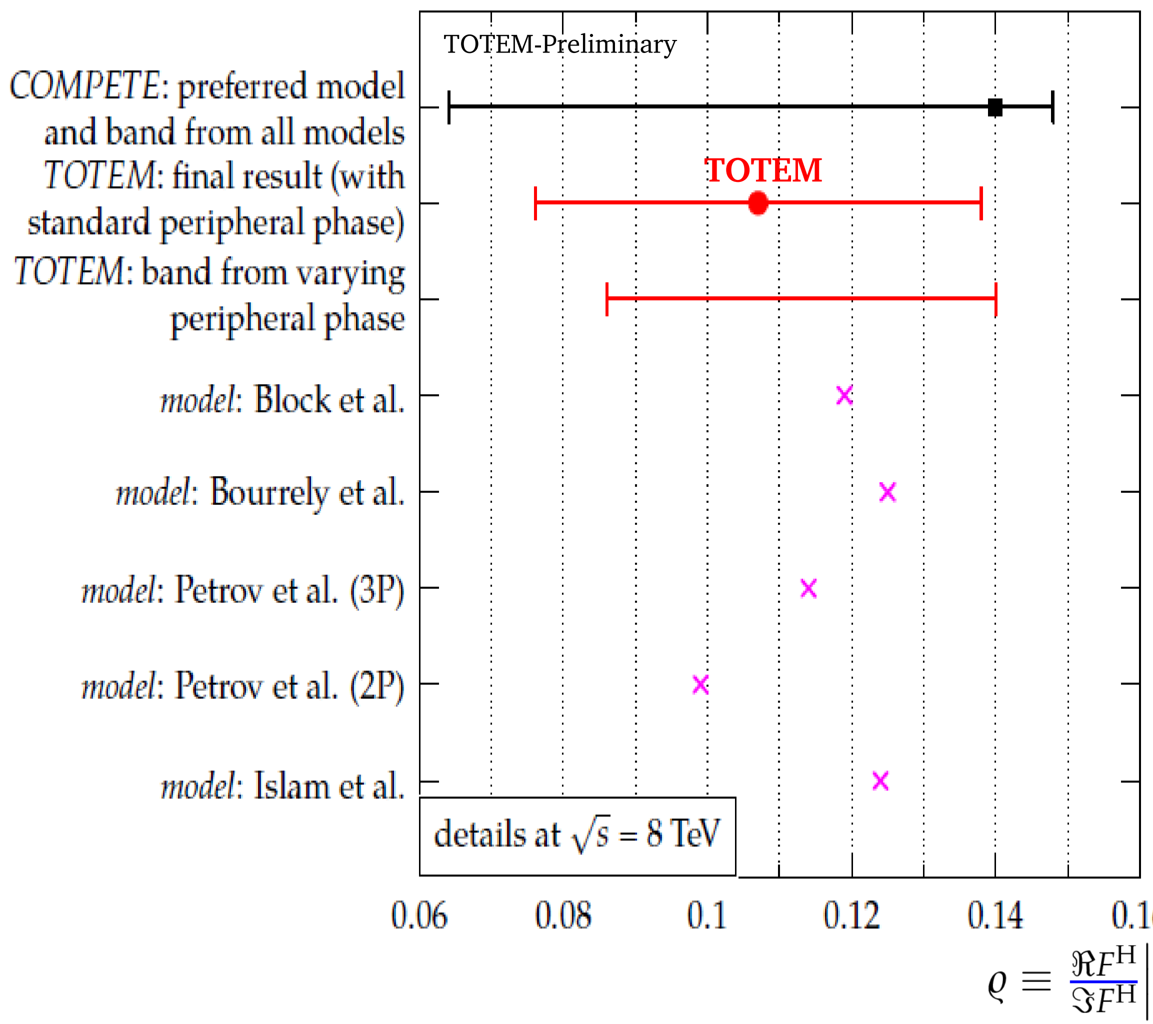
Green line + band: 8 TeV σ_{TOT} measurement (β^*=90m, Lumi-independent)

Probing the Hadronic-Coulomb interference at 8 TeV (3):

Comparison of ρ with models and measurements at lower energy

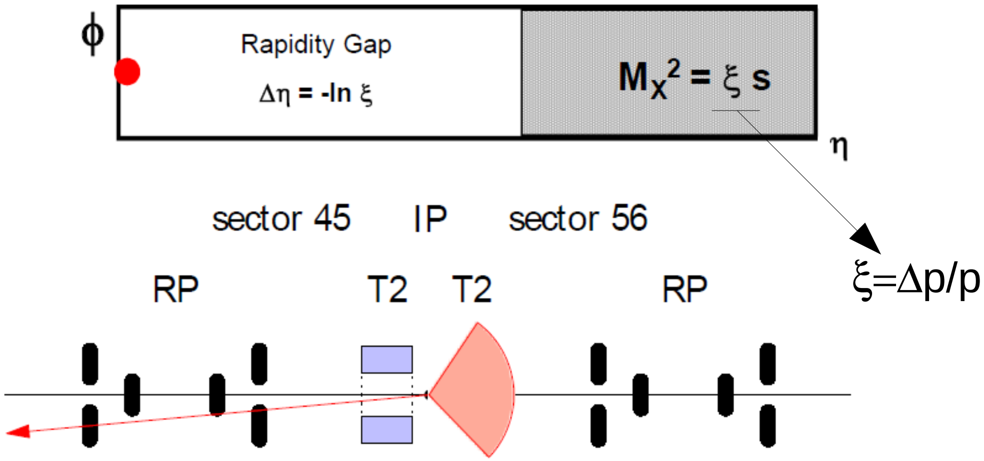
$$\rho = 0.107 \pm 0.027^{(stat)} \pm 0.010^{(syst)} \, {}^{+0.009}_{-0.009} \, (model)$$



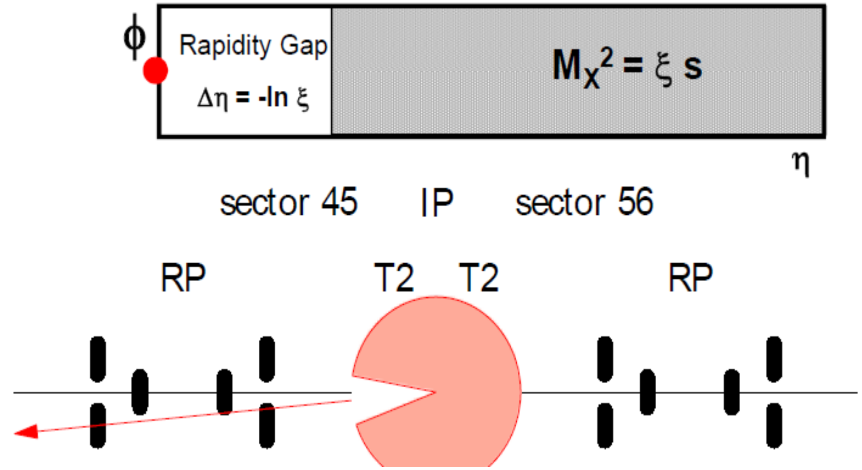


Soft Single Diffractive cross section (7 TeV)

Low mass SD:
Tracks in the T2 hemisphere opposite to the proton ($2 \cdot 10^{-7} < \xi < 0.025$)



Very High mass SD:
Tracks in the same T2 hemisphere of the proton ($\xi > 2.5\%$)



- **SD events triggered with T2, only 1 proton required in RP**
- M obtained from the rapidity gap estimation based on charged track η in T1 and T2: $\Delta\eta = -\ln(M^2/s)$. This allows a better ξ resolution ($\sigma(\xi)/\xi \sim 1$) for low-medium mass.

- SD experimentally classified into 4 categories, based on the rapidity gap:

SD class	Inelastic telescopes configuration	Mass	ξ
Low Mass	p + T2 opposite only (no T1)	3.4 - 8 GeV	$2 \cdot 10^{-7} < \xi < 10^{-6}$
Medium Mass	p + T2 opposite + T1 opposite	8 - 350 GeV	$10^{-6} < \xi < 0.25\%$
High Mass	p + T2 opposite + T1 same	0.35 - 1.1 TeV	$0.25\% < \xi < 2.5\%$
Very High Mass	p + both T2 arms	> 1.1 TeV	> 2.5%

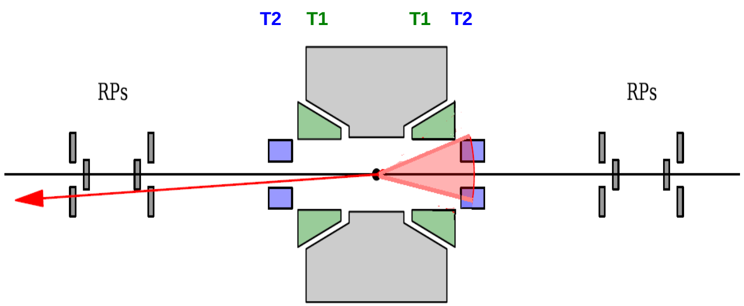
- Inelastic+beam halo background estimated from data, used mirrored events (wrt the proton)

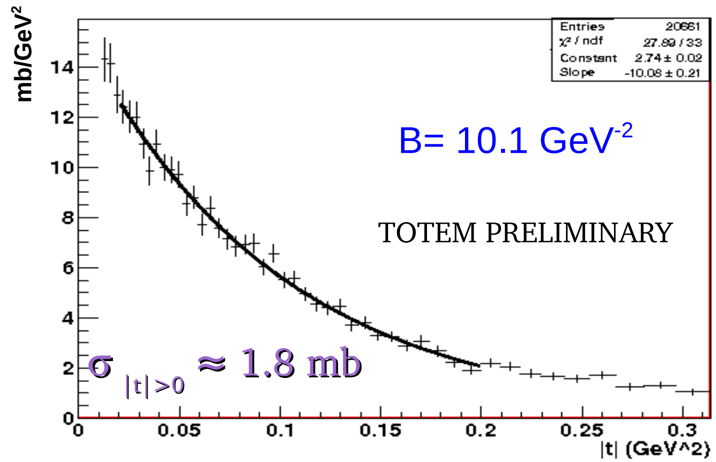
Soft Single Diffractive cross section (7 TeV)

$d\sigma/dt \sim C \cdot e^{-Bt}$

Low Mass

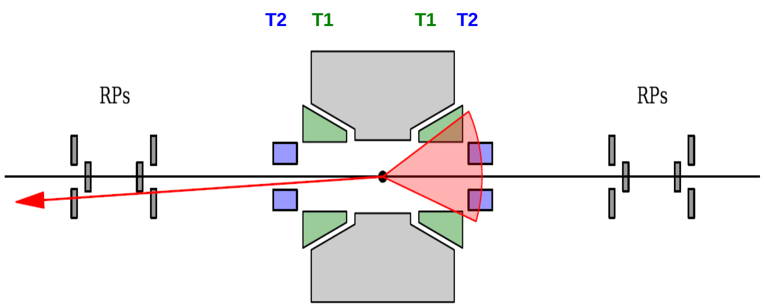
M=3.4 - 7 GeV

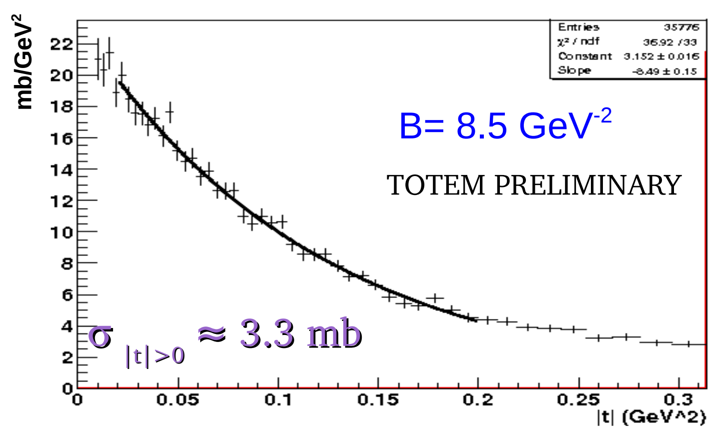




Medium Mass

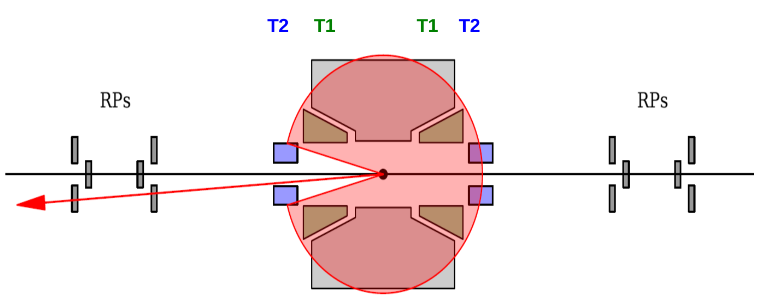
M=7 - 350 GeV

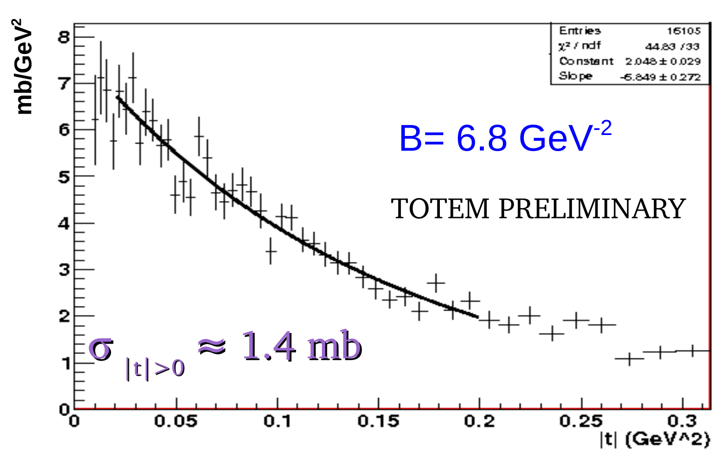




High Mass

M=0.35 - 1.1 TeV





<u>Corrections included:</u>

- Trigger efficiency
- Reconstruction efficiency
- Proton acceptance
- Background subtraction
- Extrapolation to t=0

<u>Missing corrections:</u>

ξ resolution & beam divergence effects

<u>Estimated uncertainty</u>

B ~ 15% ; σ ~ 20%

Very Preliminary:

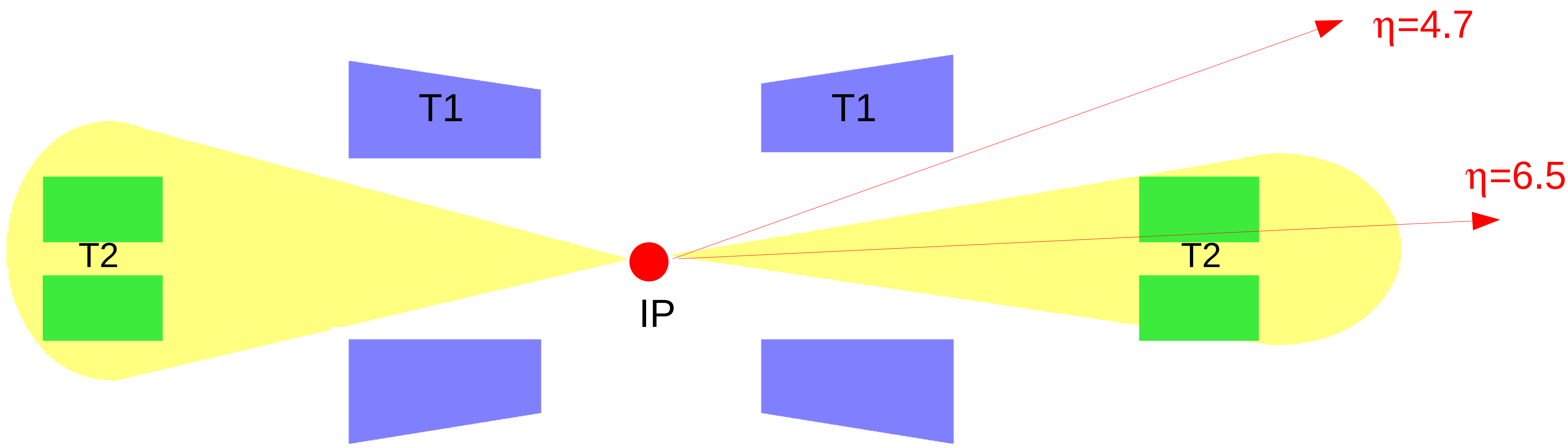
σ_{SD} = 6.5 ± 1.3 mb

($3.4 < M_{SD} < 1100$ GeV)

Very High masses measurement ongoing

Soft Double Diffractive cross section (7 TeV)

Aim: Measurement of soft double diffractive cross section with particle η_{min} visible to TOTEM T2 ($4.7<|\eta_{min}|<6.5$). → $\sigma_{DD}(|\eta_{min}|)$ for $3.4 < M_{DIFF} < 8$ GeV



Event selection: Trigger with T2, at least one track in both T2 hemispheres , no tracks in T1 "(0T1+2T2) topology".

- ND background estimated scaling the MC prediction using a control sample from data dominated by ND (2T1+2T2 events)
- SD background estimated completely from data using a SD-dominated control sample (0T1+1T2) with protons in the RP

Soft Double Diffractive cross section (7 TeV)

TOTEM

Results from 7 TeV data:

$$\sigma_{DD(4.7<|\eta_{min}|<6.5)} = 120 \pm 25 \mu b$$

	$-4.7>\eta_{min}>-5.9$	$-5.9>\eta_{min}>-6.5$
$4.7<\eta_{min}<5.9$	66±19 μb	27±4 μb
$5.9<\eta_{min}<6.5$	28±5 μb	12±4 μb

- σ_{DD} uncertainty dominated by:

  "Internal migration": real DD events that have a $|\eta_{min}|$ smaller than T1 but with no tracks in T1 η-range

MC comparisons:

Pythia 8

$$\sigma_{DD(4.7<|\eta_{min}|<6.5)} = 159 \mu b$$

	$-4.7>\eta_{min}>-5.9$	$-5.9>\eta_{min}>-6.5$
$4.7<\eta_{min}<5.9$	70 μb	37 μb
$5.9<\eta_{min}<6.5$	35 μb	17 μb

Phojet

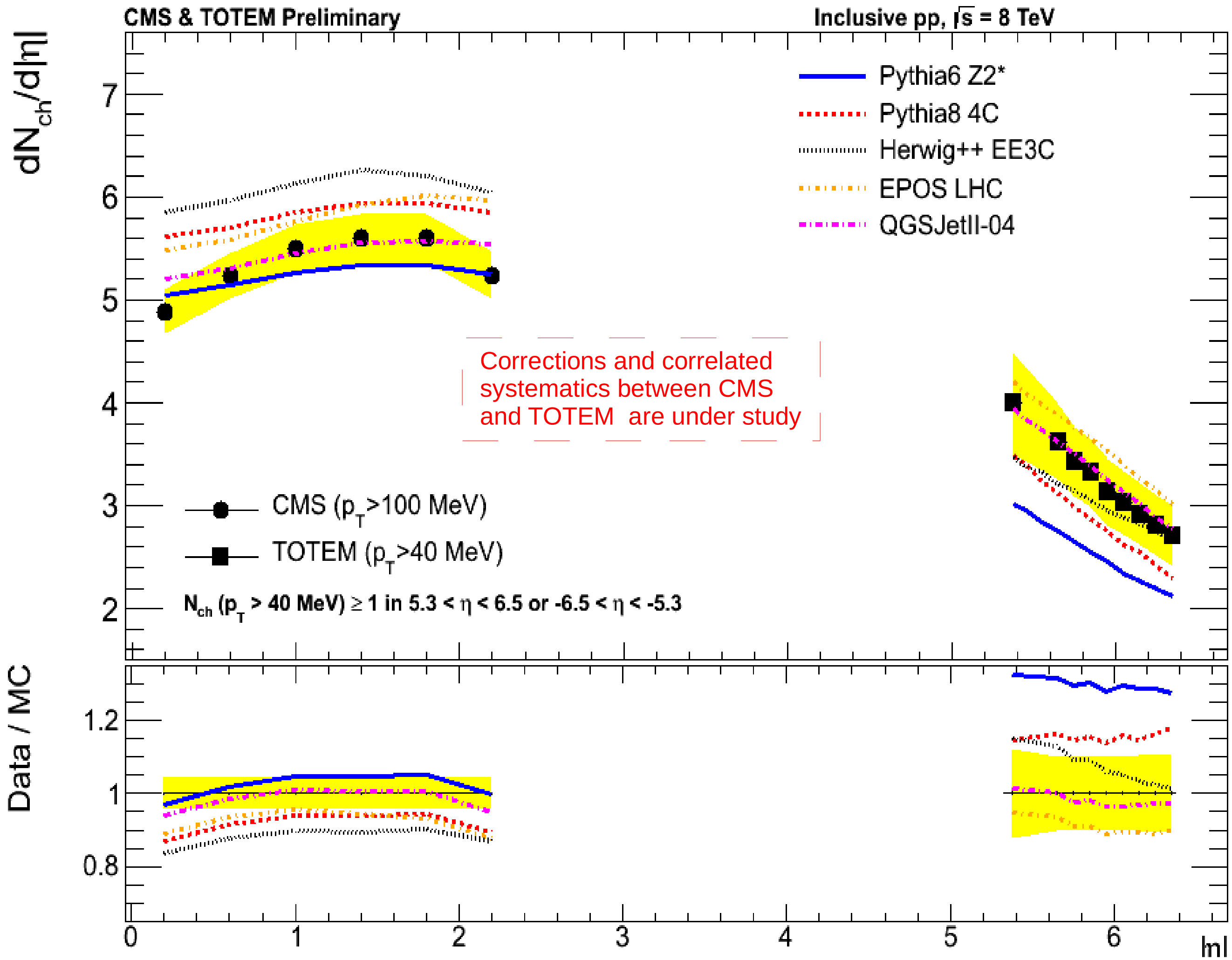
$$\sigma_{DD(4.7<|\eta_{min}|<6.5)} = 101 \mu b$$

	$-4.7>\eta_{min}>-5.9$	$-5.9>\eta_{min}>-6.5$
$4.7<\eta_{min}<5.9$	44 μb	23 μb
$5.9<\eta_{min}<6.5$	23 μb	12 μb

- Improvement expected with the 8 TeV data, including also the CMS information.

Very forward $dN_{CH}/d\eta$ measurements at 8 TeV (with CMS!)

- Inclusive TOTEM analysis very similar to the 7 TeV case but:
  - Improved simulation of the T2 detector response, secondary particles production, event selection strategy and improved alignment procedures.
  - Uses of the vertex information from CMS to reduce the pile-up correction
  - Better MC tuning to the LHC measurements (important for the estimation of the secondaries)



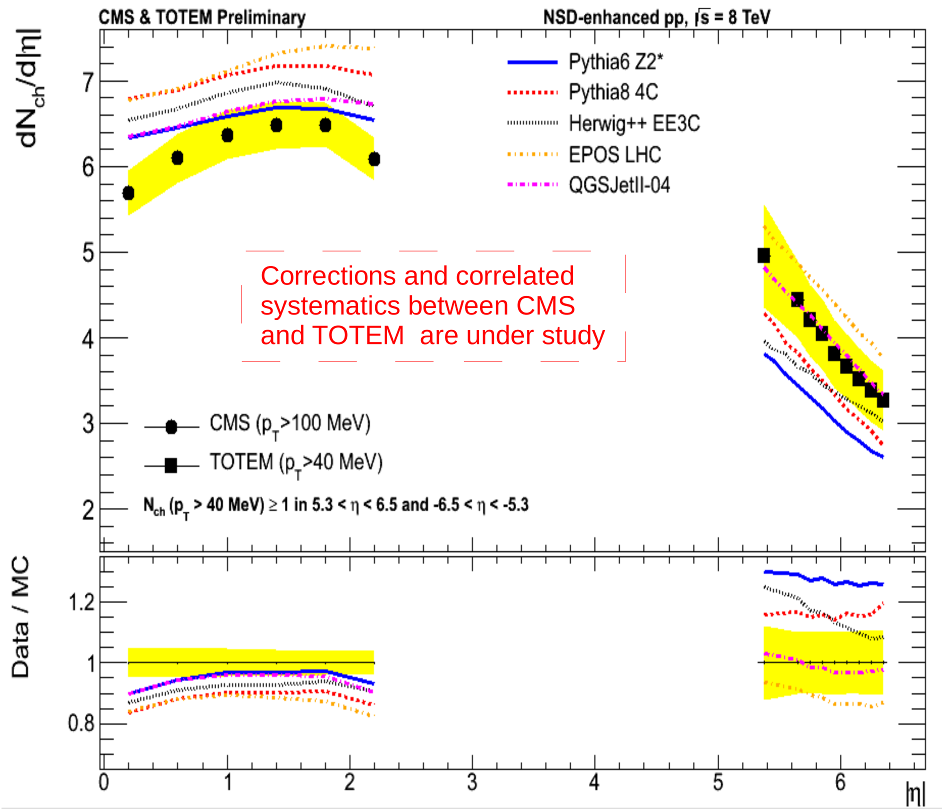
- Both CMS and TOTEM analysis obtained triggering with T2, on the same events.
- Same CMS-TOTEM event selection (at least a track reconstructed in T2)
- Measurements are representative for an inelastic event sample with at least a primary charged particle with P_T>40 MeV/c produced in the range $5.3<|\eta|<6.5$.

Very forward $dN_{CH}/d\eta$ measurements at 8 TeV

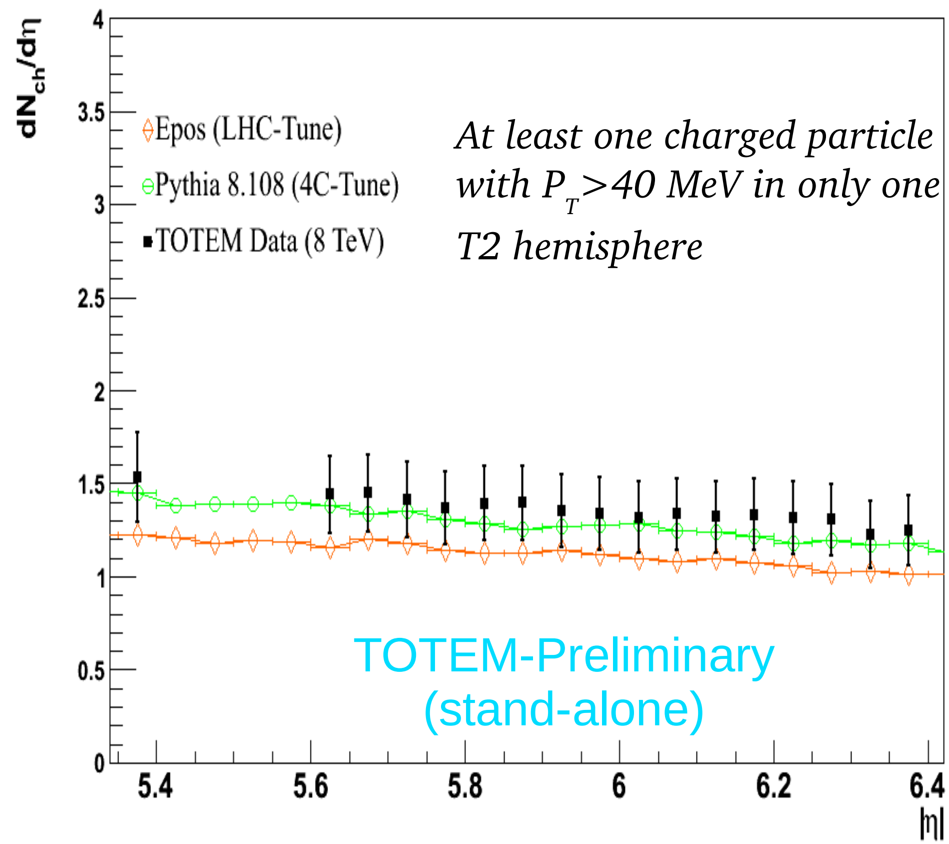
TOTEM-T2 dN/dη analysis performed also for a sample of pp events:

- "Non-Single diffractive enhanced": requiring both hemisphere of T2 ON
- "Single diffractive enhanced": requiring only one hemisphere of T2 ON

NSD-enhanced dN/dη



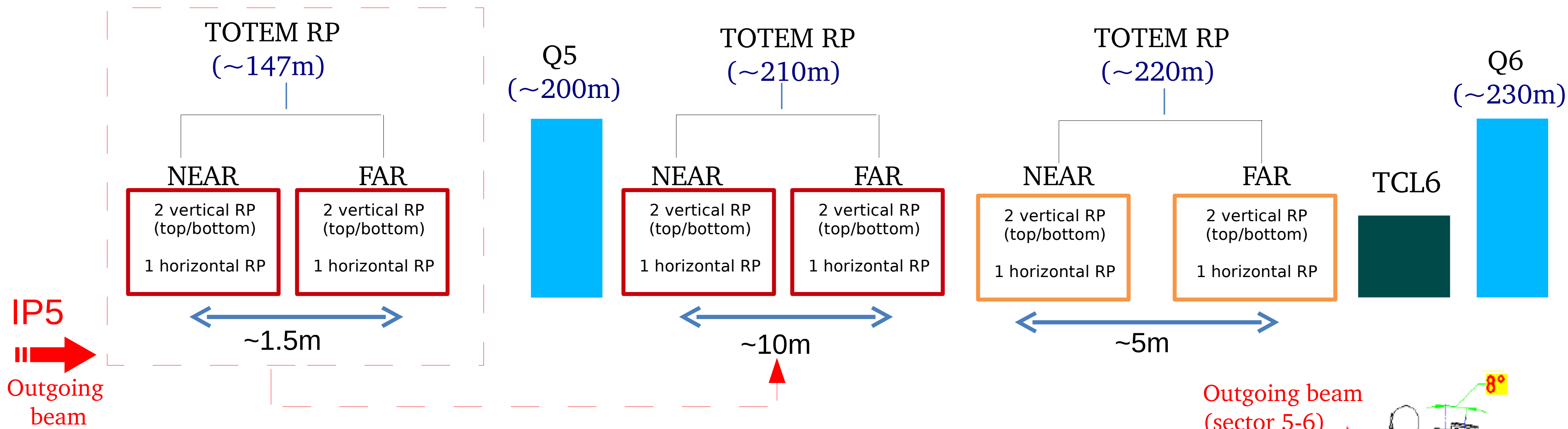
SD-enhanced dN/dη



A new version of these plots are under approval with a common $P_T=0$ thresholds extrapolation.

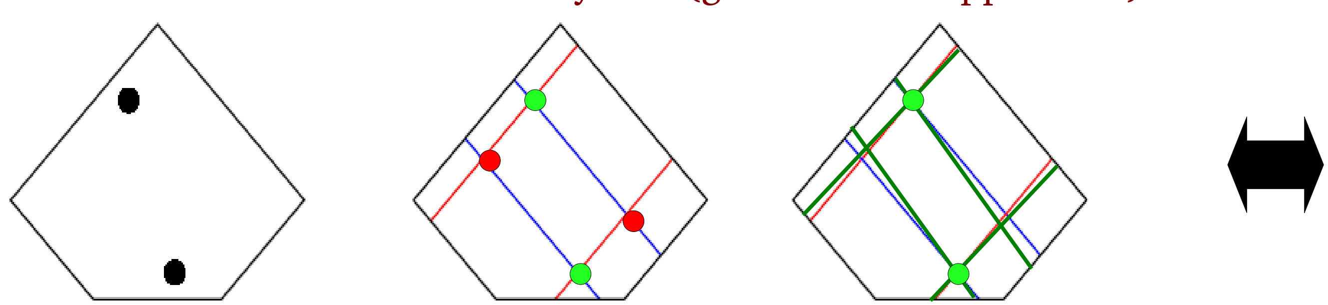
TOTEM consolidation programme during LS1 (1)

1. Station RP 147m and services have to be removed to make space for the new collimator TCL4. RP are relocated between the quadrupole Q5 and the station RP 220m.



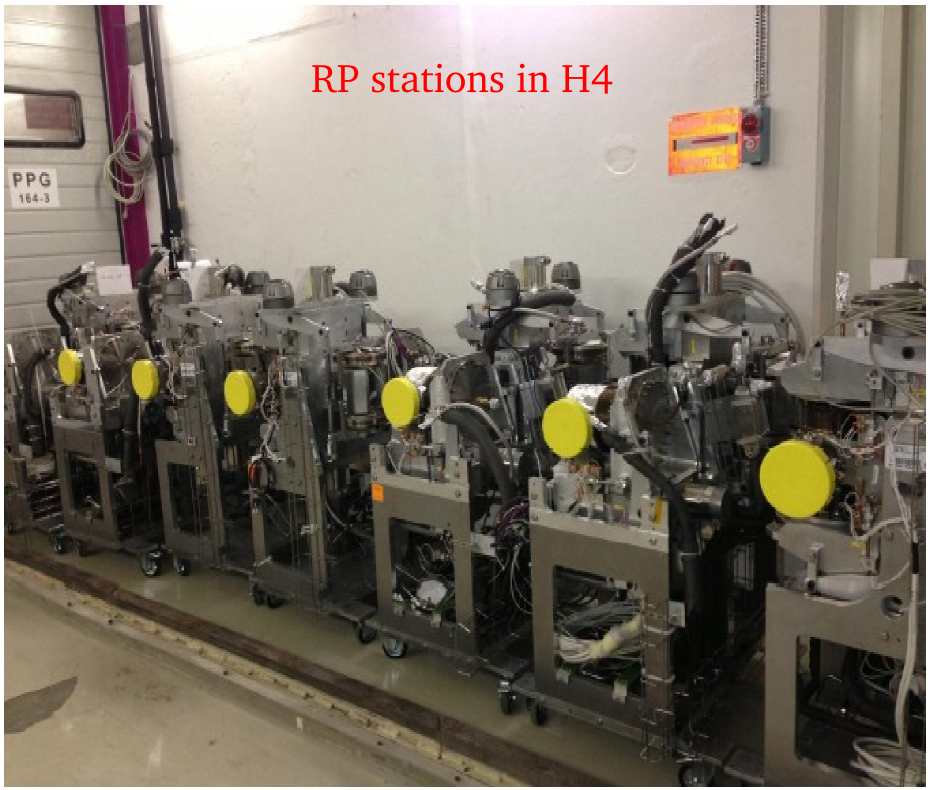
This configuration allows a better resolution for the proton *t* (a longer lever arm improves the θ_x resolution, important at β^*=90m). With the new TLC6 protecting Q6, RPs can be inserted closer to the beam (larger ξ–acceptance at low β^*)

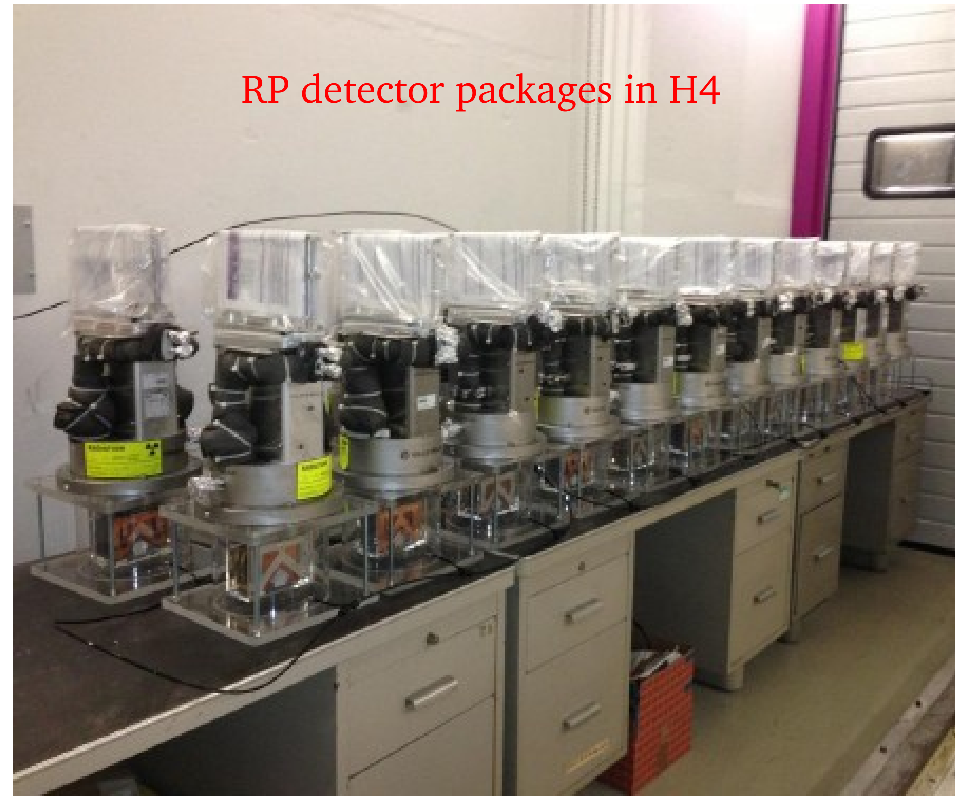
2. Studies on the optimization of multi-track reconstruction: the FAR RP station at 210m will be relocated tilted by ~8° (ghost tracks suppression)



TOTEM consolidation programme during LS1 (2)

4. All RP stations and packages already dismounted, and stored in H4. ECR for relocation ready





5. Next ~two months consolidation activities:

Ferrite bake out for RP220m, new Ferrite material for exchange (including bake out), validation of detector packages (vacuum test and cool down in H8), movement test of the rotated RP.

TOTEM upgrade programme (1)

Physics after the consolidation:

- High β* (low- pileup) physics with improved proton resolution, acceptance and multitrack-capability.

We want to do more:

- Joint studies CMS-TOTEM on hard/semihard diffraction [p+p → p + X +p].
- Need statistics (high pileup), but impossible to distinguish multiple vertex with the current RPs.

PROPOSAL:

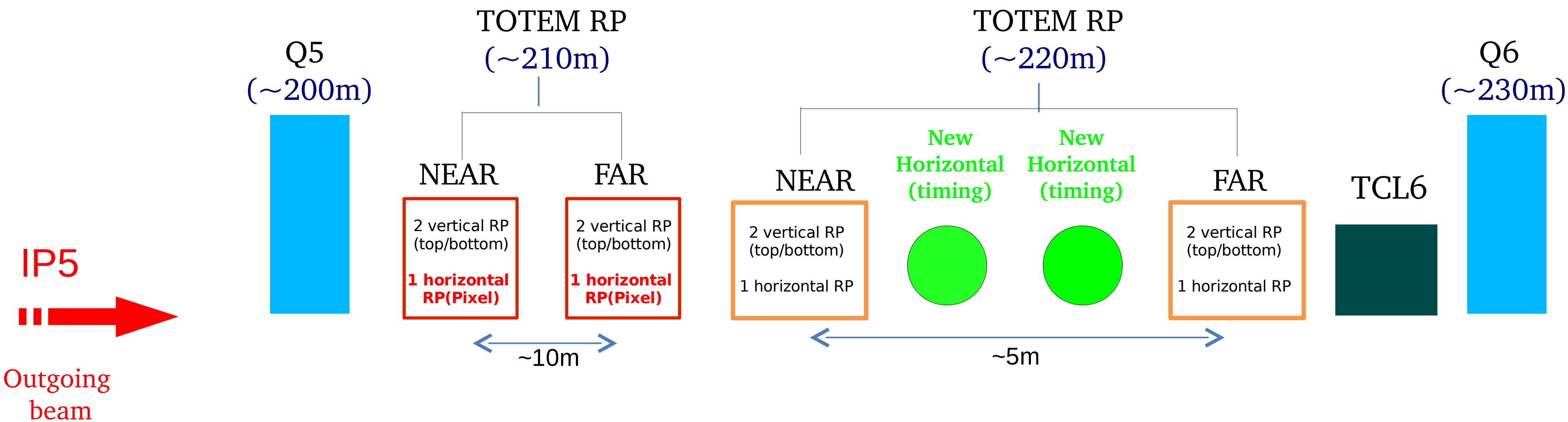
- Recognize the vertex by measuring the time of flight differences of the protons with timing detectors.
- Timing detectors will also improve the physics capability at moderate pile-up (high-β*, vertical pots).

STRATEGY:

UPGRADE of Roman Pot stations:
– Installation of 2 additional horizontal RP with a new cylindrical design @ 220 m

UPGRADE of Roman Pot detectors:
– Integration of new 3D pixel detectors in the horizontal RPs at 210 m
– Integration of new timing detectors in the new horizontal RPs between the 220m stations

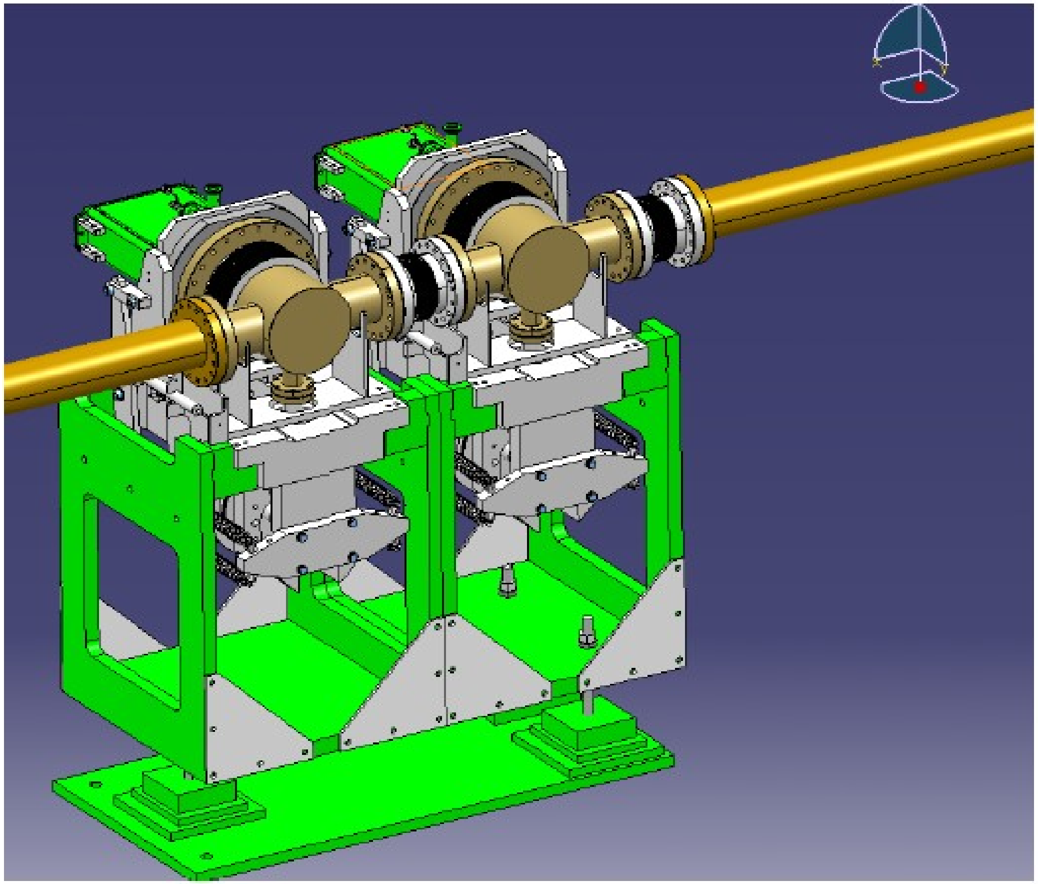
(FULLY) upgraded scenario:

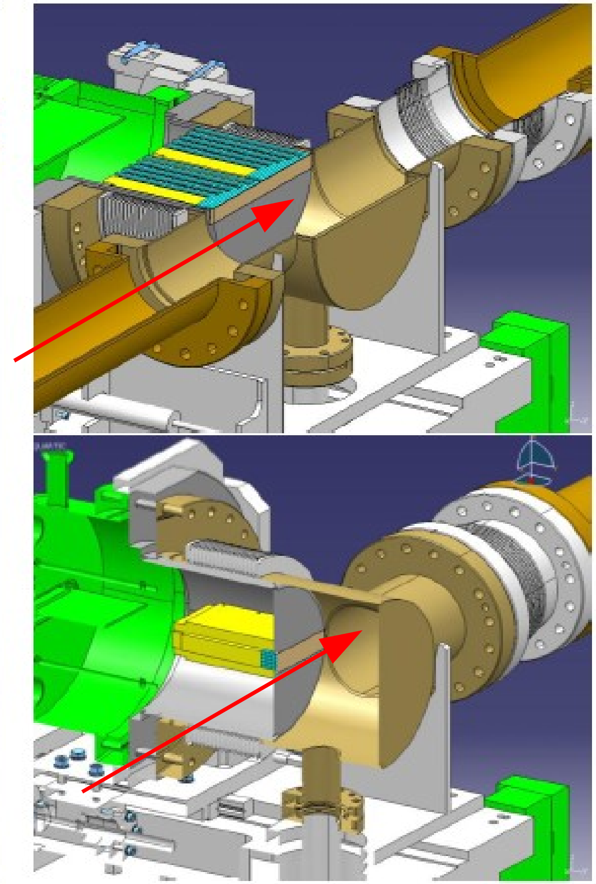


IMPORTANT: Highly flexible/scalable system!
Different combinations of tracking+timing can be used to make different physics.

TOTEM upgrade programme (2)

New cylindrical RP to host the timing detectors:





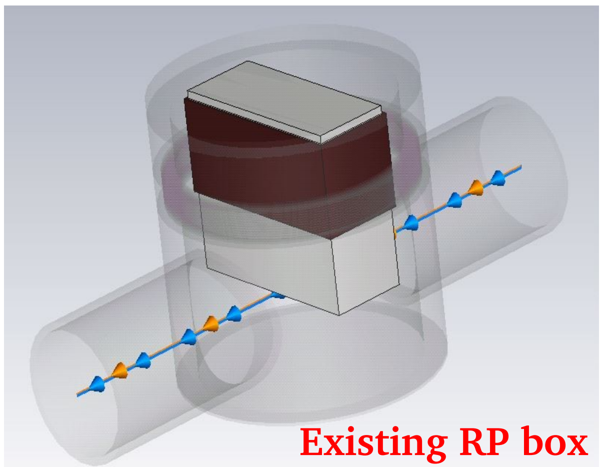
Timing detector TECHNOLOGY: Cherenkov detector + SiPM, σ_T~20 ps

[M.G. Albrow et al., "Quartz Cherenkov Counters for Fast Timing: QUARTIC", JINST 7 (2012) P10027]

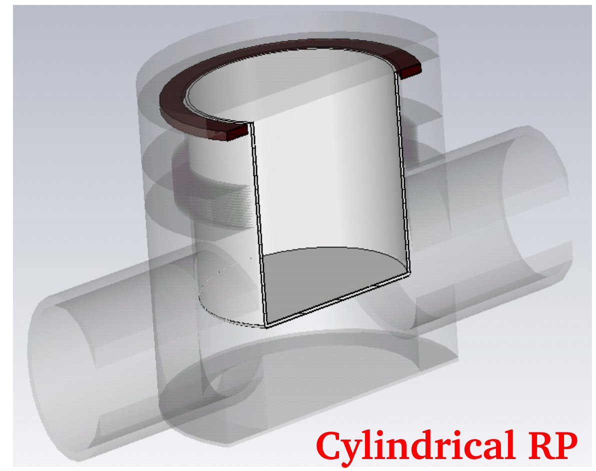
TOTEM upgrade programme (3)

To insert RPs with high intensity beam, it is important to have an optimized RP impedence (reduce the heating and the feedback on the beam).

A source of impedence for the beam is due to the empty space of the vacuum cavity between the RP box and the cylindrical flange

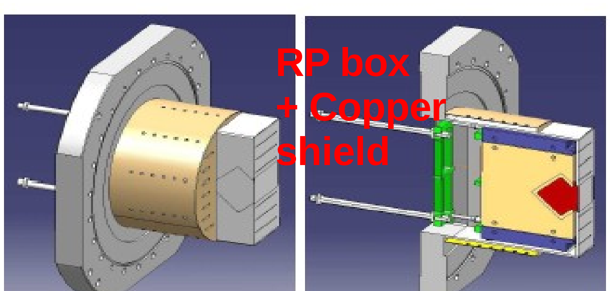


A cylindrical RP can fill the cavity: better RF behaviour and more space available inside the RP to store the timing detector.



Cylindrical RP with Ferrites shown a reduced beam power-lost:

- Factor >5 **better** in the beam power-lost with respect to the box-shape configuration **(at 1 mm from the beam).**
- Factor 35% better (at 1 mm) in the effective longitudinal impedence.



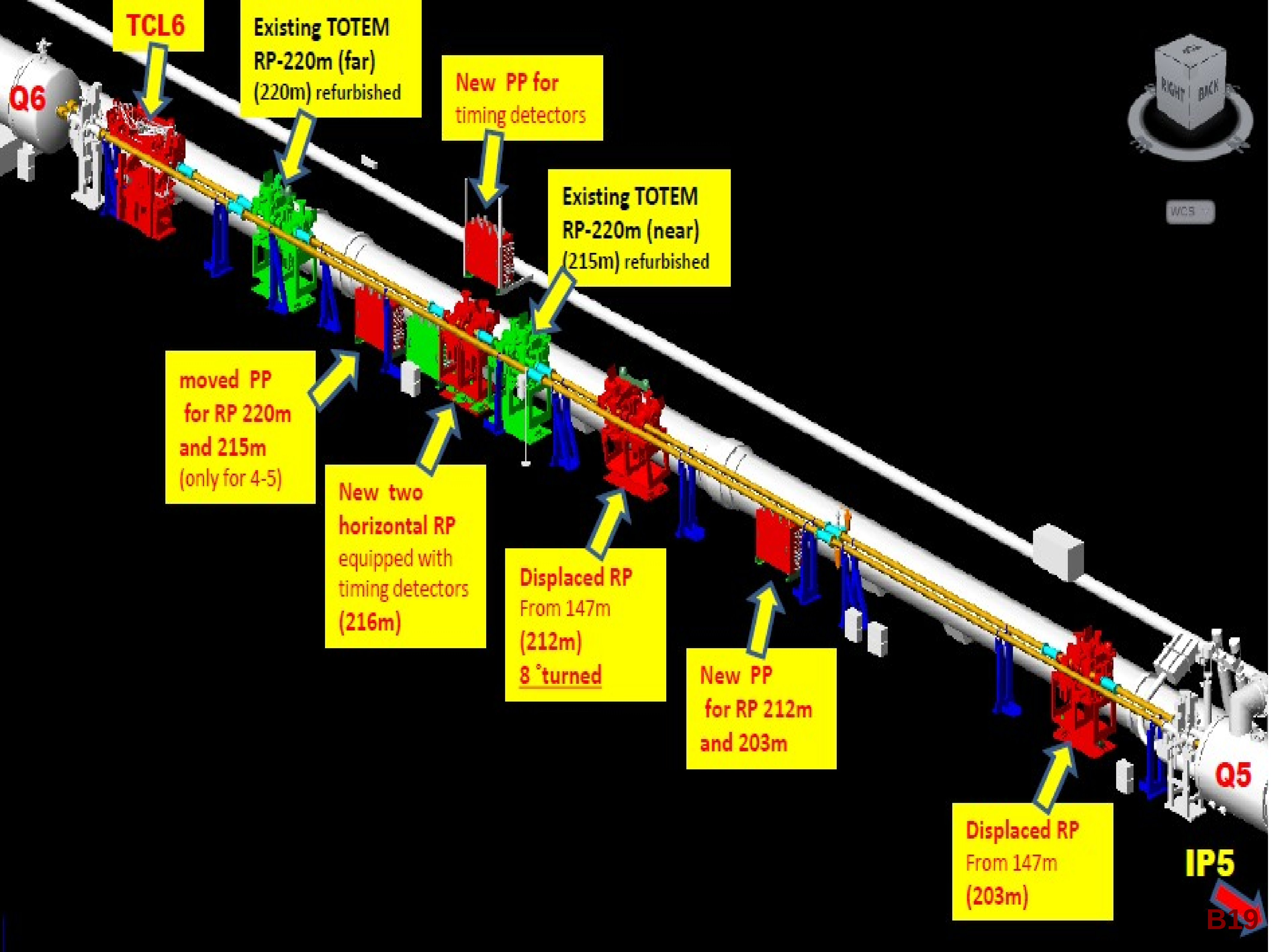
For the far-horizontal RP at 210m a proper cylindrical copper shield has been studied for the impedence reduction.

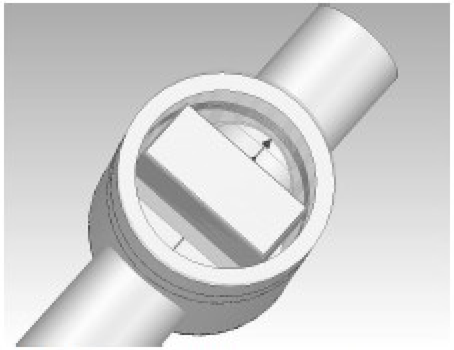
Conclusions and outlooks

- **Many physics analysis well advanced in TOTEM:**
  - Study of the Hadronic/Coulomb interference, measurement of ρ at 8 TeV
  - Measurement of the soft single diffractive cross section in the range $3.4<M_{SD}<1100$ GeV at 7 TeV
  - Measurement of the double diffractive cross section at 7 TeV ($3.4<M_{DD}<8$ GeV)
  - Measurement of the forward charged particle $dN/d\eta$ distribution with T2 at 8 TeV (CMS+TOTEM analysis) for different inelastic event categories
  - Other combined analysis with CMS are ongoing (soft CD and CD with dijets, SD & dijets, pA....)

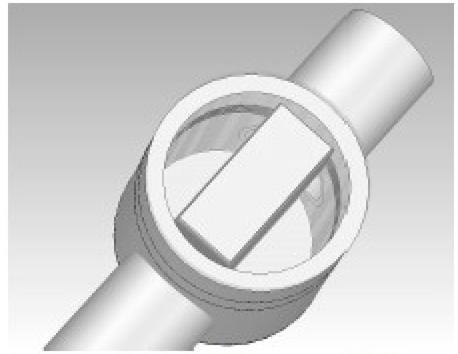
- **Consolidation and upgrade program:**
  - **Consolidation:** RP @147m and services removed, position of relocated RP and services confirmed, rotation of RP decided (mechanical design ready). Test of RP vacuum, movements and Ferrite ongoing in H4
  - **Upgrade:** introduce timing and pixel RP detectors to cope with the pileup (incremental strategy). RF optimization of cylindrical RP (and box shielding) finished, production drawing for cylindrical RP under approval, TOTEM upgrade proposal on delivery at this LHCC

Thank you for your attention

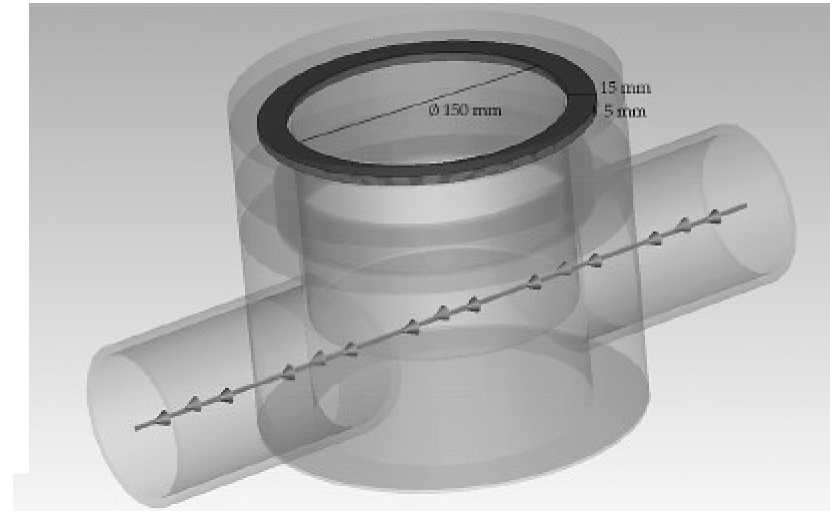

TCL6
Existing TOTEM RP-220m (far) (220m) refurbished
New PP for timing detectors
Existing TOTEM RP-220m (near) (215m) refurbished
Q6
RIGHT BACK
WCS
moved PP for RP 220m and 215m (only for 4-5)
New two horizontal RP equipped with timing detectors (216m)
Displaced RP From 147m (212m) 8 ˚turned
New PP for RP 212m and 203m
Displaced RP From 147m (203m)
Q5
IP5



(a) Top view of the present setup.



(b) Top view of the setup with the rotated RP.



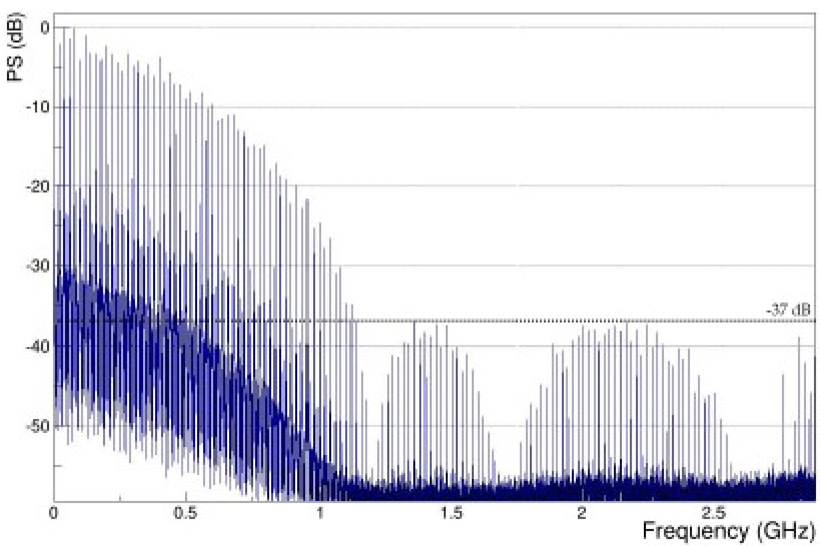


Figure 1: Power spectrum measured on the LHC before LS1 []. It should be noted that the spectrum is more than 37 dB attenuated above 1.2 GHz.

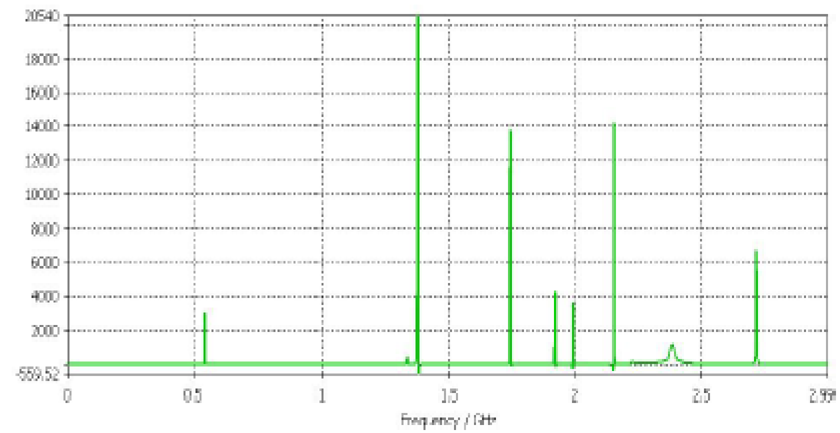
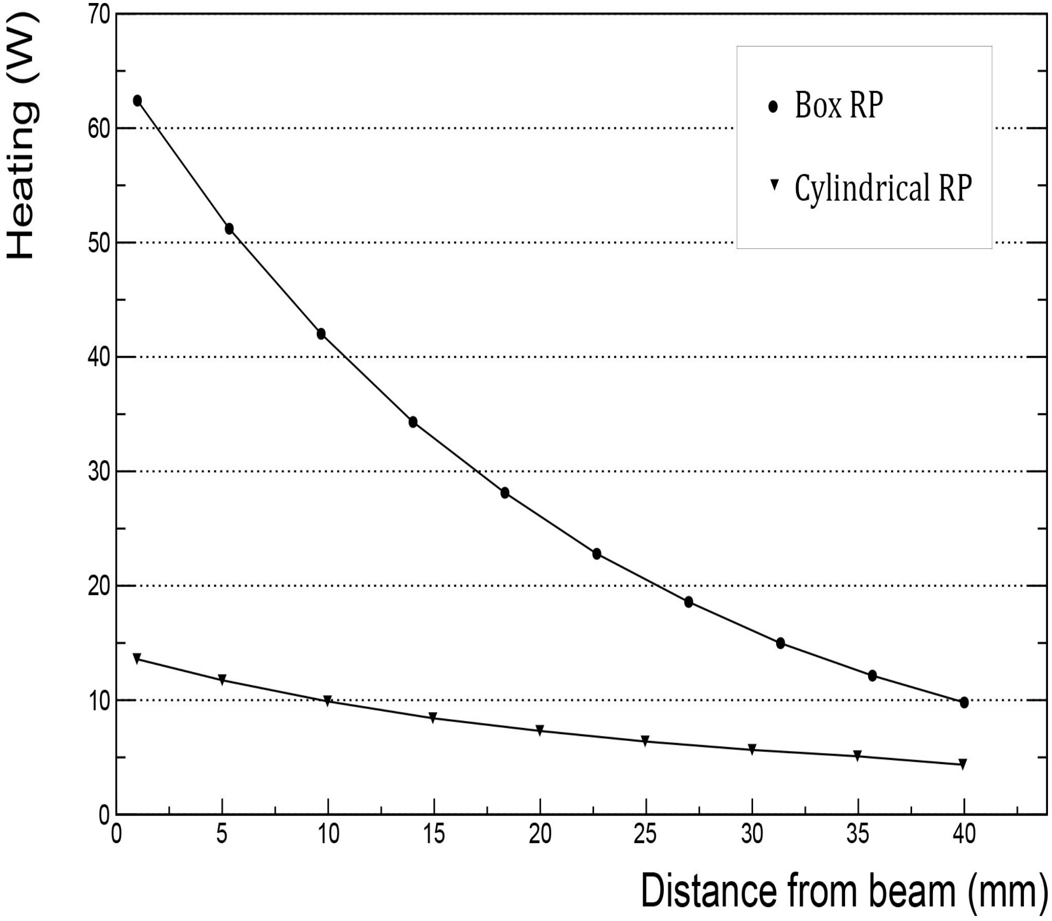
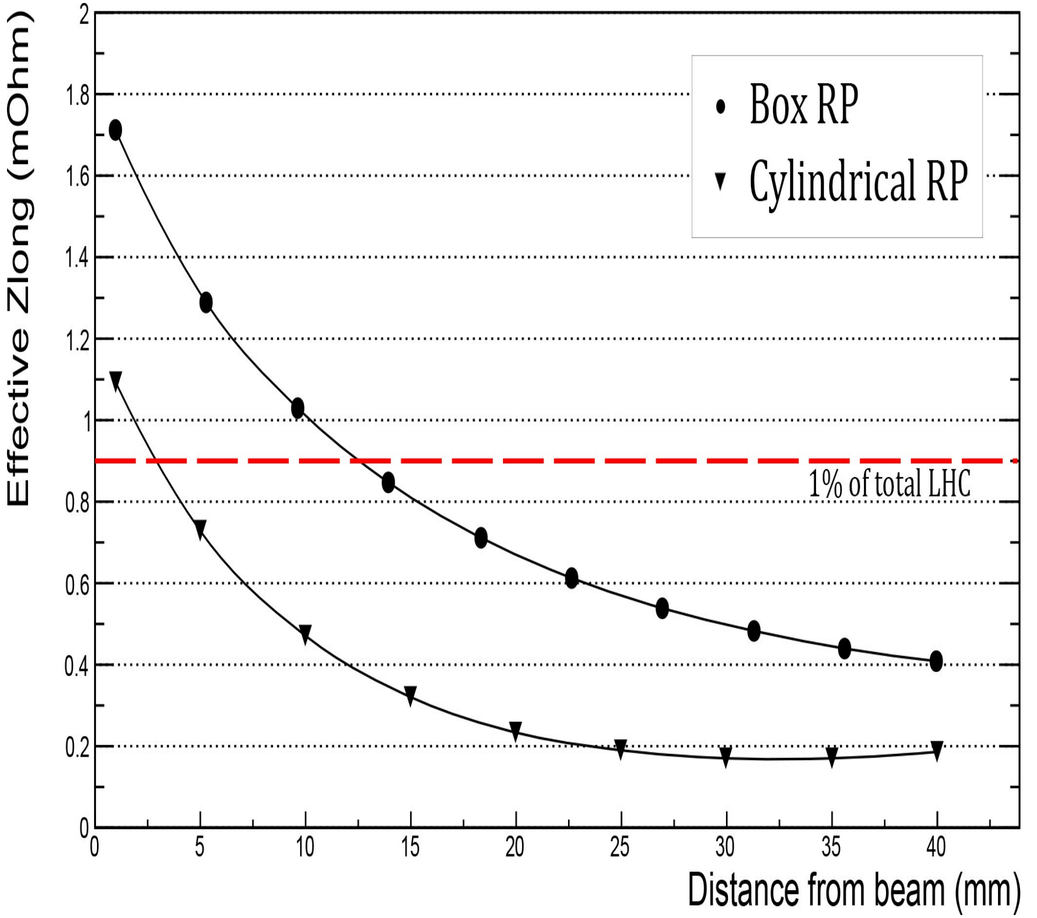
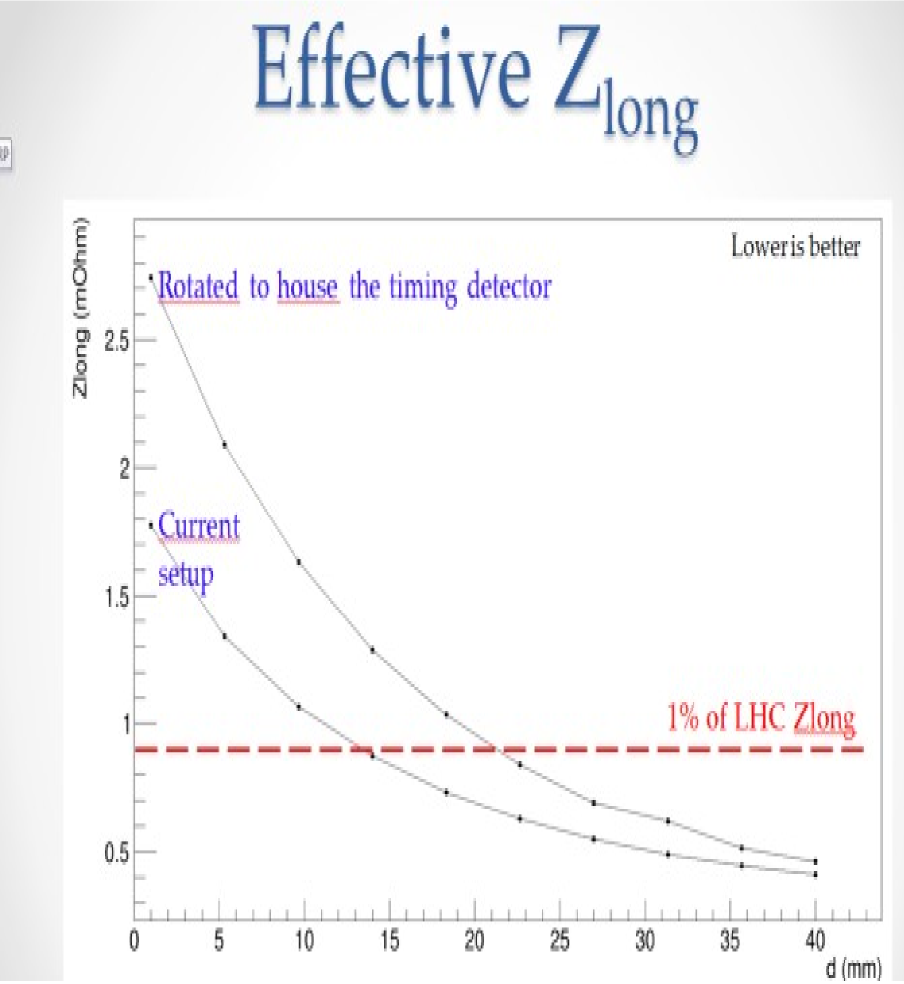


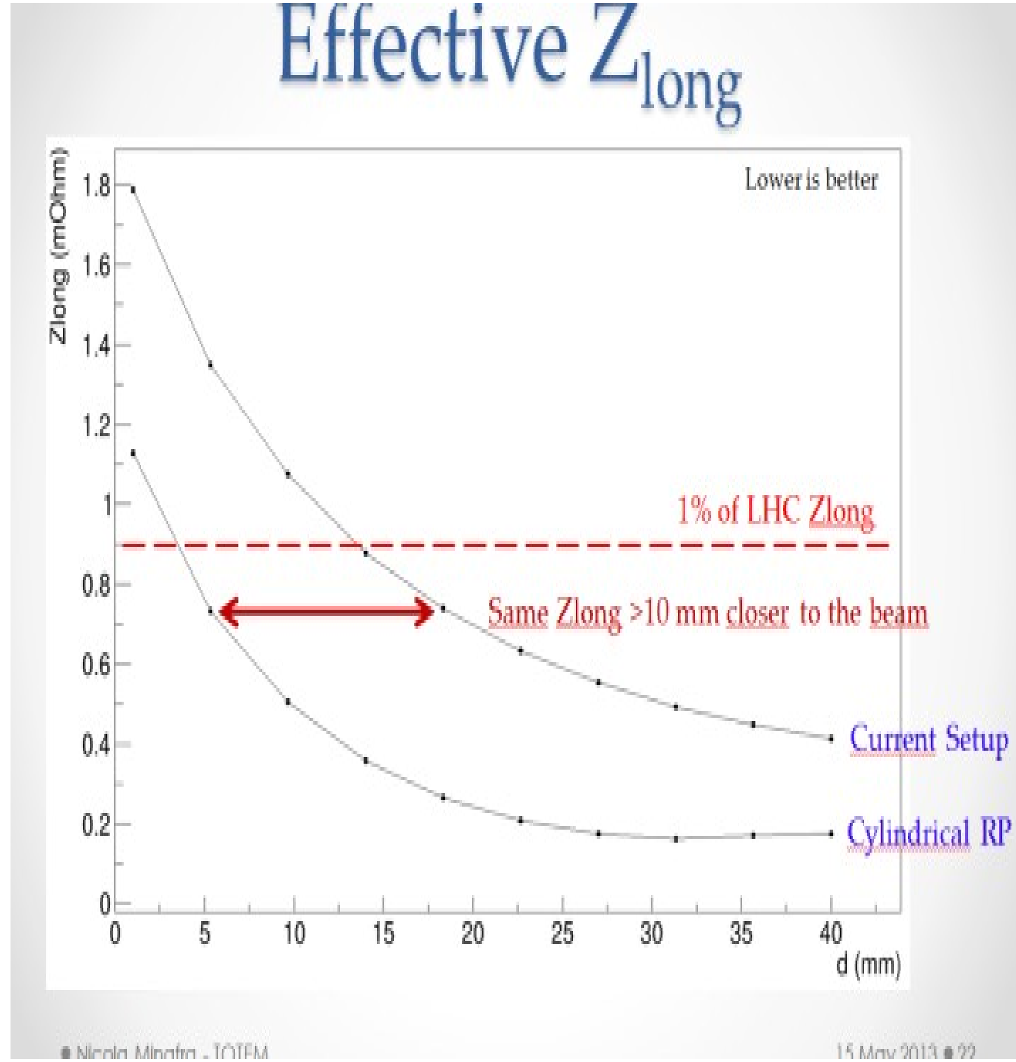
Figure 6: Simulated $\Re[Z_{long}]$ of the box shaped RP without ferrite. The resonances at 540 MHz and 1380 MHz are due to the cavity between the flange and the box and, because of the power spectrum of the LHC, they are the main problem of this setup.

Heating and impedence









RP 220 m near inserted on 16.11.2012 2.0 mm @ displaced beams-> no LHC instabilities were observed

One can assume to have problems il BLM signals: now we have it simulated in G4 to exactly match the 2012 data.

At least one H-cyl RP before end of LS1.

	Distance from the beam [mm]	$Z_{\text{long}}^{\text{Eff}}/n$ [mΩ]	fraction of total LHC (90 mΩ)	$\overline{Z}_{\text{trans}}^{\text{Eff}}$ [kΩ/m]	fraction of total LHC (25 MΩ/m)	Heating [W]
Box RP	1	1.7	1.9 %	80	∼ 0.3 %	62
	5	1.3	1.4 %			52
	40 (garage)	0.41	0.45 %			10
Cylindrical RP	1	1.1	1.2 %	60	∼ 0.2 %	13
	5	0.73	0.81 %			11
	40 (garage)	0.18	0.20 %			4
Shielded RP	1	1.2	1.3 %	70	∼ 0.3 %	10
	40 (garage)	0.30	0.33 %			2

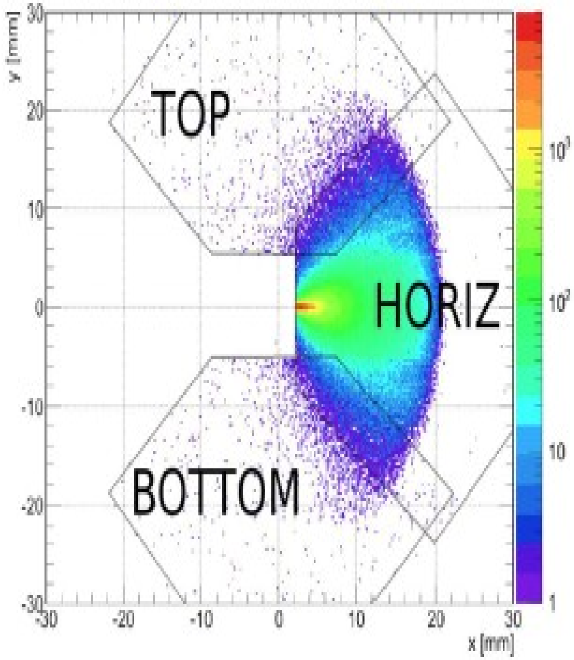
Table 2: *Main results of the simulation of the present box RP (Box RP), the cylindrical RP (Cylindrical RP), and the Box RP with Shield. The effective impedances are compared with the total values estimated for the present LHC impedances.*

$$y(s) = v_y(s)\cdot y^* + L_y(s)\cdot \Theta_y^*$$
$$x(s) = v_x(s)\cdot x^* + L_x(s)\cdot \Theta_x^* + \xi\cdot \boxed{D(s)}$$

$\xi = \Delta p/p$ — dispersion shifts diffractive protons in horizontal direction

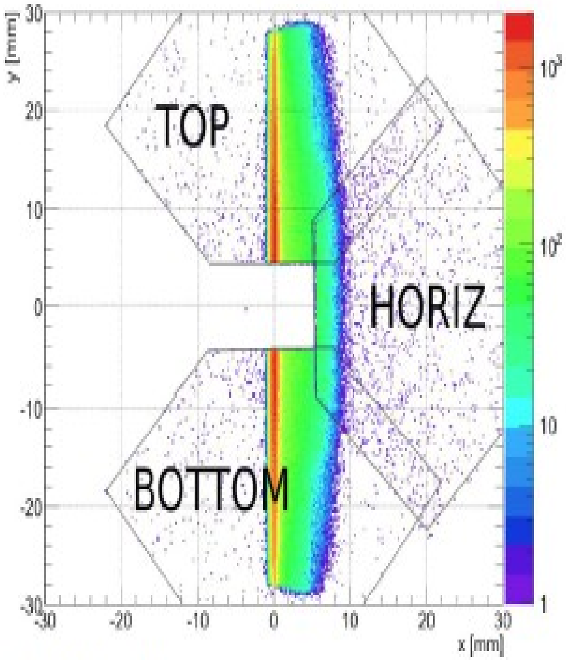
Generally $v_{x,y}$, $L_{x,y}$ & D_x functions of ξ → reconstruction non-linear problem

Low β^*: 0.5 – 3 m, ξ > 2%

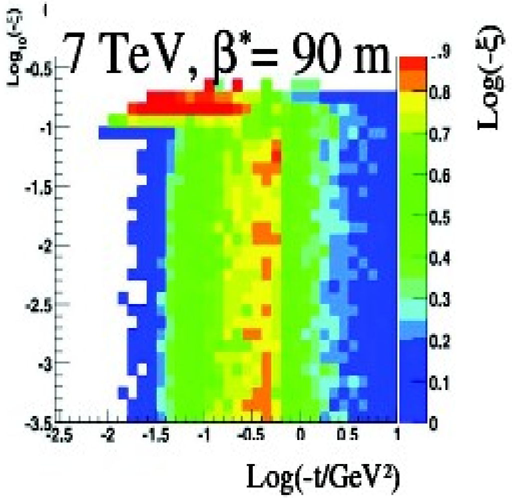


- L_x & L_y low, protons shifted due to ξ
- vertex not critical: small transverse σ_{beam}

β^*= 90 m, full ξ-coverage, $|t_y|$ > 0.01 GeV²



- L_x=0, L_y large
- large transverse σ_{beam} (~200 μm) → v_x, v_y important (worse ξ-resolution)
- CMS vertex improves ξ-resolution



β^* = 90 m

L ≈ 10^{30} cm^{-2}s^{-1}

elastic acceptance

$3\cdot 10^{-2}$ GeV² < $-t_y$ < 10 GeV²

resolution

$\sigma(\Theta)$ = 1.7 μrad

$\sigma(\xi) = 6 – 15 \cdot 10^{-3}$

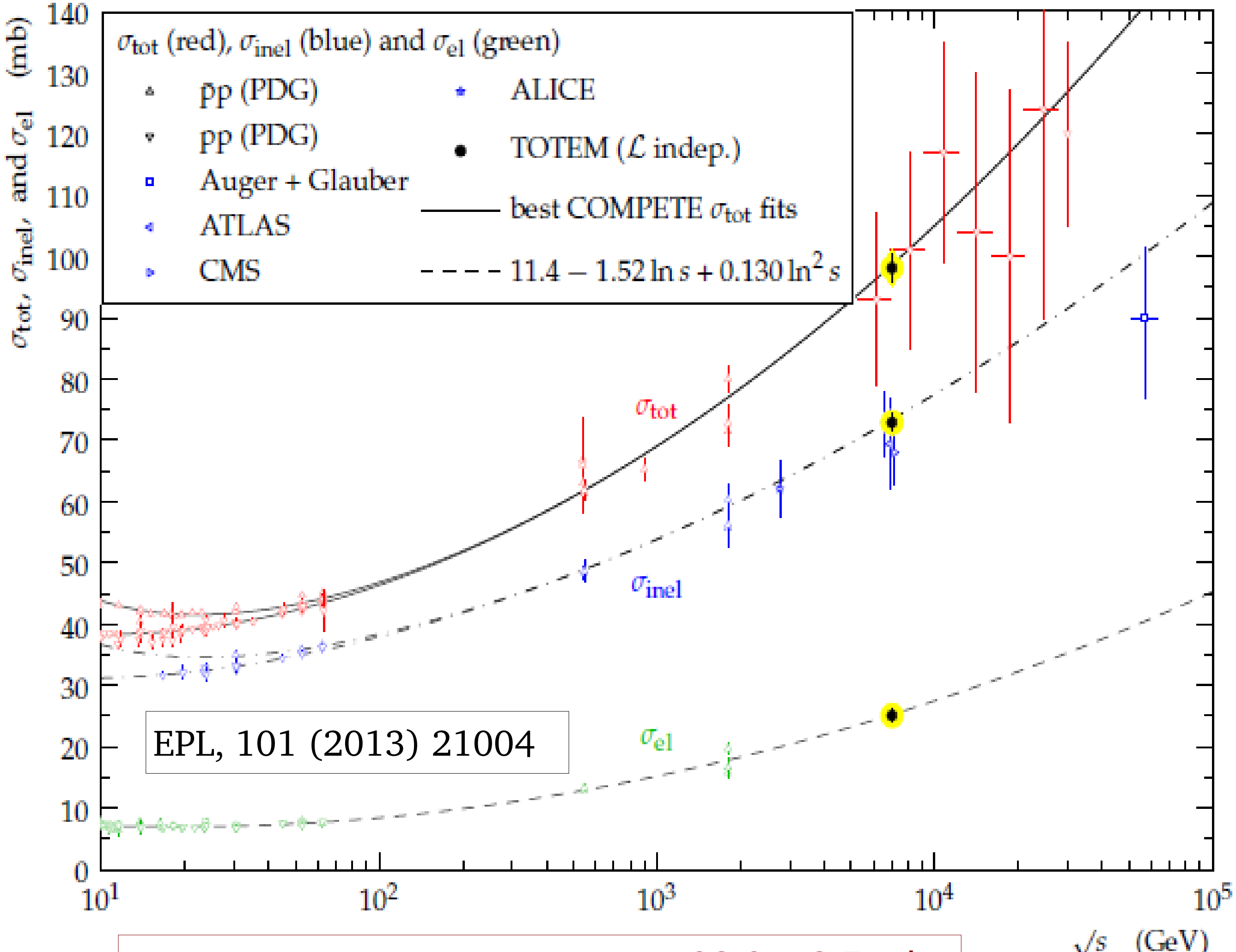
all ξ seen, universal optics

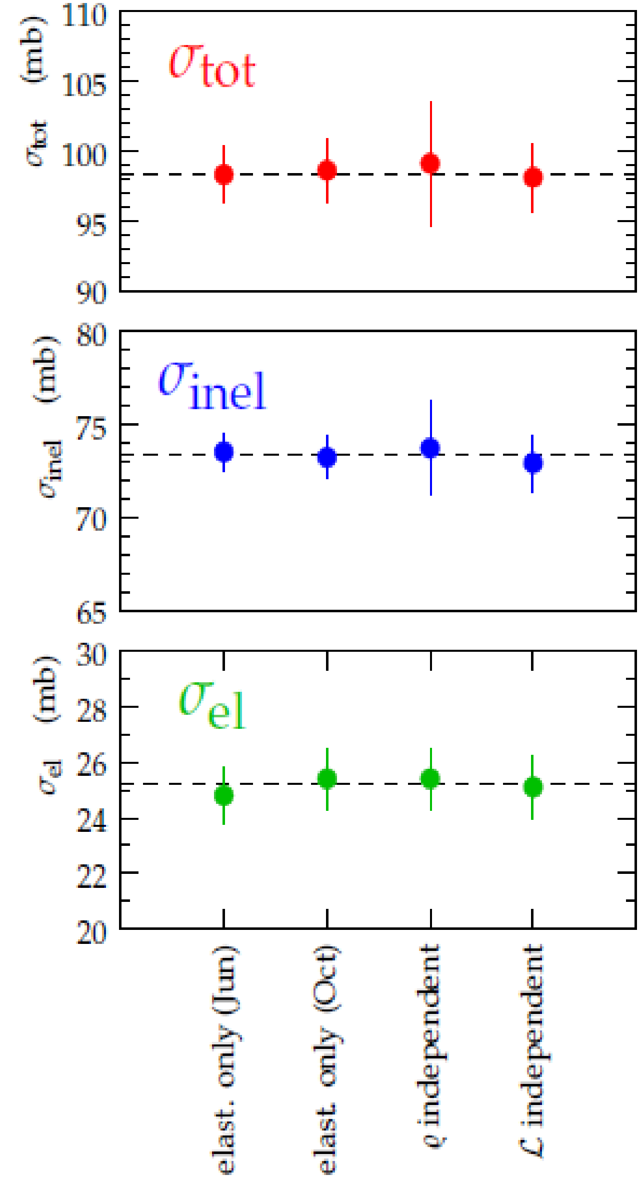
diffraction, mid |t| elastic scattering, total cross-section

Three cross section measurements (7 Tev): results

- Totem measurements compatible with the COMPETE best fit.
- All four measurements give consistent results.

Precise pp measurements are valuable for p-Air x-sect estimates in CR Physics





Lumi-independent cross sections:

σ_{TOT} =98.0 ± 2.5 mb

σ_{INEL} =72.9 ± 1.5 mb

σ_{EL} =25.1 ± 1.1 mb

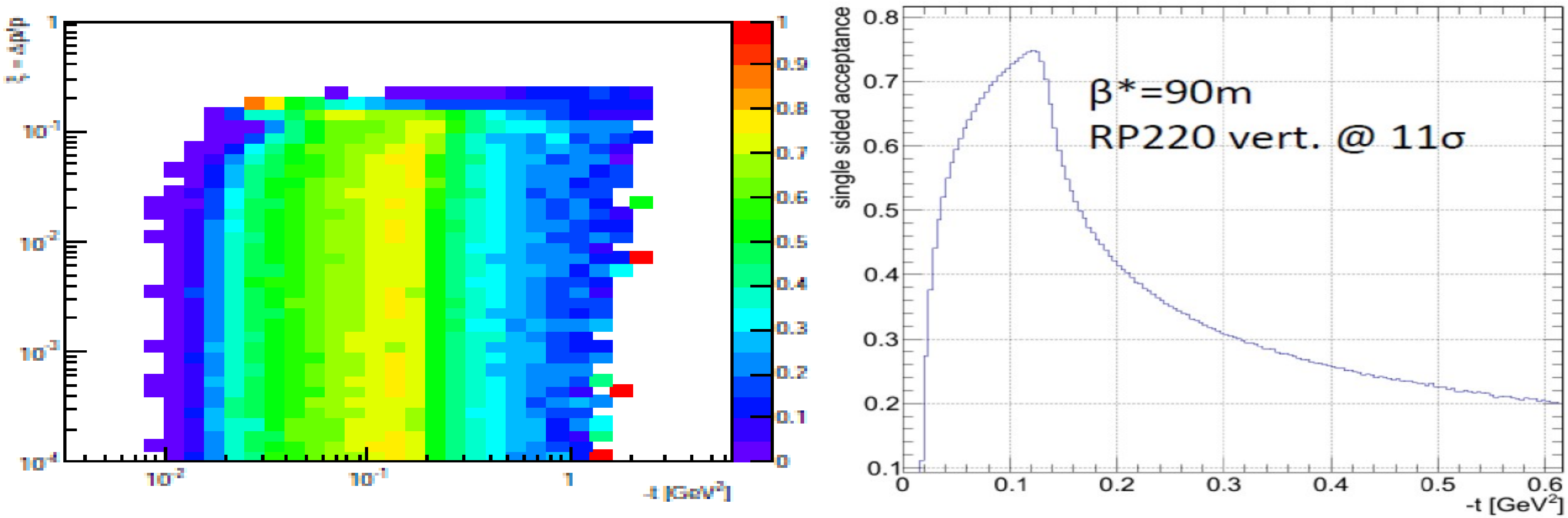


Figure 21: *Left: acceptance of the RP 220-F for diffractive protons at* $\beta^* = 90\,m$ *in* t *and* ξ*. Right: projection on the* t*-axis.*

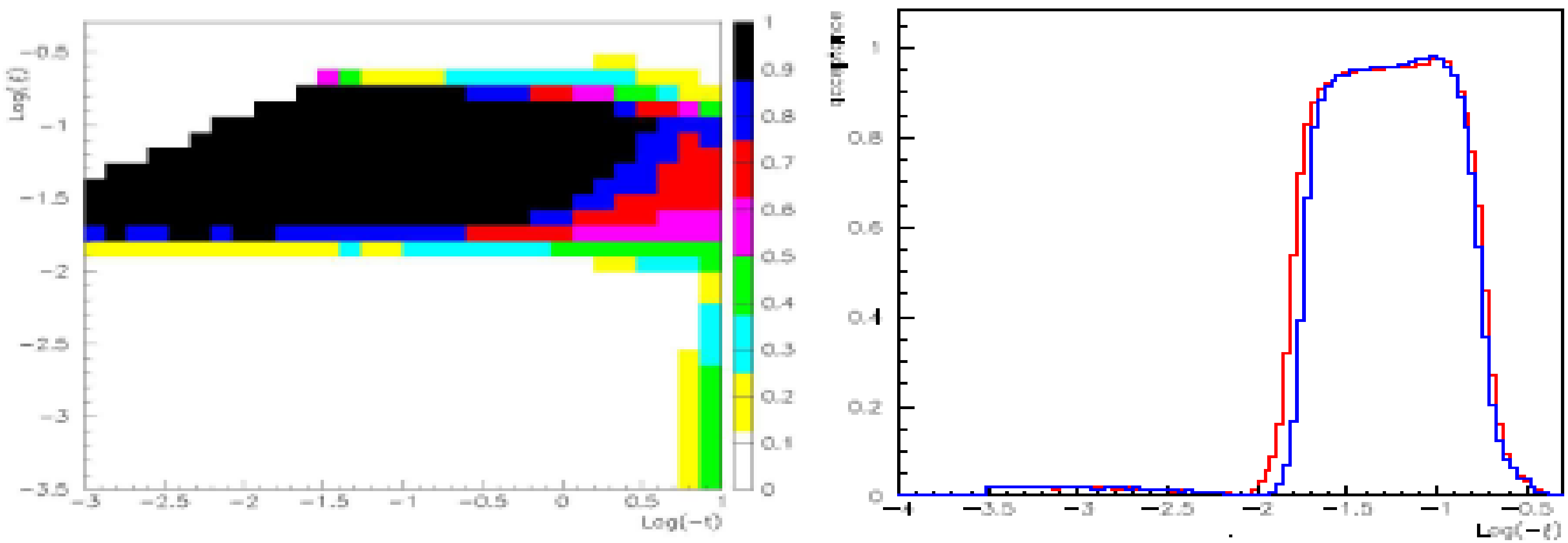


Figure 22: *Left: acceptance of the RP 220-F for diffractive protons at* $\beta^* = 0.5\,m$ *in* t *and* ξ *(for beam 1). Right: projection on the* ξ*-axis for beam 1 (red solid) and beam 2 (blue dash-dotted).*

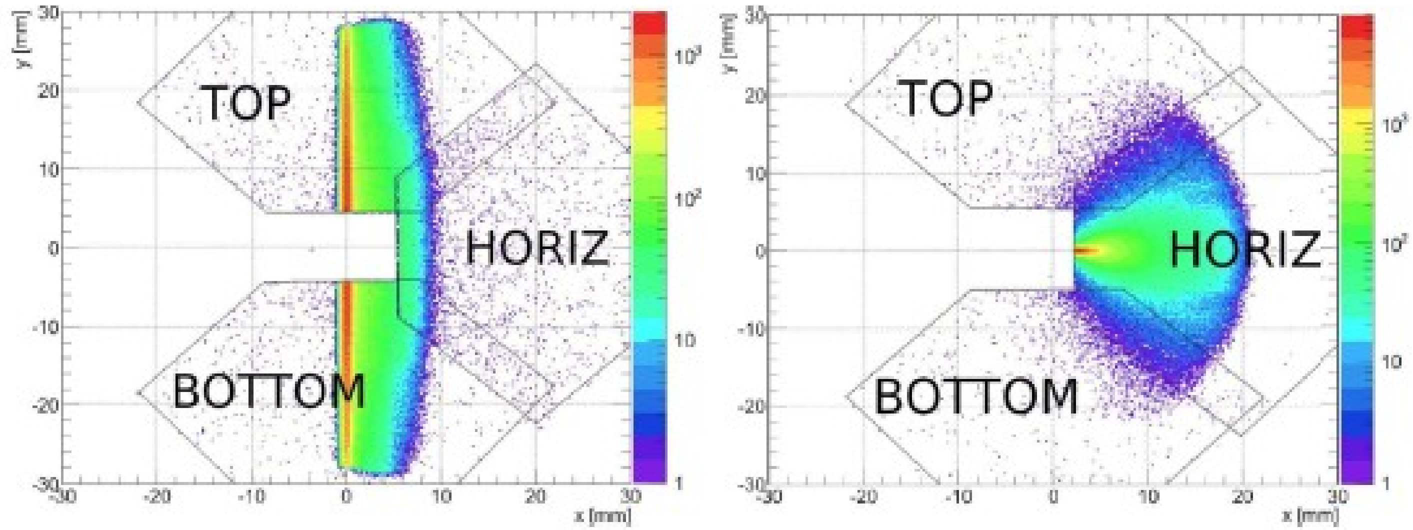


Figure 20: *Simulated hit maps in the 3 pots of the RP unit 220-F for $\beta^* = 90\,m$ (left) and $\beta^* = 0.55\,m$ (right).*

β^* [m]	s [m]	$\|t\|_{min}$ [GeV^2]	$\|\xi\|_{min}$	M_{min} [GeV]
90	202	0.04 for $\|\xi\| < 0.12$ 0 for $\|\xi\| > 0.12$	0.12 for $\|t\| < 0.04\,\mathrm{GeV}^2$ 0 for $\|t\| > 0.04\,\mathrm{GeV}^2$	1700 for $\|t\| < 0.04\,\mathrm{GeV}^2$ 0 for $\|t\| > 0.04\,\mathrm{GeV}^2$
	220	0.04	0 for $\|t\| > 0.04\,\mathrm{GeV}^2$	0 for $\|t\| > 0.04\,\mathrm{GeV}^2$
11	202	1.3 for $\|\xi\| < 0.032$ 0 for $\|\xi\| > 0.032$	0.032	450
	220	2.1 for $\|\xi\| < 0.037$ 0 for $\|\xi\| > 0.037$	0.037	510
0.55	202	6.5 for $\|\xi\| < 0.031$ 0 for $\|\xi\| > 0.031$	0.031	440
	220	7.0 for $\|\xi\| < 0.019$ 0 for $\|\xi\| > 0.019$	0.019	260

Table 7: *Acceptance in t, ξ, and M in DPE, at the RP stations 210-N and 220-F. The RPs are assumed to be placed at $11\,\sigma$ from the beam centre.*