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LHCb results on production, polarization and production asymmetries

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Outline

- The LHCb experiment
- Heavy flavour production: recent results
  - J/ψ and Υ(nS) production at √s = 8 TeV
  - $\Lambda^0_b \rightarrow J/\psi\, \Lambda$ decay amplitudes and Λ^0_b polarization
  - Forward-central $b\bar{b}$ production asymmetry
- Conclusions

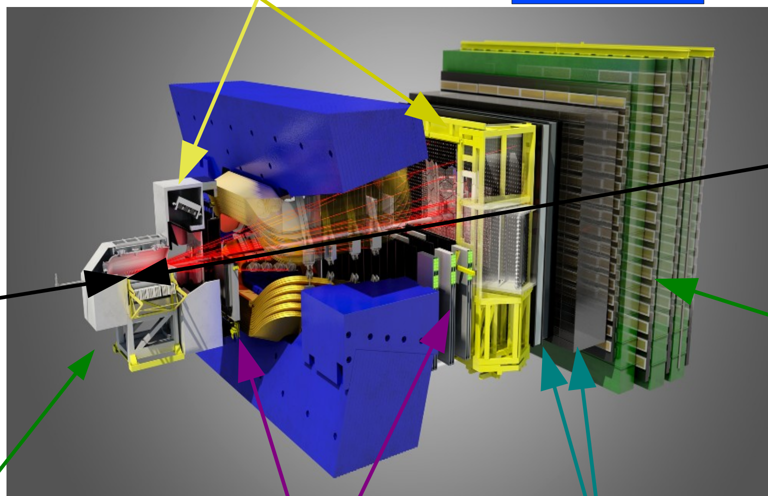
The LHCb experiment

RICH 1 & 2
$\varepsilon(K \rightarrow K) \sim 95\%$ π-K mis-id ~ 5%

$2<\eta<5$

beam 1

beam 2



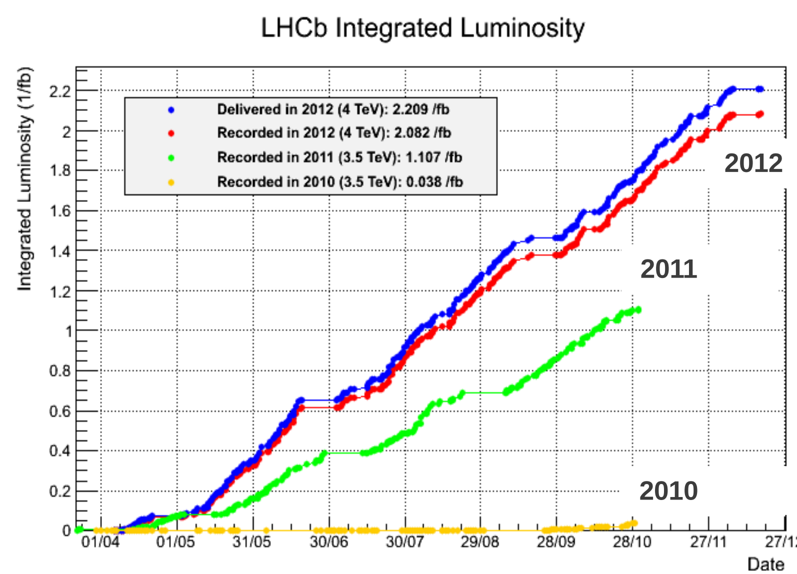
Muon system
$\varepsilon(\mu \rightarrow \mu) \sim 97\%$
$\pi-\mu$ mis-id ~ 1-3%

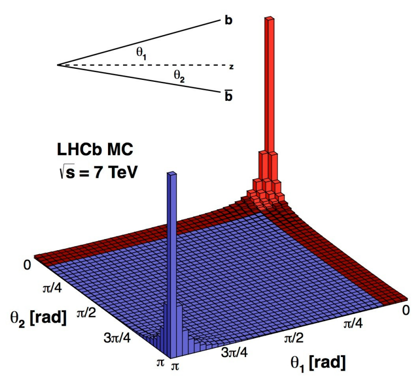
VELO
PV σ: ~13 μm in *x, y*
~70 μm in *z*

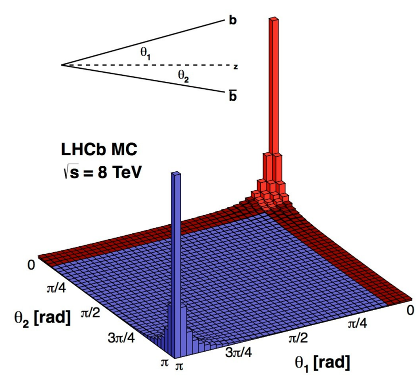
Tracking system
$\Delta p/p \sim 0.4 - 0.6\%$

Calorimeters
Ecal: $\sigma_E/E \sim 1\% + 10\%/\sqrt{E}$

- In total 3 fb^{-1} available for analyses
- In 2013 LHCb collected pA collision data: ~2 nb^{-1}







J/ψ and Υ(nS) production at $\sqrt{s}$ = 8 TeV (I)

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- LHCb has already published cross-sections at lower energies
  - EPJC 71 (2011), 1645, J/ψ at $\sqrt{s}$=7 TeV
  - EPJC 72 (2012), 2025, Υ(nS) at $\sqrt{s}$=7 TeV
  - JHEP 1302 (2013), 041, J/ψ at $\sqrt{s}$=2.76 TeV
  - Many other papers on quarkonium production ….
- $\sqrt{s}$=8 TeV measurement: **a new input for theorists**
- Experimental facts
  - p_T<15 GeV/c for Υ(nS) and p_T<14 GeV/c for J/ψ; 2.0<y<4.5 for both
  - Data collected in April 2012: 51 pb^{-1} for Υ(nS) and 18 pb^{-1} for J/ψ
  - Dimuon decays to exploit excellent trigger performances

J/ψ and Υ(nS) production at √s = 8 TeV (II)

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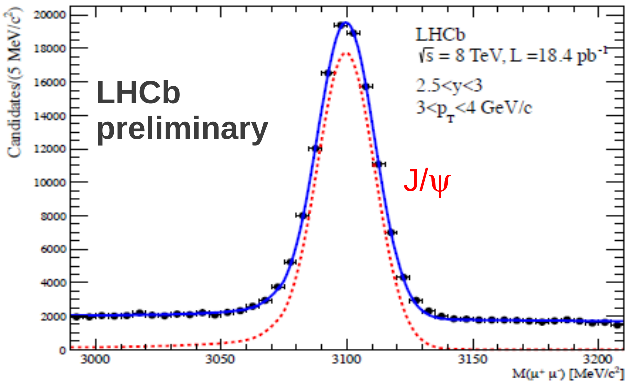

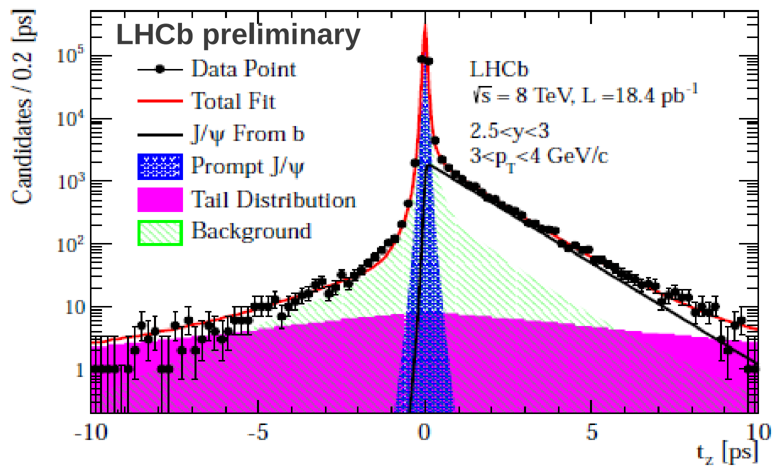

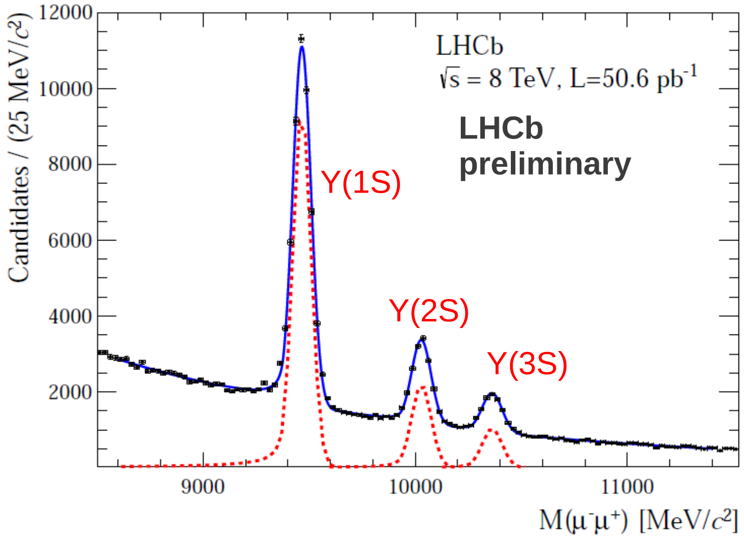

- J/ψ: prompt and from *b* decays components separated using t_z

$$t_z = \frac{(z_{J/\psi} - z_{PV}) \times M_{J/\psi}}{p_z}$$

- Invariant mass distributions modelled with Crystal Ball functions (radiative tail) and exponential background

J/ψ and Y(nS) production at √s = 8 TeV (III)

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- Vector meson *P* double differential cross-section

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}y\mathrm{d}p_{\mathrm{T}}} = \frac{N\left(P \to \mu^+\mu^-\right)}{\mathcal{L} \times \epsilon_{\mathrm{tot}} \times \mathcal{B}\left(P \to \mu^+\mu^-\right) \times \Delta y \times \Delta p_{\mathrm{T}}}$$

- Efficiency evaluated with MC and validated with data
- Many systematic uncertainties considered
- **Polarisation**: extreme scenarios would produce further variations between 1-40 % (bin dependent)
  - final result given in the hypothesis of unpolarised mesons

Systematic source	%
Correlated between bins	
Mass fits	0.7 to 2.2
Radiative tail	1.0
Muon identification	1.3
Tracking efficiency	0.9
Vertexing	1.0
Trigger	4.0
Luminosity	5.0
$\mathcal{B}(J/\psi \to \mu^+\mu^-)$	1.0
Uncorrelated between bins	
Model dependence	1.0 to 6.0
Applied only to J/ψ from b fraction	
t_z fit	1.0 to 12.0
Applied only to $\sigma(pp \to b\bar{b}X)$	
$\mathcal{B}(b \to J/\psi X)$	8.6

reducible (Trigger, Luminosity)

J/ψ and Υ(nS) production at √s = 8 TeV (IV)

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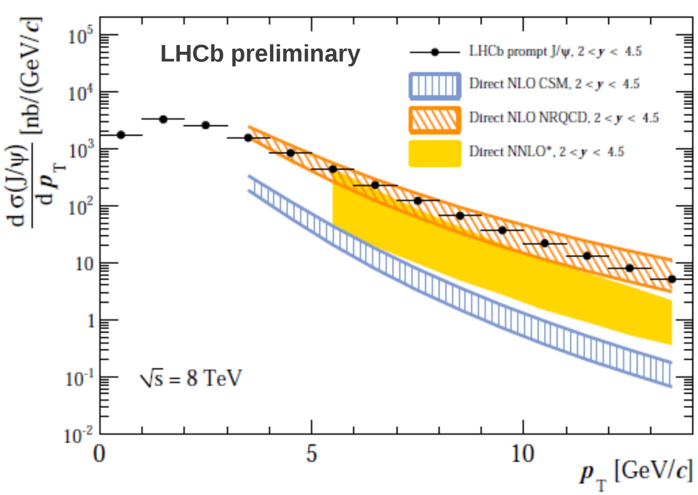
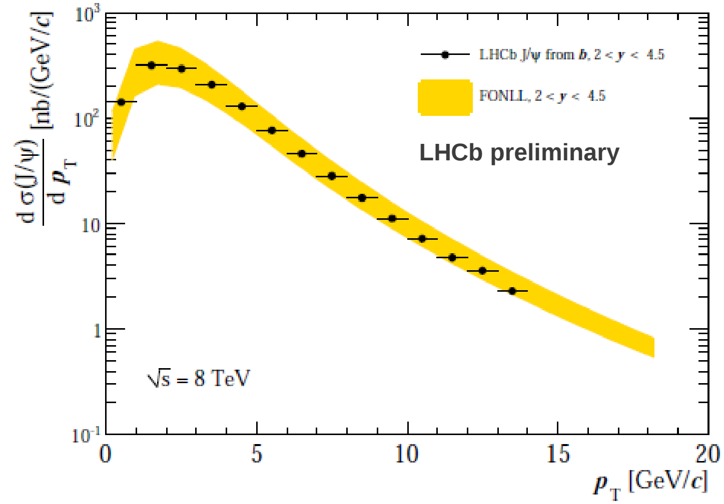
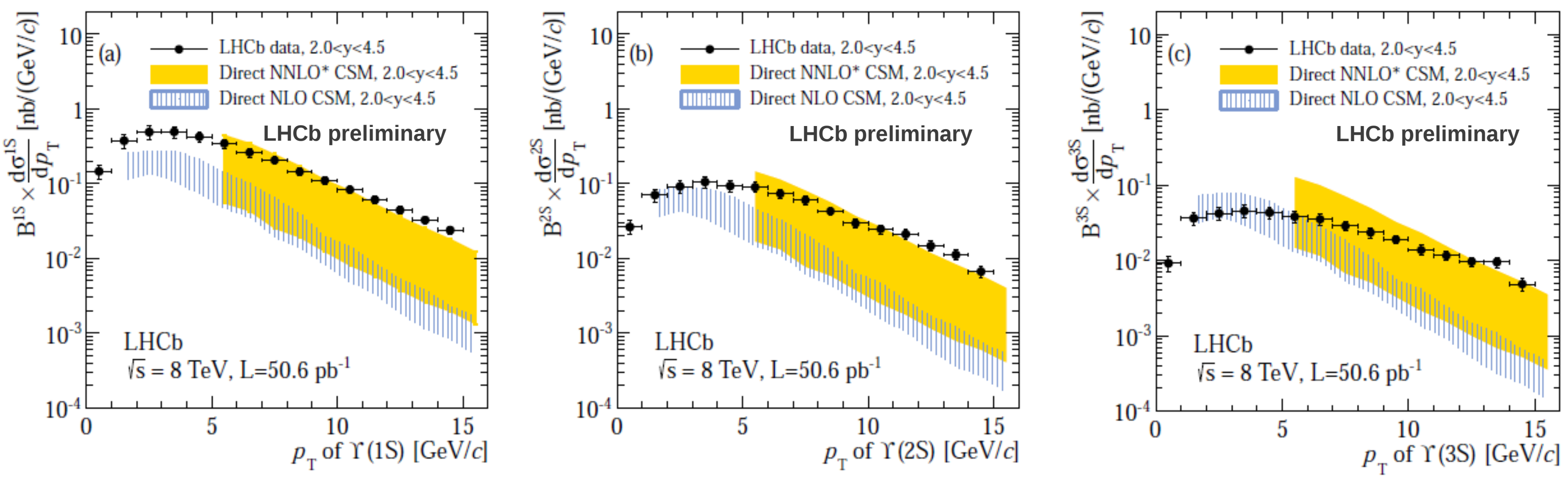
- **Preliminary results:** integrated over rapidity (unpolarised mesons)







J/ψ and Υ(nS) production at √s = 8 TeV (V)

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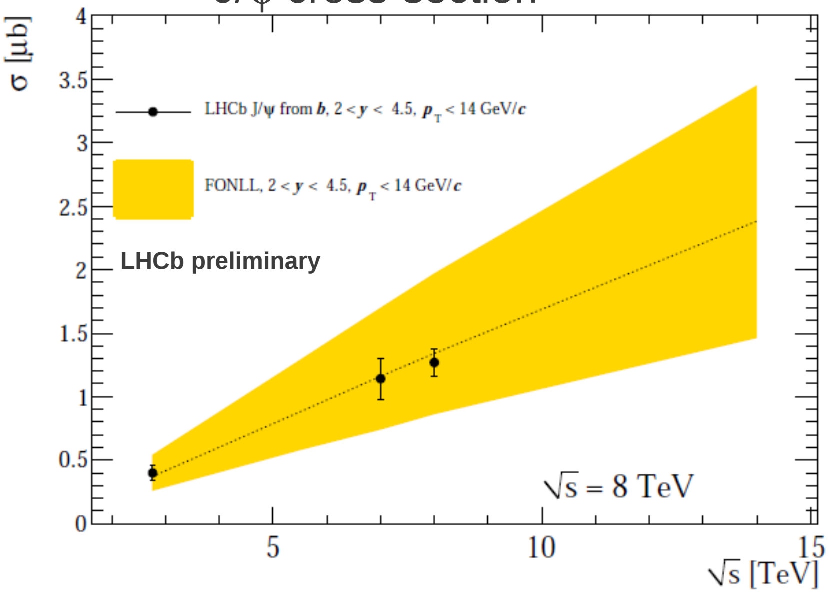
- **Preliminary results**

$$\sigma\,(\text{prompt } J/\psi\,, p_{\rm T} < 14~\text{GeV}/c,\ 2.0 < y < 4.5) = 10.94 \pm 0.02 \pm 0.79~\mu\text{b}$$

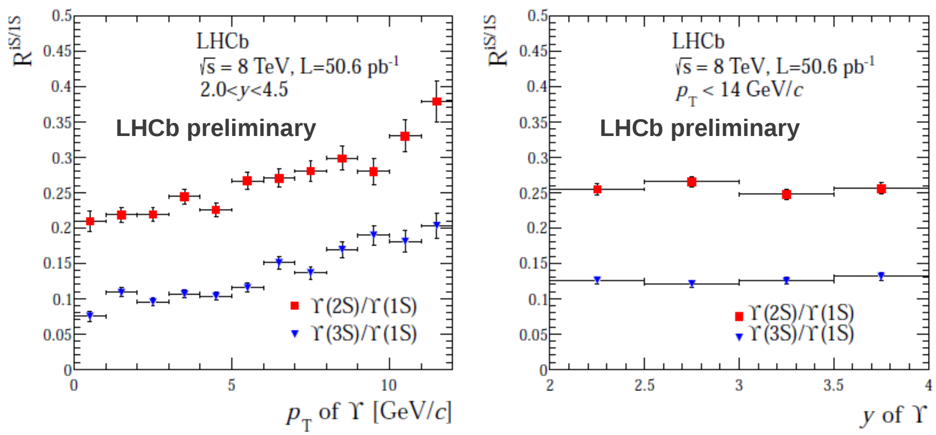
$$\sigma\,(J/\psi \text{ from } b,\ p_{\rm T} < 14~\text{GeV}/c,\ 2.0 < y < 4.5) = 1.28 \pm 0.01 \pm 0.11~\mu\text{b}$$

J/ψ cross-section



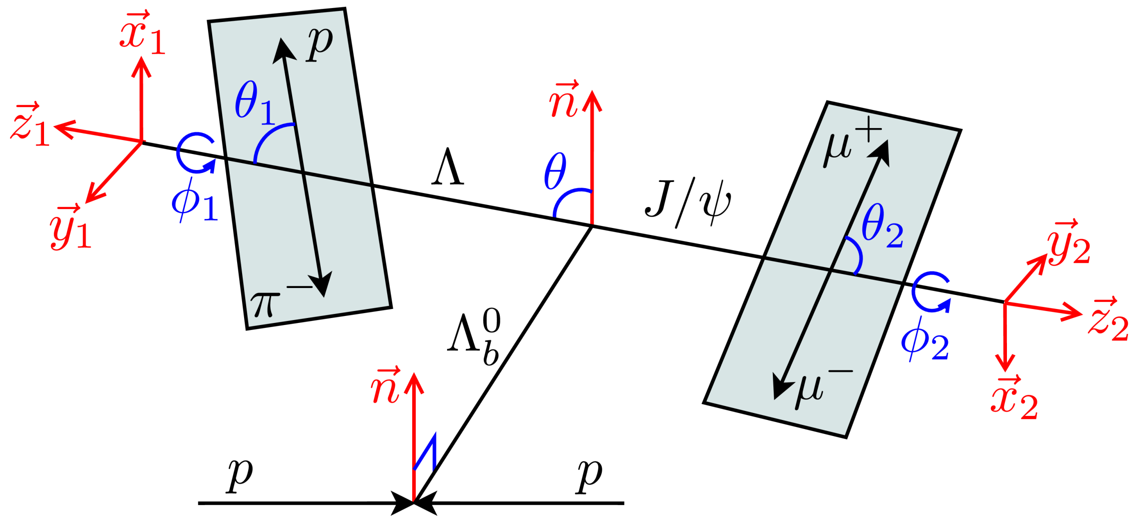
p_T<15 GeV/c

$$\sigma(pp \to \Upsilon(1S)X) \times B^{1S} = 3.241 \pm 0.019 \pm 0.160~\text{nb}$$
$$\sigma(pp \to \Upsilon(2S)X) \times B^{2S} = 0.761 \pm 0.008 \pm 0.038~\text{nb}$$
$$\sigma(pp \to \Upsilon(3S)X) \times B^{3S} = 0.369 \pm 0.005 \pm 0.019~\text{nb}$$



$\Lambda^0_b \to J/\psi\ \Lambda$ decay amplitudes and Λ^0_b polarization (I)

- Λ^0_b in *pp* collisions expected to be transversally polarized (HQET)
- Not yet measured at any hadron collider
- $\Lambda^0_b \to \Lambda\ J/\psi$ (½ → ½ + 1) with $\Lambda \to (p\pi^-)$ and $J/\psi \to (\mu^-\mu^+)$



$\vec{n}$ normal to the production plane
θ angle between $p(\Lambda)$–$\vec{n}$ in the Λ_b rest frame
$\theta 1$, $\phi 1$ in the Λ rest frame
$\theta 2$, $\phi 2$ in the J/ψ rest frame

- Decay dynamics can be probed looking at 5 angles (3 angles integrating over azimuthal ϕ_1 and ϕ_2). Sensitive to polarization and squared amplitudes

$\Lambda^0_b \to J/\psi\ \Lambda$ decay amplitudes and Λ^0_b polarization (II)

$$\frac{d\Gamma}{d\Omega_3} = \frac{1}{16\pi}\sum_{i=0}^{7} f_i(a_+, a_-, b_+, b_-)\, g_i(P_b, \alpha_\Lambda)\, h_i(\cos\theta, \cos\theta_1, \cos\theta_2)$$

$$\begin{aligned} a_+ &\equiv \mathcal{M}_{+\frac{1}{2},0} \\ a_- &\equiv \mathcal{M}_{-\frac{1}{2},0} \\ b_+ &\equiv \mathcal{M}_{-\frac{1}{2},-1} \\ b_- &\equiv \mathcal{M}_{+\frac{1}{2},+1} \end{aligned}$$

Helicity amplitudes

i	$f_i(\alpha_b, r_0, r_1)$	$g_i(P_b, \alpha_\Lambda)$	$h_i(\cos\theta, \cos\theta_1, \cos\theta_2)$
0	1	1	1
1	α_b	P_b	$\cos\theta$
2	$2r_1 - \alpha_b$	α_Λ	$\cos\theta_1$
3	$2r_0 - 1$	$P_b\alpha_\Lambda$	$\cos\theta\cos\theta_1$
4	$\frac{1}{2}(1 - 3r_0)$	1	$\frac{1}{2}(3\cos^2\theta_2 - 1)$
5	$\frac{1}{2}(\alpha_b - 3r_1)$	P_b	$\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta$
6	$-\frac{1}{2}(\alpha_b + r_1)$	α_Λ	$\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta_1$
7	$-\frac{1}{2}(1 + r_0)$	$P_b\alpha_\Lambda$	$\frac{1}{2}(3\cos^2\theta_2 - 1)\cos\theta\cos\theta_1$

to be measured simultaneously from angular distribution fit

$\alpha_b = |a_+|^2 - |a_-|^2 + |b_+|^2 - |b_-|^2$ is the asymmetry, predicted to be ~ -15% (†)

$r_0 = |a_+|^2 + |a_-|^2$

$r_1 = |a_+|^2 - |a_-|^2$

P_b is the transverse polarization, predicted to be ~ 10-20% (*)

(*) Phys. Lett. B649 (2007) 152
(*) Phys. Lett. B614 (2005) 156

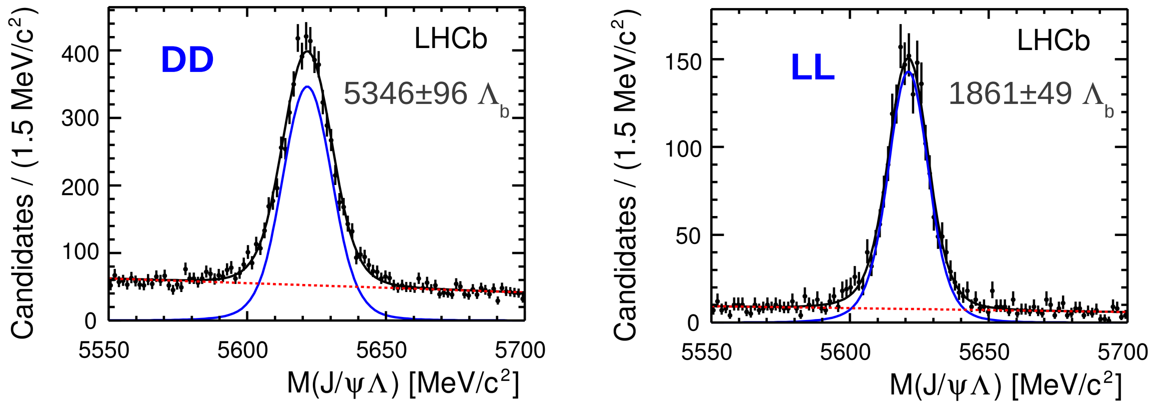
(†) Many predictions, see our paper

$\Lambda^0_b \to J/\psi\, \Lambda$ decay amplitudes and Λ^0_b polarization (III)

arXiv:1302.5578v1 [hep-ex]

- **Analysis based on 1 fb^{-1} at $\sqrt{s}$=7 TeV**

Λ decays outside the VELO: **DD** Λ decays within the VELO: **LL**



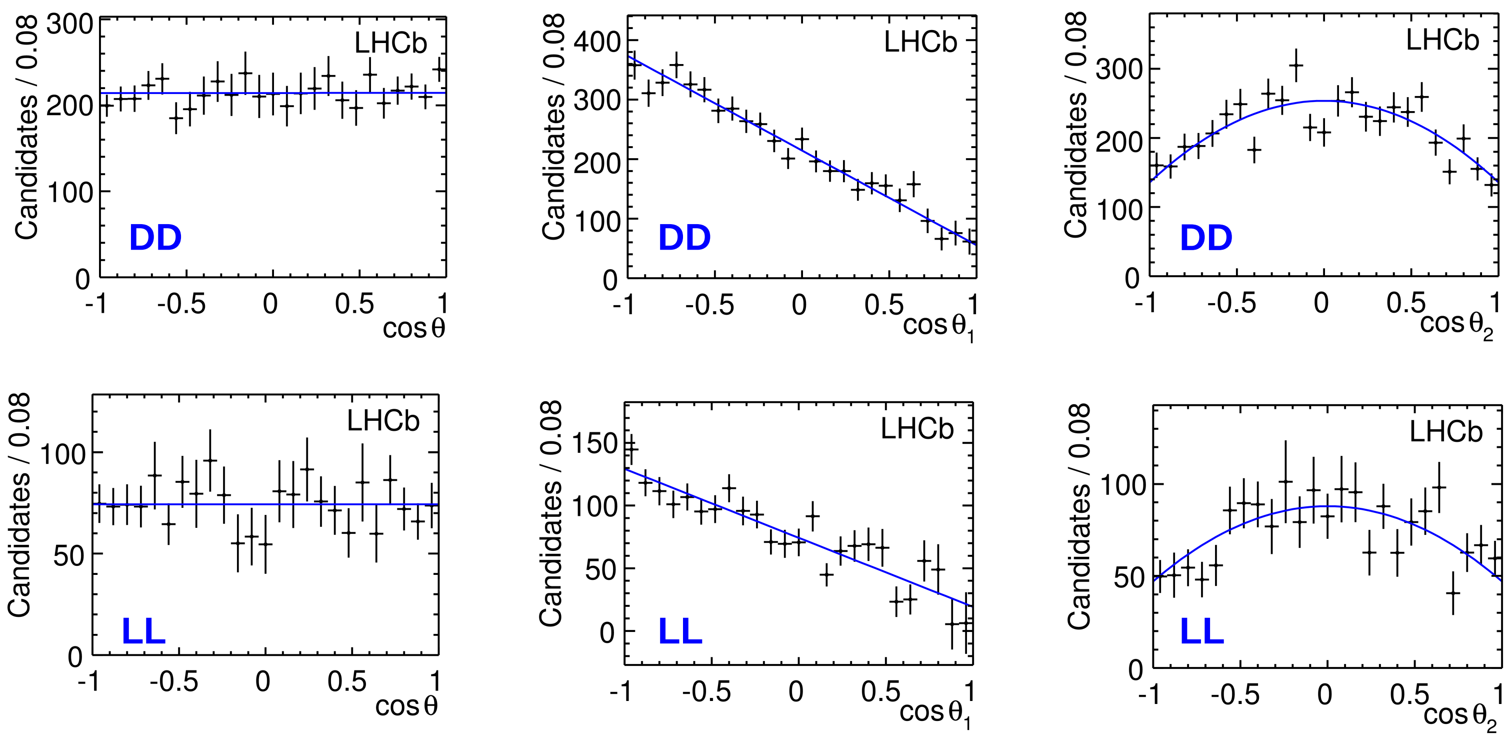
- w_{mass} weights are obtained to subtract background in 3D ($\cos\theta$, $\cos\theta_1$, $\cos\theta_2$)

- $w_{acc} = 1/f_{acc}(\cos\theta, \cos\theta_1, \cos\theta_2)$ to correct for the acceptance
- $f_{acc}(\cos\theta, \cos\theta_1, \cos\theta_2)$ obtained from simulated events
- each event is weighted by $w_{mass}\, w_{acc}$ (event by event correction)

$\Lambda^0_b \to J/\psi\, \Lambda$ decay amplitudes and Λ^0_b polarization (IV)

arXiv:1302.5578v1 [hep-ex]

Background subtracted and acceptance corrected data



- Fitting procedure checked with Monte Carlo simulation to understand its reliability

$\Lambda^0_b \to J/\psi\, \Lambda$ decay amplitudes and Λ^0_b polarization (V)

arXiv:1302.5578v1 [hep-ex]

- Results (NEW! The first time at a hadron collider)

	(value)	(stat)	(syst)
$P_b =$	0.05	± 0.07	± 0.02
$\alpha_b =$	-0.04	± 0.17	± 0.07
$r_0 =$	0.57	± 0.02	± 0.01
$r_1 =$	-0.59	± 0.10	± 0.05

→ Cannot exclude T pol of 10% (P_b)

→ Cannot exclude most predictions ~ -15% (α_b)

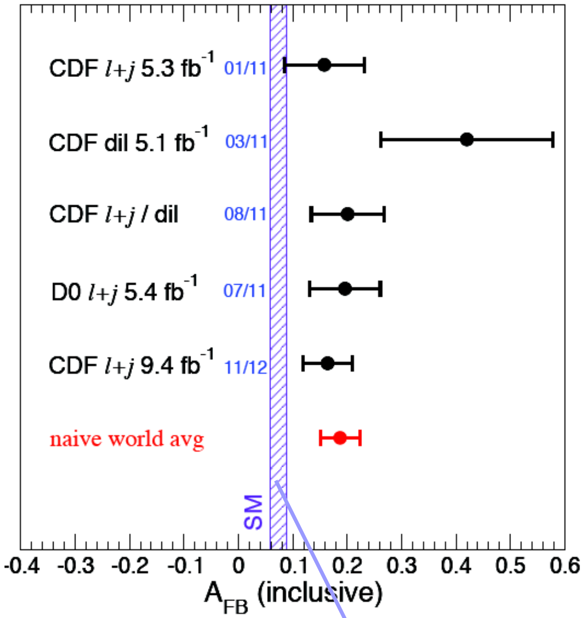
- Systematic errors mostly due to the determination of the acceptance function from Monte Carlo: ~100% of P_b error and ~60% of α_b error

Forward-central $b\bar{b}$ production asymmetry (I)

$t\bar{t}$ asymmetry at Tevatron: $p\bar{p}$ collisions allow to distinguish forward-backward

$$A_{FB}^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)} \qquad \Delta y = y_t - y_{\bar{t}}$$

How much the top quark prefers to be aligned with the initial quark



From interference between L0 and NLO
$q\bar{q} \rightarrow t\bar{t}$

- LHC: initial directions of q and $\bar{q}$ not known
- **Forward-central asymmetry is a related observable**
- Provides useful constraints to the models

Kahawala, Krohn, Strassler arXiv:1108.3301

$$A_{FC}^{b\bar{b}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

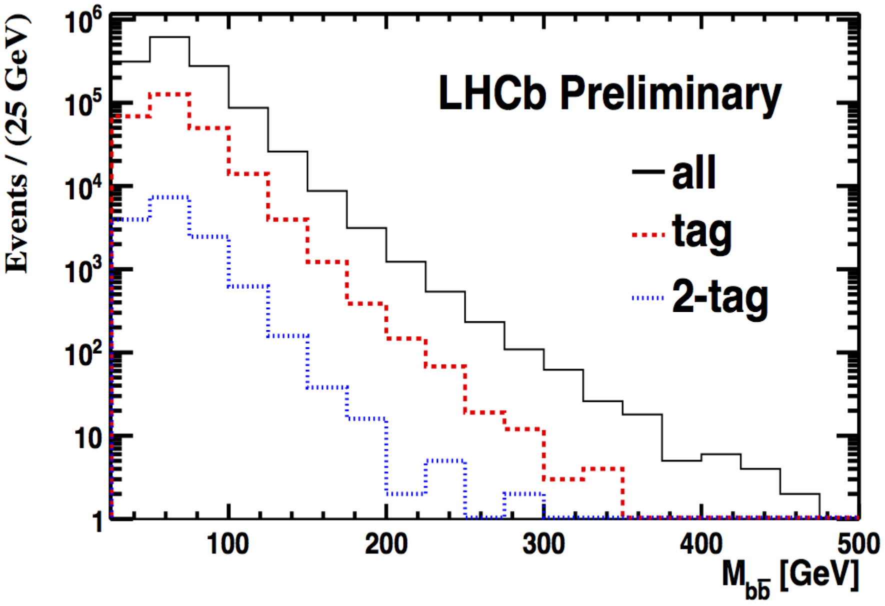
$$\Delta y = |y_b| - |y_{\bar{b}}|$$

Forward-central $b\bar{b}$ production asymmetry (II)

1 fb^{-1}, √s=7 TeV (2011)

LHCb-CONF-2013-001

- **Selection**: 2 high p_T (>15 GeV) back-to-back ($\Delta\phi$>2.5) *b*-tagged jets from the same PV (anti-k_T algorithm)
- ***b*-tagging**: only consider jets whose hardest displaced track is identified as a muon. Charge of the muon used to tag the jet as *b* or $\bar{b}$ ($b \rightarrow \mu\nu X$)
- **Jet Energy Correction**
  - Out-of-acc. particles, detector response: 20-30 %
  - Missing ν, track multiplicity 10-20 %
- **Jet E resolution**
  - σ = 15-20 %



Forward-central $b\bar{b}$ production asymmetry (III)

1 fb^{-1}, $\sqrt{s}$=7 TeV (2011)

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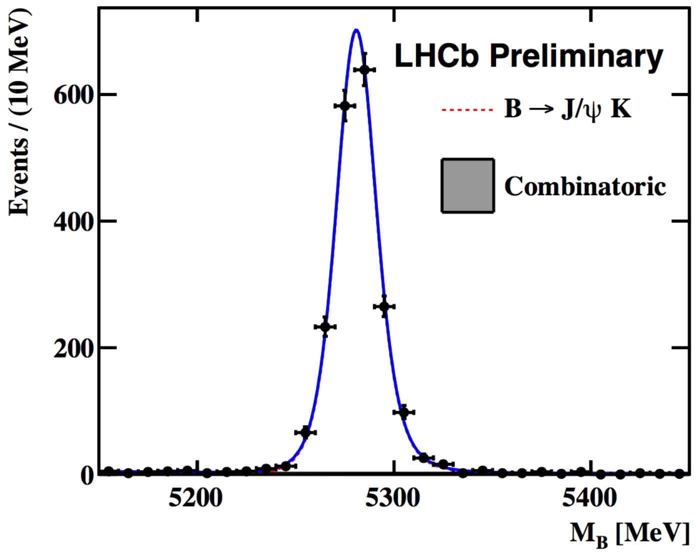
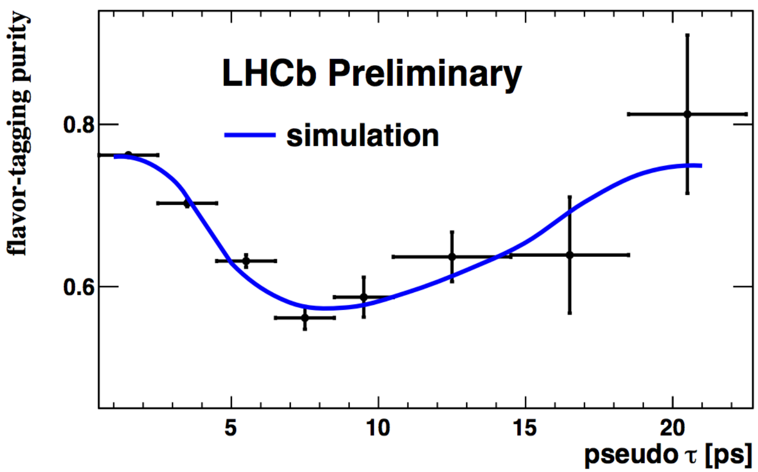
- **Flavour tagging purity:** from MC → (73±2)%



- Validated using $B^+ \to J/\psi K^+$ and $B^+ \to \bar{D}^0\pi^+$: accompanying quark flavor is known (*b*)
  - **Tagging purity (71.5±4)%**
- Validated using doubly-tagged sample
  - opposite charged muons: right tag
  - same sign muons: wrong tag



- *b*-hadron lifetime τ is estimated using the measured jet energy and flight distance
- Overall **tagging purity: (70.7 ± 0.4)%**
- Excellent agreement with B+jet and prediction!

Forward-central $b\bar{b}$ production asymmetry (IV)

1 fb^{-1}, √s=7 TeV (2011)

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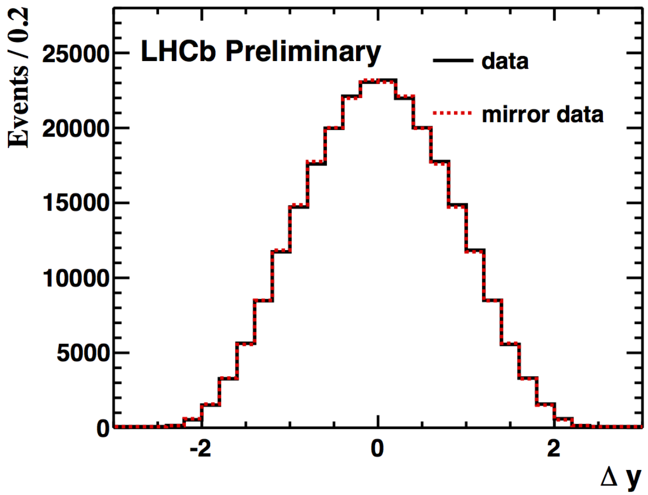

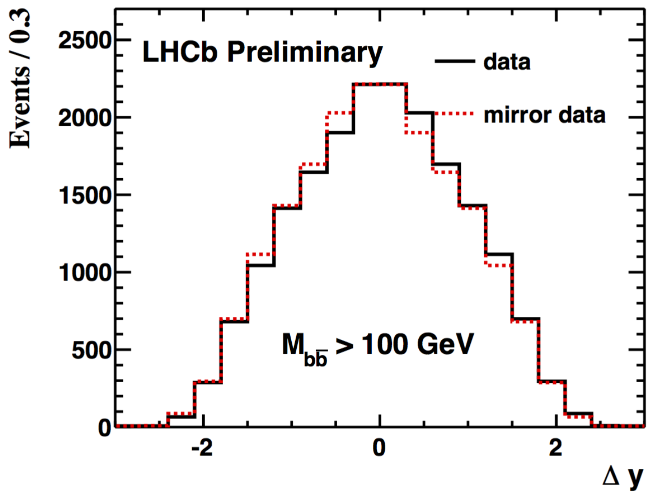

- Correcting for the dilution factor 1-2ω, where the mis-flavor tag rate ω = 0.293±0.004

$$
\begin{aligned}
A_{\mathrm{FC}}^{b\bar{b}} &= (0.5 \pm 0.5\ (\mathrm{stat}) \pm 0.5\ (\mathrm{syst}))\% \\
A_{\mathrm{FC}}^{b\bar{b}}(M_{b\bar{b}} > 100\ \mathrm{GeV}) &= (4.3 \pm 1.7\ (\mathrm{stat}) \pm 2.4\ (\mathrm{syst}))\%
\end{aligned}
$$

- **Systematics**: mainly from the flavor tagging purity
- **No significant asymmetry is observed:** consistent with the SM expectations

Conclusions

- LHCb has collected lots of good quality data during 2010-2012: 3 fb^{-1}
- **Heavy flavour production**:
  - many analyses already published and many other are going to be completed soon
  - In these slides we presented only the most recent results
  - LHCb is contributing to the understanding of some puzzles (NRQCD-CSM, Polarisation, asymmetries, ...)

Thank you!