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

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Outline

1. Introduction
2. Exotic Hadrons
3. D0 and LHCb results on the X(5568) production
4. Search for $X(5568)^+ \rightarrow B_s \pi^+$ in CMS
5. Preliminary Result and Summary

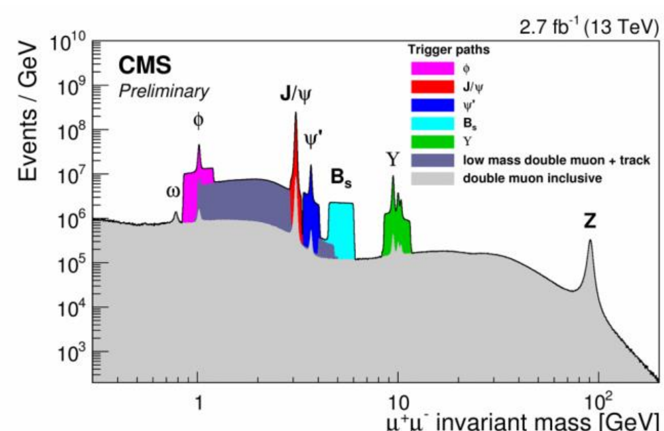
Introduction

Heavy flavor spectroscopy still is developing field in HEP:

Many multi-quark states were discovered in recent 14 years starting from X(3872) @Belle

- it is interesting to understand and **find more** of these states -

CMS is contributing into this topic



Tracker

Good pt resolution (down to $\Delta pt/pt \cong 1\%$ in the central region)

Tracking efficiency >99% for muons

Good vertex reconstruction and impact parameter resolution down to $\approx 15\mu m$

Muon System

Redundant system with large rapidity coverage ($|\eta|<2.4$)

Standalone $\Delta pt/pt \cong 10\%$

High-purity muon-ID $\varepsilon(\mu|\pi,K,p)\leq(0.1\text{-}0.2)\%$

Trigger

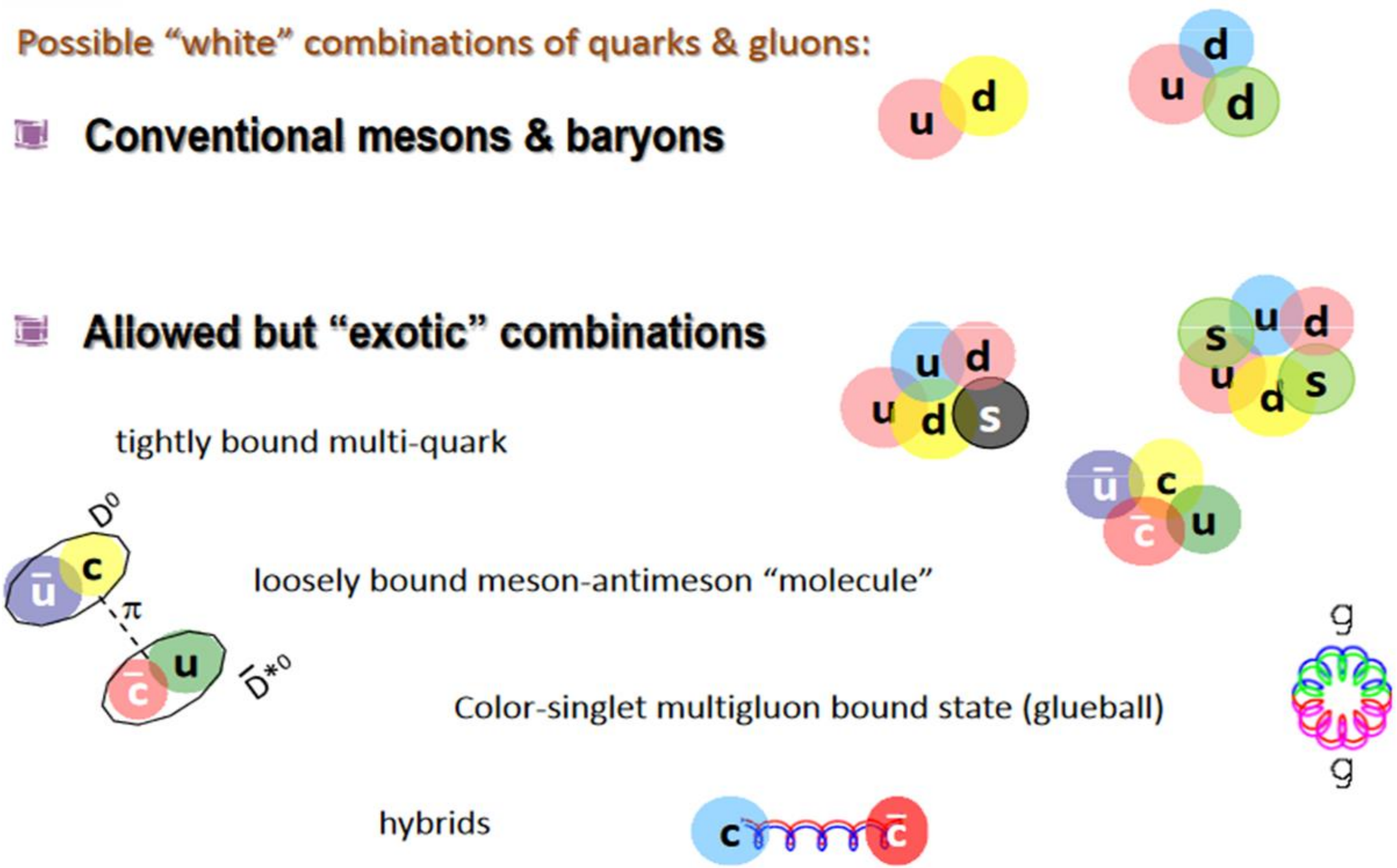
Very efficient hardware trigger

Highly flexible HLT: paths dedicated to specific analyses

In this talk *preliminary* results on a search for X(5568) from 8 TeV data sample in CMS will be presented and discussed

Hadrons: Conventional and Exotic

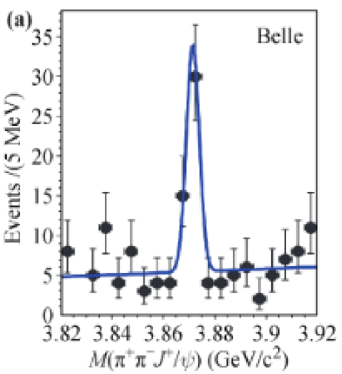
Are there any quark configurations other than mesons and baryons?
In theory such configurations are possible.
Which of them are realized in reality, in nature?

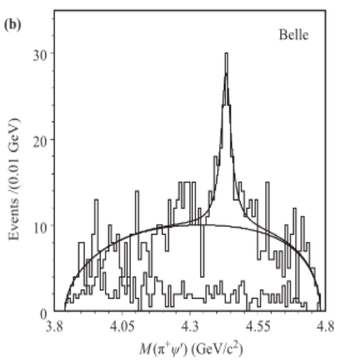


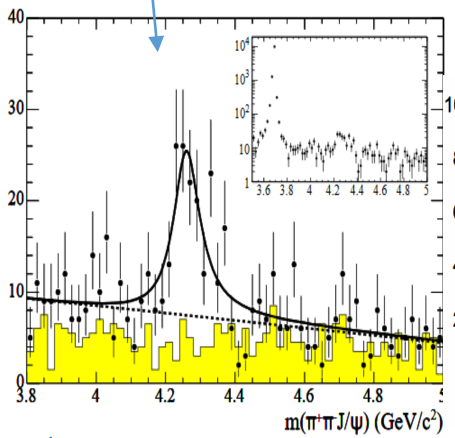
Exotic Hadrons: experimental results. and theoretical interpretation

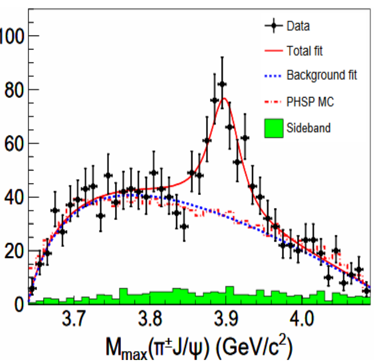
From 2003, thanks to B-factories Belle and BaBar (and then BES III and LHCb), the number of the candidates to exotic hadrons is growing continuously.
These are multiquark states. Some bright examples are
X(3872), Z(4430)+, from Belle, Y(4260) from BaBar, Z(3900)+ from BESIII

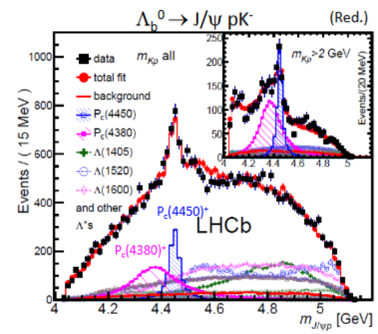
and P_c from LHCb.











This is a New Hadron Spectroscopy Era

Theoretical interpretation of all these exotic states still not clear.

No consensus has yet appeared to explain all new states by means of a unique theoretical approach

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

→ **WE NEED MORE INFORMATION !**

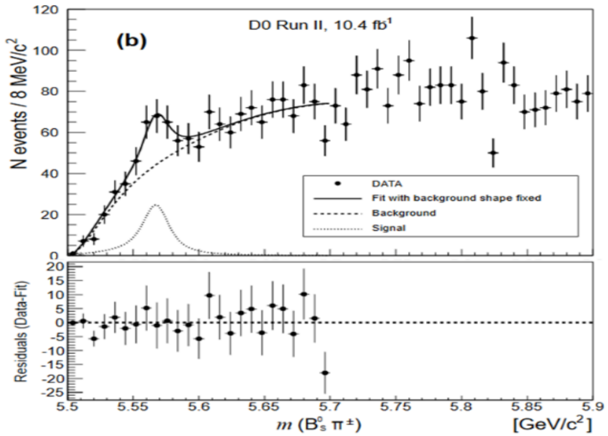
New results are coming. One of them is the evidence for X(5568) → Bs π^+ by D0 Collaboration.

$X(5568)^+ \rightarrow B_s\, \pi^+$ in D0

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

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

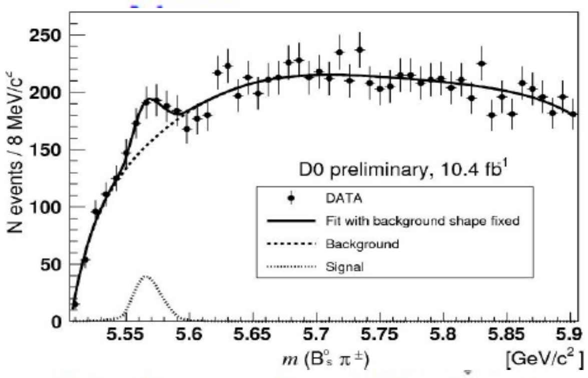
PRL 117. 022003(2016)



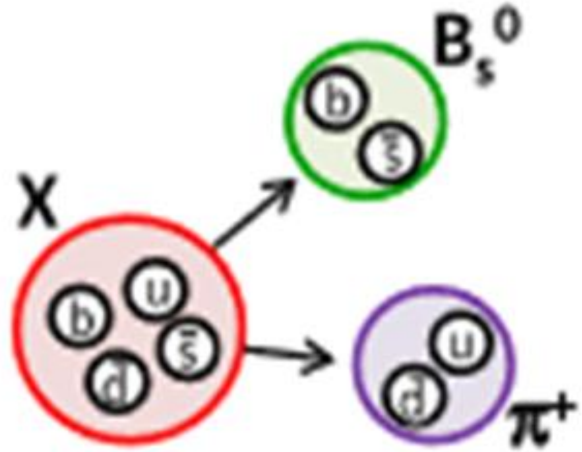
$$M = 5567.8 \pm 2.9^{+0.9}_{-1.9}\ \text{MeV},$$

$$\Gamma = 21.9 \pm 6.4^{+5.0}_{-2.5}\ \text{MeV},$$

D0 Conf. Note 6896



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



$$\rho_X^{D0} \equiv \frac{\sigma(p\bar{p} \rightarrow X + \text{anything}) \times \mathcal{B}(X \rightarrow B_s^0\pi)}{\sigma(p\bar{p} \rightarrow B_s^0 + \text{anything})}$$

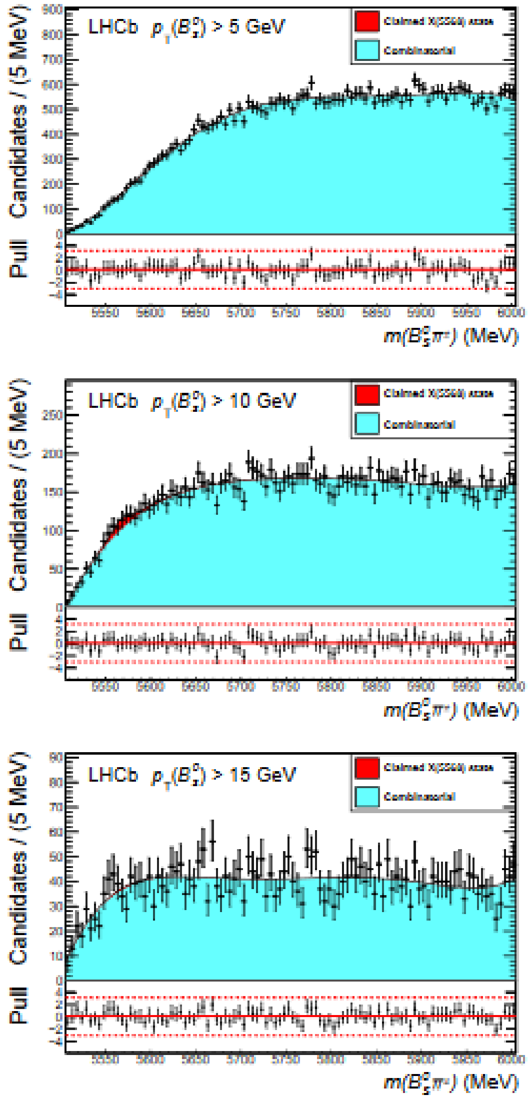
$$= (8.6 \pm 1.9 \pm 1.4)\%$$

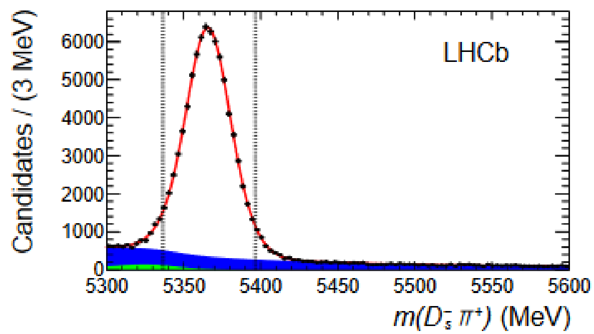
If confirmed, would be unique with 4 different flavours

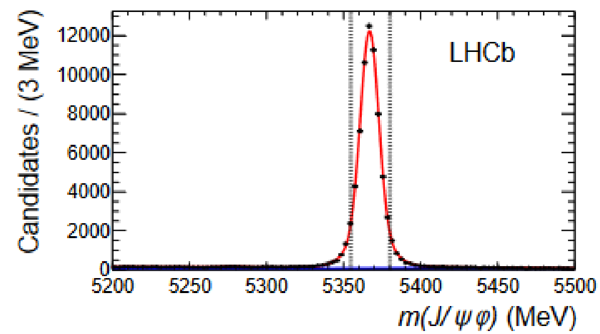
Rather big number for the prompt production of 4-quark exotic state

PRL117. 152003(2016)

$X(5568)^+ \rightarrow B_s\,\pi^+$ in LHCb







$B_s^0 \to D_s^-\pi^+$ $\qquad$ $B_s^0 \to J/\psi\,\phi$

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

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

Search for X(5568)+ in CMS:

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

Search for X(5568) in CMS

CMS-PAS-BPH-16-002

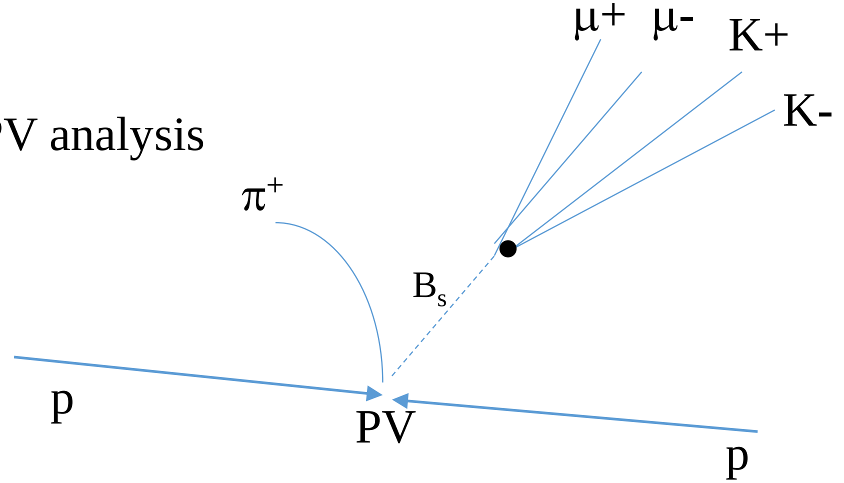
Analysis Strategy:

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

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 4 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.



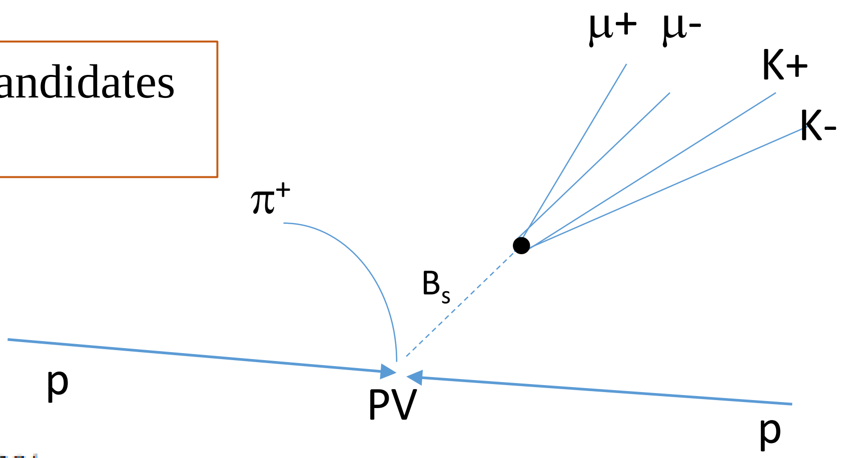
3) Add charged pion from that PV and form Bs pi+ pair

Search for X(5568) in CMS

CMS-PAS-BPH-16-002

Offline Selection Criteria:

CMS probe the pt and η region of the X(5568) candidates closer to the D0 conditions



- $p_T(\mu^\pm) > 4$ 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

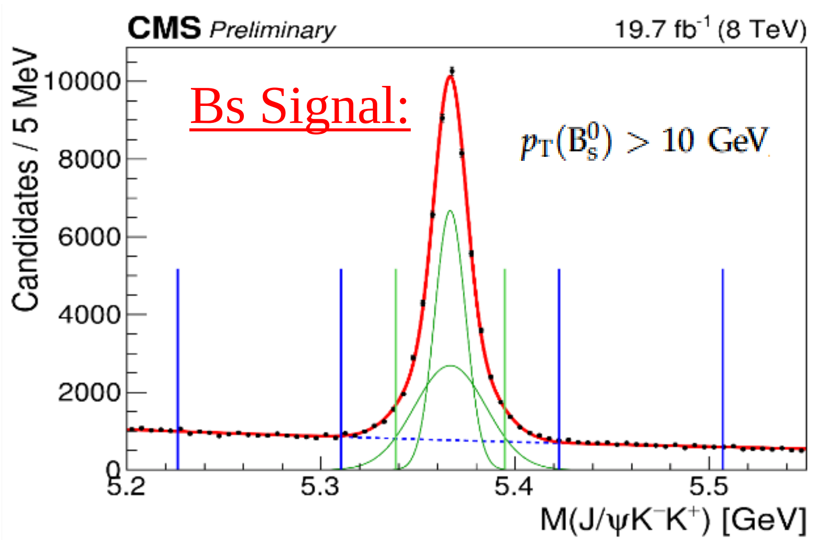
$P_{vtx}(\mu^+\mu^-K^+K^-) > 1\%$, $\cos\alpha_T(B_s^0) > 0.99$, $L_{xy}(Bs)/\sigma_{Lxy(Bs)} > 3$

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

Search for X(5568) in CMS

CMS-PAS-BPH-16-002

51398 ± 283 B_s signal candidates

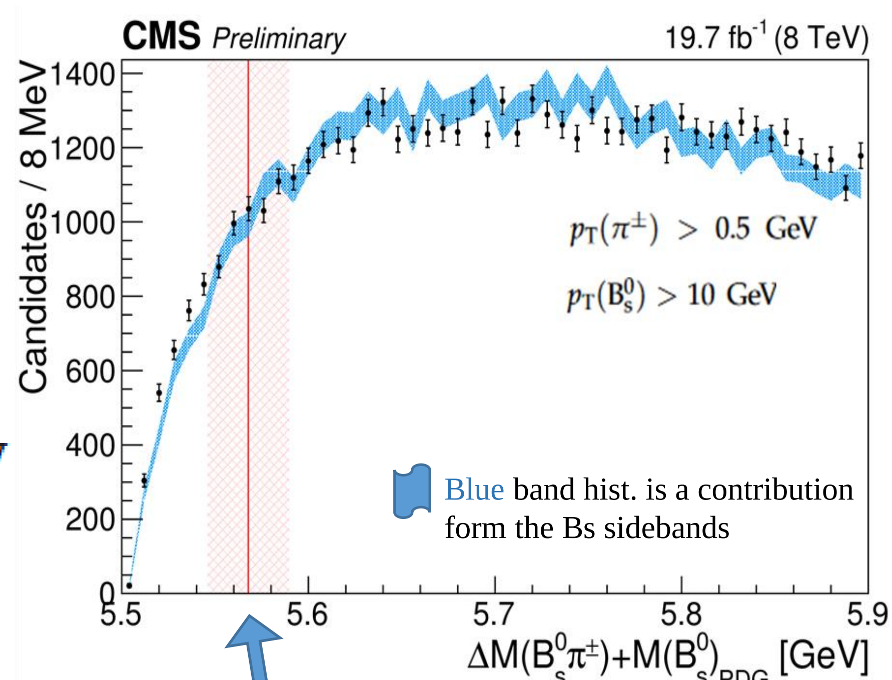


$$\sigma_{eff} = \left[(1-f)\sigma_1^2 + f\sigma_2^2\right]^{1/2} \simeq 14 \text{ MeV}$$

$$|M(J/\psi K^+K^-) - m_{B_s^0}^{fit}| < 2\sigma_{eff}$$

48204 Bs signal events (purity=93.8%)

Combine the Bs candidate with each π+ from the collection of tracks building selected PV



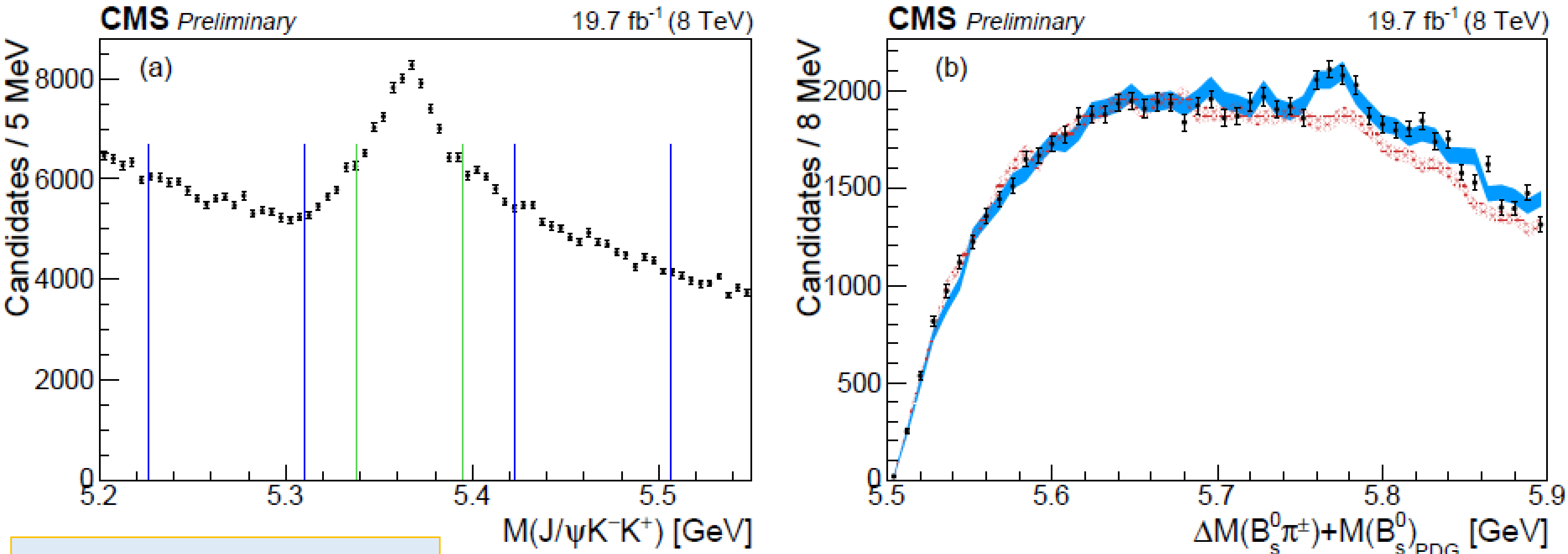
No hints for the X(5568) signal

Comparison of Bs statistics

Factor **1.16** larger than LHCb reconstructed in the same momentum interval and **9.13** larger than D0 sample.

Search for X(5568) in CMS: *the cross-check*

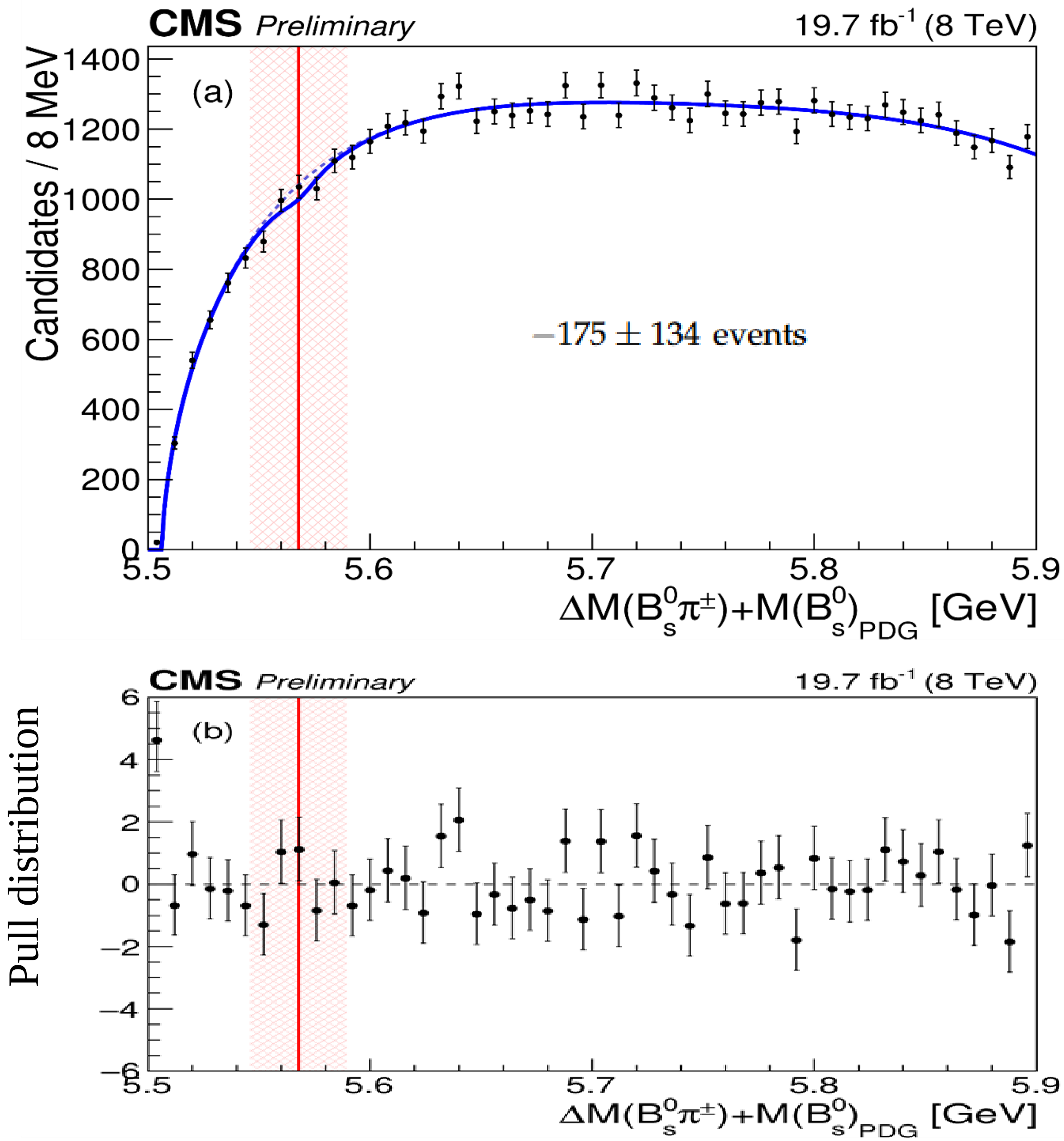
(a) $J/\psi K^+K^-$ invariant mass distribution of events for which the K^+K^- invariant mass window is removed and $p_T(B_s^0) > 25\,\text{GeV}$, $p_T(\pi^\pm) > 1\,\text{GeV}$, $p_T(K^\pm) > 1\,\text{GeV}$ (black points with error bars). The $B^0 \to J/\psi K^+\pi^-$ decay contaminates the signal and the right side-band regions. (b) $M^\Delta(B_s^0\pi^\pm)$ distribution with the requirement on $M(K^+K^-)$ removed and $p_T(B_s^0) > 25\,\text{GeV}$, $p_T(\pi^\pm) > 1\,\text{GeV}$, $p_T(K^\pm) > 1\,\text{GeV}$ for the B_s^0 signal (black points with error bars), B_s^0 left sideband (red band, made of stars) and B_s^0 right sideband (blue dotted band) regions. All distributions are equally normalized from the mass threshold up to 5.74 GeV. Contributions from $B_{1,2}^{(*)+} \to B^{(*)0}\pi^+$ decays (and the charge-conjugate ones) are clearly seen around $M^\Delta(B_s^0\pi^\pm) \sim 5.77\,\text{GeV}$ and higher masses, as expected, coming only from the B_s^0 signal and right sideband regions.



CMS-PAS-BPH-16-002

Search for X(5568) in CMS - fit results

CMS-PAS-BPH-16-002



Fit function = Signal+Background

Signal = S-wave Breit-Wigner with fixed M and Γ to D0 values

Background = $(x - \tilde{x}_0)^\alpha \times \mathrm{Pol}n(x)$

No hints for X(5568) signal

Search for X(5568) in CMS

CMS-PAS-BPH-16-002

Varying selection criteria,
Background parameterization,
Fit range and method of data description

In every case the obtained yield of $X(5568)$ is consistent with zero.

The most conservative upper limit obtained within these variations is 198 at 95% CL.

Preliminary Result: Upper Limit on the ratio of production cross-sections

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

< 3.9% @95% CL

(rel.eff.~10%)

The most conservative estimation of the efficiency ratio, determined from preliminary simulations, leads to an upper limit of $\rho_X < 3.9\%$ at 95% CL, which can be compared against the DØ measurement of $(8.6 \pm 1.9 \pm 1.4)\%$ [1].

Summary

(1) X(5568)+ → Bs π+ was found by the D0 Collaboration [PRL117.022003(2016)].
The ratio of production cross sections was measured to be

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

(2) LHCb Collaboration published [PRL117.152003(2016)] their search for X(5568)+ → Bs π+ in pt(Bs)>5, 10, 15 GeV regions and find no evidence for signal. Upper Limit on the ratio of production cross-sections in pt(Bs)>10 GeV region is **< 2.1% @90%CL**

(3) Search for X(5568) in CMS was performed *in similar conditions to the D0.*
The search gives null result: no X(5568) is evident in the Bs π+ mass spectrum.
The preliminary result [CMS-PAS-BPH-16-002] for UL on the ratio of production cross-sections in pt(Bs)>10 GeV region is **< 3.9% @95%CL**

The final result on the UL of ρ_X from 8 TeV data sample in CMS will be released very soon.