Heavy Flavor properties at CDF

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In this talk:

- CDF detector and B physics triggers
- b-Baryons observations and properties (Ξ_b , Ω_b)
- b-hadrons lifetimes (particularly Λ_b)
- Charmonium–like resonances, Y(4140)
- Conclusions

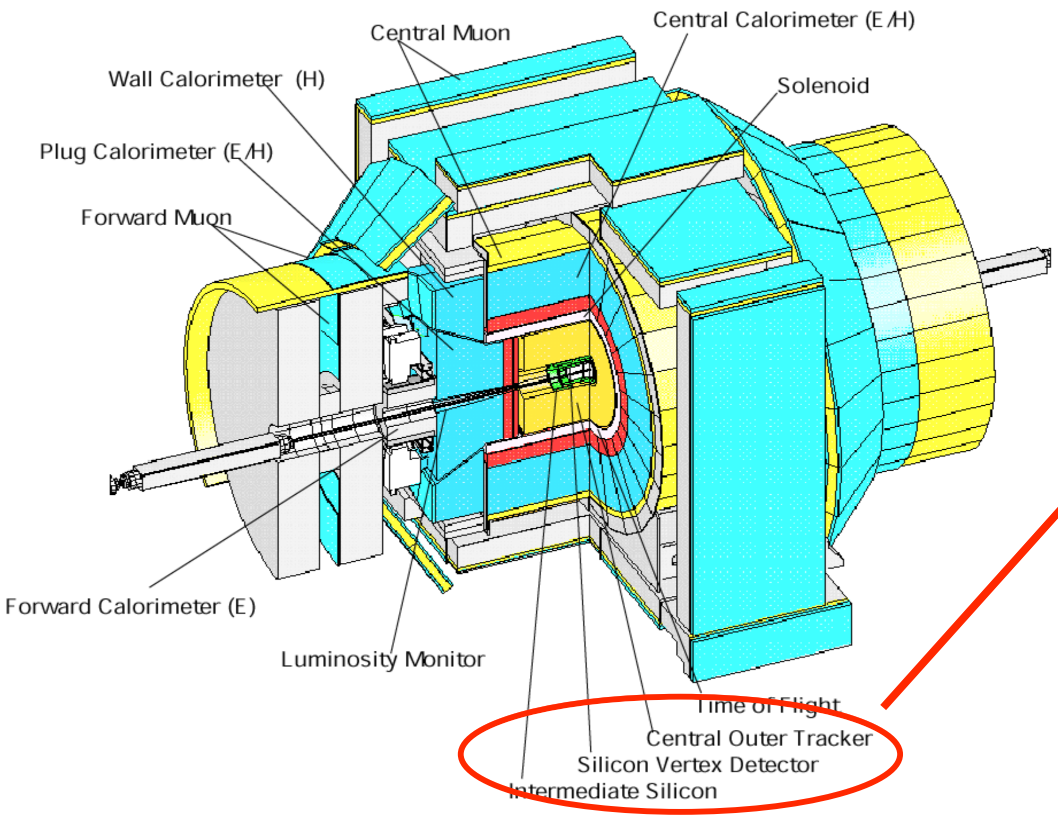
What is not in this talk:

CAVEAT: "*Heavy flavor properties*" is a huge and very rich field for Tevatron experiments, only CDF published 58 Run II papers till now !

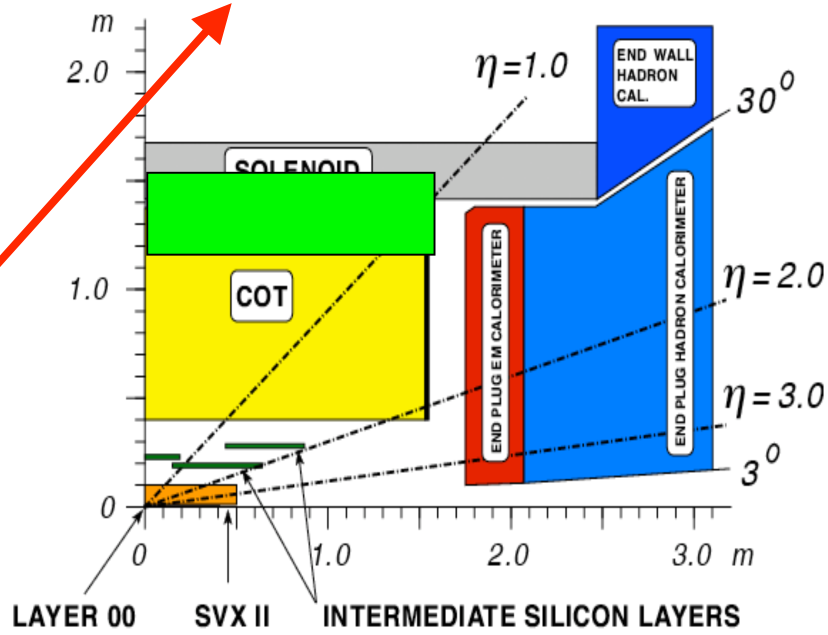
→ *choose not to cover:*

- b-bbar and c-cbar production and correlations
- Charm physics (D^0 mixing and direct CPV)
- Charmed Baryons
- and … many other heavy hadron studied decay modes

The CDF II detector



CDF Tracking System



Lepton ID

Muons: CMU, CMP, CMX ($|\eta|<1.1$)

Electrons: CEM (EM calorimeter)
CPR (pre-shower detector)

Particle ID

•dE/dX in **COT**

•**T**ime **O**f **F**light detector

B physics triggers at CDF

Conventional at colliders (Run I / D0)

Di-Muon (J/ψ)

Pt(μ) > 1.5 GeV

J/ψ modes down to low Pt(J/ψ)~0 (Run II)

+

With SVT trigger

1-Displaced track + *lepton* (e, μ)

120 μm < I.P.(trk) < 1mm

P_T(*lepton*) > 4 GeV

Semileptonic modes

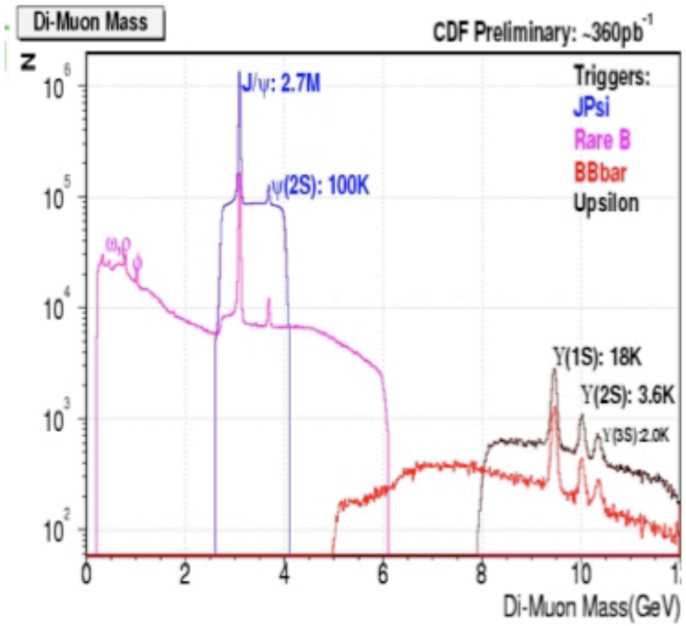
2-Displaced tracks

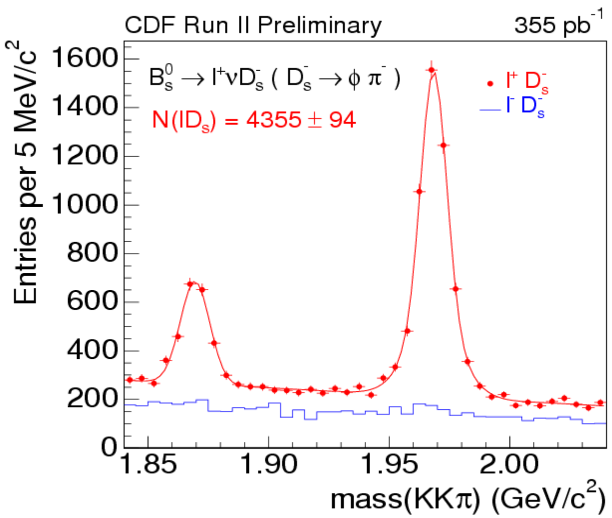
P_T(trk) > 2 GeV

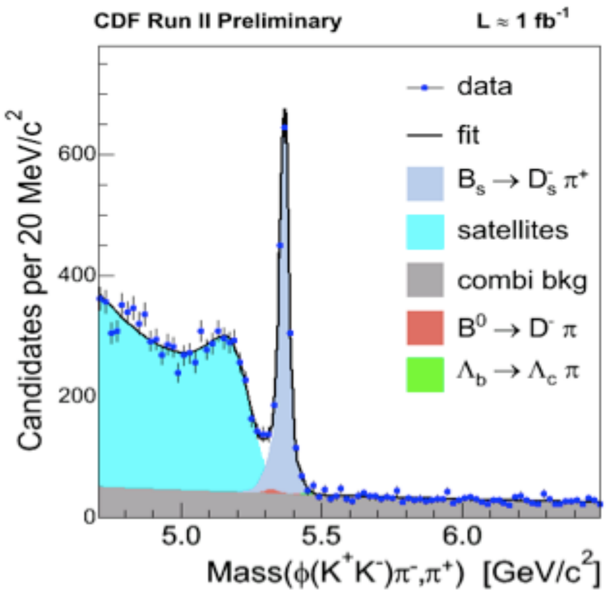
120 μm < I.P.(trk) < 1mm

Σp_T > 5.5 GeV

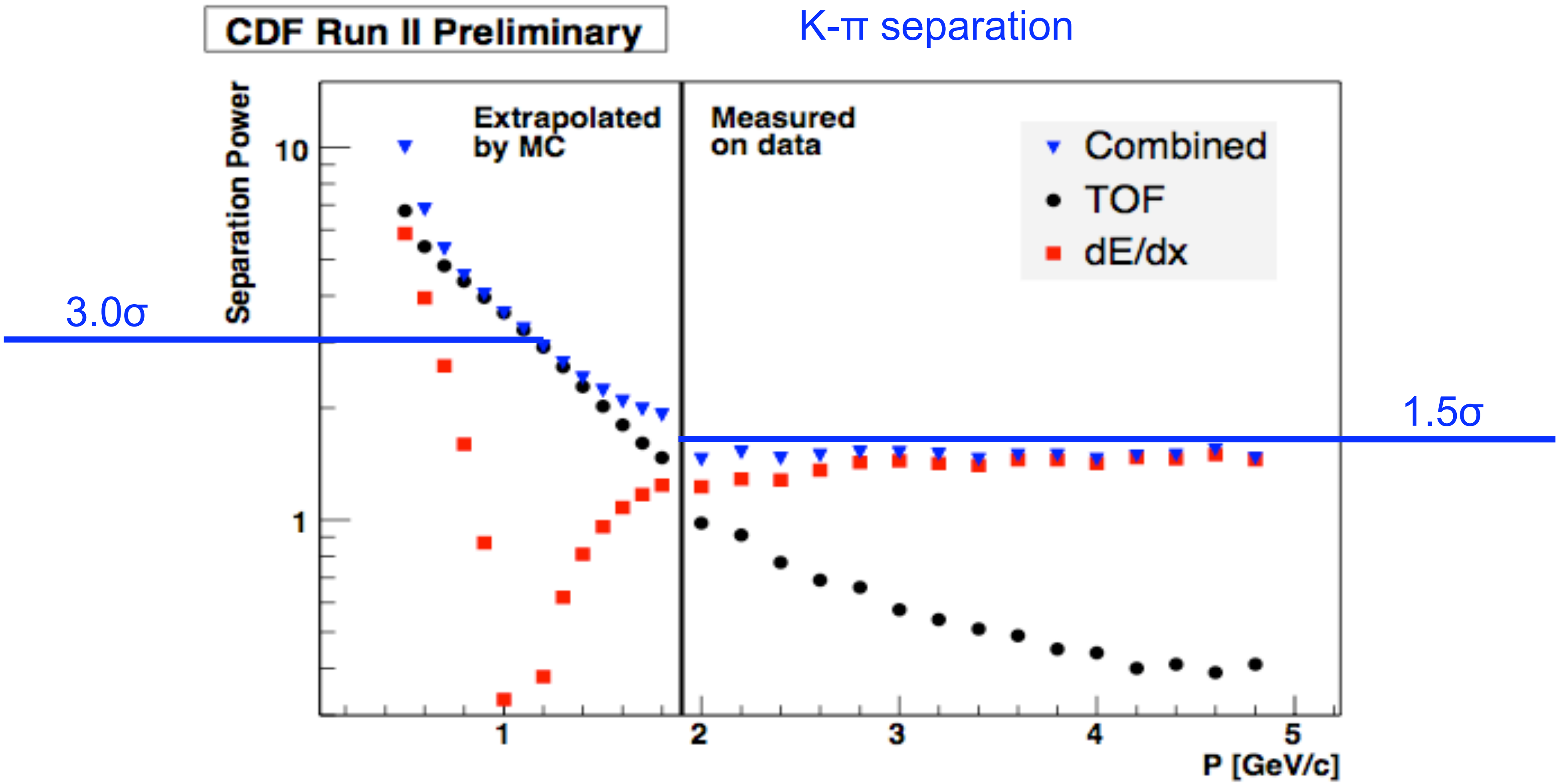
fully hadronic modes







CDF hadron PID



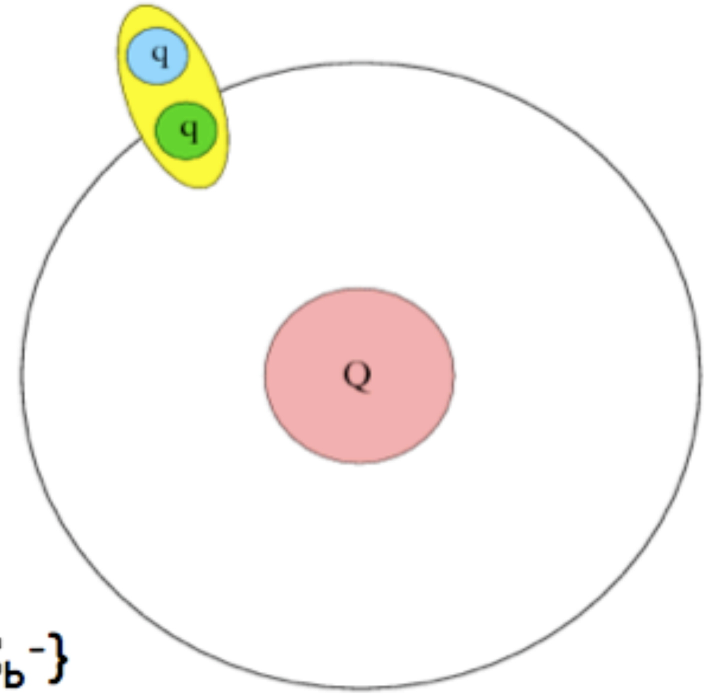
Typical B decay daughter momentum ~GeV

b – Baryons

b - Baryons

- b-baryons are nice laboratory to understand non-perturbative QCD and potential models

  - heavy b-quark → sizeable simplification in theoretical description
  - basic model: light diquark system qq surrounding the heavy b-quark „nucleus" Q
  - coupling similar as in hydrogen/helium atom



- Ground states (L=0)

$$J_{qq} = S_{qq} = 0 \rightarrow J = J_{qq} + S_Q = 1/2 \quad \{\Lambda^0_b, \Xi_b^-\}$$

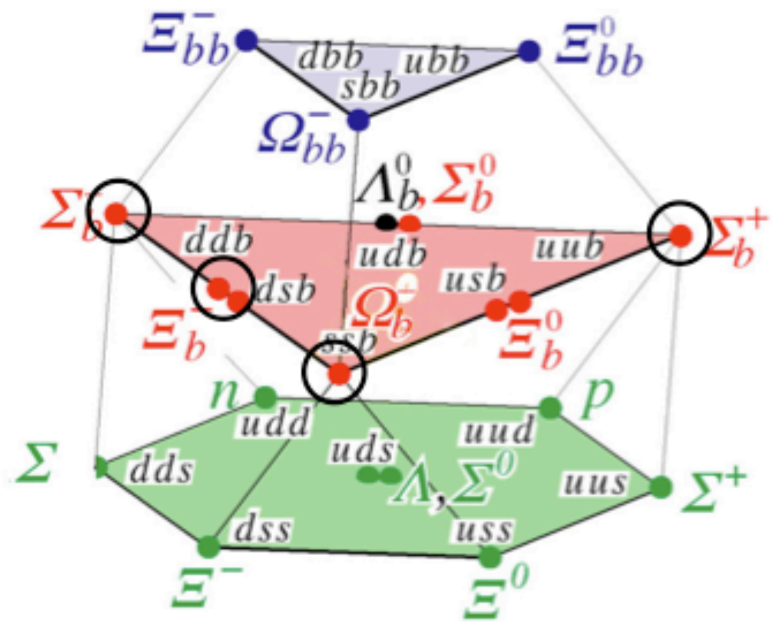
$$J_{qq} = S_{qq} = 1 \rightarrow J = J_{qq} + S_Q = 1/2 \quad \{\Sigma_b, \Xi_b', \Omega_b\}$$

$$\rightarrow J = J_{qq} + S_Q = 3/2 \quad \{\Sigma_b^*, \Xi_b^*, \Omega_b^*\}$$

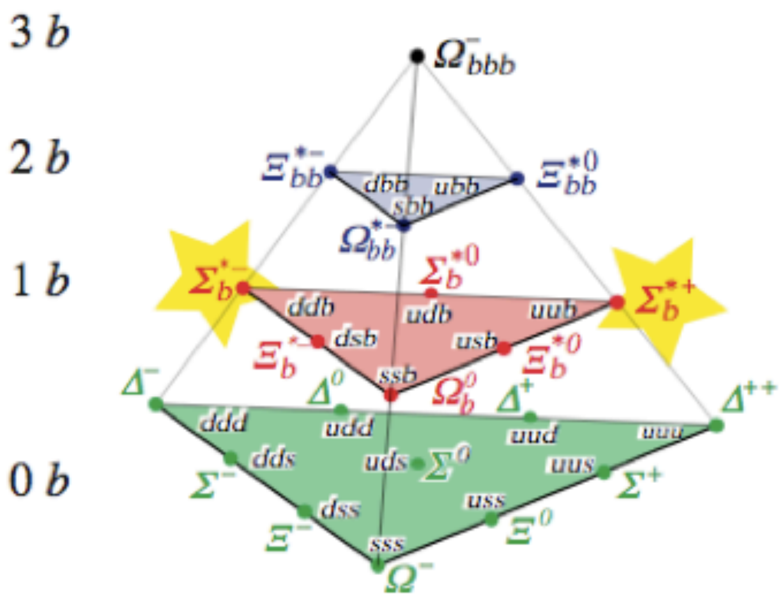
b - Baryons

- This is totally a Tevatron field (b baryons copiously produced)
  - $\Sigma_b^{(*)+}$ and $\Sigma_b^{(*)-}$ observed in 2006 → updated with 5 fb^{-1}
  - Ξ_b^- observed by in 2007
  - Ω_b^- observed in 2008 → updated with 4.3 fb^{-1}
  - Several analyses involving Λ^0_b

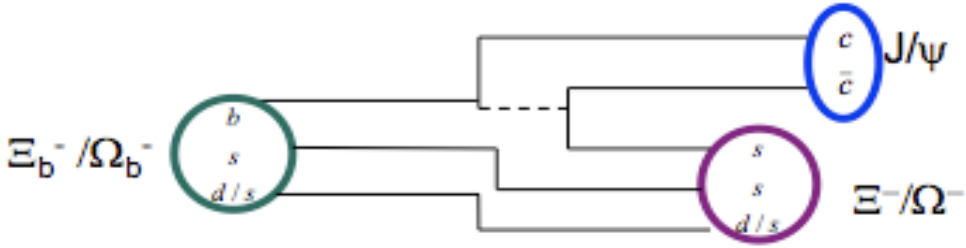
$J = 1/2$ b Baryons



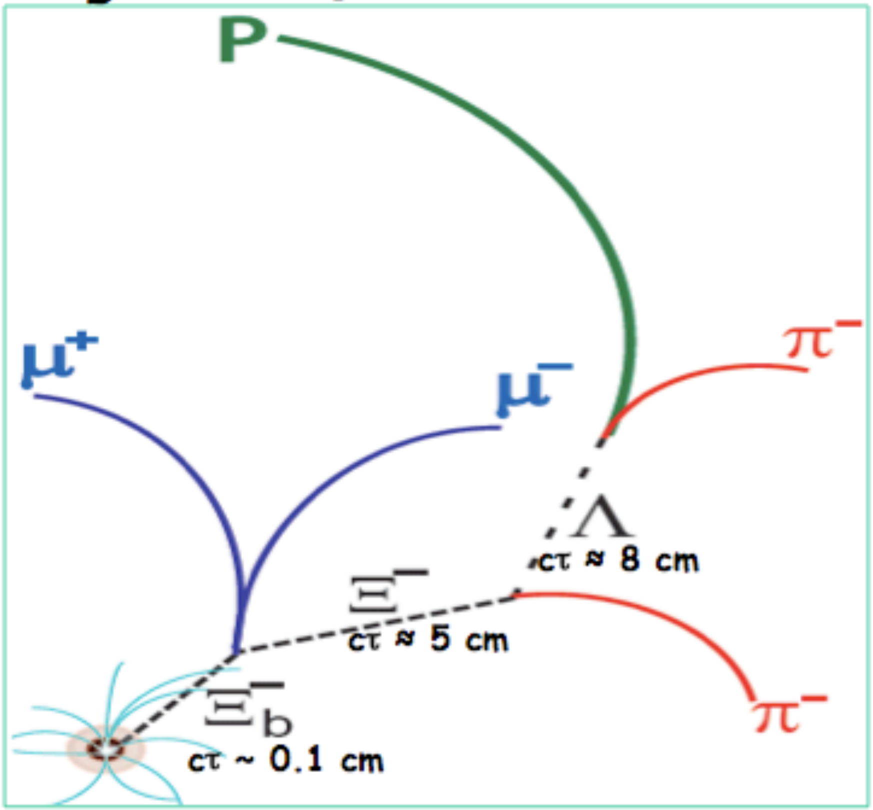
$J = 3/2$ b Baryons

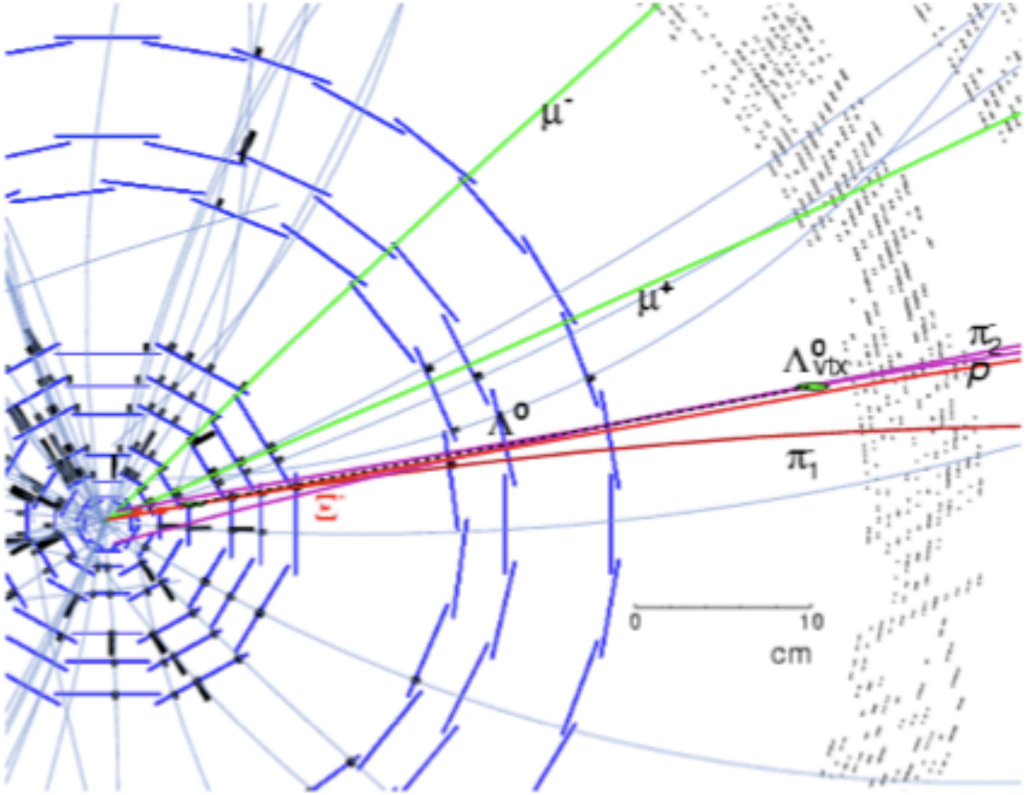


Ξ_b and Ω_b observation



$\Xi^-_b \rightarrow J/\psi \Xi^-$





Ξ_b and Ω_b reconstruction

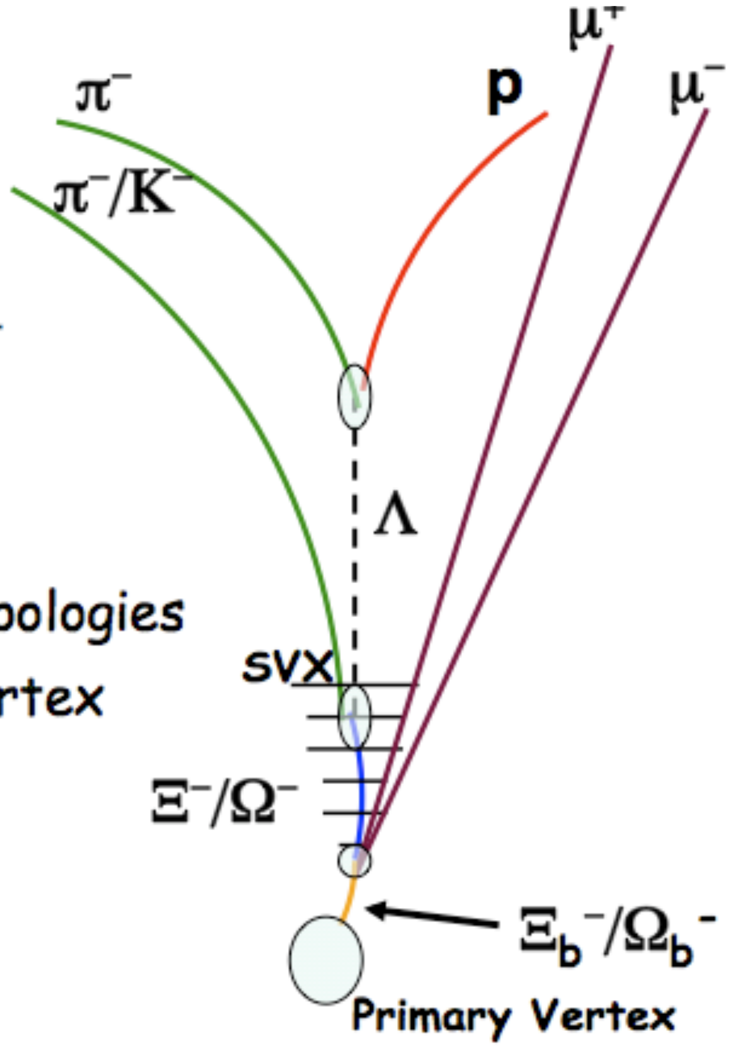
Search for Ξ_b^- and Ω_b^- in the decays

- $\Xi_b^- \rightarrow J/\psi\, \Xi^-$, $J/\psi \rightarrow \mu^+\mu^-$, $\Xi^- \rightarrow \Lambda\pi^-$
- $\Omega_b^- \rightarrow J/\psi\, \Omega^-$, $J/\psi \rightarrow \mu^+\mu^-$, $\Omega^- \rightarrow \Lambda K^-$

5-track, 3-vertex kinematic fit

- $\mu^+\mu^-$ constrained to J/ψ mass
- Trajectories constrained to appropriate topologies
- Reconstructed Ξ^-/Ω^- constrained to $\mu^+\mu^-$ vertex

Long life of the Ξ^- and Ω^- leaves hits in the silicon detector (unique to baryons)



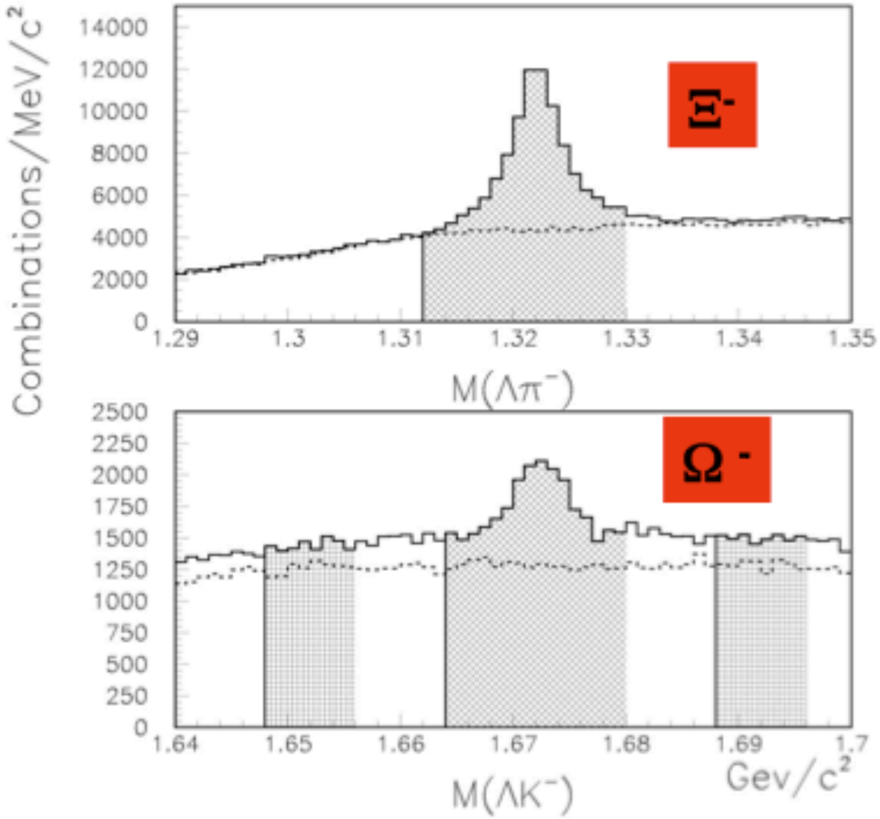
Inclusive Ξ^- and Ω^- samples

Base sample is given by

- $1.1077 < M(p\pi) < 1.1237$
- $P_T(\Xi/\Omega) > 2.0$
- Flight($\Lambda/\Xi^-/\Omega^-$) > 1 cm
- Impact(Ξ^-/Ω^-) < 3σ
- $P(\chi^2) > 10^{-4}$
- $P(\chi^2)_{used} > P(\chi^2)_{swapped}$
- Veto $1.311 < M(\Lambda\pi) < 1.331$ for ΛK sample (Ξ^- reflection)

Yields in the J/ψ sample:

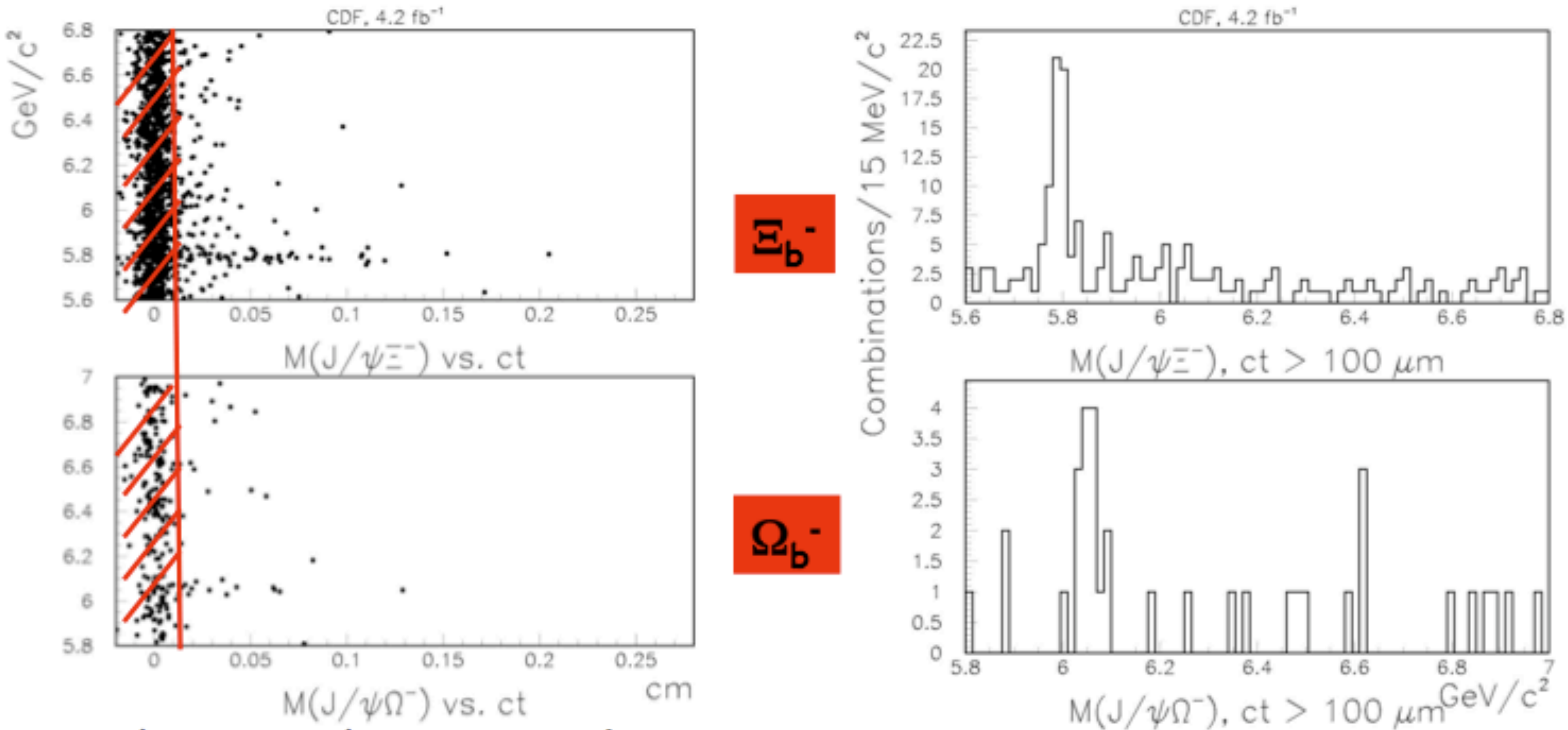
- Ξ^- : 41,000
- Ω^-: 3,500



Dashed histograms are WS $\Lambda\pi^+/K^+$

Shaded are selection and SB region

Ξ_b and Ω_b signals



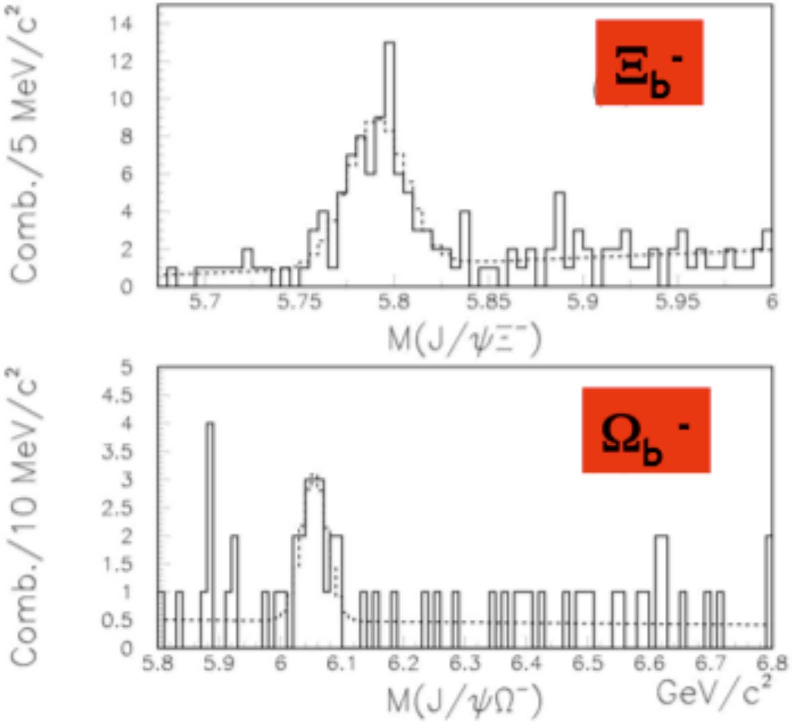
$J/\psi\Xi^-$, $J/\psi\ \Omega^-$ samples

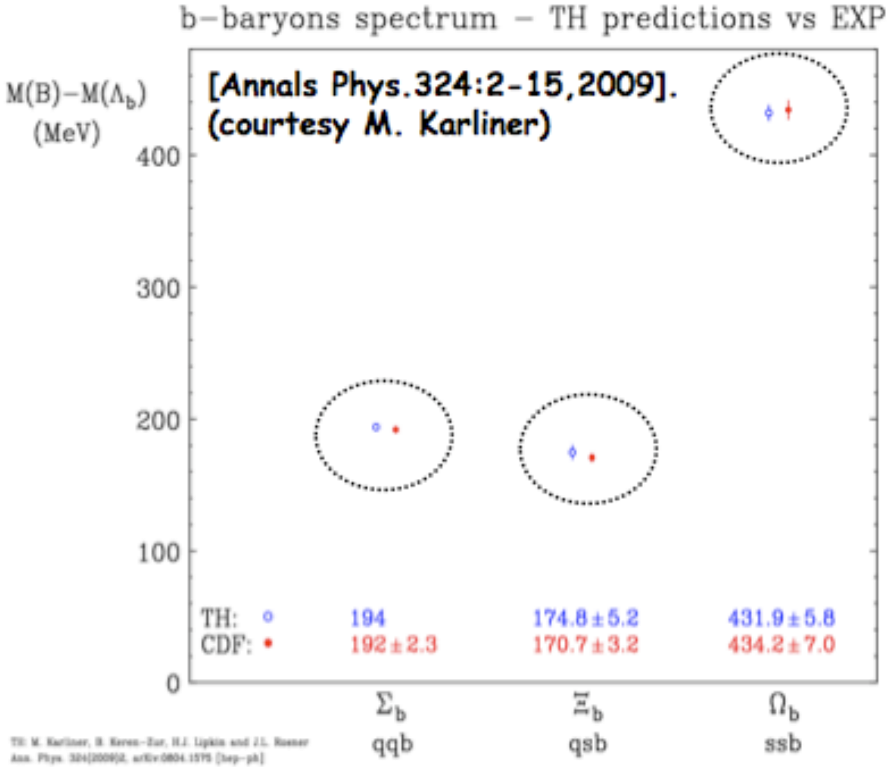
Obvious Ξ_b^- signal when **ct** > 100 μm

Cluster in the $J/\psi\ \Omega^-$ around 6.05 GeV/c²

Test of Ω_b^- significance finds 5.5σ (with no ct cut)

Ξ_b and Ω_b mass measurements





$m(\Xi_b^-)$: $5790.9 \pm 2.6(\text{stat.}) \pm 0.8(\text{syst.})$ MeV/c^2

$m(\Omega_b^-)$: $6054.4 \pm 6.8(\text{stat.}) \pm 0.9(\text{syst.})$ MeV/c^2

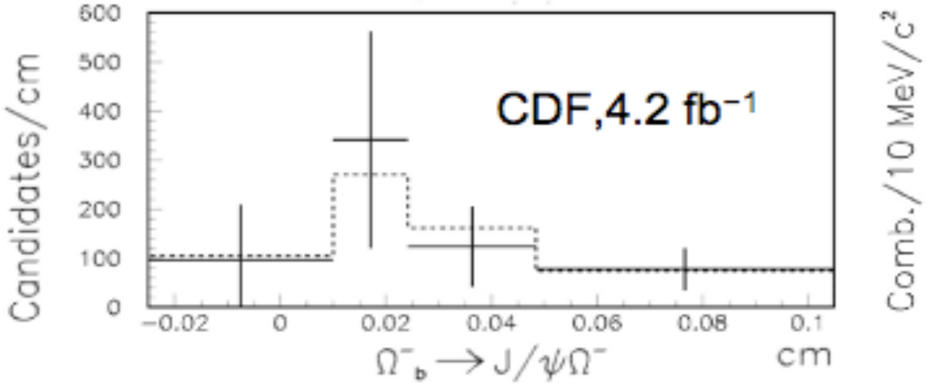
Systematic uncertainty

- 0.55 MeV from $B^0(K_s)$ error scale by 80% for kinetic energy in the decay
- 0.5 MeV from Λ_b resolution treatment (considered largest possible)
- 0.3 MeV from Ω^- mass

Ξ_b and Ω_b lifetimes and production rate

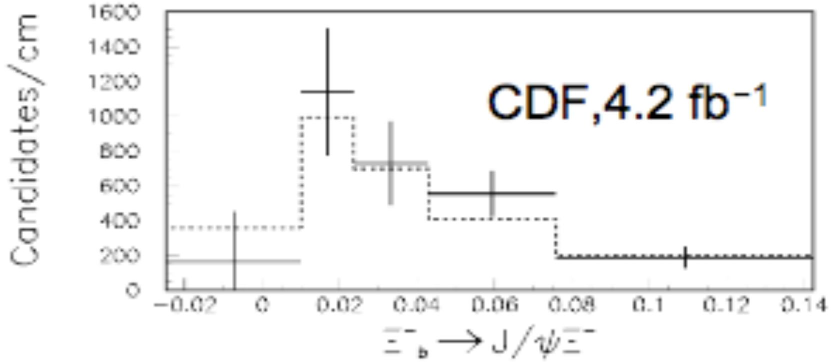
Lifetimes

Ω_b^-



$\tau(\Omega_b^-) = 1.13^{+0.53}_{-0.40}(\text{stat.}) \pm 0.02(\text{syst.})$ ps

Ξ_b^-



$\tau(\Xi_b^-) = 1.56^{+0.27}_{-0.25}(\text{stat.}) \pm 0.02(\text{syst.})$ ps

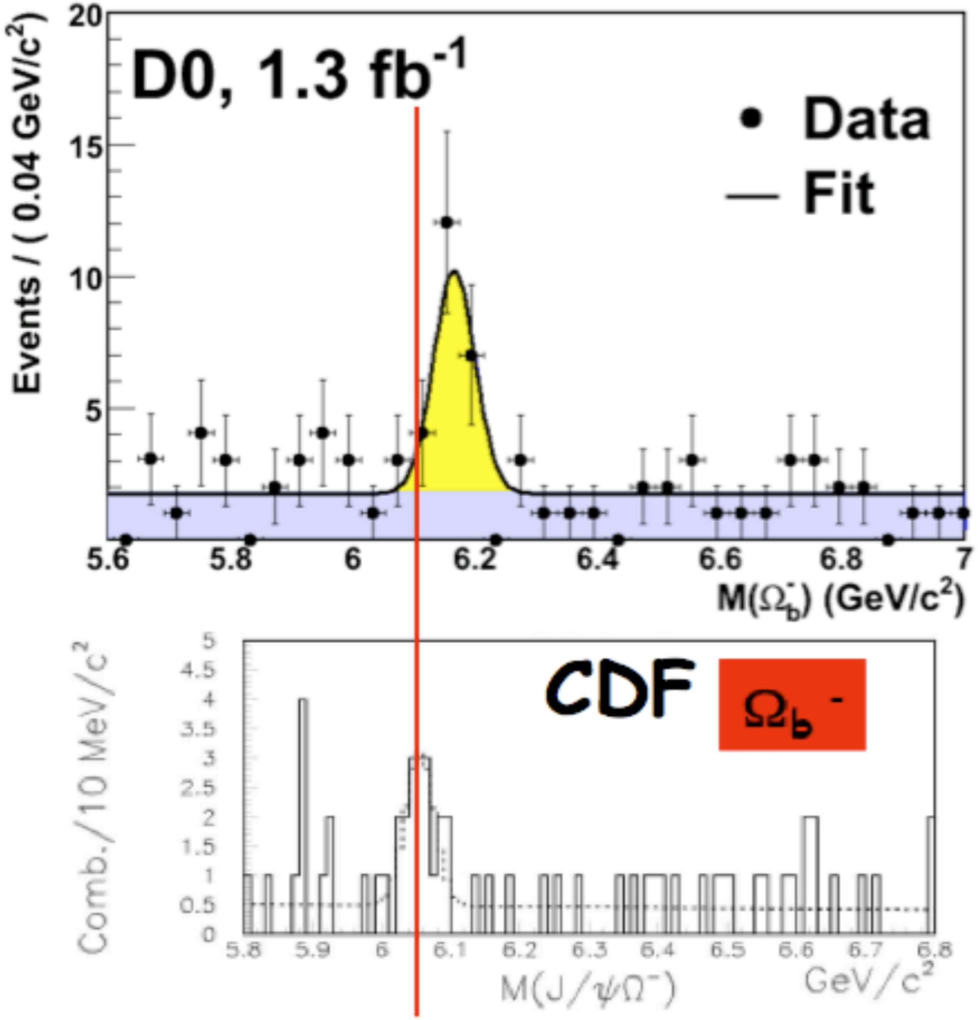
… and production rates relative to Λ_b

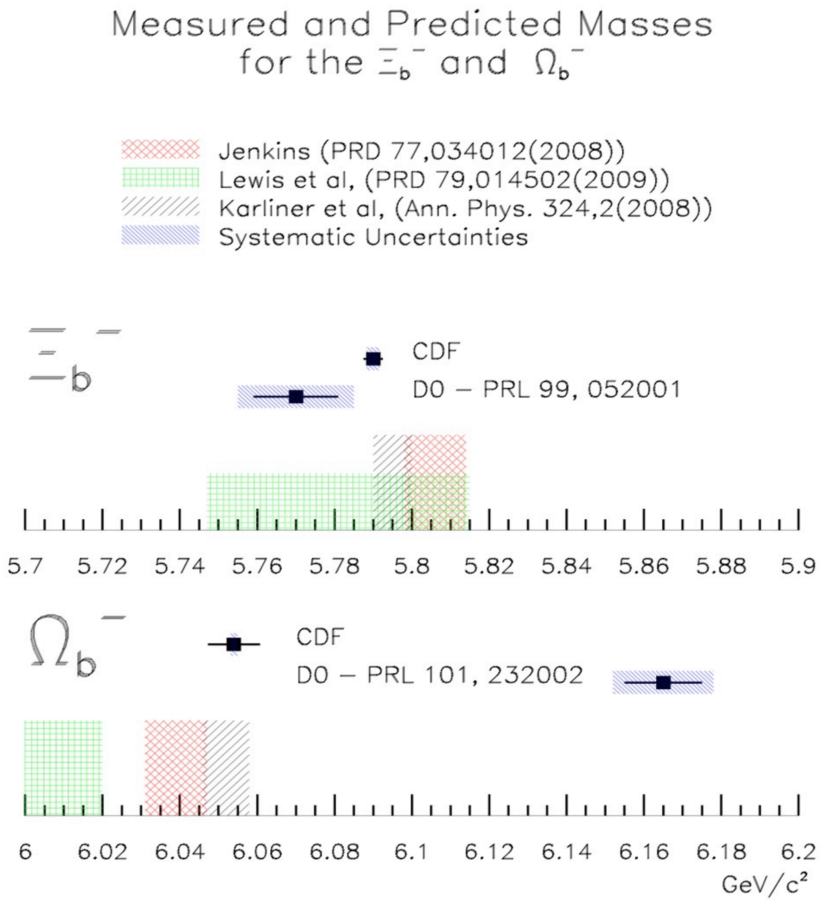
$$\frac{\sigma B(\Xi_b^- \to J/\psi\Xi^-)}{\sigma B(\Lambda_b \to J/\psi\Lambda)} = 0.167^{+0.037}_{-0.025} \pm 0.012$$

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

CDF : Phys.Rev. D80, 072003 (2009)

Comparison with D0

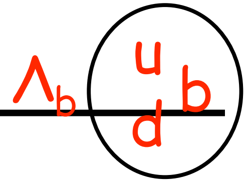




$m(\Omega_b^-)$: 6054.4 ± 6.8(stat.) ± 0.9(syst.) MeV/c^2

b – hadrons lifetimes

Λ_b Lifetime in $\Lambda_b \to \Lambda_c \pi$

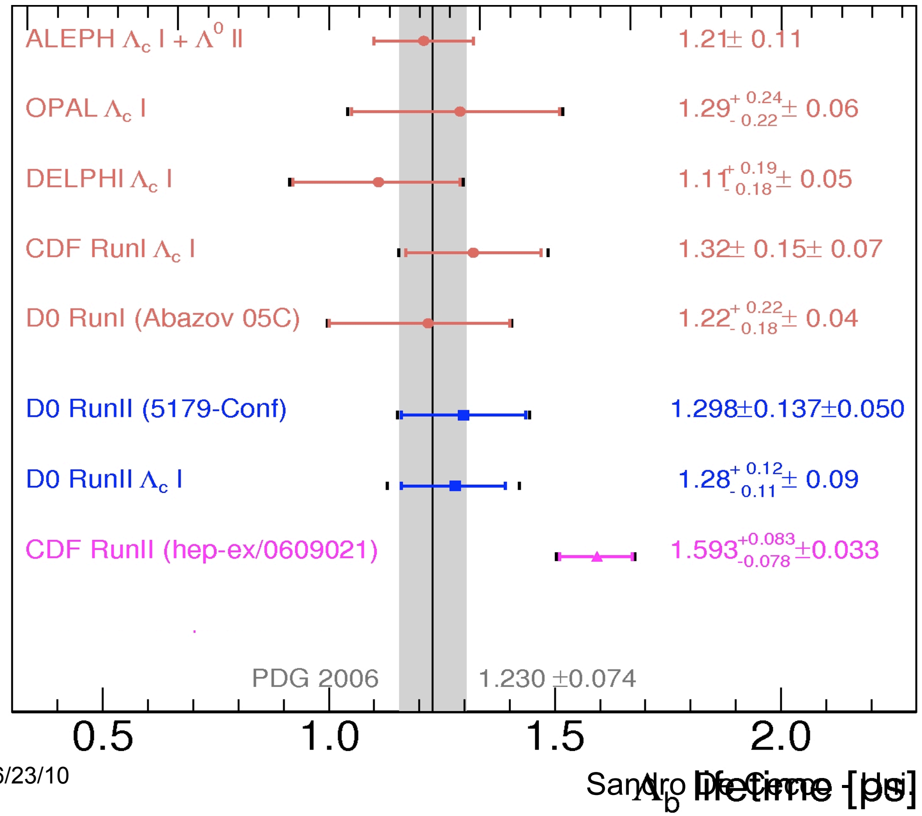


- Important test of models that describe interactions between heavy and light quarks within bound states
  - In simple spectator model all b-hadrons have same lifetime
  - Precise theoretical predictions difficult due to QCD effects
  - OPE/HQET predicts lifetime hierarchy of b-hadrons:

$$\tau(B_c) < \tau(\Lambda_b) < \tau(B_s) \approx \tau(B^0) < \tau(B^+)$$

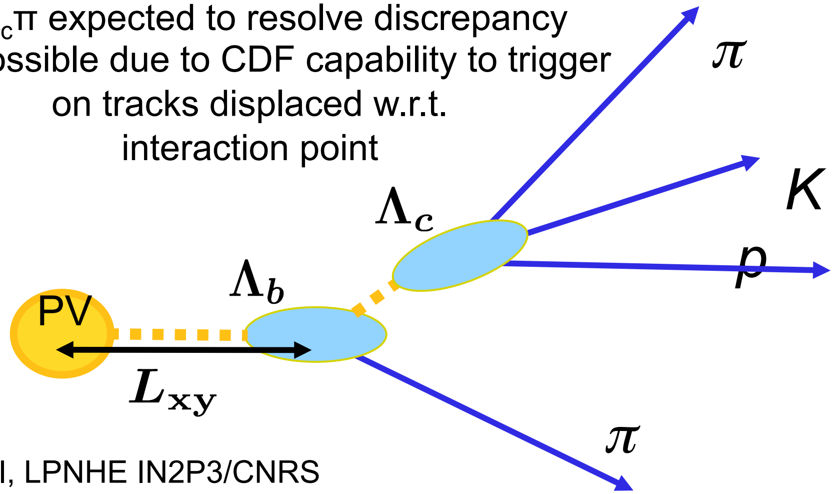
- Experimental status before this measurement

	$\frac{\tau(\Lambda_b)}{\tau(B^0)}$
Theory	0.88±0.05
Exp.	0.921±0.036



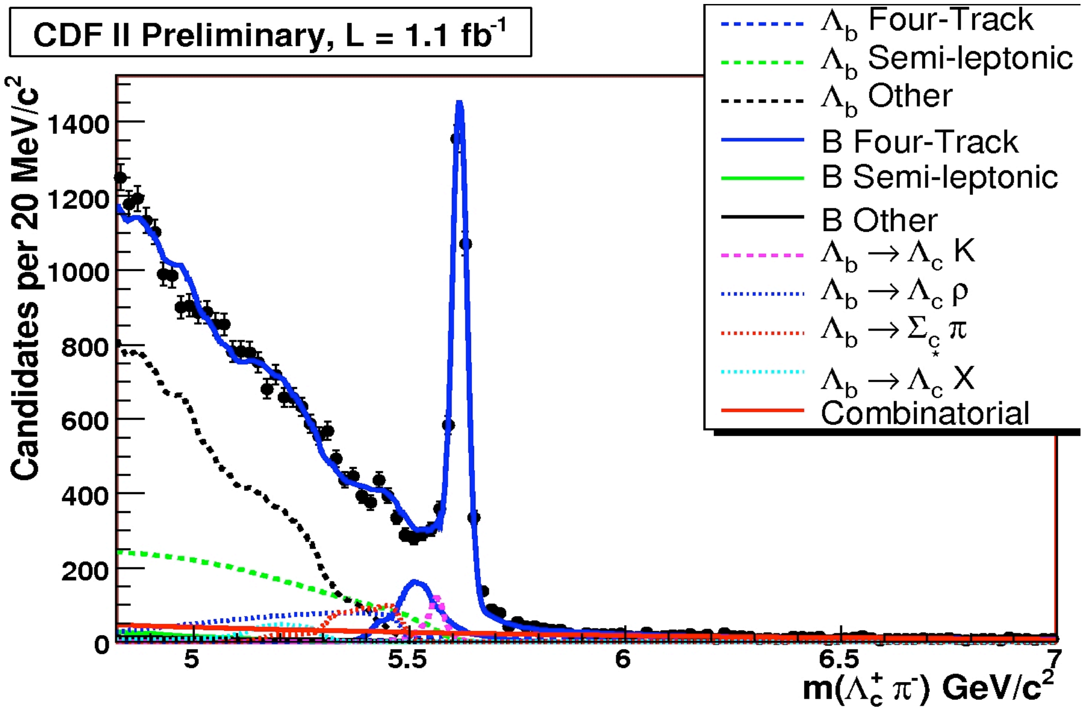
- Possible disagreement between CDF measurement in $\Lambda_b \to J/\Psi\, \Lambda$ and other experiments

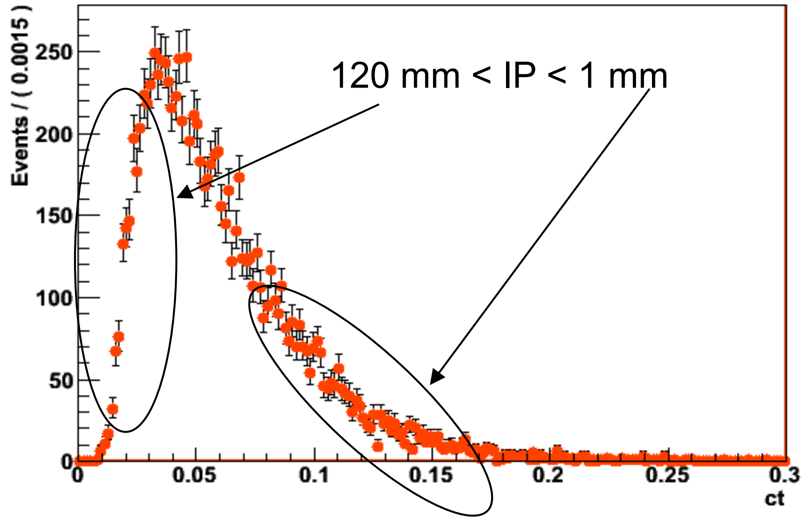
- New CDF measurement in fully hadronic $\Lambda_b \to \Lambda_c \pi$ expected to resolve discrepancy
  → possible due to CDF capability to trigger on tracks displaced w.r.t. interaction point



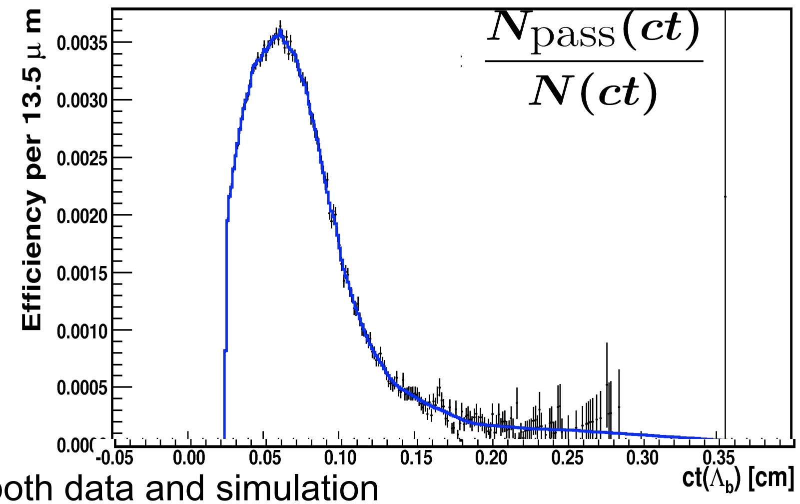
Λ_b Lifetime in $\Lambda_b \rightarrow \Lambda_c \pi$ biased lifetime distribution

- Large sample of ~3000 signal events in ~1.1 fb^{-1}
- Displaced track trigger requirements: 120 μm < IP < 1 mm
  → biased lifetime distribution
- Trigger and analysis cuts bias determined from simulation





trigger efficiency from simulation



- Trigger efficiency in unbiased J/Ψ→μμ sample determined in both data and simulation
  - find good agreement but still leads to largest systematic uncertainty of ~6 μm

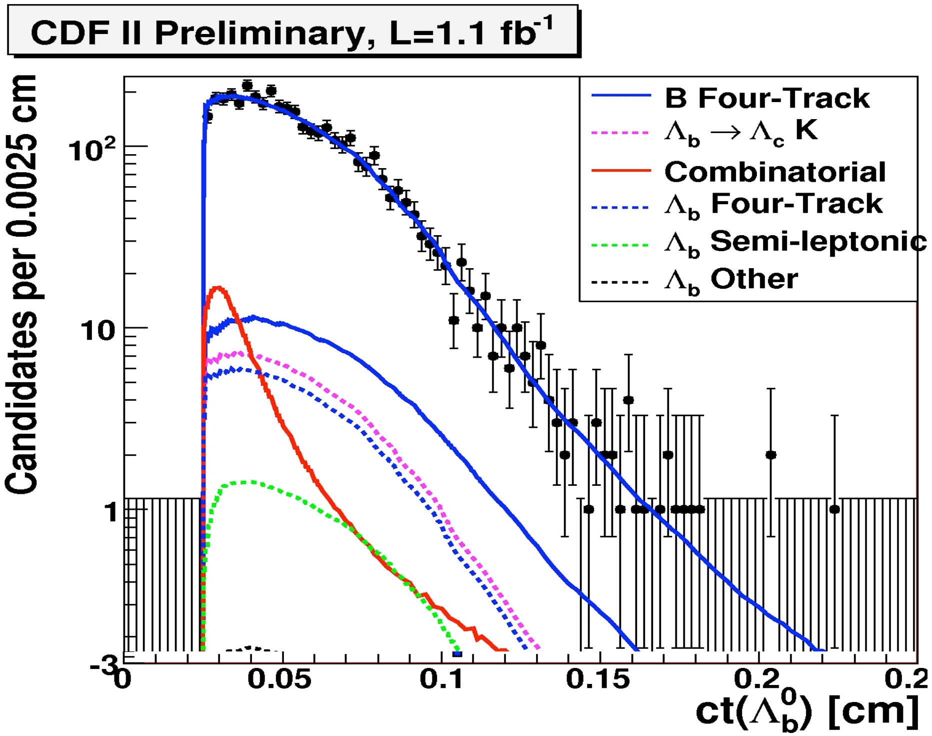
Λ_b Lifetime in $\Lambda_b \rightarrow \Lambda_c \pi$

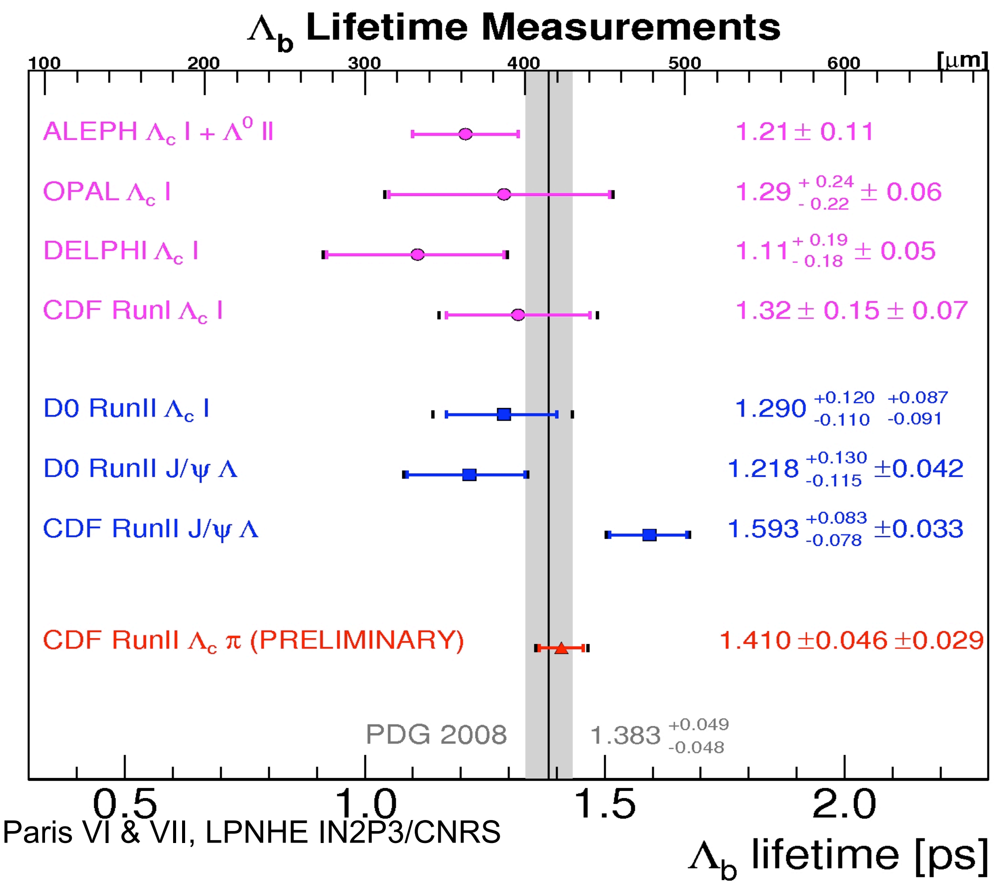
- Most precise Λ_b lifetime measurement: http://www-cdf.fnal.gov/physics/new/bottom/080703.blessed-lblcpi-ct/

$$c\tau(\Lambda_b) = 422.8 \pm 13.8\ \mu\text{m (stat.)} \pm 8.8\ \mu\text{m (syst.)}$$

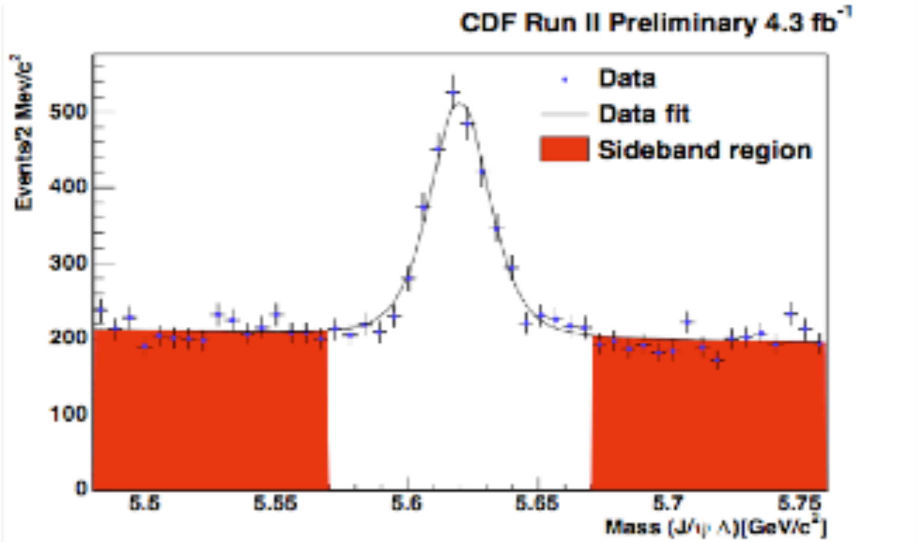
- Good agreement with theory prediction (0.88 ± 0.05 th ref…) $\dfrac{\tau(\Lambda_b)[\text{this}]}{\tau(B^0)[\text{PDG}]} = 0.922 \pm 0.039$

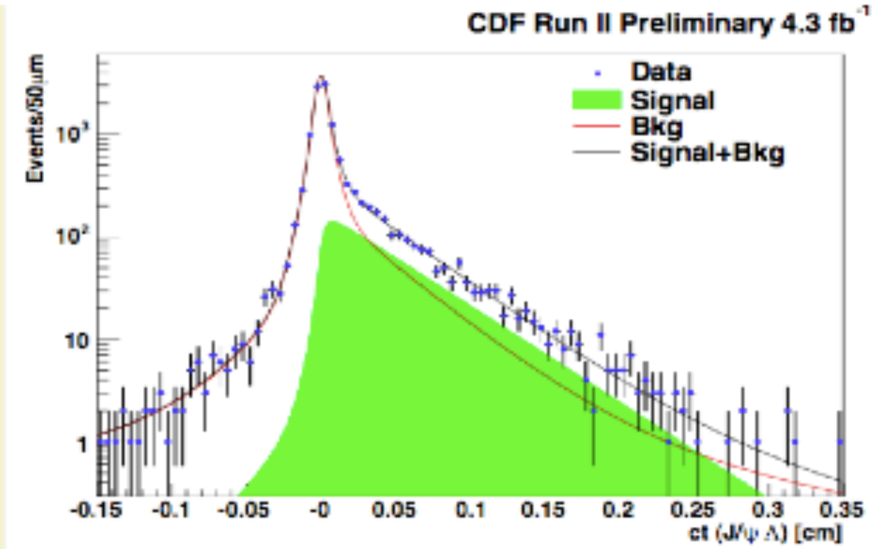
- and with previous world average

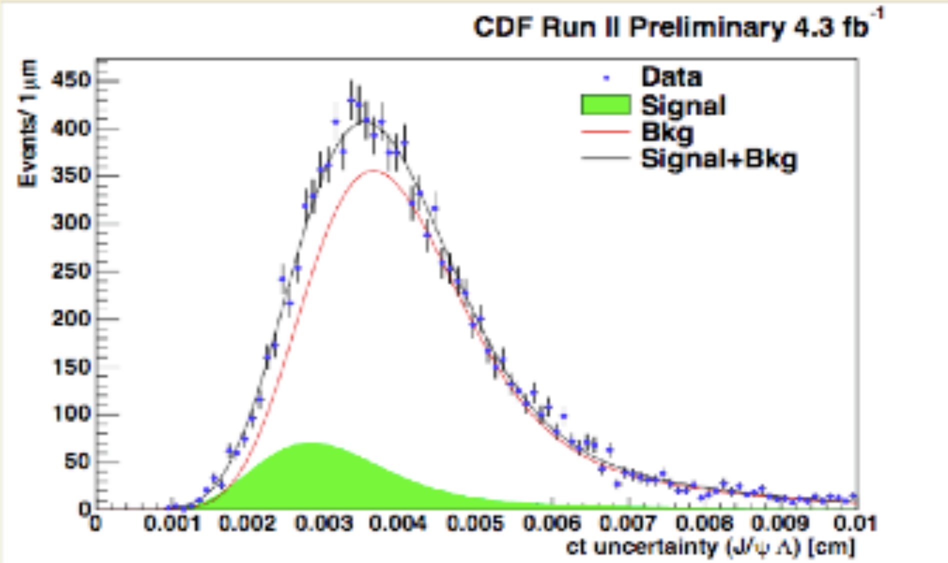




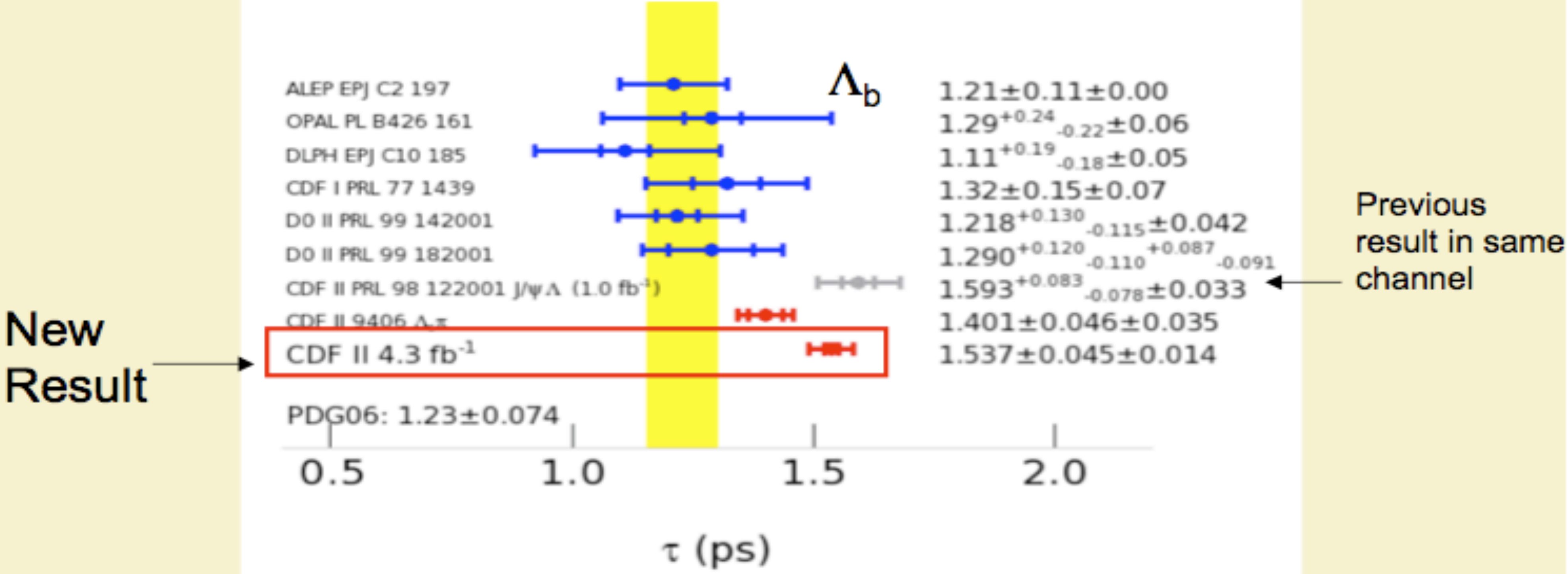
New $\Lambda_b \rightarrow J/\Psi\phi$ lifetime measurement







Λ_b lifetime results



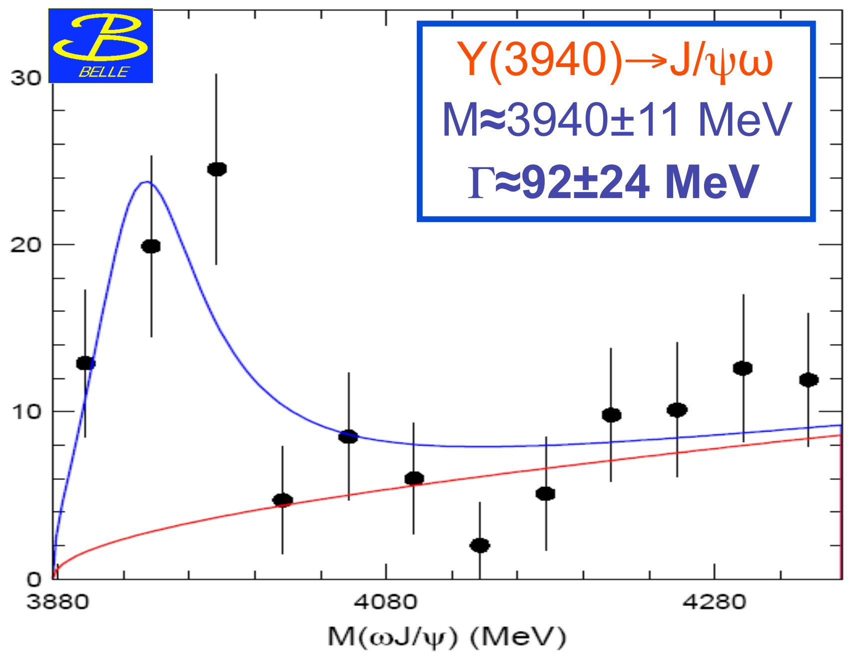
Most precise Λ_b lifetime measurement

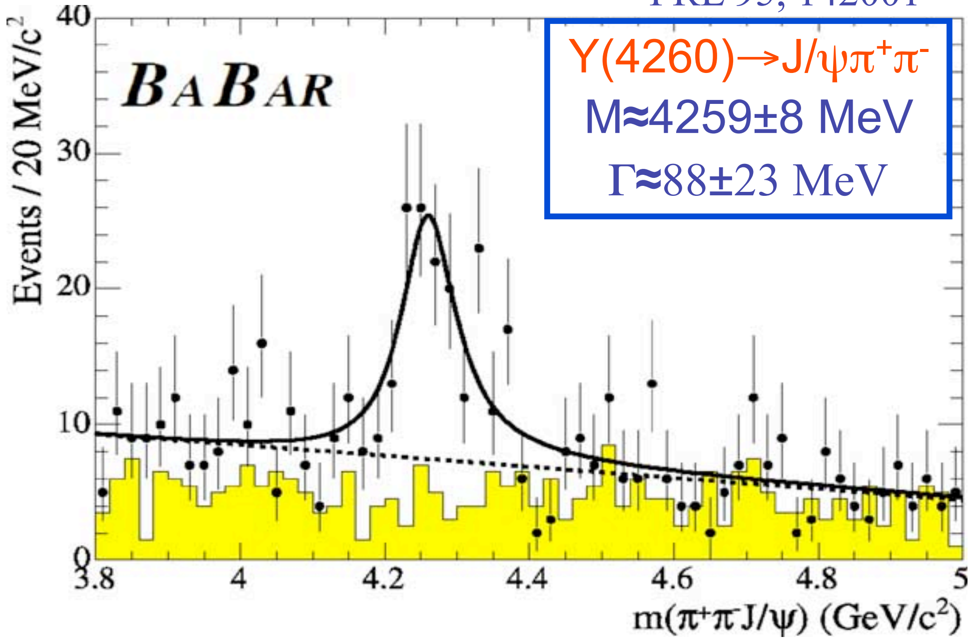
With 4.3 fb^{-1} the Λ_b lifetime remains higher in comparison to other measurements.

Measured Ratio: $\tau(\Lambda_b)/\tau(B_d) = 1.020\pm0.030(\text{stat})\pm0.008(\text{syst})$
Theory: $\tau(\Lambda_b)/\tau(B_d) = 0.88\pm0.05$, although there are theories that favor a higher ratio 0.9-1.0

Charmonium-like resonances

$Y(3940) \rightarrow J/\psi\omega$, $Y(4260) \rightarrow J\psi\pi^+\pi^-$--2005



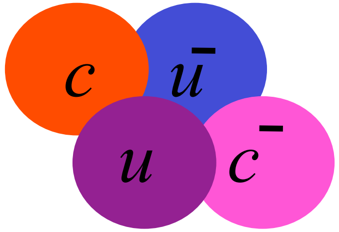


Above $D\bar{D}$ && $D\bar{D}^*$ threshold,
tiny Branching Fraction expected
New mass and width from BaBar:
$M \approx 3914^{+3.8}_{-3.4} \pm 2.0$, $\Gamma \approx 34^{+12}_{-8} \pm 5$ MeV
at the $J/\psi\omega$ threshold ?

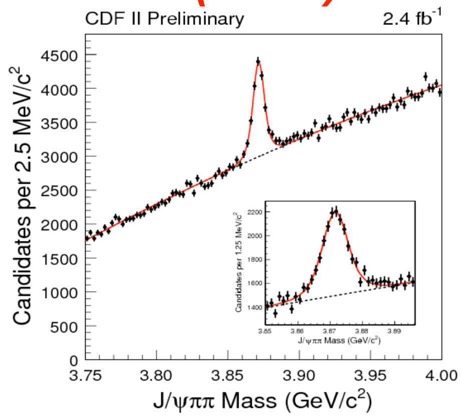
Well above $D\bar{D}$ && $D\bar{D}^*$ threshold,
tiny Branching Fraction expected
$J^{PC}=1^{--}$, plus Y(4350), Y(4660)
too many 1^{--} ?

Exotic Mesons(?) — QCD predictions

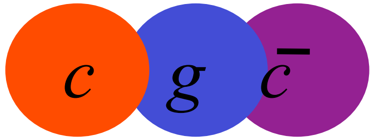
- *Multi-quark mesons*
  molecule, diquark-antidiquark



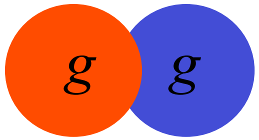
X(3872)



- *Hybrid mesons*
  quark-antiquark-gluon



- *Glueball*
  gluonic color singlet states



Explore more channels to understand

How about **J/ψφ?** *(threshold @4.116 GeV, VV, C=+)*
($c\bar{c}$) with a mass above 4.116 GeV, expect tiny branching fraction

Charmonium hybrid → $J/\psi\phi$?

J^{PC}	Open charm	Hidden charm
0^{+-}	Quantum numbers forbid $D^{(*)}D^{(*)}$	$J/\psi\{f_{\{0,1,2\}},(\pi\pi)_S\}$ $h_c\eta;\ \eta_c h_1$ $\chi_{c0}\omega$ $\chi_{c\{1,2\}}\{\omega,h_1,\gamma\}$
0^{--}	D^*D	$h_c(\pi\pi)_S$ $J/\psi\{f_{\{1,2\}},\eta^{(\prime)}\}$ $\chi_{c0}h_1;\ \eta_c\{\omega,\phi\}$ $\chi_{c\{1,2\}}\{\omega,h_1,\gamma\}$
1^{-+}	$D^*D,\ D^*D^*$	$\chi_{c\{0,1,2\}}(\pi\pi)_S$ $\eta_c\{f_{\{1,2\}},\eta^{(\prime)}\}$ $\chi_{c\{1,2\}}\eta$ $\{h_c,\underline{J/\psi}\}\{\omega,h_1,\underline{\phi},\gamma\}$
2^{+-}	$D^*D,\ D^*D^*$	$\{h_c,J/\psi\}\{f_{\{0,1,2\}},(\pi\pi)_S\}$ $\{h_c,J/\psi\}\eta^{(\prime)}$ $\{\eta_c,\chi_{c\{0,1,2\}}\}\{\omega,h_1,\phi,\gamma\}$

← PRD 57, 5653 (1998)
F. Close et al

accessible

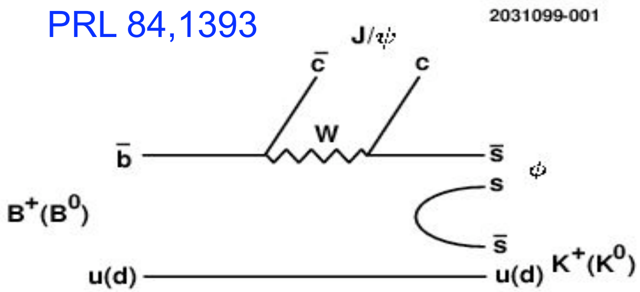
$J/\psi\phi$ is also accessible to 0^{-+}, 2^{-+}

(0^{-+}, 1^{-+}, 2^{-+}) masses are expected near Y(4260), E. Eichten

Search structures→J/ψφ through B decays

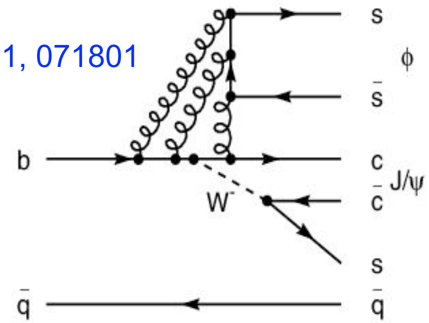
- Experimentally easy to search through clean B→J/ψφK channel
  - -- taking advantage of B lifetime and narrow B mass window
  - -- B➔J/ψφK is OZI suppressed, so low physics background

PRL 84,1393

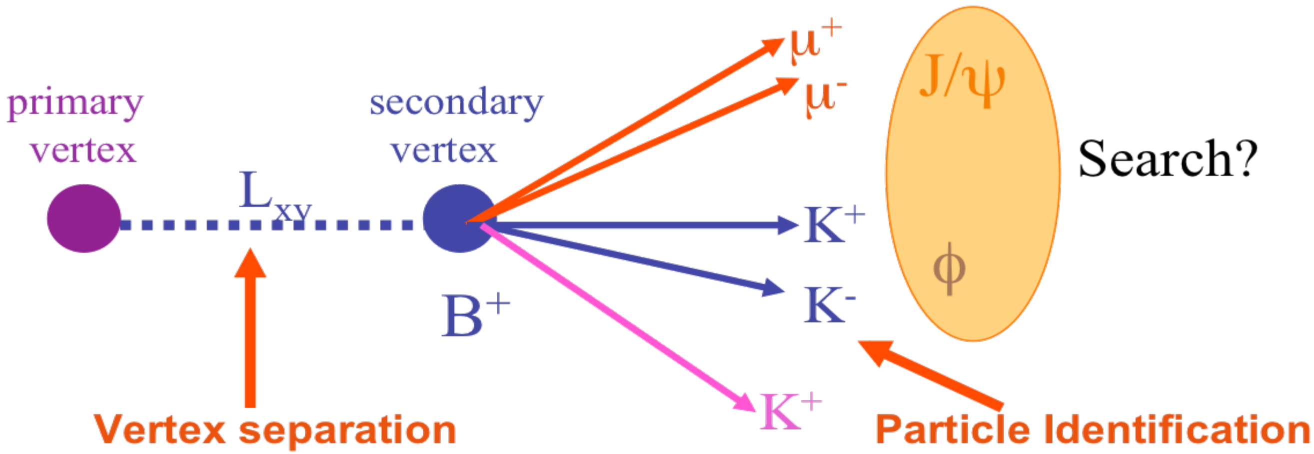


vacuum polarization

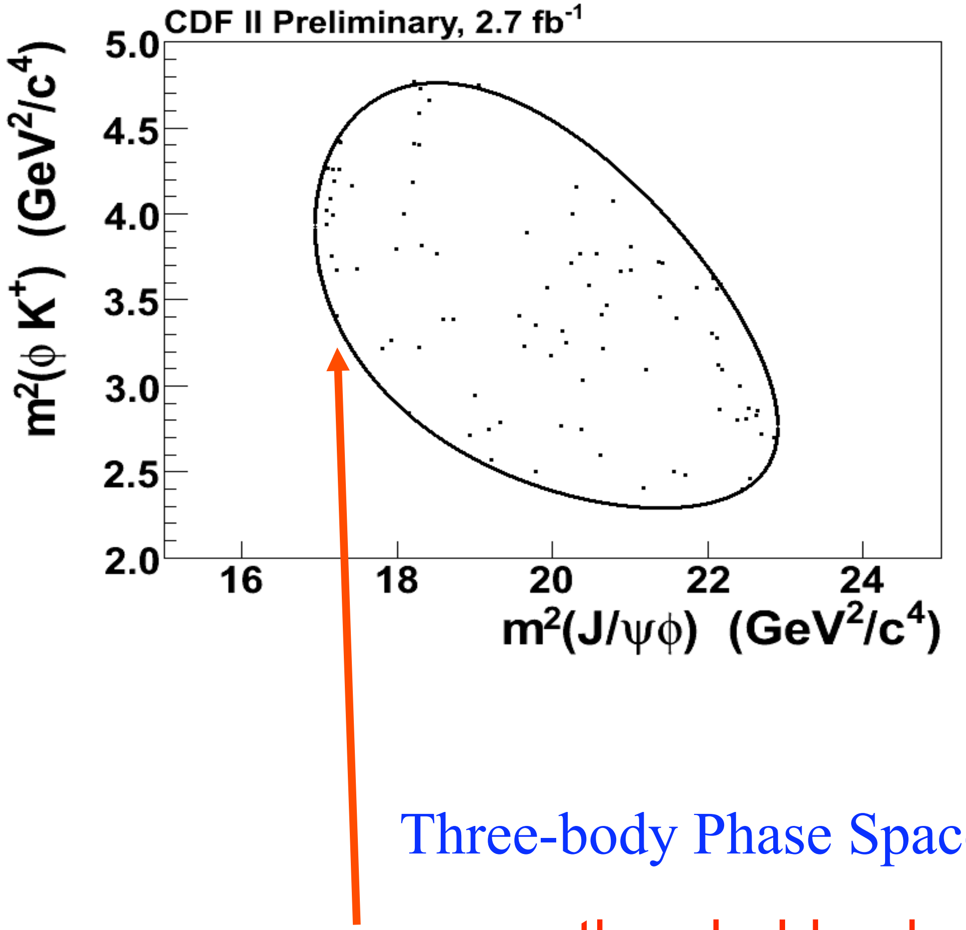
PRL 91, 071801



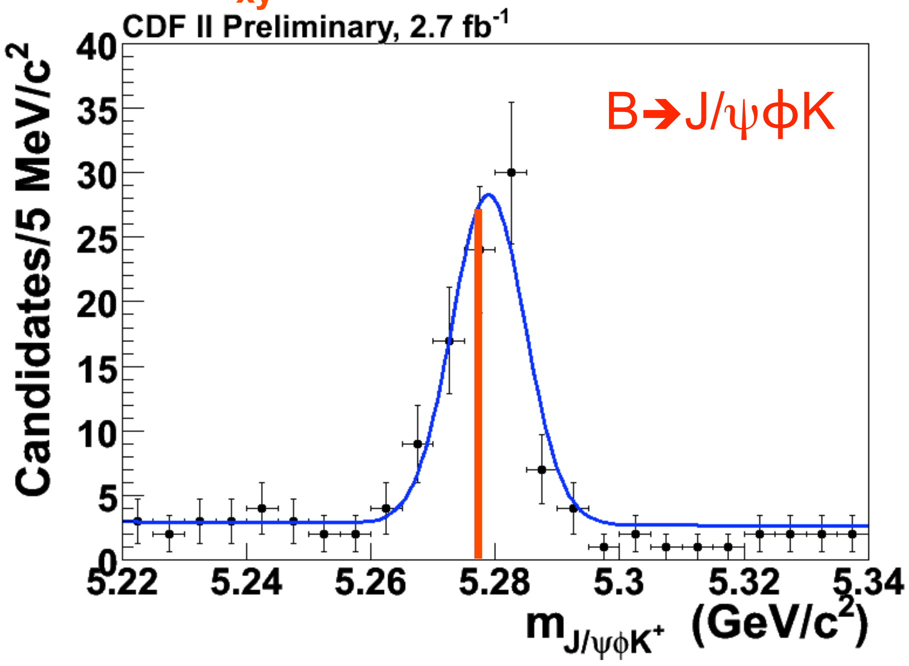
gluon coupling



Search for structures in J/ψφ mass--Data



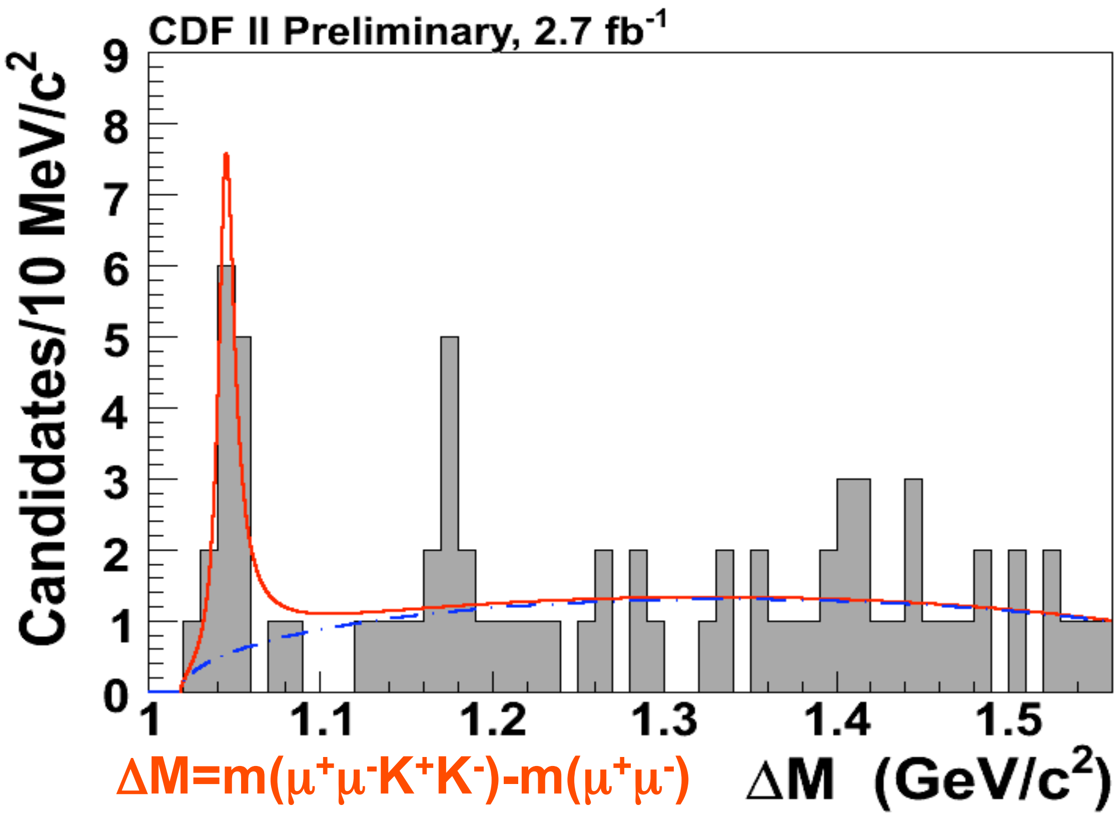
After L_{xy}>500 um, kaon LLR>0.2



Three-body Phase Space Background shape is used

a near threshold enhancement is observed in the Dalitz

Search for structures in $J/\psi\phi$ mass--Data



- **Results including systematics:**

  Yield = **14±5**

  Δm = **1046.3± 2.9 (stat)± 1.2 (syst) MeV/c^2**

  Mass = **4143.0 ± 2.9 (stat)± 1.2 (syst) MeV/c^2**

  Width = **11.7 $^{+8.3}_{-5.0}$ (stat) ± 3.7(syst) MeV/c^2**

(Convoluted with resolution of 1.7 MeV)

Width indicates a strong decay

Tentatively named: Y(4140)

$\sqrt{(-2\log(L_{max}/L_0))} = 5.3$, need Toy MC to determine significance for low statistics

Significance: at least 3.8σ for most unphysical conservative background

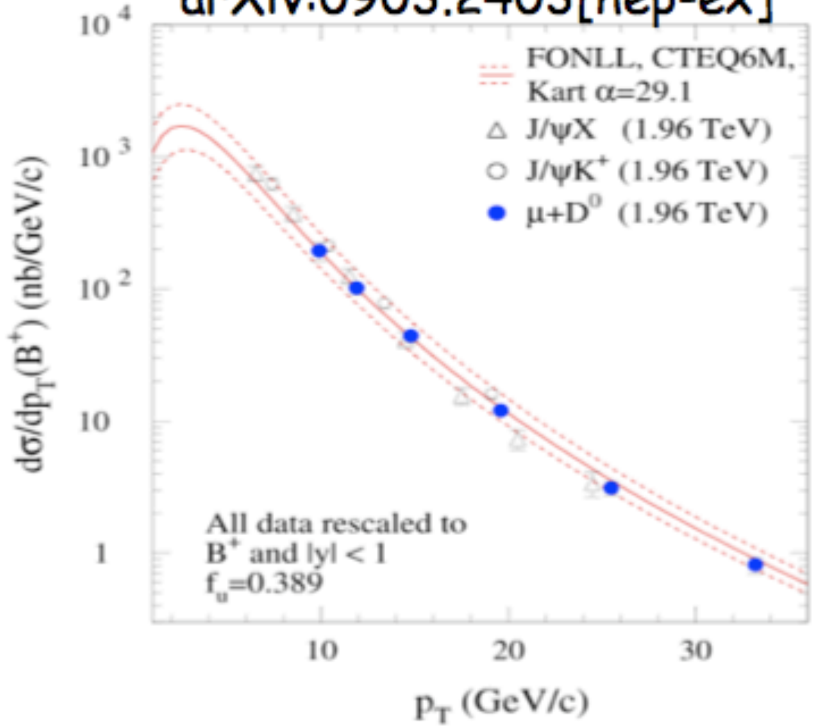
Summary:

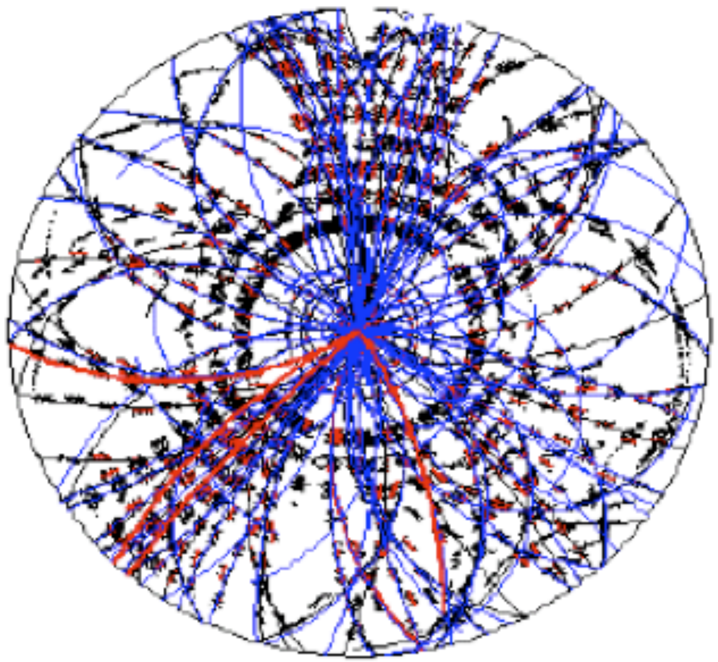
- Pioneering b-Baryons properties (Ξ_b , Ω_b) studies.
- b-hadrons lifetimes toward very high precision measurement, constraining theory predictions. The Λ_b shows some discrepancy.
- Evidence for Y(4140) state, other states?
- Many updates ongoing with 5 fb^{-1} data
- Still more (unexpected?) to come with full Tevatron statistics

Backup

Heavy Flavor production at Tevatron

arXiv:0903.2403[hep-ex]



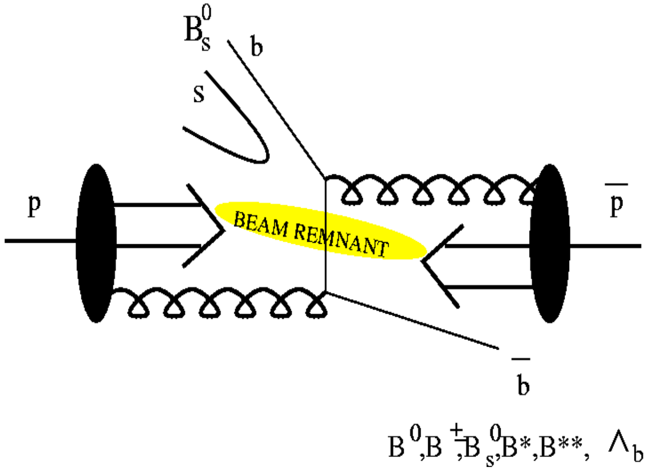


At Tevatron, b production cross section is much larger compared to B factories
→ CDF is enjoying a very rich B Physics program

Plethora of states accessible at Tevatron (B_d, B_u, B_s, Λ_b, Ξ_b, Σ_b, Ω_b)
→ Complement the B factories physics program

Total inelastic cross section at Tevatron is ~1000 larger than b cross section
→ Large backgrounds suppressed by triggers that target specific decays

B Physics at Collider



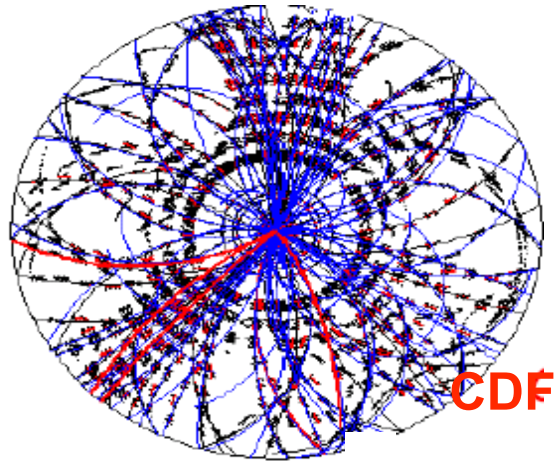
- All *B* species produced:

  $B_u, B_d, B_s, B_c, \Lambda_b, \Xi_b \ldots$

- With production fractions:

  $f_u : f_d : f_s : f_\Lambda \approx 4 : 4 : 1 : 1$

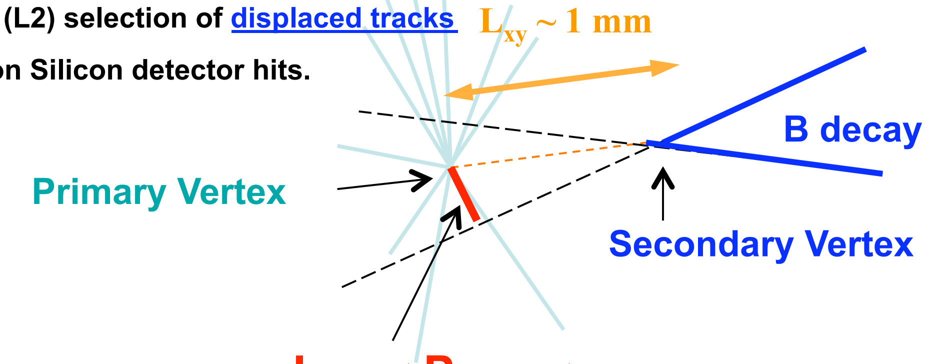
- Acceptance for other B is 20-40%

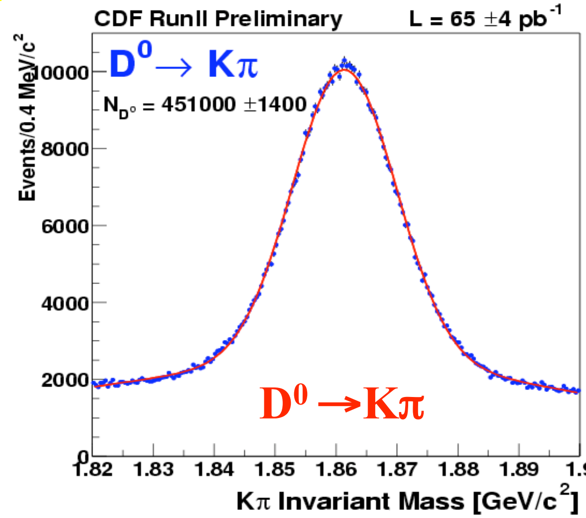


BUT: $\sigma(bb) << \sigma(pp)$ (~65 mb) $\Rightarrow$ B have to be selected with specific Triggers

the CDF **Secondary Vertex Trigger SVT**

- **Online (L2) selection of displaced tracks based on Silicon detector hits.**



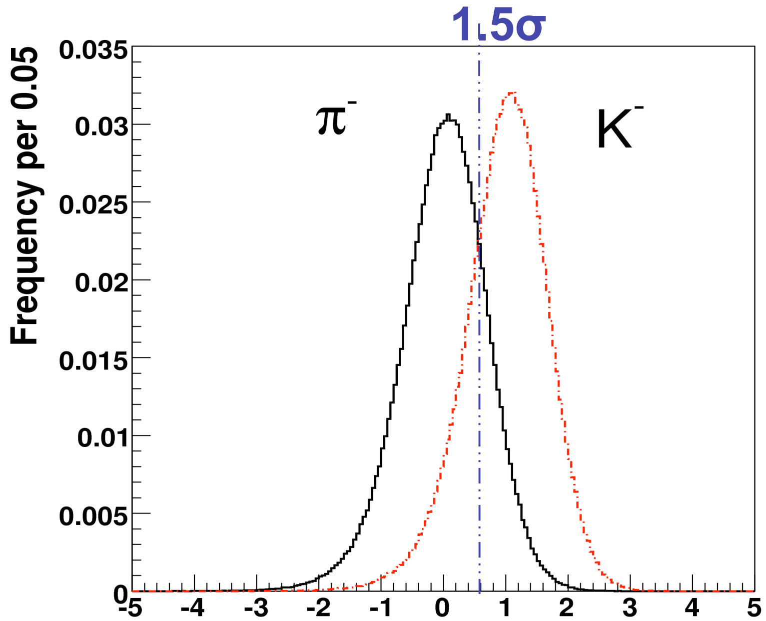


- b production is very large (~300 Hz @ 10^{32} cm^{-2} Hz) → trigger on specific decays

CDF hadron PID

Main background: prompt pions, need PID to suppress

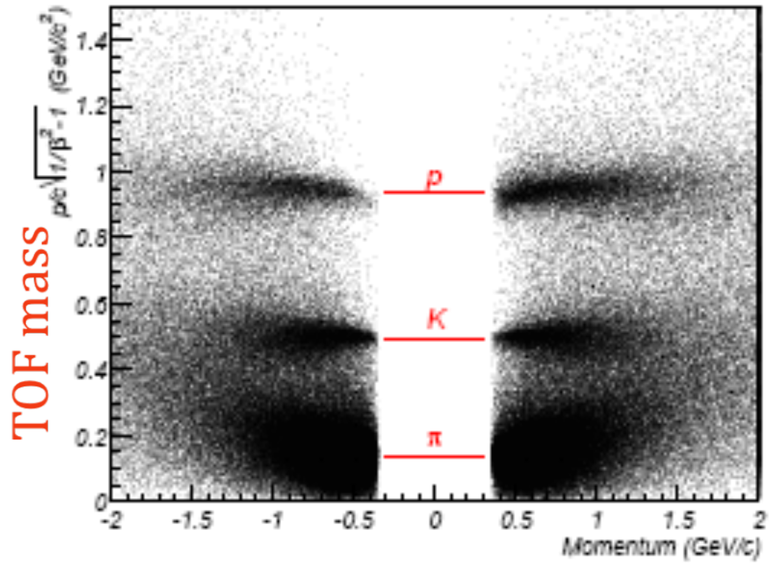
dEdx residual



dE/dx parameterized using $D^{*+(-)} \to D^0\pi^{+(-)}$ sample

dE/dx efficiency ~100%

CDF Time-of-flight: Tevatron store 860-12/23/2001

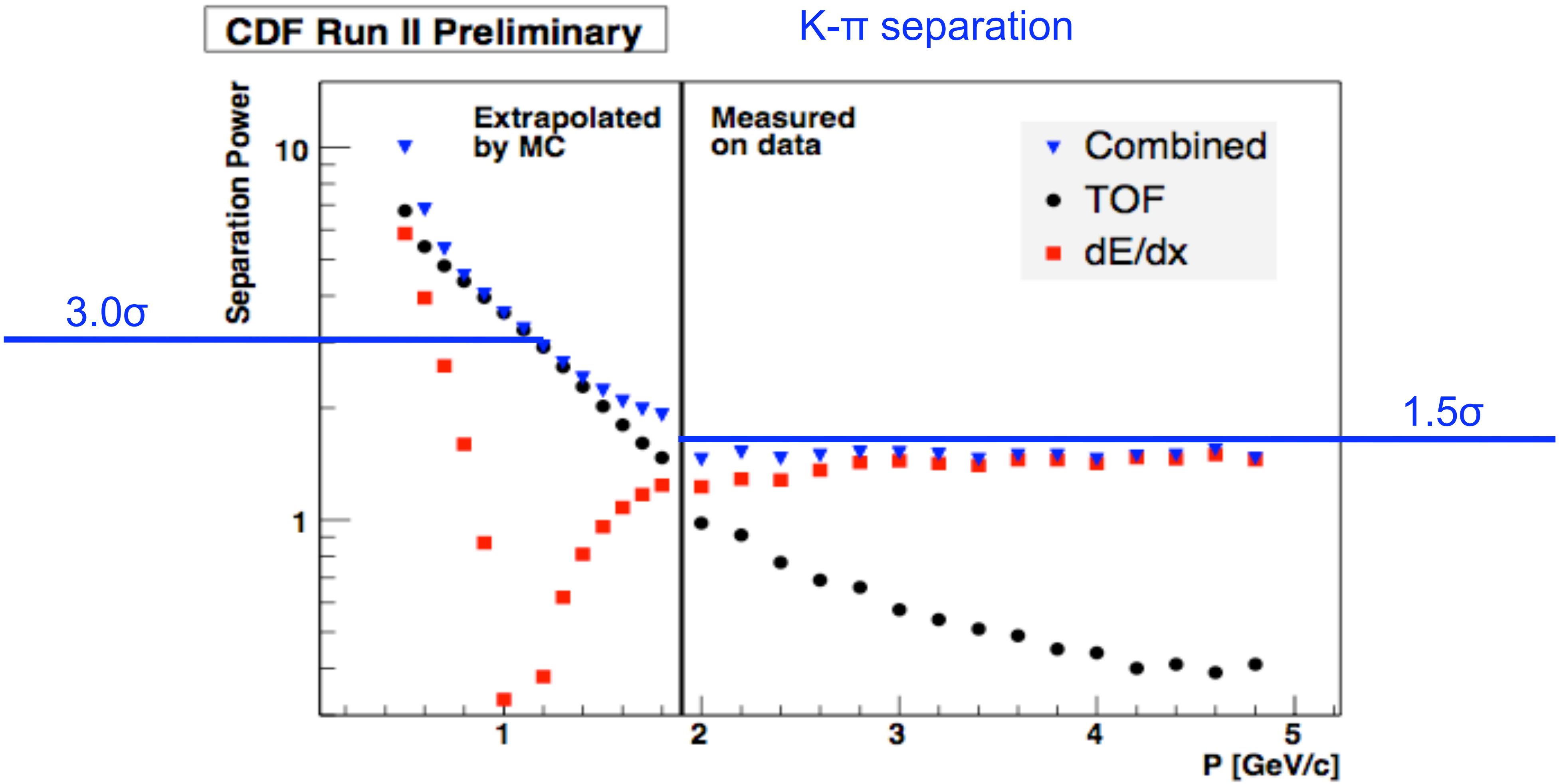


Excellent resolution

Time-of-Flight acceptance+efficiency ~60%

Make use of both dEdx and ToF for hadron PID
summarizing dEdx and ToF into a log-likelihood ratio

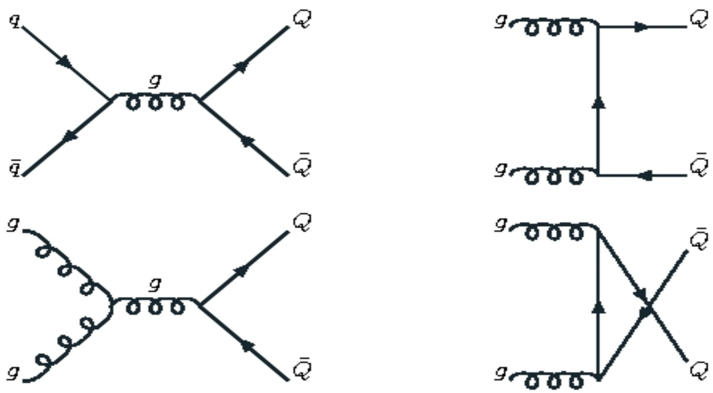
CDF hadron PID



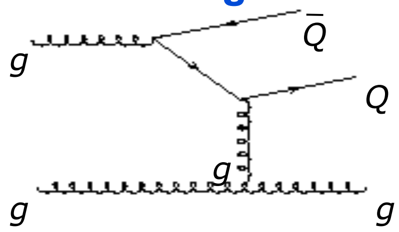
Typical B decay daughter momentum ~GeV

bb pairs production in hadronic collisions

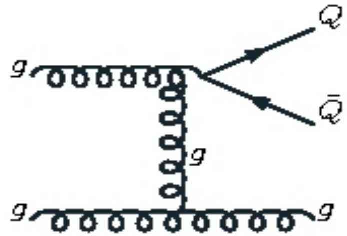
Leading Order and Next to Leading Order



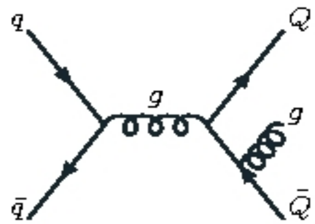
Flavor creation



Flavor excitation



Gluon splitting



and … radiative corrections

… but: b/c-jets or B/D hadrons are the observables rather than b/c-quark

<u>*Observed*</u>

Proton structure

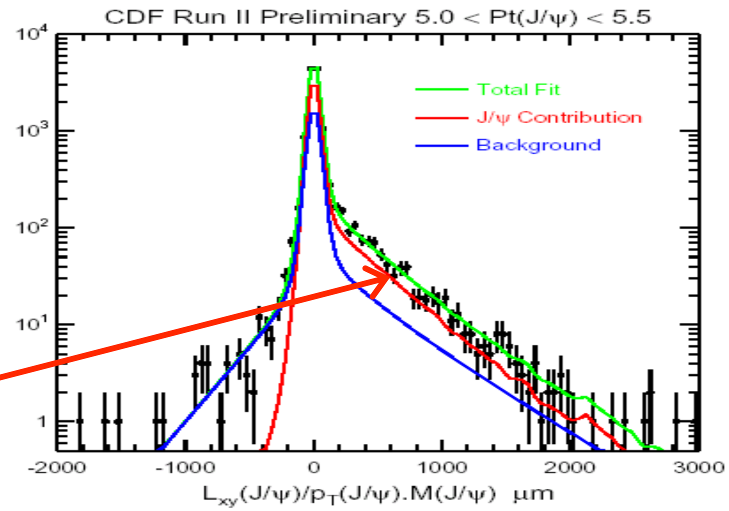
$$\frac{d\sigma\left(p\bar{p} \rightarrow B/DX\right)}{d\,p_T\left(B/D\right)} = \underbrace{\frac{d\sigma\left(q\bar{q}/gg/qg \rightarrow b/cX\right)}{d\,p_T\left(b/c\right)}}_{\text{NLO QCD}} \otimes F^{p\bar{p}} \otimes D^{b/c \rightarrow B/D}$$

Fragmentation

Factorizes into a calculable part and a non-calculable but universal piece

Inclusive b cross section - low P_T

- Run I: b cross-section ~ 3x old NLO QCD
- Theoretical approaches: Next-to-Leading-log resummations, non perturbative fragmentation function from LEP, new factorization schemes…
- **Experimentally: unbinned maximum likelihood fit to the J/ψ decay time in the R-φ plane to extract the b fraction**

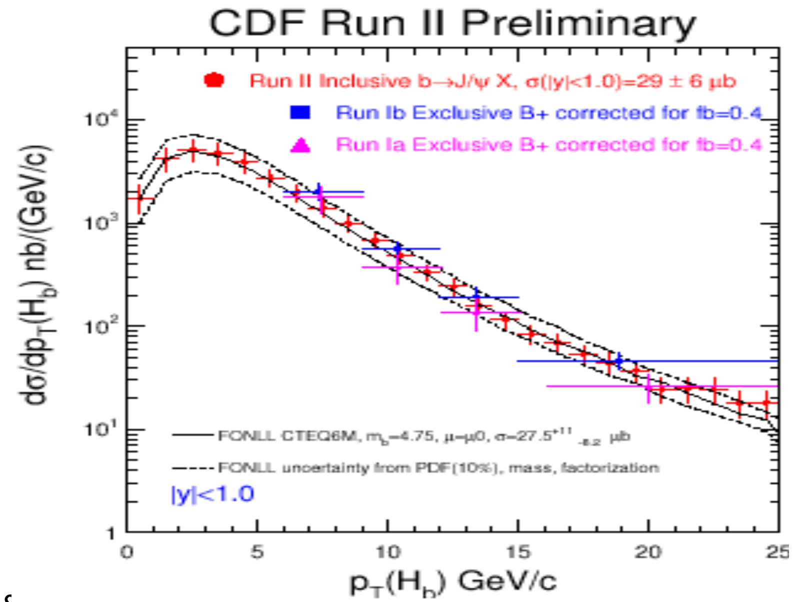


Run II: **Bottom Quark Production cross-section:**

$$\sigma(p\bar{p} \to bX)\big|_{|y|<1.0} = (29.4 \pm 0.6(stat) \pm 6.2(sys))\ \mu b$$

PRD 71, 032001 (2005)

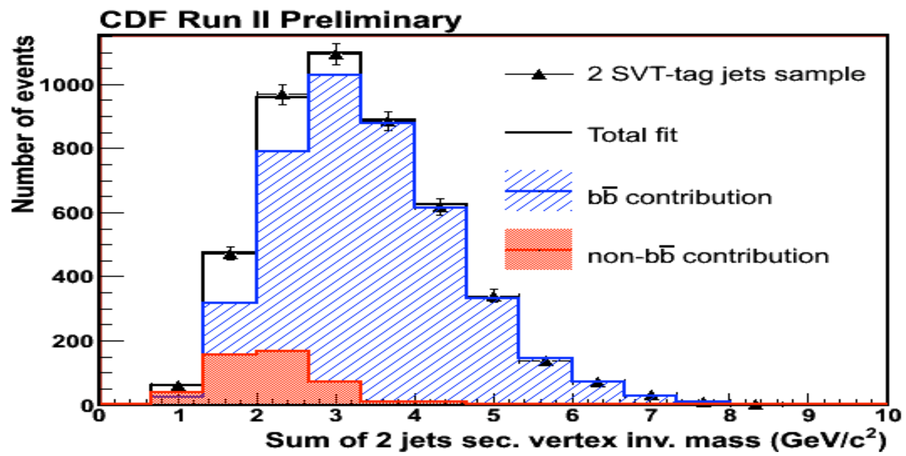
Good agreement →



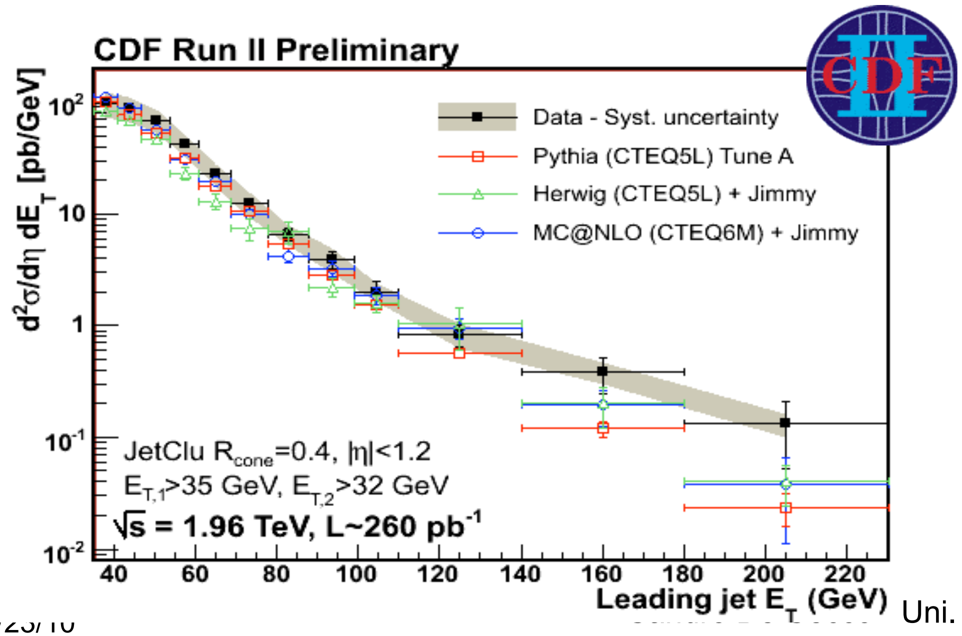
FONLL $\sigma(p\bar{p} \to bX)\big|_{|y|<1.0} = (27.5^{+11}_{-8.2})\ \mu b$

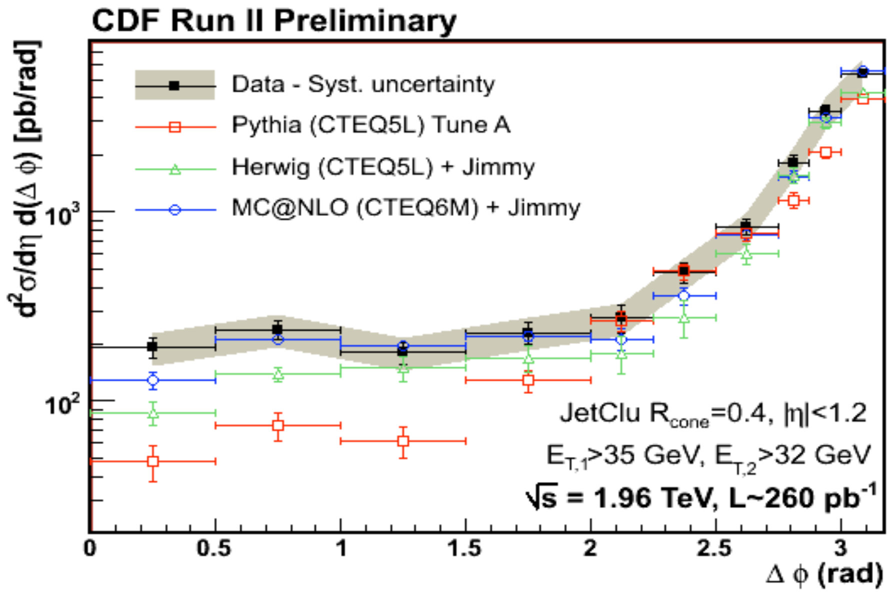
Inclusive bb di-jets production

- Specific Trigger based on L2 SVT (Secondary Vertex Trigger) used.
- Sensitive to the different production mechanisms
  - Flavor creation at high $\Delta\phi$
  - Flavor excitation or gluon splitting at low $\Delta\phi$



Purity ~ 85 % : extracted from data using shape of secondary vertex mass

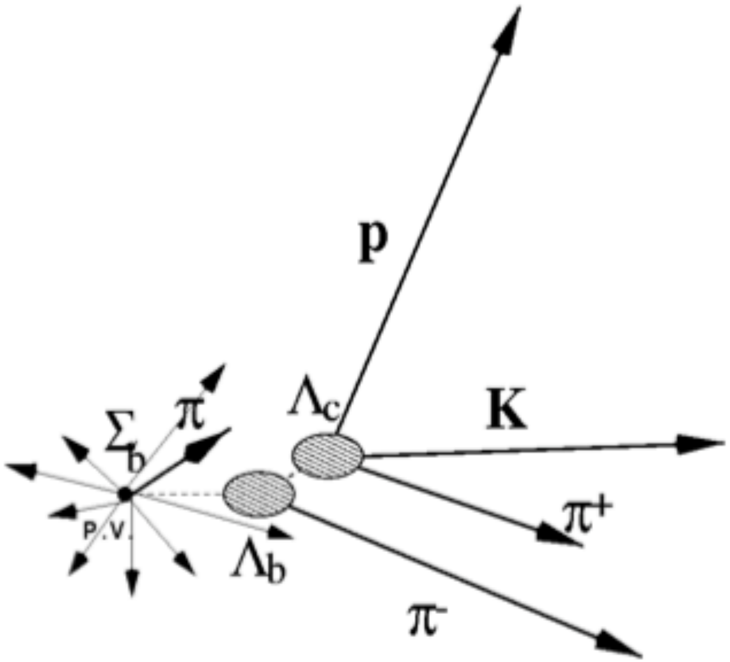


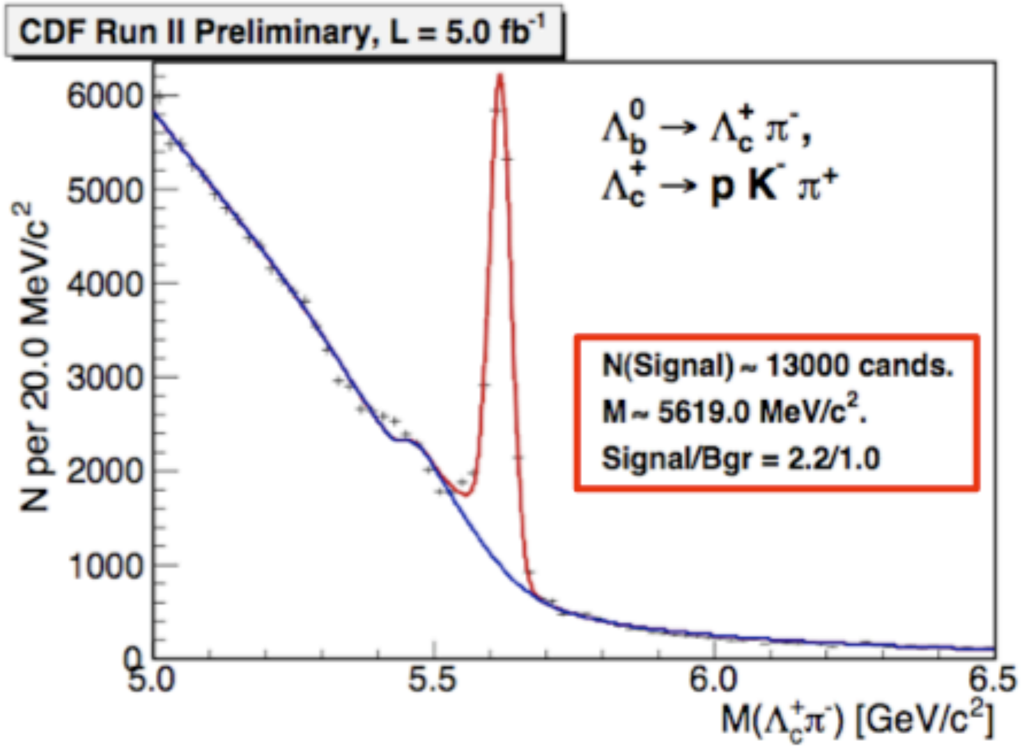


Updated analysis of $\Sigma_b^{\pm *}$ to 5 fb^{-1}

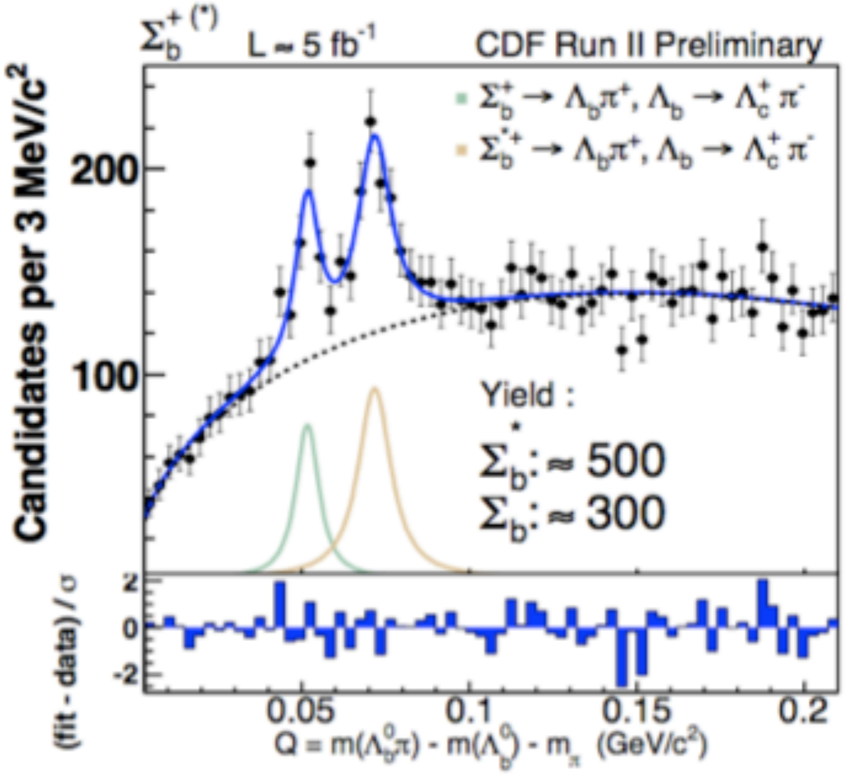
$\Sigma_b^{-(*)} \rightarrow \Lambda^0_b \pi^-$
$\Lambda^0_b \rightarrow \Lambda_c^+ \pi^-$
$\Lambda^+_c \rightarrow p K^- \pi^+$

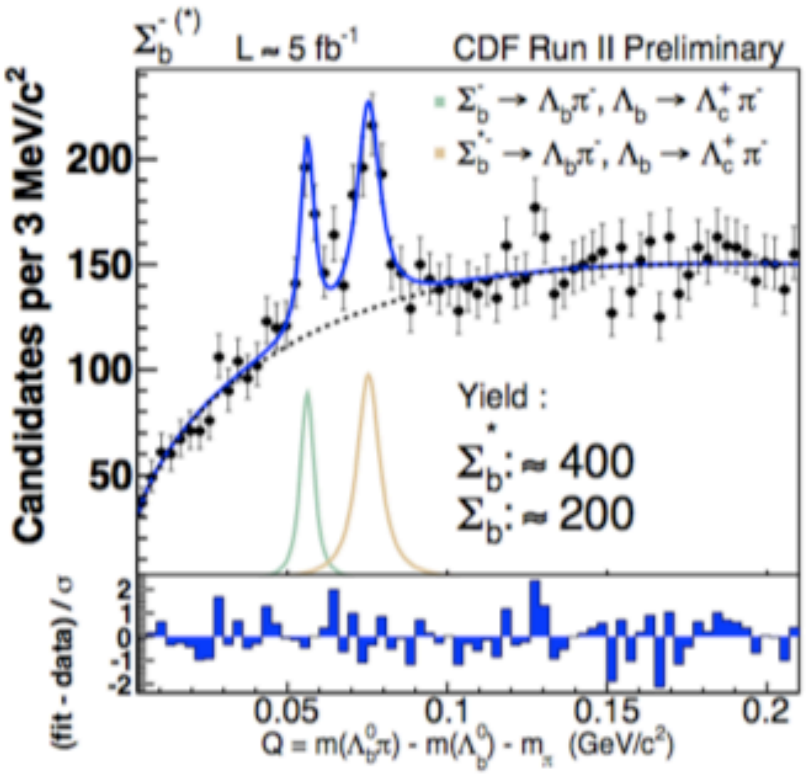
(Observation of Σ_b^+, Σ_b^-, Σ_b^{*+} and Σ_b^{*-} in 1.1 fb^{-1})
PRL 99, 202001 (2007)





≈4x increase of Λ^0_b sample wrt published analysis





Analysis Goals

- Improve mass measurements
- Measure natural widths of $(3/2)^+$ and $(1/2)^+$ states and mass splittings with no theoretical constraints

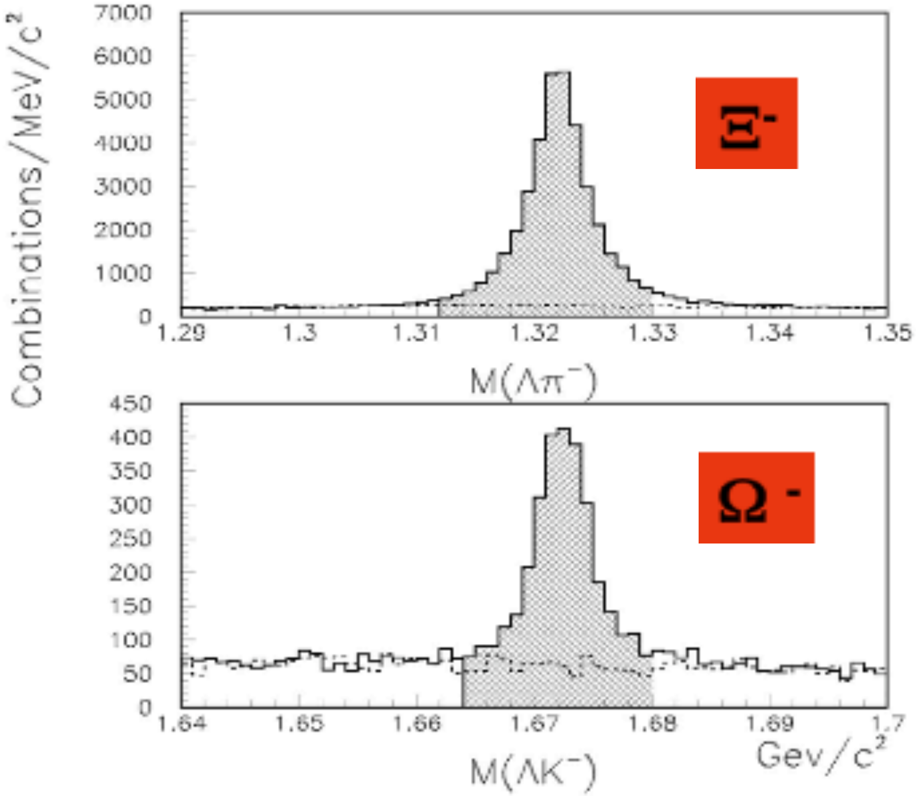
Ξ^- and Ω^- with silicon hits

Inclusive $\Lambda\pi$ and ΛK with previous selection and silicon on the Ξ^-/Ω^- track

- Ξ^- : 34,700
- Ω^-: 1,900

Shaded areas are our mass selection ranges.

- Shorter lifetime of the Ω^- (1" vs. 2") implies lower efficiency
- Many decay before reaching the silicon detector.



Comparison with D0

D0 finds $M(\Omega_b^-)$=6165±10(stat.)±13(syst.) MeV/c^2

- PRL **101**, 232002(2008)

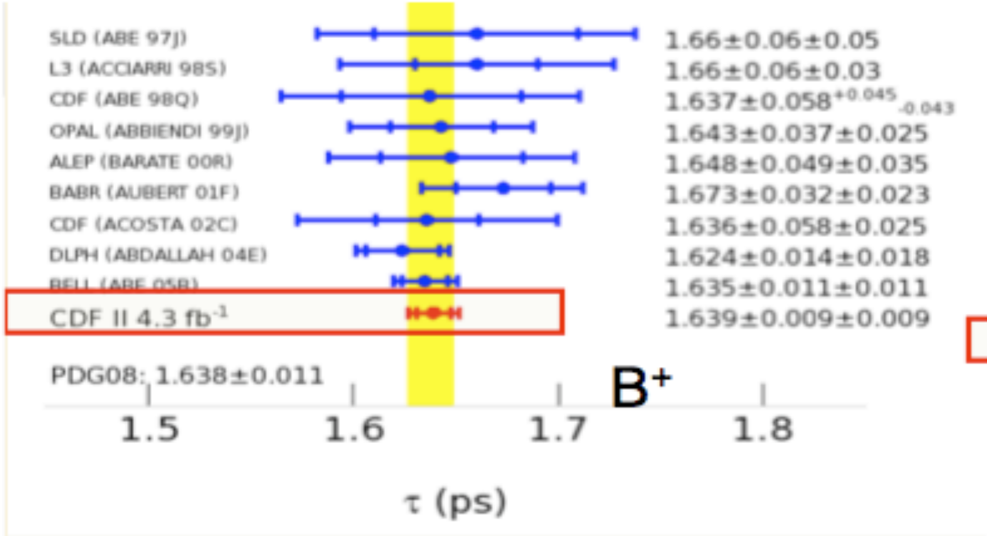
We find $M(\Omega_b)_{D0}$ - $M(\Omega_b)_{CDF}$ = 111±12(stat.)±14(syst.) MeV/c^2

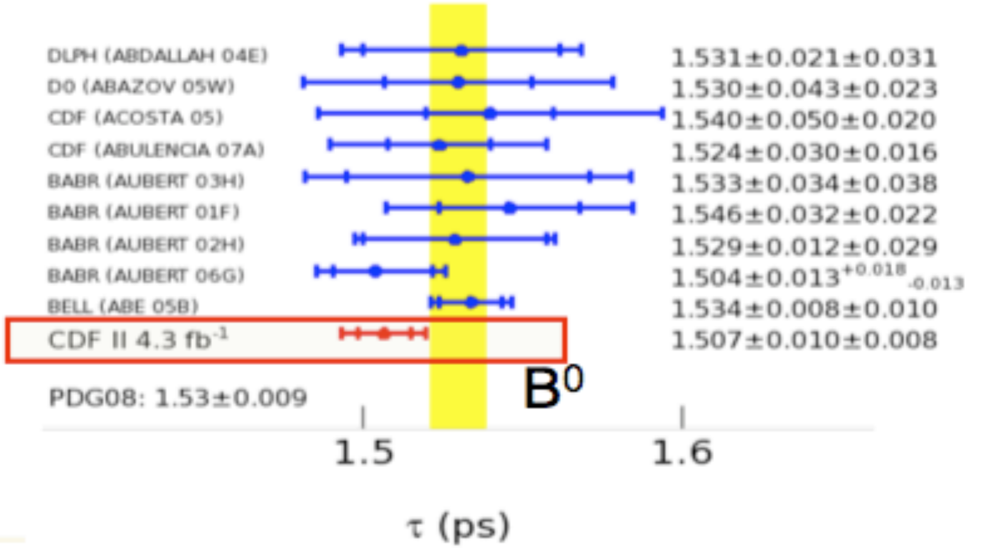
- Significant disagreement

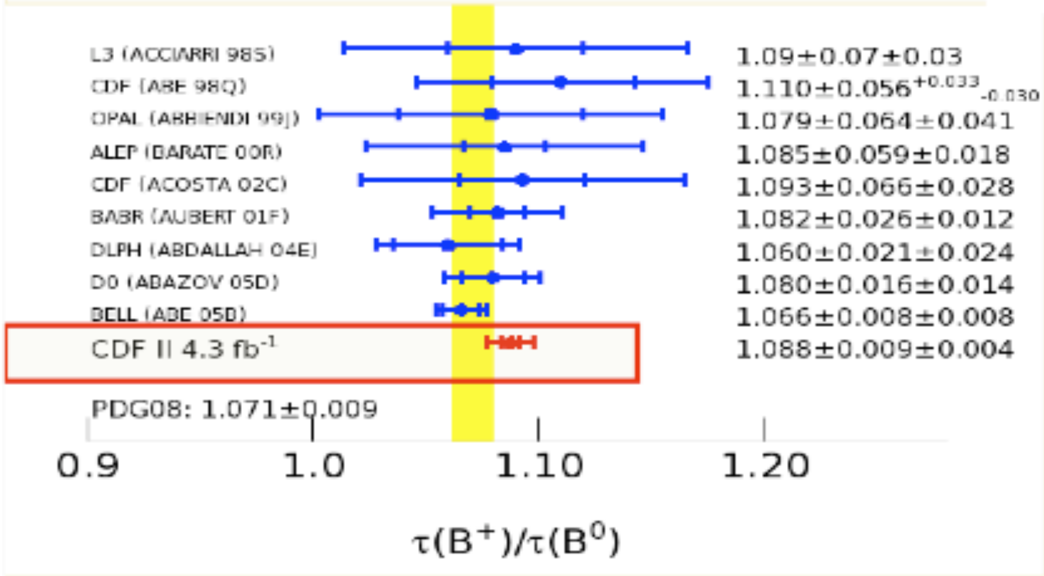
D0 finds
$$\frac{f(b \to \Omega_b^-)B(\Omega_b^- \to J/\psi\Omega^-)}{f(b \to \Xi_b^-)B(\Xi_b^- \to J/\psi\Xi^-)} = 0.80 \pm 0.32^{+0.14}_{-0.22}$$

CDF finds
$$\frac{\sigma B(\Omega_b^- \to J/\psi\Omega^-)}{\sigma B(\Xi_b^- \to J/\psi\Xi^-)} = 0.27 \pm 0.12 \pm 0.01$$

b – hadron Lifetimes







Results shown against PDG and other measurements

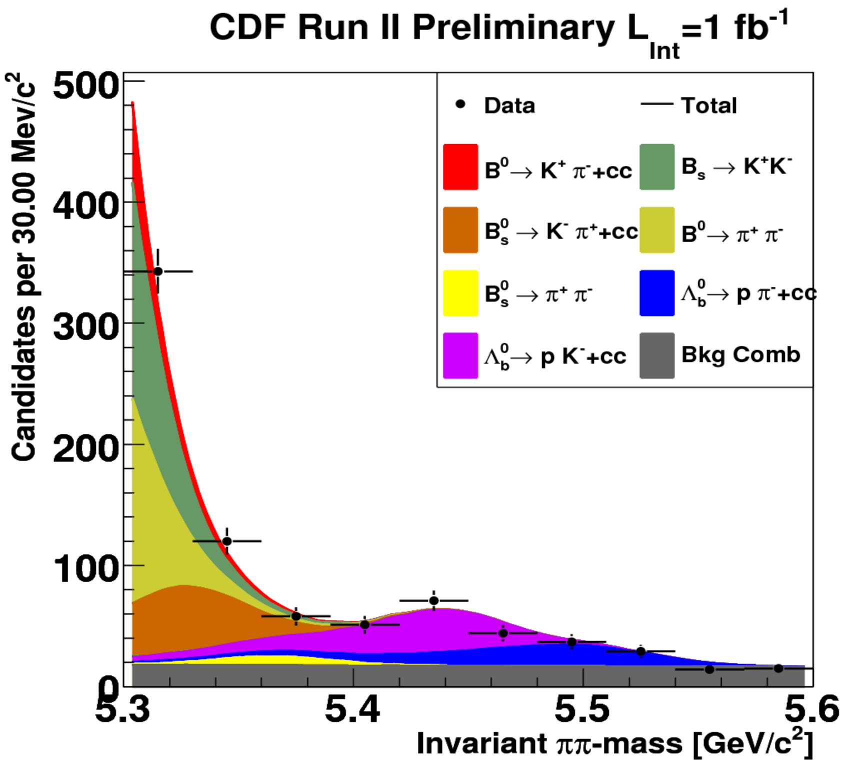
Most precise measurement of the B^+/B_0 ratio

In agreement with theoretical prediction:

$\tau(B^+)=(1.063\pm0.027)\tau(B_d)$ (theory)

$\tau(B^+)=(1.088\pm0.009 \pm0.004)\tau(B_d)$ (exp)

First Measurement of $\Lambda_b \to p\,(K,\pi)$



$$\frac{\sigma(p\bar{p} \to \Lambda_b^0 X, p_T > 6\ \mathrm{GeV/c})}{\sigma(p\bar{p} \to B^0 X, p_T > 6\ \mathrm{GeV/c})} \frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.0415 \pm 0.0074\ (stat.) \pm 0.0058\ (syst.)$$

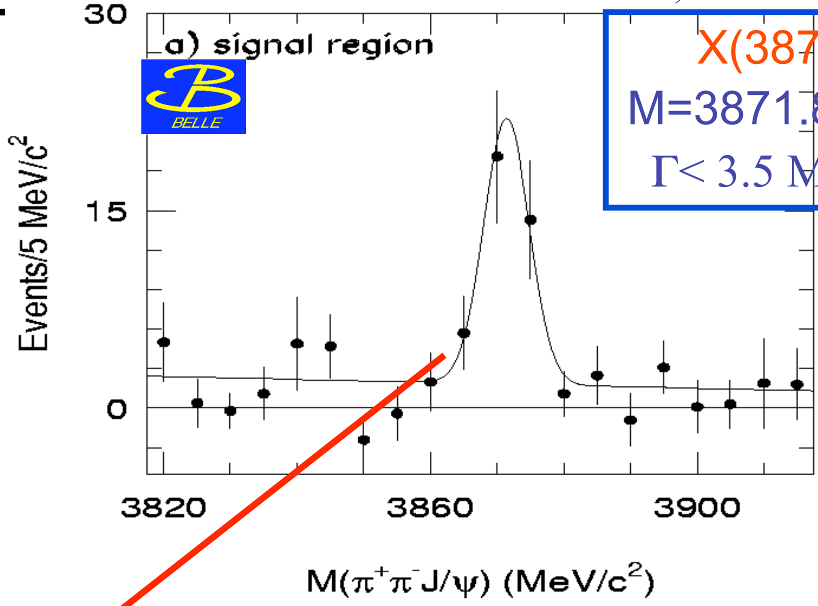
$$\frac{\sigma(p\bar{p} \to \Lambda_b^0 X, p_T > 6\ \mathrm{GeV/c})}{\sigma(p\bar{p} \to B^0 X, p_T > 6\ \mathrm{GeV/c})} \frac{\mathcal{B}(\Lambda_b^0 \to pK^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.0663 \pm 0.0089\ (stat.) \pm 0.0084\ (syst.)$$

X(3872)--2003

PRL 91, 262001

$c\bar{c}$

$N\,^{2S+1}L_J$	J^{PC}	$u\bar{d}, u\bar{u}, d\bar{d}$ $I=1$	$u\bar{u}, d\bar{d}, s\bar{s}$ $I=0$	$c\bar{c}$ $I=0$
$1\,^1S_0$	0^{-+}	π	η, η'	$\eta_c(1S)$
$1\,^3S_1$	1^{--}	ρ	ω, ϕ	$J/\psi(1S)$
$1\,^1P_1$	1^{+-}	$b_1(1235)$	$h_1(1170), h_1(1380)$	$h_c(1P)$
$1\,^3P_0$	0^{++}	$a_0(1450)^*$	$f_0(1370)^*, f_0(1710)^*$	$\chi_{c0}(1P)$
$1\,^3P_1$	1^{++}	$a_1(1260)$	$f_1(1285), f_1(1420)$	$\chi_{c1}(1P)$
$1\,^3P_2$	2^{++}	$a_2(1320)$	$f_2(1270), f_2'(1525)$	$\chi_{c2}(1P)$
$1\,^1D_2$	2^{-+}	$\pi_2(1670)$	$\eta_2(1645), \eta_2(1870)$	
$1\,^3D_1$	1^{--}	$\rho(1700)$	$\omega(1650)$	$\psi(3770)$
$1\,^3D_2$	2^{--}			??
$1\,^3D_3$	3^{--}	$\rho_3(1690)$	$\omega_3(1670), \phi_3(1850)$	
$1\,^3F_4$	4^{++}	$a_4(2040)$	$f_4(2050), f_4(2220)$	
$2\,^1S_0$	0^{-+}	$\pi(1300)$	$\eta(1295), \eta(1440)$	$\eta_c(2S)$
$2\,^3S_1$	1^{--}	$\rho(1450)$	$\omega(1420), \phi(1680)$	$\psi(2S)$
$2\,^3P_2$	2^{++}	$a_2(1700)$	$f_2(1950), f_2(2010)$	
$3\,^1S_0$	0^{-+}	$\pi(1800)$	$\eta(1760)$	

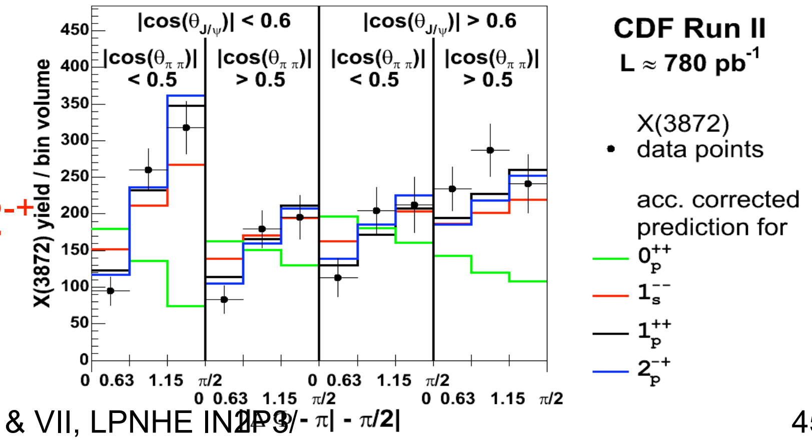


$X(3872) \to J/\psi\pi^+\pi^-$
M=3871.8±0.7±0.4 MeV
Γ< 3.5 MeV @ 90% CL

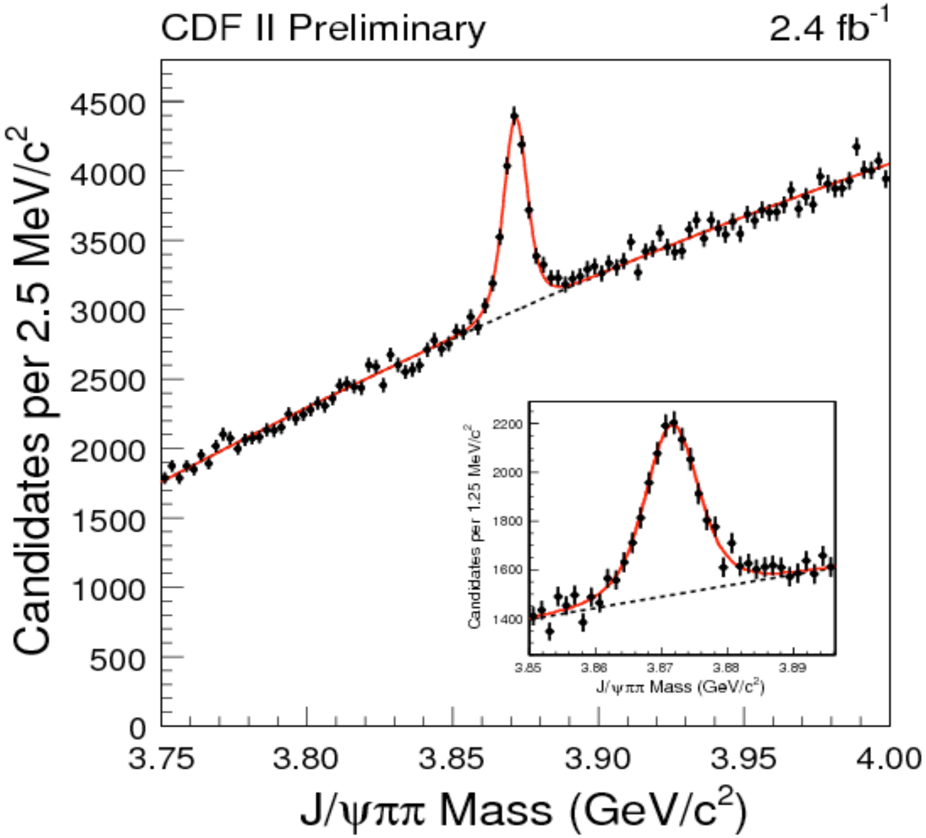
mass ~70 MeV > predictions (2003)

$\pi^+\pi^-$ peak at high value like a ρ (2003)

$J^{PC} = 1^{++}$ or 2^{-+}



New X(3872) Mass Measurement at CDF--2008



~6000 signals

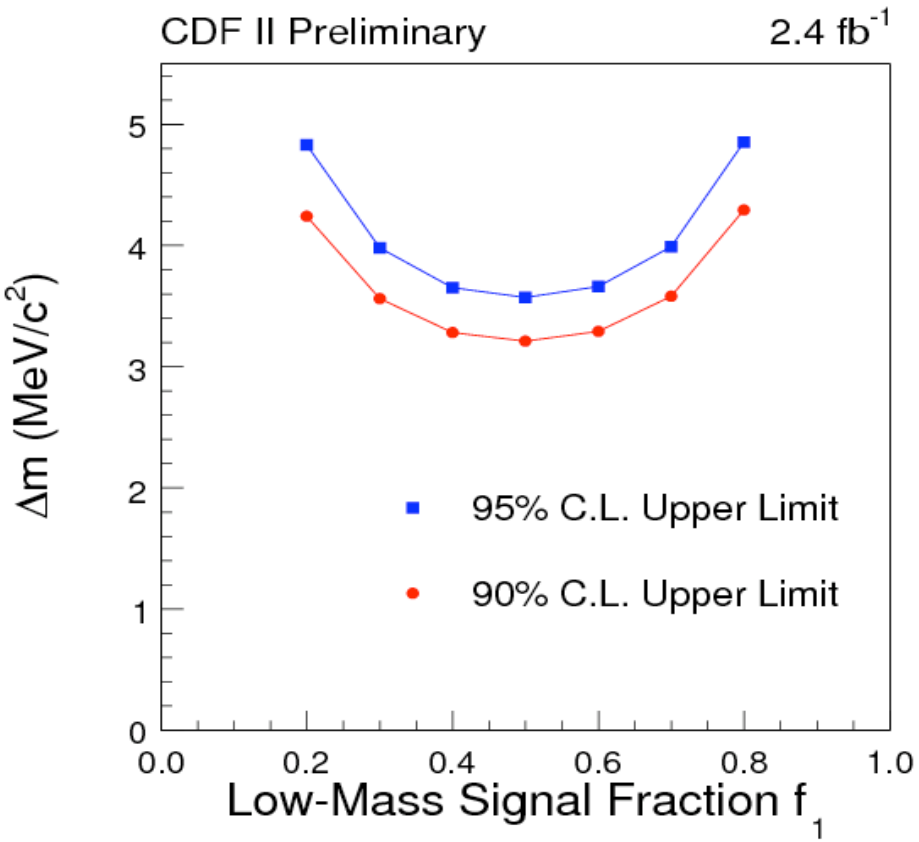
The largest sample to date

Use neural network to select

Test the hypothesis of:

X(3872) composed of two states?

New X(3872) Mass Measurement at CDF--2008



Assuming different fraction for possible two states.

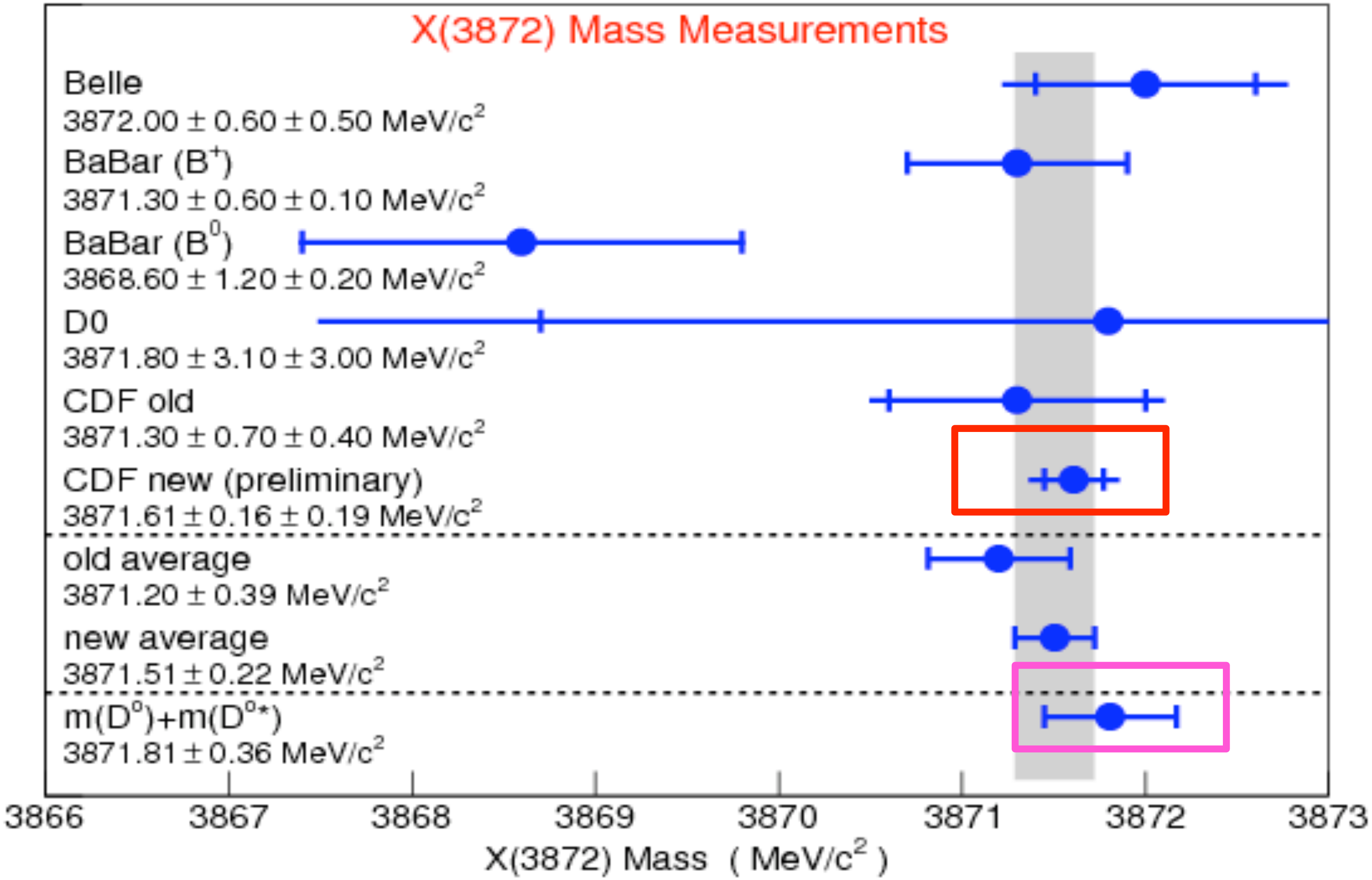
Breit-Wigner convoluted with resolution for each state

$\Delta m < 3.2\ (3.6)\ \mathrm{MeV}/c^2$ at 90% (95%) C.L.

Consistent with one state hypothesis:

$m(X(3872)) = 3871.61 \pm 0.16\ (\mathrm{stat}) \pm 0.19\ (\mathrm{syst})\ \mathrm{MeV}/c^2$

New X(3872) Mass Measurement at CDF--2008



the most precise measurement to date, still within the D*D threshold uncertainty

Charmonium hybrid→J/ψϕ ?

PRD 57, 5653 (1998)
F. Close et al

J^{PC}	Open charm	Hidden charm
0^{+-}	Quantum numbers forbid $D^{(*)}D^{(*)}$	$J/\psi\{f_{\{0,1,2\}},(\pi\pi)_S\}$ $h_c\,\eta;\ \eta_c h_1$ $\chi_{c0}\omega$ $\chi_{c\{1,2\}}\{\omega,h_1,\gamma\}$
0^{--}	D^*D	$h_c(\pi\pi)_S$ $J/\psi\{f_{\{1,2\}},\eta^{(\prime)}\}$ $\chi_{c0}h_1;\ \eta_c\{\omega,\phi\}$ $\chi_{c\{1,2\}}\{\omega,h_1,\gamma\}$
1^{-+}	$D^*D,\ D^*D^*$	$\chi_{c\{0,1,2\}}(\pi\pi)_S$ $\eta_c\{f_{\{1,2\}},\eta^{(\prime)}\}$ $\chi_{c\{1,2\}}\eta$ $\{h_c,\underline{J/\psi}\}\{\omega,h_1,\underline{\phi},\gamma\}$
2^{+-}	$D^*D,\ D^*D^*$	$\{h_c,J/\psi\}\{f_{\{0,1,2\}},(\pi\pi)_S\}$ $\{h_c,J/\psi\}\eta^{(\prime)}$ $\{\eta_c,\chi_{c\{0,1,2\}}\}\{\omega,h_1,\phi,\gamma\}$

accessible

J/ψϕ is also accessible to 0^{-+}, 2^{-+}

(0^{-+}, 1^{-+}, 2^{-+}) masses are expected near Y(4260), E. Eichten

Multi-quark states → $J/\psi\phi$?

J^{PC}	M(MeV)	Decay Channel
0^{++}	3834	-
0^{++}	3927	$J/\psi\ \omega$
0^{-+}	4277(+15)	$\boxed{J/\psi\ \phi}$, $J/\psi\ \omega$, $D_s^{*+}D_s^{*-}$
0^{-+}	4312(+30)	$\boxed{J/\psi\ \phi}$, $J/\psi\ \omega$, $D_s^{*+}D_s^{*-}$
0^{--}	4297(-5)	$\psi\ \eta(\eta')$, $D_s^{+}D_s^{*-}$
1^{++}	3890	$J/\psi\ \omega$
1^{+-}	3870	$J/\psi\ \eta$
1^{+-}	3905	$J/\psi\ \eta$
1^{-+}	4321(+15)	$J/\psi\ \omega$, $\boxed{J/\psi\ \phi}$
1^{-+}	4356 (+30)	$J/\psi\ \omega$, $\boxed{J/\psi\ \phi}$
1^{--}	4330	$\psi\ \eta(\eta')$, $D_s^{(*)+}D_s^{(*)-}$; $J/\psi\ f_0(980)$
1^{--}	4341(-5)	$\psi\ \eta(\eta')$, $D_s^{(*)+}\ D_s^{(*)-}$; $J/\psi\ f_0(980)$
1^{--}	4390(+40)	$\psi\ \eta(\eta')$, $D_s^{(*)+}D_s^{(*)-}$; $J/\psi\ f_0(980)$
1^{--}	4289(-41)	$\psi\ \eta(\eta')$, $D_s^{(*)+}D_s^{(*)-}$; $J/\psi\ f_0(980)$

← arXiv:0902.2803 (new)
N. V. Drenska et al

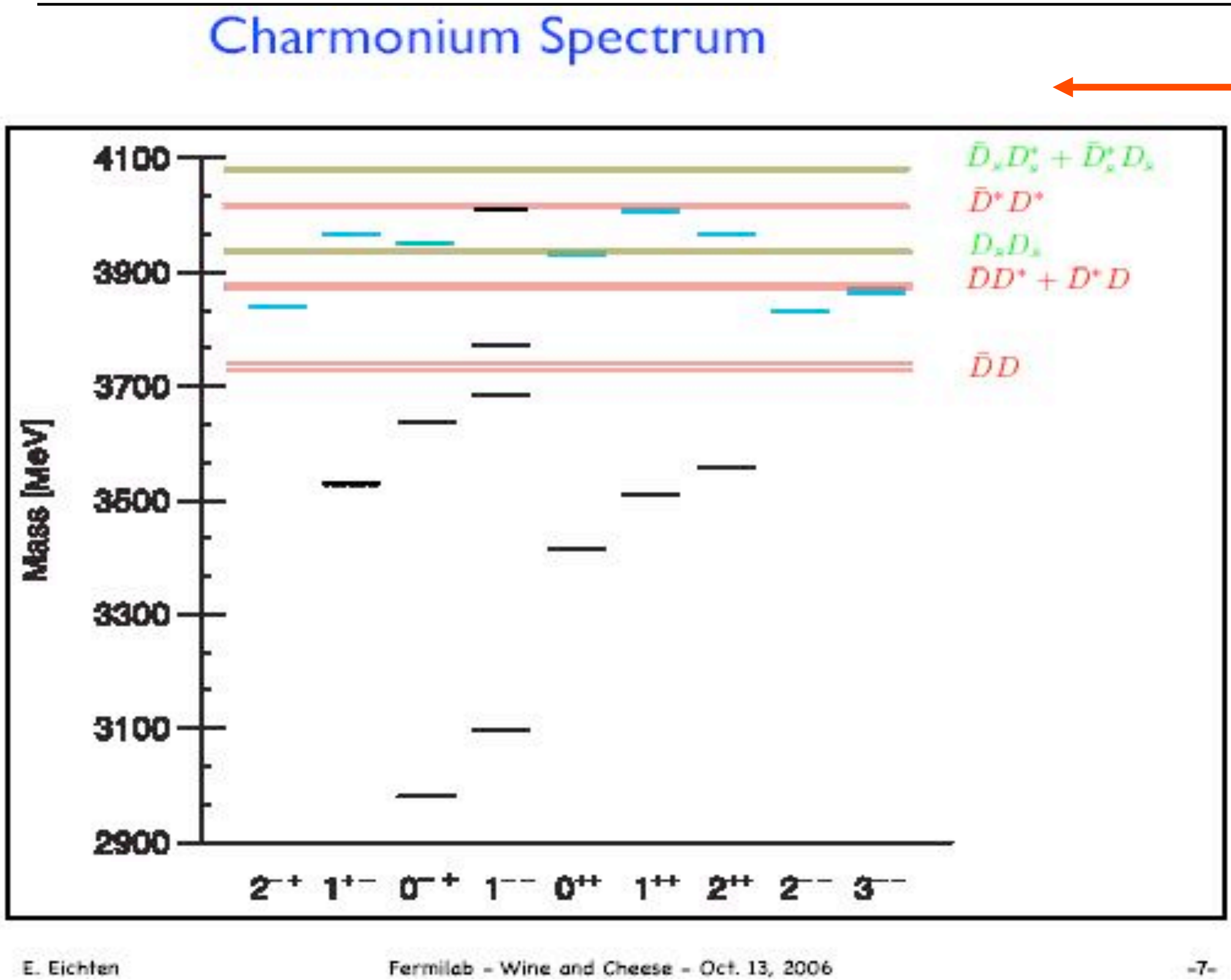
$J/\psi\phi$ is well motivated!

How to search?

Inclusive? Challenge!

Through B decays!

What is it?



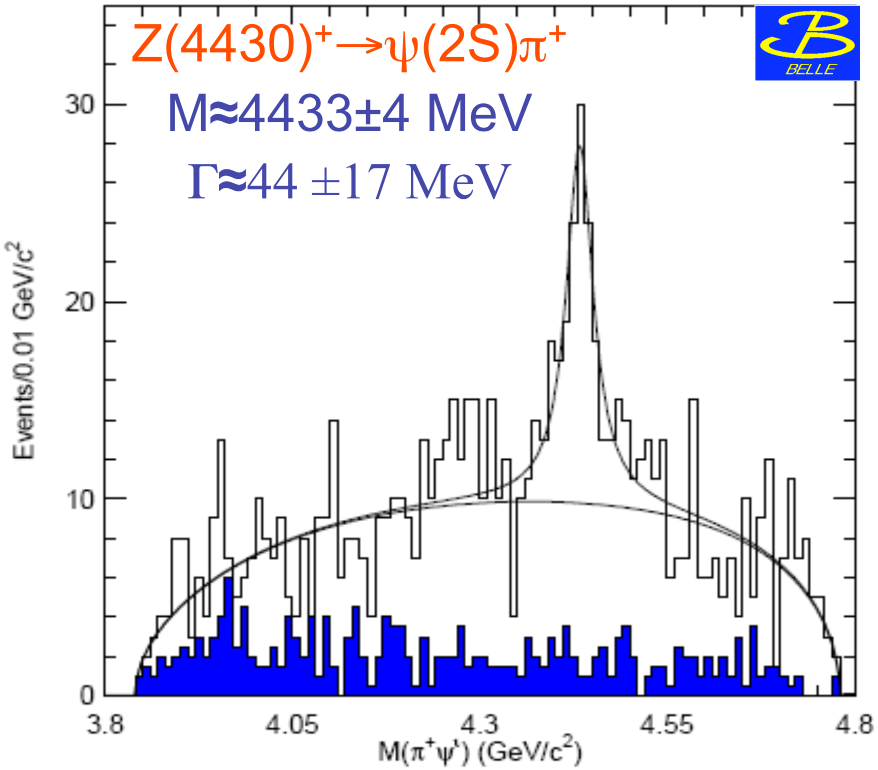
Y(4140)

- Well **above** charm pair threshold
- Expect **tiny** BF to $J/\psi\phi$
- Does **not** fit into charmonium
- Close $J/\psi\phi$ threshold like Y(3940)

arXiv:0903.2529[hep-ph] molecular?

$Z(4430)^+ \rightarrow \psi(2S)\pi^+$--2008

PRL 100, 142001



Needs confirmation

The first charged charmonium-like new state, if confirmed

Many more new states…

They do not (easily) fit into charmonium

Beyond ($q\bar{q}$) mesons: exotic mesons?