Heavy Flavour Spectroscopy @ the Tevatron

Kai Yi (University of Iowa)

For the CDF and D0 Collaborations

XXIV Rencontres de Physique de La Vallée d’Aoste

Outline

- **Heavy Baryons: Ω_b**
- **Heavy Mesons: Υ(nS) polarization**
- **Heavy Exotic Mesons: X(3872), Y(4140)**
- **Conclusion**

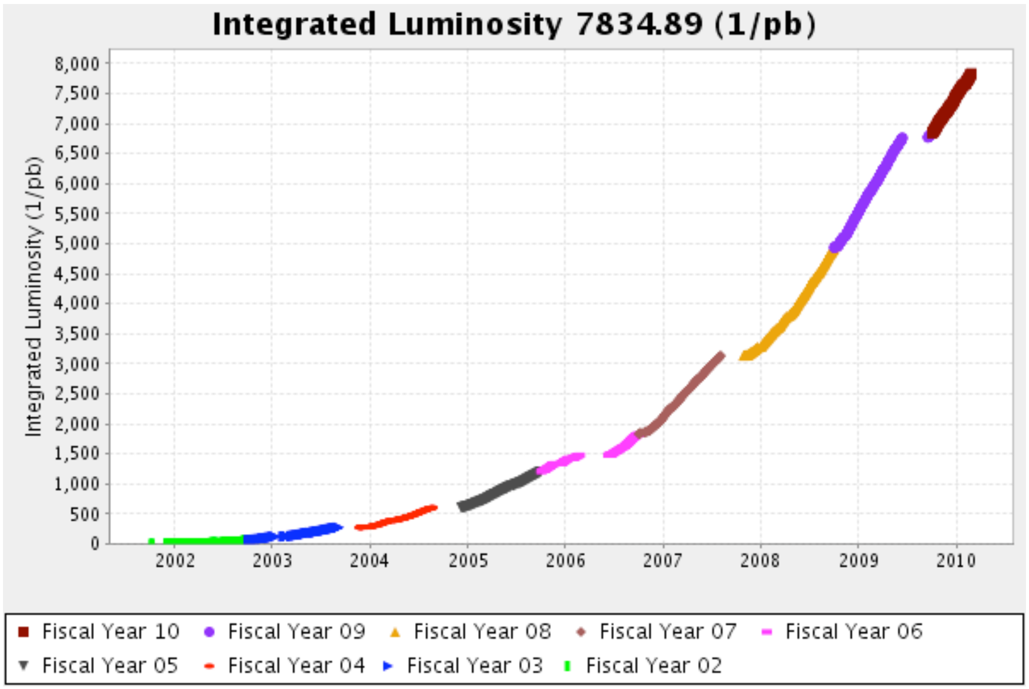
Focus on most recent Tevatron results

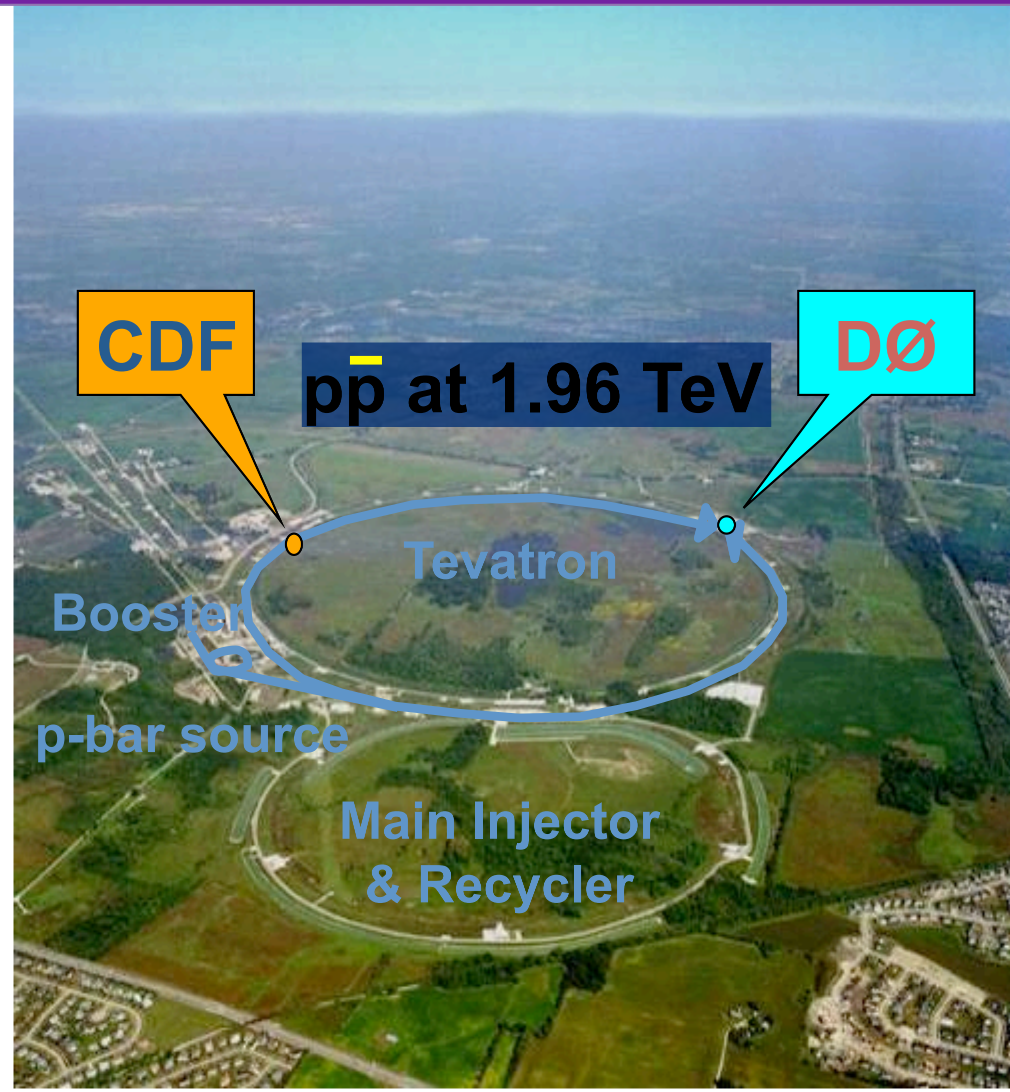
All Tevatron Bottom results at:

http://www-cdf.fnal.gov/physics/new/bottom/bottom.html

http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm

Fermilab Tevatron Run II





36×36 bunches; 396 ns spacing

Delivered luminosity: ~8 fb^{-1}
Acquired luminosity: ~7 fb^{-1}/ experiment

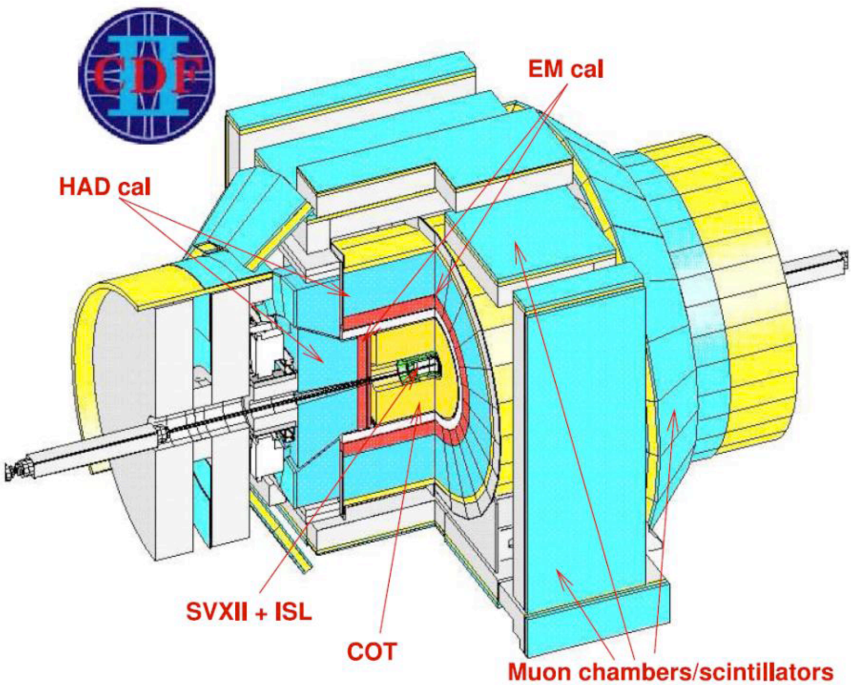
This talk: analyses covering up to 4.2 fb^{-1}

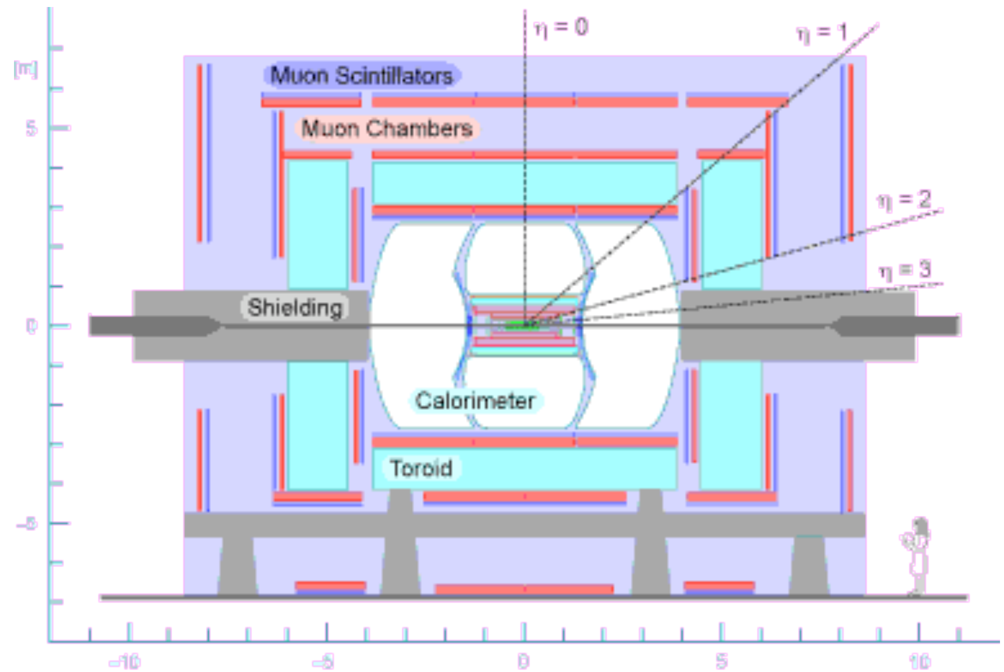
Run II goal: 10 fb^{-1} before end 2011

Detectors and Triggers

–CDF

– Excellent momentum resolution
– particle ID (TOF & dE/dx)
– Displaced track trigger and di-muon triggers





–D0

– Tracking and muon cover (|η |<2)
– Layer 0 silicon (2006)
– Efficient Single and di-muon triggers

Motivation

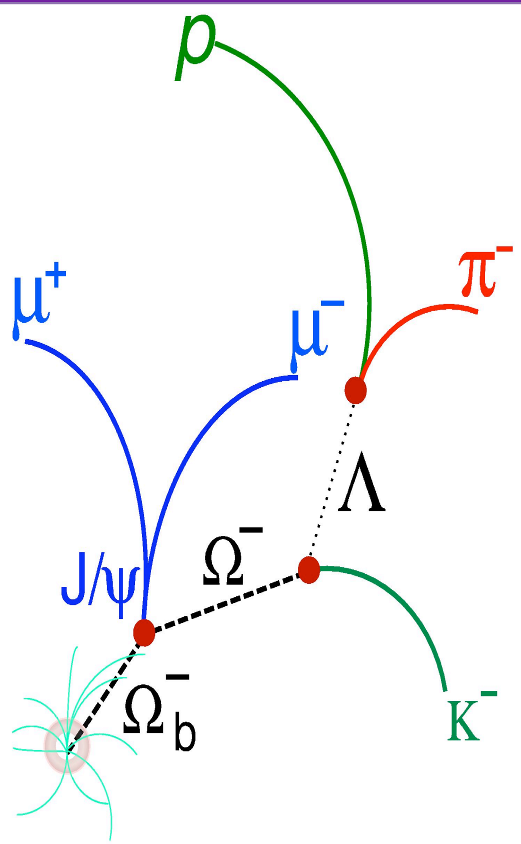
Why Heavy Spectroscopy?

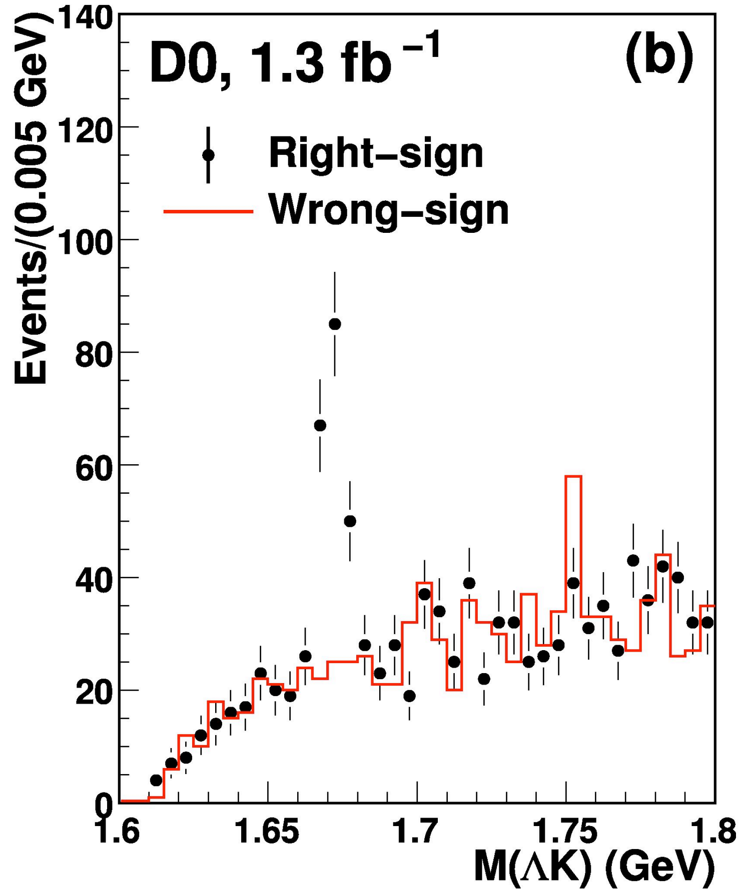
Tests: potential models, HQET, QCD, lattice gauge calculations,…
Recent observed charmonium-like states (exotics) NOT understood!

Why Heavy Spectroscopy at Tevatron?

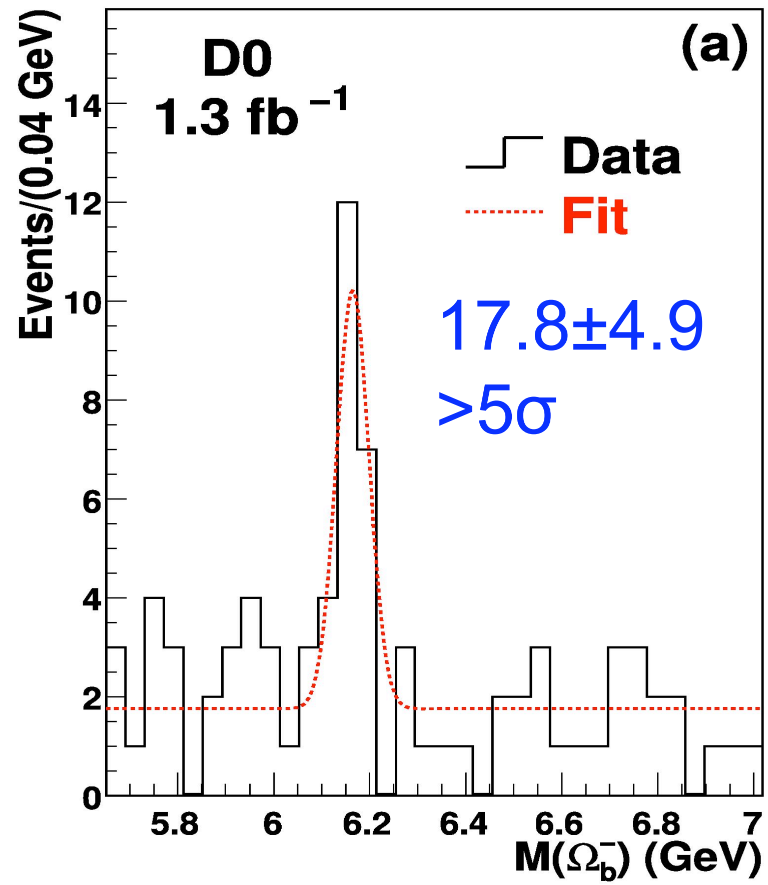
- copiously produced,
- not accessible anywhere else: B_s^0, B_c, B^{**}, B_s^*, b baryons
  Complementary to B factories
- boosted
  --vertex separation
  --boost low p_T daughters

Heavy Baryon—Ω_b (bss)





PRL101, 232002 (2008)



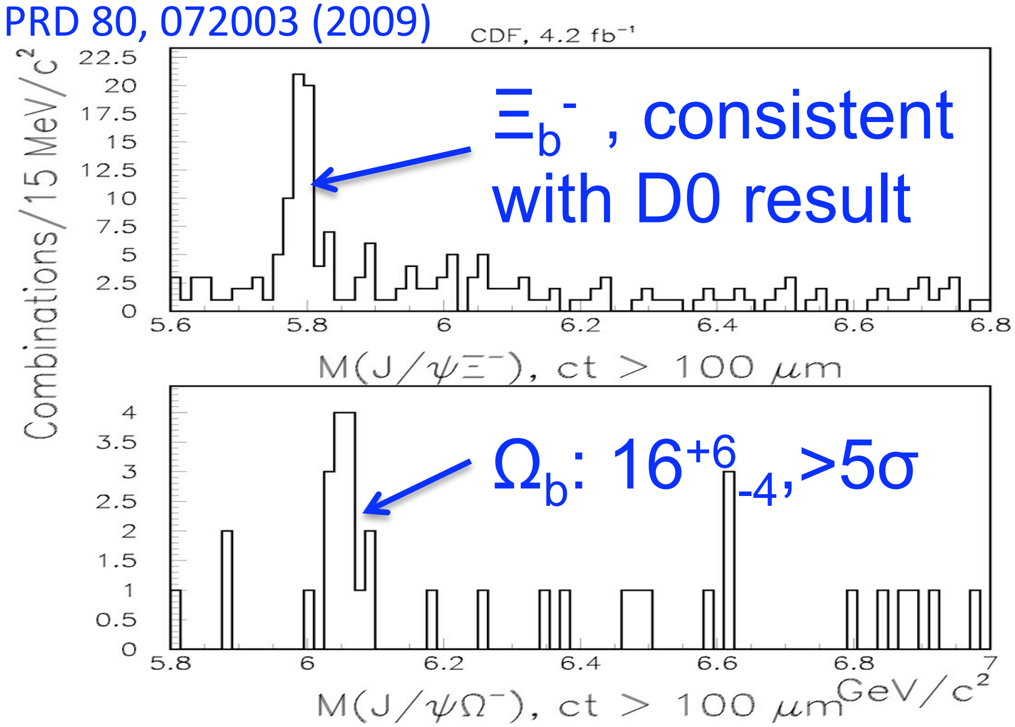
$m(\Omega_b)$=6165 ± 10 (stat) ± 13 (syst) MeV/c^2

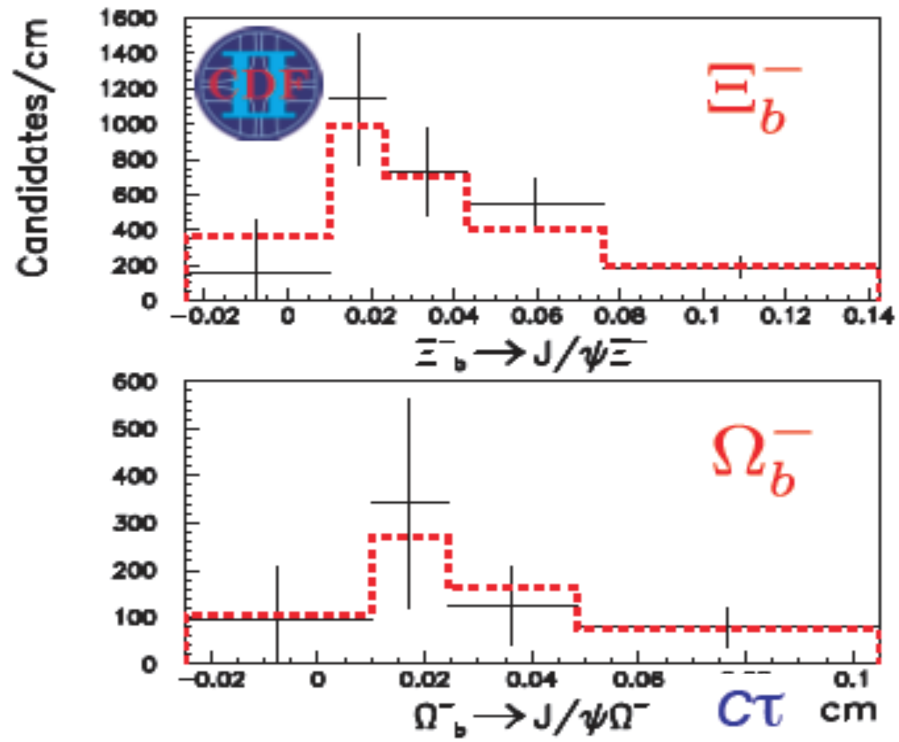
D0 uses boosted decision tree to get Ω^- signal

lifetime result consistent with expectation, τ=1.54 ps

Heavy Baryon—Ω_b (bss)

PRD 80, 072003 (2009)





$$m(\Xi_b^-) = 5790.9 \pm 2.6 \pm 0.9\,\mathrm{MeV}$$
$$\tau(\Xi_b^-) = 1.56^{+0.27}_{-0.25} \pm 0.02\,\mathrm{ps}$$

└ First exclusive Ξ_b^- lifetime!

$$m(\Omega_b^-) = 6054.4 \pm 6.8 \pm 0.9\,\mathrm{MeV}$$
$$\tau(\Omega_b^-) = 1.13^{+0.53}_{-0.40} \pm 0.02\,\mathrm{ps}$$

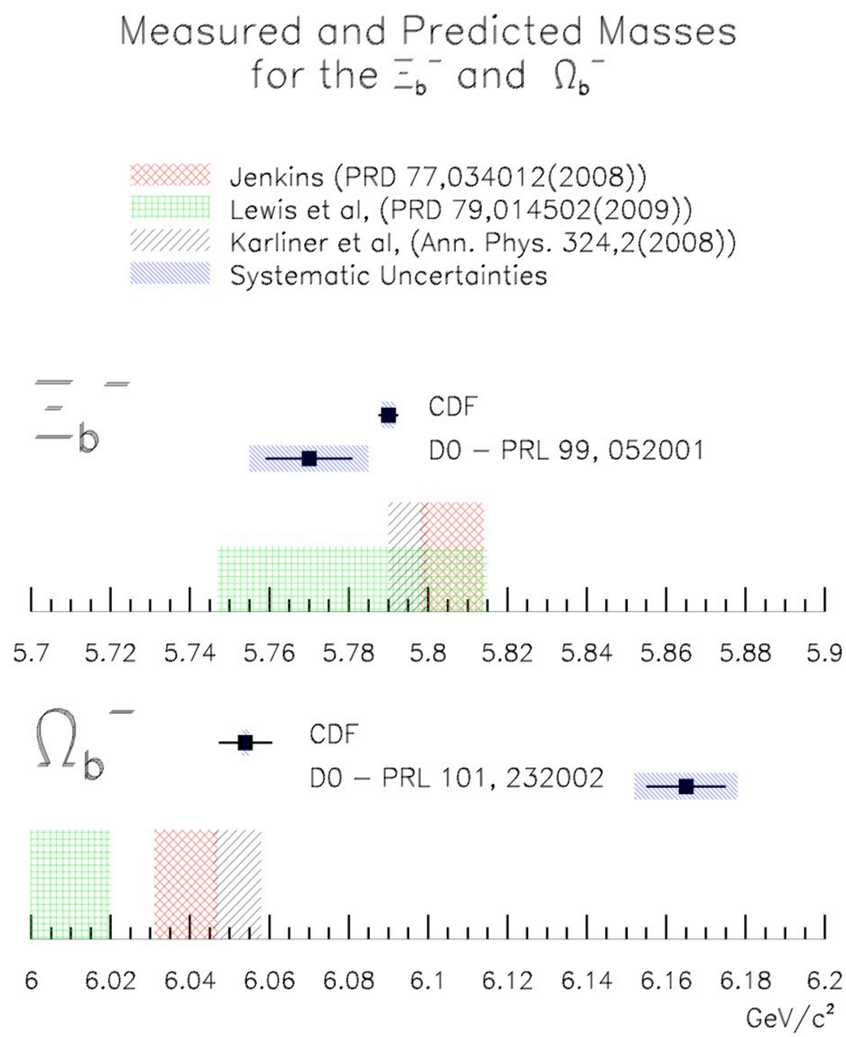
└ First ever!

$$\frac{\sigma(\Xi_b^-)\mathcal{B}(\Xi_b^- \to J/\psi\Xi^-)}{\sigma(\Lambda_b^0)\mathcal{B}(\Lambda_b^- \to J/\psi\Xi^-)} = 0.167^{+0.037}_{-0.025} \pm 0.012$$

$$\frac{\sigma(\Omega_b^-)\mathcal{B}(\Omega-_b \to J/\psi\Xi^-)}{\sigma(\Lambda_b^0)\mathcal{B}(\Lambda_b^- \to J/\psi\Xi^-)} = 0.045^{+0.017}_{-0.012} \pm 0.004$$

6 GeV<p_T(b baryon)<20 GeV

Heavy Baryon—Ω_b (bss)



Relative rate: 1.3σ difference (CDF & D0)

DØ: $$\frac{f(b\to\Omega_b^-)\cdot\mathcal{B}(\Omega_b^-\to J/\psi\Omega^-)}{f(b\to\Xi_b^-)\cdot\mathcal{B}(\Xi_b^-\to J/\psi\Xi^-)} = 0.80\pm0.32^{+0.14}_{-0.22}$$

CDF: $$\frac{\sigma\cdot\mathcal{B}(\Omega_b^-\to J/\psi\Omega^-)}{\sigma\cdot\mathcal{B}(\Xi_b^-\to J/\psi\Xi^-)} = 0.27\pm0.12\pm0.01$$

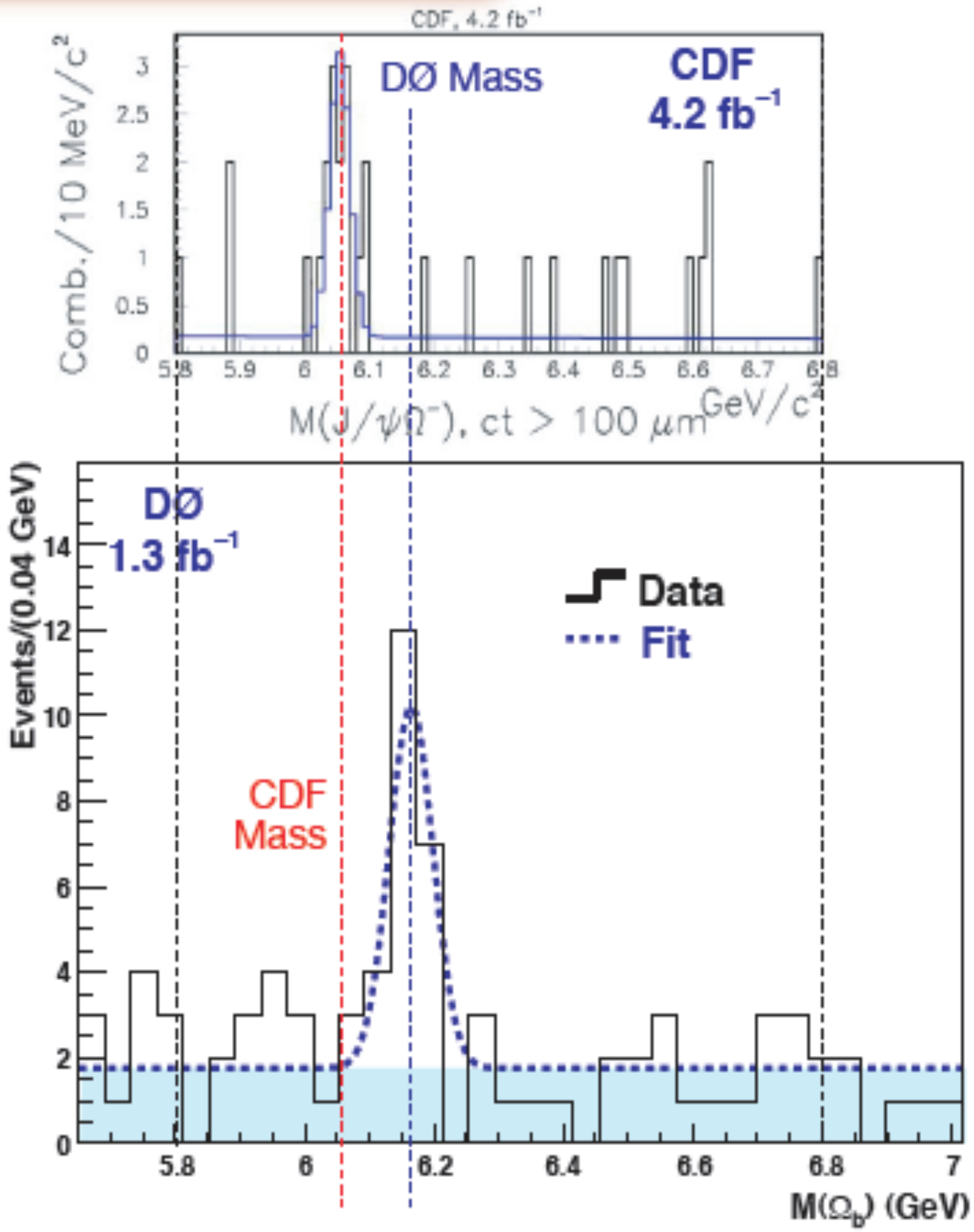
CDF and D0 disagree on mass, 10 times larger than D0's mass uncertainty

$$m(\Omega_b^-)^{\text{DØ}} - m(\Omega_b^-)^{\text{CDF}} = 111\pm12\pm14\ \text{MeV}$$

Significant (~6σ) disagreement!

D0 is working on an update with increased dataset.

Heavy Baryon—Ω_b (bss)



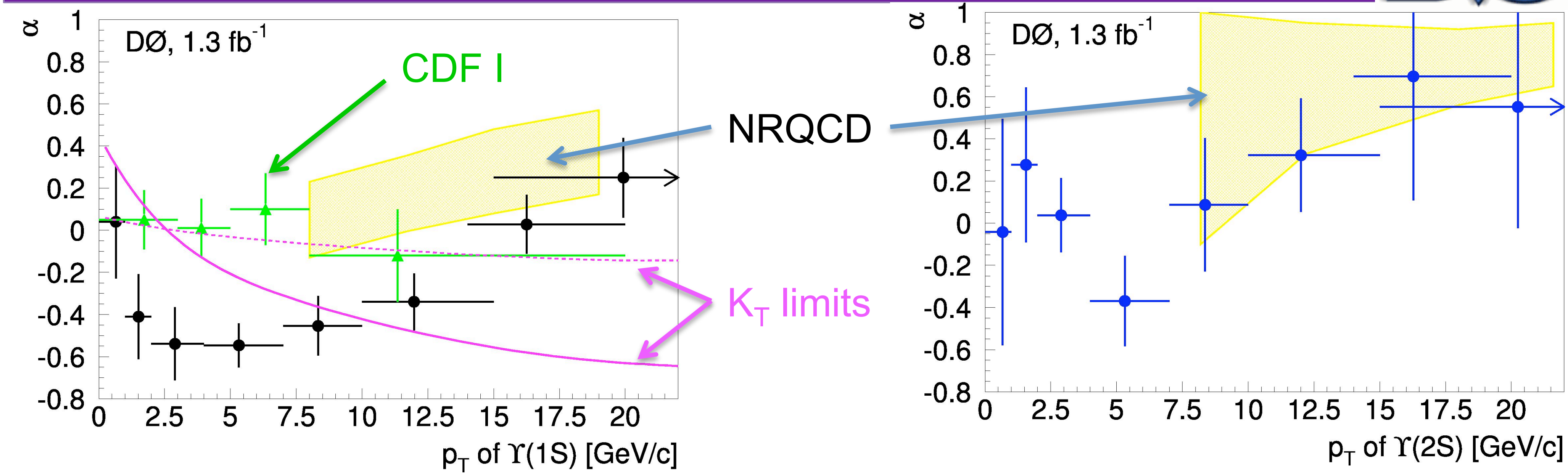
Summary:
http://www-d0.fnal.gov/Run2Physics/WWW/results/final/B/B08G/faqs.pdf

- Significance>5σ for both CDF and D0
- D0 uses BDT to get Ω- signal.
  CDF use traditional way
- Dataset: 1.3 fb^{-1} for D0, 4.2 fb^{-1} for CDF
- Significant mass difference (~6σ) between two experiments
- D0 is working on an update with much more data.

Heavy Flavor is the field where we have some disagreements.

It stimulates progress !

$\Upsilon(nS)$ ($\mu^+\mu^-$) Polarization



$$\frac{d\,\Gamma}{d\cos\theta^*} \propto 1 + \alpha\cos^2\theta^*$$

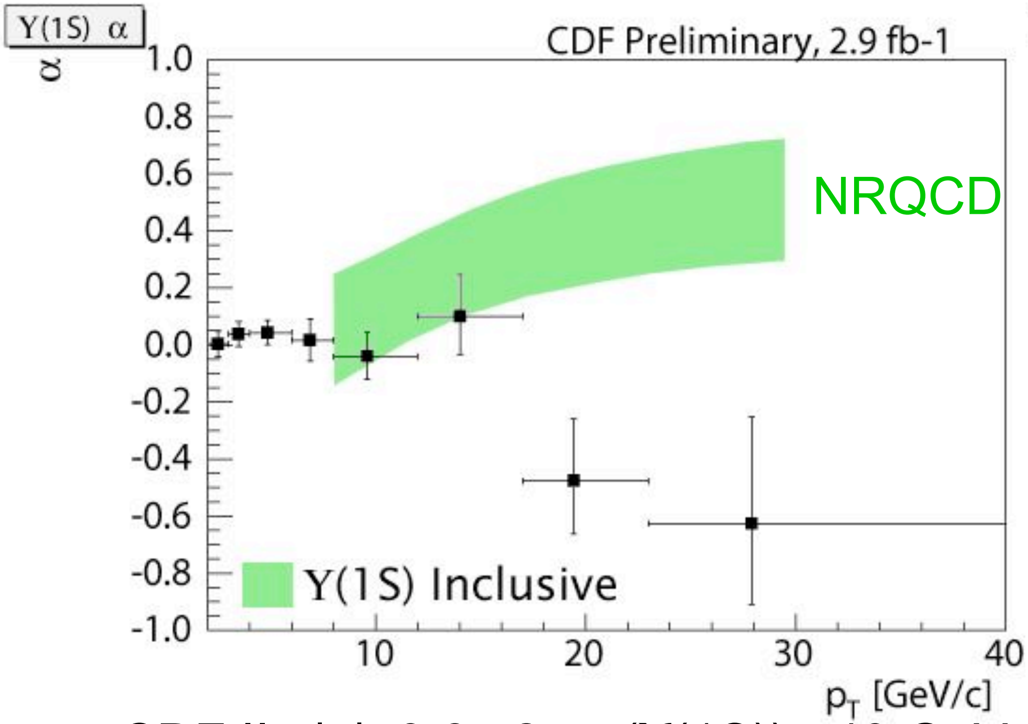
α=(+1)/(-1), fully transversely/longitudinally polarized

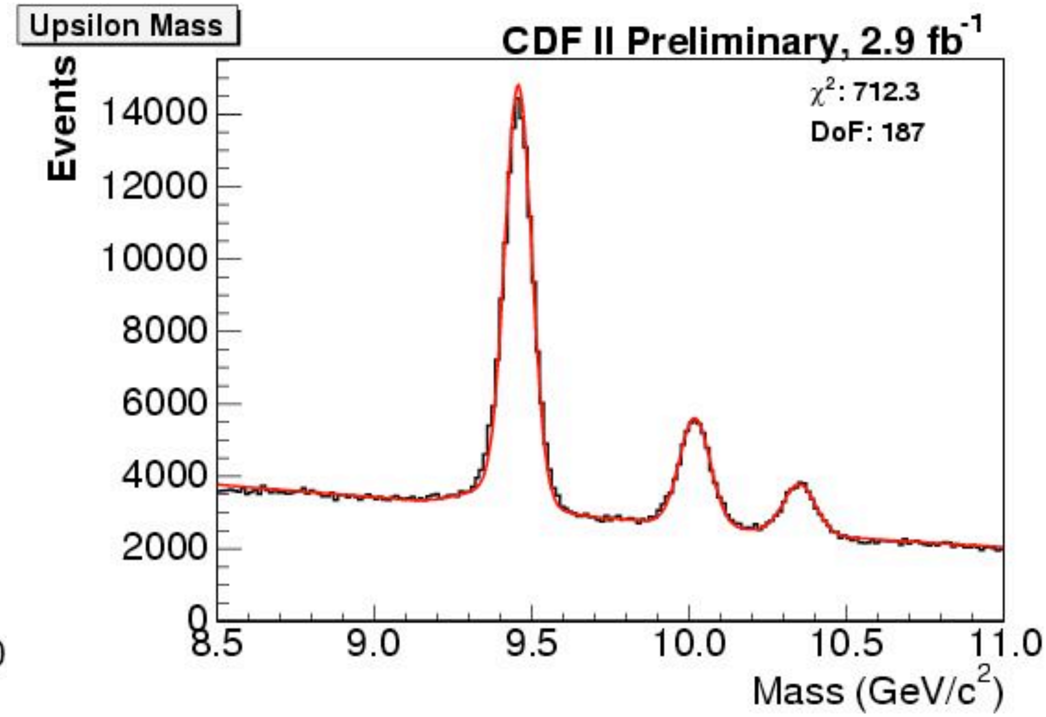
θ^* is the angle between μ^+ and $\Upsilon(nS)$ lab direction in $\Upsilon(nS)$ rest frame

NRQCD (non-relativistic QCD) predicts transverse polarization at high p_T,
K_T factorization differs.

$|y|<0.4$ for CDF I, $|y|<1.8$ for D0 *PRL 101, 182004 (2008)*

Υ(nS) Polarization





CDF II, $|y|<0.6$, $2<p_T(\Upsilon(1S))<40$ GeV
D0, $|y|<1.8$, $0<p_T(\Upsilon(1S))<20$ GeV

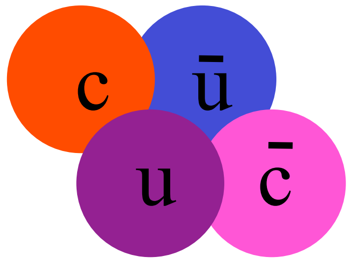
	D0	CDF	NRQCD
Low p_T	significant-longitudinal	non-polarized	
High p_T	transverse	longitudinal	transverse

CDF Run II agrees with CDF Run I

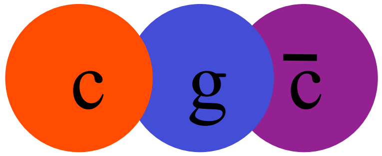
http://www-cdf.fnal.gov/physics/new/bottom/090903.blessed-Upsilon1S/polarization/blessed_plots.html

Exotic mesons—QCD prediction

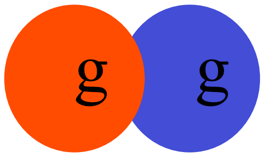
•Multi-quark mesons
  molecule
  diquark-antidiquark



• Hybrid mesons
  quark-antiquark-gluon

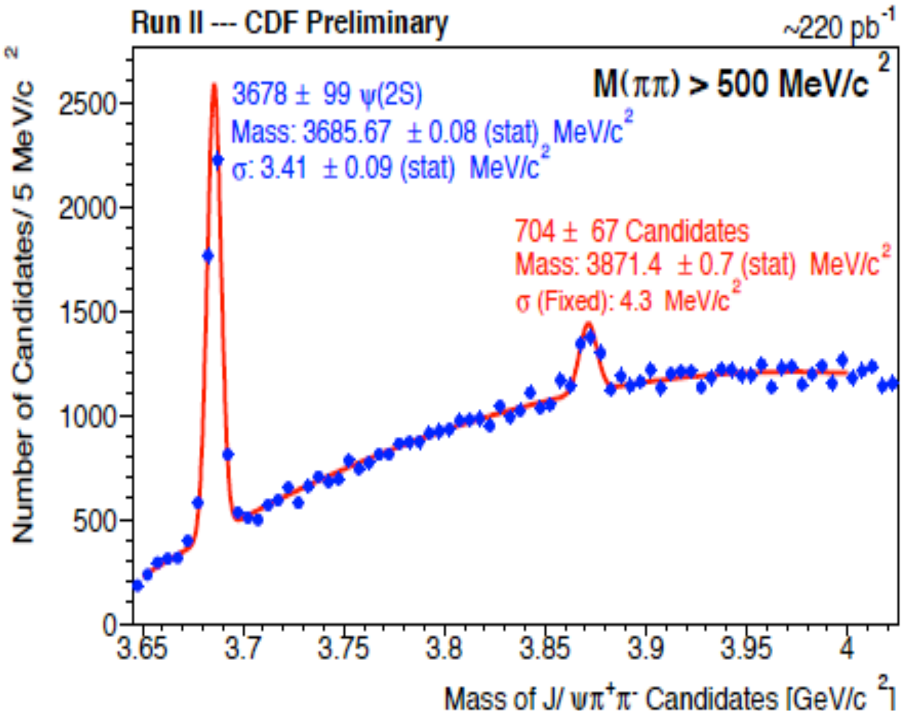


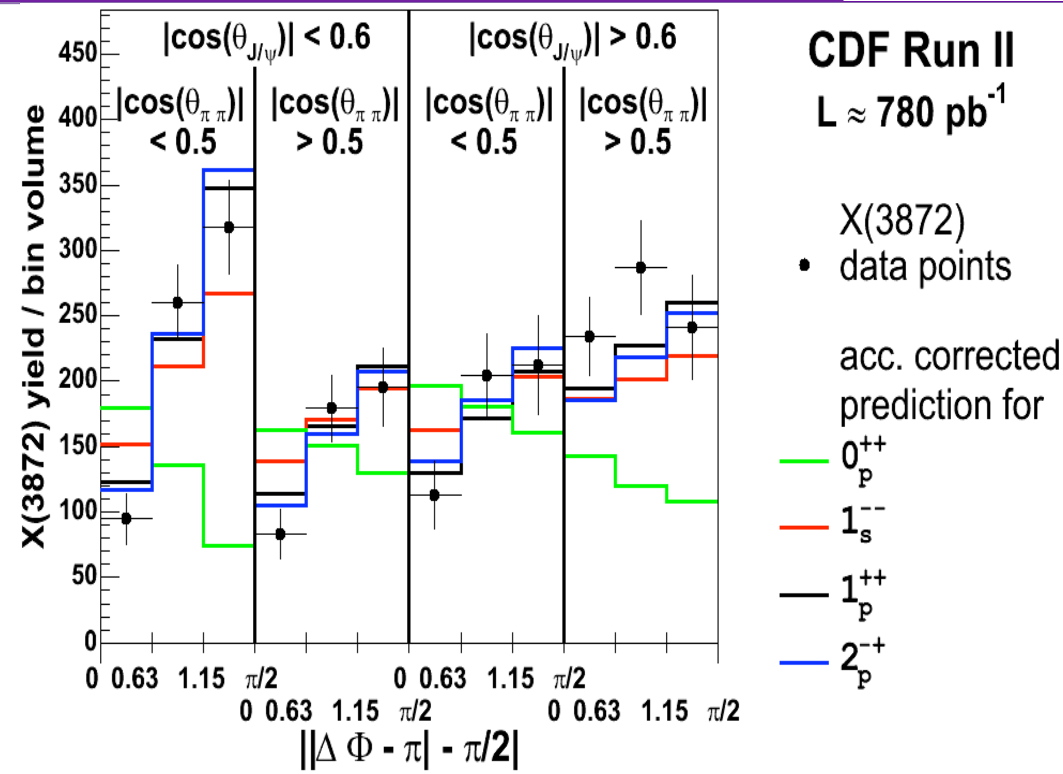
• Glueball
  gluonic color singlet states

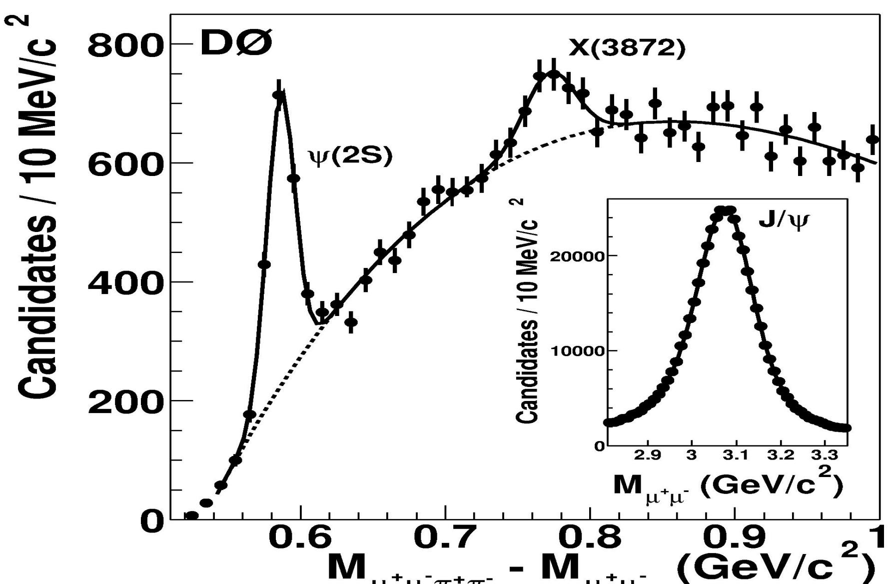


Newly discovered candidates: X/Y/Z family

Exotic mesons—X(3872)





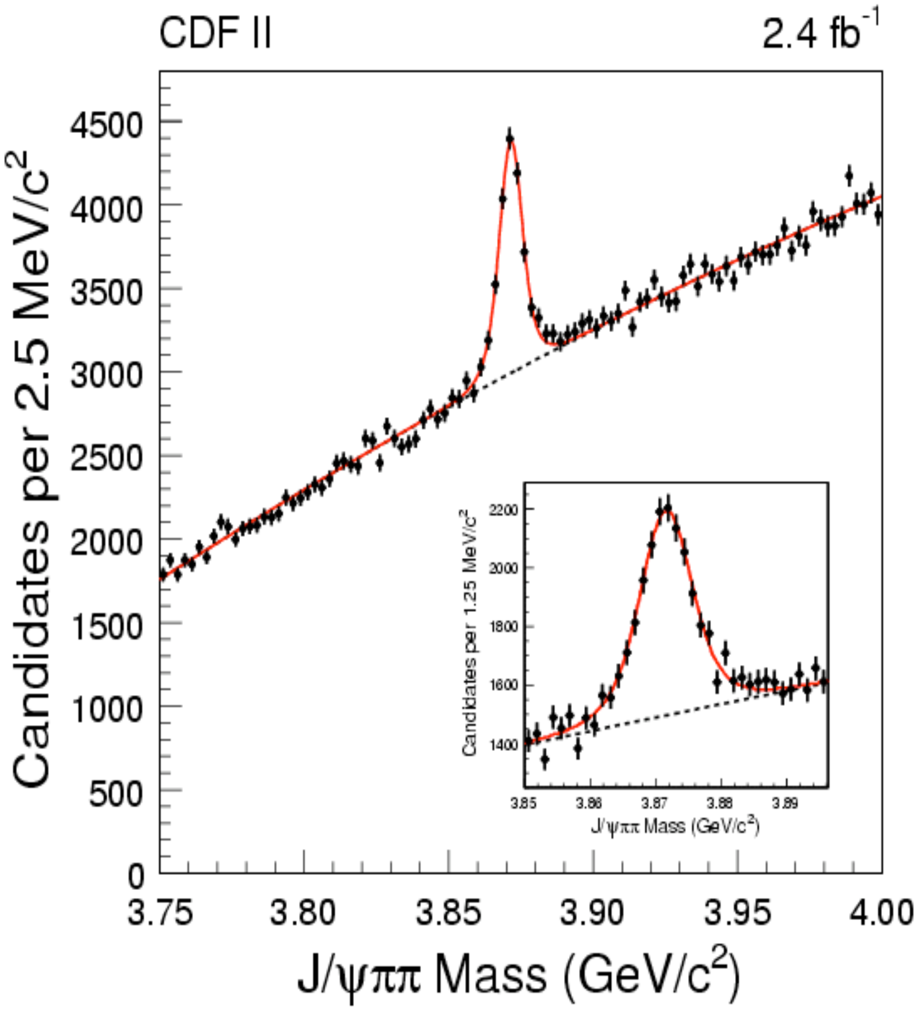


$J^{PC} = 1^{++}$ and 2^{-+} preferred, [PRL 98,132002 (2007)]

CDF/D0 were the first two experiments to confirm X(3872) after Belle's observation

Tevatron continues to make contributions to understand the nature of X(3872)

Exotic mesons—X(3872)



~6000 signal events

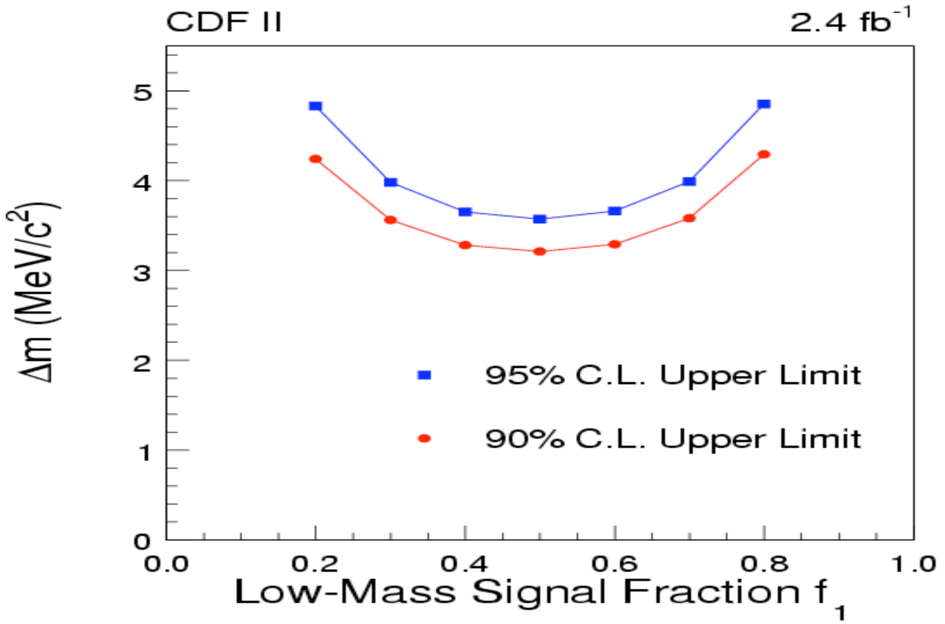
The largest sample to date

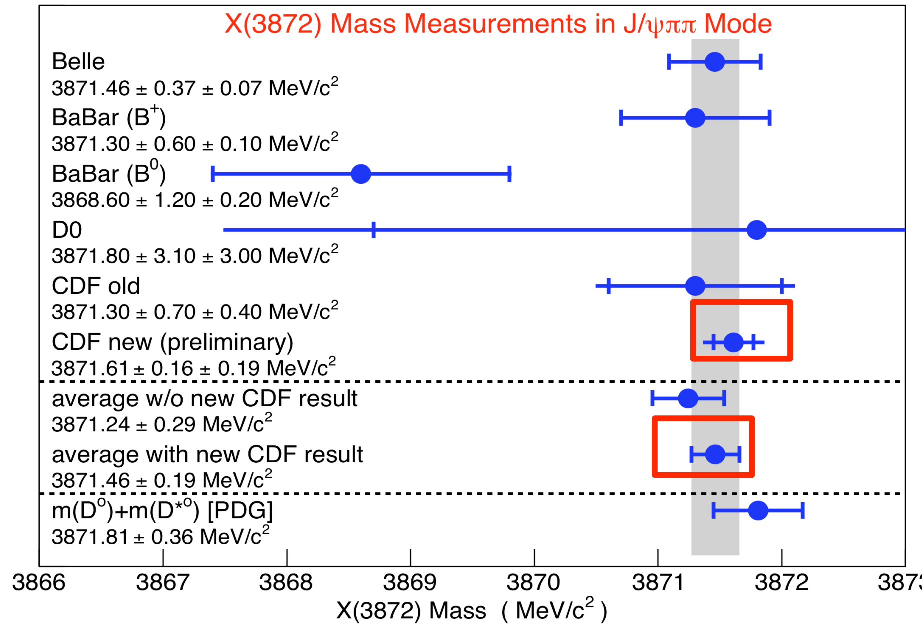
Use neural network to select

I. Test the hypothesis of:
   X(3872) composed of two states?

II. Make (most) precise mass measurement
   Relevant to DD* molecule hypothesis

Exotic mesons—X(3872)





Assuming different fraction for possible two states.

Consistent with one state in data, set limit for two state mass difference:
$\Delta m < 3.2\ (3.6)$ MeV/c^2 at 90% (95%) C.L.

m(X(3872)) = 3871.61 ± 0.16 (stat) ± 0.19 (syst) MeV/c^2 (one state hypothesis)

The most precise measurement to date, still within the D*D threshold uncertainty
PRL 103, 152001 (2009)

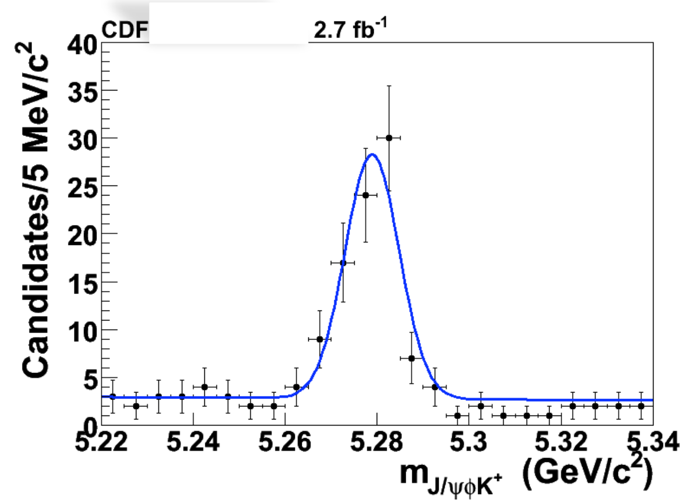
Exotic mesons—Y(4140)

Motivation: searches for exotics with heavy quarks J/ψ(c-cbar) ϕ(s−sbar)

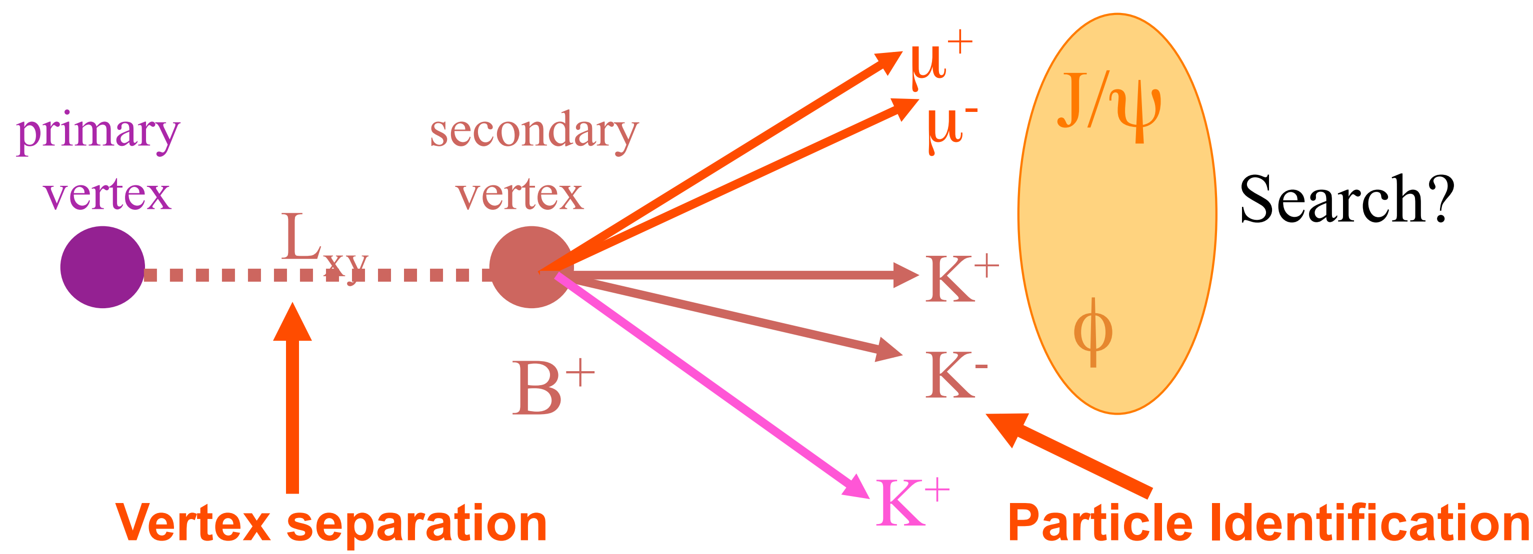
Strategy

- I) Reconstruct B^+ as:

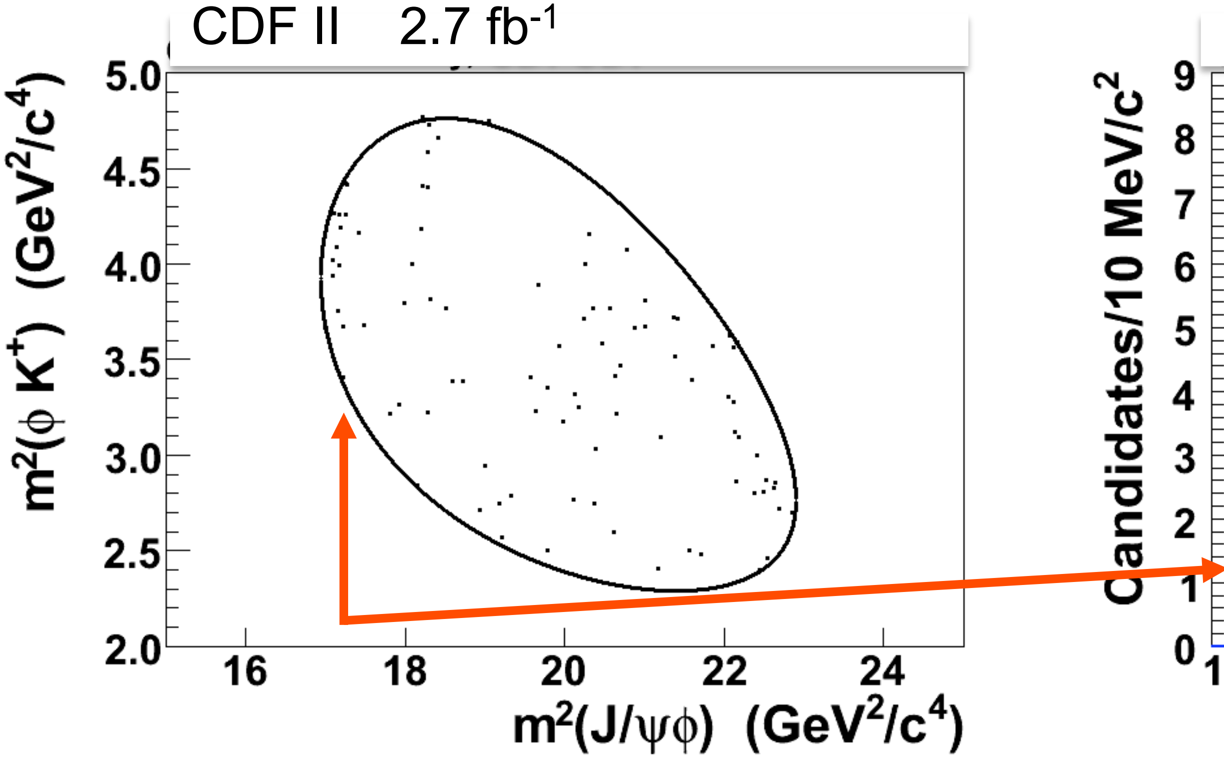
$$B^+ \rightarrow J/\psi \phi K^+$$
$$J/\psi \rightarrow \mu^+\mu^-$$
$$\phi \rightarrow K^+K^-$$

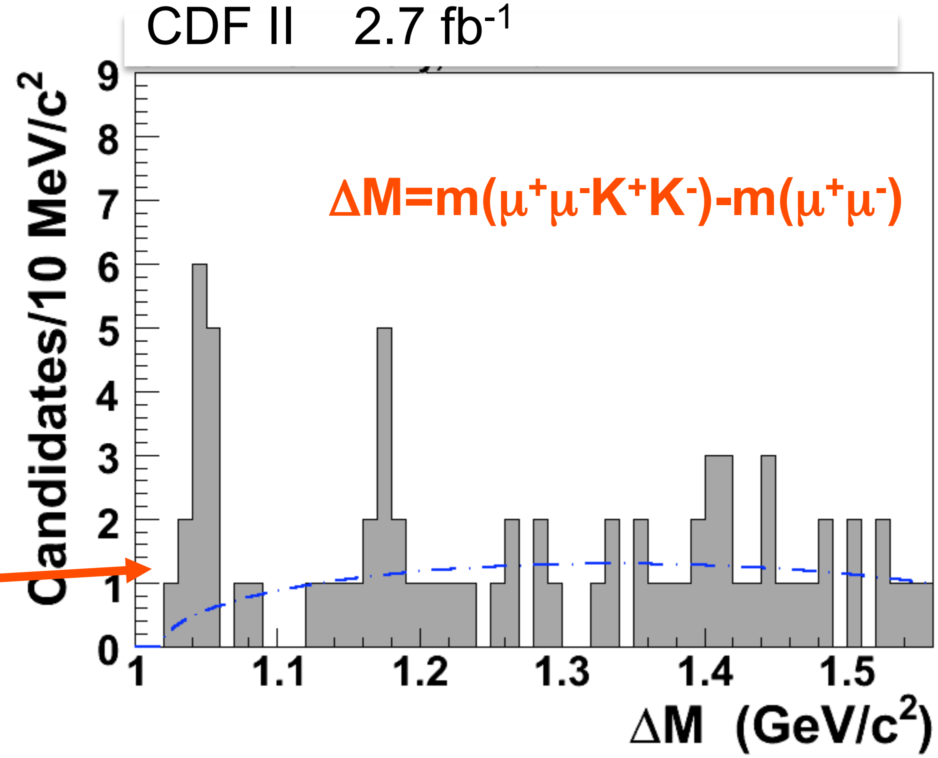


- II) Search for structure in J/ψϕ mass spectrum inside B^+ mass window



Exotic mesons—Y(4140)

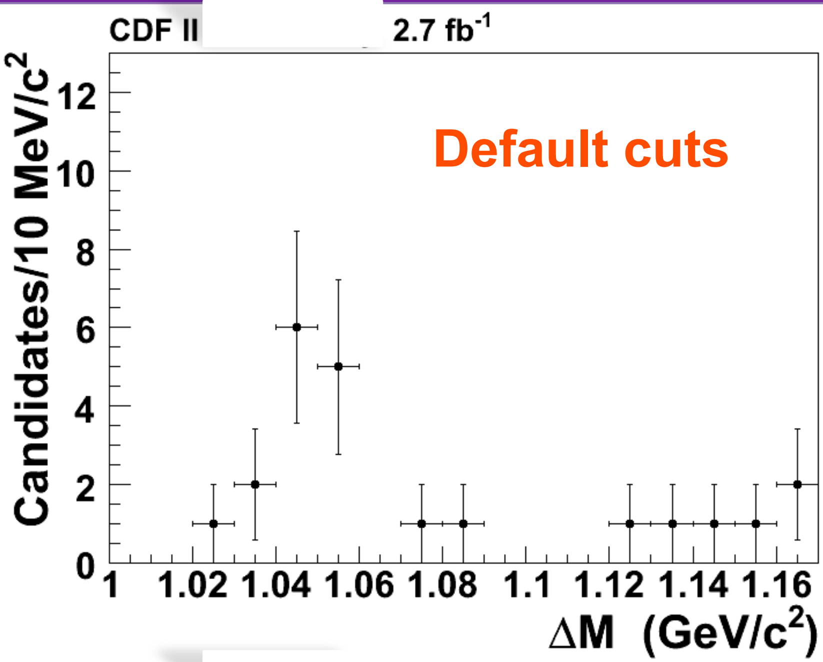


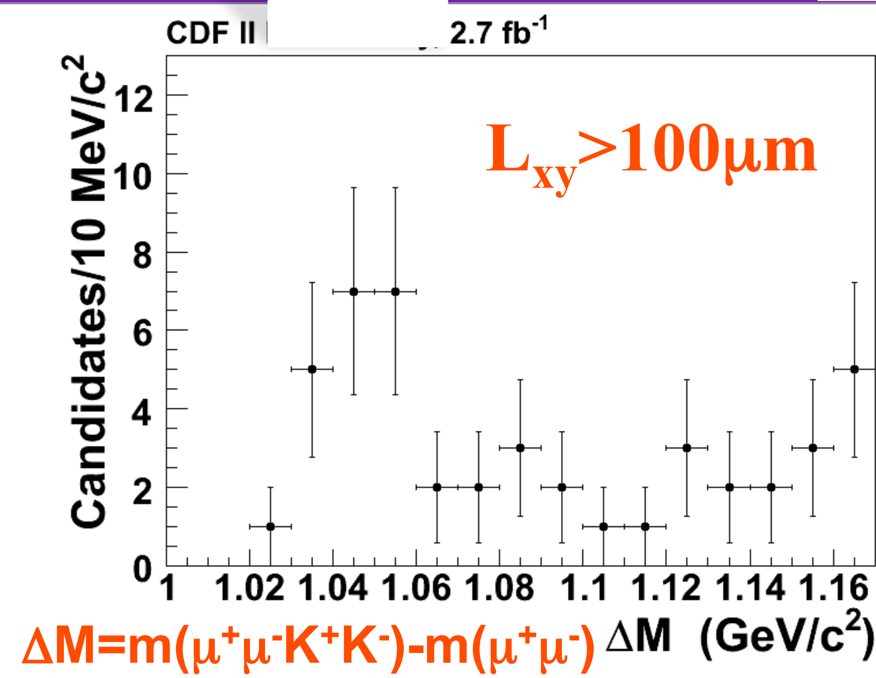


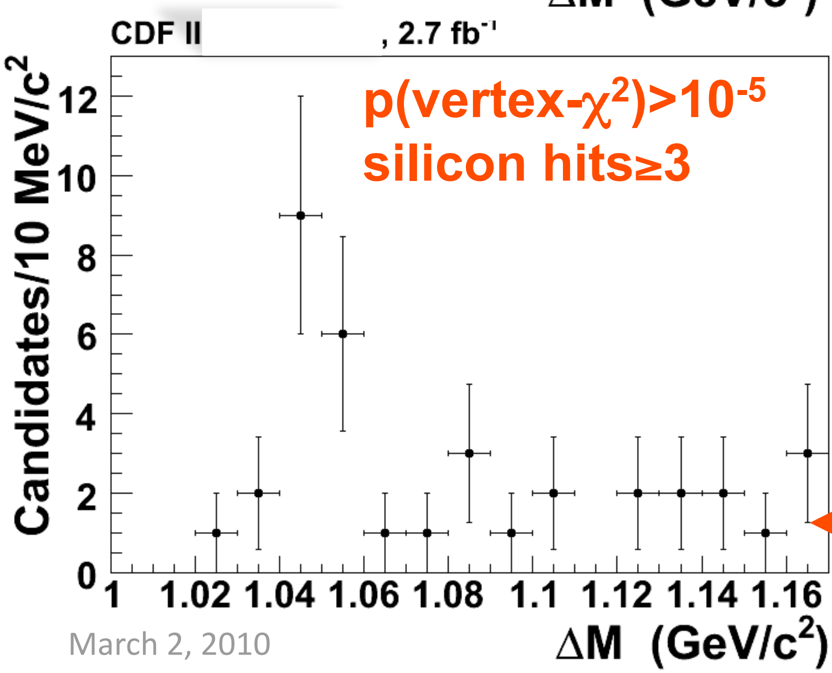
Three-body Phase Space Background shape is different from data

An near threshold enhancement is observed

Y(4140) robust check







- Extensive cross checks by varying L_{xy}, kaon PID, B^+ mass window, vertex probability, # of silicon hits,…

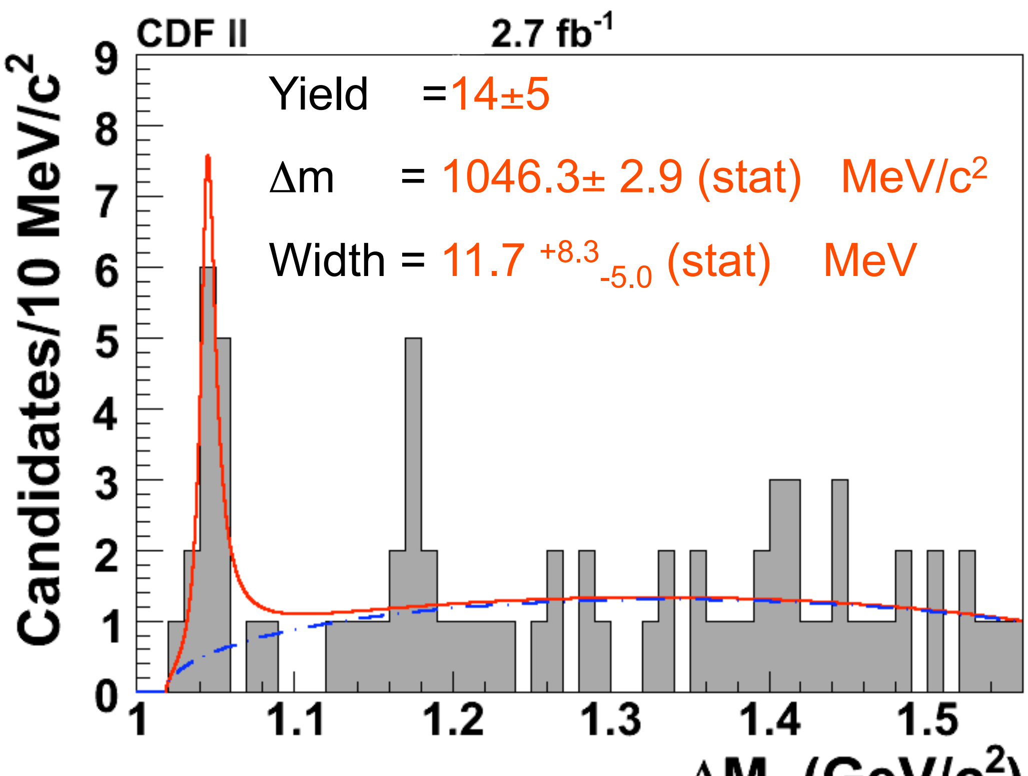
  Robust against variations

  More signal but with more background

Exotic mesons—Y(4140)

- We model the Signal (S) and Background (B) as:

S: S-wave relativistic Breit-Wigner   B: Three-body decay Phase Space



$\Delta M = m(\mu^+\mu^- K^+K^-) - m(\mu^+\mu^-)$

Convoluted with resolution (1.7 MeV)

Mass=:
4143.0 ± 2.9 (stat)± 1.2 (syst) MeV/c^2
(adding J/ψ mass)

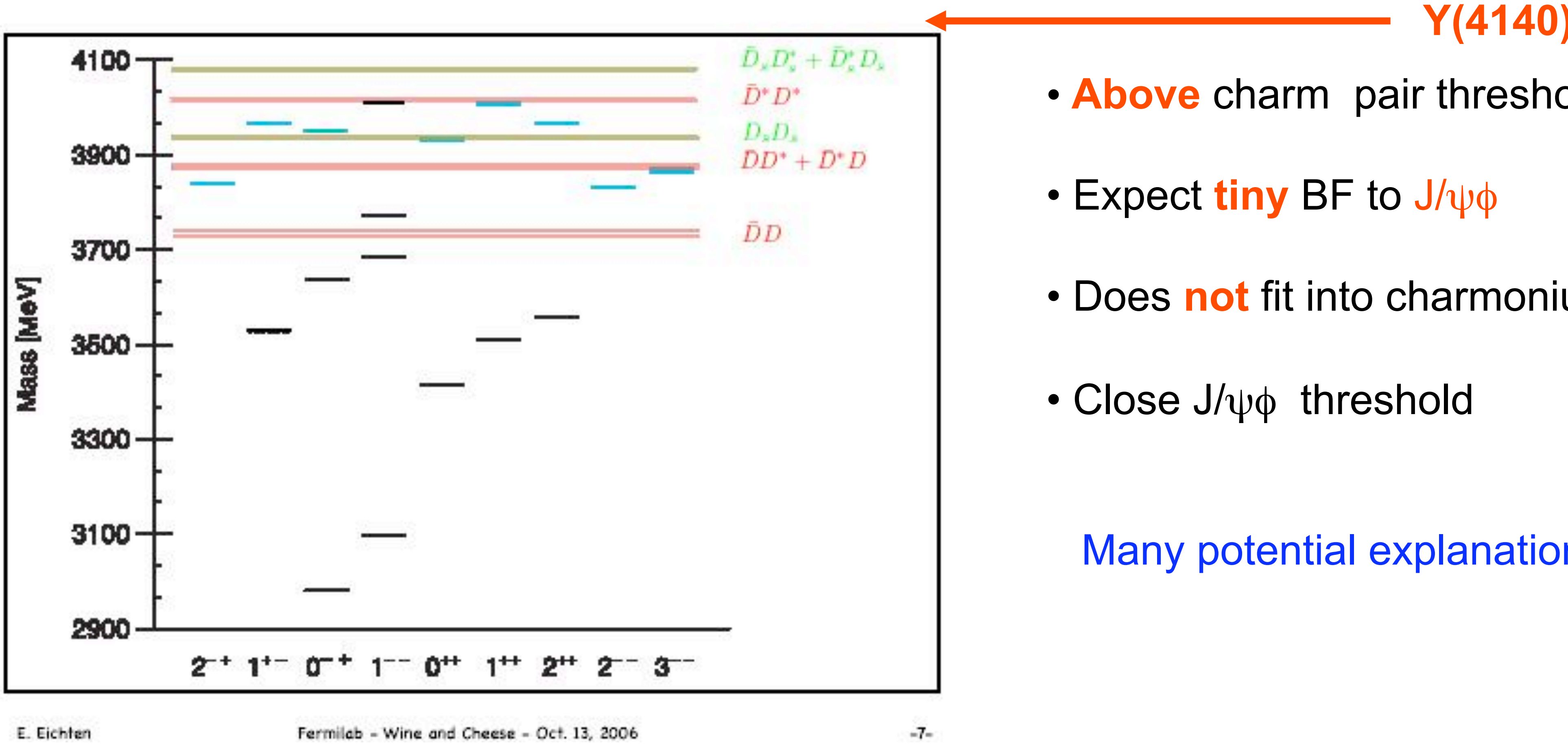
J^{PC}=**$?^{?+}$, tentatively name it as Y(4140)**

$\sqrt{(-2\log(L_{max}/L_0))}$=5.3, Toy MC to determine significance, >3.8σ

PRL 102, 242002 (2009)

Exotic mesons—Y(4140)

Charmonium Spectrum



- **Above** charm pair threshold
- Expect **tiny** BF to $J/\psi\phi$
- Does **not** fit into charmonium
- Close $J/\psi\phi$ threshold

Many potential explanation!

Increased B yield by 50-60% with more data (same cuts)
large chance for Y(4140) significance to pass 5σ

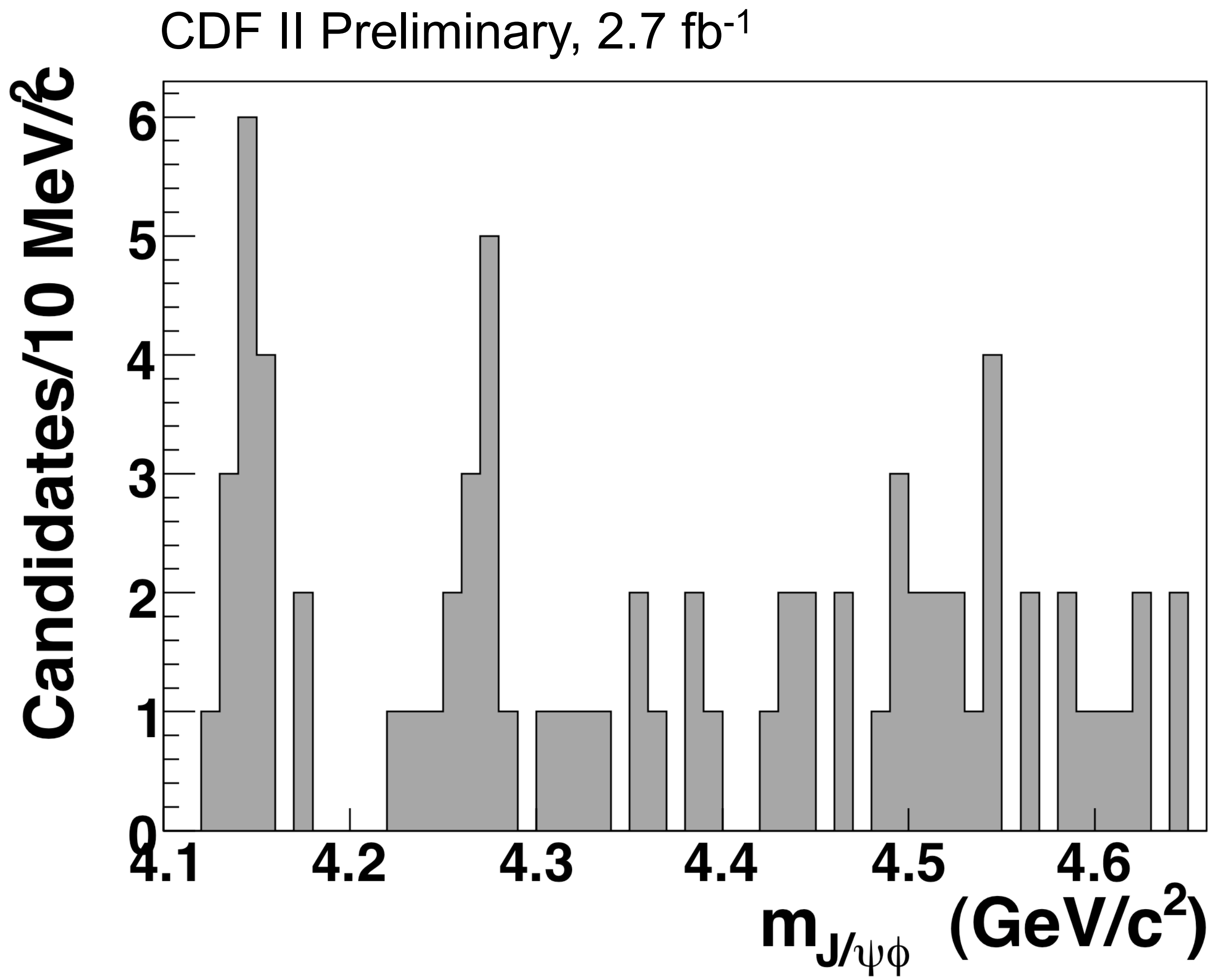
Conclusion and Prospect

- Tevatron is an important place to study heavy spectroscopy
  unique production, large rate, good detectors, …

- CDF and D0 will make many more important measurements
  Tevatron has delivered >8 fb^{-1}, more is coming

- Tevatron is ready to challenge LHC!

Backup



CDF II Preliminary, 2.7 fb-1
Candidates/10 MeV/c2
6
5
4
3
2
1
0
4.1
4.2
4.3
4.4
4.5
4.6
mJ/ψφ (GeV/c2)

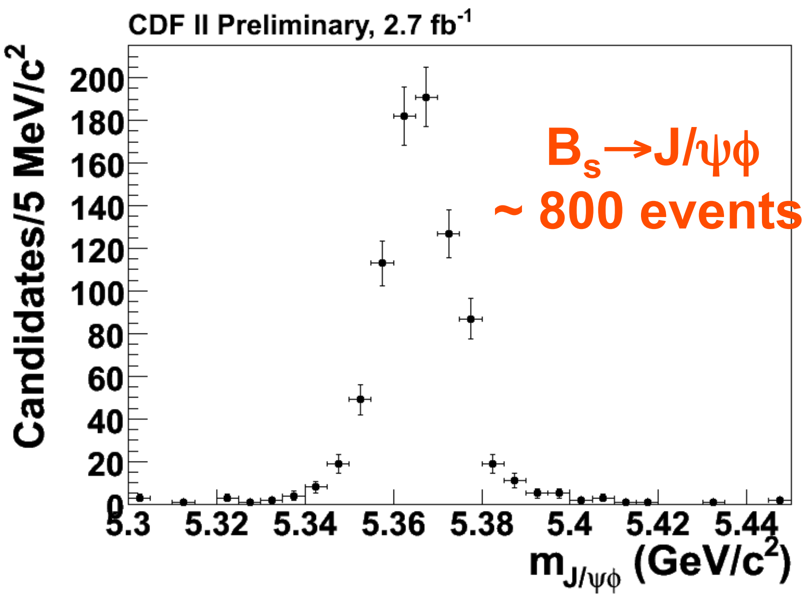
Backup

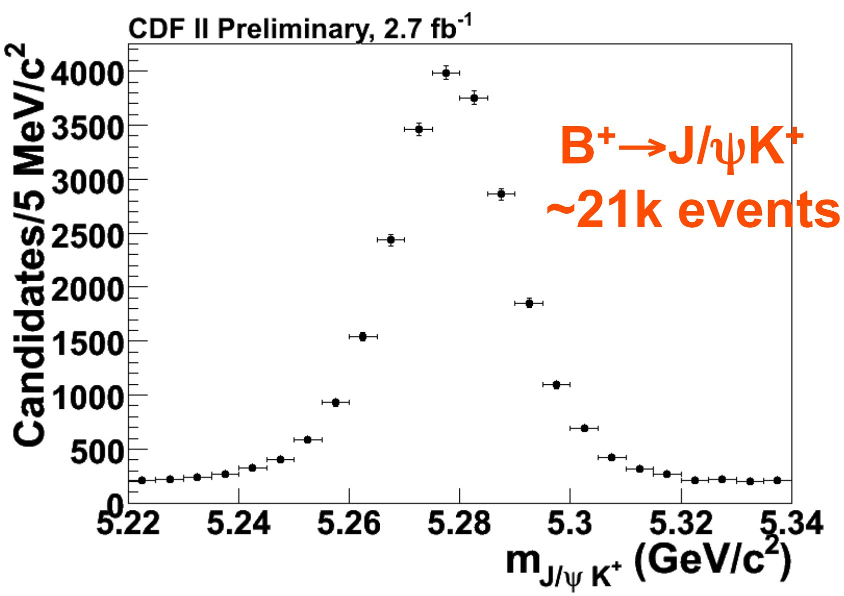
- We also reconstruct two control channels with similar cuts:

  ~3 000 $B_s \rightarrow J/\psi\phi$, ~50 000 $B^+ \rightarrow J/\psi K^+$

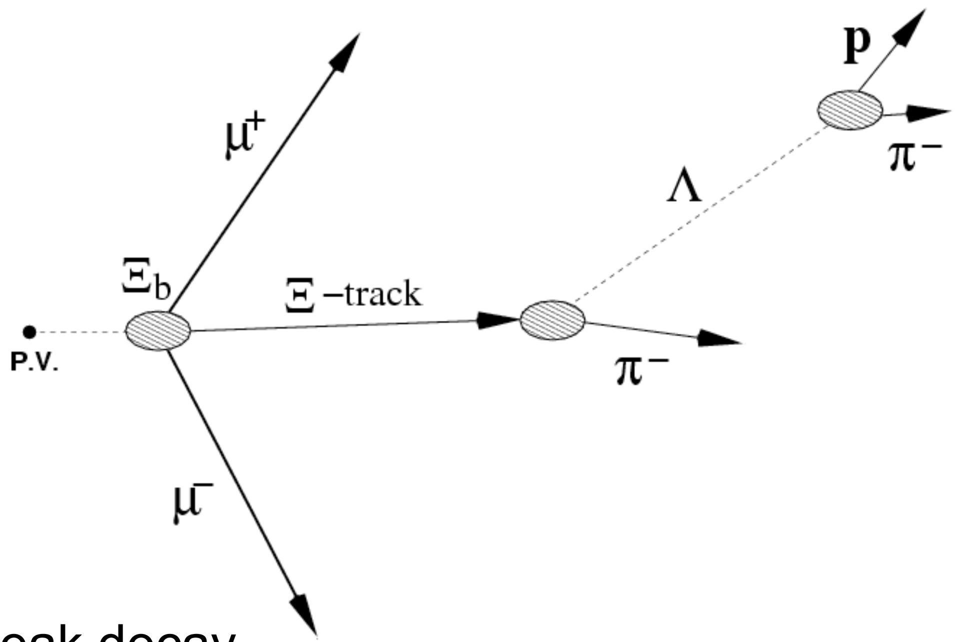
  before L_{xy} and kaon LLR cuts

- Clean control signals after L_{xy} and kaon LLR cuts
  cross check and efficiency evaluation

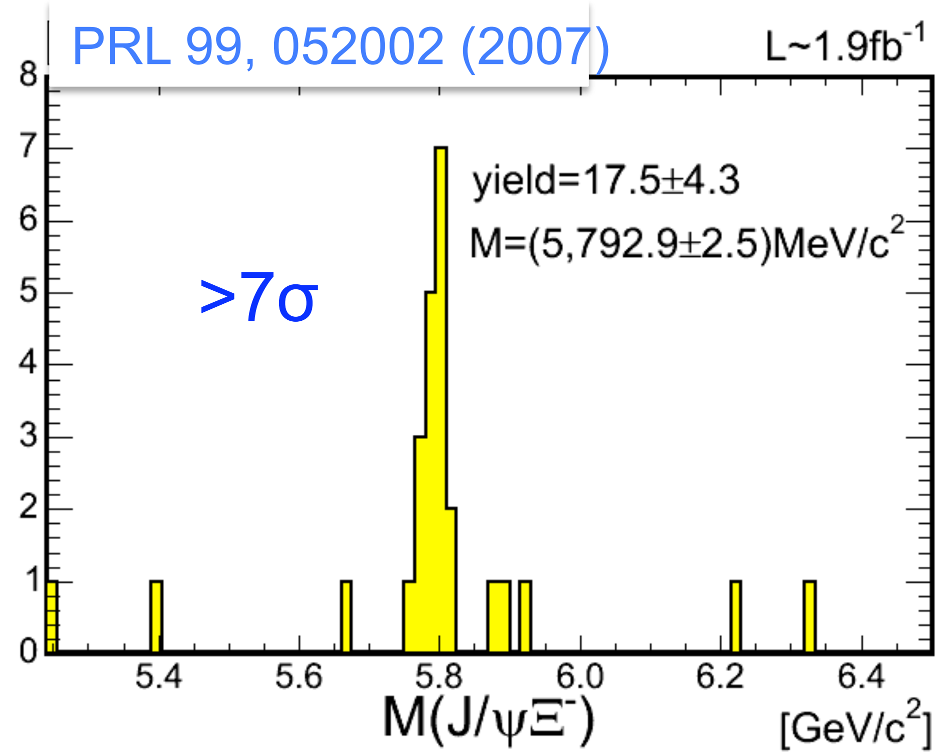




Heavy Baryon—Ξ_b^- (bsd)



weak decay

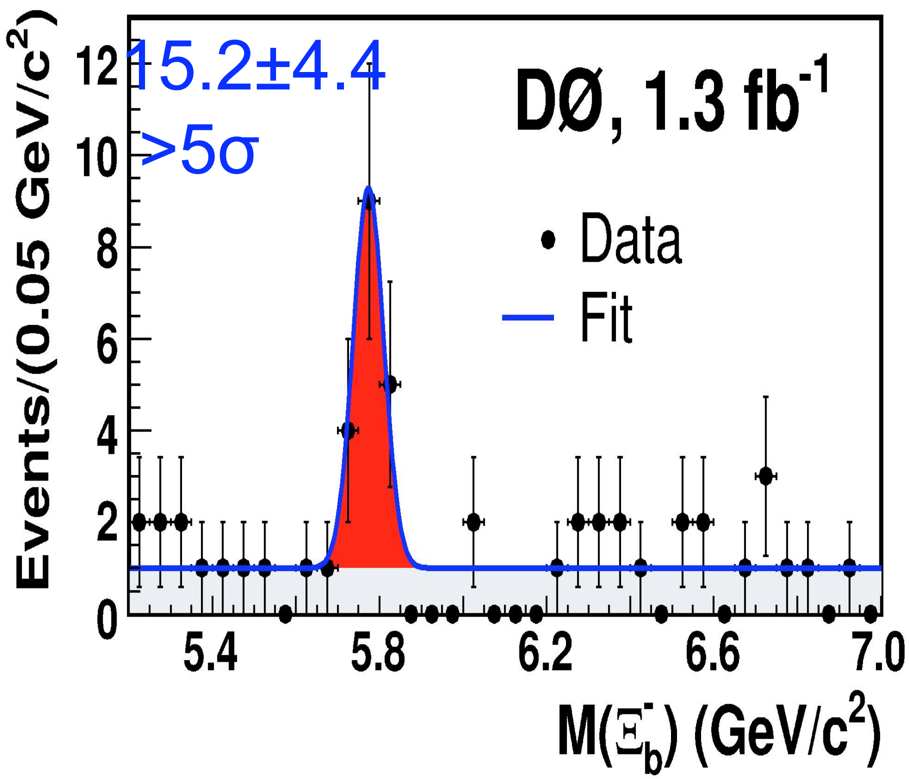


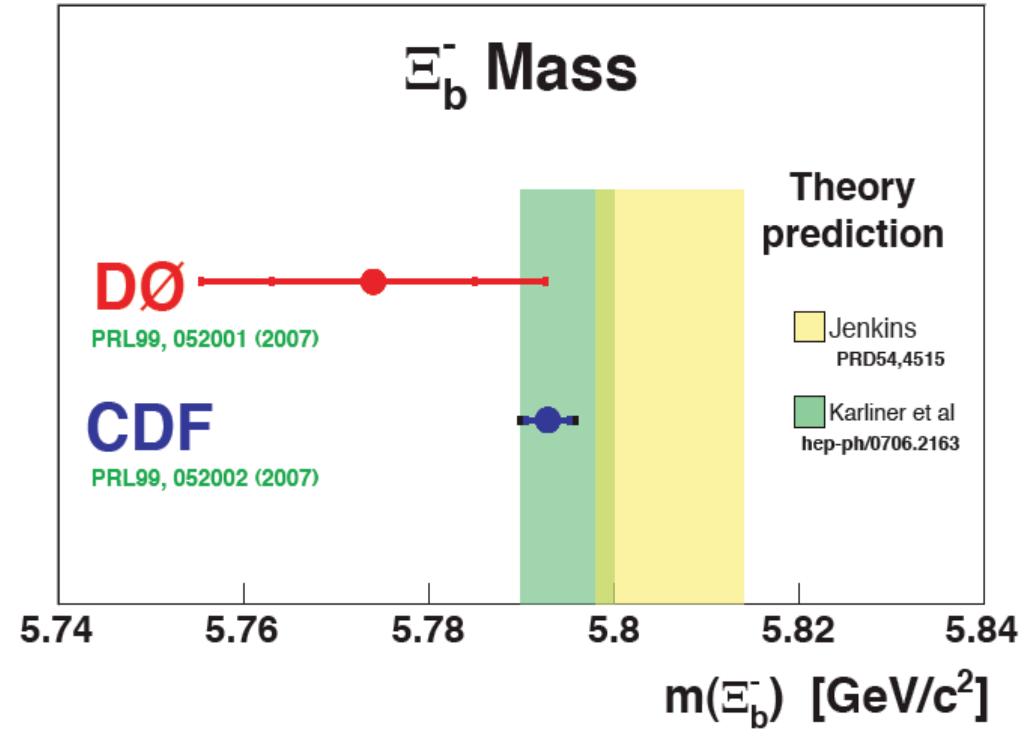
$m(\Xi_b^-)=5792.9 \pm 2.5\,(stat) \pm 1.7(syst)\ MeV/c^2$

CDF also have signal in $\Xi_b^- \to \Xi_c^0 \pi^-$ signal, and an update (later).

Heavy Baryon—Ξ_b^- (bsd)

PRL 99, 052001 (2007)





$m(\Xi_b^-)$=5792.9 ± 2.5 (stat) ± 1.7(syst) MeV/c^2,
lifetime result consistent with expectation

CDF, D0 results and theoretical prediction are consistent