Exotic spectroscopy and Quarkonia at LHCb

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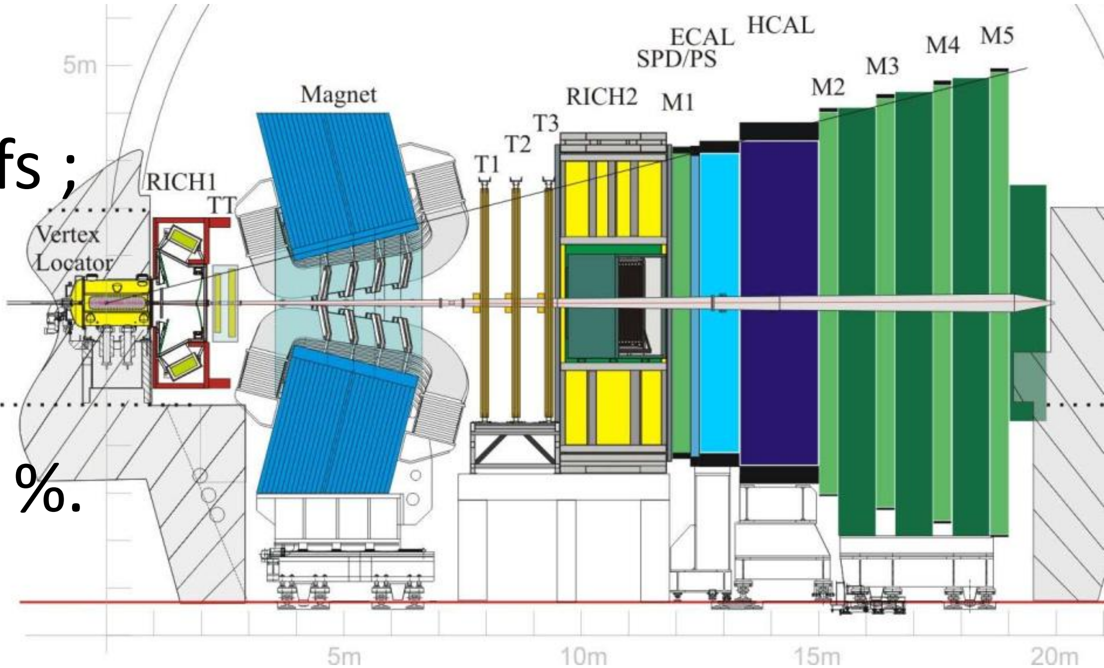
Outline

- Introduction
- Exotic measurement and prospects
  - X(3872) mass measurement;
  - XYZ prospects.
- Quarkonia measurements and prospects
  - $\psi(2S)$ production;
  - χ_{c1}, χ_{c2} cross-section ratio.
- Summary

Introduction: LHCb detector

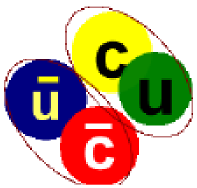
- Characteristics relevant for these analysis:
  - Proper time resolution: 30-50 fs ;
  - μ identification efficiency: ~ 95% ;
  - $\Delta p/p$: 0.35 – 0.55 %.



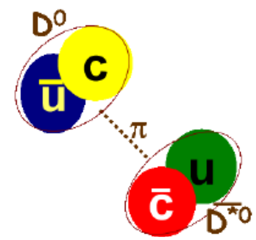
- <u>37 pb^{-1} of data collected at √s = 7TeV in 2010.</u>

Exotic mesons

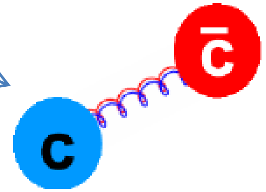
- In recent years, new exotic mesons have been observed by different experiments:
  - X(3872), X(4140), Z(4430)...
- Many models, all with limited success:
  - Tetraquark: Tightly bound four quark.
  - Molecular state: Loosely bound mesons with a quark/color exchange (short distance) or π exchange (large distance).
  - Charmonium hybrids: States with a excited gluonic degree of freedom.



Tetraquark



Molecular

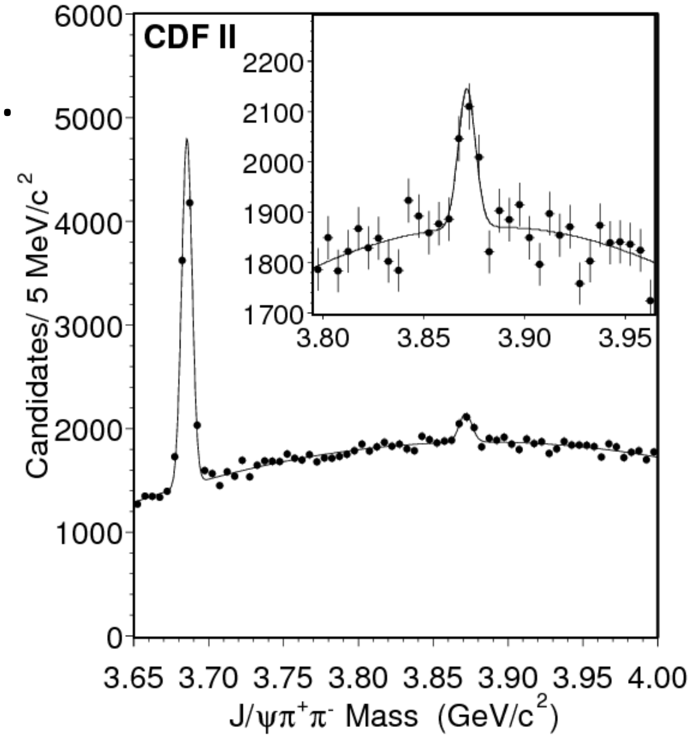


$c\bar{c}$ **hybrid**

X(3872) mass measurement

LHCb-CONF-2011-030

- Motivation
  - Measure X mass using $X \to J/\psi\, \pi^+ \pi^-$.
- Introduction
  - First observed by Belle, confirmed by CDF and Babar;
  - Quantum numbers constrained to be $J^{PC} = 1^{++}$ or 2^{-+}.
- Analysis strategy
  - Using the inclusive production;
  - Based on $L=34.8\ pb^{-1}$ of data;
  - $\psi(2S) \to J/\psi\, \pi^+ \pi^-$ as control channel.



PRL 93:072001, 2004

Fit functions and calibration

- Fit functions:
  - Background(*from same sign background shape*) :

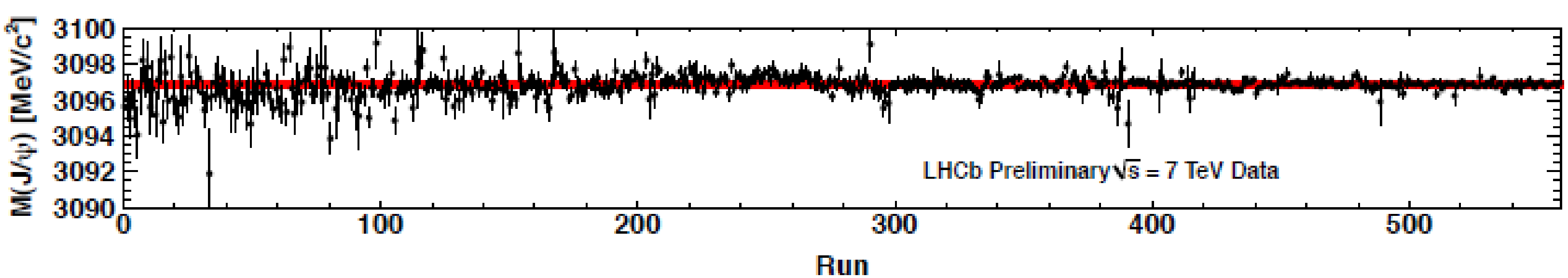
$$F_{bg}(M; m_r, c_0, c_1, c_2) = \frac{1}{a}(M - m_r)^{c_0} e^{-Mc_1 - M^2 c_2}$$

  - Signal Voigt function (*convolution of BW with Gaussian*) :

$$V(M; \mu, \sigma, \Gamma) = \int_{-\infty}^{\infty} G(M - M'; \sigma) L(M'; \mu, \Gamma)\, dM'$$

Fixed

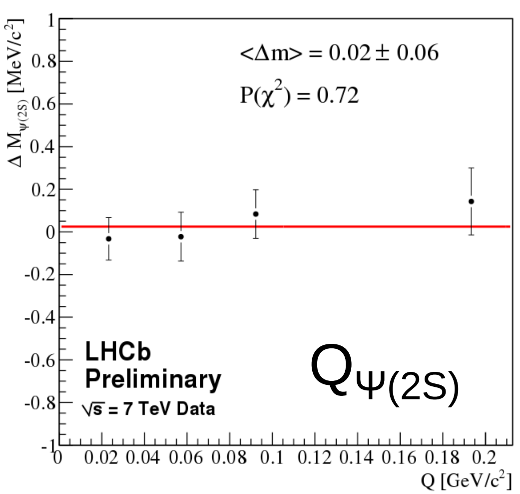
- Calibration
  - J/ψ mass is constant over the whole data-taking.

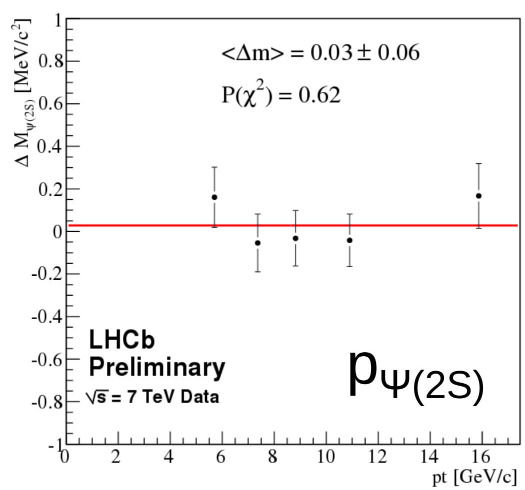


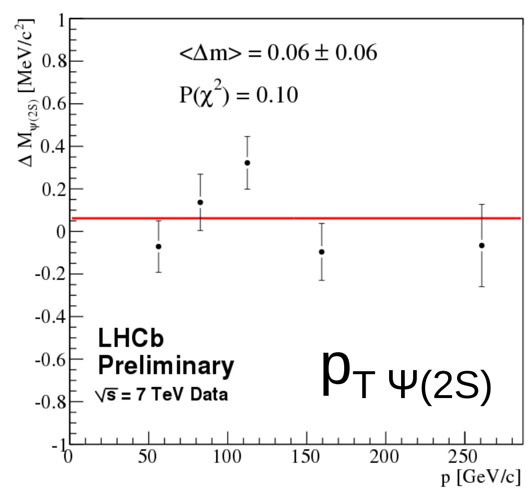
Systematics

- Systematics under control:
  - $M_{\psi(2S)} = 3686.12 \pm 0.06$ (stat) MeV/c^2 consistent with world average (3686.09 ± 0.04 MeV/c^2);
  - The $\psi(2S)$ mass does not depend on any kinematic variables.

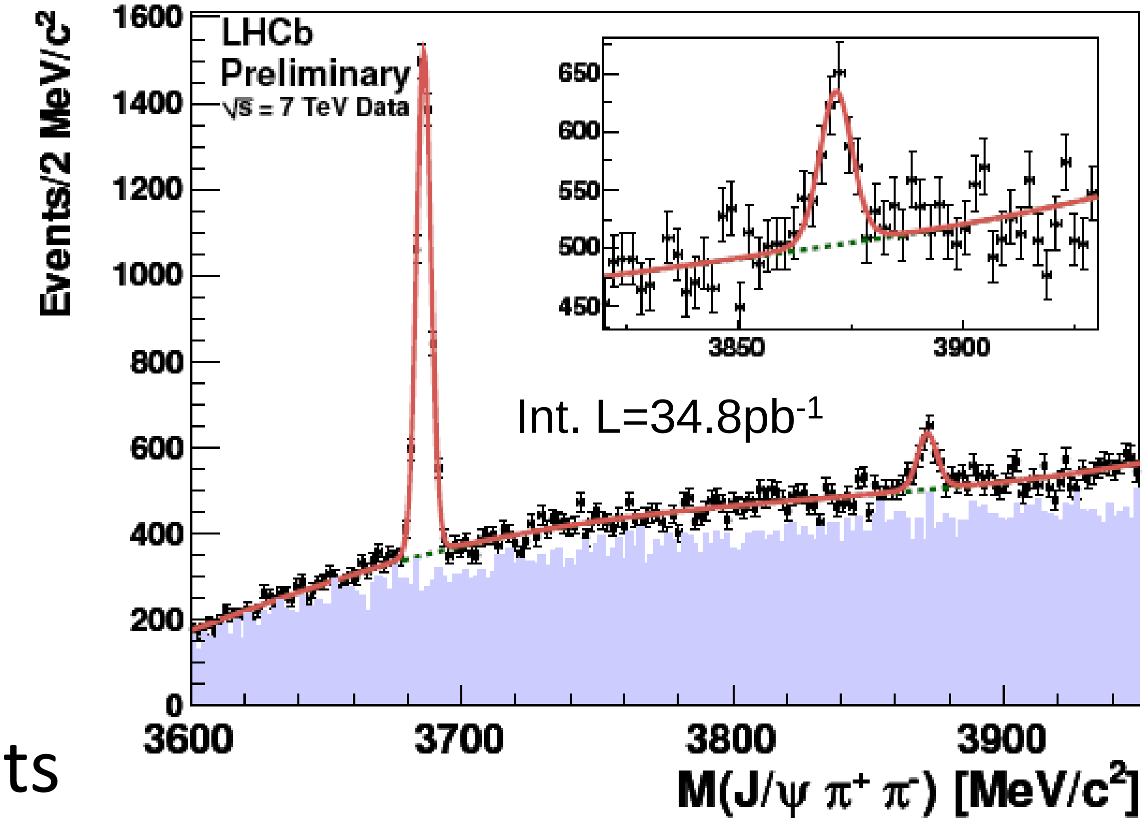
Source of uncertainty	Value [MeV/c^2]
Mass fitting:	
Signal model (natural width)	0.02
Background model	0.02
Momentum calibration:	
Average momentum scale	0.05
η dependence of momentum scale	0.03
Detector description:	
Energy loss correction	0.05
Detector alignment:	
Tracking stations (TT information)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







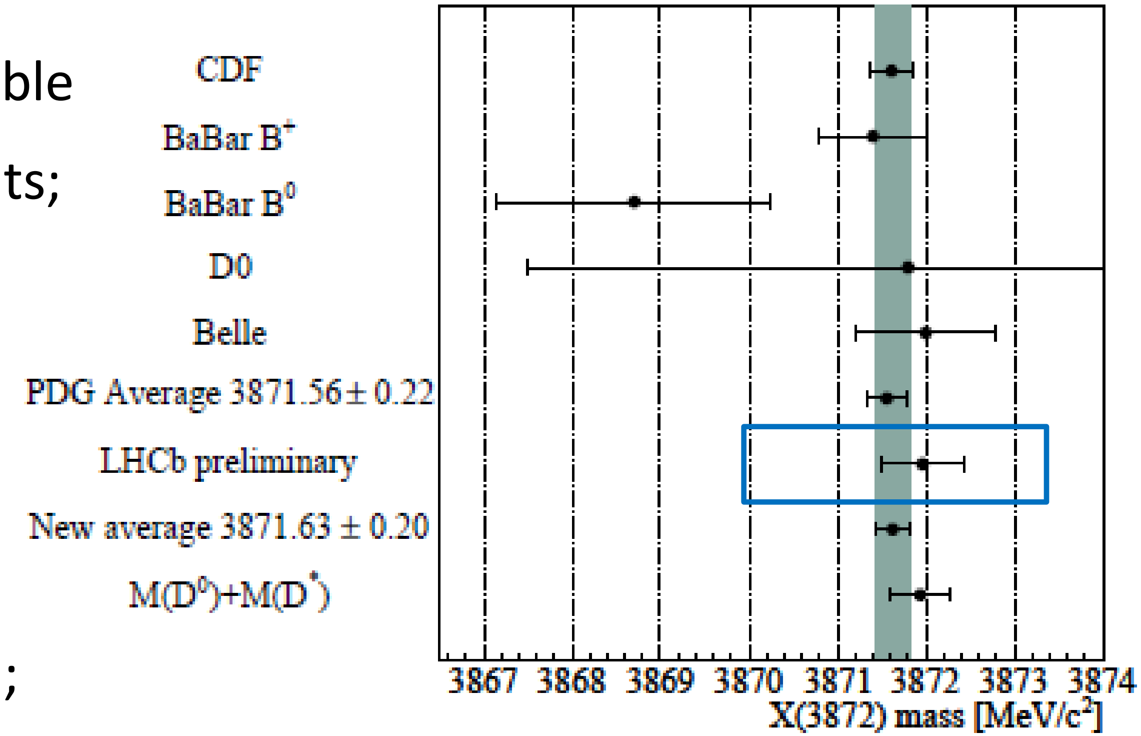
Mass spectrum



- Results
  - $M_{X(3872)}$ = 3871.96 ± 0.46 (stat) ± 0.10 (syst) MeV/c^2
  - $N_{X(3872)}$ = 585 ± 74, σ = 2.75 ± 0.54 MeV/c^2

Comparison with other experiments

- X(3872) mass is compatible with other measurements;
- New average: 3871.63 $\pm$ 0.20 MeV/c^2 , indistinguishable from the $D^{*0}\overline{D}^0$ threshold (3871.79 $\pm$ 0.29 MeV/c^2);



- A statistical error of 0.12 MeV/c^2 is expected with 500 pb^{-1};
- A measurement of the X(3872) mass respect to the $D^{*0}\overline{D}^0$ threshold to reduce systematics will be done too.

X(3872) prospects

- Production cross section measurement, for both of the prompt and b meson component;
  - Studies are underway with 2010 data.
- Determination of the quantum numbers using $B^+ \rightarrow X(3872)\,(J/\psi\,\pi^+\pi^-)\,K^+$; (CERN-LHCb-PUB-2010-003)
  - ~1000 reconstructed X(3872) events are expected with 2 fb^{-1} .
- Study of the $M_{\pi\pi}$;
  - Understand the X(3872) decay mechanism and constrain models.
- X(3872) width;
  - Now (PDG): $\Gamma < 2.3$ MeV/c^2, CL = 90%

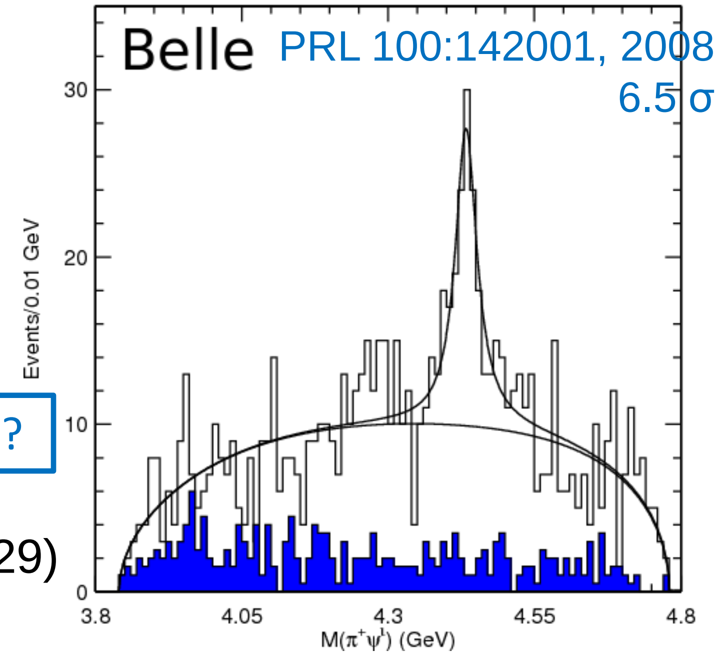
2011 data

Other exotic prospects

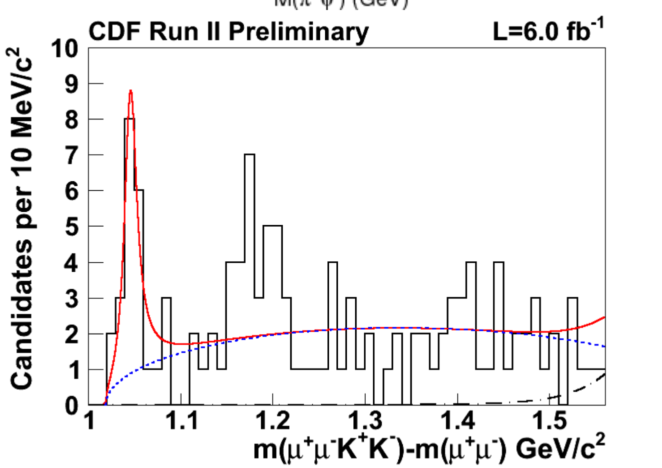
- Z(4430) confirmation
  - Discovered by Belle in the $\psi(2S)\,\pi$ system, Babar found no evidence.
  - Z(4430) yield at LHCb:
    - ~ 860 / 1 fb^{-1} expected.

1.9σ, Statistics?

(CERN-THESIS-2009-129)



- X(4140) confirmation
  - Discovered by CDF in $B^+ \rightarrow K^+[J/\psi\phi]$;
  - Not seen at Belle with larger yield.
- Exotic bottomonium
  - $X \rightarrow (\Upsilon(nS) \rightarrow \mu^+\mu^-)\,\pi^+\pi^-$.



Many other exotic studies are on-going!

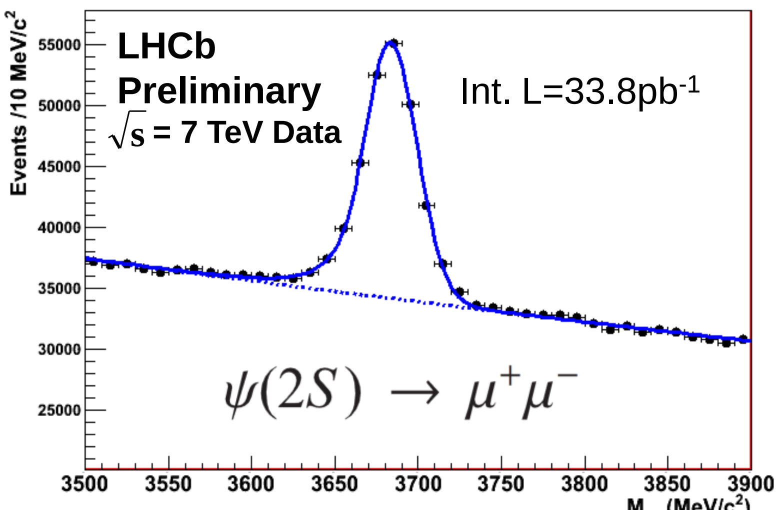
Ψ(2S) production

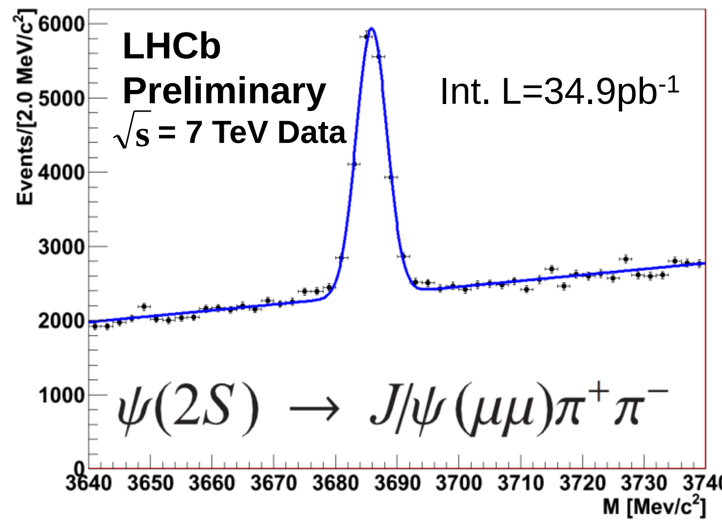
LHCb-CONF-2011-026

- Motivation
  - Testing NRQCD CS and CO mechanisms.
- Introduction
  - No appreciable feed-down from higher mass states, directly compared with the theory;
  - Two decay modes:
    - $\Psi(2S) \rightarrow J/\psi\, \pi^+\pi^-$: larger BR, lower efficiency;
    - $\Psi(2S) \rightarrow \mu^+\mu^-$: more statistics.
- Analysis strategy
  - $$\frac{d^2\sigma}{dp_T dy}(p_T, y) = \frac{N_{\psi(2S)}(p_\mathrm{T}, y)}{\mathcal{L}_{int}\, \epsilon(p_\mathrm{T}, y)\, \mathcal{B}(\psi(2S) \rightarrow e^+e^-)\, \Delta p_\mathrm{T}\, \Delta y}$$
  - $$\frac{d\sigma}{dp_T}(p_T) = \frac{N_{\psi(2S)}(p_\mathrm{T})}{\mathcal{L}_{int}\, \epsilon(p_\mathrm{T})\, \mathcal{B}(\psi(2S) \rightarrow J/\psi\pi^+\pi^-)\, \mathcal{B}(J/\psi \rightarrow \mu^+\mu^-)\ \Delta p_\mathrm{T}}$$
  - Samples in bins of p_T and y.
  - Based on L~35 pb^{-1} of data.

Extraction of N(ψ(2S))

- Mass Spectra

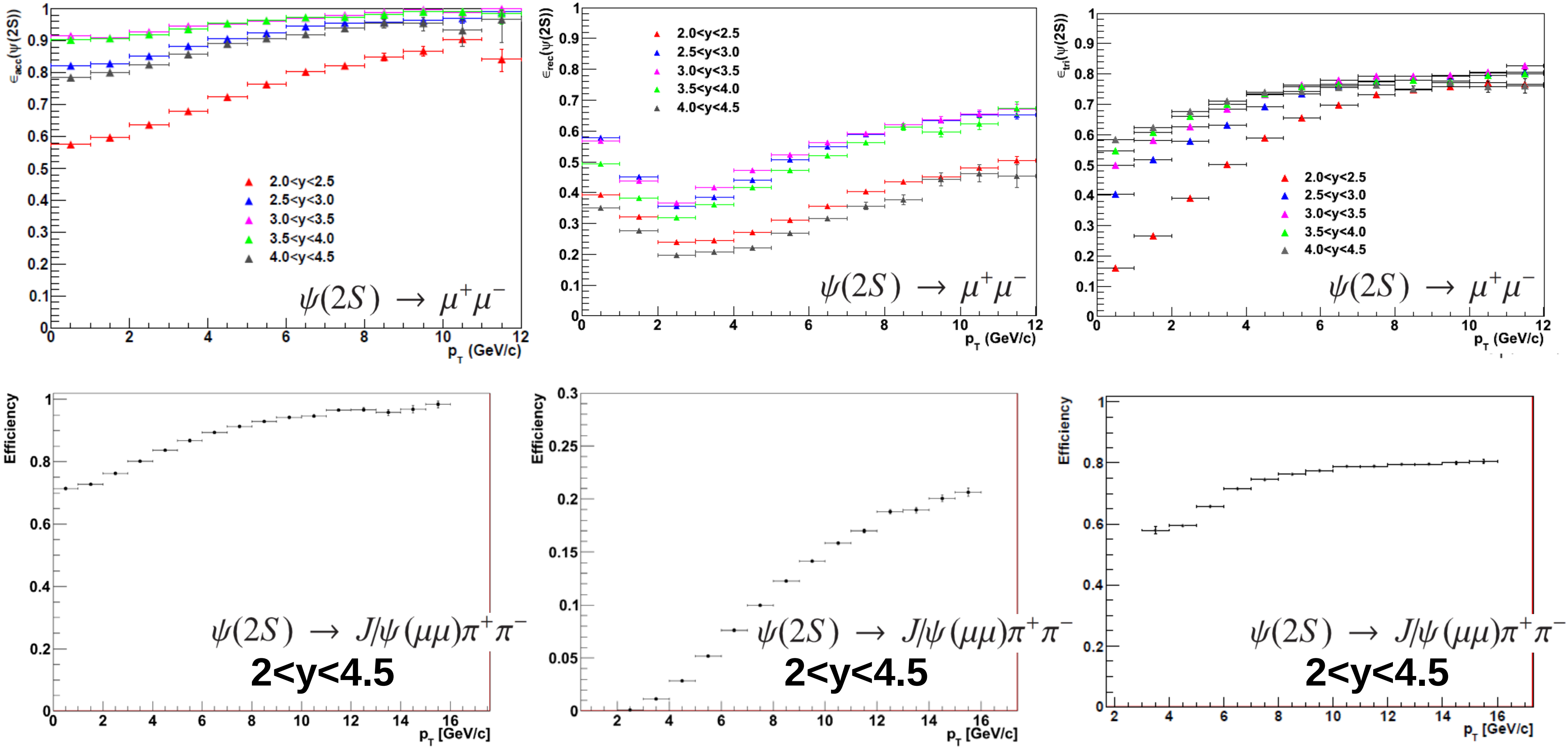




- The number of ψ(2S) extracted from mass fit.
- Efficiencies extracted from Monte Carlo, and corrected by comparing data and MC.

Efficiencies

$$\varepsilon_{total} = \varepsilon_{geo} \times \varepsilon_{rec} \times \varepsilon_{tri}$$



Systematics and results

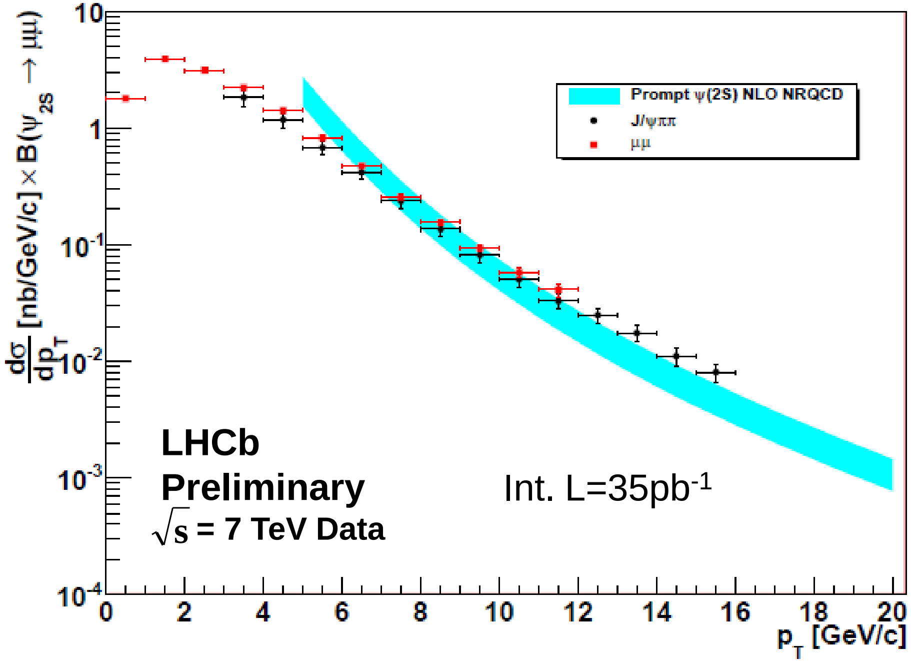
- Dominant systematics
  - Trigger efficiency;
  - Tracking efficiency;
  - Polarization;
  - Luminosity.
- Results

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

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

  - This measurement includes also non-prompt ψ(2S): a more accurate comparison will be carried out by separating prompt from non-prompt components.

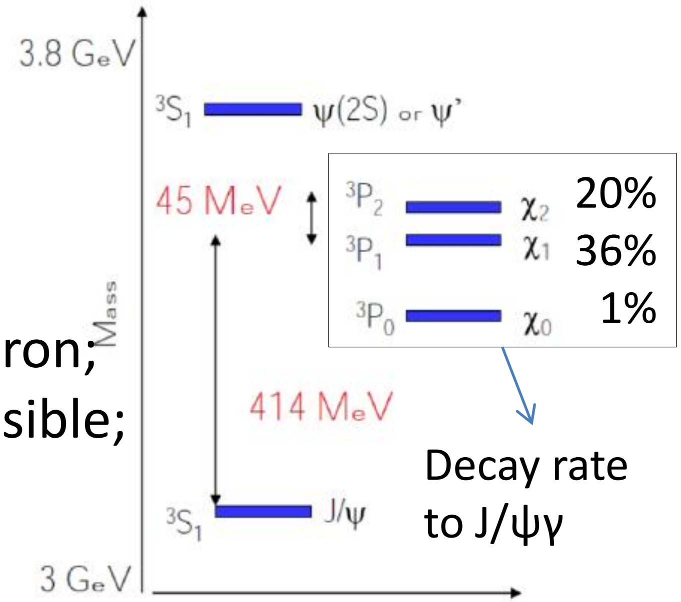
Only uncorrelated errors are shown



Y.-Q. Ma et al. PRL 106 042002 (2011) and private communication.

χ_{c1} χ_{c2} cross section ratio

LHCb-CONF-2011-020



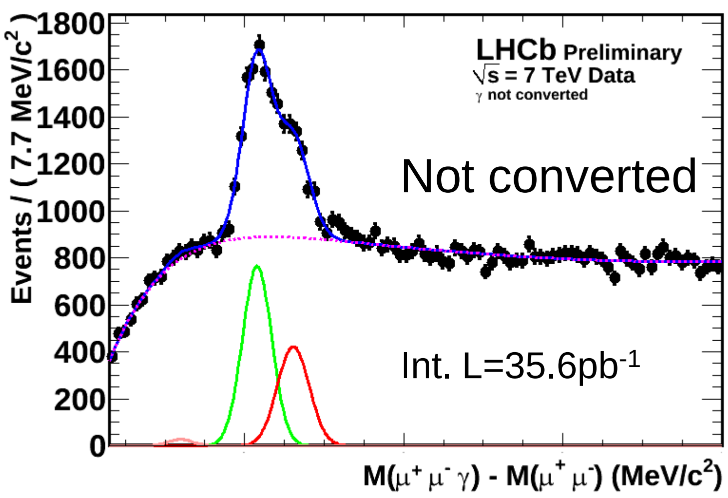
- Motivation
  - Testing NRQCD CS and CO mechanisms.
- Introduction
  - 30% of J/ψ from χ_c (1,2) → J/ψ γ : Tevatron;
  - χ_{c1} and χ_{c2} very close : two peaks impossible;
  - Very few χ_{c0} events expected.
- Analysis strategy

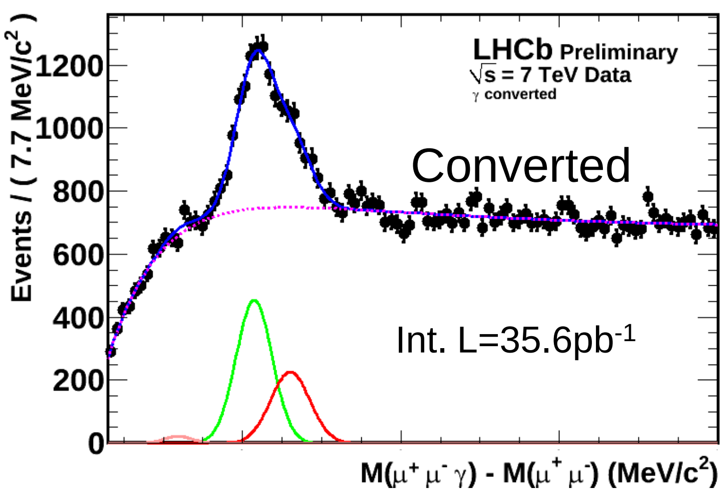
$$\frac{\sigma(\chi_{c2})}{\sigma(\chi_{c1})} = \frac{N_{\chi c2}}{N_{\chi c1}} \cdot \frac{\epsilon_{J/\psi}^{\chi c1}\,\epsilon_{\gamma}^{\chi c1}\,\epsilon_{sel}^{\chi c1}}{\epsilon_{J/\psi}^{\chi c2}\,\epsilon_{\gamma}^{\chi c2}\,\epsilon_{sel}^{\chi c2}} \cdot \frac{Br(\chi_{c1} \to J/\psi\gamma)}{Br(\chi_{c2}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

  - Separate data in converted and not converted photons, and then combine the results (all photons reconstructed in the calorimeter);
  - Final results in bins of J/ψ p_T in the range [3, 15] GeV/c.
  - Based on L=35.6 pb^{-1} of data.

Extraction of $N(\chi_{c1})$ & $N(\chi_{c2})$

- Mass spectra in Jpsi p_T [4, 5]GeV/c bin.





- The number of χ_c extracted from the mass fit.
- Efficiencies extracted from Monte Carlo.

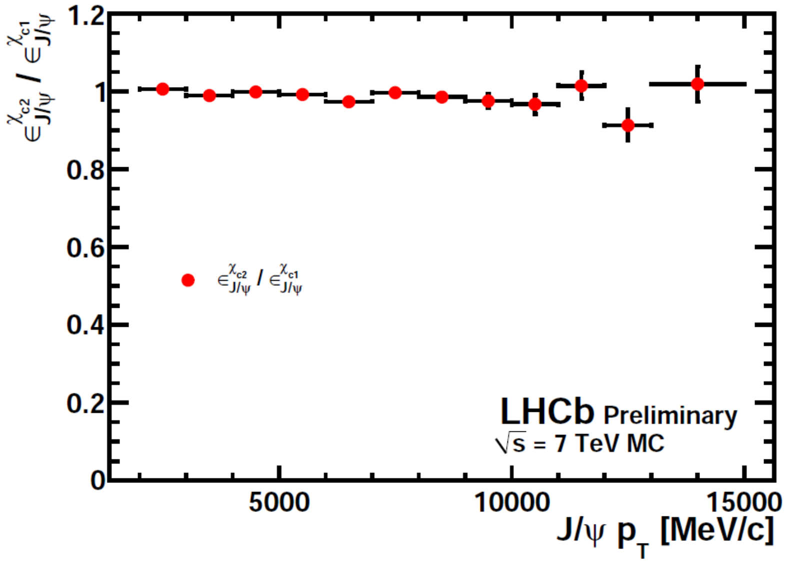
Ratio of efficiencies

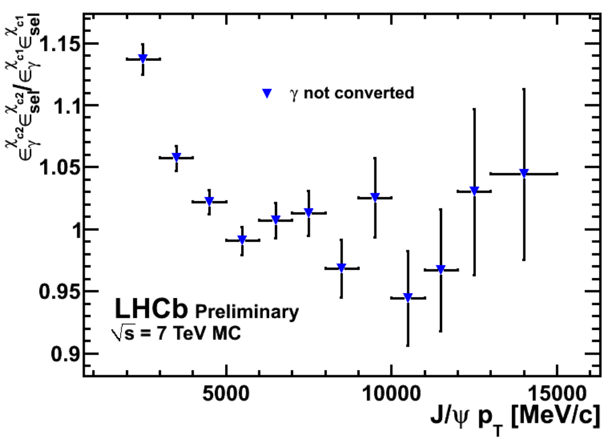
- Ratio of J/ψ efficiencies

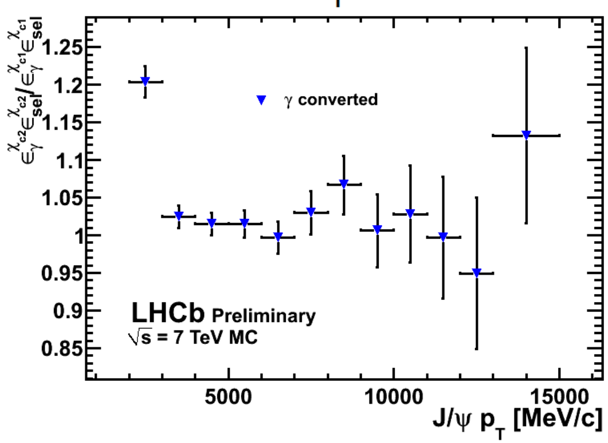
$$\frac{\epsilon_{J/\psi}^{\chi c2}}{\epsilon_{J/\psi}^{\chi c1}} = \frac{N_{J/\psi\ rec}^{\chi c2}}{N_{J/\psi\ rec}^{\chi c1}} \cdot \frac{N_{J/\psi\ gen}^{\chi c1}}{N_{J/\psi\ gen}^{\chi c2}}$$

  – consistent with unity for all p_T bins.

- $\varepsilon_{\gamma}^{\chi_{c2}} \varepsilon_{sel}^{\chi_{c2}} \Big/ \varepsilon_{\gamma}^{\chi_{c1}} \varepsilon_{sel}^{\chi_{c1}}$ calculated separately for converted and not converted photons.
- Ratio of [3, 4] bin is different from 1 but the effect is negligible

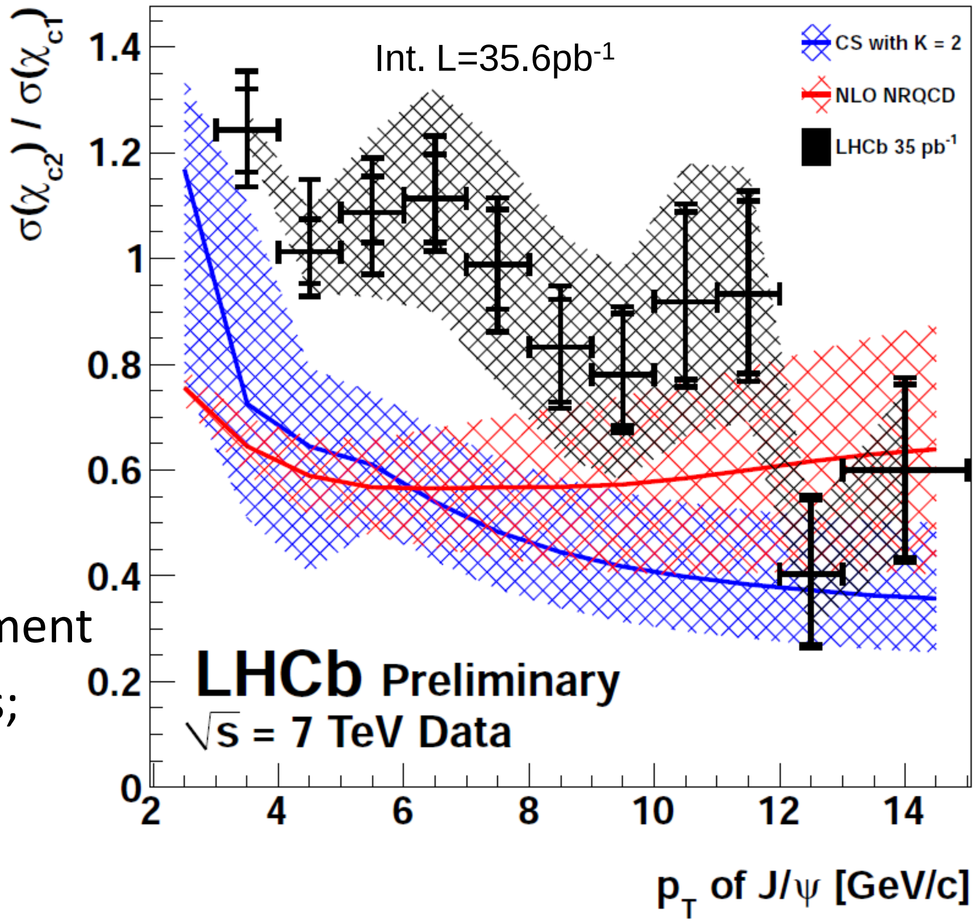






Systematics and results

- Systematics:
  - Fit;
  - Efficiencies;
  - MC statistics;
  - Br($\chi_c(1,2) \to J/\psi\ \gamma$);
  - Polarization.
- Results
  - Significant statistical improvement than previous hadron colliders;
  - Agreement with CS and CO in high p_T region.



plan to measure $\sigma(\chi_c \to J/\psi\ \gamma)/\sigma(J/\psi)$

Summary

- XYZ spectroscopy is an exciting field
  - X(3872) mass has been measured and more studies will be done;
  - On-going studies:
    - Confirmation of discoveries: Z(4430), X(4140),etc;
    - More exotic states in the $J/\psi\pi\pi$, $J/\psi\phi$, $J/\psi J/\psi$ spectra, or bottomonium states.
- Quarkonia production
  - $\psi(2S)$ and χ_c production are measured and more studies are on-going.

backup

Abstract

- The last ten years have seen a resurgence of interest in exotic spectroscopy driven by the discovery of the X(3872) in |the J/ψ ππ spectrum. Searches and studies of exotic onia form an important part of LHCbs physics program. We present results for the production of ψ(2s) and χc(1,2) in the dimuon plus pions or photon channels, as well as the first |results for X(3872) production using the dataset collected in 2010, which corresponds to about 34 pb^{-1}. A measurement of the X(3872) mass in the J/psi pipi mode together with production properties| will be presented. The ψ2s) production in the same decay channel and the χc2 to χc1 cross section ratio will also be discussed, together with future prospects on these measurements at LHCb.

Systematics

Error source	$\mu\mu$ mode	$J/\psi\ \pi\pi$ mode	Comment
Trigger efficiency	0-18%	0-5%	bin dependent
GEC	2%	2%	correlated between bins
Muon ID	1.1%	1.1%	correlated between bins
Tracking efficiency	8%	16%	correlated between bins
μ track χ^2/ndf cut	1%	2%	correlated between bins
π PID cut	None	0.5%	correlated between bins
Eff. (unknown pol.)	1-12%	2-11%	bin dependent
$\psi(2S)$ vertex cut	0.8%	1.3%	correlated between bins
Branching ratio	2.2%*	0.4%	correlated between bins
Luminosity	10%	10%	correlated between bins

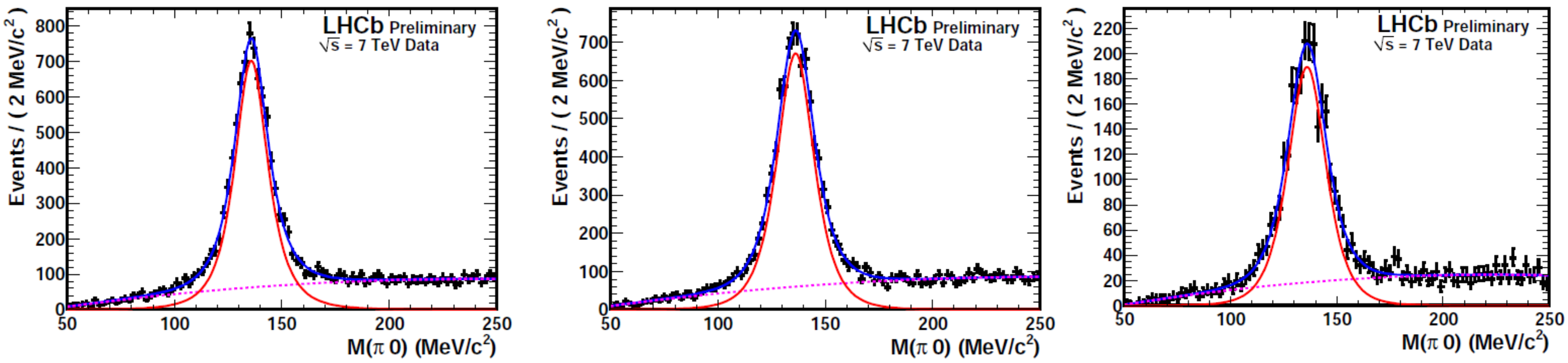
* dielectron

Systematics

Level	Quantity	Data stripping Requirement	Additional Requirement
μ	Track p_T Track quality χ^2/ndf	Track with muon detector hits > 650 MeV/c < 5	 > 700 MeV/c < 4
J/ψ	$p_T^{J/\psi}$ Mass window Vertex χ^2/ndf Vertex $p(\chi^2)$	> 1.5 GeV/c $3040 - 3140$ MeV/c^2 < 20	> 3 GeV/c $3062 - 3120$ MeV/c^2 $> 0.5\%$
Photon	Confidence level p_T^γ p^γ		> 0.5 > 650 MeV/c > 5 GeV/c
χ_c	J/ψ pseudo-proper time t_z		< 0.1 ps
Event	Number of primary vertices	> 0	

γ reconstruction

- π_0 mass fit: π_0 mass peak is symmetric in all cases.



(a) 0 γ conversion (b) 1 γ conversion (c) 2 γ conversion

- With new Calorimeter conditions and correction p_0 mass peak is symmetric in all cases