Photon-photon measurements in CMS

Ruchi Chudasama

On behalf of the CMS collaboration

Photon 2017: International Conference on the Structure and the Interaction of the Photon
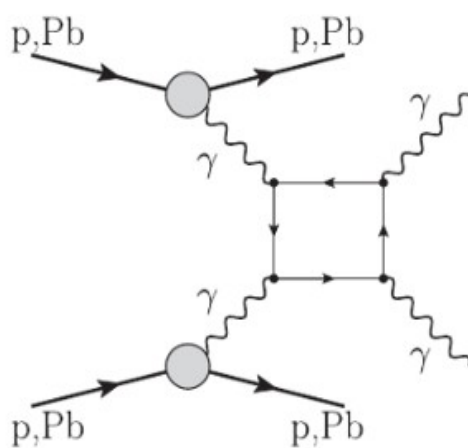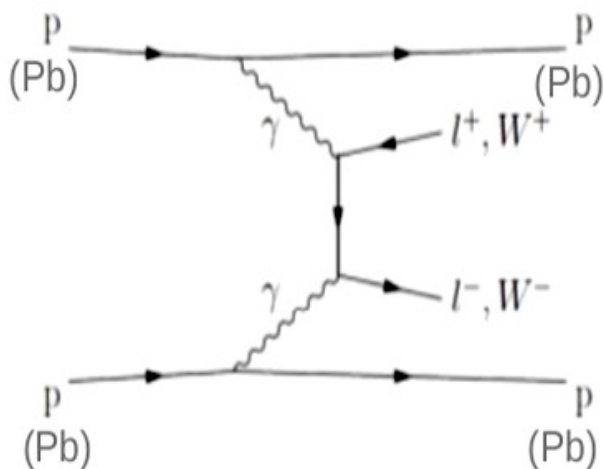
Outline

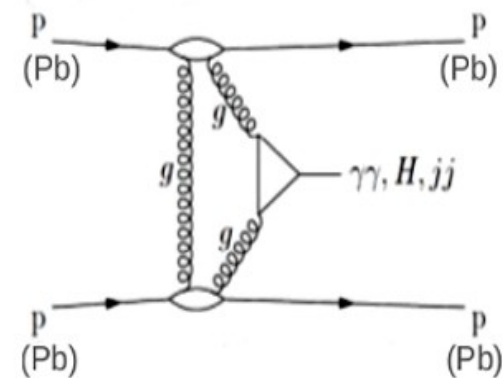➜ Photon photon interactions at the LHC CMS detector

➜ Exclusive $\gamma\gamma \to \mu^+\mu^-$ and exclusive $\gamma\gamma \to e^+e^-$ in pp collisions at 7 TeV

➜ Exclusive $\gamma\gamma \to W^+W^-$ in pp collisions at 7 and 8 TeV

➜ Exclusive diphoton production:
  ➜ Searches for central exclusive pp $\to$ gg $\to$ p $\gamma\gamma$ p at 7 TeV
  ➜ Searches for Light-by-light scattering in PbPb $\to$ Pb $\gamma\gamma$ Pb at 5.02 TeV

➜ Summary

Exclusive photon-photon interactions

➔ **Ultraperipheral (e.m.) collisions (UPCs)**
without hadronic overlap: $b_{min} > R_A + R_B$
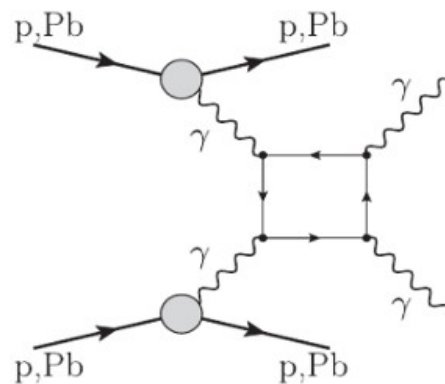
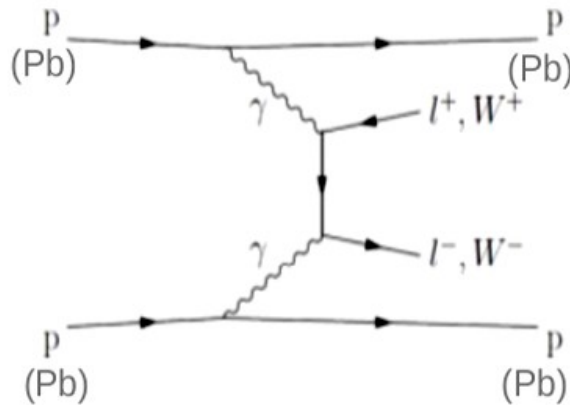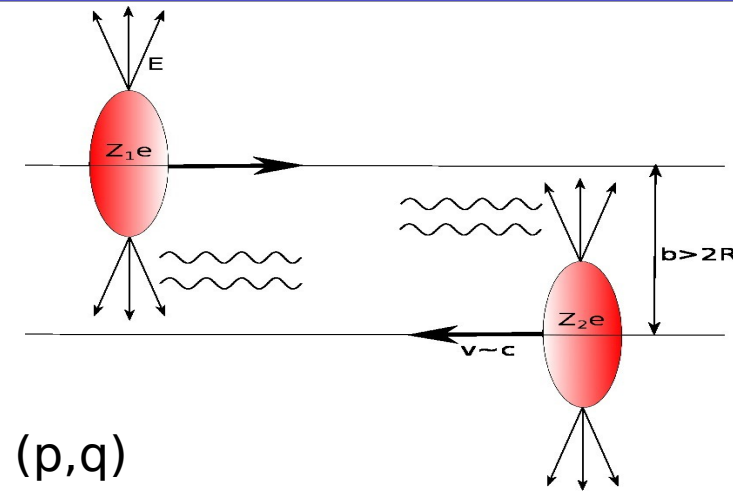➔ **Coherent e.m. field** of Z proton(s) =
Weizsäcker-Wiliams equivalent photon spectrum.

➔ Photon flux Z^2, cross-section enhanced by Z^4 in AA

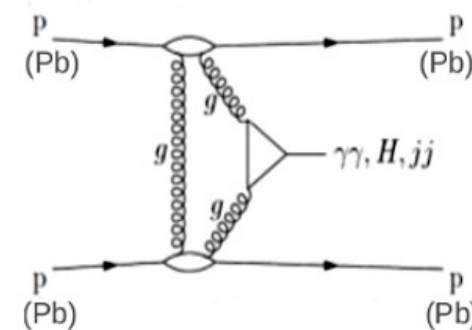➔ **Quasi-real** photons, coherent emission from all subcharges (p,q)
$Q \sim 1/R \sim$ **0.06 GeV** (Pb), **0.28 GeV** (p). Produced central system at ~rest (pT~0)

➔ Maximum γ energies (LHC): $\omega < \omega_{max} \approx \dfrac{\gamma}{R}$ ~ **80 GeV** (Pb), ~ **2.5 TeV** (p)

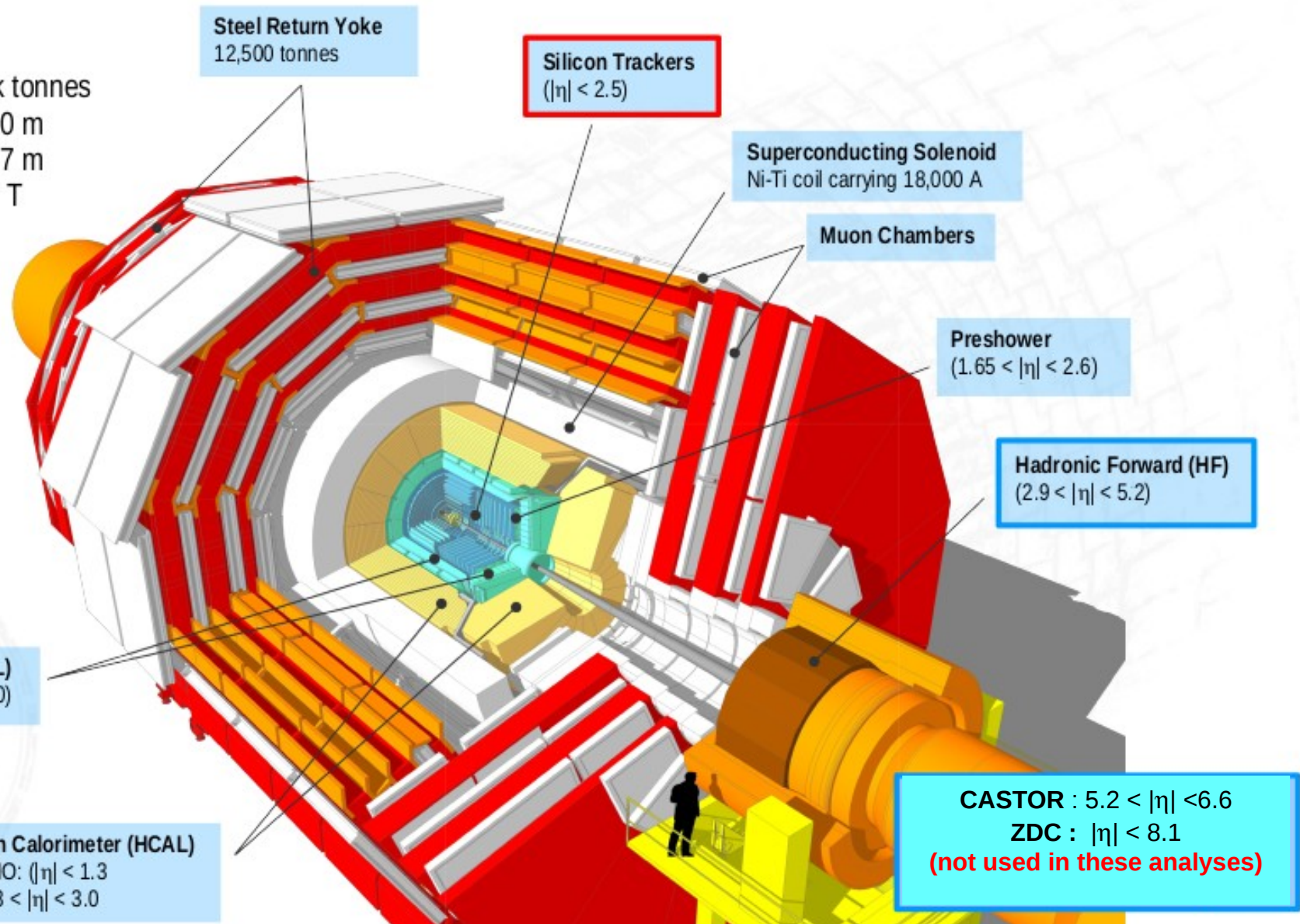(Central exclusive backgrounds):

➔ Exclusive production:
  ➔ No other particles in the final state.
  ➔ Intact protons (ions) in the final states.
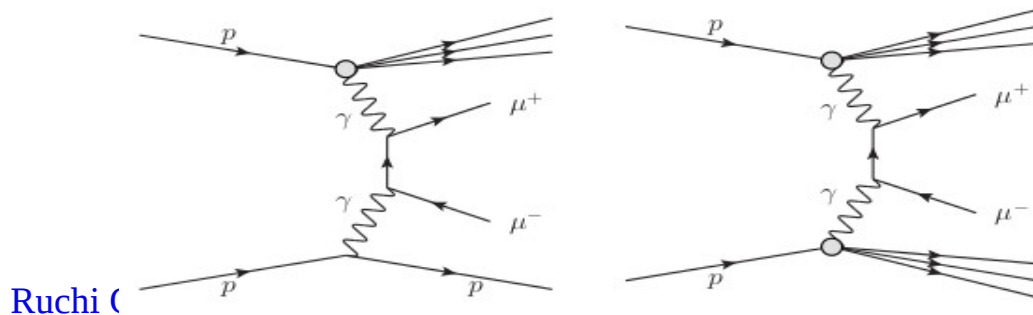   (Semi-exclusive: if proton(ion) p*(Pb*) dissociate).

The CMS Experiment

Total weight : 14k tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

Steel Return Yoke
12,500 tonnes

Silicon Trackers
($|\eta| < 2.5$)

Superconducting Solenoid
Ni-Ti coil carrying 18,000 A

Muon Chambers

Preshower
($1.65 < |\eta| < 2.6$)

Hadronic Forward (HF)
($2.9 < |\eta| < 5.2$)

Electromagnetic Calorimeter (ECAL)
EB ($|\eta| < 1.48$) + EE ($1.48 < |\eta| < 3.00$)

Hadron Calorimeter (HCAL)
HB + HO: ($|\eta| < 1.3$
HE: $1.3 < |\eta| < 3.0$

CASTOR : $5.2 < |\eta| < 6.6$
ZDC : $|\eta| < 8.1$
(not used in these analyses)

Exclusive γγ production of muon pairs in pp at 7 TeV

→ Exclusive $\mu^+\mu^-$ events compared to precision QED predictions (with and without proton dissociation)

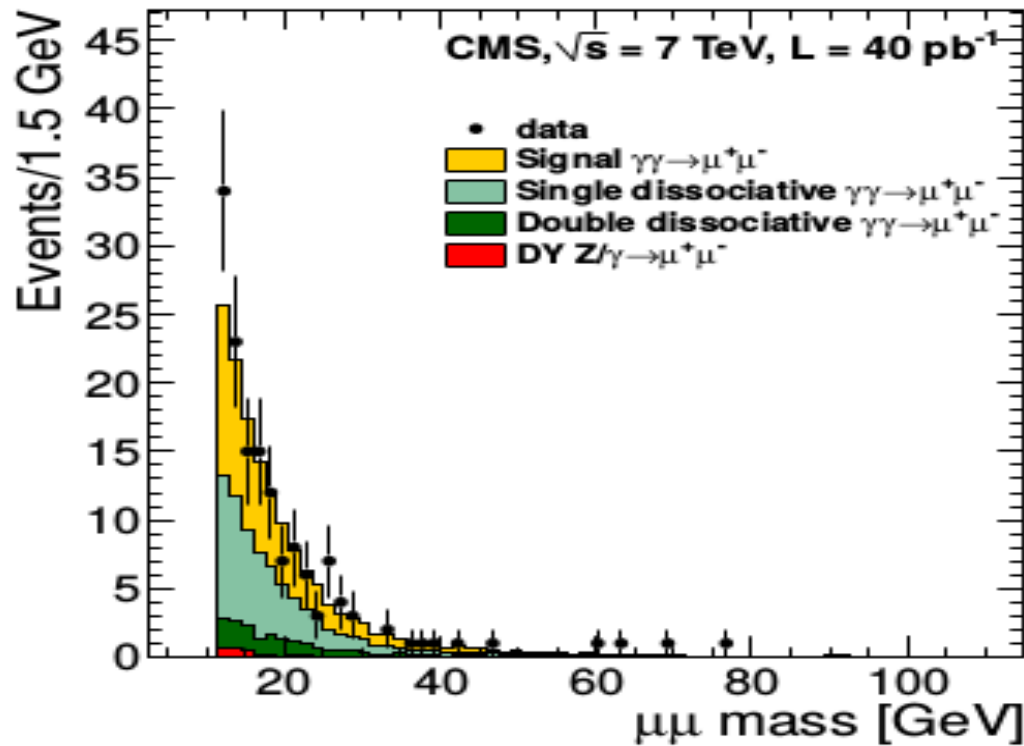→ Provides an excellent control sample for photon fluxes and cross-sections for other exclusive processes

→ 2011 pp collision data at 7 TeV with 40pb^{-1}

→ Two opposite-charge muons with p_T (μ) > 4 GeV & | η(μ)| < 2.1 from same primary vertex and nothing else in the event (exclusivity).

→ Muon pair invariant mass > 11.5 GeV, to reject $Y \to \mu^+\mu^-$

→ **Back-to-back:** $1-|\Delta\phi/\pi| < 0.1$ and $|\Delta p_T| < 1.0$ GeV

→ Contribution from proton-dissociation included

CMS, $\sqrt{s}$ = 7 TeV, L = 40 pb^{-1}

- data
- Signal $\gamma\gamma \to \mu^+\mu^-$
- Single dissociative $\gamma\gamma \to \mu^+\mu^-$
- Double dissociative $\gamma\gamma \to \mu^+\mu^-$
- DY Z/$\gamma \to \mu^+\mu^-$

JHEP 01 (2012) 052

Events/0.005

μμ $1-|\Delta\phi/\pi|$
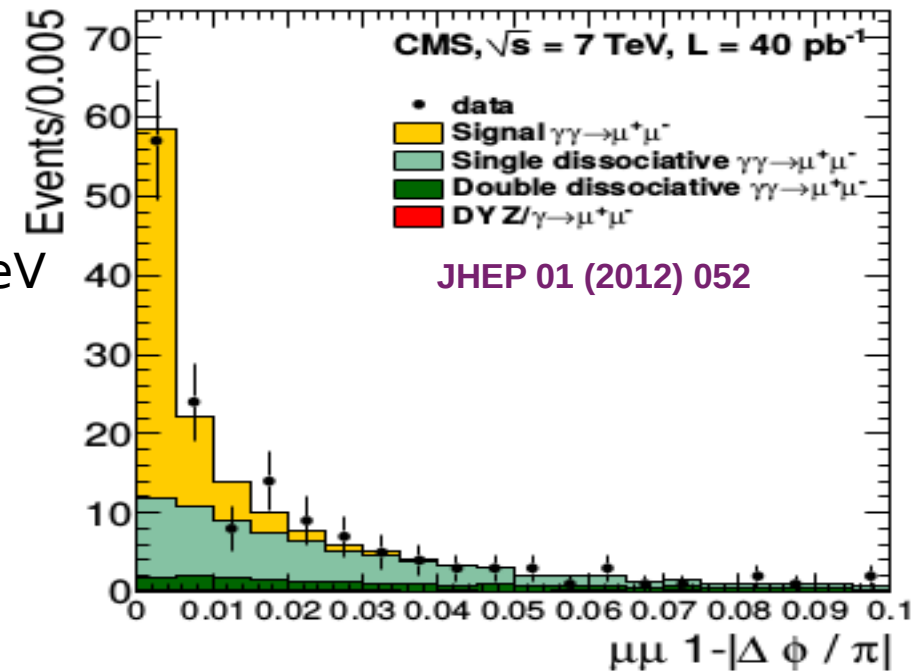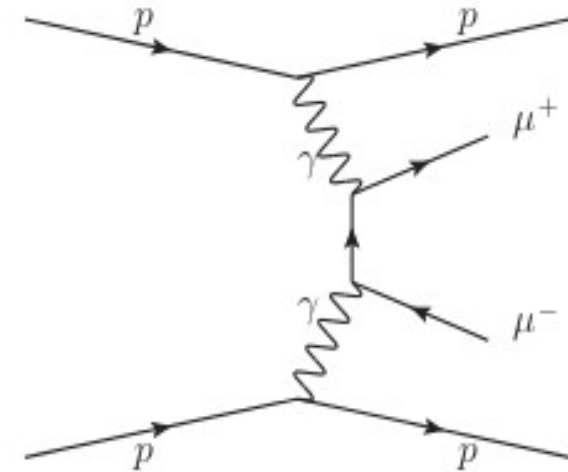
Exclusive $\gamma\gamma \to \mu^+\mu^-$ cross section at 7 TeV
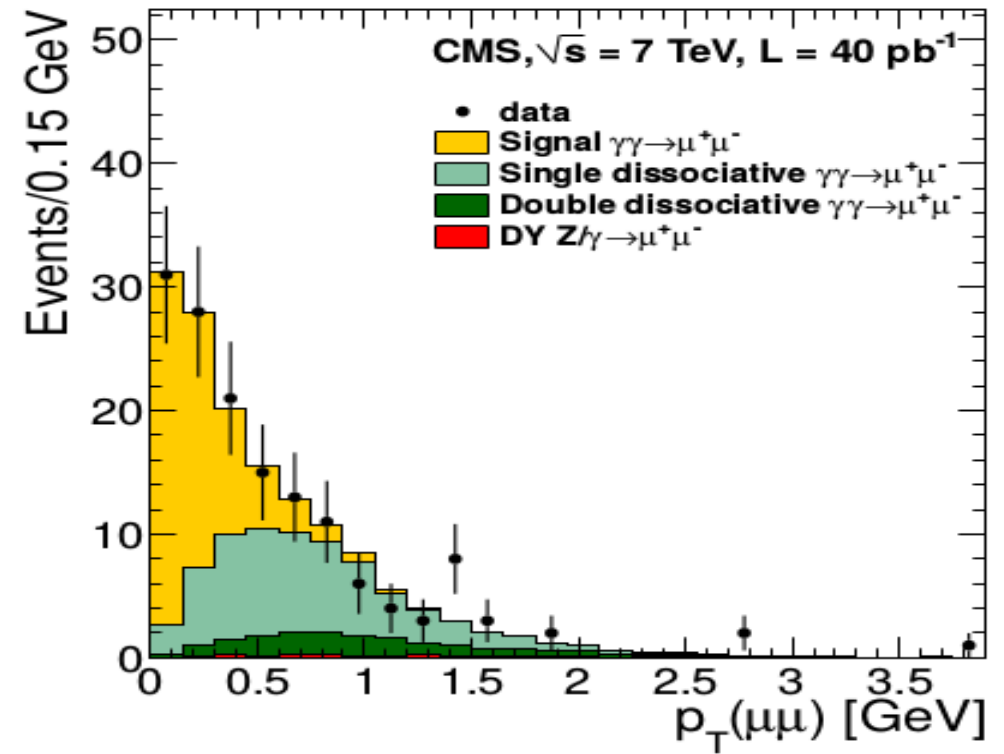
$$\sigma(pp \to p\mu^+\mu^-p) = 3.38^{+0.58}_{-0.55} \text{ (stat.)} \pm 0.16 \text{ (syst.)} \pm 0.14 \text{ (lumi.) pb}$$

Data-theory signal ratio = $0.83^{+0.14}_{-0.13}$ (stat.) ± 0.04 (syst.) ± 0.03 (lumi.)

The measured cross-section is consistent with the
predicted QED value (LPAIR event generator)

# Exclusive $\gamma\gamma \to e^+e^-$ production at 7 TeV

➔ Exclusive e^+e^- events compared to precision QED predictions (with and without proton dissociation)

➔ Provides an excellent control sample for photon fluxes and cross-sections for other exclusive processes

➔ 2011 pp collision data at 7 TeV with 36pb^{-1}

➔ Electron/positron with E_T > 5.5 GeV & $|\eta|$ < 2.5,

➔ Invariant mass > 11 GeV, to reject $Y \to e^+e^-$

➔ **Exclusivity :**
  ➔ No additional tracks in the tracker
  ➔ No additional towers above noise threshold in the calorimeters.

➔ MC predictions include elastic processes and contribution from proton dissociation
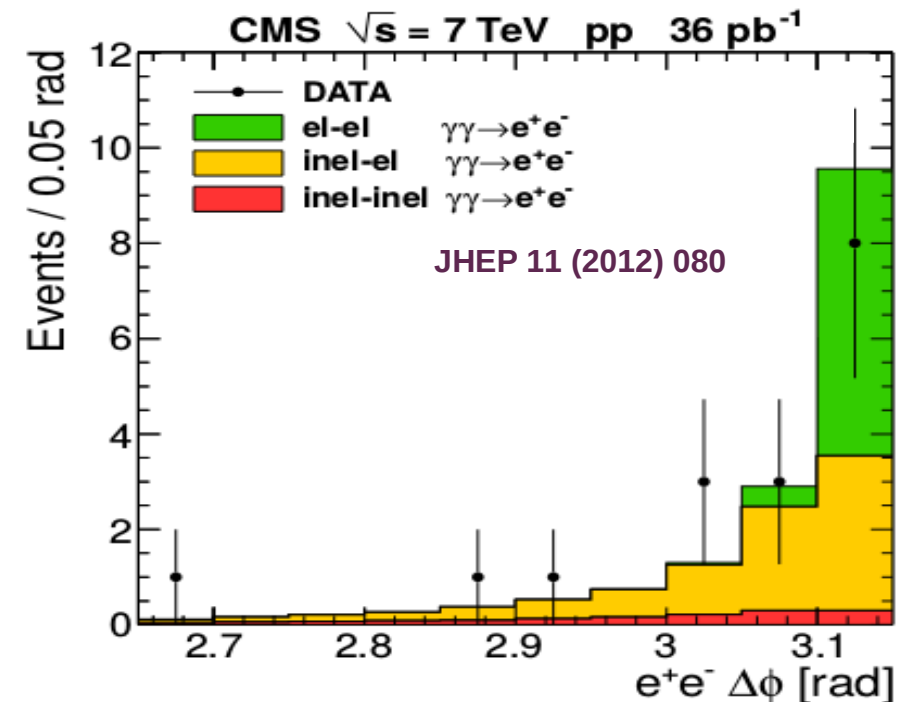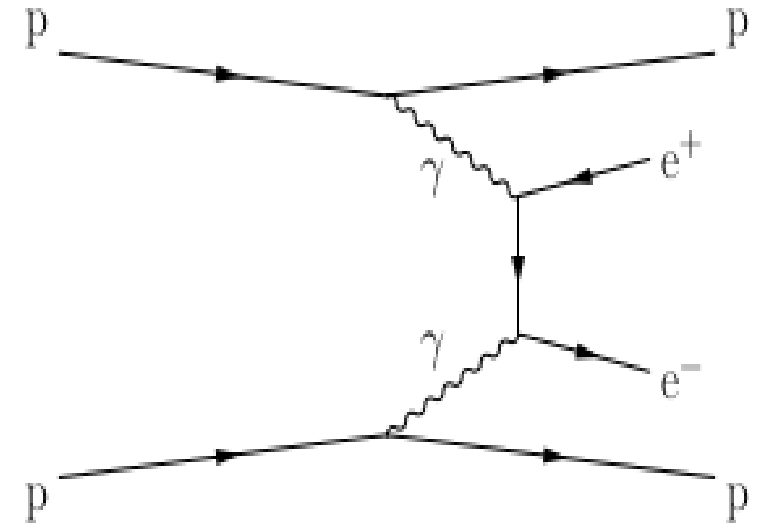
JHEP 11 (2012) 080

Observation of exclusive $\gamma\gamma \to e^+e^-$ at 7 TeV
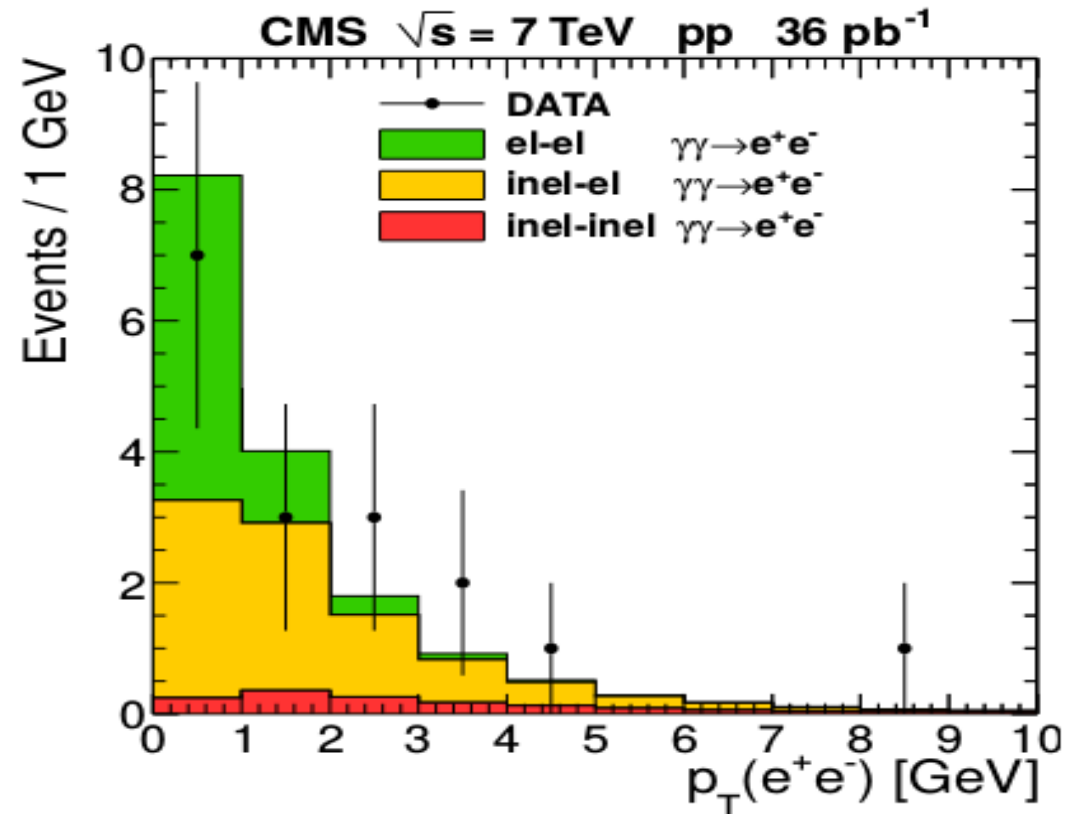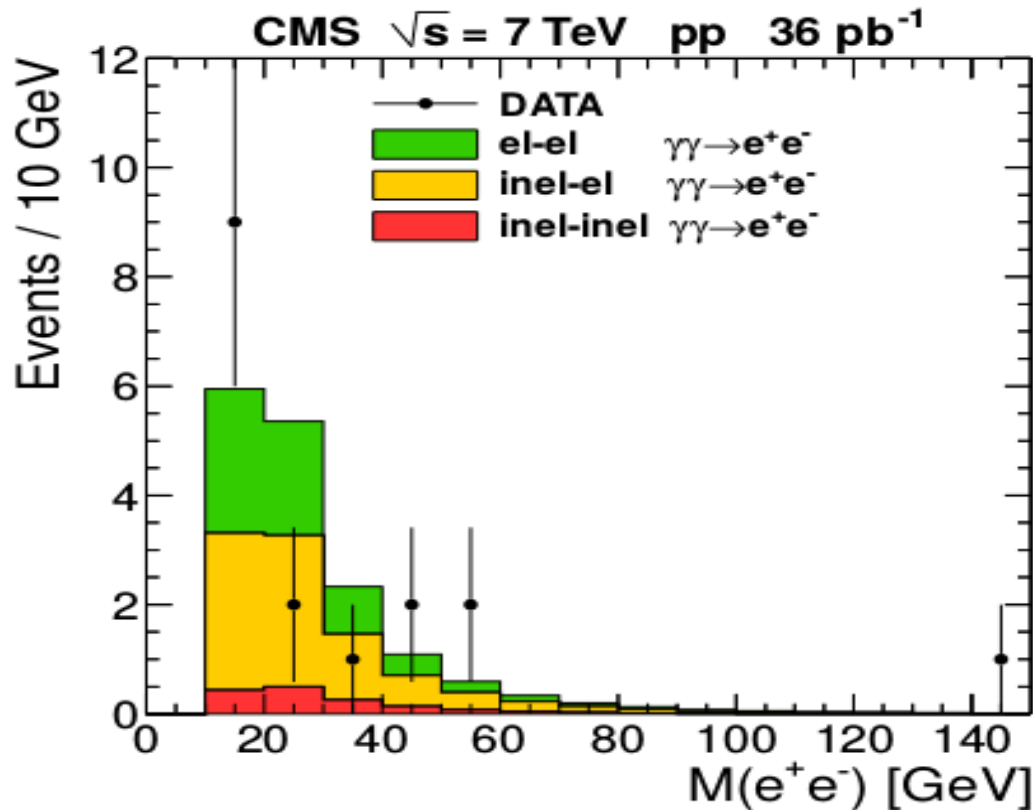
→ 17 exclusive or semi-exclusive e^+e^- candidates are observed, with an expected background of 0.85 ± 0.28 (stat.) events

→ Measurement is consistent with the theoretical QED prediction for the combined elastic and inelastic (=semiexclusive) events: 16.3 ± 1.3 (syst.) pairs.
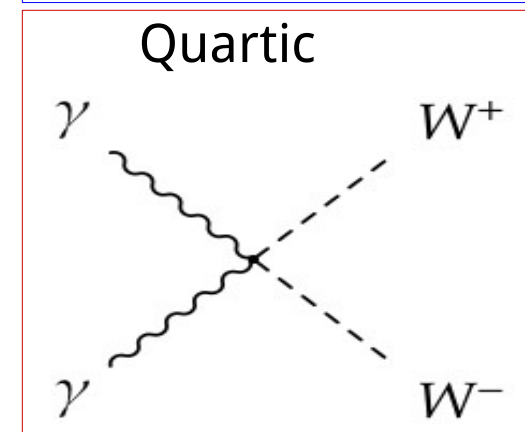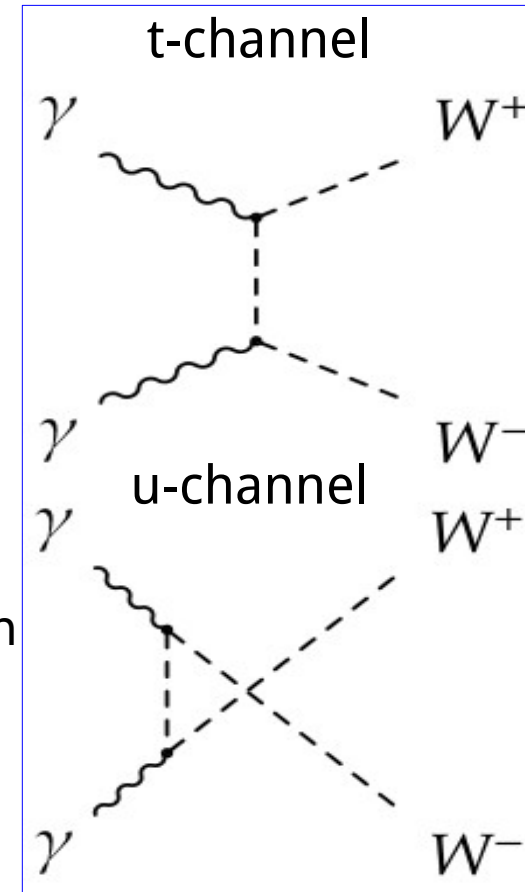
Exclusive $\gamma\gamma \to W^+ W^-$ production

→ The electro-weak sector of Standard Model predicts QGC

→ Any deviation from SM expectations can reveal a sign of new physics

→ The exclusive production of W pairs is sensitive to anomalous quartic gauge couplings (aQGC)

→ Objective: Measure SM cross section and look for aQGC.

→ aQGC are introduced via effective dimension-6 operator 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

t-channel

u-channel

Quartic

Exclusive $\gamma\gamma \to W^+ W^-$ in CMS

➔ Exclusive production of W pairs

$$pp \to p^{(*)} W^+ W^- p^{(*)} \qquad \text{(with } W \to l^{\pm}\nu\text{)}$$

$p^{(*)}$: Exclusive + Semiexcl. 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
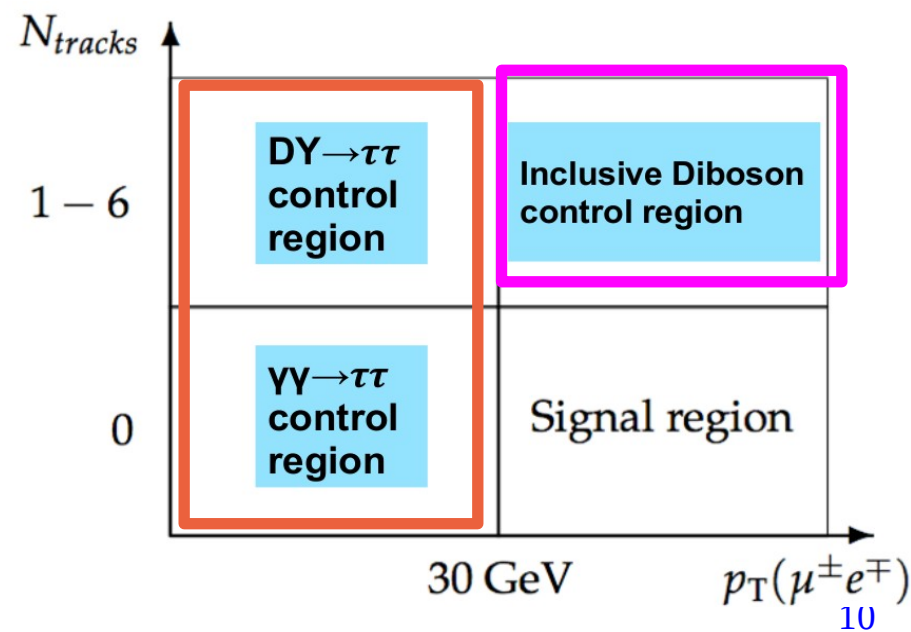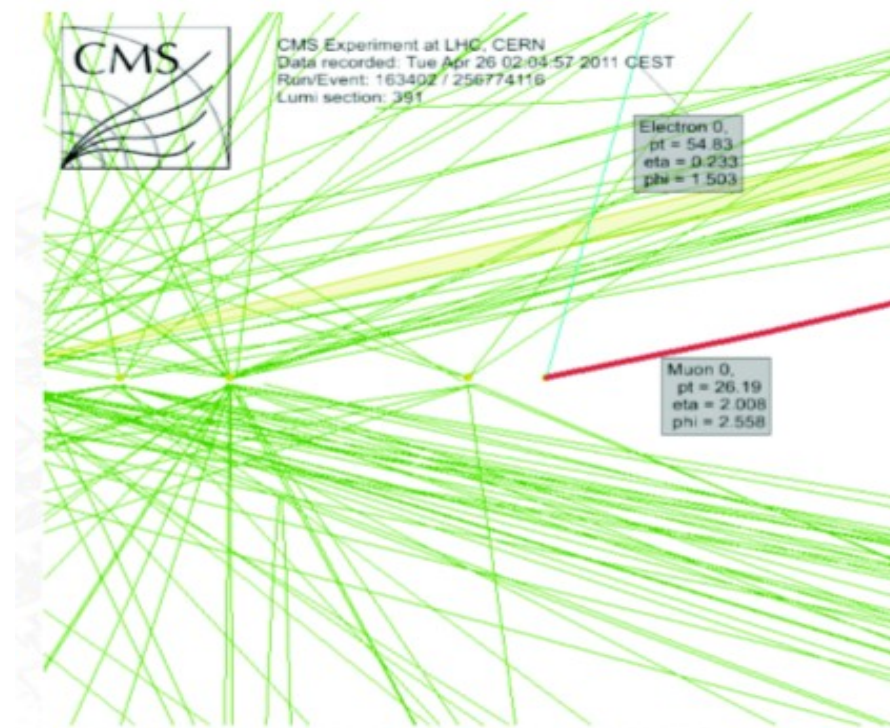 **to remove inclusive background**

- Invariant mass (eμ) > 20 GeV
  to get rid of any low mass resonances

- p_T (eμ) > 30 GeV
  to suppress DY and $\gamma\gamma \to \tau^+\tau^-$

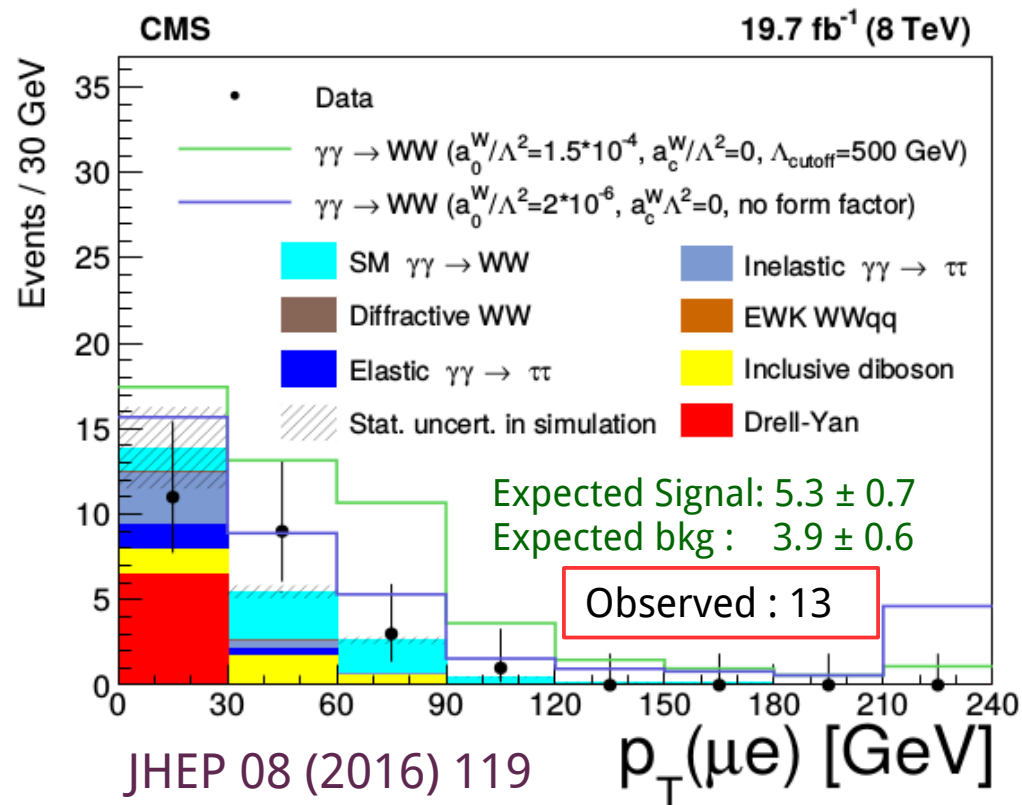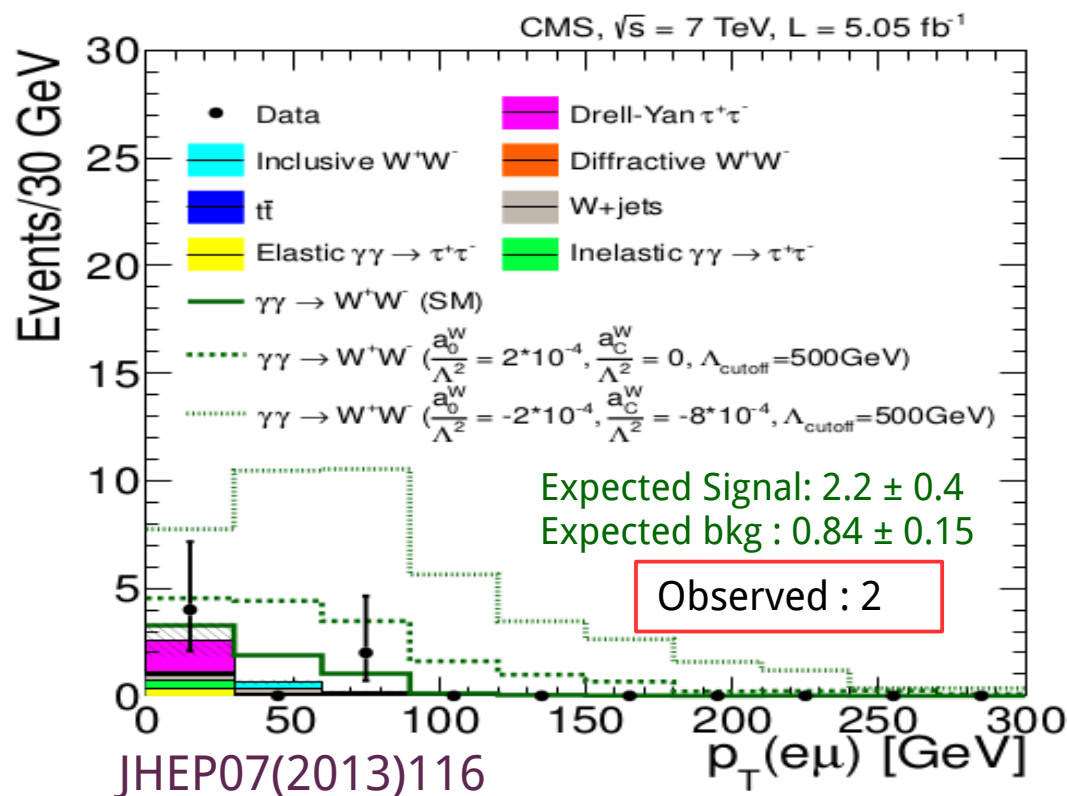➔ Proton dissociation from exclusive $\mu\mu$ sample

➔ aQGC searches region: p_T (eμ) > 100 GeV

N_{tracks}

$1-6$ | DY$\to\tau\tau$ control region | Inclusive Diboson control region

0 | $\gamma\gamma\to\tau\tau$ control region | Signal region

30 GeV | $p_T(\mu^{\pm}e^{\mp})$

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

Expected Signal: 2.2 ± 0.4
Expected bkg : 0.84 ± 0.15

Observed : 2

JHEP07(2013)116

Expected Signal: 5.3 ± 0.7
Expected bkg : 3.9 ± 0.6

Observed : 13

JHEP 08 (2016) 119

Cross section times branching fraction

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

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

SM Prediction : 4.0 ± 0.7 fb

SM Prediction : 6.2 ± 0.5 fb

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

- Used shape of p_T (eμ) distribution to search for sign of anomalous quartic gauge couplings. (high-p_T curves in previous slide)

- 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 existing so far on aQGC, two orders of magnitude more stringent than LEP.

JHEP 08 (2016) 119

CMS 5.1 fb⁻¹ (7 TeV) + 19.7 fb⁻¹ (8 TeV)

$\Lambda_{cutoff} = 500$ GeV

y-axis: a_C^W/Λ^2 [GeV⁻²]
x-axis: a_0^W/Λ^2 [GeV⁻²]

- Standard model
- 7 TeV
- 8 TeV
- 8 + 7 TeV
- 8 + 7 TeV 1-D limit
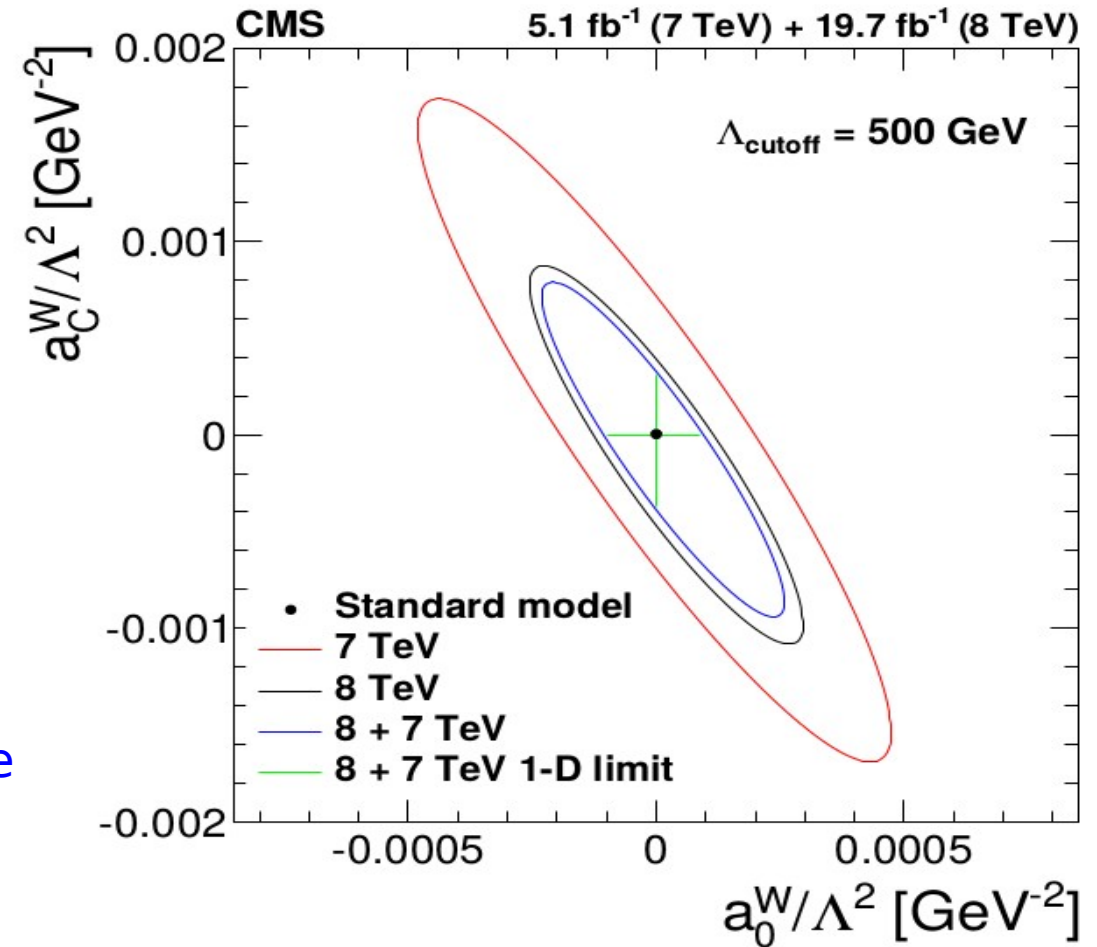
| Dimension-6 AQGC parameter	7 TeV ($\times 10^{-4}$ GeV^{-2})	8 TeV ($\times 10^{-4}$ GeV^{-2})	7+8 TeV ($\times 10^{-4}$ GeV^{-2})
a_0^W/Λ^2 ($\Lambda_{cutoff} = 500$ GeV)	$-1.5 < a_0^W/\Lambda^2 < 1.5$	$-1.1 < a_0^W/\Lambda^2 < 1.0$	$-0.9 < a_0^W/\Lambda^2 < 0.9$
a_C^W/Λ^2 ($\Lambda_{cutoff} = 500$ GeV)	$-5 < a_C^W/\Lambda^2 < 5$	$-4.2 < a_C^W/\Lambda^2 < 3.4$	$-3.6 < a_C^W/\Lambda^2 < 3.0$
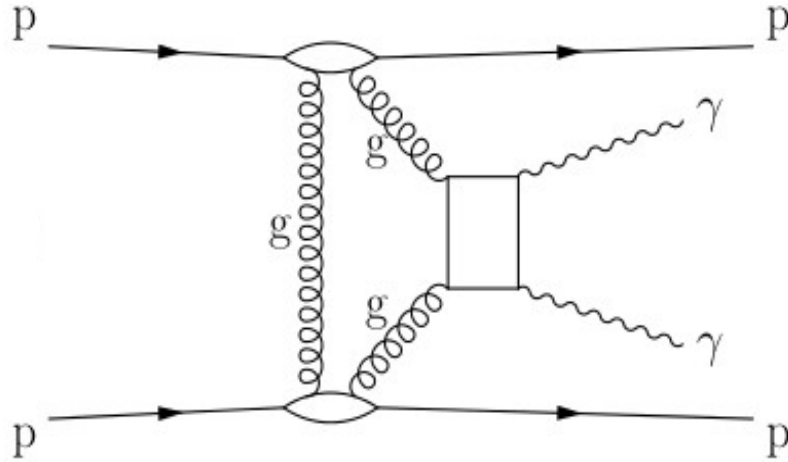
➜ Background for
Light-by-light scattering
searches (next slide):
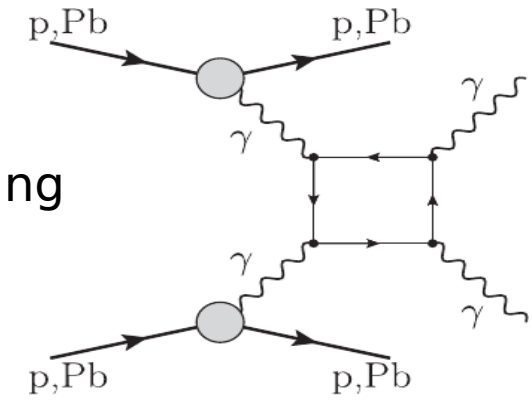
JHEP 11 (2012) 080

➜ Exclusive diphoton production is closely
related to exclusive Higgs boson production.

➜ 2011 pp collision data at 7 TeV with 36 pb^{-1}

➜ Two back-to- back photons with $E_T > 5.5$ GeV
& $|\eta| < 2.5$ and nothing else in the detector

➜ No diphoton events satisfy the selection criteria
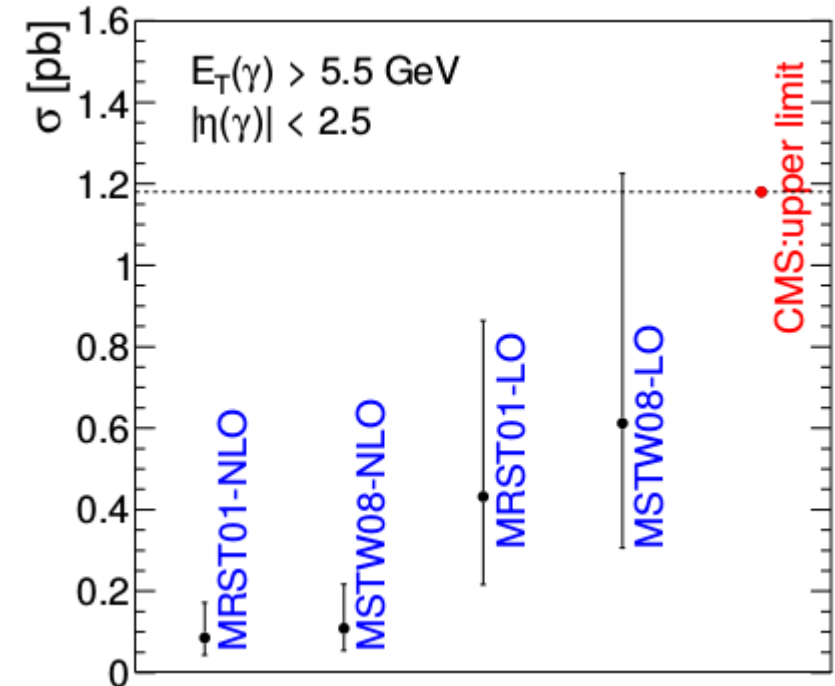
An upper limit on the cross section is set at 1.18 pb at 95% confidence level

(in agreement with NLO theoretical predictions: Durham model)

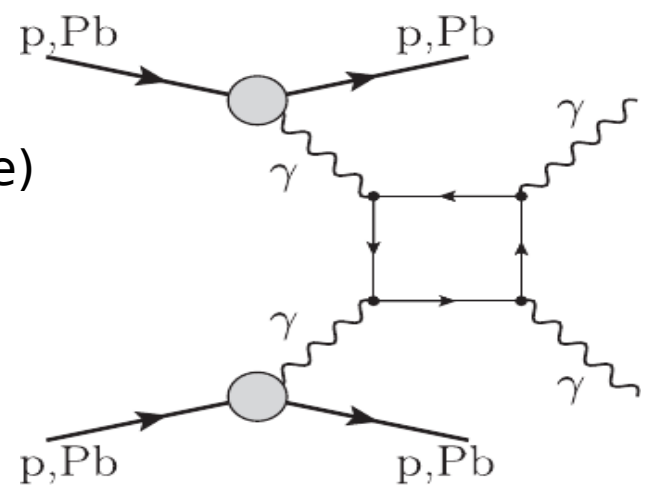# Light-by-light scattering in PbPb collisions

→ Elastic light-by-light (LbyL) scattering, fundamental quantum-mechanical process with a tiny cross section, experimentally unobserved so far (recent ATLAS 4σ evidence)

→ Study of $\gamma\gamma \to \gamma\gamma$ at high invariant mass: Neat channel to study anomalous gauge couplings, search for virtual contributions from BSM charged particles (SUSY, monopoles, axions,...)

→ **LbyL** signal events generated with MADGRAPH 5: **$N_{\gamma\gamma-\gamma\gamma}$ ~ 70** expected in PbPb at 5.5 TeV (1 nb⁻¹)
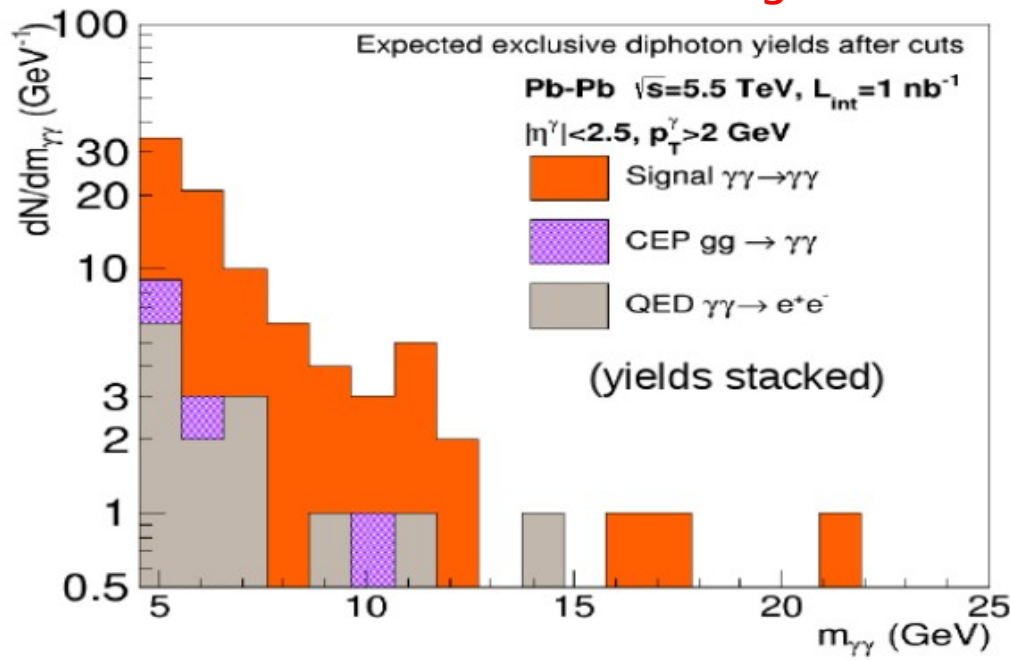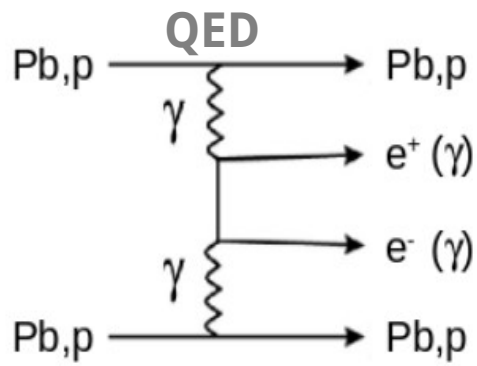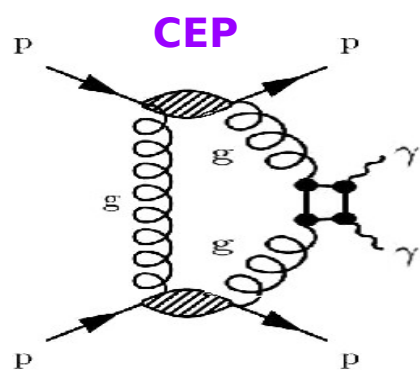
→ **Central exclusive production** generated with SUPERCHIC: N $_{CEP-gg}$ ~ 6 counts expec.

→ QED generated with STARLIGHT, $N_{QED\ ee}$ ~ 15 expected after all cuts

[D.d'Enterria, G.G. daSilveira PRL111(2013)080405]

Light-by-light signal is clearly observable over the background

Expected exclusive diphoton yields after cuts

Pb-Pb √s=5.5 TeV, L$_{int}$=1 nb⁻¹

$|\eta^\gamma|$<2.5, p_T^γ>2 GeV

Signal $\gamma\gamma \to \gamma\gamma$
CEP gg $\to \gamma\gamma$
QED $\gamma\gamma \to e^+e^-$

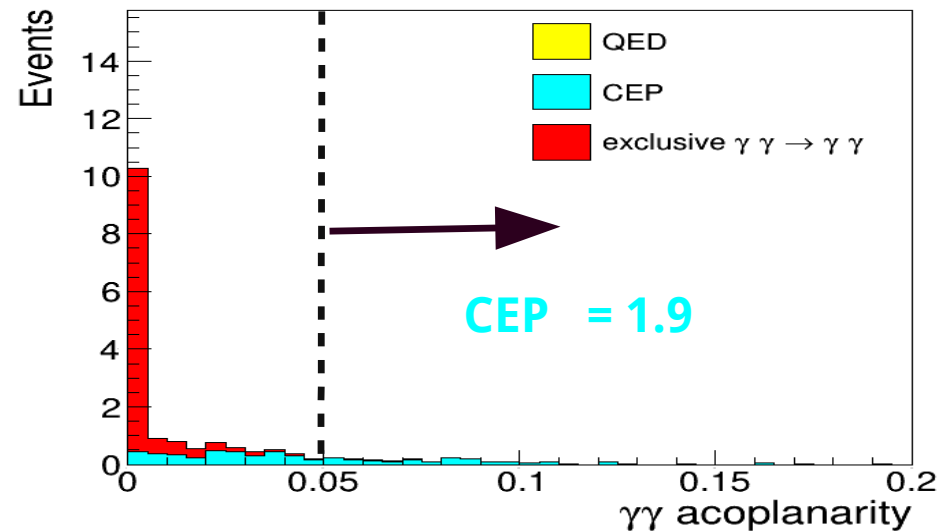(yields stacked)
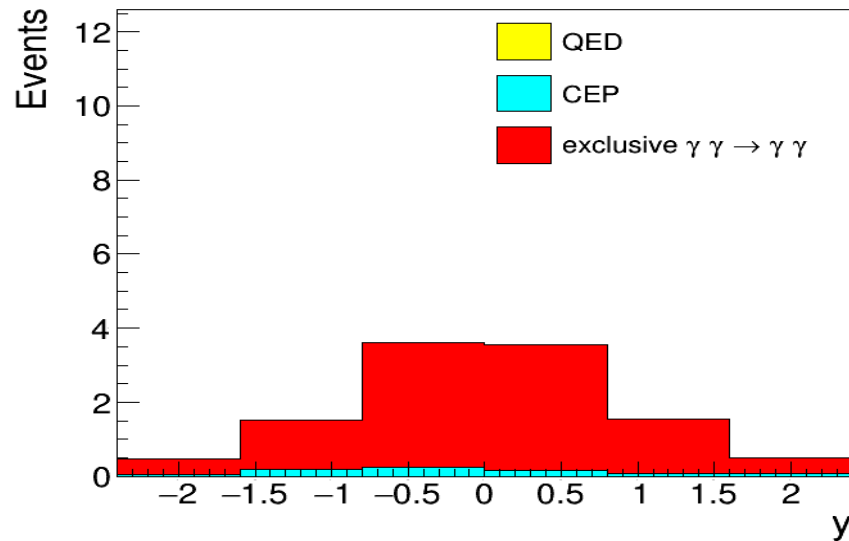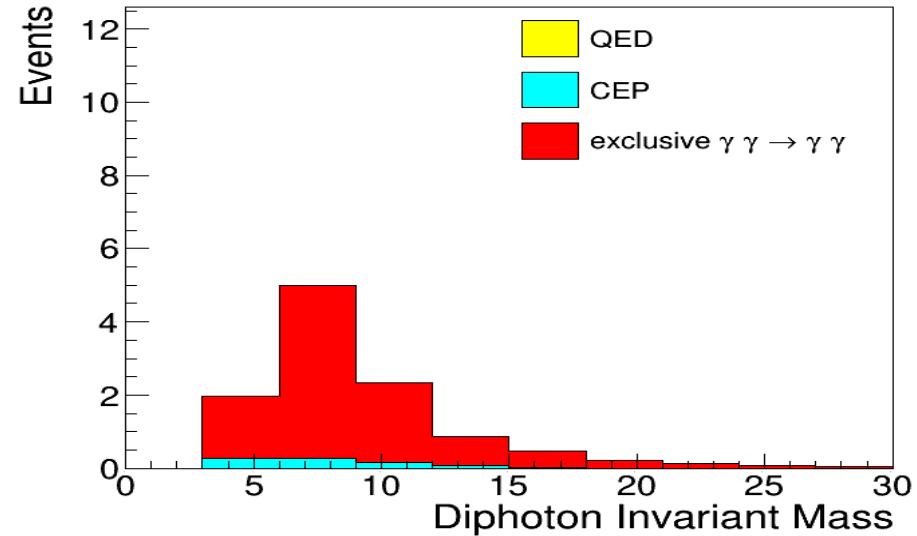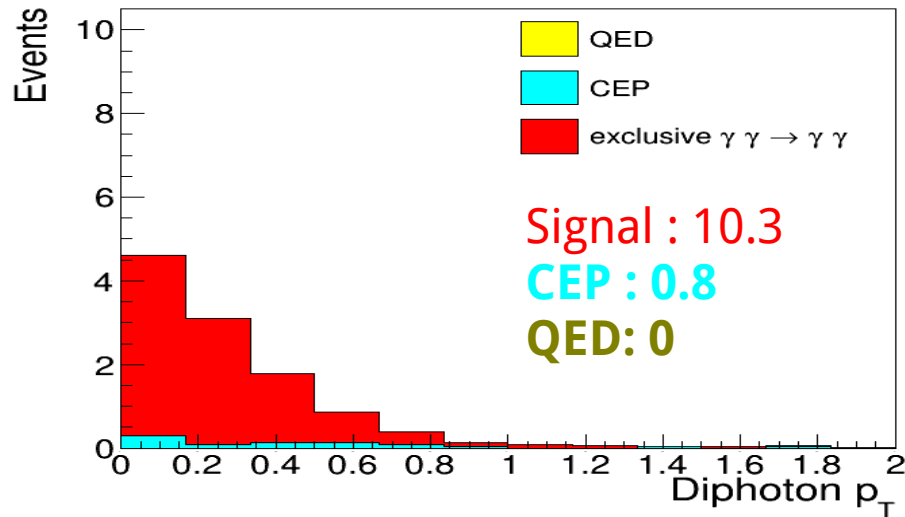
Search for light-by-light scattering in PbPb at 5.02 TeV

- 2015 PbPb data with integrated luminosity: 380 nb^{-1}

- Light by light scattering event signature: Exactly two photons back-to-back within $|\eta|<2.5$ and nothing else in the detector (tracker $|\eta|<2.5$, calorimeters $|\eta|<5$).

- Selection of two exclusive photons events:
  → Exclusive 2 photon reconstructed
  → Charged particle veto: No tracks above $p_T > 0.1$ GeV in tracker
  → Neutral particle veto: No activity above noise in ECAL, HCAL, HF

- Removal of backgrounds:
  → QED: No hit in the pixel detector
  → CEP: Very low acoplanarity($\gamma\gamma$) < 0.01, and $p_T(\gamma\gamma)$ < 2 GeV

  (Badly known CEP x-section in PbPb: we normalized it with data with aco>0.05)

Light-by-light scattering candidate event

CMS Experiment at LHC, CERN
Data recorded: Thu Dec 10 10:49:05 2015 IST
Run/Event: 263614 / 53125647
Lumi section: 491

ECAL
HCAL

Work in Progress

HCAL/ECAL "grass" below noise threshold

Ruchi Chudasama (BARC, Mumbai)

Event selection: $p_T(\gamma) > 2$ GeV, $p_T(\gamma\gamma) < 2$ GeV, aco < 0.01
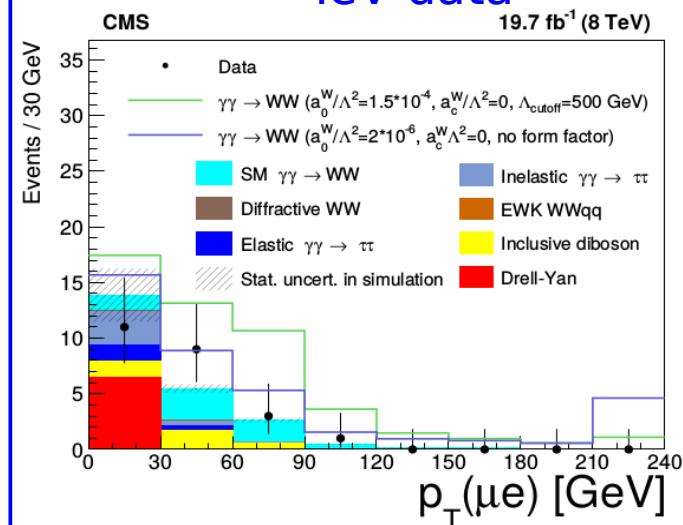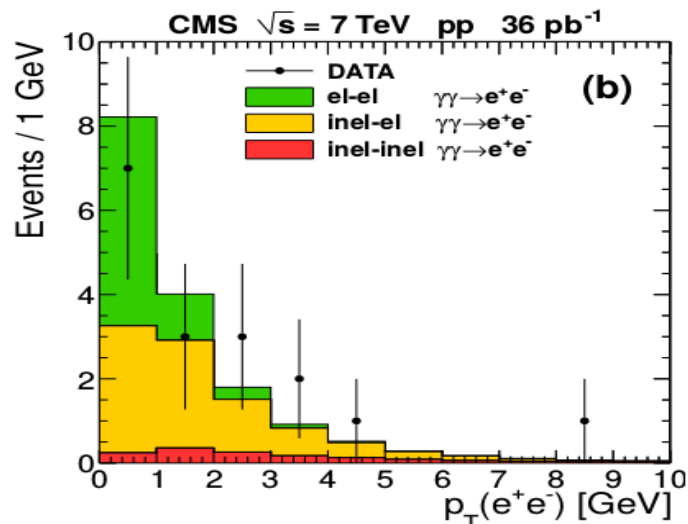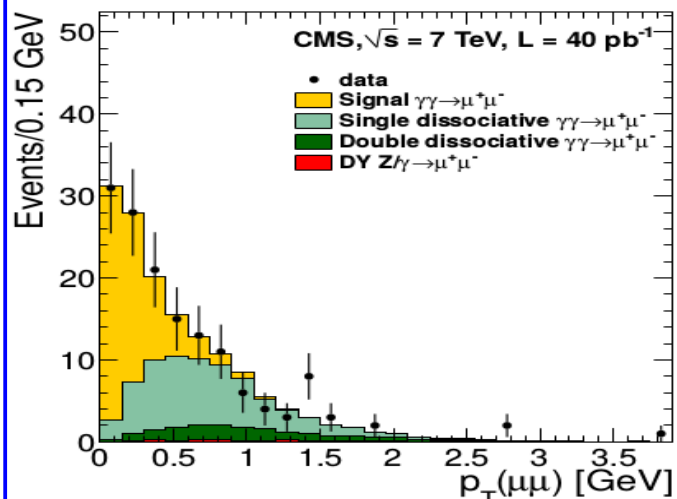

Signal : 10.3
CEP : 0.8
QED: 0

CEP = 1.9

With current luminosity, we expect ~10 exclusive photon pairs, on top of small QED+CEP backgrounds. Data analysis ongoing.

Summary

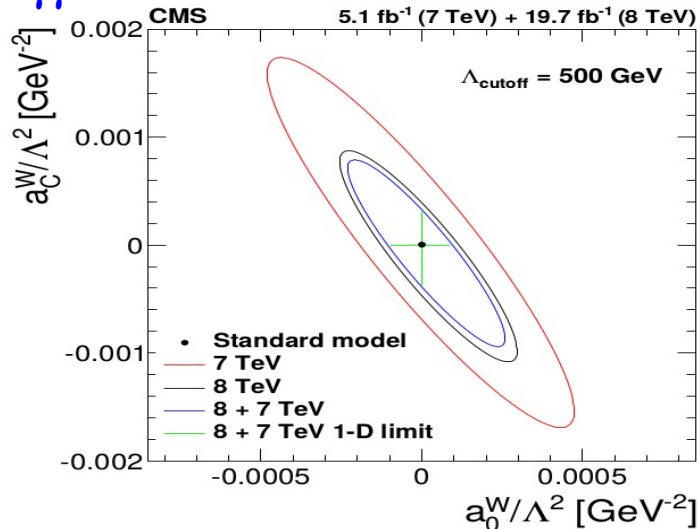## Exclusive $\gamma\gamma \to \mu^+\mu^-$ and $\gamma\gamma \to e^+e^-$ measurement consistent with QED predictions

3.4σ evidence of exclusive $\gamma\gamma \to W^+W^-$ for combined 7 & 8 TeV data

Most stringent limit on aQGC $\gamma\gamma \to W^+W^-$

Light-by-light scattering experimentally observable in PbPb at 5.02 TeV (work in progress)

Ruchi Chudasama (BARC, Mumbai)