EPS-HEP-2011

Grenoble July 21 – July 27, 2011

Quarkonium production at LHCb

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On behalf of the LHCb collaboration

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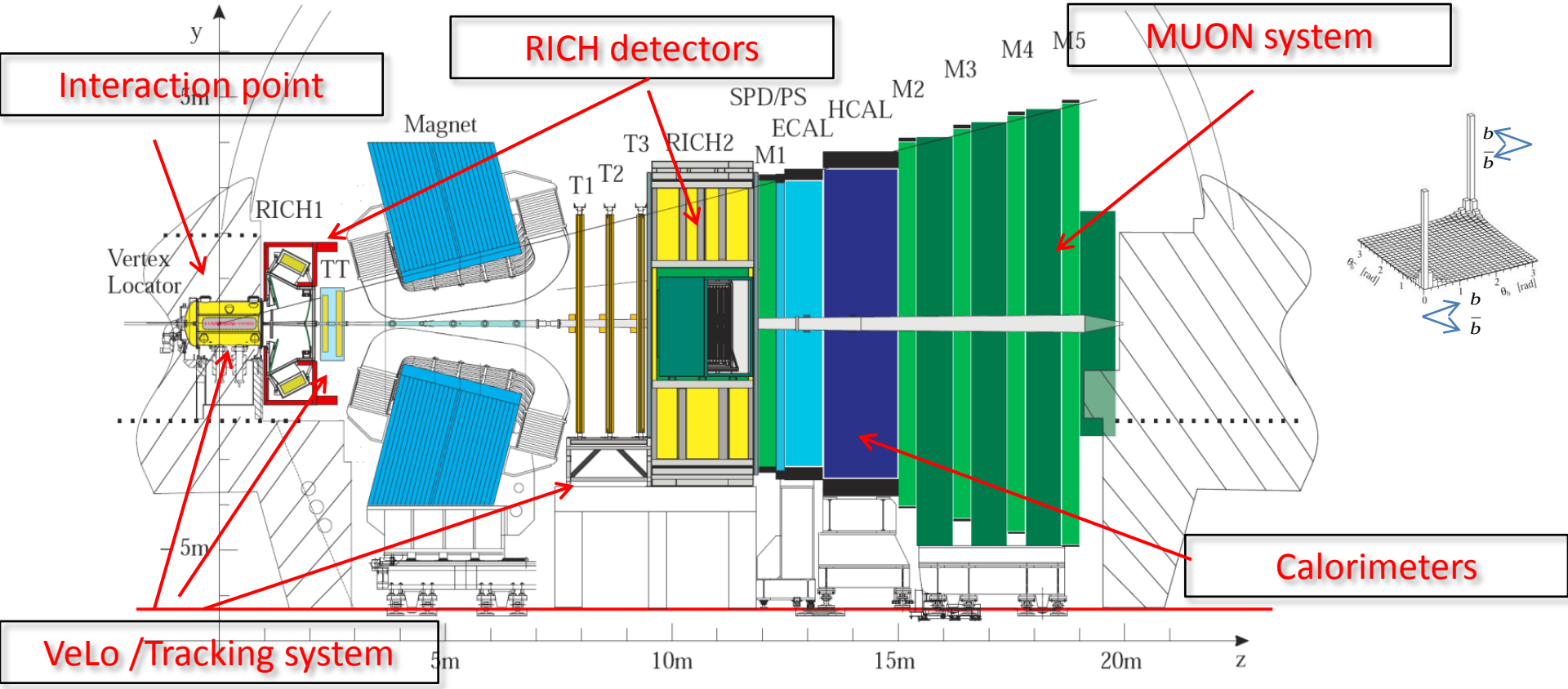
Outline

- Detector overview
- $\psi(2s)$ production
- χ_{c1} , χ_{c2} cross section ratio measurement
- Exclusive dimuon production (poster (ID 419) by Tara)
- $\Upsilon(1S)$ production
- χ_b observation at LHCb
- X(3872) production and mass measurement
- X(4140) search at LHCb

All results are preliminary

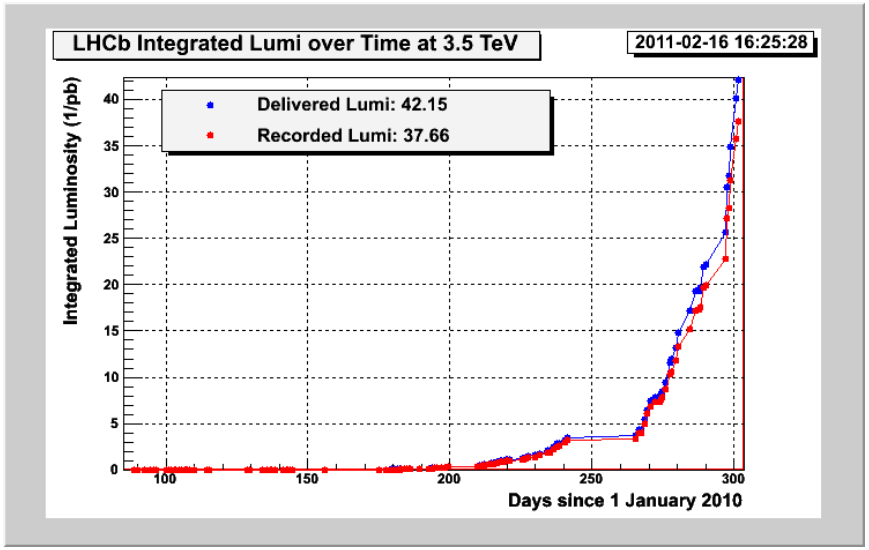
LHCb detector



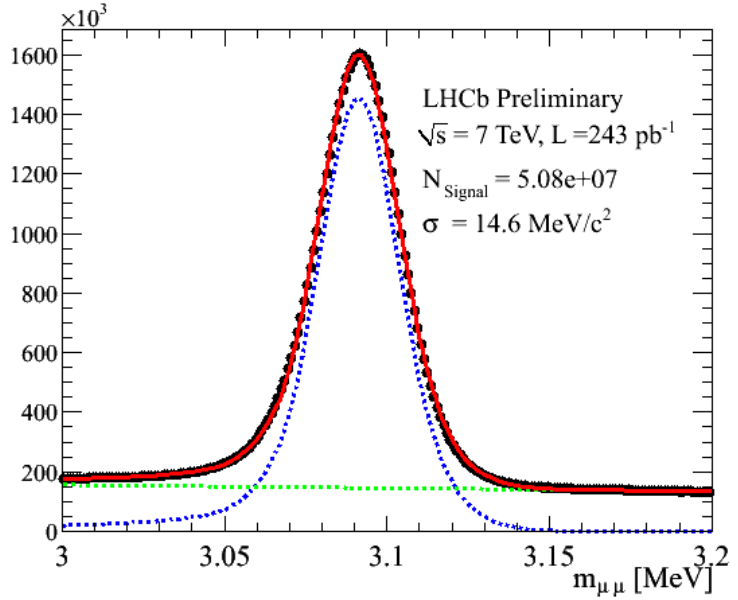
- Forward region spectrometer ($1.9 < \eta < 4.9$), 4% solid angle, 40% b-hadron cross section
- Excellent tracking: PV resolution σ_{xy}~15μm, σ_z ~75μm,
  ε>90% for tracks above few GeV, B mass resolution ~ 20 MeV
- Excellent particle identification, π/K separation over 2-100GeV, hadron mis-ID to μ ~2%
- Efficient triggers: low p_T lepton and γ, hadron thresholds

Data taking 2010/2011

LHCb 2010 luminosity



LHCb 2011



✓overall data taking efficiency ~90%
✓ ~37pb^{-1} integrated luminosity
✓ with all sub detectors fully operational

Most of the analyses based on 2010 data

LHCb expects to collect 1 fb^{-1} in 2011
✓ ~390pb^{-1} recorded already
✓ analysis updated with new data

The X(4140) analysis includes 2011 data

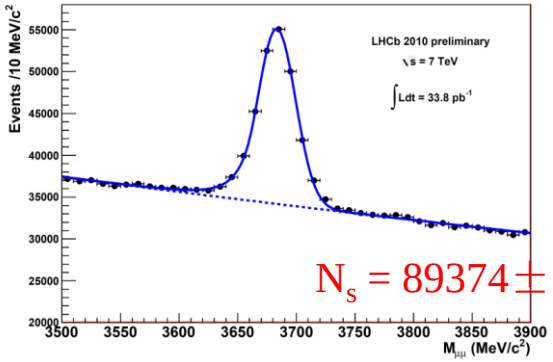
ψ(2S) production cross-section

No feed down from higher states, cleaner in theory

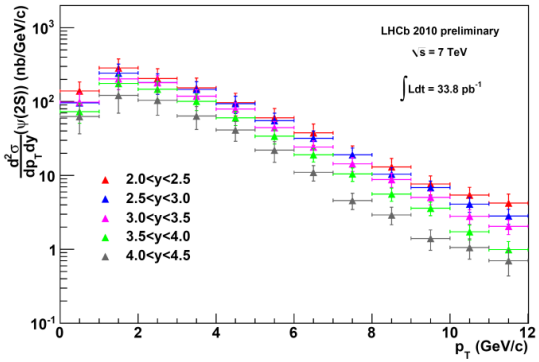
Both μμ mode and J/ψππ mode used

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

μμ mode

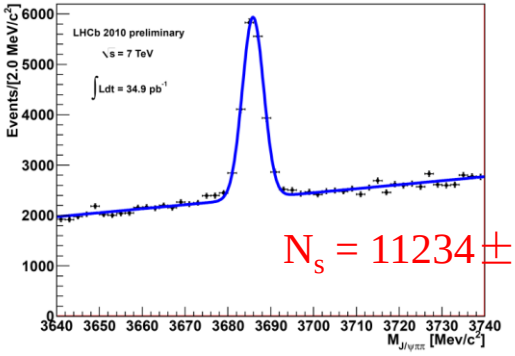


$N_s = 89374 \pm 718$

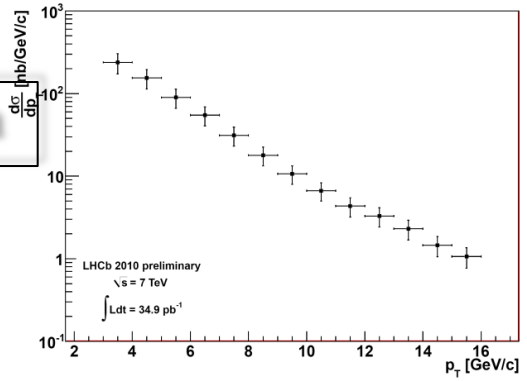


double differential cross section in y and p_T

J/ψππ mode



$N_s = 11234 \pm 174$



differential cross section in p_T

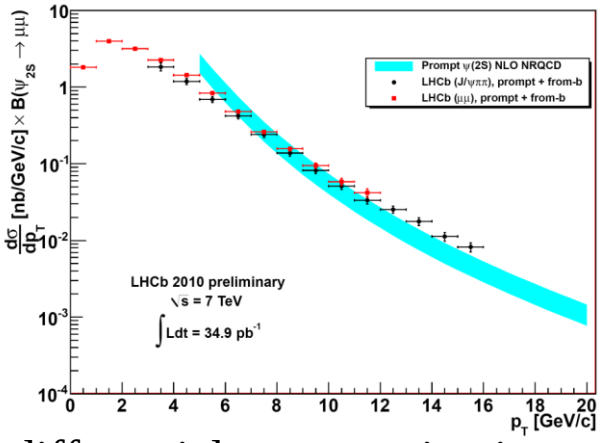
LHCb 2010 data

ψ(2S) production cross-section (cont.)

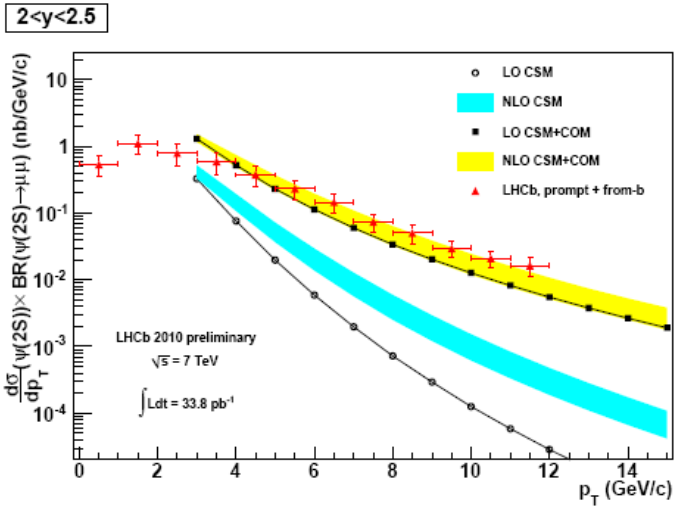
Unknown polarization

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

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



differential cross section in p_T



double differential cross section in y and p_T

LHCb data include ψ(2S) from b decay, 10% at low p_T, up to 40% to high p_T

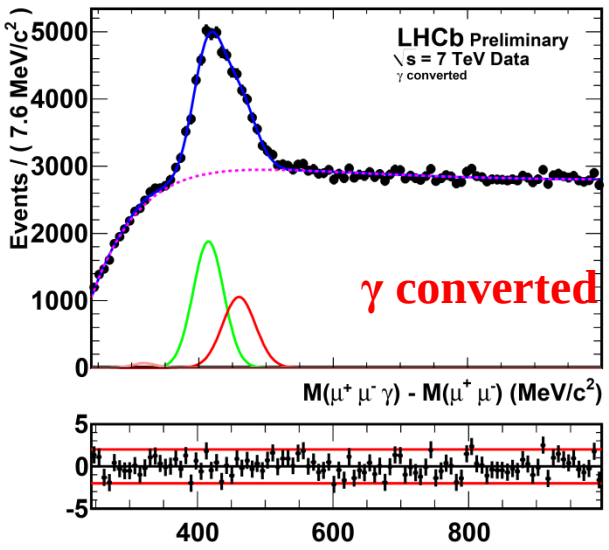
Results and theory agree very well

χ_{c1} , χ_{c2} cross section ratio study

$$\frac{\sigma(\chi_{c2})}{\sigma(\chi_{c1})} = \frac{N_{\chi_{c2}}}{N_{\chi_{c1}}} \cdot \frac{\epsilon_{J/\psi}^{\chi_{c1}} \epsilon_{\gamma}^{\chi_{c1}} \epsilon_{sel}^{\chi_{c1}}}{\epsilon_{J/\psi}^{\chi_{c2}} \epsilon_{\gamma}^{\chi_{c2}} \epsilon_{sel}^{\chi_{c2}}} \cdot \frac{B(\chi_{c1} \rightarrow J/\psi\,\gamma)}{B(\chi_{c2} \rightarrow J/\psi\,\gamma)} \qquad \frac{B(\chi_{c2} \rightarrow J/\psi\gamma)}{B(\chi_{c1} \rightarrow J/\psi\gamma)} = \frac{(19.5 \pm 0.8)\%}{(34.4 \pm 1.5)\%}$$

Efficiencies cancel out, lower systematic uncertainty

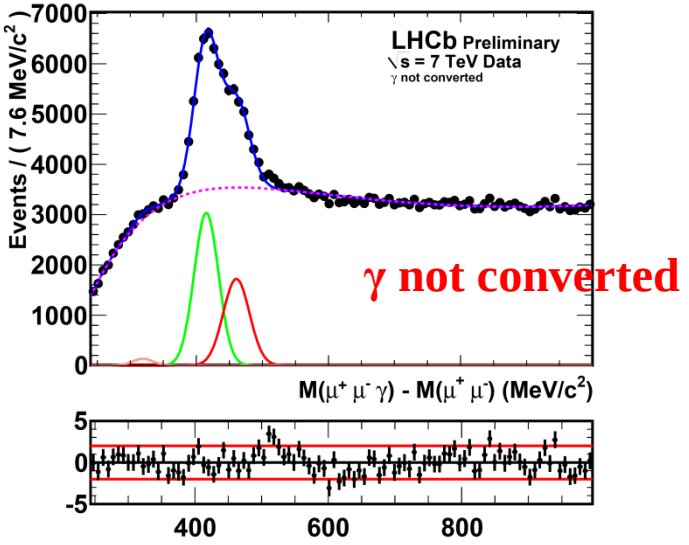
$\chi_c \rightarrow J/\psi\,\gamma$: converted γ (e^+e^- clusters) and not converted γ (γ cluster) treated separately



~35.6 pb^{-1}

χ_{c2}

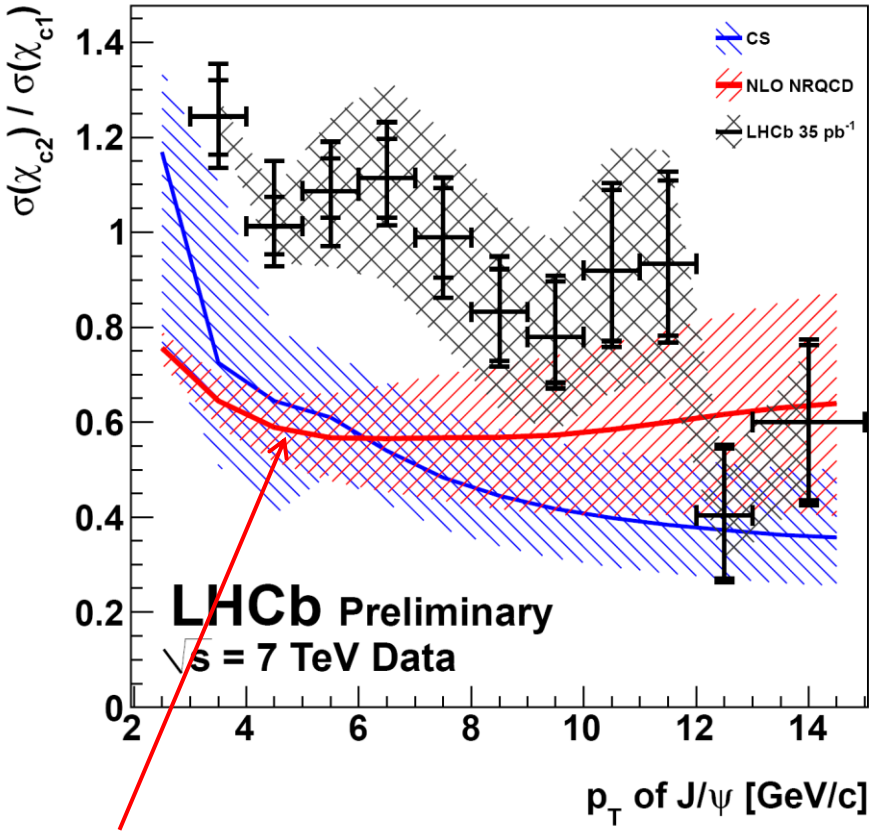
χ_{c1}



Yields from fit to χ_c J/ψ mass difference

LHCb 2010 data

χ_{c1} , χ_{c2} cross section ratio study (cont.)



The NRQCD also used for the ψ(2S) cross section prediction.

Results in J/ψ p_T bins

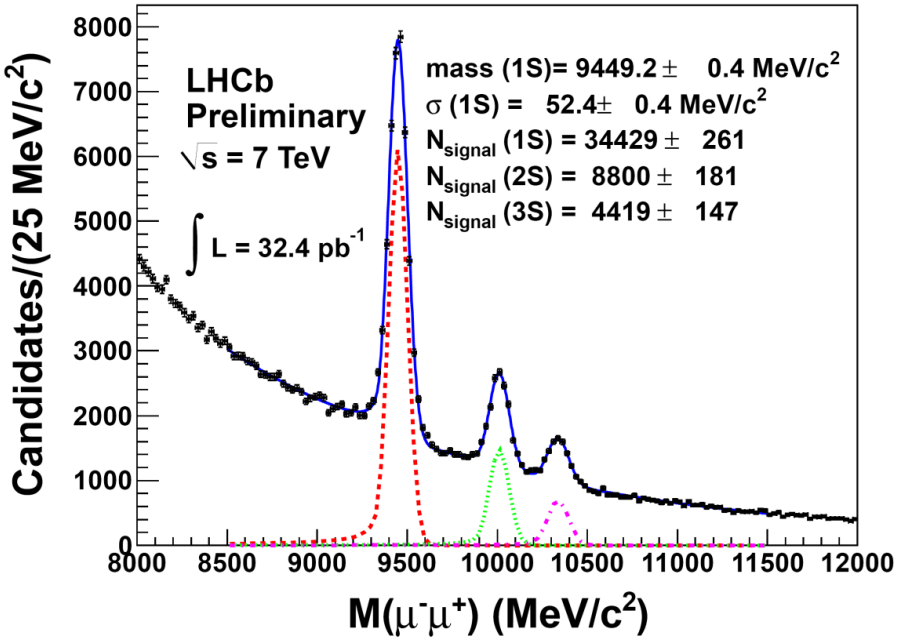
Internal error bars: statistical error from the yield extraction
External error bars: systematic uncertainty included
✓decay branch fractions
✓stability of fit
✓MC statistics
Shaded area (black): maximum effect of unknown polarization
Shaded area (red/blue): theory prediction

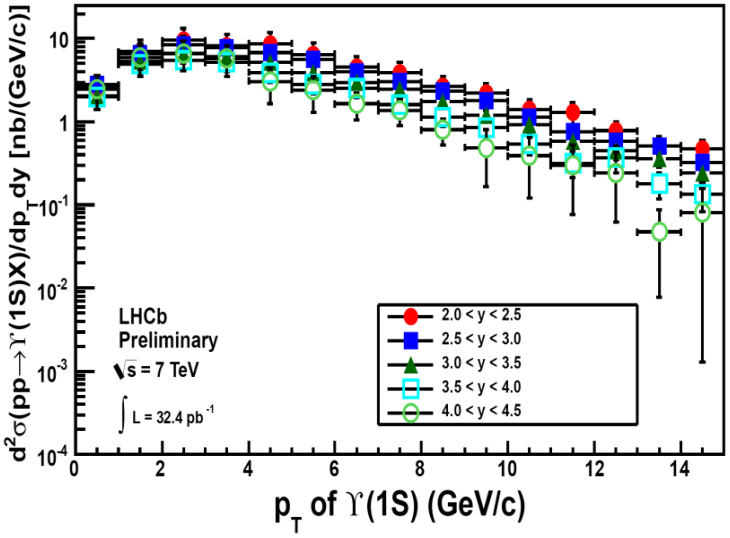
Data and theory not consistent at mid and low p_T !

$\Upsilon(1S)$ production measurement

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

LHCb 2010 data





$\Upsilon(1S)$ double differential cross section y & p_T

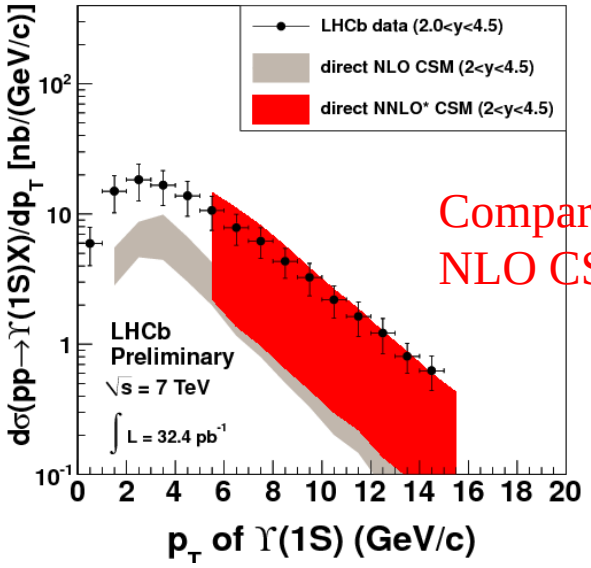
Crystal Ball + Exponential fit to mass shape

$\Upsilon(2S)$,$\Upsilon(3S)$ is understudy

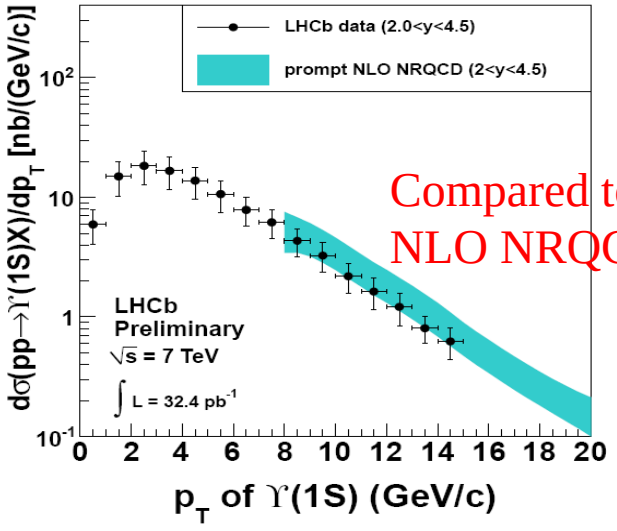
$$\sigma(pp \to \Upsilon(1S)X; 0 < p_T < 15\,\mathrm{GeV}/c, 2 < y < 4.5) = 108.3 \pm 0.7\,^{+30.9}_{-25.8}\,\mathrm{nb}$$

Main systematic uncertainty includes unknown polarization (20nb), luminosity (11nb)

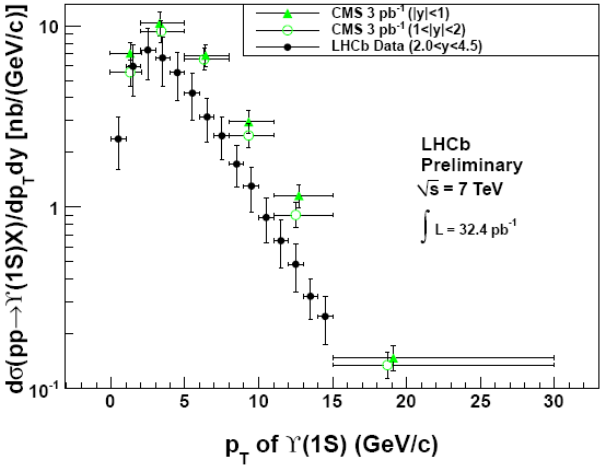
Υ(1S) production measurement



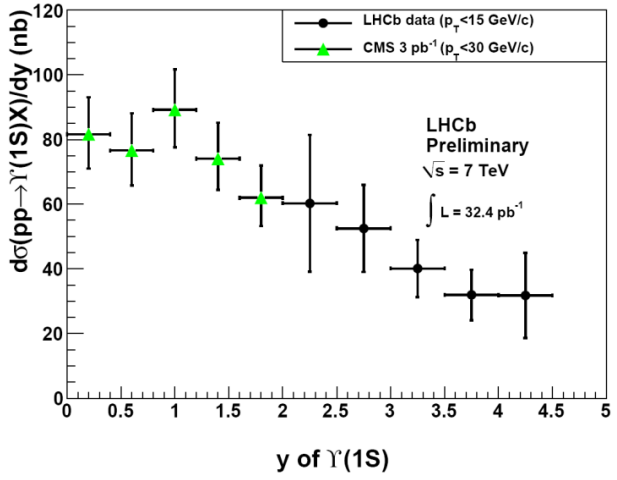
Compared to NLO CSM



Compared to NLO NRQCD



Compared to CMS acceptance region

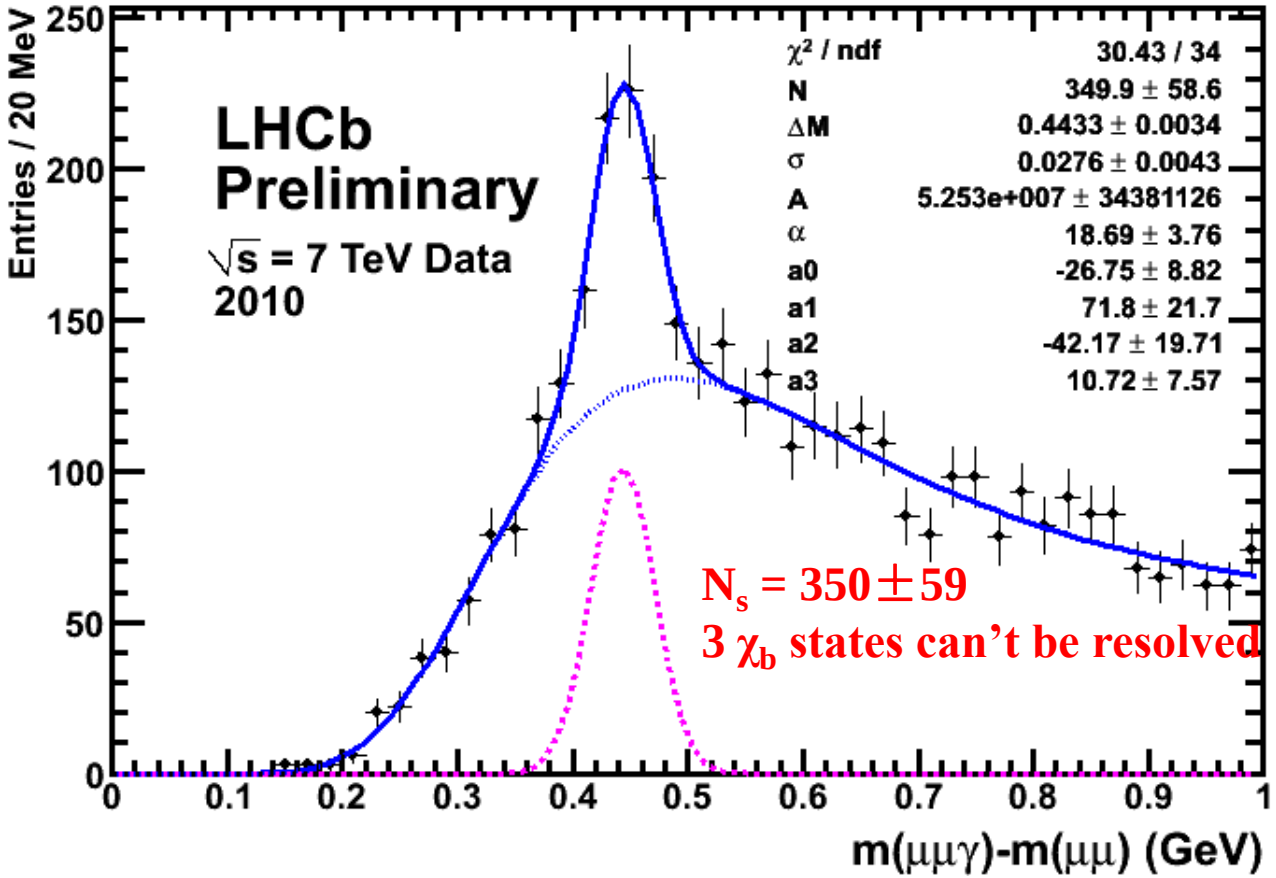


Observation of χ_b

χ_b constructed from $\Upsilon(1S)$ and photon

~37pb^{-1} LHCb 2010 data

Photon energy measured by calorimeter



NEW

Clear χ_b signal, LHCb plans to measure the cross section

X(3872) production/mass measurement

- Exotic meson, internal structure uncertain, precise mass crucial
- At LHCb reconstructed mass calibrated by scaling the track momentum

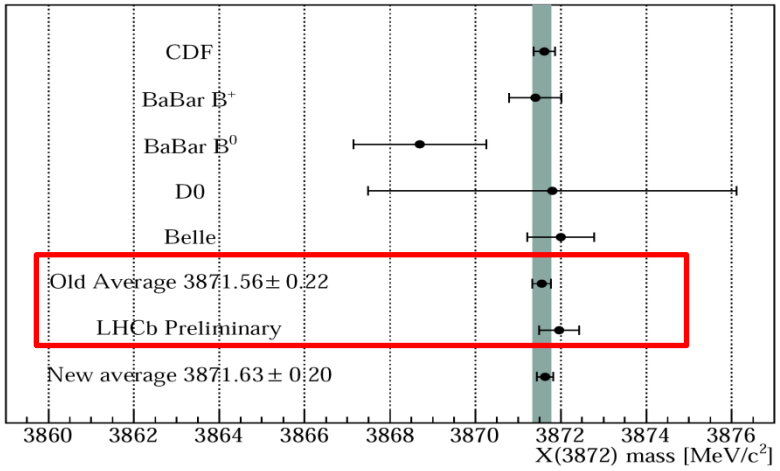
Decay	Measured mass [MeV/c^2]	PDG average [MeV/c^2]
$\Upsilon(1S) \to \mu^+\mu^-$	9459.90 ± 0.54	9460.30 ± 0.26
$J/\psi \to \mu^+\mu^-$	3096.97 ± 0.01	3096.916 ± 0.011
$D^0 \to K^-\pi^+$	1864.75 ± 0.07	1864.83 ± 0.14
$K^0_S \to \pi^+\pi^-$	497.62 ± 0.01	497.61 ± 0.02

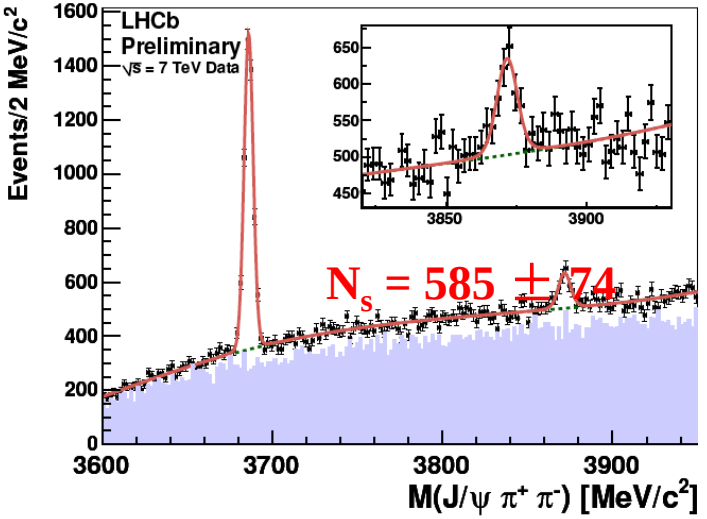
~35 pb^{-1} 2010

- checked by control channel: $\psi(2S) \to J/\psi\pi\pi$

  3686.12 ±0.06 MeV (LHCb calibrated)

  3686.09 ±0.04 MeV (PDG)





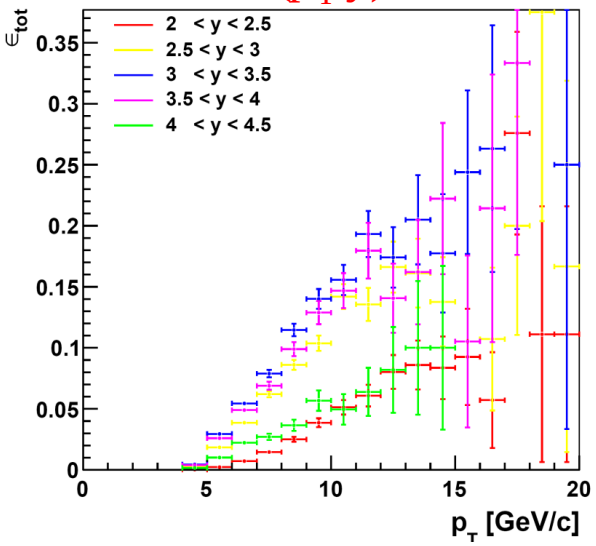
$$M(X) = 3871.96 \pm 0.46(\text{stat}) \pm 0.1(\text{syst}) \text{MeV}/c^2$$

X(3872) production/mass measurement

Statistics limited, weight every event by $1/\varepsilon(p_T,y)$.

Fiducial region: $2.5<y<4.5$, $5< p_T<20$ GeV/c

$\varepsilon(p_T,y)$



Signal distribution is modeled by
Gaussian convoluted with Breit-Wigner
$\Gamma_{BW} \equiv 1.3$ MeV(from CDF)

Efficiency corrected yield :

$$\frac{N_{X(3872)}}{\varepsilon_{tot}^{MC}} = (9.5 \pm 2.2)\times 10^3$$

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

Systematic uncertainties:

Polarization: 1.4%
Mass resolution: 1.3%
Tracking efficiency: 16%
Decay Width (Γ_{BW}): 12%

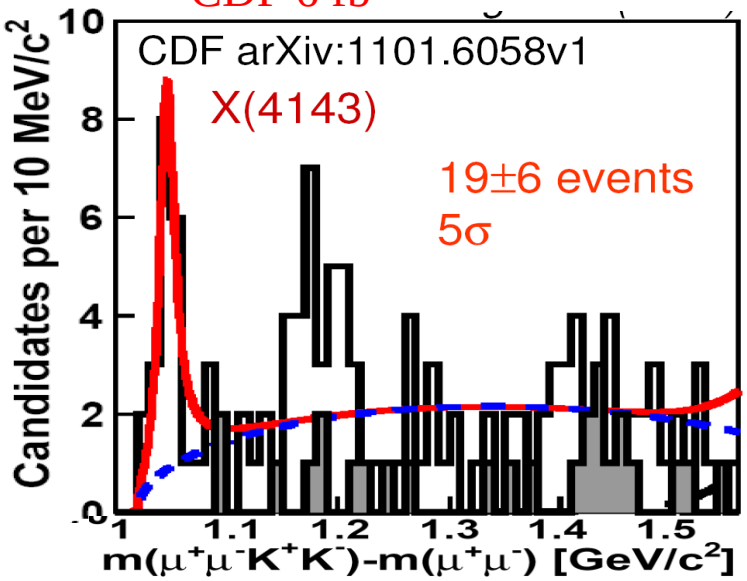
Track quality cuts: 2%
Vertex quality cut: 3%
Trigger: 5%
Luminosity: 3.5%

NEW

X(4140) search

CDF observed structure ($J/\psi\varphi$) in $B^+ \to J/\psi\varphi K^+$ ($\varphi \to K^+K^-$) decay

CDF 6 fb^{-1}

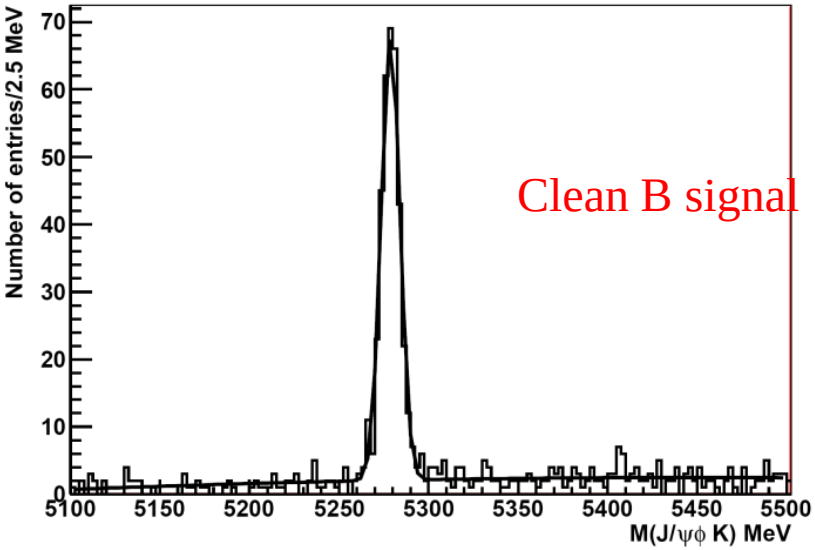


B^+: 115±12 events

X(4140) would be exotic

LHCb $B^+ \to J/\psi\varphi K^+$ ($\varphi \to K^+K^-$)

2010+2011, ~0.4fb^{-1}



B^+: 381±22 events

Tight J/ψ and φ mass cut

NEW

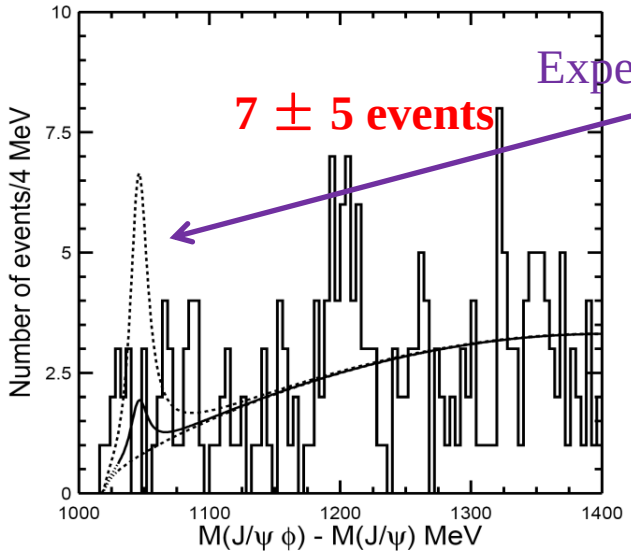
X(4140) search (cont.)

Description of M(J/ψφ)- M(φ):

Signal: Breit-Wigner convoluted with resolution mass width fixed to CDF

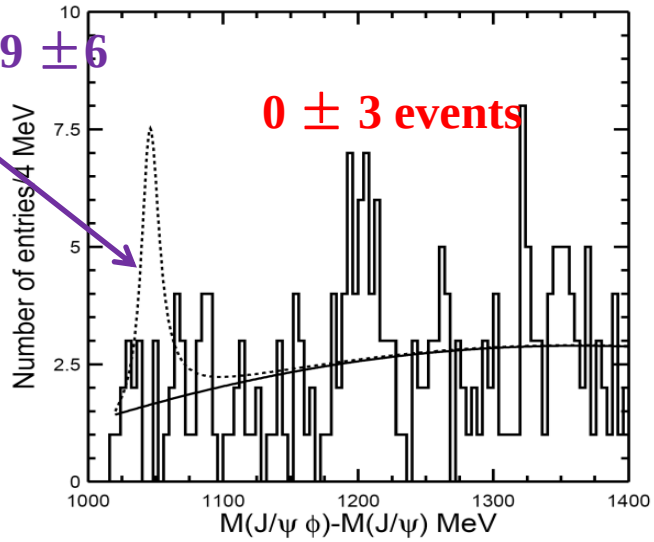
Background:

3-body phase space



Expected: **39 ±9 ±6**

quadratic polynomial



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

< 0.07 for 3-body phase space (90% C.L.)

< 0.04 for quadratic polynomial (90% C.L.)

CDF: $0.149 \pm 0.039 \pm 0024$

LHCb does not confirm X(4140)!

Conclusion

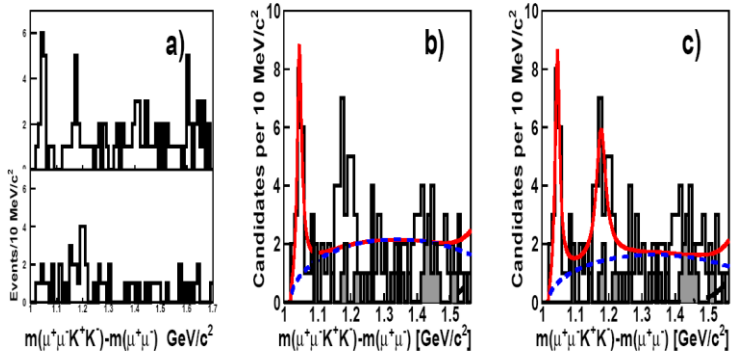
- Many quarkonium states emerged with huge statistics and good quality in LHCb 2010 data
- $\psi(2S)$ production cross section measured in agreement with NRQCD prediction
- χ_{c1} , χ_{c2} cross section ratio disagrees with theory at mid p_T
- $\Upsilon(1S)$ cross section measured at LHCb
- χ_b is observed at LHCb
- X(3872) mass measured in agreement with PDG value, cross section also given
- LHCb does not confirm the CDF X(4140)

backup slides

X(4140) search

CDF observed a narrow structure X →J/ψφ in B → J/ψφK decay arXiv: 1101.6058

LHCb study the same channel, selection and method also used to look for $B_c \rightarrow J/\psi\pi\pi\pi$



282 ± 18 B→J/ψφK events

Fit on J/ψφ and J/ψ mass difference
two background shape models used:

3-body phase space background: $7.5^{+5.2}_{-4.3}$ (CL=3.5%)

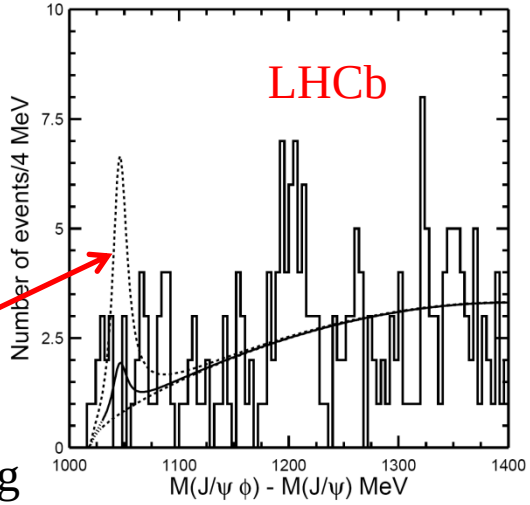
quadratic polynomial: prefer 0 (CL=13%)

$$Br(B \to X(4140)K) / Br(B \to J/\psi\phi K) < 0.03 @ 90\% C.L.$$

While CDF result:

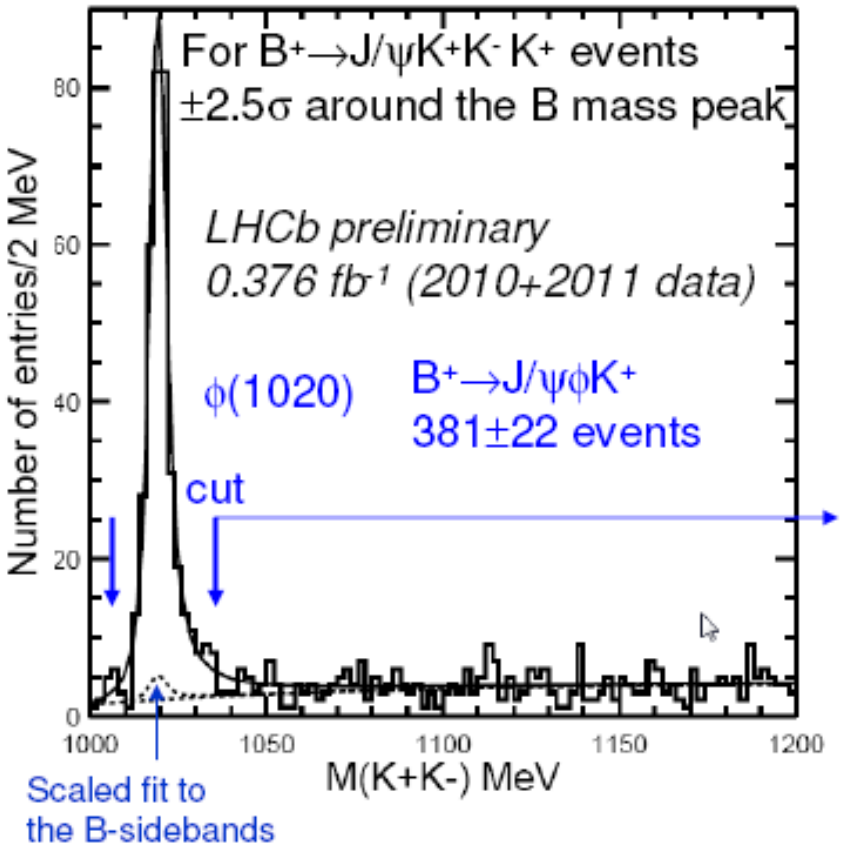
$$0.149 \pm 0.039 \pm 0.024$$

3σ disagreement



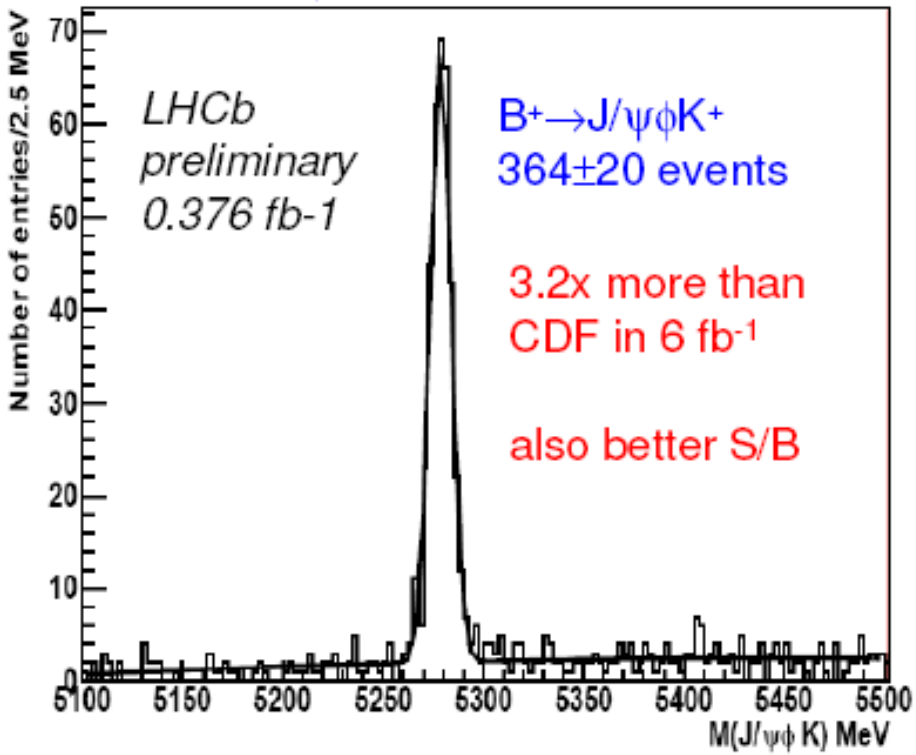
Dotted line: peak assuming CDF branch fraction

LHCb search for X(4140): $B^+ \to J/\psi\phi K^+$ sample



- Loose μ (muon system) and K (RICHes) ID cuts.
- J/ψ mass cut.
- Good $(\mu^+\mu^-)K^+K^-K^+$ vertex, separated from primary vertex but pointing to it.

After the φ mass cut:



LHCb fits to X(4140)

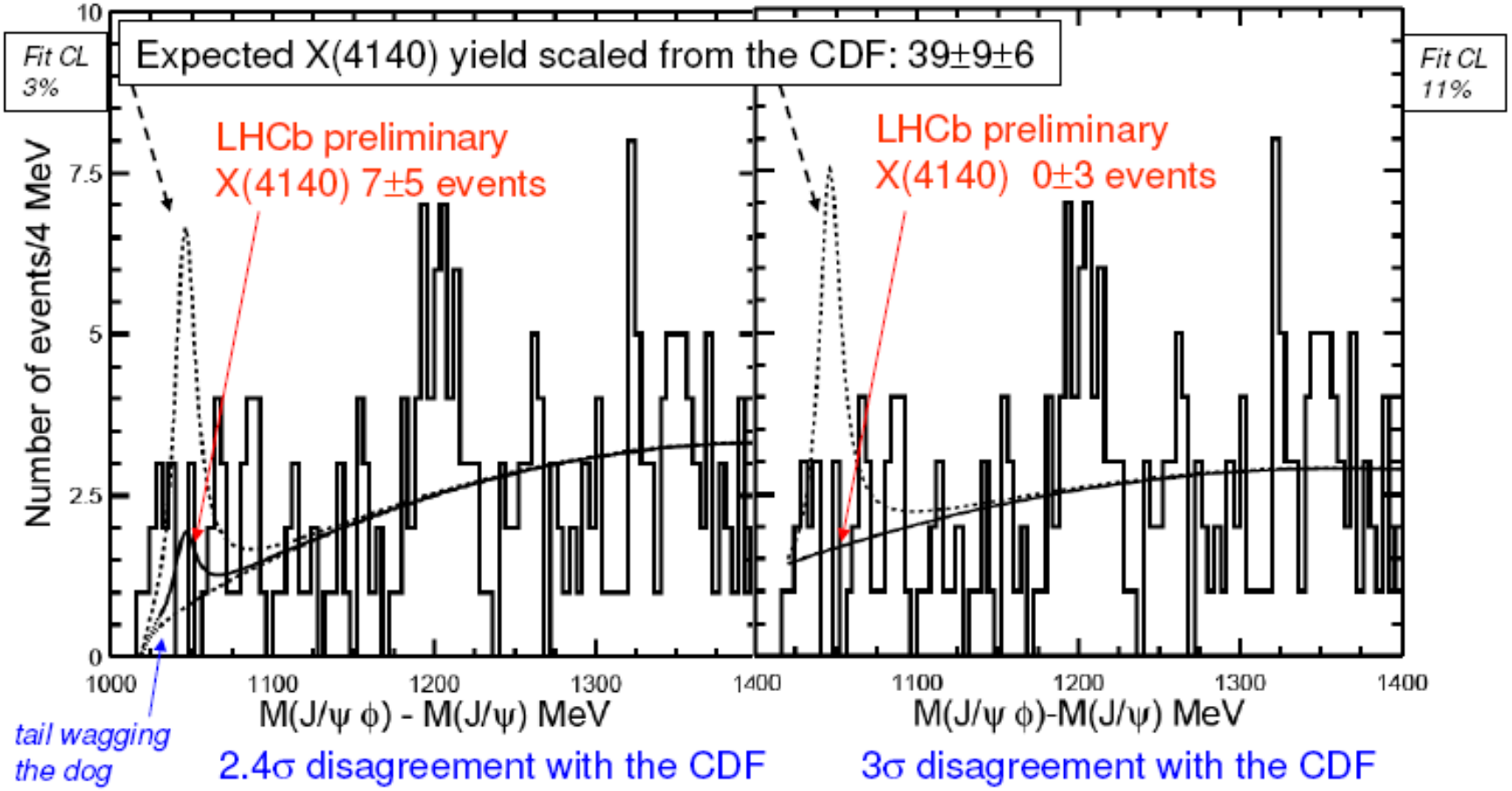
Signal:

P-wave relativistic Breit-Wigner convoluted with resolution (a la CDF)
with mass and width fixed to the CDF values

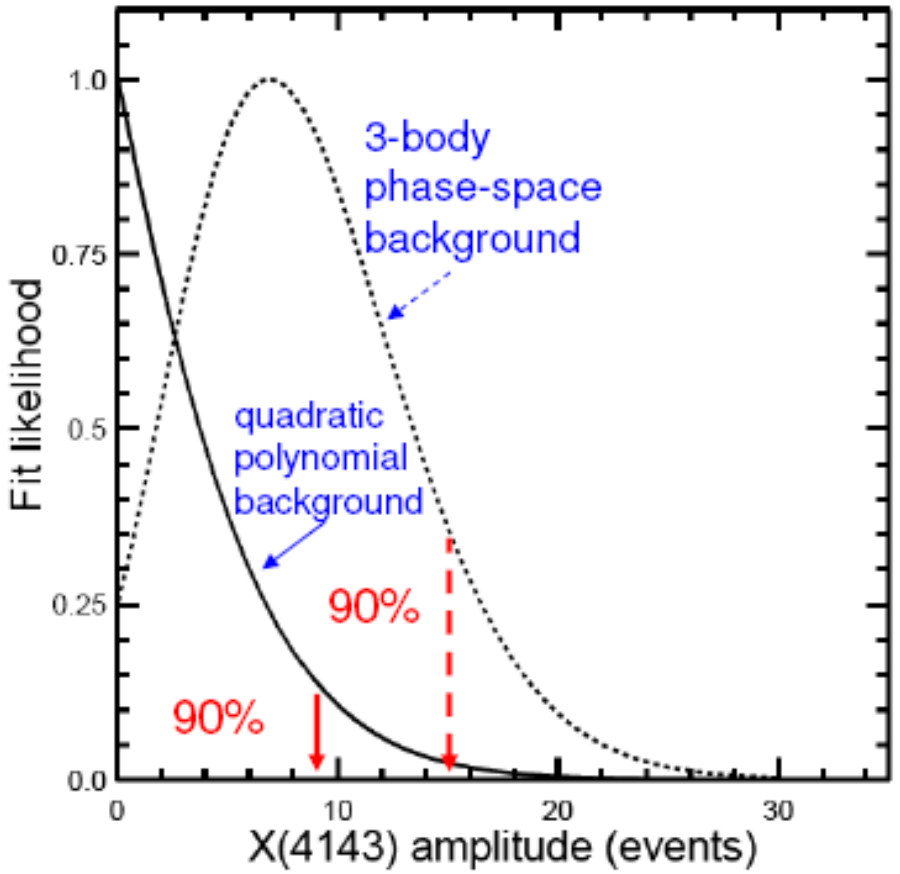
Background:

efficiency-shaped 3-body phase-space convoluted with resolution (a la CDF)

quadratic polynomial



LHCb UL on X(4140)



$BR(B^+ \to X(4140)K^+, X(4140) \to J/\psi\phi) / BR(B^+ \to J/\psi\phi K^+)$

< 0.07 (90% C.L.)

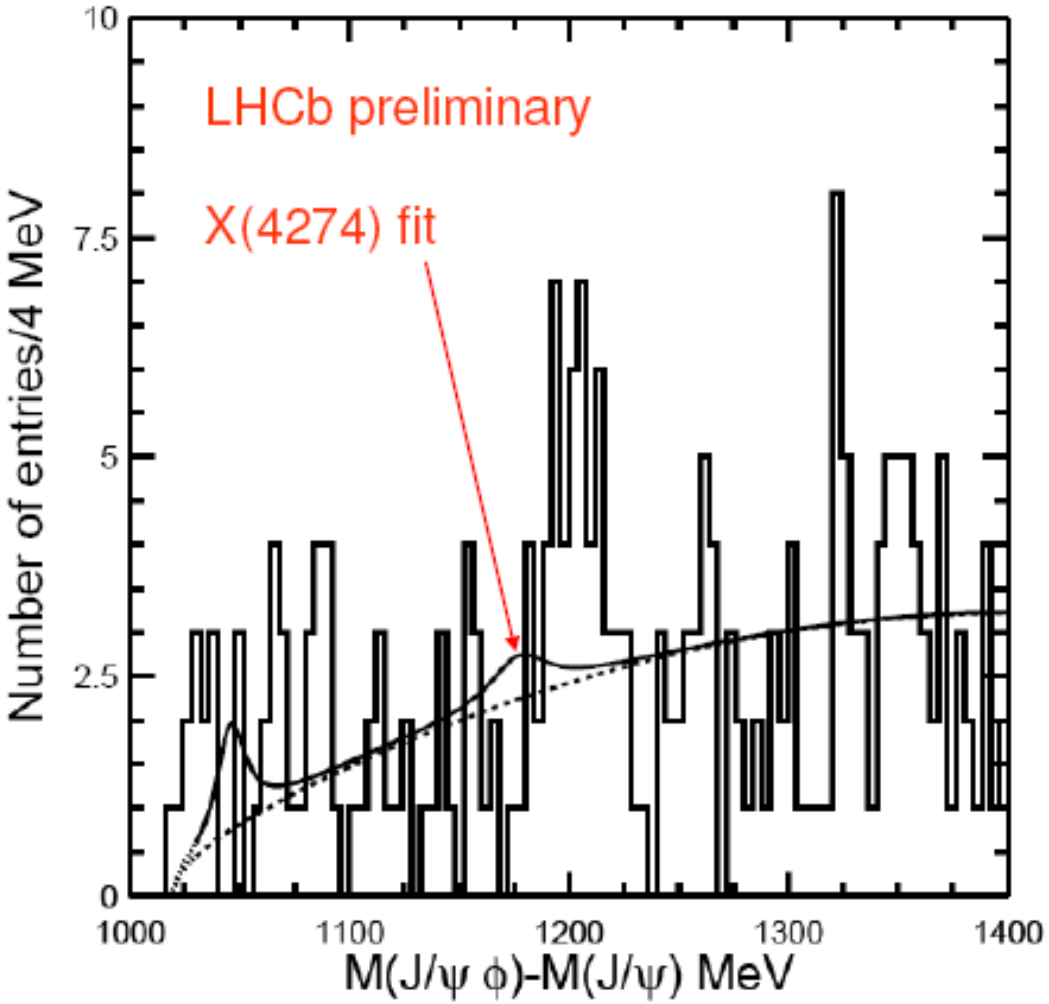
LHCb preliminary

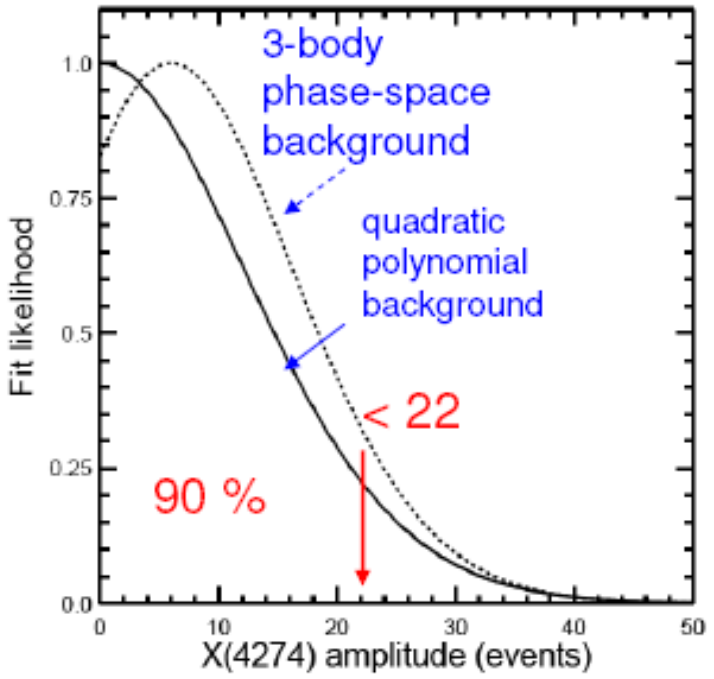
< 0.04 (90% C.L.)

vs CDF:
0.149 ±0.039 ±0.024

- We cannot confirm X(4140) existence

LHCb fits to X(4274)





Assuming CDF efficiency is the same for X(4140) and X(4274) – we expected 49±18 *(CDF stat.)* X(4274) events

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