γγ and γp measurements with forward proton taggers in CMS+TOTEM

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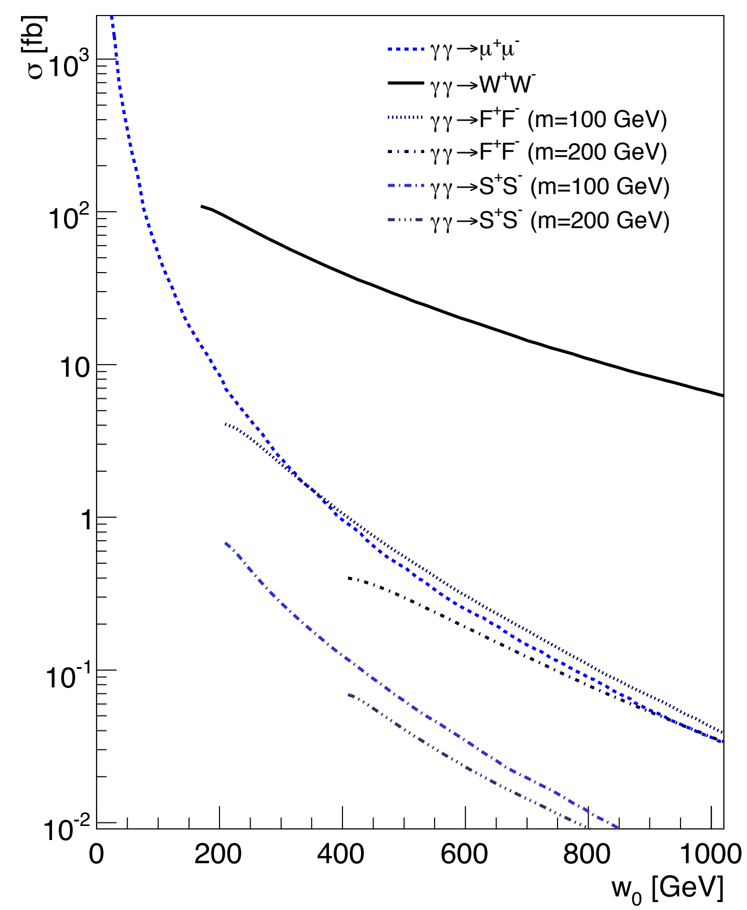
LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTICULAS

CMS + TOTEM

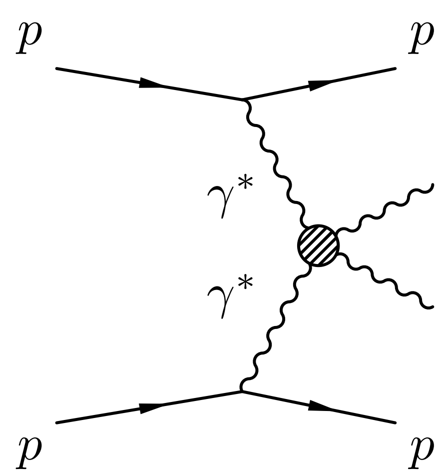
- Several joint activities of CMS+TOTEM, of relevance for γγ and γp physics
  - Common data-taking in high-β* LHC runs
    - Common triggers - separate data samples merged offline
    - Special optics allows access to low-ξ/low mass processes
  - CT-PPS (CMS TOTEM Precision Proton Spectrometer)
    - Operation at highest LHC intensities
    - Fully integrated DAQ and software
    - Large integrated luminosity for BSM searches and rare SM processes
    - -> main focus of this talk

Prospects for γγ physics with proton tagging (I)

- Significant rate of very high energy γγ collisions in pp collisions at the LHC
  - Well beyond energy range of γγ physics at LEP, HERA, Tevatron, RHIC
- Ideal case when forward scattered protons can be detected and matched to the central system
  - Strong background suppression
  - Event-by-event constraints on $\sqrt{s_{\gamma\gamma}}$
  - Reduced theory uncertainties related to dissociation of the protons

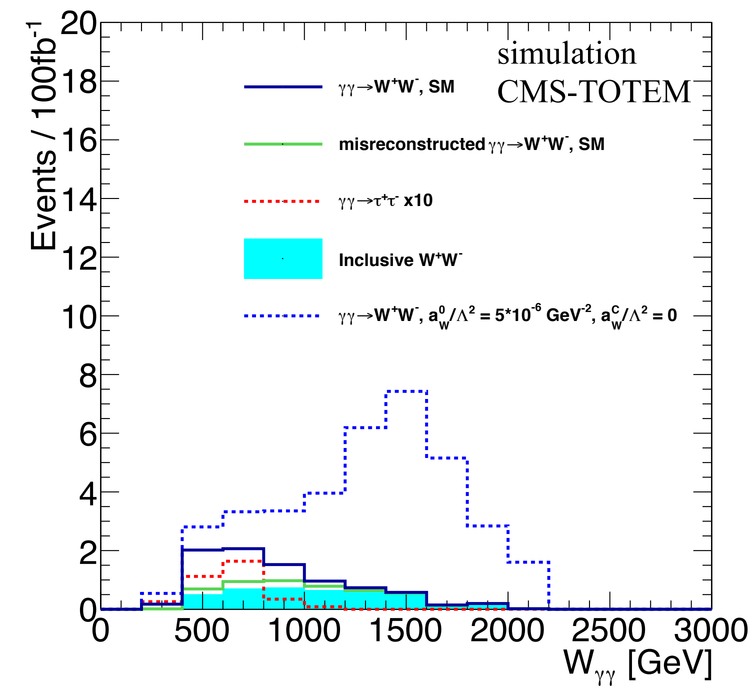


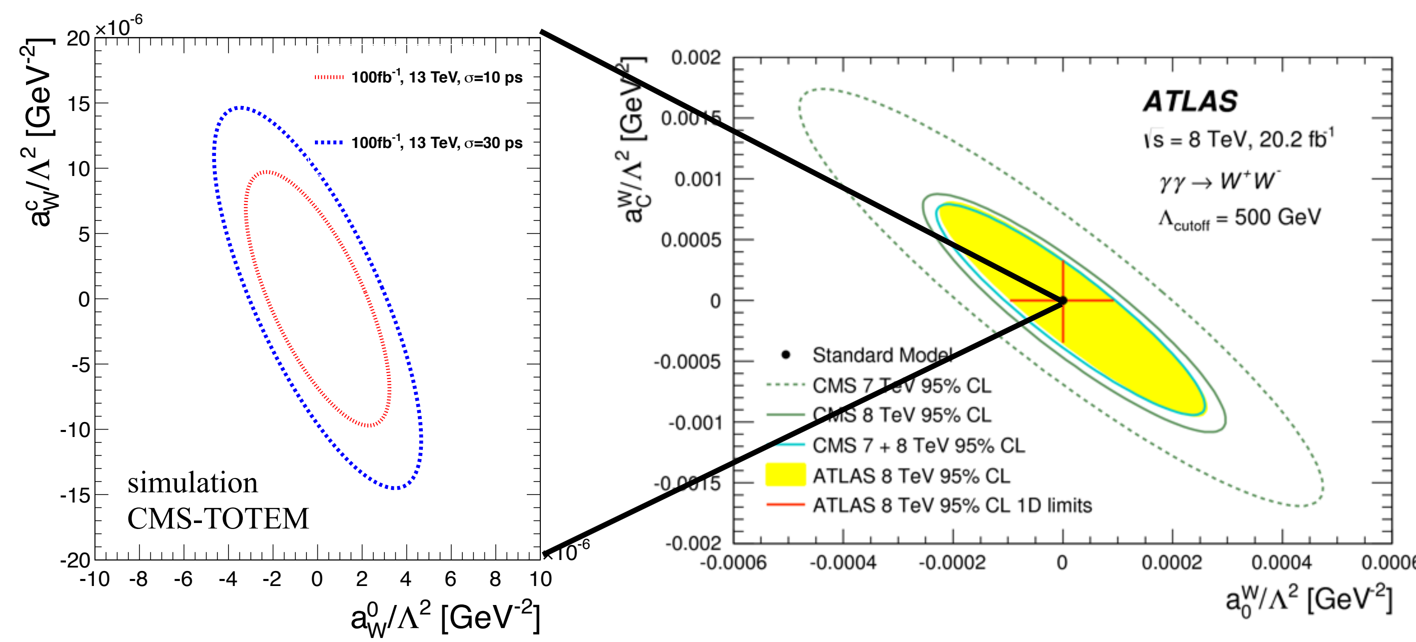
arXiv:0908.2020



Prospects for γγ physics with proton tagging (II)

- Detailed simulation studies of several final states: W^+W^-, dijets, γγ
  - Promising sensitivity in several topics
- Electroweak physics and indirect new physics searches
  - Anomalous couplings, loop-level effects
- Direct searches
  - New resonances, exotically charged particles, etc.

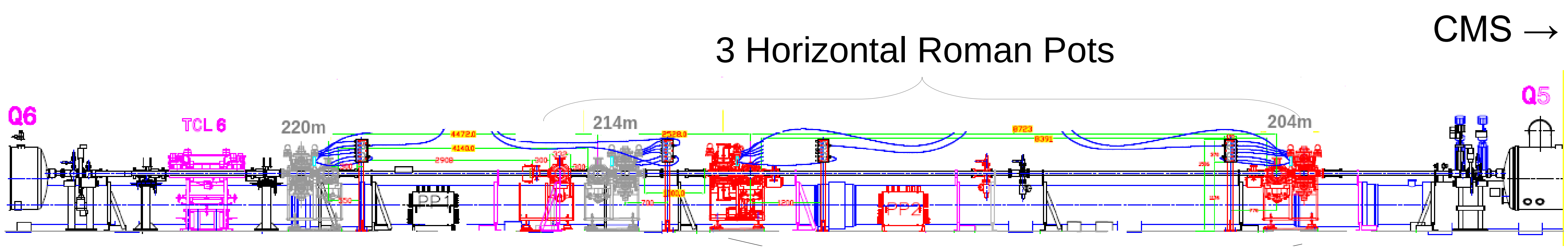


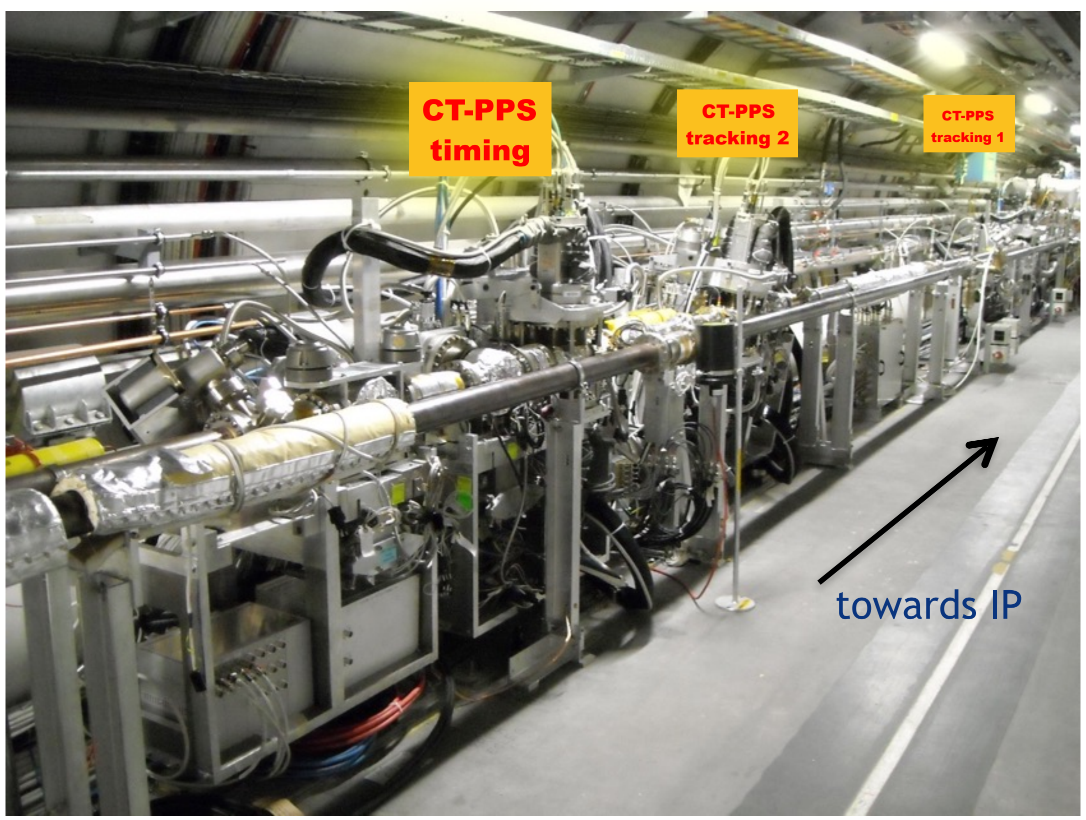


CERN-LHCC-2014-021

CT-PPS in 2016

CT-PPS: 2016 configuration

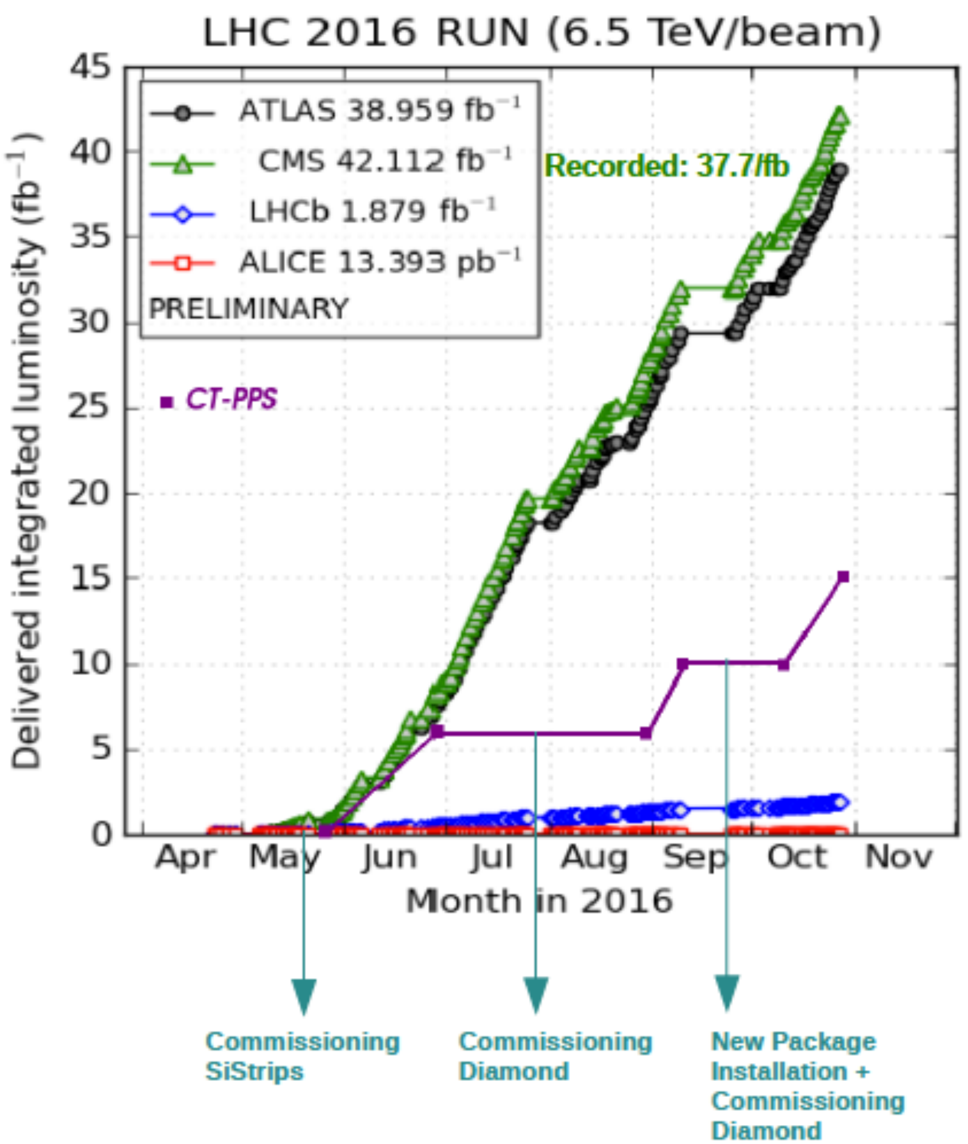




- 2 horizontal Roman Pots in 210m region from IP5, equipped with Si-strips
    - RF shielding for insertion at high luminosity
- 1 cylindrical RP, equipped with fast-timing diamond detectors

CT-PPS: 2016 operations

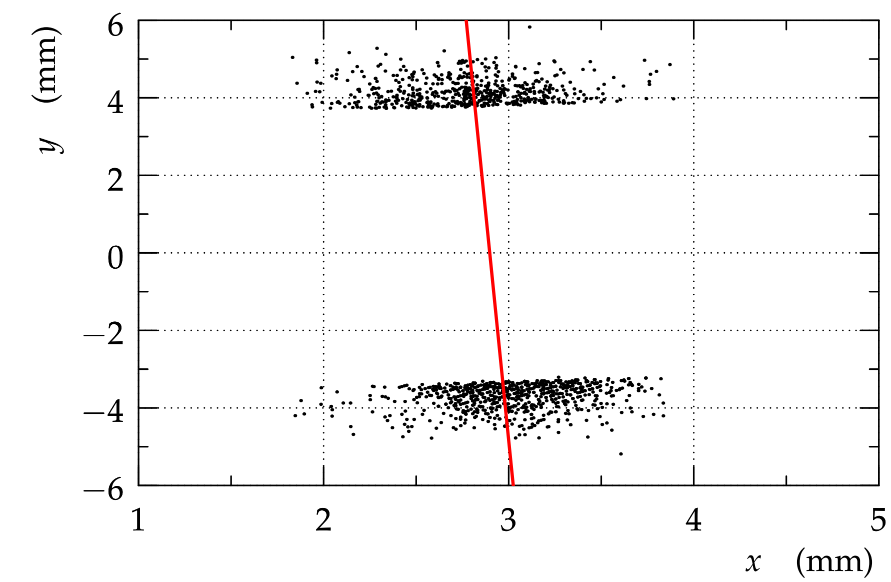
- Original concept: commissioning in 2016, physics data-taking in 2017
    - Decision in early 2016 to advance data-taking by 1 year, thanks to use of existing TOTEM Si-strip detectors
- Data acquisition and reconstruction software fully integrated, strip tracking detectors commissioned in a short time
- Total of ~15fb^{-1} collected with Si-strip tracking in RPs inserted 15σ from the beam
    - ~2.5fb^{-1} also together with diamond timing detectors

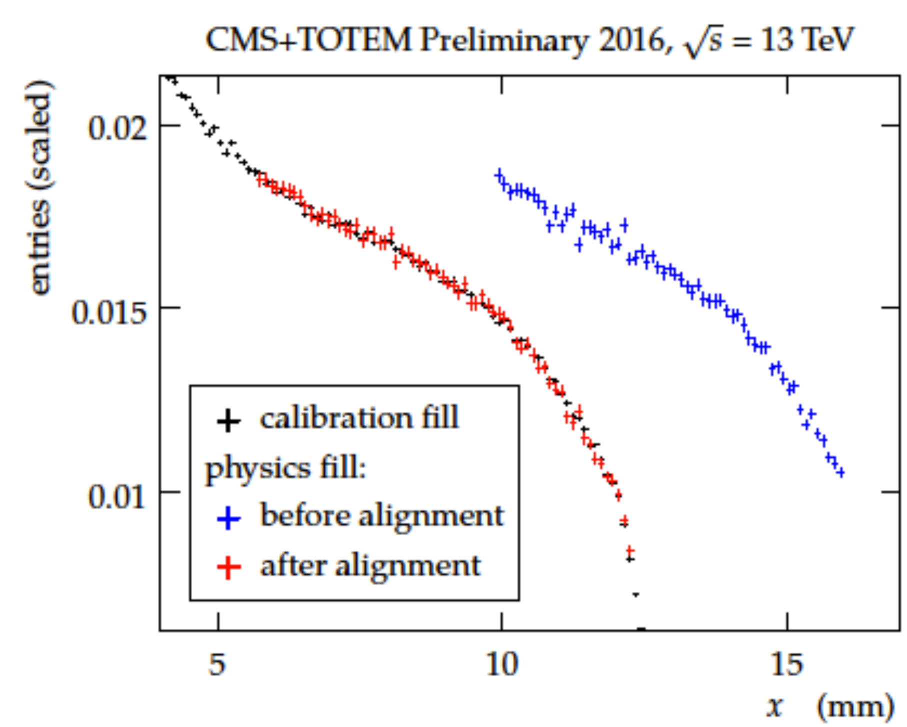


- Calibration procedures for alignment and optics established

Alignment procedure

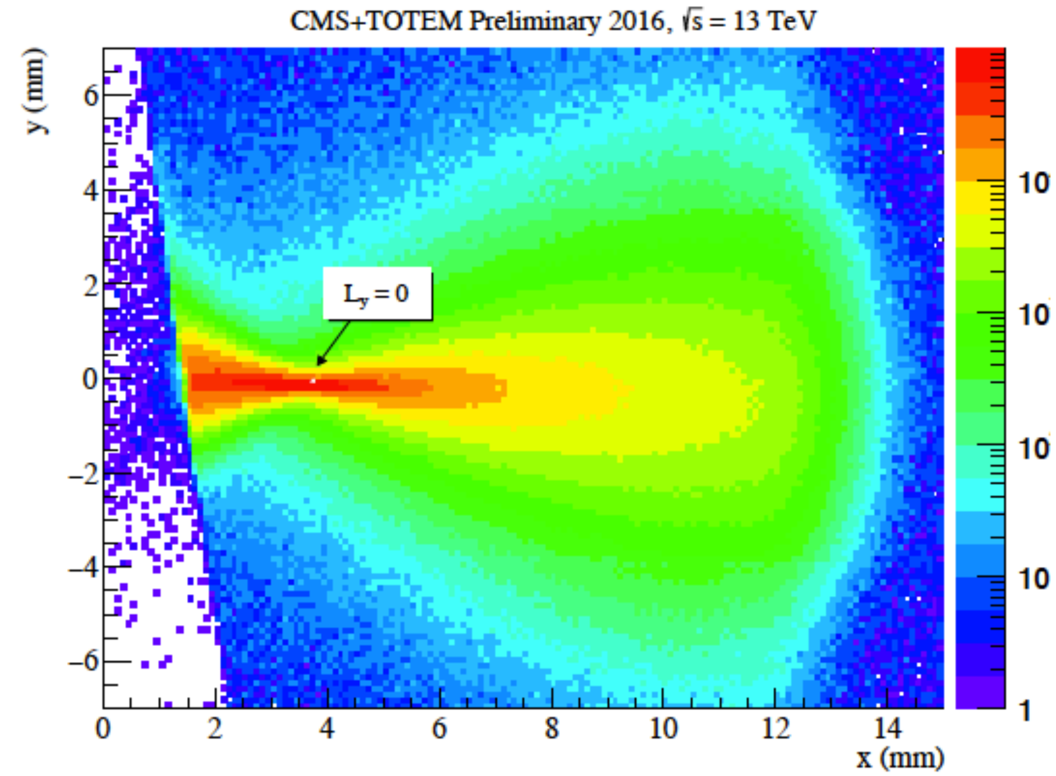
- Alignment procedure performed in 2 steps
  - 1: Absolute alignment
  - 2: Fill-by-fill alignment
- Step 1: Use elastic scattering (pp→pp) events, in special alignment runs where both horizontal and vertical RPs approach very close to the beam
- Step 2: Use inclusive sample of protons triggered by central CMS detectors
  - Match distribution of proton track positions to that of alignment runs

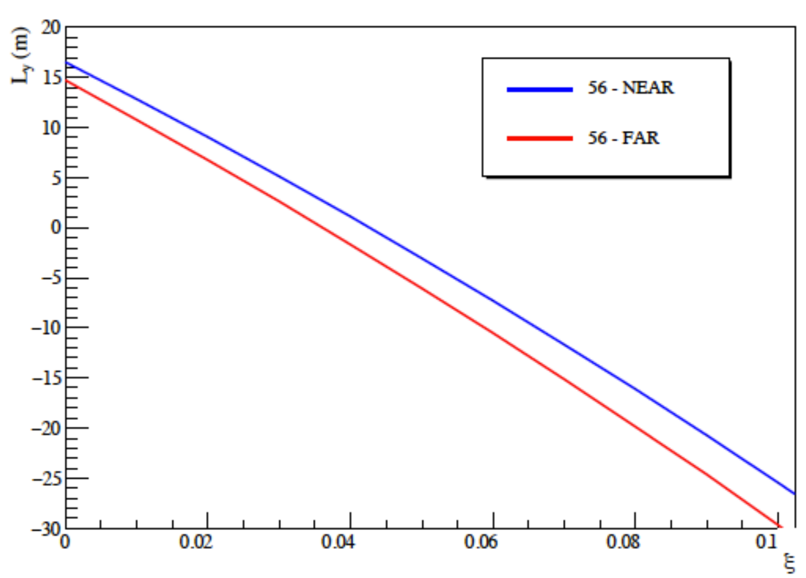




Optics determination

- Final physics variable of interest is the proton momentum loss "ξ"
- Reconstruction from measured RP track position requires precise knowledge of LHC optics & dispersion D_x
  - Standard TOTEM optics matching with elastic events [New J. Phys. 16 (2014) 103041] using measured quadrupole strengths
  - Dispersion calibration using L_y(x) = 0 point
  - LHC lattice/optics matching of crossing-angle and quadrupole positions using measured dispersions and the beam position as measured by RPs and BPMs"

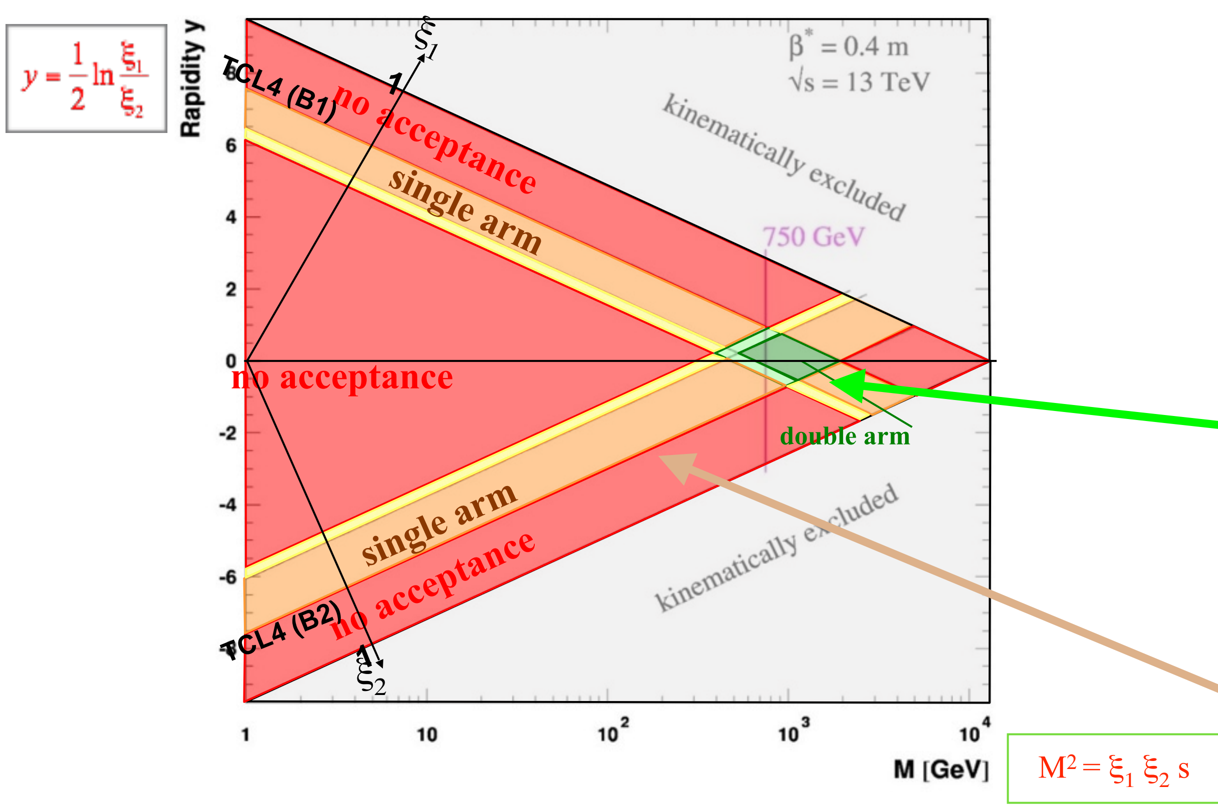




- Final result is a (non-linear) calibration of ξ vs. the measured track x position
- Overall ξ resolution of ~5.5%

Putting things together - physics acceptance

2016 optics before TS2 (data-calibrated):
$\beta^* = 0.4$ m, $\alpha_X = 370$ μrad, mild orbit bump, RPs @ 15σ



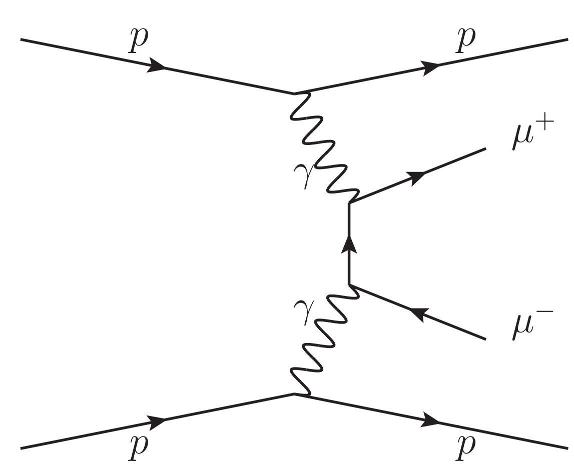
- Overall acceptance depends on invariant mass and rapidity of the central system
- For 2016 LHC optics before LHC technical stop 2 (late August)
  - Acceptance for seeing both protons at mid-rapidity and m =360GeV-~2TeV
  - Acceptance for seeing 1 proton at lower masses and forward rapidity

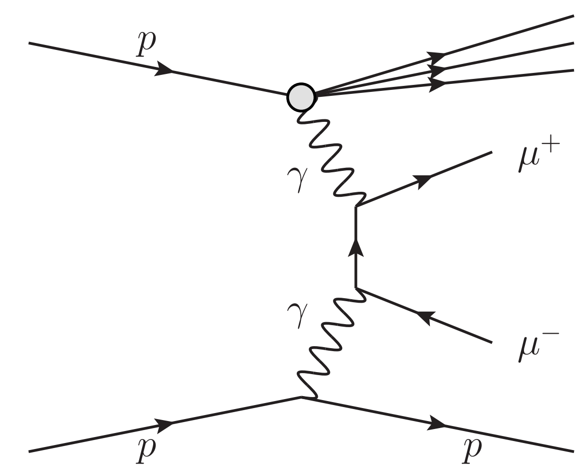
- Different acceptance in the final months of 2016 due to change of LHC crossing angle

Physics with 2016 data

γγ→μμ with forward protons (New)

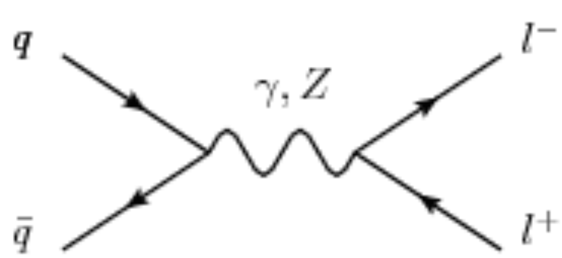
- Apply all calibrations to analysis of a well-known SM process
- γγ→μμ with one or both protons intact
  - Single arm events are used to extend acceptance to lower masses

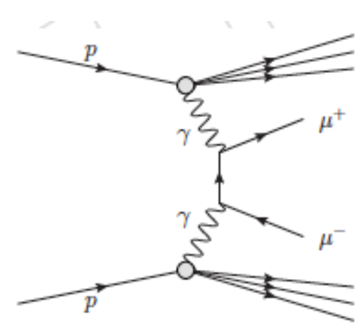




- ξ of the μμ pair can be related to the true ξ of the proton

$$\xi(\mu\mu) = \frac{1}{\sqrt{s}} \times \left(p_T(\mu_1)e^{\pm\eta(\mu_1)} + p_T(\mu_2)e^{\pm\eta(\mu_2)}\right),$$





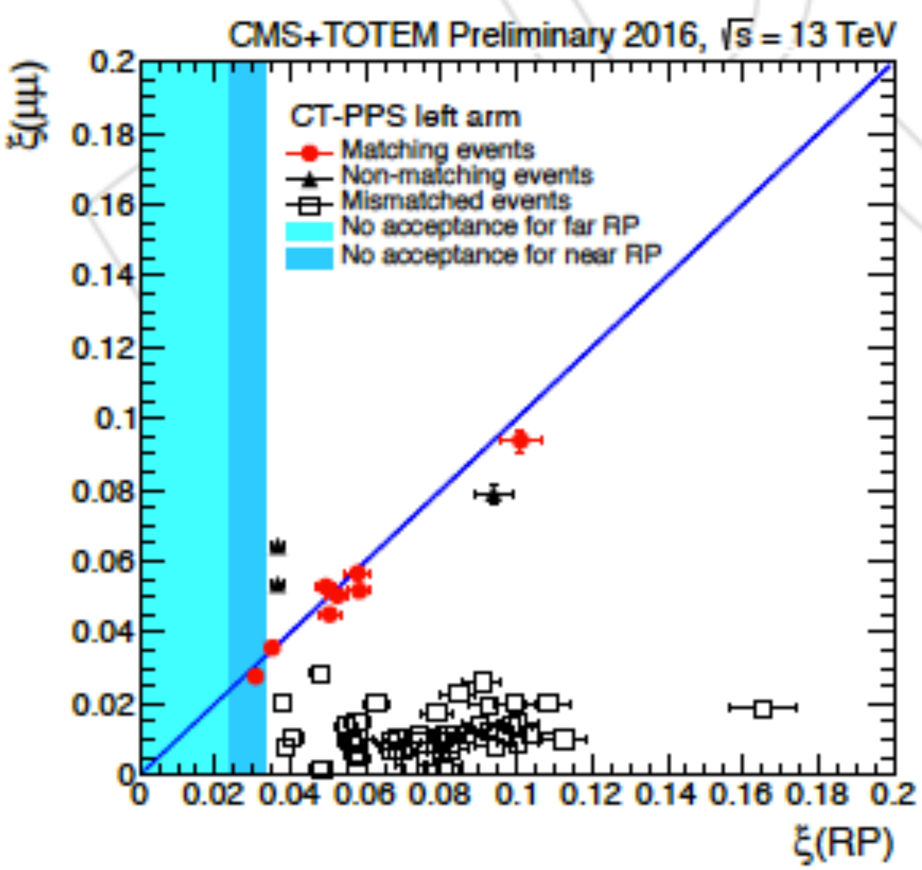
- Backgrounds primarily Drell-Yan or double proton dissociation events
  - Can fake a signal when overlapping with pileup protons or beam background

Event selection and backgrounds

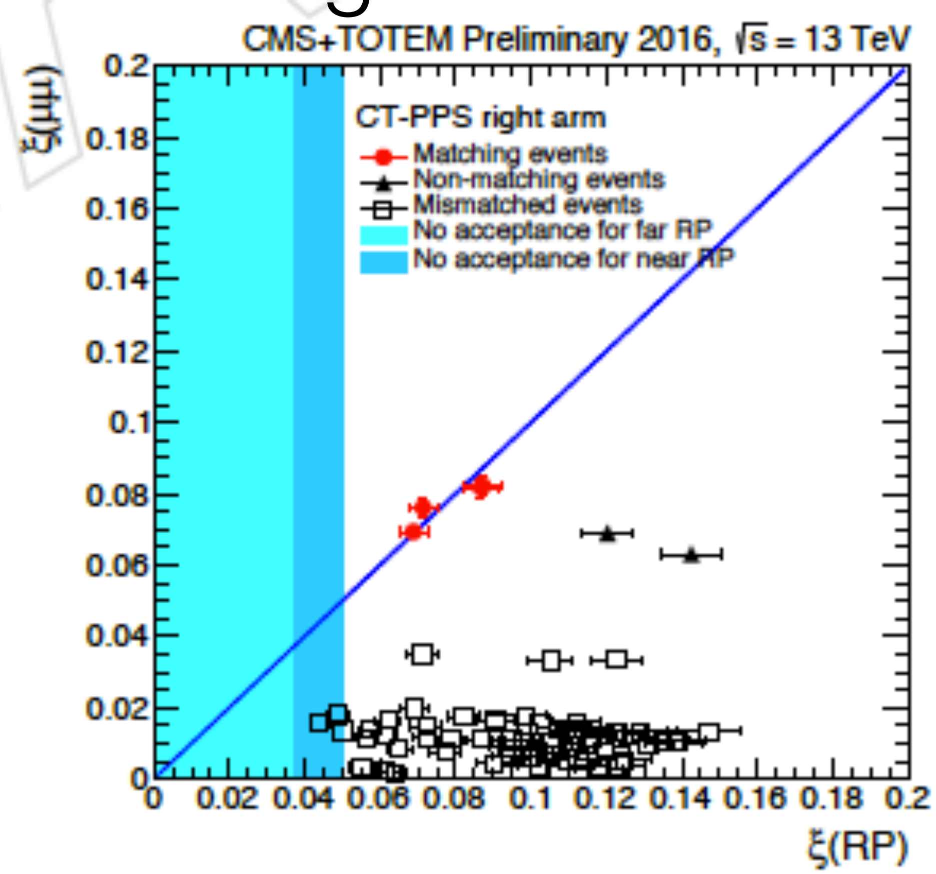
- Data sample based on ~10fb^{-1} taken with consistent optics collected in 2016 prior to TS2
    - Events selected with m(μμ)>110GeV, above the Z-peak
    - Backgrounds are suppressed by requiring the μμ vertex be separated from other tracks, and the two muons be back to back in ϕ
- Signal candidates required to have ξ(μμ) and ξ(RP) matching within 2σ of resolution
- "Data-driven" estimate of remaining backgrounds, using inclusive Z→μμ events in coincidence with pileup/background protons
    - Total background estimate: 1.47 ±0.06 (stat.) ±0.52 (syst.)

Observed ξ correlations

Left arm



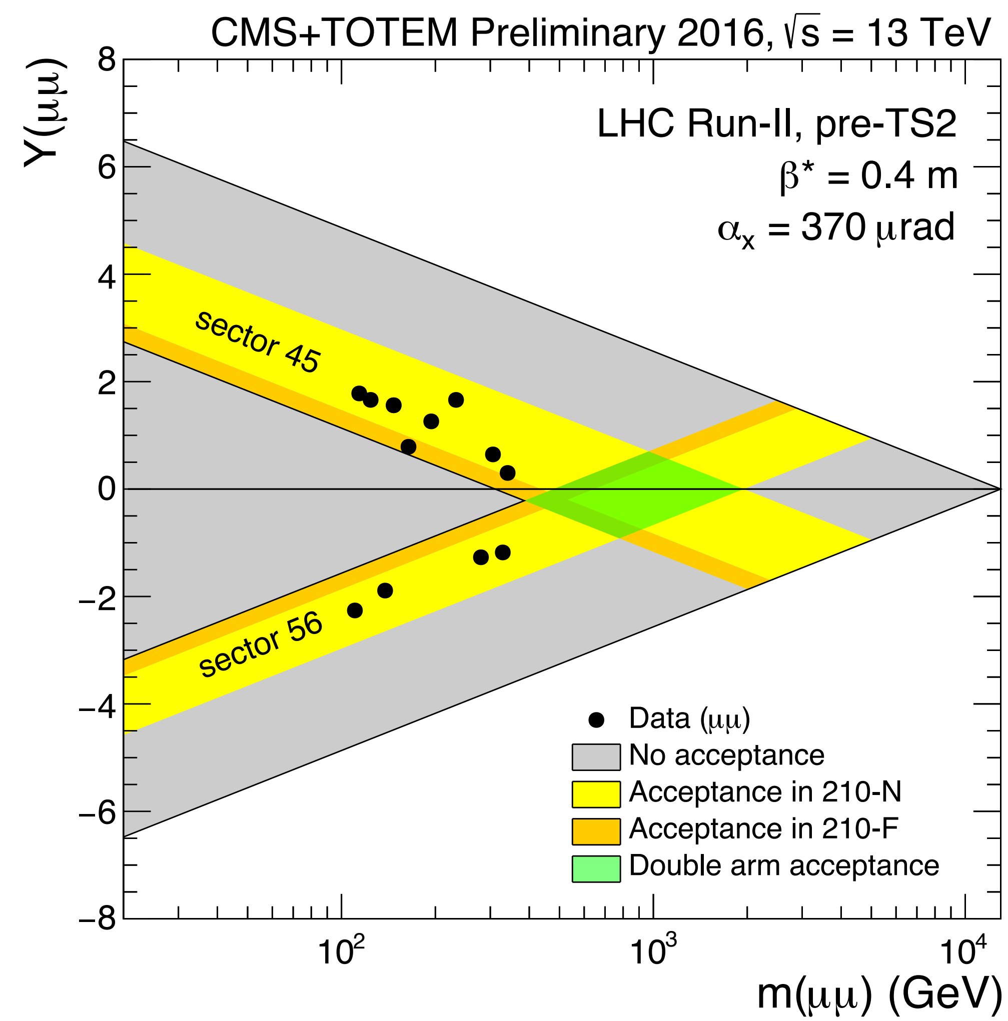
Right arm



- Total of 17 events have ξ(μμ) consistent with RP acceptance
- 12 with matching ξ(μμ) and ξ(RP) (red points)
- Estimated significance for observing 12 events for a background of 1.47 ±0.06 (stat.) ±0.52 (syst.): 4.3σ

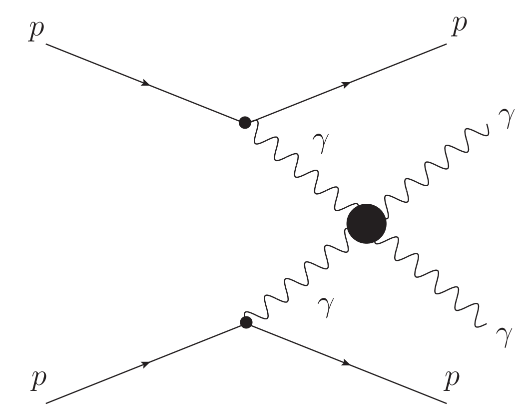
Event properties

- Dimuon invariant mass + rapidity consistent with single arm acceptance (yellow bands)
  - No double-tagged events observed (green diamond) - consistent with SM cross section * efficiency
- Spectrum extends to m(μμ)=341 GeV
  - => Tagged γγ collisions at the EWK scale!
  - Several times beyond previous measurements with proton tags

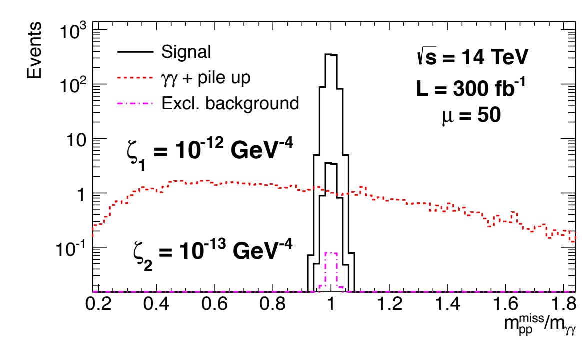


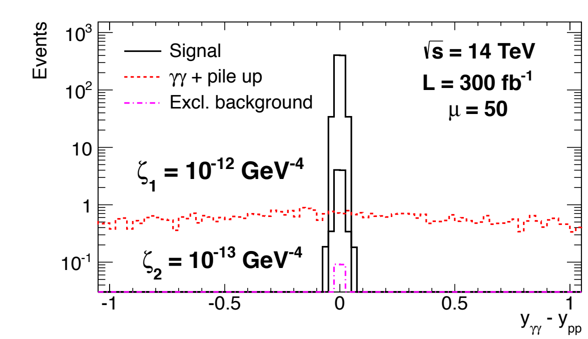
Physics prospects - 2016 data

- Several additional physics topics already planned with 2016 data



- Example search: for γγ→γγ and Neutral quartic gauge couplings (forbidden in SM)
  - Expect this channel to provide best sensitivity at LHC





- Part of program to explore quartic gauge couplings with photons: γγ→γZ, γγ→ZZ, γγ→WW (with timing detectors)

Outlook for 2017

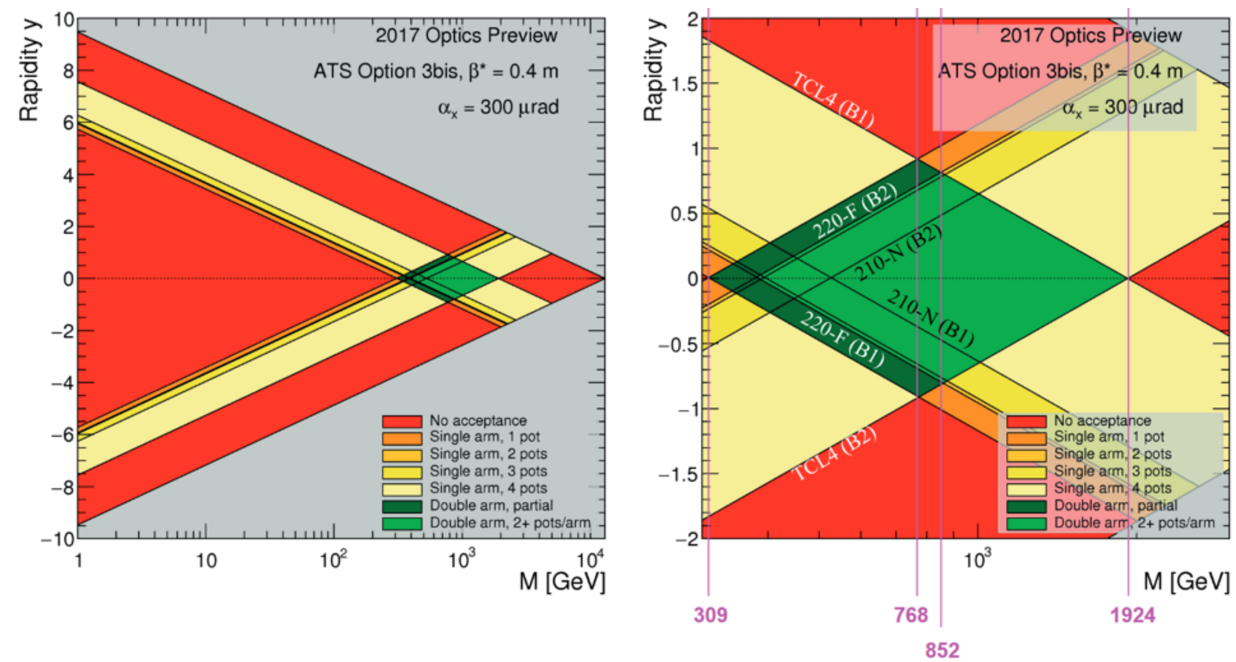
Outlook for 2017 - detectors

- Several upgrades to detectors ready for the upcoming 2017 LHC run
  - Installation of new 3d Si pixel detector detector packages
    - Increased radiation hardness and granularity for tracking

- Timing detectors: diamond detectors operated already in late 2016
  - Upgraded front end readout electronics, active precision reference clock system for 2017
  - Installation of 1 plane of fast silicon timing technology

Outlook for 2017 - physics acceptance

- Additional Roman Pots at 220m upgraded for high luminosity data taking
    - Used to house new pixel tracking detectors



- With 2017 LHC optics, extends low mass reach for double tagged events to nearly ~300 GeV
    - Improved acceptance for SM calibration processes
    - Similar to acceptance foreseen in CT-PPS TDR

Summary

- With its 2016 operation, CT-PPS has proven for the first time the feasibility of operating a near-beam proton spectrometer at a high luminosity hadron collider on a regular basis.
    - Safe RP insertions, detector commissioning, full integration of DAQ and reconstruction software established
    - Collected >15fb^{-1} of data in high luminosity runs with good physics acceptance, thanks to the LHC machine/optics experts
- RP alignment and optics corrections derived from alignment runs + inclusive proton samples, based on methods previously used in TOTEM
    - Methods applied to a first analysis of the “standard candle” $\gamma\gamma \to \mu\mu$ process with single proton tagging
    - >4σ signal for electroweak scale single proton-tagged γγ collisions at the LHC

Ref: PPS-17-110, TOTEM-NOTE-2017-003

- Major upgrades to CT-PPS RPs, tracking, and timing detectors after 2016 run
    - Ready for 2017 LHC run!

Extra