Bottom and Charm physics at CMS

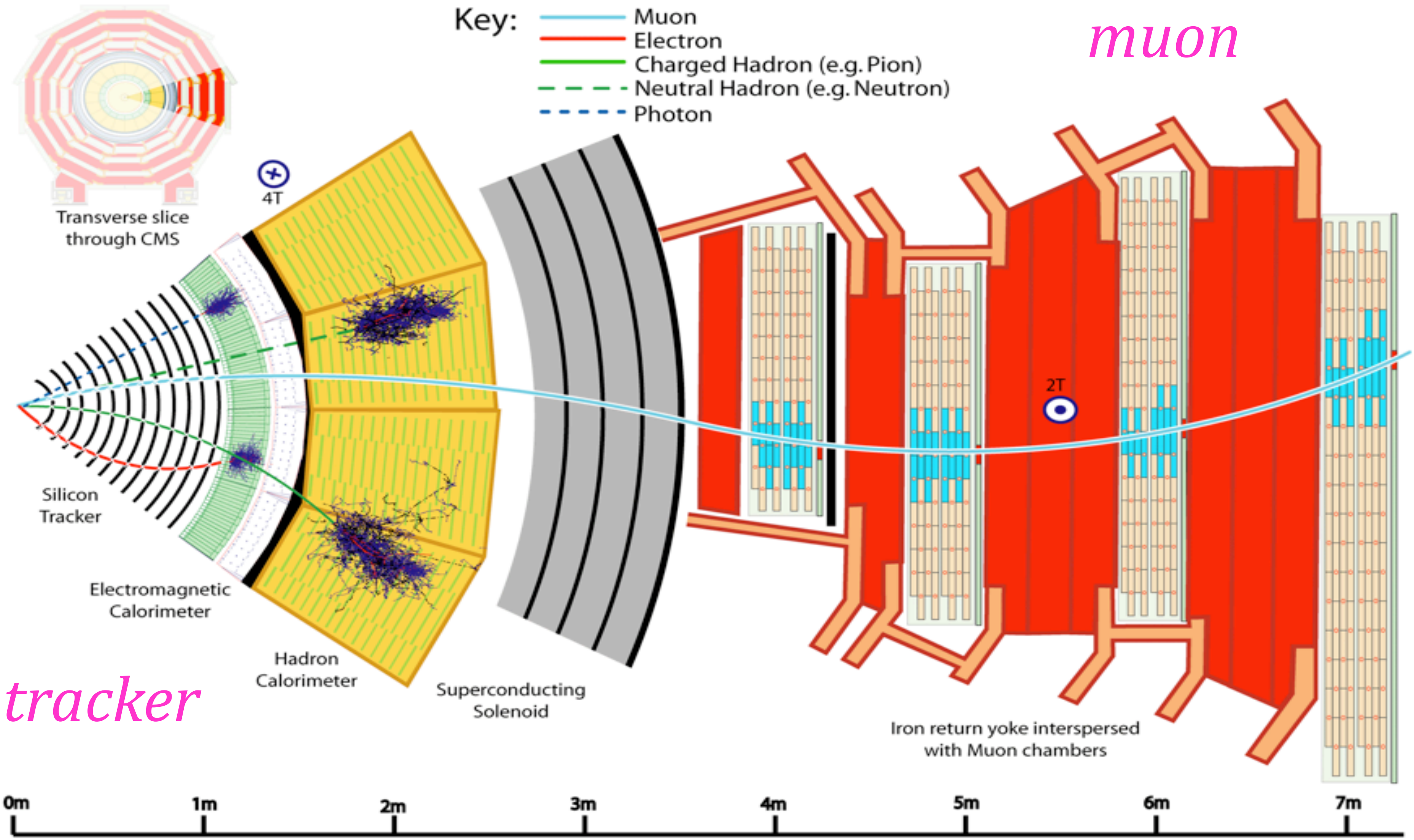
Kai Yi (University of Iowa)
for
the CMS Collaboration

From the LHC to Dark Matter and Beyond
Aspen 2017 Winter Conference, Aspen, Colorado, USA

Outline

- CMS detectors & triggers
- Bottom and charm results from CMS
  - X(3872)
  - Jpsi+phi structures
  - B decays to psi(2S)+phi+Kaon
  - Search for X(5568) decays to B_s^0+pi
  - Search for X decays to Y(1S)+pipi
  - Quarkonium cross sections at 13 TeV
  - Double Jpsi differential cross section
  - Double Upsilon observation
- Summary

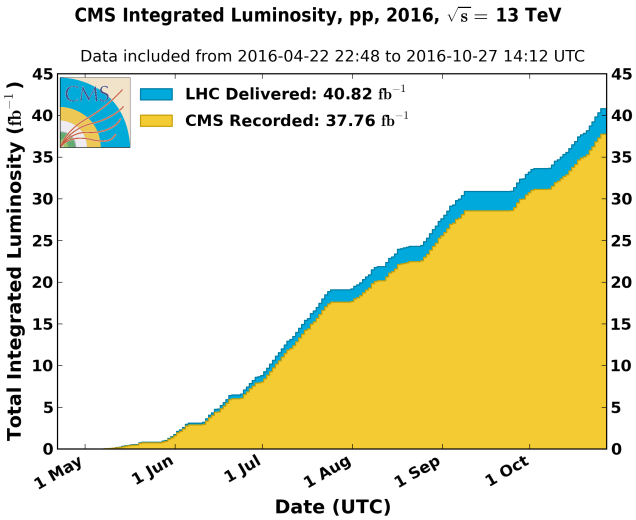
CMS Detector



CMS Detector Performance

Excellent muon/silicon detectors for quarkonium:

- Muon system
  - High-purity muon identification
  - Good dimu mass resolution ($\Delta m/m \sim 0.6\%$ for J/ψ)
- Silicon Tracking detector, B=3.8T
  - excellent track momentum resolution ($\Delta p_T/p_T \sim 1\%$)
  - excellent vertex reconstruction and impact parameter resolution



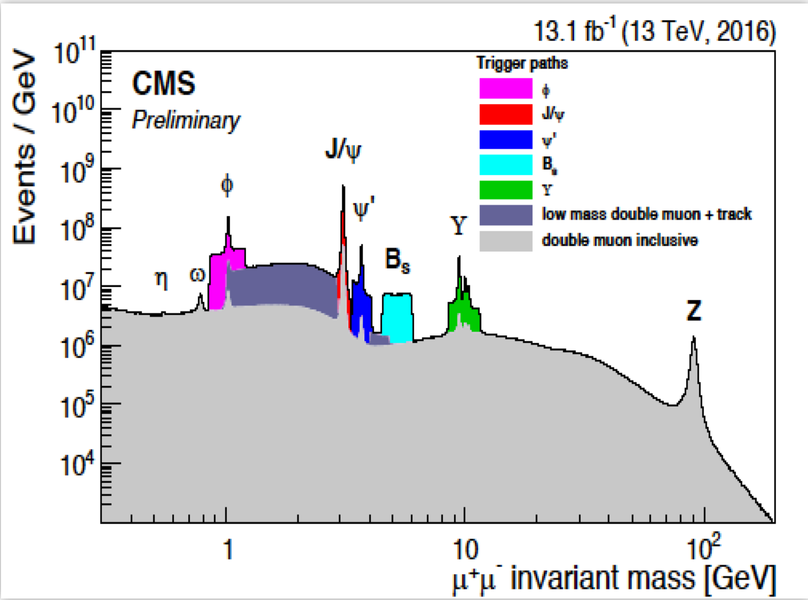
LHC luminosity and CMS trigger:

- *collect data at increasing instantaneous luminosity*
- *Triggers are essential ingredients*
  - *Special trigger for different analyses*

    combination of muon p_T, dimu p_T, dimu mass

    displaced dimuon vertex, and

    dimu+additional muon



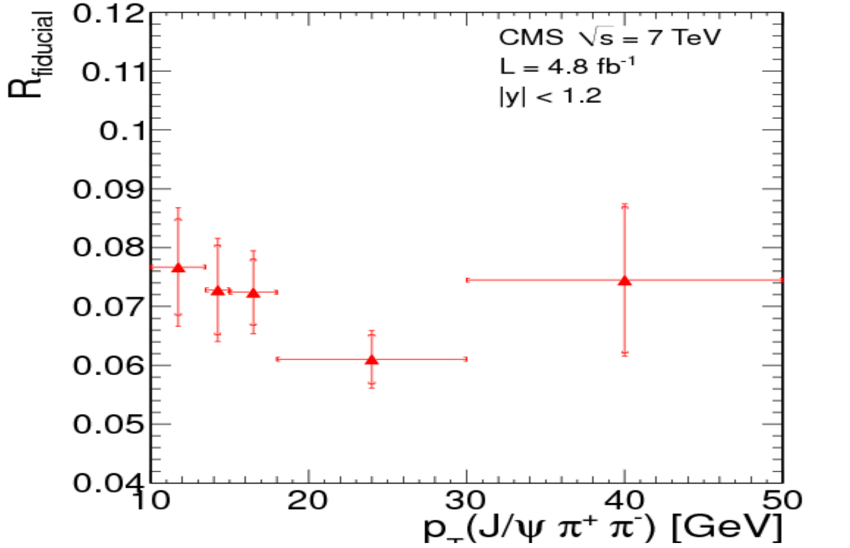
X(3872) cross section @CMS

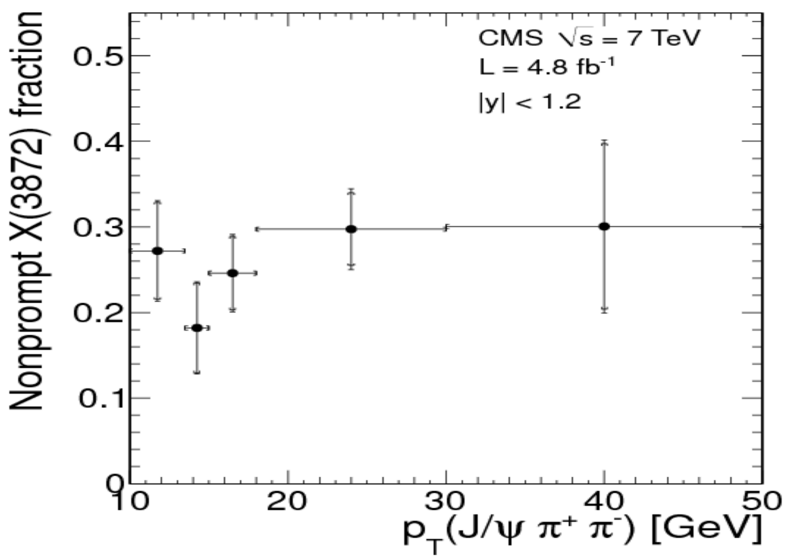
JHEP 1304 (2013) 154

- *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}*

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

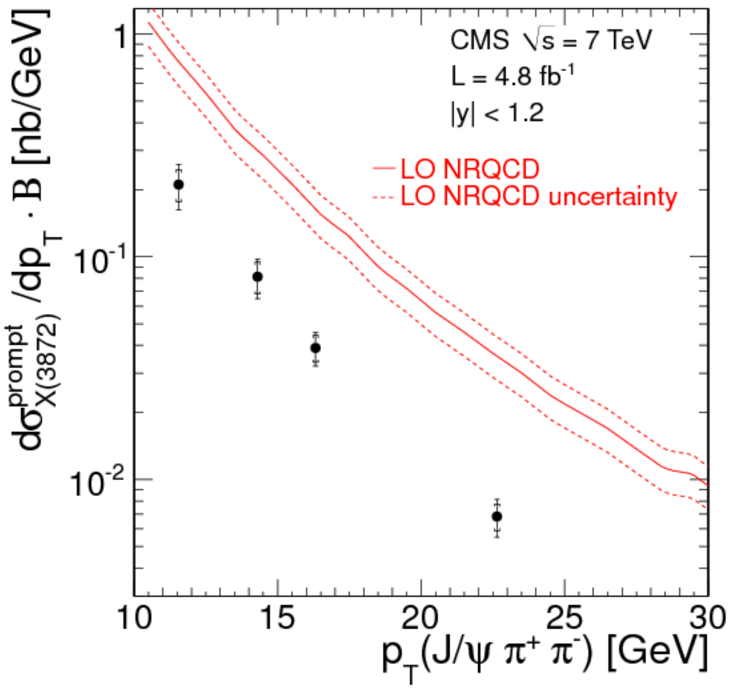
- - *Non-prompt events (lxy>100 μm)*
    - *Contribution from prompt <0.1%*
    - *Cross-checked by 2D fit to the mass and l_{xy}*





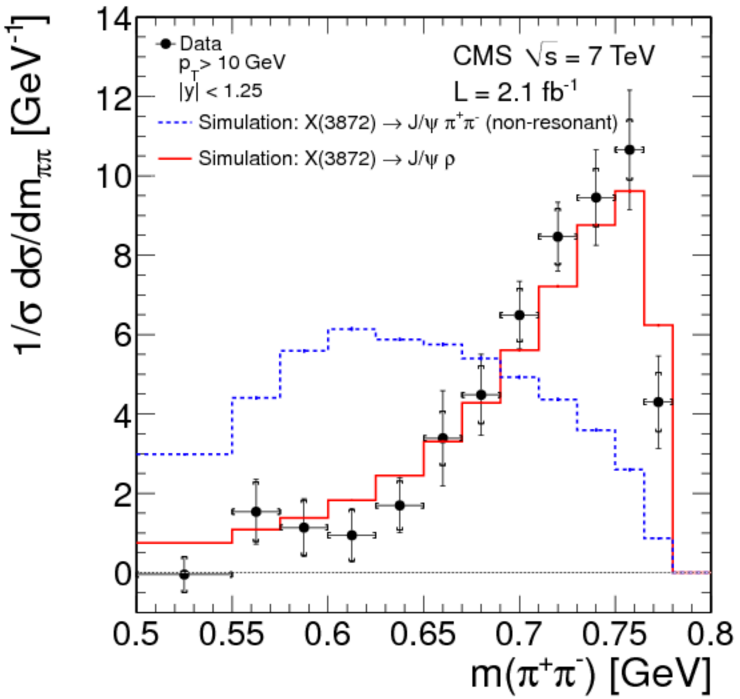
X(3872) cross section @CMS

- *Prompt cross section compared to NRQCD*
  JHEP 1304 (2013) 154



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

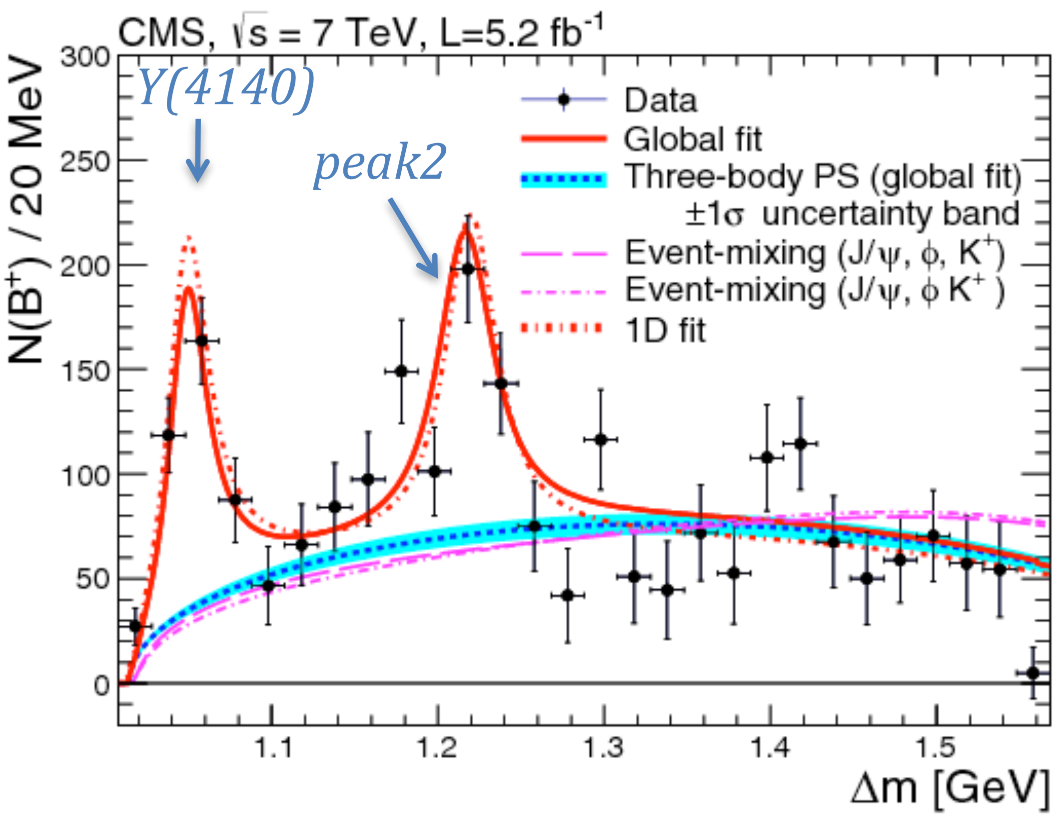
- *Compared to simulations with and w/o intermediate ρ^0 in the $J/\psi\ \pi^+\pi^-$ decay*



The intermediate ρ^0 decay gives better agreement with data

Y(4140) @ CMS (2012)

Phys.Lett. B 734 (2014) 261



M_1=4148.0±2.4(stat)±6.3(syst) MeV

M_2=4313.8±5.3(stat)±7.3(syst) MeV

$\Gamma_1=28^{+15}_{-11}$ (stat)±19(syst) MeV

$\Gamma_2=38^{+30}_{-15}$ (stat)±16(syst) MeV

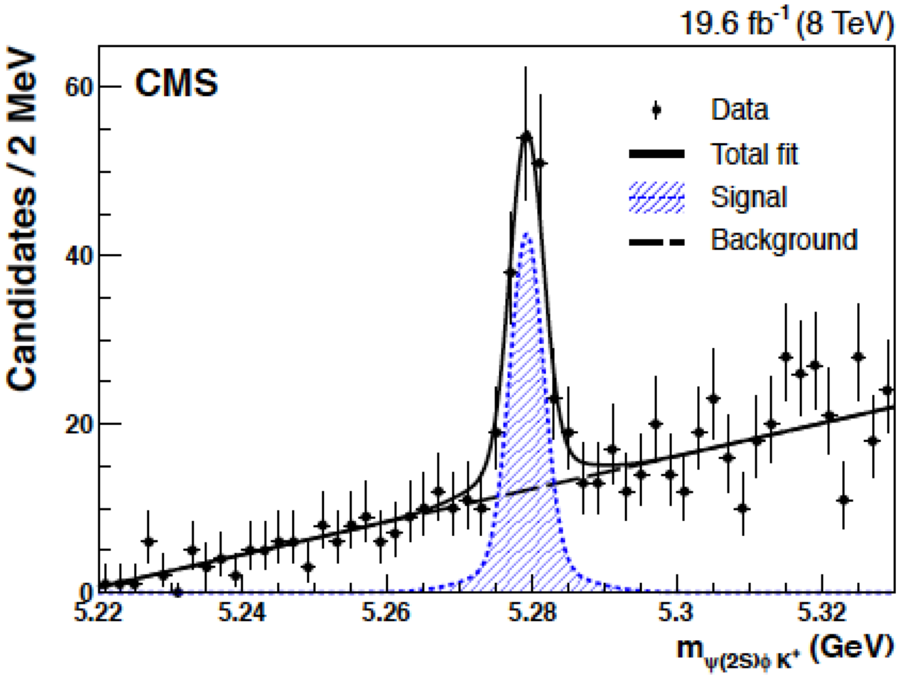
Y(4140)—Observation (>5σ), consistent with CDF Y(4140) result

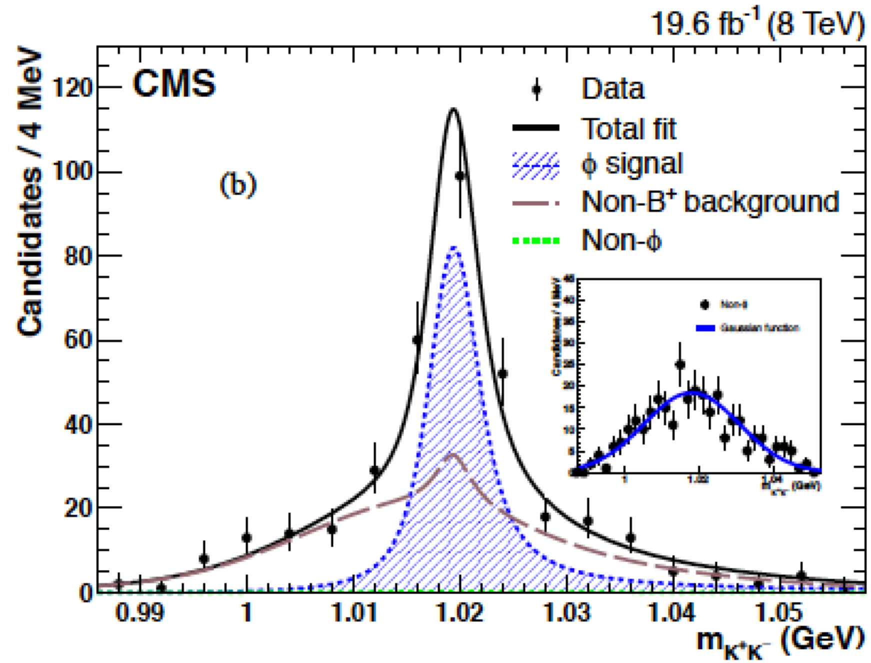
Peak2 —evidence
Width/BF (estimation) consistent with CDF result, mass is higher

CMS provides the first independent confirmation of Y(4140) with >5σ significance
The largest sample before LHCb update in 2016, X20 of CDF statistics.

Anything at ψ(2S)ϕ?—Quarkonium

Phys.Lett. B 764 (2017) 66



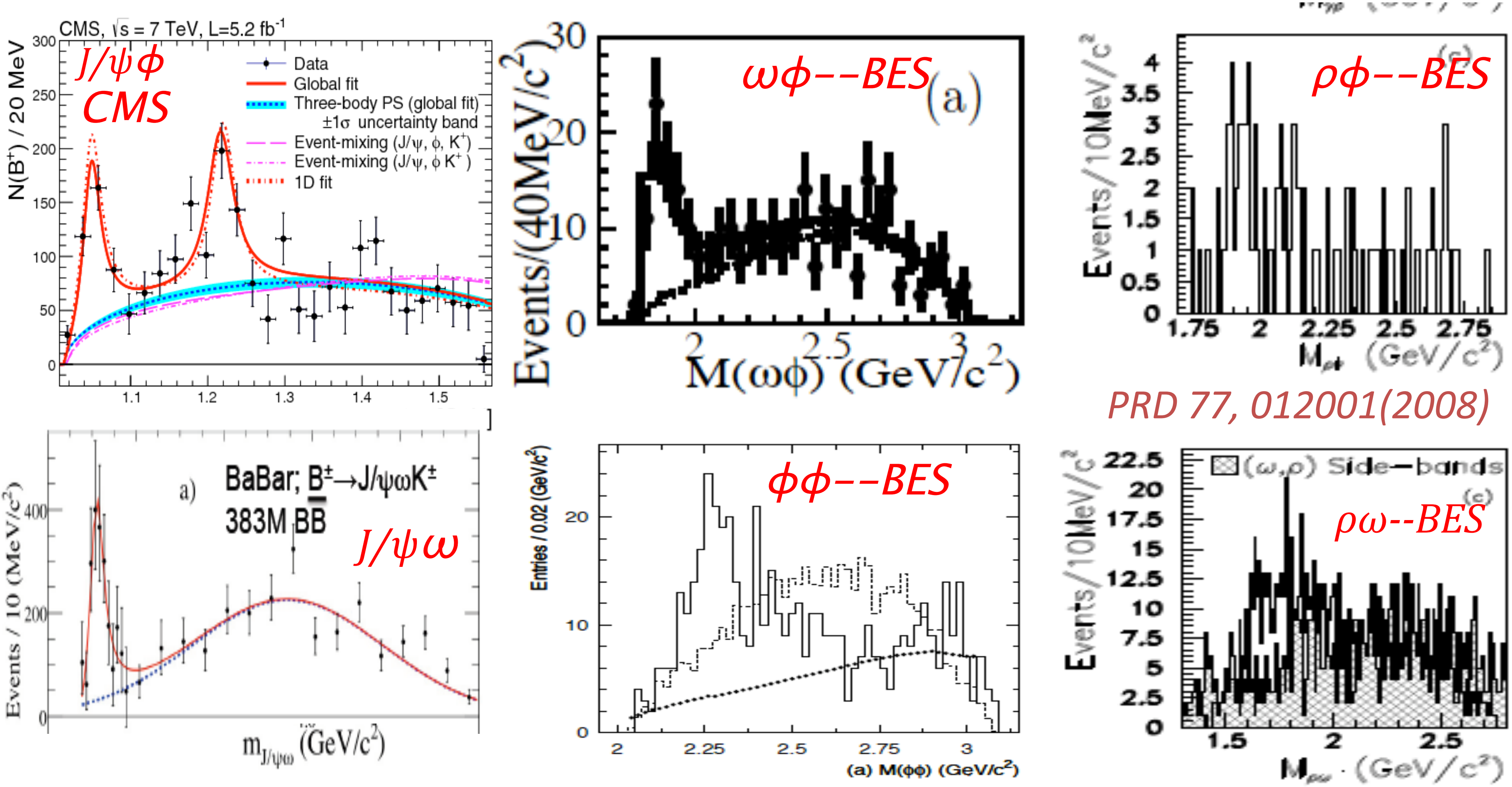


$$\mathcal{B}(B^+ \to \psi(2S)\phi K^+)$$

$$(4.0 \pm 0.4\,(\text{stat}) \pm 0.6\,(\text{syst}) \pm 0.2\,(\mathcal{B})) \times 10^{-6}$$

$B^+ \to \psi(2S)\phi K^+$ signal is clearly observed at CMS, no report on possible sub-structures—very narrow phase space.

A near VV threshold puzzle?



Near VV threshold puzzle

--Observed near threshold narrow V(I=0)V (I=0) enhancement
--No clear enhancement if one of the V (I!=0) or due to wide width of ρ

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

PLB 727 (2013) 57

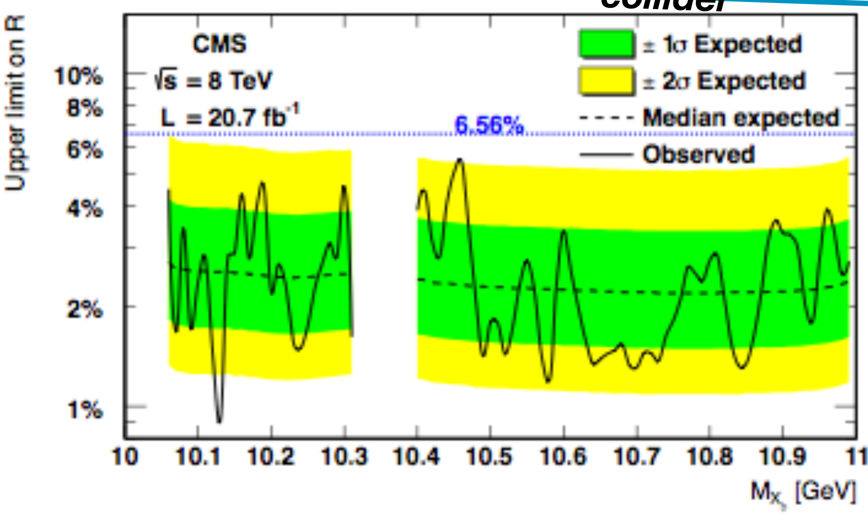
- Exotic resonance X(3872) discovered in the final state $J/\psi\pi^+\pi^-$
- A **bottomonium counterpart X_b** may exist and decays into $\Upsilon(1S)\pi^+\pi^-$
  - Mass close to the BB or BB* threshold,10.562 and 10.604 GeV
  - Similar to X(3872), narrow width and sizable branching ratio into $\Upsilon(1S)\pi^+\pi^-$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

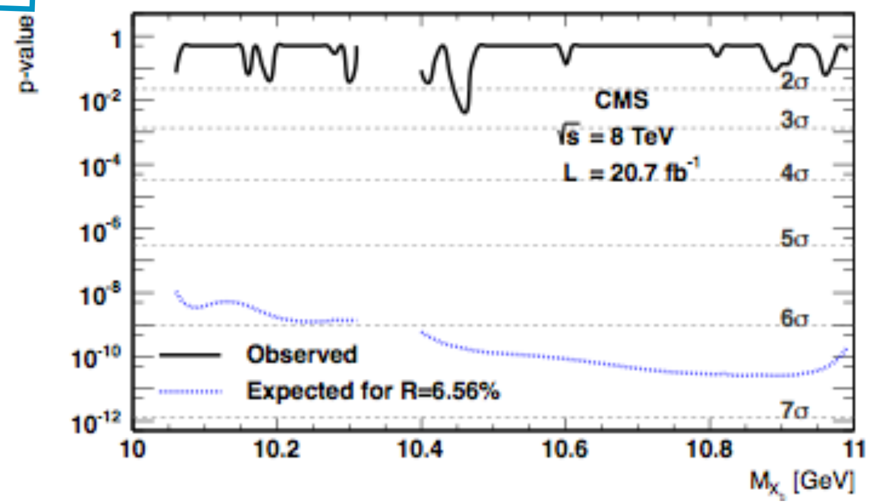
X_b Limit @CMS

- Local p-values calculated using asymptotic approach and combining results of fits to the barrel and endcap regions
- Systematic uncertainties implemented as nuisance parameters

first upper limits on X_b production at a hadron collider

PLB 727 (2013) 57



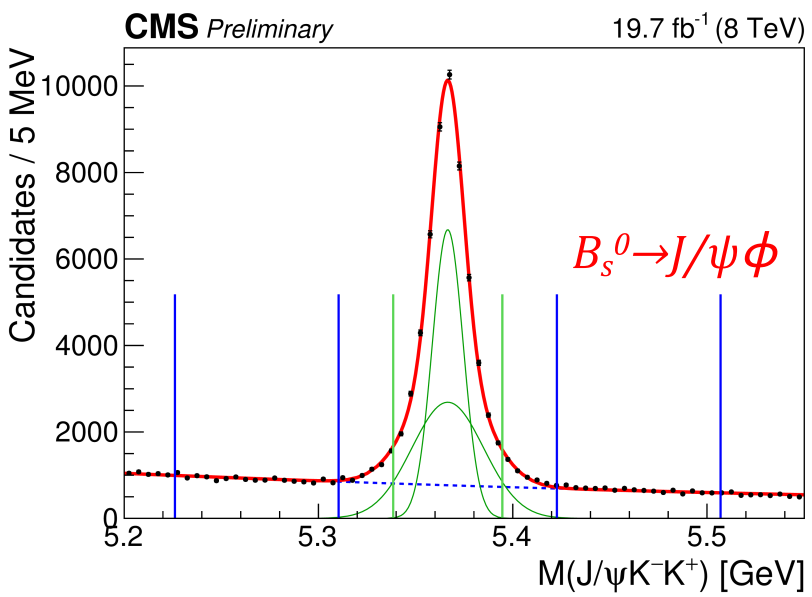


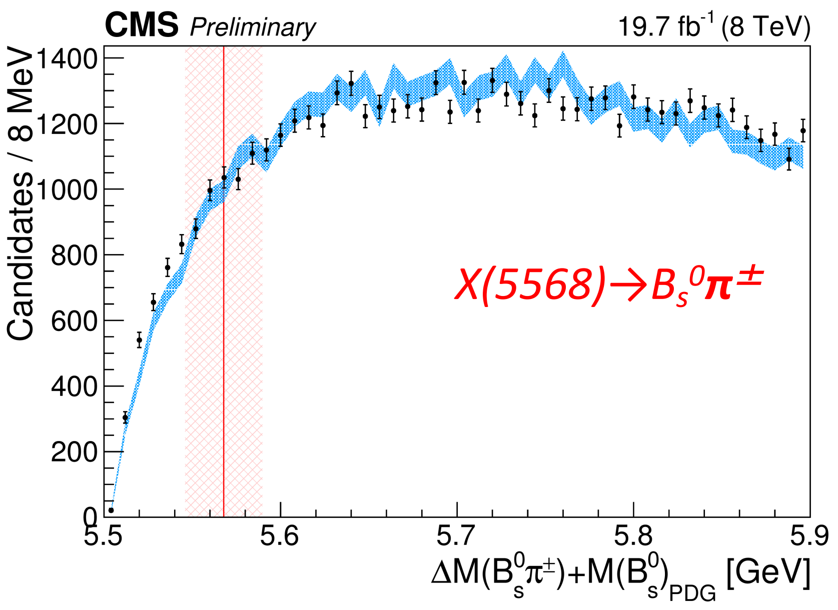
No significant excess is observed

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

Search for X(5568)

CMS-PAS-BPH-16-002





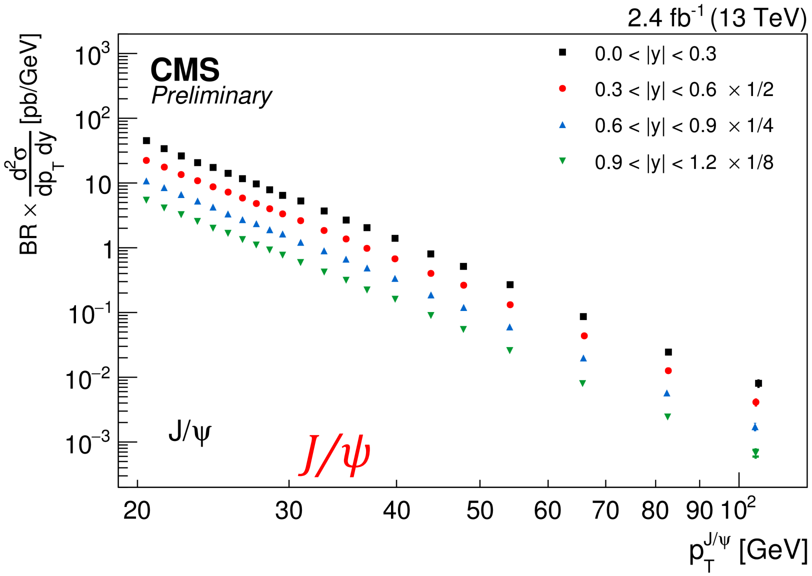
- No significant signal was found, an upper limit is set:

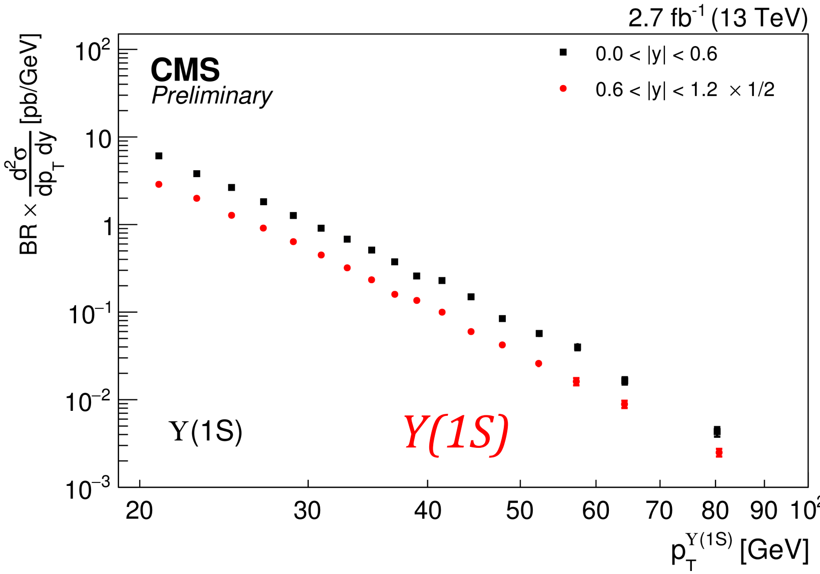
$$\rho_X \equiv \frac{\sigma(pp\to X(5568)+\text{anything}\times \mathcal{B}(X(5568)\to B_s^0\pi^\pm))}{\sigma(pp\to B_s^0+\text{anything})} = \frac{N_{X(5568)}}{N_{B_s^0}}\,\frac{\epsilon_{B_s^0}}{\epsilon_{X(5568)}} < 3.9\% \text{ at 95\% CL,}$$

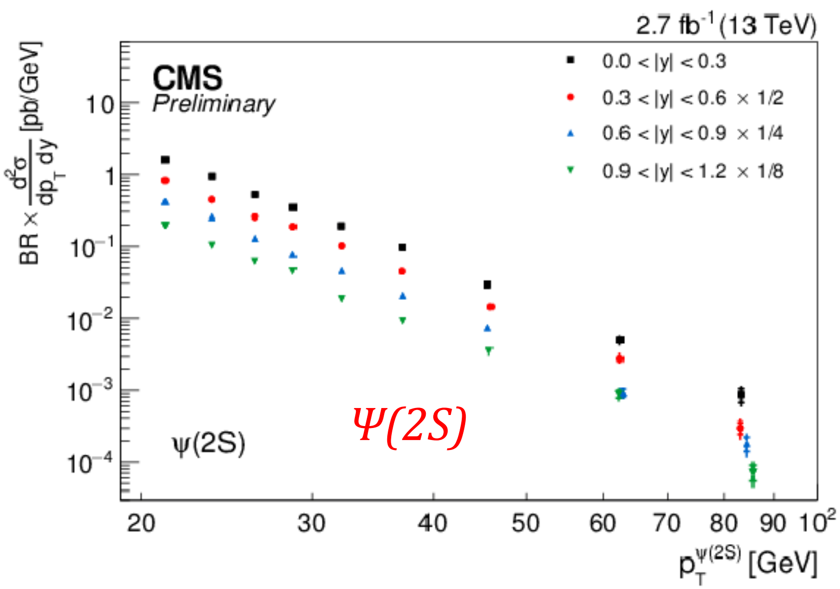
D0 measurement of (8.6 ± 1.9 ± 1.4)%

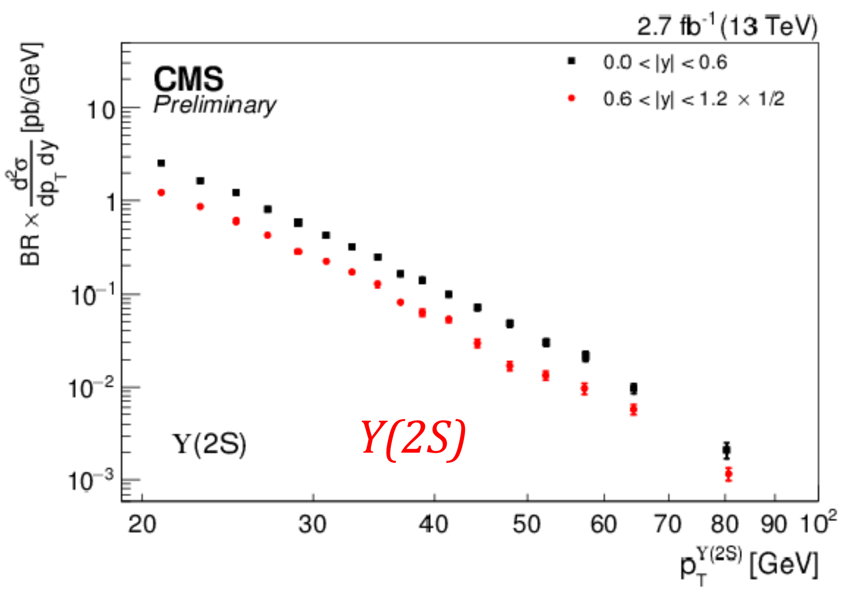
Quarkonium Cross section @ 13 TeV

CMS-PAS-BPH-15-005 *Double differential cross section times branching fraction*



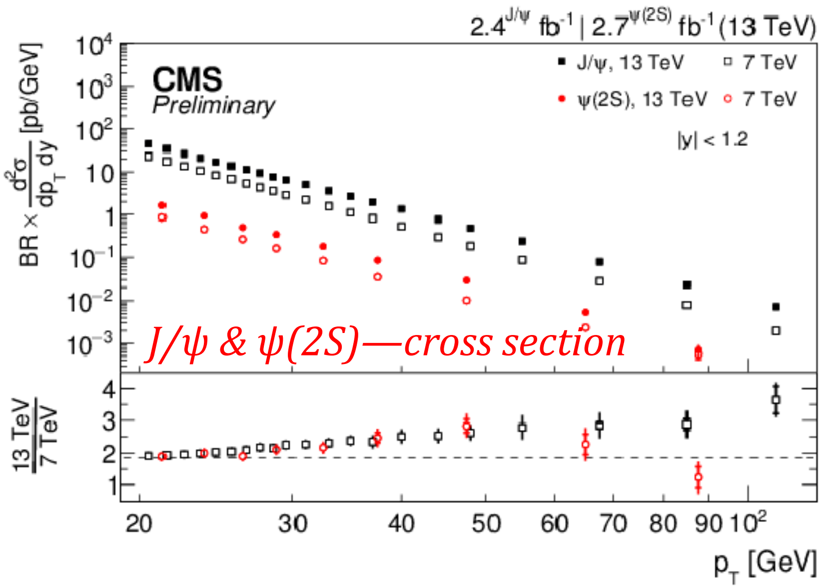


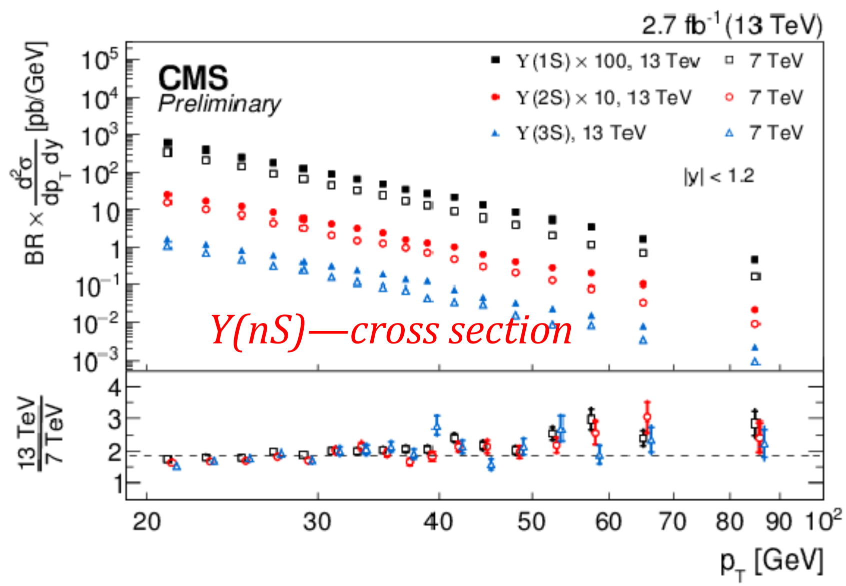


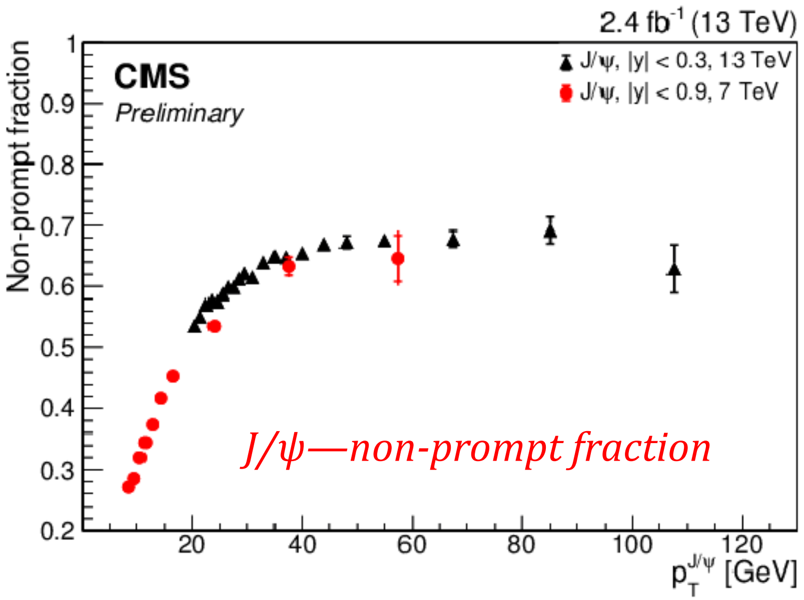


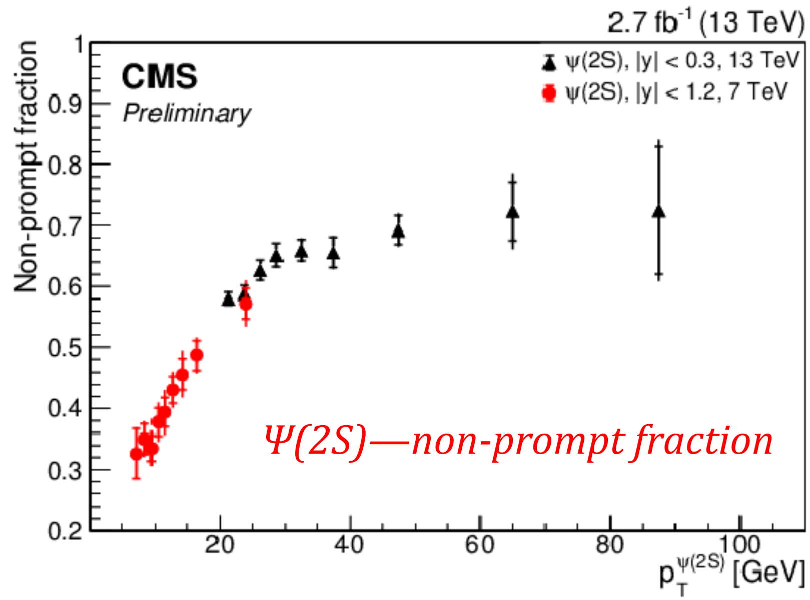
Quarkonium Cross section @ 13 TeV

CMS-PAS-BPH-15-005 *Comparison between 7 TeV and 13 TeV*



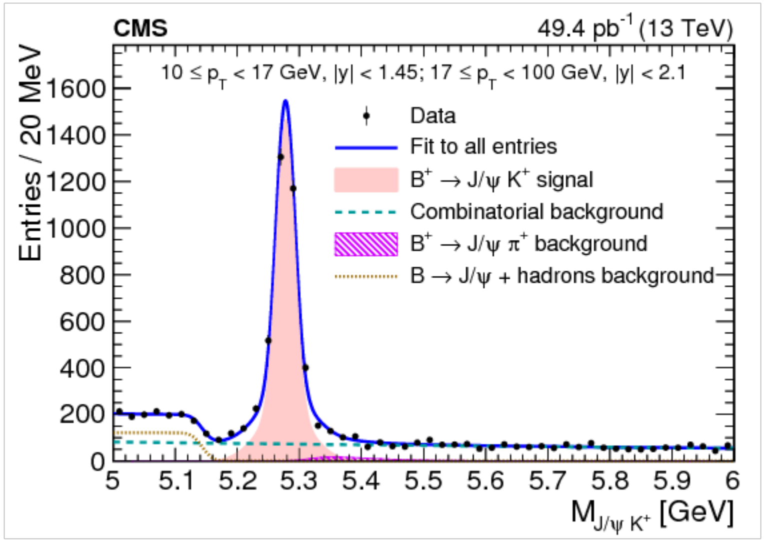


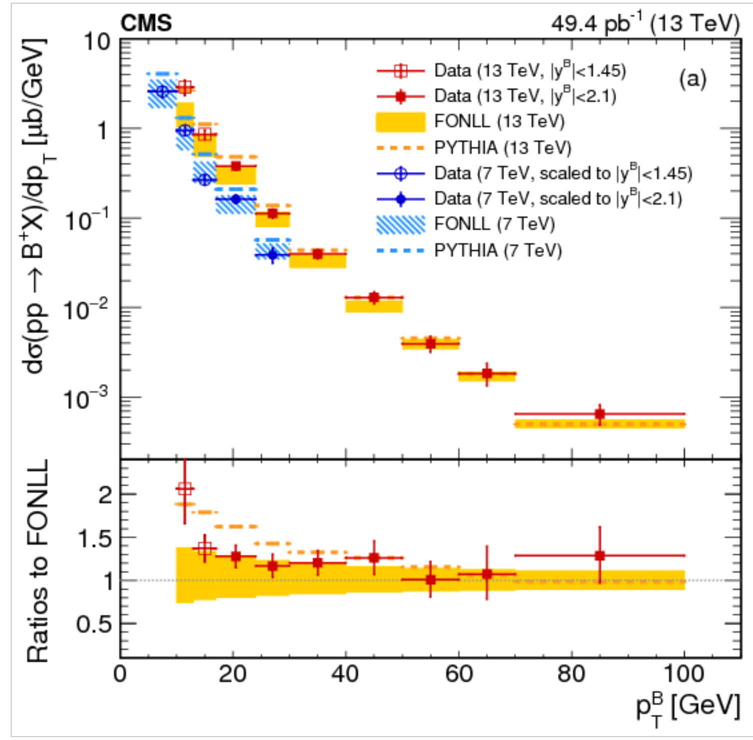


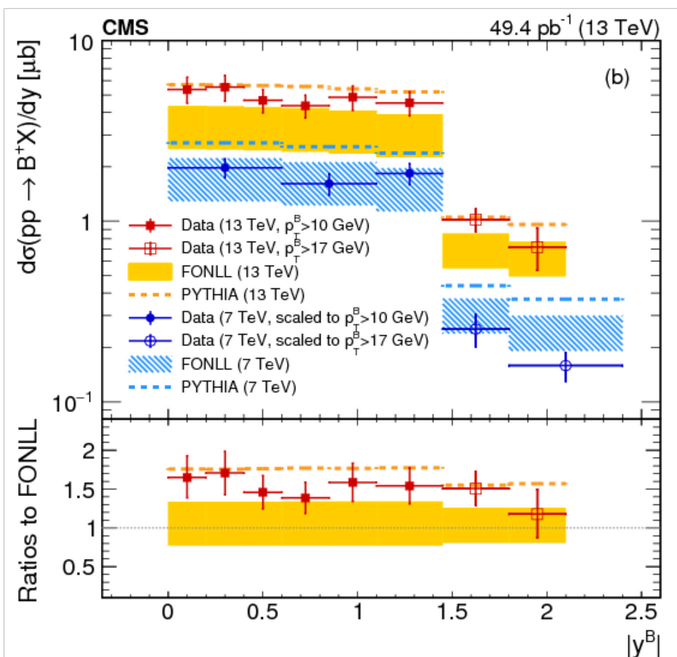


B Cross section @ 13 TeV

CMS-PAS-BPH-15-004, arXiv:1609.00873, submitted to PLB





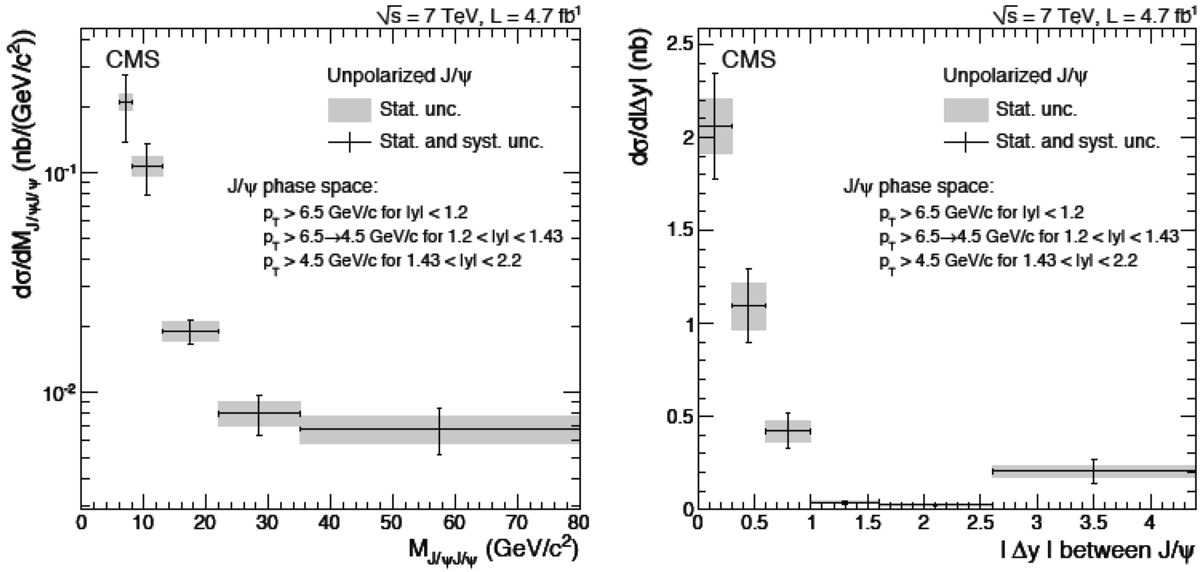


$\sigma_{tot} = 14.9 \pm 0.4(stat) \pm 2.0(syst) \pm 0.4(lumi)$ ub

Reasonably agree with FONLL in shape and normalization

Double J/ψ and Υ cross section

JHEP 1409 (2014) 094



σ_{tot} = 1.49 ± 0.07(stat) ± 0.13(syst) nb, prompt component

We have observed double J/ψ events and measured its production cross section
Dominated by SPS, hint of DPS.

We have enough statistics to investigate heavy meson pairs

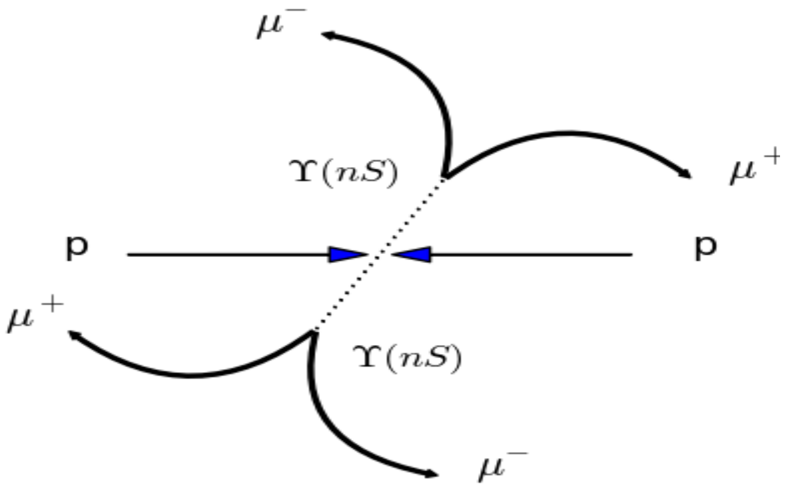
Search for exotic mesons decay into double J/ψ, J/ψμμ, Υ(nS)Υ(nS), Υμμ, Υϕ,...

Observation of Y(1S)Y(1S)

Motivation:

--Interest to investigate production mechanism: SPS vs DPS

--Benchmark measurement for 4b bound state searches



$$pp \rightarrow \Upsilon\Upsilon$$

$$\Upsilon \rightarrow \mu^+ \mu^-$$

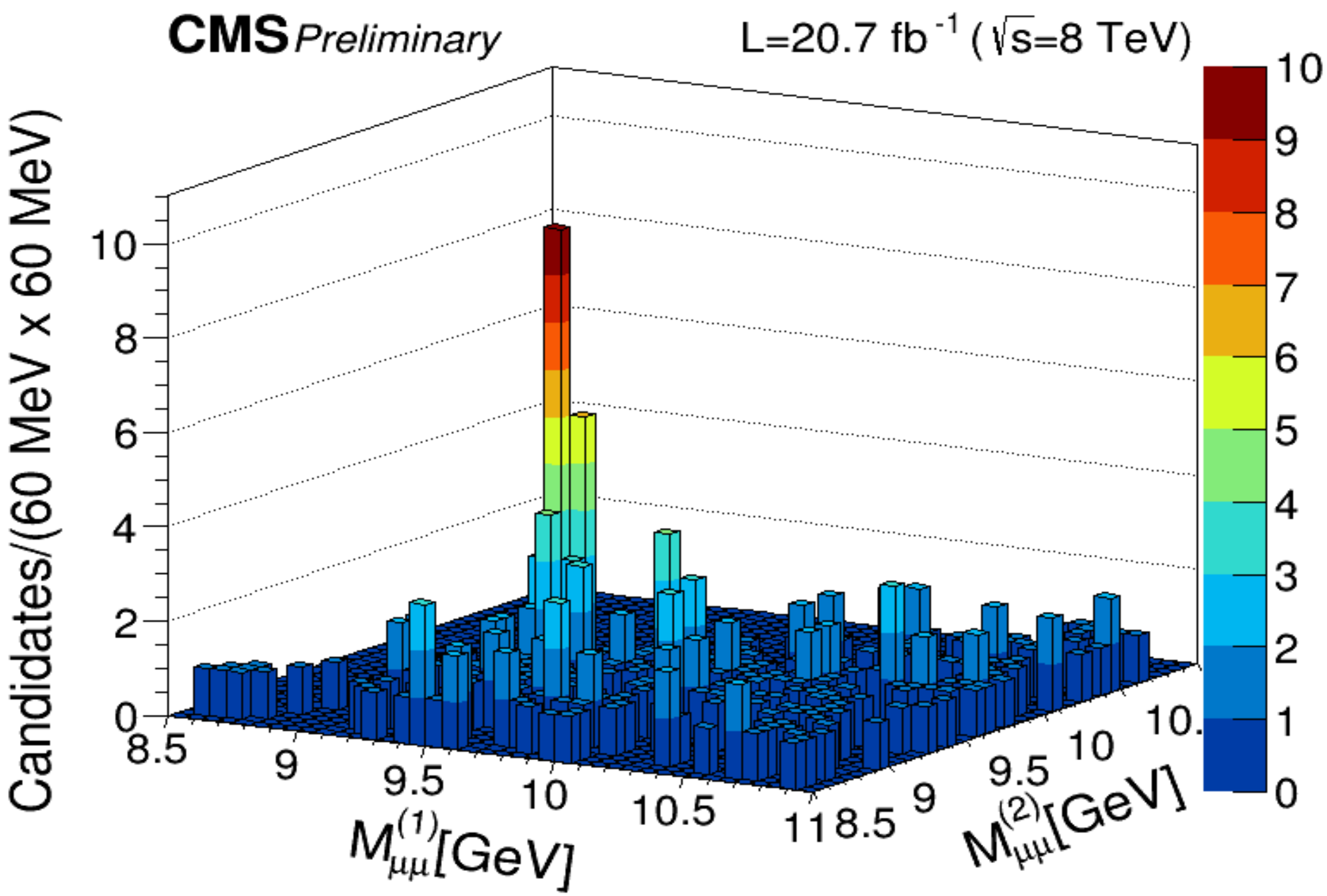
Main selections:

--muon p_T >3.5 GeV, pesuo-rapidity within 2.4

--Upsilon pesuo-rapidiy within 2.0

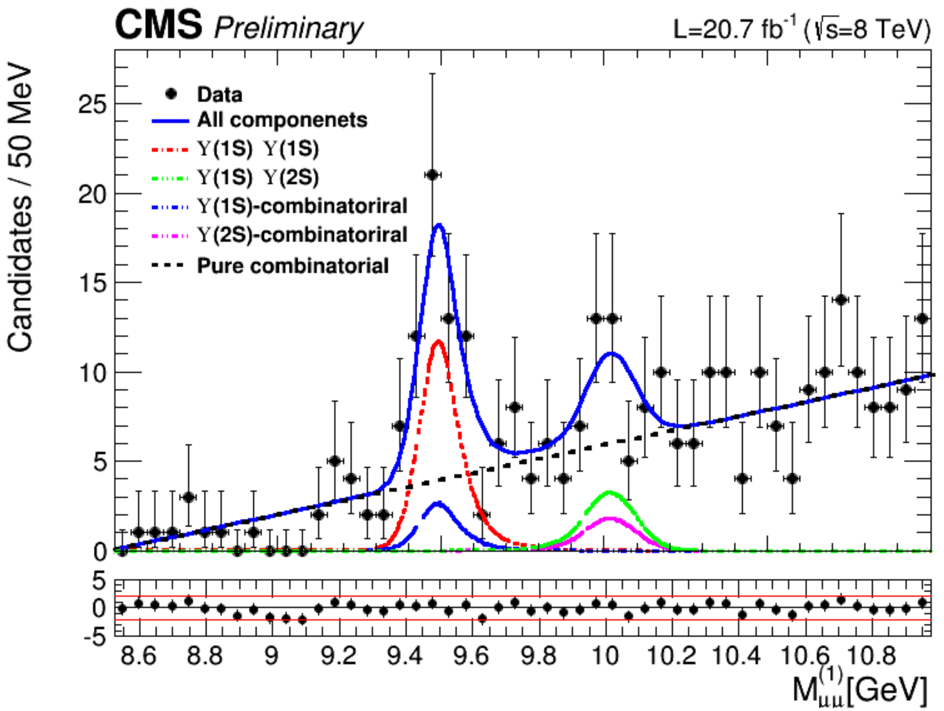
--four-muons come from the same vertex: vertex-probability>5%

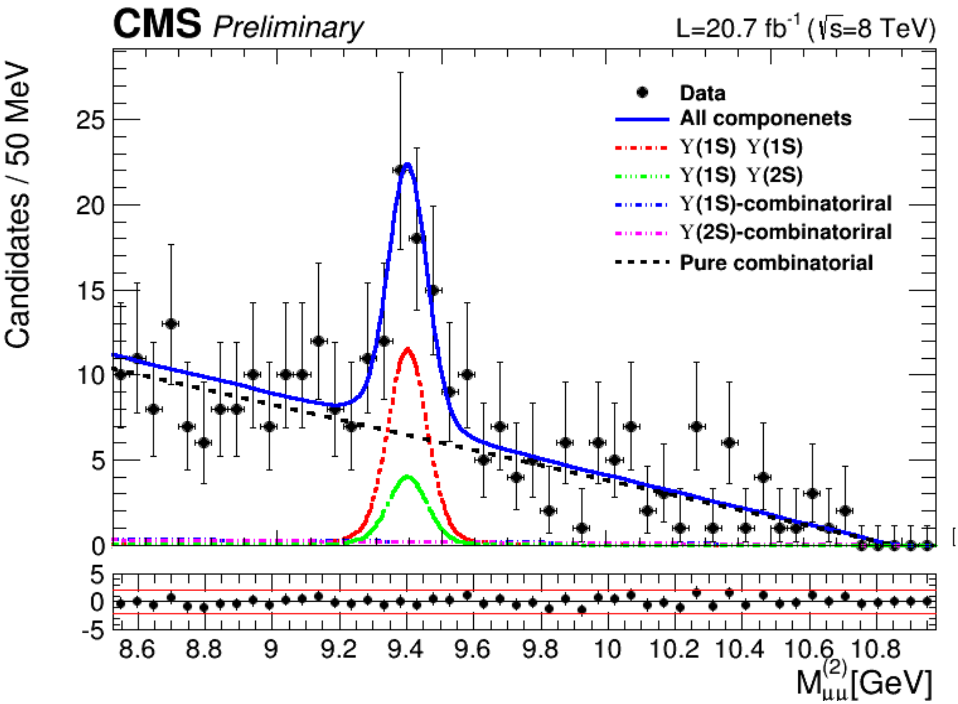
Two-dimensional scatter plot



Two dimensional scatter plot of selected events,
Striking peaks at 9.5 GeV from both dimensions.

Scatter plot projection





Main selections: Yield extraction from maximizing 2D likelihood PDF
--signal is modeled by two Crystal-ball functions
--background is modeled as 1st order polynomial

Number of Y(1S)Y(1S): 38±7
Significance: >>5sigma
Also see a hint of (Y(1S)Y(2S)

First time observation in the world

Υ(1S)Υ(1S) Cross section @ 8 TeV

Assuming un-polarized production of Υ(1S) meson, the cross section of Υ(1S)Υ(1S) with pseudo -rapidity within 2.0 for each Υ(1S), and pT less than 50 GeV at 8 TeV is measured as:

$$\sigma(pp \rightarrow YY) = 68.8 \pm 12.7(stat) \pm 7.4(syst) \pm 2.8(BR)pb$$

Different assumption of Υ(1S) polarization gives the total cross section uncertainty between -38% and 36%

No enough statistics to separate SPS and DPS fractions.

Provide a benchmark for terra-b quark state at LHC

Summary

- *CMS contribute to bottom and charm studies significantly*
- *Bright prospects for further develop*

Stay tuned!

Heavy tetra-quark bound states

- **Heavy-quark tetra-quark states** Phys. Rev. D 86, 034004 (2012)

---No solid prediction for heavy quarks, but a few simple models, i.e.

$c\bar{c}c\bar{c}$

$0^{++'}$: $M = 5.966$ GeV, $M - M_{\rm th} = -228.$ MeV,
$1^{+-'}$: $M = 6.051$ GeV, $M - M_{\rm th} = -142.$ MeV,

Above double η_c threshold
Below double J/ψ threshold
Search via ($\eta_c\eta_c$?), $J/\psi\mu^+\mu^-$, J/ψ^*

2^{++} : $M = 6.223$ GeV, $M - M_{\rm th} = 29.5$ MeV.

Above double J/ψ threshold
Search via $J/\psi J/\psi$

$bc\bar{b}\bar{c}$

$0^{++}a$: $M = 12.359$ GeV, $M - M_{\rm th} = -191.$ MeV
$0^{++}b$: $M = 12.471$ GeV, $M - M_{\rm th} = -78.7$ MeV,
$1^{+-}a$: $M = 12.424$ GeV, $M - M_{\rm th} = -126.$ MeV
$1^{+-}b$: $M = 12.488$ GeV, $M - M_{\rm th} = -62.5$ MeV,
1^{++} : $M = 12.485$ GeV, $M - M_{\rm th} = -64.9$ MeV,

Below double B_c threshold
$J/\psi\Upsilon(1S)$ threshold
? ...

2^{++} : $M = 12.566$ GeV, $M - M_{\rm th} = 16.1$ MeV.

Above double B_c threshold
$J/\psi\Upsilon(1S)$ threshold
Search via the above two channels

$b\bar{b}b\bar{b}$

$0^{++'}$: $M = 18.754$ GeV, $M - M_{\rm th} = -544.$ MeV,
$1^{+-'}$: $M = 18.808$ GeV, $M - M_{\rm th} = -490.$ MeV,
2^{++} : $M = 18.916$ GeV, $M - M_{\rm th} = -382.$ MeV.

Below double $\Upsilon(1S)$ threshold
Search via $\Upsilon(1S)\mu^+\mu^-$

Will be a breakthrough for exotic meson if established

Arguable to call below J/ψ mass events as J/ψ^* since J/ψ is very narrow, same for Υ^*