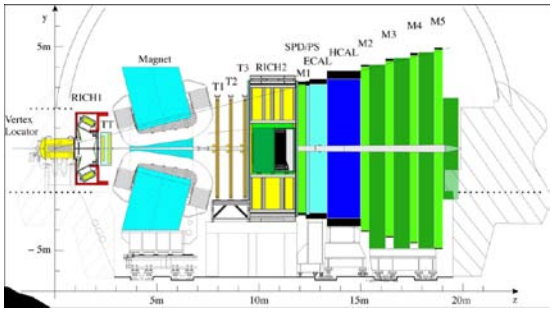
Heavy Flavour Production at LHCb

Zhenwei YANG @Tsinghua Univ.

on behalf of LAL & Tsinghua Groups



07-09, April, 2011 Shandong Univ., China

LAL-Tsinghua Collaborations

- Project leaders:

  P. Robbe/Y. Gao

- Topics:

  J/ψ production and polarization

  Bc Physics

- People involved:

  J. He (LAL)

  B. Liu (LAL/Tsinghua)

  W. Qian (LAL/Tsinghua)

  M.-H. Schune (LAL)

  Z. Yang (Tsinghua)

LAL-Tsinghua Collaborations(conti.)

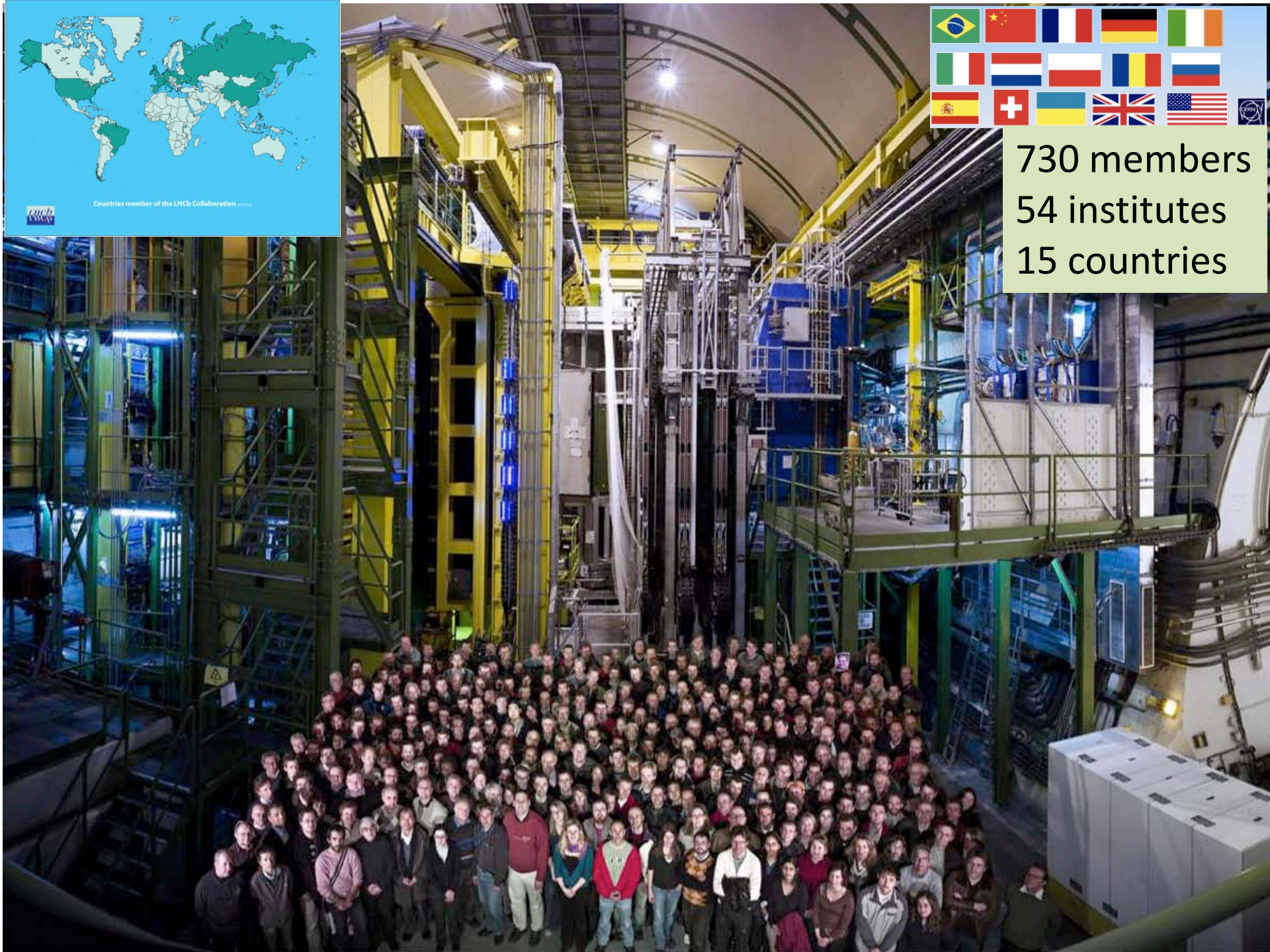
- Progress:
  J/ψ production:
  conf-note, ICHEP2010
  paper submitted to EPJC, 2011
  Bc physics:
  conf-note, BEAUTY2011

- Conference talks(2010-2011):
  P. Robbe, Quankonium2010
  Z. Yang, CHARM2010
  W. Qian, LPCC (Dec. 2010)
  J. He, BEAUTY2011
  Y. Gao, Hadron2011

Outline

- Physics aims of LHCb
- LHCb detector and performance
- Heavy flavor production at LHCb
  J/ψ production & polarization
  Bc studies
- Summary & prospective


➢ Successful running in 2009 @ 2.36 TeV
➢ First collisions @ 7 TeV on March 30, 2010
➢ Integrated Lumi ~ 37.7 pb-1 (End of 2010)
Geneva
LHCb
CERN
ATLAS
CMS
ALICE
LHC Tunnel


Countries member of the LHCb Collaboration
730 members
54 institutes
15 countries

Physics Aims of LHCb

"dedicated to heavy flavour physics at the LHC"

- **New Physics**

  CP violation: precise measurements of CKM angles

  rare decays of beauty and charm hadrons

- **Heavy Flavour Physics**

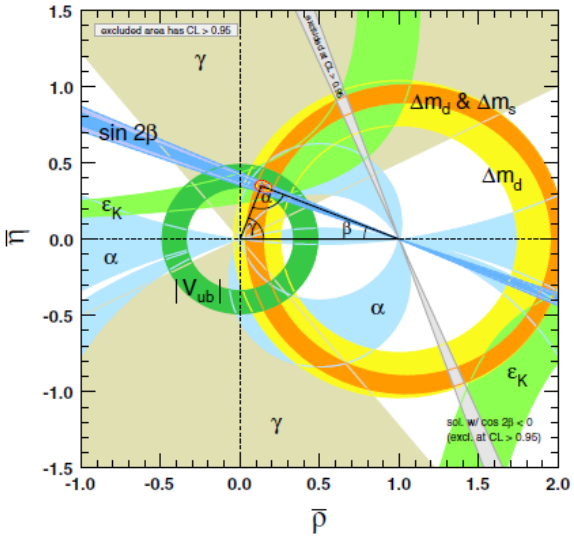
  B production

  B_c , b-baryon physics

  charm decays (e.g. D-mixing)

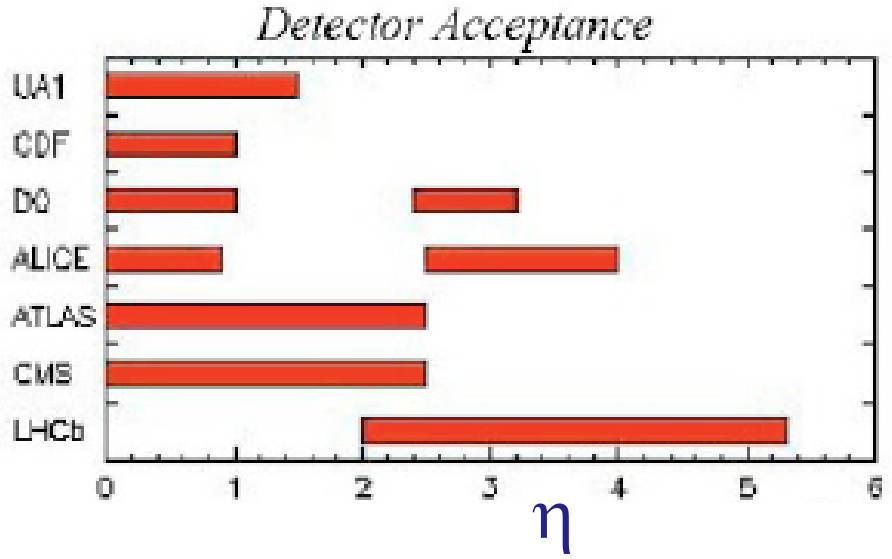
  tau lepton flavour violation

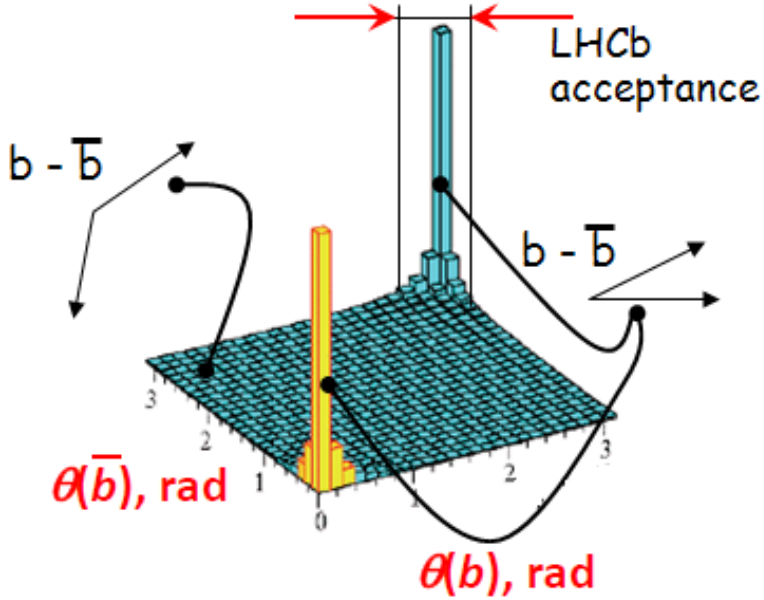
  .....



$b\bar{b}$ production at LHC

- ✓ **$b\bar{b}$ pair production correlated**
  - ➢ $\sigma_{b\bar{b}}$ ~ 300-500 μb (@7-14 TeV)
  - ➢ 15<θ<300 mrad, unique acceptance





- ✓ **Average design Luminosity ~ 2×10^{32} cm^{-2}s^{-1}**
  - ➢ 2 fb^{-1} per nominal year (10^7 s), ~ 10^{12} $b\bar{b}$ pairs per year

$b\bar{b}$ production at LHC

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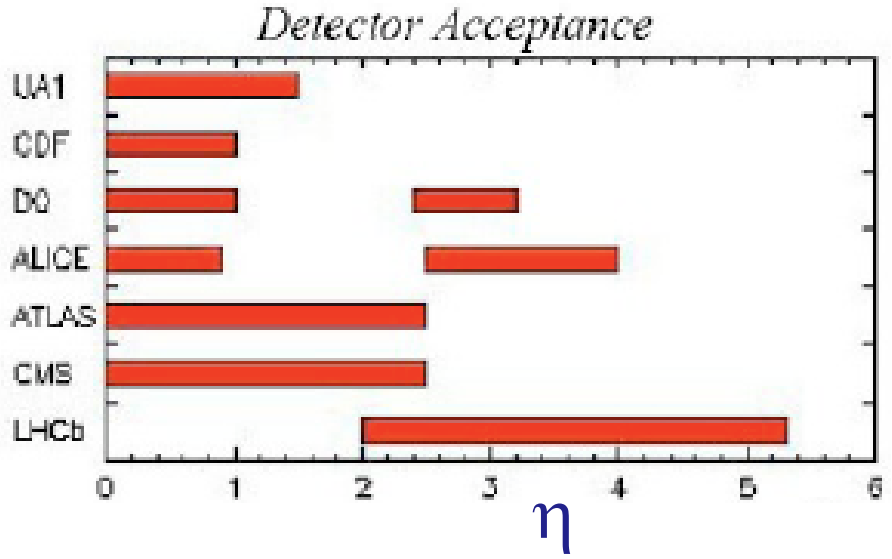

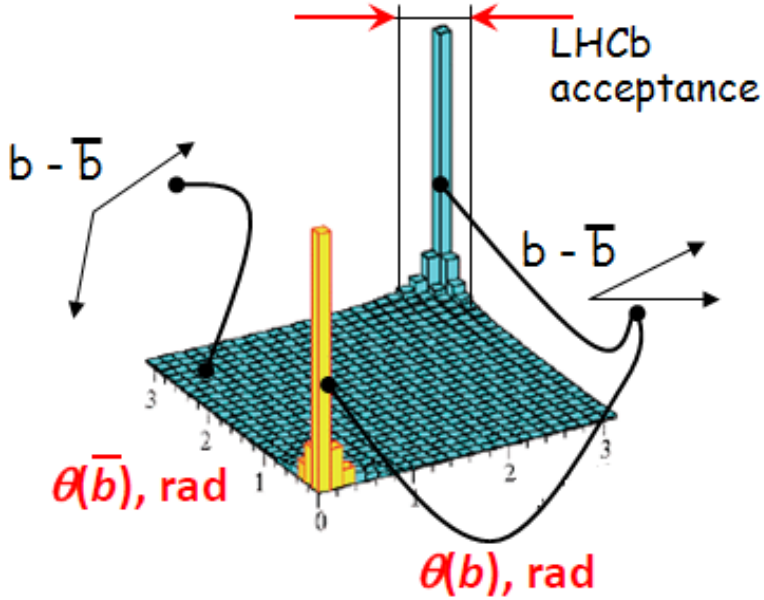

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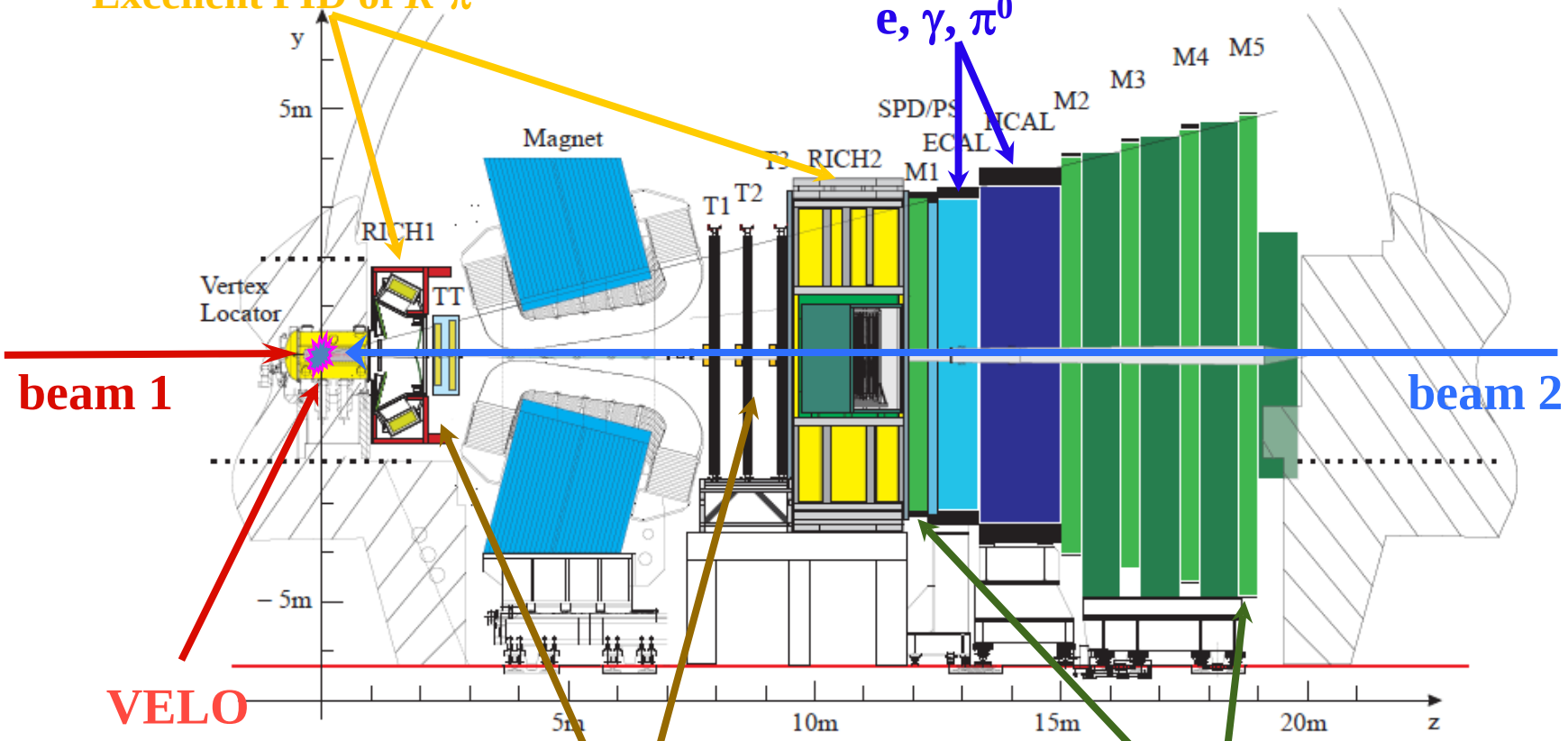
LHCb Detector

RICH1 & RICH2
Excellent PID of *K*-π

Calorimeters
e, γ, π^0



VELO

high position resolution

$\sigma_{x/y}$ ~ 10 μm

σ_z ~ 60 μm

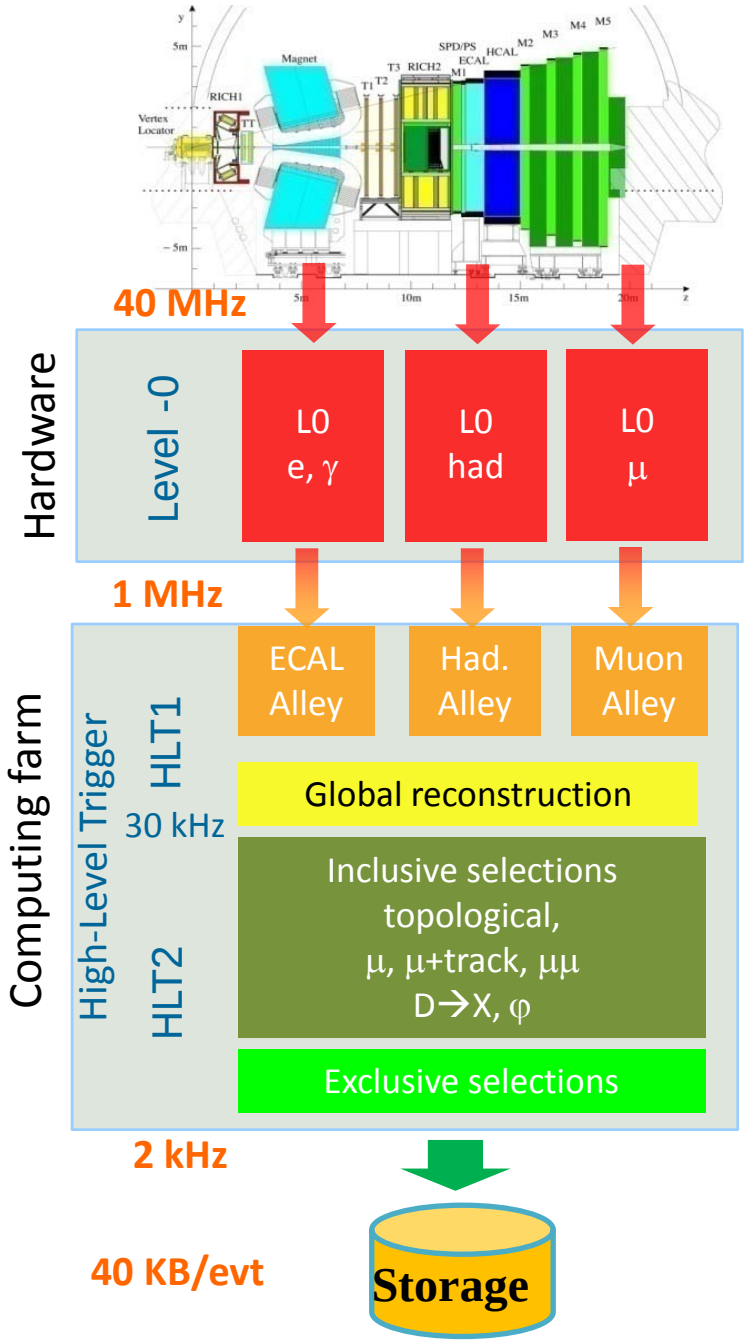
Tracking System

good tracking efficiency & momentum resolution

Muon System

good muon-ID

LHCb Trigger

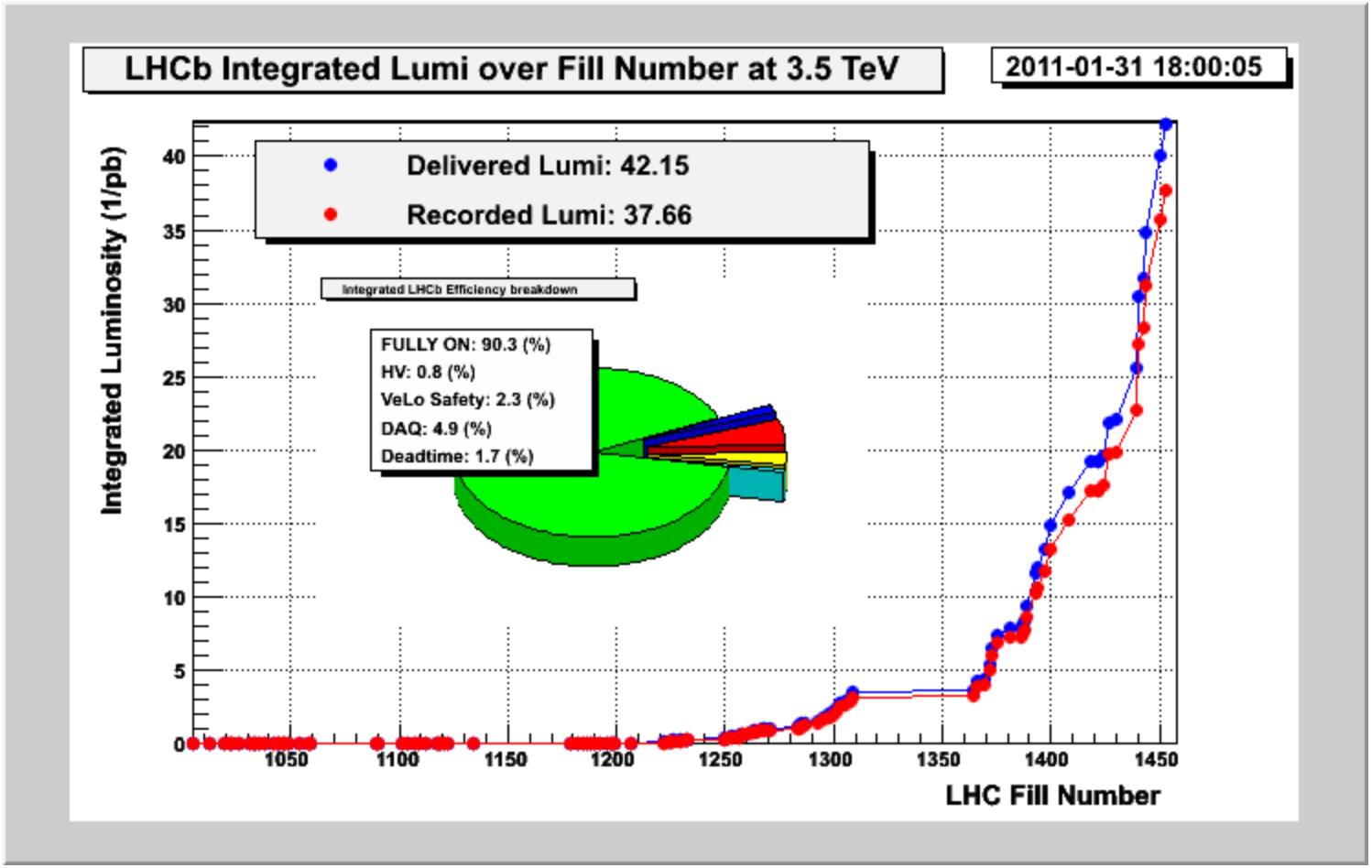


Trigger is essential to LHCb:
L0 (hardware), Hlt1, Hlt2 (software)

J/ψ and B_c related:

- L0 trigger
  - single muon: $p_T > 1.4$ GeV/c
  - di-muon: $p_{T,1} > 0.56$ GeV/c, $p_{T,2} > 0.48$ GeV/c
- Hlt1 trigger
  - single muon:
    confirm L0 single muon
    & require $p_T > 1.8$ GeV/c
  - di-muon:
    confirm L0 di-muon/single muon
    & require $m_{\mu\mu} > 2.5$GeV/c^2
- Hlt2 trigger
  - di-muon:
    $p_T(\mu) > 0.5$ GeV/c
    & $m_{\mu\mu} > 2.9$GeV/c^2

LHCb Data Taking of 2010



Stable data taking with high efficiency in all subsystems

J/ψ production

(see arXiv: 1103.0423 [hep-ex])

J/ψ cross-section (and polarization)

- **Production mechanism still not well understood, theoretical interests on direct J/ψ**
- **Three main sources of J/ψ**
  1) Direct J/ψ
  2) Decay from heavier charmonium — Prompt J/ψ
  3) Decay from b-hadrons — J/ψ from b

Using 5.2 pb^{-1} of data collected end 09/2010, with proton-proton collision at $\sqrt{s}$ = 7 TeV.

Measurement of J/ψ cross section

- Cross section (both prompt J/ψ and J/ψ from b)

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y} = \frac{N(J/\psi \to \mu^+\mu^-)}{L \cdot \varepsilon_{\mathrm{tot}} \cdot Br(J/\psi \to \mu^+\mu^-) \cdot \Delta p_{\mathrm{T}} \cdot \Delta y}$$

N : Signals from reconstruction of $J/\psi \to \mu^+\mu^-$

$\varepsilon_{\mathrm{tot}} = \varepsilon_{\mathrm{acc}} \times \varepsilon_{\mathrm{rec}} \times \varepsilon_{\mathrm{trig}}$

14 bins in p_{T} , $0 < p_{\mathrm{T}} < 14\ \mathrm{GeV}/c$

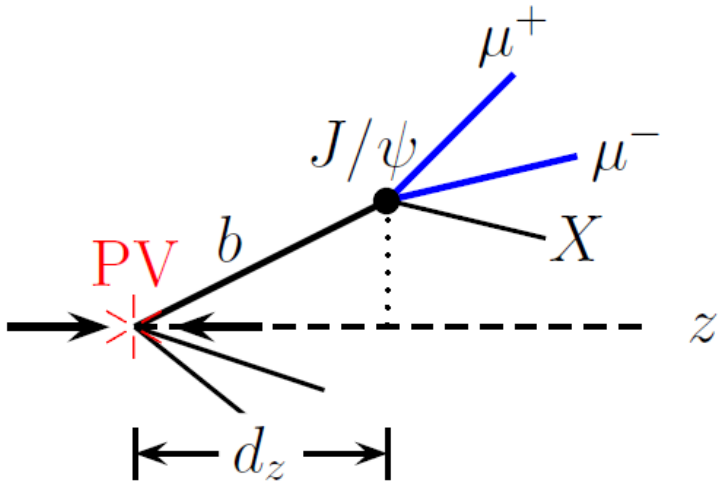
5 bins in y , $2 < y < 4.5$

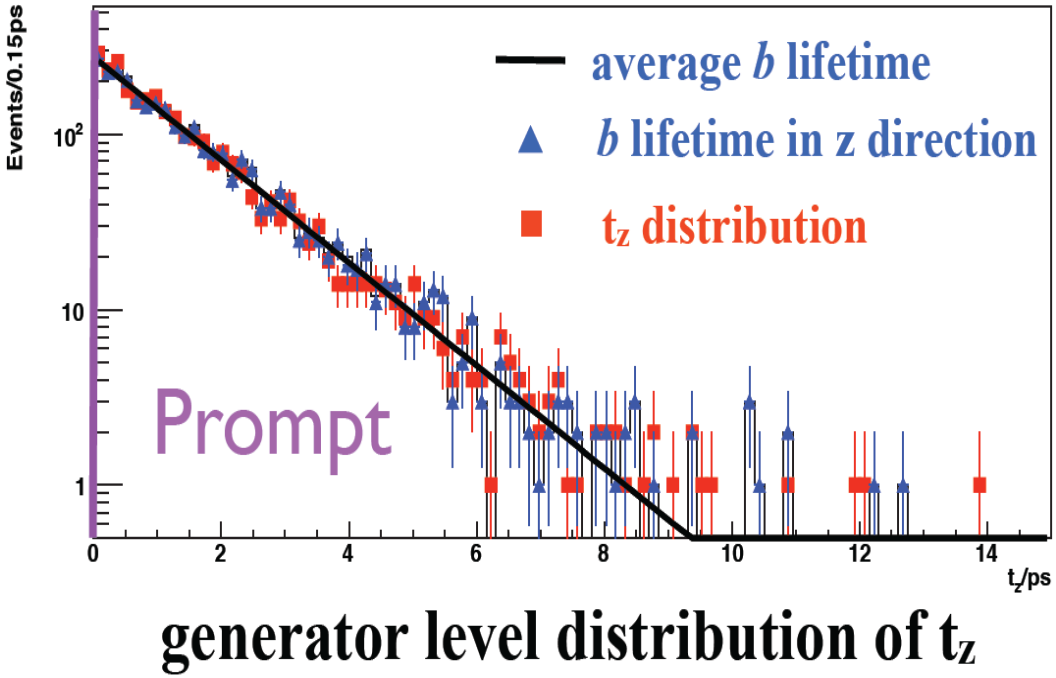
- Separate "prompt J/ψ" from "J/ψ from b" by fitting pseudo-proper time t_z

⇨ σ(incl. J/ψ)
σ(J/ψ from b)

Measurement of J/ψ cross section

$$t_z = \frac{d_z \times M_{J/\psi}}{p_z^{J/\psi}}$$





(for J/ψ from b)

- good approximation of average b lifetime
- well described by exponential distribution

Event Selection & Mass fit

- Lifetime unbiased muon trigger & offline event selection
  - * Good tracks identified as μ by muon system, loose cuts on p_T
  - * Good vertex fit quality of μ+ μ- tracks
  - * ≥ 1 primary vertex reconsructed

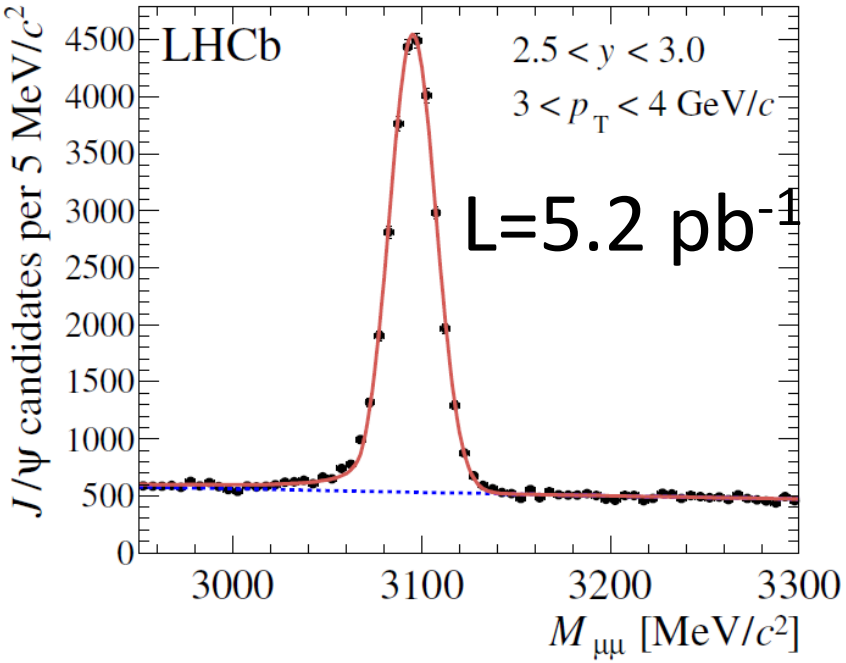
- Mass fit
  - * Signal: Crystal Ball function
  - * Background: Exponential
  - * Mass fitted separately in 70 bins

Fit results (of 1 bin):

(2.5<y<3, 3<p_T<4 GeV/*c*)

μ = **(3095.3 ± 0.1) MeV/c^2**

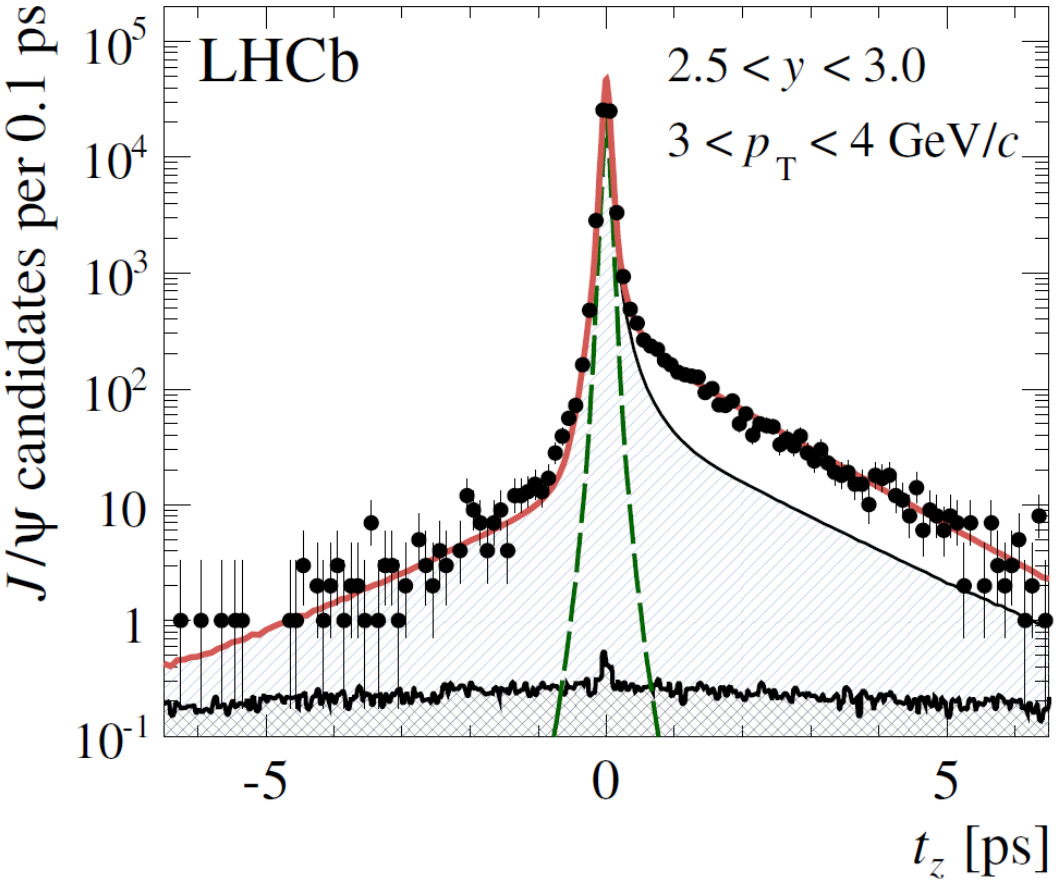
σ = **(12.3 ± 0.1) MeV/c^2**



Total signal yield

~ 560,000 J/ψ

t_z Fit Result



1) Background estimated from invariant mass sidebands

2) Long tail due to association to wrong primary vertex, obtained in data by associating J/ψ vertex to PV of next event

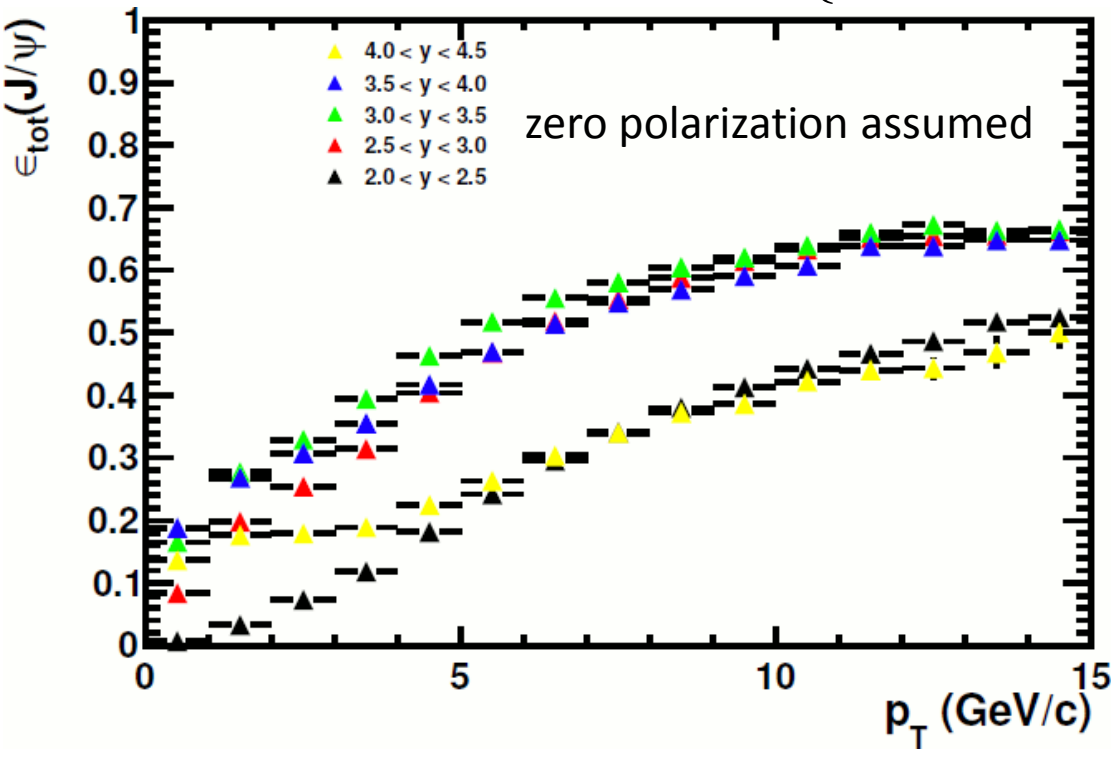
Fit results (2.5<y<3, 3<p_T<4 GeV/*c*):

$f_b = n_b/(n_p+n_b) = (12.0 \pm 0.2)\%$ $\quad \langle\sigma\rangle = 53$ fs

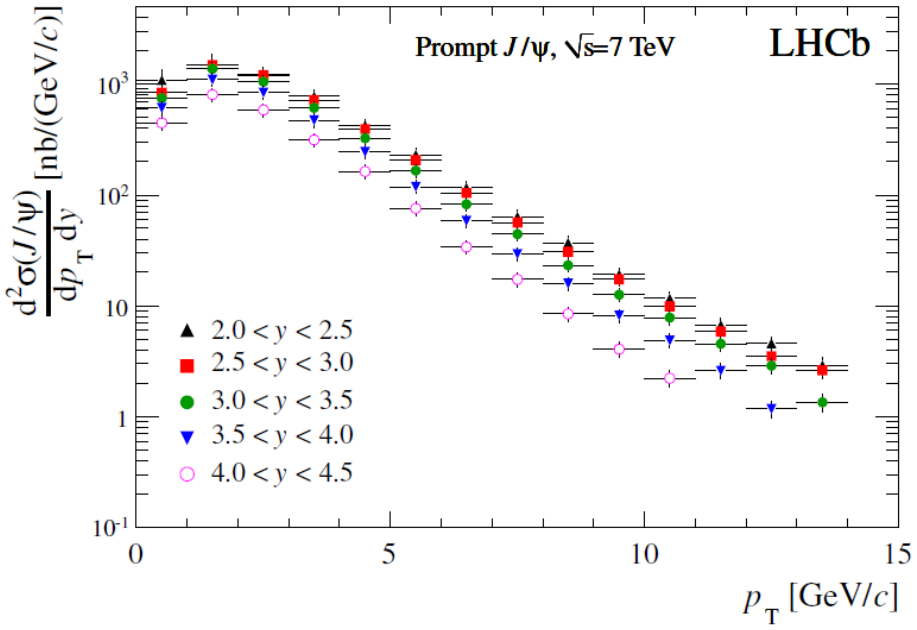
Total Efficiency and Polarization Effect

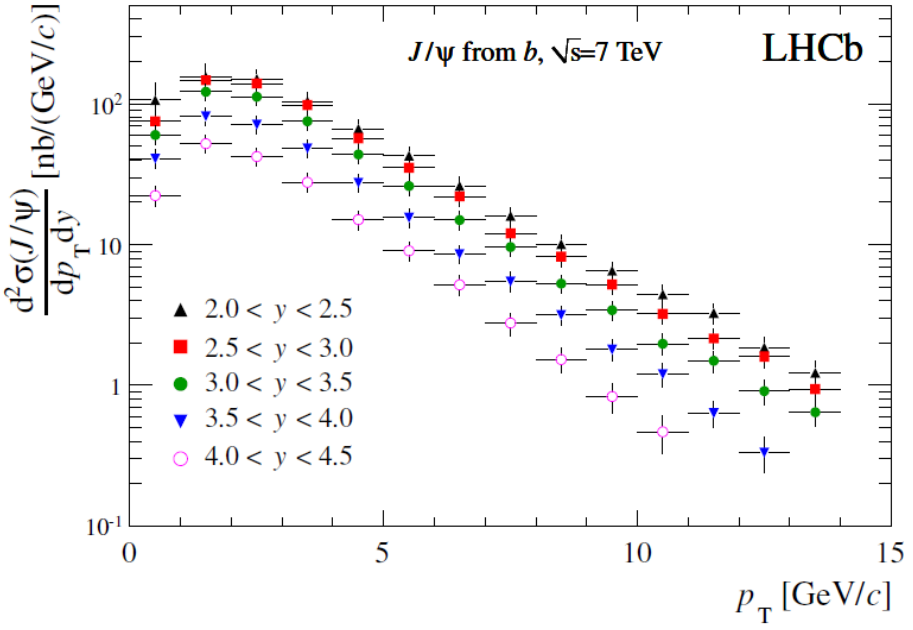
- ε depends strongly on polarization
- treated as systematic error for first measurement

$$\frac{dN}{d\cos\theta} = \frac{1+\alpha\cos^2\theta}{2+2\alpha/3}, \text{ where } \alpha = \begin{cases} +1 & \text{fully transverse} \\ 0 & \text{no polarization} \\ -1 & \text{fully longitudinal} \end{cases}$$



Production results: 5.2 pb^{-1}





$$\sigma\left(\text{prompt } J/\psi, p_{\mathrm{T}} < 14\,\mathrm{GeV}/c, 2.0 < y < 4.5\right) = 10.52 \pm 0.04 \pm 1.40^{+1.64}_{-2.20}\ \mu\mathrm{b}$$

$$\sigma\left(J/\psi \text{ from } b, p_{\mathrm{T}} < 14\,\mathrm{GeV}/c, 2.0 < y < 4.5\right) = 1.14 \pm 0.01 \pm 0.16\,\mu\mathrm{b}$$

Systematic uncertainty dominated by trigger (10%) and tracking (8%) efficiencies.

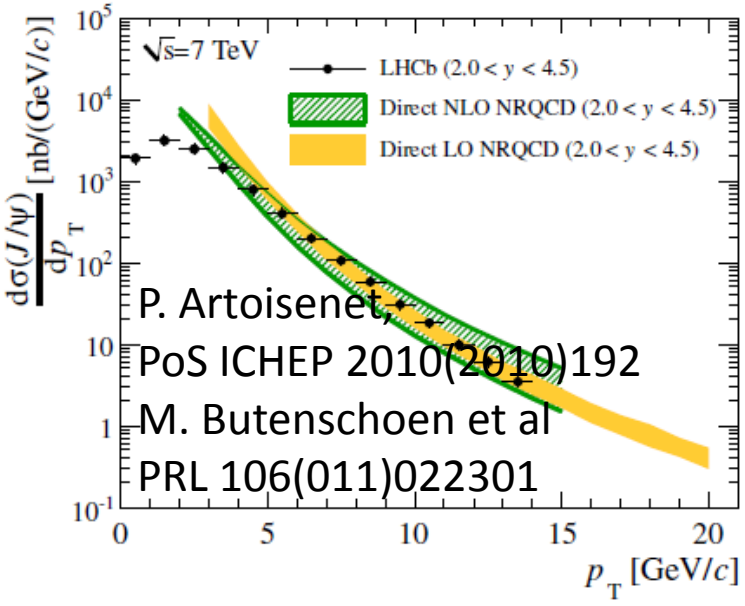
Extrapolating to the total bb cross section

$$\sigma(pp \to b\bar{b}X) = 288 \pm 4 \pm 48\ \mu\mathrm{b}$$

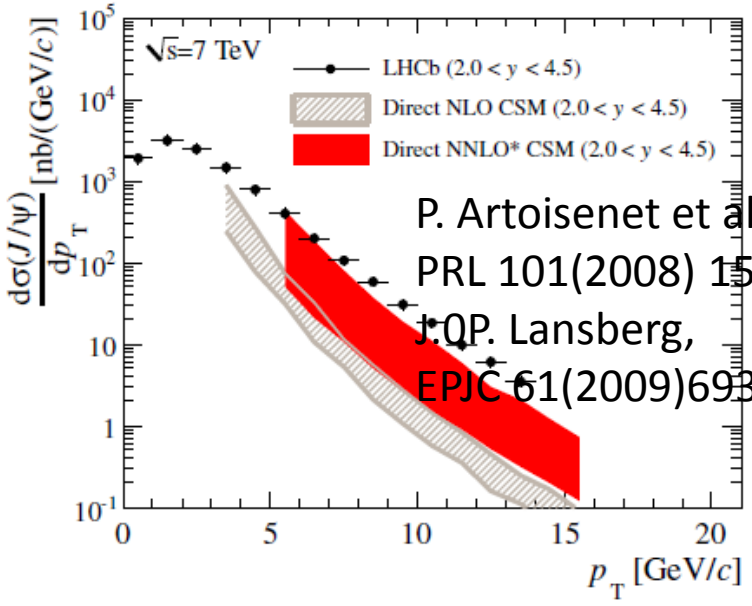
(see arXiv: 1103.0423 [hep-ex])

$$\mathscr{B}(b \to J/\psi X) = (1.16 \pm 0.10)\%$$

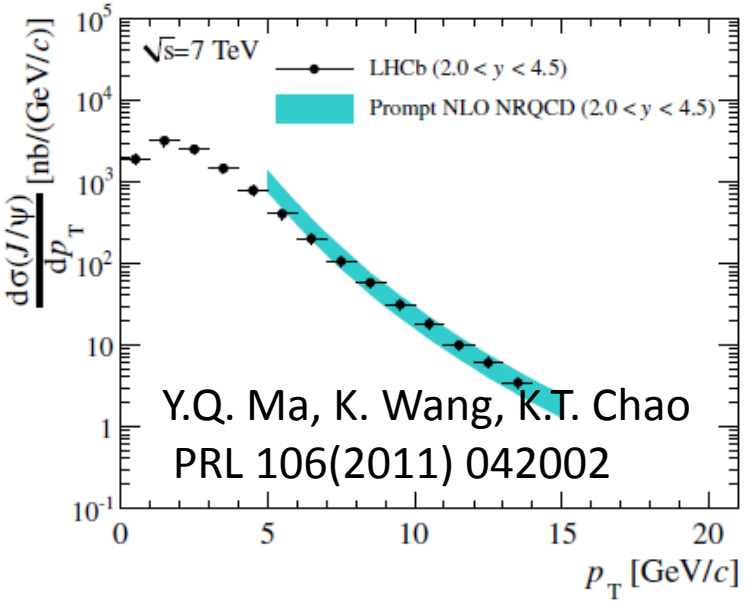
Comparison with theor. models



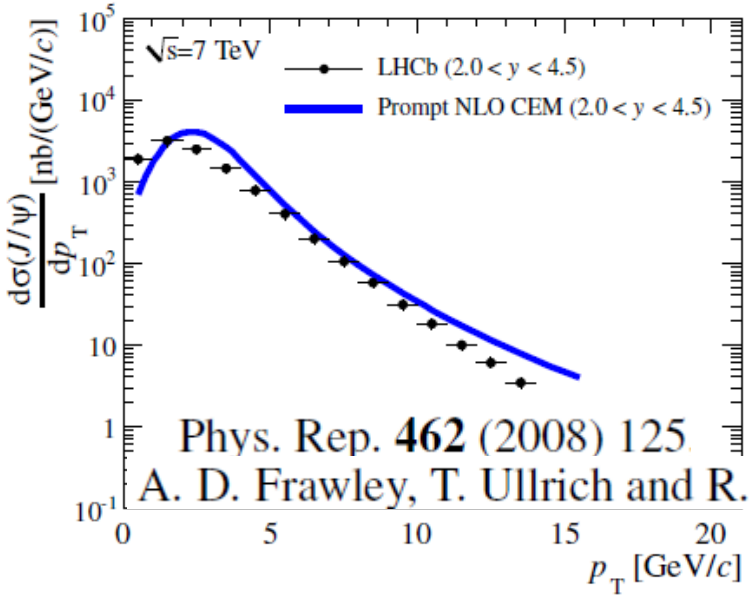
P. Artoisenet,
PoS ICHEP 2010(2010)192
M. Butenschoen et al
PRL 106(011)022301



P. Artoisenet et al,
PRL 101(2008) 152001
J.QP. Lansberg,
EPJC 61(2009)693



Y.Q. Ma, K. Wang, K.T. Chao
PRL 106(2011) 042002



Phys. Rep. **462** (2008) 125
A. D. Frawley, T. Ullrich and R. Vogt.

J/ψ polarization

- Knowledge of polarization helps to significantly reduce the error of cross-section measurement
- Great challenges (& interests?) to theoretical models
- A direct measurement of polarization with full angular analysis is under investigation and result is foreseen recently.

$$\frac{\mathrm{d}^2 N}{\mathrm{d}\cos\theta \mathrm{d}\phi} \propto 1 + \lambda_\theta \cos^2\theta + \lambda_{\theta\phi} \sin 2\theta \cos\phi + \lambda_\phi \sin^2\theta \cos 2\phi$$

- ~ 35 pb^{-1} of data used
  ~ 3.7 M J/ψ candidates

B_c cross-section

- B_c: unique meson with two open heavy flavors
- Fully reconstructed $B_c^{\pm} \to J/\psi(\mu^+\mu^-)\pi^{\pm}$ used,

  Large sample $B^{\pm} \to J/\psi\ K^{\pm}$ as reference
- Measure relative cross-section :

$$\boldsymbol{R = \frac{\sigma(B_c^{\pm}) \times Br(B_c^{\pm} \to J/\psi\pi^{\pm})}{\sigma(B^{\pm}) \times Br(B^{\pm} \to J/\psi K^{\pm})} = \varepsilon_{\text{rel}} \times \frac{N(B_c^{\pm})}{N(B^{\pm})}}$$

with $\boldsymbol{p_T(B) > 4}\ \text{GeV}/\boldsymbol{c}$ and $\boldsymbol{\eta \in (2.5, 4.5)}$

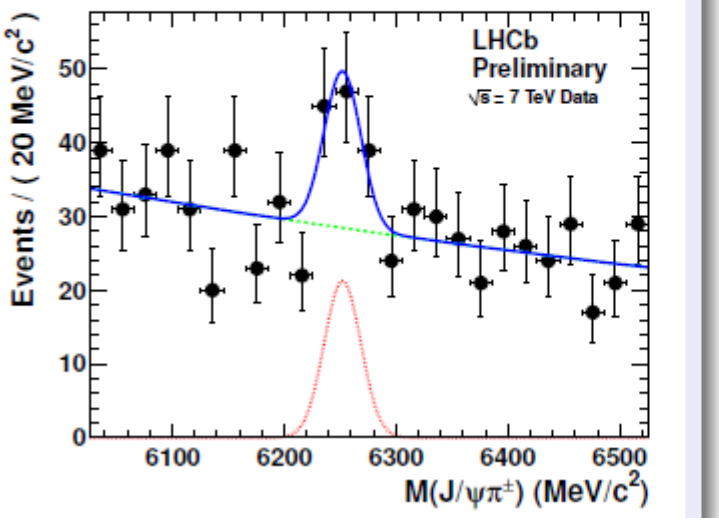
~32 pb^{-1} of data used (collected 08-10 of 2010)

see: LHCb-CONF-2011-017

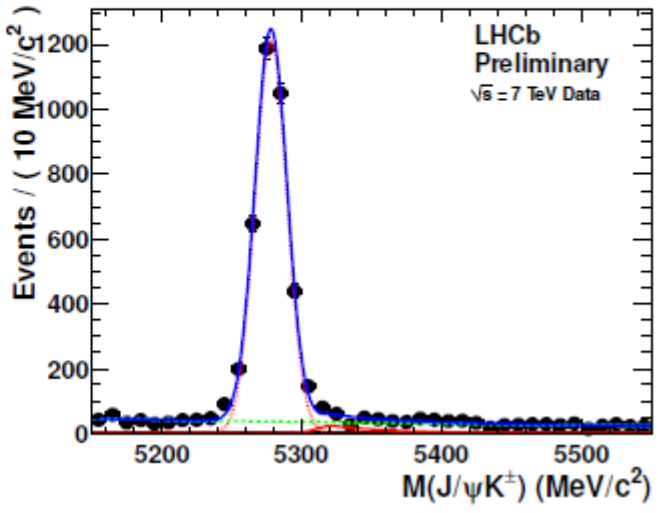
Extraction of N($B_c^{\pm}$) and N($B^{\pm}$)

- Nearly identical selections between $B_c^{\pm} \rightarrow J/\psi\pi^{\pm}$ and $B^{\pm} \rightarrow J/\psi K^{\pm}$
- Cabibbo suppressed background $B^{\pm} \rightarrow J/\psi\pi^{\pm}$ considered for $B^{\pm} \rightarrow J/\psi K^{\pm}$

$B_c^{\pm} \rightarrow J/\psi\pi^{\pm}$
$N_{\rm sig} = 43 \pm 13$



$B^{\pm} \rightarrow J/\psi K^{\pm}$
$N_{\rm sig} = 3476 \pm 62$



Results

- for $p_T(B) > 4$ GeV/c and $\eta \in (2.5,4.5)$

$$R = \frac{\sigma(B_c^{\pm}) \times Br(B_c^{\pm} \to J/\psi\pi^{\pm})}{\sigma(B^{\pm}) \times Br(B^{\pm} \to J/\psi K^{\pm})}$$

$$= (2.2 \pm 0.8|_{\text{stat.}} \pm 0.2|_{\text{sys.}})\%$$

$$= (1.4 \pm 0.4|_{\text{stat.}} \pm 0.1|_{\text{lifetime}})\%$$

if model (BcVegPy) dependent total efficiency used.

cf: C. Chang et al., Comput. Phys. Commun. **159** (2004) 192;
Comput. Phys. Commun. **175** (2006) 624

Summary & prospective

- Differential cross-section of J/ψ production in *pp* collisions at $\sqrt{s}$=7 TeV has been measured at LHCb with 5.2 pb^{-1} of data as function of p_T and y.
- Large uncertainties due to unknown J/ψ polarization will be reduced by the polarization measurement of prompt J/ ψ recently.
- $B_c^{\pm}$ production cross-section relative to that of $B^{\pm}$ measured preliminarily.
- More B_c studies are on-going(lifetime, semi-leptonic channels,...)

Thank you

back up

Event Selection of J/ψ

Data Sample

- $(5.2 \pm 0.5)\ pb^{-1}$ (low pile-up conditions)

Event selection

- 2 muons
  - good quality of track fit (χ^2/ndf < 4)
  - identified as muon by muon system
  - good vertex reconstructed (χ^2 prob. > 0.5%)
  - p_T > 700 MeV/c
  - Mass window for signal definition: $(2.95 < M_{J/\psi} < 3.30)\ GeV/c^2$
- Trigger L0
  - single muon, p_T > 1.4 GeV/c
  - dimuon, $p_{T,1}$>0.56 GeV/c, $p_{T,2}$>0.48 GeV/c
- HLT:
  - single muon, p_T > 1.8 GeV/c .OR. muon pair with $M_{\mu\mu} > 2.9 GeV/c^2$

Systematics of Jpsi

Source	Systematic uncertainty (%)
Correlated between bins	
Inter-bin cross-feed	0.5
Mass fits	1.0
Radiative tail	1.0
Muon identification	1.1
Tracking efficiency	8.0[1]
Track χ^2	1.0
Vertexing	0.8
Global event cuts	2.0
$\mathscr{B}(J/\psi \to \mu^+\mu^-)$	1.0
Luminosity	10.0[2]

[1] 4% per track, improved recently

[2] dominated by uncertainty of the LHC proton beam currents, improve recently

Systematics of Jpsi (conti-)

Source	Systematic uncertainty (%)
Uncorrelated between bins	
Bin size	0.1 to 15.0
Trigger	1.7 to 4.5
Applied only to J/ψ from b cross-sections, correlated between bins	
Global event cuts efficiency on B events	2.0
t_z fits	3.6
Applied only to the extrapolation of the $b\bar{b}$ cross-section	
b hadronisation fractions	2.0
$\mathscr{B}(b \to J/\psi X)$	9.0

Systematics of Bc(preliminary)

Table 1: Summary of systematic uncertainties.

Quantity	Systematic error (%)
B_c^+ lifetime	6.0
J/ψ vertexing	1.6
Track χ^2	3.0
Trigger	3.0
Tracking	1.0
Weight procedure	2.3
Total	7.9