Observation of a new $B_s^0\,\pi^\pm$ state at D0

Peter H. Garbincius
Fermilab
on behalf of the D0 Collaboration
May 3, 2016 @ SLAC

We report the observation of a narrow structure, $X(5568)$, in the decay sequence $X(5568) \to B_s^0\,\pi^\pm$, $B_s^0 \to J/\psi\,\phi$, $J/\psi \to \mu^+\mu^-$, $\phi \to K^+\,K^-$. This is the first observation of a hadronic state with valence quarks of four different flavors. The mass and natural width of the new state are measured to be m = 5567.8 ± 2.9 (stat) +0.9/-1.9 (syst) MeV/c^2 and Γ = 21.9 ± 6.4 (stat) +5.0/-2.5 MeV/c^2, and the significance, including look-elsewhere effect and systematic uncertainties, is 5.1 σ. If the decay is $X(5568) \to B_s^{*0}\,\pi^\pm \to B_s^0\,\gamma\,\pi^\pm$ with an unseen γ, $m(X(5568))$ will be shifted up by $m(B_s^{*0}) - m(B_s^0) \sim 49$ MeV/c^2. The observation is based on 10.4 fb^{-1} of p-pbar data at sqrt(s) = 1.96 TeV collected by the D0 experiment at the Fermilab Tevatron Collider.

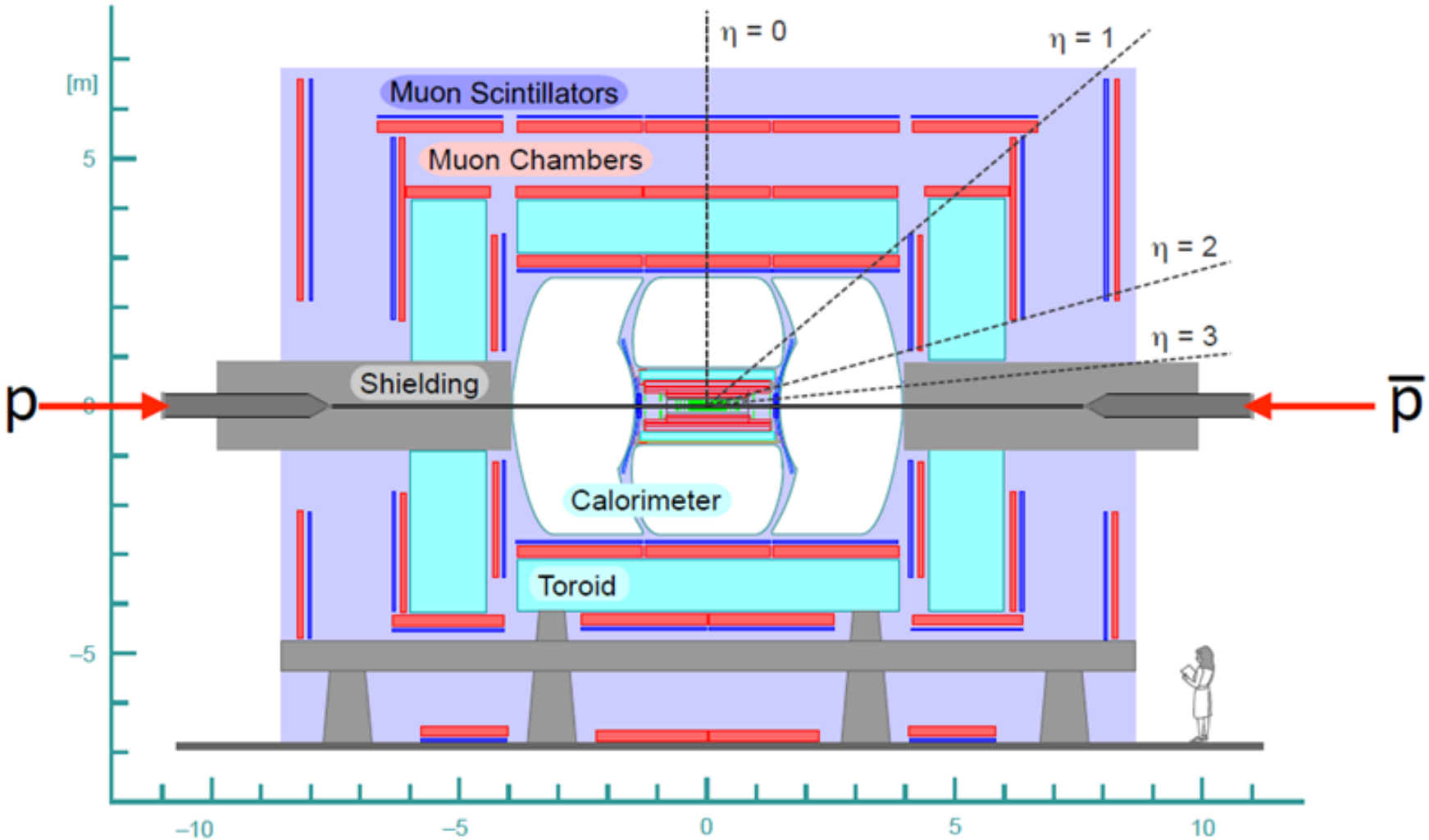
arXiv:1602.07588 – submitted to Phys. Rev. Lett.

D0: Observation of a new $B_s^0 \pi^{\pm}$ state

- Introduction to D0
- Detector, properties, representative mass spectra
- Search for $B_s^* \rightarrow B_s \pi^+ \pi^-$, then moved on to $B_s \pi^{\pm}$
- Brief Review of other recent exotics
- Backgrounds, fits, significance, checks, reflections
- $B^0 \pi$ and search for other $B_s + K^{\pm}$ or $B_s + p$ states
- Possible interpretations (and problems)
- LHCb result
- Summary

Tevatron $p\bar{p}$ collider at $\sqrt{s}$ = 1.96 TeV

DØ: Features excellent muon triggering, coverage, and i.d. along with CDF, D0 discovered the top quark in 1995



for b-physics using μ, U-LAr calorimeters are just passive absorbers

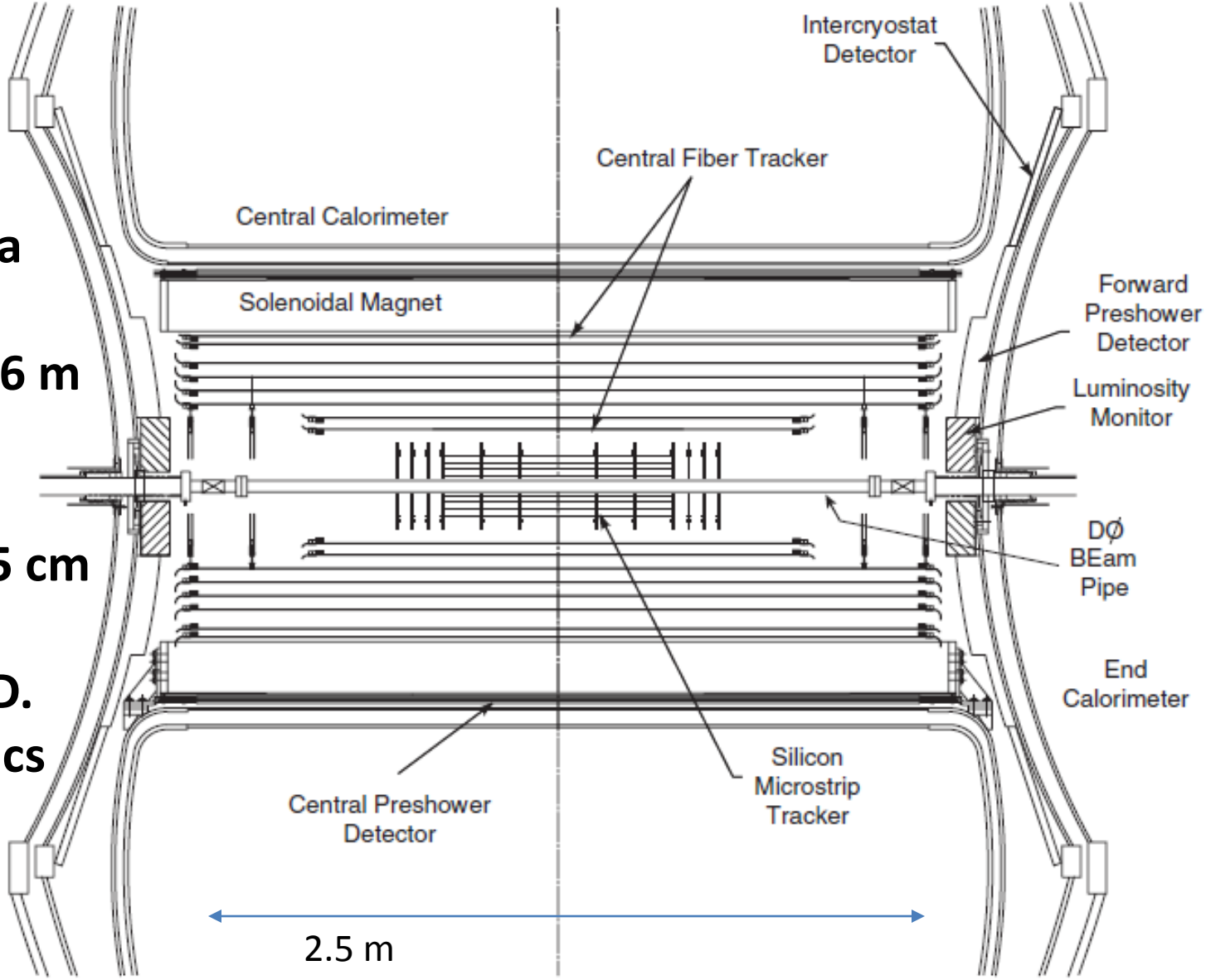
$B_{||}$ = 1.9 Tesla

R_{track}^{max} = 0.6 m

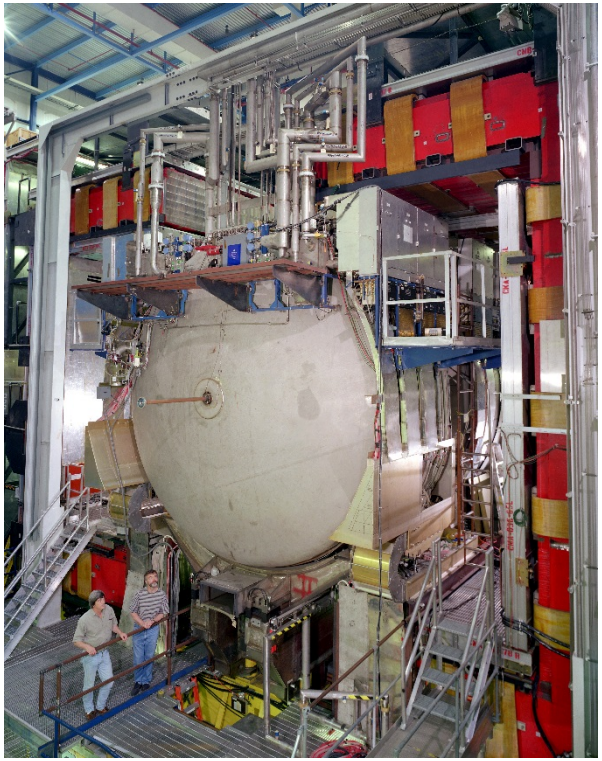
extended

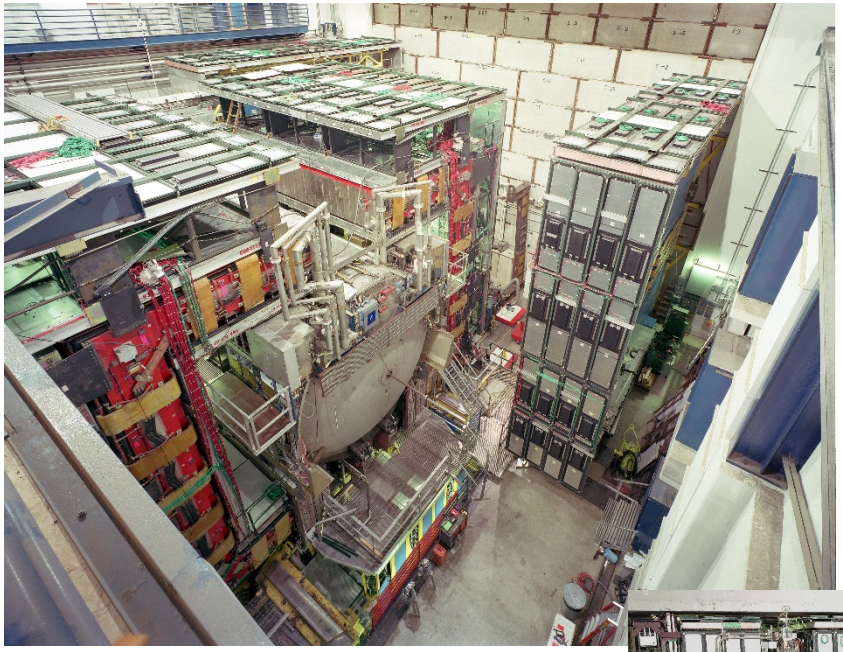
σ_z(I.R.) = ± 25 cm

no hadron I.D.
use kinematics



parameter in backup slides





D0: **named after D0 straight section IP**

17 nations

74 institutions

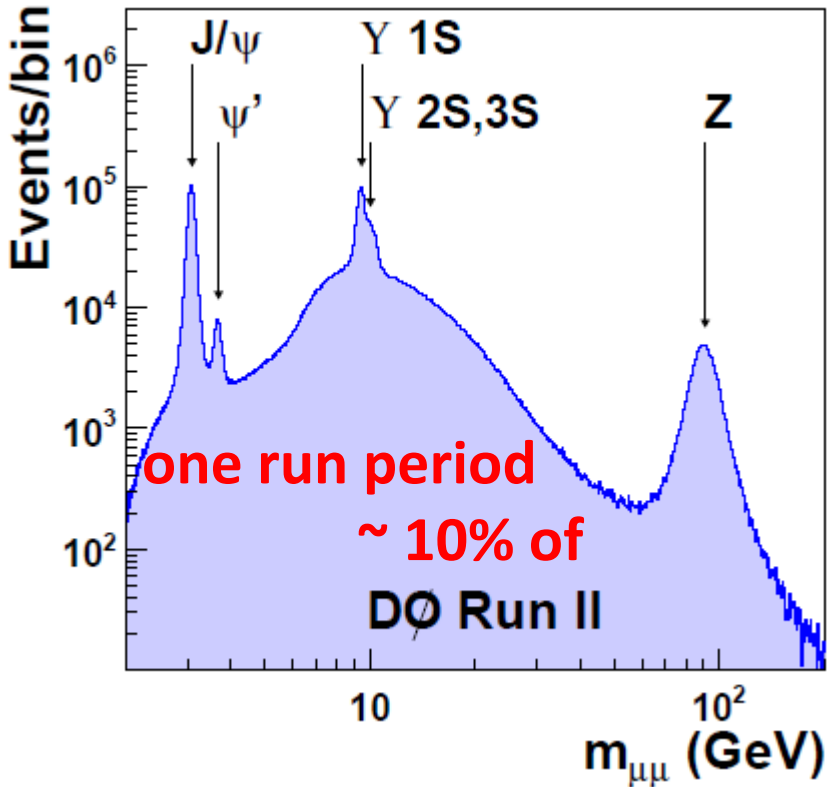
370 authors

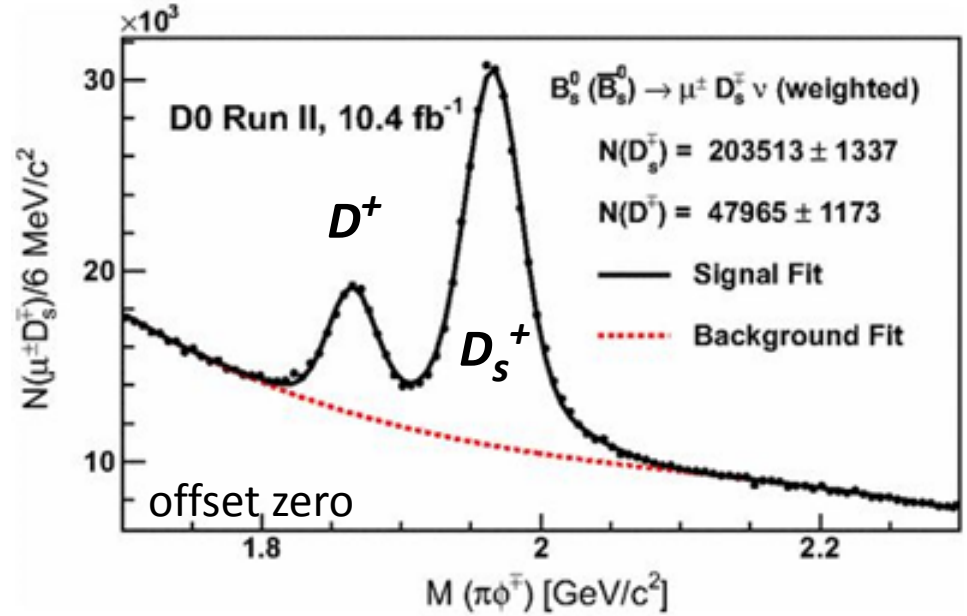
(max ~ 600 authors)

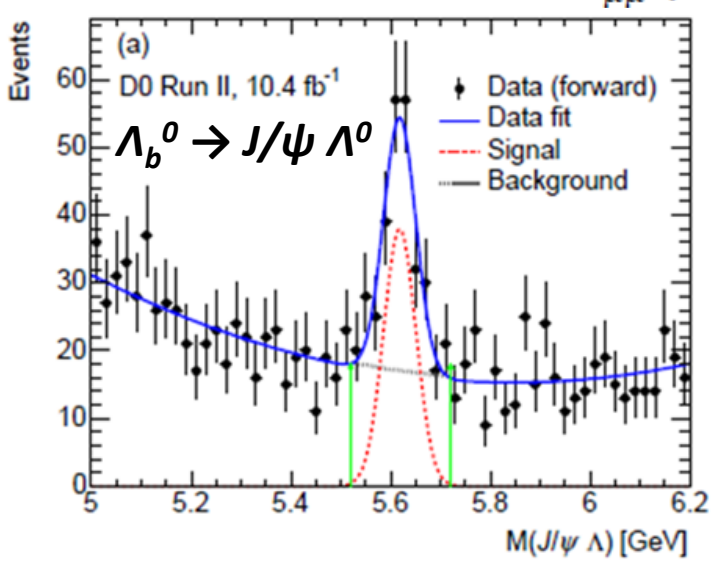
Run II: 2001-2011

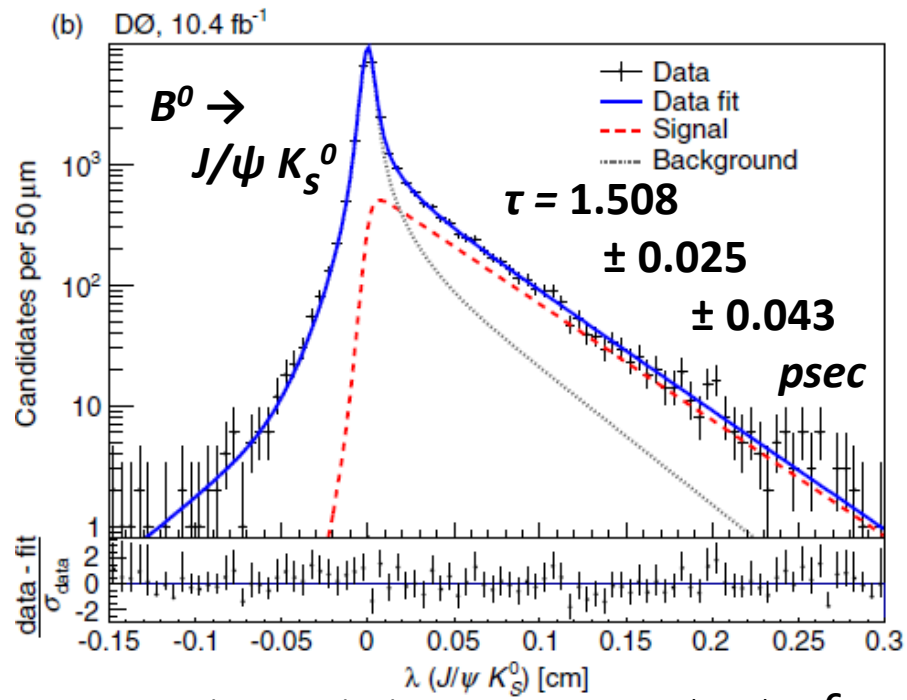
$\int \mathcal{L}\, dt = 10.4\ fb^{-1}$

$\mathcal{L}_{max} > 3 \times 10^{32}\ cm^{-2}\ sec^{-1}$





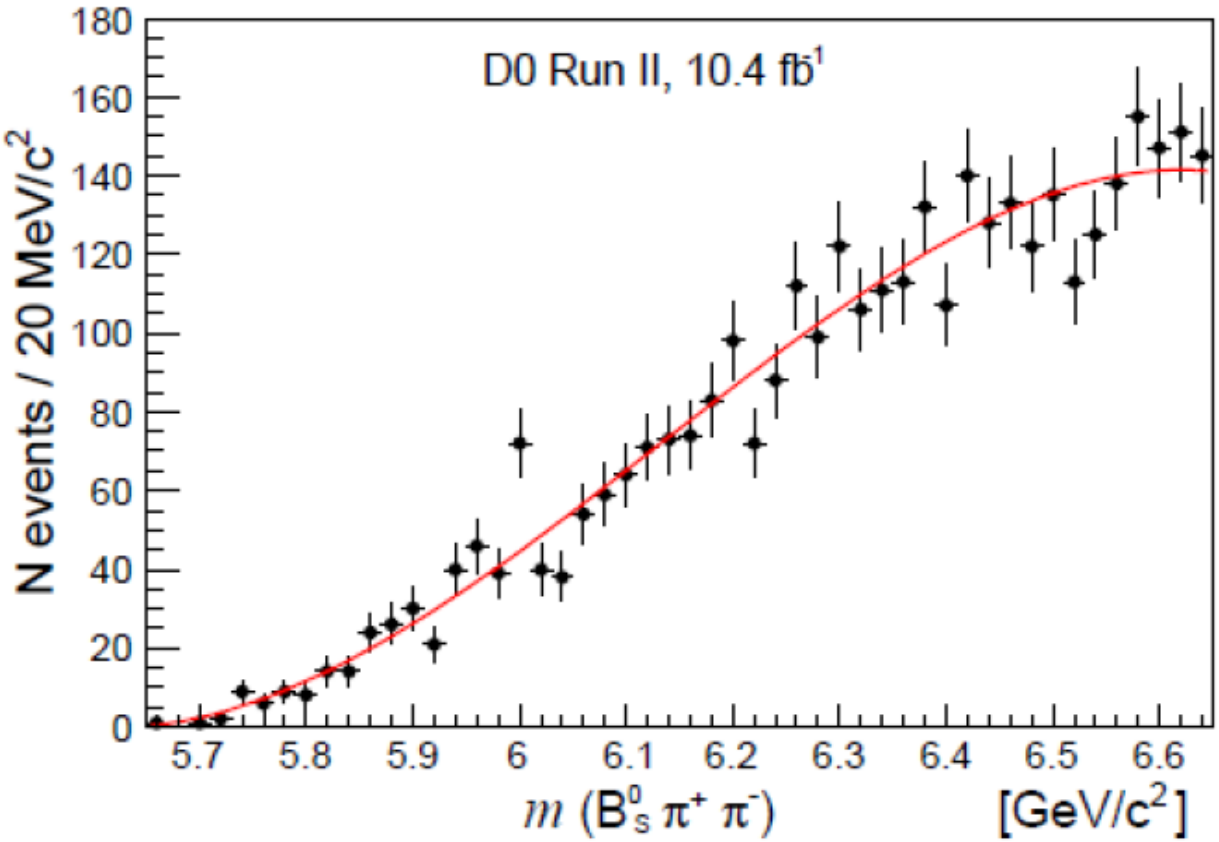




V.M. Abazov et al., Phys. Rev. D 85, 112003 (2012)
τ (B^0) = 1.508 ± 0.025 (stat) ± 0.043 (syst) psec

D0: Observation of a new $B_s^0 \pi^{\pm}$ state

start by searching for strong decays of excited $B_s^{**} \rightarrow B_s^0 \pi^+ \pi^-$



nothing seen

look at $B_s^0 \pi^{\pm}$

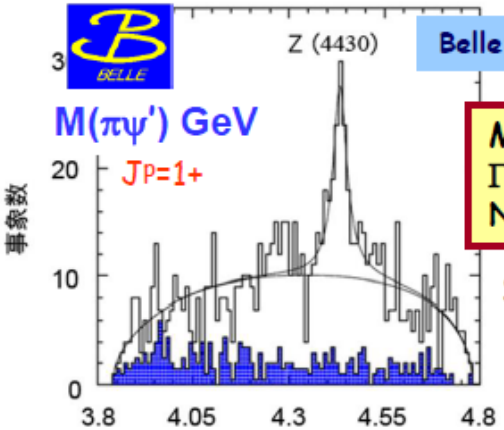
→ exotic = b, s, u, d

quite a few exotic candidates are recently reported tetra-quarks or penta-quarks

so worth looking!

Mass($B_s^0 \pi^+ \pi^-$) - GeV
(threshold 5.645 GeV)

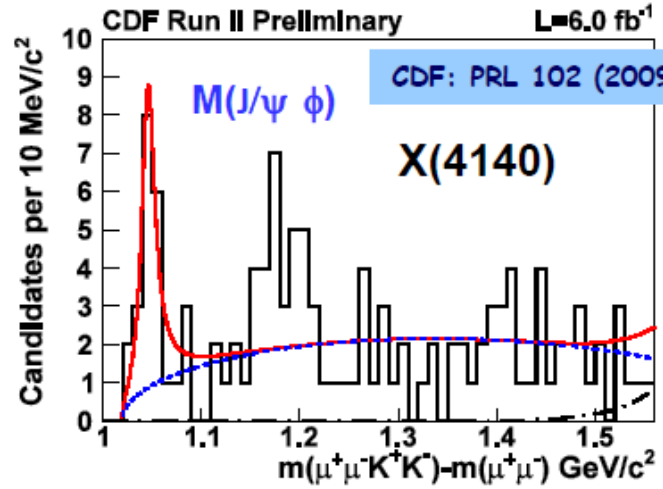
some example of exotic states recently observed



Belle: PRL 100 (2008) 142001

$M = 4433 \pm 4 \pm 2$ MeV
$\Gamma_{tot} = 45^{+18}_{-13}{}^{+30}_{-13}$ MeV
Nsig $= 121 \pm 30$ evts

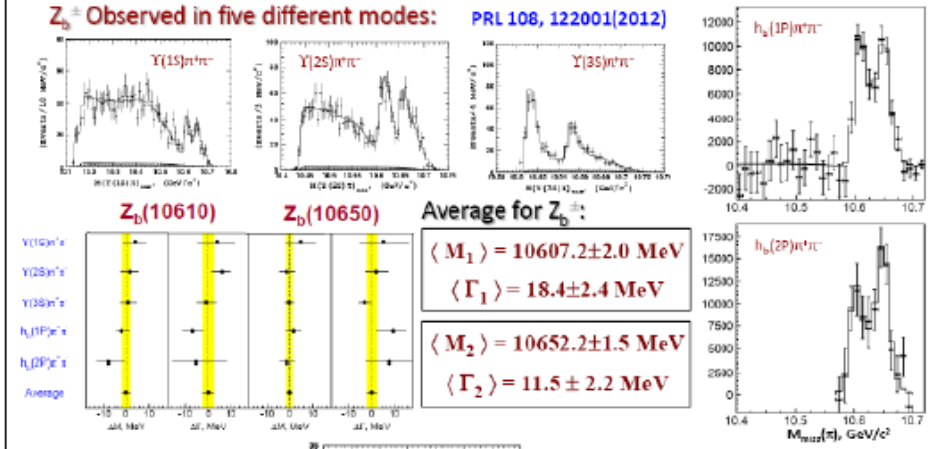
Sign = 6.1s (no syst)



CDF: PRL 102 (2009) 242002

Properties of $Z_b(10610)$ & $Z_b(10650)$

$Z_b^{\pm}$ Observed in five different modes: PRL 108, 122001(2012)



Average for $Z_b^{\pm}$:

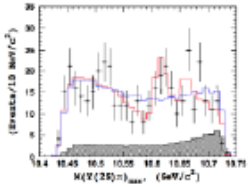
$\langle M_1 \rangle = 10607.2 \pm 2.0$ MeV
$\langle \Gamma_1 \rangle = 18.4 \pm 2.4$ MeV

$\langle M_2 \rangle = 10652.2 \pm 1.5$ MeV
$\langle \Gamma_2 \rangle = 11.5 \pm 2.2$ MeV

Z_b^0 Results:

$\langle M_1 \rangle = 10609 \pm 7 \pm 6$ MeV

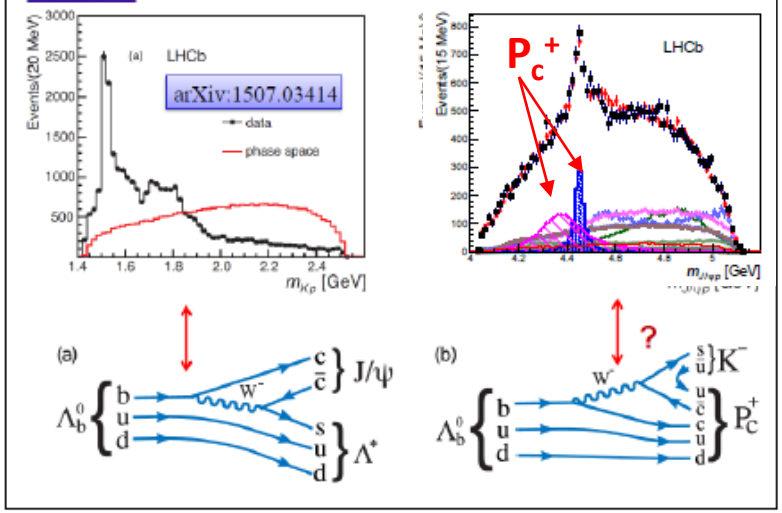
Consistent with $Z_b^{\pm}$



$M_1 - M_B - M_{B^*} = 2.36 \pm 2.1$ MeV
$M_2 - M_B - M_{B^*} = 1.8 \pm 1.75$ MeV

JP=1++ and 2++

Projections



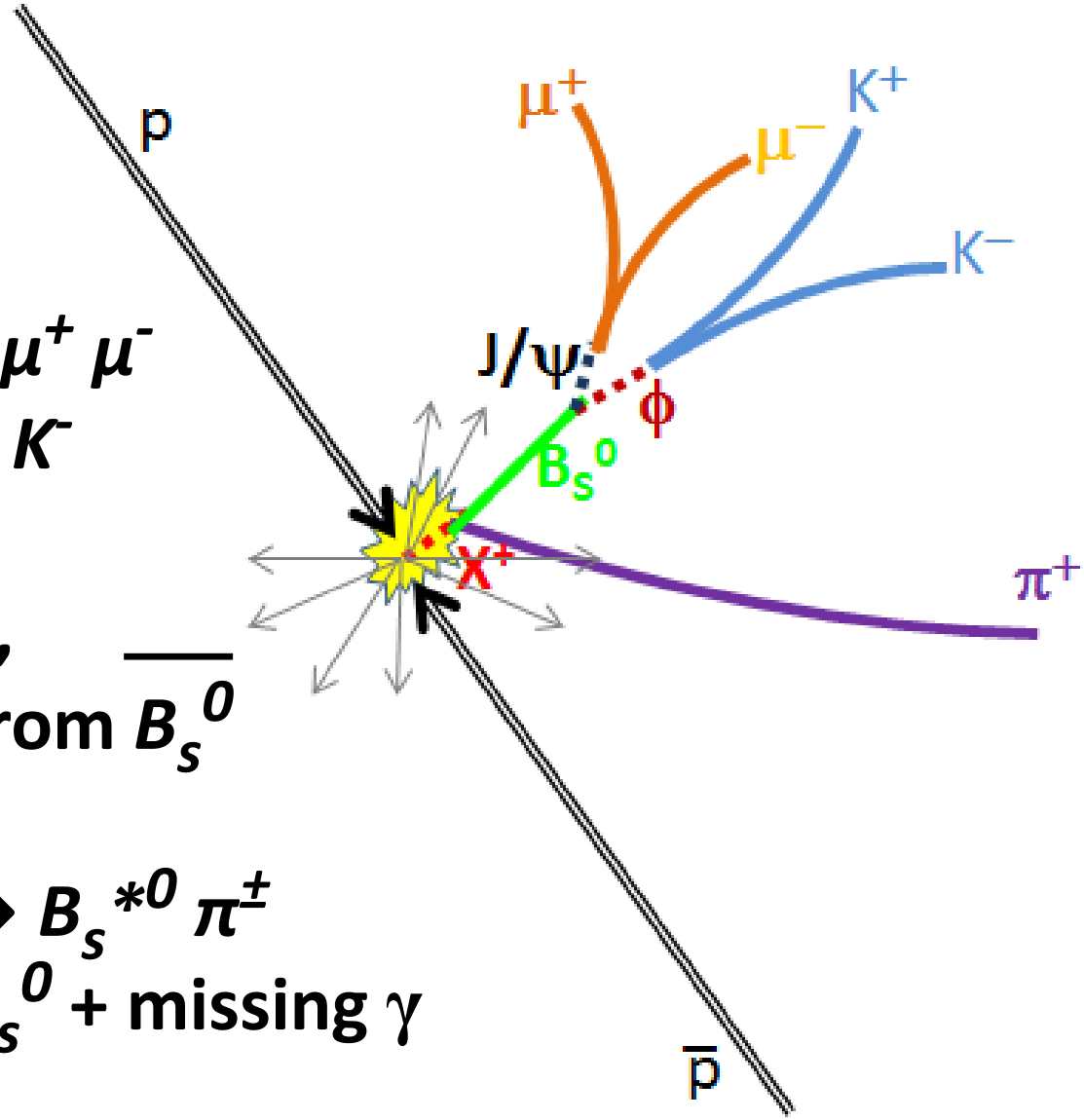
D0: Observation of a new $B_s^0 \pi^\pm$ state

$X \rightarrow B_s^0 \pi^\pm$

$B_s^0 \rightarrow J/\psi\, \phi$

$J/\psi \rightarrow \mu^+ \mu^-$

$\phi \rightarrow K^+ K^-$



without b-$\bar{b}$ tagging,

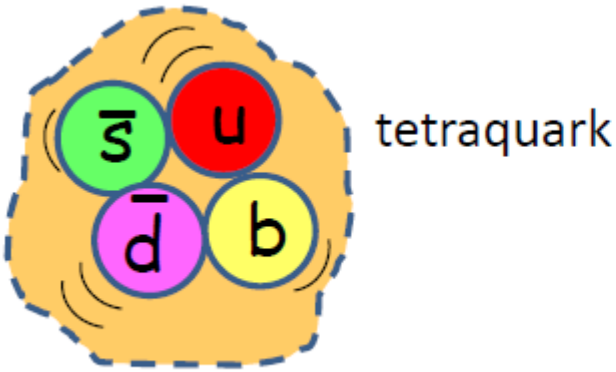
can't tell B_s^0 from $\overline{B_s^0}$

also could have $X \rightarrow B_s^{*0} \pi^\pm$

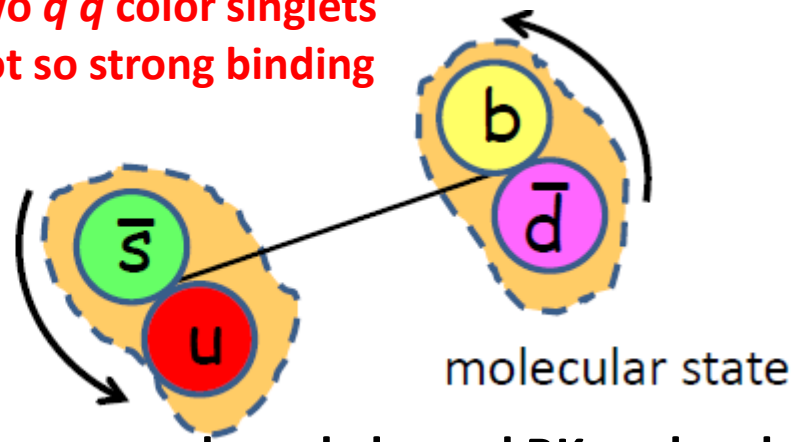
with $B_s^{*0} \rightarrow B_s^0$ + missing γ

D0: Observation of an exotic $B_s^0 \pi^{\pm}$ b, s, u, d state

in his 1964 quark paper, Gell-Mann predicted $\{q\,\bar{q}\}$, $\{q\,q\,\bar{q}\,\bar{q}\}$, etc. mesons

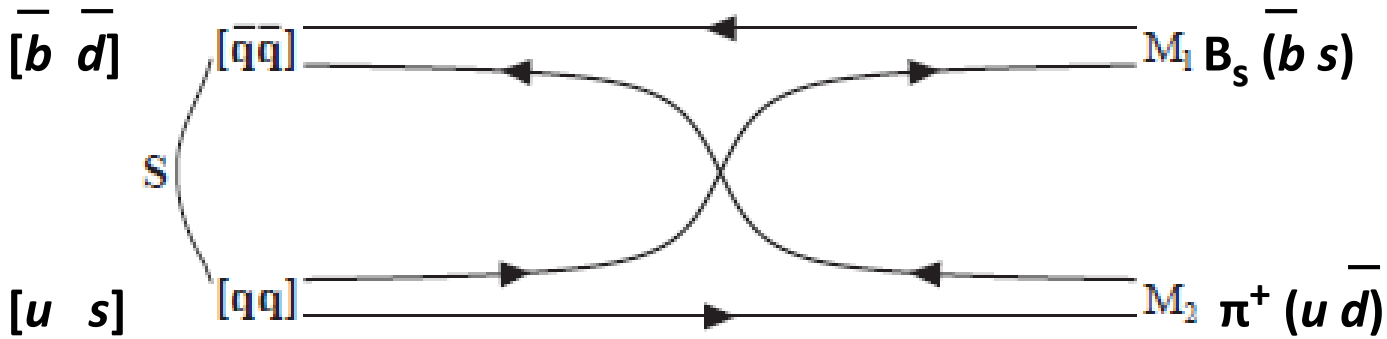


two $q\,\bar{q}$ color singlets
not so strong binding



di-quarks

loosely bound BK molecule



diquark-antidiquark-onium
color triplets
strong forces
strong binding

L. Maiani *et al.*, "New Look at Scalar Mesons", Phys. Rev. Lett. 93, 212002 (2004)

D0: Observation of a new $B_s^0 \pi^{\pm}$ state

Used full Run II data set 2001-2011 of 10.4 fb^{-1}

Require a single muon or dimuon trigger.

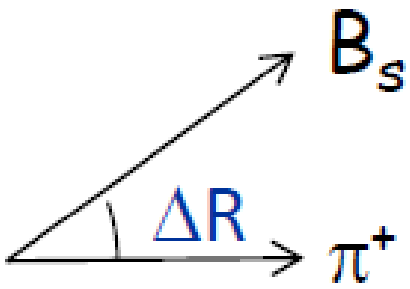
Select $B_s^0 \to J/\psi\phi$ candidates:

- $2.92 < M(\mu\mu) < 3.25$ GeV
- $p_T(K) > 0.7$ GeV; $1.012 < M(KK) < 1.03$ GeV
- $5.304 < M(J/\psi K^+K^-) < 5.424$ GeV; $L_{xy}/\sigma(L_{xy}) > 3$

Add a track assumed to be a pion, consistent with coming from PV:

- $p_T(\pi) > 0.5$ GeV, $IP_{xy} < 0.02$ cm, $IP_{3D} < 0.12$ cm
- $p_T(B_s\pi) > 10$ GeV
- $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.3$ (the "cone" cut)

  = angle between B_s^0 and $\pi^{\pm}$



D0: Observation of a new $B_s^0 \pi^{\pm}$ state

mass resolution on $M(B_s) = M(\mu\mu\ KK) \sim 32\ MeV/c^2$

to improve resolution on $M(B_s\ \pi)$, we use

$$M(B_s\ \pi) = M(\mu\mu\ KK\ \pi) - M(\mu\mu\ KK) + M(B_s)$$

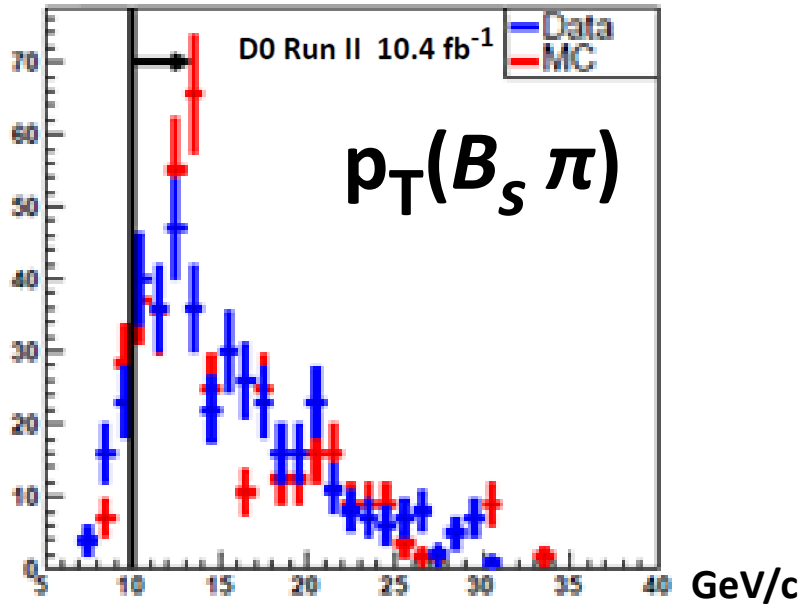
$$= M(\mu\mu\ KK\ \pi) - M(\mu\mu\ KK) + 5.3667\ GeV/c^2$$

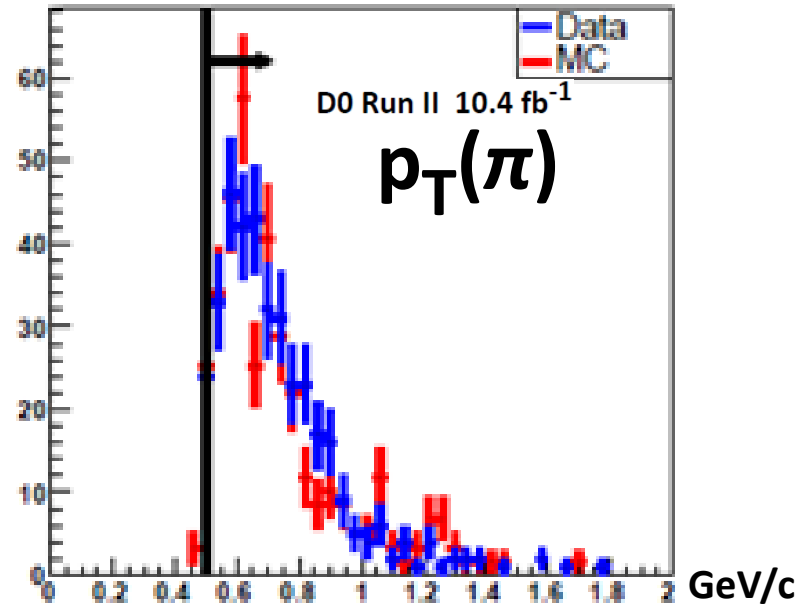
this approximation for $M(B_s\ \pi)$ has

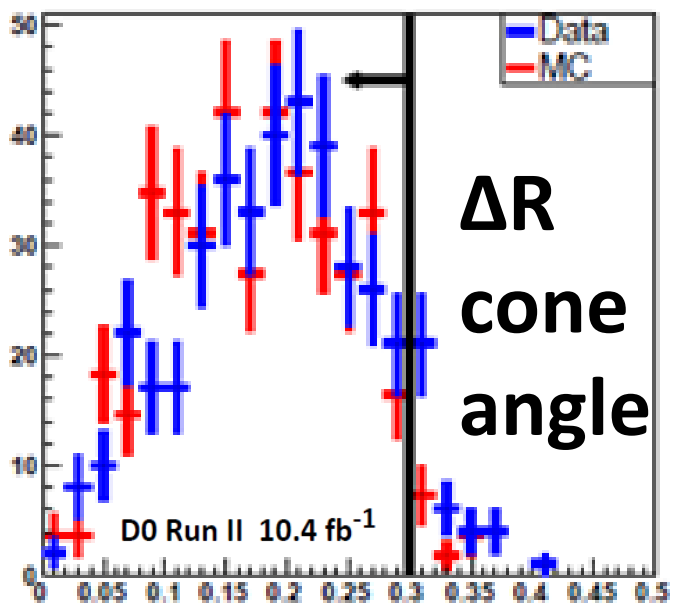
mass resolution of ~ 4 MeV/c^2

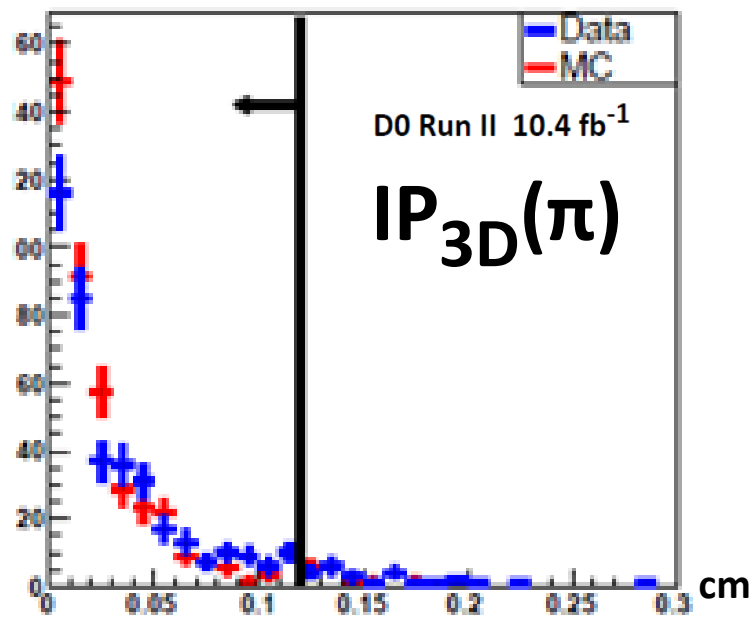
Monte Carlo works well

note: MC generator uses $\Gamma_X = 0$

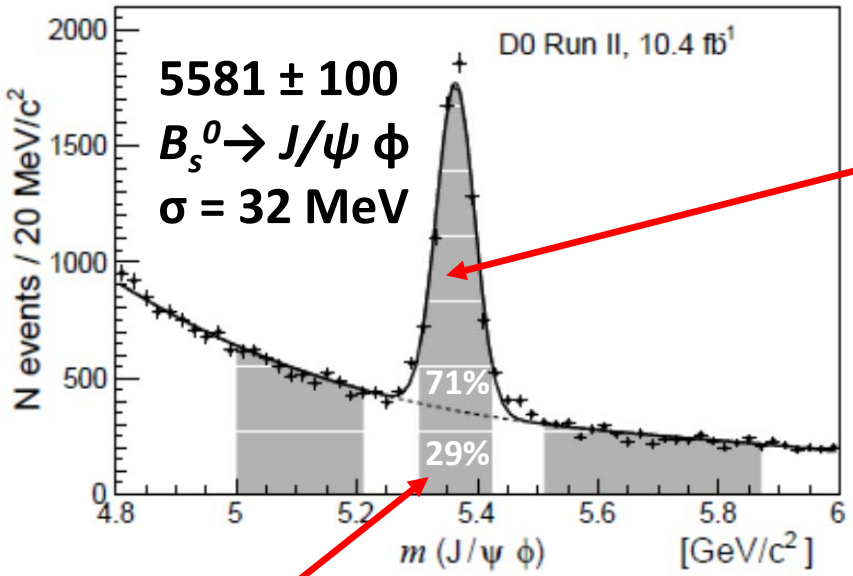








D0: Observation of a new $B_s^0 \pi^{\pm}$ state

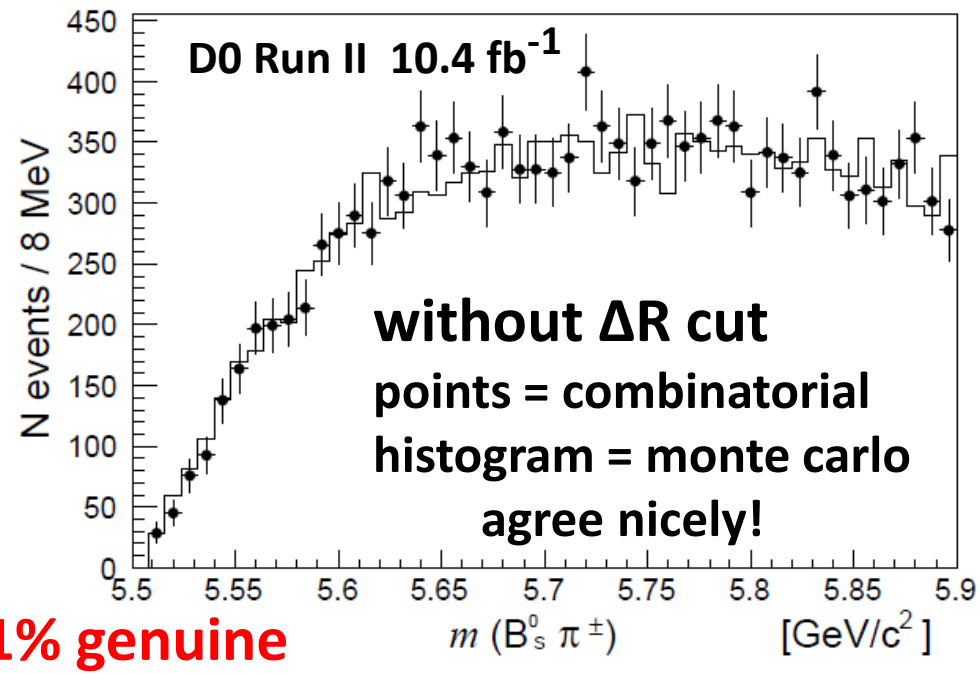


± 2 σ selection band

2 component background model:

"Genuine Background" is the B_s^0 peak: use Monte Carlo B_s^0 peak + random π

71% of total background (*histogram*) ↓



"Combinatorial Background" under the B_s^0 peak: use data: sidebands + random π

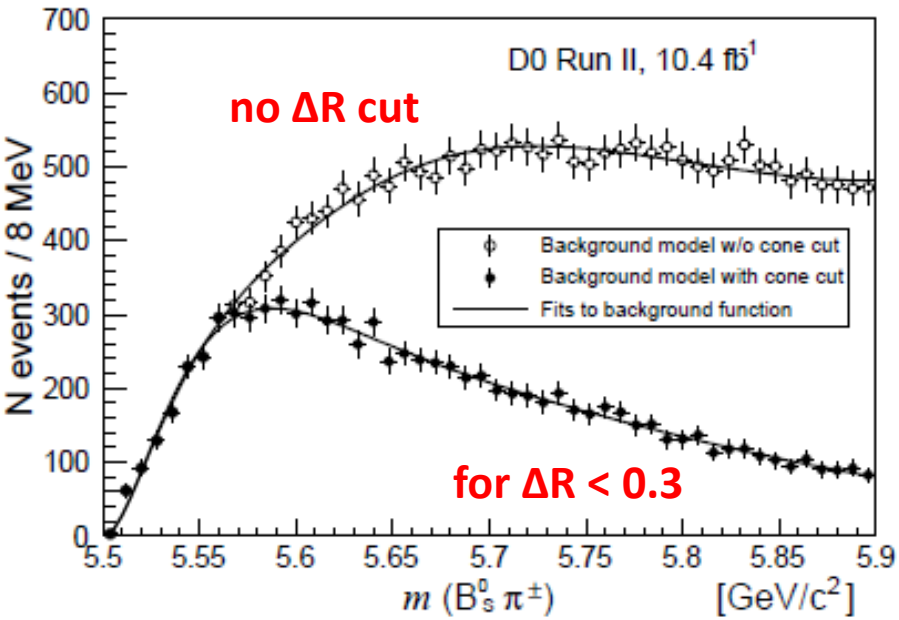
29% of total background (*points*) →

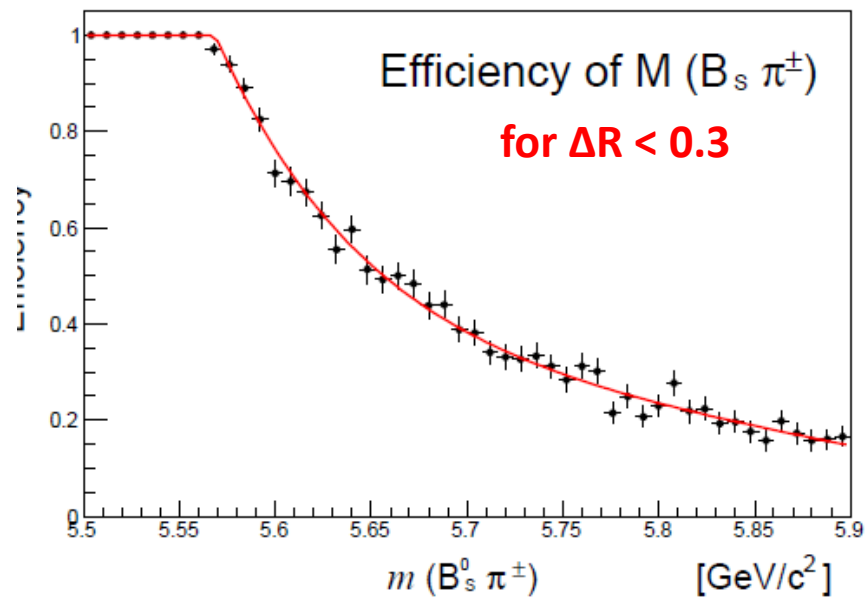
bgr = 29% combinatorial + 71% genuine

non-B_s B_s peak

D0: Observation of a new $B_s^0 \pi^\pm$ state

background model



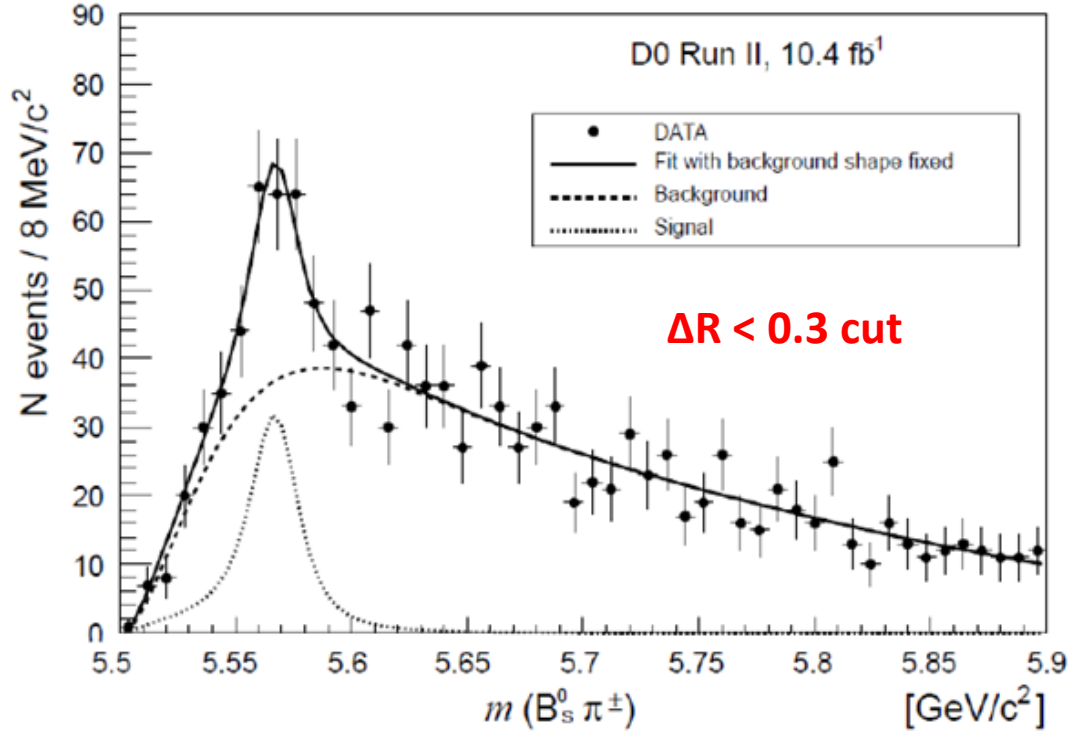


$$F_{bgr}(m_{B_s\pi}) = (C_0 + C_2 \cdot m_0^2 + C_3 \cdot m_0^3 + C_4 \cdot m_0^4) \times exp(C_5 + C_6 \cdot m_0 + C_7 \cdot m_0^2)$$

$$\text{where } m_0 = m_{B_s\pi} - m_{B_s} - m_\pi$$

D0: Observation of a new $B_s^0 \pi^\pm$ state

add π to B_s →



S-wave relativistic Breit Wigner

$$BW(m_{B\pi}) \propto \frac{M_X^2 \Gamma(m_{B\pi})}{(M_X^2 - m_{B\pi}^2)^2 + M_X^2 \Gamma^2(m_{B\pi})}$$

$$\Gamma(m_{B\pi}) = \Gamma_X \cdot (q_1/q_0)$$

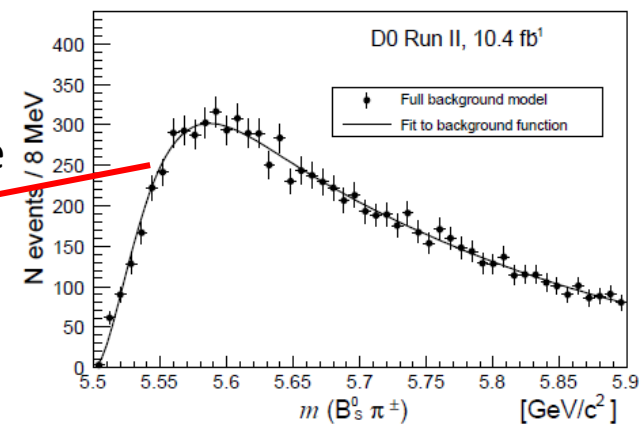
convolute *BW* with MC mass resolution σ = 3.9 MeV and multiply by Eff($M_{Bs\,\pi}$, ΔR cut) = from prior slide

fixed bgd shape

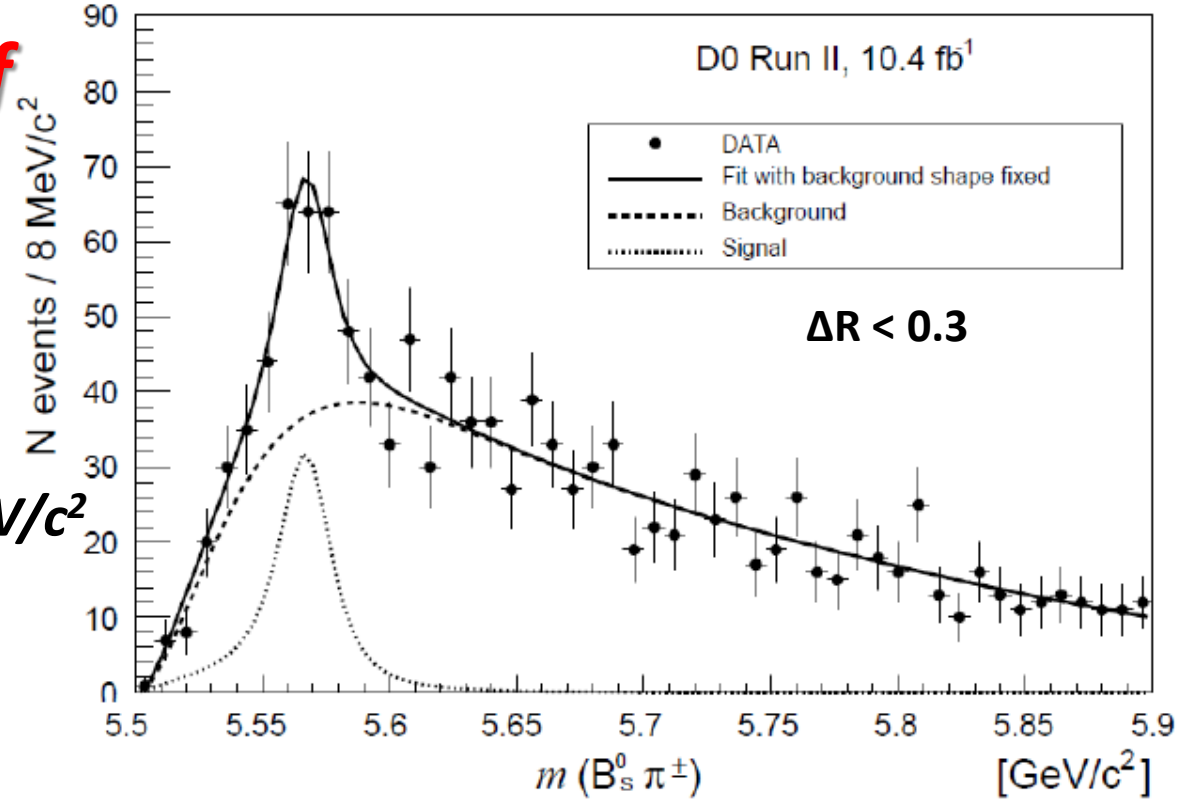
$$F = f_{sig} \times F_{sig}(m_{B\pi}, M_X, \Gamma_X) + f_{bgr} \times F_{bgr}(m_{B\pi})$$

fitting function

vary: f_{sig}, M_X, Γ_X, f_{bgr}



D0: Observation of a new $B_s^0 \pi^\pm$ state



fit for ΔR < 0.3 cut:

M_X = 5567.8 ± 2.9 (stat) *MeV/c²*
Γ_X = 21.9 ± 6.4 *MeV/c²*
↔ *strong decay!*
Mass res. σ = 3.9 *MeV/c²*
N_X = 133 ± 31 events
χ^2 = 32.4 for 46 *DF*

***Local* significance = sqrt(-2 $\ln$ (L_0/L_{max})) = sqrt(43.56) = 6.6 σ**

***Global* significance (statistical uncert only) using Gross & Vitells LEE => 6.1 σ**

"Trial factors for the look elsewhere effect in high energy physics",
Eur. Phys. J. C 70, 525 (2010).

D0: Observation of a new $B_s^0 \pi^{\pm}$ state

Systematic Uncertainties

TABLE I: Systematic uncertainties for the observed $X(5568)$ state mass, natural width and number of events.

Source	mass, MeV/c^2	width, MeV/c^2	rate, %
Background shape			
MC samples with soft or hard B_s^0	+0.2 ; −0.6	+2.6 ; −0.0	+8.2 ; −0.0
Sideband mass ranges	+0.2 ; −0.1	+0.7 ; −1.7	+1.6 ; −9.3
Sideband mass calculation method	+0.1 ; −0.0	+0.0 ; −0.4	+0.0 ; −1.3
MC to sideband events ratio	+0.1 ; −0.1	+0.5 ; −0.6	+2.8 ; −3.1
Background function used	+0.5 ; −0.5	+0.1 ; −0.0	+0.2 ; −1.1
B_s^0 mass scale, MC and data	+0.1 ; −0.1	+0.7 ; −0.6	+3.4 ; −3.6
Signal shape			
Detector resolution	+0.1 ; −0.1	+1.5 ; −1.5	+2.1 ; −1.7
Non-relativistic BW	+0.0 ; −1.1	+0.3 ; −0.0	+3.1 ; −0.9
P-wave BW	+0.0 ; −0.6	+3.1 ; −0.0	+3.8 ; −0.0
Other			
Binning	+0.6 ; −1.1	+2.3 ; −0.0	+3.5 ; −3.3
Total	+0.9 ; −1.9	+5.0 ; −2.5	+11.4 ; −11.2

applying ± 11.3% systematic uncertainty to Yield of *X*(5568) reduces significance to 5.1 σ (incl. LEE & syst.)

D0: Observation of a new $B_s^0 \pi^{\pm}$ state

alternate method:

use *all* $J/\psi\ \phi$ with

$4.8 < M(J/\psi\ \phi) < 6$ GeV,

form & bin in $M(J/\psi\ \phi\ \pi)$,

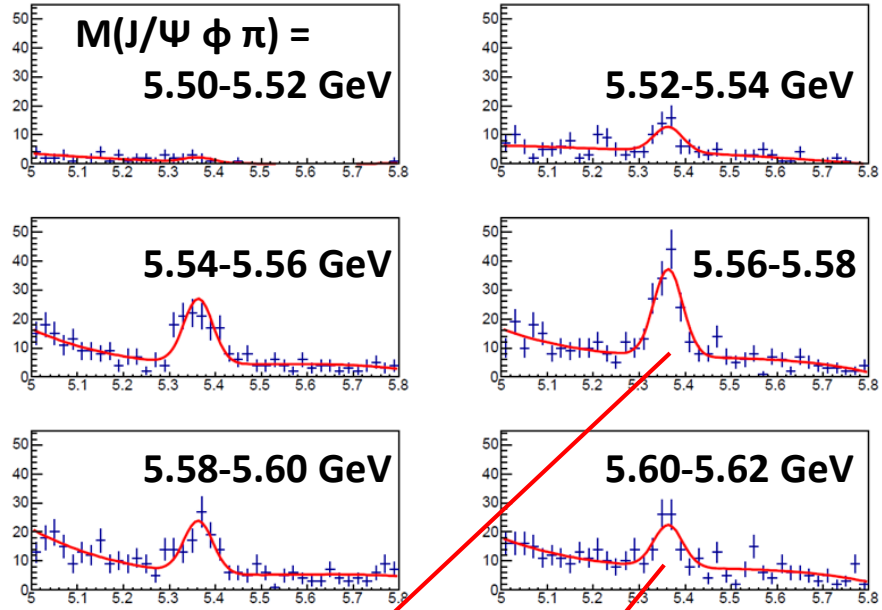
and then fit for B_s^0,

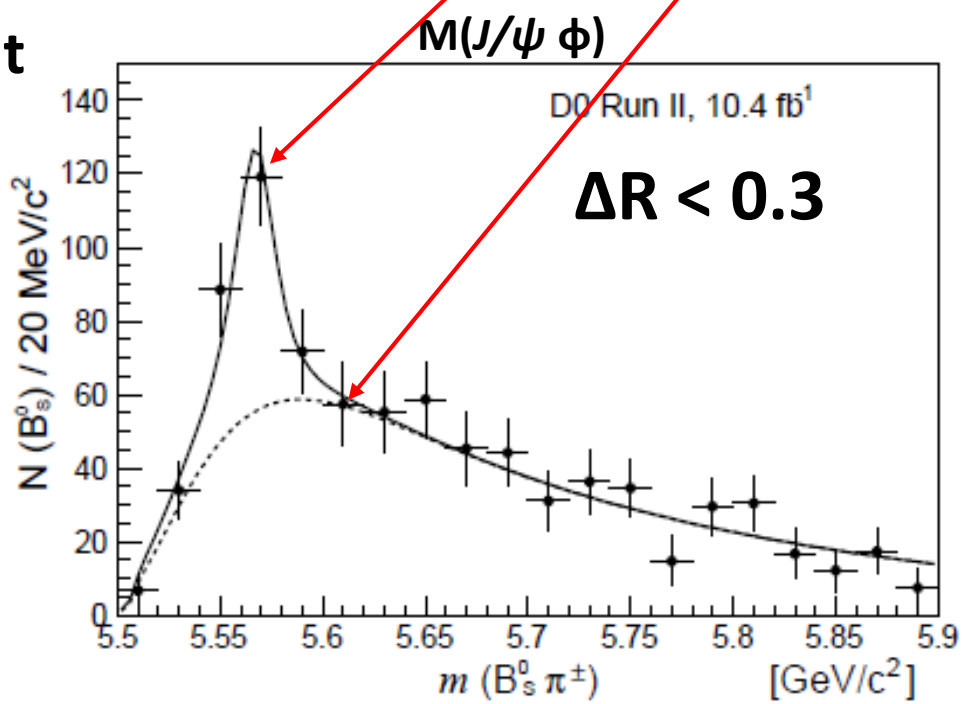
rather than mass selection cut

This removes the "combinatorial" background component

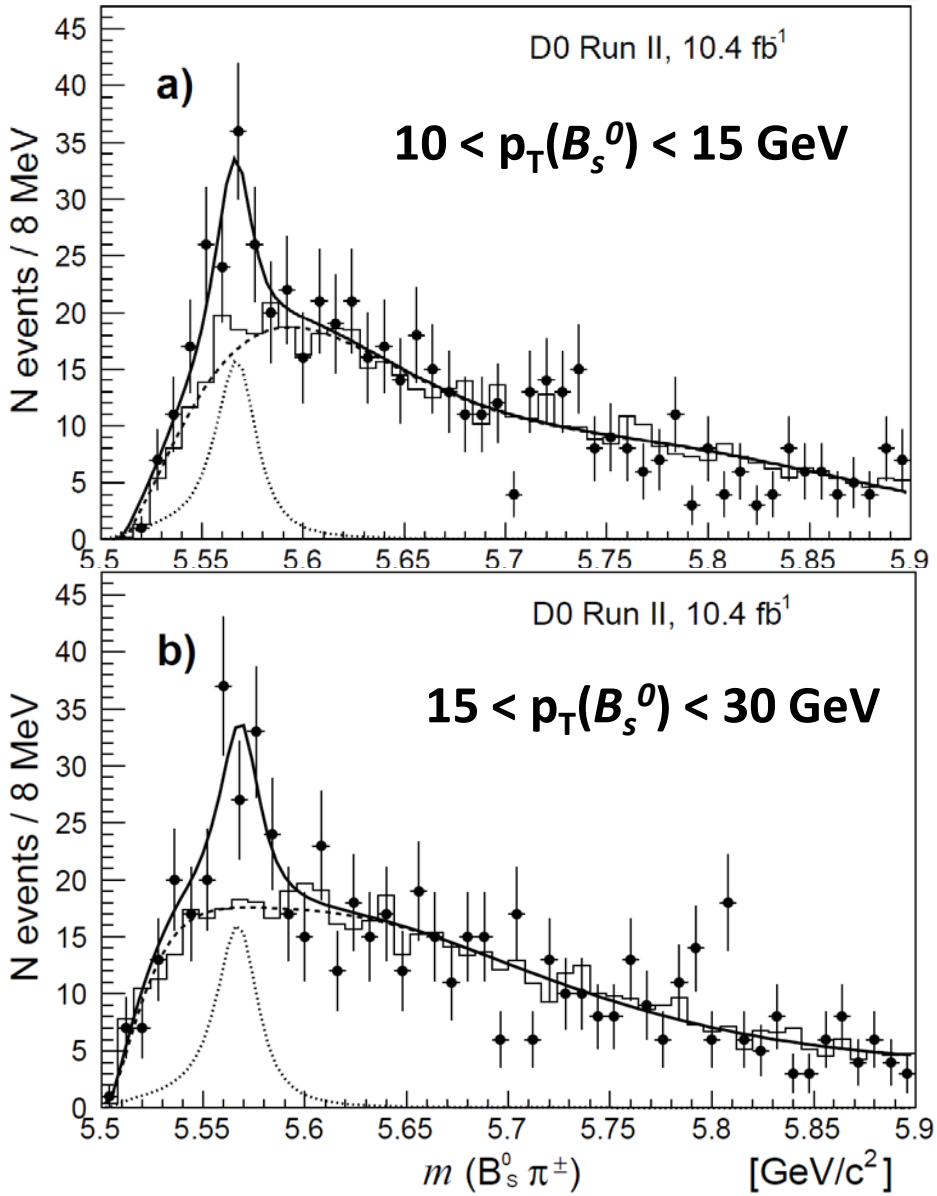
fix M_X and Γ_X

fit $N_X = 118 \pm 22$ events





D0: Observation of a new $B_s^0 \pi^\pm$ state



a cross-check

$p_T(B_s^0)$	10-15	15-30	GeV
N_X	58.6 ± 16.7	67.5 ± 21.8	events
M_X	5566.3 ± 3.3	5568.9 ± 4.4	MeV
Γ_X	18.4 ± 7.0	21.7 ± 8.4	MeV

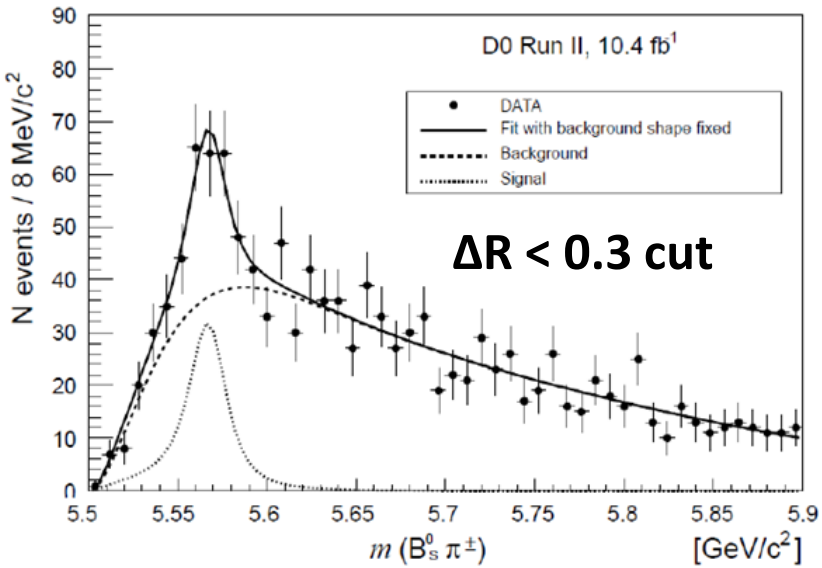
background shape varies, but M_X and Γ_X do not!

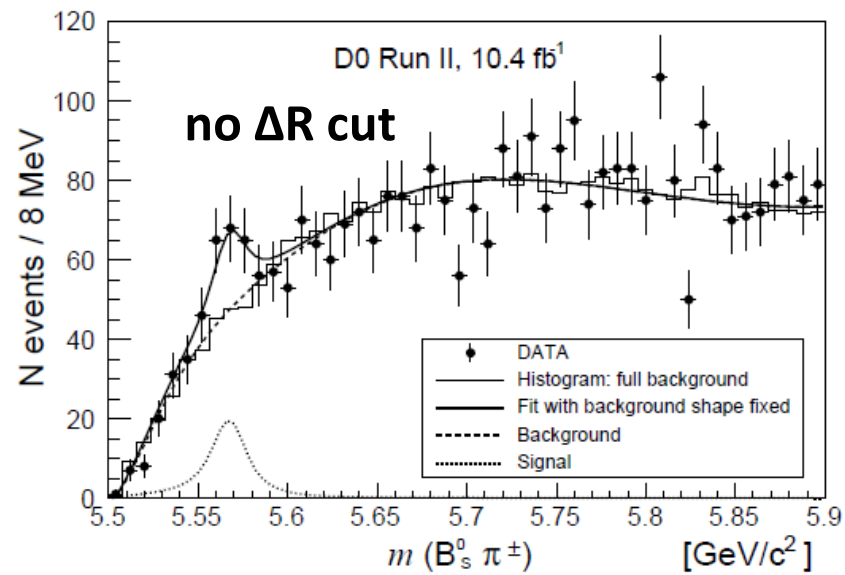
X **leads bkgd max for lower p_T**

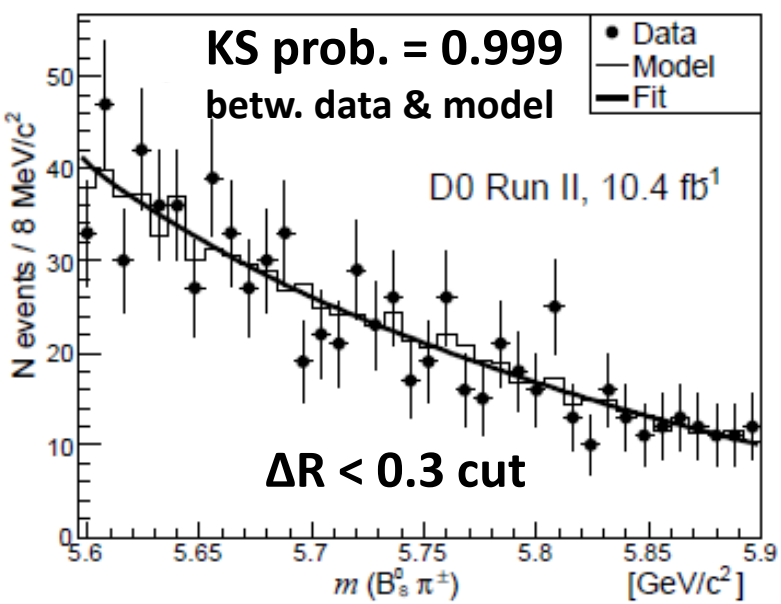
bkgd max leads *X* for higher p_T

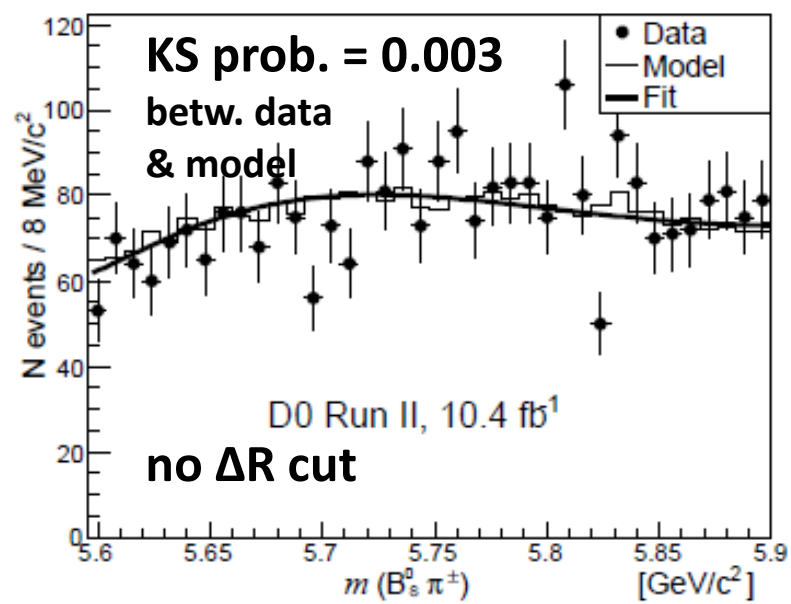
D0: Observation of a new $B_s^0 \pi^{\pm}$ state

How well does background model fit the data, above the X(5568) peak for M > 5.6 GeV?



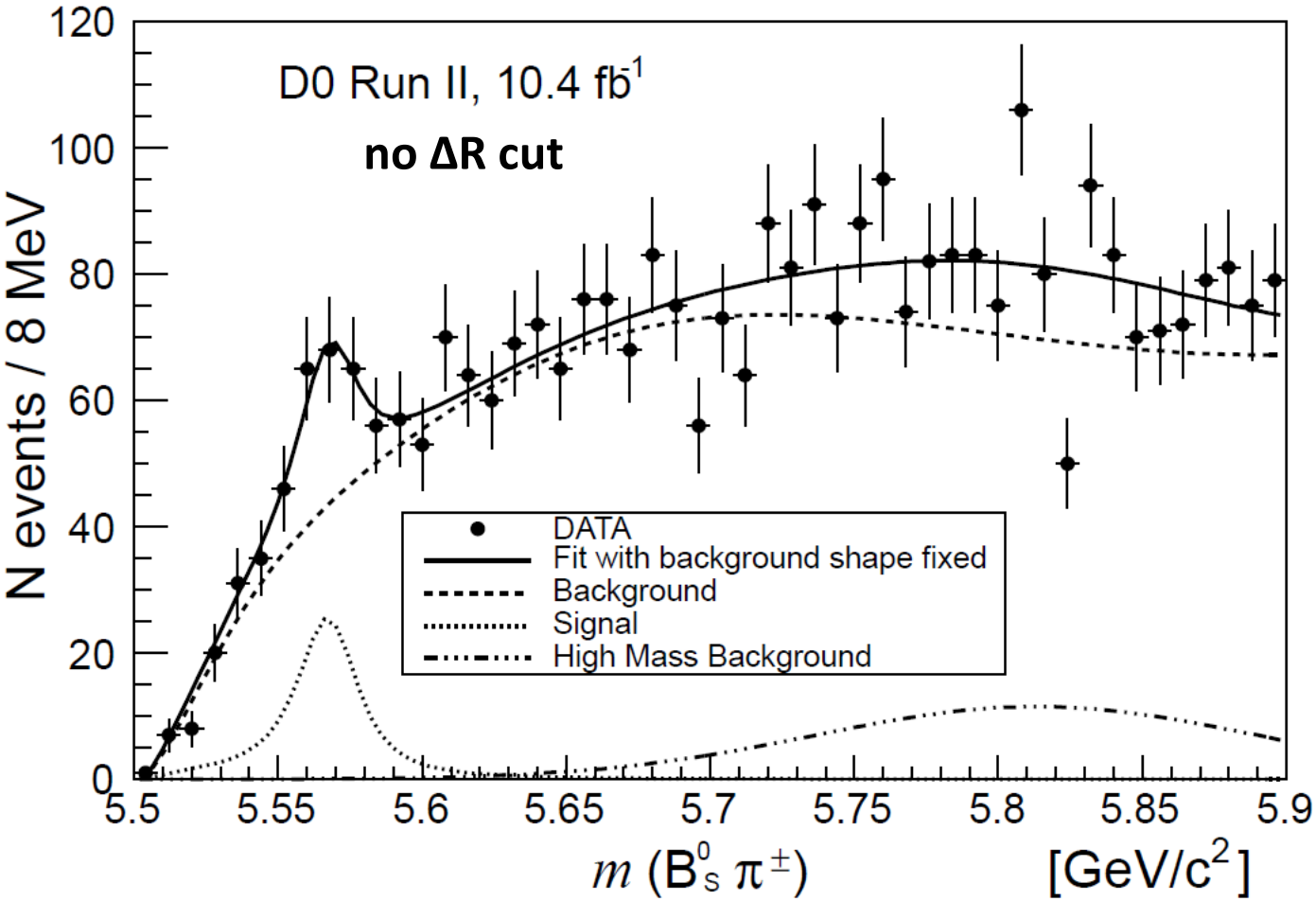






D0: Observation of a new $B_s^0 \pi^{\pm}$ state

How well does background model fit the data, above the X(5568) peak for M > 5.6 GeV? We can get good fit for no ΔR cut if we add another (*ad hoc*) high-mass Gaussian which could arise from partial reconstruction of decays of higher mass states, e.g. B_c^+



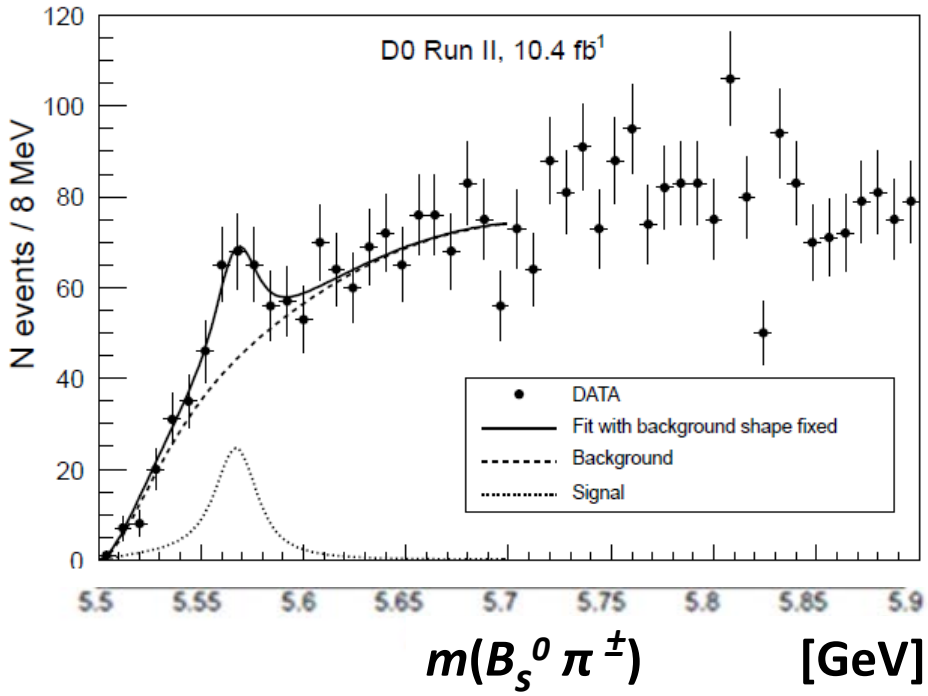
high mass Gaussian background term

mean = 5813 ± 38 *MeV/c²*

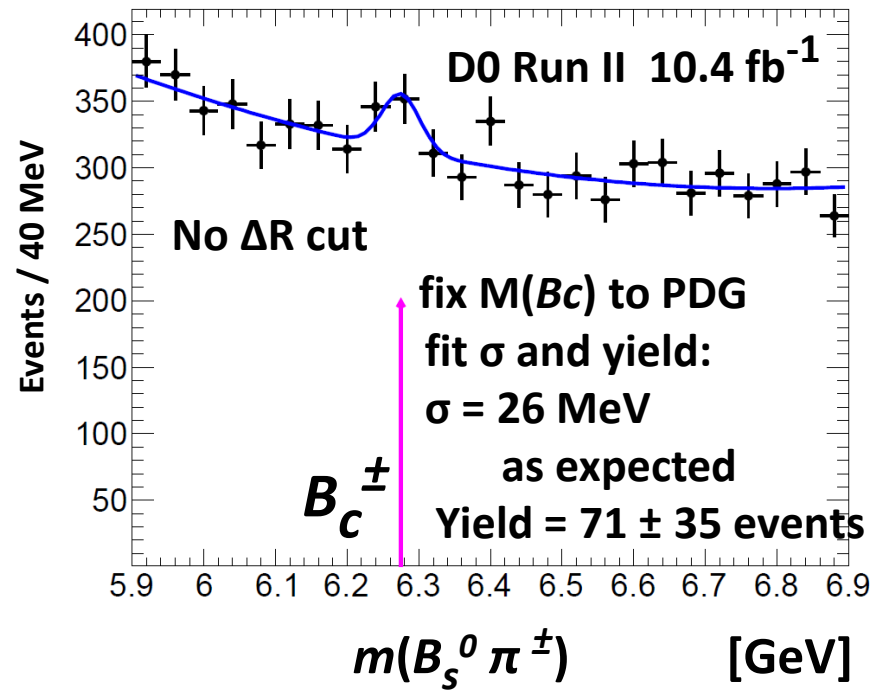
σ = 77 ± 55 *MeV/c²*

D0: Observation of a new $B_s^0 \pi^\pm$ state

without ΔR cut



do we see $B_c^\pm \rightarrow B_s^0 \pi^\pm$?



for no ΔR cut, $5.506 < M(B_s^0 \pi^\pm) < 5.700$ GeV

fix: $M_X = 5567.8$ MeV as for $\Delta R < 0.3$

fix: $\Gamma_X = 21.9$ MeV as for $\Delta R < 0.3$

fit: $N_X = 106 \pm 25$ events $\chi^2 = 18.4$ for 23 *DF*

D0: Observation of a new $B_s^0 \pi^{\pm}$ state

cross-checks performed

Use left (right) sideband for the non-B_s^0 background

Use two versions of Pythia for the B_s^0 background

Compare sidebands with "undersignal"

Allow background shape parameters to be free

Extract the signal yield without the cone cut

Use different B_s^0 mass ranges; modify the B_s^0 vertex cuts

Compare π^+ and π^- subsamples

Examine different detector regions (ϕ, η)

Test $B_s^0 K$ and $B_s^0 p$ hypotheses

Study $m(B_d^0 \pi^{\pm})$ on the full Run II data sample

Look for decay $B_s^{**} \to B_s^0 \pi^+ \pi^-$

D0: Observation of a new $B_s^0 \pi^{\pm}$ state

How many *X*(5568) particles are produced?

Ratio = $\sigma(X)*\mathcal{B}(X \rightarrow B_s \pi)/\sigma(Bs)$

Since we have same B_s decay mode,

$$\sigma(X)*\mathcal{B}(X \rightarrow B_s \pi)/\sigma(B_s) = \frac{N(X \rightarrow B_s \pi)}{N(B_s)} \quad \frac{1}{eff(\pi) \sim 34\ \%}$$

TABLE II: The $X^+(5568)$ number of events, mass, and natural width, the number of reconstructed B_s^0 mesons, the reconstruction efficiency of the soft pion $\epsilon(\pi^{\pm})$, and the production ratio R $(X^+(5568)/B_s^0)$ for two $p_T(B_s^0)$ ranges.

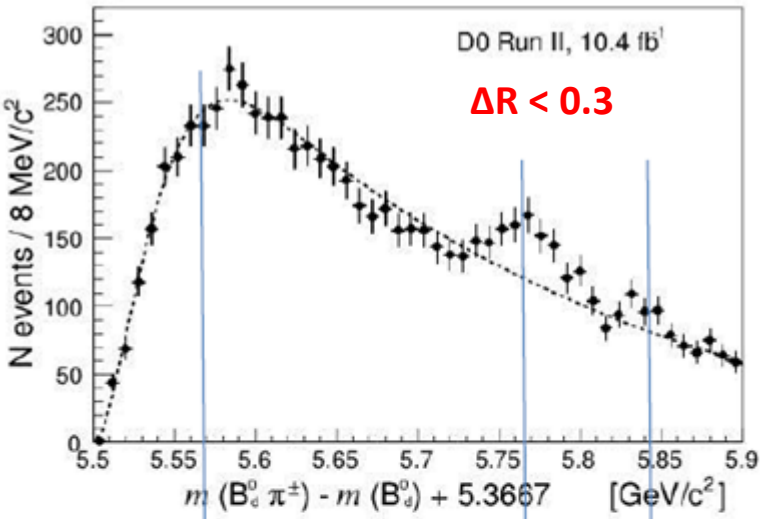
Parameter	$10 < p_T(B_s^0) < 15$ GeV/c	$15 < p_T(B_s^0) < 30$ GeV/c
N $(X^+(5568))$	58.6 ± 16.7	67.5 ± 21.8
M $(X^+(5568))$	5566.3 ± 3.3	5568.9 ± 4.4
Γ $(X^+(5568))$	18.4 ± 7.0	21.7 ± 8.4
N (B_s^0)	2463 ± 63	1961 ± 56
$\epsilon(\pi^{\pm})$	$(26.1 \pm 3.2)\%$	$(42.1 \pm 6.5)\%$
R $(X^+(5568)\ /\ B_s^0)$	$(9.1 \pm 2.6 \pm 1.6)\%$	$(8.2 \pm 2.7 \pm 1.6)\%$

average Ratio($10 < p_T(B_s) < 30$ GeV) =

$$\sigma(X)*\mathcal{B}(X \rightarrow B_s \pi)/\sigma(B_s) = (8.6 \pm 1.9 \pm 1.4)\%$$

D0: Observation of a new $B_s^0 \pi^{\pm}$ state

-6 MeV Q = $m(B_d^0 \pi) - m(B_d^0) - m(\pi)$ 394 MeV



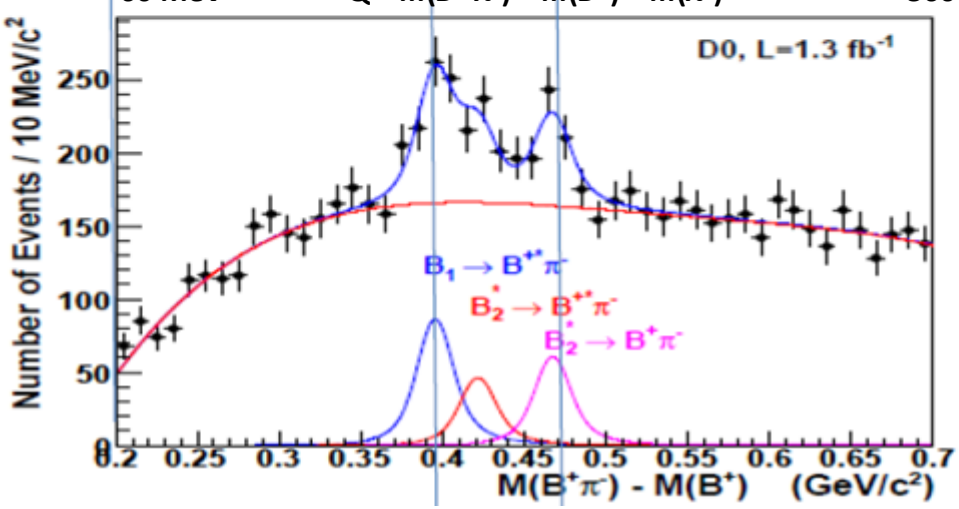
$B_d^0 \pi^+$; $B_d^0 \rightarrow J/\psi K^{*0}$;

$J/\psi \rightarrow \mu^+ \mu^-$; $K^{*0} \rightarrow K^+ \pi^-$

Cuts are very similar to $B_s^0 \pi^+$ analysis **identical topology**

Cone cut does not produce peaks

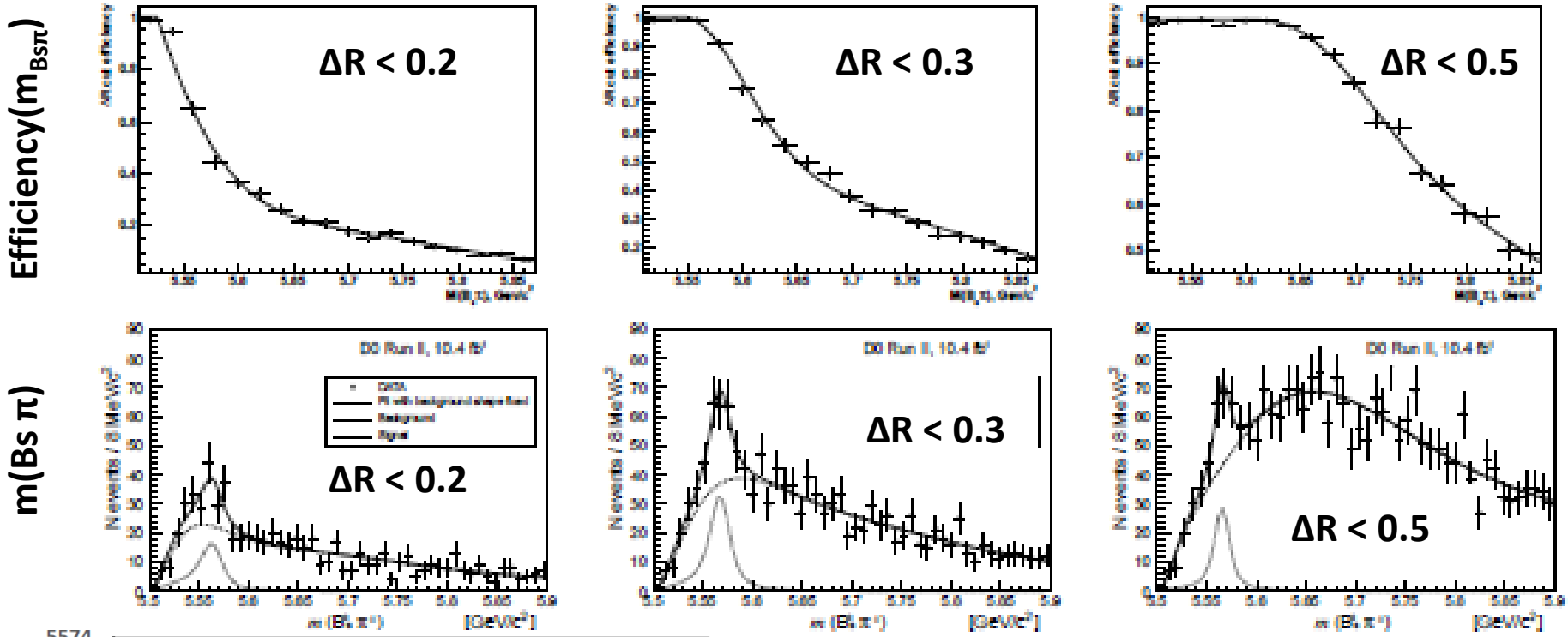
60 MeV Q = $m(B^+ \pi^-) - m(B^+) - m(\pi^-)$ 560 MeV

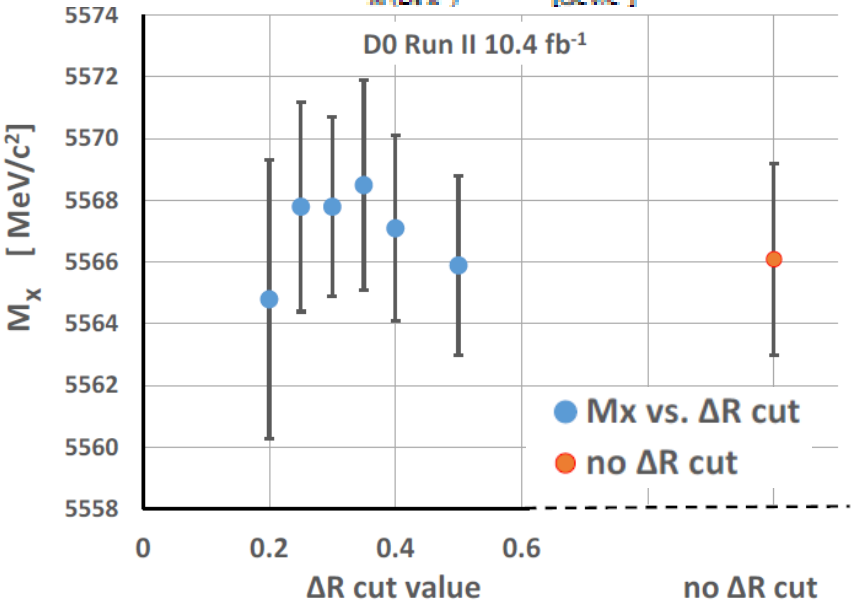


D0 published paper:
Phys.Rev.Lett.99:172001,2007

$m(B^+ \pi^-)$

with $B^+ \rightarrow J/\Psi K^+$



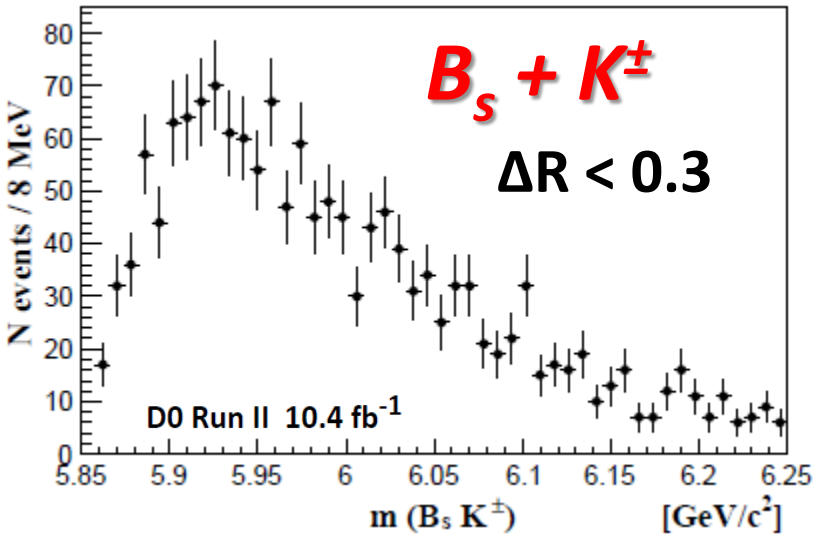


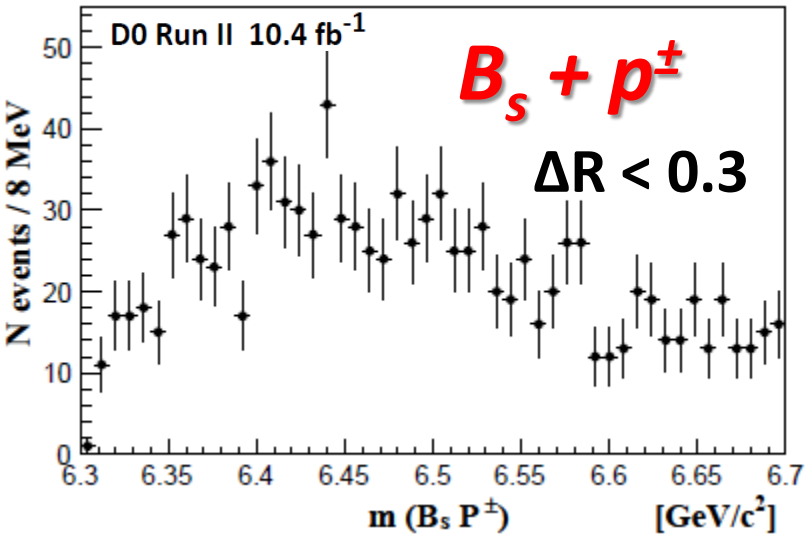
fitted M_X is independent of the ΔR cut - cone cut doesn't generate peak

even though relative positions of signal peak & maximum of background vary

D0: Observation of a new $B_s^0 \pi^{\pm}$ state

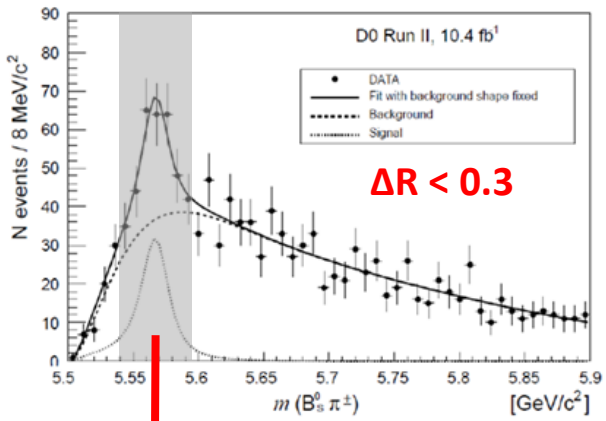
assign the mass of $K^{\pm}$ or $p^{\pm}$ to the $\pi^{\pm}$

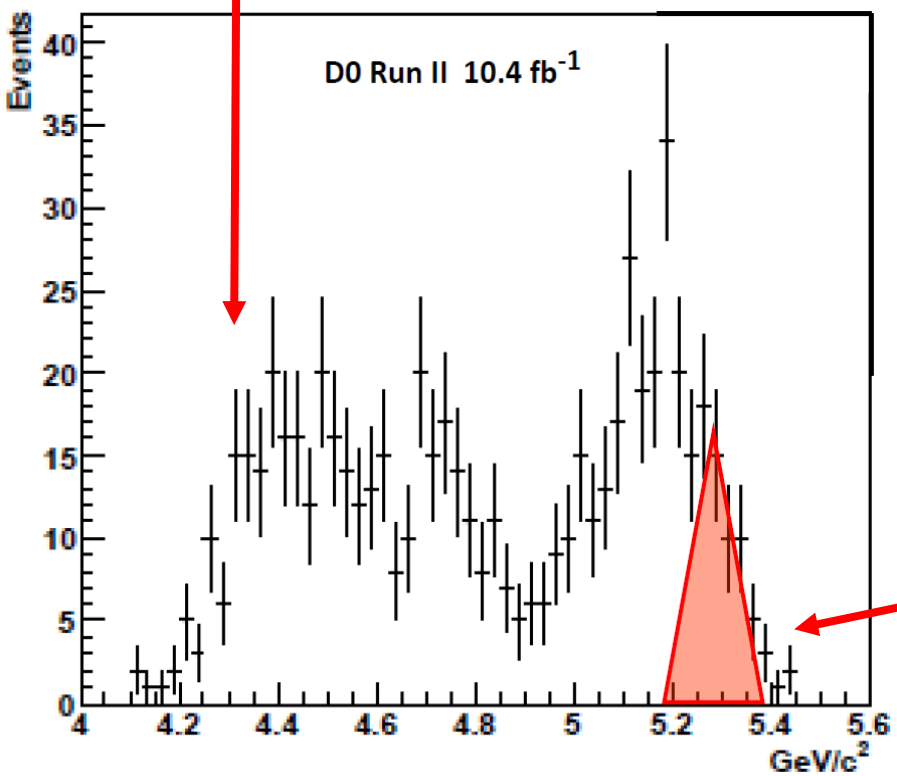




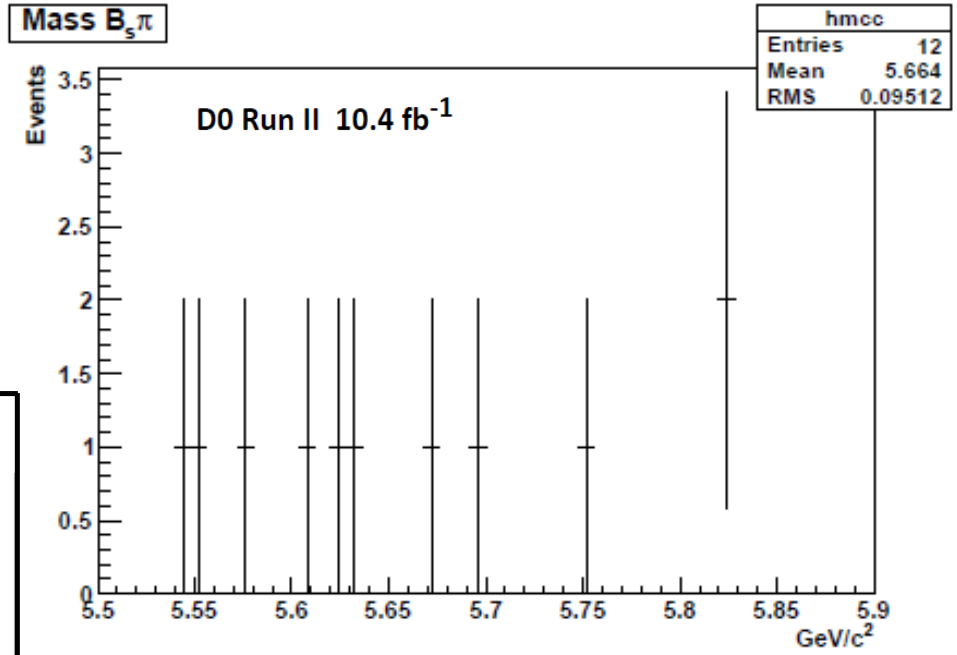
cone cut doesn't generate peak

D0: Observation of a new $B_s^0 \pi^{\pm}$ state





m (J/Ψ K K(mis-id as π))



m("Bs" π) for 1.6 Million Monte Carlo simulations of B^0 mis-id as B_s^0 = no peak!

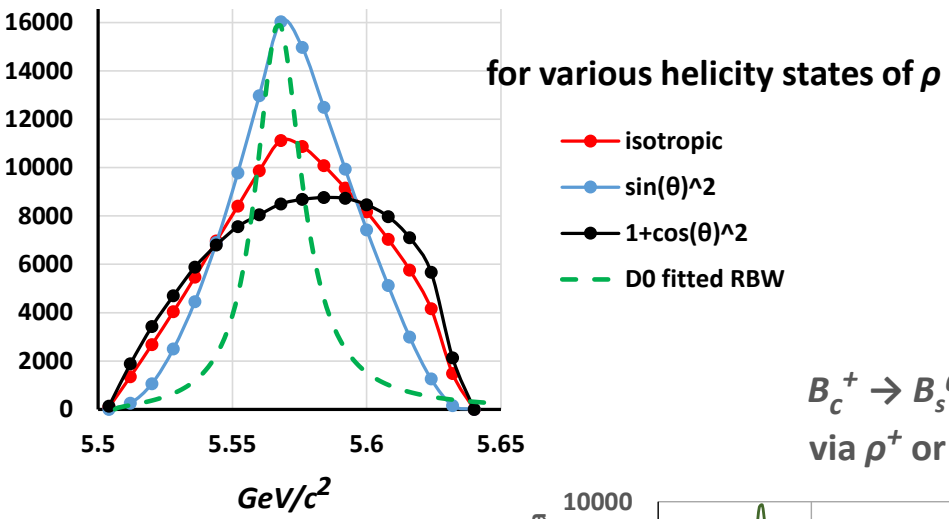
reflection of $B_d^0 \rightarrow J/\Psi\ K^{*0}$?

D0: Observation of a new $B_s^0 \pi^{\pm}$ state

search for peaking backgrounds:

$M(BK_{threshold}) \rightarrow B_s\, \rho\, (\rightarrow \pi^{\pm}$ & missing $\pi)$

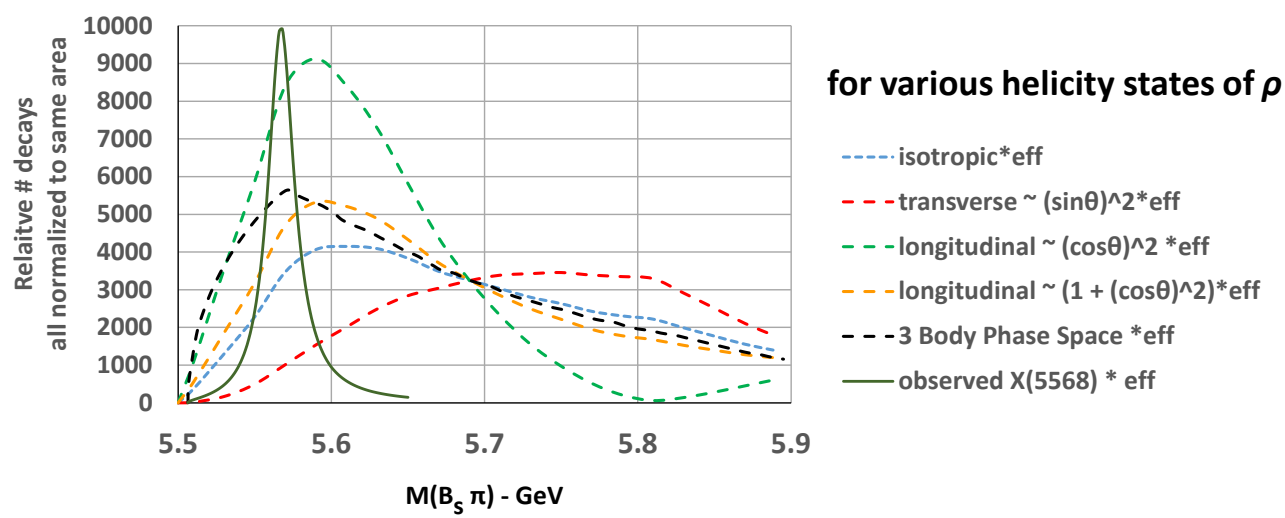
peaks near $X(5568)$



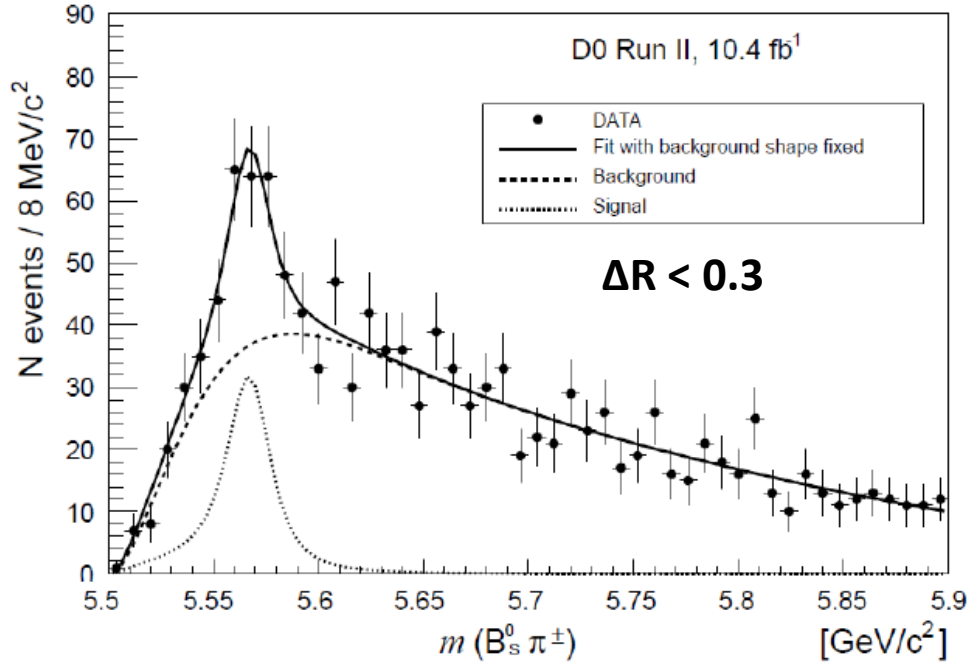
$B_c^+ \rightarrow B_s^0\, \pi^+$ + unobserved π^0

via ρ^+ or 3 Body Phase Space

both are much wider than $X(5568)$



D0: Observation of a new $B_s^0 \pi^\pm$ state



assuming observed state is

L=0 ground state,

if this state is a direct decay

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

then $J^P = 0^+$

If this really were $X \rightarrow B_s^{0*} \pi^\pm$

with $B_s^{0*} \rightarrow B_s^0$ with missing 48.7 MeV γ

then M_X = 5567.8 + 48.7 (± 2.2) MeV → 5616.5 MeV

and $J^P = 1^+$

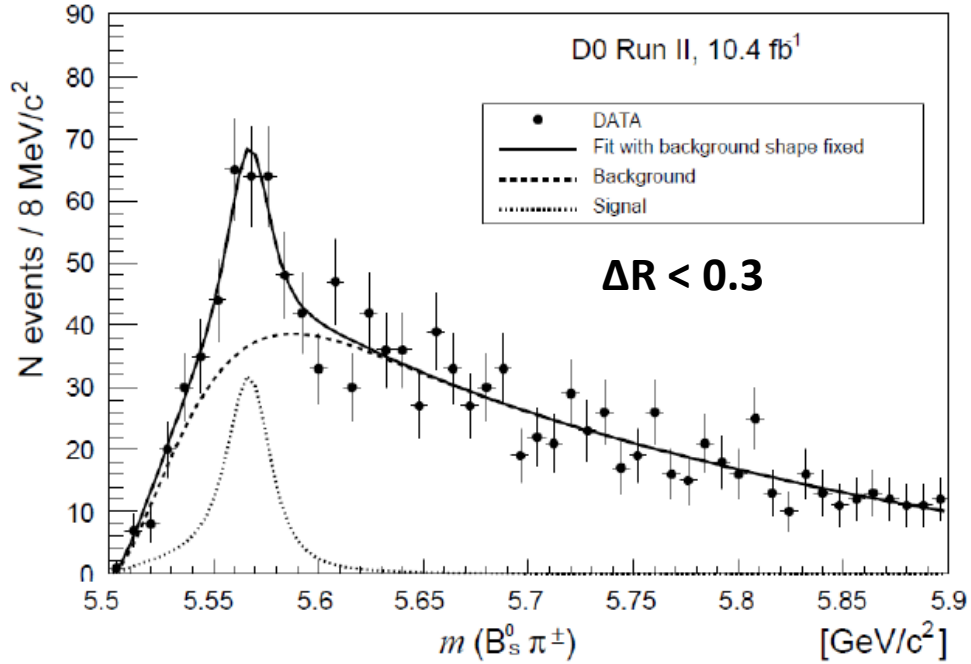
smearing due to missing γ gives a

± 0.85 MeV r.m.s. contribution to M_X

D0: Observation of a new $B_s^0 \pi^\pm$ state

following Maiani *et al.*,

Phys. Rev. Lett. 93, 212002 (2004)



***X*(5568) $J^P = 0^+$ would be counterpart of**

$a_0(980)^+ \{\bar{s}\,\bar{d}\}\{u\,s\}$

replacing *s* with *b* → {*u d s b*}

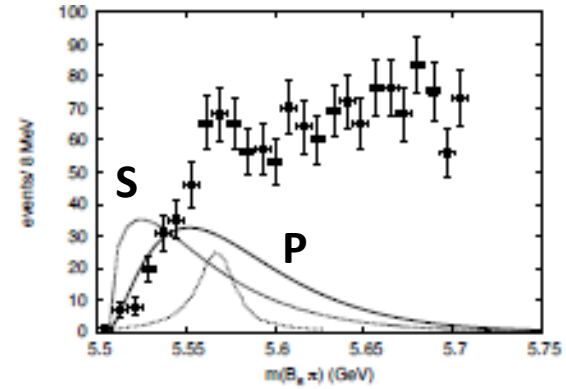
***X*(5617) $J^P = 1^+$ would be counterpart of**

$Z_b^+ \{\bar{b}\,\bar{d}\}\{b\,u\} \rightarrow \Upsilon(nS)\,\pi^+$

replacing *b* by *s* → {*u d s b*}

Short Survey of Interpretations of $B_s^0 \pi^\pm$ state

through Friday 4/29, there are 28 theory articles on arXiv:



<u>Threshold Enhancement</u>

T.J. Burns & E.S. Swanson – arXiv:1603.04366

– S & P waves - *unlikely* – wrong shape!

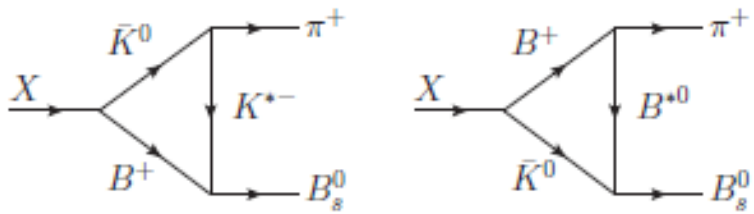
<u>CUSP Rescattering Effects</u> – singularities in loop diagrams

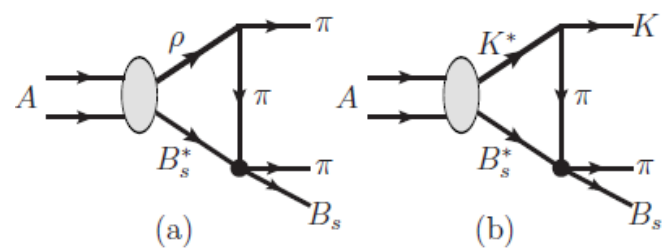
T.J. Burns & E.S. Swanson – arXiv:1603.04366

M. Albaladejo, *et al*. - arXiv: 1603.09340

X-H Liu & G. Li – arXiv:1603.00708

C-J Xiao & D-Y Chen – arXiv:1603.00228





shape (solid curve) fits - why not?

need $B_s^* \pi \rightarrow B_s^* \pi$ rescattering at 5555 MeV

not likely: P-wave scatter too weak,

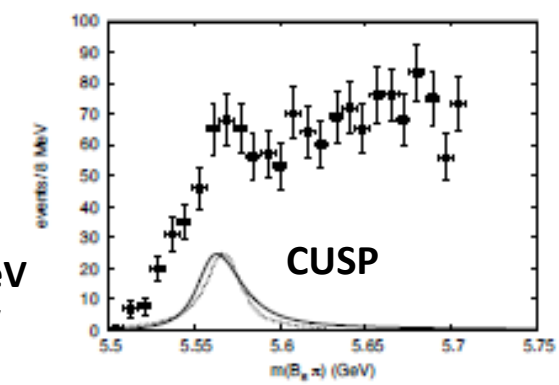
scale to produce Γ_X = 22 MeV is an

order of magnitude smaller than typical,

$B_s^* \pi \rightarrow B_s \pi \gamma$ is unusual since no flavor exchange.

a cusp in $B K \rightarrow B_s \pi$ scattering is more likely, but would be at 5570 MeV

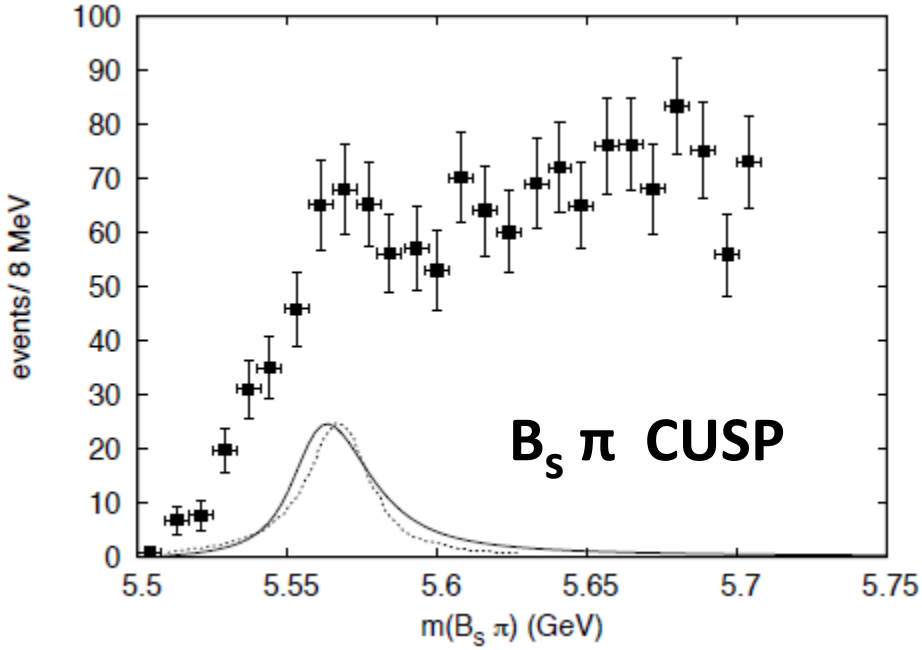
→ expect an analog $B \pi$ state ~ 5465 MeV and $B_s K$ state ~ 5909 MeV

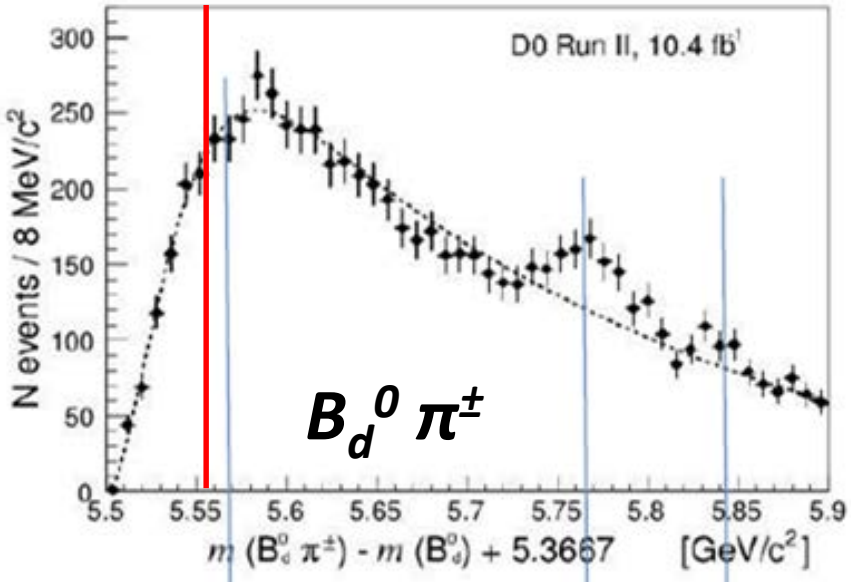


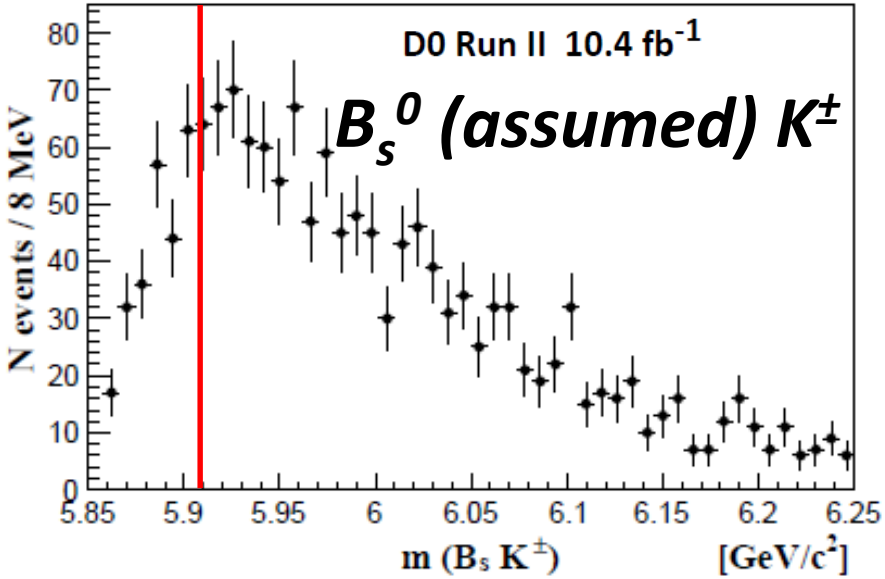
Is $B_s^0 \pi^{\pm}$ state a CUSP?

T.J. Burns & E.S. Swanson
- arXiv:1603.04366

***no* analogous CUSP observed**
for *$B\pi$* state ~ 5465 *MeV/c²*
(5552 *MeV/c² on plot below left*)
or *$B_s K$* state ~ 5909 *MeV/c²*







note: {Q=5465-(5279.6+139.5)}+5506=5552

Short Survey of Interpretations of $B_s^0 \pi^{\pm}$ state

Loosely-Bound Molecule

T.J. Burns & E.S. Swanson – arXiv:1603.04366

– *unlikely* since Binding Energy of *B-K* > 200 MeV

S.S. Agaev *et al*. - arXiv: 1603.02708 – QCD two-point and light-cone sum rules

expect lowest mass X_b to be a *B-K* molecule with M_{Xb} = 5764 ± 142 MeV

Tetraquark

T.J. Burns & E.S. Swanson – arXiv:1603.04366

– *X*(5568) {*u d s b*} is *unexpectedly light*

Ξ_b & Ξ_b^* (*bsu*) 5794 & 5945 MeV add d-quark

¼ (3 B^* + B + 3 K^* + K) = 6107 MeV

¼ (3 B_s^* + B_s + 3 ρ + π) = 6019 MeV

$|I, I_3\rangle = |1, \pm1\rangle$ *X*(5568) should also have

2 neutral $B_s\,\pi^0$ partners $|1,0\rangle$ and $|0,0\rangle$

narrow, since no open hadronic channels

Short Survey of Interpretations of $B_s^0 \pi^{\pm}$ state

<u>diquark – antidiquark</u> = {color triplet} X anti{color triplet)

→ leading to strong forces and strong binding

L. Maiani *et al*., *New Look at Scaler Mesons*, PRL 93, 212001 (2004)

A. Ali *et a*l. - arXiv: 1604.01731 – est lightest X_b0+ {*bdus*} at 5770 MeV, just below BK threshold

predict 0+ & 1+ {*cdus*} at 2365 & 2501 MeV ~ 50 MeV heavier than Ds0(2317) & Ds1(2460)

suggests search for $B_c^+ \rightarrow \pi^+ + X_b^0 (\rightarrow B_s^0 \pi^0)$ or $B_c^+ \rightarrow \pi^0 + X_b^+ (\rightarrow B_s^0 \pi^+)$

Q-F Lu & Y-B Dong - arXiv: 1603.06417 – relativized quark model by Godfrey and Isgur

minimum M{*sqbq*} = 6196 MeV and minimum M{*sqcq*} = 2873 MeV

Z-G Wang – arXiv: 1603.20498 - use three point QCD sum rules

for M_X = 5568 MeV, predicts Γ_x = 20.5 ± 8.1 MeV, agreeing with D0 Γ_x ~ 22 MeV

C.M. Zanetti et al. – arXiv:1602.09041 – QCD sum rule – predicts MX = 6.39 ± 0.10 MeV

<u>hybridized tetraquarks</u>

A. Esposito *et al*. arXiv: 1603.07667 – neither purely compact tetraquarks or molecule

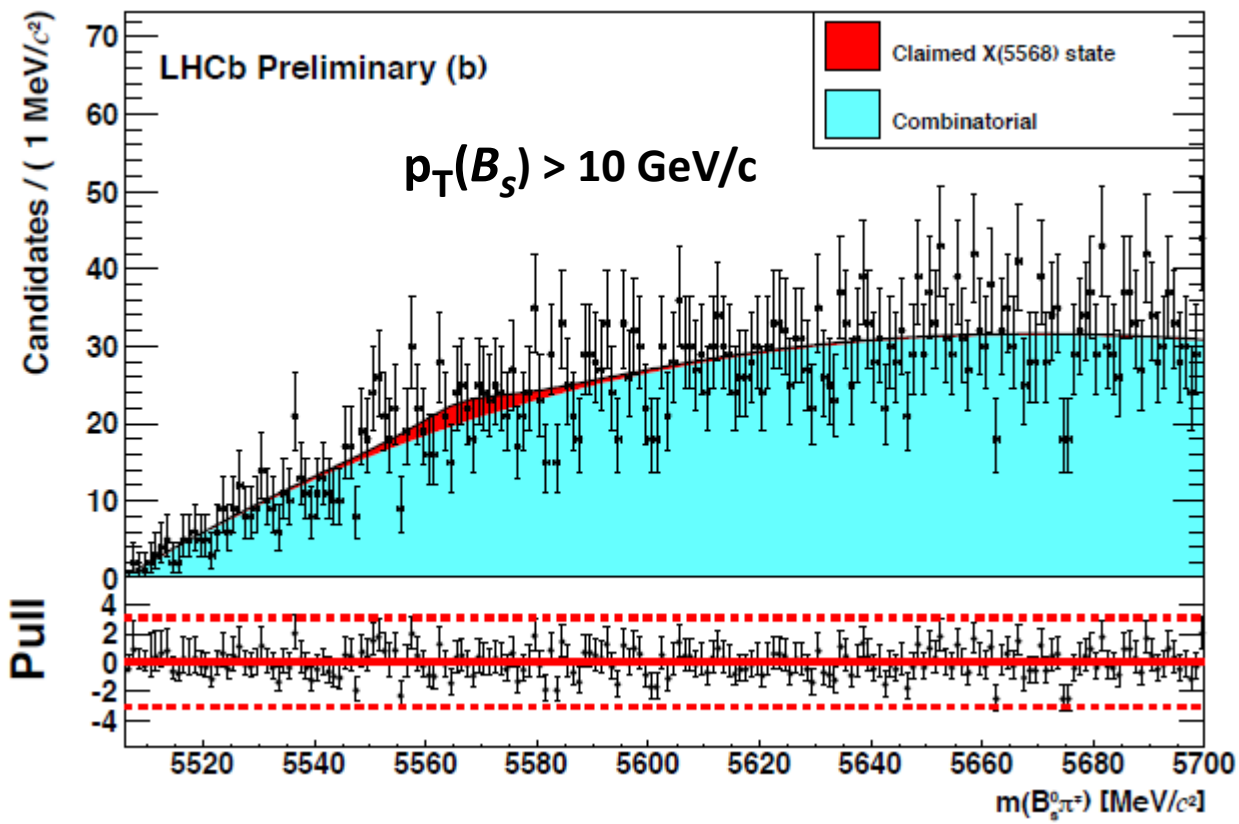
inspired by Feshbach metastable states, expect MX ~ 5771 MeV

LHCb-CONF-2016-004

3 fb^{-1} at 7 & 8 TeV, $2 < \eta < 5$, $p_T(B_s) > 10$ GeV/c

$m(B_s^0 \pi^{\pm})$ for $B_s^0 \to J/\Psi\ \phi$ and $B_s^0 \to D_s^- \pi^+$

~ 20 X the sample of B_s^0 decays by D0



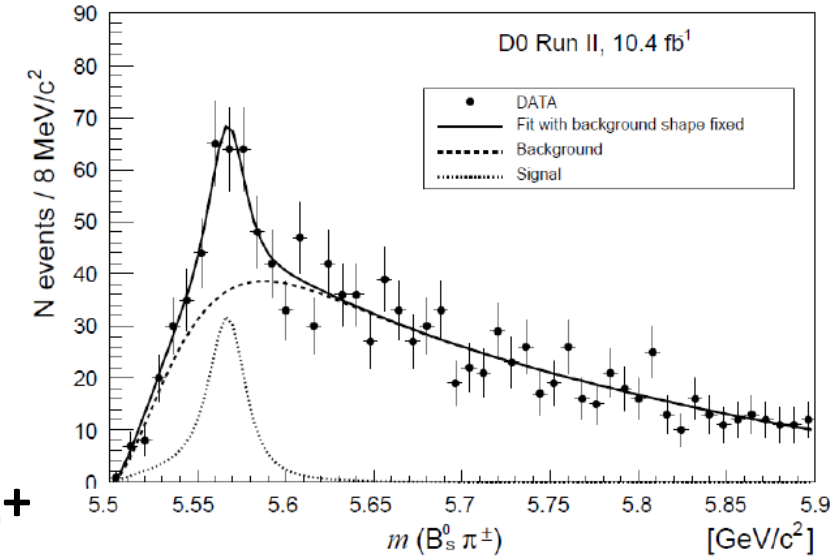
note: *X(4140)* → *J/Ψ* φ was *not* seen by LHCb although observed by CDF, CMS, and D0 (two modes)

only X(3872) → *J/Ψ* $\pi^+\pi^-$ *was seen by all*

$$\mathcal{R} = \sigma(X)*\mathcal{B}(X \to B_s \pi)/\sigma(B_s) < 1.6\ \%\ @\ 90\%\ \mathrm{CL}$$

reminder D0: $\mathcal{R} = (8.6 \pm 1.9 \pm 1.4)\%$

D0: Observation of a new $B_s^0 \pi^\pm$ state summary



4 different flavors = *b, s, u, d*

$X(5568)^\pm \rightarrow B_s^0 \pi^\pm$ *with* $J^P = 0^+$

$M_X = 5567.8 \pm 2.9\ (\text{stat})\ ^{+0.9}_{-1.9}\ (\text{syst})$ MeV

$\Gamma_X = 21.9 \pm 6.4$ MeV

with significance of 5.1 σ incl. LEE & systematics

$\sigma(X)*\mathcal{B}(X \rightarrow B_s^0 \pi)/\sigma(B_s^0) = (8.6 \pm 1.9 \pm 1.4)\%$

→ 8-9% of all B_s^0 are from $X(5568)^\pm$

or $X(5615)^\pm \rightarrow B_s^{*0} \pi^\pm$ *with* $J^P = 1^+$

D0: Observation of a new $B_s^0 \pi^{\pm}$ state

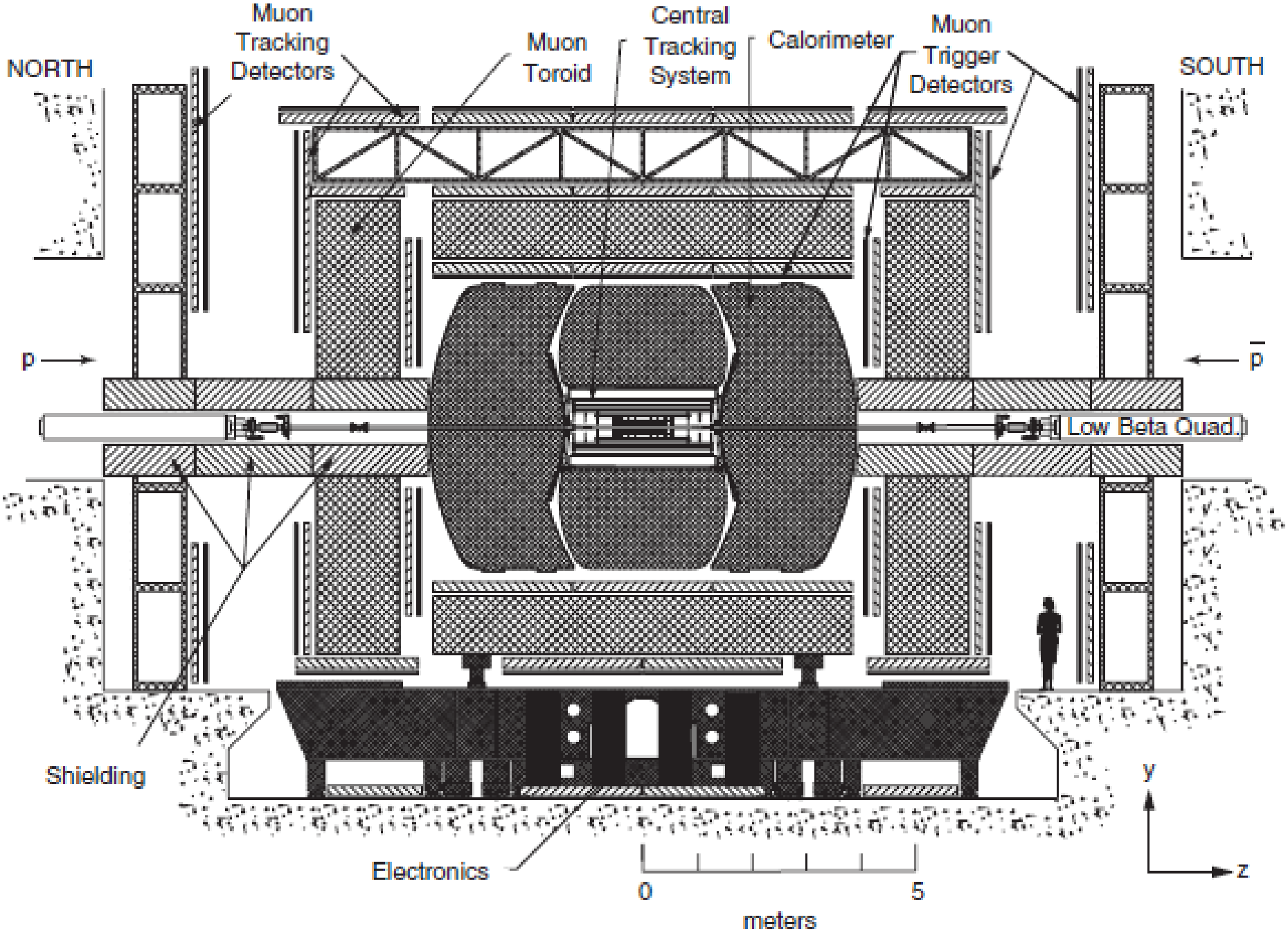
We eagerly await
the investigations by
CDF, CMS, ATLAS

Thank you!

Peter

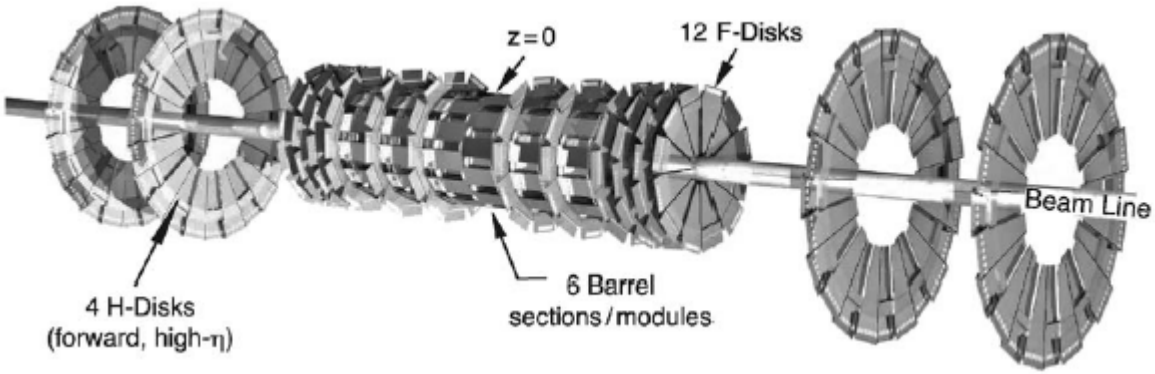
D0: Observation of a new $B_s^0 \pi^{\pm}$ state

Spare Tires


Muon
Tracking
Detectors
Muon
Toroid
Central
Tracking
System
Calorimeter
Muon
Trigger
Detectors
NORTH
SOUTH
p
p̄
Low Beta Quad.
Shielding
Electronics
0
5
meters
y
z

charged particle tracking parameters

- Silicon Microstrip Tracker (SMT)



  - Barrels: 50 μm with 62.5 or 153.5 μm 90° stereo 2.71-7.58 cm (central) & 4.55-10.5 cm (outer) radius
  - F Disks: 40 μm – 2.57-9.96 cm radius
  - H Disks: 50 & 62.5 μm 30° stereo – 9.5-26 cm radius
- Layer 0 silicon:
  - 71μm @ 1.61 cm & 81 μm @ 1.76 cm radius
- Interaction Region: $\sigma_z = \pm 25$ cm

charged particle tracking parameters

- Central Fiber Tracker (CFT) – VLPC readout
  - 835 µm diameter, double clad, 928-993 µm spacing
  - 16 layers: 8 ||, 4 +3°, 4 -3° stereo; 20-52 cm radius

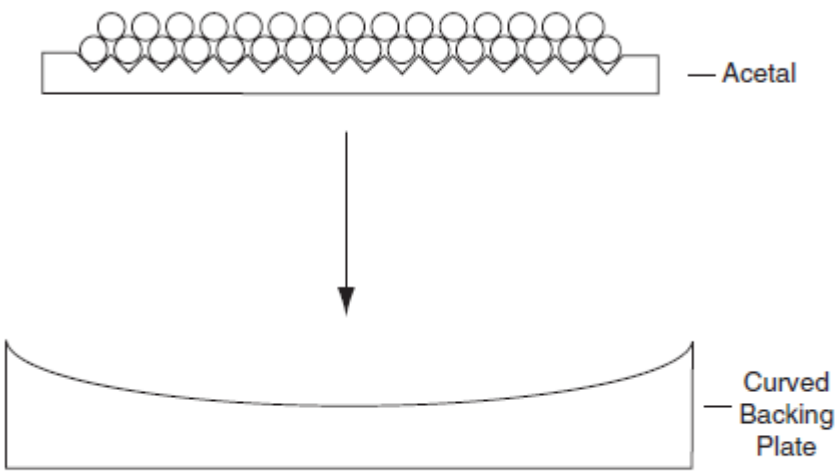
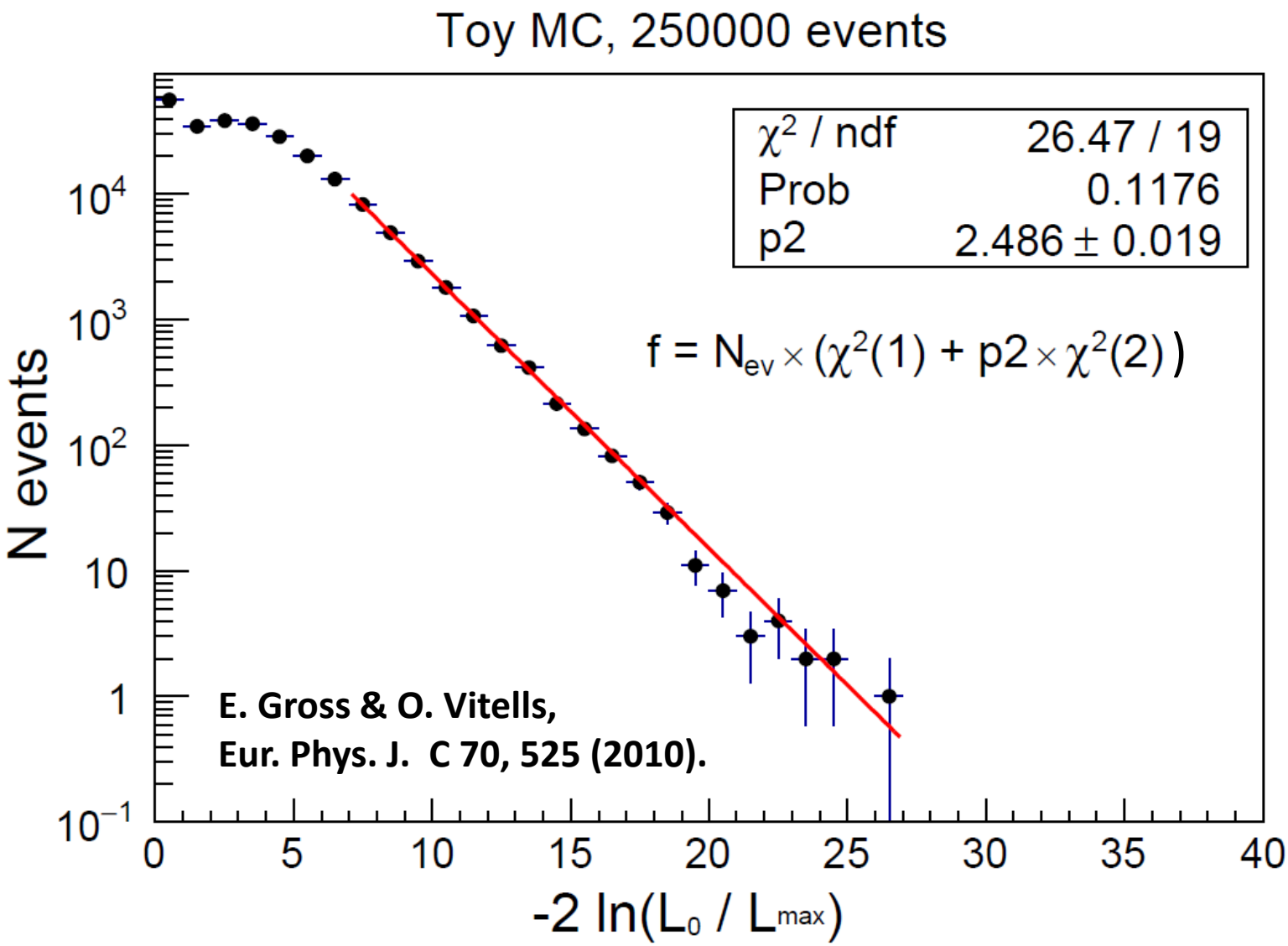


Fig. 13. Technique for curved scintillating fiber ribbon fabrication.

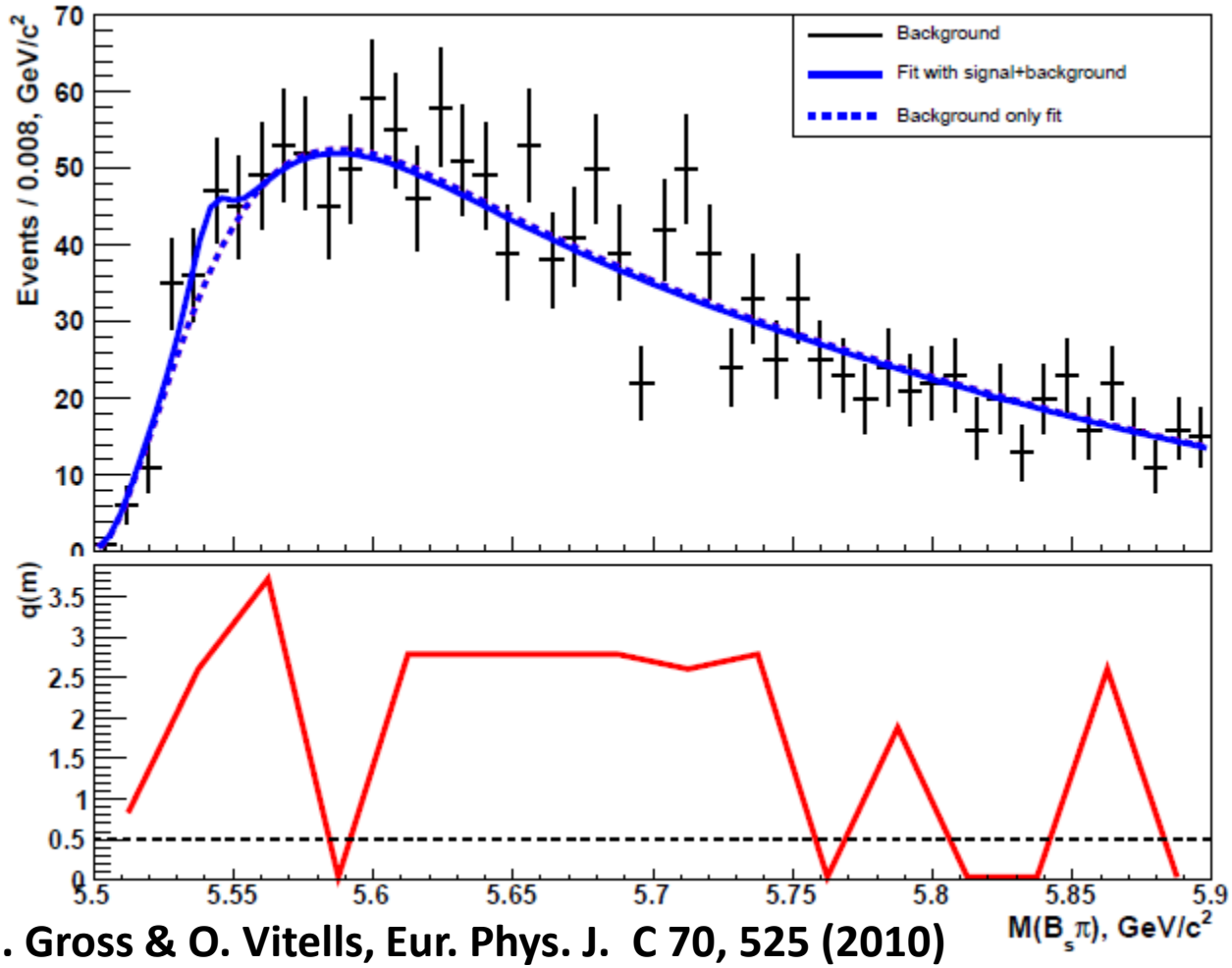
- Solenoid 1.9 Tesla Magnetic Field
- Interaction Region: $\sigma_z = \pm 25$ cm

D0: Observation of a new $B_s^0 \pi^{\pm}$ state



D0: Observation of a new $B_s^0 \pi^{\pm}$ state

<level crossings (200 eq. exp)> = 2.255 ± 0.021



example for 1 equivalent experiment

reference level c_0 = 0.5 for search for one peak

E. Gross & O. Vitells, Eur. Phys. J. C 70, 525 (2010)

D0: Observation of a new $B_s^0 \pi^{\pm}$ state

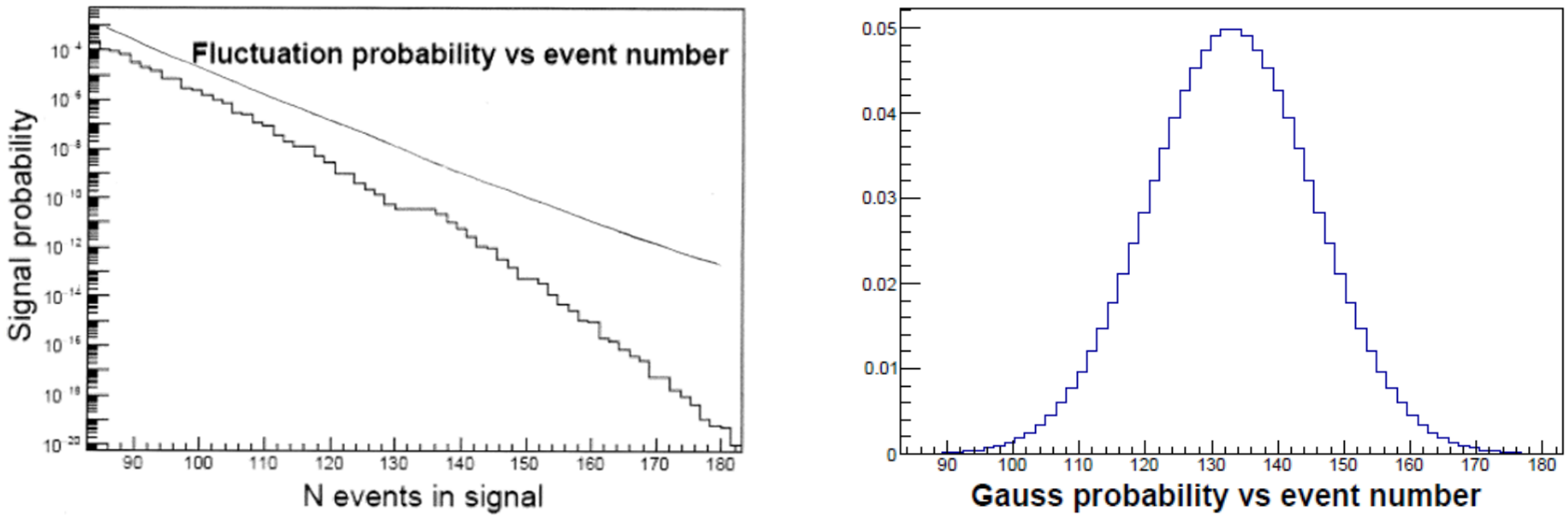


FIG. 16: The probability to observe a signal due to background fluctuation as a function of number of events (left). This distribution is convolved with the gaussian probability density function (right), corresponding to systematic uncertainties, as a function of event number.

Signal significance

We obtained from fit (using Wilks's theorem) local significance (fixed mass and width):

S (local) = 6.6 σ $\qquad t_0 = -2 \ln (\mathcal{L}_0 / \mathcal{L}_{max})$, $P(t_0) = P(\chi^2(t_0,1))$

Probability, corresponding to local significance with systematic uncertainty incuded:

$$P(t_0)_{\text{local+sys}} = \int P(t_0 | N_{evt}) \, G(N_{evt}) dN_{evt}$$

where $P(t_0 | N_{evt})$ – fluctuation probability as function of t_0 for given N_{evt} and $G(N_{evt})$ – gaussian distribution corresponding to systematic uncertainty.

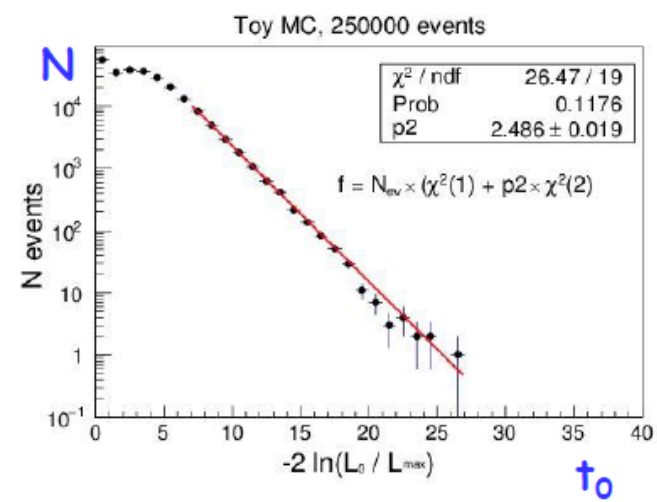
S (local+syst) = 5.6 σ (includes uncertainty due to background shape)

Look-elsewhere effect (LEE) is calculated based on Gross & Vitells approach. Distribution of t_0 for trial experiments imitating signal distribution is extrapolated with $f = N (\chi^2(1)+P_2 \chi^2(2))$ formula.

Integrating over $t_0 > S^2_{\text{local (+syst)}}$ range we obtain fluctuation probability and, respectively, signal significance:

S (LEE) = 6.1 σ

S (LEE+syst) = 5.1 σ



D0: Observation of a new $B_s^0 \pi^{\pm}$ state

Notes for Peter

Daria – 10march2016

Let me try. We have the D0 data: dNevents/dm (Fig 3a in the PRL) with fitted Nsig=133. From the fits with and without signal we get the likelihood ratio of 43.5 with the corresponding probability of something around 10^-10.

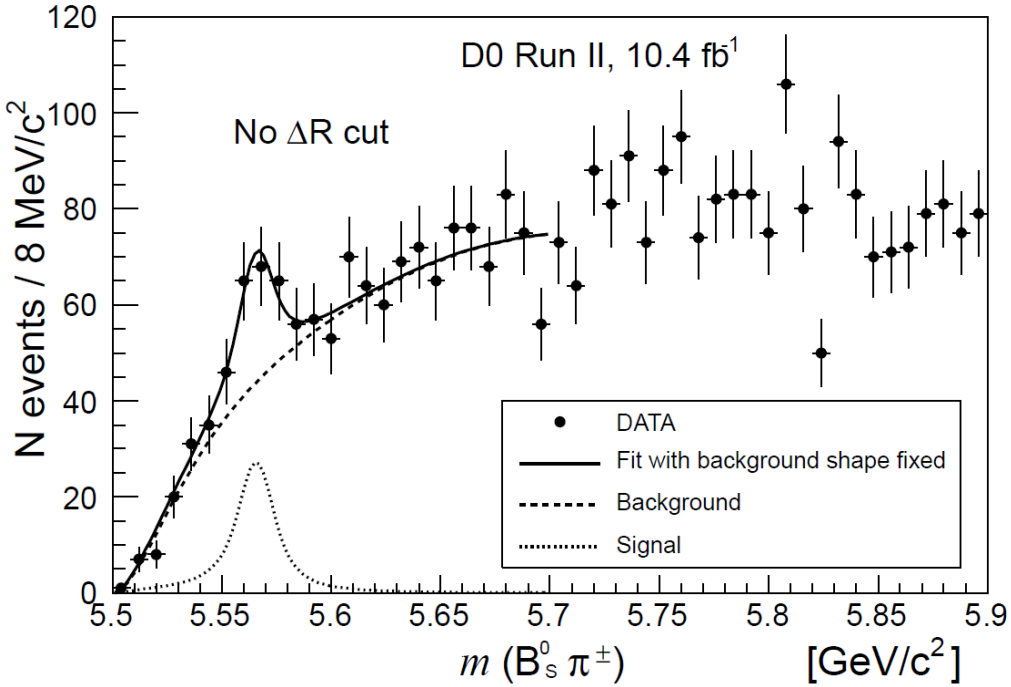
We want to know what would be the corresponding probability with the same background plus the same signal shape but normalized to values of between Nsig=80 and 180 (this is the range where the syst Gaussian is nonzero). So, Alexey makes histograms of the signal with the signal model but normalized to 80, 81, 82, ...180. He subtracts the histogram corresponding to Nsig=133 from the data histogram to obtain the net background, adds the simulated signal histogram one at a time and obtains the likelihood ratio for that number of Nsig. The probability ranges from something like 10^-4 for Nsig around 80 to 10^-19 for Nsig=180. This procedure gives him Fig 15 (left) from the note.

Alexey – 8march2016

> The procedure is following. The basic Bs pi+ mass distribution was fitted and signal shape was obtained. Then I produced a histogram having the signal shape, which had a specific integral. This integral was changed with a small step (X-axis). This histogram was added (and also subtracted) to (from) the basic histogram. The new histogram (basic + produced) was executed with the same procedure, as basic, to obtain significance. These significance values are given in Y-axis for each step, when 133+-step is X-axis.

D0: Observation of a new $B_s^0 \pi^{\pm}$ state

allowing M_x and Γ_x to float in fit



Date: Monday, March 21, 2016 7:22:16 AM
Attachments: nocut.eps

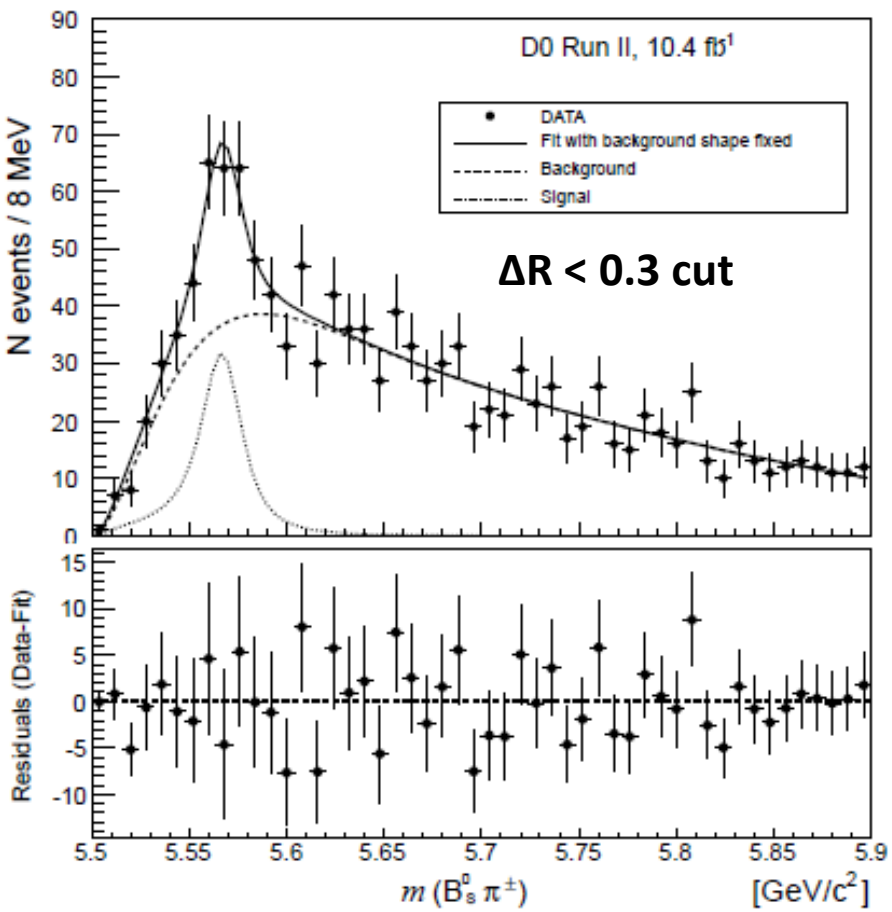
Dear Peter,

The fit figure is in the attachment (without additional Gaussian background, I'll do it later and for the full mass range). The mass and width are:
M_x = 5566.1 \pm 3.1 MeV
\Gamma_x = 16.5 \pm 7.4 MeV
Within the uncertainties they are ok.

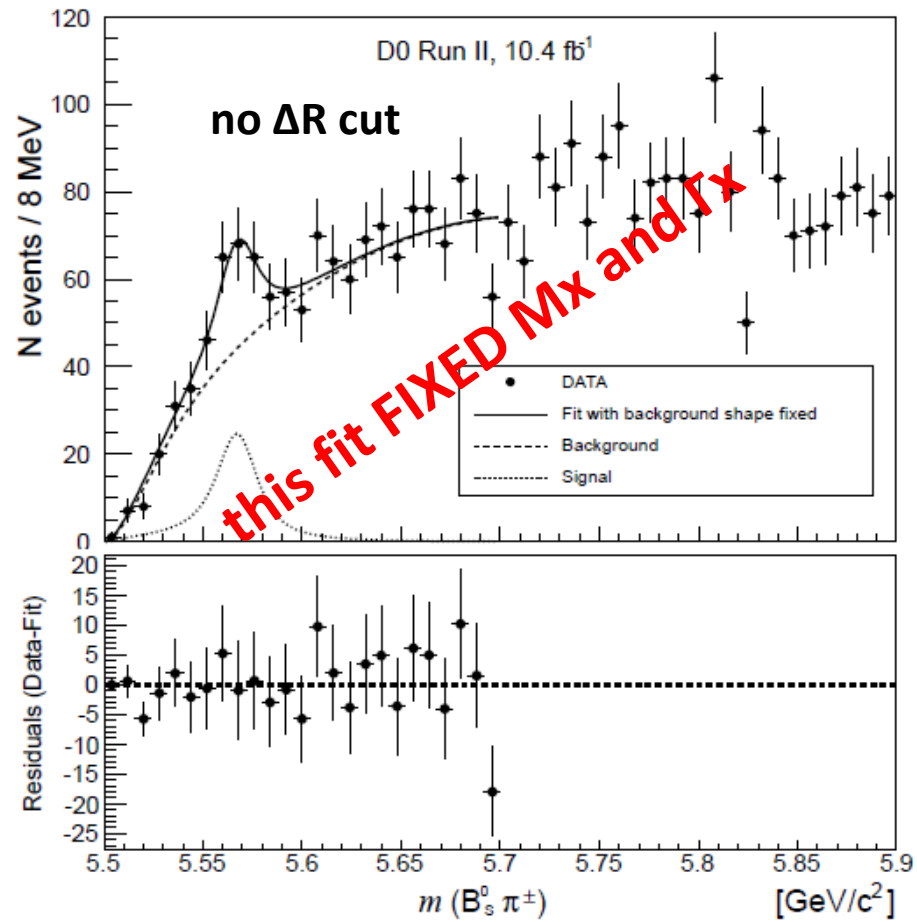
Alexey P.

D0: Observation of a new $B_s^0 \pi^{\pm}$ state

χ^2 = 32.4 for 46 DF

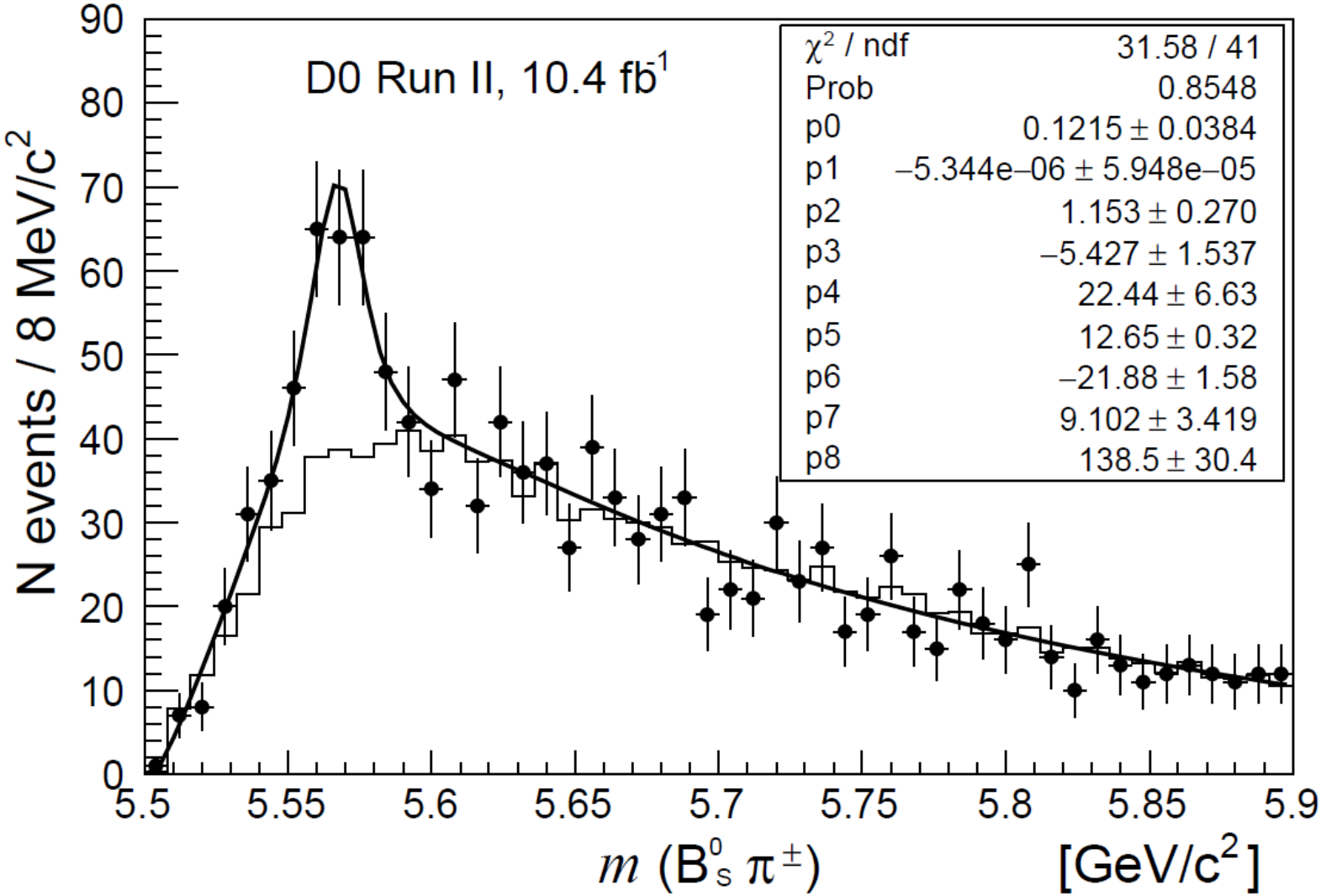


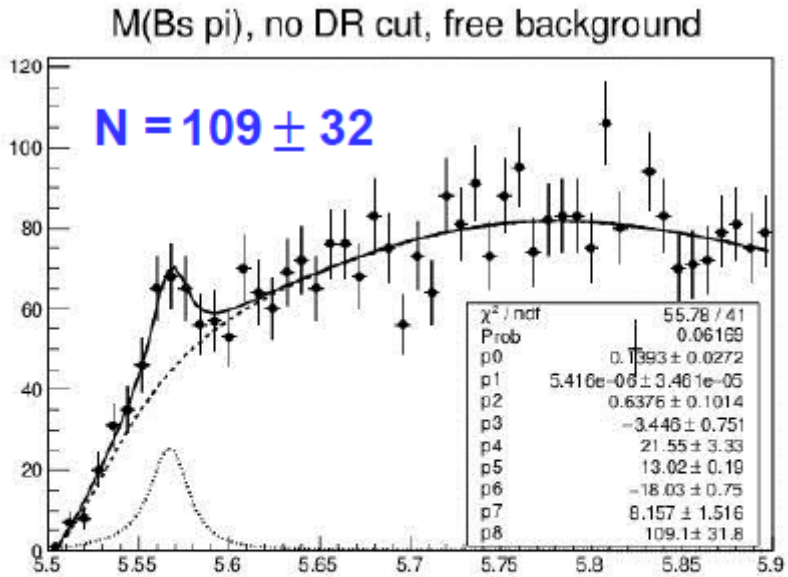
χ^2 = 18.4 for 23 DF



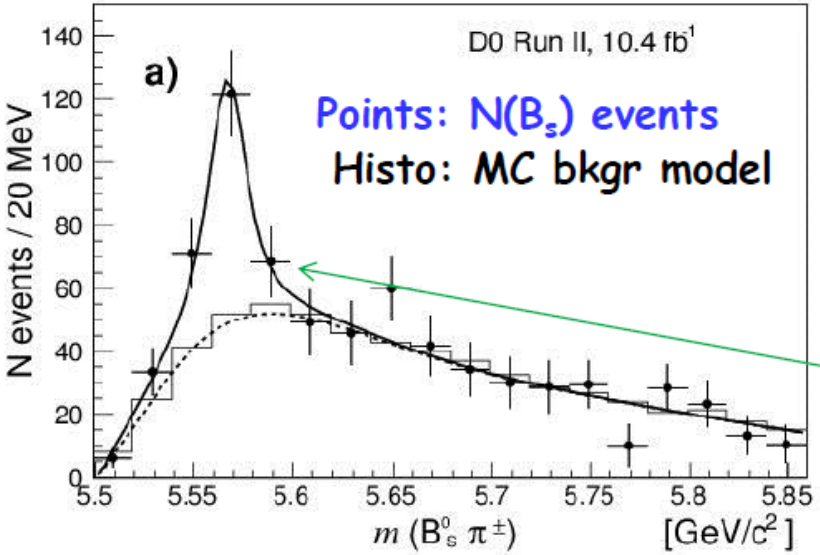
D0: Observation of a new $B_s^0 \pi^\pm$ state

fix M_X and Γ_X, allow N_X and bkgd shape to float

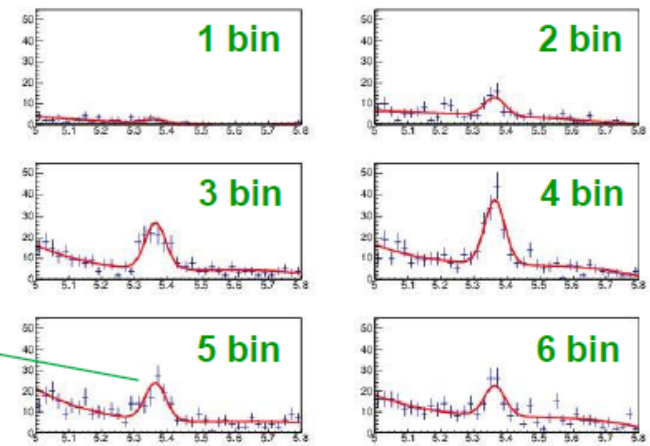




More flexibility in background shape, when all background shape parameters are free.



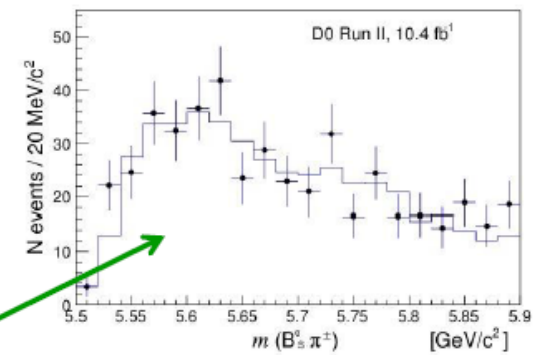
Fits in first six bins

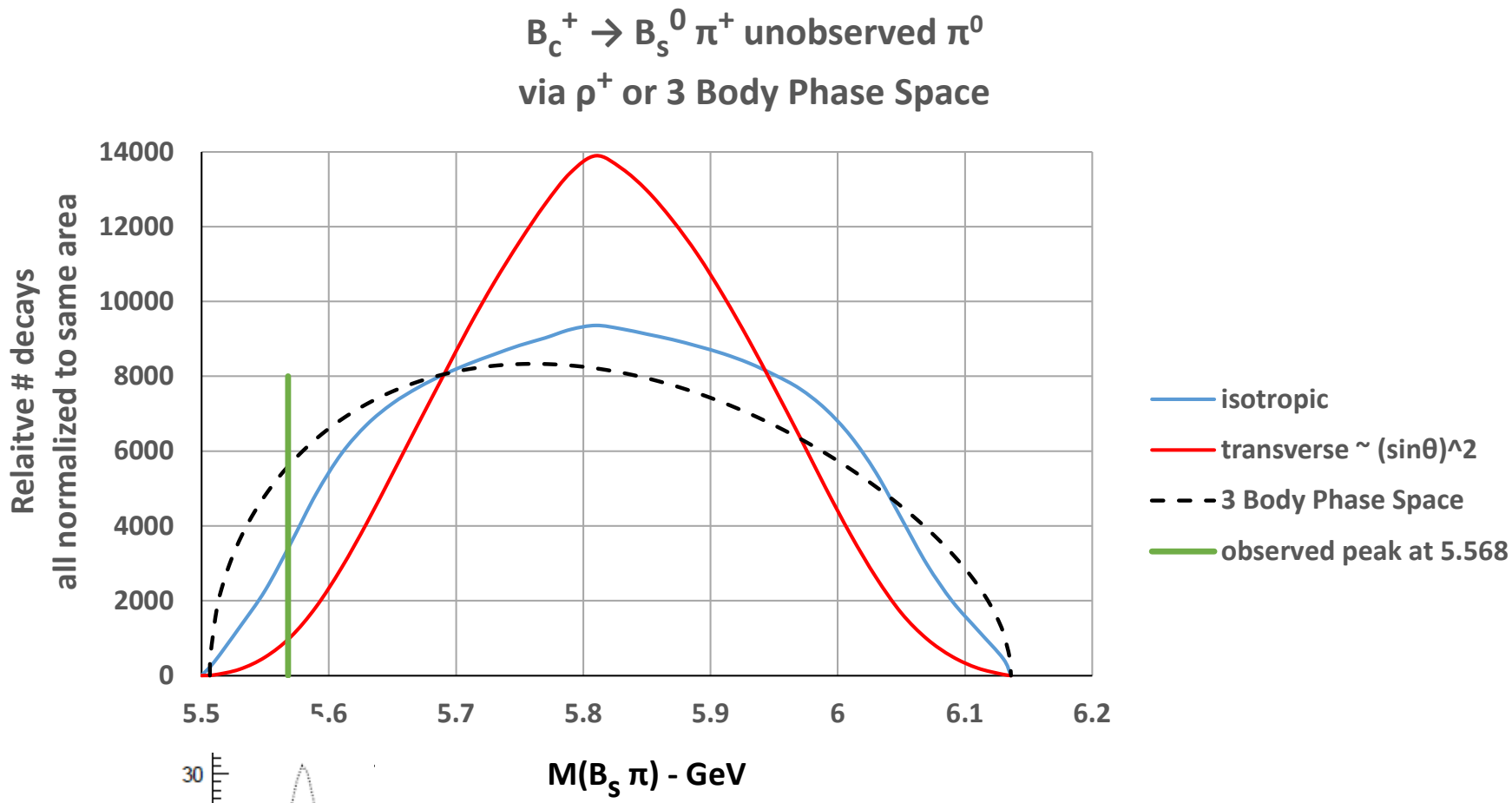


We fit M(B$_s$) in each M(B$_s$ π+) bin, using second order polynomial to model background and gaussian with fixed mass and width to model signal.

With this method (cone cut) we get 118 ± 22 events, comparing with 133 ± 31 using standard method.

No signal for events under B$_s$ gaussian peak (event number difference in B$_s$ signal range and from B$_s$ fit), agreement with background shape modeled using SB.



Points: events under gaussian
Histo: SB bkgr model

D0: Observation of a new $B_s^0 \pi^{\pm}$ state