Exclusive W^+W^- production in CMS

and other Forward Physics Results

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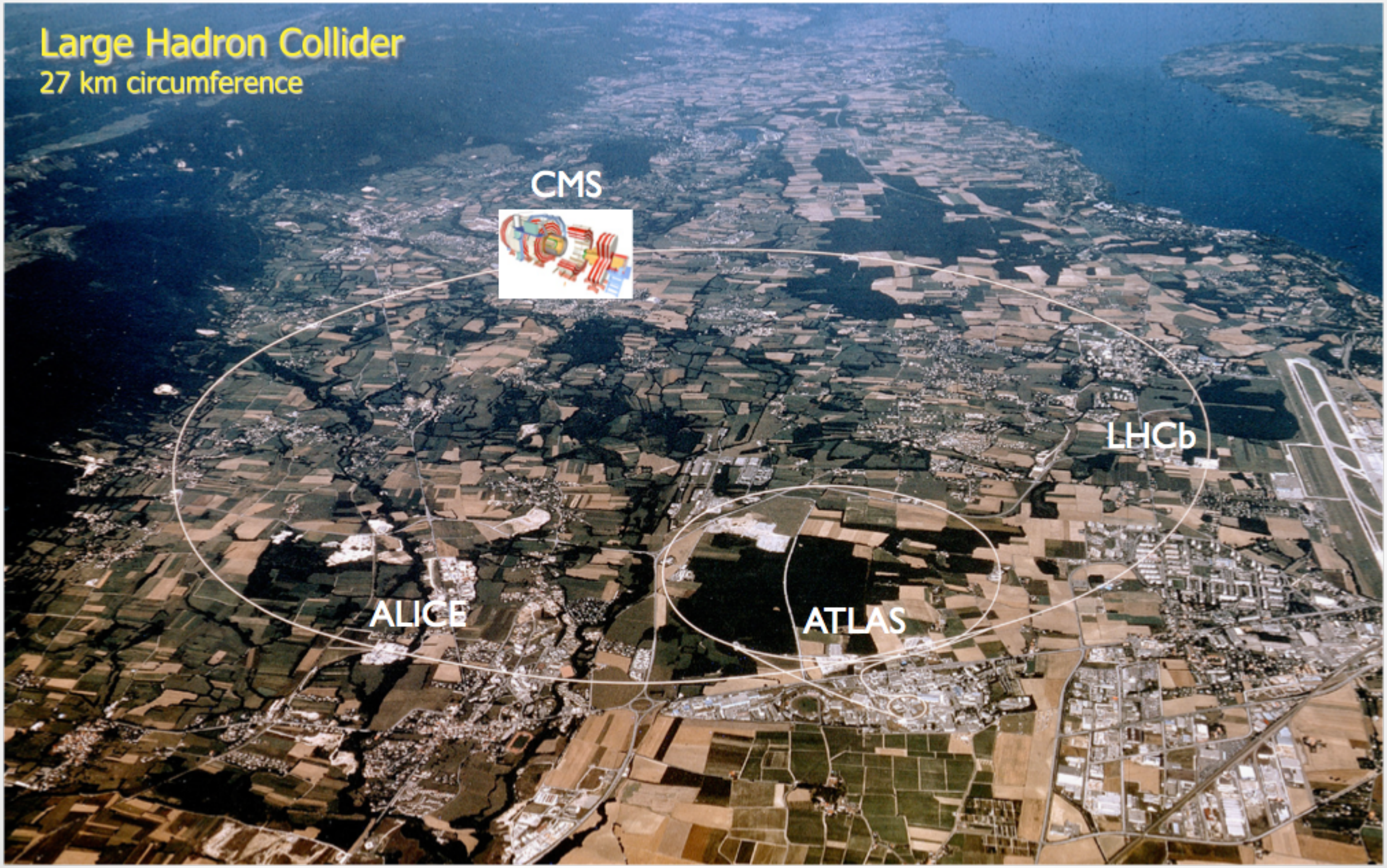
On Behalf of the CMS Collaboration

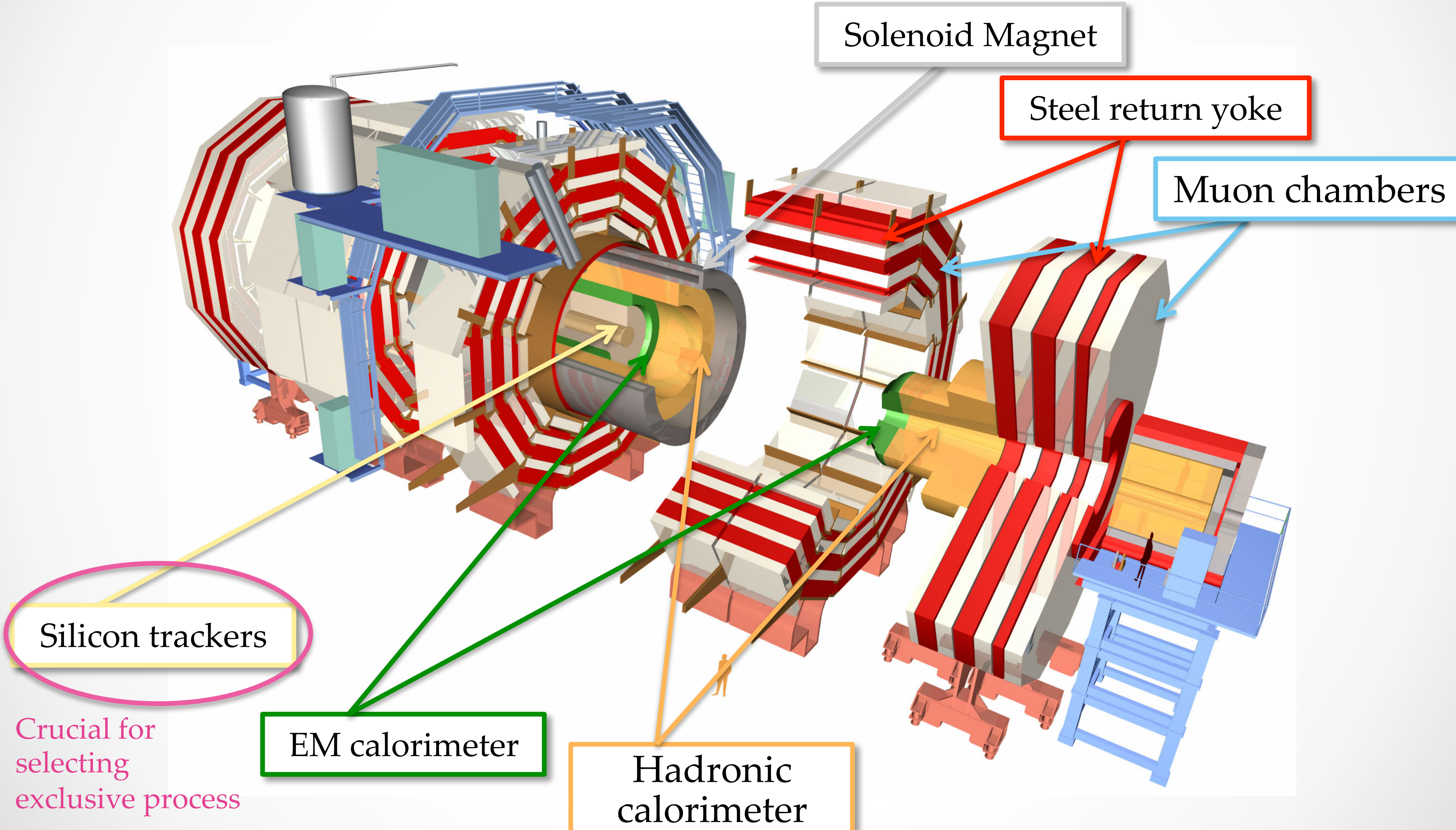
Outline

- The CMS Experiment
- Recent Forward Physics Results
  - Underlying Event @ 13 TeV
  - Ridge @ 13 TeV
  - dN/dη @13 TeV
- Evidence of Exclusive W^+W^- production @ 8 TeV

The CMS Experiment

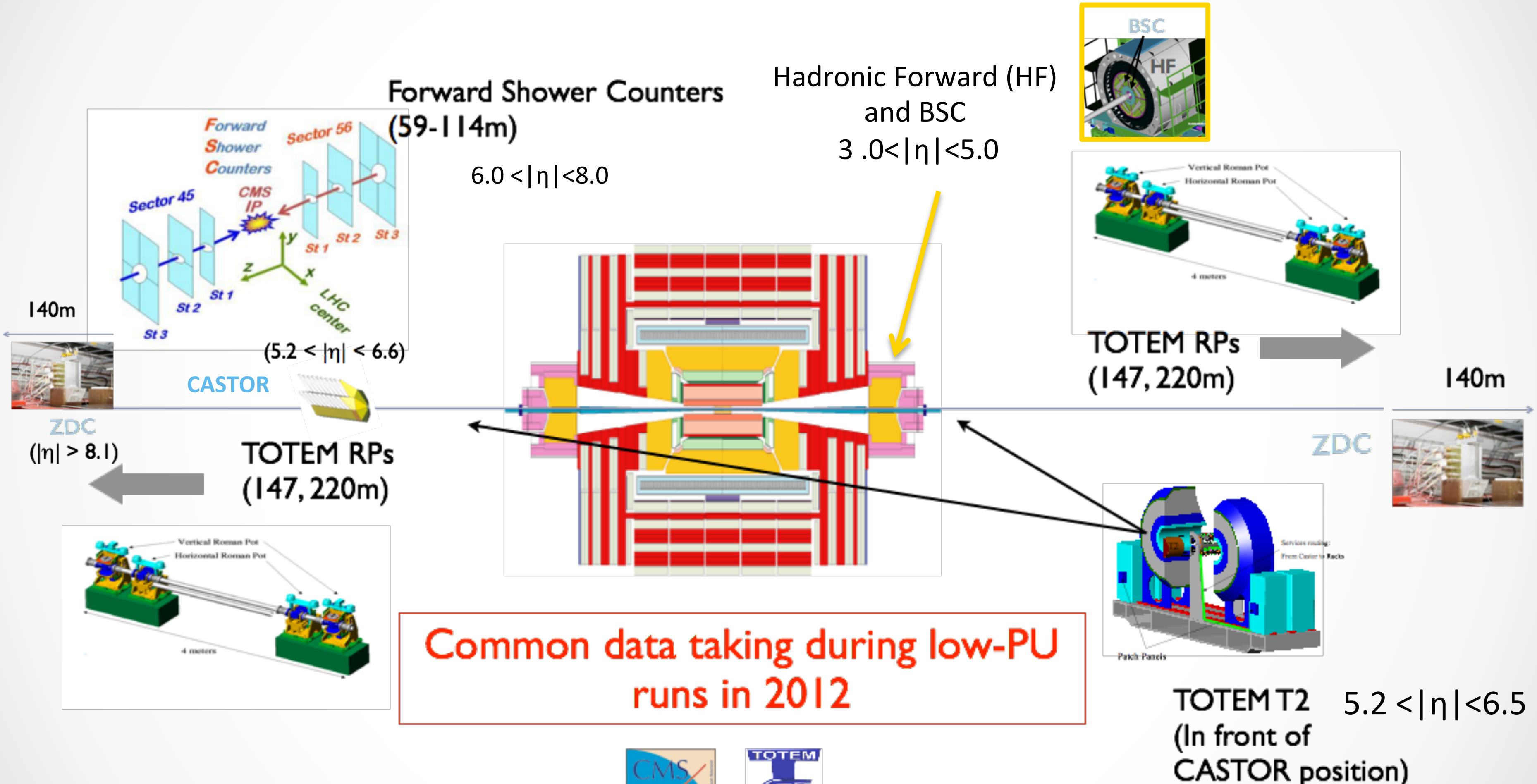


The CMS Detector



Crucial for selecting exclusive process

CMS Forward Region and TOTEM



Common data taking during low-PU runs in 2012

check out Antonio Pereira's talk about plans for CT-PPS

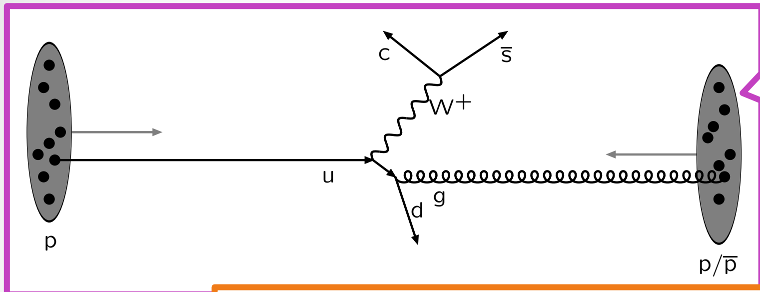
Prospects for Diffractive and Forward Physics at the LHC
CERN-LHCC-2006-039-G-124

Recent Forward Physics Results @ 13 TeV

…

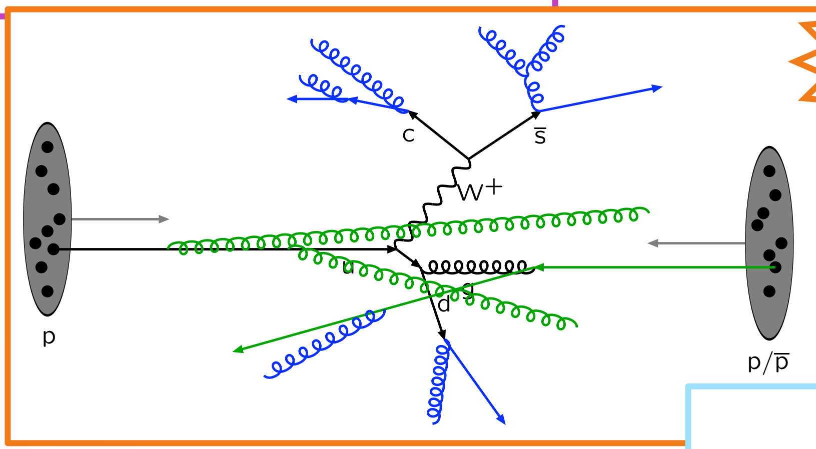
Underlying Event Definition

1



Hard scattering

2

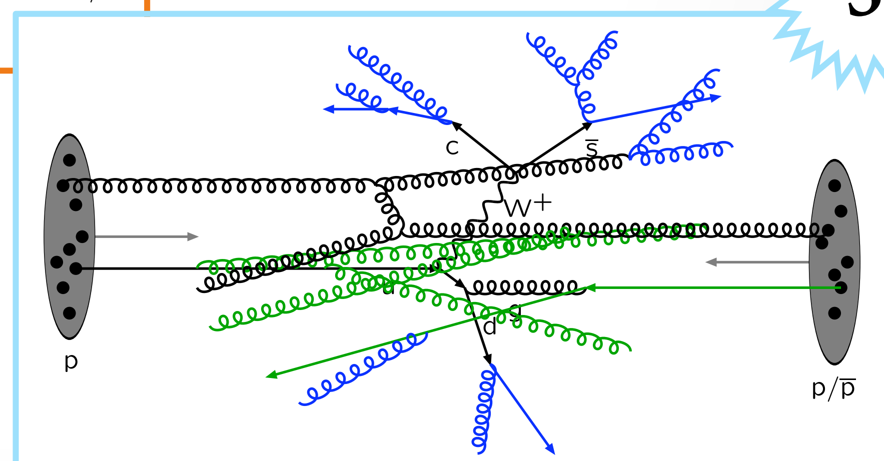


Initial and Final State Radiation

T. Sjostrand

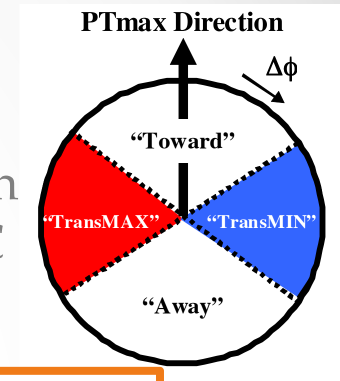
3

And Multiple Parton Interactions

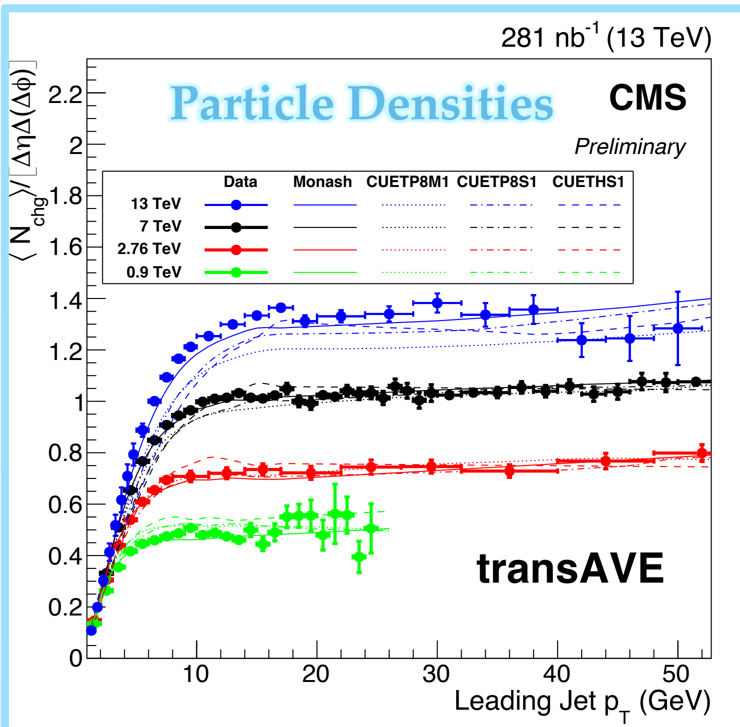


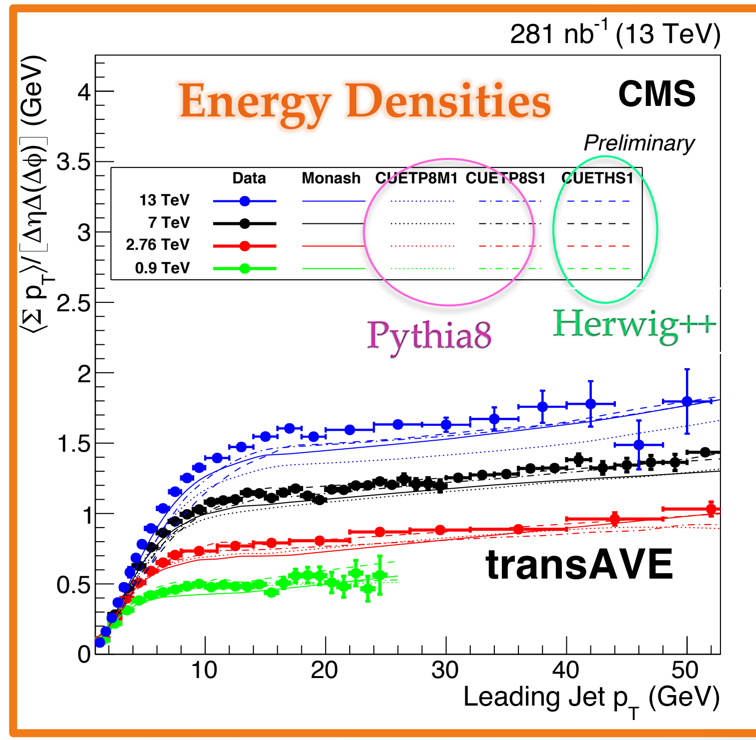
Underlying Event at 13 TeV

- Comparison with previous measurements at lower energies show good description of energy dependence.
- **Charged particle multiplicity** and **p_T sum density** in the region *transverse to highest-p_T jet* well described (10-20%) by tested MC tunes.



CMS-PAS-FSQ-15-007

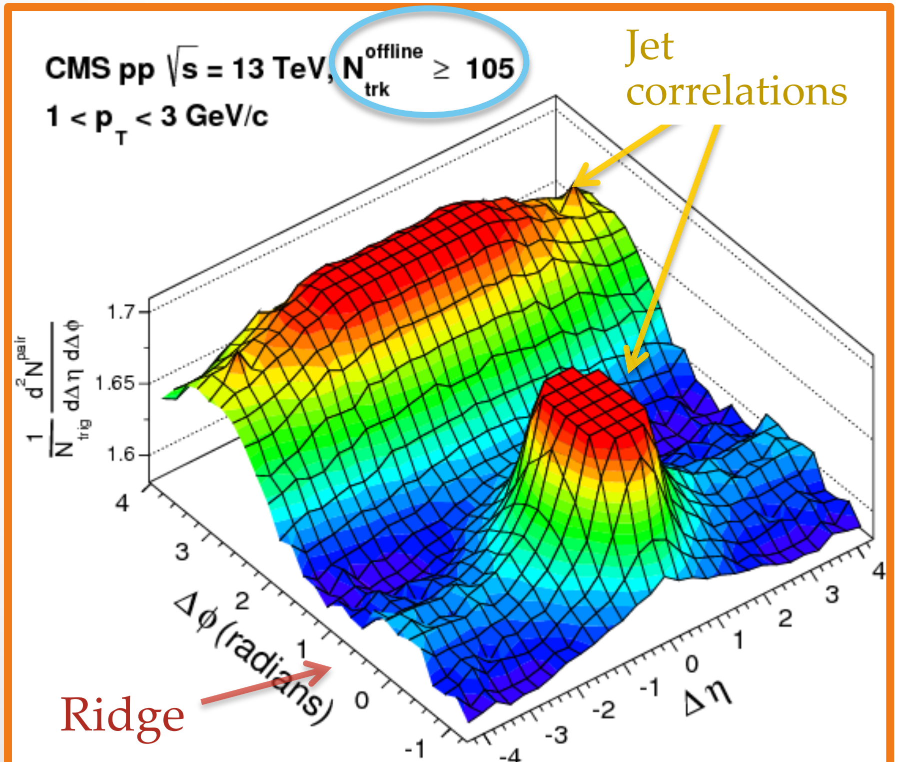


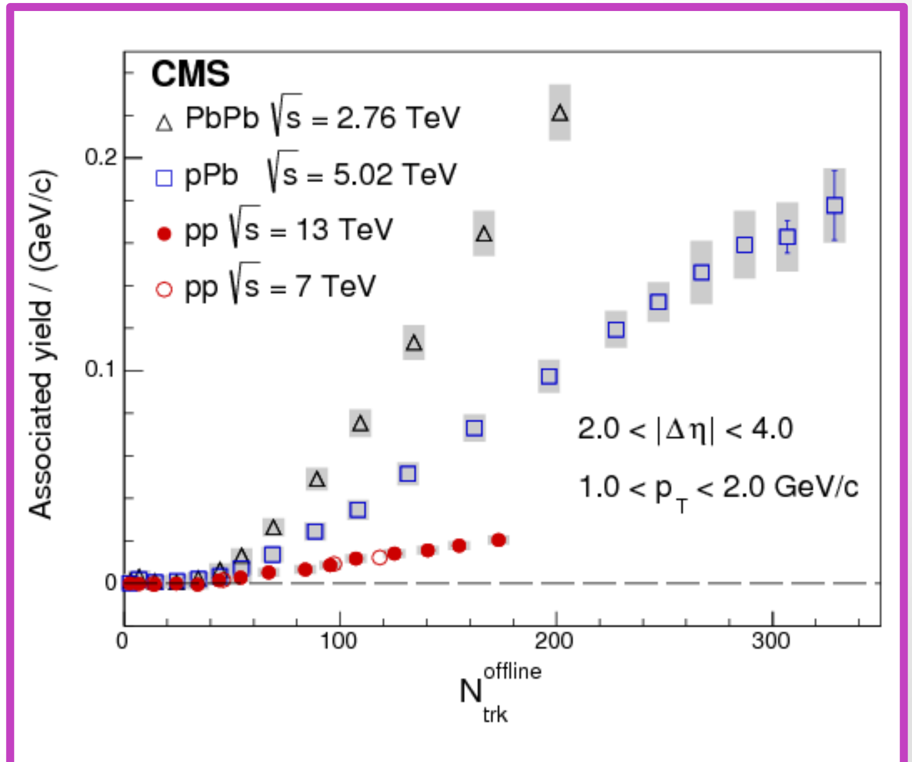


The “Ridge”

- two-particle correlations confirm the presence of a ridge-like structure for same-side (Δϕ~ 0) pairs in high-multiplicity events at 13 TeV.
- strong collision system size dependence observed when comparing data from pp, pPb, and PbPb collisions

CMS-PAS-FSQ-15-002 → arXiv:1507.05915

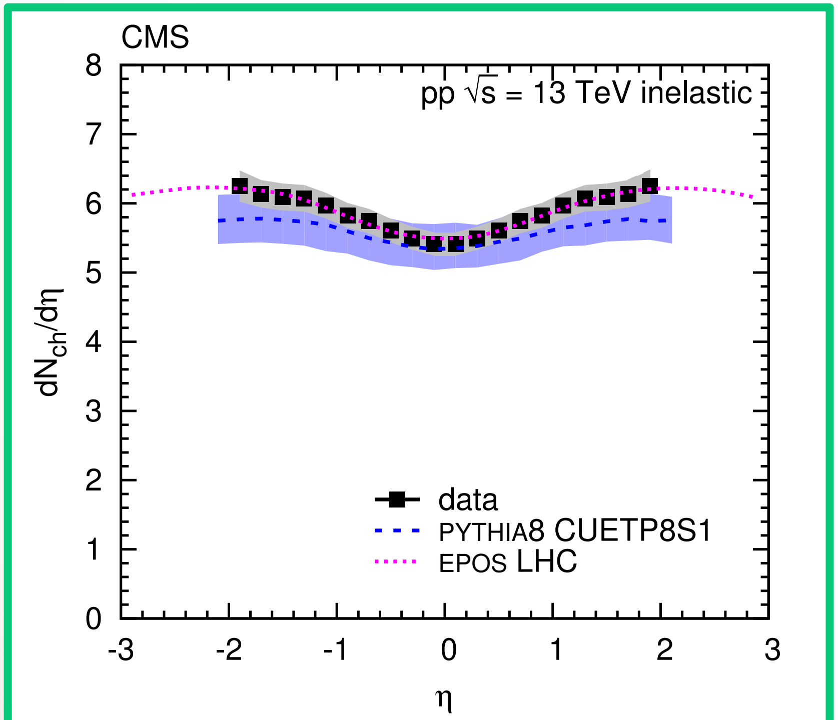


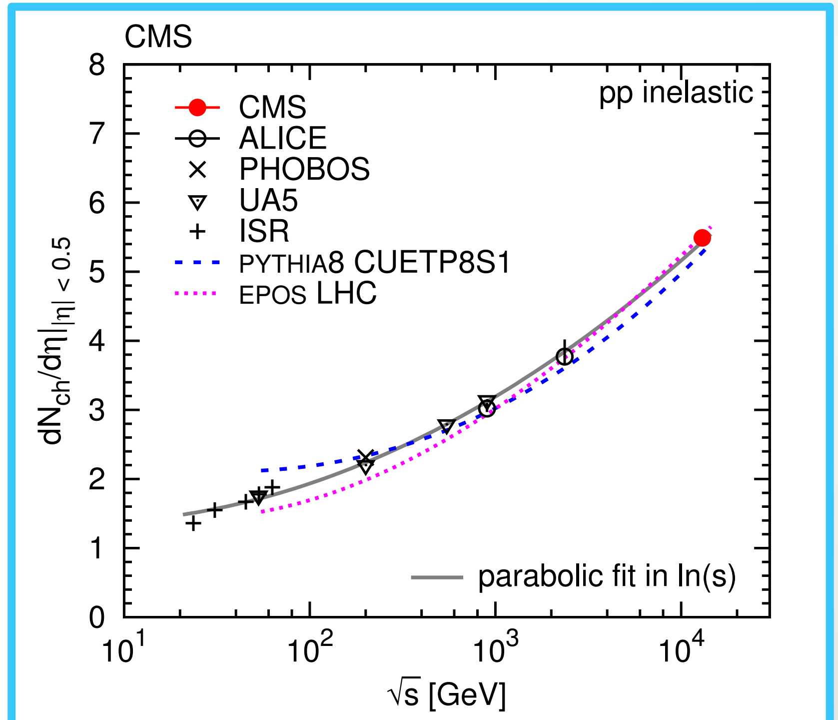


Charged-hadron dN/dη

- Measured charged-hadron production as a function of pseudorapidity, and multiplicity in central region consistent with previous measurements at lower energies and theoretical models.

CMS-PAS-FSQ-15-001 → PLB 751 (2015) 143





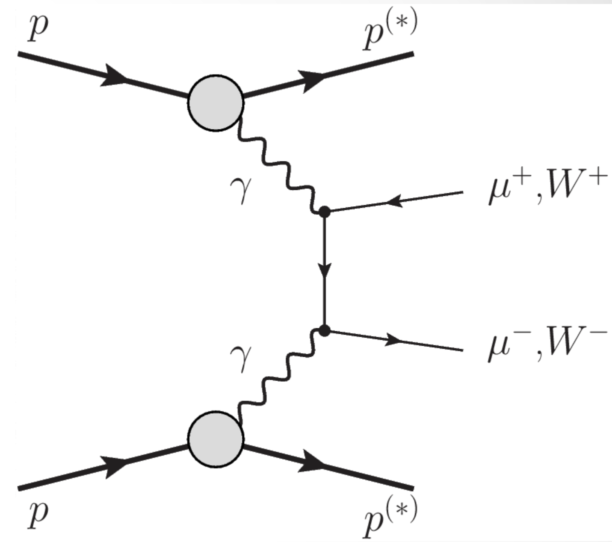
Exclusive W^+W^- production @ 8 TeV

And limits on anomalous Quartic Gauge Couplings

Motivation

The exclusive production of W pairs:

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

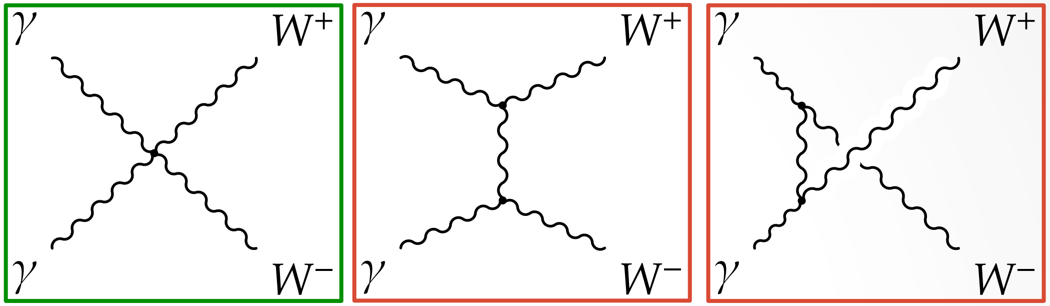


is sensitive to anomalous quartic gauge couplings (aQGC)

- QGCs predicted by standard model's electroweak sector
- any deviation from SM expectation can signal new physics
- untagged proton $p^{(*)}$ → final states where the proton is either intact or dissociates into undetected low-mass system.

Exclusive $\gamma\gamma \rightarrow W^+W^-$

In the SM we have:



- provide clean $\ell\ell'$ final state with no hadronic activity
- goal: measure SM and look for aQGC
  - New physics → effective lagrangean:

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

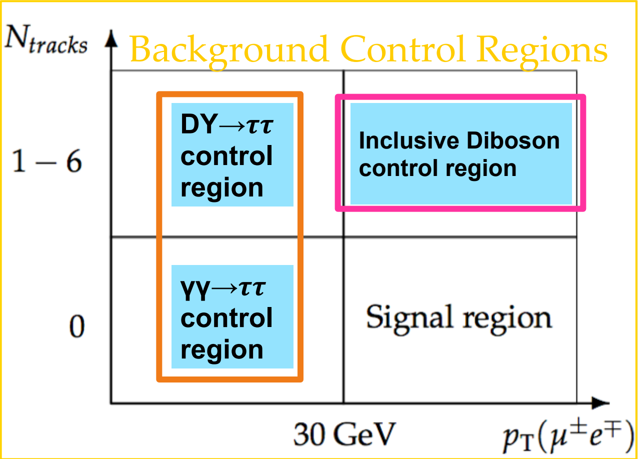
$$\mathcal{L}_6^C = -\frac{e^2}{16}\frac{a_c^W}{\Lambda^2}F^{\mu\alpha}F_{\mu\beta}(W^{+\alpha}W_\beta^- + W^{-\alpha}W_\beta^+)$$

Λ= scale of NP

Anomalous coupling constants for quartic vertex $\gamma\gamma \rightarrow W^+W^-$

Signal Selection and Control Regions

- opposite-sign eμ pair originating from a common primary vertex
  - DY and $\gamma\gamma\to\ell\ell$ backgrounds too big in ee, μμ channels
- invariant mass m(eμ) > 20 GeV
  - to get rid of any low mass resonances
- 0 extra tracks at dilepton vertex
  - to remove most of the inclusive WW background
- p_T(eμ) > 30 GeV
  - to supress DY and $\gamma\gamma\to\tau\tau$



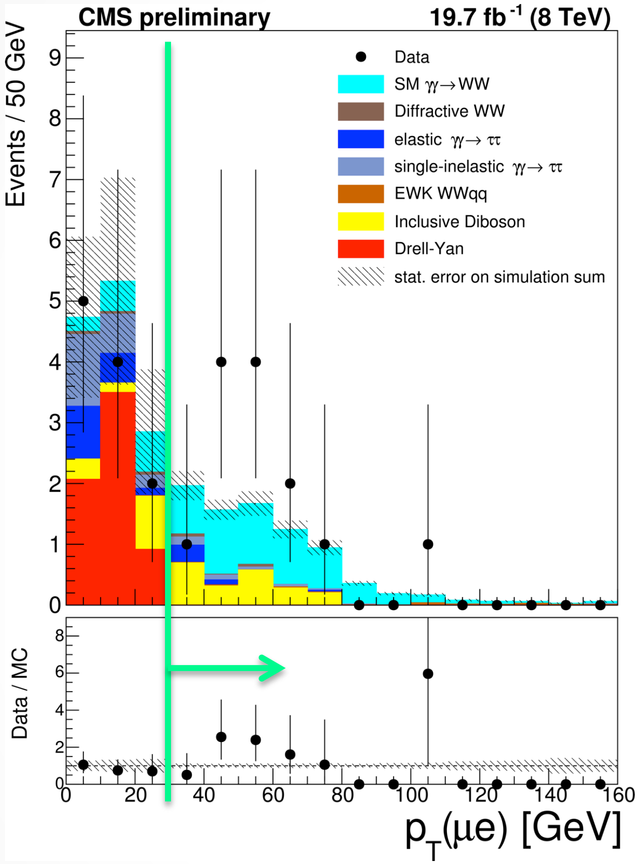
CMS-PAS-FSQ-13-008

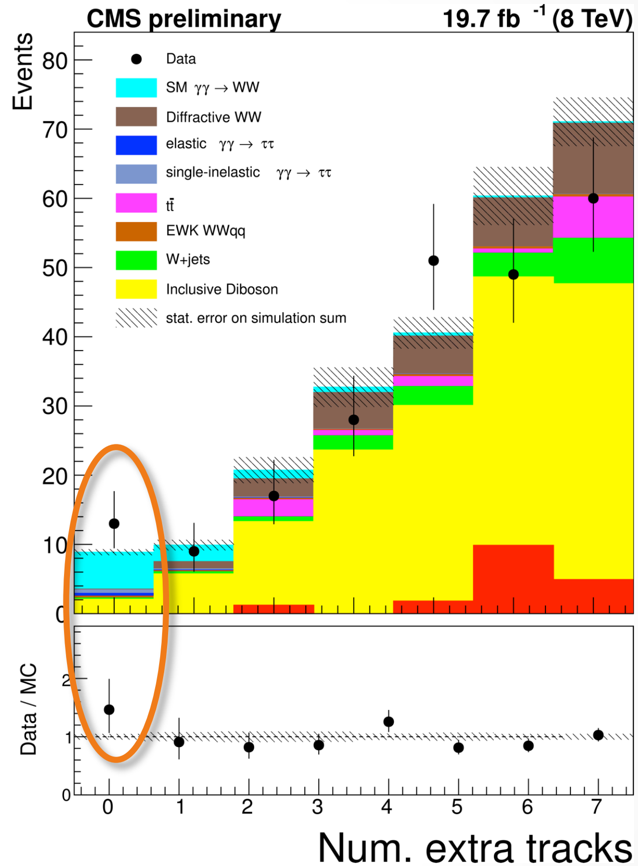
MC Expectation

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

SM evidence

CMS-PAS-FSQ-13-008



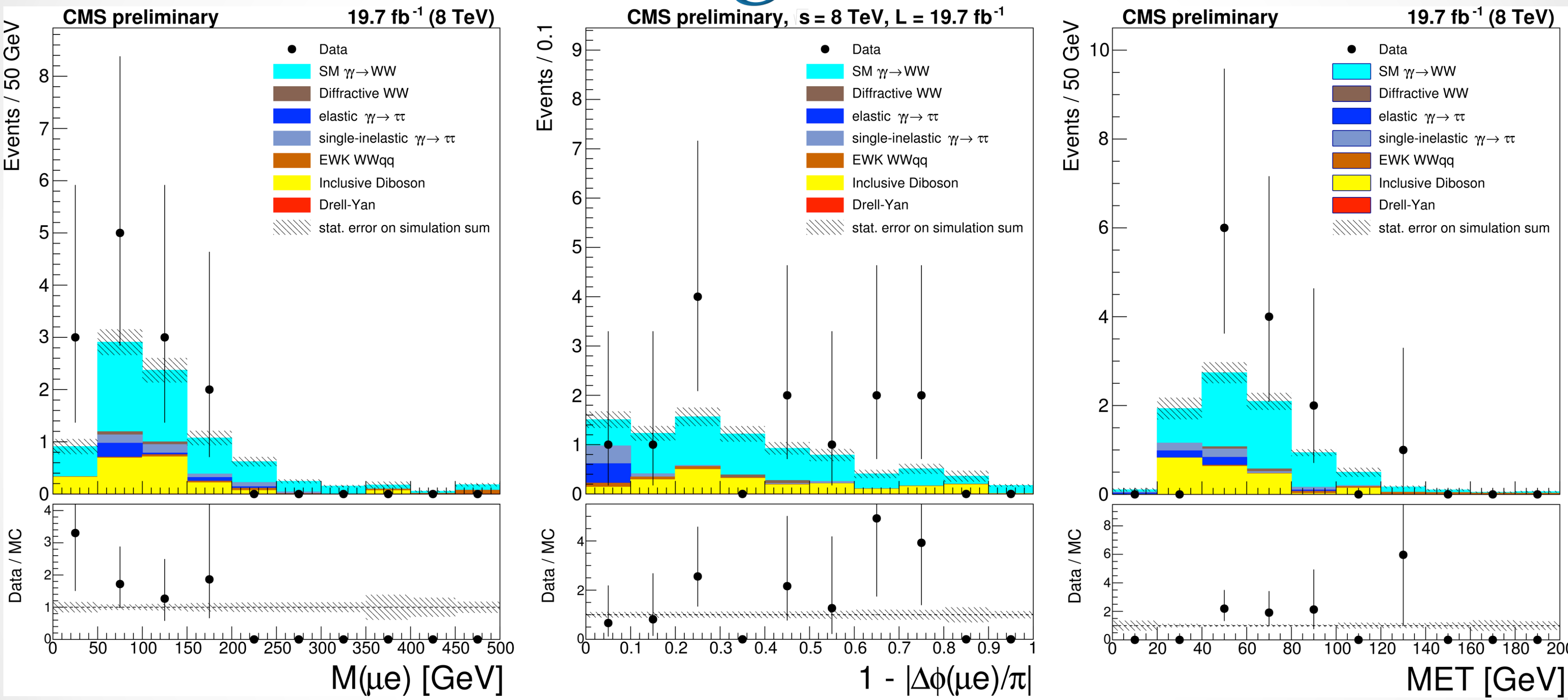


- observed 13 events in signal region (5.3±0.1 signal and 3.5±0.5 background exp.)
- 3.6 σ excess over background-only hypothesis (with 2.4 σ expected)

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

Distributions in Signal Region

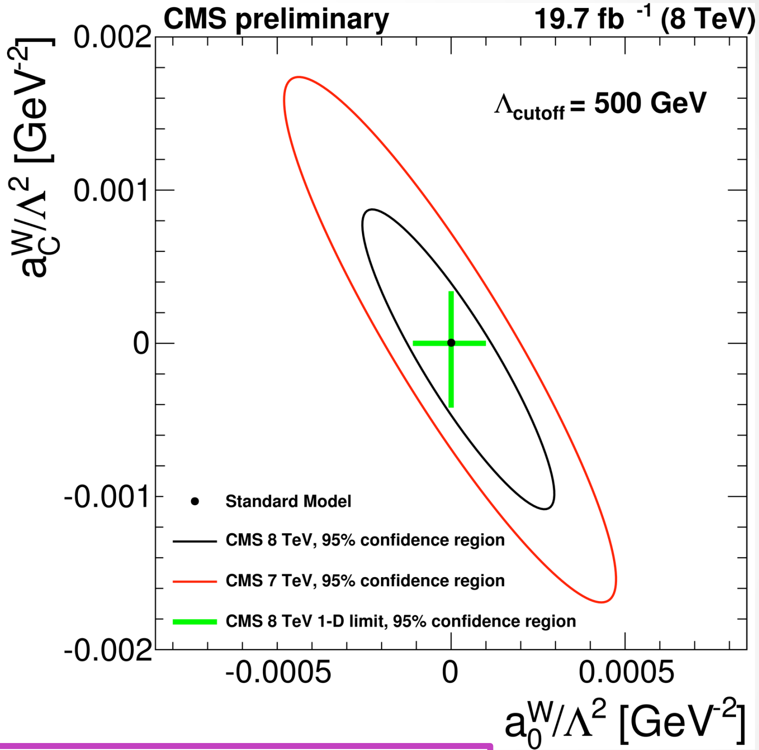
CMS-PAS-FSQ-13-008



For invariant mass, acoplanarity and missing E_T there's agreement in shape, slightly higher normalization in data due to excess of observed events.

aQGC Search and Limits

- Use shape of $p_T(e\mu)$ distribution to search for sign of anomalous quartic gauge couplings
  - 2 bins : $30 < p_T(e\mu) < 130$ GeV and $p_T(e\mu) > 130$ GeV
- Region outside solid line is excluded at 95% C.L.



CMS-PAS-FSQ-13-008

$$-1.1 \times 10^{-4} < a_0^W/\Lambda^2 < 1.0 \times 10^{-4}\,\mathrm{GeV}^{-2} \;\; (a_C^W/\Lambda^2 = 0, \Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV}),$$
$$-4.2 \times 10^{-4} < a_C^W/\Lambda^2 < 3.4 \times 10^{-4}\,\mathrm{GeV}^{-2} \;\; (a_0^W/\Lambda^2 = 0, \Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV}).$$

25% improvement over 7 TeV limits with dipole Form Factor →

$$a_{0,C}^W(W_{\gamma\gamma}^2) = \frac{a_{0,C}^W}{\left(1 + \frac{W_{\gamma\gamma}^2}{\Lambda_{\mathrm{cutoff}}^2}\right)^2}.$$

Summary

- 13 TeV early measurements:
  - Underlying event → MC tunes
  - Pseudorapidity distribution of charged hadrons
  - Ridge structure in near-side two-particle correlations observed

- Exclusive $\gamma\gamma$→WW
  - 13 events observed with expected background of 3.5 events → excess of 3.6 σ consistent with first SM evidence of the $\gamma\gamma$→WW process
  - Measured cross-section x branching ratio

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

  - Search for aQGC → the most stringent upper limits so-far

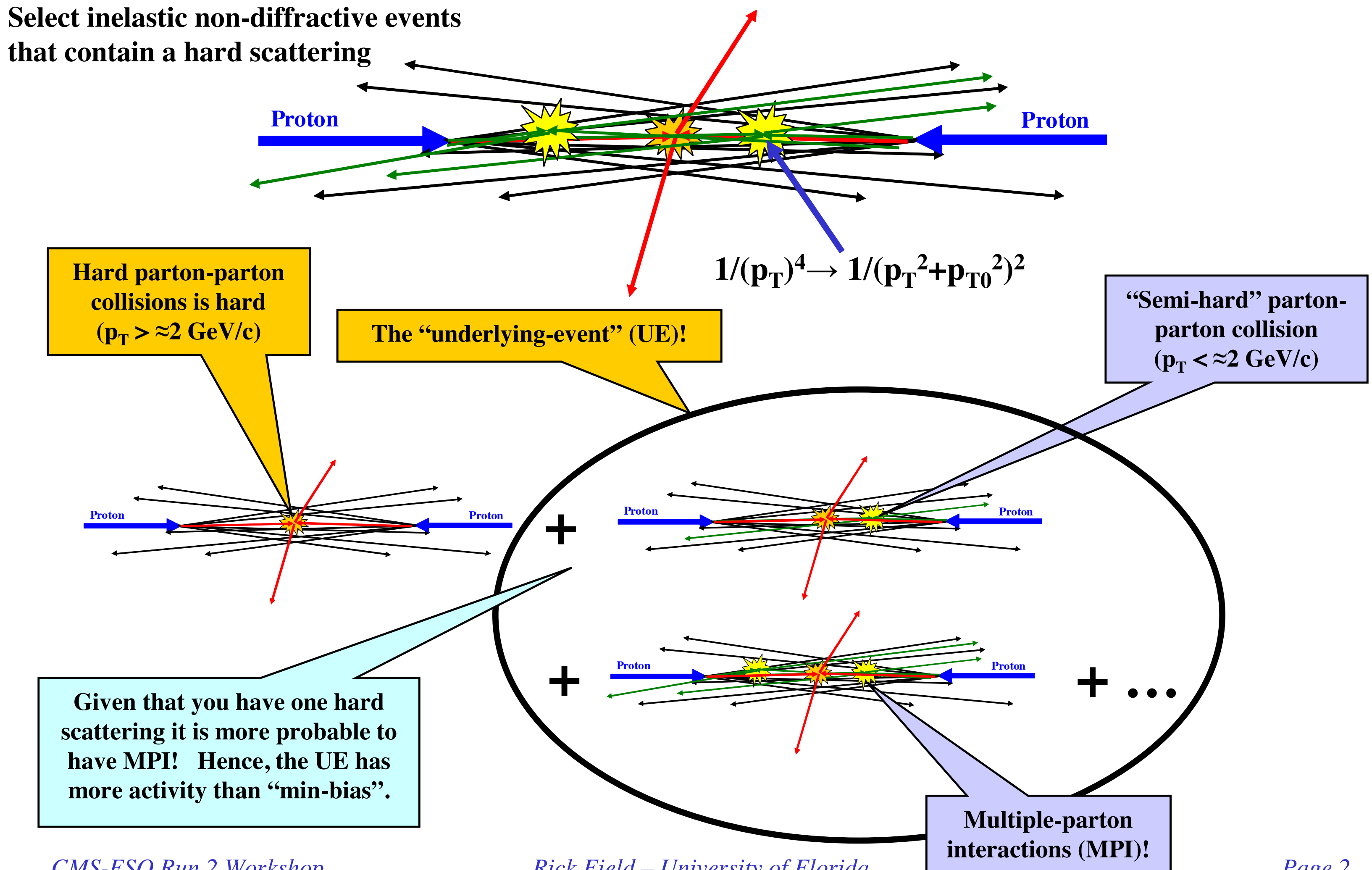
$$-1.1 \times 10^{-4} < a_0^W/\Lambda^2 < 1.0 \times 10^{-4}\,\text{GeV}^{-2}\ (a_C^W/\Lambda^2 = 0, \Lambda_{\text{cutoff}} = 500\,\text{GeV}),$$
$$-4.2 \times 10^{-4} < a_C^W/\Lambda^2 < 3.4 \times 10^{-4}\,\text{GeV}^{-2}\ (a_0^W/\Lambda^2 = 0, \Lambda_{\text{cutoff}} = 500\,\text{GeV}).$$

  - Expect more results in the future (13 TeV) with CT-PPS

Backup Slides

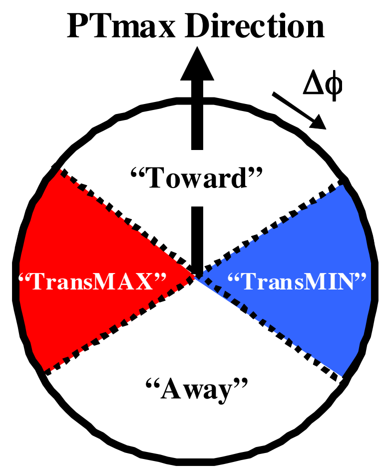
Additional material

Underlying Event Definition



Underlying Event Observables

- **"transMAX" and "transMIN" Charged Particle Density:** Number of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the the maximum (minimum) of the two "transverse" regions as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.
- **"transMAX" and "transMIN" Charged PTsum Density:** Scalar p_T sum of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the the maximum (minimum) of the two "transverse" regions as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.



$\eta_{cut} = 0.8$

Overall "Transverse" = "transMAX" + "transMIN"

Note: The overall "transverse" density is equal to the average of the "transMAX" and "TransMIN" densities. The "TransDIF" Density is the "transMAX" Density minus the "transMIN" Density

"Transverse" Density = "transAVE" Density = ("transMAX" Density + "transMIN" Density)/2

"TransDIF" Density = "transMAX" Density - "transMIN" Density

Underlying Event Tunes

➡ **PYTHIA 8 Tunes:** **Corke & Sjöstrand Tune 4C-CTEQ6L and CMS Tune CUETP8S1-CTEQ6L (CMS1).**

	4C	CMS1
PDF	CTEQ6L	CTEQ6L
ecmRef	1800	1800
pT0Ref	2.085	**2.1006**
ecmPow	0.19	**0.21057**
expPow	2.0	**1.60889**
reconnectRange	1.5	**3.31257**
MultipartonInteractions:alphaSvalue	0.135	0.135
SigmaProcess:alphaSvalue	0.135	0.135
SpaceShower:alphaSvalue	0.137	0.137
TimeShower:alphaSvalue	0.1383	0.1383
TimeShower:pTmin	0.4	0.4
TimeShower:pTminChgQ	0.4	0.4
BeamRemnants:halfScaleForKT	1.0	1.0
BeamRemnants:primordialKThard	2.0	2.0
BeamRemnants:primordialKTsoft	0.50	0.50
Tune:ee	3	3

Start with Tune 4C and vary 4 parameters!

CMS Tune CUETP8S1-CTEQ6L
pT0Ref = 2.1006
ecmPow = 0.21057
ecmRef = 1800

Ecm (TeV)	pT0 (GeV/c)
0.3	1.440
0.9	1.815
1.96	2.139
7	2.796
13	3.185

$$pT0(E_{cm}) = pT0Ref \times (E_{cm}/ecmRef)^{ecmPow}$$

Underlying Event Tunes

➡ **PYTHIA 8 Tunes: Peter Skands Tune Monash-NNPDF2.3LO and CMS Tune CUETP8M1-NNPDF2.3LO (MonashStar).**

	Monash	MonashStar
PDF	NNPDF2.3LO	NNPDF2.3LO
ecmRef	7000	7000
pT0Ref	2.280	**2.402374**
ecmPow	0.2150	**0.25208**
expPow	1.85	**1.6**
reconnectRange	1.80	1.80
MultipartonInteractions:alphaSvalue	0.13	0.13
SigmaProcess:alphaSvalue	0.13	0.13
SpaceShower:alphaSvalue	0.1365	0.1365
TimeShower:alphaSvalue	0.1365	0.1365
TimeShower:pTmin	0.5	0.5
TimeShower:pTminChgQ	0.5	0.5
BeamRemnants:halfScaleForKT	1.5	1.5
BeamRemnants:primordialKThard	1.8	1.8
BeamRemnants:primordialKTsoft	0.9	0.9
Tune:ee	7	7

New from CMS

Start with Monash and change 3 parameters!

CMS Tune MonashStar
pT0Ref = 2.402374
ecmPow = 0.25208
ecmRef = 7000

Ecm (TeV)	pT0 (GeV/c)
0.3	1.086
0.9	1.432
1.96	1.743
7	2.402
13	2.808

Skands-Monash
pT0Ref = 2.280
ecmPow = 0.2150
ecmRef = 7000

Ecm (TeV)	pT0 (GeV/c)
0.3	1.158
0.9	1.467
1.96	1.734
7	2.280
13	2.605

The Ridge

Data: proton-proton collisions at √s = 13 TeV

Compact Muon Solenoid experiment at CERN's LHC

- Integrated luminosity: **270 nb^{-1}**
- Pile-up conditions: **1.3** (average number of collisions per bunch crossing)
- Data collected with full solenoid magnetic field ($B = 3.8T$)
- Extension of the 7 TeV results to **higher energy and higher multiplicity.**
- Trigger (online): $E_{CAL} > 15$ or 40 GeV (L1 trigger)

  pixel tracking $N_{trk} > 60, 85, 110$ with $|\eta|>2.4$, $p_T > 0.4$ GeV/c
- Trigger (offline): at least one tower in each of the two HF calorimeters ($3 < |\eta| < 5$) with more than 3 GeV (suppress diffraction)
- Pile-up rejection: vertices cannot be too close above some multiplicity
- Tracks are weighted by 1/efficiency

The Ridge

Systematic uncertainties

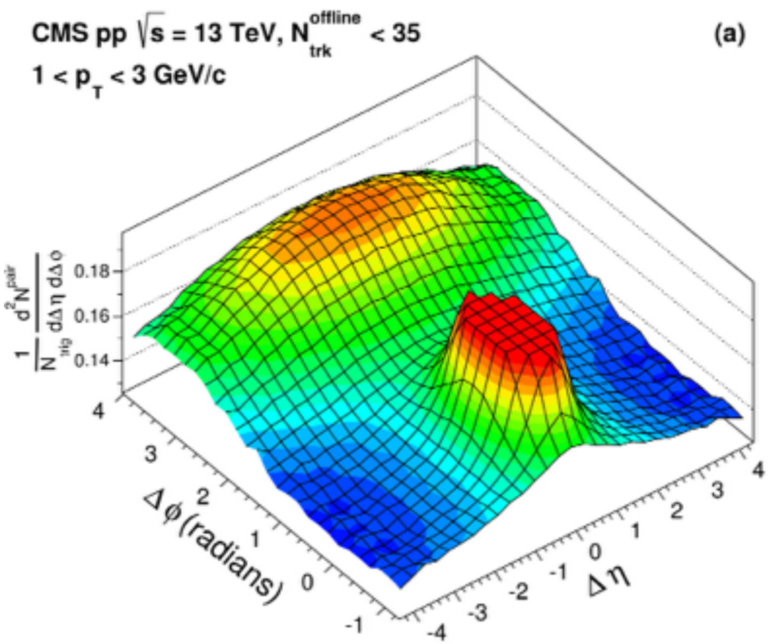
Compact Muon Solenoid experiment at CERN's LHC

- Results are **insensitive** to tracking efficiency (ratios)
- Requiring 1 vertex and no pile-up rejection has only a small effect
- Different trigger combinations were tested
- Various fit functions to determine the ZYAM factor

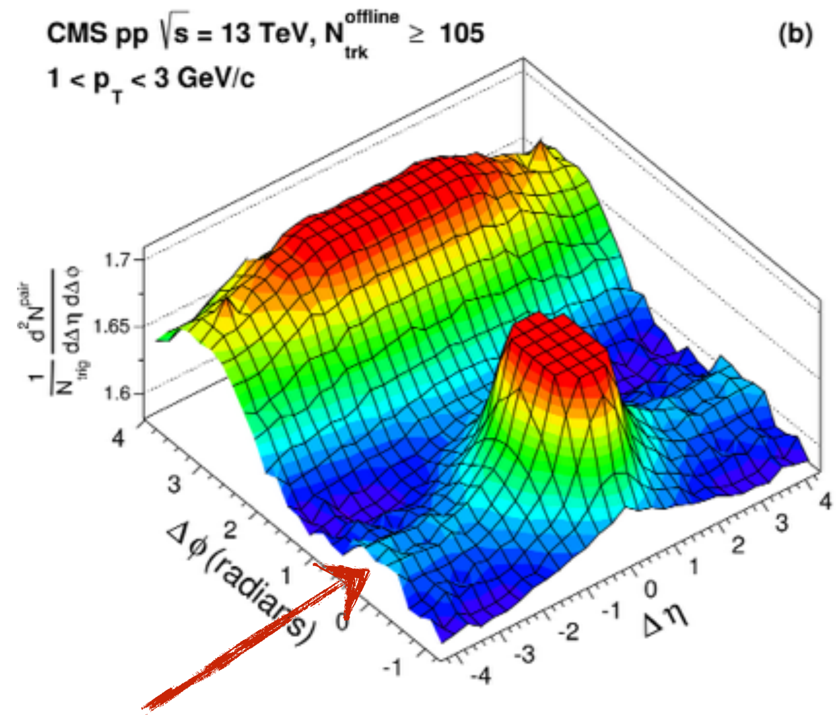
Systematic uncertainty sources	Abs. uncertainty ($\times 10^{-3}$)
Track quality requirements	0.6
Trigger efficiency	1.5
Correction for tracking efficiency	<0.08
Effect of pile-up events	0.6
Vertex selection	1.0
ZYAM procedure	0.7
Total	2.1

Two-particle correlations in pp at $\sqrt{s}$=13 TeV

Compact Muon Solenoid experiment at CERN's LHC



Low multiplicity



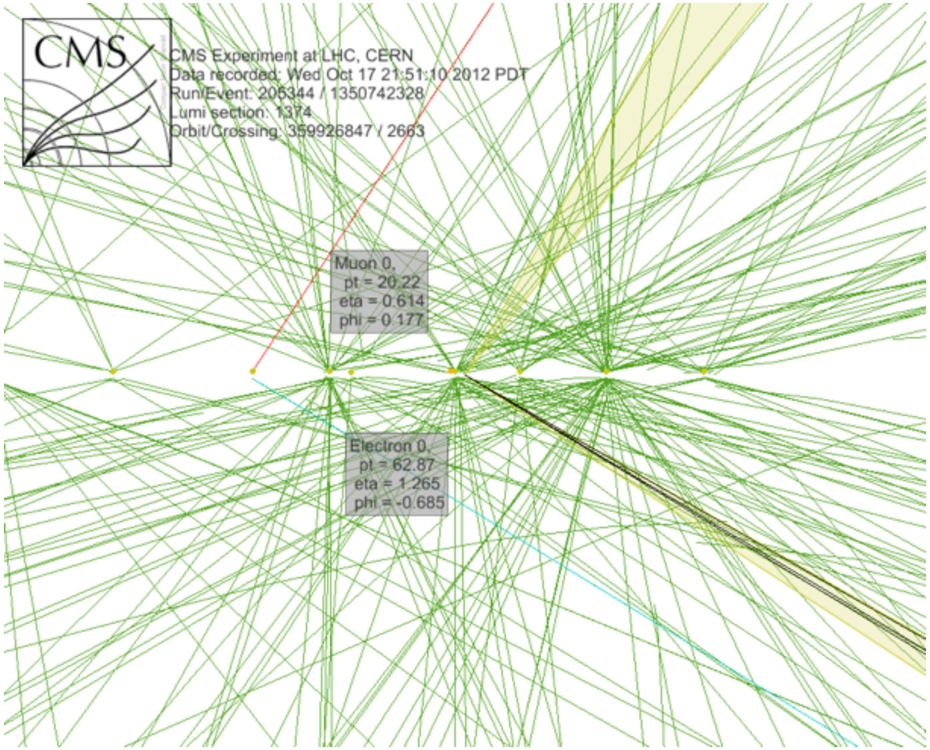
High multiplicity

Features:

- jet peak (truncated)
- away-side back-to-back jet correlation
- near-side, long-range "ridge"

Exclusive WW Preselection

- Integrated luminosity 19.7 fb^{-1}
- Preselection:
  - opposite sign μ and e from same vertex
  - $p_T(l)>20GeV$ and $|\eta_l|<2.4$
  - < 16 extra tracks
- m(eμ) > 20 GeV
- lepton ID for both leptons
- 0 extra tracks at dilepton vertex
- $p_T(e\mu)$ > 30 GeV



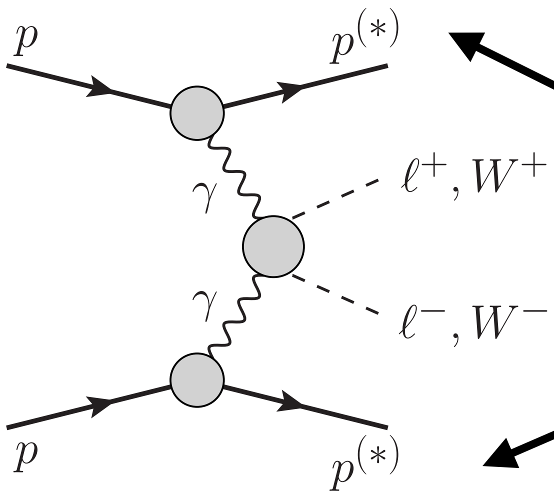
- **Event display of signal event**
- **$p_T(e\mu)$ = 77 GeV**

Exclusive WW Systematics

- $\gamma\gamma \rightarrow \ell^+\ell^-$ used to test exclusivity requirement and proton dissociation
- Corrections for proton dissociation factor (only elastic contribution of signal sample is simulated) and for efficiency of 0 extra-tracks cut contribute most to uncertainty

	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%

Proton dissociation factor



Need to take into account proton dissociation for signal samples

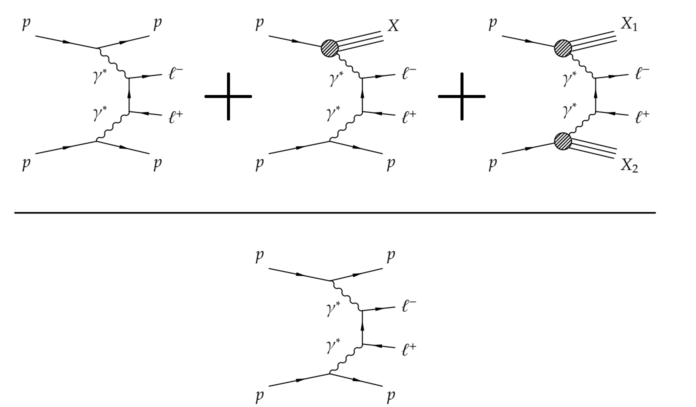
- **Our signal samples are pure elastic samples, do not have contribution from single dissociation or double dissociation production**
- **To estimate contribution for single dissociation, double dissociation γγ→W,W production use γγ→l,l as control sample**
- **Estimate proton dissociation factor (F) at above twice the W mass in γγ→l,l control samples.**
- **Multiply F by elastic exclusive SM WW to get full contribution including non-elastic**

$$F = \left.\frac{N_{ll\ data} - N_{DY}}{N_{elastic}}\right|_{m(l^+l^-)>160\ \mathrm{GeV}}$$

Proton dissociation Factor

$$\sigma^{total}_{\gamma\gamma} = F \times \sigma^{elastic}_{\gamma\gamma}$$

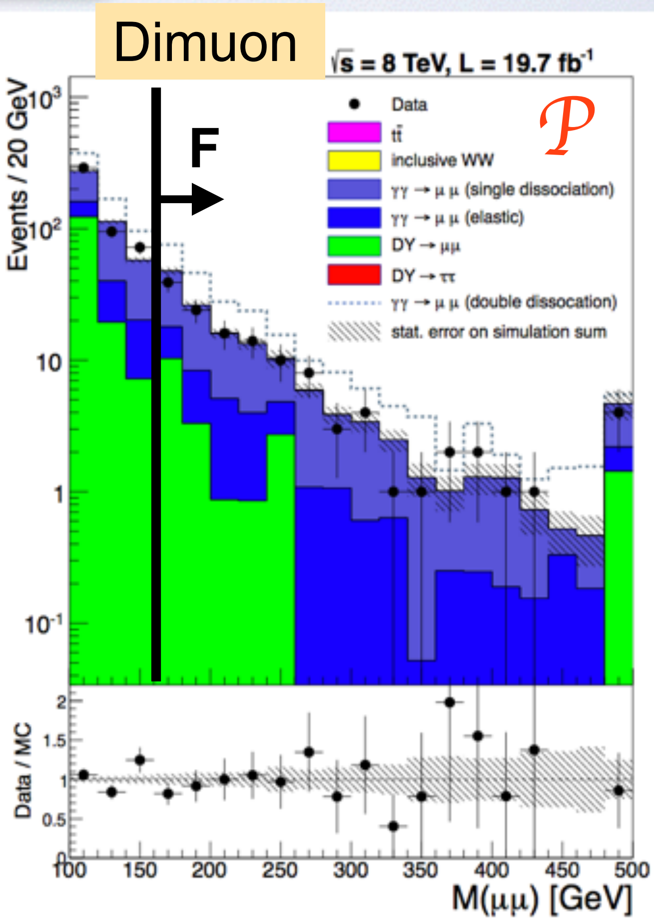
$F =$

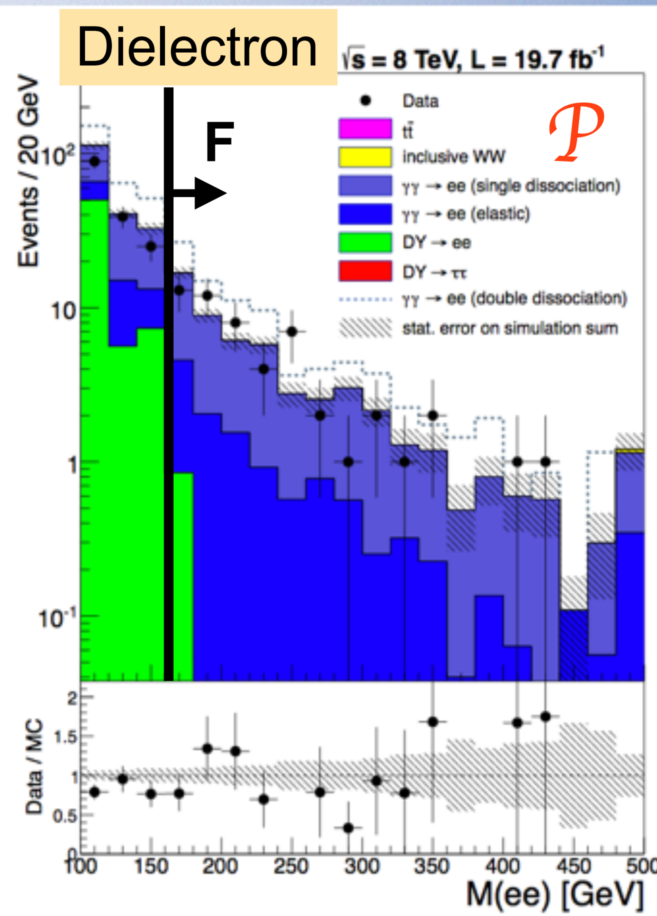


signal kinematic region

- Proton dissociation factor is the following ratio: (Elastic + Single Dissociative + Double-Dissociative) / Elastic
- Proton dissociation factor calculated from data: 4.10 ± 0.43. Slightly higher than 7 TeV analysis, 3.23 ± 0.61
- Proton dissociation factor calculated from MC:
  - Assuming survival probability of 1 for single dissociative, and 0 for double dissociative: 4.39 ± 0.48
  - Assuming survival probability of 1 for both signal dissociative and double dissociative: 7.71 ± 0.57
- Theory predicts large survival probability for single dissociative and small survival probability for double dissociative (arXiv:1204.4803)
  - Data is consistent with this prediction

Proton dissociation factor





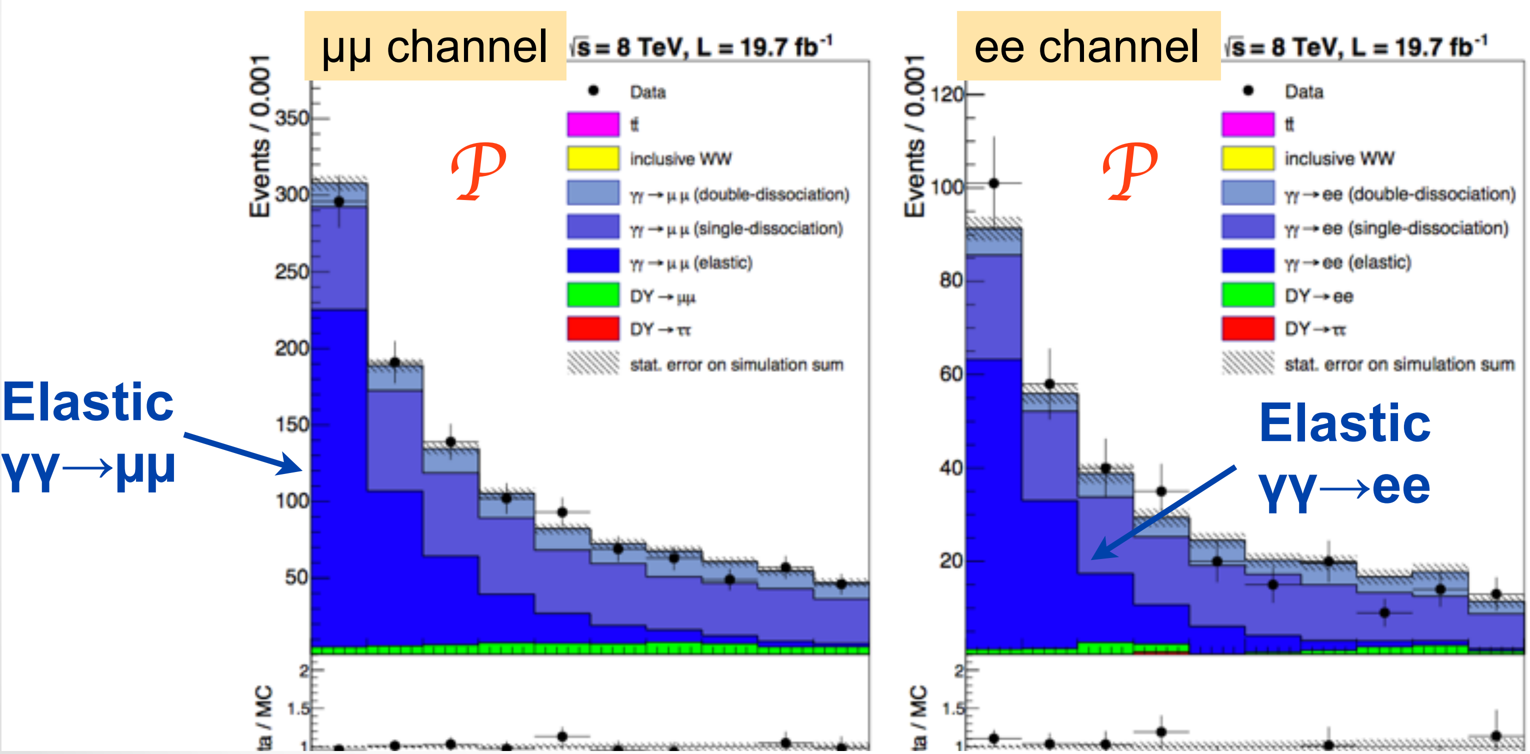
- Plots made for 0 extra tracks, efficiency correction applied to MC
- Proton dissociation factor calculated with 0 extra tracks, Mass(ll)>160 GeV

$$F = \frac{N_{ll\ data} - N_{DY}}{N_{elastic}}\Bigg|_{m(l^+l^-)>160\ \mathrm{GeV}}$$

- Factor is essentially ratio of data points divided by elastic contribution (dark blue histogram)
- Combined μμ and ee channel proton dissociation factor: 4.10 ± 0.43

Efficiency correction (I)

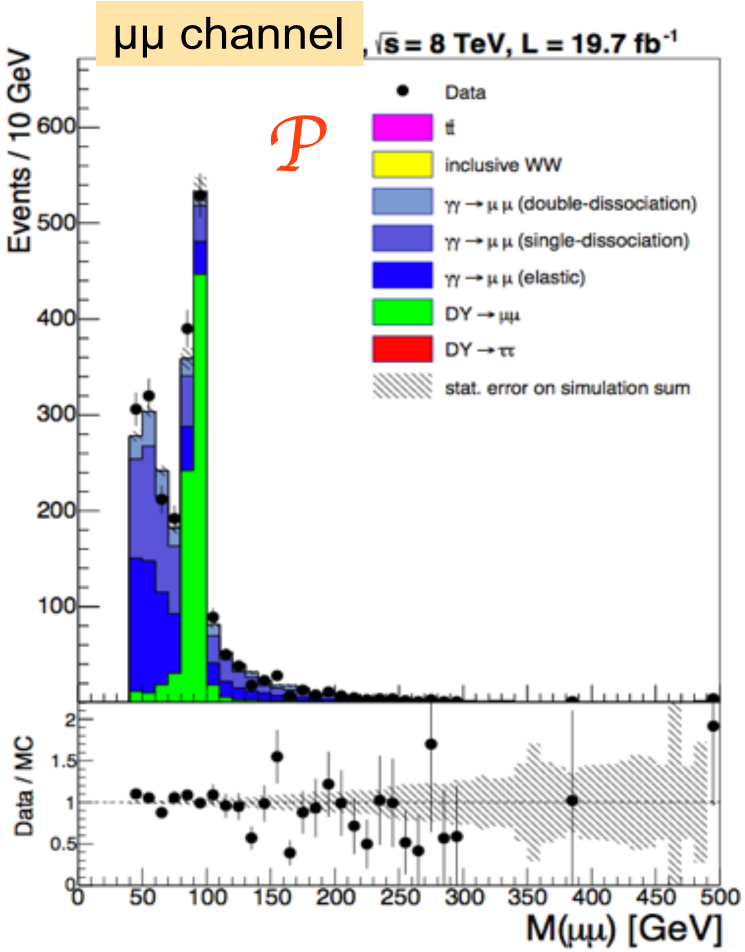
- To account for efficiency difference apply correction to 0 extra tracks efficiency
  - μμ channel: 0.63 ± 0.04, ee channel: 0.63 ± 0.07
- Efficiency difference is coming from MC not simulating well tracks from pileup vertices getting associated to the dilepton vertex in exclusive events
- Apply this correction to exclusive WW, exclusive $\tau\tau$ samples in signal region

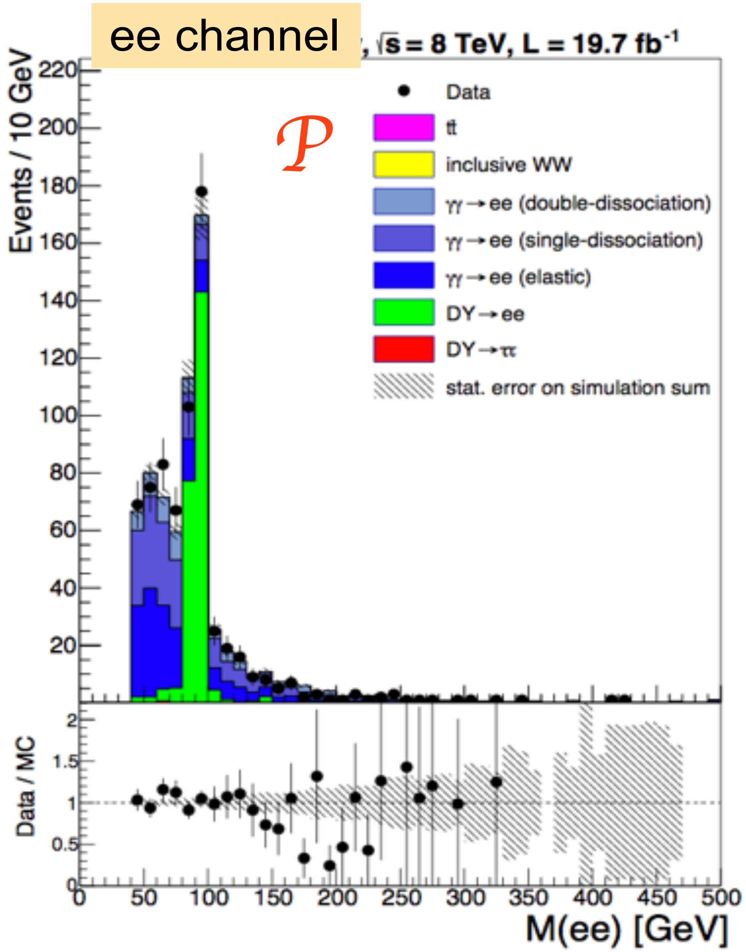


MC normalized to data for these plots

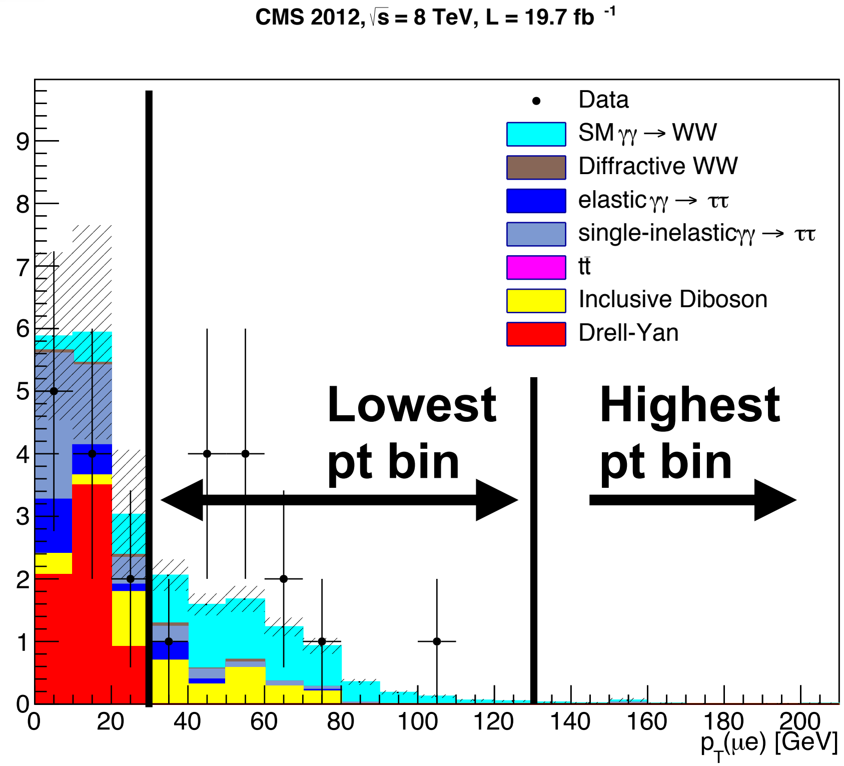
Efficiency correction (II)

- **Kinematic distributions agree well after efficiency correction, see backup slides for more distributions (MET, lepton pt, eta, number of primary vertices, etc.)**





γγ→WW aQGC search



- For $p_T(e\mu)$ = 30 GeV - 130 GeV:
  - 13 data events
  - 8.6±0.5 expected SM events (5.3±0.1 SM exclusive WW, 3.3±0.5 other background)
- For $p_T(e\mu)$>130 GeV no events in data. 0.1 SM exclusive WW events expected

AQGC exclusion limits (dimension 6 operators) 95% CL

With Form Factor, cutoff = 500 GeV

8 TeV:

$$-1.1 \times 10^{-4} < a_0^W/\Lambda^2 < 1.0 \times 10^{-4}\,\mathrm{GeV}^{-2}\ (a_C^W/\Lambda^2 = 0, \Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV}),$$
$$-4.2 \times 10^{-4} < a_C^W/\Lambda^2 < 3.5 \times 10^{-4}\,\mathrm{GeV}^{-2}\ (a_0^W/\Lambda^2 = 0, \Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV}).$$

7 TeV:

$$-0.00015 < a_0^W/\Lambda^2 < 0.00015\,\mathrm{GeV}^{-2}\ (a_C^W/\Lambda^2 = 0, \Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV}),$$
$$-0.0005 < a_C^W/\Lambda^2 < 0.0005\,\mathrm{GeV}^{-2}\ (a_0^W/\Lambda^2 = 0, \Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV}).$$

8 TeV limit ~25% better than 7 TeV limit

No Form Factor

8 TeV:

$$-1.2 \times 10^{-6} < a_0^W/\Lambda^2 < 1.2 \times 10^{-6}\,\mathrm{GeV}^{-2}\ (a_C^W/\Lambda^2 = 0, \text{no form factor}),$$
$$-4.5 \times 10^{-6} < a_C^W/\Lambda^2 < 4.5 \times 10^{-6}\,\mathrm{GeV}^{-2}\ (a_0^W/\Lambda^2 = 0, \text{no form factor}).$$

7 TeV:

$$-4.0 \times 10^{-6} < a_0^W/\Lambda^2 < 4.0 \times 10^{-6}\,\mathrm{GeV}^{-2}\ (a_C^W/\Lambda^2 = 0, \text{no form factor}),$$
$$-1.5 \times 10^{-5} < a_C^W/\Lambda^2 < 1.5 \times 10^{-5}\,\mathrm{GeV}^{-2}\ (a_0^W/\Lambda^2 = 0, \text{no form factor}).$$

8 TeV limit 3x better than 7 TeV limit

AQGC exclusion limits (dimension 8 operators)

Relationship between dimension 6 and dimension 8 operators.
-Additional constraint that the WWZγ vertex should vanish (similar to what is done in SMP-13-015)

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

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

With Form Factor, cutoff = 500 GeV

$$-4.2 \times 10^{-10} < f_{M,0}/\Lambda^4 < 3.8 \times 10^{-10}\,\mathrm{GeV}^{-4} \quad (\Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV}),$$
$$-16 \times 10^{-10} < f_{M,1}/\Lambda^4 < 13 \times 10^{-10}\,\mathrm{GeV}^{-4} \quad (\Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV}),$$
$$-2.1 \times 10^{-10} < f_{M,2}/\Lambda^4 < 1.9 \times 10^{-10}\,\mathrm{GeV}^{-4} \quad (\Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV}),$$
$$-8.0 \times 10^{-10} < f_{M,3}/\Lambda^4 < 6.6 \times 10^{-10}\,\mathrm{GeV}^{-4} \quad (\Lambda_{\mathrm{cutoff}} = 500\,\mathrm{GeV}).$$

AQGC exclusion limits (dimension 8 operators)

No Form Factor

$$-4.6\times10^{-12} < f_{M,0}/\Lambda^4 < 4.6\times10^{-12}\,\text{GeV}^{-4}\ \text{(no form factor)},$$
$$-17\times10^{-12} < f_{M,1}/\Lambda^4 < 17\times10^{-12}\,\text{GeV}^{-4}\ \text{(no form factor)},$$
$$-2.3\times10^{-12} < f_{M,2}/\Lambda^4 < 2.3\times10^{-12}\,\text{GeV}^{-4}\ \text{(no form factor)},$$
$$-8.5\times10^{-12} < f_{M,3}/\Lambda^4 < 8.5\times10^{-12}\,\text{GeV}^{-4}\ \text{(no form factor)}.$$

7-16 times more stringent than SMP-13-009 (Search for WWγ and WZγ)

Observed Limits
-77 (TeV^{-4}) $< f_{M,0}/\Lambda^4 <$ 81 (TeV^{-4})
-131 (TeV^{-4}) $< f_{M,1}/\Lambda^4 <$ 123 (TeV^{-4})
-39 (TeV^{-4}) $< f_{M,2}/\Lambda^4 <$ 40 (TeV^{-4})
-66 (TeV^{-4}) $< f_{M,3}/\Lambda^4 <$ 62 (TeV^{-4})

3-7 times more stringent than SMP-13-015 (Vector Boson Scattering)

TABLE II. Observed and expected upper and lower limits at 95% C.L. on the nine dimension-eight operators that affect quartic couplings between the weak gauge bosons. Limits from unitarity are reported. The units are TeV^{-4}.

Operator coefficient	Exp. lower	Exp. upper	Obs. lower	Obs. upper	Unitarity limit
$F_{S,0}/\Lambda^4$	−42	43	−38	40	0.016
$F_{S,1}/\Lambda^4$	−129	131	−118	120	0.050
$F_{M,0}/\Lambda^4$	−35	35	−33	32	80
$F_{M,1}/\Lambda^4$	−49	51	−44	47	205
$F_{M,6}/\Lambda^4$	−70	69	−65	63	160
$F_{M,7}/\Lambda^4$	−76	73	−70	66	105
$F_{T,0}/\Lambda^4$	−4.6	4.9	−4.2	4.6	0.027
$F_{T,1}/\Lambda^4$	−2.1	2.4	−1.9	2.2	0.022
$F_{T,2}/\Lambda^4$	−5.9	7.0	−5.2	6.4	0.08

caveat: don’t believe SMP-13-015 makes assumption that WWZ**γ** vertex should vanish