γ-Pb and $\gamma-\gamma$ collisions in CMS

Patricia Rebello Teles

CBPF (Rio de Janeiro - Brazil)-CERN

on behalf of CMS Collaboration

PHOTON 2015

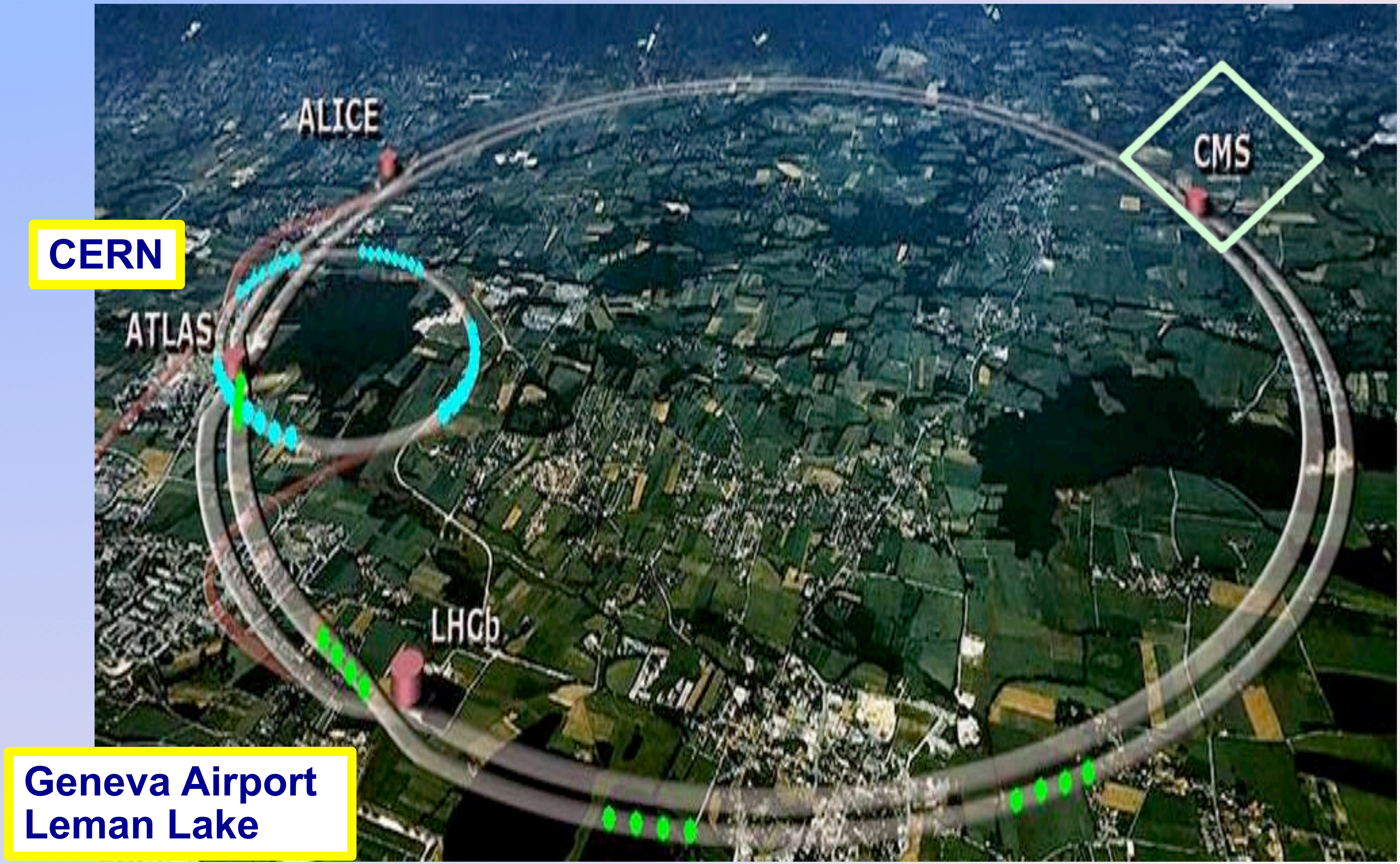
BINP Novosibirsk

15^{th} – 19^{th} June 2015

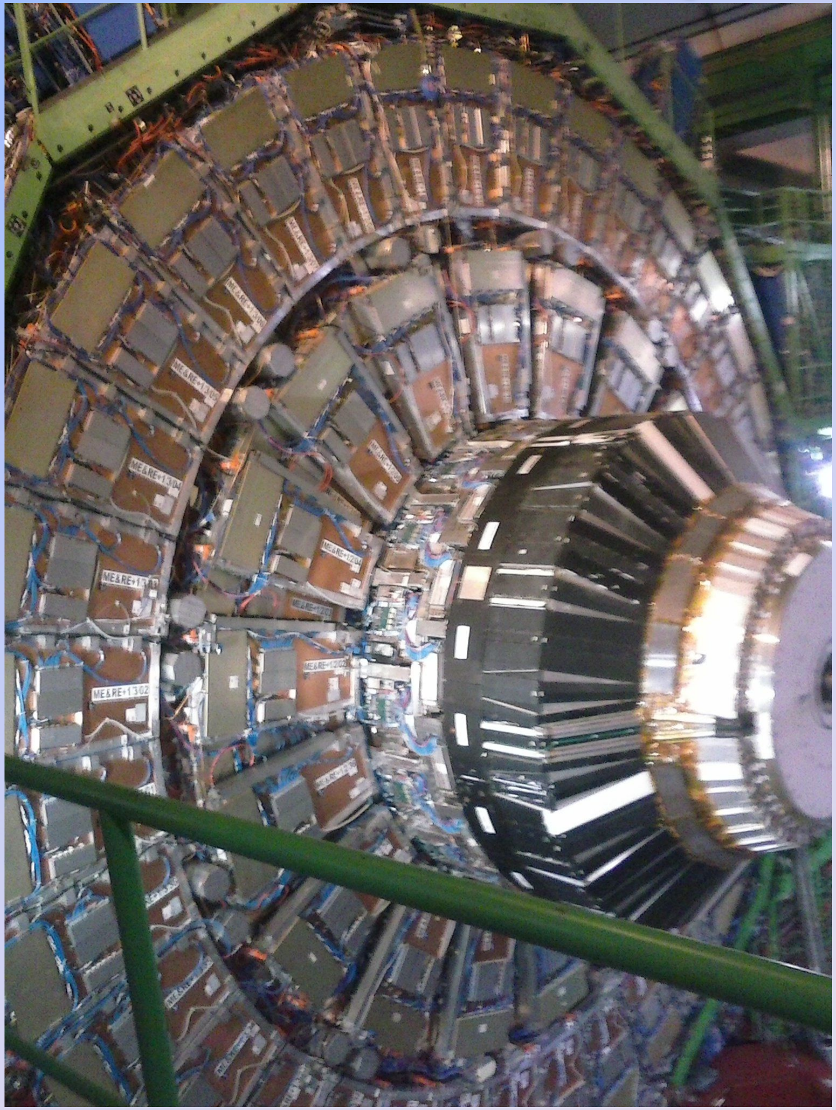
Outline

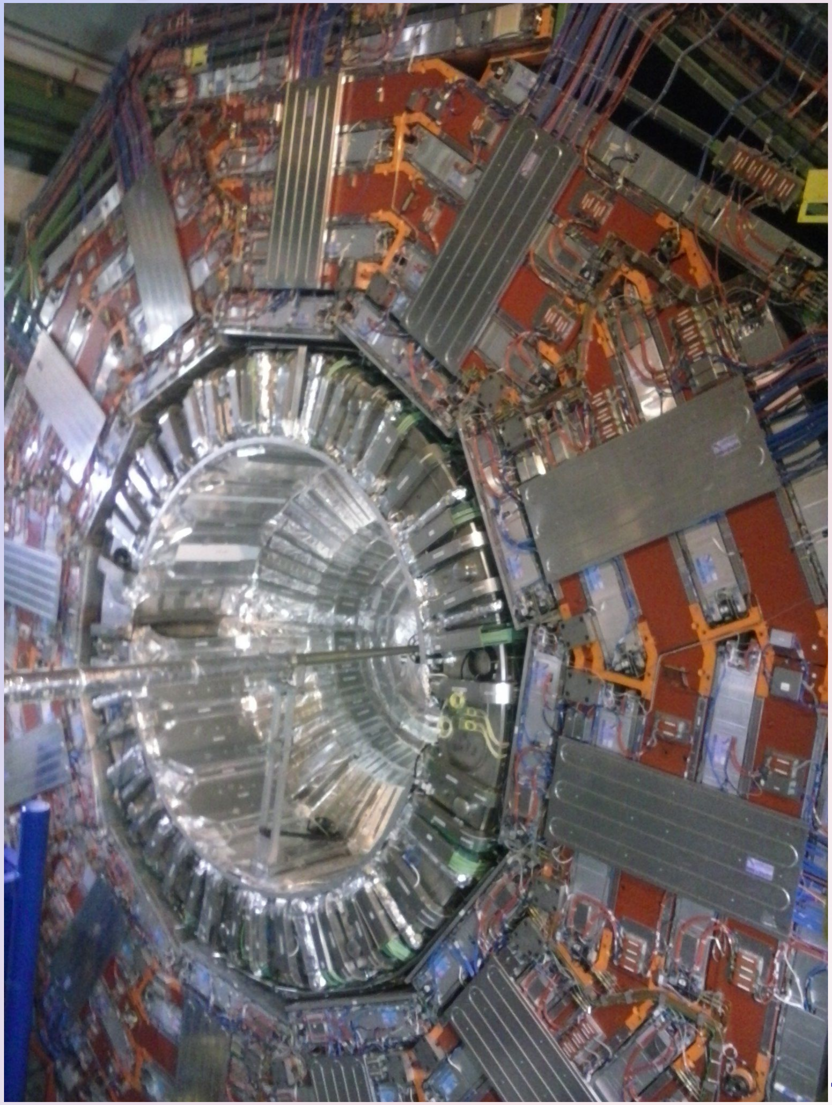
- ✧ **Apparatus**:
  - ❖ **LHC and CMS detectors**;
- ✧ **Photon-Hadron**:
  - ❖ **“Photoproduction of the coherent J/ψ in ultra-peripheral PbPb collisions at 2.76 TeV”** (CMS-HIN-12-009)
- ✧ **Photon-Photon**:
  - ❖ **“Evidence for exclusive $\gamma\gamma \rightarrow W^{+}W^{-}$ production in pp collisions at 8 TeV”** (CMS-FSQ-13-008)
- ✧ **Summary**

Large Hadron Collider @ CERN

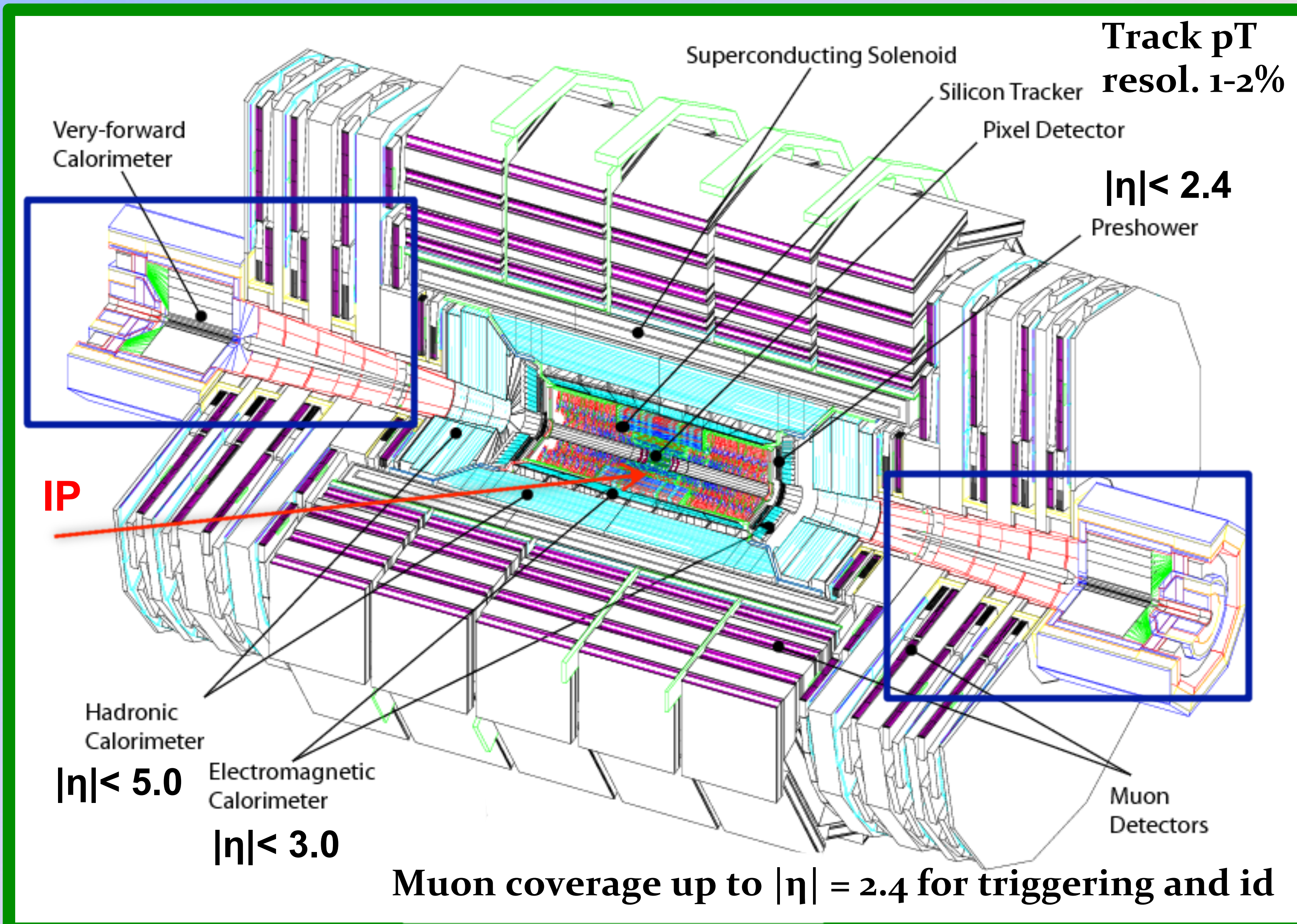


The Compact Muon Solenoid (central)





The CMS central & forward detectors



Calorimeters coverage helping to ensure exclusivity

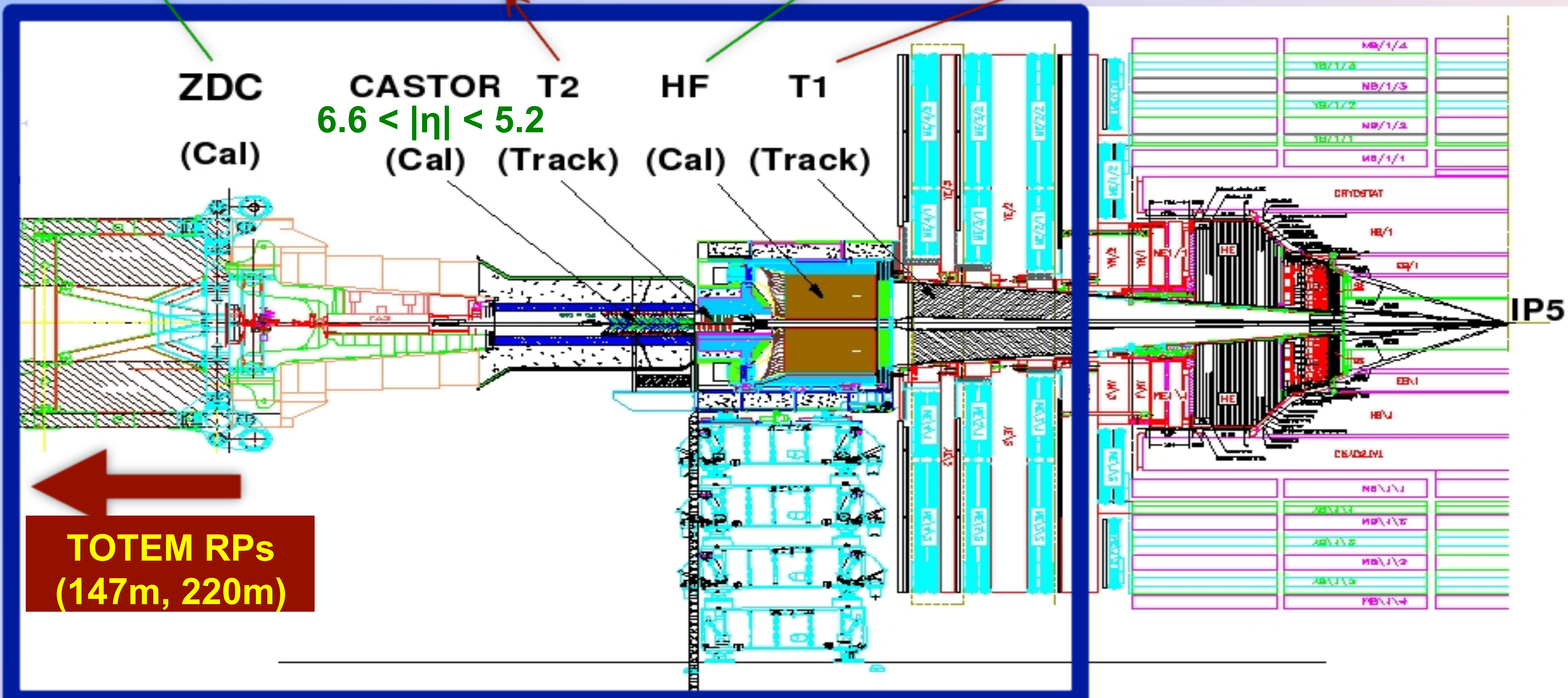
Forward Region

Zero Degree Calo
$|\eta|>8.4$

Totem (T2)
$5.2 < |\eta| < 6.5$

Hadronic Forward**
$3.0 < |\eta| < 5.0$

Totem (T1)
$3.1 < |\eta| < 4.7$



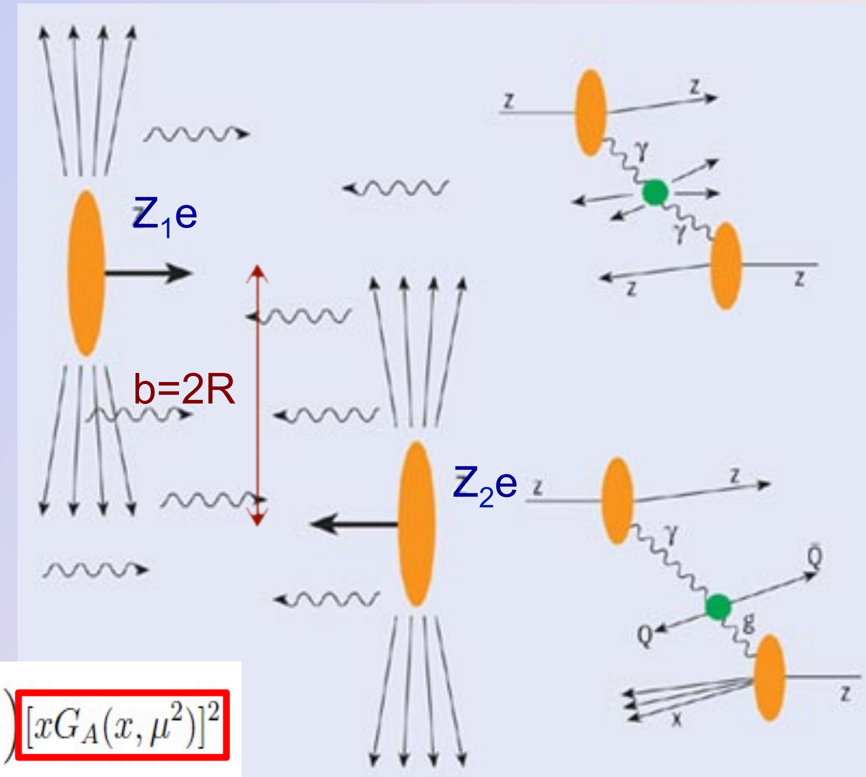
Beam Scintilator Counters (BSC) : $3.0 < |\eta| < 5.0$**
Forward Showers Counters (FSC) : $6.0 < |\eta| < 8.0$

Photon-Hadron @ CMS

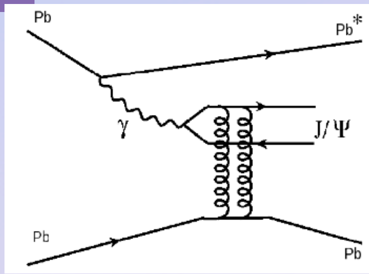
Photoproduction of the coherent J/ψ accompanied by the forward neutron emission in ultra-peripheral PbPb collisions (UPCs) at 2.76 TeV

CMS-PAS-HIN-12-009

- ✓ γN and γγ collisions are abundantly produced at the LHC.
  - UPCs involve EM interactions at impact parameters b larger than the sum of the radii of colliding nuclei R.
- ✓ Coherent γ-production: the γ couples to the nucleus N as a whole.
  - The cross section (XS) for producing vector mesons, such as J/ψ , is prop. square of the nuclear gluon density



$$\left.\frac{d\sigma_{\gamma A\to J/\Psi A}}{dt}\right|_{t=0} = \xi_{J/\Psi}\left(\frac{16\pi^3\alpha_s^2\Gamma_{l+l-}}{3\alpha M_{J/\Psi}^5}\right)\boxed{[xG_A(x,\mu^2)]^2}$$

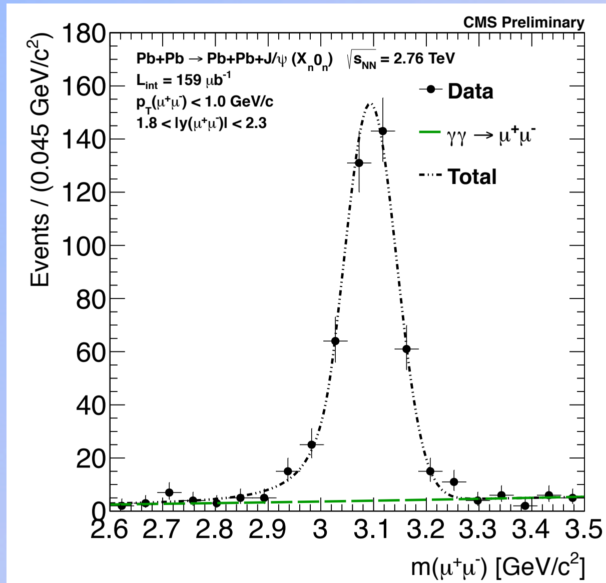


Nuclear breakup modes (**X_n0_n dominant)**

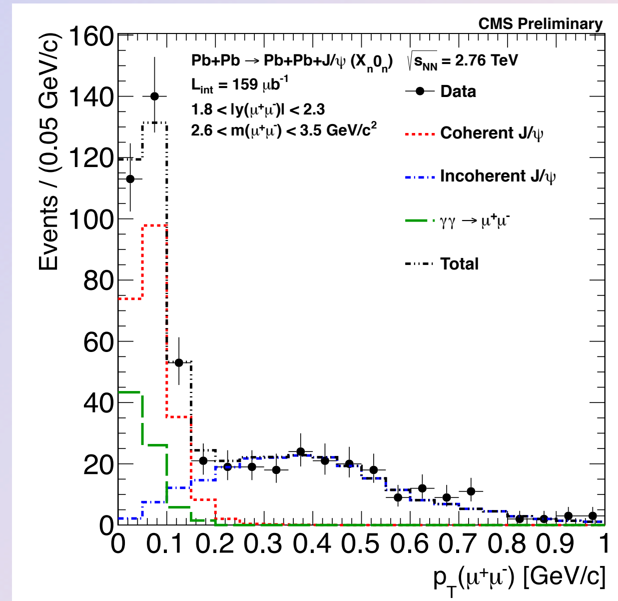
- **X_n0_n** : one of the ZDCs with at least one neutron "n" the other ZDC has no signal;
- X_nX_n both ZDCs have at least one "n";
- 1_n0_n one of the ZDCs has exactly one "n" while the other has no signal;
- 1_n1_n both ZDCs have exactly one "n";

Signal extraction, corrections, syst. & X_nX_n ratios

CMS-PAS-HIN-12-009



- ✓ $\mu^+\mu^-$, produced in the X_n0_n breakup mode, having a $p_T(\mu^+\mu^-) < 1.0$ GeV/c and $2.6 < M(\mu^+\mu^-) < 3.5$ GeV/c^2.
- ✓ distributions are not corrected for acceptance or efficiency and only the statistical uncertainties are shown.



- ✓ acceptance and efficiency correction factor, **(A×ε)J/ψ**, including the efficiency for the other selection cuts, corresponds to 5.9%.

$$\frac{d\sigma^{coh}_{X_n0_n}}{dy}(J/\psi) = \frac{N^{J/\psi}_{coh}}{BR(J/\psi \to \mu^+\mu^-)\cdot \mathcal{L}_{int}\cdot \Delta y \cdot (A\times\varepsilon)^{J/\psi}}$$

	Uncertainty
(1) Neutron tagging	6%
(2) HF energy cut	1%
(3) signal extraction	5%
(4) MC input	1%
(5) ZDC efficiency estimation	3%
(6) Tracking reconstruction	4%
(7) Luminosity determination	5%
(8) Branching ratio	1%
Total	11%

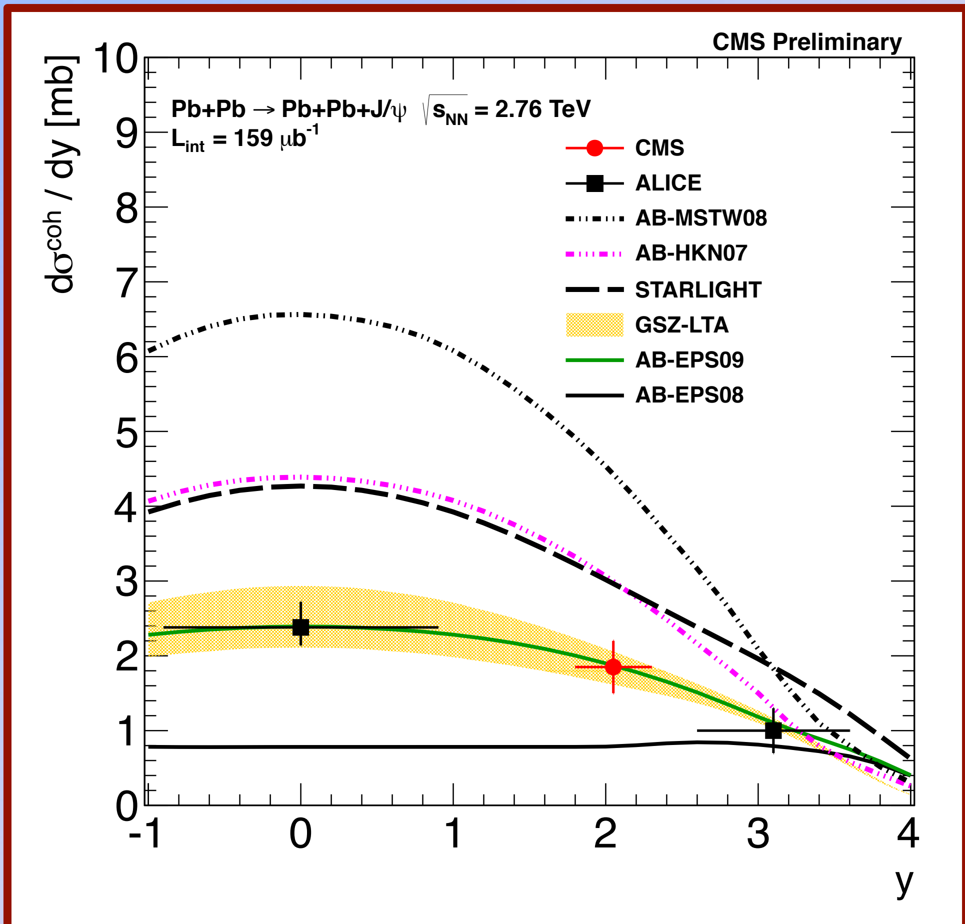
Systematic uncertainties

J/ψ with p_T < 0.15 GeV/c	X_nX_n/X_n0_n	$1_n0_n/X_n0_n$	$1_n1_n/X_n0_n$
Data	0.36±0.04	0.26±0.03	0.03±0.01
STARLIGHT	0.37	N/A	0.02
GSZ	0.32	0.30	0.02

1st measurement of break-up ratios for UPC J/ψ

Coherent J/ψ Diff. XS in ultra-peripheral PbPb

CMS-PAS-HIN-12-009



Data favor calculations that include nuclear gluon shadowing (GSZ-LTA model*), suggesting a significant reduction in the density of soft gluons within the nucleus.

Direct evidence of nuclear gluon shadowing at small-x values at LHC!

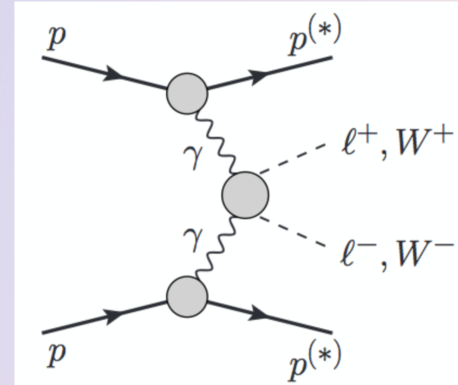
$$d\sigma^{coh}_{Xn0n}/dy\ (J/\psi) = 0.37 \pm 0.04\ (\text{stat.}) \pm 0.04\ (\text{syst.})\ \text{mb}$$

(*) V. Guzey, M. Strikman, and M. Zhalov, “Disentangling coherent and incoherent quasielastic J/ψ photoproduction on nuclei by neutron tagging in ultraperipheral ion collisions at the LHC”, Eur.Phys.J. C74 (2014) 2942, arXiv:1312.6486

Photon-Photon @CMS

Evidence for exclusive $\gamma\gamma \to W^+W^-$ production and constraints on Anomalous Quartic Gauge Couplings at $\sqrt{s}$ = 8 TeV

CMS-PAS-FSQ-13-008



- ✓ Exclusive processes: events with intact protons, but here also accounting for proton dissociation p*
- ✓ Clean final states with no hadronic activity =>remove inclusive backgrounds by requiring 0 extra tracks at dilepton vertex
- ✓ $\gamma\gamma \to \mu^+\mu^-$, e^+e^- : test exclusivity requirement and proton dissociation;
- ✓ $\gamma\gamma \to W^+W^-$: based on Madgraph EPA; measure SM XS and look for anomalous quartic gauge couplings (aQGC) with dim6 and dim8 effective operator for $\gamma\gamma W^+W^-$ vertex (hep-ph/9908254 & hep-ph/0606118);

$$L_6^0 = \frac{e^2}{8}\frac{a_0^W}{\Lambda^2} F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_\alpha - \frac{e^2}{16\cos^2\Theta_W}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha$$

$$L_6^C = \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W^-_\beta + W^{-\alpha}W^+_\beta) - \frac{e^2}{16\cos^2\Theta_W}\frac{a_C^Z}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}Z^\alpha Z_\beta$$

$$a^W_{0,C}(W^2_{\gamma\gamma}) = \boxed{\frac{a^W_{0,C}}{\left(1+\frac{W^2_{\gamma\gamma}}{\Lambda^2_{\text{cutoff}}}\right)^p}}$$

$$\mathcal{L}_{M,0} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right]$$
$$\mathcal{L}_{M,1} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right]$$
$$\mathcal{L}_{M,2} = \left[B_{\mu\nu}B^{\mu\nu}\right] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right]$$
$$\mathcal{L}_{M,3} = \left[B_{\mu\nu}B^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right]$$

vanishing WWZγ

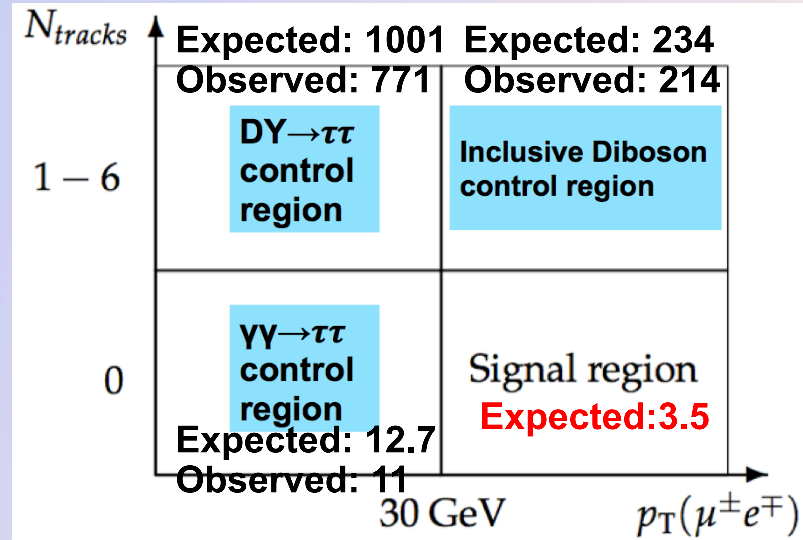
$$\frac{a_0^W}{\Lambda^2} = -\frac{4M_W^2}{g^2}\frac{f_{M,0}}{\Lambda^4} - \frac{8M_W^2}{g'^2}\frac{f_{M,2}}{\Lambda^4}$$
$$\frac{a_C^W}{\Lambda^2} = \frac{4M_W^2}{g^2}\frac{f_{M,1}}{\Lambda^4} + \frac{8M_W^2}{g'^2}\frac{f_{M,3}}{\Lambda^4}$$

- ✓ p=2 (dipole FF)
- ✓ unitarity bound @ $W_{\gamma\gamma}$ ~ 1 TeV
- ✓ Λ_{cutoff} = 500GeV

Backgrounds, strategy & systematics

CMS-PAS-FSQ-13-008

- ✓ Signal: opposite-sign eμ pair (DY and γγ→ll backs too big in ee, μμ channels), originating from a common primary vertex with pt(eμ) > 30GeV
- ✓ for high-purity pp->p $l^+ l^-$ p #events:
  - ✓ acoplanarity < 0.01 (due small Q^2 of exchanged γs),
  - ✓ inv. mass outside M_Z window,
  - ✓ 0 extra tracks at dilepton vertex to remove most of the inclusive WW back
  - ✓ pt(eμ) > 30GeV for supress γγ→ττ
- ✓ high pT(eμ) tail to look for SM exclusive WW and aQGC



Systematics

	Uncertainty
Proton dissociation factor	10.5%
0 extra tracks Efficiency Correction	5.0%
Trigger and lepton ID	2.4%
Luminosity	2.6%
Total	12.1%

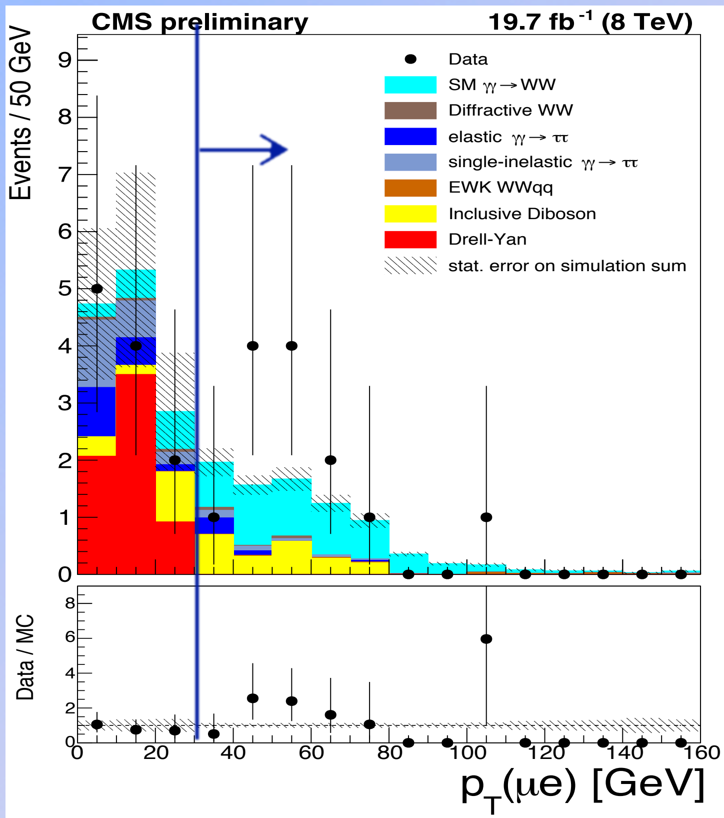
MC simulation

Selection step	Excl. $\gamma\gamma \to WW$	Total Background	WW+jets	$\gamma\gamma \to \tau\tau$	DY $\to \tau\tau$	Pompyt WW	Other Backgrounds
Trigger and preselection	26.9±0.2	12560±230	1057.5±8.1	18.1±0.8	7000±75	206.2±3.0	4280±210
$m(\mu^\pm e^\mp) > 20$ GeV	26.6±0.2	12370±220	1035.5±8.0	18.1±0.8	6974±75	202.2±3.0	4140±210
Electron and Muon ID	22.5±0.2	6458±93	1027.9±8.0	12.6±0.7	4172±58	197.2±2.9	1048±72
$\mu^\pm e^\mp$ vertex with 0 extra tracks	6.7±0.2	14.9±2.5	2.8±0.4	4.3±0.5	6.5±2.3	0.3±0.1	1.1±0.6
$p_T(\mu^\pm e^\mp) > 30$ GeV	5.3±0.1	3.5±0.5	2.0±0.4	0.9±0.2	0	0.1±0.1	0.5±0.2

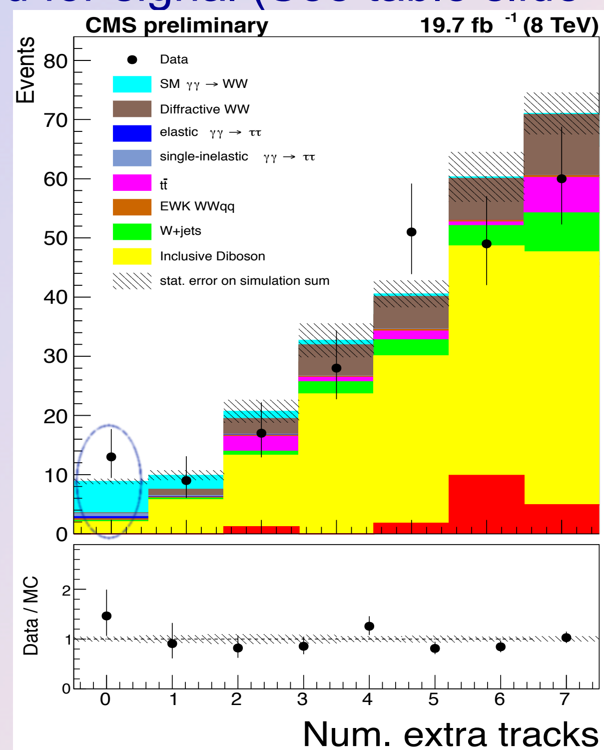
#evts for 19.7fb-1; opposite sign μ and e from same vertex, p_T^l>20GeV, $|\eta_l|$<2.4, < 16 extra tracks.

CMS-PAS-FSQ-13-008

RESULT 1: evidence for exclusive $\gamma\gamma \rightarrow W^+W^-$ production



- ✓ 0 extra tracks plot
- ✓ In signal region ($p_T(\mu e)$ > 30 GeV): 13 events observed (data) over 3.5±0.5 (statistics) events expected for background and 5.3±0.1 (statistics) expected for signal (See table slide 13)

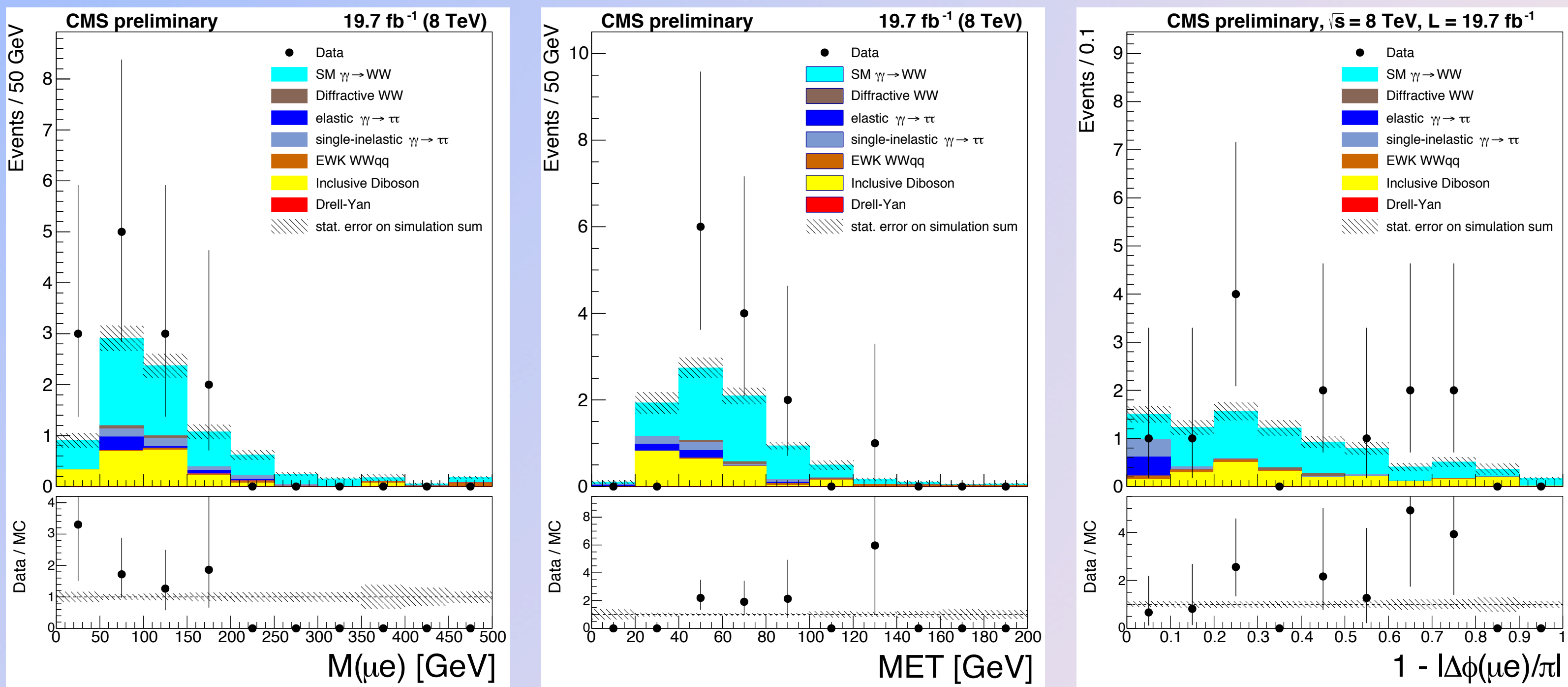


- ✓ **Excess of 3.6σ** over the background only hypothesis, including systematics.
- ✓ XS:

$$\sigma(pp \rightarrow p^{(*)}W^+W^-p^{(*)} \rightarrow p^{(*)}\mu^{\pm}e^{\mp}p^{(*)}) = 12.3^{+5.5}_{-4.4}\text{fb}.$$

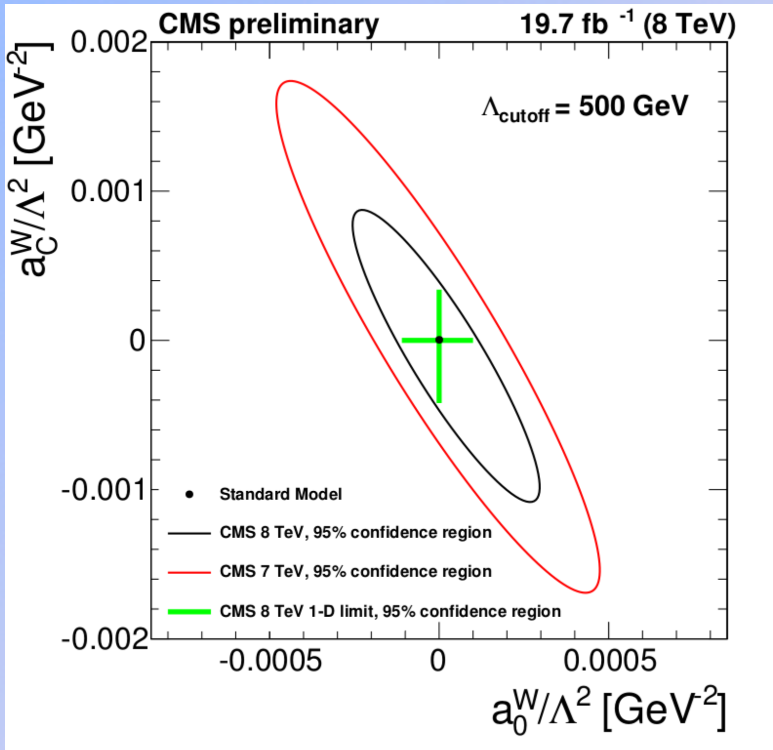
CMS-PAS-FSQ-13-008

RESULT 1: evidence for exclusive γγ → W^+W^- production (signal region distributions)



- ✓ Muon-electron invariant mass, acoplanarity, and missing transverse energy in the γγ → W^+W^- signal region.
- ✓ Agreement in shape
- ✓ The data is shown by points with error bars, the histograms indicate the expected SM signal and backgrounds.

RESULT 2: constraints on γγWW AQCG



- ✓ The area outside the contour is excluded at 95% CL
- ✓ **7-16 times** more stringent than search for WWγ and WZγ production at Phys. Rev. D 90, 032008 (2014)
- ✓ **3-7 times** more stringent than Vector Boson Scattering approach at Phys. Rev. Lett. 114 (2015) 051801)

Dim6, no FF, 95%CL

$$-1.2\times10^{-6} < a_0^W/\Lambda^2 < 1.2\times10^{-6}\,\mathrm{GeV}^{-2}\ \ (a_C^W/\Lambda^2 = 0,\text{no form factor})$$
$$-4.4\times10^{-6} < a_C^W/\Lambda^2 < 4.4\times10^{-6}\,\mathrm{GeV}^{-2}\ \ (a_0^W/\Lambda^2 = 0,\text{no form factor})$$

Dim6, FF, 95%CL

$$-1.1\times10^{-4} < a_0^W/\Lambda^2 < 1.0\times10^{-4}\,\mathrm{GeV}^{-2}\ \ (a_C^W/\Lambda^2 = 0, \Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV})$$
$$-4.2\times10^{-4} < a_C^W/\Lambda^2 < 3.4\times10^{-4}\,\mathrm{GeV}^{-2}\ \ (a_0^W/\Lambda^2 = 0, \Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV})$$

Dim8, no FF, 95%CL

$$-4.6\times10^{-12} < f_{M,0}/\Lambda^4 < 4.6\times10^{-12}\,\mathrm{GeV}^{-4}\ \ (\text{no form factor})$$
$$-17\times10^{-12} < f_{M,1}/\Lambda^4 < 17\times10^{-12}\,\mathrm{GeV}^{-4}\ \ (\text{no form factor})$$
$$-2.3\times10^{-12} < f_{M,2}/\Lambda^4 < 2.3\times10^{-12}\,\mathrm{GeV}^{-4}\ \ (\text{no form factor})$$
$$-8.3\times10^{-12} < f_{M,3}/\Lambda^4 < 8.3\times10^{-12}\,\mathrm{GeV}^{-4}\ \ (\text{no form factor})$$

Dim8, FF, 95%CL

$$-4.2\times10^{-10} < f_{M,0}/\Lambda^4 < 3.8\times10^{-10}\,\mathrm{GeV}^{-4}\ \ (\Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV})$$
$$-16\times10^{-10} < f_{M,1}/\Lambda^4 < 13\times10^{-10}\,\mathrm{GeV}^{-4}\ \ (\Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV})$$
$$-2.1\times10^{-10} < f_{M,2}/\Lambda^4 < 1.9\times10^{-10}\,\mathrm{GeV}^{-4}\ \ (\Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV})$$
$$-8.0\times10^{-10} < f_{M,3}/\Lambda^4 < 6.4\times10^{-10}\,\mathrm{GeV}^{-4}\ \ (\Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV})$$

Summary

- **Coherent J/ψ photoproduction cross section in ultra-peripheral PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV in conjunction with forward neutrons has been measured, extending previous measurement to a new rapidity range.**

  - ✓ **The ratios of J/ψ production in different nuclear breakup modes have been measured for the first time at the LHC and found to be consistent with STARLIGHT and GSZ-LTA.**

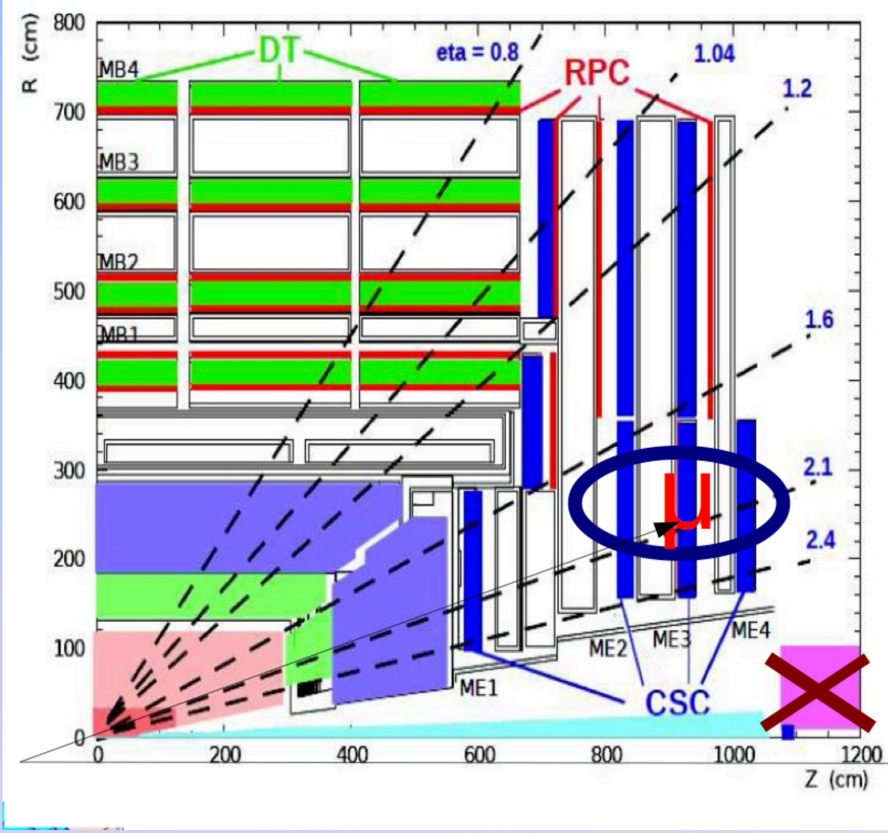
  - ✓ **Data favor calculations that include nuclear gluon shadowing, suggesting a significant reduction in the density of soft gluons within the nucleus.**

- **Evidence for exclusive $\gamma\gamma \rightarrow W^+W^-$ production**

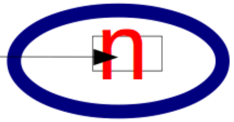
  - ✓ **13 events observed over expected background of 3.5 ± 0.5 events: excess of 3.6σ over the background only hypothesis.**

  - ✓ **Significant improvement on aQGC limits.**

BACKUP



- L1: hardware trigger system from calorimeters and muon systems only
  - Loosest muon trigger
  - At least one ZDC above threshold
  - No activity on both sides of the interaction point in the BSC detectors, $3 < |\eta| < 5$
- HLT: software trigger system using the full detector
  - Require reconstruction of at least one pixel track



1 https://indico.cern.ch/event/336283/session/24/contribution/101/material/slides/0.pdf