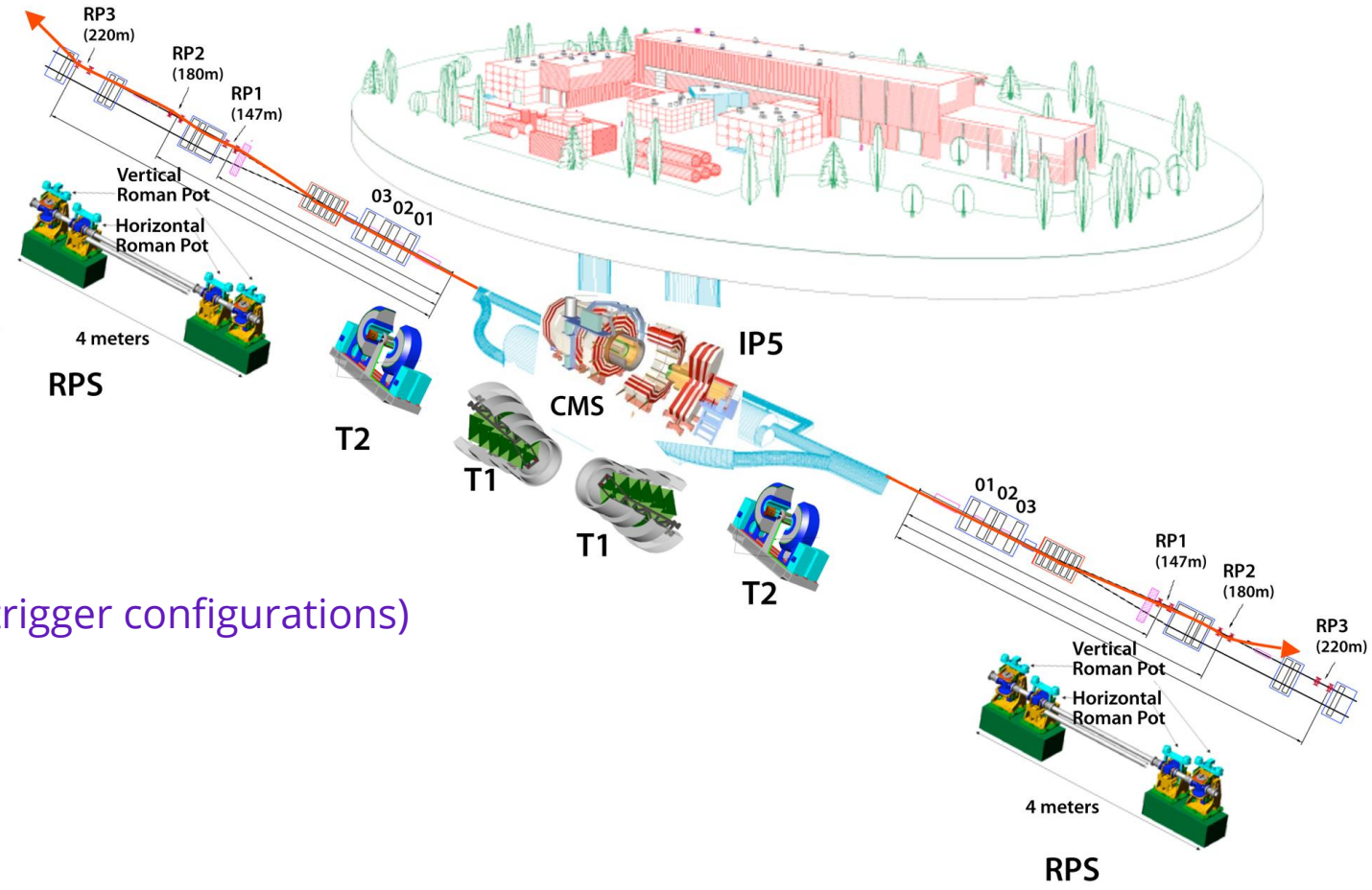
Latest results from the TOTEM-CMS combined data

Nicola Minafra University of Kansas

On behalf of the CMS and TOTEM Collaborations

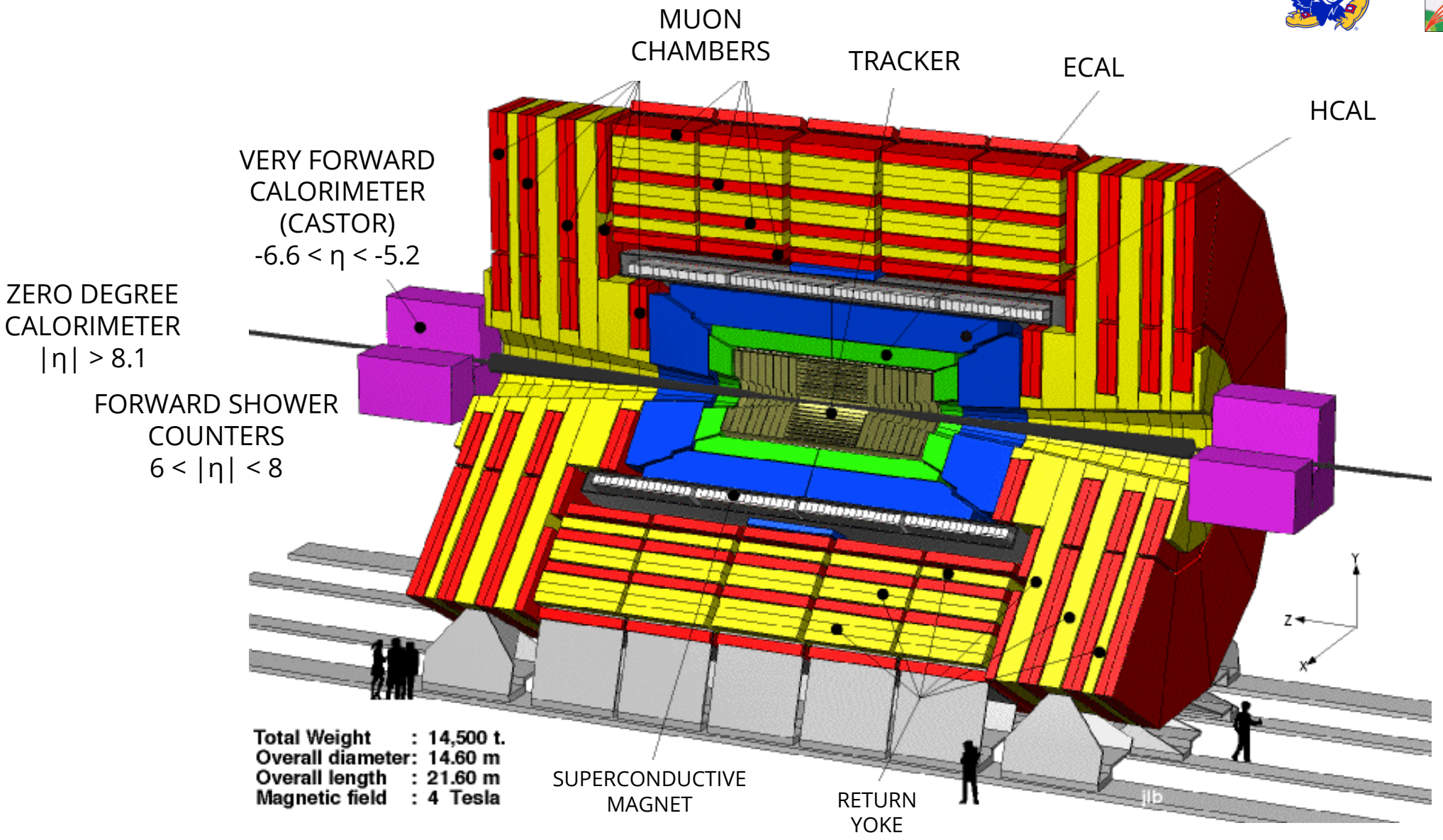
06-11 June 2016

Outline



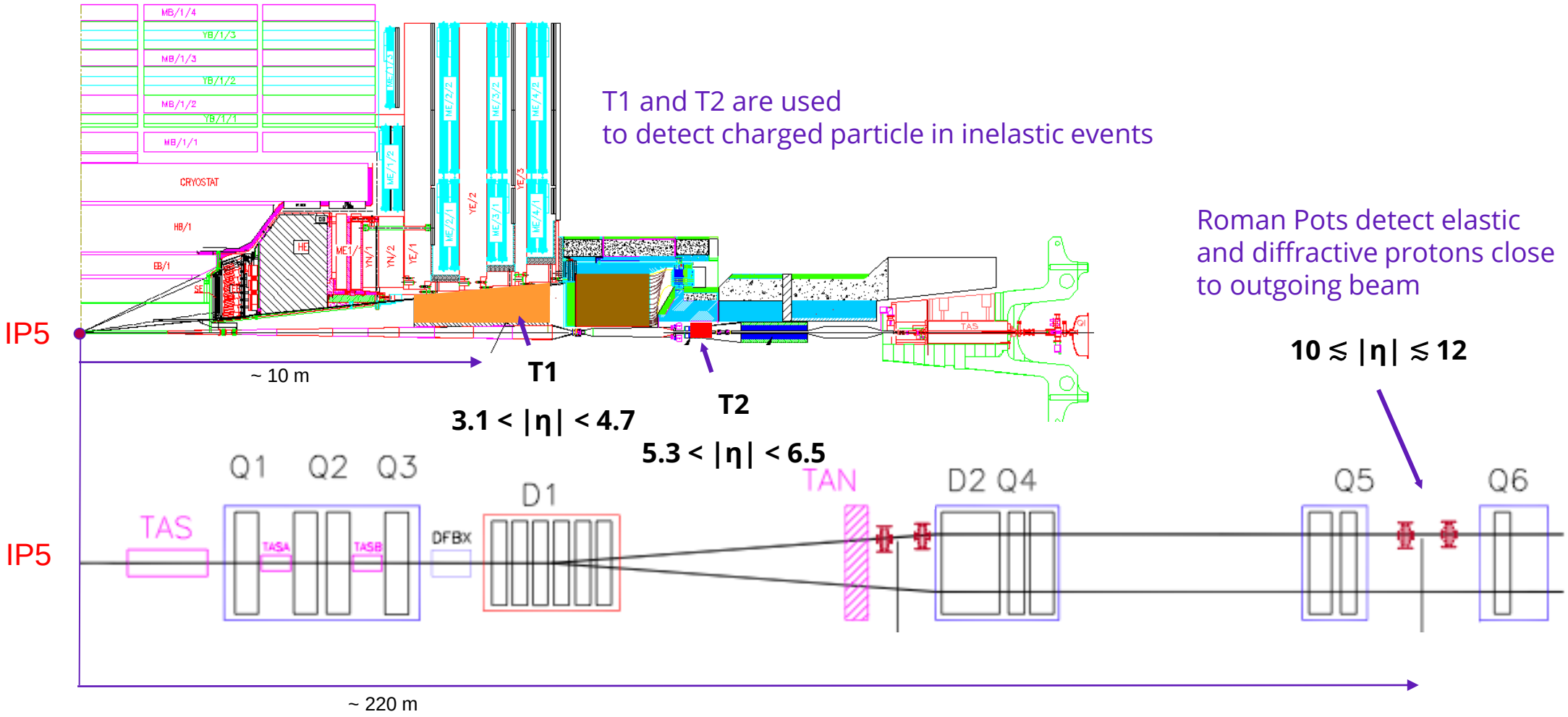
- CMS and TOTEM experiments at LHC
- Advantages of joint data taking
- Different run conditions (LHC optics and trigger configurations)
- Glueball candidates search
- Charged particles distribution
- Other analyses

The CMS detector at the LHC



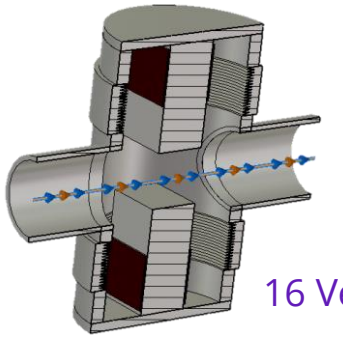
The TOTEM detector at the LHC

The TOTEM experimental apparatus is designed to measure the Total Cross Section and to study Elastic Scattering and Diffraction Dissociation at the LHC

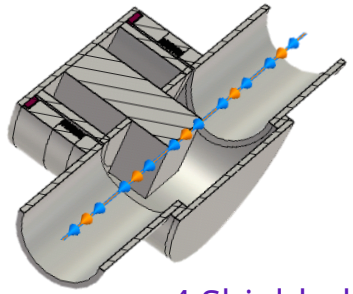


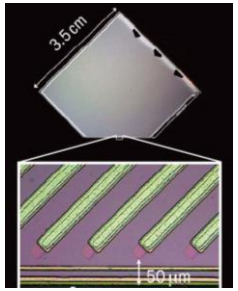
The TOTEM Roman Pot system

A Roman Pot is a movable section of the beam pipe that allows the insertion of a detector at few millimeters from the beam

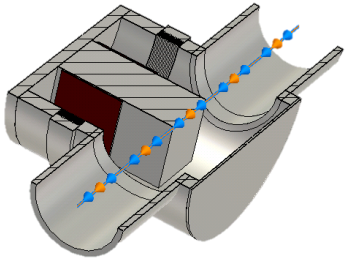


16 Vertical RPs

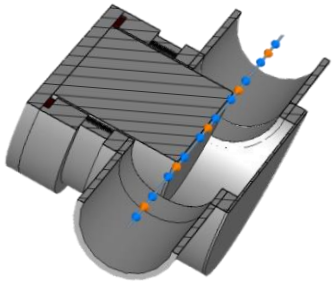


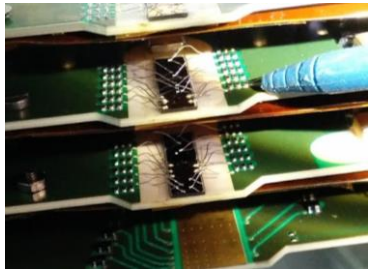


4 Shielded RPs
for high-luminosity operation



4 Horizontal RPs





2 Cylindrical RPs
for time-of-flight detector

High intensity runs

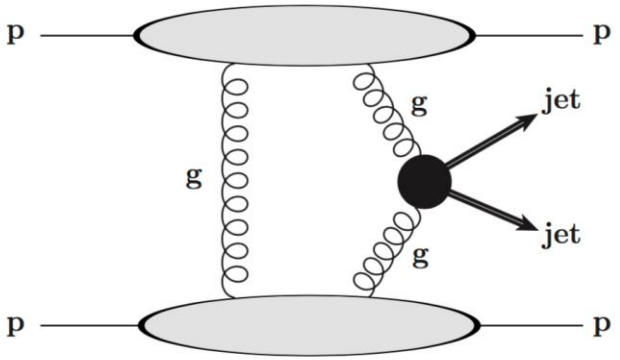
- 4 Vertical RPs (per arm)
- 2 Shielded RPs
- Cylindrical RP

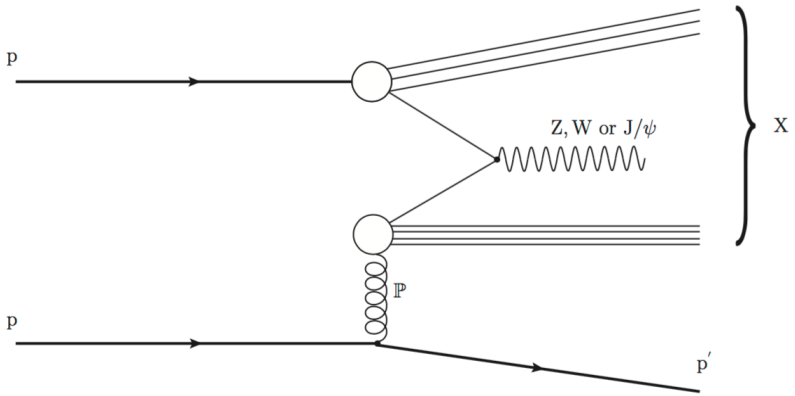
Dedicated runs

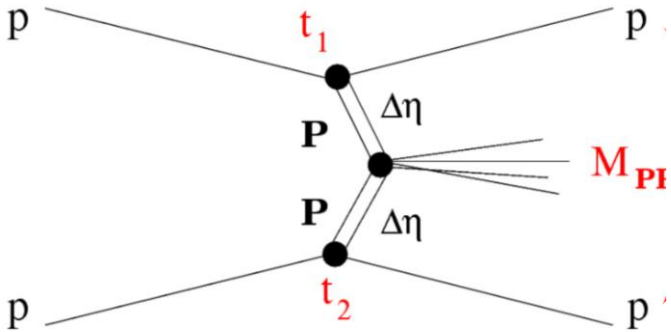
$\beta^* = 90\ m, 1\ km, 2.5\ km$

- 6 Vertical RPs
- 2 Horizontal RPs
- 1 Shielded RP

Physics objectives for dedicated runs during Run II







Central Exclusive Dijet production:

- low-mass resonances and glueball candidates
- $c\bar{c}$ production (X_c, J/ψ, ..)
- missing mass searches

Single diffractive Z, W and J/ψ production

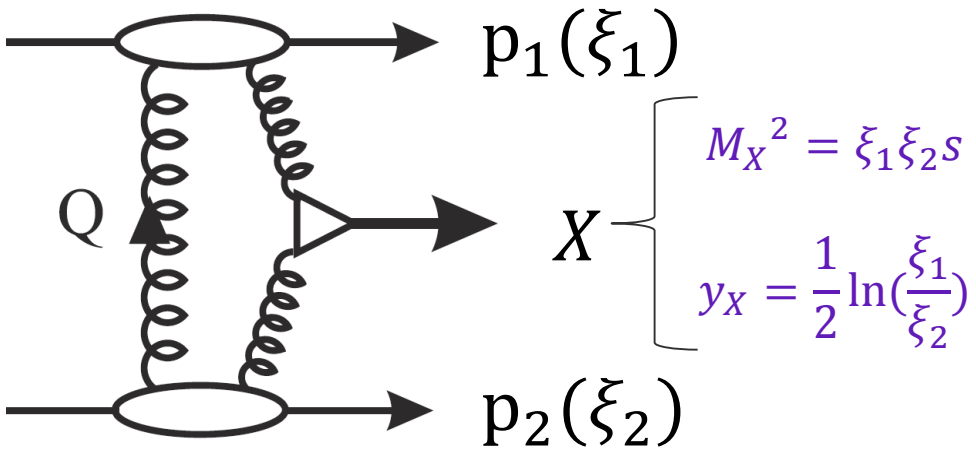
- Visible cross sections for single-diffractive Z and W boson production, single-diffractive J/ψ production, and CEP dijet production estimation

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

Already started during Run I:

- inclusive diffraction
- total cross sections (SD/CD..)
- SD dijet production
- forward particle/energy flow
- ...

Exclusive Central Diffraction



Selection rules for system X:

$$J^{PC} = 0^{++}, 2^{++}$$

$\xi = \Delta p/p$: fractional momentum loss

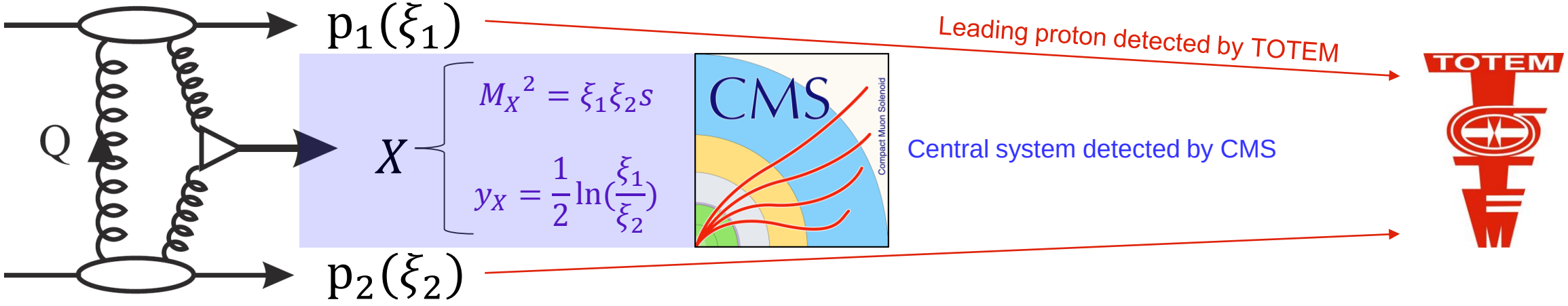
Examples:

Low mass resonances $X = \pi^+\pi^-, K^+K^-, \rho^0\rho^0, \pi^+\pi^-K^+K^-$, with $M_X \sim 1-4$ GeV (@LHC $x \sim 10^{-4}$ for gluons)

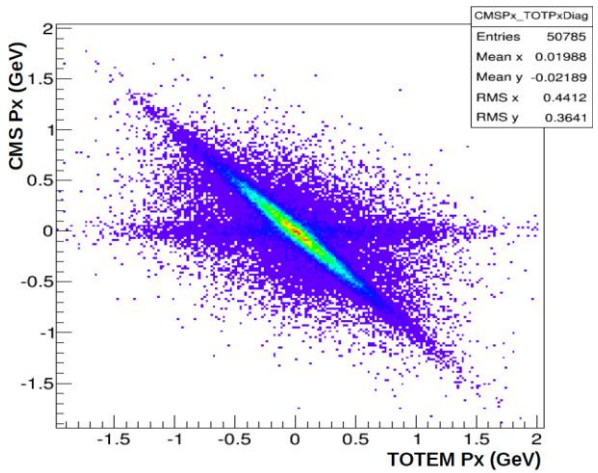
Glueball studies, $f_0(1710) \to \rho^0\rho^0 \to 4\pi^\pm$ Not yet reported in PDG!

Exclusive charmonium production; Missing Mass & Momentum (large mass);
Low mass (non-exclusive) central diffractive dijets; Exclusive central diffractive dijets

What is the advantage of CMS + TOTEM?



$\xi = \Delta p/p$: fractional momentum loss



Diagonal RP Topology: P_X CMS TOTEM

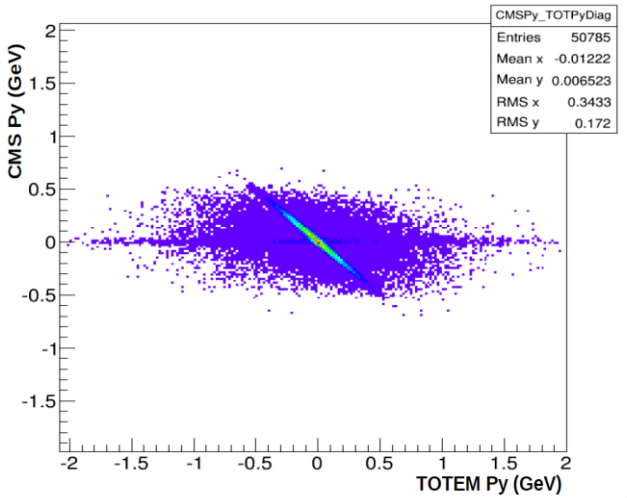
Comparison between forward and central system:

$$M(pp) \sim M(CMS)$$
$$p_T(pp) \sim p_T(CMS)$$
$$\text{vertex}(pp) \sim vertex(CMS)$$

Prediction of rapidity gaps from protons :

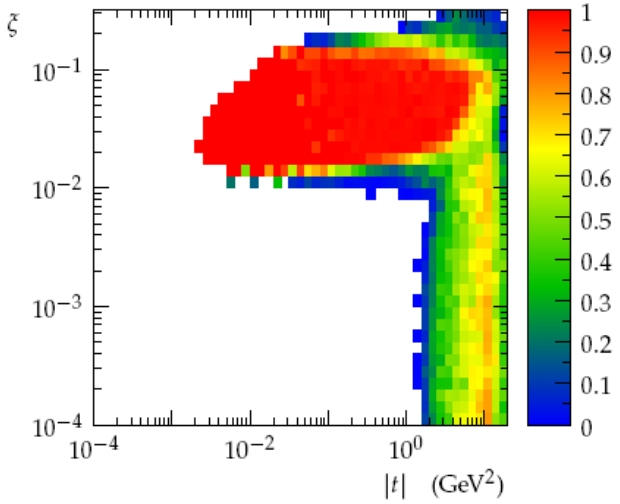
$$\Delta\eta_{1,2} = -ln\xi_{1,2}$$

Diagonal RP Topology: P_Y CMS TOTEM

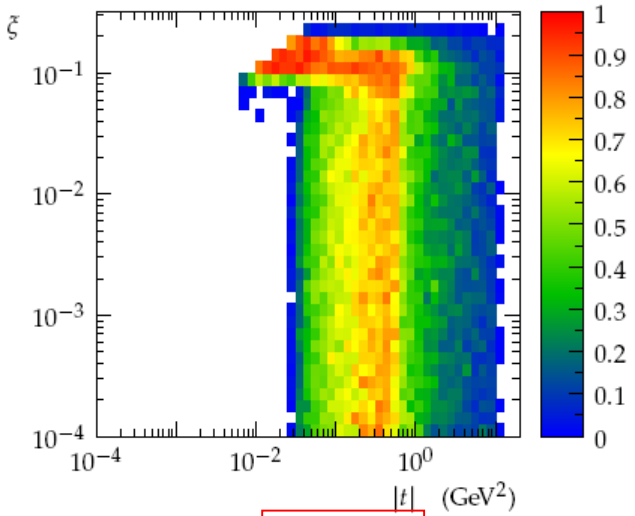


LHC optics & leading proton acceptance

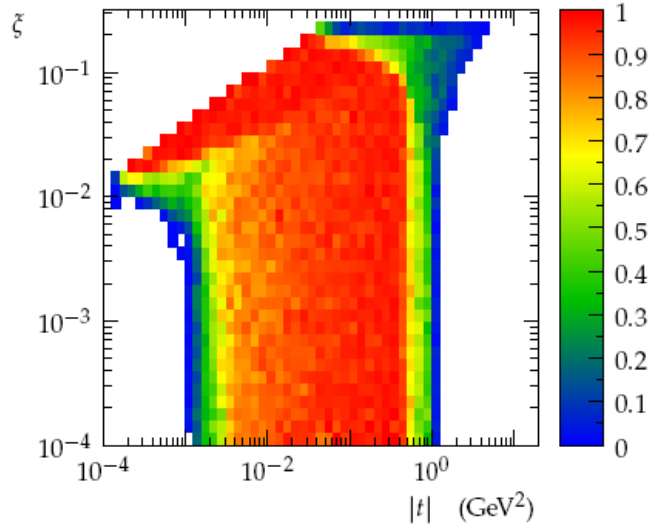
$\beta^* = 0.55\ m$



$\beta^* = 90\ m$



$\beta^* = 1000\ m$



$> 10^{33}\ cm^{-2}\ s^{-1}$ ← $\mathcal{L} \propto \frac{1}{\beta^*}$ → $\sim 10^{27}\ cm^{-2}\ s^{-1}$

Diffraction: ξ > ~0.03,
low cross-section processes
(hard diffraction)
Elastic scattering: large |t|

M_X > ~ 300 GeV at any t's
$\mu \sim 25 - 50 \Rightarrow O(fb^{-1}/day)$

Diffraction: all ξ if |t| > 0.01 GeV^2 soft
& semi-hard diffraction
Elastic scattering: low to mid |t|
Total cross-section

any M_X if both t's > ~0.01 GeV^2
$\mu \sim 0.1 - 1 \Rightarrow 0.1 - 4\ pb^{-1}/day$

Elastic scattering: very low |t|
Coulomb-hadronic interference
Total cross-section

$t \approx -p^2\theta^2$: four-momentum transfer squared
$\xi = \Delta p/p$: fractional momentum loss

CMS-TOTEM joint data taking with β* = 90 m

CMS-TOTEM 8 TeV

Sample: 0.75 nb^{-1}, μ<5%

Trigger: RP 45-56 vertical proton coincidence (request of one reco track done offline)

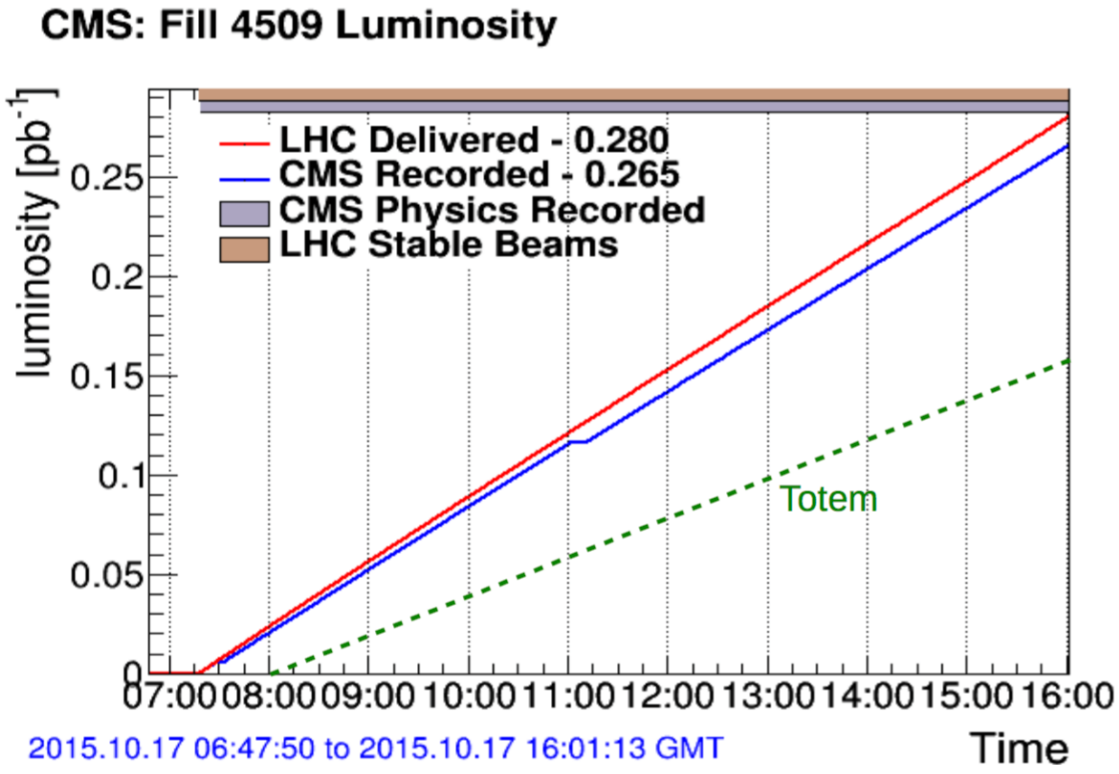
CMS-TOTEM 13 TeV, Oct 15-17, 2015

β* = 90m, low Pile Up

CMS details: No CASTOR, B = 3.8 T

L1 Trigger exchange

Independent DAQs, Offline merging



Integrated Luminosity

LHC delivered : 0.74/pb

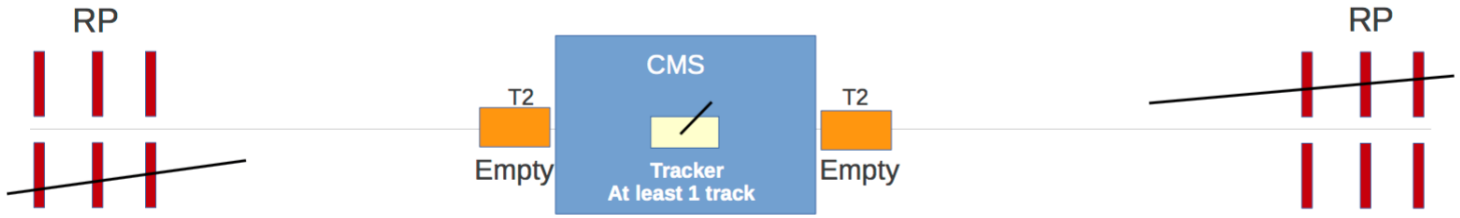
CMS recorded : 0.68/pb

Totem recorded : 0.4/pb

Totem Trigger & CMS data : 0.55/pb

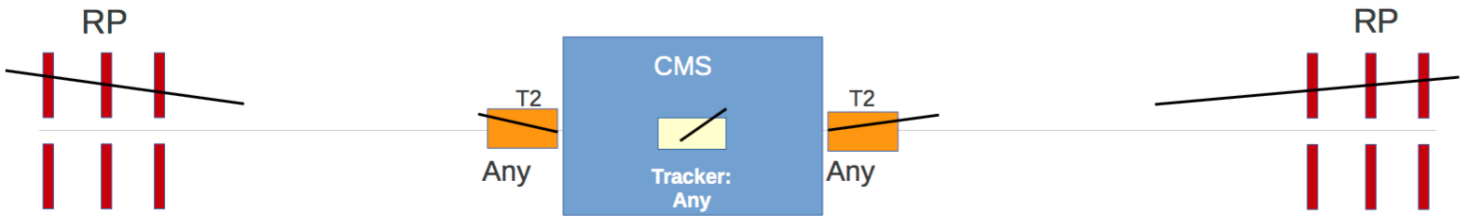
Trigger configurations

Glueball searches, low mass Central Diffraction (DPE): exclusive channels; J/ψ, $\pi^+\pi^-$,...



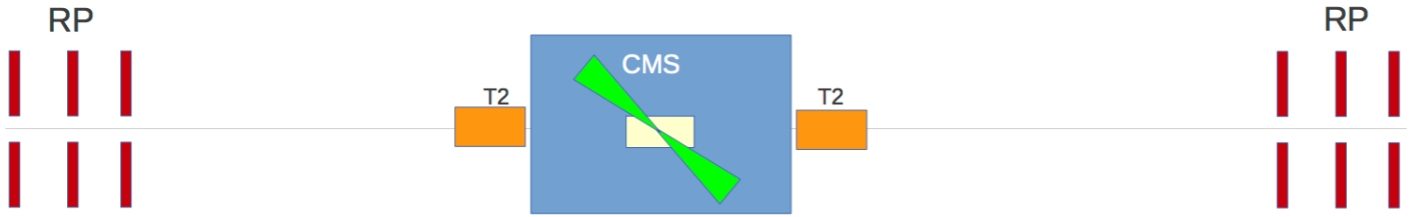
RP double-arm **&** T2 Veto **&** CMS >1 track
TOTEM Rate ~45 kHz (high elastic contr.)
CMS HLT Tate ~ 2 kHz

High mass central diffraction, missing mass searches



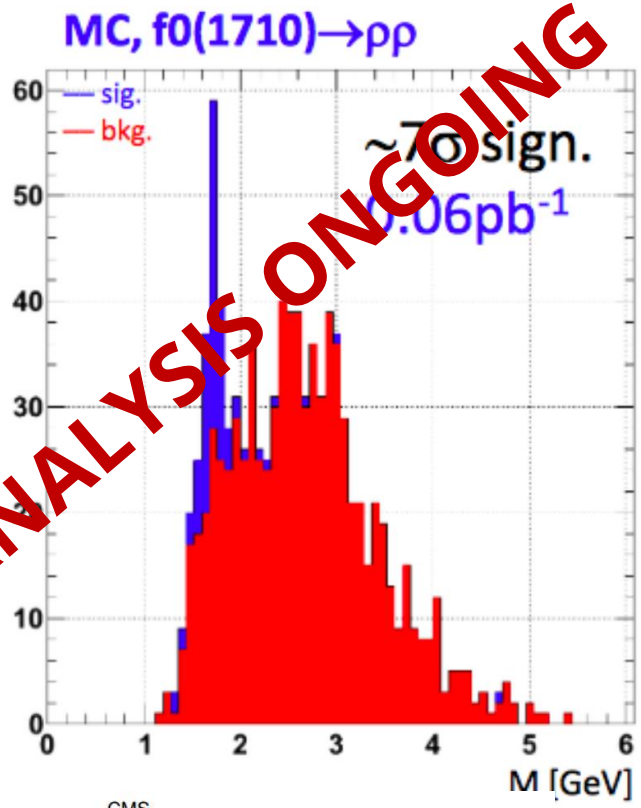
RP Top-Top OR Bot-Bot **&** T2 **&** CMS
TOTEM Rate ~5 kHz (No elastic bkg)
CMS HLT Tate ~ 5 kHz

Single Diffractive Dijets, Exclusive Dijets

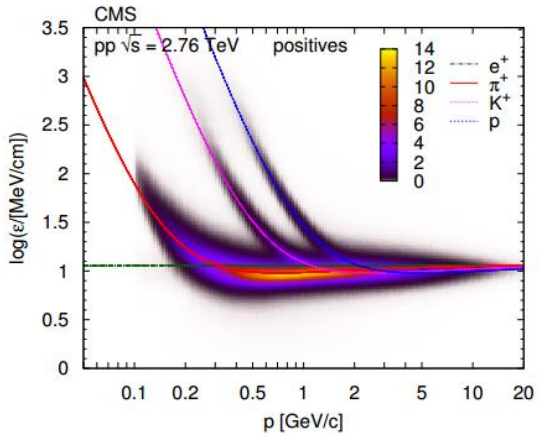


CMS: DiJets $p_T \sim 20\ GeV$, $p_T \sim 32\ GeV$
Also: Double muon, single muon with HF gap, Min Bias (T2), Zero Bias
CMS HLT Tate ~ 1 kHz

Glueball candidates search



ANALYSIS ONGOING



Most of the recent literature and experimental results from the past suggest $f_0(1370)$ $f_0(1500)$ and $f_0(1710)$ as glueball candidates, the latter being favoured from recent calculations.

Interesting structures found in the two tracks mass spectrum by requiring the following (main) conditions:

- Protons $\xi<1\%$
- System P_X/P_Y balance <20 MeV between TOTEM and CMS
- Relative distance of the tracks on the Z axis $<1\sigma$;
- Track in the central region of the tracker $|\eta|<1.5$;
- Total charge of the tracks = 0;
- RP x vertex reconstructed at $\Delta X<2\sigma$;
- System P_Y/P_X cut for background reduction;
- Anti-elastic cuts: remove elastics from the selection of collinear protons.

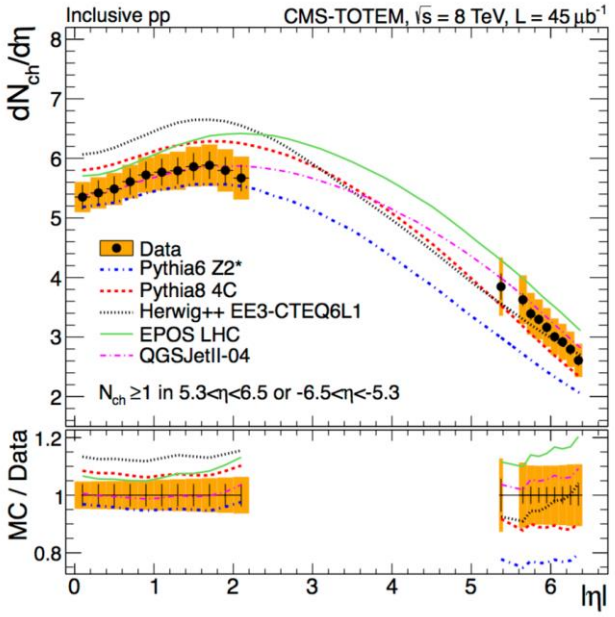
In a subsample of events where at least one track has enough low P to be tagged safely as Kaons or pions, is possible to identify the resonance decay channel.

TO DO:

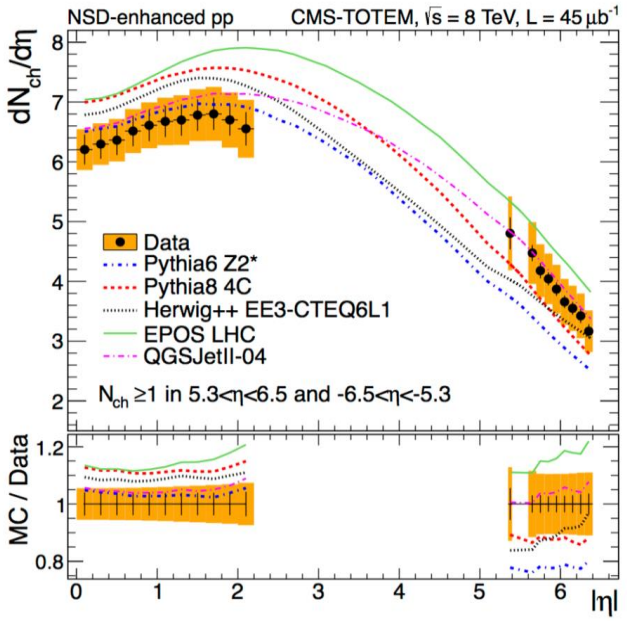
- Understand the background (especially beam halo comparison between 2012 and 2015 data;
- Introduce improved dE/dx measurement to allow optimal π/K separation;
- Optimization of the tracking capability for low-P_t tracks

Charged Particles Distribution

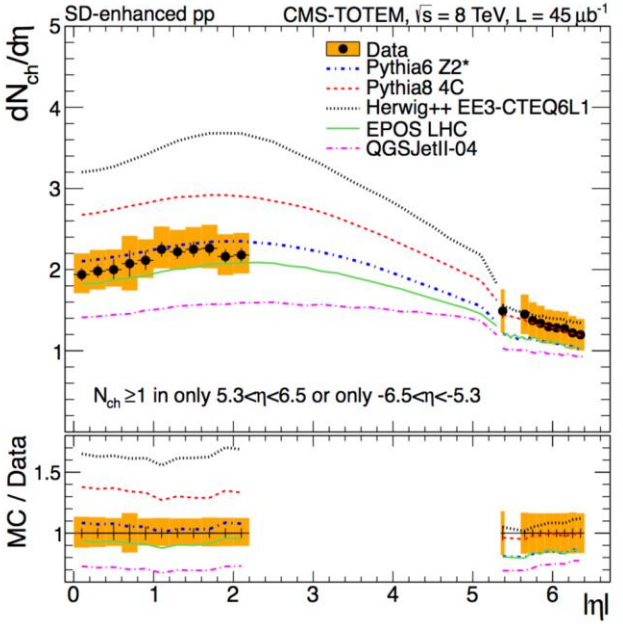
(inclusive)



(NSD)



(SD enriched)

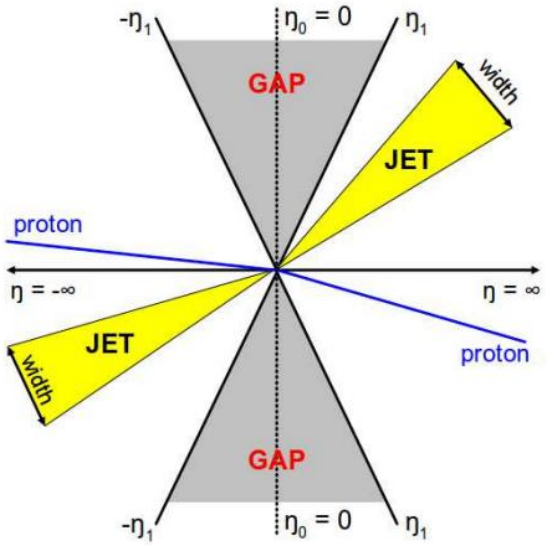


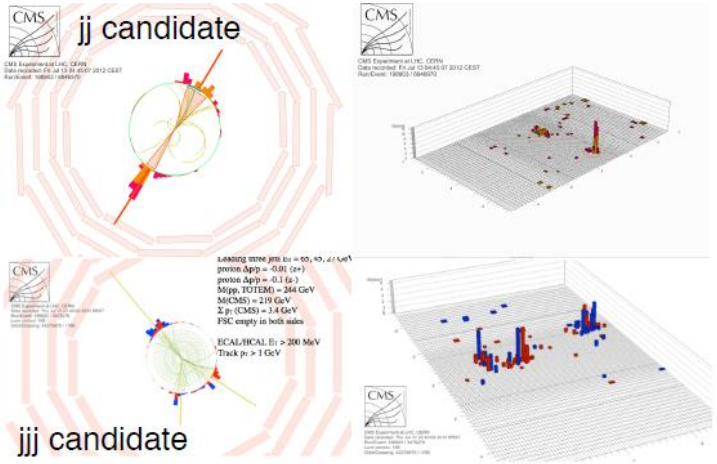
Three event samples with different final-state topologies are selected offline: a sample of **inclusive inelastic pp events**, a sample dominated by **non-single diffractive dissociation** (NSD) events and a sample **enriched in single diffractive dissociation** (SD) events.

Measurement of pseudorapidity distributions of charged particles in proton–proton collisions at √s=8 TeV by the CMS and TOTEM experiments, EPJC 74 (2014) 3053.

High-pT jets with two leading protons

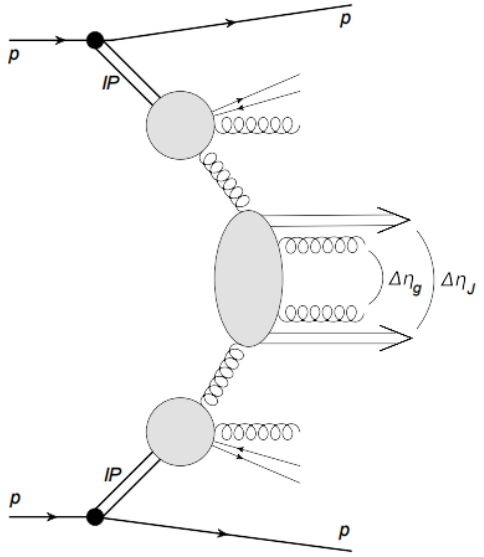
Possibility to measure jet-gap-jet final states in double-Pomeron-exchange events at the LHC

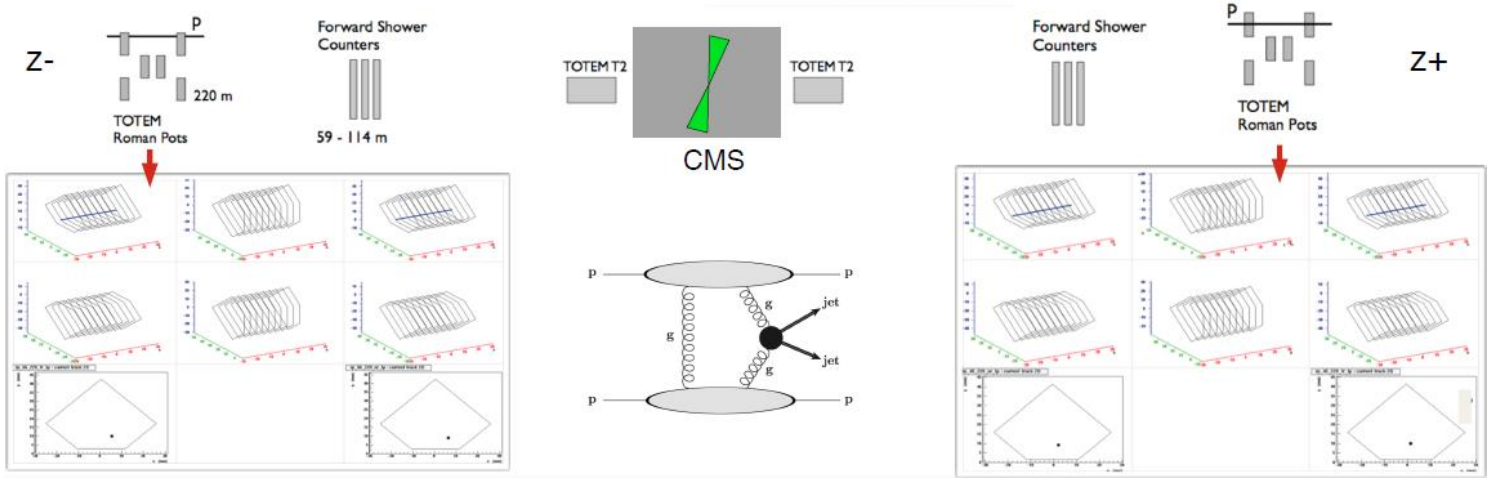




Leading three jets E_T = 65, 45, 27 GeV
proton Δp/p = -0.01 (z+)
proton Δp/p = -0.1 (z-)
M(pp, TOTEM) = 244 GeV
M(CMS) = 219 GeV
Σ p_T (CMS) = 3.4 GeV
FSC empty in both sides

ECAL/HCAL E_T > 200 MeV
Track p_T > 1 GeV





DPE event, with a diffractive final state made of two high-pT jets surrounding a large rapidity gap.

Gaps between jets in double-Pomeron-exchange processes at the LHC, arXiv:1212.2059v2

Summary

- **CMS and TOTEM** detectors provide **unique pseudorapidity coverage** and **unprecedented measurement possibilities**.
- CMS-TOTEM the charged-particle density measurements, span the **largest pseudorapidity interval ever measured at the LHC!**
- Now the overall **statistics** for β* = 90 m Runs **in 2015** is an order of magnitude **larger with respect to 2012**. Acceptance at very low |t| for any ξ.
- 0.5 1/pb of data of CMS and TOTEM data reconstructed independently and merged successfully.
- Analysis on low mass DPE is ongoing: both central and leading proton information are found to be essential in order to reconstruct the exclusive low mass spectrum with reduced background.
- Optimization needed for many reconstruction tools in order to exploit the data (dE/dx, low pt track reconstruction …)
- Various new analysis scenario still to be exploited

References:

S. Sen, Results from combined CMS-TOTEM data, DIS 2016: XXIV International Workshop on Deep-Inelastic Scattering and Related Subjects, Apr 2016

V. Avati, Combined CMS TOTEM runs at beta*=90m, LHC Working Group on Forward Physics and Diffraction, October 2015

M. Berretti, CMS-TOTEM glueball analysis, 3rd Elba Workshop on Forward Physics @ LHC Energy, May 2016

Backup slides

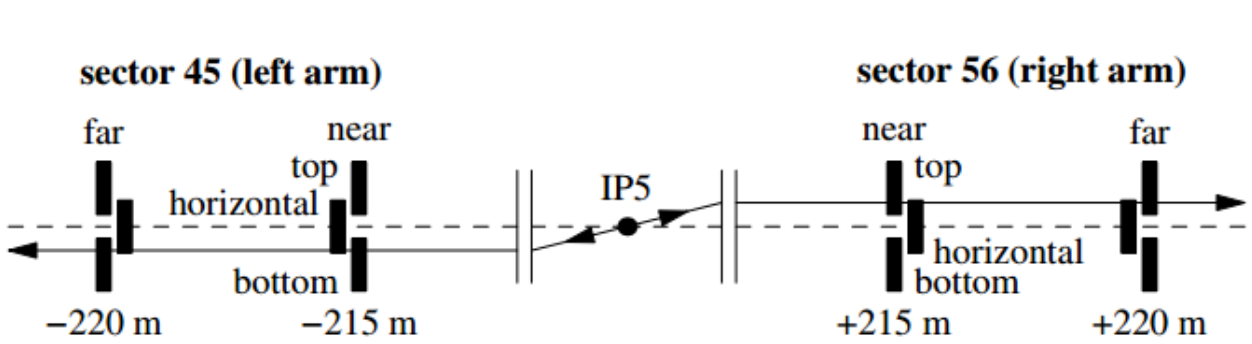
TOTEM & CMS

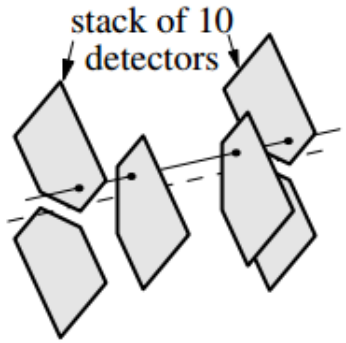
TOTEM
LHC experiment dedicated to measurement of:
total cross-section, elastic scattering and diffractive processes
Designed to study rapidity gaps, particles in very forward region, surviving protons

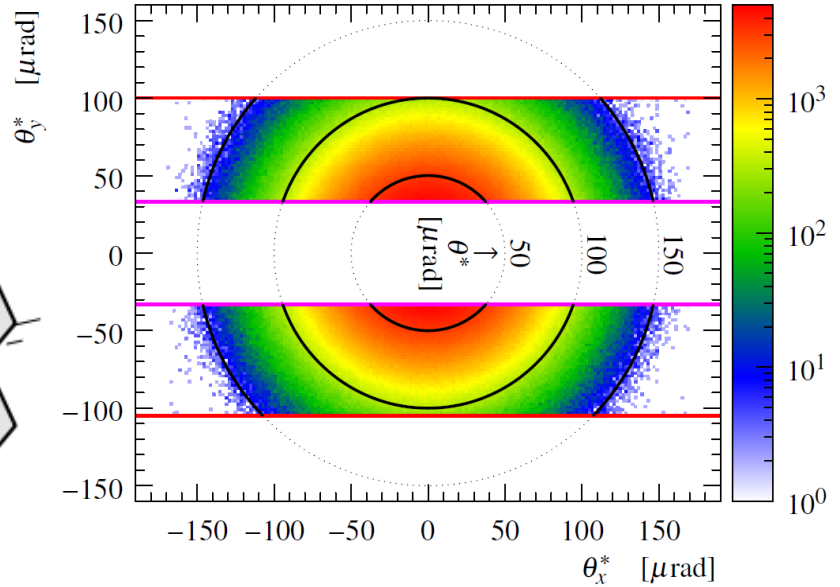
TOTEM + CMS
both experiments at LHC Interaction Point 5
excellent pseudorapidity coverage: optimal for hard diffraction studies
cooperation mode: independent experiments and DAQ, exchange of triggers for off-line syncronization

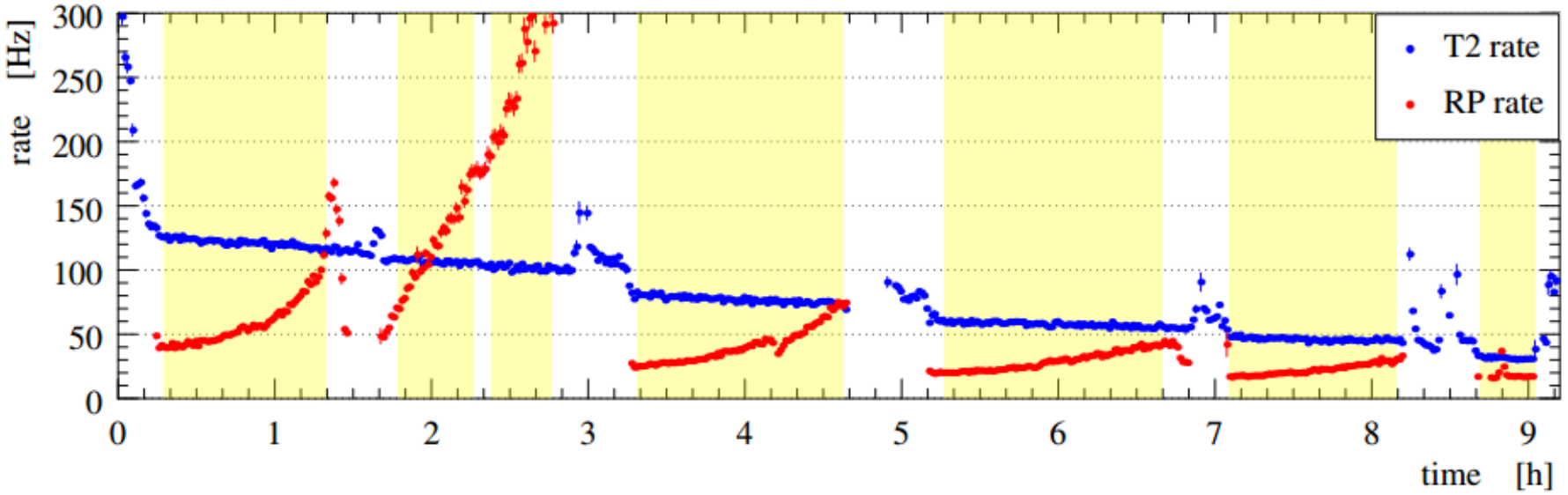
CT-PPS (CMS-TOTEM Precision Proton Spectrometer)
all sub-detectors fully integrated under CMS
Infrastructure for high luminosity and high-pileup configurations of the LHC: RF optimized RP, timing and pixel detectors

Tricks to obtain lower |t|

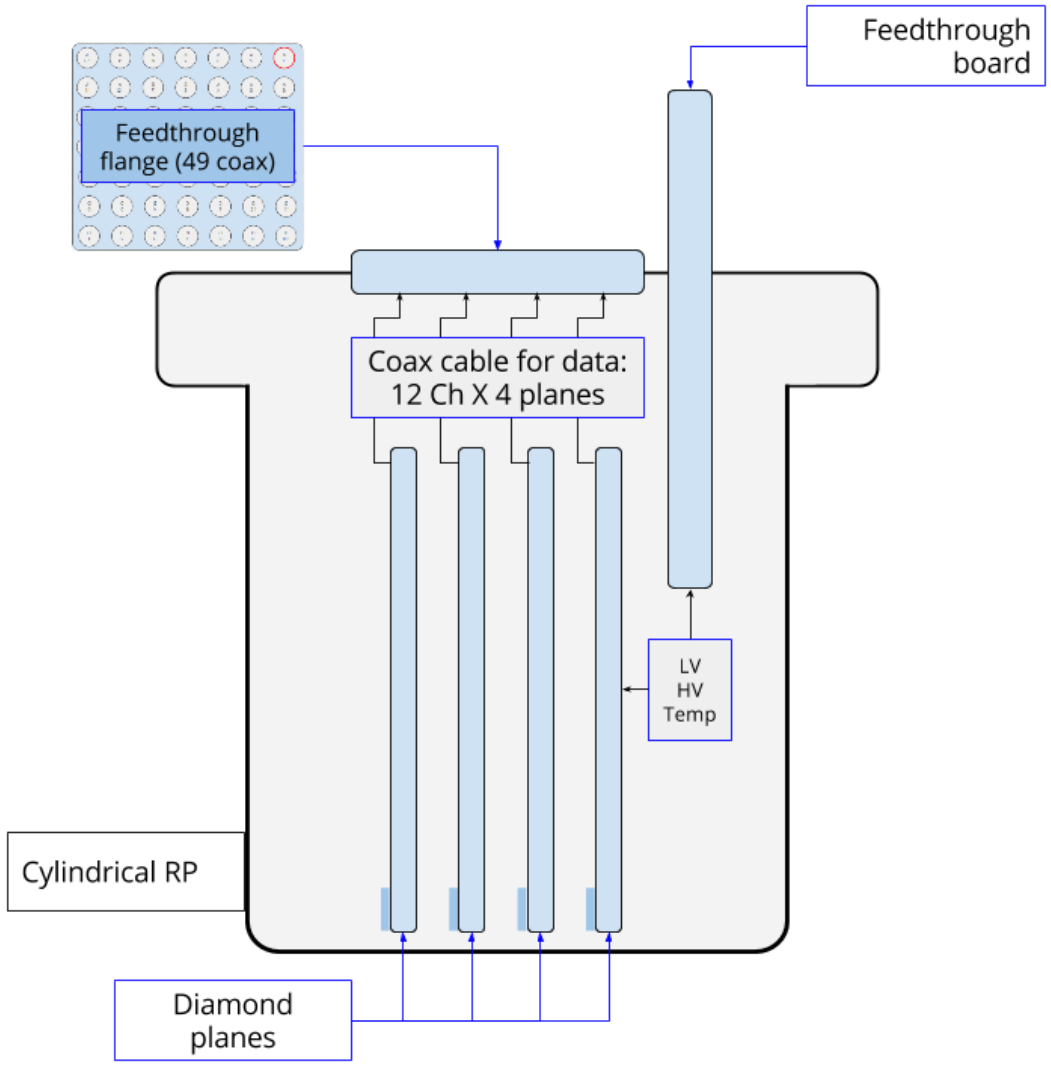


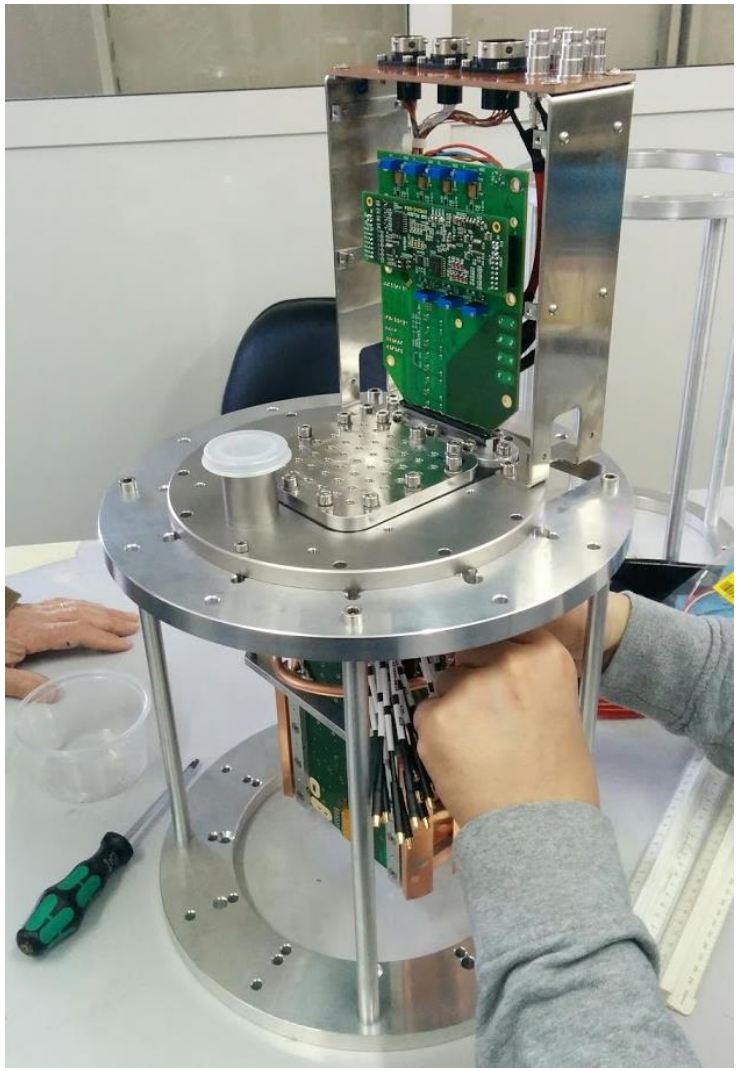




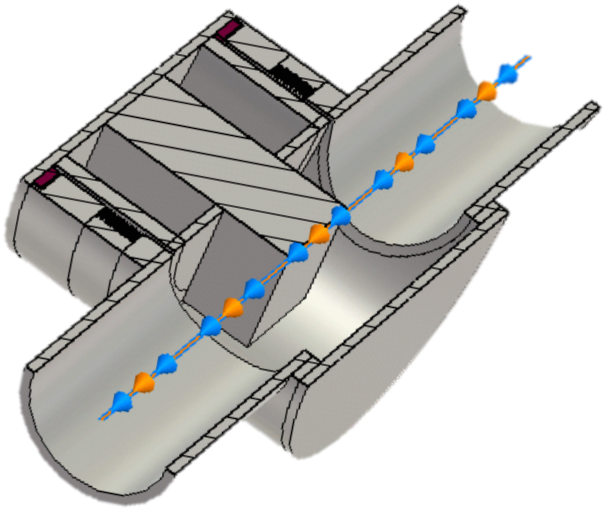


Diamond timing detector for Cylindrical RP





Roman Pot insertion in 2016

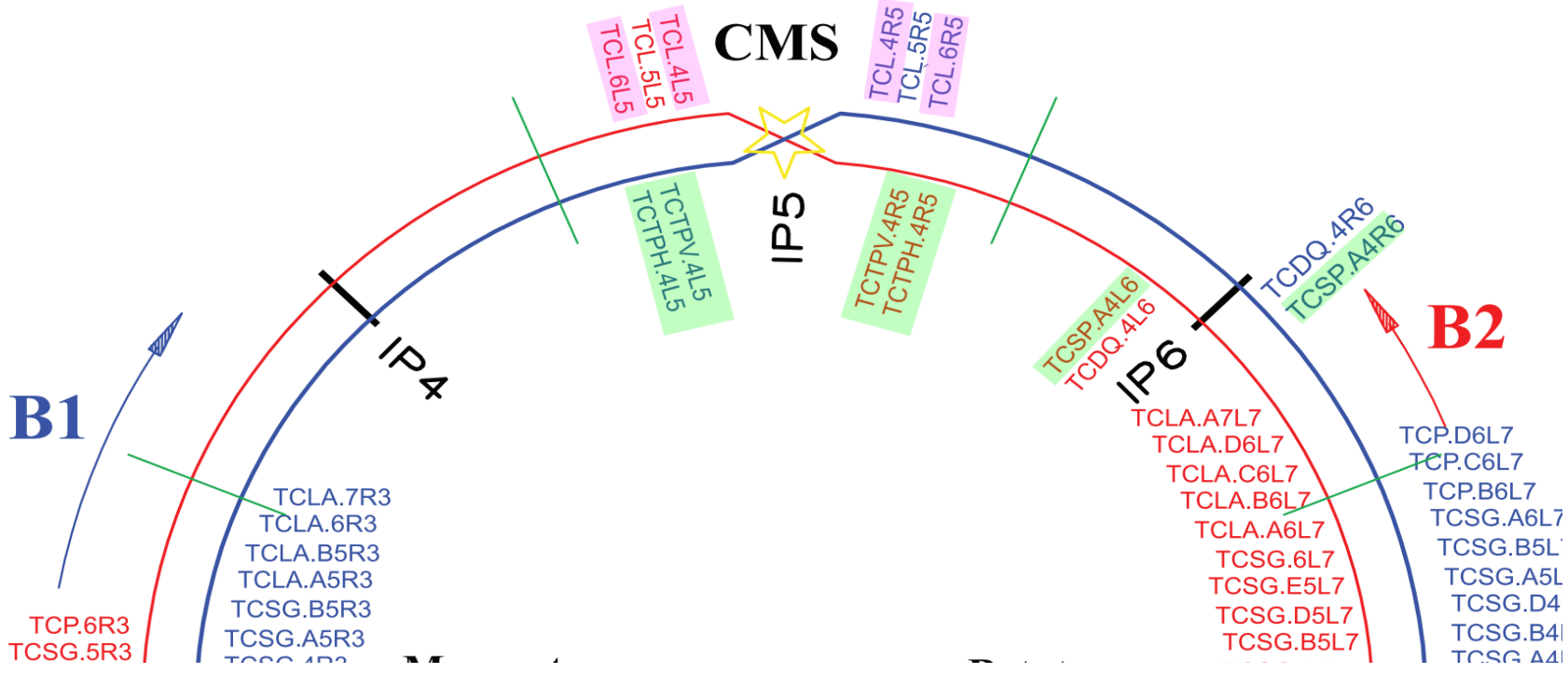


Roman Pot insertion allowed at 15 σ from June 2016!

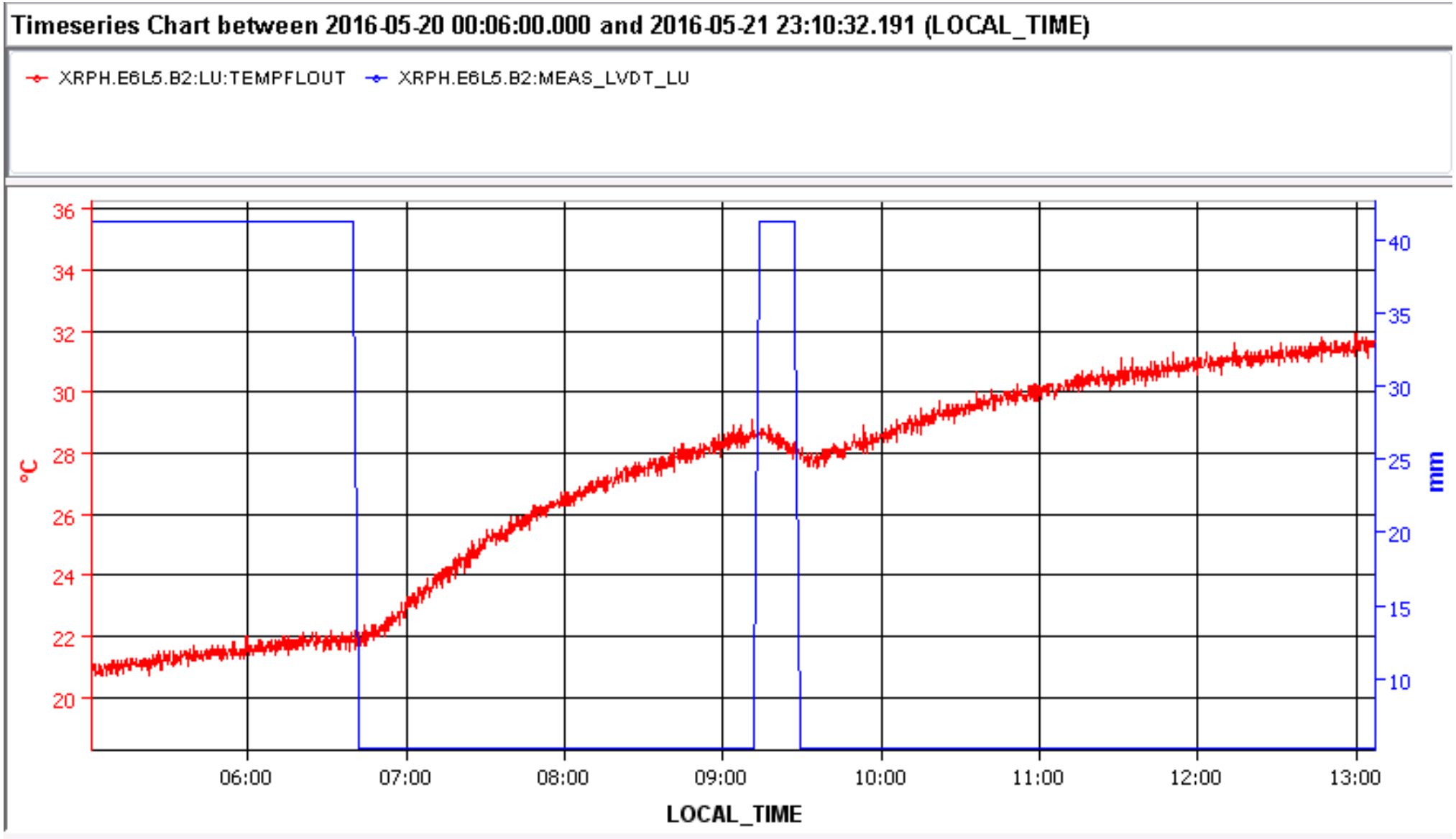
Before:
2 hours after declaration of stable beam the RPs could be inserted at 15 σ + 0.5 mm.

The second fill of each intensity step the 0.5 mm margin was removed and then subsequent insertions were possible

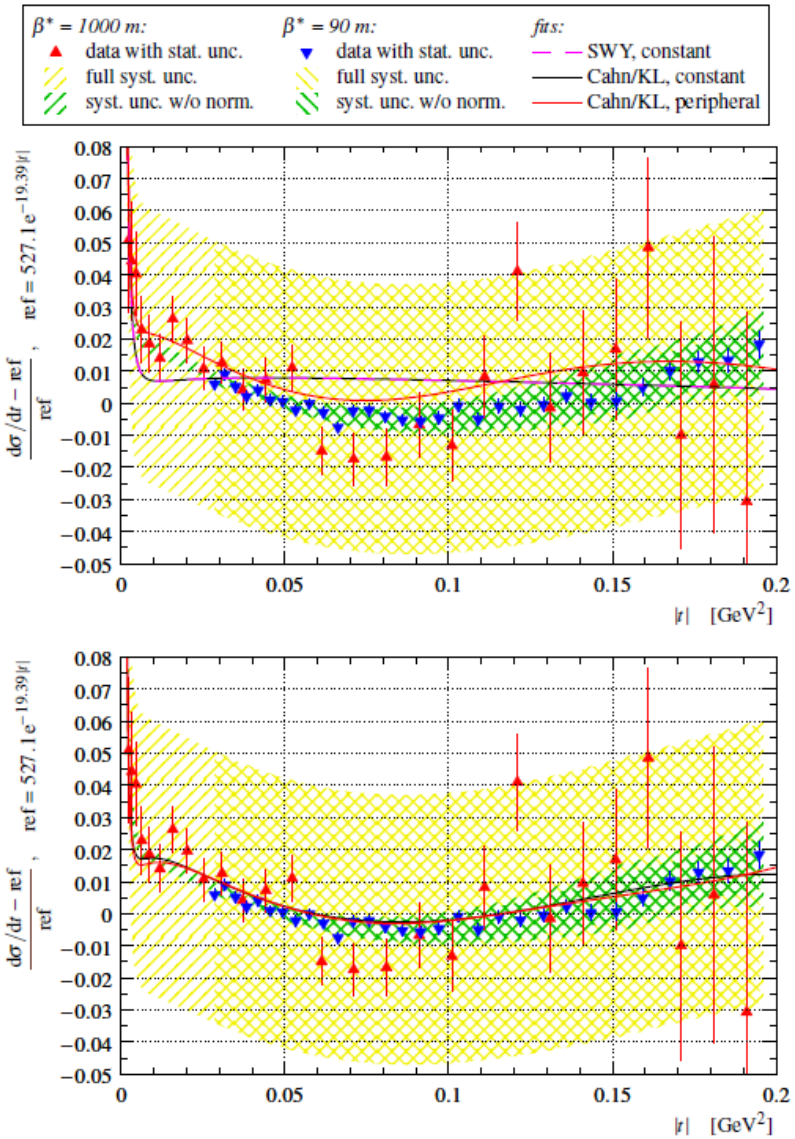
Successful insertion with 2244 bunches (max in 2015)



Temperature of the Cylindrical Roman Pot



Elastic scattering : *Coulomb interference – Fits*



⇐ **purely-exponential hadronic amplitude**

- *constant phase excluded* (with both SWY and KL formulae) ⇒ application of SWY formula excluded too
- *peripheral phase* not excluded by data, but *disfavoured*
  - ρ value outside a consistent pattern of other fits and theoretical predictions
  - number of theoretical reasons for non-exponential hadronic amplitude

⇐ **non-exponential hadronic amplitude**

- both constant and peripheral phases compatible with data ⇒ *centrality not necessity*