Exclusive Production of J/ψ and double J/ψ Tevatron and LHCb Results

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on behalf of the LHCb collaboration

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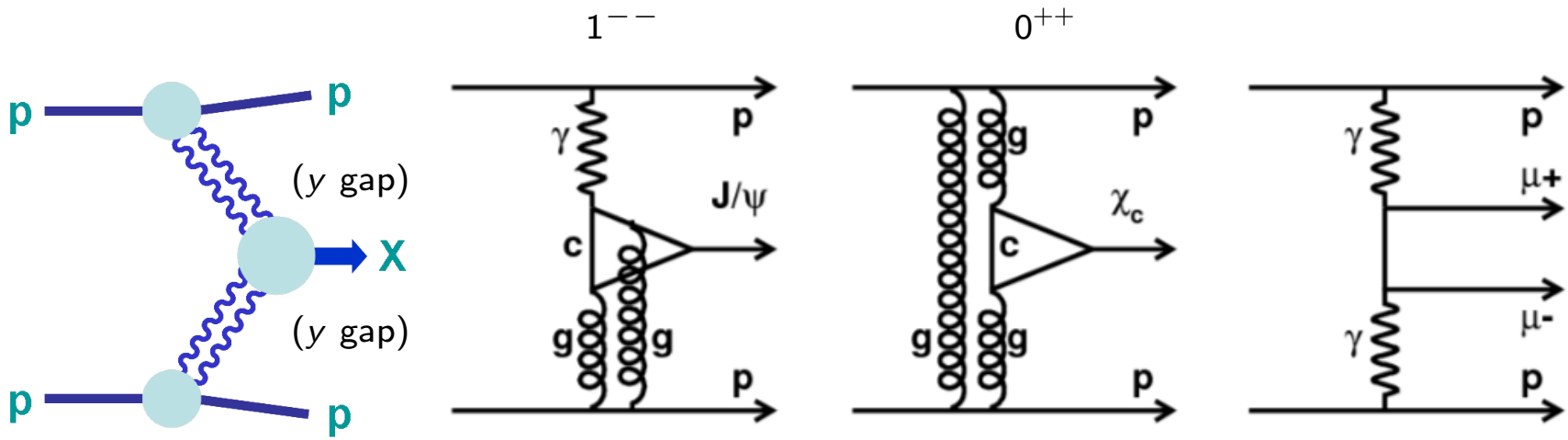
ECT* - New Observables in Quarkonium Production

University of BRISTOL

Central Exclusive Production

It is a process defined as $pp \to p + X + p$ where X is a *colourless central object* with the protons remaining *intact* after the interaction.
Examples of mechanisms that produce pairs of *charm* quarks with the overall process being colour neutral:

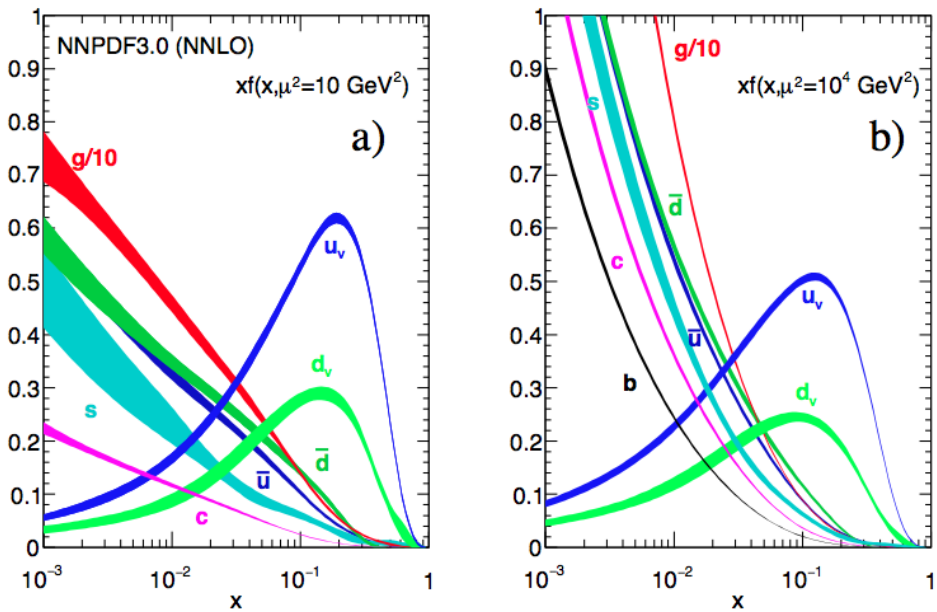


General | Photo production | Double pomeron exchange | QED (BG)

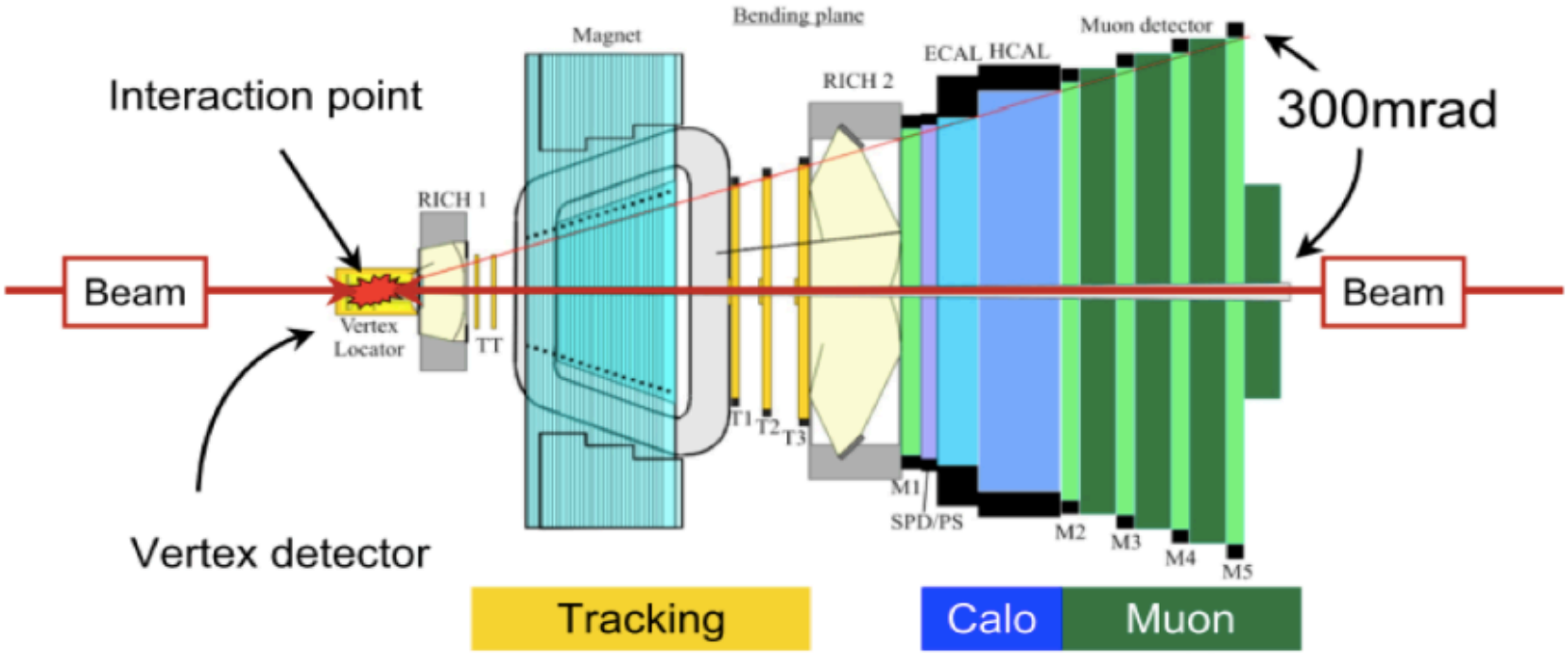
Colour neutral object diagrams creating muon pairs and charmonium resonances. Note: $J/\psi \to \mu^+\mu^-$ and $\chi_c \to J/\psi\gamma$. See arXiv:1401.3288v2

Motivation

- **Understanding of vacuum**
- **Understanding diffraction phenomena**
- **Good environment to search for exotica**
- **Gluon density function**
  Photo production cross section is proportional to the gluon's cross-section squared (currently a high uncertainty at small fractional momentum x)



The LHCb



Fully instrumented: $2 < \eta < 5$

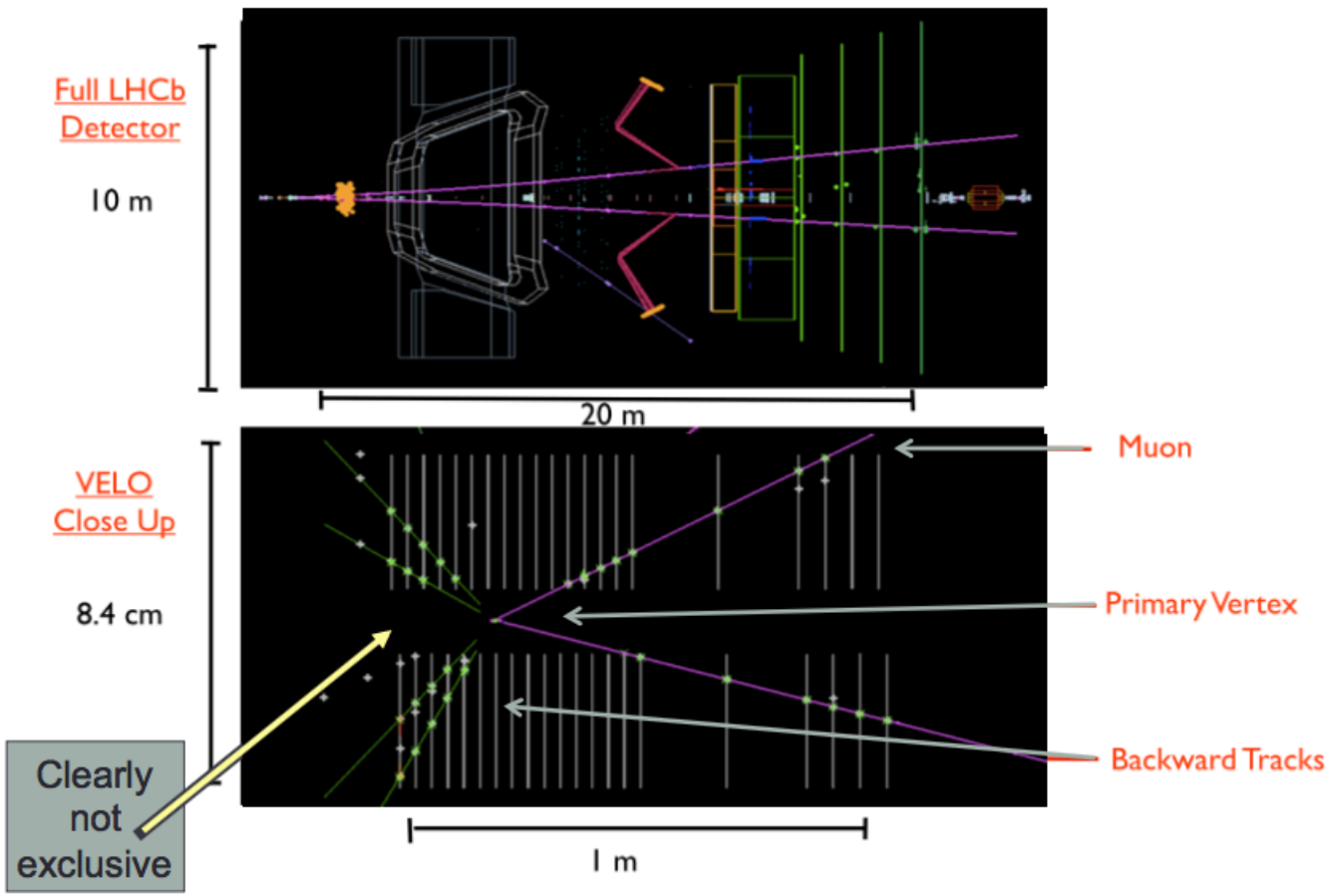
Some sensitivity: $-3.5 < \eta < -1.5$

CEP at the LHCb

Event Selection

Use VELO information to veto non-exclusive processes:

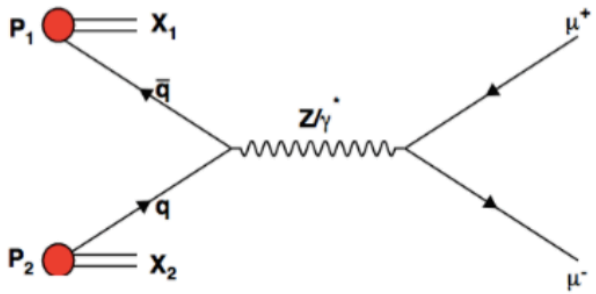
- Precisely two forward muons.
- No backwards tracks.
- No photons.



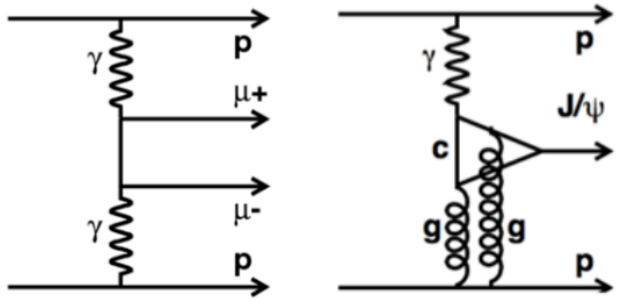
Event Displays

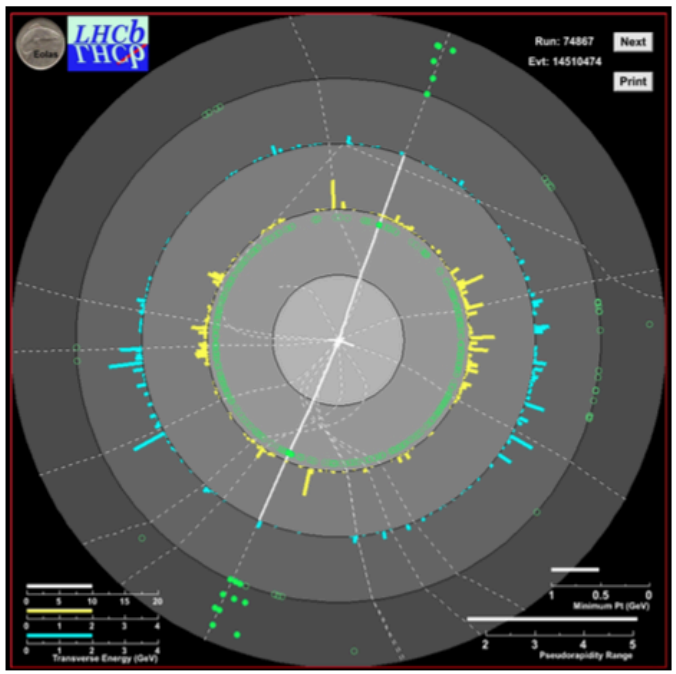
For low multiplicity muon triggered events...

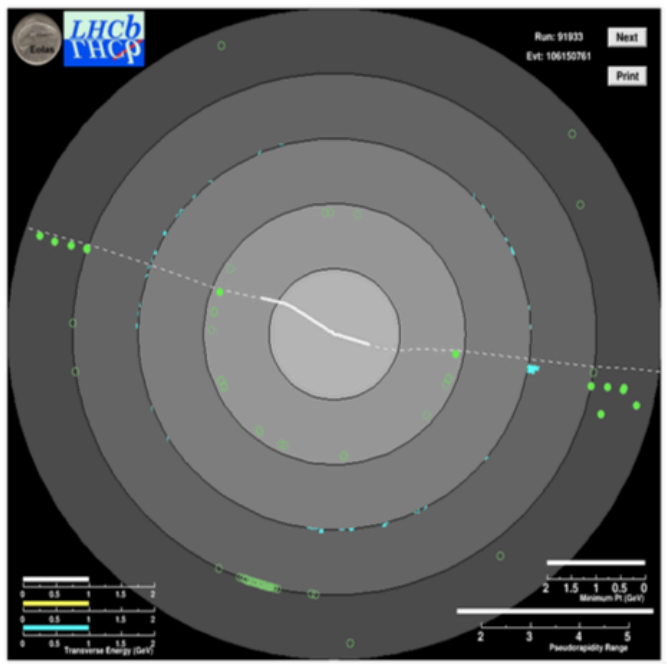
non-CEP



CEP



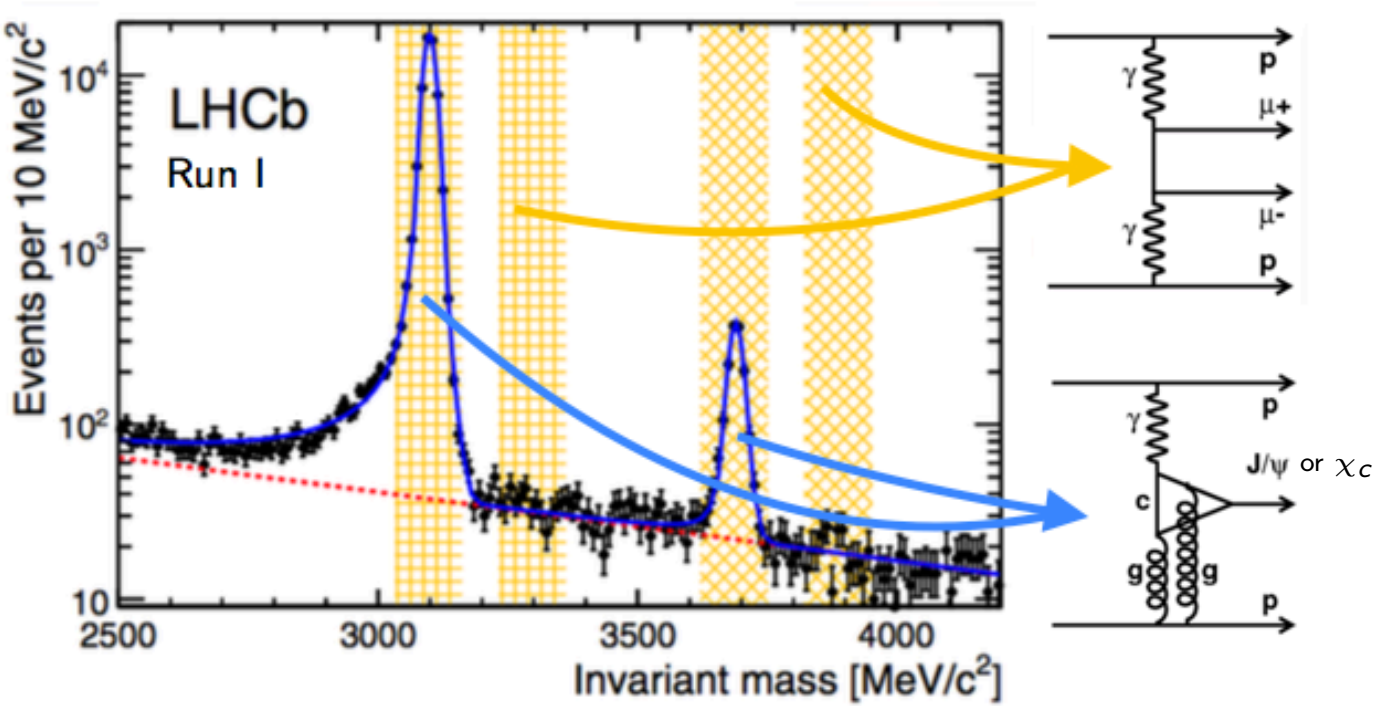




Where the coordinates (R, ϕ) corresponds to z and the azimuthal angle respectively. The transverse energy (in GeV) for ECAL and HCAL coloured in yellow and cyan.

J/ψ and $\psi(2S)$ Observation at LHCb

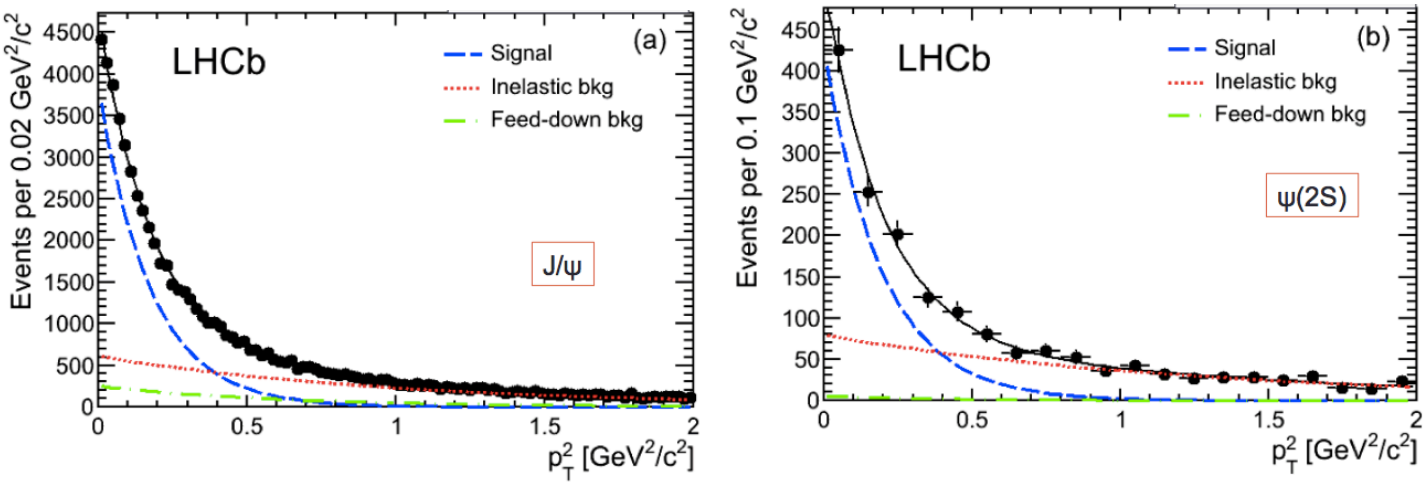
JPG 41 (2014) 055002

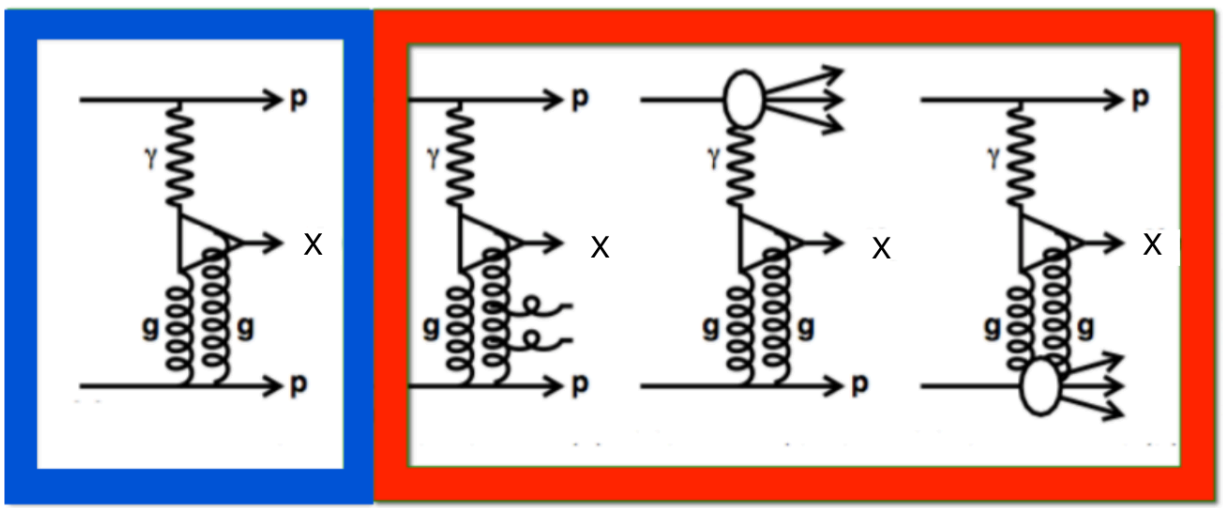


J/ψ and $\psi(2S)$ signal and non-resonant BG regions. The data are fitted (solid curve) with crystal ball functions for the signals and an exponential function for the non-resonant background.

J/ψ and $\psi(2S)$ Inelastic Background

JPG 41 (2014) 055002

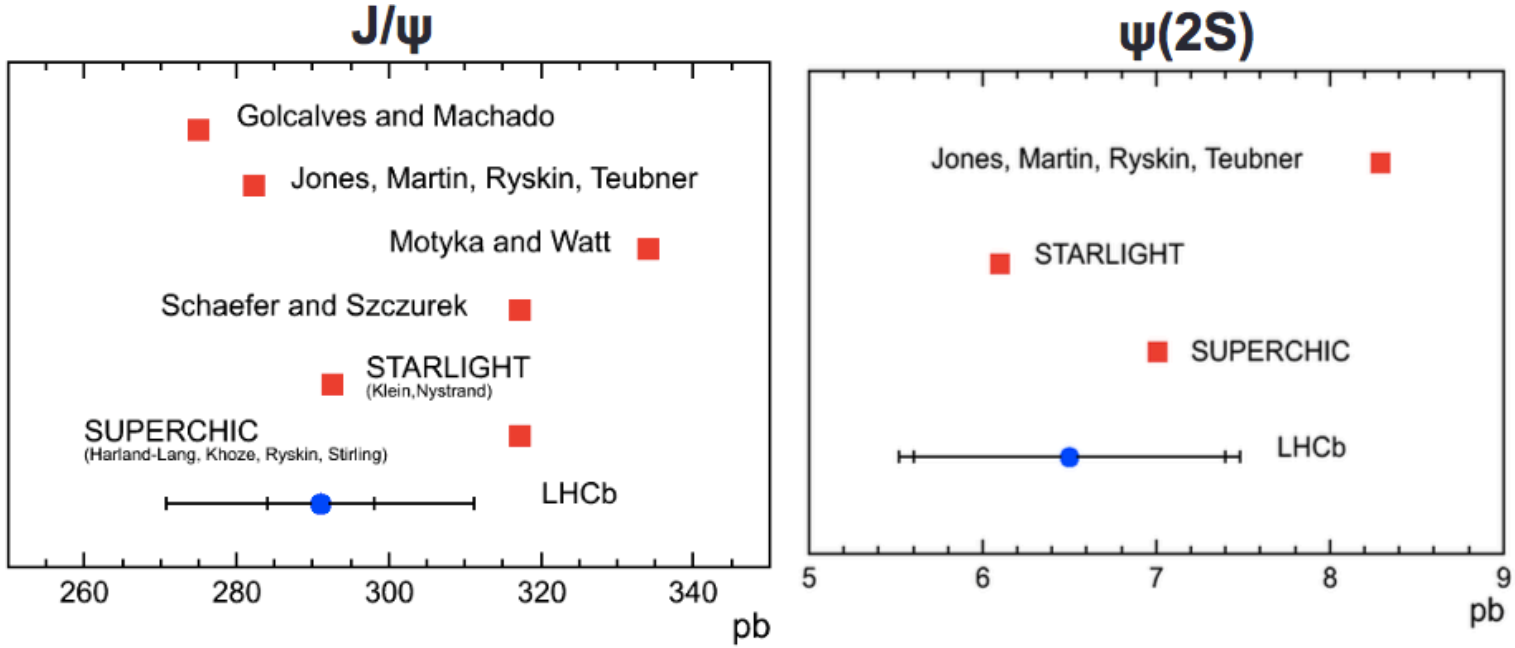




Signal (blue) candidates and different sources of inelastic BG (red) for $X = J/\psi$ plot (a) and $\psi(2S)$, plot (b). Feed-down (green) $\chi_c \to J/\psi\gamma$ if photon outside acceptance or undetected.

Integrated Cross-sections

See JPG 41 (2014) 055002, Table 4



LHCb measurement of integrated cross-sections, with a BR for muons in the pseudo rapidity range $2.0 < \eta < 4.5$, compared with different theory predictions.

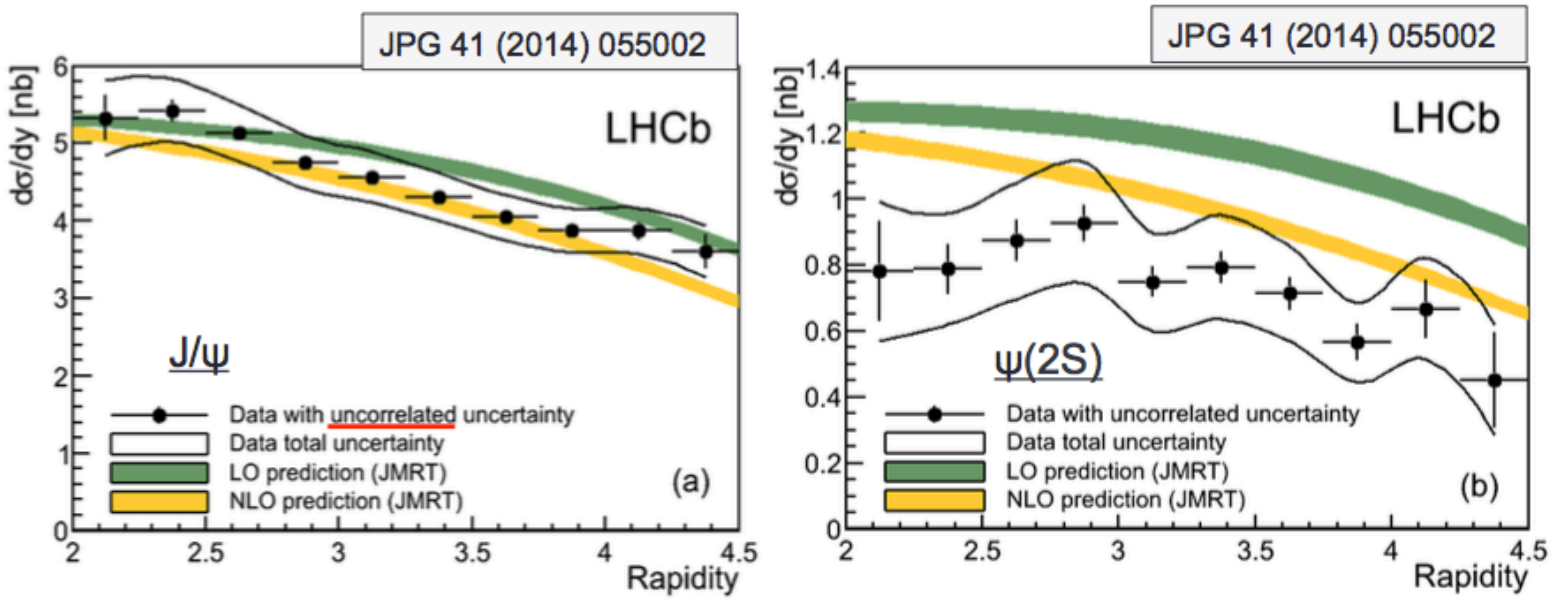
CDF Cross-section results at $\sqrt{s} = 1.96$ TeV

$$\frac{d\sigma(J/\psi)}{dy}|_{y=0} = 3.92 \pm 0.25(stat) \pm 0.52(syst) \text{ nb}$$
$$\frac{d\sigma(\psi(2S))}{dy}|_{y=0} = 0.53 \pm 0.09(stat) \pm 0.10(syst) \text{ nb}$$

Phys.Rev.Lett. 102 (2009) 242001

Differential Cross-sections

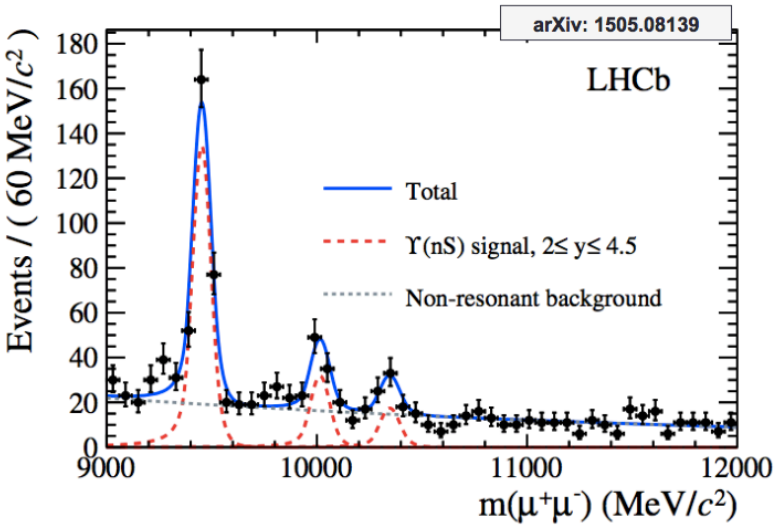
For J/ψ and $\psi(2S)$

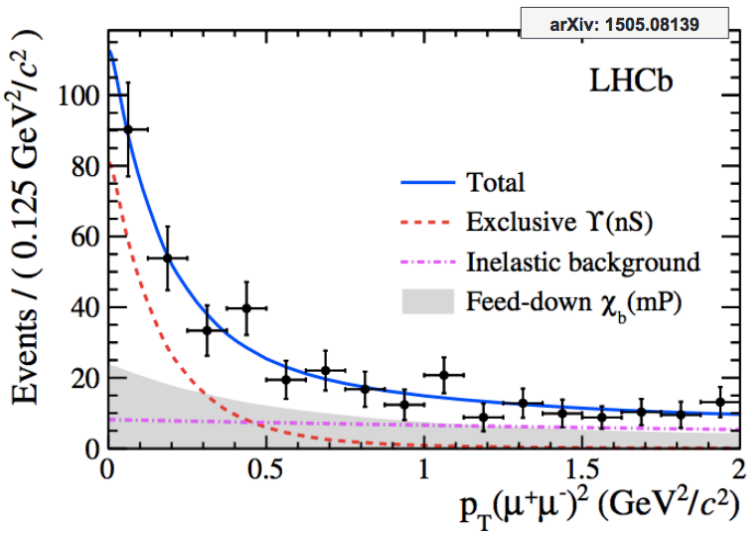


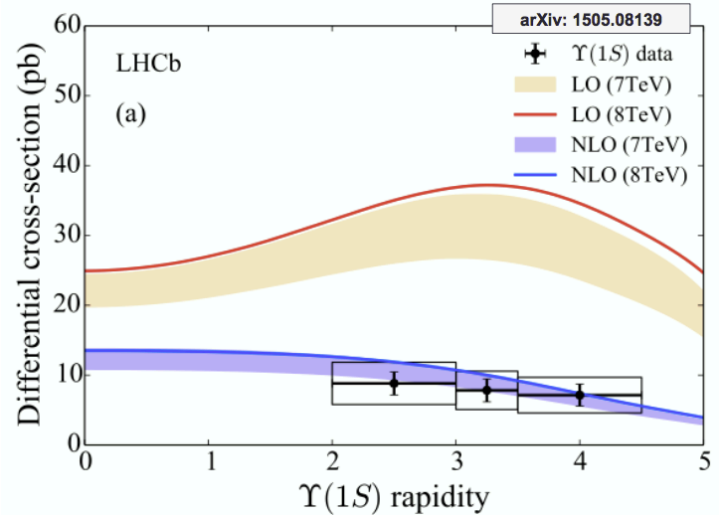
NLO agrees better than LO.

Upsilon Results

Observation of $\Upsilon(1S), \Upsilon(2S), \Upsilon(3S)$



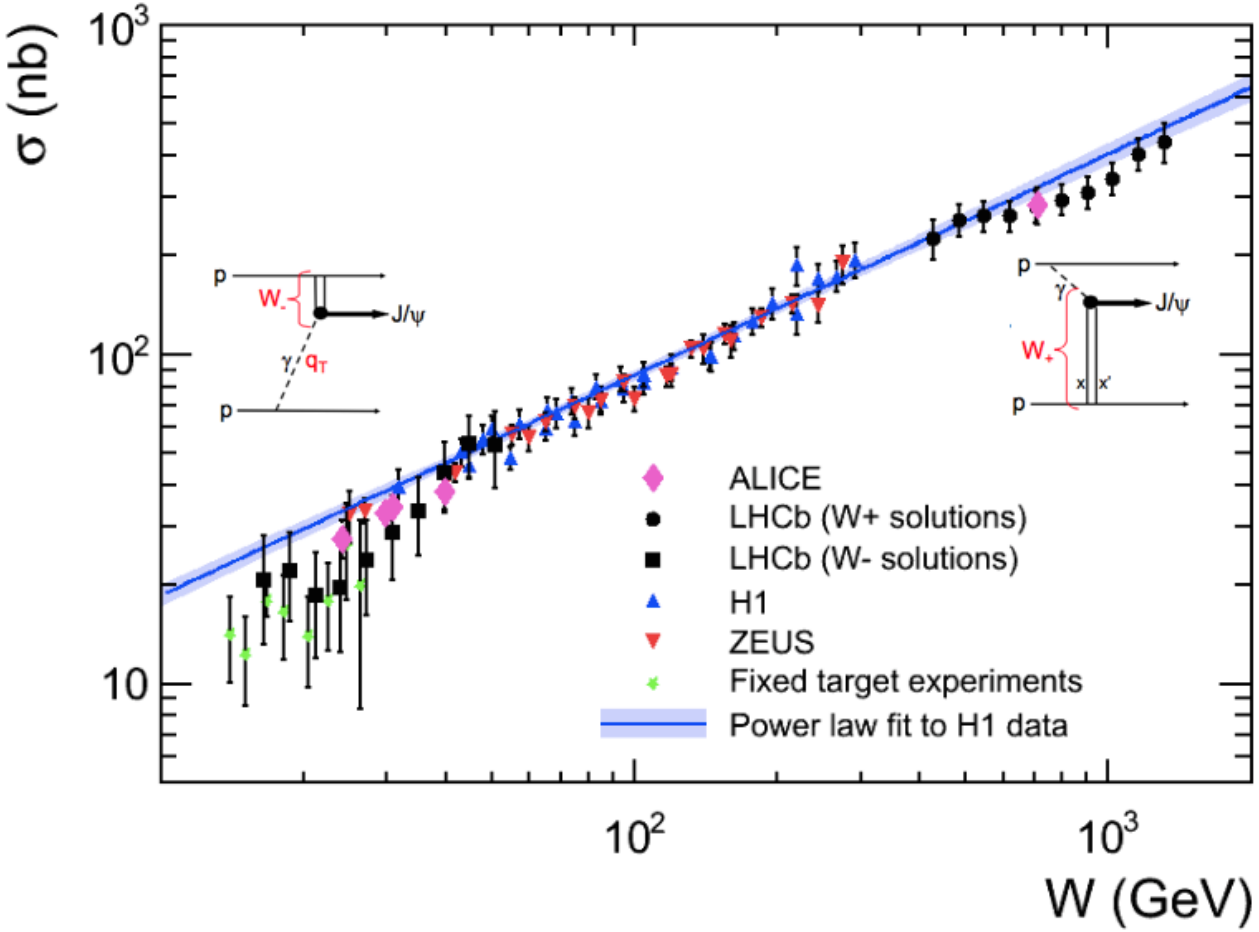




NLO agrees better than LO (again).

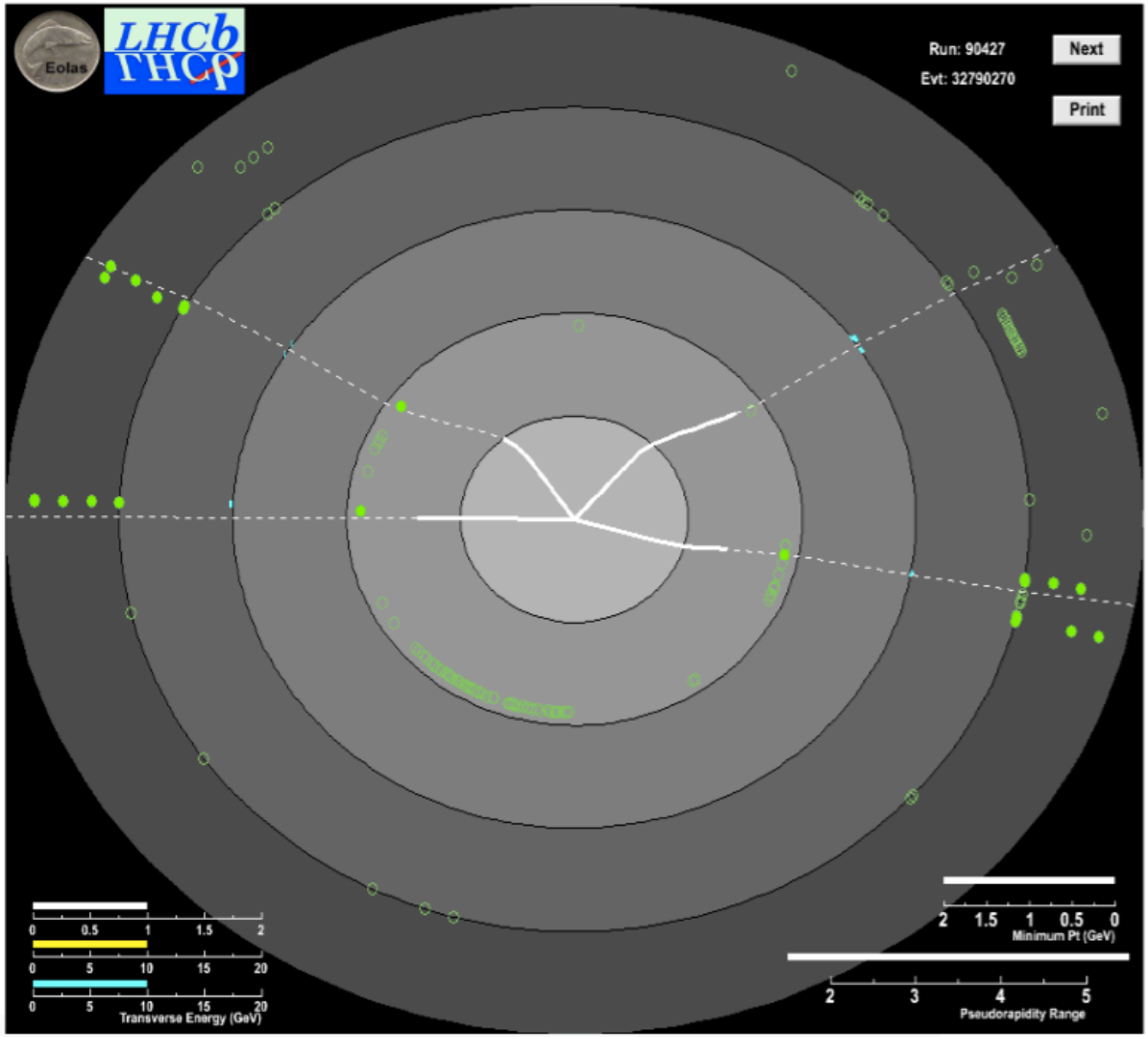
Summary of J/ψ Photo-production
Cross-section measurements

JPG 41 (2014) 055002

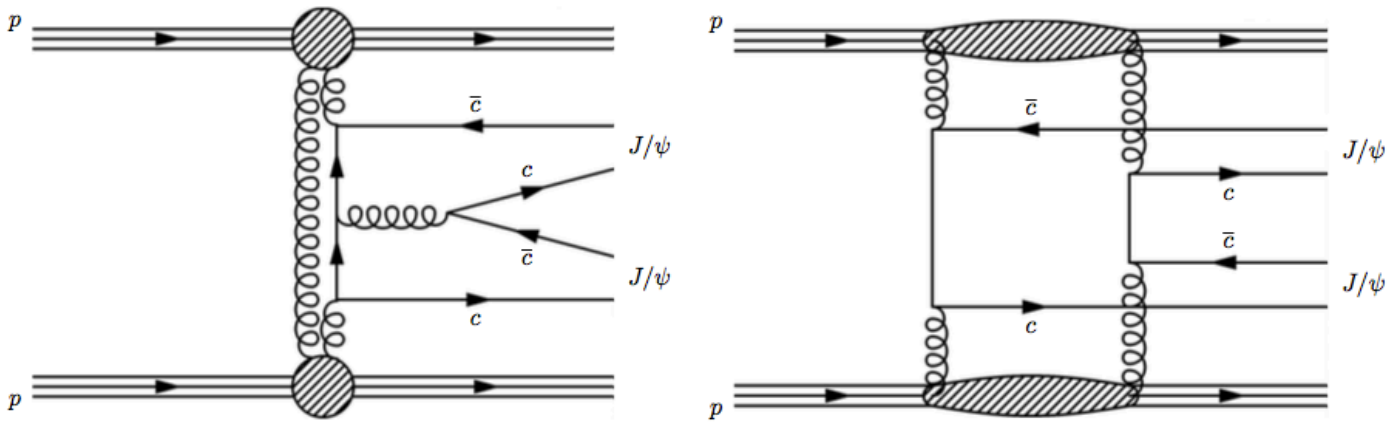


Results of J/ψ photo-production across wide range of energies and colliders.
The W_+ and W_- solutions allow to compare LHCb results to HERA.

Double J/ψ production through Double Pomeron Exchange



Double J/ψ production through Double Pomeron Exchange



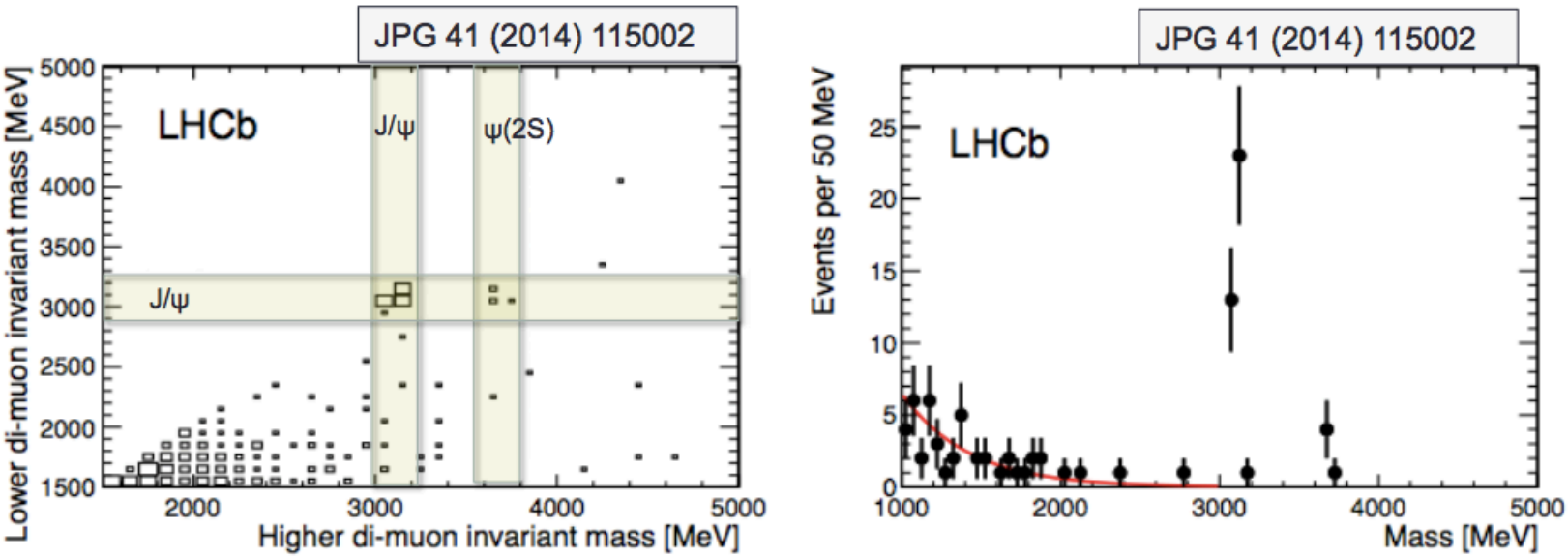
Double J/ψ CEP production diagrams.

Why is it important?

- Study the role of the Pomeron
- Presents an opportunity to search for exotic states in a low-background experimental environment
- Compare mass spectrum of exclusive production where DPS is almost negligible

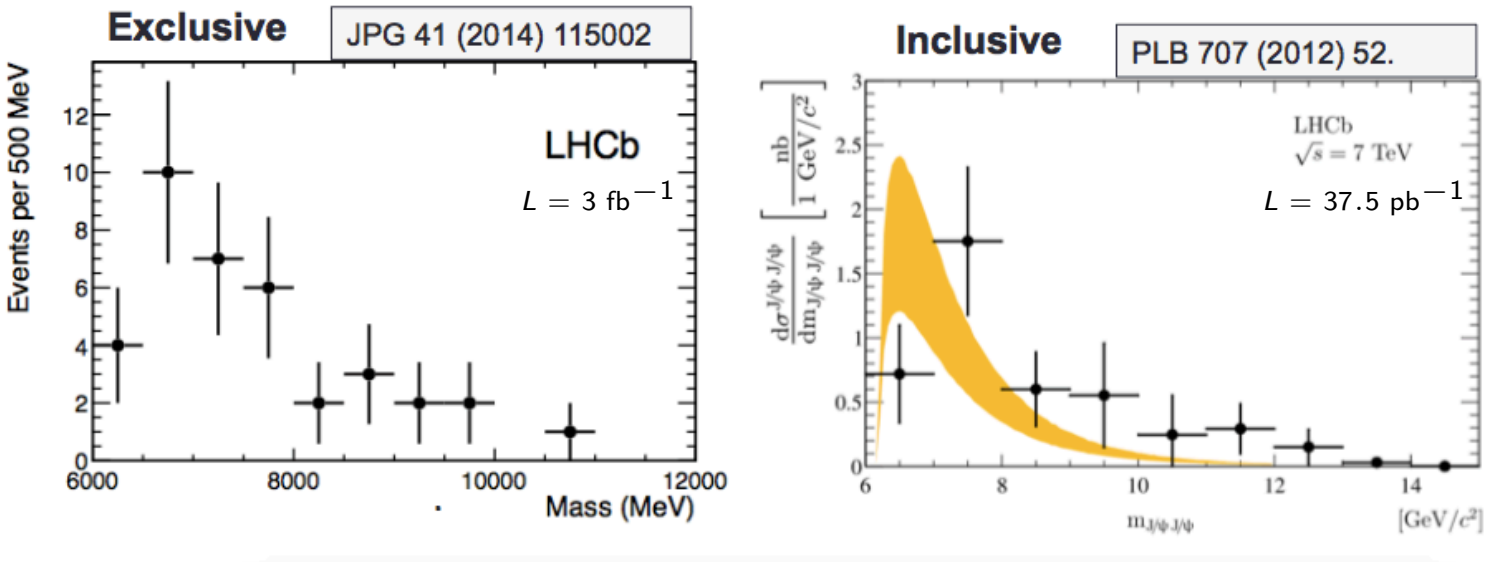
Note: The case of $\gamma\gamma \to J/\psi J/\psi$ It's been widely studied, see A. Cisek, W. Schäfer, and A. Szczurek, Phys. Rev. C86 (2012) 014905, arXiv:1204.5381.

Exclusive Double J/ψ Results



Invariant mass of the four-muon (left) and di-muon systems (right).

Double J/ψ Cross-section



Differential cross-sections of exclusive (left) and inclusive (right) double J/ψ.

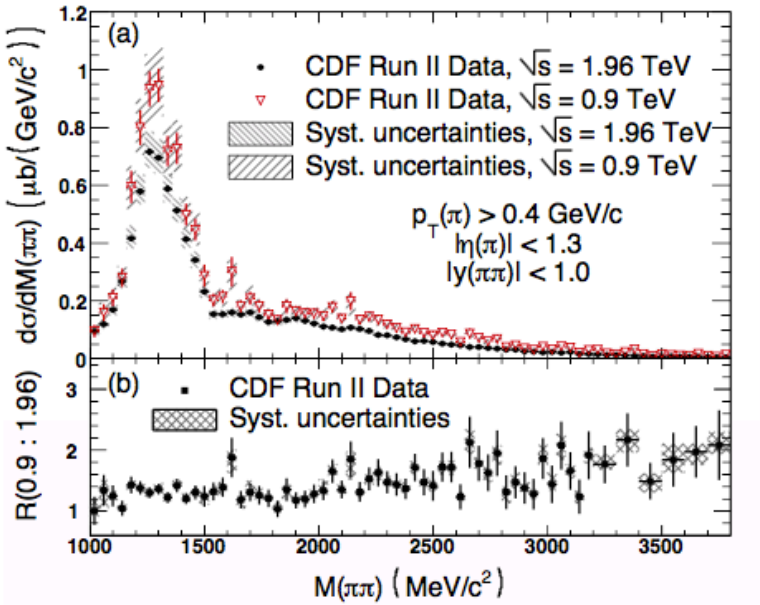
Integrated (Exclusive) cross-section LHCb results in $2 < \eta < 4.5$ range:

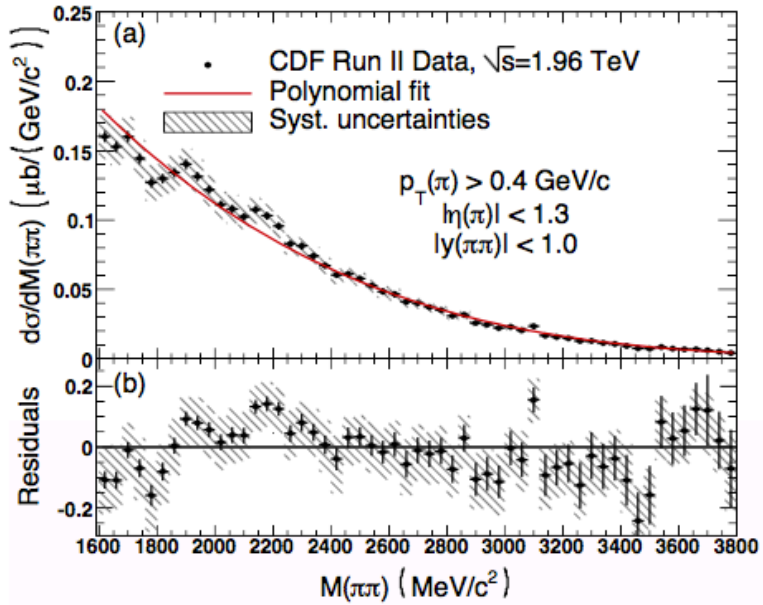
$$\begin{aligned} \sigma^{J/\psi J/\psi} &= 58 \pm 10(stat) \pm 6(syst) \text{ pb} \\ \sigma^{J/\psi \psi(2S)} &= 63^{+27}_{-18}(stat) \pm 10(syst) \text{ pb} \\ \sigma^{\psi(2S)\psi(2S)} &< 247 \text{ pb} \end{aligned}$$

CEP of $\pi^+\pi^-$ at Tevatron CDF

Phys.Rev. D91 (2015) 9, 091101
arXiv:1502.01391

The $\pi^+\pi^-$ production is dominated by double pomeron exchange.

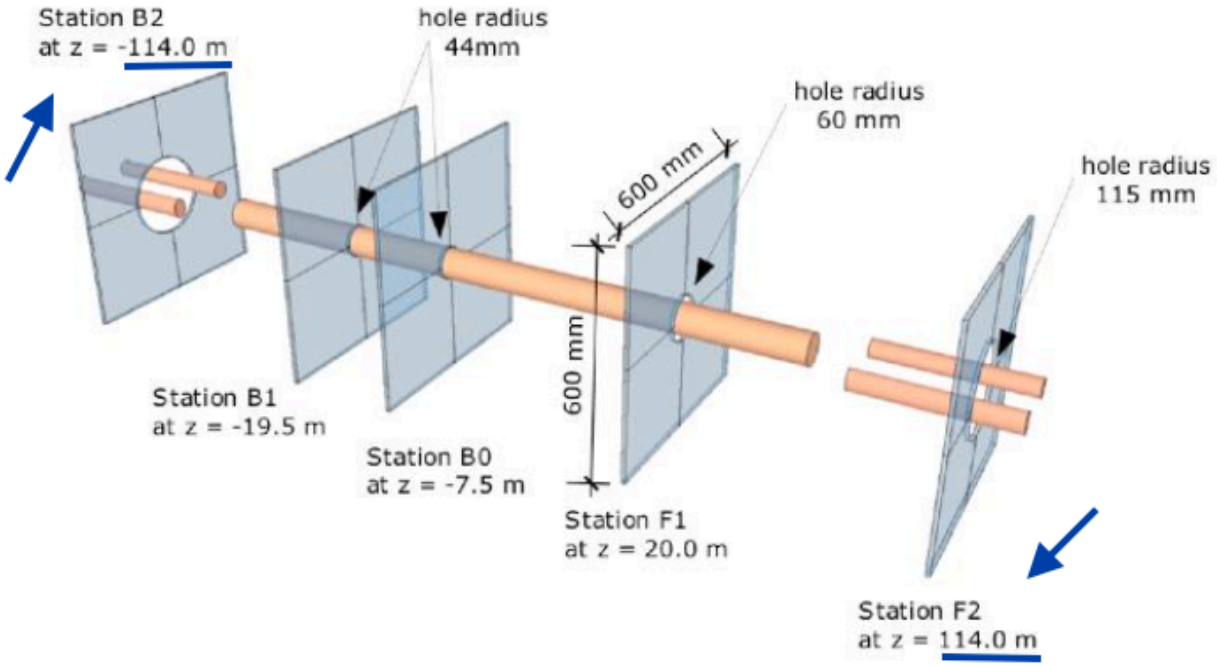


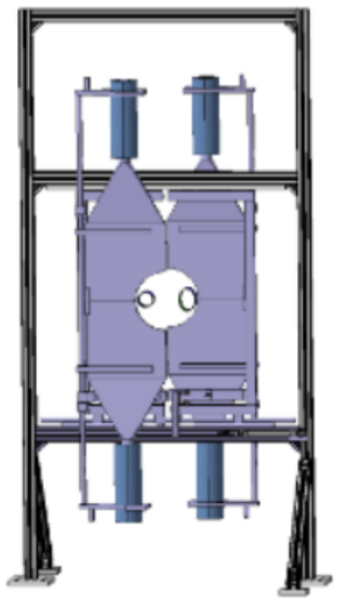


Invariant mass of a pion pion system. The peak in the 1000-1500 MeV/c^2 region could be associated with the $f_2(1270)$ (2^{++}) and $f_0(1370)$ (0^{++}) resonances.

Prospects

HeRSCheL: High Rapidity Shower Counters for LHCb



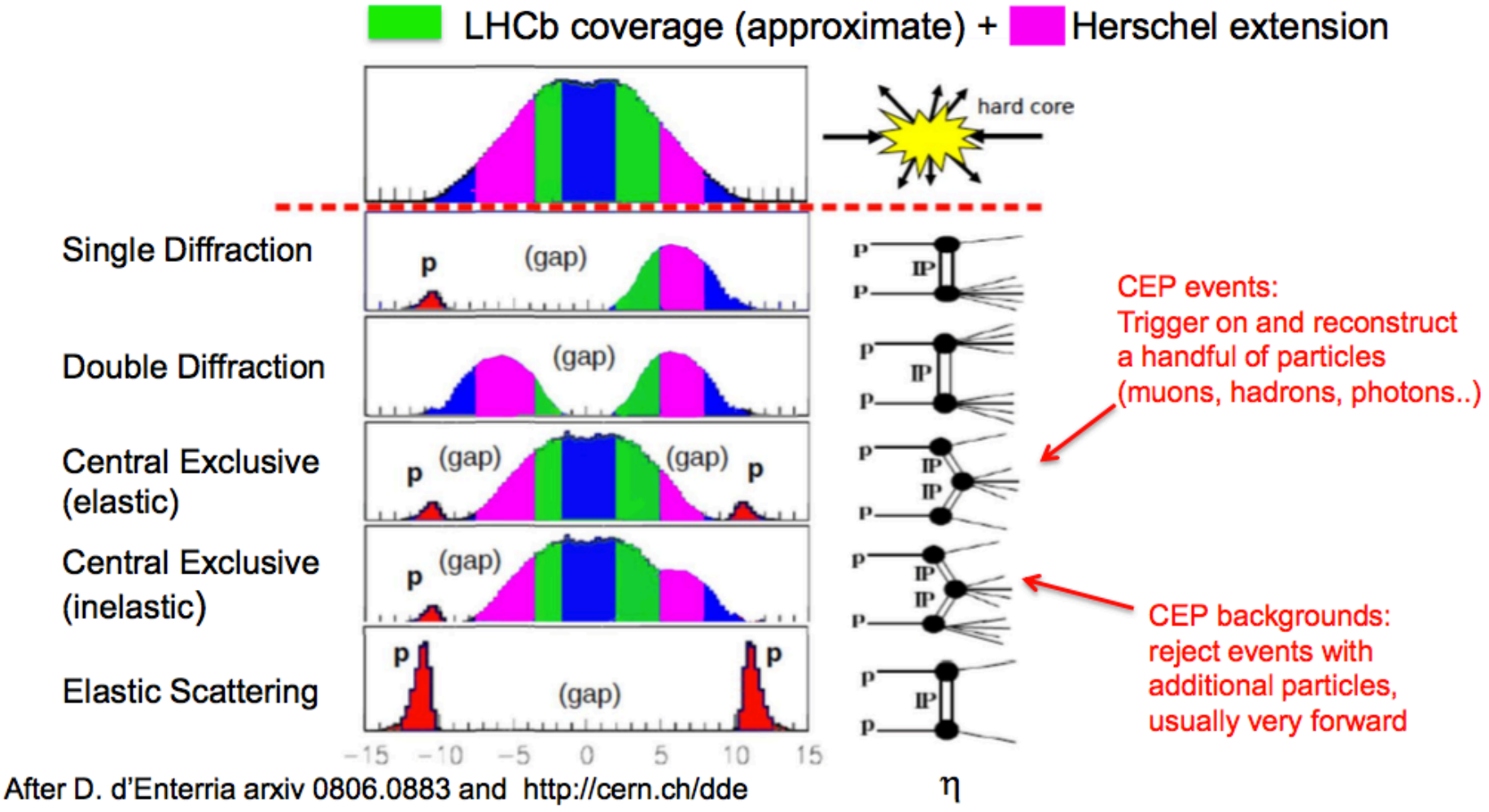


- Extension of the upstream and downstream coverage LHCb in a very forward region $5 < \eta < 8$.
- Additionally the low pileup in Run II favours CEP studies.
- On 21 May, 13 TeV centre-of-mass energy collisions were performed for the first time.

https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbHerschel

Prospects

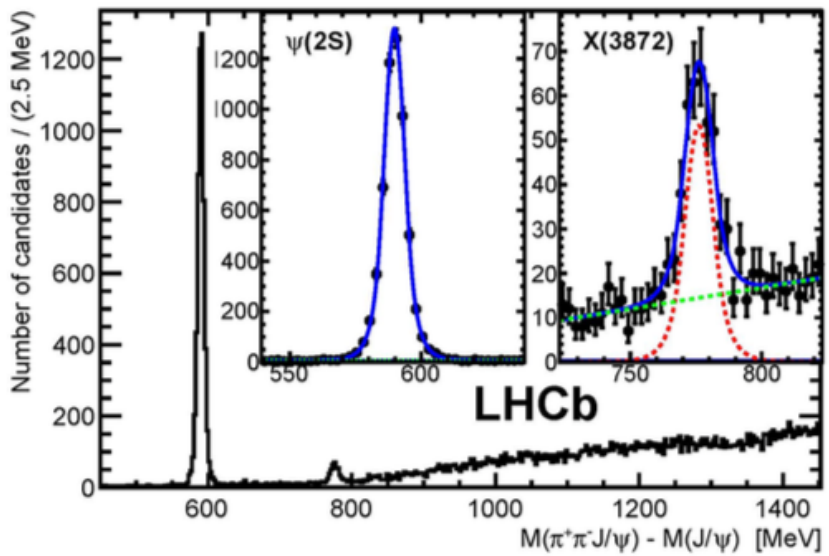
HERSCHEL Extra Rapidity Coverage



Prospects

$X(3872)$ studies

- Study of other charmonium resonances, i.e. $X(3872)$ already observed inclusively, J^{PC} shown to be 1^{++} by LHCb (arXiv:1302.6269). Is it possible to produce it exclusively?

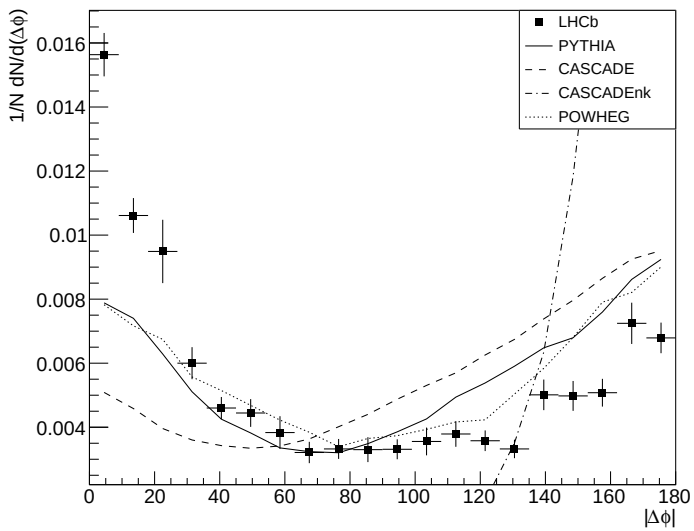


Eur.Phys.J. C72 (2012) 1972.

Prospects

$D\bar{D}$ studies

- Studies on inclusive charm pair production have been performed by LHCb and its results compared with different QCD theoretical frameworks (DGLAP, CCFM).



J.Phys. G43 (2016), 015001

- Exclusive $D\bar{D}$ production studies are already taking place but combinatoric backgrounds are still large.
- CEP complements the standard QCD production mechanism. However, relative rates between CEP/no-CEP processes are expected to be different

Summary

- CEP provides a clean (controlled) environment to test QCD predictions and search for complex effects i.e. exotica.
- Several CEP measurements performed by the LHCb:
  - J/ψ and $\psi(2S)$
  - $\Upsilon(1S), \Upsilon(2S), \Upsilon(3S)$
  - $J/\psi, \psi(2S)$ and $J/\psi, J/\psi$
- And by Tevatron experiments (D0, CDF)
  - J/ψ and $\psi(2S) \rightarrow$ fist (CEP) observation in hadron collisions (arXiv:0902.1271v4 2009)
  - $\pi^+\pi^-$
- Herschel will allow us to significantly reduce inelastic backgrounds in future CEP studies

Thank you