

# *SEARCH FOR STRUCTURE IN THE $B_s^0 \pi^\pm$ INVARIANT MASS SPECTRUM*

**LHCb-CONF-2016-004**

<http://cds.cern.ch/record/2140095/>

A decorative graphic on the left side of the slide consisting of several blue circles of varying sizes, arranged in a vertical cluster.

**Marco Pappagallo**

University and INFN Bari

On behalf of the LHCb collaboration

LHC Seminar, 22 March 2016, CERN

# A NEW $B_s^0 \pi^\pm$ STATE CLAIMED BY DØ

[DØ: arXiv:1602.07588]

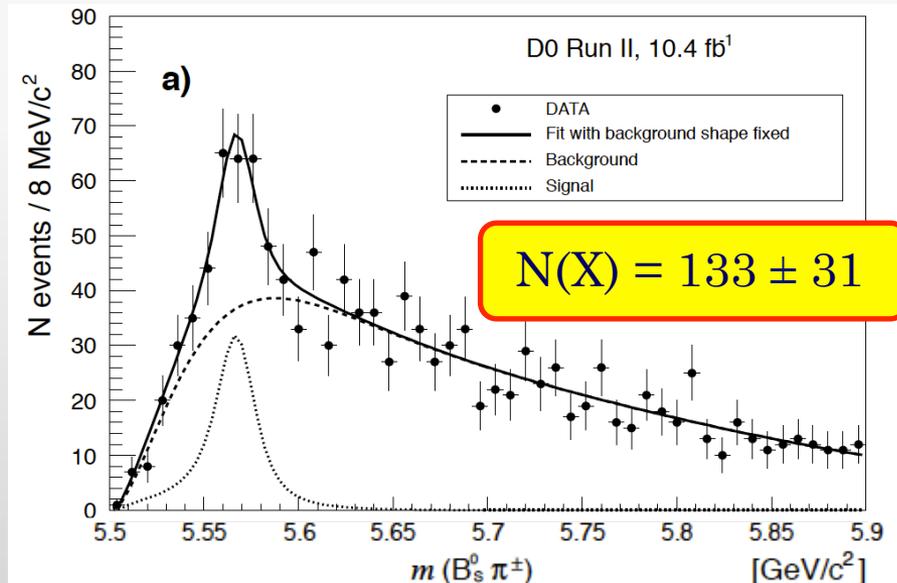
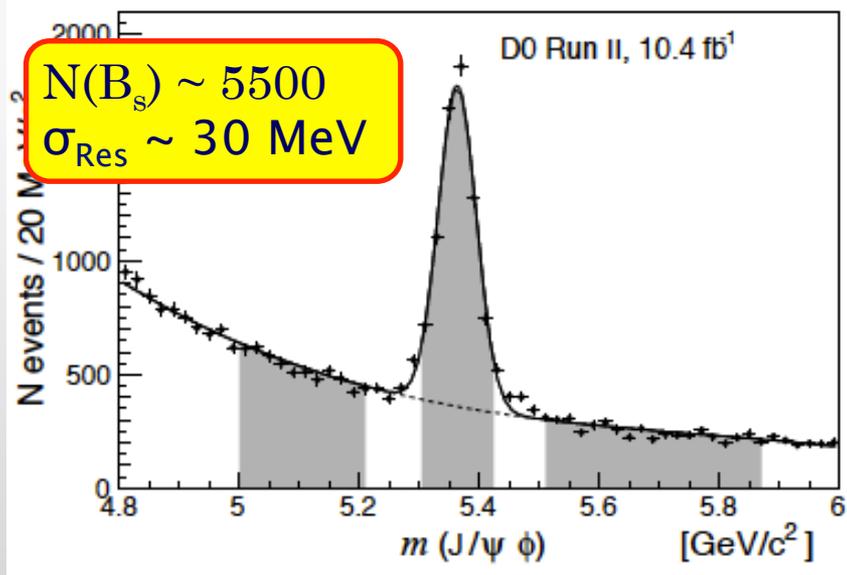
Claimed observation with  $5.1 \sigma$  significance of an exotic state

✓  $X(5568) \rightarrow B_s^0 \pi^\pm$ ,  $B_s^0 \rightarrow J/\psi \phi$ ,  $J/\psi \rightarrow \mu^+ \mu^-$ ,  $\phi \rightarrow K^+ K^-$

$$M = 5567.8 \pm 2.9_{-1.9}^{+0.9} \text{ MeV}/c^2$$

$$\Gamma = 21.9 \pm 6.4_{-2.5}^{+5.0} \text{ MeV}/c^2$$

✓ Fraction of  $B_s^0$  from X decay:  $\rho_X^{\text{DØ}} = (8.6 \pm 1.9 \pm 1.4) \%$



# WHAT COULD IT BE?

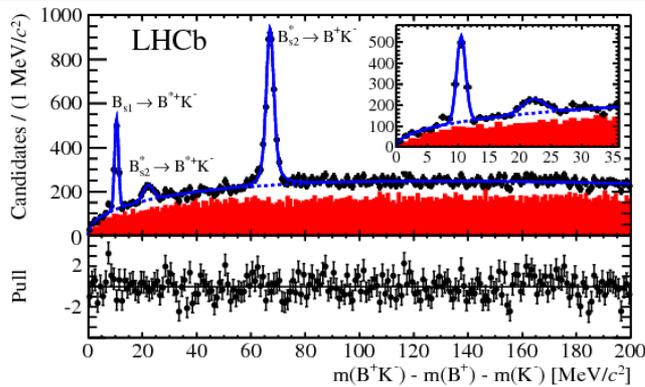
- Citation rate: 0.7 paper/day (source: INSPIRE)
- Most claiming that it fits the author's favourite model
  - ✓ Measured mass well below the BK threshold => Tight bound state in the molecular picture => Disfavored
  - ✓ Diquark-Antidiquark models are popular
- Notable exception: Burns&Swanson arXiv:1603.04366
  - ✓ Threshold, cusp, molecular, and tetraquark models are all unfavoured

- Many exotic states discovered recently, so why not another one?
  - ✓ Would be unique with 4 different flavours ( $\bar{b}sud$ )
  - ✓ No onia ( $c\bar{c}$  or  $b\bar{b}$ ) component
  - ✓ It might be  $0^+ \rightarrow B_s \pi$  or feed-down of  $1^+ \rightarrow B_s^* (B_s \gamma) \pi$
  - ✓ Some papers match X(5568) to  $D_{s0}^*(2317)$ , others predict a charmed partner at  $m = 2.55$  GeV. Large uncertainties  $O(100$  MeV)

# ANALYSIS STRATEGY

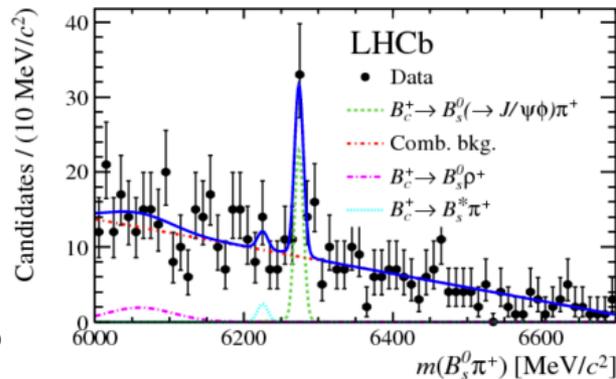
Stick closely to tried and trusted analysis methods

1<sup>st</sup> observation of  $B_{s2}^{*0} \rightarrow B^{*+} K^{-}$



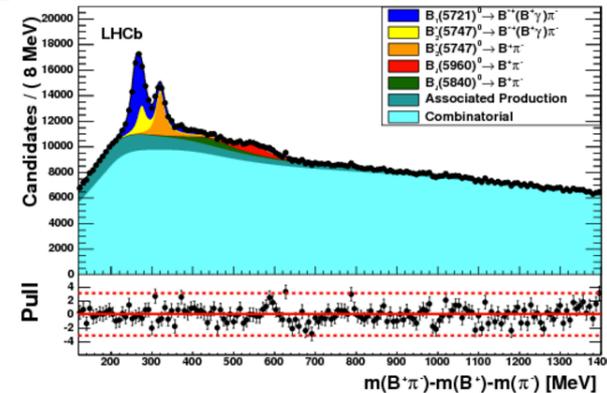
PRL 110 (2013) 151803

1<sup>st</sup> observation of  $B_c^+ \rightarrow B_s^0 \Pi^+$



PRL 111 (2013) 181801

$B^+ \Pi^-$  &  $B^0 \Pi^+$

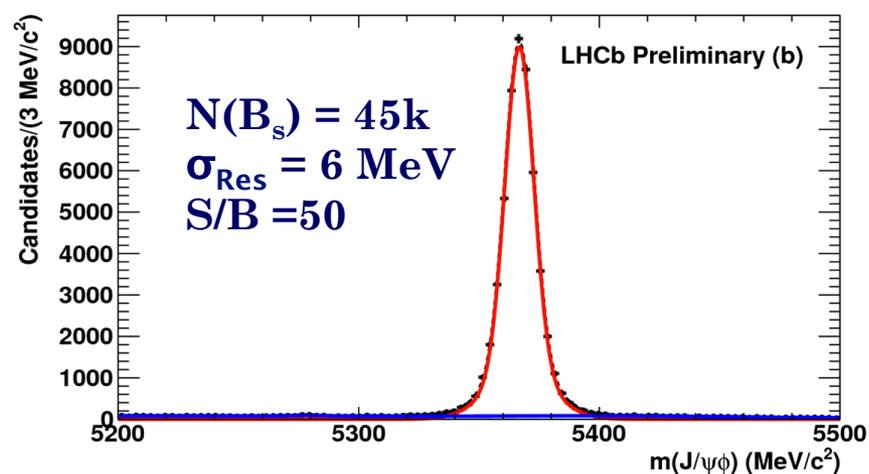
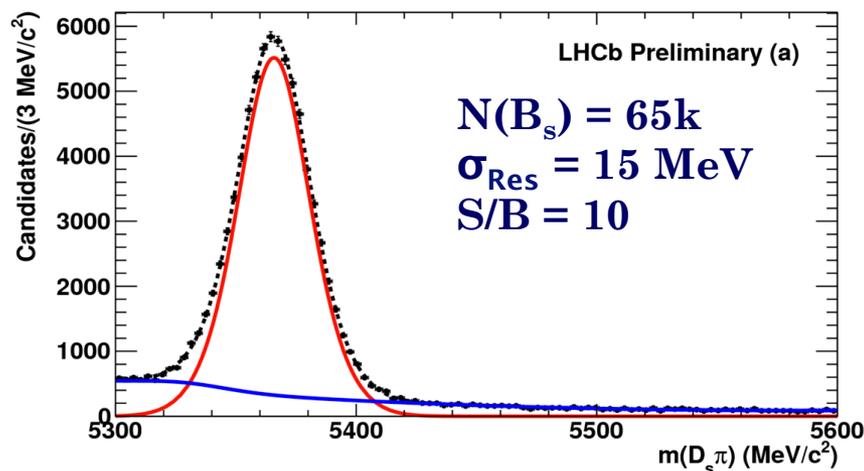


JHEP 1504 (2015) 024

Initially 3 independent selections, confirm qualitative agreement, then proceed with single baseline approach

# B<sub>s</sub> SELECTION

- RUN I data (3 fb<sup>-1</sup>)
- Cut-based selections aiming to very clean B<sub>s</sub><sup>0</sup> samples
  - ✓ Both B<sub>s</sub><sup>0</sup> → D<sub>s</sub><sup>-</sup>π<sup>+</sup> and J/ψ φ (Mass constraints on the D<sub>s</sub> and J/ψ)
  - ✓ Track quality, impact parameter & vertex quality cuts
  - ✓ PID and vetoes to remove mis-ID backgrounds
  - ✓ Baseline: p<sub>T</sub>(B<sub>s</sub><sup>0</sup>) > 5 GeV/c; Tight: p<sub>T</sub>(B<sub>s</sub><sup>0</sup>) > 10 GeV/c to match the DØ selection



B<sub>s</sub> sample 20x larger and much cleaner than DØ

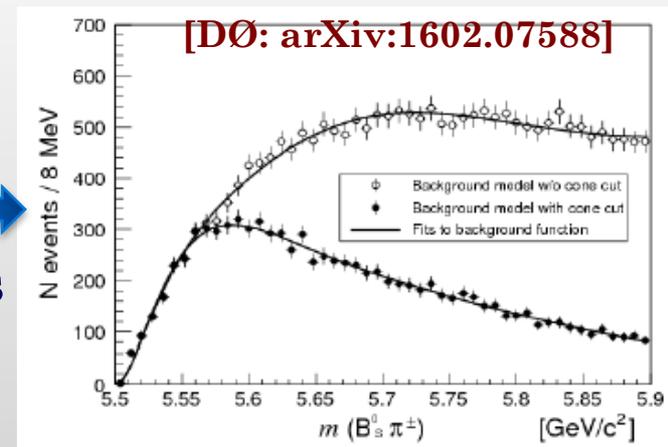
# SELECTION OF $B_s \pi^\pm$ CANDIDATES

- Require  $B_s^0$  and  $\pi$  to come from same PV & form good quality vertex
- $p_T(\pi) > 500$  MeV/c; loose pion PID requirement
- Candidates refitted by constraining the  $B_s^0$  mass
- Keep multiple candidates ( $\sim$ all same  $B_s^0$  with different  $\pi$ )
- *All very similar to previous analyses*

No “cone” cut:

$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

because highly correlated with mass



## Signal

- Signal shape is *S*-wave Breit-Wigner
  - ✓ Mass and width parameters fixed to the  $D\bar{0}$  central values (varied in systematics)
  - ✓ Mass resolutions are negligible  $O(1\text{MeV})$

## Background

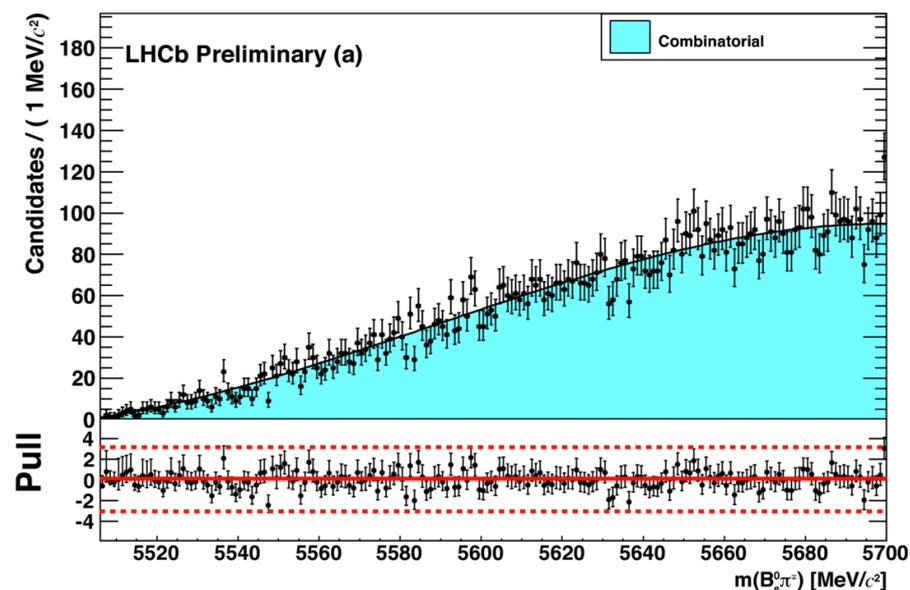
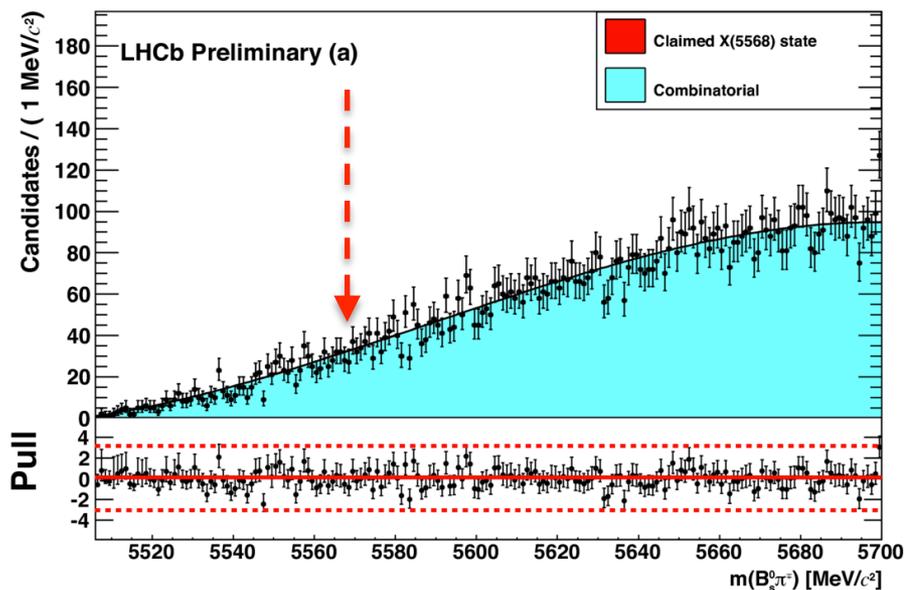
- Two possible sources of background:
  - True  $B_s^0$  with random track (dominant but hard to study – investigate with MC)
  - Fake  $B_s^0$  with random track (subdominant but can use  $B_s^0$  sidebands)
- Fortunately, background shape is consistent for both, and can be modeled with a polynomial

# FIT RESULT (I)

(Both modes combined:  $p_T(B_s) > 5 \text{ GeV}/c$ )

Fit with signal component

Fit without signal component

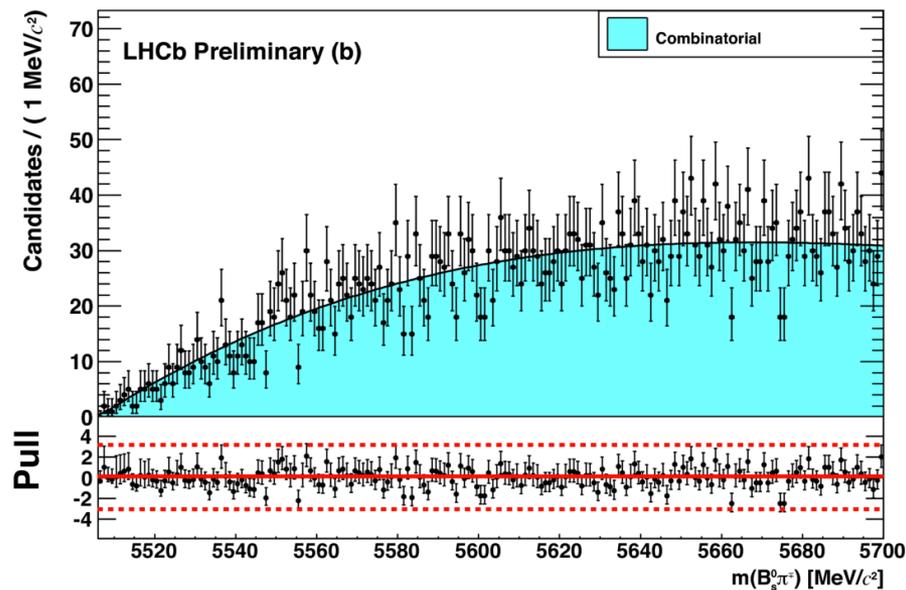
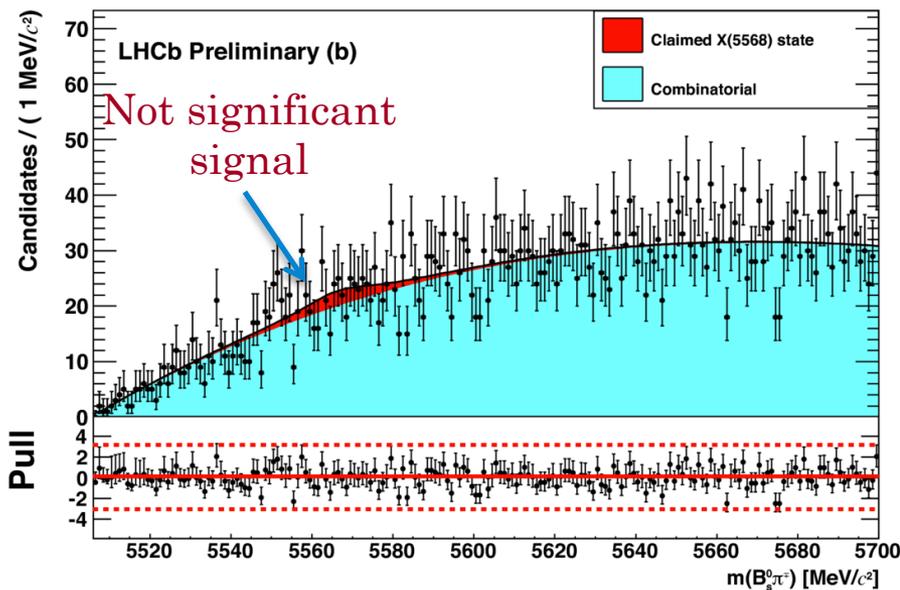


# FIT RESULT (II)

(Both modes combined:  $p_T(B_s) > 10 \text{ GeV}/c$ )

Fit with signal component

Fit without signal component



# NUMERICAL RESULT (I)

		$B_s^0 \rightarrow D_s^- \pi^+$	$B_s^0 \rightarrow J/\psi \phi$	Sum
$N(B_s^0)$	$B_s^0 p_T > 5 \text{ GeV}/c$ ( $10^3$ )	$66.3 \pm 0.3$	$46.3 \pm 0.2$	$112.6 \pm 0.4$
$N(B_s^0)$	$B_s^0 p_T > 10 \text{ GeV}/c$ ( $10^3$ )	$30.1 \pm 0.2$	$14.1 \pm 0.1$	$44.2 \pm 0.2$
$N(X)$	$B_s^0 p_T > 5 \text{ GeV}/c$	$23 \pm 55$	$-15 \pm 37$	$8 \pm 66$
$N(X)$	$B_s^0 p_T > 10 \text{ GeV}/c$	$70 \pm 48$	$11 \pm 30$	$81 \pm 57$
$\epsilon^{\text{rel}}(X)$	$B_s^0 p_T > 5 \text{ GeV}/c$	$0.141 \pm 0.002$	$0.102 \pm 0.001$	—
$\epsilon^{\text{rel}}(X)$	$B_s^0 p_T > 10 \text{ GeV}/c$	$0.239 \pm 0.003$	$0.230 \pm 0.003$	—

$\epsilon^{\text{rel}}(X) = \epsilon(X)/\epsilon(B_s^0) \simeq \epsilon(\pi^\pm)$  determined from simulation

# NUMERICAL RESULT (II)

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

$$= \frac{N(X)}{N(B_s^0)} \times \frac{1}{\epsilon^{\text{rel}}(X)}$$



All numbers from previous table

$$\rho_X^{\text{LHCb}}(B_s^0 \rightarrow D_s^- \pi^+; B_s^0 p_T > 5 \text{ GeV}/c) = 0.0025 \pm 0.0059 \pm 0.0021$$

$$\rho_X^{\text{LHCb}}(B_s^0 \rightarrow D_s^- \pi^+; B_s^0 p_T > 10 \text{ GeV}/c) = 0.0097 \pm 0.0067 \pm 0.0052$$

$$\rho_X^{\text{LHCb}}(B_s^0 \rightarrow J/\psi \phi; B_s^0 p_T > 5 \text{ GeV}/c) = -0.0032 \pm 0.0079 \pm 0.0027$$

$$\rho_X^{\text{LHCb}}(B_s^0 \rightarrow J/\psi \phi; B_s^0 p_T > 10 \text{ GeV}/c) = 0.0034 \pm 0.0092 \pm 0.0034$$

$$\rho_X^{\text{LHCb}}(B_s^0 p_T > 5 \text{ GeV}/c) = 0.0004 \pm 0.0050_{\text{stat.}+\text{syst.}}$$

$$\rho_X^{\text{LHCb}}(B_s^0 p_T > 10 \text{ GeV}/c) = 0.0070 \pm 0.0064_{\text{stat.}+\text{syst.}}$$

Combination by weighted average, assuming no correlations

# SYSTEMATIC UNCERTAINTIES

## ➤ $N(X)$

- ✓ **Changing mass and width parameters by  $\pm 1\sigma$  (DØ range)**
- ✓ Using P-wave Breit-Wigner, instead of S-wave
- ✓ **Effect of efficiency dependence on signal shape**

Dominant



## ➤ $N(B_s^0)$

- ✓ Changing fit function or using sideband subtraction

## ➤ $\epsilon^{\text{rel}}(X)$

- ✓ MC statistics
- ✓ Effect of efficiency dependence on  $m(B_s^0\pi)$
- ✓ Companion pion reconstruction efficiency data/MC difference
- ✓ Companion pion PID efficiency data/MC difference

*Systematic uncertainties result always smaller than statistical errors*

# UPPER LIMITS ON THE PRODUCTION OF X(5568) AT LHCb



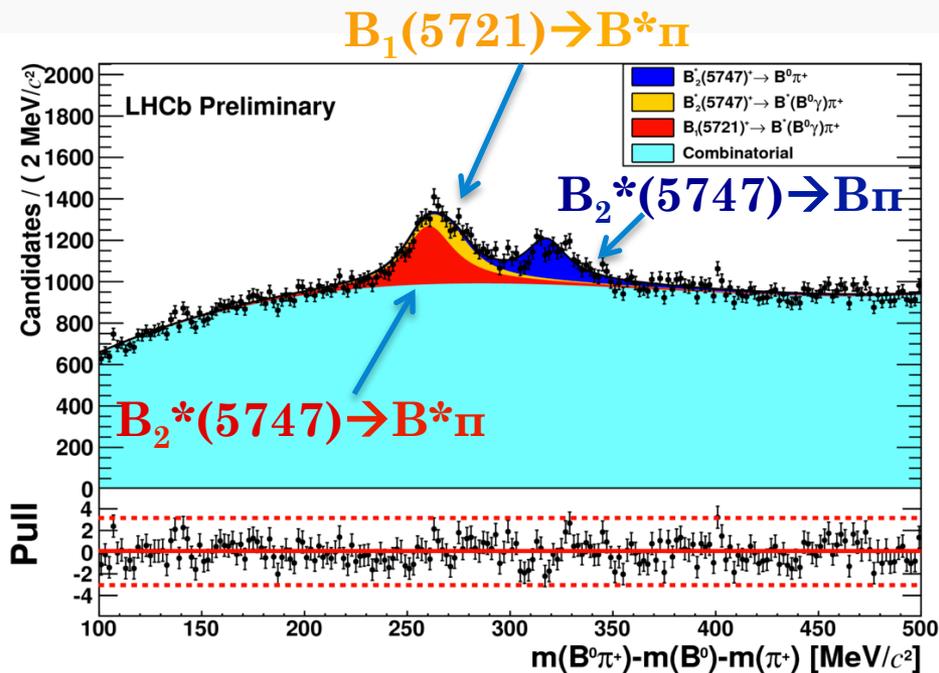
LHCb-CONF-2016-004

Since the signal is not significant, upper limits on  $\rho_X^{\text{LHCb}}$  are obtained by integration of the likelihood in the physical (non-negative  $\rho$ ) region:

$$\begin{aligned}\rho_X^{\text{LHCb}}(B_s^0 p_T > 5 \text{ GeV}/c) &< 0.009 (0.010) @ 90 (95) \% \text{ CL} \\ \rho_X^{\text{LHCb}}(B_s^0 p_T > 10 \text{ GeV}/c) &< 0.016 (0.018) @ 90 (95) \% \text{ CL}\end{aligned}$$

# SANITY CHECK: $B^0\pi^+$

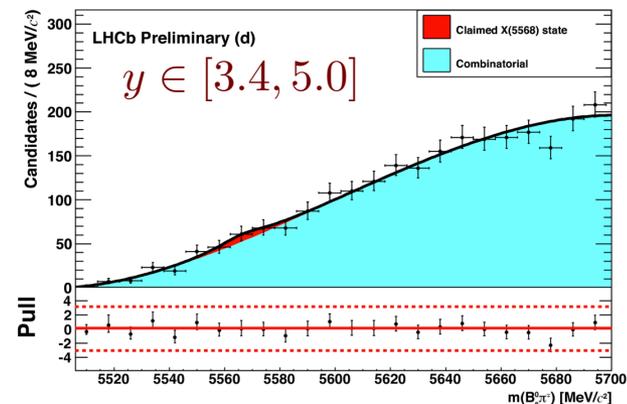
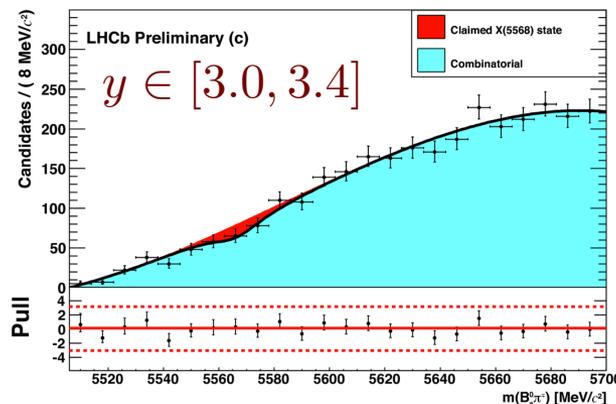
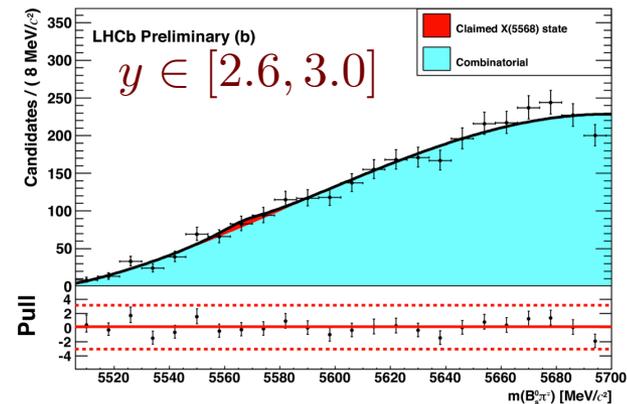
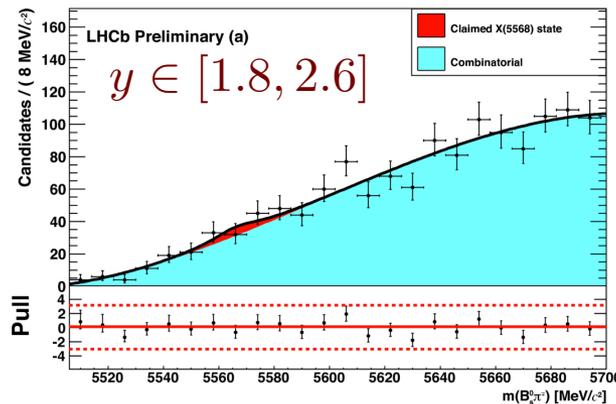
- Large sample of  $B^0 \rightarrow D^- \pi^+$ ,  $D^- \rightarrow K^+ \pi^- \pi^-$  combined with  $\pi^+$
- Selection very similar to  $B_s^0 \pi^\pm$



If production of X(5568) similar to  $B^{**}$ , then large signal expected:  $O(10^3)$  events

# POSSIBLE KINEMATIC DEPENDENCE?

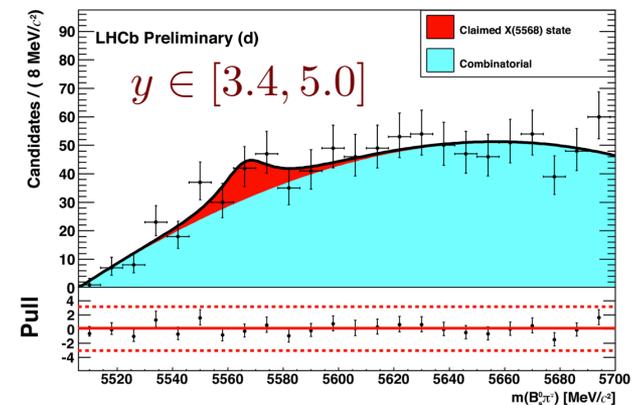
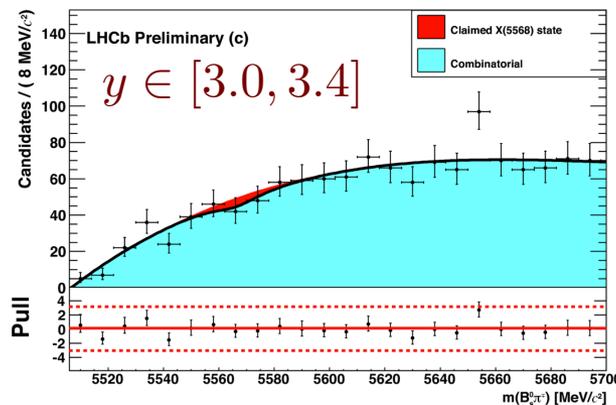
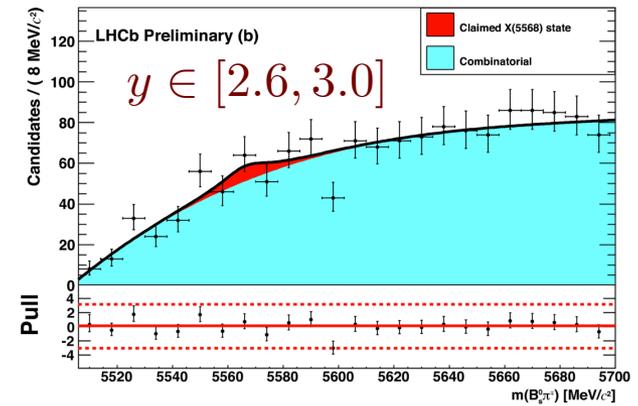
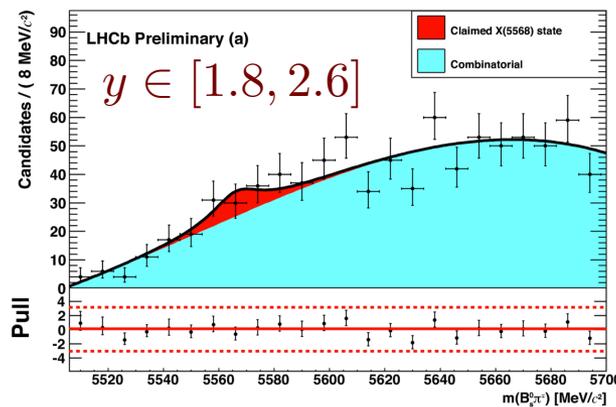
Check in bins of rapidity  
(Both modes combined:  $p_T(B_s) > 5 \text{ GeV}/c$ )



No significant signal

# POSSIBLE KINEMATIC DEPENDENCE?

Check in bins of rapidity  
(Both modes combined:  $p_T(B_s) > 10 \text{ GeV}/c$ )



No significant signal

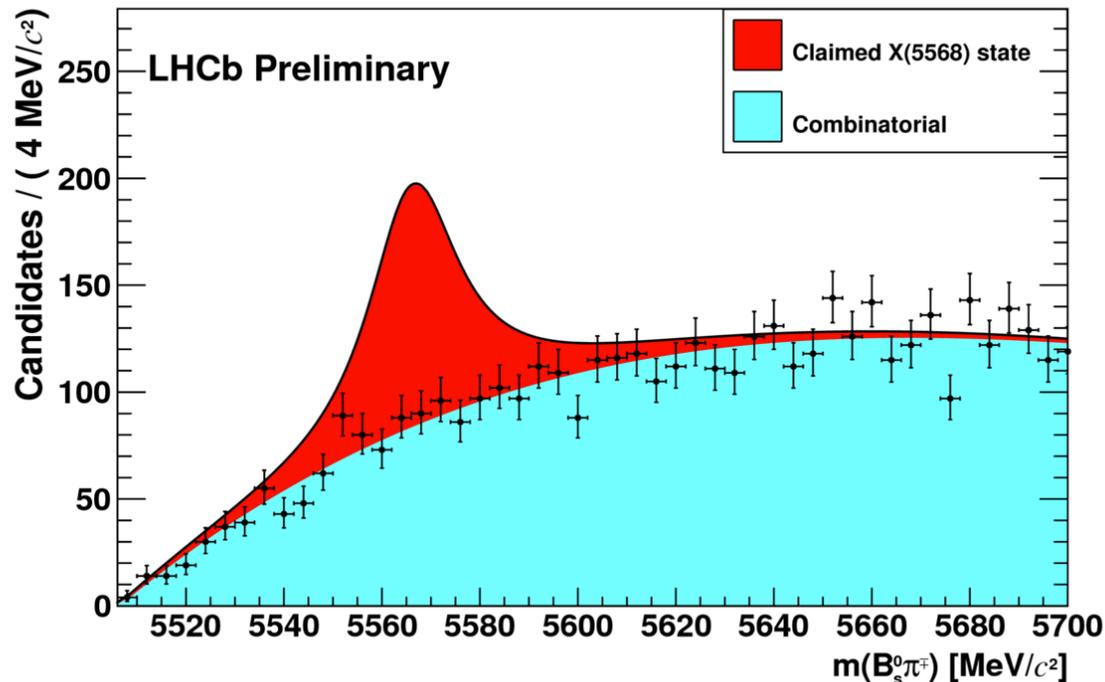
# JUST FOR CURIOSITY...

If  $\rho_X^{\text{LHCb}} = \rho_X^{\text{DØ}} = 8.6\%$ , how would the X(5568) signal look like?

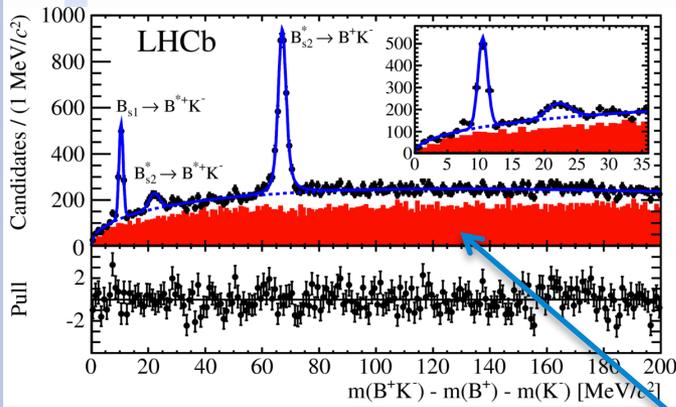
# JUST FOR CURIOSITY...

If  $\rho_X^{\text{LHCb}} = \rho_X^{\text{DØ}} = 8.6\%$ , how would the X(5568) signal look like?

(Both modes combined:  $p_T(\text{B}_s) > 10 \text{ GeV}/c$ )

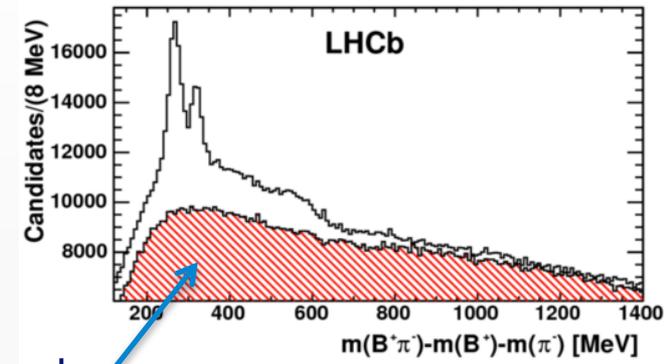


# OTHER "IMPLICIT" SEARCHES



**PRL 110 (2013) 151803**

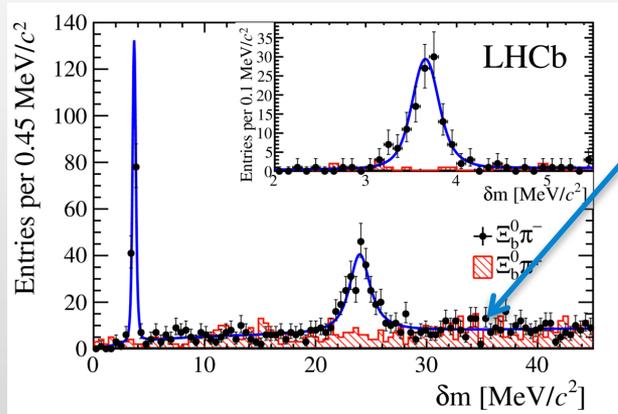
$B^+K^-$



**JHEP 1504 (2015) 024**

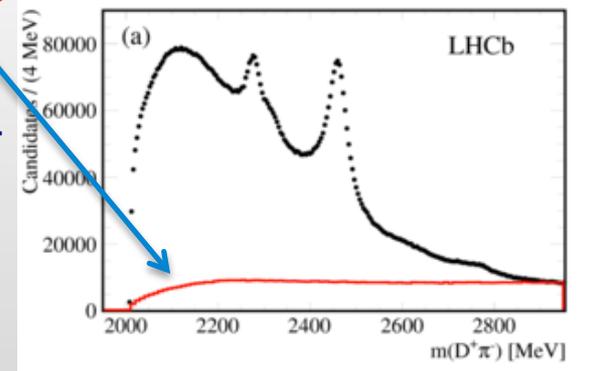
$B^+\pi^+$

The red histograms, referred as Wrong Sign plots, are implicitly searches for tetra/pentaquark



**PRL 114 (2015) 062004**

$\Xi_b^0 \pi^+$



**JHEP 09 (2013) 145**

$D^+\pi^+$

# CONCLUSION

- A search for the  $X(5568) \rightarrow B_s^0 \pi^\pm$  has been performed at LHCb by using the RUN I dataset ( $3 \text{ fb}^{-1}$ )
- A complete analysis, including generating dedicated MC samples, and the internal review procedure resulting in a public document, performed in  $< 4$  weeks
- No evidence of the claimed  $X(5568)$  state

$$\rho_X^{\text{LHCb}}(B_s^0 p_T > 5 \text{ GeV}/c) < 0.009 (0.010) @ 90 (95) \% \text{ CL},$$
$$\rho_X^{\text{LHCb}}(B_s^0 p_T > 10 \text{ GeV}/c) < 0.016 (0.018) @ 90 (95) \% \text{ CL}.$$

*LHCb will continue to study exotic and non-exotic spectroscopy in data from Run I, Run II and (with an upgraded detector) Run III.  
In the meantime...*

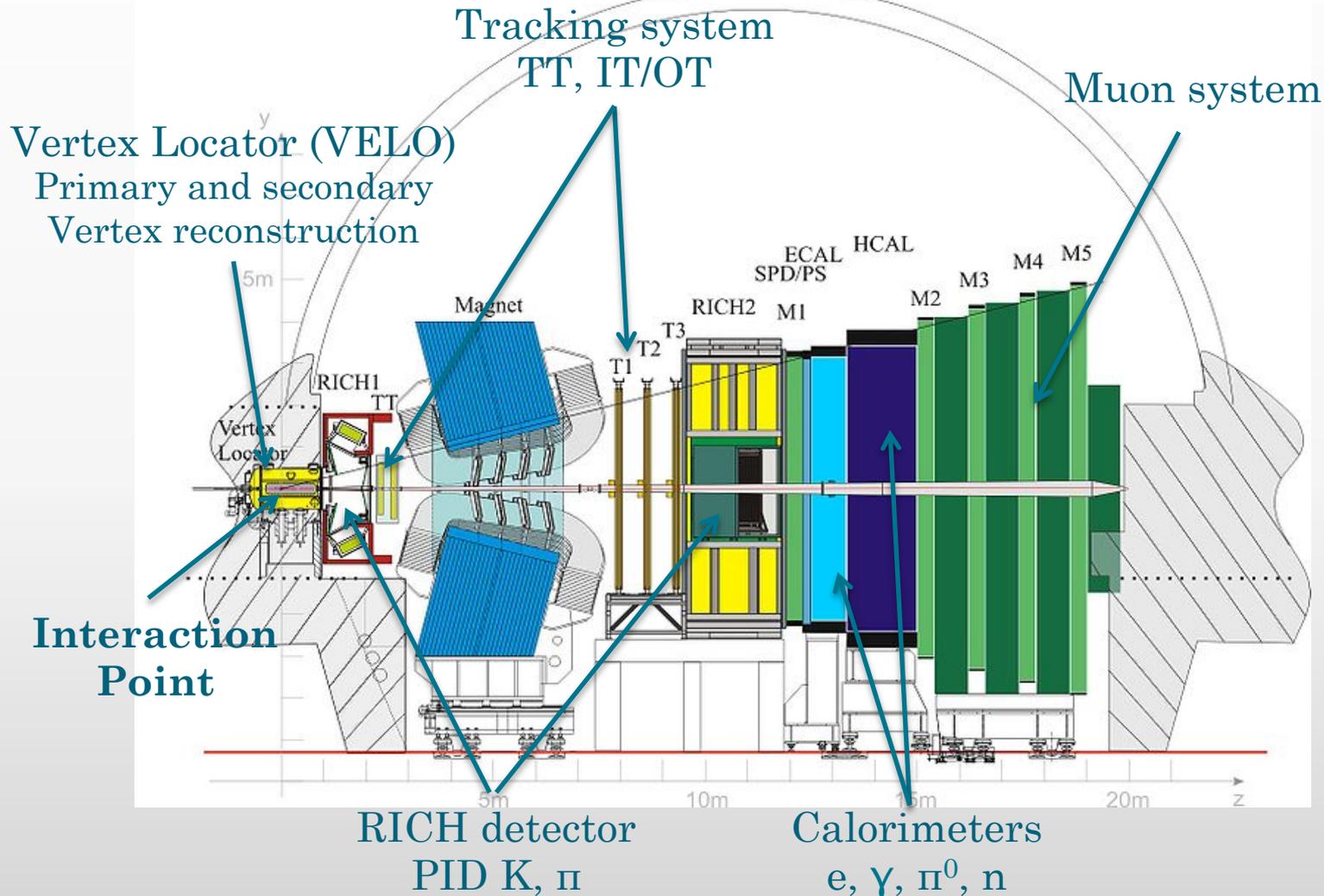
*...we look forward to hearing from ATLAS, CMS and CDF about X(5568)*



# Back-up slides

# THE LHCb DETECTOR

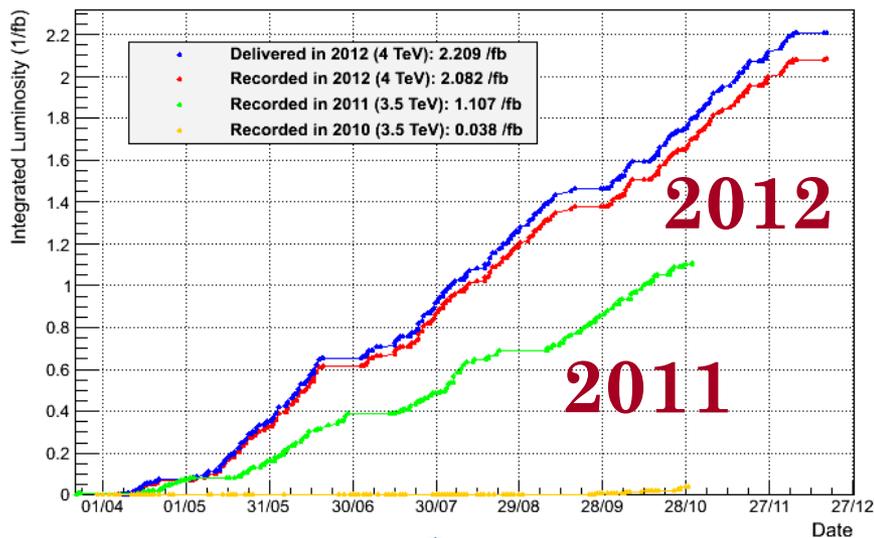
JINST 3 (2008) S08005



# DATASETS

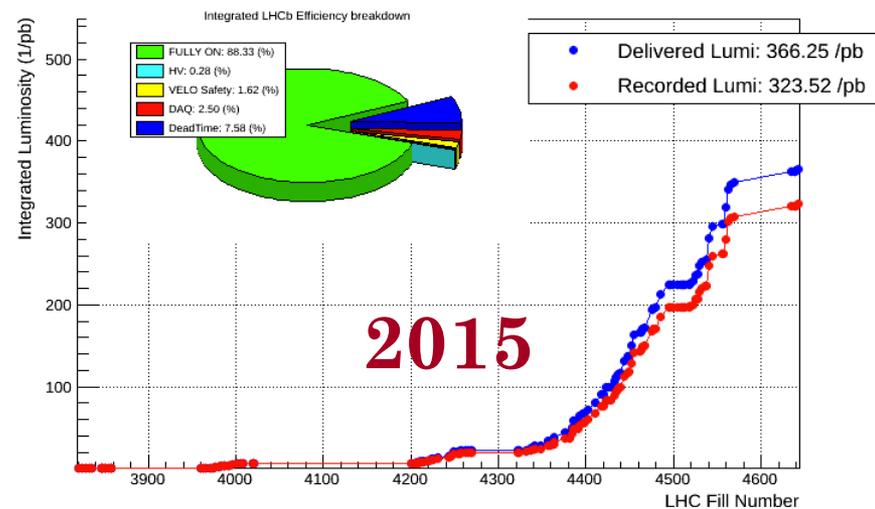
LHCb collected  $1. \text{ fb}^{-1}$  at 7 TeV (2011) +  $2. \text{ fb}^{-1}$  at 8 TeV (2012) +  $0.3 \text{ fb}^{-1}$  at 13 TeV (2015)

LHCb Integrated Luminosity pp collisions 2010-2012



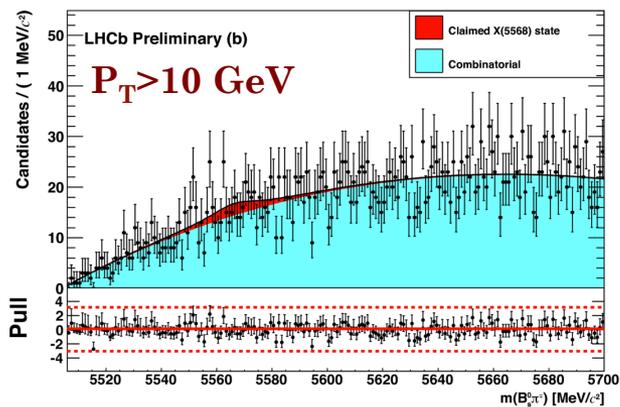
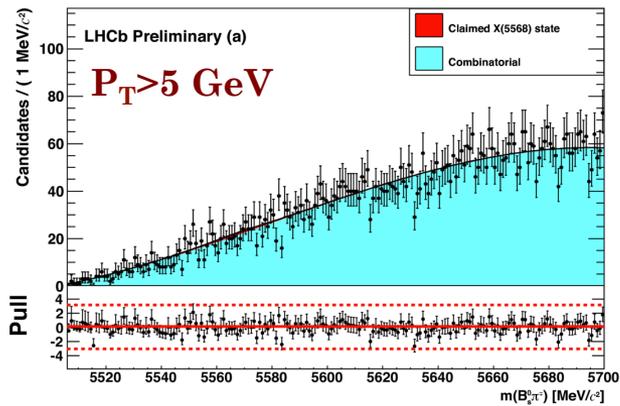
Used for this analysis

LHCb Integrated Luminosity at p-p in 2015



# FIT RESULTS SPLIT BY $B_s$ DECAY MODE

$B_s \rightarrow D_s \pi$



$B_s \rightarrow J/\psi \phi$

