EXCLUSIVE J/Ψ AND Ψ(2S) PRODUCTION IN PP COLLISIONS AT √S=7 TEV

Ronan McNulty (UCD Dublin)

on behalf of the LHCb collaboration.

DIS Marseilles 22-26 April 2013

Exclusive J/ψ and ψ(2S)

OPEN ACCESS
IOP PUBLISHING JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICS

J. Phys. G: Nucl. Part. Phys. **40** (2013) 045001 (17pp) doi:10.1088/0954-3899/40/4/045001

Exclusive J/ψ and $\psi(2S)$ production in pp collisions at $\sqrt{s} = 7$ TeV

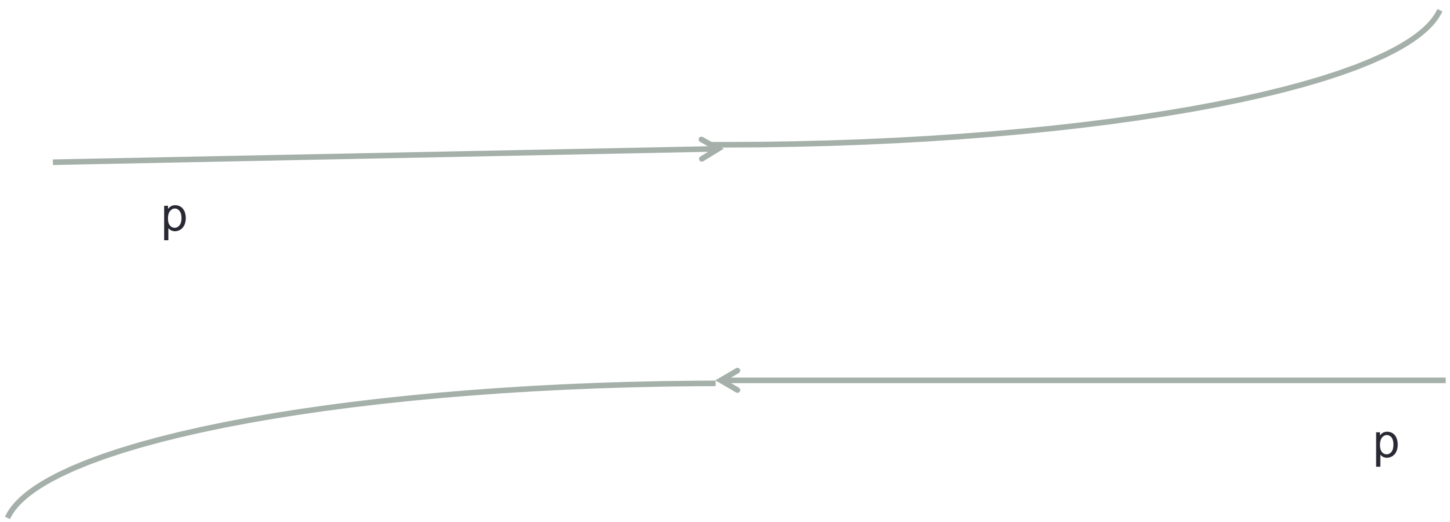
Results based on $37 pb^{-1}$ of data taken in 2010

Overview

- Motivations
  - Investigation of the pomeron
  - Gluon PDF
- Exclusive J/ψ
  - Selection
  - Efficiency and Purity
  - Results.
- Discussion
  - Comparison with HERA
  - Prospects for future
- Summary

Physics of the Vacuum

Elastic



It's QCD – but not as we normally see it. It's colour-free

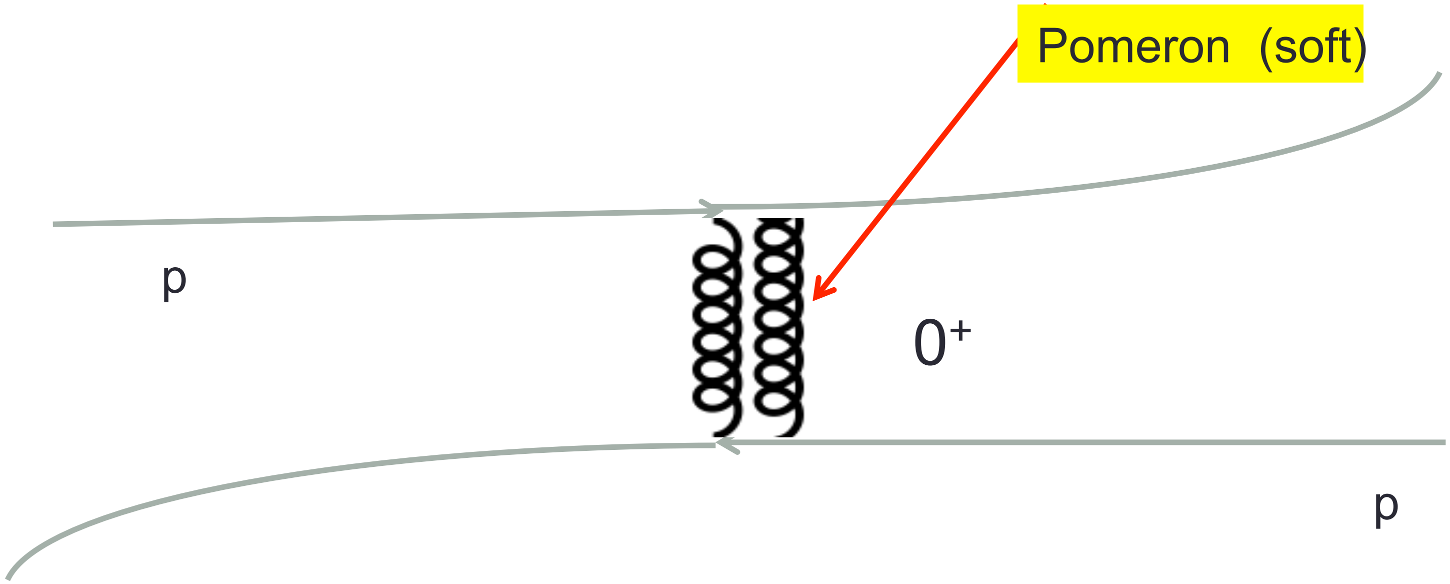
$\sigma_{elastic} \approx 40\text{mb}$

$\sigma_{diffractive} \approx 10\text{mb}$

$\sigma_{inelastic} \approx 60\text{mb}$

Physics of the Vacuum

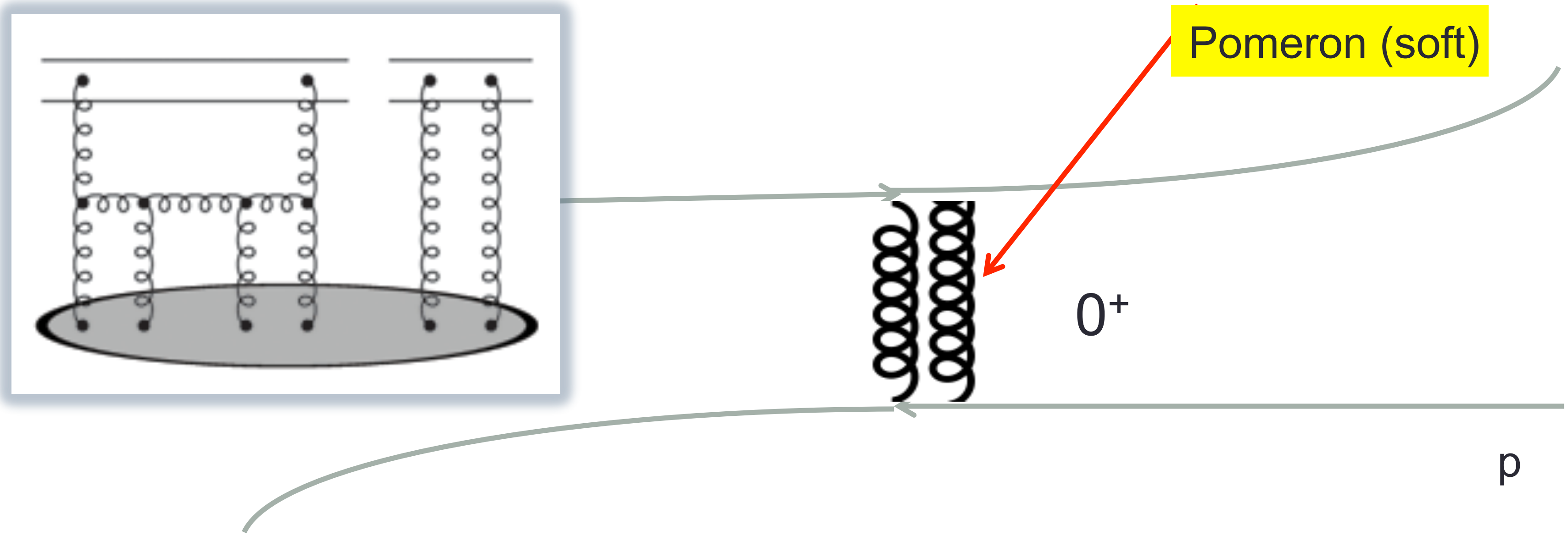
Elastic



It's QCD – but not as we normally see it. It's colour-free

$\sigma_{elastic} \approx 40mb$
$\sigma_{diffractive} \approx 10mb$
$\sigma_{inelastic} \approx 60mb$

Physics of the Vacuum

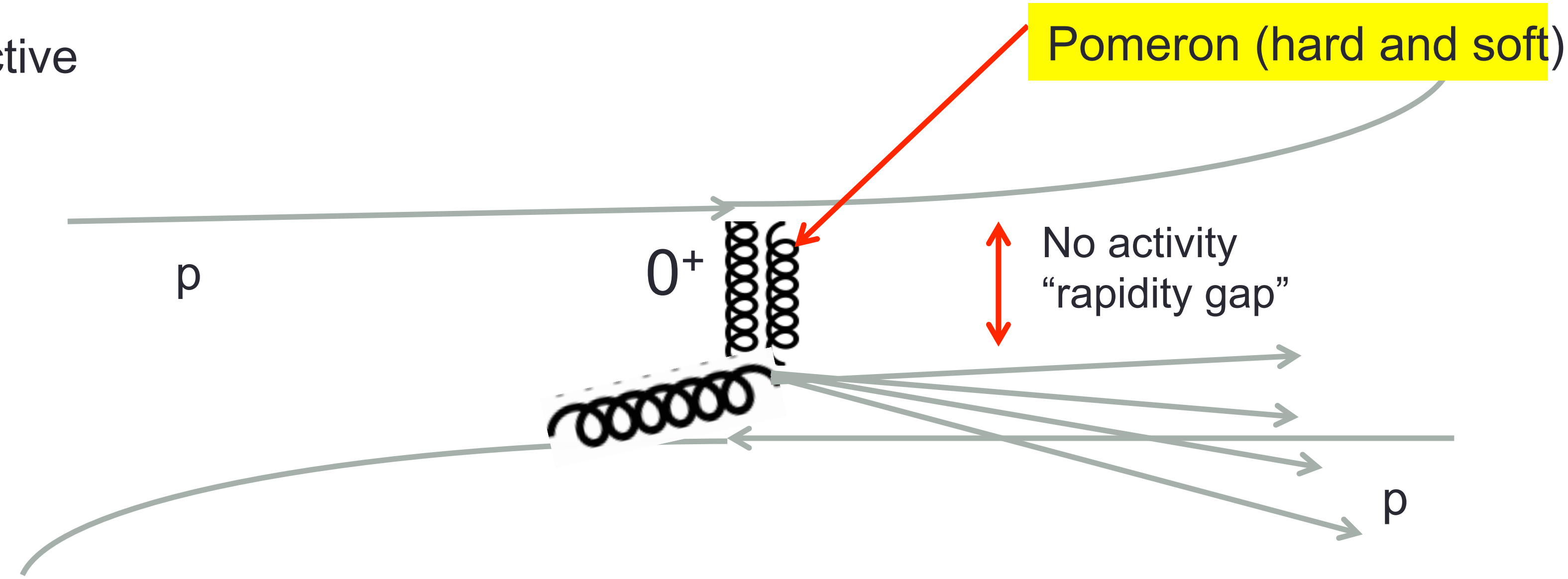


It's QCD – but not as we normally see it. It's colour-free

$\sigma_{elastic} \approx 40mb$
$\sigma_{diffractive} \approx 10mb$
$\sigma_{inelastic} \approx 60mb$

Physics of the Vacuum

Diffractive

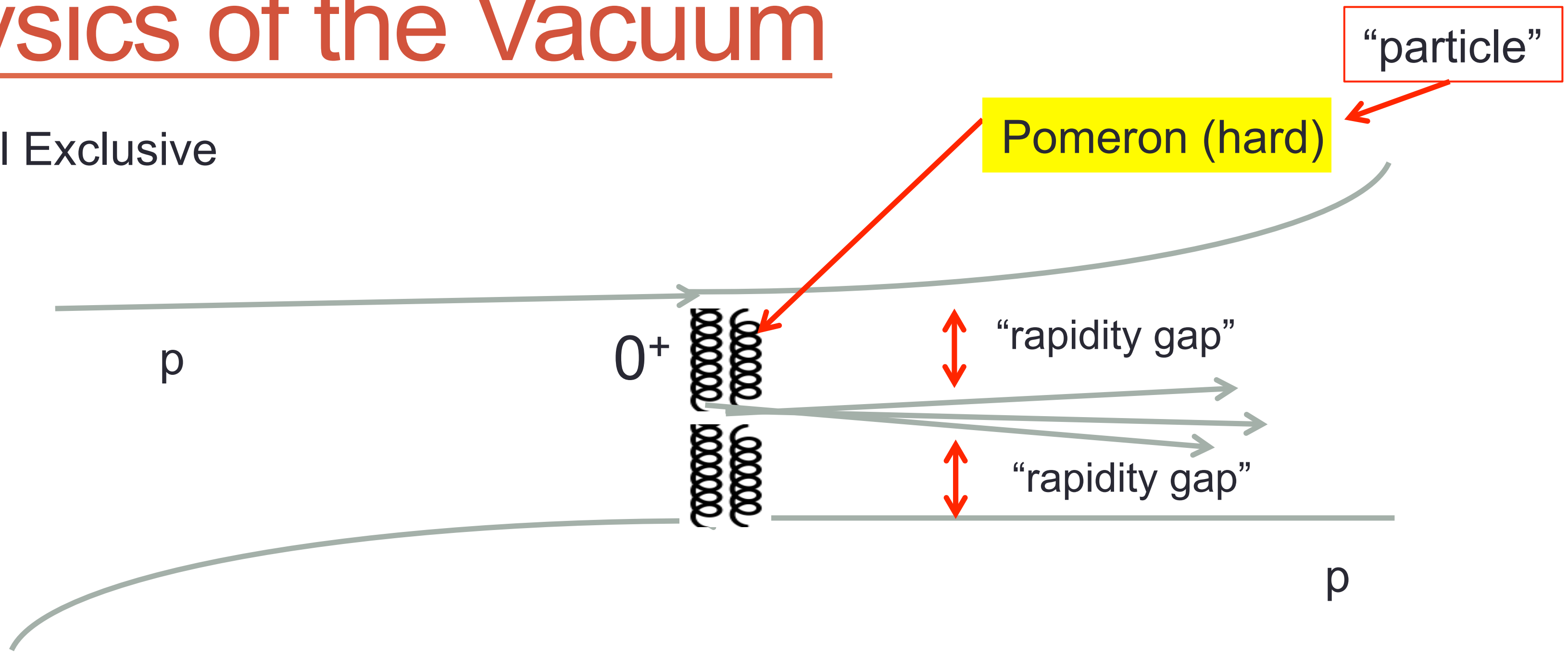


It's QCD – but not as we normally see it. It's colour-free

$\sigma_{elastic}$ ≈ 40mb
$\sigma_{diffractive}$ ≈ 10mb
$\sigma_{inelastic}$ ≈ 60mb

Physics of the Vacuum

Central Exclusive

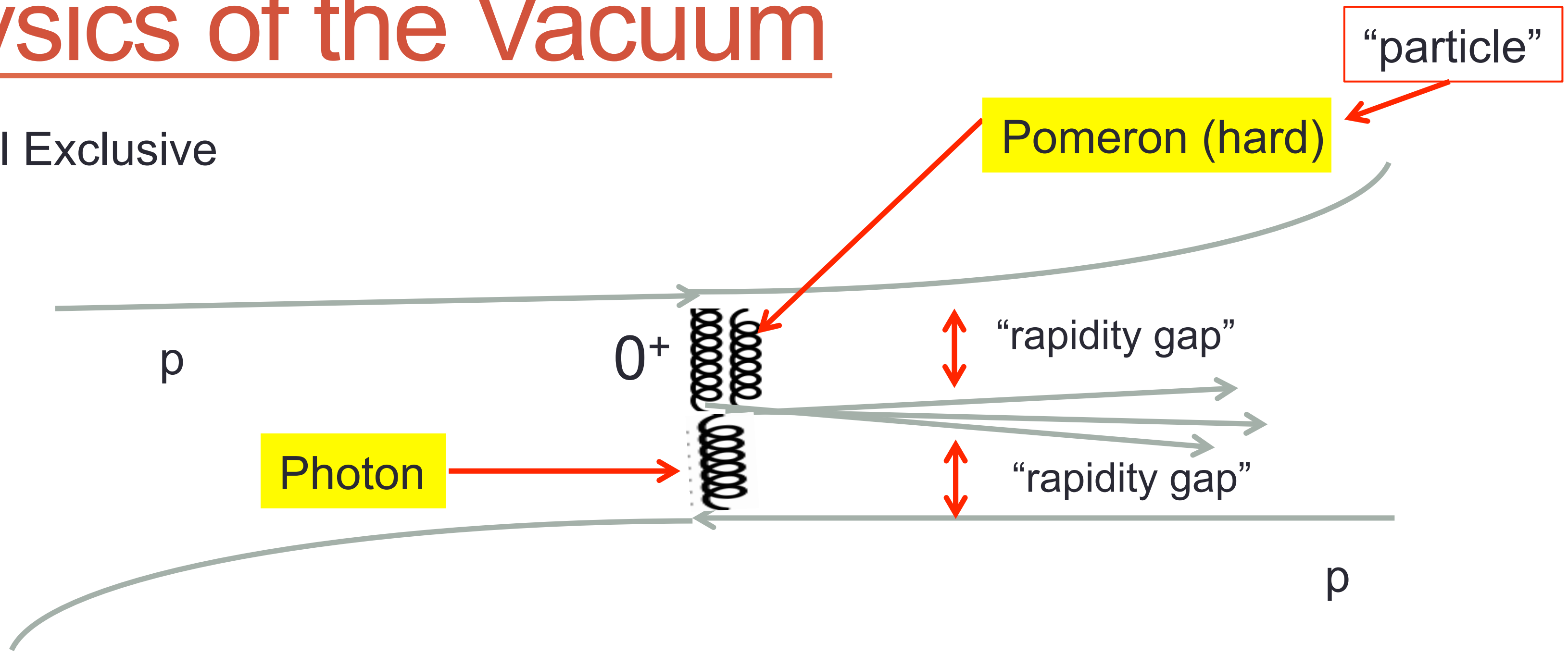


Elastic diffractive: clean environment to study vacuum, and in particular, transition between soft and hard pomeron.

$\sigma_{elastic}$ ≈ 40mb
$\sigma_{diffractive}$ ≈ 10mb
$\sigma_{inelastic}$ ≈ 60mb

Physics of the Vacuum

Central Exclusive



Elastic diffractive: clean environment to study vacuum, and in particular, transition between soft and hard pomeron.

$\sigma_{elastic} \approx 40mb$
$\sigma_{diffractive} \approx 10mb$
$\sigma_{inelastic} \approx 60mb$

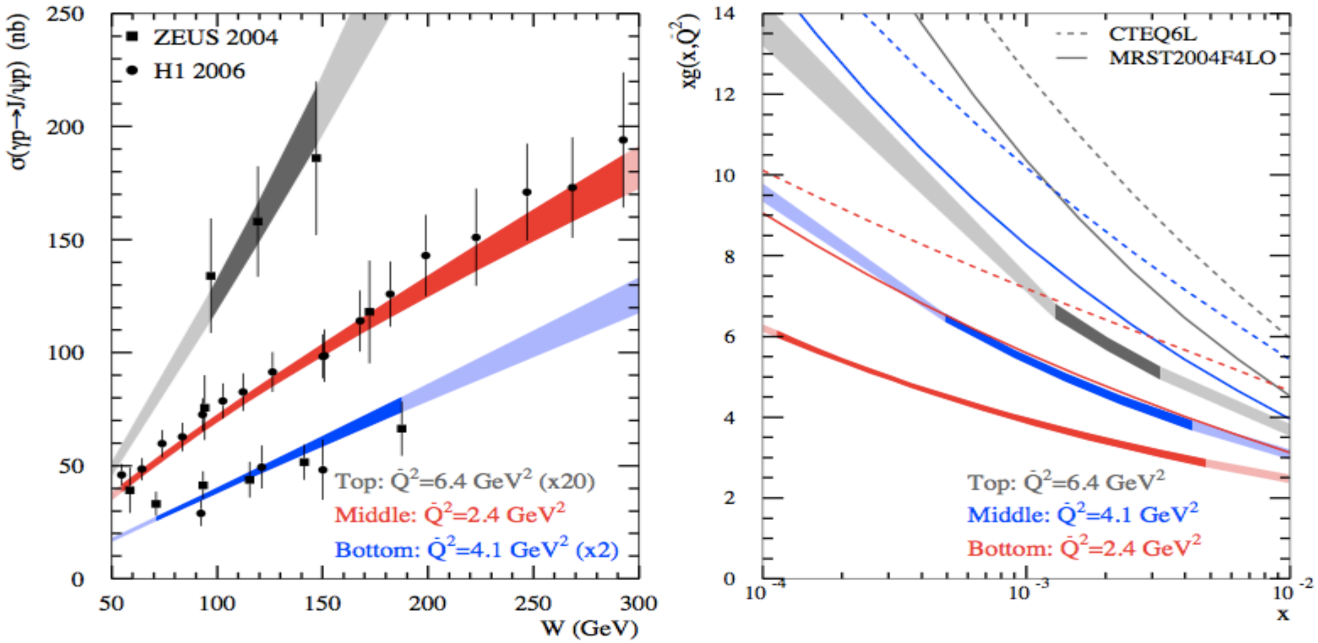
Sensitivity to gluon PDF

$xg \propto x^{-\lambda}$

Gluon PDF enters squared

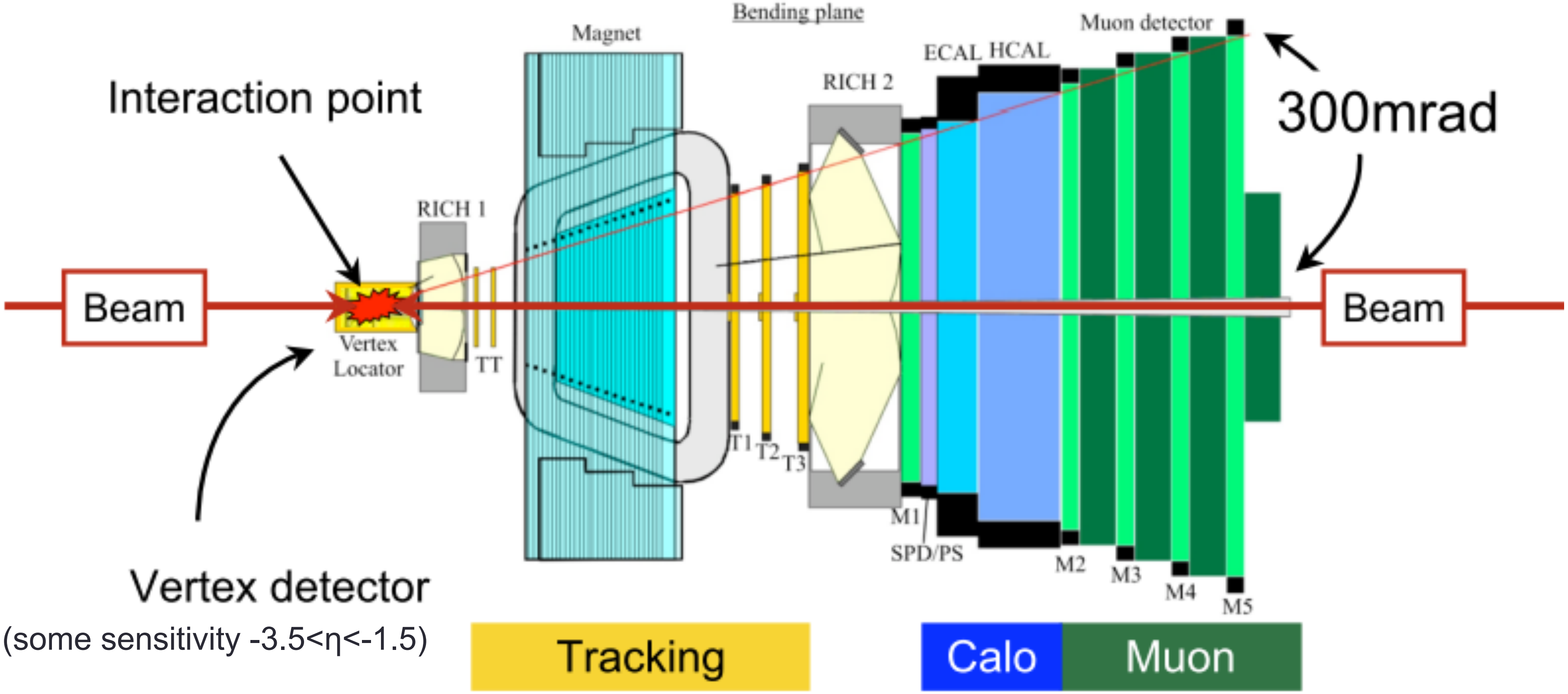
Leading order cross-section

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



Examples of dependence of Jpsi cross-section on PDF (left) and extraction of gluon PDF (right) from Martin, Nockles, Ryskin, Teubner, arXiv:0709.4406v1

The LHCb detector

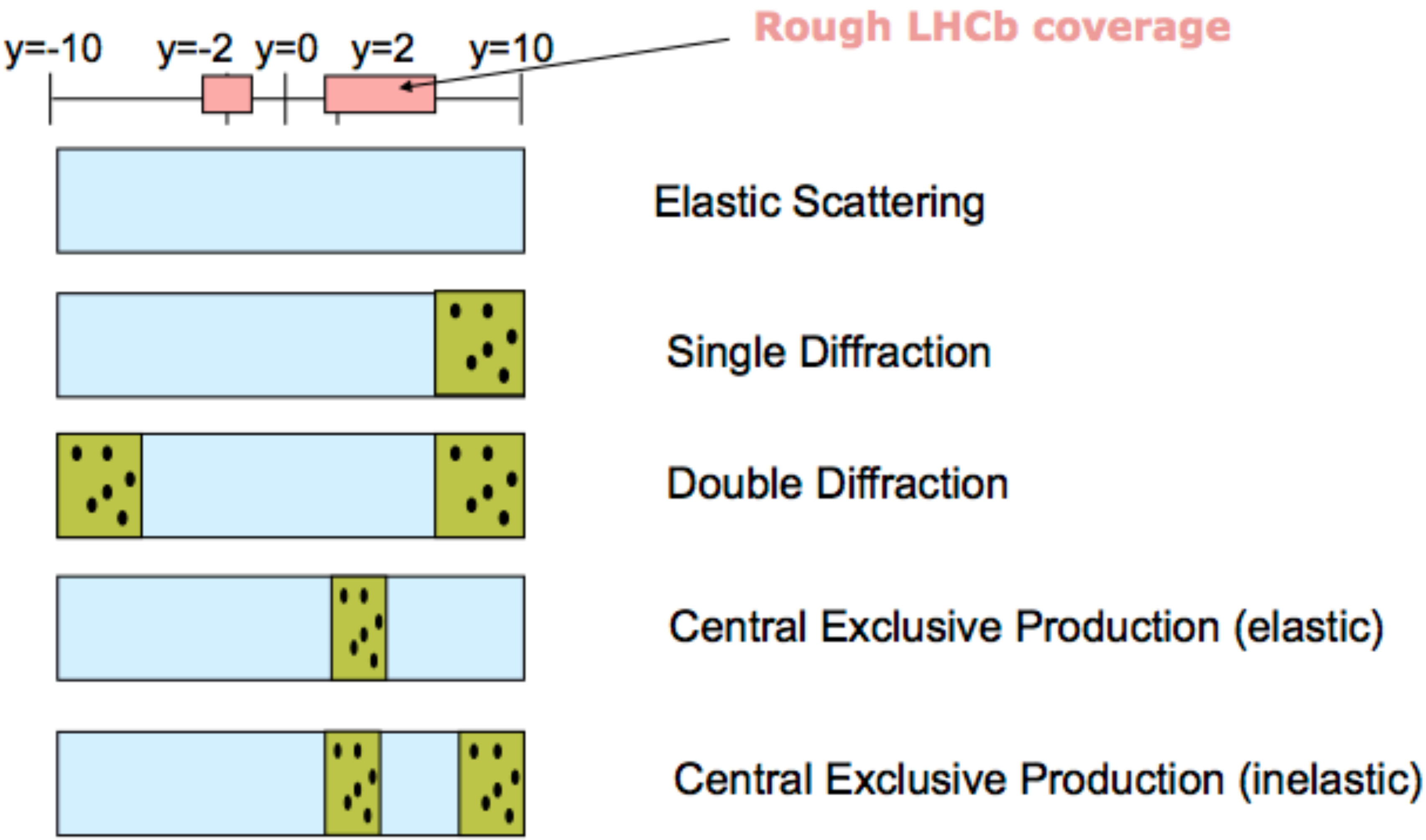


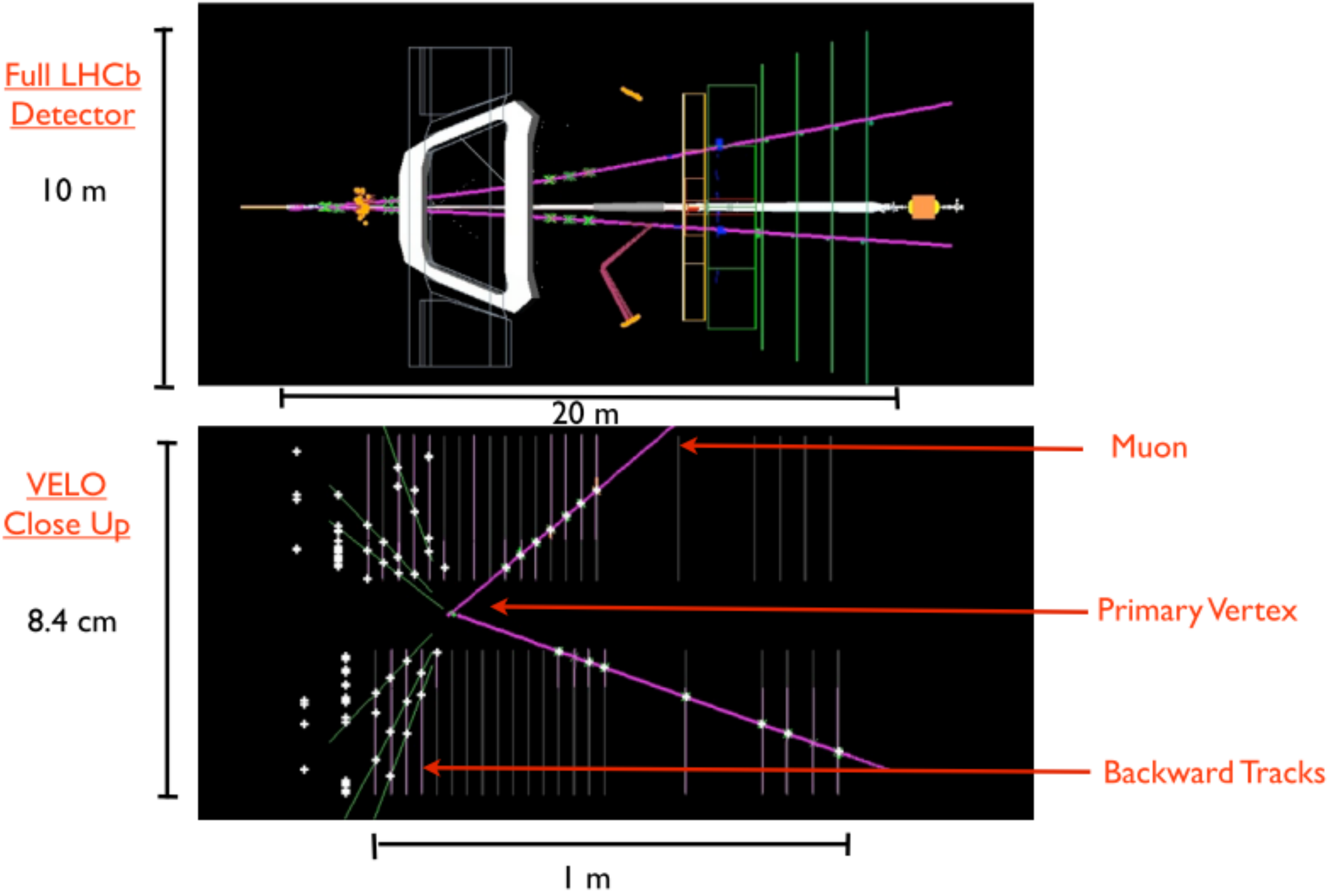
Fully instrumented within $1.9 \leq \eta \leq 4.9$

Trigger: $p_\mu > 3$ GeV, $pt_\mu > 0.4$ GeV, $m_{\mu\mu} > 2.5$ GeV

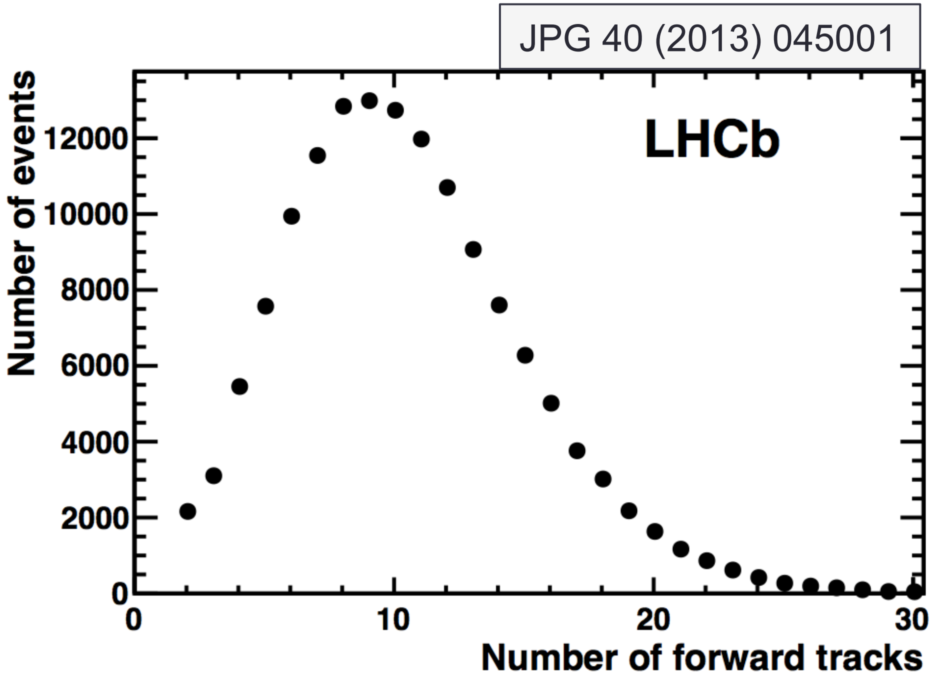
Low multiplicity required. Restricts to single-interaction collisions

Graphical Representation

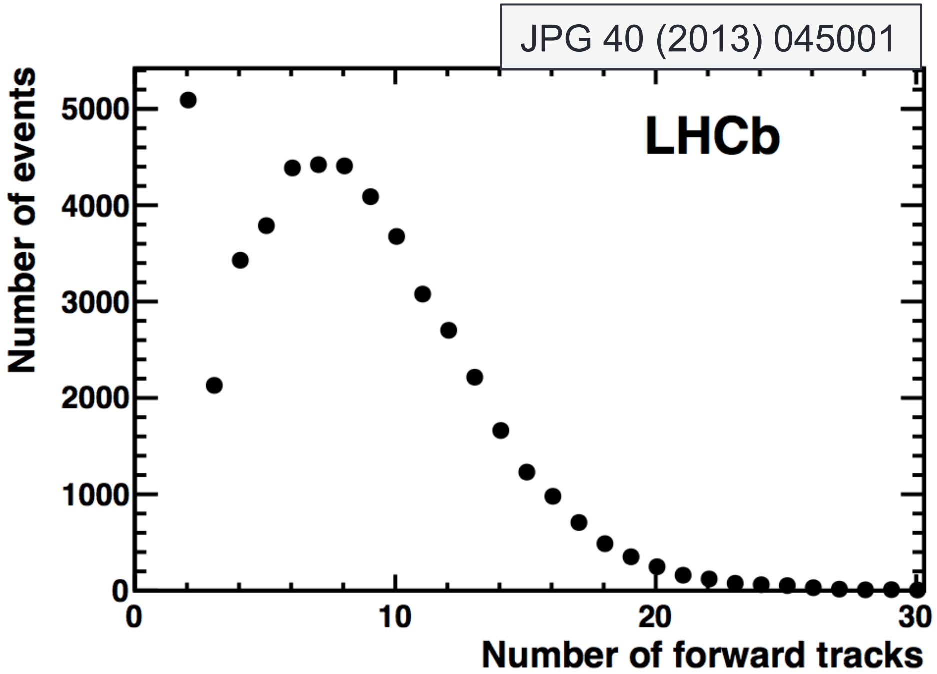



Full LHCb Detector
10 m
20 m
VELO Close Up
8.4 cm
1 m
Muon
Primary Vertex
Backward Tracks

Effect of rapidity gap requirement on muon triggered events

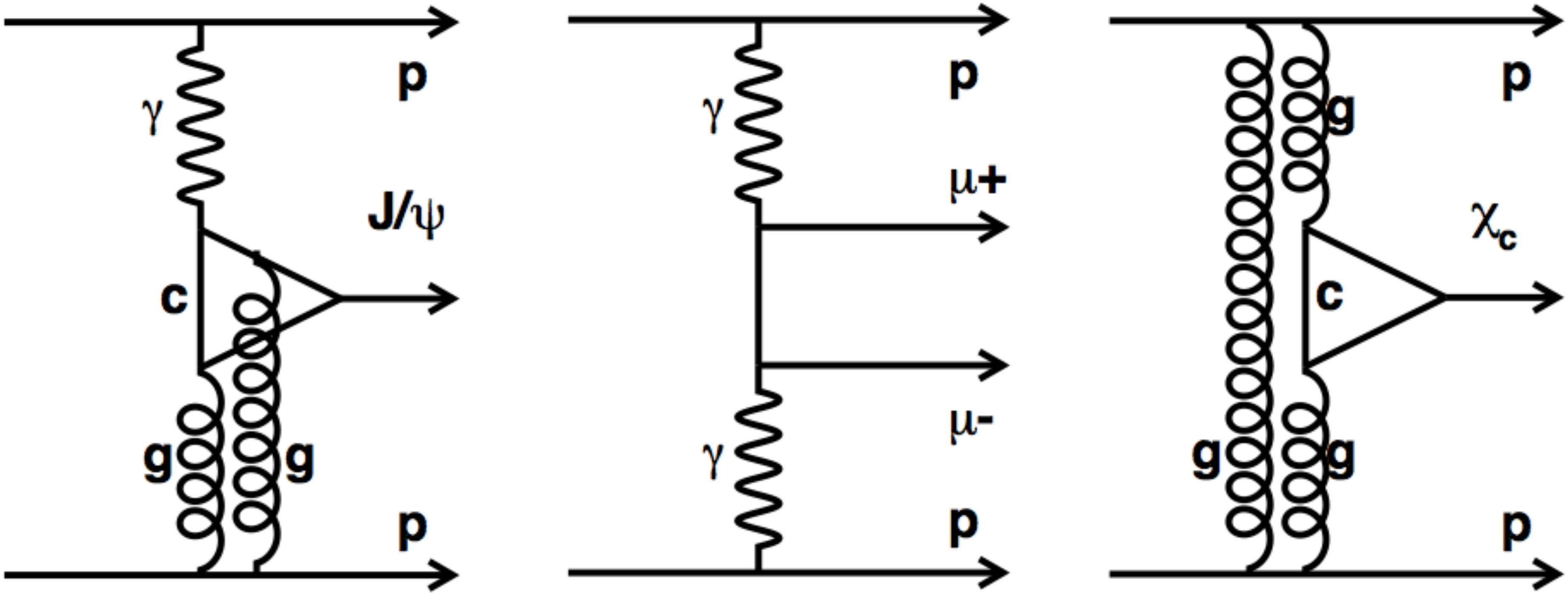


All triggered events



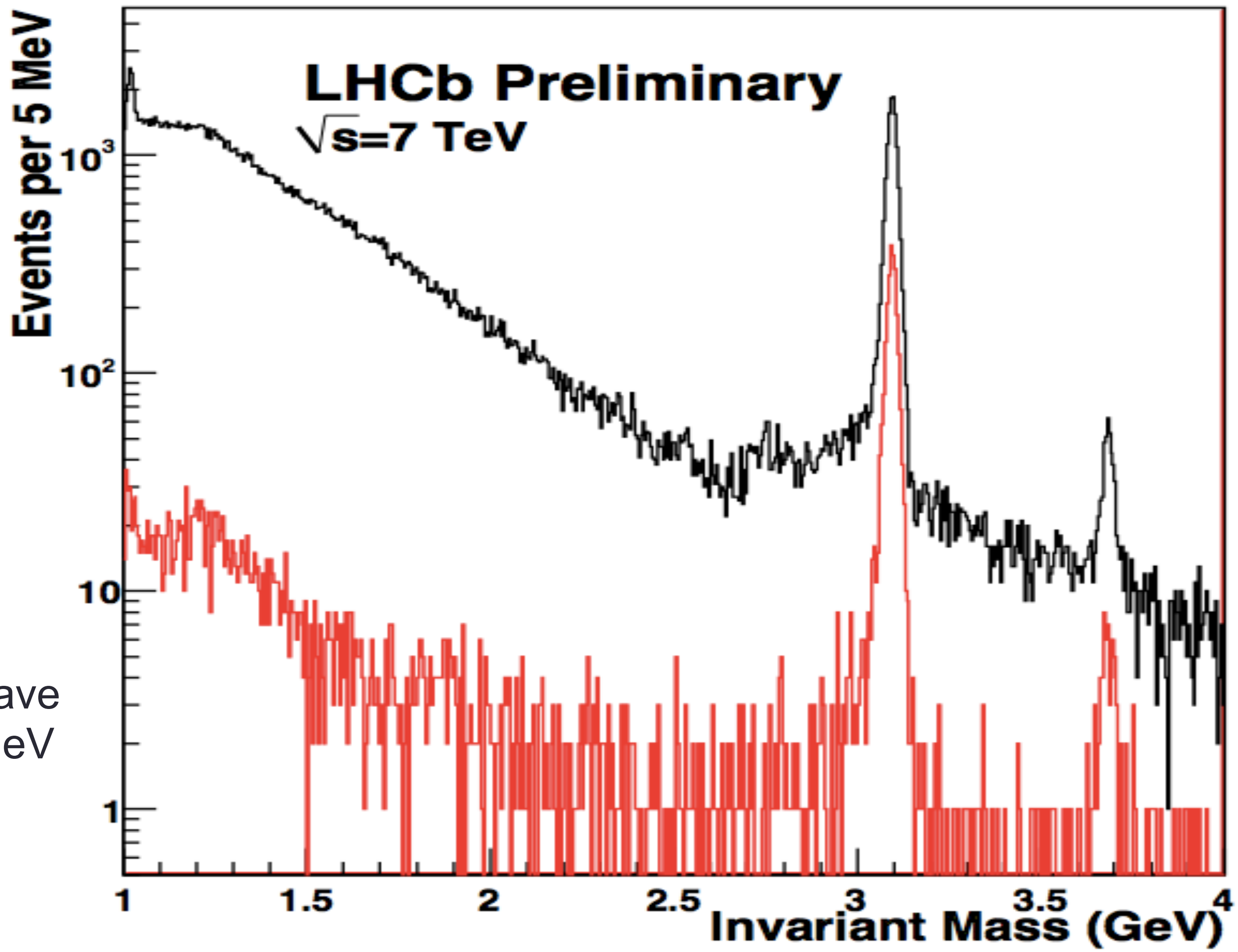
With veto on backward tracks

Central exclusive di-muon signals



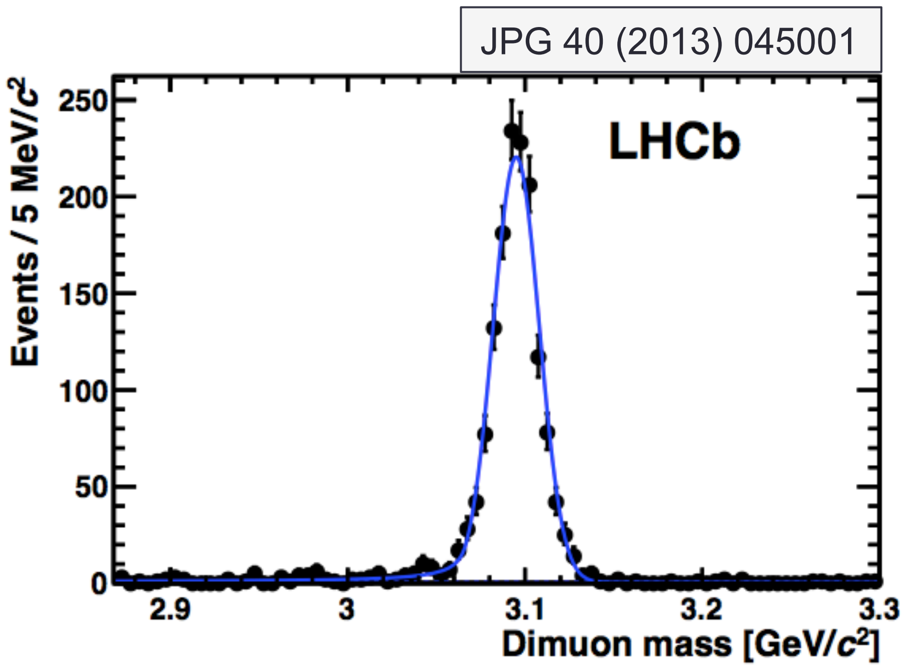
SuperChic: L. Harland-Lang, V. Khoze, M. Ryskin, W. Stirling, EPJ.C65 (2010) 433-448
Starlight: S.R. Klein & J. Nystrand, PRL 92 (2004) 142003.

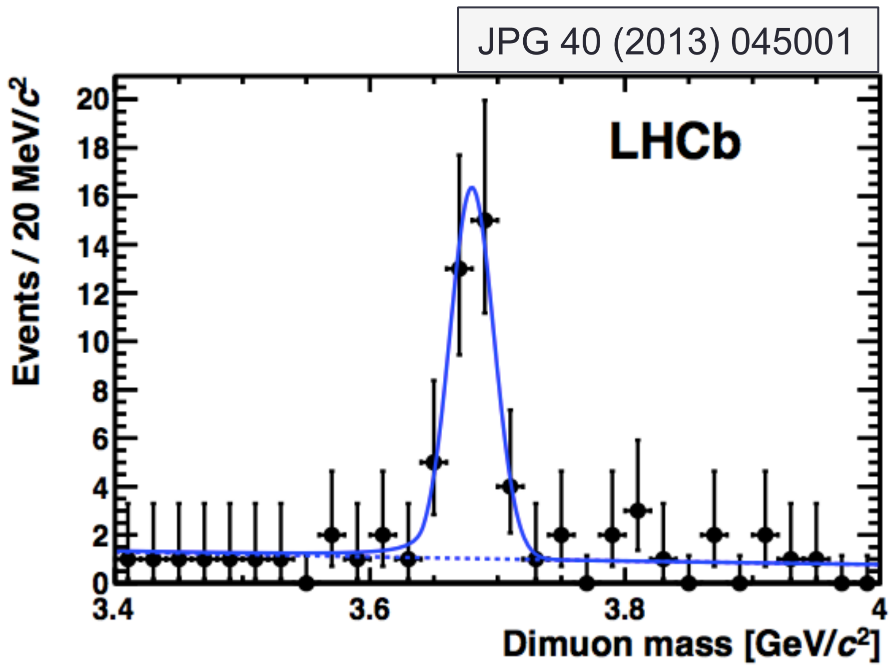
Before and after requiring precisely two tracks



Tracks have
p_T>400MeV
2<η<5

Non-resonant background very small





Distributions are not background-subtracted.
37pb-1 of data: 1492 J/ψ and 40 ψ(2s)

Cross-section measurement

Purity:
1. non-resonant bkg (1%)
2. Chi_c feeddown (9%)
3. Psi' feedown (2%)
4. Inelastic Jpsi production (30%)

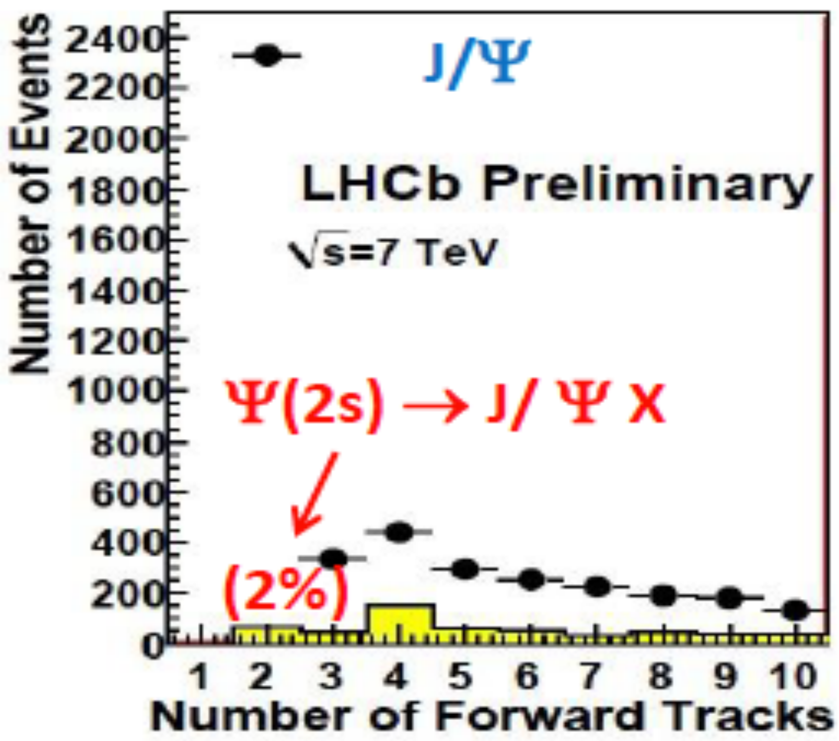
Number of events observed

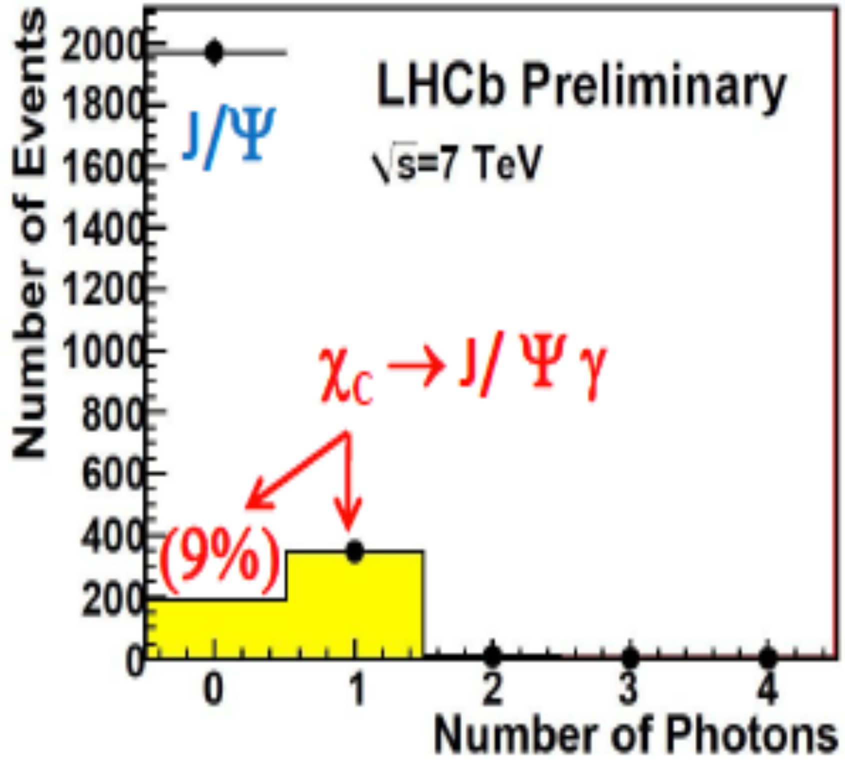
$$\sigma = \frac{pN}{\varepsilon L}$$

Luminosity

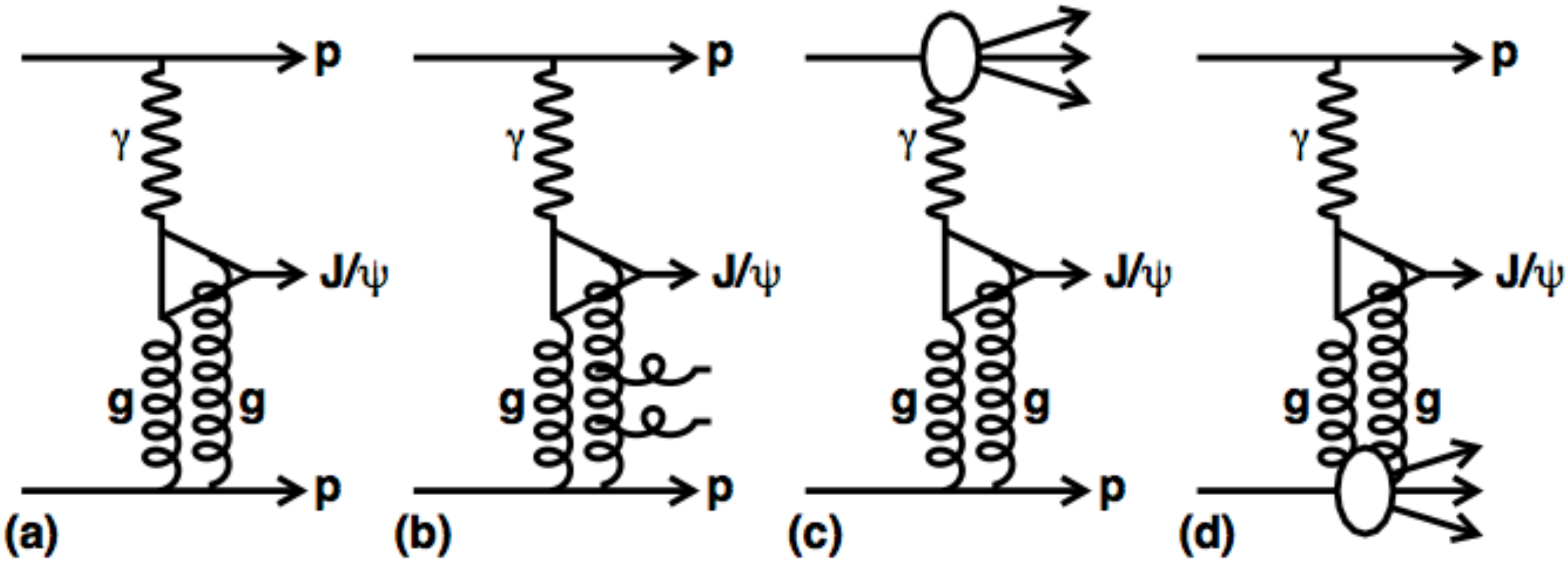
Efficiency:
1. Trigger
2. Tracking & muon id.
3. Single interaction beam-crossing ← $P(n) = \mu^n e^{-\mu} / n!$

Feed-down backgrounds





Inelastic background



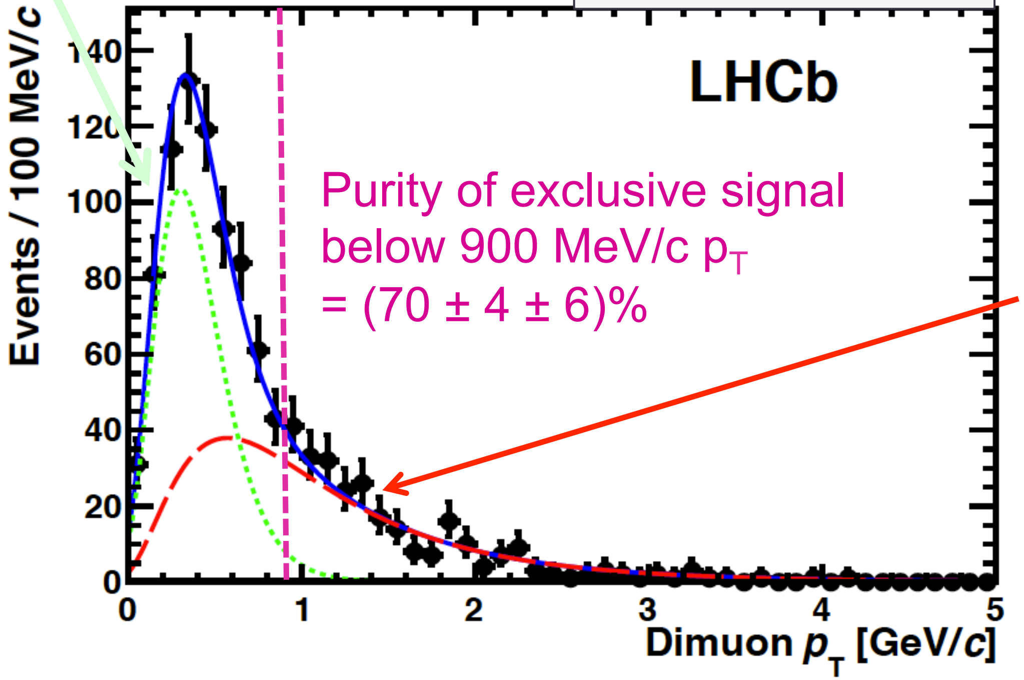
Characterise p_T spectrum of background using shapes with 3-8 tracks and extrapolate to 2 track case.

Inelastic background

Signal shape

Estimated from Superchic using exp(- b p_T^2) (arXiv: 0909.4748)
Take b from HERA data. Extrapolate to LHCb energies to get b= 6.1 +/- 0.3 GeV^{-2}
Crosscheck: Fit to spectrum below with b free gives b = 5.8 +/- 1 GeV^{-2}

JPG 40 (2013) 045001



Inelastic background shape

Estimated from data.
Characterise shape for 3-8 tracks and extrapolate to 2 tracks.

This approach works for QED production of dimuons, tested using LPAIR simulation.
Also checked with PYTHIA simulation of diffractive events.

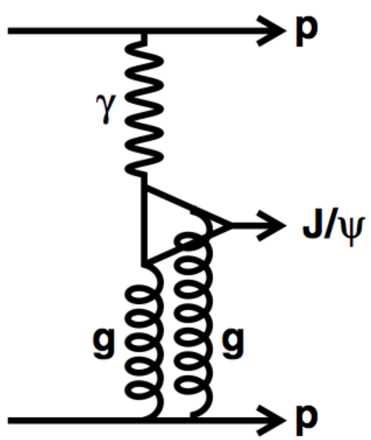
LHCb compared to theory & experiment

Predictions	$\sigma_{pp\to J/\psi\,(\to\mu^+\mu^-)}$	$\sigma_{pp\to\psi(2S)(\to\mu^+\mu^-)}$
Gonçalves and Machado	275	
STARLIGHT	292	6.1
Motyka and Watt	334	
SUPERCHIC[a]	396	
Schäfer and Szczurek	710	17
LHCb measured value	$307 \pm 21 \pm 36$	$7.8 \pm 1.3 \pm 1.0$

[a] SUPERCHIC simulation does not include a gap survival factor.

All predictions (bar Schaefer&Szcaurek) have similar approach and give similar results and are consistent with our data.

LHCb compared to HERA

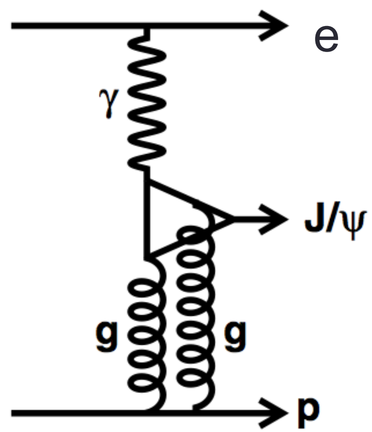


$$W^2 \equiv (q + p_2)^2 = x_\gamma s - Q^2 \,,$$

$$x_\gamma = \frac{M_{\psi_\perp}}{\sqrt{s}} e^{y_\psi} \,,$$

$$x = \frac{M_{\psi_\perp}}{\sqrt{s}} e^{-y_\psi} \,,$$

Twofold ambiguity



LHCb c/s is HERA c/s weighted by photon spectrum + gap survival factor (r)

$$\frac{\mathrm{d}\sigma}{\mathrm{d}y}_{pp\to pVp} = r(y)\left[k_+ \frac{\mathrm{d}n}{\mathrm{d}k_+}\sigma_{\gamma p\to Vp}(W_+) + k_- \frac{\mathrm{d}n}{\mathrm{d}k_-}\sigma_{\gamma p\to Vp}(W_-)\right],$$

$$k_\pm \approx (m_V/2)\exp(\pm|y|),$$

LHCb differential data fitted assuming power law dependence $\sigma(W) = aW^\delta$

Power law results

LHCb	HERA
$a = 0.8^{+1.2}_{-0.5}\,nb$	$a = 3nb$
$\delta = 0.92 \pm 0.15$	$\delta = 0.72$

LHCb compared to theory & experiment

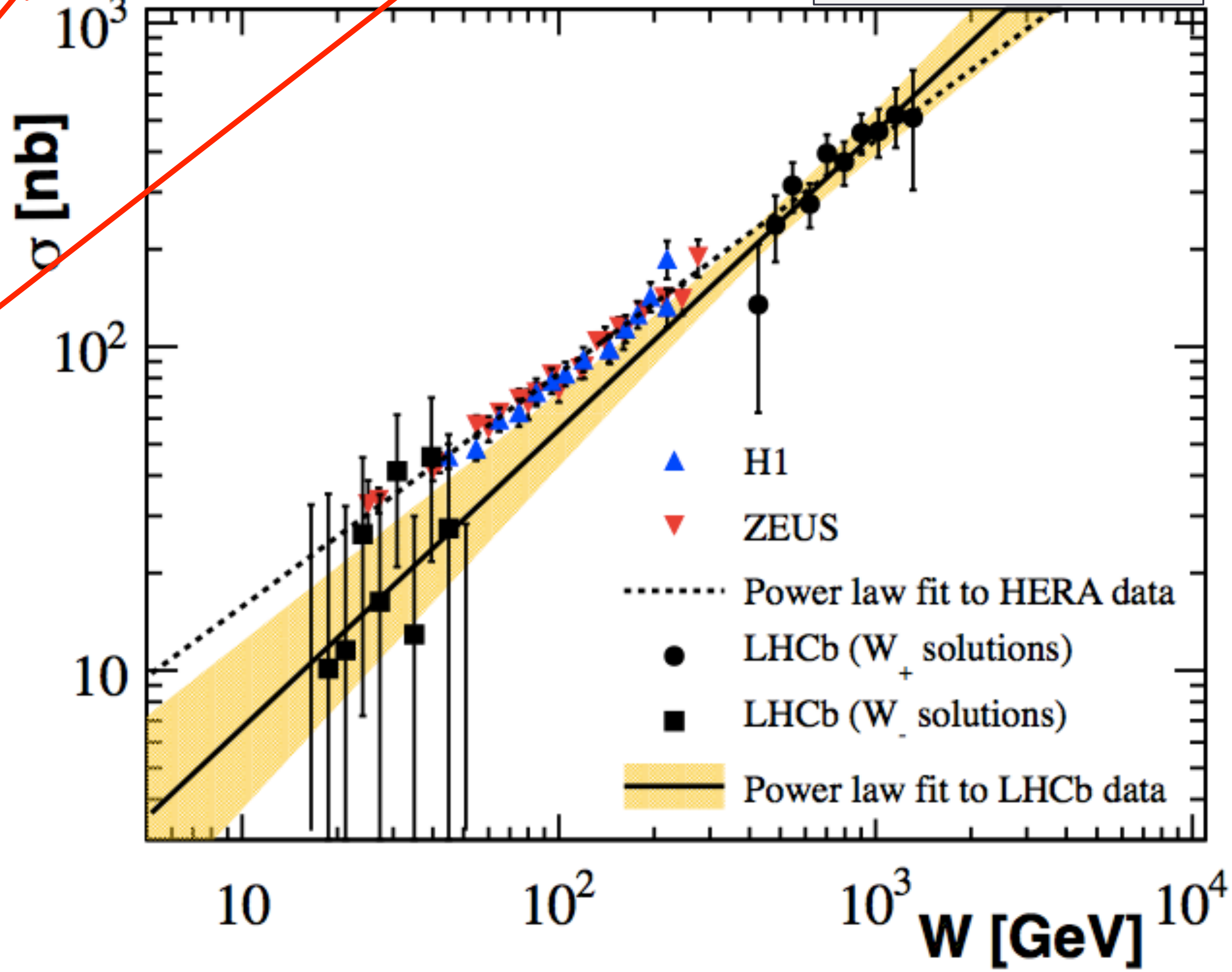
$$\frac{d\sigma}{dy}_{pp\to pVp} = r(y)\left[k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to Vp}(W_+) + k_- \frac{dn}{dk_-}\sigma_{\gamma p\to Vp}(W_-)\right]$$

measured

from fit

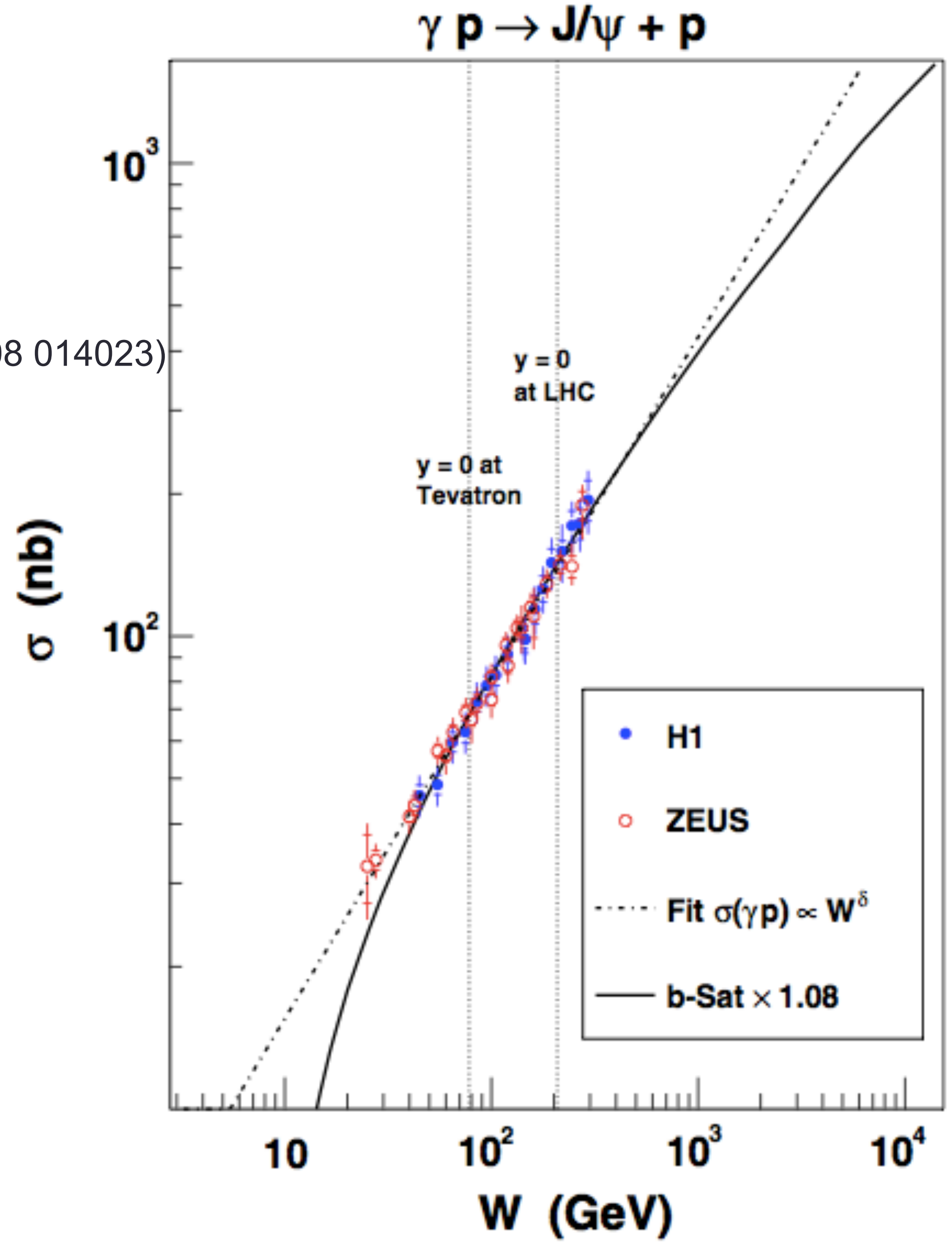
plotted

JPG 40 (2013) 045001

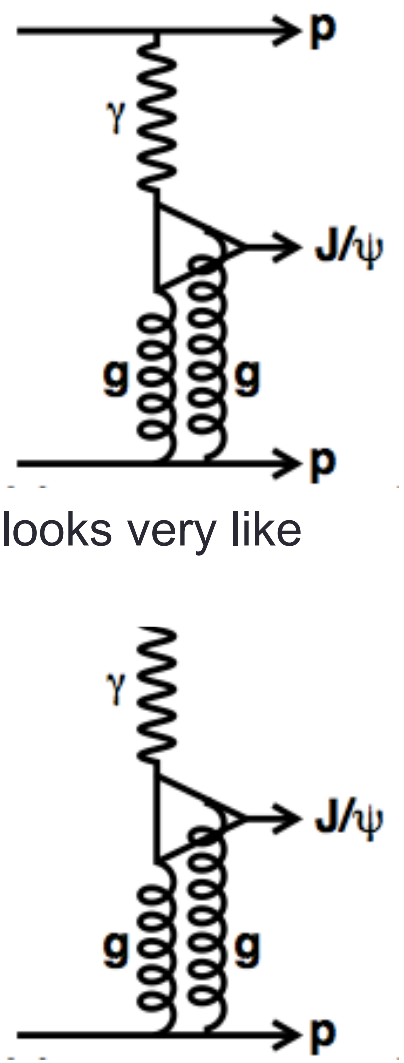


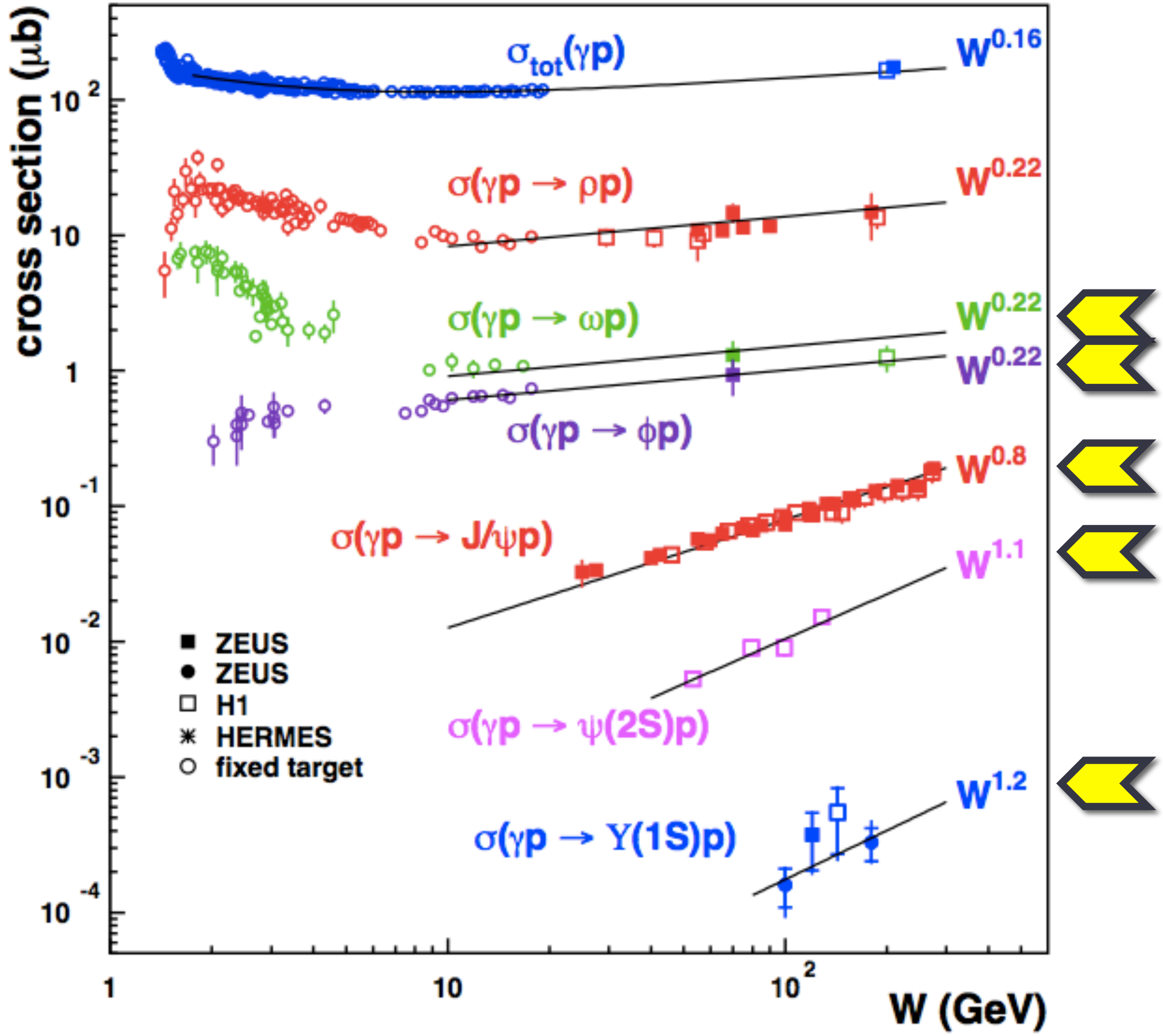
Deviations from power law

Saturation model (Motyka&Watt PRD 78 2008 014023) has deviation from pure power law.



LHCb compared to theory & experiment



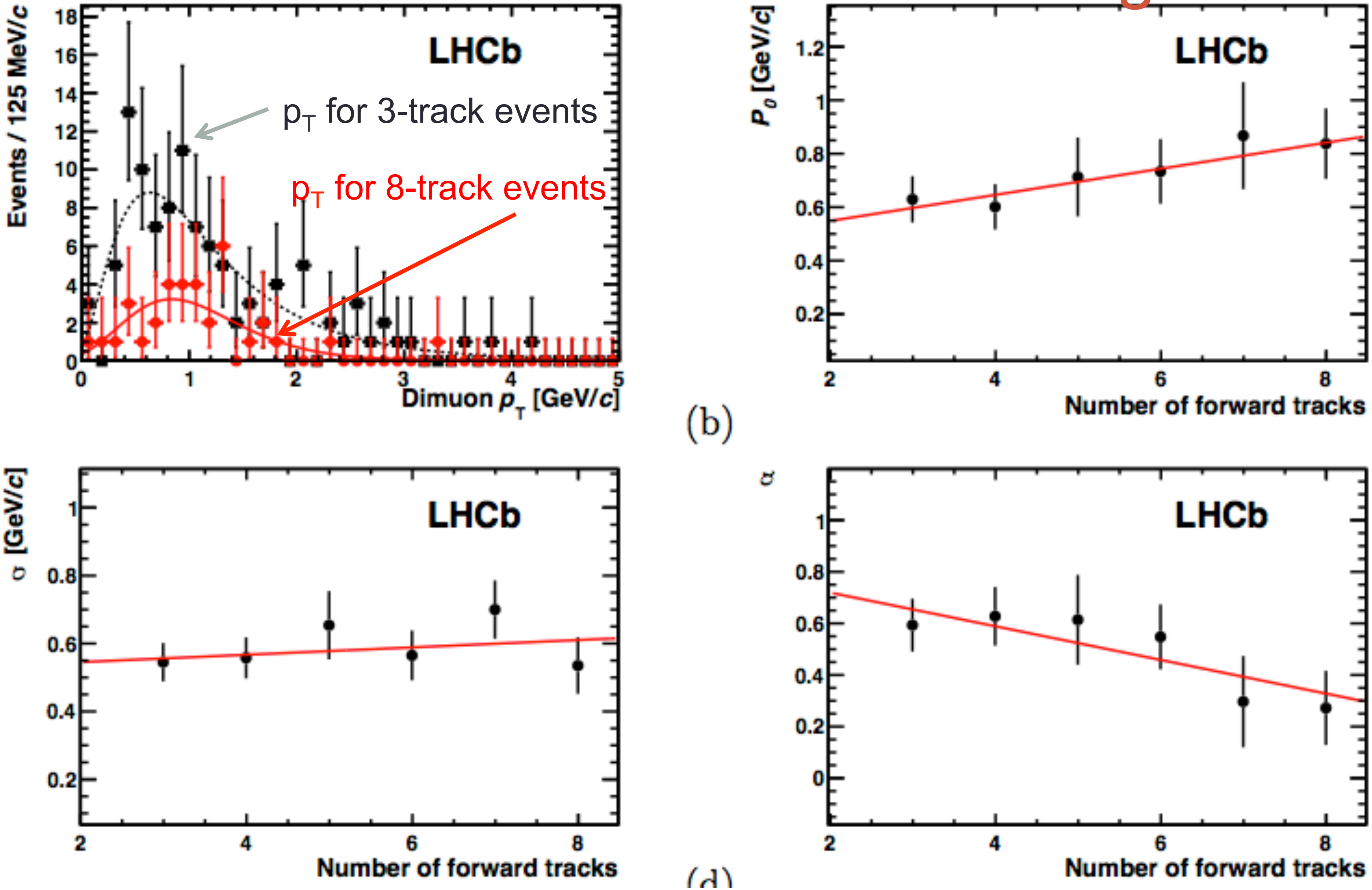


Conclusions

- Exclusive J/ψ and $\psi(2s)$ cross-sections have been measured at LHCb
- Results are consistent with photo-production results from HERA
- We have x100 luminosity from 2011/12 data which will allow more precise comparisons, investigations of the pomeron, and measurements of the gluon PDF.

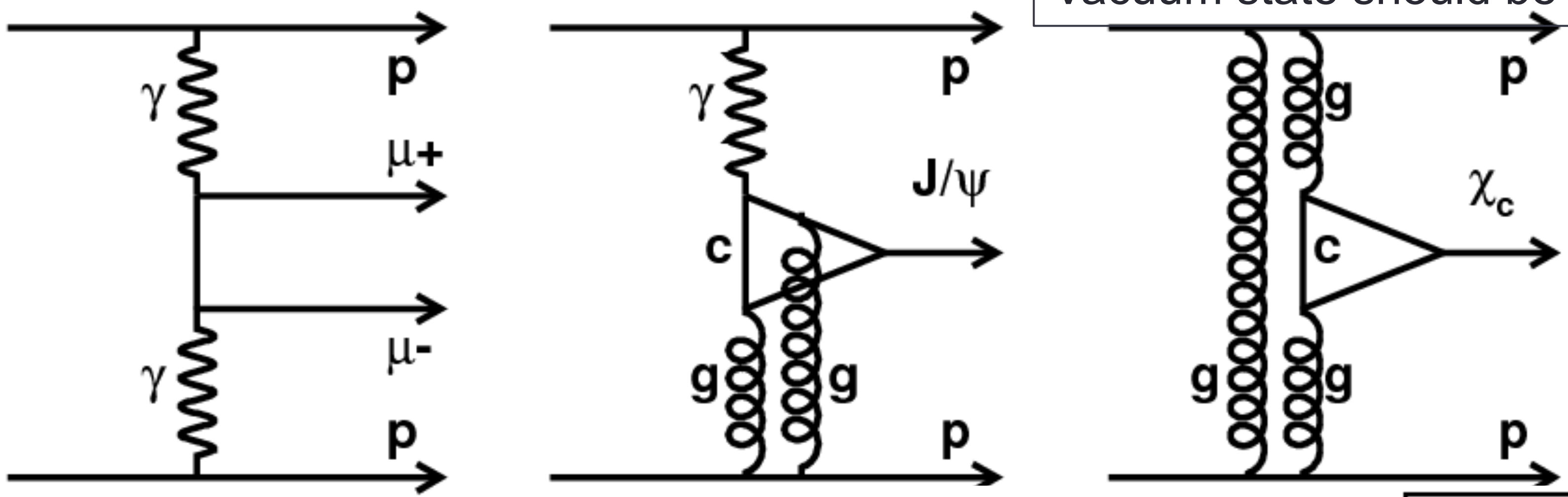
Backup

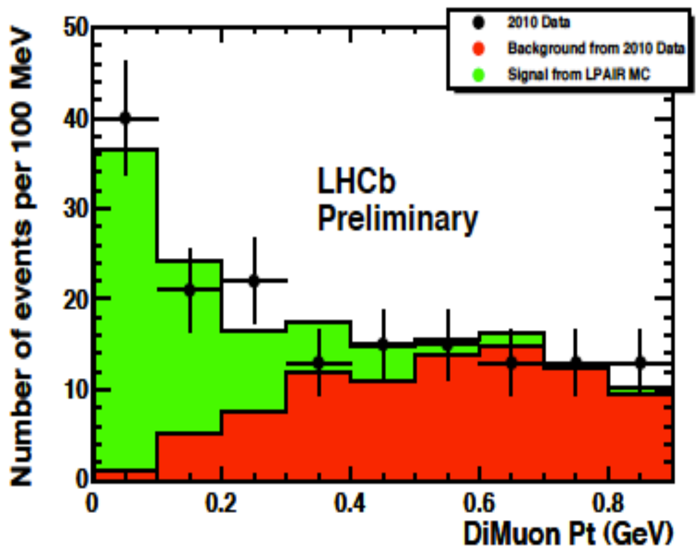
Determination of non-resonant background

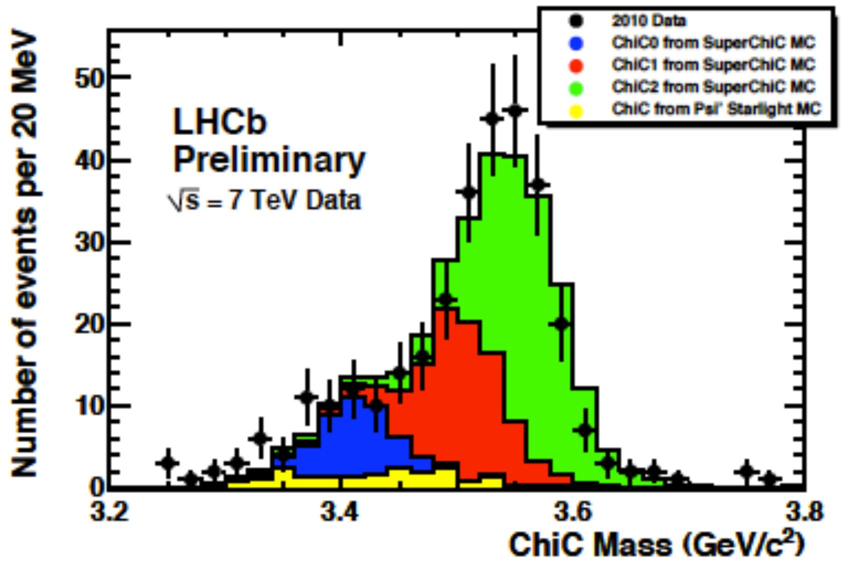


Other ways to fill the vacuum with muons

χ_c 0,1,2 decay to Jpsi+photon
Vacuum state should be 0







Exclusive pseudo-vector production

$\sigma_{\chi_{c0}\to\mu^+\mu^-\gamma}$ = 9.3 +/- 2.2 +/- 3.5 +/- 1.8 pb

$\sigma_{\chi_{c1}\to\mu^+\mu^-\gamma}$ = 16.4 +/- 5.3 +/- 5.8 +/- 3.2 pb

$\sigma_{\chi_{c2}\to\mu^+\mu^-\gamma}$ = 28.0 +/- 5.4 +/- 9.7 +/- 5.4 pb

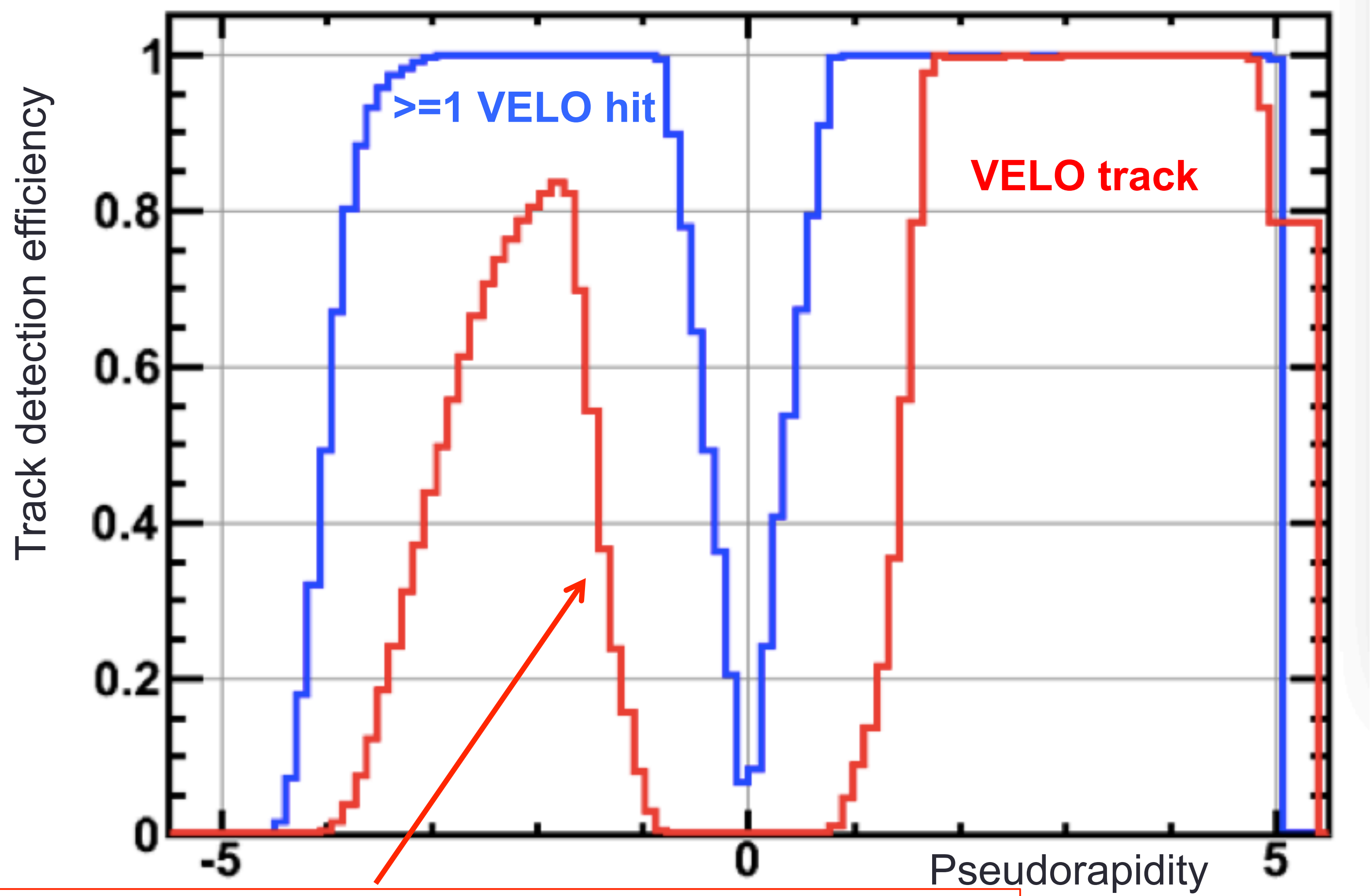
LHCb preliminary results with 2010 data

BR(χc0->J/ψγ)=1.2%
BR(χc1->J/ψγ)=34.4%
BR(χc2->J/ψγ)=19.5%

Dominance of Xc0 is confirmed.

Experimentally difficult to separate three resonances and determine non-resonant background for each.

Extension of rapidity gap possible (work in progress)



All results I show imply red region void, except for signal.