Results from LHCb and their relation with HERA data

Ronan McNulty (UCD Dublin)
on behalf of the LHCb collaboration

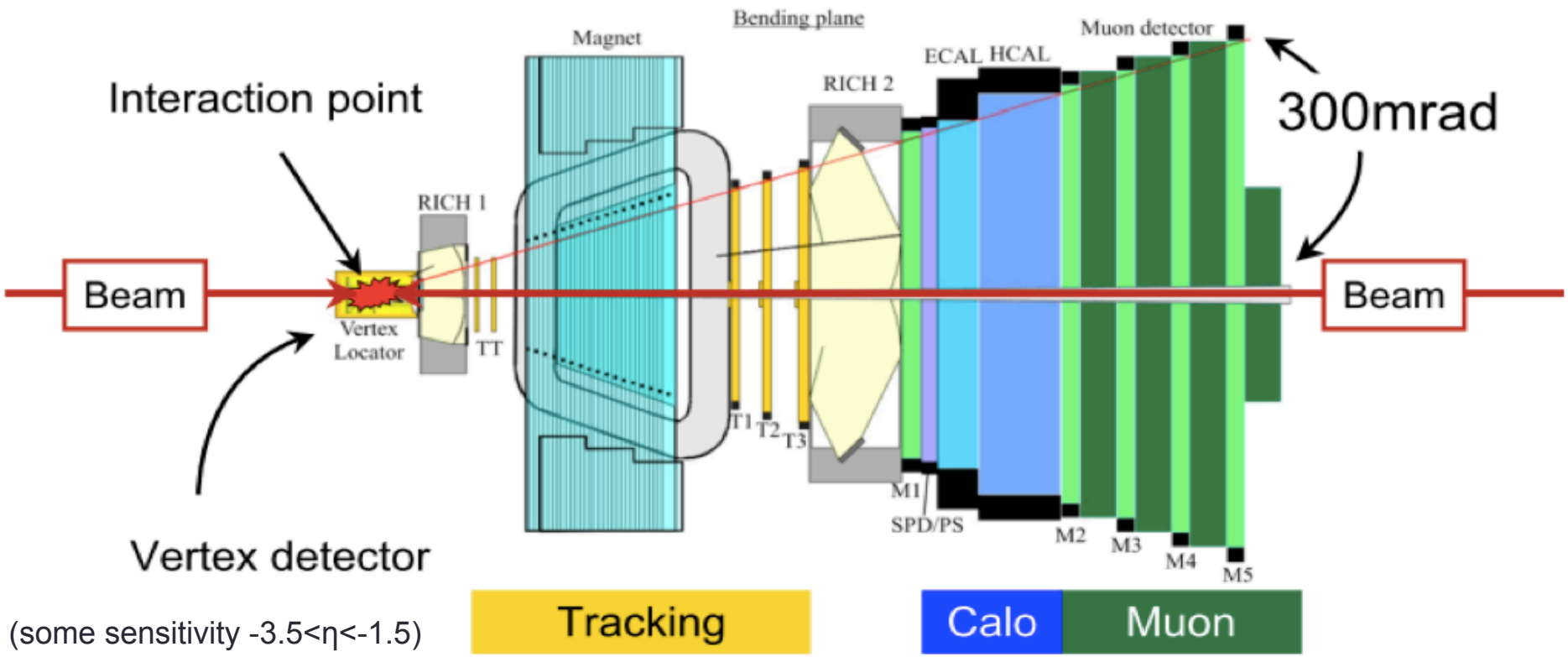
Future Physics with HERA Data for Current and Planned Experiments

11-13 November 2014 DESY Hamburg

Outline

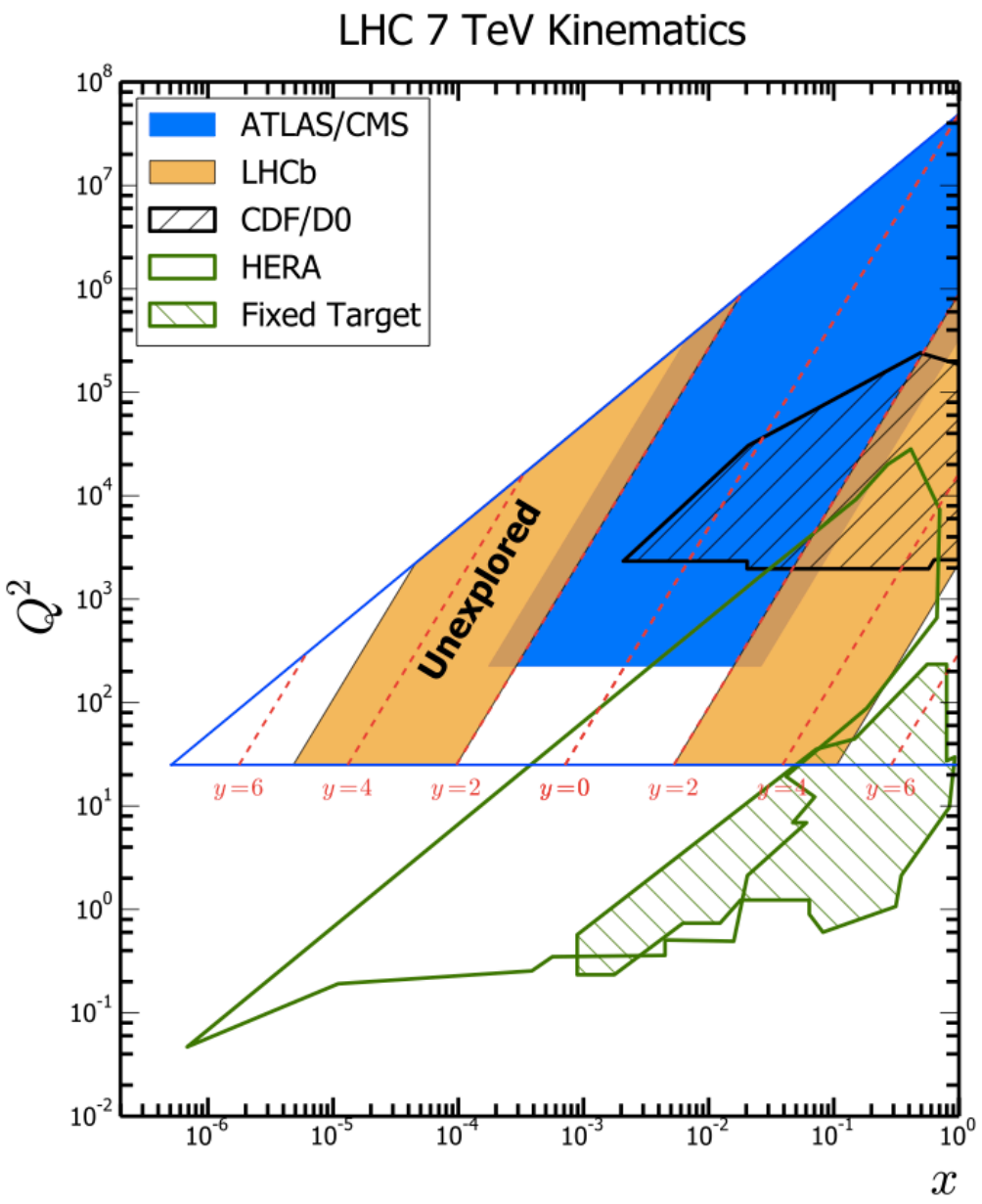
- Introduction: (x,Q^2) Rapidity Plane
- PDFs
  - Z->μμ, Z->ee, Z+jets
  - W->μν
  - Effect of LHCb data on HERA derived PDFs
- Diffraction: Central Exclusive Production
  - Photoproduction J/ψ
  - Double pomeron exchange $\chi_c \quad J/\psi J/\psi$

The LHCb detector



(some sensitivity -3.5<η<-1.5)

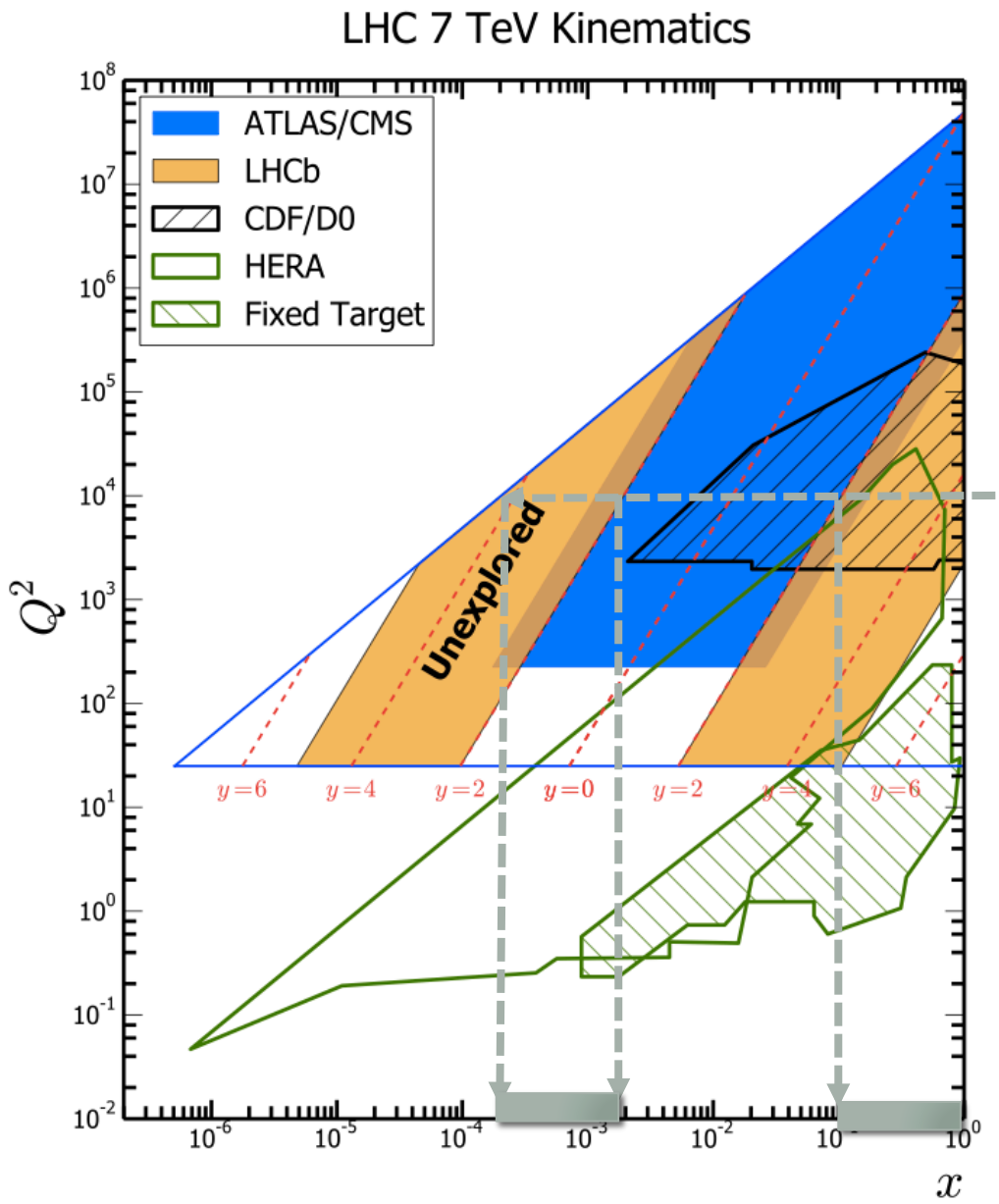
Fully instrumented from $2 < \eta < 5$



Scatters at LHCb are between one high-*x* and one low-*x* parton.

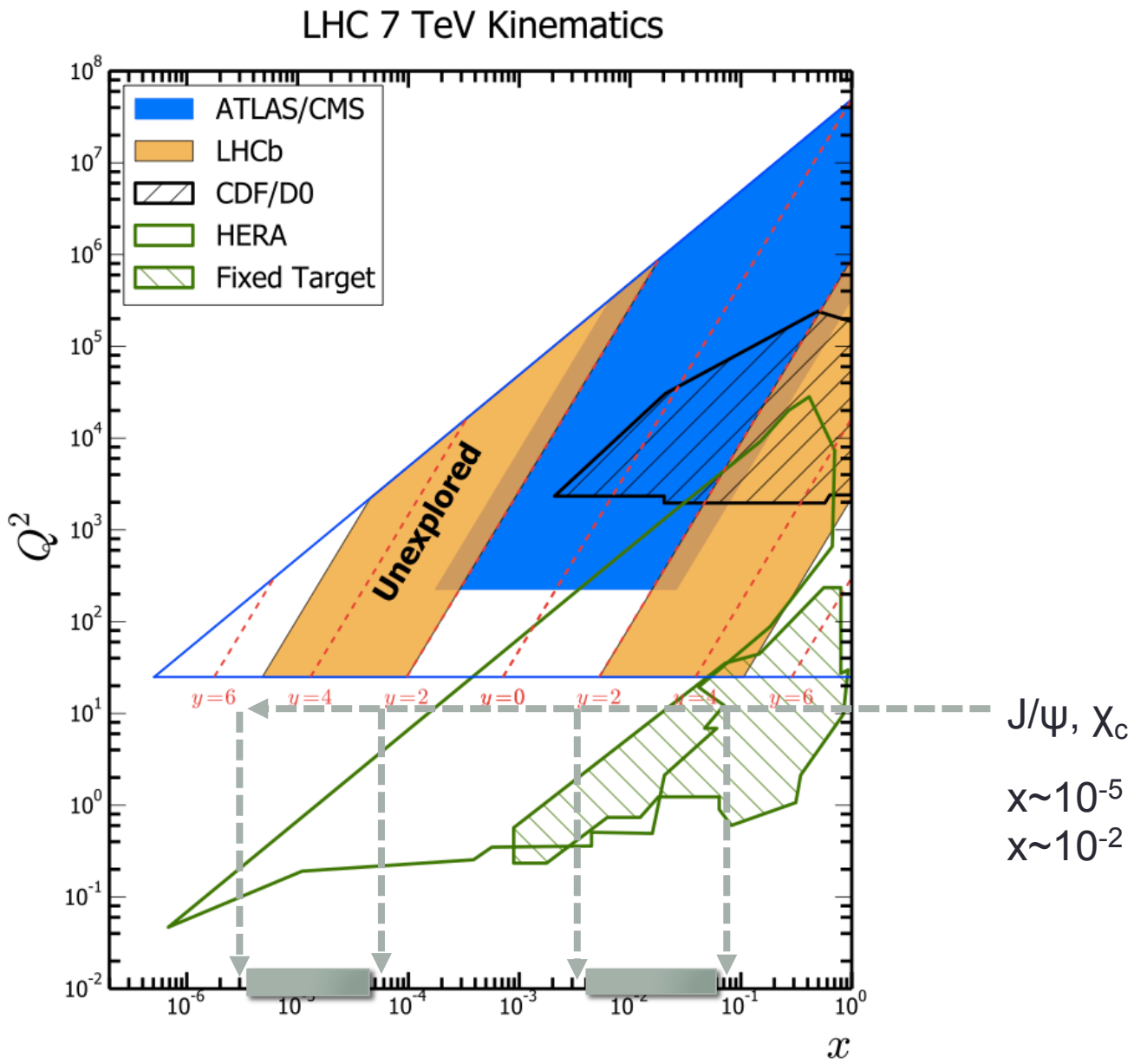
One region overlaps strongly with HERA.

One region is either unexplored or requires large DGLAP evolution from HERA.



W,Z bosons

x~0.5
x~10^{-3}

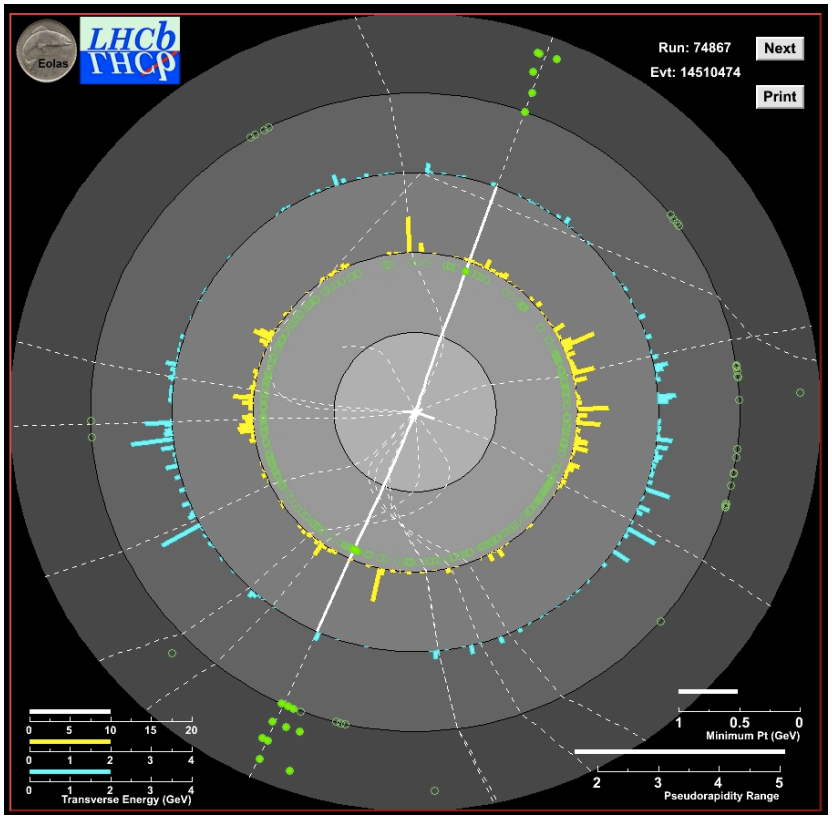


J/ψ, χ_c

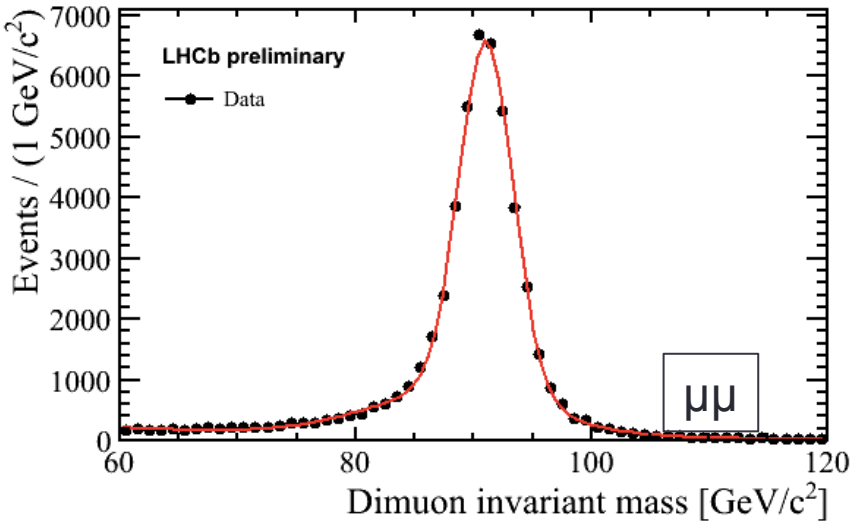
$x\sim10^{-5}$

$x\sim10^{-2}$

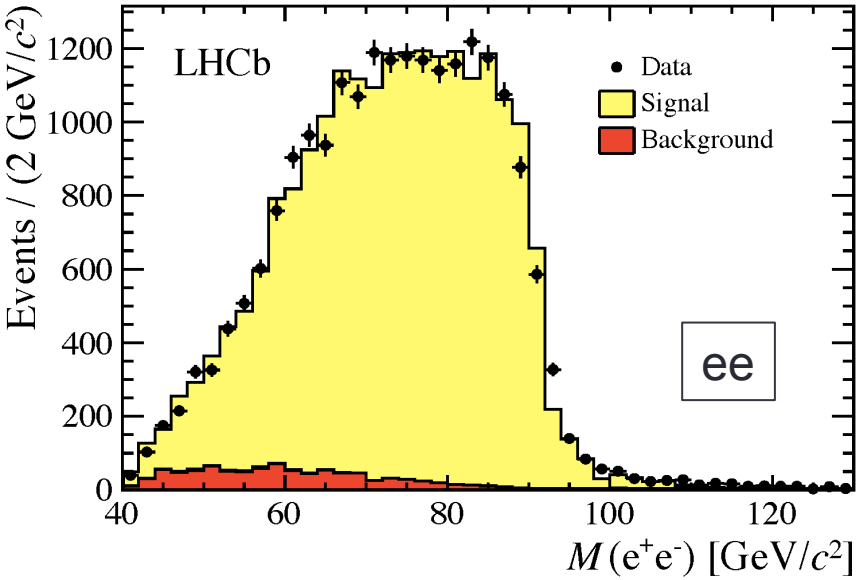
Z->μμ Z->ee



LHCb-CONF-2013-007



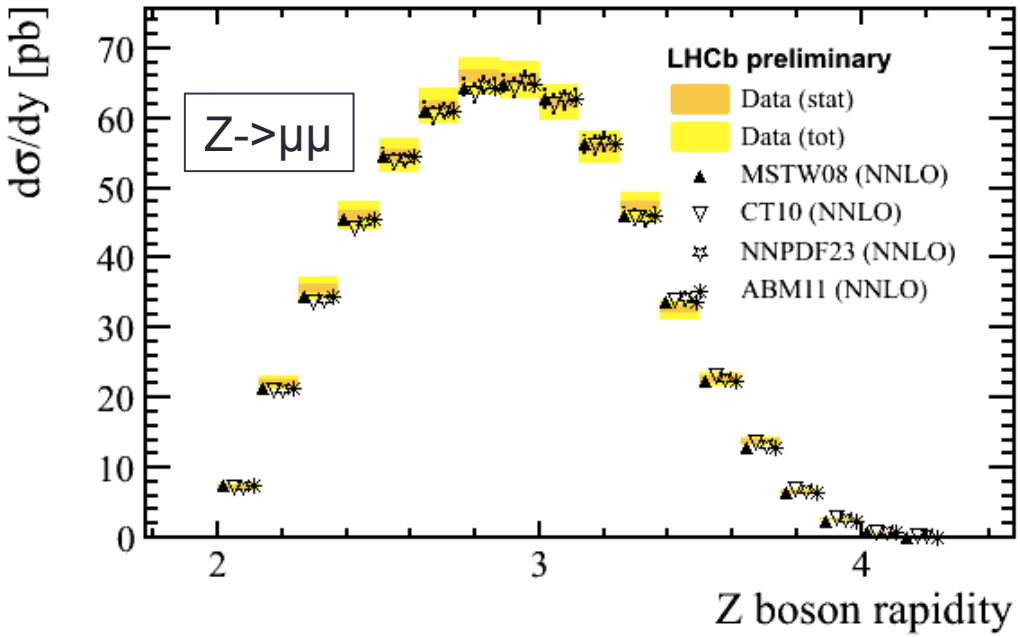
JHEP 02 (2013) 106



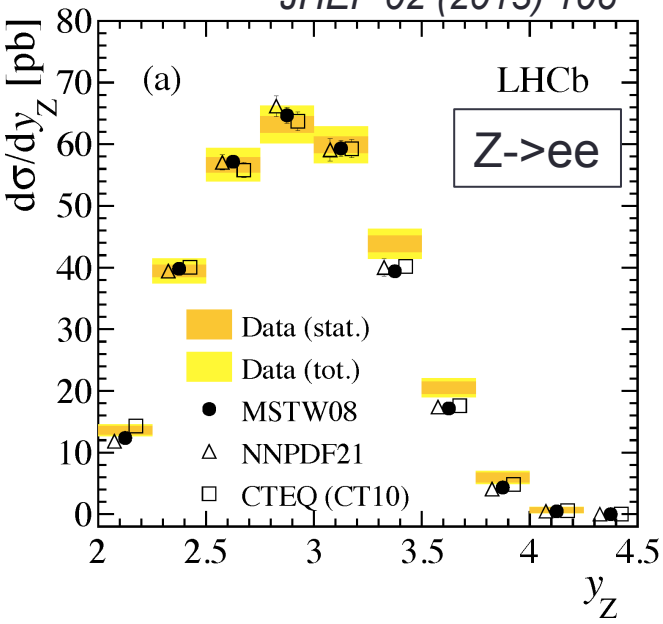
Purity of Z->μμ > 99%
Purity of Z->ee ~95%

Z->μμ Z->ee rapidity and PDF dependence

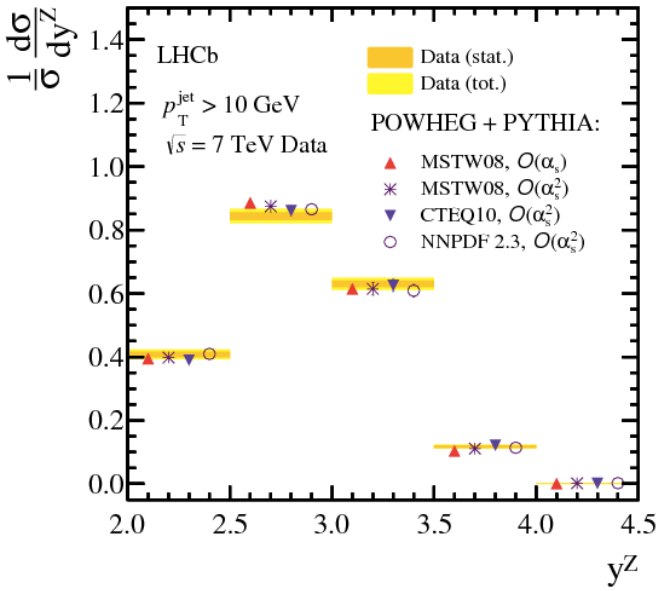
LHCb-CONF-2013-007

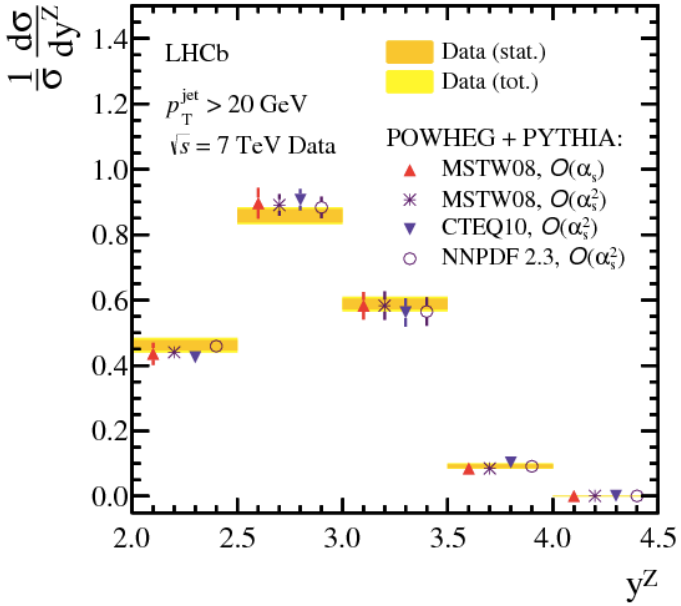


JHEP 02 (2013) 106

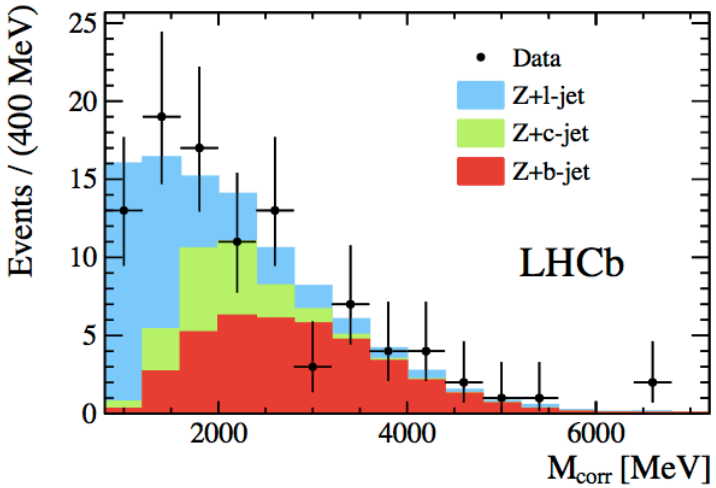


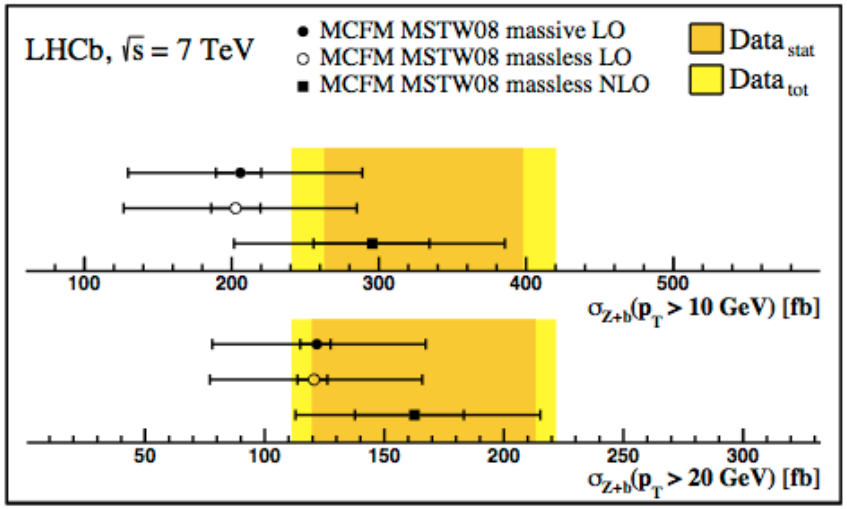
Z+jets, Z+b, (Future: Z+c, W+b, W+c)





Z+jets
JHEP 01(2014) 033

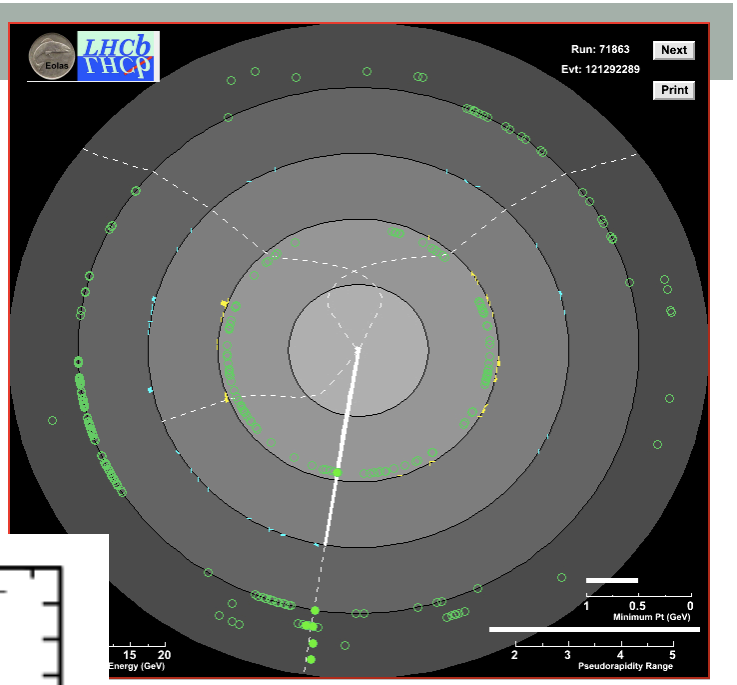




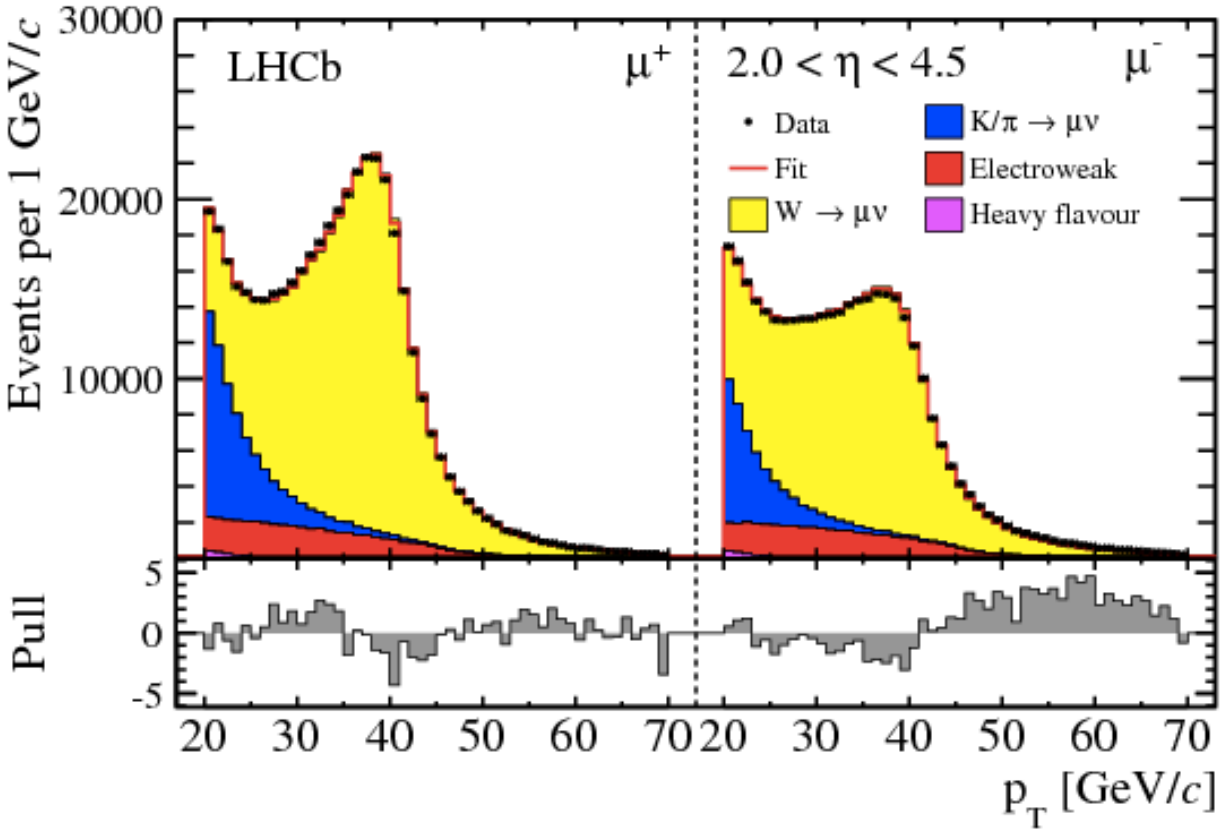
Z+b
arXiv:1411.1264

W->μν

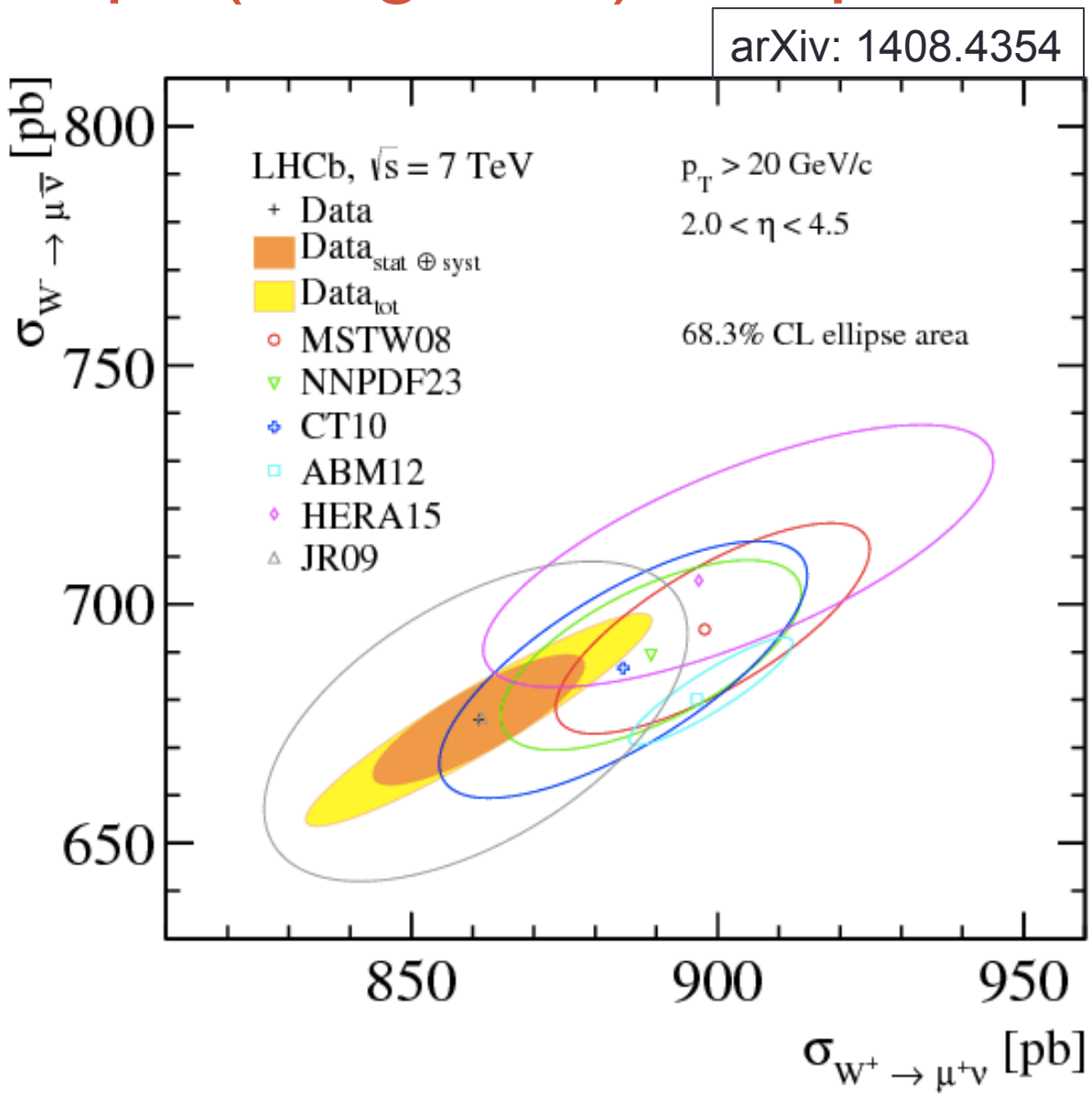
Purity from 30-90% depending on muon p_T



arXiv: 1408.4354

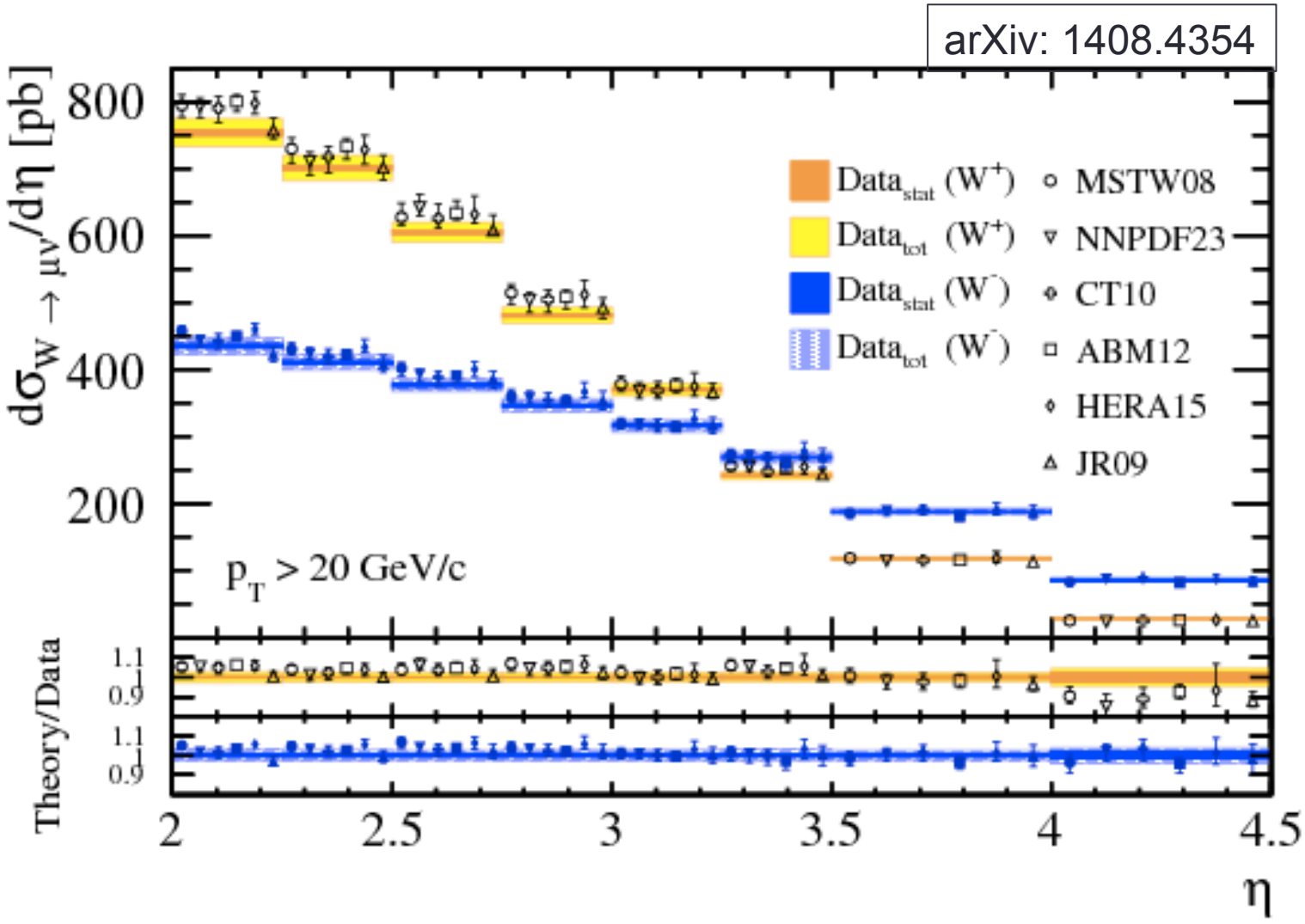


W->μν (integrated) & dependence on PDFs



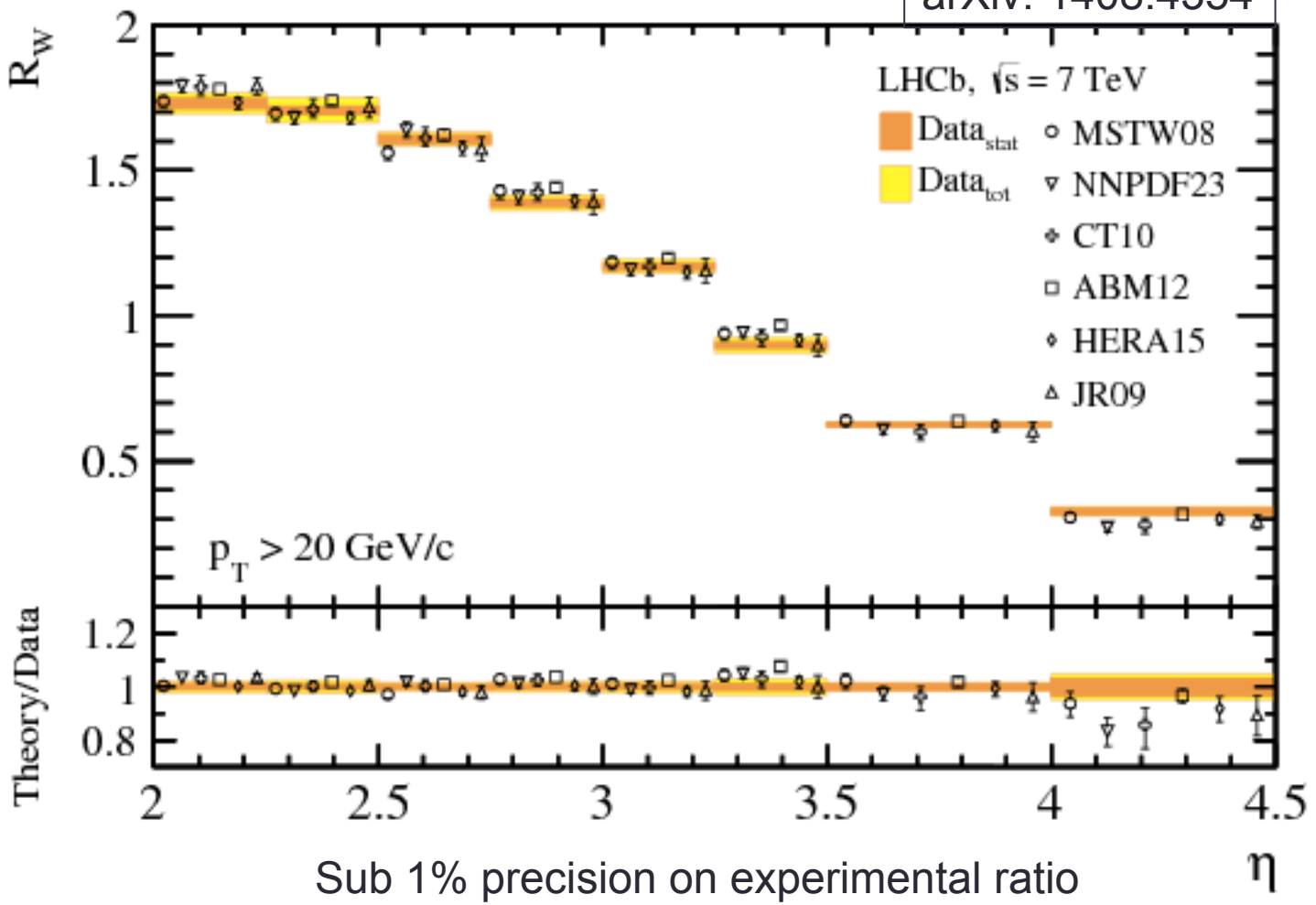
$$Slope^{-1} : \frac{\sigma(W^+)}{\sigma(W^-)} \approx \frac{\bar{d}u}{\bar{u}d} = \frac{u}{d}$$

W->μν (differential) & dependence on PDFs



W->μν (differential) & dependence on PDFs

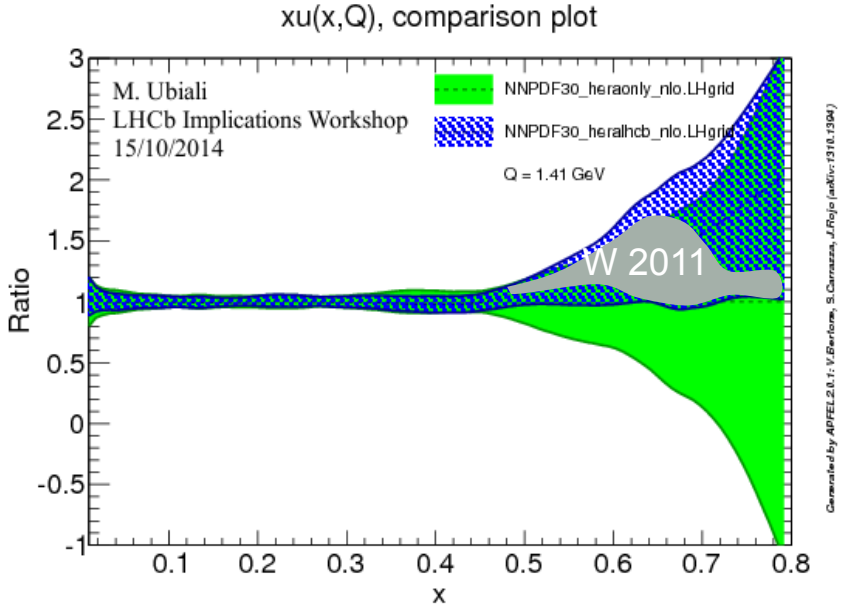
arXiv: 1408.4354

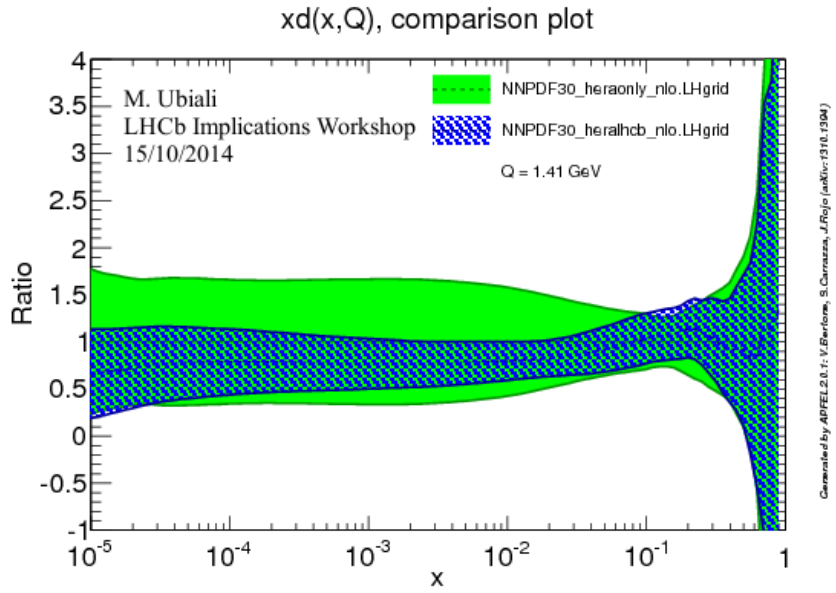


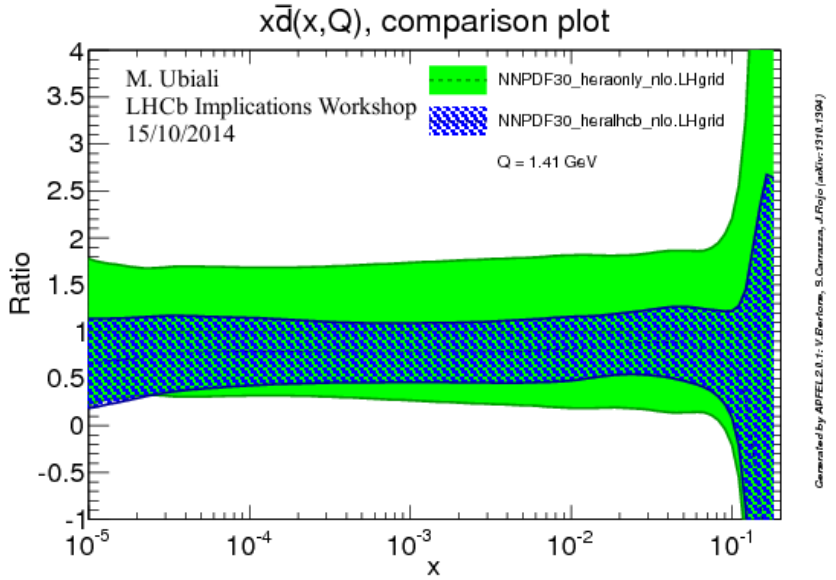
Sub 1% precision on experimental ratio

Measure of u/d ratio at different x

Effect of 37pb^{-1} of LHCb data on HERA-derived PDFs



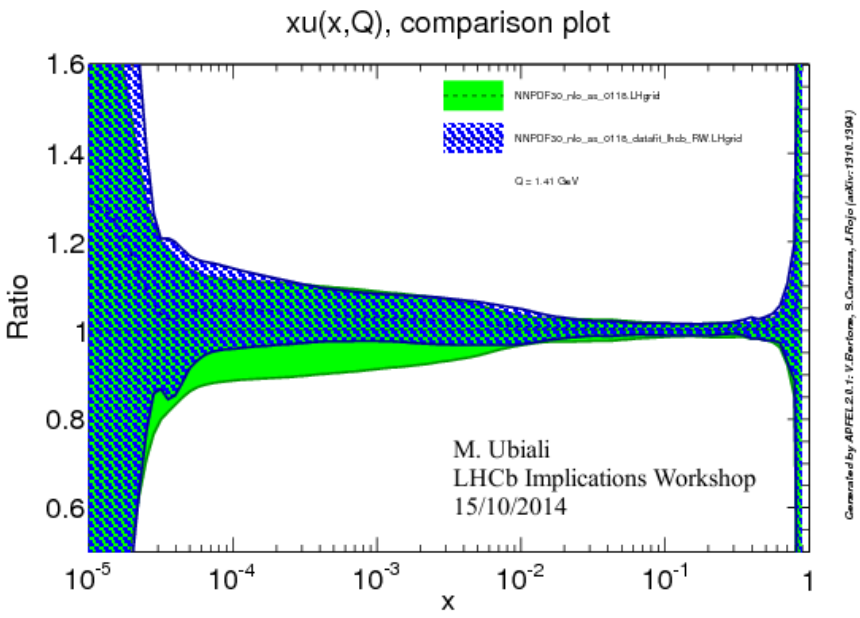


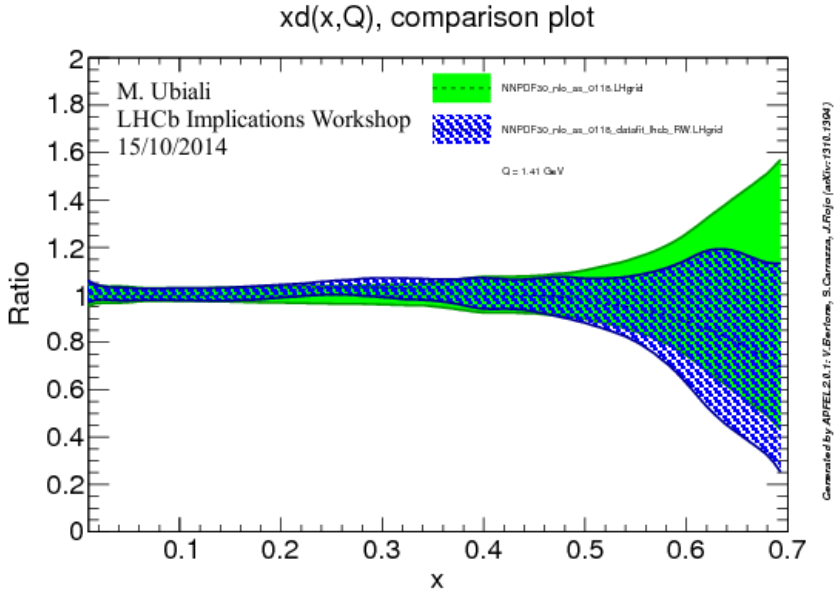


Improvement in u quark at high-x.
Improvement in d quark at low-x.

Sensitivity outside W,Z x-regions through sum-rule constraints.

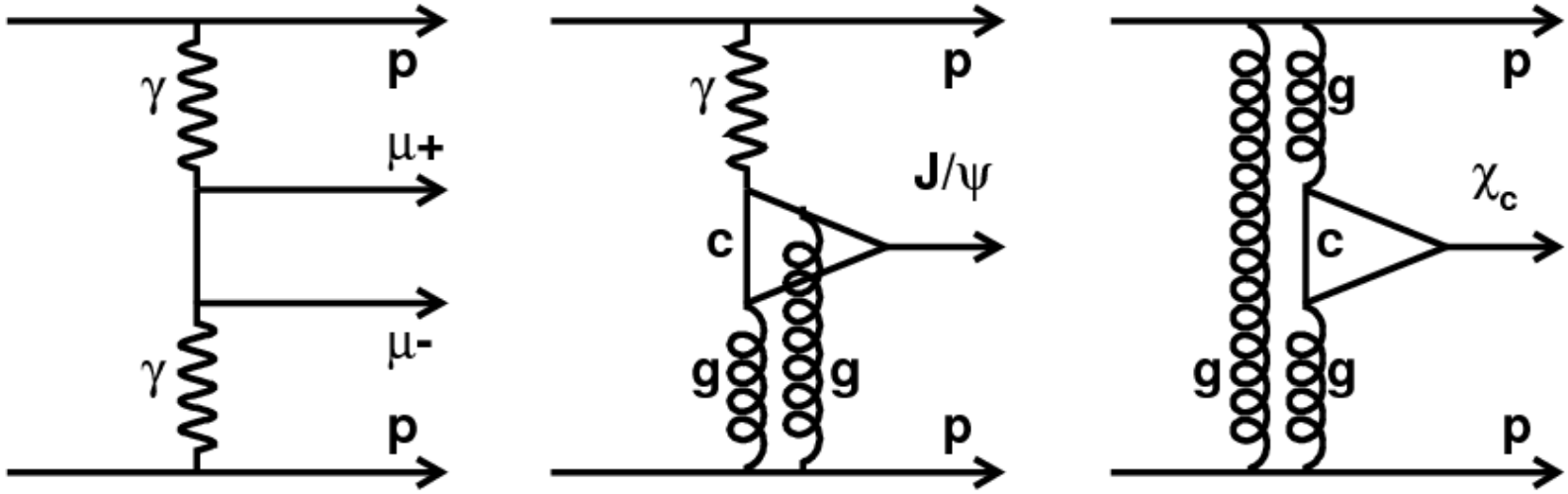
Effect of 1fb^{-1} of LHCb W data on LHC-derived PDFs





LHCb has impact at high and low x.

Central Exclusive Production with Dimuon final states



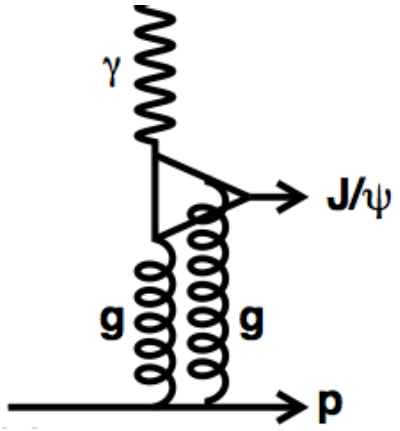
QED **Photo production** **Double pomeron exchange**

(Note: $J/\psi \rightarrow \mu\mu$ and $\chi_c \rightarrow J/\psi\gamma$)

Related phenomena where the colourless object creates a particle

Photo-production cross-section

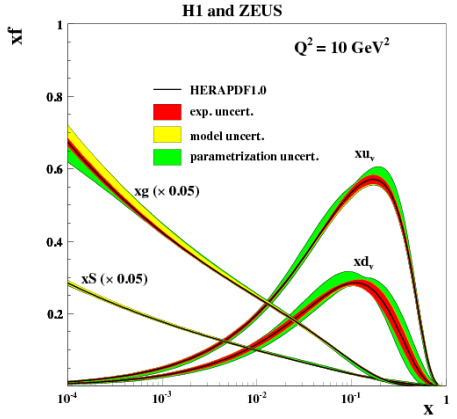
$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}t}(\gamma^* p \to J/\psi\, p)\right|_{t=0} = \frac{\Gamma_{ee} M_{J/\psi}^3 \pi^3}{48\alpha}\left[\frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4} x g(x,\bar{Q}^2)\right]^2 \left(1+\frac{Q^2}{M_{J/\psi}^2}\right)$$



$$\bar{Q}^2 = (Q^2 + M_{J/\psi}^2)/4, \qquad x = (Q^2 + M_{J/\psi}^2)/(W^2 + M_{J/\psi}^2).$$

Cross-section proportional to gluon^2 $\sigma \sim (xg)^2$

and so $\sigma \sim x^{\lambda}$



[1] Martin A D, Nockles C, Ryskin M and Teubner T 2008 Small x gluon from exclusive J/ψ production *Phys. Lett.* B **662** 252 (arXiv:0709.4406)

[2] Ryskin M G 1993 J/ψ electroproduction in LLA QCD *Z. Phys.* C **57** 89

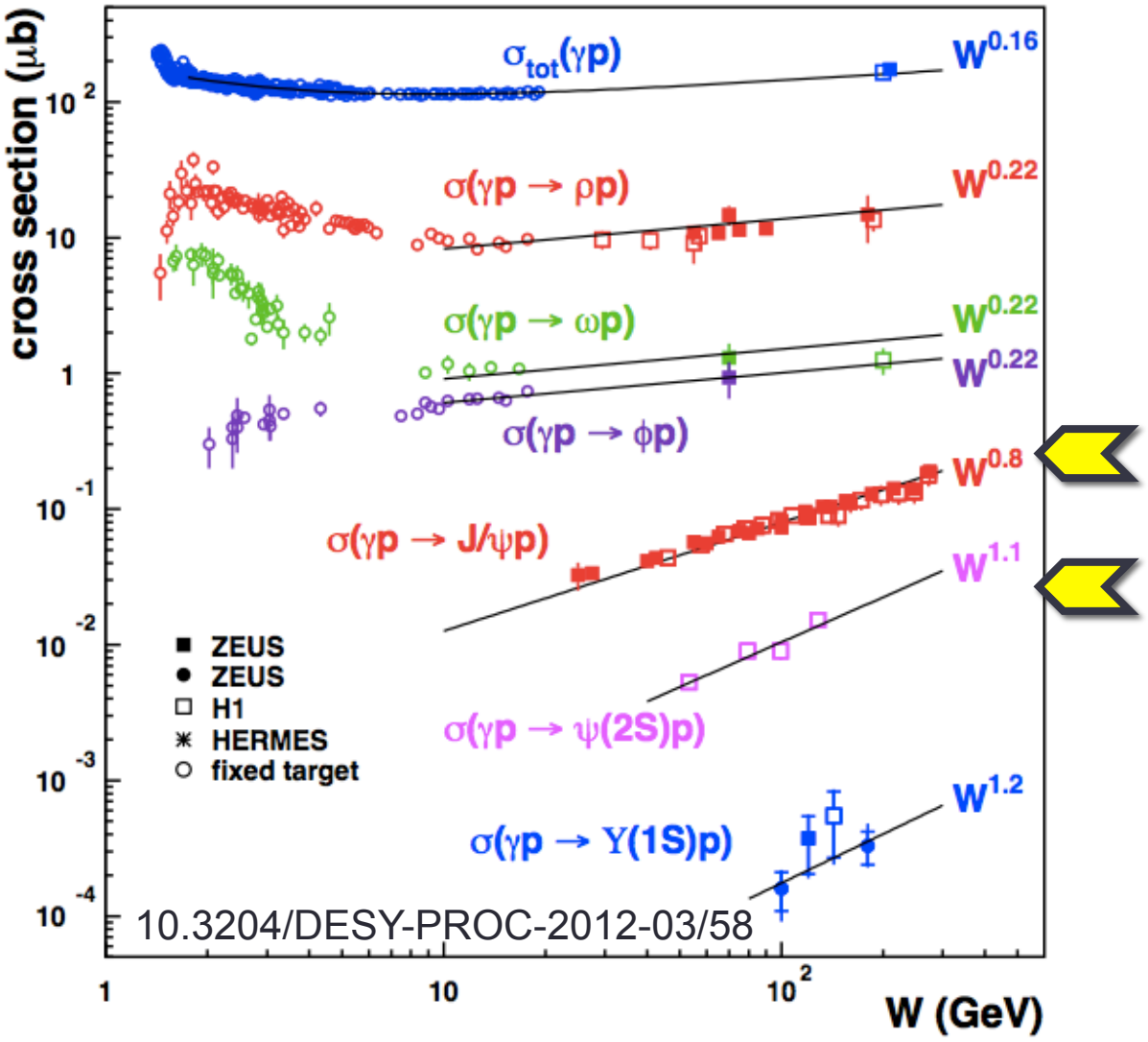
[3] Ryskin M G, Roberts R G, Martin A D and Levin E M 1997 Diffractive J/ψ photoproduction as a probe of the gluon density *Z. Phys.* C **76** 231 (arXiv:hep-ph/9511228)

[4] S. Jones, A. Martin, M. Ryskin, and T. Teubner, *Probes of the small x gluon via exclusive J/ψ and Υ production at HERA and the LHC*, JHEP **1311** (2013) 085, arXiv:1307.7099.

HERA vector meson photo-production results

Note:

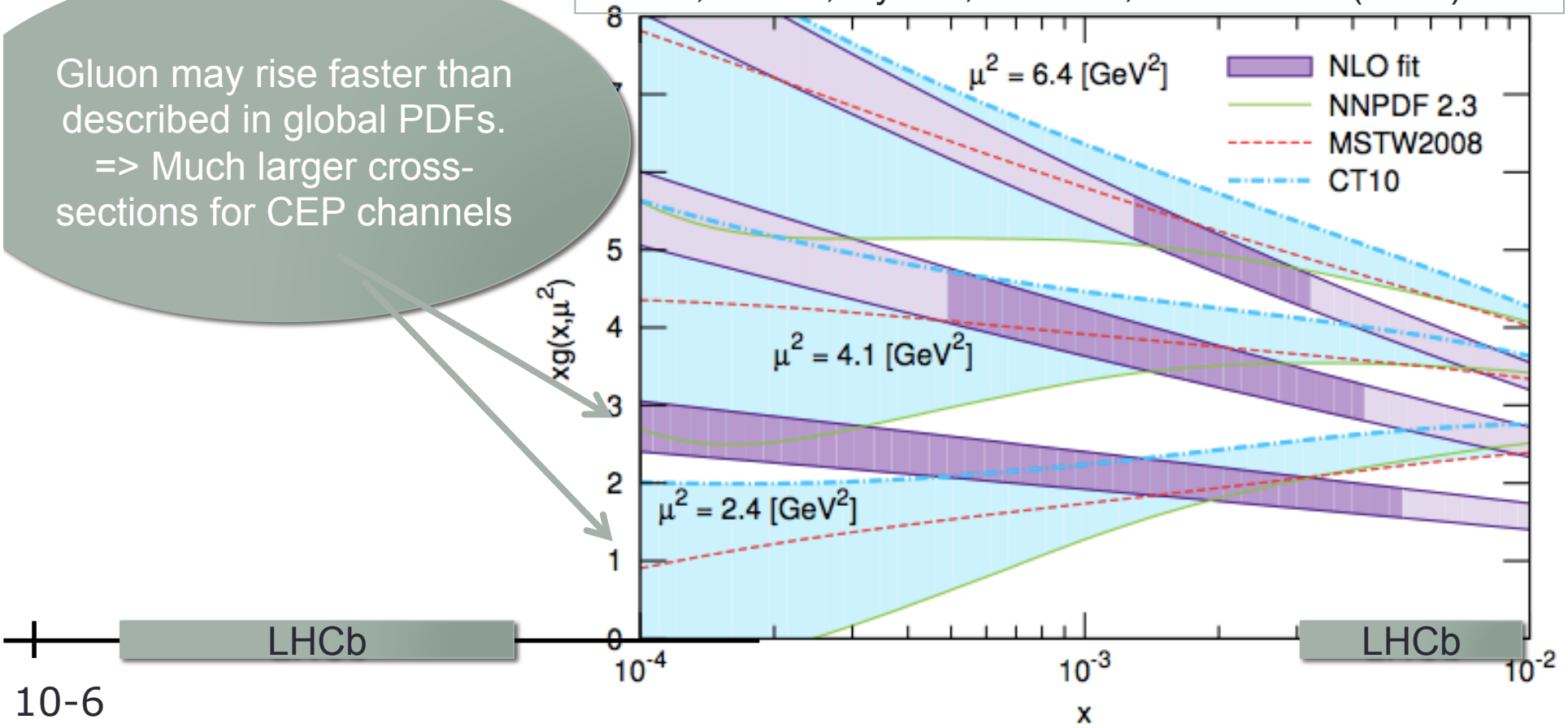
- $\sigma \sim x^{\lambda}$
- soft/hard
- g(x,Q^2)



Sensitivity to gluon pdf

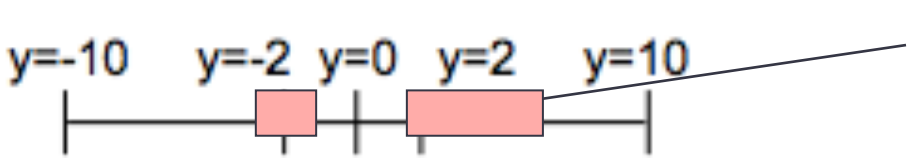
Gluon may rise faster than described in global PDFs.
=> Much larger cross-sections for CEP channels

Jones, Martin, Ryskin, Teubner, JHEP 1311 (2013) 085

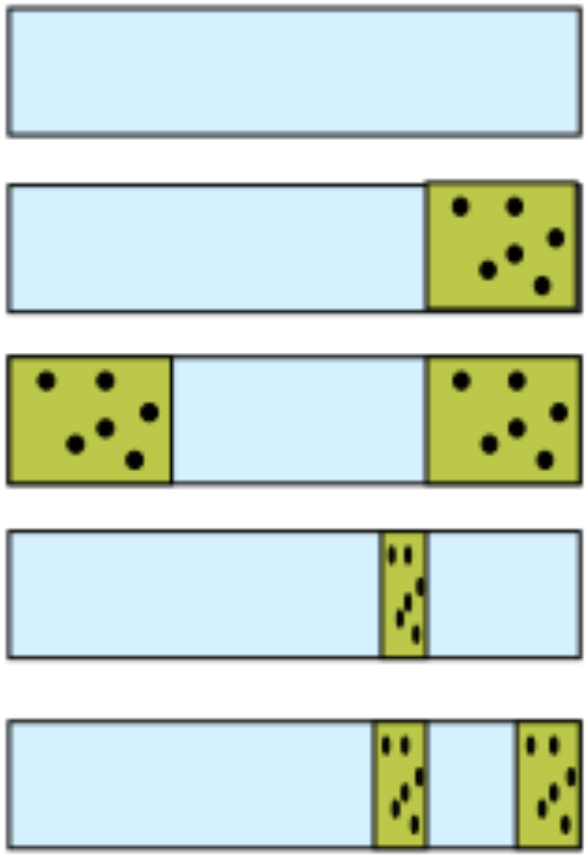


S. Jones, A. Martin, M. Ryskin, and T. Teubner, *Probes of the small x gluon via exclusive J/ψ and Υ production at HERA and the LHC*, JHEP **1311** (2013) 085, arXiv:1307.7099.

Graphical Representation



Rough LHCb coverage



Elastic Scattering

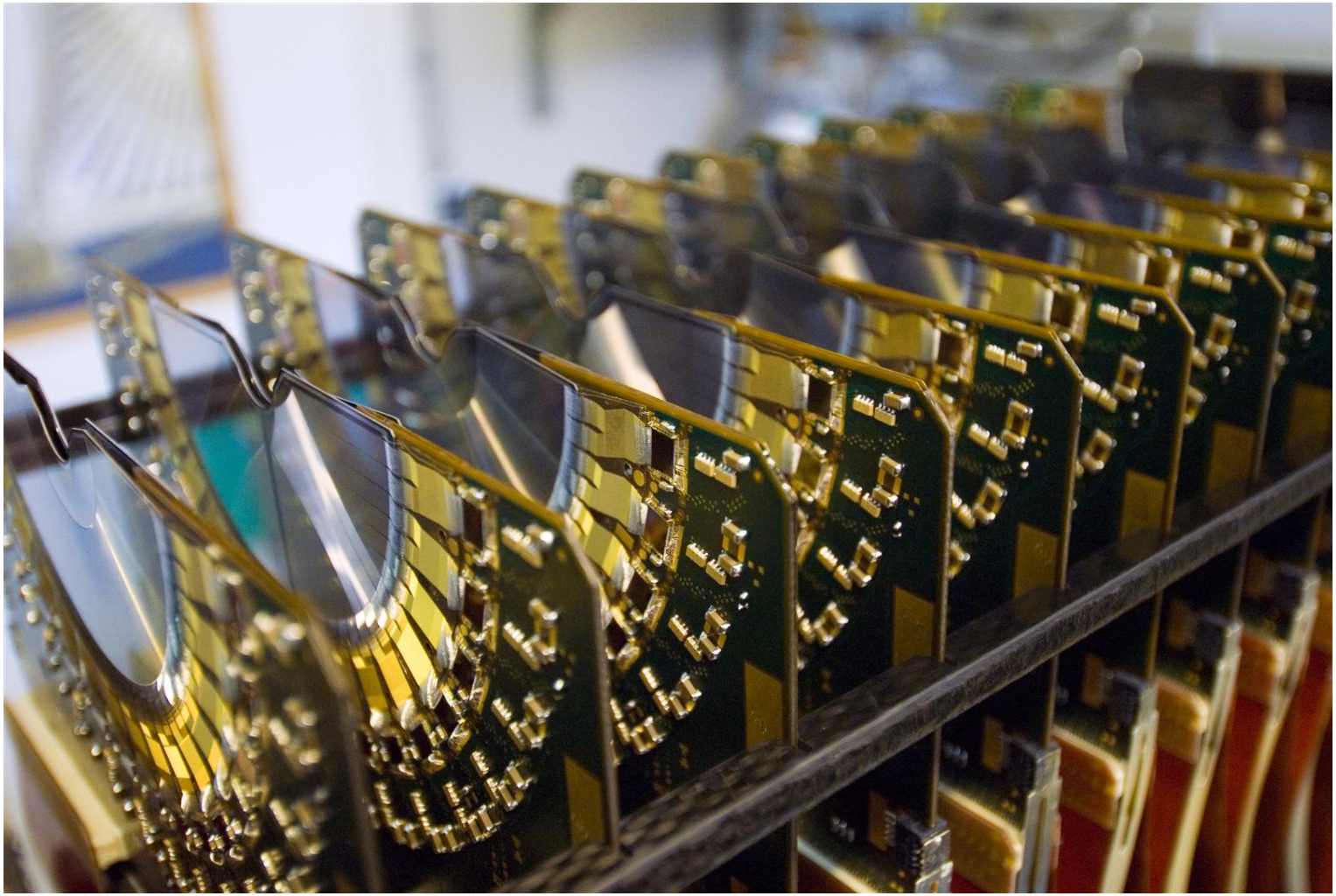
Single Diffraction

Double Diffraction

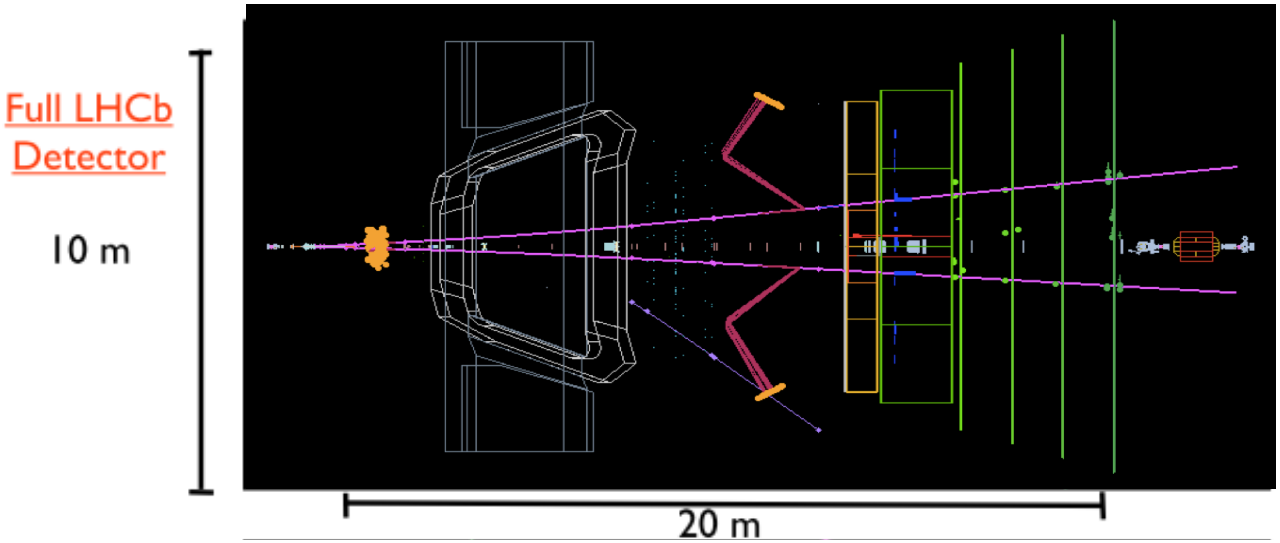
Central Exclusive Production (elastic)

Central Exclusive Production (inelastic)

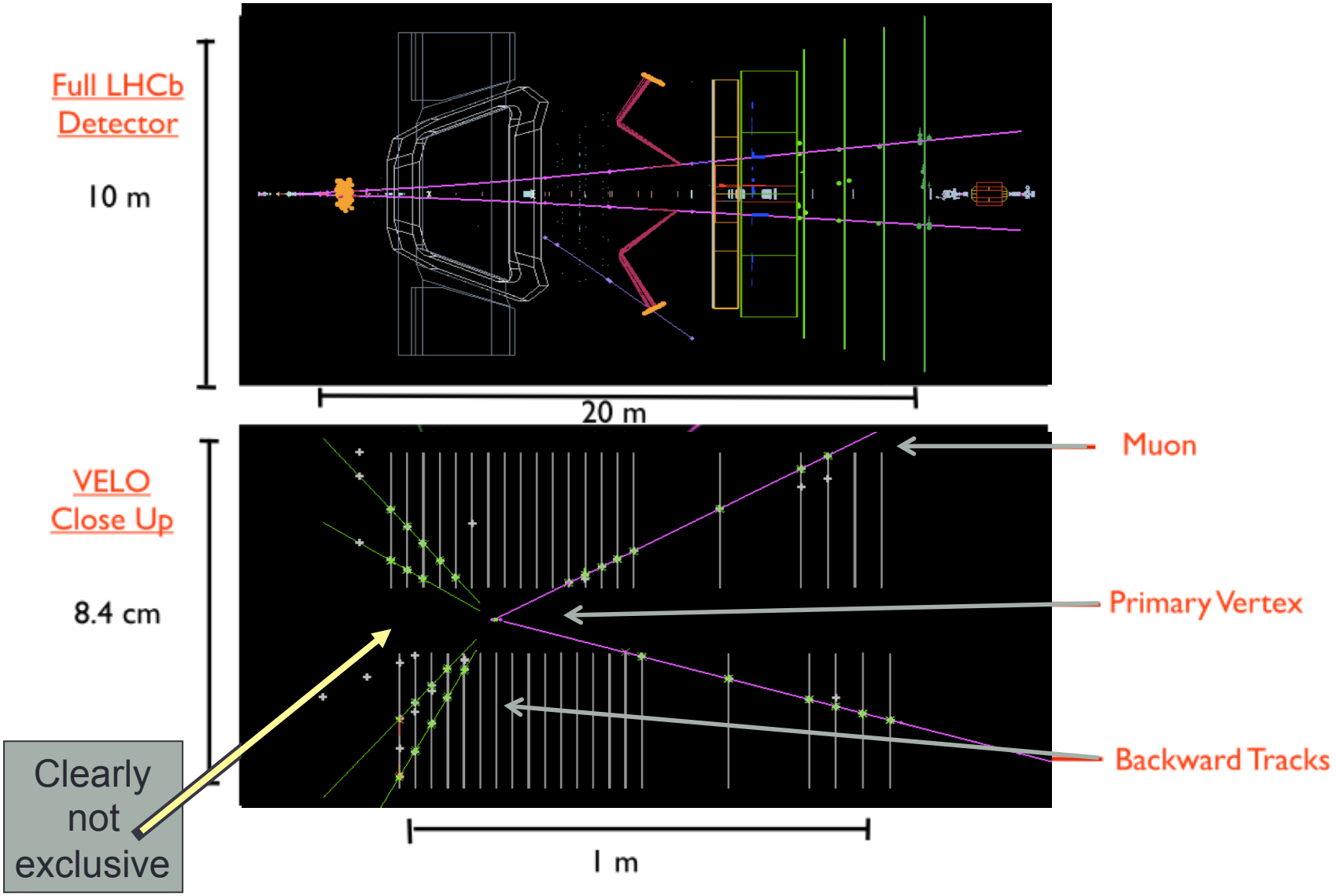
VELO sub-detector



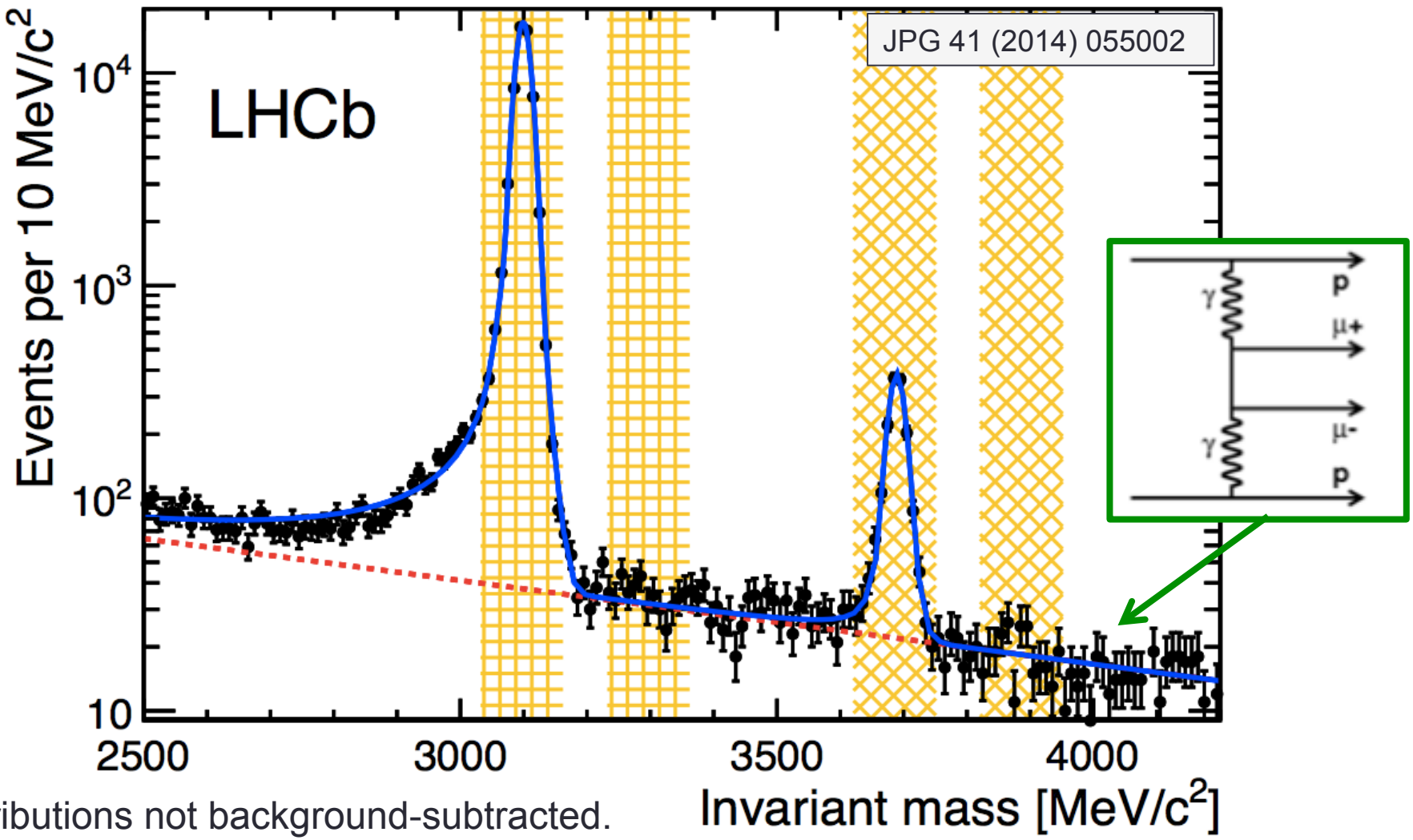
Use of backwards tracks



Use of backwards tracks

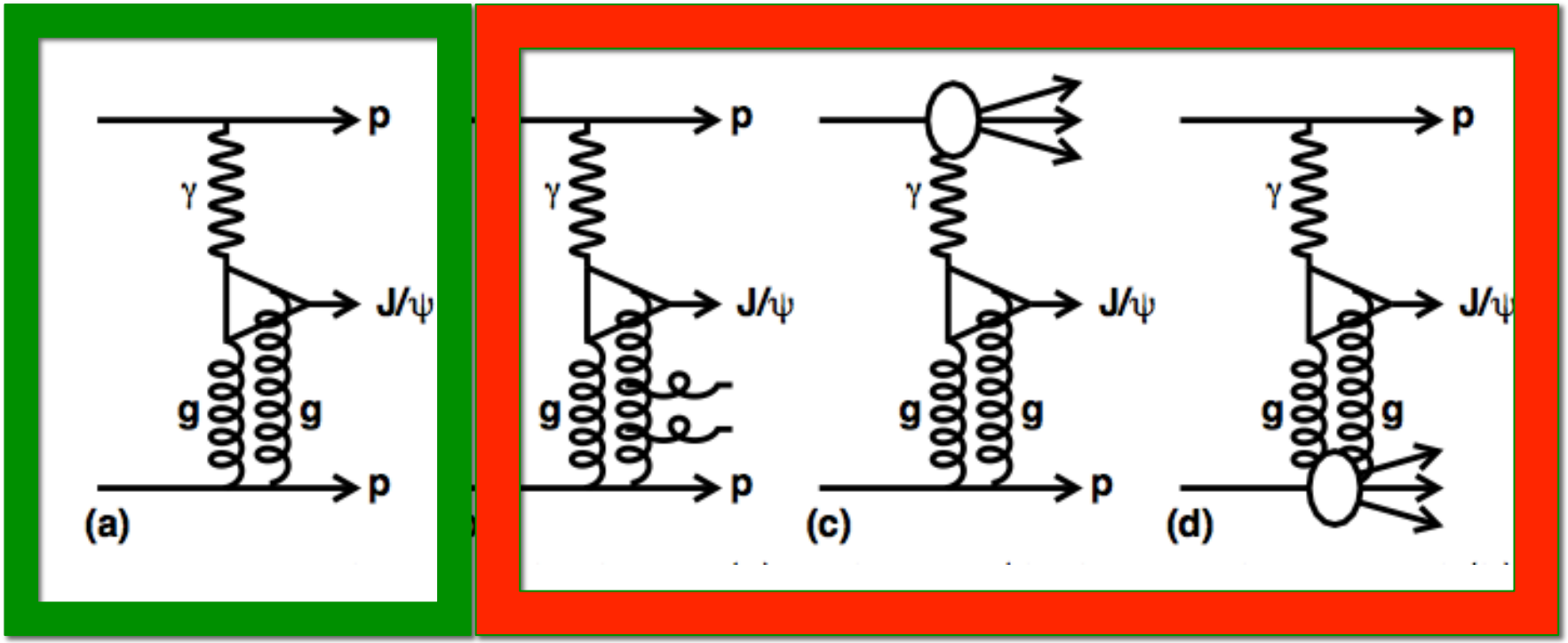


Invariant mass of exclusive muon pairs



Distributions not background-subtracted.
55985 J/ψ and 1565 ψ(2s)

Inelastic background



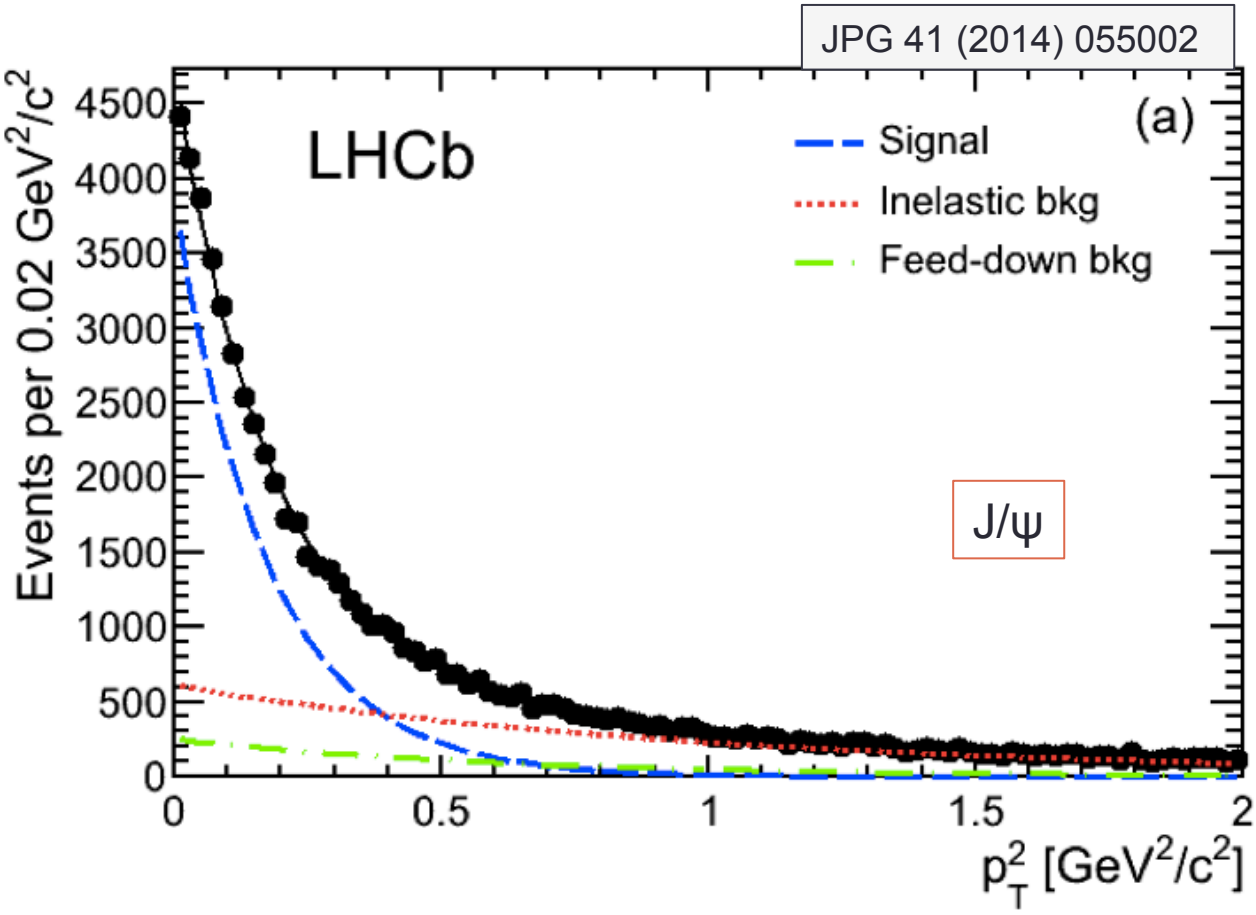
Signal

Background

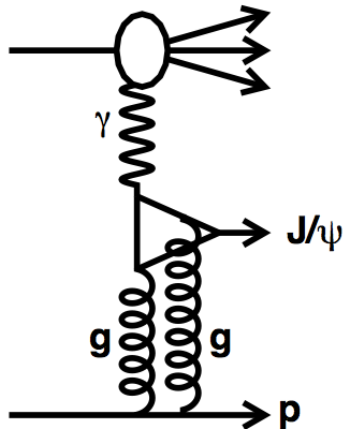
How to reject what you can't see?

...Regge theory suggests exponential dependence $\frac{d\sigma}{dt} \sim e^{bt}$

Inelastic background J/ψ



Over greater range, H1 require $(1 + b_{pd} p_T^2/n)^{-n}$
(EPJ C73 (2013) 2466)



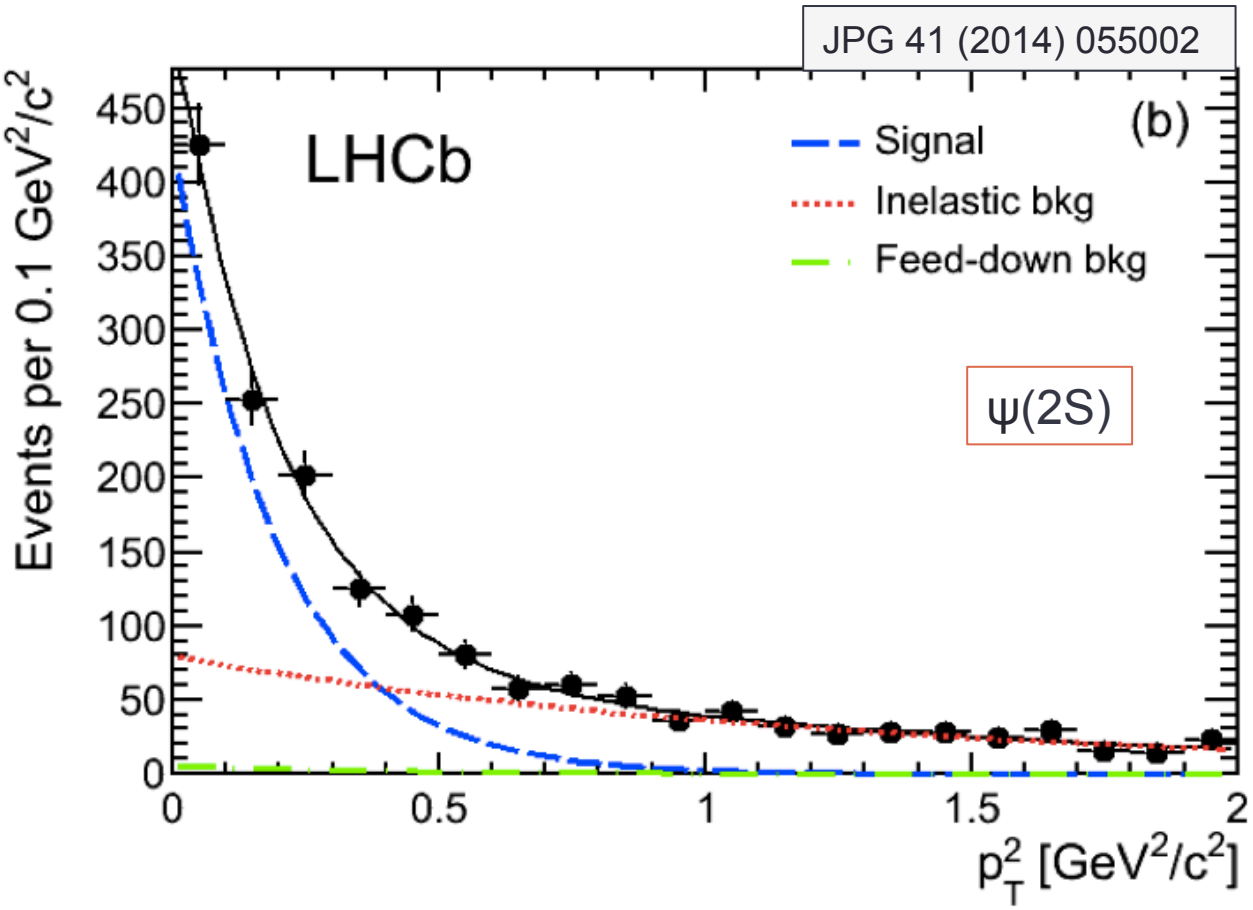
Regge theory: $\frac{d\sigma}{dt} \sim e^{bt}$

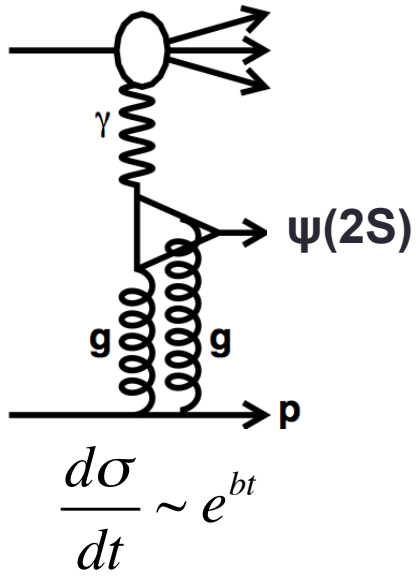
HERA measured:
b_s=4.9 GeV^{-2}
b_{pd}=1.1 GeV^{-2}

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}

Inelastic background ψ(2S)





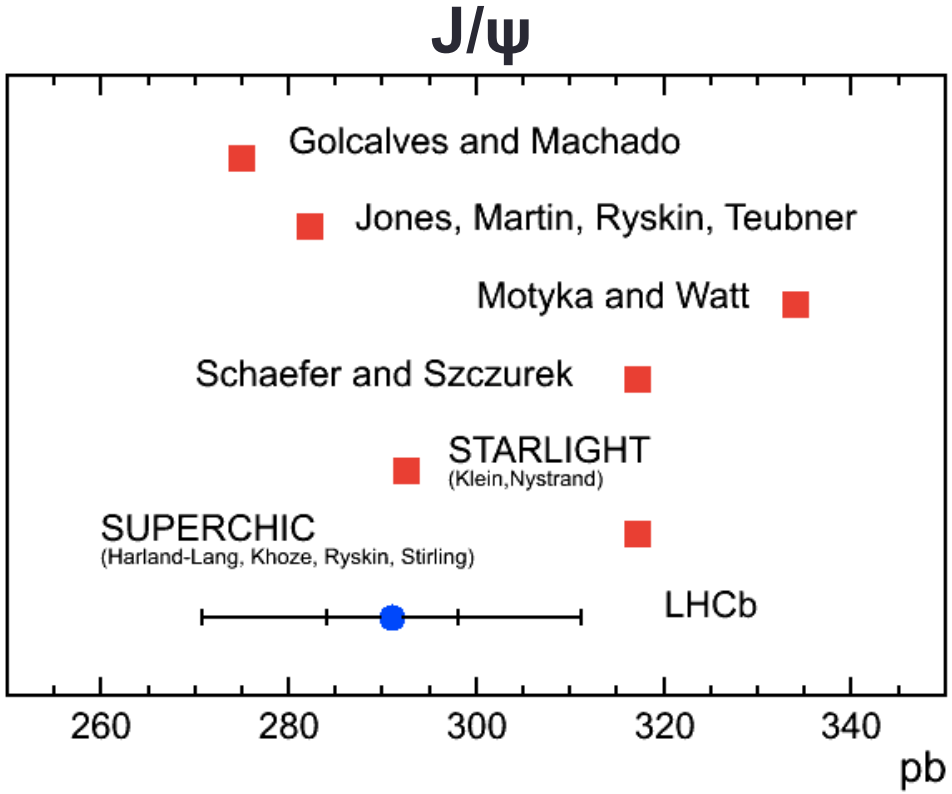
HERA measured:
b_s=4.2 GeV^{-2}
b_{pd}=0.6 GeV^{-2}

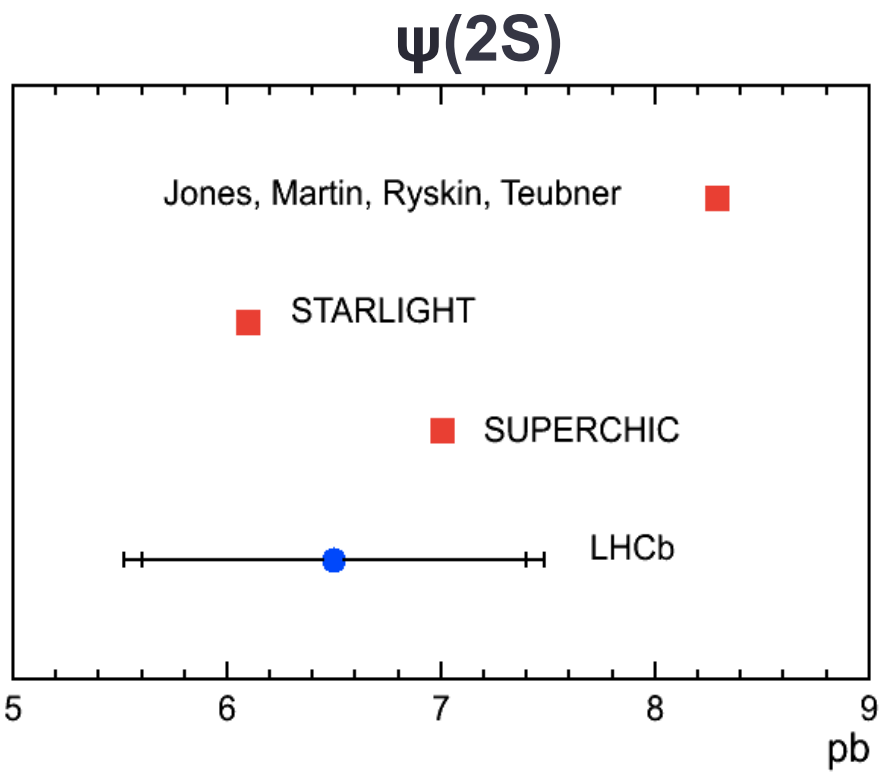
LHCb Expect:
b_s ~ 5.5 GeV^{-2}
b_{pd}~ 0.6 GeV^{-2}

LHCb Fit:
b_s=5.1±0.7 GeV^{-2}
b_{pd}=0.8±0.2 GeV^{-2}

Integrated Cross-sections

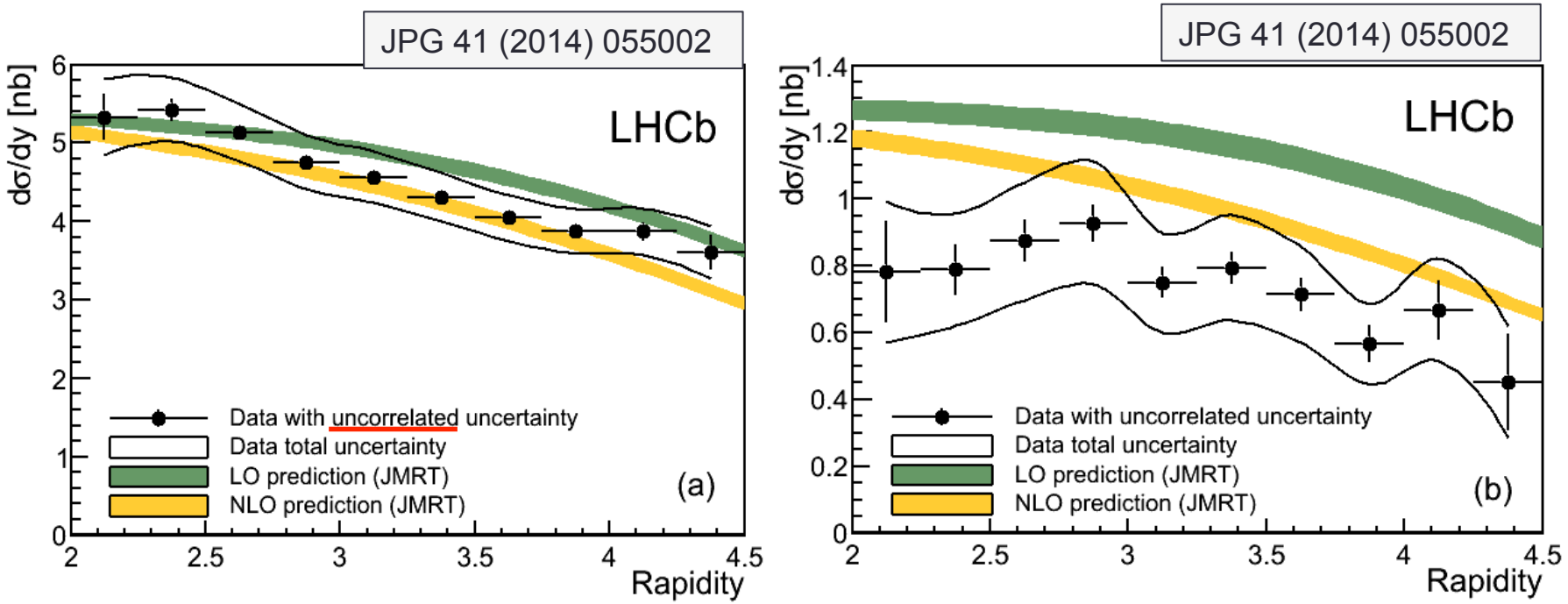
Cross-section*BR for both muons in pseudorapidity range 2<η<4.5:





Good agreement with all theory estimates

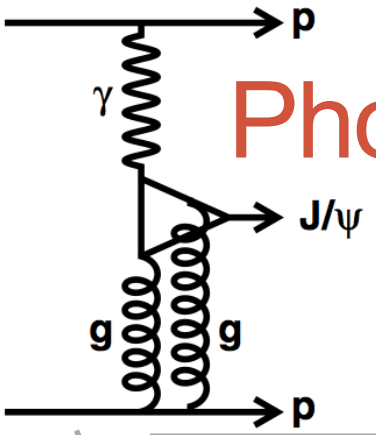
Differential cross-sections J/ψ and ψ(2S)



NLO agrees better than LO

S. Jones, A. Martin, M. Ryskin, and T. Teubner, *Probes of the small x gluon via exclusive J/ψ and ϒ production at HERA and the LHC*, JHEP **1311** (2013) 085, arXiv:1307.7099.

Photo-production cross-section



LHCb measure

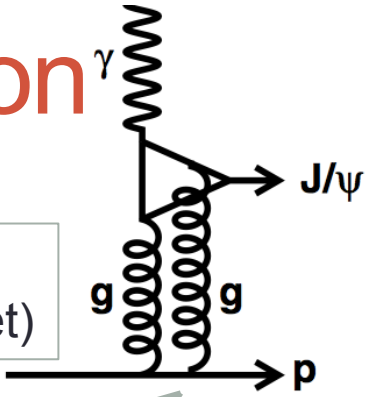


Photo-production
(HERA / fixed target)

$$\frac{d\sigma}{dy}_{pp\to pJ/\psi p} = r_+ k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to J/\psi p}(W_+) + r_- k_- \frac{dn}{dk_-}\sigma_{\gamma p\to J/\psi p}(W_-)$$

Gap
Survival

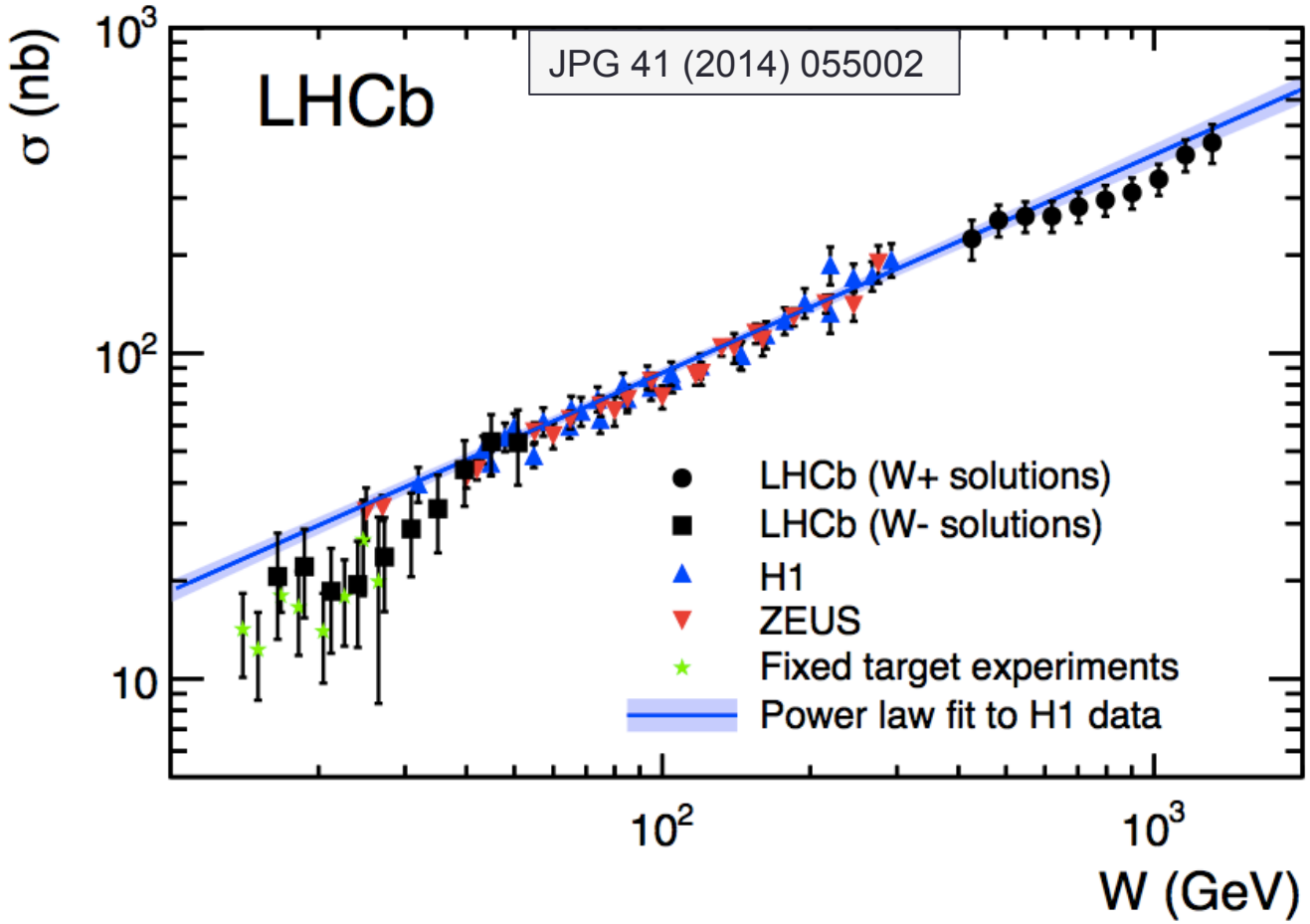
Photon
Flux

HERA measured power-law: $\sigma_{\gamma p\to J/\psi p}(W) = 81(W/90\,\mathrm{GeV})^{0.67}\,\mathrm{nb}$
Use this for one cross-section on RHS – LHCb measure the other solution

Photo-production cross-section

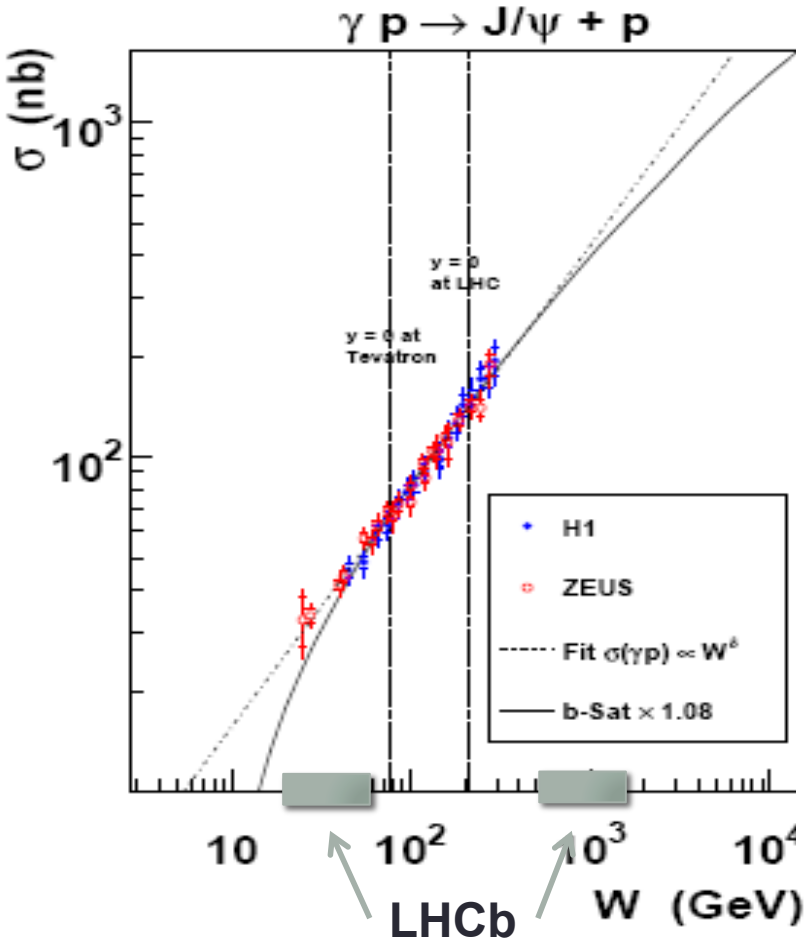
Measure Plot HERA

$$\frac{d\sigma}{dy}_{pp\to pJ/\psi p} = r_+ k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to J/\psi p}(W_+) + r_- k_- \frac{dn}{dk_-}\sigma_{\gamma p\to J/\psi p}(W_-)$$

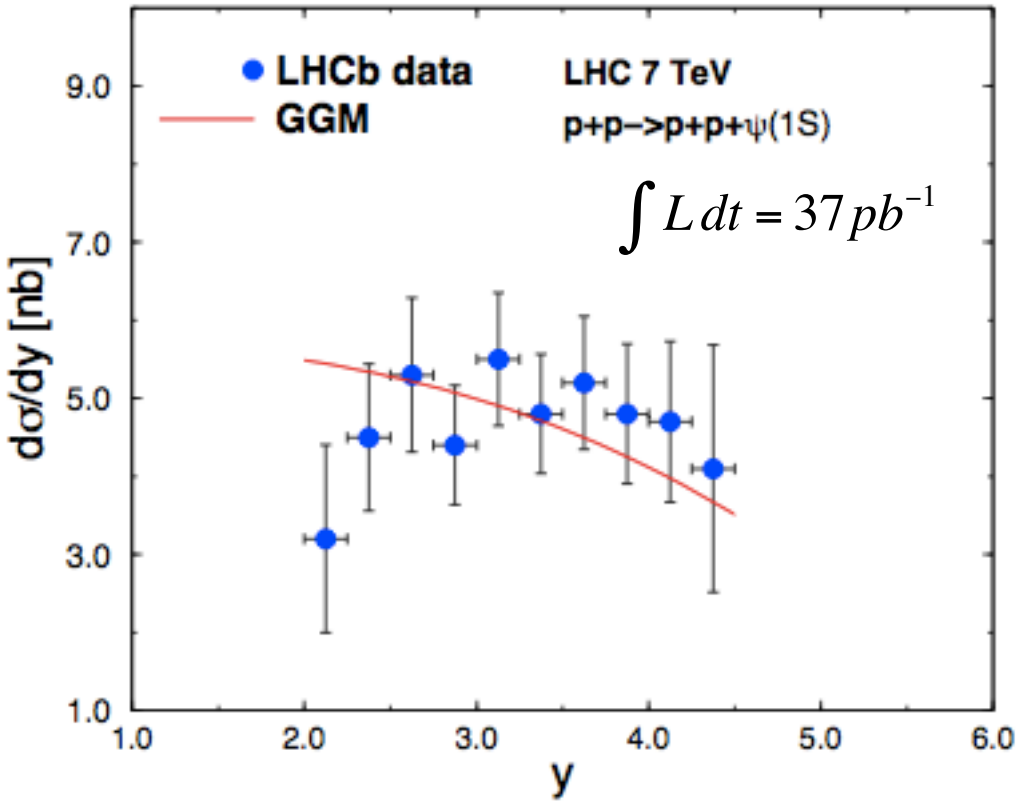


Deviation from pure power-law. i.e. NLO required or only power-law for $W>W_0$

Sensitivity to saturation effects

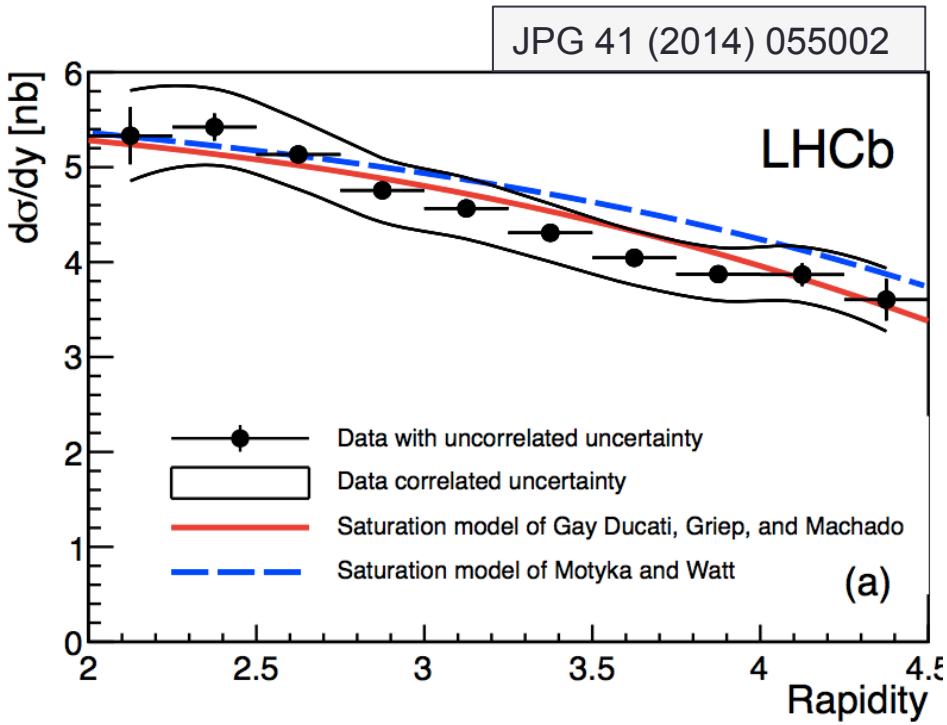


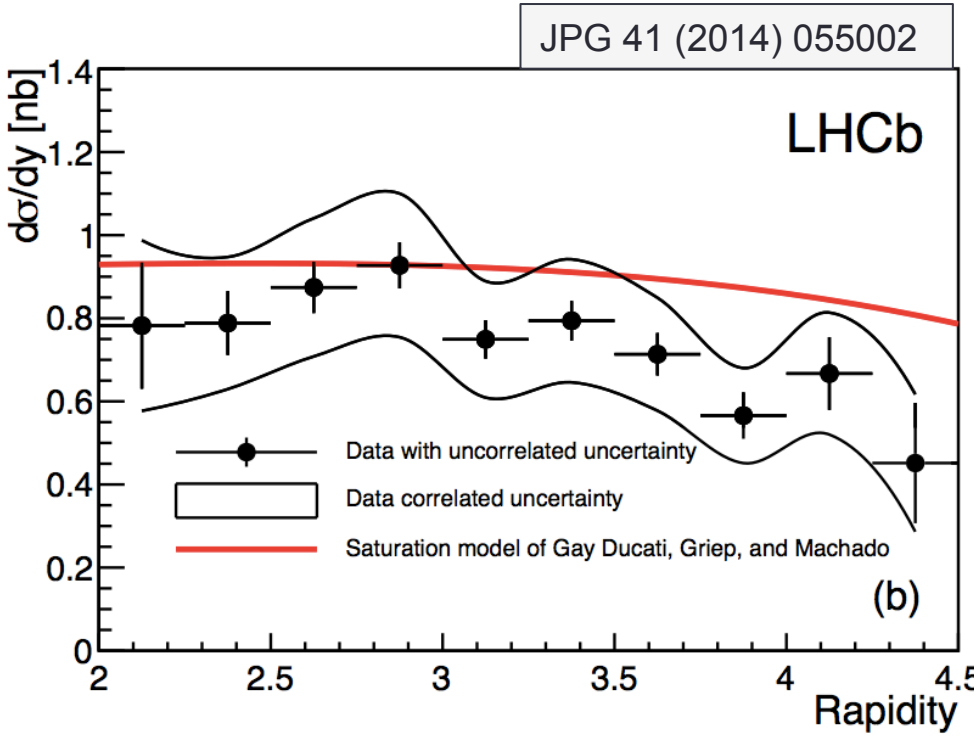
Motyka, Watt: PRD 78, 014023 (2008)



Gay Ducati et al., arXiv: 1305.4611

Sensitivity to saturation effects: J/ψ ψ(2S)



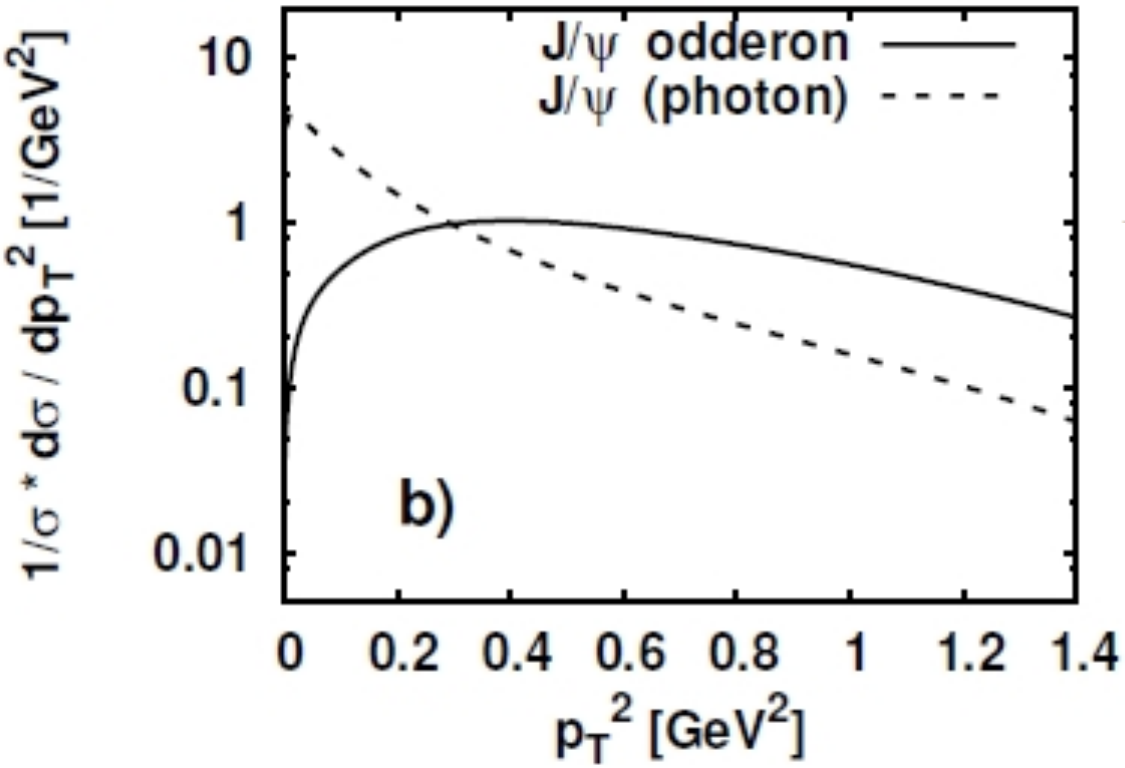


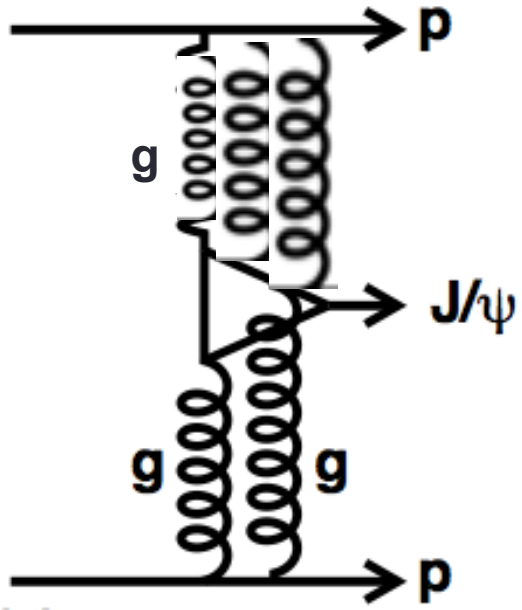
L. Motyka and G. Watt, *Exclusive photoproduction at the Fermilab Tevatron and CERN LHC within the dipole picture*, Phys. Rev. **D78** (2008) 014023, arXiv:0805.2113.

M. B. Gay Ducati, M. T. Griep, and M. V. T. Machado, *Exclusive photoproduction of J/ψ and ψ(2S) states in proton-proton collisions at the CERN LHC*, arXiv:1305.4611.

Search for odderon

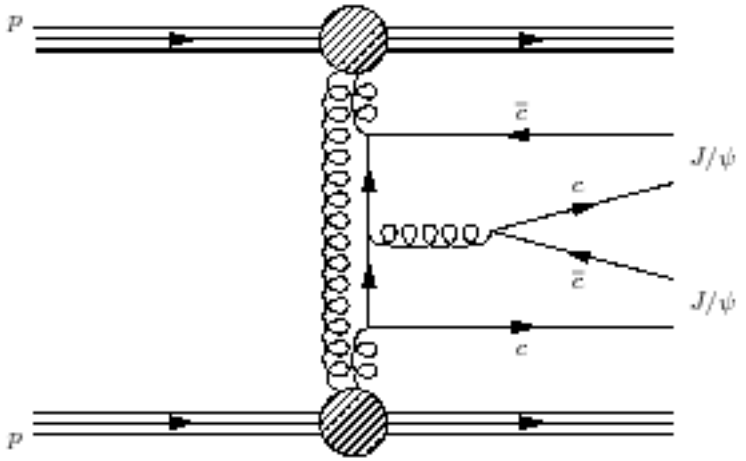
- Motyka, DIS 2008.



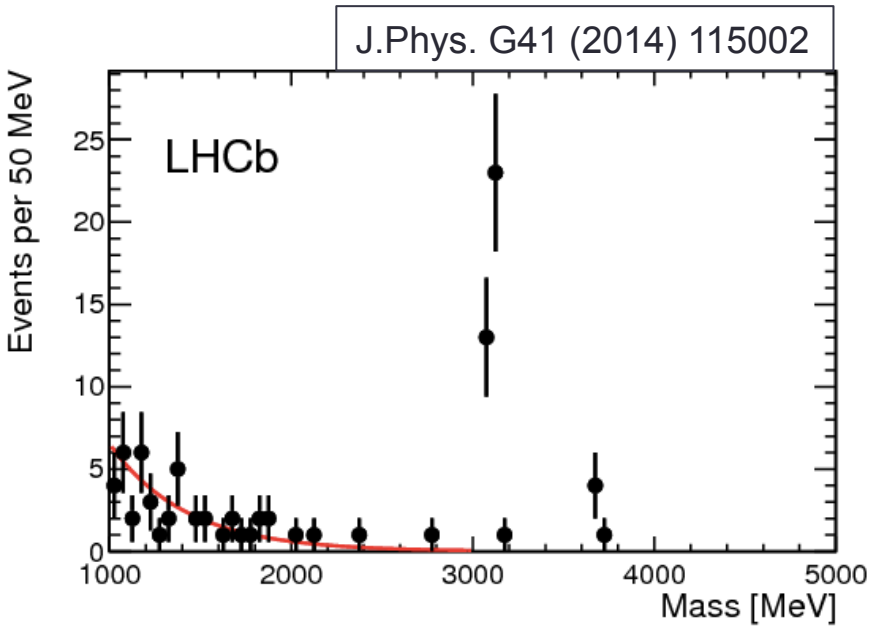


Odderon identification requires good modelling of inelastic background

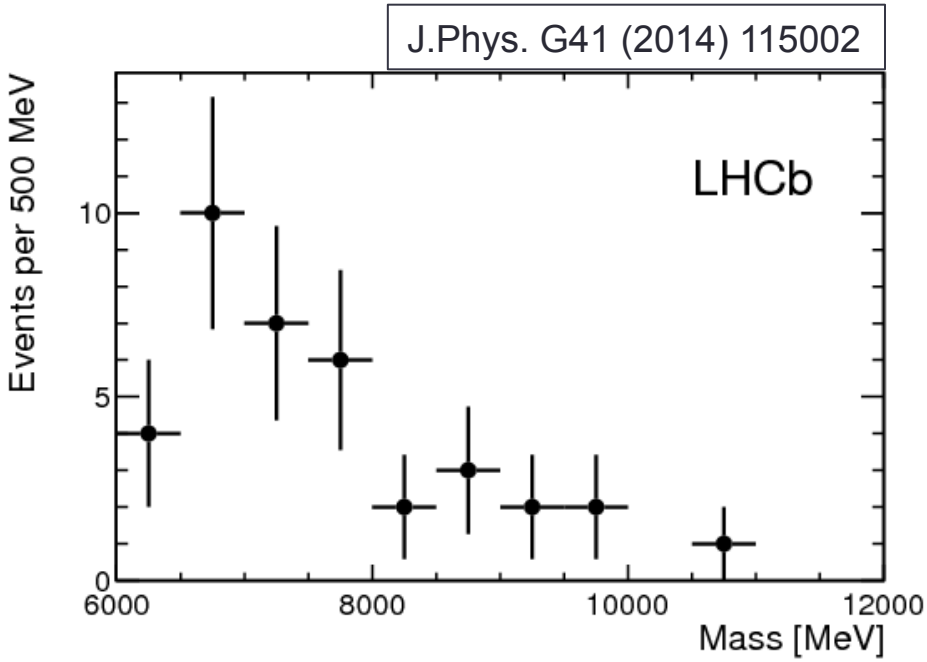
Probing pomerons: J/ψ+J/ψ



(CEP at LHCb is glue laboratory. Measure χ_c , meson pairs, low-mass spectroscopy, search for glueballs, odderons etc.)

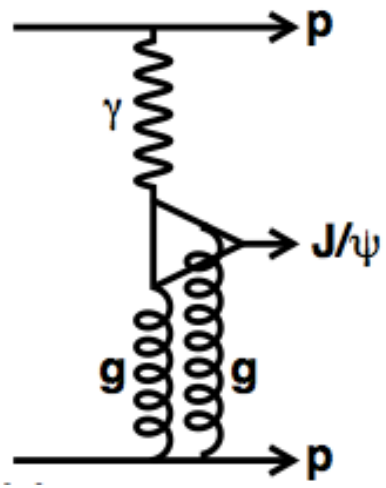


Mass of second muon pair

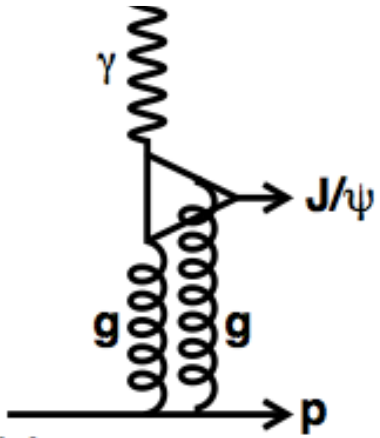


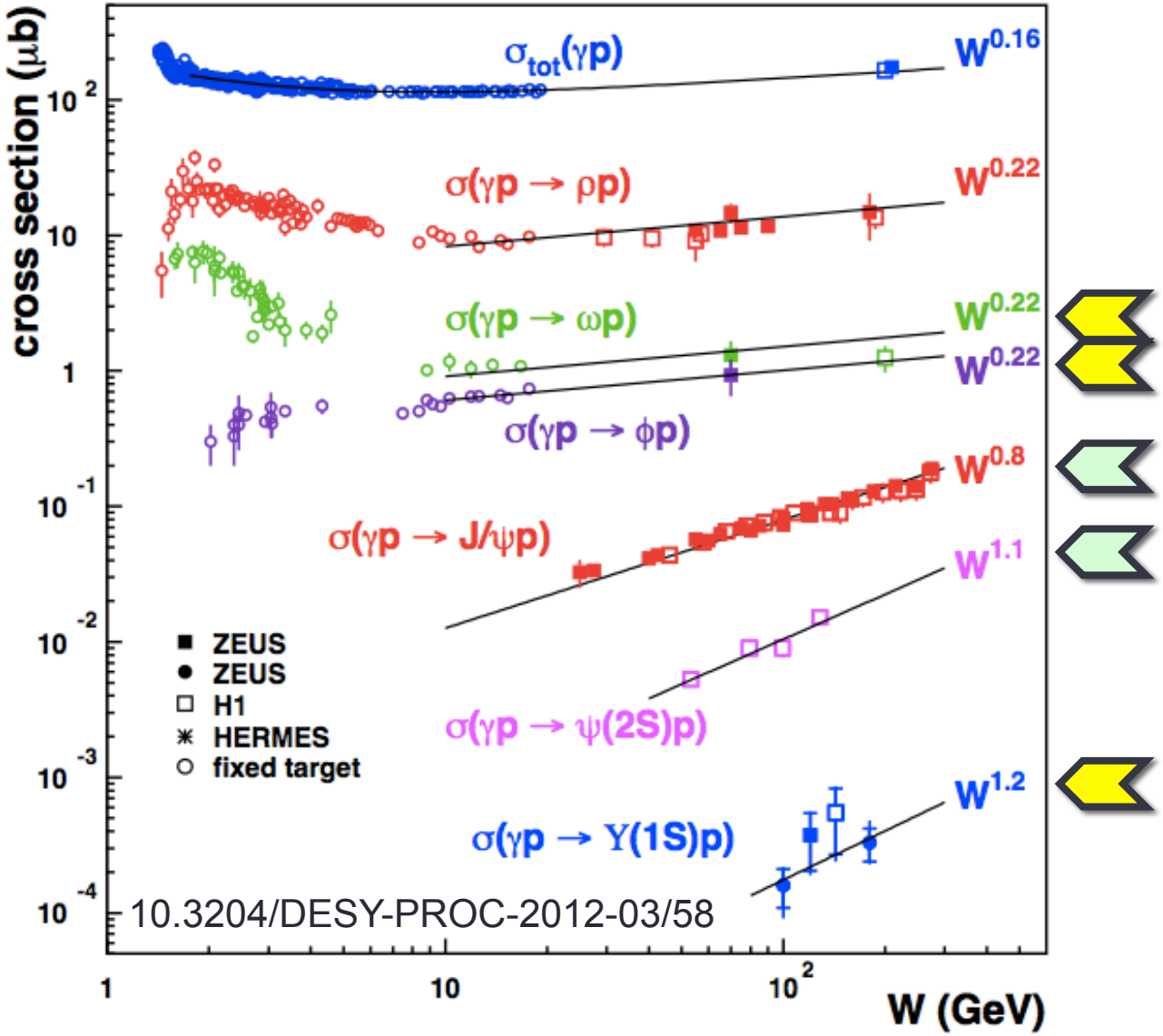
Mass of J/ψ pair

Investigate other vector mesons

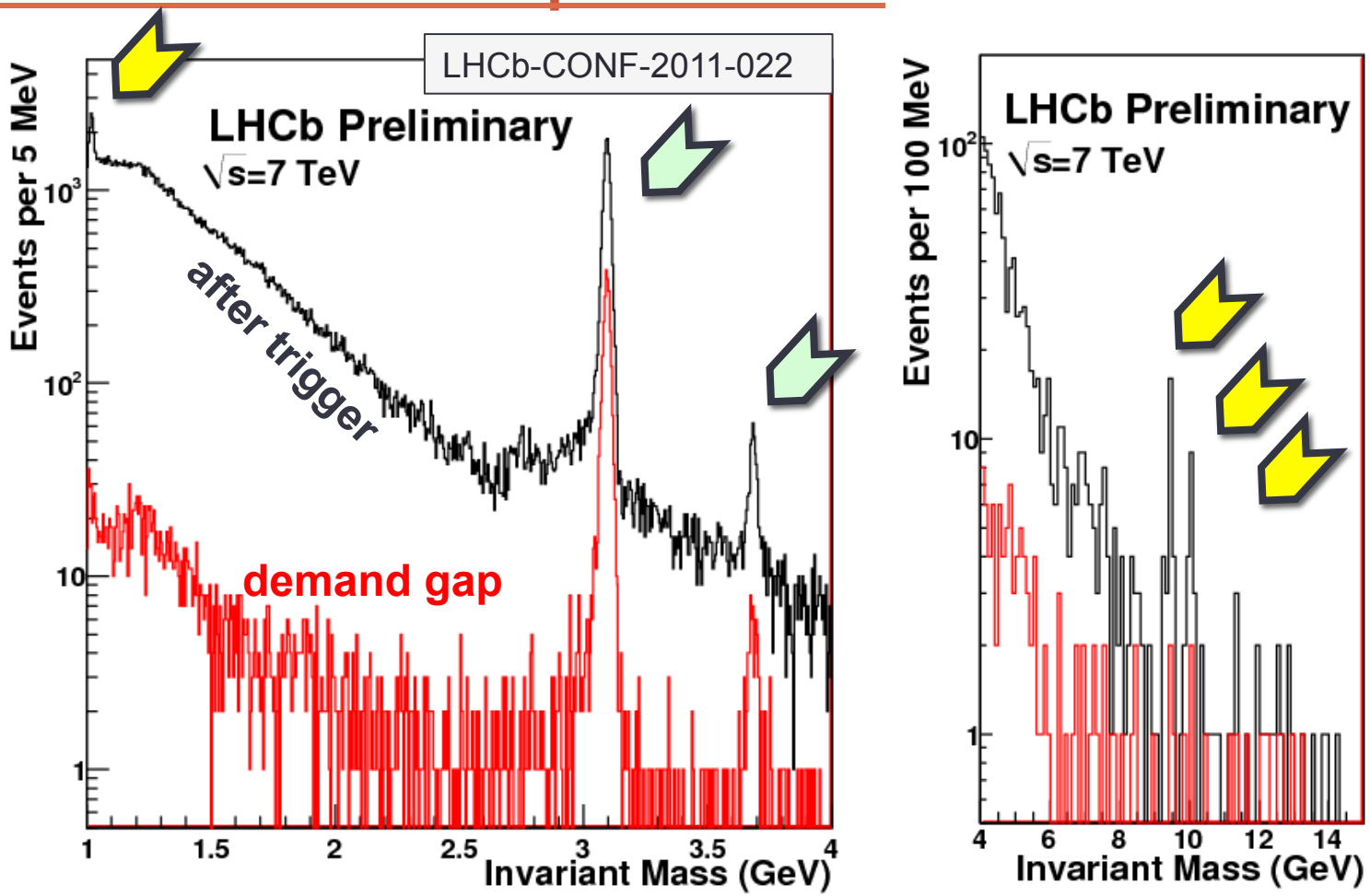


looks very like





Dimuon Mass Spectrum

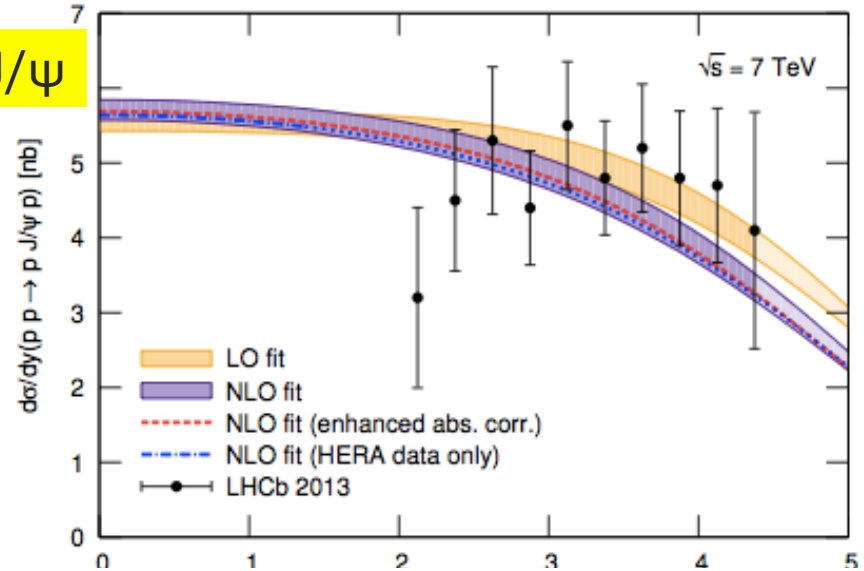


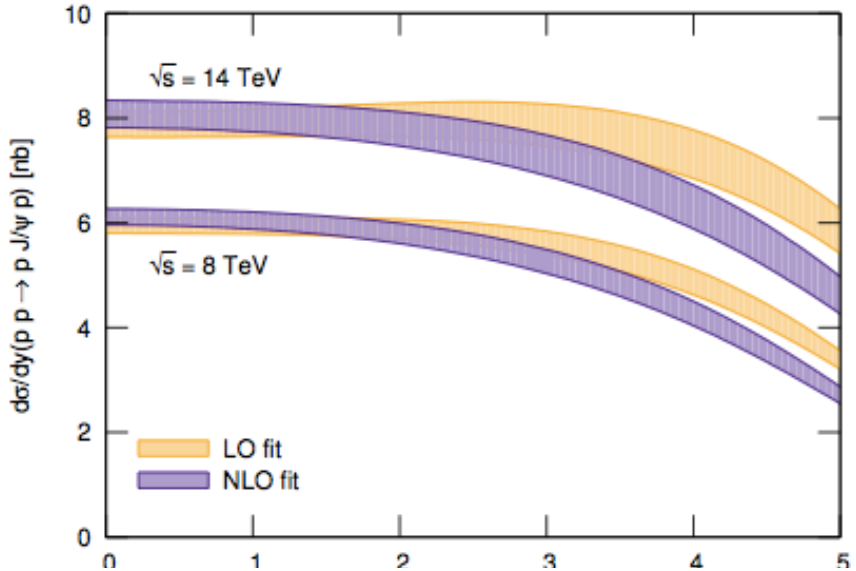
Factor ~ *100 data now available with 2011+2012 (~3fb^{-1})

Predictions

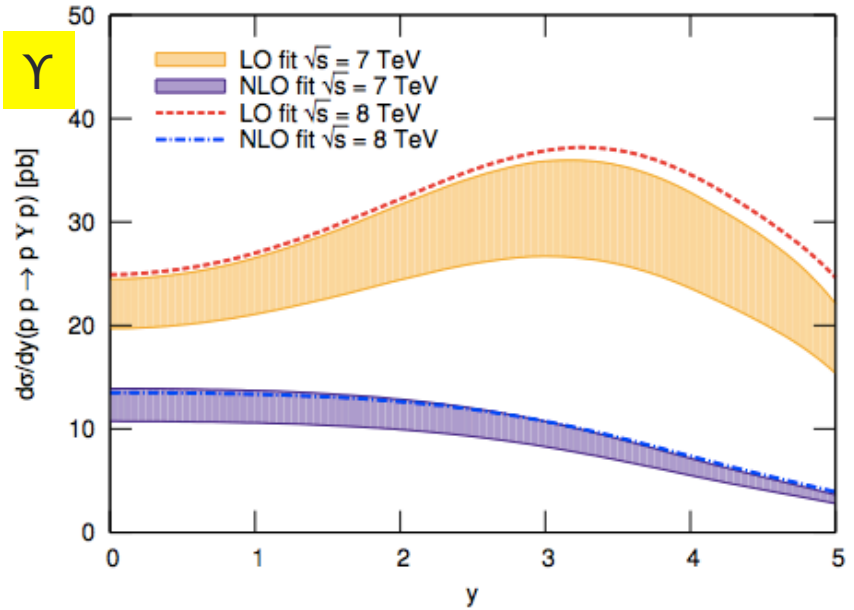
Jones, Martin, Ryskin, Teubner, JHEP 1311 (2013) 085

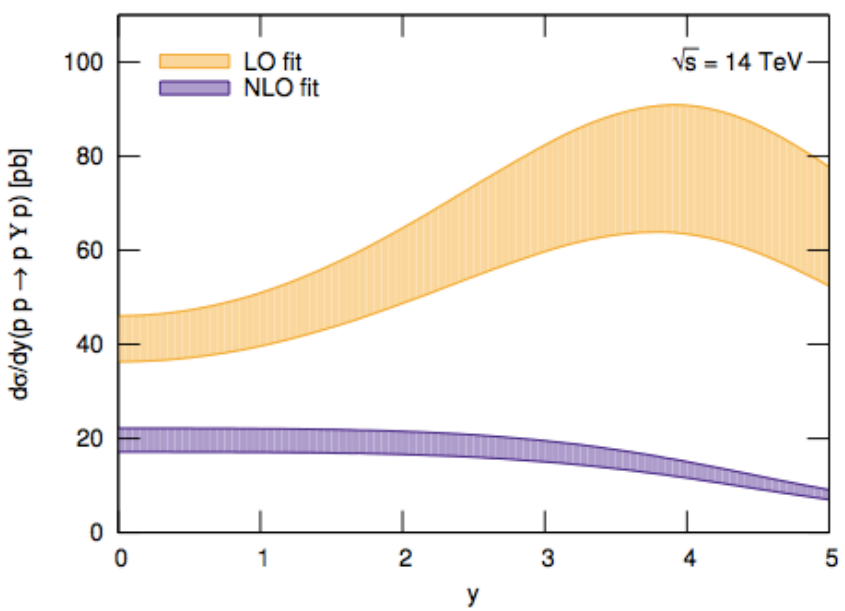
J/ψ





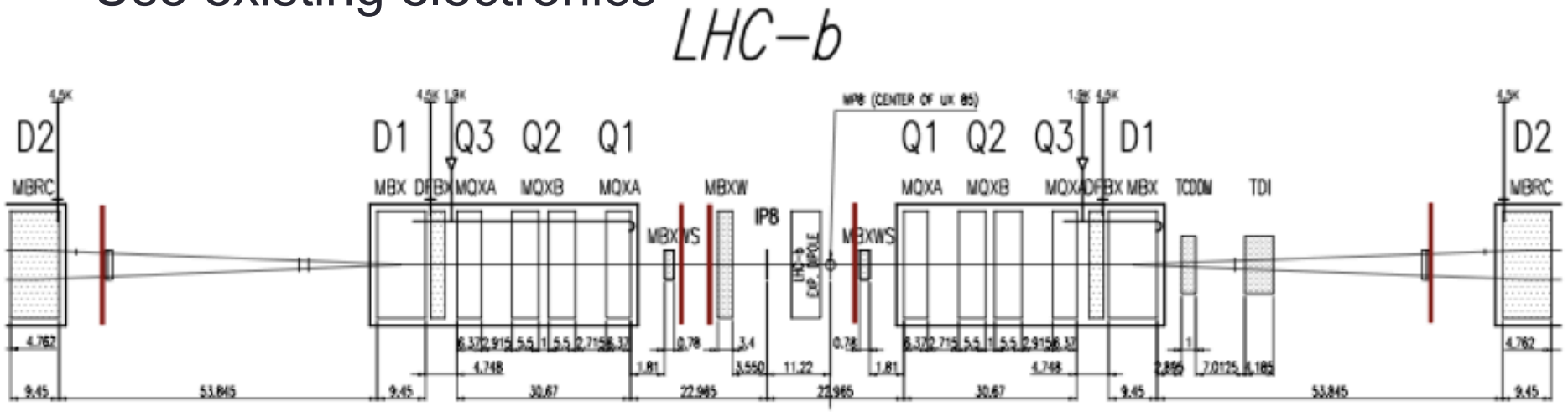
ϒ





High rapidity shower counters for LHCb

- Increase rapidity gap with scintillators in forward region
- Use existing electronics

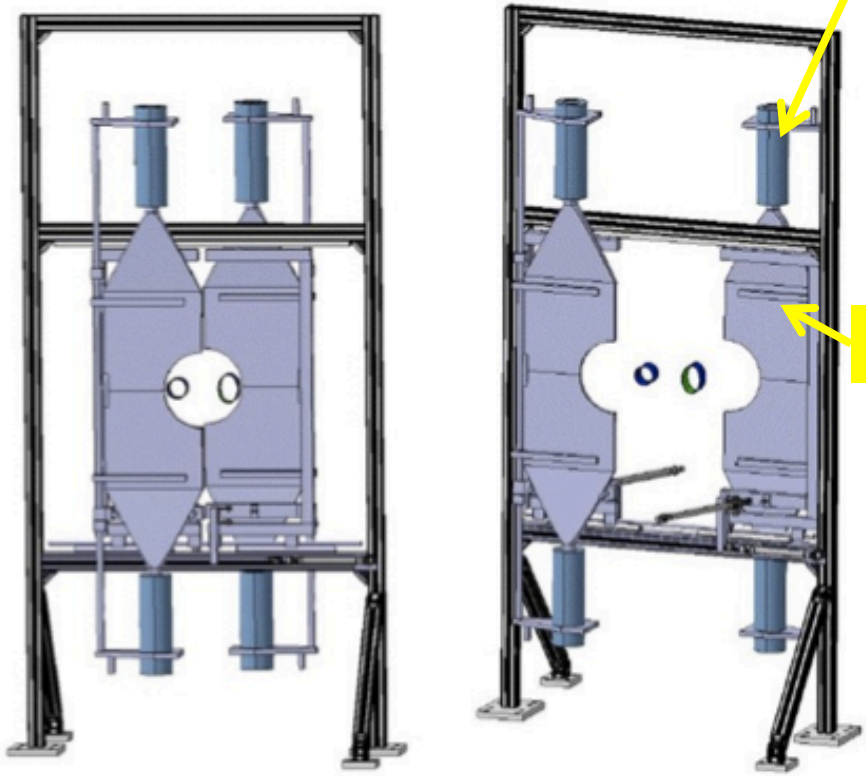


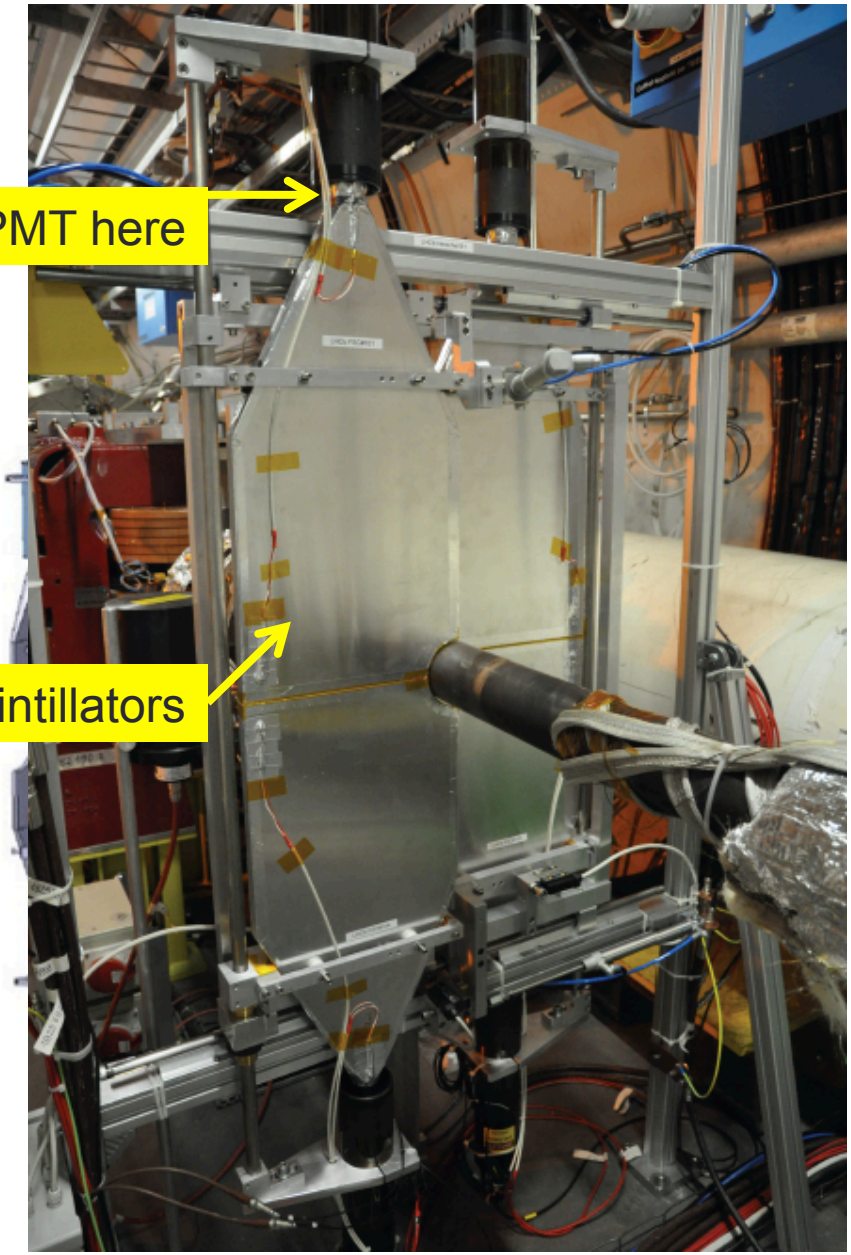
Left
1. z ~ -7.5 m (after MBXW)
2. z ~ -19m (before MBXWS)
3. z ~ -114m (after BRANS)

Right
1. z ~ 19 m (close to MBXWS)
2. z ~ 114m (after BRANS)

First simulations suggest veto region for charged and neutral particles can be extended to include $5<|\eta|<8$ - an extra 6 units in pseudorapidity.

Herschel Integration inside Tunnel





Summary

- EW measurements at LHCb constrain PDFs and complement the constraints obtained from HERA data
- Photoproduction of vector mesons is measured in different kinematic regimes by LHCb and HERA, showing consistent results.
- Through CEP, soft QCD at very low x values can be investigated in a remarkably clean experimental environment (down to $x=10^{-6}$ in new 13 TeV running).