Exclusive physics results from CMS

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on behalf of CMS Collaboration

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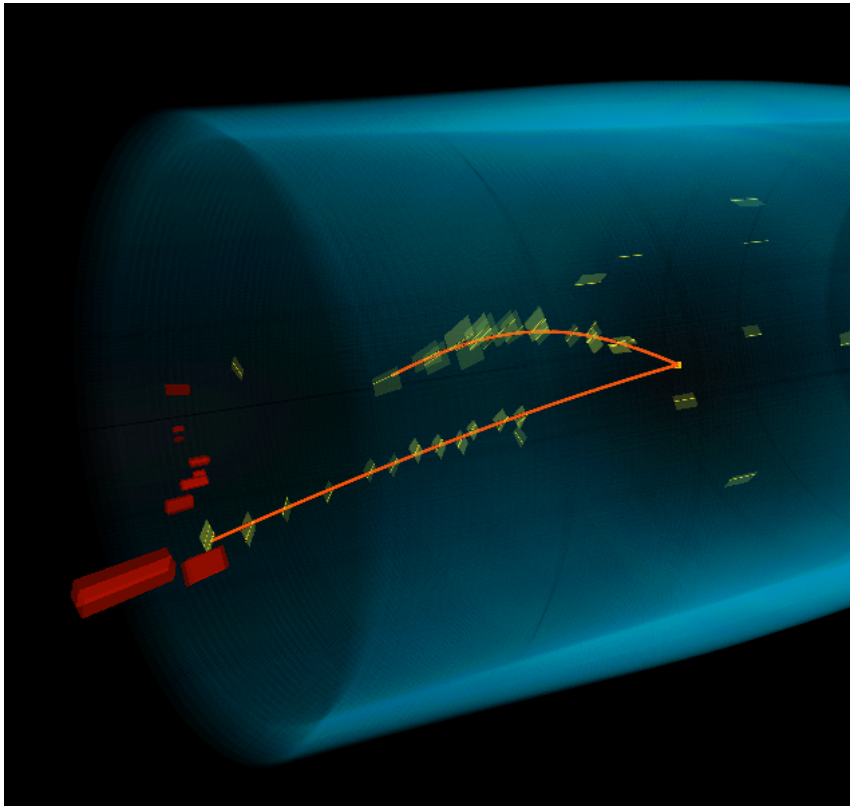
Debrecen, QCD@LHC

Exclusive physics processes

- Colliding particles remain intact.
- Low multiplicity central system is produced.
- Classification by exchanged object:
  - Photon-photon
  - Photon-pomeron
  - Pomeron-pomeron
  - ...
- Advantage: central system with **fixed quantum numbers**.

Photon: $I(J^{PC}) = 0, 1(1^{--})$

Pomeron: $I^G(J^{PC}) = 0^+(0^{++})$



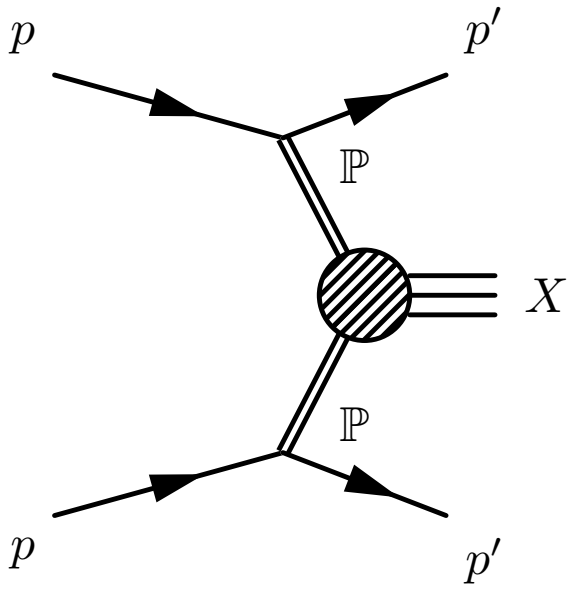
Exclusive $\pi\pi$ production (MC simulation)

- Exclusive $\pi\pi$ production in pp collisions: *arXiv:1706.08310 [hep-ex]*
- Exclusive photoproduction of Υ in pPb collisions: *CMS-PAS-FSQ-13-009*
- Search for $\gamma\gamma \to \mathrm{W}^+\mathrm{W}^-$ processes and limits on anomalous quartic gauge couplings: *arXiv:1604.04464 [hep-ex]*

Exclusive $\pi\pi$ production in pp collisions

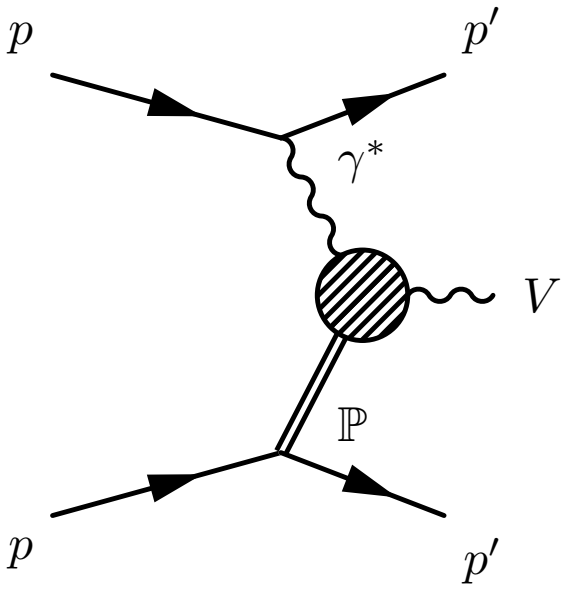
Motivation

- Restricted quantum numbers.
- Filter certain low mass resonances.
- Gluon-rich environment in DPE $\rightarrow$ glueball search.



Double pomeron exchange (DPE)

$I^G(J^{PC}) = 0^+(J^{++})$, J is even



Vector meson photoproduction

$I(J^{PC}) = 0, 1(1^{--})$

Dataset, trigger, event selections

Dataset: low-pileup data at $\sqrt{s} = 7$ TeV, 450 μb^{-1}

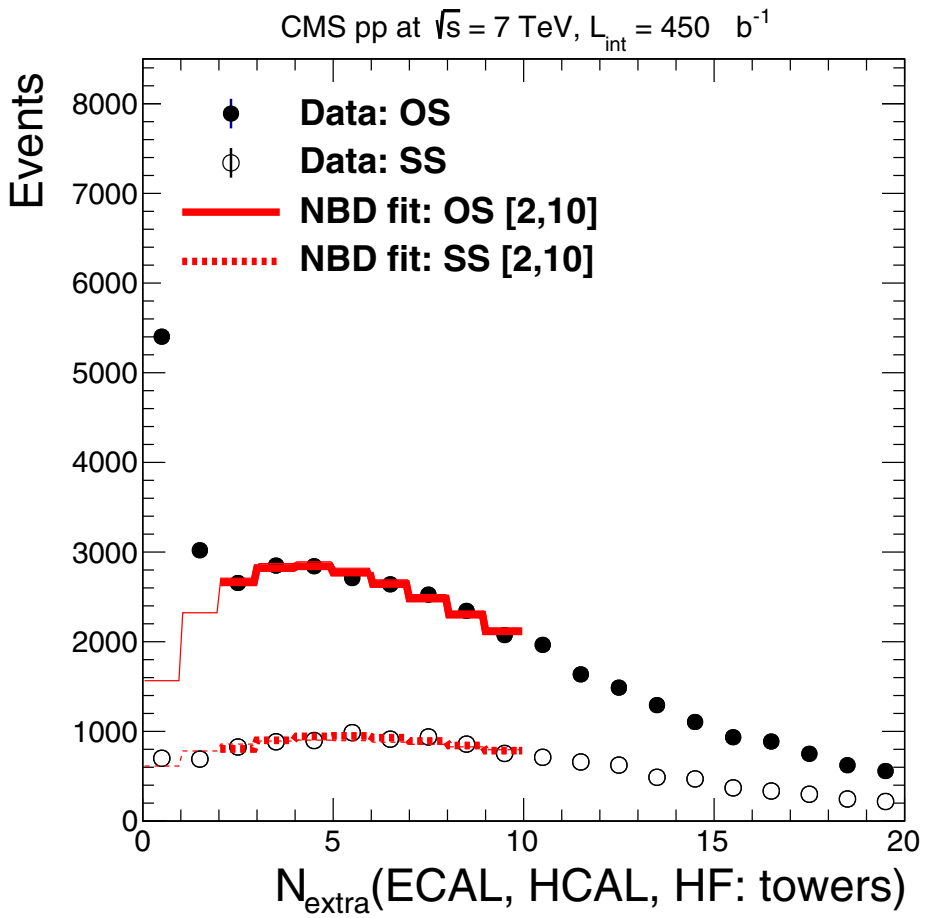
Trigger: random bunch-crossings (zero bias).

Event selection:

- Two tracks, passing high purity criteria.
- Single interaction vertex.
- No activity in calorimeters,
  except $\Delta R < 0.1$ cone around track hits.
- $p_T(\pi) > 0.2$ GeV, $|y(\pi)| < 2$.

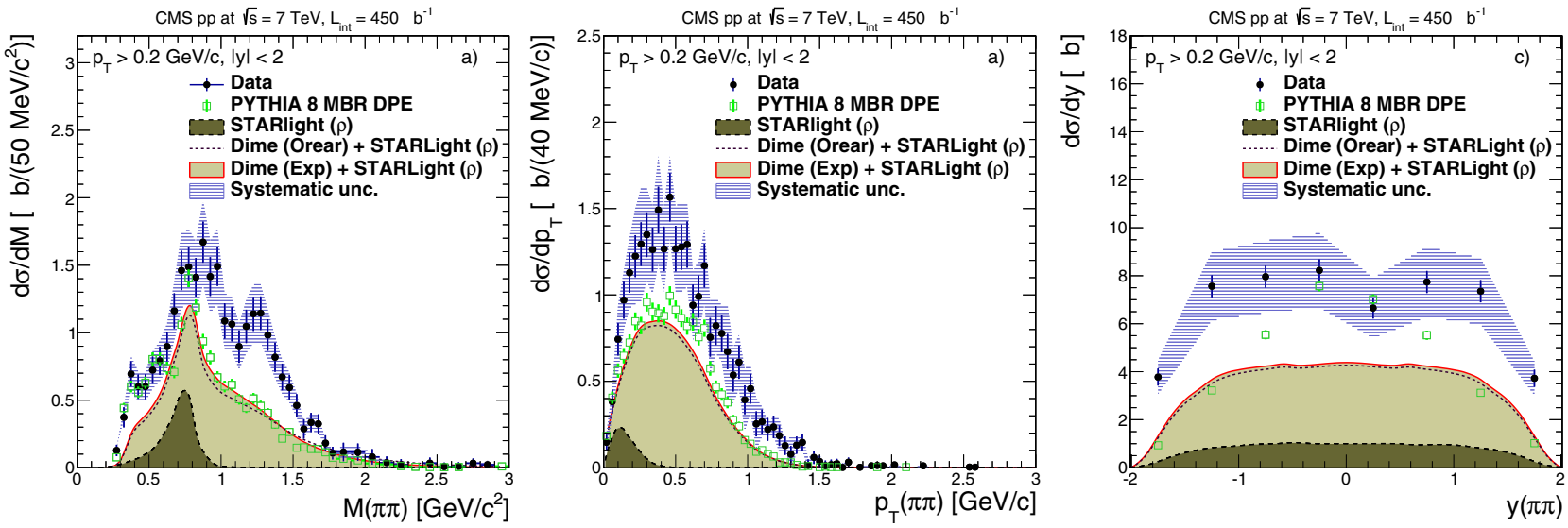
- Inclusive background estimation: control sample with extra calorimeter activity.

Background estimation



- Using a sample with extra calorimeter hits.
- Background shape from the region of 2 – 10 extra calorimeter hits.
- Normalization: fit with negative binomial distribution.
- Systematic uncertainties are calculated from varying the fit range of the background control region.

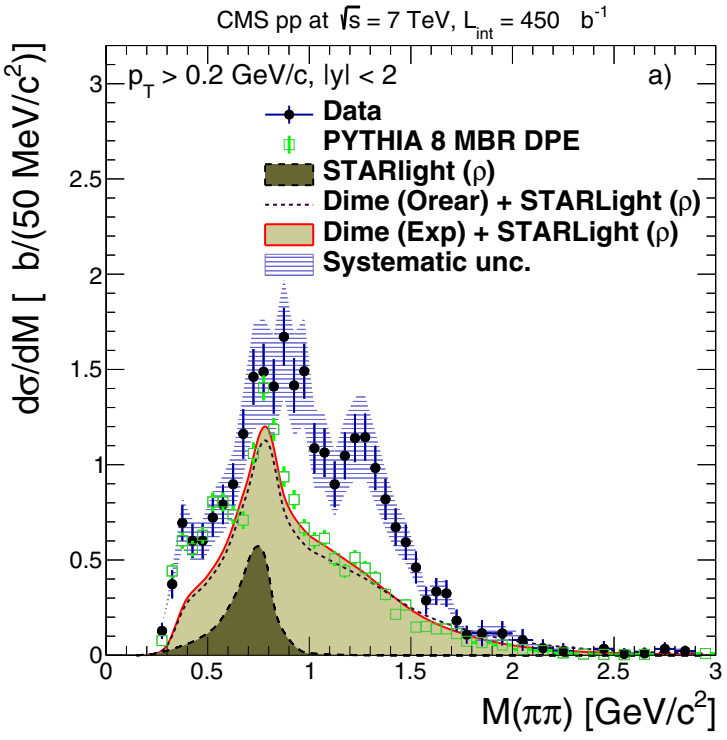
Results



- Cross-sections are unfolded by iterative Bayesian method.
- Monte Carlo simulations:
  - STARLIGHT: exclusive $\rho(770)$ photoproduction.
  - DIME MC: DPE continuum contribution.
- No simulation describes certain low mass resonances (f_0 and f_2).
- Total exclusive $\pi^+\pi^-$ cross section in $p_T(\pi) > 0.2$ GeV, $|y| < 2$ region:

$$\sigma = 26.5 \pm 0.3\,(\text{stat.}) \pm 5.0\,(\text{syst.}) \pm 1.1\,(\text{lumi})\ \mu b$$

Results – invariant mass distribution



- Slightly larger cross section measured in the region of $\rho(770)$ $\rightarrow$ semi-exclusive processes are not modelled by MC.
- Sharp drop at around 1 GeV.
  - Indication of $f_0(980)$ resonance.
  - Interference between resonance and continuum.
- Significant peak at $f_2(1270)$.
- $f_0(980)$ and $f_2(1270)$ parameters are consistent with PDG values.

Exclusive photoproduction of ϒ in pPb collisions

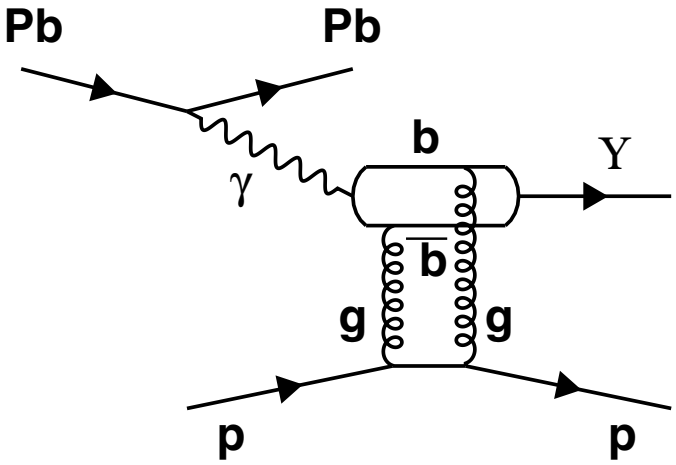
Motivation

- First observation of this process in pPb collisions
- Enchanced photoproduction cross-section due to high photon flux ($\propto Z^2$).
- Production cross-section is related to gluon PDF of proton:

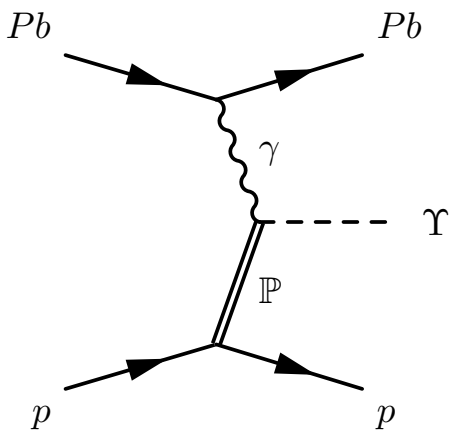
$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} \propto (x\, G(x, Q^2))^2$$

- Probing gluon density in unexplored $x \approx 10^{-2} - 10^{-4}$ region.

pQCD description



Regge theory

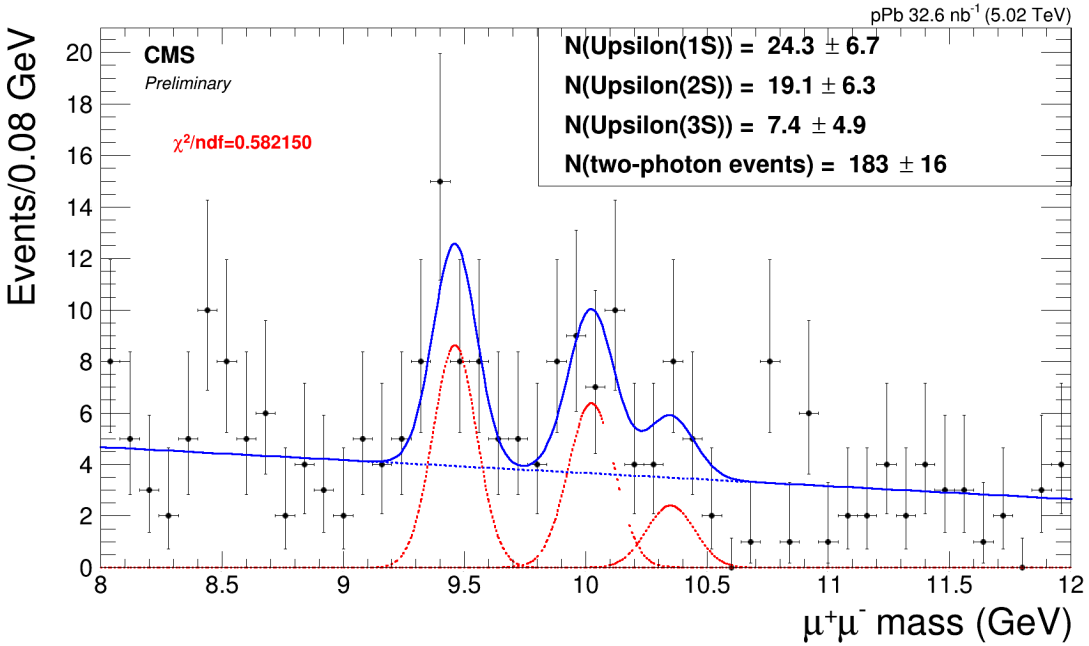


Trigger, event selection

Trigger: single muon + $N_{tracks} \leq 6$.

Event selection:

- $p_T(\mu) > 3.3$ GeV, $|y| < 2.2$
- $p_T(\mu\mu) \in [0.1, 1]$ GeV
  - Low-p_T: reduce $\gamma\gamma \to \mu\mu$
  - High-p_T: reduce inclusive and semi-exclusive ϒ production



Fit of three Gaussians to ϒ(1S), ϒ(2S) and ϒ(3S).
Parameters: linear background, amplitudes and ϒ(1S) width.

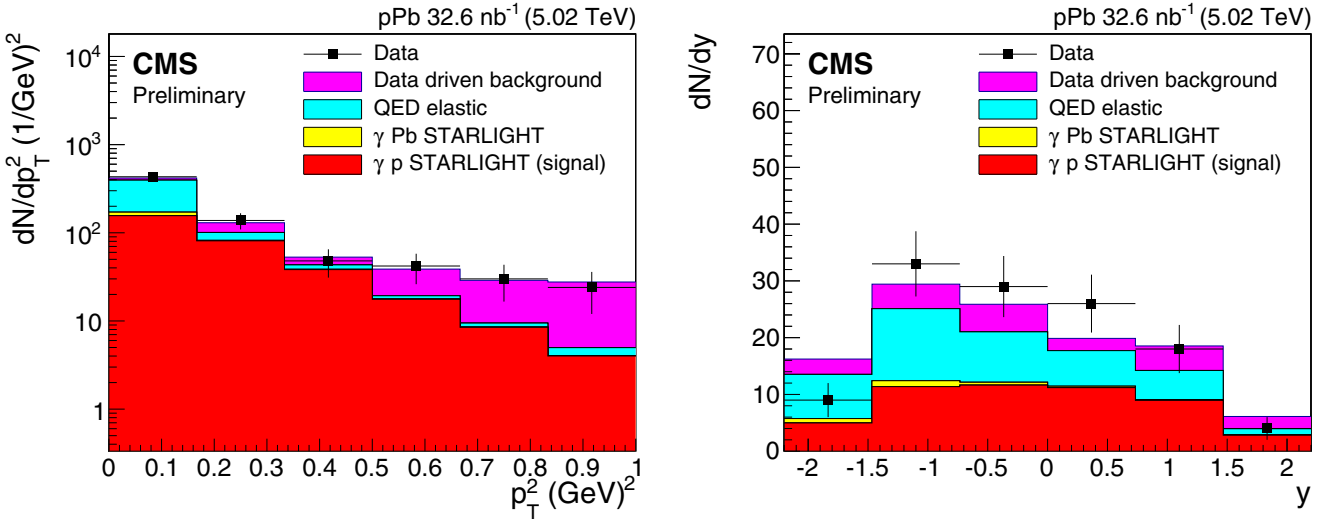
Simulation results

- STARLIGHT MC simulation is used.
- Cross-section is re-weighted to data, according to:

$$\frac{d\sigma}{d|t|} \propto e^{-b|t|}$$

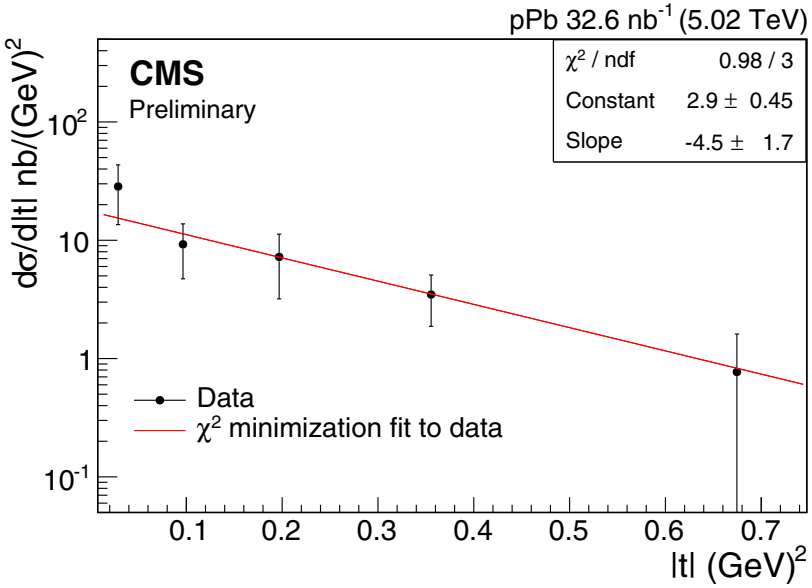
$$\sigma(W_{\gamma p}) \propto (W_{\gamma p})^{\delta}$$

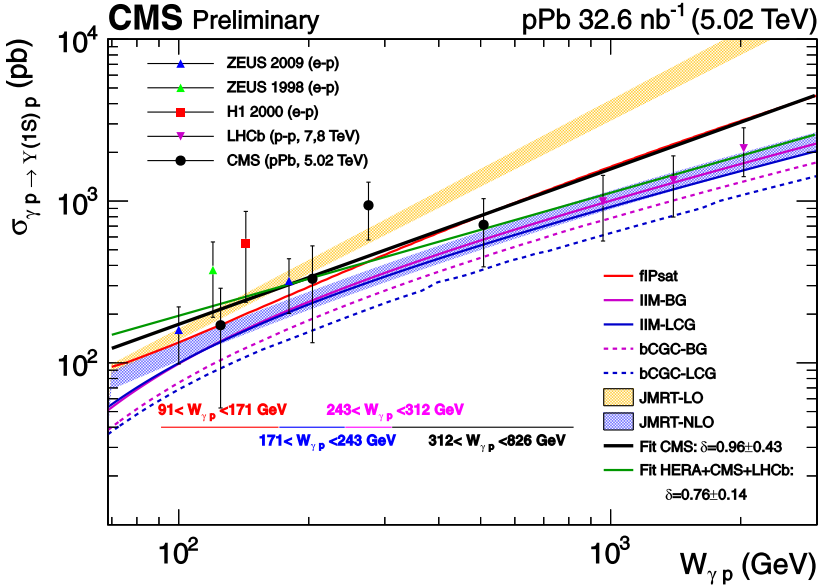
- Good agreement between data and MC:



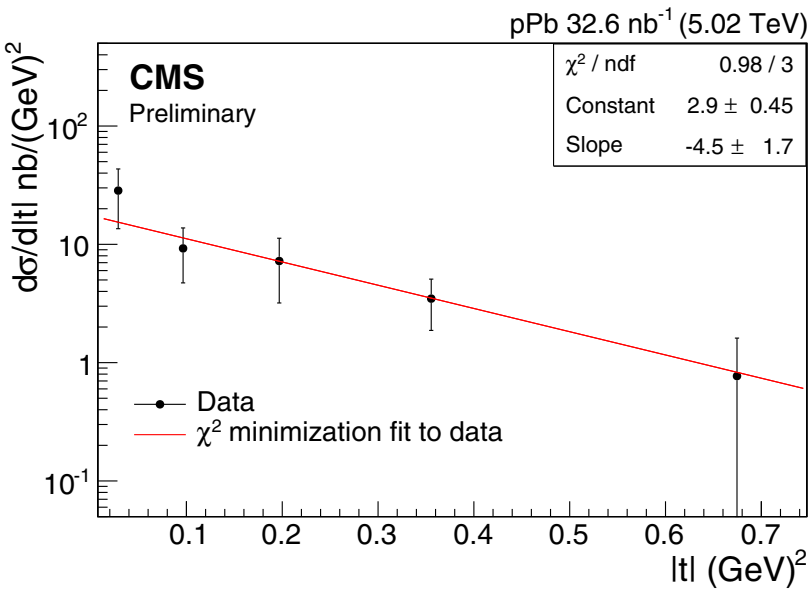
Results

- Cross-section is unfolded by iterative Bayesian method.
- $p_T^2(\mu\mu) \approx |t|$ used to get $\mathrm{d}\sigma/\mathrm{d}|t|$.
- Exponential fit for $\mathrm{d}\sigma/\mathrm{d}|t|$ and power law fit for $\sigma(W_{\gamma p})$





$d\sigma/d|t|$ fit results



- Fit function:

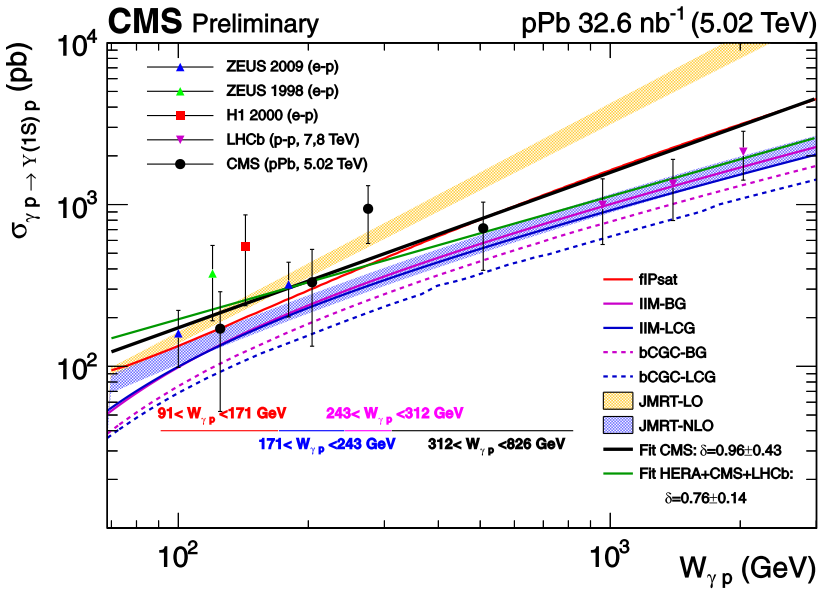
$$\frac{d\sigma}{d|t|} = Ne^{-b|t|}$$

- $b = 4.5 \pm 1.7\,(\text{stat.}) \pm 0.6\,(\text{syst.})\ \text{GeV}^{-2}$

Compatible with HERA measurements:

- H1: $4.73 \pm 0.25\,(\text{stat.})\ \text{GeV}^{-2}$ (arXiv:hep-ex/0003020)
- Zeus: $4.3^{+2.0}_{-1.3}$, (stat.) GeV^{-2} (arXiv:1111.2133)

$\sigma(W_{\gamma p})$ fit results



- Calculated from $\mathrm{d}\sigma/\mathrm{d}y$:

$$\sigma_{\gamma p} = \frac{1}{\phi}\frac{\mathrm{d}\sigma_{\Upsilon(1S)}}{\mathrm{d}y} \propto (W_{\gamma p})^2,$$

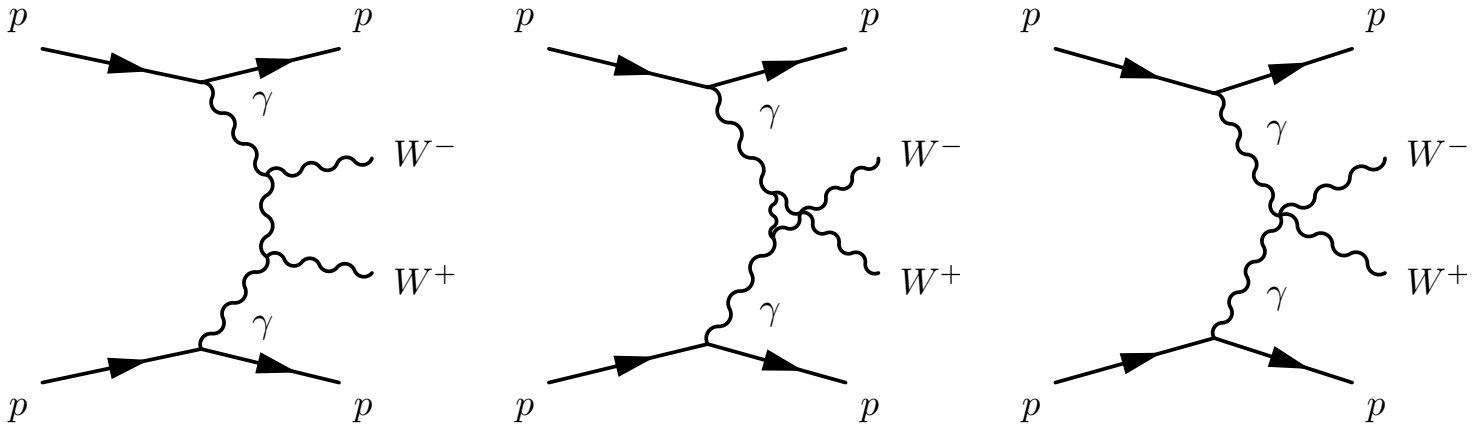
  where ϕ is photon flux – from STARLIGHT.
- Combined fit to HERA and LHC results.
- Disfavours LO pQCD results.
- Consistent with NLO pQCD calculations.
- Consistent with color dipole predictions.
- Color glass condensate models systematically underestimates underestimates cross-section, but still consistent within uncertainties.

Search for $\gamma\gamma \to W^+W^-$ processes and limits on anomalous quartic gauge couplings

Exclusive *WW* production

$$\mathrm{pp} \longrightarrow \mathrm{p(*)} + \mathrm{WW} + \mathrm{p(*)} \longrightarrow \mathrm{p(*)} + \ell^+\ell'^-\nu\bar{\nu} + \mathrm{p(*)}$$

Leading order processes at LHC energy:



Datasets, trigger and event selection

Datasets:

- 7 TeV: 5.5 fb^{-1}
- 8 TeV: 19.7 fb^{-1}

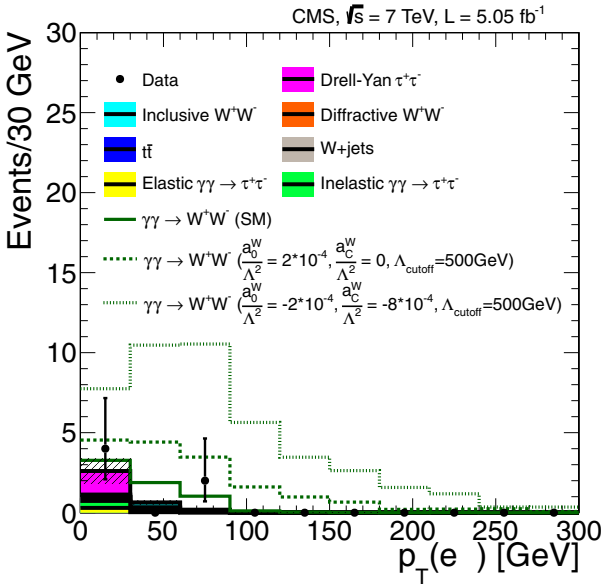
Trigger: two leptons with $p_T(\ell) > 17$ GeV for the leading and $p_T(\ell) > 8$ GeV for the subleading lepton.

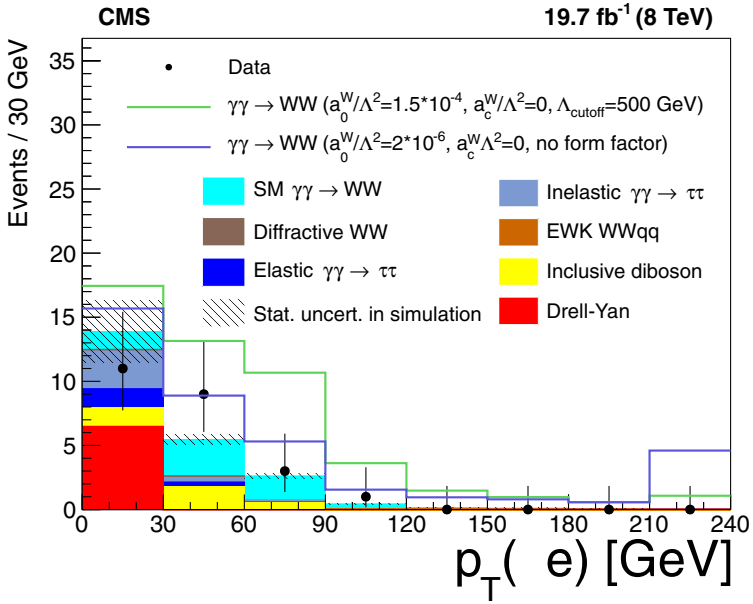
Event selection:

- Opposite charged $e^{\pm}\mu^{\mp}$ pair.
- $p_T(\mu)$, $E_T(e) > 20$ GeV and $|\eta(\mu, e)| < 2.4$.
- Common vertex with no other tracks.
- $M(e\mu) > 20$ GeV.
- $\ell^+\ell^-$ samples used as control samples.

Signal region: $p_T(e\mu) > 30$ GeV.

Results





Selection step	7 TeV	8 TeV
Trigger	9086	19406
$m(e\mu) > 20$ GeV	8200	19406
Leptons ID	1222	6541
No extra tracks	6	24
$p_T(e\mu) > 30$ GeV	**2**	**13**

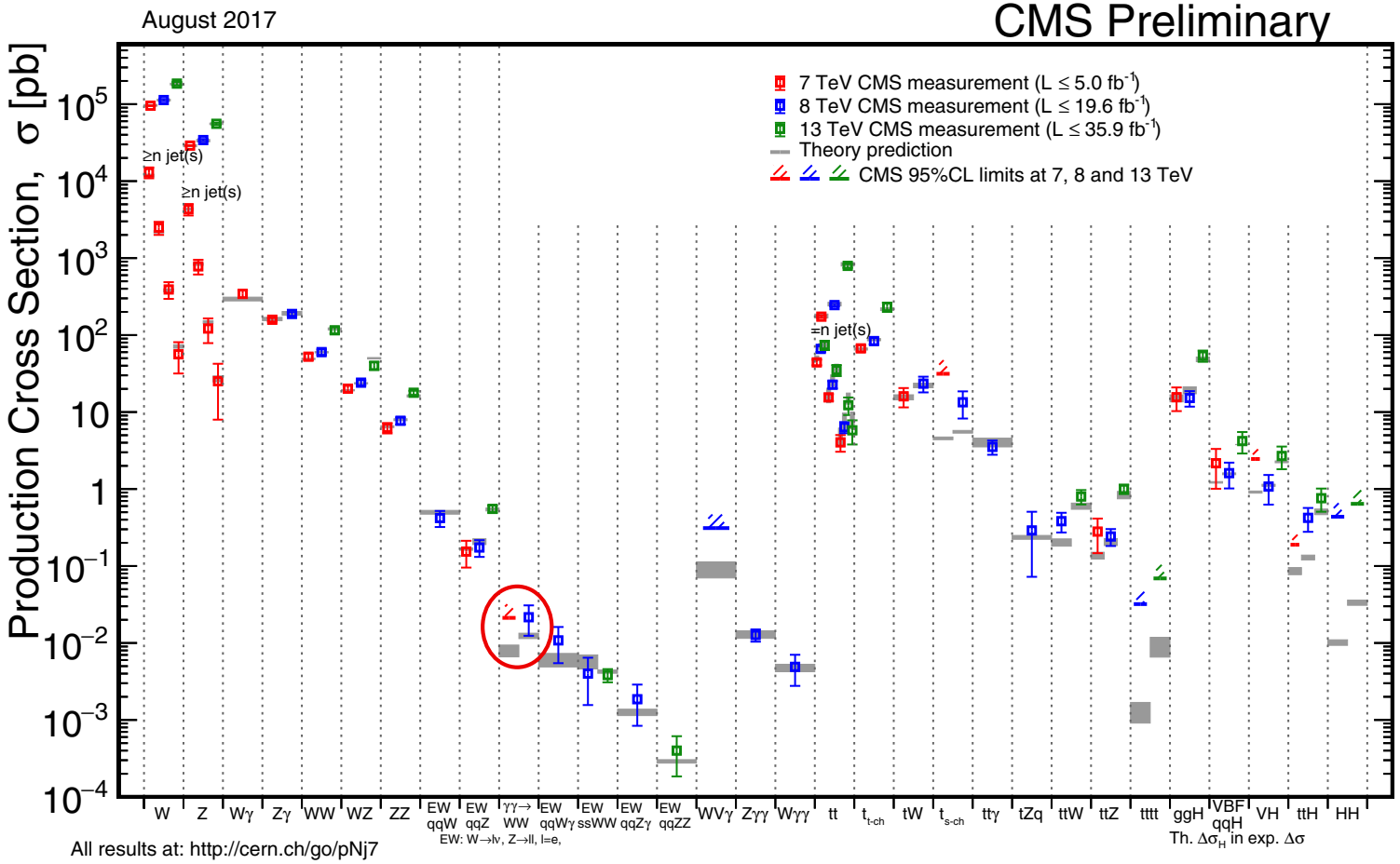
Observed cross-section for process $pp \to p^{(*)}(\gamma\gamma \to W^+W^- \to e^\pm\mu^\mp\nu\bar{\nu})p^{(*)}$:

- at 7 TeV: $\sigma_{\text{obs}} = 2.2^{+3.3}_{-2.0}$ fb, $\sigma_{SM} = 4.0 \pm 0.7$ fb
- at 8 TeV: $\sigma_{\text{obs}} = 11.9^{+5.6}_{-4.5}$ fb, $\sigma_{SM} = 6.9 \pm 0.6$ fb

Consistent with SM

Combined significance: 3.4 σ

One of the lowest cross-section process observed at LHC:



Anomalous gauge couplings

- SM allows gauge couplings obeying gauge invariance.
- Effective models can have other gauge couplings $\to$ signs of new physics beyond SM (SUSY, extra dimensions, additional gauge bosons. . .).
- Extra terms in effective Lagrangian:
  - 6-dimensional, 'LEP-legacy' model:

$$\mathcal{L}_6^c = -\frac{e^2}{16}\frac{a_c^W}{\Lambda}F_{\mu\alpha}F^{\nu\beta}(W^{+\alpha}W_\beta^- - W^{-\alpha}W_\beta^+) + \dots$$
$$\mathcal{L}_6^0 = -\frac{e^2}{8}\frac{a_0^W}{\Lambda}F_{\mu\nu}F^{\mu\nu}(W^{+\alpha}W_\alpha^-) + \dots$$

- Λ is the energy scale of new physics.

Anomalous gauge couplings

- 8-dimensional operators ($f_{M,0-3}$), expressed with 6-dimensionals:

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

$$(g = e/\sin\theta_W \text{ and } g' = e/\cos\theta_W)$$

- Assuming that $WWZ\gamma$ vanishes:

$$f_{M,0} = 2f_{M,2}$$
$$f_{M,1} = 2f_{M,3}$$

- 6-dimensional operators were ruled out by LEP.

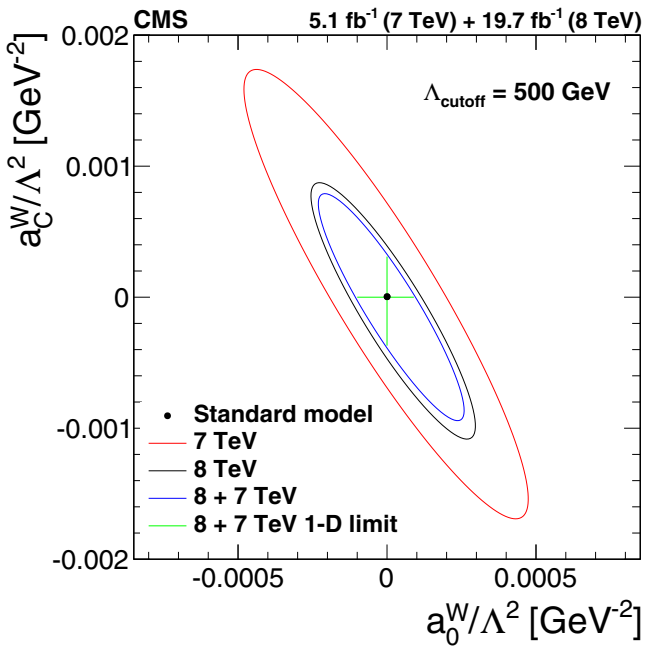
Limits on AQGCs

Assuming unitarity restoring form factor with $\Lambda_{\text{cutoff}} = 500$ GeV:

$$a_{0,C}^{W} \longrightarrow \frac{a_{0,C}^{W}}{1 + \frac{W_{\gamma\gamma}}{\Lambda_{\text{cutoff}}}}$$

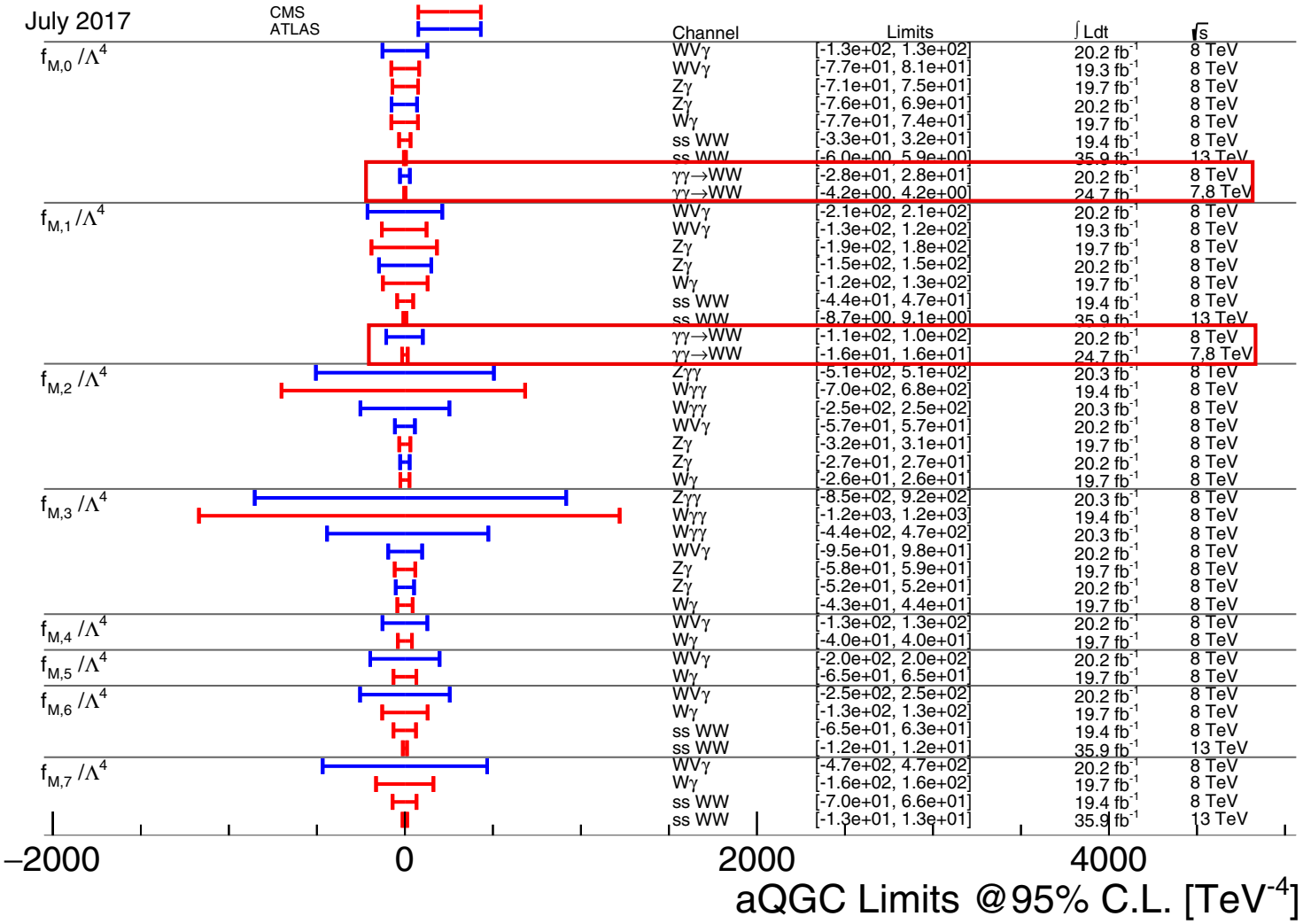
7+8 TeV combined limits:

- a_0^W/Λ^2: $[-0.9, 0.9] \times 10^{-4}$ GeV^{-2}
- a_C^W/Λ^2: $[-3.6, 3.0] \times 10^{-4}$ GeV^{-2}



Most stringent limit on $f_{0,M}$ operator, two magnitudes lower than LEP results.

Comparison with other results



Summary

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- Exclusive $\pi\pi$ production in pp collisions:
  - ρ_0, $f_0(980)$ and $f_2(1270)$ are observed in the invariant mass distribution.
  - Total exclusive $\pi^+\pi^-$ cross section in $p_T(\pi) > 0.2$ GeV, $|y| < 2$ region:

$$\sigma = 26.5 \pm 0.3\,(\text{stat.})\ \pm 5.0\,(\text{syst.})\ \pm 1.1\,(\text{lumi})\ \mu b$$

- Exclusive photoproduction of Υ in pPb collisions:
  - First observation of this process in hadron-nucleus collisions.
  - Differential cross sections as a function of $|t|$ and y are measured.
  - Better picture of gluon density evolution at low-x.
- Search for $\gamma\gamma \to \mathrm{W}^+\mathrm{W}^-$ processes and limits on anomalous quartic gauge couplings:
  - Evidence set for this process (3.7σ observed significance).
  - Most stringent limits on $f_{0,M}$ operator.

Thank you for your attention!