4 June 2014

118th LHCC - Open session

TOTEM status report

Marco Bozzo

On behalf of the TOTEM Collaboration

Overview

- TOTEM Physics program
- Recent progress consolidation and upgrade work in LHC ,
- Timing measurements in the Vertical RP (TDR preparation)
  - Physics
  - Running
  - Detectors
  - Electronics
  - Trigger
- CMS TOTEM-Proton Precision Spectrometer (TDR preparation)
- Recent analysis

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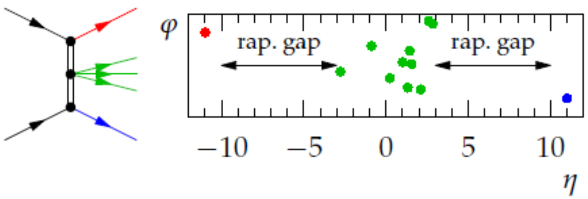
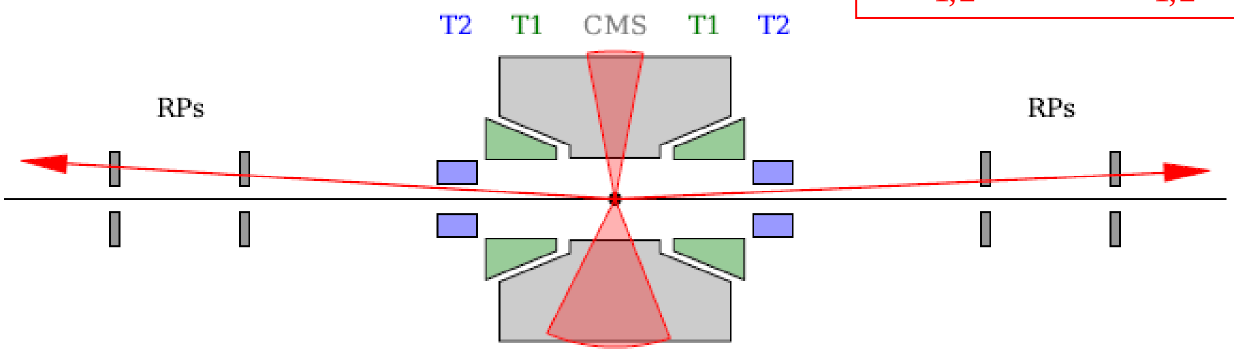
TOTEM Physics program

- Standard measurement of elastic scattering
  (from the largest to the smallest *t*)
  and of the total and inelastic cross section at the new LHC energy
- Physics search on low mass spectroscopy (1-3GeV)
  - gluonic states and glueball searches
  - diffractive χ_c production
- central-diffractive jet production
- missing/escaping mass

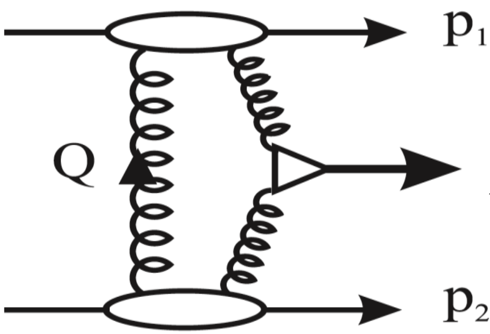


$$\Delta\eta_{1,2} = -\ln \xi_{1,2}, \quad M^2 = \xi_1 \xi_2 s$$



Preliminary investigation of some Physics Channels in progress with the analysis of data from joint CMS-TOTEM high β^* run (90m) , 8 TeV , July 2012

Central exclusive production (CEP)



(ξ_1)

$M^2 = \xi_1 \, \xi_2 \, s$

X at rapidity y_X

gg collider !

(ξ_2)

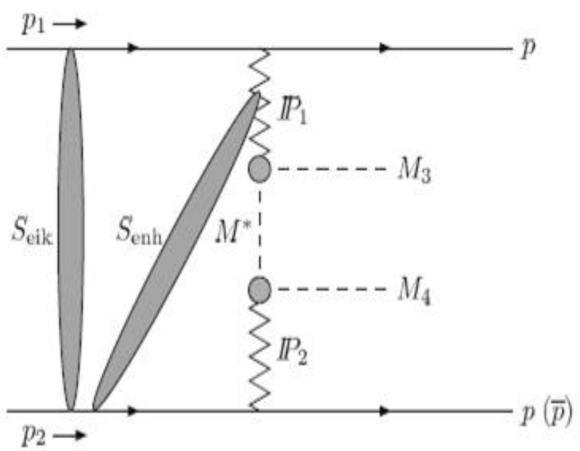
$$y_X = \frac{1}{2} \ln \frac{\xi_1}{\xi_2}$$

also $\gamma\gamma$ fusion & photoproduction

- exchange of colour singlets with vacuum quantum numbers
  $\Rightarrow$ selection rules for system X: $J^{PC} = 0^{++}$, 2++, … resonances, jets,?….
- <u>With double-arm proton detection:</u>
  β^* = 90 runs: all M(pp), $\mu \sim 0.05 - 0.5$ $\Rightarrow$ O(0.1-10 pb^{-1}/day)
  low β^* runs: M(pp) > ~ 350 GeV, $\mu \sim 30 - 50$ $\Rightarrow$ O(1 fb^{-1}/day)
- Comparison/prediction from forward to central system:
- M(pp) =? M(central), $p_{T,z}$(pp) =? $p_{T,z}$(central), vertex(pp) =? vertex(central)
- Prediction of central particle flow topology from proton ξ's (rapidity gaps): $\Delta\eta_{1,2} = -\ln\xi_{1,2}$
- CMS & TOTEM common runs: access to O(pb) cross-sections,

CEP low mass states & glueballs

X = low M resonance / meson pair
($\pi\pi$, KK, $\rho\rho$, $\eta\eta$)



LHC: an excellent place to study CEP low M states

- small p_T's of final state mesons
  $\Rightarrow$ CMS tracking $\Delta M \sim 10$ MeV (« ISR, RHIC, Tevatron)
- π/K/p separation using CMS tracker dE/dx
- proton tagging in $\beta^* = 90$ runs
  $\Rightarrow p_T$ central system ~ 40 MeV
- RP proton tagging $\Rightarrow$ no need to invoke rapidity gaps
- large η coverage & protons $\Rightarrow$ exclusivity ensured with excellent S/B
- spin determination from decay angles & proton azimuthal correlations

Small ($\xi \sim 10^{-3}$ 10^{-4}) at LHC from RP vertices $\Rightarrow$ pure gluon pair $\Rightarrow$ masses ~ 1-3 GeV

Pomeron $\approx$ colourless gluon pair/ladder
$\Rightarrow$ Pomeron fusion likely to produce glueballs

- Past luminosity: ~ 0.003 pb^{-1} $\Rightarrow$ need $\times$ 300 ($\sim$ 1 pb^{-1}) to produce resonances
- Study of glueballs & χ_c in hadronic modes require $\times$ 3000 ($\sim$ 10 pb^{-1})
- Increase in integrated luminosity in high β runs may be obtained :

  Increasing bunch number (requires crossing angle for high β runs)

  Increasing running time

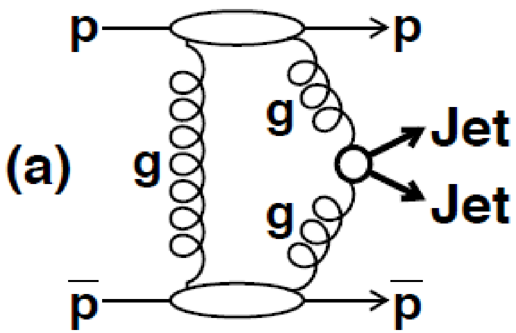
CEP jets

$$pp \to p + \text{dijet} + p$$

- J_z= 0 selection rule: $gg \to \bar{q}q, \bar{b}b$ suppressed by a factor 10^2-10^3
- CEP dijets: 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 & CEP 3-jet topologies
  - Durham model: $gg \to \bar{q}qq$ (more Mercedes-like) & $gg \to ggg$ ("more back-to-back").

Durham group (KHARYS MC)



Predictions for CMS-TOTEM selection:

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

Past luminosity: ~ 0.1 pb^{-1} $\Rightarrow$ need × 1000 (~ 100 pb^{-1}) for sufficient statistics (~ 10k)

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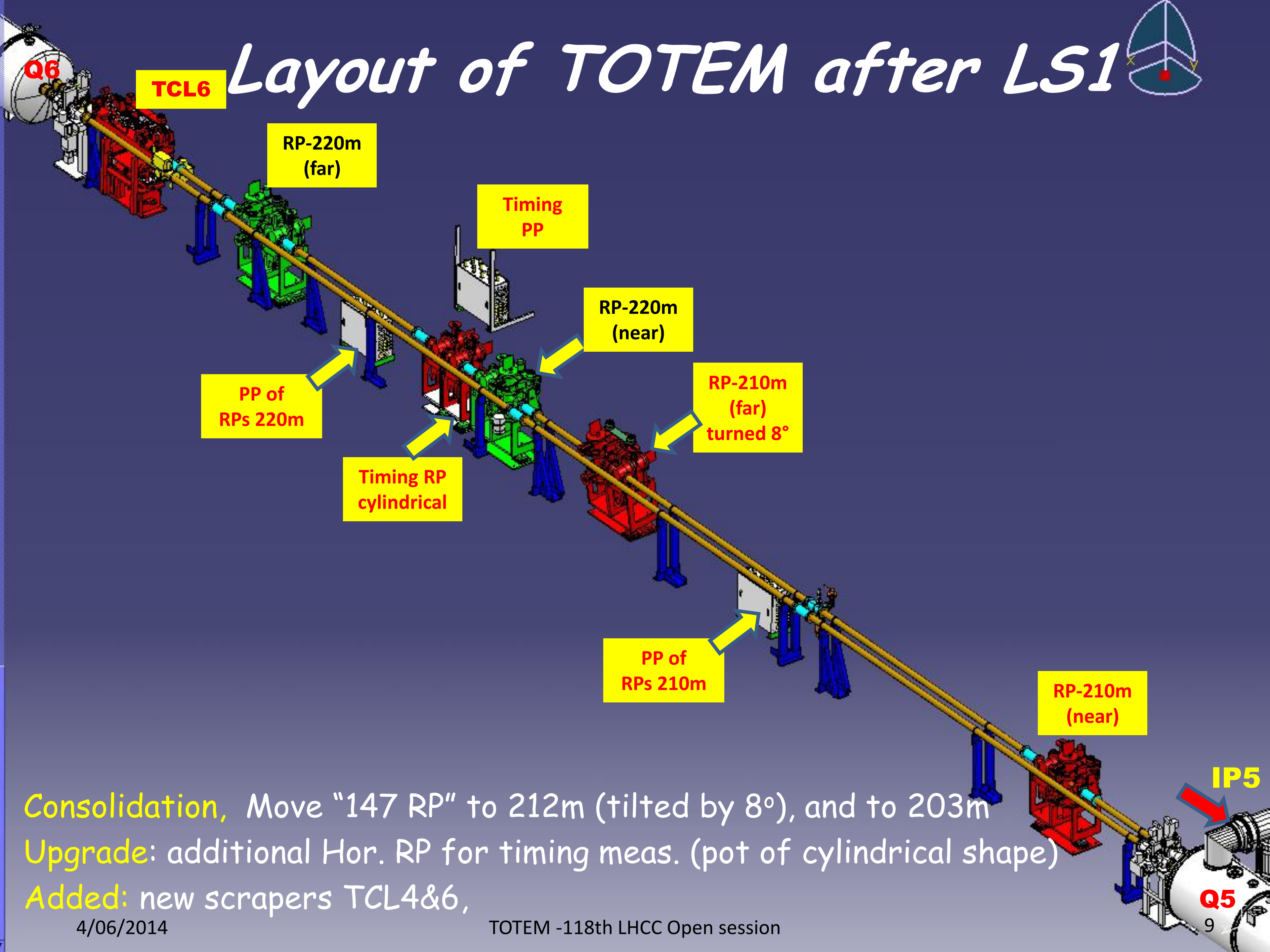
Layout of TOTEM after LS1



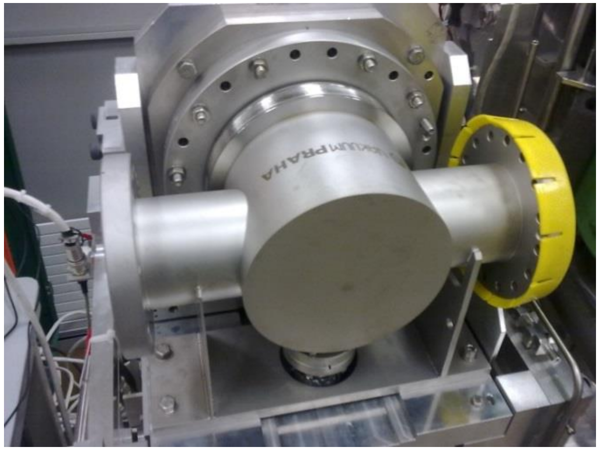
Consolidation, Move “147 RP” to 212m (tilted by 8°), and to 203m

Upgrade: additional Hor. RP for timing meas. (pot of cylindrical shape)

Added: new scrapers TCL4&6,

Progress on Roman Pots

- Location of new horizontal RP confirmed by LHC integration, vacuum and impedance groups.
- 6 horizontal vacuum chambers have been produced and installed in LHC: technology OK, all tests passed.
- New ferrites (ring) simulated, designed, produced, tested and integrated into RP;
- RF shields (Faraday cage) produced, mechanical and integration tests passed;

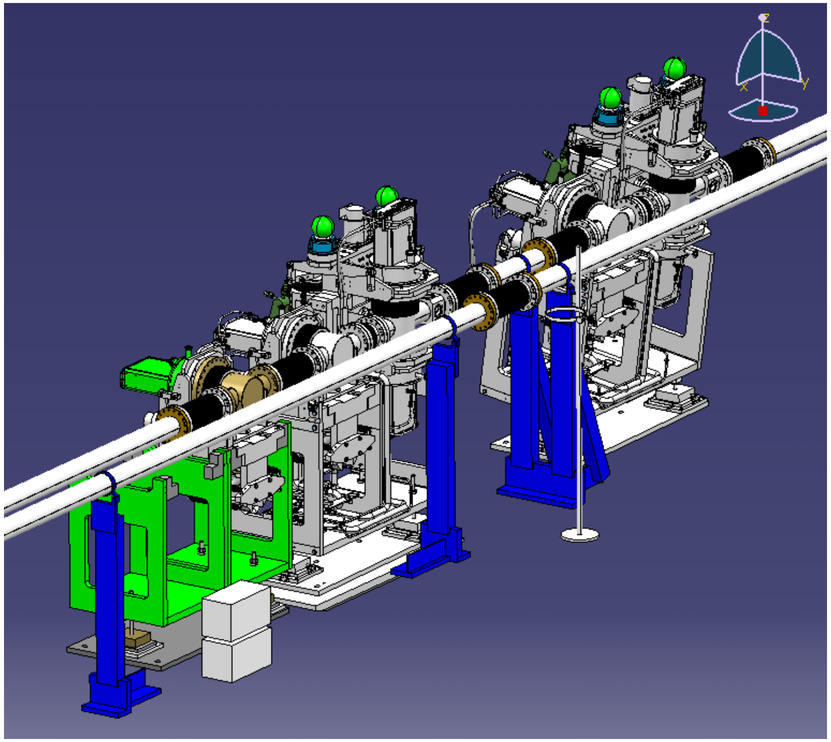


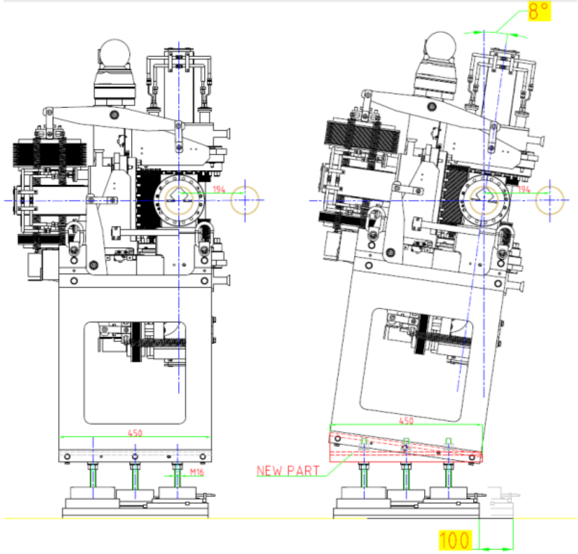
- Four 220m RP stations refurbished (new ferrites and anti-collision switches), tested and already installed in the LHC tunnel.
- Four 210m RP stations have been refurbished (new ferrites, RF shield, anti-collision switches), tested,
  - under bakeout
  - will be installed in the LHC at the beginning of June (next weeks).
  - within LHC schedule

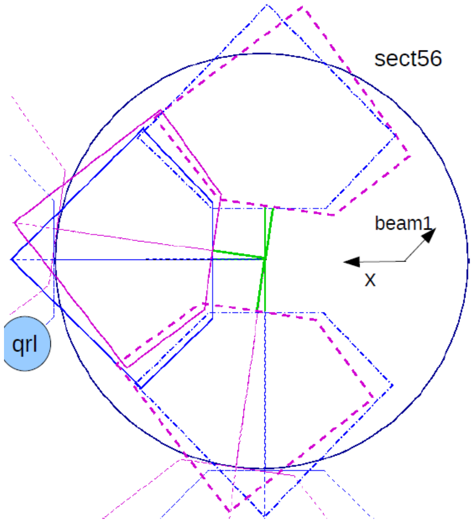
Consolidation improves RP tracking

at 210 m

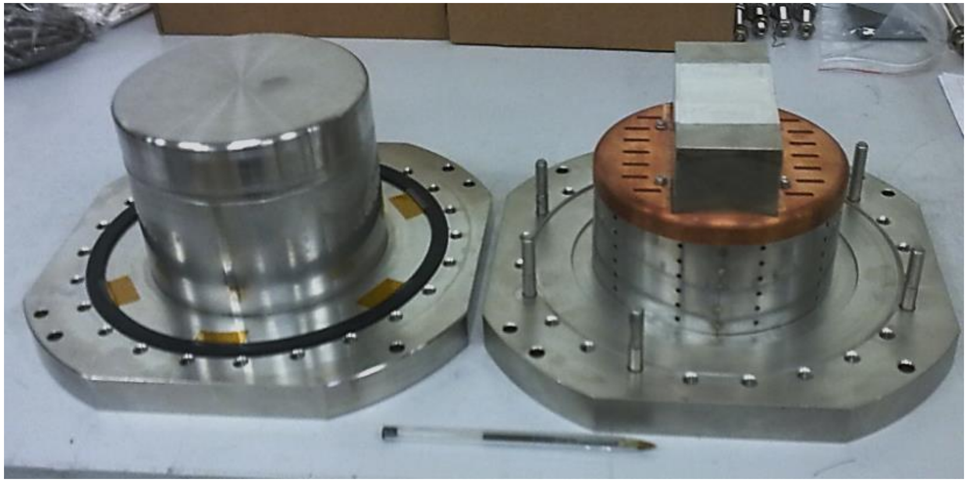
- RP F rotated by 8°
  - improves multitrack tracking efficiency by adding stereo angle capability
- RP N Increases lever arm for angle measurement





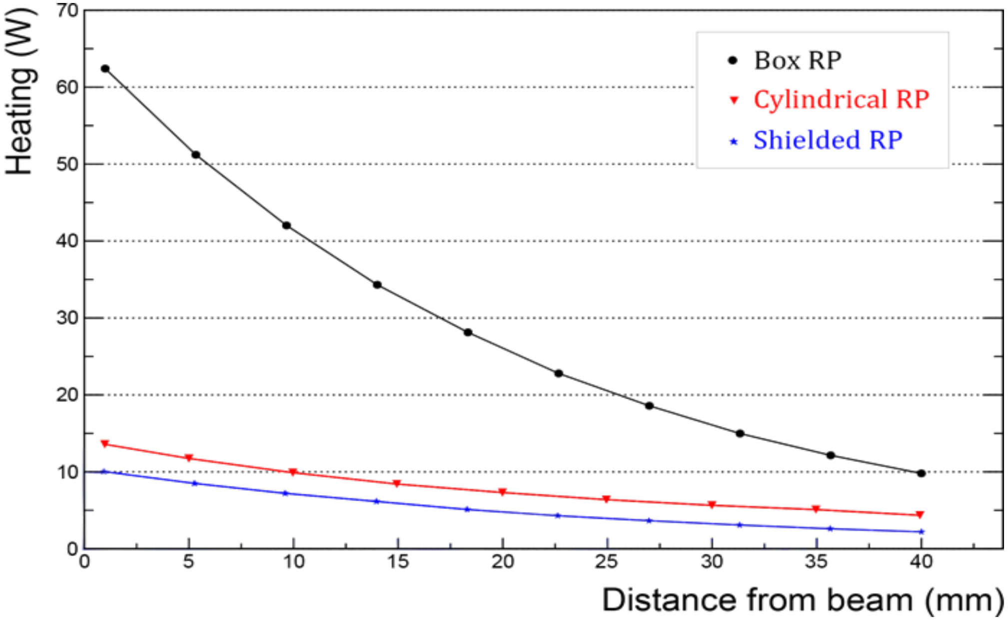


Optimization, tests, production



RF studies (impact on machine),

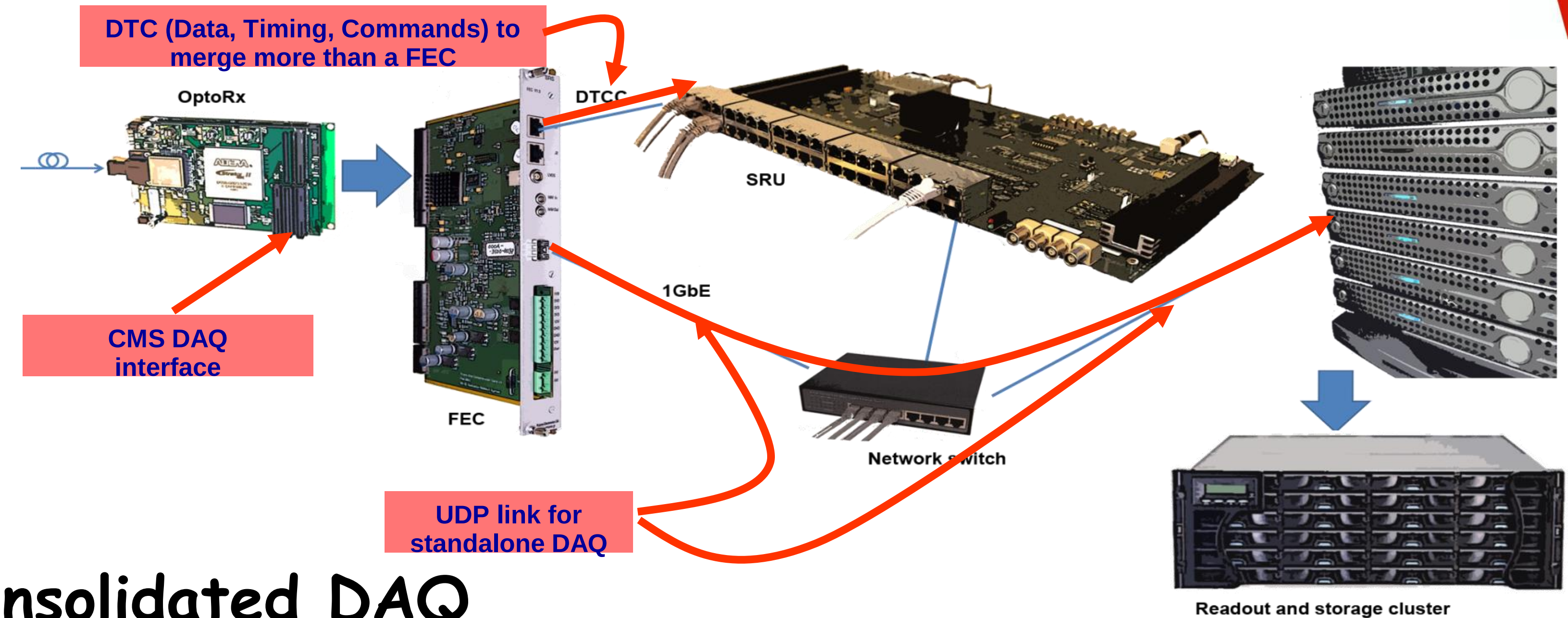
- RF shield for square pots of Run I,
- Ferrites to control induced RF
- New Pots cylindrical with thin window



50 ns

I_B=0.6 A

DAQ consolidation



Consolidated DAQ

- Full compatibility with CMS DAQ
- Full compatibility with LHC Trigger Timing and Control (TTC)
- Higher L1 trigger rate (20kHz trigger rate, ~20x w.r.t. previous DAQ system)
  - measured on 1 FEC with 1 OptoRx through a standard PC.
- Replacement of the VME back-end with Ethernet 1Gb links
- Full TTC commands set, L1A and TTC clock distribution integrated in the system.
- Hardware resources (FPGA) at different level enables real-time data filtering.

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Timing measurements in vertical Roman Pots

Integrated luminosity of 100 pb^{-1} is necessary to probe O(pb) cross-sections for the study of

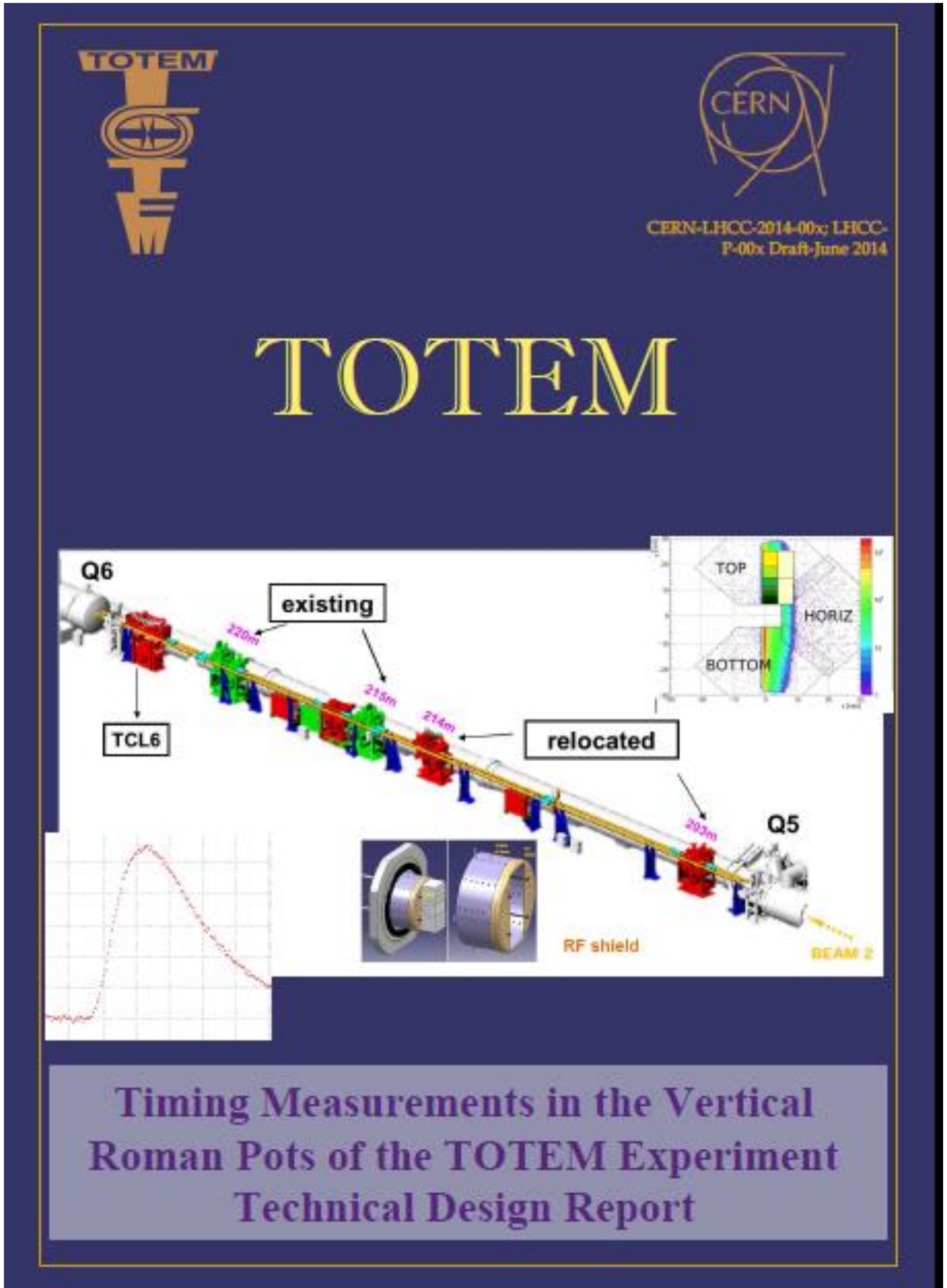
- High statistics hard diffractive processes in CD (jet physics)
- Study of BR and quantum numbers of gluonic states candidates
- Missing mass candidates with inclusive production cross section of O(pb)

Such integrated luminosity becomes reasonable for high β runs if a pile up $\mu \sim 0.5$ is generated by increasing bunch population

$\Rightarrow$ forward physics in special runs with vertical pots requires presence of timing to identify the collision vertex

- Signal and background scale with intensity

Remark: Timing improves background reduction also in low pileup runs



Vertical RP timing project TDR

- At the previous LHCC meeting TOTEM announced that had started preparation of a TDR
- Goal was to use production technologies to implement it by end 2015
- Status and progress on TDR preparation
- Test beam campaigns during summer (PSI, PS, SPS)
- Delivery of TDR to LHCC in September 2014

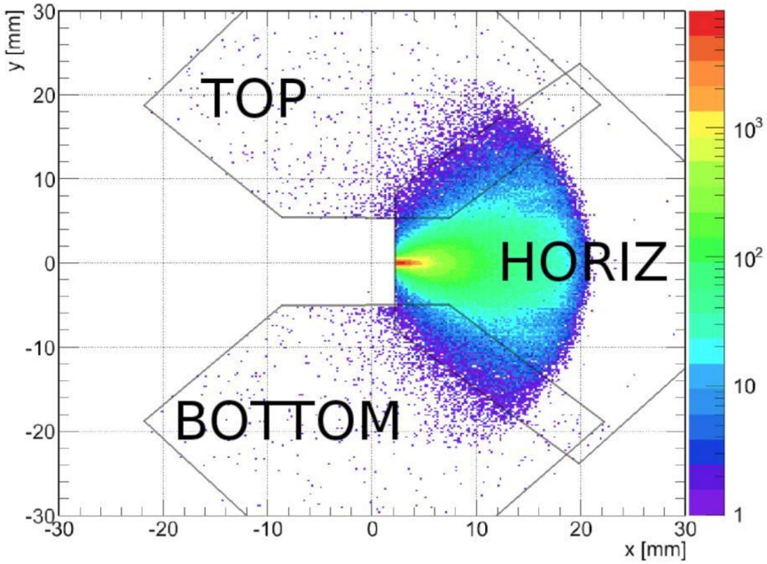
New TOTEM TDR:
Timing measurements in
vertical Roman Pots

Contents

Different LHC Optics

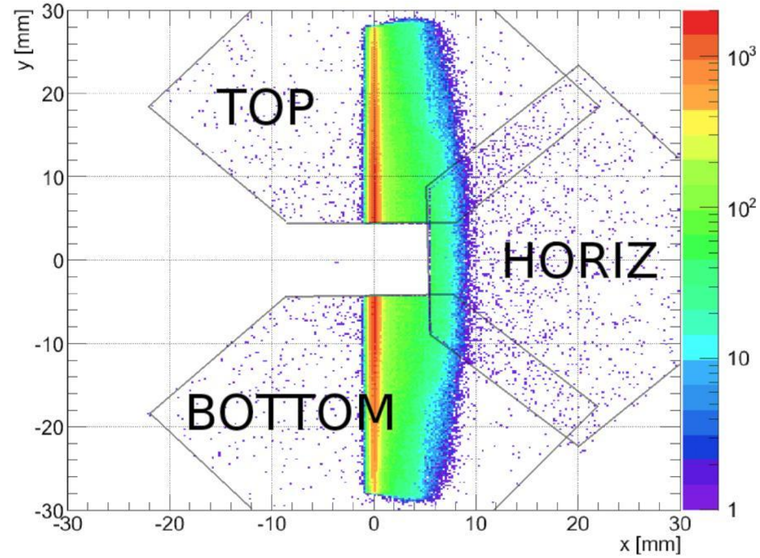
Hit maps of simulated diffractive events for 2 optics configurations
(labelled by β* = betatron function at the interaction point)

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



L_x = 1.7 m, L_y = 14 m, D_x = 8 cm
diffractive protons: mainly in **horizontal** RP
elastic protons: in vertical RP near x ~ 0
sensitivity only for large scattering angles

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



L_x = 0, L_y = 260 m, v_y = 0, D_x = 4 cm
diffractive protons: mainly in **vertical** RP
elastic protons: in narrow band at x ≅ 0,
sensitivity for small vertical scattering angles

	Beam width @ vertex		Angular beam divergence		Min. reachable |t|	
β* ~ 0.5–3.5 m	$\sigma^*_{x,y} = \sqrt{\frac{\varepsilon_n \beta^*}{\gamma}}$	small	$\sigma(\Theta^*_{x,y}) = \sqrt{\frac{\varepsilon_n}{\beta^* \gamma}}$	large	$\left\| t_{\min} \right\| = \frac{n_\sigma^2 p \varepsilon_n m_p}{\beta^*}$	~ 0.3–1 GeV²
β* = 90 m		large		small		~ 10^{-2} GeV²

Timing Detectors

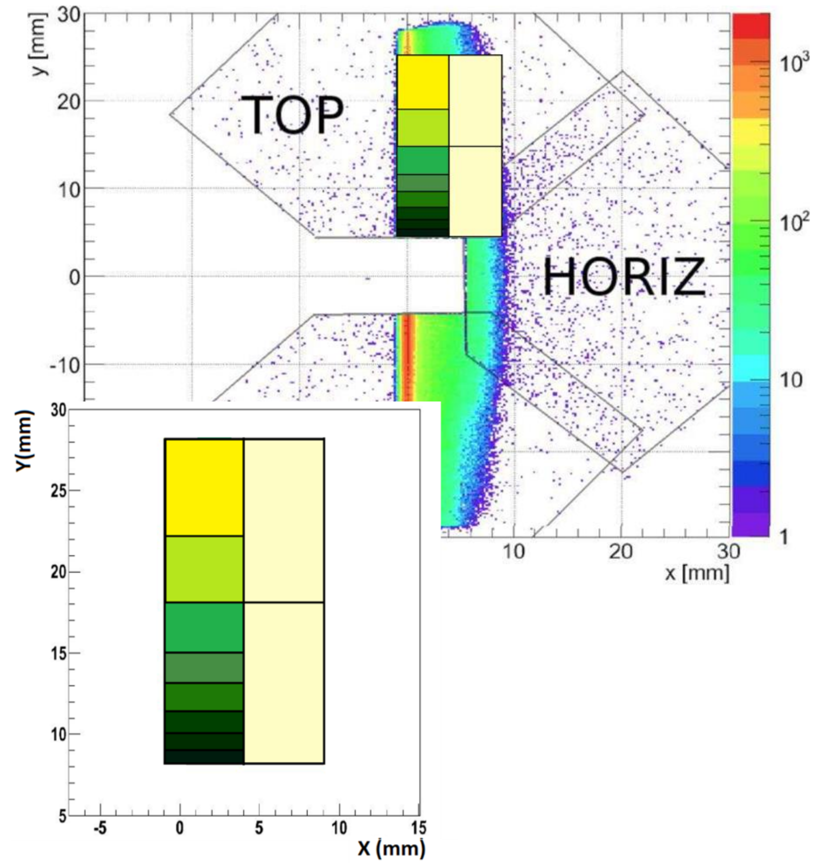
Goal: have a working detector prototype by end 2015

Optimization driven by physics and technical choices

- Minimize number of channels without compromising the physics program
  - Map plane with different size pads with same occupancy
  - Minimum number optimized with simulation

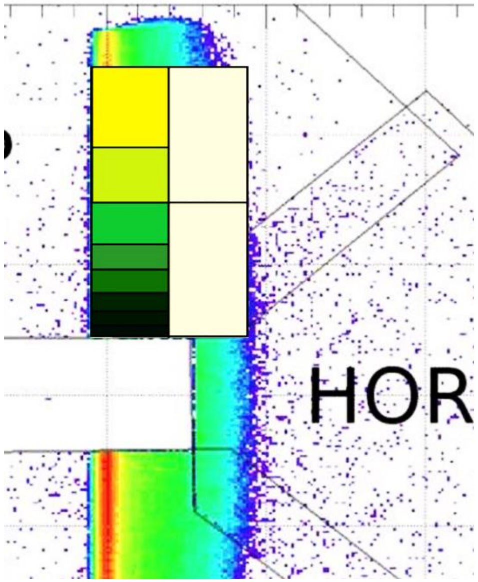
- Detector
  - Dimensions: 10mm X 20mm
  - 10 pixels with dimensions adapted to track density
  - *A stack of 4 Planes improves the single plane timing resolution (1/2)*
  - *Available on the market is 5X10 mm* and 10X10 mm, 500 μm thick

- Timing Specifications
  - Measure time of arrival of proton with a resolution better than 50ps



Detector choice

- Chose a Detector technology easily available w/o special development; detector must be "thin" to fit in Vert RP
  - Diamond detectors
    - Rad hard
    - Fast signal from low capacity
    - No variation in time response with size
    - Easy segmentation to a small number of channels by metallization
    - High impedance yet small charge released for MIPS: low S/N
  - Silicon detectors
    - Large pixels have charge collection time skew, hence necessity to have large number of pixels (unless new 'Ultra-fast' silicon ?)
    - Segmentation to be performed in industry (construction delays)
    - Large number of channels requires special ASICs development.



- Preamplifier (discrete components)
  - Charge amplifier
    - Good S/N ratio
    - Slow (~1/200 ps resolution)
  - Current amplifier
    - Fast (2GHz RF amplifier)
    - Low S/N ratio (1/2)
- Time measurement:

  Fast TDC : FPGA or Asics

  SAMPIC chip or DRS5

Tests with particles beams

Test with particle beams to validate final design

- Small diamond detector telescope built

  2 diamond planes 4 mm X 4 mm and commercial amplifiers

  Custom Amplifiers (ongoing development)

- Test Beam dates and goals
  - Early June (PSI)
    Test preamplifiers: full signal study (Preamp + High bandwidth Oscilloscope)
  - Late July (CERN PS)
    Test Discriminator resolution and corrections
  - Late October (CERN SPS)
    Test TDC option and full chain
  - December (CERN SPS)
    Define detector package
- By end 2015
  - construction of full detector prototype
  - installation of prototype in vertical pots (Winter shut down ?)
- All detectors will be tested in a SPS beam before installation

Trigger

- Multiple tracks from RP tracking
- CMS L1 limited(?) to Calorimetry and muons
- Need HLT to match vertices

Recipe:

- Cut on track multiplicity ≤2 on each side
- Sum and difference of *t* at L1
  - Cut on time sum (gives bunch crossing) to remove secondary particles from collisions debris
  - Cut on time difference (Z position) for vertex identification
- Check consistency of vertices position at HLT (High Level Trigger of CMS) comparing with CMS list

- SAMPIC may provide a discriminator output for fast output to be used for trigger

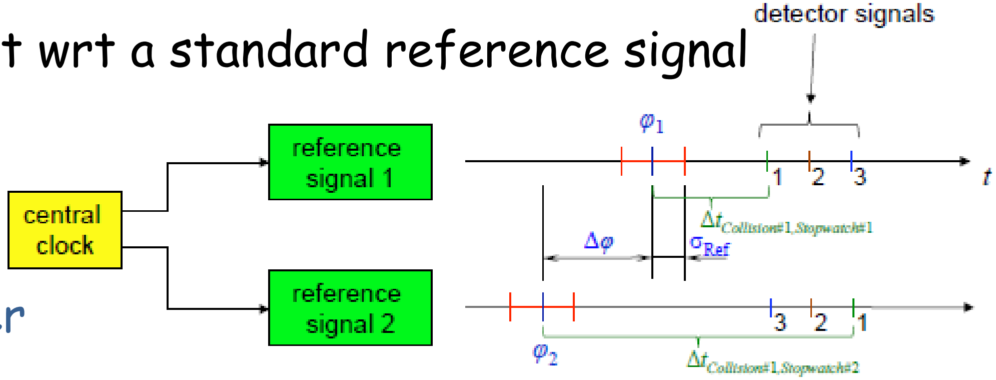
Clock distribution

Precise and stable timing reference is required for a final precision of measurement with 20-50 ps resolution.

Clock distribution will use system studied and tested for the FAIR facility at Darmstadt

- standardized method of transmitting on fibers DWDM (ITU-T)
- commercially available electro-optical components
- one reference signal measures the fiber length (time) and allows corrections for time fluctuations

- Time is measured as the offset wrt a standard reference signal
  - offset doesn't need to be the same on the two sides
    - $|\varphi 1-\varphi 2| = \Delta\varphi \neq 0$ is ok
  - but should be constant over short time periods
    - $\Delta\varphi$ = constant with a drift tolerance < 1 ps/min



Remark: $\Delta\varphi$ drift can be obtained from the measurements data base (in approx 10 minutes) and corrected

- Jitter : Standard deviation σ_{Ref} < 10 ps

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CT-PPS TDR

- The signature of the MoU between CERN CMS and TOTEM was already reported at last LHCC:
- Formed Management team of joint CT-PPS project
- Kick off meeting of Institution Board
- Organization to write the common project TDR (editorial board)

June 2, 2014

DRAFT
CMS-TOTEM Precision Proton Spectrometer
Technical Design Report

Abstract

Section	Editor
Overview	Joao Varela
Physics with the CMS-TOTEM Precision Proton Spectrometers	Mike Albrow, Ken Osterberg, Michele Arneodo
Strategy and Running Scenarios	Joachim Baechler, Mario Deile
Detector and physics performance	Michele Gallinaro, Valentina Avati
Moving Beam-Pipe	Jonathan Hollar
Roman Pots	Joachim Baechler
Silicon Sensors	Nicolo Cartiglia
Silicon Readout and Mechanical	Maurizio Lo Vetere
Fast Timing Cherenkov Detectors	Mike Albrow
Fast Timing Silicon Detectors	Nicola Turini
Fast Timing Electronics	Joao Varela
Reference Timing System	Doug Wright, Nicola Turini
Trigger Strategy	Nicola Turini
Organization, Cost, Schedule	Doug Wright, Joachim Baechler

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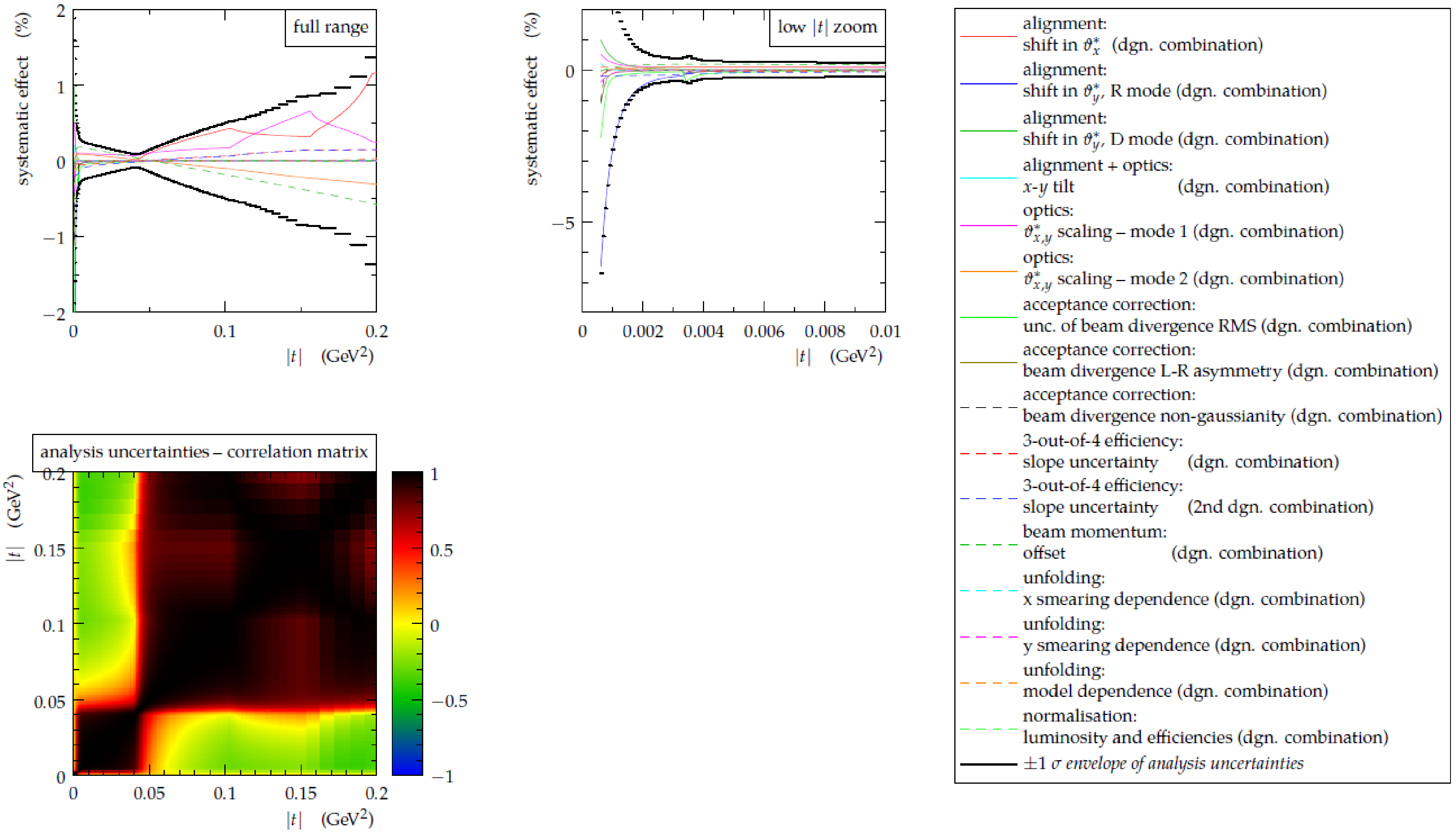
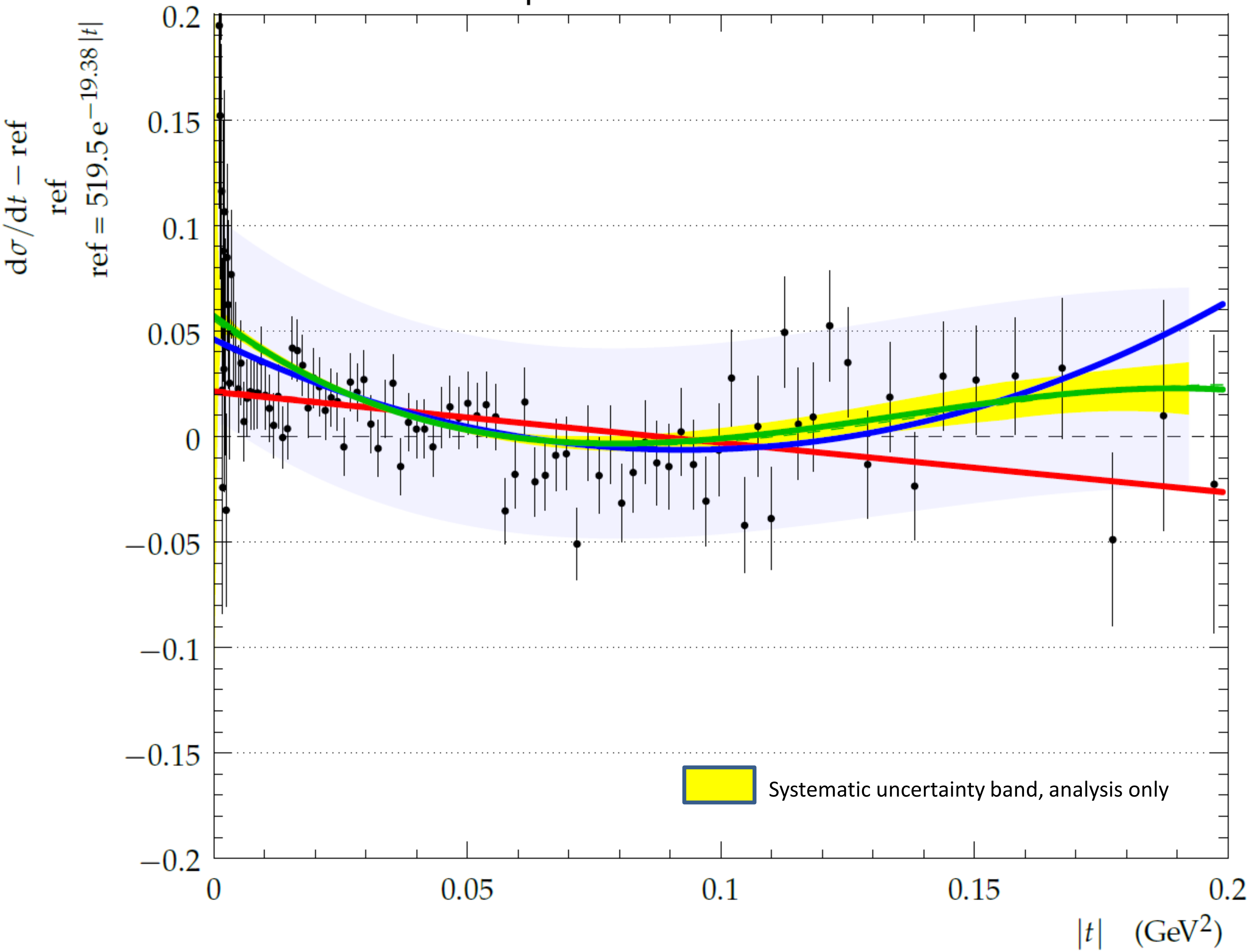
Recent analysis

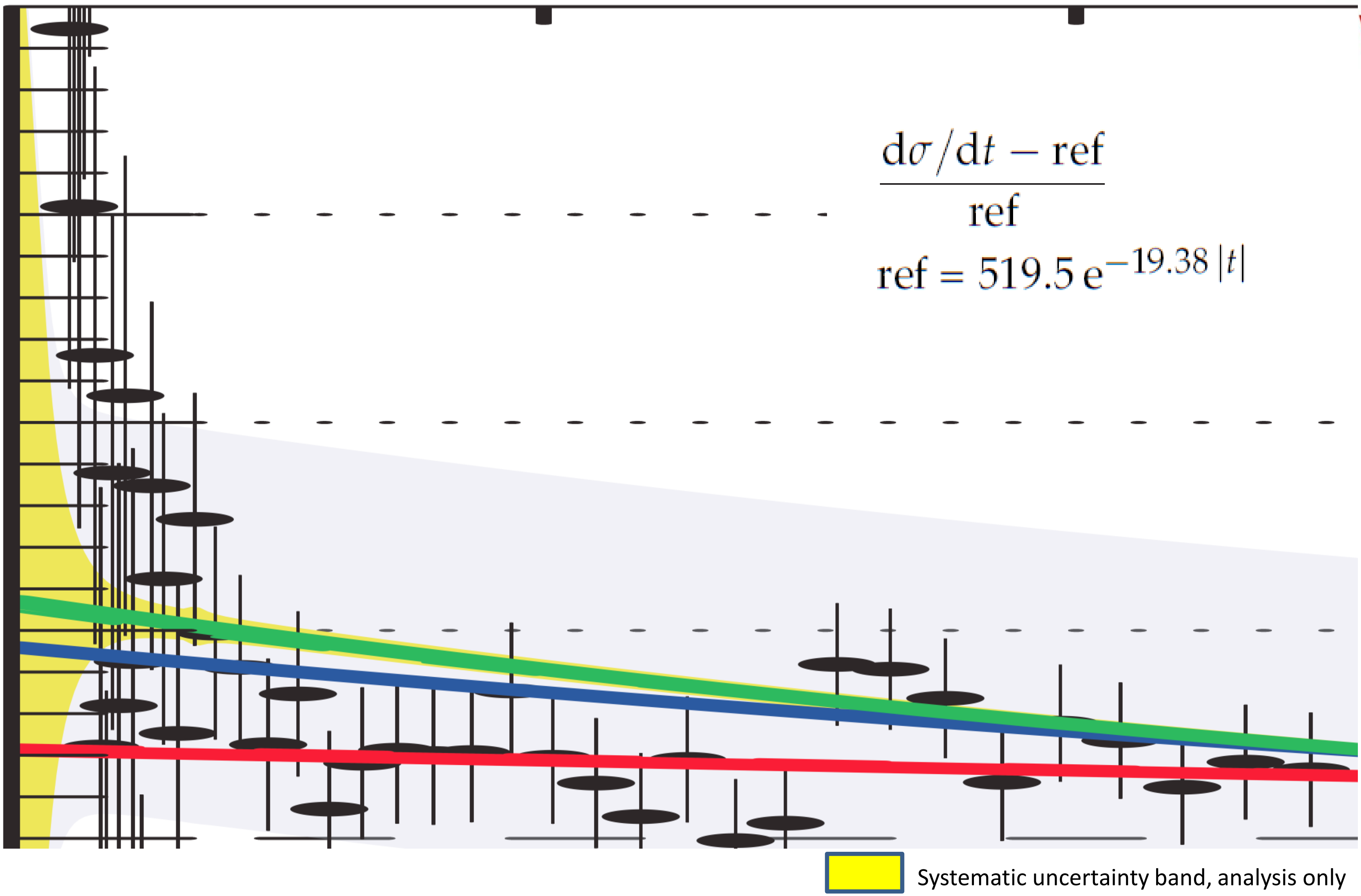
- The 1km β data measured elastic scattering down to the Coulomb Interference Region
- 1km analysis has been brought to the same level (even if with much lower statistics) of the elastic scattering one at 90 m (shown at the previous LHCC meeting)
- Systematic effects study
- t-distribution
- Next step is to publish the combination of the results taken with the $\beta = 1000$ m and 90 m optics.

1km β run – systematic effects





$\frac{d\sigma/dt - \text{ref}}{\text{ref}}$
$\text{ref} = 519.5\,e^{-19.38|t|}$
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
0
0.05
0.1
0.15
0.2
$|t|$ (GeV^2)
Systematic uncertainty band, analysis only



$\frac{d\sigma/dt - \text{ref}}{\text{ref}}$
$\text{ref} = 519.5\, e^{-19.38\,|t|}$
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