Recent Diffractive and Exclusive Results from CMS

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On behalf of the CMS Collaboration

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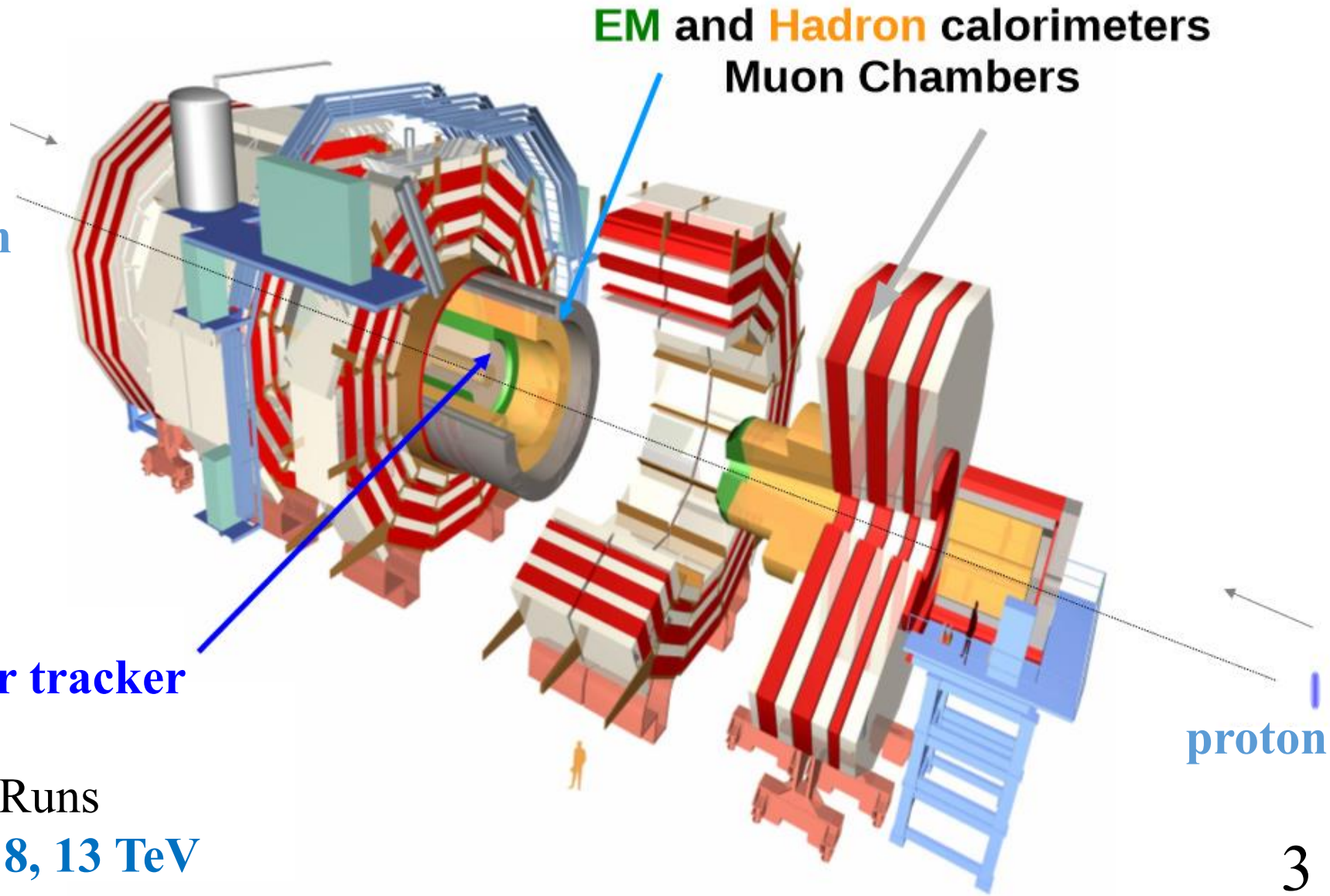
Outline

- Introduction
- Proton-proton collisions
  - Exclusive $\gamma\gamma \rightarrow W^+W^-$ production
    - Limits on anomalous quartic gauge couplings
  - Exclusive $\pi^+\pi^-$ production
    - Differential and integrated cross-sections
- Ongoing analyses and future prospects
  - Using CMS-TOTEM data to extend studies of central exclusive production

The CMS Experiment



LHC Runs

pp 7, 8, 13 TeV

Exclusive electroweak boson pairs

Motivation: Exclusive electroweak boson pairs

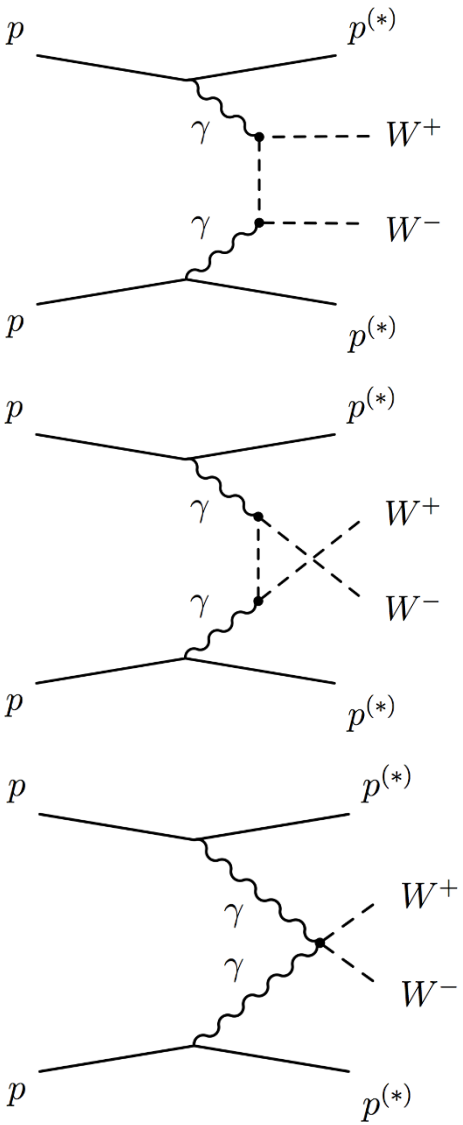
- The exclusive production of W pairs is sensitive to anomalous quartic gauge couplings (aQGC)
- **The electroweak sector of Standard Model predicts QGC**
- **Any deviation from SM expectations can reveal a sign of new physics**
- Objective: Measure SM cross section and look for aQGC.
- aQGC are introduced via effective Lagrangian

$$\mathcal{L}_6^0 = \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W_\alpha^-$$

$$\mathcal{L}_6^C = \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W_\beta^- - W^{-\alpha}W_\beta^+) \cdot$$

Anomalous coupling constant for quartic vertex

Λ : Scale for New Physics



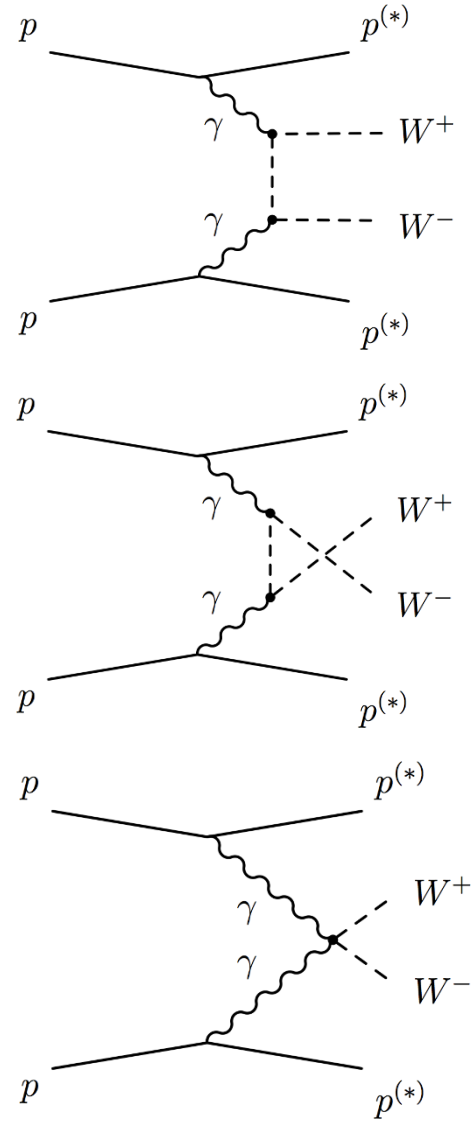
Exclusive $\gamma\gamma \to W^+W^-$: event selection

- Exclusive production of W pairs

  $pp \to p^{(*)} W^+ W^- p^{(*)}$

  $p^{(*)}$: Elastic + Inelastic contributions

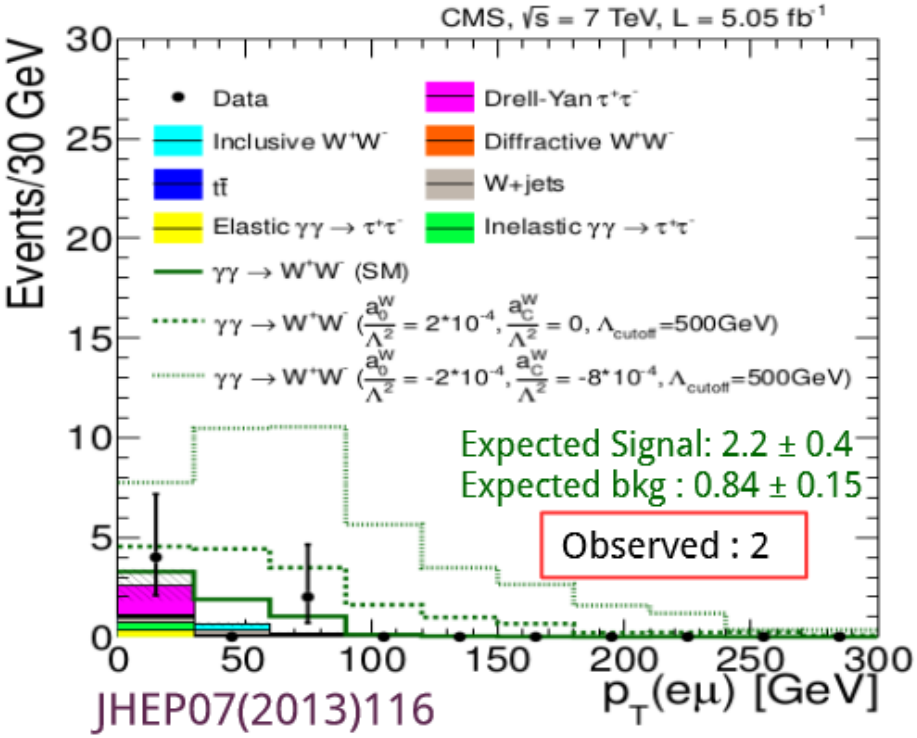
- 2011 pp collision data at 7 TeV with 5.05 fb^{-1}
- 2012 pp collision data at 8 TeV with 19.7 fb^{-1}
- Offline exclusive $\gamma\gamma \to W^+ W^-$ signal selection
  - Opposite-sign eμ pair (final state) originating from commom primary vertex
  - No extra tracks at eμ vertex
    to remove inclusive background
  - Invariant mass (eμ) > 20 GeV
    to get rid of any low mass resonances
  - p_T (eμ) > 30 GeV
    to suppress DY and $\gamma\gamma \to \tau^+\tau^-$



- Proton dissociation factor from μμ sample

Exclusive $\gamma\gamma \to W^+W^-$ production at 7 and 8 TeV

SM signal region : N extra tracks =0 , p_T (eμ) > 30 GeV



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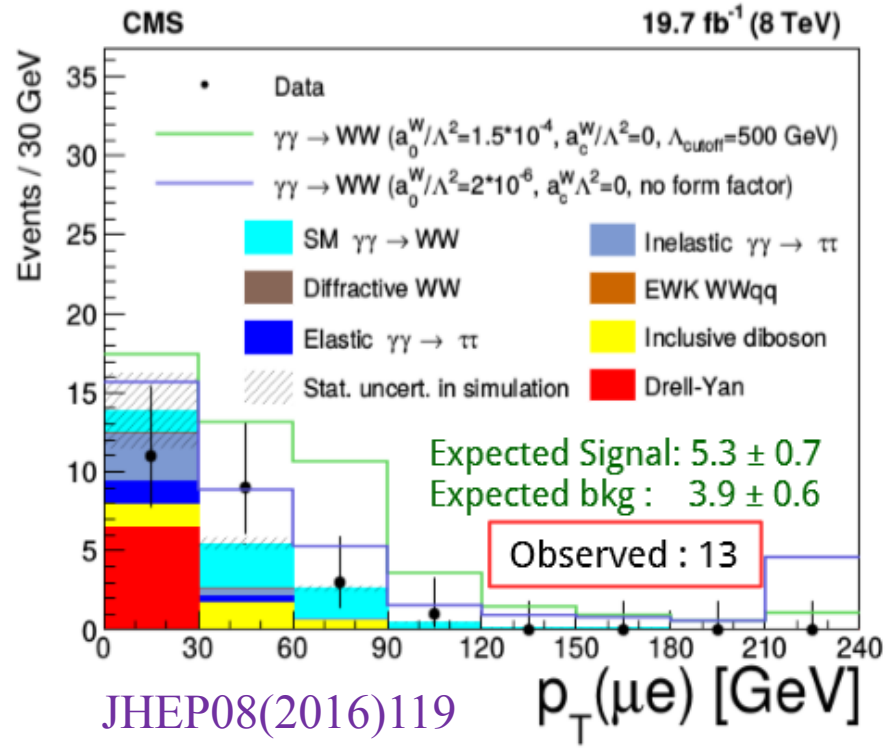


JHEP08(2016)119

Cross section times branching fraction

$$\sigma(pp \to p^{(*)}W^+W^-p^{(*)} \to p^{(*)}\mu^\pm e^\mp p^{(*)}) = 2.2^{+3.3}_{-2.0}\,\text{fb}$$

SM Prediction : 4.0 ± 0.7 fb

$$\sigma(pp \to p^{(*)}W^+W^-p^{(*)} \to p^{(*)}\mu^\pm e^\mp p^{(*)}) = 10.8^{+5.1}_{-4.1}\,\text{fb}$$

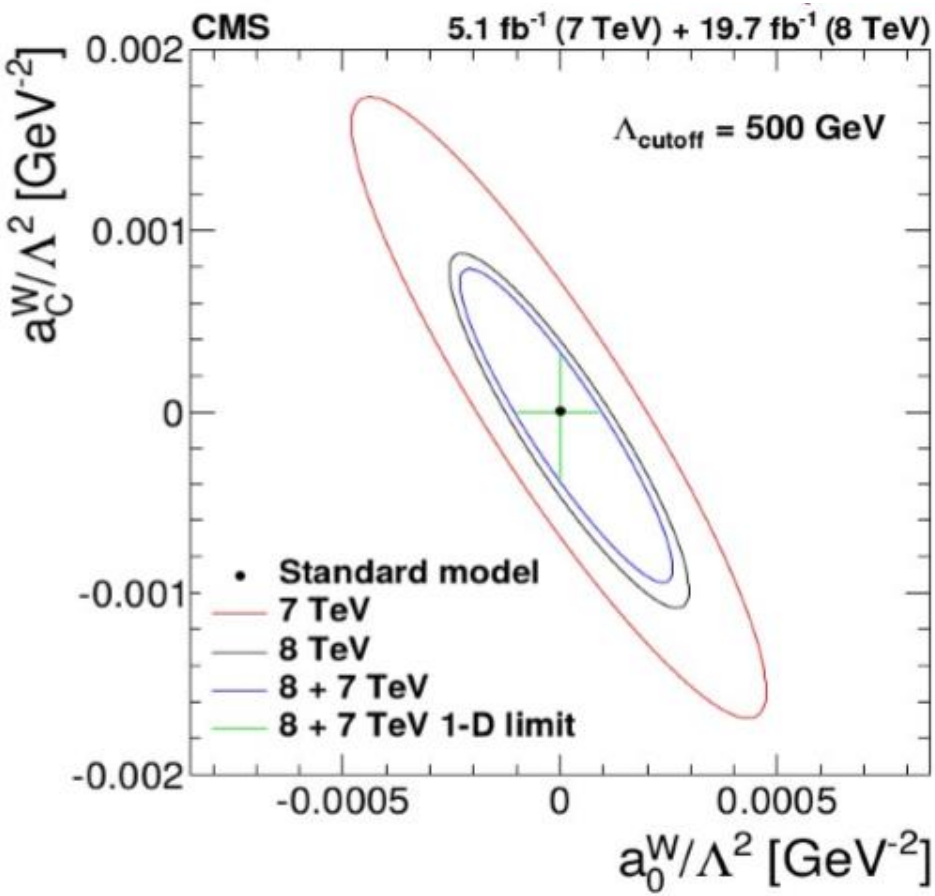
SM Prediction : 6.9 ± 0.6 fb

The observed significance for 7 and 8 TeV combination is 3.4σ

Exclusive $\gamma\gamma \to W^+W^-$: aQGC limit

JHEP08(2016)119

- Used shape of p_T (eμ) distribution to search for sign of anomalous quartic gauge couplings
- p_T (eμ) > 100 GeV used at 7 TeV
- Two bins at 8 TeV 30 < p_T (eμ) < 130 GeV and p_T (eμ) > 130 GeV
- Region outside solid line is excluded at 95% CL
- **The most stringent limit so far, two orders of magnitude more stringent than LEP**



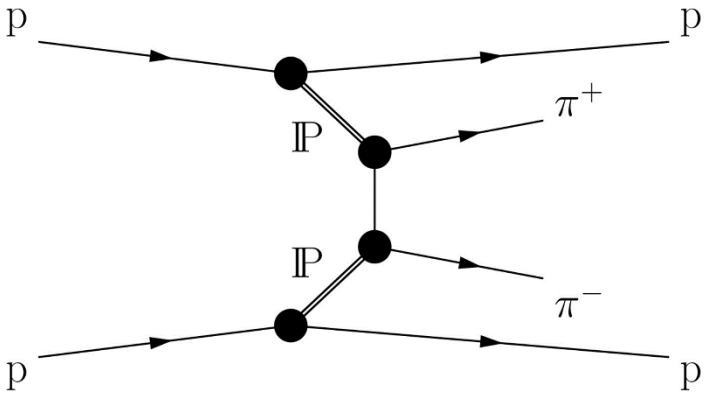
Dimension-6 AQGC parameter	7 TeV ($\times 10^{-4}$ GeV^{-2})	8 TeV ($\times 10^{-4}$ GeV^{-2})	7+8 TeV ($\times 10^{-4}$ GeV^{-2})
$a_0^W/\Lambda^2(\Lambda_{\text{cutoff}} = 500\,\text{GeV})$	$-1.5 < a_0^W/\Lambda^2 < 1.5$	$-1.1 < a_0^W/\Lambda^2 < 1.0$	$-0.9 < a_0^W/\Lambda^2 < 0.9$
$a_C^W/\Lambda^2(\Lambda_{\text{cutoff}} = 500\,\text{GeV})$	$-5 < a_C^W/\Lambda^2 < 5$	$-4.2 < a_C^W/\Lambda^2 < 3.4$	$-3.6 < a_C^W/\Lambda^2 < 3.0$

Exclusive $\pi^+\pi^-$production

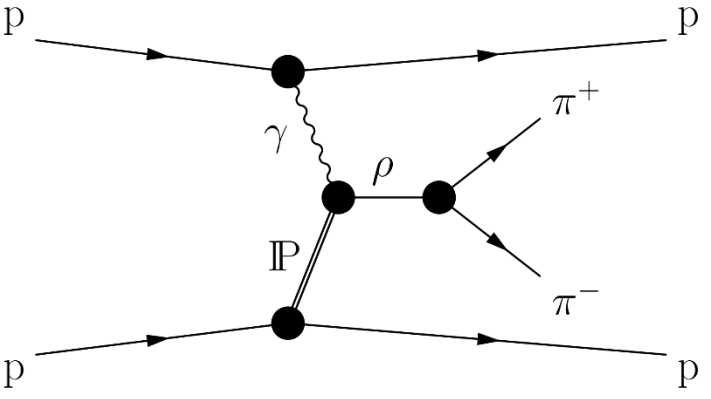
Exclusive $\pi^+\pi^-$production: Experimental signature

CMS-FSQ-12-004
arXiv:1706.08310

- Exclusive production of hadrons at central rapidities phenomenologically described in terms of “DPE” Double Pomeron Exchange when the mass of central system is low, or pertubatively in “CEP”



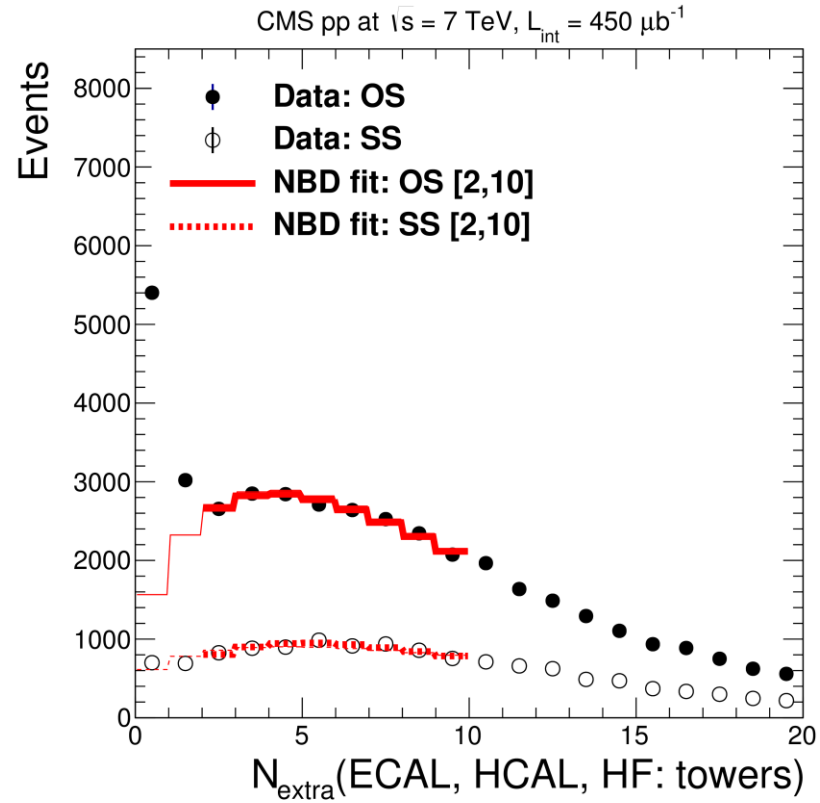
- **Experimental signature:**
  - Only two opposite sign tracks ($\pi^{\pm}$) from the same primary vertex
  - No additional signal in calorimeters
  - $p_T(\pi) > 0.2$ GeV
  - $|y(\pi)| < 2$



Exclusive $\pi^+\pi^-$production: Background estimation

CMS-FSQ-12-004
arXiv:1706.08310

- **Signal:** (Zero-bin with opposite-sign (OS) events)
- **Background:**
  - Make "data-driven"
  - Both normalization and shape for different distributions
  - OS and SS data for $2 \leq N_{extra} \leq 10$ are very well described with NBD
  - Extrapolation to $N_{extra} = 0$ is used
- Use the same procedure on same-sign (SS) events (purely background)



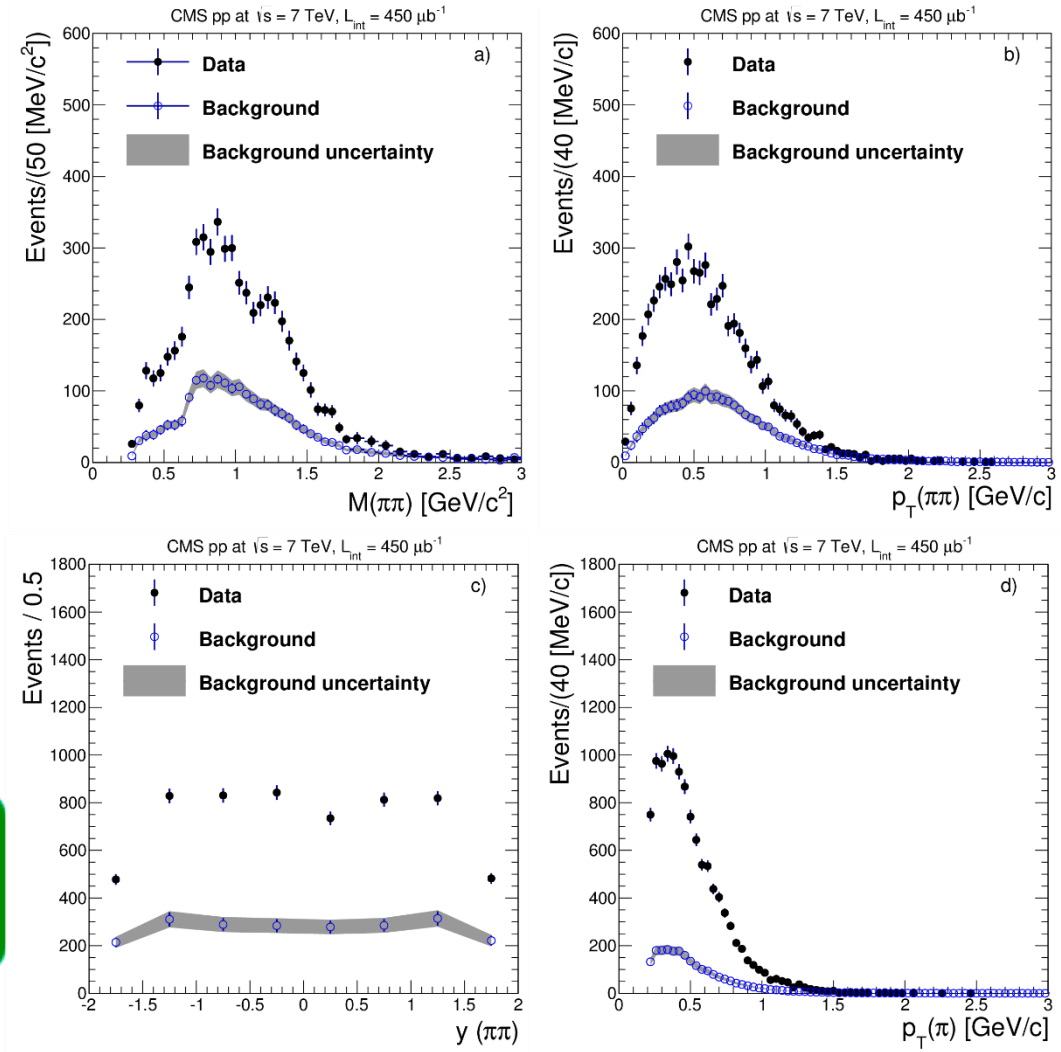
Exclusive $\pi^+\pi^-$production: Signal distribution

CMS-FSQ-12-004
arXiv:1706.08310

- Signal events ($N_{extra} = 0$)

- Background events

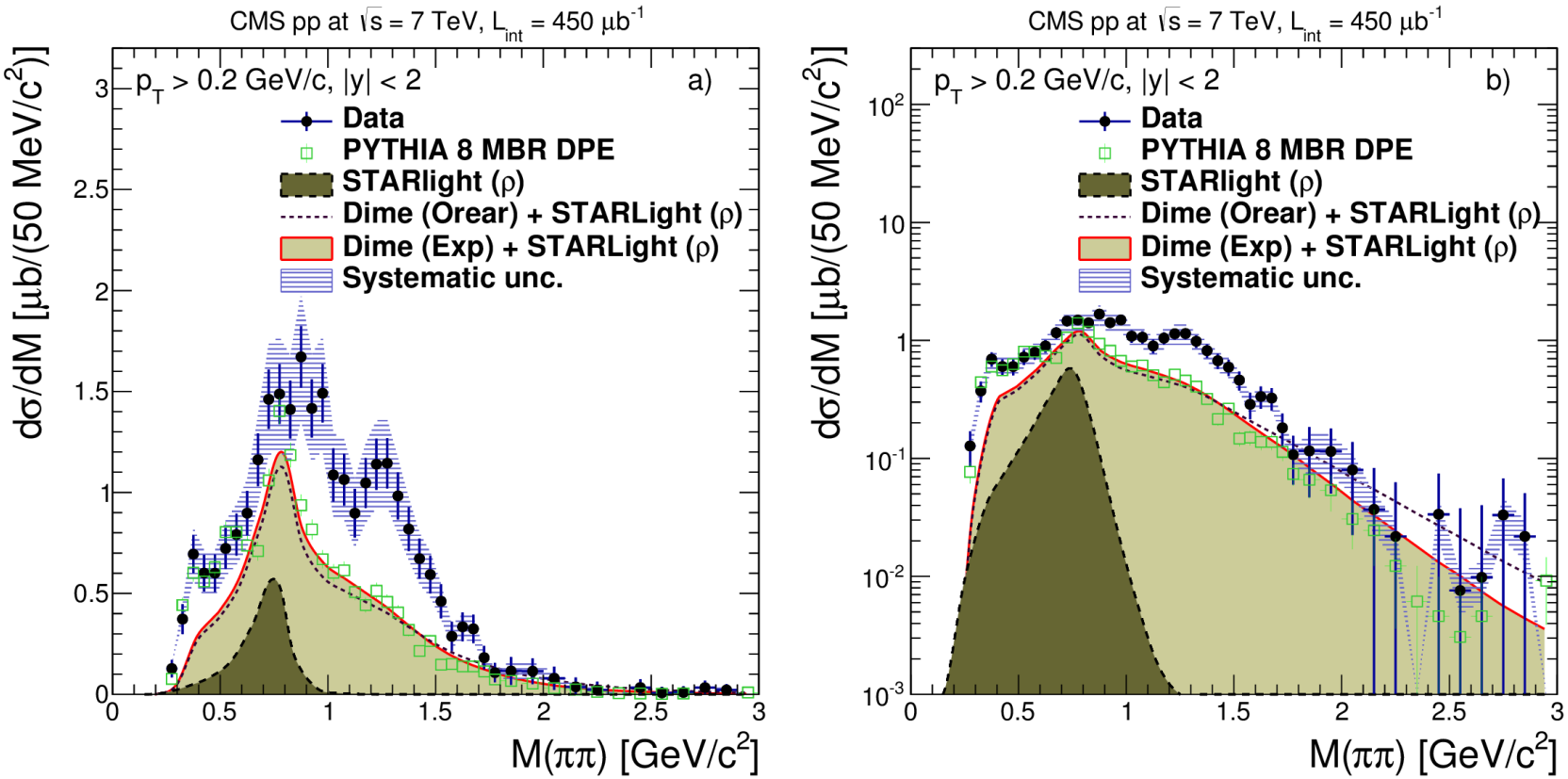
  obtained by scaling the events in the region $2 \leq N_{extra} \leq 10$ according to the amount predicted by the NBD for $N_{extra} = 0$



Background is $\pi^+\pi^-$ events but with additional activity

Exclusive $\pi^+\pi^-$production: Results $d\sigma/dM$

CMS-FSQ-12-004 arXiv:1706.08310

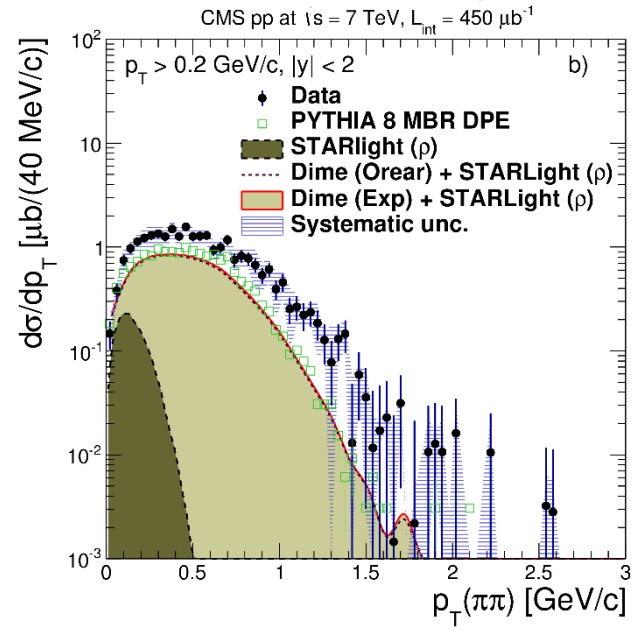


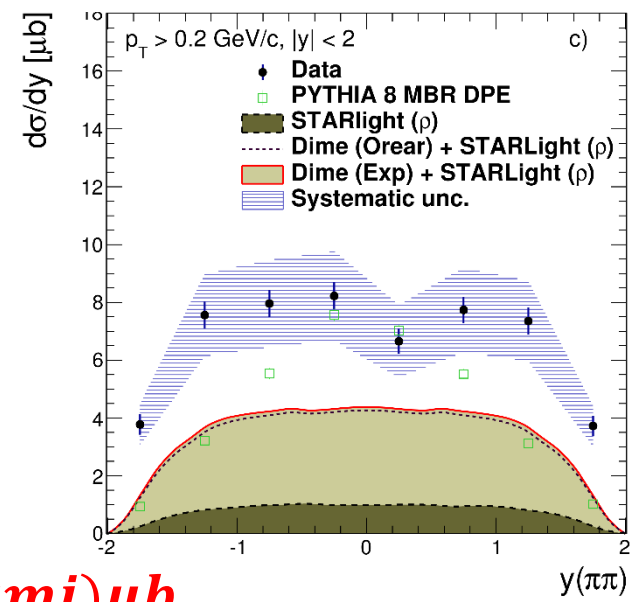
- **Differential cross section:**
  - with $p_T(\pi) > 0.2$ GeV and $|y(\pi)| < 2$
  - Compared to the predictions of DPE production from the **Dime MC** (red/green curves), and **STARLIGHT** (dash). (Here: Dime MC & Starlight are stacked)
  - The shaded blue band shows the overall systematic uncertainty, and the thin error bar indicates the statistical uncertainty
  - The results are plotted on a linear scale (left) and a logarithmic scale (right)

Exclusive $\pi^+\pi^-$production: Results $d\sigma/dp_T$, $d\sigma/dy$

CMS-FSQ-12-004
arXiv:1706.08310

- **Differential cross sections as a function of p_T and rapidity:**
  - with $p_T(\pi) > 0.2$ GeV and $|y(\pi)| < 2$
  - Compared to the predictions of DPE production from the **Dime MC** (red/green curves), and **STARLIGHT** (dash).
  - (Here: Dime MC & Starlight are stacked) The shaded blue band shows the overall systematic uncertainty, and the thin error bar indicates the statistical uncertainty
  - The results are plotted on a logarithmic scale (top) and a linear scale (bottom)

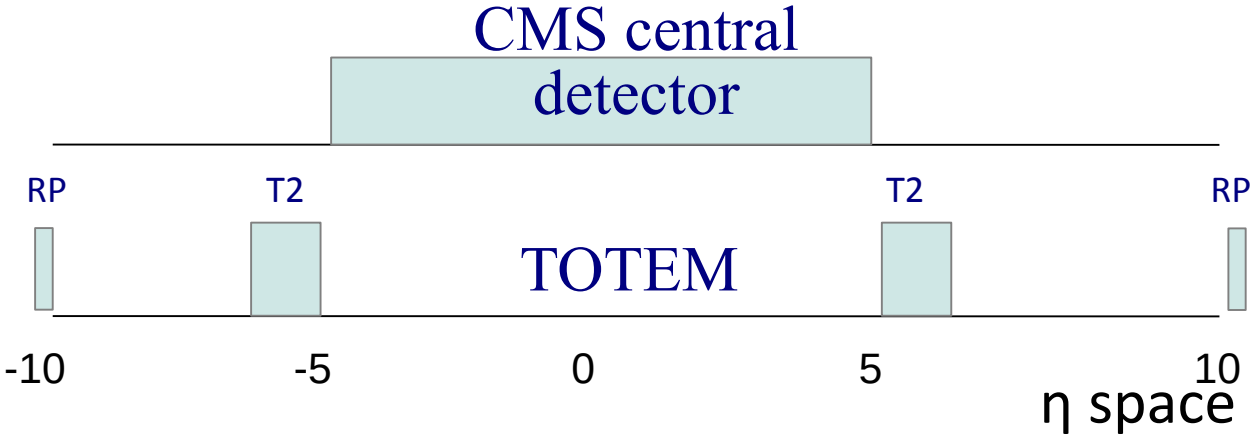




$$\sigma_{\pi^+\pi^-} = 26.5 \pm 0.3(stat) \pm 5.0(syst) \pm 1.1(lumi)\mu b$$

Future prospects

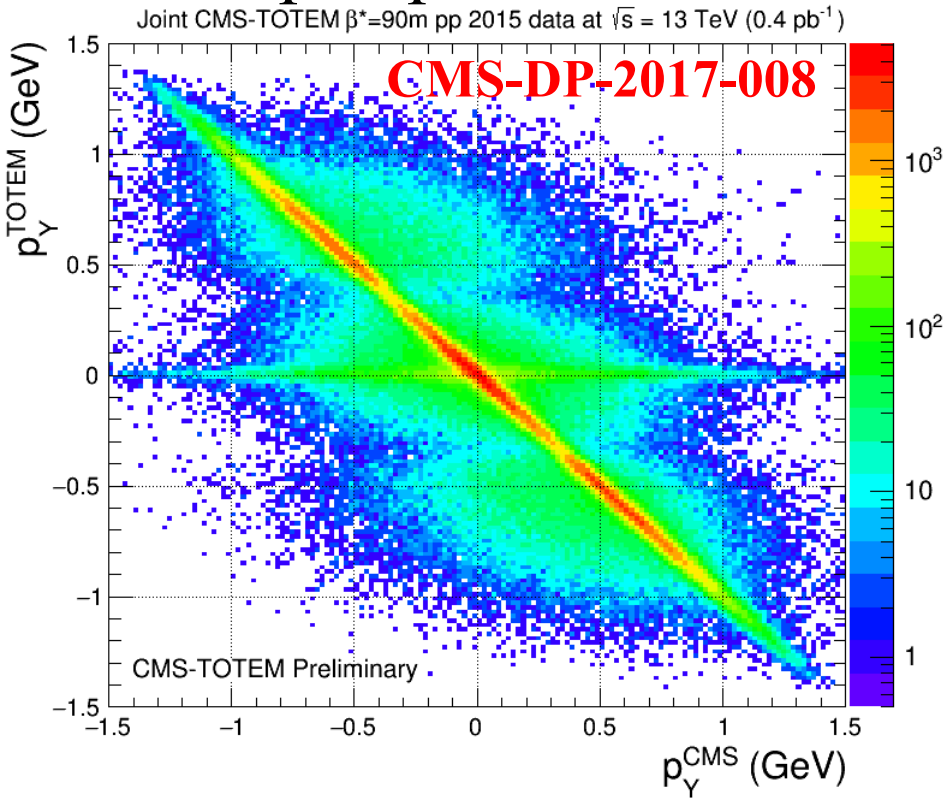
Future prospects: Joint CMS-TOTEM run @13 TeV

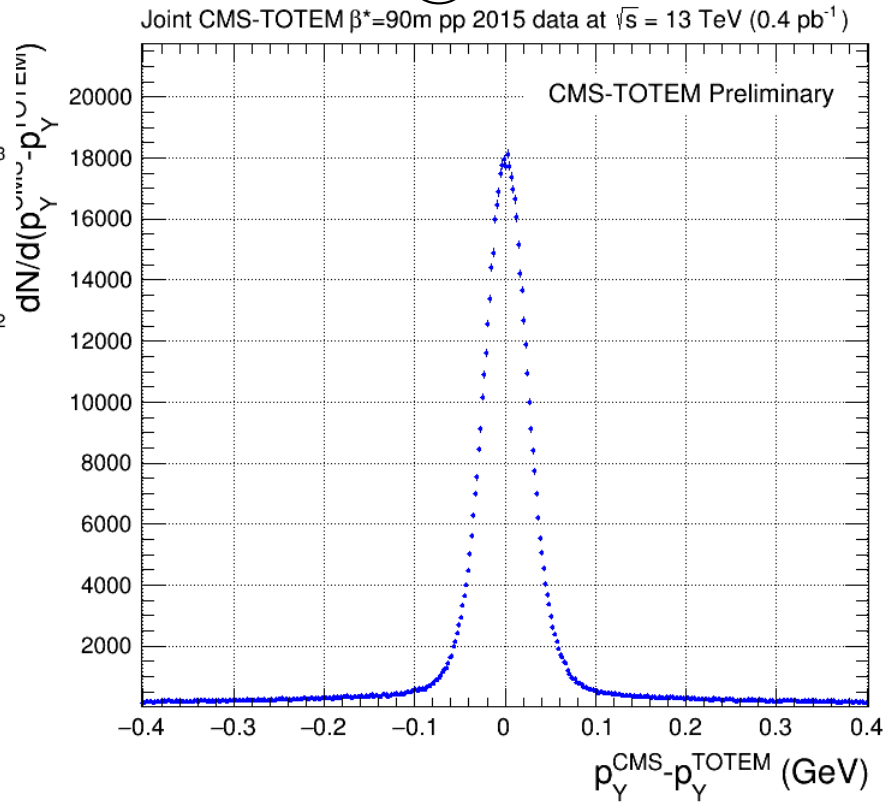


- Joint CMS-TOTEM **β*=90m** runs in October 2015
- About 0.4/pb of **low-pileup** (μ = 0.06-0.15) data at 13 TeV
- Events with central system in CMS and diffractive protons in TOTEM Roman Pots
- Separate DAQ systems with trigger exchange
- CMS and TOTEM **data reconstructed separately**, then merged offline (event by event based on the same orbit and bunch crossing)
- Dedicated CMS track reconstruction tune, to assure high track-finding efficiency for low-p_T tracks and high vertex-finding efficiency for 2-track events

Trigger: Two scattered protons in the TOTEM Roman Pots (RP), no activity in the TOTEM T2 telescopes, at least 5 clusters in the CMS pixel detector

Future prospects: Joint CMS-TOTEM run @13 TeV

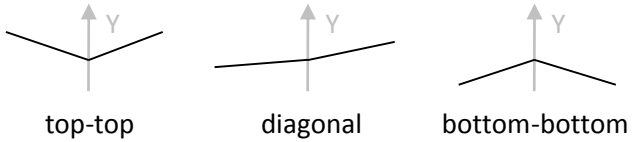




Transverse momenta p_Y of the scattered protons detected in Roman Pots (TOTEM) vs transverse momenta of two pion tracks measured in the central tracking system (CMS) for the pp → pp$\pi^+\pi^-$ production. Events on the diagonal correspond to the exclusive $\pi^+\pi^-$ production

Adding tagged protons from TOTEM greatly helps to select exclusive pp → pp$\pi^+\pi^-$ process with no proton-dissociation

The three distinct regions along the p_Y^{TOTEM} axis correspond to the top-top, diagonal and bottom-bottom proton configurations



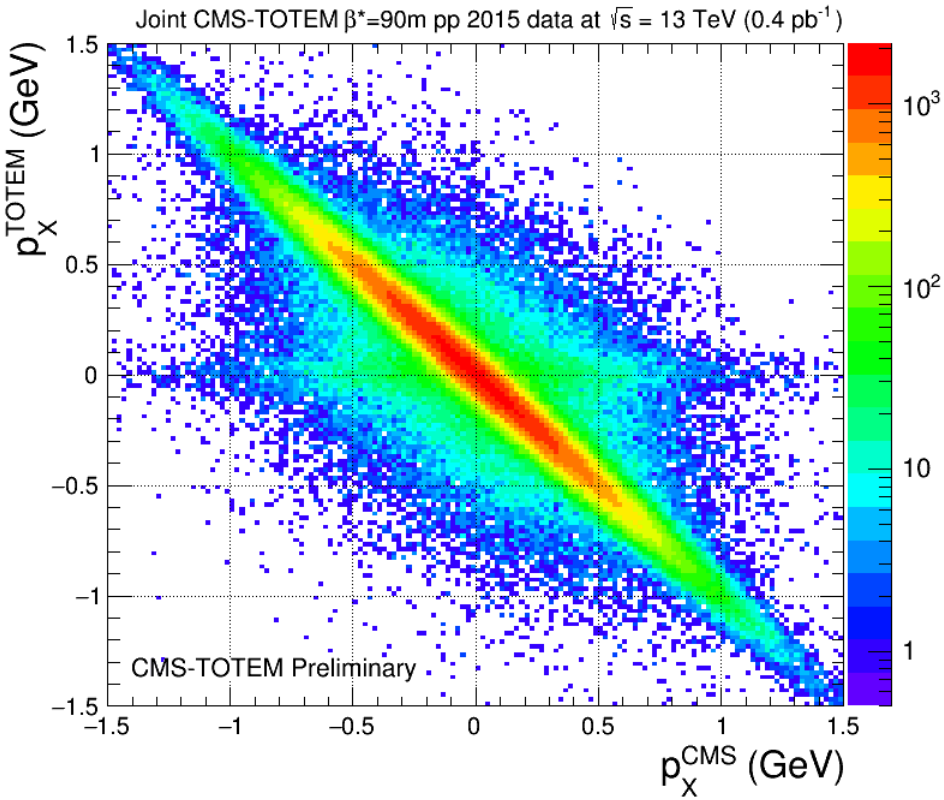
Summary

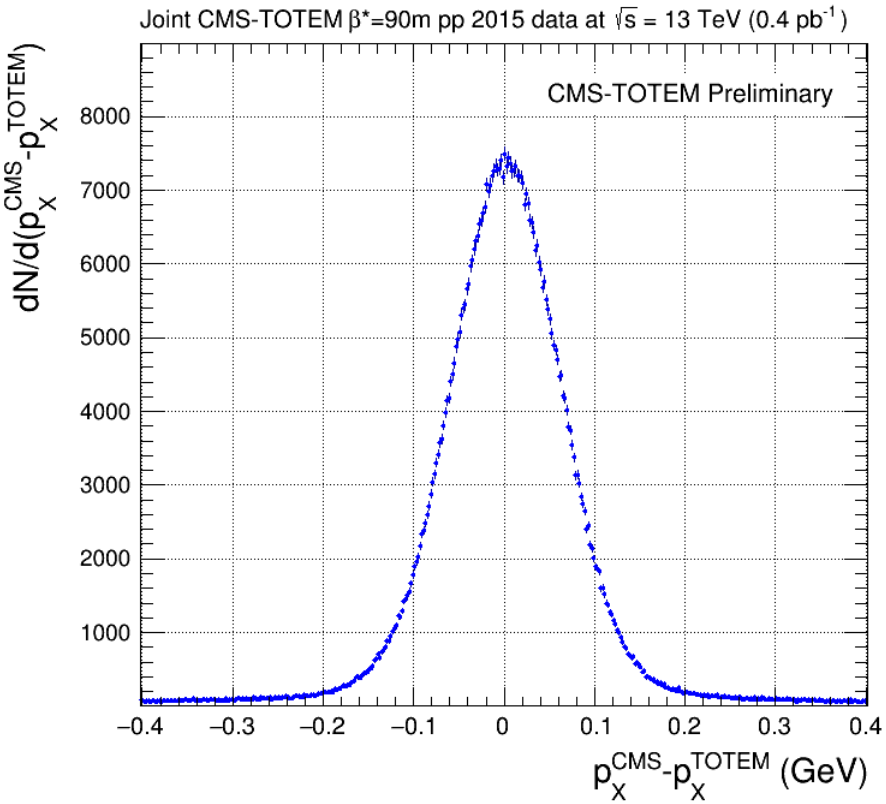
- Exclusive $\gamma\gamma \rightarrow W^+W^-$
  - 2 events observed at 7 Tev, 13 events observed at 8 Tev in SM region
  - No indication of aQGC found
- Exclusive $\pi^+\pi^-$
  - Differential cross-sections above exclusive $\pi^+\pi^- + \rho$ photoproduction predictions for high-pt
  - The invariant mass spectrum shows some features not included in the purely non-resonant predictions
- Using combined CMS-Totem data provides a very clean sample with no proton-dissociation background
- More exciting exclusive results to be presented this year
  - Not only in pp data, but also in pPb data and in PbPb!

Thank you for your attention!

Additional slides

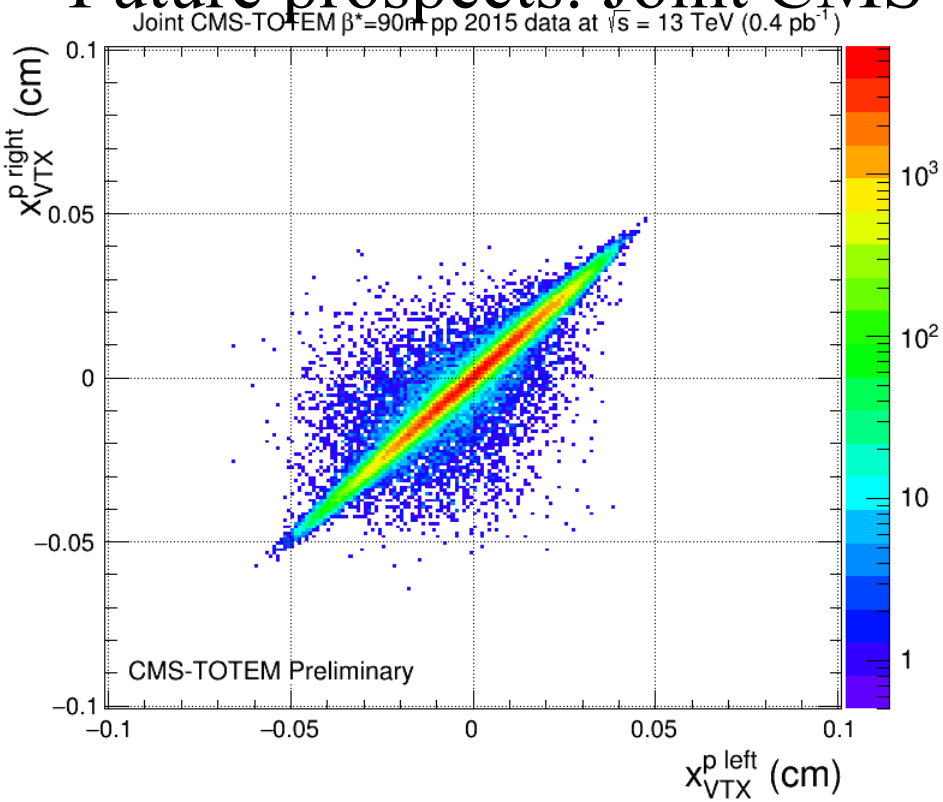
Future prospects: Joint CMS-TOTEM run @13 TeV

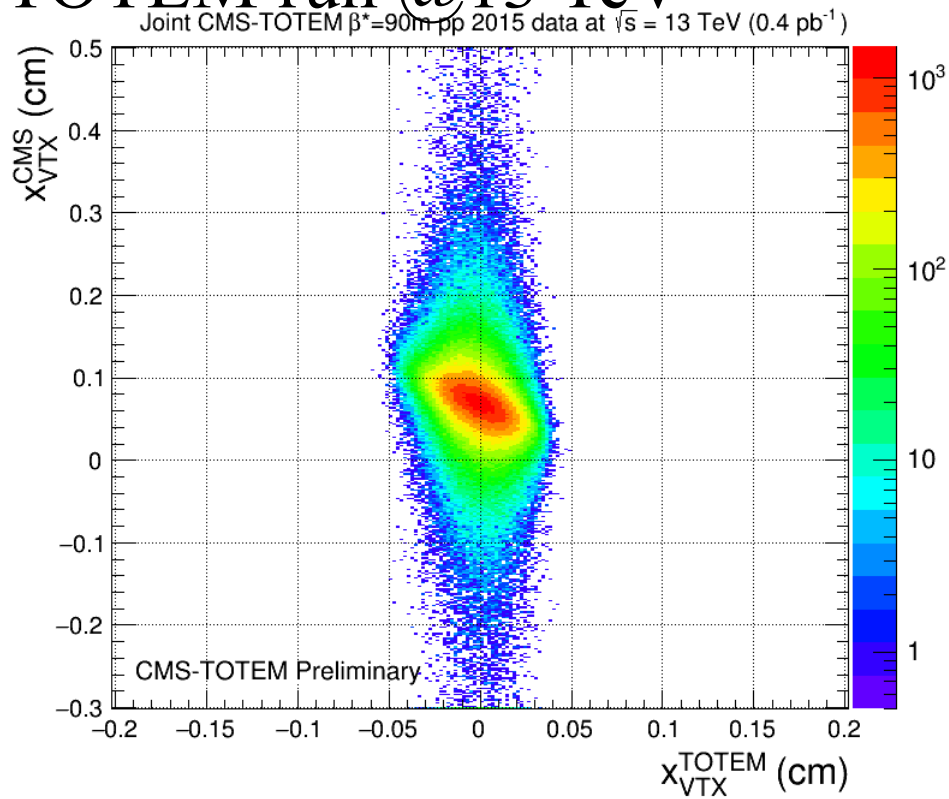




Requirements of the transverse momentum balance $|p_Y^{CMS} + p_Y^{TOTEM}| < 2\sigma_{dpY}$ and $|p_X^{CMS} + p_X^{TOTEM}| < 2\sigma_{dpX}$ are applied to reject background and select events of central exclusive production, pp → ppX with $X=\pi^+\pi^-$, K^+K^-, $\pi^+\pi^-\pi^+\pi^-$, $K^+K^-K^+K^-$, … .

Future prospects: Joint CMS-TOTEM run @13 TeV



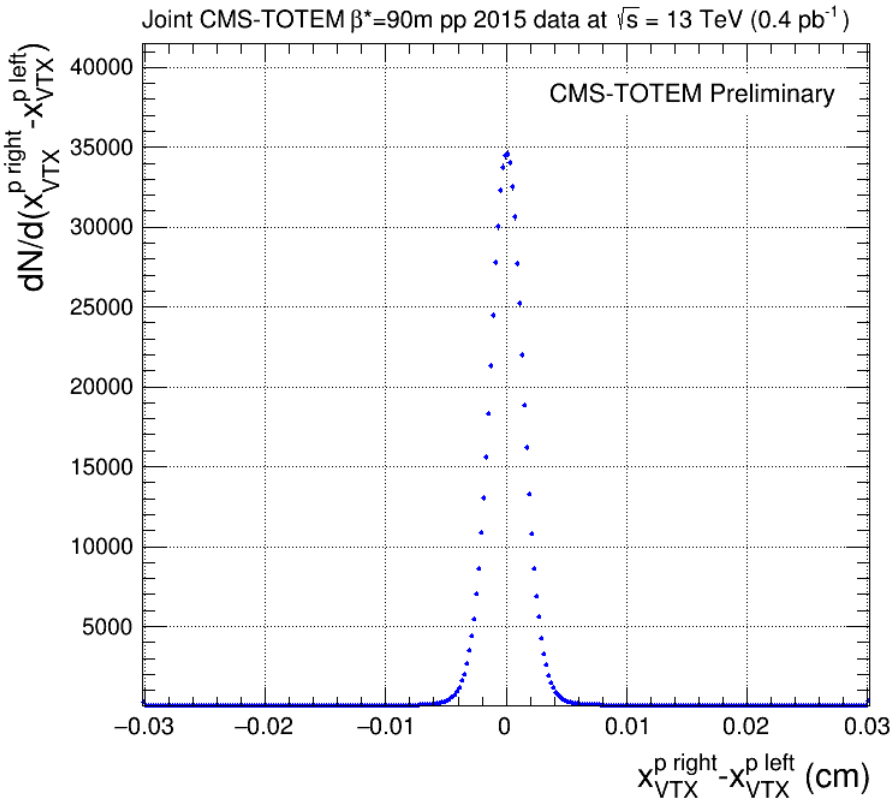


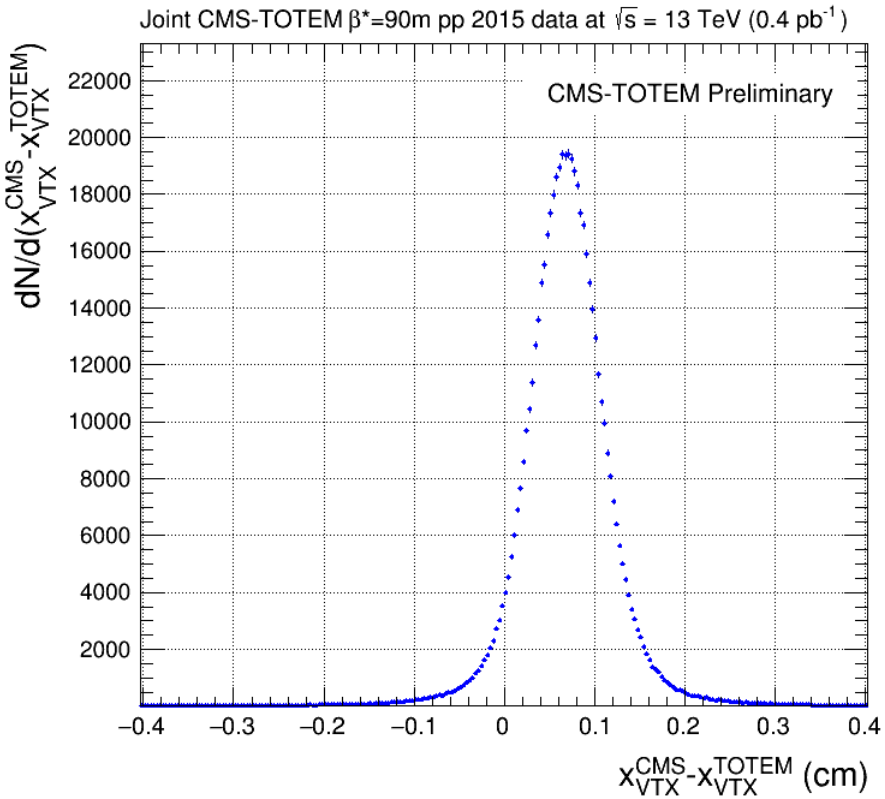
Left: the x position of the event vertex for pp->pp$\pi^+\pi^-$ events reconstructed from an extrapolation of the proton tracks measured in the right (z>0) vs left (z<0) TOTEM Roman Pot.

Right: The CMS vs TOTEM measurement of the x position of the event vertex for pp->pp$\pi^+\pi^-$ events. The CMS value is measured in the CMS reference frame, while the TOTEM value is measured in the LHC reference frame.

The β*=90m optics has parallel-to-point focusing for the y plane –
the RP measurement in y has no sensitivity on the vertex (only on the scattering angle).

Future prospects: Joint CMS-TOTEM run @13 TeV





Requirements of the vertex compatibility $|x_{VTX}^{p\ right} - x_{VTX}^{p\ left}| < 2\sigma^{TOTEM}_{dxVTX}$ and $|x_{VTX}^{CMS} - x_{VTX}^{TOTEM} - x_0| < 2\sigma_{dxVTX}$ are applied to reject background and select events of central exclusive production, $pp \rightarrow ppX$ with $X=\pi^+\pi^-$, K^+K^-, $\pi^+\pi^-\pi^+\pi^-$, $K^+K^-K^+K^-$, … .