Open Charm and Charmonium Production: First Results from LHCb

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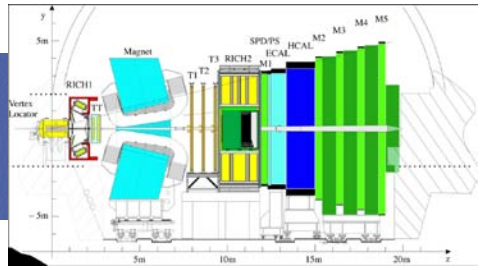
on behalf of the LHCb collaboration

Charm 2010

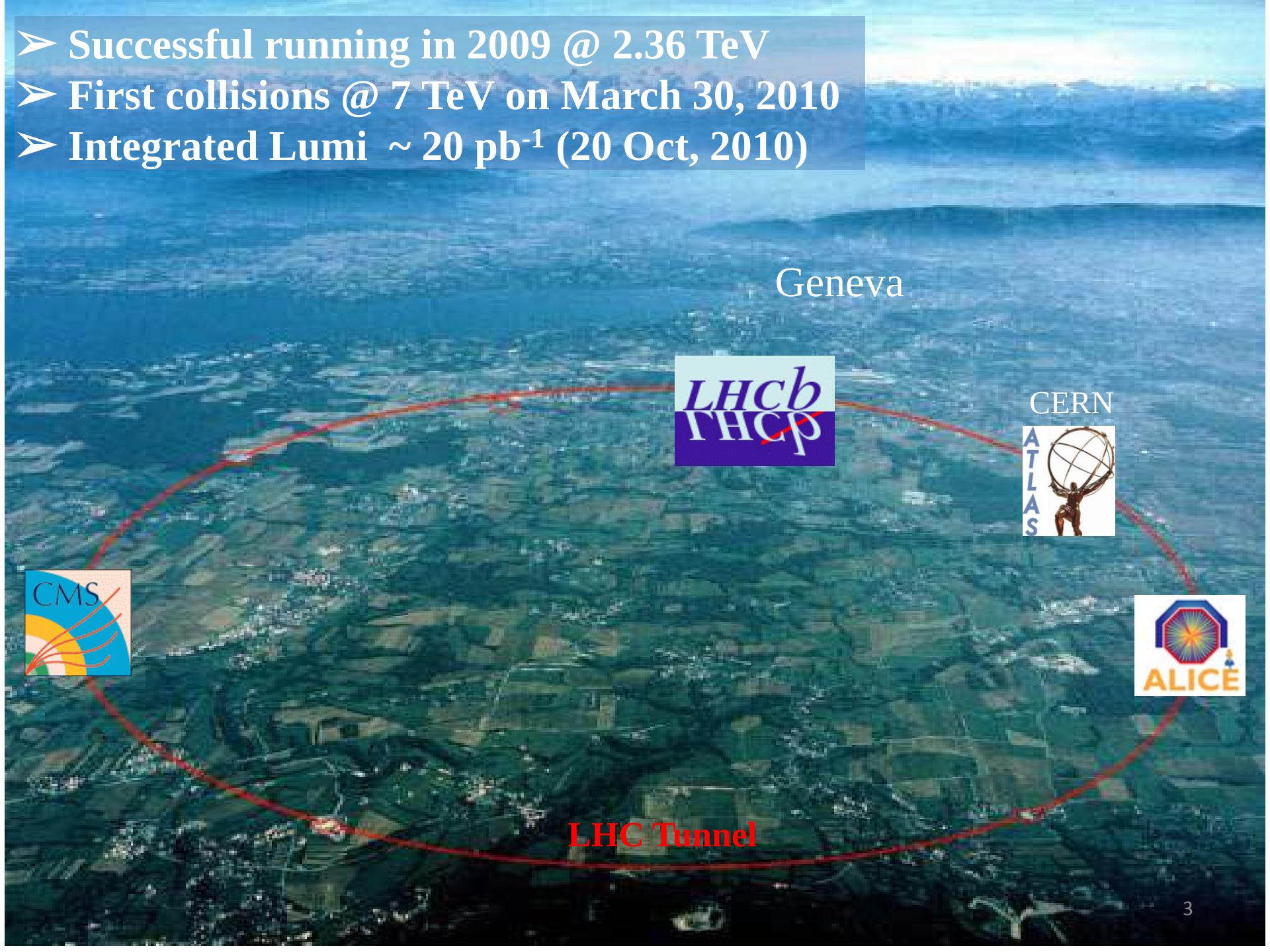
The 4th International Workshop on Charm Physics

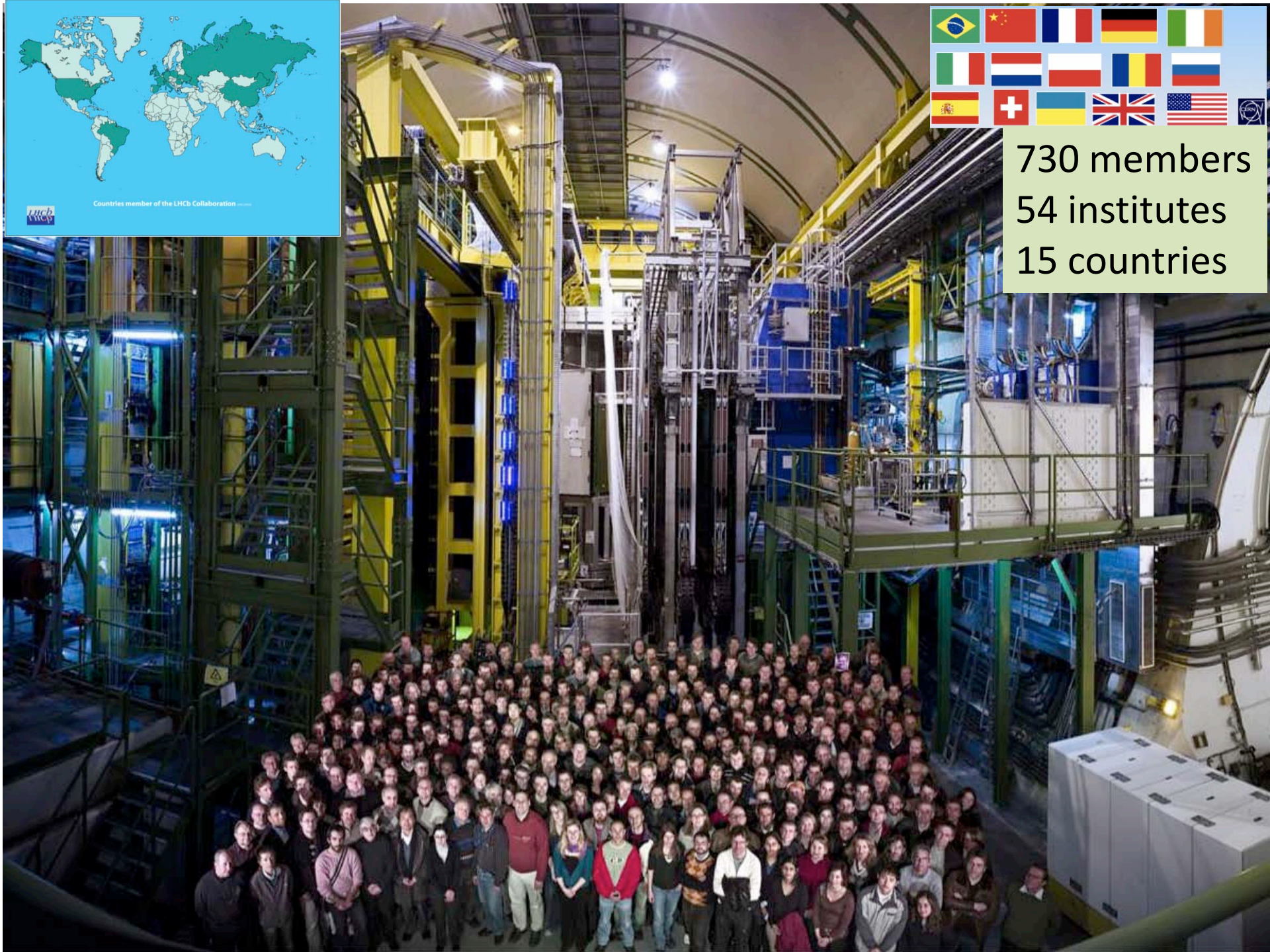


21-24, October, 2010 IHEP, Beijing, China

Outline

- Physics ambition of LHCb
- LHCb detector and performance
- Physics interests on charm
- First results on charmonium and open charm
- Summary


➢ Successful running in 2009 @ 2.36 TeV
➢ First collisions @ 7 TeV on March 30, 2010
➢ Integrated Lumi ~ 20 pb-1 (20 Oct, 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

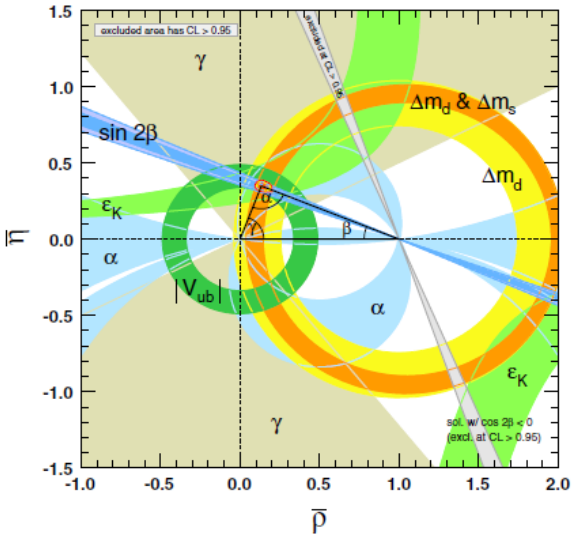
"dedicated to heavy flavour physics at the LHC"

- **New Physics**

  CP violation: precise measurements of CKM angles
  rare decays of beauty and charm hadrons

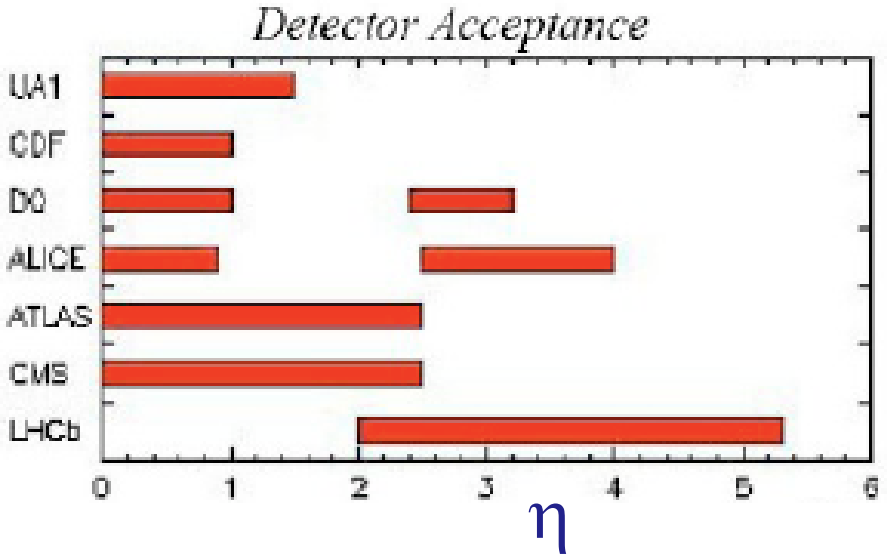
- **Heavy Flavour Physics**

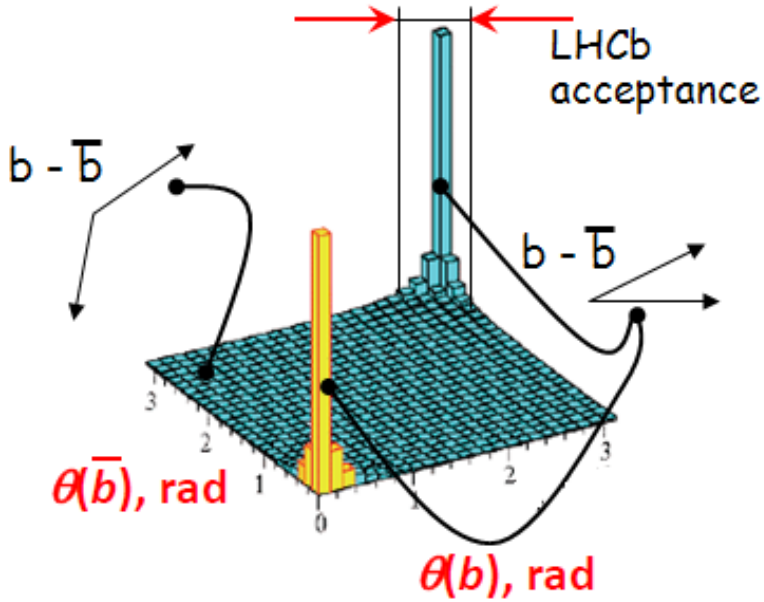
  B production
  B_c , b-baryon physics
  charm decays (e.g. D-mixing)
  tau lepton flavour violation
  .....



$b\bar{b}$ 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



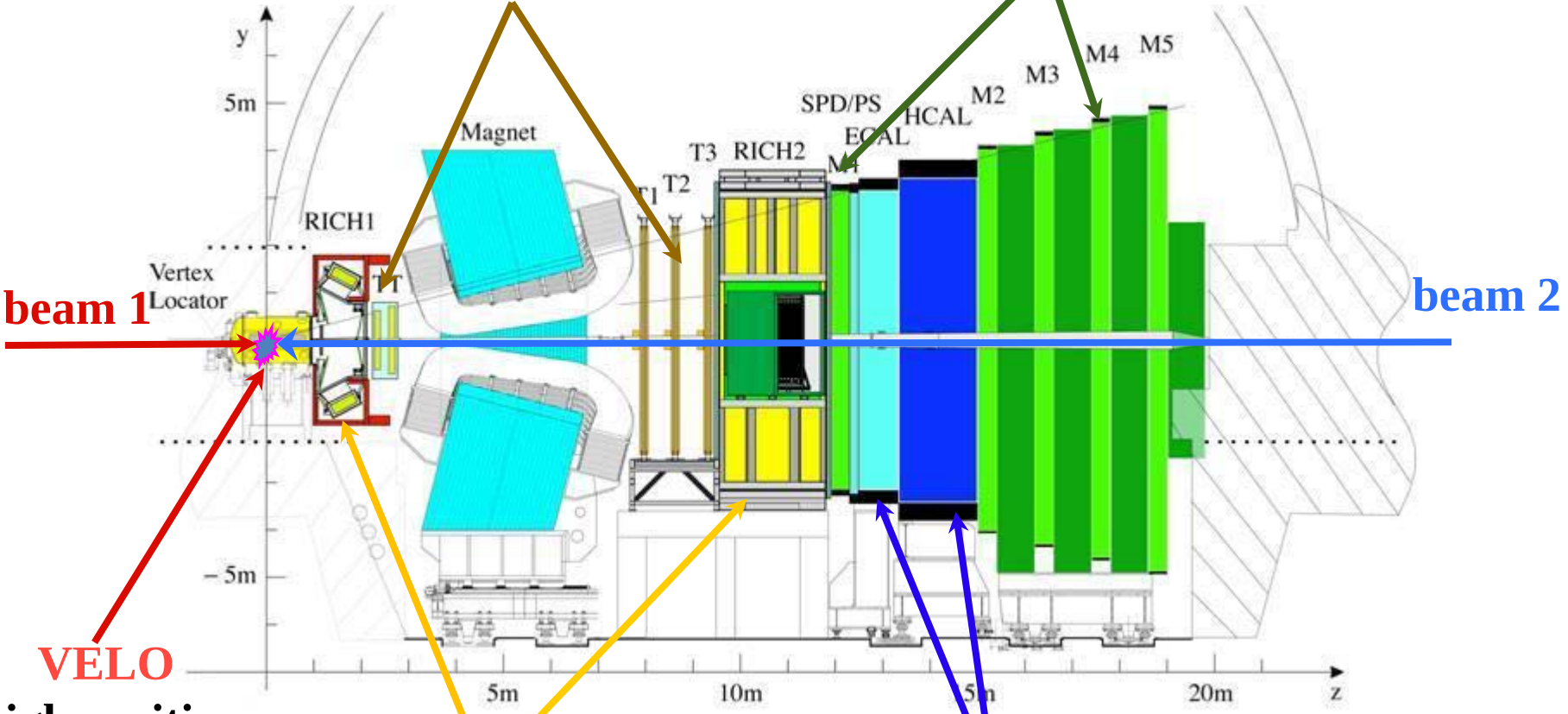


- ✓ **Average design Luminosity ~ 2×10^{32} cm^{-2}s^{-1}**
  - ➢ 2 fb^{-1} per nominal year (10^7 s), ~ 10^{12} $b\bar{b}$ pairs per year

LHCb Detector

Tracking System
good tracking efficiency & momentum resolution

Muon System
good muon-ID

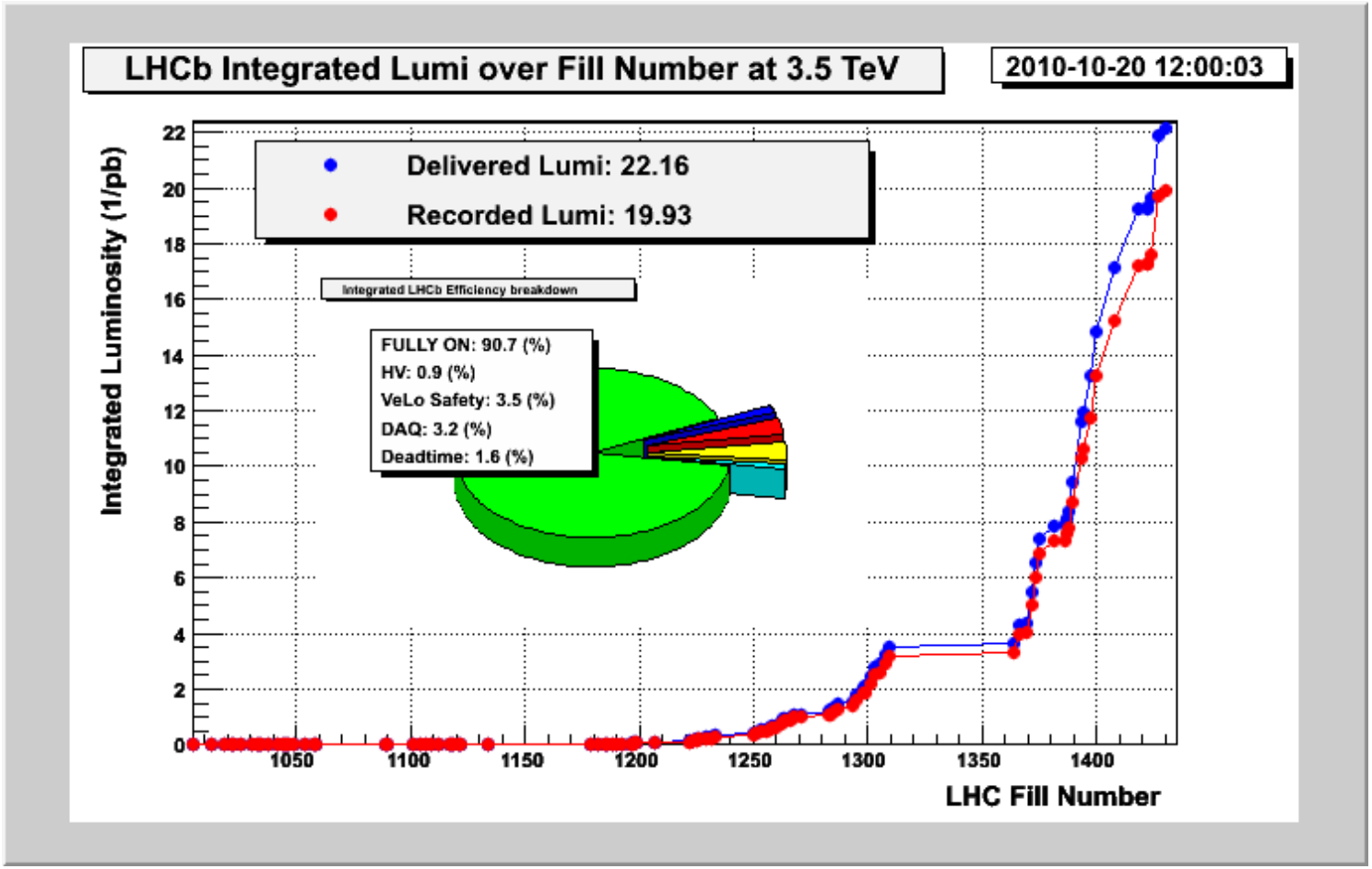


VELO
high position resolutions

RICH1 & RICH2
Excellent PID of K-pi

Calorimeters
e, γ, π^0

LHCb Data Taking



Stable data taking with high efficiency in all subsystems

Physics Interests on Charm

1) 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
  3) Decay from b-hadrons

  } Prompt J/ψ

  } J/ψ from b
- **fractions of heavier charmonia are helpful**

2) Essentially related to many investigations of CP violation and rare decays

(see talk of Patrick Spradlin tomorrow afternoon)

3) Understanding of charm is fundamental for later analyses

Measurement of J/ψ cross section

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

$$\sigma = \frac{N(J/\psi \to \mu^+\mu^-)}{L \cdot \varepsilon \cdot Br(J/\psi \to \mu^+\mu^-)}$$

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

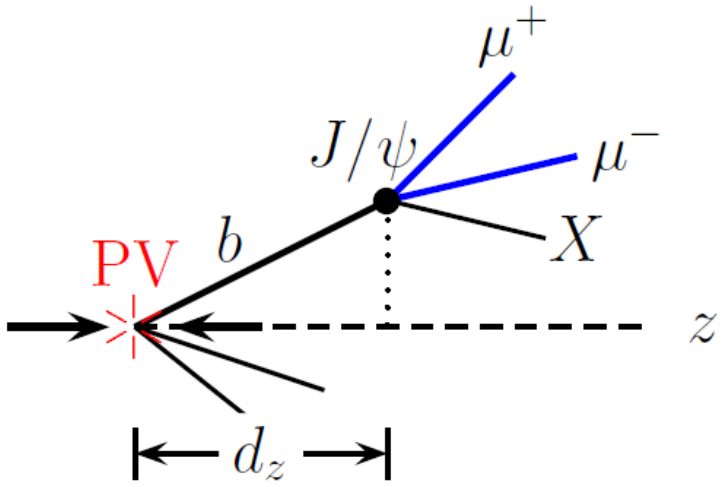
$$\varepsilon = \varepsilon_{\text{acc}} \times \varepsilon_{\text{rec}} \times \varepsilon_{\text{trig}}$$

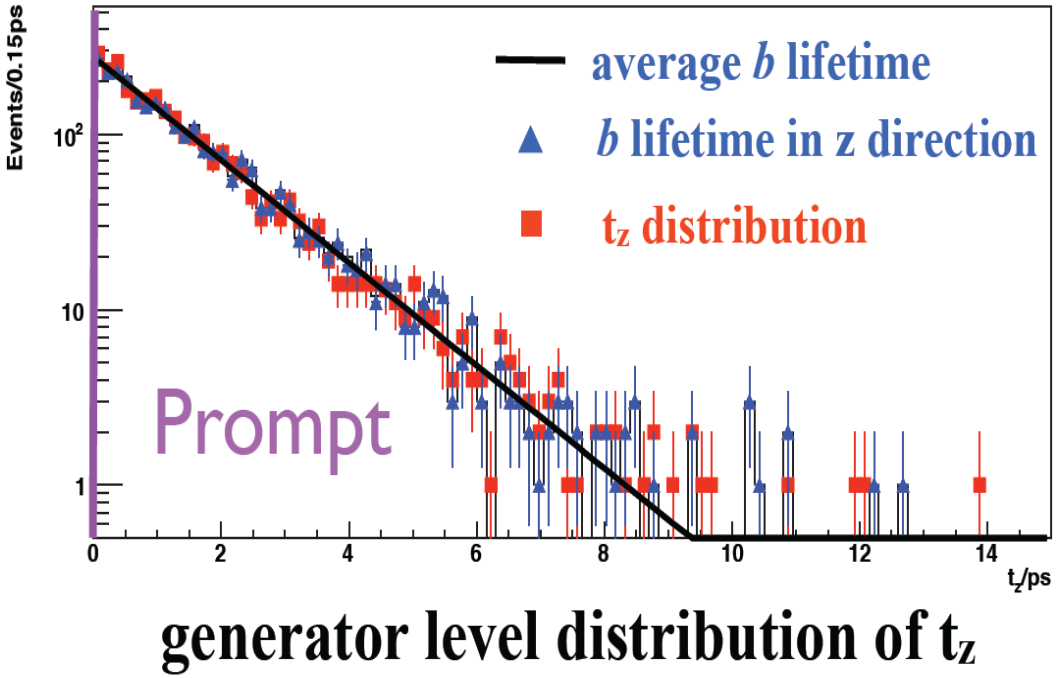
- Separate "prompt J/ψ" from "J/ψ from b" by fitting pseudo-proper time t_z

⇨ 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

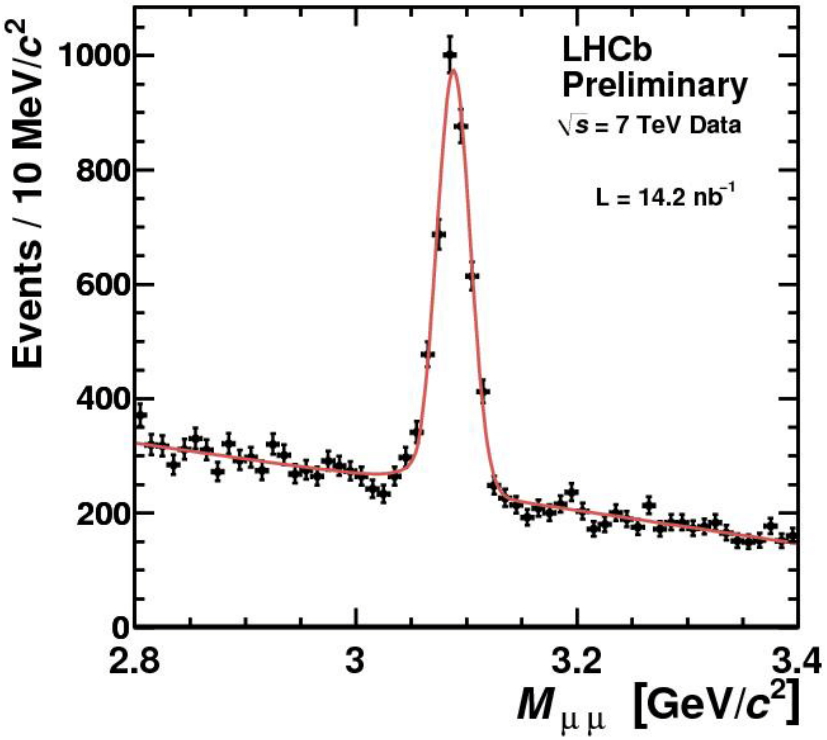
Mass fit

Signal: Crystal Ball function

Background: 1st order polynomial

$$f(m,\mu,\sigma,\alpha,n) = \begin{cases} \dfrac{\left(\frac{n}{|\alpha|}\right)^n e^{-\frac{1}{2}\alpha^2}}{\left(\frac{n}{|\alpha|} - |\alpha| - \frac{m-\mu}{\sigma}\right)^n} & \dfrac{m-\mu}{\sigma} < -|\alpha| \\ \exp\left(-\dfrac{1}{2}\left(\dfrac{m-\mu}{\sigma}\right)^2\right) & \dfrac{m-\mu}{\sigma} > -|\alpha|, \end{cases}$$

L=14.2 nb^{-1}



Fit results (2.5<y<4, p_T<10 GeV/c):

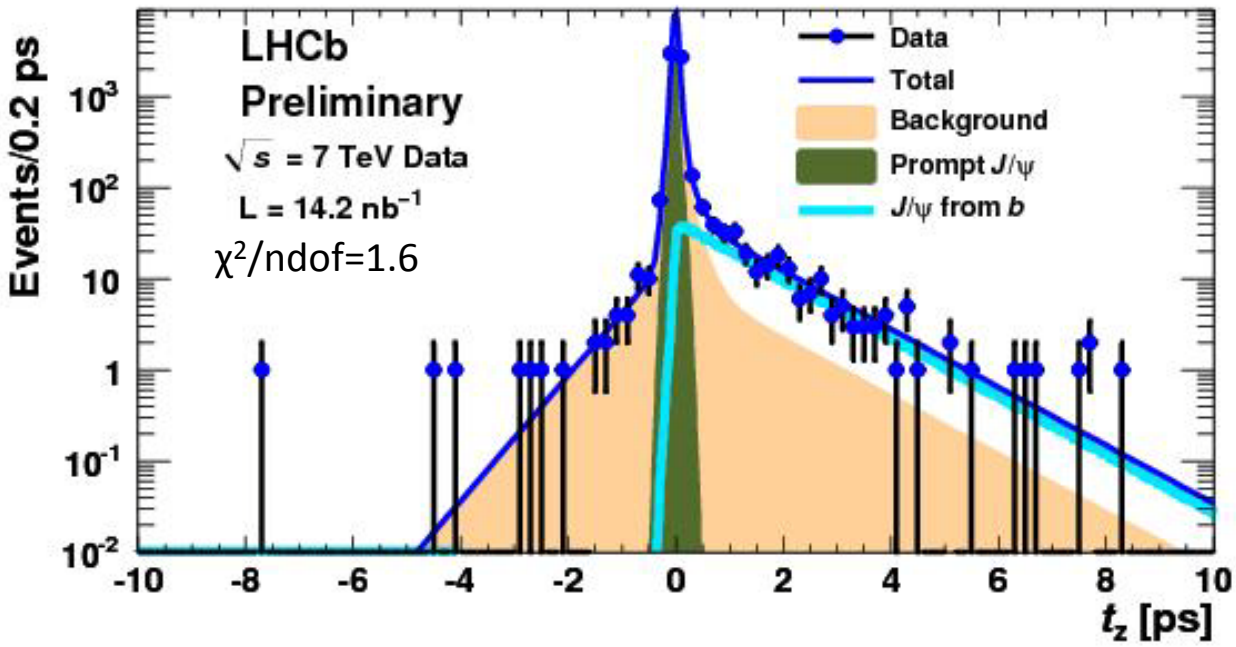
Signal = **2872 ± 73**

S/B = **1.3**

μ = **(3088 ± 0.4) MeV/c²**

σ = **(15.0 ± 0.4) MeV/c²**

t_z Fit Result



1)Background from invariant mass sidebands

2)Crosscheck with a binned fit gives consistent results

Fit results :

Number of prompt J/ψ, n_p : 2527 ± 74

Number of J/ψ from *b*, n_b : 316 ± 24

$f_b = n_b/(n_p+n_b)$ = (11.1 ± 0.8)%

σ of two Gaussian: (111±13) fs, (40 ±3) fs

Core resolution fraction between: 0.74 ± 0.06

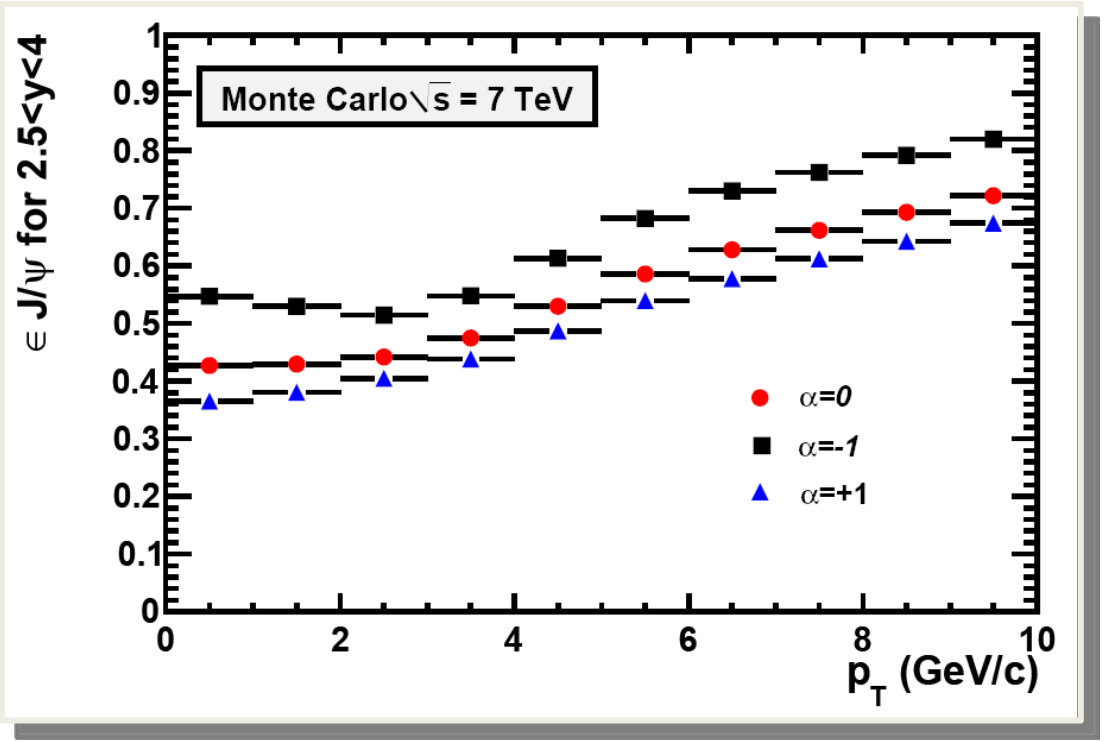
$\langle\sigma\rangle$ = 58 fs

Average *b* lifetime τ_b = (1.35 ± 0.10) ps

Total Efficiency and Polarization Effect

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

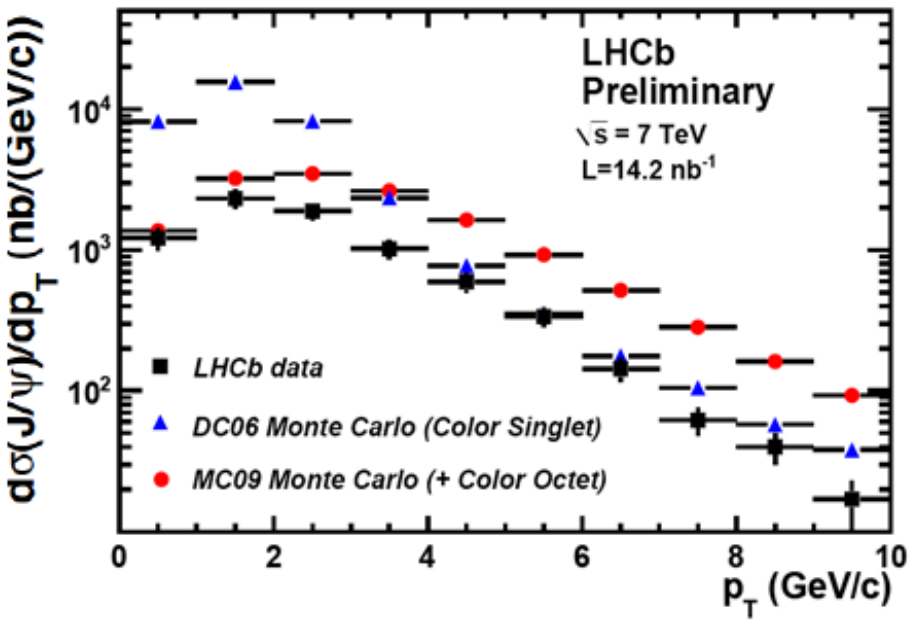
$$\frac{dN}{d\cos\theta} = \frac{1+\alpha\cos^2\theta}{2+2\alpha/3}, \text{ where } \alpha = \begin{cases} +1 & \text{fully transverse} \\ 0 & \text{no polarization} \\ -1 & \text{fully longitudinal} \end{cases}$$



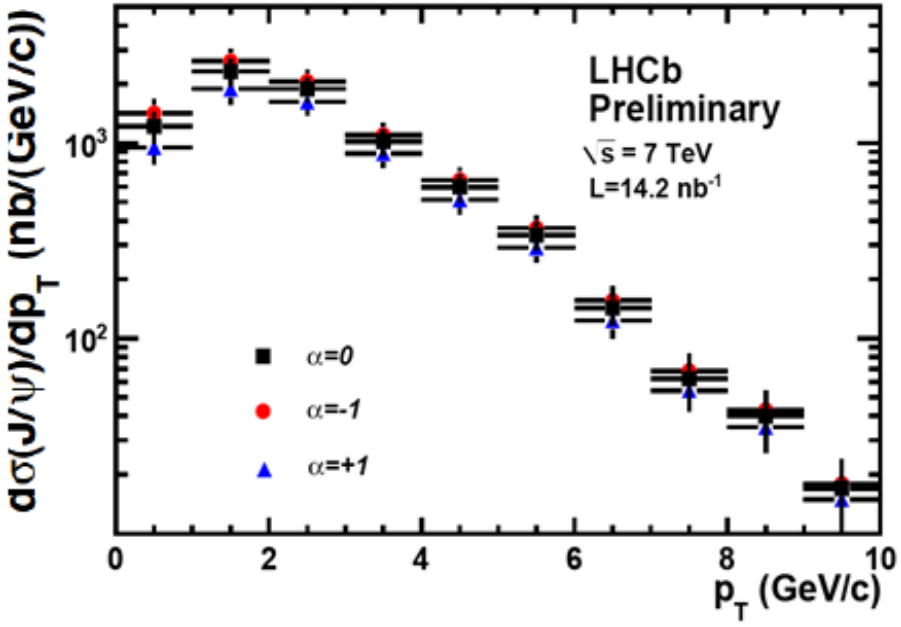
With more statistics, a direct measurement of polarization with full angular analysis, in different reference frames and bins of y and p_T, is foreseen.

Preliminary Results: 14.2 nb^{-1}

Compare to Monte-Carlo (zero-polarization)



Compare between Different Polarizations



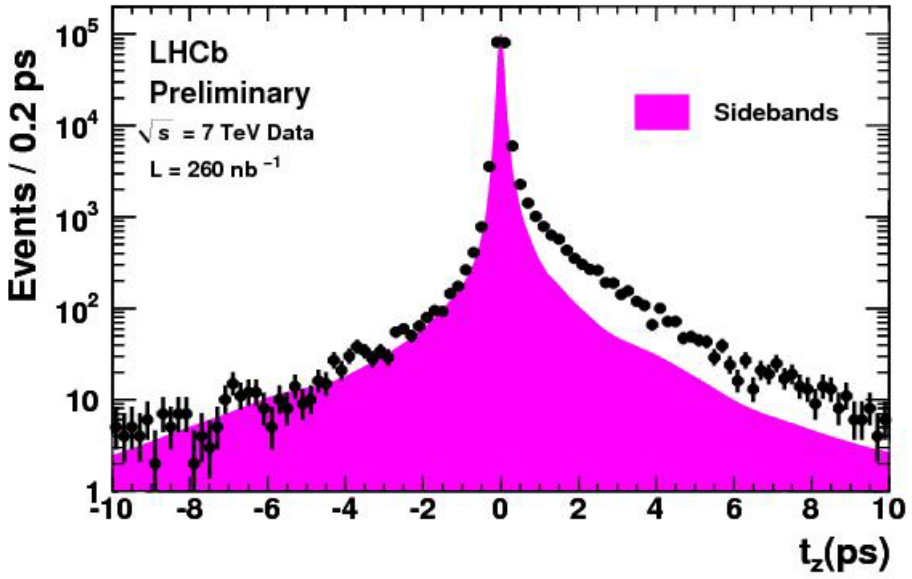
$$\sigma(\text{incl. } J/\psi,\ p_T < 10\text{GeV}/c,\ 2.5 < y < 4) = 7.65 \pm 0.19 \pm 1.10^{+0.87}_{-1.27}\ \mu\text{b}$$

$$\sigma(J/\psi \text{ from } b,\ p_T < 10\text{GeV}/c,\ 2.5 < y < 4) = 0.81 \pm 0.06 \pm 0.13\ \mu\text{b}$$

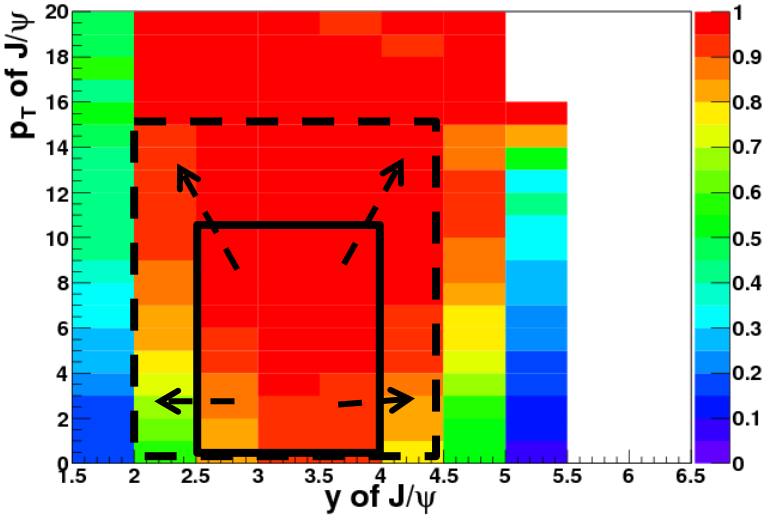
Systematic errors mainly come from data/MC discrepancy.
Dominant contributions from trigger and tracking efficiencies.

(see CERN-LHCb-CONF-2010-010)

Perspectives with More Data

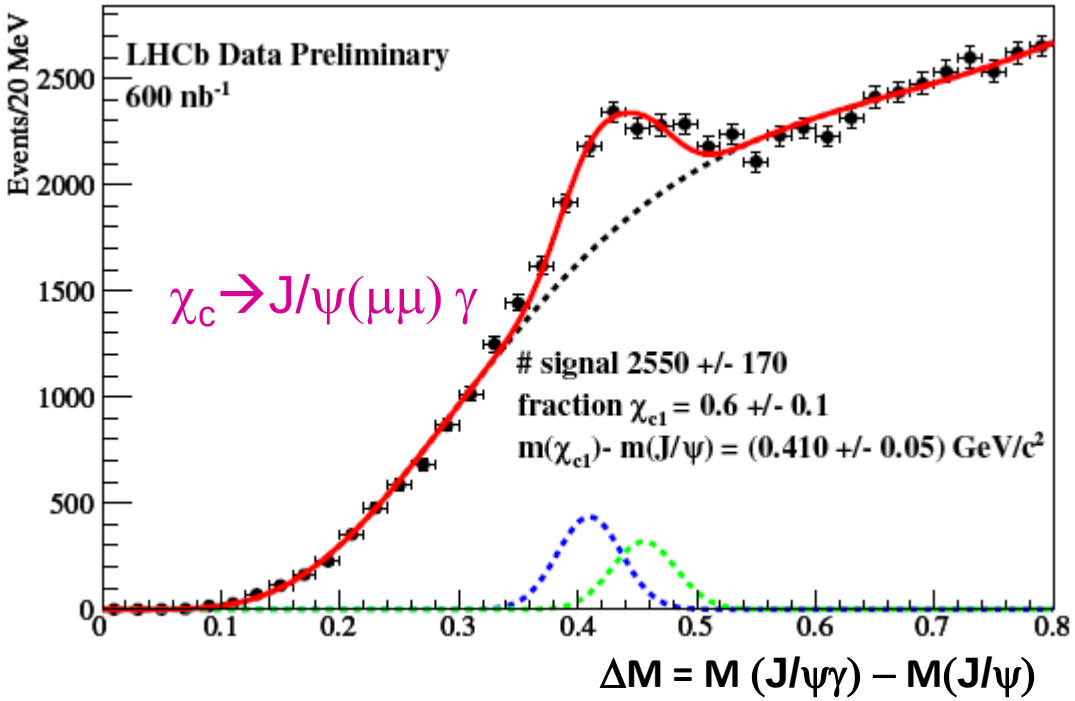


- Much more data since ICHEP
  O(1M) J/ψ for 20 pb^{-1}



- Will measure also polarization
- Region of measurement (y, p_T) will be extended with more data, some overlap with CMS/ATLAS

χ_c (L=600 nb^{-1})

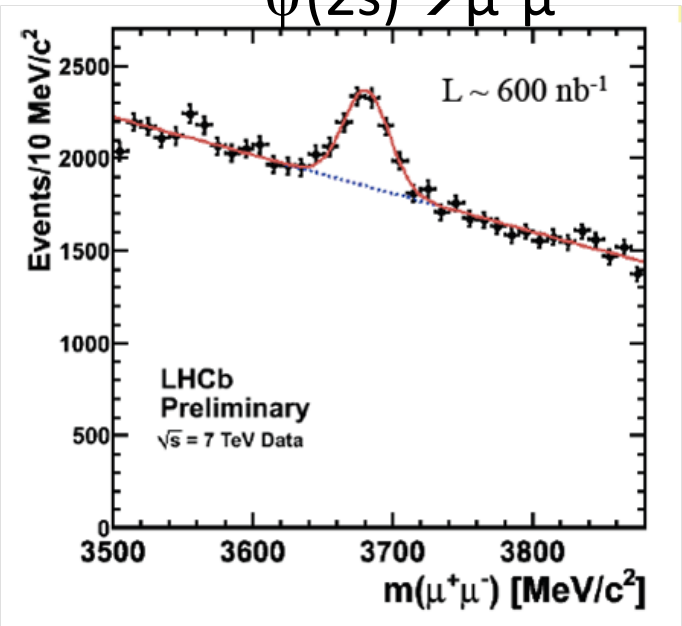


1) Already seen χ_c peak
2) With more statistics, we will measure $\sigma(\chi_{c1}+\chi_{c2})/\sigma(J/\psi)$ separately for prompt χ_c and χ_c from b

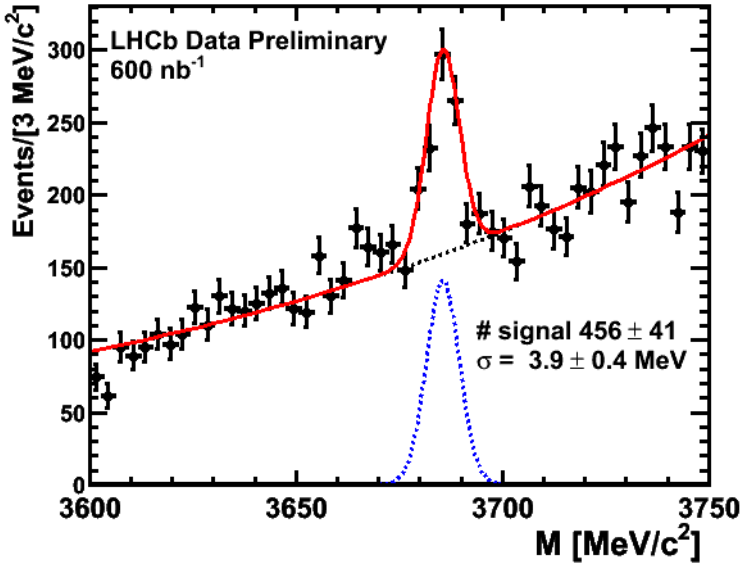
This will help us to interpret J/ψ cross section.

$\psi(2S)$ (L=600 nb^{-1})

$\psi(2s) \rightarrow \mu^+\mu^-$



$\psi(2s) \rightarrow J/\psi\pi\pi$

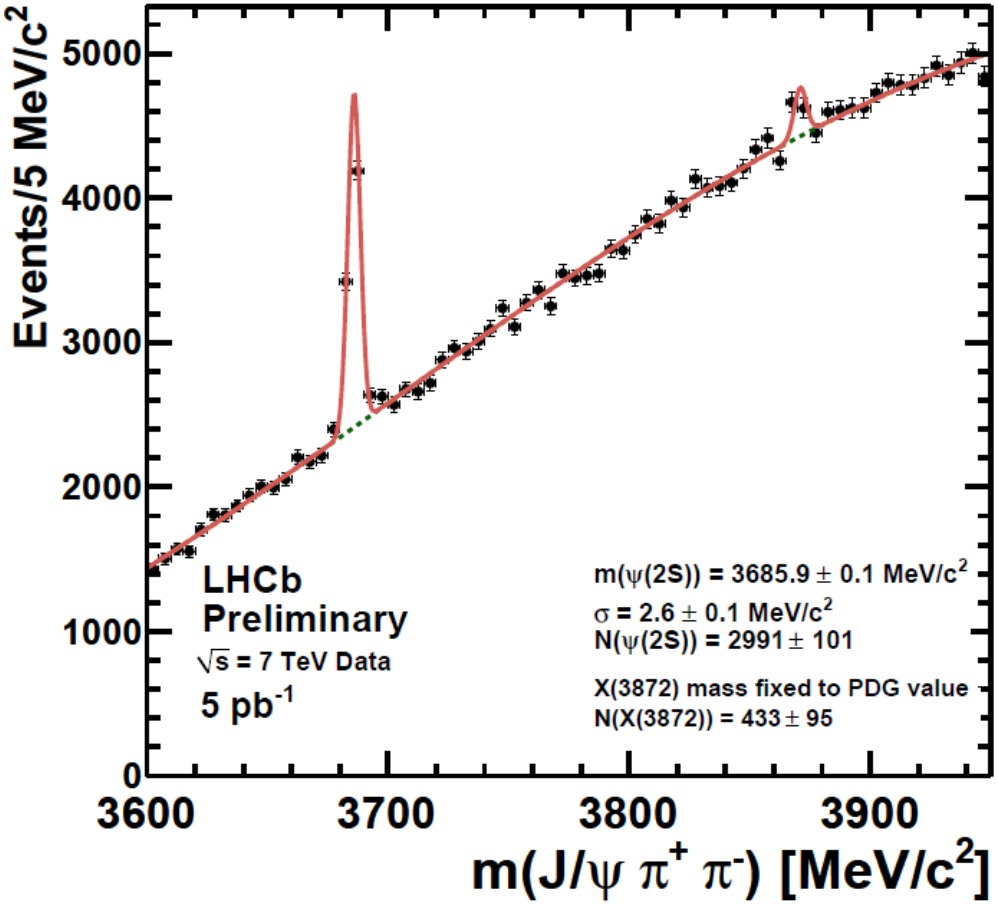


1)Well reconstructed through two decay channels

2)With more statistics, we will measure separately cross sections of prompt $\psi(2S)$ and $\psi(2S)$ from b, and eventually polarization, like for J/ψ

3)No feed-down contribution from heavier charmonia, easier to interpret

X(3872) (L=5 pb^{-1})



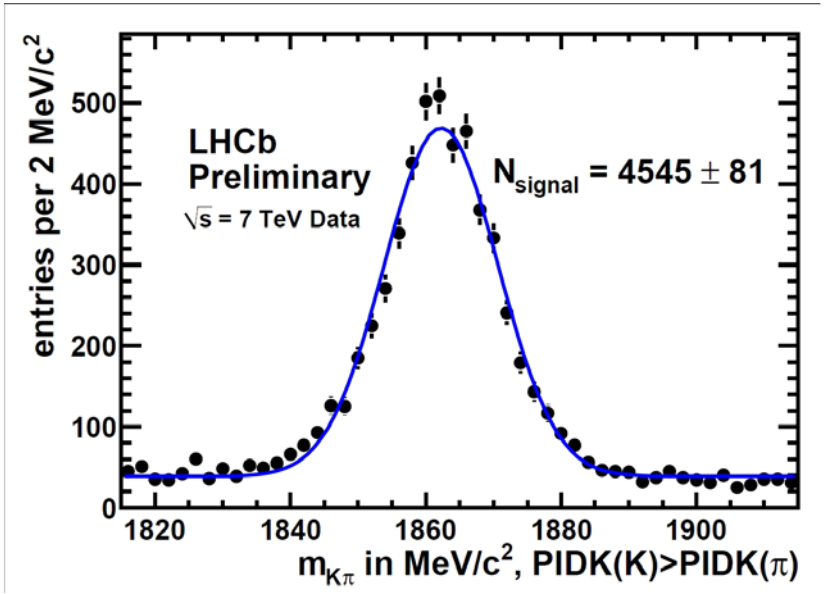
- Mass fixed to PDG value M_X=3871.56±0.22 MeV/c^2
- ψ(2S) could be used as calibration channel
- Mass measurement when O(0.1) MeV/c^2 statistical uncertainty is reached
- Production measurement
- J^{PC} as ultimate goal

Open Charm Production

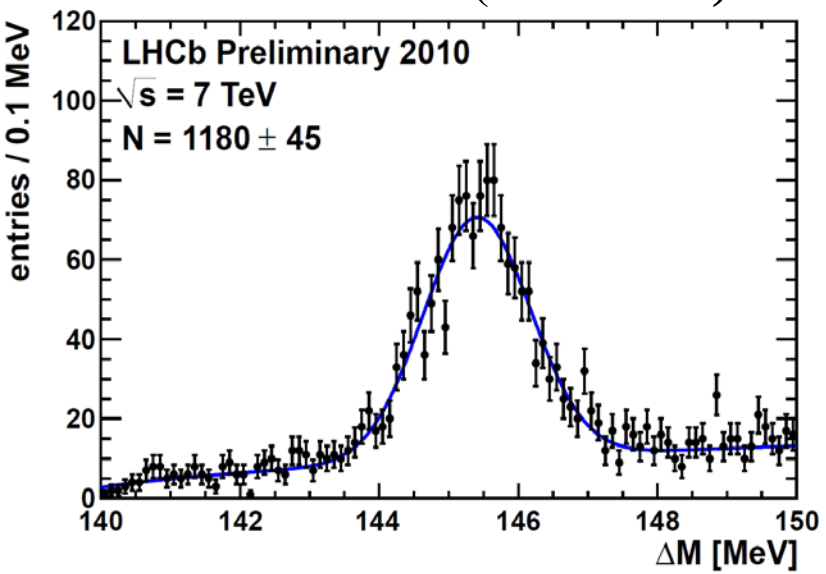
- First measurements at $\sqrt{s}$=7 TeV.
- Measure cross section vs y, p_T in 1.8 nb^{-1}, with open trigger.
- Use impact parameter distributions to separate prompt D and those from b-hadrons
- Good agreement with expectations!

Mass Peaks of Open Charm (L=1.8 nb^{-1})

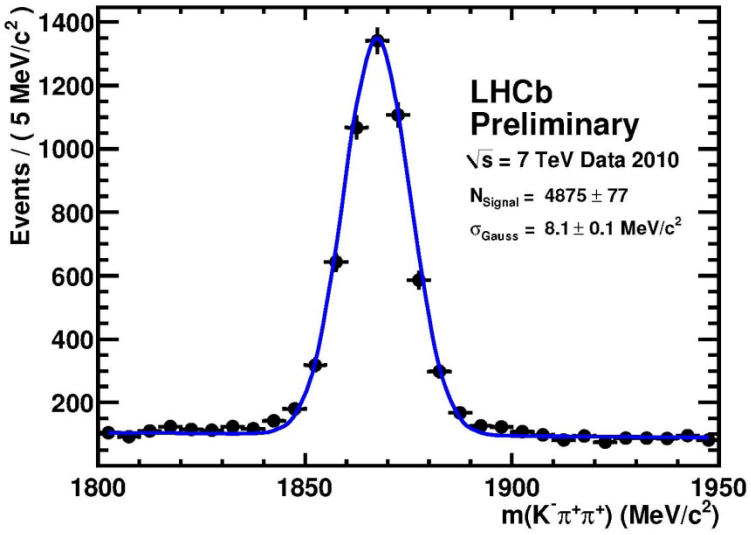
$D^0 \rightarrow K^- \pi^+$



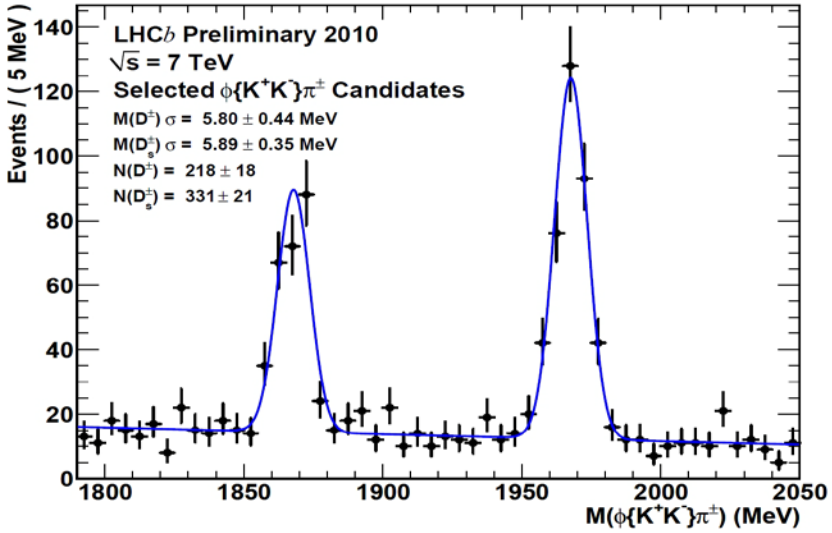
$D^{*+} \rightarrow (D^0 \rightarrow K^-\pi^+)\pi^+$



$D^+ \rightarrow K^- \pi^+ \pi^+$

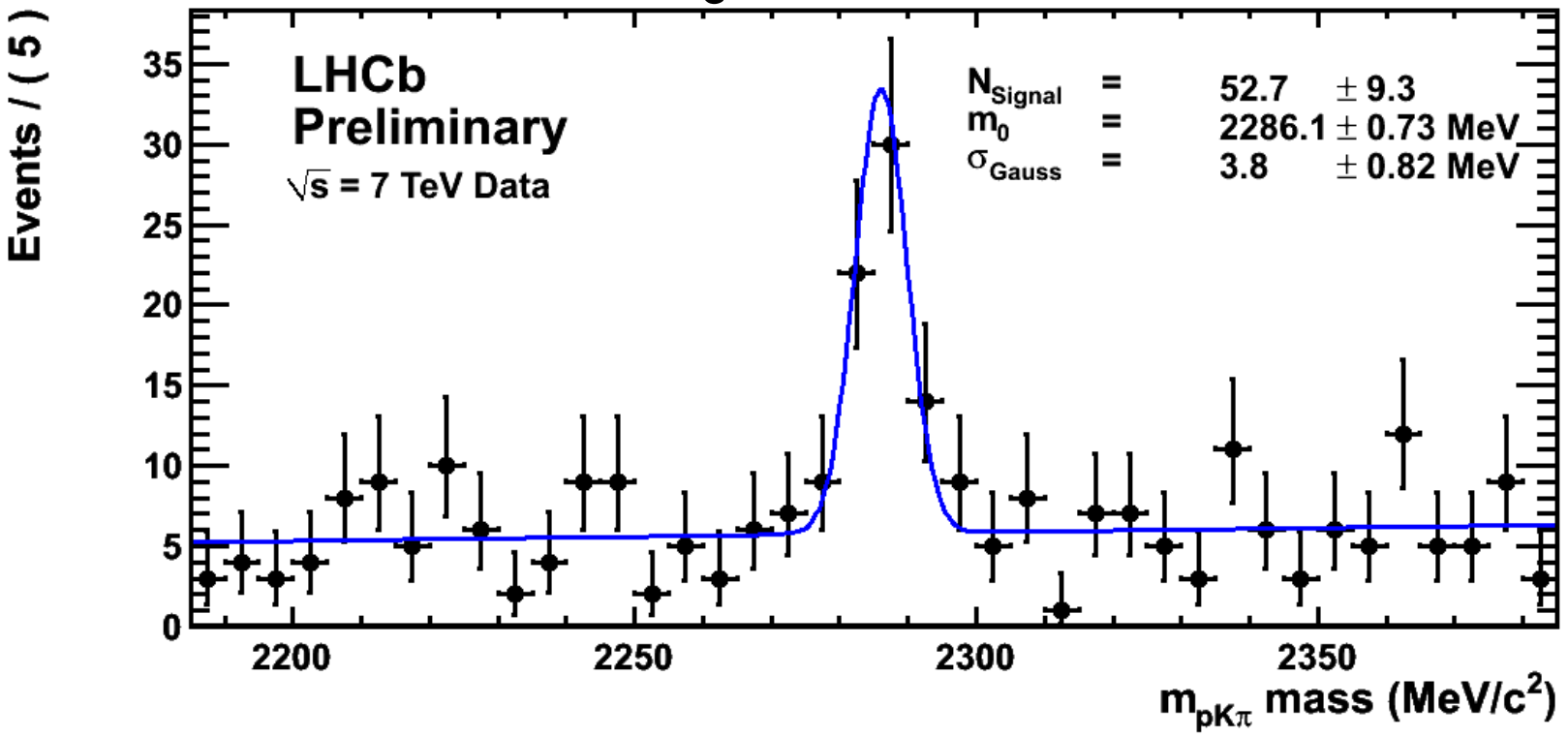


$D_s \rightarrow (\phi \rightarrow K^-K^+)\pi^+$



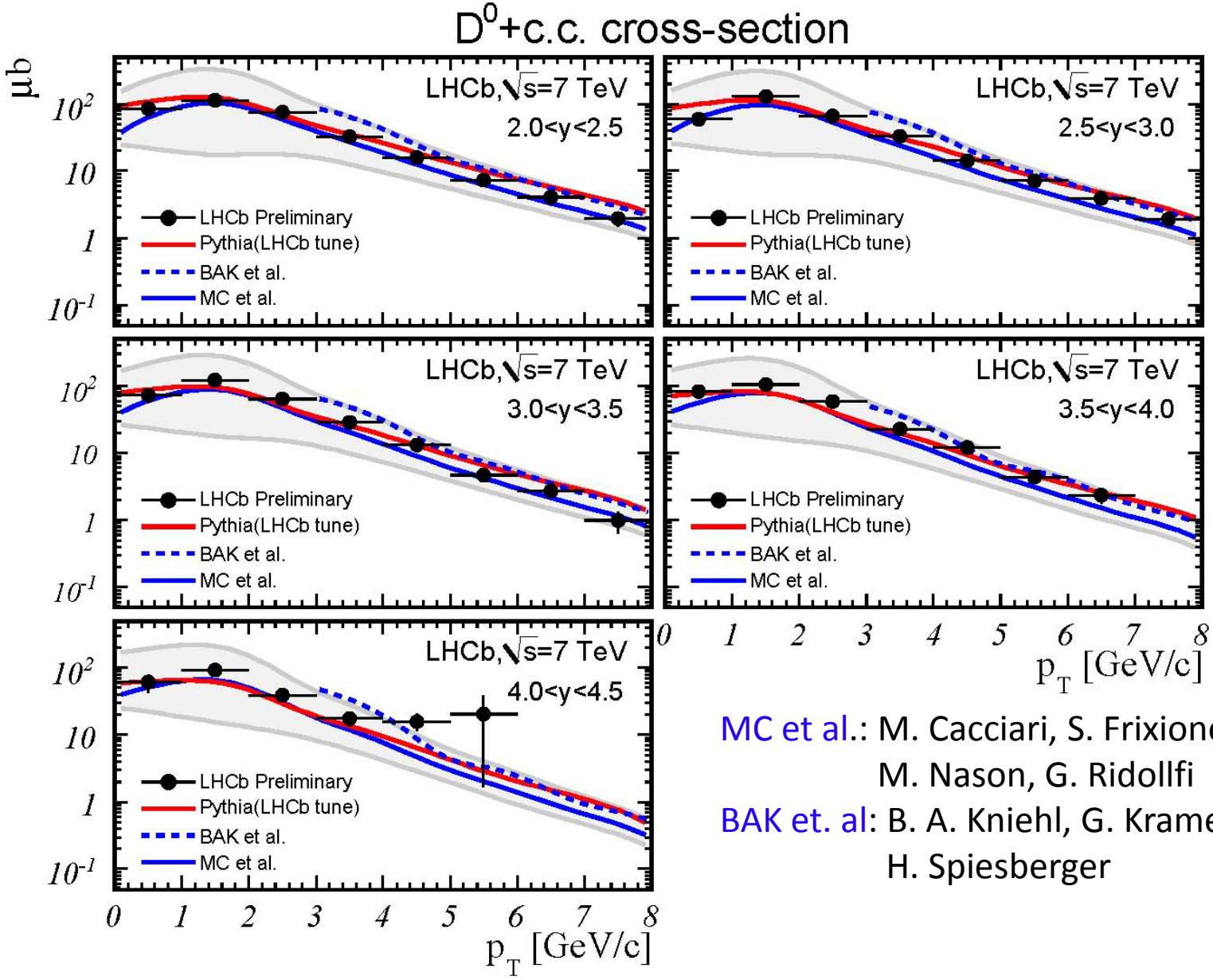
Mass Peaks of Open Charm

$\Lambda_c^+ \rightarrow pK^-\pi^+$



- Luminosity only 0.8 nb^{-1} for this plot

D^0 cross section (L=1.8 nb^{-1})

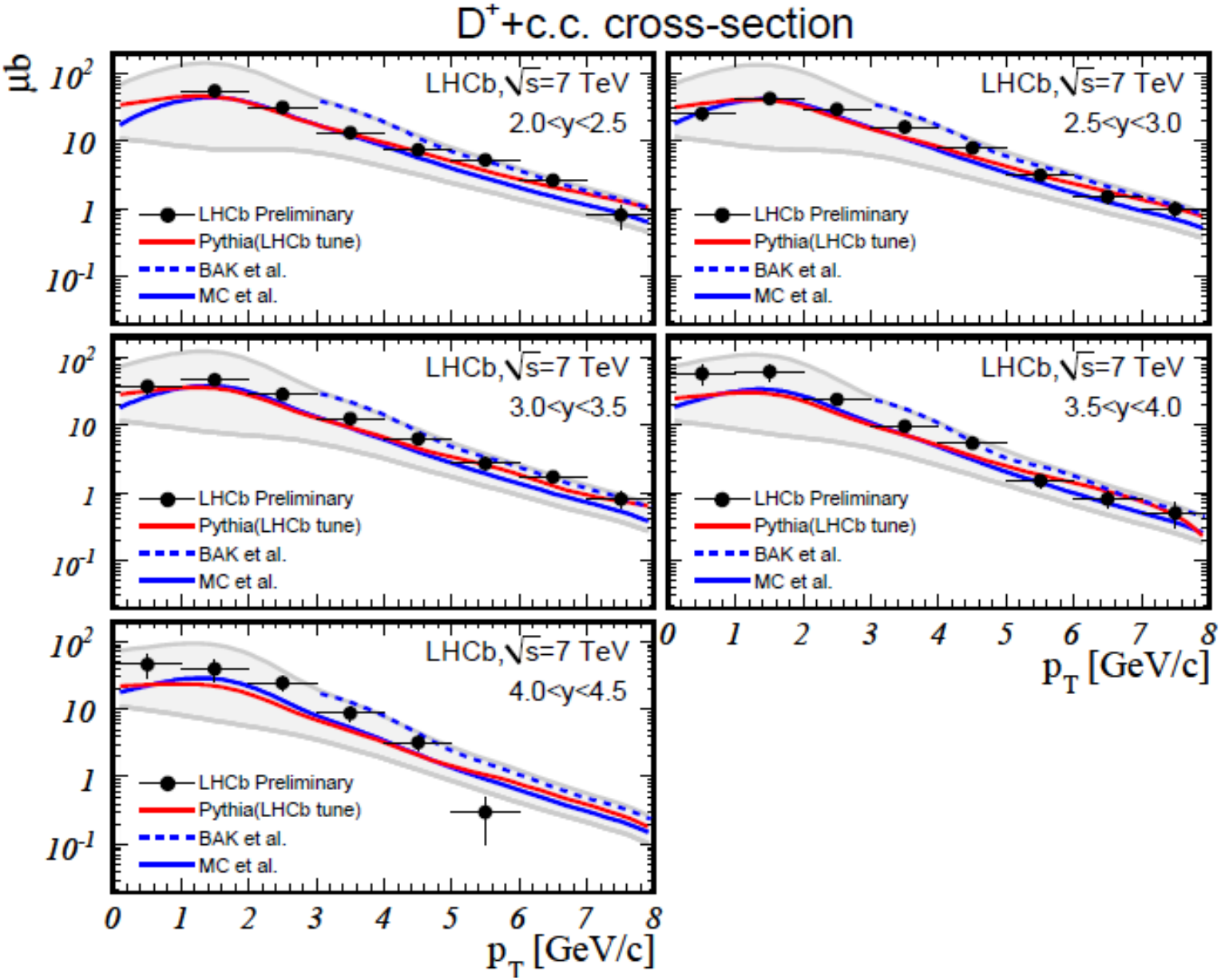


Shadow: theoretical uncertainty from MC et al.

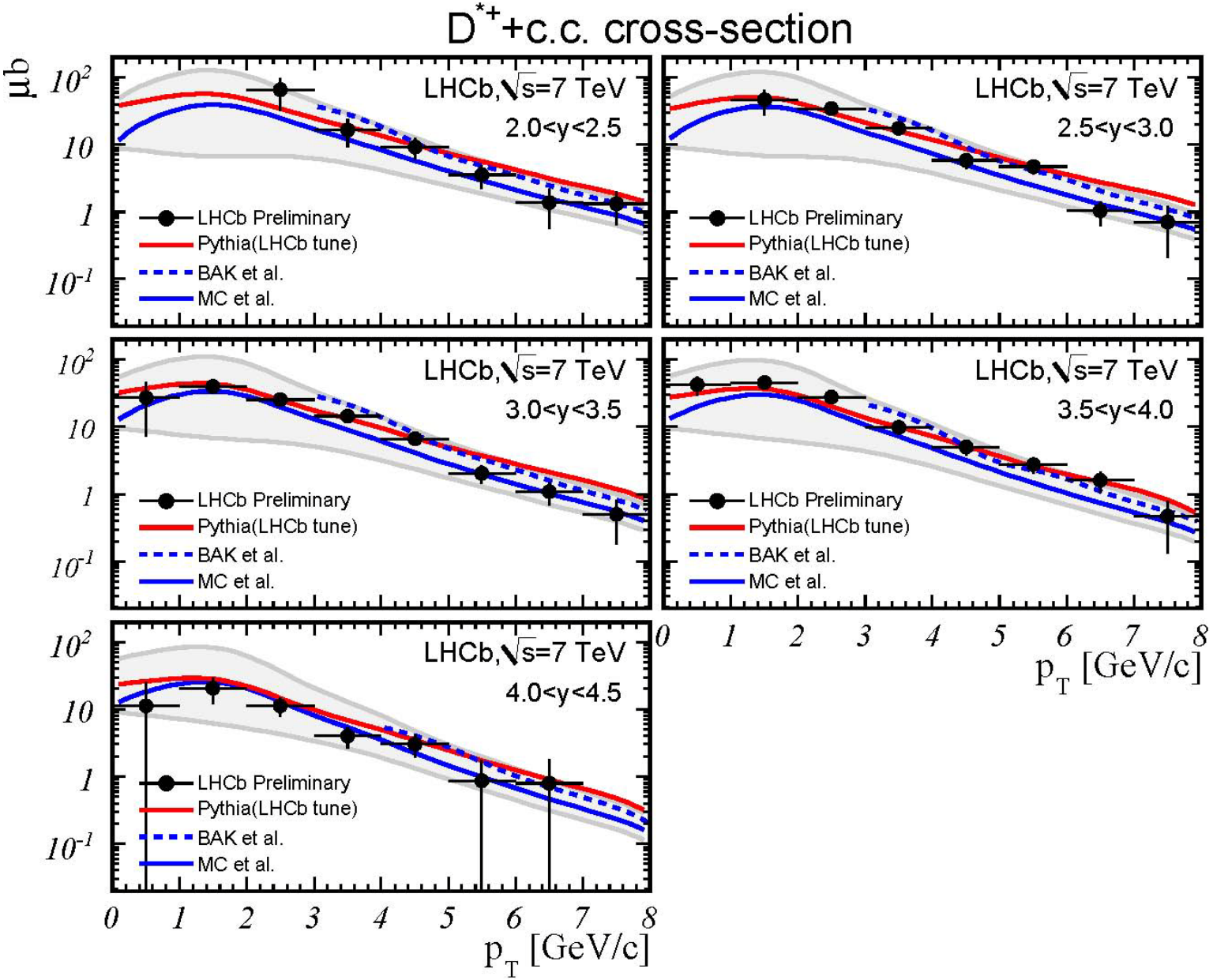
MC et al.: M. Cacciari, S. Frixione, M. Mangano, M. Nason, G. Ridollfi

BAK et. al: B. A. Kniehl, G. Kramer, I. Schienbein, H. Spiesberger

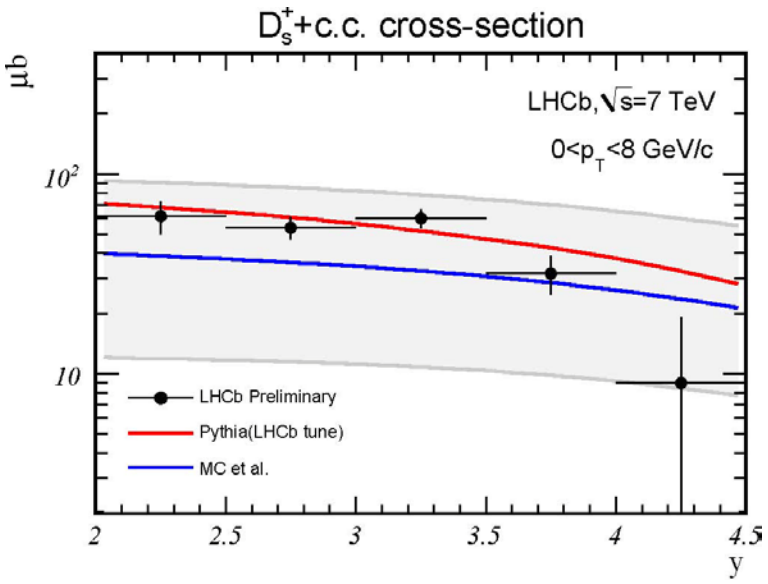
D^+ cross section (L=1.8 nb^{-1})

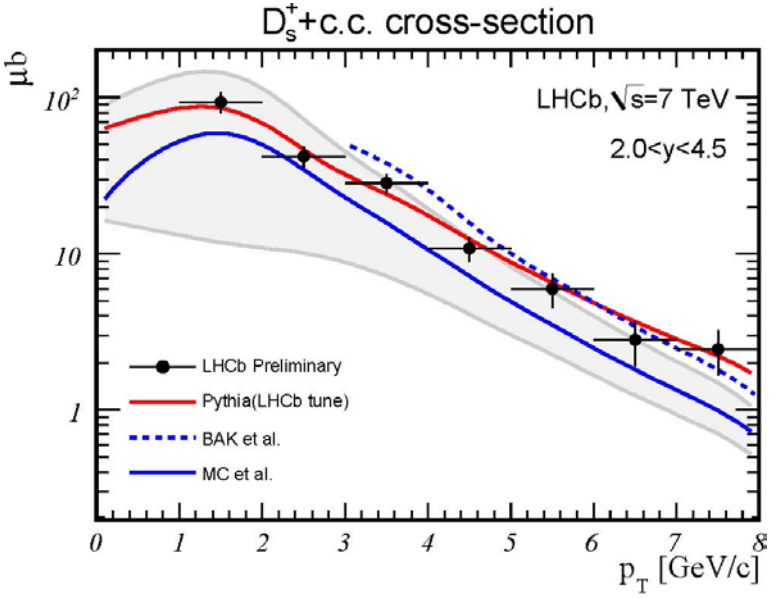


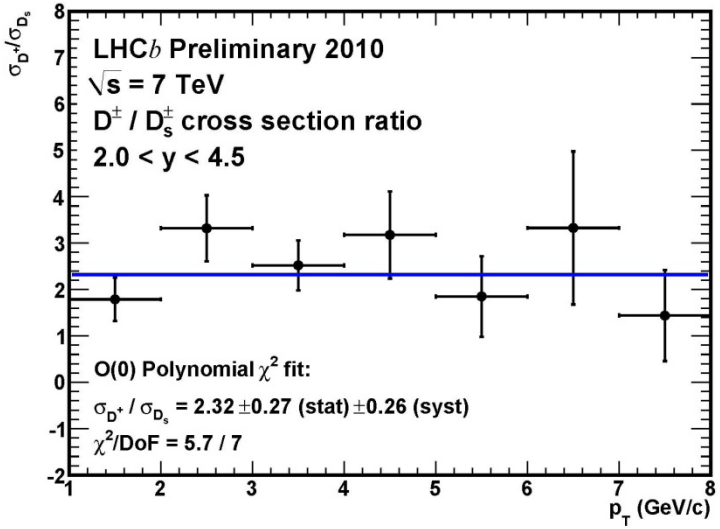
D^{*+} cross section (L=1.8 nb^{-1})



D_s cross section (L=1.8 nb^{-1})







- $\sigma(D^+)/\sigma(D_s^+)=2.32\pm0.27\ \pm0.26$
- Consistent with PDG:
  $f(c\rightarrow D^+)/f(c\rightarrow D_s^+)=3.08\pm0.70$

Summary

- LHCb producing physics measurements with high quality @ √s = 7 TeV
- Cross sections of prompt J/ψ and J/ψ from b measured separately
- Cross sections of D^0,D^*,D^+,D_s^+ are measured, good agreement with theor. expectations
- Heavier charmonia well reconstructed and waiting for more statistics

Thank you

back up

Event Selection of J/ψ

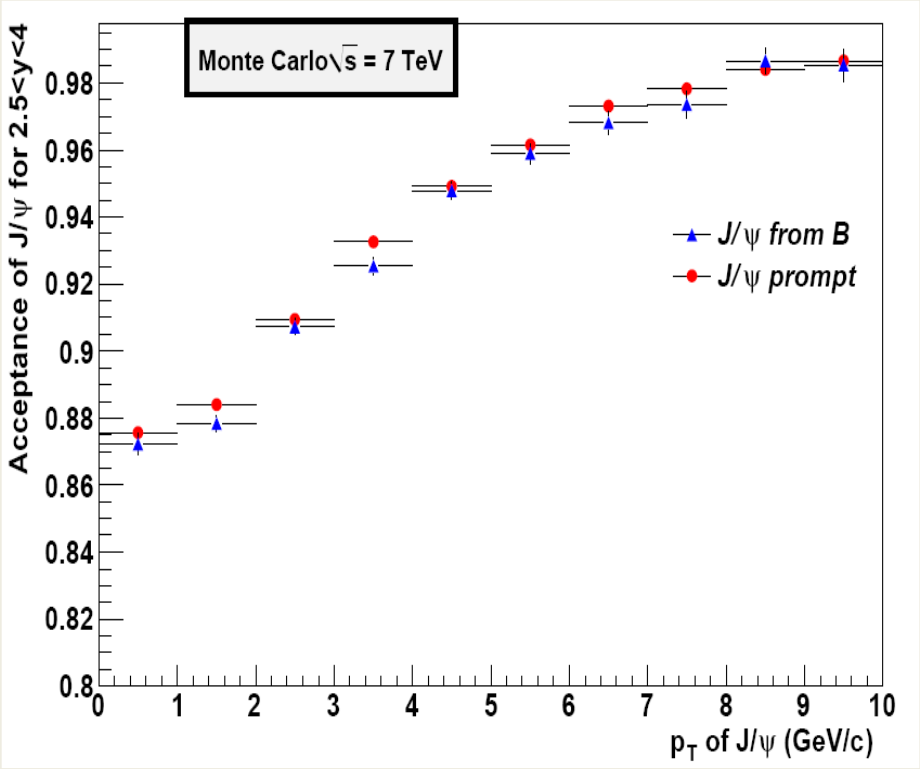
Data Sample

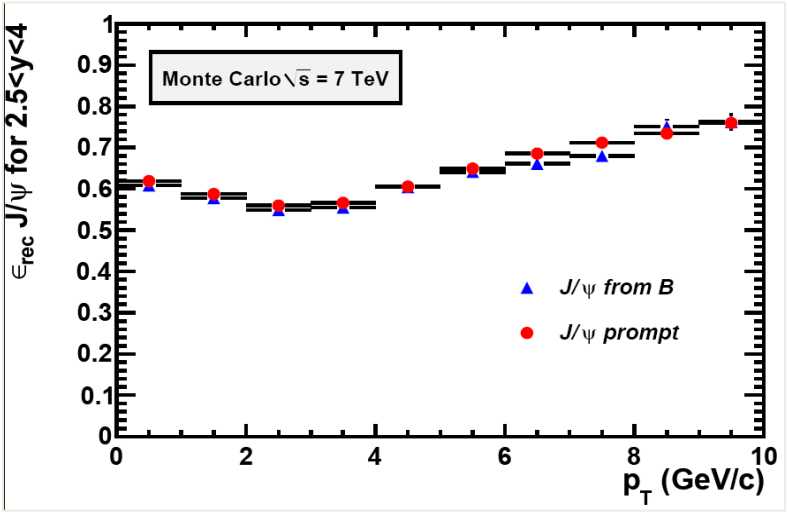
- $(14.15 \pm 1.42)\ nb^{-1}$ (low pile-up conditions)

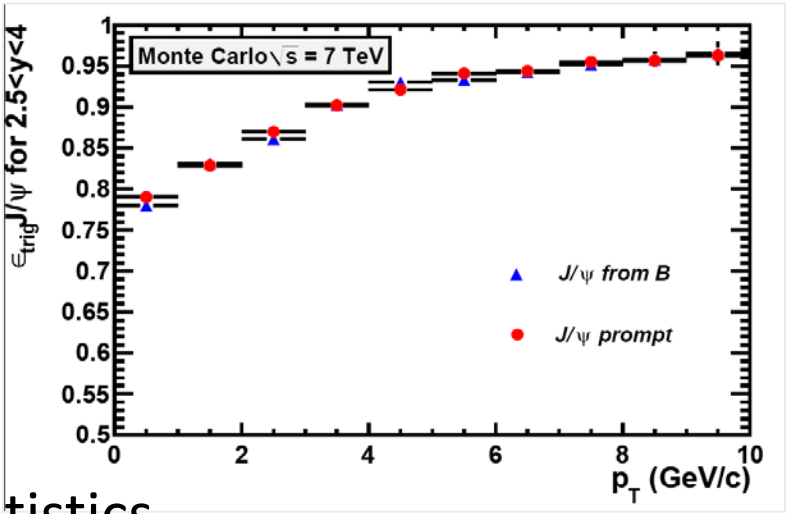
Event selection

- 2 muons
  - with fully reconstructed tracks (VELO + Tracker)
  - identified bymuon system
  - good vertex reconstructed
  - $p_T > 700$ MeV/c
  - Mass window for signal definition: $(M_{J/\psi} \pm 390)$ MeV/c^2
- Trigger L0
  - single muon, $p_T > 480$ MeV/c
- HLT:
  - single muon, $p_T > 1.3$ GeV/c .OR. muon pair with $M_{\mu\mu} > 2700$ MeV/c^2

Efficiencies: $\varepsilon = \varepsilon_{acc} \times \varepsilon_{rec} \times \varepsilon_{trig}$



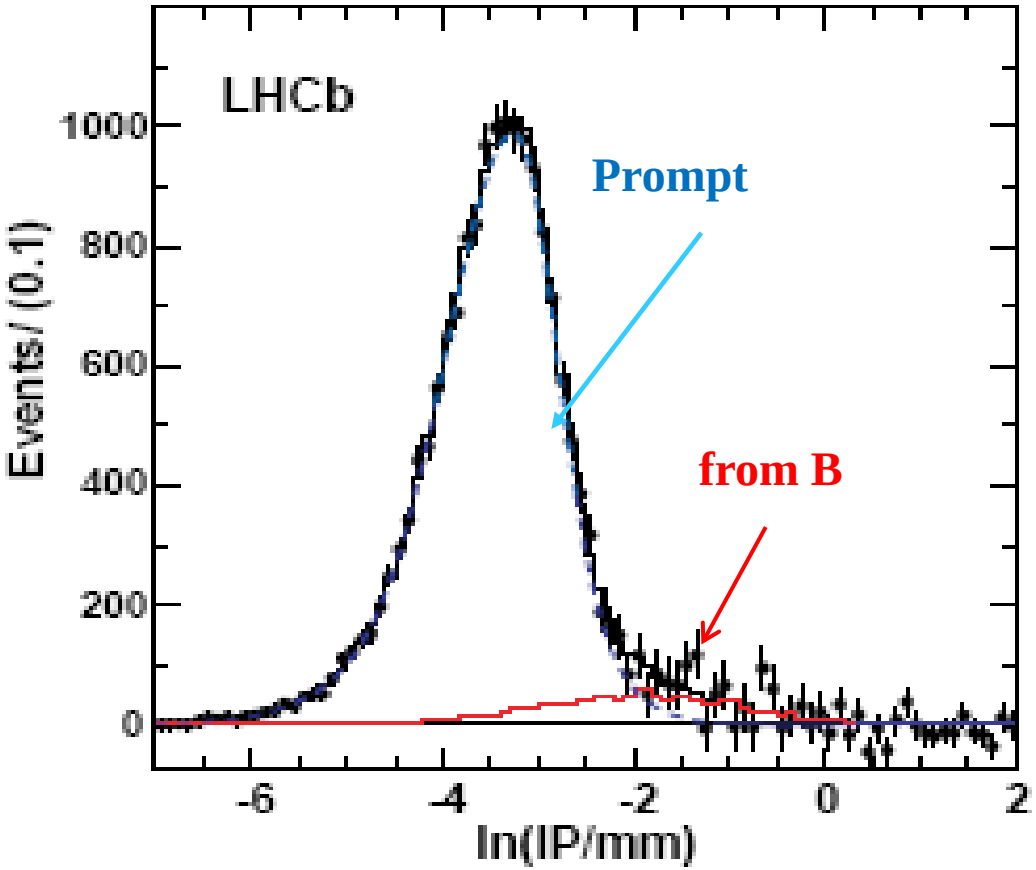




- $0<P_T<10$ GeV/c divided into 10 bins
- integrate over $2.5<y<4$ due to low statistics
- plenty of cross check with data

Using log(IP) to separate direct D-meson and D meson from b

Open (microbias trigger): 2.9 nb^{-1}



Data Set of J/ψππ (1)

Data

- 600 nb^{-1} from stripping 7, di-muon strip
- Tracks refitted with alignment v4.1

J/ψ selection

- Loose J/ψ candidates from the DST, TOS
- Muon cuts $\chi^2/dof < 4$, pt > 700 MeV, 8 < p < 500 GeV
- pt > 2 GeV
- | dM(J/ψ) | < 50 MeV

Global event cuts

- < 10000 OT hit, < 3000 IT hits

Data Set of J/ψππ (2)

π pair selection

- Pion pair selection χ^2/dof < 4, pt > 300 MeV, pidE < 0, p < 500 GeV
- pt1 + pt2 > 800 MeV

Candidate selection

- Q < 300 MeV
- Refit with J/ψ mass constraint (DecayTreeFitter), require χ^2/dof < 8

Quite similar to selection of Stefano

- Mass constrained fit
- Use of electron veto
- Tighter cut on pt sum, no cut on product of pts

Selections of D0 & D*

$D^0 \rightarrow K^- \pi^+$ and $D^{*+} \rightarrow (D^0 \rightarrow K^- \pi^+) \pi^+$

K,π : χ^2(track)/DoF < 9
χ^2(IP) > 9
pT > 700 MeV/*c*
K : ΔLL(K-π) > π : ΔLL(K-π)
D^0 : χ^2(vertex) <9
χ^2(flight) > 16
χ^2(IP) < 9
θ < 12 mrad

K,π : χ^2(track)/DoF < 10
K,πD : χ^2(IP) > 9
K : ΔLL(K-π) > 0
π : ΔLL(π-K) > 0
D^0 : χ^2(vertex) <9
$c\tau$ > 90 μm
χ^2(IP) < 9
D^{*+} : χ^2(vertex)< 9

Selections of D+ and Ds

$D^+ \rightarrow K^- \pi^+ \pi^+$ and $D_s \rightarrow (\phi \rightarrow K^- K^+)\pi^+$

K,π : Prob(χ^2(track)) > 10^{-4}

pT > 200 MeV/*c*

p > 3.2 GeV/*c*

χ^2(IP) > 3.0

2 daugthters: pT > 400 MeV/c

χ^2(IP) > 10

1 daughter: χ^2(IP) > 50

K : ΔLL(K-π) > 3.3

π : ΔLL(π-K) > -10

D+ : χ^2(vertex) <8

θ < 14 mrad

χ^2(flight) > 90

τ < 0.01 ns

K,π:χ^2(track)/DoF<4

K : χ^2(IP) > 2

π : χ^2(IP) > 10

K : ΔLL(K-π) > 9

π : ΔLL(π-K) > -2

φ : |ΔM|<20MeV/c^2

Ds : χ^2(vertex)/DoF<5

Ds : χ^2(flight)> 67