Central Exclusive Production at LHCb

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on behalf of the LHCb collaboration

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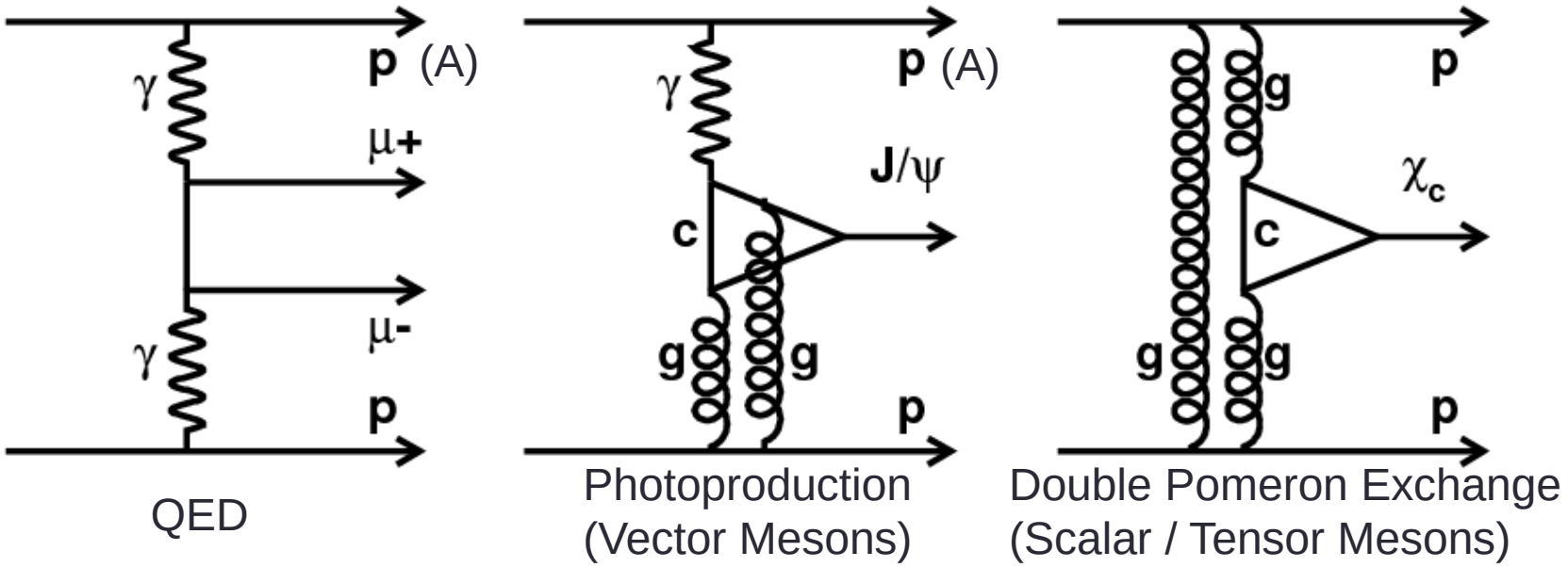
Outline

- Introduction
- Run 1: Results at 7 and 8 TeV
  - Exclusive J/ψ and ψ(2S) at 7 TeV JPG 41 (2014) 055002
  - Exclusive ϒ at 7,8 TeV JHEP 1509 (2015) 084
  - Double charmonia at 7&8 TeV JPG 40 (2013) 045001
  - Preliminary χc and μμ LHCb-CONF-2011-022
- New Herschel Detector
- Run 2: Results at 13 TeV
  - Exclusive J/ψ and ψ(2S) at 13 TeV LHCb-CONF-2016-007
  - Prospects for CEP in future

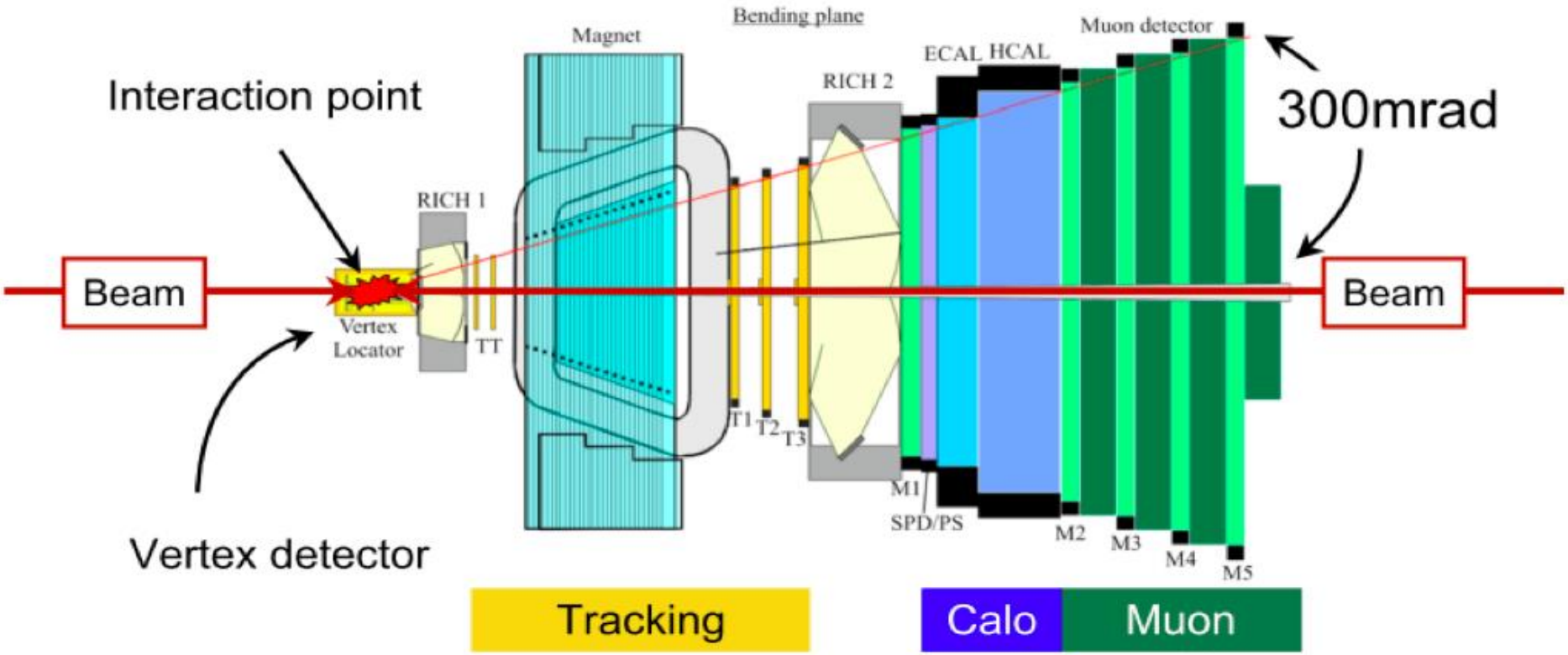
CEP: Colourless propagators



- Signal: central system with rapidity gaps down to proton
- Background: proton dissociation & finite detector acceptance.

The LHCb detector

Int. J. Mod. Phys. A 30 (2015) 1530022

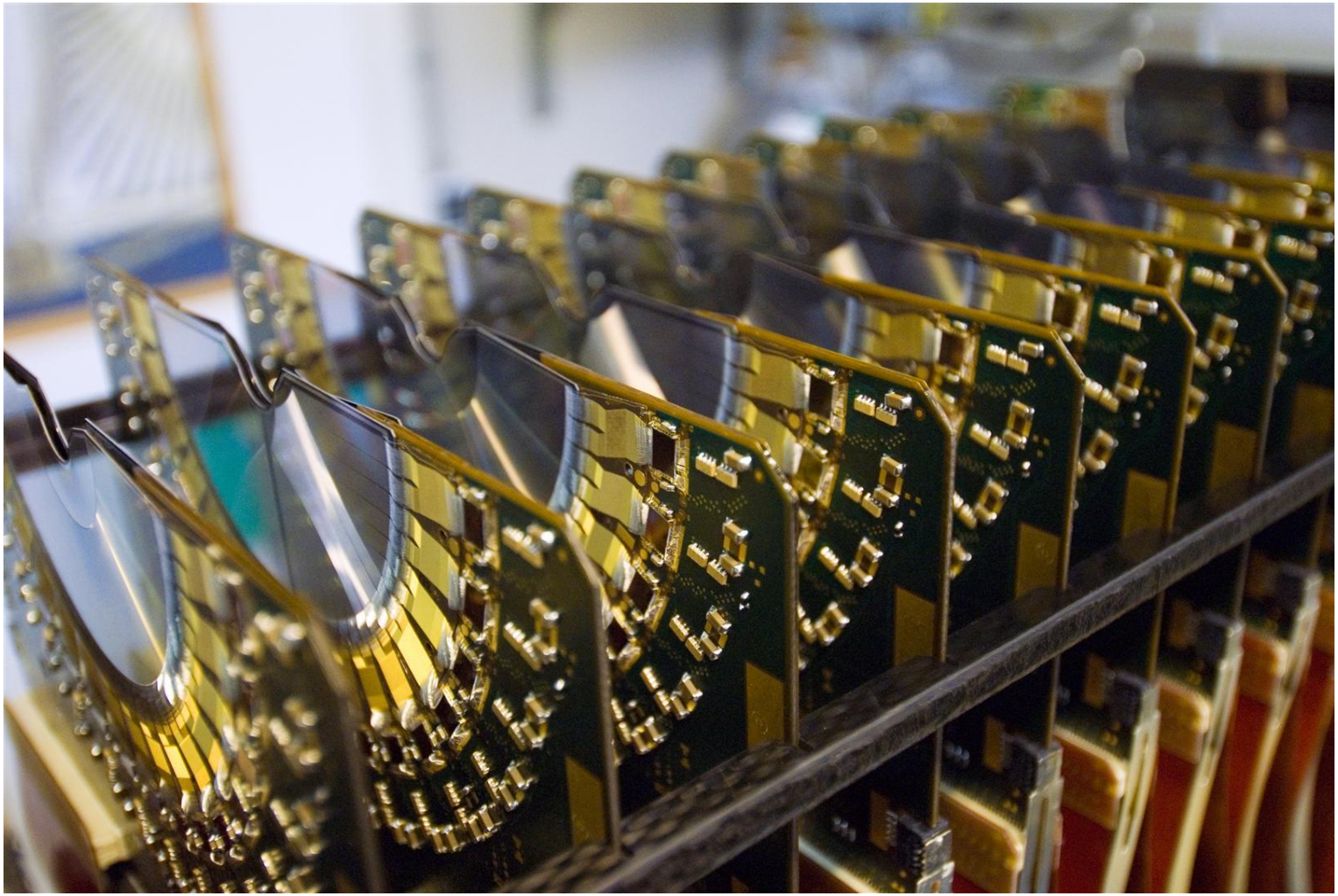


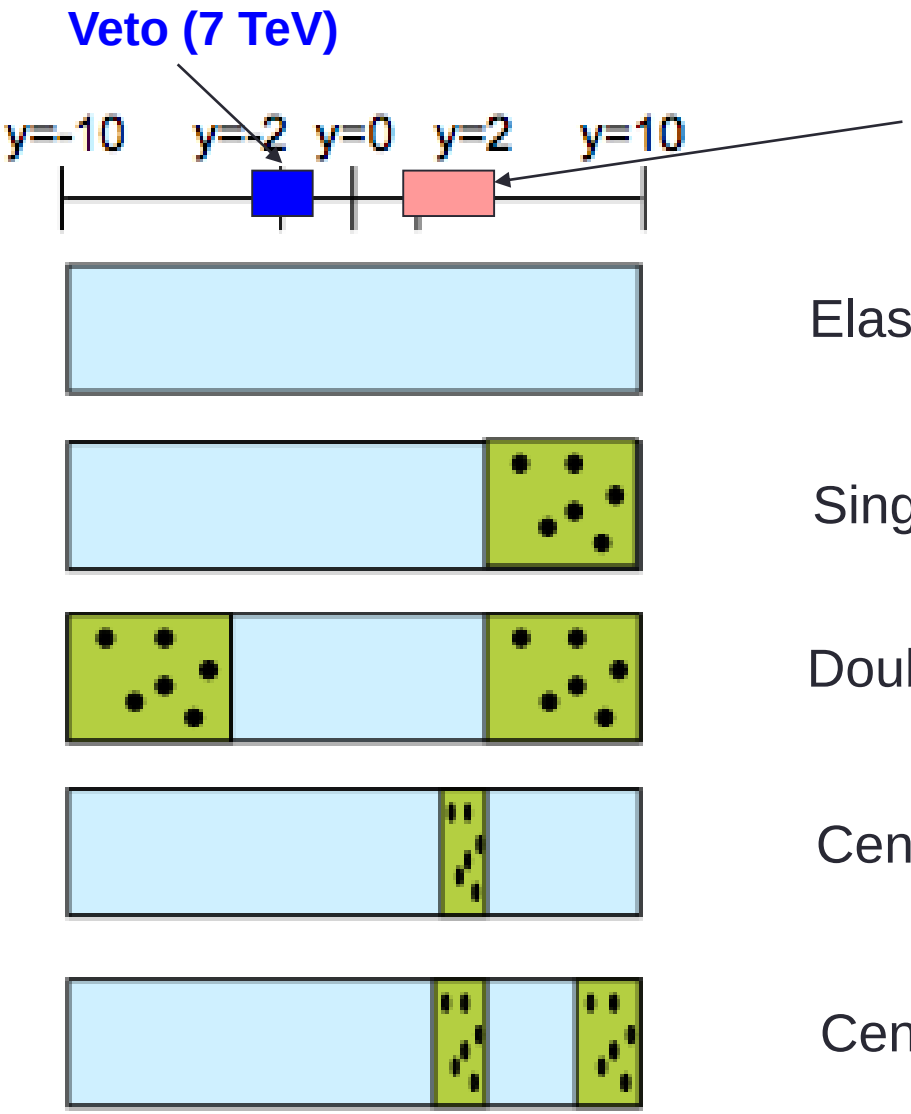
Fully instrumented: $2 < \eta < 5$

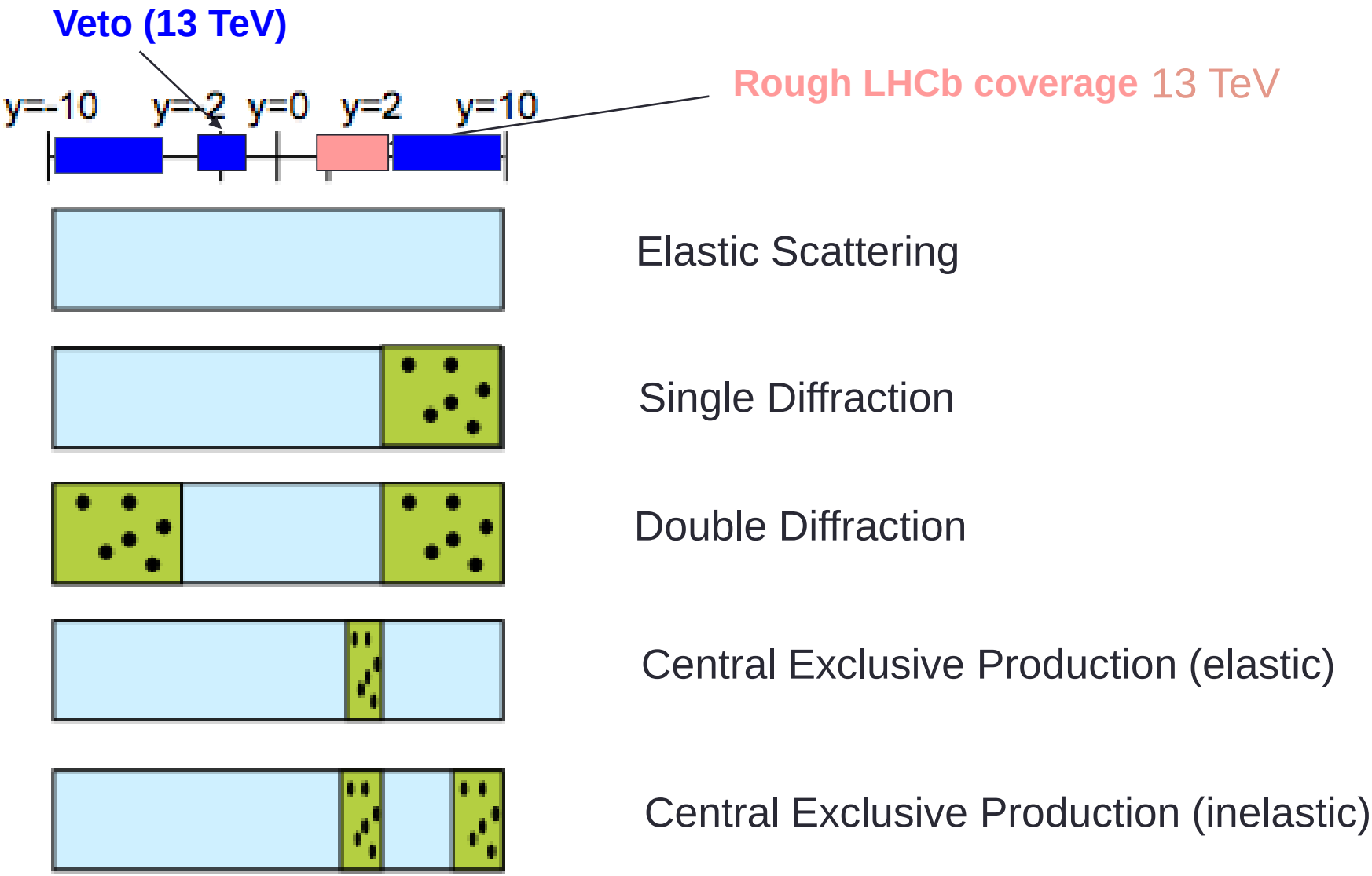
Veto region (Run 1): $-3.5 < \eta < -1.5$

Veto region (Run 2): $-10 < \eta < -5$, $5 < \eta < 10$

VELO sub-detector




Veto (7 TeV)
y=-10
y=-2
y=0
y=2
y=10
Rough LHCb coverage 7,8 TeV
Elastic Scattering
Single Diffraction
Double Diffraction
Central Exclusive Production (elastic)
Central Exclusive Production (inelastic)


Veto (13 TeV)
y=-10
y=-2
y=0
y=2
y=10
Rough LHCb coverage 13 TeV
Elastic Scattering
Single Diffraction
Double Diffraction
Central Exclusive Production (elastic)
Central Exclusive Production (inelastic)

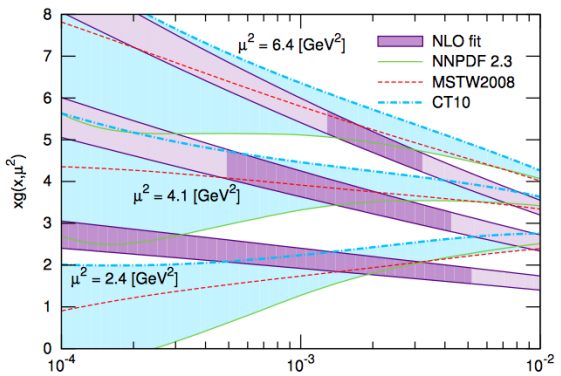
HERA vector meson photo-production results

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

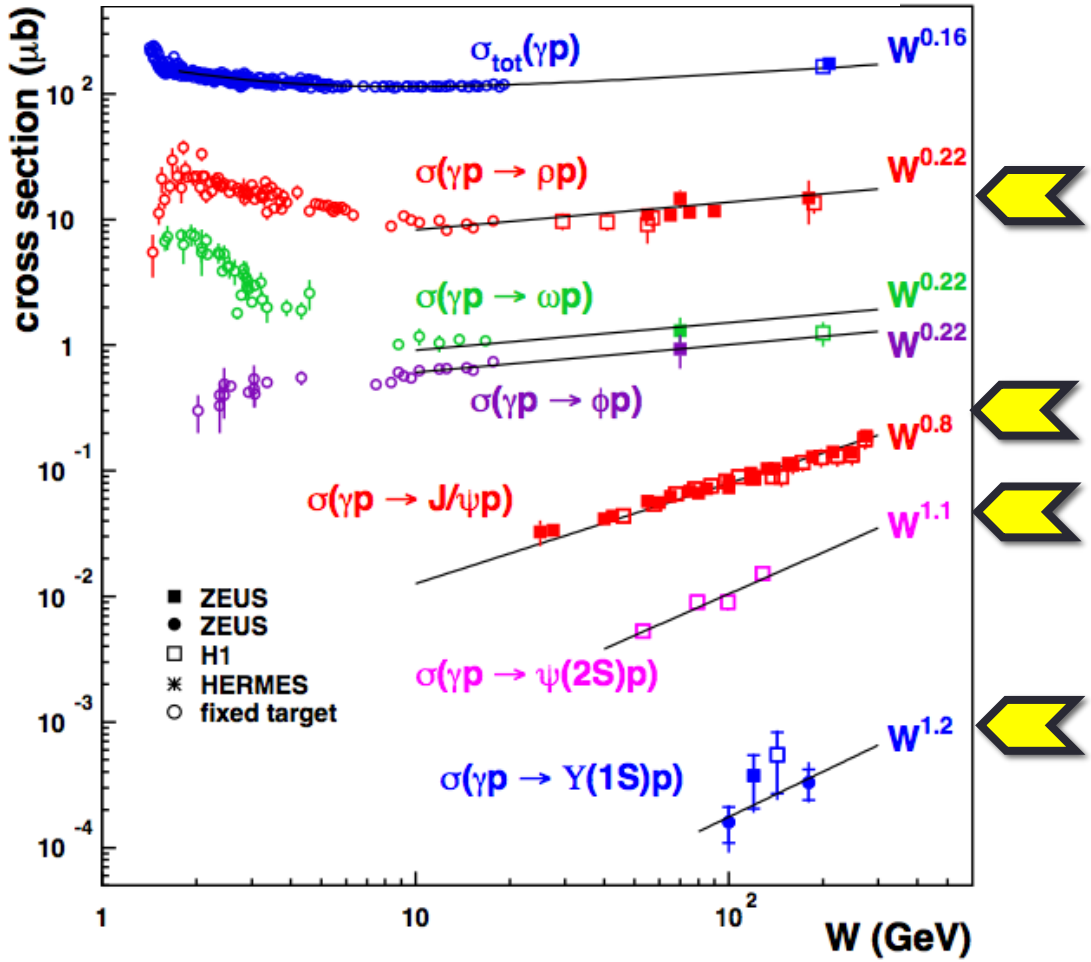
Note:

- soft/hard transition
- $s \sim x'$
- g(x,Q^2)

  (down to x=2E-6)

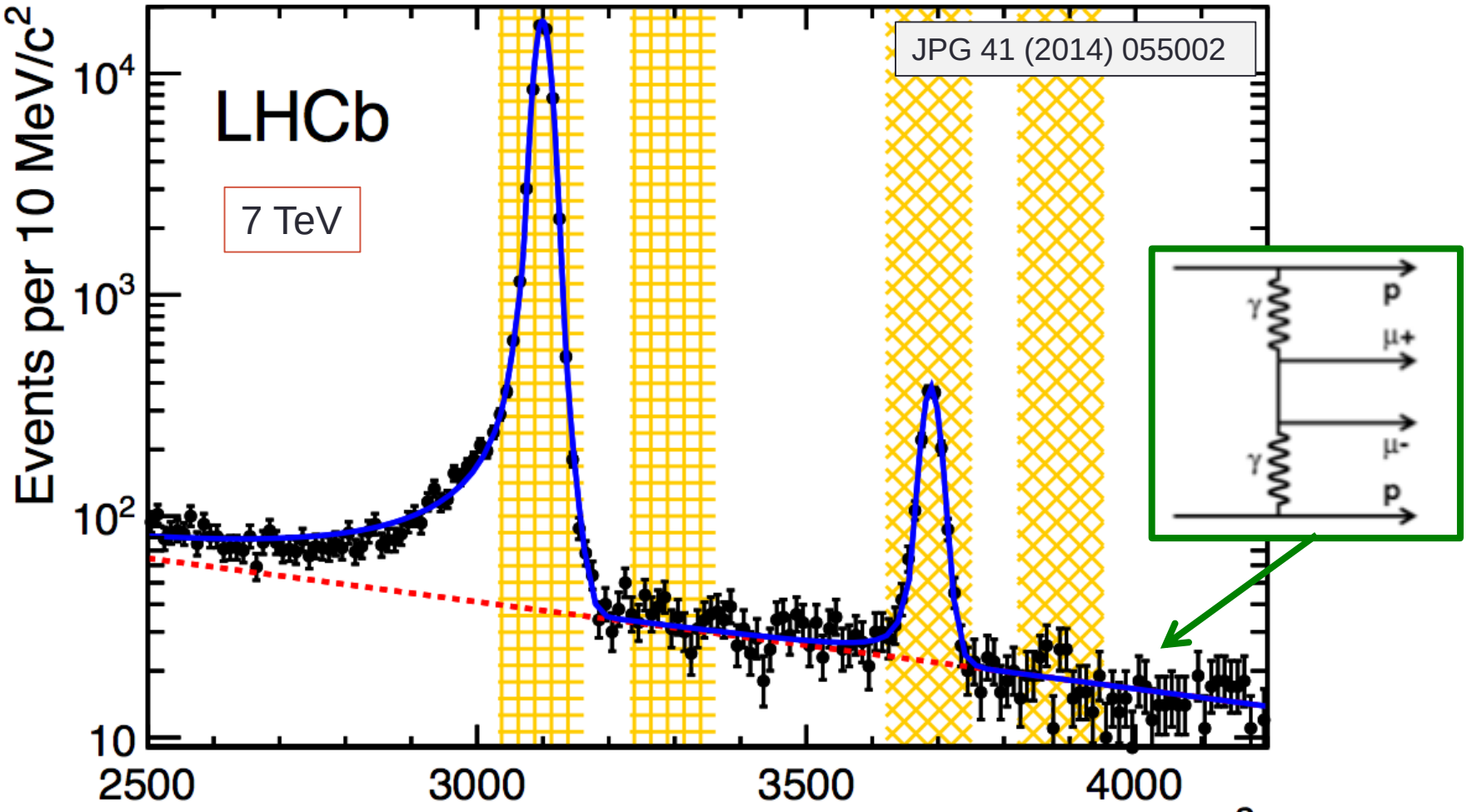


JHEP 1311 (2013) 085



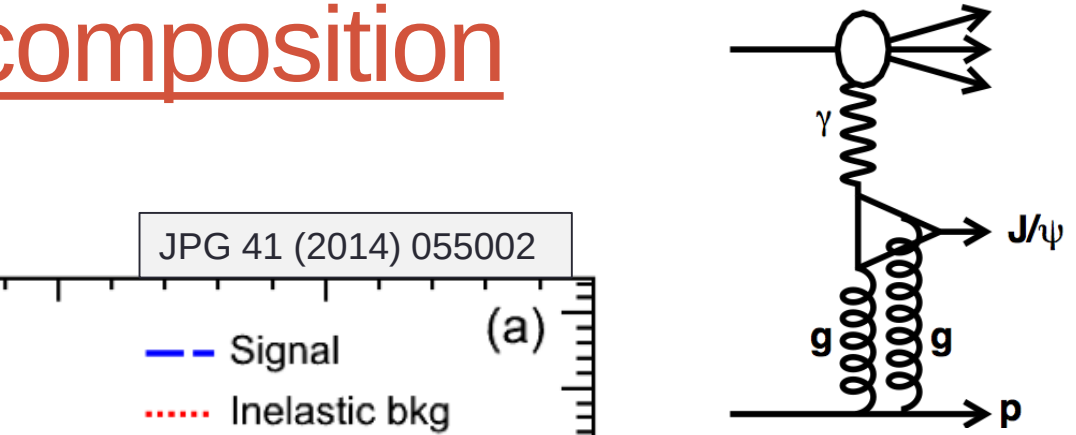
10.3204/DESY-PROC-2012-03/58

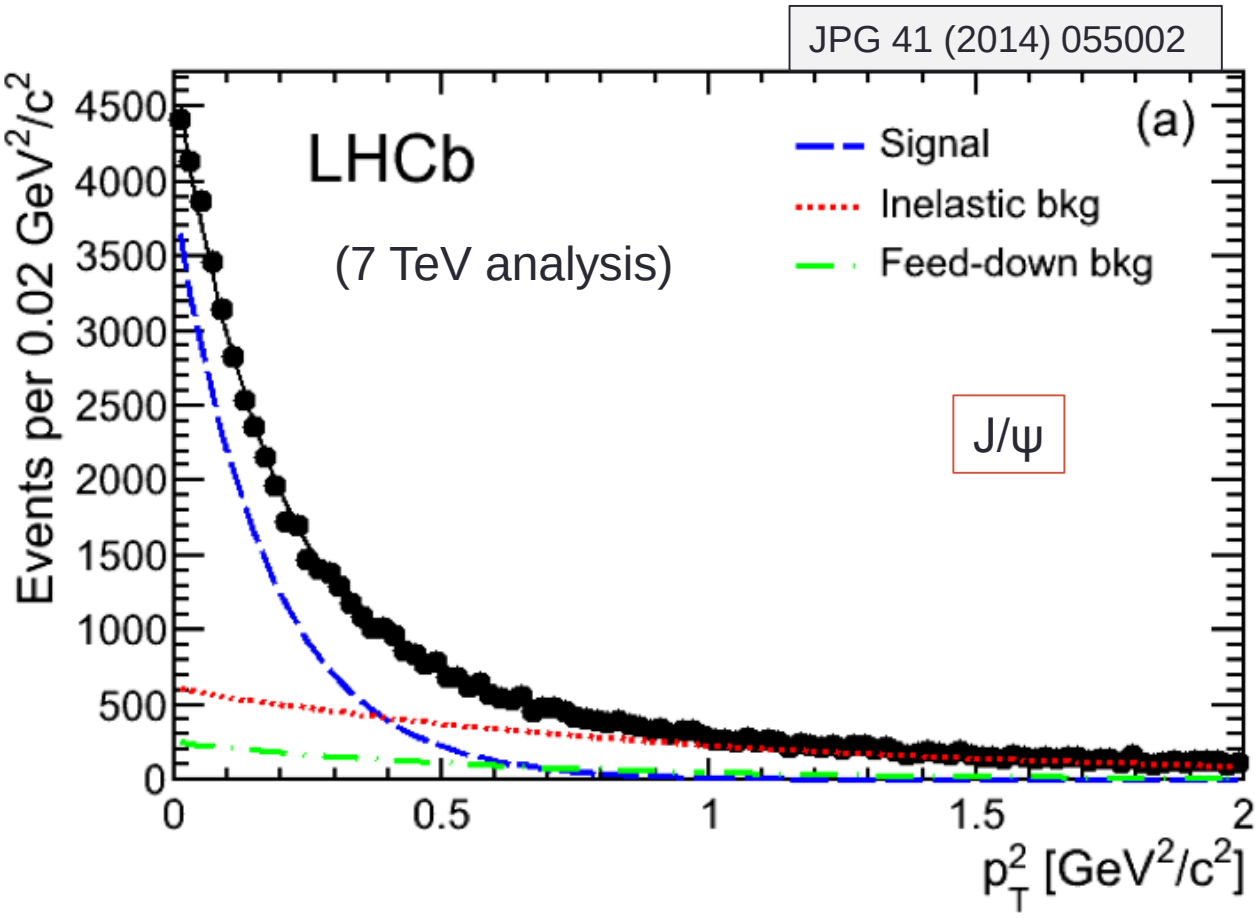
CEP: J/ψ and ψ(2S) mesons



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

J/ψ sample composition





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

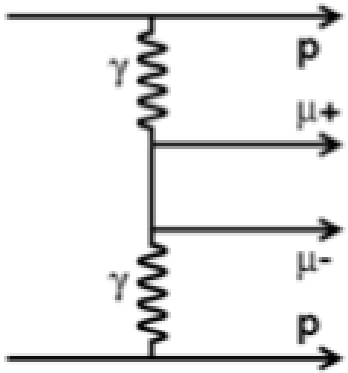
HERA measured:
b_s=4.9 GeV^{-2}
b_{pd}=1.1 GeV^{-2}

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 ~ 40%
Feed-down ~ 10%

Continuum sample composition



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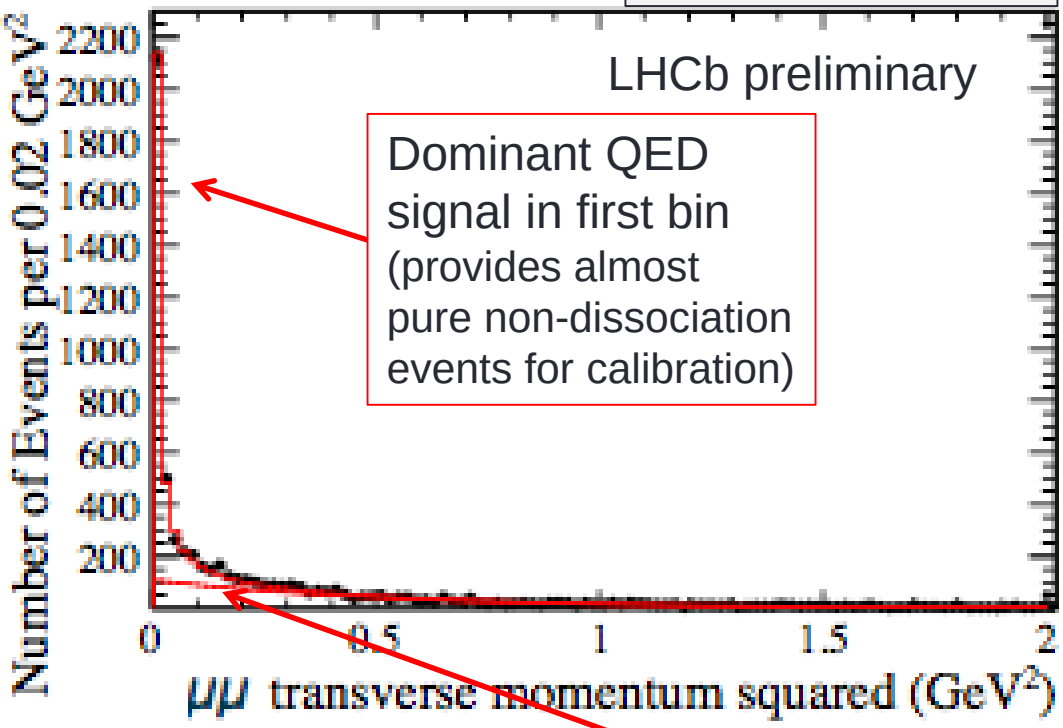
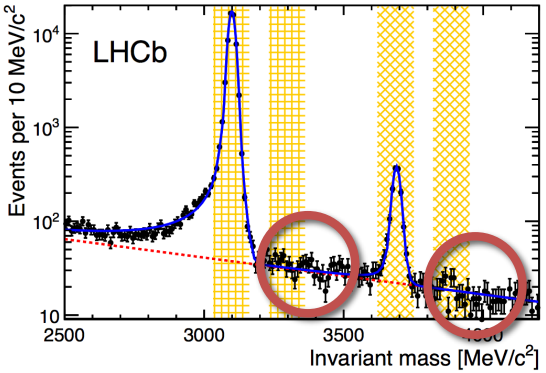


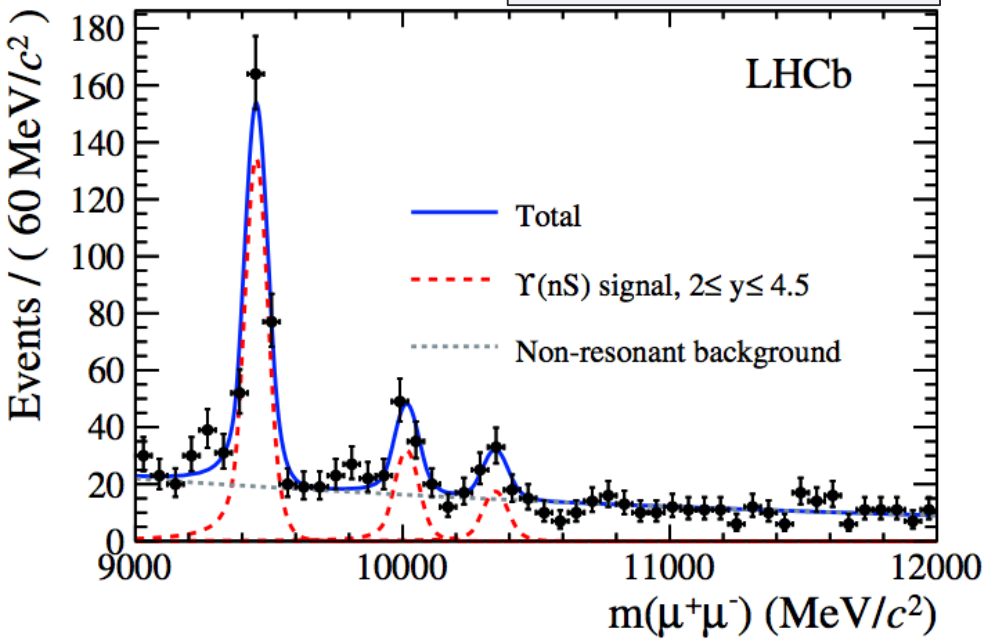
Dominant QED signal in first bin (provides almost pure non-dissociation events for calibration)

Single exponential to describe proton dissociation

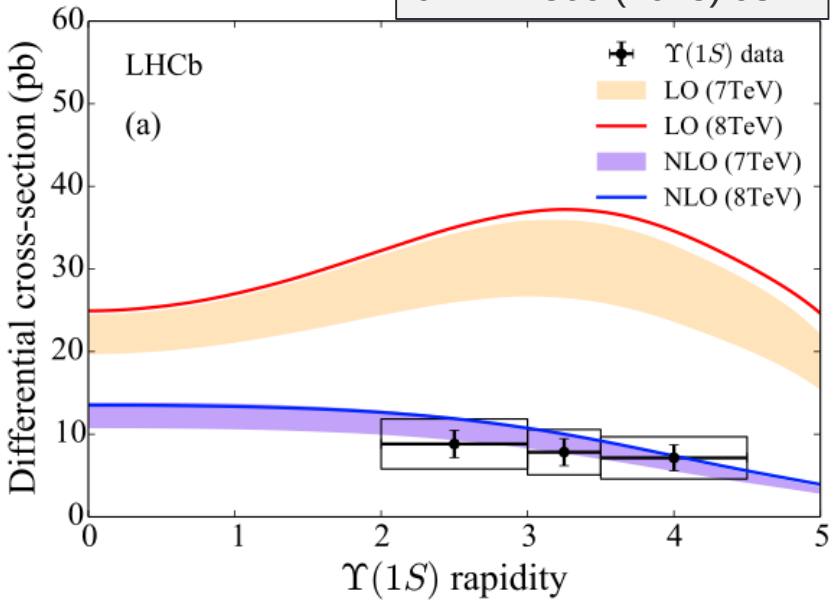


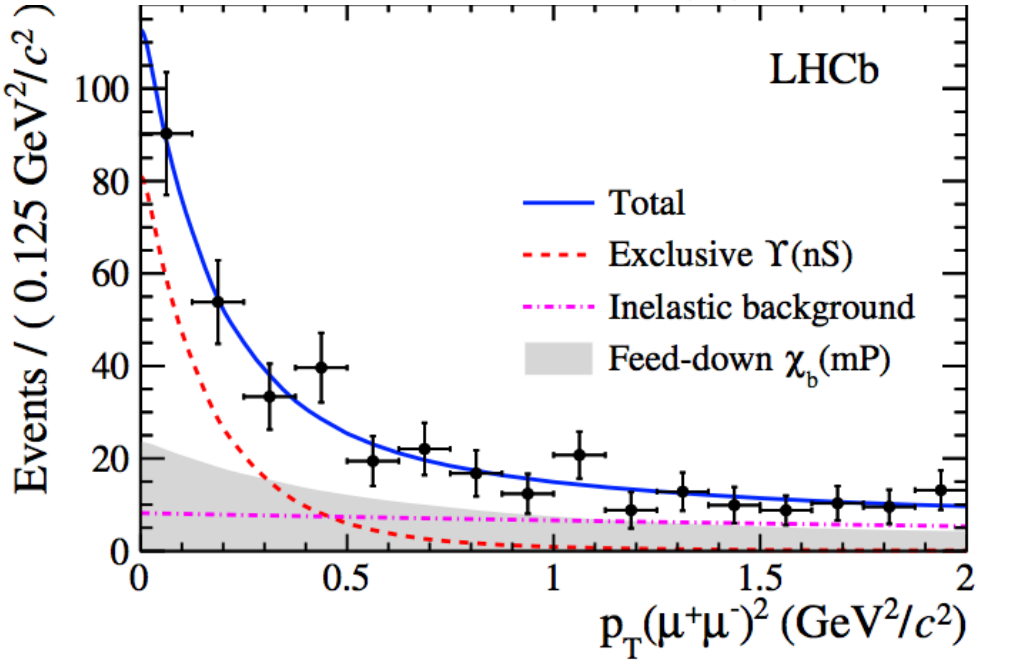
Υ analysis

JHEP 1509 (2015) 084



JHEP 1509 (2015) 084

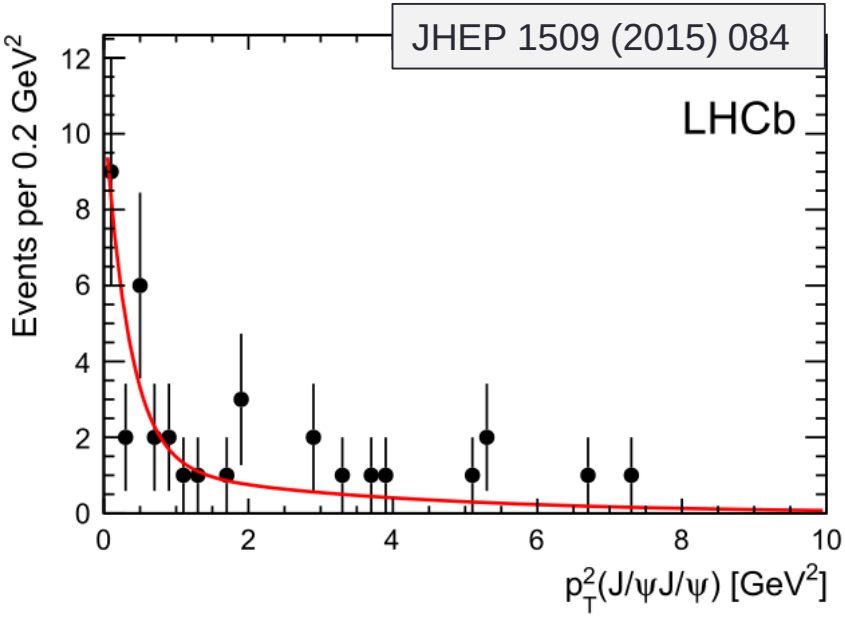




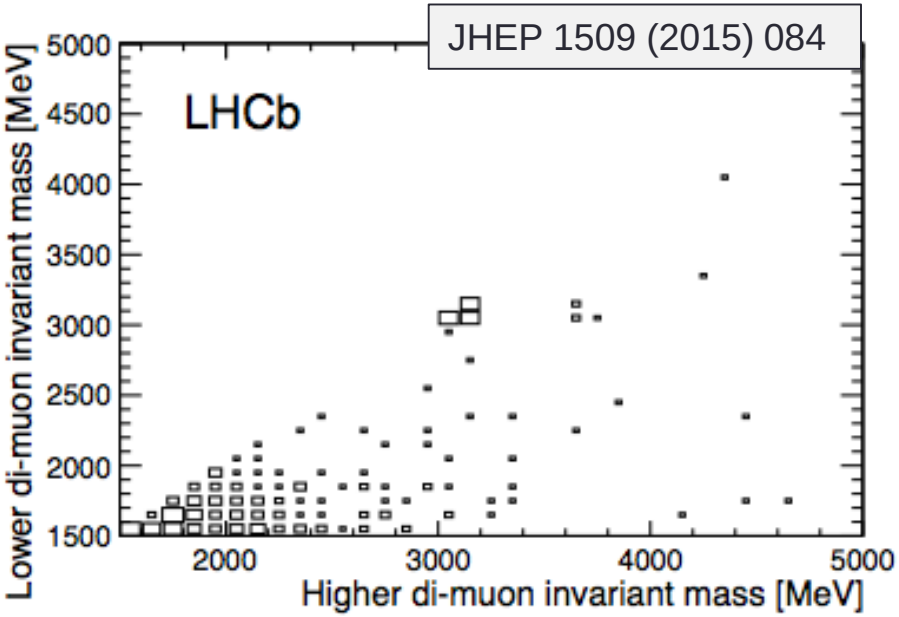
Double charmonia

$$
\begin{aligned}
\sigma^{J/\psi\,J/\psi} &= 58 \pm 10(\text{stat}) \pm 6(\text{syst})\,\text{pb}, \\
\sigma^{J/\psi\,\psi(2S)} &= 63^{+27}_{-18}(\text{stat}) \pm 10(\text{syst})\,\text{pb}, \\
\sigma^{\psi(2S)\psi(2S)} &< 237\,\text{pb}, \\
\sigma^{\chi_{c0}\chi_{c0}} &< 69\,\text{nb}, \\
\sigma^{\chi_{c1}\chi_{c1}} &< 45\,\text{pb}, \\
\sigma^{\chi_{c2}\chi_{c2}} &< 141\,\text{pb},
\end{aligned}
$$

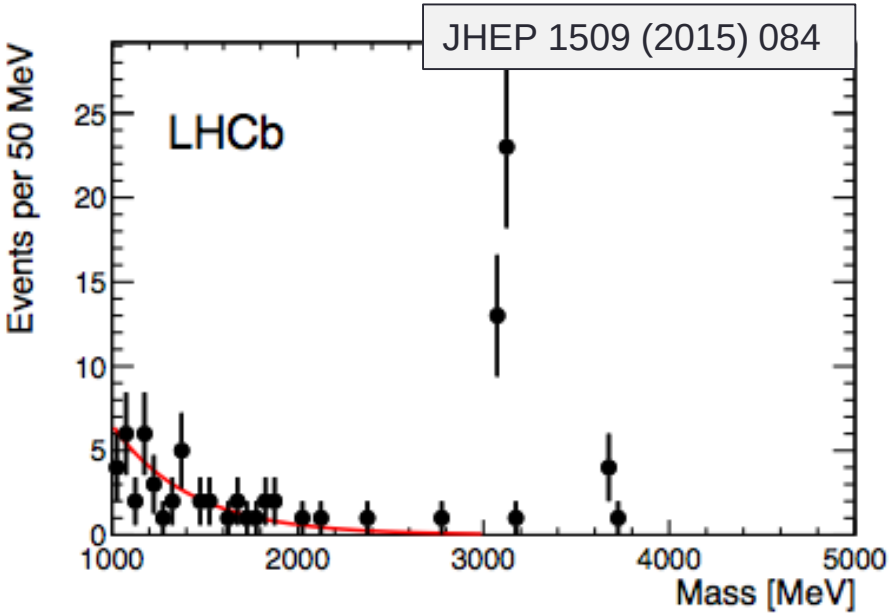
JHEP 1509 (2015) 084



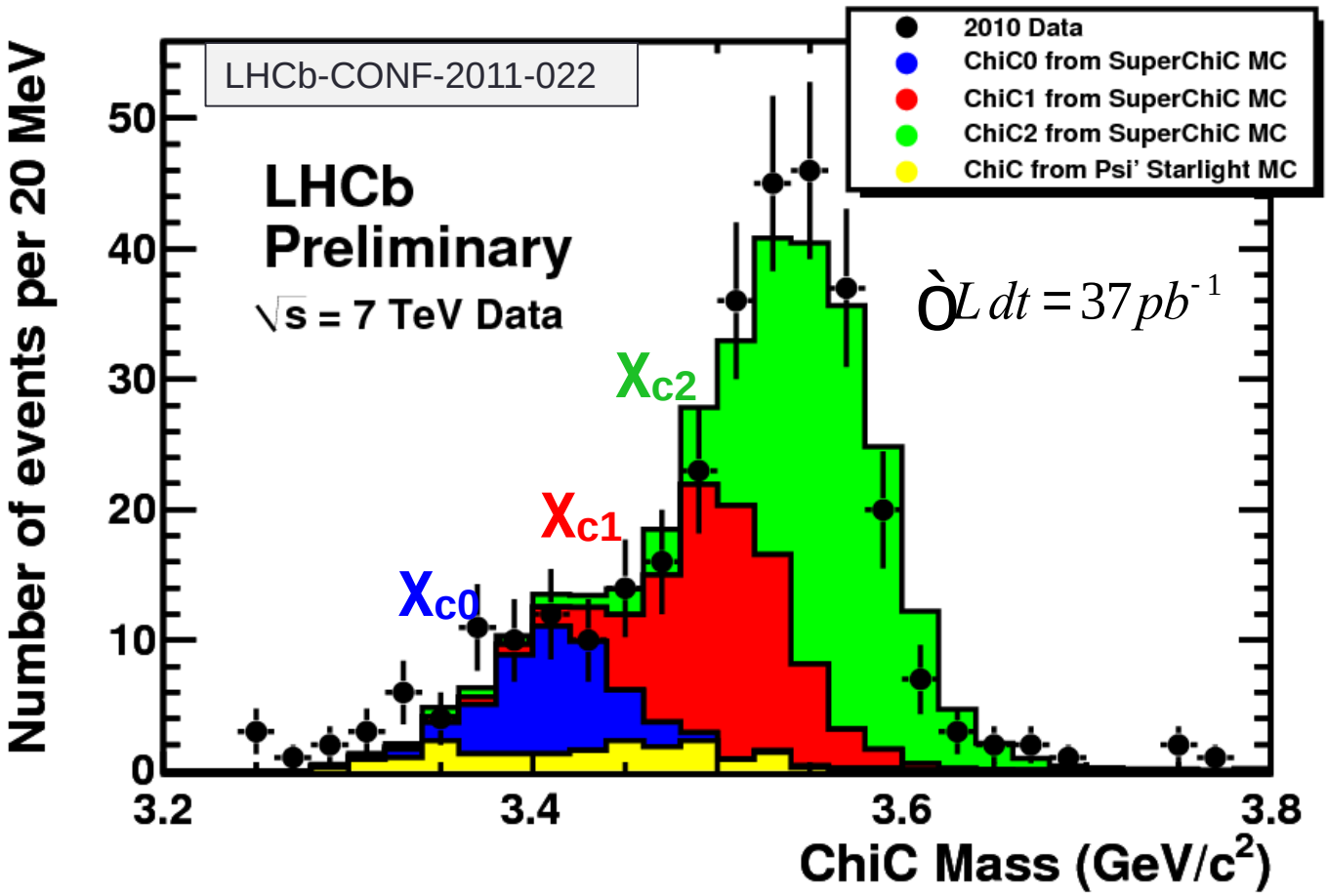
JHEP 1509 (2015) 084

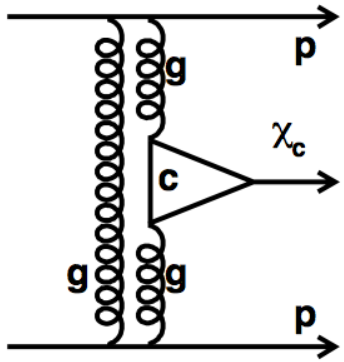


JHEP 1509 (2015) 084



Selected $\chi_{c0,1,2}$ candidates

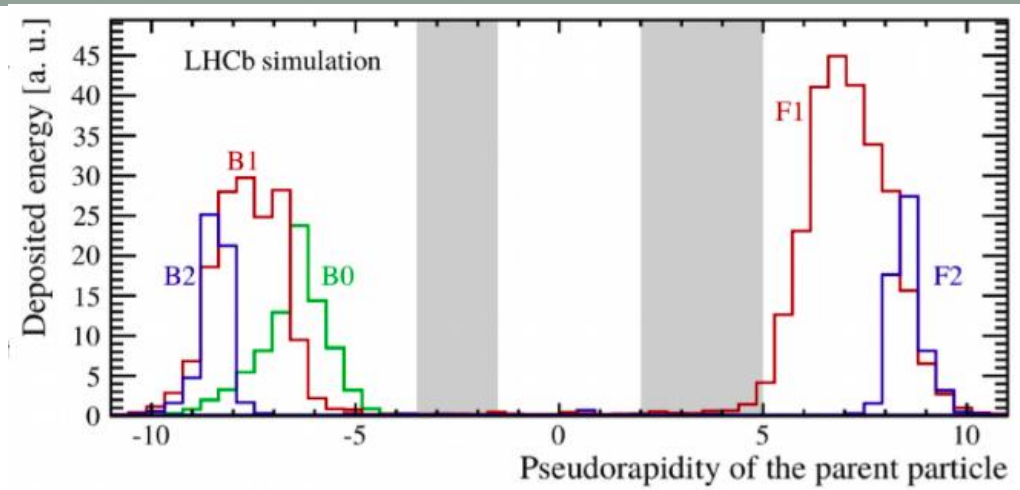


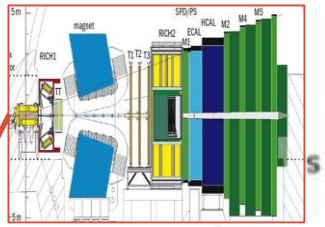


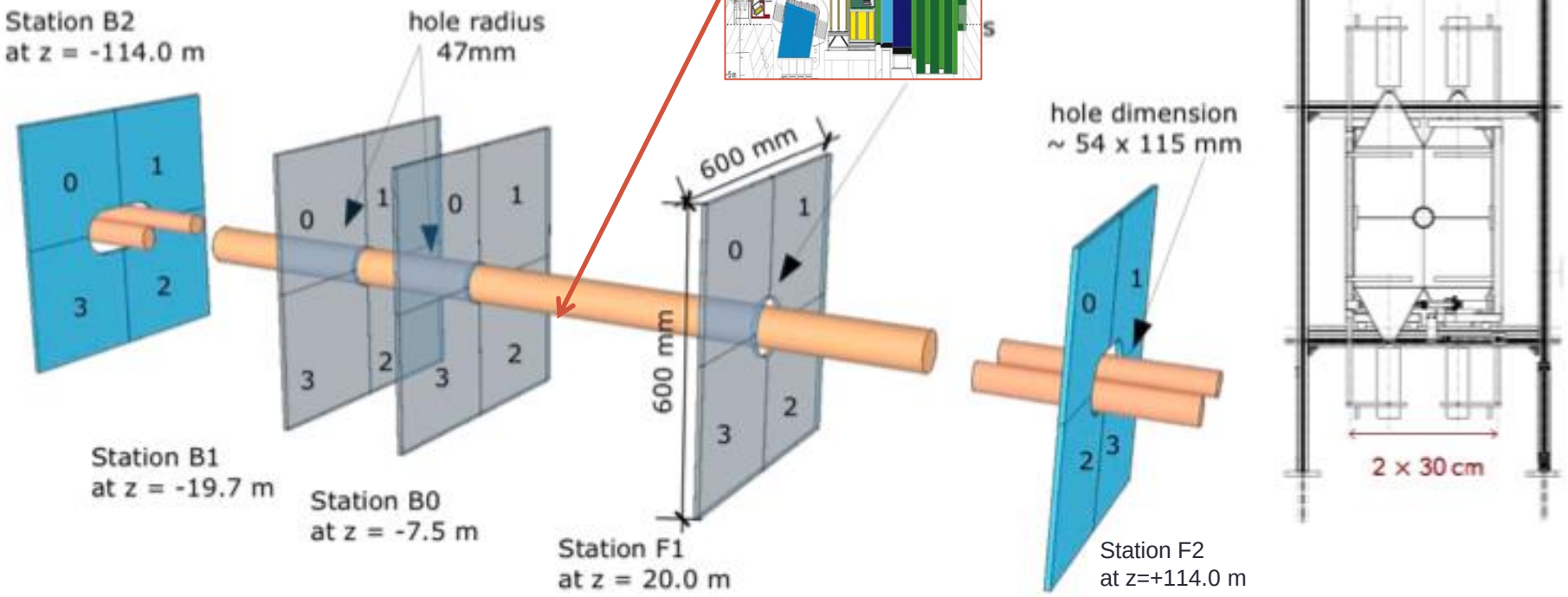
- Difficulty separating states and exclusive fractions

Herschel: High rapidity shower counters for LHCb

- Increase rapidity gap with scintillators in forward region
- Detects secondary particles



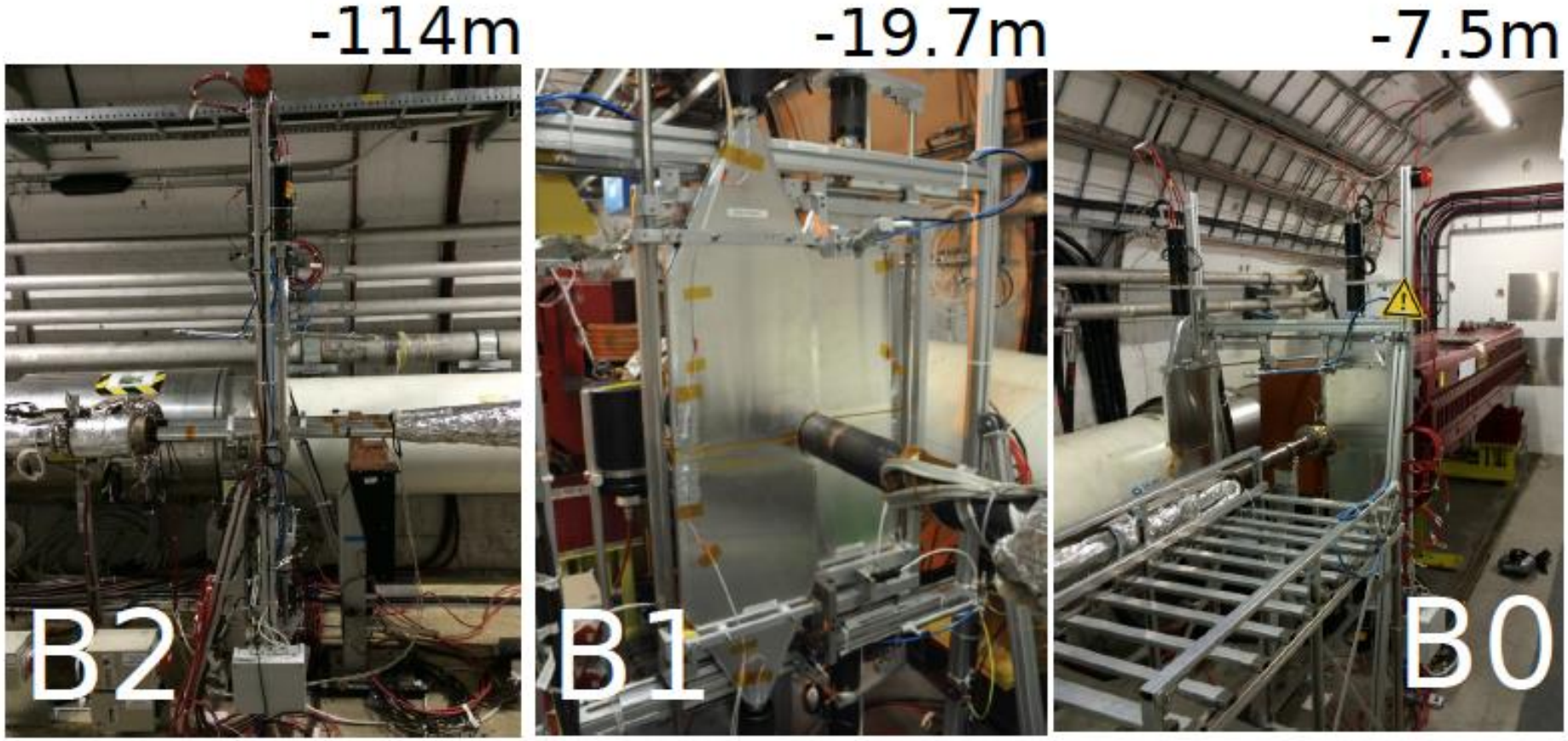




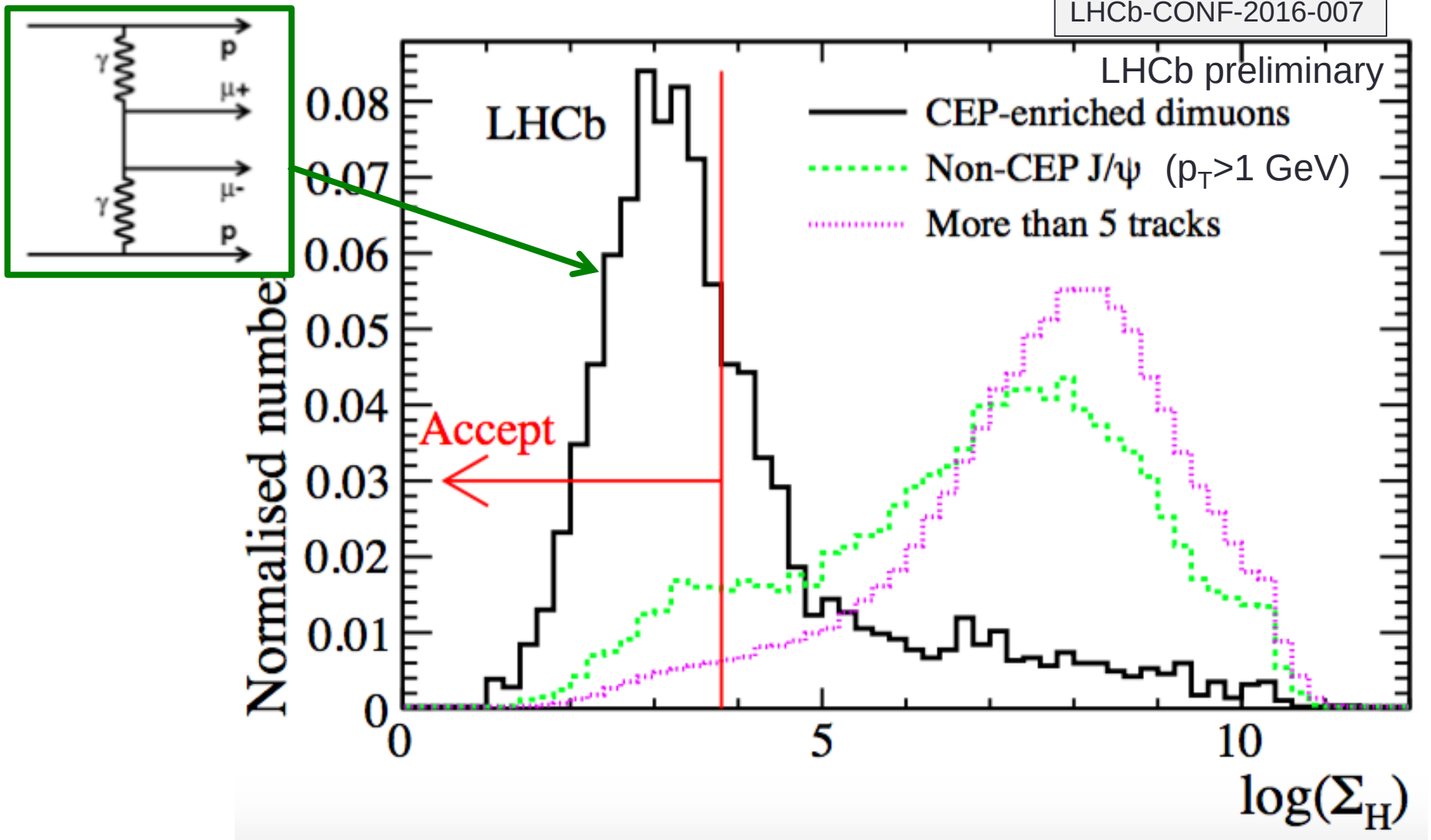
Scintillators and PMTs

Backward Stations

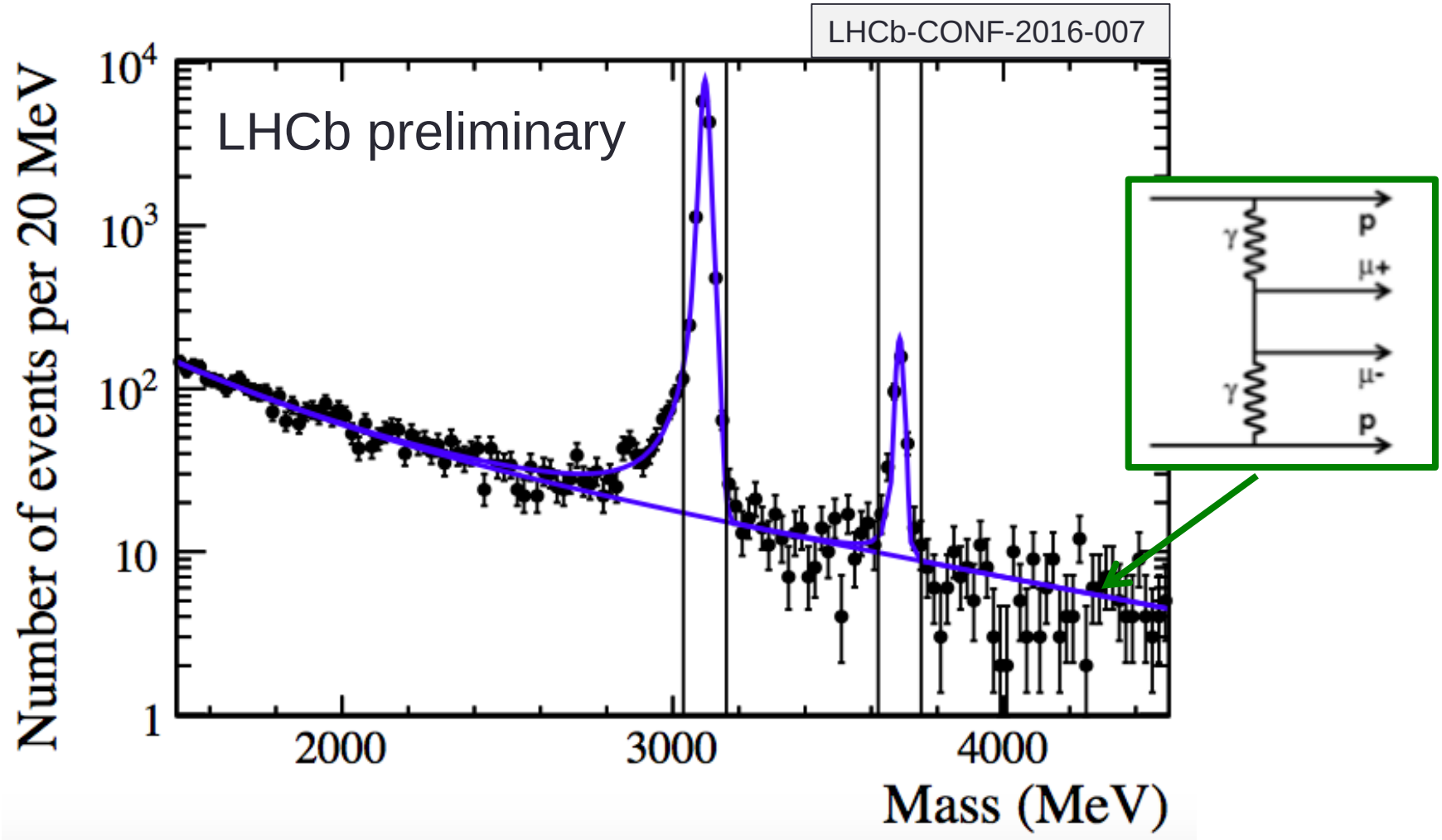
Installation finished in 2014



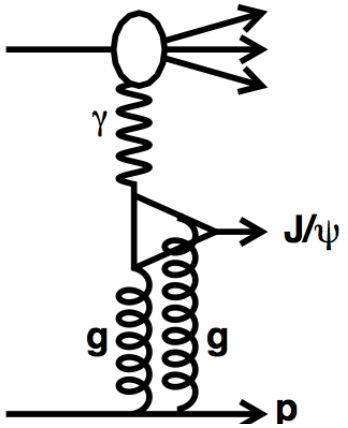
Sum Herschel deposits in quadrature



J/ψ and ψ(2S) at 13TeV

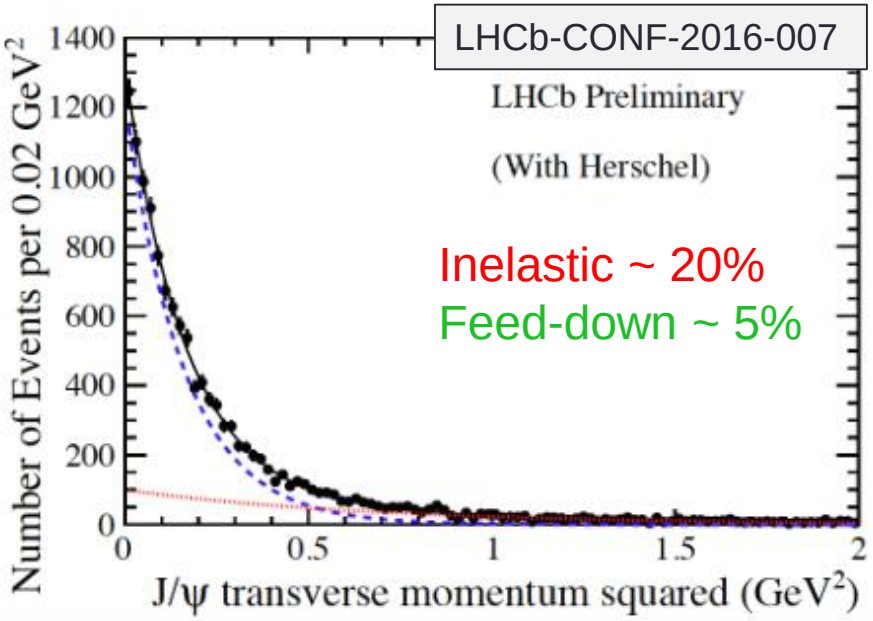


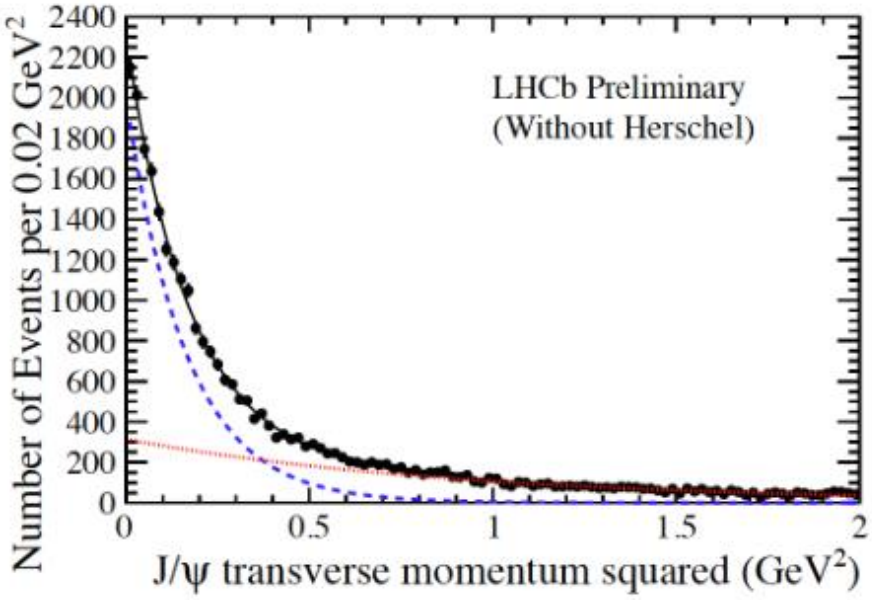
Inelastic background J/ψ



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

b-slope of signal is same with/without Herschel
b-slope of bkg changes (because you veto higher-pT events)





Consistent cross-section results with/without Herschel.
Backgrounds roughly halved using Herschel (but not eliminated.....)

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

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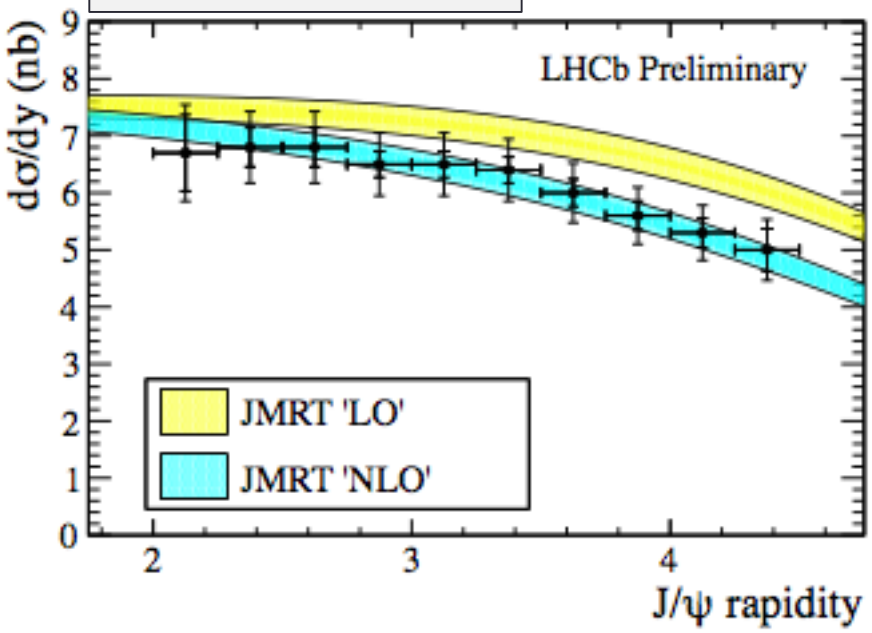
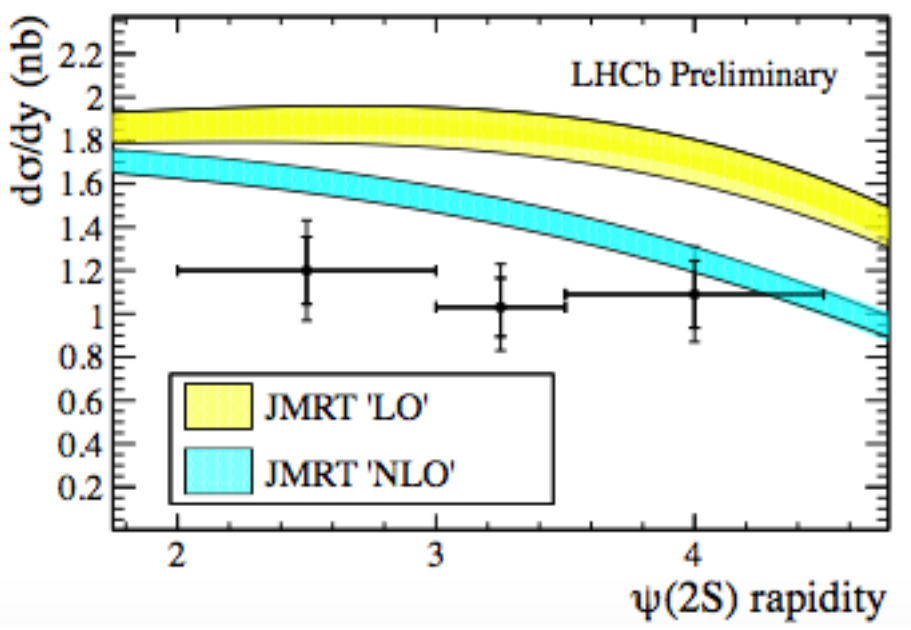


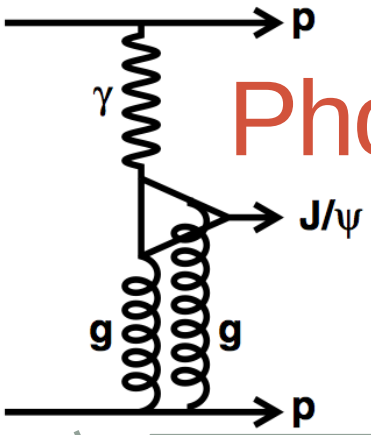


NLO agrees better than LO

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.

S. P. Jones, A. D. Martin, M. G. Ryskin, and T. Teubner, *Predictions of exclusive ψ(2S) production at the LHC*, J. Phys. **G41** (2014) 055009, arXiv:1312.6795.

Photo-production cross-section



LHCb measure

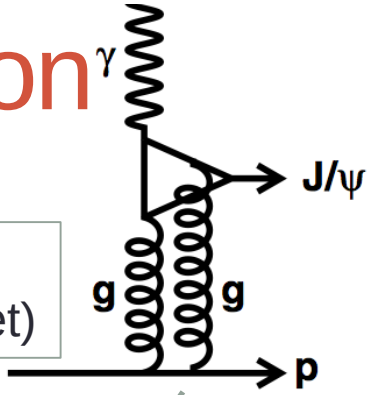


Photo-production
(HERA / fixed target)

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

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 W- solution (in previously measured region). LHCb measures W+

Photo-production cross-section

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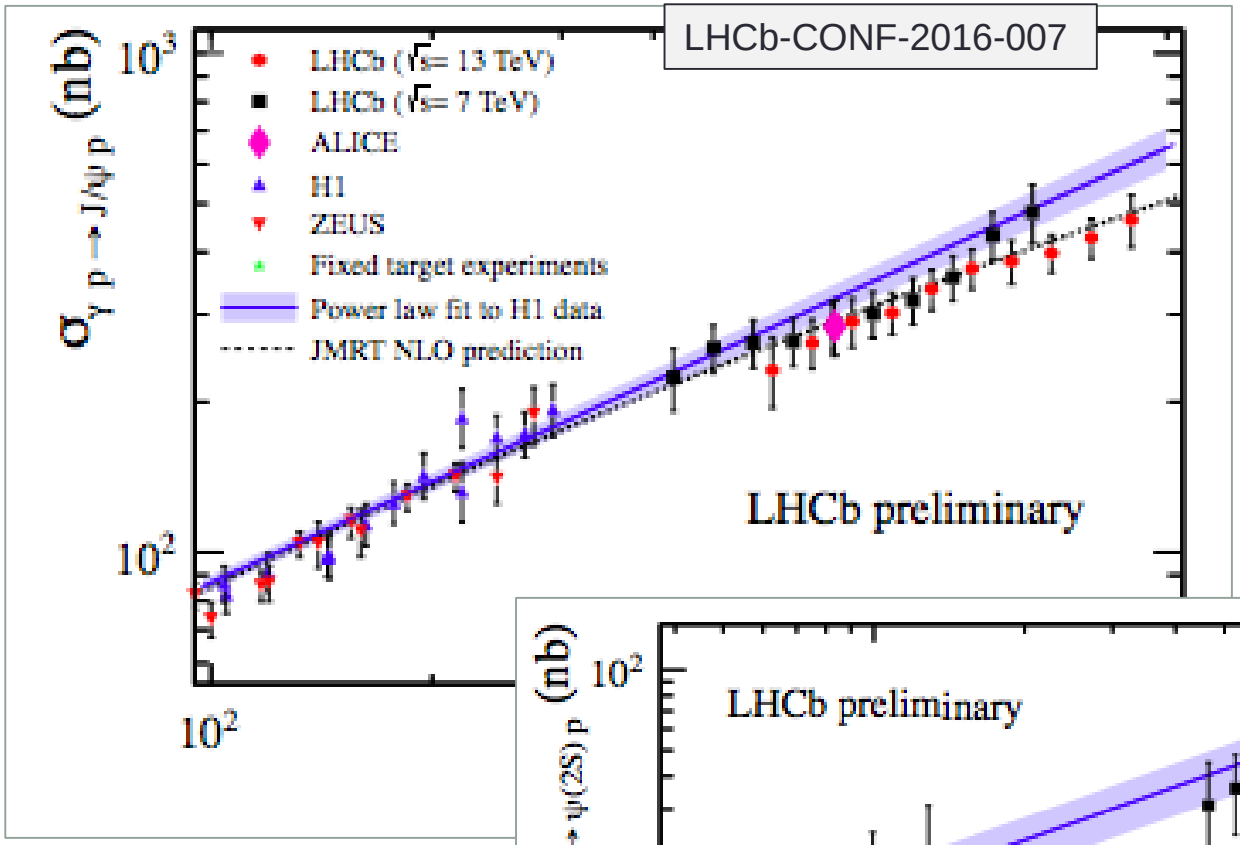
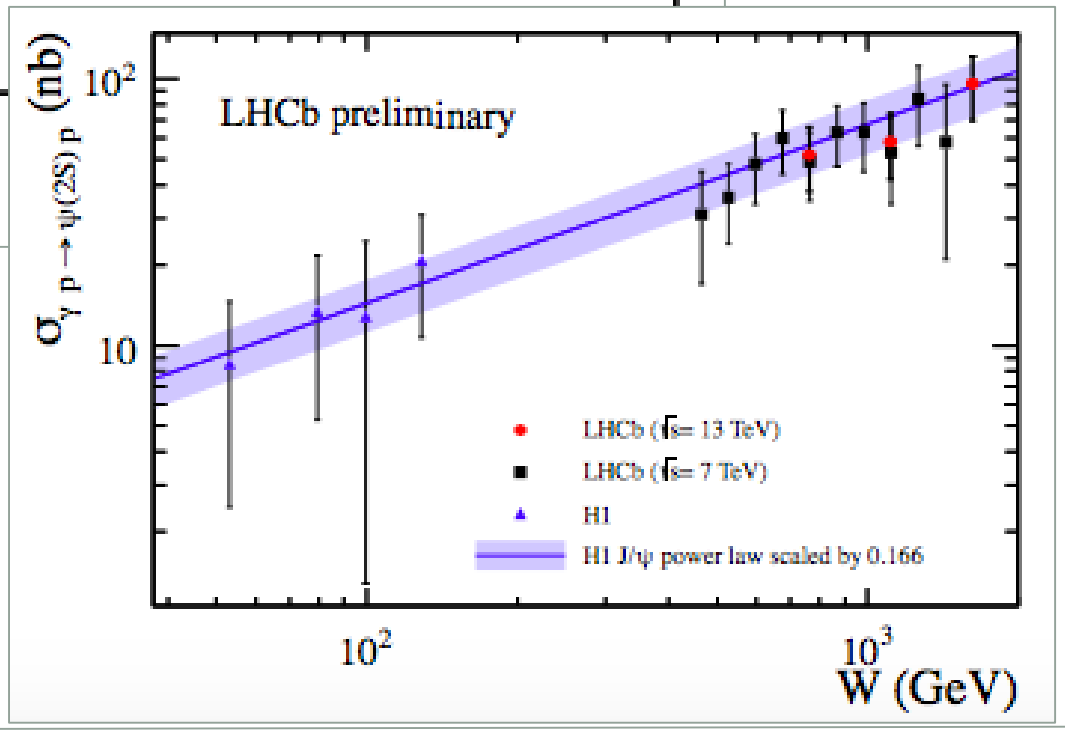


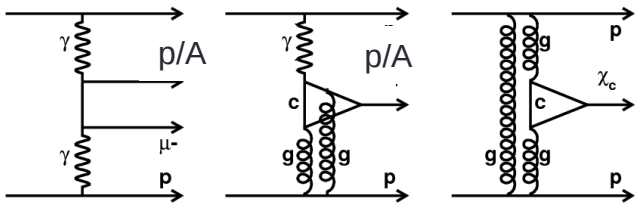
J/ψ

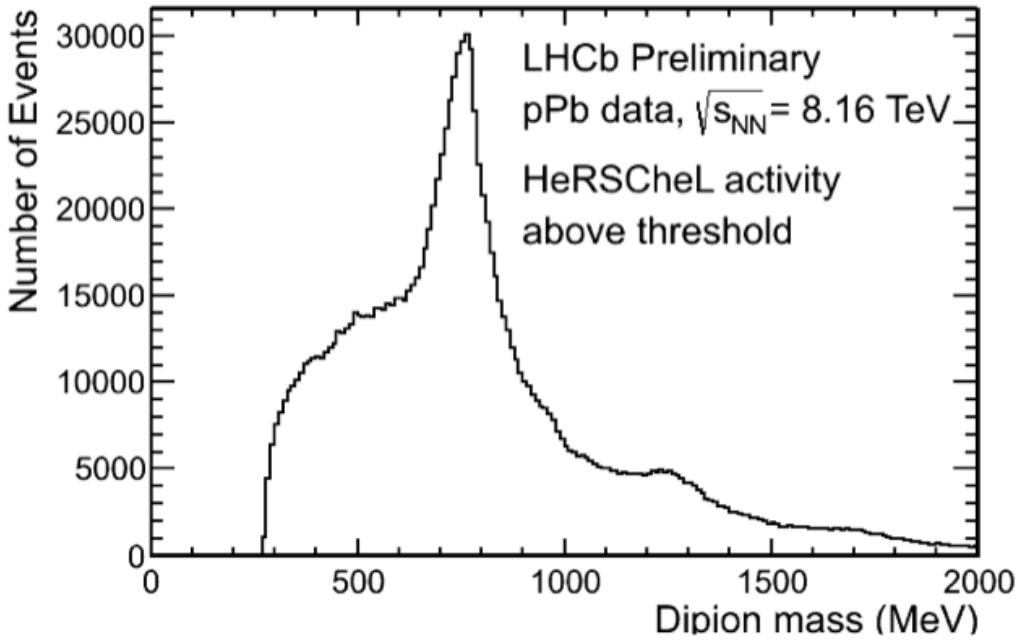


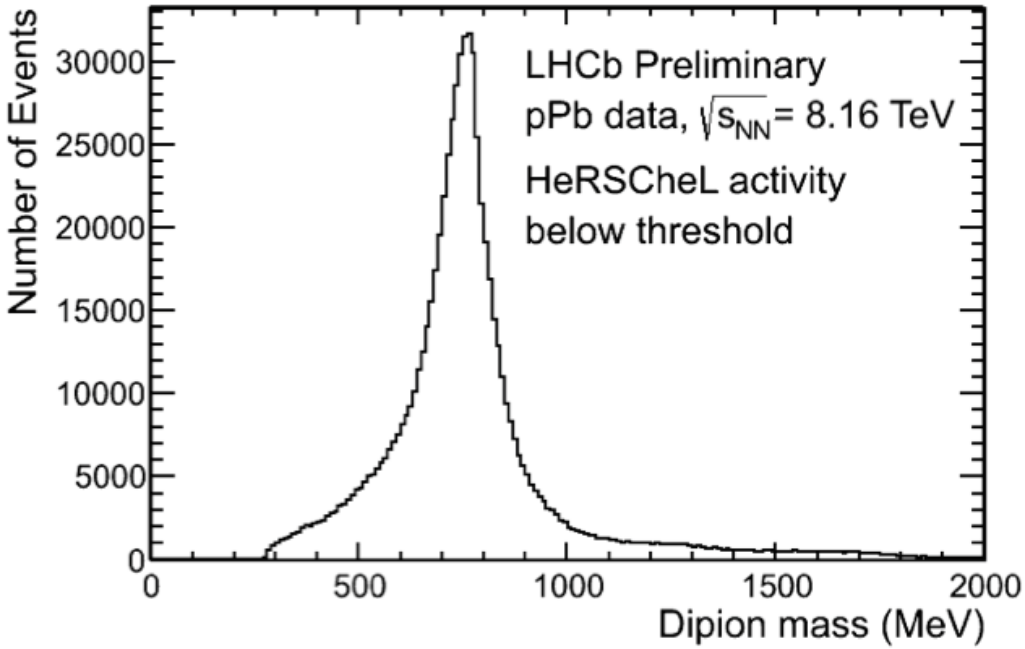
ψ(2S)

Future Analyses

- χc production:
  - Will Herschel enrich the χc0 component?
- Low mass and charm spectroscopy
  - New hadronic triggers selecting pions with pT>100 MeV
  - Ability of Herschel to suppress non-exclusive backgrounds







Summary

- Several CEP pp measurements at 7 and 8 TeV using muons.
- Limited by understanding exclusivity.
- New Herschel detector for Run 2.
- First measurement at 13 TeV with lower backgrounds.
- Excellent prospects for future, including hadronic modes.