

Studies of Onia & Strangeness Production in pp-collisions at LHCb

Nick Brook

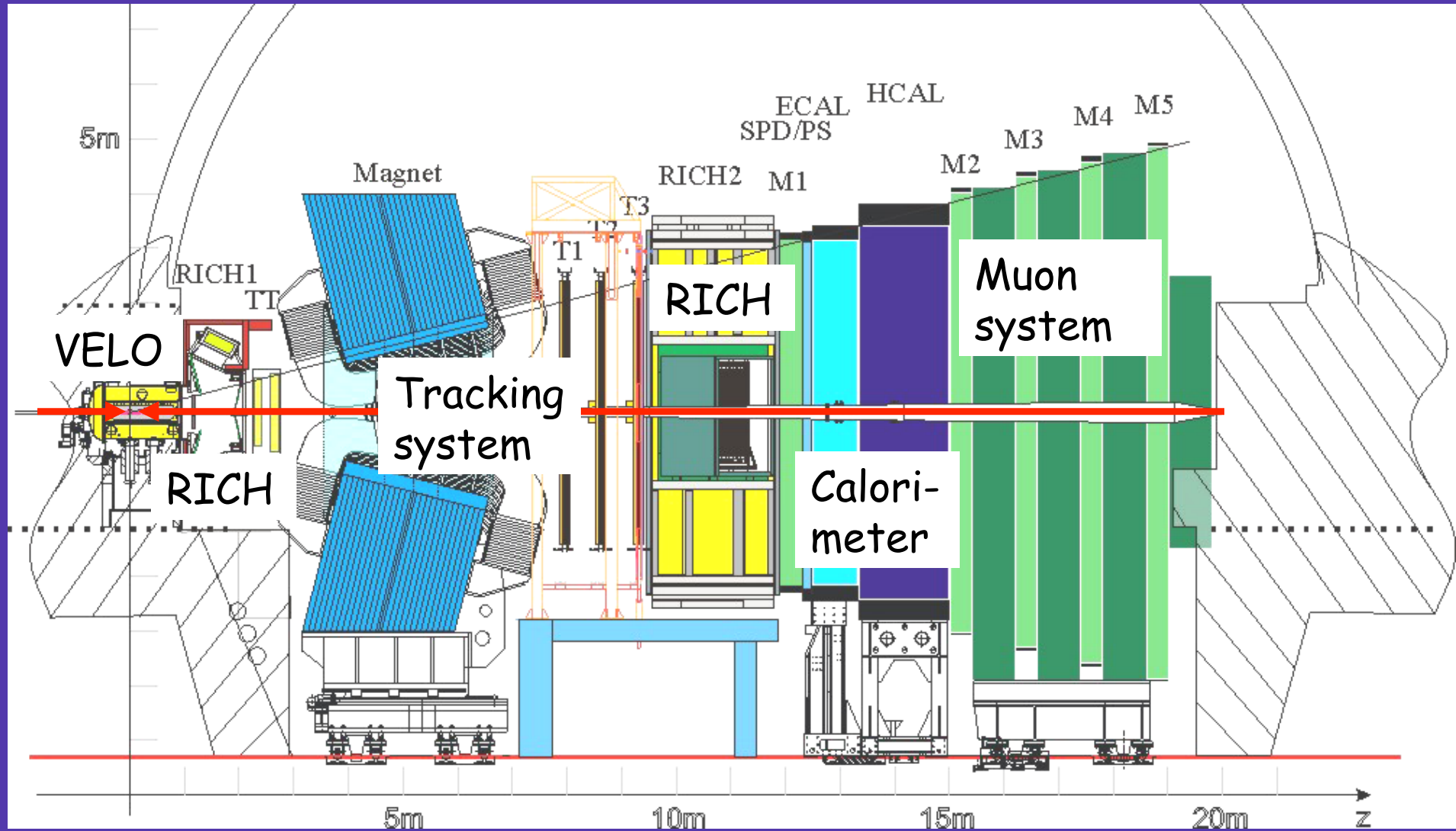
(on behalf of the  collaboration)



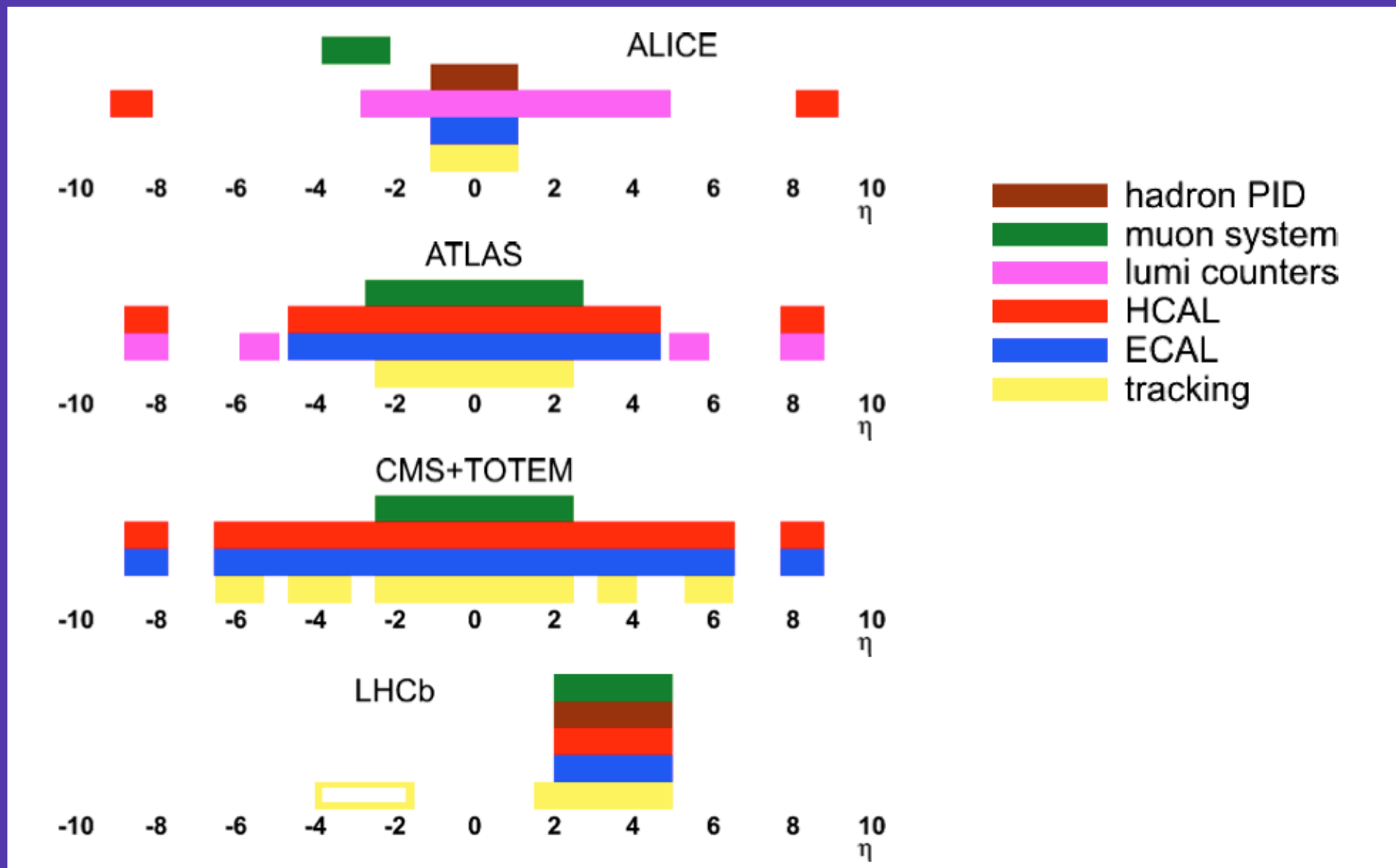
Outline

- LHCb detector
- Quarkonia Production
 - Charmonium, bottomonium, χ_c
 - Double charmonium & associated open charm
- Strangeness Production
 - Charged Particle ratios
 - V^0 production
 - Other strange baryon production

LHCb spectrometer



Acceptance of LHC Expts



Quarkonia Production

Motivation

- Heavy $q\bar{q}$ simple application of QCD(!)
 - Ideal testing ground for QCD
- Experimentally clean
 - Expt calibration
- Radial & orbital excitations
 - Good testing ground from QCD based models

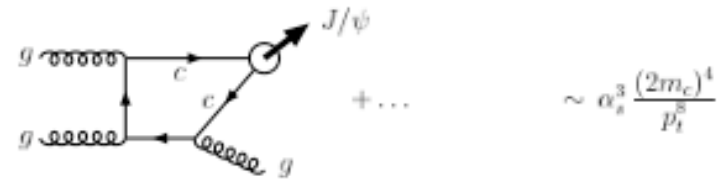
Motivation

- Quarkonia usually described in framework of NRQCD
 - short distance (partonic calculations+PDF)
 - long distance matrix elements for quarkonia production
 - Colour octet(CO) + colour singlet(CS) models - kinematics
 - Problems in describing kinematics & polarisation in consistent manner
- Other models:
 - Colour evaporation model (CEM)
 - heavy quark pair in pQCD not in colour-singlet state
 - Colour & spin of state is "randomized" by soft interactions after production
 - Production of 3S_1 state is now possible via a single gluon

CSM vs COM

- CSM can be thought of as approx NRQCD
 - Only keep leading terms in v
- CSM & COM both also have "fragmentation" contributions
- In fact "fragmentation" is expected to dominate production
 - Colour octet fragmentation expected to dominate
 - BUT...

(a) leading-order colour-singlet: $g + g \rightarrow c\bar{c}[^3S_1^{(1)}] + g$



(b) colour-singlet fragmentation: $g + g \rightarrow [c\bar{c}[^3S_1^{(1)}] + gg] + g$



M. Kramer, Prog.Part.Nucl.Phys.47(2001)
141-201

(c) colour-octet fragmentation: $g + g \rightarrow c\bar{c}[^3S_1^{(8)}] + g$

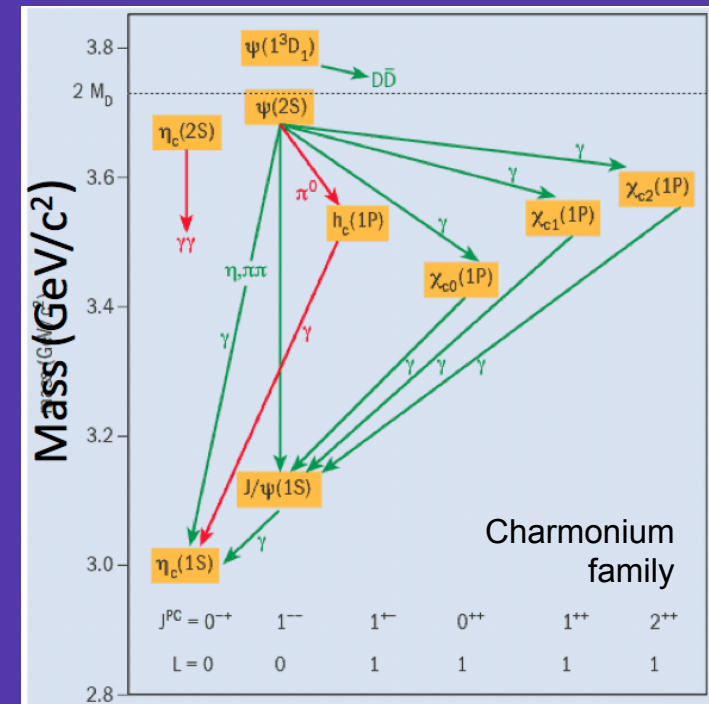
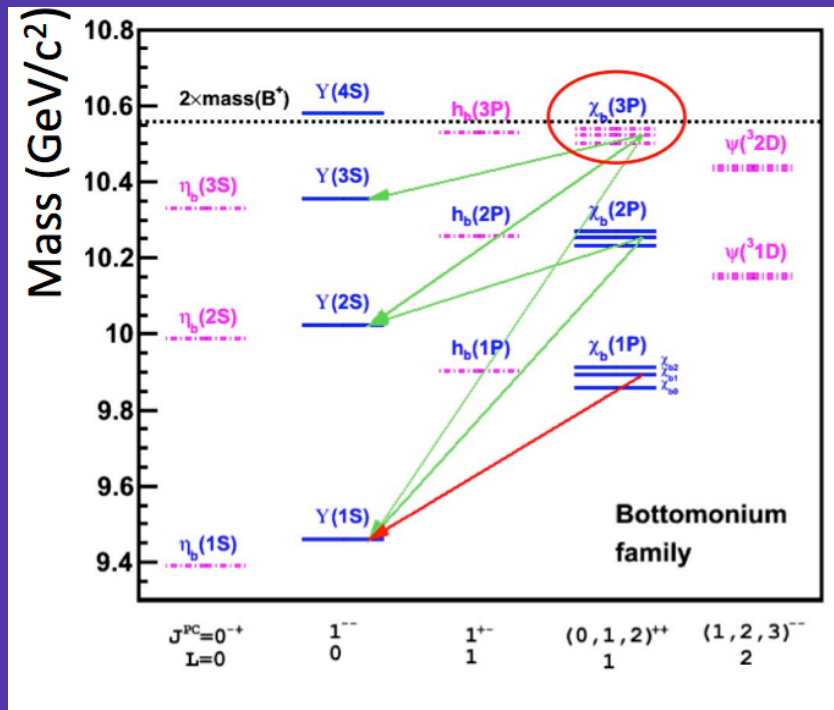


(d) colour-octet t -channel gluon exchange: $g + g \rightarrow c\bar{c}[^1S_0^{(8)}, ^3P_J^{(8)}] + g$



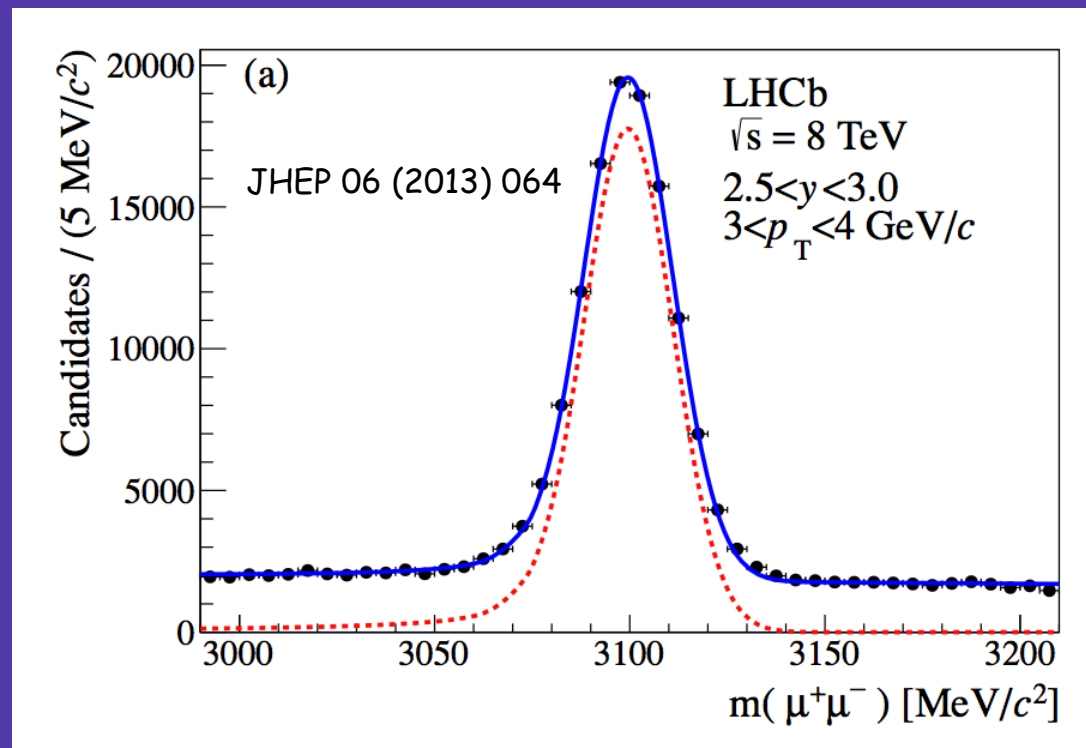
Heavy Onia

- Measurements also important tests of CS & CO production mechanism
 - Feed down fractions
 - Ratio of spin states
- Needed for polarisation measurements



LHCb measurements

- Analysis rapidity range: $2 < y < 4.5$
- Low p_T triggers
 - Track p_T typically $\sim 0.5 \text{ GeV}/c^2$



Quarkonia - prompt charmonia

J.M. Campbell et al. PRL 98 (2007) 252002

M. Butenschoen et al. PRL 106 (2011) 022003

M. Butenschoen et al. PRD 84 (2011) 051501

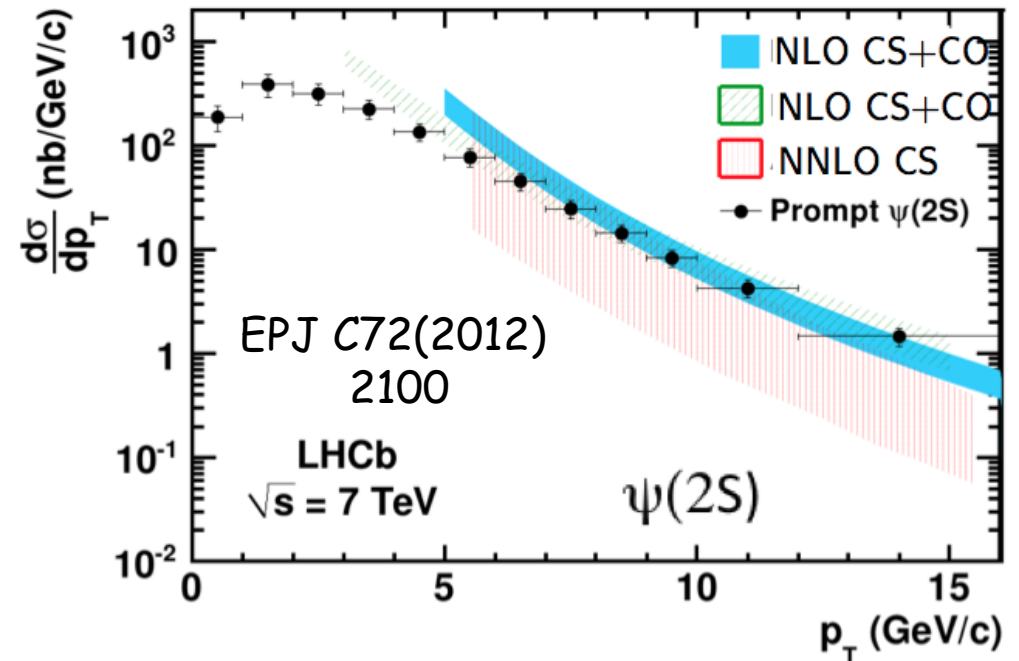
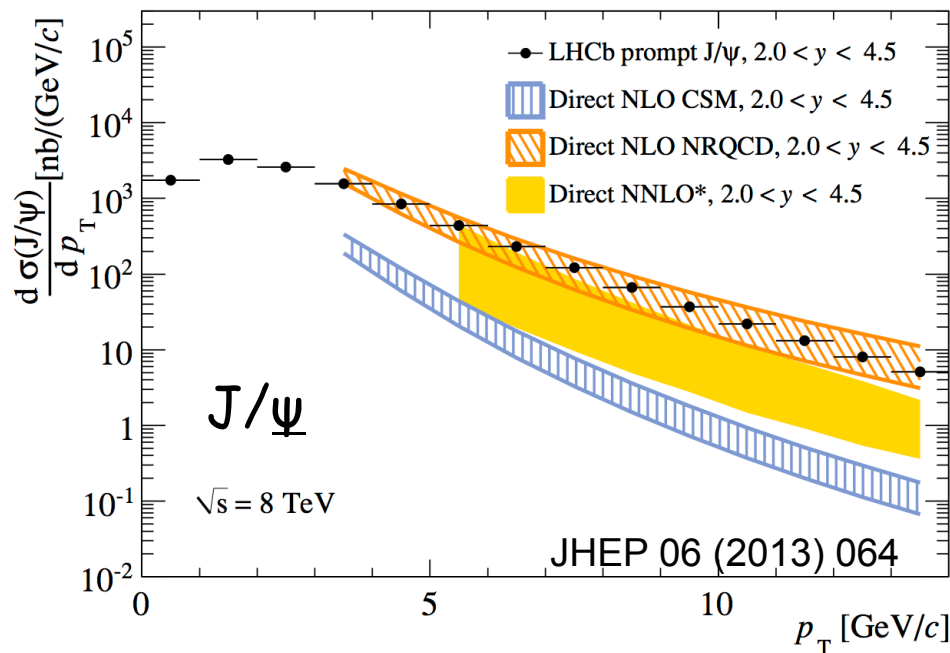
J.-P. Lansberg, EPJ C61 (2009) 693.

Y.-Q. Ma et al. PRD 84 (2011) 114001

B. Kniehl et al. PRL 106 (2011) 022003

P. Artoisenet et al. PRL (2008) 152001

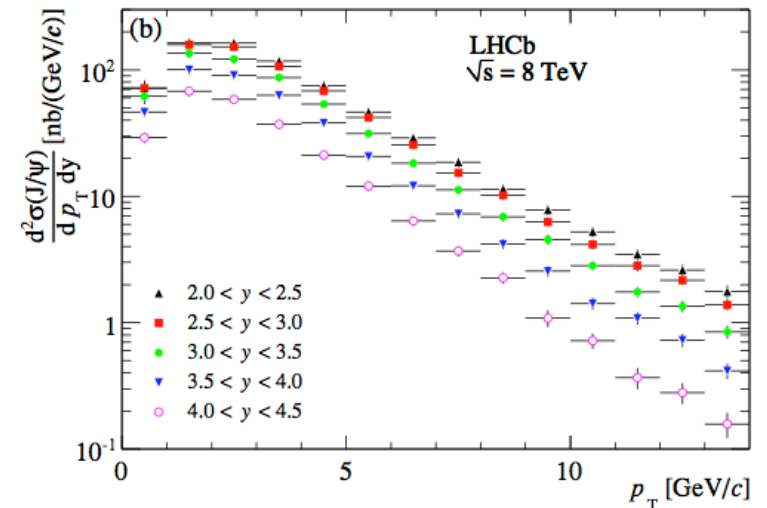
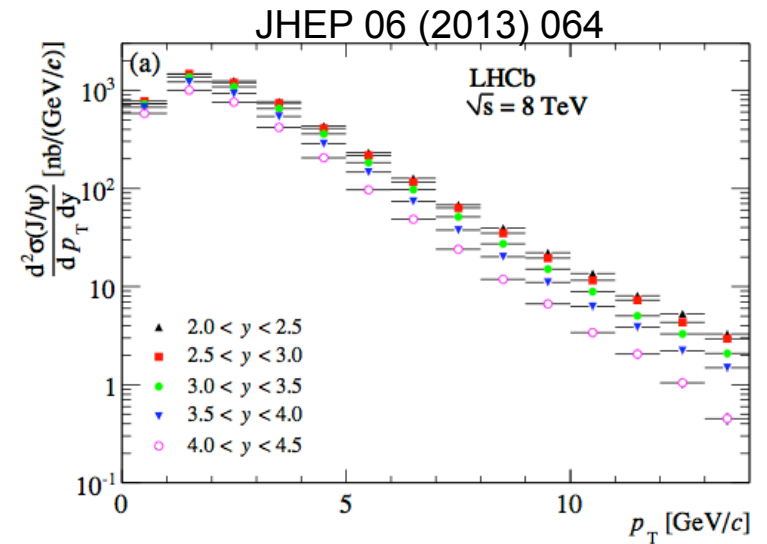
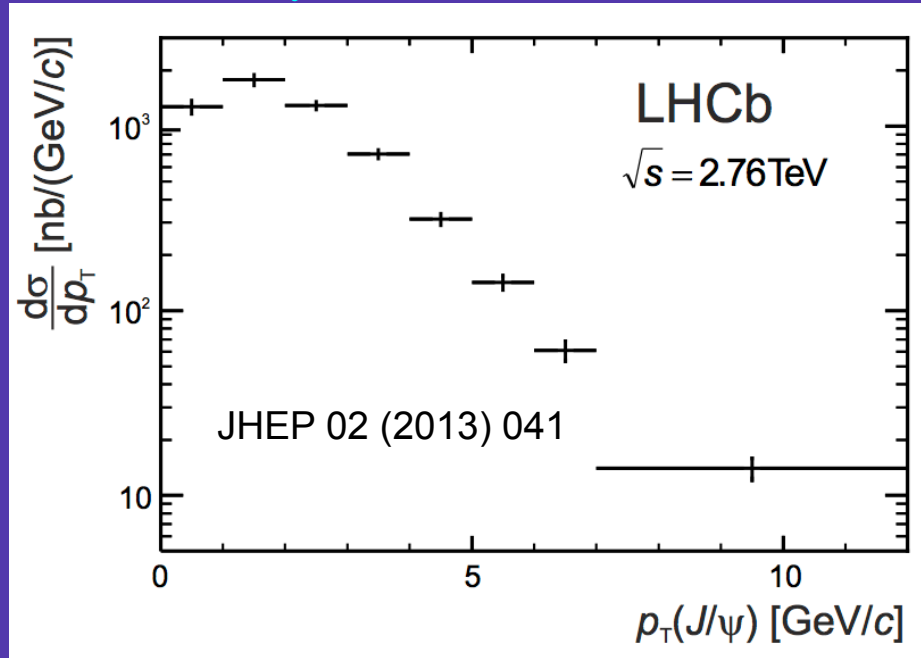
J.-P. Lansberg, EPJ C61 (2009) 693.



- Large p_T tails well reproduced especially in CO models

Quarkonia

Prompt J/ψ



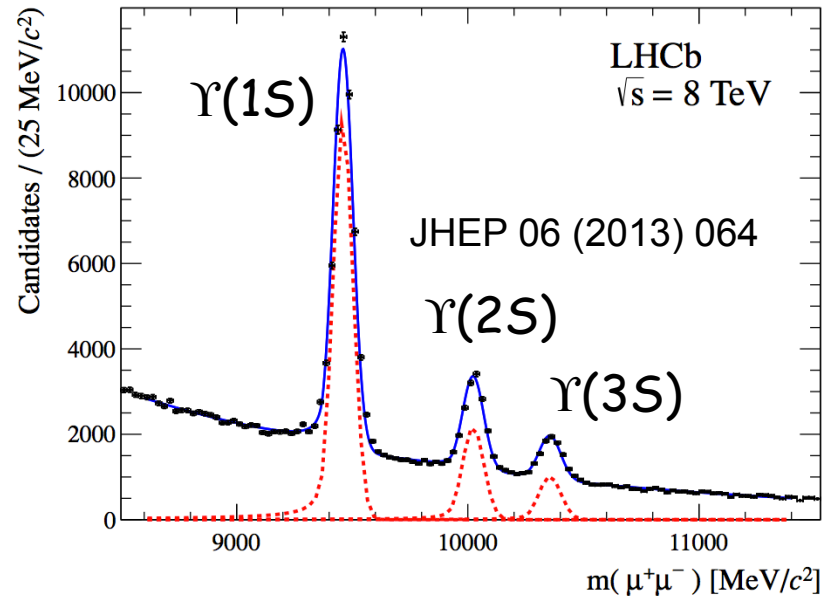
$$\sigma(\text{prompt } J/\psi, p_T < 14 \text{ GeV}/c, 2.0 < y < 4.5, \sqrt{s} = 8 \text{ TeV}) = 10.94 \pm 0.02 \pm 0.79 \mu\text{b}$$

$$\sigma(\text{prompt } J/\psi, p_T < 12 \text{ GeV}/c, 2.0 < y < 4.5, \sqrt{s} = 2.76 \text{ TeV}) = 5.6 \pm 0.1 \pm 0.4 \mu\text{b}$$

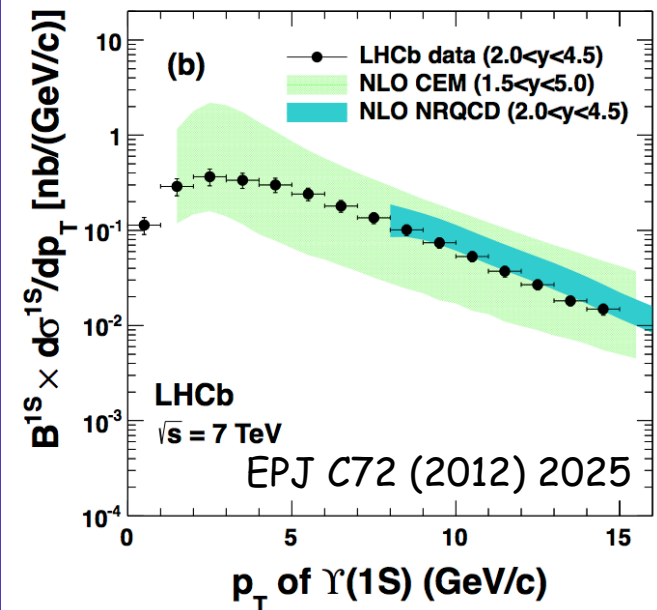
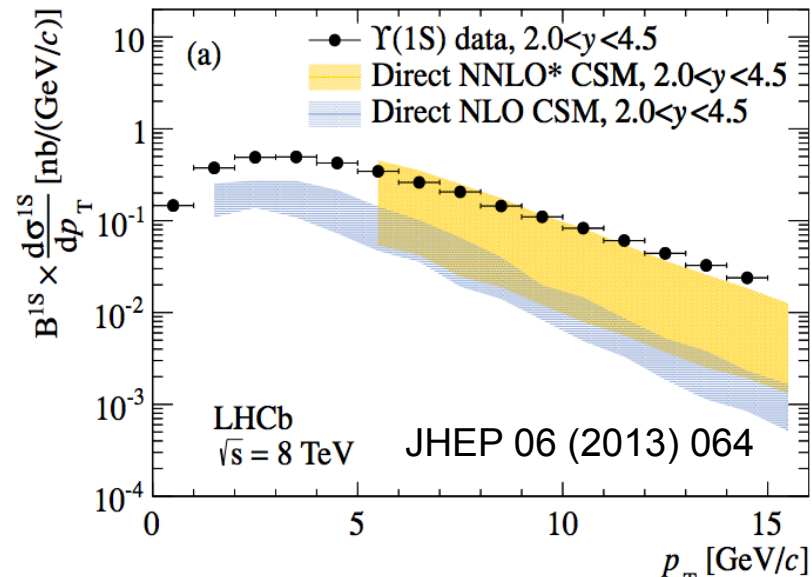
Quarkonia - Prompt bottomonium

- Discrimination of theoretical models not yet feasible with differential dist^{bn}
 - except NLO CSM out by order of magnitude

J.M. Campbell et al PRL 98 (2007) 252002
 P. Artoisenet et al PRL 101 (2008) 152001



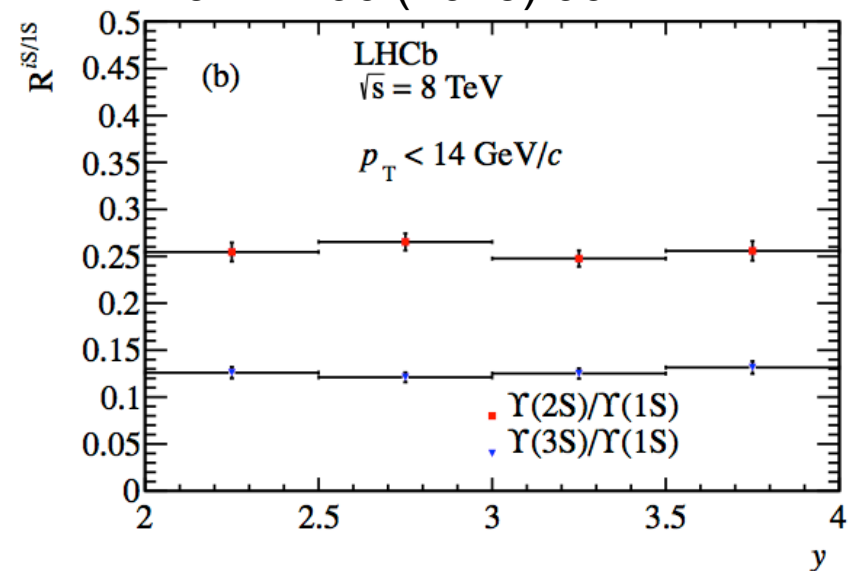
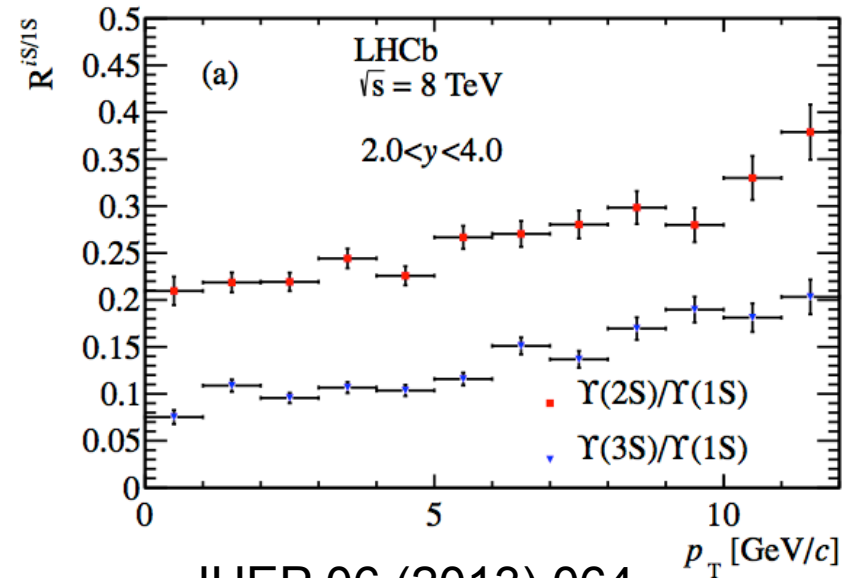
CEM: Y.-Q. Ma et al. PRD 84 (2011) 114001
 NRQCD: A.D. Frawley et al. Phys.Rep. 462 (208) 125



Quarkonia @ 8TeV

Ratio of Upsilon production flat as a function of y & increases as a function of p_T

Results consistent with 7 TeV observation



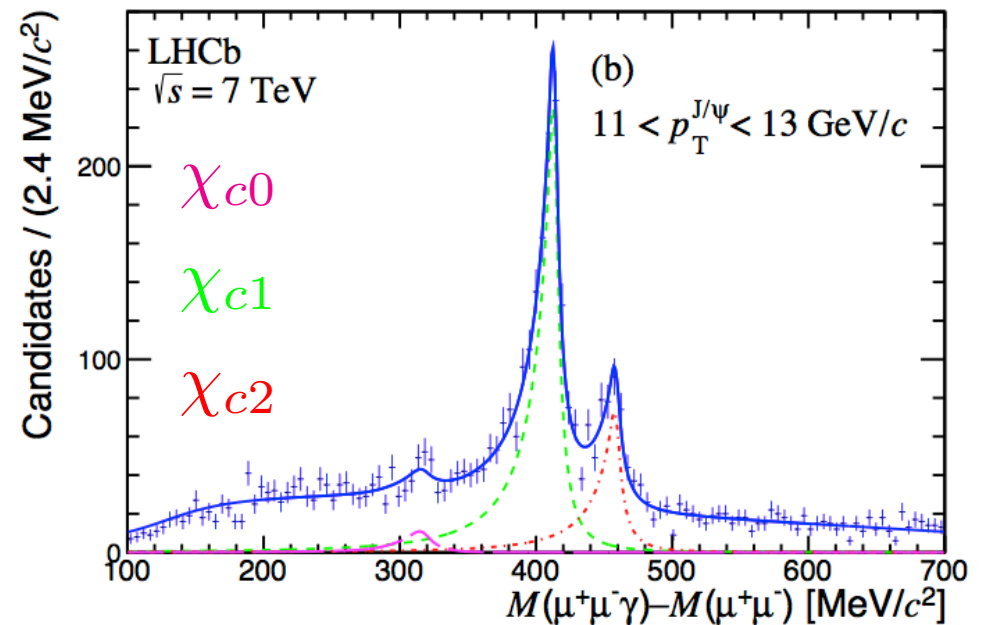
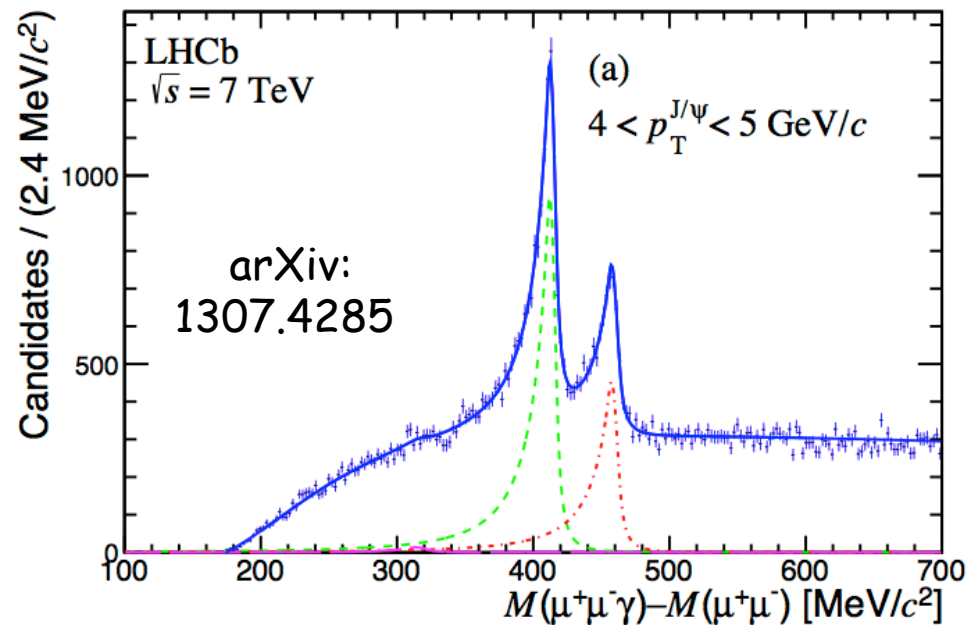
Higher Excited Onia

- Photons can be identified
 - Directly in ECAL
 - Converted before magnet

$$\chi_{cJ}(nP) \rightarrow J/\Psi \gamma$$

Phys.Lett. B714 (2012) 215
Phys.Lett.B718 (2012) 431
arXiv:1307.4285

First evidence of χ_{c0} at a hadron collider

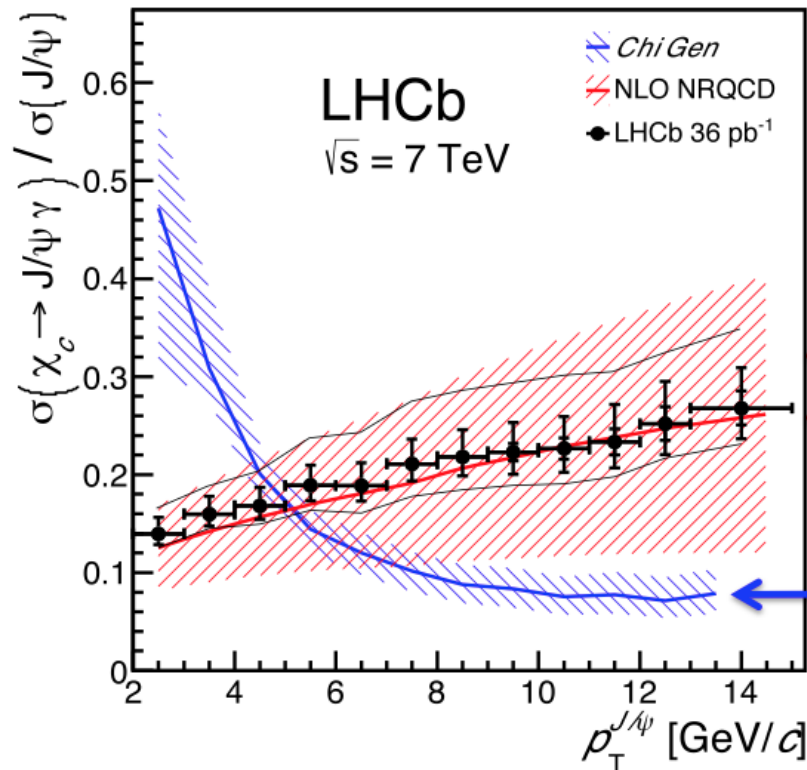


Heavy Onia: χ_c

$$\chi_{cJ}(nP) \rightarrow J/\Psi\gamma$$

$$\frac{\sigma(\chi_c \rightarrow J/\Psi\gamma)}{\sigma(J\Psi)} \approx \frac{\sigma(\chi_c \rightarrow J/\Psi\gamma)}{\sigma^{\text{dir}}(J\Psi) + \sigma(\Psi(2S) \rightarrow J/\Psi X) + \sigma(\chi_c \rightarrow J/\Psi\gamma)}$$

$$2 < \gamma_{J/\psi} < 4.5 \quad 2 < p_{T J/\psi} < 15 \text{ GeV}/c$$



PLB 718 (2012) 431

NRQCD: Y.-Q. Ma et al.
PRD 83 (2011) 111503

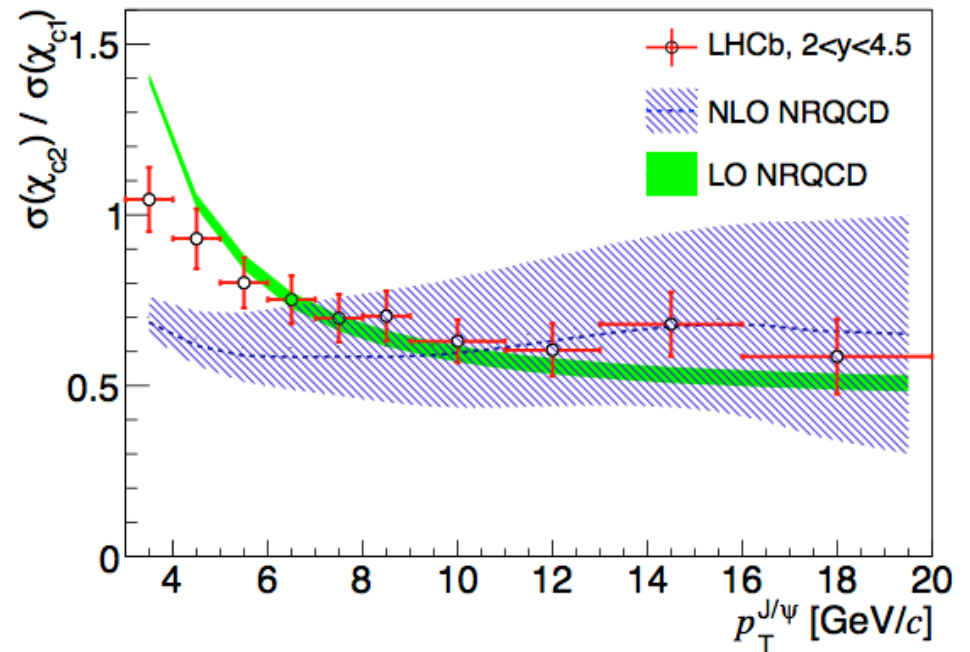
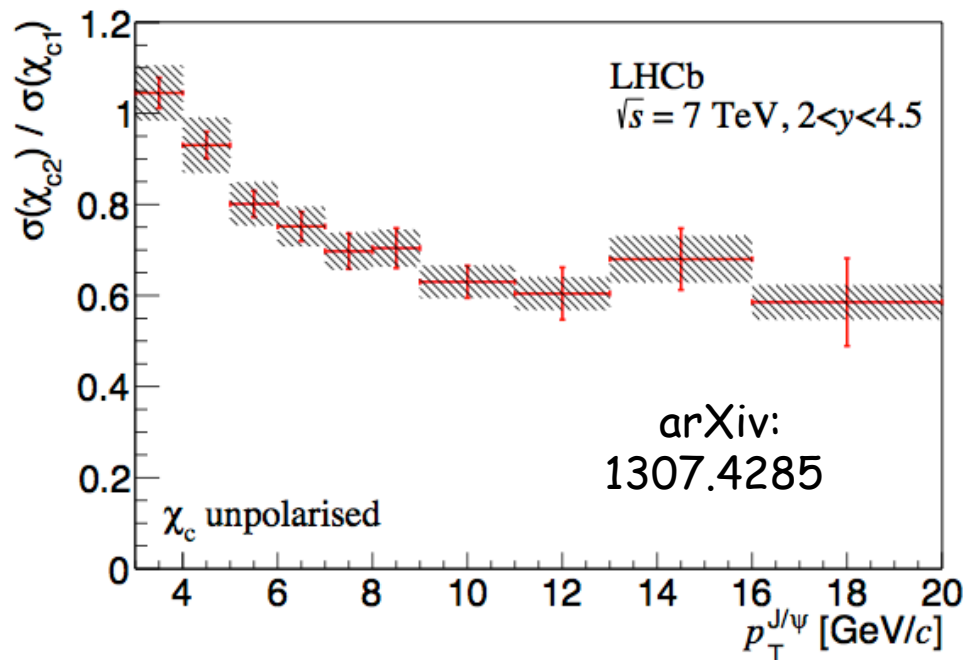
Maximum effect due
to polarization of χ_c
and J/ψ

LO CS model
L. Harland-Lang & W.J.Stirling

LO CS model
fails to
describe
data

Higher Excited Onia

$$\chi_{cJ}(nP) \rightarrow J/\Psi \gamma$$



NLO NRQCD: Y.-Q. Ma et al. PRD 83 (2011) 111503

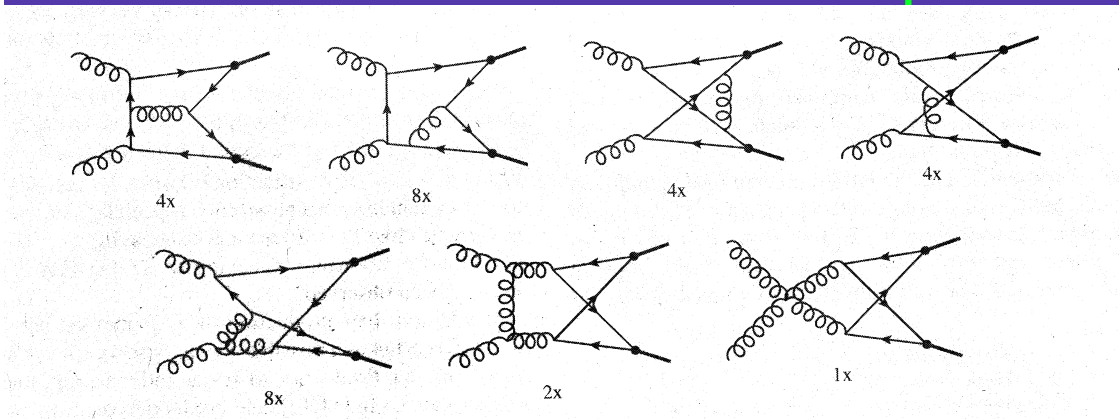
LO NRQCD: A. Likhoded et al. arXiv:1305.2389

Good agreement with NLO NRQCD
prediction

Multiple Quarkonia Production & associated open charm

Double J/ψ production

- Production of multiple heavy flavour states tests
 - pQCD (dominantly gluon fusion @ LHC)
 - Double parton scattering (DPS)
 - Intrinsic charm of the proton



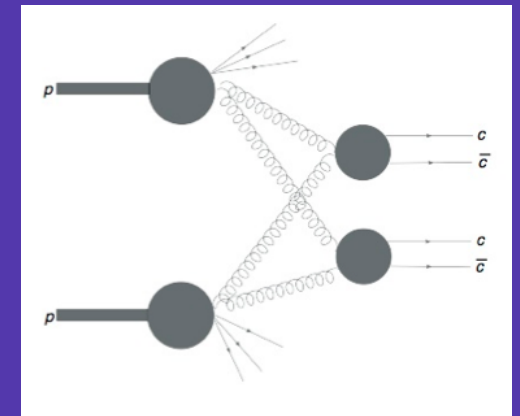
gg fusion

LHCb: $2 < \gamma_{J/\psi} < 4.5$ $p_{T J/\psi} < 10 \text{ GeV}/c$

$$\sigma^{J/\psi J/\psi} = 5.1 \pm 1.01 \pm 1.1 \text{ nb}$$

$$\sigma^{J/\psi J/\psi}$$

$$\frac{\sigma^{J/\psi J/\psi}}{\sigma^{J/\psi}} = (5.1 \pm 1.0(\text{stat}) \pm 0.6(\text{syst})_{-1.0}^{+1.2}(\text{pol})) \times 10^{-4}$$



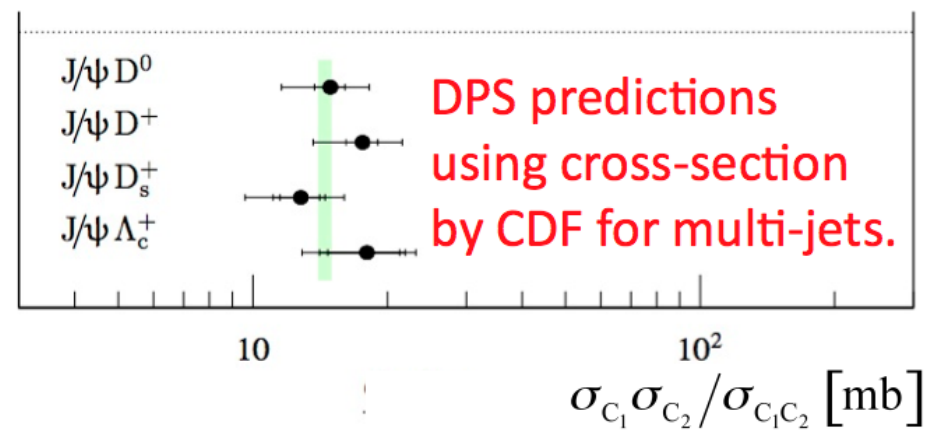
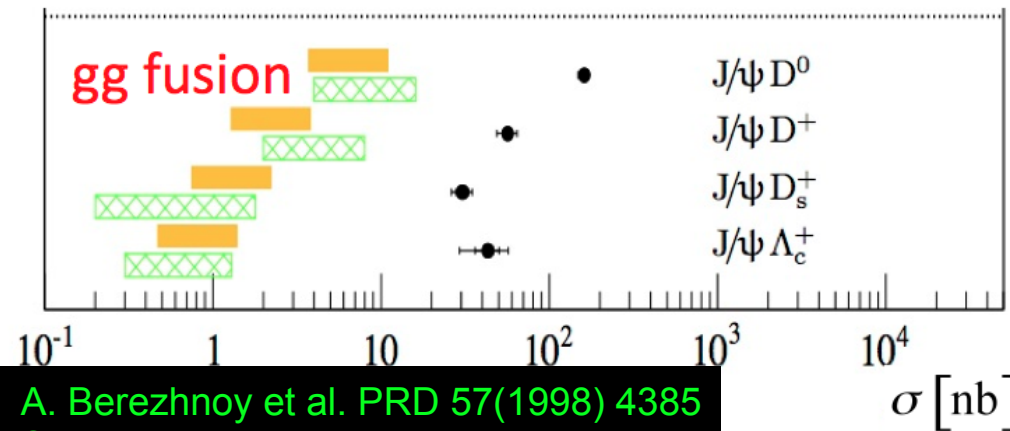
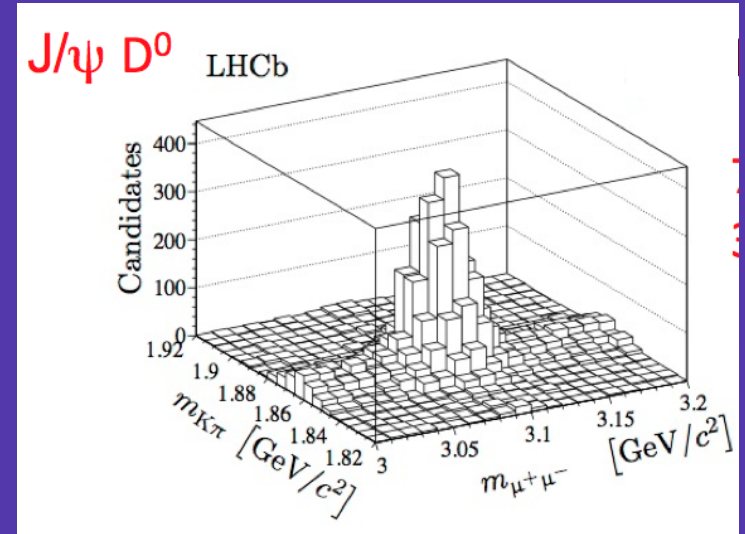
DPS

Phys.Lett. B707
(2012) 52

J/ψ production & associated charm

LHCb: $2 < \gamma_{J/\psi} < 4$ $p_{T J/\psi} < 12 \text{ GeV}/c$;
 $2 < \gamma_{\text{charm}} < 4$ $3 < p_{T \text{charm}} < 12 \text{ GeV}/c$

JHEP 06 (2012) 141



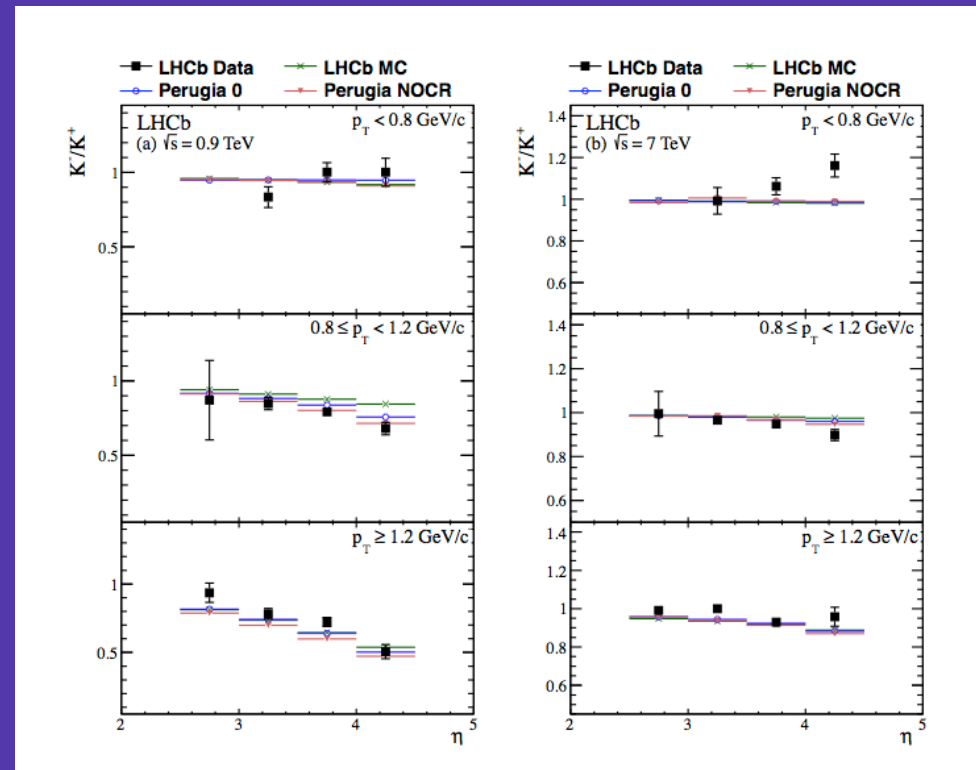
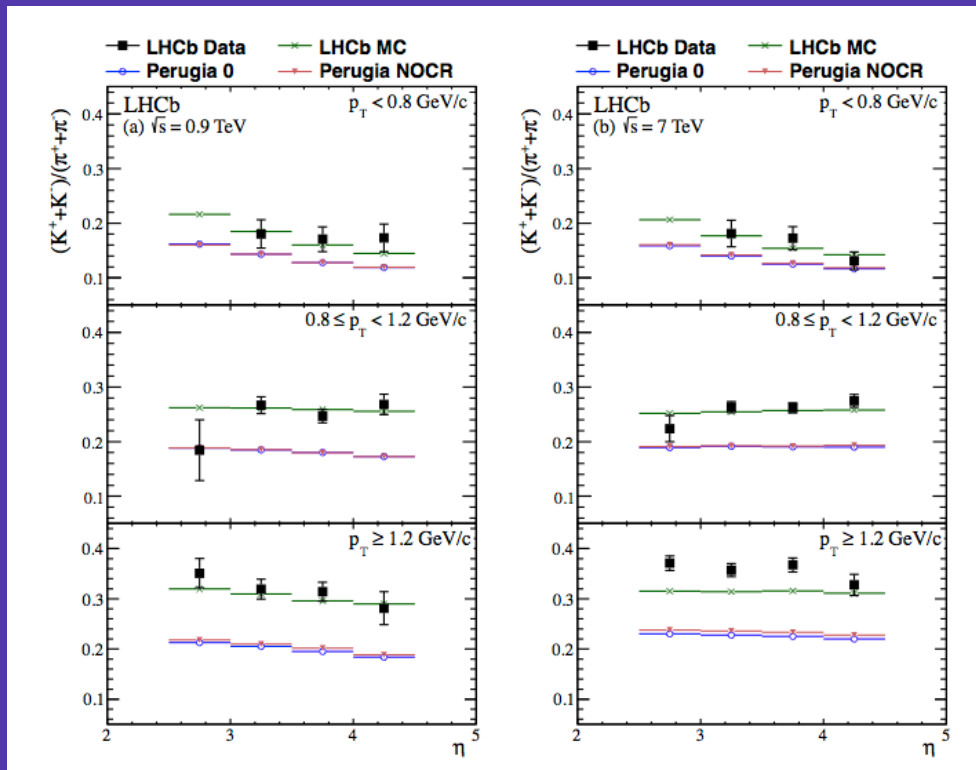
A. Berezhnoy et al. PRD 57(1998) 4385
 S. Baranow PRD 73 (2006) 074021
 J.-P. Landsberg EPJ C61 (2009) 693

• Measured X-sections suggest DPS needed

Strange Particle Production

Charged kaon production

Eur.Phys.J. C72 (2012)
2168

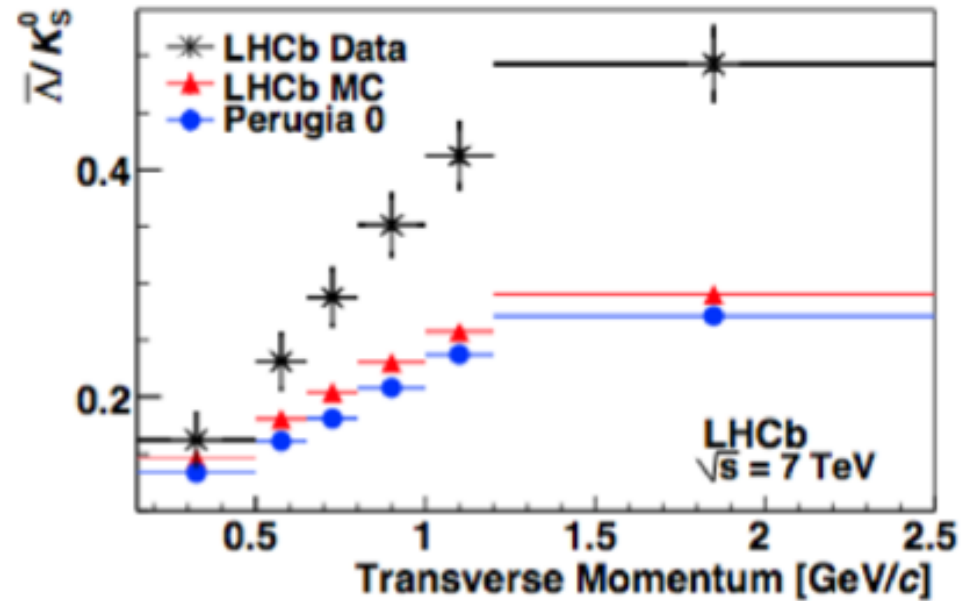
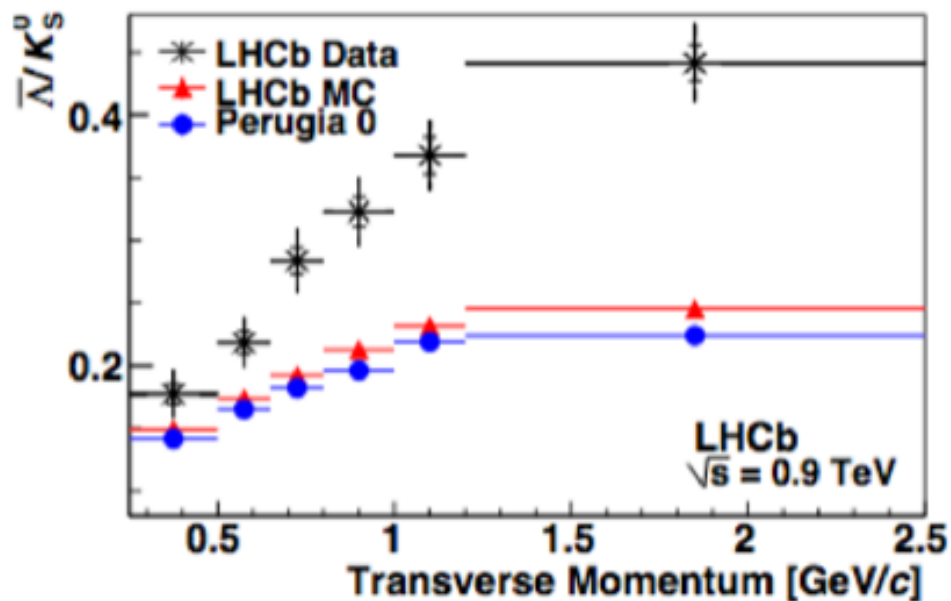


K/π ratio best described
by LHCb tune (I. Belyaev et al
IEEE Nucl.Sci.Symp.Conf.Rec. (2010) 1155)

Clear rise as $p_T \uparrow$

+/- ratio not unity.
In general well
described by MC
models.

$\Lambda(\Lambda\text{bar})/K_S^0$ production ratios



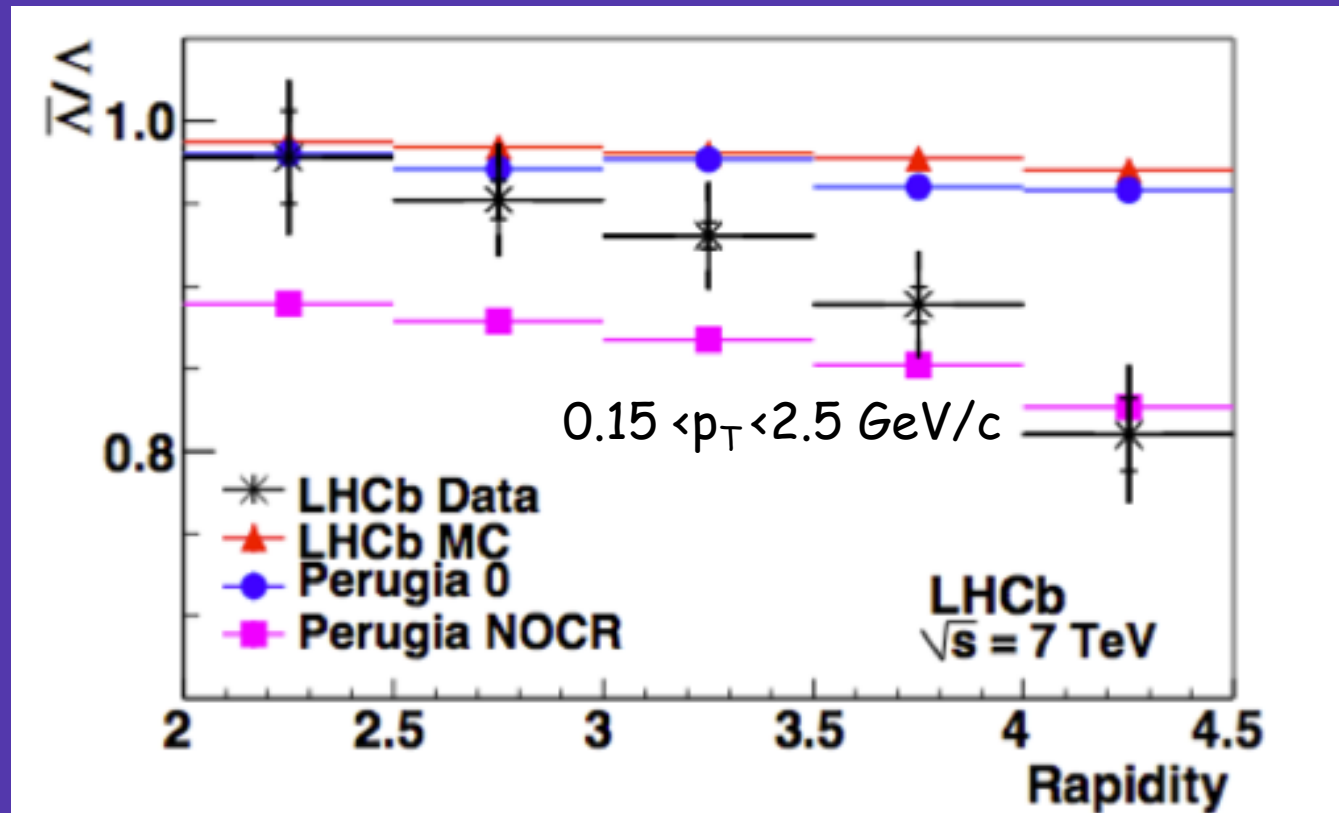
Ratio rises at p_T raises as expected

Rise in forward region greater than MC predictions

JHEP 08 (2011) 034

Λ production ratios

JHEP 08 (2011) 034

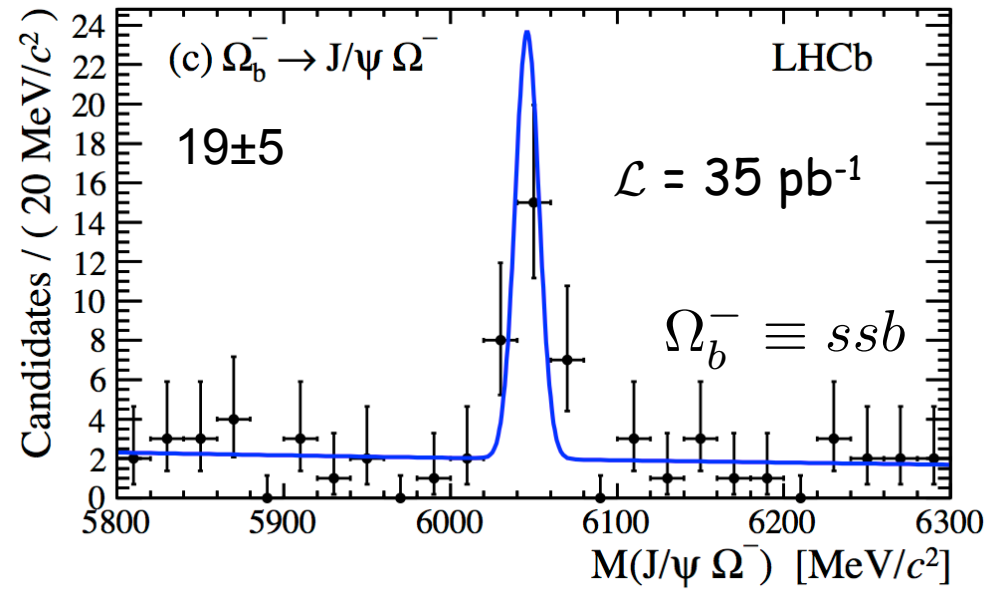
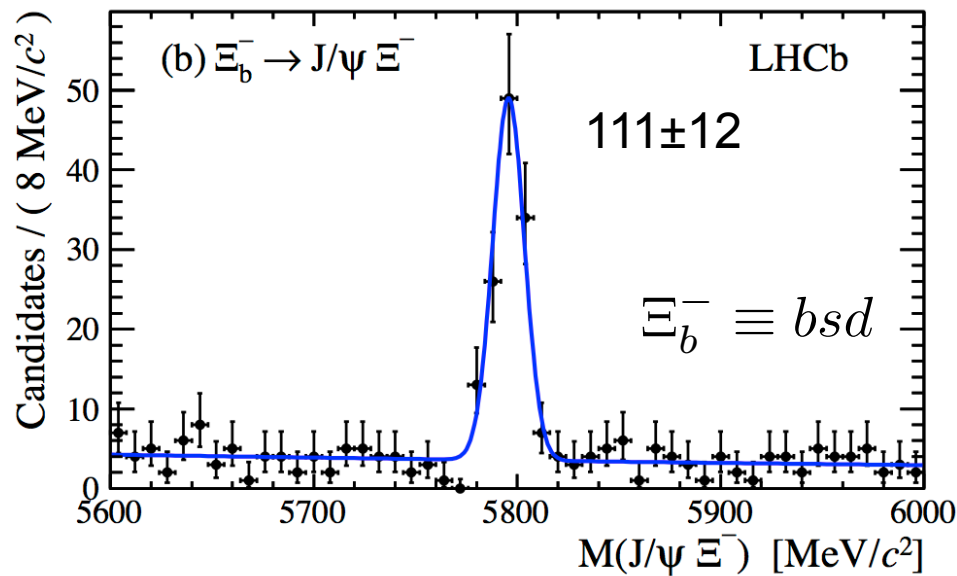


AntiParticle/particle ratio flat (~ 1) in central region

Ratio falls off go to forward region

MC predictions remain essentially flat

Ω_b^- & Ξ_b^- production



	$M(\Xi_b^-) \text{ (MeV}/c^2)$	$M(\Omega_b^-) \text{ (MeV}/c^2)$
CDF	5790.9 ± 2.7	6054.4 ± 6.9
DO	5774 ± 19	6165 ± 16
PDG	5791.1 ± 2.2	6071 ± 40
LHCb	5795.8 ± 1.0	6046.0 ± 2.3

Test of constituent quark models/
 lattice QCD

World's most precise mass measurements

Summary & Prospects

- LHCb has very many important production results
 - First observations
 - X-section measurements
 - Evidence for the importance of DPS
 - Excited quarkonia
- Polarisation measurements on the way
- More detailed studies of kinematic distribution of double J/ψ production
- Unique measurements on the forward rapidity region
- Much data still to analyse
 - $\mathcal{L} = 2.08 \text{ fb}^{-1}$ (2012); $\mathcal{L} = 1.1 \text{ fb}^{-1}$ (2010-11)