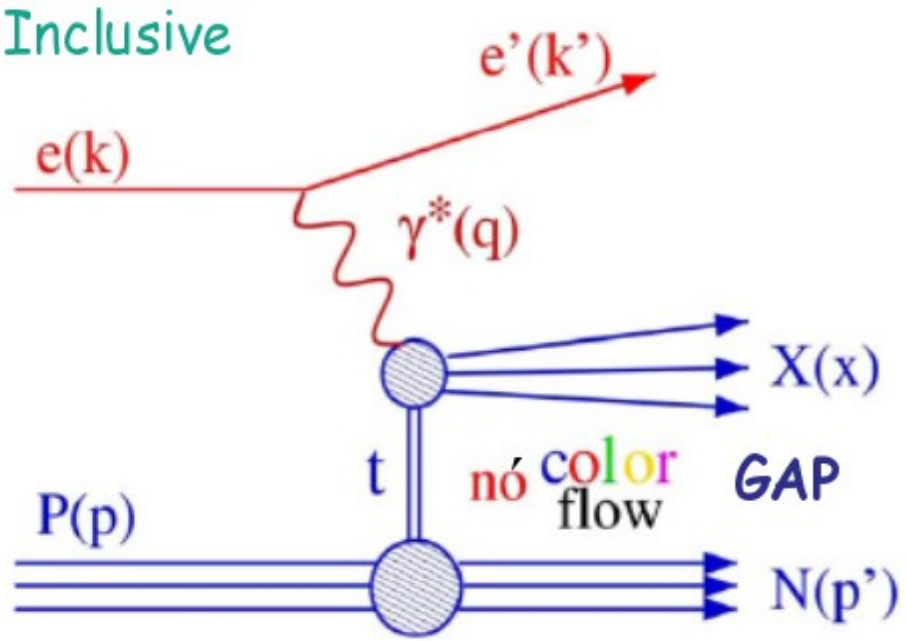
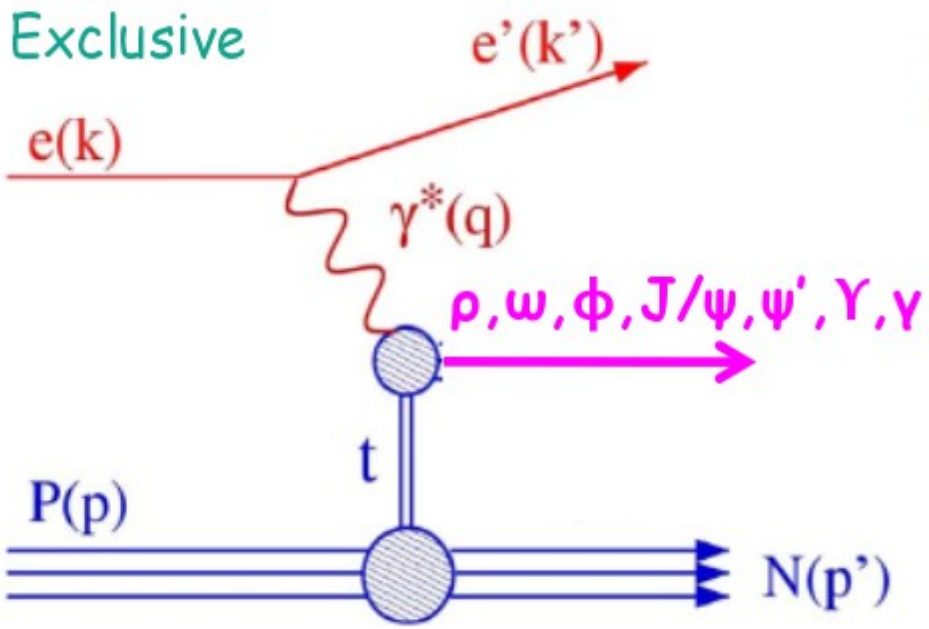
Exclusive processes at collider kinematics

K. Wichmann

Thanks to M. Ruspa and R. Ciesielski for help in preparing the talk and for discussions

Inclusive and exclusive diffraction





Q^2 = virtuality of photon =
= (4-momentum exchanged at e vertex)^2

W = invariant mass of γ^*-p system

t = (4-momentum exchanged at p vertex)^2
typically: $|t|<1$ GeV^2

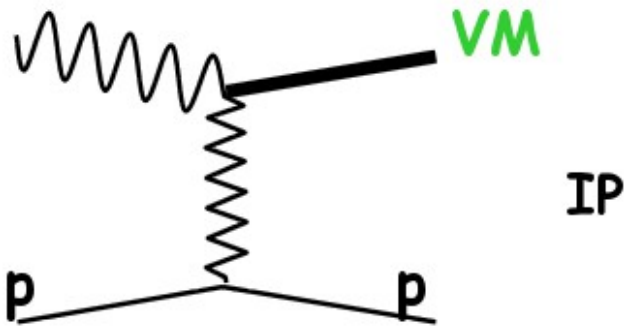
M_X = invariant mass of γ^* -IP system

x_{IP} = fraction of proton's momentum carried by IP

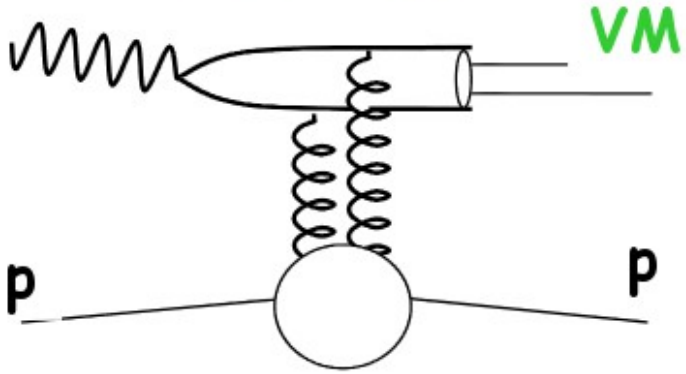
β = Bjorken's variable for the IP
= fraction of IP momentum carried by struck quark
= x/x_{IP}

Transition soft → hard

Soft - Regge



Hard - QCD



VM ($J^{PC}=1^{--}$): γ, ρ, ϕ, J/ψ, Υ,...

2-gluon exchange:
LO realisation of vacuum
quantum numbers in QCD

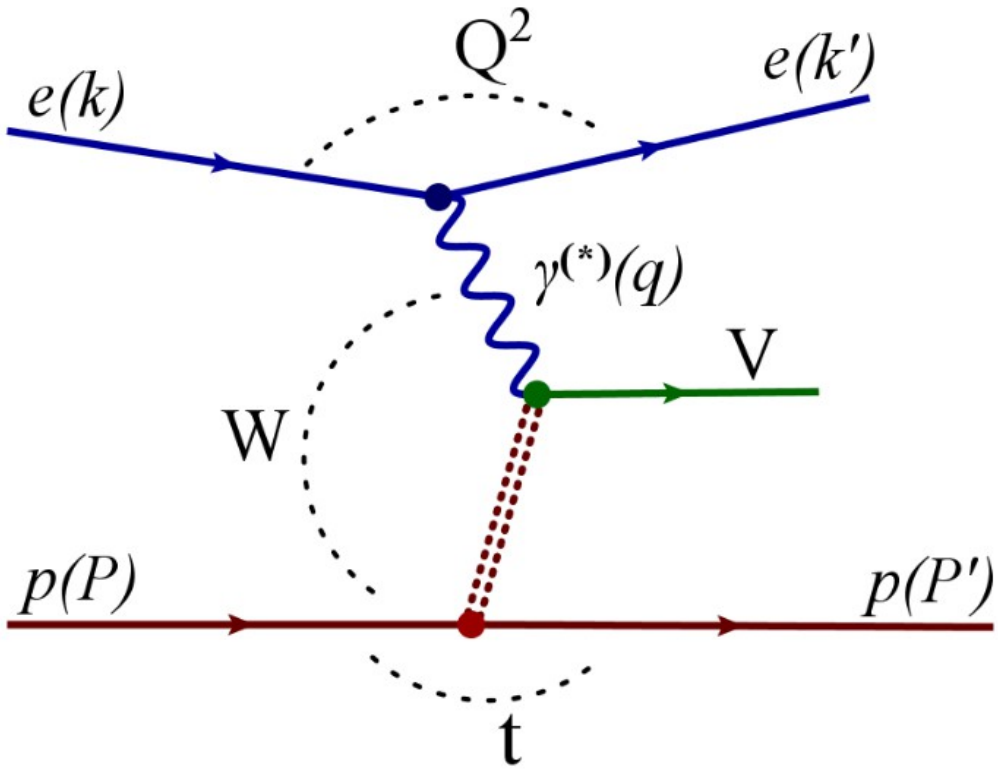
$$\sigma(W) \propto W^{\delta}$$

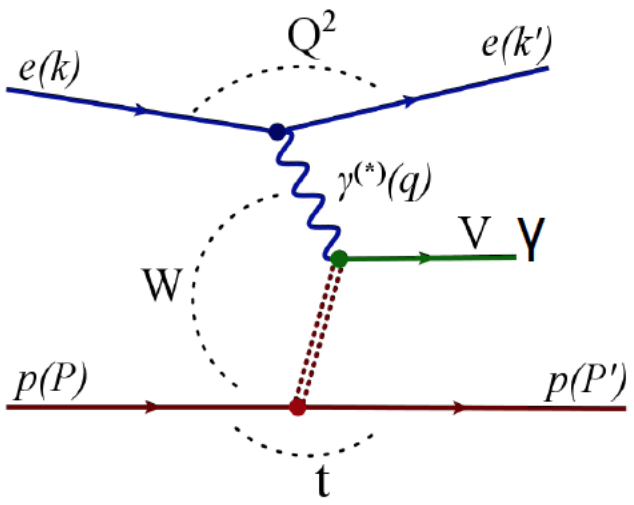
$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

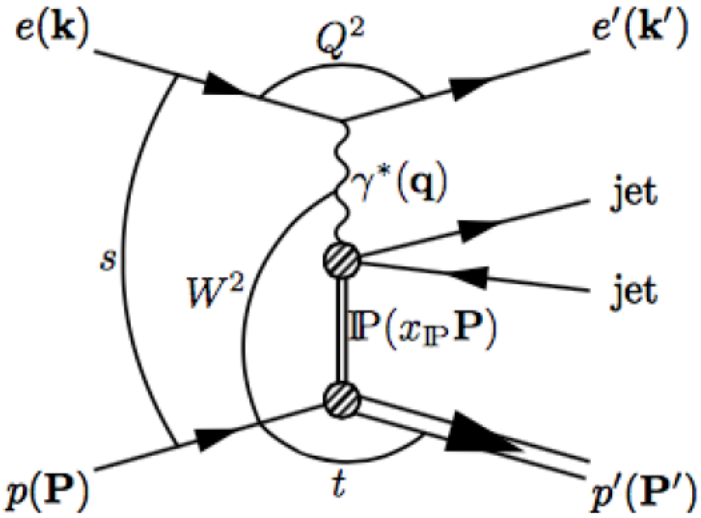
$$\sigma \propto [x\,g]^2 \leftarrow !$$

Gluon density in the proton

Vector Meson (VM) production







Exclusive production of Vector mesons, photons, or jets:

Q^2 photon virtuality

W photon-proton centre-of-mass energy

$t=(p-p')^2$ – four momentum transfer squared at proton vertex

x–Bjorken x–fraction of proton's momentum carried by struck quark

x_{IP} – fraction of proton's momentum carried by exchanged colour singlet

Kinematic variable fully reconstructed, usually measuring scattered electron (in DIS) and vector meson decay products or final photons or jets.

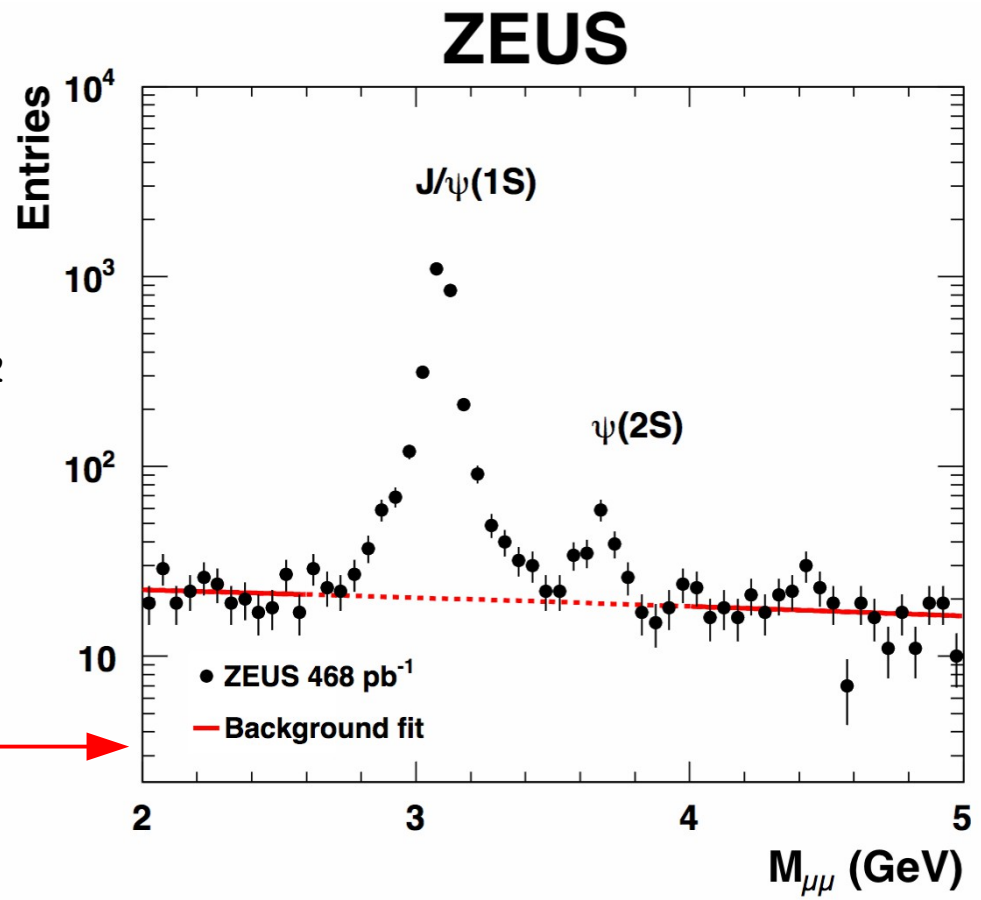
Scattered p detected with lower acceptance

ψ(2s)/Jpsi in DIS

DESY-16-008, accepted by Nucl. Phys. B

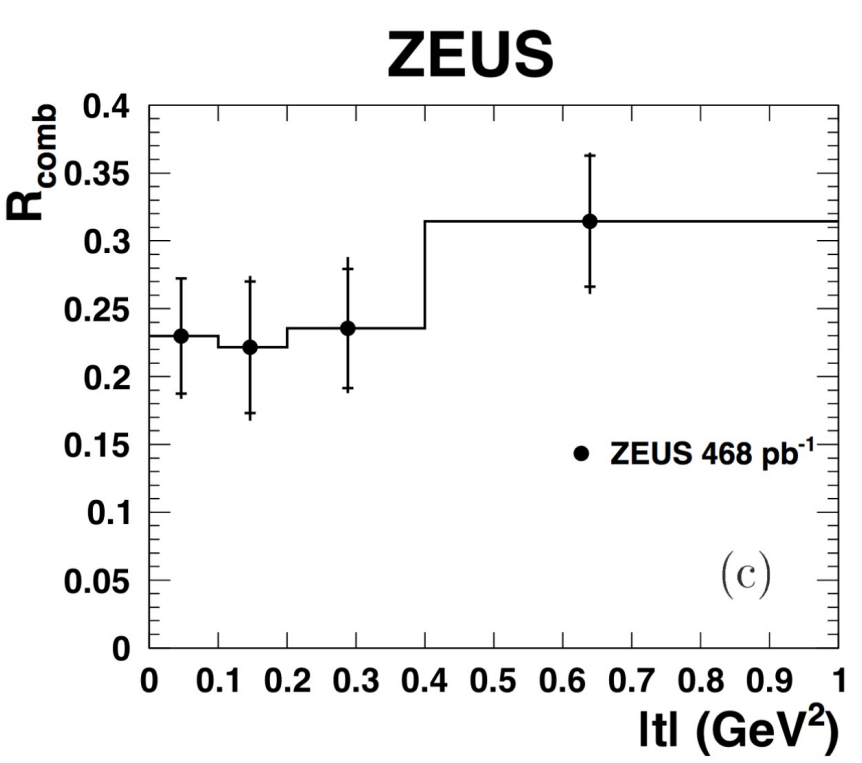
- ψ(2s) wave function different from J/ψ wave function
- pQCD predicts R ~ 0.17 for photoproduction and rise with Q^2

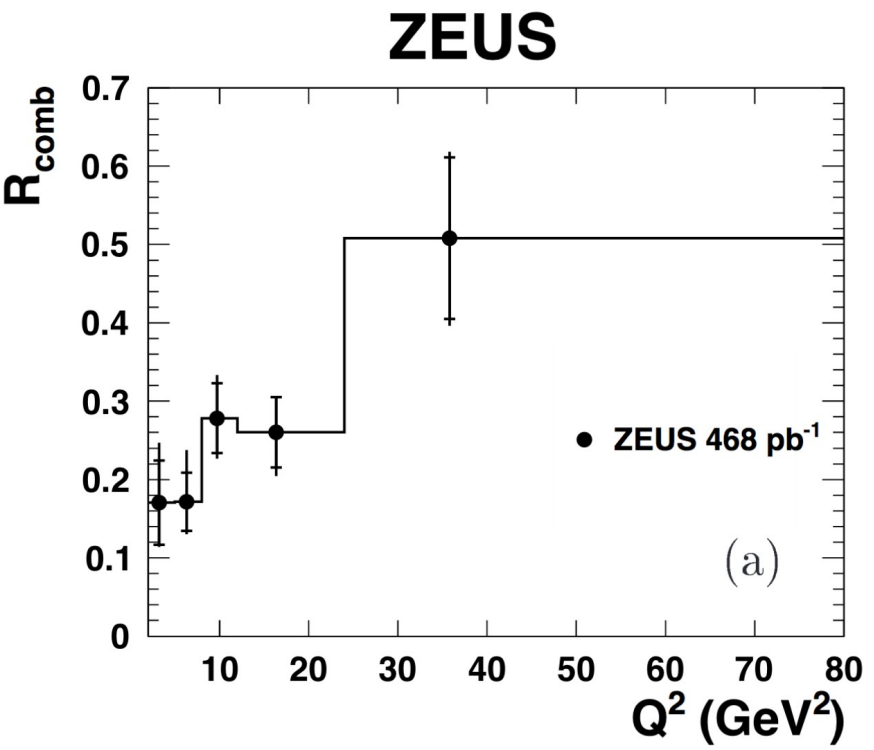
$\Psi(2S) \rightarrow J/\psi\, \pi^+ \pi^-;\ J/\psi \rightarrow \mu^+ \mu^-$
$\Psi(2S) \rightarrow \mu^+ \mu^-$
$J/\psi \rightarrow \mu^+ \mu^-$



ψ(2s)/Jpsi in DIS

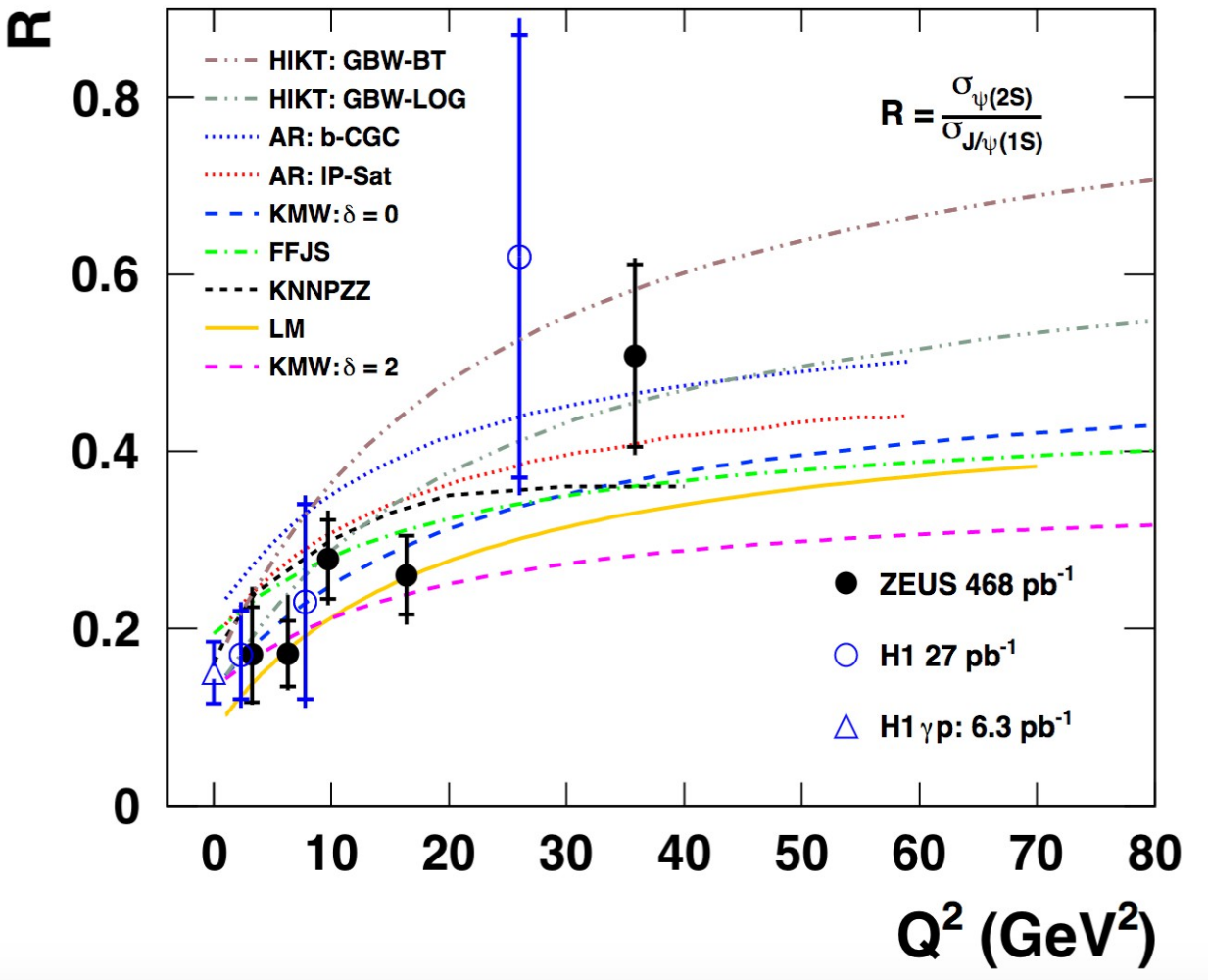
R_{comb} - ratio for combination of both channels





Ratio independent of |t| and W, rises with Q^2

Comparison with H1 measurement and with models

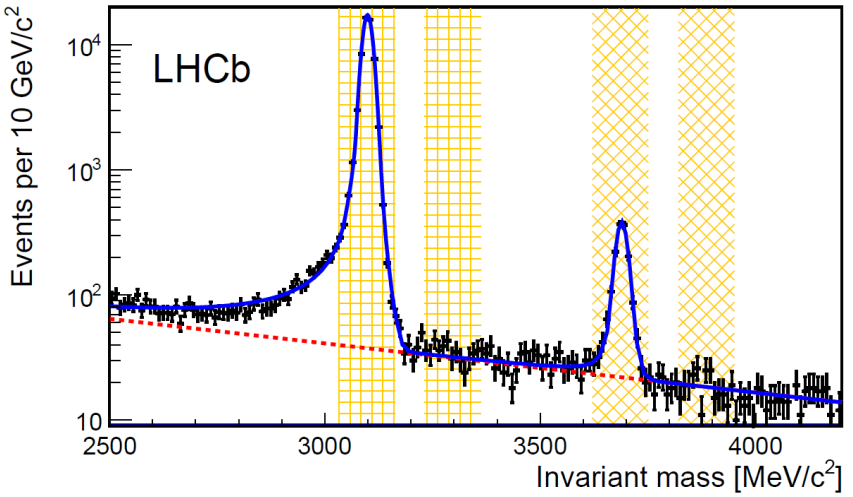


HIKT, Hufner et al.:dipole model, dipole-proton constrained by inclusive DIS data
AR, Armesto and Rezaeian: impact parameter dependent CGC and IP-Sat model
KMW,Kowalski Motyka Watt: QCD description and universality of quarkonia production
FFJS, Fazio et al.: two component Pomeron model
KNNPZZ, Nemchik et al.: color-dipole cross section derived from BFKL generalised eq.
LM, Lappi and Mäntysaari : dipole picture in IP-Sat model

Vector Mesons @ LHC

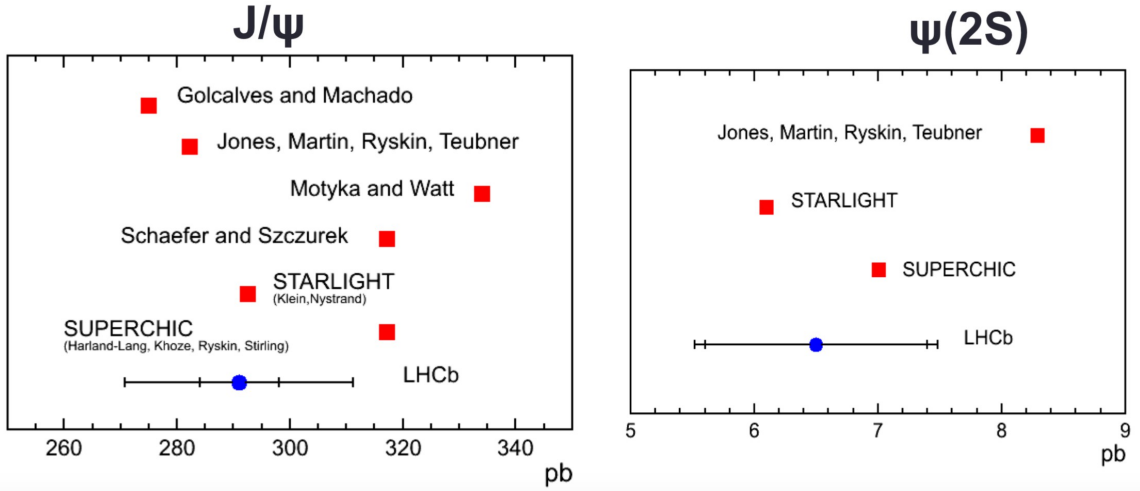
ψ(2s) and J/psi @ LHCb

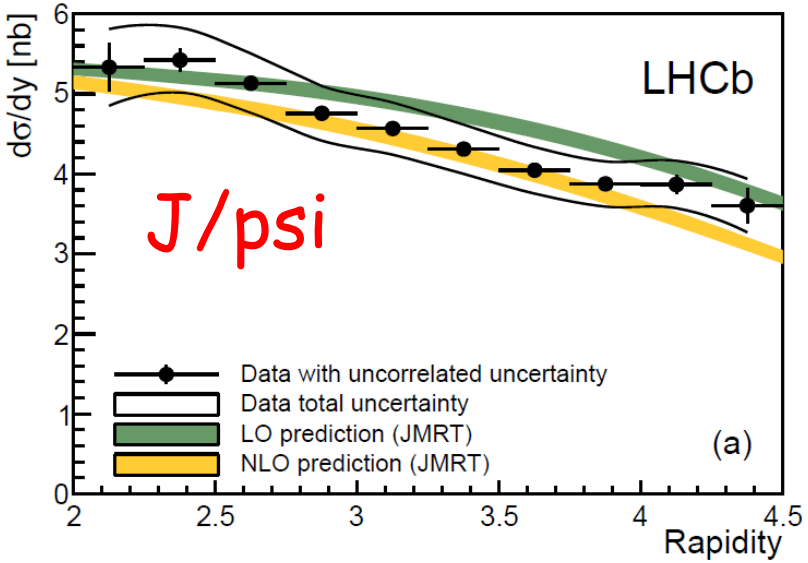
JPG 41 (2014) 055002

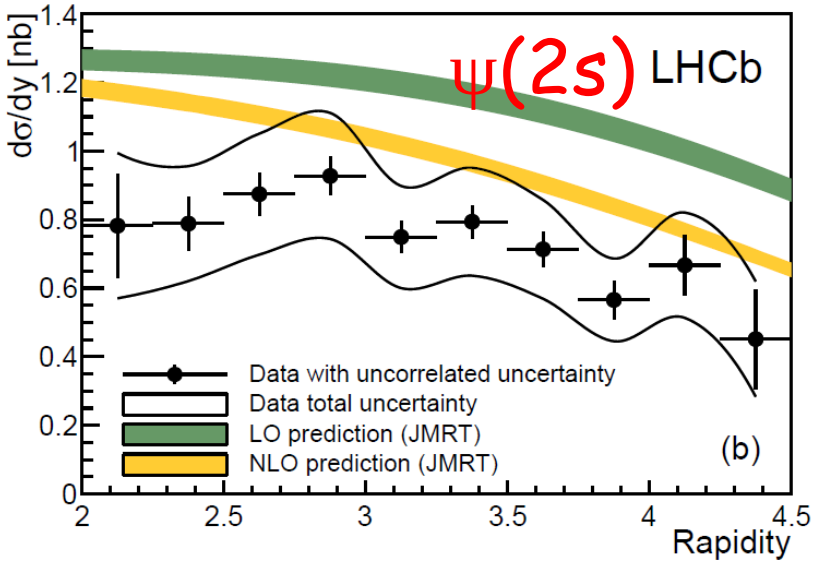


Integrated cross sections

Cross-section*BR for both muons in pseudorapidity range 2<η<4.5:

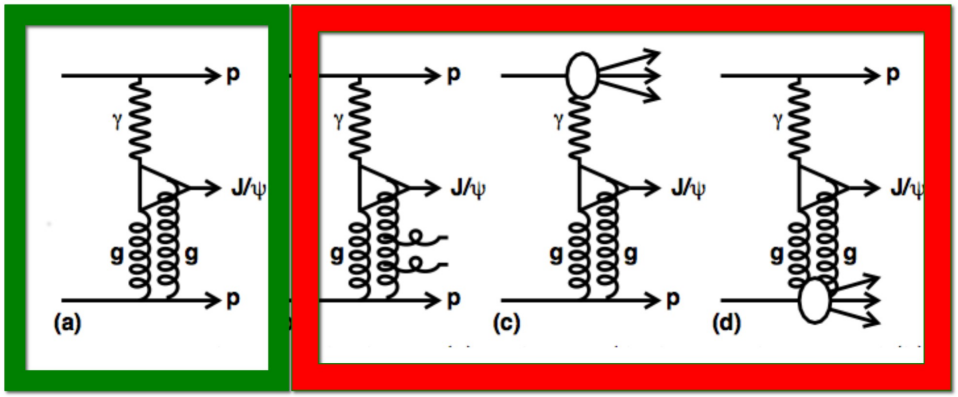




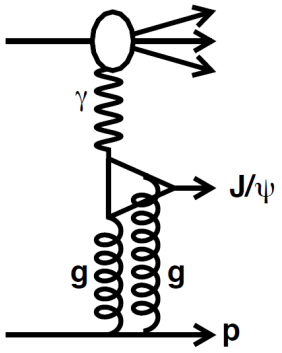


Good agreement with NLO predictions

Inelastic background: J/psi, similar for ψ(2s)

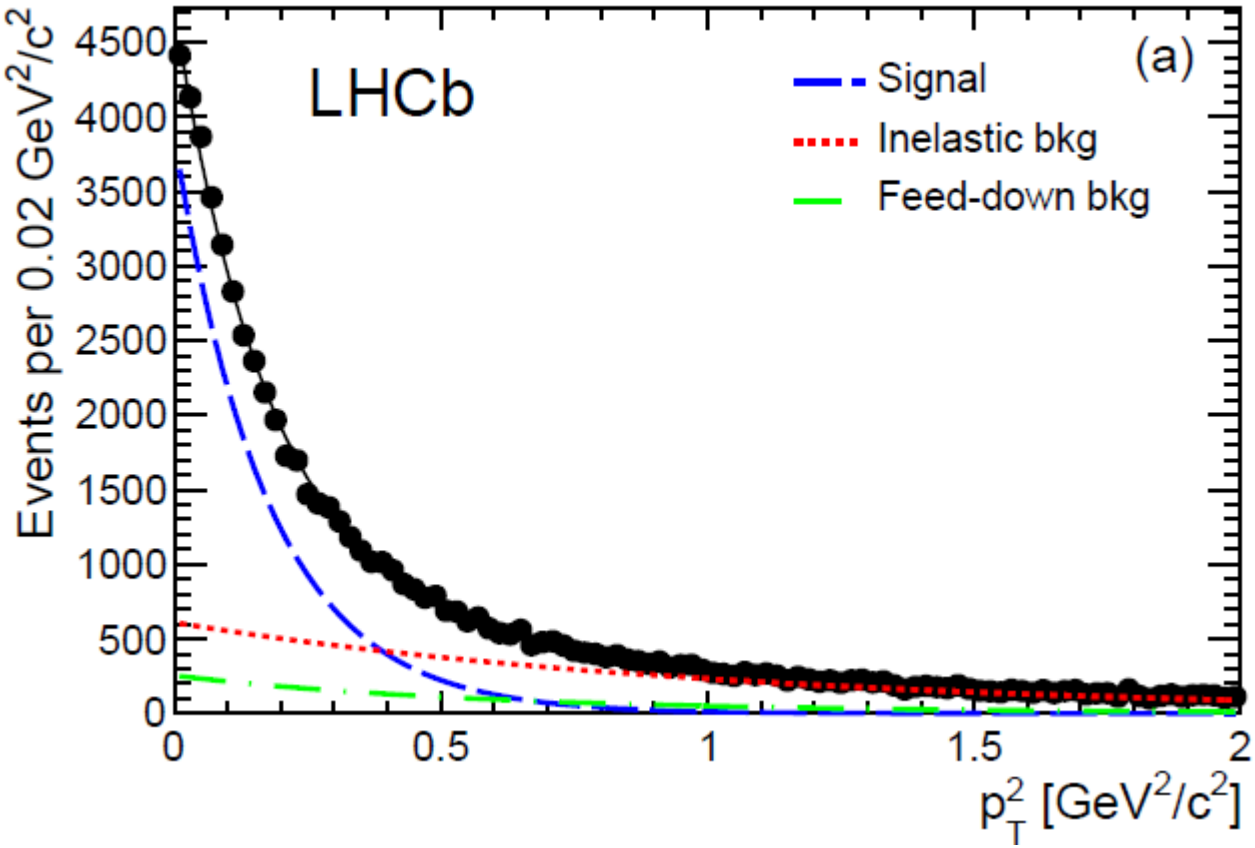


Signal Background



Regge theory: $\frac{d\sigma}{dt} \sim e^{bt}$

JPG 41 (2014) 055002



HERA measured:

b_s=4.9 GeV^{-2}

b_{pd}=1.1 GeV^{-2}

LHCb Expect:

b_s ~ 6 GeV^{-2}

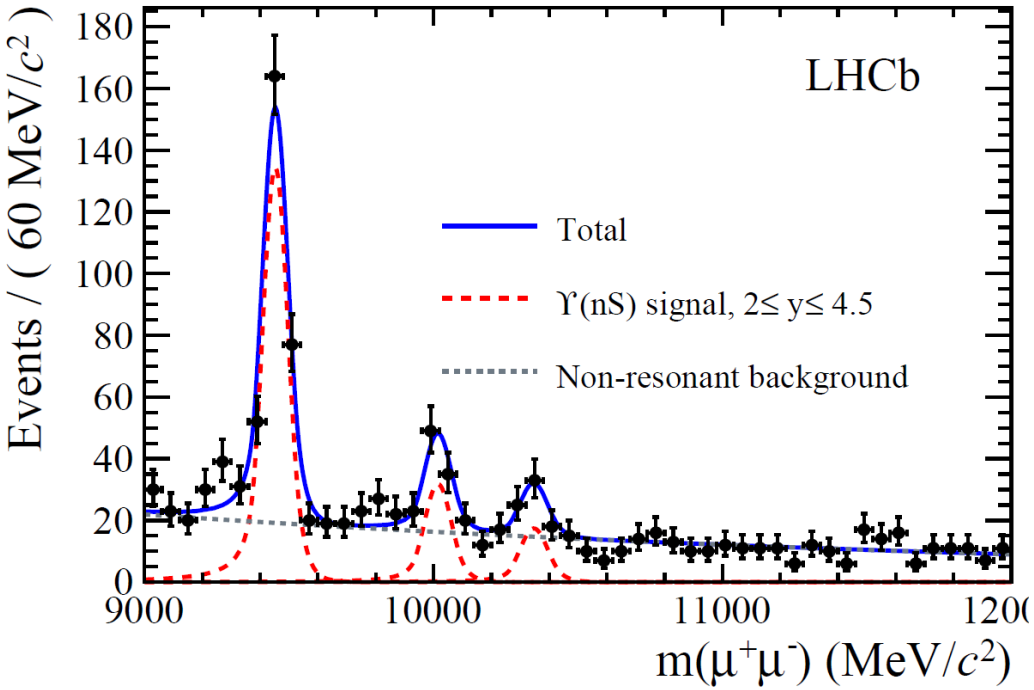
b_{pd}~ 1 GeV^{-2}

LHCb Fit:

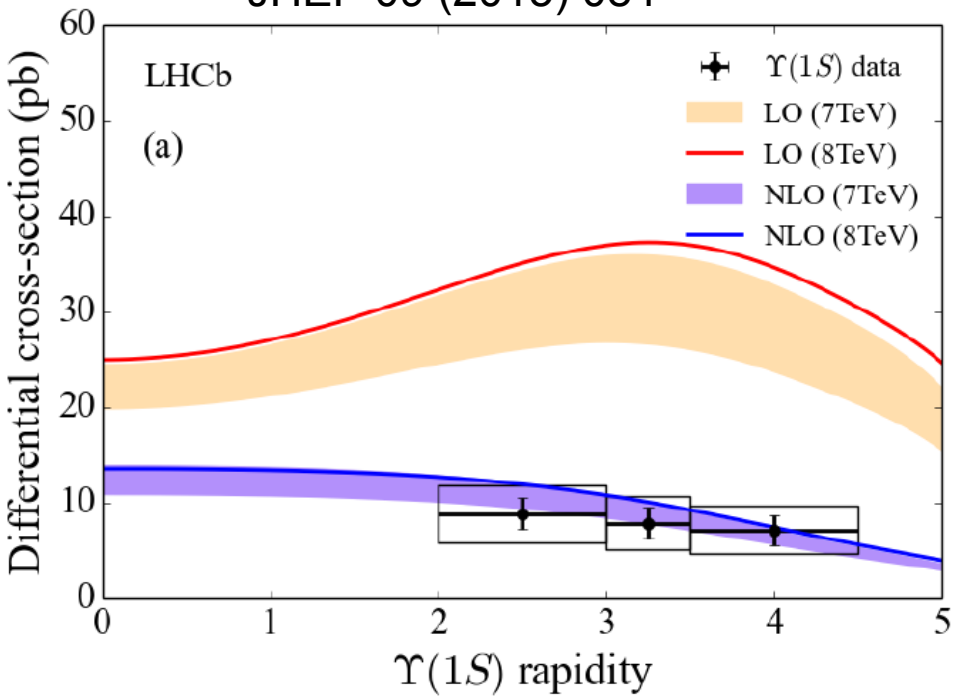
b_s=5.70±0.11 GeV^{-2}

b_{pd}=0.97±0.04 GeV^{-2}

LHCb, first measurement of Υ in pp



JHEP 09 (2015) 084



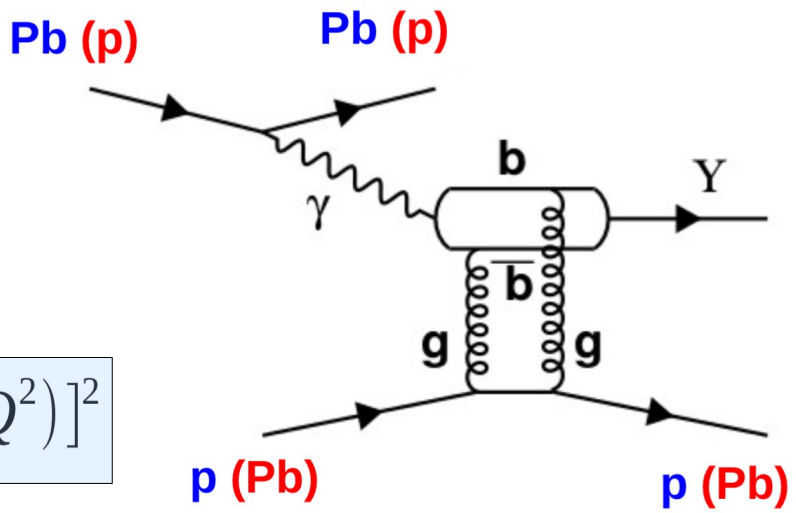
Integrated cross sections

$$\sigma(pp \to p\Upsilon(1S)p) = 9.0 \pm 2.1 \pm 1.7 \text{ pb},$$
$$\sigma(pp \to p\Upsilon(2S)p) = 1.3 \pm 0.8 \pm 0.3 \text{ pb, and}$$
$$\sigma(pp \to p\Upsilon(3S)p) < 3.4 \text{ pb at the 95\% confidence level.}$$

Good agreement with NLO predictions

Exclusive Υ photoproduction in pPb

- Υ photoproduction studies in pPb ultra peripheral collisions
- Sensitivity to gluon density at low x

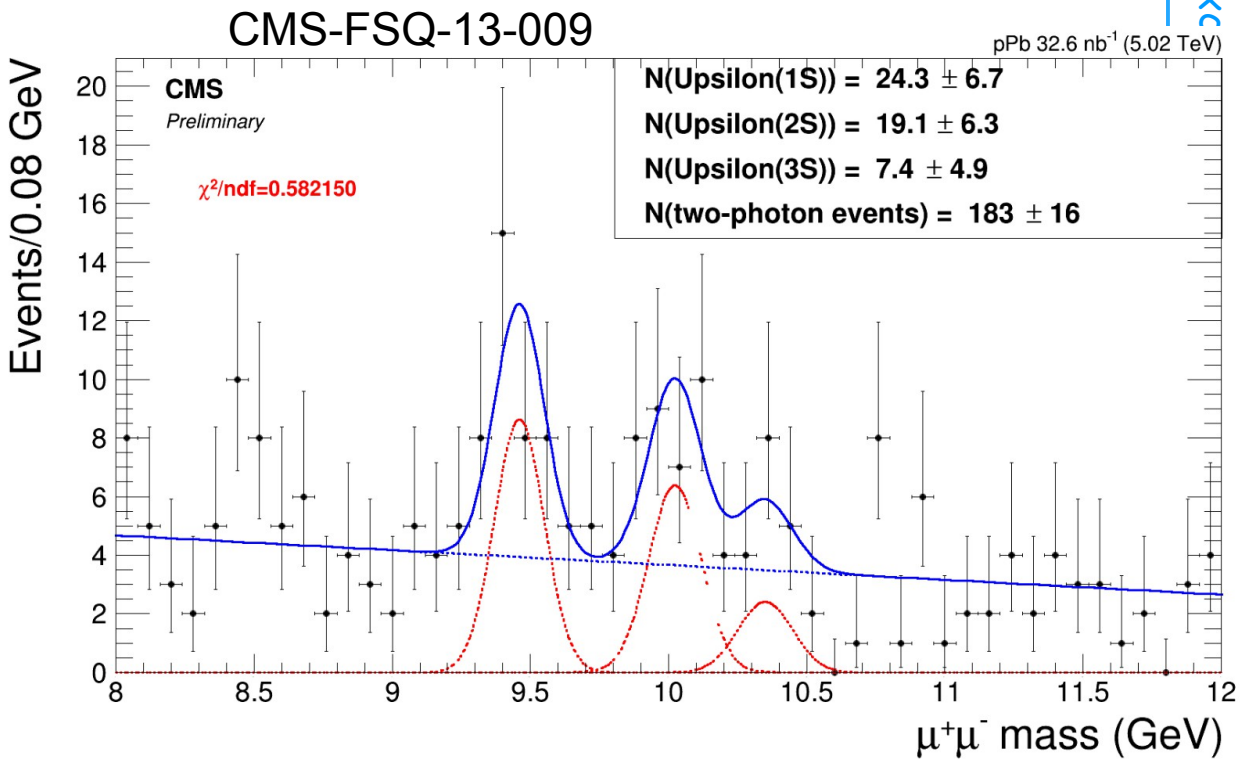


$$\left.\frac{d\sigma_{\gamma p, A\to V p, A}}{dt}\right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 \left[xG\left(x, Q^2\right)\right]^2$$

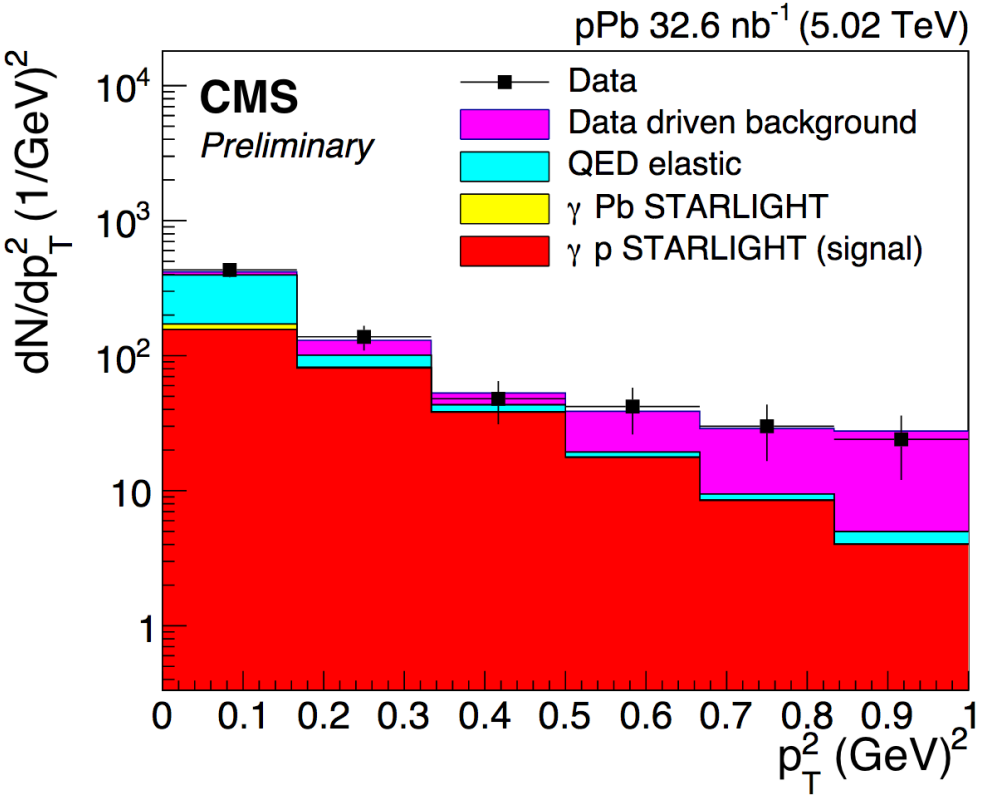
- Expected cross section dependence on $W_{\gamma p}$

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

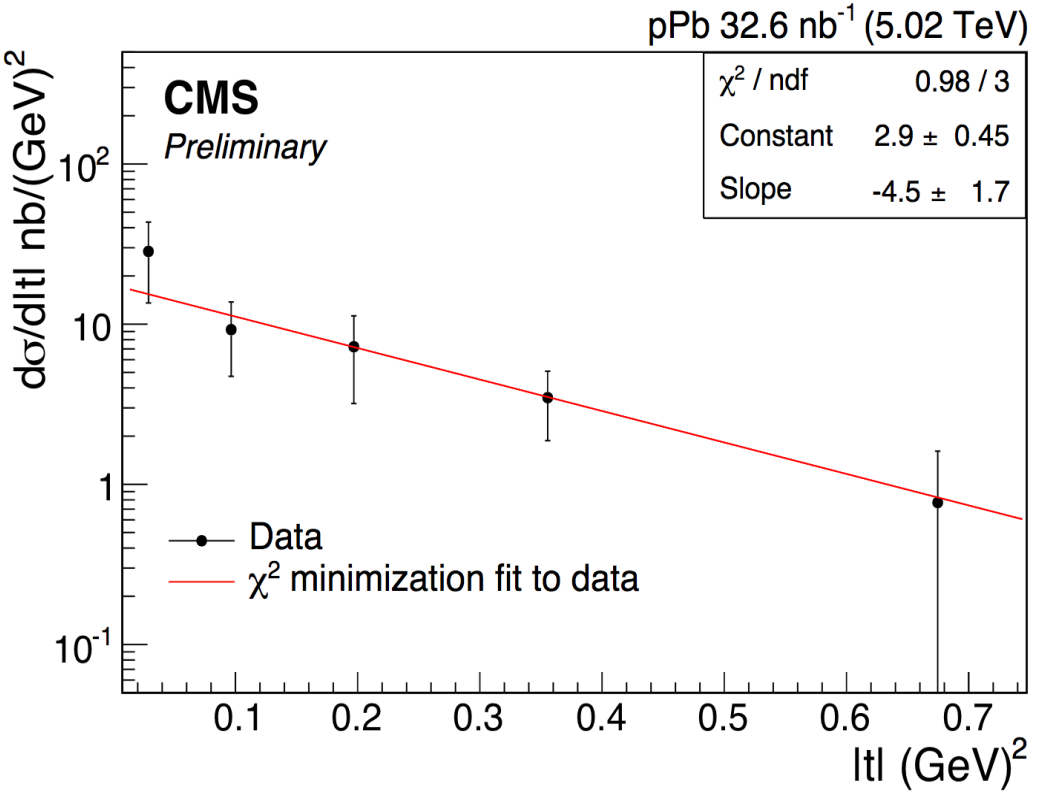
- 2013 pPb data at 5.02 TeV with 32.6 nb^{-1}
- exclusive pPb → Υ(gp) → $\mu^+\mu^-$



Exclusive Υ photoproduction in pPb



CMS-FSQ-13-009

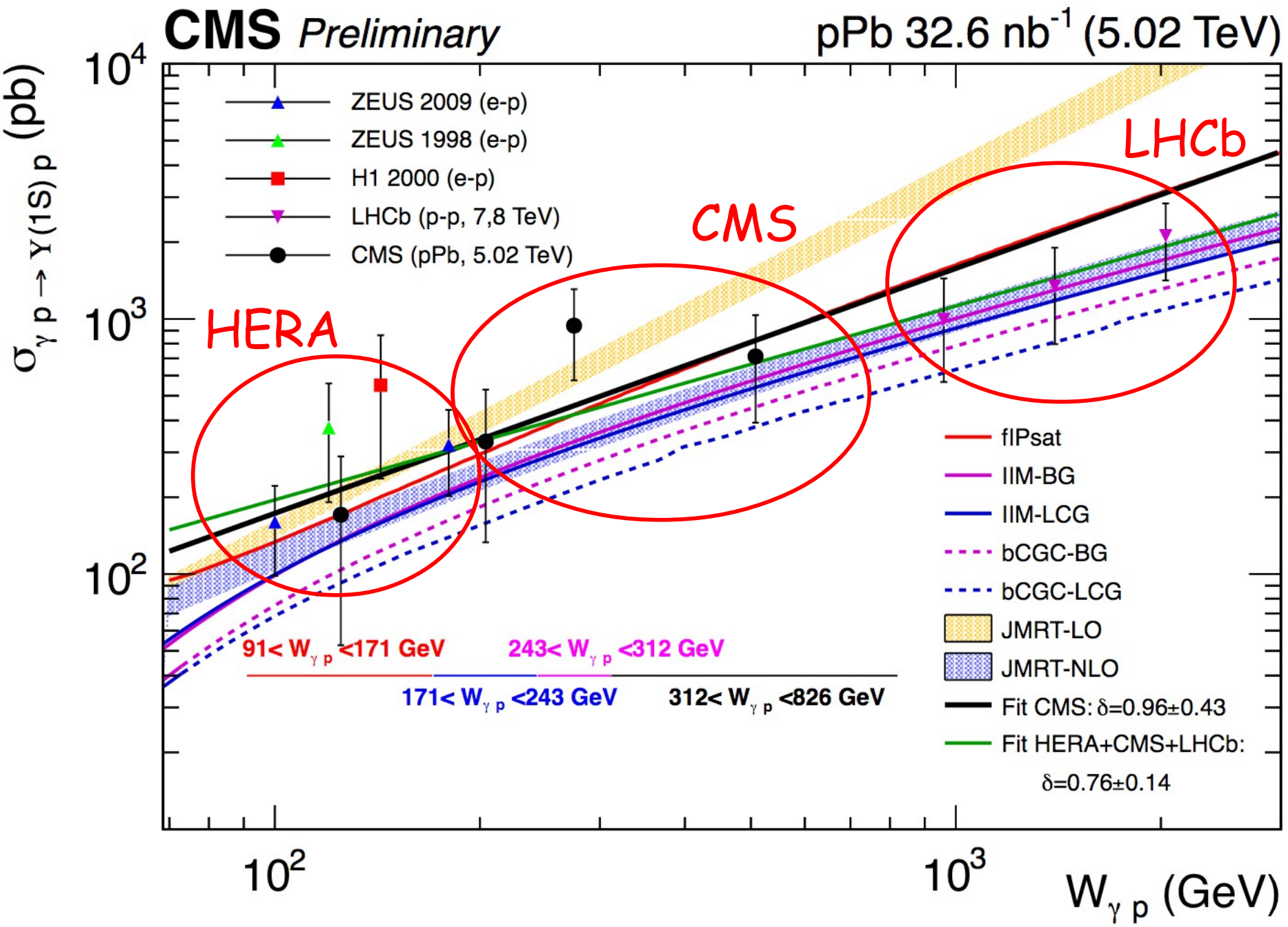


Good agreement between data and MC

CMS Results
b= 4.5 ± 1.7 (stat.) ± 0.6 (syst.) GeV^{-2}
Data is in agreement with ZEUS measurements and consistent with predictions based on pQCD models

ZEUS for Y(1S)
b = 4.3$^{+2.0}_{-1.3}$ (stat)
Phys.Lett.B 708 (2012) 14

Cross section as a function of $W_{\gamma p}$



Exclusive dijet production

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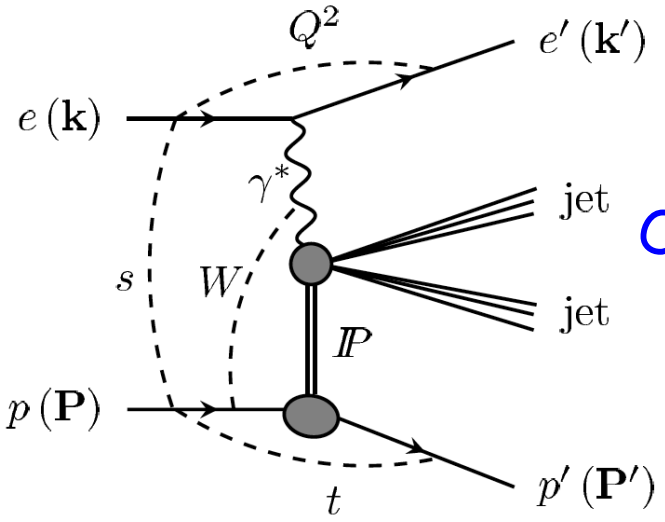
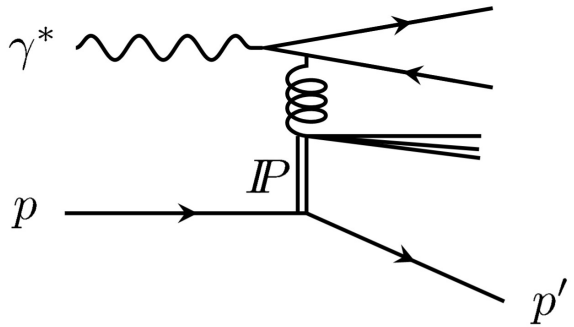
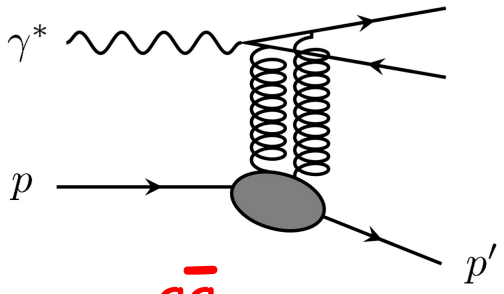


OR

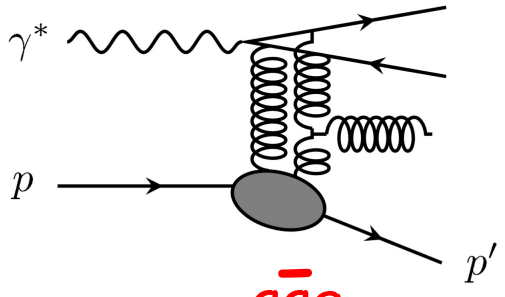
Resolved Pomeron



2-gluon exchange



$q\bar{q}$



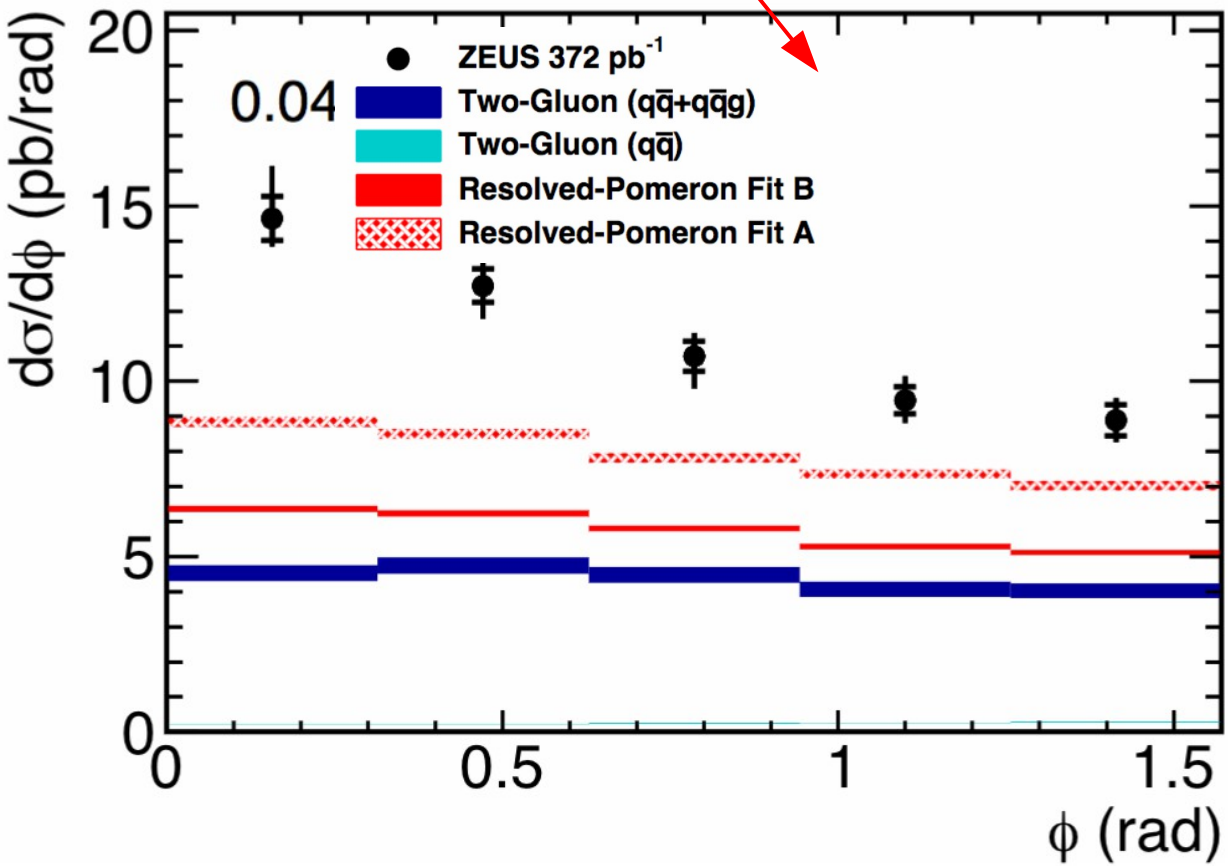
$q\bar{q}g$

Exclusive dijet production

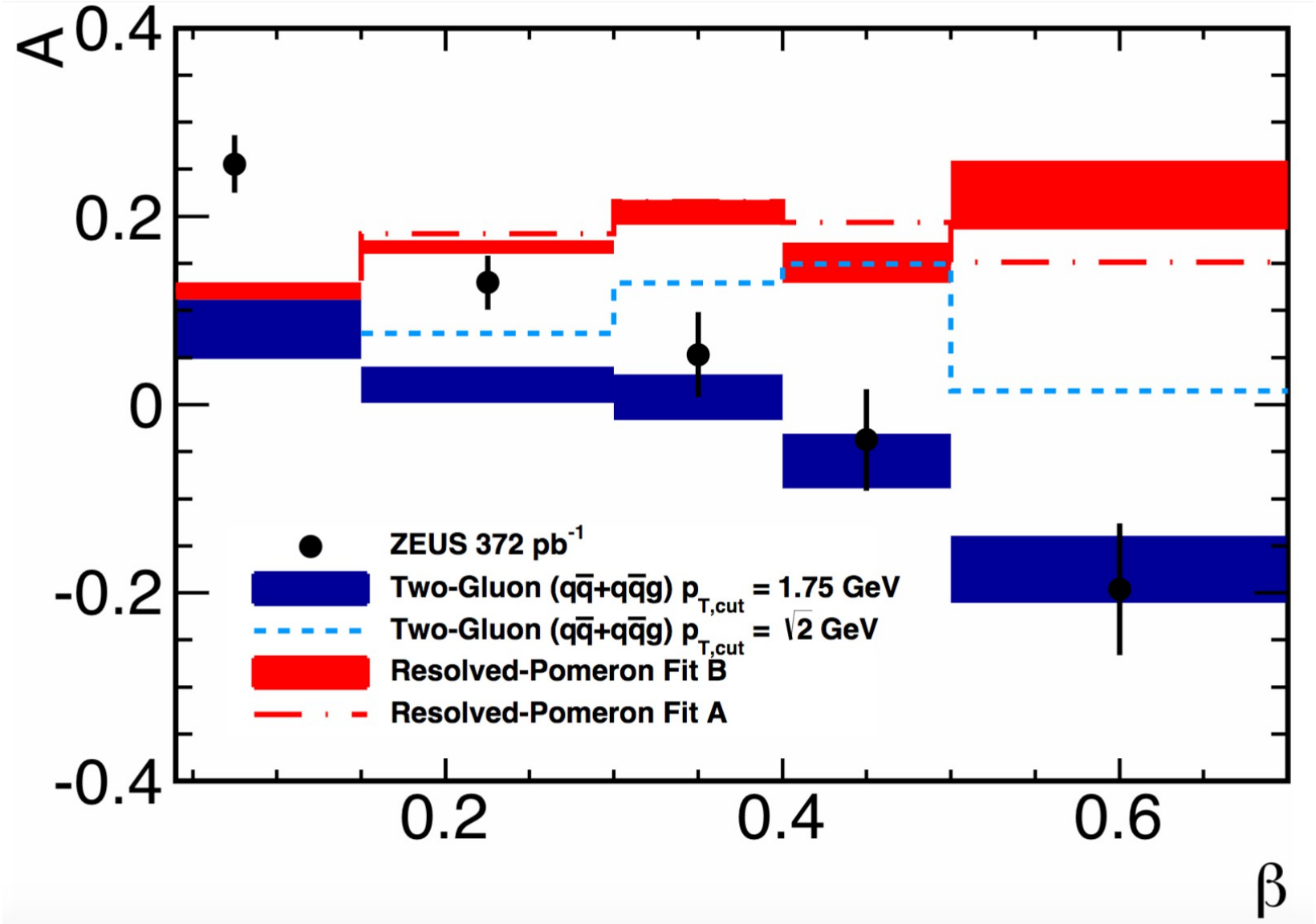
- Resolved Pomeron or 2-gluon exchange?
  - Different predictions for azimuthal angle between lepton and jet plane
  - Fit Φ distributions in bins of β

$d\sigma/d\Phi \sim 1 + A(pTjet)\cos(2\Phi)$

$\beta = x/x_{IP}$, x_{IP} is proton fractional longitudinal momentum loss



Fit results



Data favor the Two-Gluon-Exchange model

Exclusive ρ^0 photoproduction with leading neutron

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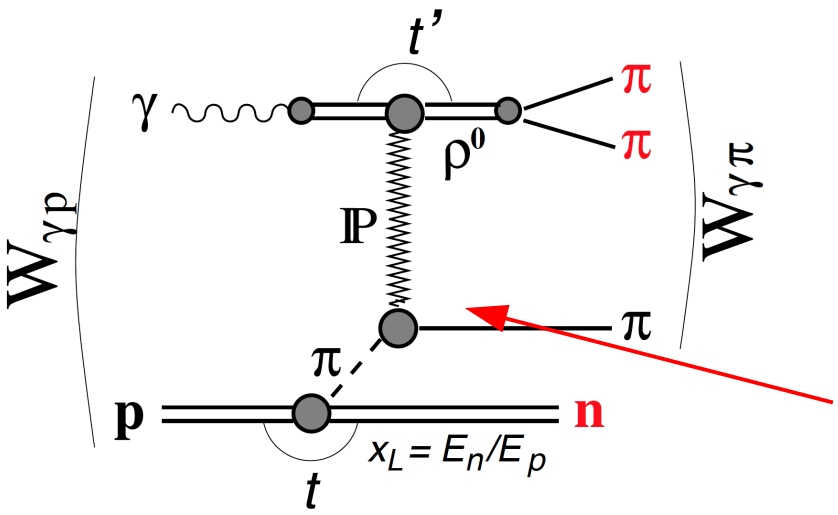
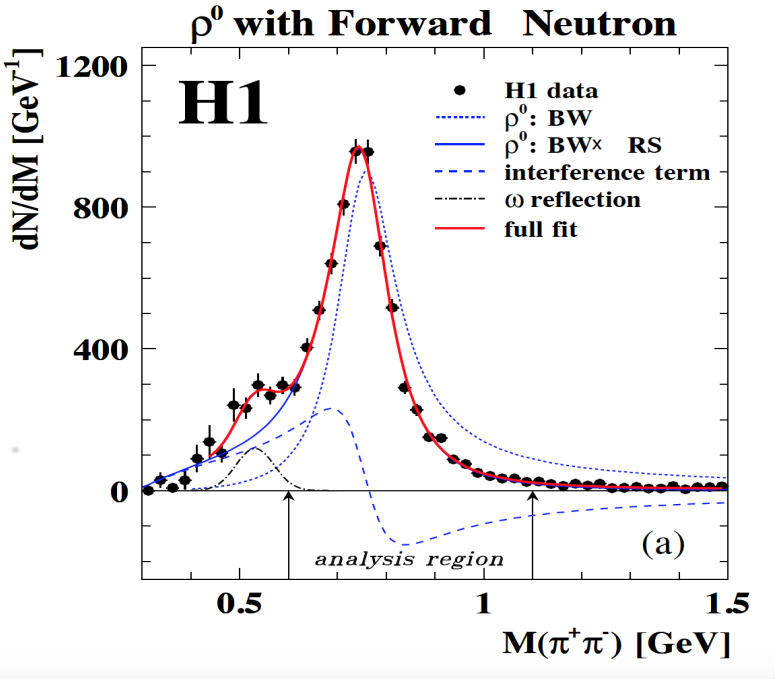
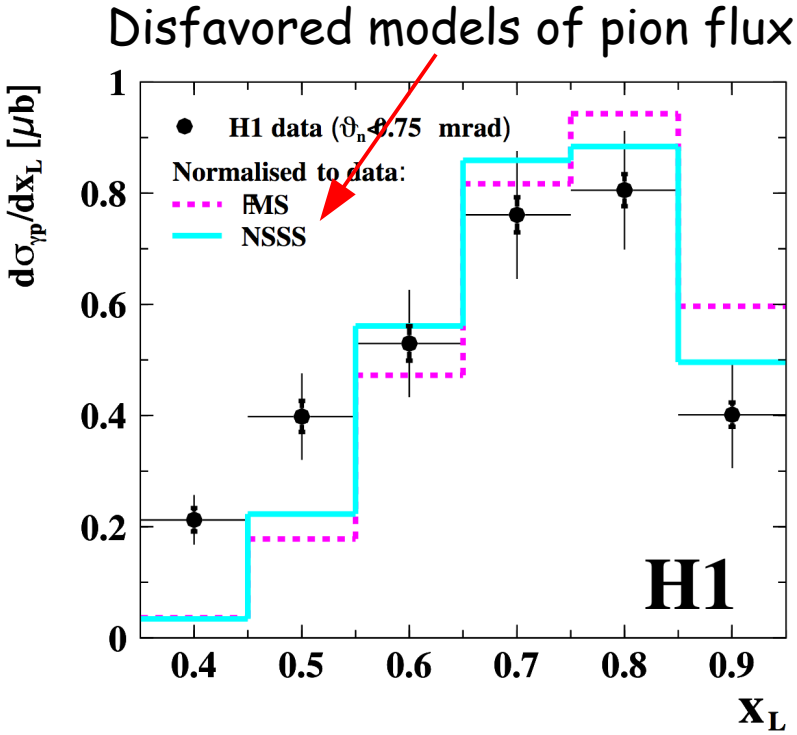
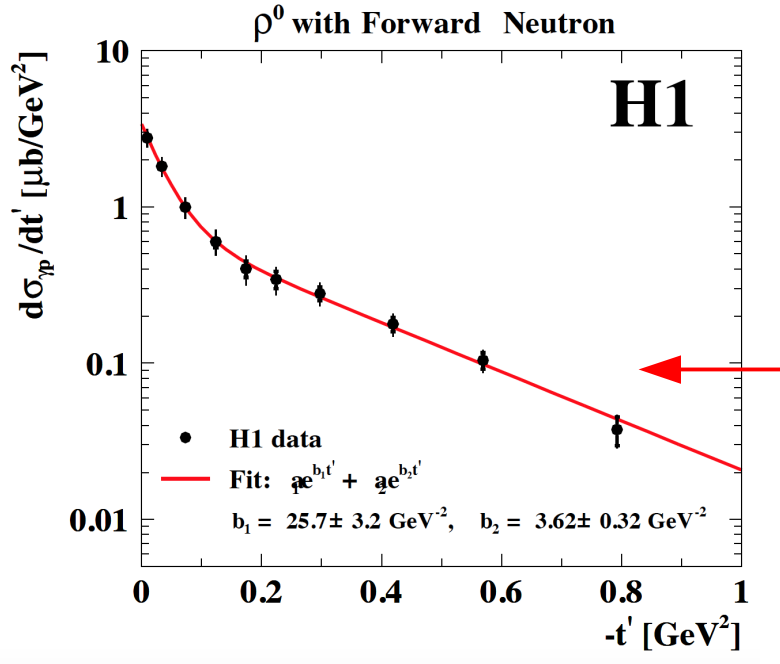


exchange of two Regge trajectories in double-peripheral scattering process (DPP)

Exclusive ρ^0 + leading neutron



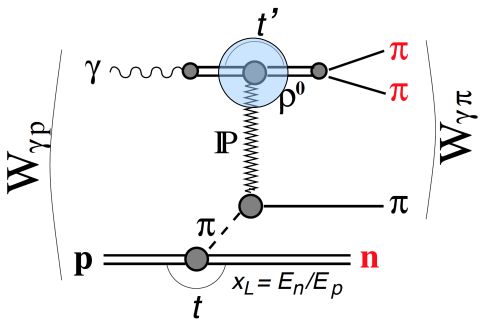




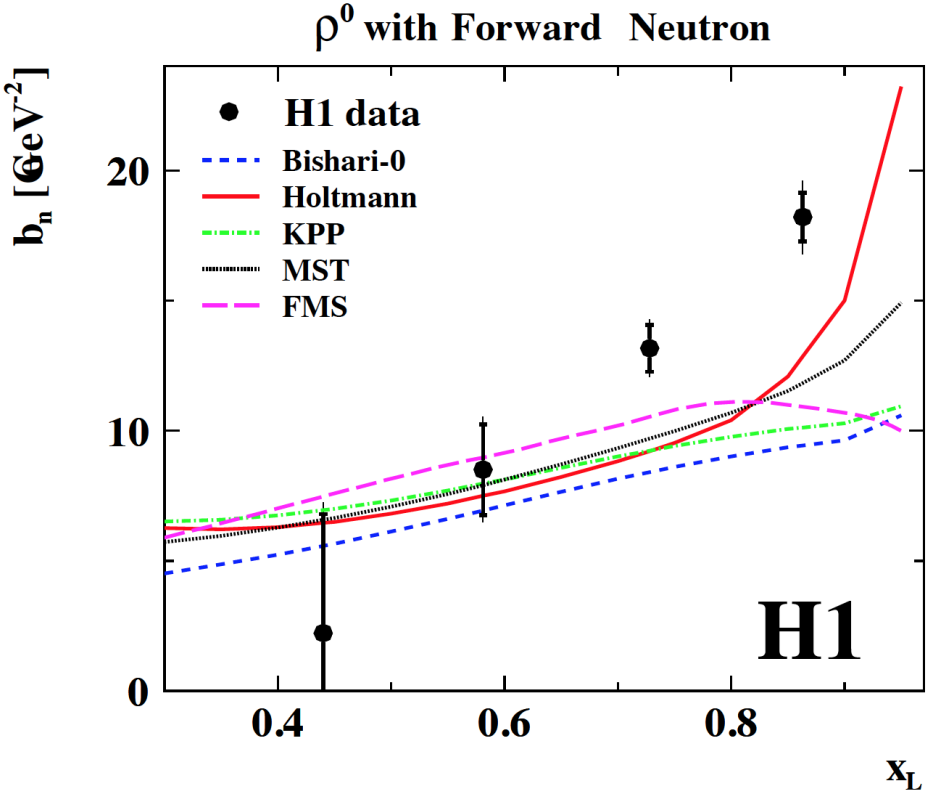
Key observables :

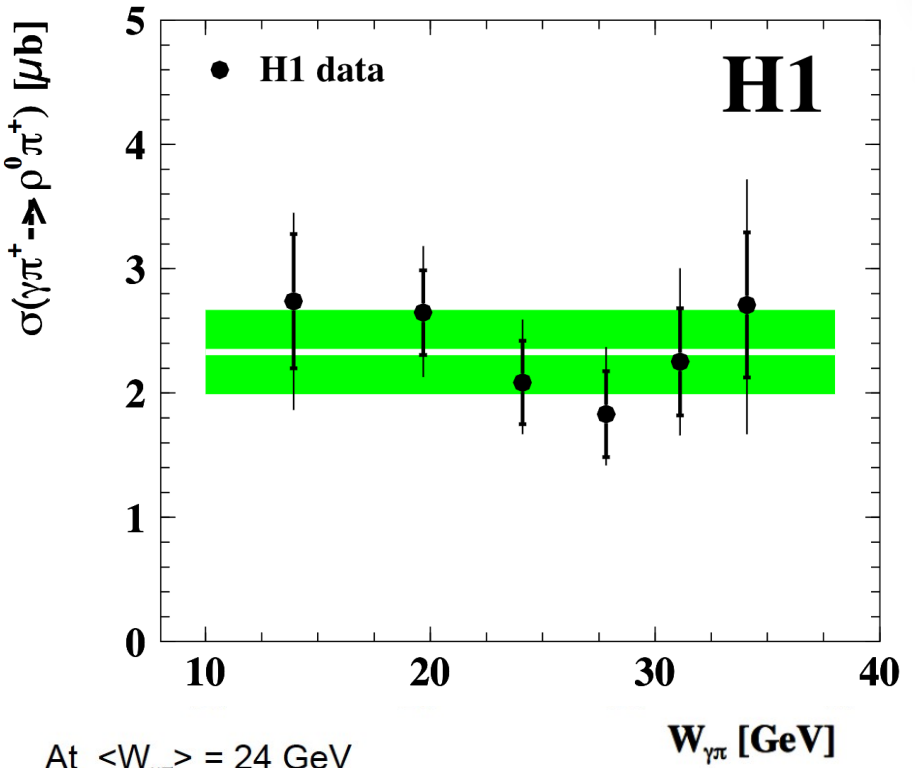
- $x_L = E_n / E_p$ (or $x_\pi = 1 - x_L$)
- W dependence : ~ W^δ
- t-slope of ρ^0

Two components due to double exchange



Exclusive ρ^0 + leading neutron





At $\langle W_{\gamma\pi} \rangle$ = 24 GeV

$$\sigma(\gamma\pi^+ \to \rho^0\pi^+) = (2.33 \pm 0.34(\text{exp})^{+0.47}_{-0.40}(\text{model}))\ \mu\text{b}$$

$$\sigma(\gamma\pi^+)/\sigma(\gamma p) = 0.25 \pm 0.06$$

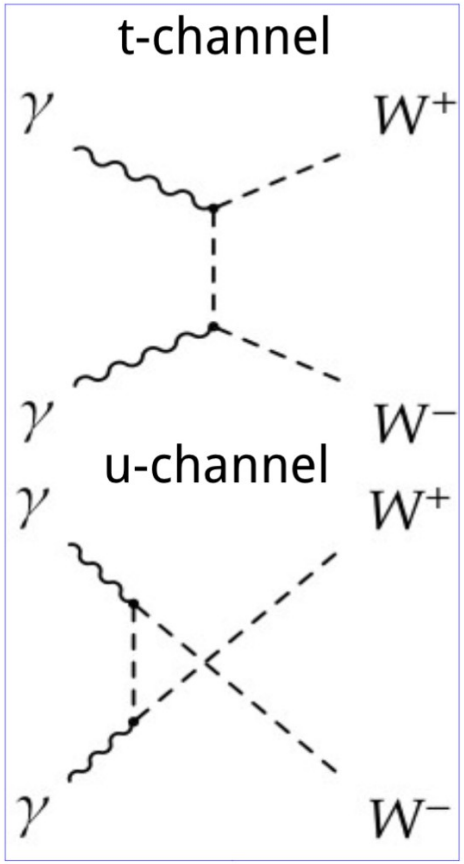
- No model describes t-dependence of neutron → effect of absorptive corrections ?

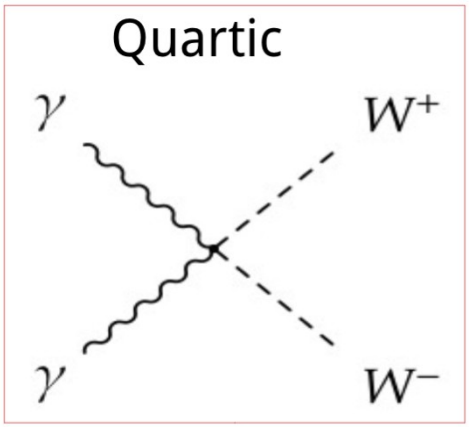
- in agreement with a previous ZEUS measurement [ZEUS, NP B637 (2002) 3]
- Significantly lower than expected → suggesting large absorptive corrections

Search for new physics with exclusive processes

CMS-FSQ-13-008

exclusive and quasi-exclusive $\gamma\gamma \to W^+W^-$ production





aQGC are introduced via effective Lagrangian

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

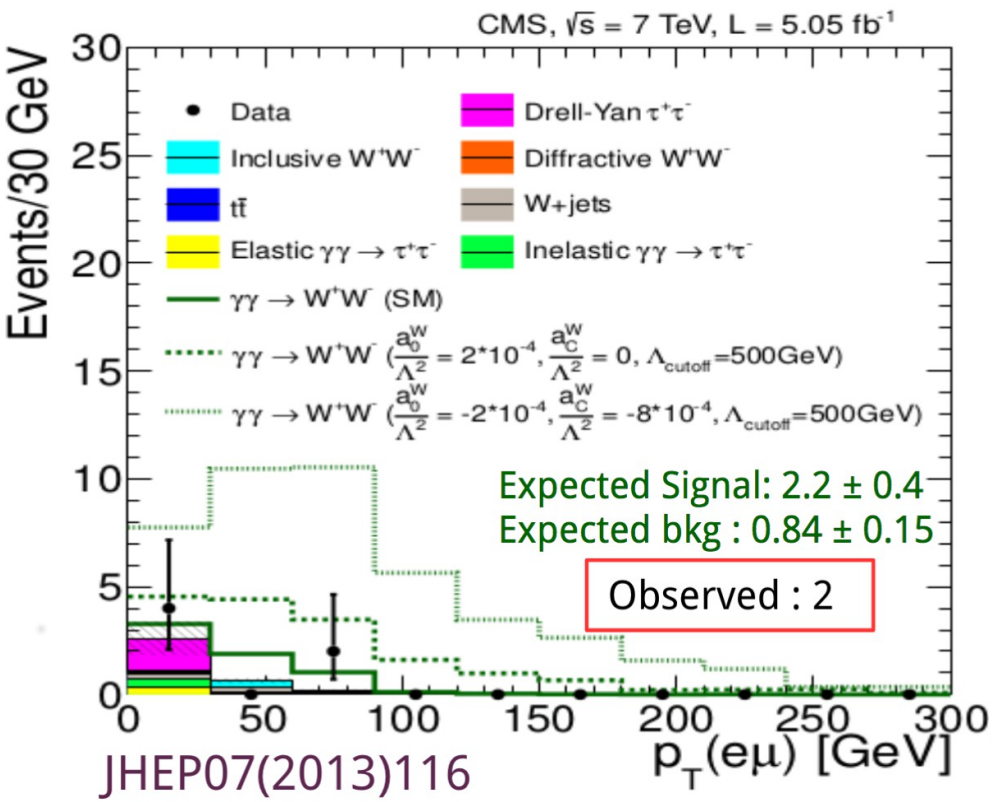
$$\mathcal{L}_6^C = \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2} F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W^-_{\beta} - W^{-\alpha}W^+_{\beta})$$

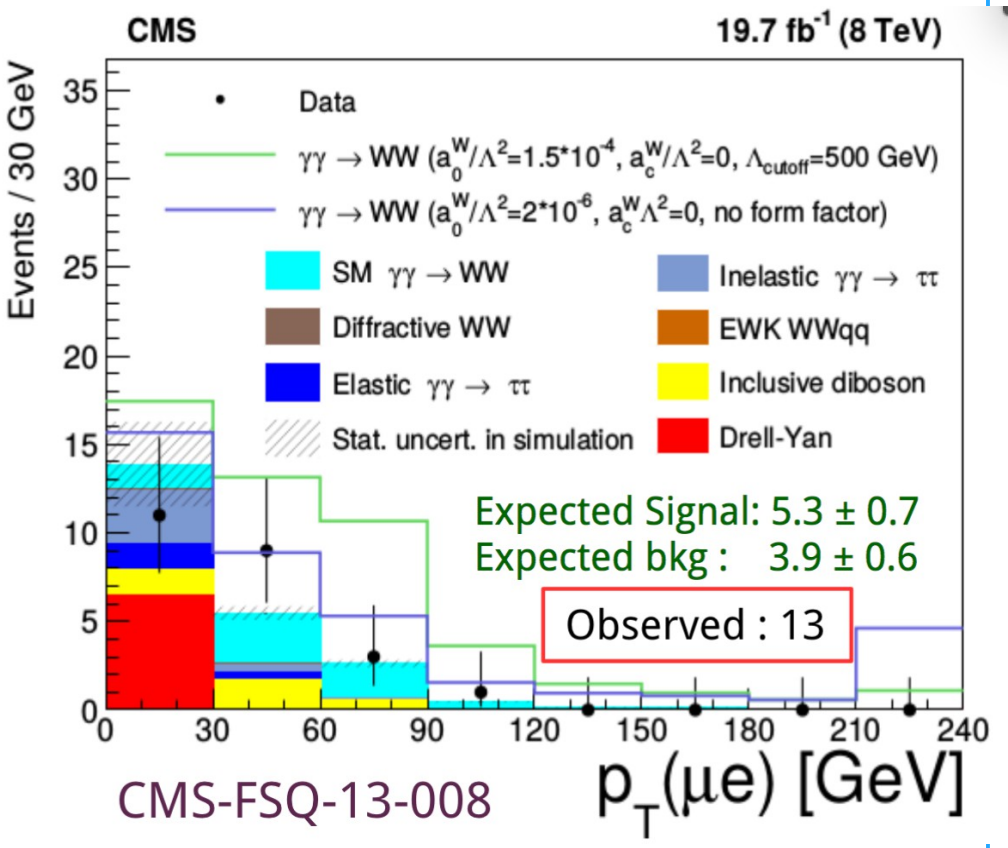
- SM EW predicts QGC
  - Deviations → sign of new physics

Anomalous coupling constant for quartic vertex

Λ : Scale for New Physics

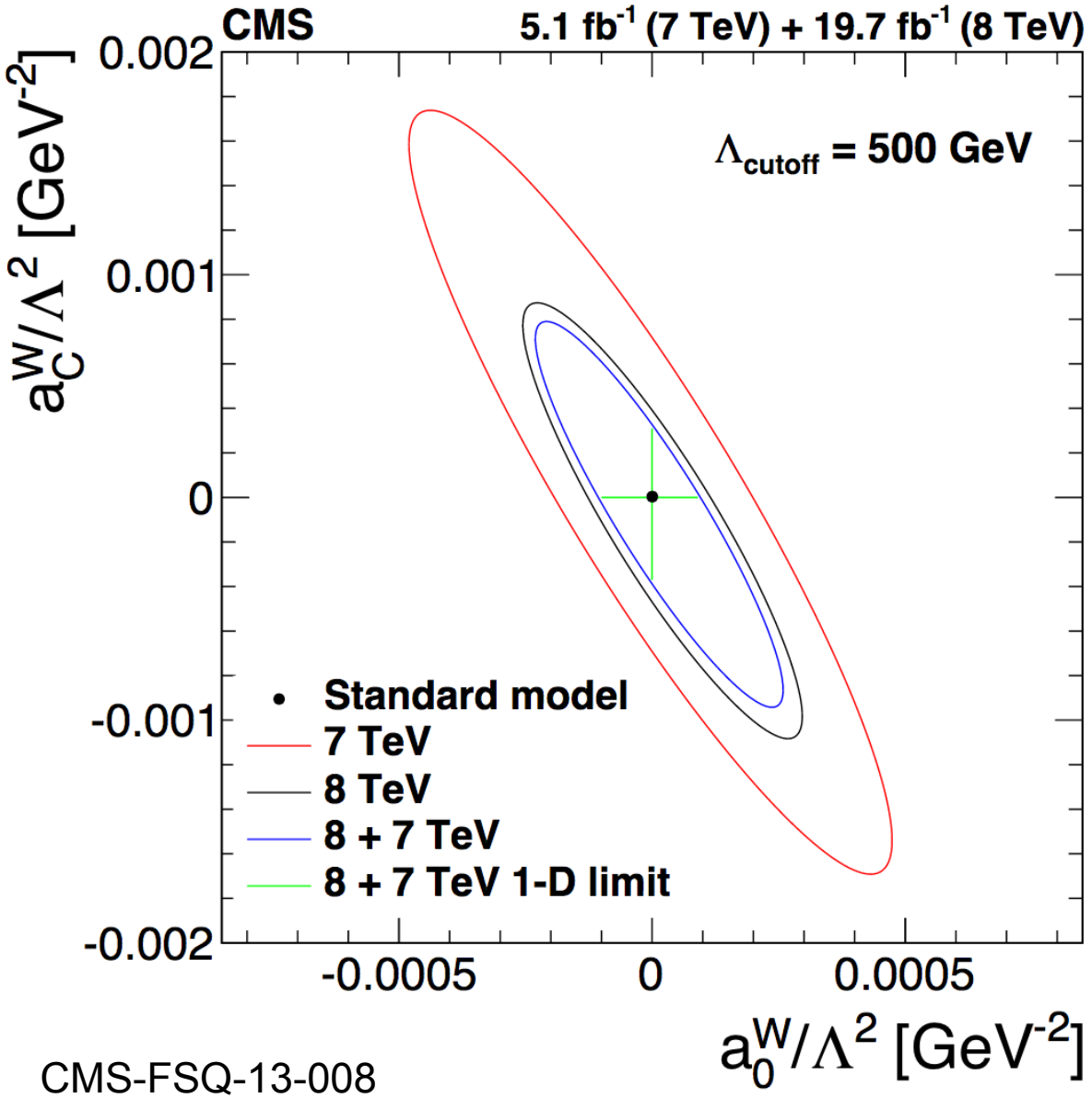
Exclusive electroweak W-pair production





Observed significance @ 7 and 8 TeV combination is 3.4 σ

Most stringent limits on AQGC @ 7 & 8 TeV



CMS-FSQ-13-008

Dimension-6 AQGC parameter
$a_0^W/\Lambda^2(\Lambda_{\text{cutoff}} = 500\,\text{GeV})$
$a_C^W/\Lambda^2(\Lambda_{\text{cutoff}} = 500\,\text{GeV})$

7 TeV ($\times 10^{-4}\,\text{GeV}^{-2}$)
$-1.5 < a_0^W/\Lambda^2 < 1.5$
$-5 < a_C^W/\Lambda^2 < 5$

8 TeV ($\times 10^{-4}\,\text{GeV}^{-2}$)
$-1.1 < a_0^W/\Lambda^2 < 1.0$
$-4.2 < a_C^W/\Lambda^2 < 3.4$

7+8 TeV ($\times 10^{-4}\,\text{GeV}^{-2}$)
$-0.9 < a_0^W/\Lambda^2 < 0.9$
$-3.6 < a_C^W/\Lambda^2 < 3.0$

Limits 2 orders of magnitude more stringent then LEP

Summary & Outlook

- Very interesting measurements on VMs, exclusive jets and W-pair production

<u>Present challenges & outlook</u>

- In ATLAS and CMS exclusive physics challenging due pileup: vertexing and tracking (only one vertex and fixed number of tracks)
  - LHCb and ALICE have lower pileup
- For Run II - proton taggers
  - CMS taking data with TOTEM roman pots: 7&8 TeV total pp x-section
  - ATLAS with ALFA roman pots: 7TeV total elastic x-section measurement, more to come
- Possible 750 GeV resonance might appear in central exclusive production
- ultra peripheral collisions in proton-lead runs - big opportunity for VM photoproduction - photon flux goes with Z^2
- attempt to measure central exlusive production of low mass resonances (glueballs?) with data commonly taken by CMS and TOTEM
  - soon something similar with LHCb