Exotic Quarkonium Spectroscopy & Production

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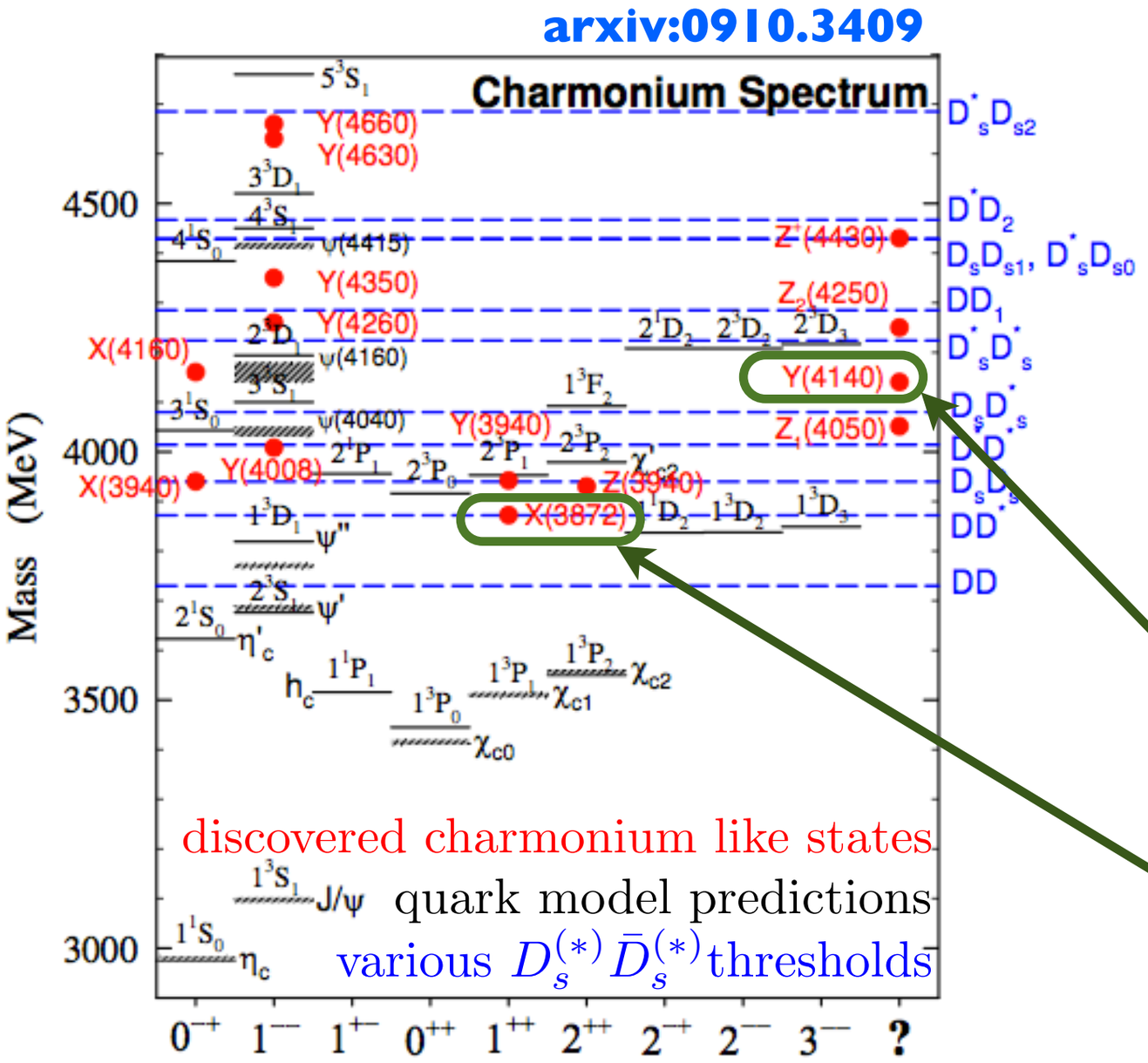
XXI. International Workshop on Deep-Inelastic Scattering and Related Subjects

Introduction

Observation of the new states which do not fit into conventional quark model renewed the interest in exotic states.



Many models are proposed to explain charmonium spectroscopy, however, the agreement with the experiments is not satisfied.

Today's presentation is focusing on

(based on 2011, 7 TeV, ~5 fb^{-1} CMS data)

<u>Observation of structures in the J/ψϕ mass spectrum</u>

<u>Production of X(3872) via decay to J/ψπ⁺π⁻</u>

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

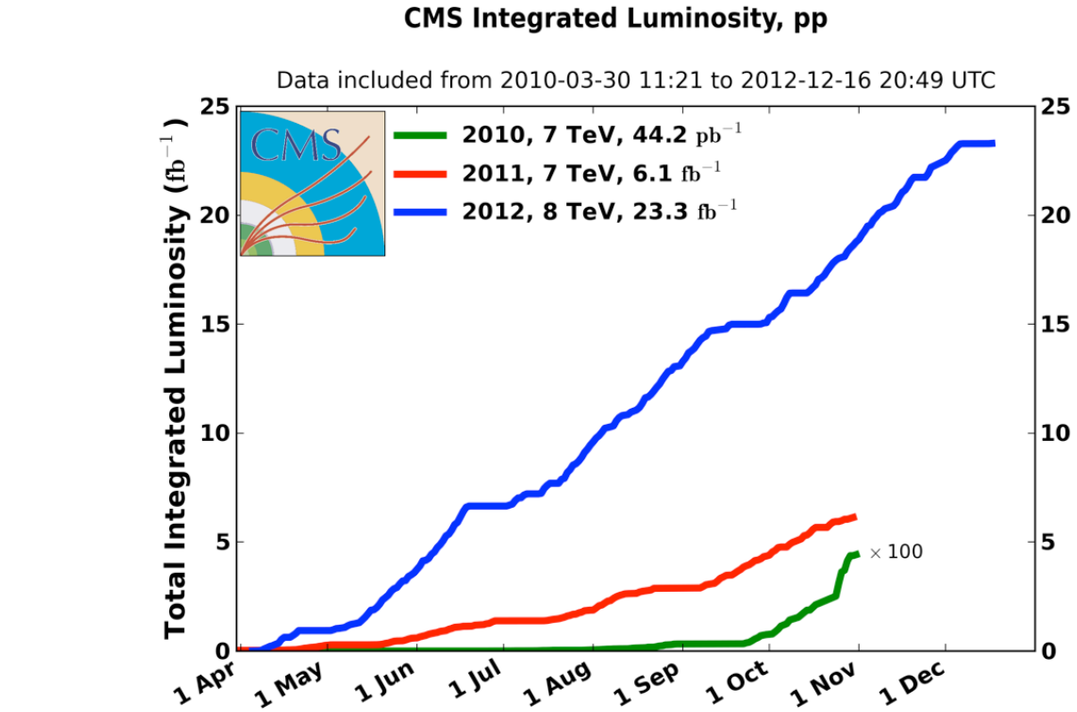
➡ High purity muon identification

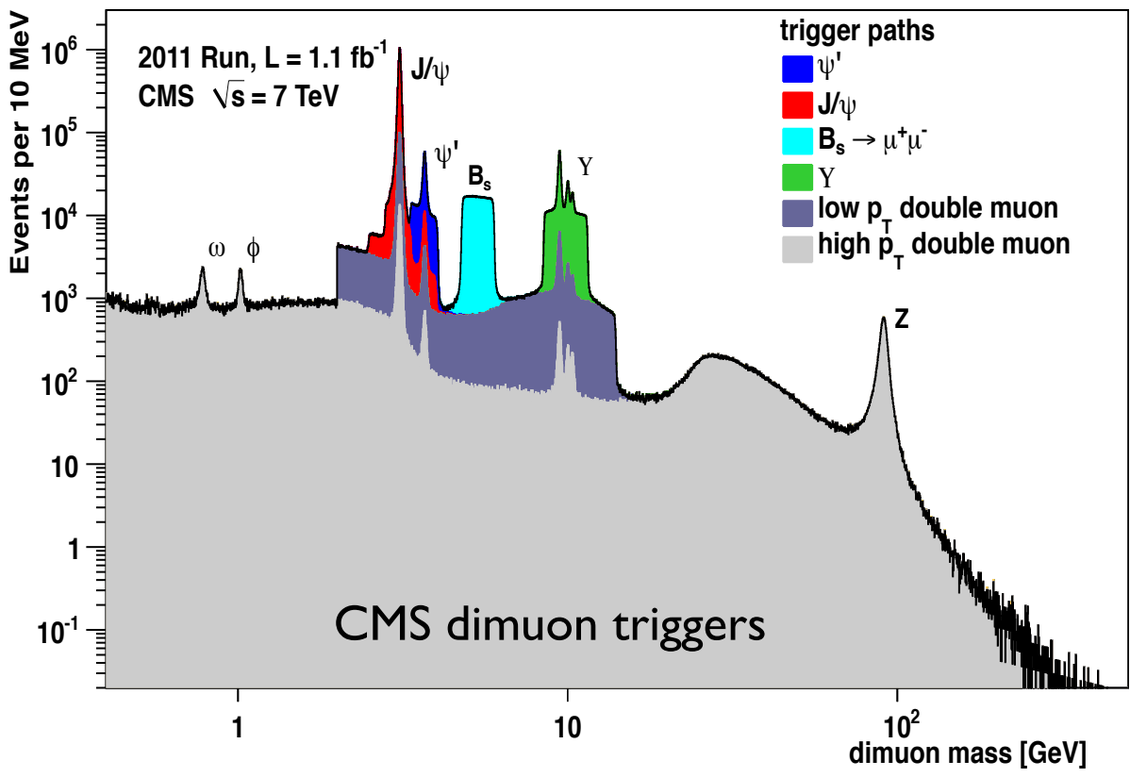
➡ Good dimuon mass resolution
($\Delta m/m \sim 0.6\%$ for J/ψ)

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





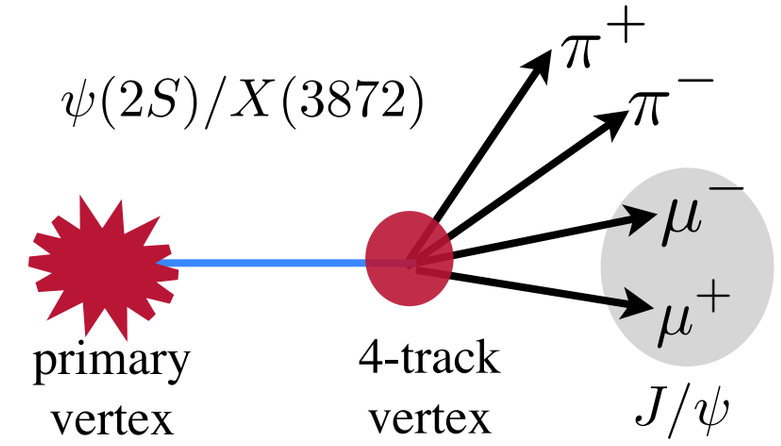
Production of X(3872)

X(3872) production via decays to $J/\psi\pi^+\pi^-$

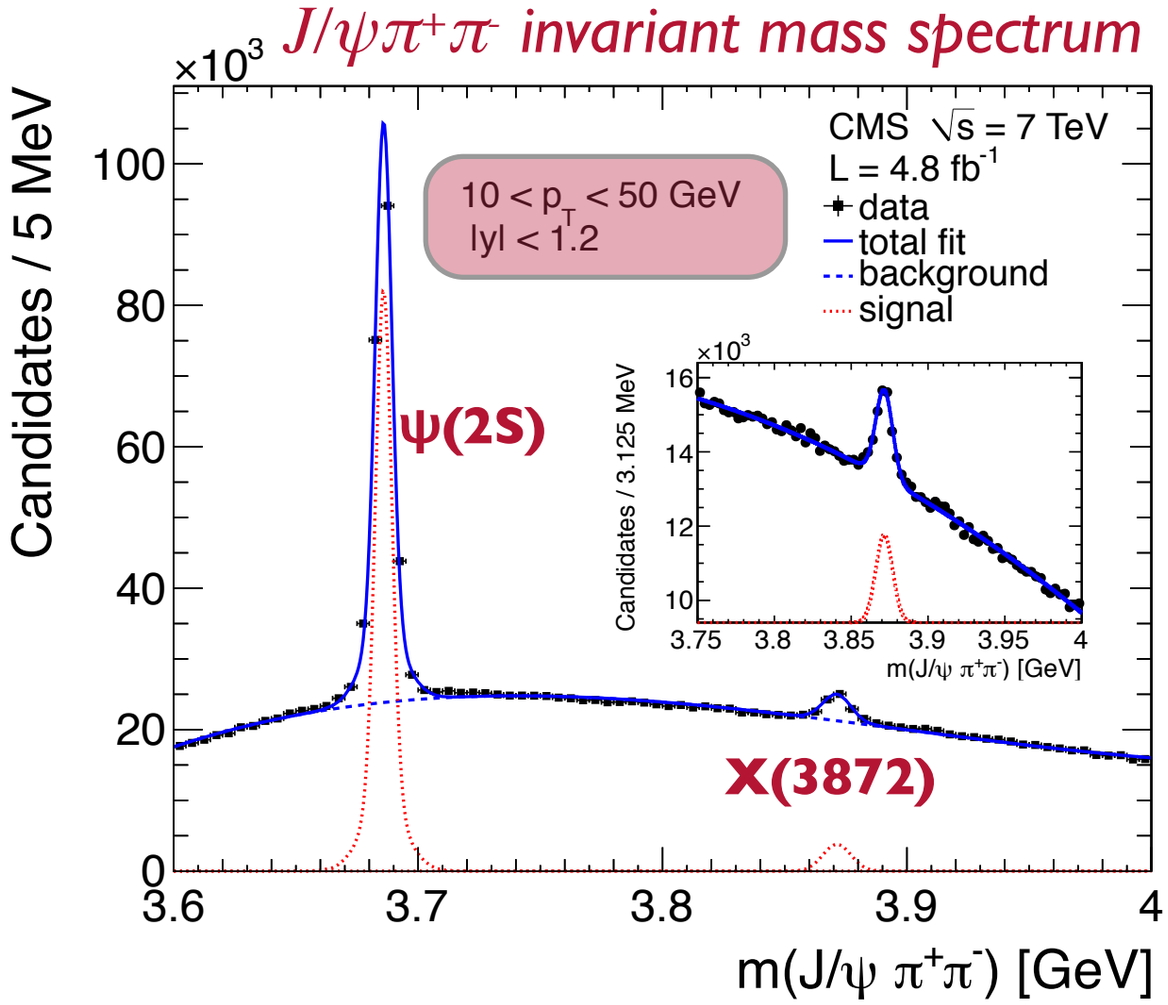
X(3872) has been observed in several decay channels
$J/\psi\pi^+\pi^-$, D^*D^0, $\gamma J/\psi$, $\gamma\psi(2S)$ and $\omega J/\psi$
motivating interpretations as
a charmonium state, a D^*D^0 molecule and a tetra-quark state

LHC provides a big opportunity to study the properties of X(3872) at a new energy scale.

CMS studied the production of X(3872) via decays to $J/\psi(\rightarrow\mu^+\mu^-)\pi^+\pi^-$ using 4.8 fb^{-1} pp data collected at $\sqrt{s}$ = 7 TeV center of mass energy.



- Two opposite sign muons from J/ψ
  - $p_T(\mu^+\mu^-) > 7$ GeV & $|y(\mu^+\mu^-)| < 1.25$
- $p_T(\mu) > 4$ (3.3) GeV for $|\eta(\mu)| < 1.2$ ($1.2 < |\eta(\mu)| < 2.4$)
- Two opposite sign well reconstructed tracks (assumed to be pion) with $p_T > 600$ MeV
- Four tracks are constraint to have a common vertex with $\chi^2 > 5\%$
- $\Delta R(J/\psi, \pi^\pm) < 0.55$
- $m(\mu^+\mu^-\pi^+\pi^-) - m(J/\psi)^{PDG} - m(\pi^+\pi^-) < 300$ MeV



http://arxiv.org/abs/1302.3968

X(3872): Measurement of the cross section ratio

$$R = \frac{\sigma(pp \to X(3872) + \text{anything}) \times B(X(3872) \to J/\psi\pi^+\pi^-)}{\sigma(pp \to \psi(2S) + \text{anything}) \times B(\psi(2S) \to J/\psi\pi^+\pi^-)}$$

Ratio of the σ×Br is obtained from the measured numbers of signal events for X(3872) and ψ(2S).

- ➡ The signal events for X(3872) and ψ(2S) are extracted from fits to the $J/\psi\pi^+\pi^-$ invariant mass spectrum.
- ➡ Acceptance (A) and efficiencies (ε) are estimated from simulation, assuming X(3872) and ψ(2S) are unpolarized and J^{PC} of X(3872)=1^{++}

$$R_{fiducial} = \frac{N_{X(3872)} \cdot \epsilon_{\psi(2S)}}{N_{\psi(2S)} \cdot \epsilon_{X(3872)}}$$

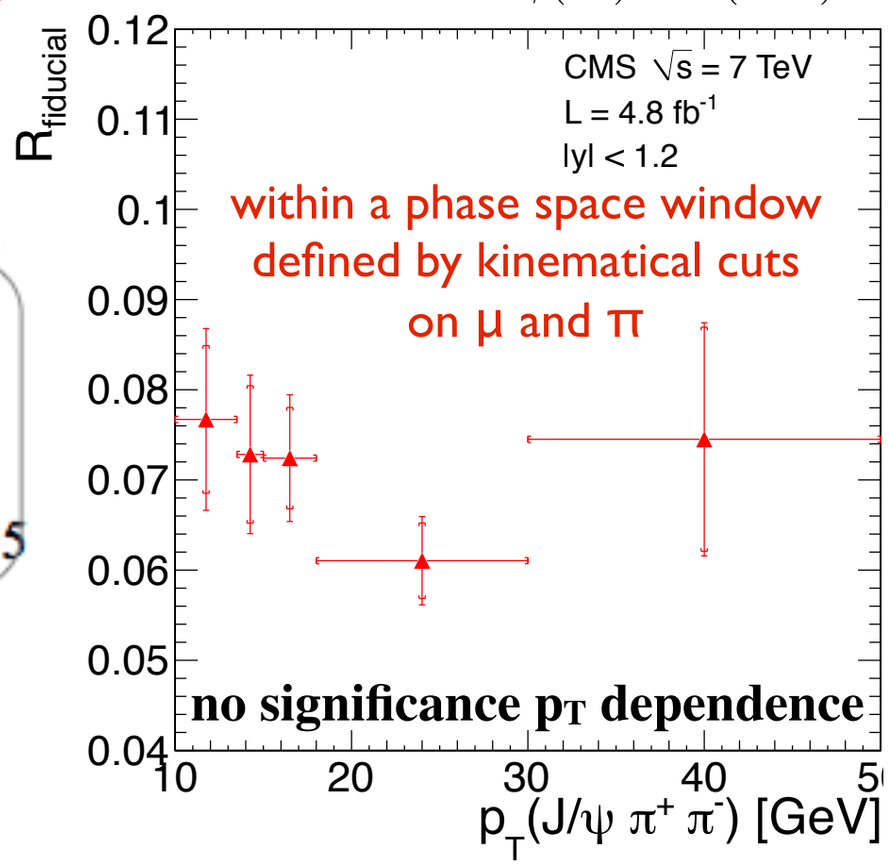
$$R = \frac{N_{X(3872)} \cdot A_{\psi(2S)} \cdot \epsilon_{\psi(2S)}}{N_{\psi(2S)} \cdot A_{X(3872)} \cdot \epsilon_{X(3872)}}$$

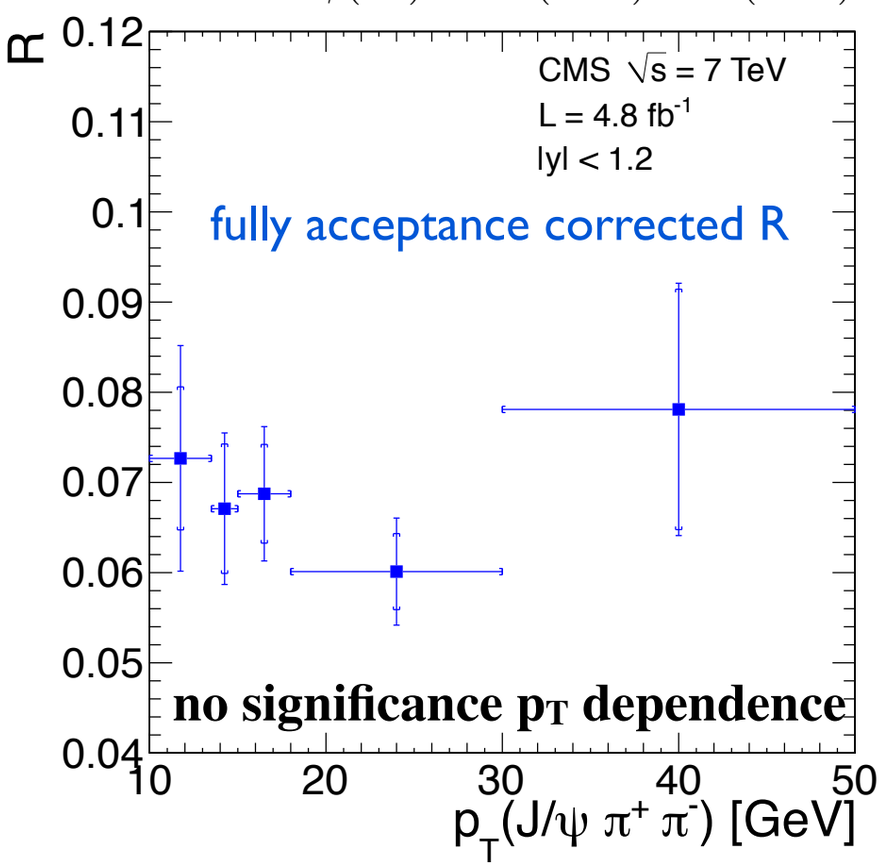
$p_T^\mu > 4\text{GeV}$ in $|\eta^\mu| < 1.2$

$p_T^\mu > 3.3\text{GeV}$ in $1.2 < |\eta^\mu| < 2.4$

$p_T^{\mu\mu} > 7\text{GeV}$ in $|y^{\mu\mu}| < 1.25$

$p_T^\pi > 0.6\text{GeV}$ & $\Delta R(\pi,\mu\mu) < 0.55$





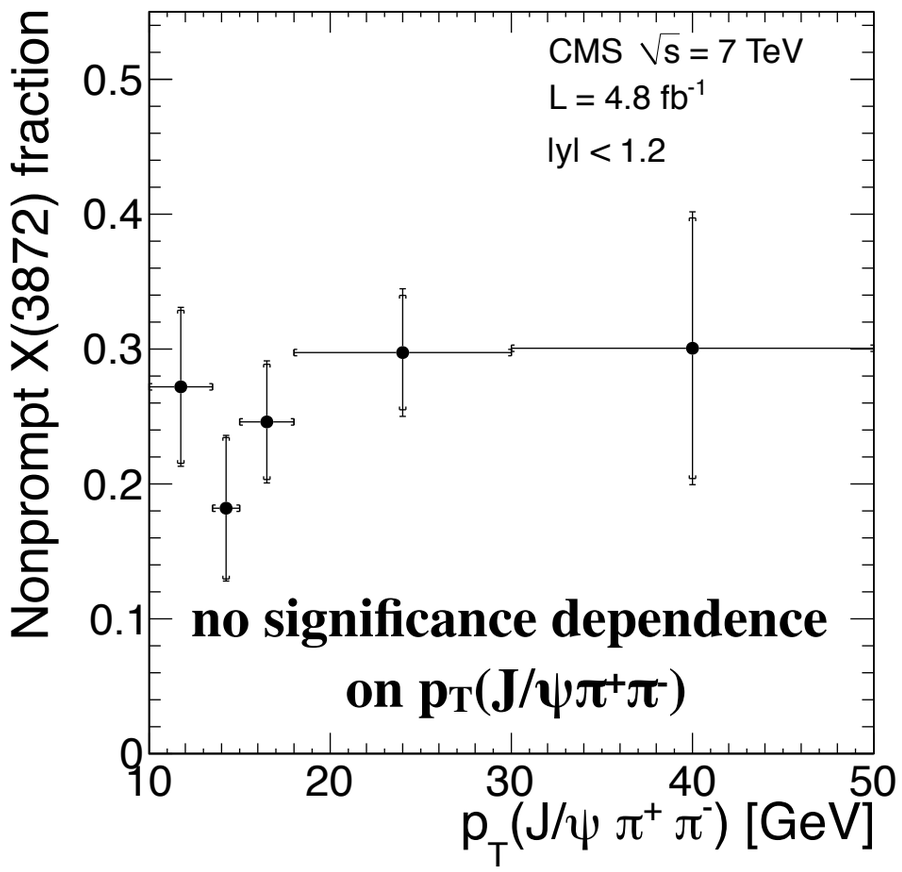
X(3872): Measurement of non-prompt production

CMS determined the non-prompt fraction of X(3872) (from decays of B hadrons) from the decay lifetime distribution.

➡ B enriched sample is selected requiring pseudo-proper-decay-length $l_{xy} > 100$ μm

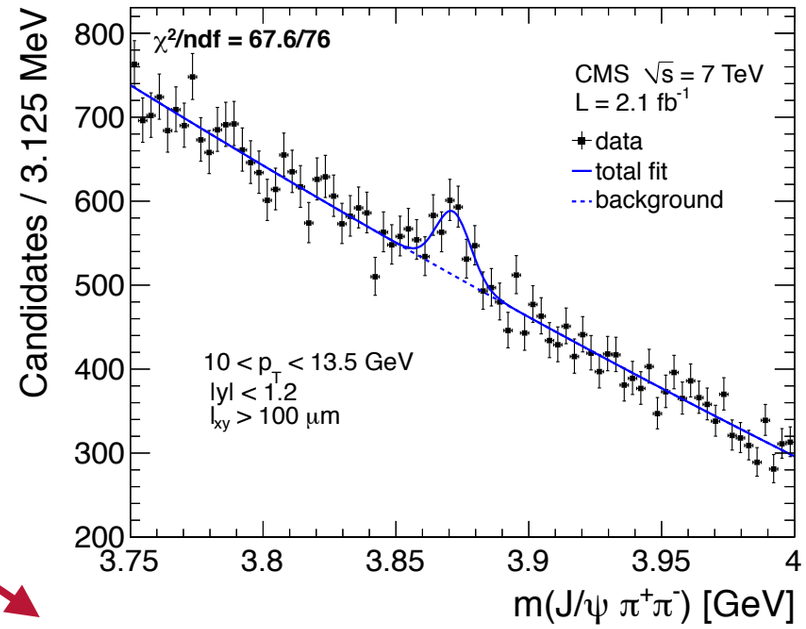
$$l_{xy}^{X(3872)} = \frac{L_{xy}^{X(3872)} \cdot m_{X(3872)}}{p_T}$$

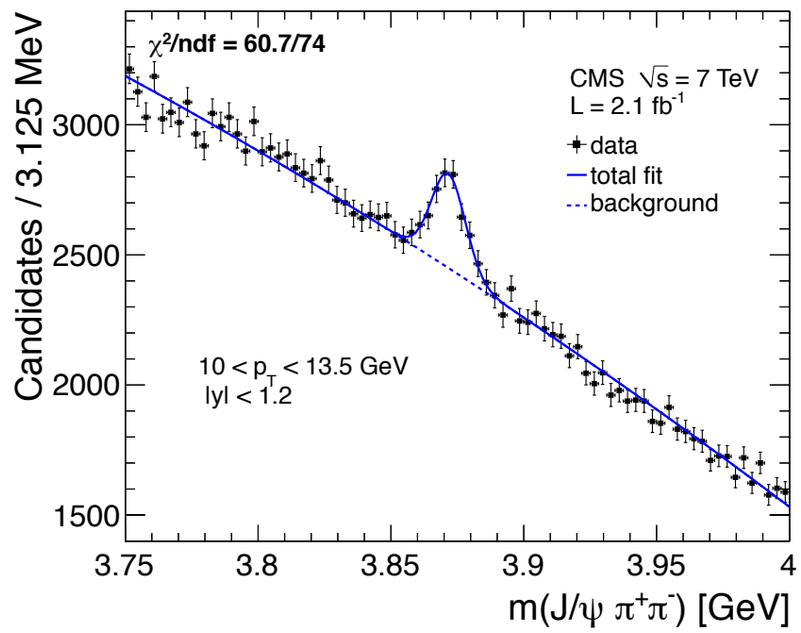
$$\text{non-promt fraction} = \frac{\text{Signal Yield (B hadron enriched sample)}}{\text{Signal Yield (whole sample)}}$$



measurement is stable wrt variations of l_{xy} (50-250 μm)

non-prompt fraction equals
0.263±0.023(stat)±0.016(syst)
(10-50 GeV p_T & |y| < 1.2)





X(3872): Measurement of prompt production cross section

$(\sigma \times \mathcal{B})$ of the prompt X(3872) is determined by:

$$\sigma^{prompt}_{X(3872)} \cdot \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) = \frac{1 - f^B_{X(3872)}}{1 - f^B_{\psi(2S)}} \cdot R \cdot (\sigma^{prompt}_{\psi(2S)} \cdot \mathcal{B}(\psi(2S) \to \mu^+\mu^-)) \cdot \frac{\mathcal{B}(\psi(2S) \to J/\psi\pi^+\pi^-)}{\mathcal{B}(\psi(2S) \to \mu^+\mu^-)}$$

non-prompt fraction

non-prompt fraction

cross section ratio

from previous CMS measurement
JHEP02 (2012) 011

from PDG
Phys. Rev. D 86 (2012)

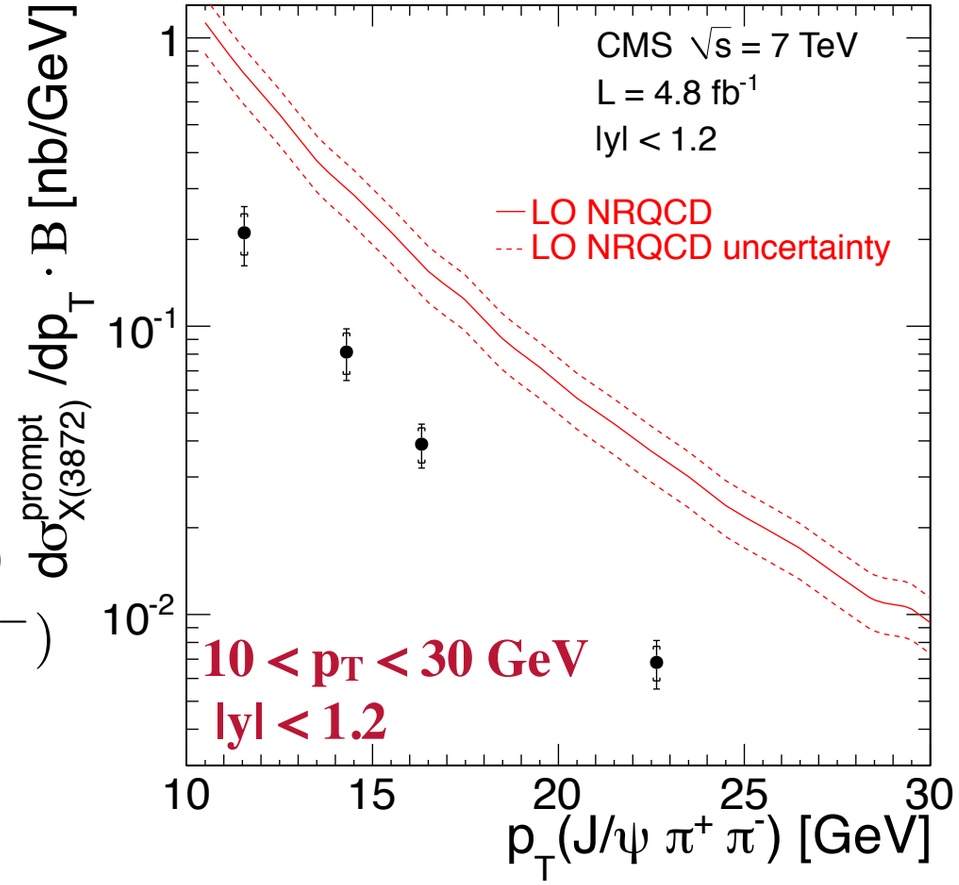
- Cross section times branching ratio is provided as a function of transverse momentum up to 30 GeV.
  first time measured differentially in p_T
- Predicted differential prompt cross section is calculated using the NRQCD factorization formalism.
  - (Phys. Rev. D 81 (2010) 114018)

integrated cross section times branching fraction (p_T: 10-30 GeV)

$$\sigma^{\text{prompt}}(pp \to X(3872) + \text{anything}) \cdot \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-)$$

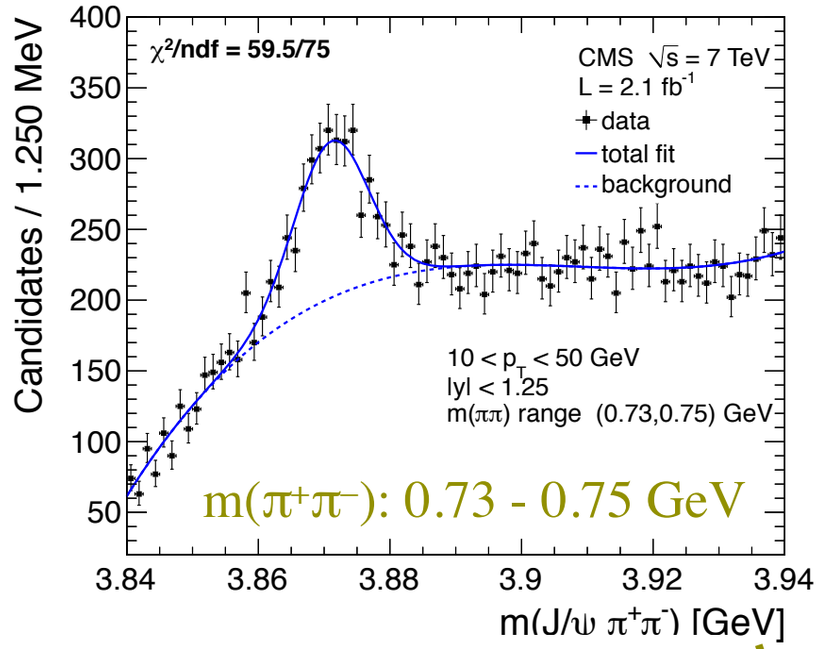
$$= 1.06 \pm 0.11(\text{stat.}) \pm 0.15(\text{syst.}) \text{ nb}$$

Significantly lower than theoretical prediction: 4.01 ± 0.88 nb



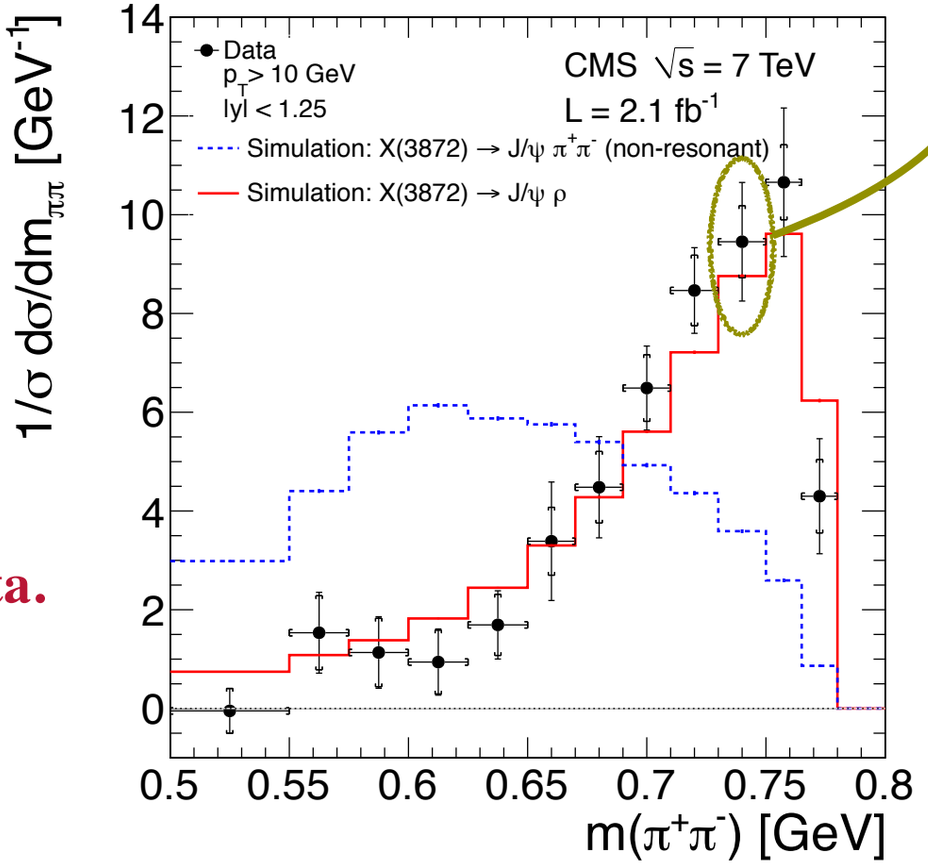
X(3872): Measurement of the $\pi^+\pi^-$ invariant mass distribution

The background subtracted $\pi^+\pi^-$ pair invariant mass spectrum is extracted from likelihood fit to the $J/\psi\pi^+\pi^-$ invariant mass spectrum.



- ➡ Sample is divided into twelve dipion invariant mass intervals
- ➡ X(3872) yields are extracted in each mass interval
- ➡ The yields are corrected for detector acceptance and efficiency
- ➡ Obtained spectrum is compared to the simulation w/ and w/o an intermediate ρ^0 in the $J/\psi\pi^+\pi^-$ decay

$$X(3872) \rightarrow J/\psi\rho^0 \rightarrow \mu^+\mu^-\pi^+\pi^-$$



The intermediate ρ^0 decay gives better agreement with the data.

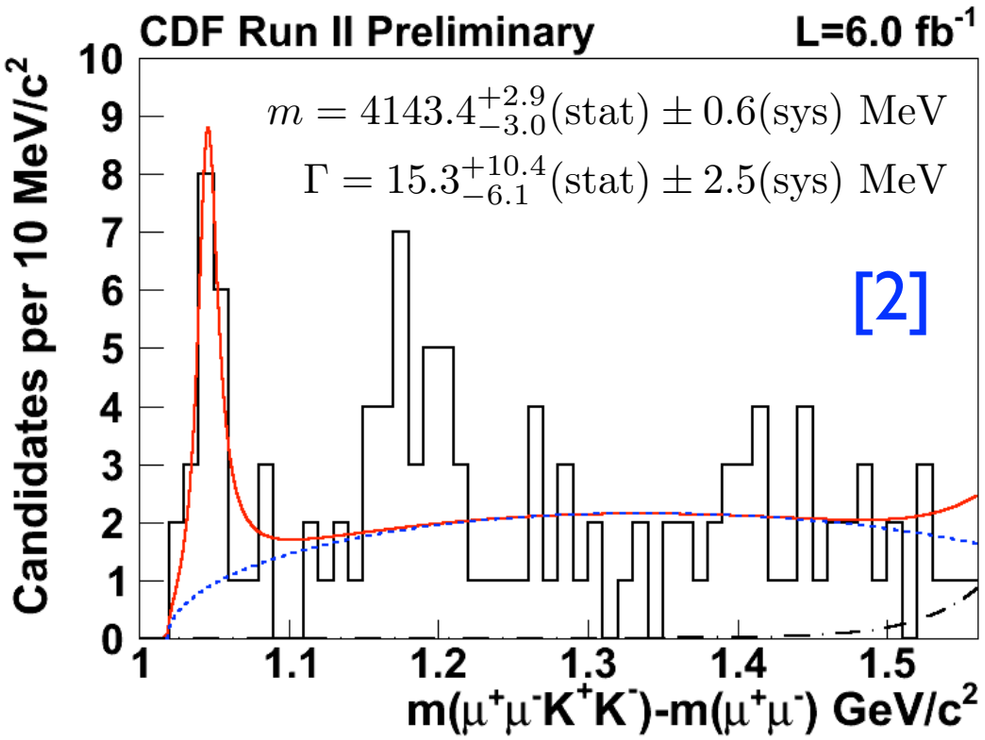
Observation of the structures in the $J/\psi\phi$ mass spectrum

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.

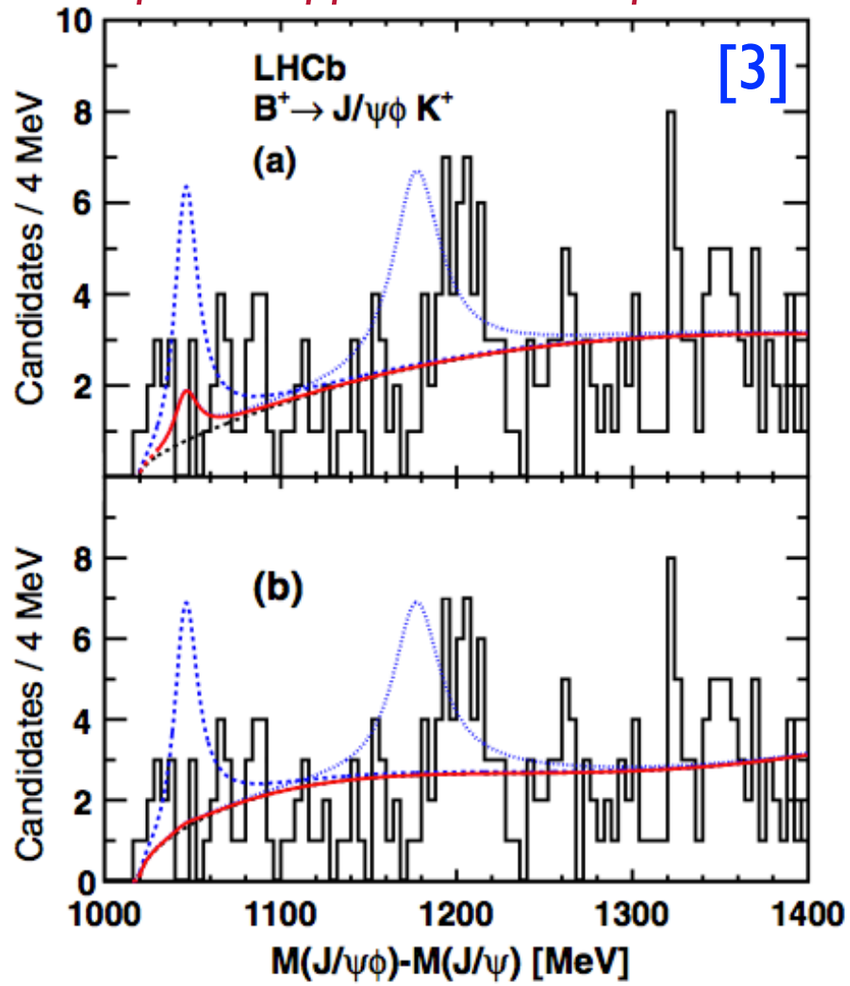
Especially the observation of Y(3930)[1] near the J/ψω threshold motivates the searches for similar structures near J/ψφ threshold

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



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

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



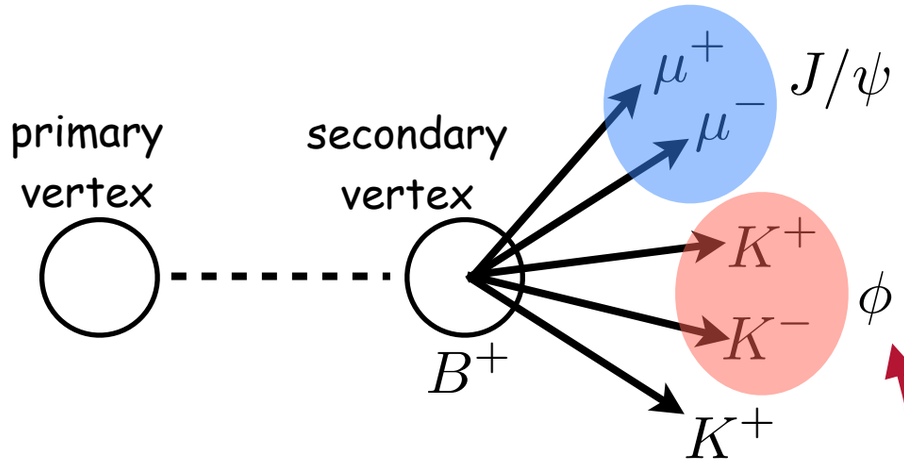
[1] BABAR-Phys. Rev. Lett. 94, 182002 (2005), BELLE-Phys. Rev. Lett. 101, 082001 (2008)

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

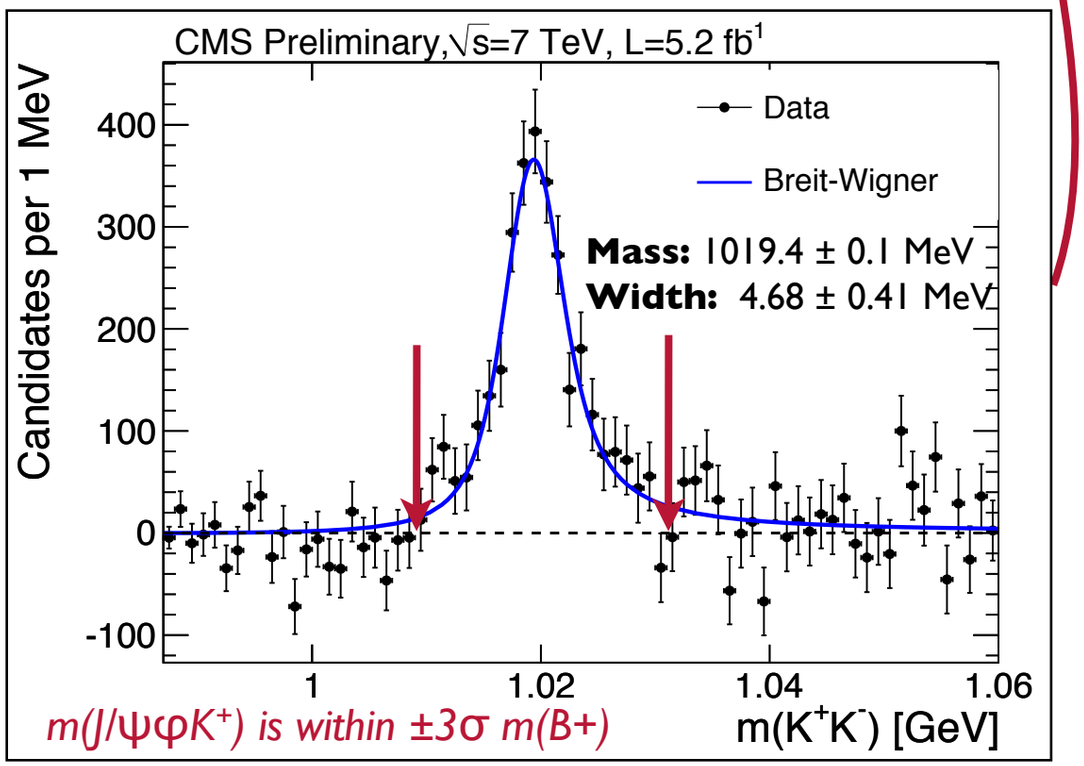
[3] arXiv:1202.5087

CMS search in the J/ψϕ mass spectrum

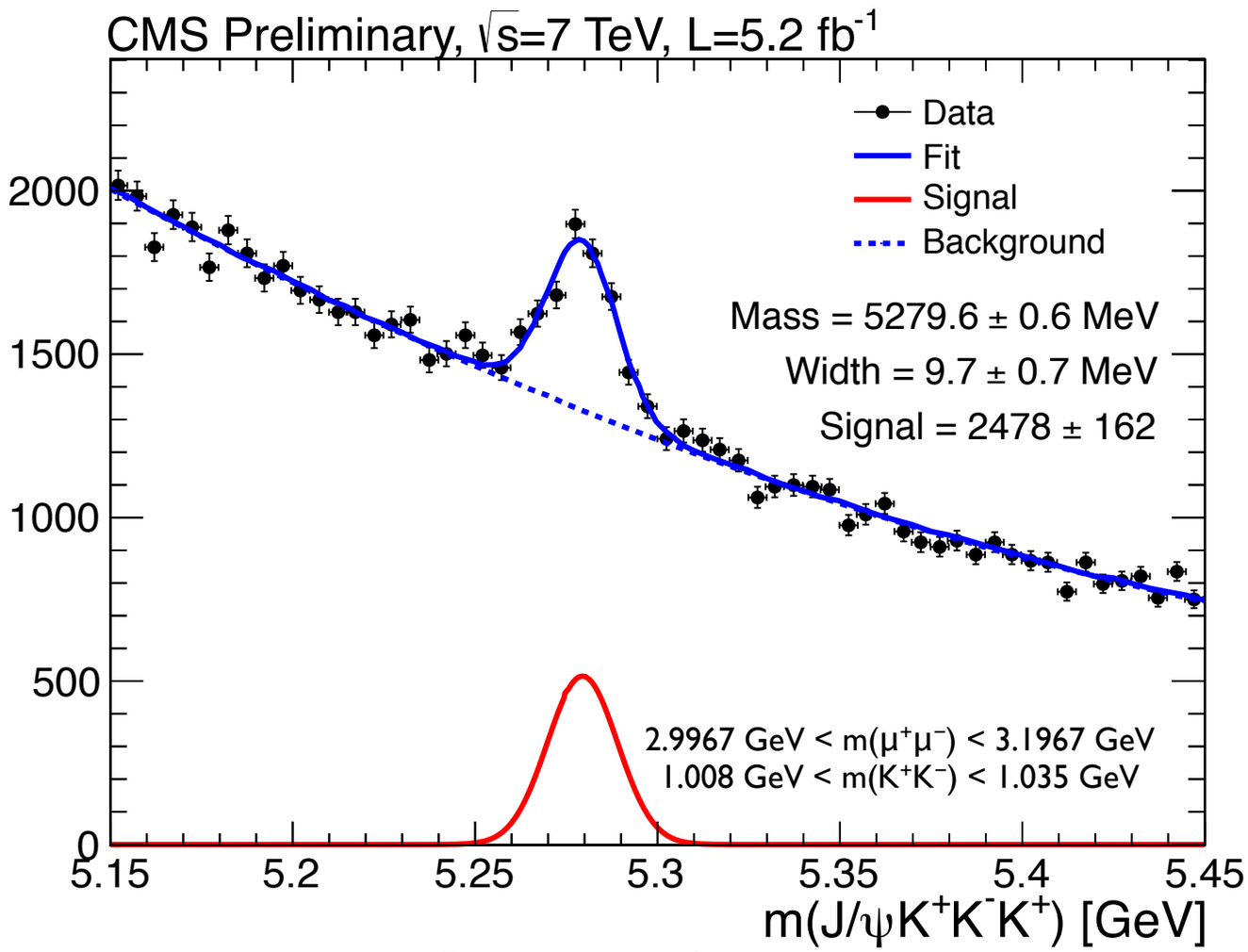
CMS tries to solve the puzzle and confirm the results of one of the experiments by searching for states in the $J/\psi\Phi$ mass spectrum via the $B^{\pm} \rightarrow J/\psi\Phi K^{\pm}$ decay



The B^+ sideband subtracted $m(K^+K^-)$



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



Signal PDF: A Gaussian signal

Background PDF: A second order Chebychev polynomial

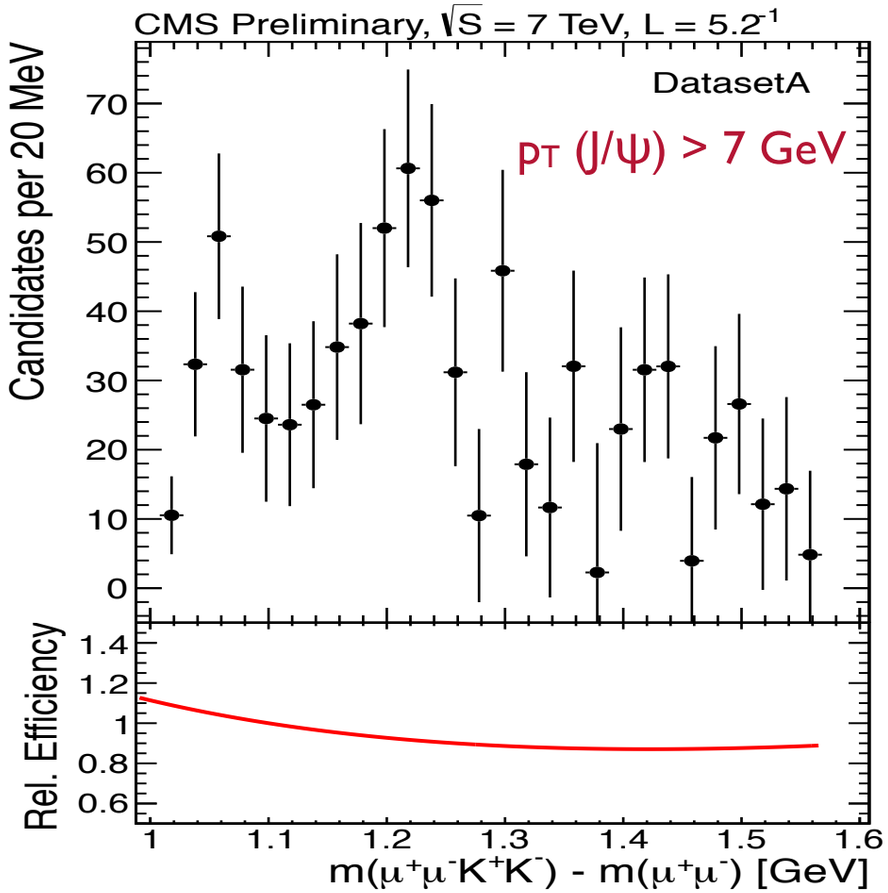
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11026

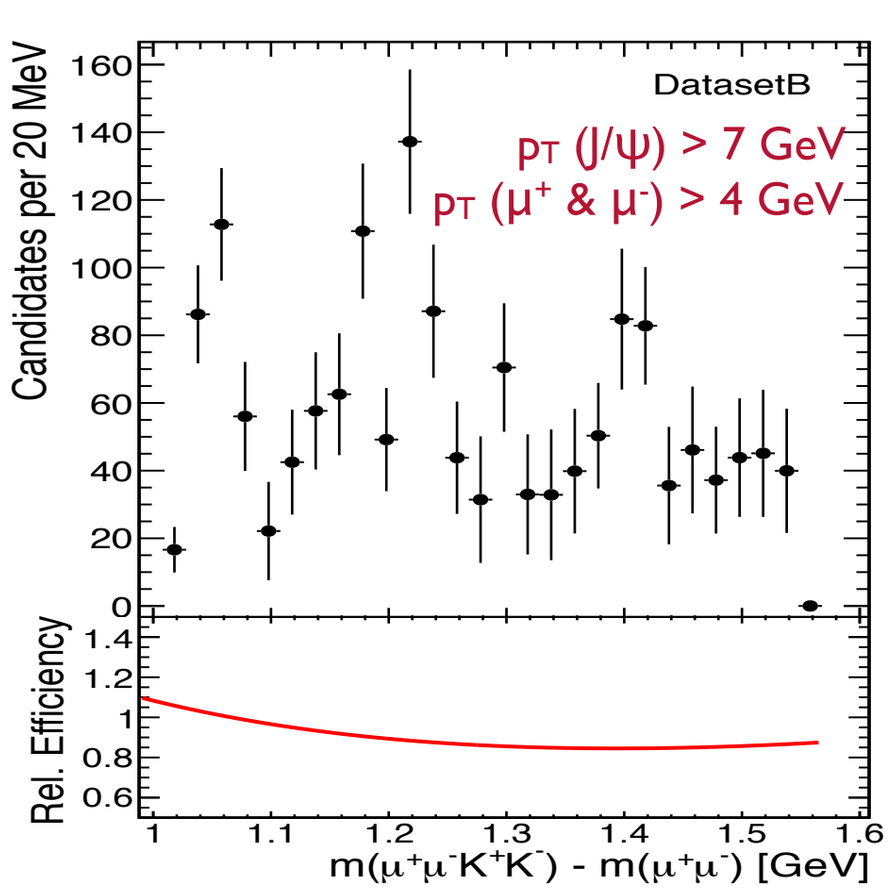
Observation of structures in the J/ψϕ mass spectrum

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

Extracting the Δm Spectrum

- 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



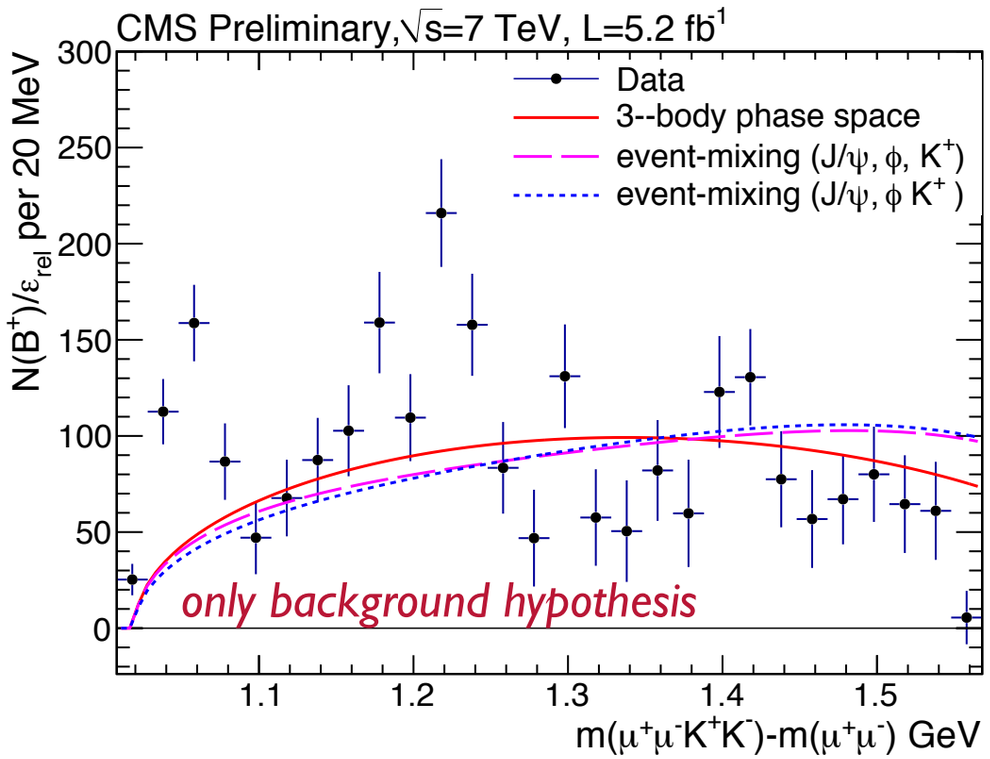


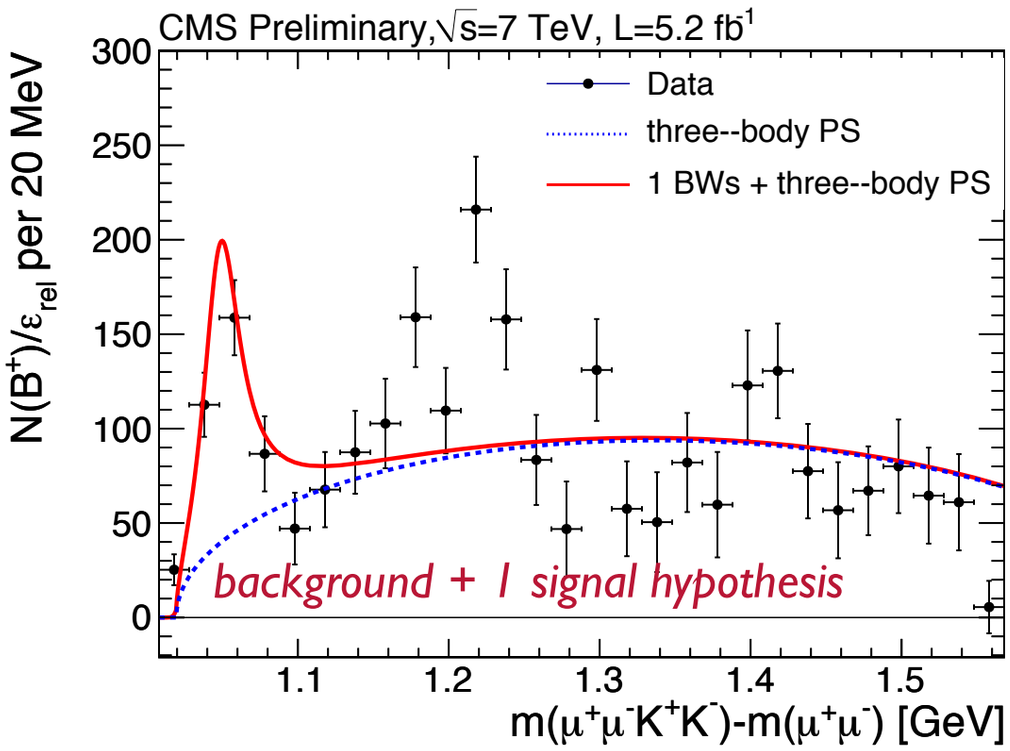
Observation of structures in the J/ψϕ mass spectrum

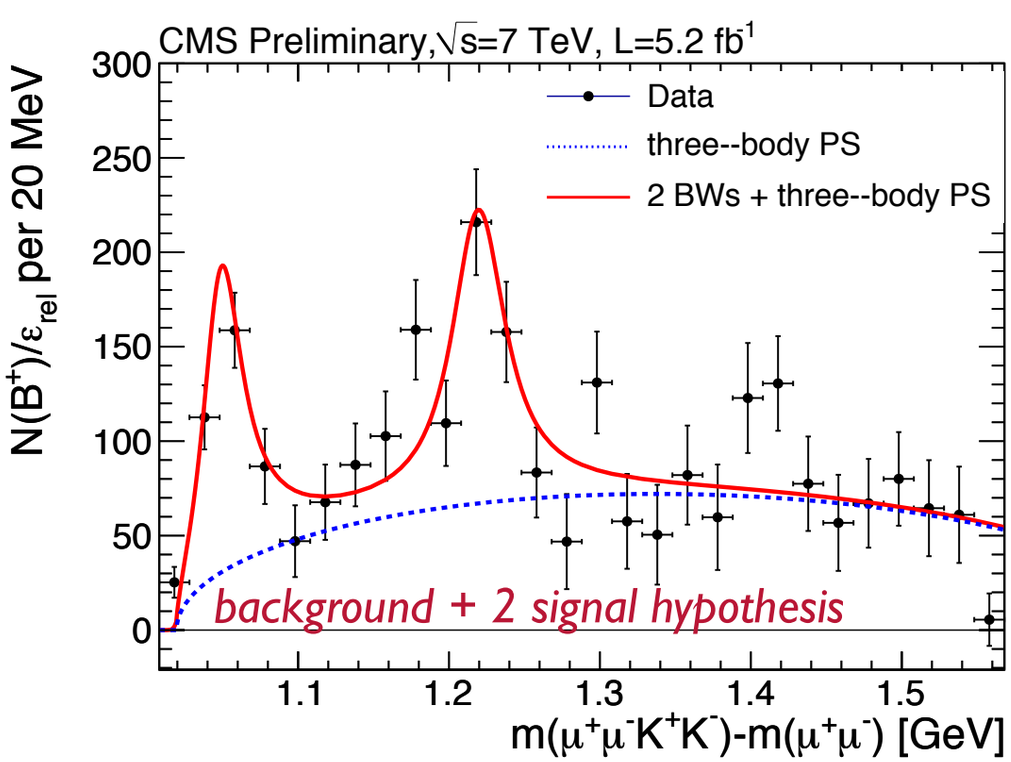
The relative efficiency corrected Δm distributions from $B^{\pm} \rightarrow J/\psi \Phi K^{\pm}$ decays

Background: *3-body phase space*

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





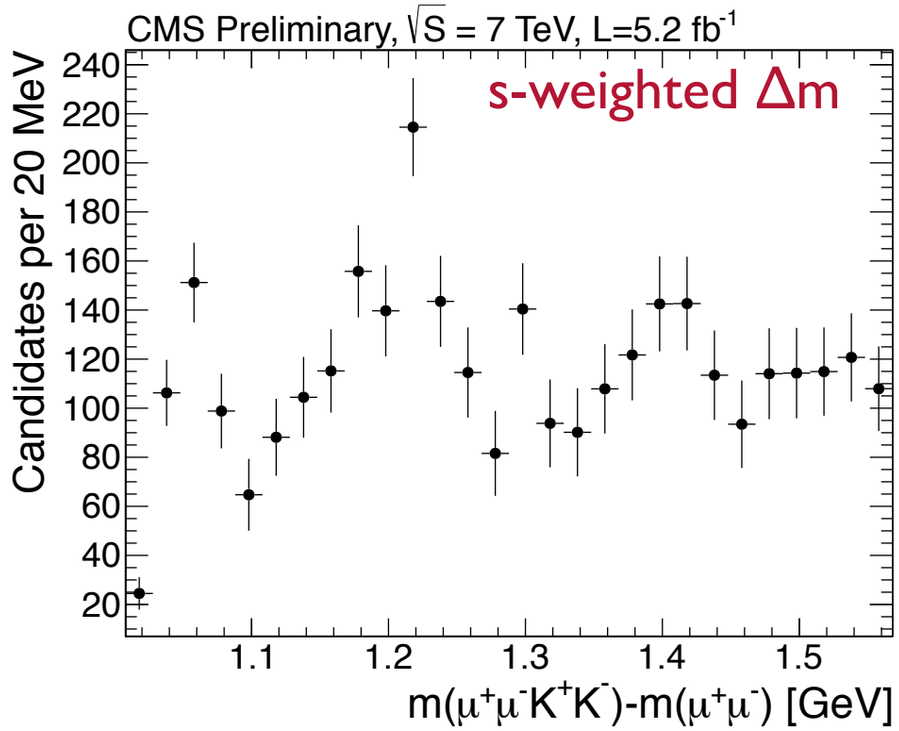


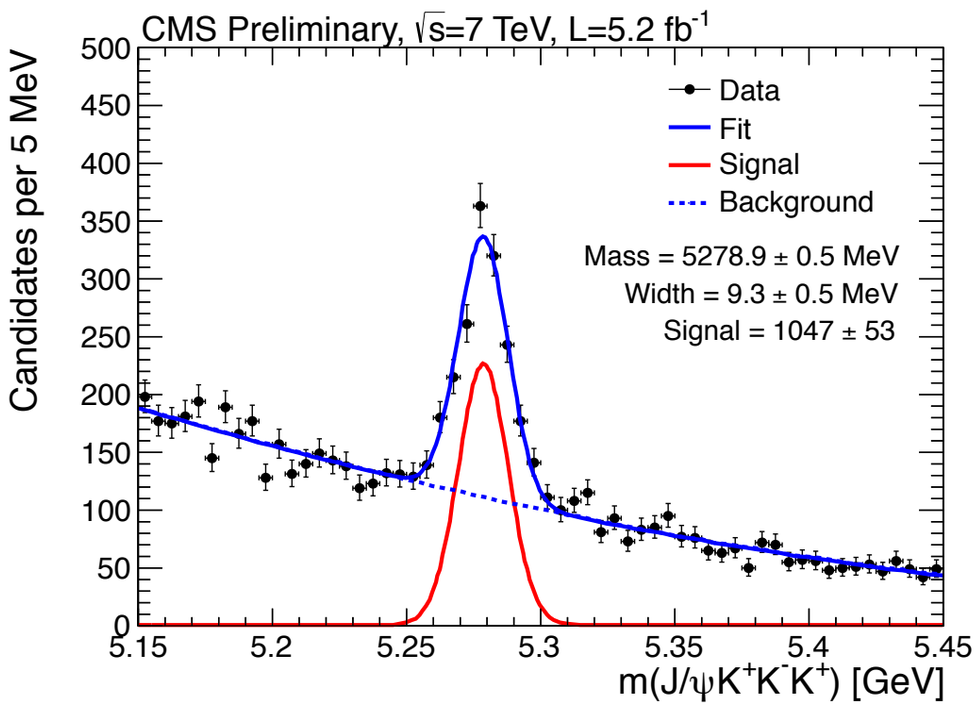
Robustness of the observed structures

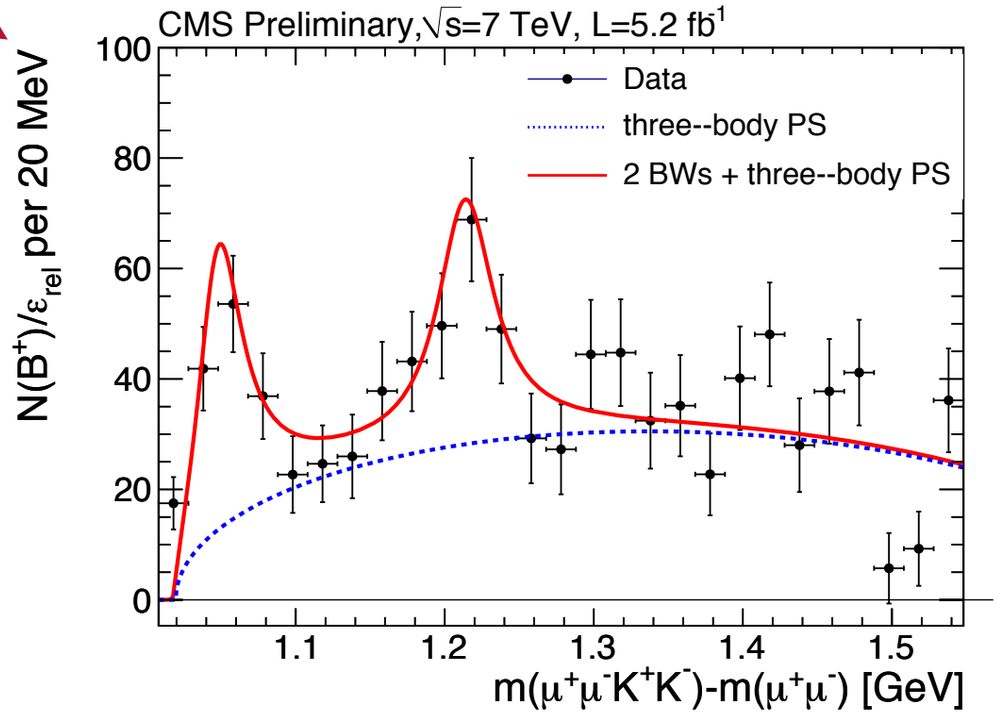
Several checks are performed to validate the robustness of the two structures

- ➡ 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



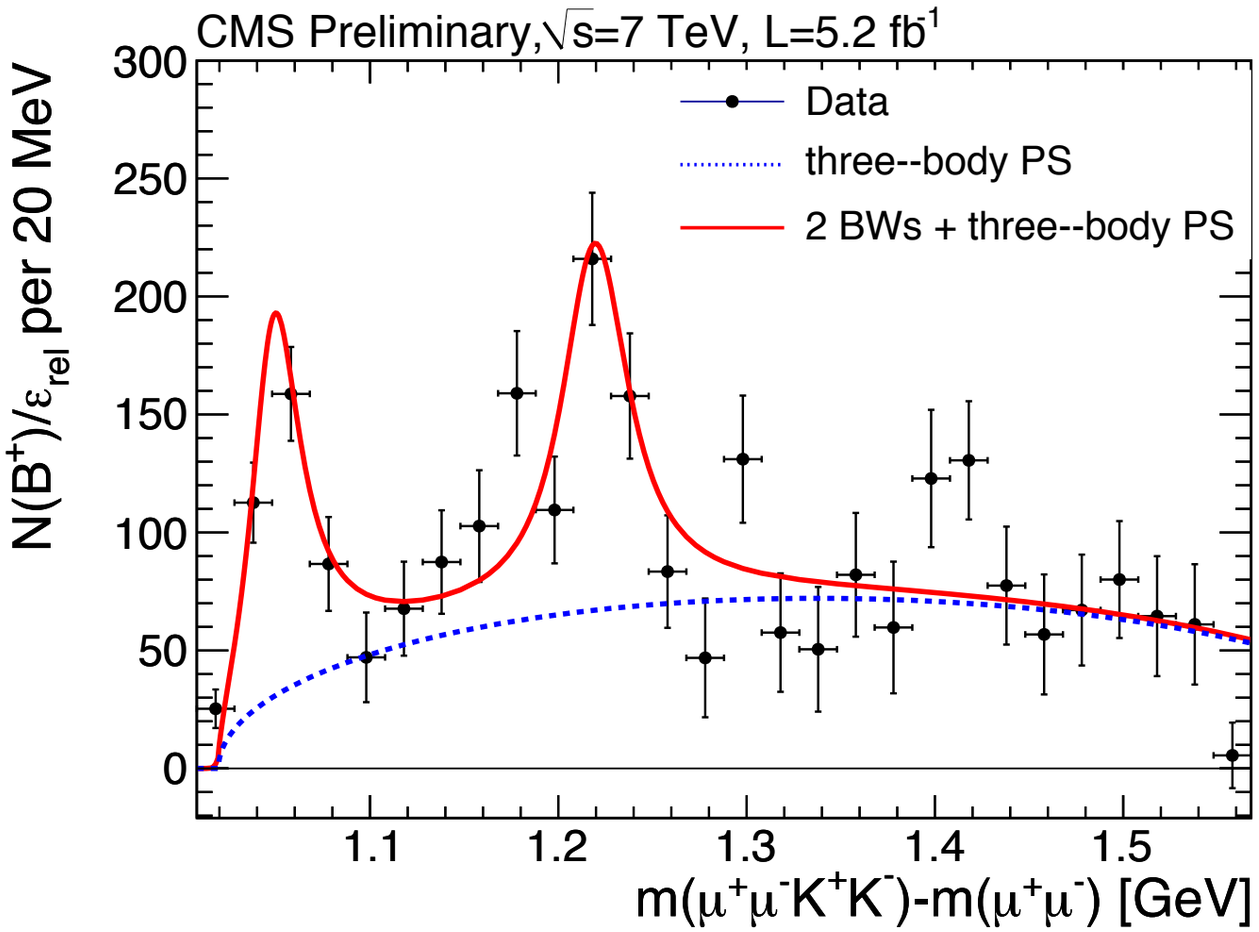




Observation of structures in the J/ψϕ mass spectrum

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



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

$m(1^{st}) = 4148.2 \pm 2.0(stat) \pm 5.2(sys)$ 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.*

Summary

- Thanks to excellent LHC and CMS performances, an active exotic spectroscopy program has been carried out on 2011 data
  - Production of X(3872) via decay to $J/\psi\pi^+\pi^-$
    - *ratio of σxBr of X(3872) and ψ(2S)*
    - *fraction of X(3872) from B decays (first time at LHC)*
    - *prompt X(3872) σxBr as a function of p_T (first time ever)*
    - *dipion invariant mass spectrum (favors an intermediate ρ^0 decay)*
  - Observation of structures in $J/\psi\Phi$ spectrum at 4148MeV & 4317MeV
    - *confirm the existence of Y(4140)*
    - *find evidence for a second structure*
- **!!!More to be expected with 2012 data**

All CMS B-Physics results are available at
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH