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Heavy Flavor Physics at ATLAS and CMS

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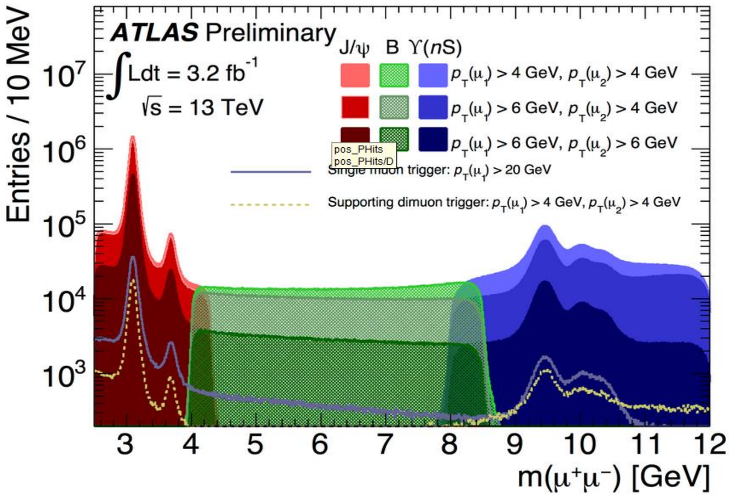
Outline:

1. Introduction
2. Search for X(5568)+ $\rightarrow$ Bs π+
3. Study of $B_{s2}^*(5840)^0 \rightarrow B^+K^-$ and observation of $B_{s2}^*(5840)^0 \rightarrow B^0 K^0_s$
4. Study of X(3872) production properties
5. Observation of two resolved states $\chi_{b1,2}(3P)$
6. Search for New Physics in $B \rightarrow K^{(*)} \mu^+\mu^-$ decays
7. Summary

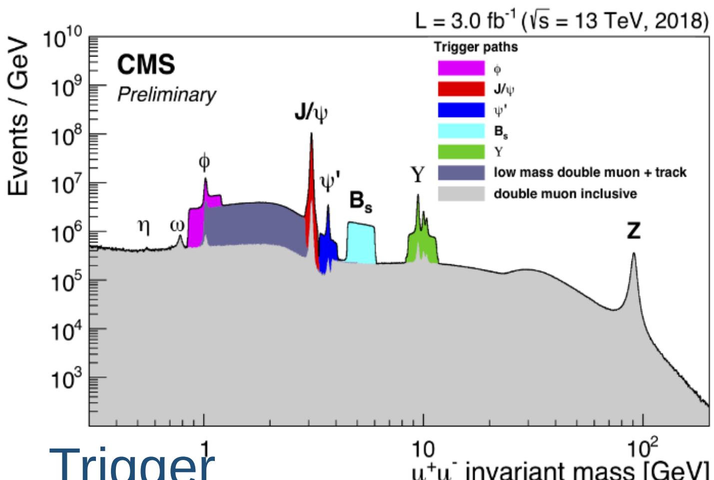
Introduction

Heavy flavor spectroscopy is important in further understanding of QCD.

Rare decays of B-mesons like B→ K ll are very promising places in searching for new physics



ATLAS and CMS are contributing intensively into these topics



Trigger

Very efficient hardware trigger

Highly flexible HLT: paths dedicated to specific analyses

Tracker

Good pt resolution (down to Δpt/pt ≅ 1% in the central region)

Tracking efficiency >99% for muons

Good vertex reconstruction and impact parameter resolution down to ≈15μm

Muon System

Redundant system with large rapidity coverage (|η|<2.4)

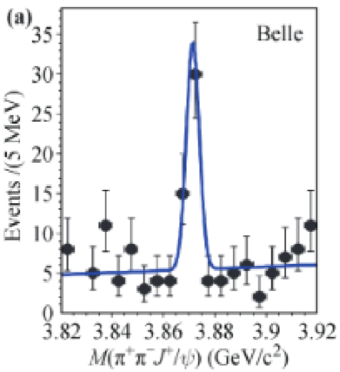
Standalone Δpt/pt ≅ 10%

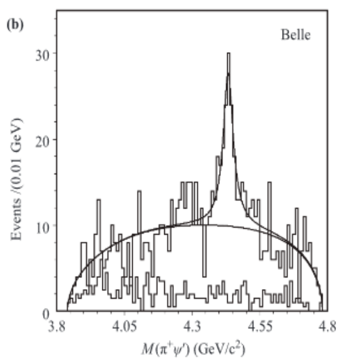
High-purity muon-ID ε(μ|π,K,p)≤(0.1-0.2)%

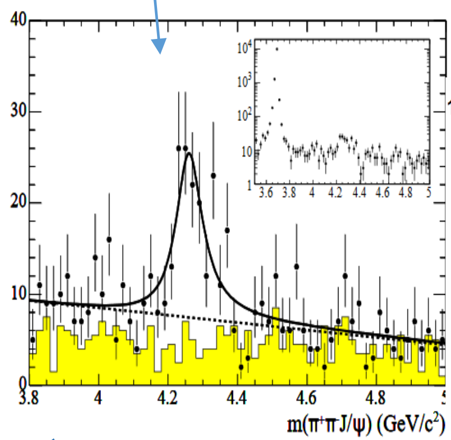
In this talk selected recent highlights from 13 and 8 TeV data samples will be discussed

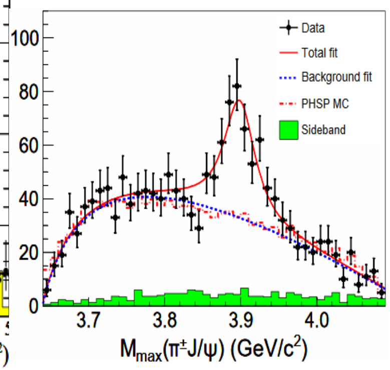
Exotic Hadrons: experimental results and theoretical interpretation

From 2003, thanks to B-factories Belle and BaBar (and then BES III and LHCb), the number of the candidates to exotic hadrons is growing continuously.
These are multiquark states. Some bright examples are
X(3872), Z(4430)+, from Belle, X(4260) from BaBar, Z(3900)+ from BESIII /Belle

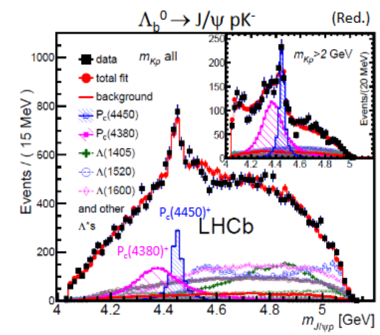








and P_c from LHCb.



This is a New Hadron Spectroscopy Era

Theoretical interpretation of all these exotic states still not clear.

Hadrocharmonium ?
Molecule ?
Rescattering
(threshold effect, cusp) ?
Tetraquark ?

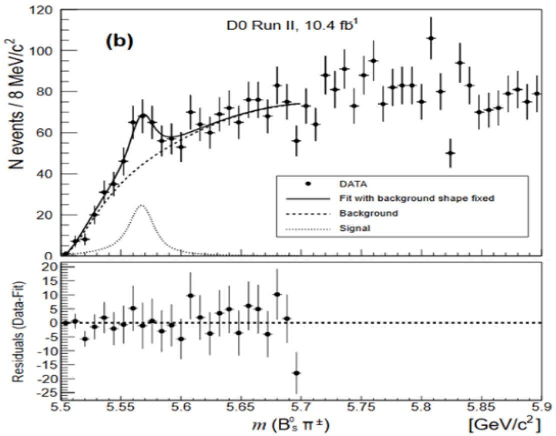
→ **WE NEED MORE INFORMATION !**

New results are coming. One of them is the evidence for X(5568) → Bs π^+ by D0 Collaboration.

Search for $X(5568)^+ \rightarrow B_s \pi^+$

D0 Collaboration: Evidence for X(5568), new state decaying into Bs π+

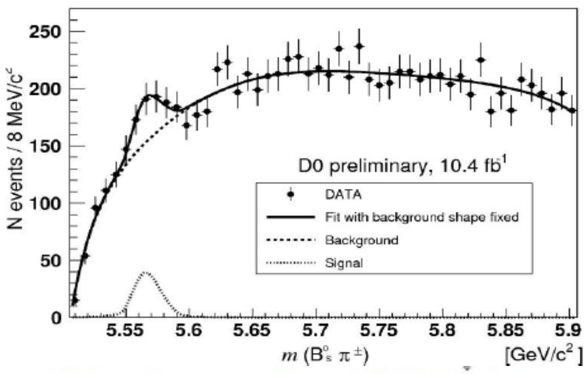
PRL117. 022003(2016)



$$M = 5567.8 \pm 2.9^{+0.9}_{-1.9}\ \text{MeV},$$
$$\Gamma = 21.9 \pm 6.4^{+5.0}_{-2.5}\ \text{MeV},$$

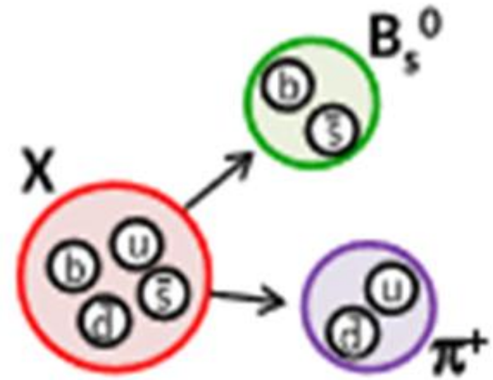
$$\rho_X^{D0} \equiv \frac{\sigma(p\bar{p} \to X + \text{anything}) \times \mathcal{B}(X \to B_s^0\pi)}{\sigma(p\bar{p} \to B_s^0 + \text{anything})} = (8.6 \pm 1.9 \pm 1.4)\%$$

D0 Conf. Note 6896

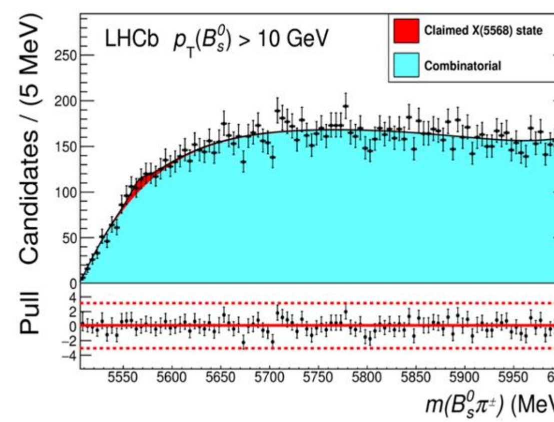


Similar results with $B_s^0 \to D_s \mu \nu$

If confirmed, would be unique with 4 different flavors



Rather big number for the prompt production of 4-quark exotic state



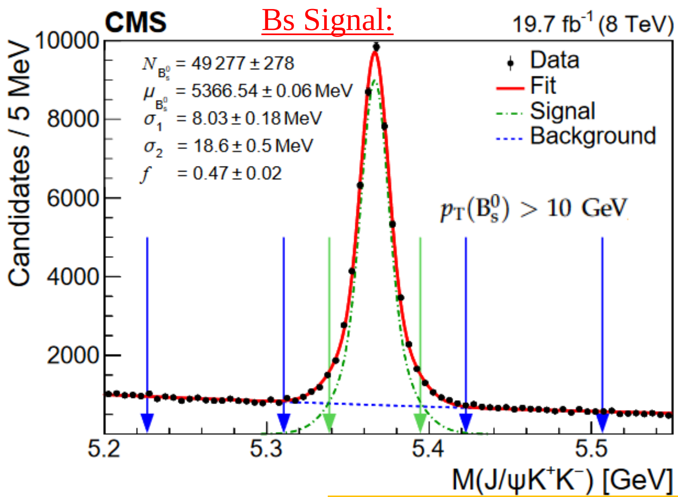
PRL117. 152003(2016)

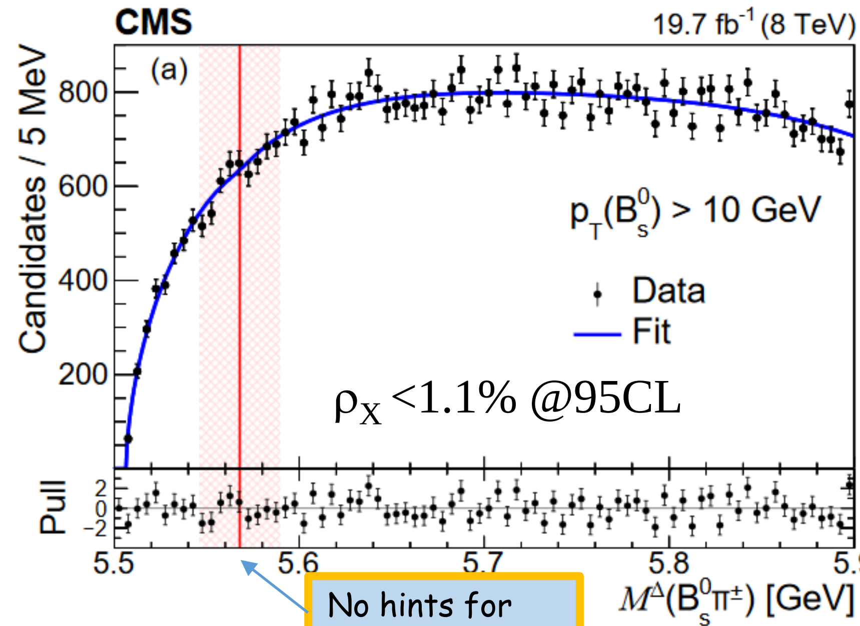
$$\rho_X^{\text{LHCb}}(p_T(B_s^0) > 5\,\text{GeV}) < 0.011\ (0.012)$$
$$\rho_X^{\text{LHCb}}(p_T(B_s^0) > 10\,\text{GeV}) < 0.021\ (0.024)$$
$$\rho_X^{\text{LHCb}}(p_T(B_s^0) > 15\,\text{GeV}) < 0.018\ (0.020)$$

Search for X(5568)+ in ATLAS and CMS was very actual:

- Different η interval with LHCb,
- B-hadron production conditions are similar in D0 and ATLAS and CMS.

Search for X(5568) in ATLAS and CMS



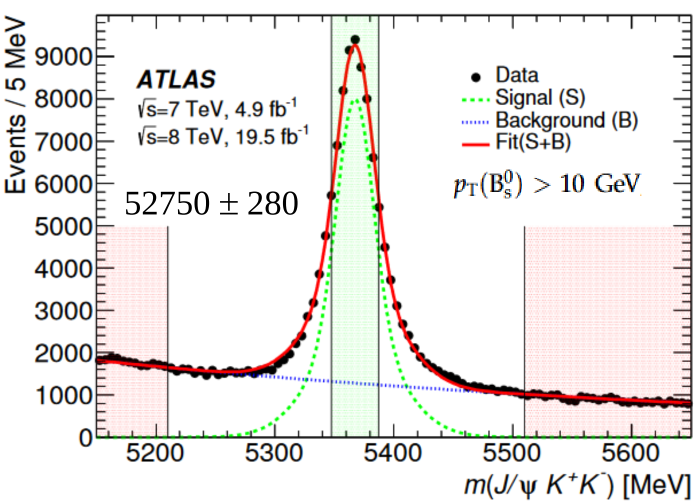


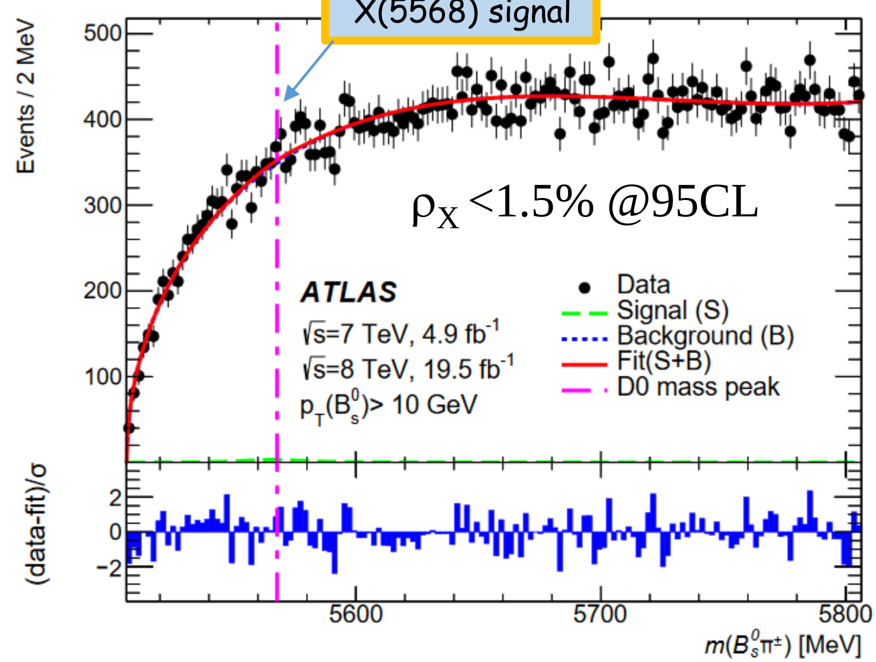
PRL 120 (2018) 202005

Comparison of Bs statistics

Factor **1.16** larger in CMS and **1.24** in ATLAS than LHCb reconstructed in the same momentum interval and for both ATLAS and CMS more than **9** larger than D0 sample.

No hints for X(5568) signal



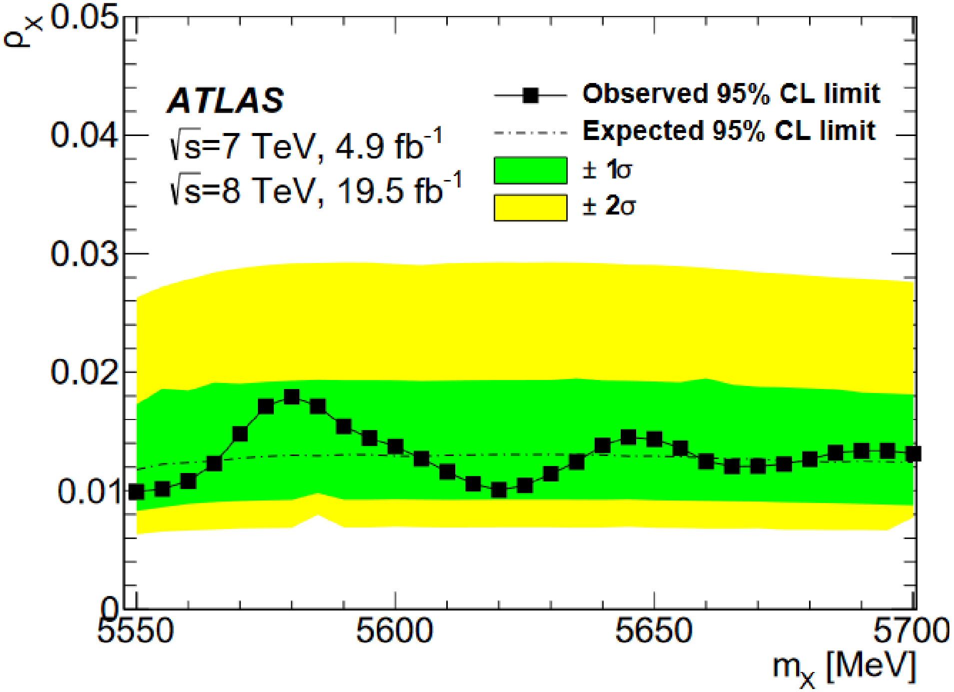


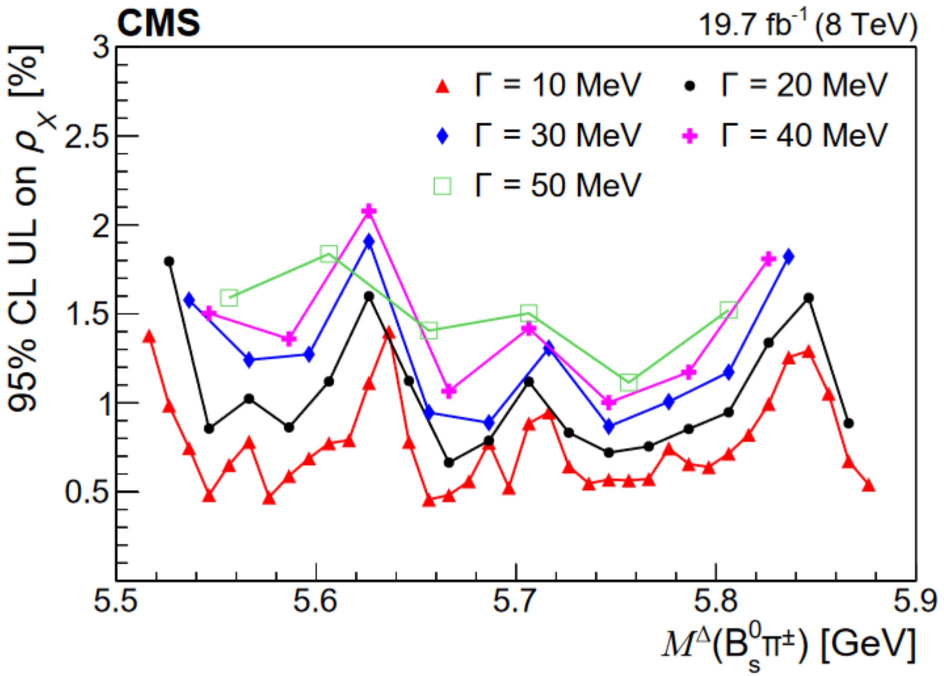
PRL 120 (2018) 202007

Search for X(5568) in ATLAS and CMS: **results**

By varying selection criteria, background parameterization, fit range and method of data description, the yield for X(5568) remains consistent with 0 ➞

No evidence of X(5568) at the LHC





$\rho_X^{\rm ATLAS} < 0.015$ at 95% CL for $p_T(B_s^0) > 10$ GeV

$\rho_X^{\rm ATLAS} < 0.016$ at 95% CL for $p_T(B_s^0) > 15$ GeV

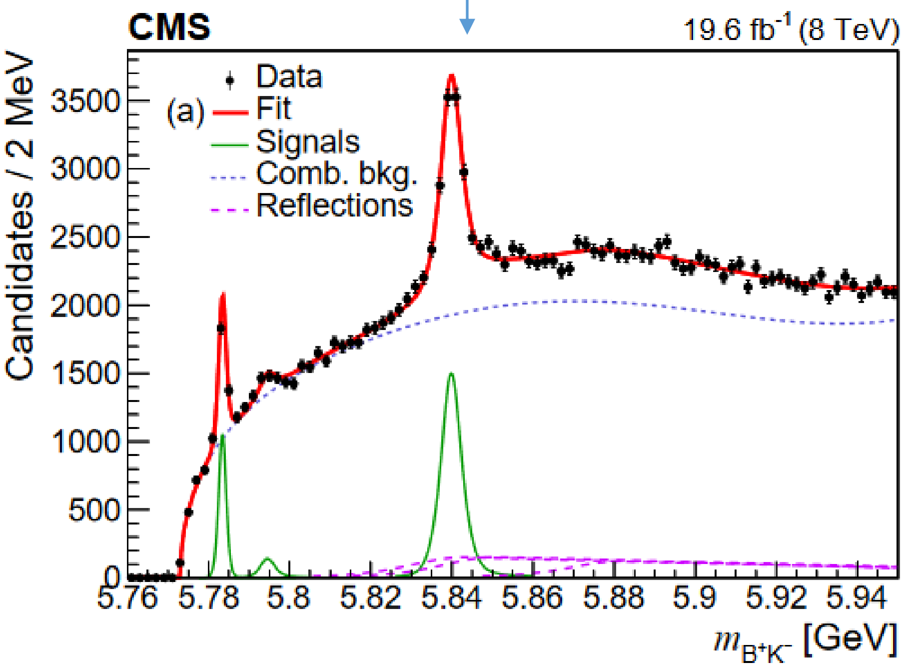
$\rho_X^{\rm CMS} < 1.1\%$ at 95% CL for $p_T(B_s^0) > 10$ GeV

$\rho_X^{\rm CMS} < 1.0\%$ at 95% CL for $p_T(B_s^0) > 15$ GeV

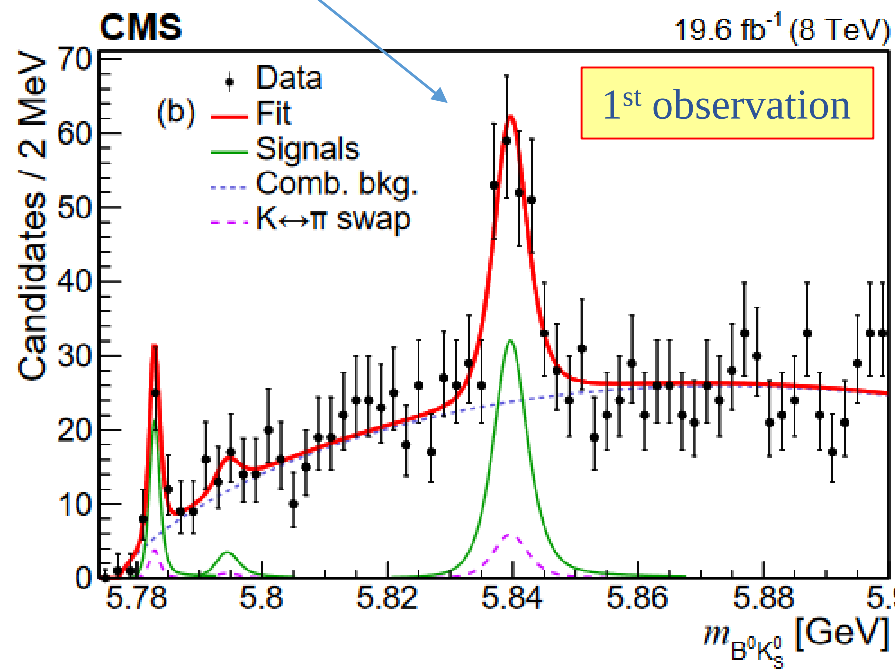
CMS: Studies of $B_{s2}^*(5840)^0$ and $B_{s1}(5830)^0$ decaying into B^+K^- and observation of $B_{s2}^*(5840)^0 \rightarrow B^0 K_s^0$

arXiv:1809.03578v1, submitted to EPJC

$B_{s2}^*(5840)^0 \rightarrow B^+ K^-$



$B_{s2}^*(5840)^0 \rightarrow B^0 K_s^0$



Masses, ΔM and ratios of σ∗Br measured.
Results are in agreement with existing measurements by CDF and LHCb

LHCb 2013: doi:10.1103/PhysRevLett.110.151803
CDF 2014: doi:10.1103/PhysRevD.90.012013

First observation of the decay $B_{s2}^* \rightarrow B^0 K_S^0$

First evidence of the decay $B_{s1} \rightarrow B^{*0} K_S^0$

See special presentation by Sergey Polikarpov in this session.

Study of ψ(2S) and X(3872) production at ATLAS

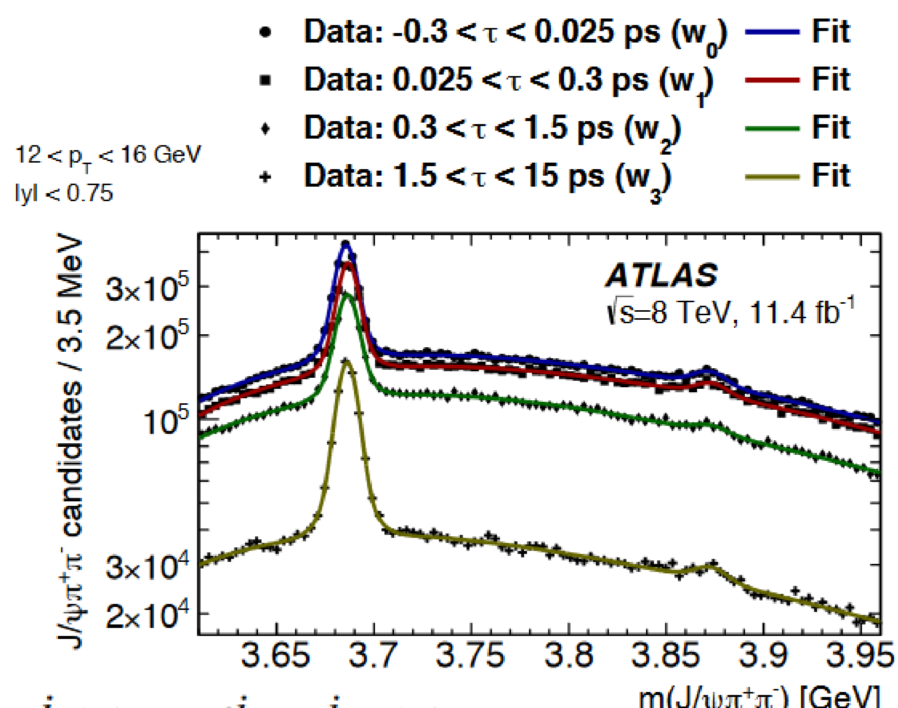
JHEP 01 (2017) 117

→ Test theoretical models which predict the pt dependence of ψ(2S) and X(3872) production in pp collisions → shed light on the nature of X(3872).

Differential cross-section for ψ(2S) and X(3872) in $J/\psi(\mu\mu)\pi^+\pi^-$ decay mode at 8 TeV, L ~ 11.4fb^{-1}

- |y| < 0.75, 10 < pT < 70 GeV.
- Each pT bin subdivided by 4 bins of $\tau = \frac{L_{xy} m}{p_T}$ pseudo-proper decay time.

  Separate prompt-, short- and long-lived contributions.
- Isotropic unpolarised decays taken as nominal; extrema considered.



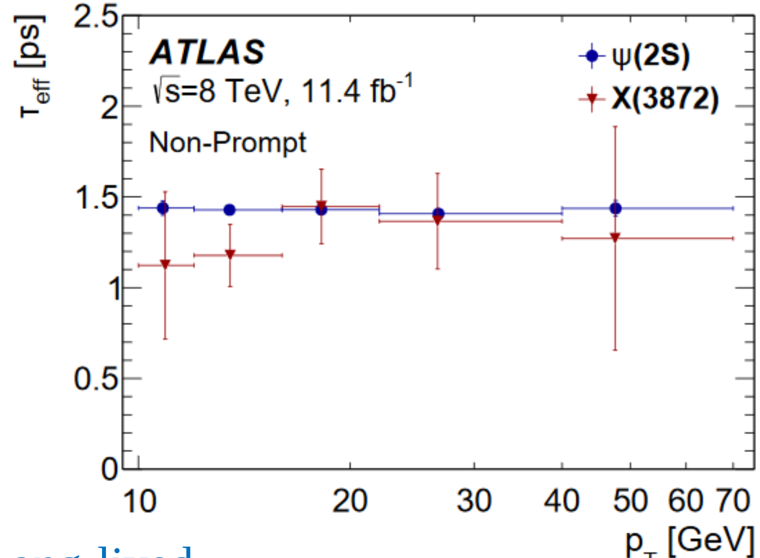
$$F^i(\tau) = (1 - f^i_{NP}) F^i_P(\tau) + f^i_{NP} F^i_{NP}(\tau)$$

Study of ψ(2S) and X(3872) production at ATLAS

JHEP 01 (2017) 117

- Ratio of average Branching Fractions

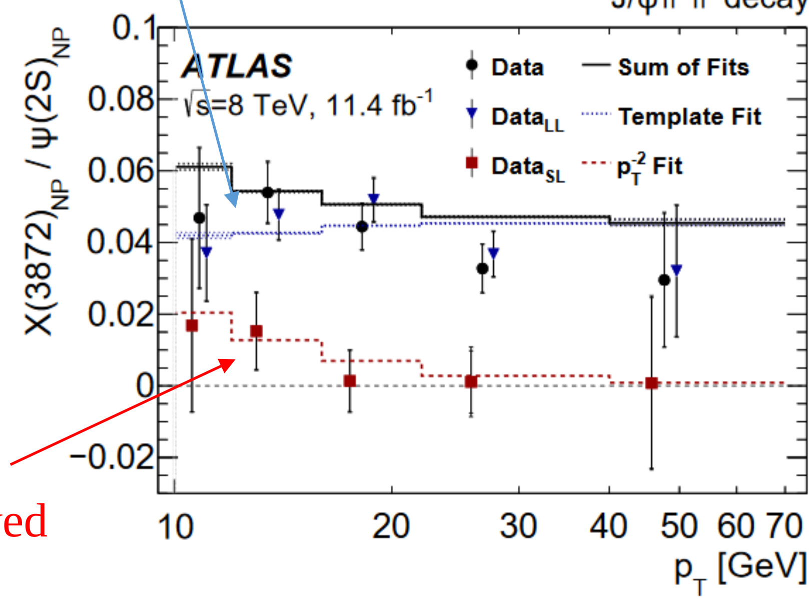
$$\frac{\mathcal{B}(B \to X(3872) + \text{any})\mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-)}{\mathcal{B}(B \to \psi(2S) + \text{any})\mathcal{B}(\psi(2S) \to J/\psi\pi^+\pi^-)} = \begin{cases} (3.95 \pm 0.32(\text{stat}) \pm 0.08(\text{sys})) \times 10^{-2} & 1\tau \\ (3.57 \pm 0.33(\text{stat}) \pm 0.11(\text{sys})) \times 10^{-2} & 2\tau \end{cases}$$



$$F^i_{NP}(\tau) = (1 - f^i_{SL})F_{LL}(\tau) + f^i_{SL}F_{SL}(\tau)$$

Long-lived

J/ψπ+π- decay



Short-lived

- Non-prompt production of X(3872) suggests enhancement of production shorter-lived contributions at low pT from B_c:

$$\frac{\sigma(pp \to B_c + \text{any})\mathcal{B}(B_c \to X(3872) + \text{any})}{\sigma(pp \to \text{non-prompt } X(3872) + \text{any})} = (25 \pm 13(\text{stat}) \pm 2(\text{sys}) \pm 5(\text{spin}))\%$$

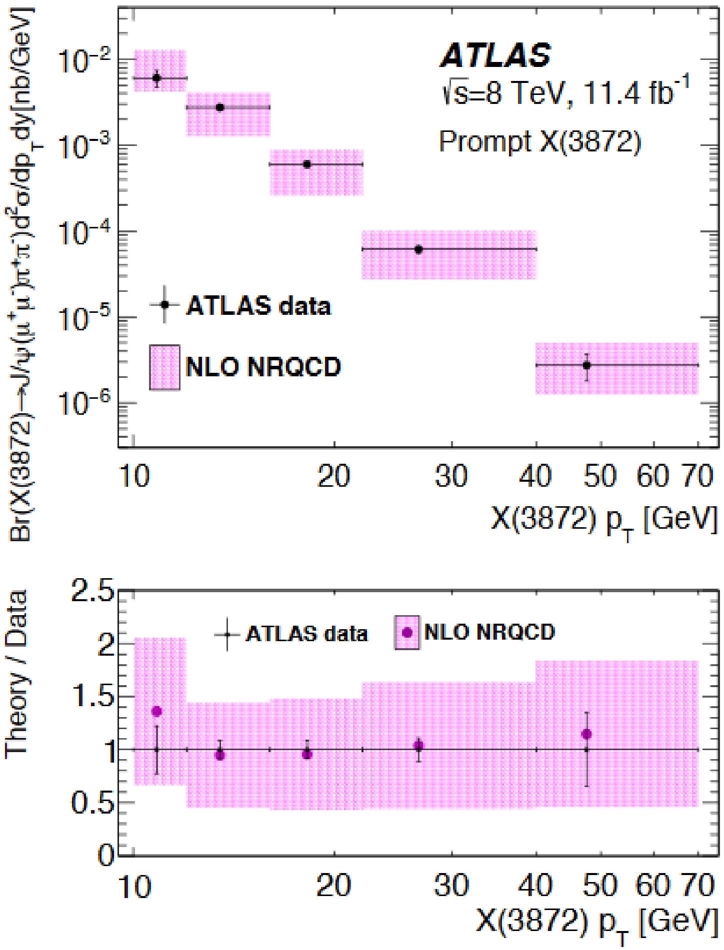
  – $\psi(2S)$ modelled well with single lifetime

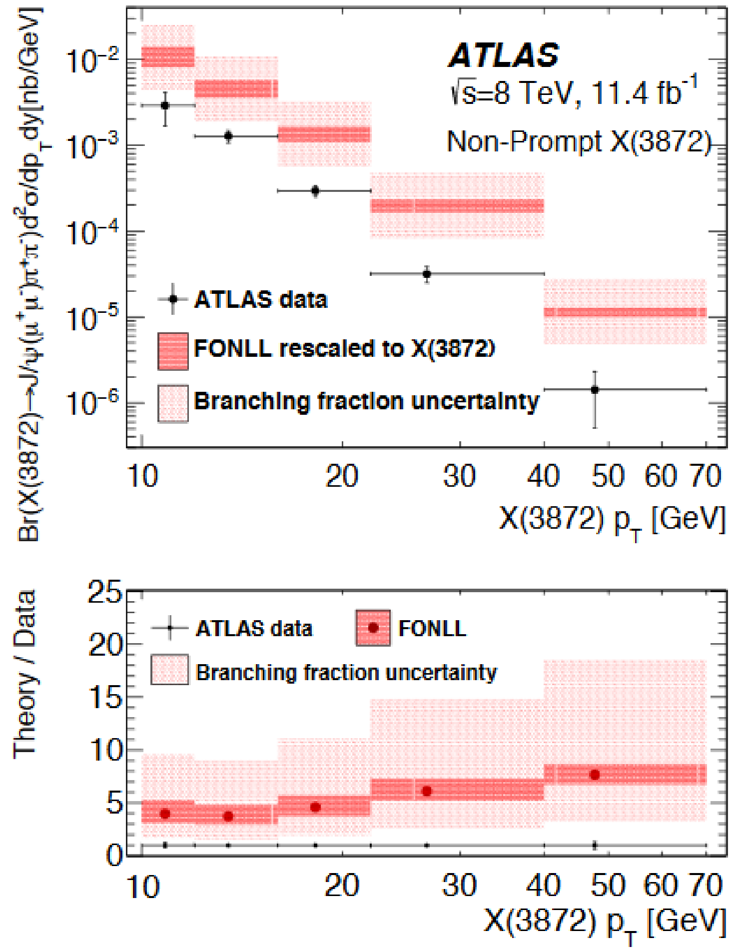
Study of ψ(2S) and X(3872) production at ATLAS

JHEP 01 (2017) 117

Prompt data compares well to NLO NRQCD (mixture of χ_{c1}(2P) and D*0D0-bar molecular state).

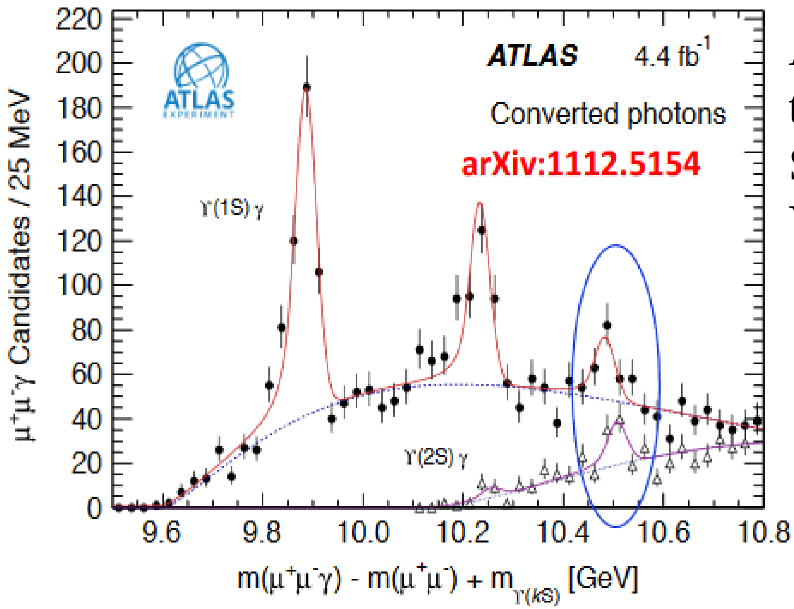
Non-prompt: FONLL, rescaled from ψ(2S) prediction with kinematic template fit, overestimates data by factor 4-8.



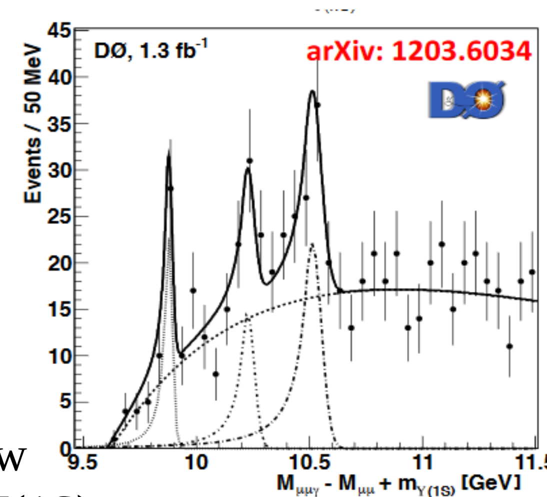


CMS: Observation of two resolved states $\chi_{b1,2}(3P)$

The history of the topic:

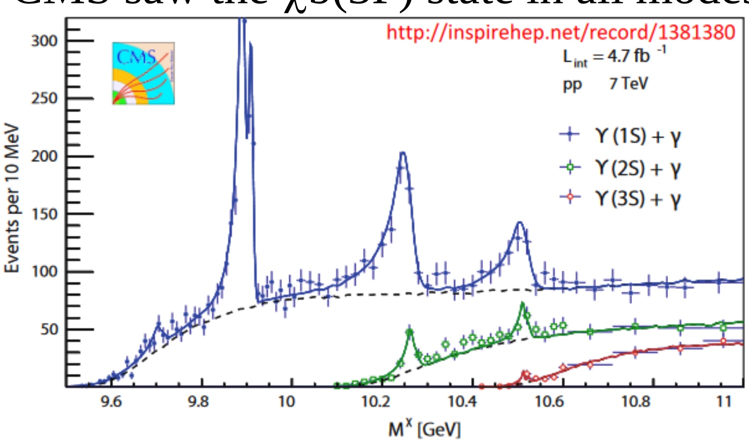


ATLAS observed the $\chi b(3P)$ state as a new Structure in Y(1S) γ and Y(2S) γ decays.

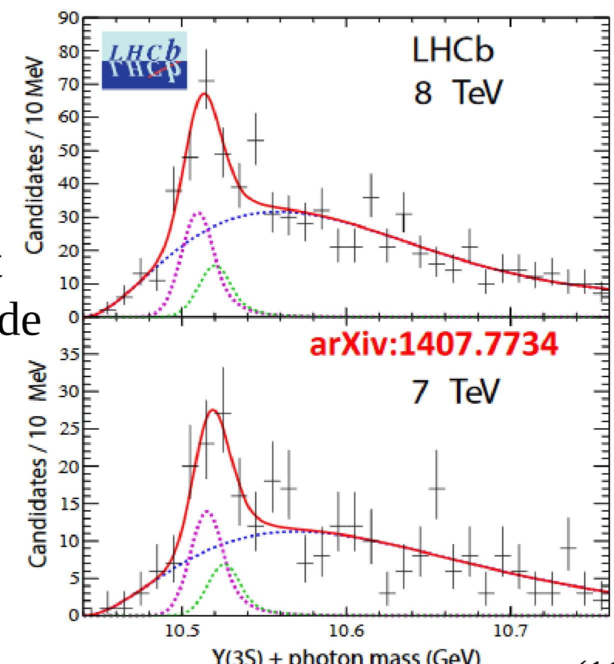


The D0 saw $\chi b(3P) \rightarrow Y(1S)\gamma$

CMS saw the $\chi b(3P)$ state in all modes



LHCb confirmed it In a new decay mode Y(3S) γ



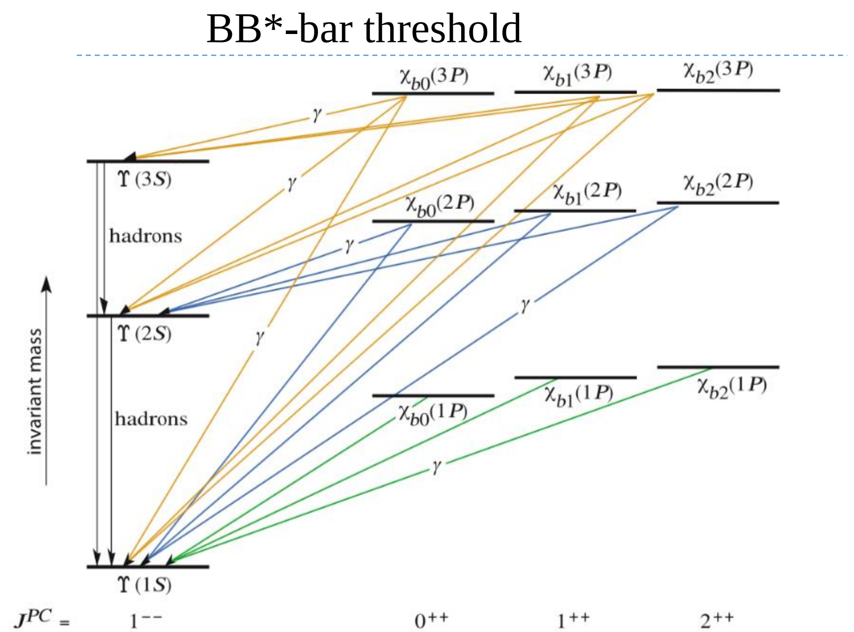
CMS: Observation of two resolved states $\chi_{b1,2}(3P)$

Motivation:

PRL 121 (2018) 092002

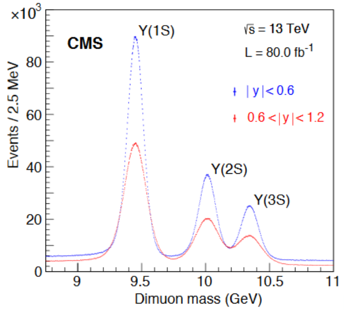
∗ The (bb-bar) family plays a special role in understanding how the strong force binds quarks since, due to the high mass, allows two important theoretical simplifications:
(1) the hard scattering production of a proto-quarkonium can be described in perturbation theory;
(2) the binding of the qq-bar pair can be described in terms of lattice NR potentials.
So, particularly stringent tests of current theories of quarkonium production can be achieved by examining the individual spin states of the quarkonium multiplets.

∗ Measurements of the masses of the $\chi_{bJ}(3P)$ triplet states, with J=0,1,2, probe details of the bb-bar interaction and test theoretical treatments of the influence of open-beauty states on the bottomonium spectrum. The bottomonium analogues of the $\chi_{c1}(2P)$ and X(3872) states would be the $\chi_{b1}(3P)$ state and a possible X_b state at the BB*-bar threshold. Confirming that the $\chi_{b1}(3P)$ is well below the open-beauty threshold would suggest differences with the charmonium system. And the observation of a doublet structure in the 10.5 GeV peak should confirm the nature of the state and clarify the existence or absence of effects induced by the nearby open-beauty threshold.



Picture from : V. Knünz, Measurement of Quarkonium Polarization to Probe QCD - DOI 10.1007/978-3-319-49935-2_2

CMS: Observation of two resolved states $\chi_{b1,2}(3P)$



← Upsilon(1,2,3S) sample

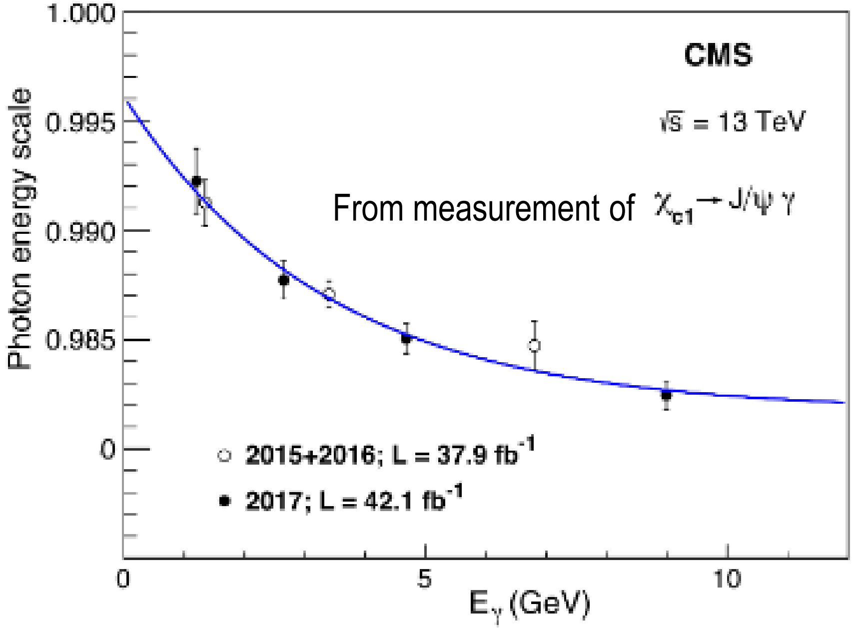
PRL 121 (2018) 092002

- Analyzing the full LHC Run 2 dataset (**13 TeV, 80 fb^{-1}**), CMS has **observed for the first time** the split in the **χ_{b1} (3P) - χ_{b2} (3P) doublet** and measured the masses of the two states

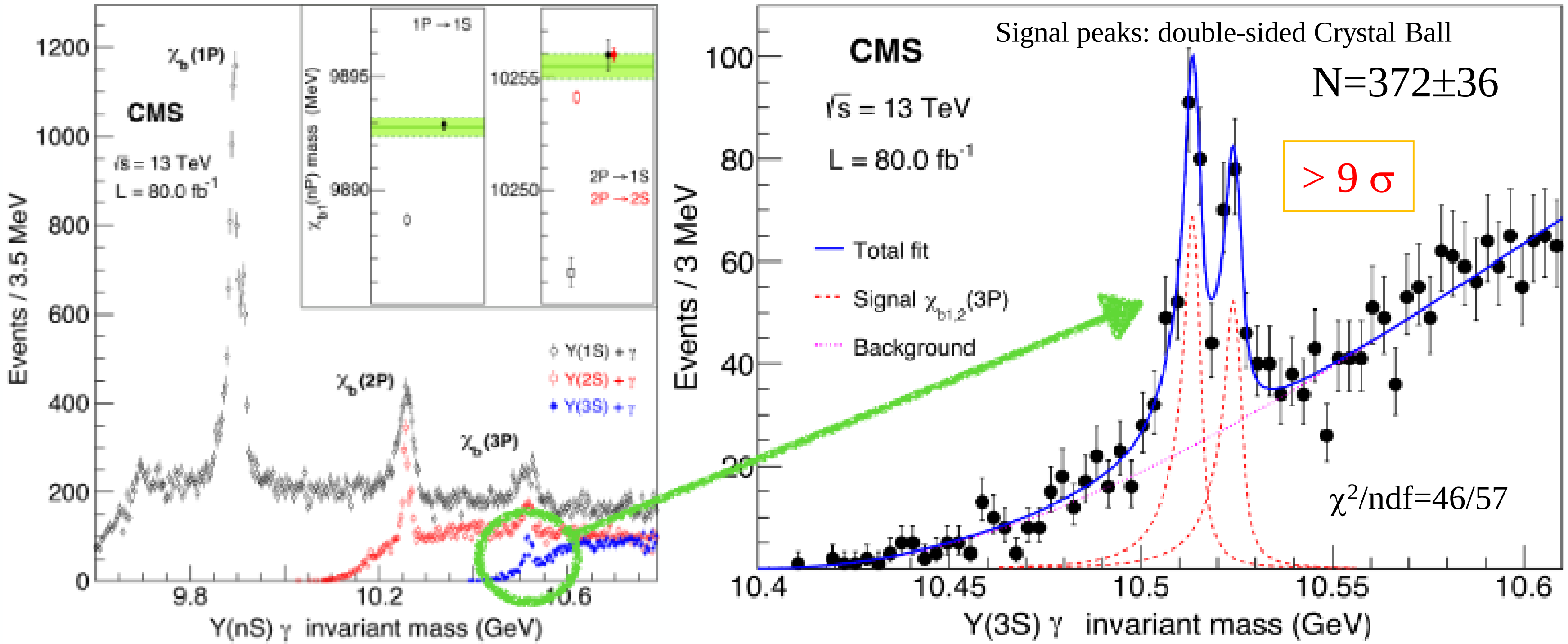
- **χ_b (3P)** is reconstructed in **Υ(3S) + γ** mode. The low energy **γ** is detected through **$\gamma \rightarrow e^+e^-$** conversion inside the silicon tracker

- Photon energy scale is calibrated using high yield **$\chi_{c1} \rightarrow J/\psi + \gamma$** samples for high accuracy mass measurements

- Tested with **χ_b (1P, 2P)** states



CMS: Observation of two resolved states $\chi_{b1,2}(3P)$



PRL 121 (2018) 092002

M_1 = 10513.42 ± 0.41(stat) ± 0.18(syst) MeV

M_2 = 10524.02 ± 0.57(stat) ± 0.18(syst) MeV

ΔM = 10.6 ± 0.64(stat) ± 0.17(syst) MeV

This result strongly disfavours the breaking of the conventional pattern of splittings and supports the standard mass hierarchy.

J=1,2 states well resolved for the first time

Significantly constrains theoretical predictions, which give mass splits in the range [-2, 18] GeV

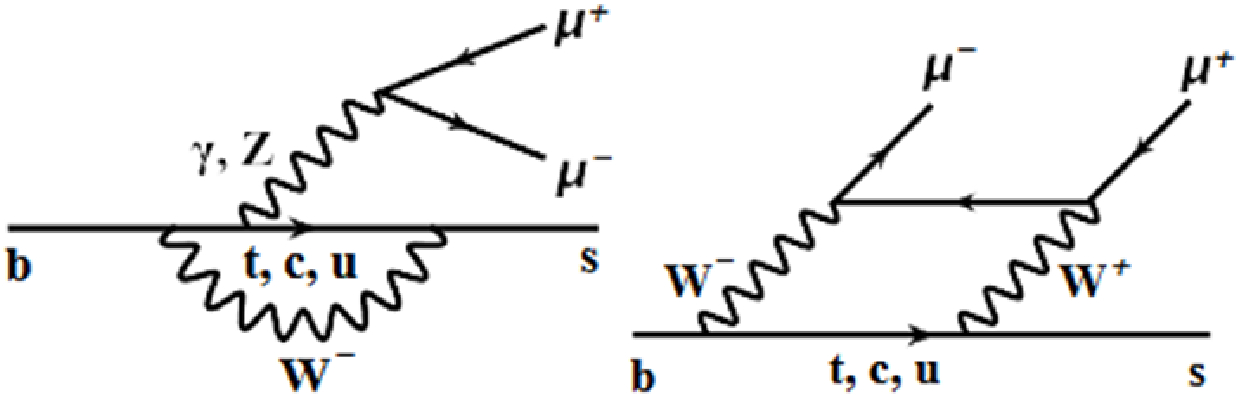
This measurement fills a gap in the spin-dependent bottomonium spectrum below the open-beauty threshold and should significantly contribute to an improved understanding of the non-perturbative spin-orbit interactions affecting quarkonium spectroscopy.

Search for New Physics in EW penguin B-meson decays: $B \rightarrow K^{(*)} \mu^+\mu^-$

B decays in $b \rightarrow s/d\ ll$ transition provides good probe for new physics in the penguin loop.

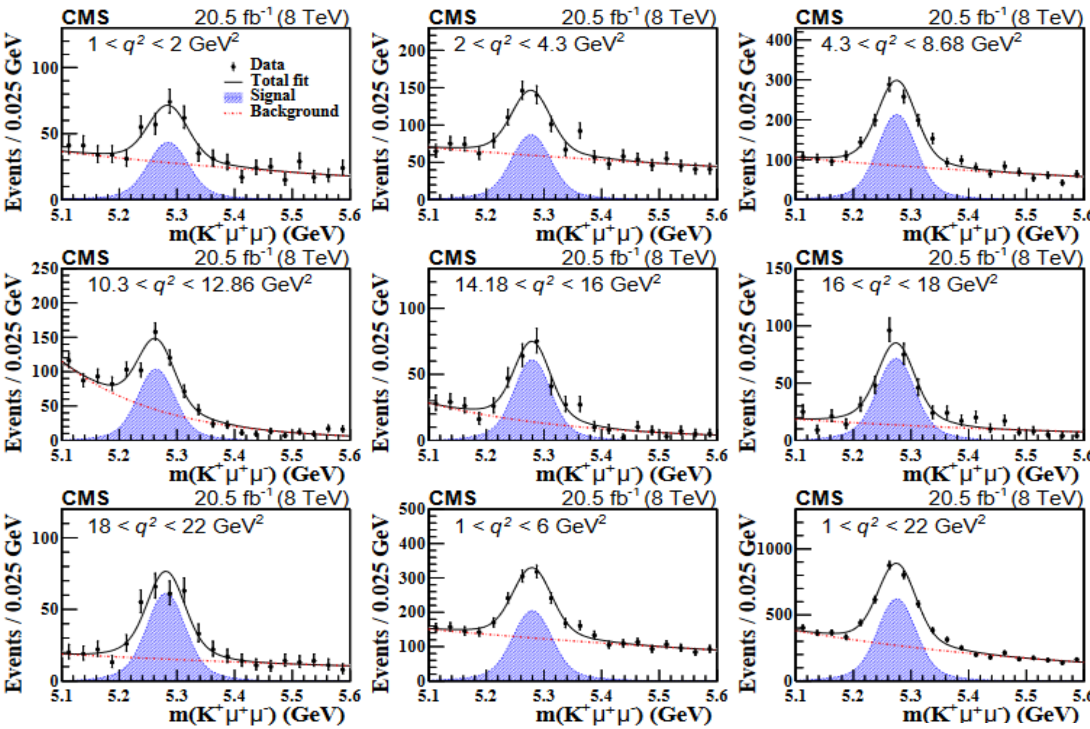
- Small Standard Model branching fractions;
- More precise theoretical predictions;

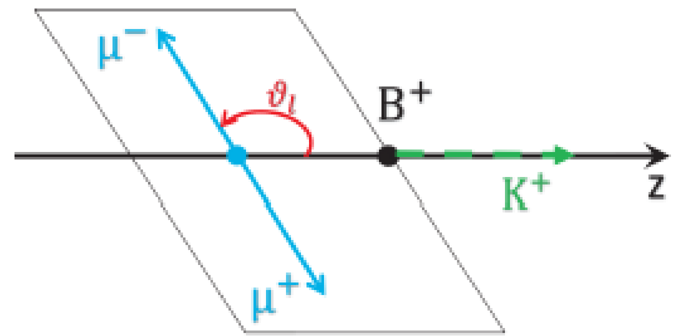
Many observables: Br, A_{FB}, P_5'… and decay amplitudes depend on $q^2=(p_l^+ + p_l^-)^2$



CMS: Search for New Physics in $B^+ \to K^+ \mu^+\mu^-$

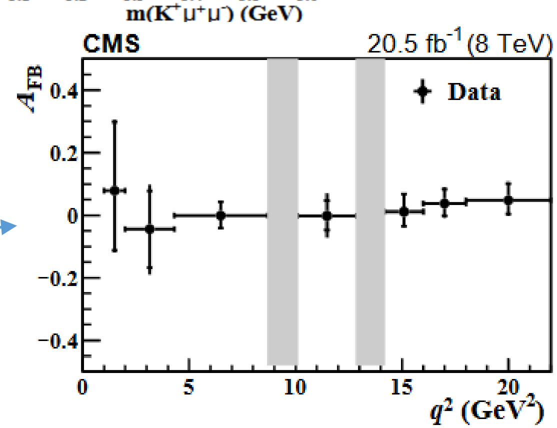
$$\frac{1}{\Gamma_\ell}\frac{d\Gamma_\ell}{d\cos\theta_\ell} = \frac{3}{4}(1-F_H)(1-\cos^2\theta_\ell) + \frac{1}{2}F_H + A_{FB}\cos\theta_\ell.$$

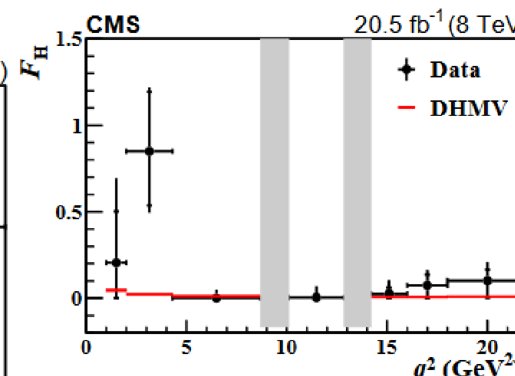




arXiv:1806.00636,
submitted to PRD

The results are consistent with previous measurements and compatible with three different standard model predictions

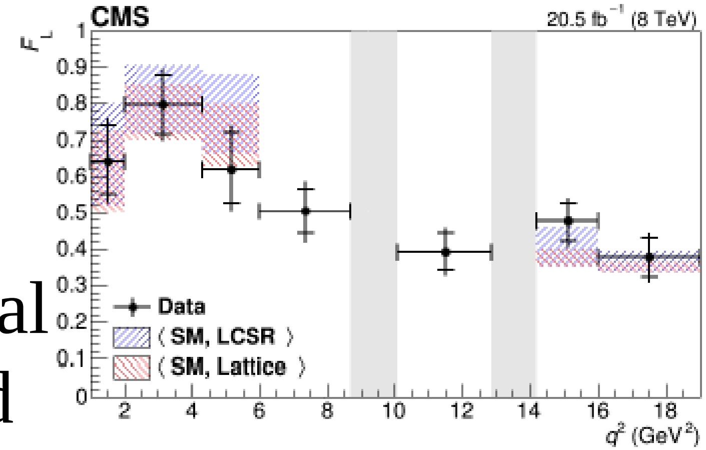


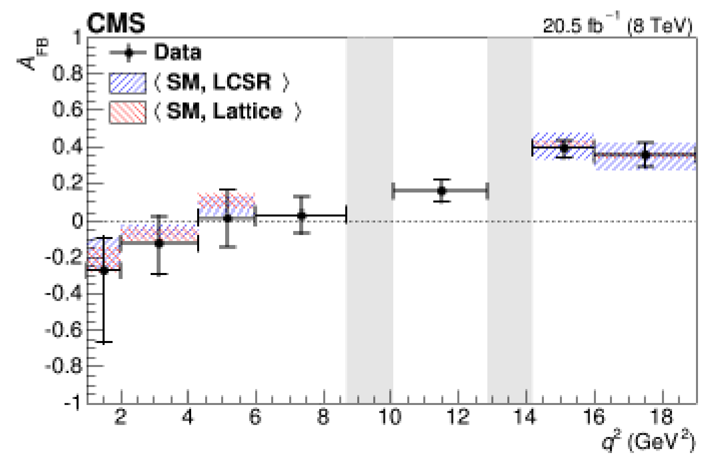


CMS: Search for New Physics in $B^0 \rightarrow K^{*0}\ \mu^+\mu^-$

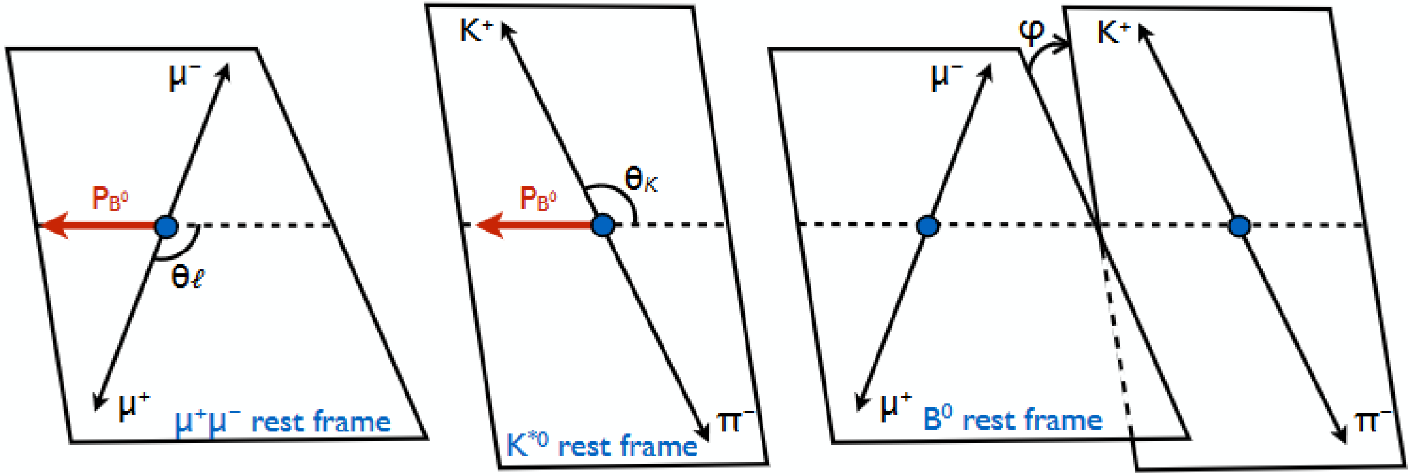
- Two analyses were published by CMS with RUN I data
- The parameter space was reduced by integrating over the ϕ angular variable
- A_{FB} and F_L parameters and differential branching fractions were measured
- No deviations form SM predictions was found
- The analysis presented in a new publication was performed on the same data set and uses the same selection criteria as previous one.

2011 data: Phys. Lett. B 727 (2013) 77
2012 data: Phys. Lett. B 753 (2016) 424





CMS: Search for New Physics in B0 → K*0 μ+μ-



PLB 781 (2018) 517

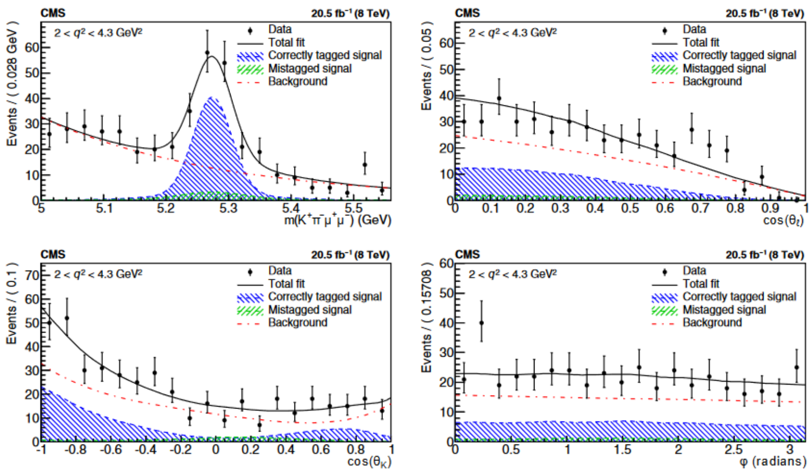
P-wave(K*) and S-wave (Kpi nonres.) and interference contribute to the Kπμμ f.s.

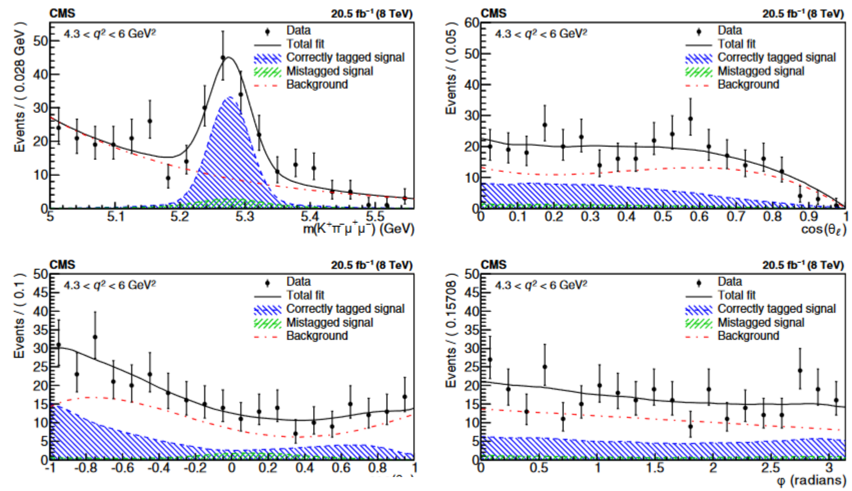
$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\varphi}=\frac{9}{8\pi}\left\{\frac{2}{3}\left[(F_S+A_S\cos\theta_K)\left(1-\cos^2\theta_\ell\right)\right.\right.$$
$$\left.+A_S^5\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_\ell}\cos\varphi\right]$$
$$+(1-F_S)\left[2F_L\cos^2\theta_K\left(1-\cos^2\theta_\ell\right)\right.$$
$$+\frac{1}{2}(1-F_L)\left(1-\cos^2\theta_K\right)\left(1+\cos^2\theta_\ell\right)$$
$$+\frac{1}{2}P_1(1-F_L)(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\varphi$$
$$\left.\left.+2P_5'\cos\theta_K\sqrt{F_L(1-F_L)}\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_\ell}\cos\varphi\right]\right\}$$

F_L, F_S, and A_s fixed from previous CMS measurement

P_1 and P_5' measured, A_s^5 nuisance parameter

CMS: Search for New Physics in B0 → K*0 μ+μ-





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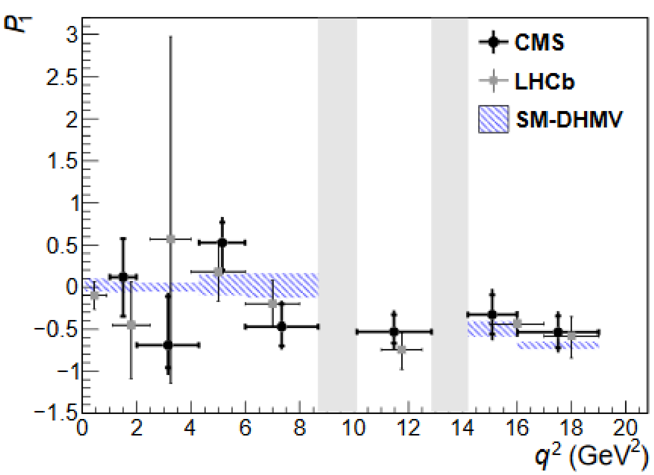
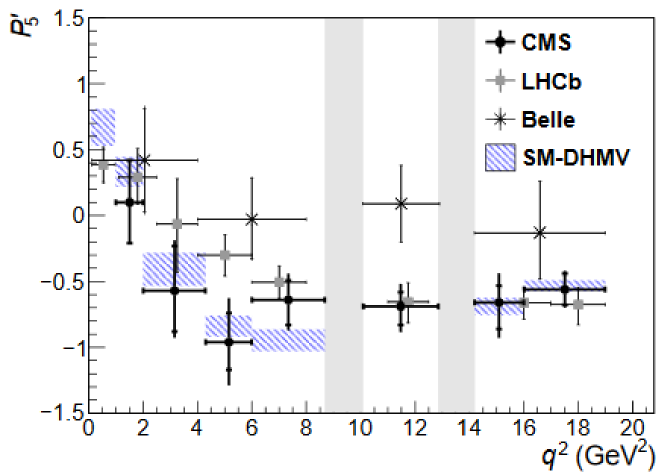




No significant deviations from other experimental results.

SM prediction is
in agreement with CMS results.

q^2 (GeV^2)	Signal yield	P_1	P_5'	Correlations
1.00–2.00	80 ± 12	$+0.12\,^{+0.46}_{-0.47} \pm 0.10$	$+0.10\,^{+0.32}_{-0.31} \pm 0.07$	-0.0526
2.00–4.30	145 ± 16	$-0.69\,^{+0.58}_{-0.27} \pm 0.23$	$-0.57\,^{+0.34}_{-0.31} \pm 0.18$	-0.0452
4.30–6.00	119 ± 14	$+0.53\,^{+0.24}_{-0.33} \pm 0.19$	$-0.96\,^{+0.22}_{-0.21} \pm 0.25$	$+0.4715$
6.00–8.68	247 ± 21	$-0.47\,^{+0.27}_{-0.23} \pm 0.15$	$-0.64\,^{+0.15}_{-0.19} \pm 0.13$	$+0.0761$
10.09–12.86	354 ± 23	$-0.53\,^{+0.20}_{-0.14} \pm 0.15$	$-0.69\,^{+0.11}_{-0.14} \pm 0.13$	$+0.6077$
14.18–16.00	213 ± 17	$-0.33\,^{+0.24}_{-0.23} \pm 0.20$	$-0.66\,^{+0.13}_{-0.20} \pm 0.18$	$+0.4188$
16.00–19.00	239 ± 19	$-0.53 \pm 0.19 \pm 0.16$	$-0.56 \pm 0.12 \pm 0.07$	$+0.4621$

ATLAS: Search for New Physics in angular analysis of $B^0 \rightarrow K^{*0} \mu^+\mu^-$

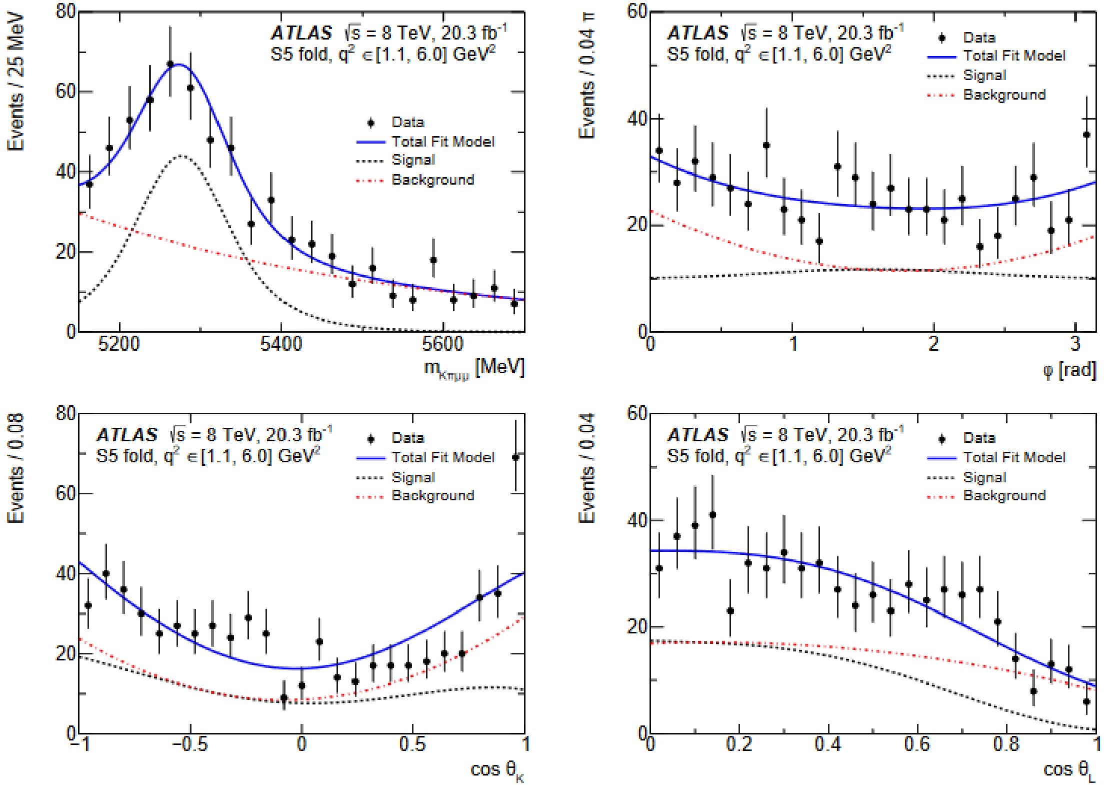
JHEP 10 (2018) 047

ATLAS extracts P_1 and P_i' (i=4,5,6,8) parameters. S-wave component (non-resonant Kπ) neglected and included as a systematics.

CMS P_1 and P_5'. S-wave included in PDF.

ATLAS: fit signal and background

- Four diferent fits, 3 free parameters each
- F_L , S_3 common to each fit
- S_4, S_5, S_7, S_8 fited parameters
- P_1, P_i' extracted from fit parameters

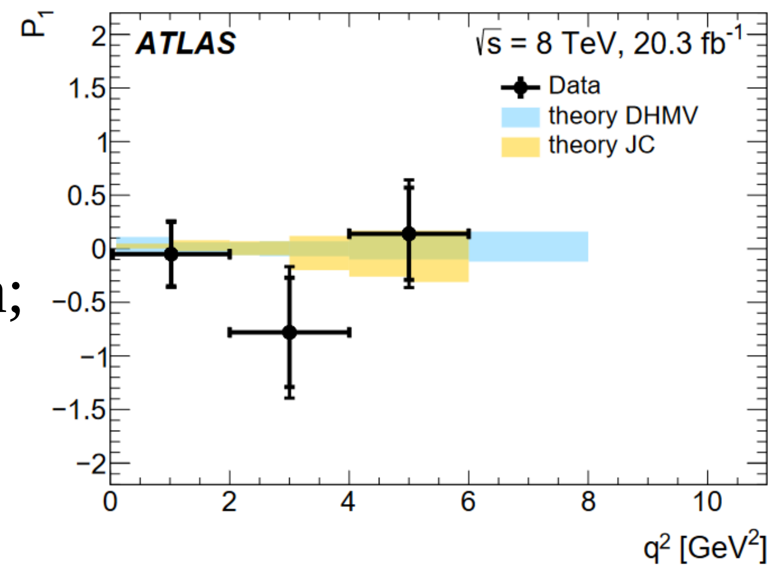


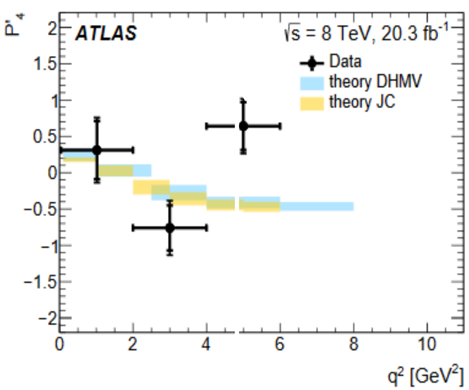
ATLAS: Search for New Physics in $B^0 \to K^{*0} \mu^+\mu^-$

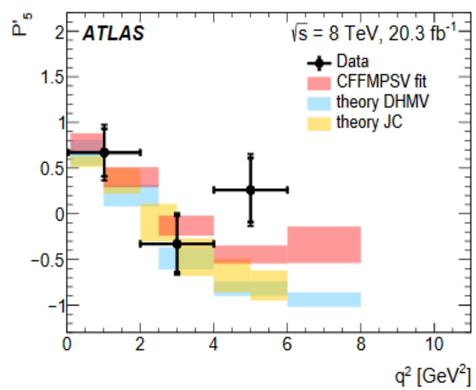
JHEP 10 (2018) 047

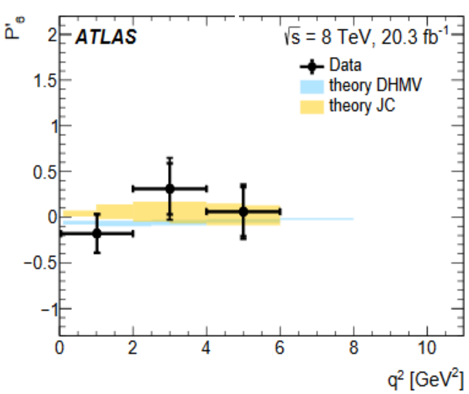
Theory:

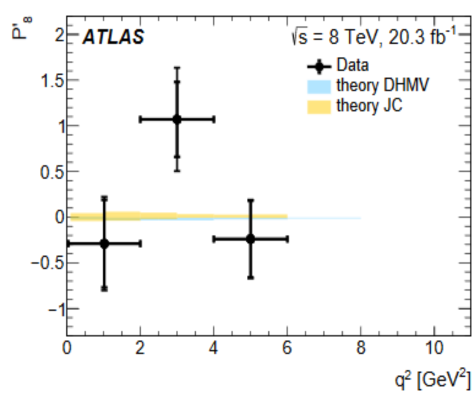
- DHMV/JC : QCD factorization, hadronic uncert.'s from calculations;
- HEPfit/CFFMPSV fit: hadronic charm contributions fitted from LHCb data;











- ATLAS generally in good agreement with SM, except a ~2.5 sigma deviation from DHMV for P4', P5' in one bin;
- LHCb sees a > 3 sigma discrepancy on P5';
- CMS data compatible with SM in the whole range and favouring DHMV at low q2.

Summary

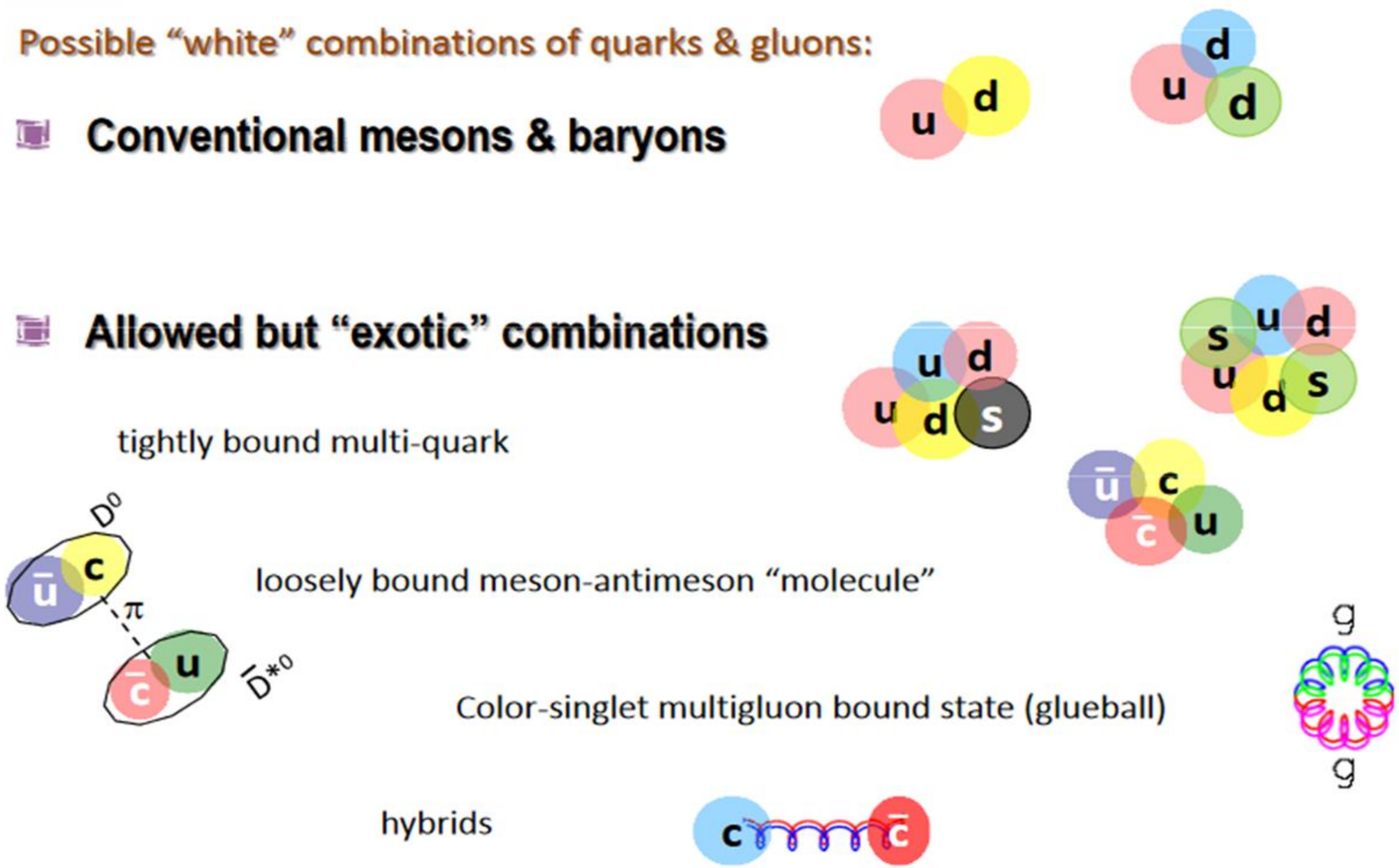
Although designed for high-pt physics, ATLAS and CMS are very good experiments for heavy flavor physics!

- Study of $B_s \pi^+$ spectrum and setting an UL on the production of X(5568):
  - ATLAS and CMS (also, LHCb and CDF) do not confirm the production of X(5568)
- Study of $B_{s(1,2)}^* \rightarrow B^+K^-$ and observation of $B_{s2}^*(5840) \rightarrow B^0 K^0_s$ by CMS
- Study of X(3872) production properties by ATLAS:
  - new tests of theory predictions of production and first hints (btw stat. uncert. is large) of enhanced Br(Bc+ → X(3872)..)
- Observation of two resolved states $\chi_{b1,2}(3P)$ by CMS
- Search for New Physics in $B \rightarrow K^{(*)}$ μ+μ- decays by ATLAS and CMS:
  - in CMS the $B^0 \rightarrow K^{*0}$ μ+μ- angular analysis has been extended to measure P1 and P5' parameters;
  - the B+ → K+ μ+μ- angular analysis performed for the 1st time in CMS and for both analyses no significant deviation from SM prediction is seen within uncertainties;
  - ATLAS generally in good agreement with SM, except a ~2.5 σ deviation from DHMV for P4', P5' in one bin.

Backup slides

Hadrons: Conventional and Exotic

Are there any quark configurations other than mesons and baryons?
In theory such configurations are possible.
Which of them are realized in reality, in nature?



Search for X(5568) in CMS

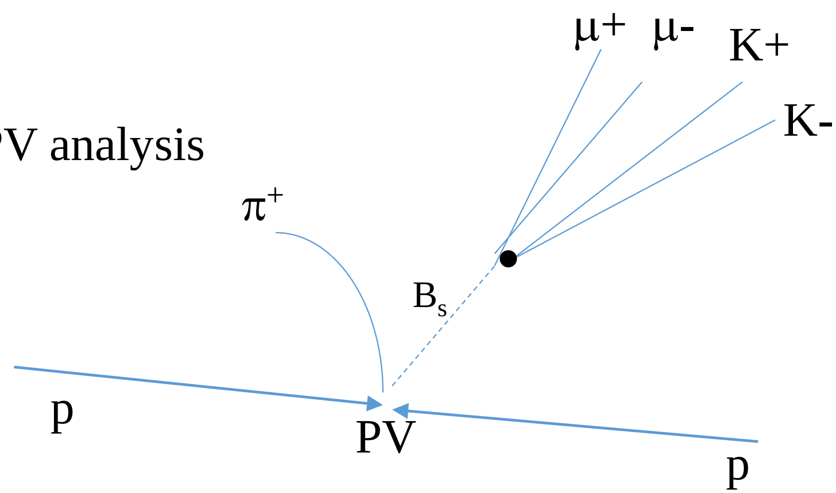
Analysis Strategy:

$$B_s^0 \to J/\psi\phi \; (J/\psi \to \mu^+\mu^-, \phi \to K^+K^-)$$

HLT - select events with mu+ mu- originating from J/psi decaying at a significant distance from the beamspot.

1) Reconstruct Bs by combining J/psi and phi and then fit 4t racks into the common vertex
→know Bs momentum and its decay vertex.
(This procedure follows closely that from Bs CPV analysis *Phys. Lett.* **B757** (2016) 97–120 .)

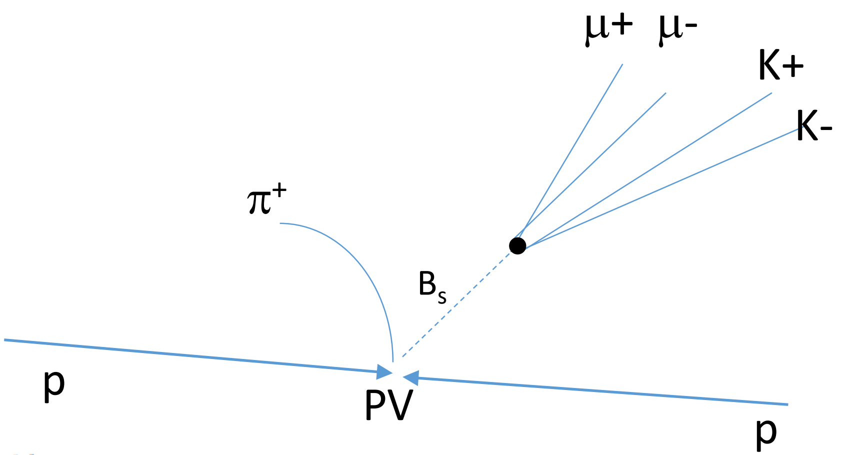
2) Select Primary Vertex (PV):
from all pp collision points, the PV is chosen as the one with the smallest angle between the vector from the collision point to the Bs decay vertex and the Bs momentum.



3) Add charged pion from that PV and form Bs pi+ pair

Search for X(5568) in CMS

Offline Selection Criteria:



- $p_T(\mu^\pm) > 4$ GeV,
- $|\eta(\mu^\pm)| < 2.2$,
- $p_T(\mu^+\mu^-) > 7$ GeV,
- dimuon vertex χ^2 fit probability $P_{vtx}(\mu^+\mu^-) > 10\%$,
- distance between the beamspot and the reconstructed dimuon vertex positions in the transverse plane divided by its uncertainty $L_{xy}(\mu^+\mu^-)/\sigma_{L_{xy}(\mu^+\mu^-)} > 3$,
- $\cos\alpha_T(\mu^+\mu^-) > 0.9$, where $\alpha_T(\mu^+\mu^-)$ is the angle between the vector from the beamspot position to the dimuon vertex in the transverse plane and the transverse dimuon momentum vector,
- dimuon invariant mass in the region $3.04 < M(\mu^+\mu^-) < 3.15$ GeV.

$p_T(K^\pm) > 0.7$ GeV. $p_T(B_s^0) > 10$ GeV

$P_{vtx}(\mu^+\mu^-K^+K^-) > 1\%$, $\cos\alpha_T(B_s^0) > 0.99$. $L_{xy}(Bs)/\sigma_{Lxy(Bs)} > 3$

$|M(K+K-) - M_{PDG}(\phi)| < 10$ MeV

Prospects for the further X_b searches

- According to Karliner&Rosner [PRD91 (2015) 014014],

this search decay ($\Upsilon(1S)\,\pi^+\pi^-$) should be forbidden by G-parity conservation.
While for the X(3872) the isospin-conserving decay to $J/\psi\omega$ 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 for

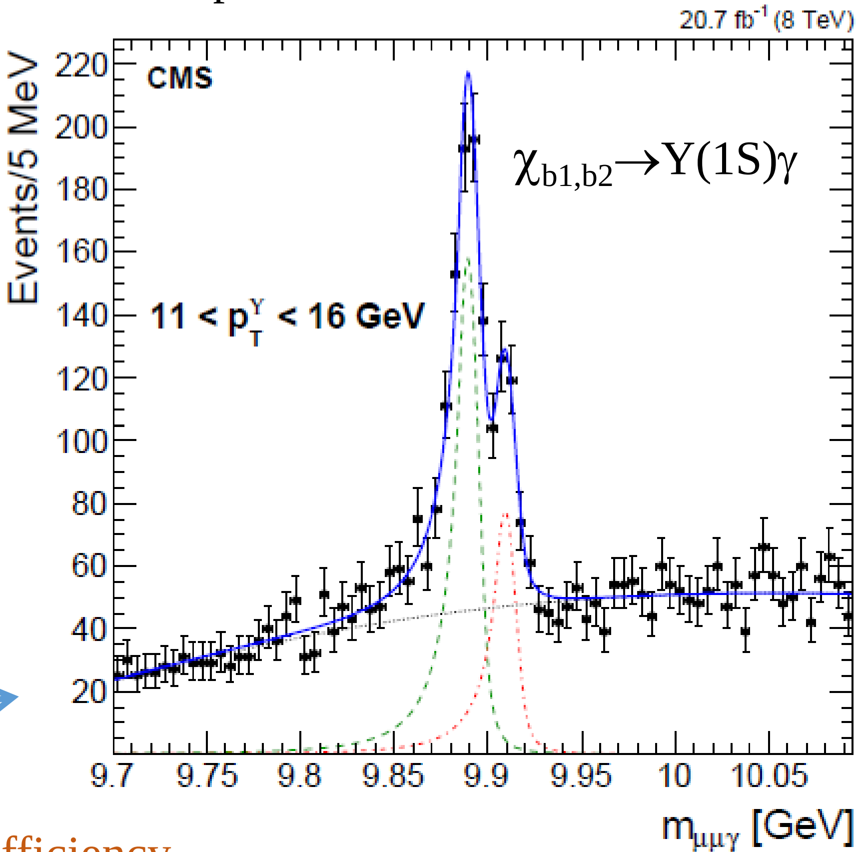
$$X_b \to \Upsilon(1S)\,\omega(\to \pi^+\pi^-\pi^0)$$

$$X_b \to \Upsilon(3S)\gamma$$

$$X_b \to \chi_{b1}(1P)\pi^+\pi^-$$

- Tasks for CMS for Run2.

The possibility to work with converted γ's was excellently demonstrated with the reconstruction of $\chi_{b1,b2} \to \Upsilon(1S)\gamma$.
But it is not easy task due to soft photons: low conversion and, therefore, reconstruction efficiency.



PLB 743(2015) 383

Also, Karliner&Rosner suggest that the X_b may be close in mass to the $\chi_{b1}(3P)$, mixing with it and sharing its decay.

Study of X(3872) at CMS

JHEP 1304(2013)154

CMS inclusively reconstructed $X(3872) \to J/\psi\pi^+\pi^-$
[of about 12k events with 4.8 fb-1 @7TeV]
and measured:

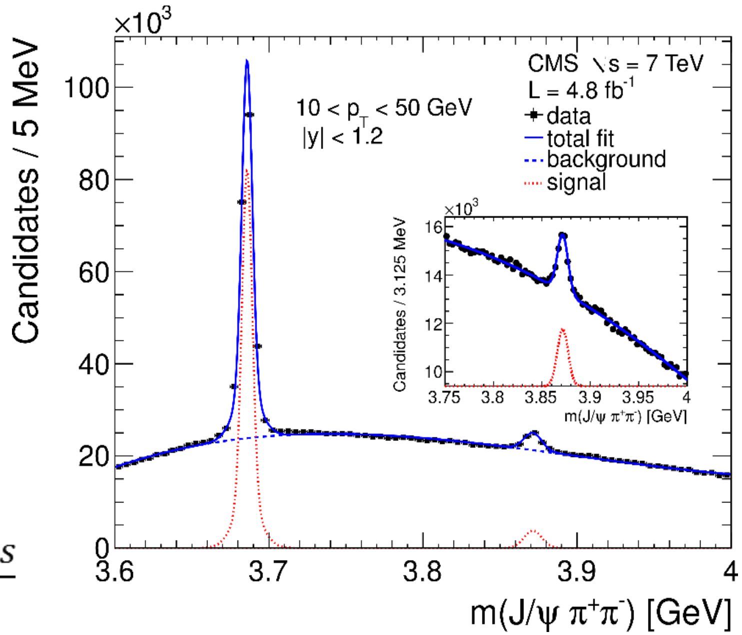
- cross-section ratio

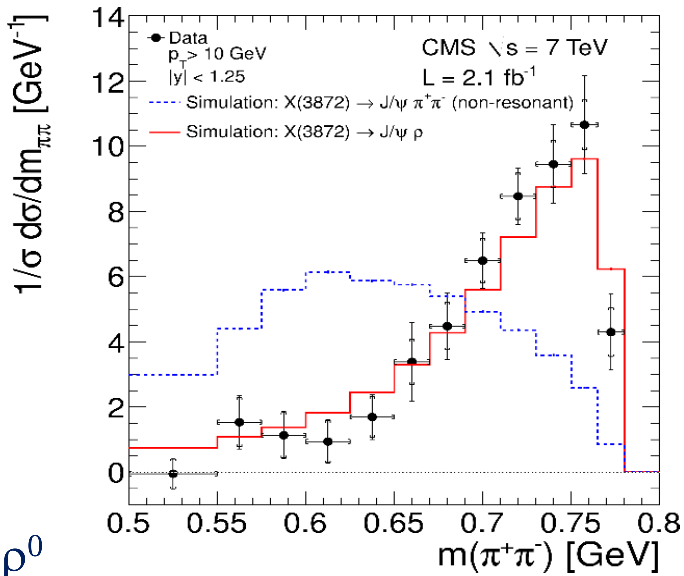
$$R \equiv \frac{\sigma\left(pp \to X(3872) + \text{anything}\right) \cdot B\left(X(3872) \to J/\psi\,\pi^+\pi^-\right)}{\sigma\left(pp \to \psi(2S) + \text{anything}\right) \cdot B\left(\psi(2S) \to J/\psi\,\pi^+\pi^-\right)}$$

- non-prompt fraction $= \dfrac{number\ of\ X(3872)\ from\ b{-}hadrons}{total\ inclusive\ number\ of\ X(3872)}$

- prompt cross-section of X(3872)

- invariant mass distribution of the $\pi^+\pi^-$ system



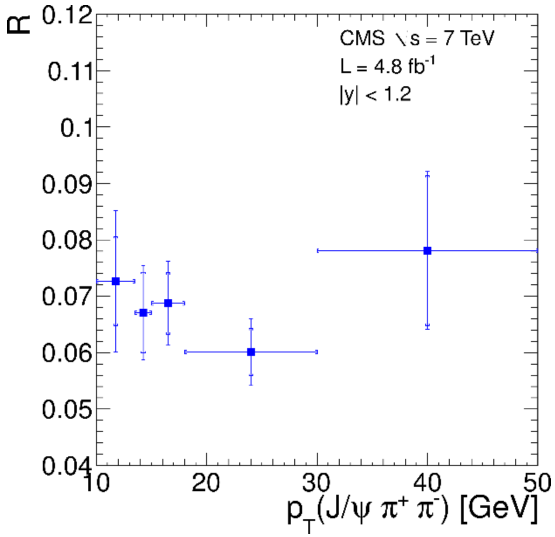


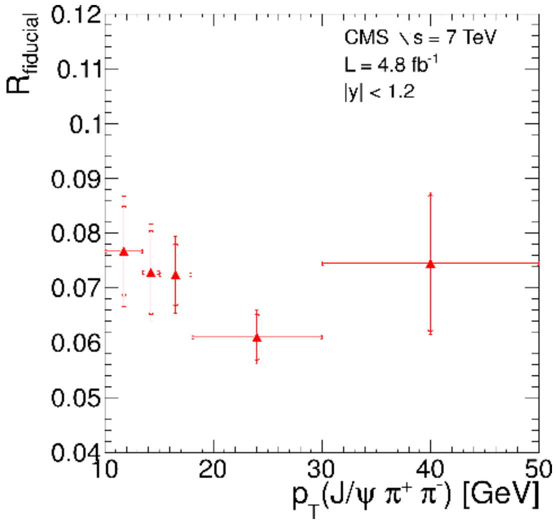
Previous studies of $m(\pi^+\pi^-)$ at Belle and CDF favor to two-body decay $X(3872) \to J/\psi\ \rho^0$.

CMS confirms that conclusion: the spectrum obtained from data is compared to simulations with and w/o an intermediate ρ^0 in the $X(3872) \to J/\psi\pi^+\pi^-$ decay. The ρ^0 hypothesis gives better agreement with data.

Study of X(3872) production properties at CMS

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





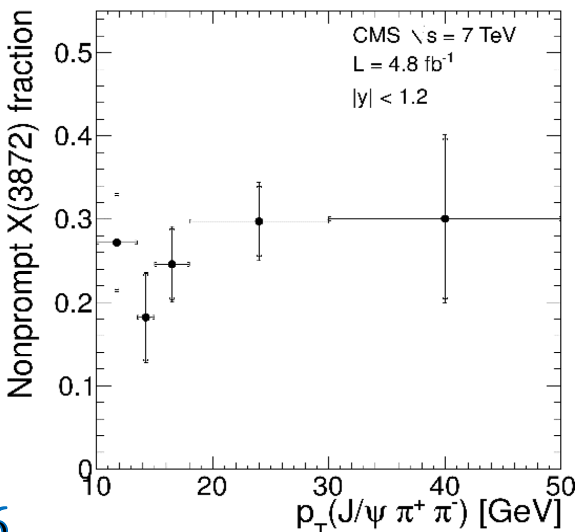
Acceptance corrections depend on assumptions on the angular distribution of the final states. So, w/o acc. corr. one can derive R in a fiducial region.

NO SIGNIFICANT dependence on the pt

Integrated over 10<pt<50 GeV:
R=0.0656 ± 0.0029 ± 0.0065

Integrated over 10<pt<50 GeV:
$R_{fiducial}$=0.0694 ± 0.0029 ± 0.036

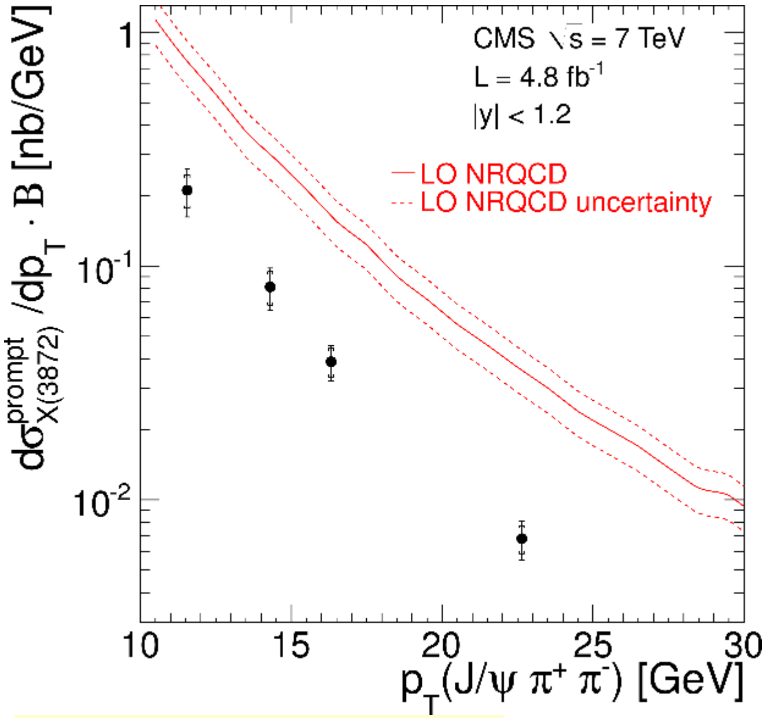
- Non-prompt fraction also shows no dependence on pt
- But measurement is dominated by statistics
- For 10<pt<50 GeV, |y|<1.2:



Non-prompt X(3872) fraction: f_{np}=0.263 ± 0.023 ± 0.016

Study of X(3872) production properties at CMS

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



- Main syst. uncertainties are related to the measurement 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 and Braaten [PRD.81.114018] with calculations normalized using Tevatron results, modified by the authors to match the phase-space of the CMS measurement.

Predictions by Artoisenet & Brateen assume, within an S-wave molecular model, the relative momentum of the mesons being bound by an upper limit of 400*MeV* which is quite high for a loosely bound molecule, but they assume it is possible as a result of rescattering effects.

The shape is reasonably well described by the theory while the predicted cross-section is overestimated by over 3σ.

On the other hand, one order of magnitude lower upper limit would imply lower prompt production rates of few orders of magnitude [Bignamini et al., PRL 103 (2009) 162001]

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

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

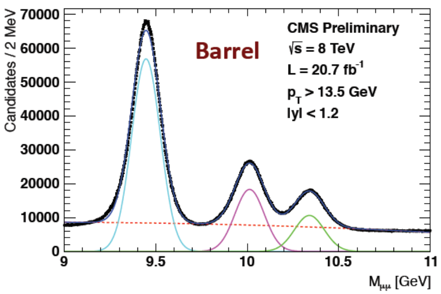
$$\sigma^{\rm prompt}(pp \to X(3872) + {\rm anything}) \cdot \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) = 1.06 \pm 0.11\,({\rm stat.}) \pm 0.15\,({\rm syst.})\,{\rm nb} \quad (14)$$

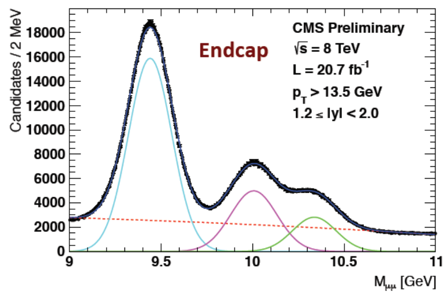
PLB 727 (2013) 57

Search for exotic bottomonium states X_b decaying into Υ(1S) π+π-

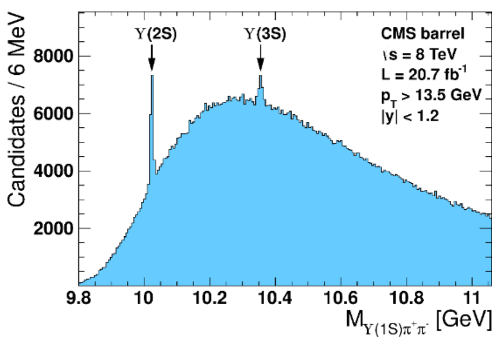
• The discovery of the X(3872) has prompted the search for a bottomonium counterpart X_b decaying into Υ(1S) π+π- - according to HQS considerations - with mass close to the BB or BB* threshold, 10.562 and 10.604 GeV.

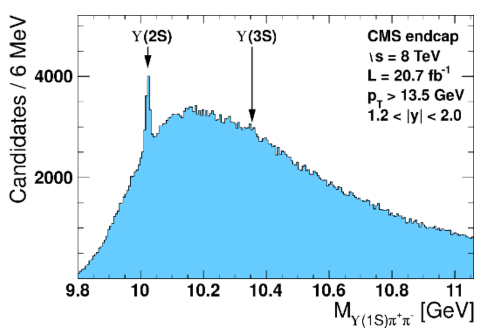
• It is expected that this X_b would be narrow, similar to X(3872), and has sizable Br.fr. to Υ(1S) π+π-.





CMS has collected a large sample of Υ(nS)→μ+μ- produced in pp collisions at 8TeV.
Separate barrel and endcap events to exploit better mass resolution and lower background in the barrel region.





$p_T(\Upsilon(1S)\pi^+\pi^-) > 13.5$ GeV and $|y(\Upsilon(1S)\pi^+\pi^-)| < 2.0$

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

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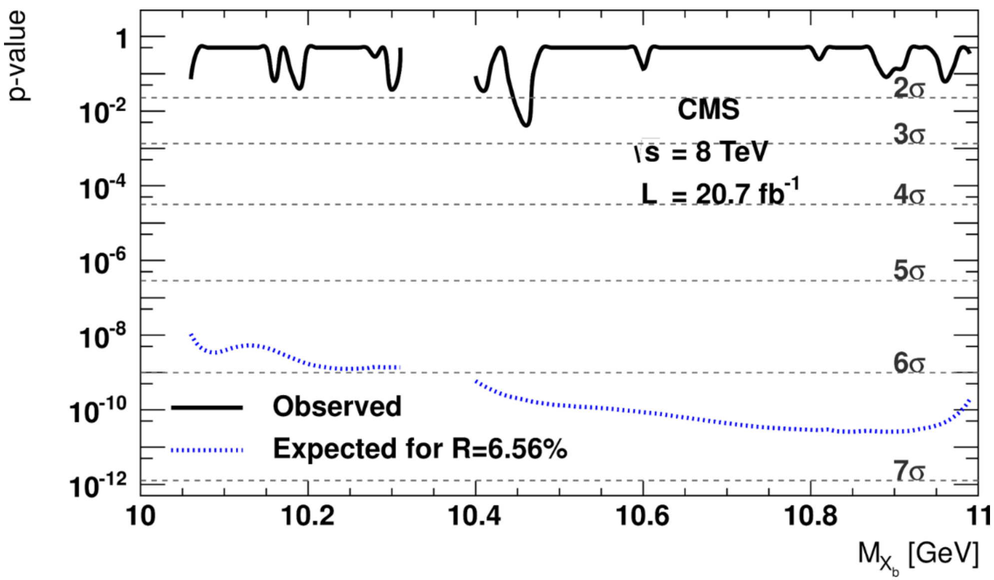
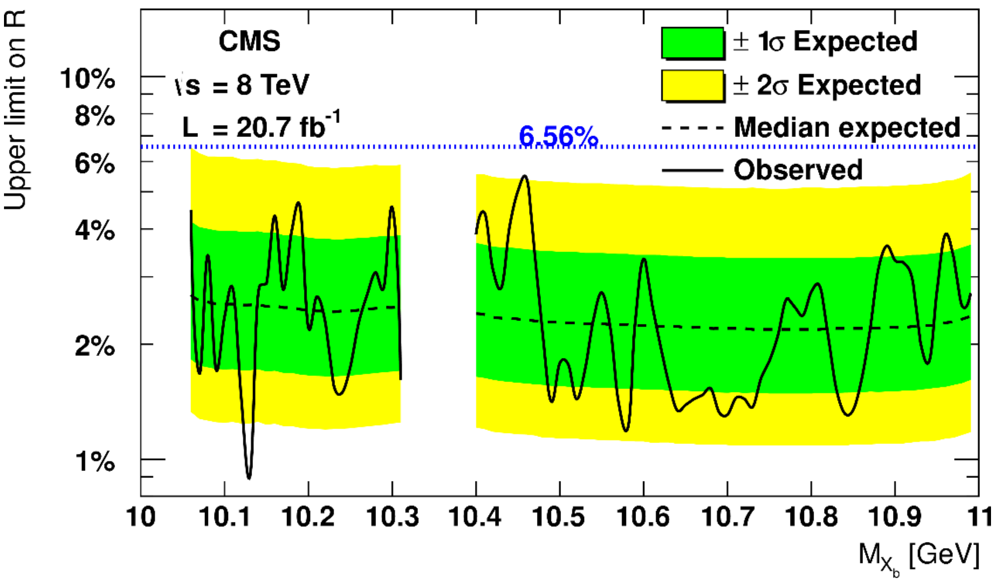
Mass scan for $X_b \rightarrow Y(1S)\ \pi^+\pi^-$



In analogy with the X(3872), expected signal significance > 5 σ if X_b(Br x cross-section)>6.5% of the corresponding product for $Y(2S) \rightarrow Y(1S)\ \pi^+\pi^-$ (R value)

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

Systematic uncertainties implemented as nuisance parameters.



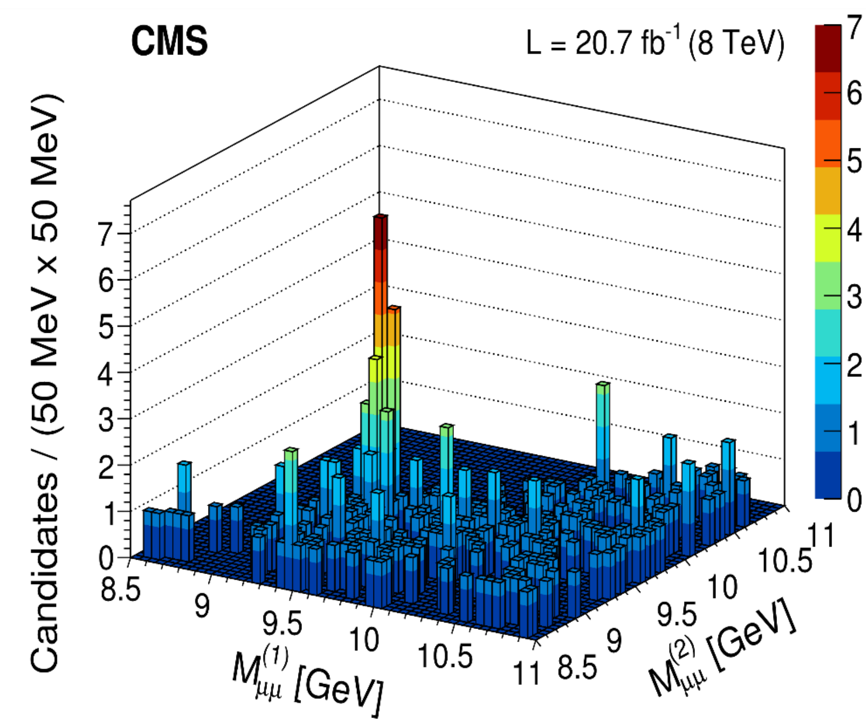
The smallest local p-value is 0.004 at 10.46 GeV, corresponding to a stat. signif. of 2.6 σ, which is reduced to 0.8 σ when LEE is taken into account.

No significant excess is observed.
95% CL UL on the R varies from 0.9% to 5.4%.

JHEP 05(2017)13

The First Observation of Υ(1S)Υ(1S) pair production

Motivation: cross-section measurements of quarkonium pair production are essential in understanding of SPS and DPS contributions and the parton structure of the proton.

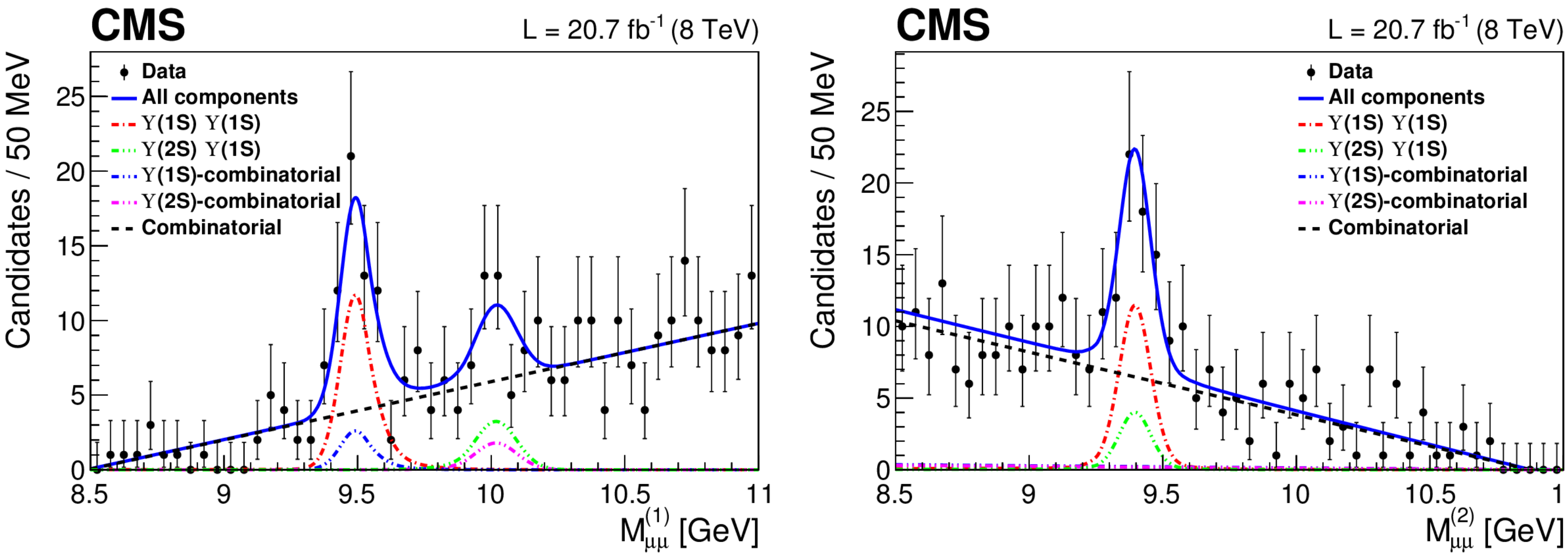


Υ(1S) pair production in pp collisions at $\sqrt{s}$=8 TeV is **observed** by CMS using a data set of 20.7 fb^{-1}, using dimuon Υ decay

$p_T(\mu) > 3.5$ GeV, $|\eta(\mu)| < 2.4$, $|y(\Upsilon)| < 2.0$
$P_{vtx}(\Upsilon) > 0.005$, $P_{vtx}(4\mu) > 0.05$,

JHEP 05(2017)13

The First Observation of Y(1S)Y(1S) pair production



A signal yield of 38±7 Y(1S)Y(1S) events is measured with a significance exceeding 5 σ and of 13^{+6}_{-5} Y(2S)Y(1S) events with a significance of 2.6 σ.

assuming that both mesons decay isotropically

$$\boldsymbol{\sigma(\Upsilon(1S)\Upsilon(1S)) = 68.8 \pm 12.7(\mathrm{stat}) \pm 7.4(\mathrm{syst}) \pm 2.8(\mathcal{B})}$$

in pp collisions at $\sqrt{s}$=8 TeV, for $|y(\Upsilon)| < 2.0$

JHEP 05(2017)13

The First Observation of Υ(1S)Υ(1S) pair production

Discussion of the result

In quarkonium pair production, the measurement of the effective cross section depends on the fraction of DPS, which is usually estimated either as a residual to the SPS prediction or as the result of a fit to the rapidity or azimuthal angle between quarkonia pairs.

$$\sigma_{\text{eff}} = \frac{[\sigma(\Upsilon)]^2}{2\, f_{\text{DPS}}\, \sigma_{\text{fid}}\, [\mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-)]^2} \quad [1]$$

we use $\sigma(\Upsilon) = 7.5 \pm 0.6\,\text{nb}$ and a value of $f_{\text{DPS}} \approx 10\%$ [2] $\to \sigma_{\text{eff}} \approx 6.6$ mb

In agreement with the values from heavy quarkonium measurements (2-8 mb), but is smaller than that from multijet studies (12-20 mb).

And it might indicate that the average transverse distance between gluons in the proton is smaller than between quarks, or between gluons and quarks.

[1] S.P.Baranov et al., PRD87(2013)034035

[2] A.V.Berezhnoy, A.K.Likhoded and A.A.Novoselov, PRD87(2013)054023

LHCb (JHEP 06(2012)141) and CMS (JHEP 09(2014)094) have measured total&diff. cross-sections for prompt double J/ψ production in complementary regions of pt and y.

New findings in double quarkonia frontier can be the preliminary step for searches of heavy 4quark bound states with Run-II data (or even suppressed decays like, for instance, eta_b into double J/psi)