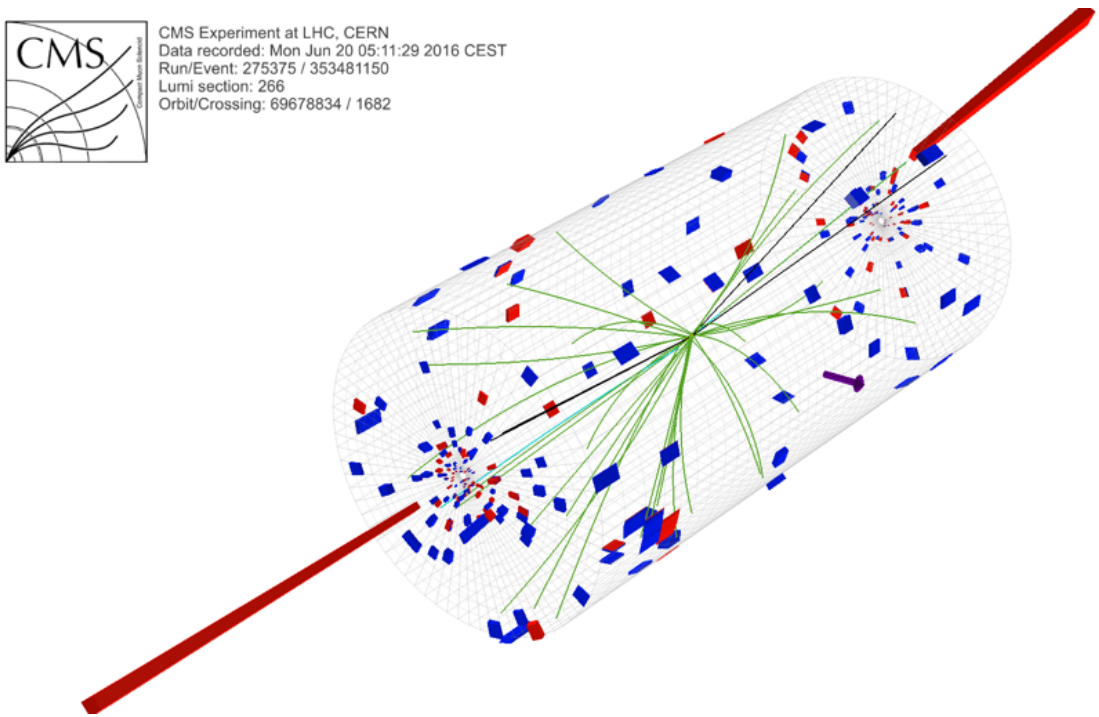
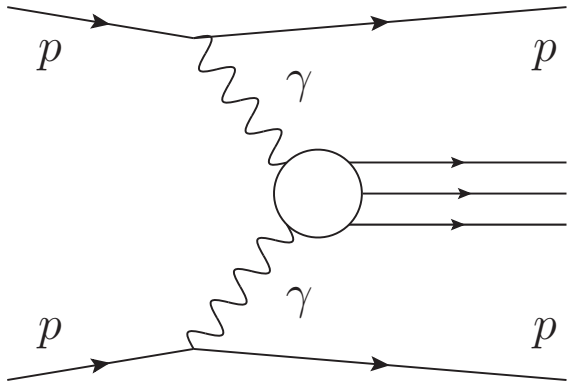
CT-PPS Physics Results And Prospects

Justin Williams

On behalf of the CMS and TOTEM Collaborations

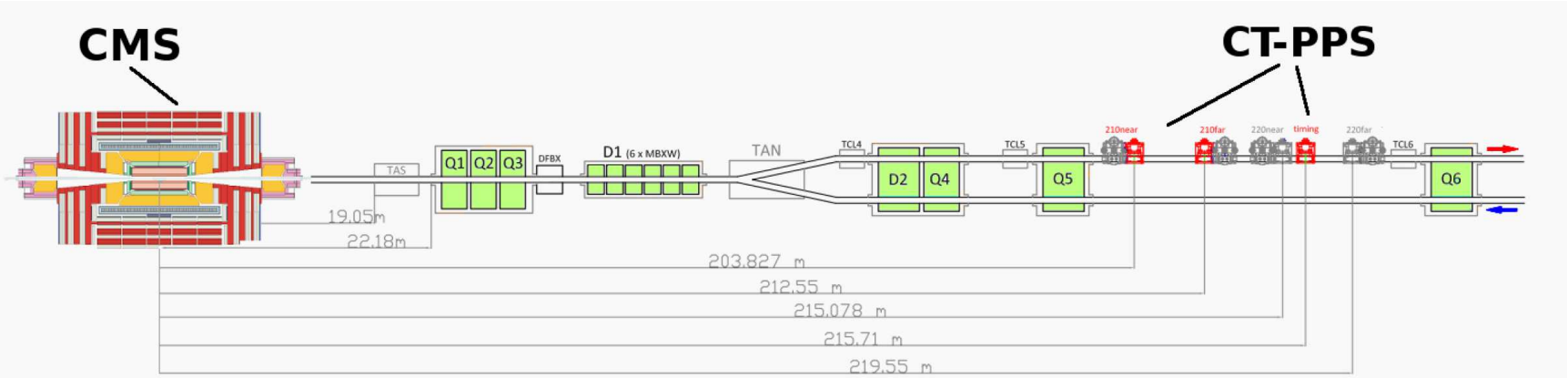


Overview



- LHC can be used as a $\gamma\gamma$ collider
- CT-PPS provides an opportunity for new searches and measurements
- Possibility of a very strong background suppression using intact protons
- Discussion of
  1. CT-PPS (CMS-TOTEM Precision Proton Spectrometer)
  2. Physics Results - Dilepton analysis
  3. Prospects - anomalous couplings, axions, central exclusive dijets

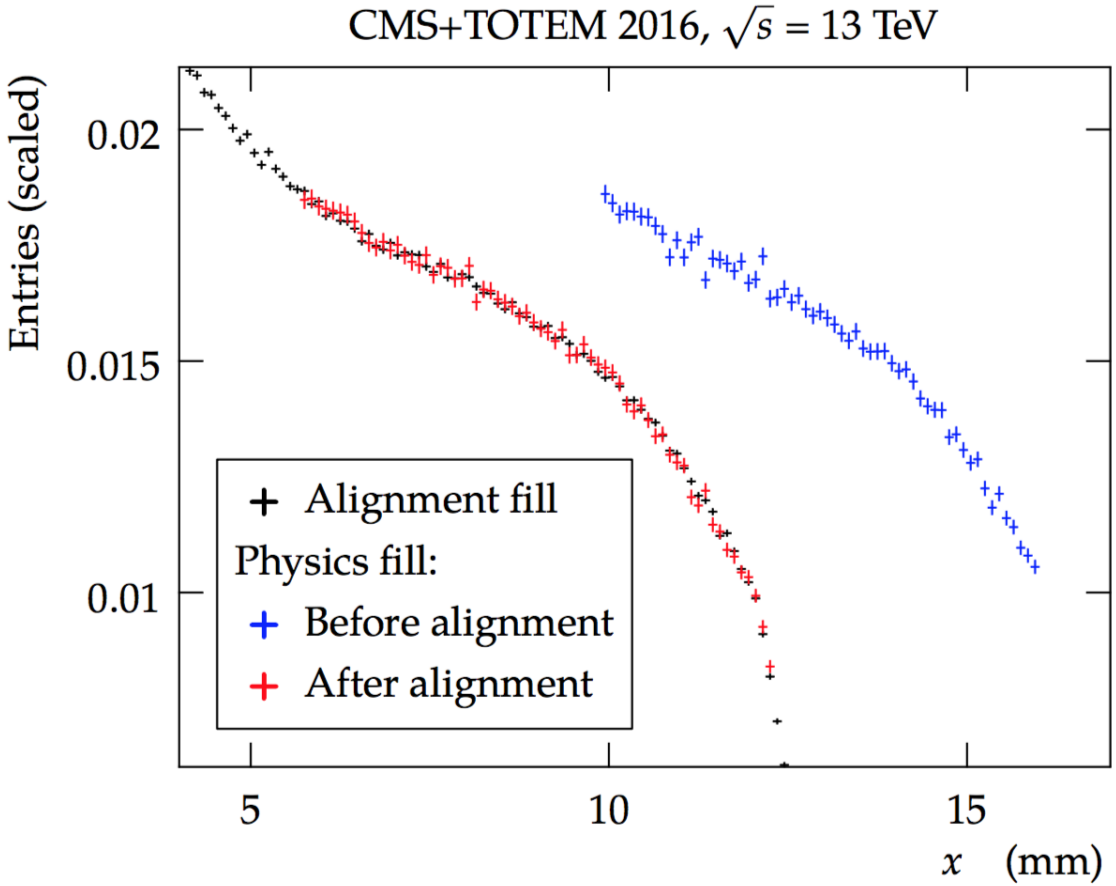
What is CT-PPS?



- Joint CMS and TOTEM project[1]
- LHC magnets bend scattered protons outside of the beam envelope
- Intact protons are detected by Roman Pots
- Protons measured a few mm from the beamline
- Detect protons at about $\pm$ 200 m from IP5
- Collected $\sim$ 15 fb^{-1} of data in 2016 and $\sim$ 40 fb^{-1} in 2017
- See talk by Joachim on Friday

[1] https://cds.cern.ch/record/1753795

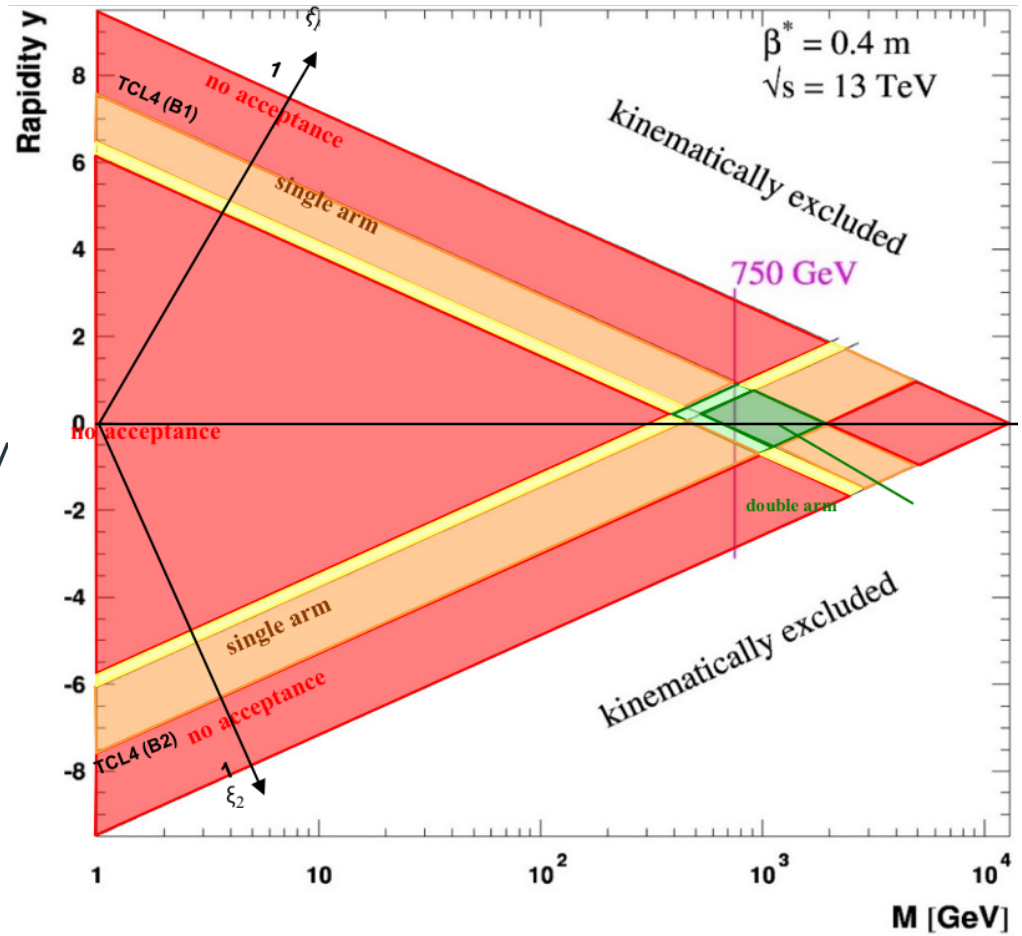
CT-PPS Alignment



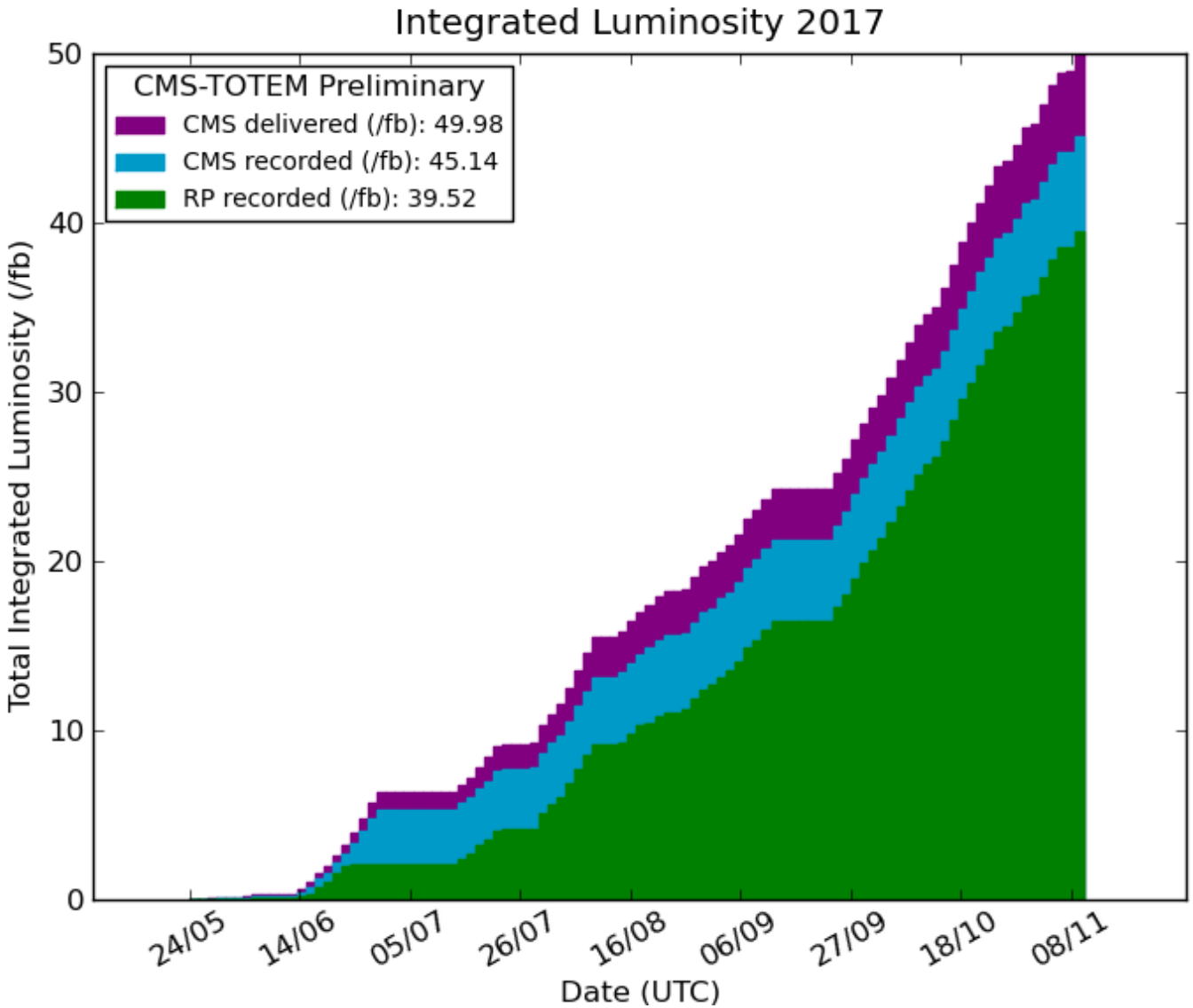
- Roman Pots move and beam position changes
- RPs moved very close to beam for alignment fill
- Alignment fill $\rightarrow$ Physics fill $\rightarrow$ Correction
- Total uncertainty is 150 μm
- See talk by Frigyes on Friday

Proton Acceptance

- Roman Pots measure fractional momentum loss ($\xi = \frac{\Delta p}{p}$) of protons
- Acceptance for both protons
  - Mid rapidity
  - 350 GeV $< m_{pp} <$ 2000 GeV
- Acceptance for single proton
  - Forward Rapidity
  - Lower masses

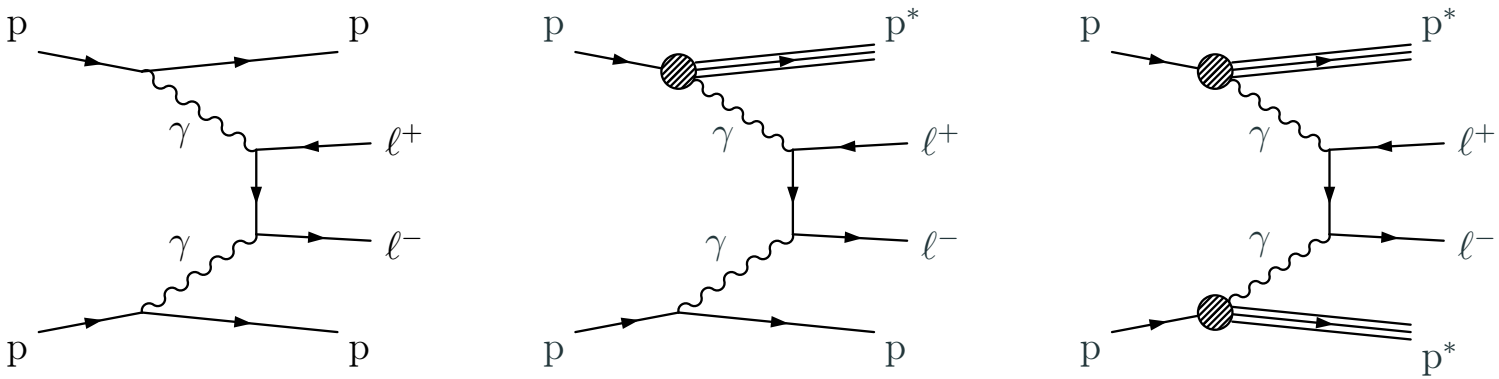


Luminosity Comparison - 2017



Physics Results

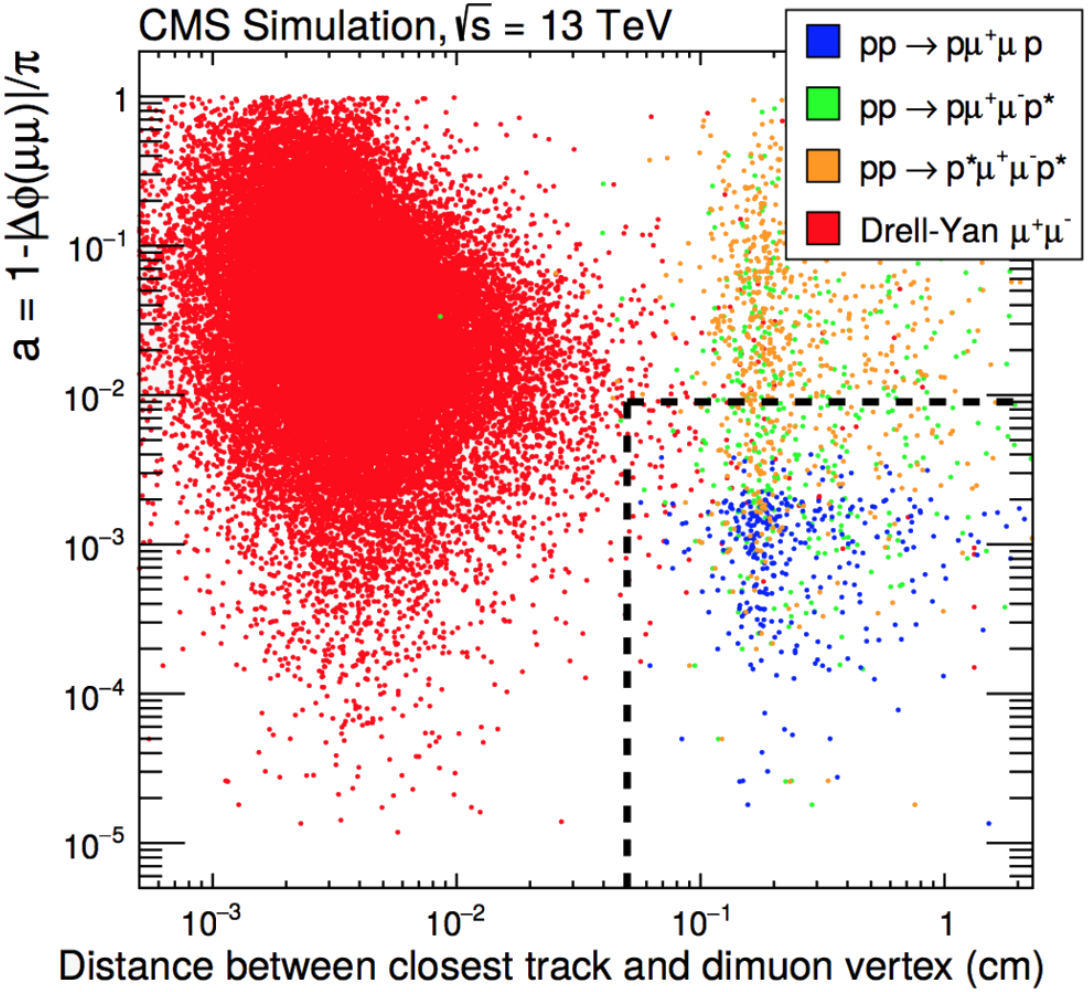
Dilepton Analysis in CT-PPS



- First measurement of the process at high mass with intact protons
- Analysis performed with normal optics and pileup conditions
- Proof that the alignment, optics, trigger, proton tagging are all working
- CMS - TOTEM paper [2]

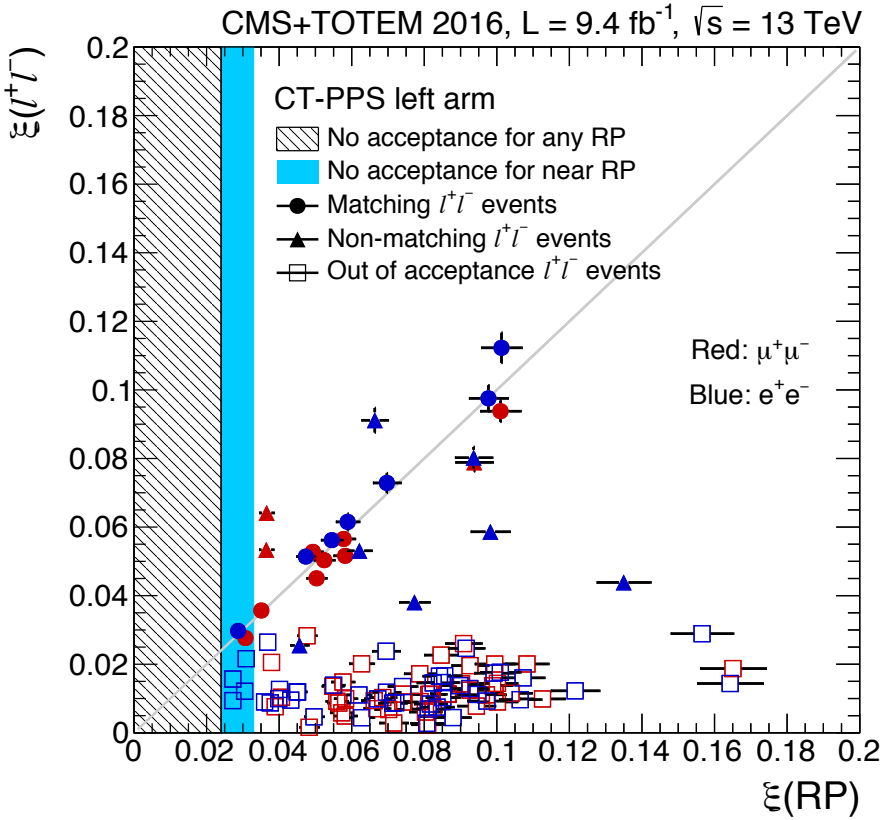
[2] *arXiv:1803.04496*

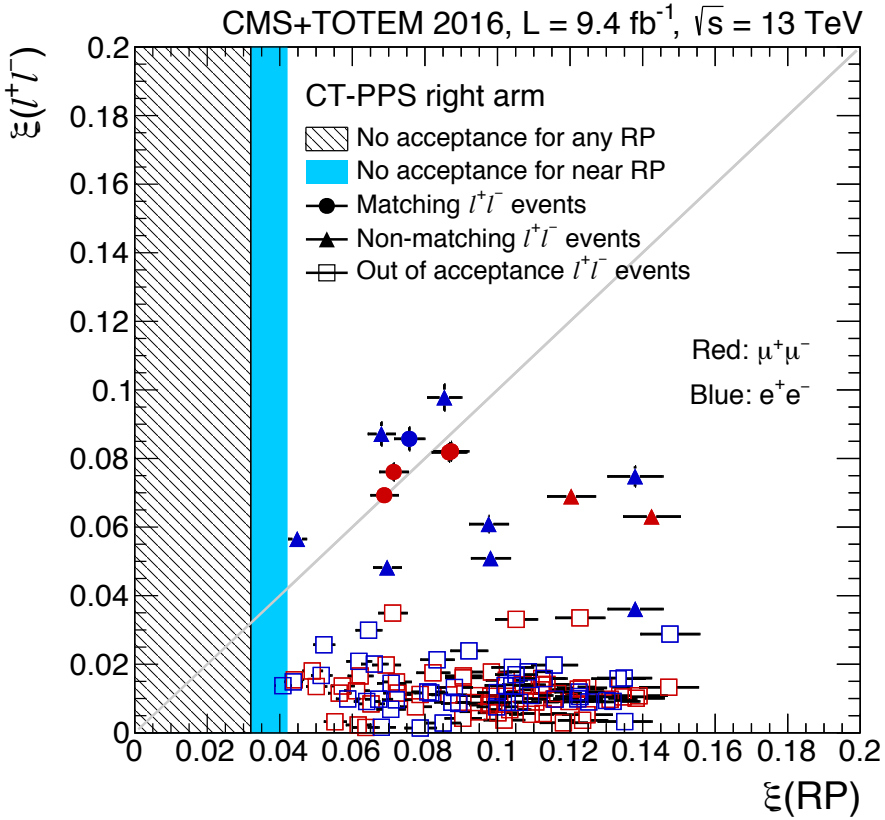
Event Selection



- Request pair of opposite sign leptons with
  - pT $>$ 50 GeV
  - $M_{\ell\ell} > 110$ GeV (Above Z boson peak)
- Selection based on the acoplanarity and cleanliness of the dilepton vertex

Dilepton Analysis in CT-PPS

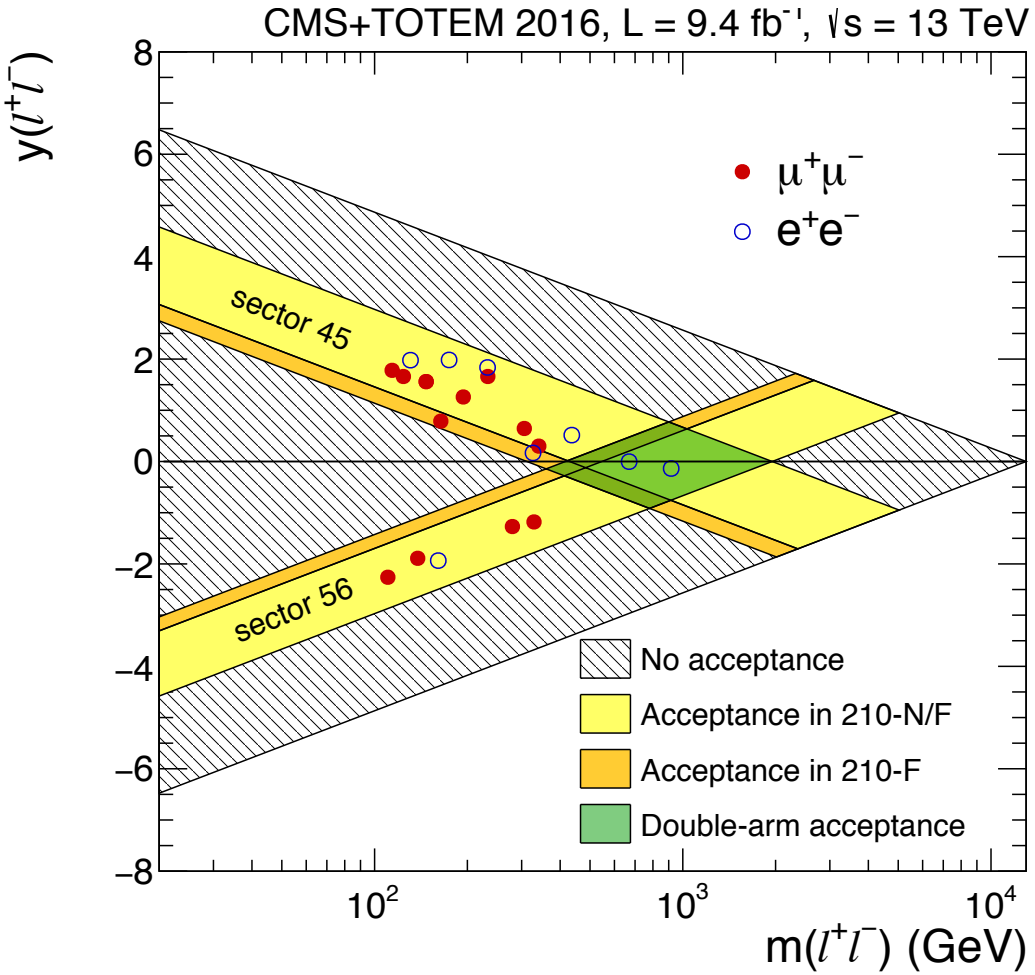




- 12 events have $\xi(\mu\mu)$ consistent with RP acceptance[3] and matching with the proton kinematics
- 8 events have ξ(ee) consistent with RP acceptance and matching with the proton kinematics
- Background: 1.49$\pm$0.07(stat)$\pm$ 0.53(syst) $\mu\mu$; 2.36$\pm$ 0.09(stat)$\pm$0.47(syst) ee
- Combined events $> 5.1\sigma$ over background

[3] *arXiv:1803.04496*

Dilepton Events in CT-PPS



- Dilepton invariant mass and rapidity within expected range of acceptance
- Highest mass events - 342 GeV ($\mu\mu$), 917 GeV (ee)
- Demonstrates excellent performance of CT-PPS and potential for high-mass (proton-tagged) exclusive measurements

Dilepton Paper

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2018-014
2018/03/12

CMS-PPS-17-001
TOTEM 2018-001

Observation of proton-tagged, central (semi)exclusive production of high-mass lepton pairs in pp collisions at 13 TeV with the CMS–TOTEM precision proton spectrometer

The CMS and TOTEM Collaborations*

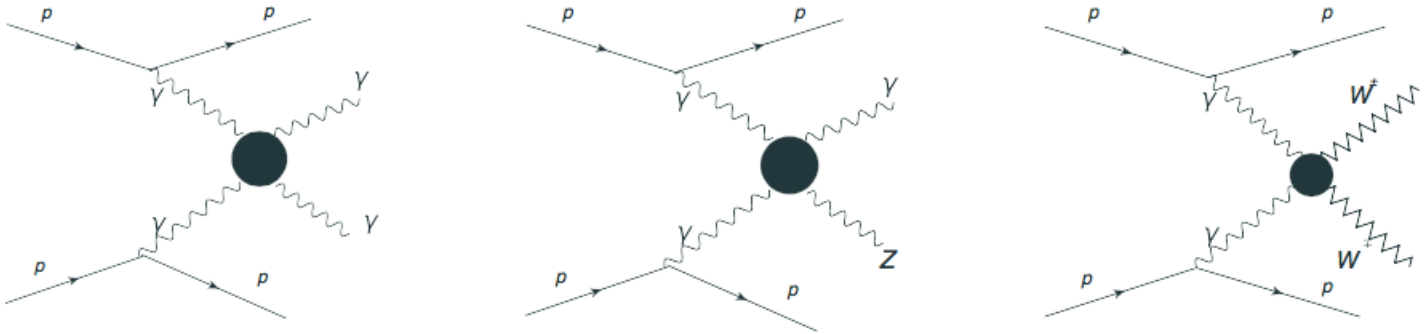
Abstract

The process $pp \to p\ell^+\ell^- p^{(*)}$, with $\ell^+\ell^-$ a muon or an electron pair produced at midrapidity with mass larger than 110 GeV, has been observed for the first time at the LHC in pp collisions at $\sqrt{s} = 13$ TeV. One of the two scattered protons is measured in the CMS–TOTEM precision proton spectrometer (CT–PPS), which operated for the first time in 2016. The second proton either remains intact or is excited and then dissociates into a low-mass state p^*, which is undetected. The measurement is based on an integrated luminosity of 9.4 fb^{-1} collected during standard, high-luminosity LHC operation. A total of 12 $\mu^+\mu^-$ and 8 e^+e^- pairs with $m(\ell^+\ell^-) > 110$ GeV, and matching forward proton kinematics, are observed, with expected backgrounds of $1.49 \pm 0.07\,(\text{stat}) \pm 0.53\,(\text{syst})$ and $2.36 \pm 0.09\,(\text{stat}) \pm 0.47\,(\text{syst})$, respectively. This corresponds to an excess of more than five standard deviations over the expected background. The present result constitutes the first observation of proton-tagged $\gamma\gamma$ collisions at the electroweak scale. This measurement also demonstrates that CT–PPS performs according to the design specifications.

Submitted to the Journal of High Energy Physics

Prospects of CT-PPS

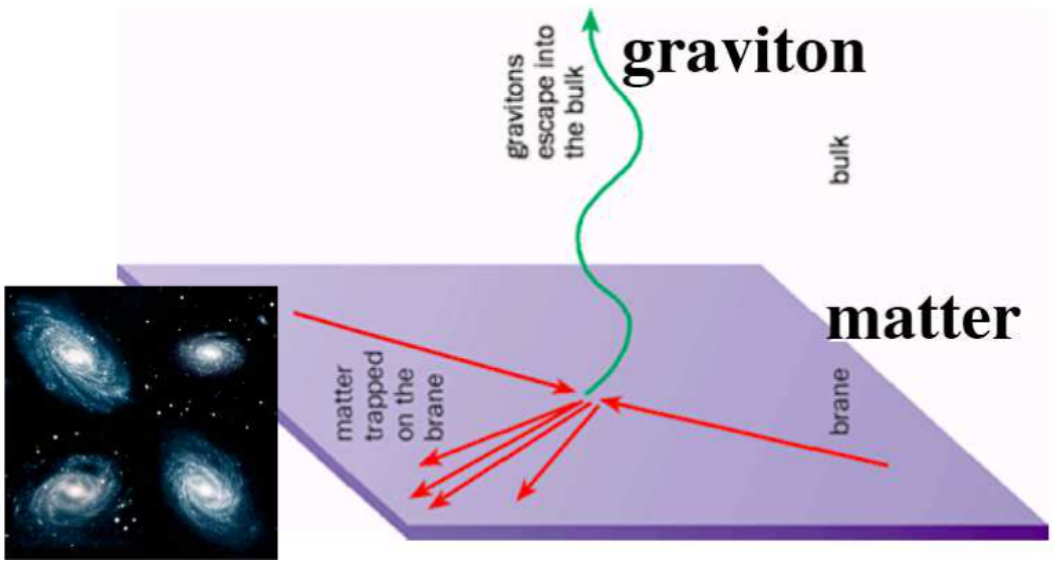
Anomalous Quartic Gauge Couplings



- Photon emission $\rightarrow$ Photon fusion $\rightarrow$ Intact outgoing protons
- These are exclusive processes
- CT-PPS provides the best sensitivity to anomalous couplings

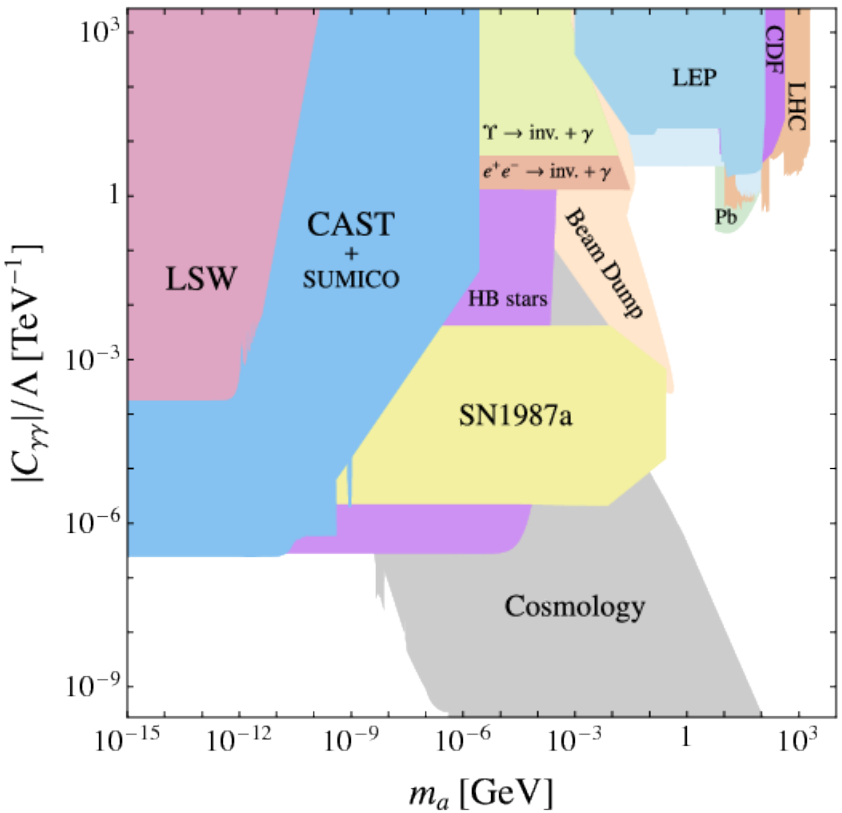
Motivations For AQGCs

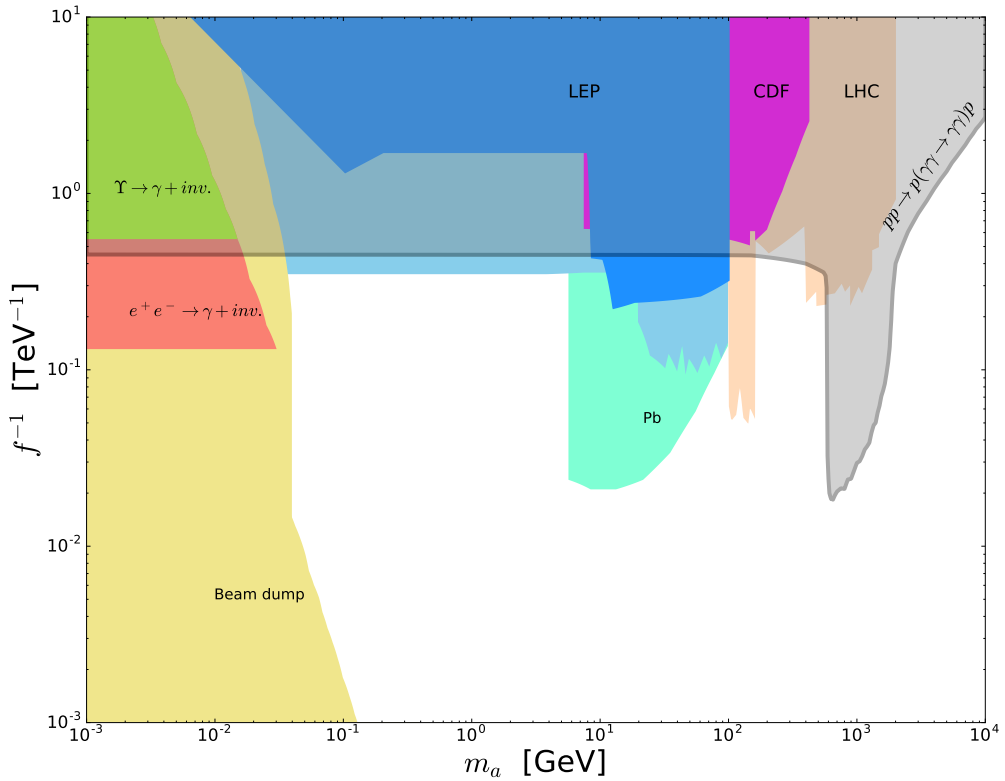
- BSM Physics by studying electroweak symmetry breaking
- Predicted by Composite Higgs and Extra-Dimensional models
- Couplings can be probed independently of models
- Muon g-2[4], Axions[5], Polarizable Dark Particle[6]



[4] *arXiv:1712.05980*
[5] *arXiv:1708.00443v2*
[6] *arXiv:1609.01762v1*

Search For Axions

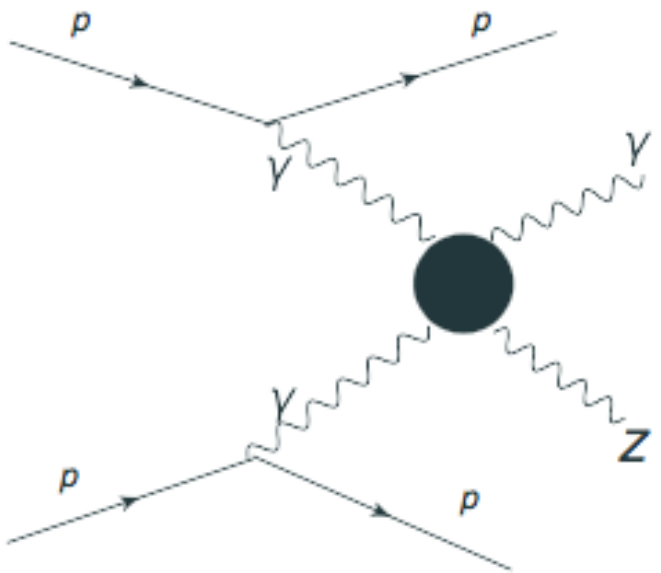




- Production of axions via photon exchange with proton tagging
- Sensitivity at high axion mass
- Existing limits on the Axion Like Particle from [7]

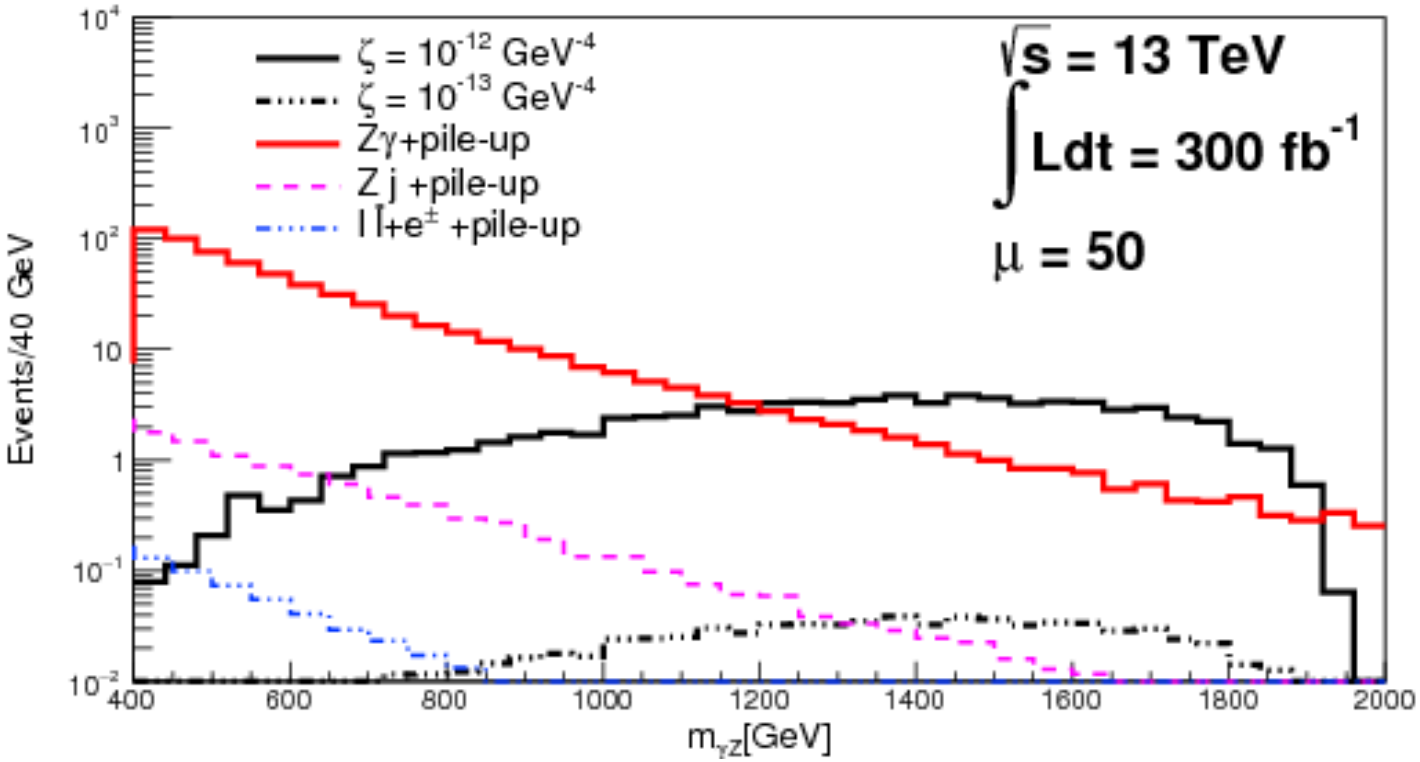
[7] *arXiv:1708.00443v2*

$\gamma\gamma \to \gamma Z$ Anomalous Coupling



- Z can decay leptonically or hadronically
- Hadronic decay requires use of timing detectors
- Forward-central matching allows us to look in both channels

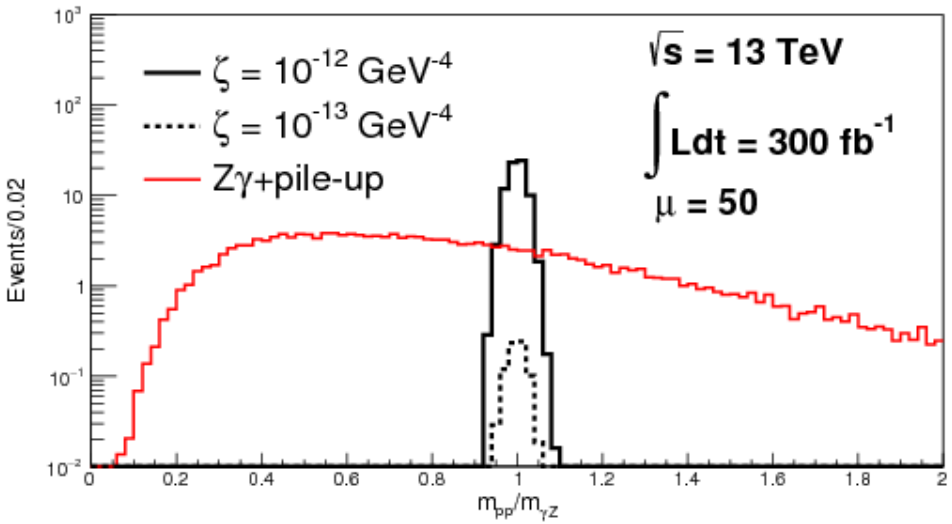
$\gamma\gamma \to \gamma Z$ Leptonic Decay

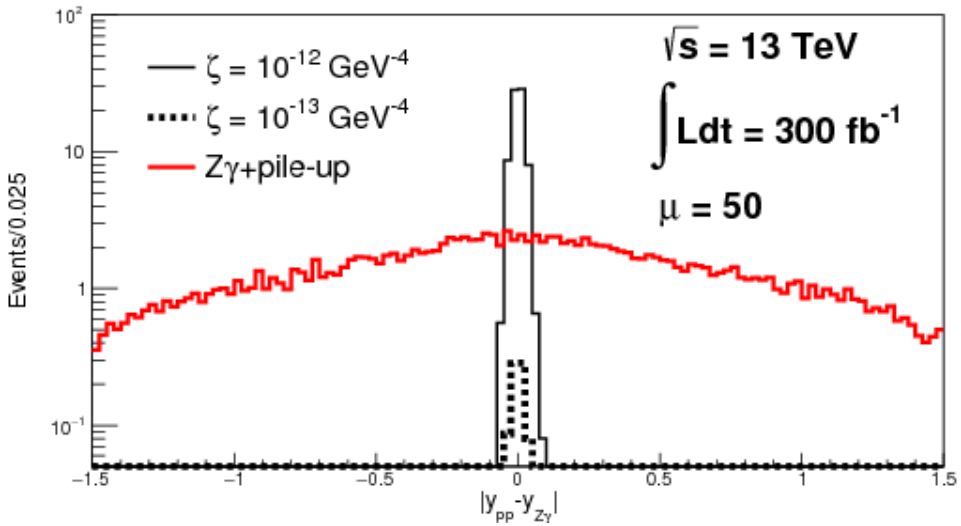


- Only prominent source of background is $Z\gamma$ + pileup
- For events with the Roman Pot acceptance $0.015 < \xi < 0.15$
- Figure from [8]

[8] C. Baldenegro, S. Fichet, G. von Gersdorff, C. Royon, JHEP 1706 (2017) 142

$\gamma\gamma \to \gamma Z$ Leptonic Decay

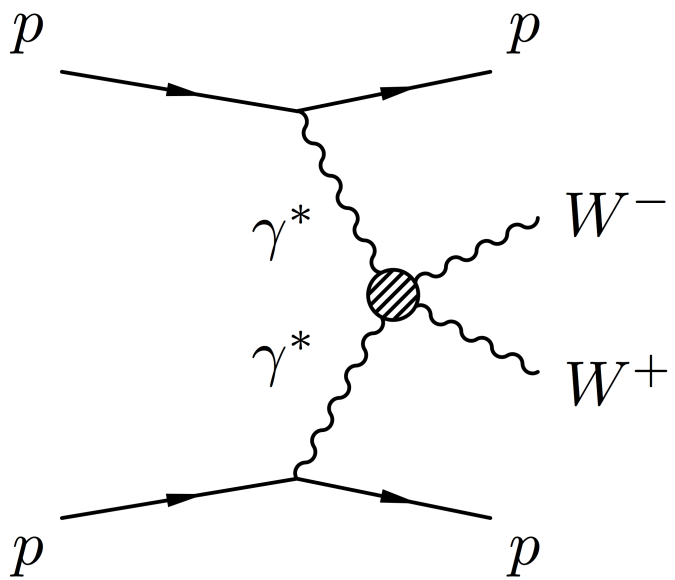




- Background is flat
- Signal peaks at values for correlation
- Forward-central matching diminishes pileup background
- Figures from [9]

[9] C. Baldenegro, S. Fichet, G. von Gersdorff, C. Royon, JHEP 1706 (2017) 142

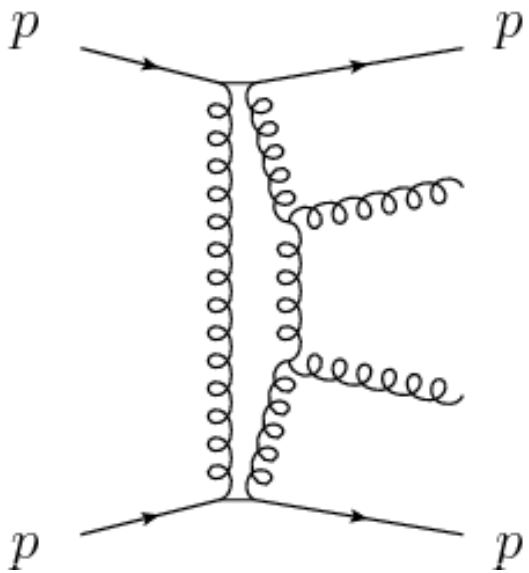
$\gamma\gamma \to WW$ Anomalous Coupling



- W decays into lepton + neutrinos
- Requires use of timing detectors because of missing E_T
- Signal appears at high lepton p_T
- Previous study with μe final state in CMS with 5 fb^{-1} at $\sqrt{s} = 7$ TeV[10]

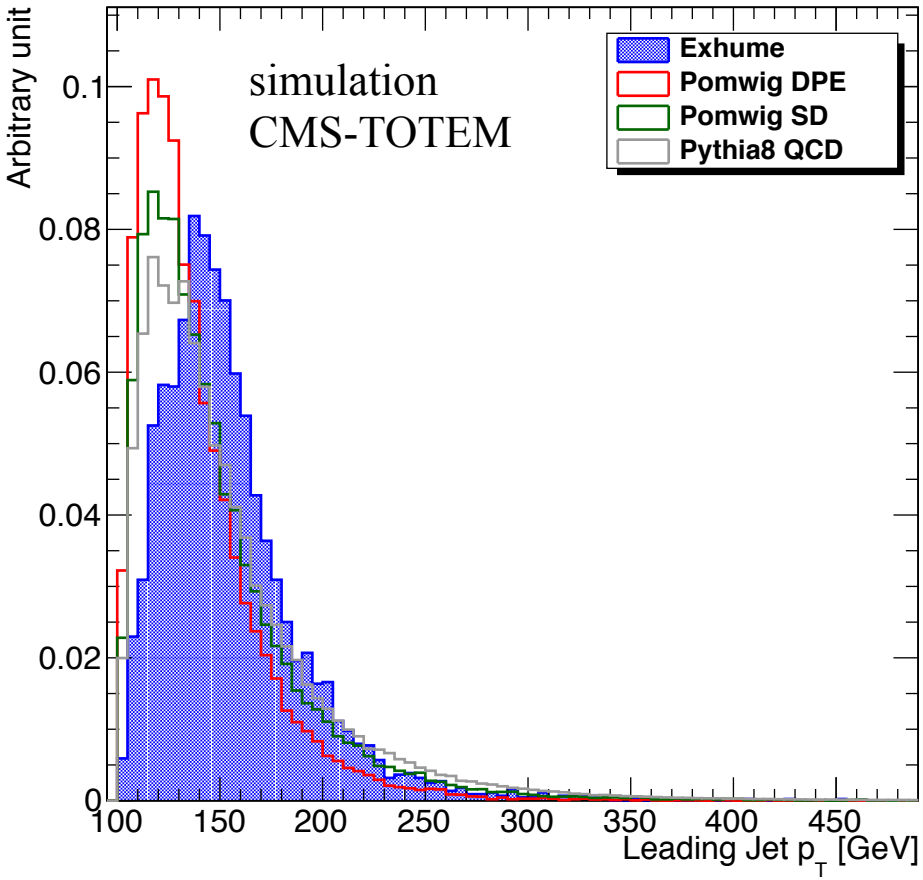
[10] JHEP 1307, 116 (2013)

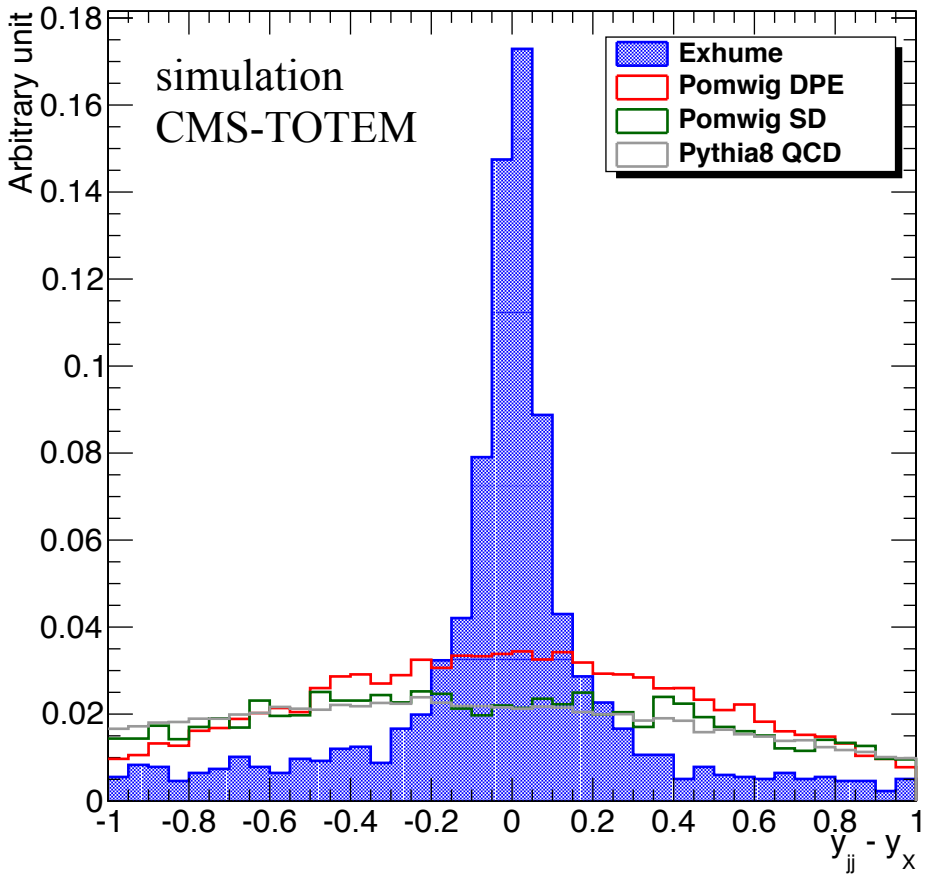
Central Exclusive Dijet Production



- Determine gluon distributions
- Constraints on exclusive Higgs production
- Working on dedicated HLT to improve efficiency for low p_T jets

Exclusive Dijet Production





- Selection Cuts:[11]
  - $p_T > 150$ GeV
  - $|\eta_{jj}| < 2.0$
  - $0.7 < \frac{M_{jj}}{M_X} < 1.15$
  - $|y_{jj} - y_X| < 0.1$

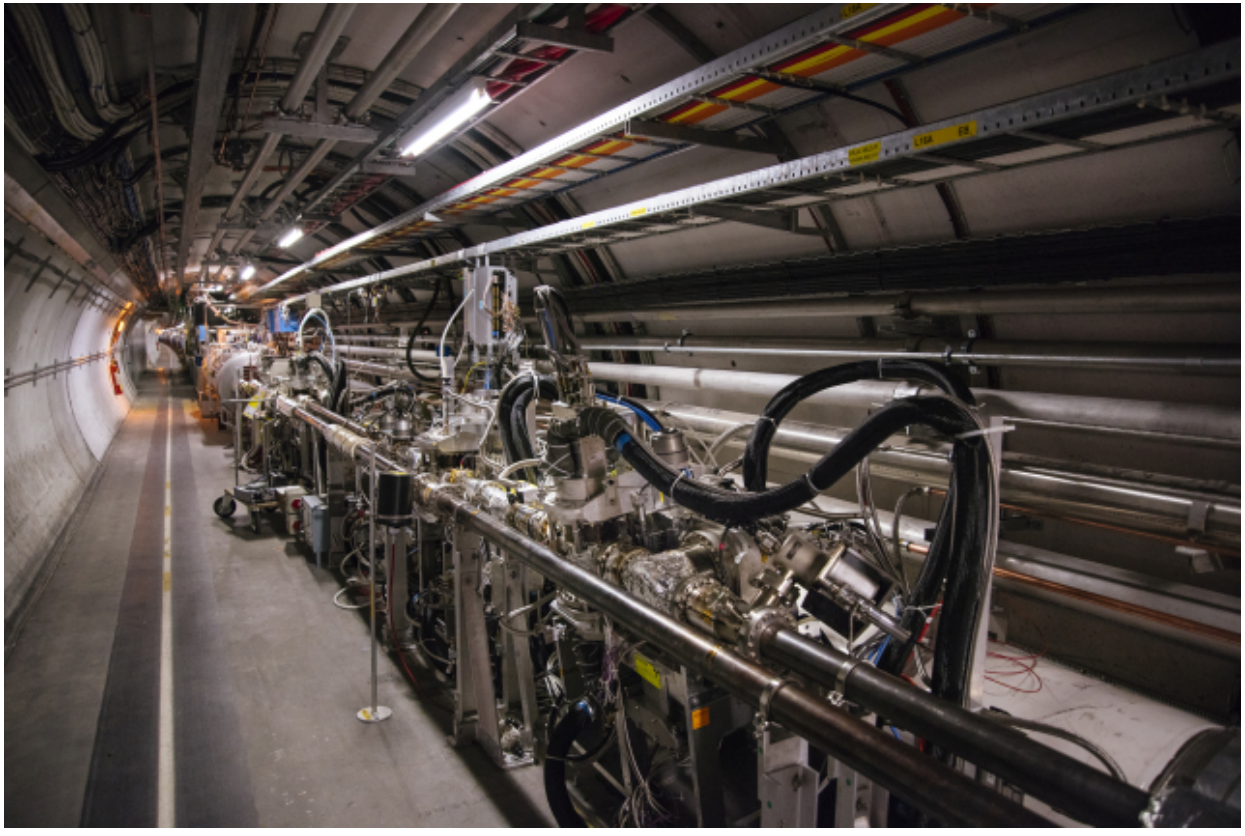
[11] CERN-LHCC-2014-021

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
- First observation of $\gamma\gamma \to \ell\ell$ with single proton tag
- Prospects for anomalous couplings, axion searches, and exclusive jet production
- CT-PPS has ~ 55 fb^{-1} and will acquire more in 2018

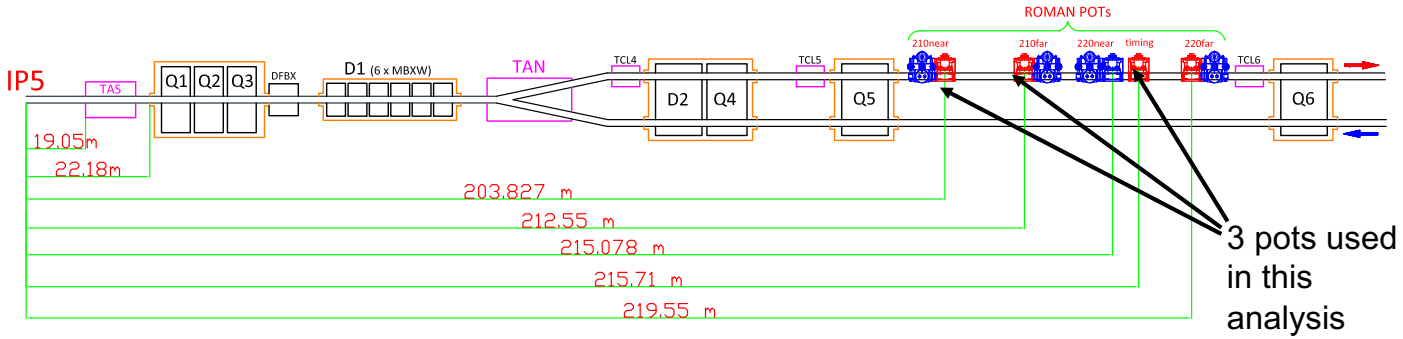
Questions?

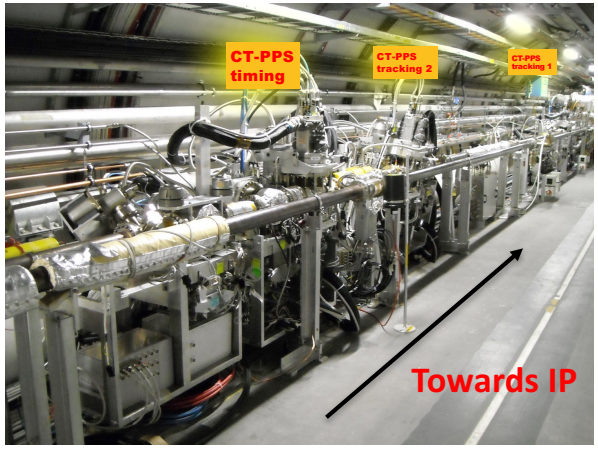
Backup slides - CTPPS



Backup slides - CTPPS 2016 Configuration

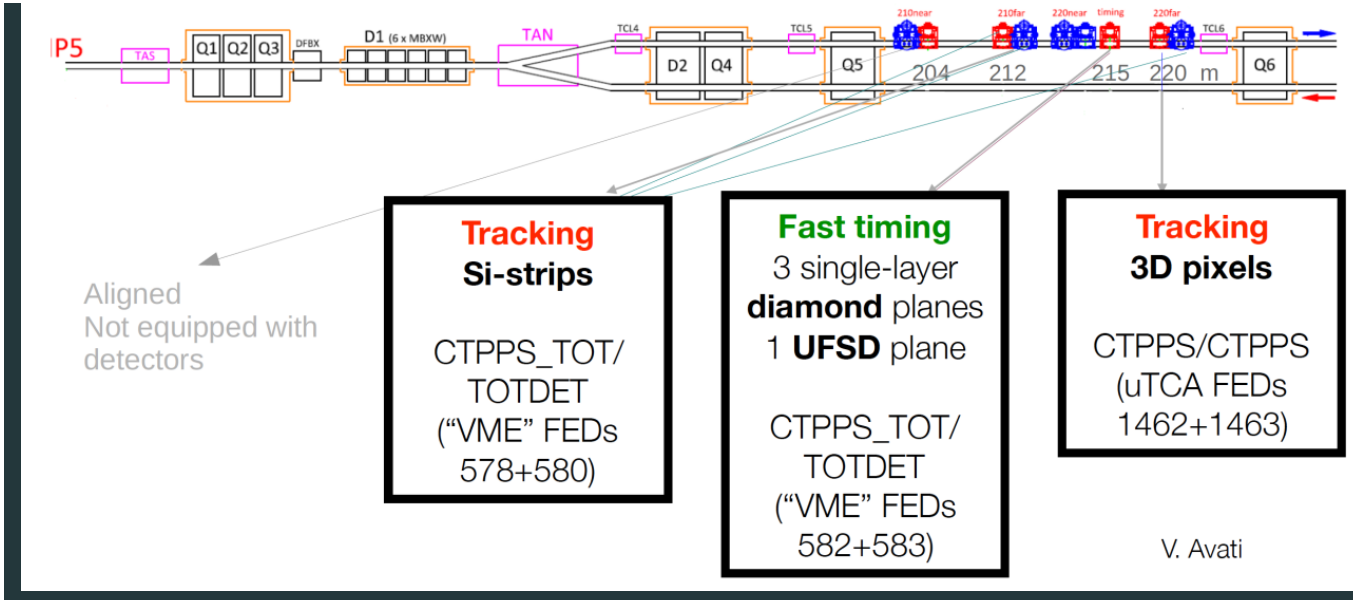
CT-PPS in 2016

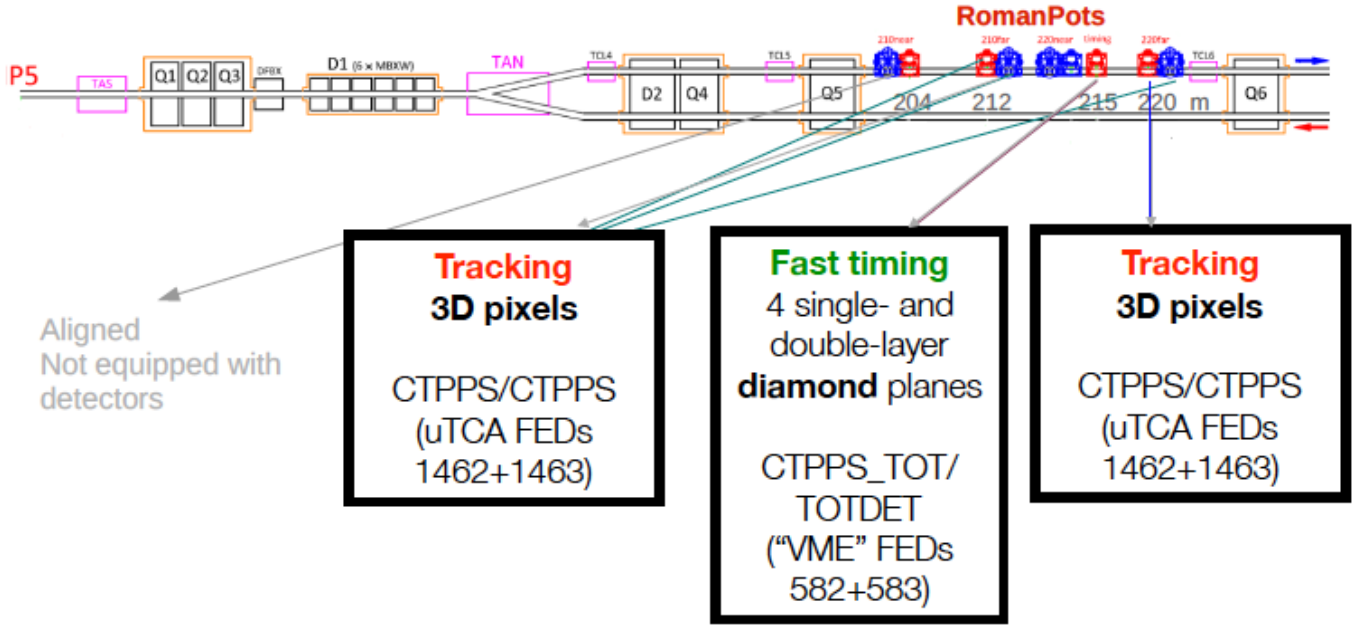




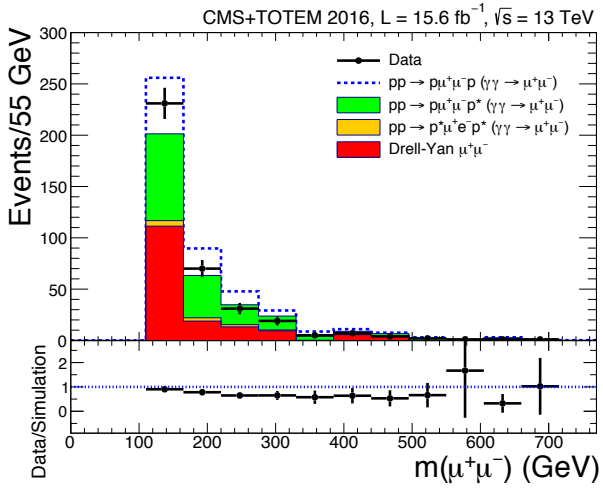
- 2 horizontal Roman Pots , equipped with Si-strips & RF shielding for insertion at high luminosity
- 1 cylindrical RP, equipped with fast-timing diamond detectors

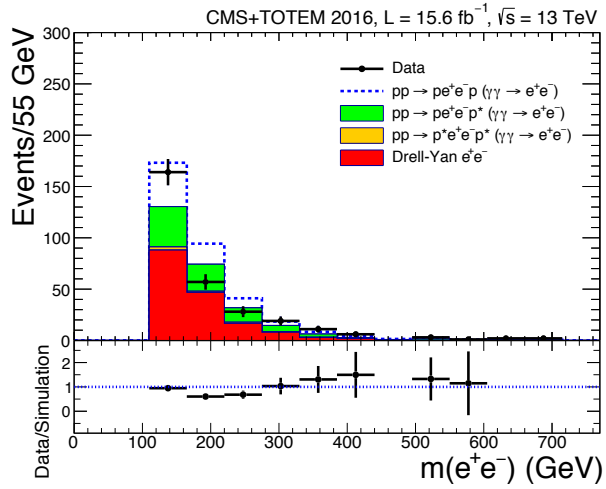
Backup slides - CTPPS 2017 and 2018 Configuration

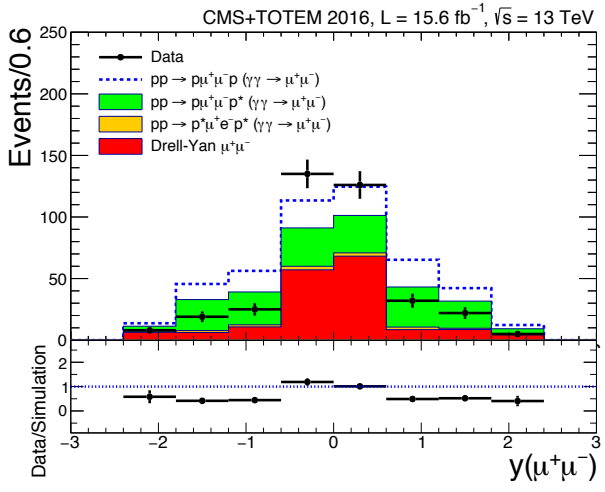


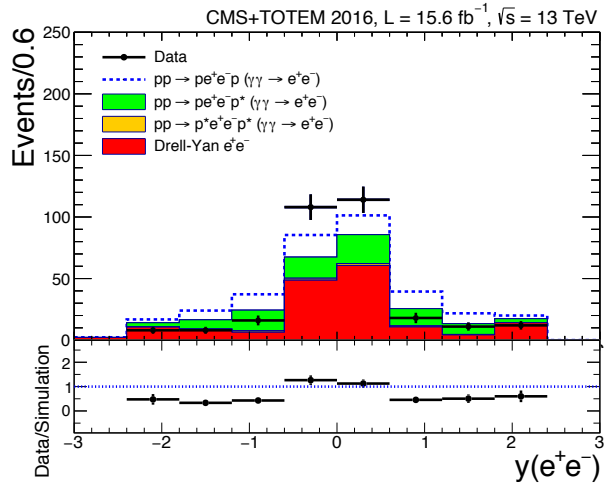


Backup slides - Dilepton Distributions



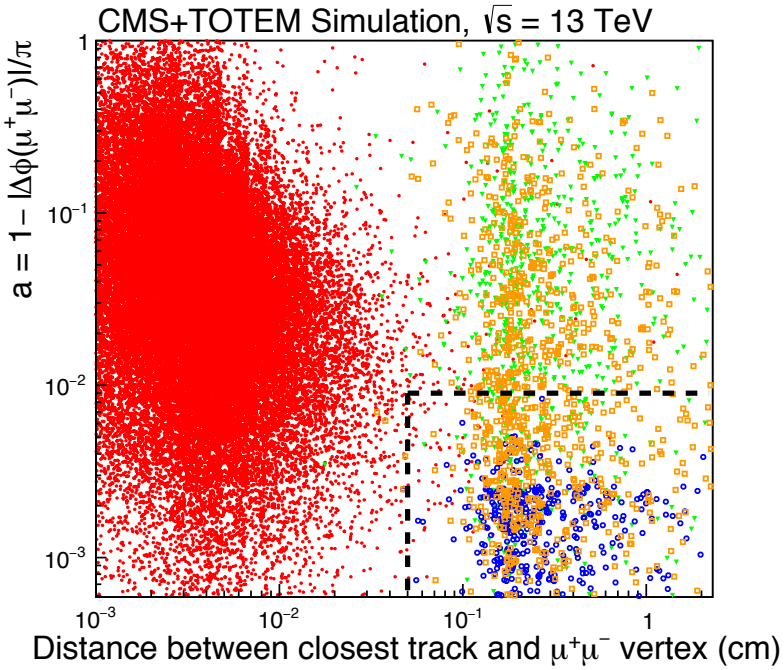


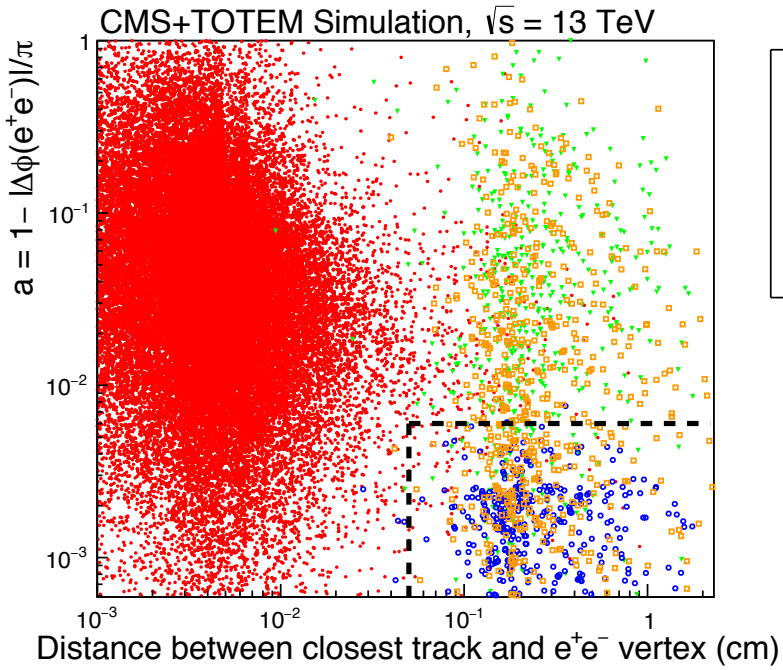




$$\xi\left(\ell^{+}\ell^{-}\right)=\frac{1}{\sqrt{s}}\left[p_{T}\left(\ell^{+}\right)e^{\pm\eta\left(\ell^{+}\right)}+p_{T}\left(\ell^{-}\right)e^{\pm\eta\left(\ell^{-}\right)}\right]$$

Backup slides - Dilepton Selection





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2. S. Fichet, G. von Gersdorff, B. Lenzi, C. Royon, and M. Saimpert, JHEP 02, 165 (2015), arXiv:1411.6629 [hep-ph].
3. S. Fichet, G. von Gersdorff, O. Kepka, B. Lenzi, C. Royon, and M. Saimpert, Phys. Rev. D89, 114004 (2014), arXiv:1312.5153 [hep-ph].
4. M. Boonekamp, R. Peschanski, and C. Royon Phys. Rev. Lett. 87, 251806
5. E. Chapon, C. Royon, and O. Kepka, Anomalous Quartic WW$\gamma\gamma$, ZZ$\gamma\gamma$, and Trilinear WWγ, couplings in two-photon processes at High Luminosity at the LHC, Phys. Rev. D 81, 074003 (2010).
6. C. Baldenegro, S. Fichet, Gero von Gersdorff, and C. Royon. Probing the anomalous $\gamma\gamma\gamma$Z coupling at the LHC with proton tagging. *JHEP*, 06:142, 2017.