Studies with onia at LHCb

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Meeting of the division of Particle and Fields of the American Physics Society

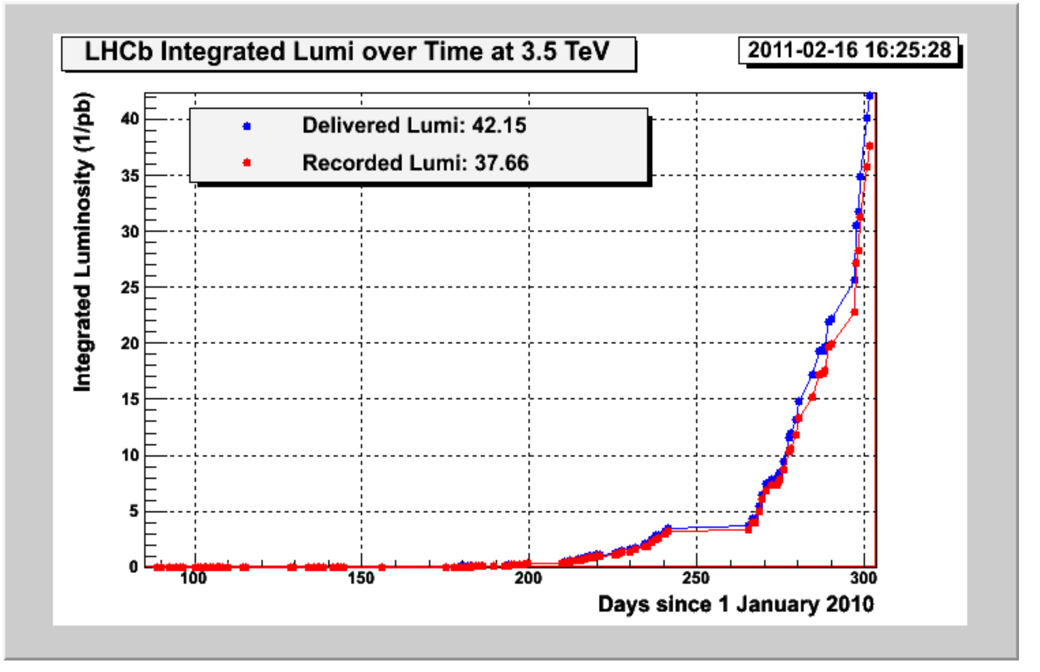
Providence, 9th August 2011

Outline

LHCb results of production of $c\bar{c}$ and $b\bar{b}$ states and comparison with theoretical models

Few results from exotic states

- $\psi(2S)$ production cross section
- $\Upsilon(1S)$ production cross section
- χ_{c2} and χ_{c1} cross section ratio
- χ_b observation
- X(3872) mass measurement
- X(3872) production cross section
- Search of X(4140)
- Exclusive dimuon production

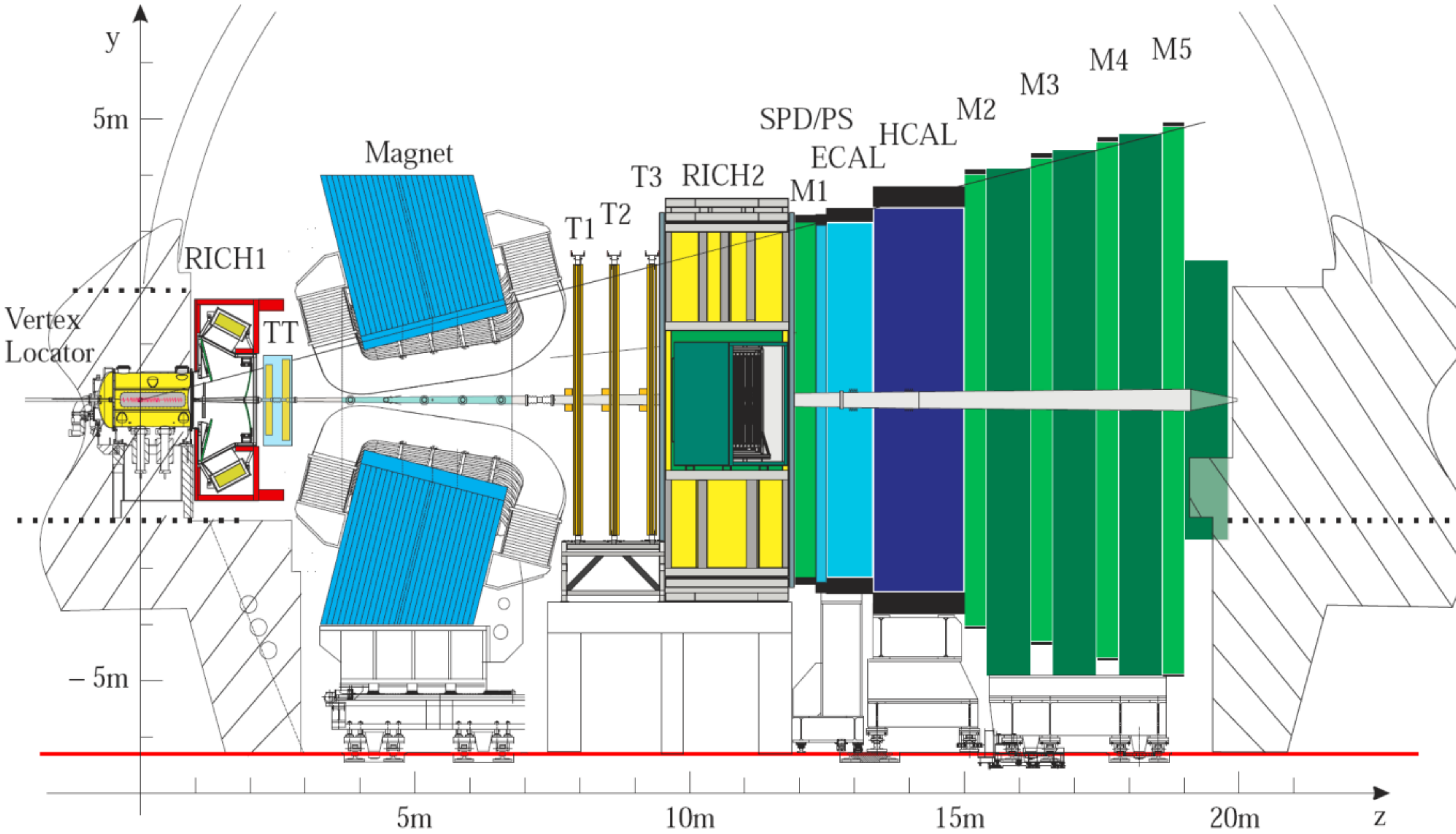


2010 LHCb integrated luminosity

Most of the analysis based on 2010 data = 35 pb^{-1}

564 pb^{-1} recorded so far

LHCb detector



Forward region spectrometer (1.9 < η < 4.9), 4% solid angle, 40% b-hadron cross section

$\psi(2S)$ production cross section (I)

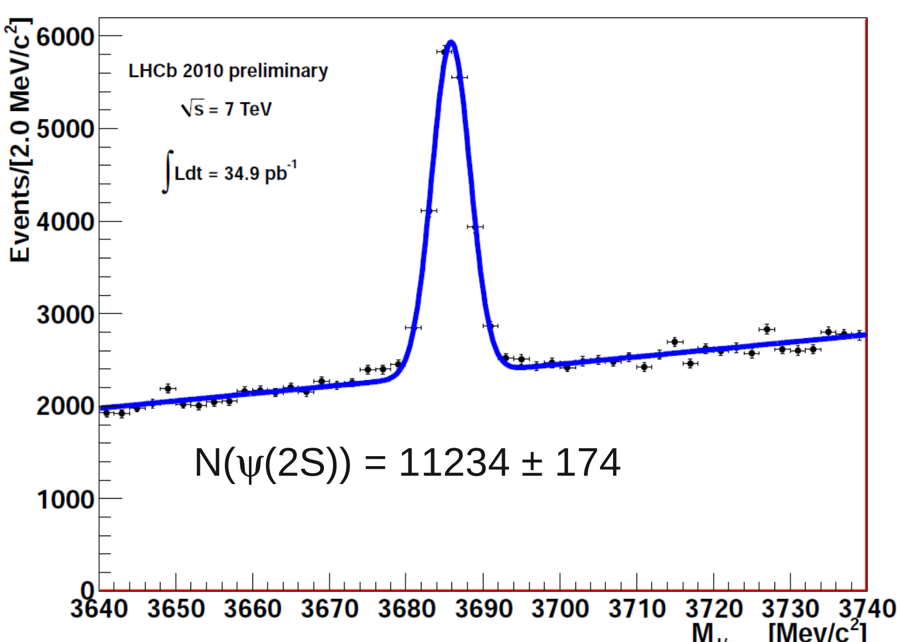
LHCb-CONF-2011-026

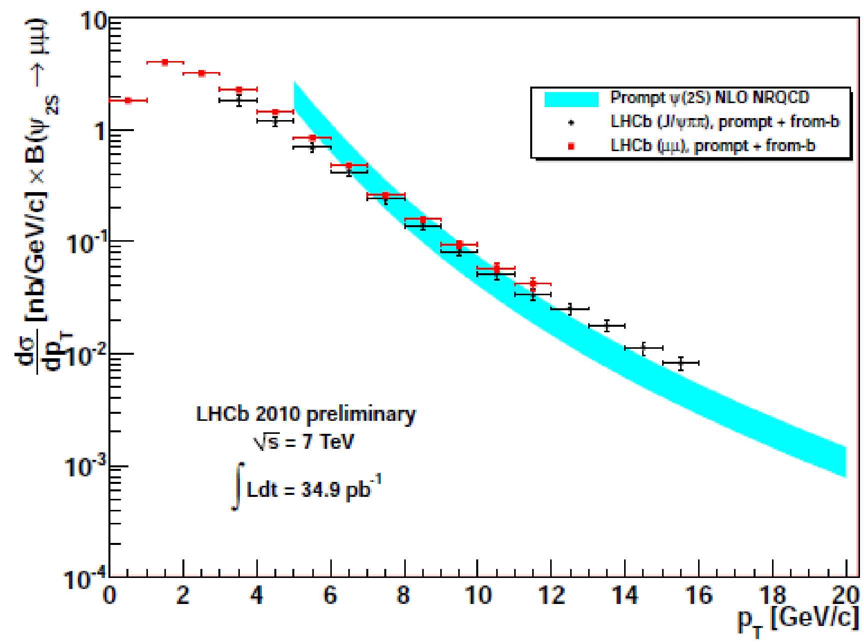
- Two decay modes: $\psi(2S) \to J/\psi\, \pi\, \pi$, $\psi(2S) \to \mu\, \mu$
- Data include also $\psi(2S)$ from b: from 10% (low PT) to 40% (high PT)

$$\frac{d\sigma}{dp_T}(p_T) = \frac{N_{\psi(2S)}(p_T)}{\mathcal{L}_{int}\, \epsilon(p_T)\, \mathcal{B}(\psi(2S) \to J/\psi\pi^+\pi^-)\, \mathcal{B}(J/\psi \to \mu^+\mu^-)\ \Delta p_T}$$

Unknown polarization

$$\sigma(3 < p_T \leq 16\ GeV/c, 2 < y \leq 4.5) = 0.62 \pm 0.04 \pm 0.12^{+0.07}_{-0.14}\ \mu b$$

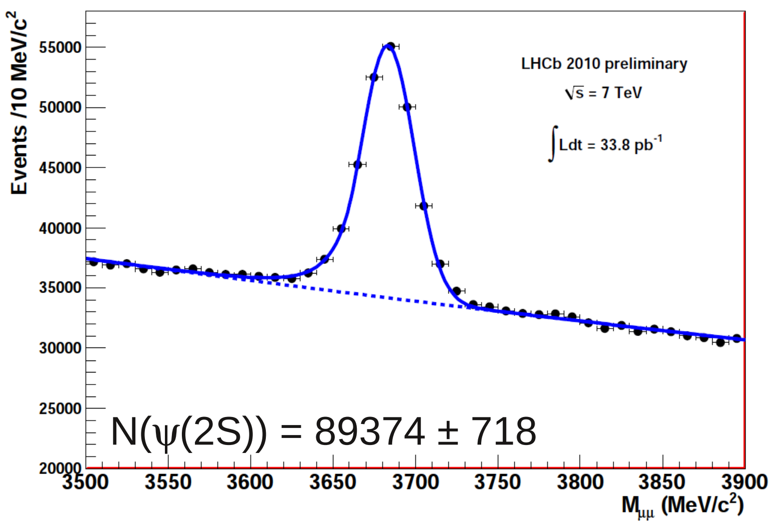


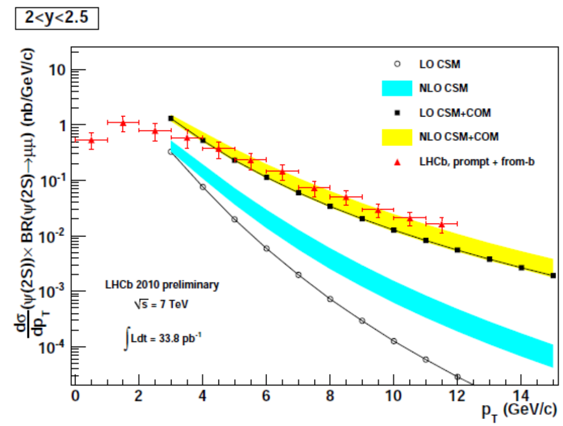


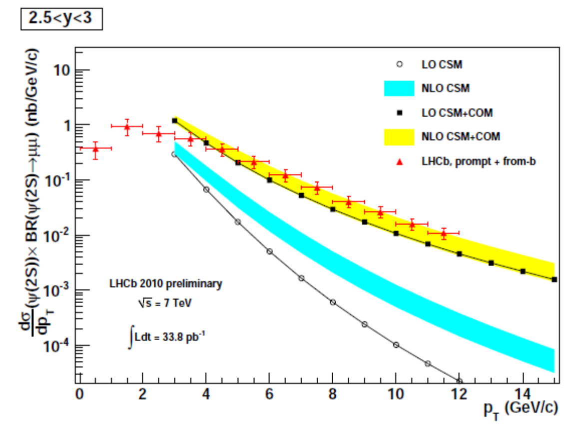
ψ(2S) production cross section (II)

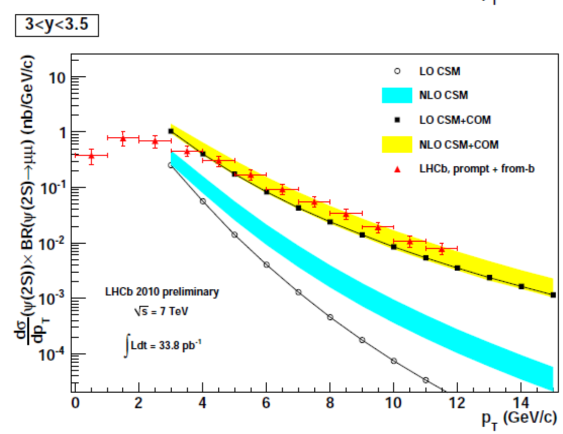
$$\frac{d^2\sigma}{dp_T dy}(p_T, y) = \frac{N_{\psi(2S)}(p_T, y)}{\mathcal{L}_{int}\, \epsilon(p_T, y)\, \mathcal{B}(\psi(2S) \to e^+e^-)\, \Delta p_T\, \Delta y}$$

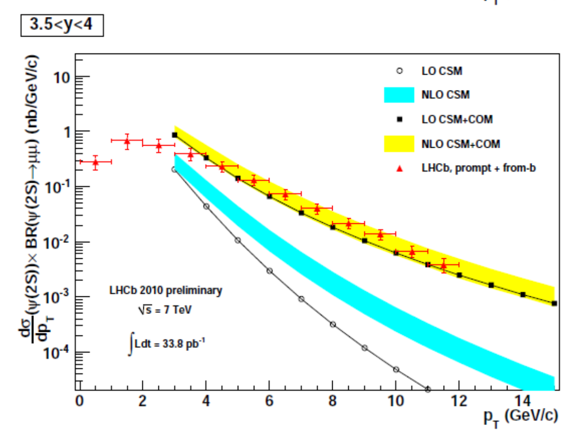
- Lepton universality assumed
- Smaller error respect to B(ψ(2S) → μ μ)



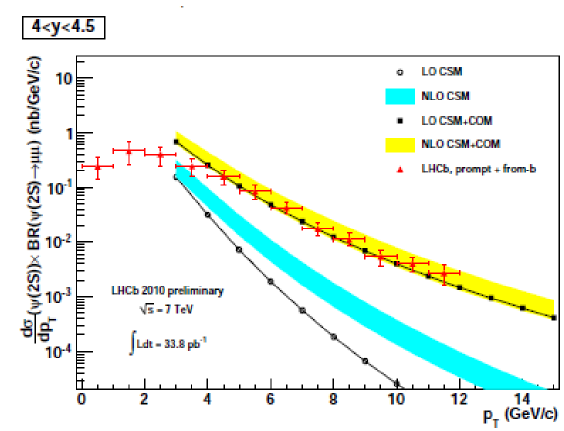








$$\sigma(\text{ inclusive } \psi(2S); 0 < p_T \le 12 \text{ GeV}/c, 2 < y \le 4.5) = 1.88 \pm 0.02 \pm 0.31^{+0.25}_{-0.48}\ \mu\text{b}$$



Unknown polarization

Good agreement with **NLO: CSM + COM**

Theory predictions:Y.Q Ma, K. Wang and K. T. Chao, B. Kniehl, M. Butenschoen

Y(1S) production cross section (I)

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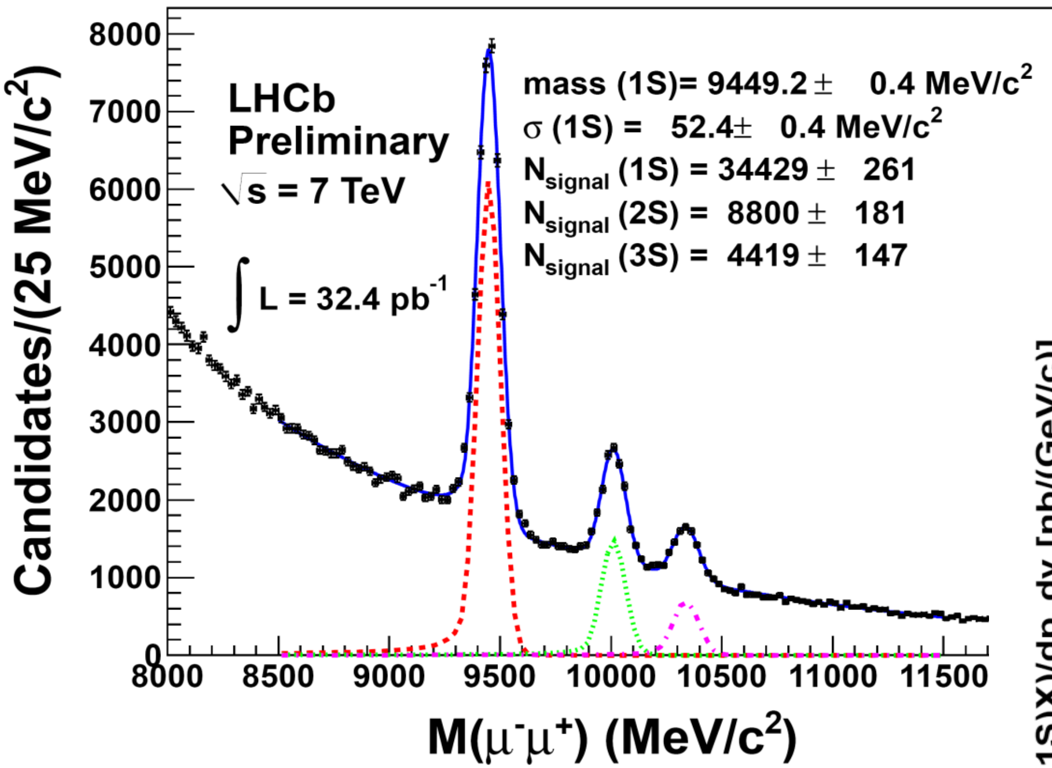
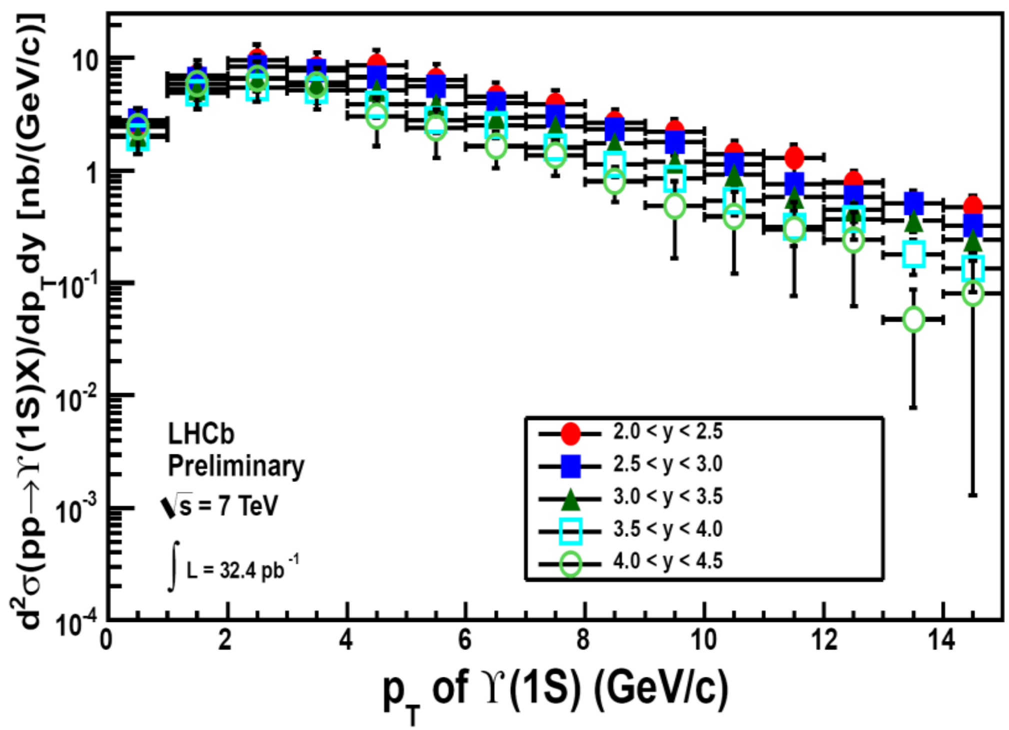


$$\frac{d^2\sigma}{dp_T dy} = \frac{N(\Upsilon(1S) \to \mu^+\mu^-)}{\mathcal{L} \times \varepsilon \times \mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) \times \Delta y \times \Delta p_T}$$



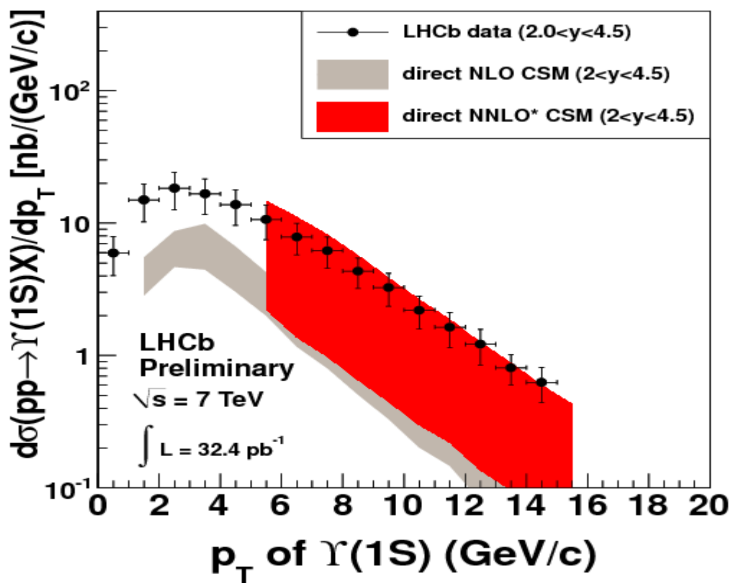
- Y(1S),Y(2S),Y(3S) reconstructed
- Result of Y(1S)
- Cross section of Y(2S) and Y(3S) soon

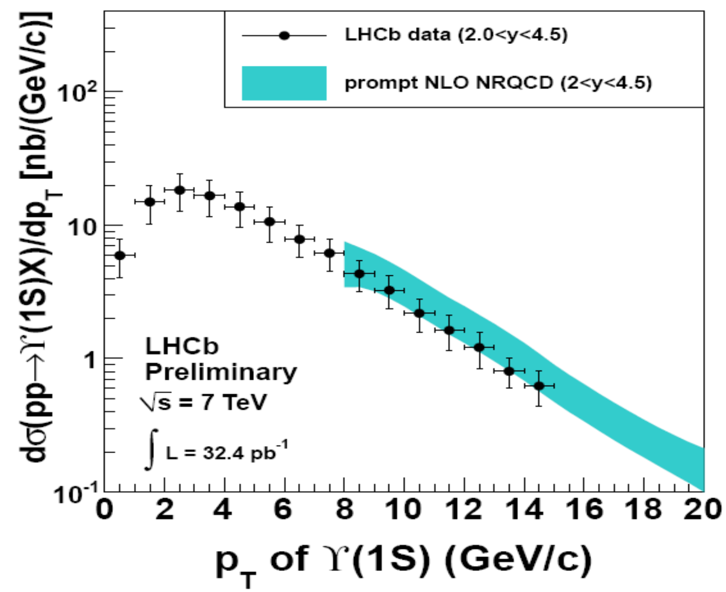
$$\sigma(pp \to \Upsilon(1S)X; 0 < p_T < 15\,\mathrm{GeV}/c, 2 < y < 4.5) = 108.3 \pm 0.7^{+30.9}_{-25.8}\ \mathrm{nb}$$

Unknown polarization and luminosity uncertainty

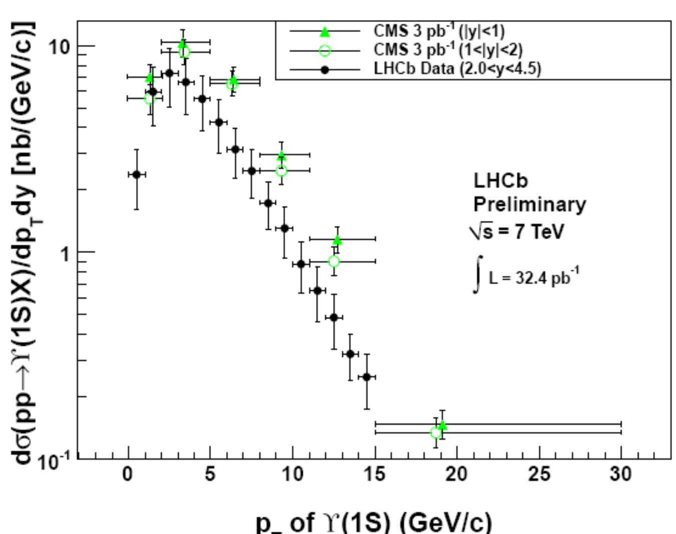
Υ(1S) production cross section (II)

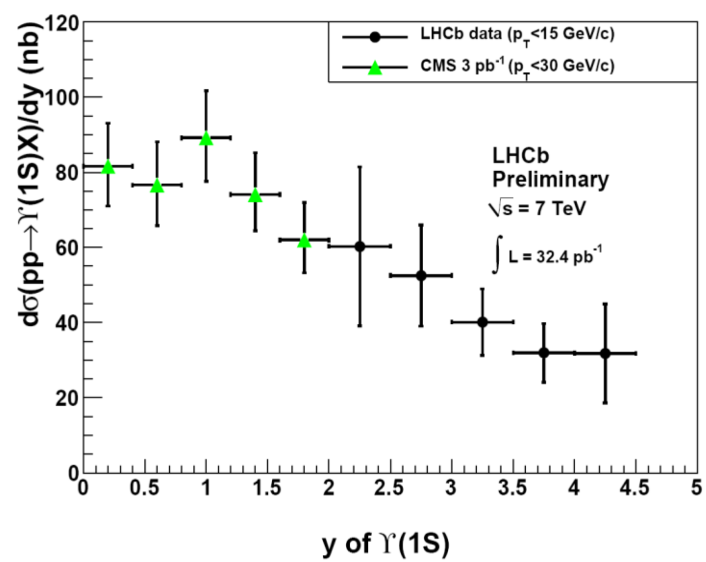
Comparison with theory (P. Artoisenet, K.T. Chao, J.P. Lansberg and R. Vogt)





Comparison with CMS results (arXiv:1012.5545)





χ_{c2} and χ_{c1} cross section ratio (I)

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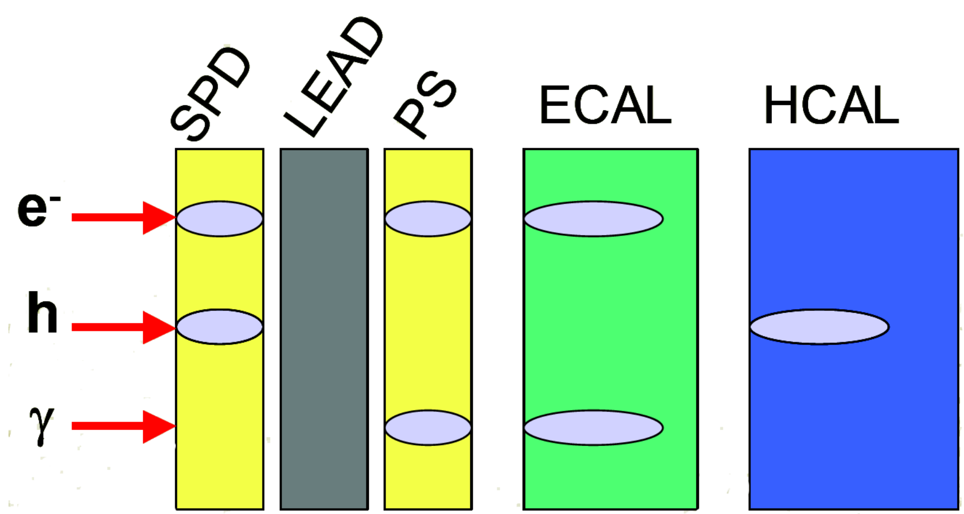
$$\frac{\sigma(\chi_{c2})}{\sigma(\chi_{c1})}=\frac{N_{\chi c2}}{N_{\chi c1}}\cdot\frac{\epsilon_{J/\psi}^{\chi c1}\,\epsilon_{\gamma}^{\chi c1}\,\epsilon_{sel}^{\chi c1}}{\epsilon_{J/\psi}^{\chi c2}\,\epsilon_{\gamma}^{\chi c2}\,\epsilon_{sel}^{\chi c2}}\cdot\frac{Br(\chi_{c1}\rightarrow J/\psi\,\gamma)}{Br(\chi_{c2}\rightarrow J/\psi\,\gamma)}$$

- $N(\chi_c i)$: from fit on data sample
- Efficiencies (ε) : from Monte Carlo
  - $\varepsilon_{J/\psi}^{\chi c}$ is the total detection efficiency for J/ψ from χ_c
  - $\varepsilon_{\gamma}^{\chi c}\ \varepsilon_{sel}^{\chi c}$ is the photon total detection efficiency times the χ_c selection efficiency

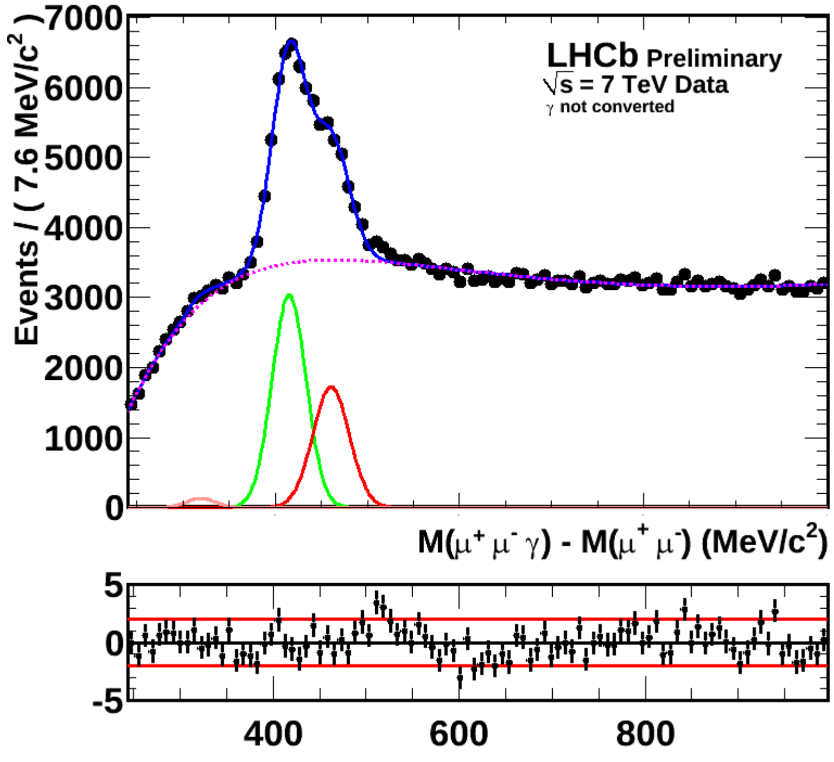
Photons recontruction:

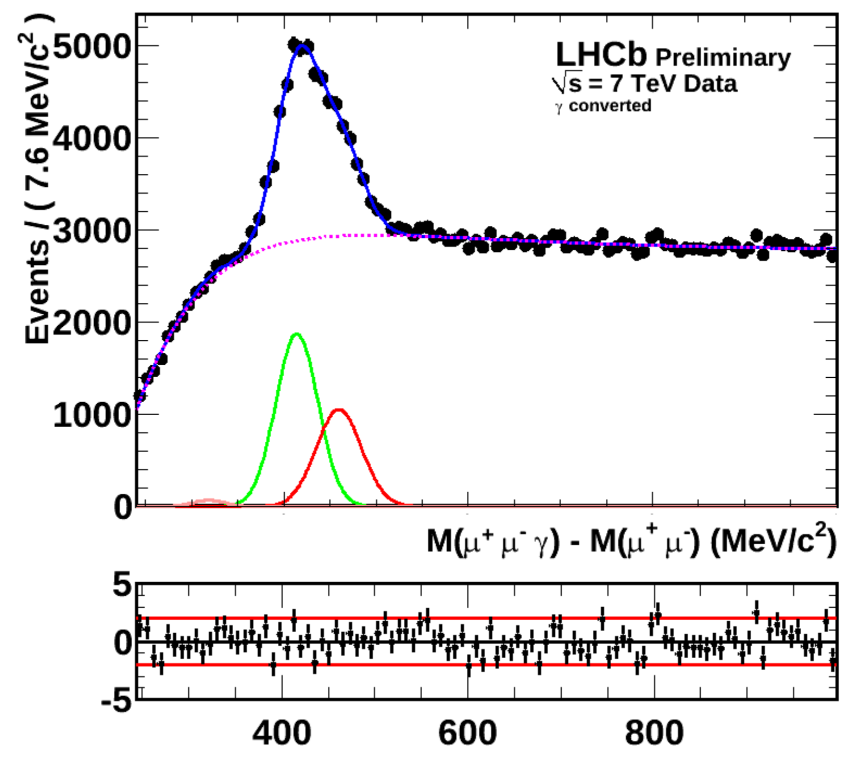
- Unconverted photons
- Converted photons ($\gamma\rightarrow e^+e^-$) after the magnet are identified by requiring a signal in the Scintillating Pad Detector (SPD). We cannot reconstruct converted photons before the magnet.
- Particle identification using a “confidence level likelihood”
  - Calorimeter information
  - Tracking information
  - Ratio of track seed energy to ECAL cluster energy



LHCb calorimeter

χ_{c2} and χ_{c1} cross section ratio (II)

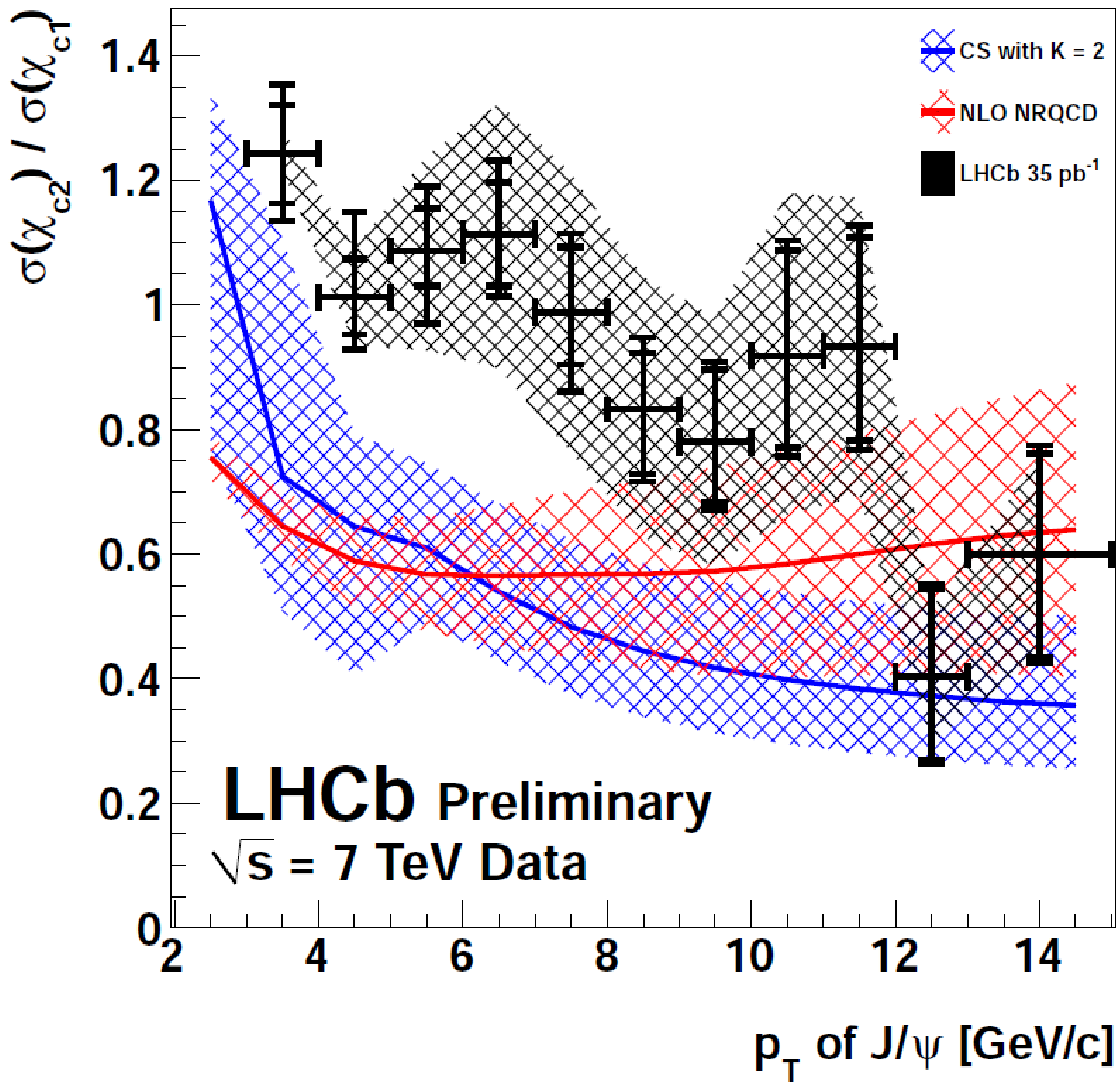




- Data sample separated in converted (after the magnet) and non converted photons. Extraction From each sub-sample of $N(\chi_{ci})$ from a fit in $M(J/\psi\ \gamma) – M(J/\psi)$ in bin of $J/\psi\ P_T$
- Combination of the two results
- Evaluate the largest uncertainty due to the unknown polarization on the combined results

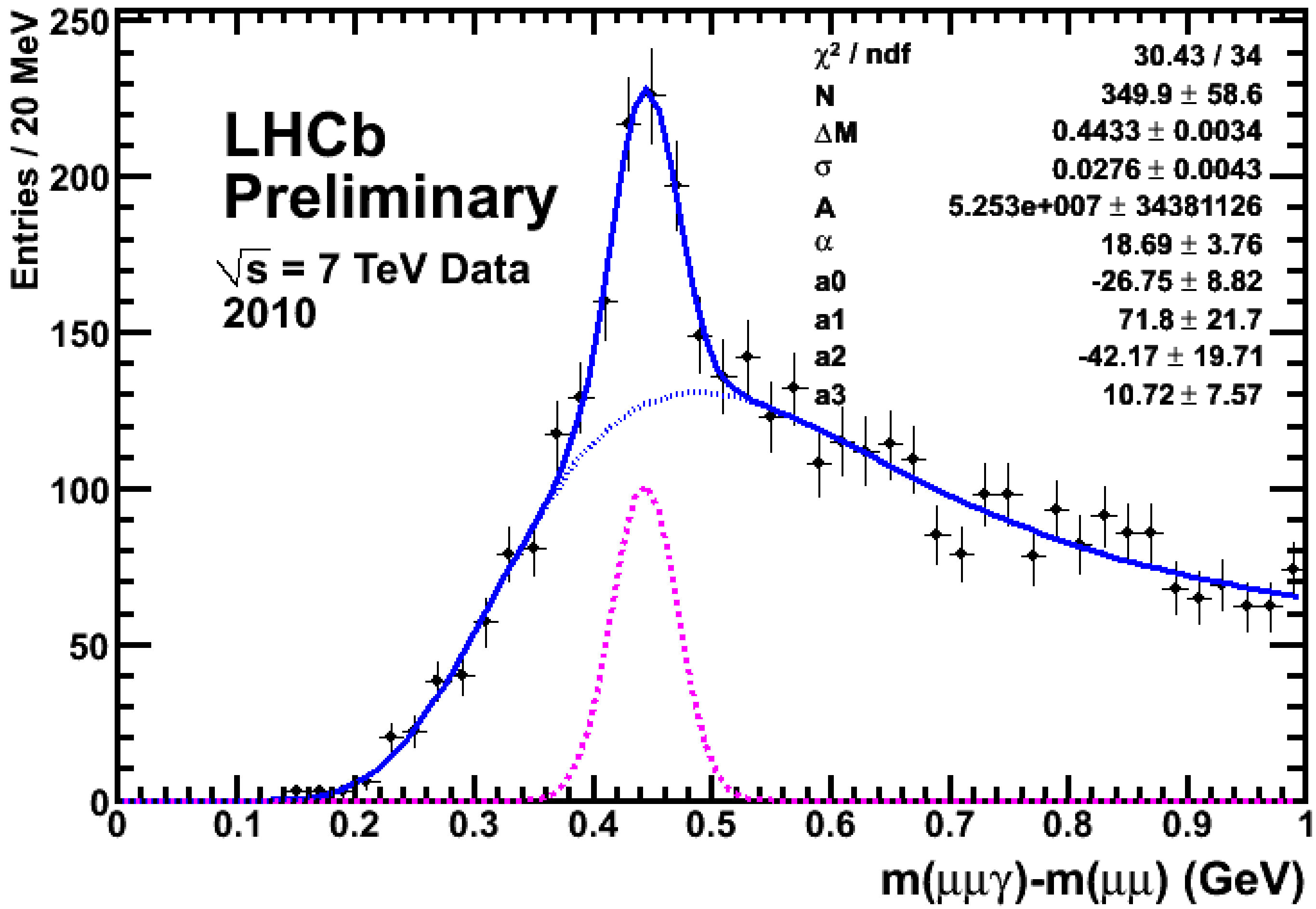
χ_{c2} and χ_{c1} cross section ratio (III)

- Result in bins of J/ψ PT
- NLO NRQCD: same model used for the ψ(2S) analysis
- Results: statistical and statistical + systematic errors
- Shaded black area: uncertainty due to the unknown polarization
- Some differences respect to the theory predictions: Kuang-Ta Chao, Lucian Harland-Lang



χ_b observation

- χ_b reconstructed from Y(1S) and a photon
- Clear signal. The 3 χ_b states cannot be resolved
- Plan to measure cross section



X(3872) mass measurement (I)

- Exotic meson, internal structure unclear
- Most X of prompt. The b fraction is 8 ± 3 (stat) %

LHCb-CONF-2011-021

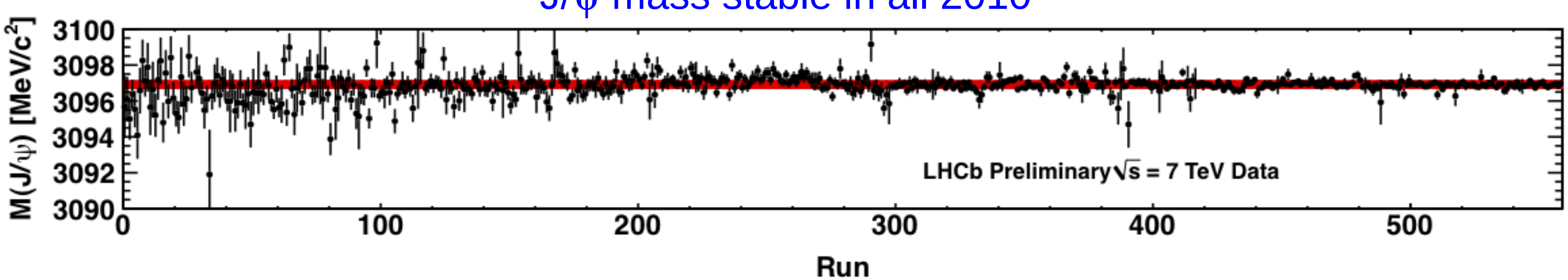
Momentum scale

- Accounts effects related imperfections in the knowledge of the magnetic field map and of the alignment of the tracking system
- Average overall scale factor to be applied on all raw measurements of the track momenta
- Detailed studies with J/ψ and other resonances
  - Stability versus time
  - Variation with decay kinematics
  - Calibration checked with $\psi(2S) \to J/\psi\,\pi^+\pi^-$ decay: $\psi(2S) \to J/\psi\,\pi^+\pi^-$ mass becomes 3686.12±0.06(stat) MeV/c^2, in good agreement with the PDG value of 3686.09 ± 0.04 MeV/c^2

Momentum scale checked on other two body decays

Decay	Measured mass $[MeV/c^2]$	PDG average $[MeV/c^2]$
$\Upsilon(1S) \to \mu^+\mu^-$	9459.90 ± 0.54	9460.30 ± 0.26
$J/\psi \to \mu^+\mu^-$	3096.97 ± 0.01	3096.916 ± 0.011
$D^0 \to K^-\pi^+$	1864.75 ± 0.07	1864.83 ± 0.14
$K^0_S \to \pi^+\pi^-$	497.62 ± 0.01	497.61 ± 0.02

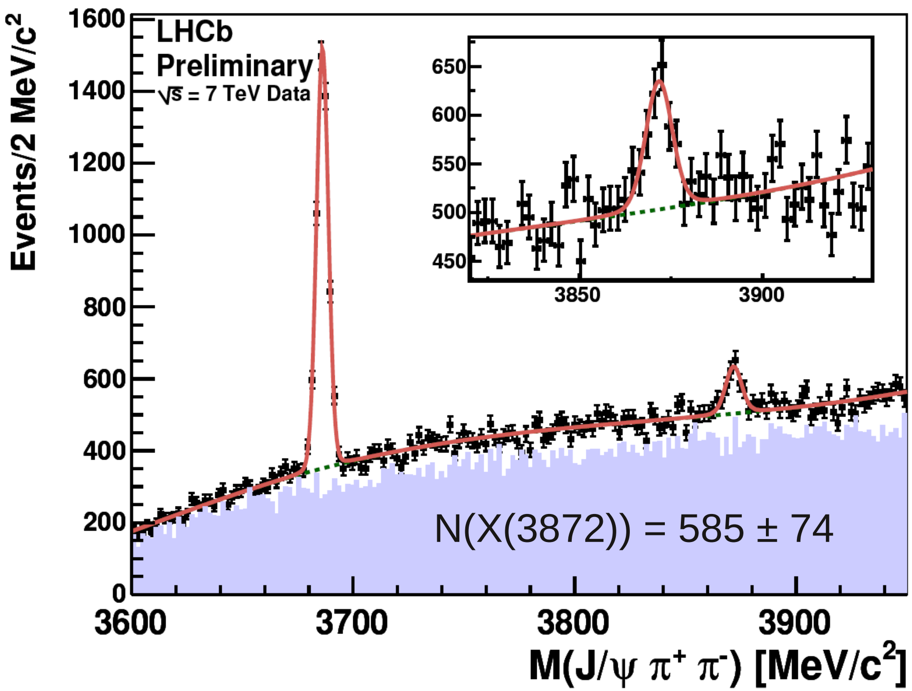
J/ψ mass stable in all 2010



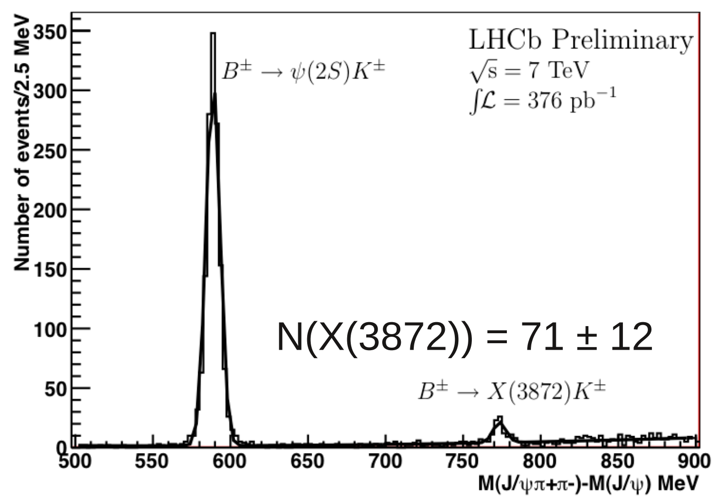
X(3872) mass measurement (II)

Unbinned maximum likelihood fit to M(J/ψ $\pi^+\pi^-$)

- ψ(2S) described by Breit-Wigner convolved with Gaussian (Voigt profile)
- X(3872) also described by Voigt, width fixed to 1.3 MeV (CDF average from BaBar and Belle limits)
- Background described by threshold function (gives good description of same sign background: J/ψ $\pi^\pm\pi^\pm$)



X(3872) observation in $B^\pm \rightarrow X(3872)\ K^\pm$



$$M_{X(3872)} = 3871.96 \pm 0.46\ (\text{stat}) \pm 0.10\ (\text{syst})\ \ \text{MeV}/c^2$$

X(3872) production cross section

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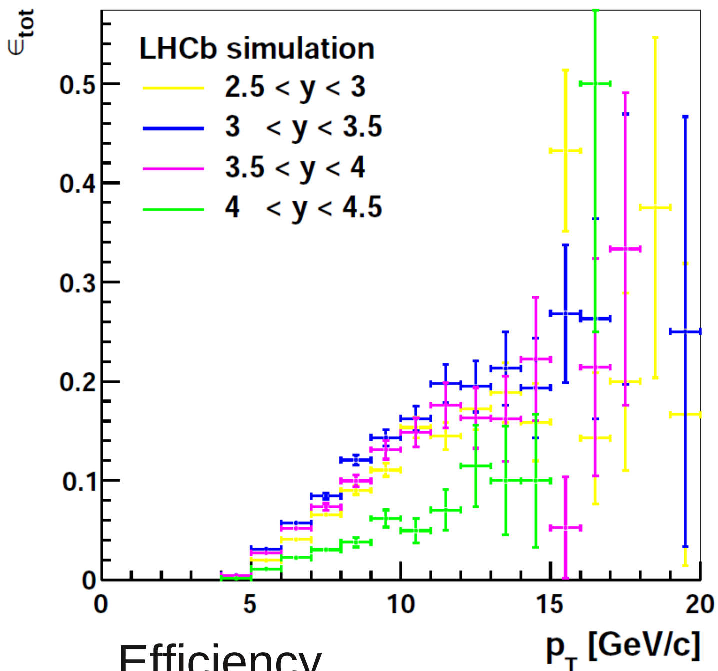
$$\sigma_{X(3872)} \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) = \frac{N^{corr}_{X(3872)}}{\mathcal{L}_{\text{int}} \times \eta_{\text{tot}} \times \mathcal{B}(J/\psi \to \mu^+\mu^-)}$$



Efficiency

Source	Uncertainty (%)
$X(3872)$ polarization	1.4
$X(3872)$ decay model	negligible
$X(3872)$ decay width	11.8
Mass resolution	1.3
Tracking efficiency	16
Track χ^2 cut	2
Trigger	5
Global event cuts	2.1
Vertex χ^2 cut	3
Muon identification	1.1
Integrated luminosity	3.5
$J/\psi \to \mu^+\mu^-$ branching fraction	1
Total	21.3

systematics

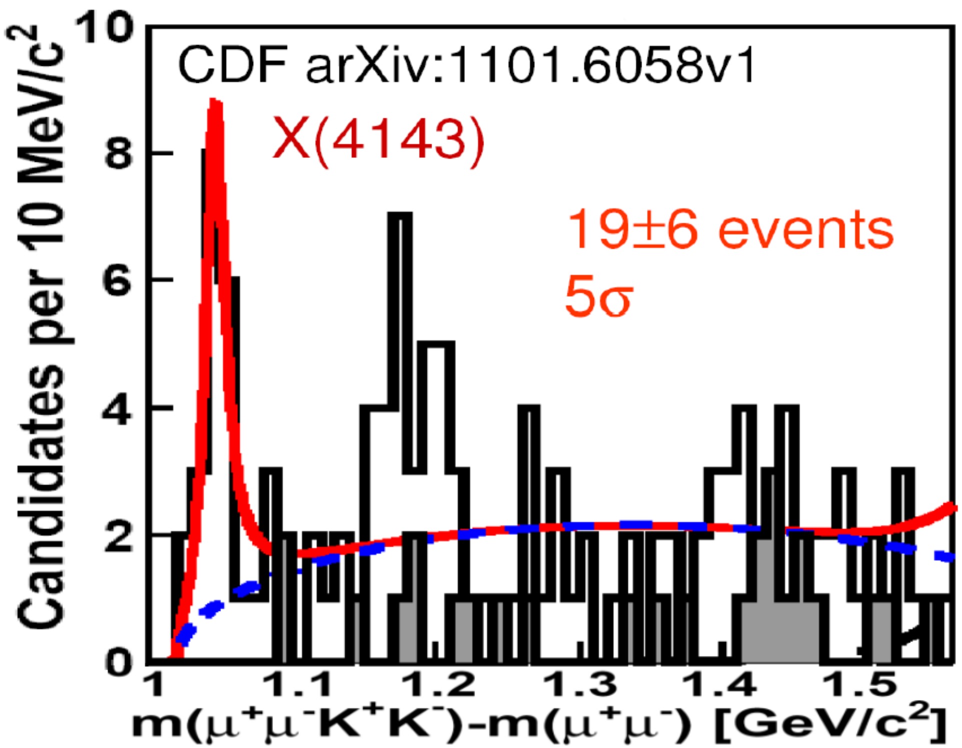
The yield efficiency corrected $N^{corr}_{X(3872)} = 9597 \pm 2217$

$$\sigma_{X(3872)} \times \mathcal{BR}(X(3872) \to J/\psi\pi^+\pi^-) = 4.74 \pm 1.10(\text{stat}) \pm 1.01(\text{syst})\ \text{nb}$$

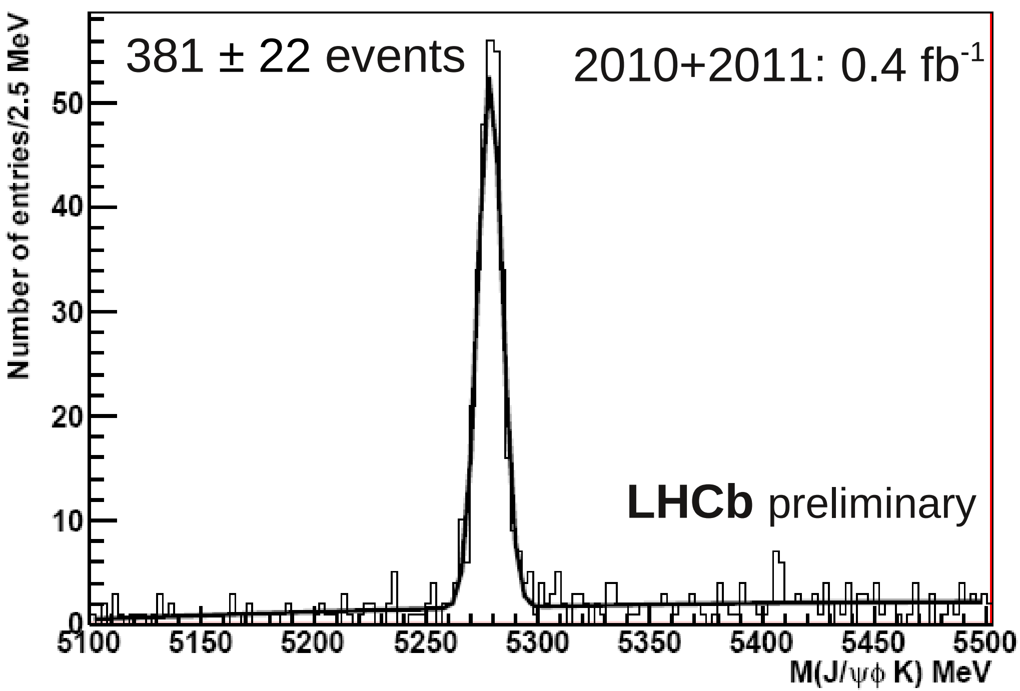
Search of X(4140) (I)

LHCb-CONF-2011-045

- Search of X(4140) in $B^+ \rightarrow J/\psi\, \phi\, K^+$, $\phi \rightarrow K^+ K^-$
- CDF observed a X(4140) structure with a significance of 5 σ
- If real these are candidates of exotic bound state



$B^+ \rightarrow J/\psi\, \phi\, K^+$: J/ψ and ϕ mass cut applied



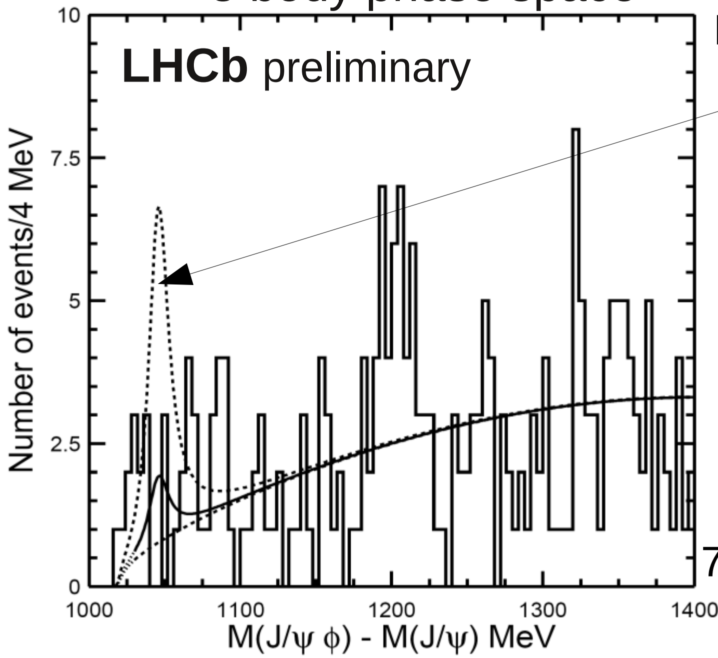
CDF: 115 ± 12 events in 6 fb^{-1}

Search of X(4140) (II)

Fit of M(J/ψ ϕ) -M(J/ψ)

- Signal: relativistic spin 0 Breit-Wigner smeared with the resolution
- Background: efficiency shaped 3 body phase space (smeared with the resolution), quadratic polynomial

3 body phase space

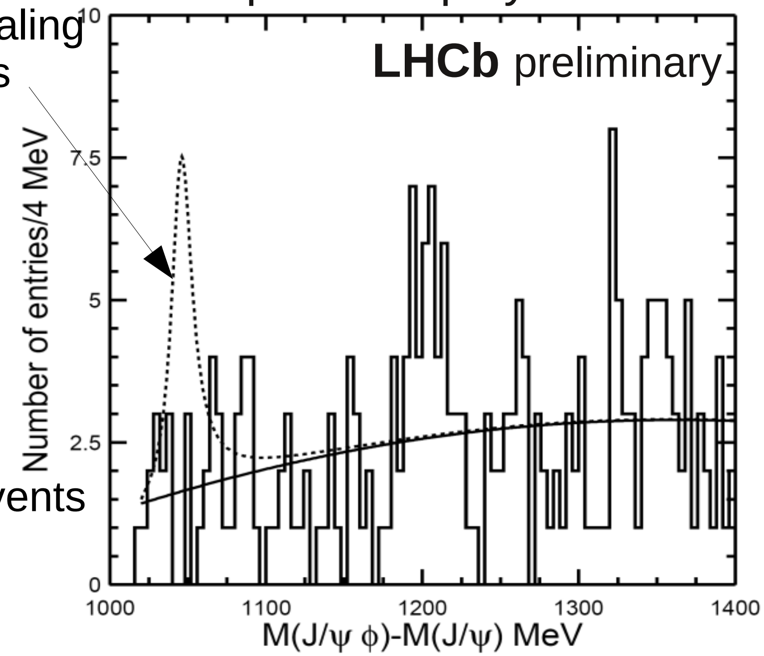


Expected events scaling with CDF results
39 ± 9 ±6

7 ± 5 events

0 ± 3 events

quadratic polynomial



$$\frac{B_r\left(B^+ \to X(4140)K^+,\, X(4140) \to J/\psi\phi\right)}{B_r\left(B^+ \to J/\psi\phi K^+\right)}$$

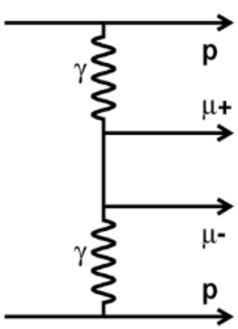
< 0.07 (90%CL) 3 body phase space
< 0.04 (90%CL) quadratic polynomial

CDF: 0.149 ± 0.039 ± 0.024
arXiv:1101.6058v1

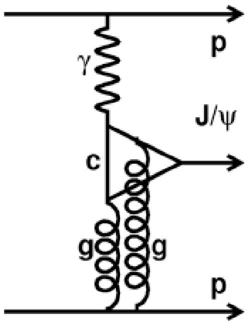
LHCb doesn't confirm X(4140)

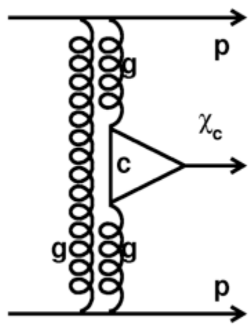
Exclusive dimuon (I)

LHCb-CONF-2011-022

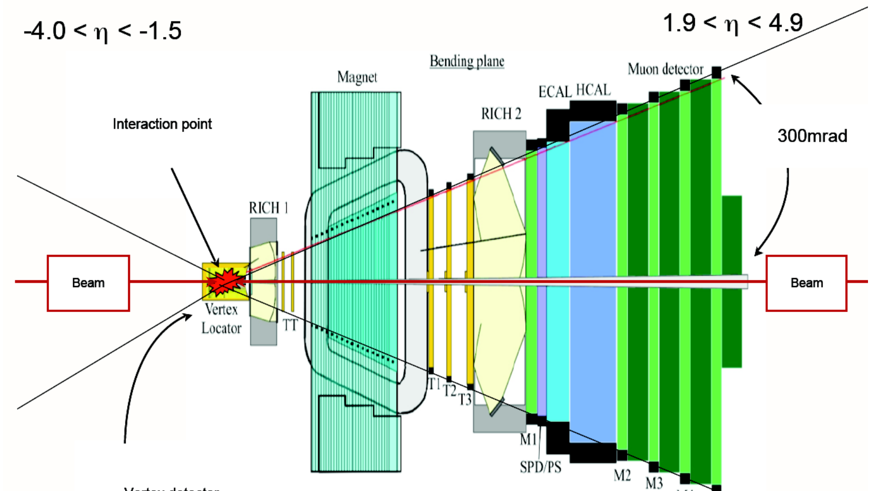


QED used for indirect precise luminosity measurement



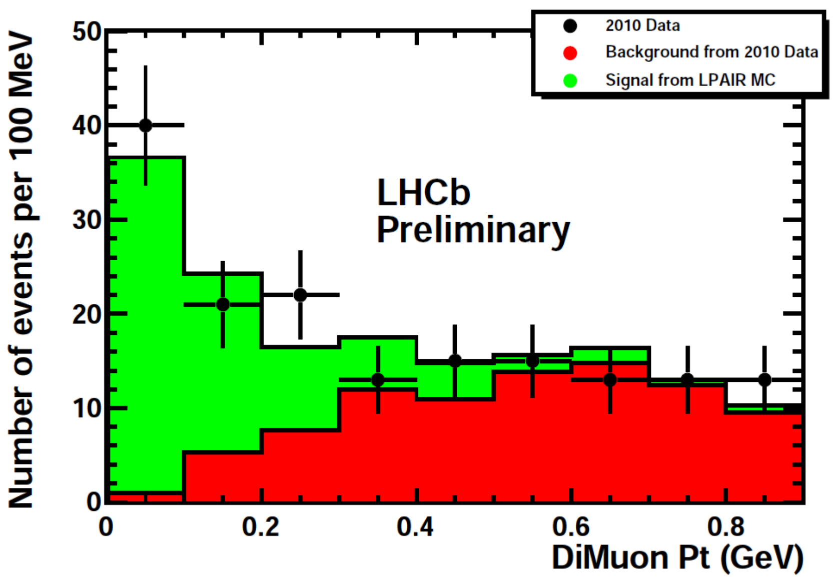


QCD can test prediction in a low multiplicity environment



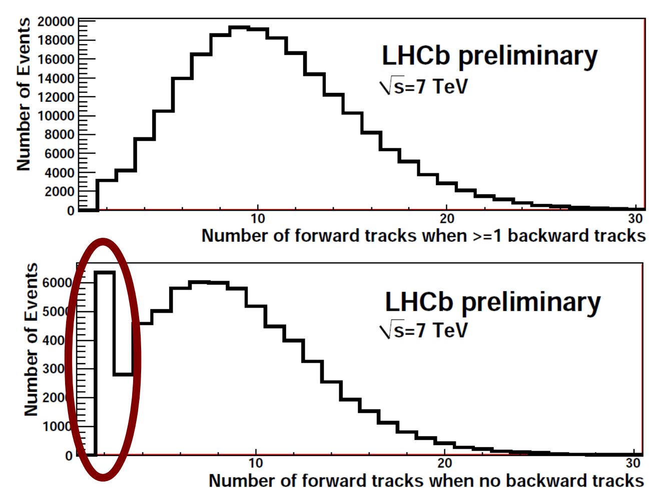
Vertex detector can reconstruct backward tracks (no momentum measurement)

$M(\mu\mu) > 2.5$ GeV/c^2 , resonances removed



Background estimation from data > 2 tracks

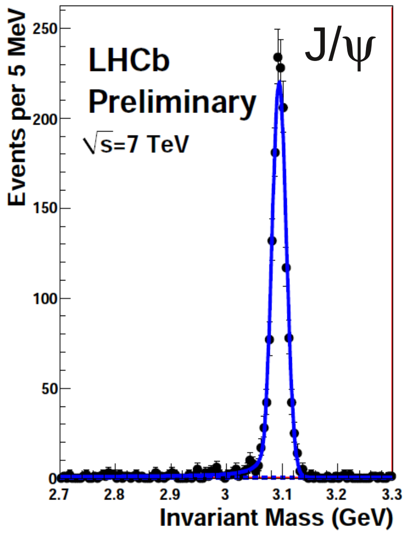
- Reconstruct of forward and backward tracks
- Exclusive = only 2 forward tracks in total

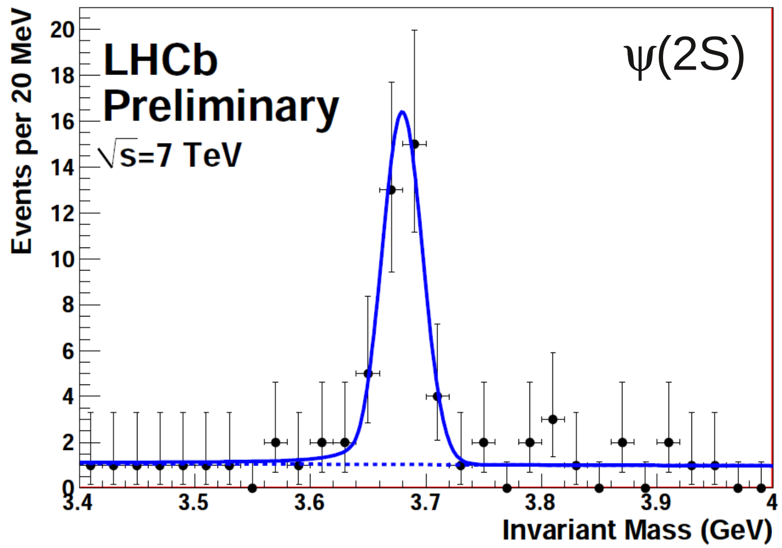


Exclusive dimuon (II)

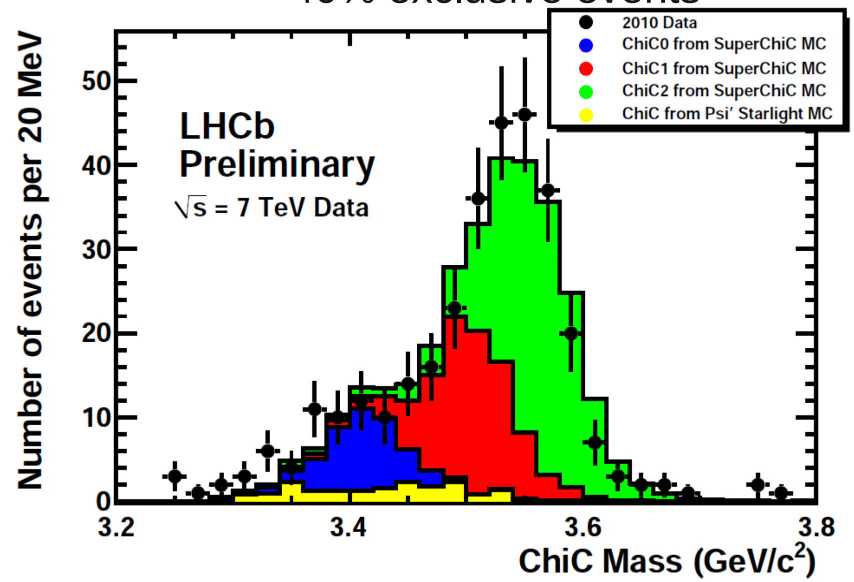
$P_T(\mu\mu)$<900 MeV/c, two tracks, 1 photon for χ_c

No background subtracted. ~80% exclusive events





~40% exclusive events



Result and theory predictions

1) σ(QED): 67 ± 10 ± 5 ± 15 pb

2) σ(J/ψ): 474 ± 12 ± 45 ± 92 pb
3) σ(ψ(2S)): 12.2 ±1.8 ±1.2 ± 2.4 pb
4) σ(ψ(2S))/σ(J/ψ): 0.20 ± 0.03

5) σ(χc0): 9.3 ± 2.2 ± 3.5 ± 1.8 pb
6) σ(χc1): 16.4 ± 5.3 ± 5.8 ± 3.2 pb
7) σ(χc2): 28.0 ± 5.4 ± 9.7 ± 5.4 pb

Luminosity

1) 42 pb (**LPAIR**)

2) 292 pb (**Starlight**) 330 pb (**SuperChic**) 330 pb (**Motyka&Watt**) 710 pb (**Schafer&Szczurek**)
3) 6.1 pb (**Starlight**) 17 pb (**Schafer&Szczurek**)
4) 0.16 (**Starlight**) 0.2 (**Schafer&Szczurek**)
0.166 ± 0.012 (**HERA**) 0.14 ± 0.05 (**CDF**)

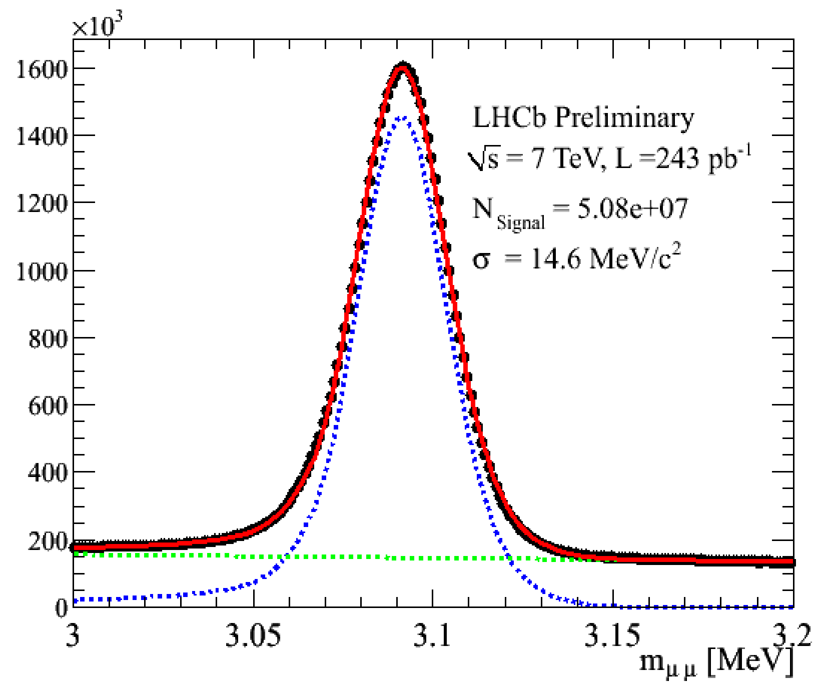
5) 14 pb (**SuperChic**)
6) 10 pb (**SuperChic**)
7) 3 pb (**SuperChic**)

Summary

- LHCb performed many analysis of the quarkonium states using 2010 collected data
  - Good agreement of ψ(2S) cross section measurement with NRQCD
  - These results are useful to test theoretical models
  - Good agreement of Y(1S) cross section
  - Some disagreement of χ_{c2} and χ_{c1} cross section ratio with theory models
  - Comparison of different exclusive dimuon production cross sections with theory predictions

- Results from X(...) states
  - Precise measurement of X(3872) mass
  - X(3872) production cross section measurement
  - LHCb doesn't confirm CDF X(4140)

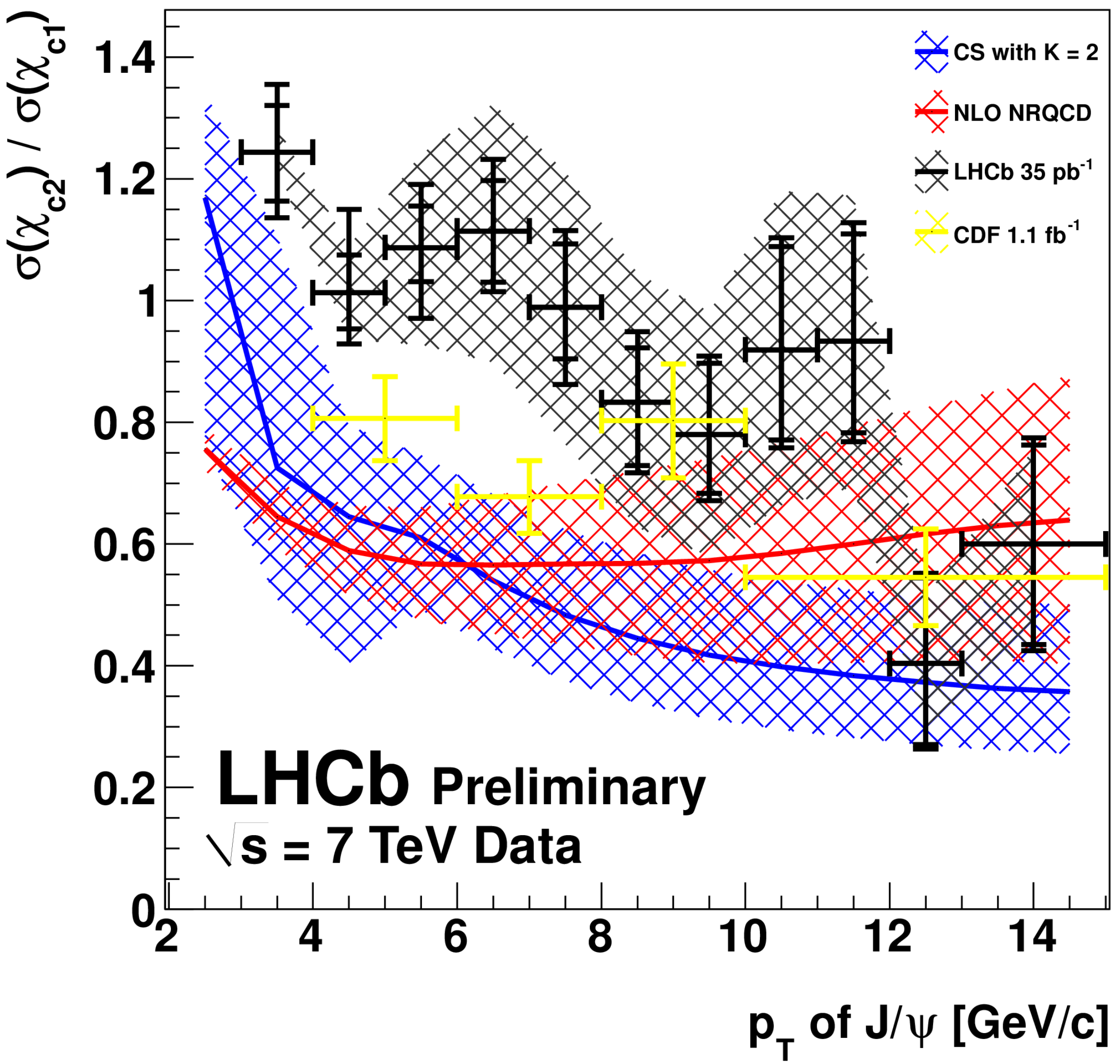
- LHCb has a very high J/ψ statistic in 2011 data
  - 564 pb^{-1} recorded so far
  - 1 fb^{-1} expected in 2011
  - A lot of new results expected in the future



Number of J/ψ in 2011 data

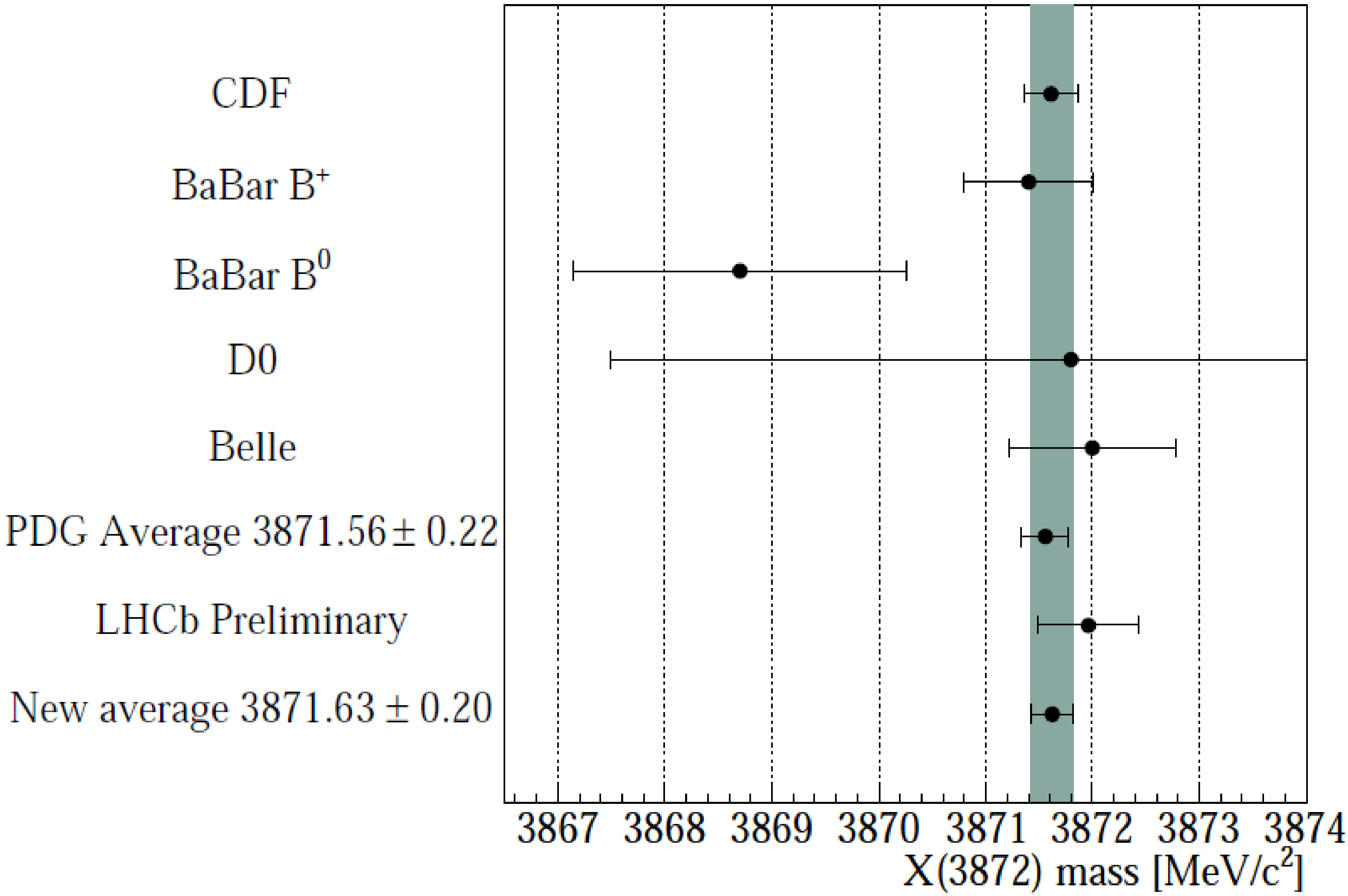
Backup slides

χ_{c2},χ_{c1}: comparison with CDF results



X(3872) mass average

Average according to the prescriptions of PDG 2010



X(3872) : mass measurement syst.

Signal Modeling

- Vary fit range
- Vary natural width from 0 – 2.6 MeV
- Embed MC in same-sign background and check for bias from background fit model

Calibration

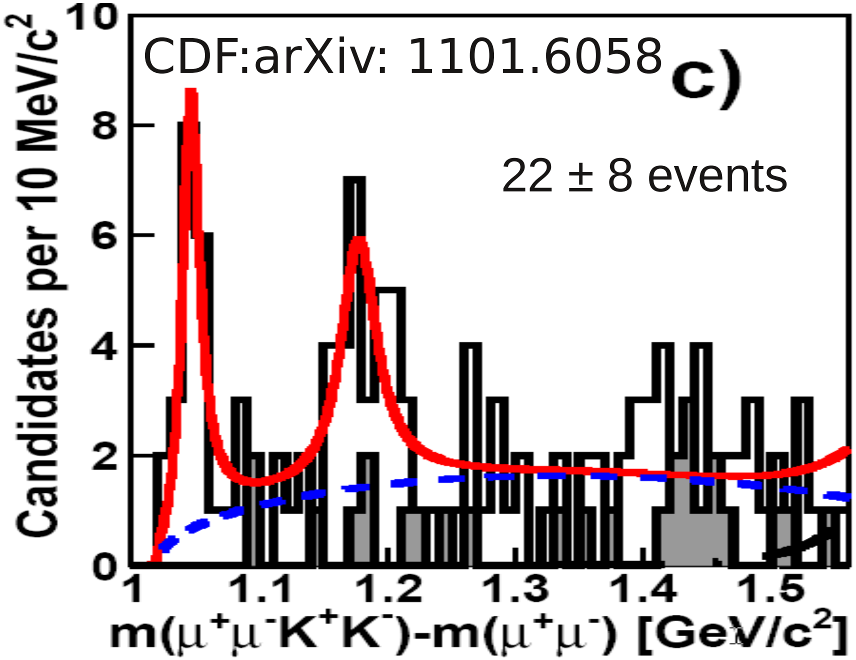
- Vary momentum scale by ± 0.1 per mille [quoted uncertainty]
- Parameterize residual η bias and make dependent scale factor
- Vary amount of material by 10 %

Alignment

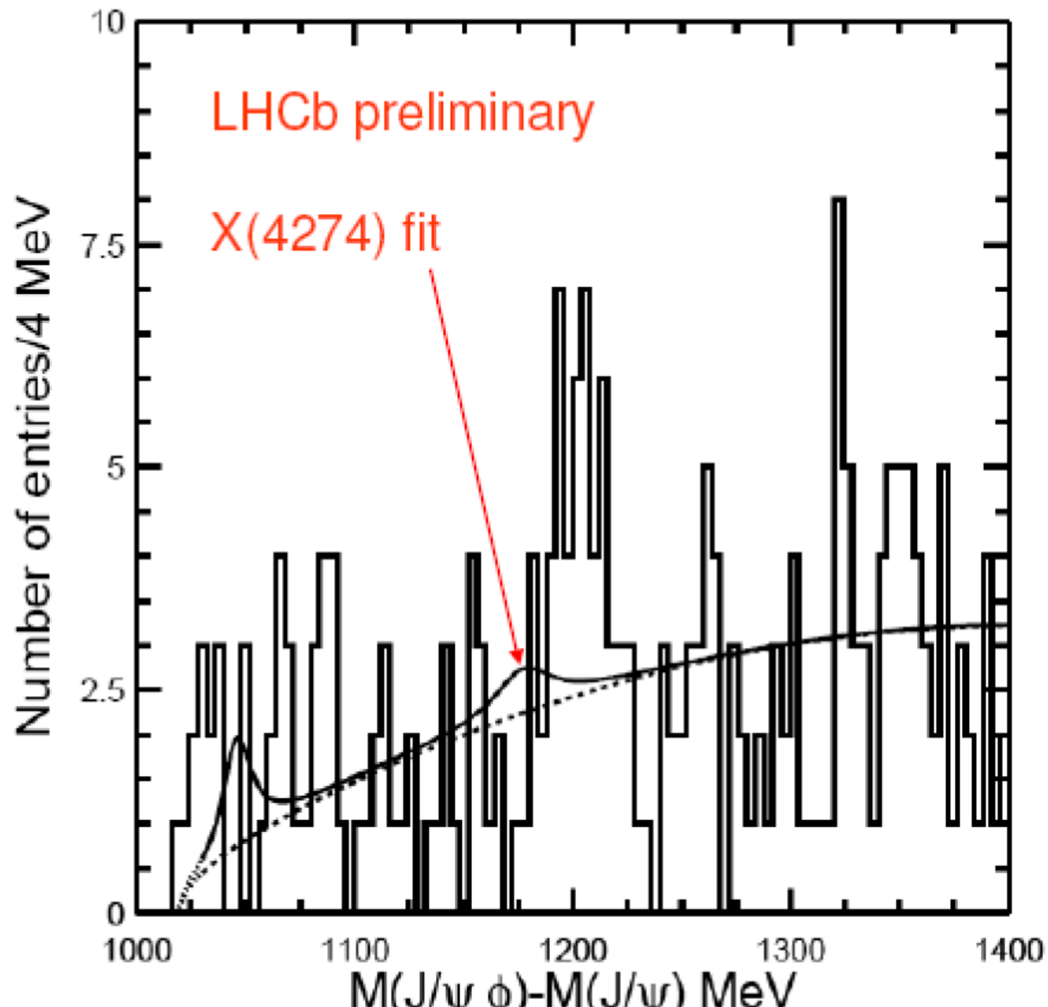
- Drop TT hits and repeat procedure
- Scale track slopes in velo by per mille

Source of uncertainty	Value $[MeV/c^2]$
Mass fitting:	
Natural width	0.02
Background model	0.02
Fit range	0.01
Momentum calibration:	
Average momentum scale	0.05
η dependence of momentum scale	0.03
Detector description:	
Energy loss correction	0.05
Detector alignment:	
Tracking stations (TT information)	0.05
Vertex detector (track slopes)	0.01
Quadratic sum	0.10

LHCb fit of X(4274)



49 ± 18 events expected from CDF results assuming the same efficiency of X(4140) from CDF



$BR(B^+ \to X(4274)K^+, X(4274) \to J/\psi\phi) / BR(B^+ \to J/\psi\phi K^+) < 0.08$ (90% C.L.)