Diffractive and Exclusive results from CMS

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EDS Blois 2017 – Prague - 26th to 30th June

CMS Compact Muon Solenoid

CERN

CBPF Centro Brasileiro de Pesquisas Físicas

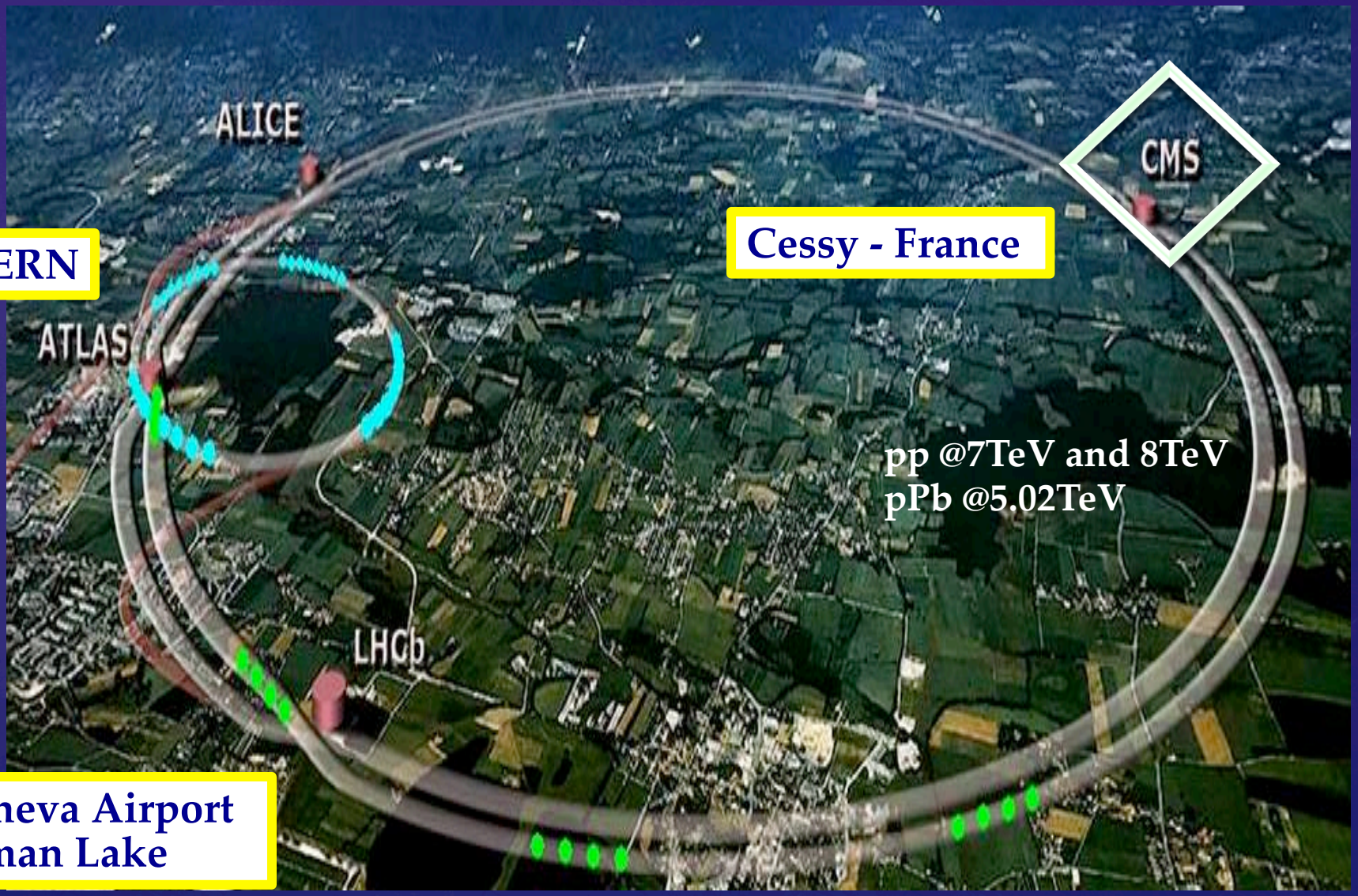
Outline:

- **LHC & CMS Detectors (central and forward)**
- **Exclusive di-hadron production in pp @7TeV** [1]
- **Exclusive ϒ production in p-Pb @5.02 TeV** [2]
- **Evidence of exclusive W+W- production @7 & 8TeV** [3]
- **Summary**

[1] CMS PAS FSQ-12-004
[2] CMS PAS FSQ-13-009
[3] JHEP08(2016)119

All CMS results of Forward and Small-x QCD Physics group can be found in the links below:
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/FSQ/index.html
http://cms-results.web.cern.ch/cms-results/public-results/publications/FSQ/index.html

Large Hadron Collider @ CERN

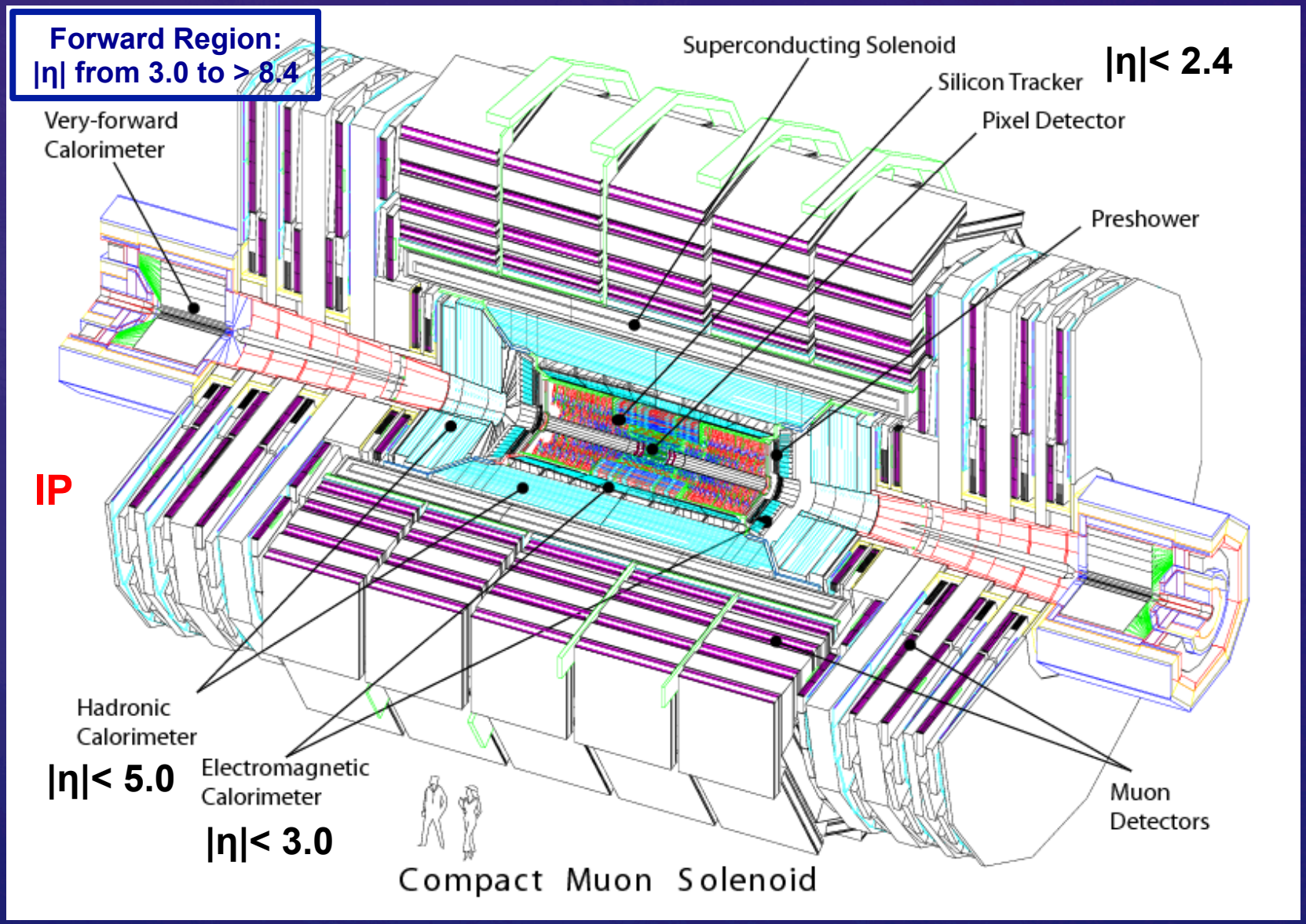


CERN

Cessy - France

Geneva Airport
Leman Lake

The CMS central & forward detectors



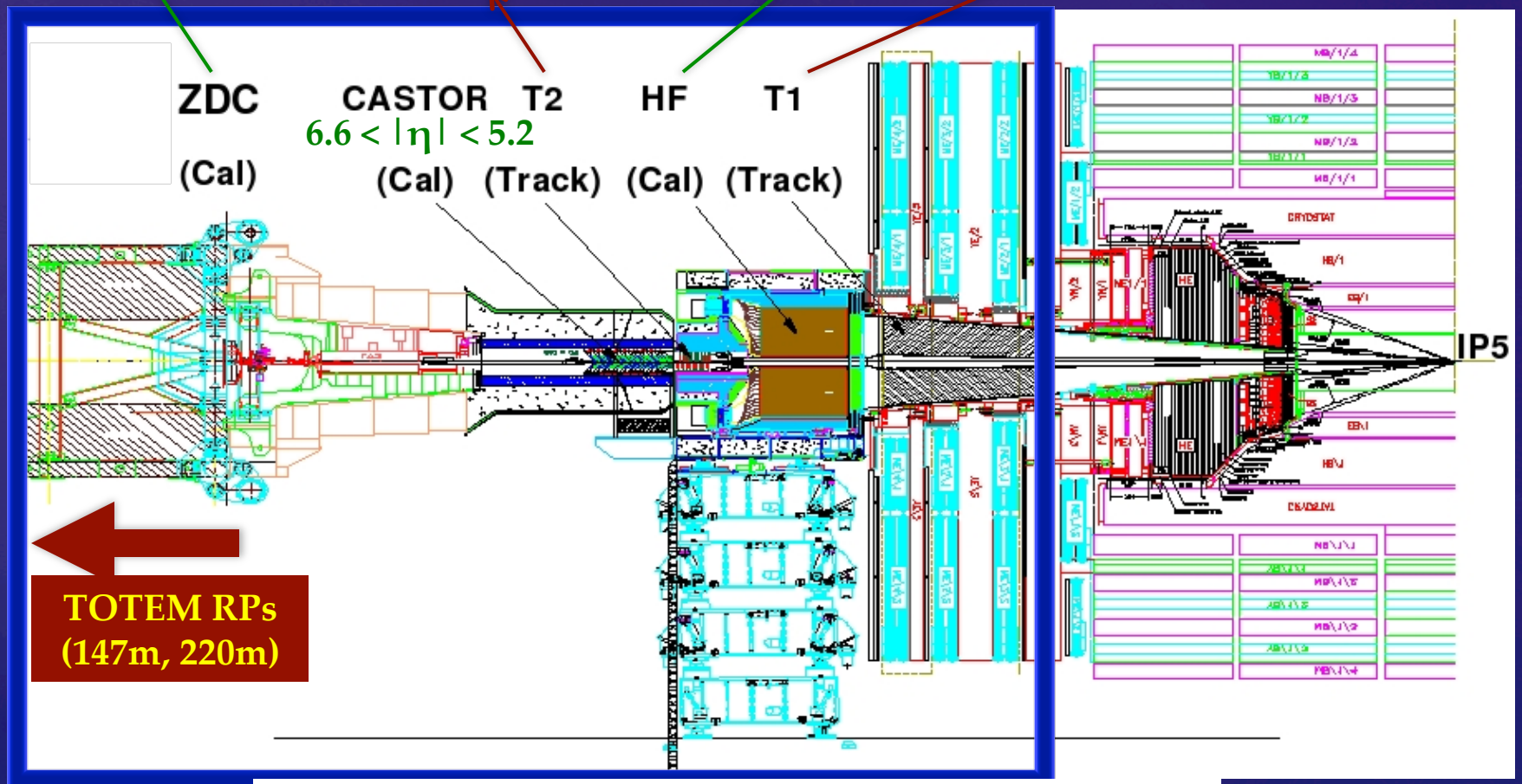
Forward Region - The CMS & TOTEM Collaborations (both sides)

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) : $6.0 < |\eta| < 8.0$

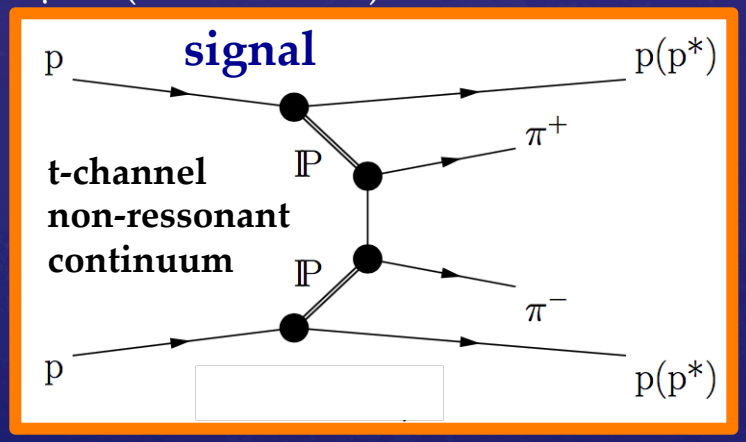
Exclusive and semi-exclusive $\pi^+\pi^-$ production in pp @7 TeV

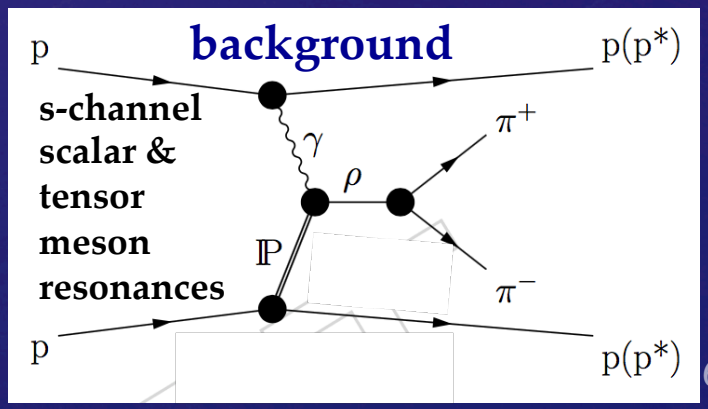
CMS-PAS-FSQ-12-004

- The first measurement at the LHC from the non resonant continuum and from possible decays of various low-mass meson resonances;
- **Motivation**: gluons are the main Pomeron constituents => excellent channel for glueballs production; better understanding of Pomeron exchange physics (non-perturbative model-dependent process)
- **Signal** : p p -> p(p*) + $\pi^+\pi^-$ + p(p*) dominated by Double Pomeron Exchange (DPE)
- Background: exclusive ρ-meson photoproduction with ρ -> $\pi^+\pi^-$; **γγ -> $\pi^+\pi^-$ (very small)**
- For DPE: **PYTHIA 8.165** with MBR (renormalized pomeron flux model) and with 4C (rescaled Schuler and Sjöstrand model); also **Durham Dime** MC for the exclusive process;

MBR – minimum bias Rockefeller model

- For Background: **STARlight** v.110 that uses EPA and parametrisation of ρ production XS from HERA;
- Data: L = 450 μb^{-1} (2010 @ 7TeV) at low PU ~ 1 inelastic pp interaction/BX;





CERN-EP-2016-261
Submitted to arXiv
and Phys.Rev.D

Exclusive and semi-exclusive $\pi^+\pi^-$ production in pp @7 TeV

CMS-PAS-FSQ-12-004

Event selection:

- $M(\pi^+\pi^-)$ up to ≈ 3 GeV/c^2 with differential and total dipion XS for single pion with p_T > 0.2 GeV/c and |y|< 2
- two charged-particle tracks (standard high-purity track selection*) from a common point on the beam line;
- Non-exclusive rejection: no additional tracks and no activity in the calorimeters above the noise threshold**; no events with more than a single pp interaction vertex (pile-up);
- two selected tracks are required to intersect at a vertex with |z| < 15 cm from the center of the detector;
- CEP of same-sign pairs forbidden by charge conservation => used as control sample for "residual multi hadron" backgrounds***.

Generator	Process	σ (μb)	Fiducial σ_{had} (μb)
PYTHIA 8 MBR	DPE	800	16.8
PYTHIA 8 (4C tune)	DPE	800	17.6
Dime	DPE	400	12.7
STARlight	$\rho \to \pi^+\pi^-$	13.2	2.4

Number of events remaining after each step of the analysis.

Selection	Data events
Trigger	33 214 795
No. of tracks ≤ 2	215 139
Track purity	170 990
$\lvert y\rvert < 2$	128 375
$p_T > 0.2$ GeV/c	103 038
Exactly two tracks	58 468
$\lvert z_{vtx}\rvert < 15$ cm	57 602
$E_{EB} < 0.52$ GeV	49 462
$E_{EE} < 2.18$ GeV	42 988
$E_{HB} < 1.18$ GeV	41 703
$E_{HE} < 1.95$ GeV	32 565
$E_{HF} < 4.0$ GeV	6 102
Opposite-sign tracks	5 402
Same-sign tracks	700

*it reduces number of false tracks based on information of number of hits, normalized χ^2, and the transverse and longitudinal impact parameters of the tracks

**the noise thresholds depend on the calorimeter region, assuming values from 0.52 GeV (in the Ecal Barrel , EB) up to 4 GeV (in the Hadronic Forward, HF)

*** where two or more charged particles are not detected or do not pass the reconstruction criteria.

Exclusive and semi-exclusive $\pi^+\pi^-$ production in pp @7 TeV

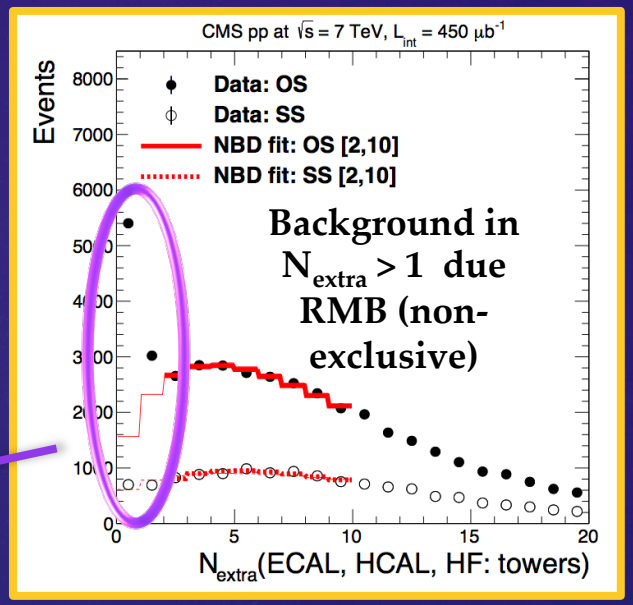
CMS-PAS-FSQ-12-004

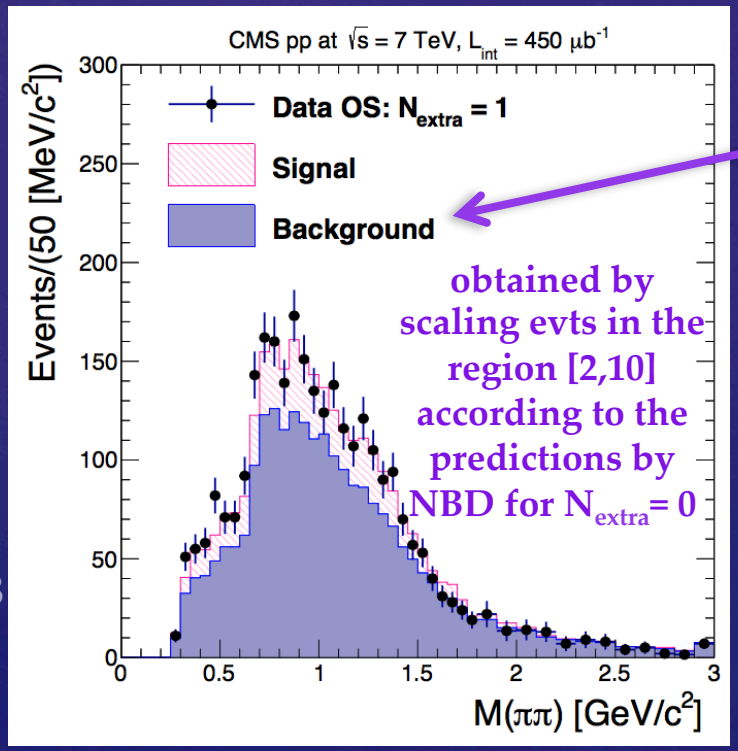
Background estimation:

- Data driven method

Distribution of the multiplicities of calorimeter towers above noise thresholds, N_{extra}, with **clear increase in the #events for $\pi^+\pi^-$ for N_{extra} = 0 (signal region)**

- Residual Multihadron Background (RMB): acc MC, $N_{extra} > 1$ contains neutral and charged particles out of tracker acceptance (mainly in HF detector); in the range $2 < N_{extra} < 10$, RMB well described by negative binomial distribution (NBD) => extrapolated down to N_{extra} = 0 and 1 to provide reliable estimation of the RMB in $\pi^+\pi^-$ signal events in this region;





N_{extra} = 0 (signal) and N_{extra} = 1 (add 19% to signal) events are compatible => both included in the total XS measurement.

Systematics

Source	Uncertainty (%)
Tracking efficiency (pion pair)	7.8
Background	3.8
HF energy scale	2.0
Barrel, endcap energy scale	3.9
Unfolding	10.3
Exclusivity efficiency	12.5
Integrated luminosity	4.0
Total uncertainty excluding luminosity	18.9

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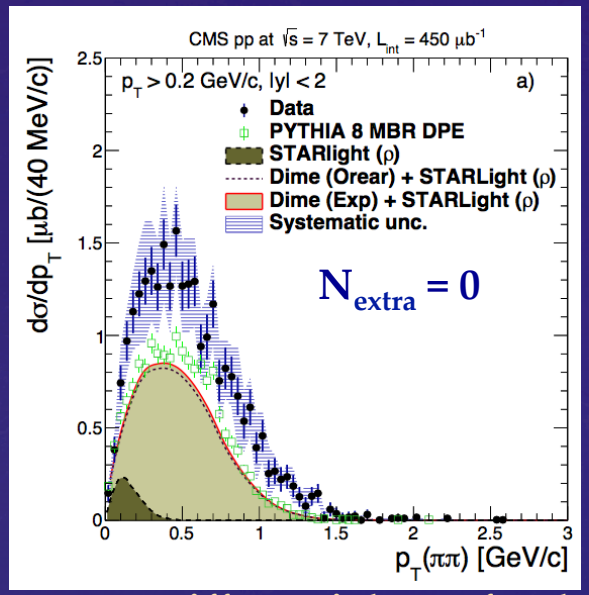
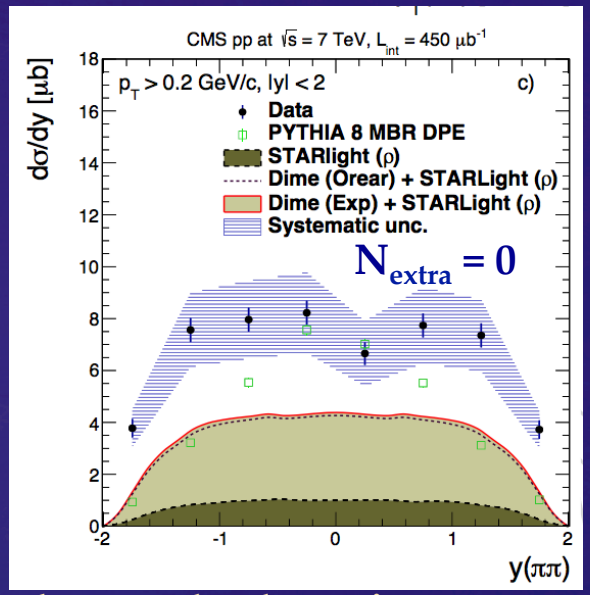
Exclusive and semi-exclusive $\pi^+\pi^-$ production in pp @7 TeV

Results: $\sigma_{\pi^+\pi^-} = 26.5 \pm 0.3\ (\text{stat}) \pm 5.0\ (\text{syst}) \pm 1.1\ (\text{lumi})\ \mu b$

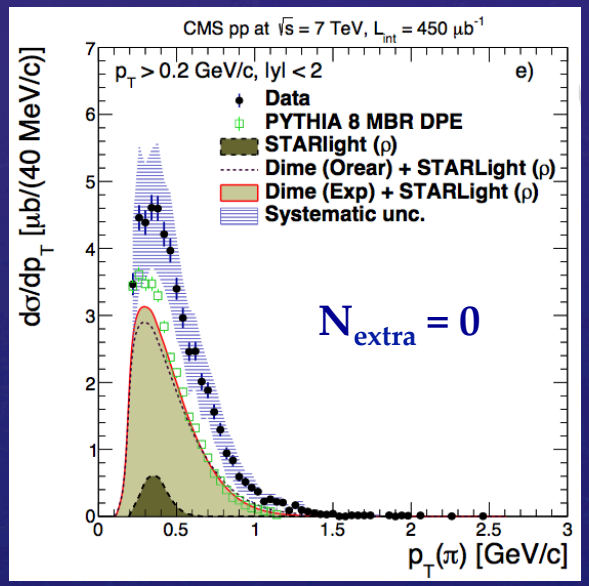
$p_T(\pi) > 0.2$ GeV/c ; $|y| < 2$
$N_{extra} \leq 1$

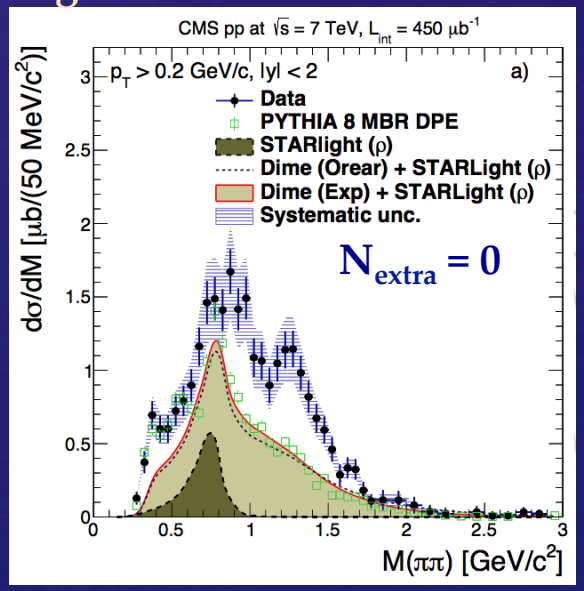
- 50% larger than Pythia8 and Dime predictions; adding Starlight then 35% larger;
- p_T distribution with larger average p_T and a higher tail above $p_T > 0.5$ GeV/c than predicted by the models => suggesting the presence in the data of semi-exclusive production with proton dissociation;
- MC does not include effect of low-mass proton dissociation and specific resonances production decaying into a pion pair => improvements needed in DPE models.





Differential XS after background subtractions



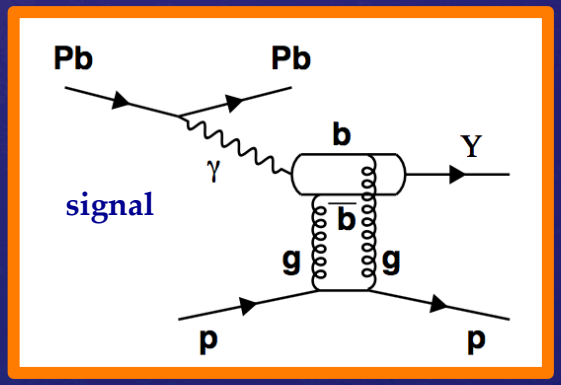


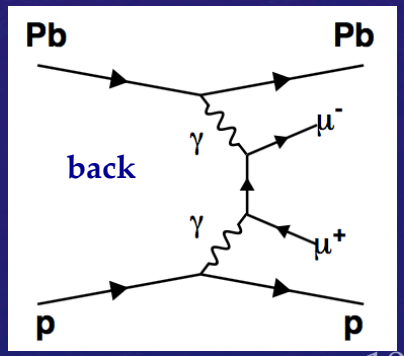
Exclusive ϒ production in $\mu^+\mu^-$ decay mode in UPC @5.02 TeV

CMS-PAS-FSQ-13-009

- First observation of ϒ photoproduction in the pPb system
- **Exchange of (quasi)real photon appearing as qqbar bound state after interacting with the gluon field of the target proton (ion)**
- **Motivation**: photoproduction of J/ψ and ϒ mesons off protons is sensitive to the generalized parton distributions of the proton, being approximated in terms of the gluon density in the proton squared for the present kinematic region:
  - here the gluon density is probed in the proton in an unexplored region of low values of Bjorken x where non-linear QCD effects (gluon recombination) may become important, possibly leading to the saturation of the parton distribution functions (PDF) $x \approx M_{\Upsilon}^2/W_{\gamma p}^2 \approx 10^{-4}$–$10^{-2}$

- **Signal**: photon is emitted from the Pb ion $\mathrm{pPb} \to (\gamma p) \to \mathrm{pPbY(nS)}$
- Data: L = 32.6 nb^{-1} of pPb collisions recorded in 2013 at center-of-mass energy per nucleon-nucleon pair 5.02 TeV;
- STARLIGHT MC event generator for signal and background simulation that uses EPA with an empirical fit of the exclusive vector meson photoproduction XS to the existing HERA γp data





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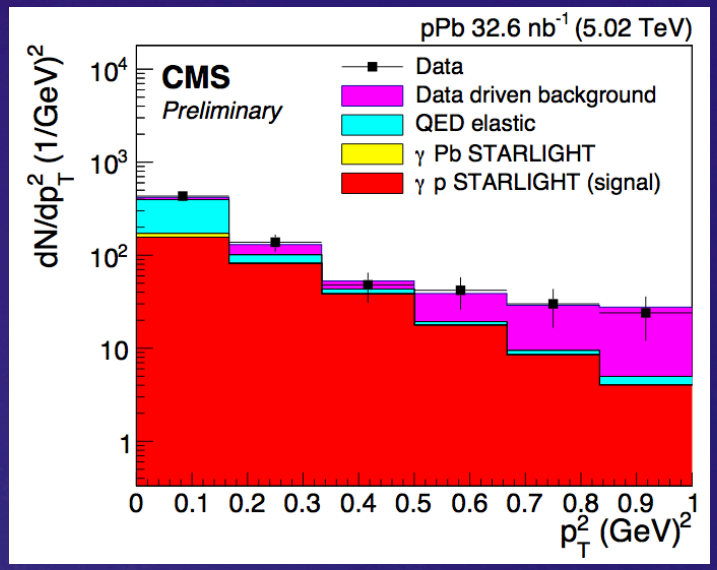
Exclusive ϒ production in $\mu^+\mu^-$ decay mode in UPC @5.02 TeV

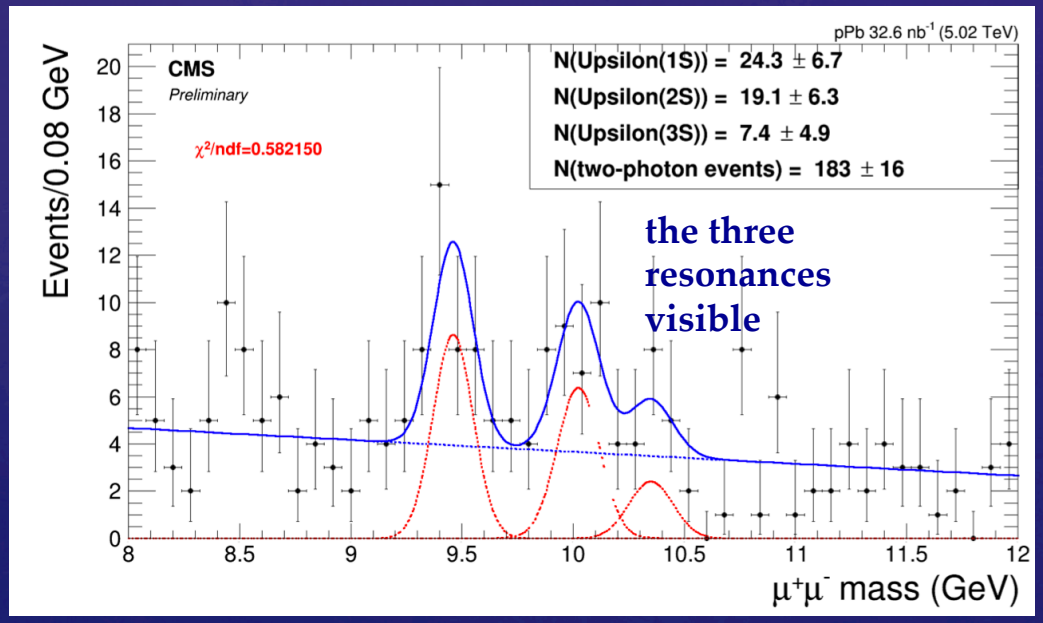
CMS-PAS-FSQ-13-009

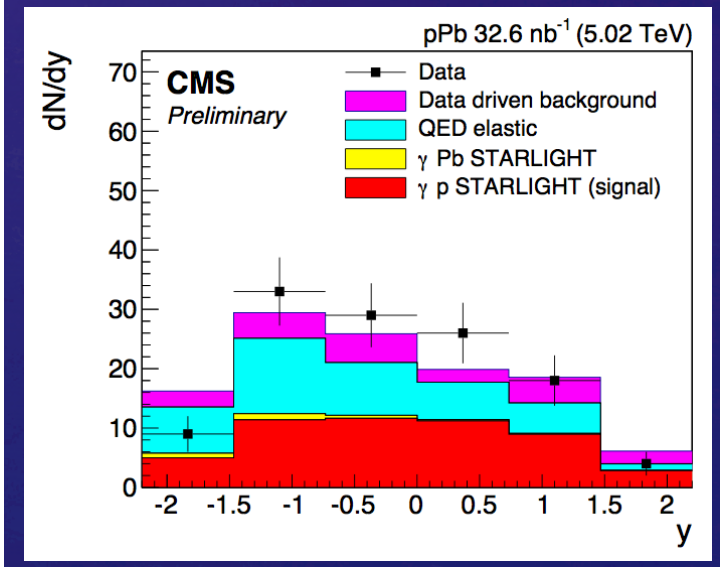
Event selection and Data-MC comparison:

- Pair of opposite-sign muons originating from same primary vertex;
- No extra tracks at dimuon vertex => suppression of non-exclusive background;
- Dimuon invariant mass $9.12 < M_{\mu\mu} < 10.64$ GeV; $p_{Tm} > 3.3$ GeV/c; $|\eta_m| < 2.2$;
- For ϒ : $0.1 < p_T < 1$ GeV/c to suppress QED and non-exclusive backgrounds, and $|y| < 2.2$ to ensure high efficiency for detecting μ



Good agreement between Data and MC





Exclusive ϒ production in $\mu^+\mu^-$ decay mode in UPC @5.02 TeV

CMS-PAS-FSQ-13-009

Cross Section extraction:

- The signal events in STARLIGHT assumes an **exponential dependence on the four-momentum transfer square at the proton vertex**, $\exp^{-b|t|}$ with slope b = 4 GeV^{-2}, and a **power law dependence on the XS on the photon-proton center-of-mass energy** $(W_{\gamma p})^{\delta}$ with $\delta = 1.7$, from HERA data. These two parameters were tuned to reproduce the data by using a reweighting procedure, to minimize difference between Data and MC => see next slide;
- The background events are obtained from data-driven method: Data/MC events (integrated over the kinematic region of the analysis) equals 1.03 ± 0.10 => **simulation reproduces data very well!!**

Systematics

Source	b	$d\sigma/dy$
Inclusive background modeling	11%	10%
Exclusive QED background modeling	6%	18%
Muon efficiency (Tag and Probe)	–	11%
Unfolding	2%	1%
MC modeling	2%	7%
Feed-down	–	2%
Branching ratios	–	2%
Luminosity	–	4%
Total	13%	25%

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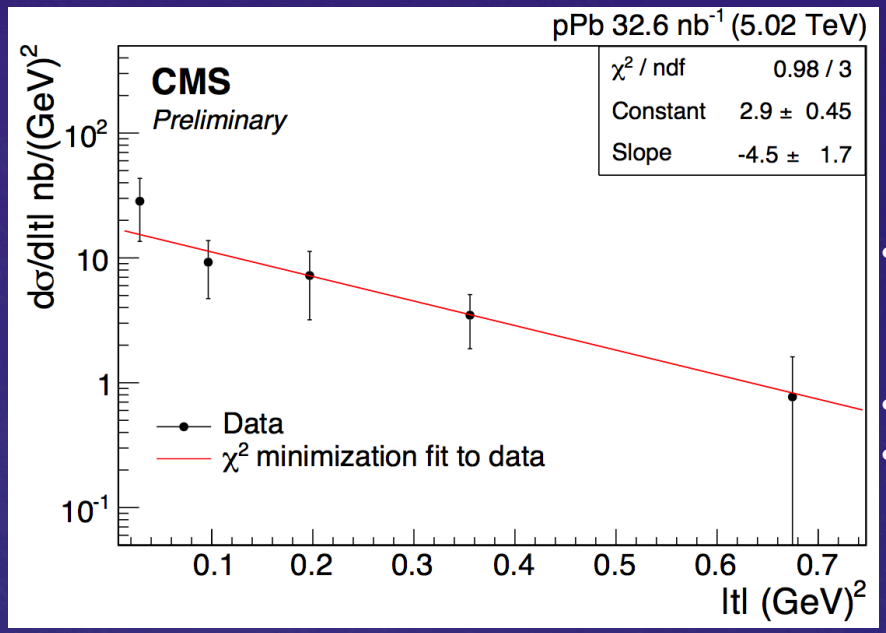
Exclusive ϒ production in $\mu^+\mu^-$ decay mode in UPC @5.02 TeV

CMS-PAS-FSQ-13-009



$$\frac{d\sigma_\Upsilon}{d|t|} = \frac{N^{\Upsilon(nS)}}{\mathcal{L} \times \Delta|t|}$$

Results

- $N^{\Upsilon(nS)}$ number of signal events after background subtraction, unfolding and correction for acceptance;
- fitted with Nexp(-b|t|) ; range $|t| < 1.0$ GeV^2
- measured in four bins of $|t| = p_T^2$ for $|y| < 2.2$

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

$$\sigma_{\gamma p \to \Upsilon(1S) p}(W^2_{\gamma p}) = \frac{1}{\Phi}\frac{d\sigma_{\Upsilon(1S)}}{dy}$$

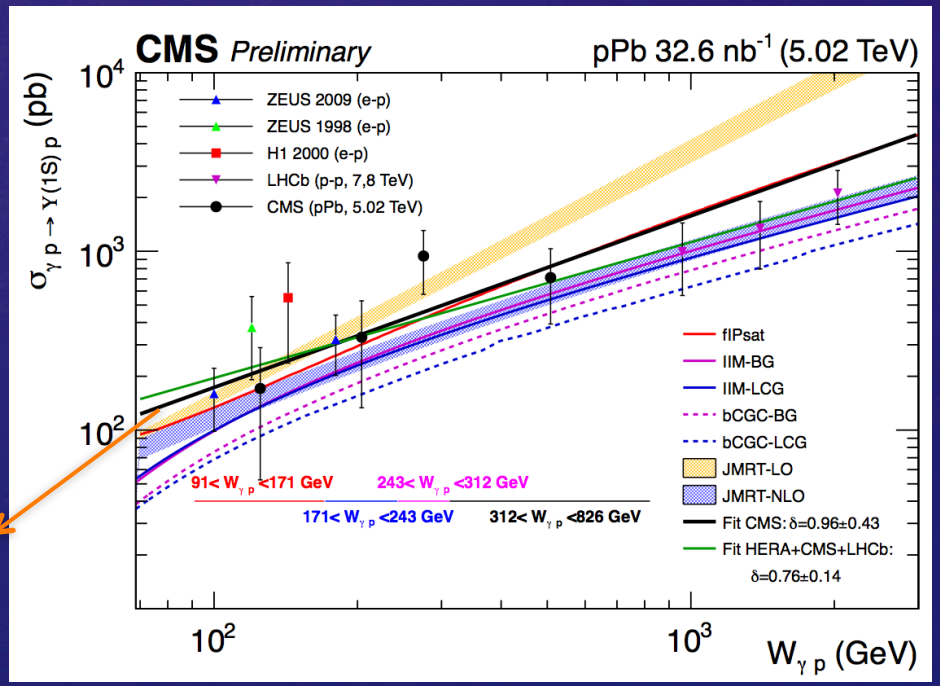
$$W_{\gamma p} = \sqrt{2E_p M_\Upsilon \exp(y)}$$

Φ photon flux at the mean of rapidity bin (see backup slide)

- The cross sections at the value W_0 for the γp center-of-mass energy $W_{\gamma p}$ (corresponding to the average pseudorapidity over a bin, ⟨y⟩)
- Fit of the CMS data to a power function

$A \times (W/400)^\delta$ $\delta = 0.96 \pm 0.43$ and $A = 655 \pm 196$,

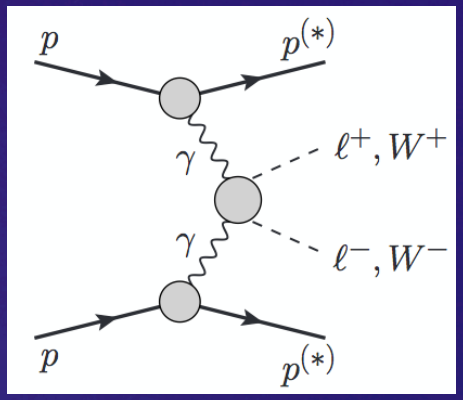
disfavor a faster increase with energy as predicted by LO pQCD models



Evidence for exclusive W^+W^- production and constraints on aQGC in pp @7 & 8TeV

JHEP08(2016)119

- ✓ 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



- ✓ $\gamma\gamma \rightarrow \mu^+\mu^-$, e^+e^- : test exclusivity requirement and proton dissociation;
- ✓ $\gamma\gamma \rightarrow W^+W^-$: 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);

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

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

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

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

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

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

vanishing WWZγ

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

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

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

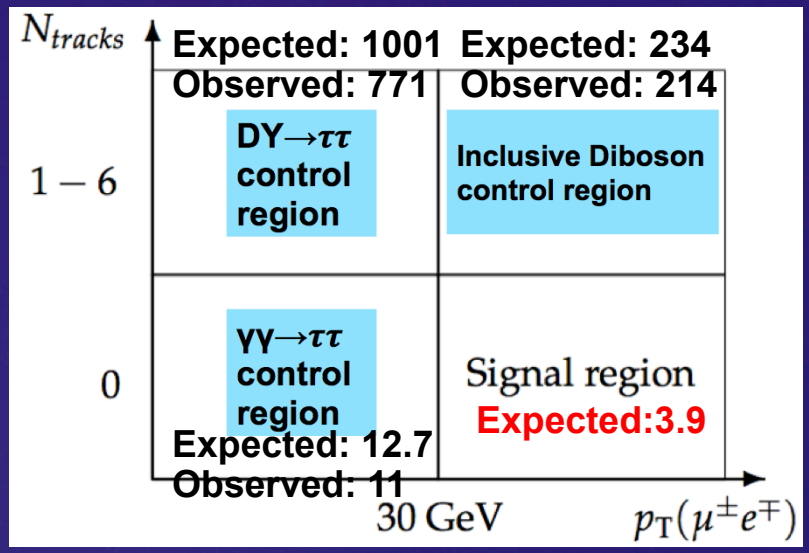
- ✓ p=2 (dipole FF)
- ✓ unitarity bound @ Wγγ ~ 1 TeV
- ✓ L_{cutoff} = 500GeV

Evidence for exclusive W^+W^- production and constraints on aQGC in pp @7 & 8TeV

JHEP08(2016)119

Backgrounds, strategy & systematics

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



Systematics

	Uncertainty
Proton dissociation factor	10.5%
Efficiency correction for no add. tracks	5.0%
Trigger and lepton identification	2.4%
Integrated luminosity	2.6%
Total	12.2%

MC simulation

Selection step	Data	Exclusive $\gamma\gamma \to$ WW	Total background	Inclusive diboson	Drell-Yan	$\gamma\gamma \to \tau\tau$	Other backgrounds
Trigger and Preselection	19406	26.9±0.2	22180±1890	1546±15	7093±75	18.1±0.8	13520±1890
$m(\mu^\pm e^\mp) > 20$ GeV	18466	26.6±0.2	21590±1850	1507±15	7065±75	18.1±0.8	13000±1850
Muon and electron identification	6541	22.5±0.2	6640±93	1306±11	4219±58	12.6±0.7	1102±72
$\mu^\pm e^\mp$ vertex with no add. tracks	24	6.7±0.2	15.2±2.5	3.7±0.7	6.5±2.3	4.3±0.5	0.7±0.1
$p_T(\mu^\pm e^\mp) > 30$ GeV	13	5.3±0.1	3.9±0.5	2.3±0.4	0.1±0.1	0.9±0.2	0.6±0.1

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

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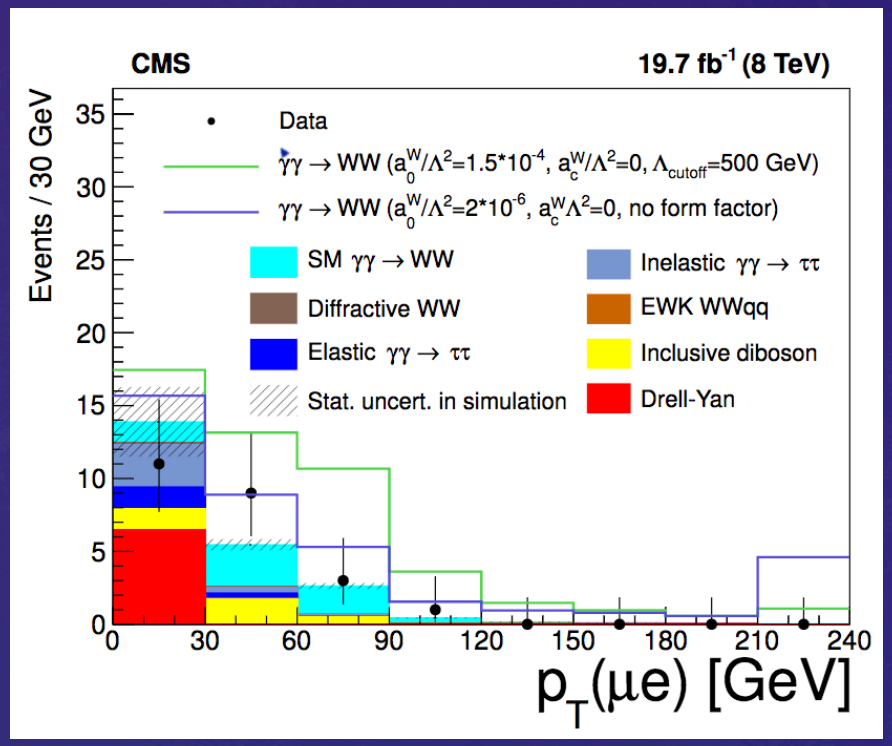
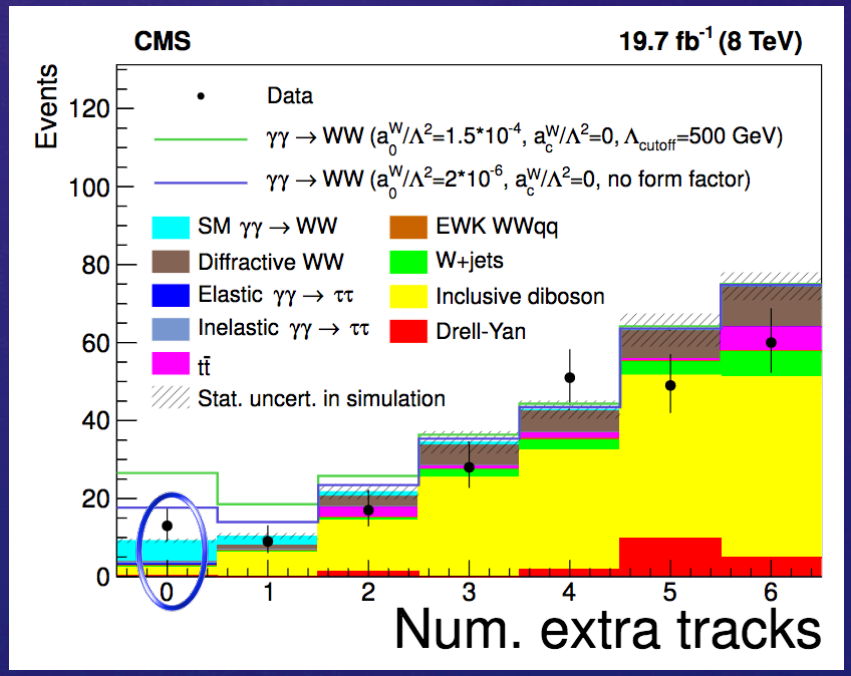
RESULT 1: evidence for exclusive $\gamma\gamma \rightarrow W^+W^-$ production



- ✓ 0 extra tracks plot
- ✓ In signal region ($p_T(\mu e)$ > 30 GeV): 13 events observed (data) over 3.9 ± 0.5 (statistics) events expected for background and 5.3 ± 0.1 (statistics) expected for signal (See table slide 15)



- ✓ **Excess of 3.4σ** over the background only hypothesis, including systematics, for the 7 and 8 TeV combination
- ✓ XS for 8TeV:

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

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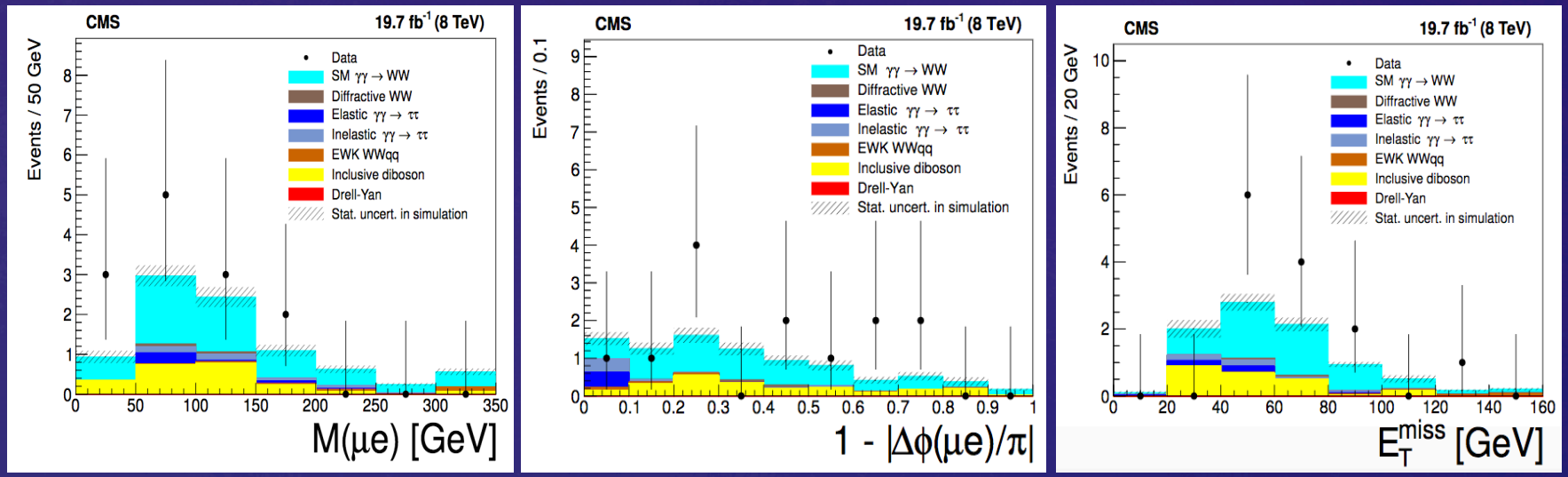
RESULT 1: evidence for exclusive $\gamma\gamma \rightarrow W^+W^-$ production (signal region distributions)



- ✓ Muon-electron invariant mass, acoplanarity, and missing transverse energy in the $\gamma\gamma \rightarrow W^+W^-$ 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

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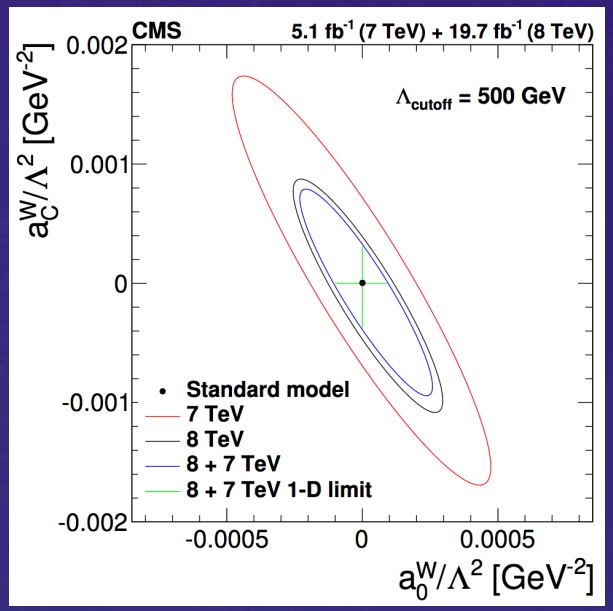

- The area outside the contour is excluded at 95% CL
- 7-16 times more stringent than search for WWγ and WZγ production at 8TeV Phys. Rev. D 90, 032008 (2014)
- 3-7 times more stringent than Vector Boson Scattering approach at Phys. Rev. Lett. 114 (2015) 051801)

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})
$a_0^W/\Lambda^2(\Lambda_{cutoff} = 500\,\text{GeV})$	$-1.5 < a_0^W/\Lambda^2 < 1.5$	$-1.1 < a_0^W/\Lambda^2 < 1.0$	$-0.9 < a_0^W/\Lambda^2 < 0.9$
$a_C^W/\Lambda^2(\Lambda_{cutoff} = 500\,\text{GeV})$	$-5 < a_C^W/\Lambda^2 < 5$	$-4.2 < a_C^W/\Lambda^2 < 3.4$	$-3.6 < a_C^W/\Lambda^2 < 3.0$
Dimension-8 AQGC parameter	7 TeV ($\times 10^{-10}$ GeV^{-4})	8 TeV ($\times 10^{-10}$ GeV^{-4})	7+8 TeV ($\times 10^{-10}$ GeV^{-4})
$f_{M,0}/\Lambda^4(\Lambda_{cutoff} = 500\,\text{GeV})$	$-5.7 < f_{M,0}/\Lambda^4 < 5.7$	$-3.8 < f_{M,0}/\Lambda^4 < 4.2$	$-3.4 < f_{M,0}/\Lambda^4 < 3.4$
$f_{M,1}/\Lambda^4(\Lambda_{cutoff} = 500\,\text{GeV})$	$-19 < f_{M,1}/\Lambda^4 < 19$	$-16 < f_{M,1}/\Lambda^4 < 13$	$-14 < f_{M,1}/\Lambda^4 < 12$
$f_{M,2}/\Lambda^4(\Lambda_{cutoff} = 500\,\text{GeV})$	$-2.8 < f_{M,2}/\Lambda^4 < 2.8$	$-1.9 < f_{M,2}/\Lambda^4 < 2.1$	$-1.9 < f_{M,2}/\Lambda^4 < 1.9$
$f_{M,3}/\Lambda^4(\Lambda_{cutoff} = 500\,\text{GeV})$	$-9.5 < f_{M,3}/\Lambda^4 < 9.5$	$-8.0 < f_{M,3}/\Lambda^4 < 6.5$	$-6.8 < f_{M,3}/\Lambda^4 < 5.7$
Dimension-6 AQGC parameter	7 TeV ($\times 10^{-6}$ GeV^{-2})	8 TeV ($\times 10^{-6}$ GeV^{-2})	7+8 TeV ($\times 10^{-6}$ GeV^{-2})
a_0^W/Λ^2(no form factor)	$-4 < a_0^W/\Lambda^2 < 4$	$-1.2 < a_0^W/\Lambda^2 < 1.2$	$-1.1 < a_0^W/\Lambda^2 < 1.1$
a_C^W/Λ^2(no form factor)	$-15 < a_C^W/\Lambda^2 < 15$	$-4.4 < a_C^W/\Lambda^2 < 4.4$	$-4.1 < a_C^W/\Lambda^2 < 4.1$
Dimension-8 AQGC parameter	7 TeV ($\times 10^{-12}$ GeV^{-4})	8 TeV ($\times 10^{-12}$ GeV^{-4})	7+8 TeV ($\times 10^{-12}$ GeV^{-4})
$f_{M,0}/\Lambda^4$(no form factor)	$-15 < f_{M,0}/\Lambda^4 < 15$	$-4.6 < f_{M,0}/\Lambda^4 < 4.6$	$-4.2 < f_{M,0}/\Lambda^4 < 4.2$
$f_{M,1}/\Lambda^4$(no form factor)	$-57 < f_{M,1}/\Lambda^4 < 57$	$-17 < f_{M,1}/\Lambda^4 < 17$	$-16 < f_{M,1}/\Lambda^4 < 16$
$f_{M,2}/\Lambda^4$(no form factor)	$-7.6 < f_{M,2}/\Lambda^4 < 7.6$	$-2.3 < f_{M,2}/\Lambda^4 < 2.3$	$-2.1 < f_{M,2}/\Lambda^4 < 2.1$
$f_{M,3}/\Lambda^4$(no form factor)	$-28 < f_{M,3}/\Lambda^4 < 28$	$-8.4 < f_{M,3}/\Lambda^4 < 8.4$	$-7.8 < f_{M,3}/\Lambda^4 < 7.8$

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Summary:

- **Exclusive and semi-exclusive $\pi^+\pi^-$ production in pp @7 TeV :**
  - The first measurement at the LHC from the non resonant continuum and from possible decays of various low-mass meson resonances:
  - MC does not include effect of low-mass proton dissociation and specific resonances production decaying into a pion pair => improvements needed in DPE models.

- **Exclusive Υ production in $\mu^+\mu^-$ decay mode in UPC @5.02 TeV :**
  - First observation of Υ photoproduction in the pPb system
  - Fit of the CMS data to a power function disfavor a faster increase with energy as predicted by LO pQCD models

- **Evidence for exclusive W^+W^- production and constraints on aQGC in pp @7 and 8TeV:**
  - Excess of 3.4σ over the background only hypothesis, including systematics, for the 7 and 8 TeV combination
  - The most stringent exclusion limits on aQGC to date

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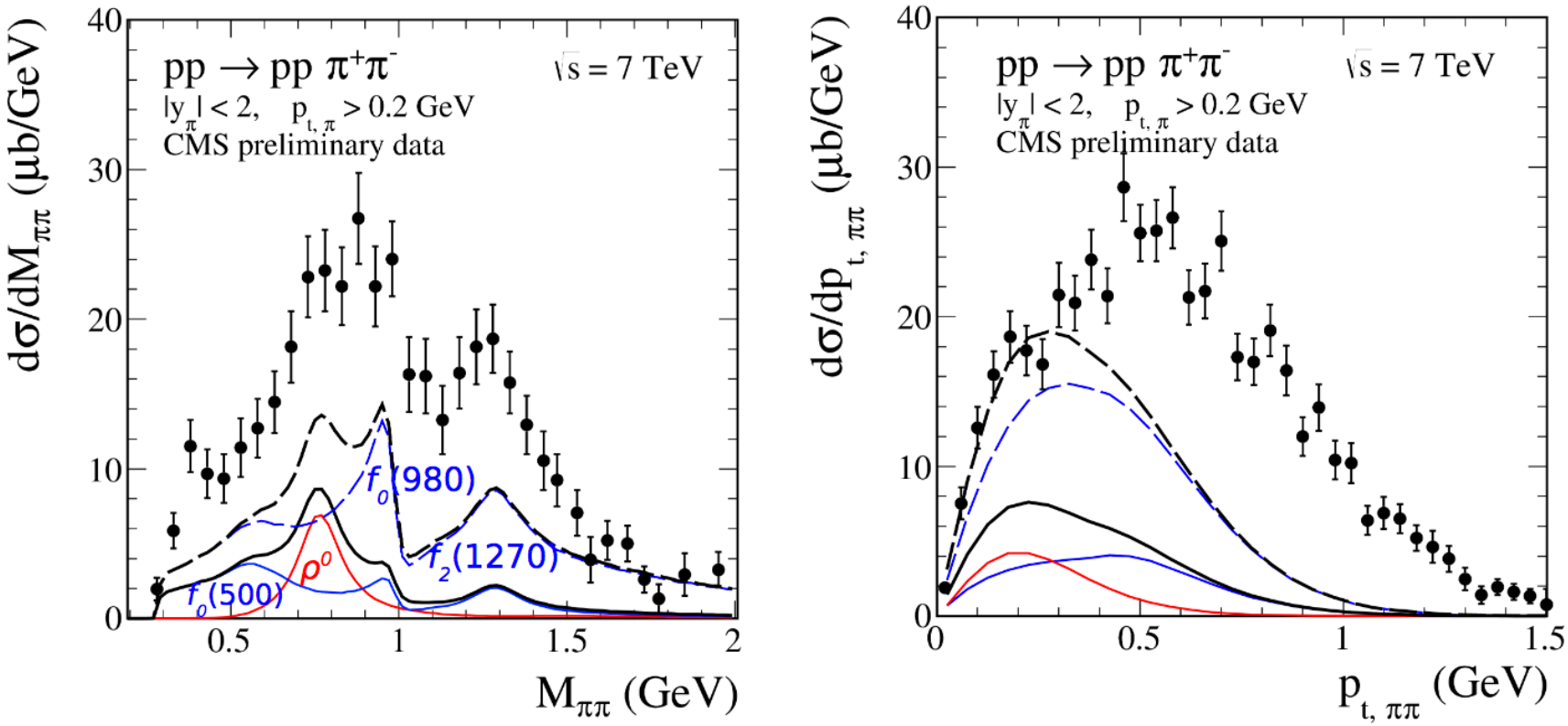
Backup

Table 3: Relevant parameters for the extraction of the Υ(1S) photoproduction cross section in four rapidity bins (corresponding to four different ranges in γ-p center-of-mass energies) in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The symbols, $N^{\Upsilon(nS)}_{back-sub}$, $N^{\Upsilon(nS)}_{unfol}$ and $N^{\Upsilon(nS)}_{corr}$ give the number of Υ(nS) after the background subtraction, unfolding and extrapolation with A_{corr} factor, respectively. The factors, $f_{\Upsilon(1S)}$ and f_{FD}, are discussed in Section 6. The first (second, if given) uncertainty quoted corresponds to the statistical (systematical) uncertainty. Φ is the effective photon flux used to evaluate $\sigma_{\gamma p}$ cross section from the $d\sigma_{\Upsilon(1S)}/dy$ at each average (W_0) photon-proton center-of-mass energy, given with theoretical uncertainty (discussed in text).

y range	$(-2.2, -0.95)$	$(-0.95, -0.25)$	$(-0.25, 0.25)$	$(0.25, 2.2)$
$\langle y \rangle$	-1.575	-0.6	0.0	1.225
$N^{\Upsilon(nS)}_{back-sub}$	10 ± 6	11 ± 6	16 ± 5	17 ± 6
$N^{\Upsilon(nS)}_{unfol}$	13 ± 8	15 ± 8	23 ± 7	23 ± 9
A_{corr}	2.4 ± 0.03	1.65 ± 0.02	1.63 ± 0.02	1.87 ± 0.01
$N^{\Upsilon(nS)}_{corr}$	$31 \pm 20 \pm 7$	$24 \pm 13 \pm 5$	$37 \pm 11 \pm 8$	$44 \pm 16 \pm 10$
$N^{\Upsilon(1S)} = \frac{f_{\Upsilon(1S)} N^{\Upsilon(nS)}}{(1+f_{FD})}$	$18 \pm 12 \pm 5$	$14 \pm 8 \pm 4$	$22 \pm 7 \pm 5$	$26 \pm 10 \pm 7$
$d\sigma_{\Upsilon(1S)}/dy$ (nb)	$18 \pm 12 \pm 5$	$25 \pm 14 \pm 6$	$54 \pm 16 \pm 14$	$17 \pm 6 \pm 4$
$W_{\gamma p}$ range (GeV)	91–171	171–243	243–312	312–826
W_0 (GeV)	125	204	275	508
Photon flux (Φ)	106.0 ± 2.1	75.7 ± 2.3	57.4 ± 1.7	23.1 ± 2.1
$\sigma_{\gamma p \to \Upsilon(1S) p}$ (pb)	$171 \pm 110 \pm 43$	$331 \pm 179 \pm 83$	$941 \pm 280 \pm 235$	$713 \pm 259 \pm 178$

Piotr Lebiedowicz's talk



In diff. continuum term: (solid blue line) $\Lambda_{off,M}$ = 0.7 GeV (the same couplings as for CDF predictions)
(dashed blue line) $\Lambda_{off,M}$ = 1.2 GeV, and enhanced *f0*(980) and *f2* couplings

Our model results are much below the CMS preliminary data (CMS-PAS-FSQ-12-004) which could be due to a contamination of non-exclusive processes (one or both protons undergoing dissociation).

Maciej Trzebinski's talk

GenEx MC Generator

- GenEx – a C++ class structure for the construction of a Monte Carlo event generators which can produce unweighted events within relativistic phase space.
- Generator is self-adapting to the provided matrix element and acceptance cuts.
- Existing and planned features:
  - resonant and non-resonant exclusive meson production processes,
  - scalar, vector and tensor Pomeron,
  - pp and $p\bar{p}$ collisions,
  - spin (polarization) effects,
  - absorption and re-scattering corrections,
  - simple, user friendly interface,
  - output in formats usable by experiments (LesHouches, HEPMC, ...).
- First version (basic features) is already available: `https://github.com/rkycia/GenEx`.

- For now, implemented models are based mainly on work of P. Lebiedowicz, A. Szczurek & co.
- This includes:
  - non-resonant (continuum) pion and kaon pair production,
  - $f_0(500)$, $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_2(1270)$, $f_2'(1520)$ and ρ_0 particles and their decays into two pions or kaons.

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