Heavy Flavour Production@LHCb

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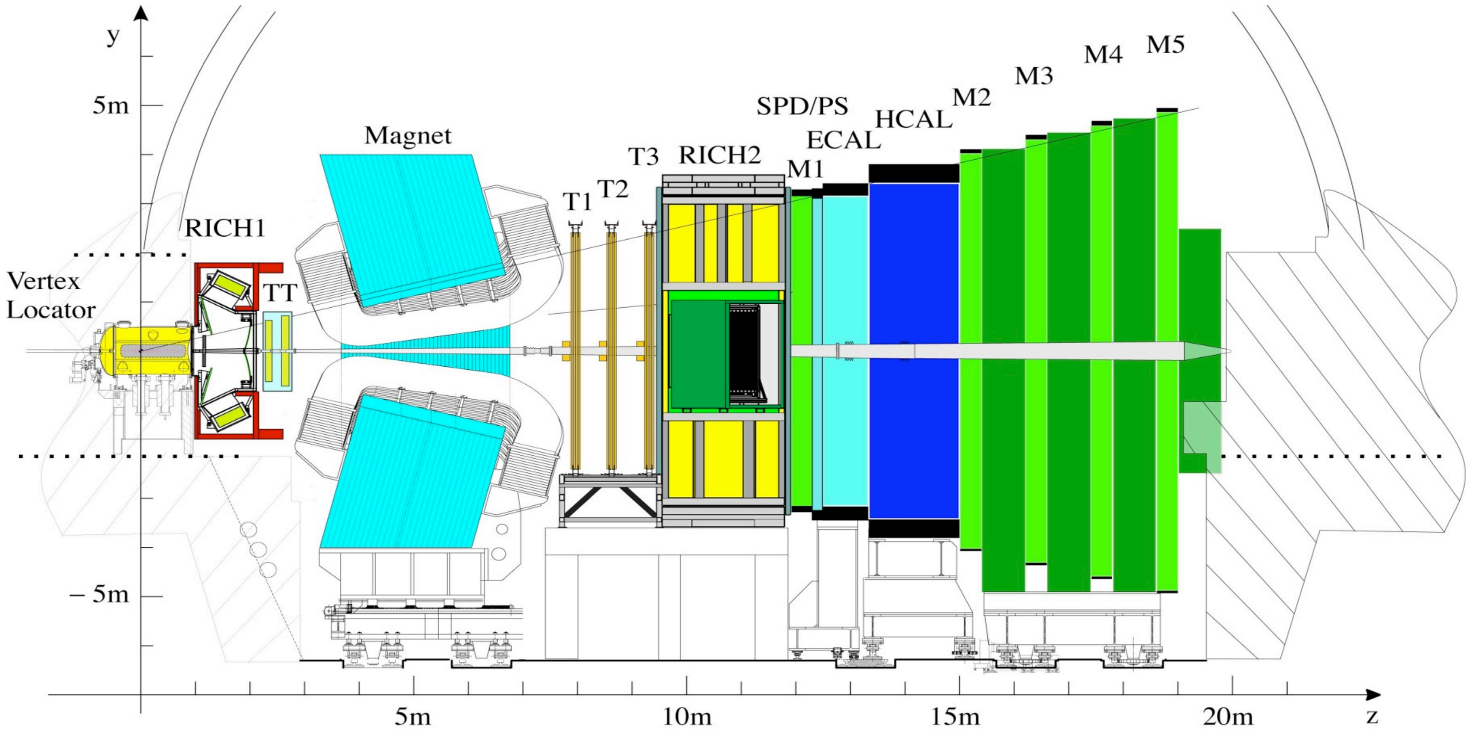
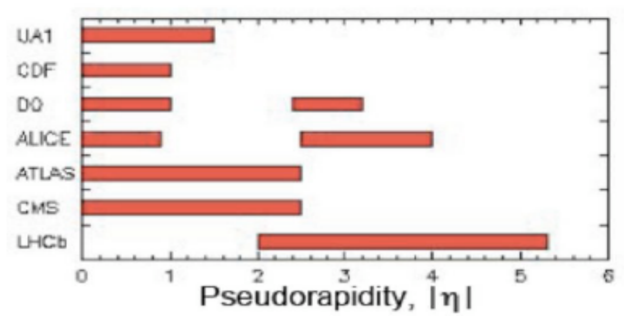
On behalf of the LHCb collaboration

Workshop on “SM Benchmarks at the Tevatron and LHC”
Fermilab November 19-20th 2010

The LHCb experiment

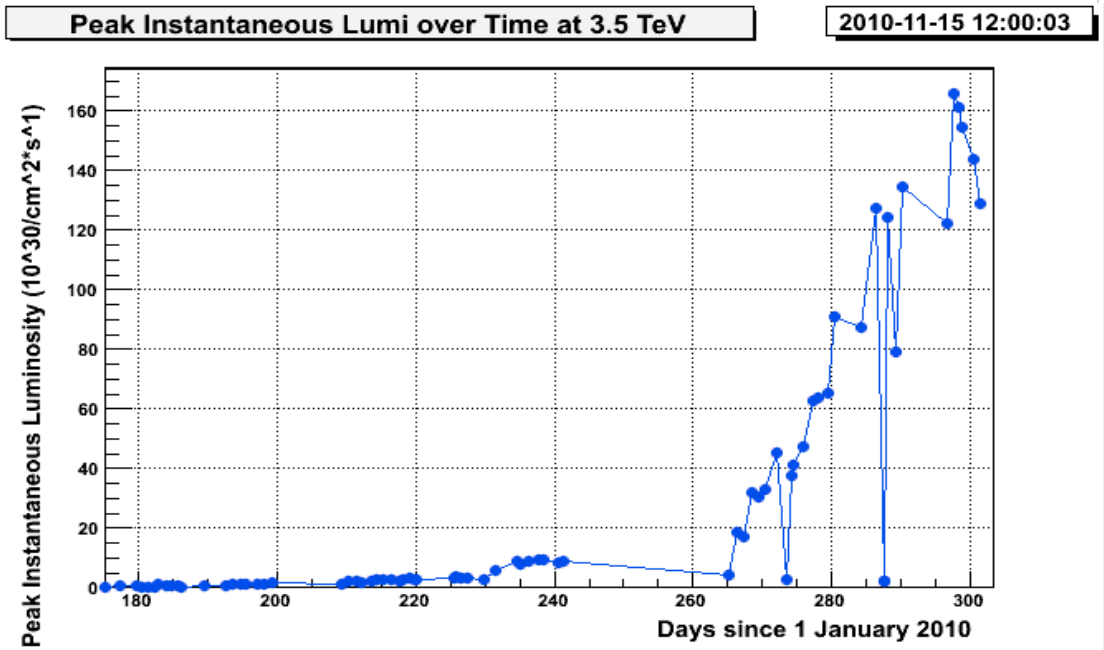


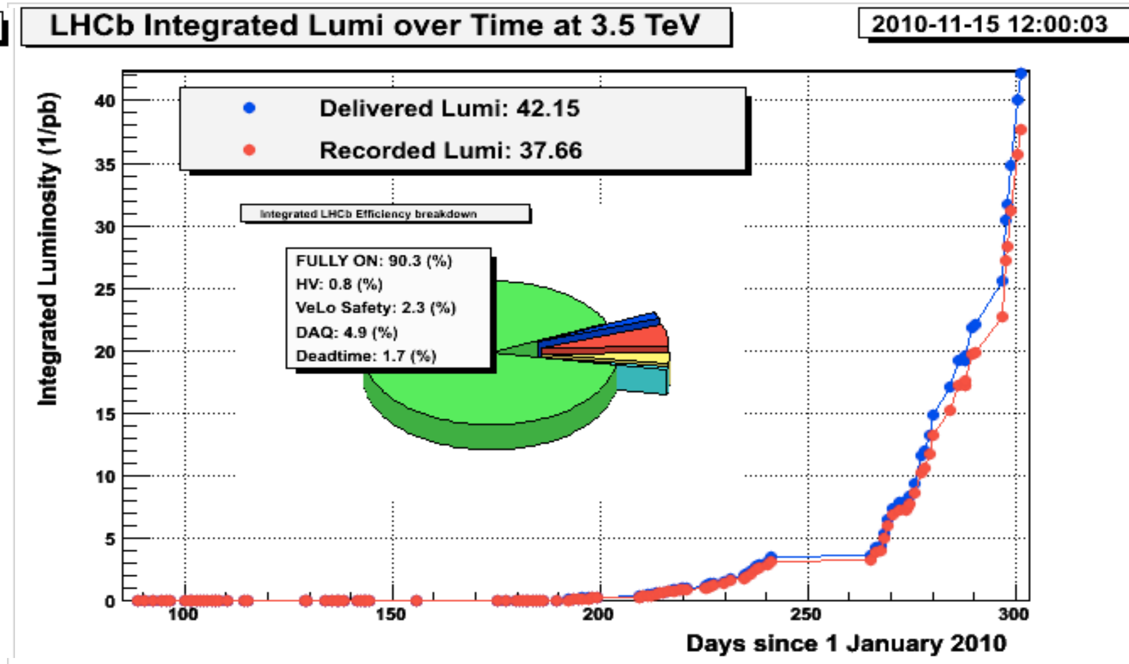


$2<|\eta|<5$
partially overlaps with
ATLAS/CMS/ALICE

- LHCb experiment optimized to study b-physics
- Excellent also for charm physics at startup
- Detector:
  - **Vertex & Tracking:** secondary vertex momentum & mass resolution
  - **Particle Identification** (π/K/p RICH, e/γ ECAL, μ, MUON)
  - **Trigger: L0** (hardware: high p_T e/γ/hadron/μ candidates) + **HLT1** (software: L0 confirmation + cuts on impact patameters) + **HTL2** (software: Global event reconstruction & selection)

LHCb run in 2010





- 2010 LHC run √s=7 TeV
  - Almost reached already the nominal instantaneous luminosity for LHCb: $2x10^{32}$ $cm^{-2}s^{-1}$, even if not at the same pile-up multiplicity
  - Different running conditions:
    - Trigger thresholds adjusted to the instantaneous luminosity
    - The pile-up multiplicity also changed in time
  - 37.7 pb^{-1} stored on tape (90% efficiency)
  - Will present results on the first period with partial statistics sample.

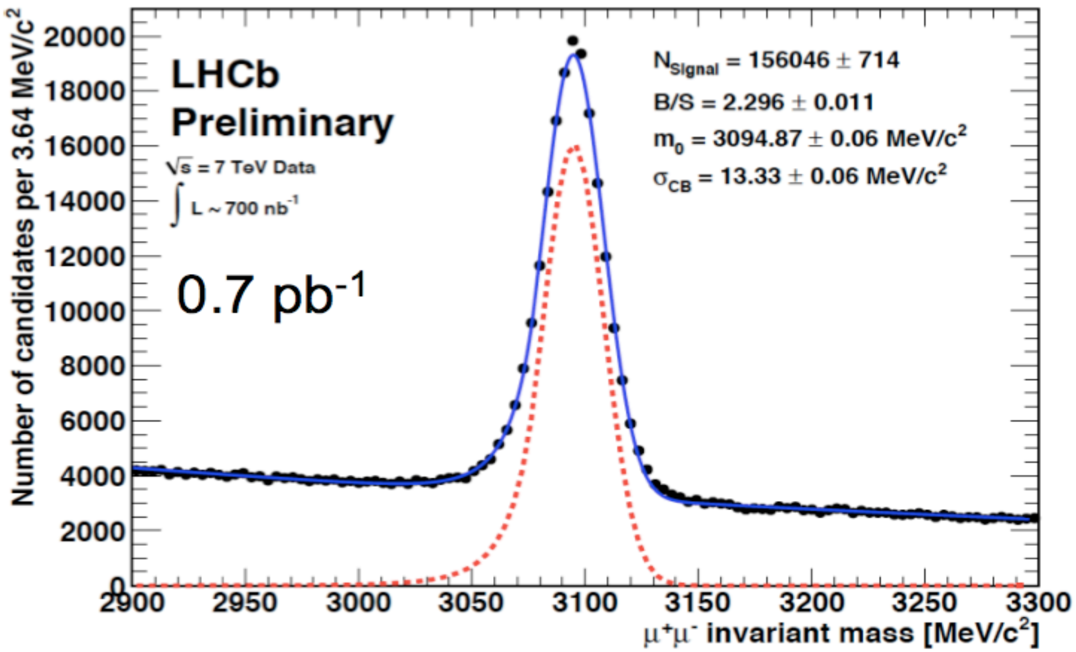
Heavy Flavour at LHCb

- LHCb Physics program: perform precise measurements on b-and c-hadron decays
  - CP violation
  - Rare decays
  - D^0 mixing

  Aim: Improve the knowledge of the SM or find evidences of NP contributions to flavour physics.
- With first data LHCb can study b and c production for
  - Test the production models by measuring the cross section/polarization
  - Heavy flavour spectroscopy by looking for/confirm new resonant states
  - Measure the fragmentation fractions
  - Tuning of montecarlo generators

Quarkonia: J/ψ(1S)

$J/\psi(1S) \rightarrow \mu^+\mu^-$ with 700 nb^{-1}



- J/ψ(1S) **cross section** & **polarization** measurements @LHC provide important reference to test the production mechanism
  - Color singlet/octet models
  - Compare with existing results
- J/ψ(1S) sources:
  - Direct pp production
  - Feed-down from heavier charmonium: $\chi_c \rightarrow J/\psi(1S)\gamma$, $\psi(2S) \rightarrow J/\psi(1S)\pi\pi$
  - From b-hadrons decays $H_b \rightarrow J/\psi(1S)X$

Quarkonia production: J/ψ(1S)

- Cross section measurement with first 14.2nb^{-1}

  $\sigma(pp \rightarrow J/\psi(1S)X)$
  $=(7.65 \pm 0.19 \pm 1.10^{+0.87}_{-1.27})\mu b$

  p_T<10 GeV/c ,2.5<y<4 √s= 7 TeV

  – efficiency depend on the polarization (systematic)

- J/ψ(1S) measurement are not well represented by either the results of the simulation of color singlet and octet models

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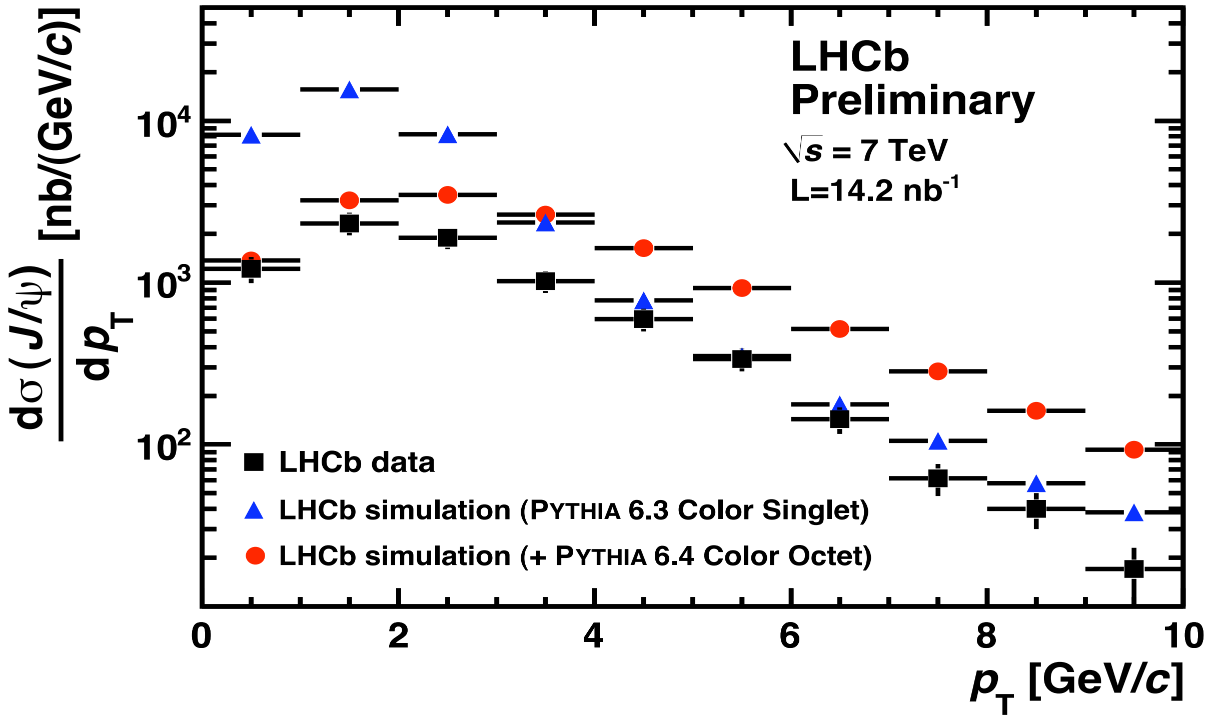
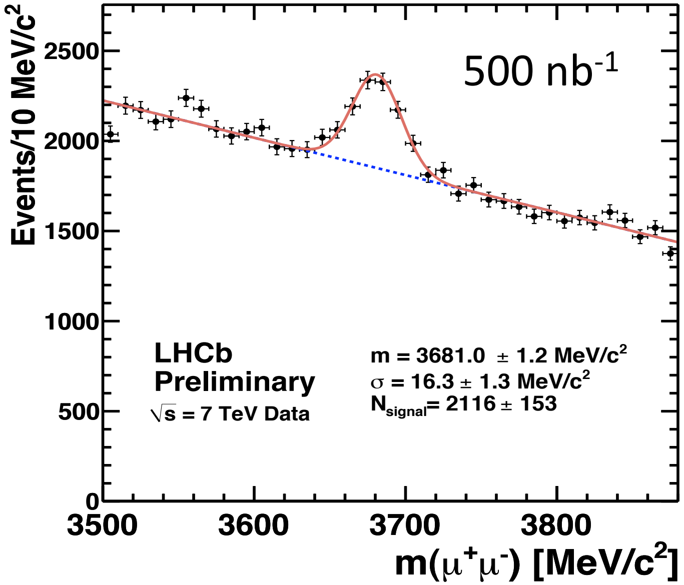


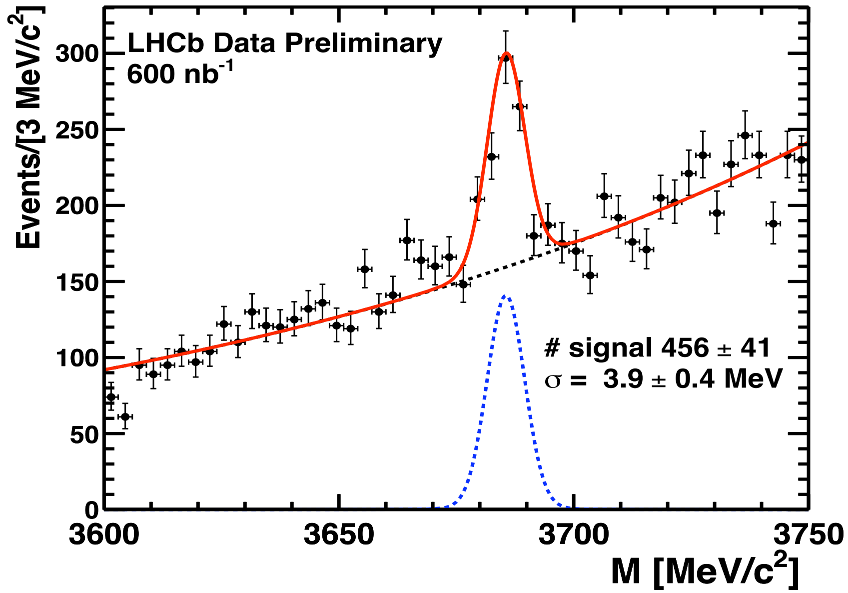
- Plans:
  – Publish soon more detailed measurement with a larger data sample 5.3pb^{-1} in finer bins of p_T&y and extended p_T range.
  – Measure the J/ψ(1S) polarization.

Quarkonia: $\psi(2S)$

$\psi\,(2S) \rightarrow \mu^+\mu^-$



$\psi\,(2S) \rightarrow J/\psi(1S)\pi^+\pi^-$



- Lower yield than $J/\psi(1S)$ (~2%)
- The production cross section is easier to interpret than $J/\psi(1S)$.
  - dominant direct pp production
  - suffers less from higher charmonium states feed-down
  - Feed-down from b-hadron decays
- Plans:
  - Measure the production relative to $J/\psi(1S)$ (systematics due to polarization ~22%)
  - Measure the production cross section as a function of p_T and y from prompt and from b
  - Measure the polarization (statistics)

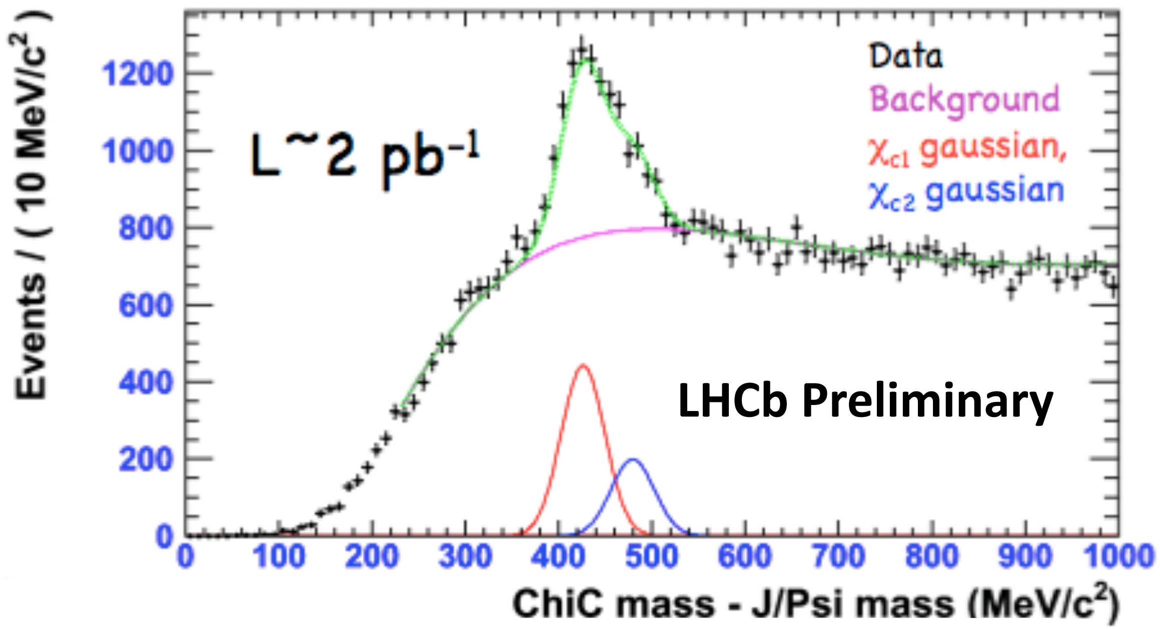
Quarkonia: χ_c states

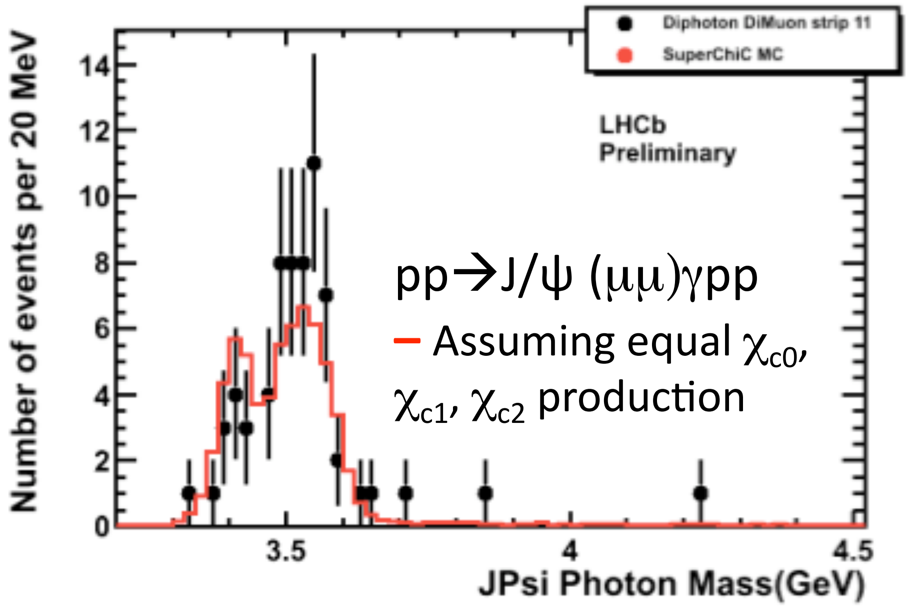
- Evidence of χ_c with sensitivity to $\chi_{c1}(1P)$ and $\chi_{c2}(2P)$ if the mass resolution is fixed.
- Plans:
  - Measure $\sigma(\chi_c \rightarrow J/\psi(1S)\gamma)/\sigma(J/\psi(1S))$ from prompt and b and $\sigma(\chi_{c1})/\sigma(\chi_{c2})$ in bins of $J/\psi(1S)$ p_T
  - important to interpret the inclusive $\sigma(J/\psi(1S))$ correctly
- Similarly we can study $\chi_{b2}(1P) \rightarrow \Upsilon(1S)\gamma$
- Under study the exclusive production of heavy quarkonia:
  - Already some candidates of:

    $J/\psi(1S)$ – photon pomeron fusion

    $\chi_c \rightarrow J/\psi(1S)\gamma$ – double pomeron exchange
- important tests for QCD.

$\chi_c \rightarrow J/\psi(1S)\gamma$

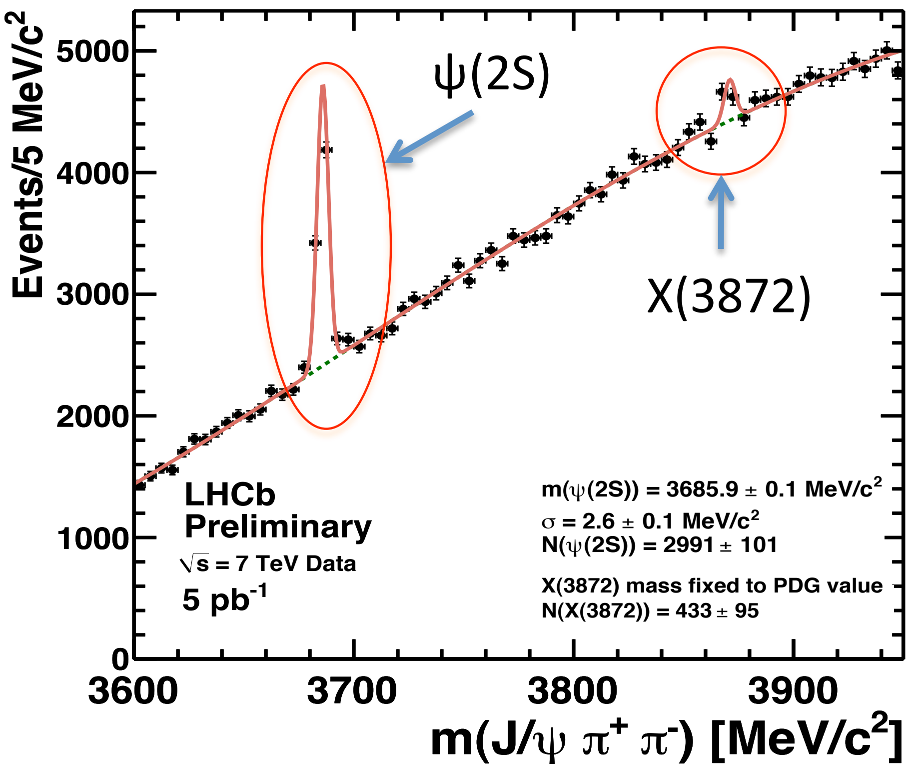




Quarkonia: heavier charmonia states

- Prompt X(3872) shows up @5pb^{-1}
- Plans:
  - Measure the mass precisely: reference ψ(2S) (O(0.2MeV/c^2))
  - Measure the cross section relative to ψ(2S)
    - →helps the interpretation of this state

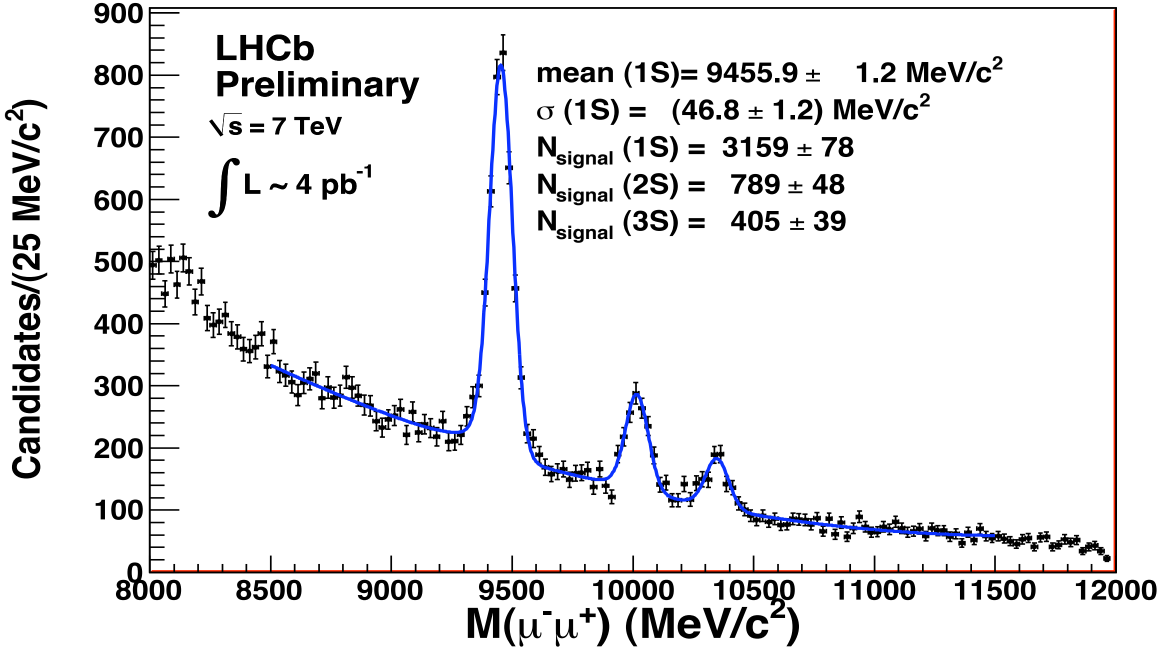
X(3872)→J/ψ(1S) $\pi^+\pi^-$ 5 pb^{-1}



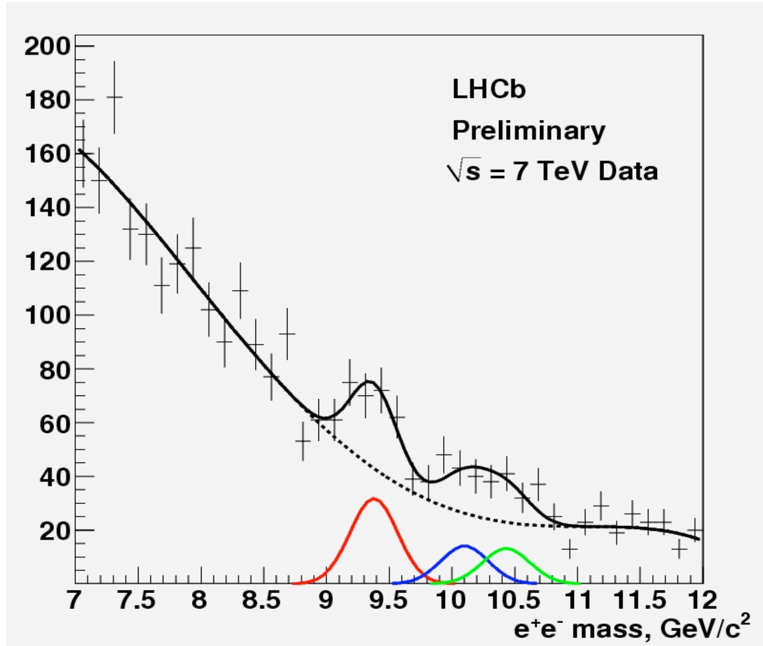
- Feasibility studies on montecarlo
  - X(3872) can be also studied in B→X(3872)K → determine J^{PC}
  - $Z(4430)^{\pm}$ can be studied $B \to Z(4430)^{\pm}K$, $Z(4430)^{\pm} \to J/\psi(1S)\,\pi^{\pm}$
  - $B_c^{\pm} \to J/\psi(1S)\,\pi^{\pm}$ study mass, lifetime and cross section

Quarkonia: Υ states

$\Upsilon \rightarrow \mu^+\mu^-$ 4 pb^{-1}

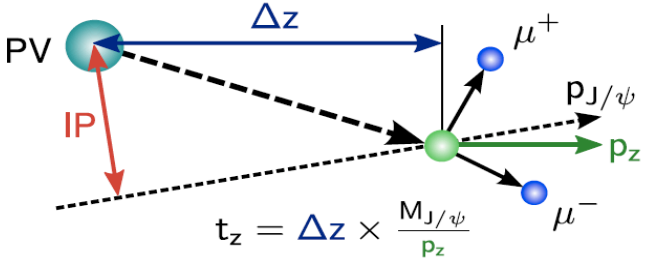


$\Upsilon \rightarrow e^+e^-$ 1 pb^{-1}



- Plans:
  - Measure the production cross-section times the BR($\Upsilon(1S) \rightarrow \mu^+\mu^-$) in p_T and/or y
  - Measure the ratio of production cross sections between different Υ states
  - Measure the polarization

$\bar{b}b$ cross section measurement (1/3): $\bar{b}b \rightarrow J/\psi(1S)X$



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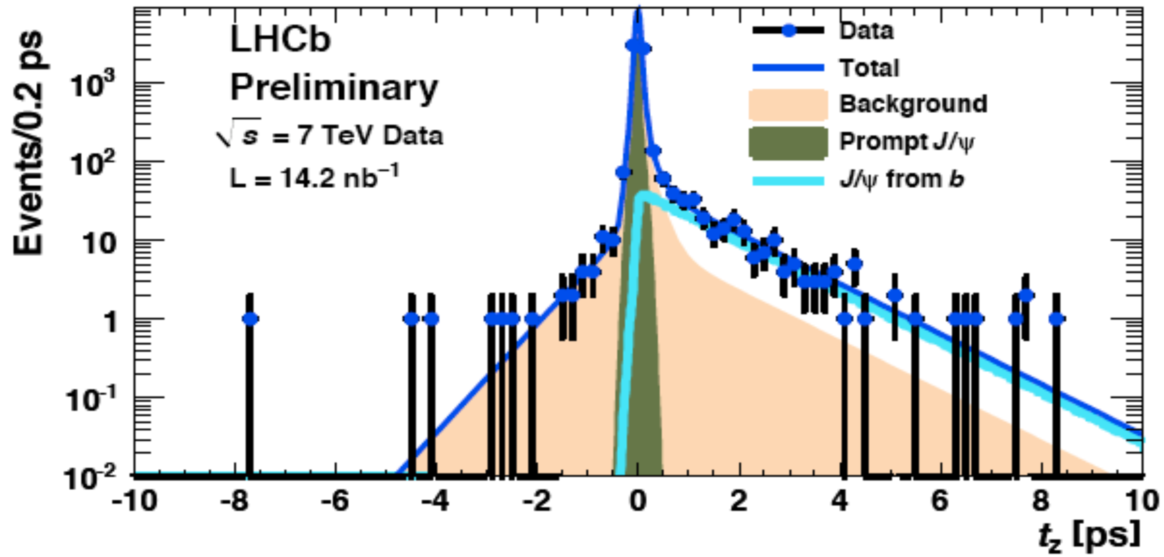
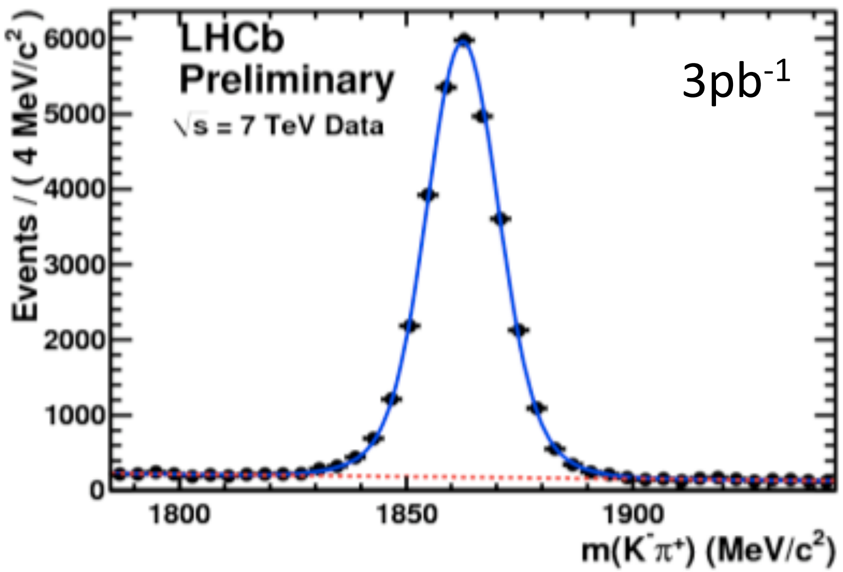
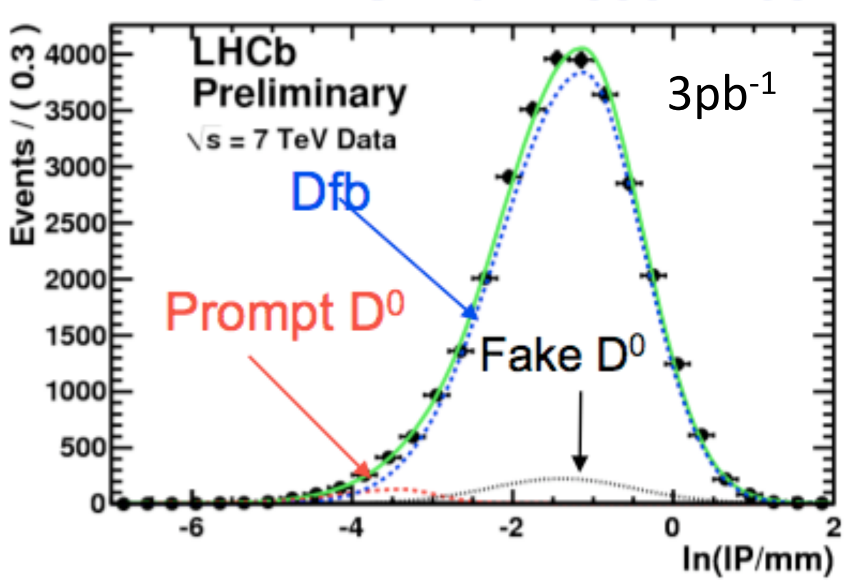


- $J/\psi(1S)$ produced can be prompt or detached, from a b-hadron decay. Analysis of the "pseudo" proper time to disentangle the two components:
  - **f_b=11.1±0.8 %** in the acceptance
  - **$\sigma(J/\psi(1S)$ from b) = (0.81±0.06±0.13)μb** p_T<10GeV/c, 2.5<y<4
  - Using MC:
    - **$\sigma(pp \rightarrow H_b X)$ = (84.5±6.3±15.6)μb** 2<$\eta(H_b)$<6
    - **$\sigma(pp \rightarrow b\bar{b} X)$ = (319±24±59)μb** in 4π
- Plans: measure the $\sigma(J/\psi(1S)$ from b) in bins of p_T and y like for the inclusive $J/\psi(1S)$

$b\bar{b}$ cross section measurement (2/3): $B \rightarrow D^0\mu^-\nu_\mu$

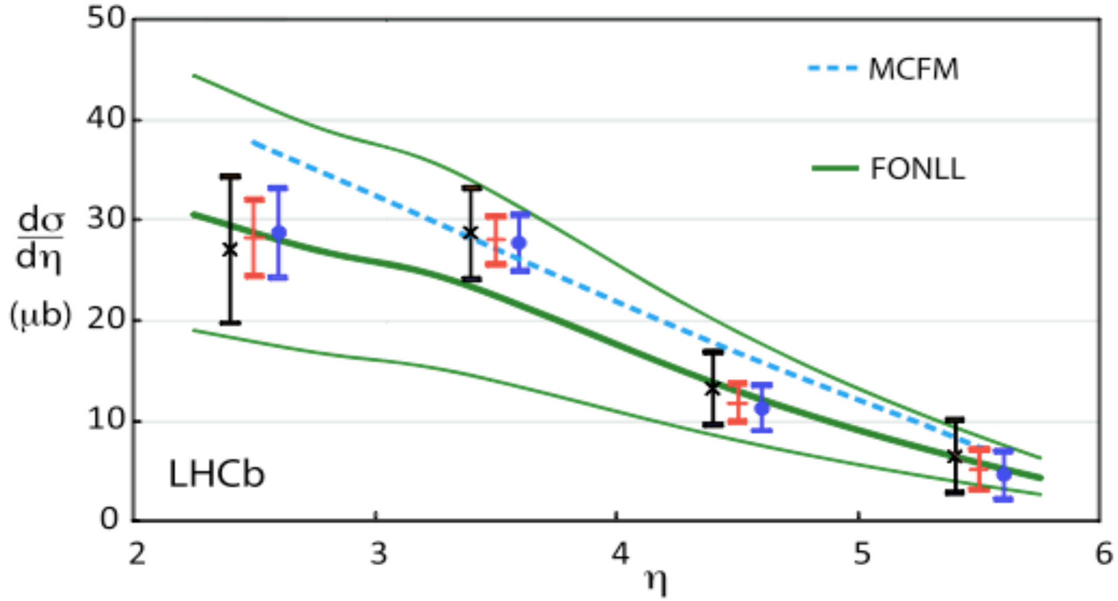




- First measurement of the cross section using the decay $B \rightarrow D^0(K^-\pi^+)\mu^-\nu_\mu$ published $15nb^{-1}$: **Phys. Letters B 694 (2010) 209**
  - Use Wrong Sign $D^0\mu^-$ combination to disentangle background
  - Fit the distribution of the **I**mpact **P**arameter (**IP**) of the D^0 respect to the primary vertex to separate D^0 prompt from the signal (from B).

$\bar{b}b$ cross section measurement (2/3): $B \rightarrow D^0 \mu^- \nu_\mu$

Data:
microbias trigger (x)
triggered (•)
average (+)
Only stat error displayed



- Comparison with:
  - **MCFM** (NLO with a PDF MSTW8NL http://mcfm.fnal.gov)
  - **FONLL** (CTE6.5 PDF; NLO + improvements with the resummation of p_T logarithms up to the next-to-leading order. Includes the b-quark fragmentation into hadrons. Cacciari, Nason, … Mangano)
- Measurement:
  - **$\sigma(pp \rightarrow H_b X) = (75.3 \pm 5.4 \pm 13.0)\mu b$** $2<\eta(H_b)<6$ → Agreement with the other measurement
  - **$\sigma(pp \rightarrow b\bar{b} X) = (284 \pm 20 \pm 49)\mu b$** in 4π using LEP fragmentation fractions (+19% if Tevatron fb)
- Plans: update with larger statistics
  - Analyze different inclusive semileptonic decays to extract b-hadronization fractions

$b\bar{b}$ cross section measurement (3/3): $B^0 \rightarrow D^{*-}\mu^+\nu_\mu$

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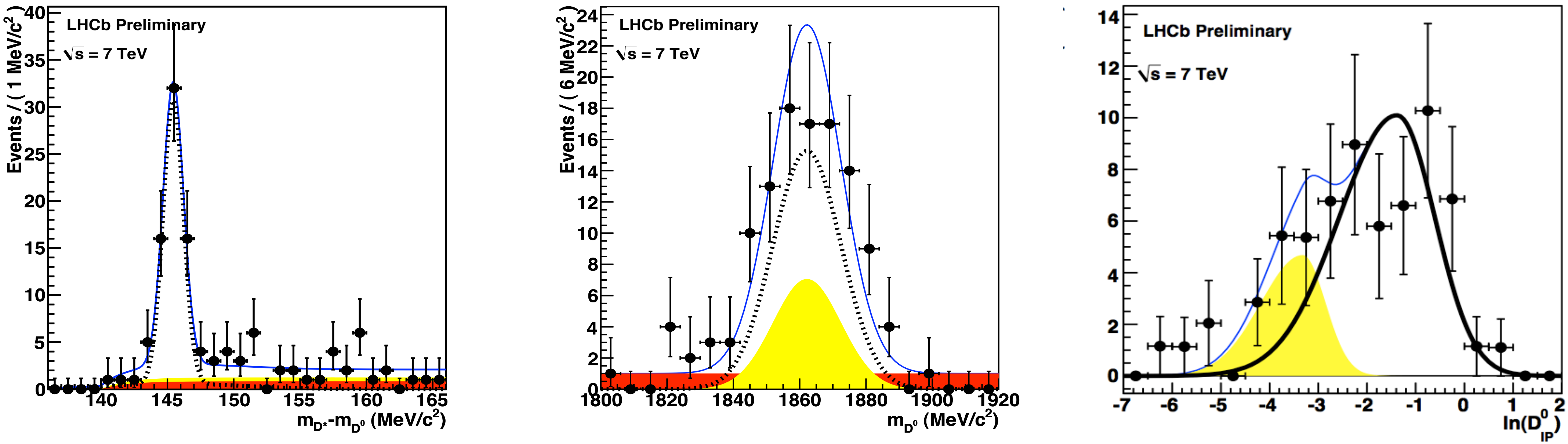
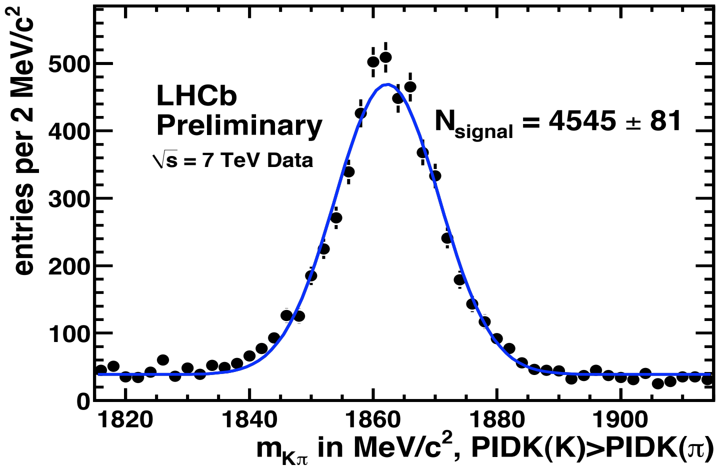
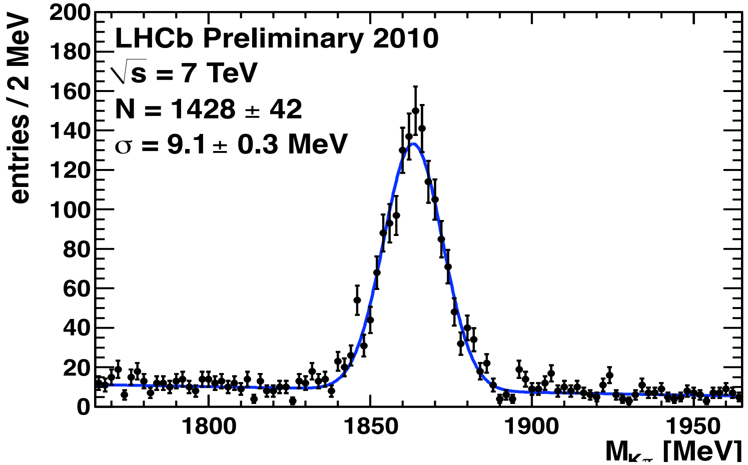


- Measurement of the cross section using $B^0 \rightarrow D^{*-}(\pi^- D^0(K^+\pi^-))\ \mu^-\nu_\mu$ 14.9nb^{-1}:
  - D^0 tagged by the D^*
  - Use Wrong Sign $D^{*-}\mu^+$ combination to disentangle background
  - Fit the distribution of the **I**mpact **P**arameter (**IP**) of the D^0 respect to the primary vertex to separate D^0 prompt from the signal (from B).
- **$\sigma(pp \rightarrow H_b\ X) = (59 \pm 9 \pm 14)\mu b$** $2<\eta(H_b)<6$ → Agreement with the other measurements
- **$\sigma(pp \rightarrow b\bar{b}\ X) = (275 \pm 44 \pm 66)\mu b$** in 4π using LEP fragmentation fractions (+19% if Tevatron fb)

Open charm production

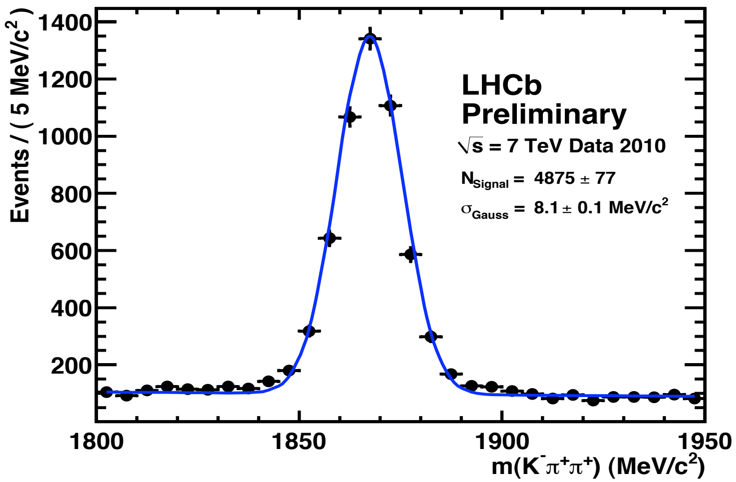
$D^0 \rightarrow K^- \pi^+$

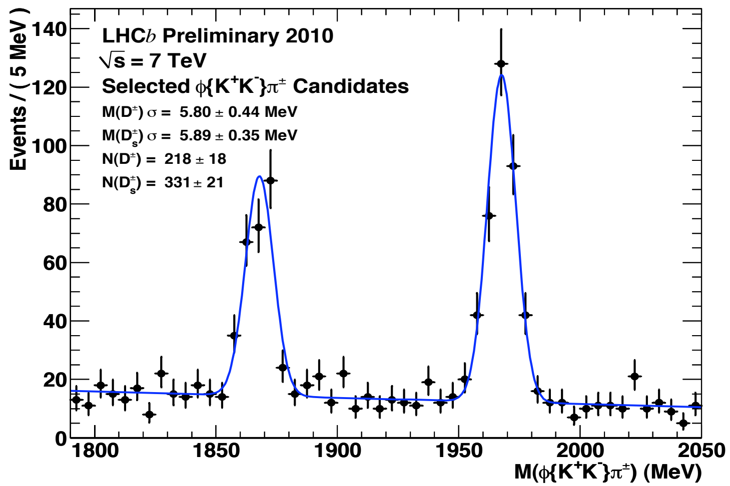




$D^{*+} \rightarrow D^0 \pi^+$

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

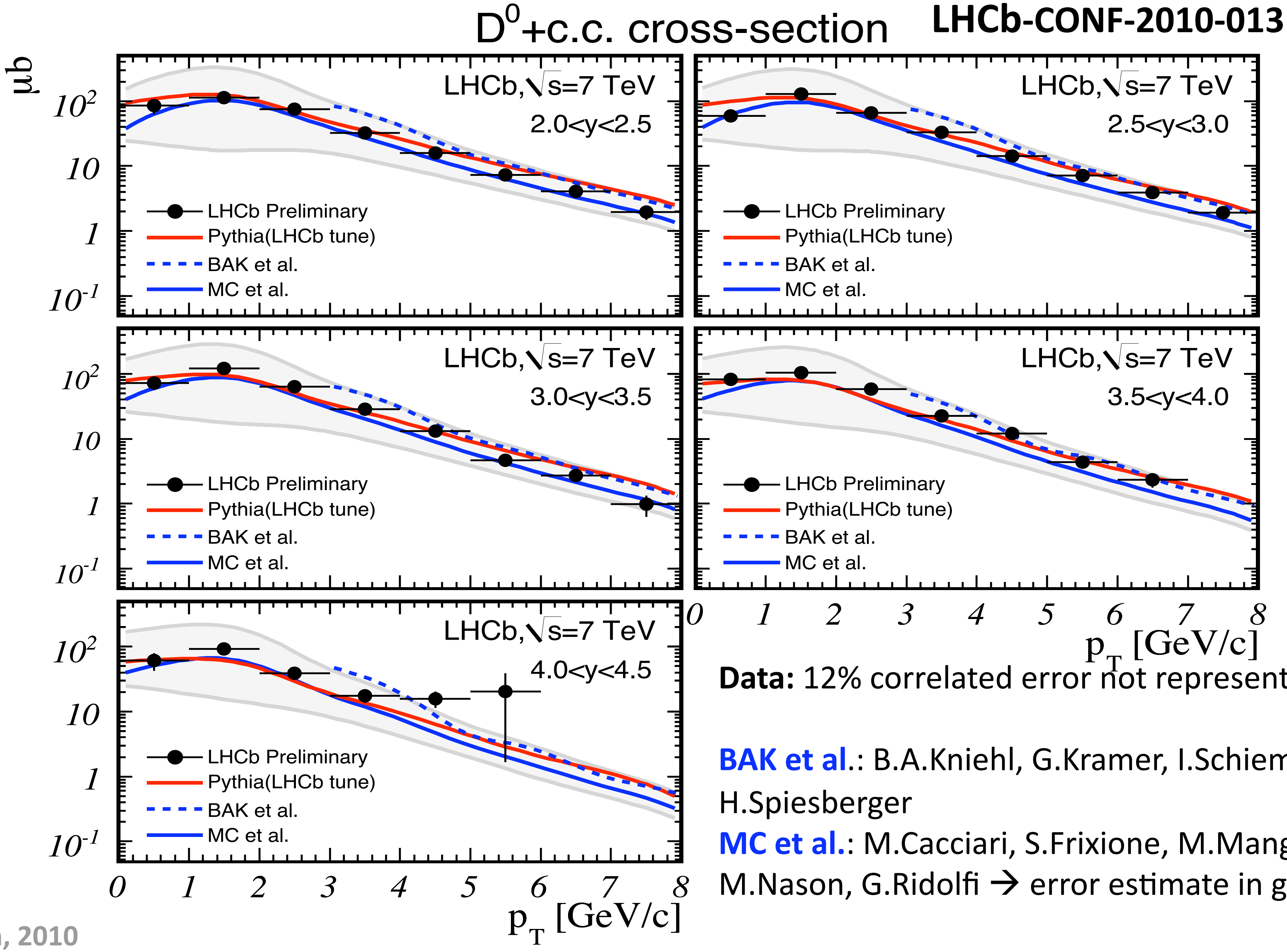




$D^+_{u/s} \rightarrow \phi(K^+K^-)\pi^+$

- Measurement of the open charm production cross sections and ratios using four independent channels in bins of p_T<8GeV/c and 2<y<4.5.
  - Sample 1.9nb^{-1},micro-bias 100% efficient trigger
- Fit the D IP distribution to disentangle prompt contribution (signal) from D from b-hadron decays

Open charm production: D^0+cc

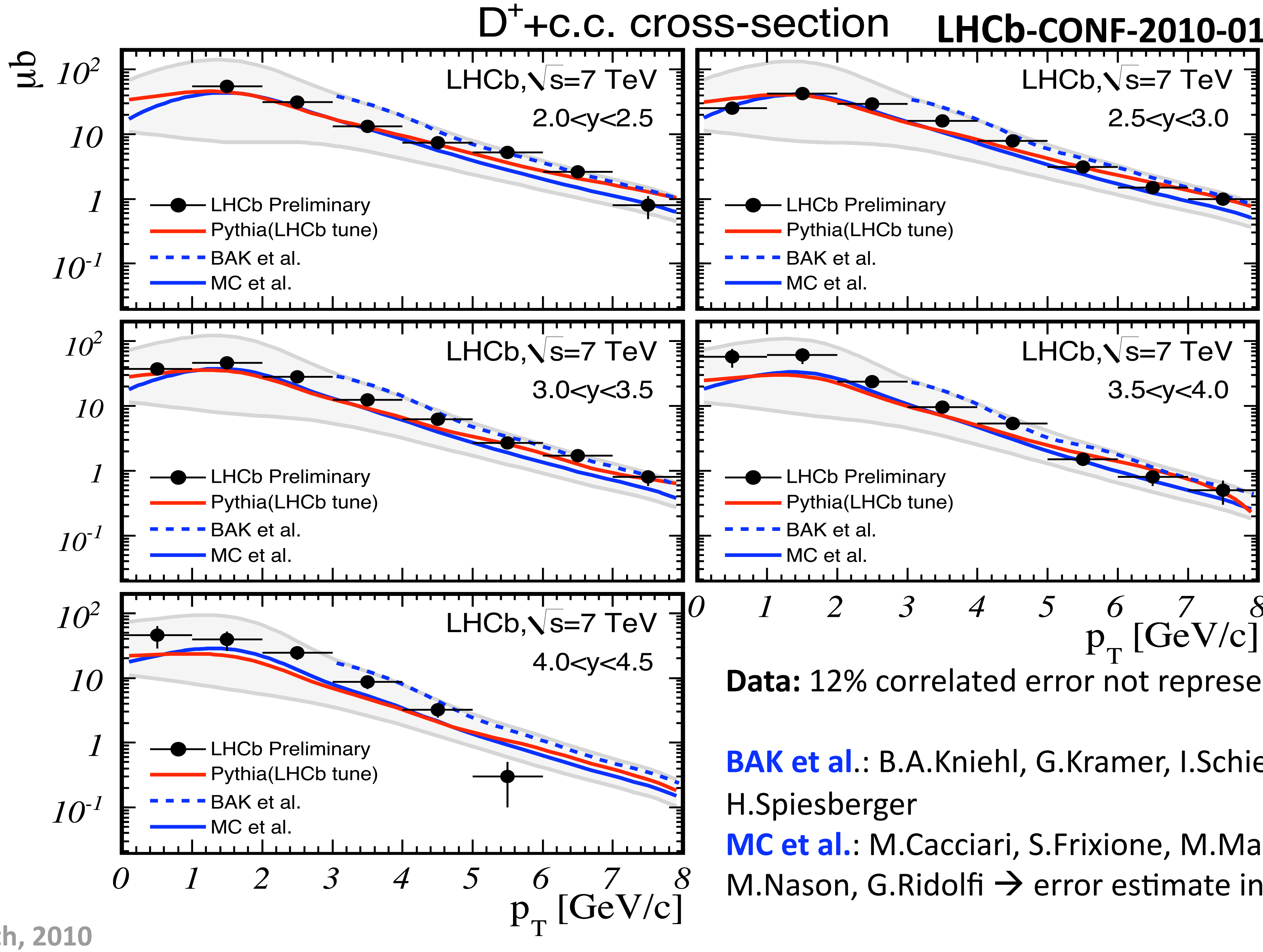


Data: 12% correlated error not represented

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

MC et al.: M.Cacciari, S.Frixione, M.Mangano, M.Nason, G.Ridolfi → error estimate in grey

Open charm production: D^{+}+cc



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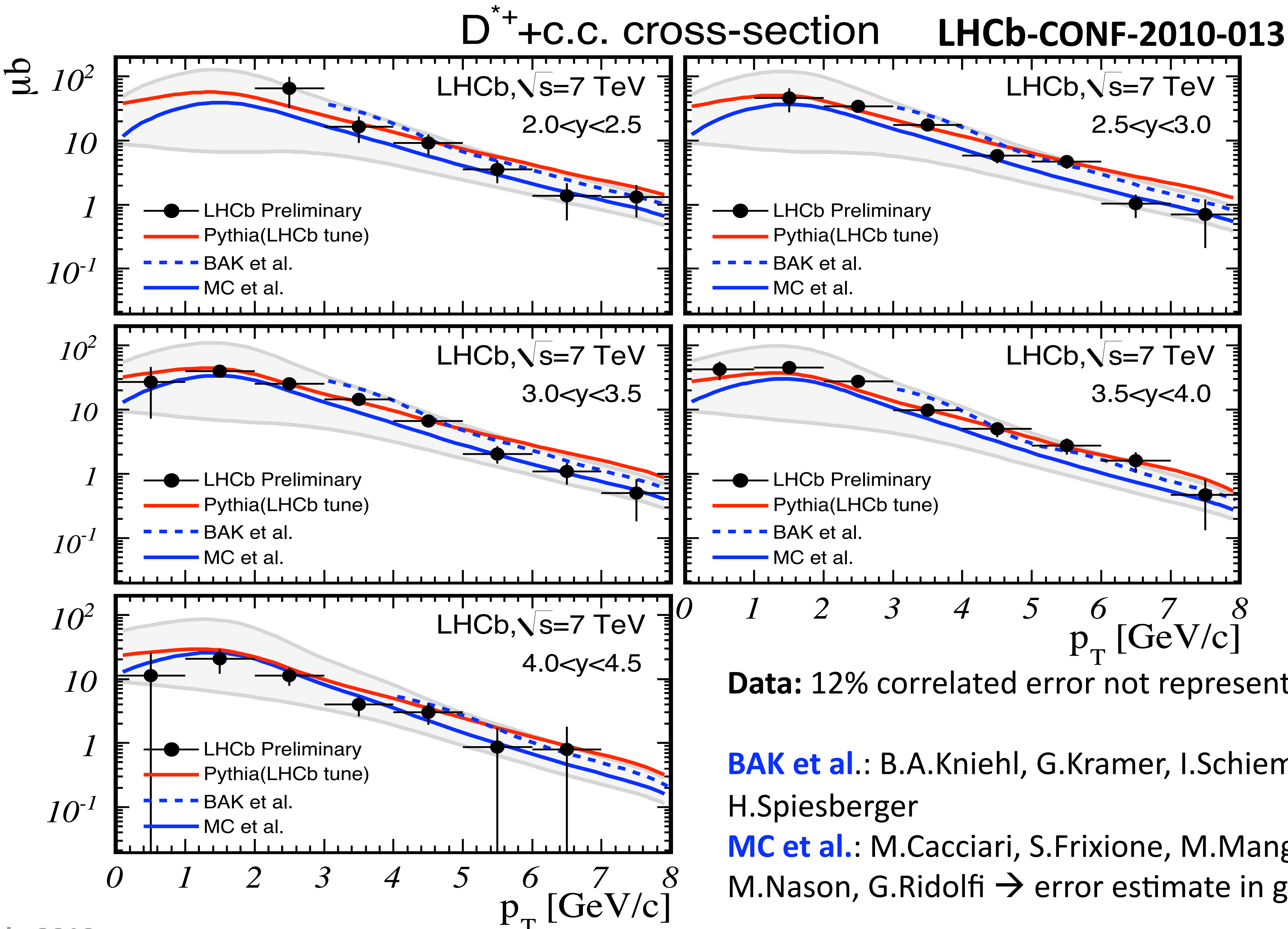
Open charm production: D^{*+}+cc



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Open charm production: D_s^++cc

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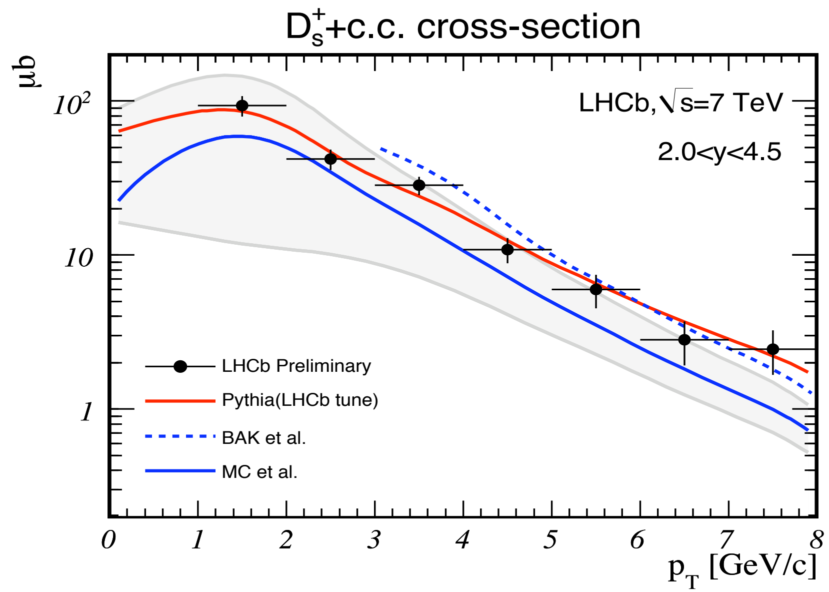
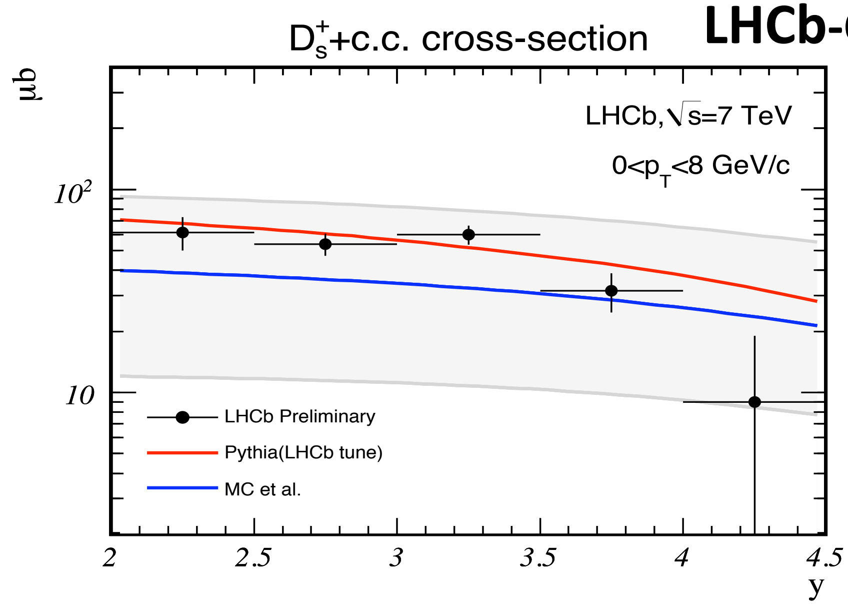
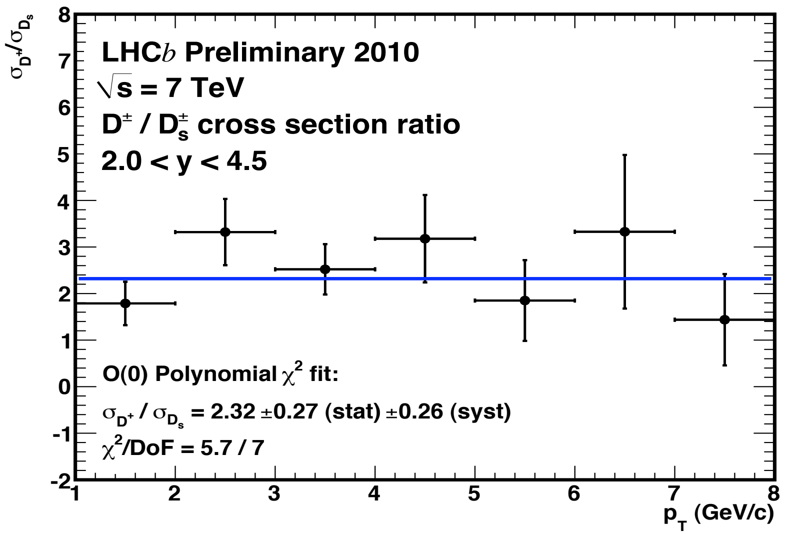






From the analysis of the $\phi(K^+K^-)\pi^+$ final state the ratio D^+/D_s^+ can be extracted.

$\sigma(D^+)/\sigma(D_s^+) = 2.32 \pm 0.27 \pm 0.26$

Consistent with

$f(c \rightarrow D^+)/f(c \rightarrow D_s^+) = 3.08 \pm 0.70$ (PDG)

Combining the $D^0/D^+/D^{*+}/D_s^+$ results

$\sigma(pp \rightarrow c\overline{c}) = 1234 \pm 189\ \mu b$ in p_T<8GeV/c 2<y<4.5

$\sigma(pp \rightarrow c\overline{c}) = 6100 \pm 934\ \mu b$ in the full acceptance

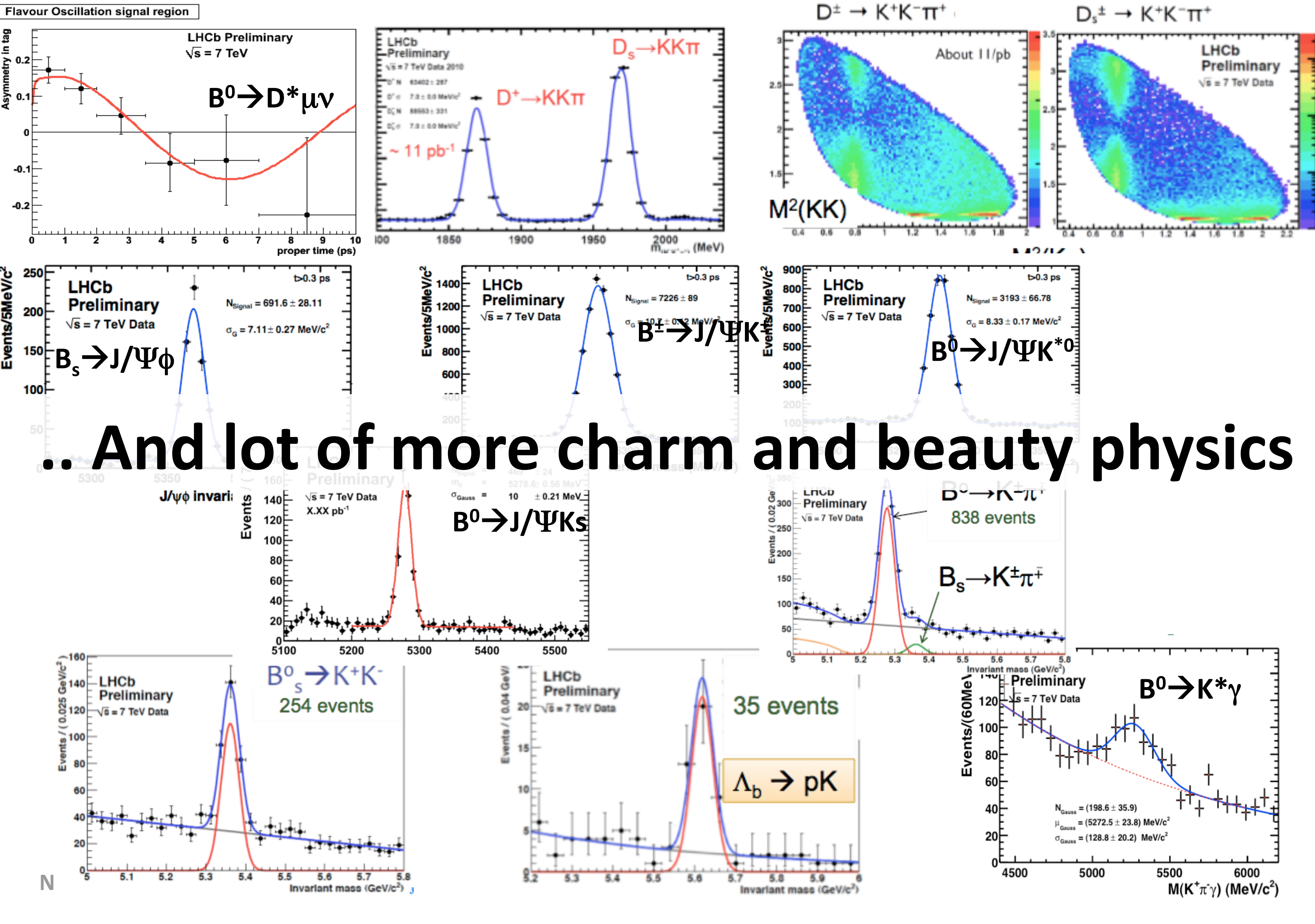
Plans:

update with more statistics ($14 nb^{-1}$), add the Λc production

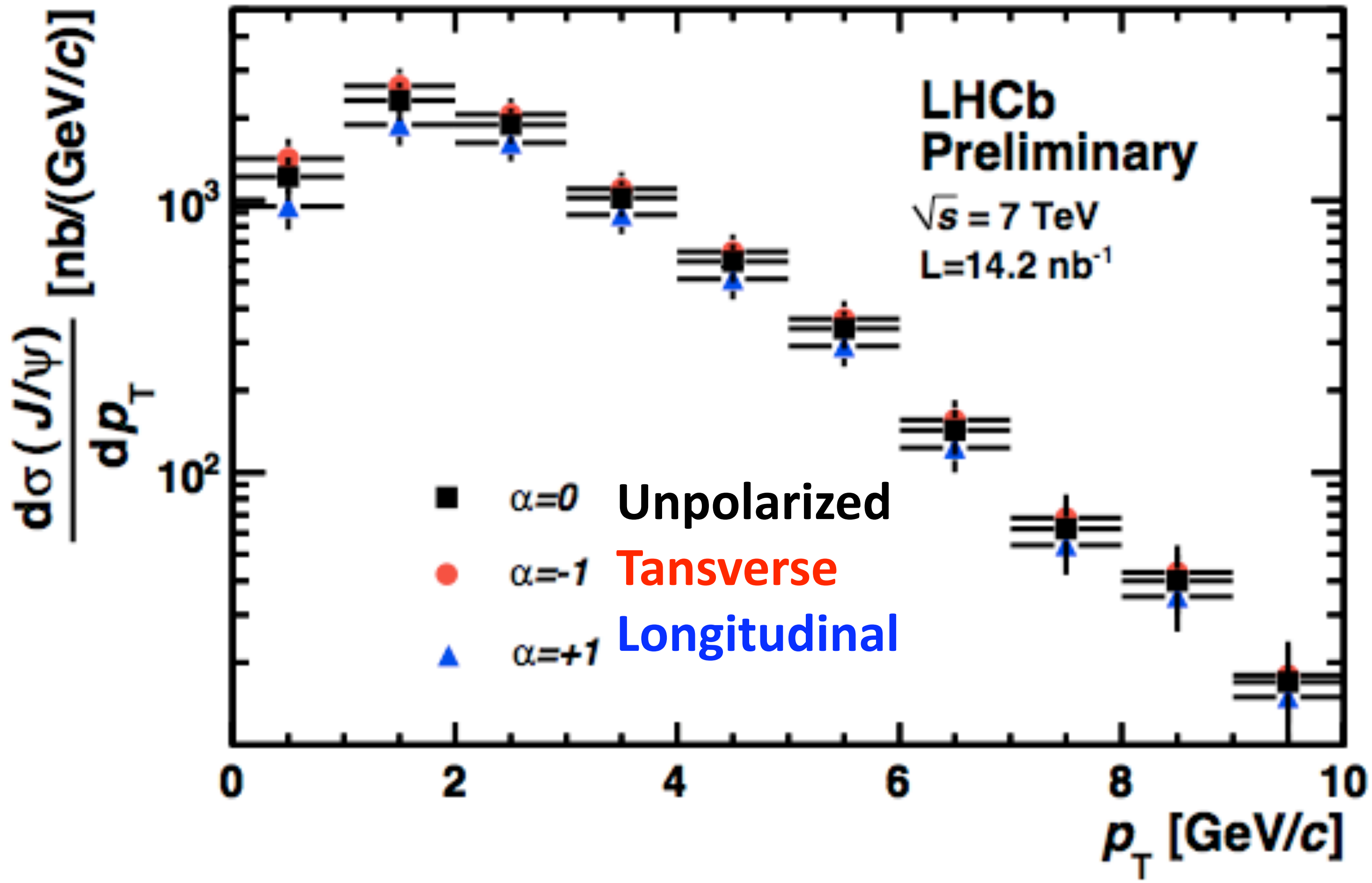
Conclusions

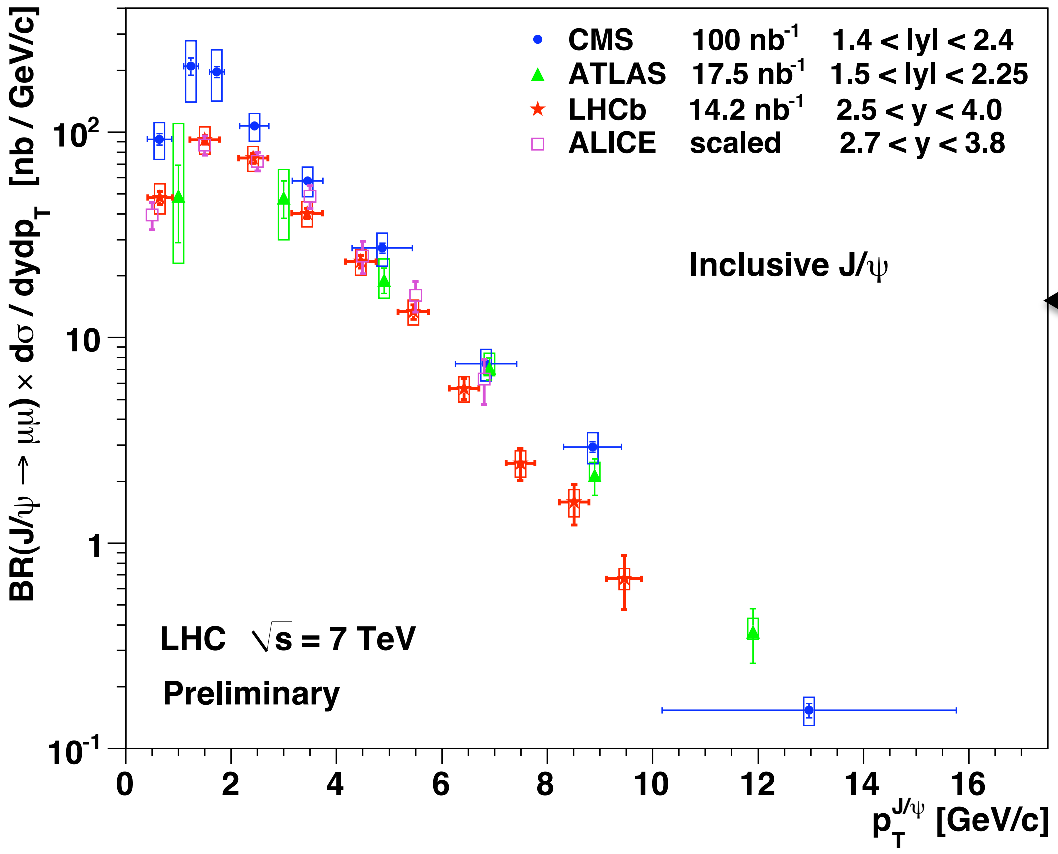
- Many analyses on the heavy flavour production and spectroscopy are ongoing at LHCb.
- With the first sample collected in 2010 at $\sqrt{s}$=7 TeV 2-15nb^{-1} several results were already obtained:
  - Inclusive J/ψ(1S) production cross section in p_T bins, p_T<10 GeV/c ,2.5<y<4
  - b-hadron & $b\bar{b}$ cross section in η bins using $B \rightarrow D^0\mu^-\nu_\mu$, $B^0 \rightarrow D^{*-}\mu^+\nu_\mu$ and $H_b \rightarrow J/\psi(1S)X$.
    - Nice agreement with the expectation
  - Open charm & $c\bar{c}$ cross sections measured in different modes in p_T and y bins, p_T<8 GeV/c , 2<y<4.5
    - Nice agreement with the expectation (shape and normalization)
- More results will be presented in the coming months based on larger statistics samples:
  - Quarkonia production cross sections or ratios: J/ψ(1S), ψ(2S), χ_c,ϒ
  - J/ψ(1S) , ψ(2S) ,ϒ polarization
  - c and b-Hadron production
  - Study of conventional and non-conventional HF states X(3872),$Z^{\pm}$(4440), $B^{\pm}_c$

.. And lot of more charm and beauty physics

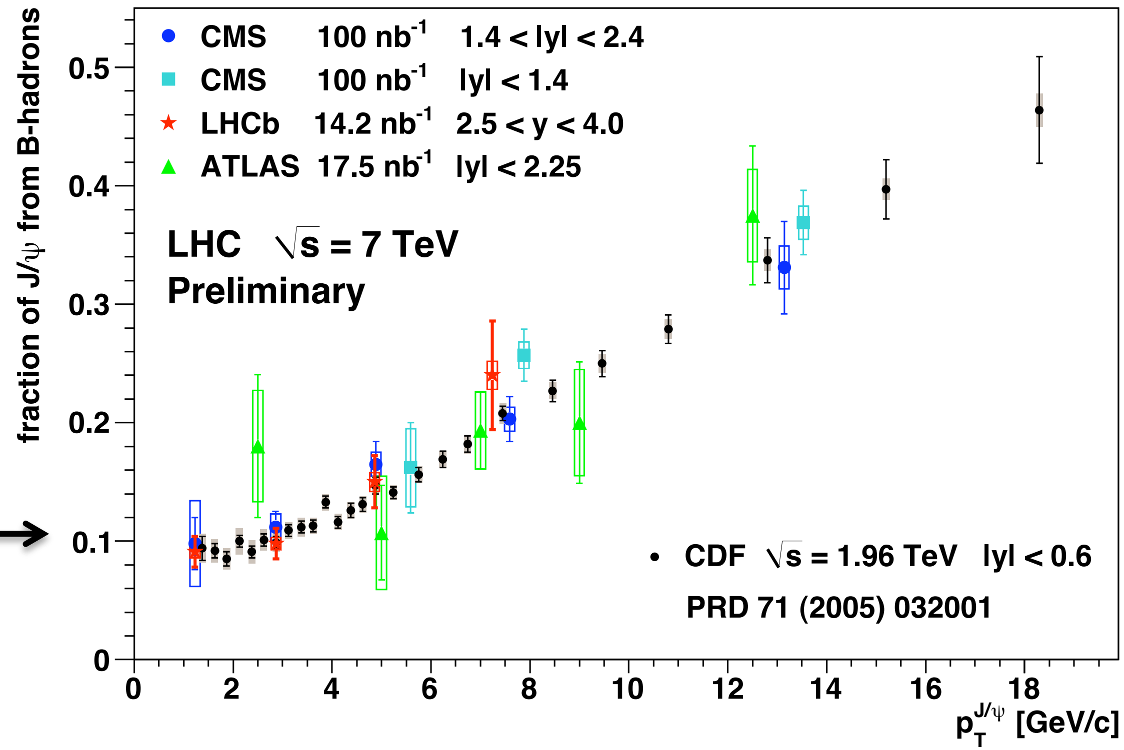


spares


LHCb
Preliminary
√s = 7 TeV
L=14.2 nb⁻¹
α=0 Unpolarized
α=-1 Tansverse
α=+1 Longitudinal
dσ(J/ψ)/dp_T [nb/(GeV/c)]
p_T [GeV/c]
10³
10²
0
2
4
6
8
10



Inclusive Jpsi cross section



Fraction of jpsi from b

Open charm cross section

- From the measurement of the differential cross section, integrating over the p_T and y range we get: (p_T<8GeV/c & 2<y<4.5)
- **NB:** the cross sections are for the sum of a D-meson + its cc

$$\sigma(D^0) = 1488 \pm 41 \pm 34 \pm 174\,\mu b = 1488 \pm 182\,\mu b$$
$$\sigma(D^{*+}) = 676 \pm 64 \pm 21 \pm 119\,\mu b = 676 \pm 137\,\mu b$$
$$\sigma(D^+) = 717 \pm 39 \pm 26 \pm 98\,\mu b = 717 \pm 109\,\mu b$$
$$\sigma(D_s^+) = 194 \pm 23 \pm 16 \pm 26\,\mu b = 194 \pm 38\,\mu b\,.$$

- With a proper treatment of the error propagation (separate correlated/uncorrelated global systematic errors) we calculate the production ratios:

$$\frac{\sigma(D^0)}{\sigma(D^{*+})} = 2.20 \pm 0.48 \qquad \frac{\sigma(D^0)}{\sigma(D^+)} = 2.07 \pm 0.37 \qquad \frac{\sigma(D^0)}{\sigma(D_s^+)} = 7.67 \pm 1.67$$
$$\frac{\sigma(D^{*+})}{\sigma(D^+)} = 0.94 \pm 0.22 \qquad \frac{\sigma(D^{*+}}{\sigma(D_s^+)} = 3.48 \pm 0.93 \qquad \frac{\sigma(D^+)}{\sigma(D_s^+)} = 3.70 \pm 0.84$$

- Correcting for the f(c-->H) probability (different measurement at different energy scales exist, use the range covered by measurement @ Z, ϒ)
- Vaues agree: $\chi 2$/ndof =2.28/3

$$\sigma(c\bar{c}, D^0) = 1280 \pm 36 \pm 151 \pm 150\,\mu b = 1280 \pm 216\,\mu b$$
$$\sigma(c\bar{c}, D^{*+}) = 1474 \pm 140 \pm 176 \pm 260\,\mu b = 1474 \pm 343\,\mu b$$
$$\sigma(c\bar{c}, D^+) = 1474 \pm 80 \pm 164 \pm 202\,\mu b = 1474 \pm 272\,\mu b$$
$$\sigma(c\bar{c}, D_s^+) = 1092 \pm 130 \pm 151 \pm 147\,\mu b = 1092 \pm 247\,\mu b$$