Production measurements at LHCb: Electroweak Bosons, Jets and Heavy Flavor

Low-x meeting, Bari, June 13-17

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LHCb

Outline

recent results on production of

- electroweak bosons (plus jets)
- top
- open charm
- bottom: production asymmetry
- J/ψ: @13 TeV, in jets (new)
- double parton scattering
  ϒ plus open charm, double J/ψ (new)

in pp collisions at LHC with

centre of mass energies of 5, 7, 8 and 13 TeV

LHCb detector

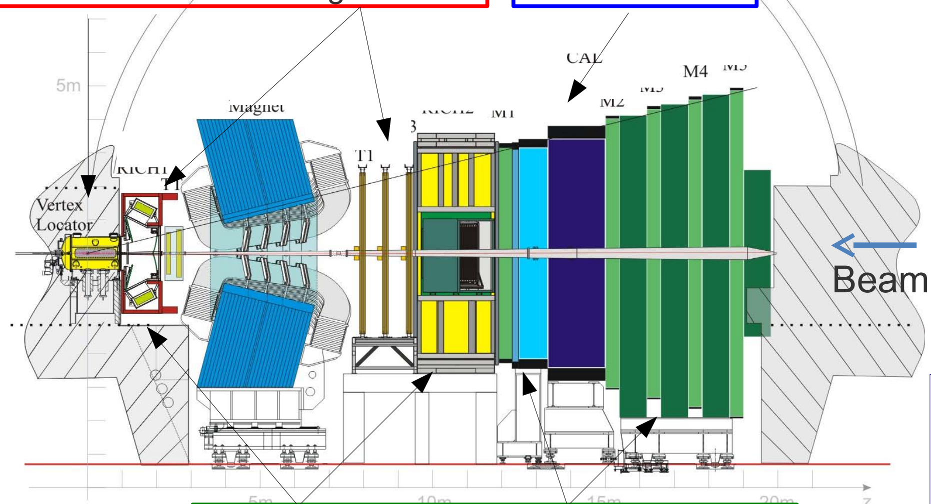
Int. J. Mod. Phys. A 30 (2015) 1530022

- single arm spectrometer – designed for precision measurements in b and c physics
- fully instrumented in the forward region ($2 < \eta < 5$)
- some detection capability in backward region ($-3.5 < \eta < -1.5$)
- very flexible trigger → able to trigger on low momentum objects
- run II: additional scintillators upstream and downstream (up to 114 m)
  ($-8 < \eta < -1.5$, $2 < \eta < 8$)

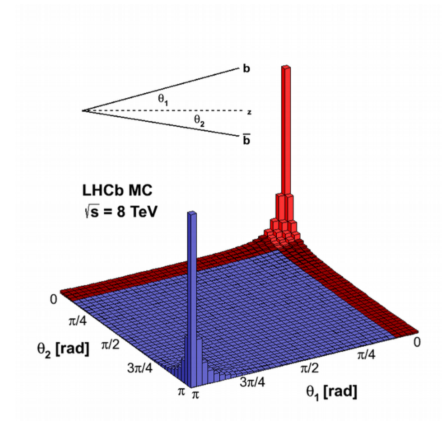
Momentum & Vertices: Vertex locator, Tracking stations

Energy: Calorimeters

Beam 1 → ← Beam 2



Particle ID: RICH detectors, Muon stations



25% of b-bbar pairs in LHCb acceptance

data sets

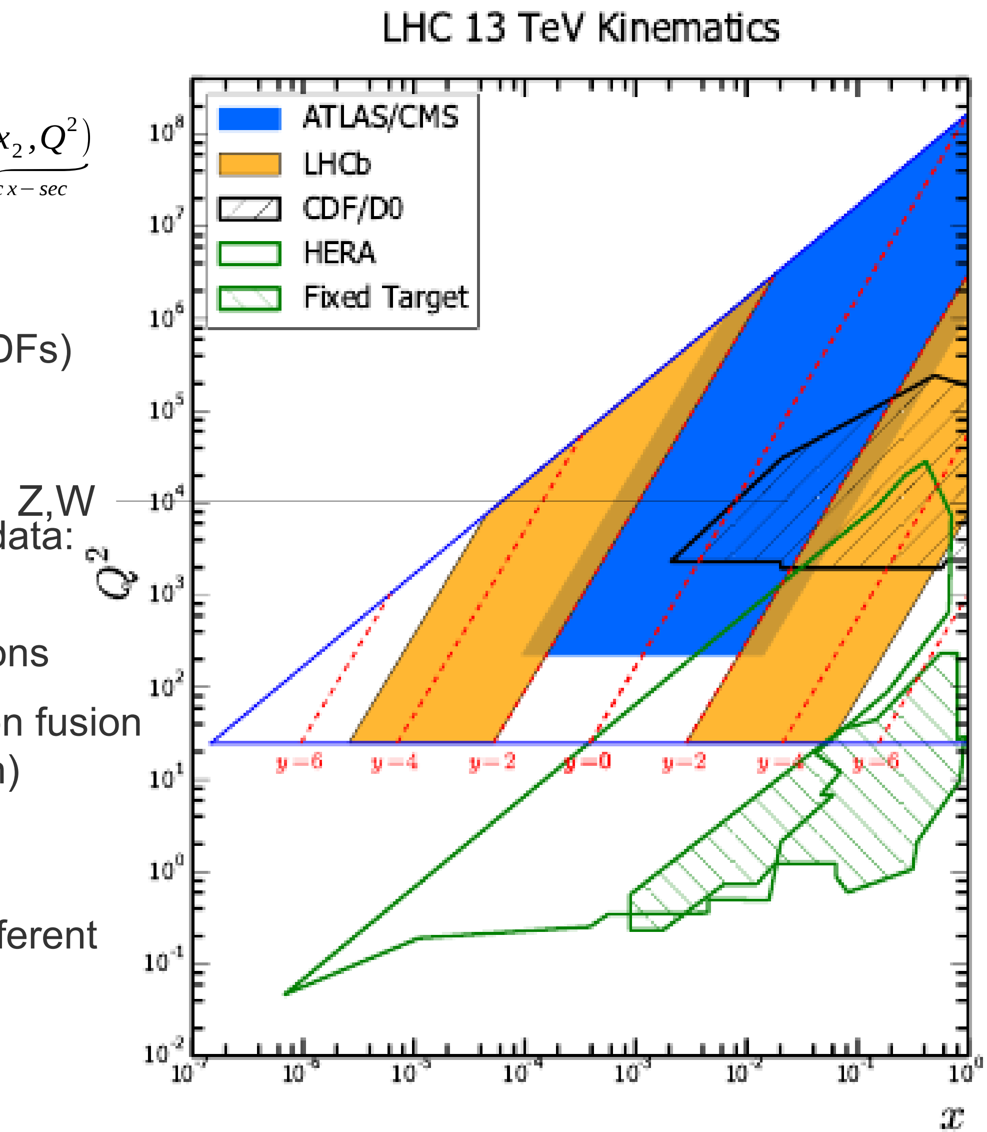
$\sqrt{s}$=5 TeV	9 pb^{-1} (2015)
$\sqrt{s}$=7 TeV	1 fb^{-1} (2011)
$\sqrt{s}$=8 TeV	2 fb^{-1} (2012)
$\sqrt{s}$=13 TeV	>2 fb^{-1} (2015-16)

Kinematics at LHCb

motivation for production measurements:

$$\underbrace{\sigma(x,Q^2)}_{hadronic\ x-sec.} = \sum_{a,b}\int_0^1 dx_1\, dx_2 \underbrace{f_a(x_1 Q^2) f_b(x_2 Q^2)}_{PDFs} \times \underbrace{\hat{\sigma}(x_1, x_2, Q^2)}_{partonic\ x-sec}$$

- x-section measurements and ratios sensitive to parton density functions (PDFs)
- measurements used to constrain PDFs
  → important for e.g. searches
- LHC, HERA, Tevatron and fixed target data: cover wide range in x-Q^2 plane
- W&Z production: probe quark distributions
- HF production dominated by gluon-gluon fusion
  → LHCb has sensitivity to low (and high) x gluon distribution
- HF: scale uncertainty dominant
  → almost cancels by taking ratios at different cm energies

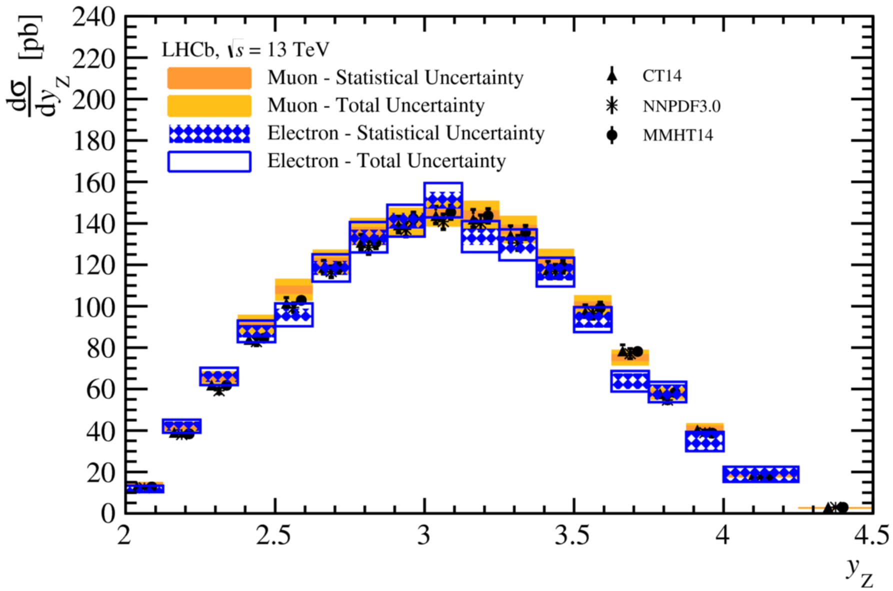


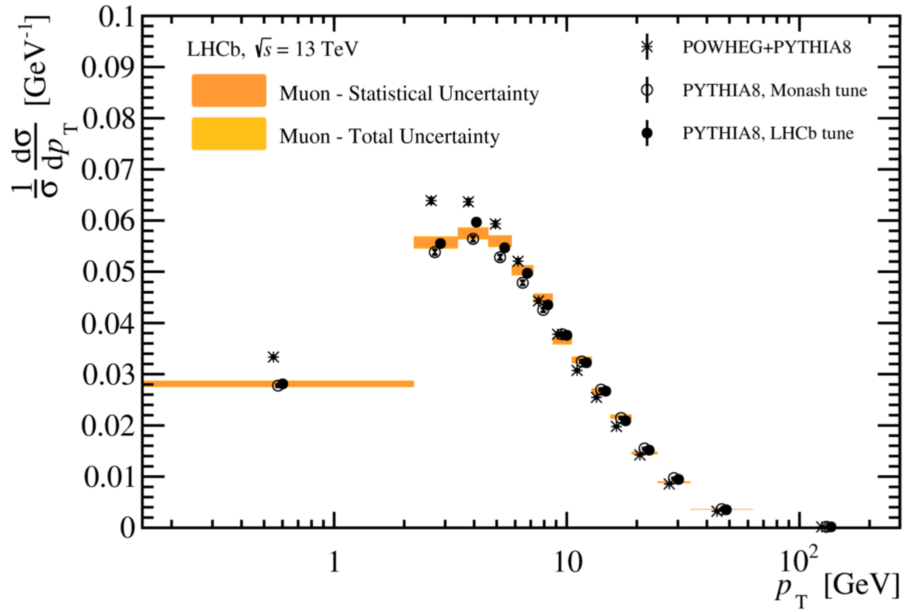
Electroweak Bosons

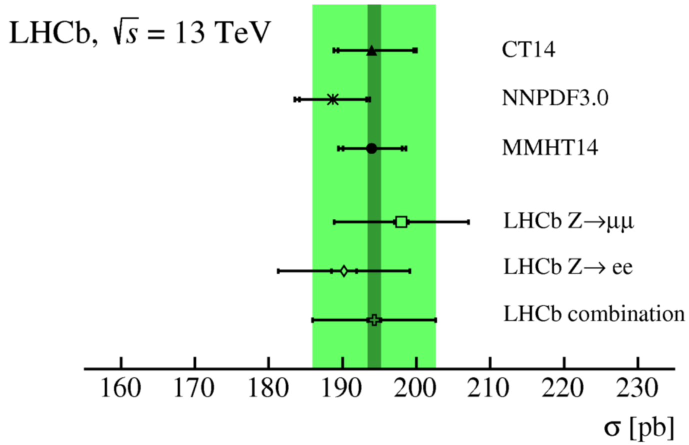
Z boson production @ 13 TeV

JHEP 09 (2016) 136

leptons: p_T > 20 GeV, 2.0 < η < 4.5, 60 < $m_{\mu\mu}$ < 120 GeV







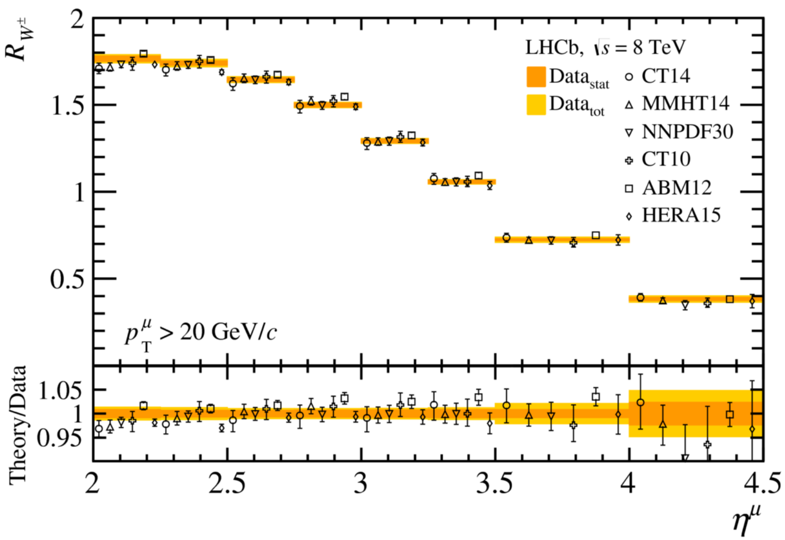
- luminosity uncertainty: 3.9%
- very good agreement between electron and muon channel
- rapidity: good agreement with NNLO predictions with different PDF sets
- p_T: good agreement with Pythia 8

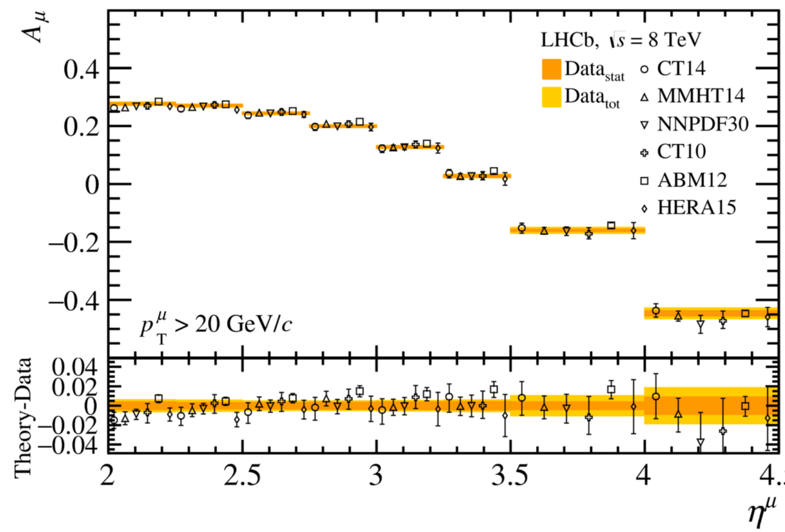
W boson production @ 8 TeV

JHEP 01 (2016) 155

Ratio W^+/W^-

Asymmetry: $A = \frac{\sigma(W^+) - \sigma(W^-)}{\sigma(W^+) + \sigma(W^-)}$





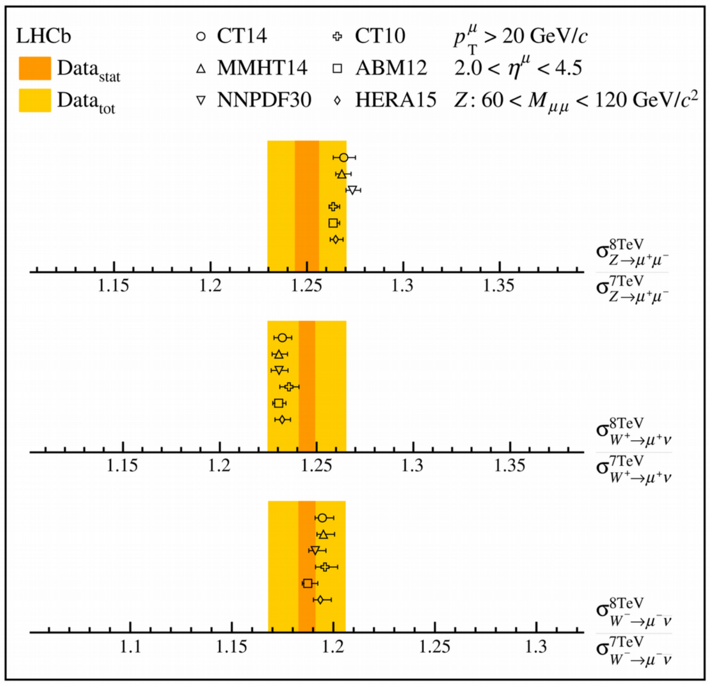
ratios: high experimental precision – uncertainties at sub-% level

agreement with different PDF sets within 1-2%
most sensitive to PDF as scale uncertainties mostly cancel in the ratio

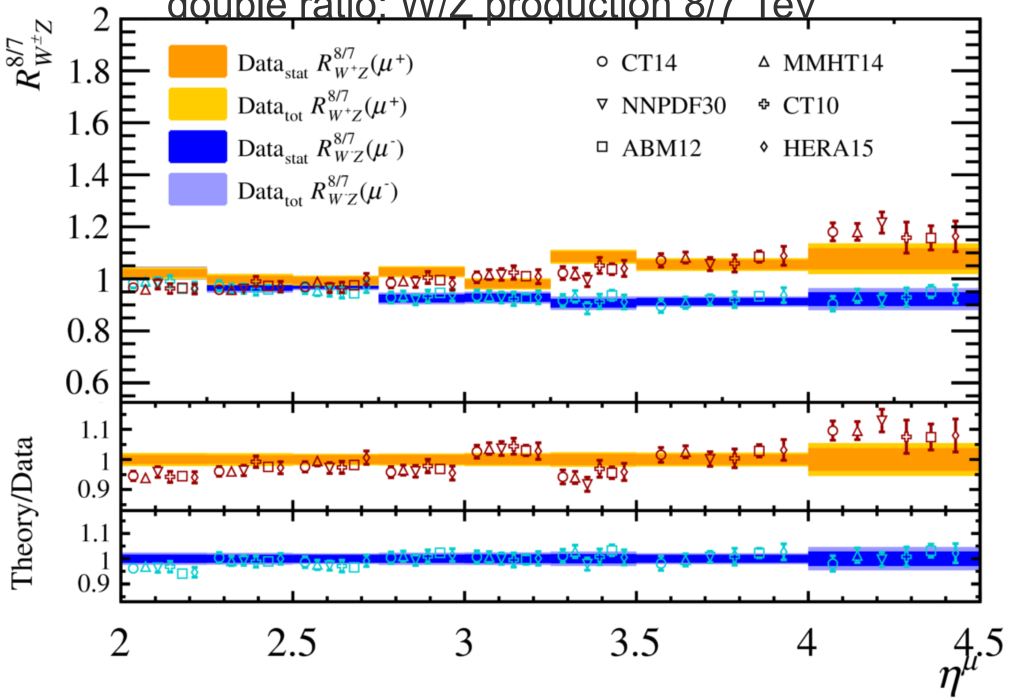
→ asymmetry and W^+/W^- constrain u/d PDF ratio

W,Z ratios at different CM energies

ratio at different cm energies: less sensitive to higher order effects
luminosity uncertainty: 1.2%
PDF uncertainties reduced but do not completely cancel as different x-regions are probed
→ better PDF sensitivity with 13 TeV measurement



double ratio: W/Z production 8/7 TeV



W,Z plus Jets

W, Z plus jet @ 8 TeV

JHEP 05 (2016) 1

$2.2<\eta^{jet}<4.2$, $p_T^{jet}>20$ GeV

$\Delta R(jet,\mu)>0.5$

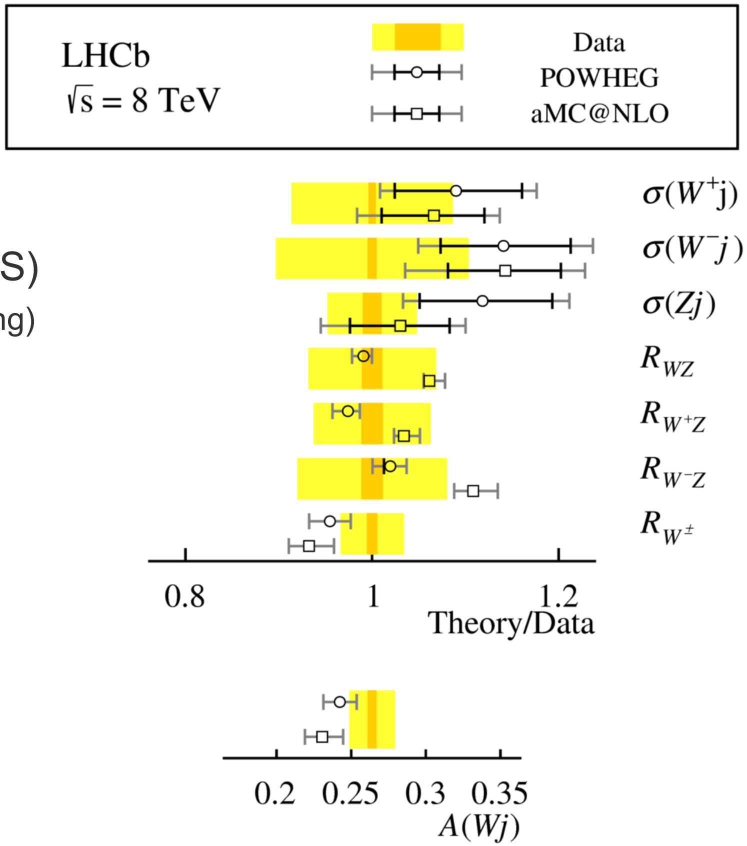
Z: purity very high: about 98%

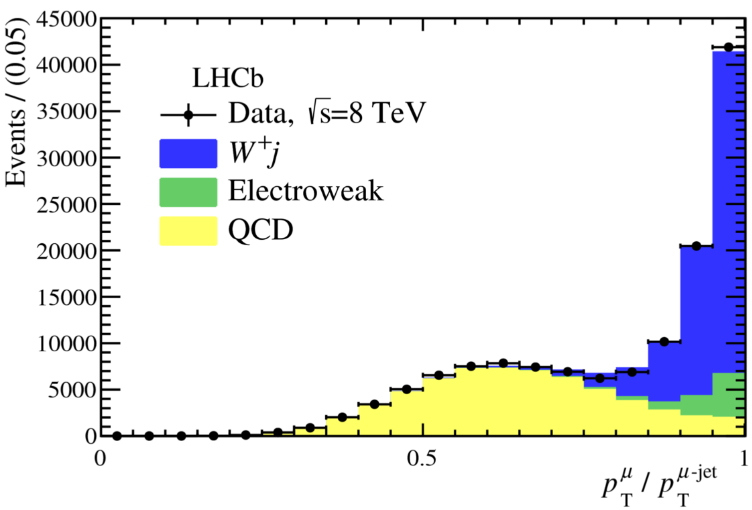
W: determined from fit to isolation 46% (37)%

general good description by predictions $O(\alpha_s^2)$ (+PS)

POWHEG and aMC@NLO with NNPDF3.0 and Pythia (showering)

x-sections: scale uncertainty dominating



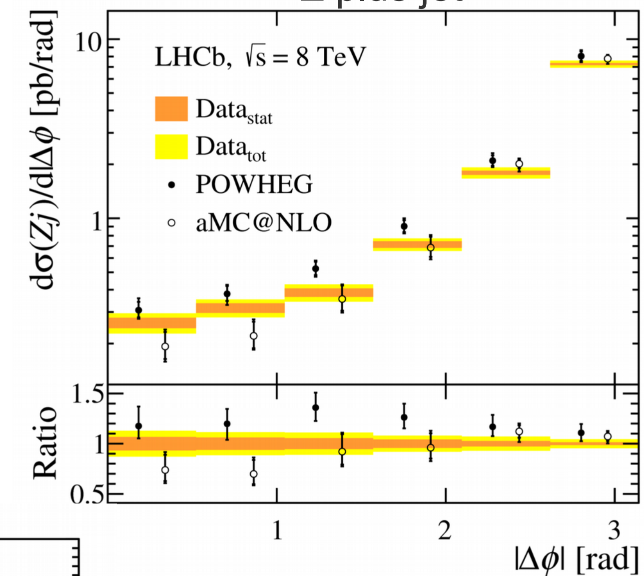


W,Z plus jet @ 8 TeV

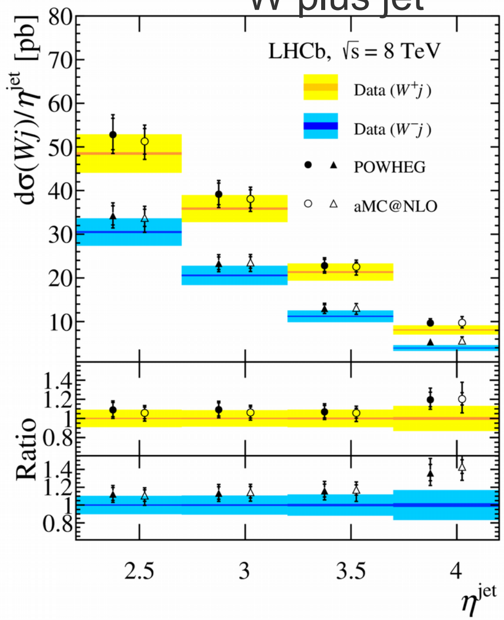
JHEP 05 (2016) 1

- many differential distributions available:
  W: p_T^{jet}, η^{μ}, η^{jet} Z: p_T^{jet}, η^{Z}, η^{jet}, $|\Delta\varphi|$
- reasonable agreement with ($O(\alpha_s^2)$ +PS)
  and fixed order predictions even in extreme regions of phase space
- lepton charge asymmetry → some sensitivity to PDFs
- main uncertainties: jet energy scale ~10%
  W purity ~7%

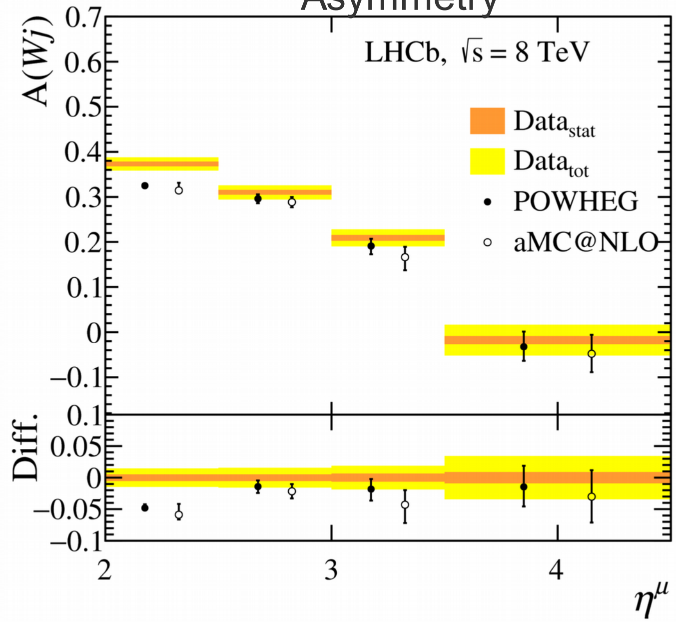
Z plus jet



W plus jet



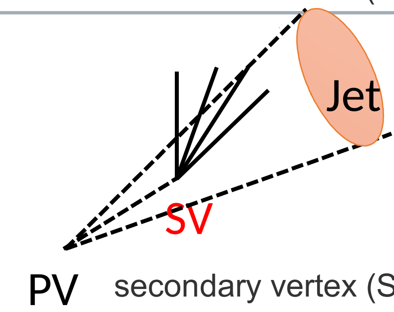
Asymmetry



Identification of beauty and charm quark jets

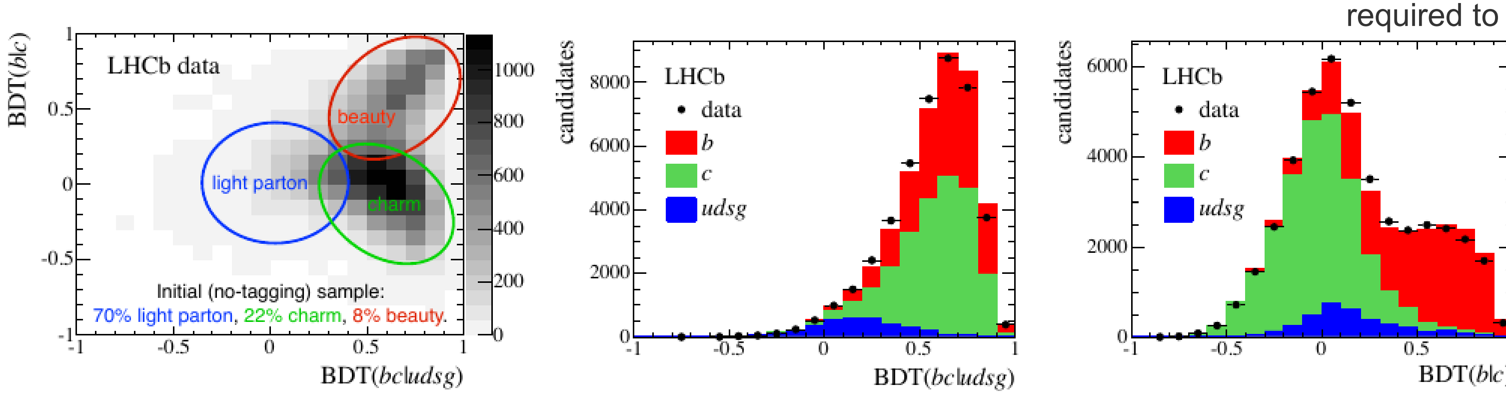
J. Instrum. 10 (2015) P06013

b, c tagging with secondary vertex in jet cone
two BDTs to separate
1) heavy from light jets (bc|udgs)
2) bottom from charm jets (b|c)

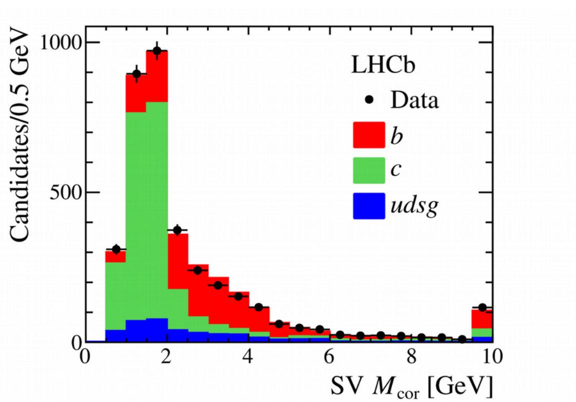


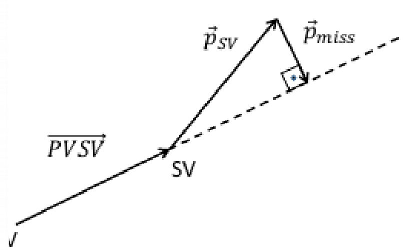
secondary vertex (SV) required to be in the jet

D+jet sample: enriched in b- and c-jets



c-b-jet separation from corrected mass: accounts for invisible momentum transverse to the PV to SV direction.





$$M_{corr} = \sqrt{M_{SV}^2 + \vec{p}^{\,2}_{miss}} + \vec{p}_{miss}$$

powerful heavy jet tagging
jets with 20 GeV < p_T < 100 GeV :

- efficiency of b-jet tagging ~ 65%
- efficiency of c-jet tagging ~ 20%
- misidentification of a light-jet ~ 0.3%

performance validated in data

Top in the forward region

PRL 115 (2015) 112001

SM top production in forward region: 75% tt-bar pair
25% s-channel single top qq-bar → t b-bar

forward:

qq-bar and qg production enhanced
charge asymmetry → better sensitivity to New Physics
LHCb: direction of quark better known

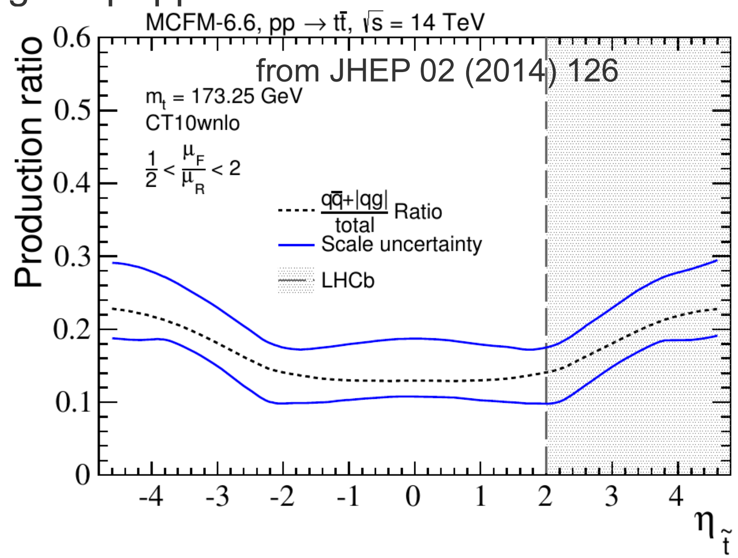
sensitive to PDF at large and low x

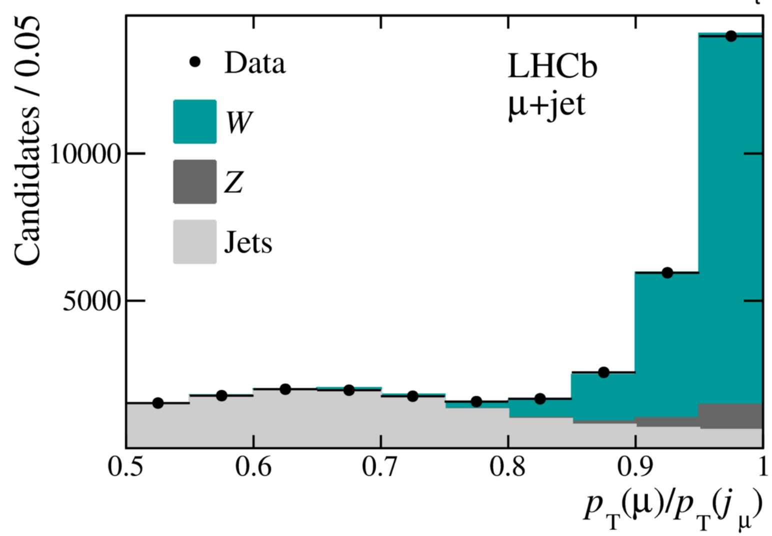
searching for top: $t \to W(\to \mu \nu_\mu) b$

final state: one isolated muon and a b-jet
b-tagging: secondary vertex in jet
p_T (μ) > 25 GeV and 50 < p_T (b) < 100 GeV

background from QCD jets:
fit to $p_T(\mu)/p_T$ (μ-jet)

$p_T(\mu + b)$ and charge asymmetry provides discrimination between top and W + b-jets

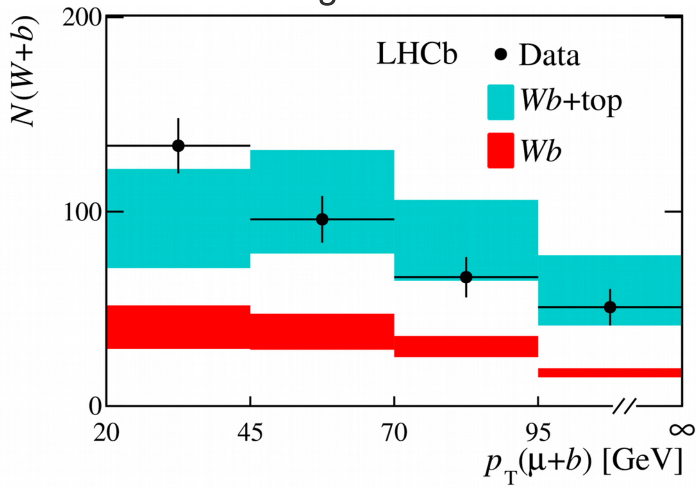


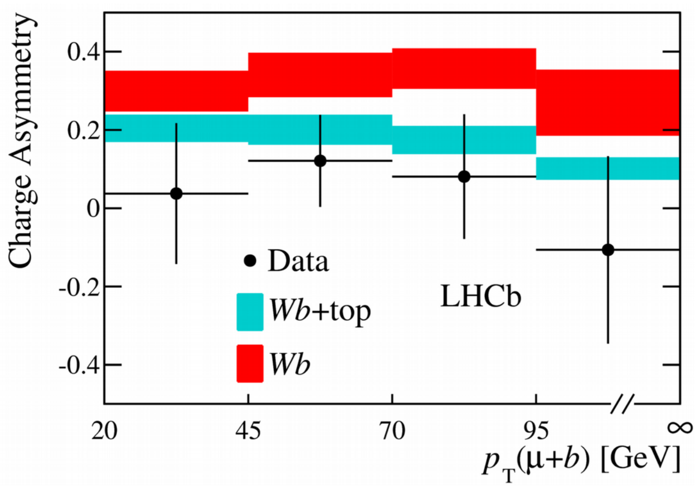


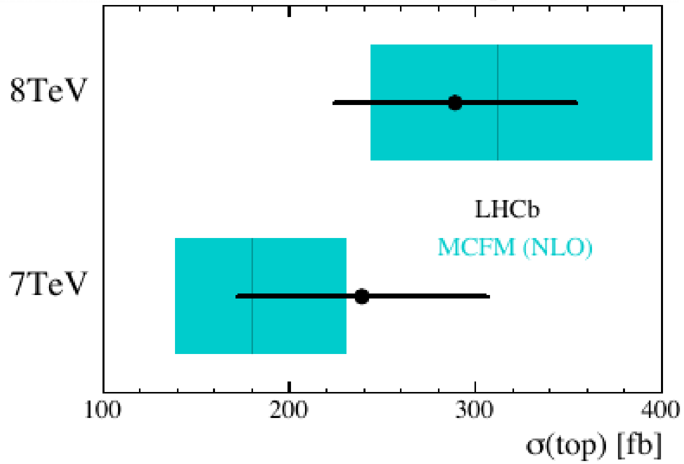
Top in the forward region

Run I: select W plus b-jet (isolated muon plus b-jet)

$p_T(\mu + b)$ and charge asymmetry provides discrimination between top and W + b-jets
→ data requires top - Wb alone is not sufficient to describe yield and asymmetry
5 σ statistical significance







Run 2: expect about 20 times more top

→ reduce large-x gluon uncertainty by ~10-20%
R. Gauld arXiv 1311.1810

W+b-bbar, W+c-cbar and t-tbar production

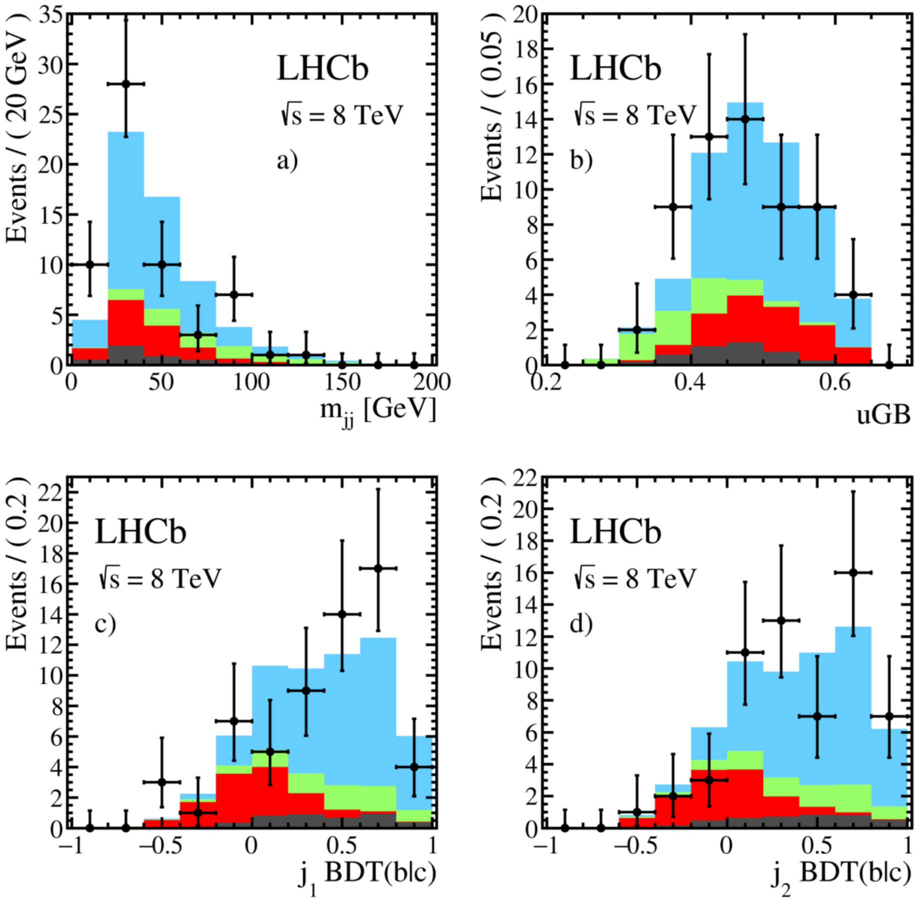
Phys. Lett. B767 (2017) 110

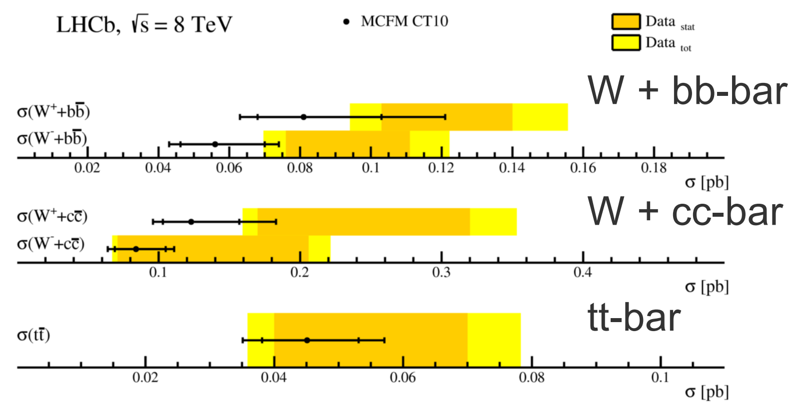
high p_T isolated lepton plus two b-jets

t-tbar production → sensitivity to the gluon

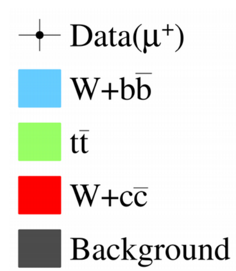
discrimination: m_{JJ}, BDT(b|c) and MVA(W+bb|tt), 4d dimensional fit

simultaneous for e^+, e^-, μ^+, μ^-





results in agreement with NLO predictions
(MCFM with CT10, interleaved with PYTHIA 8)



Heavy Quark Production

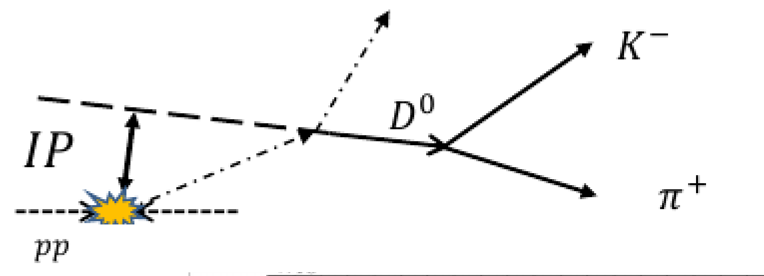
Charm production: new 13 & 5 TeV

JHEP 03 (2016) 159
Erratum JHEP 09 (2017) 074
arXiv: 1610.02230

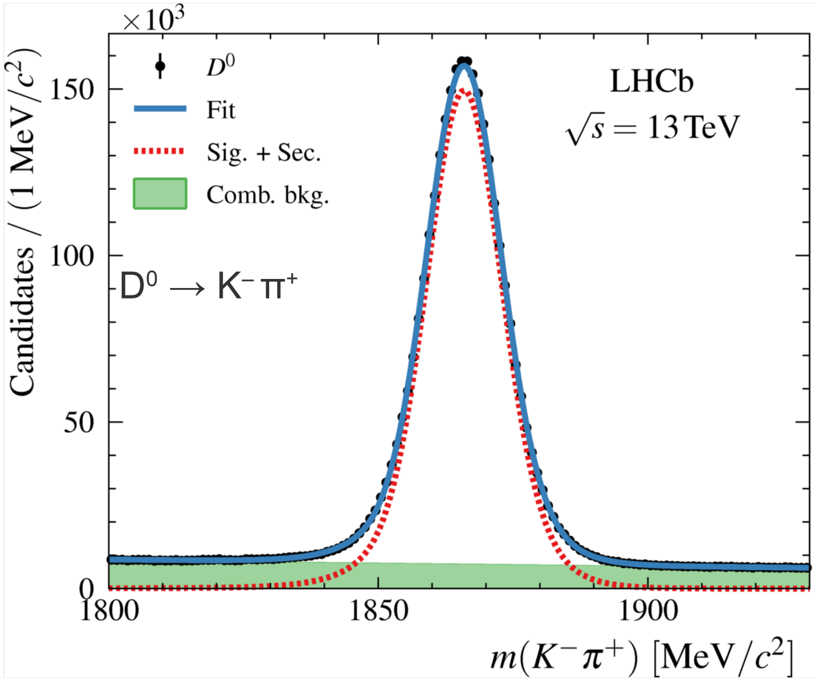
D^0, D^+, D^+_s, and D^{*+} production

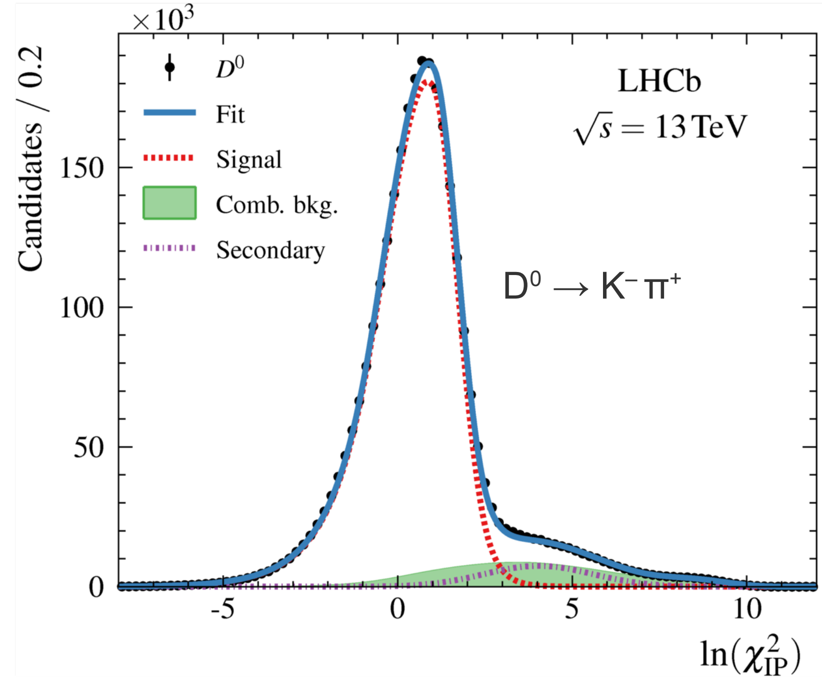
$0 < p_T < 15$ GeV and $2.0 < y < 4.5$

separate prompt charm from secondaries
fit of impact parameter significance, $\log(IP\chi2)$



New in Run II: analysis of trigger candidates [Comput. Phys. Commun. 208, 35-42]





signal:	Crystal Ball + Gaussian	signal:	asym Gaussian + exp tail
background:	linear	secondaries:	Gaussian

previous LHCb measurement @ 7 TeV Nuclear Physics, Section B 871 (2013), pp. 1-20

Run II production measurements - Erratum

an issue was identified in the simulated samples used to calculate track reconstruction efficiencies for some LHCb Run || production papers

reason: LHCb VELO simulation updated prior to Run II to account for radiation damage, but error made in the parametric correction for the effect.

track efficiency calibration procedure in data was unable to correct mis-modeling,

→ track reconstruction efficiency underestimated in simulation,

→ most affected: low pseudorapidity and low p_T

‘Measurements of prompt charm production cross-sections in pp collisions at $\sqrt{s}$ = 13 TeV’, JHEP 1609 (2016) 013, arXiv:1510.01707

‘Measurements of prompt charm production cross-sections in pp collisions at $\sqrt{s}$ = 5 TeV’, arXiv:1610.02230, submitted to JHEP

‘Measurement of forward J/ψ production cross-sections in pp collisions at $\sqrt{s}$ = 13TeV’, JHEP 1510 (2015) 172, arXiv:1509.00771

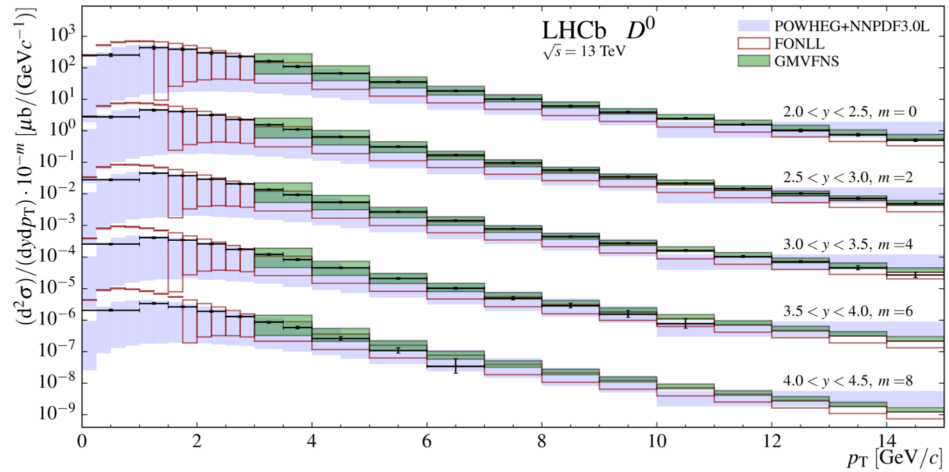
‘Measurement of the J/ψ pair production cross-section in pp collisions at $\sqrt{s}$ = 13 TeV’ arXiv:1612.07451, submitted to JHEP

errata have been submitted, preprints on arXiv have been updated.

Charm @ 13 & 5 TeV

JHEP 03 (2016) 159
Erratum JHEP 09 (2017) 074
arXiv: 1610.02230

double differential x-section for D^0, D^+, D^+_s, and D^{*+}



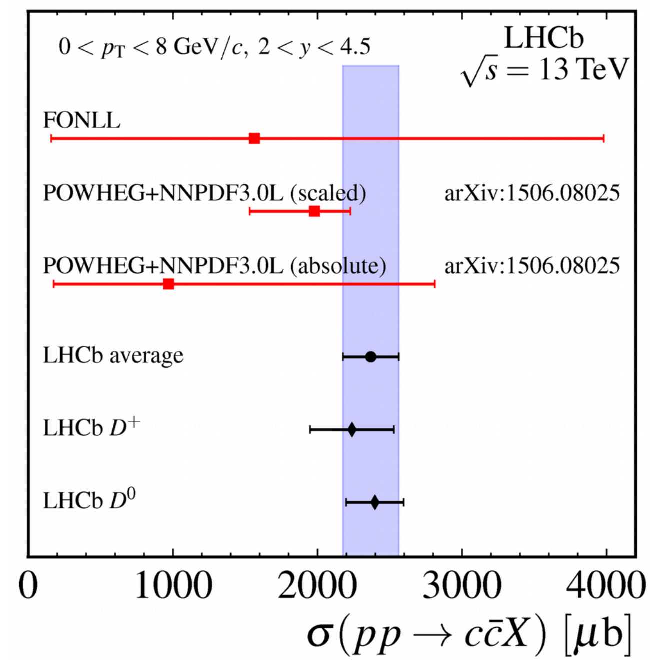
agreement with predictions
large uncertainties at low p_T

data tends to lie at upper end
also at 7 and 5 TeV

→ evaluate total cc-bar production cross-section using fragmentation fractions from electron colliders

$\sqrt{s}$ = 13 TeV: 2369 ± 3 ± 152 ± 118 μb

p_T < 8 GeV/c, 2.0 < y < 4.5



Predictions:

FONLL Eur. Phys. J. C75 (2015) 610
fixed order next-to-leading logarithms

GMVFNS Eur. Phys. J. C72 (2012) 2082
general mass variable flavor number scheme

POWHEG JHEP11 (2015)
modified NNPDF3.0 using 7 TeV LHCb results

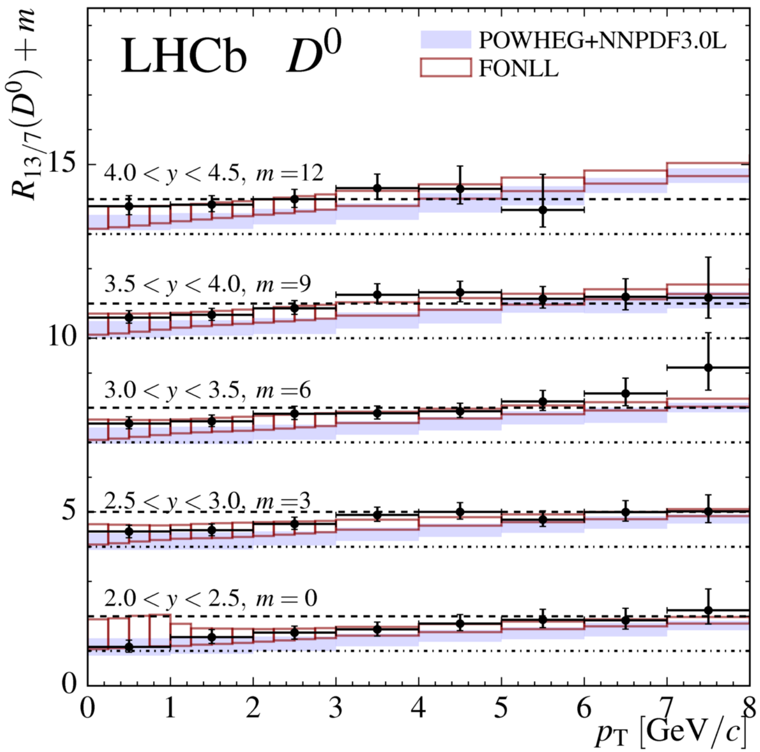
Charm: ratios 13/7 TeV and 13/5 TeV

ratios: experimental and theory uncertainties partially cancel

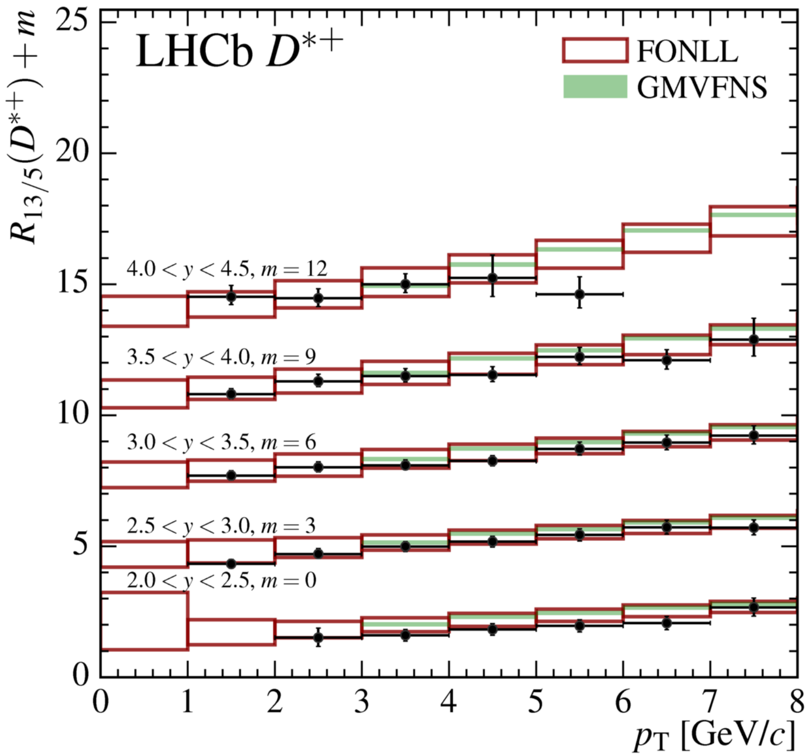
→ ratio between different cm energies well described

luminosities: 7 TeV 15 nb^{-1} , 13 TeV: 5.0 pb^{-1} , 5 TeV: 8.6 pb^{-1}

ratio 13/7 TeV JHEP 03 (2016) 159
JHEP 09 (2017) 074



ratio 13/5 TeV arXiv: 1610.02230



for each interval, the dash-dotted line represents a ratio of 1

b- hadron production asymmetries

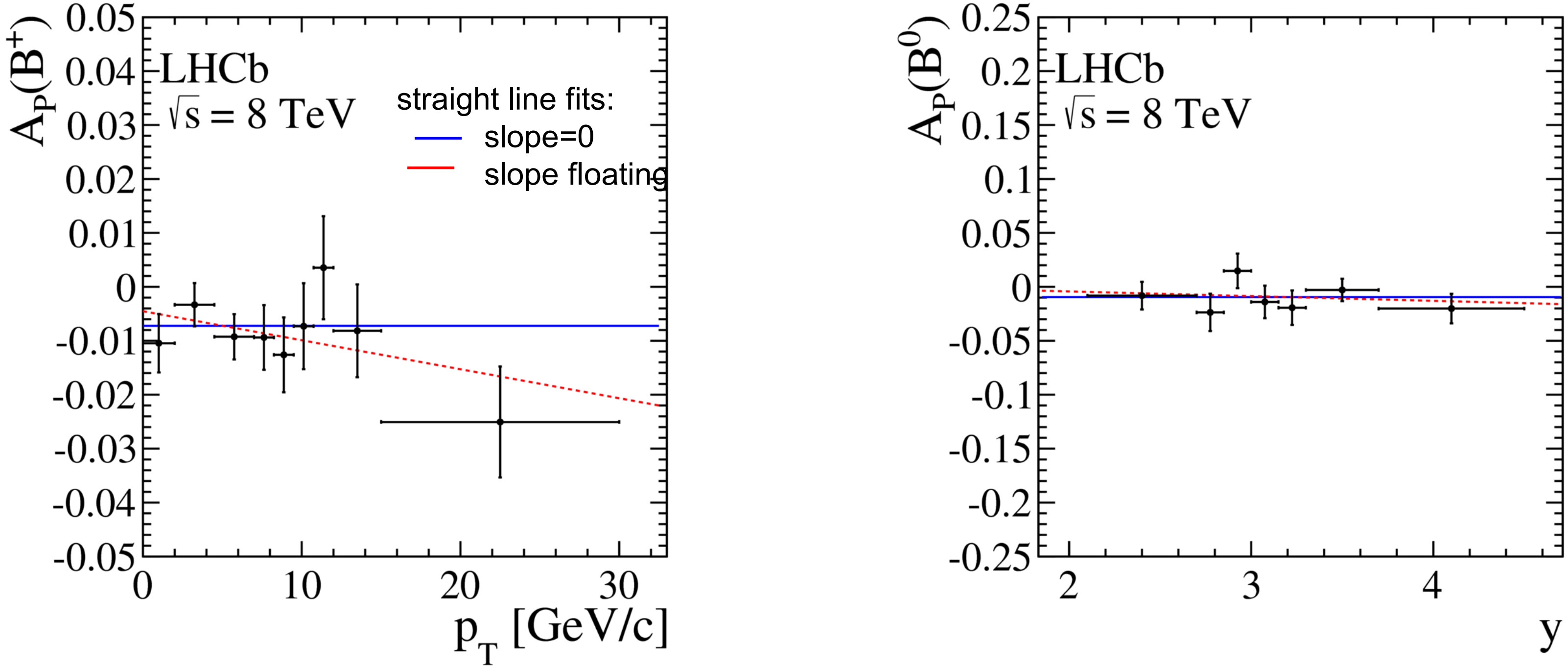
arXiv 1703.08464

pair production of b-bbar dominant, but valence quarks may introduce asymmetries.

→ important for precision CP violation studies

asymmetry measured for B^0 , B^+ , and B_s as functions of (p_T , y)

$$A_P \equiv \frac{\sigma(\overline{H}_b) - \sigma(H_b)}{\sigma(\overline{H}_b) + \sigma(H_b)}$$

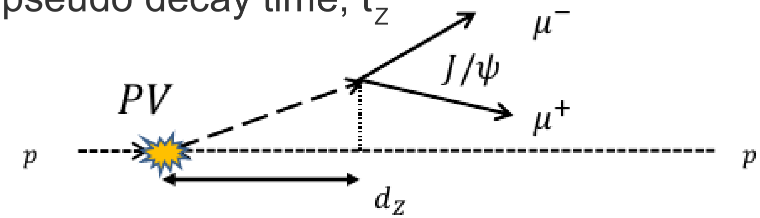


- fits with a constant and a first-order polynomial function → no evidence for any dependence
- integrated → all results consistent with zero within 2.5 standard deviations

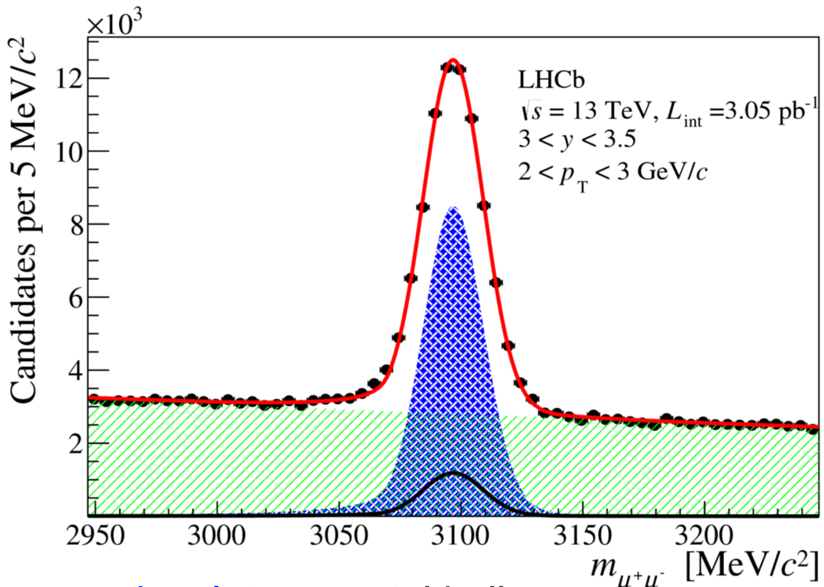
Quarkonia Production

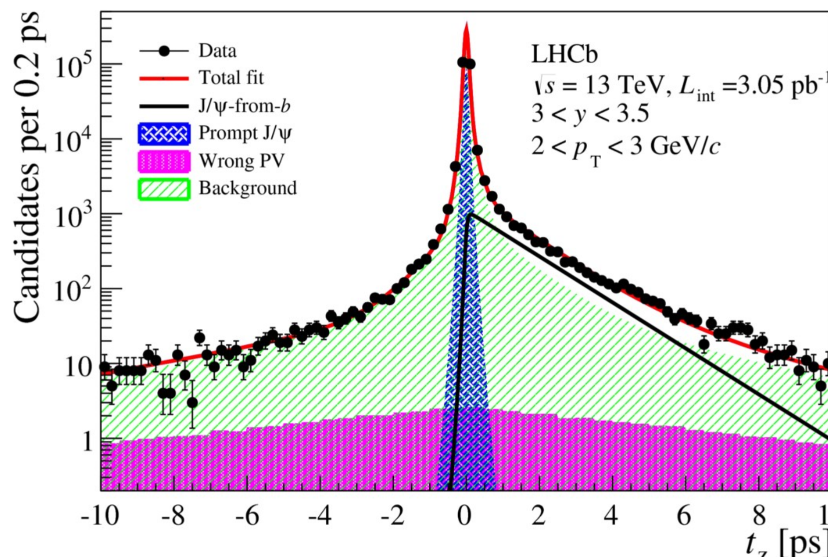
- p_T < 14 GeV, 2 < y < 4.5 13 TeV: L = 3.05 ± 0.12 pb^{-1}, double differential measurement (p_T,η)
- analysis based on trigger candidates, with no offline processing [Comput. Phys. Commun. 208, 35-42]
- prompt J/ψ and J/ψ from b decays are separated using pseudo decay time, t_z

$$t_z = \frac{dz \cdot M_{J/\psi}}{p_z}$$



- signal yield: simultaneous fit to invariant mass and t_Z





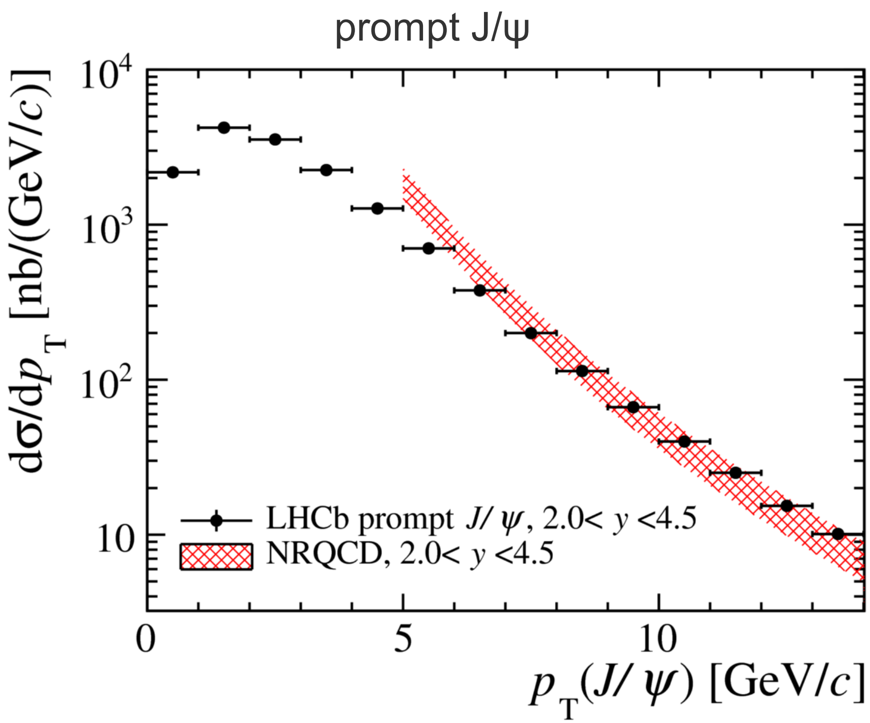
signal: two crystal ball
background: exponential

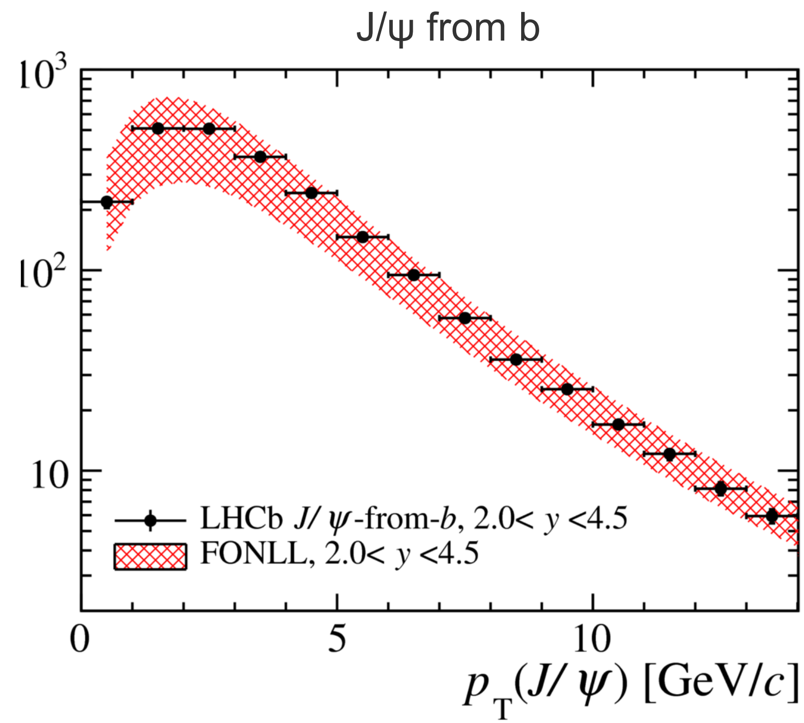
prompt: δ function conv. with double Gaussian
from b: exponential

- previous LHCb measurements @ 7, 8 and 2.76 TeV
  Eur.Phys.J.C71 (2011) 1645, JHEP 06 (2013) 064, JHEP 1302 (2013) 041

J/ψ production cross sections @13 TeV

JHEP 10 (2015) 172
Erratum: JHEP 1705 (2017) 063





overall very good agreement with prediction for both J/ψ and J/ψ from b, coverage up to 15 GeV

NRQCD JHEP 05 (2015) 103
hadronisation of cc state described by long-distance matrix elements (from CDF)

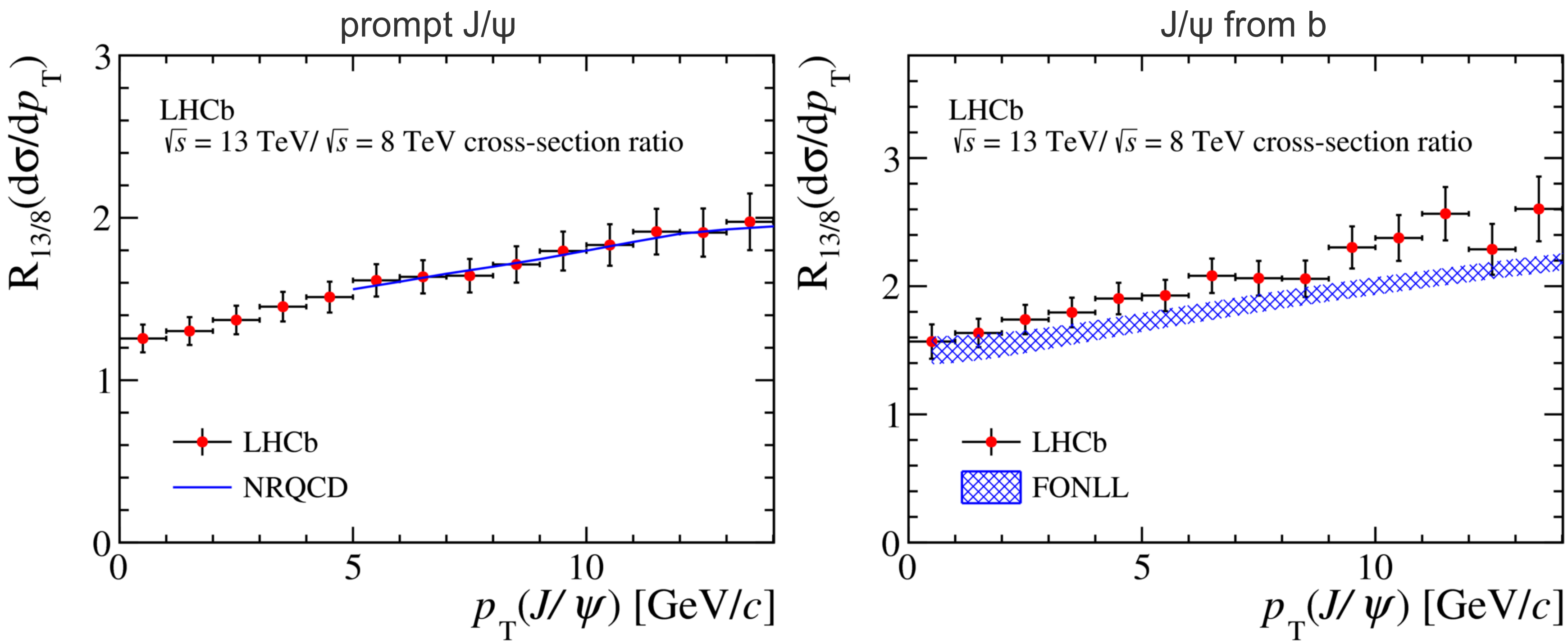
FONLL: JHEP 10 (2012) 137
fixed-order next-to-leading log (match NLO QCD with NLL in the limit $p_T >> m(q)$)

→ extrapolated* total bb-bar x-section $\sigma_{bb\text{-}bar}$ = 495 ± 2 (stat) ± 52 (syst) μb

*B(b → J/ψ X) = 1.16 ± 0.10 %, naïve PYTHIA 6 extrapolation

J/ψ ratio13/8 TeV

JHEP 10 (2015) 172
Erratum: JHEP 1705 (2017) 063



x-section @ 13TeV: harder than @ 8 TeV

NRQCD JHEP 05 (2015) 103, uncertainty from LDME mainly cancels
FONLL: JHEP 10 (2012) 137, uncertainties: scale, b-quark mass, gluon PDF

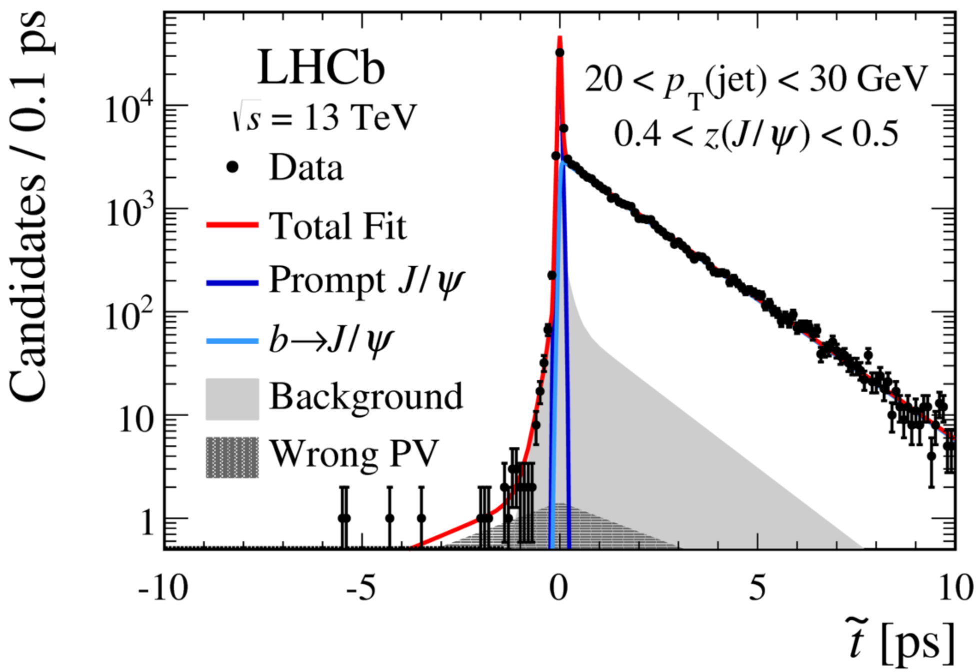
NRQCD describes data very well, FONLL tends to be slightly low

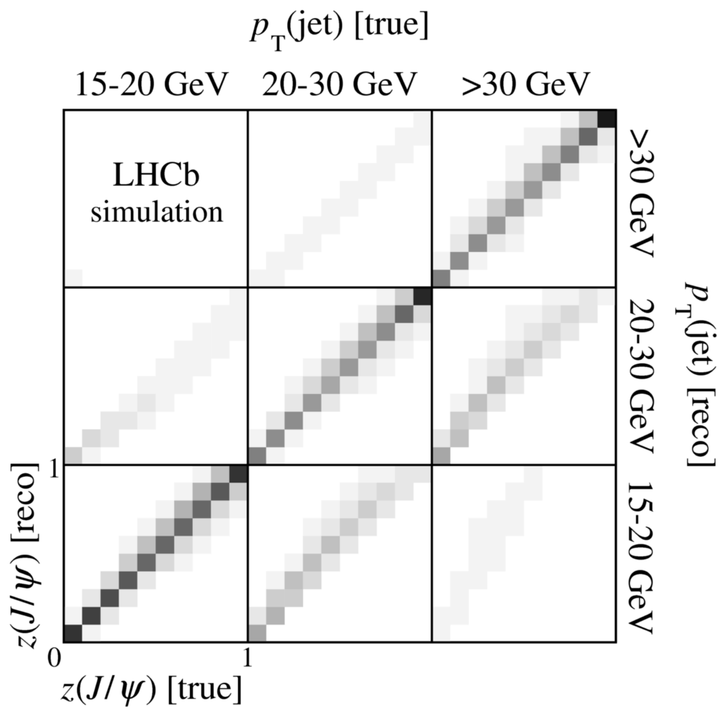
J/ψ in jets @13 TeV

PRL 118 (2017) 192001

new analysis: measurement of z: fraction of p_T (jet) carried by J/ψ, z=p_T(J/ψ)/p_T(jet)
→ QCD phenomenology, e.g., J/ψ isolated if produced directly in parton-parton scattering

- separate prompt J/ψ and J/ψ from b using pseudo decay time
- unfolding of detector response:
  → correct for z and p_T(jet) resolution, ~ 20 − 25%
  2D unfolding in z and p_T(jet) (iterative Bayesian)





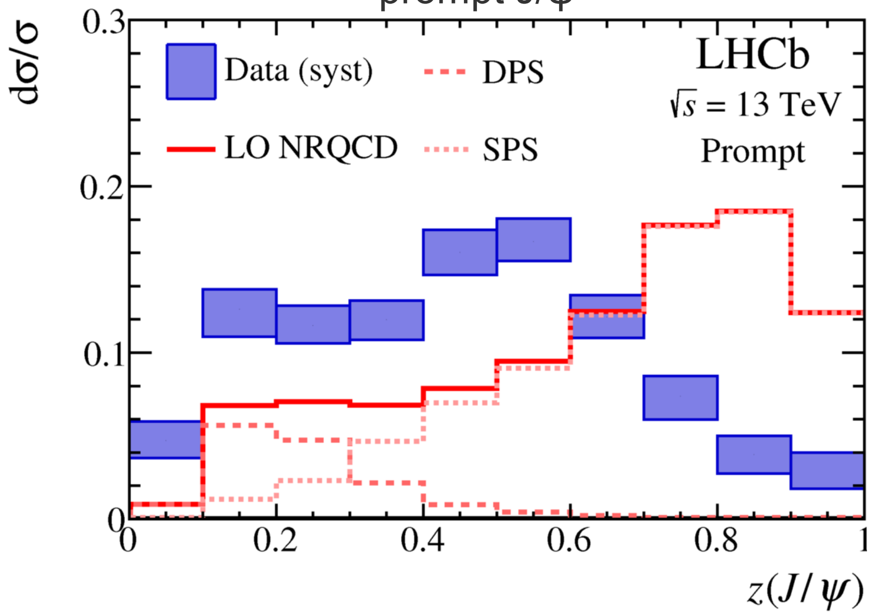
J/ψ in jets @13 TeV

PRL 118 (2017) 192001

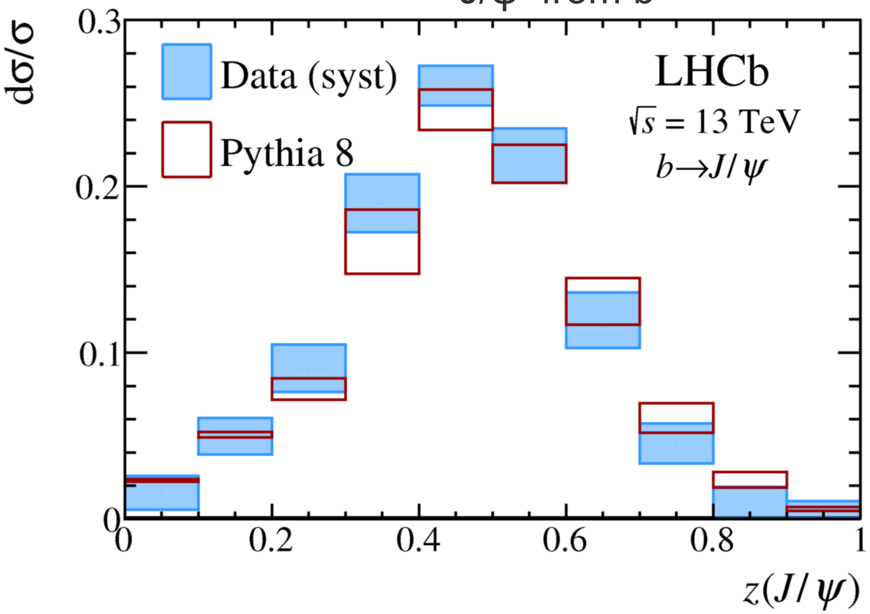
$z=p_T(J/\psi)/p_T(\text{jet})$, $p_T(\text{jet})>20$ GeV, $2.5<\eta(\text{jet})<4.0$

- prompt J/ψ: not described by LO NRQCD as implemented in PYTHIA 8
  dominant uncertainty at large z: underlying event
  → data much less isolated than predicted
  → high p_T J/ψ produced in parton showers rather than directly in parton-parton scattering
  or contributions from higher orders
- J/ψ from b: consistent with predictions from PYTHIA8
  PYTHIA8 uncertainty: b-quark fragmentation

prompt J/ψ



J/ψ from b



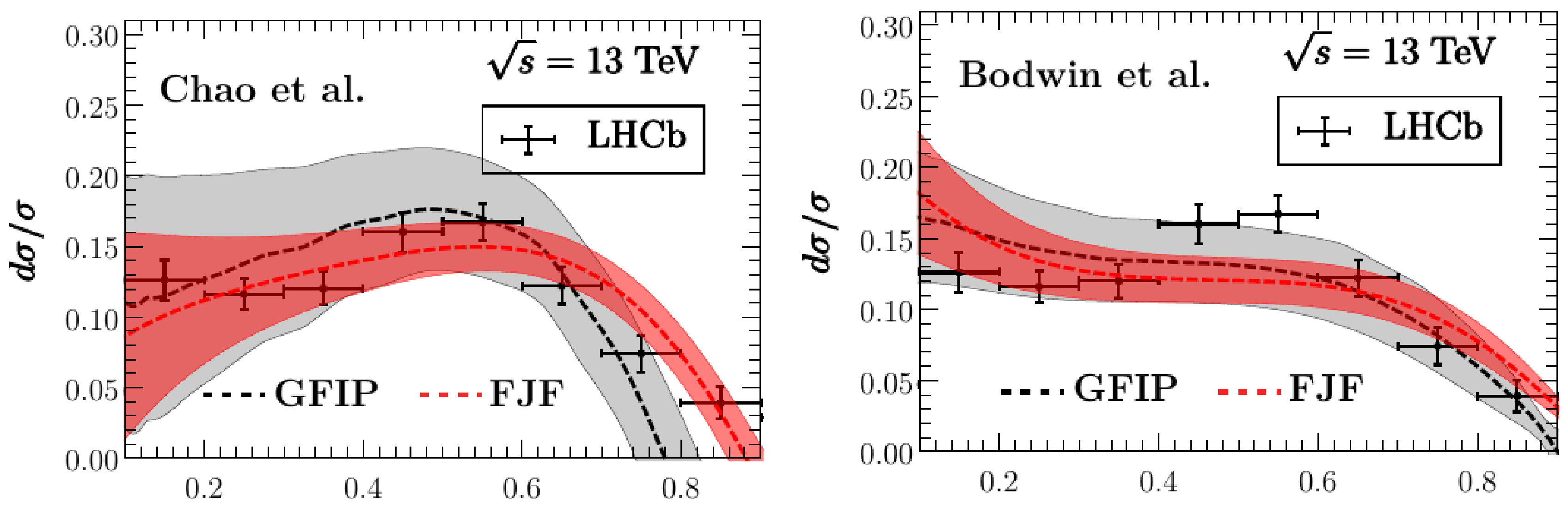
J/ψ in jets @13 TeV

PRL 118 (2017) 192001

$z = p_T(J/\psi)/p_T(\text{jet})$, $p_T(\text{jet}) > 20$ GeV, $2.5 < \eta(\text{jet}) < 4.0$

- prompt J/ψ: not described by LO NRQCD as implemented in PYTHIA 8
  → data much less isolated than predicted
  → high p_T J/ψ produced in parton showers rather than directly in parton-parton scattering or contributions from higher orders

- NLL predictions (arXiv:1702.05525) with alternative quarkonium production show qualitatively good agreement



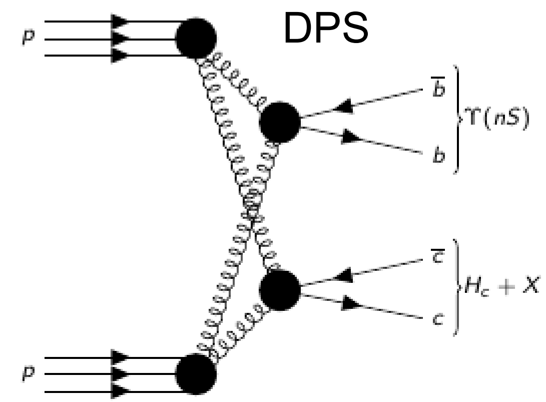
Sensitivity to Double Parton Scattering

Υ and open charm @ 7 and 8 TeV

JHEP 17 (2016) 052

sensitive to double parton scattering (DPS)

LHCb previously measured J/ψ and
open charm pair production
PLB 707 (2012) 52

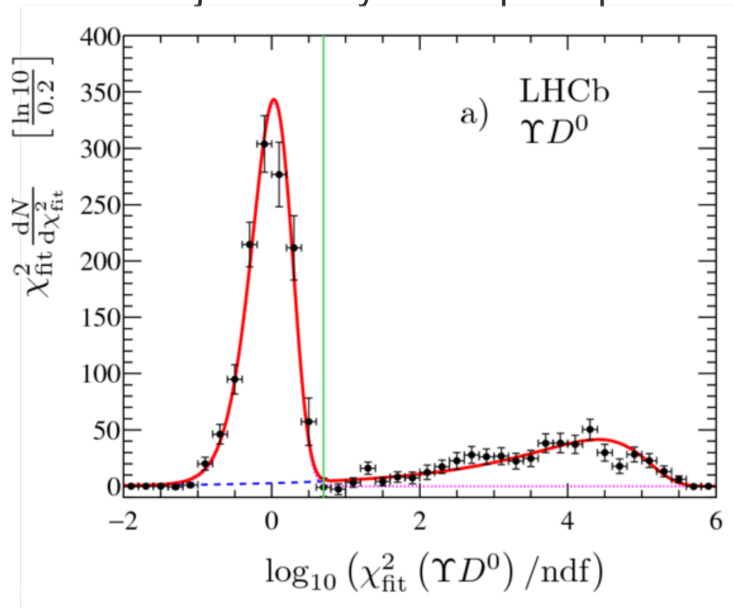


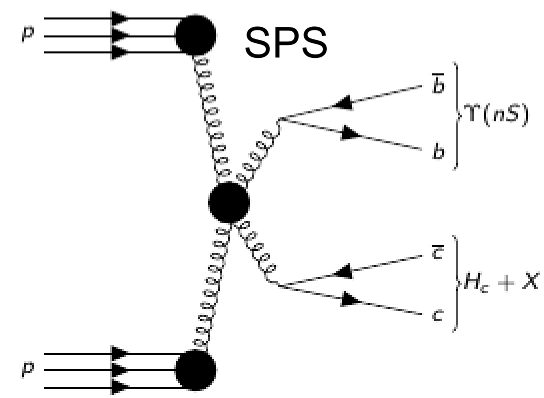
$$\sigma^{\Upsilon c\bar{c}} = \frac{\sigma^{\Upsilon}\cdot\sigma^{c\bar{c}}}{\sigma_{\mathrm{eff}}},$$

$$\Rightarrow R_{\mathrm{DPS}} = \frac{\sigma^{\Upsilon c\bar{c}}}{\sigma^{\Upsilon}} = \frac{\sigma^{c\bar{c}}}{\sigma_{\mathrm{eff}}} \approx 10\%.$$

$\Upsilon(nS) \to \mu^+ \mu^-$ combined with
$D^0 \to K^- \pi^+$, $D^+ \to K^- \pi^+ \pi^+$ or $D_s^+ \to K^- K^+ \pi^+$

χ^2/ndf requirement on the common Υ- D production vertex to reject decays from pile-up.

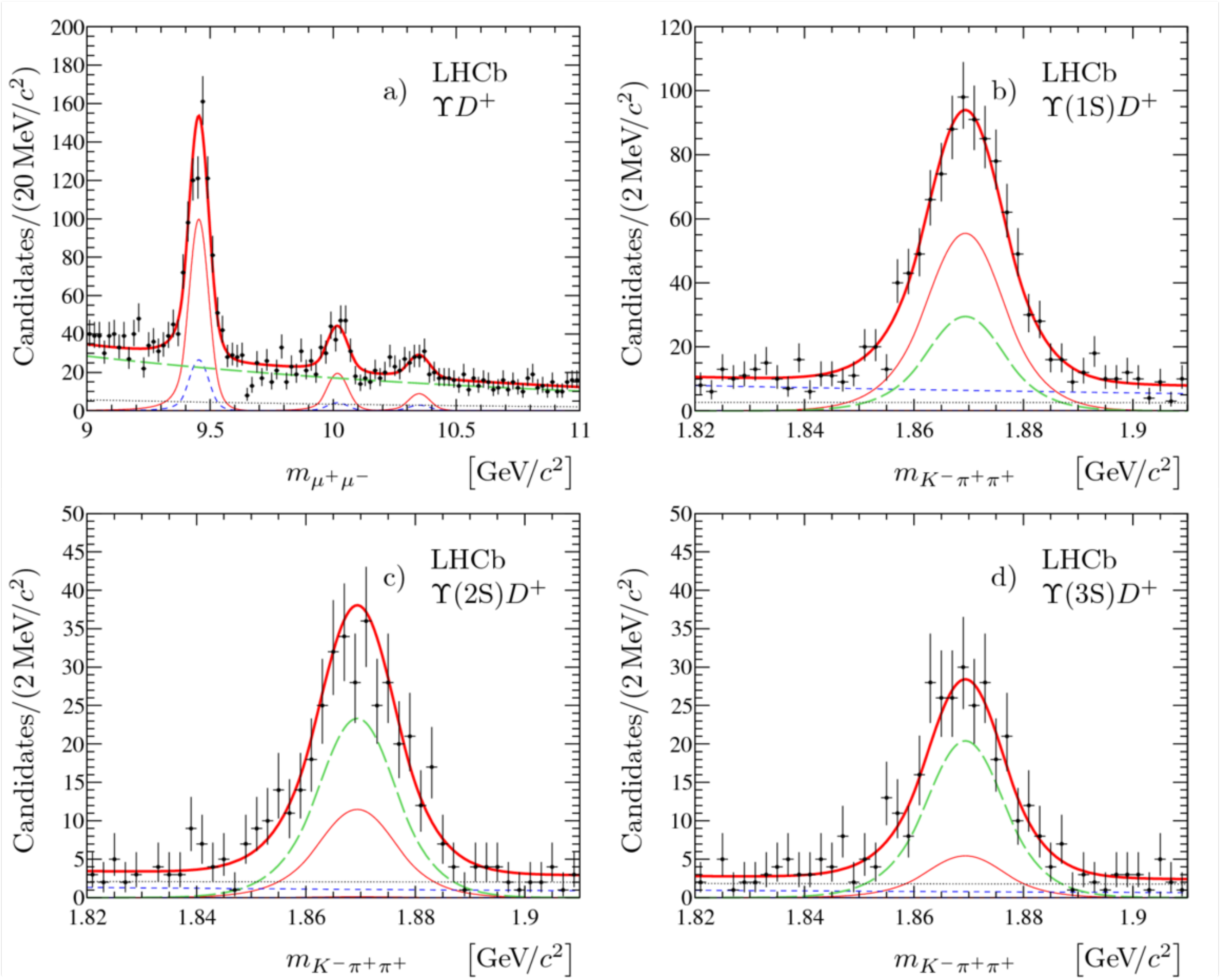




$$R_{\mathrm{SPS}} = \frac{\sigma^{\Upsilon c\bar{c}}}{\sigma^{\Upsilon}} \approx 0.2 - 0.6\%.$$

Υ and open charm @ 7 and 8 TeV

Signal yield: fit to Υ(nS) and D invariant mass



signal Υ-D

Υ + comb. $K^- \pi^+ \pi^+$

D + comb. μμ

comb. μμ + $K^- \pi^+ \pi^+$

ϒ and open charm @ 7 and 8 TeV

JHEP 17 (2016) 052

→ first observation of associated production of ϒ(1S,2S)D^0, ϒ(1S,2S)D^+ and ϒ(1S)D_s^+

integrated cross-section measurements for ϒ(1S)D^0 and ϒ(1S)D^+ modes:

→ ϒ(1S)c-cbar = (0.080 ± 0.009)ϒ(1S)

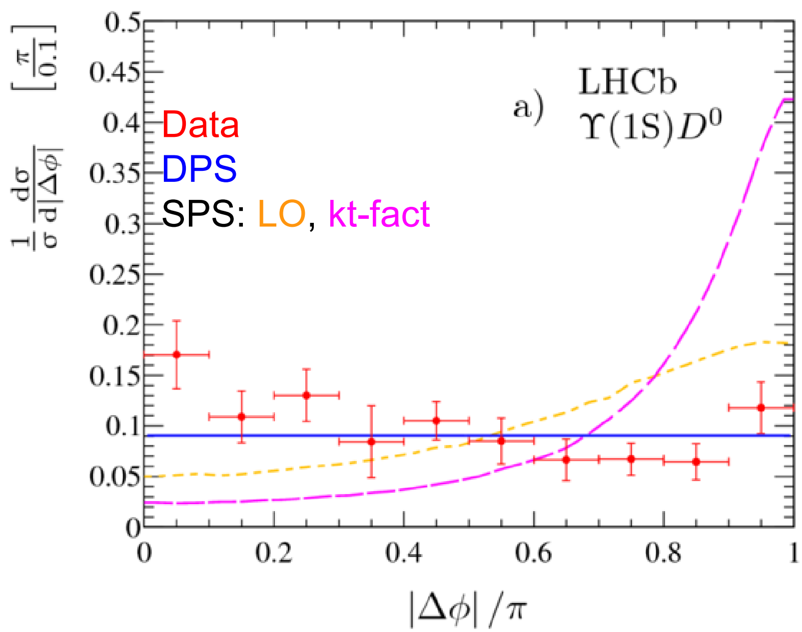
significantly higher than expectation from SPS (0.001-0.006)·σ(ϒ)

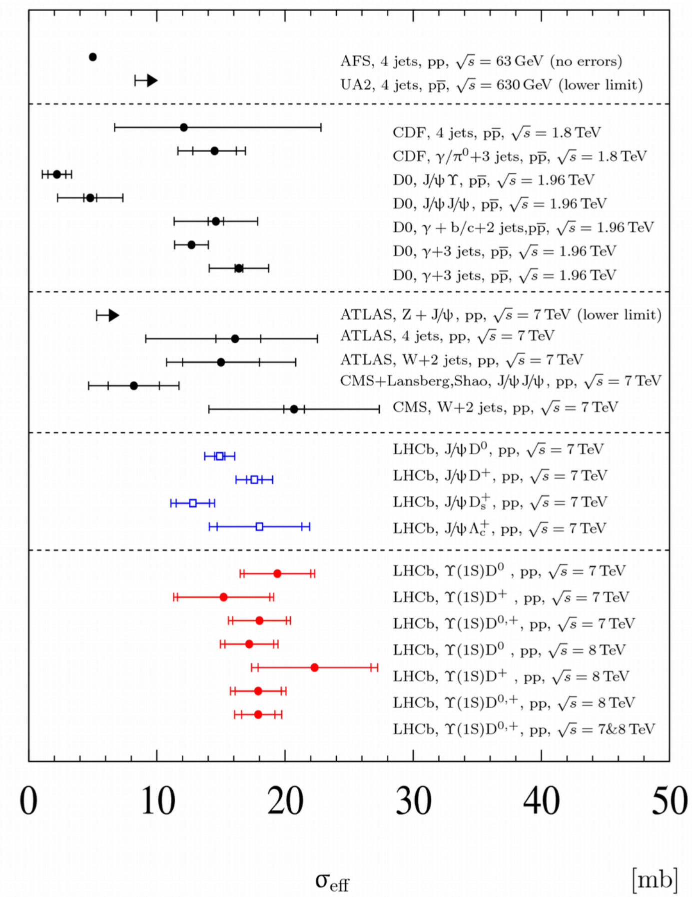
in agreement with DPS 0.1·σ(ϒ)

ΔΦ(ϒD) indicate dominant production via DPS

→ assuming 100% DPS: σ(ϒD)=σ(ϒ)·σ(D) / σ_{eff}

σ_{eff} = 18.0 ± 1.3 (stat) ± 1.2 (syst) mb





J/ψ pair production cross sections @13 TeV

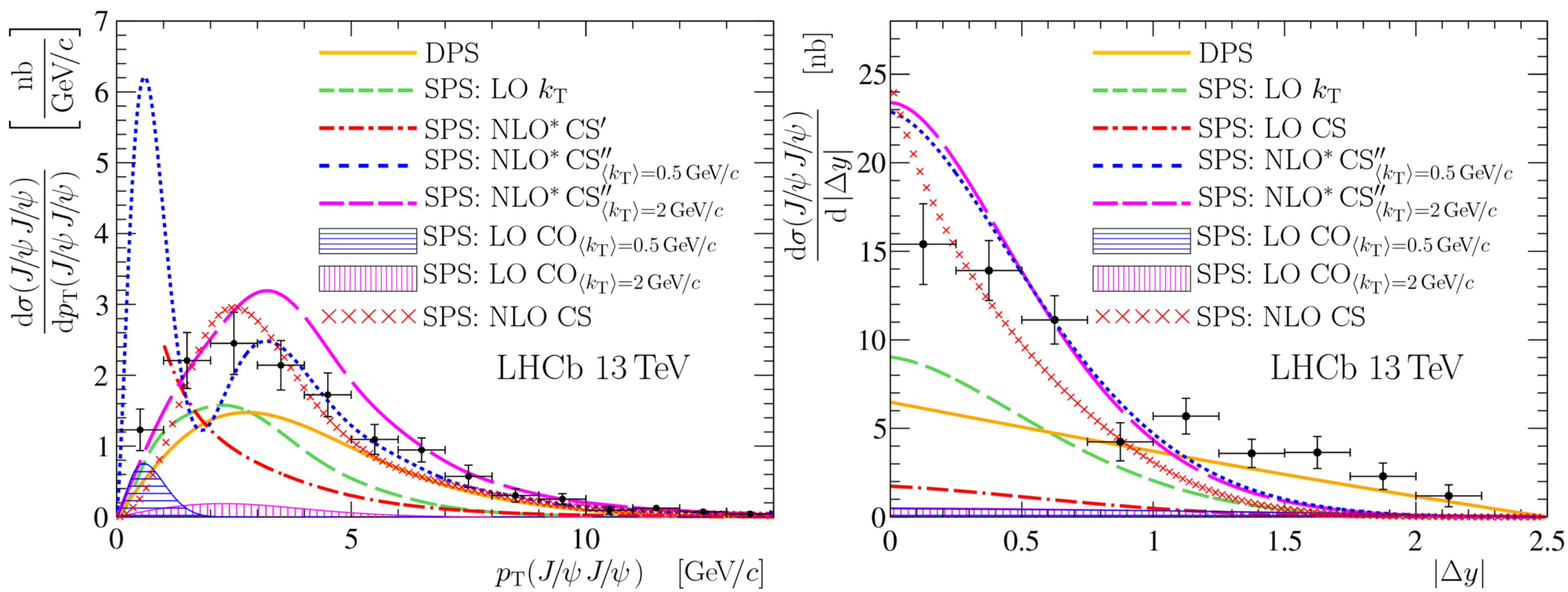
arXiv:1612.07451

contribution from DPS and SPS

$\sigma(J/\psi\ J/\psi) = 15.2 \pm 1.0\ (\text{stat}) \pm 0.9\ (\text{syst})$ nb

→ DPS or SPS alone fail to describe differential distribution
→ sum of DPS and SPS contributions can describe x-section & differential distributions

DPS predictions: pseudo-experiments with large samples of J/ψ



J/ψ pair production cross sections @13 TeV

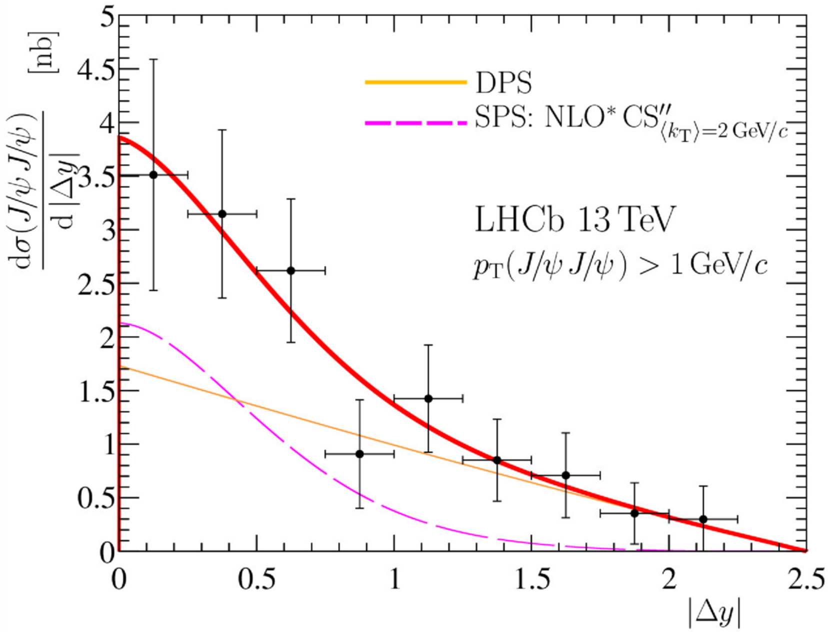
arXiv:1612.07451

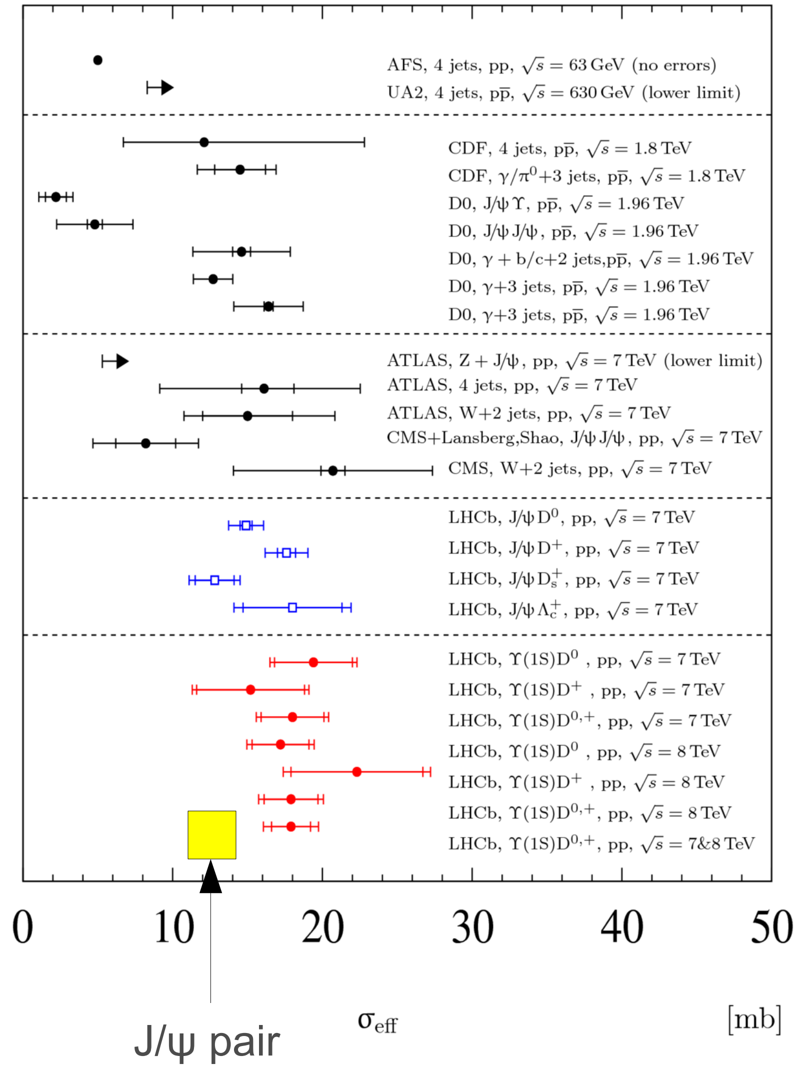
template fit to get DPS contribution

- large DPS contribution: 40-90%

→ extract $\sigma_{eff} = \sigma(J/\psi)^2/(2\,\sigma_{DPS})$: 10-12.5 mb

smaller than LHCb measurements of double charm and ϒ(nS) plus charm
slightly larger than in central J/ψ pair production from CMS and ATLAS





Conclusions

recent results on production of

- electroweak bosons
- heavy flavour: beauty, charm and top production
- quarkonia: J/ψ and Υ

at various centre of mass energies: 5, 7, 8, 13 TeV

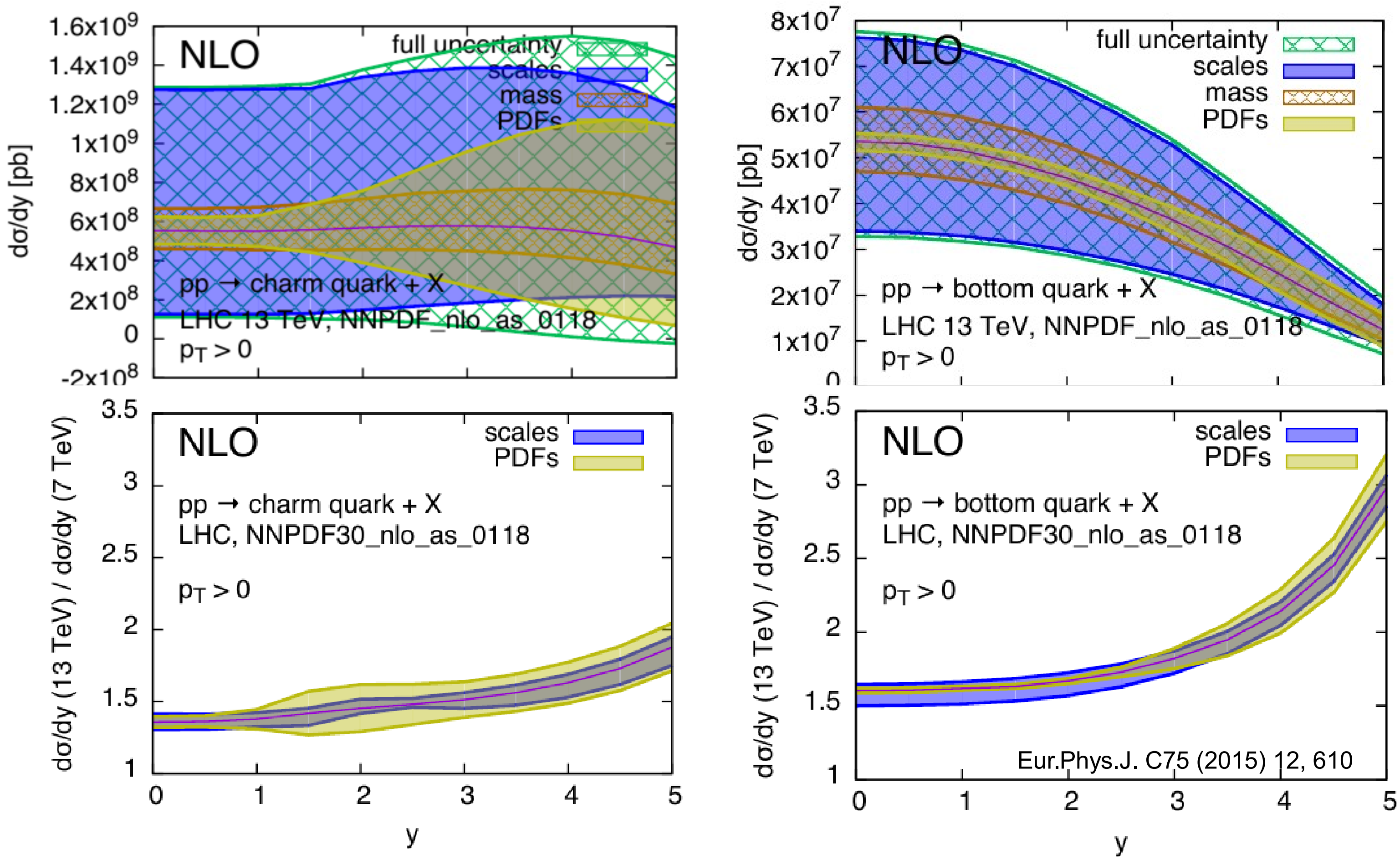
- sensitivity to low and high x gluon PDF
- heavy quark: good description of cross sections and ratios at different cm energies by predictions
- top production in the forward region
  excellent prospects for measurements in Run II and beyond
- double parton scattering:
  associated production of Υ and open charm
  → indication of DPS dominating production process
  double J/ψ → SPS and DPS contribution

Backup

Heavy flavour production

dominant uncertainty of predictions: scale uncertainty
forward: PDF uncertainty important
→ scale uncertainty largely reduced in ratios between different energies

charm bottom



ϒ production @ 7 and 8 TeV

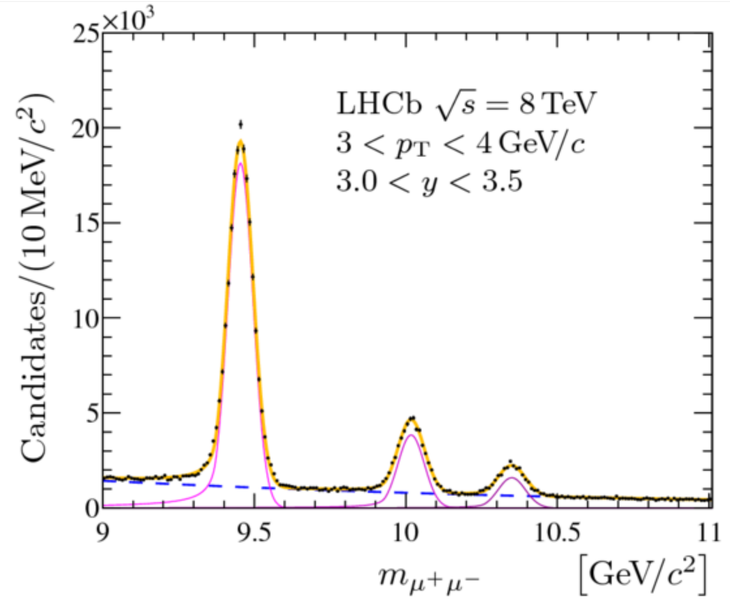
JHEP 11 (2015) 103

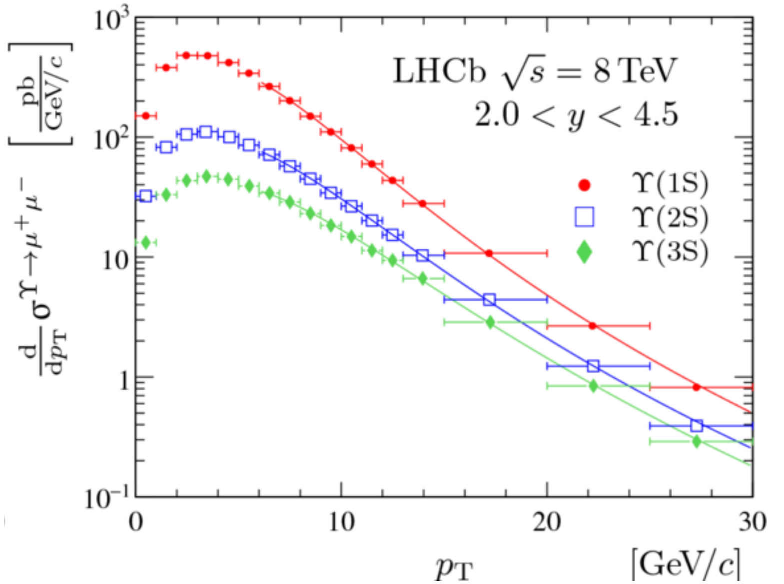
fiducial volume: $1 < p_T < 30$ GeV/c, $2 < \eta < 4.5$

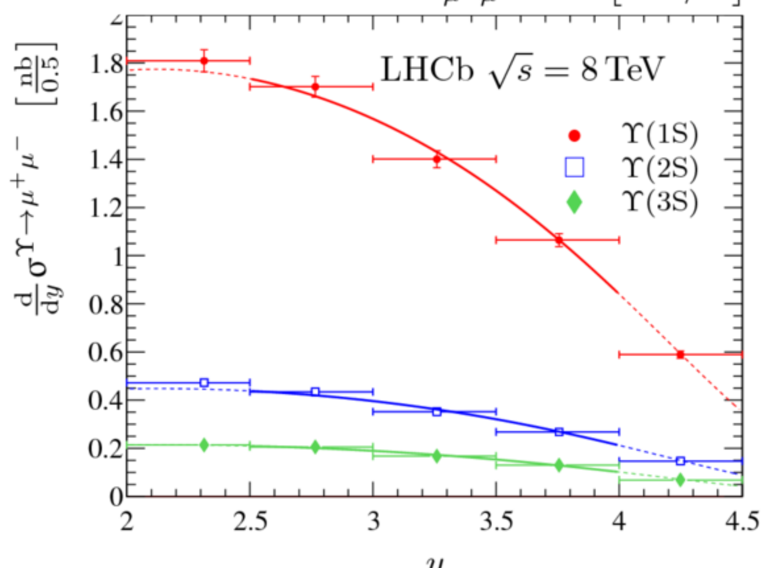
cross sections in pb:	$\sqrt{s} = 7$ TeV	$\sqrt{s} = 8$ TeV
$\sigma^{\Upsilon(1S)\to\mu^+\mu^-}$	$2510 \pm 3 \pm 80$	$3280 \pm 3 \pm 100$
$\sigma^{\Upsilon(2S)\to\mu^+\mu^-}$	$635 \pm 2 \pm 20$	$837 \pm 2 \pm 25$
$\sigma^{\Upsilon(3S)\to\mu^+\mu^-}$	$313 \pm 2 \pm 10$	$393 \pm 1 \pm 12$

p_T: fit Tsalis function

rapidity: CO model

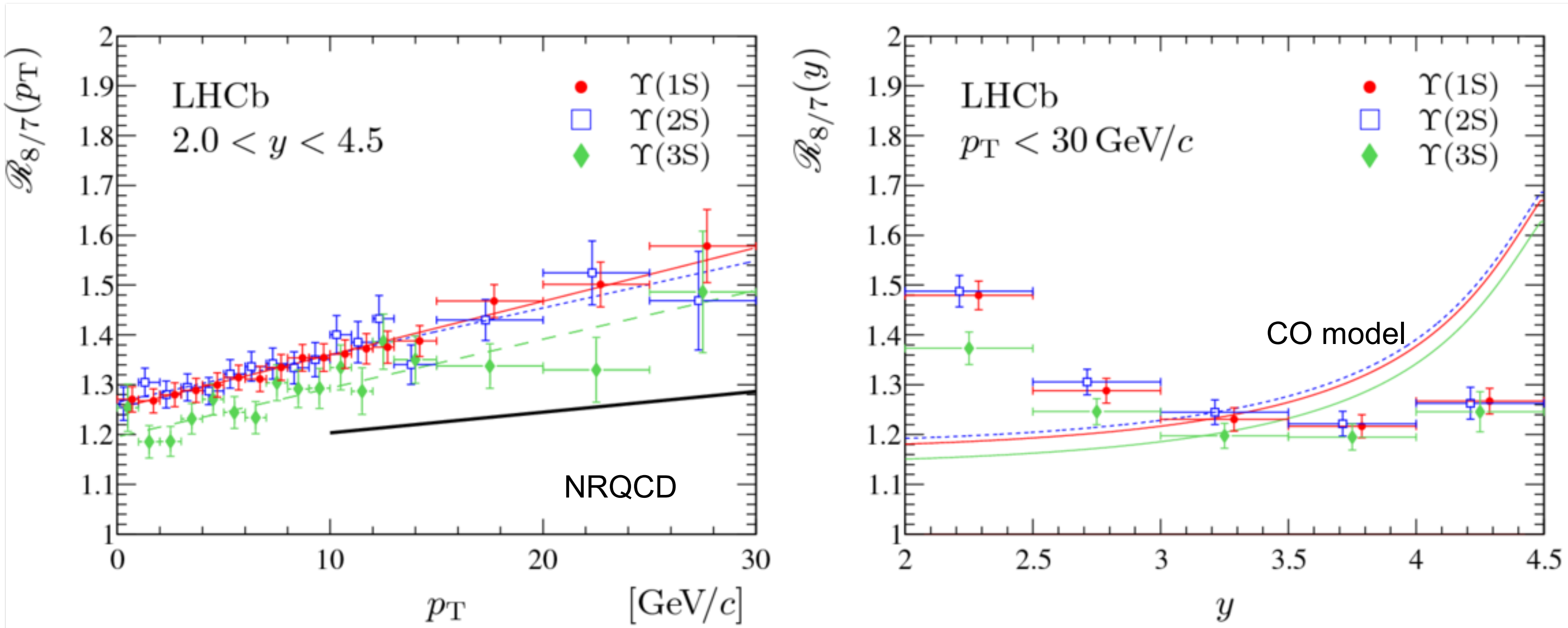






Υ cross section ratios 8/7 TeV

JHEP 11 (2015) 103



- Υ cross section increases by about 30% when increasing cm energy from 7 to 8 TeV
- observed increase in production cross section ratio larger than predicted by NRQCD
- rapidity distribution does not follow the pure CO model

NRQCD arXiv:1410.8537
heavy quark-antiquark pair is created at short distances, and subsequently evolves non-perturbatively into a quarkonium state

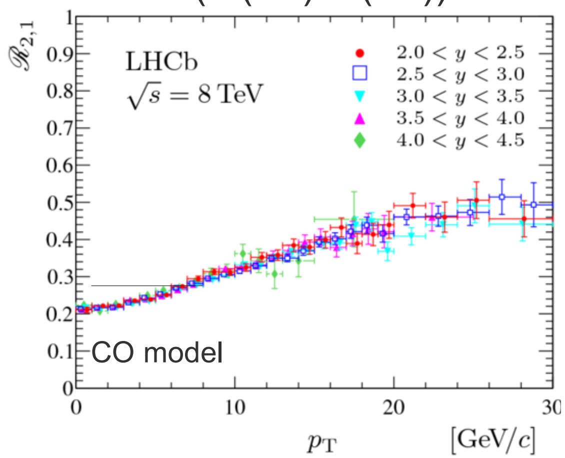
CO model Mod. Phys. Lett. A28 (2013) 1350120, Mod. Phys. Lett. A29 (2014) 1450082
normalisation fixed

Υ cross section ratios: different states

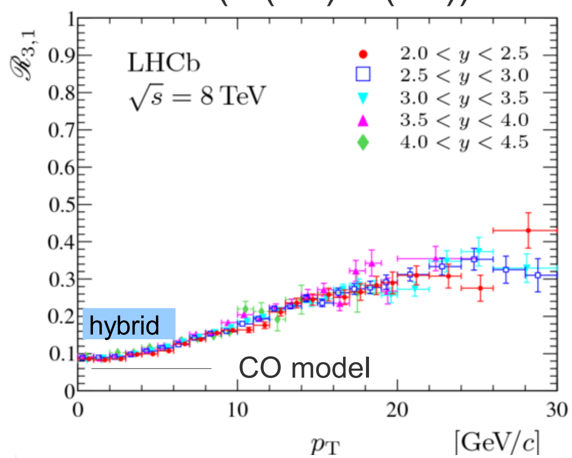
JHEP 11 (2015) 103

$1 < p_T < 30$ GeV/c, $2 < \eta < 4.5$

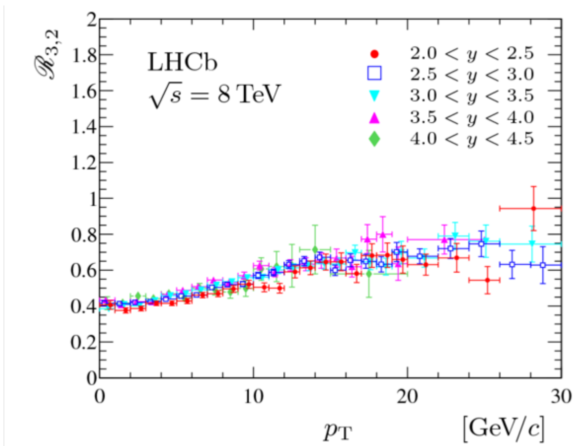
R(ϒ(2S)/ϒ(1S))



R(ϒ(3S)/ϒ(1S))



R(ϒ(3S)/ϒ(2S))



- ratios $R_{i,j}$ show little dependence on rapidity and increase as a function of p_T
- observation agree with measurement at 7 TeV
- CO model: R(ϒ(2S)/ϒ(1S)) = 0.27 → in agreement with measured value
  R(ϒ(3S)/ϒ(1S)) = 0.04 → much lower than measurement
- admixture of hybrid ϒ(3S) → $R_{3,1}$ = 0.14-0.22 Mod. Phys. Lett. A28 (2013) 1350067

J/ψ production cross sections @13 TeV

JHEP 10 (2015) 172
Erratum: JHEP 1705 (2017) 063

p_T (J/ψ) < 14 GeV/c and 2 < y(J/ψ) < 4.5

σ_{prompt} = 15.03 ± 0.03 (stat) ± 0.94 (syst) μb

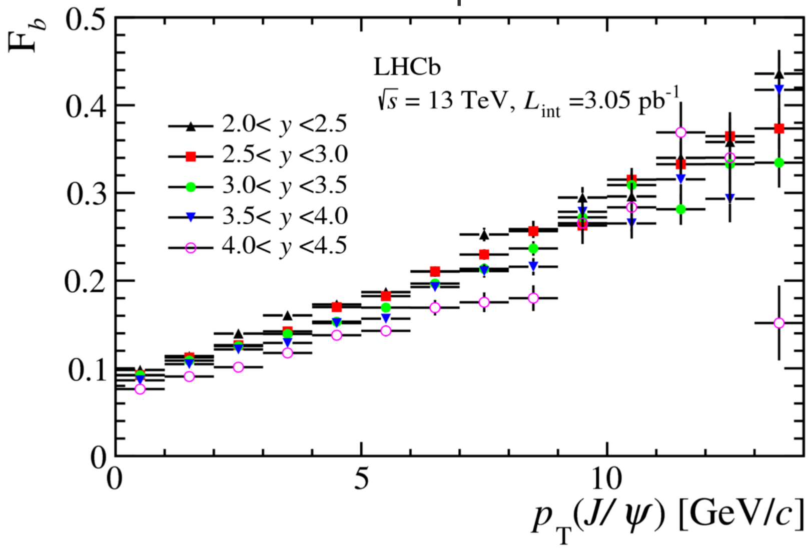
$\sigma_{from\ b}$ = 2.25 ± 0.01 (stat) ± 0.14 (syst) μb

→ extrapolated* total bb-bar x-section

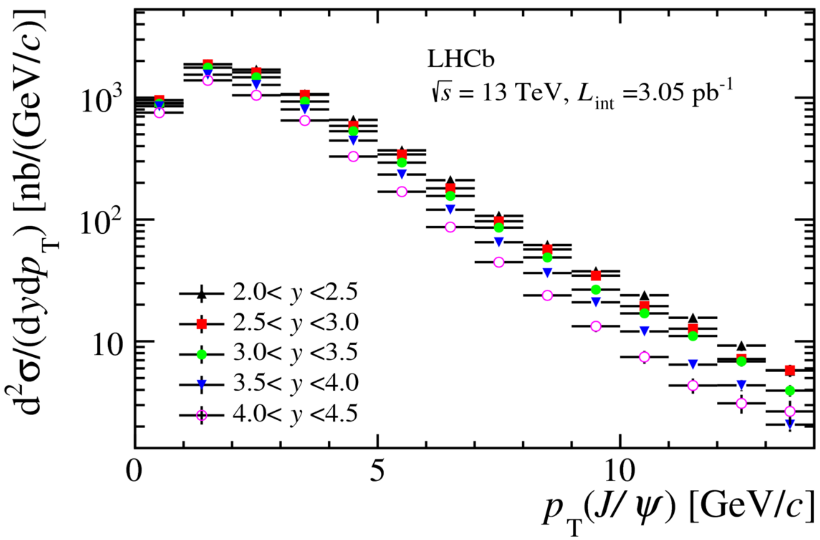
$\sigma_{bb\text{-}bar}$ = 495 ± 2 (stat) ± 52 (syst) μb

*B(b → J/ψ X) = 1.16 ± 0.10 %
naïve PYTHIA 6 extrapolation

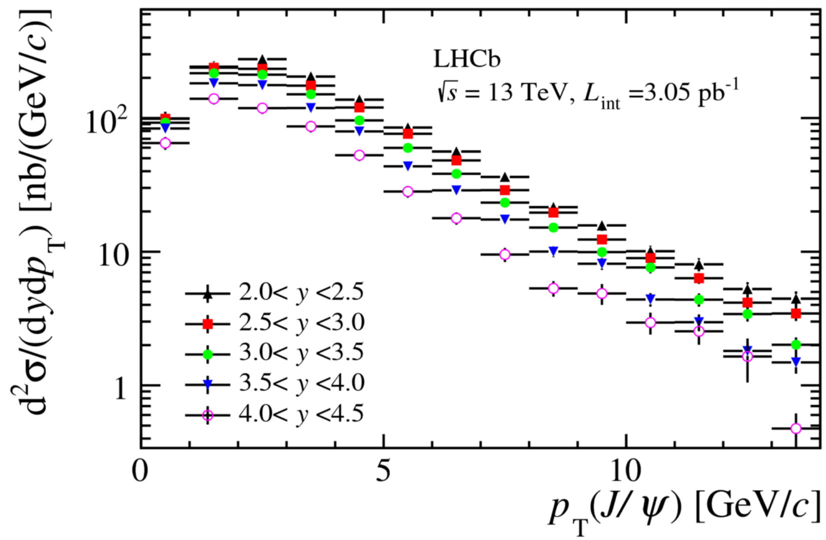
fraction of J/ψ from b



prompt J/ψ



J/ψ from b



b- hadron production asymmetries

arXiv 1703.08464

$$A_{\mathrm{P}} \equiv \frac{\sigma(\overline{H}_b) - \sigma(H_b)}{\sigma(\overline{H}_b) + \sigma(H_b)}$$

integrated over p_T and y $\rightarrow$ all results consistent with zero within 2.5 standard deviations

$$\begin{aligned}
A_{\mathrm{P}}(B^+)_{\sqrt{s}=7\,\mathrm{TeV}} &= -0.0023 \pm 0.0024\ (\mathrm{stat}) \pm 0.0037\ (\mathrm{syst}),\\
A_{\mathrm{P}}(B^+)_{\sqrt{s}=8\,\mathrm{TeV}} &= -0.0074 \pm 0.0015\ (\mathrm{stat}) \pm 0.0032\ (\mathrm{syst}),\\
A_{\mathrm{P}}(B^0)_{\sqrt{s}=7\,\mathrm{TeV}} &= 0.0044 \pm 0.0088\ (\mathrm{stat}) \pm 0.0011\ (\mathrm{syst}),\\
A_{\mathrm{P}}(B^0)_{\sqrt{s}=8\,\mathrm{TeV}} &= -0.0140 \pm 0.0055\ (\mathrm{stat}) \pm 0.0010\ (\mathrm{syst}),\\
A_{\mathrm{P}}(B^0_s)_{\sqrt{s}=7\,\mathrm{TeV}} &= -0.0065 \pm 0.0288\ (\mathrm{stat}) \pm 0.0059\ (\mathrm{syst}),\\
A_{\mathrm{P}}(B^0_s)_{\sqrt{s}=8\,\mathrm{TeV}} &= 0.0198 \pm 0.0190\ (\mathrm{stat}) \pm 0.0059\ (\mathrm{syst}),\\
A_{\mathrm{P}}(\Lambda^0_b)_{\sqrt{s}=7\,\mathrm{TeV}} &= -0.0011 \pm 0.0253\ (\mathrm{stat}) \pm 0.0108\ (\mathrm{syst}),\\
A_{\mathrm{P}}(\Lambda^0_b)_{\sqrt{s}=8\,\mathrm{TeV}} &= 0.0344 \pm 0.0161\ (\mathrm{stat}) \pm 0.0076\ (\mathrm{syst}).
\end{aligned}$$

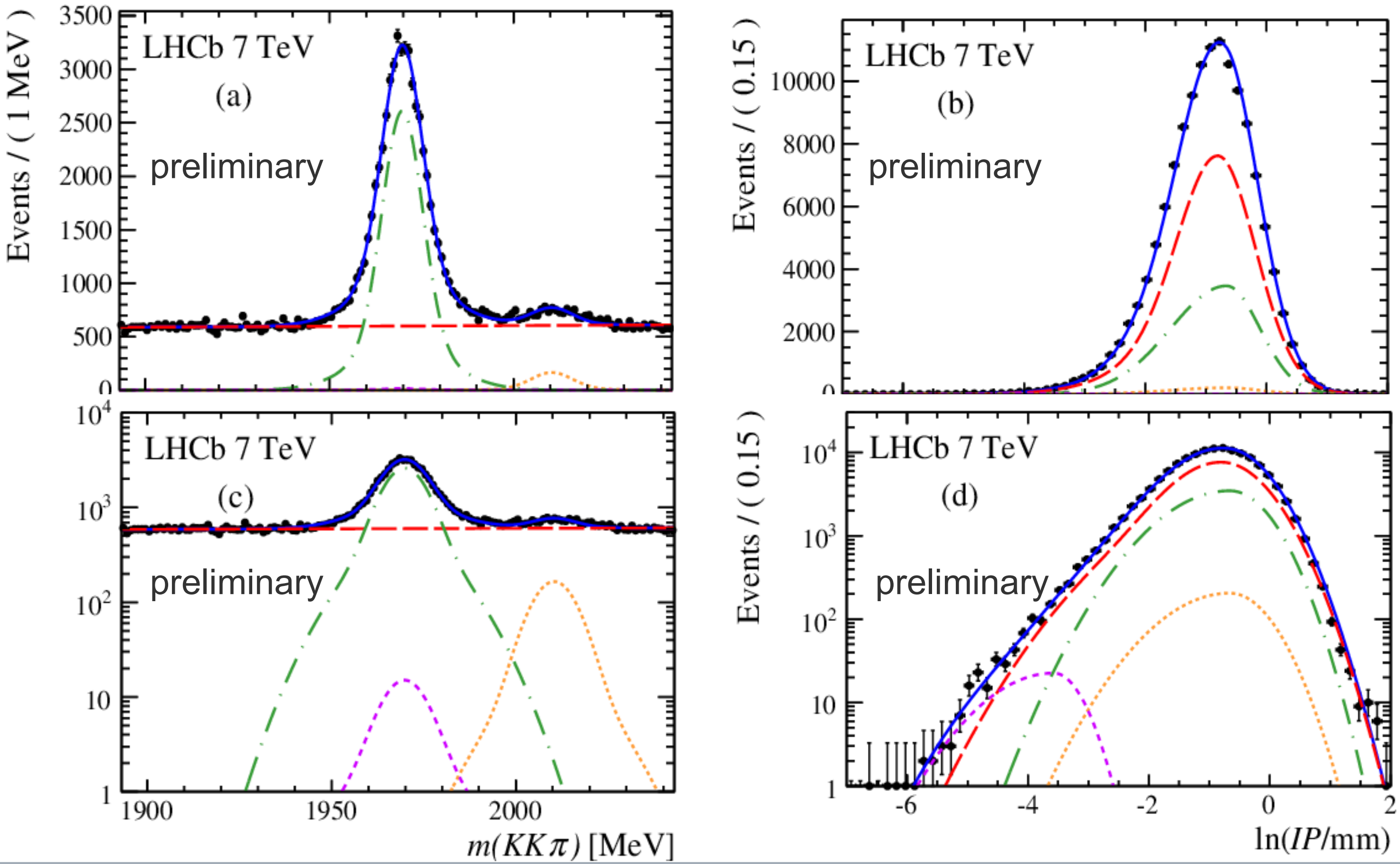
for λ_b $$A_{\mathrm{P}}(\Lambda^0_b) = -\left[\frac{f_u}{f_{\Lambda^0_b}} A_{\mathrm{P}}(B^+) + \frac{f_d}{f_{\Lambda^0_b}} A_{\mathrm{P}}(B^0) + \frac{f_s}{f_{\Lambda^0_b}} A_{\mathrm{P}}(B^0_s) + \mathcal{O}(2 \cdot 10^{-3})\right]$$

with fragmentation fractions from JHEP 1304 001, JHEP 1408 143

Bottom @7 and 13 TeV

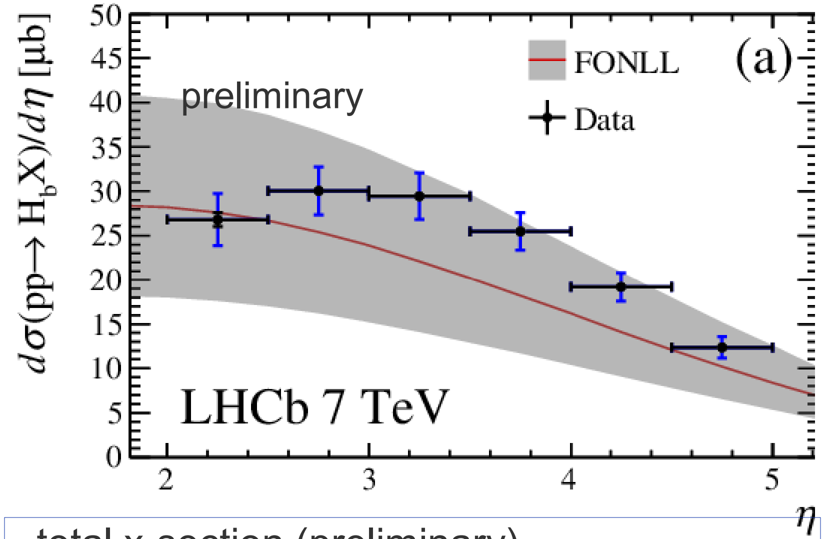
Phys. Rev. Lett. 118, 052002 (2017)

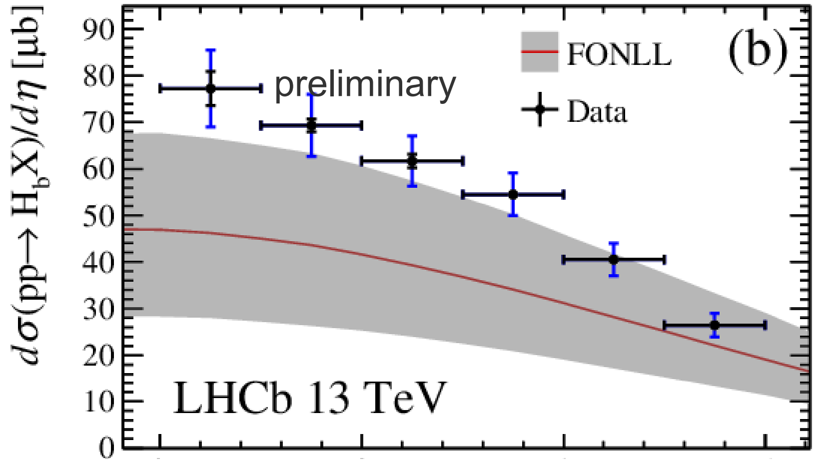
- b quark production cross-section at 7 and 13 TeV from semi-leptonic decays of b-hadrons
- right-sign combination of charm-hadron (D^0,D^+,D_s, Λ_c) and μ not pointing at the PV
- ln(IP) distribution of the charm-hadron to separate prompt charm from D from b-hadron
- signal extraction: simultaneous fit to invariant mass and ln(IP)



Bottom @7 and 13 TeV

Phys. Rev. Lett. 118, 052002 (2017)

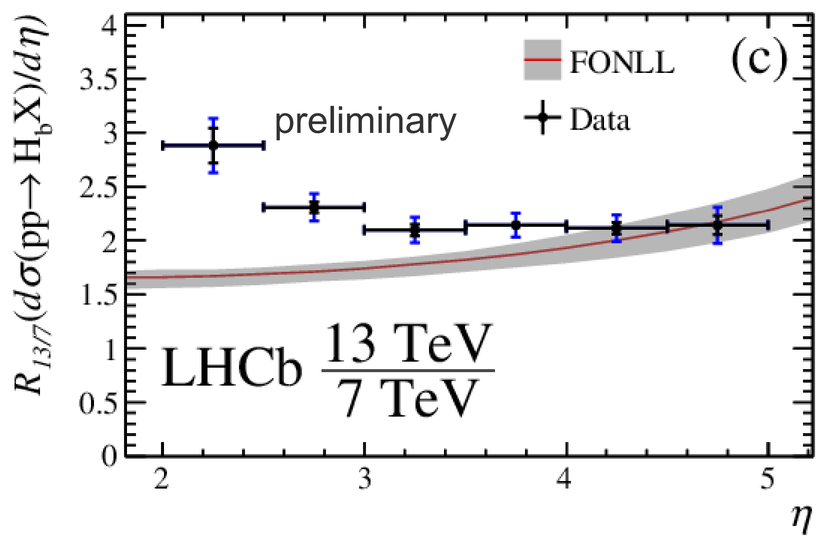




total x-section (preliminary)
$\sigma(pp\to H_b+X)$ in $2 < \eta(H_b) < 5$

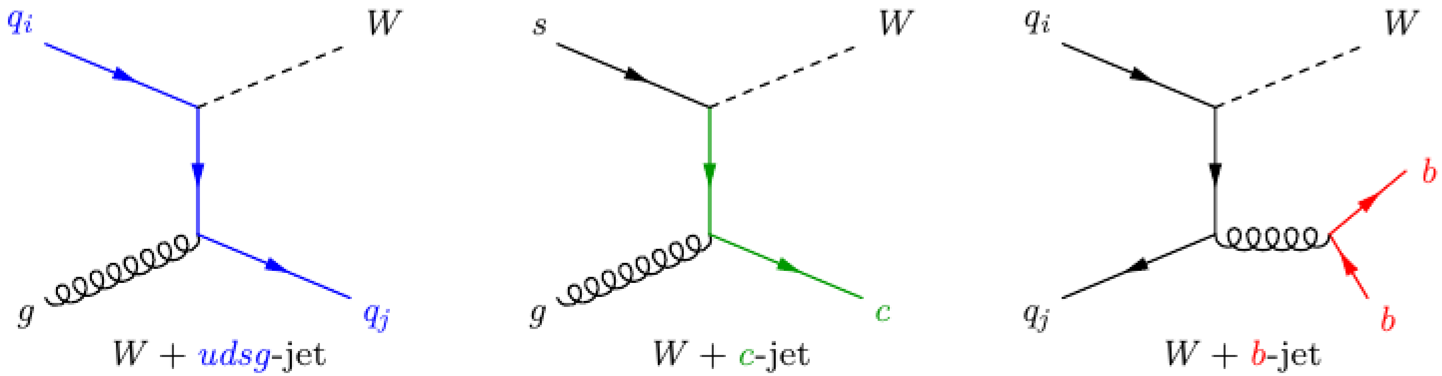
σ(7 TeV)	=	71.5 ± 0.5 ± 6.5 μb
σ(13 TeV)	=	164.6 ± 2.3 ± 14.6 μb
ratio 13/7	=	2.3 ± 0.2 ± 0.2

- 7 TeV: in agreement with FONLL prediction
- 13 TeV: tendency to be above prediction

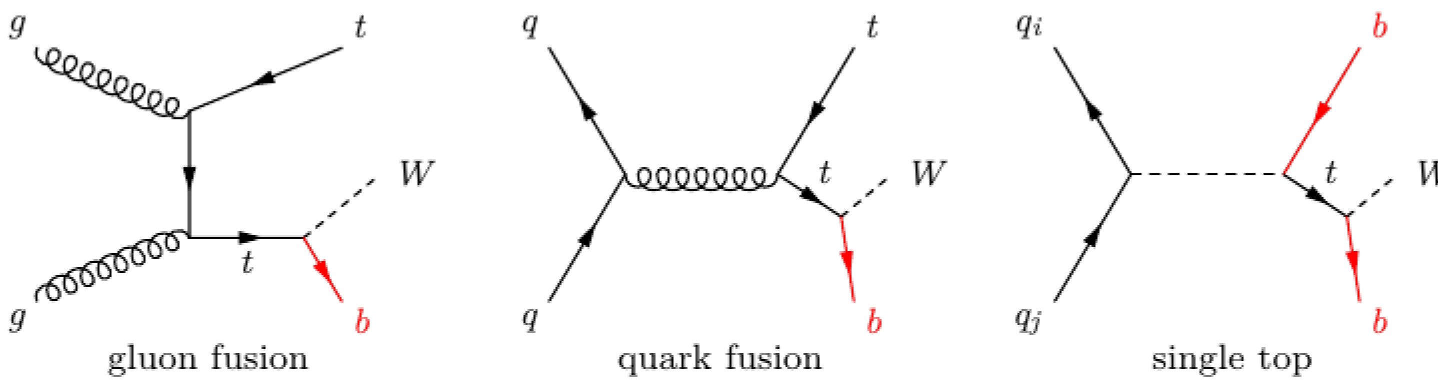


Erratum being prepared, bug in simulation will affect low η @13 TeV
result will likely be in agreement with FONLL

W plus jet production



→ W + udsg, bbbar or c-jet: Sensitivity to valence PDFs and strange quark asymmetries



→ W bbbar or b-jet: Sensitivity to gluon PDFs and top quark asymmetries