Exotic Quarkonium Spectroscopy & Production in CMS

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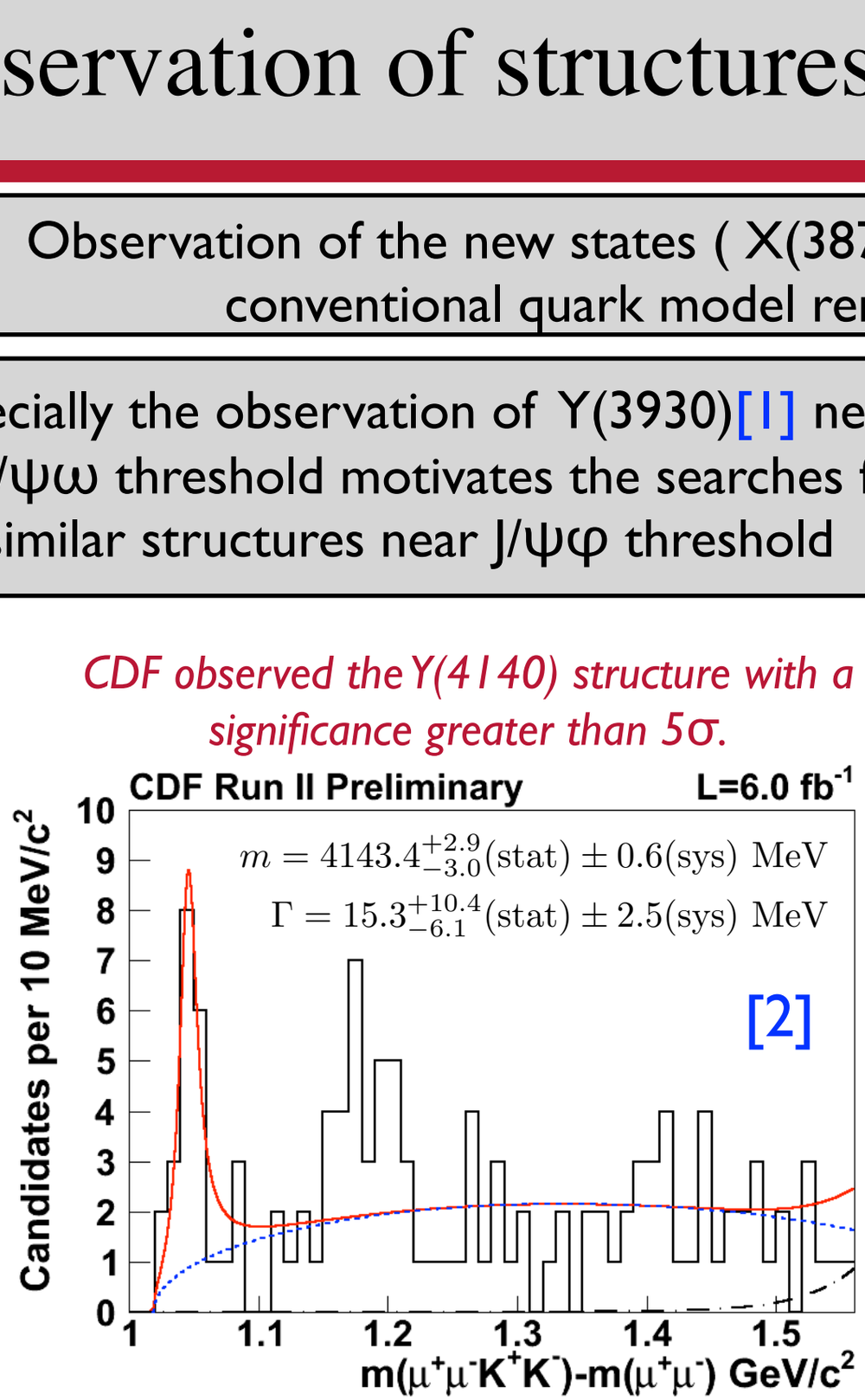
Observation of structures in the J/ψϕ mass spectrum

Observation of the new states (X(3872) ,Y(3940) ,Y(4260)) which do not fit into conventional quark model renewed the interest in exotic states.

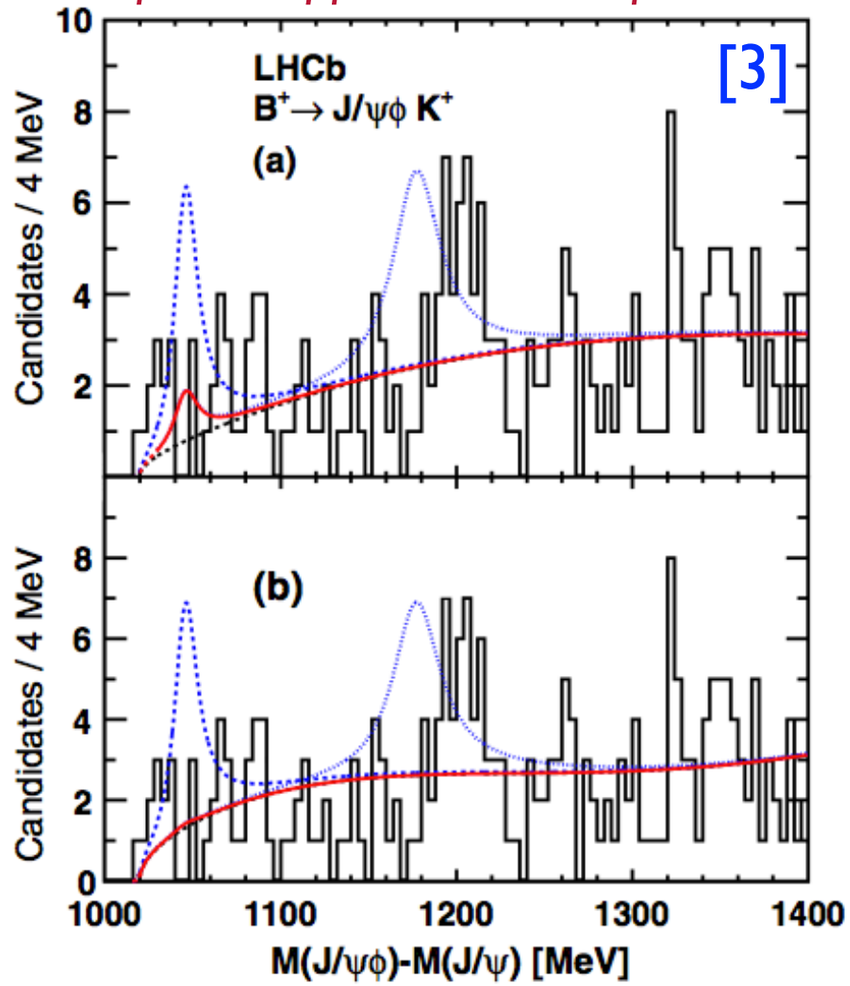
Especially the observation of Y(3930)[1] near the J/ψω threshold motivates the searches for similar structures near J/ψφ threshold

CDF observed the Y(4140) structure with a significance greater than 5σ.



$$B^+ \to J/\psi\phi K^+$$

LHCb did not confirm the existence of Y(4140) and put an upper limit on its production



[1] BABAR-Phys. Rev. Lett. 94, 182002 (2005), BELLE-Phys. Rev. Lett. 101, 082001 (2008)

[2] http://www-cdf.fnal.gov/physics/new/bottom/100701.blessed-jpsiphi6.0/myFig11.eps

[3] arXiv:1202.5087

CMS detector performance

Excellent CMS performances for quarkonium studies

Silicon Tracking Detector

➡ Excellent track momentum resolution
($\Delta p_T / p_T \sim 1\%$ for barrel)

➡ Excellent vertex reconstruction and impact parameter resolution

Muon System

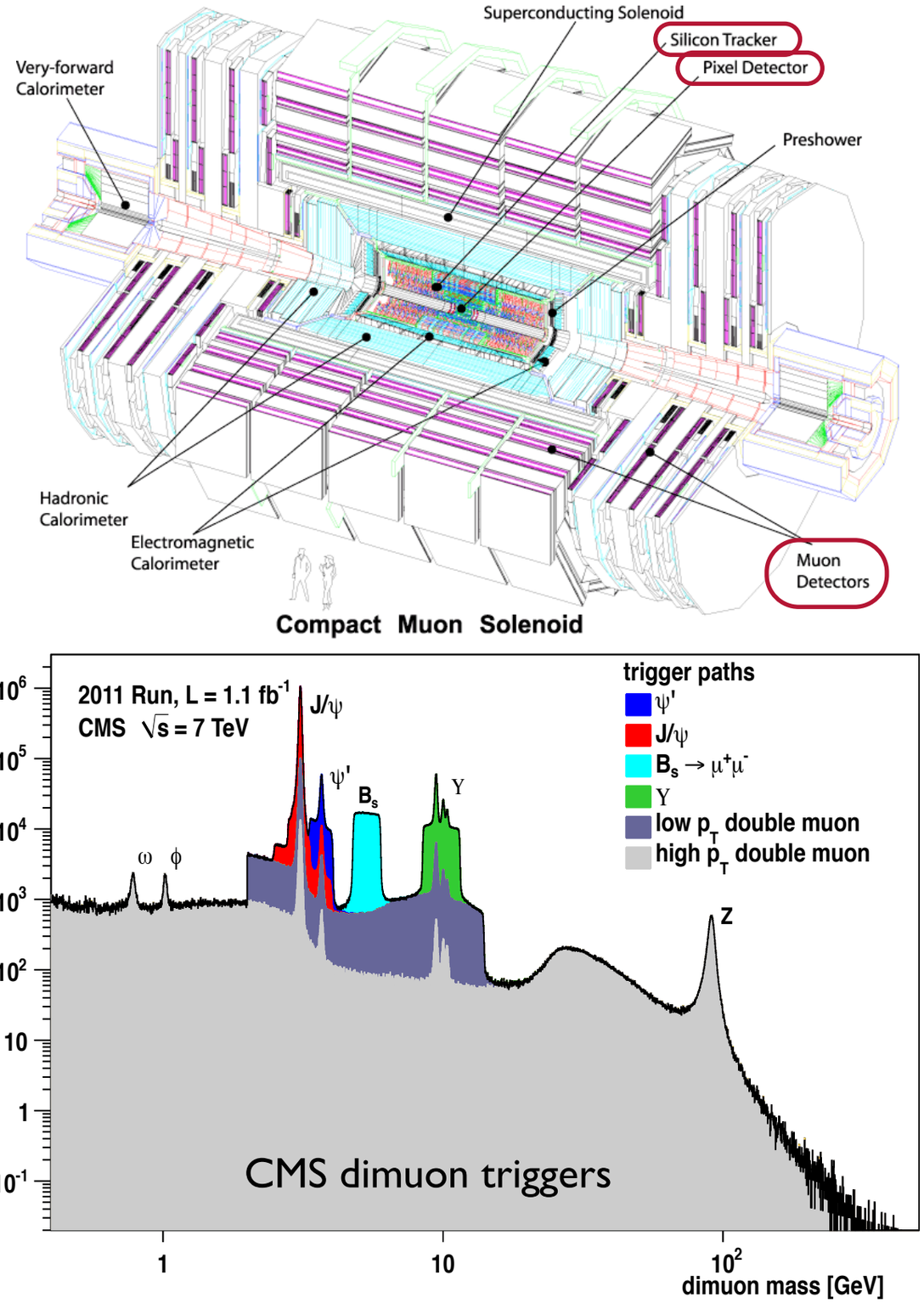
➡ High purity muon identification

➡ Good dimuon mass resolution
($\Delta m/m \sim 0.6\%$ for J/ψ)

LHC Luminosity and CMS Triggers

➡ CMS collected ~5 fb^{-1} data at increasing instantaneous luminosity during 2011 at $\sqrt{s}$=7 TeV

➡ Specific trigger paths are developed for different analyses



CMS analysis description

- Step I: Reconstructing B^+ signal

$$B^+ \to J/\psi\phi K^+$$
$$J/\psi \to \mu^+\mu^-$$
$$\phi \to K^+K^-$$

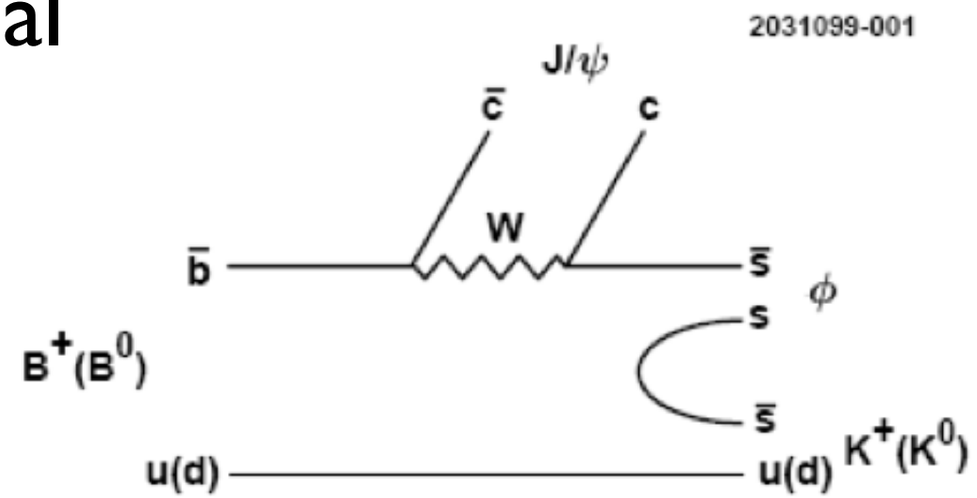
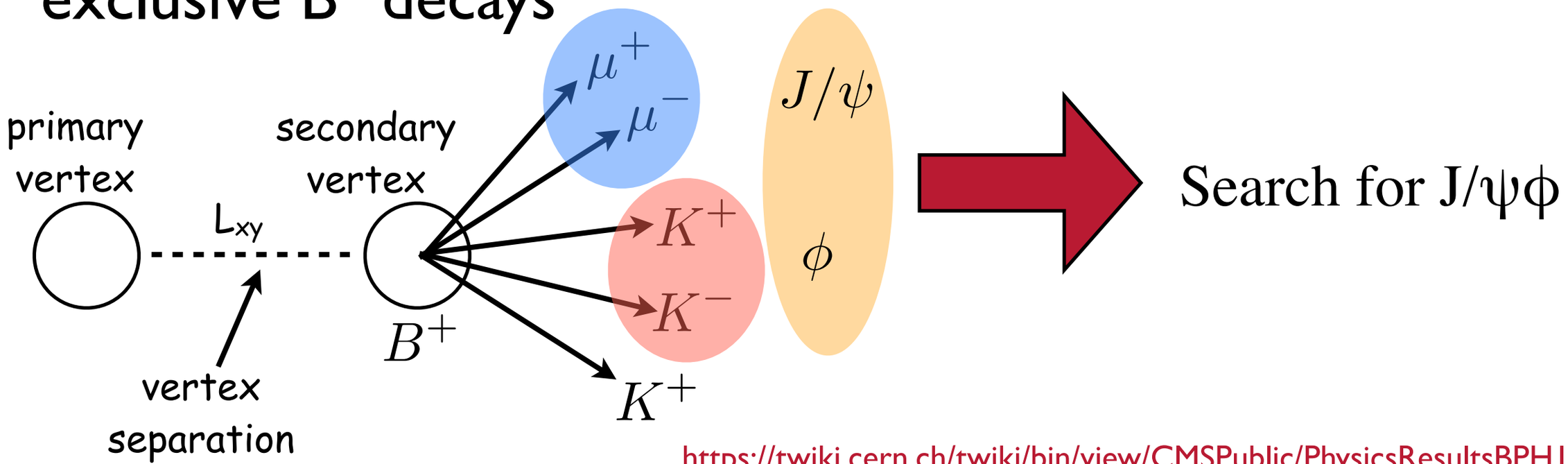


FIG. 1. Most likely $B \to J/\psi\phi K$ decay mechanism.

- Step II: Search for structure in J/ψΦ mass spectrum from exclusive B^+ decays



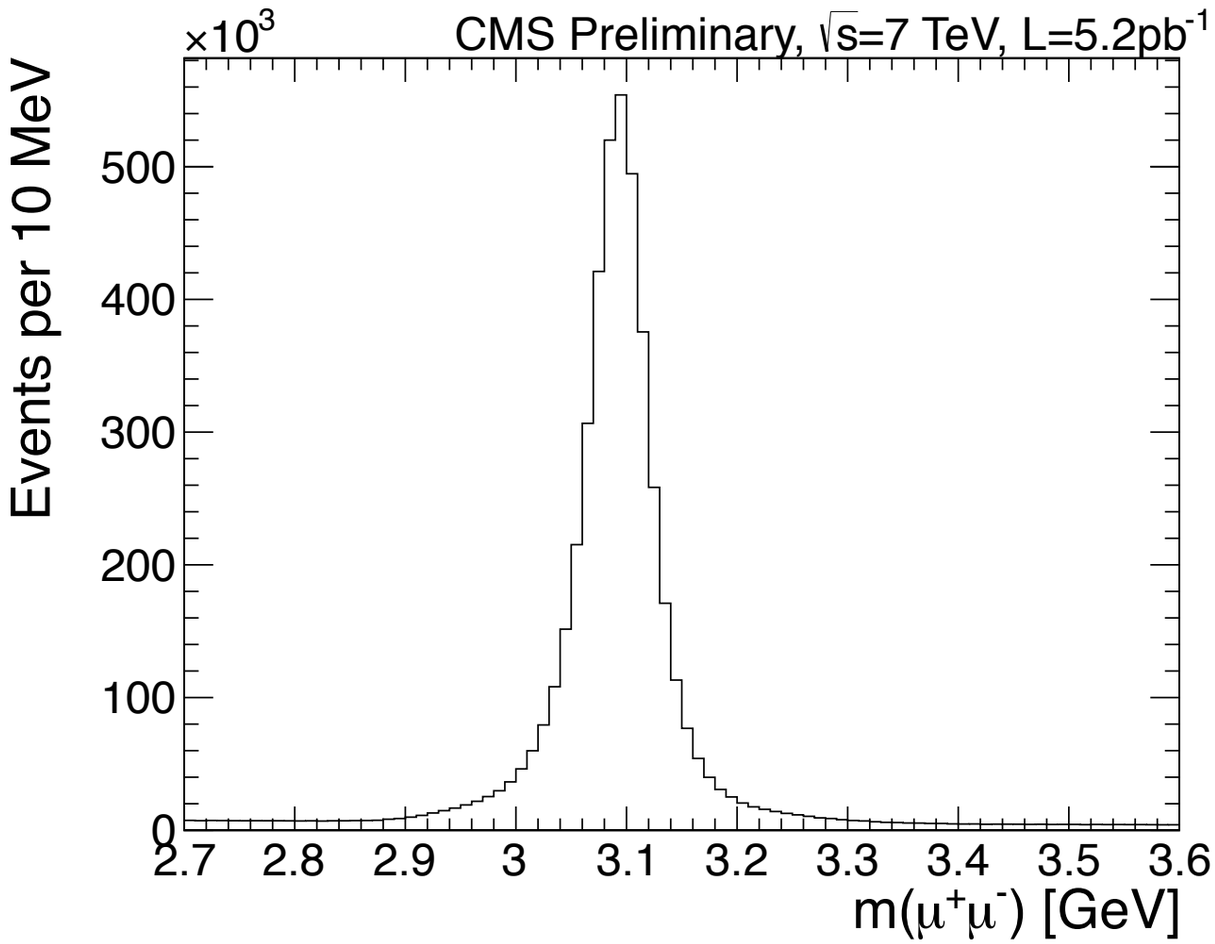
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11026

Data and MC Samples

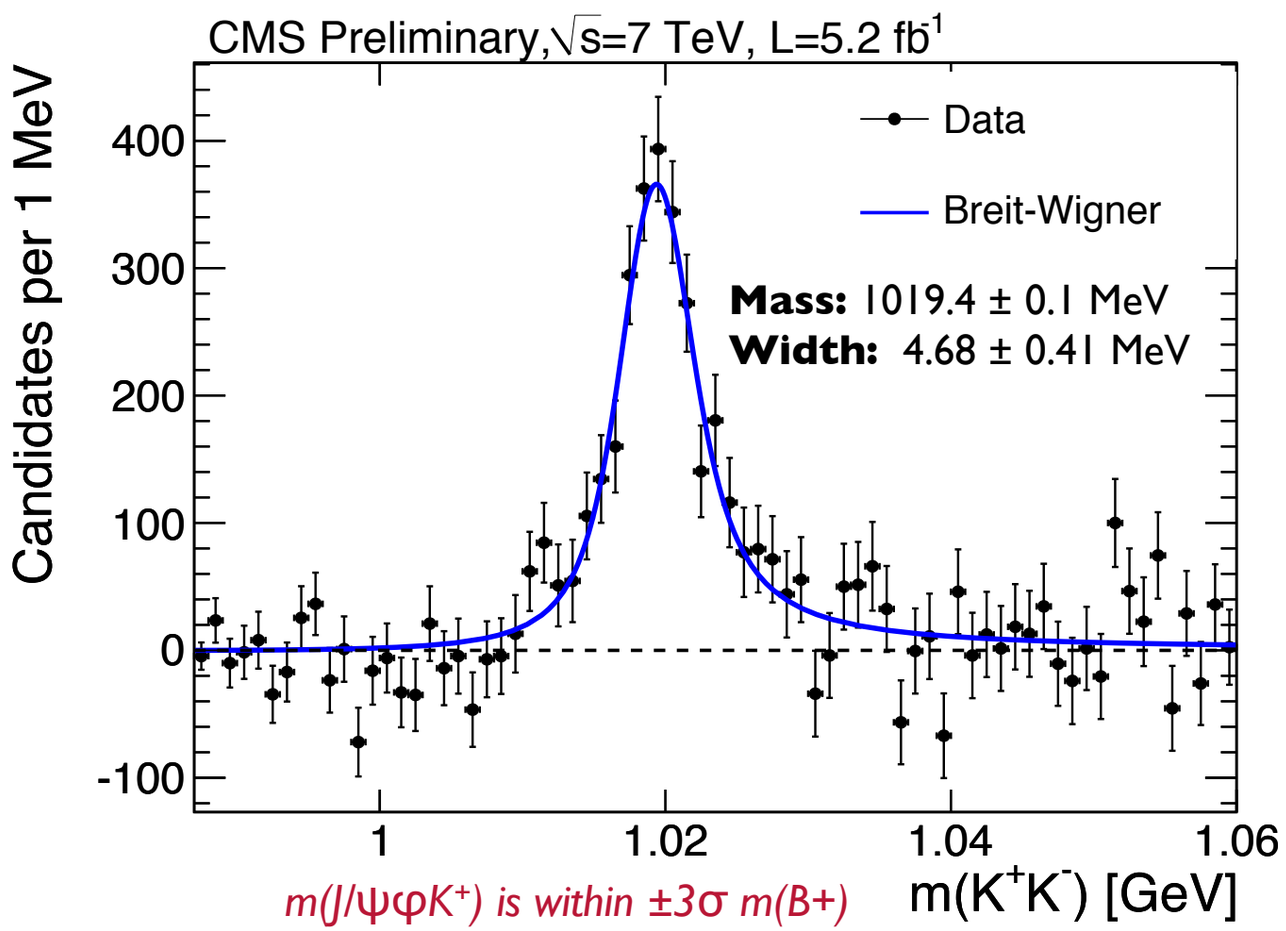
- Data
  - The data were collected in 2011 with the Compact Muon Solenoid (CMS) detector from proton-proton collisions at the Large Hadron Collider (LHC) operating at a center-of-mass energy of 7 TeV
  - Events with non-prompt J/ψ candidates coming from the decays of B mesons are selected at HLT.
- MC
  - Signal MC Sample ($B^+ \rightarrow YK^+, Y \rightarrow J/\psi\phi$)
    - Estimate the mass resolution in the J/ψϕ mass spectrum
    - Efficiency estimation
  - Phase Space MC ($B^+ \rightarrow J/\psi\phi K$)
    - Study Dalitz plot for phase space
  - Background MC Sample ($B^+/B^0/B_s \rightarrow J/\psi + X$)
    - To check possible reflection from other B hadrons

J/ψ and ϕ signal

Clean J/ψ before exclusive B reconstruction



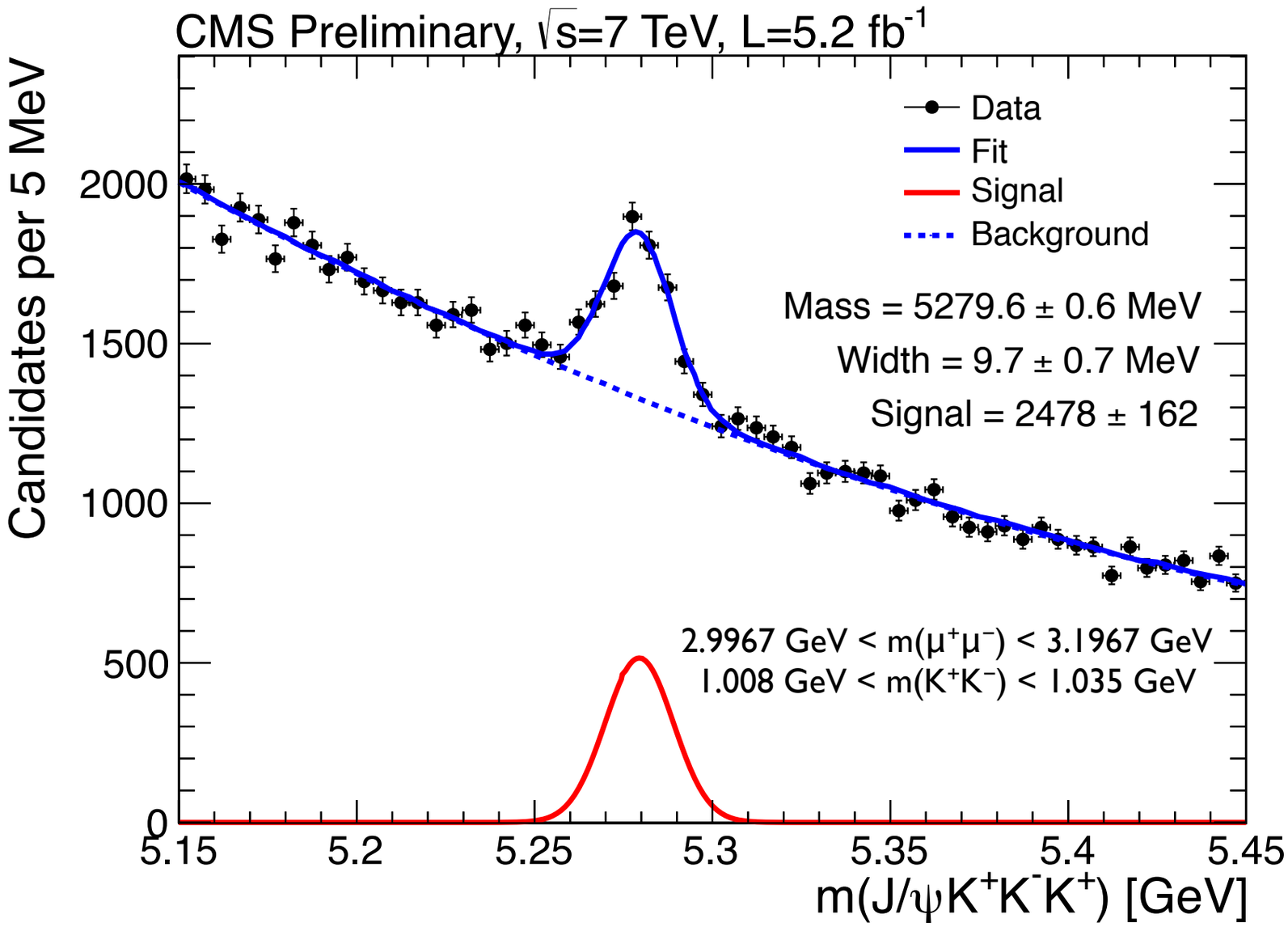
Pure ϕ signal after B^+ sideband subtraction



The m(K^+K^-) distribution is fitted to a P-wave relativistic Breit Wigner function convolved with a Gaussian resolution function. The fit has χ^2 probability of 23% ⇒ we observe $B^+ \to J/\Psi \Phi K^+$ in our selected ϕ mass window with negligible other components

The exclusive $B^+ \to J/\psi\phi K^+$ signal

Largest B sample with $B^+ \to J/\psi\phi K^+$ in the world up to date



Signal PDF: A Gaussian signal

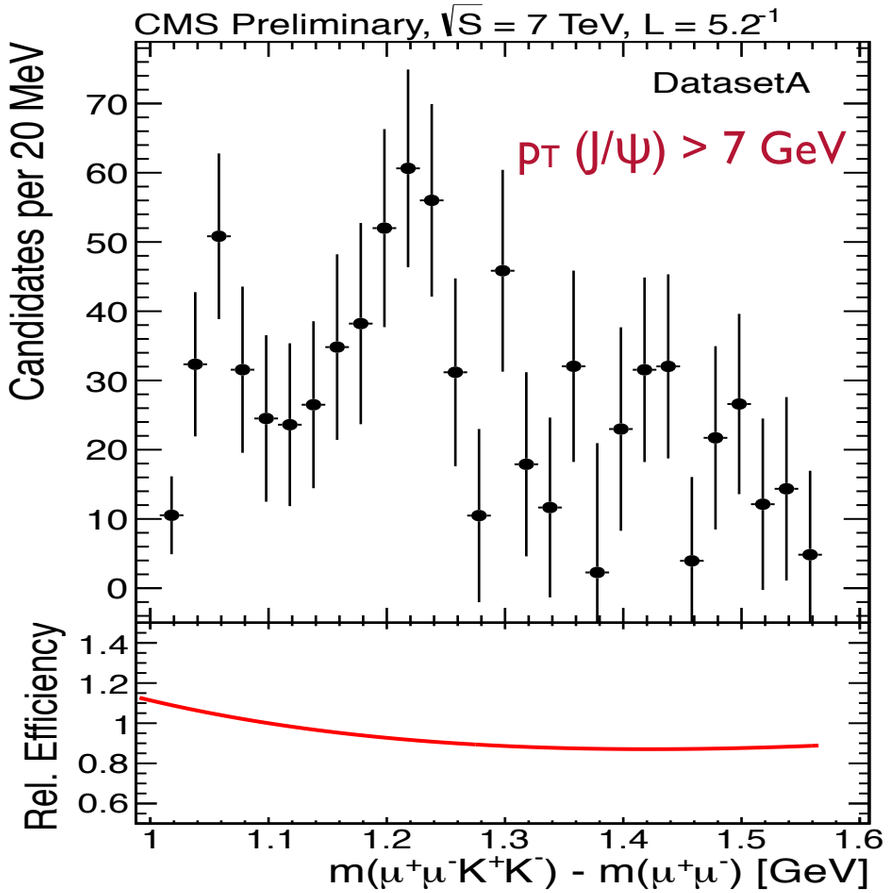
Background PDF: A second order Chebychev polynomial

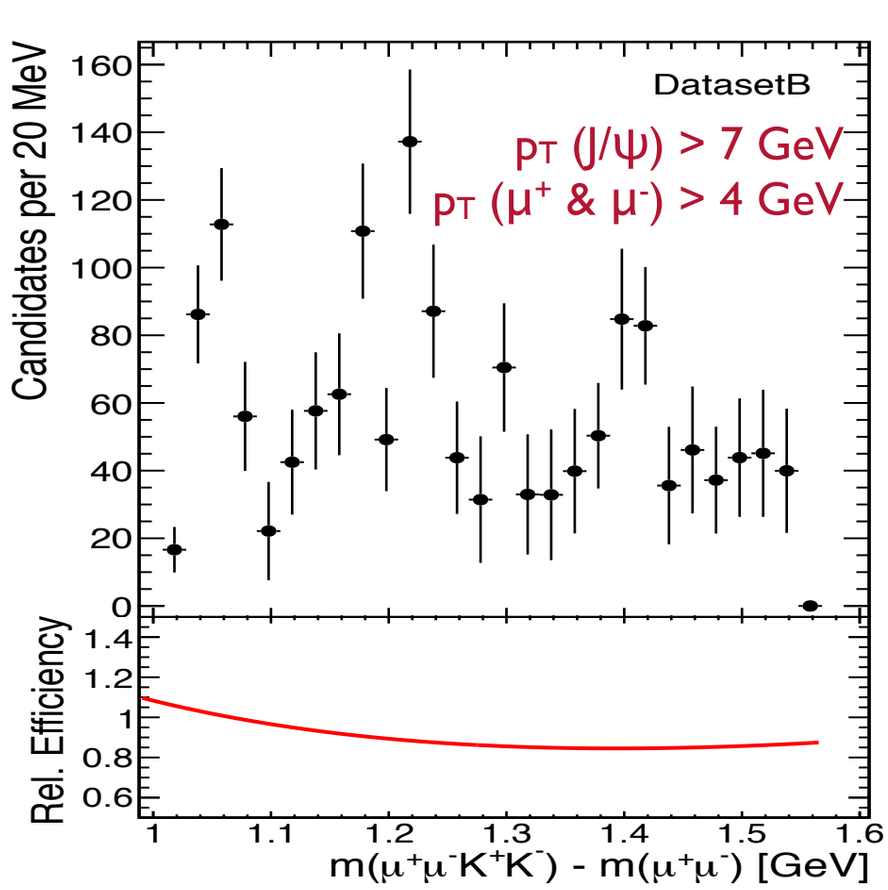
Extracting J/ψϕ signal from B

The $\Delta m = m(\mu^+\mu^- K^+K^-) - m(\mu^+\mu^-)$ is used to investigate the possible structures

- ➡ Divide the dataset into the 20 MeV Δm bins
- ➡ Extract the number of B signal for each Δm by fitting the J/ψφK spectrum
  - ➡ Mean is fixed to the PDG value of B mass
  - ➡ RMS is fixed to the number predicted by signal MC
- ➡ Plot the B yield with uncertainty in each bin
- ➡ Correct the spectrum by relative efficiency

Same method as Belle and BaBar's
Y(3940)→J/ψω from B→J/ψωK analysis
(PRL 94 (2005) 182002, PRL 101 (2008) 082001)



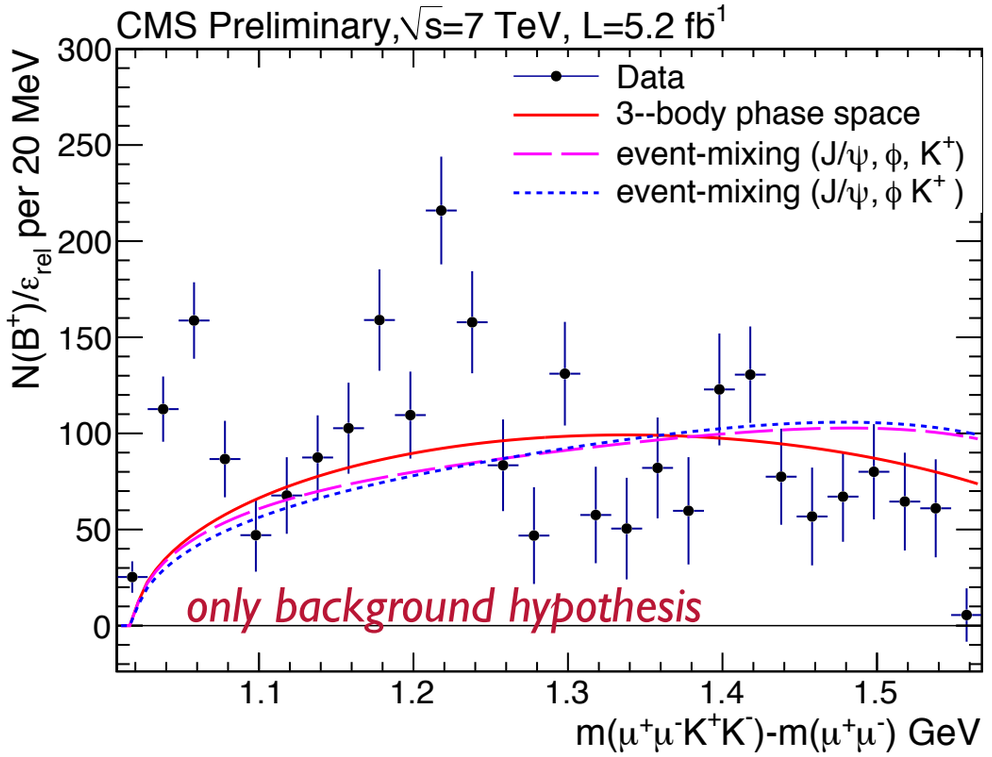


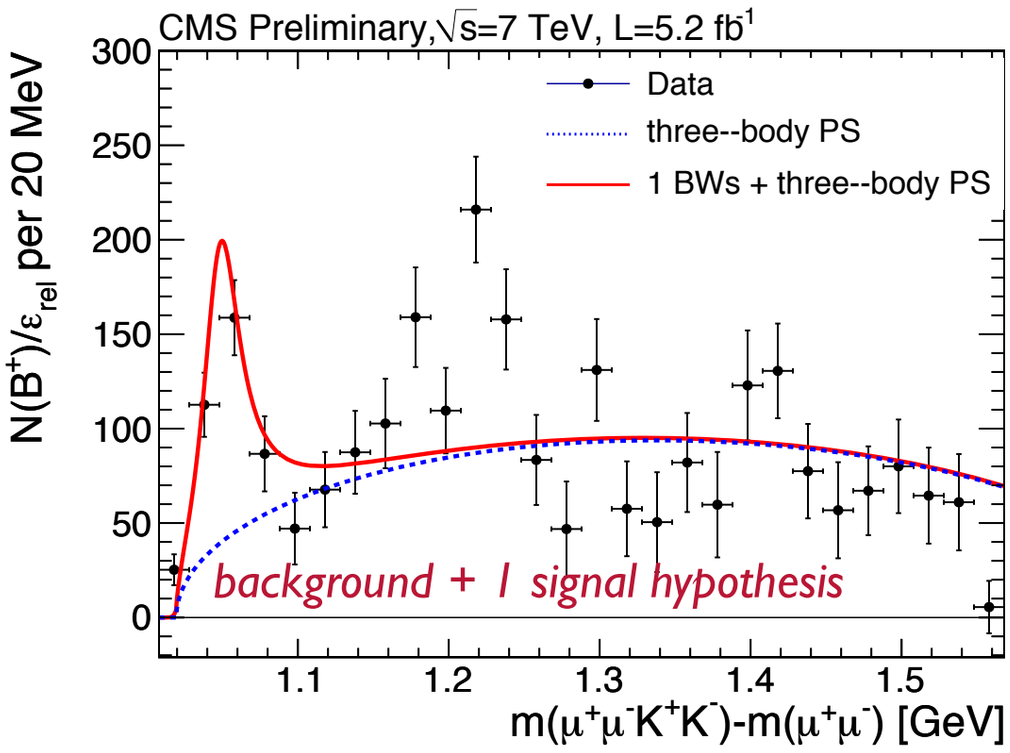
Observation of structures in the J/ψϕ mass spectrum

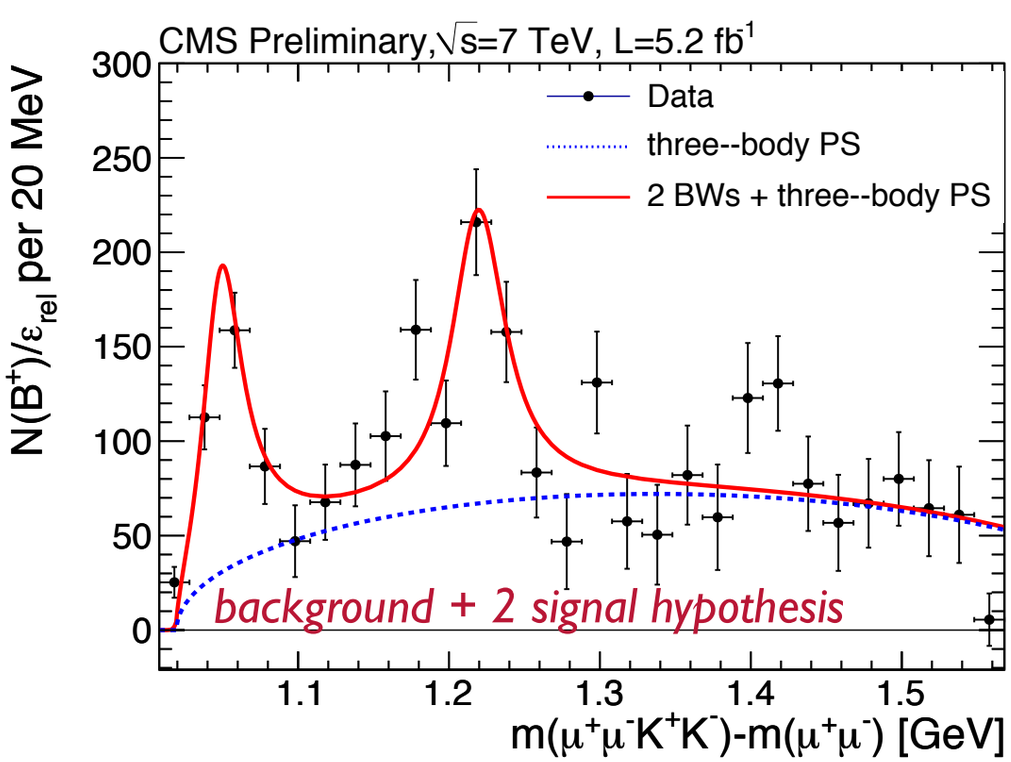
The relative efficiency corrected Δm distributions from $B^{\pm} \rightarrow J/\psi\phi K^{\pm}$ decays

Background: *3-body phase space*

Signal*: S-wave relativistic Breit-Wigner functions convoluted with a Gaussian resolution function*





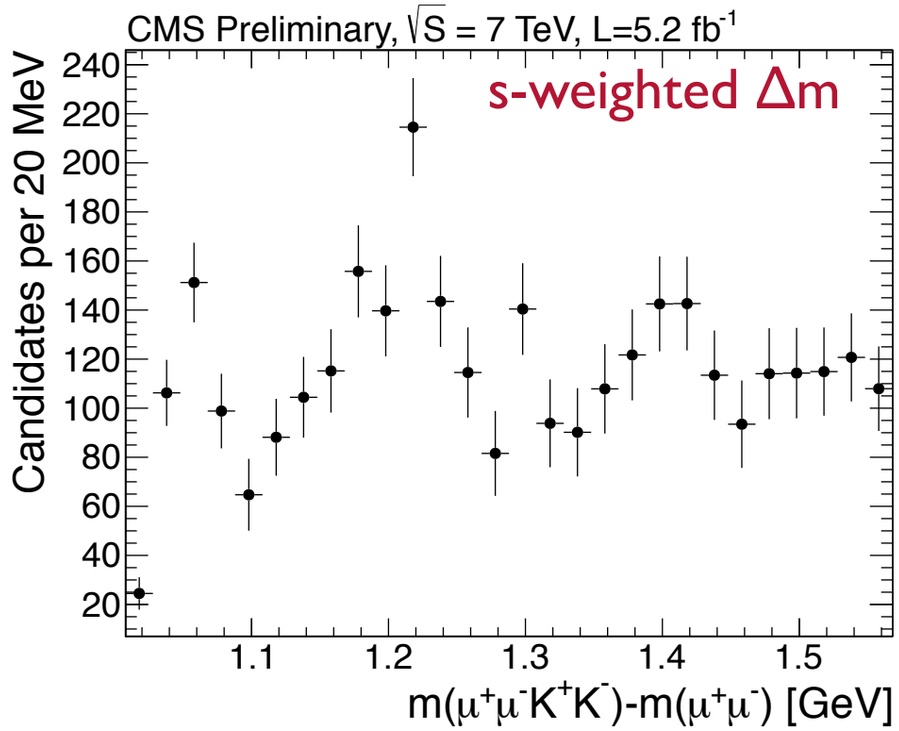


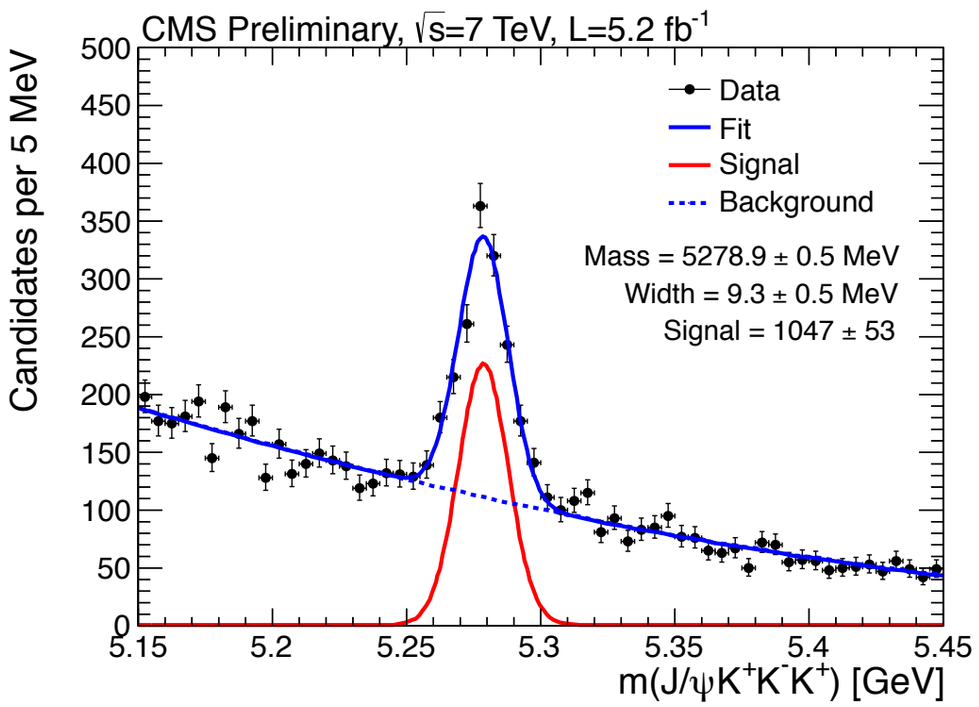
Robustness of the observed structures

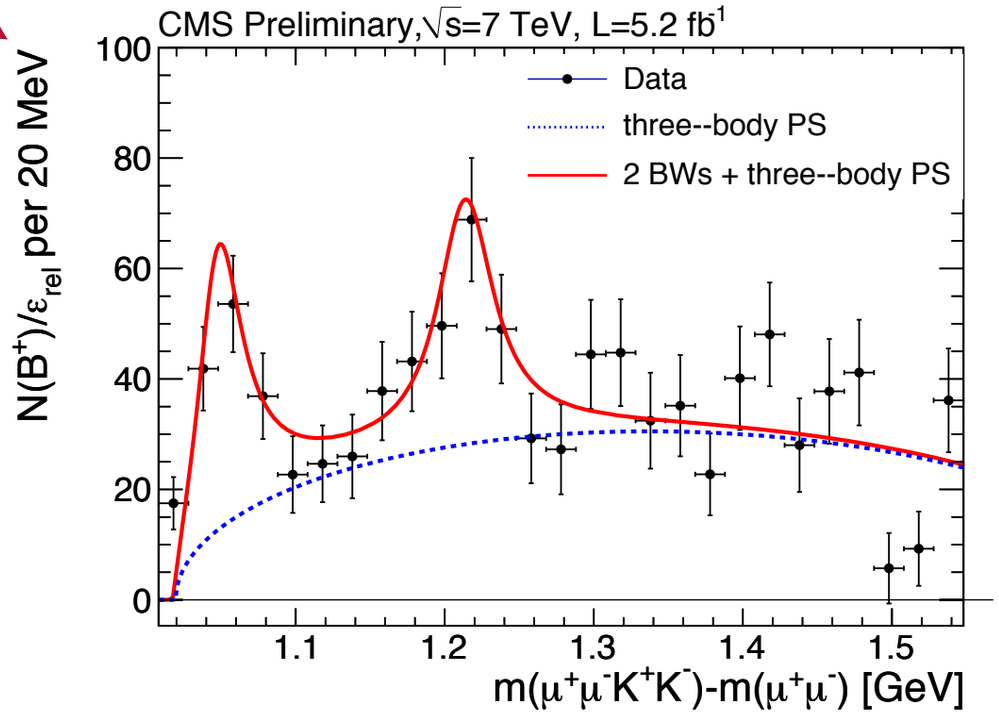
Several checks are performed to validate the robustness of the two structures

- ➡ Variations on the selection cuts, Δm binning, background and signal models
- ➡ Background subtraction technique based on sPlot formalism
- ➡ Tighter B selection to reduce the combinatorial background

reduced the background by a factor of 10 while keeping 1047 B signal events







Systematic Uncertainties

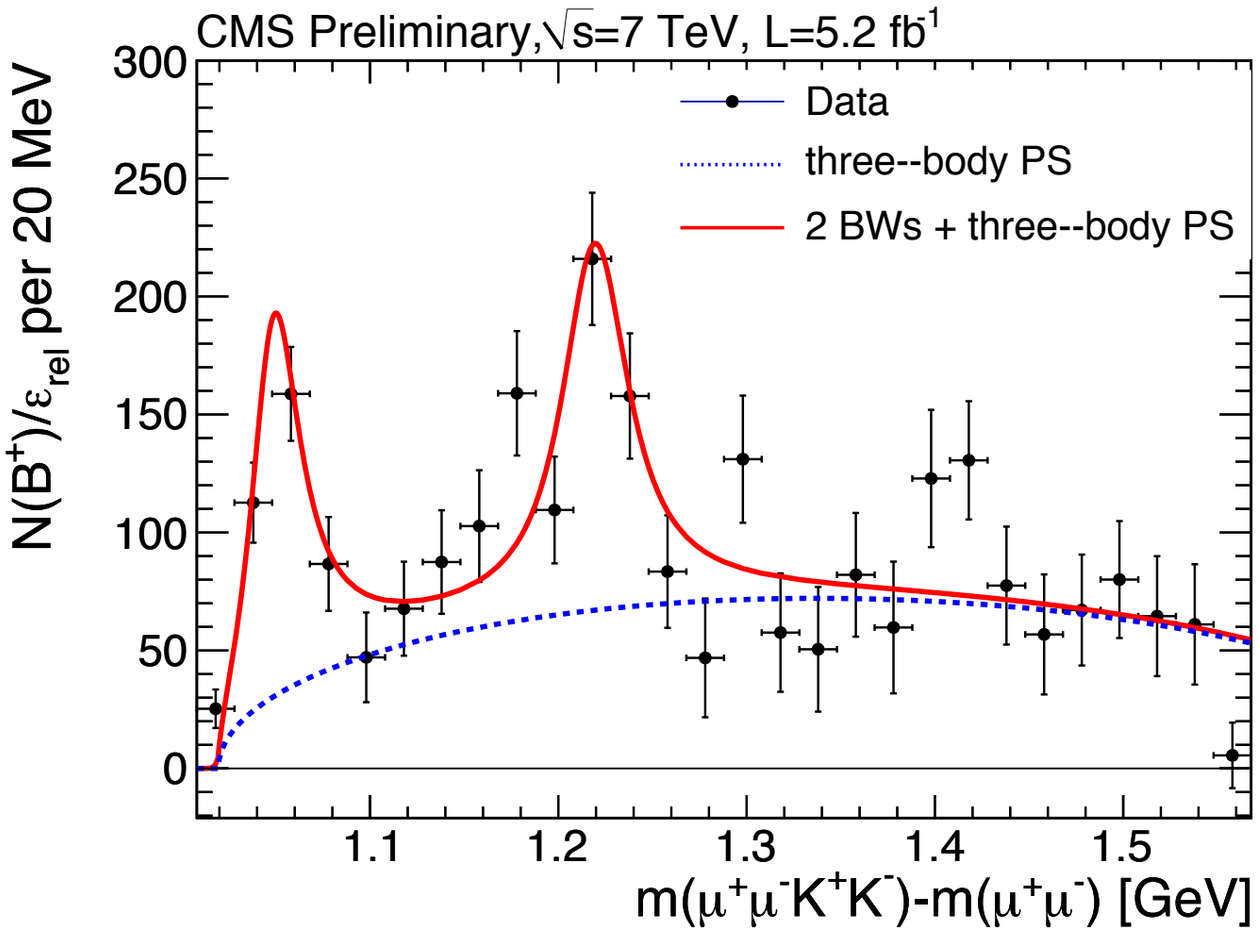
To study the systematic uncertainties of the mass and the width of the observed structures the Δm fit is repeated for several options and the largest variations are assigned as systematic

- signal and the background model for B
- Δm binning, Δm mass resolution, Δm structure PDF, and Δm background shape
- relative efficiency
- selection criteria
- additional signal model

Observation of structures in the J/ψϕ mass spectrum

The $\Delta m = m(\mu^+\mu^- K^+K^-) - m(\mu^+\mu^-)$ is used to investigate the possible structures

The relative efficiency corrected Δm from the exclusive $B^+ \to J/\psi\varphi K^+$ signal



Δm

	Mass (MeV)	Signal Yield
First Peak	1051.5 ± 2.0	355 ± 46
Second Peak	1220.0 ± 3.0	445 ± 83

$\Delta m + m(J/\psi)_{PDG}$

$m(1^{st}) = 4148.2 \pm 2.0(stat) \pm 5.2(sys)$ MeV
$m(2^{nd}) = 4316.7 \pm 3.0(stat) \pm 10.0(sys)$ MeV

*CMS **confirmed** a structure at 4148 MeV with a significance greater than 5σ and **saw an evidence for the second structure** in the same mass spectrum.*

Our purpose for 2012 analysis

- What we are aiming
  - main objective is to perform the analysis with a cleaner B sample with large 2012 data
    - try various ways to have a pure B sample
    - Perform an amplitude analysis, including possible angular information into the fit
- What are the problems we have to solve
  - all the available information on the amplitude analysis is based on the scalars however in our case we have vector mesons.
  - to perform an amplitude analysis we need a clean sample but our data have lots of background

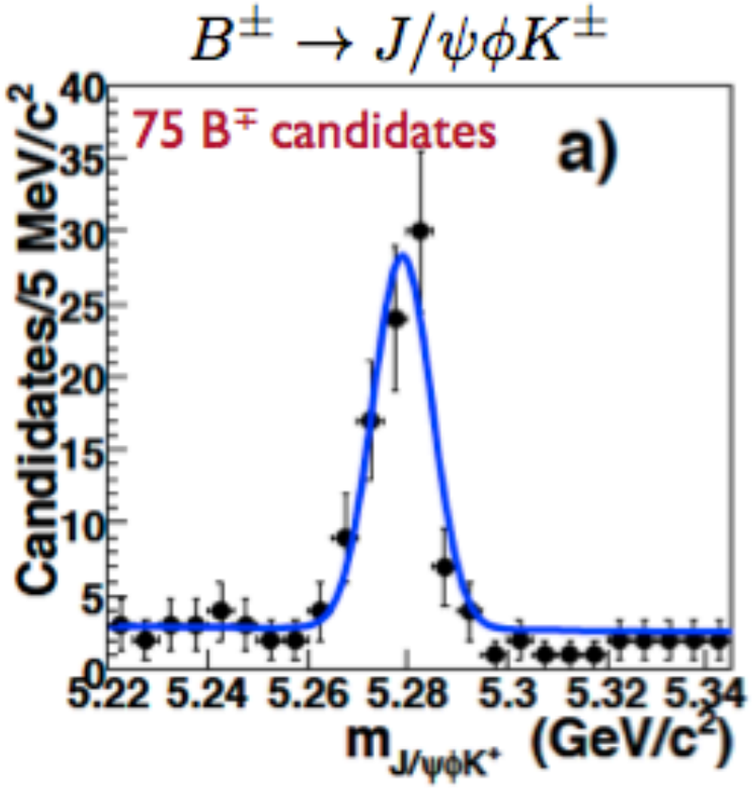
Summary

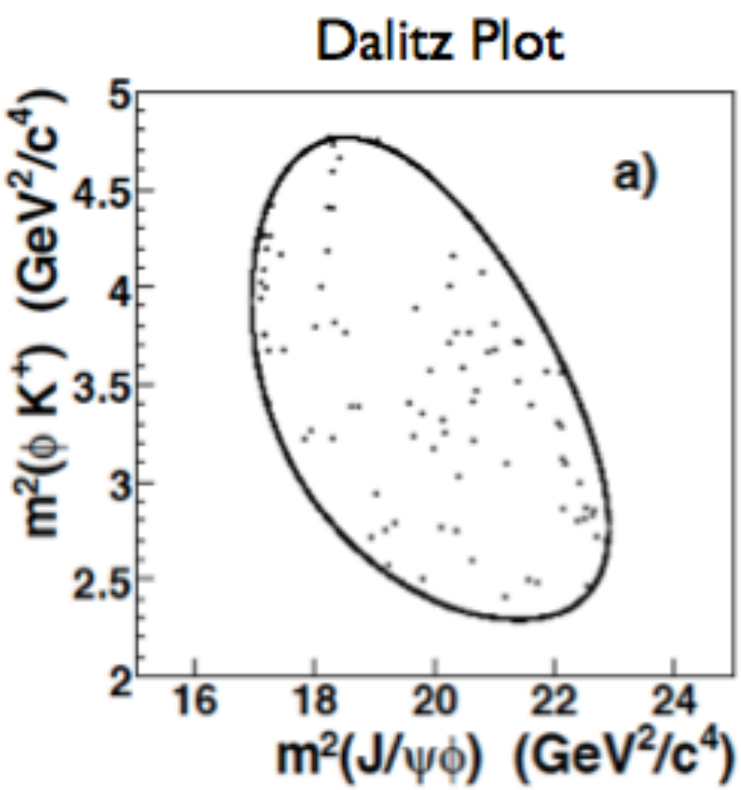
- By using the data were collected in 2011 with CMS from pp collisions at the LHC operating at a center-of-mass energy of 7 TeV we observed two structures in $J/\psi\Phi$ spectrum at 4148MeV & 4317MeV
  - confirm the existence of Y(4140)
  - find evidence for a second structure
- Adding the 2012 data we would like to perform an amplitude analysis where we can include angular information in the final fit.

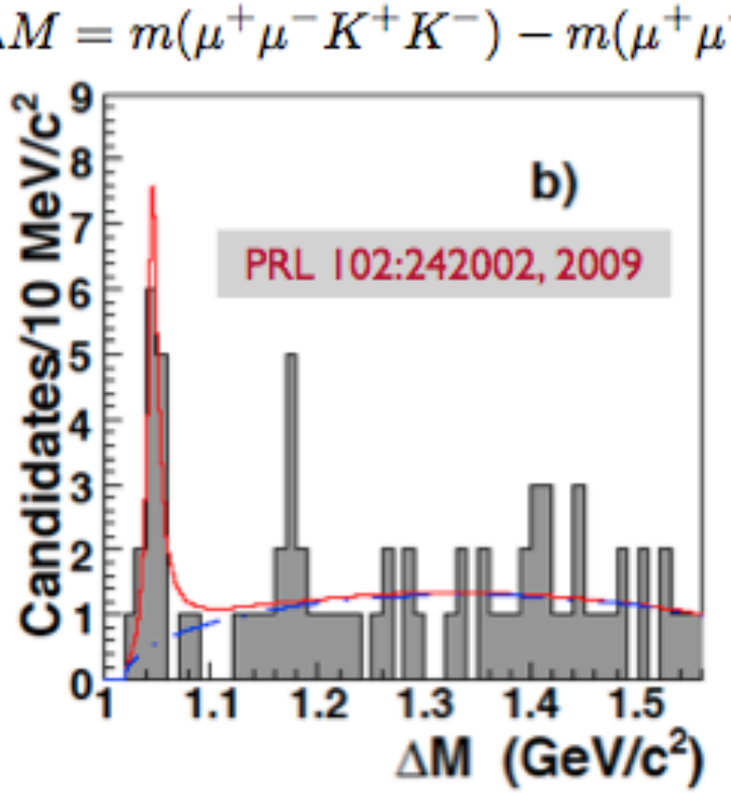
Backup

First Report by CDF - 2009

Total integrated luminosity: 2.7 fb^{-1}







Near threshold peak called "Y(4140)"

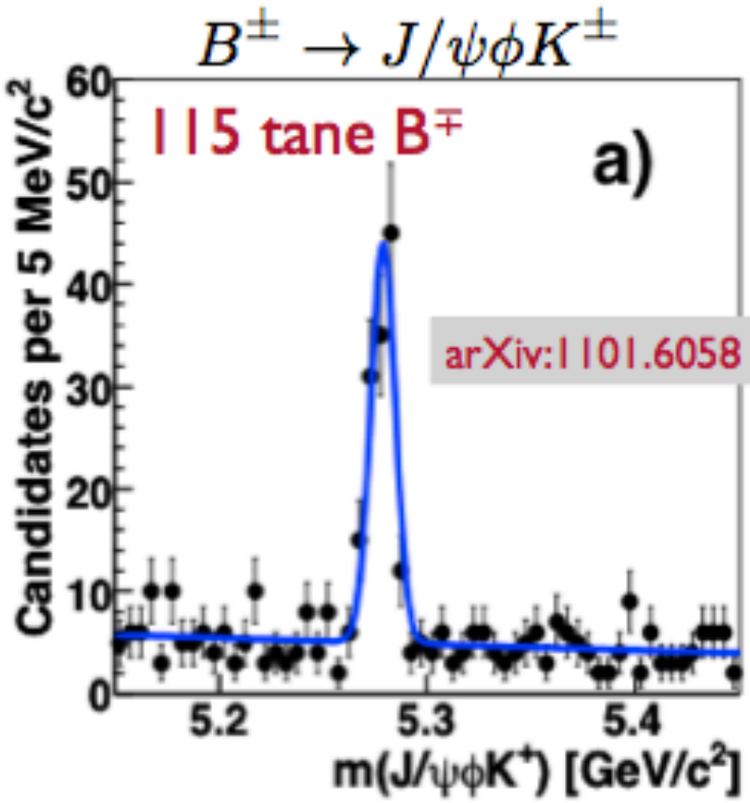
$M = 4143 \mp 2.9(\text{stat}) \mp 1.2(\text{sys})$ MeV

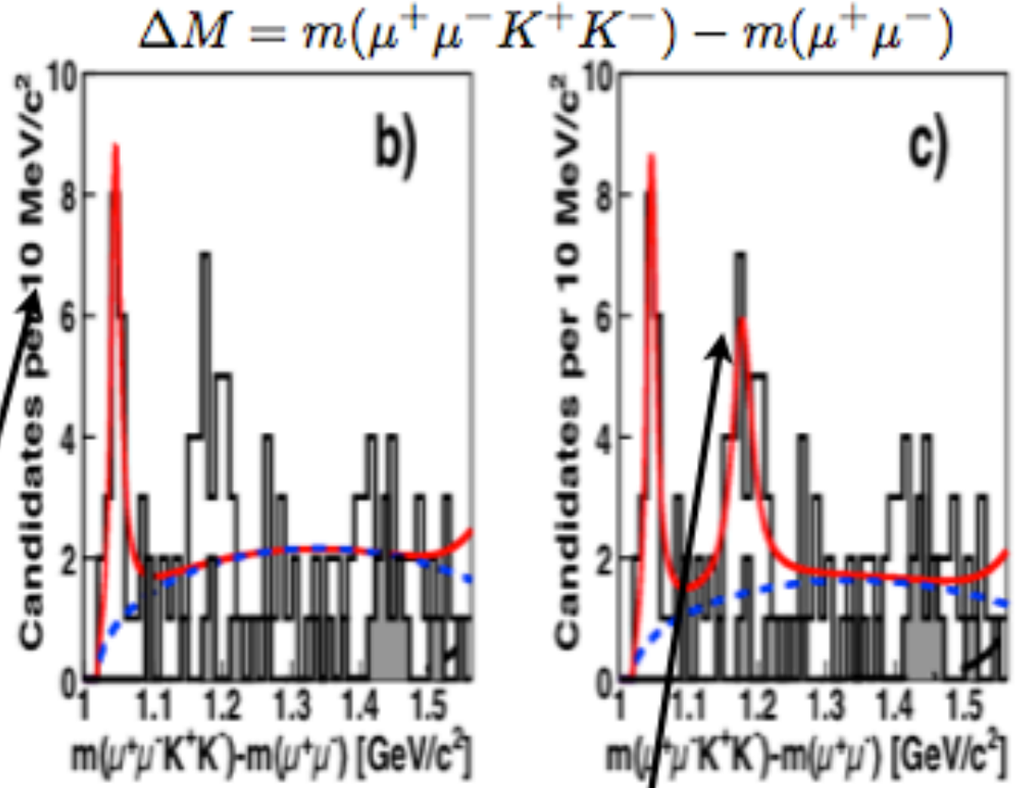
$\Gamma = 11.7\ ^{+8.3}_{-5.0}(\text{stat}) \mp 3.7(\text{sys})$ MeV

Significance for the signal is 3.8σ

Update from CDF - 2010

Total integrated luminosity: 6.0 fb^{-1}





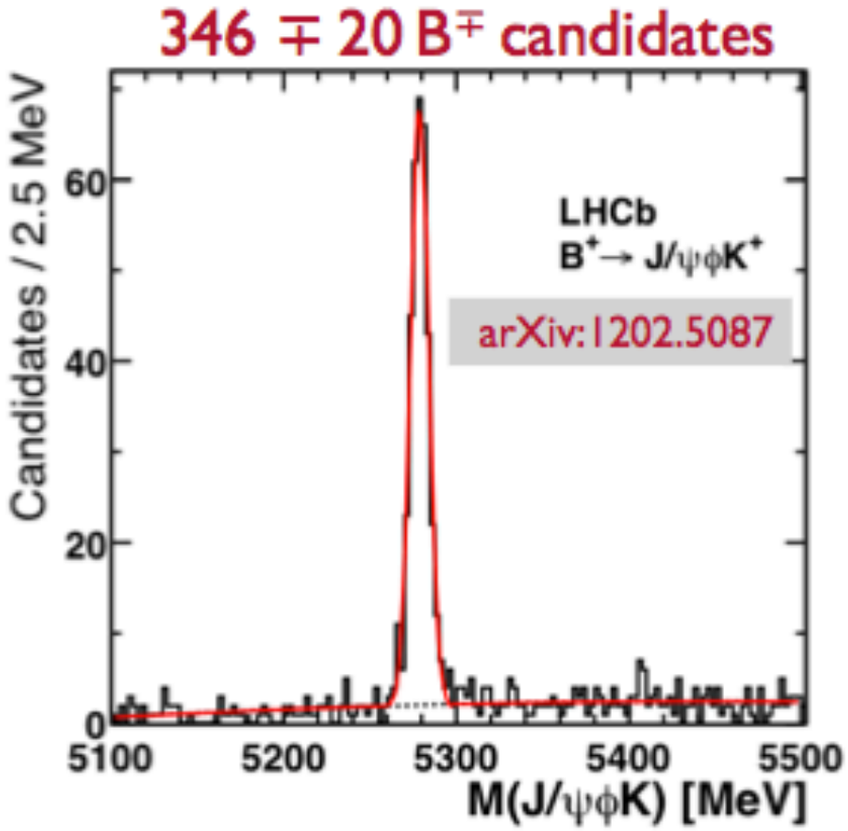
$M = 4143.4\ ^{+2.9}_{-3.0}(\text{stat}) \mp 0.6(\text{sys})$ MeV
$\Gamma = 15.3\ ^{+10.4}_{-6.1}(\text{stat}) \mp 2.5(\text{sys})$ MeV
Significance for the signal $> 5\sigma$

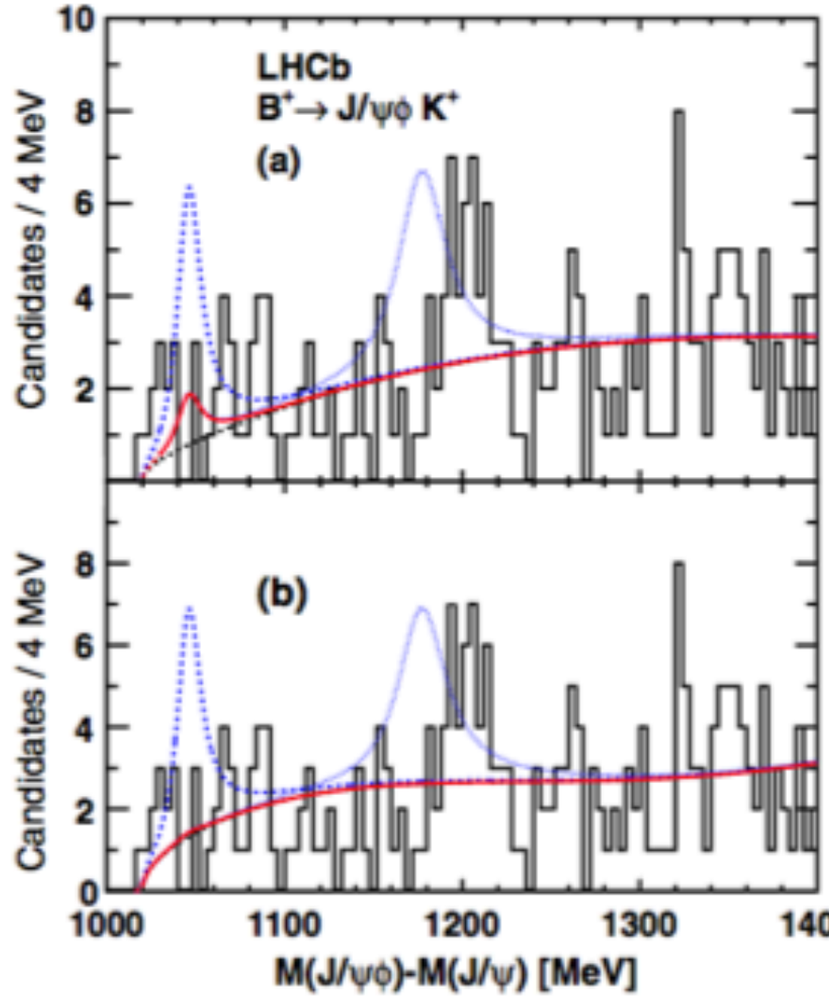
$M = 4277.4\ ^{+8.4}_{-6.7}(\text{stat}) \mp 1.9(\text{sys})$ MeV
$\Gamma = 32.3\ ^{+21.8}_{-15.3}(\text{stat}) \mp 7.6(\text{sys})$ MeV
Significance for the signal 3.1σ

$$\frac{\mathcal{B}(B^+ \to Y(4140), Y(4140) \to J/\psi\phi)}{\mathcal{B}(B^+ \to J/\psi\phi K)} = 0.149 \pm 0.039(\text{stat}) \pm 0.034(sys)$$

Results from LHCb - 2011

Total integrated luminosity: 0.37 fb^{-1}





LHCb did not confirm the two structures.
There is 2.4σ disagreement with CDF measurement

$$\frac{\mathcal{B}(B^+ \to X(4140)K^+) \times \mathcal{B}(X(4140) \to J/\psi\phi)}{\mathcal{B}(B^+ \to J/\psi\phi K^+)} < 0.07$$

$$\frac{\mathcal{B}(B^+ \to X(4274)K^+) \times \mathcal{B}(X(4274) \to J/\psi\phi)}{\mathcal{B}(B^+ \to J/\psi\phi K^+)} < 0.08$$

Event selection - preselection

- Tracks with p_T > 0.5 GeV
- $\mu^+\mu^-$ pair with a valid vertex fit
  - mass in 2.7-3.4 GeV
  - each muon has at least 1 pixel and at least 8 silicon hits
- Additional three tracks
  - total charge +/-1, assigned with kaon mass, $\Delta R(\mu^+\mu^-, K) < 1.5$
- Mass of the 5 tracks ($\mu^+\mu^-K^+K^-K^\mp$) in 5.0-5.6 GeV
- Two K^+K pairs from three kaon tracks
  - The pair with lower mass is considered as Φ candidate
- Vertex fit to the five tracks and constraint $\mu^+\mu^-$ to nominal J/ψ mass

Event Selection - final selection

- Tracks with $|\eta| \leq 2.4$
- Probability (χ^2)
  - J/ψ vertex fit > 10%, B vertex fit > 1%
- p_T (kaon tracks) > 1 GeV
- J/ψ vertex flight length significance ≥ 3
- Offline p_T selection
  - datasetA: p_T(J/ψ) > 7 GeV
  - datasetB: p_T(J/ψ) > 7 GeV & $p_T(\mu^+ \& \mu^-)$ > 4 GeV
- Mass window
  - J/ψ (∓ 150 MeV) & Φ in 1.008-1.035 GeV (Breit-Wigner shape)
  - constrain $\mu^+\mu^-$ to J/ψ PDG mass value