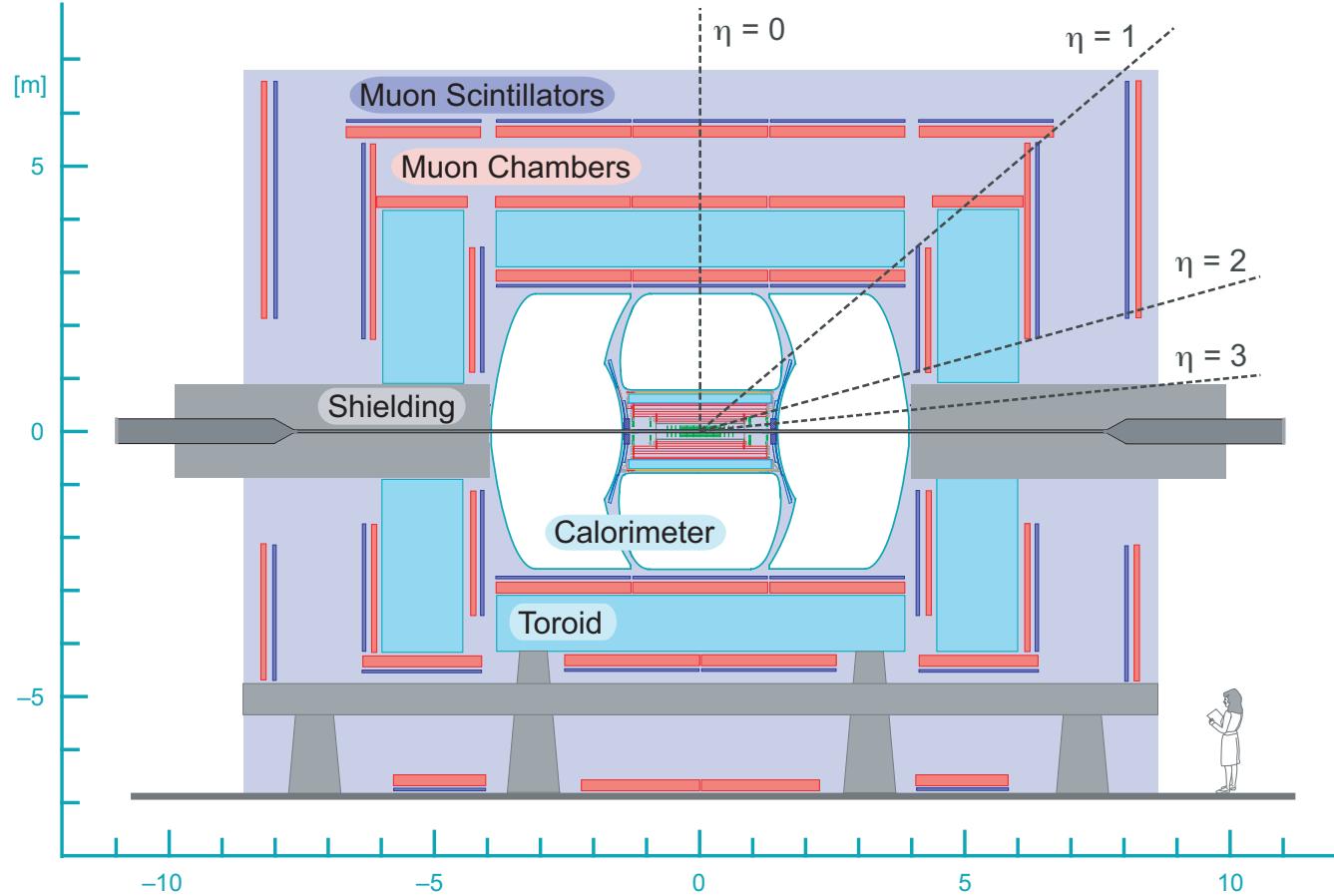


Part I: Heavy baryon forward-backward  
asymmetries in  $p\bar{p}$  collisions

Part II: Confirmation of the exotic state  
 $X(5568) \rightarrow B_s^0 \pi^\pm$  in  $p\bar{p}$  collisions

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Universidad San Francisco de Quito  
Representing the DØ Collaboration  
EPS-HEP 5-12 July 2017



The DØ detector at the  $p\bar{p}$  Tevatron collider.  $\sqrt{s} = 1.96$  TeV.

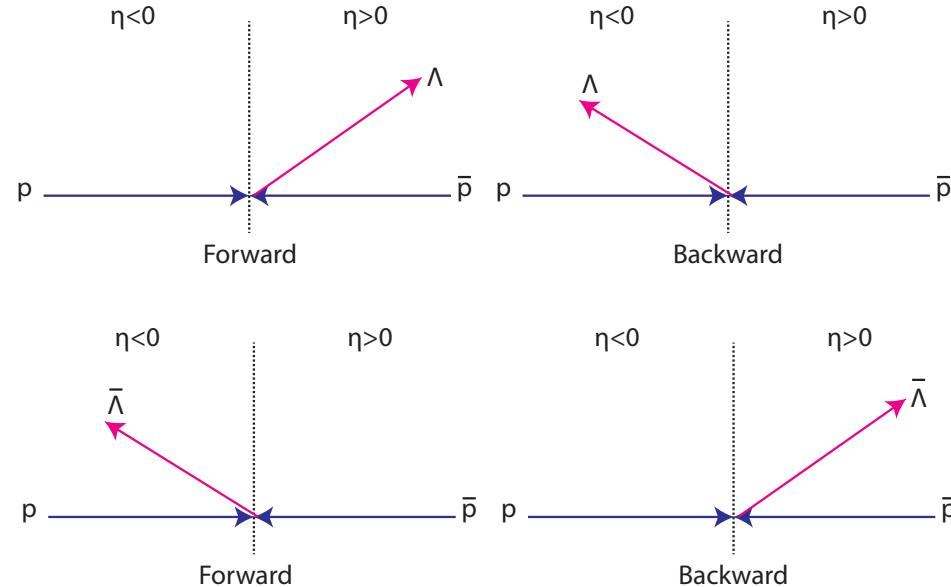
## Part I: Heavy baryon forward-backward asymmetries in $p\bar{p}$ collisions

The DØ detector is well suited to measure forward-backward asymmetries:

- the initial state is CP eigenstate  $p\bar{p}$ ,
- the solenoid and toroid magnetic fields are reversed periodically allowing studies and cancellations of systematic uncertainties.

Measurements of forward-backward asymmetries are a legacy of the Tevatron that test models of forward production.

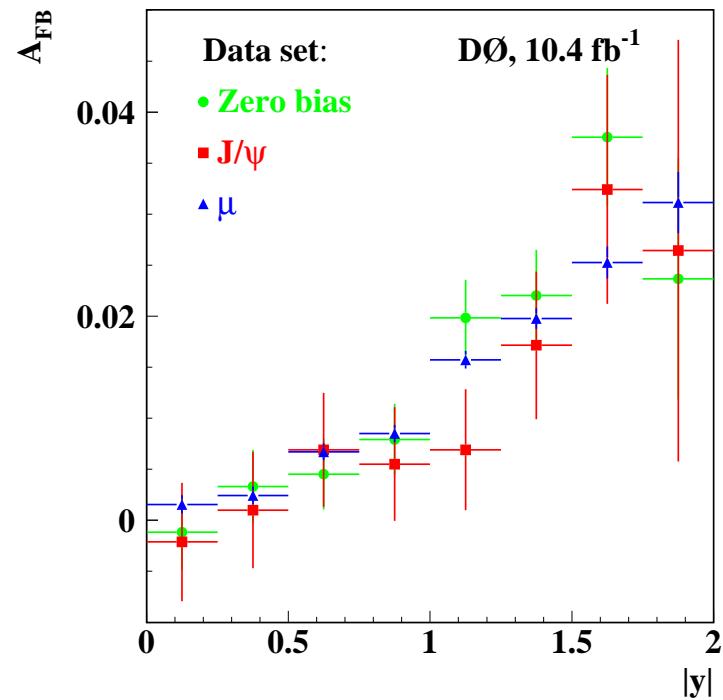
Definition of the forward-backward asymmetry  $A_{FB}(\Lambda, \bar{\Lambda})$ :



Forward  $\Lambda$ 's have longitudinal momentum in the  $p$  direction.  
 Forward  $\bar{\Lambda}$ 's have longitudinal momentum in the  $\bar{p}$  direction.

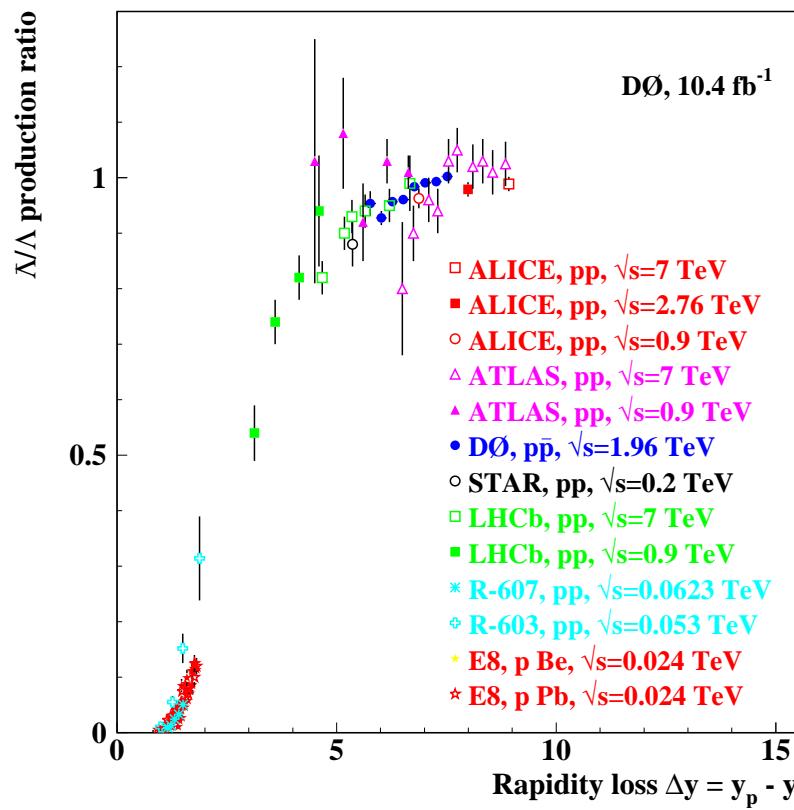
Asymmetry in a bin of rapidity  $|y|$ :  $A_{FB} \equiv \frac{N_F - N_B}{N_F + N_B}$

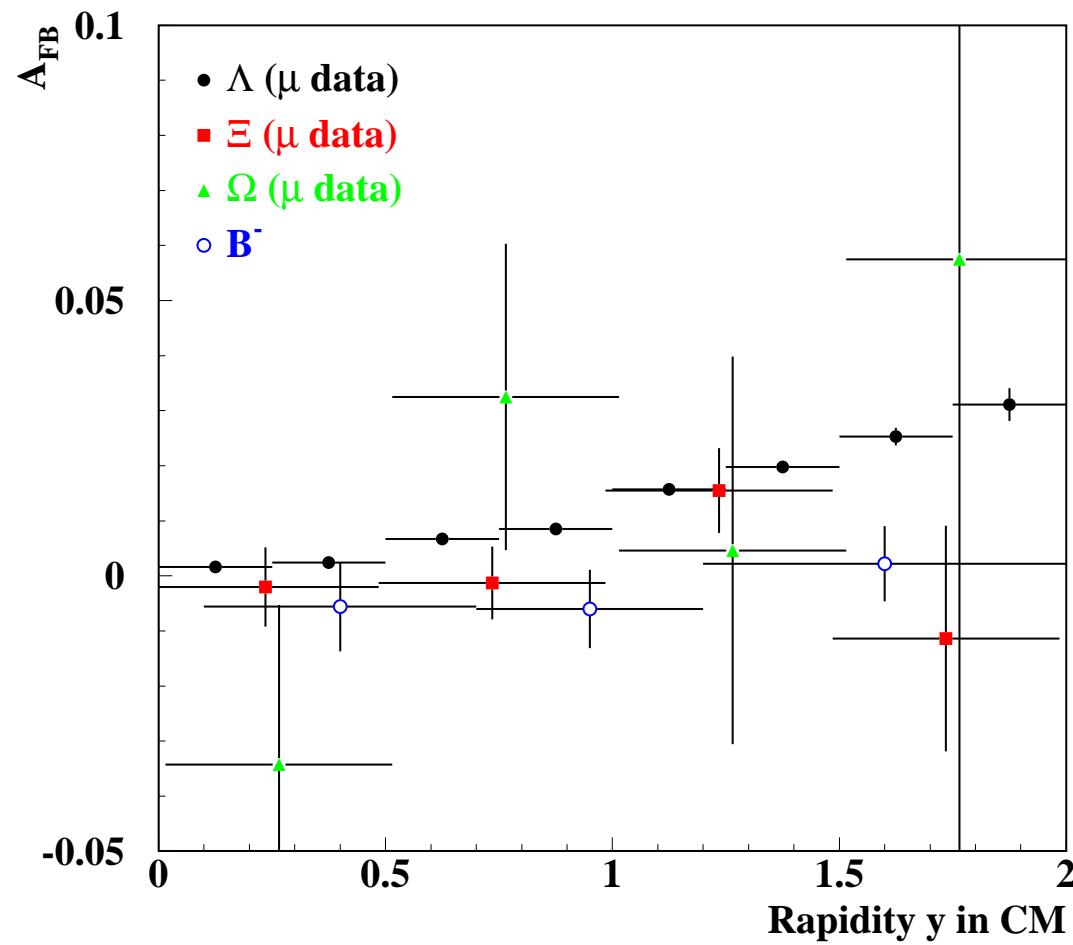
Forward-backward asymmetry  $A_{FB}(\Lambda, \bar{\Lambda})$  in  $p\bar{p}$  collisions.



Phys. Rev. D 93, 032002 (2016), arXiv:1511.05113

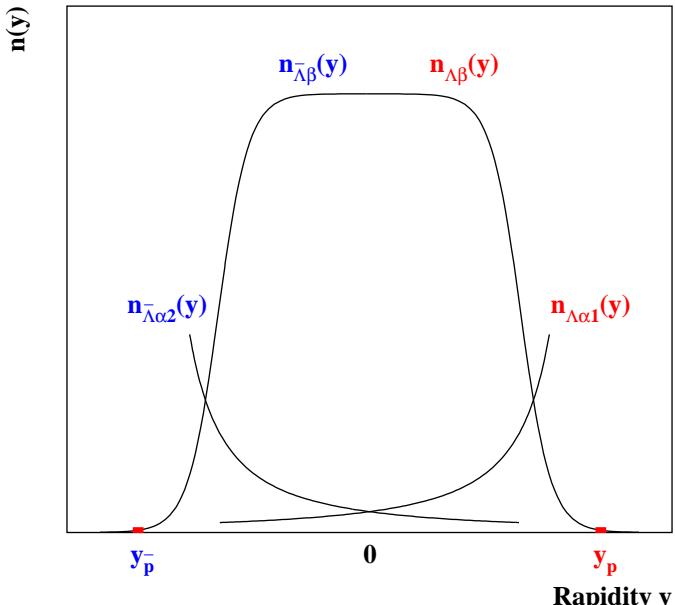
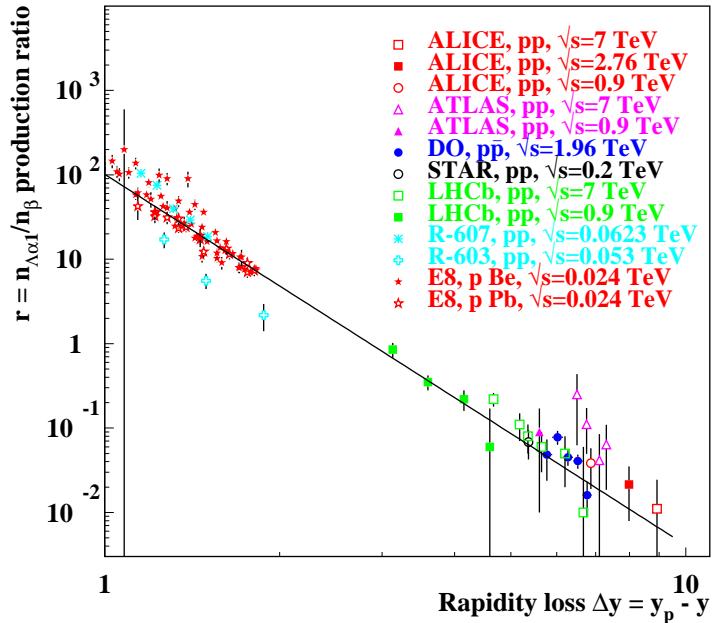
$\bar{\Lambda}/\Lambda$  production ratio vs “rapidity loss”  $y_p - y$  for  $pZ \rightarrow \Lambda(\bar{\Lambda})X$





Phys. Rev. **D** 93, 032002 (2016), arXiv:1511.05113  
 Phys. Rev. **D** 93, 112001 (2016), arXiv:1605.03513

Phys. Rev. Lett. 114, 051803 (2015), arXiv:1411.3021



**Conclusions:** A simple 2 component production model (central production  $\beta$  and forward production  $\alpha$ ) adequately represents all data. At small rapidity loss, the presence of the  $\alpha$  component depends on having a shared (di)quark between the outgoing baryon and the parent proton.

$$r \equiv \sigma(\Lambda)/\sigma(\bar{\Lambda}) - 1, \text{ B.H., Phys. Lett. B 760, p. 242 (2016), arXiv:1604.05379}$$

## Part II: Confirmation of the exotic state $X(5568) \rightarrow B_s^0 \pi^\pm$ in $p\bar{p}$ collisions.

$$X(5568)(bu\bar{s}\bar{d}) \rightarrow \bar{B}_s^0(b\bar{s})\pi^+(u\bar{d})$$

DØ saw  $B_s\pi^\pm$  resonance at  $M = 5568$  MeV, slightly above threshold.  $B_s^0$  is fully mixed so quark anti-quark composition is undetermined. The non-zero width implies a strong decay. (Phys. Rev.Lett., 117, 022003 (2016))

Models:

Molecular state, e.g. colorless  $\bar{B}_d^0(b\bar{d})$  loosely coupled to colorless  $K^+(u\bar{s})$  should have a mass close to  $m(B_d^0) + m(K^+) = 5773$  MeV. This model is disfavored.

Tightly bound tetraquark e.g.  $(bd)(\bar{s}\bar{u})$ ,  $(bu)(\bar{s}\bar{d})$ ,  $(su)(\bar{b}\bar{d})$ , or  $(sd)(\bar{b}\bar{u})$ .

See arXiv:1705.03741 for scalar-scalar diquark-antidiquark  $0^+$  state.

Published:  $B_s^0$  is reconstructed in hadronic channel:

$$B_s^0 \rightarrow J/\psi\phi, \quad J/\psi \rightarrow \mu^+\mu^-, \quad \phi \rightarrow K^+K^-.$$

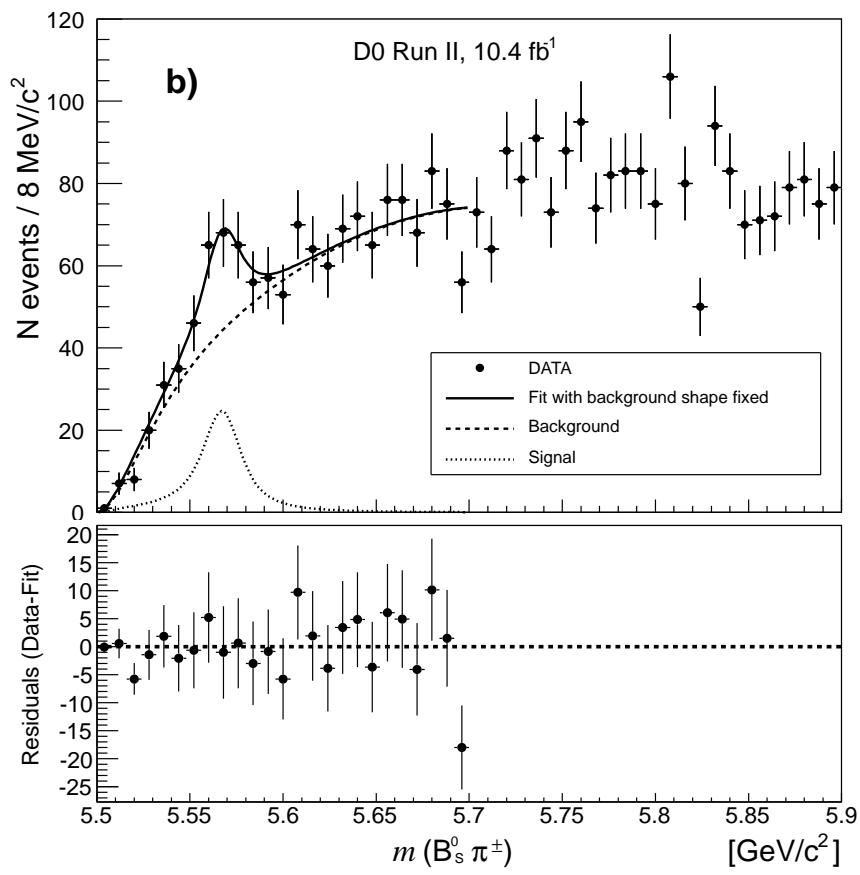
Confirmation:  $B_s^0$  is reconstructed in semi-leptonic channel:

$$B_s^0 \rightarrow \mu^\mp D_s^\pm X, \quad D_s^\pm \rightarrow \phi\pi^\pm, \quad \phi \rightarrow K^+K^-.$$

$4.5 \text{ GeV} < m(\mu^+D_s^-) < m(B_s^0)$  to reduce  $\nu_\mu$  contribution.

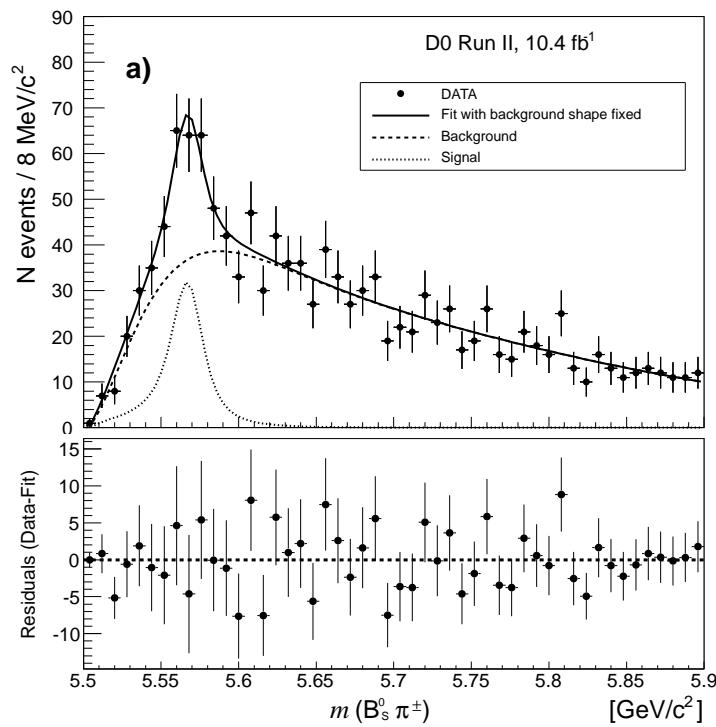
The hadronic and semileptonic channels have independent events, signals, backgrounds and triggers.

$$X(5568) \rightarrow B_s^0 \pi^\pm$$



$$X(5568) \rightarrow B_s^0 \pi^\pm$$

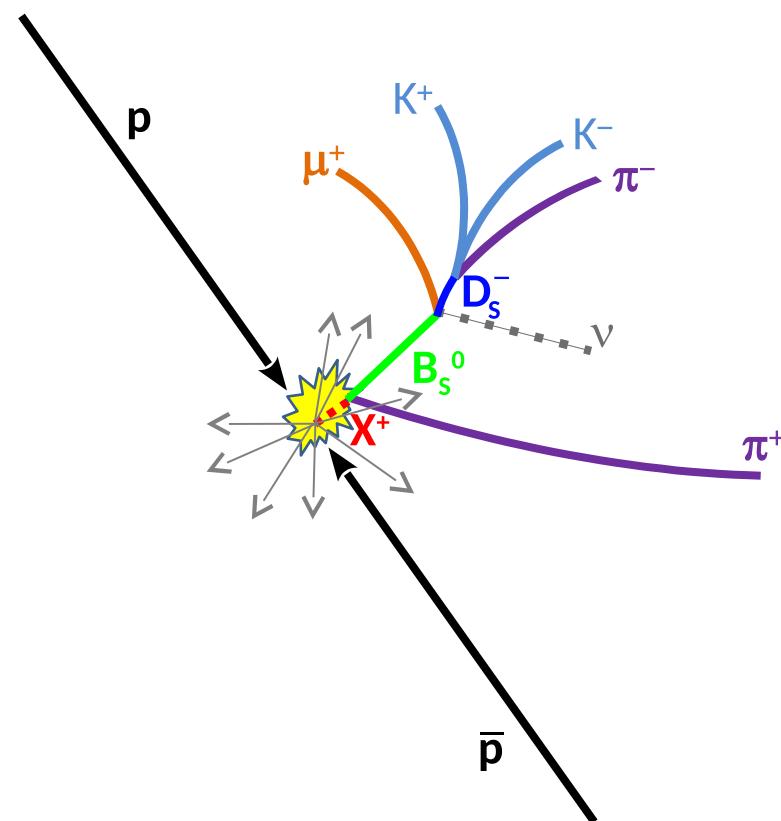
with cone cut  $\Delta R(B_s^0, \pi) = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.3$



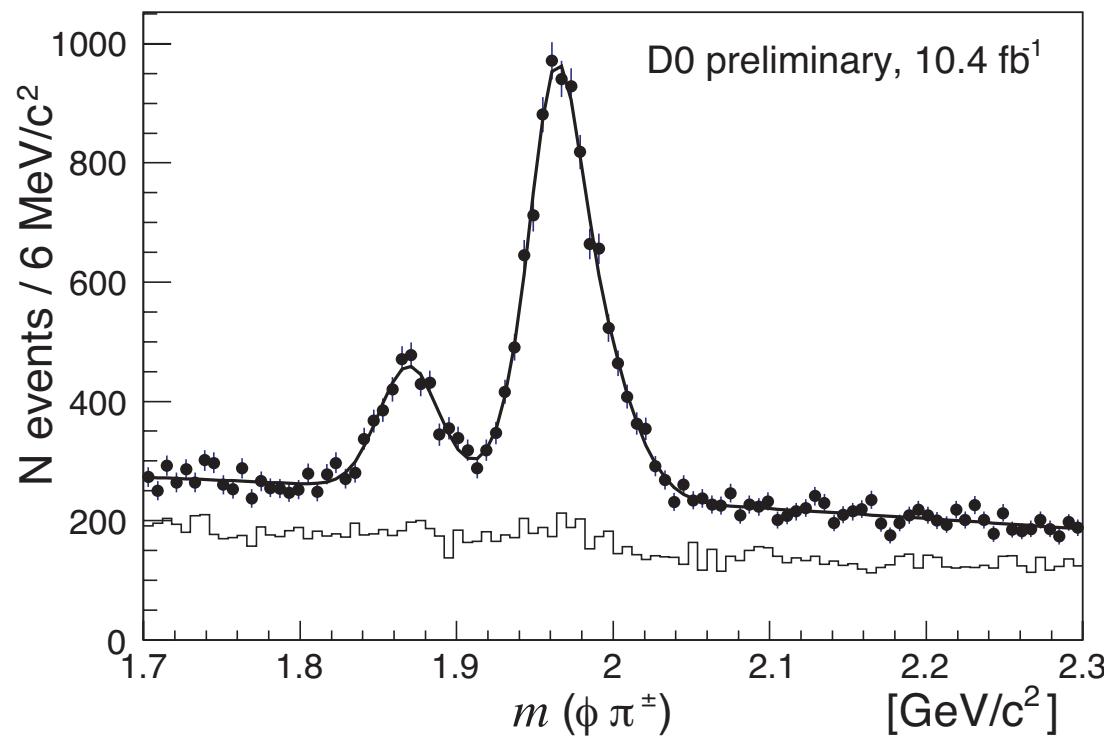
$$X(5568) \rightarrow B_s^0 \pi^\pm$$

$$B_s^0 \rightarrow \mu^\mp D_s^\pm X,$$

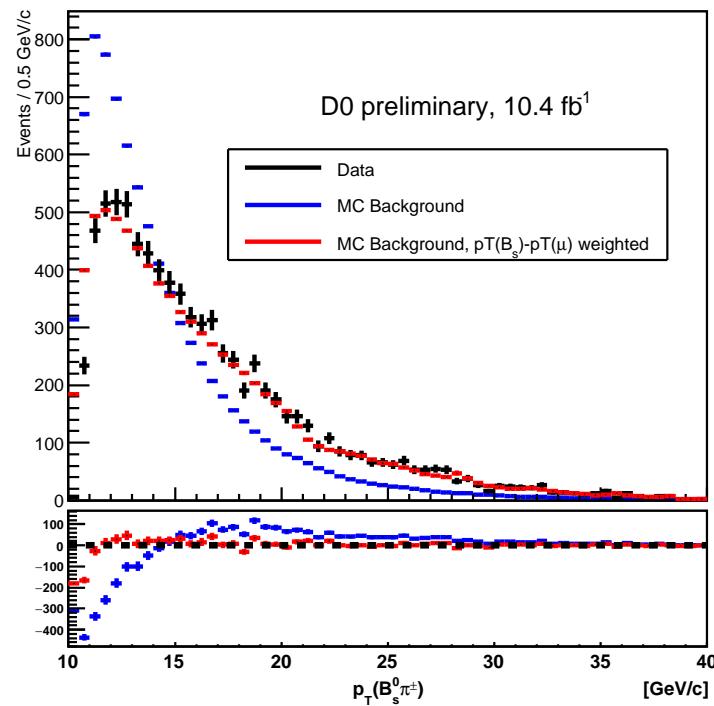
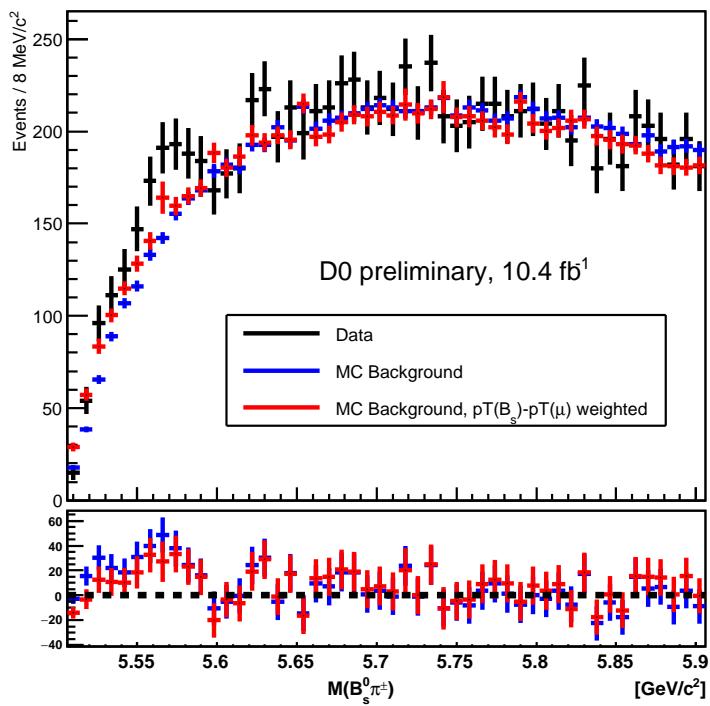
with  $B_s$  in semi-leptonic channel.

$$D_s^\pm \rightarrow \phi \pi^\pm, \quad \phi \rightarrow K^+ K^-$$


$m(K^+K^-\pi^\pm)$  for right sign  $\mu^\pm\phi\pi^\mp$  showing  $D^\pm$  and  $D_s^\pm$  meson decays (and wrong sign combination).

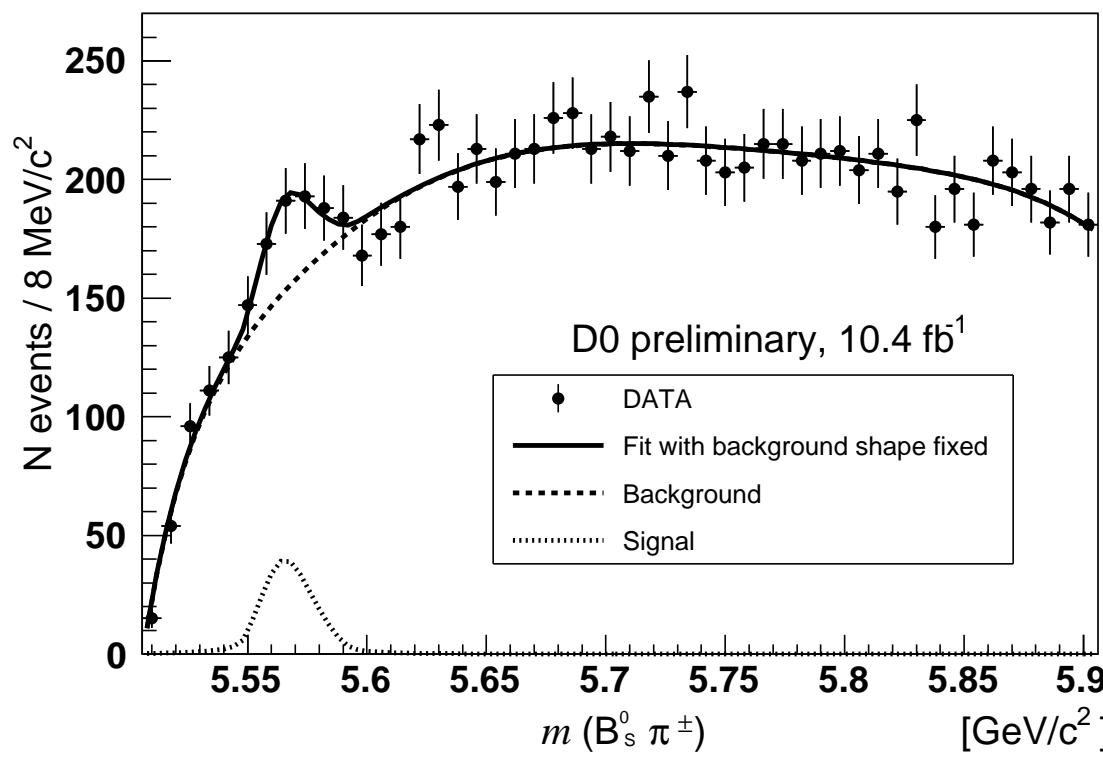


$m(B_s^0\pi^\pm)$  and  $p_T(B_s^0\pi^\pm)$



Weight MC in  $p_T(\mu)$  and  $p_T(\mu D_s)$  to fit data.

## Semileptonic channel (no cone cut is applied)



	Semileptonic	Hadronic with cone cut	Hadronic no cone cut
Mass [MeV]	$5566.7^{+3.6}_{-3.4} \pm 1.0$	$5567.8 \pm 2.9^{+0.9}_{-1.9}$	5567.8
Width [MeV]	$6.0^{+9.5+1.9}_{-6.0-4.6}$	$21.9 \pm 6.4^{+5.0}_{-2.5}$	21.9
Events	$139^{+51+10.9}_{-63-31.5}$	$133 \pm 31 \pm 15$	$106 \pm 23$
Significance*	$3.2\sigma$	$5.1\sigma$	$3.9\sigma$
Fraction**	$7.3^{+2.8+0.6\%}_{-2.4-1.7\%}$	$8.6 \pm 1.9 \pm 1.4\%$	

\* with systematics (and LEE for hadronic). \*\* Fraction of  $B_s^0$  from  $X(5568)$ .

Combined semileptonic and hadronic channel significance with (without) hadronic channel cone cut is  $5.7\sigma$  ( $4.7\sigma$ ), including systematics and LEE.

## Conclusions

- Confirmed observation of  $X(5568)$  in  $p\bar{p}$  collisions with  $B_s^0$  decaying in semileptonic channel.
- $X(5568)$  is not observed by LHCb or CMS in  $pp$  collisions, so the production may be enhanced in the  $p\bar{p}$  initial state.

## References

- V.M. Abazov et al. (D0 Collaboration), “Confirmation of the  $X(5568)$  with semileptonic decays of the  $B_s^0$  meson”, conference note,  
<https://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B68/>.
- V.M. Abazov et al. (D0 Collaboration), “Evidence for a  $B_s\pi^\pm$  state”, Phys. Rev. Lett. 117, 022003 (2016), arXiv:1602.07588.
- V.M. Abazov et al. (D0 Collaboration), “Measurement of the forward-backward asymmetries in the production of  $\Xi$  and  $\Omega$  baryons in  $p\bar{p}$  collisions” Phys. Rev. D 93, 112001 (2016), arXiv:1605.03513.
- B. Hoeneisen, “Ratio between two  $\Lambda$  and  $\bar{\Lambda}$  production mechanisms in  $p$  scattering”, Phys. Lett. B 760, p. 242 (2016), arXiv:1604.05379.

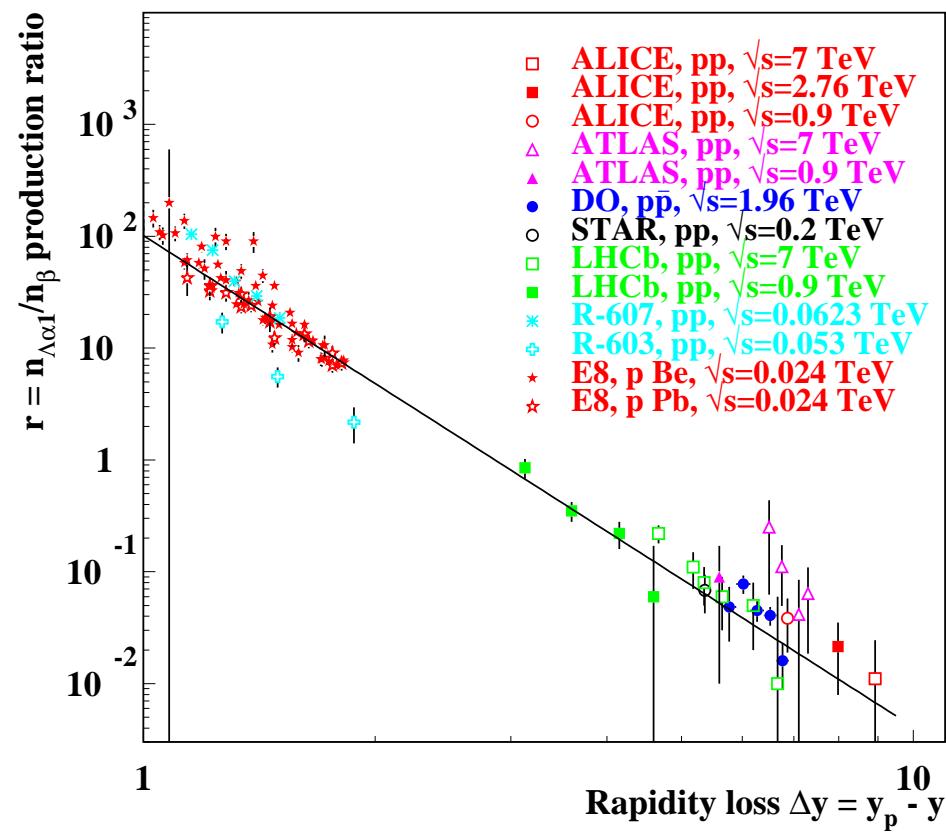
V.M. Abazov et al. (D0 Collaboration), “Measurement of the forward-backward asymmetry of  $\Lambda$  and  $\bar{\Lambda}$  production in  $p\bar{p}$  collisions”, Phys. Rev. **D** 93, 032002 (2016), arXiv:1511.05113.

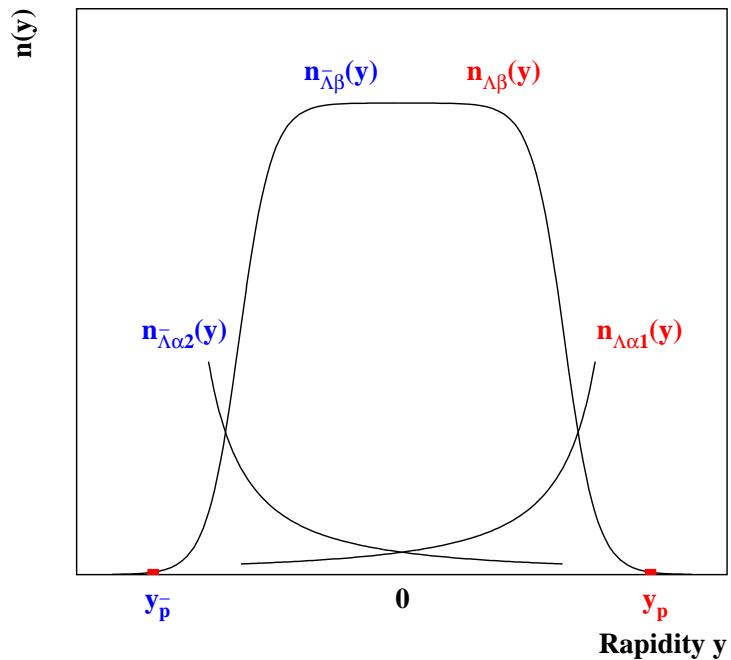
V.M. Abazov et al. (D0 Collaboration), “Measurement of the forward-backward asymmetry in  $\Lambda_b^0$  and  $\bar{\Lambda}_b^0$  baryon production in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV”, Phys. Rev. **D** 91, 072008 (2015). arXiv:1503.03917.

V.M. Abazov et al. (D0 Collaboration), “Measurement of the forward-backward asymmetry in the production of  $B^\pm$  in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV”, Phys. Rev. Lett. 114, 051803 (2015), arXiv:1411.3021.

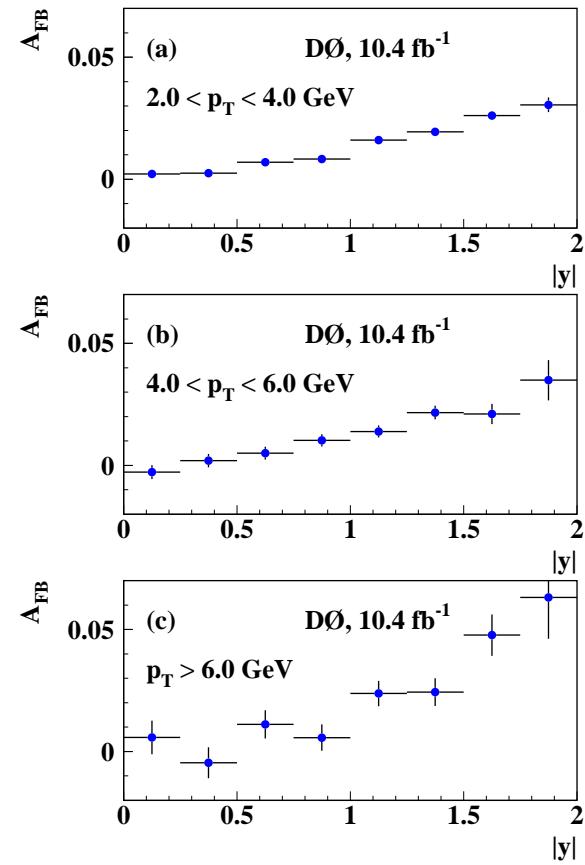
# Backup slides

Ratio  $r$  as a function of rapidity loss  $y_p - y$  from the listed experiments.



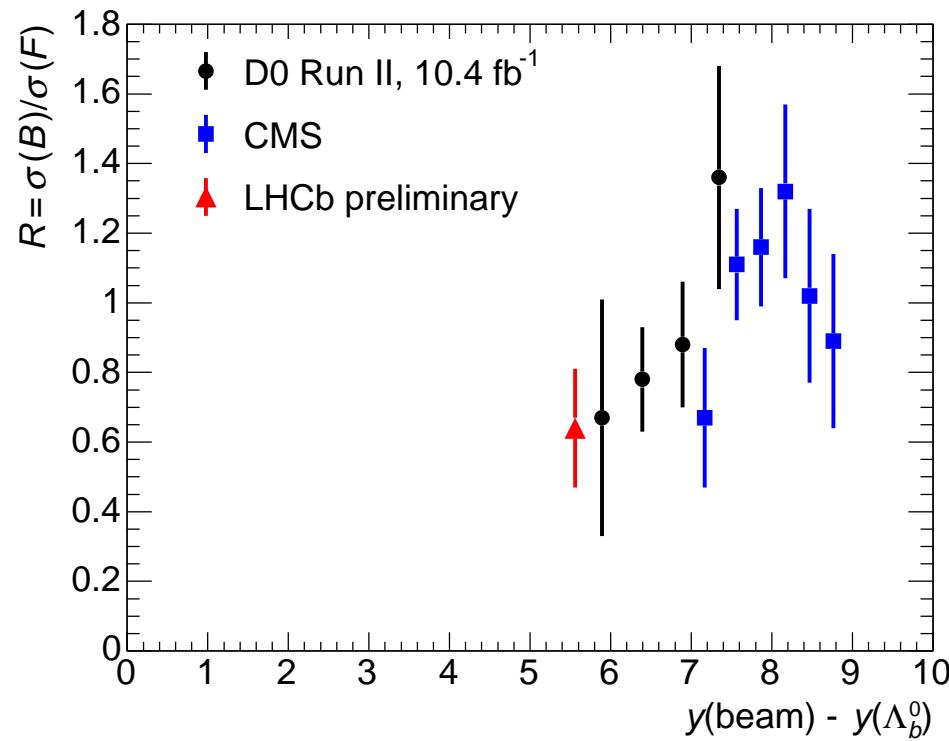


$$\begin{aligned}
 r &\equiv \frac{n_{\Lambda\alpha 1}(y)}{n_\beta(y)}, \\
 A_{FB} &\equiv \frac{r}{2+r} \quad \text{if } p\bar{p}; \quad \frac{\sigma(\bar{\Lambda})}{\sigma(\Lambda)} \equiv \frac{1}{1+r} \quad \text{if } pp.
 \end{aligned}$$



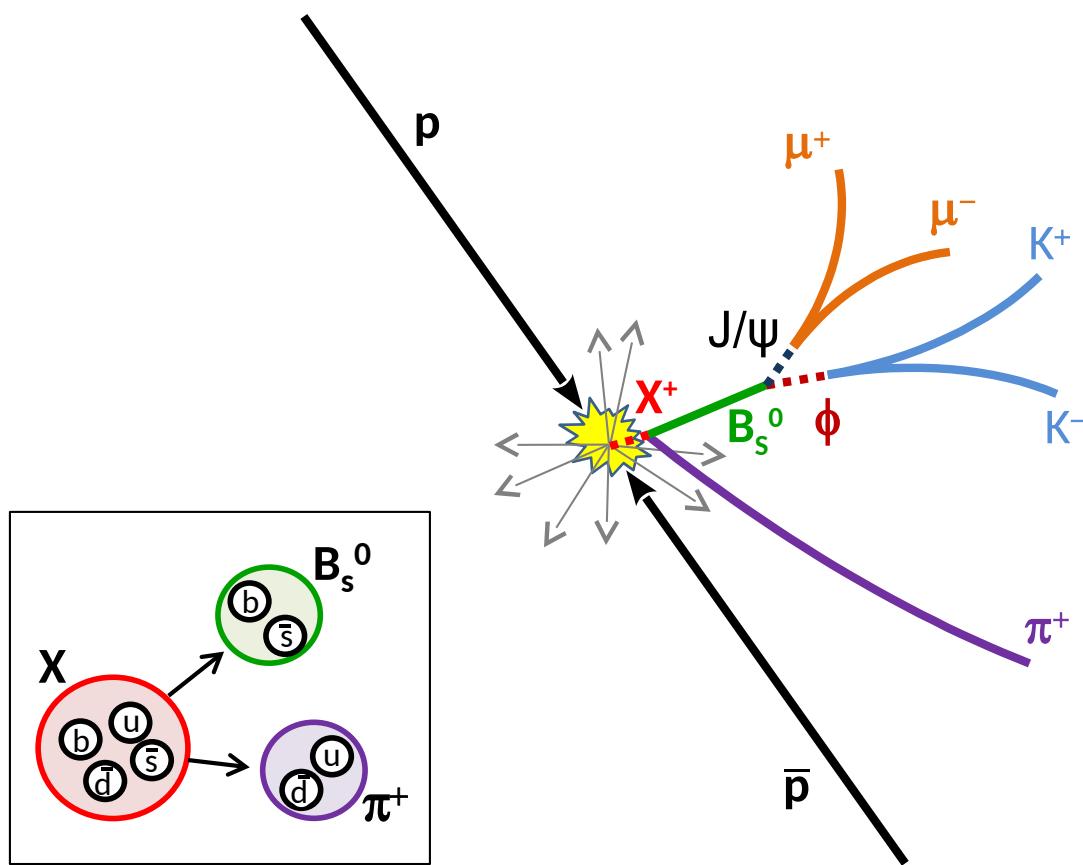
Dependence of  $A_{FB}(\Lambda, \bar{\Lambda})$  on  $p_T$ .

Ratio  $\bar{\Lambda}_b/\Lambda_b$  vs “rapidity loss”  $y(\text{beam}) - y(\Lambda_b)$ , from CMS, LHCb and DØ.

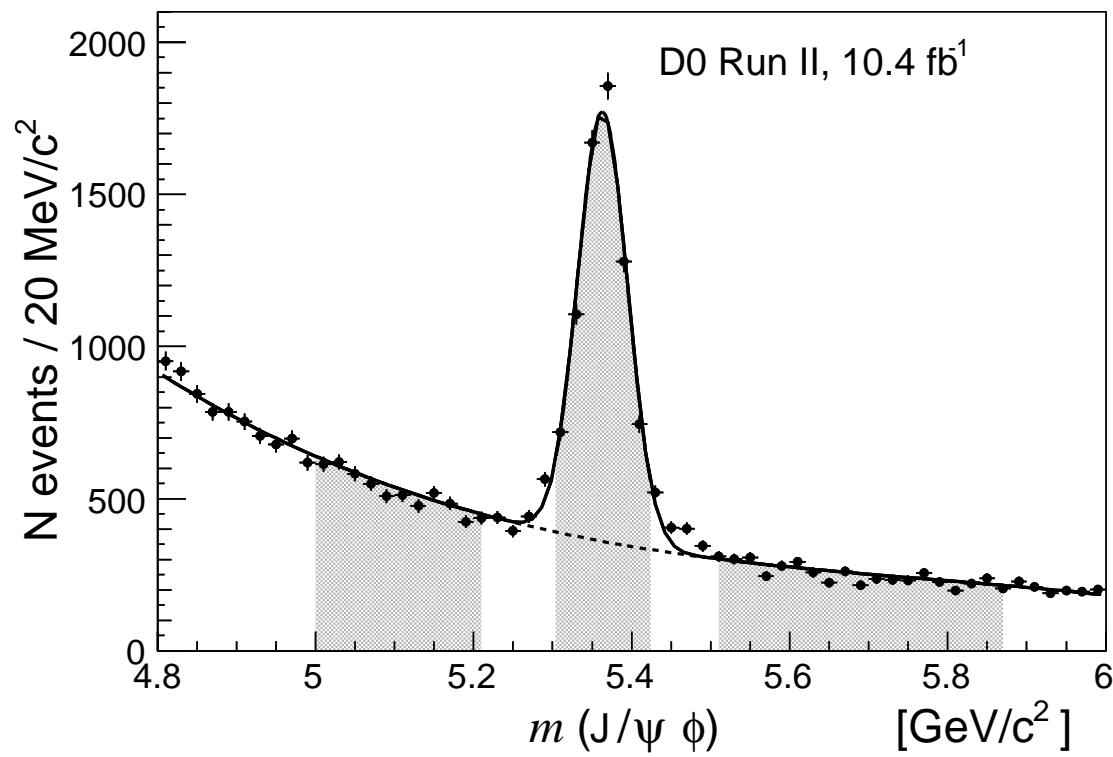


$\bar{\Lambda}_b/\Lambda_b$  and  $\bar{\Lambda}/\Lambda$  vs “rapidity loss” are similar.

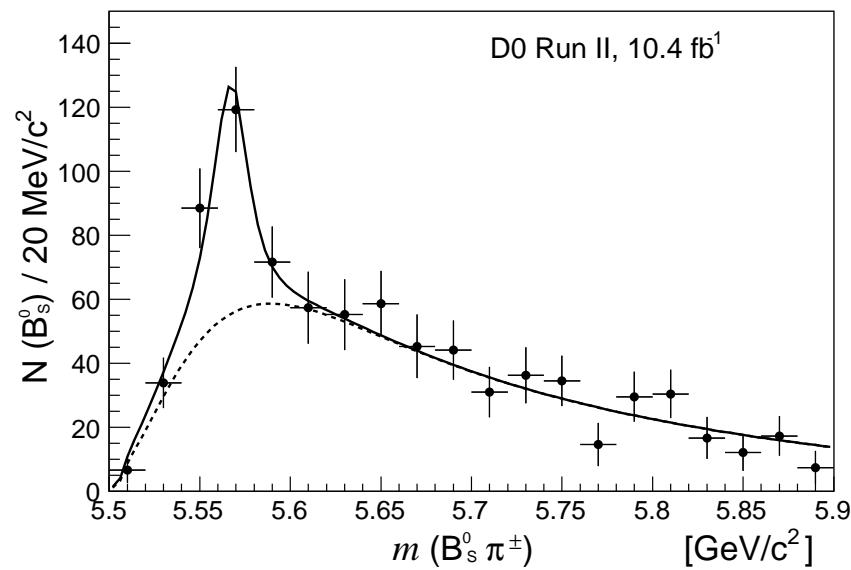
$X(5568) \rightarrow B_s^0 \pi^\pm$  with  $B_s$  in hadronic channel

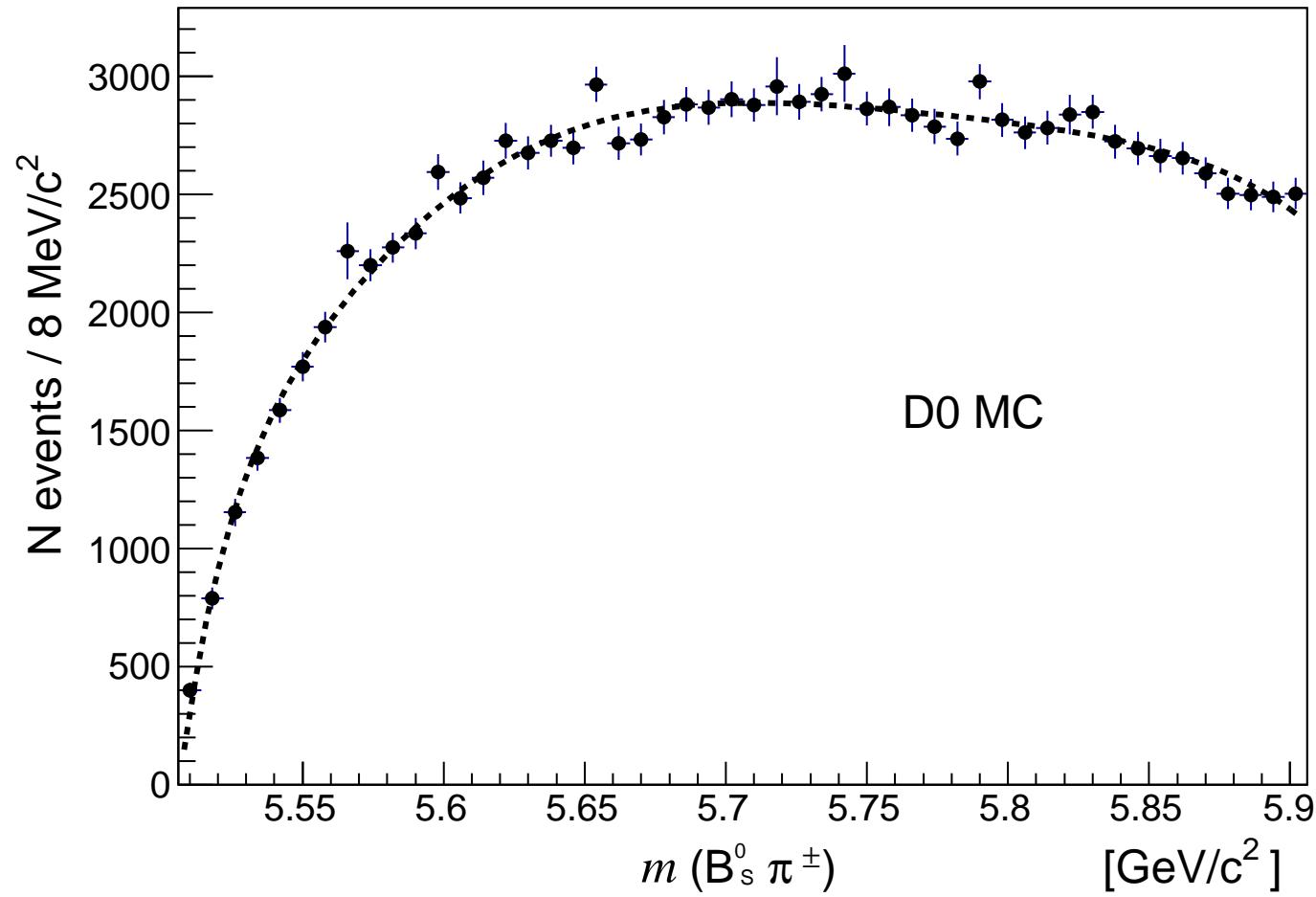


$B_s \rightarrow J/\psi \phi$



From **fits to  $m(J/\psi\phi)$**  instead of sideband subtraction





Universal  $\bar{\Lambda}/\Lambda$  production ratio vs “rapidity loss”  $\Delta y \equiv y_p - y$  (with logarithmic scale).

