



Exclusive Physics at the LHC



Searching for the Gap

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LHCb collaboration

ICHEP 2016
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Chicago



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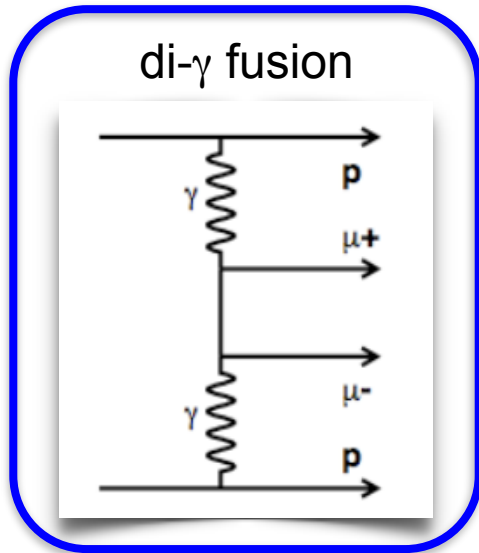
- Introduction to Physics and Detectors
- Recent and New Results
 - Exclusive $\gamma\gamma \rightarrow W^+W^-$ (ATLAS and CMS)
 - Exclusive Higgs search (ATLAS)
 - Exclusive production in Pb-Pb collisions (ALICE)
 - Exclusive Upsilon production in pPb (CMS)
 - Exclusive $\pi^+\pi^-$ production (CMS)
 - Updated exclusive J/ψ and $\psi(2S)$ production at $\sqrt{s}=13$ TeV, using the new Herschel Forward Shower Counters (LHCb)
- Conclusion

Central Exclusive Production processes

$$pp(\bar{p}) \rightarrow p + X + p(\bar{p})$$

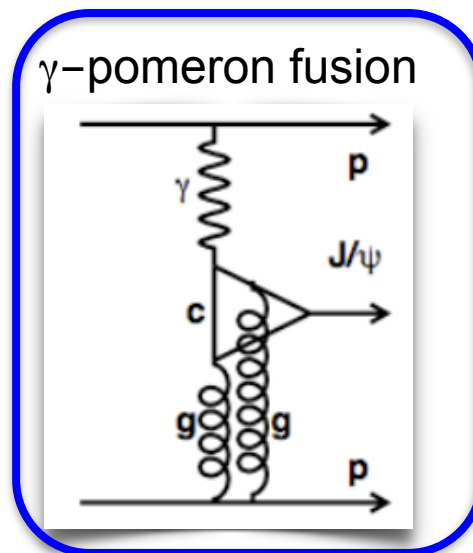
t-channel exchange of a colourless object: γ , pomeron $\rightarrow X +$ rapidity gaps

Single elastic process \rightarrow protons escape undetected in beampipe



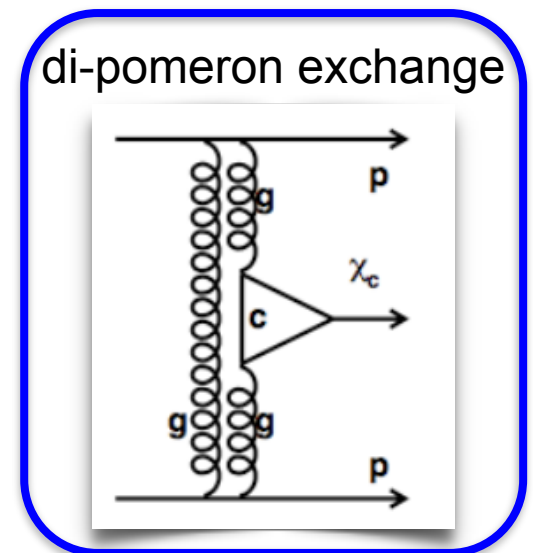
$\mu^+\mu^-$, e^+e^- , $\pi^+\pi^-$, W^+W^-

QED “standard candle” process
continuum lepton pair production



ρ , J/ψ , Υ , Z , ...

Photoproduction: Test of QCD and description of diffraction and soft processes. Sensitive to diffractive PDF at very low x (to 5×10^{-6})

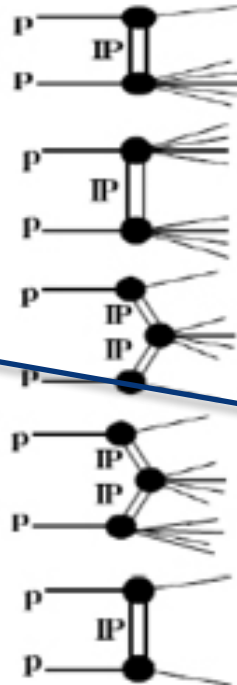
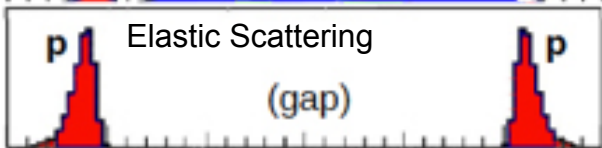
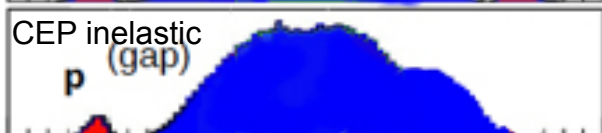
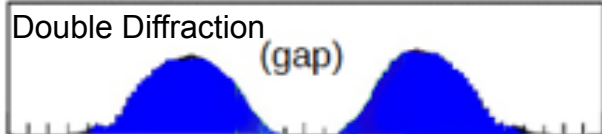
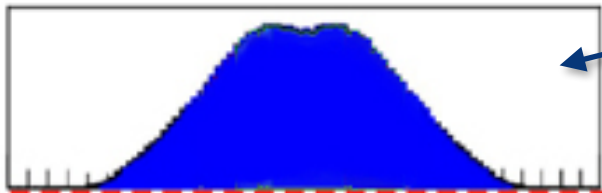


X_c , X_b , $\pi^+\pi^-$, Dijet, gg , ...

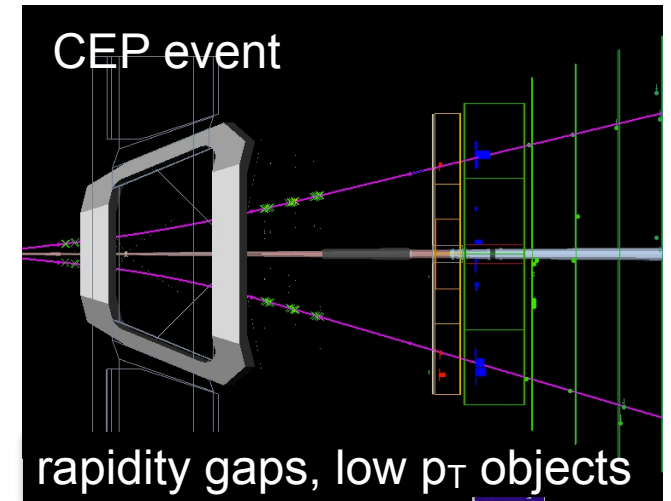
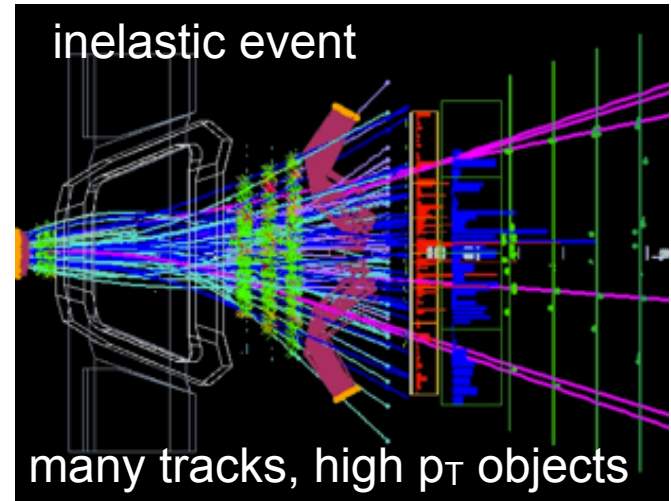
Test of QCD, and hadron spectroscopy
Pomeron content at low Q^2 dominated by gluons; access to scalar and tensor glueballs

CEP experimental signatures

η of particles, primary protons



examples from LHCb



After D. d'Enterria arxiv 0806.0883

Forward Physics @ the GPDs

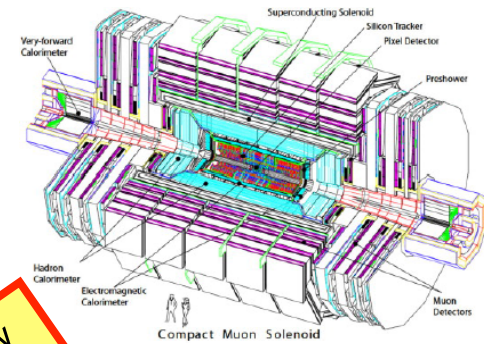
CMS and TOTEM

Excellent calorimetric rapidity coverage:

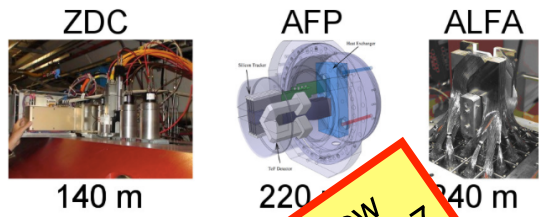
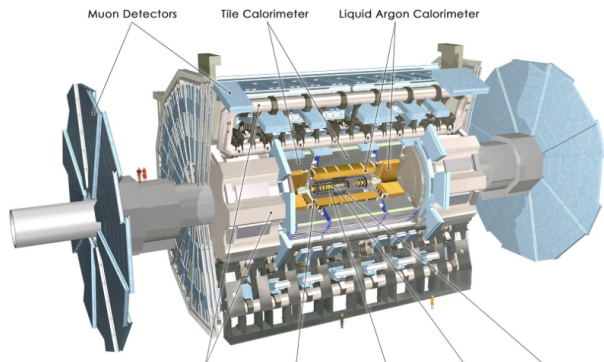
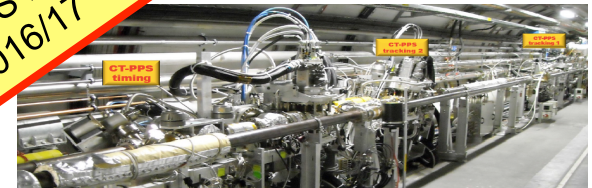
- Hadronic Forward Calorimeter & CASTOR
- ZDC (zero degree calorimeter)

Forward Shower Counters

Embedded Totem telescopes T1/T2 and Roman Pots
 CT-PPS (CMS-TOTEM Proton Precision Spectrometer)
 for double arm proton tagging at high pile-up



CT-PPS new for 2016/17



AFP new for 2016/17

ATLAS and ALFA/AFP

Calorimetry at high η

- LUCID (LUminosity Cerenkov Integrating Detector)
- ZDC

ALFA (Absolute Luminosity for ATLAS): RP stations placed 240m from IP

AFP single arm installed and integrated

Forward Physics at ALICE and LHCb

ALICE

Zero Degree Calorimeters

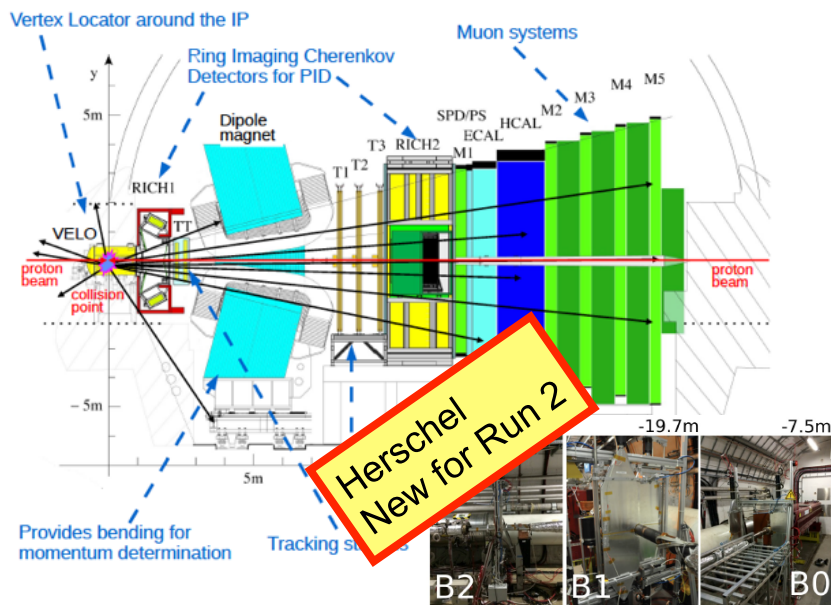
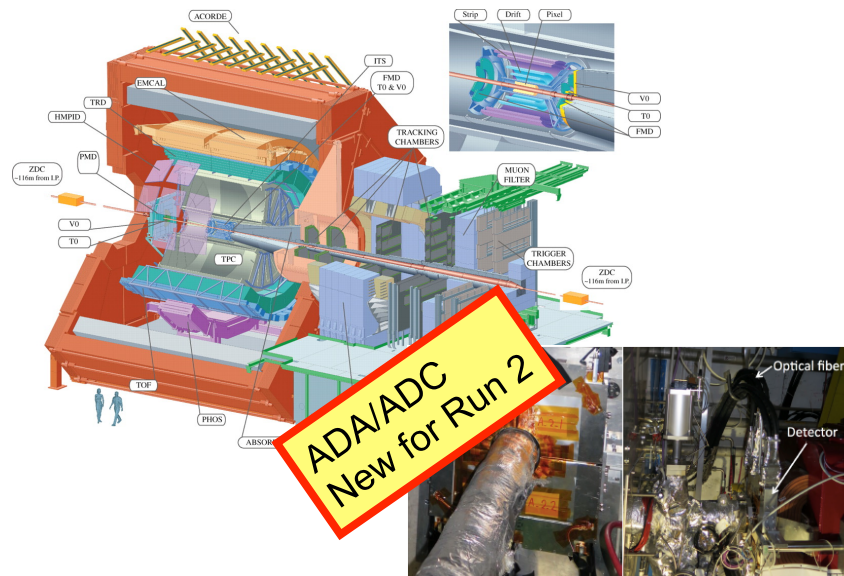
- neutron, proton, EM

Forward multiplicity Detector (FMD)

T0 and V0 (fast timing and triggering)

ADA and ADC scintillator planes

- Rapidity veto
- 300-500 ps time resolution allows rejection of out of time background



LHCb

Optimised for forward physics (single arm)

Reach in low p_T and PID

Some sensitivity in backwards region

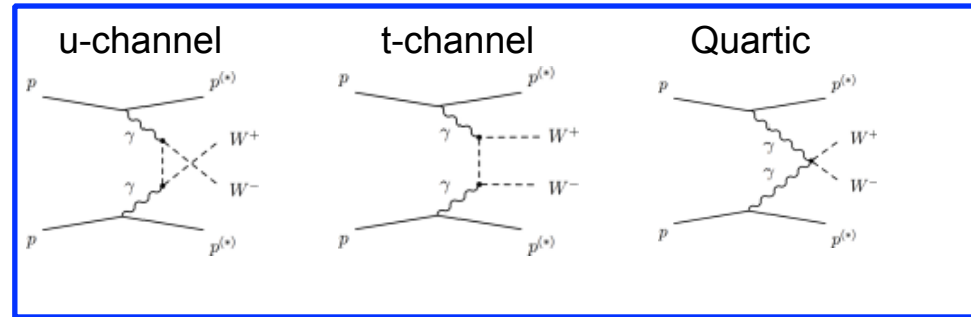
New for Run 2: enhanced rapidity coverage with HERSHEL - first physics results this talk

Exclusive $\gamma\gamma \rightarrow W^+W^-$, exclusive Higgs production

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

- Measure Standard Model Cross section
- Search for anomalous quartic gauge couplings (aQGC)

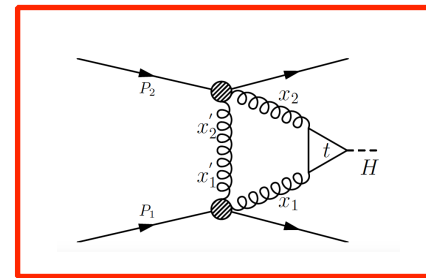
ATLAS & CMS



Search for exclusive Higgs production via $H \rightarrow WW$

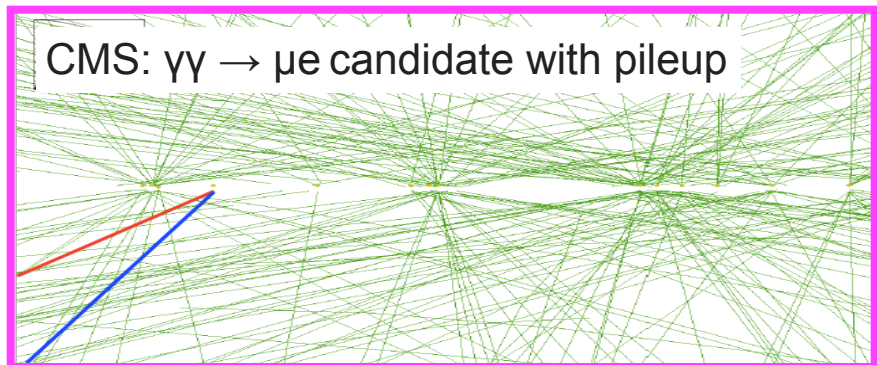
- Production mechanism via gluon fusion
- opportunity to study Higgs properties in clean environment

ATLAS



Both cases: Similar characteristics

- Opposite sign μe pair (final state) originating from common primary vertex (same sign not used due to high Drell Yan and elastic production)
- Vertex must be isolated from other objects
- $p_T(\mu\mu) > 30$ GeV (SM), $p_T(\mu\mu) > 100$ GeV (aQGC)



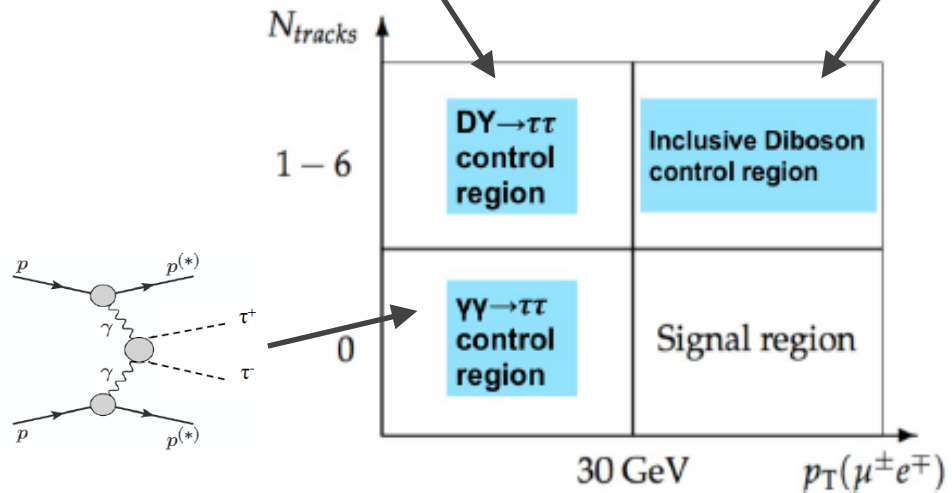
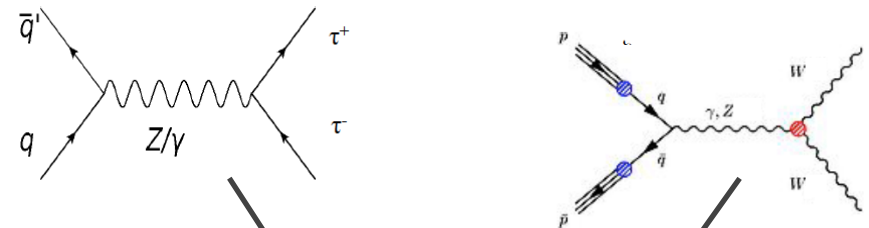
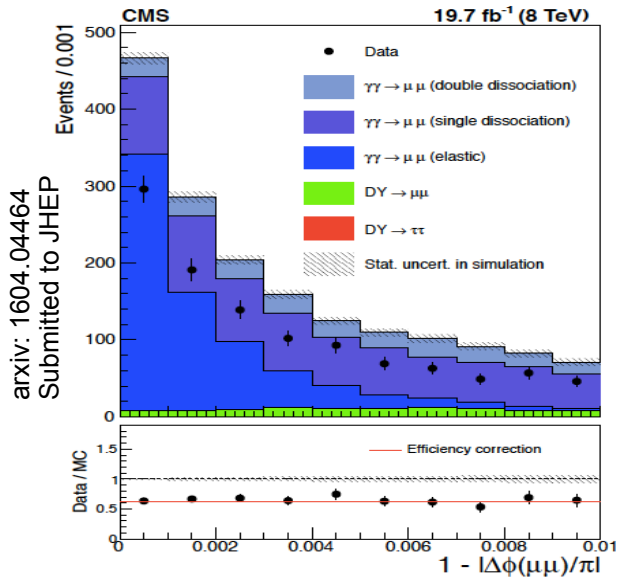
Exclusive $\gamma\gamma \rightarrow W^+W^-$: control channels, backgrounds

$\gamma\gamma \rightarrow l^+l^-$ crucial to estimate contamination from data

Pure elastic $\gamma\gamma \rightarrow l^+l^-$ selection

- cut on p_T , acoplanarity & invariant mass

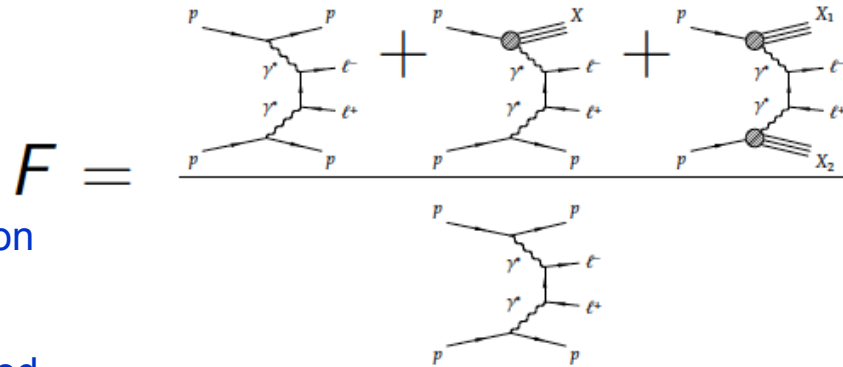
Data and simulation show good shape agreement: overall normalisation gives correction factor of 0.6-0.7 (ATLAS/CMS)



Other backgrounds: control regions

Exclusive $\gamma\gamma \rightarrow W^+W^-$: Proton Dissociation Backgrounds

$$\sigma_{\gamma\gamma}^{\text{total}} = F \times \sigma_{\gamma\gamma}^{\text{elastic}}$$



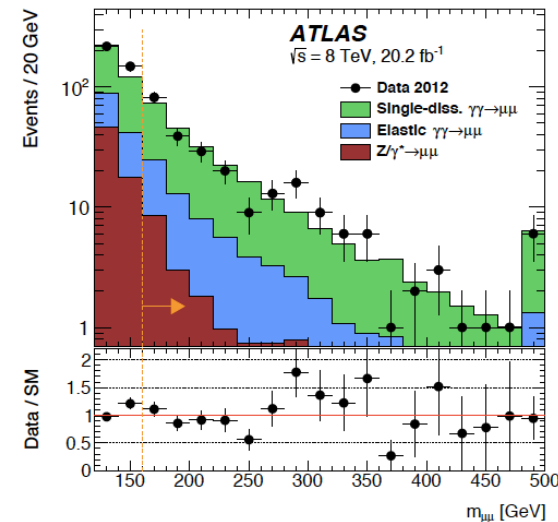
- F measures the single and double proton dissociation contribution to signal
- It is extracted using a data driven method

signal
kinematic
region

Pure elastic $\gamma\gamma \rightarrow l^+l^-$ selection at > twice W mass

$$F = \frac{N_{\text{Data}} - N_{\text{MC Background}}}{N_{\text{MC Elastic}}}$$

.Resulting correction factor ~ 3.3 (ATLAS) / 4.1 (CMS)
Uncertainties of $\sim 7\%$ dominated by statistical uncertainty



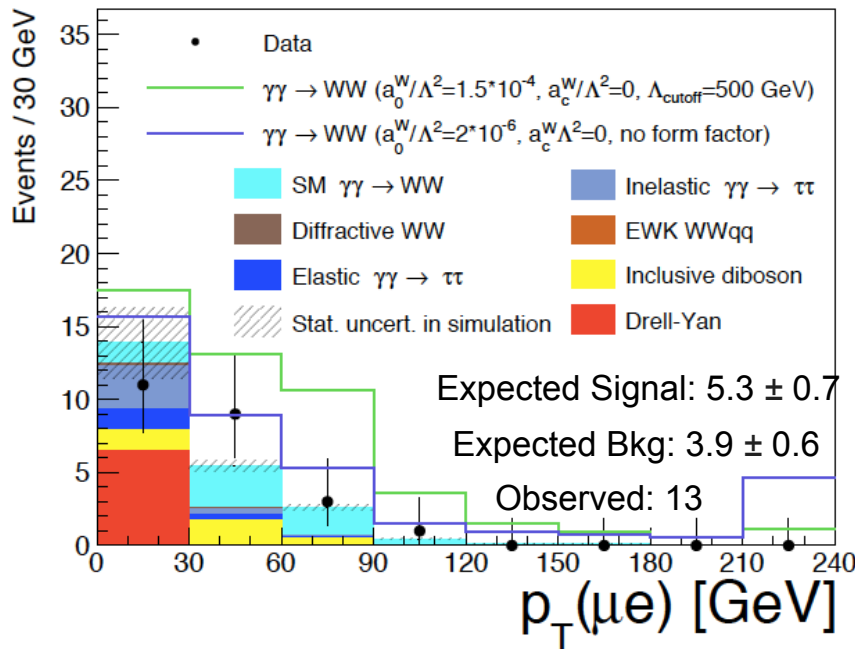
ATLAS: control sample
including correction factor F

arxiv: 1607.03745
Submitted to Phys.Rev.D

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

arxiv: 1604.04464
Submitted to JHEP

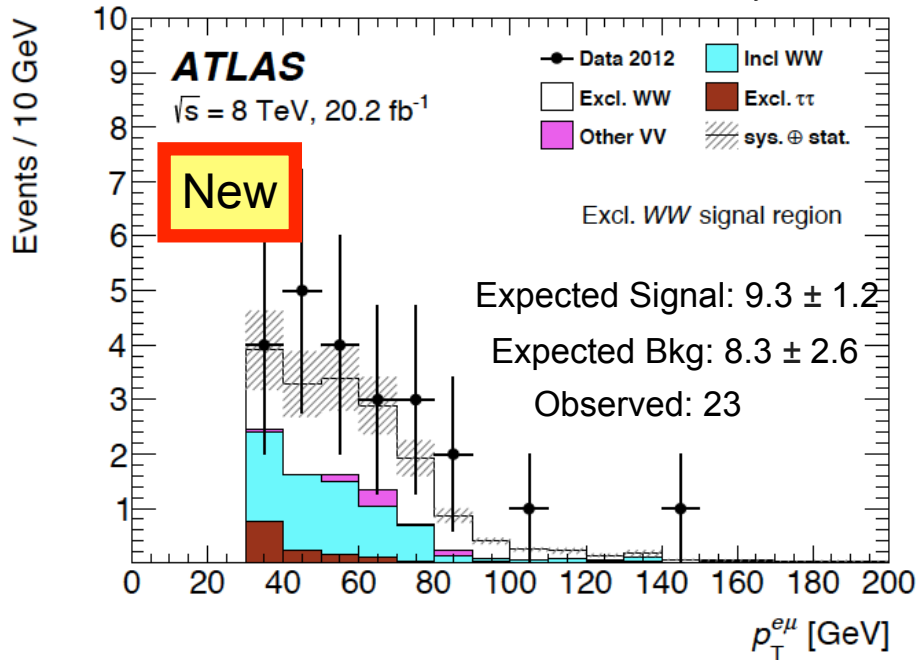
19.7 fb⁻¹ (8 TeV)



$$\sigma(pp \rightarrow p^{(*)}W^+W^-p^{(*)} \rightarrow p^{(*)}\mu^\pm e^\mp p^{(*)}) = 11.9_{-4.5}^{+5.6} \text{ fb.}$$

SM prediction: 6.9 ± 0.6 ,
combined 7+8 TeV significance 3.4σ

arxiv: 1607.03745
Submitted to Phys.Rev.D



$$\sigma_{\gamma\gamma \rightarrow W^+W^- \rightarrow e^\pm \mu^\mp X}^{\text{Measured}} = 6.9 \pm 2.2 \text{ (stat.)} \pm 1.4 \text{ (sys.) fb}$$

SM prediction: 4.4 ± 0.3 fb,
8 TeV signal significance 3.0σ

Among the lowest production cross sections measured at the LHC!

aQGC, Exclusive Higgs Results

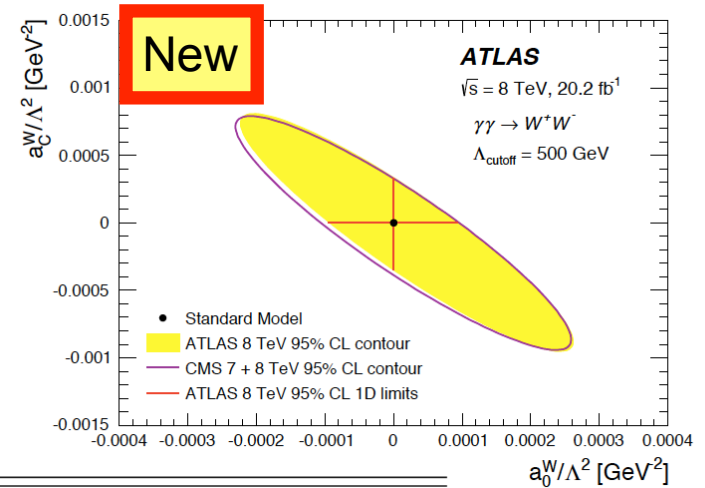
arxiv: 1607.03745
Submitted to Phys.Rev.D

Use shape of $p_T(e\mu)$ distribution to search for sign of aQGC

CMS: 8 TeV ($30 < p_T(e\mu) < 130$ GeV) and $p_T(e\mu) > 130$ GeV

ATLAS: $p_T(e\mu) > 120$ GeV

Region outside solid line excluded at 95% CL
2 orders of magnitude more stringent than LEP

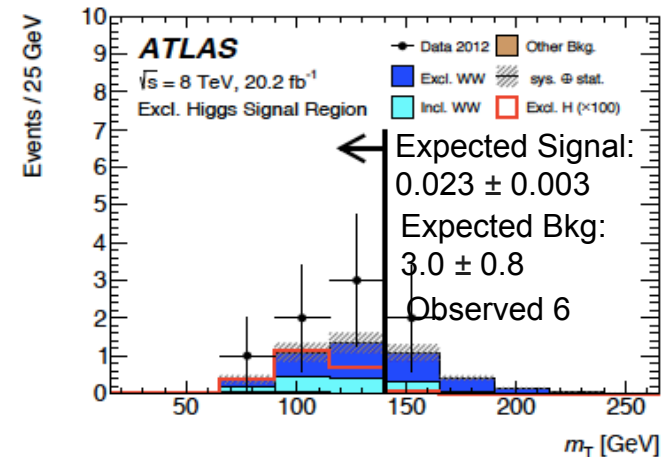


ATLAS,
New

Coupling	Λ_{cutoff}	Observed allowed range [GeV^{-2}]	Expected allowed range [GeV^{-2}]
a_0^W/Λ^2	500 GeV	$[-0.96 \times 10^{-4}, 0.93 \times 10^{-4}]$	$[-0.90 \times 10^{-4}, 0.87 \times 10^{-4}]$
a_C^W/Λ^2	500 GeV	$[-3.5 \times 10^{-4}, 3.3 \times 10^{-4}]$	$[-3.3 \times 10^{-4}, 3.1 \times 10^{-4}]$

ATLAS Higgs search:

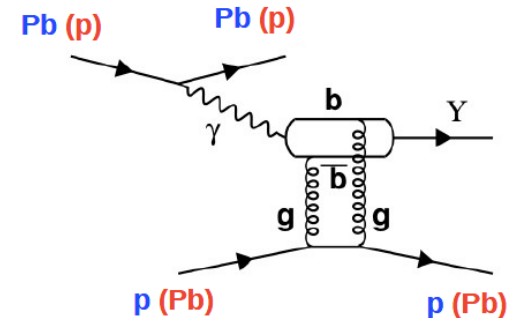
Upper limit at 95% CL on total production
Cross section: 1.2 pb (expected limit 0.7 pb)



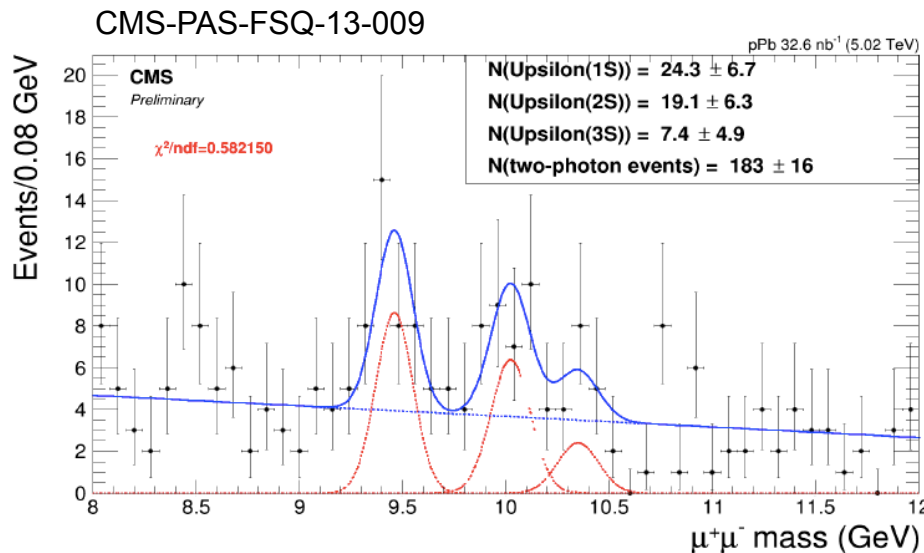
Exclusive Upsilon Production in pPb

Exclusive photoproduction of Y in pPb ultra peripheral collisions

- Sensitive to the gluon density squared in the nucleon
- Probes gluon distribution in the proton at low x
- Expected power law dependence with $W_{\gamma p}$ (mass of photon-proton system)



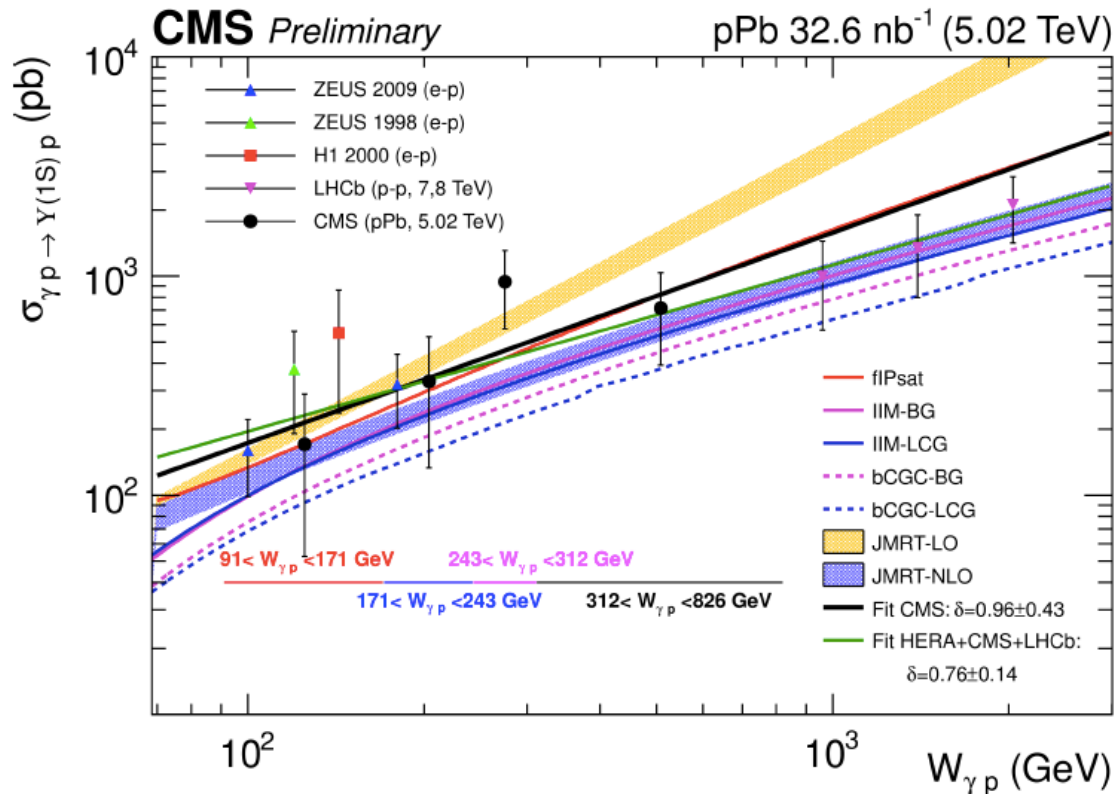
Photon flux proportional to Z^2
 γp : Dominant contribution
 γPb : Small contribution



CMS: 32.6 nb⁻¹ of 2013
 pPb 5.02 TeV data

- opposite sign $\mu\mu$ pair
- no extra tracks
- Upsilon p_T : 0.1-1 GeV

Exclusive Upsilon Production in pPb



CMS-PAS-FSQ-13-009

Power-law fit $A \times (W/400)^\delta$ to the CMS data $\delta = (0.96 \pm 0.43)$, $A = 655 \pm 196$

Data compatible with power law dependence and disfavours LO predictions

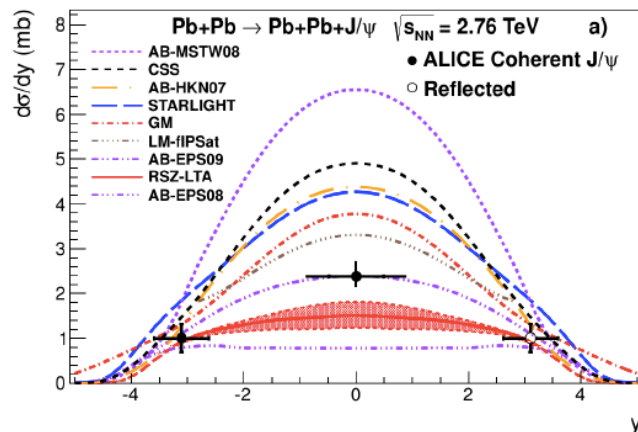
Data collated with Zeus, H1 and recent LHCb measurement (JHEP 09 (2015) 084)

Exclusive Production in Pb-Pb collisions

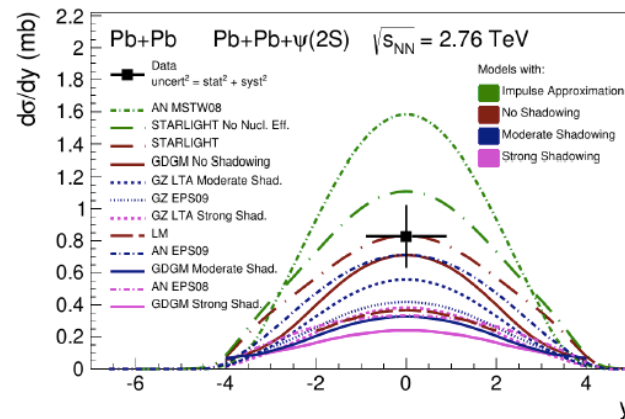
Vector meson dominance - Exclusive vector meson production dominates
 Forward scattering amplitude for heavy VM calculable from pQCD

$$\frac{d\sigma}{dt}\Big|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 \left[xg(x, \frac{M_V^2}{4}) \right]^2 \quad \text{Ryskin (Z. Phys C 57 (1993) 89)}$$

The proportionality $d\sigma/dt [g(x, Q^2)]^2$ factorises through whole equation
 leading to $d\sigma/dy [g(x, Q^2)]^2$



ALICE Collaboration Phys. Lett. B 718 (2013) 1273; EPJC 73 (2013) 2617.



ALICE Collaboration Phys. Lett. B 751 (2015) 358.

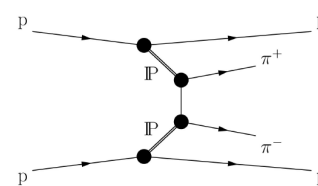
Results in agreement with models which include moderate nuclear gluon shadowing
 consistent with the EPS09 parameterization.

Increased statistics in Run 2 @ 5.02 TeV; x6 at mid-, x50 at forward rapidity

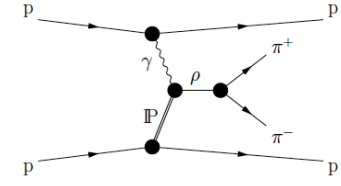
Central exclusive $\pi^+\pi^-$ production

CMS: Dedicated data sample (2010)
with $450 \mu\text{b}^{-1}$ in low pileup conditions

Large cross sections:
Access to spectroscopic study of low mass resonances
search for glueball candidates
Large backgrounds; estimated from calo multiplicities

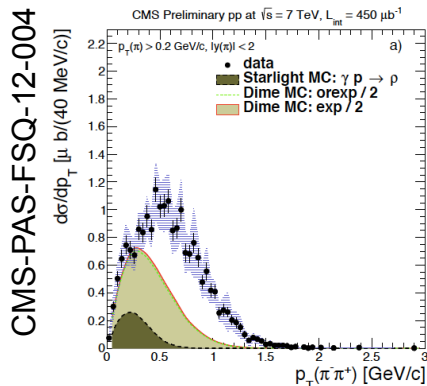


Double Pomeron Exchange - dominant process

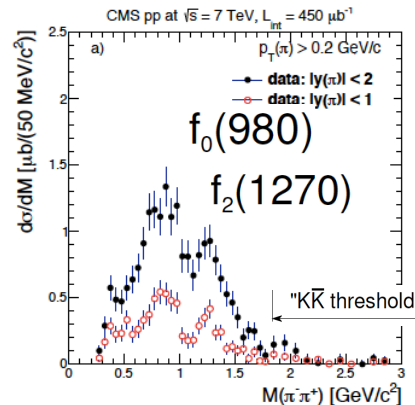


exclusive ρ meson photoproduction

Total cross section: $\sigma_{\text{vis}} = 20.5 \pm 0.3(\text{stat.}) \pm 3.1(\text{sys.}) \pm 0.8(\text{lumi}) \mu\text{b}$



CMS-PAS-FSQ-12-004



Differential Cross section, for $|y(\pi)| < 2$ and $|y(\pi)| < 1$
some evidence of resonant structures

Unfolded cross sections:

$$|y(\pi^\pm)| < 2.0: \sigma_{\text{vis}} = 20.5 \pm 0.3 (\text{stat.}) \pm 3.1 (\text{sys.}) \pm 0.8 (\text{lumi}) \mu\text{b}$$

$$|y(\pi^\pm)| < 1.0: \sigma_{\text{vis}} = 8.1 \pm 0.2 (\text{stat.}) \pm 1.2 (\text{sys.}) \pm 0.3 (\text{lumi}) \mu\text{b}$$

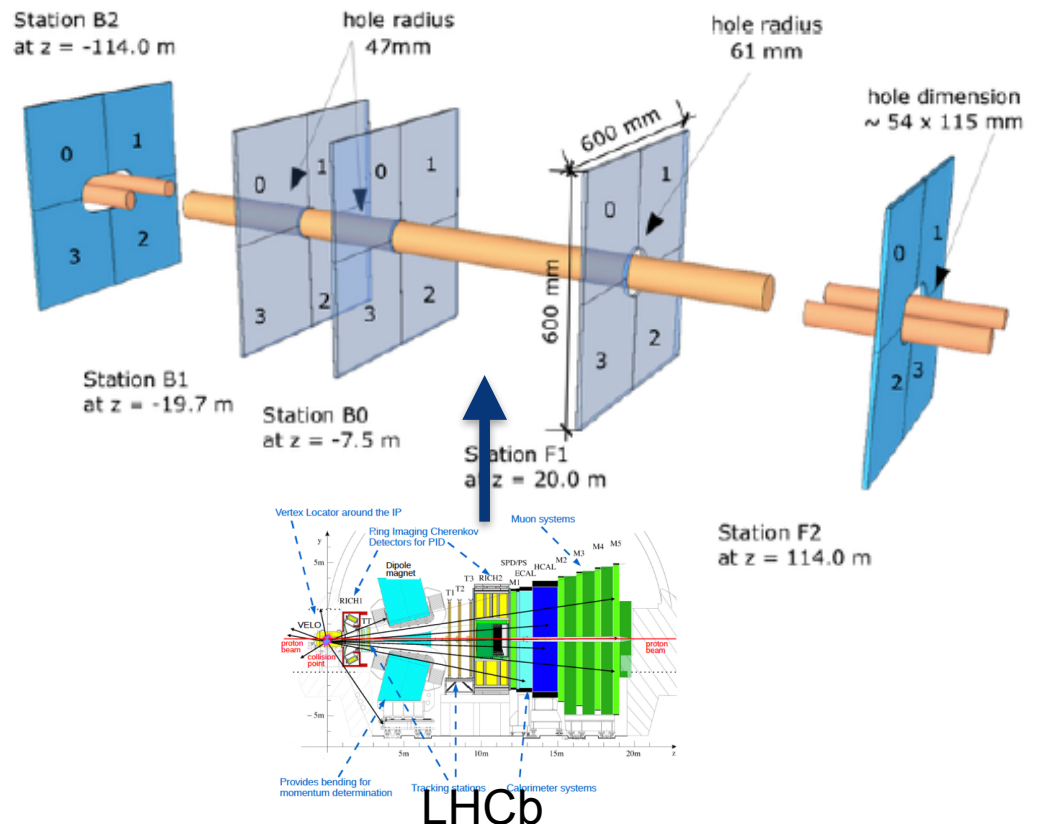
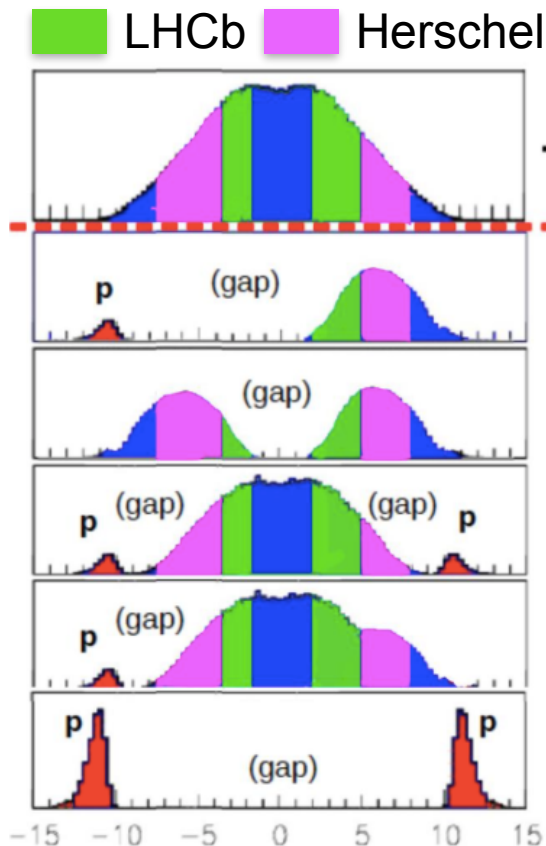
Eagerly waiting for new results from all experiments!

DPE production predictions from IME MC and STARLIGHT (stacked) data enhancement at higher p_T

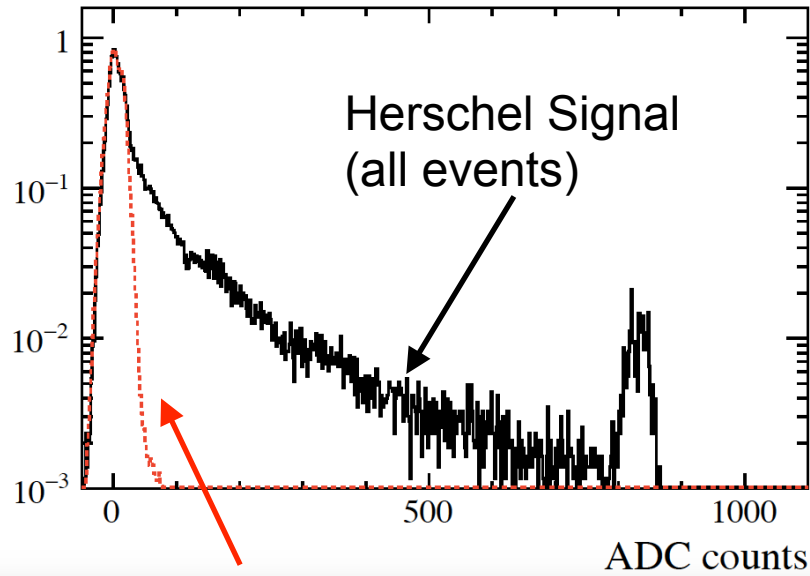
Central exclusive J/ψ and $\psi(2S)$ @ LHCb

Use of new **HERSCHEL** detectors

High **R**apidity **S**hower **C**ounters for **L**H**C**b

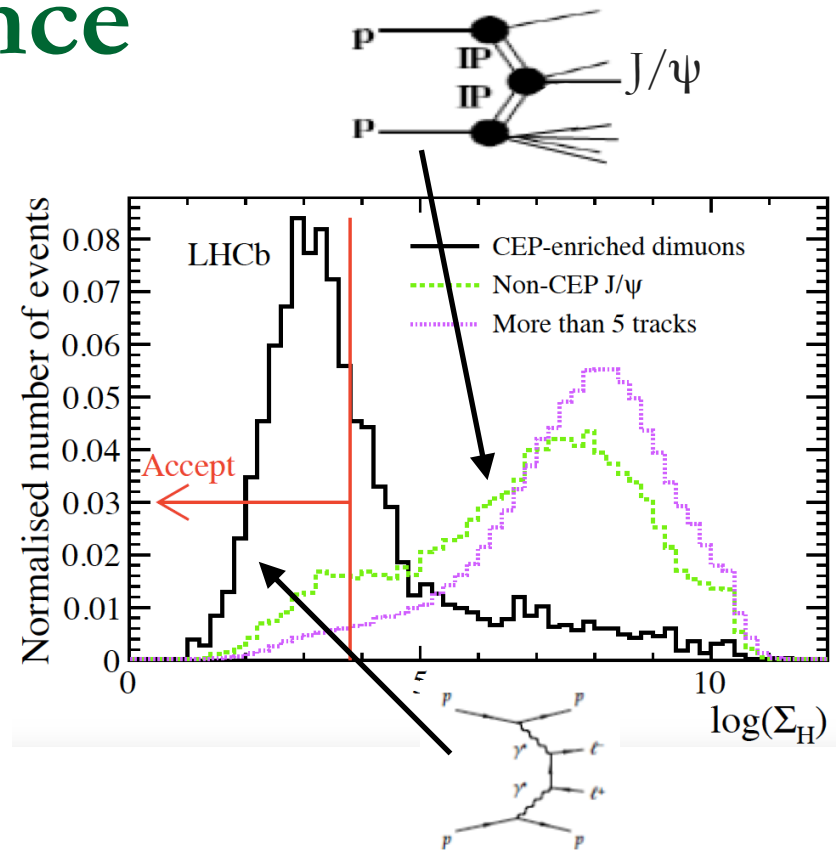


Herschel Performance



Herschel Pedestal
(including spillover)

- Clean pedestals and complete suppression of pileup
- Pedestals calibrated using non connected channels
- Quadratic sum of normalised signals (Σ_H)
- used to create veto



Response checked against 3
classes of events

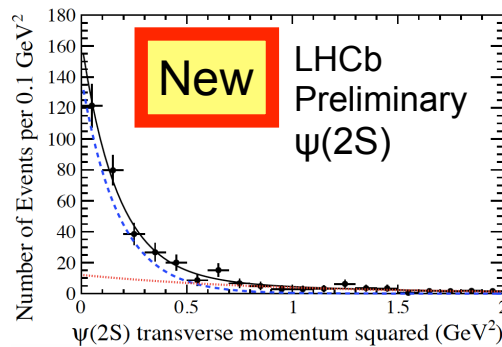
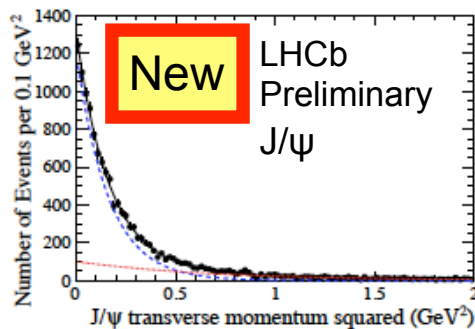
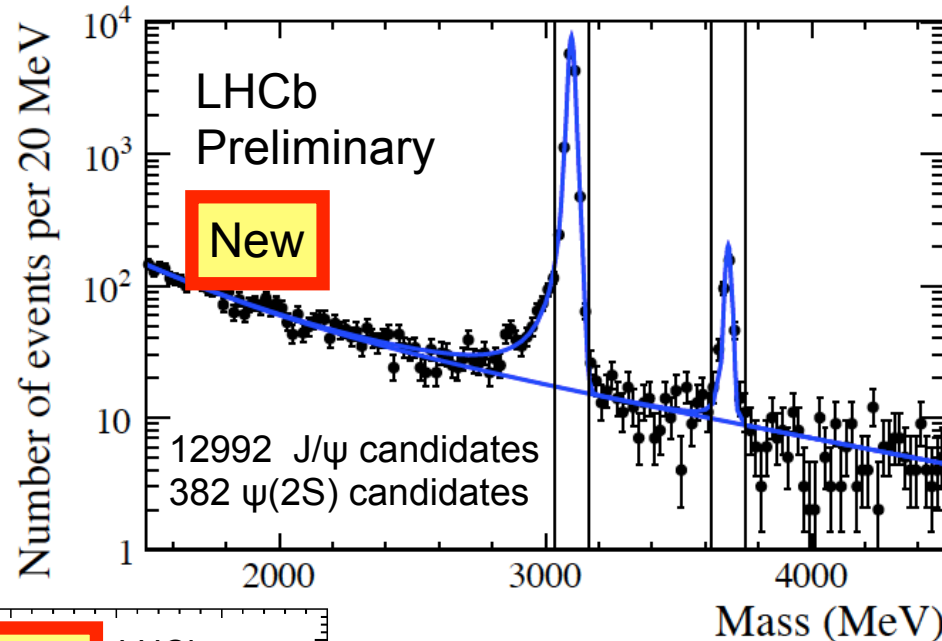
Clear signal/background
enhancement

Central exclusive J/ψ and $\psi(2S)$ @ LHCb

New measurement, using 200 pb⁻¹ of data at 13 TeV CM energy

Candidate selection

- two reconstructed muons with $2 < \eta < 4.5$
- no additional tracks/energy
- Within 65 MeV/c² of $m_{J/\psi}$
- Herschel VETO



Background halved relative to previous analyses

Central exclusive J/ψ and ψ(2S) @ LHCb

LHCb Preliminary Cross Section

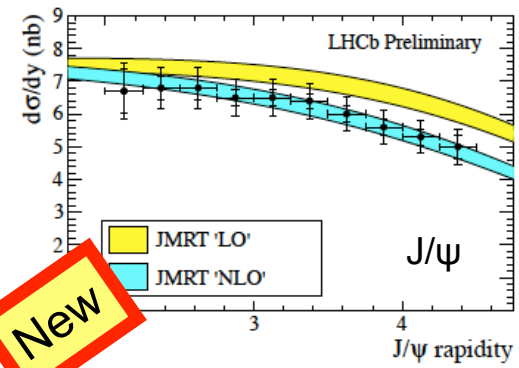
New

$$\sigma_{J/\psi \rightarrow \mu^+ \mu^-} (2 < \eta_{\mu^+ \mu^-} < 4.5) = 407 \pm 8 \pm 24 \pm 16 \text{ pb}$$

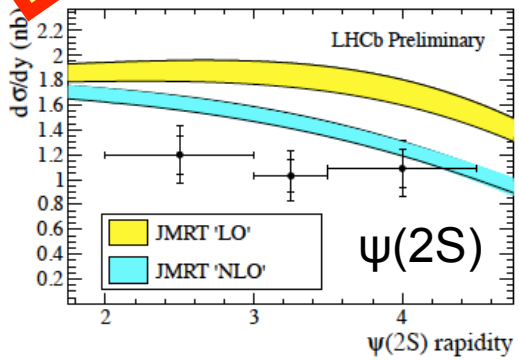
$$\sigma_{\psi(2S) \rightarrow \mu^+ \mu^-} (2 < \eta_{\mu^+ \mu^-} < 4.5) = 9.4 \pm 0.9 \pm 0.6 \pm 0.4 \text{ pb}$$

LHCb-CONF-2016-007-001

New

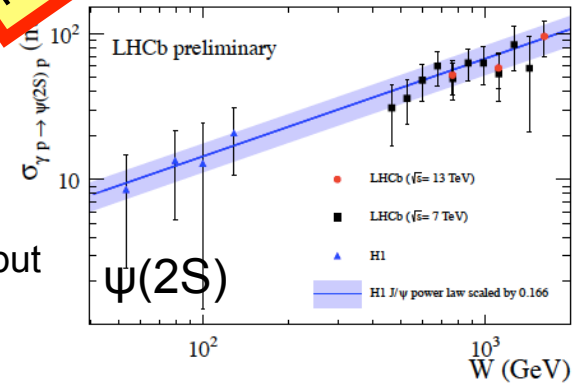
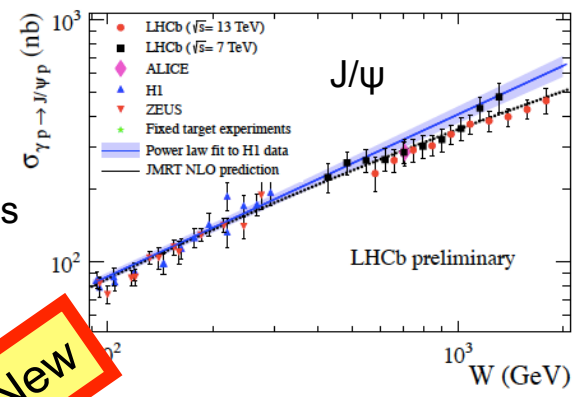


Differential cross section in better agreement with JMRT NLO rather than LO predictions



13 TeV data allows significant extension of the reach in W
Simple power law insufficient but data well described by NLO

New



LHCb-CONF-2016-007-001

Conclusions

- New results have been presented on the search for $\gamma\gamma \rightarrow W^+W^-$ and the search for exclusive Higgs production via $H \rightarrow W^+W^-$
 - New cross sections are compatible with SM
 - Best limits on aQGC couplings
- First results using Herschel at LHCb have been presented for Central exclusive J/ψ and $\psi(2S)$ production
 - Backgrounds are halved, reducing errors and model dependence
 - Reach in W is extended to 2 TeV and NLO models favoured
- With the hardware improvements in all LHC detectors and more data to analyse we anticipate an exciting future for Central Exclusive Production measurements at the LHC

Many thanks to ATLAS, CMS and ALICE colleagues for the material



Backup

Herschel impact on backgrounds

