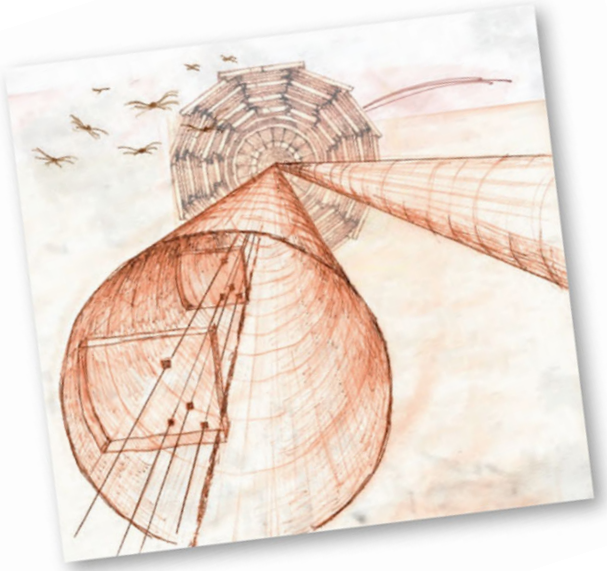
The CMS Precision Proton Spectrometer

Workshop On Forward Physics

Justin Williams

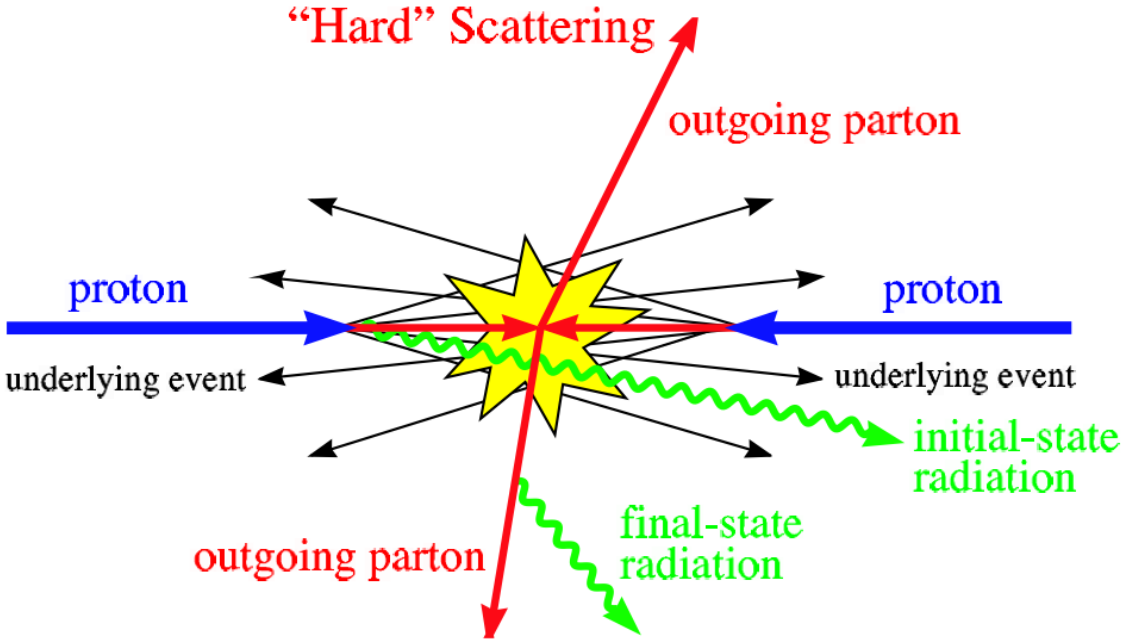
January 23, 2021

justinwilliams@ku.edu



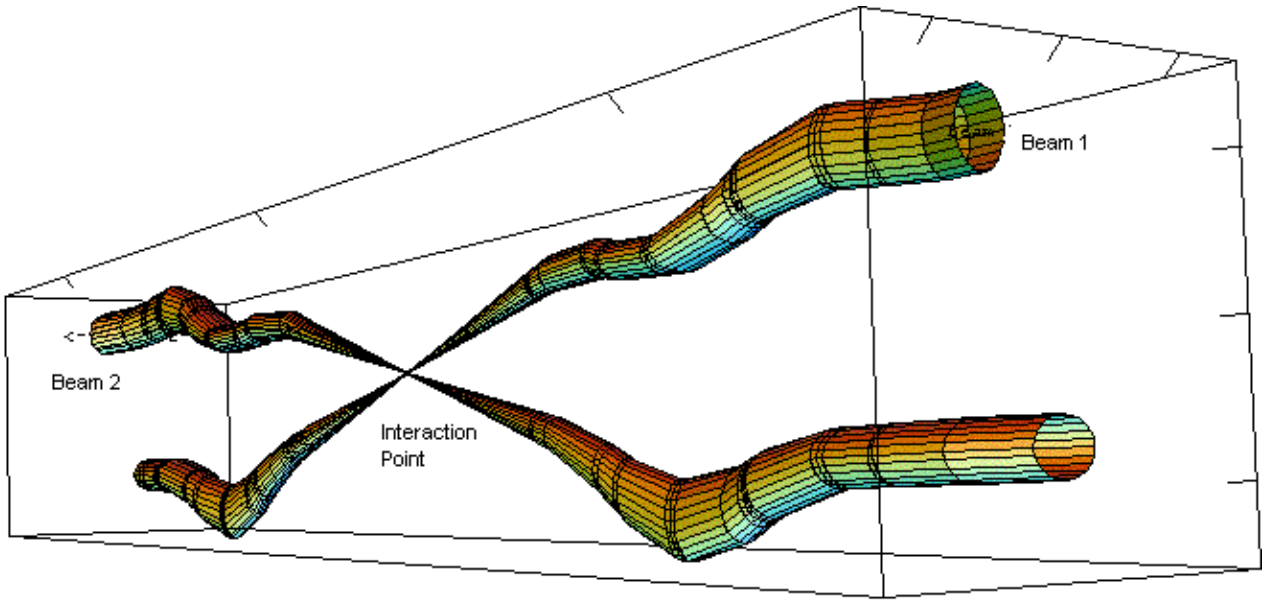
Setting The Scene

The typical collision at the LHC includes parton interactions



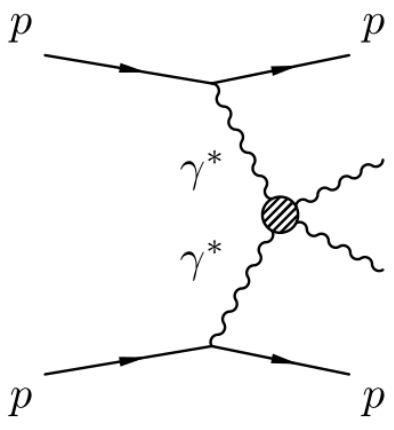
Setting The Scene

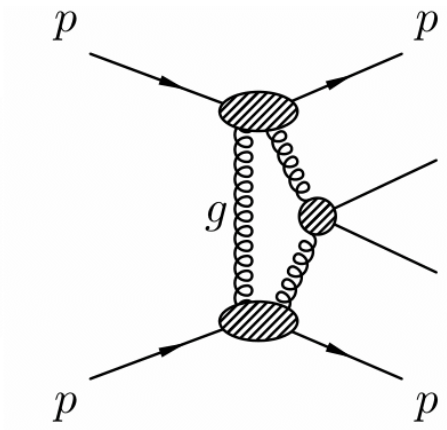
There's a significant number of collisions that leave protons intact



Setting The Scene

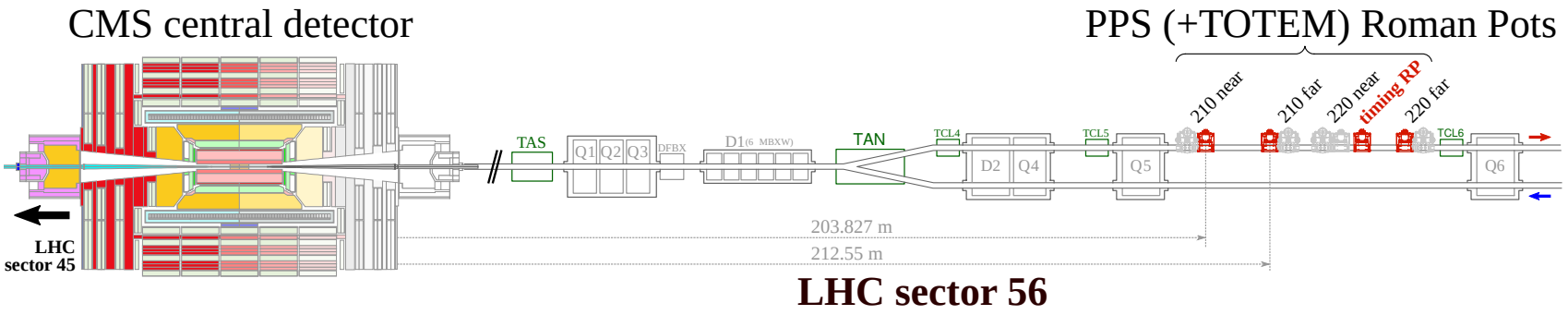
A colorless exchange of objects can produce these types of events





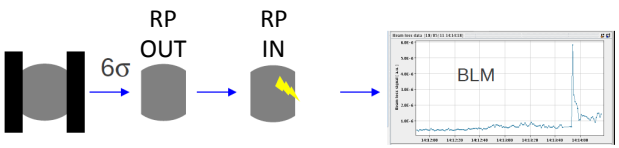
- The central system can be measured by the CMS detector, and the intact protons can be measured by forward proton detectors
- Possibility of a very strong background suppression using intact protons
- Outline
  1. Description of proton detection technology
  2. Physics results
  3. PPS at the HL-LHC

Proton Tagging at the LHC

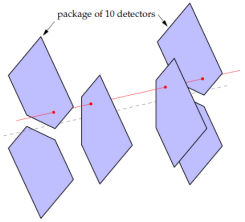


- Stations of detectors at $\pm$ 210 and 220 m from IP
- Measure x (and/or y) position of proton
- Displacement of the protons from the beam gives the protons' momentum loss $\xi = \frac{\Delta p}{p}$
- Each side equipped with timing detectors – see the talk by Tommaso Isidori

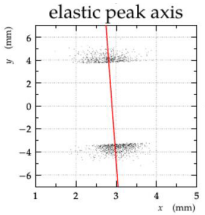
Alignment



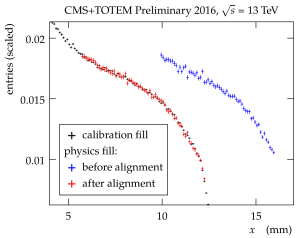
1. Alignment wrt the collimators



2. Relative RP alignment



3. Global alignment wrt the beam using elastic scattering

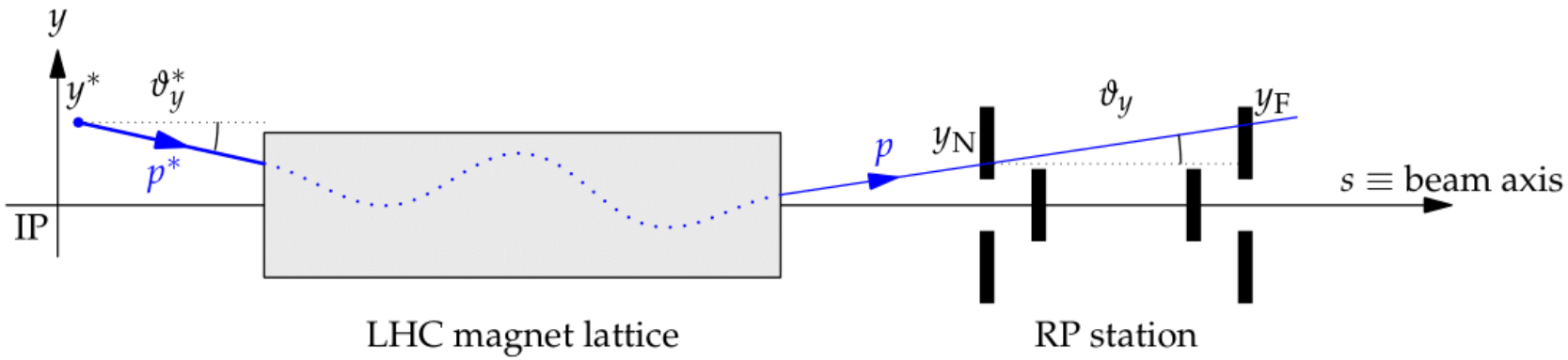


4. Fill-by-fill comparison of hit X distribution

Alignment Procedure

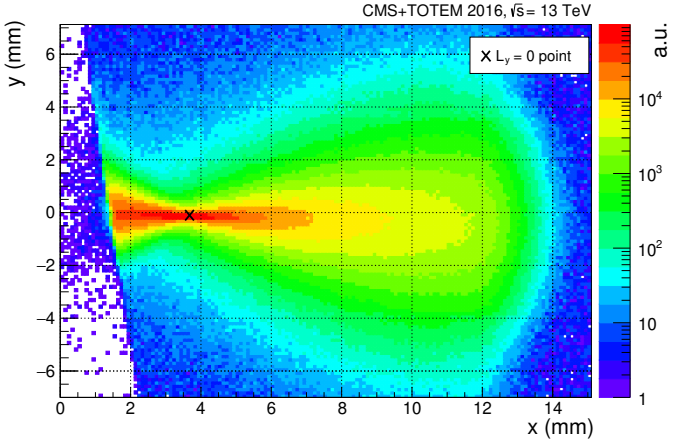
- RP moved very close to beam for alignment fill
- Use low luminosity, elastic runs for reference
- Correct physics run to reference runs
- Full documentation at CERN-TOTEM-NOTE-2017-001

Optics



measured at RP — values at IP

$$\begin{pmatrix} x \\ \Theta_x \\ y \\ \Theta_y \\ \xi \end{pmatrix}_{RP} = \begin{pmatrix} v_x & L_x & m_{13} & m_{14} & D_x \\ v'_x & L'_x & m_{23} & m_{24} & D'_x \\ m_{31} & m_{32} & v_y & L_y & D_y \\ m_{41} & m_{42} & v'_y & L'_y & D'_y \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x^* \\ \Theta^*_x \\ y^* \\ \Theta^*_y \\ \xi^* \end{pmatrix}$$



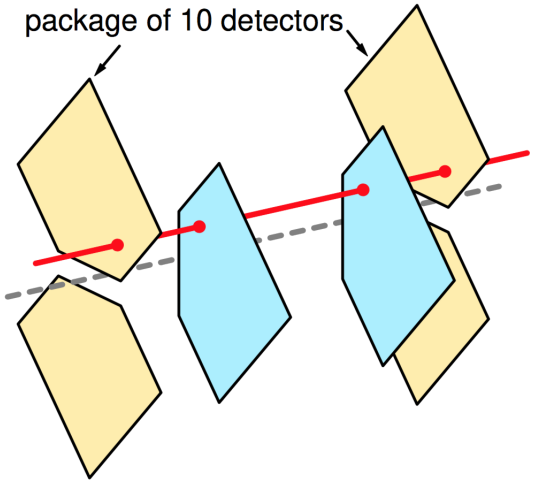
CERN-TOTEM-NOTE-2017-002

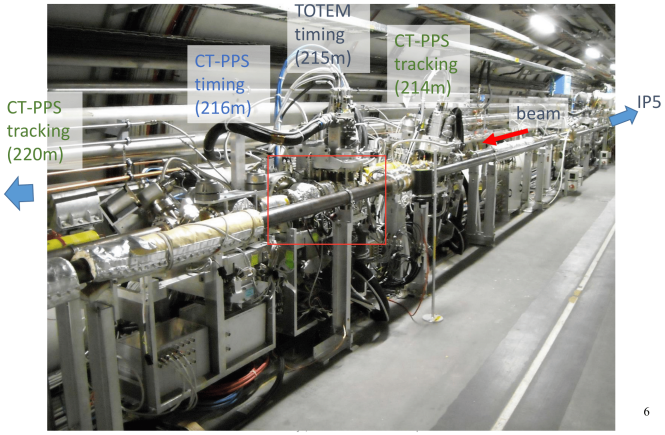
Roman Pot Technology

Roman Pots are the movable machinery that houses the detectors

Roman Pots

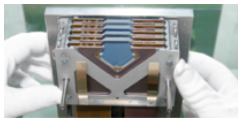
- Multiple planes of detectors
- Silicon strips
  - Better resolution
  - Can only reconstruct one track
- 3D Pixels
  - More radiation hard
  - Reconstruct multiple tracks
- Horizontal and vertical RPs
- Designed to operate at standard running conditions

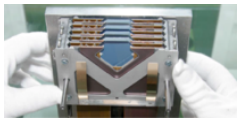


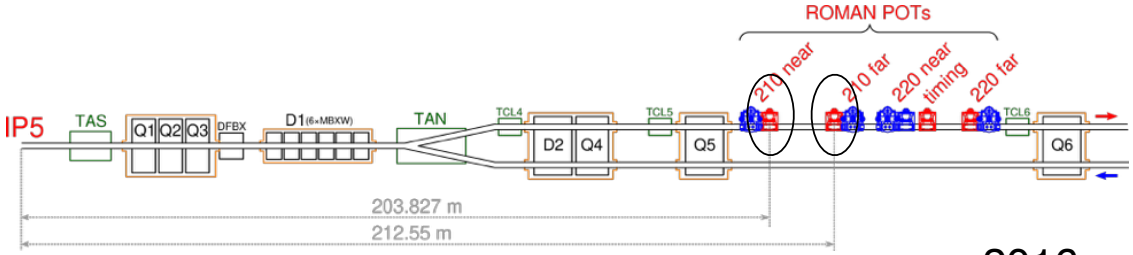


PPS Configuration

SiStrip + SiStrip

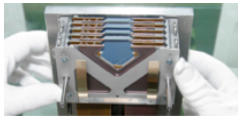


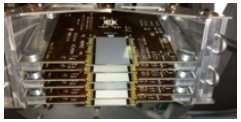


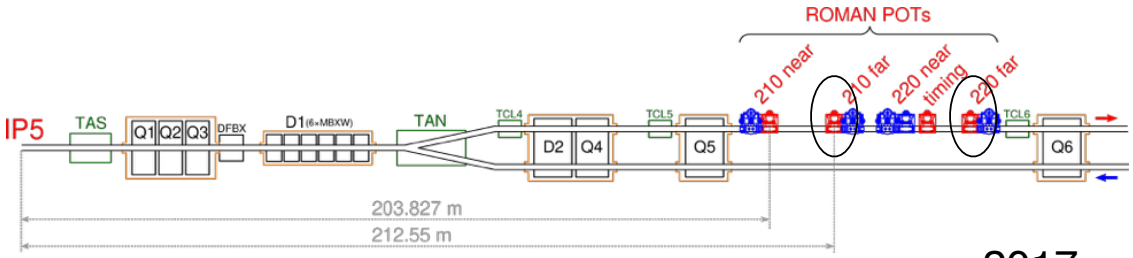


2016

SiStrip + 3D Pixel

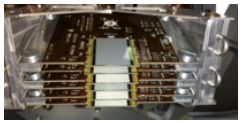


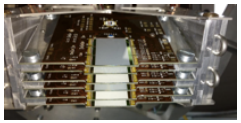


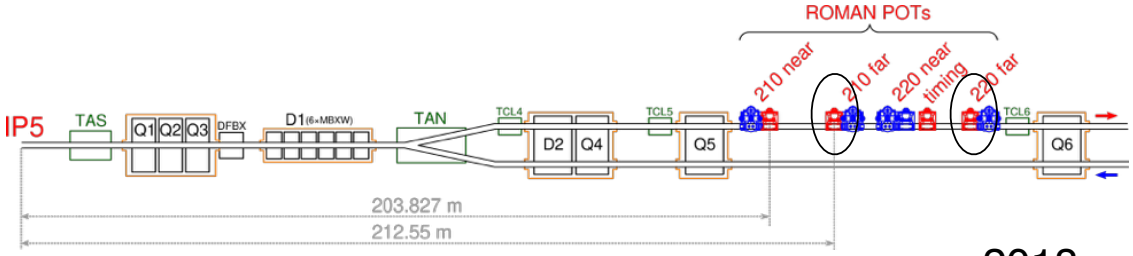


2017

3D Pixel + 3D Pixel

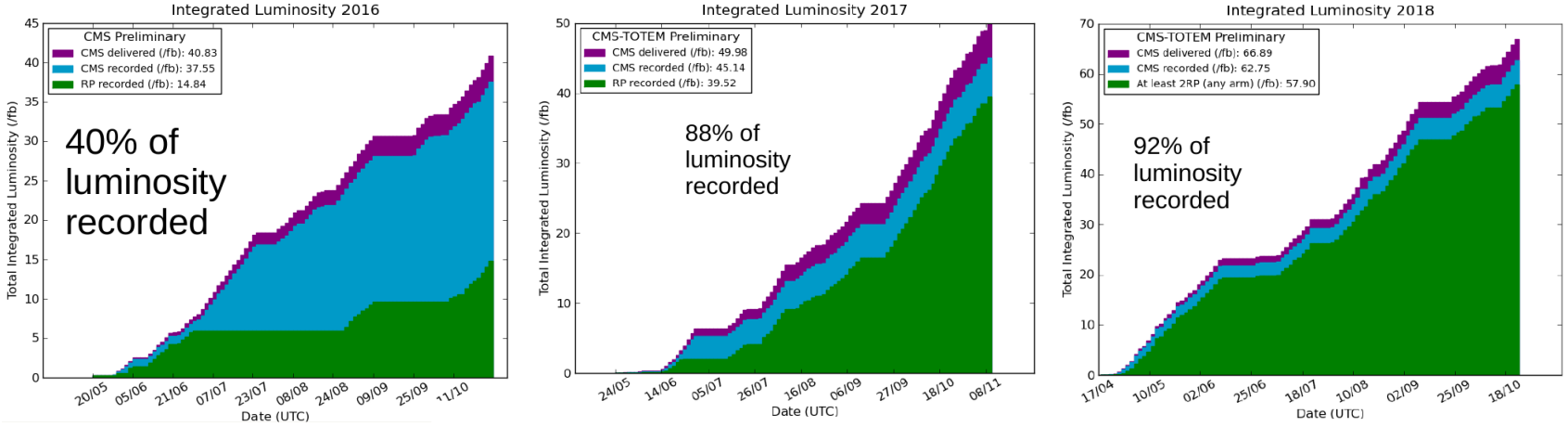






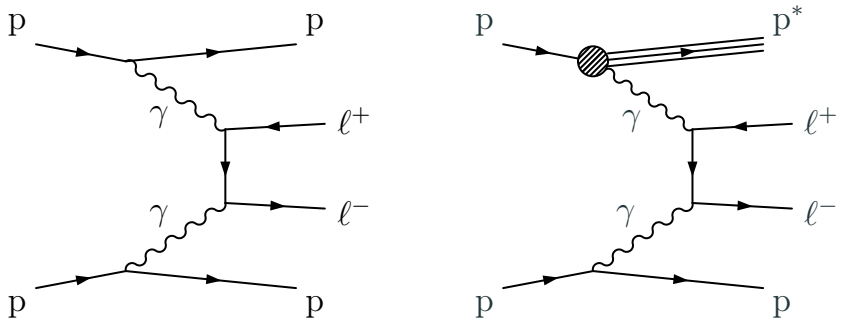
2018

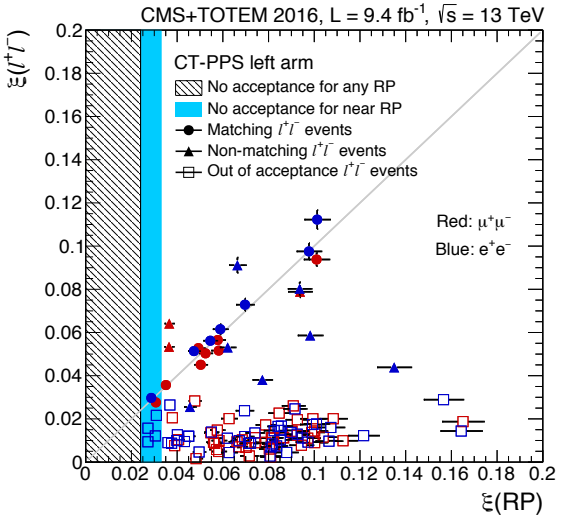
Data Collected in Run II

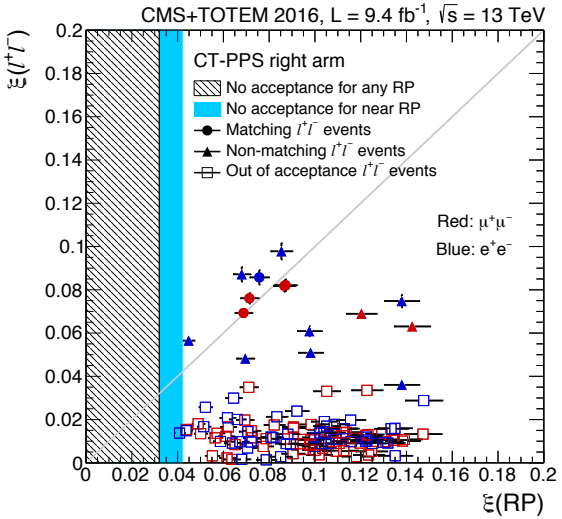


- Collected over 110 fb^{-1} of data in Run II
- Collected 92% of the luminosity relative to CMS in 2018
- Many analyses ongoing with the full Run II dataset

Physics Results - Dilepton







- Observation of high-mass dilepton pairs with an intact proton
- $p_T^{\ell} > 50$ GeV, $M_{\ell\ell} > 110$ GeV, 1-$|\Delta\phi|/\pi < 0.01$
- Matching performed between proton ξ and $\xi_{\ell\ell}^{\pm} = \frac{1}{\sqrt{s}} \sum_{i=1}^{2} p_{\mathrm{T}}^{\ell_i} e^{\pm\eta_{\ell_i}}$
- 20 events observed over a background of 3.85 $\pm$ 0.16(stat) $\pm$ 1.0(syst)

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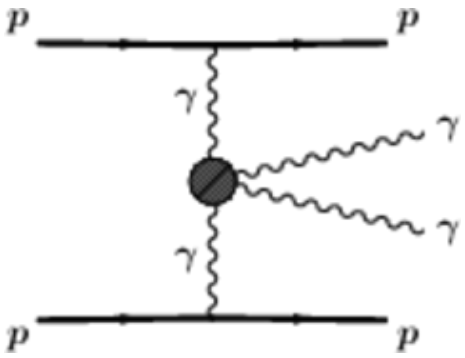
Physics Results - Diphoton

Search for high-mass diphoton events with two intact protons using 9.4 fb^{-1} of data from 2016

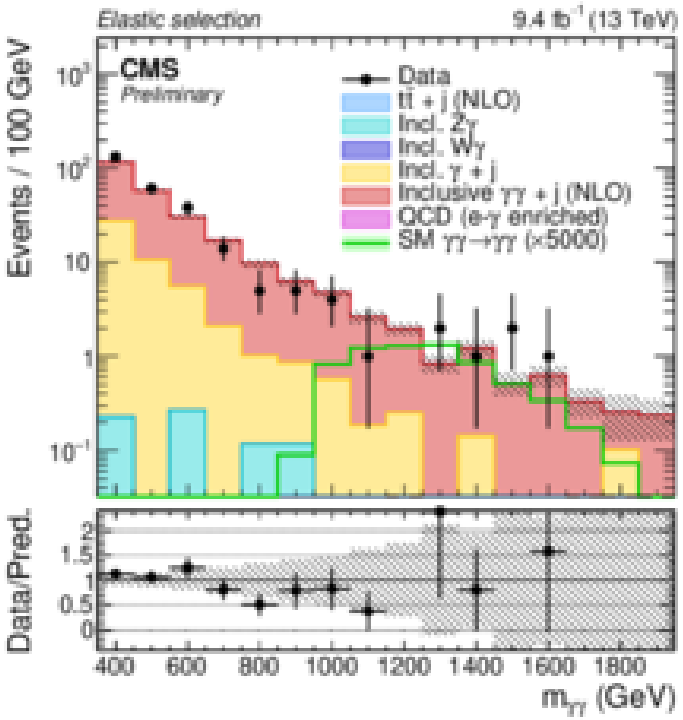


Analysis

- $p_T^\gamma > 75$ GeV, $m_{\gamma\gamma} > 350$ GeV, 1-$|\Delta\phi|/\pi < 0.005$
- Require matching in mass and rapidity between diphoton and diproton systems where

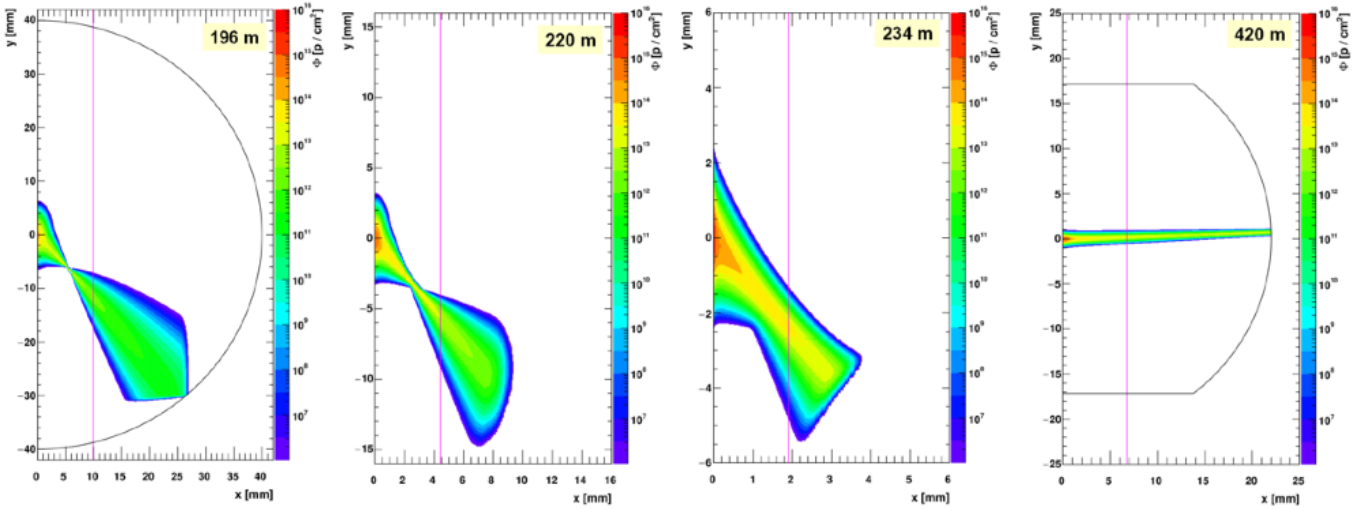
$$m_{pp} = \sqrt{s\xi_1\xi_2}, \quad y_{pp} = \frac{1}{2}\log(\xi_1/\xi_2)$$

- 0 events observed over an expected background of $0.23^{+0.08}_{-0.04}$



CMS-PAS-EXO-18-014

PPS At the HL-LHC



- Four potential detector placements with corresponding physics motivations
- Harsh pileup and radiation conditions
- With all four proposed stations, possibility of acceptance between 43 GeV $< M <$ 2.8 TeV

Station	M_{min} (GeV)	M_{max} (GeV)
196m	1100 - 1200	2750
220m	520 - 533	960
234m	262 - 265	370
420m	43 - 47	163

Conclusion

- Proton tagging provides a broad physics program, from the study of proton structure to BSM physics
- PPS has collected over 110 fb^{-1} of data with near-beam proton detectors
- Published physics results with more Run II studies in progress
- PPS has plans to operate in the LHC Run III and HL-LHC

Done ☺