# Production of Exotic Hadrons at CMS

Beauty 2014

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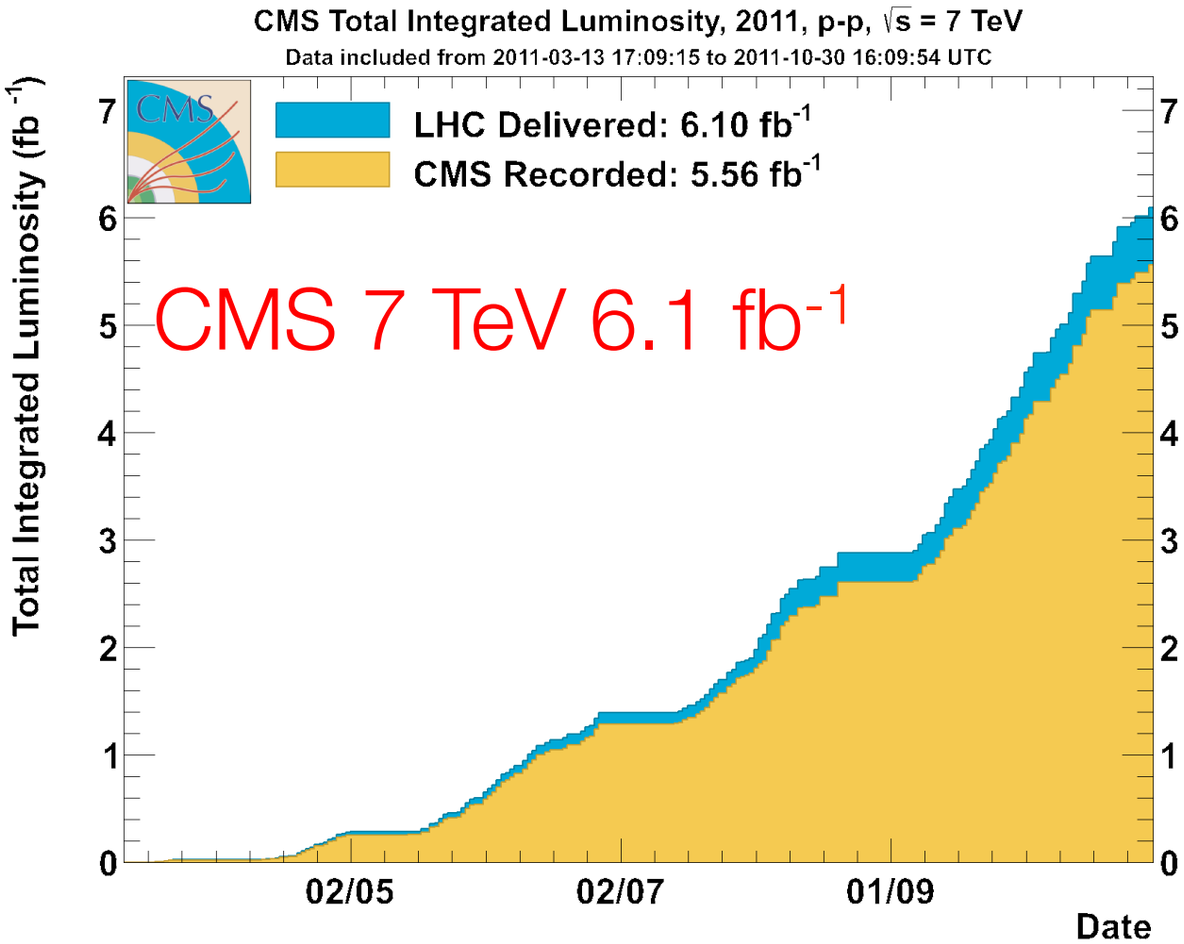
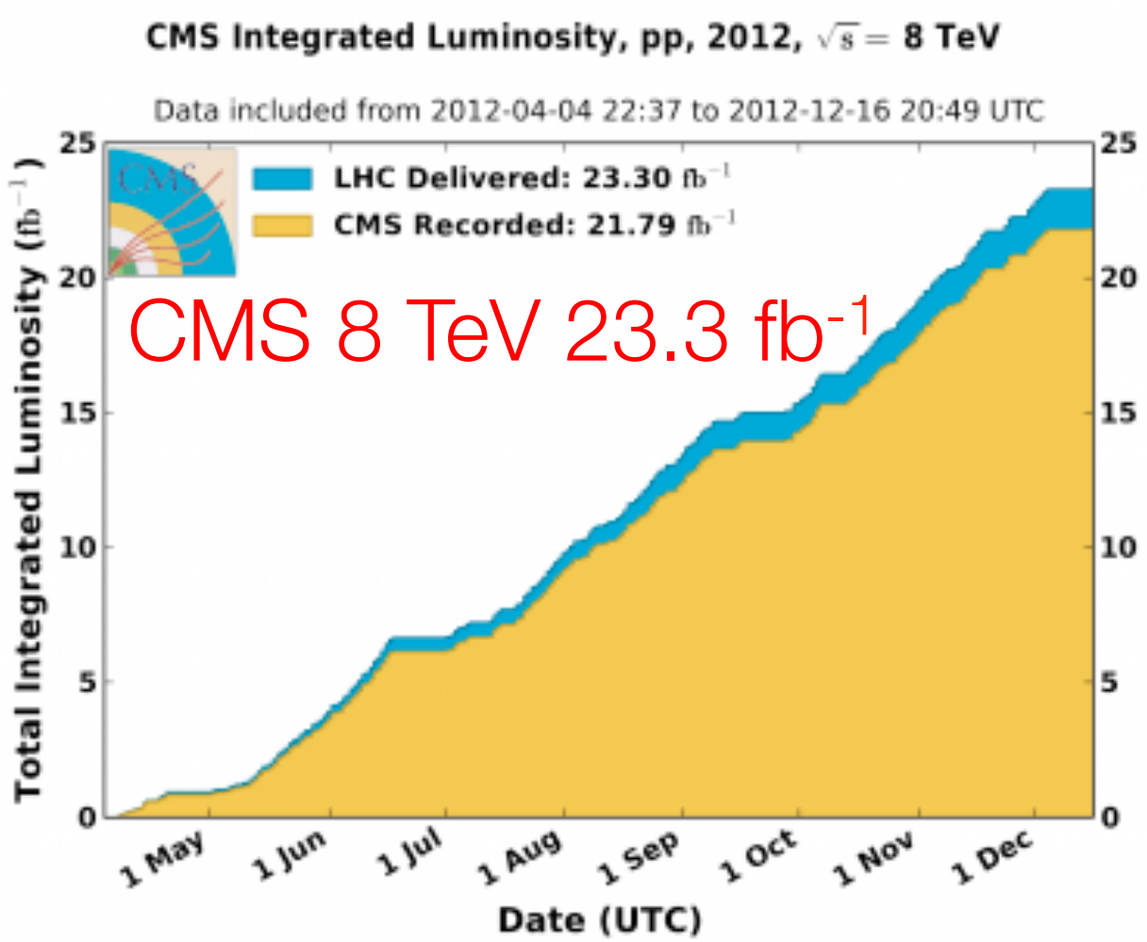
on behalf of the CMS Collaboration
July 15, 2014

# CMS & LHC



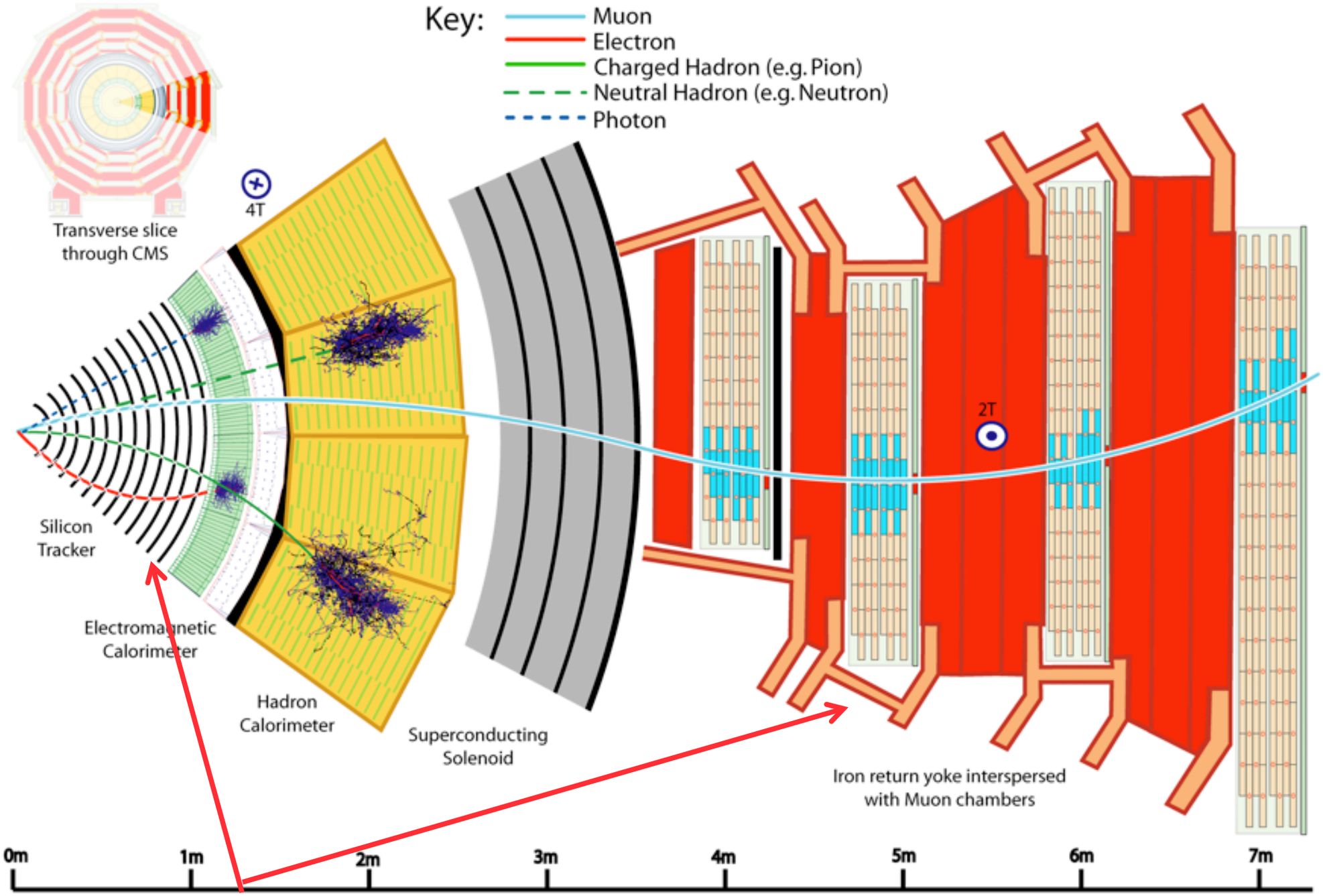




- *LHC yields large amounts of data at the world's* ***highest collision*** *energy*
- *Discovery of the Higgs boson, confirming & completing the Standard Model*
- *Opportunities to search for new phenomena, i.e., exotic hadrons*

# Outline

- Introduction
- Observation of peaking structures in the J/ψϕ mass spectrum
- Search for a new state $X_b$ decaying to $Y(1S)\pi^+\pi^-$
- X(3872) production cross section
- Summary

# CMS Detector

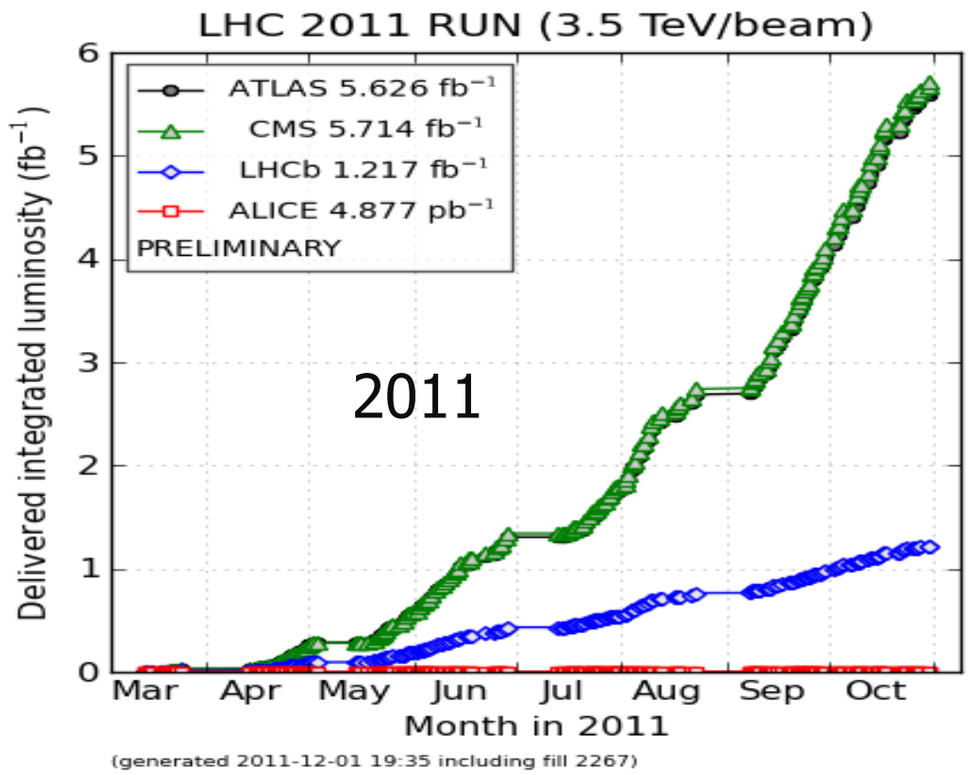



*Relevant subdetectors*

# CMS Detector Performance

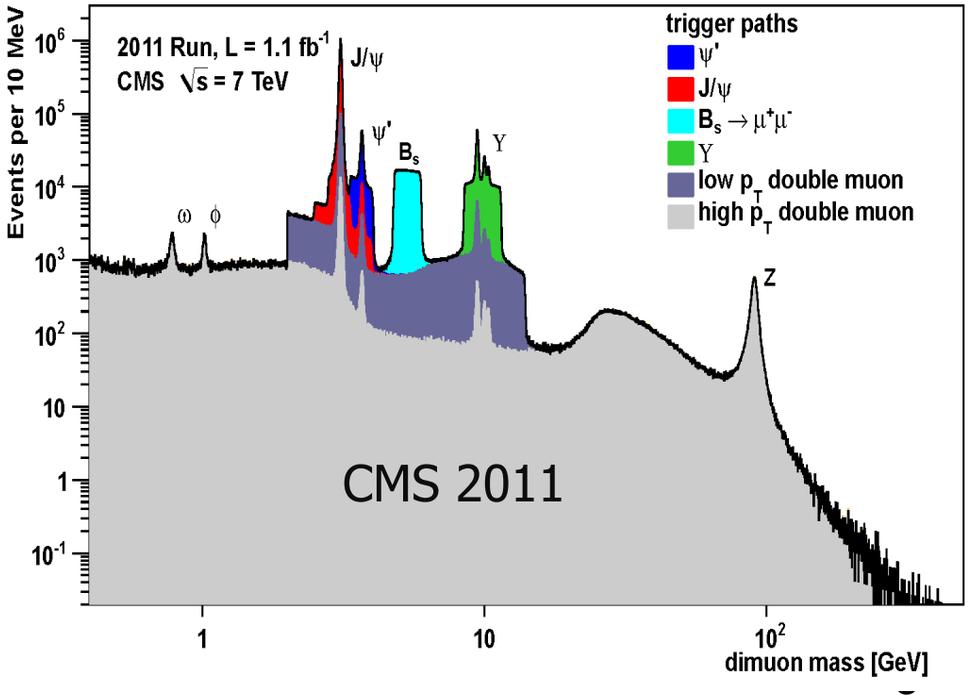
Excellent muon/silicon detectors:

- Muon system
  - High-purity muon identification
  - Good dimuon mass resolution (Δm/m~0.6% for J/Ψ)
- Silicon Tracking detector
  - excellent track momentum resolution ($\Delta p_T / p_T$~1%)
  - excellent vertex reconstruction and resolution




LHC luminosity & CMS trigger:

- Collect data at increasing instantaneous luminosity
- Triggers are essential ingredients
  - Special triggers for different analyses
  - Combination of dimuon vertex, minimum dimuon transverse momentum, and displaced dimuon vertex



https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11026
arXiv 1309.6920 [hep-ex], PLB 734 (2014) 261

# Observation of peaks in the J/ψϕ mass spectrum in B decays

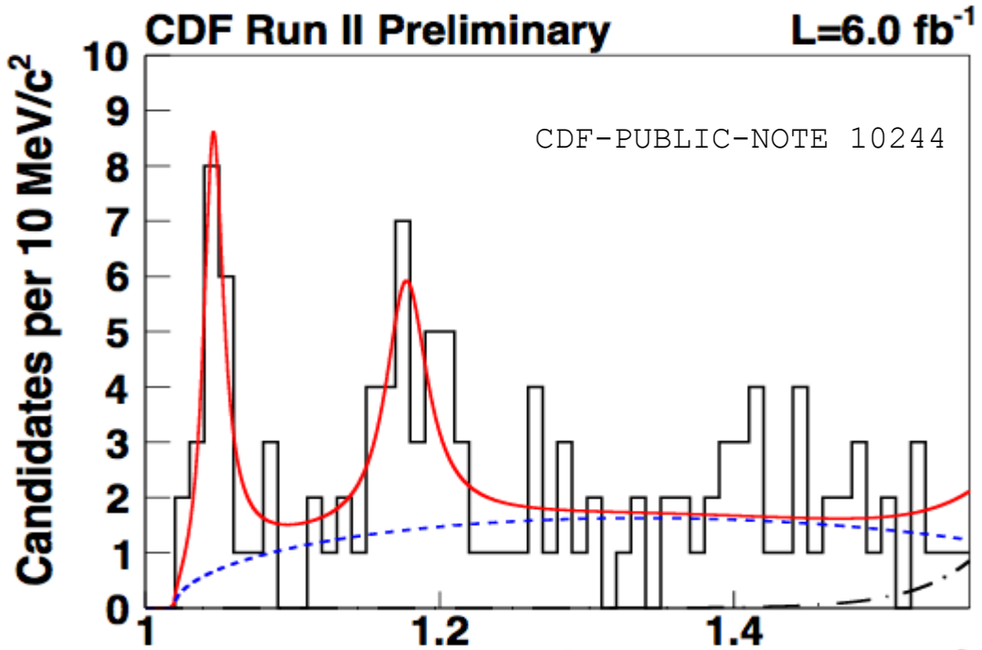
- New X/Y/Z states pose a challenge to the conventional quark model. The origin of these states is not understood.

- CDF reported evidence for a structure Y(4140) with mass $4143.4^{+2.9}_{-3.0}\pm1.2_{(syst)}$ MeV and width $15.3^{+10.4}_{-6.1}\pm 2.5_{(syst)}$ MeV

  - if confirmed, candidate for an exotic meson

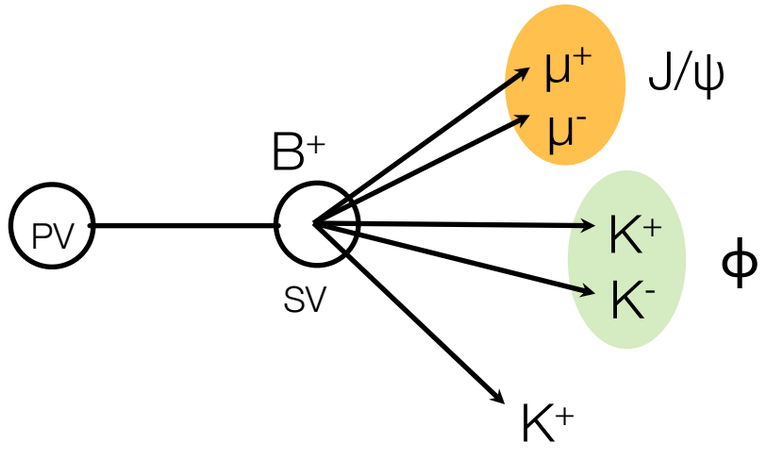
    - LHCb did not confirm the existence of Y(4140) and put an upper limit on its production

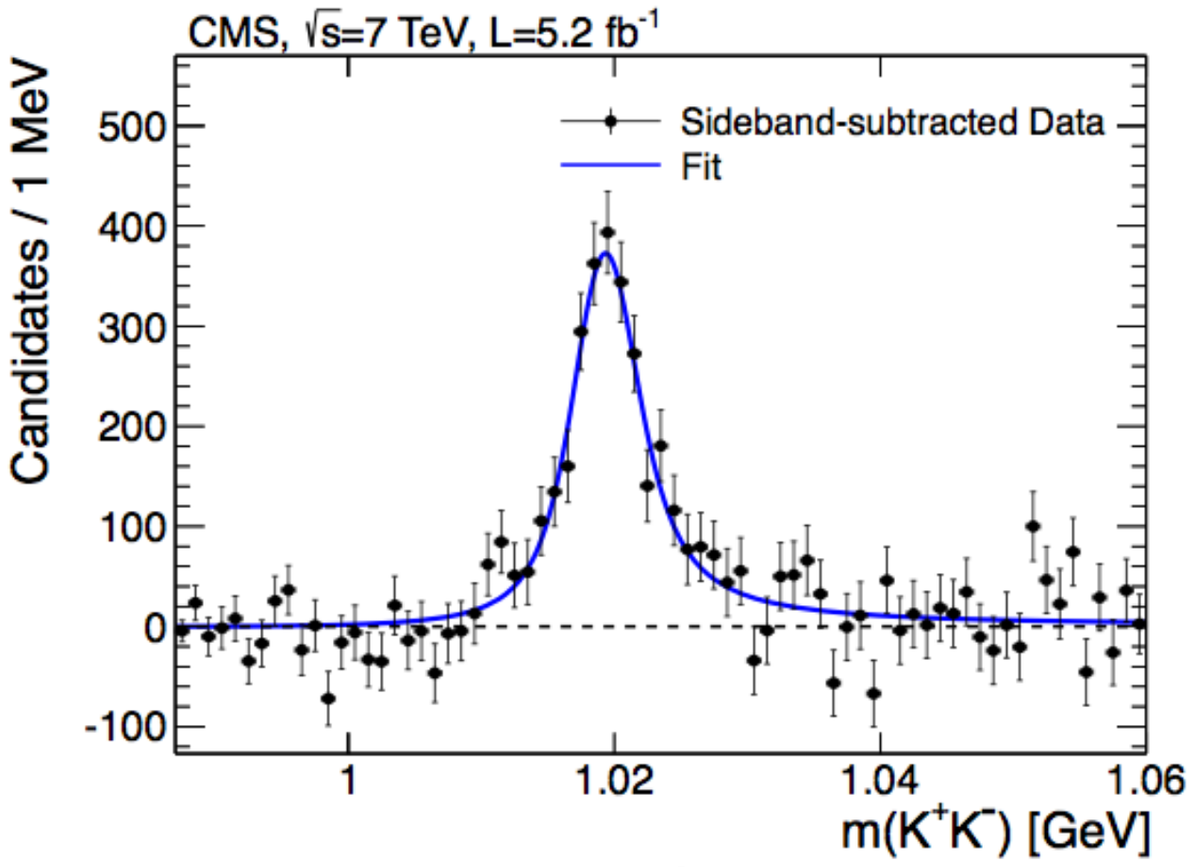
  - An independent check by CMS



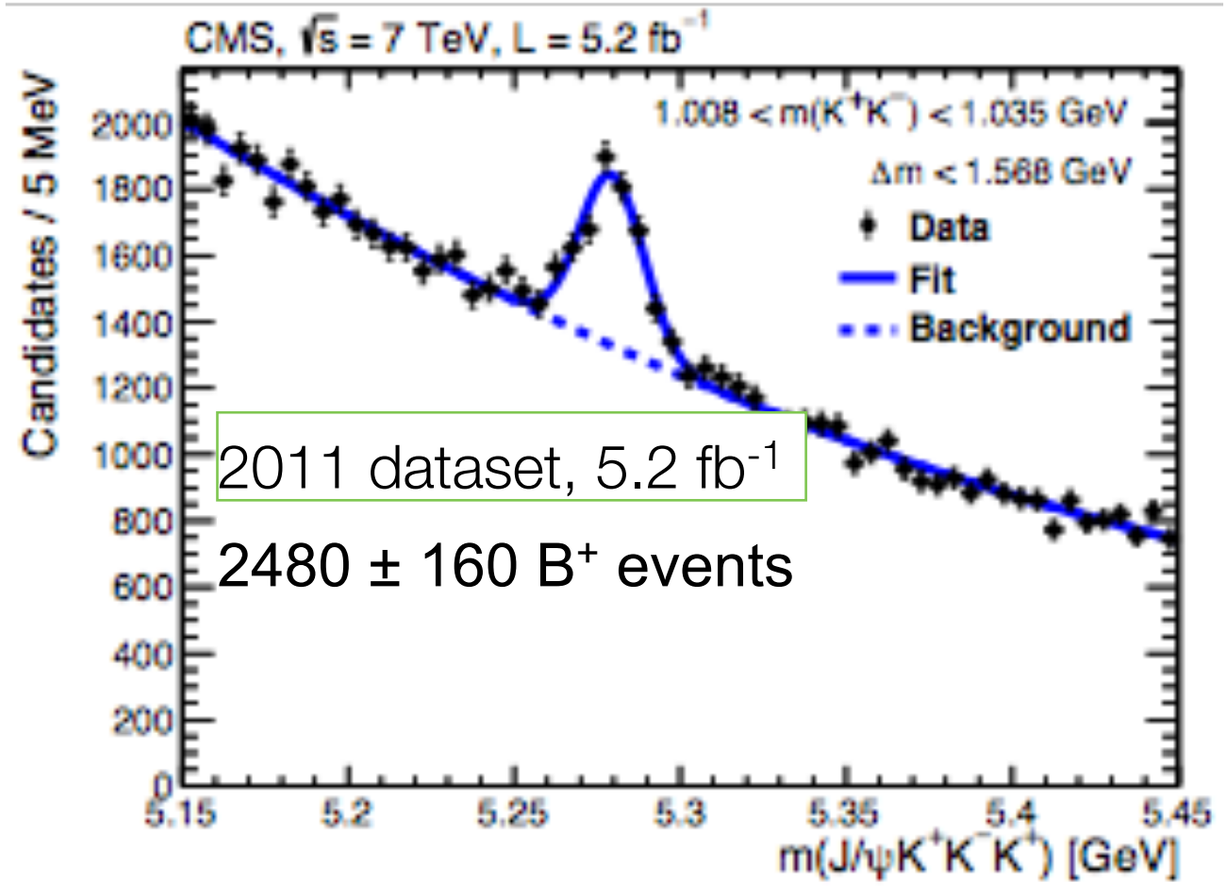
[arXiv 1309.6920 [hep-ex], PLB 734 (2014) 261]

# Observation of peaks in the J/ψϕ mass spectrum in B decays




Negligible non-ϕ components.




Largest $B^+ \rightarrow J/\psi\phi K^+$ sample to date.

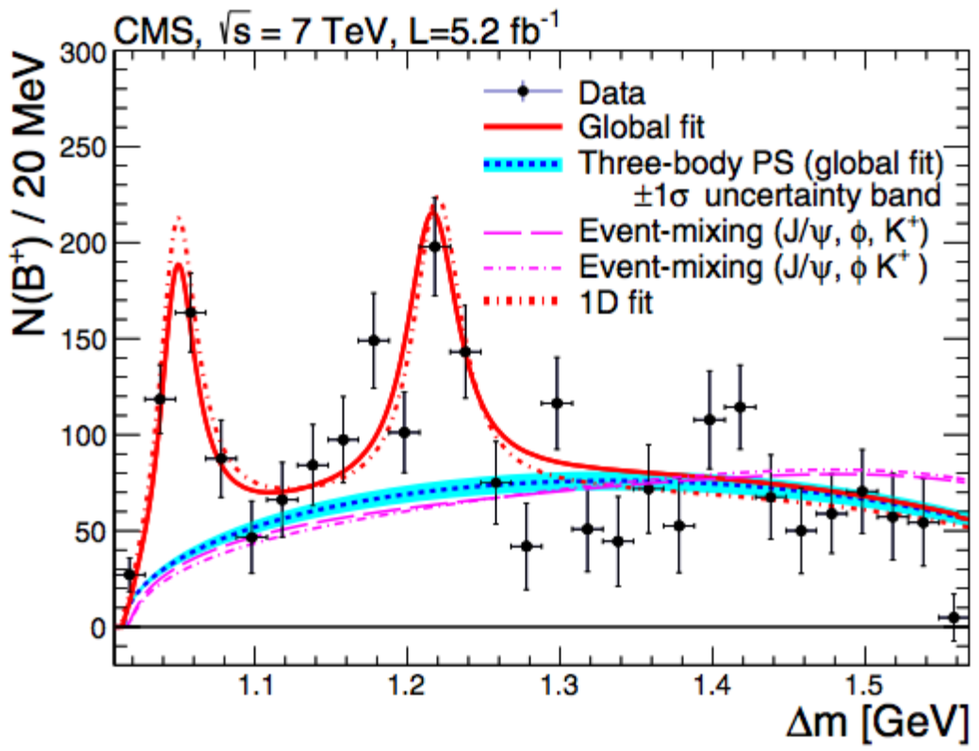
# Observation of peaks in the J/ψϕ mass spectrum in B decays

Investigating the $\Delta m = m(\mu^+\mu^-K^+K^-) - m(\mu^+\mu^-)$

- exclude $\Delta m$ >1.568 GeV region to avoid bkg from $B_s \rightarrow \psi(2S)\phi \rightarrow J/\psi\pi^+\pi^-\phi$ decays

$\Delta m$ spectrum obtained by:

- dividing the dataset in 20MeV $\Delta m$ bins
- extracting the number of B signal in each $\Delta m$ bin by fitting the $J/\psi\phi K$ spectrum




arXiv:1309.6920,
PLB 734 (2014) 261

| Yield | Mass (MeV) | $\Gamma$ (MeV) |
|---|---|---|
| 310 ± 70 | 4148.0 ± 2.4(stat) ± 6.3(syst) | $28^{+15}_{-11}$(stat) ± 19(syst) |
| 418 ± 170 | 4313.8 ± 5.3(stat) ± 7.3(syst) | $38^{+30}_{-15}$(stat) ± 16(syst) |

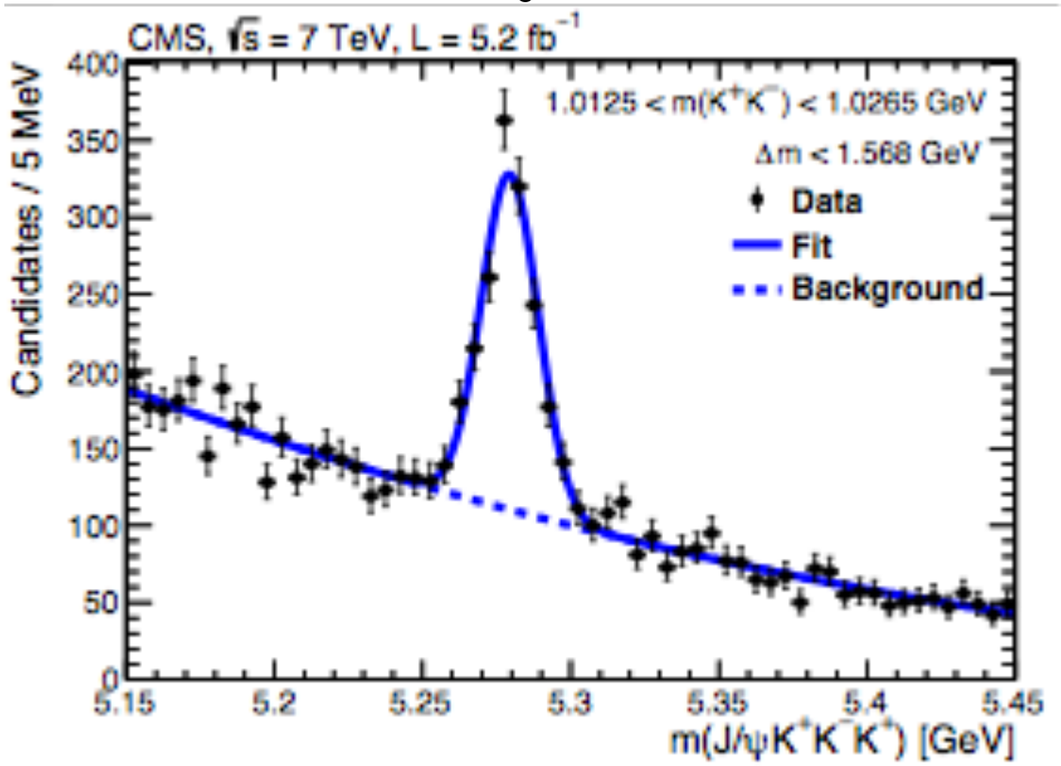
CMS confirmed Y(4140) with a significance >5 standard deviations, and saw evidence for a second structure in the same mass spectrum

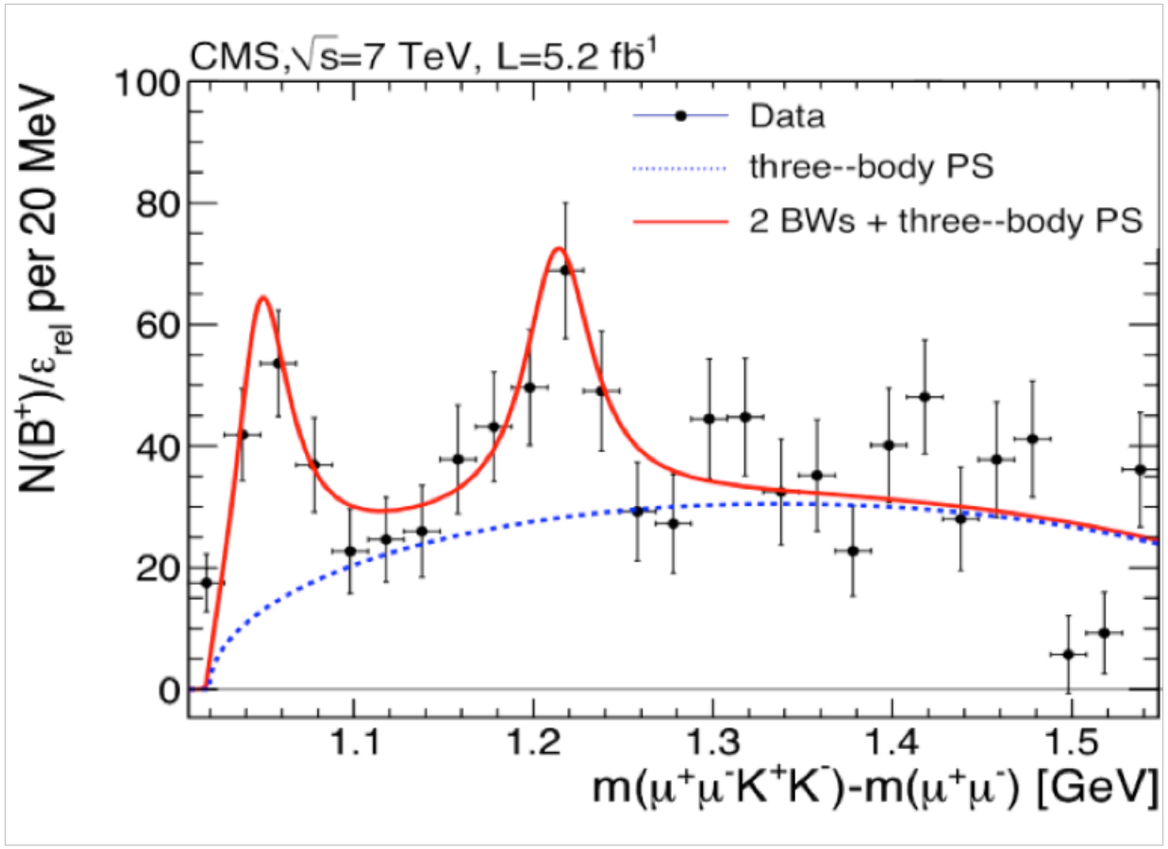
Later D0 also confirmed Y(4140) with a significance of 3σ

# Crosscheck with cleaner $B^+ \to J/\psi\phi K$ sample

**Additional requirements:**

- kaon $p_T$ > 1.5 GeV
- $B^+$ vertex CL > 10%
- $B^+$ vertex detachment: >7$\sigma$ from beamspot
- m(K+K-) within 7 MeV of $\phi$ mass



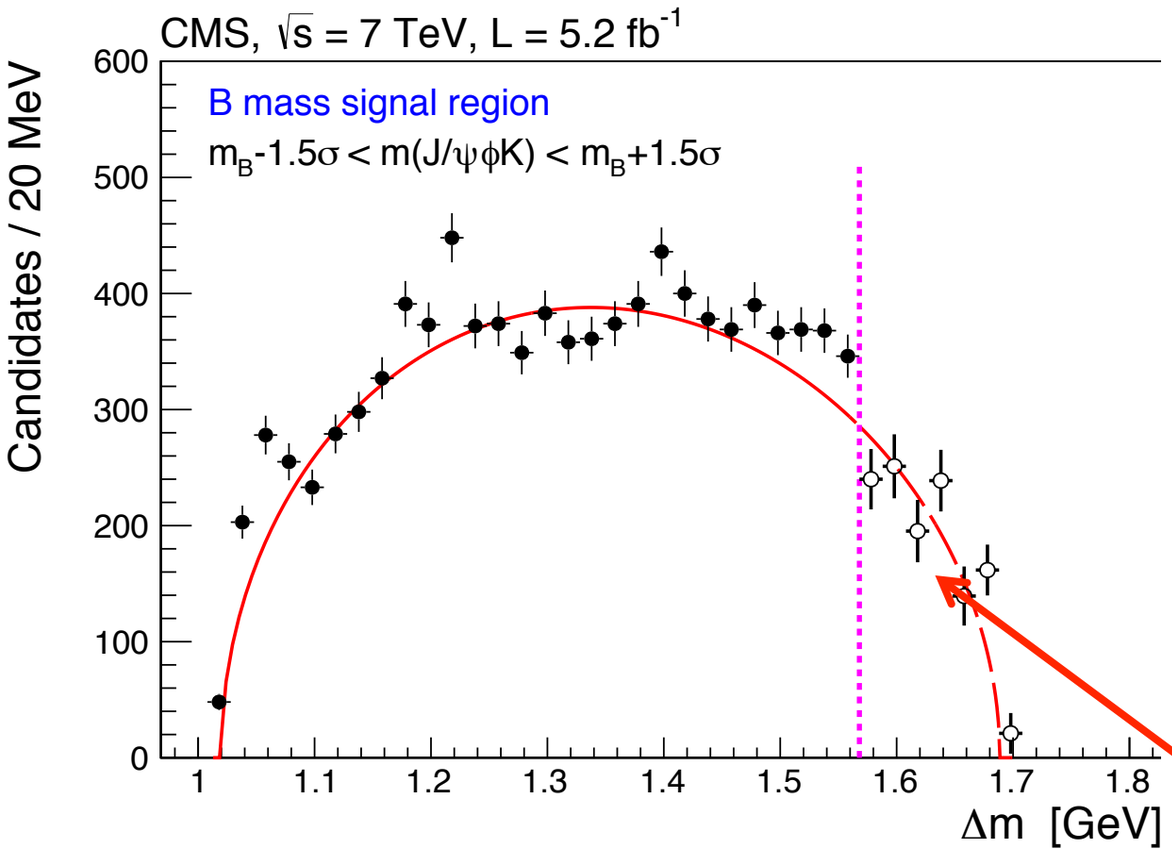




**Solid structures appear in the clean B sample.**

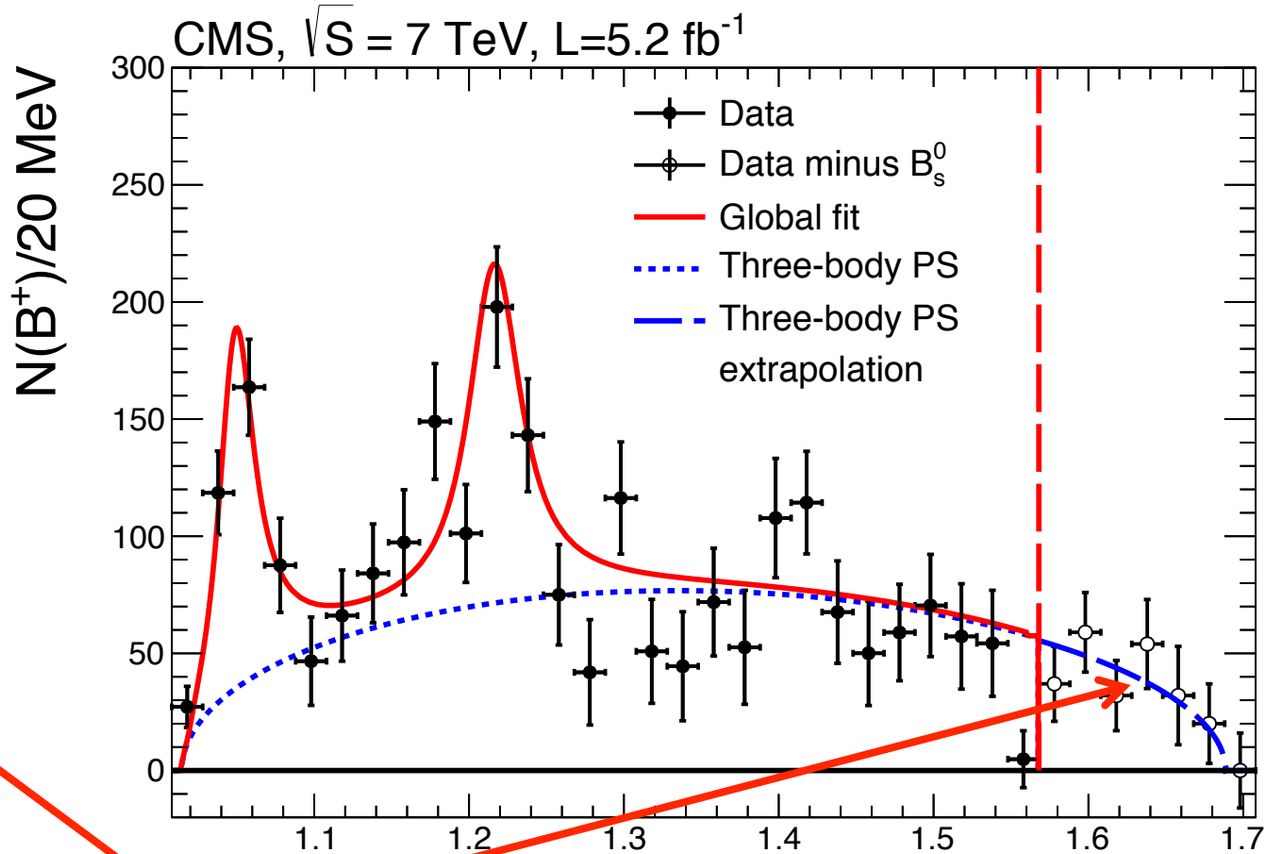
**40% of the default B signal, 10 x less background**

# Further investigation of the whole Δm region

The Δm spectrum after subtracting $B^0_s$ contribution but including non-B events, within 1.5σ *(σ = 9.3MeV) of the B mass.*




The extension of the Δm spectrum, after subtracting non-B background, to the full phase space.




The events in the cutoff region are consistent with phase space.

**The absence of strong activity in the high-Δm region reinforces our conclusion that the near-threshold narrow structure is not due to a reflection of other resonances.**

**Demands an explanation**

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11016
arXiv:1309.0250 [hep-ex], PLB 727 (2013) 57

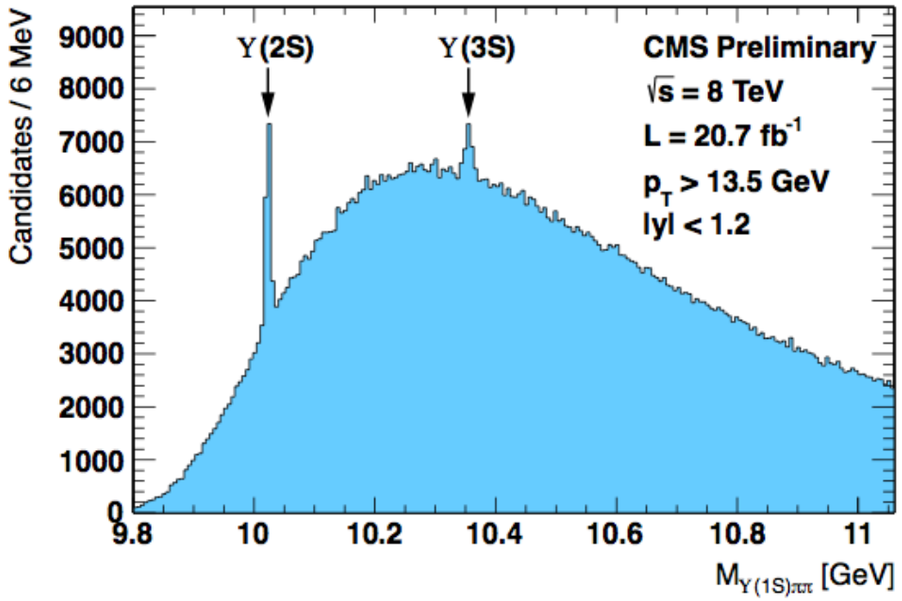
# Search for new bottomonium state decaying to Y(1S)$\pi^+\pi^-$

- Exotic resonance X(3872) discovered in the final state J/$\psi\pi^+\pi^-$
- A **bottomonium counterpart $X_b$** may exist and decays into Y(1S)$\pi^+\pi^-$
  - Mass close to the BB or BB* threshold,10.562 and 10.604 GeV
- Similar to X(3872), narrow width and sizable branching ratio into Y(1S)$\pi^+\pi^-$
- Look for a peak in the Y(1S)($\mu^+\mu^-$)$\pi^+\pi^-$ invariant mass spectrum
  - **Measure** $R = \frac{\sigma_{X_b} \times BR(X_b \to Y(1S)\pi^+\pi^-)}{\sigma_{Y(2S)} \times BR(Y(2S) \to Y(1S)\pi^+\pi^-)}$ **as a function of $X_b$ mass—[10,11] GeV**
  - kinematic region: $p_T$( Y(1S)$\pi^+\pi^-$) > 13.5 GeV and |y(Y(1S)$\pi^+\pi^-$)| < 2.0

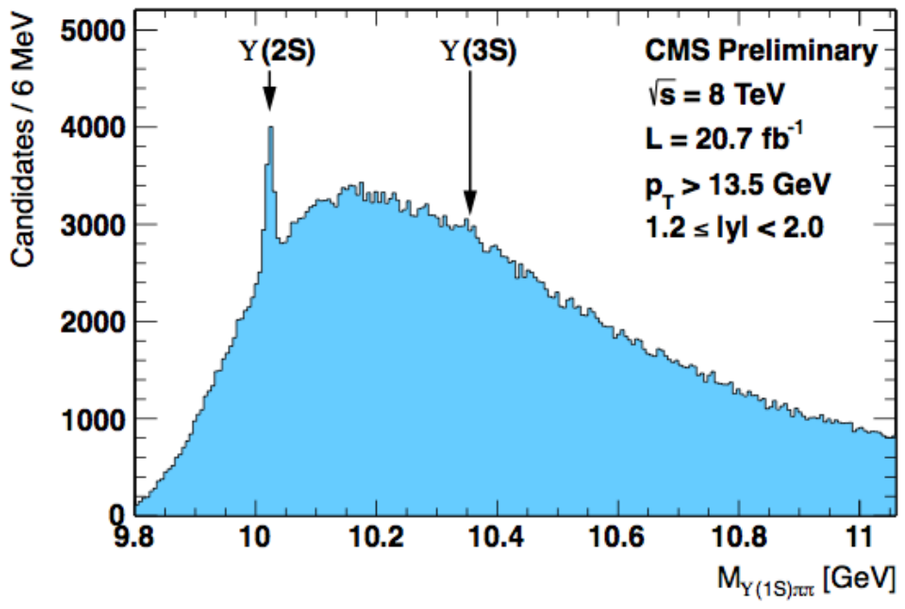
2012 dataset ~20 $fb^{-1}$

# $X_b$ candidate reconstruction

- $X_b$ candidates reconstructed by associating the Y(1S) to 2 pion tracks
  - Optimized by maximizing the expected signal significance near the Y(2S) mass
  - Expected significance > 5σ if $X_b$ BR * cross-section > 6.56% of the corresponding Y(2S) → Y(1S)$\pi^+\pi^-$ value (analogous to X(3872) → J/ψ$\pi^+\pi^-$, see CMS results in *JHEP* **04** (2013) 154)




- Separate "barrel" and "endcaps" events to exploit better mass resolution and lower background in the barrel region
- **No structure** apart from Y(2S) and Y(3S)



# $X_b$ search: mass scan

- Explore 10.06-10.31 and 10.40-10.99 GeV mass regions
- Shift $X_b$ expected mass in **10 MeV intervals** and evaluate signal significance
  - $X_b$ signal modeled with a Gaussian function
    - Fix signal width to value from the simulation (3.8 to 16.4 MeV)
    - background parametrized with a 3rd order polynomial
    - for each mass point, evaluate

$$R = \frac{N^{\text{obs}}_{X_b}}{N^{\text{obs}}_{Y(2S)}} \frac{\epsilon_{Y(2S)}}{\epsilon_{X_b}}$$

observed yields of $X_b$ and Y(2S) candidates

overall efficiencies estimated from simulation

**Assumptions:**

- same production mechanism for Y(2S) and $X_b$
- both produced unpolarized
- same dipion mass distribution for $X_b$ and Y(2S)

# $X_b$ Limit

- Local p-values calculated using asymptotic approach and combining results of fits to the barrel and endcap regions

- Systematic uncertainties implemented as nuisance parameters

**first upper limits on $X_b$ production at a hadron collider**

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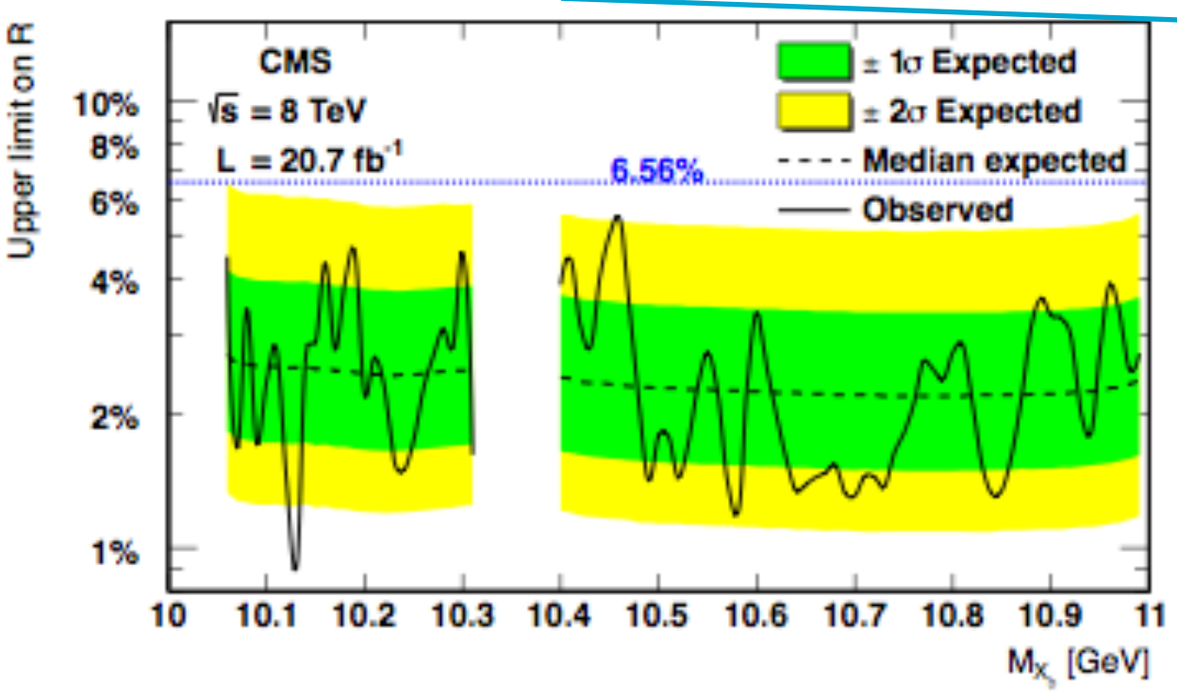
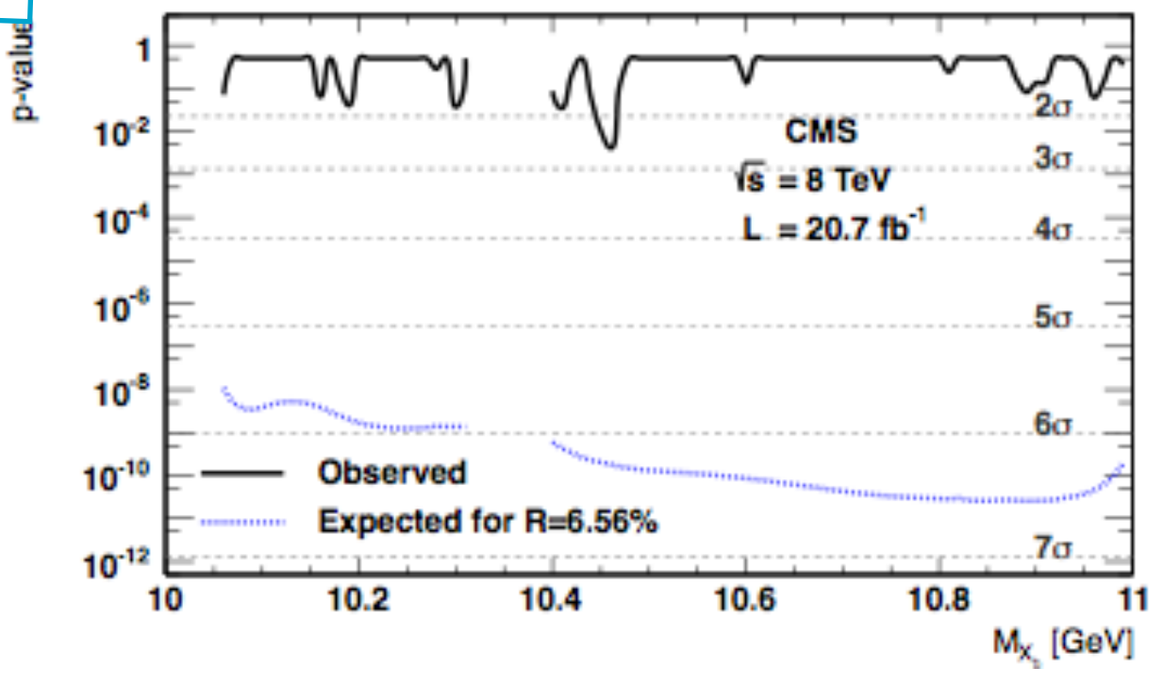


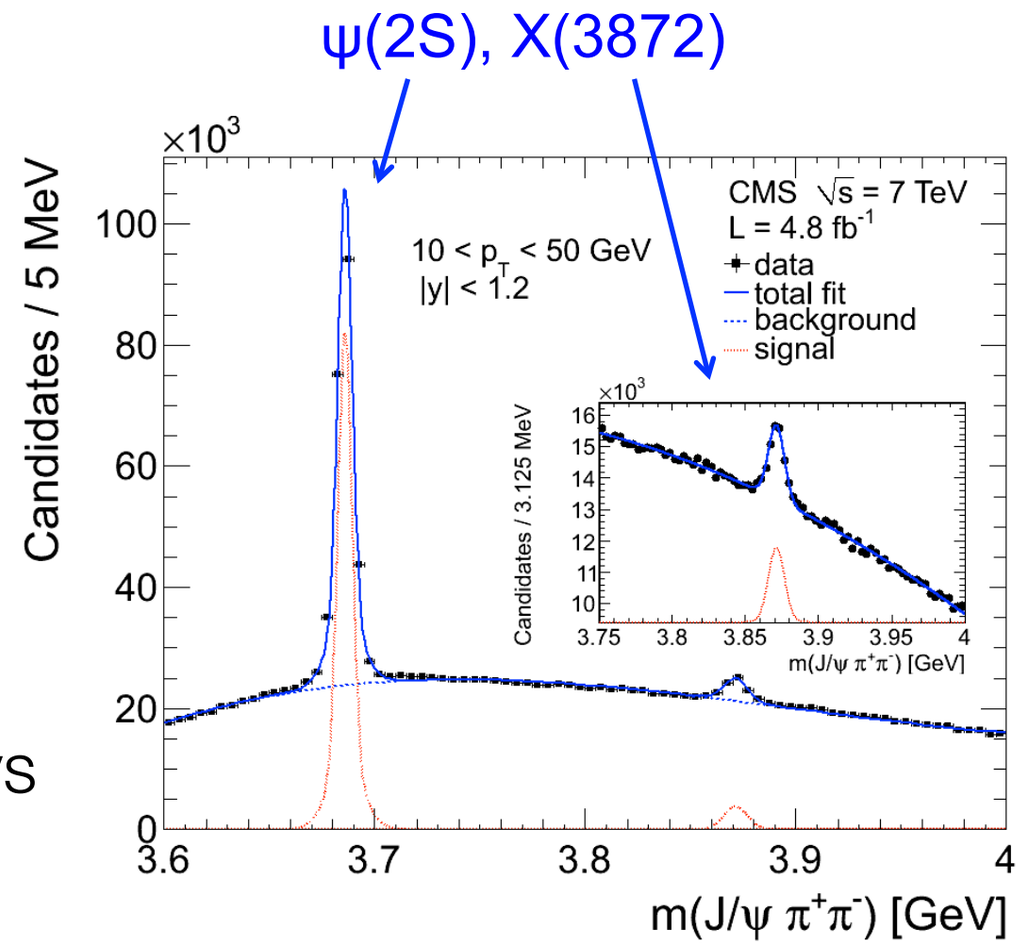

**No significant excess is observed**

**95% CL upper limit on the cross-sections*branching fractions ratio: 0.9 - 5.4 %**

# X(3872) cross section

- The X(3872) was discovered in 2003 by Belle
  - Later it was confirmed by CDF, D0, Babar
  - Its nature is uncertain➔exotic candidate
- Previous analyses prefer $J^{PC}=1^{++}$ or $2^{-+}$
  - CMS measurement assumed $1^{++}$
  - LHCb measured its $J^{PC}$ as $1^{++}$, PRL 110, 222001 (2013)
- It is produced both promptly and from B decays at LHC
  - CMS measures both prompt and non-prompt cross section

CMS JHEP 04 (2013) 154



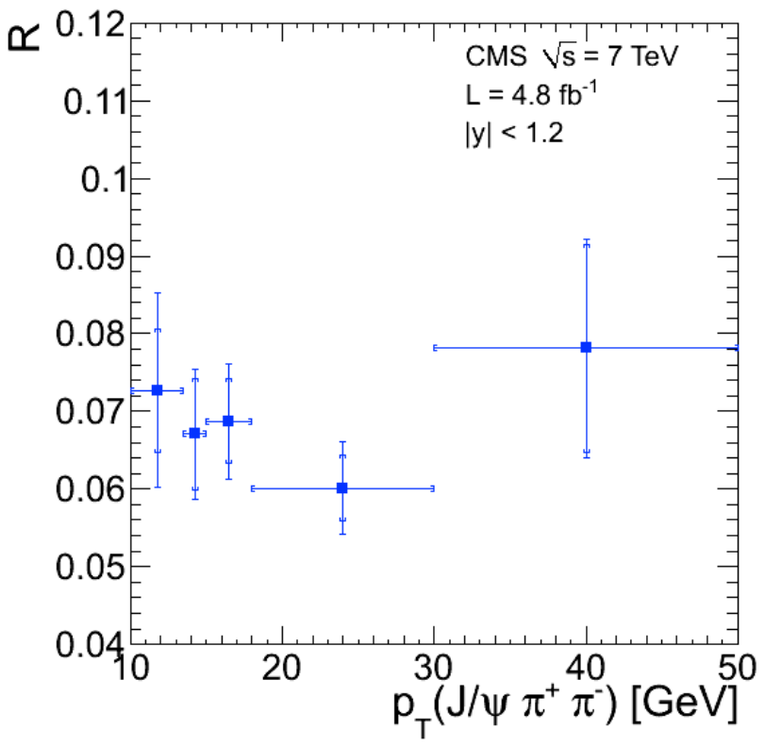
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11011
arXiv:1302.3968 [hep-ex], JHEP 04 (2013) 154

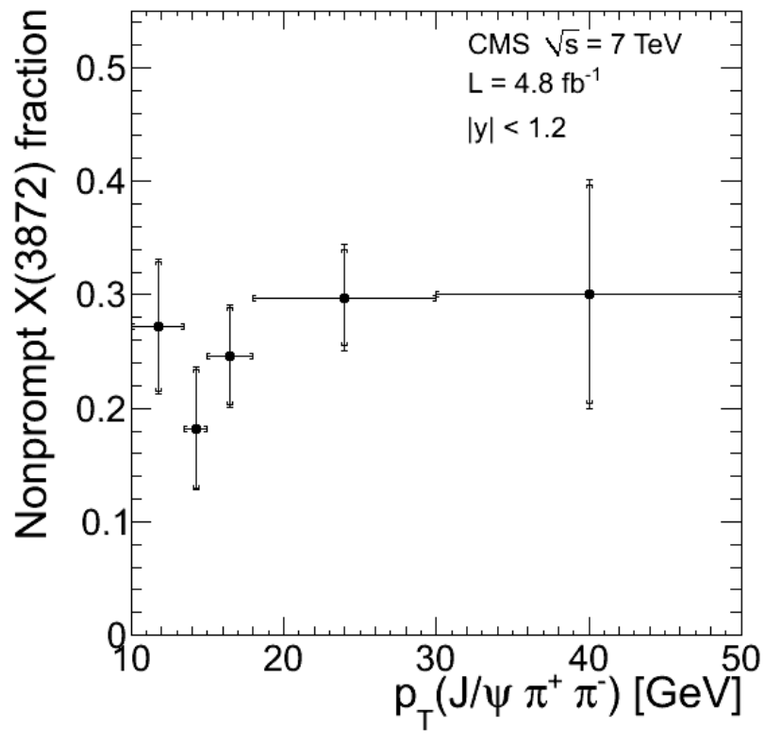
# X(3872) cross section

- R=X(3872)/ψ(2S) cross section ratio
  - X(3872) and ψ(2S) are assumed unpolarized
  - Variation up to 90% due to polarization
- Non-prompt fraction (B decays)
  - Separated based on $L_{xy}$

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

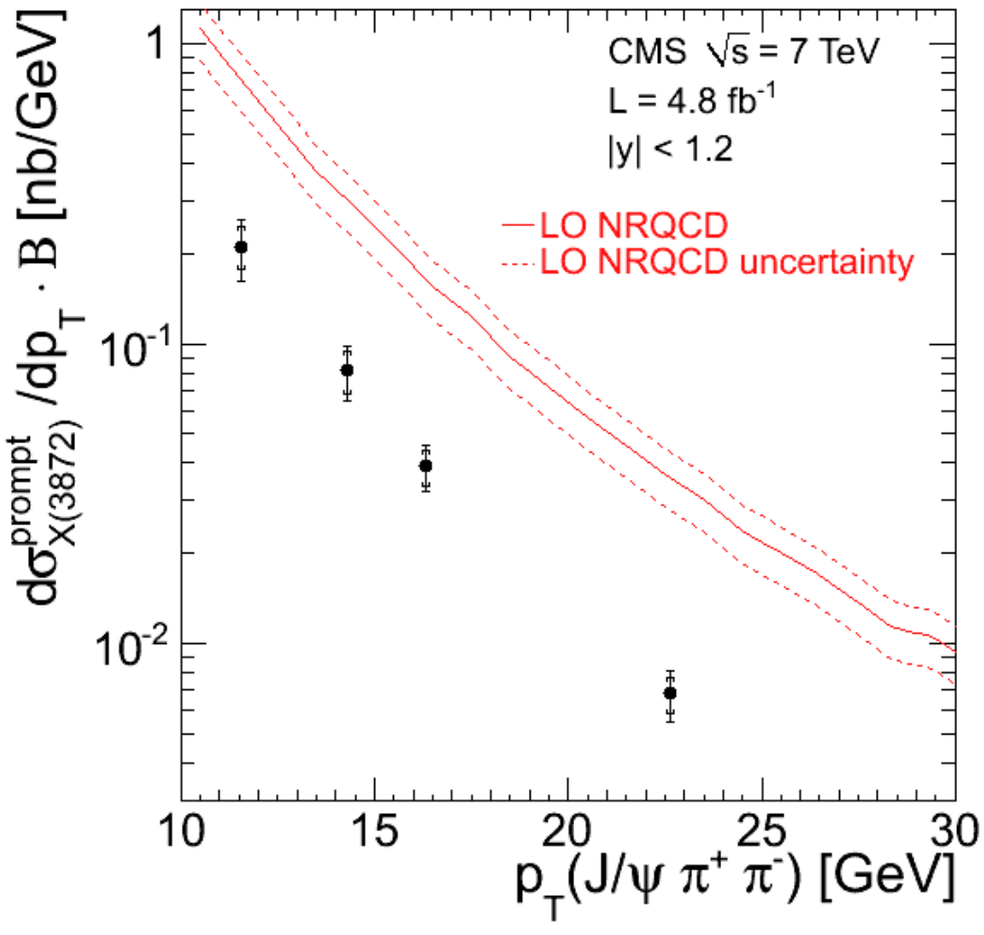
  - Non-prompt events ($l_{xy}$>100 μm)
  - Contribution from prompt <0.1%
  - Cross-checked by 2D fit to the mass and $l_{xy}$



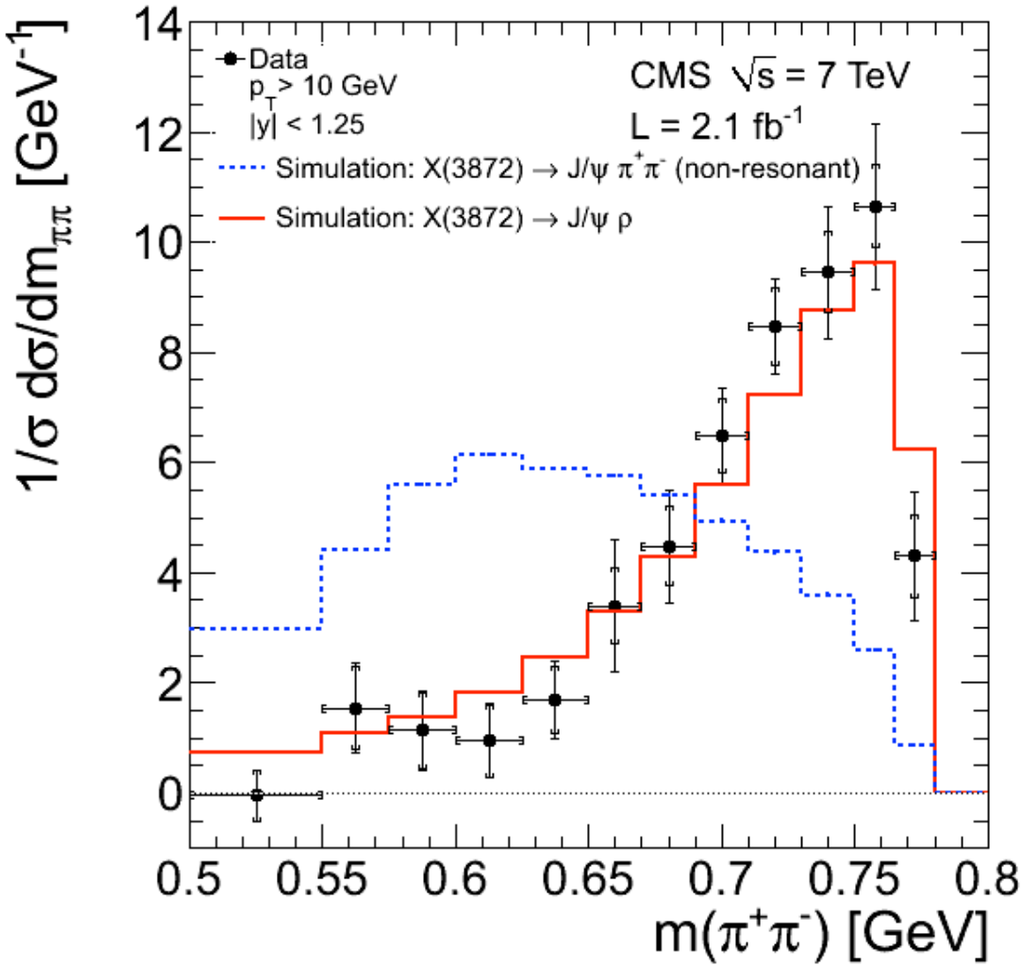
# X(3872) cross section

- Prompt cross section compared to NRQCD
- NRQCD: Artoisenet and Braaten, *Phys Rev D81 114018,* normalized to Tevatron data and modified by the authors for CMS phase space




NRQCD predictions significantly exceed the measured value, while $p_T$ dependence Is reasonably well described

- Compared to simulations with and w/o intermediate $\rho^0$ in the $J/\psi\ \pi^+\pi^-$ decay




The intermediate $\rho^0$ decay gives better agreement with data

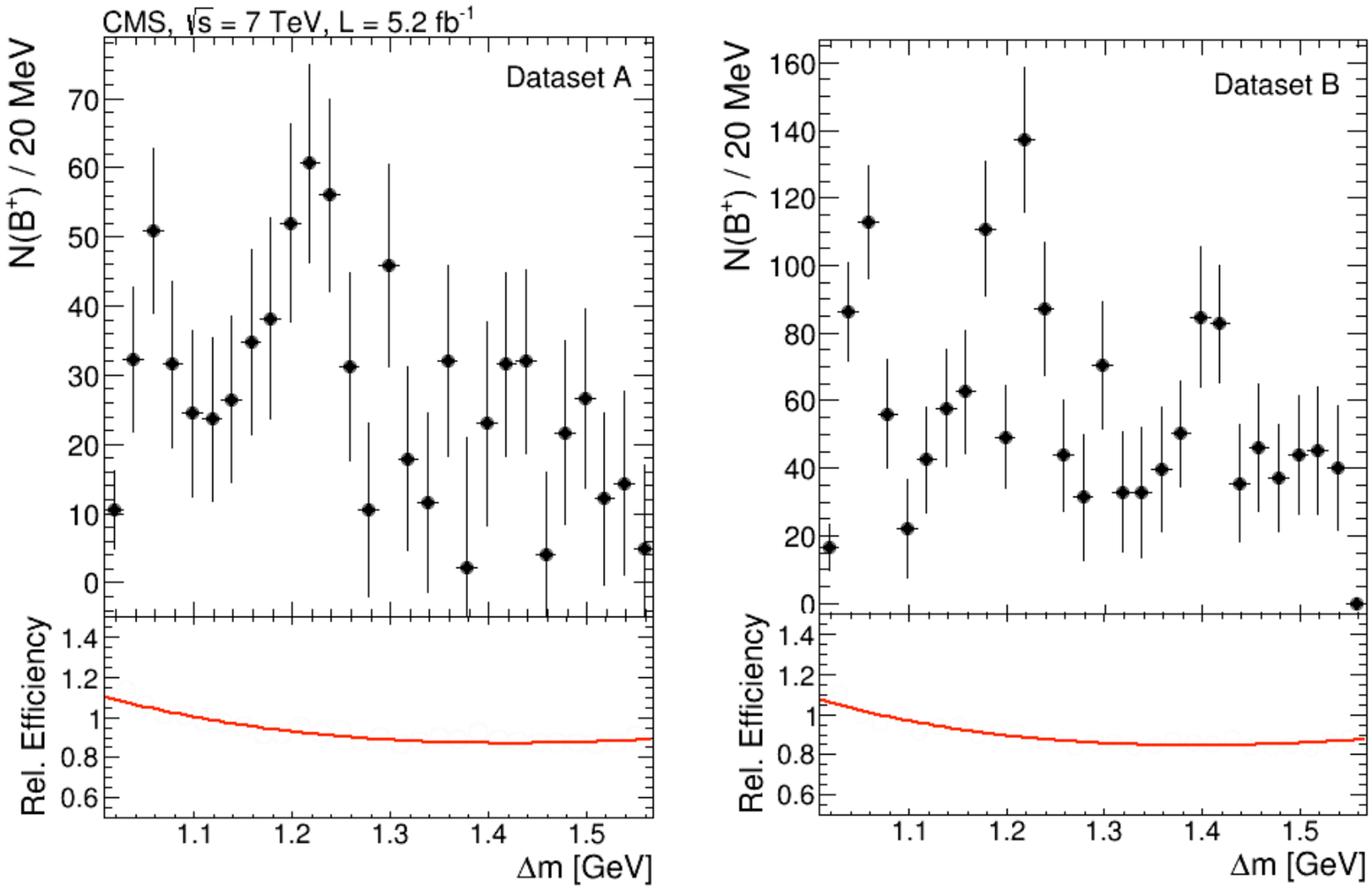
# Summary

- Thanks to the excellent performance of LHC and CMS
- Important measurements of exotic quarkonia made by CMS
- Demonstrated CMS can/will play important role in exotic states studies

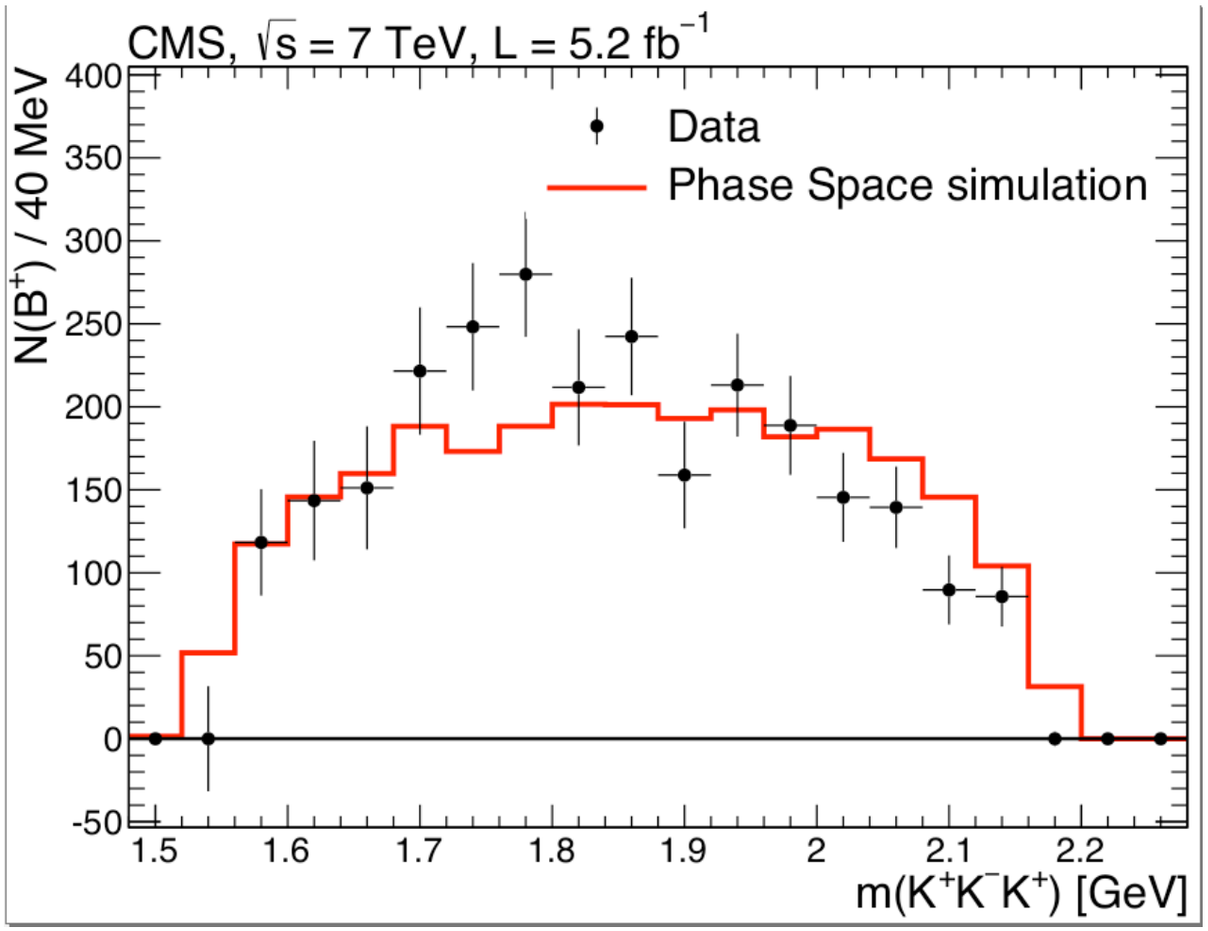
Stay tuned!

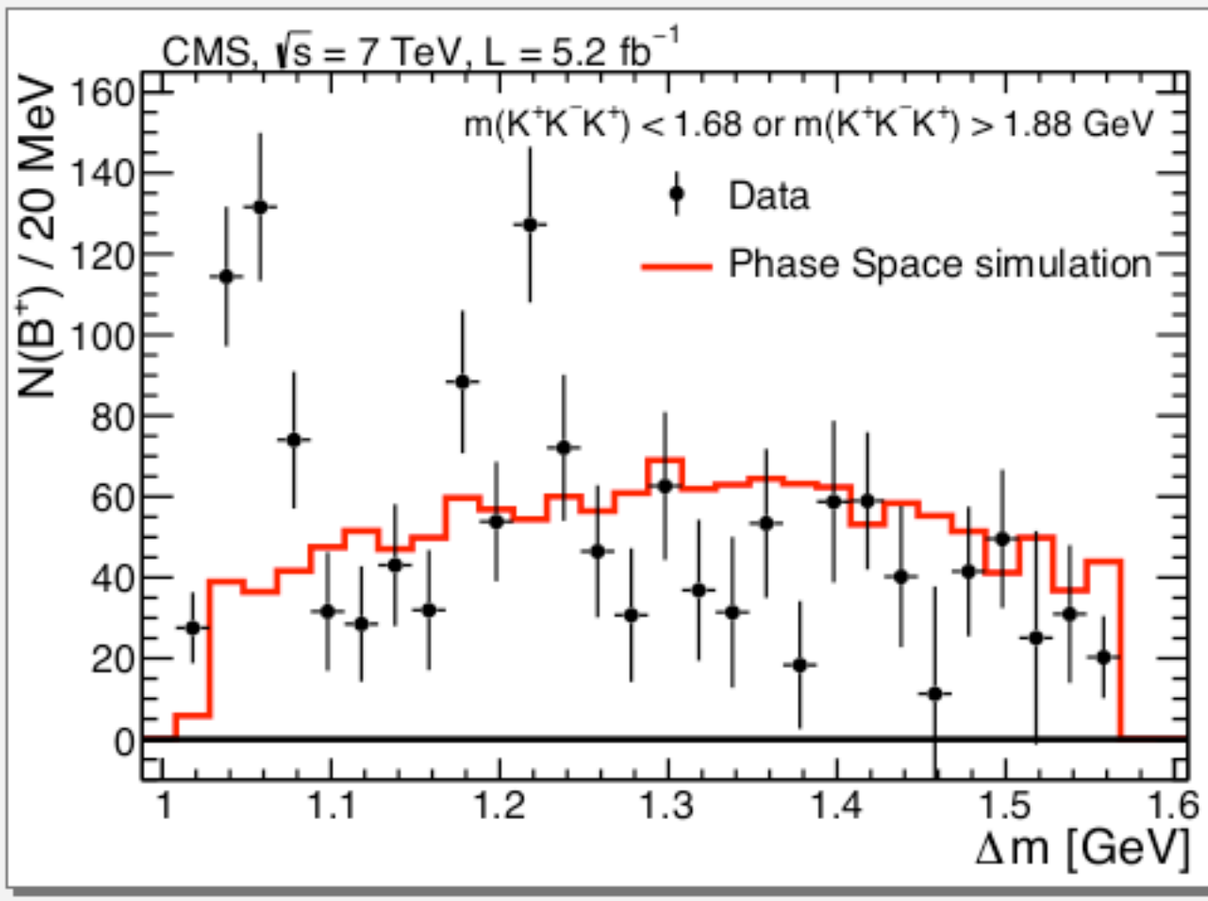
All CMS B-Physics results are available at
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH

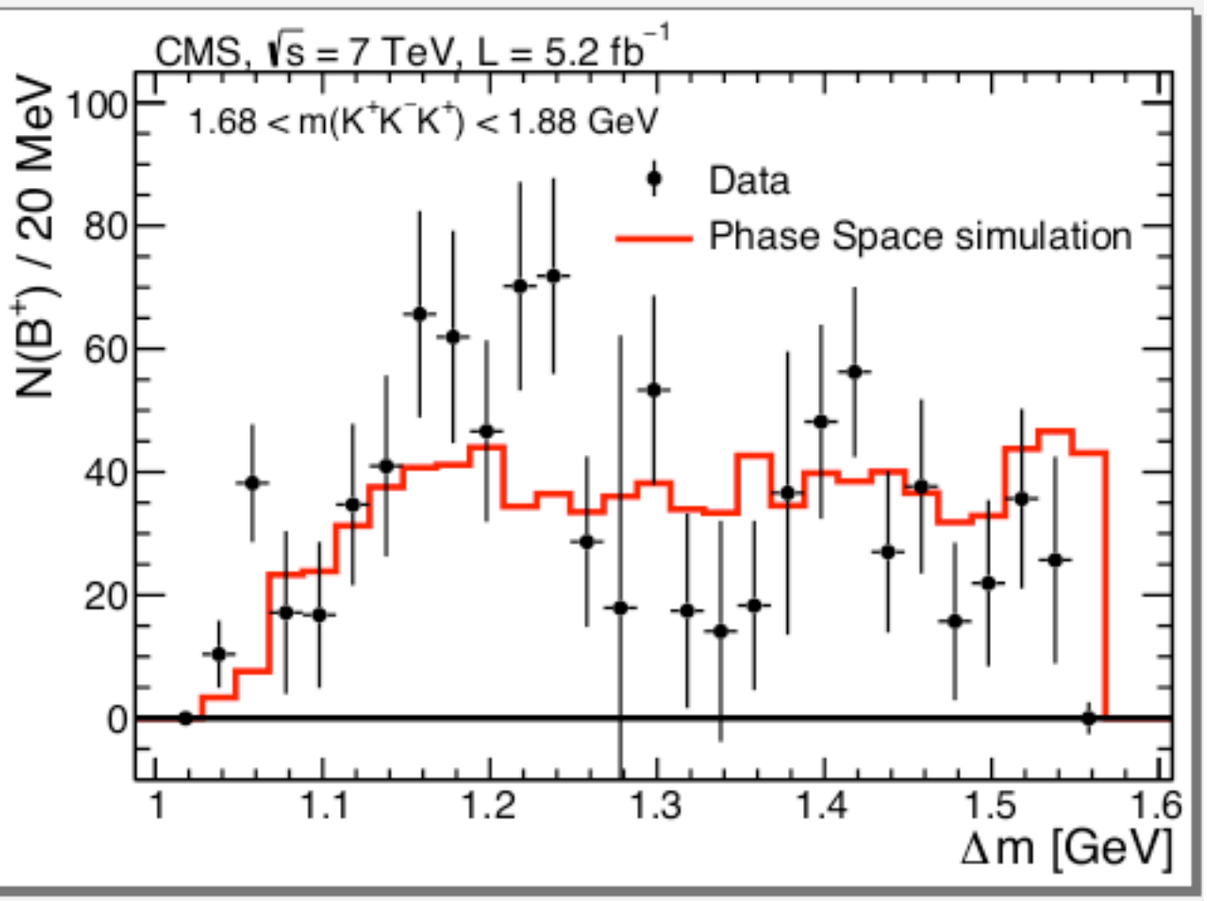
# Backup




The Δm spectrums for datasetA (left, dimuon pT>7 GeV), datasetB(right, dimuon pT>7 GeV and each muon pT>4 GeV) with corresponding relative efficiency curves


CMS, √s = 7 TeV, L = 5.2 fb⁻¹
Data
Phase Space simulation
N(B⁺) / 40 MeV
m(K⁺K⁻K⁺) [GeV]


CMS, √s = 7 TeV, L = 5.2 fb⁻¹
m(K⁺K⁻K⁺) < 1.68 or m(K⁺K⁻K⁺) > 1.88 GeV
Data
Phase Space simulation
N(B⁺) / 20 MeV
Δm [GeV]


CMS, √s = 7 TeV, L = 5.2 fb⁻¹
1.68 < m(K⁺K⁻K⁺) < 1.88 GeV
Data
Phase Space simulation
N(B⁺) / 20 MeV
Δm [GeV]