First ReteQuarkonii Workshop
(RQW2010)

LHCb open heavy flavour results

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on behalf of the LHCb Collaboration

Outline

- Introduction
- LHCb detector
  - Detector, trigger, collected data.
- Open charm production cross-section
  - Cross-section: D^0, D^+, D^{*+}, D_s^+.
  - Ratio D^+/D_s^+.
- Open beauty production cross-section: $\sigma(pp \rightarrow bbX)$
  - $B \rightarrow D^0\mu\nu X$, $B \rightarrow D^*\mu\nu X$.
  - J/ψ from b.
  - Fragmentation fractions.
- Summary

Introduction

- LHCb is a dedicated b-physics experiment at LHC:
  - measurement of CP-violating observables and rare decays.
  - indirect search for NP beyond SM.

- First results in heavy flavour sector with LHCb:
  - Open charm production cross-section
  - Beauty production cross-section

- Mass peaks for different modes show the performance of LHCb detector.

LHCb detector

- Nominal conditions: $2 \cdot 10^{32}$ $cm^{-2}s^{-1}$ @ 14 TeV
  - $2fb^{-1}$ per nominal year (10^7 s)
  - 10^{12} bb-pairs produced per year

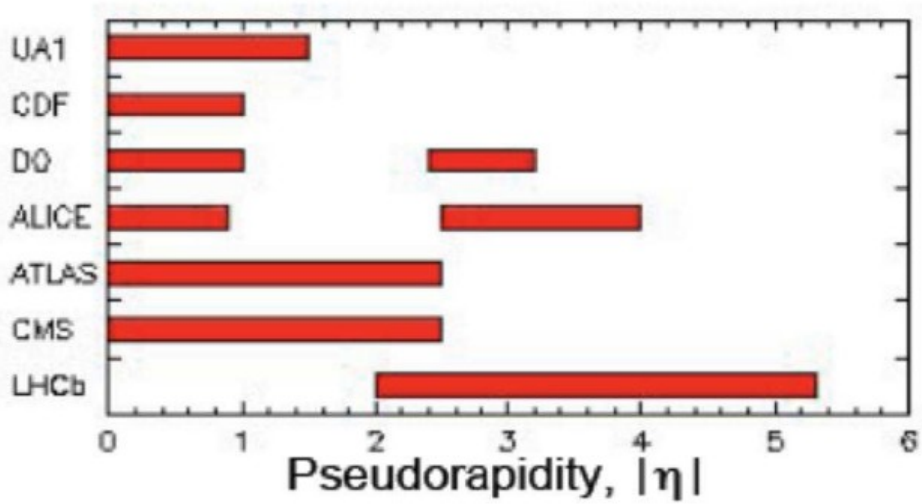
- Currently running @ 7 TeV energy
  - 40 pb^{-1} expected by the end of 2010

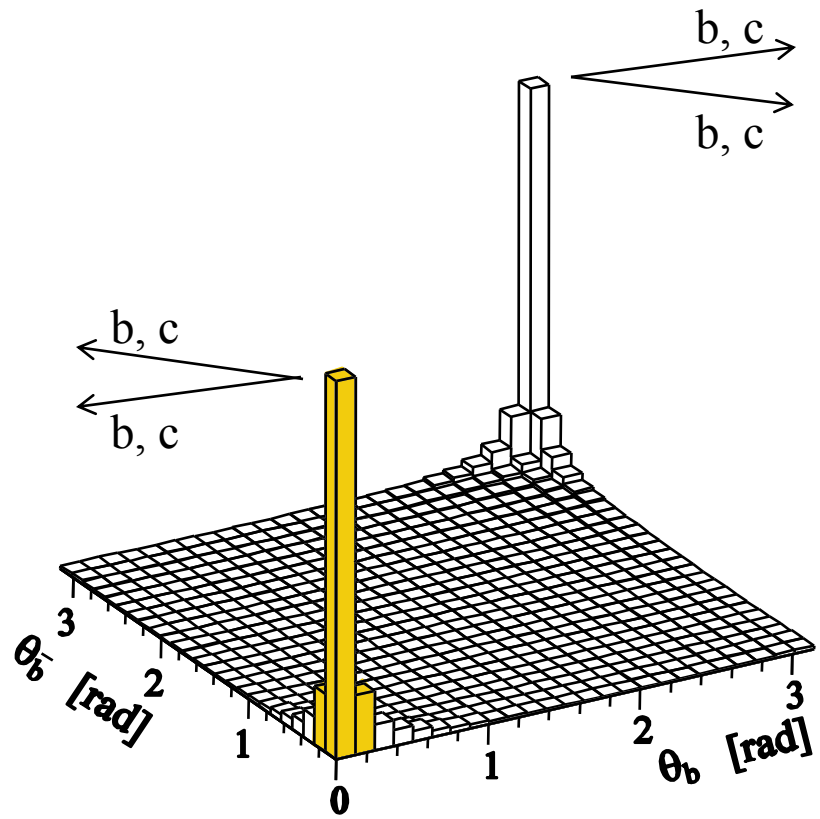
- B and D physics @ 7 TeV:
  - $\sigma_{bb} \sim 0.3$ mb (~25% is in the acceptance)
  - $\sigma_{cc} \sim 6$ mb

- Performance:
  - efficient trigger
  - primary and secondary vertex reconstruction
  - good momentum resolution: $\delta p/p \sim 0.4$–0.6 %
  - particle identification (PID): good kaon and pion separation

LHCb detector

- LHCb is a forward spectrometer:
  - b-hadrons are produced at small angles.
- Unique pseudo-rapidity range:
  - $2 < \eta < 5.3$
  - Unexplored range.



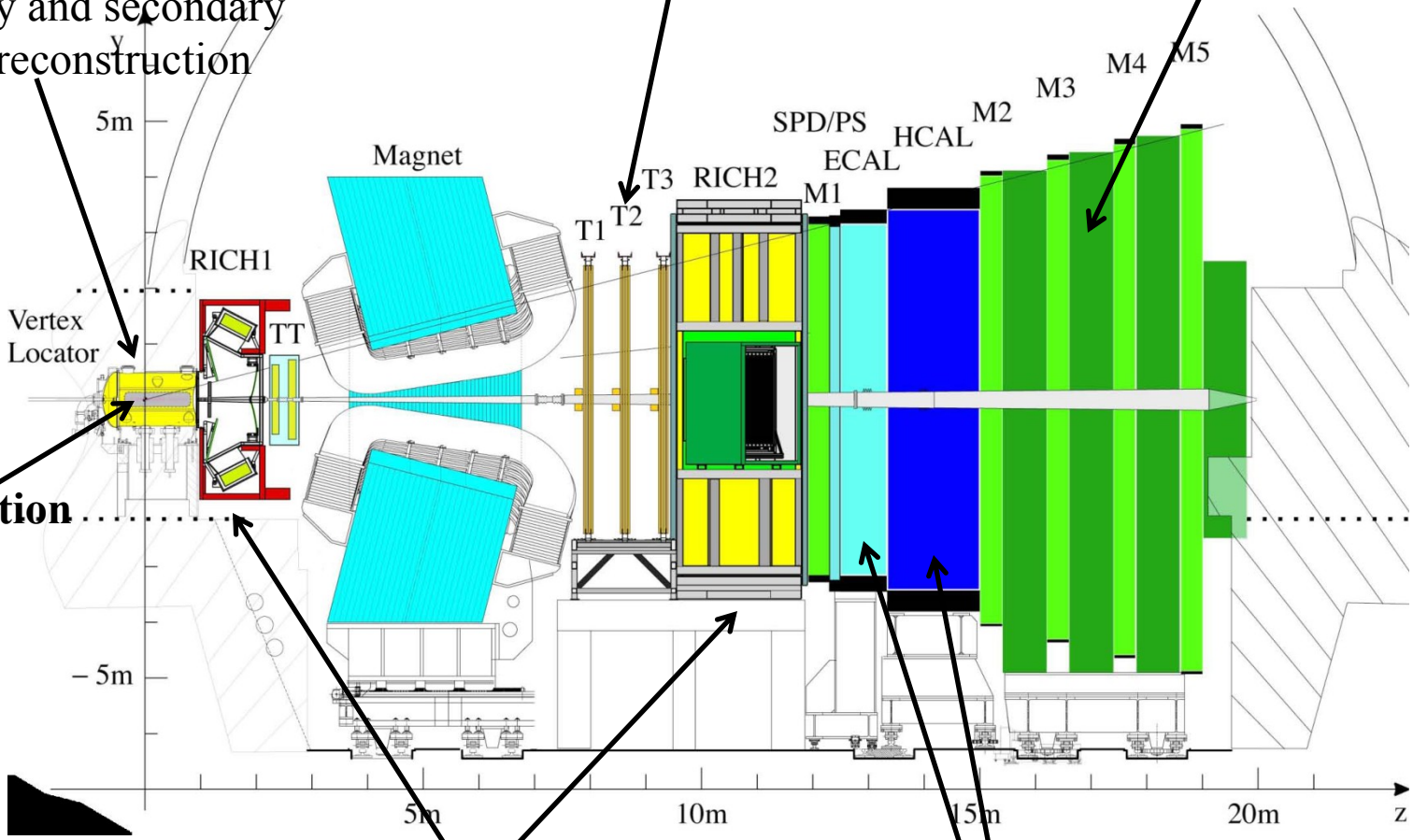


LHCb detector

VELO:
Primary and secondary vertex reconstruction

Tracking stations

Muon system

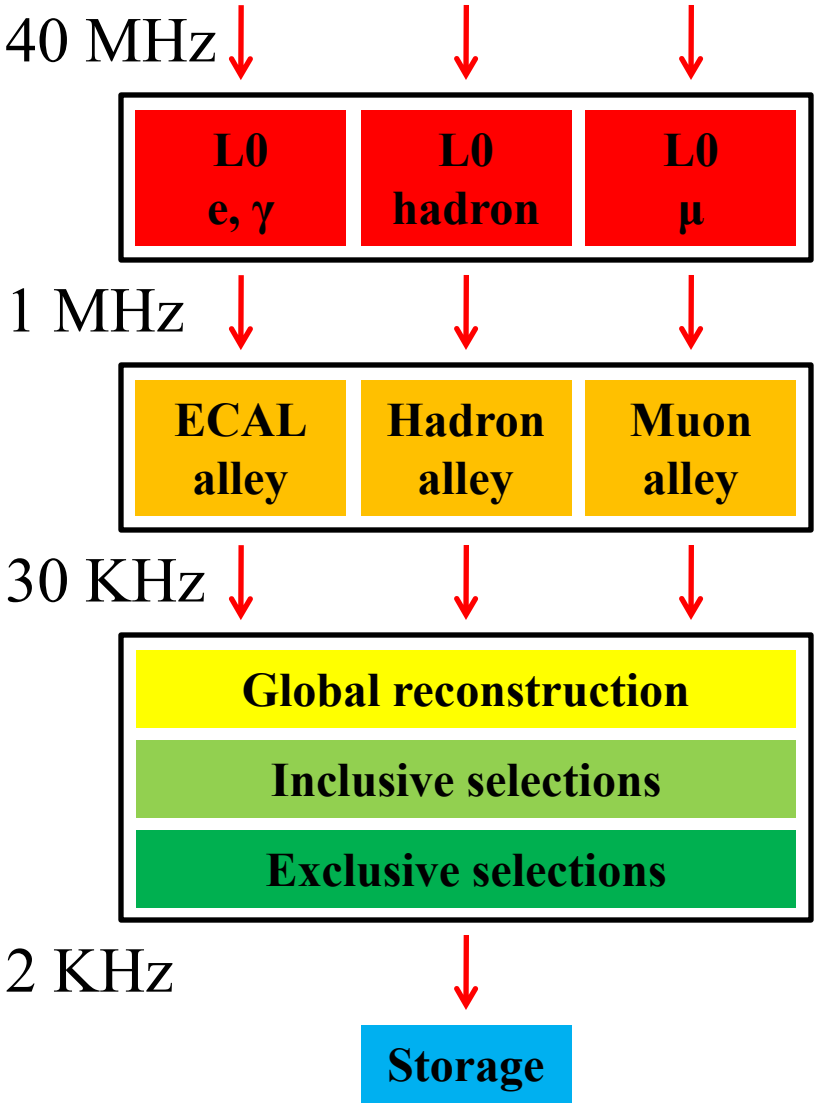


Interaction point

RICH detectors:
PID: K, π

Calorimeters:
PID: e, γ, π^0

Trigger

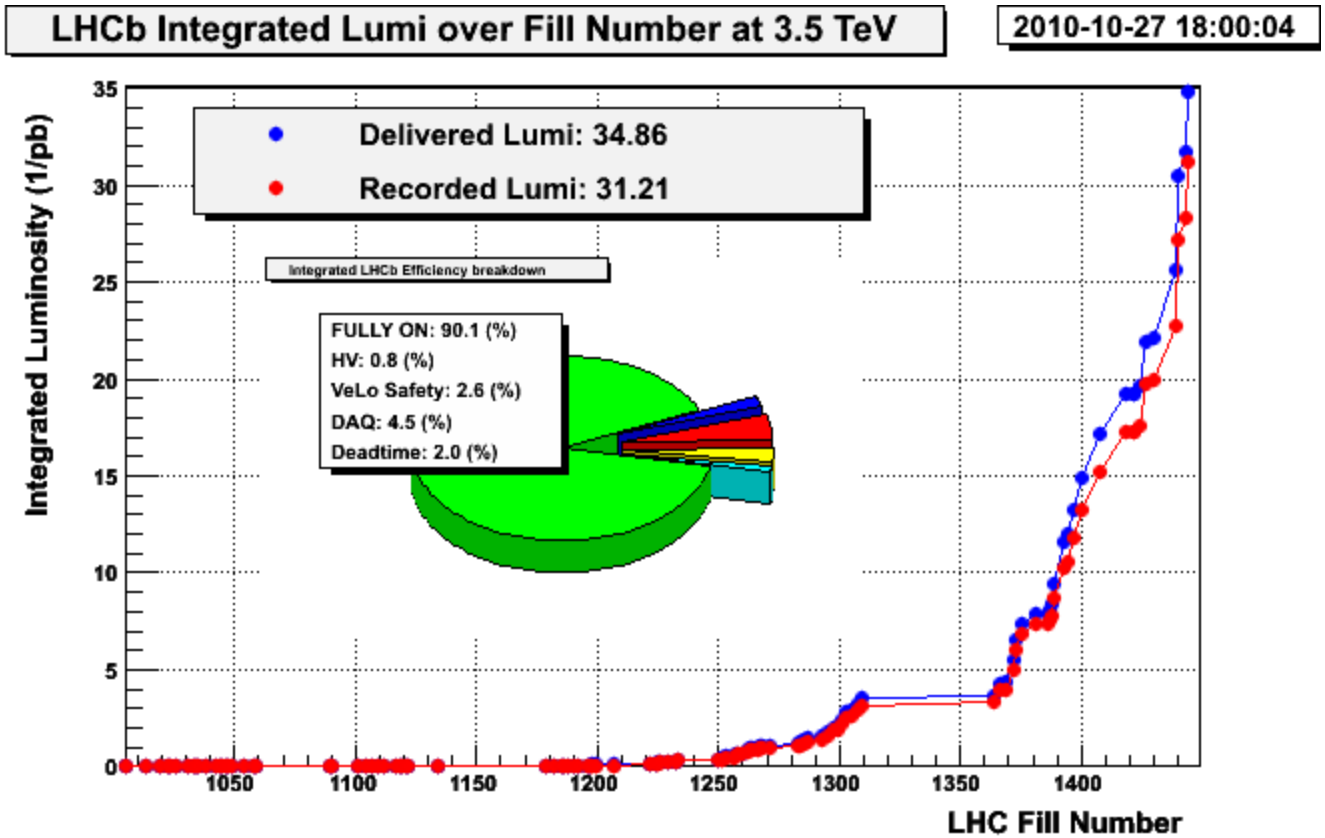


Level-0:
High p_t signals in calorimeter and muon systems.

HLT1:
Partial reconstruction, confirm L0 decision, cuts on IP, etc.

HLT2:
Look for inclusive signatures. Exclusive selections for key channels.

Accumulated data by LHCb



- More then 30 pb^{-1} on tape, 90% efficiency.
- 40 pb^{-1} expected by the end of 2010.
- Currently more then 5 pb^{-1} per good fill (12 hours).

Open charm production cross-section

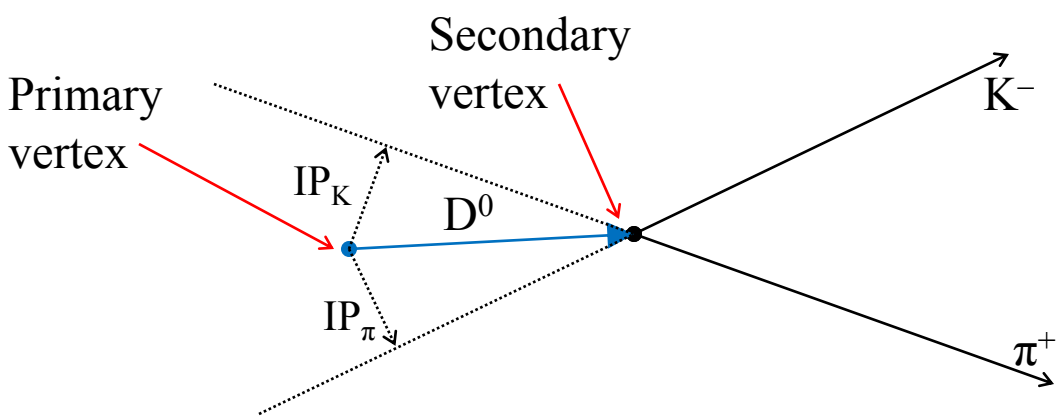
- Production cross-section measurement for D^0, D^+, D^{*+}, D_s^+.
- Ratios: D^{*+}/D^0, D_s^+/D^+.
- Full σ_{cc} cross-section measurement.
- Unique rapidity range.
- Possible to measure cross-section up to $p_t = 0$.

Dataset:

- LHCb collected several pb^{-1} @ 7 TeV.
- The charm cross-section is measured using the first 1.81 nb^{-1}:
  - Simple trigger conditions (MicroBias trigger)
  - Small pile-up (on average one pp interaction per bunch collision)
- Work in progress for 12 nb^{-1}.

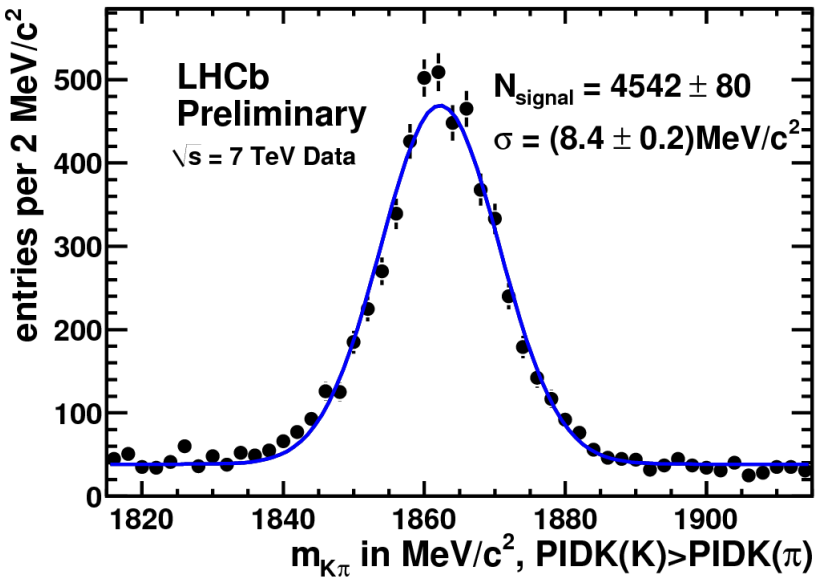
Open charm analysis strategy

- Use of finite lifetime of charm mesons (cut on flight distance or proper time):
  - D^0 lifetime – 0.41 ps
  - D^+ lifetime – 1.04 ps
  - D_s^+ lifetime – 0.5 ps
- Products of charm meson form secondary vertex.
- Pointing of reconstructed charm meson to primary vertex.
- RICH particle identification for K-π separation.

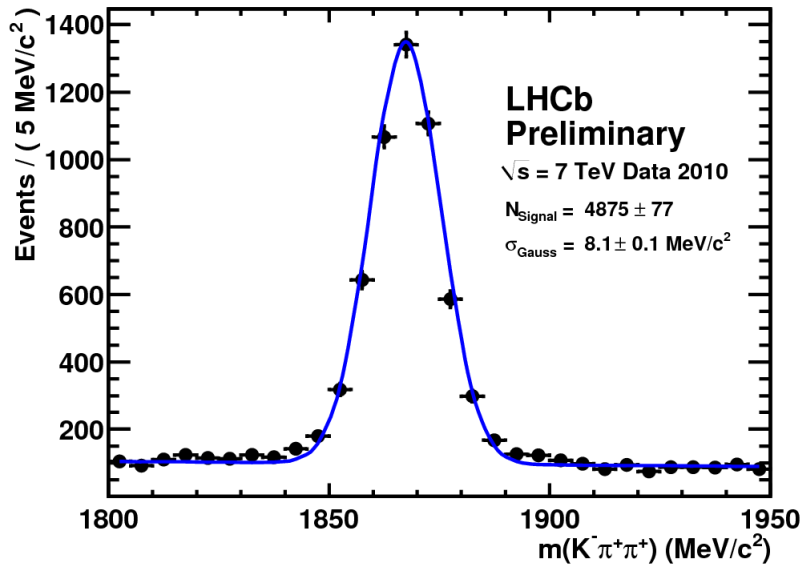


Charm mass plots: 1.81 nb^{-1}

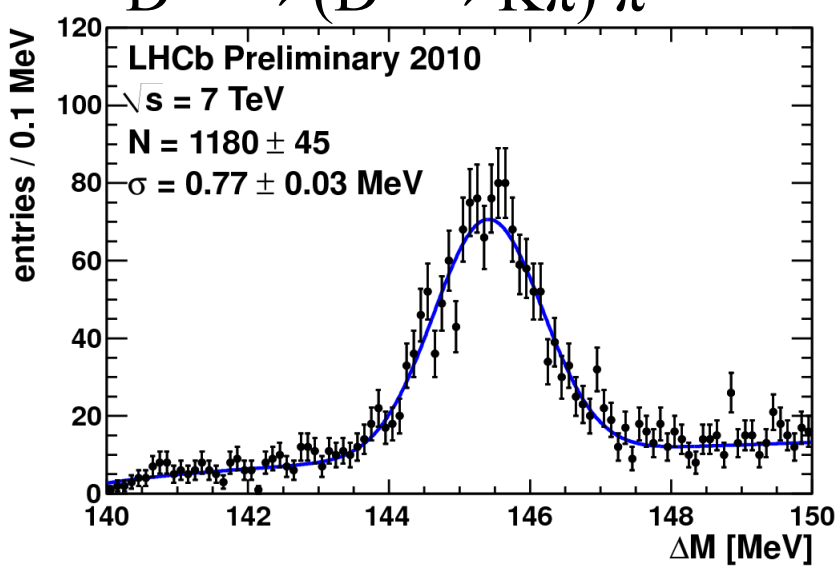
$D^0 \rightarrow K\pi$



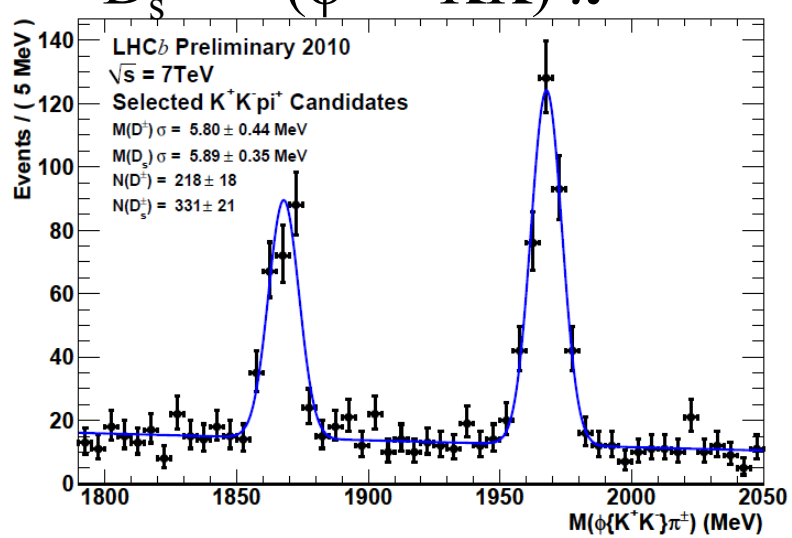
$D^+ \rightarrow K\pi\pi$



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

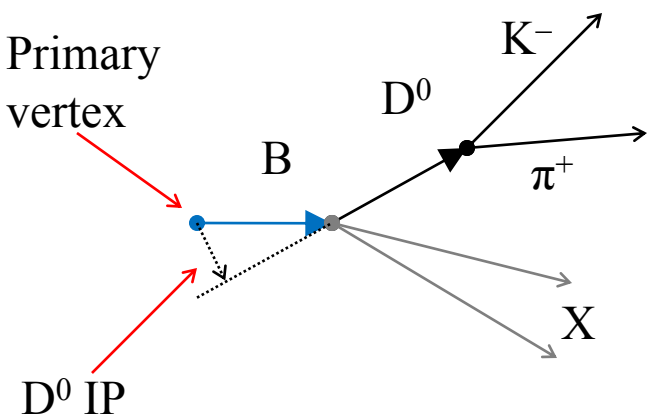


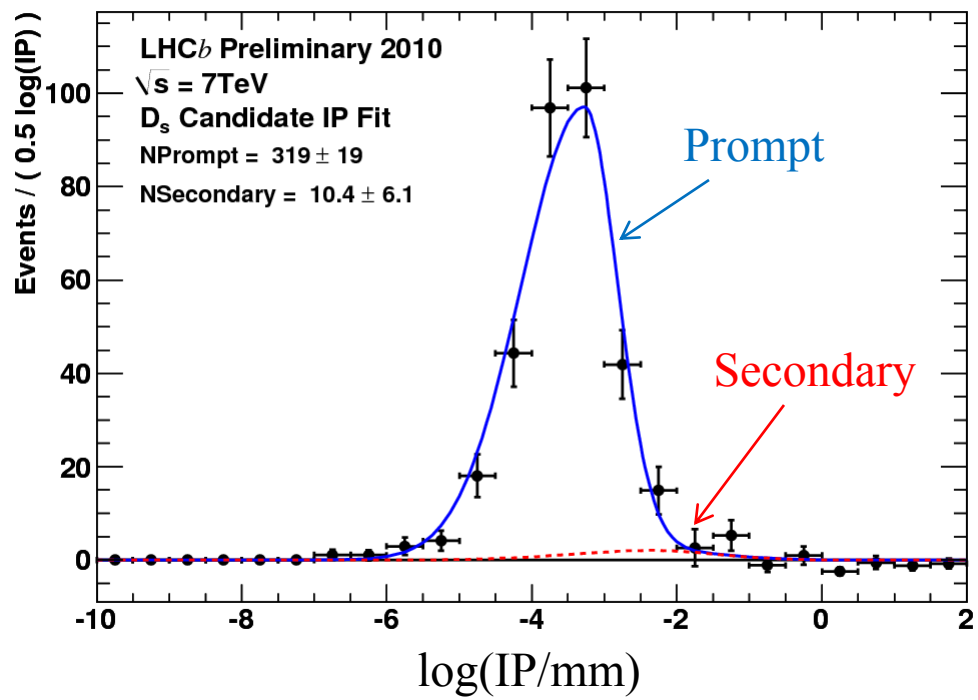
$D_s^+ \rightarrow (\varphi \rightarrow KK)\ \pi$



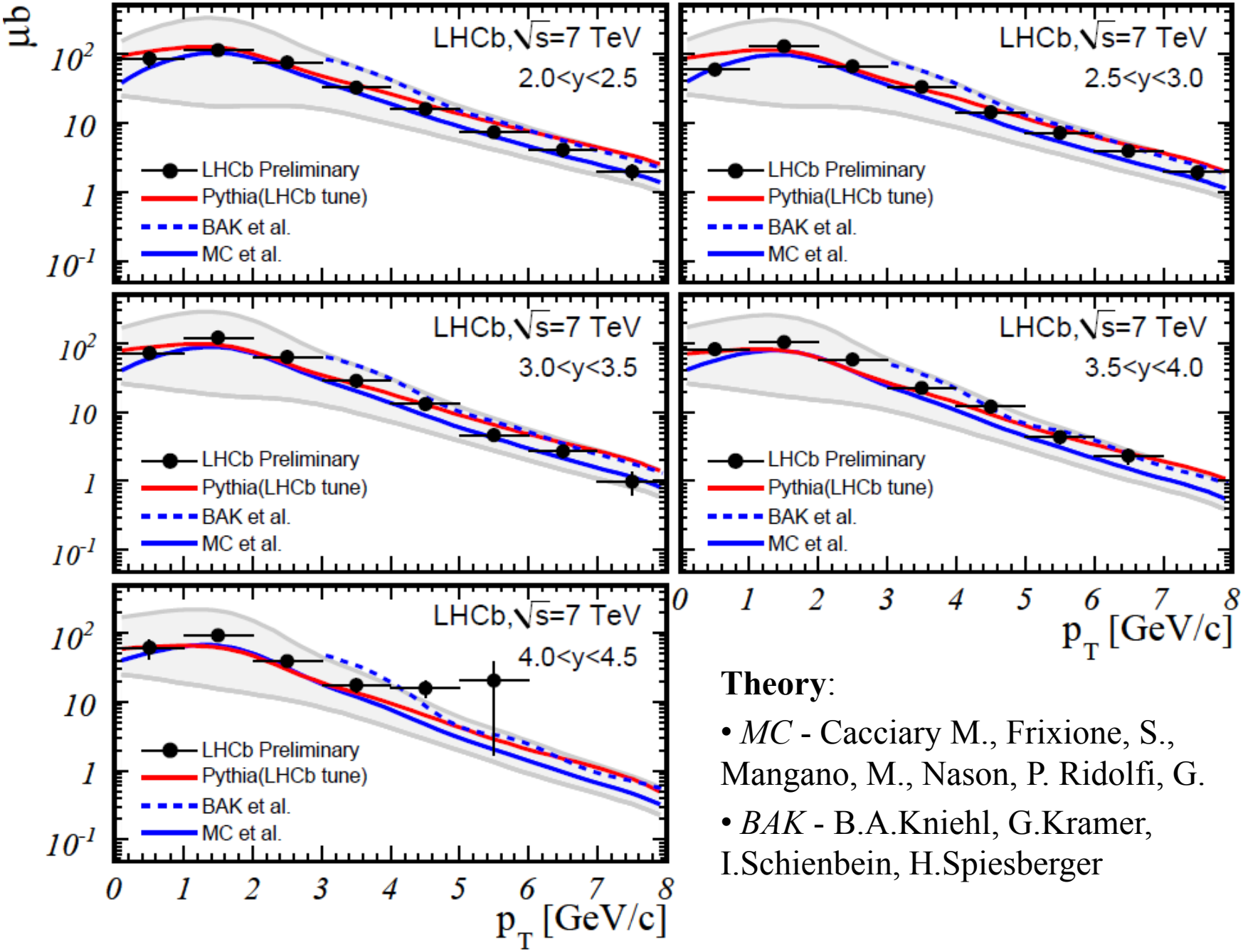
Prompt/secondary separation

- There is a non-prompt contribution of D mesons from B decays.
- Fit to log(IP/mm) to extract prompt yield.
- Secondary contribution is less then 5%.





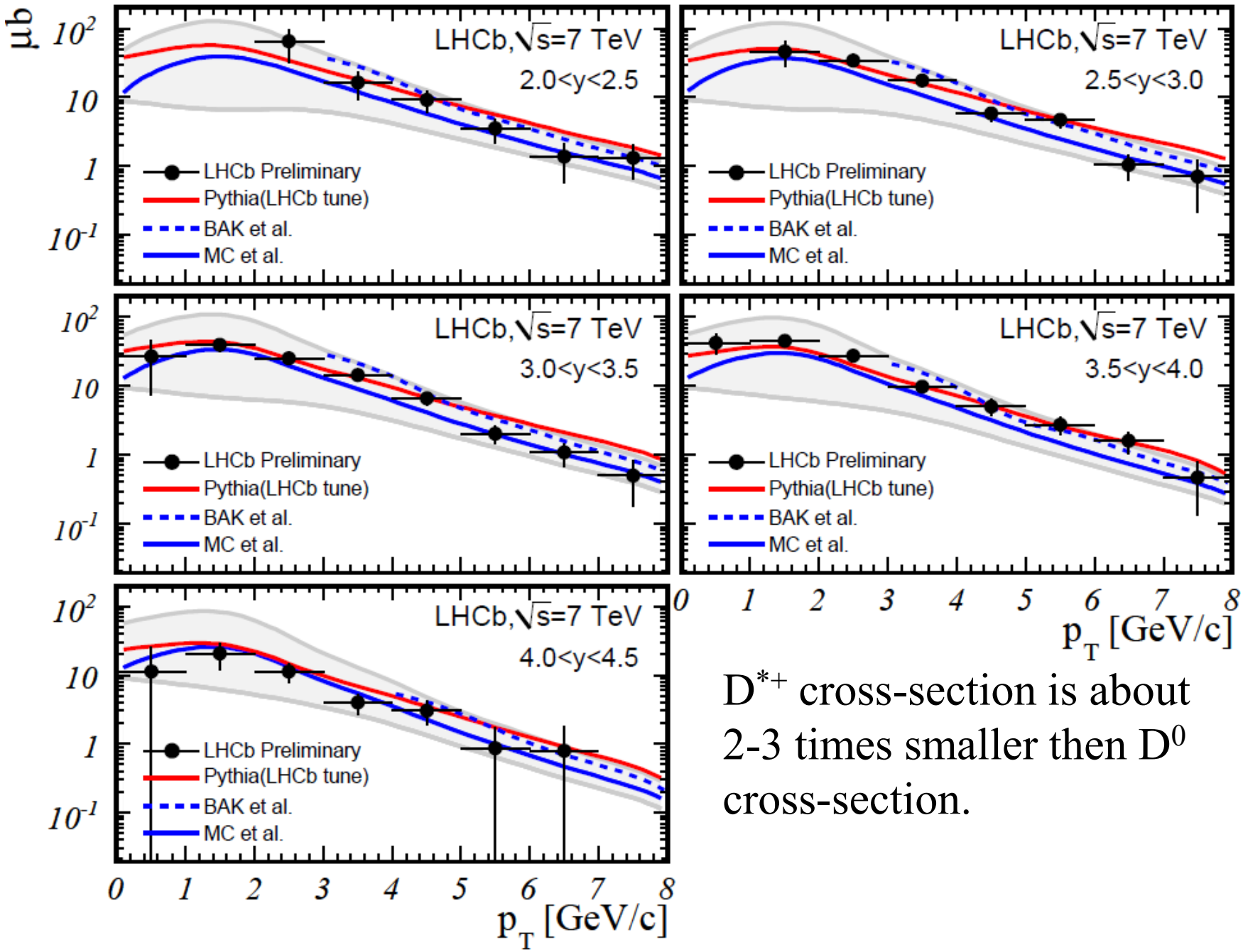
D^0+c.c. cross-section



Theory:

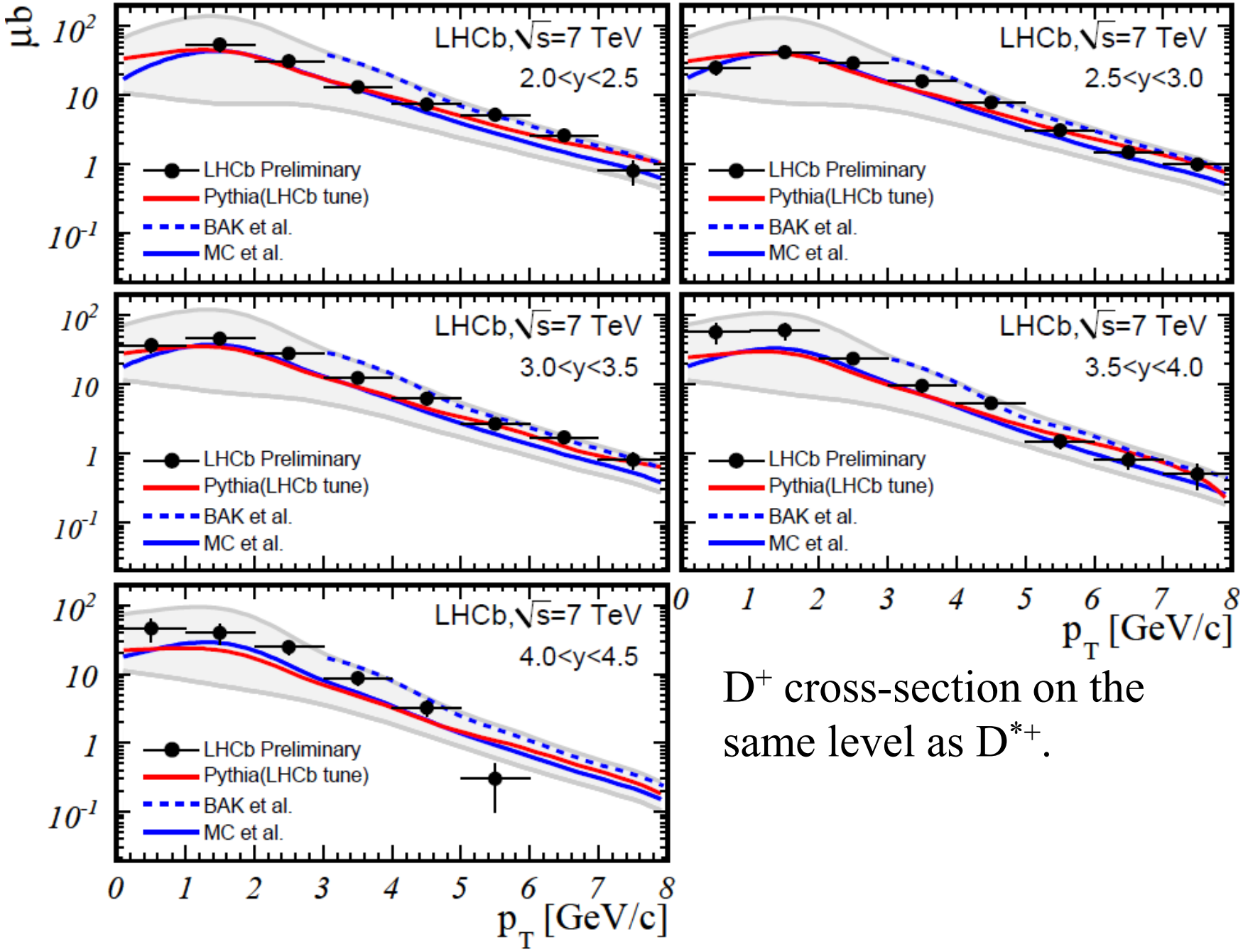
- *MC* - Cacciary M., Frixione, S., Mangano, M., Nason, P. Ridolfi, G.
- *BAK* - B.A.Kniehl, G.Kramer, I.Schienbein, H.Spiesberger

D^{*+}+c.c. cross-section



D^{*+} cross-section is about 2-3 times smaller then D^0 cross-section.

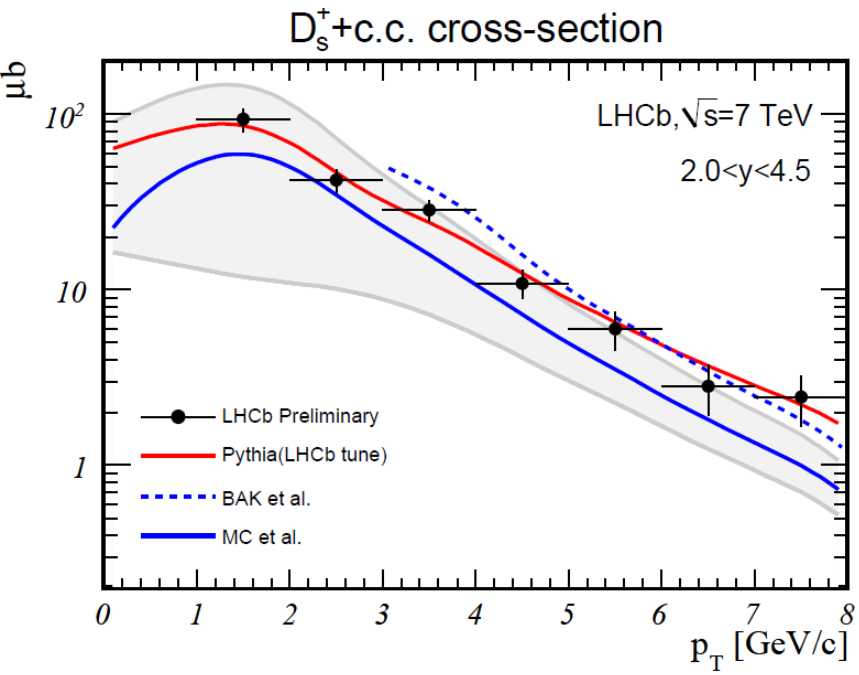
D^++c.c. cross-section

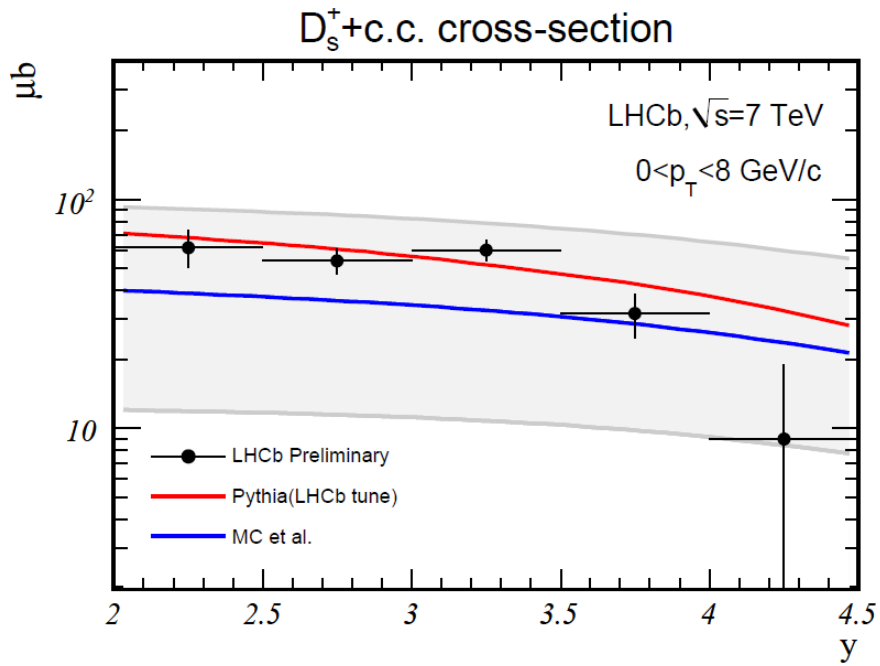


D^+ cross-section on the same level as D^{*+}.

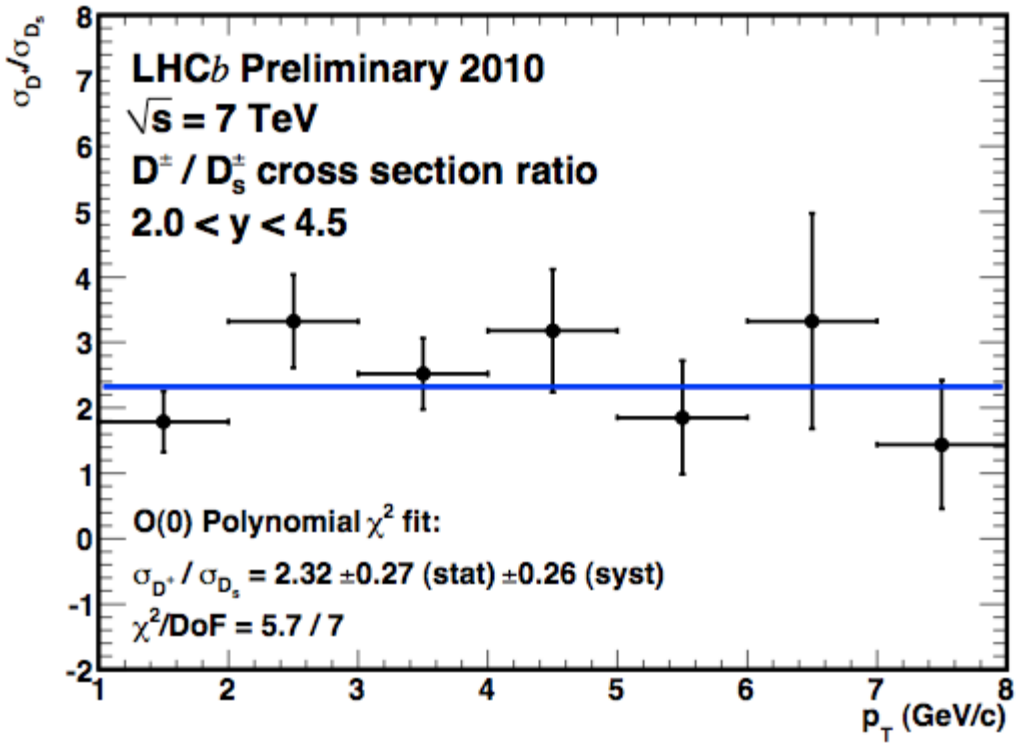
D_s^+ cross-section results

D_s^+ cross-section measured in bins of p_t and rapidity separately.





D^+/D_s^+ cross-section ration



- Ratio $\sigma(pp \rightarrow D^+X) / \sigma(pp \rightarrow D_s^+X) = 2.32 \pm 0.27 \pm 0.26$
  - many systematic uncertainties drop out.
  - consistent with PDG value: 3.1 ± 0.7.

Open charm production summary

- Clean signals of D^0, D^+, D^{*+}, D_s^+ mesons.

- Cross section measured in bins of p_t and rapidity:
  - 8 bins in p_t from 0 to 8 GeV.
  - 5 bins in rapidity from 2 to 4.5.

- In all modes agreement with theoretical predictions.

- Measured ratio $\sigma(pp \rightarrow D^+X) / \sigma(pp \rightarrow D_s^+X)$.
  - In agreement with PDG.

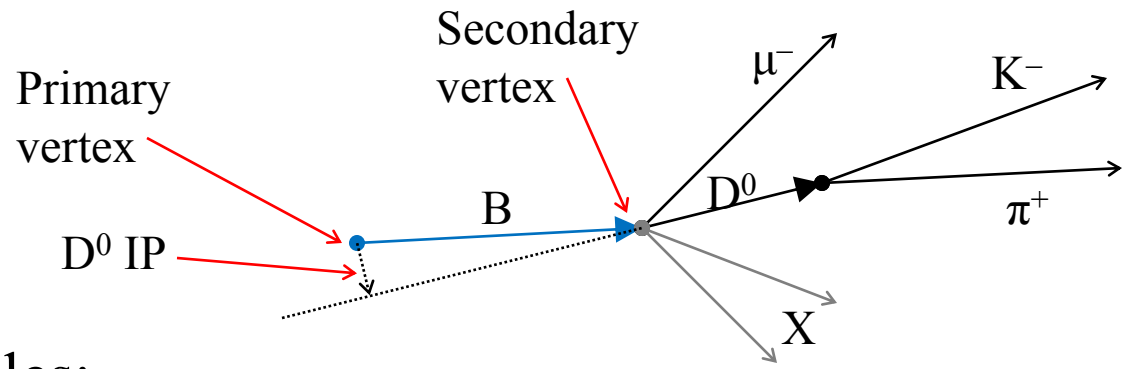
- Total production cross-section (average from all modes):
  - $\sigma(pp \rightarrow ccX)_{4\pi} = (6100 \pm 934)\ \mu b$

Prospects with charm physics

- Cross-section and ratios measurement at 10 TeV and 14 TeV.
  - Depending on LHC schedule.
- CPV from lifetime difference of $D^0 \rightarrow KK, K\pi$.
- Mixing and CP-violation: $D^0 \rightarrow K_s hh$.
- Direct CP-violation: $D^+ \rightarrow K^- K^+ \pi^+$.
- Search for rare decay $D^0 \rightarrow \mu\mu$.

$\sigma(pp \rightarrow bbX)$ from $B \rightarrow D^0\mu\nu X$

- $B \rightarrow D^0\mu\nu X$
  - Assuming $Br(b \rightarrow D^0\mu\nu X) = (6.82 \pm 0.35)$ %
  - Tag by high p_t muon.
  - Reconstruct $D^0\mu$ pair using tracks not pointing to primary vertex and forming common vertex.
- D^0 is produced not only in B-decay (prompt contribution).
- Cross section determined in 4 bins of pseudo-rapidity ($2 < \eta < 6$).

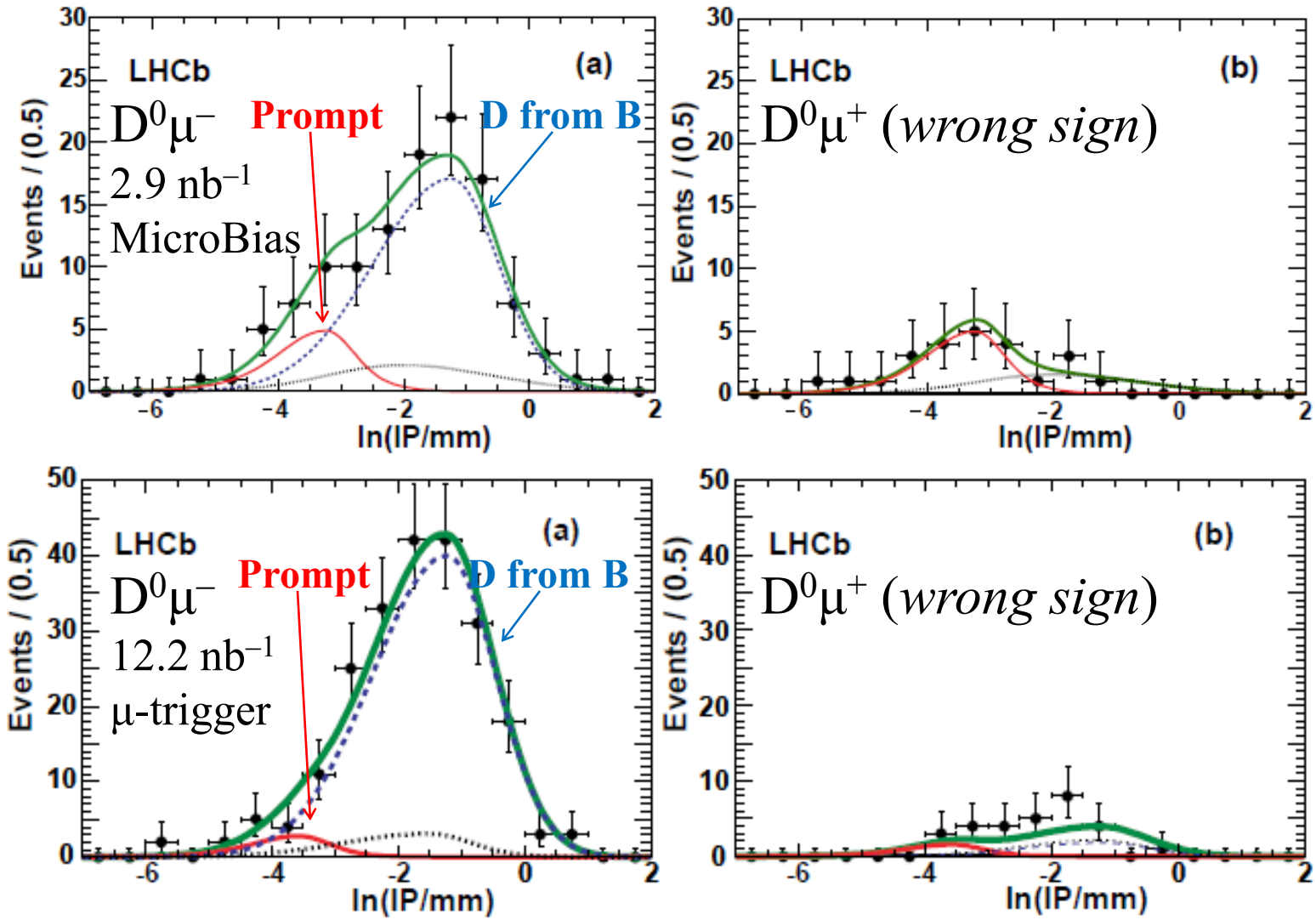


Data samples:

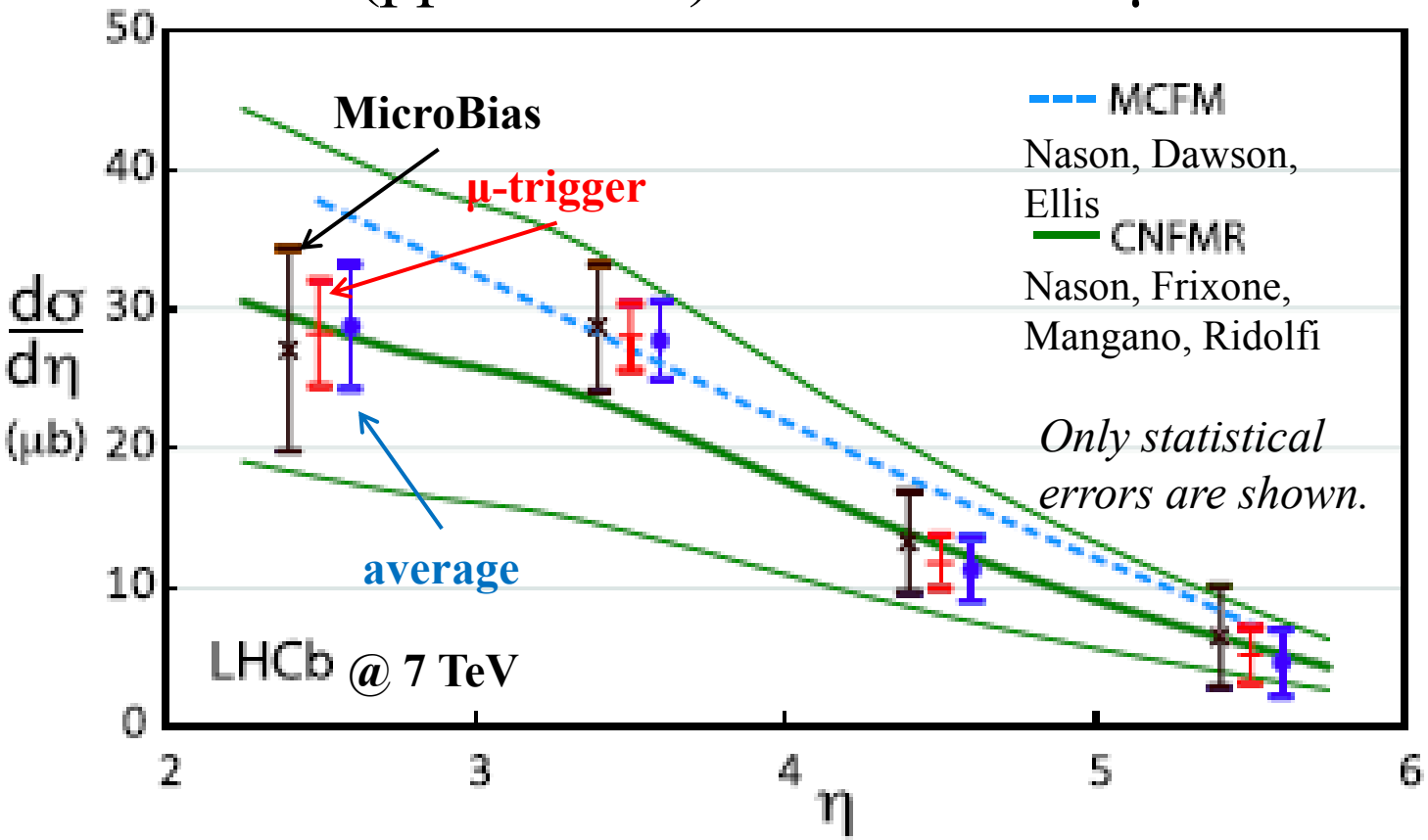
- 2.9 nb^{-1} – MicroBias trigger
- 12.2 nb^{-1} – single muon trigger (μ-trigger)

Prompt/secondary

- Prompt D^0 is the dominant background.
- Fit to log(IP/mm) distribution to determine the yield.

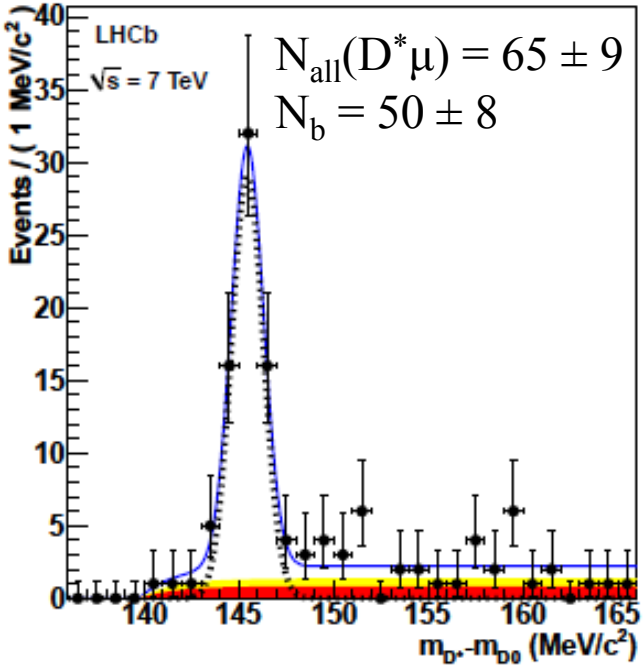


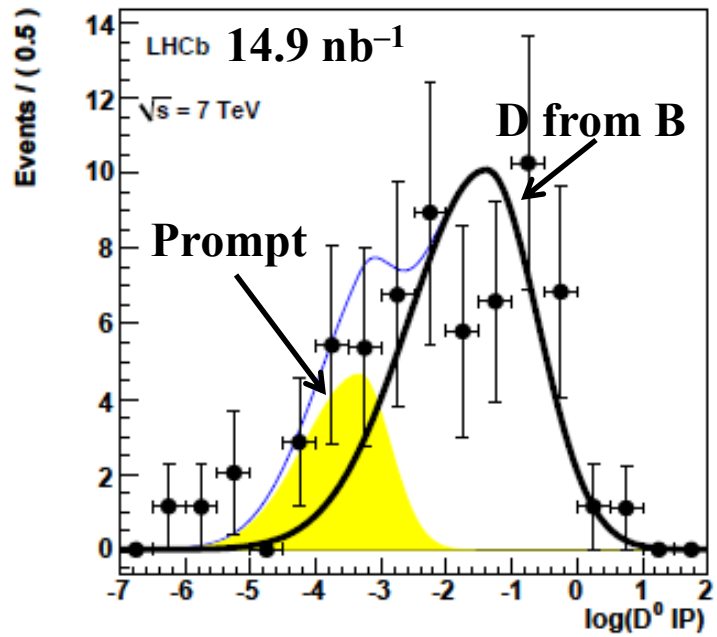
$\sigma(pp \rightarrow bbX)$ from $B \rightarrow D^0\mu\nu X$



- '*Unique*' pseudo-rapidity range ($2 < \eta < 6$).
  - $\sigma(pp \rightarrow bbX) = (75.3 \pm 5.4 \pm 13.0)$ μb with LEP fragmentation fraction.
- Usuing Pythia MC to extrapolate to 4π: $\sigma = (284 \pm 20 \pm 49)$ μb.
- In agreement with theoretical predictions.

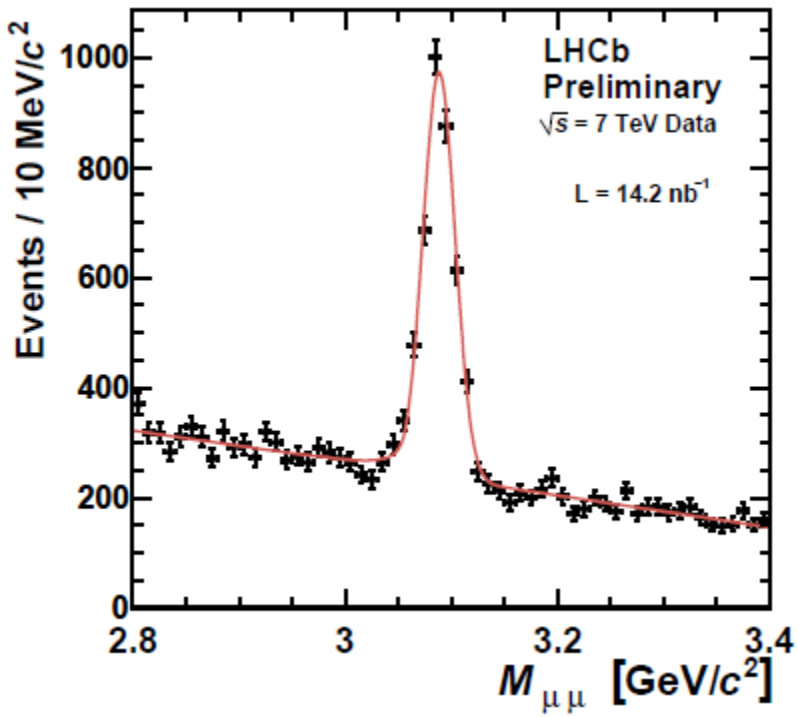
$\sigma(pp \to bbX)$ from $B \to D^*\mu\nu X$





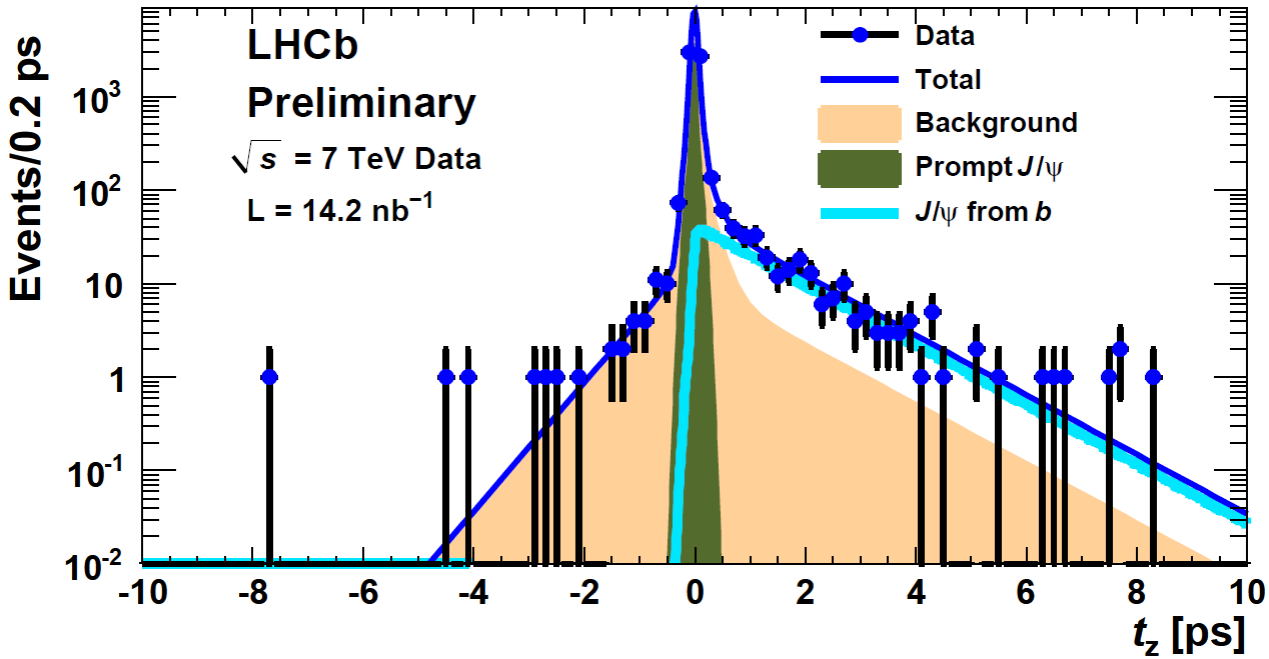
- For cross-check $\sigma(pp \to bbX)$ was measured using channel $B \to D^*\mu\nu X$.
- $2 < \eta < 6$:
  - $\sigma(pp \to bbX) = (73 \pm 12 \pm 17)$ μb using LEP fragmentation fraction.
- Extrapolating to 4π: $\sigma(pp \to bbX) = (275 \pm 44 \pm 66)$ μb.

$\sigma(pp \rightarrow bbX)$ from $B \rightarrow J/\psi X$



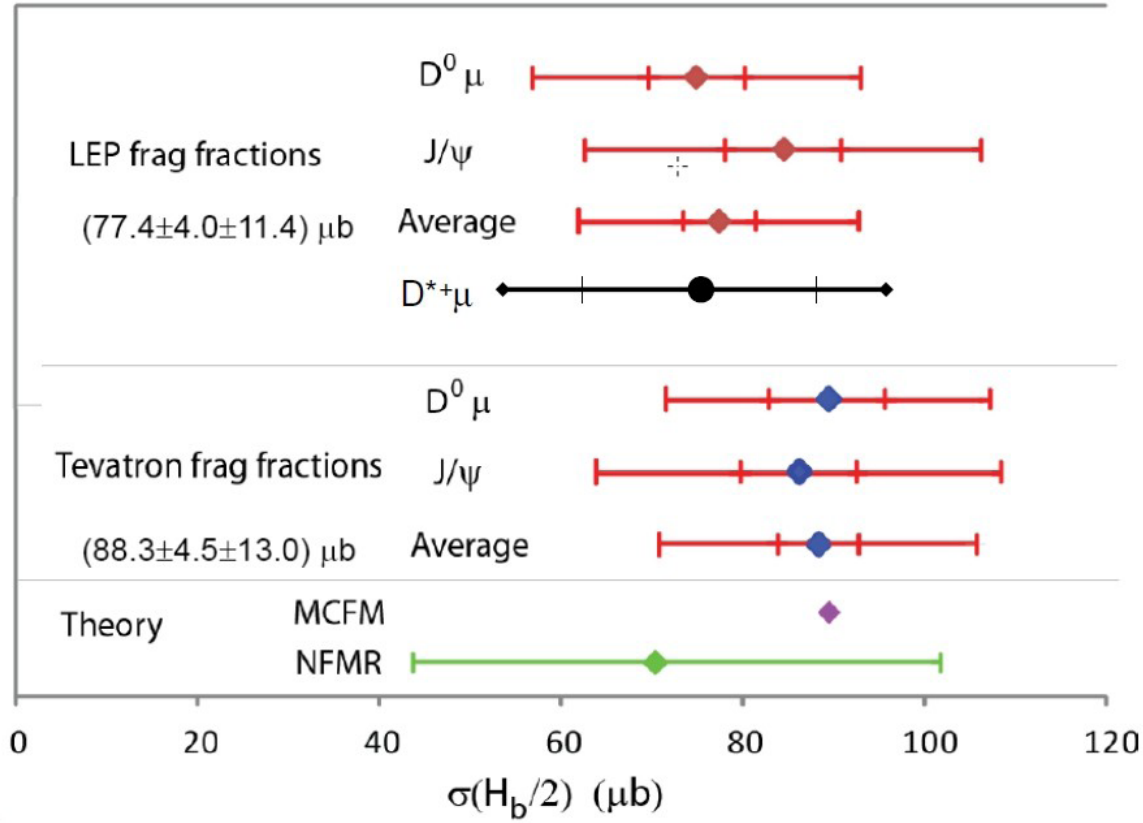
- J/ψ from b:
  - $Br(b \rightarrow J/\psi X) = (1.16 \pm 0.10)\%$
  - J/ψ: $p_t < 10$ GeV, $2.5 < y < 4$
- Fractions of prompt and detached J/ψ are determined via fit to mass and pseudo proper time: $t_z = (z_{J/\psi} - z_{PV}) \cdot m_{J/\psi} / p_{z,J/\psi}$.

$\sigma(pp \rightarrow bbX)$ from $b \rightarrow J/\psi X$



- $p_t(J/\psi) < 10$ GeV, $2.5 < y(J/\psi) < 4$
  - $\sigma(J/\psi \text{ from B}) = (0.81 \pm 0.06 \pm 0.13)$ μb.
- Assuming $Br(b \rightarrow J/\psi X) = (1.16 \pm 0.10)\%$ and using Pythia MC to extrapolate to $2 < \eta_b < 6$:
  - $\sigma(pp \rightarrow bbX, 2 < \eta_b < 6) = (84.5 \pm 6.3 \pm 15.6)$ μb.
- Extrapolating to 4π using Pythia MC:
  - $\sigma(pp \rightarrow bbX) = (319 \pm 24 \pm 59)$ μb.
  - excellent agreement with $\sigma(pp \rightarrow bbX)$ from $B \rightarrow D^0\mu\nu X$

Beauty production cross-section

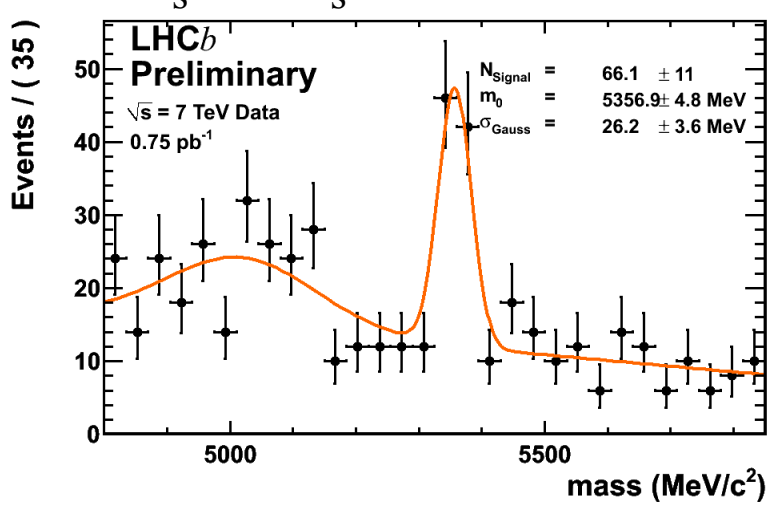


- Averaging $\sigma(pp \rightarrow bbX)$ from $B \rightarrow D^0\mu\nu X$ and $b \rightarrow J/\psi X$:
  - $\sigma(pp \rightarrow bbX, 4\pi) = (292 \pm 15 \pm 43)\ \mu b$
  - Theory: $\sigma_{NFMR} = 254\ \mu b$, $\sigma_{MCFM} = 332\ \mu b$
- All measurements are compatible and in good agreement with theory.

Fragmentation fractions

- Fragmentation fraction f_d measured at LEP and Tevatron.
  - Different environment:
    - *LHC – proton-proton machine*
    - *LEP – e^+e^-*
    - *Tevatron – proton-antiproton.*
- Hopefully will measure f_d and f_s at LHCb.
  - Semileptonic: using $B_s \to D_s\mu\nu$ and $B \to D\mu\nu$.
  - Measurement of f_d/f_s using $B_s \to D_s^-\pi^+$ and $B^0 \to D^-K^+$.

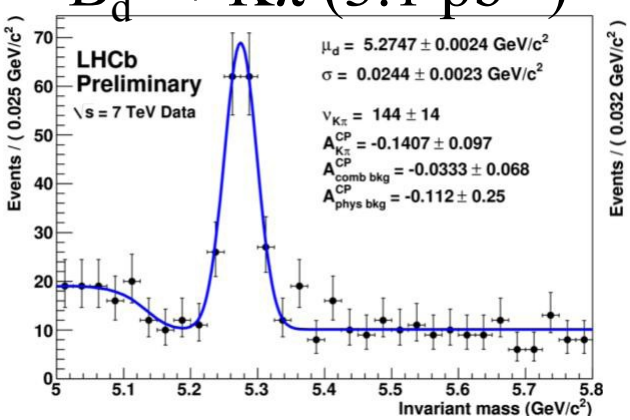
$B_s \to D_s^-\pi^+$



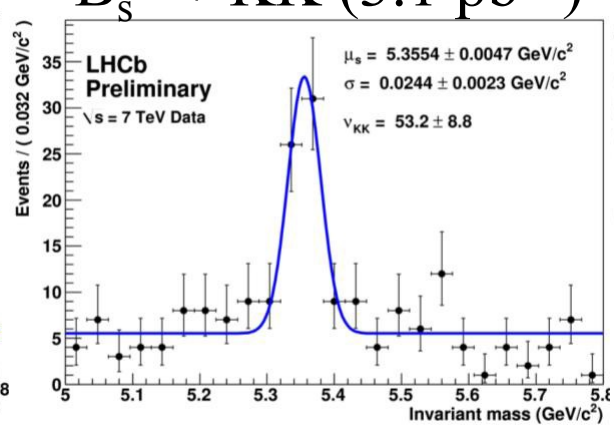
$B_d, B_s \rightarrow KK, K\pi, \pi\pi$

- Rare charm-less B decays.
- Very important to have good PID and mass resolution.
- In 2011 the sample of B mesons will be the largest in the world.

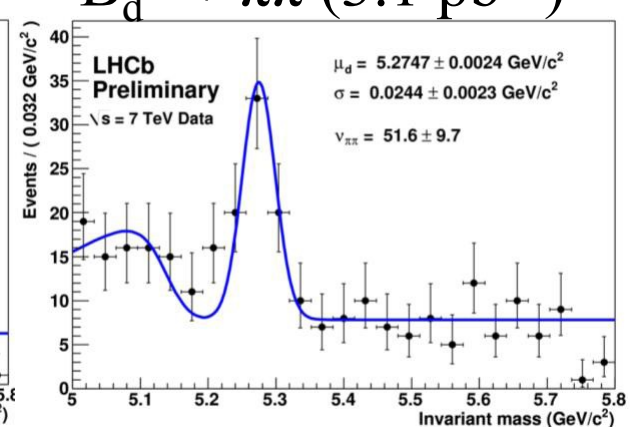
$B_d \rightarrow K\pi$ (3.1 pb^{-1})



$B_s \rightarrow KK$ (3.1 pb^{-1})



$B_d \rightarrow \pi\pi$ (3.1 pb^{-1})



Summary

- Good performance of the LHCb detector:
  - Good momentum and spatial resolution.
  - Particle identification.
  - Calibration and alignment in good shape.

- Several results on charm and beauty production cross section on initial data samples shown.

- Many mass peaks and beautiful results.

- Already collected 30 pb^{-1}.
  - Expect 40 pb^{-1} by the end of 2010.

- Already very nice result and expect new competitive results in beauty and charm physics next year.

Backup

Open charm selections

D^0:

- D^0 daughters: K, π
  - track χ^2/DoF < 9
  - p_t > 700 MeV
  - IP χ^2 > 9
  - pion $\Delta_{LL}(K - \pi) < 0$
  - kaon $\Delta_{LL}(K - \pi) > 0$
- p > 5 GeV
- vertex χ^2 < 9
- IP χ^2 < 9
- flight distance χ^2 > 16
- pointing angle < 12 mrad

D^{*+}:

- D^0 daughters: K, π
  - track χ^2/DoF < 10
  - IP χ^2 > 9
  - pion $\Delta_{LL}(K - \pi) < 0$
  - kaon $\Delta_{LL}(K - \pi) > 0$
- slow pion track χ^2/DoF < 10
- $\cos(\theta_\pi)$ in D^0 rest frame < 0.9
- D^0 vertex χ^2 < 9
- D^0 IP χ^2 < 9
- D^0 proper time > 90μm
- D^{*+} vertex χ^2 < 9

Open charm selections

D^+:

- D^+ daughters: K, π
  - track χ^2/DoF < 10
  - p > 3.2 GeV
  - p_t > 200 MeV (2: > 400 MeV)
  - IP χ^2 > 3 (2: > 10, 1: > 50)
  - pion $\Delta_{LL}(K - \pi) < 10$
  - kaon $\Delta_{LL}(K - \pi) > 3.3$
- vertex $\chi^2 < 8$
- flight distance $\chi^2 > 90$
- pointing angle < 14 mrad
- proper time < 10 ps

D_s^+:

- D_s^+ daughters: K, π
  - track χ^2/DoF < 4
  - pion IP $\chi^2 > 10$
  - kaon IP $\chi^2 > 2$
  - pion $\Delta_{LL}(K - \pi) < -2$
  - kaon $\Delta_{LL}(K - \pi) > 9$
- $\Delta M_\varphi < 20$ MeV
- vertex χ^2/DoF < 5
- flight distance $\chi^2 > 67$
- pointing angle < 14 mrad