DIFFRACTION 2014

The CT-PPS Project

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On behalf of the CMS and TOTEM Collaborations
Outline

- Introduction and Physics motivations
- Experimental challenges and Detectors
- Project planning and Summary
The CMS-TOTEM Precision Proton Spectrometer (CT-PPS) will allow precision proton measurements in the very forward regions on both sides of CMS during standard LHC running:

- Two stations for tracking detectors and two stations for timing detectors installed at ~210 m from the common CMS-TOTEM interaction point (IP5) on both sides of the central apparatus

- LHC magnets between IP5 and the detector stations used to bend out of the beam envelope protons that have lost a small fraction of their initial momentum in the interaction

→ fractional longitudinal momentum loss (ξ) between 2% and 10%

LHC lattice between IP5 and CT-PPS detector stations
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A Memorandum of Understanding between CERN and the CMS and TOTEM Collaborations for a common physics program and detector development signed in December 2013

The TDR is ready and approved by the two Collaborations
Now presented to the LHCC (next meeting on Sep. 23rd-25th)
[CERN-LHCC-2014-021, CMS-TDR-13, TOTEM-TDR-003]
Primary goal: study of central exclusive production (CEP) in proton-proton collision during standard low-β* LHC running at high luminosity

CEP:

\[
p p \rightarrow p + X + p
\]

\( X = \mu^+\mu^-, W^+W^-, ZZ, \text{ high } E_T \text{ jets, } Z, H \ldots \)

\( + = \text{rapidity gap} \)

\( i, j = \text{only photon and gluon exchanges are allowed} \)

The measurement of the two scattered protons fully determines the kinematics of the central system \( X \), irrespective of its decay mode.

\[
M_X = \sqrt{s} \cdot \xi_1 \cdot \xi_2
\]

CEP is a powerful process to access a variety of physics topics:

- \( \gamma\gamma \) exclusive production of \( W^+W^- \), \( I^+I^- \), but also \( ZZ \) and \( \gamma\gamma \)
- QCD program on hard diffraction: exclusive high \( E_T \) jets, dPDFs, GPDs, \( S^2 \), …
- photoproduction
- search of new resonances beyond the SM (quantum numbers 0++, 2++)
Physics motivations

LHC as a photon-photon collider

- Measure $\gamma\gamma \rightarrow W^+W^-$, $e^+e^-$, $\mu^+\mu^-$, $\tau^+\tau^-$
- Search for anomalous quartic gauge couplings (AQGC) with high sensitivity for $M_X > 1$ TeV
- Search for SM forbidden $ZZ\gamma$, $\gamma\gamma\gamma\gamma$ couplings
- Note: $\gamma\gamma \rightarrow \mu^+\mu^-$ can be used to calibrate the momentum scale of the spectrometer

LHC as a gluon jet factory

- Gluon jet samples with small component of quark jets
- Exclusive two and three jet events, with $M_X$ up to $\sim 700-800$ GeV
- Test of pQCD mechanisms of exclusive production

Two processes studied in detail for the TDR

Exclusive WW production

Exclusive dijet production
M_χ acceptance and resolution

- With detectors at 15σ from the beam centre, PPS selects exclusive systems in the 350-1700 GeV range (ε>5%)

Search for exclusive (light) Higgs production is not possible

- At 15σ acceptance larger wrt 20σ for lower mass range

- γγ central system acceptance greater than that for gluon-gluon events because of smaller |t|

- Mass resolution ~1.5% at 500 GeV
Exclusive WW production

- Study only **eμ final state**
- Dominant **background**: inclusive WW and exclusive ττ pair production

Tail of the $W_{\gamma\gamma}$ distribution ($W_{\gamma\gamma} = M_X = \sqrt{s \cdot \xi_1 \cdot \xi_2} > 1$ TeV), where SM contribution is expected to be small, provides a very clear separation of AQGC events.

Proton timing is a powerful tool to reject background.

Timing resolution of **10 ps** is assumed.
AQGC expected limits

Expected limits @95%CL:
(areas outside the contours are excluded)
Exclusive dijet production

- Require 2 jets with $p_T>100$ GeV and $|\eta|<2$

Proton timing as powerful discriminant for exclusive states:
- retain ~66% (1σ) of signal
- rejects ~70% of QCD bkg

Dijet mass fraction:
- $M_{jj}$ (central detector)
- $M_X$ (PPS)

Rapidity difference:
- $y_{jj}$ (central detector) – $y_x$ (PPS)
Yields per 1/\text{fb} - Pileup=25

Event yields for signal and background processes as a function of the cuts applied.

⇒ S/B \sim 1/3
CT-PPS in the LHC beam line

RP units at: 220m ~ 215m 204m → IP5

- 2 vertical + 1 horizontal RPs per station (relocated from 147m)

New collimator TCL6 to protect magnet Q6

Extreme flexibility in using Roman Pot units according to the running scenario

In particular, in the exploratory phase of 2015-2016:
- pursue the TOTEM / TOTEM+CMS physics programme at high-β* low/medium luminosity
- prove the RP insertions and data taking at high luminosity and pileup

Relevant pots/detectors for low-β* high luminosity runs:

- 2 new horizontal cylindrical RPs equipped with timing detectors
- 2 horizontal rectangular RPs equipped with tracking detectors
Experimental challenges

- **Ability to operate the detectors close to the beam (15-20σ)** to maximize acceptance for low momentum-loss protons

  Need to **limit the additional RF impedance introduced by beam pockets:**
  - now RPs with improved RF shielding
  - R&D on Movable Beam Pipe as future beam pocket option

  Need to **sustain very high radiation levels.** For 100 fb^{-1}:
  - proton flux up to $5 \times 10^{15}$ cm^{-2} in the **tracker detectors**
  - $10^{12}$ n_{eq}/cm^{2} and 100 Gy in **photosensors and readout electronics**
  - upgrade Si-strips to 3D Si pixel detectors
  - R&D on solid state timing detectors (diamond, LGAD, 3D)

- **Ability to reject the background** expected in the high pile-up ($\mu=50$) environment of normal LHC running, mainly inelastic events overlapping with SD protons from the same bunch crossing

  Use **proton timing** for primary vertex determination

  **Exploit the kinematical constraints** of CEP events

Position of scattered protons at 204m, for fixed ($\xi,t$)

2% < $\xi$ < 10%
Proton timing measurement from both sides of CMS allows to determine the primary vertex, correlate it with that of the central detector and reject pile-up

- Time resolution ~10 ps → Vertex z-by-timing: ~2 mm
- Segmentation to cope with the high occupancy expected
- Edgeless (~ 200 µm)
- Radiation hard

\[ \sigma_v \sim 2 \text{ mm} \]
Timing detectors

- **Baseline:** L-bar Quartic, Čerénkov detectors with quartz radiators

4x5=20 3x3 mm² bar elements

Beam test results:
Time resolution: $\sigma(t) = 33$ ps

2+2 in-line modules: $\sigma(t) \sim 15$ ps

Detector installation foreseen at the end 2015

Occupancy for $\mu = 50$ pileup

High occupancy causes inefficiency due to overlapping hits (may reach $\sim 40\%$)

- **R&D on solid state detectors**
as future alternative solutions:
  - Diamonds, LGADs, 3Ds

Promising for:
  - more radiation hardness
  - smaller segmentation
  - thin $\rightarrow$ more layers
Tracking detectors

Position and angle, combined with the beam magnets, allow to determine the momentum of the scattered proton

- Position resolution of \(\sim 10 \mu m\)
- Angular resolution of \(\sim 1-2 \mu rad\)
- Slim edges on side facing the beam
  \(\rightarrow\) dead region \(\sim 100 \mu m\)
- Tolerance to inhomogeneous irradiation
  \(\rightarrow\) \(\sim 2 \cdot 10^{15} \text{n}_{\text{eq}}/\text{cm}^2\) close to the beam (for 100 fb\(^{-1}\))

- Detectors should fit into existing RPs

- Baseline: 3D silicon pixel detectors
Tracking detectors

6 detector planes per station

For each plane:

- 16 x 24 mm² 3D silicon pixel sensors
- 150(x) x 100(y) μm² pixel pattern same as CMS pixel detectors
- 6 PSi46dig readout chips (52x80 pixels each)

Same readout scheme as Phase-I upgrade of CMS Forward Pixel Tracker
→ Existing CMS DAQ components and software can be reused

3D sensors consist of an array of columnar electrodes
- Mature technology after ATLAS IBL

Interesting features w.r.t. planar sensors:
- **Low depletion voltage** (~10 V)
- Fast charge collection time
- Reduced charged trapping probability and therefore **high radiation hardness**
- **Slim edges**, with dead area of ~100-200 μm or **Active edges**, with dead area reduced to a few μm
- Spatial resolution comparable with planar detectors

Detector installation foreseen in 2016
Tracking detectors

Preliminary results of un-irradiated FBK 3D sensors read out by PSI46dig ROCs, tested at Fermilab with a 120 GeV proton beam

Efficiency vs angle

FBK_11-43-01: Efficiency vs Angle

![Efficiency vs angle graph](image)

- $V_{BIAS} = -25 \text{ V}$
- $\text{Thr} \sim 2700 \text{ e}^-$

Detectors are tilted to reduce the geometrical inefficiency due to the empty electrode columns

Efficiency $> 99.5\%$ already at $5^\circ$

Spatial resolution for 2 pixel clusters: $\sim 12 \text{ µm}$

Edge Efficiency

FBK_11-26-03: Edge Efficiency

![Edge Efficiency graph](image)

- 300 um pixel
- 200 um edge

Efficiency remains high up to 150 µm from the sensor’s boundary

Measurements with the same detectors, irradiated at fluences from $1 \cdot 10^{15}$ to $1 \cdot 10^{16} \text{ n}_{eq}/\text{cm}^2$, were just taken during the last two weeks at Fermilab.

Data analysis is on-going: results are promising.
The CT-PPS project includes an exploratory phase in 2015-2016 and a production phase until LHC LS2 (2018)

• **Exploratory phase** (2015-16)
  – Prove the ability to operate detectors close to the beamline at high luminosity
    • Show that CT-PPS does not prevent the stable operation of the LHC beams and does not affect significantly the luminosity performance of the machine.
  – In 2015:
    • Evaluate RPs in the 204-215 m region
    • Demonstrate the timing performance of the Quartic baseline
    • Use TOTEM silicon strip detectors at sustainable radiation intensity
    • Integrate the CT-PPS detectors into the CMS trigger/DAQ system.
  – In 2016:
    • Evaluate the MBP option
    • Upgrade the tracking to pixel detectors
    • Upgrade the timing detectors if required/possible

• **Data Production phase**
  – Aim at accumulating 100 fb$^{-1}$ of data before LHC LS2
Summary

The joint CMS-TOTEM Proton Precision Spectrometer project has started. The TDR has been approved by the CMS and TOTEM Collaborations and will be examined by the LHCC in two weeks.

CT-PPS adds **precision proton tracking and timing detectors** in the very forward region on both sides of CMS at ~200 m from IP5 to **study CEP events** in pp collisions during **standard low-β* LHC running at high luminosity**.

Central Exclusive Production allows to study a **variety of physics topics**.

New radiation-hard, slim-edge timing and tracking detectors are necessary for the low-β* high luminosity data taking.

**Detector baseline:** Roman Pots
- Čerenkov L-bar Quartic detectors for timing
- 3D silicon pixel detectors for tracking

**R&D:** Movable Beam Pipe
- Solid state timing detectors (Diamonds, Low Gain Avalanche Diodes, 3Ds)

**Project planning:** **Exploratory phase in 2015-2016**
- **Data Production phase, aiming to collect 100 fb⁻¹ of data**