Measurement of the X(3872) and exotic charmonium states with CMS

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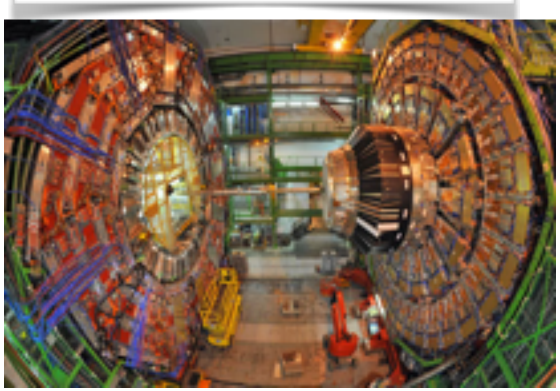
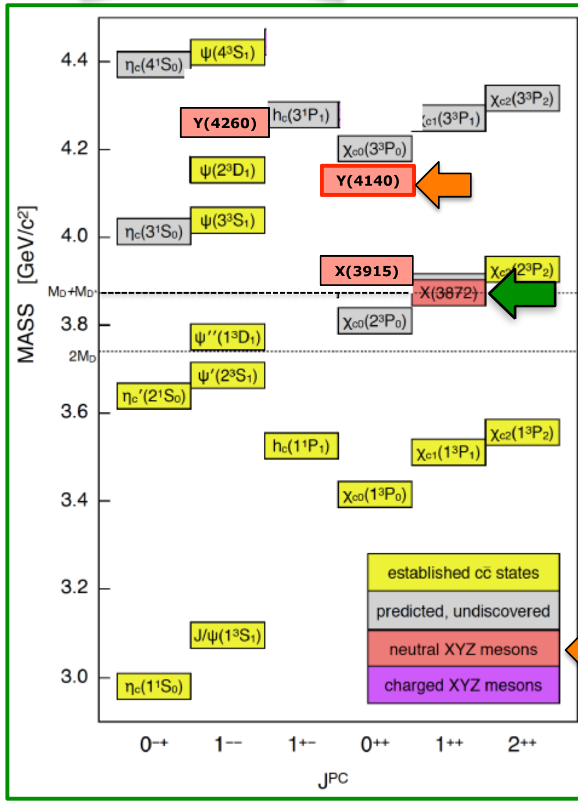
Outline

- The CMS Detector

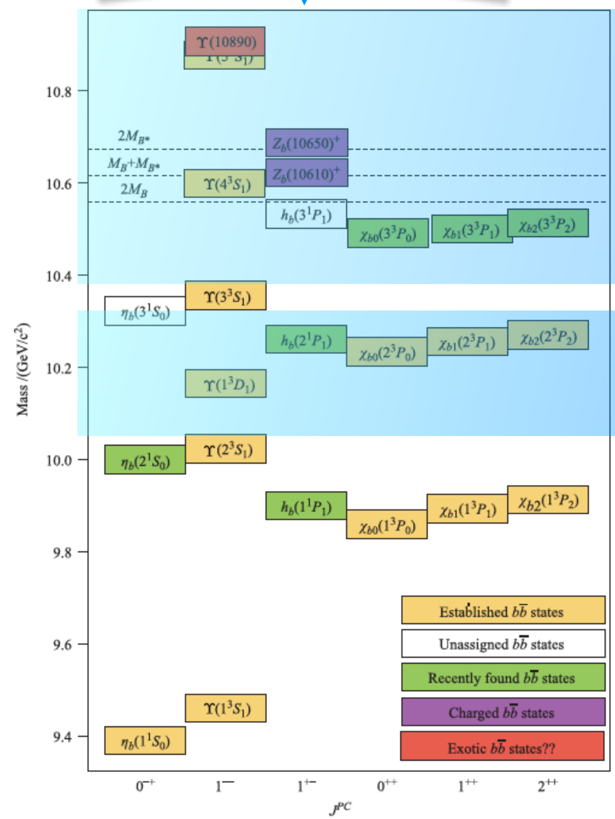


- X(3872)



- Y(4140)

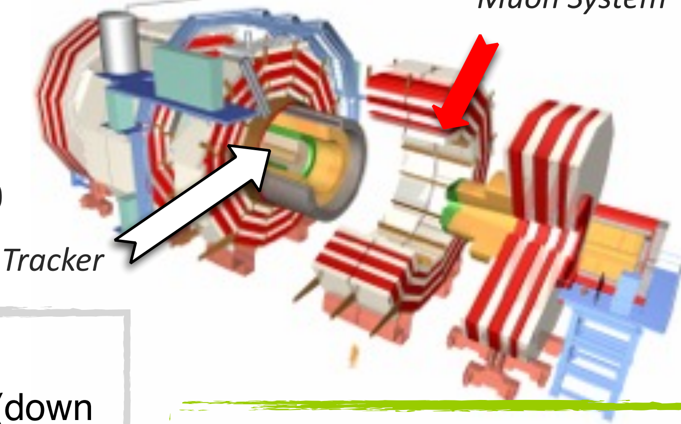
- Search for X_b



- Summary and perspectives

The CMS Detector

- CMS is a general purpose detector optimized for high-pT physics with a great B-physics potential
- Collected 5.2 fb^{-1} at 7 TeV and 20.1 fb^{-1} at 8 TeV from 2010 to 2013

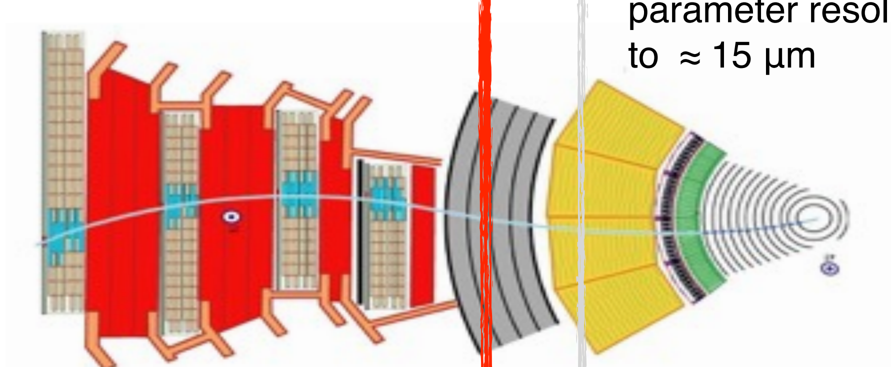


Muon System

- Redundant system with large rapidity coverage ($|\eta|<2.4$)
- Standalone $\Delta pT/pT \simeq 10\%$
- High-purity muon-ID: $\varepsilon(\mu \mid \pi,K,p) \leq (0.1 \div 0.2)\%$

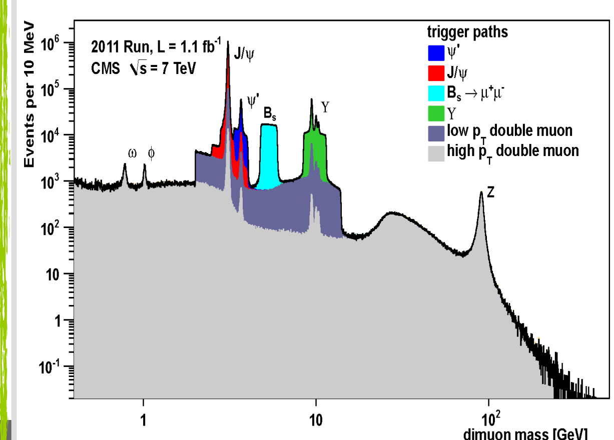
Silicon tracker

- Good pT resolution (down to $\Delta pT/pT \simeq 1\%$ in the central region)
- Tracking efficiency >99% for muons
- Good vertex reconstruction and impact parameter resolution down to ≈ 15 μm



Trigger

- Very efficient Hardware trigger
- Highly flexible High Level Trigger: paths dedicated to specific analyses.



The X(3872)

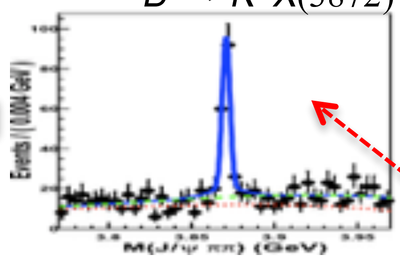
- **First exotic states discovered by Belle in 2003 in the decay** $B \to KX(3872) \to K(J/\psi\ \pi^+\pi^-)$

X(3872) sits on $\bar{D}^0 D^{*0}$ threshold and is narrow:

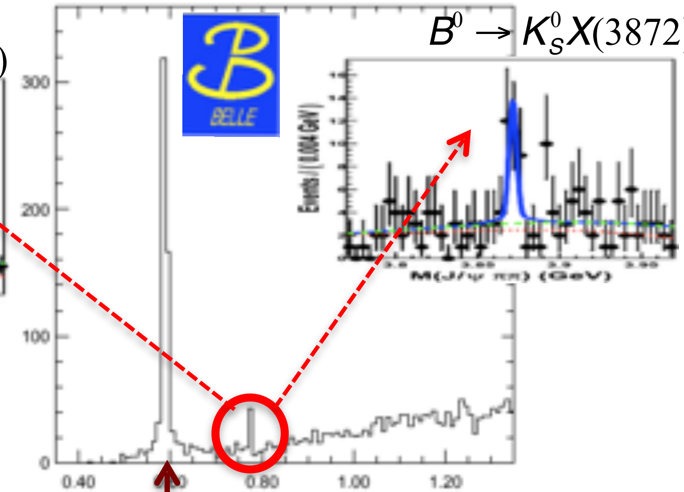
$$\Gamma_{J/\psi\pi\pi} < 2.3\,MeV @\ 90\%\ C.L.$$

$$B\left(B^+ \to K^+ X\right) \times B\left(X \to J/\psi\,\pi^+\pi^-\right) \approx 8.5 \cdot 10^{-6}$$

$B^{\pm} \to K^{\pm} X(3872)$



$B^0 \to K_S^0 X(3872)$



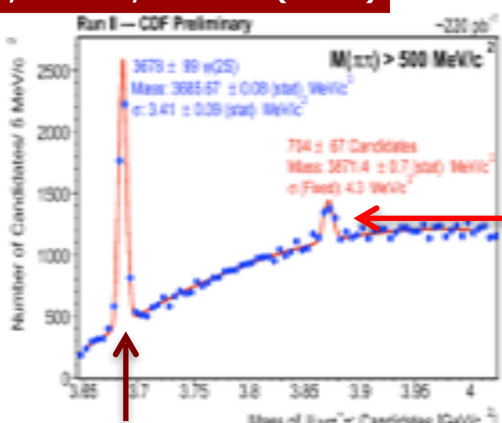
$B \to K\psi(2S) \to K(J/\psi\ \pi^+\pi^-)$ control signal

Belle, PRL 91, 262001 (2003)

- **Quickly confirmed by CDF and D0 with inclusive $p\bar{p}$ collisions**

CDF, PRL 93, 072001 (2004)

$p\bar{p} \to X(3872) + \text{other}$

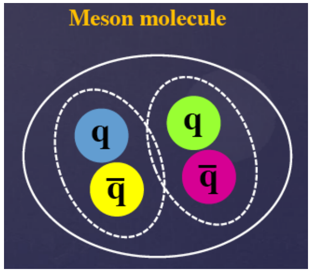


$p\bar{p} \to \psi(2S) + \text{other}$

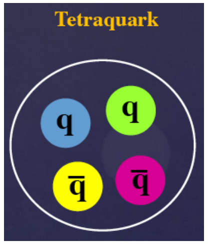
Mainly prompt production (only ~16% from B's)

Nature of the X(3872)

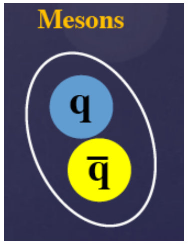
After more than 10 years no definitive answer on the nature of the X(3872). Main hypothesis are:



- **Loosely bound molecular state:** suggested by close proximity to $D^0\bar{D}^{*0}$ threshold
  - mass value is crucial but not enough experimental sensitivity so far
  - molecular states is compatible with $\mathbf{J^{PC} = 0^{-+}, 1^{++}}$
- **Tetraquark**
  - BaBar (2005) searched for a charged partner state $X^+ \to J/\psi\,\rho^+ \to J/\psi\,(\pi^+\pi^0)$ suggested by the 4-quark interpretation → no charged equivalent (D^+D^{*0}) observed!
  - favored assignment would be $\mathbf{J^{PC}=1^{++}}$



- **Conventional charmonium** : assignments would be $\chi_{c1}(2^3P_1)$ or $\eta_{c2}(1^1D_2)$



- quantum numbers would be respectively $\mathbf{J^{PC}=1^{++}}$ **or** $\mathbf{2^{-+}}$
- $c\bar{c} \to \rho\, J/\psi$ maximally violates isospin
- somehow ruled out by the fact that should be a pure isoscalar state; X(3872) shows an equal amount of isospin components (I=0 & I=1):

taking into account kinematical suppression it is still strong ~25% [Suzuki], while usual sizes of isospin symmetry breaking is at most a few %

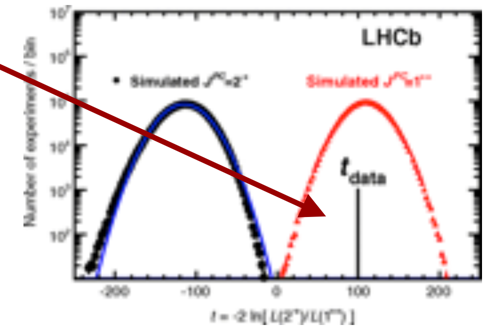
$$\frac{\mathrm{BR}\,(X \to J/\psi\pi^+\pi^-\pi^0)}{\mathrm{BR}\,(X \to J/\psi\pi^+\pi^-)} = 0.8 \pm 0.3$$

$\pi^+\pi^-\pi^0 \to \omega^0$

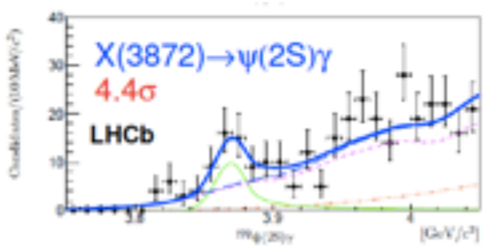
$\pi^+\pi^- \to \rho^0$

Actual experimental status

- LHCb made a sophisticated angular analysis **[PRL 110 (2013) 222001]** of the whole $B^+ \to X(3872)(\to J/\psi\pi^+\pi^-)K^+$ decay chain and unambiguously determine the quantum numbers to be **J^{PC}=1^{++}**
  - LHCb presented **[LHCb-PAPER-2015-015]** a re-analysis dropping the assumption of lowest possible orbital angular momentum (**L**) in the X(3872) sub-decay.
    - J^{PC}=1^{++} again confirmed under more general hypothesis
    - D-wave fraction in the decay $\rho J/\psi$ for J^{PC}=1^{++} results to be consistent with 0
      - **No hints for a large size of X(3872)**

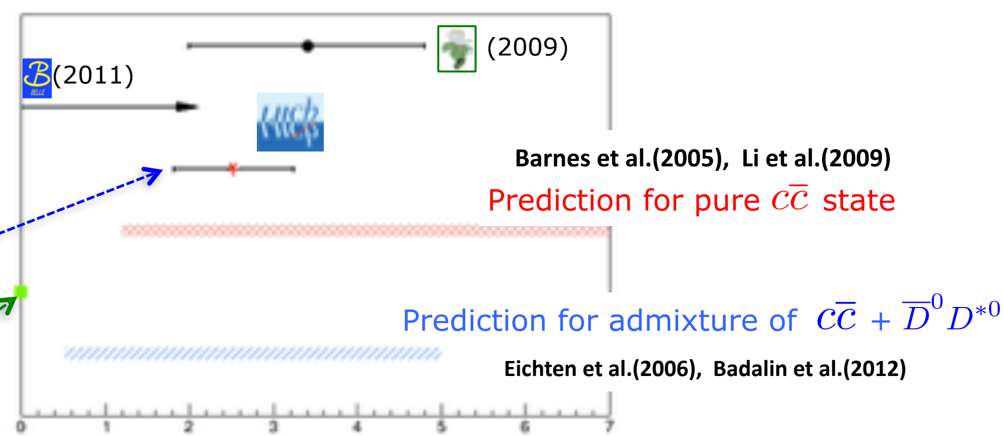


- Pure molecular model is also not supported by recent measurement by LHCb [NPB 886 (2014) 665] of the radiative decay $X(3872) \to \psi(2S)\gamma$



$$R_{\psi\gamma} = \frac{\mathcal{B}(X(3872) \to \psi(2S)\gamma)}{\mathcal{B}(X(3872) \to J/\psi\gamma)} = 2.46 \pm 0.64 \pm 0.29$$

Prediction for pure $\overline{D}^0 D^{*0}$ molecule



- Alternatively to the tetraquark option the X(3872) may have a significative $\chi_{c1}(2^3P_{1++})$ component [see Karliner&Rosner, PRD91 (2015) 014014]: mixed wave function $\overline{D}^0 D^{*0} + c\overline{c}[\chi_{c1}(2^3P_{1++})]$

X(3872) at CMS

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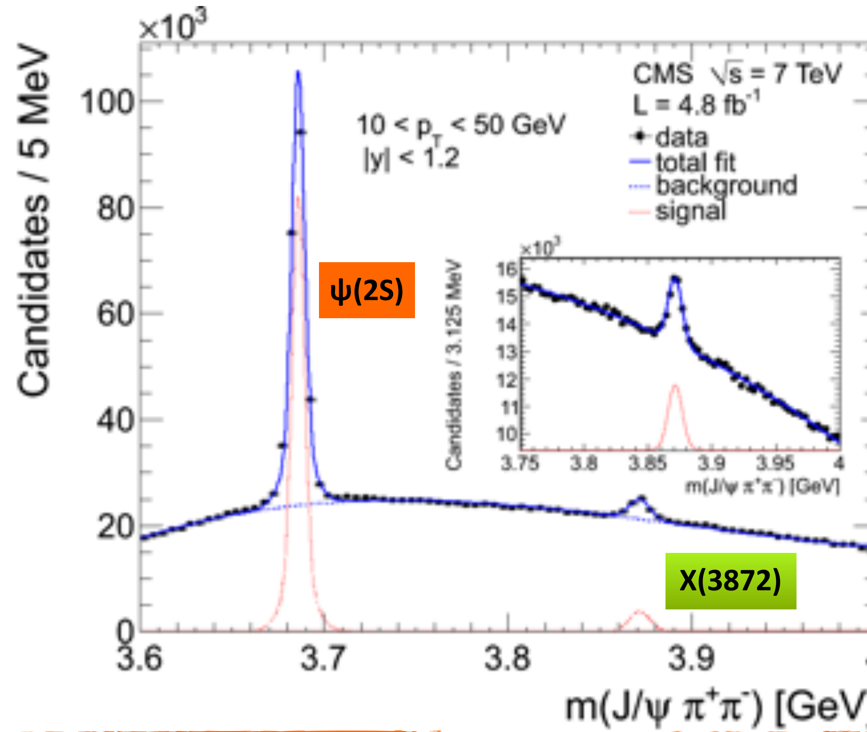
- CMS can easily reconstruct the X(3872) in the decay channel $J/\psi(\rightarrow\mu\mu)\,\pi^+\pi^-$
- With 4.8 fb^{-1} of data at 7 TeV reconstructed about **12.000 X(3872)** signal events
- CMS studied:
  - Cross section ratio w.r.t. ψ(2S)
  - Non-prompt component vs p_T
  - Prompt X(3872) cross section
  - Invariant mass distribution of the ππ system



Signal reconstruction:

- 2 μ with p_T > 4GeV coming from J/ψ in the central region of the detector ($|y(\mu^+ \mu^-)| < 1.25$).
- 2 tracks with opposite charge and p_T > 600 MeV
- combination of these four tracks with constraint on common vertex.
- selection on common vertex probability, angular distance between J/ψ and π, Q value [$M_{\pi\pi\mu\mu}$-$M_{J/\psi(PDG)}$-$M_{\pi\pi}$].

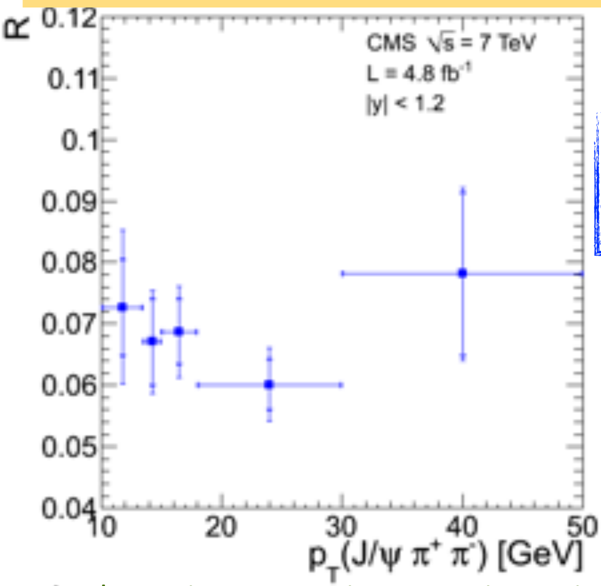
Cross Section Ratio Measurement

- A ratio of the cross section have been measured, to cancel out many systematic sources
- Given the unknown production mechanism of the X(3872) a result without acceptance corrections in a fiducial region is given

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

$10 < p_T < 50$ GeV, $|y| < 1.2$

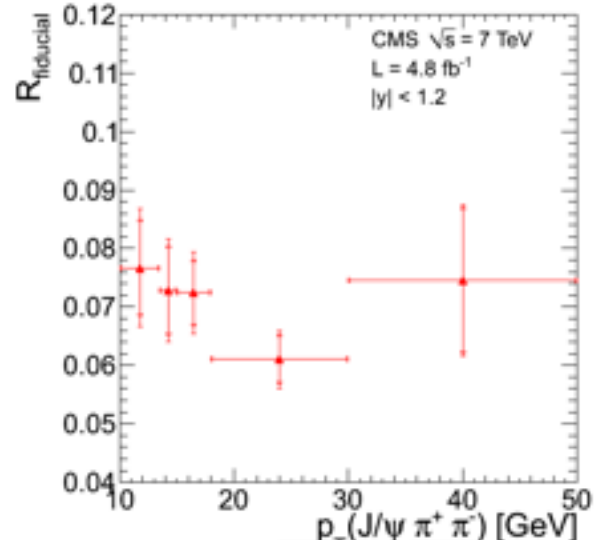
$$R = 0.0656 \pm 0.0029\,(\text{stat.}) \pm 0.0065\,(\text{syst.})$$



Yields from UML fit on $J/\psi\ \pi^+\pi^-$ mass spectrum

Acceptance estimated assuming X(3872) and ψ(2S) are unpolarized and J^{PC} X(3872) = 1^{++}

Efficiency correction from simulation and cross checks on data



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

$10 < p_T < 50$ GeV, $|y| < 1.2$

$$R_{\text{fiducial}} = 0.0694 \pm 0.0029\,(\text{stat.}) \pm 0.0036\,(\text{syst.})$$

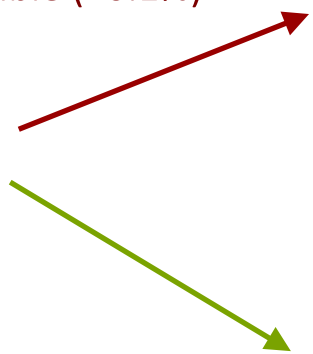
- The main systematic uncertainty arises from the limited knowledge of the X(3872) transverse momentum. The uncertainty for each p_T interval is: ~ 10% stat. and 5-13% syst.

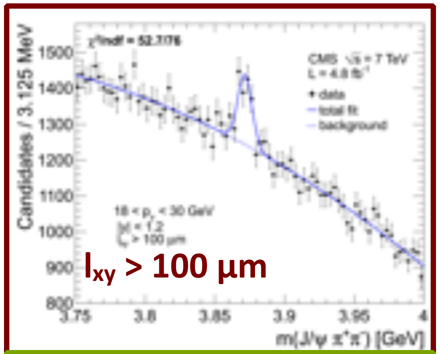
- **The ratio shows no significant dependence on the p_T of the $J/\psi\ \pi^+\pi^-$ system**

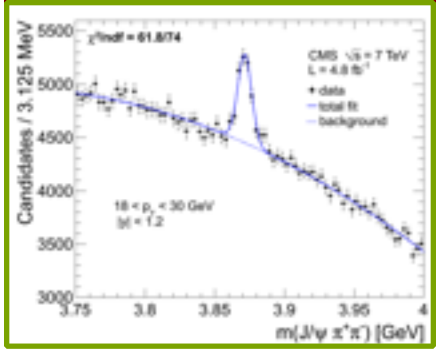
Non prompt fraction

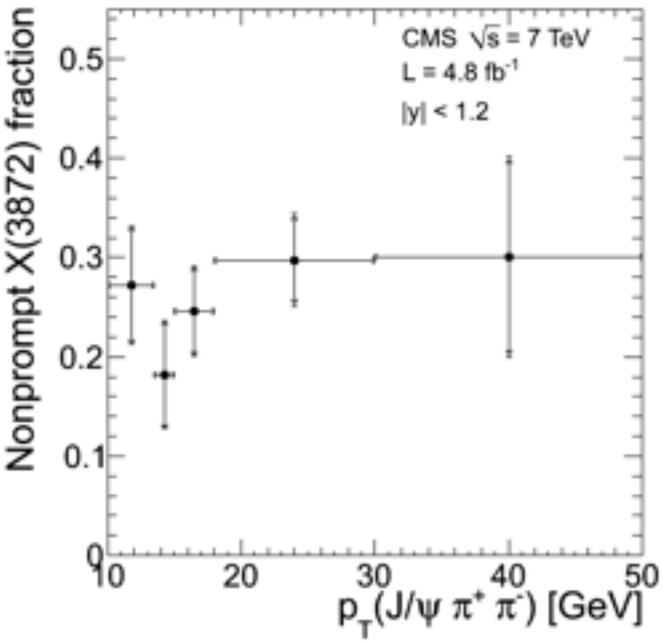
- The X(3872) can be produced from decays of B hadrons in a secondary vertex related to the decay length (l_{xy}) of the B meson.
- Events with X(3872) from B decays are selected by requiring l_{xy} > 100 μm
  - X(3872) prompt fraction with l_{xy} > 100 μm is negligible (<0.1%)

$$\textit{nonprompt fraction} = \frac{\textit{Nr. of X(3872) from B}}{\textit{Nr. of X(3872)}}$$









- Measurement dominated by statistics: ~20% stat., 6-10% syst. for each p_T interval
- **The fraction of X(3872) produced from decay of B does not show a dependence on $p_T(J/\psi\ \pi^+\pi^-)$.**
- For 10 < p_T < 50 GeV, |y| <1.2:
  X(3872) non prompt fract. = 0.263 ± 0.023(stat) ± 0.016(syst)

Prompt X(3872) production cross section

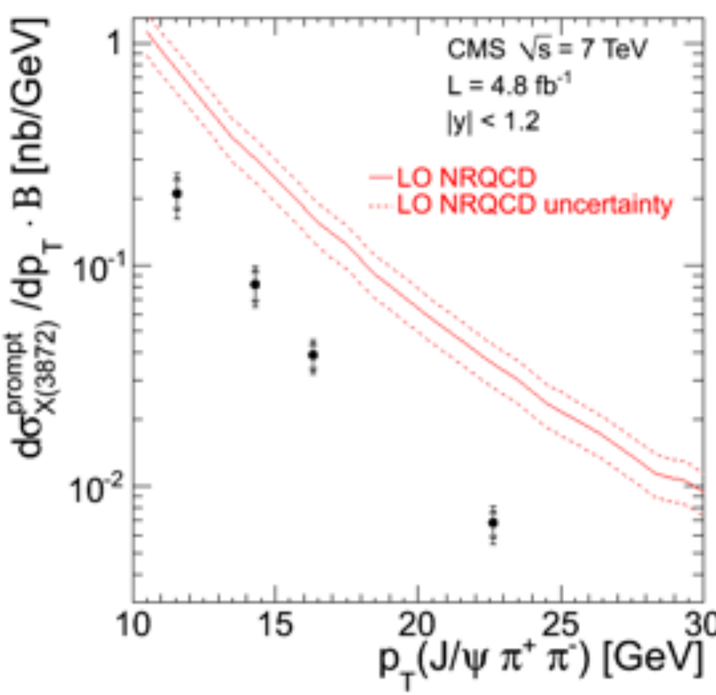
- Putting together the previous measurements the production of X(3872) state is measured for the first time as a function of transverse momentum as

Non prompt fraction

Measured by CMS in JHEP 02 (2012) 011

From PDG
BR in muons = BR in electrons

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



- Main systematic uncertainties are related to the measurements of R and prompt ψ(2S) cross section.
- X(3872) and ψ(2S) are assumed to be unpolarized.
- The results are compared with a theoretical prediction based on NRQCD factorization approach by Artoisenet & Brateen **[PhysRevD.81.114018]** with calculations normalized using Tevatron results, modified by the authors to match the phase-space of the CMS measurement
- The shape is reasonably well described by the theory while the predicted cross-section is overestimated by over 3 σ

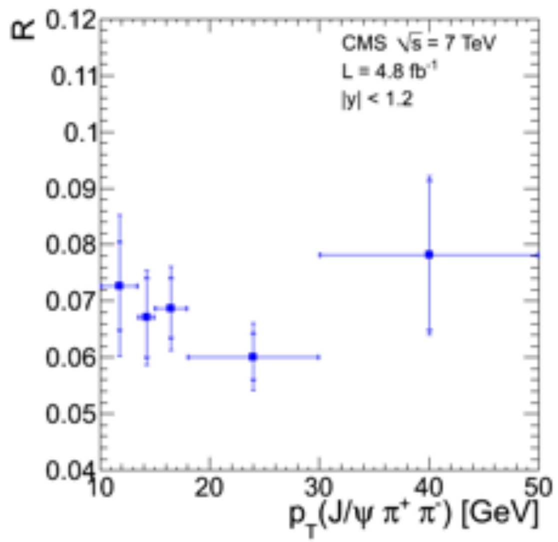
Measured integrated cross section times branching fraction for 10 < pT < 30 GeV, |y| <1.2

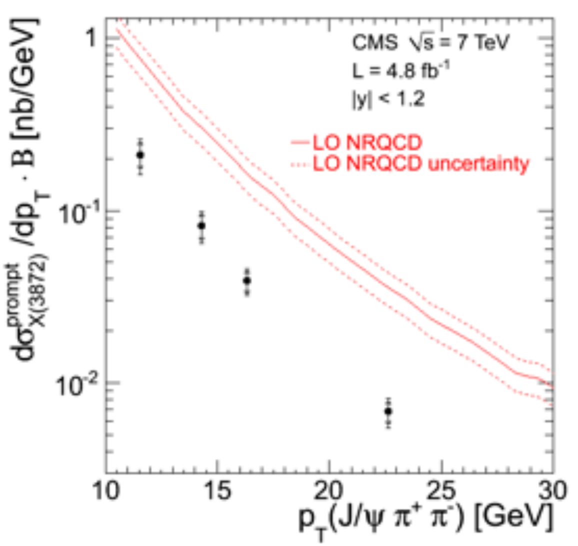
$$\sigma^{prompt}_{X(3872)} \times B\left(X(3872) \to J/\psi\ \pi^+\pi^-\right) \cong (1.06 \pm 0.11 \pm 0.15)nb$$

Theoretical prediction for 10 < pT < 30 GeV, |y| <1.2

$$\sigma^{prompt}_{X(3872)} \times B\left(X(3872) \to J/\psi\ \pi^+\pi^-\right) \cong (4.01 \pm 0.88)nb$$

Are CMS results compatible with X(3872) being a molecule?

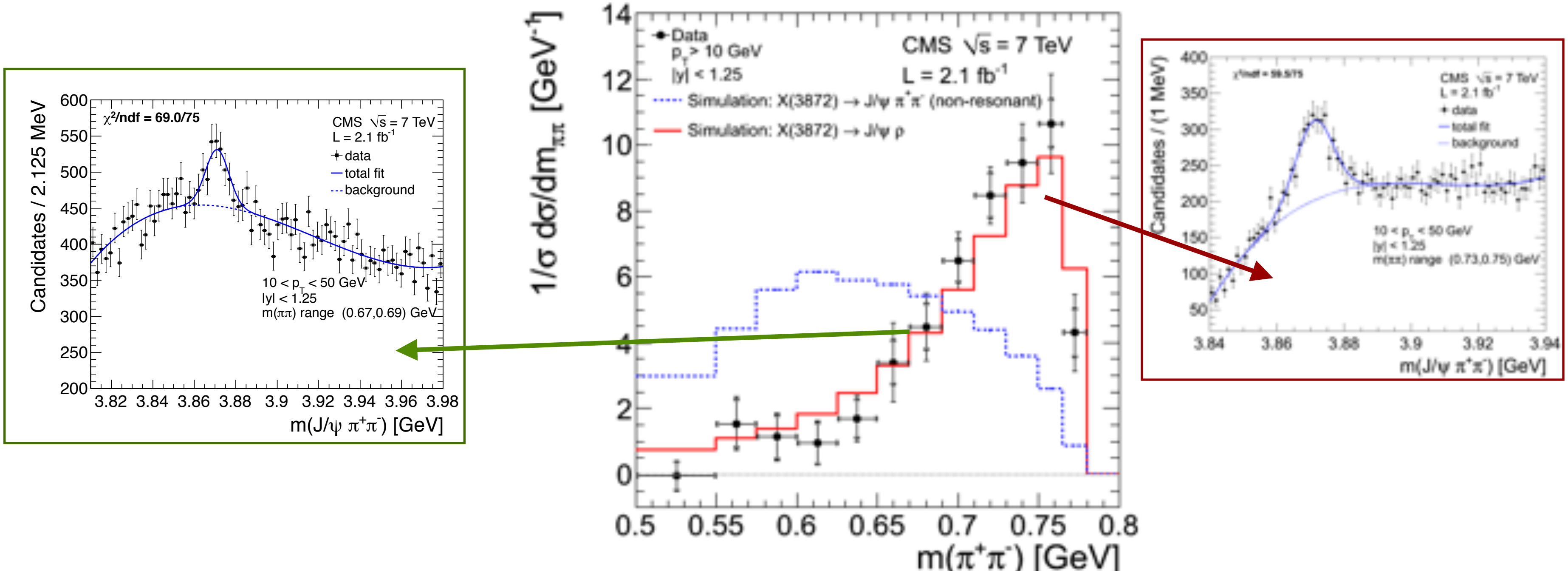




- The size of the X(3872) as a DD* molecule is determined by its scattering length which in turn depends, by quantum mechanical considerations, upon the binding energy;
  - **X(3872) would be a large & fragile molecule with a miniscule binding energy.**
- **Questions**:
  - How its production characteristics in high energy pp collisions match those of the nearly pointlike and tightly bound ψ(2S)!?
  - And how can a loosely bound molecule be produced in the wild LHC environment of hadronic collisions?
- Predictions by Artoisenet & Brateen assume, within an S-wave molecular model, **the relative momentum of the mesons being bound by un upper limit of 400MeV** which is quite high for a loosely bound molecule, but they assume it is possible as a result of rescattering effects
- On the other hand, an upper limit **lower of one order of magnitude** would imply lower prompt production rates of few orders of magnitude **[Bignamini et al., Phys. Rev. Lett., 2009, 103(16)]**

Invariant mass distribution of the ππ system

- Studies at CDF and Belle suggest that X(3872) decays in J/ψ and ρ^0.
- The $\pi^+\pi^-$ invariant-mass distribution from X(3872) decays to J/ψ $\pi^+\pi^-$ is measured in order to investigate the decay properties of the X(3872).
- Event sample divided into **$m(\pi^+\pi^-)$** intervals and X(3872) yields extracted from fits to **$m(J/\psi\ \pi^+\pi^-)$**



- The spectrum obtained from data is compared to simulations with and without an intermediate ρ^0 in the J/ψ$\pi^+\pi^-$ decay.
- **The assumption of intermediate ρ^0 decay gives better agreement with the data.**

Search for $X_b \to \Upsilon(1S)\pi^+\pi^-$

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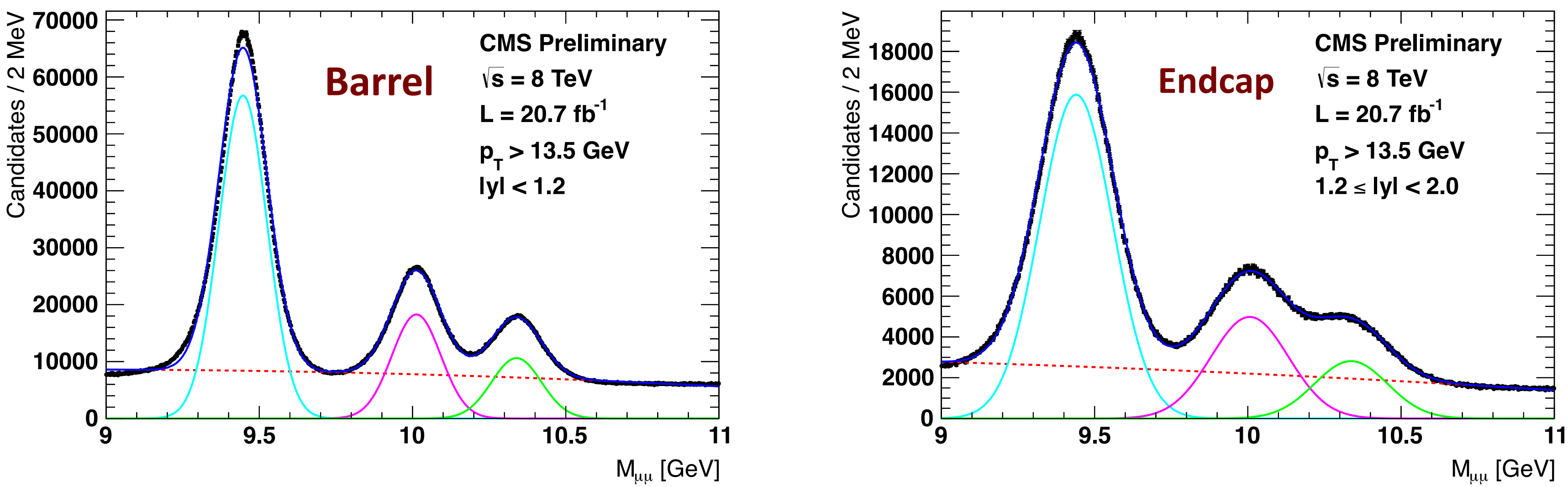
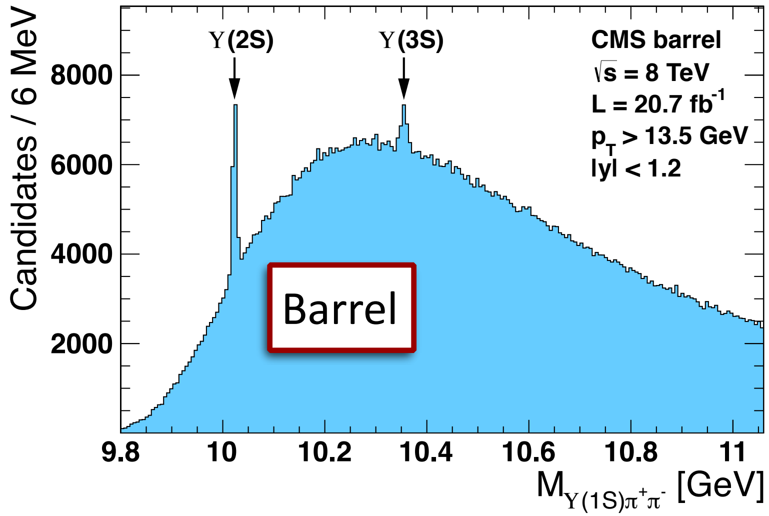
- The discovery of the X(3872) has prompted the search for a bottomonium counterpart X_b decaying into Y(1S) $\pi^+\pi^-$ according to Heavy Quark symmetry considerations
  - Mass close to the BB or BB* threshold,10.562 and 10.604 GeV
    - Model dependent mass prediction are present:
      e.g. m ≈ 10.561 GeVc for a BB* molecule (Swanson, 2004)
  - Expected similar to X(3872), narrow width and sizable branching ratio into Y(1S) $\pi^+\pi^-$
- CMS has collected a large sample of Y(ns) →μμ in 20 fb^{-1} of collisions at 8 TeV in 2012
- Separate "barrel" and "endcaps" events to exploit better mass resolution and lower background in the barrel region

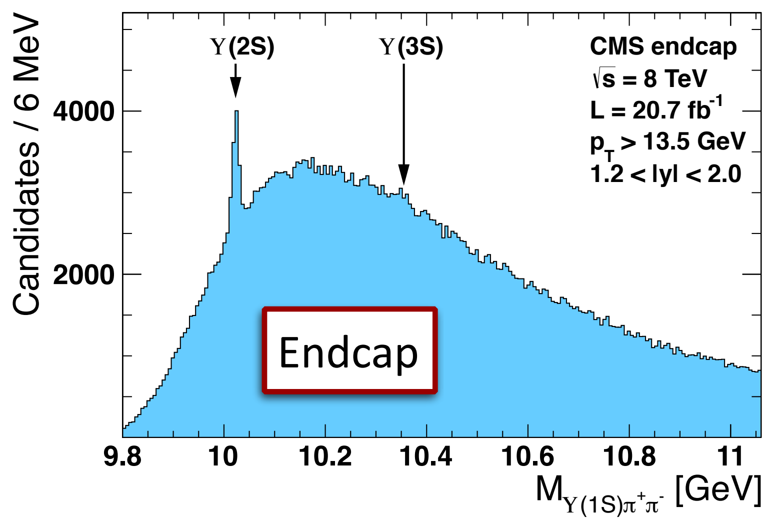


X_b Candidate reconstruction

- X_b candidates reconstructed by associating 2 pions to the Y(1S)
- Y(1S)$\pi^+\pi^-$ mass spectrum studied in the kinematic region
  p_T(Y(1S)$\pi^+\pi^-$) > 13.5 GeV and |y(Y(1S)$\pi^+\pi^-$)| < 2.0
- Optimized by maximizing the expected signal significance near the Y(2S) mass
- In analogy with X(3872) expected significance **> 5σ** if X_b (BR x cross-section) > 6.56% of the corresponding Y(2S) → Y(1S)$\pi^+\pi^-$value

No structure found apart from Y(2S) and Y(3S)





Mass scan for X_b

- Explored 10.06-10.31 and 10.40-10.99 GeV mass regions
  - X_b expected mass shifted 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, evaluated

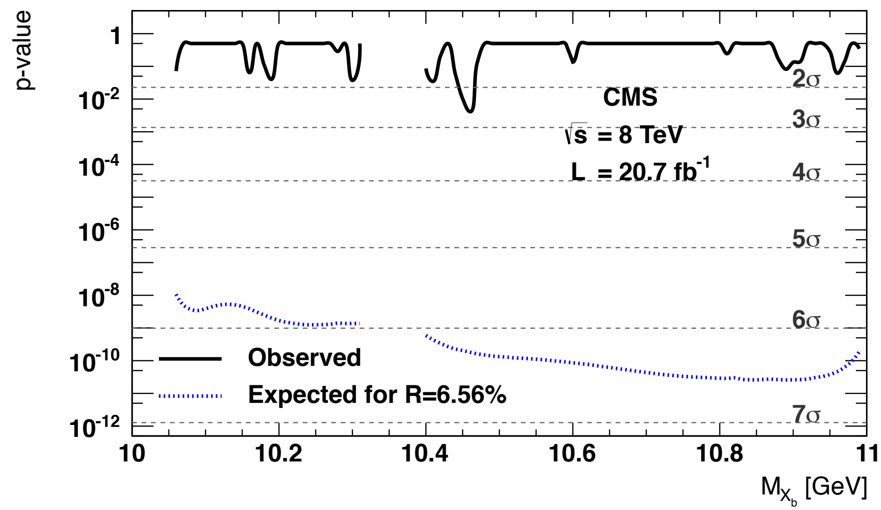
$$R = \frac{\sigma_{X_b} \times BR(X_b \to Y(1S)\pi^+\pi^-)}{\sigma_{Y(2S)} \times BR(Y(2S) \to Y(1S)\pi^+\pi^-)} = \frac{N^{obs}_{X_b}}{N^{obs}_{Y(2S)}} \cdot \frac{\epsilon_{Y(2S)}}{\epsilon_{X_b}}$$

observed yields of X_b and Y(2S) candidates

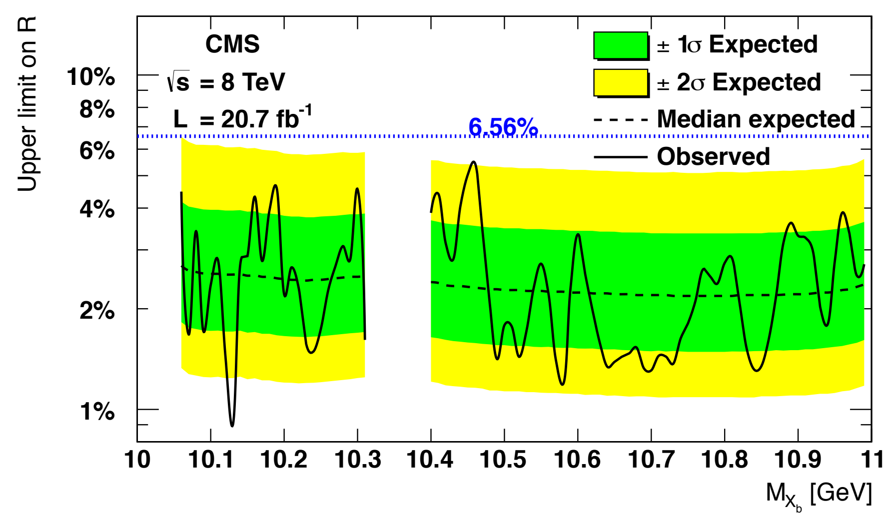
Overall efficiencies estimated from simulation
Assumptions:
- same production mechanism for Y(2S) and X_b
- both assumed unpolarized
- same dipion mass distribution

X_b Limit at CMS

- Local p-values calculated using asymptotic approach and combining results of fits to the barrel and endcap regions
- Systematic uncertainties implemented as nuisance parameters
- The smallest local p-value is 0.004 at 10.46 GeV, corresponding to a statistical significance of 2.6σ, which is reduced to 0.8σ when taking into account the "look- elsewhere effect"

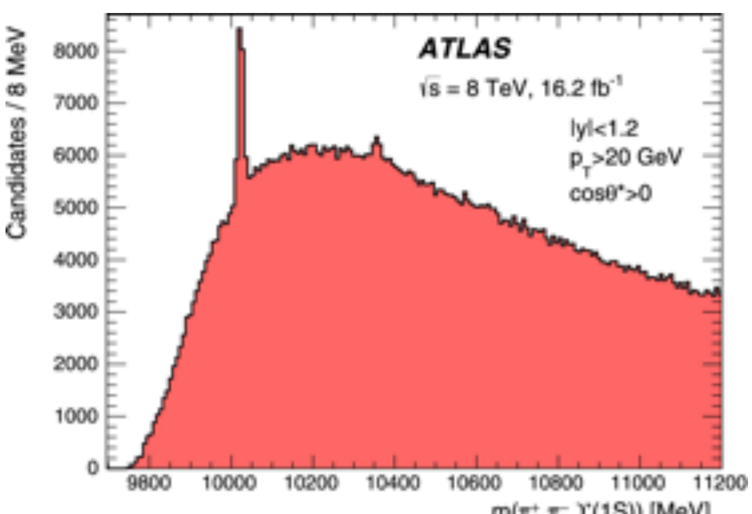


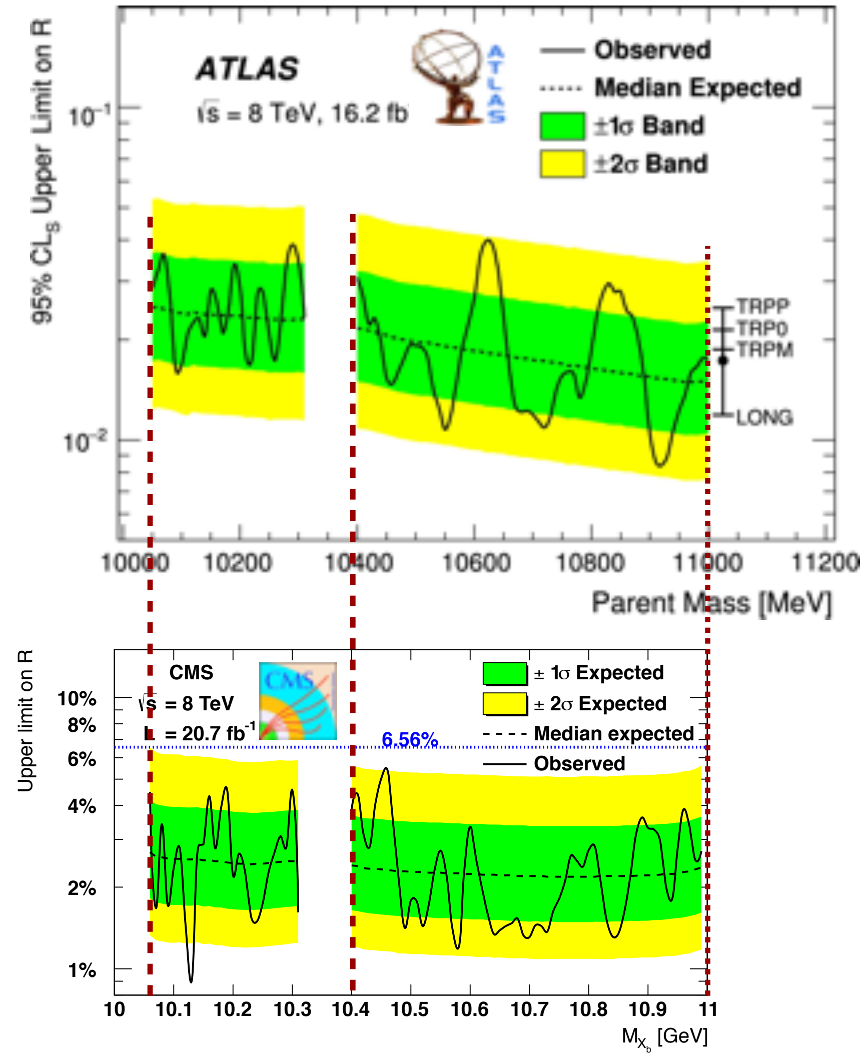
- **No significant excess is observed**
- **95% CL upper limit on the (cross-sections x BR): 0.9-5.4 %**



Comparison with ATLAS

- Similar search performed in Atlas
- Fit in 2x2x2 bins of (|y|,PT, cosθ*), where cosθ* is the angle between the dipion momentum and the lab-frame parent momentum.
- The split of the analysis into these bins take advantage of varying bin sensitivity, which allowed for a more restrictive limits than CMS
- **No significant access found**
  - Upper limit set on R: 95% CL for R:0.8-4%

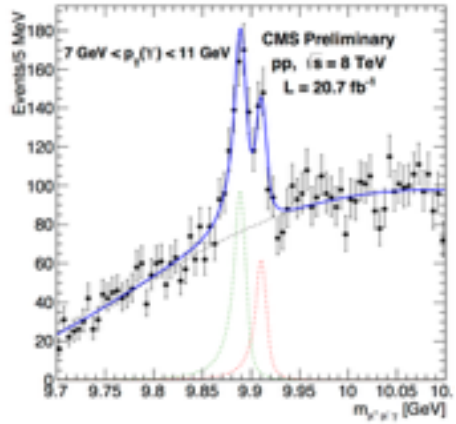




X_b searches: prospects

- According to Karliner & Rosner **[PRD91 (2015) 014014]**, this search decay should be **forbidden by G-parity conservation**. While for the X(3872) the isospin-conserving decay to **ωJ/ψ** was kinematically suppressed, the same is not true for a bottomonium-like $J^{PC}=1^{++}$ counterpart

- The strategy for X_b observation should include search of
  - $X_b \to \Upsilon(1S)\,\omega(\to \pi^+\pi^-\pi^0)$
  - $X_b \to \Upsilon(3S)\gamma$
  - $X_b \to \chi_{b1}(1P)\pi^+\pi^-$



$\chi_{b1,b2} \to \Upsilon(1S)\gamma$

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- **not an easy task for CMS (low energy γ), for Run 2!**

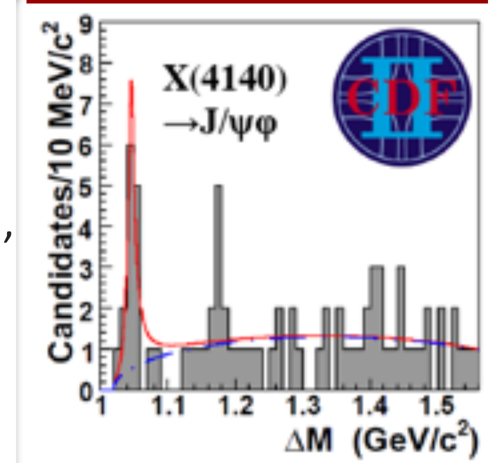
- Moreover Karliner & Rosner suggest that the X_b may be close in mass to the $\chi_{b1}(3P)$, mixing with it and sharing its decay channels (just as they suppose for X(3872))

- Thus the experiments (ATLAS, DØ, LHCb both with non-converted & converted photons) that reported observing $\chi_{b1,b2} \to \Upsilon(1S,2S)\gamma$ might have actually discovered the X_b or a mixture of the two states!
  - It would be worthwhile to examine the $\Upsilon(1S,2S)\gamma$ mass spectra for any departure from single BW behavior.

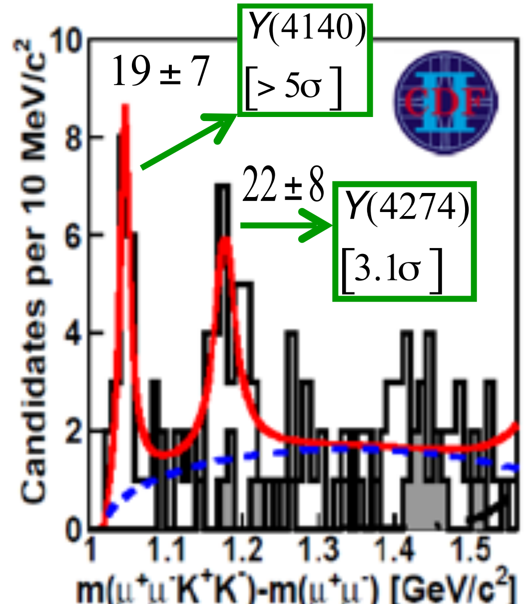
Y(4140): Another long story…

- CDF (2009) reported evidence (@3.8σ) for … narrow peak in $J/\psi\varphi$ mass spectrum, close to the kinematical threshold, in decays $B^{\pm} \rightarrow J/\psi\ \phi\ K^{\pm}$

[PRL 102 (2009) 242002]

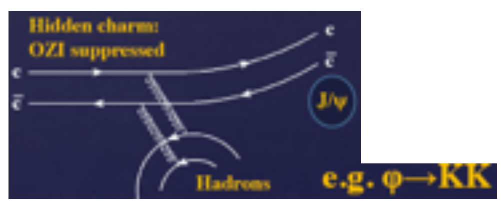


- CDF (2011) presents update analysis with larger dataset,(6.0fb^{-1} vs 2.7fb^{-1})observing



[arXiv:1101.6058 (2011)]

- **Masses are well above 3770MeV open charm threshold;**
the conventional charmonium should decay into $D\bar{D}$, with tiny B.R. to $J/\psi\varphi$

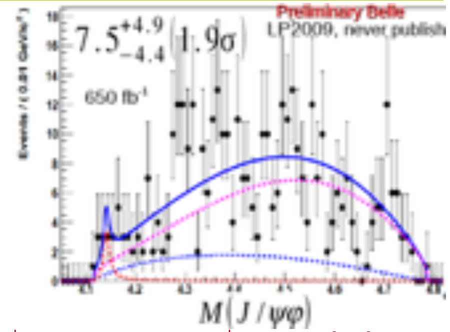


- This OZI suppressed transition is rare [*B.R. ~10^{-5}*] can proceed either as a 3-body decay and/or as a quasi- 2-body decay, in which J/ψ and φ come from an intermediate state $Y(c\bar{c}s\bar{s})$.
Constrained phase-space would favor forming of 2-body intermediate structures.

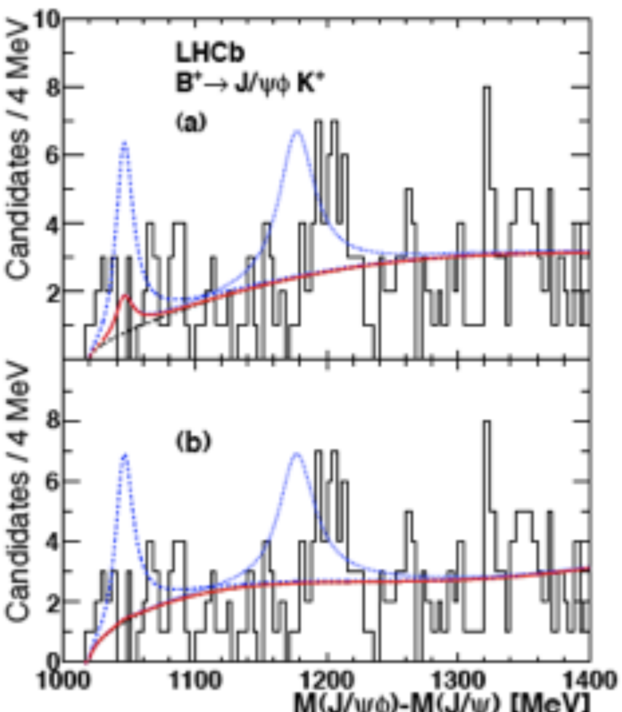
- If this *Y* state exists and it decays into $J/\psi\varphi$, its inv. mass must be below the $D\bar{D}^*$ threshold (~4.3*GeV*) : above this threshold, the dominant decay would be $Y \rightarrow D\bar{D}^*$

The Y(4140) search

- Belle (2009) searched and did not find this state in the same decay.
- Limit set on production rate, but cannot exclude CDF peak.
- Upper limit value lower than CDF's central value! [efficiency depletion at the threshold]



- LHCb (2012) has searched for these two states reconstructing $(383 \pm 22) B^+ \to J/\psi\phi K^+$ candidates



LHCb observed no signals; this implies a 2.4σ tension with CDF.

@90%CL upper limits on ratios of branching fractions :

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

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

[PRD 85 (2012) 091103]

CMS search for Y(4140)

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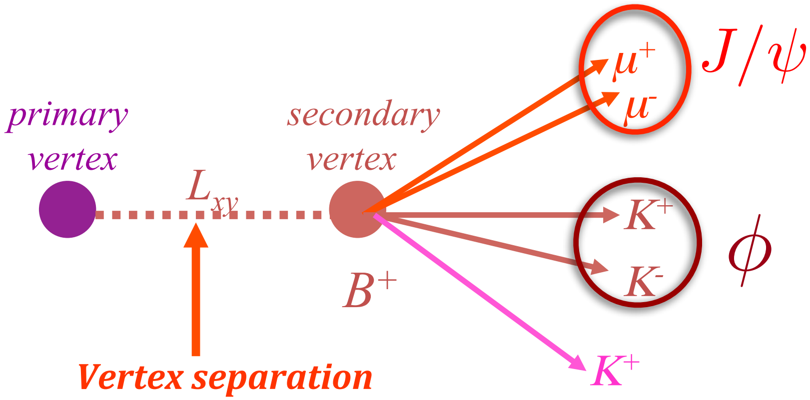
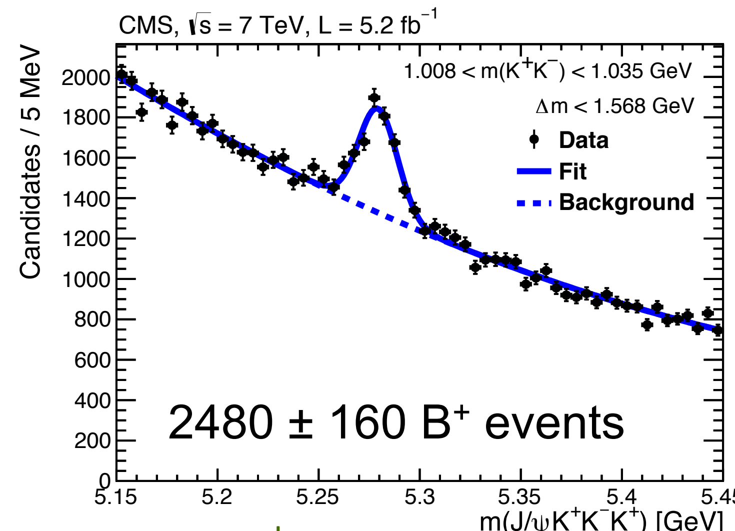
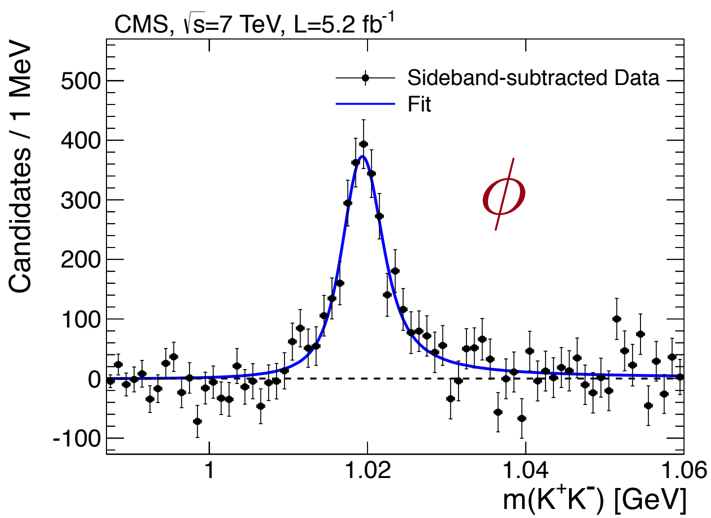
- Search performed with 5.2 fb^{-1} of collision at 7 TeV





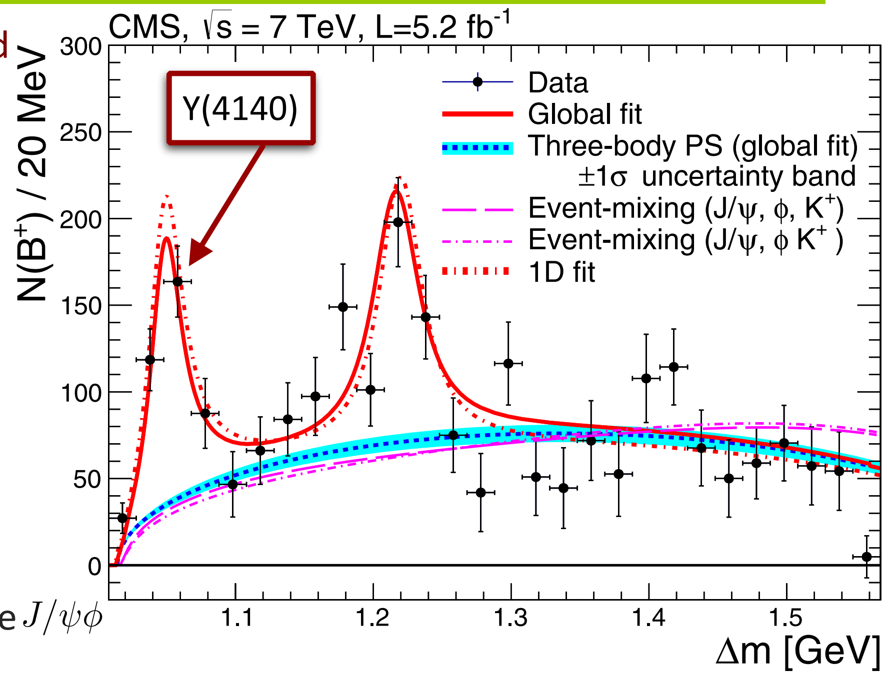
- Largest B^+ sample to date
  - 20 times CDF
  - 7 times LHCb



- B+ candidates are consistent to be solely $J/\psi\phi K^+$ ⇒ $J/\psi f_0(980) K^+$, $J/\psi K^+ K^- K^+$ negligible

The J/ψϕ mass spectrum

- The $\Delta m = m(\mu^+\mu^-K^+K^-) - m(\mu^+\mu^-)$ spectrum is obtained
  - dividing the dataset in **20 MeV Δm** bins
  - fitting every bin with
    - **Signal PDF**: S-wave Relativistic Breit-Wigner (BW) convoluted with mass resolution
    - **Background PDF**: 3-body Phase Space Shape
    - **1-D Fit**: Binned χ^2 fit to the extracted Δm spectrum using the BW and PS shape.
    - Global 2-D Fit: simultaneous fit of m(B^+) and Δm with implicit background subtraction
  - extracting the number of B signal in each Δm bin fitting the $J/\psi\phi$ spectrum



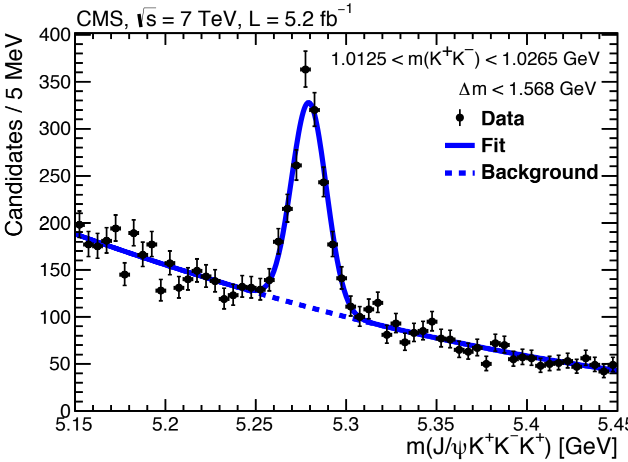
- The region **Δm >1.568 is excluded** to avoid bkg from $B_S \to \psi(2S)\phi \to J\psi\pi^+\pi^-\phi$

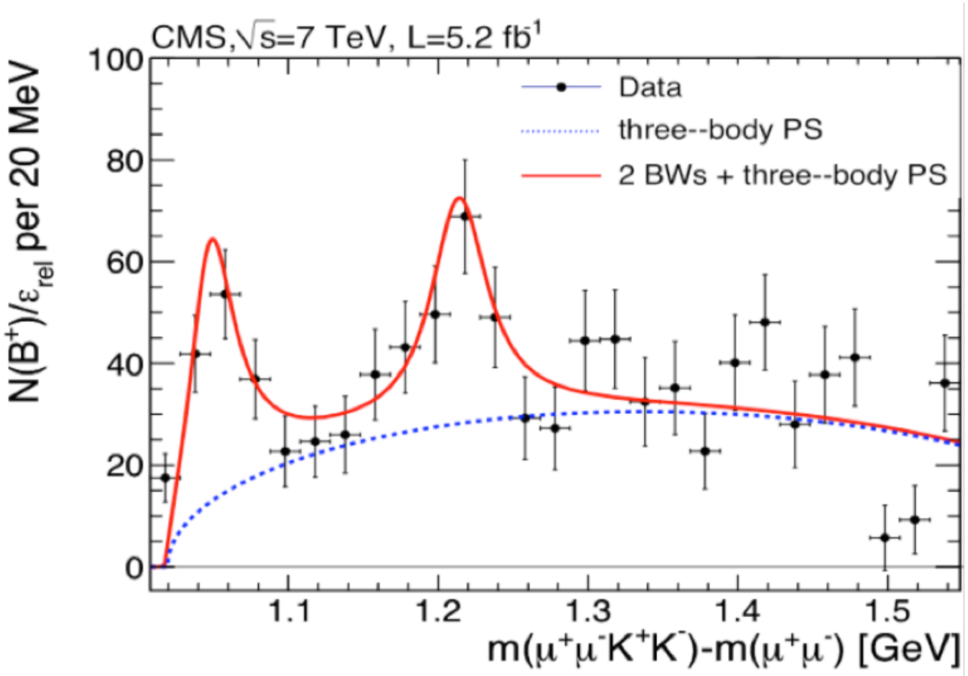
Yield	Mass (MeV)	*Γ* (MeV)
310 ± 70	4148.0 ± 2.4(stat) ± 6.3(syst)	28^{+15}_{-11}(stat) ± 19(syst)
418 ± 170	4313.8 ± 5.3(stat) ± 7.3(syst)	38^{+30}_{-15}(stat) ± 16(syst)

- **First structure consistent with Y(4140) of CDF observed with more than 5 σ, and saw evidence for a second structure in the same mass spectrum**
- Naïve yields' ratio estimate: $\frac{\mathrm{BR}\ (Y(4140))}{\mathrm{BR}\ (J/\psi\phi K)} \approx 0.10 \pm 0.03\%$ consistent with CDF & LHCb UL

Crosscheck with cleaner B^+ sample

- More stringent quality and kinematic cuts are used to produce a **cleaner sample**
  - **40% of the defaults B signal**
  - **10 times less background**



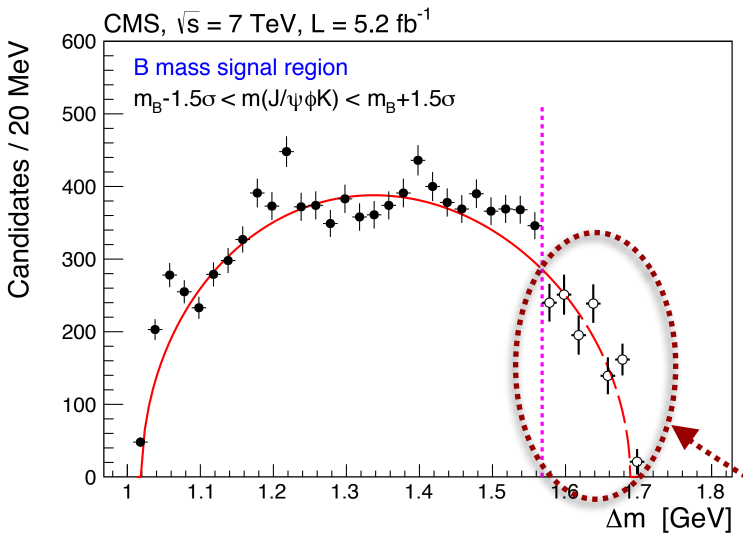


- **Found structure can be clearly seen also with this selection**

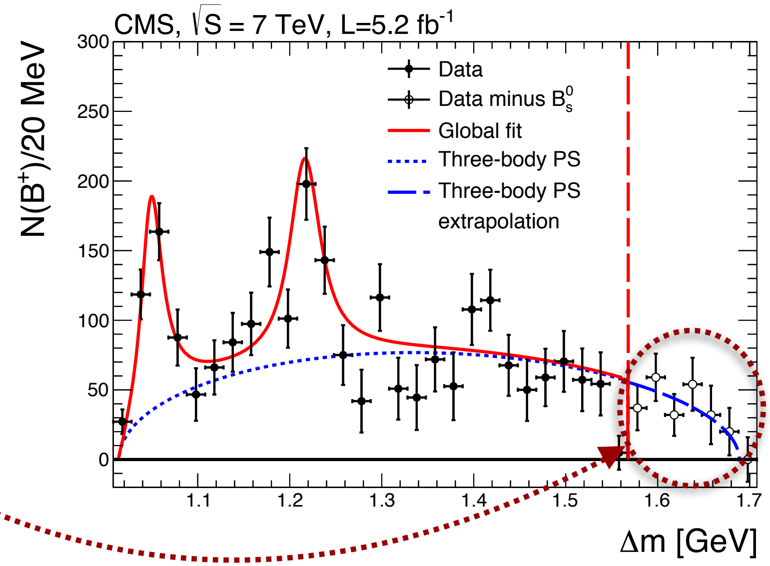
Investigation of the whole Δm region

- Check the events with Δm larger than 1.568 GeV (eliminated from the analysis) to ensure that they could not cause reflections in the low-Δm region

- The Δm spectrum after subtracting B0s contribution but including non-B events within 1.5 σ of the B mass



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

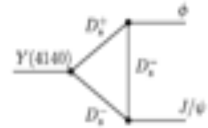


The events in the cutoff region are consistent with phase space.

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.

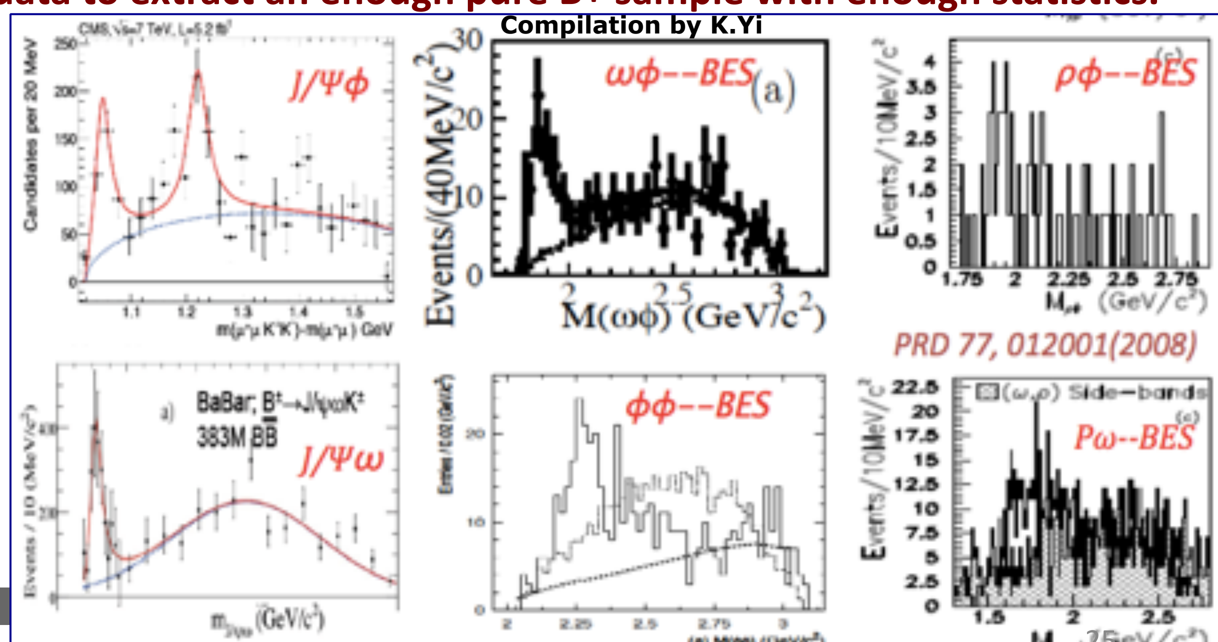
Y(4140) interpretations

- For the Y(4140) decaying several interpretations have been proposed:
  - $D_s^* \overline{D}_s^*$ molecule, that is the molecular strange partner of the Y(3940)
  - $cs\overline{cs}$ tetraquark
  - threshold kinematic effect
  - hybrid charmonium
  - weak transition with $D_s \overline{D}_s$ rescattering ⇨



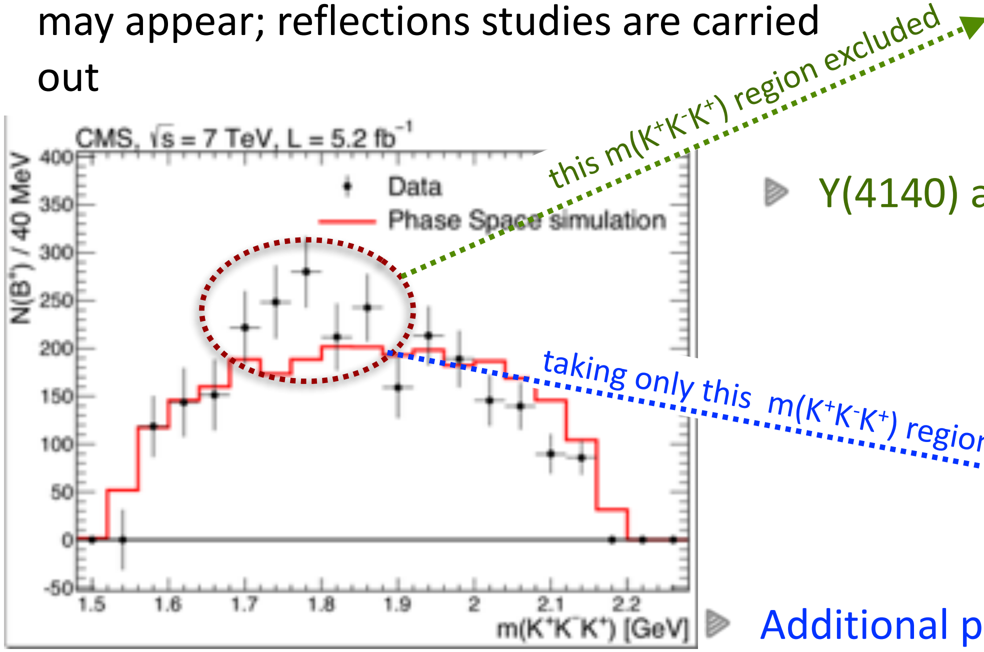
- Understanding the nature of both structures needs further investigation & requires a full amplitude analysis (not easy task: 2 vectors in the final state!).
- **It is suitable for CMS adding RunII data to extract an enough pure B+ sample with enough statistics.**

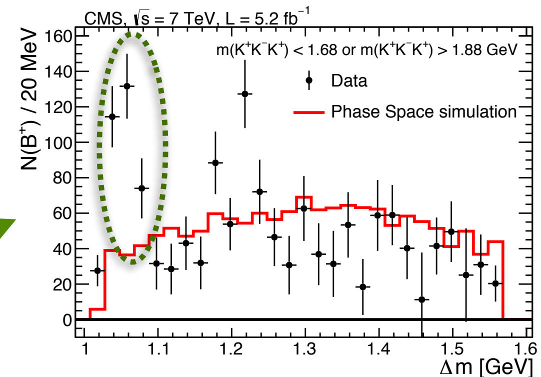
- Worthy to note that the Y(4140) state is the most recent of a series of vector-vector threshold enhancements from OZI suppressed strong processes:
- Possibility to similar behavior in pairs of heavy quarkonia?



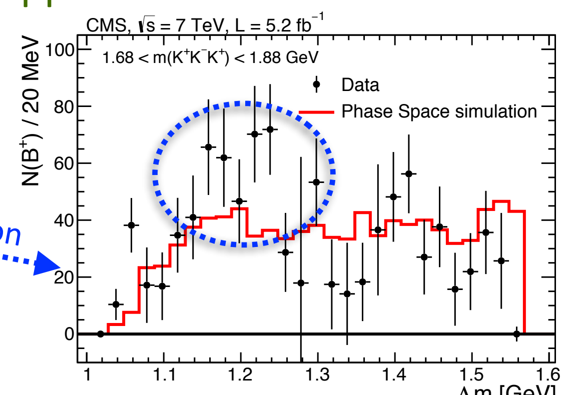
Next steps for Y(4140)

- **Understanding the nature of both structures needs further investigation**
- The ϕK⁺ mass distrib. shows **an excess** w.r.t. PHSP profile in the region where large resonances [**K2(1770) & K2(1820)**] may appear; reflections studies are carried out





- Y(4140) appears to be uncorrelated to ϕK+ resonances

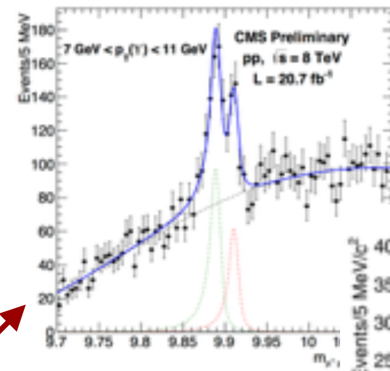


- Additional peak (m-shifted wrt CDF) maybe affected by them

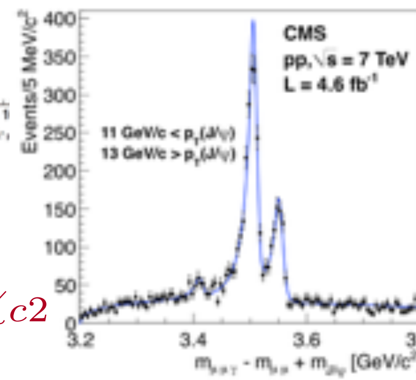
- A full amplitude analysis is required: not easy task due to 2 vectors in the final state!
- **It is suitable for CMS adding RunII data to extract an enough pure B^+ sample with enough statistics.**

Summary and perspectives

- CMS has greatly contributed to the study of exotic states
  - X(3872) prompt cross section
  - Y(4140) confirmation
  - Search for X_b
- **Their actual nature is still a challenge!**
- **Many channels still to be explored**
  - **Particularly promising is the good resolution for radiative decays from converted photons**



χ_{b1}, χ_{b2}

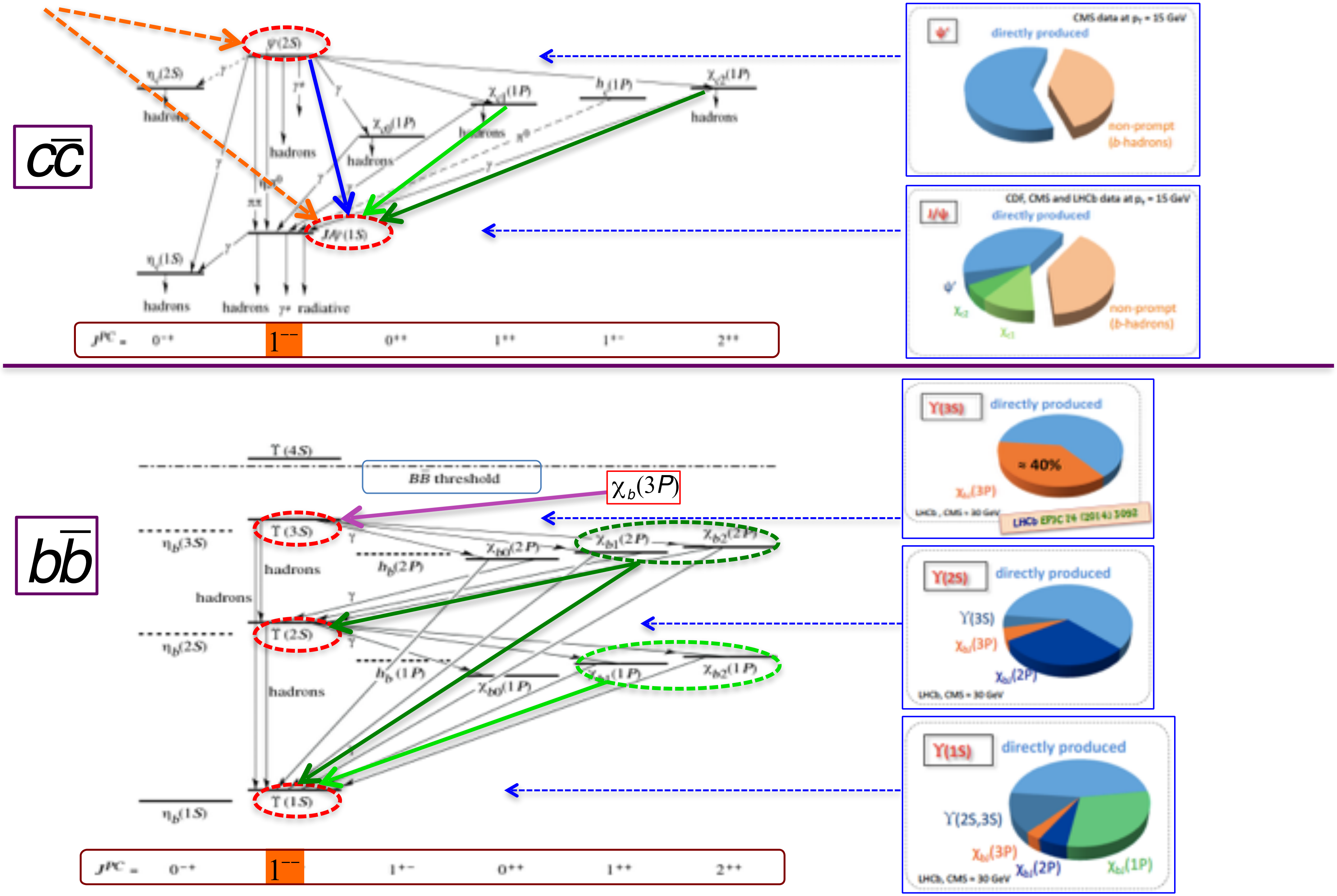


χ_{c1}, χ_{c2}

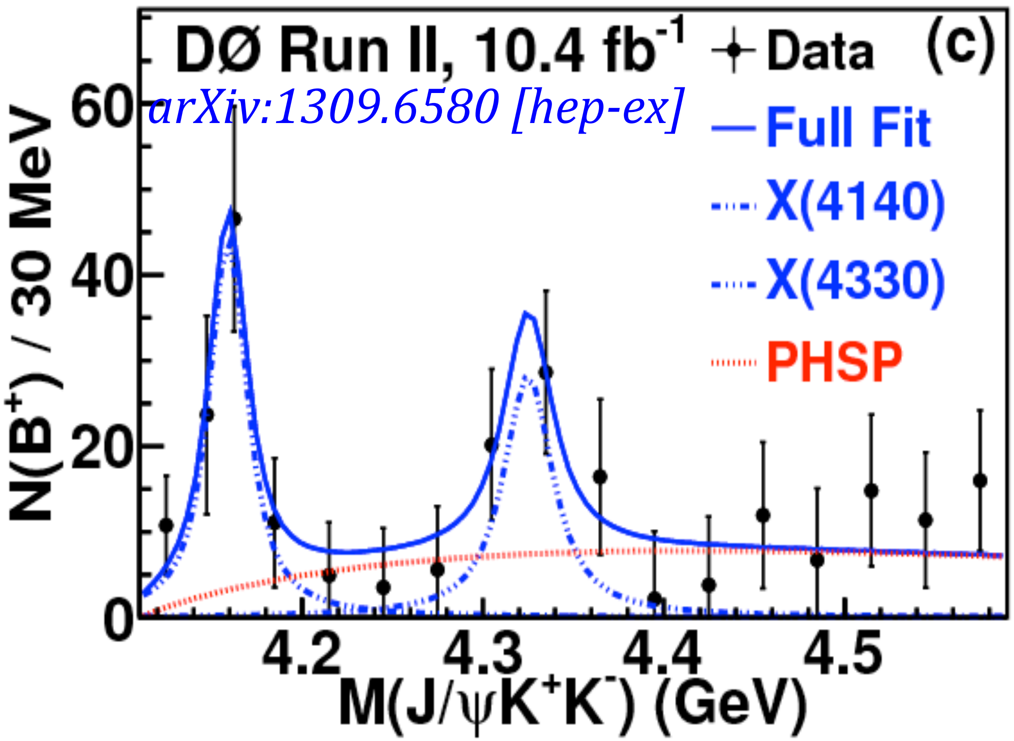
- **Run-2 just started**
  - CMS will record much larger integrated luminosity than LHCb, in an harsher environment
  - Dedicated triggers developed for the most important analyses

Backup

Quarkonium spectra & overview of feed-down into spin-triplet S-wave states



Y(4140) at DØ



M_1=4159.0±4.3(stat)±6.6(syst) MeV
M_2=4328.5±12.0(stat) MeV

Γ_1=19.9±12.6(stat)$^{+1.0}_{-8.0}$(syst) MeV
Γ_2=? MeV

Y(4140)—Evidence (3.1σ), consistent with CDF Y(4140) result

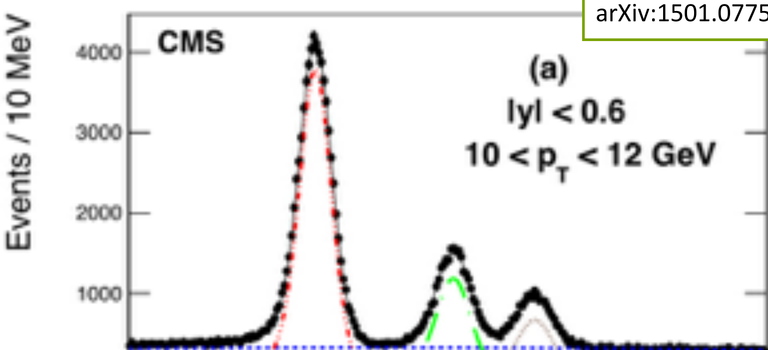
Peak2 — hint w/ fixed width

B-physics at CMS

Some example of the capabilities of the CMS detector…

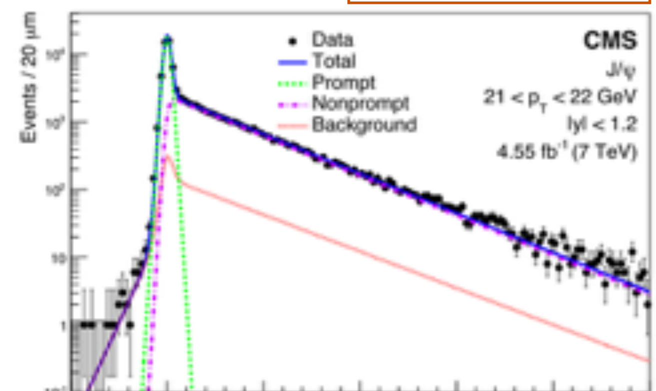
- dd

arXiv:1501.07750



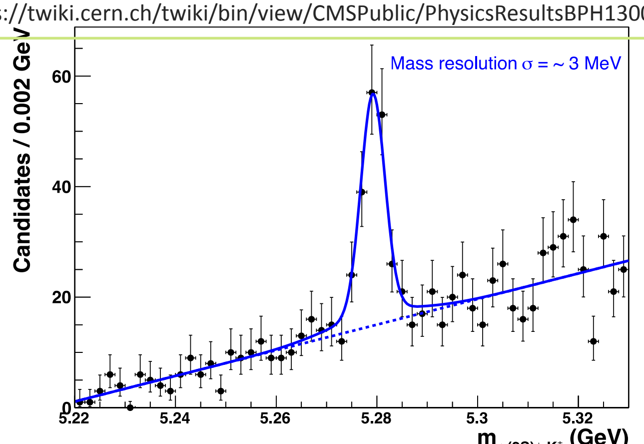
High resolution on Dimuon Mass (Y(nS) states)

PRL114 (2015) 191802



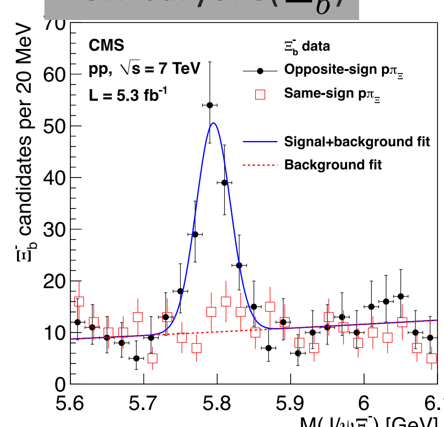
Precise separation of non-prompt decays (J/ψ)

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH13009



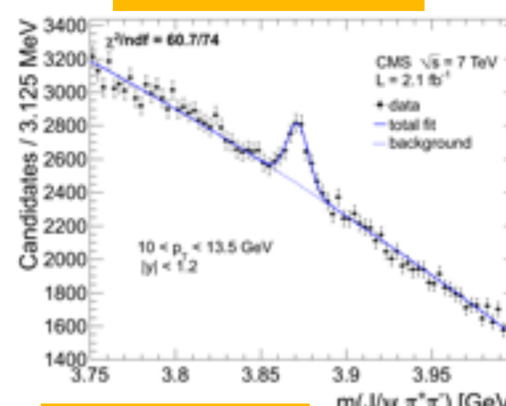
New Decay Channels ($B^+ \to \psi(2S)\phi K^+$)

New baryons(Ξ_b^0)



PRL 108, (2012) 252002

Exotics (X(3872))



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and keeps going..