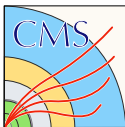# Exclusive physics results from CMS

Olivér Surányi

on behalf of CMS Collaboration

Wigner RCP
Eötvös Loránd University
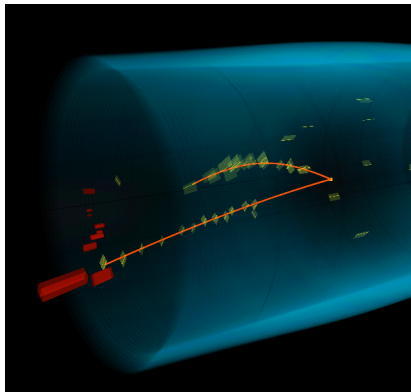Budapest, Hungary

8. December 2016

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: $I(J^{PC}) = 0, 1(1^{--})$
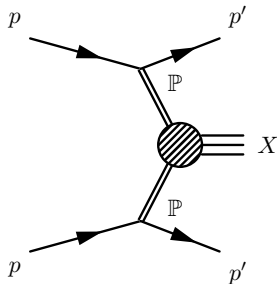Pomeron: $I^G(J^{PC}) = 0^+(0^{++})$

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

- Exclusive $\pi\pi$ production in pp collisions:
  CMS-PAS-FSQ-12-004

- Exclusive photoproduction of Υ in pPb collisions:
  CMS-PAS-FSQ-13-009

- Search for $\gamma\gamma \to W^+W^-$ processes and limits on anomalous quartic gauge couplings:
  arXiv:1604.04464 [hep-ex]

Exclusive $\pi\pi$ production in pp collisions
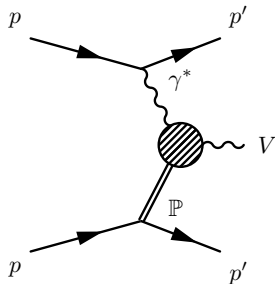
Motivation

- 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

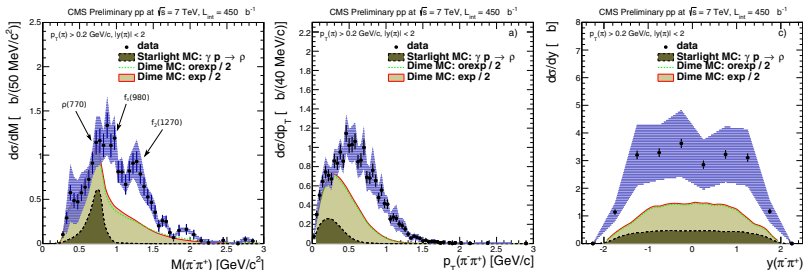**Dataset:** low-pileup data at $\sqrt{s} = 7$ TeV, 450 μb^{-1}

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, $|y(\pi)| < 2.0$.

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

Results

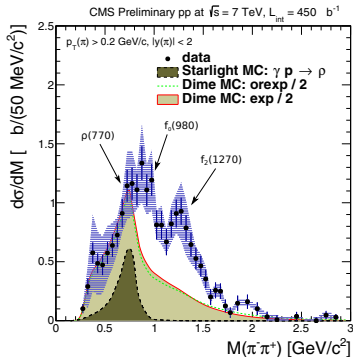- Cross-sections are unfolded by iterative Bayesian method.
- Monte Carlo simulations:
    - STARLIGHT: exclusive $\rho(770)$ photoproduction.
    - DIME MC: DPE continuum contribution.
- No simulation describes certain low mass resonances (f_0 and f_2).
- Total cross section in $p_T(\pi) > 0.2$ GeV,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

$$\sigma = 20.5 \pm 0.3\,(\text{stat.}) \pm 3.1\,(\text{syst.}) \pm 0.8\,(\text{lumi})\ \mu b$$

Results – invariant mass distribution

- Good agreement with MC in the region of $\rho(770)$.
- Sharp drop at around 1 GeV.
  - Indication of $f_0(980)$ resonance.
  - Interference between resonance and continuum.
- Significant peak at $f_2(1270)$.
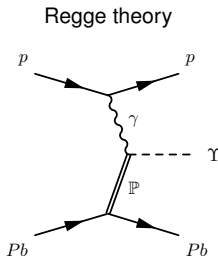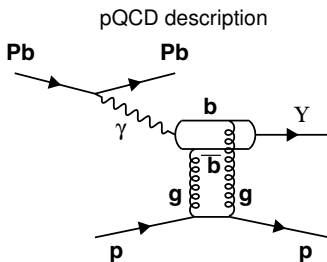
Exclusive photoproduction of ϒ in pPb collisions

Motivation

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

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

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

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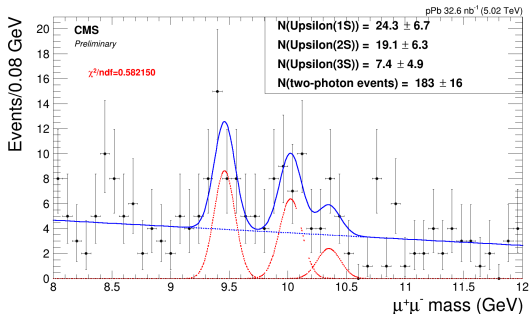
Fit of three Gaussians to $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$.
Parameters: linear background, amplitudes and $\Upsilon(1S)$ width.

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:
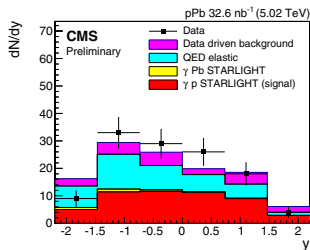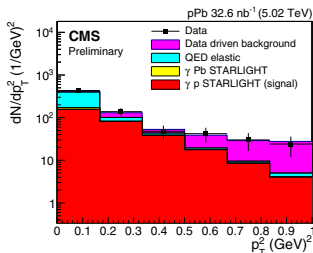
Results

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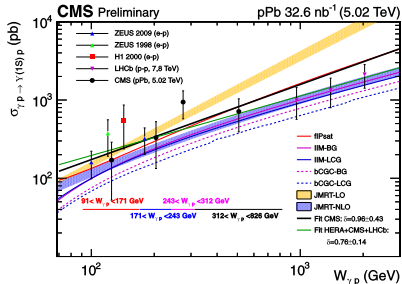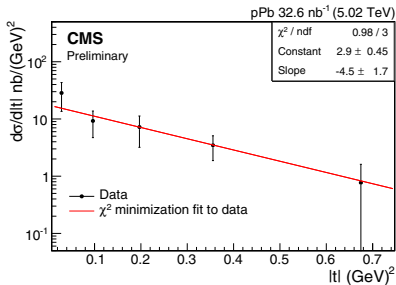
dσ/d|t| fit results
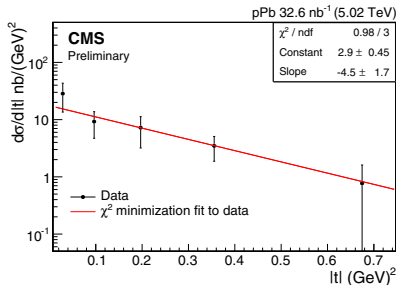
- Fit function:

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

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

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)

$\sigma(W_{\gamma p}^2)$ fit results
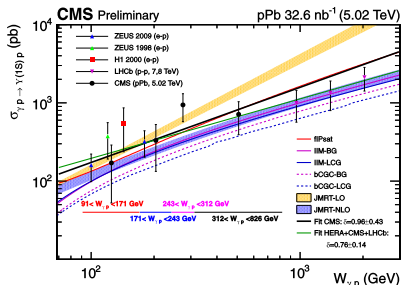
- Calculated from $d\sigma/dy$:

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

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.
- CGC 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

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:

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

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

- Λ is the energy scale of new physics.

Exclusive *WW* production

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

Leading order processes at LHC energy:

SM processes   AQGC - non SM
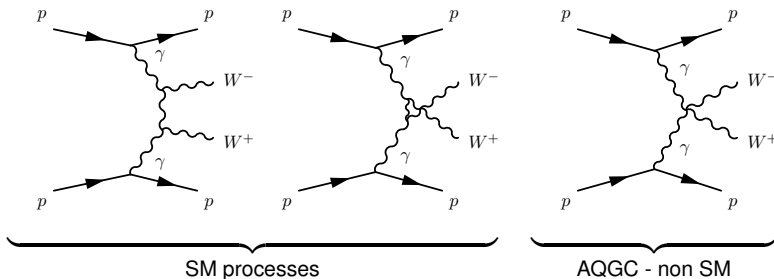
Datasets, trigger and event selection

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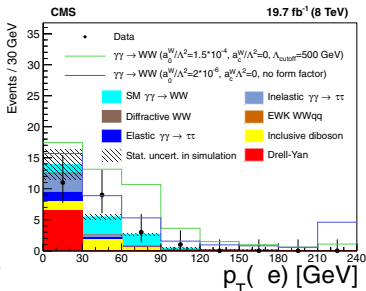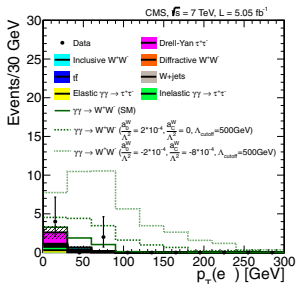
Selection step	7 TeV	8 TeV
Trigger	9086	19406
$m(e\mu) > 20$ GeV	8200	19406
Leptons ID	1222	6541
No extra tracks	6	24
$p_T(e\mu) > 30$ GeV	**2**	**13**

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:
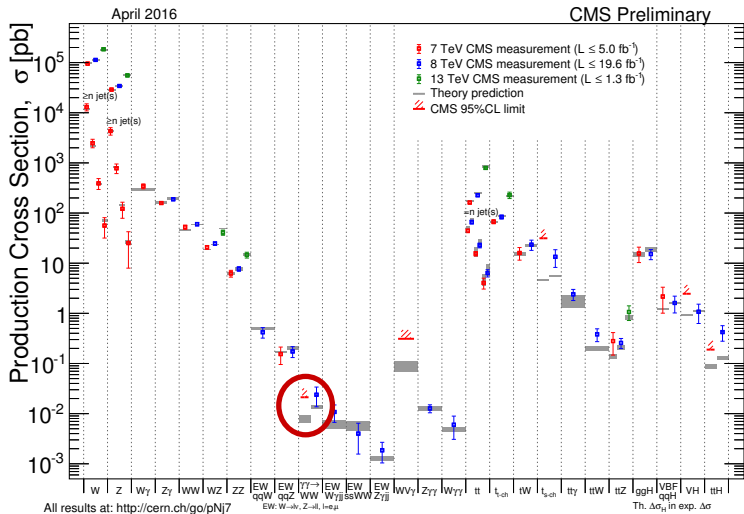
Limits on AQGCs

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

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

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 these operators,
two magnitudes lower than LEP results.**

Comparison with previous results

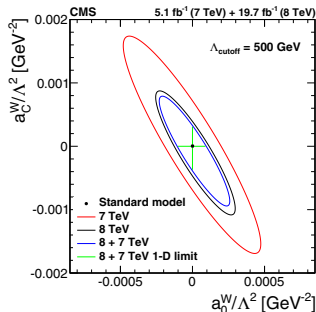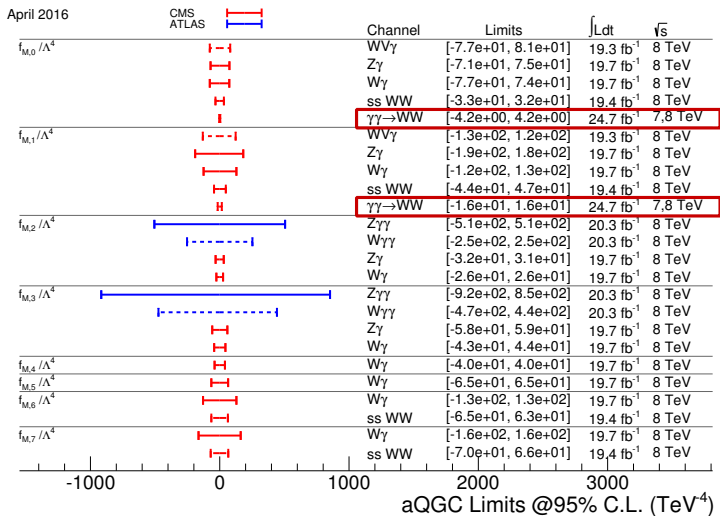|	Channel	Limits	$\int Ldt$	$\sqrt{s}$
April 2016				
$f_{M,0}/\Lambda^4$	WVγ	[-7.7e+01, 8.1e+01]	19.3 fb^{-1}	8 TeV
	Zγ	[-7.1e+01, 7.5e+01]	19.7 fb^{-1}	8 TeV
	Wγ	[-7.7e+01, 7.4e+01]	19.7 fb^{-1}	8 TeV
	ss WW	[-3.3e+01, 3.2e+01]	19.4 fb^{-1}	8 TeV
	$\gamma\gamma \rightarrow$WW	[-4.2e+00, 4.2e+00]	24.7 fb^{-1}	7,8 TeV
$f_{M,1}/\Lambda^4$	WVγ	[-1.3e+02, 1.2e+02]	19.3 fb^{-1}	8 TeV
	Zγ	[-1.9e+02, 1.8e+02]	19.7 fb^{-1}	8 TeV
	Wγ	[-1.2e+02, 1.3e+02]	19.7 fb^{-1}	8 TeV
	ss WW	[-4.4e+01, 4.7e+01]	19.4 fb^{-1}	8 TeV
	$\gamma\gamma \rightarrow$WW	[-1.6e+01, 1.6e+01]	24.7 fb^{-1}	7,8 TeV
$f_{M,2}/\Lambda^4$	Z$\gamma\gamma$	[-5.1e+02, 5.1e+02]	20.3 fb^{-1}	8 TeV
	W$\gamma\gamma$	[-2.5e+02, 2.5e+02]	20.3 fb^{-1}	8 TeV
	Zγ	[-3.2e+01, 3.1e+01]	19.7 fb^{-1}	8 TeV
	Wγ	[-2.6e+01, 2.6e+01]	19.7 fb^{-1}	8 TeV
$f_{M,3}/\Lambda^4$	Z$\gamma\gamma$	[-9.2e+02, 8.5e+02]	20.3 fb^{-1}	8 TeV
	W$\gamma\gamma$	[-4.7e+02, 4.4e+02]	20.3 fb^{-1}	8 TeV
	Zγ	[-5.8e+01, 5.9e+01]	19.7 fb^{-1}	8 TeV
	Wγ	[-4.3e+01, 4.4e+01]	19.7 fb^{-1}	8 TeV
$f_{M,4}/\Lambda^4$	Wγ	[-4.0e+01, 4.0e+01]	19.7 fb^{-1}	8 TeV
$f_{M,5}/\Lambda^4$	Wγ	[-6.5e+01, 6.5e+01]	19.7 fb^{-1}	8 TeV
$f_{M,6}/\Lambda^4$	Wγ	[-1.3e+02, 1.3e+02]	19.7 fb^{-1}	8 TeV
	ss WW	[-6.5e+01, 6.3e+01]	19.4 fb^{-1}	8 TeV
$f_{M,7}/\Lambda^4$	Wγ	[-1.6e+02, 1.6e+02]	19.7 fb^{-1}	8 TeV
	ss WW	[-7.0e+01, 6.6e+01]	19.4 fb^{-1}	8 TeV

aQGC Limits @95% C.L. (TeV^{-4})

(plot from twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC)

Summary

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  anomalous quartic gauge couplings:
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Thank you for your attention!