# TOTEM consolidation & upgrade program


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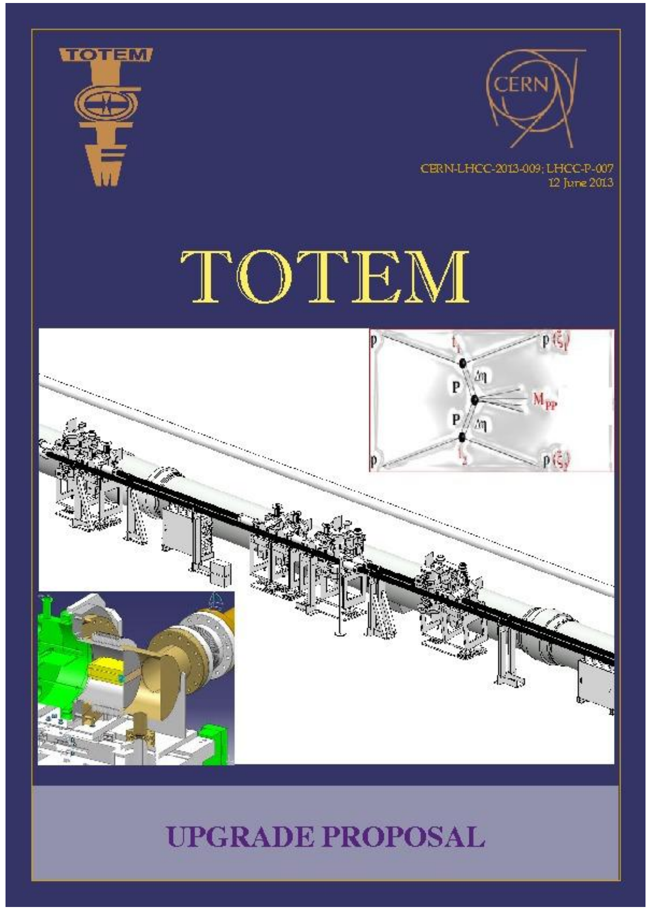
on behalf of
**TOTEM collaboration**

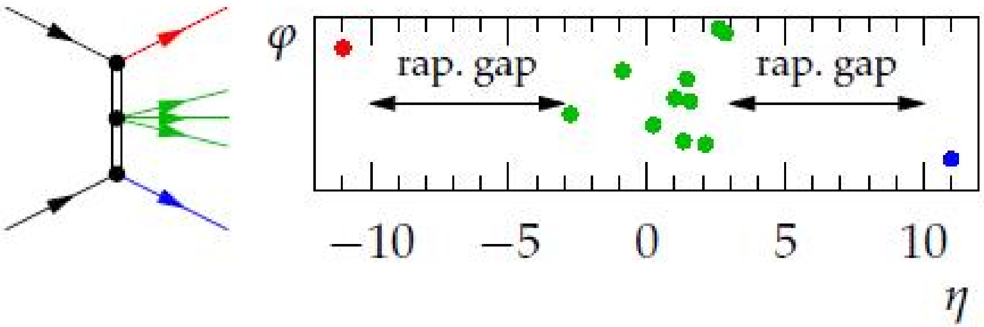

**EDS'13 workshop**

- **Physics**
- **Optics**
- **Instrumentation**




CERN-LHCC-2013-009; LHCC-P-007

# Central diffraction
# (“Double Pomeron Exchange”)

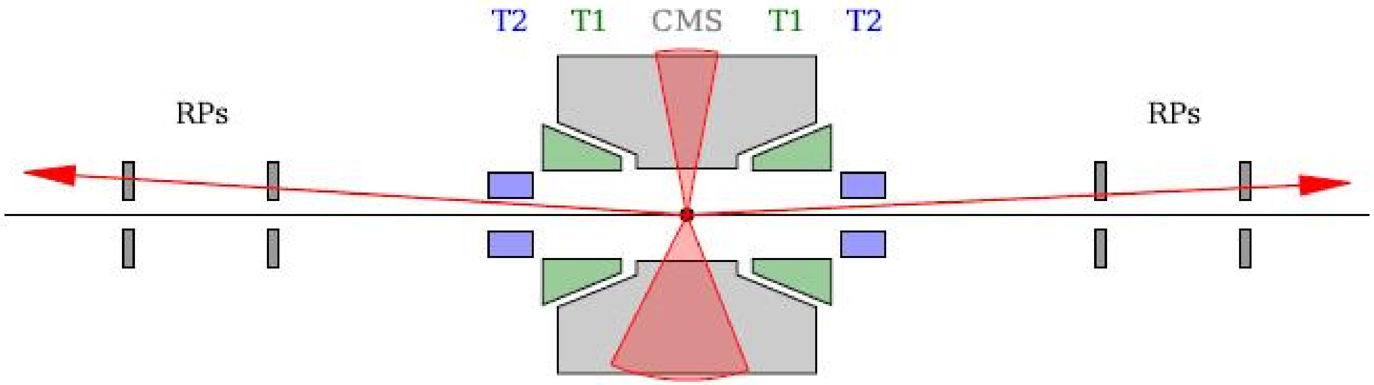



- both p survive with $\xi_1$, $\xi_2$ ($\xi = \Delta p/p$)
- central diffractive mass M
- 2 rapidity gaps $\Delta\eta_1$, $\Delta\eta_2$

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

**CMS + TOTEM:**

- **Large pseudorapidity coverage**
- **Redundancy forward vs central: M, $p_T$, vertex, $\Delta\eta_{1,2}$**



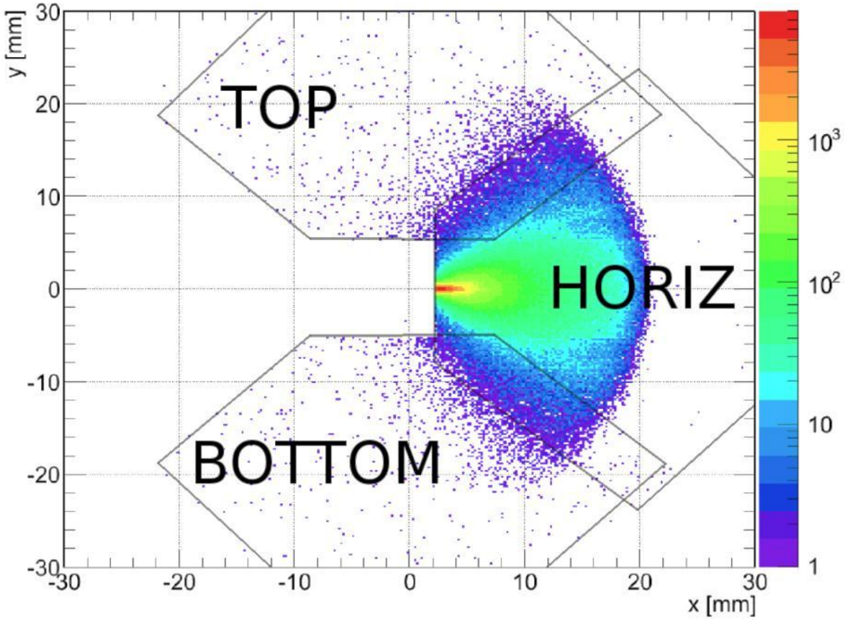

Large η-coverage:

- CMS: -5.5<η<5.5
- T1: 3.1 < |η| < 4.7
- T2: 5.3 < |η| < 6.5
- FSC: 6 < |η| < 8

# Different LHC Optics

Hit maps of simulated diffractive events for 2 optics configurations

**Standard low β* runs:**



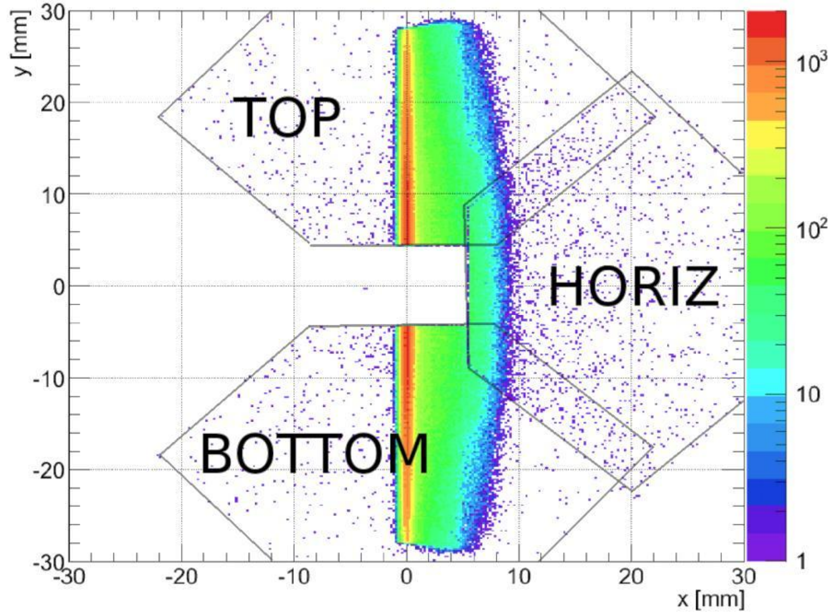

diffractive protons in **horizontal** RP

$\mu$ = 25 – 50 (~5 with reduced $N_p$/bunch)

low cross-section processes (hard diffraction) – continuous running (with reduced $N_p$/bunch?)

**~ $10^{34}$ cm$^{-2}$ s$^{-1}$**

**Special high β* runs:**




diffractive protons in **vertical** RP

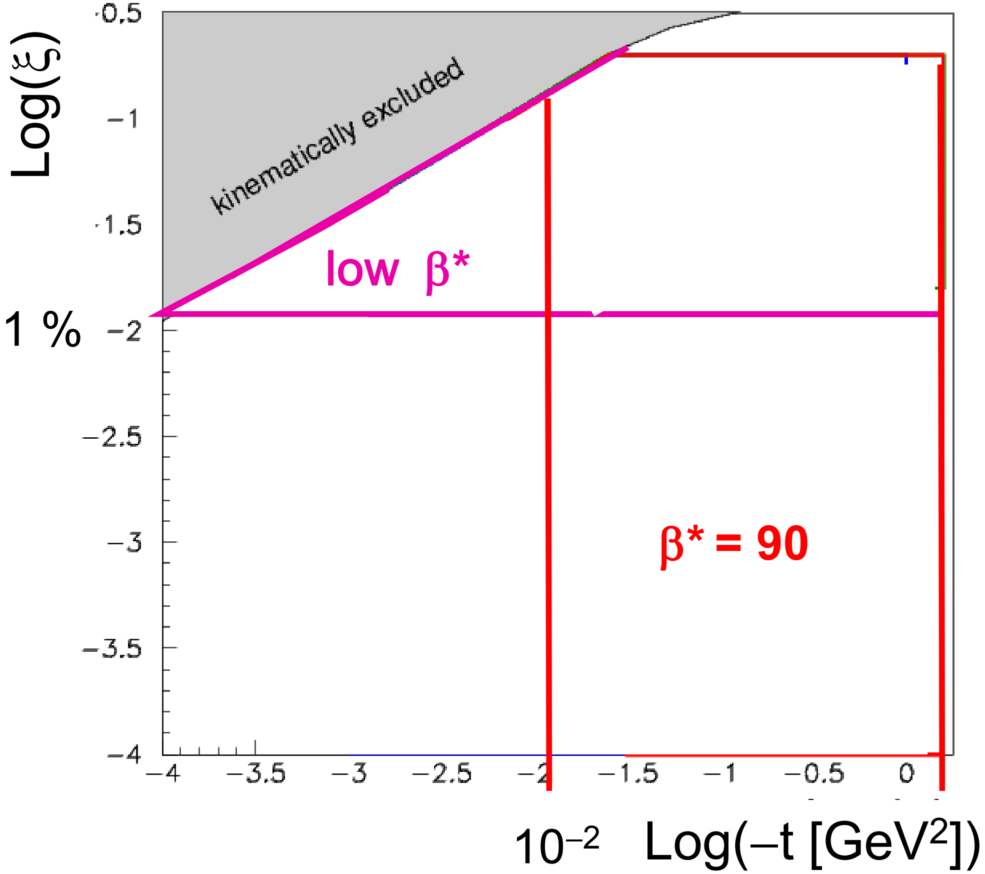
$\mu$ = 0.05 – 0.5

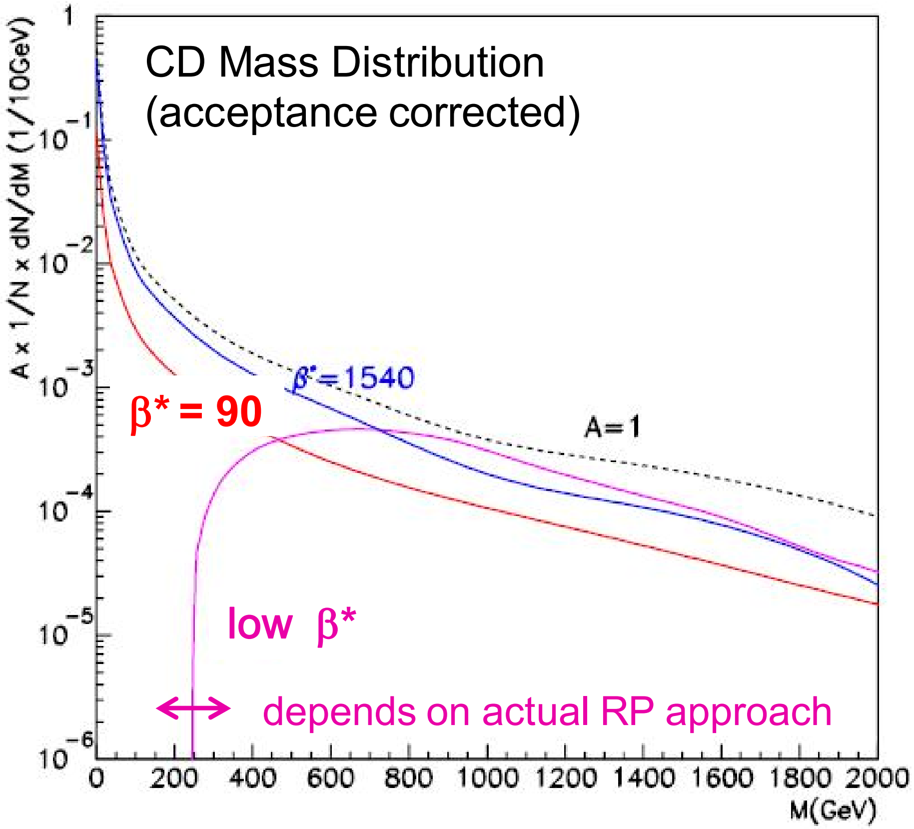
high cross-section processes – dedicated short runs with optimized conditions

**~$10^{30\text{-}32}$ cm$^{-2}$ s$^{-1}$**

$$\mathcal{L} \propto \frac{1}{\beta^*}$$

# Proton & CD mass acceptance

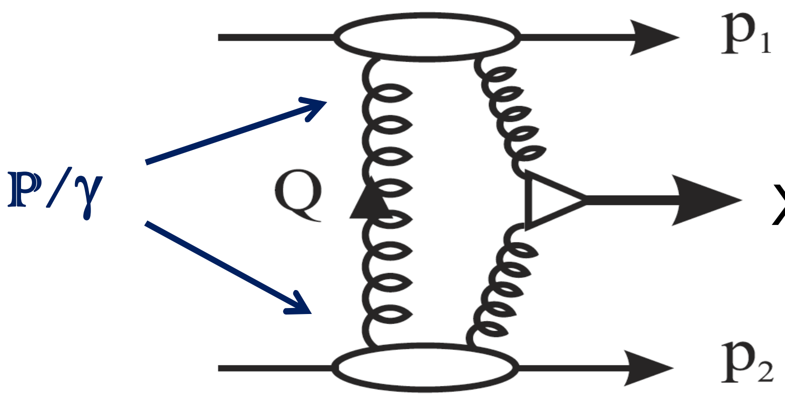



| $\beta^*$ [m] | $\sigma(\Theta_x^*)$ [$\mu$rad] | $\sigma(\Theta_y^*)$ [$\mu$rad] | $\sigma(t)$ [GeV$^2$] | $\sigma(\Phi^*)$ [rad] | $\sigma(\xi)$ | $\sigma(M)$ [GeV] |
|---|---|---|---|---|---|---|
| 90 (no vtx.) | 17 | 2.3 | $0.22\|t\|^{0.67}$ | $0.075/\|t\|^{0.59}$ | $0.003 \div 0.006$ | $40 \div 200$ |
| 90 (w. vtx.) | 5 | 2.3 | $0.13\|t\|^{0.79}$ | $0.026/\sqrt{\|t\|}$ | 0.0012 | $10 \div 100$ |
| 0.55 | $32 \div 35$ | 30 | $0.45\sqrt{\|t\|}$ | $0.23/\sqrt{\|t\|}$ | $0.001 \div 0.007$ | $(0.025 \div 0.03)M$ |

Exception: for very low $|\xi|$ can be neglected improving $\sigma(\theta_x^*) \approx 2.3\ \mu$rad = beam divergence

# Exclusive central diffraction




($\xi_1$) ($\xi_2$)

$M^2 = \xi_1 \xi_2 s$

X at rapidity $y_X$

gg collider !

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

exchange of colour singlets with vacuum quantum numbers
$\Rightarrow$ Selection rules for system X: $J^{PC} = 0^{++}, 2^{++}$

X = $\pi\pi$, KK, $\rho\rho$, $\eta\eta$, $\chi_{c0}$, $\chi_{cb}$, di-/multijet, ? (unknown)….

$\beta^* = 90 - 0.5$ m

$\mu = 0.05 - 50$

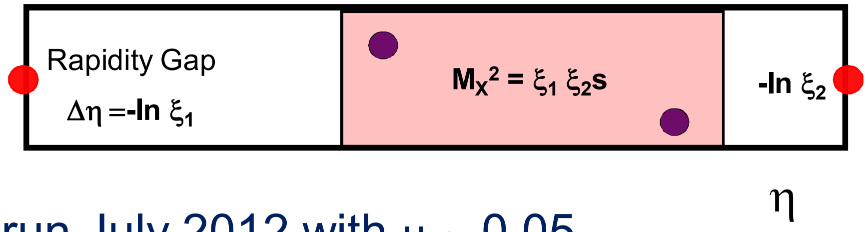
M = $\pi\pi$ threshold – ~ 2 TeV,

$\sigma = O(\mu b) - O(fb)$

Flexibility !

**Studies on-going to implement $\beta^* = 90$ m with 1000 bunches, pileup ~0.05-0.5; $\mathcal{L}$~$10^{31-32}$ $cm^2 s^{-1}$ →1-10 $pb^{-1}$/day**

# Central diffraction: TOTEM + CMS




Cuts:
- Vertex ≤ 1
- RP near edge area removed (background suppression)
- RP top-top/bot-bot topology
- $\xi > 1.5\%$, better resolution
- FSC empty (suppress background)

**Demo:** common run July 2012 with $\mu \sim 0.05$
Dijet (diproton) triggered sample: 40 $nb^{-1}$ (1 $nb^{-1}$)

Categories of events :

- Forward and central consistent (within resolution)
  $M_{CMS}$(Particle Flow) = $M_{TOTEM}$(pp)
  $p_{CMS}$(Particle Flow) = $p_{TOTEM}$(pp) → Few candidates in dijet sample; none exclusive!

- Missing "objects" in central
  $M_{CMS}$(Particle Flow + missing momentum) ≤ $M_{TOTEM}$(pp)

➢ <u>particles violating $\xi$-predicted gaps $\Delta\eta_{1,2}$</u> → No candidates in dijet sample

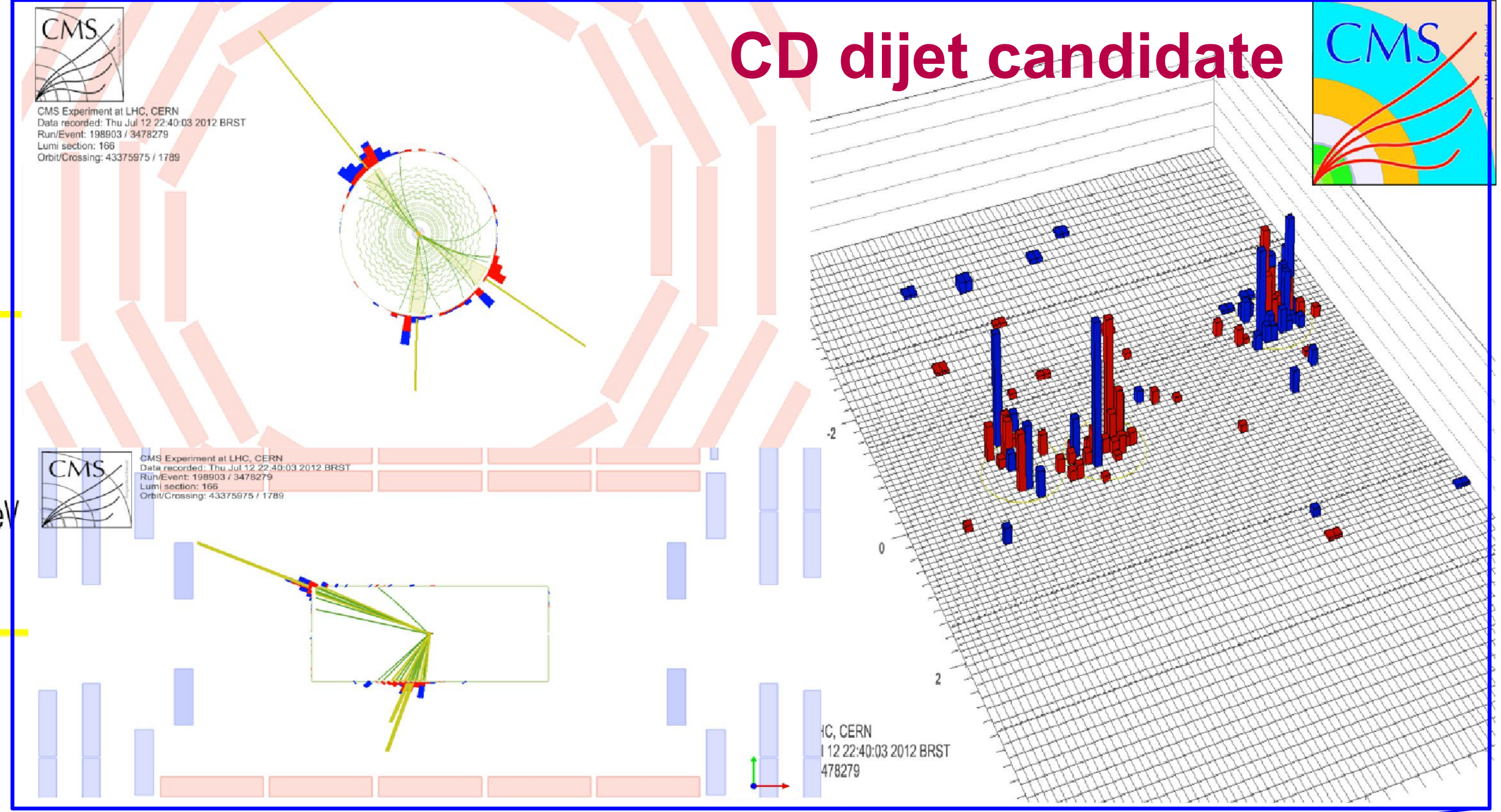
➢ <u>escaping-mass candidates</u>
Additional particles NOT observed in forward detectors where allowed/required by $\xi$-predicted gaps → Few candidates with $\Delta M \geq 400$ GeV
Real escaping energy or artifact (detector inefficiency/cracks, N*)? ZDC !

Additional particles NOT observed in forward detectors forbidden by $\xi$-predicted gaps → No candidates

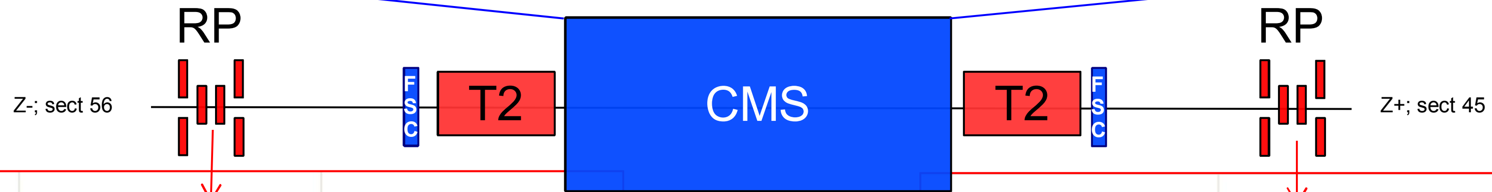
# CD dijet candidate

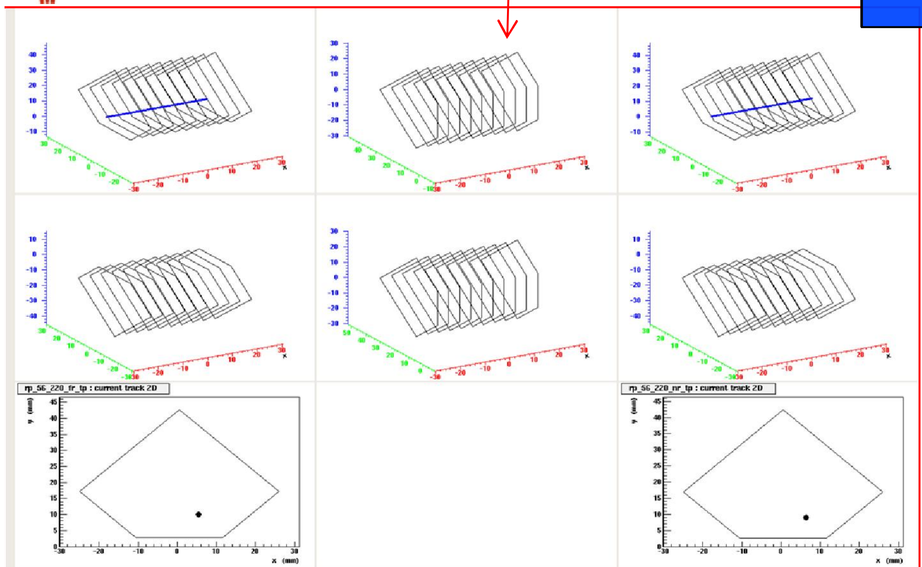
CMS + TOTEM 90m β*
Run/Event 198903/3478279
Jets $E_T$ = 65,45,27 GeV

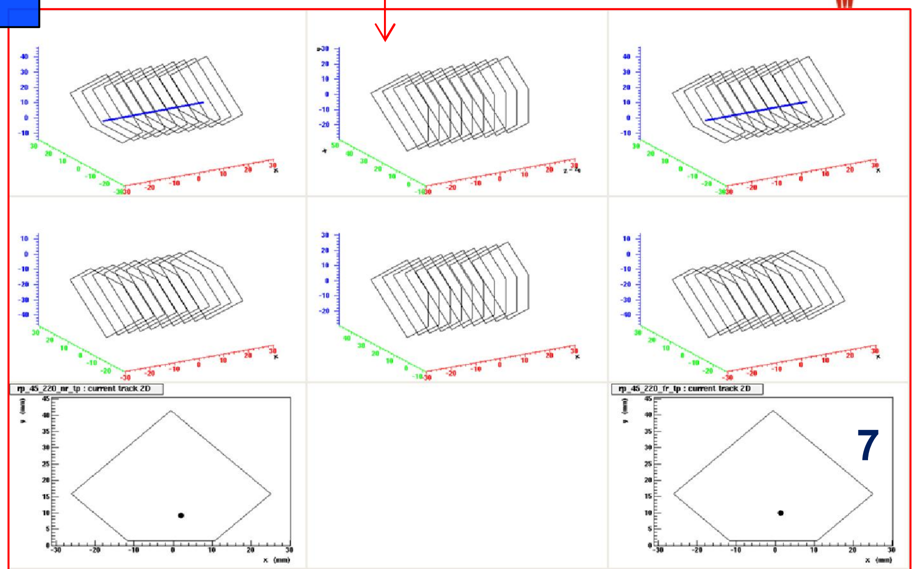
MM(pp) = 244 GeV; M(CMS) = 219 GeV
$\Sigma p_T$(CMS) = 3.4 GeV
FSC empty both sides




**M(pp) = 244 GeV**
**≈ M(central)**
**$\xi_1$ = 0.1   $\xi_2$= 0.01**

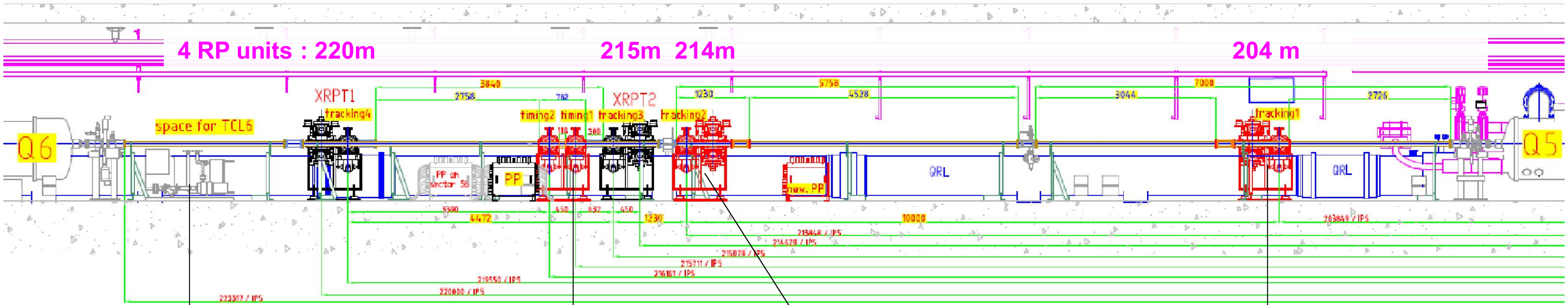




# RP consolidation & upgrade summary

## mechanics/infrastructure in LS1, timing sensors/replacement of Si strips later




**Install collimator to protect Q6**

**Infrastructure to install 2 new horizontal pots**

**RP147 (fully equipped) relocated at 203-213 m 1 unit rotated by 8 degrees**

Allow insertion of (horizontal) RPs closer to beam in high intensity scenario
→ **improved ξ acceptance**

Cylindrical pots to host **timing detectors**

Long lever arm (~15m) **improves angular resolution** (until beam divergence limit)

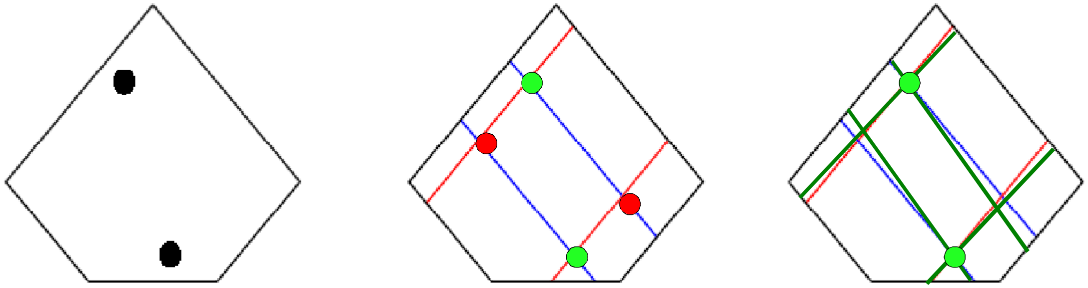
Si-strip detectors rotated to **improve multitrack** event reconstruction (beam halo pileup, background)

- RP system will consist of 4 RP units/arm, each with 2 vertical + 1 horizontal pots equipped with 10 planes Si-strip detectors, with full trigger capability
- Extreme flexibility in using 4 units according to running scenario; possibility to dedicate pots to new **Si-pixel detectors** as well as to timing detectors with low material budget

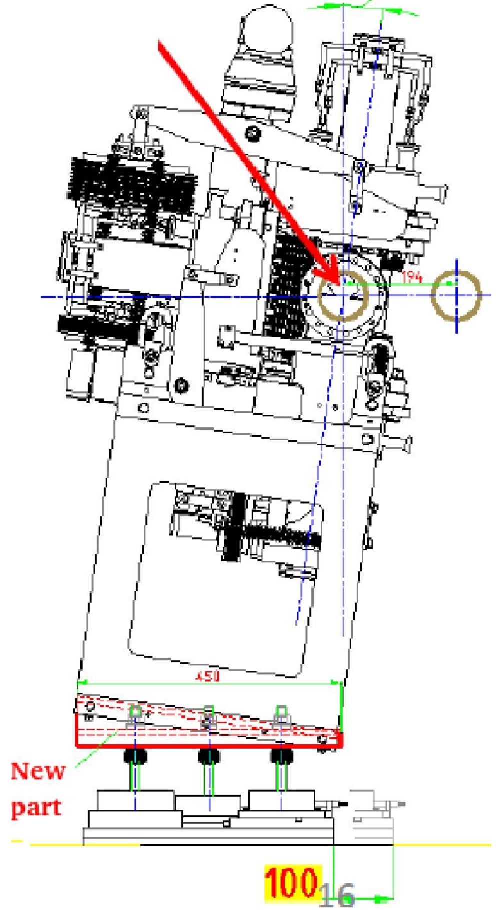
# Improving RP multi-track capability

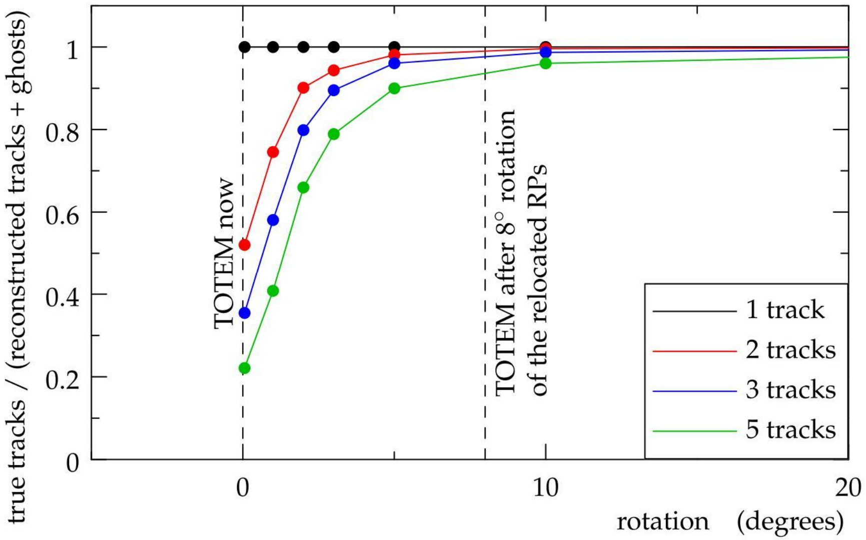
**Current limitation:** not able to reconstruct events with ≥ 2 tracks in same pot

**Remedy 1:** **tilt by ~8°** FAR RP station at 210m (ghost tracks suppression)



Outgoing beam



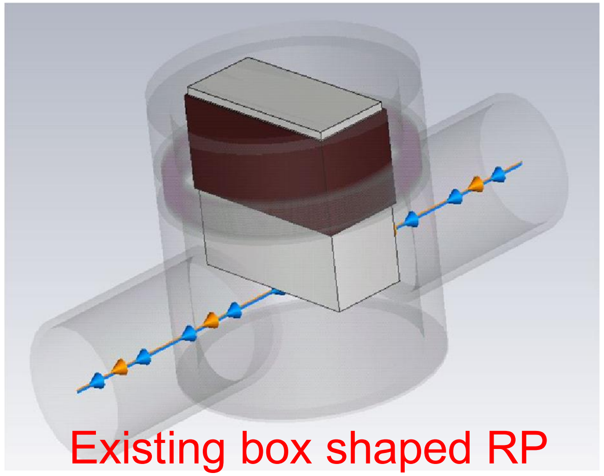




**Remedy 2:** Replace existing strip detectors with **pixel detectors**

# Reducing RP-beam coupling

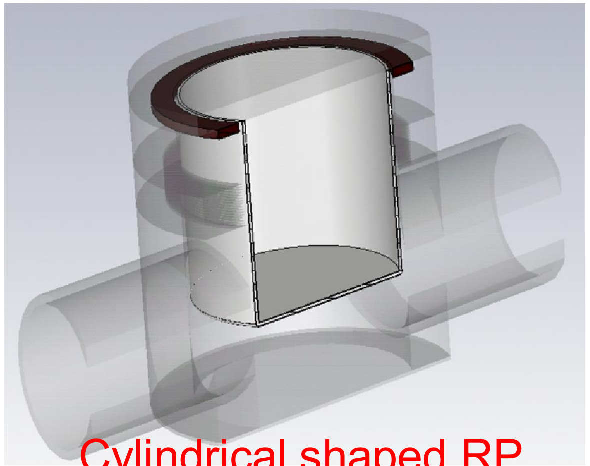
To insert RPs close to high intensity beam, important to have an optimized RP impedance (reduce heating & feedback).

A source of impedance for the beam is the empty space of cavity between RP box and cylindrical flange



Existing box shaped RP

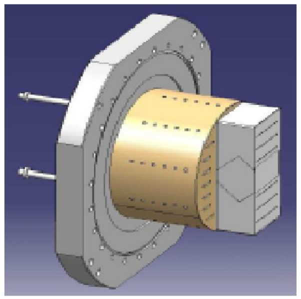
A cylindrical RP fills the cavity: better RF behaviour and more space available inside RP for timing detector.

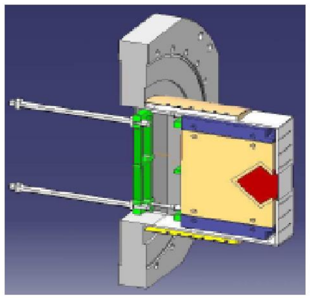


Cylindrical shaped RP

Cylindrical RP with Ferrites shown a reduced beam power-loss:
- Factor >5 better in beam power-loss compared to box-shape configuration (@1 mm approach).
- 35% better (@ 1 mm approach) for effective longitudinal impedance.

box shaped RP + Copper shield





*For 210m far-horizontal RP a cylindrical copper shield is studied for impedance reduction.*

# Improving proton left-right correlation capability

**Timing sensors with O(10 ps) timing resolution**

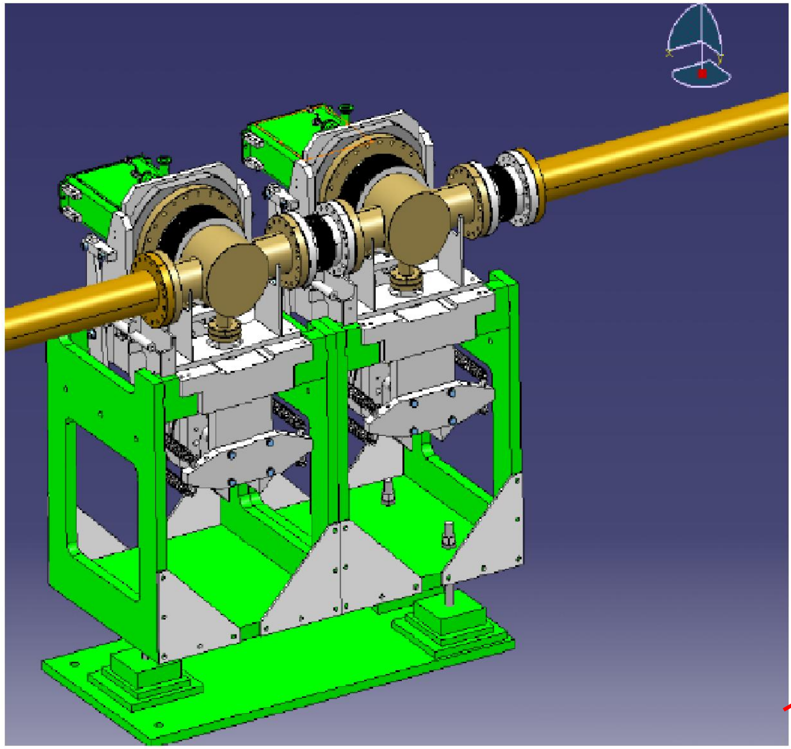
- Cherenkov detector + SiPM

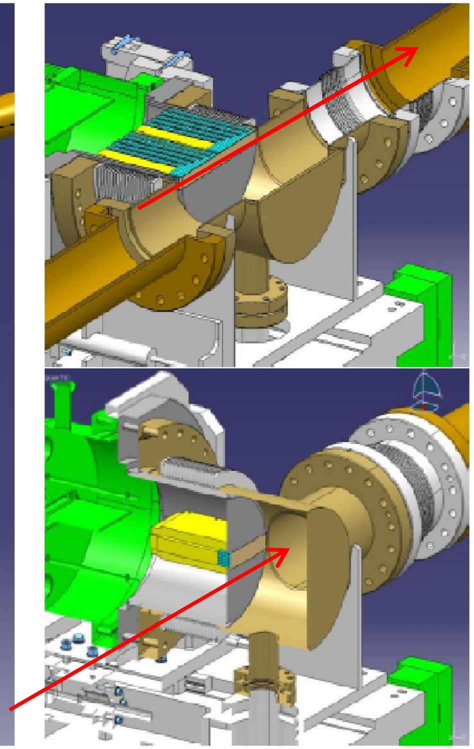
*[M.G. Albrow et al., "Quartz Cherenkov Counters for Fast Timing: QUARTIC", JINST 7 (2012) P10027]*

- diamond detectors → allow more flexibility on cell size

*[M. Ciobanu et al., "In-Beam Diamond Start Detectors", IEEE Trans.Nucl.Sci. 5 (2011) 2073.7]*

New cylindrical RP to host timing detectors



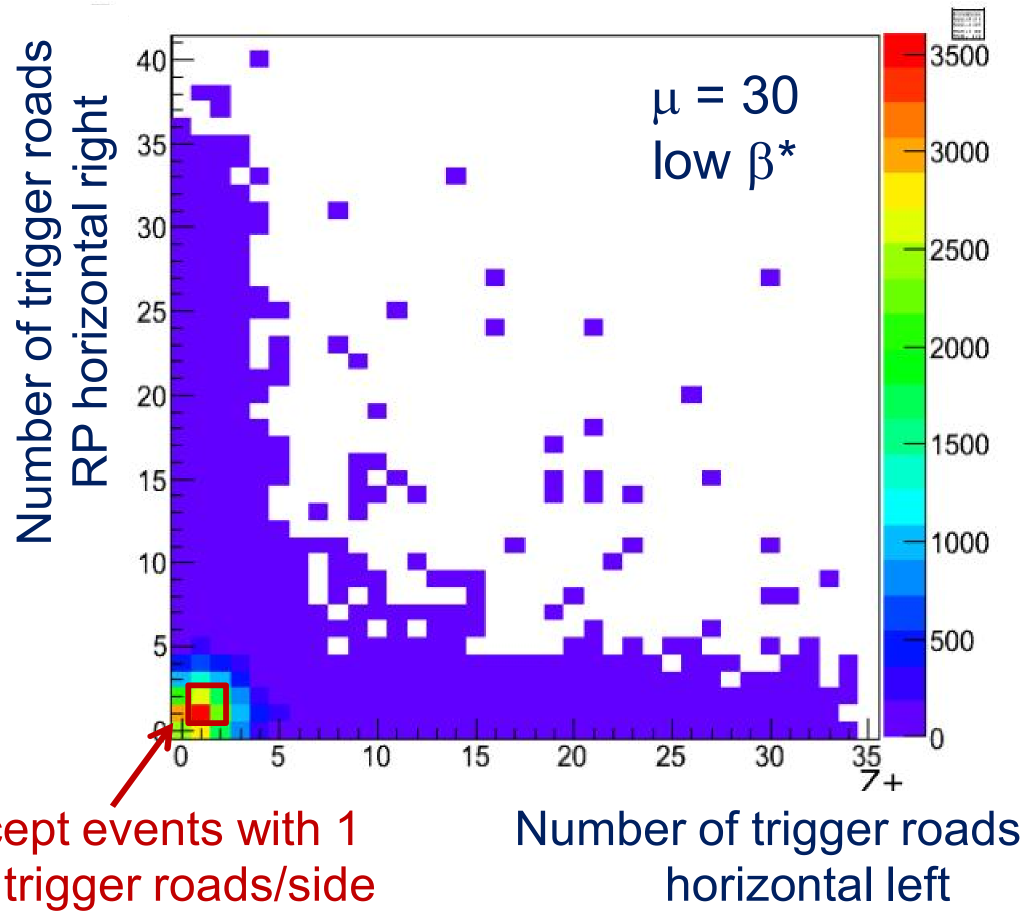


# Trigger for low β*

Reduce trigger rates using proton left-right time correlation without killing CD signal $\Rightarrow$ need reliable description of raw RP track rates & distributions!

Use data of a $\mu \approx 9$ low β* run at $\sqrt{s}$ = 8 TeV with horizontal RP @ 6 σ (RP alignment run): physics acceptance & background using RP-T2 topology

- Scale physics acceptance & background separately to reproduce any μ
- Add CD event to study performance

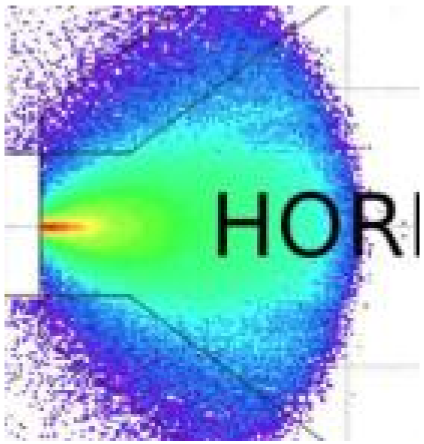



Estimate rate & CD purity + efficiency !

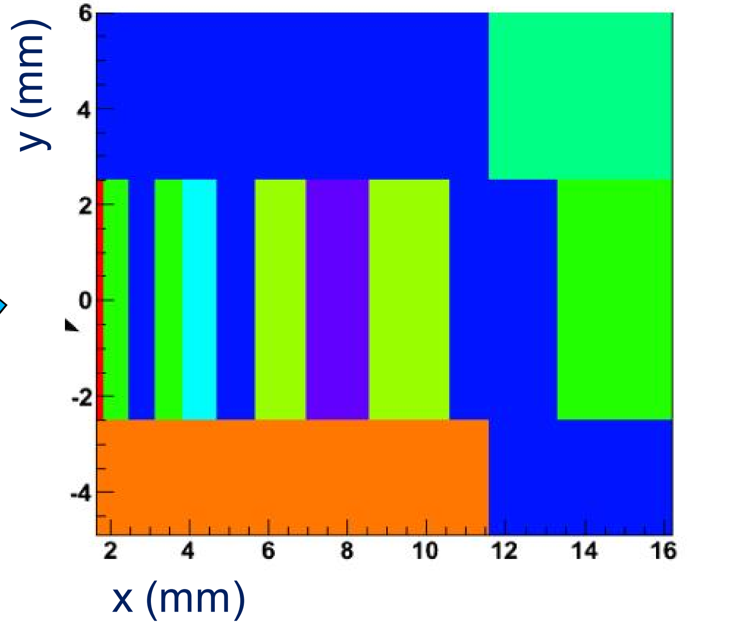
Optimizing timing sensor cell division !

# Multiplicity & distribution studies for low β*

Optimizing timing sensor cells equalizing rate/cell ($\mu$ = 30):

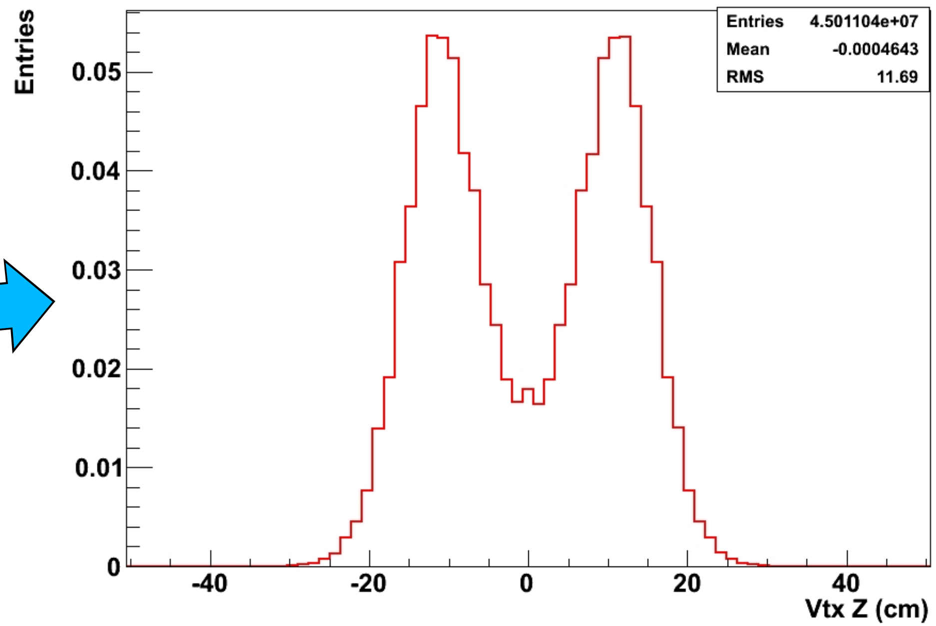


$N_{cell}$ = 16 with progressive pitch




Inefficiency due to ≥ 2 tracks / cell reduced by factor ~2 w.r.t. fixed square cell size!

Enhance CD purity (at cost of CD efficiency) of triggered proton pair by selecting isolated ($\Delta z$ ~1 cm) vertices in z vertex distribution tails ⇒ reduce trigger rates to acceptable levels (~1 kHz)

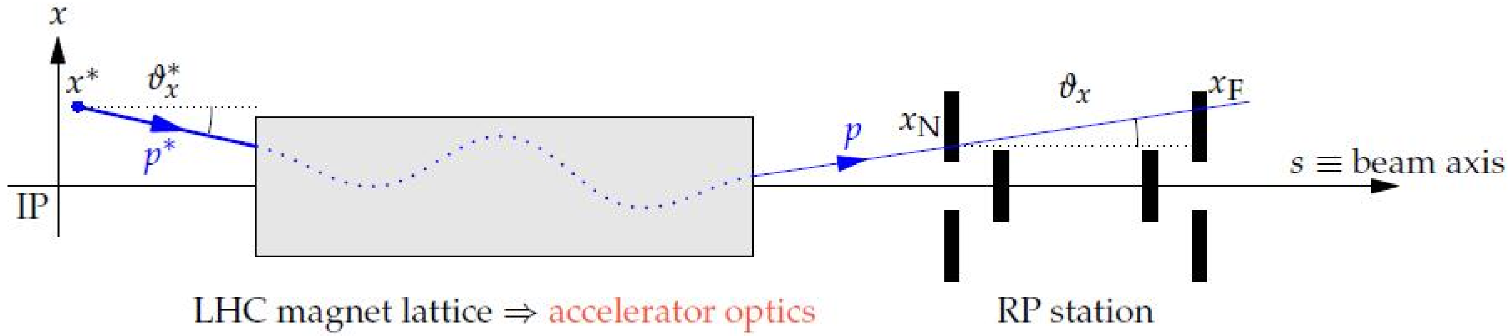


# TOTEM RP consolidation & upgrade summary

- CMS + TOTEM allows large rapidity coverage & redundcy (central vs forward)
- TOTEM RP consolidation & upgrade programme launched expanding the TOTEM physics reach
- mechanics & infrastructure changes/installation in current LHC shutdown, new sensors later
- aim: improve RP multi-track capability, proton left-right correlation capability & RP approach capability at high beam intensity

# The End

# Proton transport & reconstruction




$(x^*, y^*)$: vertex position
$(\theta_x^*, \theta_y^*)$: 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
Transport matrix elements depend on $\xi$ ➔ non-linear problem (except in elastic case!)

**Excellent optics understanding needed.**