"Everything you always wanted to know about
X (5568)
* BUT WERE AFRAID TO ASK"
Diego Tonelli (INFN Trieste)
for CDF and D0
CK ROLLINS-CHARLES H. JOFFE and BRODSKY/GOULD Production

YOU HAVEN'T SEEN ANYTHING
UNTIL YOU'VE SEEN
EVERYTHING*
"Everything you always wanted to know about sex*
* BUT WERE AFRAID TO ASK"
A JACK ROLLINS-CHARLES H. JOFFE and BRODSKY/GOULD Production
WOODY ALLEN'S
"EVERYTHING YOU ALWAYS WANTED TO KNOW ABOUT SEX*
*BUT WERE AFRAID TO ASK"
co-starring (in alphabetical order) WOODY ALLEN · JOHN CARRADINE · LOU JACOBI
LOUISE LASSER · ANTHONY QUAYLE · TONY RANDALL · LYNN REDGRAVE · BURT REYNOLDS · GENE WILDER
Produced by CHARLES H. JOFFE Executive Producer JACK BRODSKY Associate Producer JACK GROSSBERG Screenplay and Director WOODY ALLEN
R
Based upon the book by DR. DAVID REUBEN Music Composed and Conducted by MUNDELL LOWE
United Artists

Flavor Physics at the Tevatron

In 2002 through 2011: 10/fb of pp at 2 TeV for each of CDF and D0, two detectors not optimized for flavor but sufficiently well designed to make world class flavor.

Strengths: trigger on displaced-tracks and tracking (CDF), muon coverage (D0). A small group of very dedicated people (both)

≈150 papers with unique B^0_s and competitive D and B^0/B^+ physics

Impact hard to match in terms of putting to sleep BSM models:

- First (and very precise) B^0_s mixing frequency (1000+ cited)
- O(100) improvements in $B^0_s \to \mu\mu$ exclusions (500+ cited)
- First constraint on the B^0_s mixing phase (500+ cited)
- ...

Plus, a lot of spectroscopy, production, etc...

What's going on these days

Relying on a few die hards who secretly keep working on unfinished business or analyses relevant for their Tevatron-uniqueness (e.g., stuff specific to the ppbar initial state)

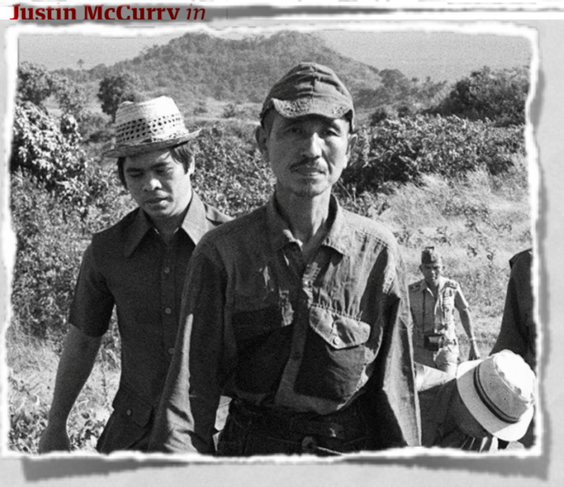
World ▸ Europe US Americas Asia Australia Middle East Africa Inequality Cities Global develop n

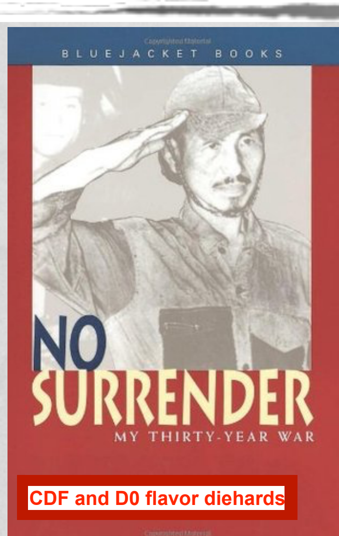
World news

60 years after the war ends, two soldiers emerge from the jungle

Mystery surrounds Japanese men, both in their 80s, who say they have been in hiding since second world war

Justin McCurry *in*





The X(5568) files

Exotic hadrons

Massive experimental evidence supports existence of mesons that aren’t qqbar and baryons that aren’t qqq

Most observations in final states involving cc or bb in large data sets from Belle, BESIII, LHCb,

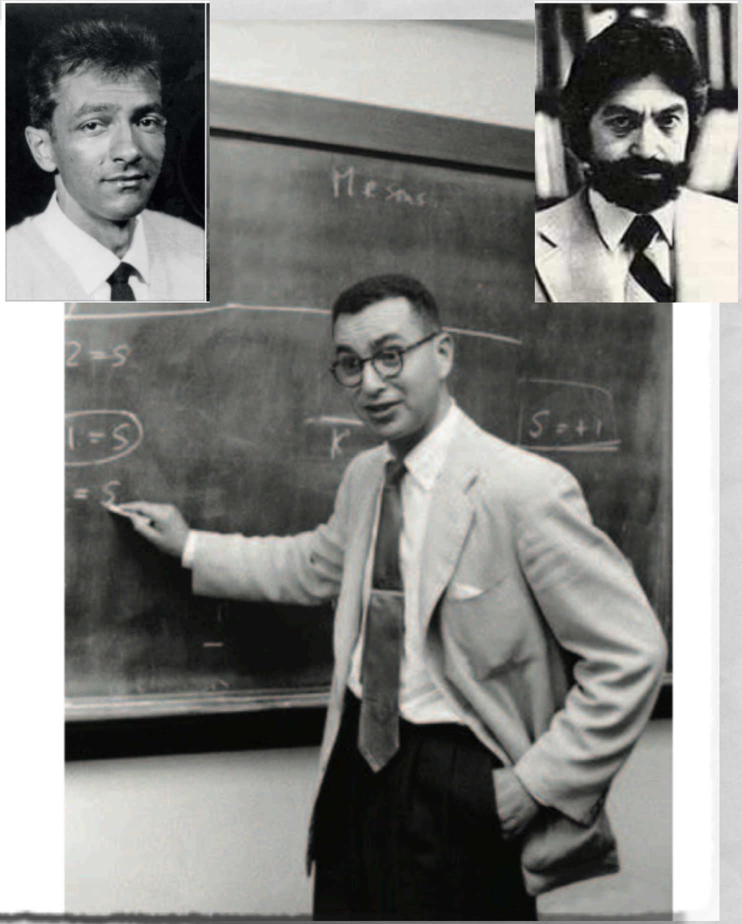
- $X(3872) \rightarrow J/\psi\ \pi^+\pi^-$, $X(3915) \rightarrow J/\psi\ \omega$, $Y(4260) \rightarrow J/\psi\ \pi^+\pi^-$
- $Z^+ (4430) \rightarrow \psi(2S)\ \pi^+$
- $P_c^+(4380) \rightarrow J/\psi\ p^+$

Understanding is lacking.

Exotic hadrons?

"...Baryons can now be constructed from quarks by using the combinations (qqq), $(qqqq\bar{q})$, etc, while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q}$, etc...."

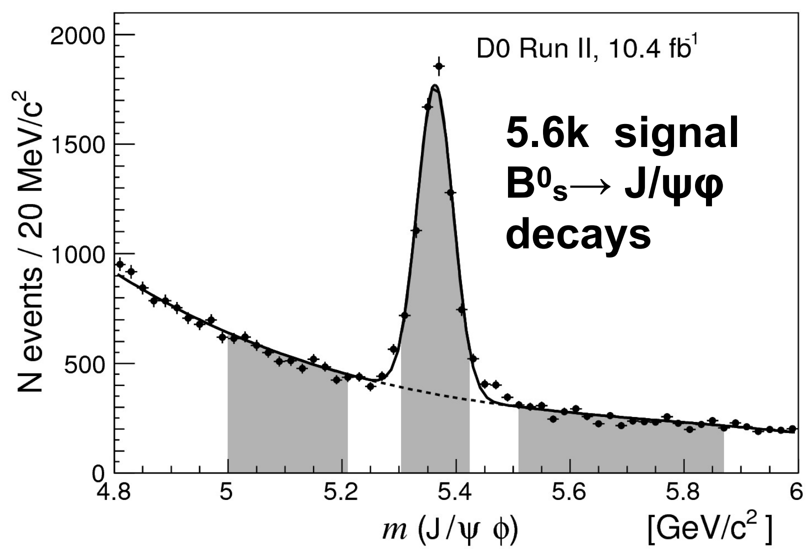
M. Gell-Mann "A schematic model of baryons and mesons", PL 8 (1964) 214

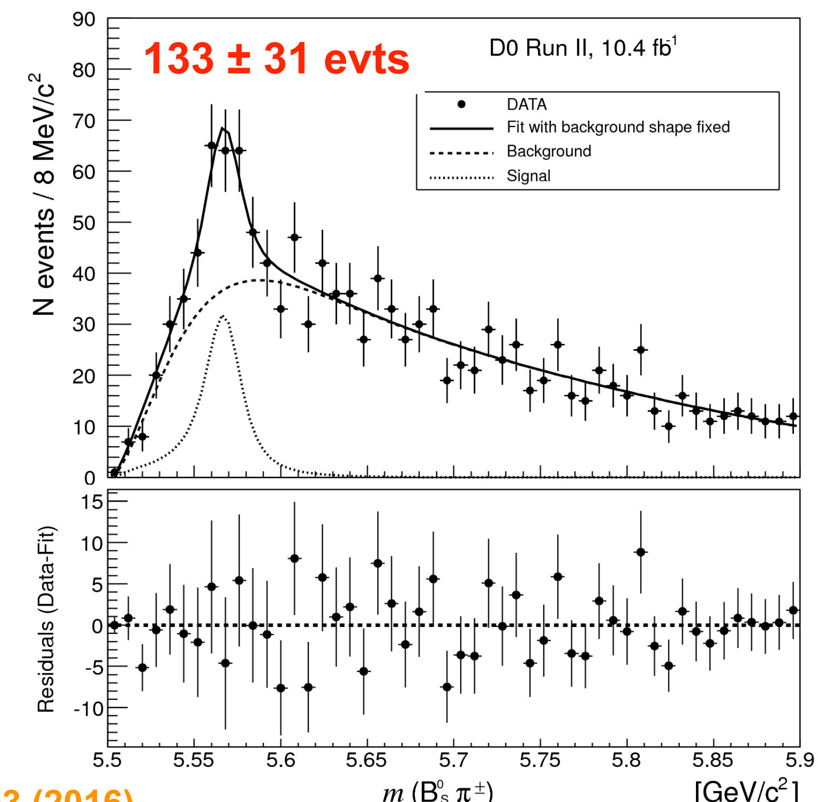


The DO observation

2 years ago

D0 observes a near-threshold enhancement in the $B^0_s(\to J/\psi\varphi)\pi^\pm$ mass spectrum.





- Final state with four flavors (*b,s,u,d*)
- Signal with a mass of $5567.8\pm2.9^{+0.9}_{-1.9}$ MeV/c^2
- $\Gamma = 21.9\pm6.4^{+5.0}_{-2.5}$ MeV/c^2

PRL 117 022003 (2016)

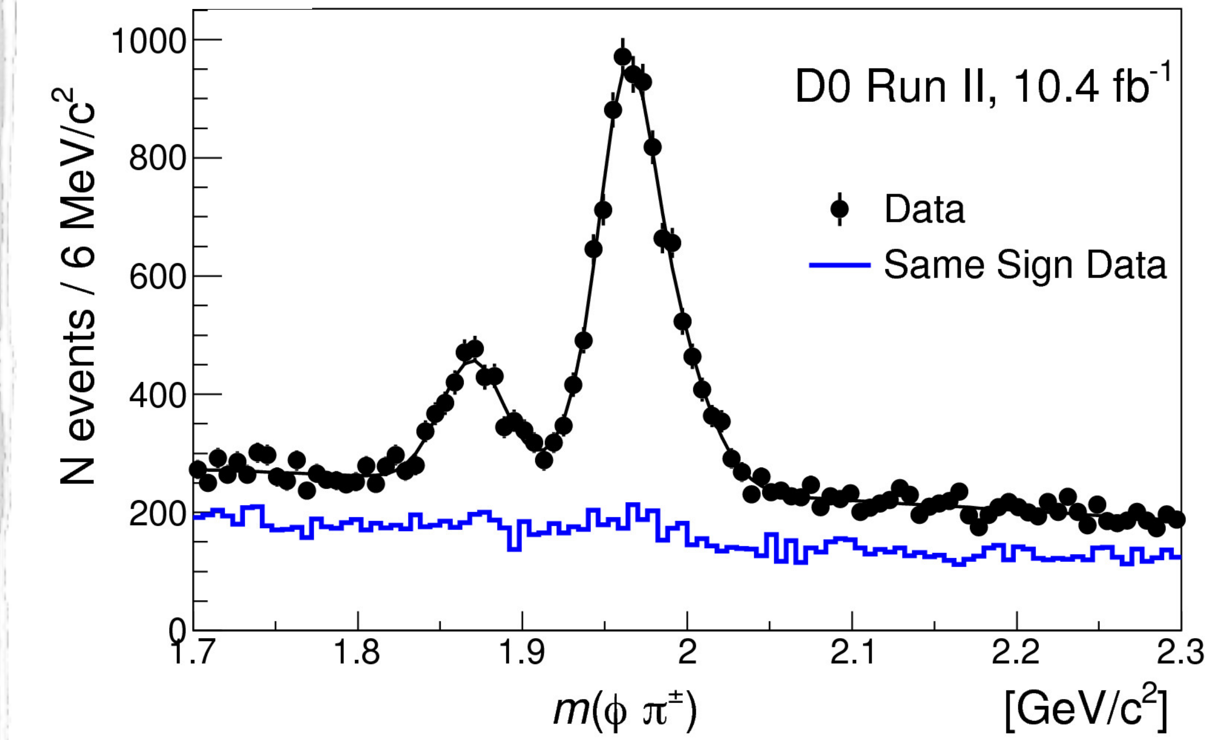
5σ. Strong decay. Suggestive of a tetraquark composition

X(5568) confirmation

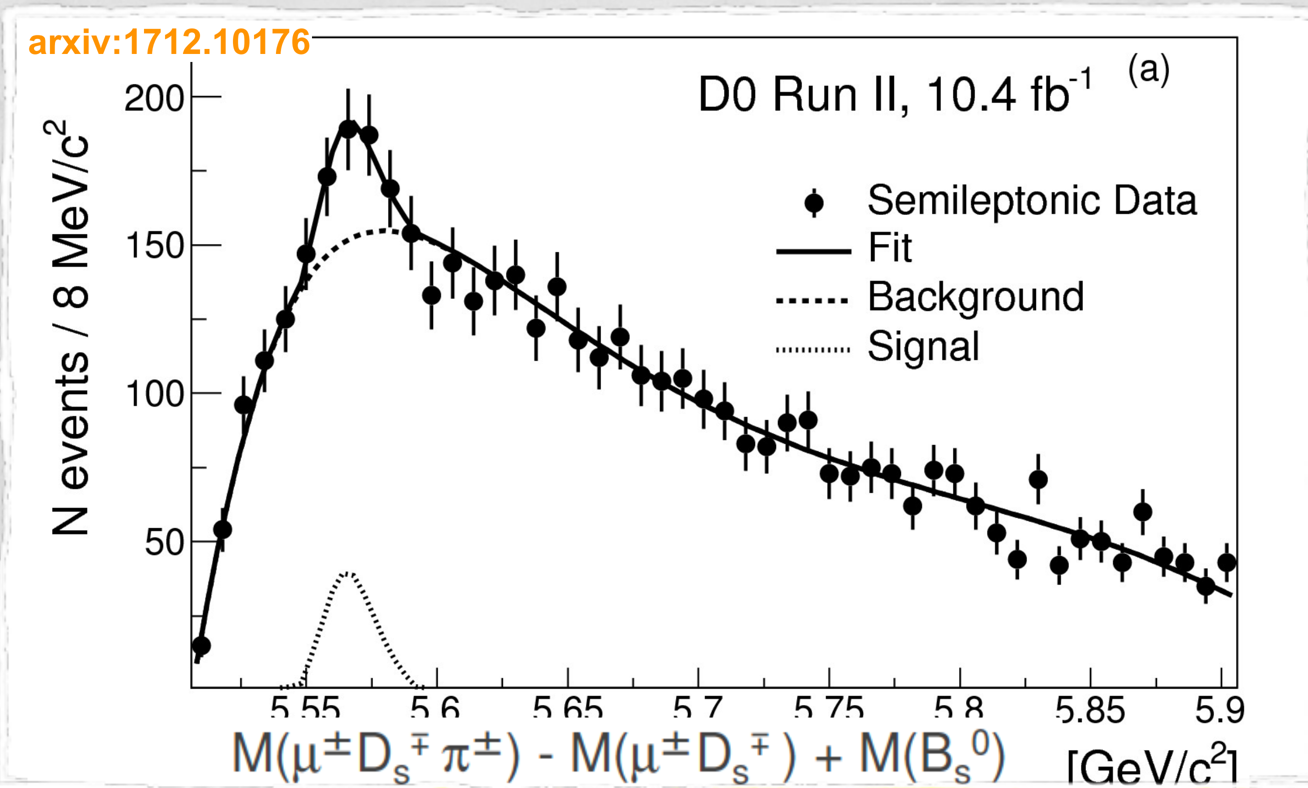
A couple of months ago, D0 confirms the observation by reconstructing the B^0_s in a semileptonic final state

$X(5568) \rightarrow B^0_s \pi^{\pm}$, with $B^0_s \rightarrow D^-_s(\varphi \pi^+) \mu + X$

arxiv:1712.10176



X(5568) confirmation



Combined significance up to 6.7σ and resonance parameters updated to

$$m = 5566.9^{+3.2}_{-3.1}\,(\text{stat})^{+0.6}_{-1.2}\,(\text{syst})\ \text{MeV}/c^2,$$

$$\Gamma = 18.6^{+7.9}_{-6.1}\,(\text{stat})^{+3.5}_{-3.8}\,(\text{syst})\ \text{MeV}/c^2$$

The D0 analysis

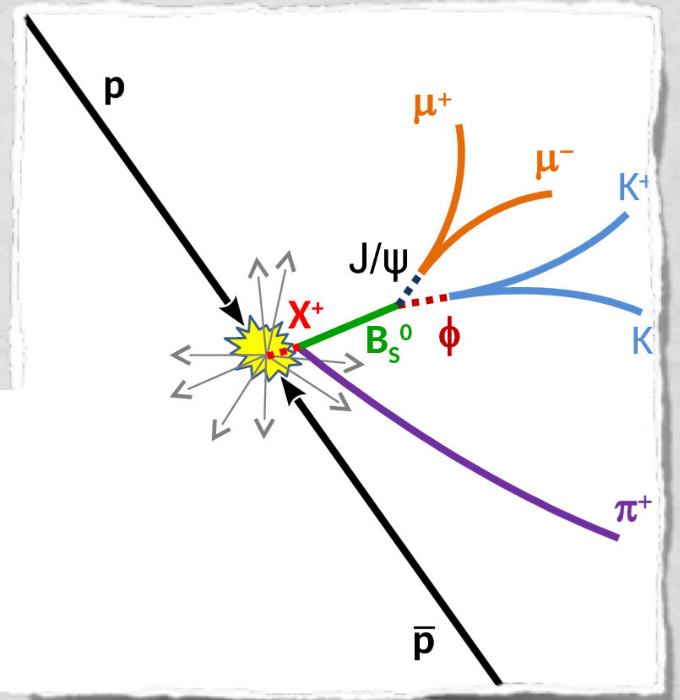
Trigger on central and forward single muons and dimuon (pT(μ)> 1.5)

Standard pT cuts on B^0_s decay products and B^0_s flight

Pion required to point to the primary interaction.

pT ($B^0_s \pi^+$)> 10 GeV/c

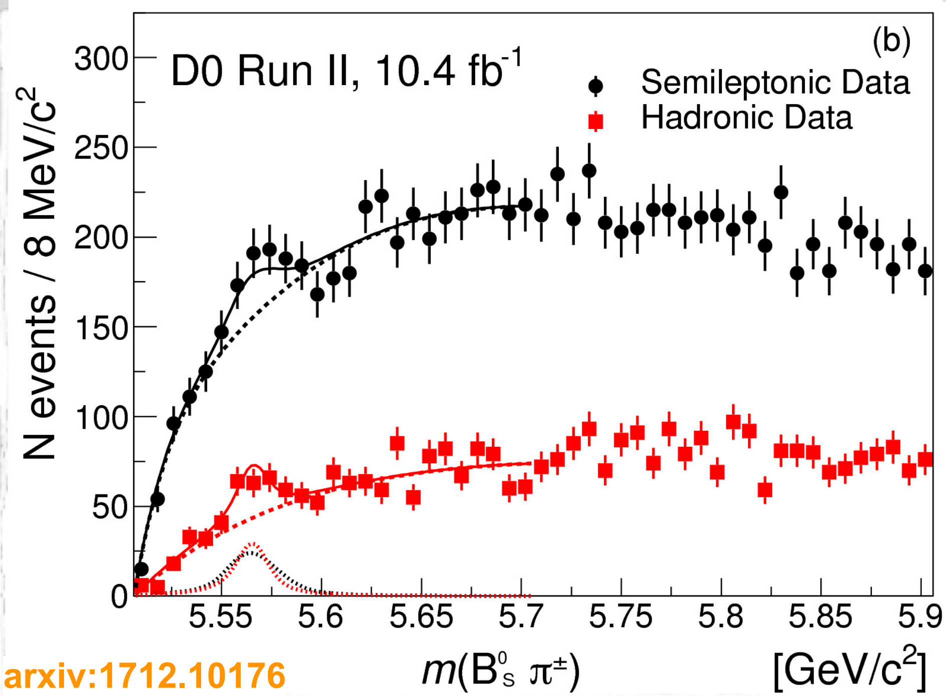
Cut on the spatial opening between B^0_s and π^+ (more next)



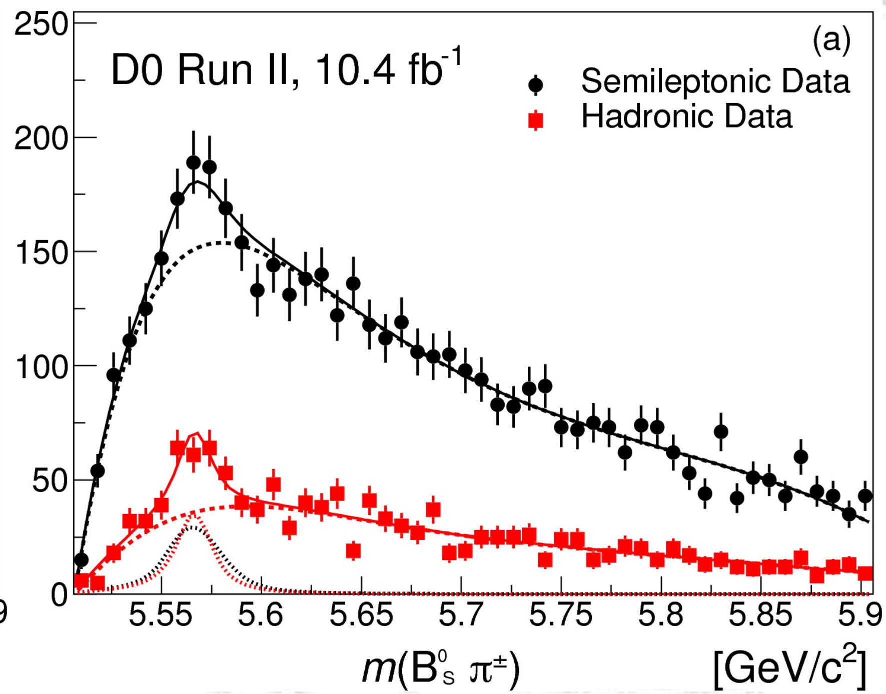
Fit with mixed bckg model (Pythia + B^0_s sidebands) and relativistic BW for the signal taking into account the mass-dependent efficiency and 3.8 MeV/c² smearing

The cone-cut

The one crucial requirement to enhance the S/B is the "cone-cut": a restriction of the solid-angle opening between B^0_s and π^+ (η-phi distance).



Without



With

Outside D0

LHCb and CMS are fastest in looking into their data.

Analysis	$f_{Bs/X(5568)}$	Ref.
D0 ($J/\psi\ \phi$)	8.6 ± 1.9 ± 1.4%	PRL 117,022003(2016)
D0 ($\mu\ D_s$)	$7.3^{+2.8}_{-2.4}{}^{+0.6}_{-1.7}$%	arXiv:1712.10176
LHCb	< 2.4% ($p_T(B_s^0)$ > 10 GeV)	PRL 117,152003 (2016)
CMS	< 1.1% ($p_T(B_s^0)$ > 10 GeV)	arXiv:1712.07588

They see nothing.

CDF prepares to fight back.

The CDF search

CDF approach

The better is the enemy of the good — prioritize robustness over optimality.

Adapt techniques well established through the long-standing program of previous successful particle searches in final states with dimuons.

- Obtain a J/ψ sample
- Combine with a φ sample in a constrained fit that requires decay time inconsistent with prompt production
- Add a charged pion and measure

$$f_{B_s^0/X(5568)} = \frac{\sigma(p\bar{p} \to X(5568)+x) * B(X(5568) \to B_s^0\pi^\pm)}{\sigma(p\bar{p} \to B_s^0 + x)} = \frac{N_{X(5568)}}{\alpha_{X(5568),B_s^0}} * \frac{1}{N_{B_s^0}}$$

- $N_{X,B}$ number of X(5568), B_s^0
- α is the X(5568) acceptance, having reconstructed the B_s^0

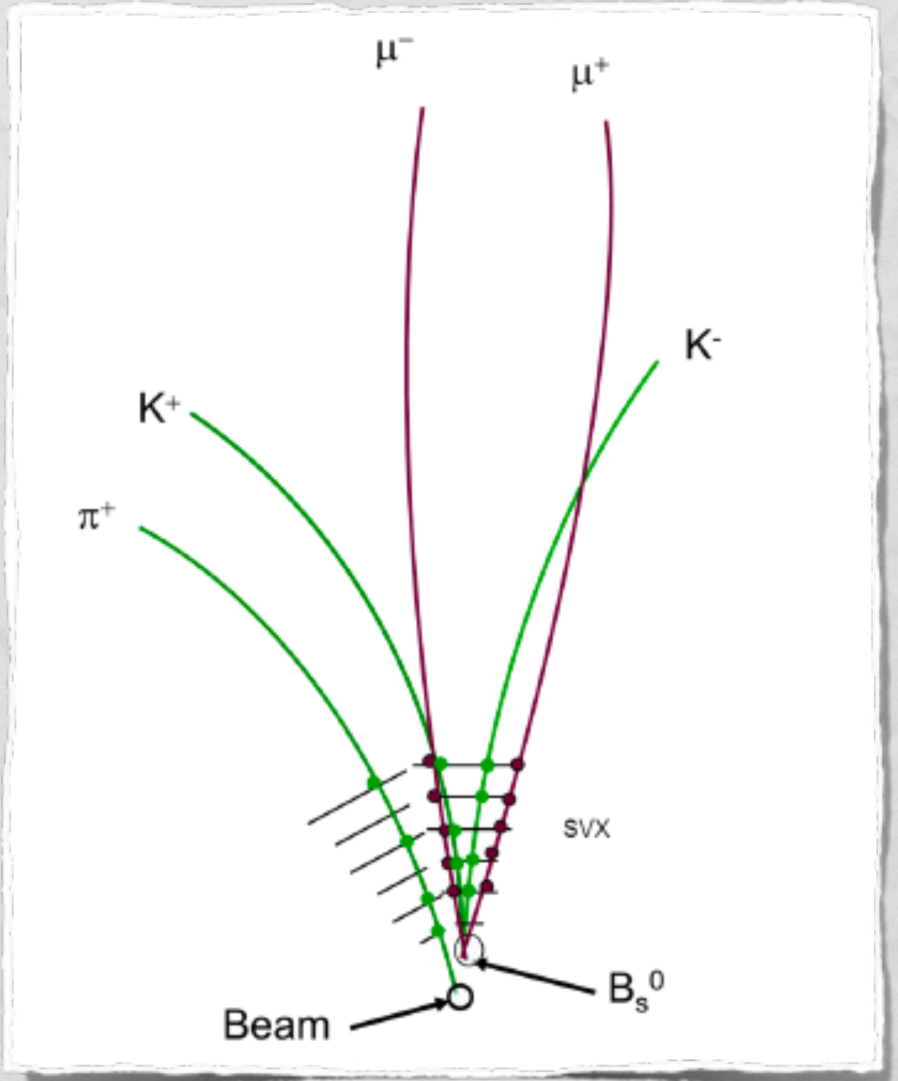
Back to basics

Standard silicon track cuts

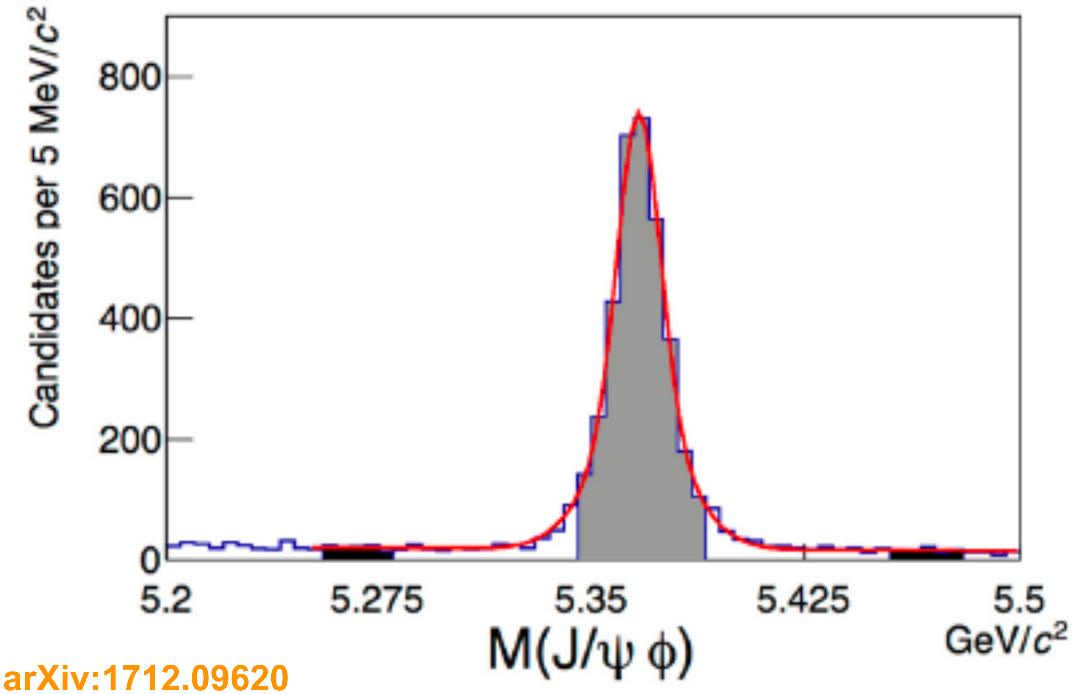
Standard pT cuts on tracks and mass windows around known resonances.

$pT(B^0_s) > 10$ GeV/c and $ct > 100$ um

Pion points to the primary



Bs signal

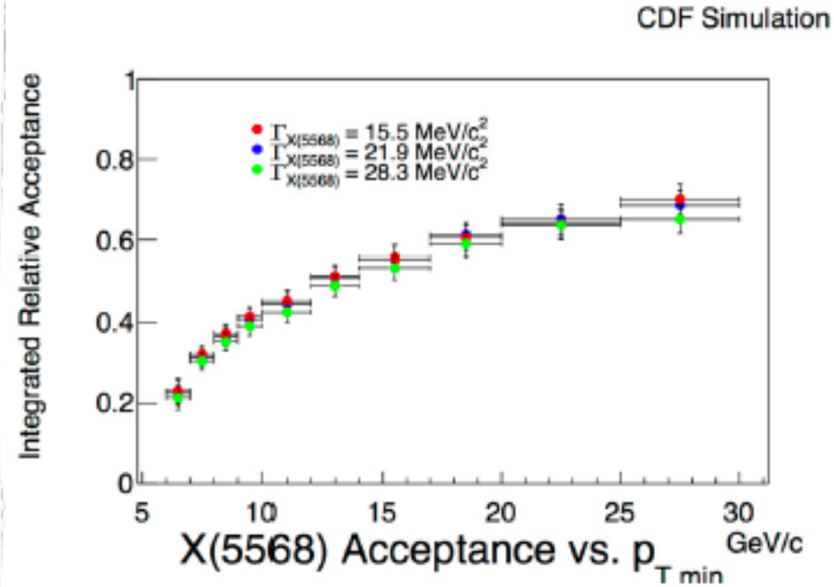


arXiv:1712.09620

3.5k signal $B^0_s \rightarrow J/\psi(\rightarrow \mu\mu)\varphi(\rightarrow KK)$ decays

Acceptance

Use a simulation of the D0 signal to determine the acceptance as a function of pT(B^0_s)



The relative X(5568) acceptance and reconstruction efficiency is 0.445 ±0.027 ±0.018 for $p_T(B_s^0)$ > 10 GeV/c

arXiv:1712.09620

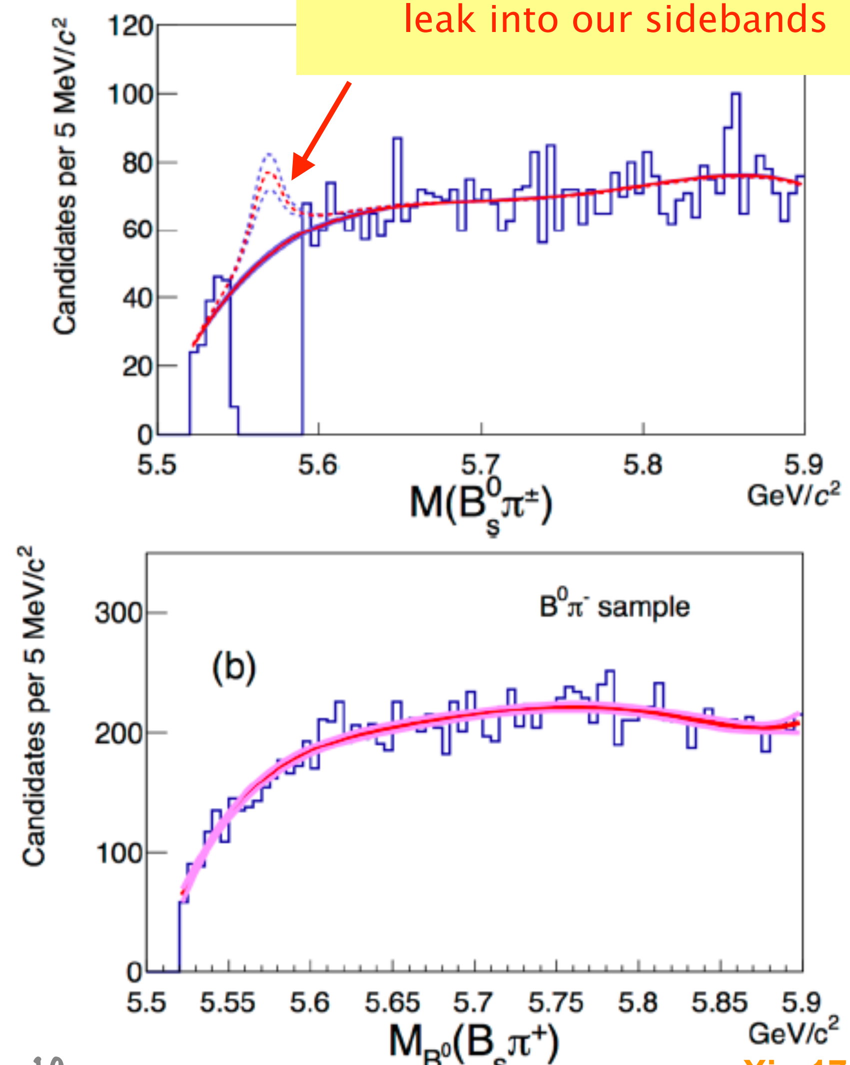
Backgrounds

An empirical model based on $B^0_s \pi^+$ sidebands suffices to capture main offenders:

- Prompt charged particles produced in association with B^0_s
- Fake B^0_s

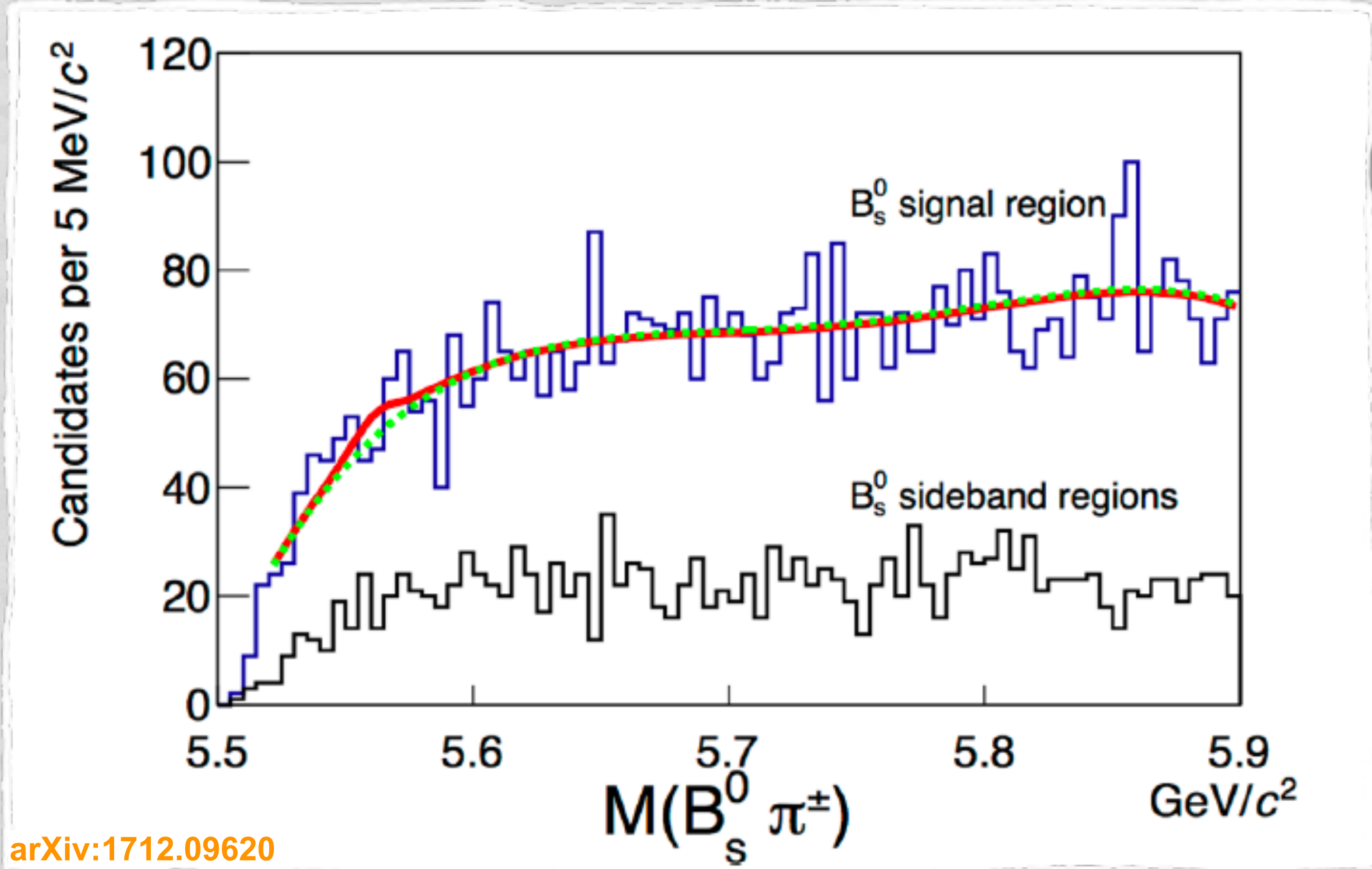
An alternative model based on a fit of the $B^0 \pi^+$ mass spectrum is also tested: no difference wrt default model

D0 signal fixed in the fit to assess leak into our sidebands



arXiv:1712.09620

CDF's spectrum



Two fits: floating signal amplitude (red) and bckg-only (green).
B^0_s fraction from X(5568) is (2.3 ± 1.9)%

No evidence of any structure

Results

Issue	Relative change in yield
Width of X(5568)	17%
Amplitude	31%
Mass	17%
B_s^0 yield	1.8%
Acceptance and Efficiency	6.1%
Total	39%

Fraction of B^0_s from X(5568) = 2.3% ± 1.9% ± 0.9%.
This is not inconsistent with D0 values, but 2σ away.

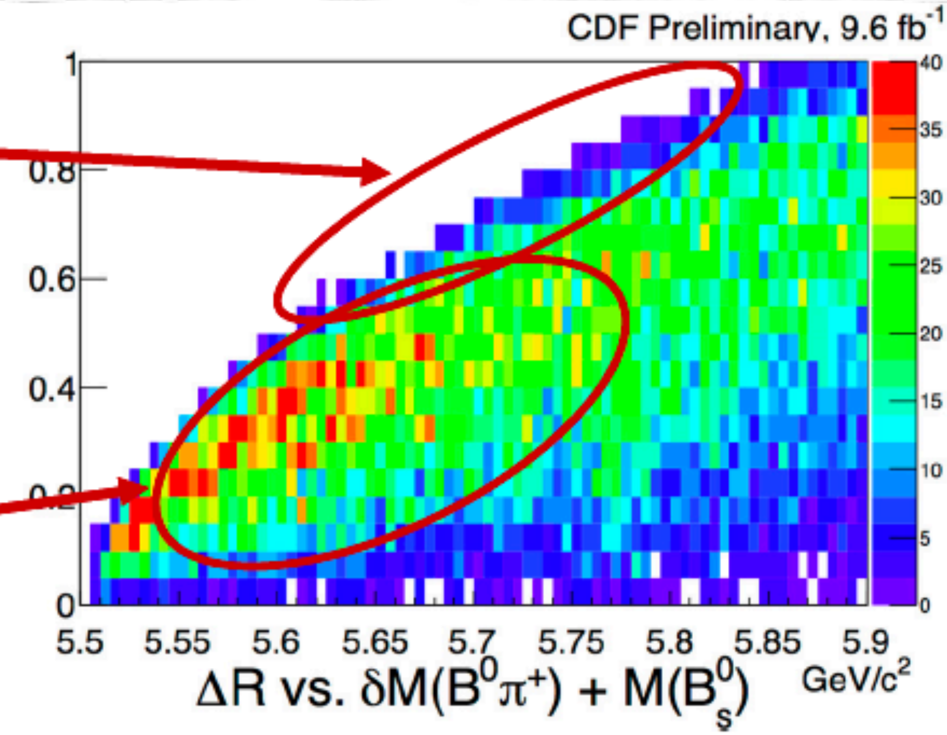
Neyman upper limit on the fraction

f < 6.7% at the 95 CL

Why didn't CDF uses cone cut?

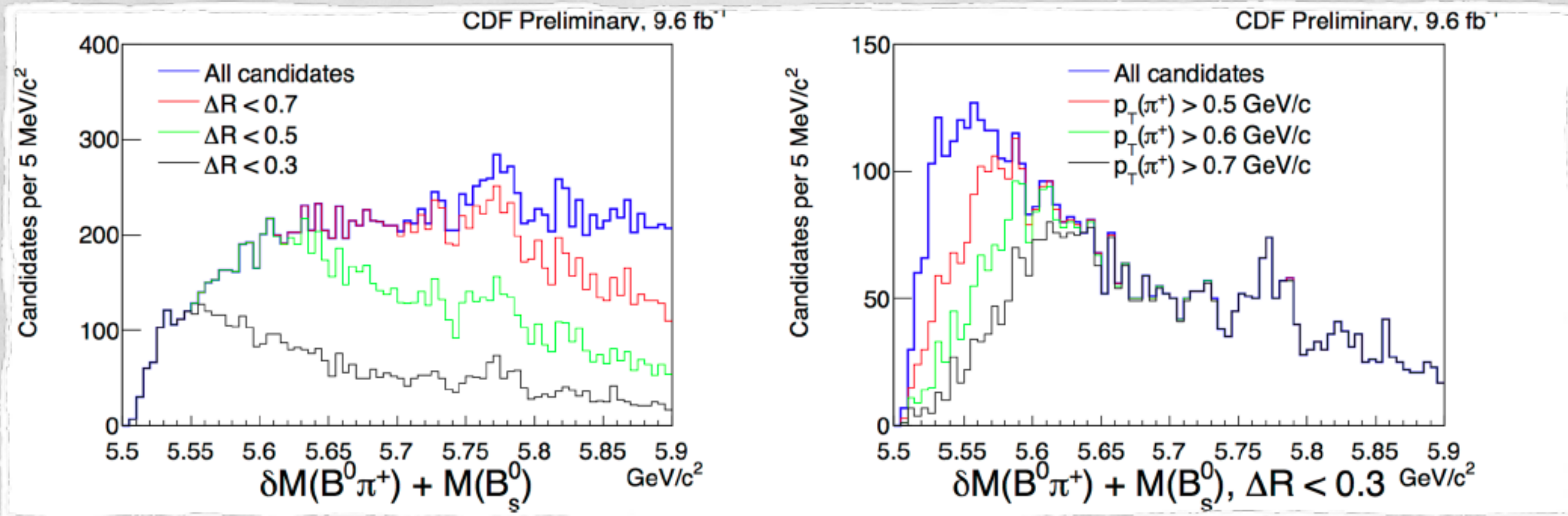
Sharp cut off due to $p_T(\pi) > 400$ MeV/c requirement

Strong correlation between ΔR and mass



Because it's strongly correlated with mass in CDF data

Why didn't CDF uses cone cut?



Because it's strongly correlated with mass and $pT(\pi^+)$

in CDF data

The plot thickens

D0 has recently confirmed its 2016 observation of the X(5568), a candidate tetraquark, using semileptonic B^0_s decays.

CDF performed a search for X(5568) in $B^0_s \to J/\psi\varphi$ decays. Prioritize robustness to optimality: no fancy new techniques.

CDF does not observe a signal.

D0 remains the only experiment that sees the X(5568).

CDF Could look at the $B^0_s \to D^-_s \pi^+$ mode too. Needed effort would probably prevent this.

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CMS	$< 1.1\%$ ($p_T(B_s^0) > 10$ GeV)	arXiv:1712.07588
ATLAS	$< 1.5\%$ ($p_T(B_s^0) > 10$ GeV)	arXiv:1802.01840

Thank you