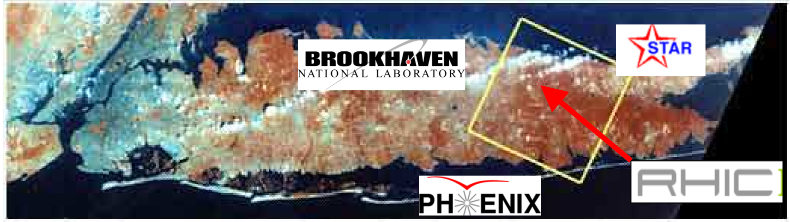
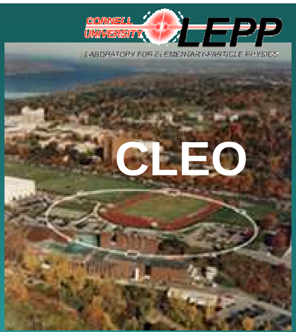




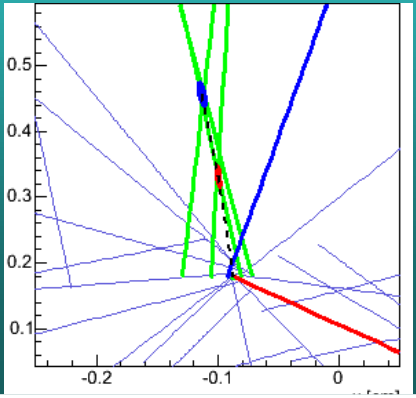
European Physical Society

HEP 2007

Flavour Physics at the other facilities

Aurore Savoy-Navarro, LPNHE, Université Pierre et Marie Curie/CNRS-IN2P3

MANCHESTER UNITED



Why the heavy flavoured world is so appealing?

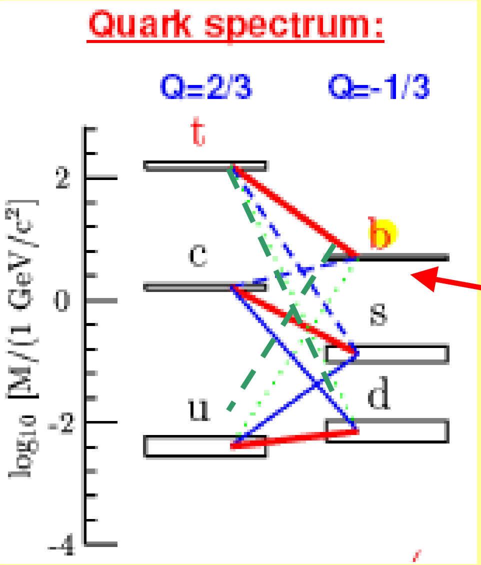
- Heavy Flavour Physics (HFPh) is QCD Physics.
- Heavy Flavour Physics is EWK Physics.
- Heavy Flavour is a puzzle for BSM and,
- Heavy flavour objects are probes for new Physics.
- Heavy b and c- quarks have a measurable lifetime:
- b- & c-quark hadronize and couple with other quarks.
- HF produced in e+e-, ep, pp, heavy ion collisions.
- Thanks to HFPh and experimentalists prowess: hadron colliders, called once upon the time ‘’discovery machines’’, became high precision machines

(thus: charming, beautiful and at the top Physics, isn’t ??)

Heavy Flavour Physics

- QCD:
  - ► HF production processes, bound states & lifetimes, decays & BR's are well predicted by Theory.
  - ► Study of heavy-light quarks bound states at all facilities provides accurate test of QCD predictions or new inputs to it.
  - ► HF are probes to investigate QGP
- EWK:
  - ► Study of Bs or D mixing and CP violation are tests of the fundamental properties of the EWK interactions
- BSM:
  - ► CP violation in B_s and D^0 systems (very sensitive to BSM)
  - ► Rare B (D) decays (very sensitive to BSM)
  - ► HF processes are physics backgrounds for NP or HF objects are key objects in NP signatures

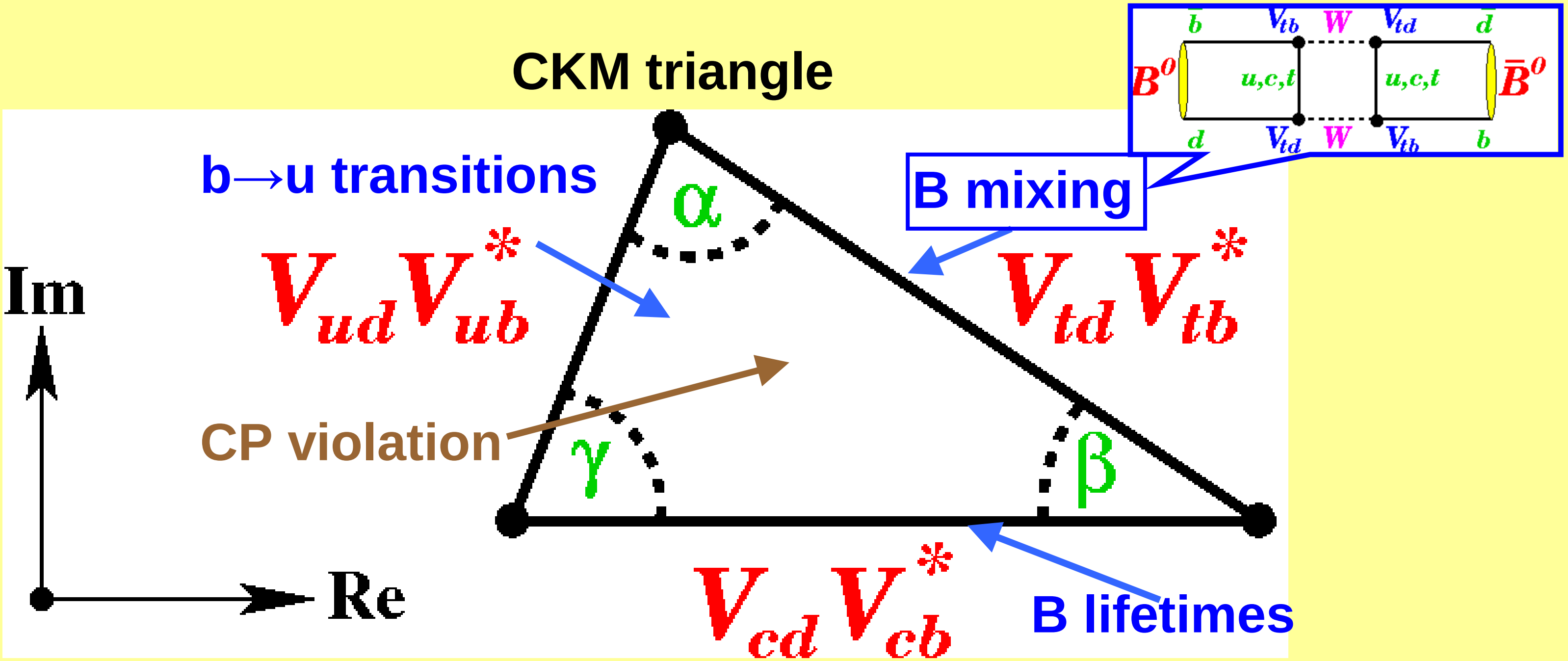
Heavy Flavour Physics: some basics



$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

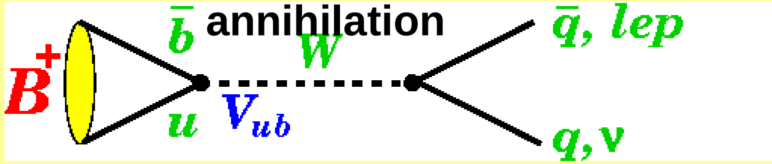
- Quark transitions described by CKM Matrix
- *CKM matrix elements not predicted by SM => to be measured*
- *B decays determine 5 CKM matrix elements*
- *Unitarity of CKM matrix:* $V_{ub}V^*_{ud}+V_{cd}V^*_{cb}+V_{td}V^*_{tb}=0$

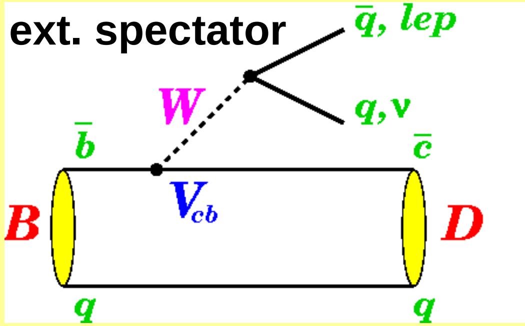
CKM triangle

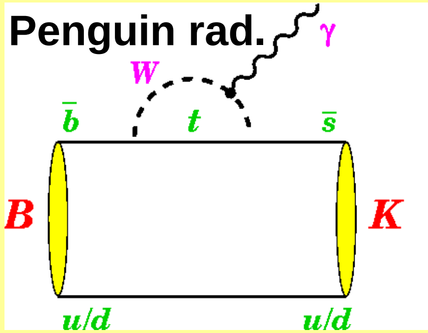


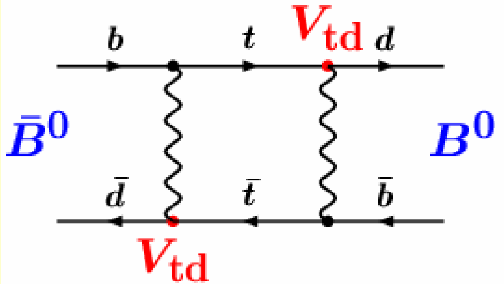
B decay processes in SM

Similar scenarios for D decays

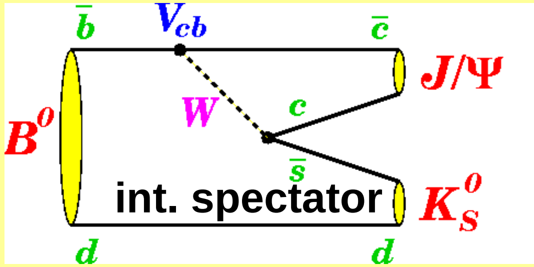


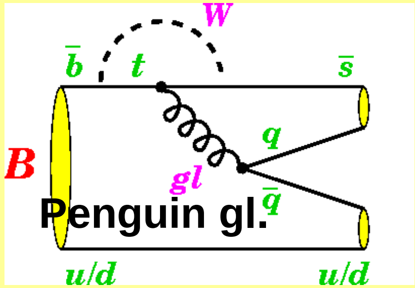


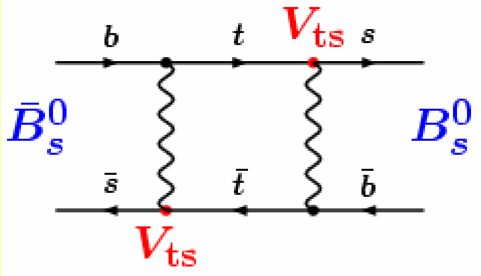




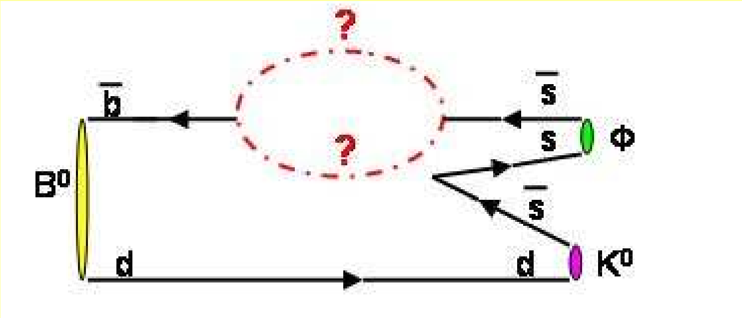
oscillations



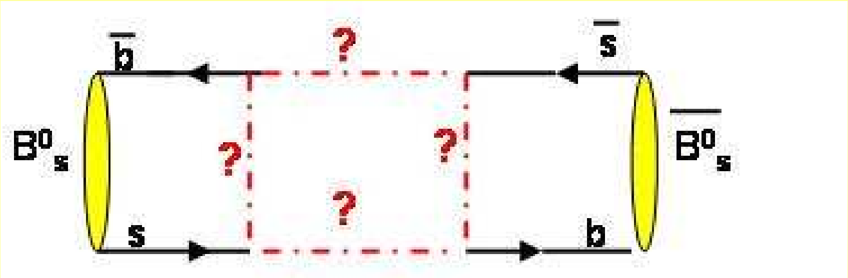




NEW PHYSICS : virtual particles (i.e. in loop processes) leading to observable deviations from SM expectations in B Physics and CPV



$B^0 \rightarrow \Phi K^0$ decay: "Penguin diagram"



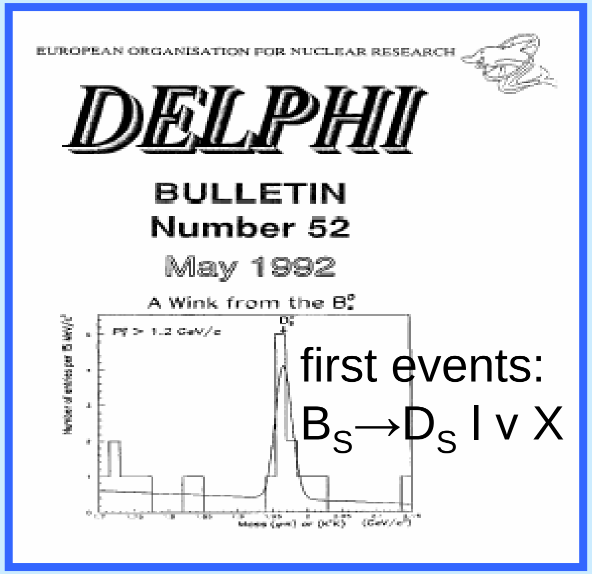
Bs – $\overline{\text{Bs}}$ oscillations: "Box" diagram

The Large electron-positron collider at CERN has been exploring all the Heavy Physics topics sometimes in a pioneering way.

SLC at SLAC did pretty well too.

Still new results from LEP are produced.

Bs oscillations at LEP/SLC



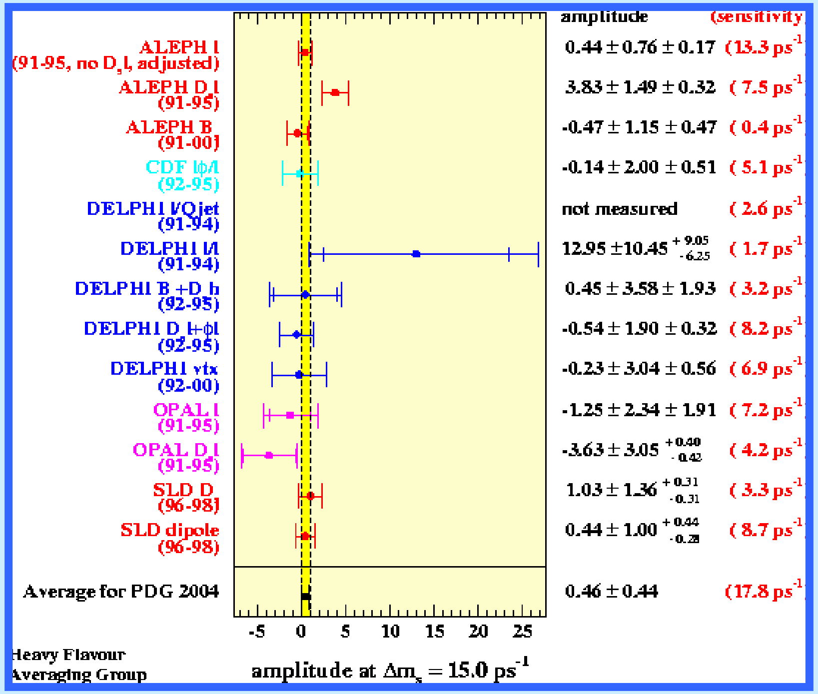
EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

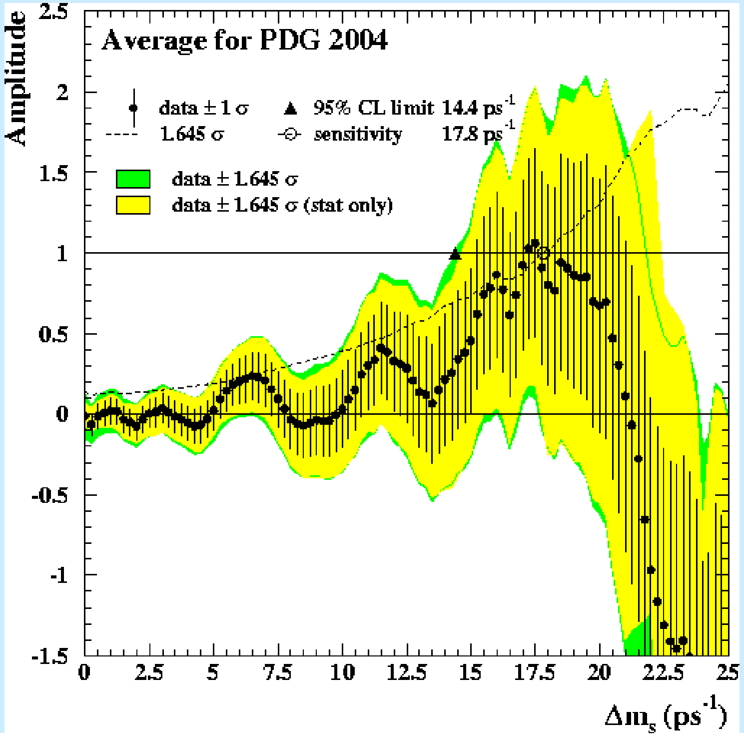
DELPHI

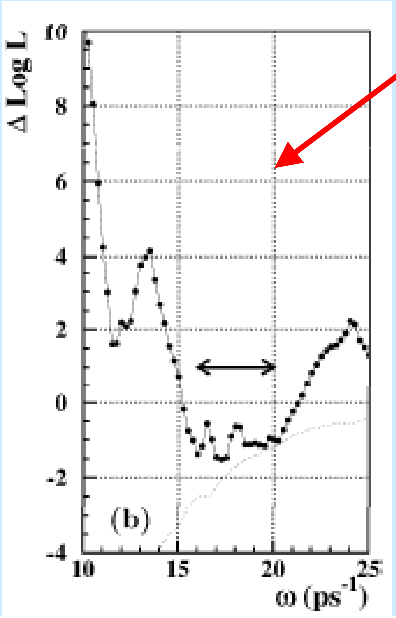
BULLETIN
Number 52
May 1992

A Wink from the B_s^0

first events:
$B_S \rightarrow D_S\ l\ \nu\ X$

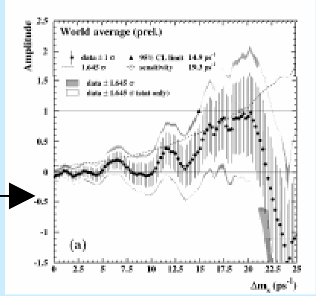






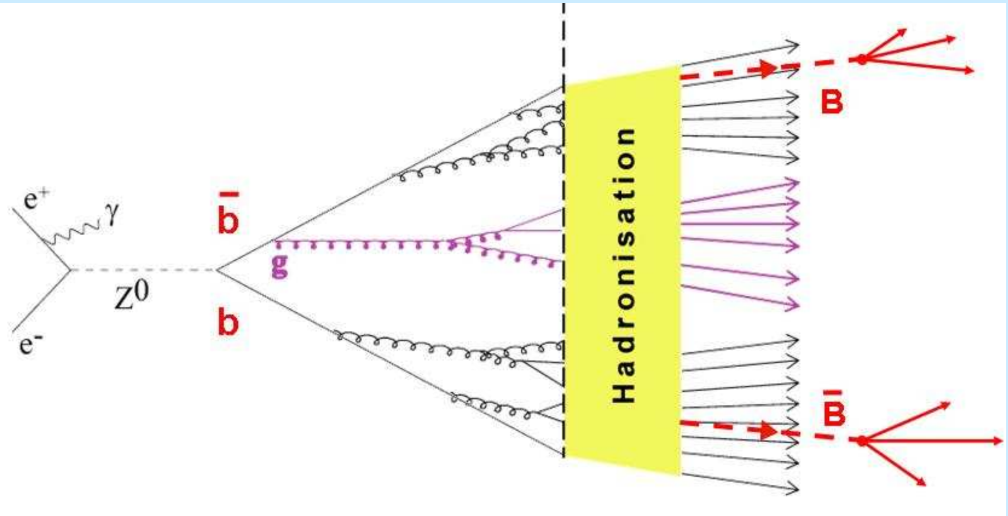
LEP (ALEPH) pioneered the analysis procedure.
LEP/SLD almost got there….

Frequencies <14.9 ps^{-1}excluded @ 95%CL. Expected limit: 19.4ps^{-1}, substantially higher because amplitude values different from 0 & ~ 1, are found in frequency range **16-20 ps^{-1}.**



AFB$_b$, b-quark fragmentation etc…

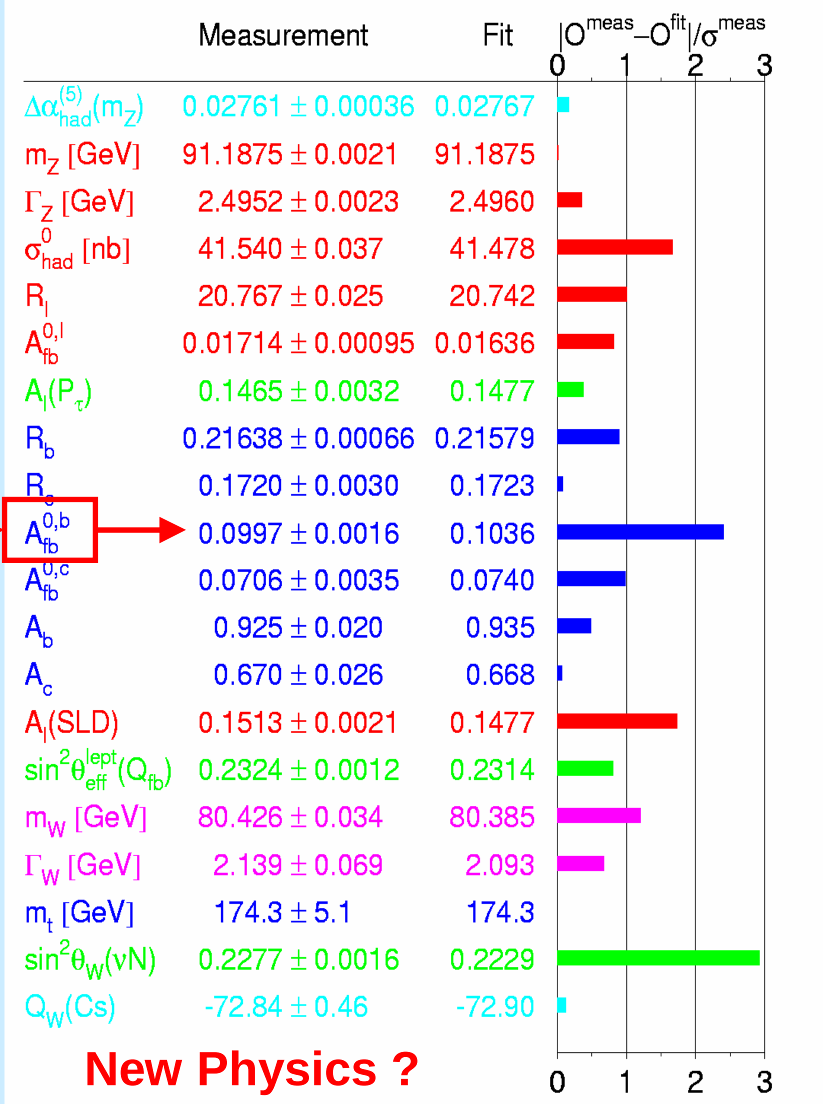
Update on b-fragmentation



Still ongoing work (DELPHI)

Forward/Backward Asymmetry @ Z pole

2.5σ discrepancy wrt SM (0.1038)

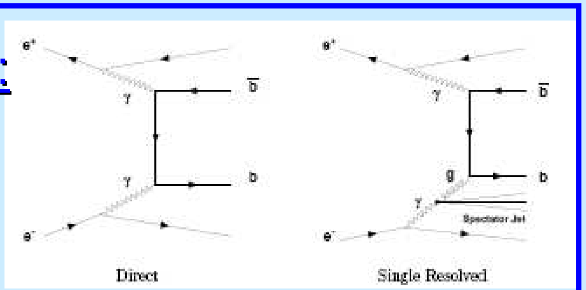


	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02761 ± 0.00036	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4960
σ_{had}^0 [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.742
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01636
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1477
R_b	0.21638 ± 0.00066	0.21579
R_c	0.1720 ± 0.0030	0.1723
$A_{fb}^{0,b}$	0.0997 ± 0.0016	0.1036
$A_{fb}^{0,c}$	0.0706 ± 0.0035	0.0740
A_b	0.925 ± 0.020	0.935
A_c	0.670 ± 0.026	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1477
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.426 ± 0.034	80.385
Γ_W [GeV]	2.139 ± 0.069	2.093
m_t [GeV]	174.3 ± 5.1	174.3
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	0.2229
$Q_W(Cs)$	-72.84 ± 0.46	-72.90

New Physics ?

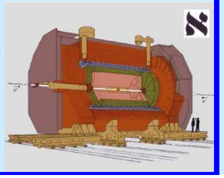
Latest from ALEPH:

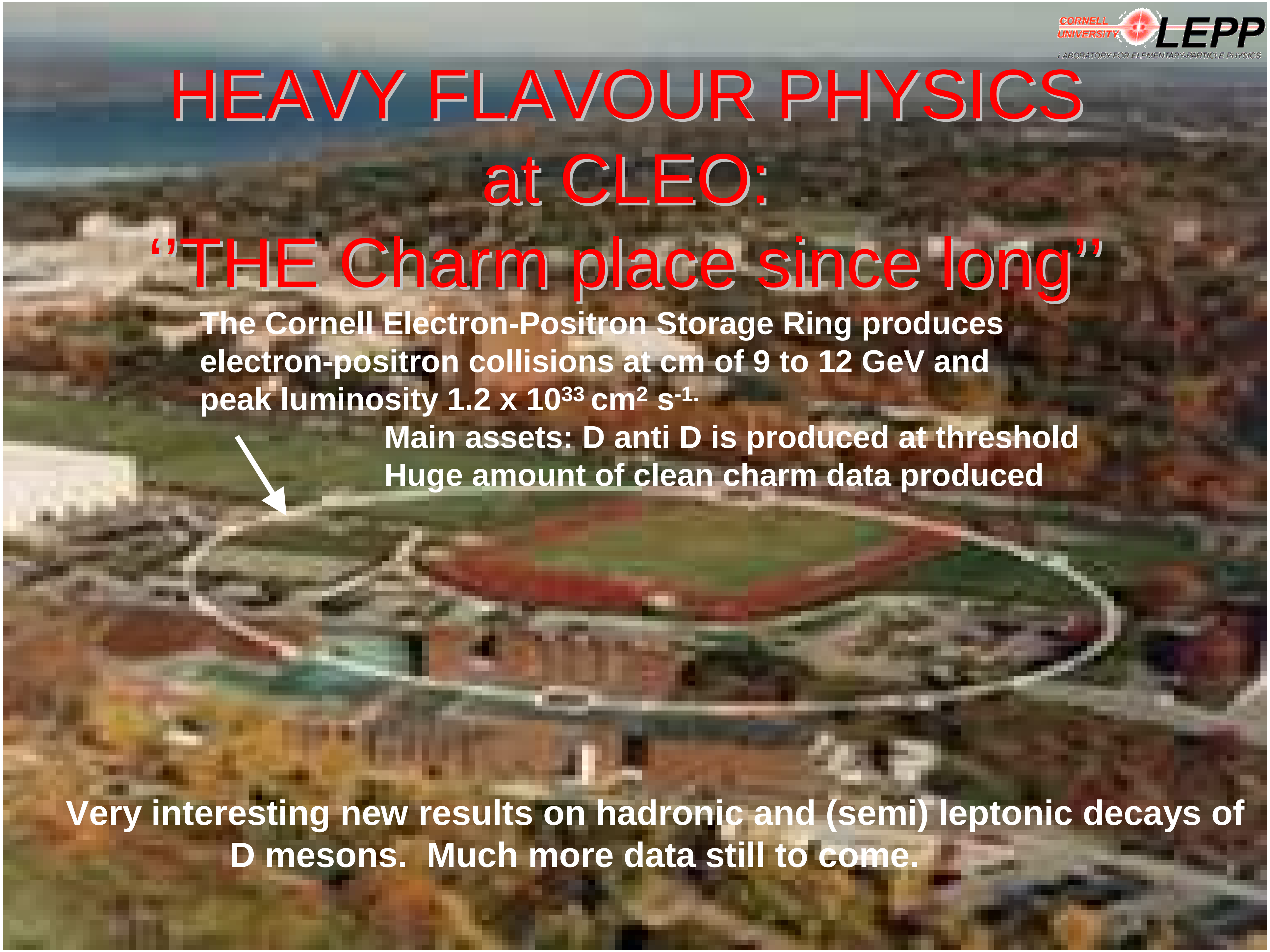
Cross-section for open b-quark production in 2 photon interactions:



σ(e+e-→e+e-bbX)=5.4 ± 0.8(stat) ± 0.8(syst) pb

Agrees with NLO QCD but barely consistent with L3: 12.8 ± 1.7(stat) ± 2.3 (syst) pb





HEAVY FLAVOUR PHYSICS at CLEO: ''THE Charm place since long''

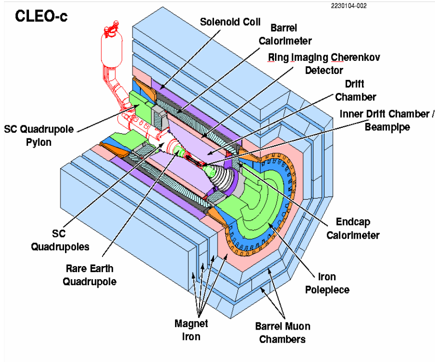
The Cornell Electron-Positron Storage Ring produces electron-positron collisions at cm of 9 to 12 GeV and peak luminosity 1.2 x 10^{33} cm^{2} s$^{-1.}$

Main assets: D anti D is produced at threshold
Huge amount of clean charm data produced

Very interesting new results on hadronic and (semi) leptonic decays of D mesons. Much more data still to come.

Hadronic D decays

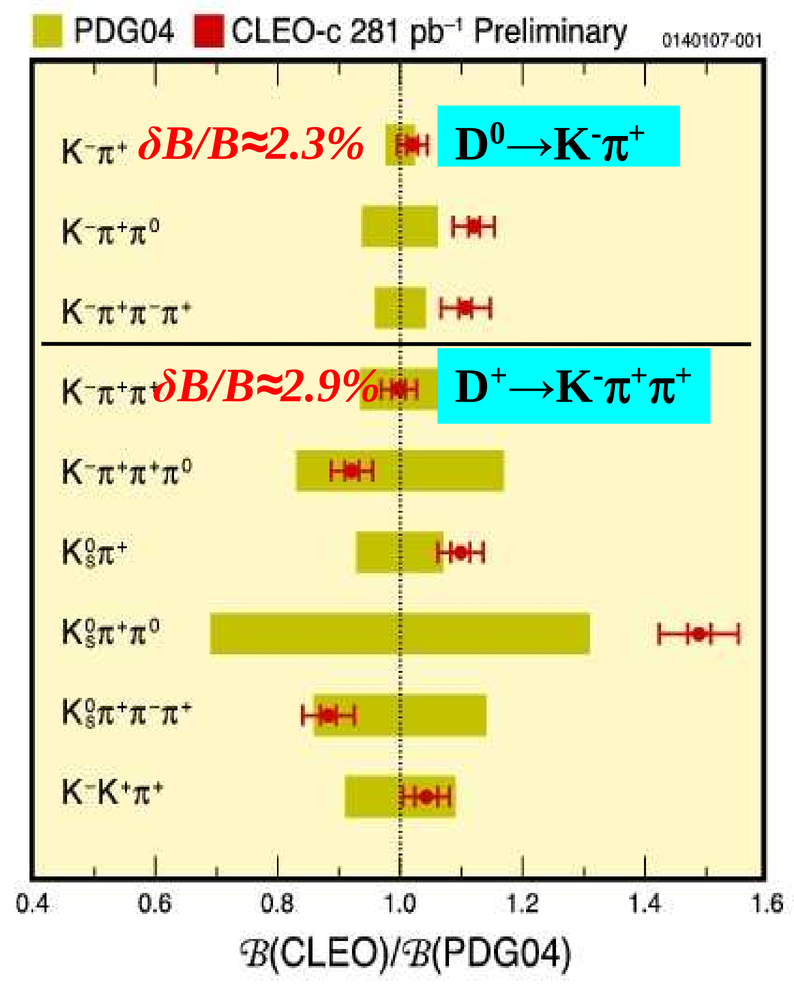
CORNELL UNIVERSITY LEPP
LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS



$D\bar{D}$ production at threshold:
=> low multiplicity, clean

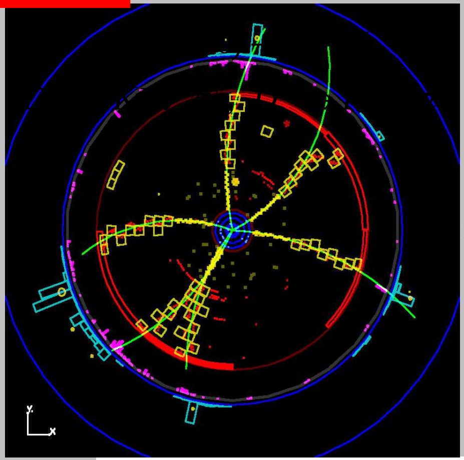
$e^+e^- \rightarrow \psi(3770) \rightarrow D\bar{D}$

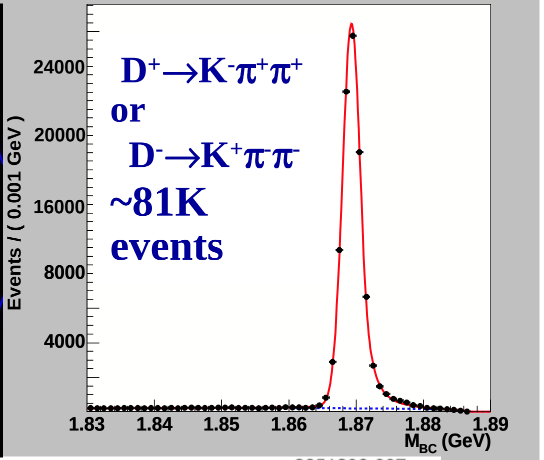
$D^+ \rightarrow K^-\pi^+\pi^+$ $D^- \rightarrow K^+\pi^-\pi^-$

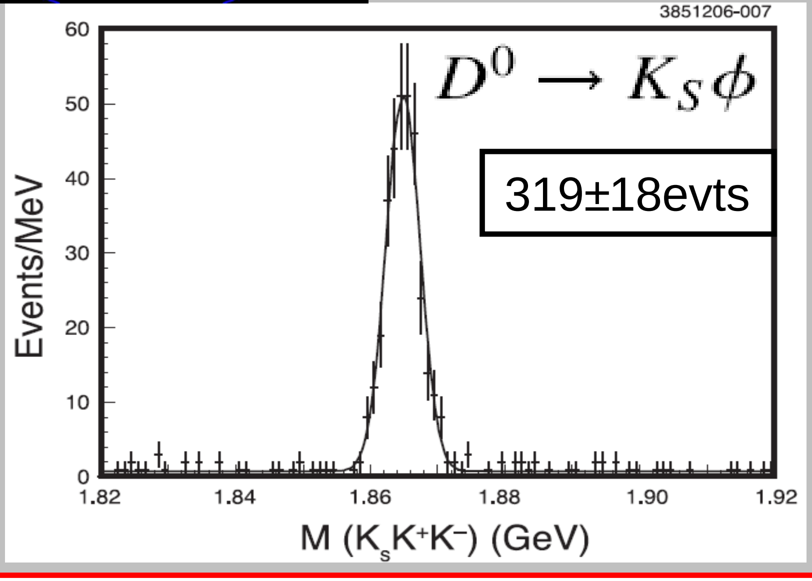


$\delta B/B \approx 2.3\%$ $D^0 \rightarrow K^-\pi^+$

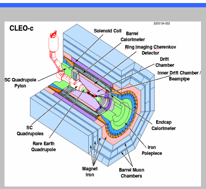
$\delta B/B \approx 2.9\%$ $D^+ \rightarrow K^-\pi^+\pi^+$







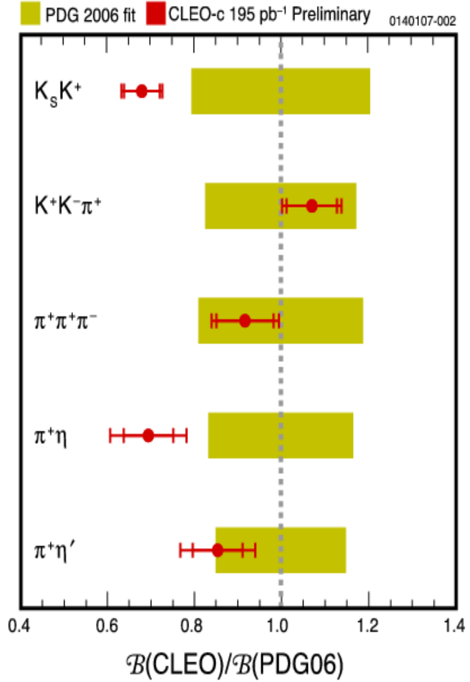
$$M(D^0) = 1864.847 \pm 0.150(\text{stat}) \pm 0.095(\text{syst})\ \text{MeV}$$



Absolute D_s hadronic $\mathcal{B}$'s

CLEO-c, 4170MeV, 195pb^{-1} (preliminary)

D_s^+ Mode	$\mathcal{B}$ (%)
$K_S K^+$	$1.50 \pm 0.09 \pm 0.05$
$K^- K^+ \pi^+$	$5.57 \pm 0.30 \pm 0.19$
$K^- K^+ \pi^+ \pi^0$	$5.62 \pm 0.33 \pm 0.51$
$\pi^+ \pi^+ \pi^-$	$1.12 \pm 0.08 \pm 0.05$
$\pi^+ \eta$	$1.47 \pm 0.12 \pm 0.14$
$\pi^+ \eta'$	$4.02 \pm 0.27 \pm 0.30$



Cabibbo Suppressed:

$\pi^0 K^+$

$K^+\eta$

$K^+\eta'$

$K^0\pi^+$

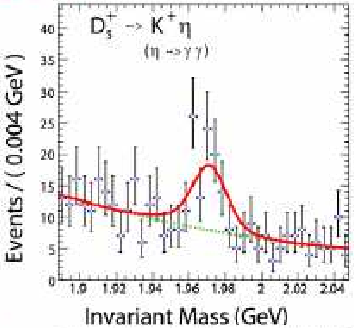
$\pi^+ \pi^0$ Forbidden

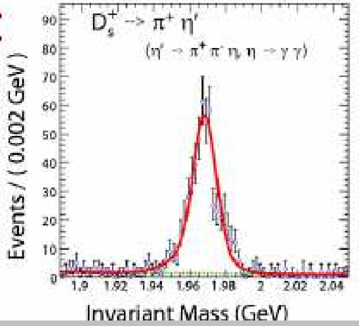
Cabibbo Favored:

$\pi^+\eta$

$\pi^+\eta'$

K^+K^0





D_s decay to 2 pseudoscalars

Suppressed/favoured:

$(D_s \to K^+\eta)/(D_s \to \pi^+\eta) = 0.080 \pm 0.015$

$(D_s \to K^+\eta')/(D_s \to \pi^+\eta') = 0.039 \pm 0.013$

$(D_s \to K^0\pi^+)/(D_s \to K^+K^0) = 0.083 \pm 0.009$

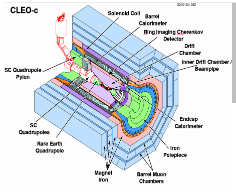
$(D_s \to K^+\pi^0)/(D_s \to K^+K^0) = 0.042 \pm 0.012$

$(D_s \to \pi^+ \pi^0)/(D_s \to K^+K^0) < 0.04$

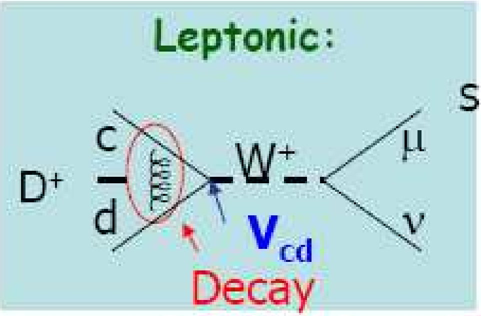
(compare with $(V_{cd}/V_{cs})^2$ of 1/20)

Statistics Dominated – more statistics will come

(Semi)-Leptonic decays



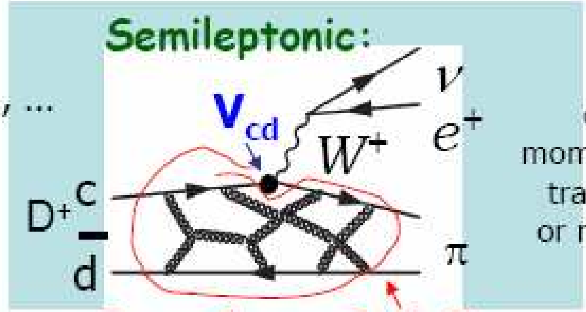
Examples:



Similar for D_s, B, B_s, …

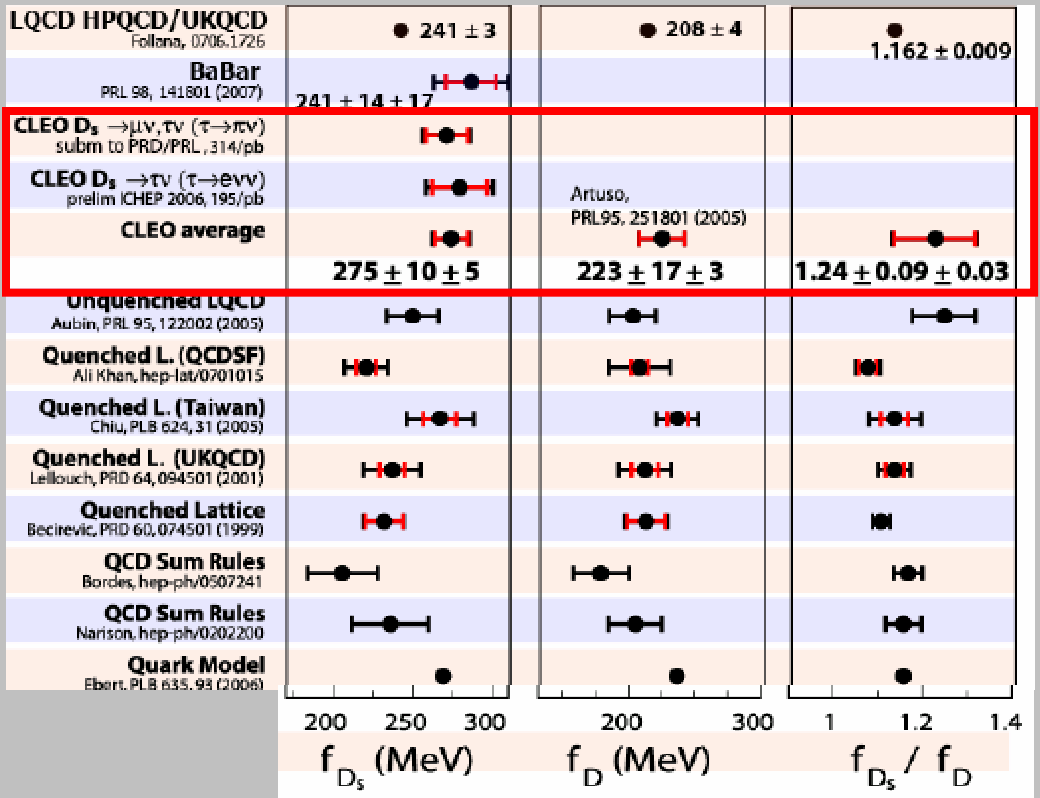
Decay constant f_D

Challenge: understand QCD portion in a "simple" weak process



q^2: momentum transfer or $m(W^+)$

Form factor $f_+(q^2)$



❖ **Using V_{cd} & V_{cs} , f_D & f_{Ds} can be determined from $D_{(s)}\rightarrow\ell^+\nu$**

❖ **$f_{D(s)}$: calibrate/validate LQCD**

❖ **Impact HF Physics: constrain the CKM matrix:**

❖ **New physics: relative decay rate to different lepton flavours very well predicted => any deviations imply new physics.**

$D_s\rightarrow\mu\nu,\tau\nu$: two nice new measurements of f_{Ds} (5% CLEO, 8% BaBar)

$D\rightarrow\mu\nu$: fairly precise measurement of f_D (8%)

HEAVY FLAVOUR Physics at HERA electron proton collider at DESY

THE H1 EXPERIMENT AT HERA

H1 Collaboration at DESY, Notkestr.85, D-22607 Hamburg, Germany

E_p = 920 GeV
E_e = 27.5 GeV
$\sqrt{s}$ ~ 318 GeV

Last run, ended July 2 2007: results from H1 and ZEUS

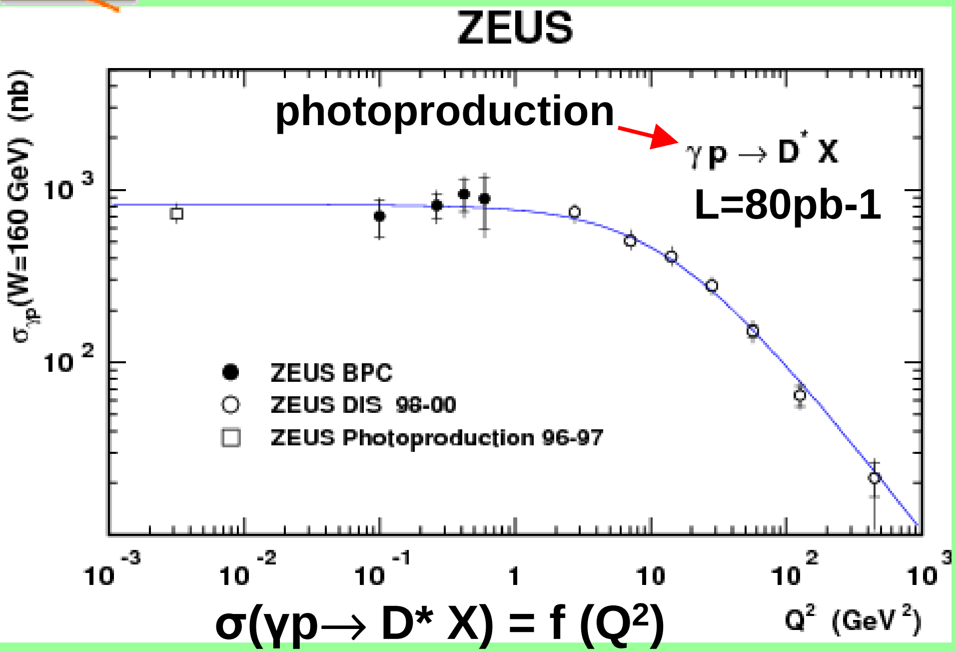
Delivered luminosity:
500 pb^{-1}/expt 02-07 (HERA II)

ZEUS

Why to study Heavy Quark production?

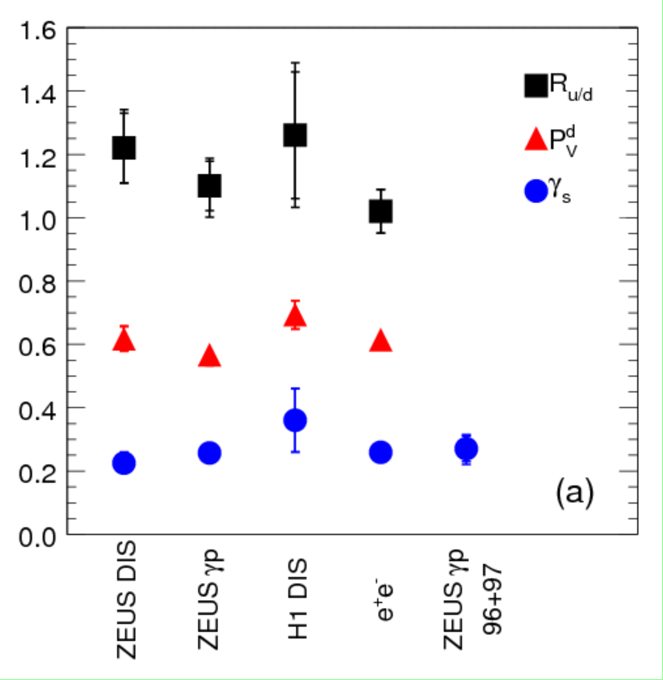
- ❖ Test of perturbative QCD due to the hard scale given by the heavy quark mass.
- ❖ Better understanding of proton structure

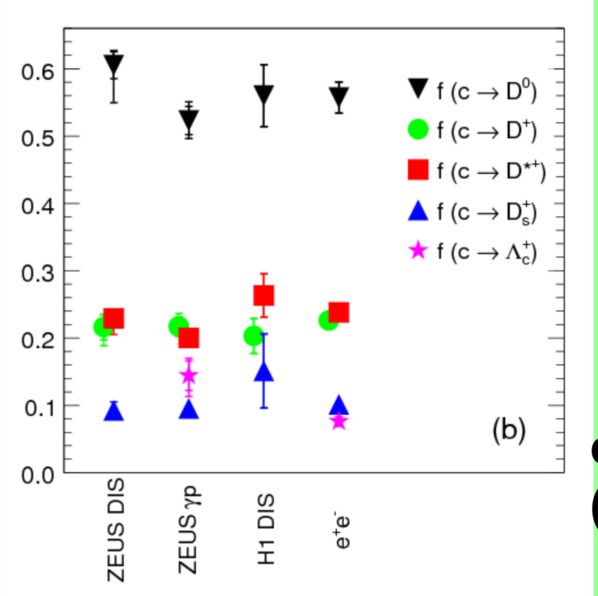
Production of charm mesons



$\sigma(\gamma p \rightarrow D^* X) = f(Q^2)$

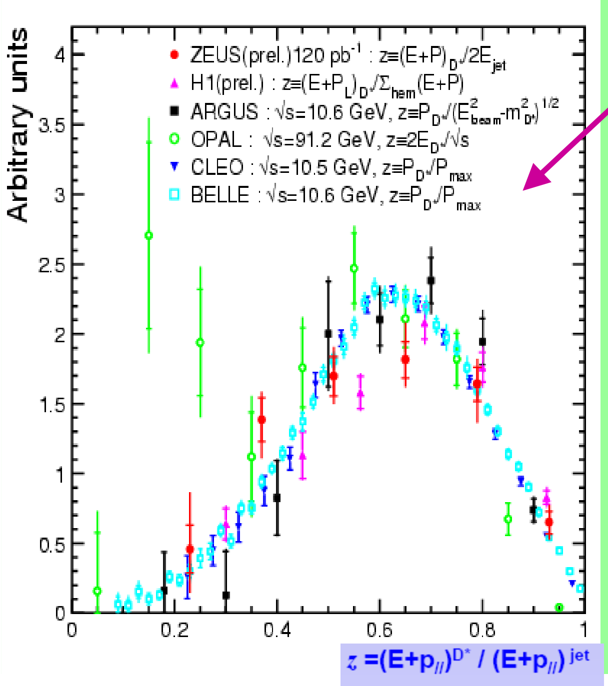
Ratio D^0 to $D^\pm$ production rate, $R_{u/d}$, strangeness suppression factor in charm fragmentation, γ_s, and fraction of $D^\pm$ produced in a vector state, P_v^d





Fractions of c quarks hadronising as D^+, D^0 & D_s^+ charm ground-state mesons, as D* mesons & Λ_c baryons (competitive result with e+e-)

charm-fragmentation function

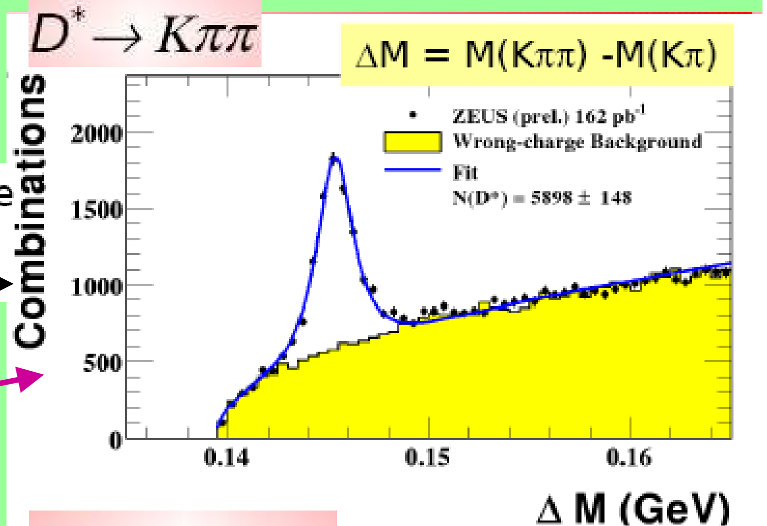


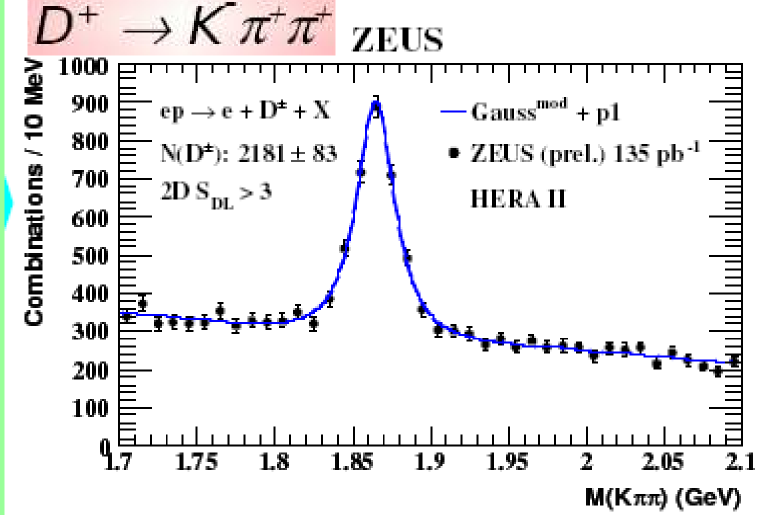
Golden mode: can be double tagged by the slow pion and the D^0 in the final state. →

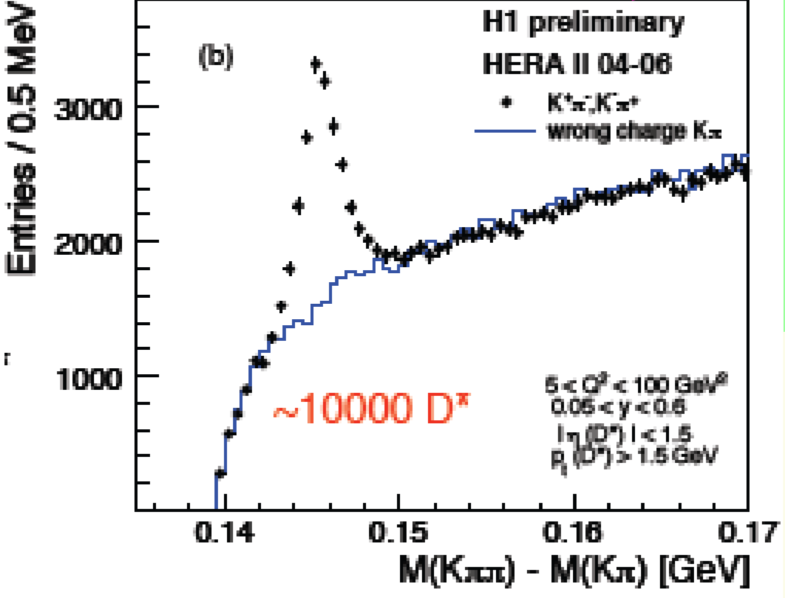
Charm

Spectroscropy

at HERA





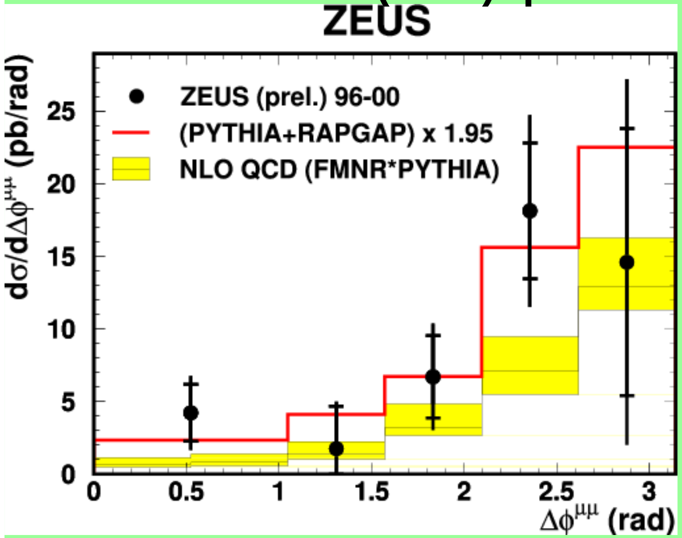


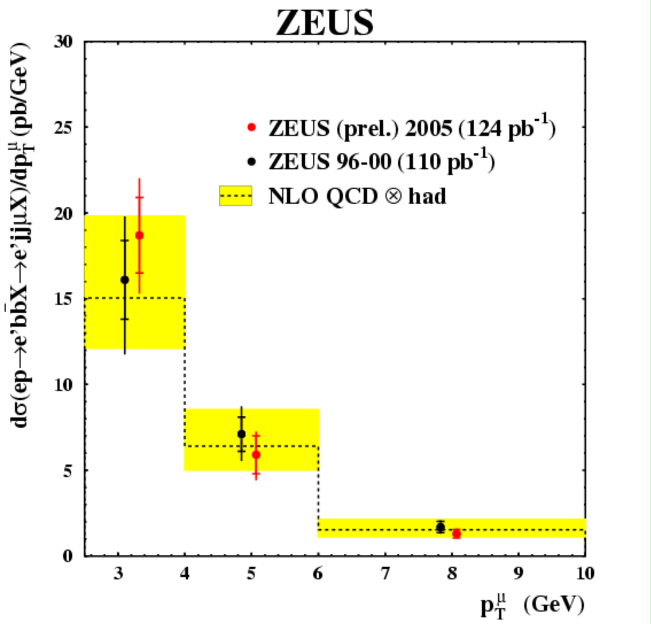
New preliminary result:

$$\sigma^{tot}_{vis}(e^{\pm}p \to e^{\pm}D^{*\pm}X) =$$

$$4.23 \pm 0.09\ (\text{stat.}) \pm 0.37\ (\text{syst.})\ \text{nb}$$

$d\sigma/d\Delta\Phi^{\mu\mu}$ for di-μ events from bbbar decays; each μ originates from a different b(bbar) quark





$d\sigma/dx = f(Pt(\mu))$ with μ from semi-leptonic b decay

Various differential cross-sections of b-quark

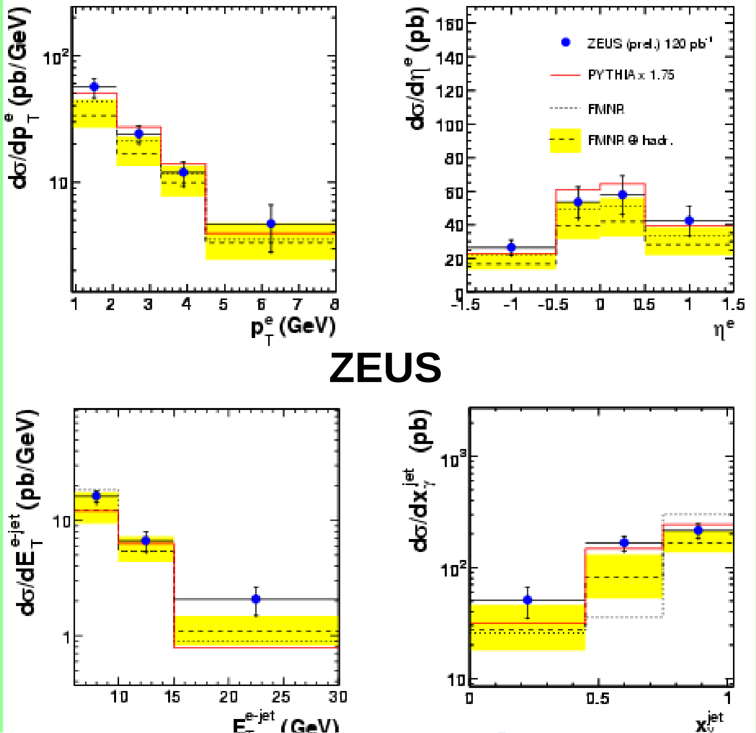
General good

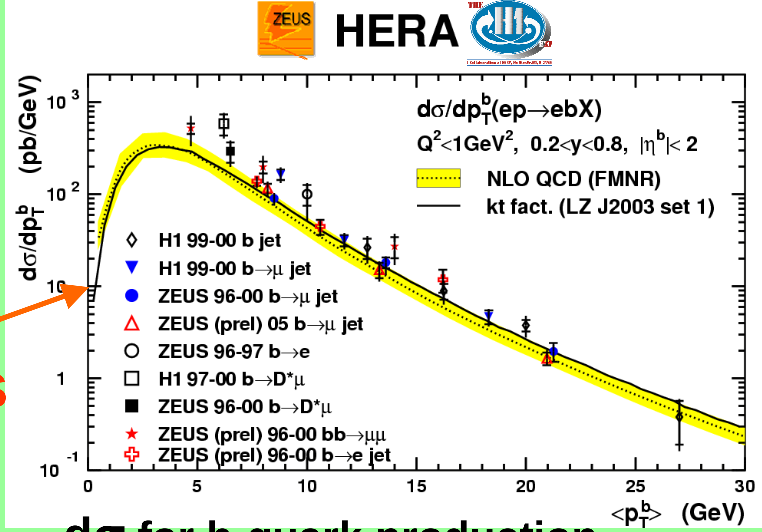
Agreement with NLO

QCD predictions

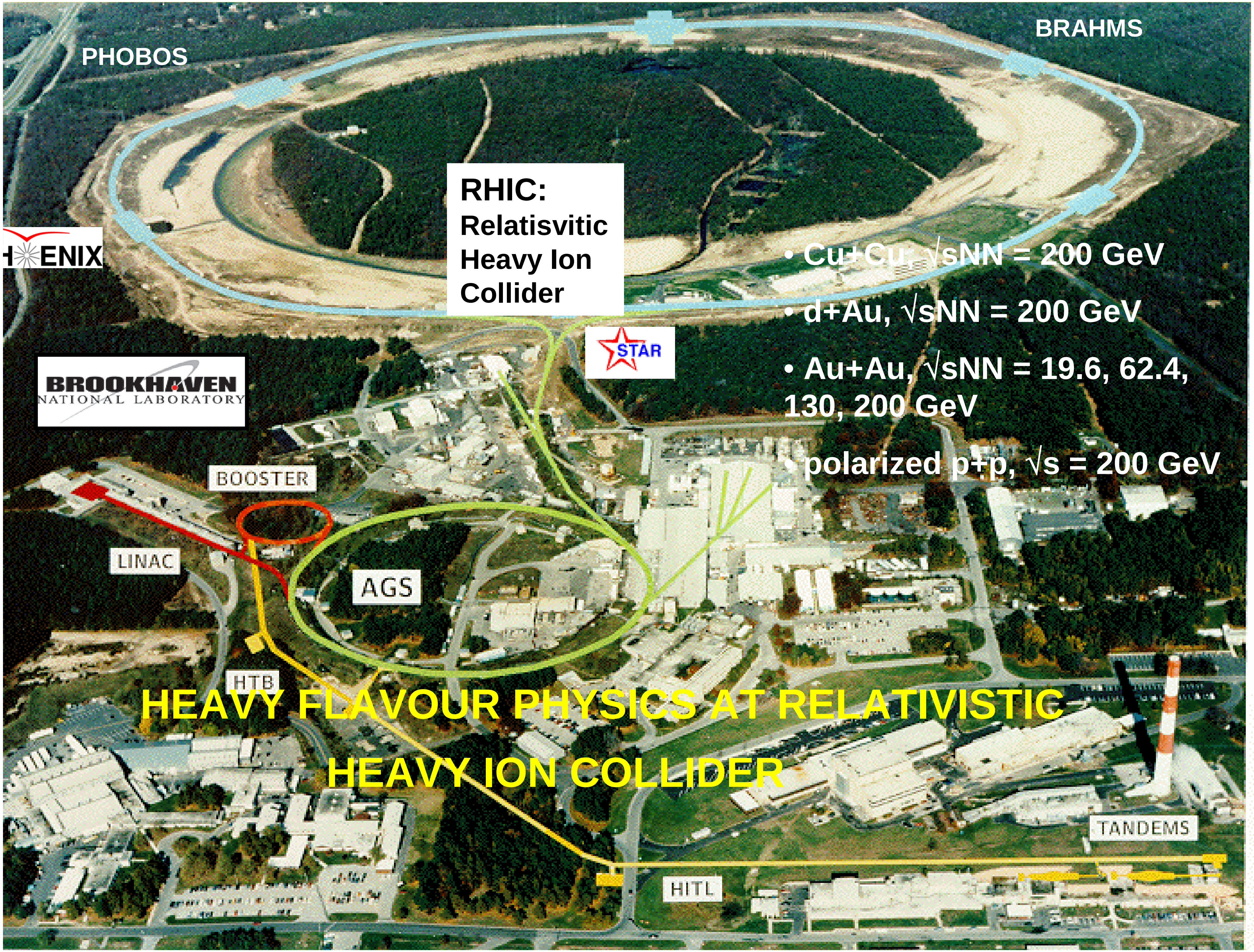
& between H1 & ZEUS

$d\sigma = f(Pt(e-), \eta(e-), x_{\gamma}, Et($ jet rel to e-)





dσ for b-quark production as a function of the b-quark Pt



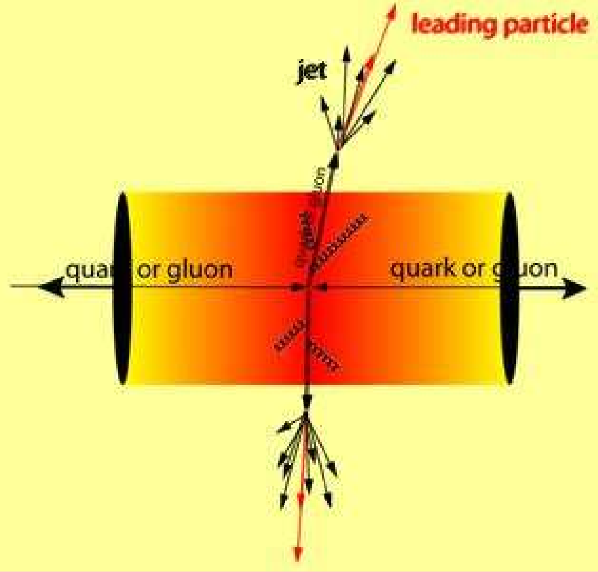
RHIC:
Relatisvitic Heavy Ion Collider

- Cu+Cu, √sNN = 200 GeV
- d+Au, √sNN = 200 GeV
- Au+Au, √sNN = 19.6, 62.4, 130, 200 GeV
- polarized p+p, √s = 200 GeV

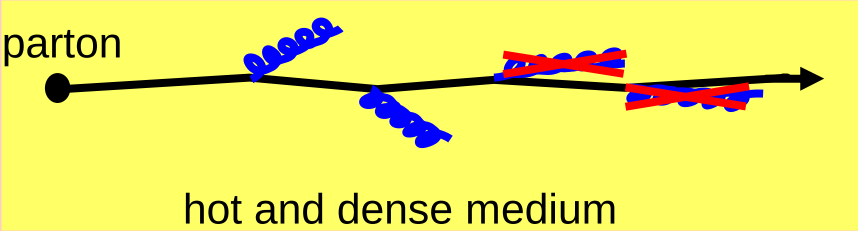
HEAVY FLAVOUR PHYSICS AT RELATIVISTIC HEAVY ION COLLIDER

Heavy quarks as a probe

(courtesy of Jaroslav Bielcik)



- Studying energy loss of heavy quarks → independent way to extract properties of the medium



- Due to their large mass heavy quarks are primarily produced by gluon fusion
→ production rates calculable by pQCD
→ sensitive to initial gluon distribution

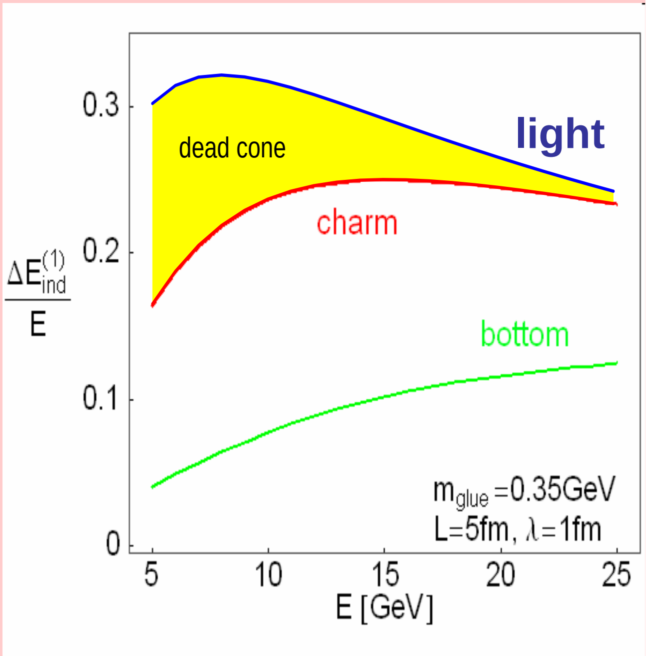
- Heavy quarks lose less energy due to suppression of small angle gluon radiation (dead-cone effect)

Dokshitzer and Kharzeev, PLB 519, 199 (2001)

Amount of collisional and radiative energy losses seems to be similar

M.G. Mustafa, PRC72, 014905

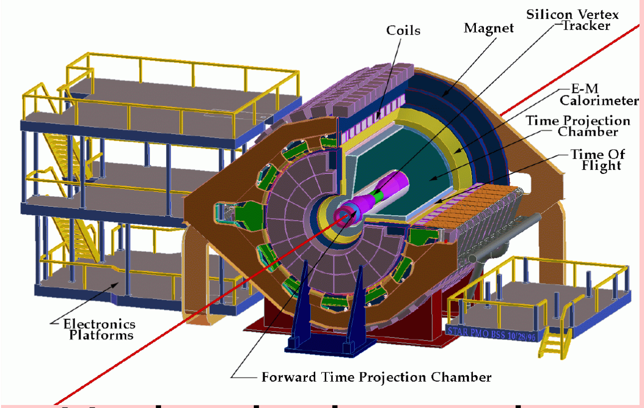
ENERGY LOSS



M.Djordjevic PRL 94 (2004)

⇒ Important to distinguish b vs c: very challenging experimentally

HF measurements at STAR



- <u>Hadronic decay channels:</u> $D^0 \rightarrow K\pi$

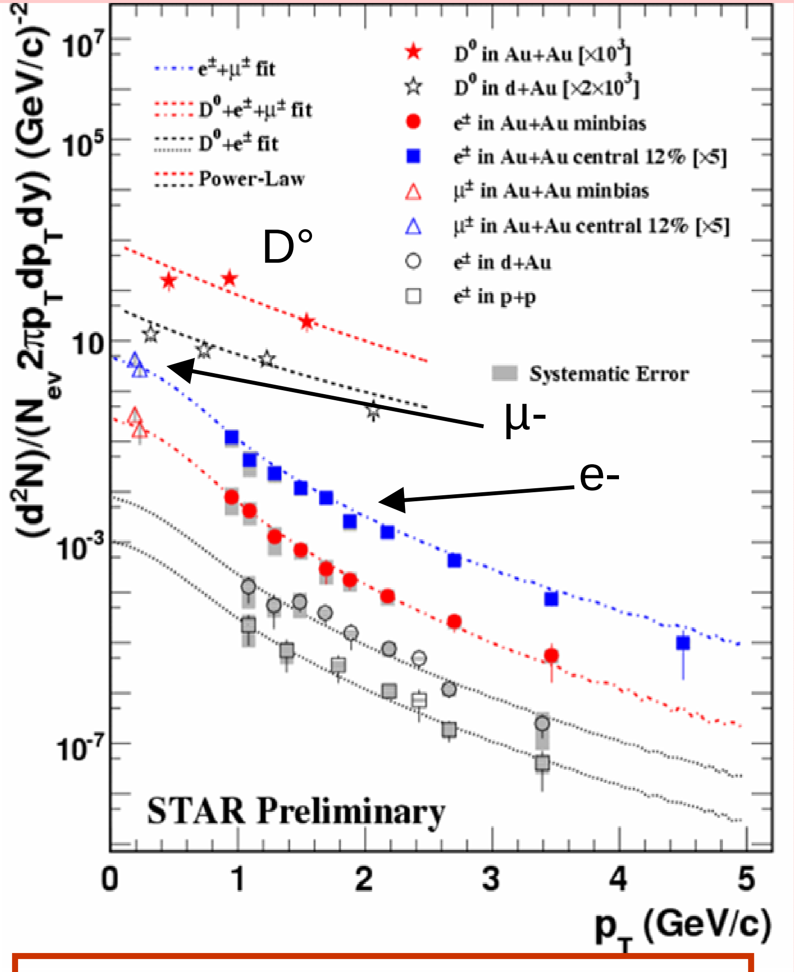
→ Direct clean probe (signal in inv.mass dist)

→ Difficulty: large combinatoric background

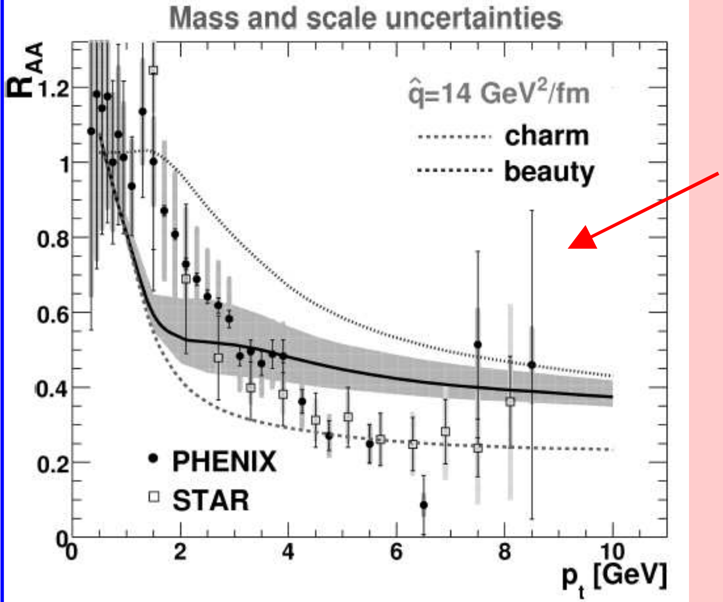
- <u>Semi-leptonic channels (incl. modes)</u>

$c/b \rightarrow \ell^+ +$ anything (B.R.: ~10%) $\ell = e$ or μ

→ Single (non-photonic) electrons sensitive to c & b



$\sigma_{cc} = 1.40 \pm 0.11 \pm 0.39$ mb
in 0-12% most central Au+Au



AuAu: Strong suppression

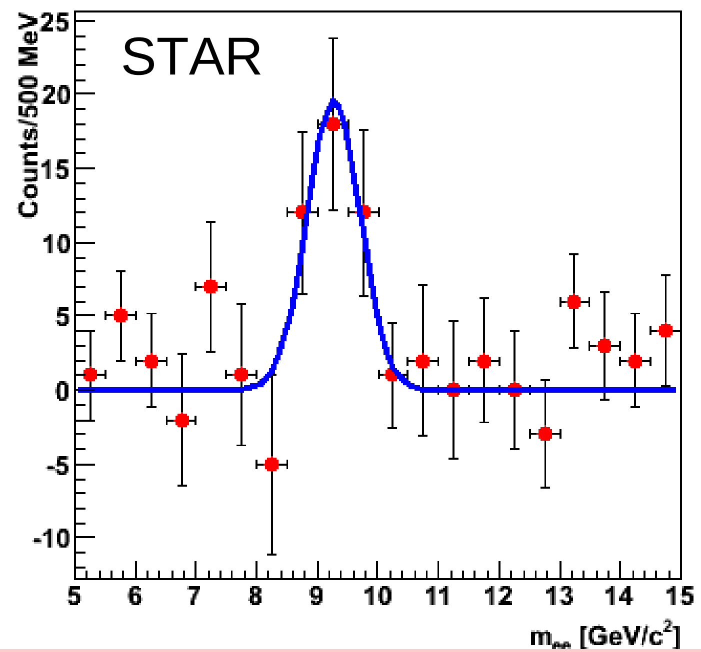
Difficulty to describe it theoretically

⇒ **Both > NLO calculations**

⇒ **STAR ~x2 higher than PHENIX**

Υ(1s+2s+3s) and J/Ψ at RHIC

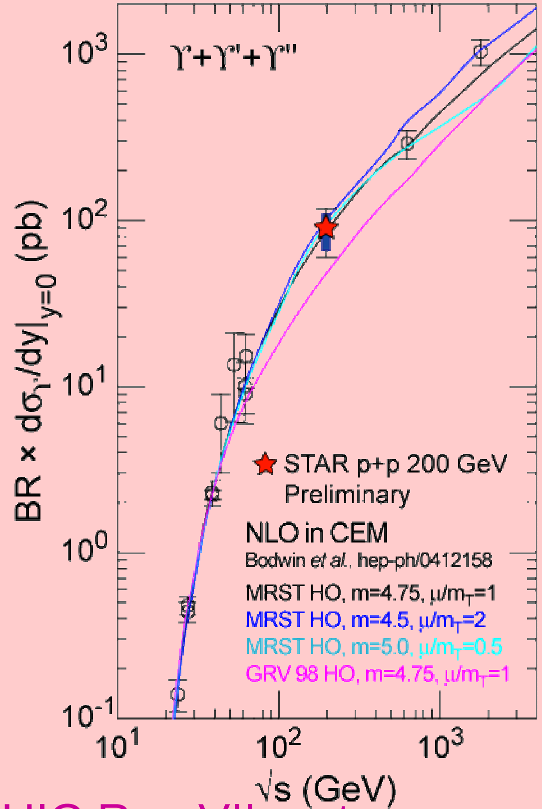
- Large dataset sampled in Run VI
- Measure Υ(1s+2s+3s) dσ/dy at y=0



QM 2006, nucl-ex/0701075

BRee × dσ/dy = 91 ± 28(stat.) ± 22(sys.) pb

Consistent with NLO pQCD calculations & world data trend



PHENIX: J/Ψ

Au Au vs pp:

disappearance

of J/Ψ (?)

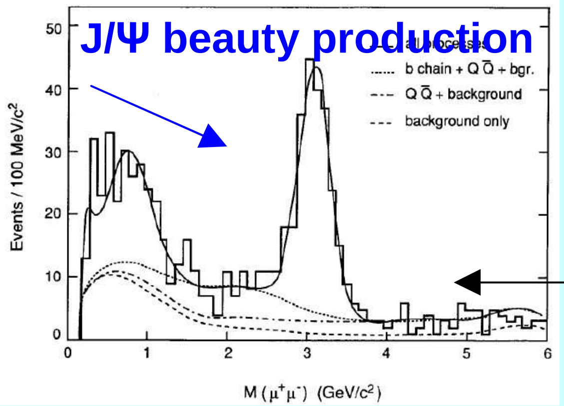
(see next talk)

=> Next: Au+Au measurement in RHIC Run VII on tape are going to be analyzed

More exciting results are about to come with the detector upgrades (full barrel ToF and Heavy Flavour Tracker based on active pixel sensor tech.)

HF Physics at pp colliders

- **The SppbarS proton-antiproton collider with UA1 experiment** = **a precursor**



First hadron collider experiment with high precision

(drift ch.) tracking in B-field+ Muons => B Physics

First observation of B oscillations (Phys.LetB, 186, 1989)

σ(pp→bb +X)=19.3 ±7(exp) ± 9(th) μb;

Phys Let B,256,1991

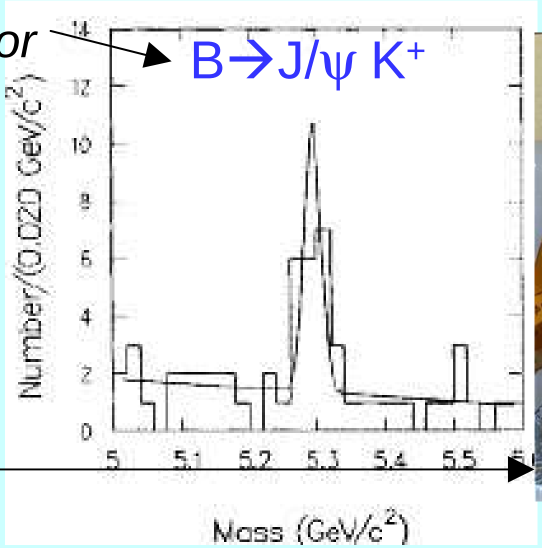
- **The Run I proton-antiproton at Tevatron with CDF I experiment**: **a pioneer**

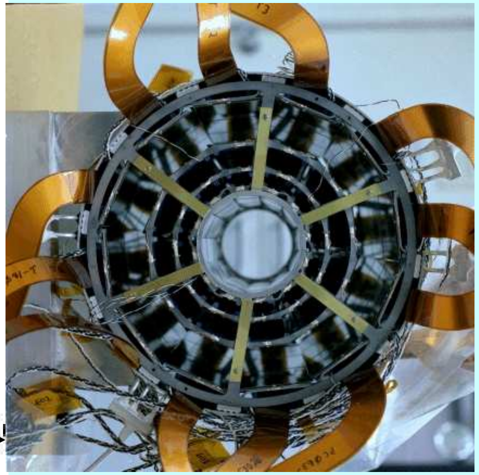
First fully reconstructed B mesons: for CP violation studies (proved to be harder); PRL 68, 1992

Drift Chamber + B field +

L2-track (CTC) +1st μvertex

in pp experiment (1992)



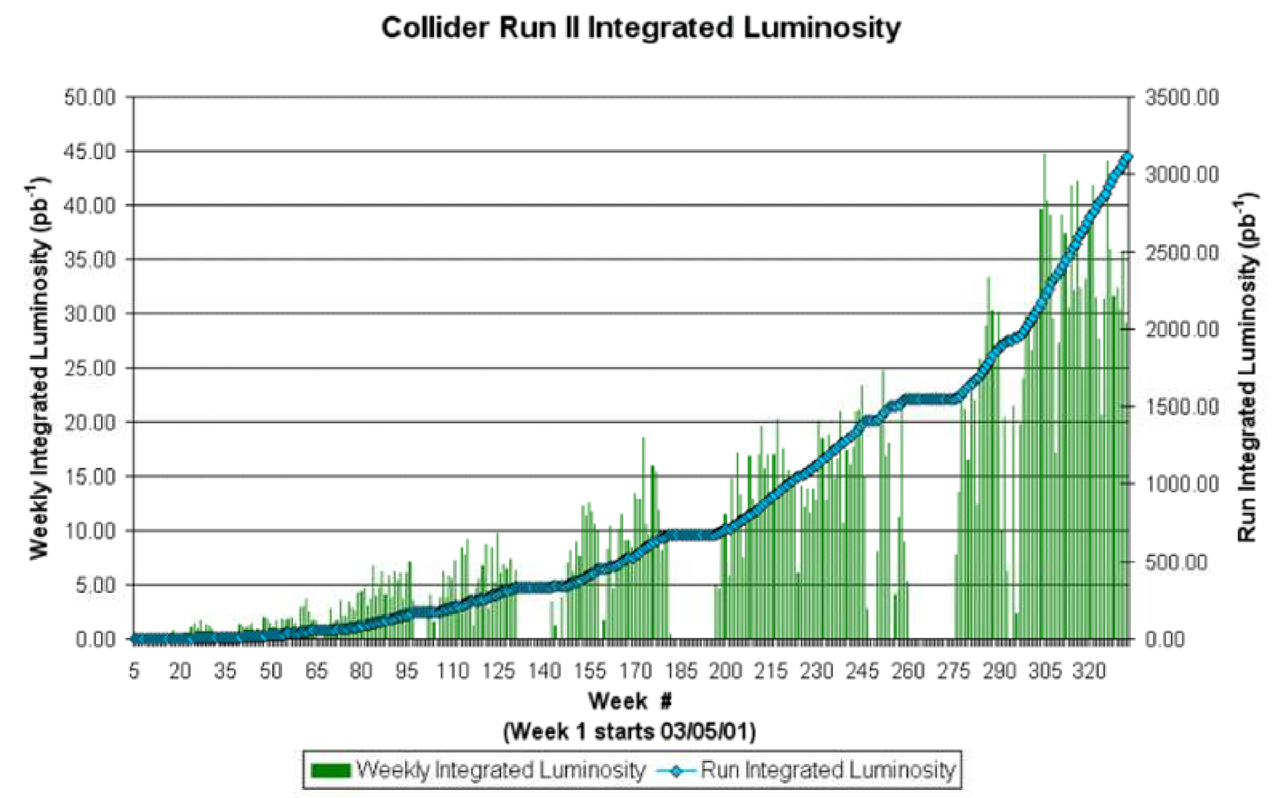


- **The TevatronII, CDFII and D0I I=** **a new HF Physics era with hadron colliders**
- **The LHC with ATLAS, CMS, LHCb & ALICE =** **breaking the N.P. frontiers ?**

Heavy Flavour Physics at the Tevatron: an incredibly successful year!

Discoveries, breakthroughs and much more still to come

The Tevatron is doing quite well!

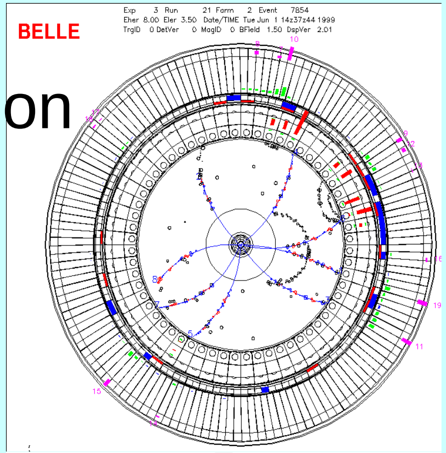


More than 3.2 fb^{-1} delivered/experiment, more than 2.7 fb^{-1} recorded/experiment, about 40pb^{-1} delivered per week, max peak luminosity: 2.85x10^{32} cm^{-2}s^{-1}

Heavy Flavour Physics at the Tevatron
(true for any hadron collider)

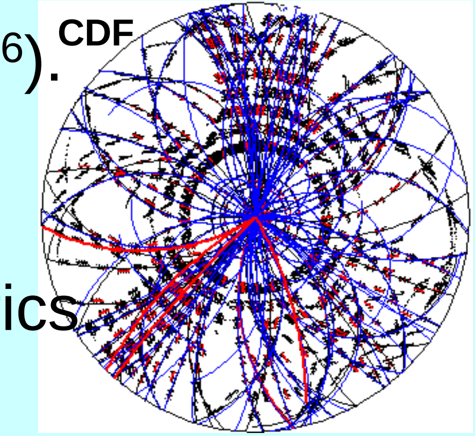
The Good

$b\bar{b}$ production x-section O(10^5) larger than e^+e^- at Y(4S) /Z^0. Incoherent strong production of all *b*-hadrons: B^+, B^0, B^0_s, B_c, Λ_b, Ξ_b …



The Bad

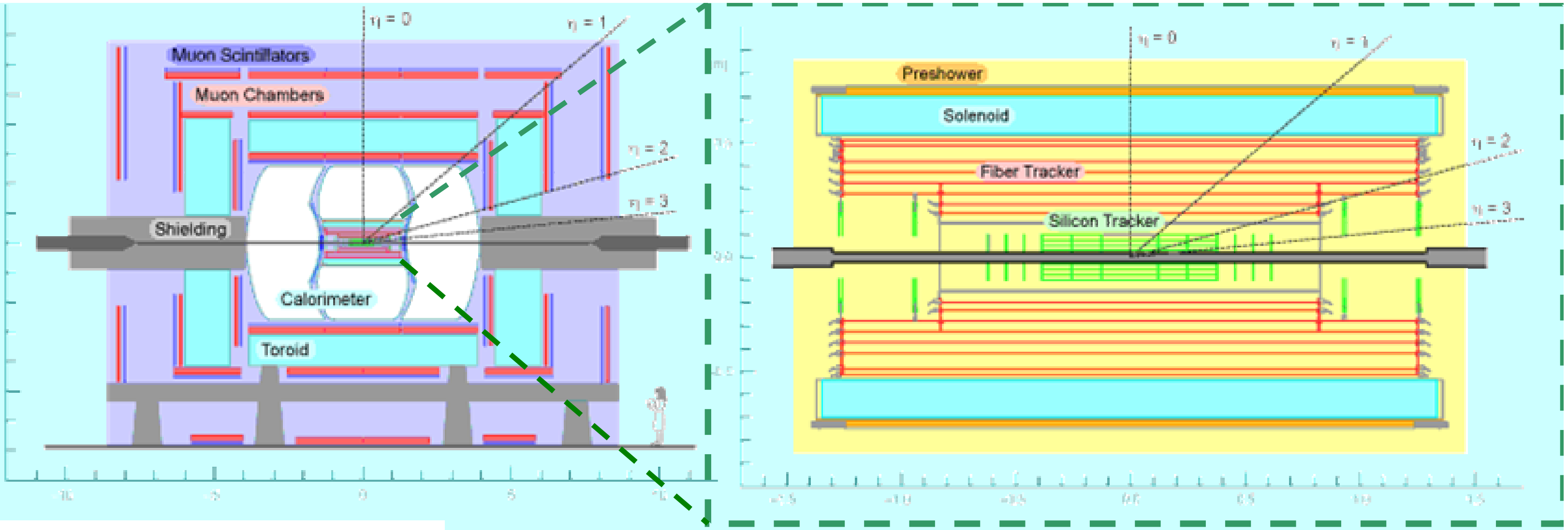
Total inelastic x-section ×10^3 larger than $\sigma(b\bar{b})$. BRs' for interesting processes O(10^{-6}).

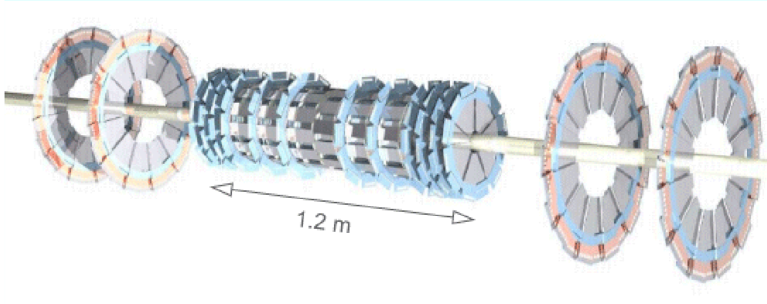


…and The Ugly

Messy environments with large combinatorics

=> Mandatory: highly selective triggers

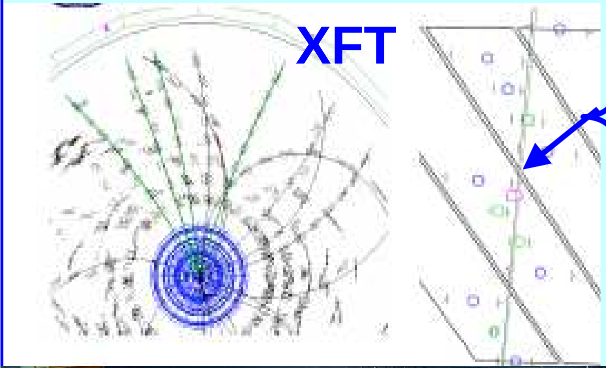




- Excellent coverage of the Muon and tracking η <2
- Excellent calorimetry & electron ID
- High efficiency muon trigger with Pt measurement at Level 1 (toroid)
- 2T solenoid & 1.8 T toroidal reversed weekly (OK for μ asymmetry systematics)

Trigger	CDF	D0
2 Tracks	Pt> 2GeV/c Pt1+Pt2>5.5GeV/c 100μm<ld12l<1mm	No
1-muon	No	Pt(μ)>3, 4.5GeV/c
2-muon	Pt(μ's)>1.5GeV/c	Pt(μ's)>2.0 GeV/c

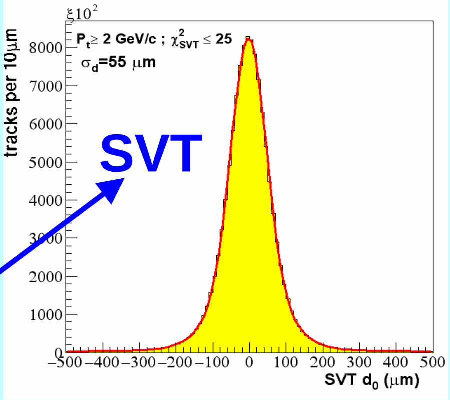
High Precision Drift + Si Tracking & L1xL2 Track Triggering

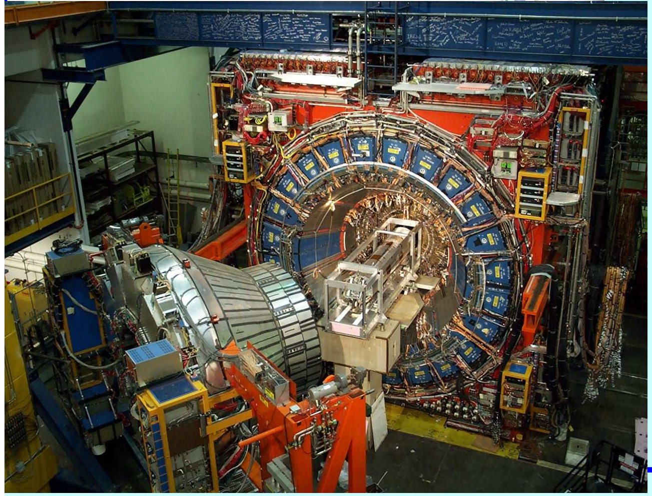


Finds Pt>1.5GeV tracks in 1.9μs For every bunch Crossing

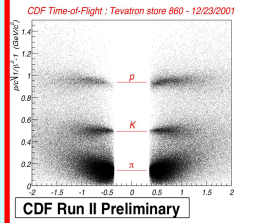
σ(1/Pt)=1.7%/GeV

35μm ⊕ 33μm resol ⊕ beam ⇒ σ = 48μm

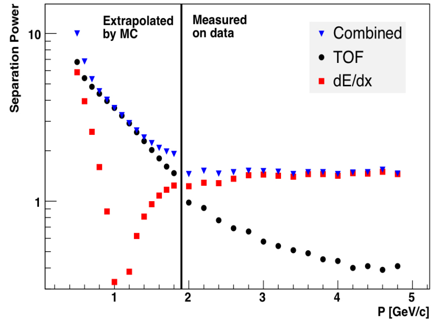




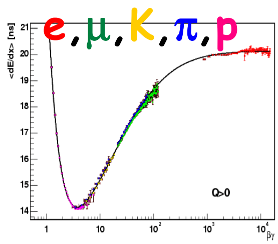
Particle ID

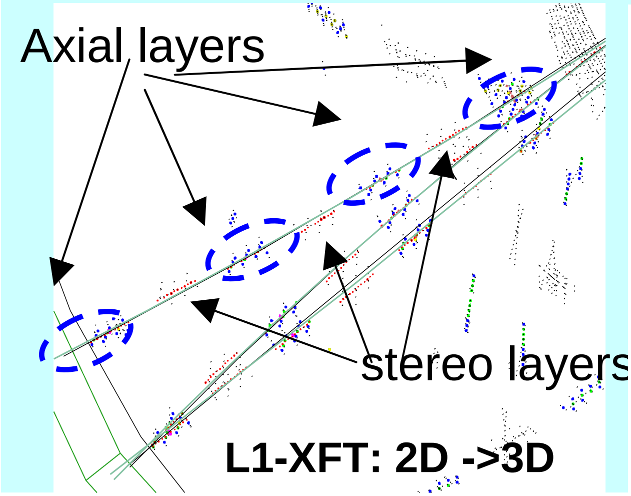


ToF

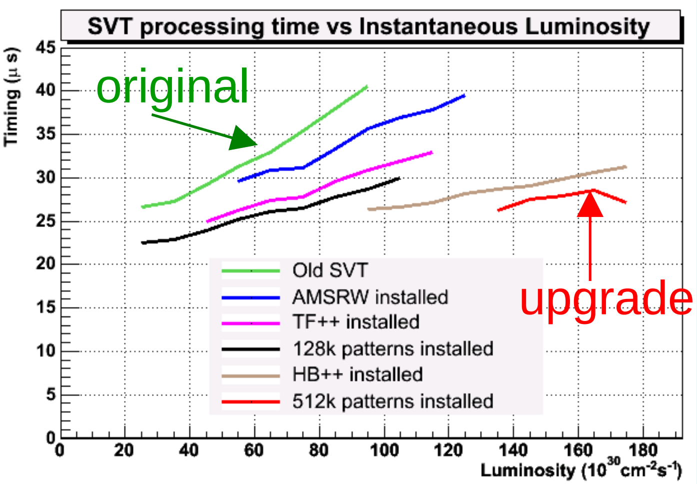


dE/dx





L1-XFT: 2D ->3D



Luminosity increase

Upgrade =>

- good data @ High L
- more data @ Low L

L2-SVT: faster devices

& new AM 32K→ 512K patterns

Track Triggers and B Physics

Di-Muon (J/ψ)

- Pt(μ) > 1.5 GeV

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

ψ(2S), X(3872)→J/ψππ (quarkonia)

$B_s \rightarrow J/\psi\ \phi$, $B_{u,d} \rightarrow J/\psi\ K^{(*)}{}_s$ $\Lambda_b \rightarrow J/\psi\ \Lambda$ (masses, life-times, mix. calibration)

$B_{s,d} \rightarrow \mu\mu$ (rare decays)

$\Upsilon \rightarrow \mu\mu$

Bc (part.rec.B→J/ψ lX)

Displaced trk + lepton (e, μ)

- $p_T(l) > 4.$ GeV
- $p_T(\text{track}) > 2.0$ GeV
- $120 < d_0 < 1000\mu m$

Semileptonic modes

High statistics lifetime

Sample for tagging

studies, mixing

2 displaced trk

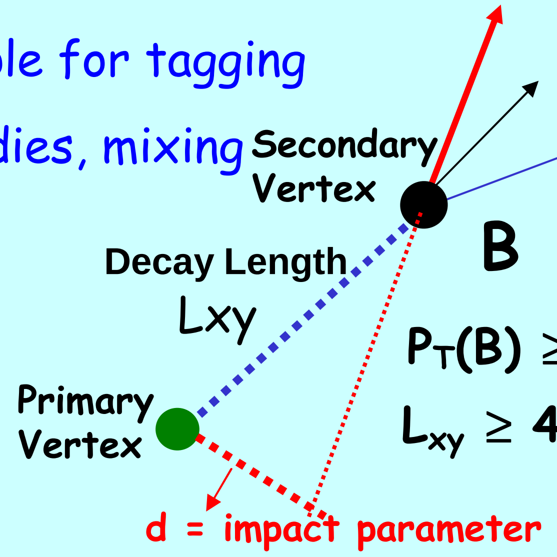
- $p_T(\text{trk}) > 2$ GeV
- $\Sigma\ p_T(\text{trk}) > 5.5$ GeV
- $120 < d_0 < 1000\mu m$

Fully hadronic modes

- CP asymmetry in 2-body charmless decays

- B_S mixing

- Charm physics



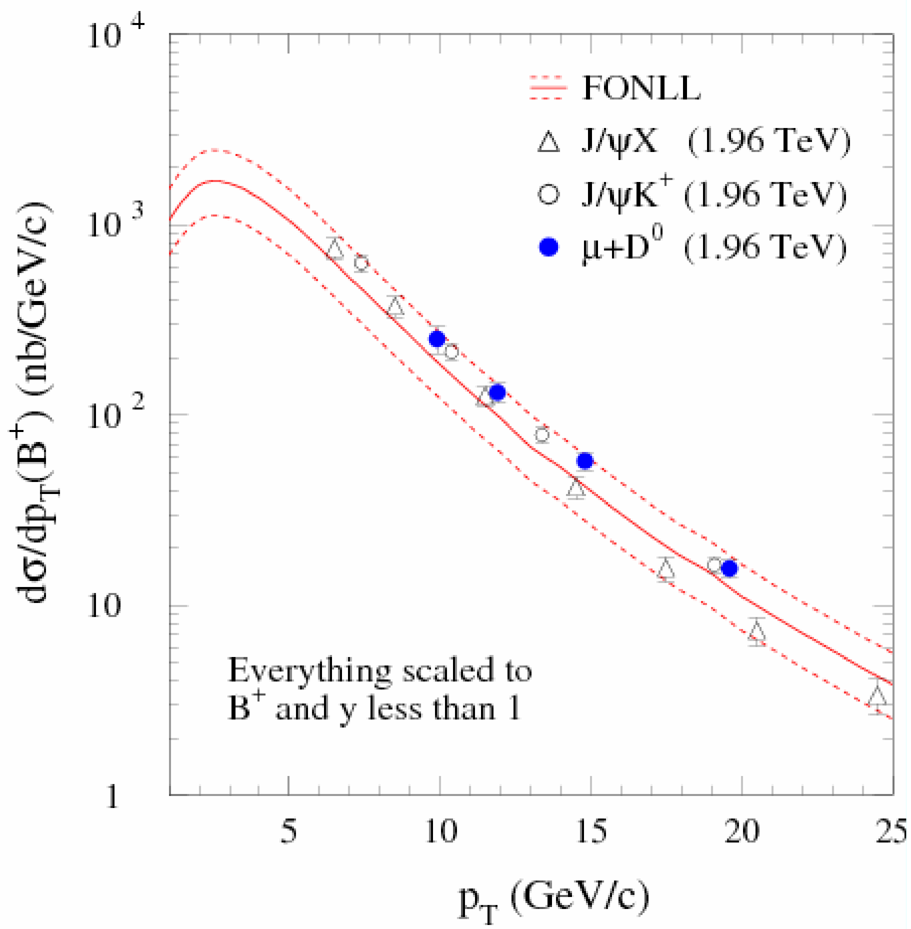
$P_T(B) \geq 5$ GeV

$L_{xy} \geq 450\mu m$

Understanding b cross sections

better experimental inputs to calculations (a community effort)

- PDFs, Frag. Funct., α_s
- better calculation: FONLL
- more accurate measurements

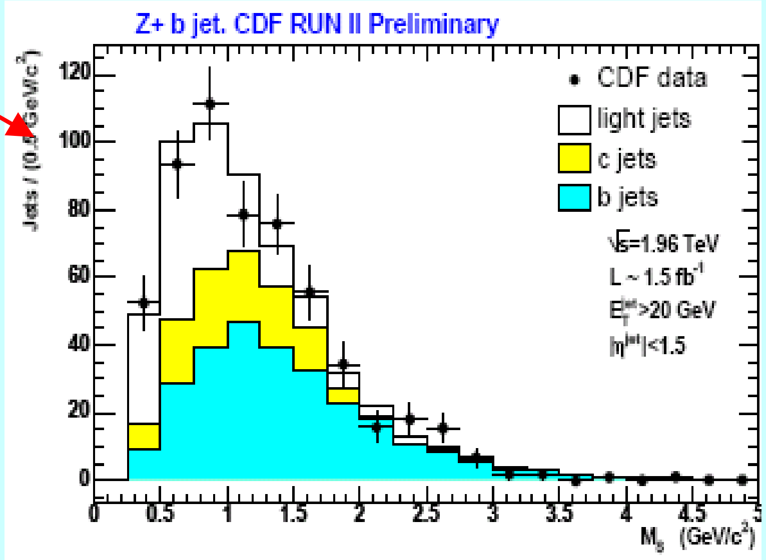


CDF II measurement error down to 10%. In agreement with theory

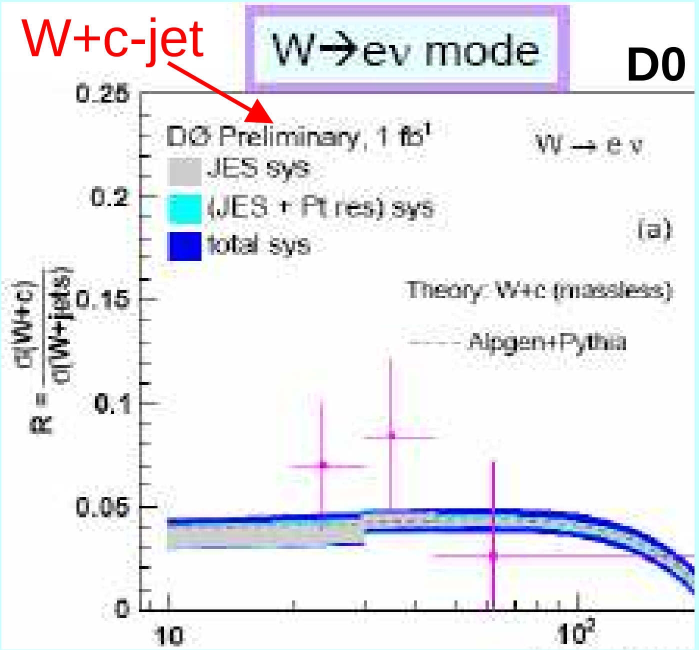
b/c-Jets production at Tevatron

W/Z+HF not yet fully studied, now starting to characterize at Tevatron.

Z+b-jet



W+c-jet



CDF measures: 0.90±0.32 pb for **W+bb**

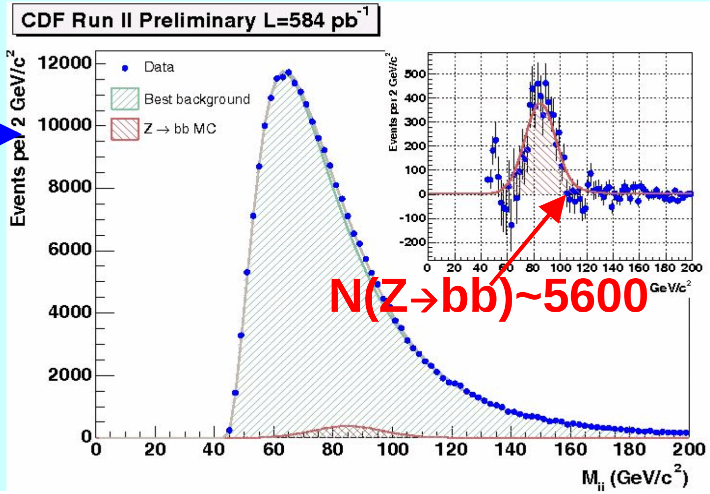
(E_T(j)>20 GeV, |η|<2.0)

LO calculation (ALPGEN): 0.74±0.18 pb

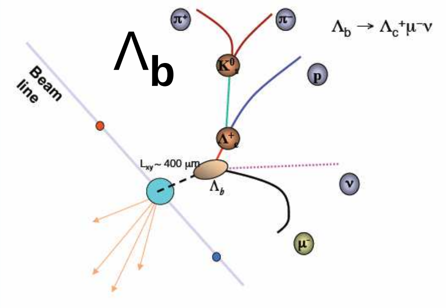
- b-jet energy scale and **Z->bb**
- New generation NN Jet Flavor Tagger being developed at CDF and being tested in Z+b, Z+c measurement

Lot of work in progress at CDF & D0

Important for many Physics issues

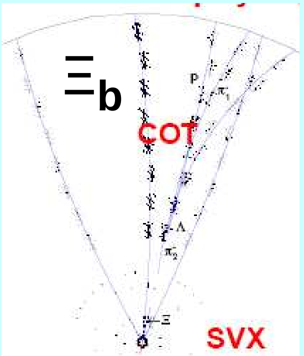


N(Z→bb)~5600



Heavy Flavour Spectroscopy

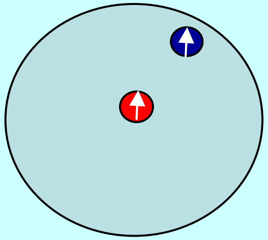
Discoveries of new hadrons, decays, mass and lifetimes measurements

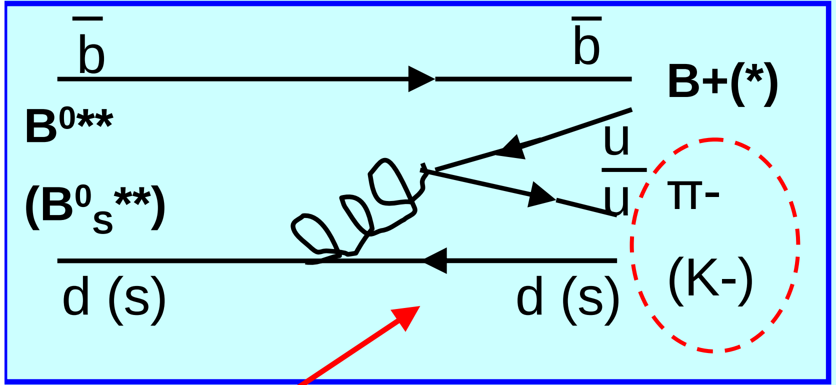


Not just about updating a number in the PDG!

- Width (i.e. lifetime) related to dynamics governing the decay. Decaying quarks bound into hadrons. Lifetime probes interplay between weak (decay) and strong (bounding) forces.
- Tests QCD in non-perturbative regime i.e. validity of effective models for heavy-flavour quantities.
- Situation far from being resolved. Λ^0_b lifetimes always showed puzzling behaviour in theory-experiment comparison (CDF).
- Lifetime tools necessary for width-difference measurement.

Orbitally Excited B^{0**} & $B^0_s{}^{**}$ Mesons:



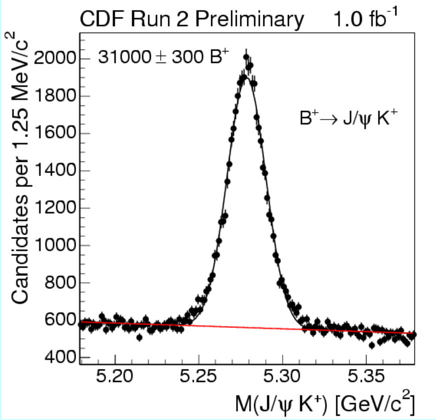


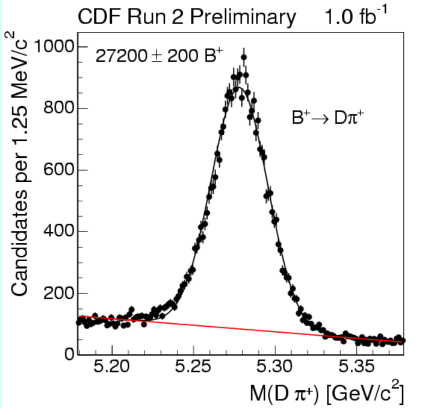
Why study the spectroscopy of heavy-light systems?

- *Like H-atoms: bound by strong interaction*
- *M(B**s)~ hyperfine H structure but for QCD*
- *B**'s probe the potential in a new regime*

Basic analysis idea: add a ''soft'' π

B^+ decays

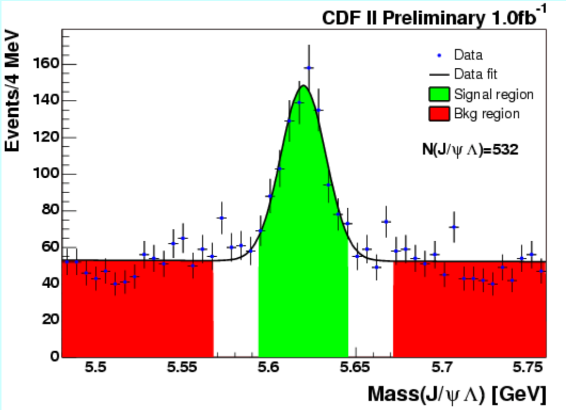


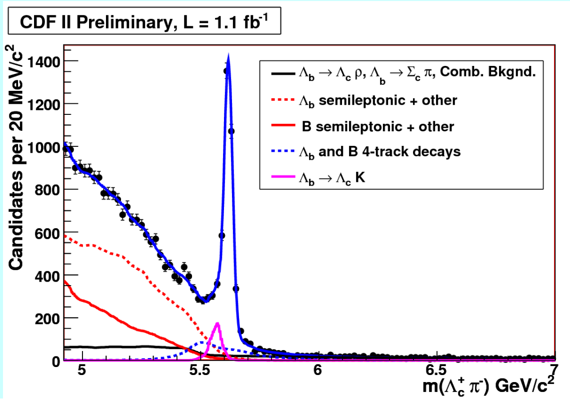


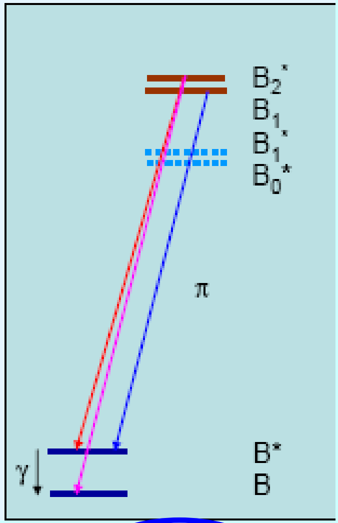
J/Ψ trigger

Hadronic B trigger

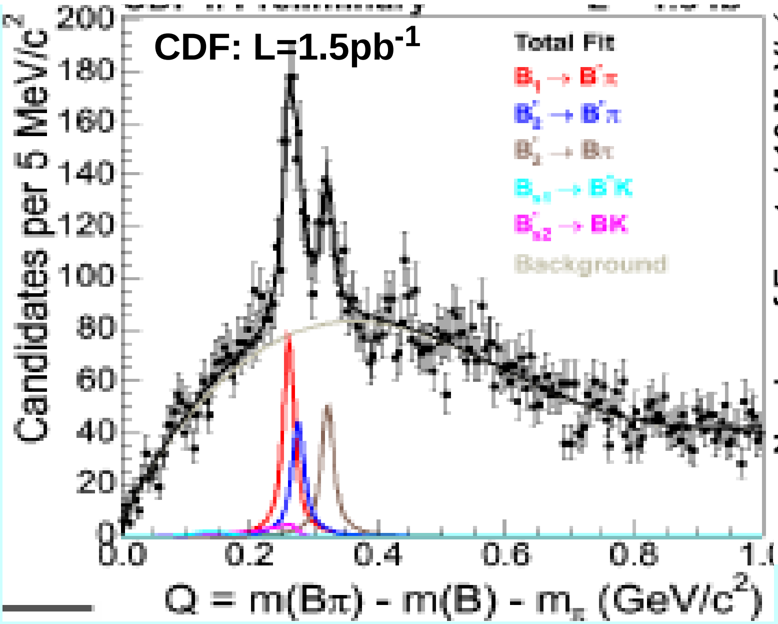
Λ^0 decays

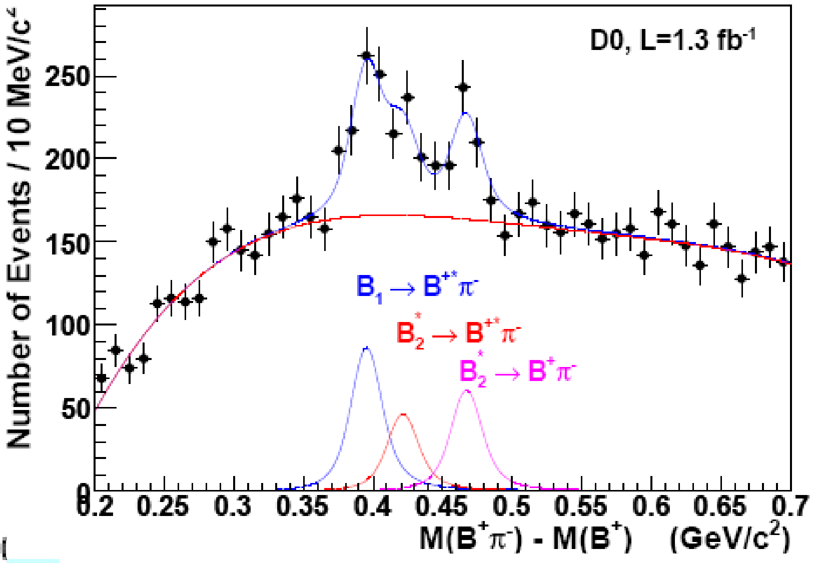






B^{0**}

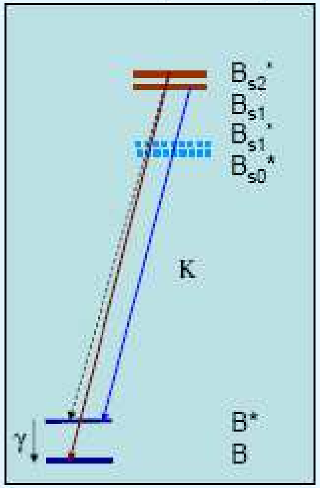


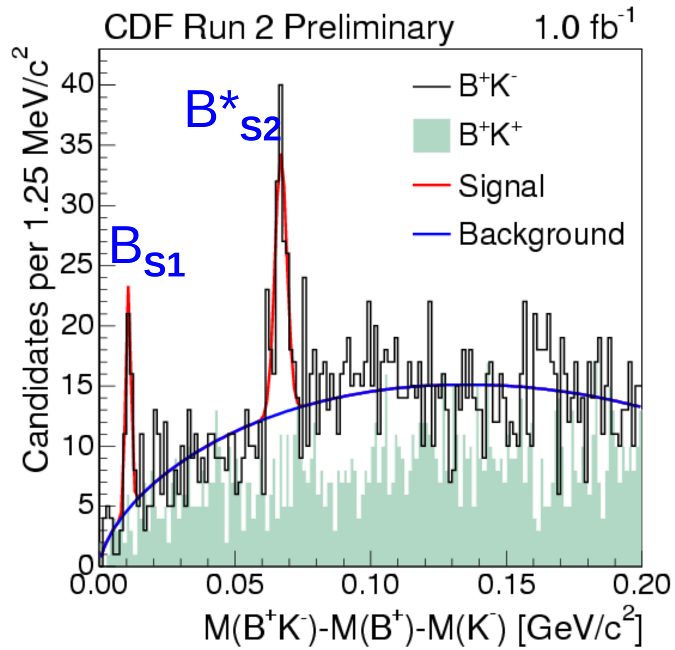


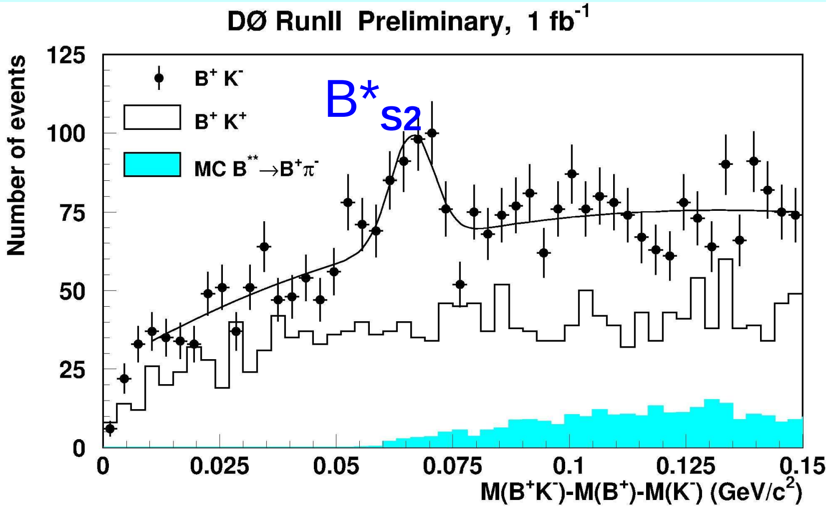
$$M(B_1) = 5720.6 \pm 2.4 \pm 1.4 \text{ MeV}/c^2,$$
$$M(B_2^*) = 5746.8 \pm 2.4 \pm 1.7 \text{ MeV}/c^2.$$

B_s^{**}

B_s^{**} : same transitions as for B^{0**} except substitute p→K. Expected:

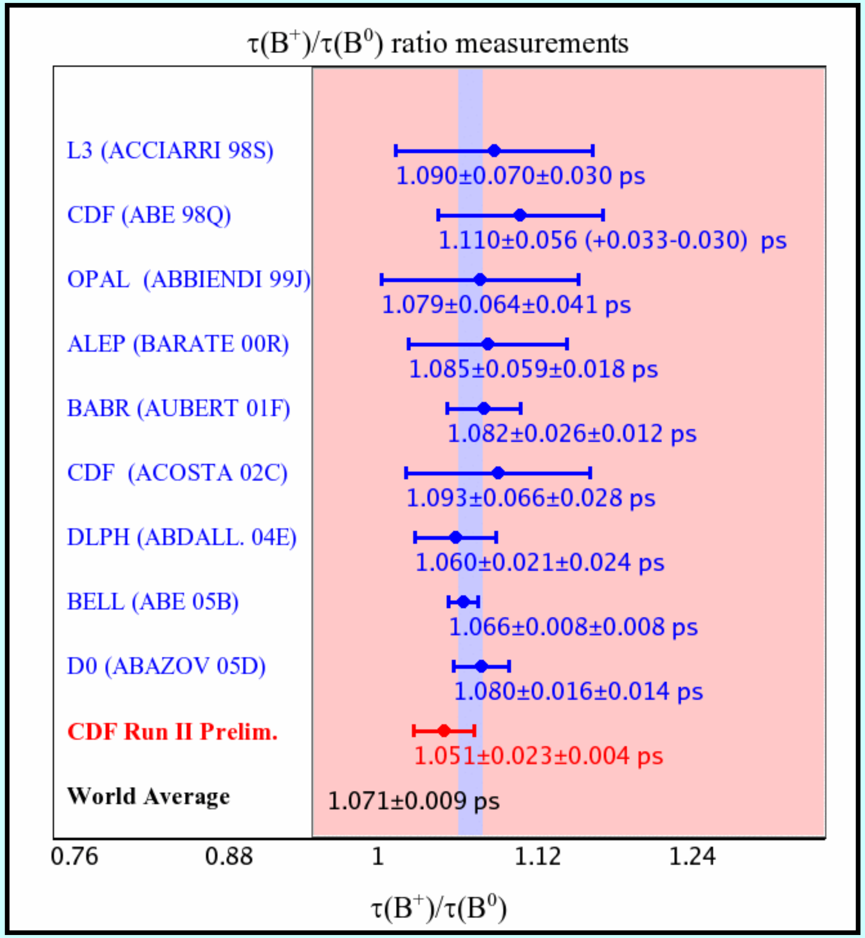


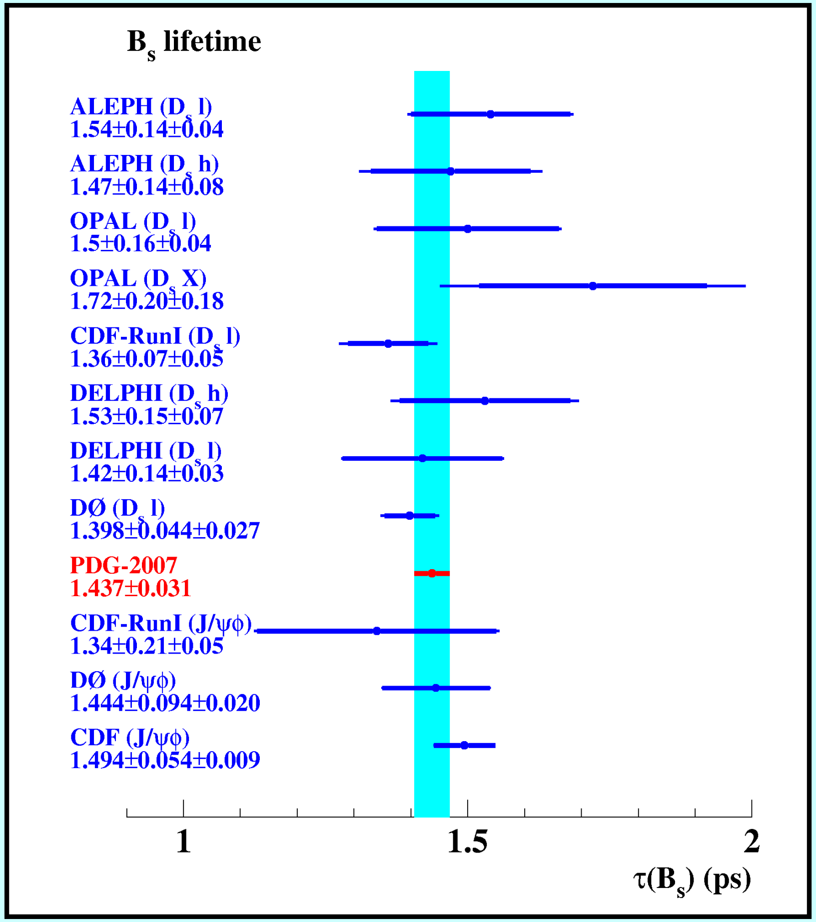




B_{s1}: only at CDF 6.3σ significance

B lifetimes: new results





$$\tau(B^+) = 1.630 \pm 0.016 \pm 0.011\,\text{ps}$$

$$\tau(B^0) = 1.551 \pm 0.019 \pm 0.011\,\text{ps}$$

$$\tau(B^+)/\tau(B^0) = 1.051 \pm 0.023 \pm 0.004$$

$$\tau(B_s^0) = 1.494 \pm 0.054 \pm 0.009\,\text{ps}$$

Heavy Flavoured baryon: Λ_b

NEW

Semi Leptonic decay:

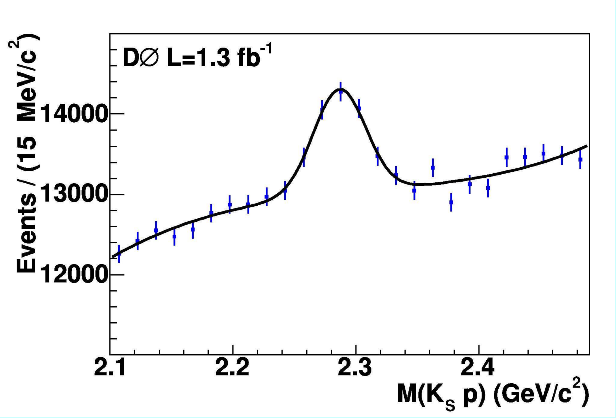
$\Lambda^0_b \rightarrow \mu\, \bar{\nu}\, \Lambda^+_c X$

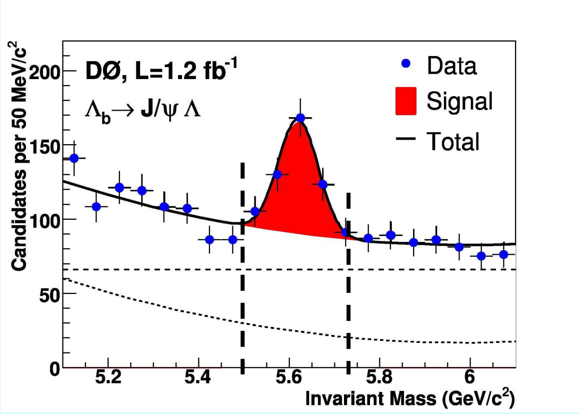
Hadronic decay:

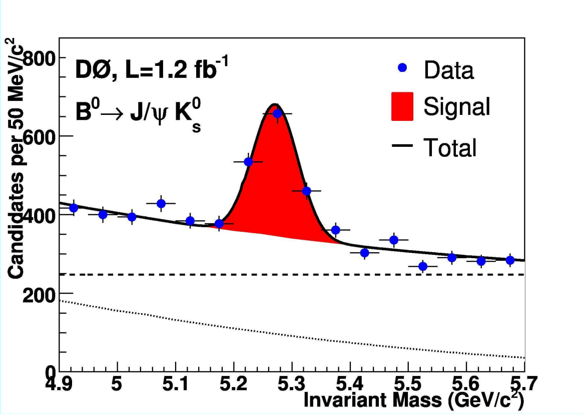
$\Lambda^0_b \rightarrow J/\Psi(\rightarrow\mu\mu)\ \Lambda(\rightarrow p\pi)$

And:

$B^0 \rightarrow J/\Psi(\mu\mu)\ K^0_s(\pi\pi)$

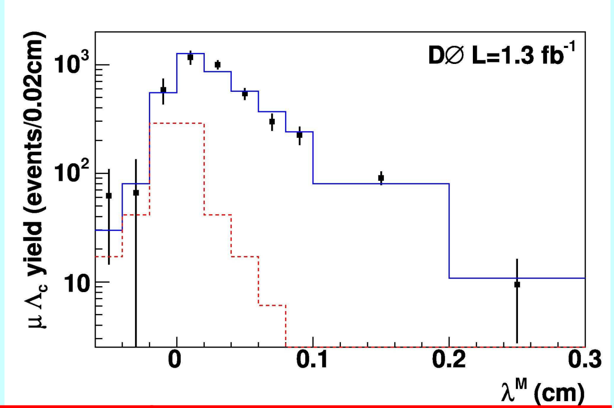


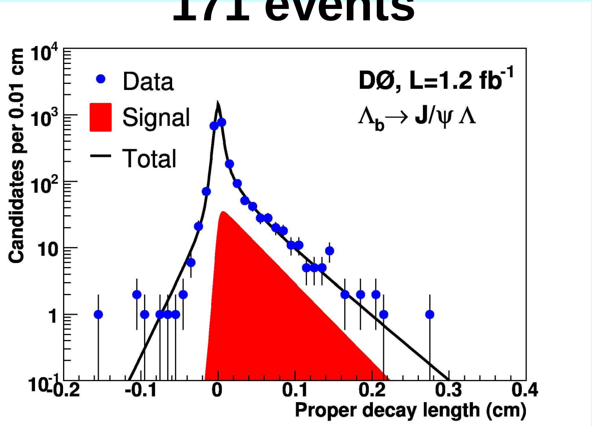


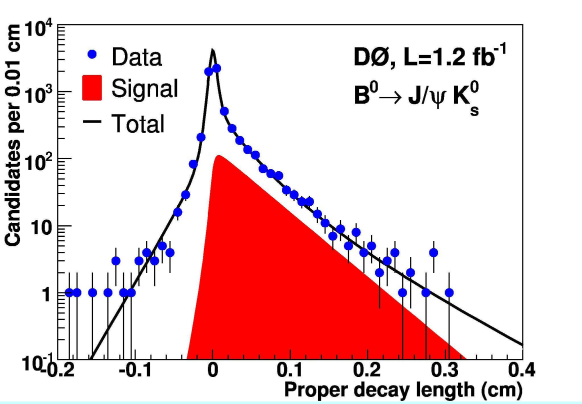


4437 ±329 signal candidates

171 events







Λ^0_b Lifetime (ps):

$1.290^{+0.119}_{-0.110}(\text{sta})^{+0.087}_{-0.091}(\text{sys})$

Λ^0_b Lifetime (ps):

$1.218^{+0.130}_{-0.115}(\text{sta})\pm0.042(\text{sys})$

B^0 lifetime (ps):

$1.501^{+0.078}_{-0.074}\ (\text{st})\ \pm0.050(\text{sy})$

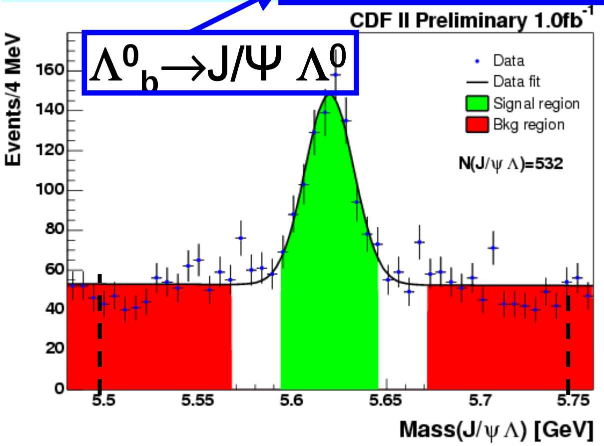
Among most precise semi-lept.

$\tau(\Lambda^0_b)/\tau(B^0) = 0.811\ ^{+0.096}_{-0.087}(\text{sta})\pm0.042(\text{sys})$

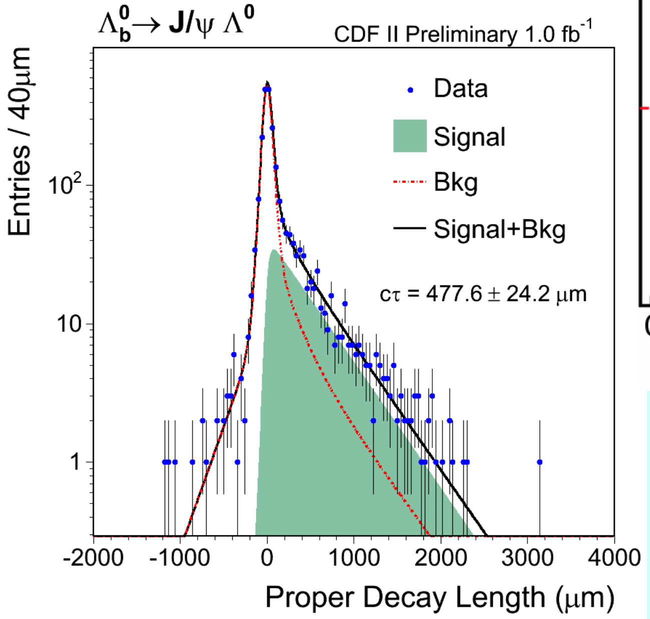
COMBINED RESULT: $\tau(\Lambda^0_b)$ = 1.251+0.102-0.096 ps =>Agreement with world average

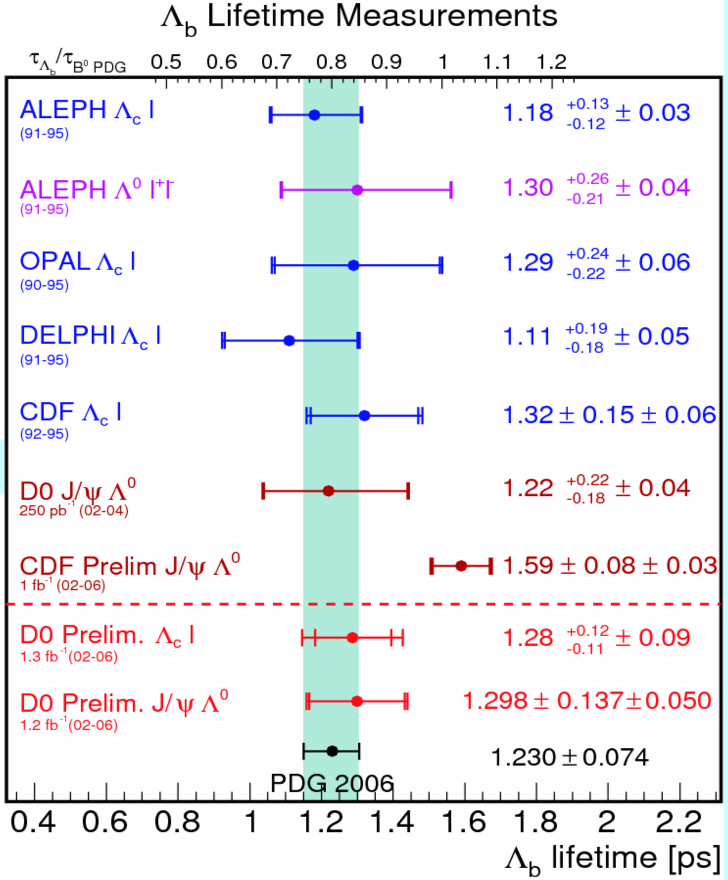
Heavy Flavoured baryon: Λ_b lifetime

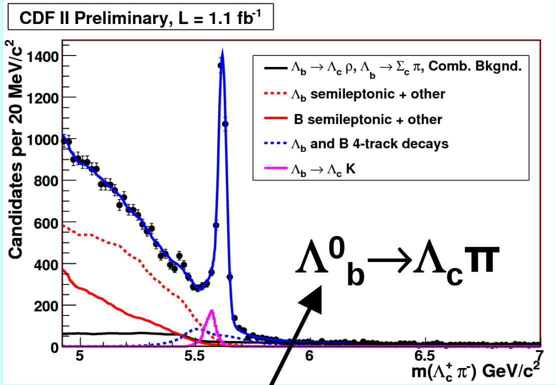
Fully reconstructed channel with best uncertainty



532 events **(not used for Σ_b)**







Another decay channel under study:2.8K evts

New results soon, and:

$\Lambda^0_b \to \Lambda_c^+ K^-$ & $\Lambda_c^+ 3\pi^-$

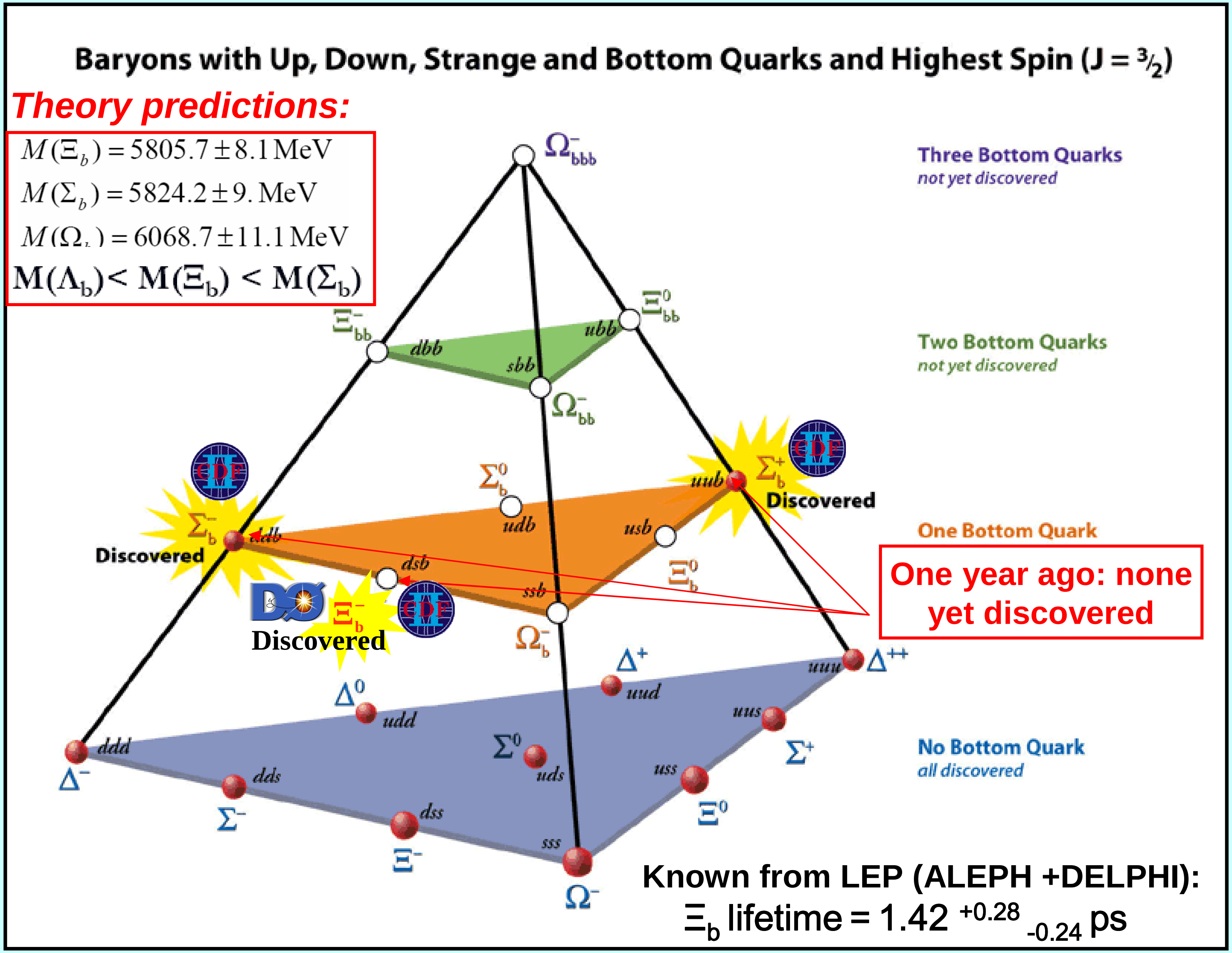
$$1.593^{+0.083}_{-0.078}\ (\text{stat.}) \pm 0.033\ (\text{syst.}) = \tau(\Lambda^0_b)$$

$$1.018 \pm 0.062\ (\text{stat}) \pm 0.007\ (\text{syst}) = \tau(\Lambda^0_b)/\tau(B^0)$$

(QCD:0.88±0.05)

Most precise result. But ~3σ wrt world average, QCD expectations & D0

New Heavy Flavoured baryons



Theory predictions:

$M(\Xi_b) = 5805.7 \pm 8.1\,\text{MeV}$

$M(\Sigma_b) = 5824.2 \pm 9.\,\text{MeV}$

$M(\Omega_b) = 6068.7 \pm 11.1\,\text{MeV}$

$\mathbf{M(\Lambda_b) < M(\Xi_b) < M(\Sigma_b)}$

One year ago: none yet discovered

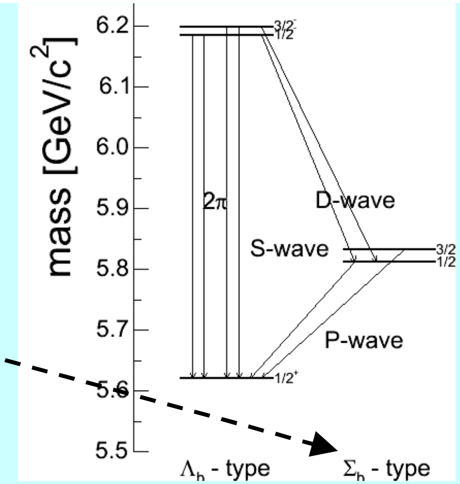
Known from LEP (ALEPH +DELPHI):

Ξ_b lifetime = $1.42^{+0.28}_{-0.24}$ ps

Σ_b Baryons discovery

State knowledge on Heavy b-hadrons last year: B_s seen by UA1(1987); Λ_b seen by LEP & CDF I
Tevatron II: large cross-section and samples of Λ_b baryons.

First heavy baryon to look for



Σ_b Reconstruction

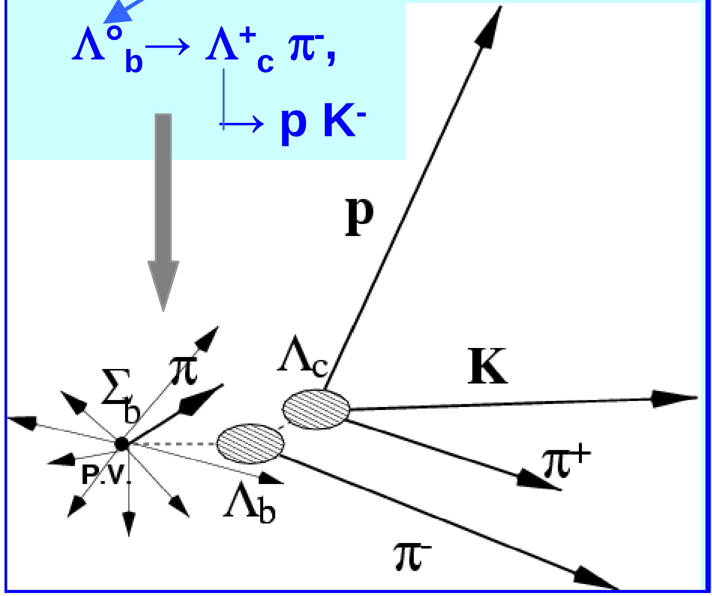
Strategy:

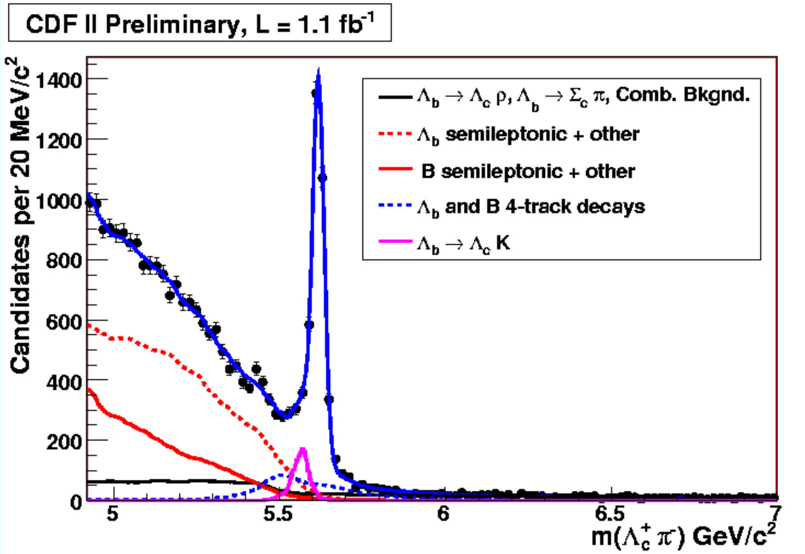
Establish a large sample of decays with an optimized selection and search for:

$\Sigma_b \rightarrow \Lambda^\circ_b \pi^\pm_{soft}$

$\Lambda^\circ_b \rightarrow \Lambda^+_c\ \pi^-,$

$\hookrightarrow$ p K^-





Estimate backgrounds:

- **Random Hadronization tracks**
- **Combinatoric**
- **Other B hadrons**

Extract signal in combined fit of Q distribution

Σ_b Observation

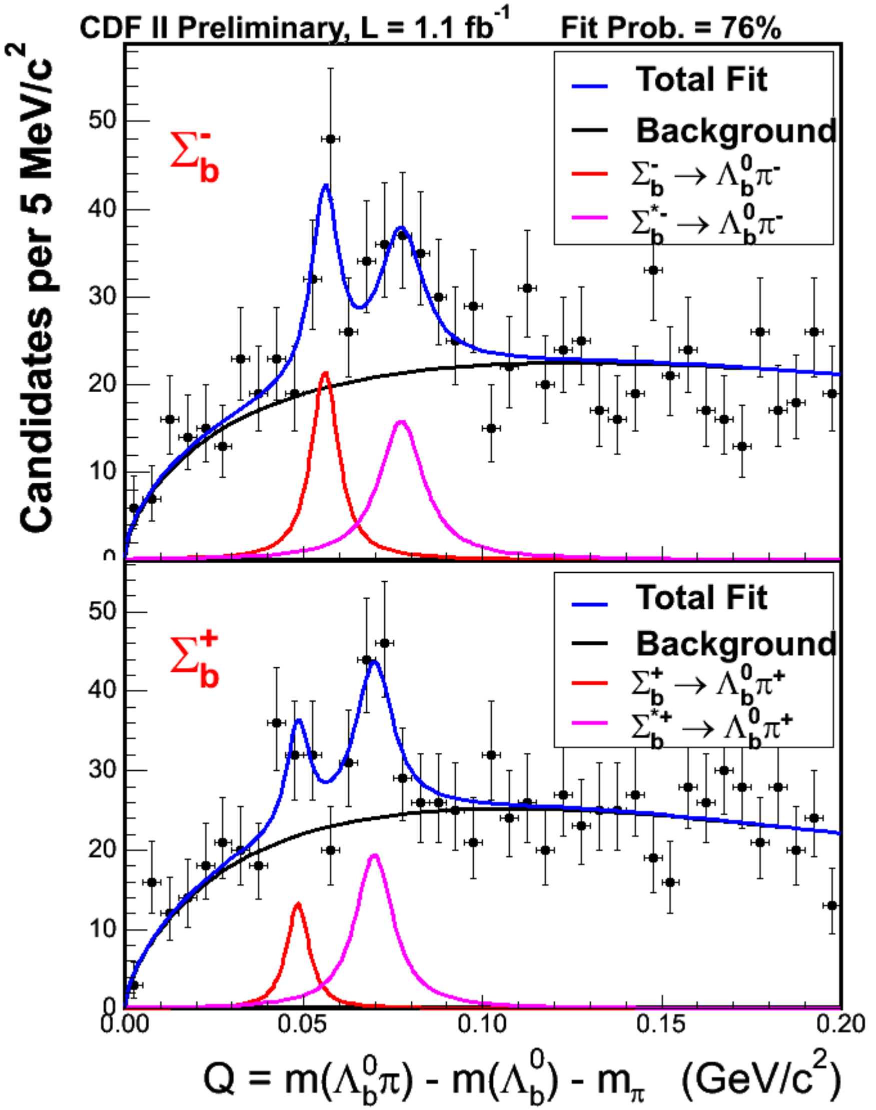
Σ_b observed for all 4 expected states with 5σ significance level

- **Yields:**

$$N(\Sigma_b^-) = 60^{+14.8}_{-13.8}\ (\text{stat})\ ^{+8.4}_{-4.0}\ (\text{syst})$$
$$N(\Sigma_b^+) = 29^{+12.4}_{-11.6}\ (\text{stat})\ ^{+5.0}_{-3.4}\ (\text{syst})$$
$$N(\Sigma_b^{*-}) = 74^{+18.2}_{-17.4}\ (\text{stat})\ ^{+15.6}_{-5.0}\ (\text{syst})$$
$$N(\Sigma_b^{*+}) = 74^{+17.2}_{-16.3}\ (\text{stat})\ ^{+10.3}_{-5.7}\ (\text{syst})$$

- **Masses (MeV/c²):**

$m(\Sigma^+_b) = 5807.8^{+2.0}_{-2.2} \pm 1.7$
$m(\Sigma^-_b) = 5815.2 \pm 1.0 \pm 1.7$
$m(\Sigma^{*+}_b) = 5829.0\ ^{+1.6+1.7}_{-1.8-1.8}$
$m(\Sigma^{*-}_b) = 5836.4 \pm 2.0^{+1.8}_{-1.7}$

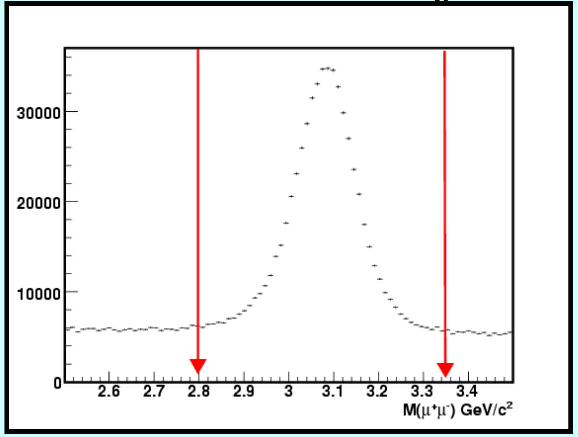


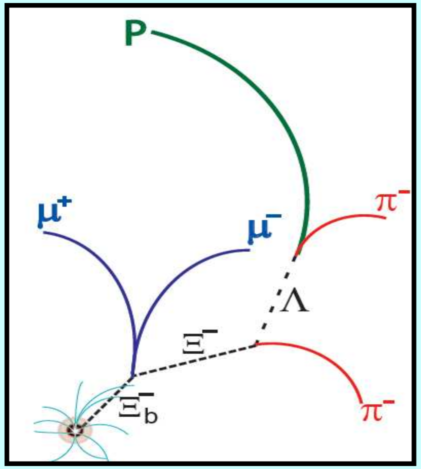
- **Mass differences:**

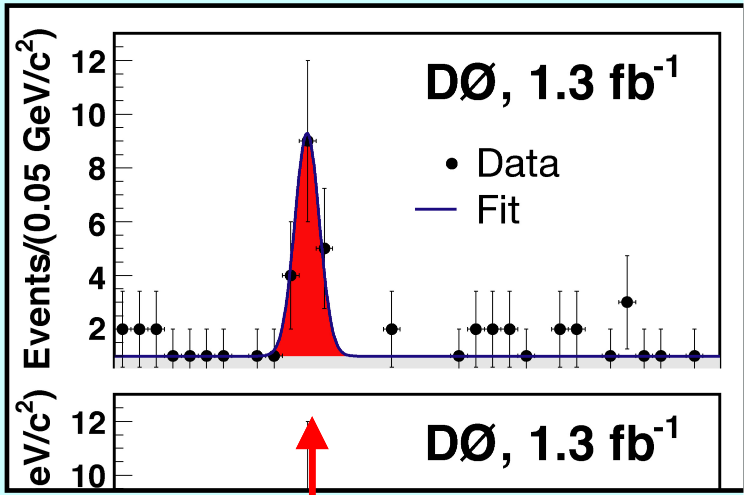
$$m(\Sigma_b^-) - m(\Lambda_b^0) - m_\pi = 55.9^{+1.0}_{-1.0}\ (\text{stat}) \pm 0.1\ (\text{syst})\ \text{MeV}/c^2$$
$$m(\Sigma_b^+) - m(\Lambda_b^0) - m_\pi = 48.4^{+2.0}_{-2.3}\ (\text{stat}) \pm 0.1\ (\text{syst})\ \text{MeV}/c^2$$
$$m(\Sigma_b^*) - m(\Sigma_b) = 21.3^{+2.0}_{-1.9}\ (\text{stat})\ ^{+0.4}_{-0.2}\ (\text{syst})\ \text{MeV}/c^2$$

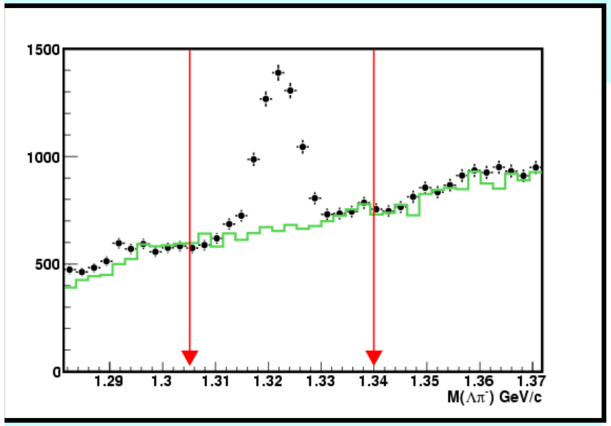
Ξ_b discovery: cascade b ("Triple scoop")

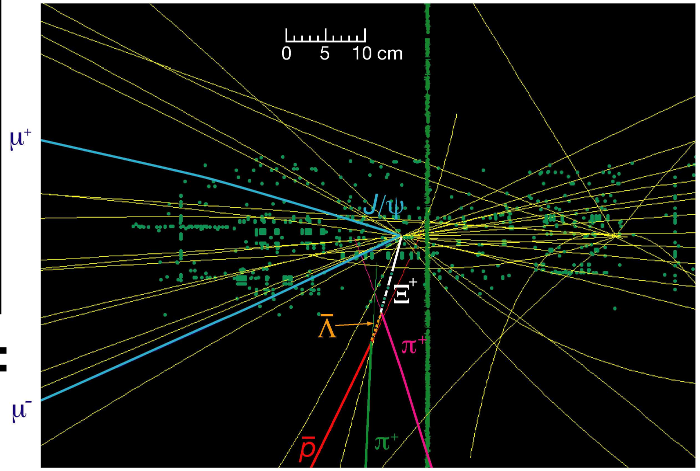
$$\Xi_b^- \to J/\psi\,\Xi^-;\ J/\psi \to \mu^+\mu^-;\ \Xi^- \to \Lambda\pi^-;\ \Lambda \to p\pi^-;$$











Run 179200, Event 55278820, $M(\Xi_b)$ = 5.788 GeV

Simple selection cuts, on:

- **Particles Pt**
- **Lifetime significance**

Clear excess of events

@mass = 5780 MeV

-Nb events: 15.2 ± 4.4

-Significance: 5.5σ

-Mass of the Peak.

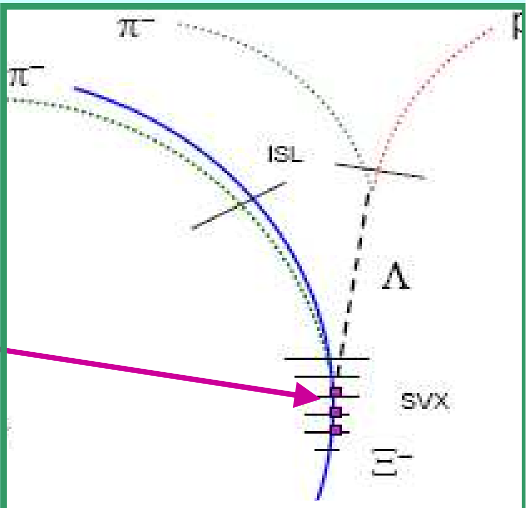
(hepex/0706.1690, submitted PRL)

$$M(\Xi_b^-) = 5774 \pm 11\,(\text{stat}) \pm 15\,(\text{syst}) \quad \text{MeV/c}^2$$

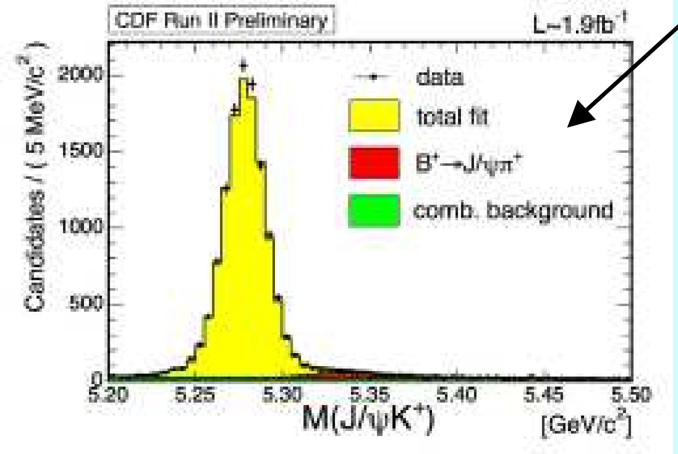
Ξ_b Baryons discovery: "CDF back to back"

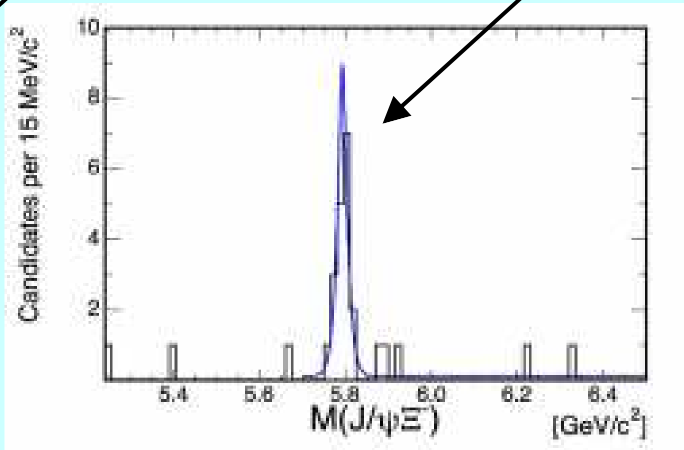
- Analysis makes use of 15 M J/Ψ triggered sample in 1.9 fb^{-1}
- Search for $\Xi^-_b \rightarrow J/\Psi\ \Xi^-$; **$J/\Psi \rightarrow \mu^+\mu^-$ and $\Xi^- \rightarrow \Lambda\pi^-$ with $\Lambda \rightarrow p\pi^-$**
- Straightforward: **In J/Ψ search for (pπ- combination) near Λ mass; search for remaining tracks Λπ-combination near Ξ- and select clean sample J/Ψ Ξ**

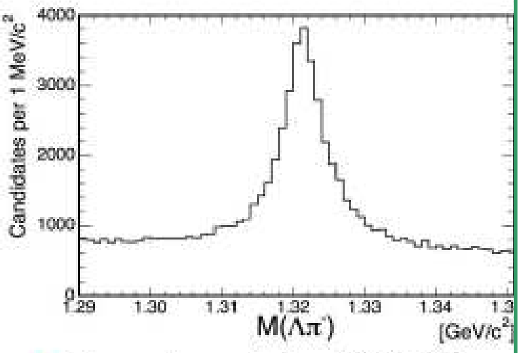
N.B. Fairly complicated pair of displaced vertices:
Ξ- leaves a long time (cτ=4.9cm); Λ lives cτ=7.9cm
The analysis coalesces the measured tracks into a new object, Ξ- track, so Ξ- treated as any other track



Selection guided by $B^\pm \rightarrow J/\Psi K^\pm$ applied to $J/\Psi\ \Xi^-$

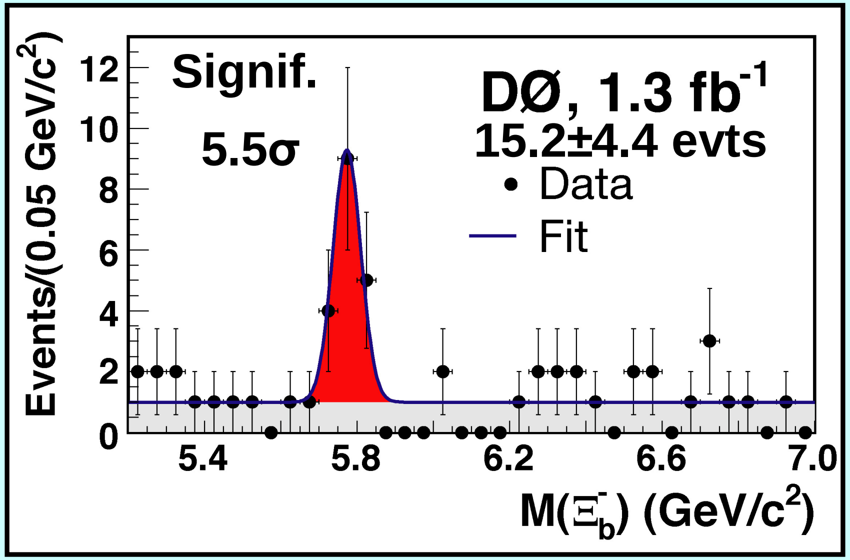




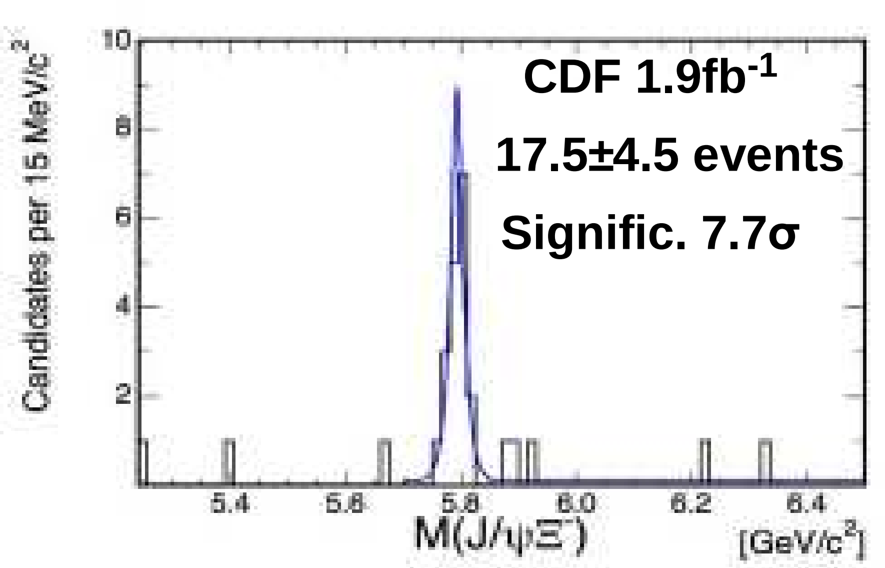


- Sample contains 23.5K Ξ^-.

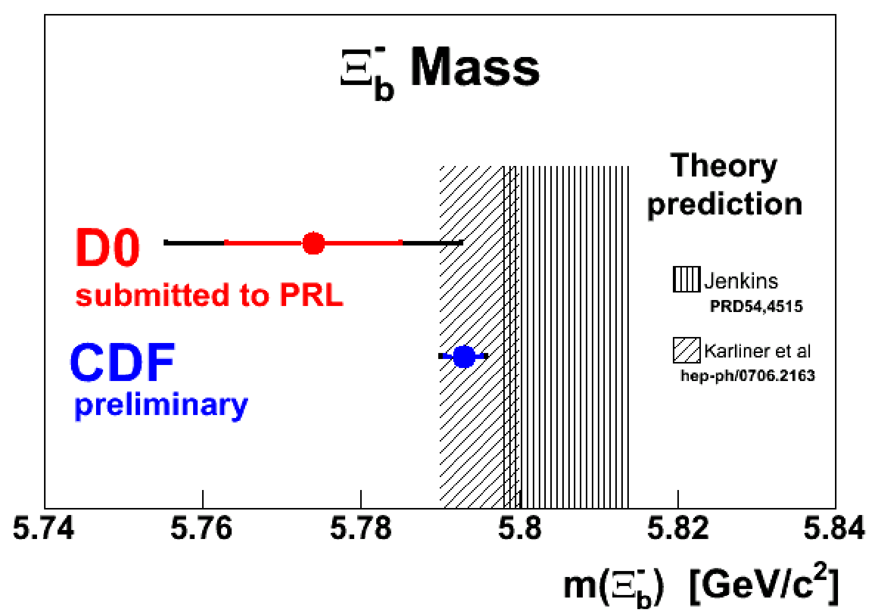
Ξ_b Baryon: D0 &CDF results comparison



5774±11(stat)±15(syst) MeV/c^2



5792.9 ± 2.5 (stat.) ± 1.7 (syst.) MeV/c^2



CDF and D0 consistent with Theory and each other

CDF momentum precision sets the current standard for B mass measurement

More underway also using 2-track trigger

Bs Mixing: from the discovery to the exploration of the Bs mixing sector

B_s and D^0 as special probes for New Physics

- Bs Discovery: The EPS Prize for young researchers, Hurrah!!!
- After the discovery: refining the measurement of oscillation frequency
- The other parameters of the Bs mixing sector
- What else? asymmetries
- And the D^0 mixing….and much more to come soon and later

Hurrah to Stephie, Guillelmo, Ivan

Bs Mixing: EPS Award

Special Thanks to the SVX, L00, ISL !

Special Thanks to the XFT + SVT !

Special Thanks to the dE/dX(COT)+ToF !

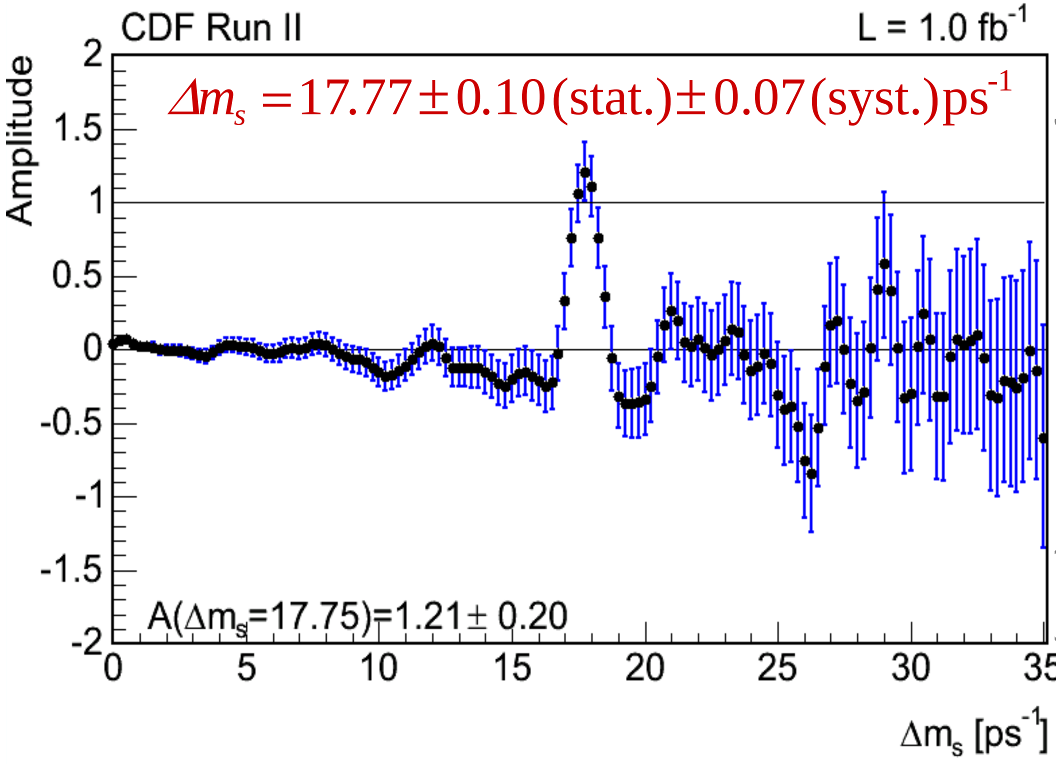
Thanks to OST and SST algorithms and NN’s !

Thanks to all the CDF Detector !

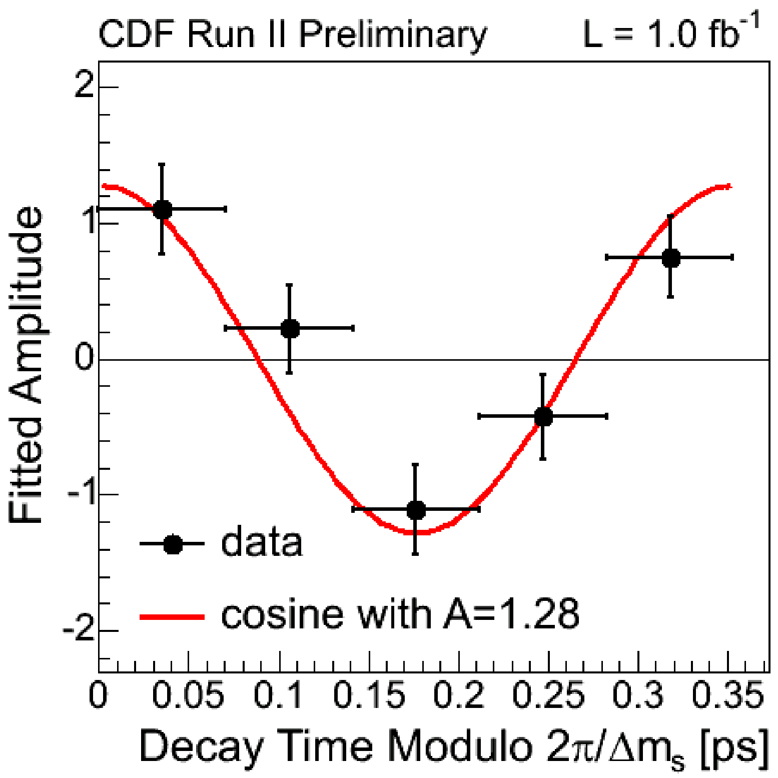
Thanks to the Tevatron !

And to all the people that gave their ideas and efforts in this enterprise !!

Bs Oscillations: the yet refined result



Phys. Rev. Lett. 97, 242003 (2006)



Probability that a random fluctuation mimics signal = 8 x $10^{-8} \Rightarrow 5.4\sigma$

$|V_{td}| / |V_{ts}| = 0.2060 \pm 0.0007$ (stat + syst) $^{+0.0081}_{-0.0060}$(lat. QCD)

Theorists: back to work…

(Current uncertainty of $\Delta M_s|_{th}$ ~14% how long to get to 1-2%?)

The Bs Mixing sector now:

Weak interaction eigenstates ≠ from those of strong interaction => mixing in quark families

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Bs meson is special:

Contrary to any other system is has very high frequency of transition;

Two physical states B_{sH} (heavy) and B_{sL} (light) with distinct masses and lifetimes;

This system is described by 5 parameters:

$$\Delta M_s = M_H - M_L \approx 2|M_{12}|$$

$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}|\cos\phi_s$$

$$\phi_s = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$$

$$\bar{\tau}_s = \frac{2}{\Gamma_L + \Gamma_H}; M_s = \frac{M_L + M_H}{2}$$

The mass eigenstates are expected to be almost pure CP eigenstates

$$\Delta\Gamma = \overbrace{\Gamma_L - \Gamma_H}^{\textbf{mass eigenstates}} \approx \overbrace{\Delta\Gamma_{CP,SM}}^{\textbf{SM value}} \cos(\phi)$$

Φ_S~0.04 in SM, NP increases φ thus decreasing width-difference

➡ ***Present Goal: Measure $\Delta\Gamma_S$ and Φ_S***

Γ_S and Φ_S measurements from:

- Analysis of time evolution of polarisation amplitudes in Bs→J/ψφ;
- Measurement of Br(Bs→Ds(*)Ds(*));
- Measurement of Afs in Bs decays;

Direct measurement on Γ_S with Bs → J/ψ ϕ

$B_s \rightarrow J/\Psi\ (\rightarrow \mu^+\mu^-)\ \Phi(\rightarrow K^+K^-)$

Final state (J/ψφ) contains both CP-even and CP-odd amplitudes;

They produce different angular distributions;

The lifetime of two CP eigenstates can be determined from evolution of these amplitudes with time

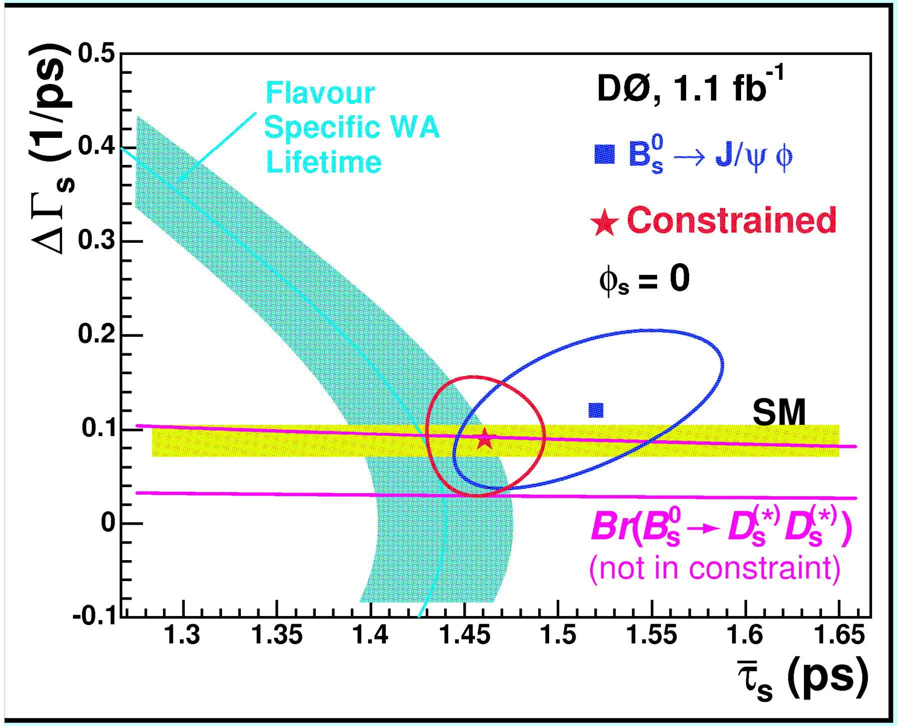
$$\Delta\Gamma_s = 0.12^{+0.08}_{-0.10} \pm 0.02\,\mathrm{ps}^{-1} \qquad (\phi_s \equiv 0)$$

$$\bar{\tau}_s = \frac{1}{\bar{\Gamma}_s} = 1.52 \pm 0.08^{+0.01}_{-0.03}\,\mathrm{ps}$$

$B_s \rightarrow D_s^{(*)} D_s^{(*)}$

This decay mode, which contains mainly CP-even state, provides an estimate of $\Delta\Gamma_s^{CP}$ (width difference between CP-even and CP-odd states):

$$\boxed{2 \cdot \mathrm{Br}(B_s \rightarrow D_s^{(*)} D_s^{(*)}) \approx \frac{\Delta\Gamma_s^{CP}}{\Gamma_s}}$$



$$B_s \rightarrow D_s^{(*)} D_s^{(*)}\ ;\ D_s \rightarrow \mu\nu\varphi\ ;\ D_s \rightarrow \varphi\pi$$

A strong indirect constraint on the value of ΔΓs is obtained using relation:

$$\boxed{2 \cdot \mathrm{Br}(B_s \rightarrow D_s^{(*)} D_s^{(*)}) \approx \frac{\Delta\Gamma_s^{CP}}{\Gamma_s}}$$

Result consistent with other measurements of related quantities

$$\boxed{\mathrm{Br}(B_s \rightarrow D_s^{(*)} D_s^{(*)}) = 0.039^{+0.019}_{-0.017}(\mathrm{stat})^{+0.016}_{-0.015}(\mathrm{syst})}$$

Measurement of Φ_S with $B_s \to J/\psi\ \Phi$

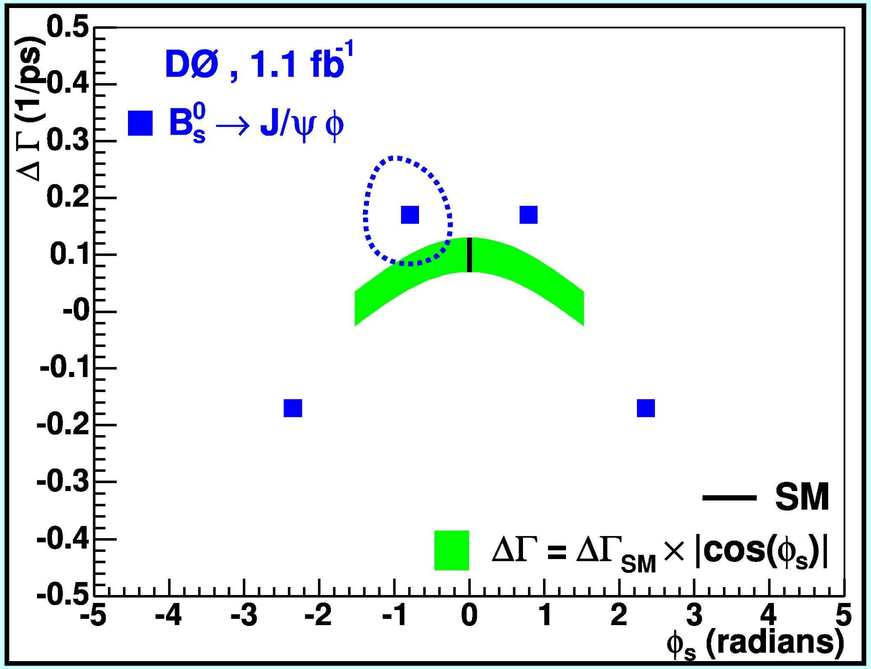
- No tagging of the initial B_s state;
- Interference of CP-even and CP-odd amplitudes gives a contribution ~$\sin(\phi_S)$, provided there is a large width difference between B_s^L and B_s^H:

$$\boxed{\Gamma(t) \sim (e^{-\Gamma_L t} - e^{-\Gamma_H t})\sin\phi_s}$$

Without initial state tagging, the result is invariant to the simultaneous flip of sign of ΔΓs and even-odd strong phase difference ⇒ 4-fold ambiguity;

First measurement of ϕs:

$$\left|\Delta\Gamma_s\right| = 0.17 \pm 0.09 \pm 0.03\ \text{ps}^{-1}$$
$$\left|\phi_s\right| = -0.79 \pm 0.56^{+0.14}_{-0.01}$$



Consistent with SM value:

$$\Delta\Gamma_s(\text{SM}) = 0.088 \pm 0.017\ \text{ps}^{-1}$$
$$\phi_s(\text{SM}) = 0.0042 \pm 0.0014$$

Semileptonic Charge Asymmetries A_{sL}

- A^s_{SL} in B decays depends on the CP violation phase:

$$A_{SL} = \frac{N(\bar{B}\to l^+X) - N(B\to l^-X)}{N(\bar{B}\to l^+X) + N(B\to l^-X)} = \frac{\Delta\Gamma}{\Delta m}\tan(\phi)$$

- Non-zero A_{sl} corresponds to CP violation in mixing;
- The only type of CP violation not observed yet in B decays;
- Very small in Standard Model:

  $A_{SL}(d) = (4.8\pm1.1)\times10^{-4}$;

  $A_{SL}(s) = (2.07\pm0.57)\times10^{-5}$;

  - ***Suppressed by $\Delta\Gamma/\Delta m$;***
  - ***Suppressed by $\tan(\phi)$;***

A^s_{SL} is measured from:

- dimuon charge asymmetry:

$$A = \frac{N(b\bar{b}\to\mu^+\mu^+X) - N(b\bar{b}\to\mu^-\mu^-)}{N(b\bar{b}\to\mu^+\mu^+X) + N(b\bar{b}\to\mu^-\mu^-)} = A^d_{SL} + 0.7\cdot A^s_{SL}$$

$$= (-9.2\pm4.4(stat)\pm3.2(syst))\times10^{-3}$$

- untagged semileptonic decays Bs→μνDs:

$$A^{unt}_{SL} = \frac{N(B_s\to\mu^+\nu D_s) - N(B_s\to\mu^-\bar{\nu}D_s)}{N(B_s\to\mu^+\nu D_s) + N(B_s\to\mu^-\bar{\nu}D_s)} \cong \frac{1}{2}A^s_{SL};$$

$$x_s = \Delta m_s/\Gamma_s >> 1$$

$$A^s_{SL} = (2.45\pm1.93\pm0.35)\times10^{-2}$$

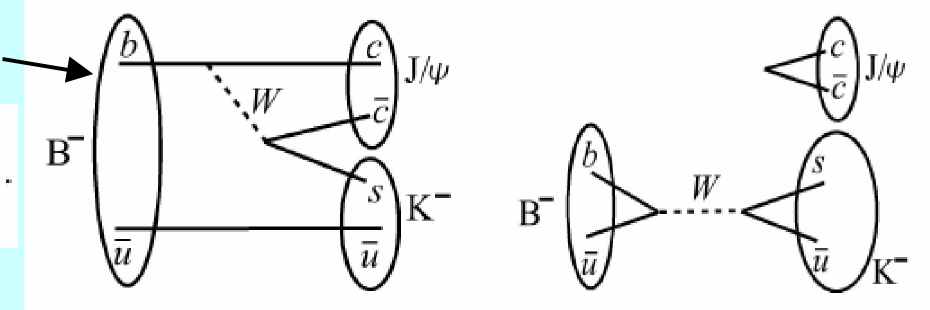
Combination → best estimate of charge asymmetry in semileptonic Bs =>

$$A^s_{SL} = 0.0001\pm0.0090$$

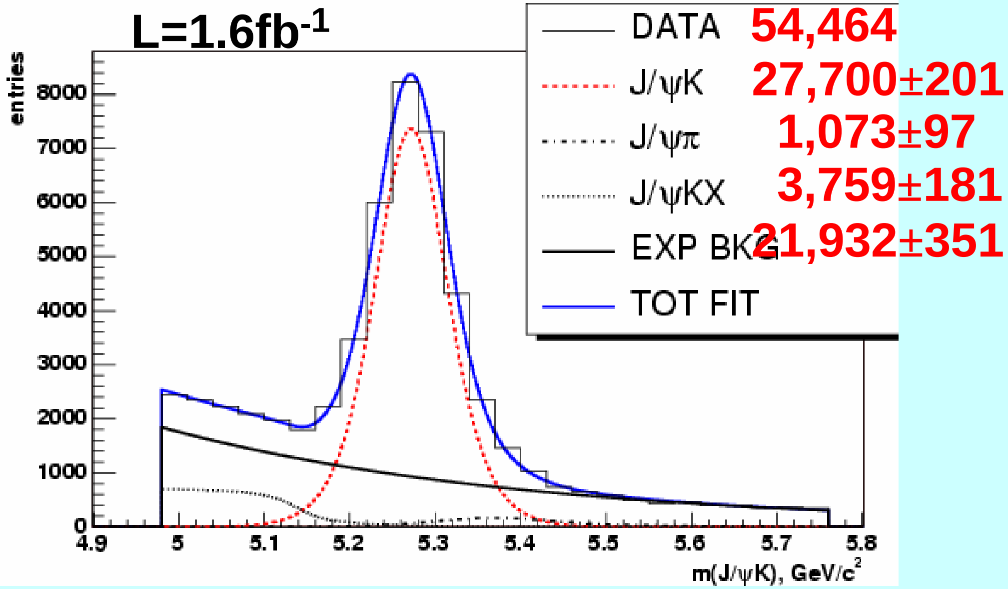
$$\Delta\Gamma_s\tan\phi_s = 0.02\pm0.16\ \mathrm{ps}^{-1}$$

Direct CP violation in $B^\pm \to J/\Psi K^\pm$

SM predicts a small DCPV (~1%) in this decay(through b→ccbar s) due to interference between these 2 amplitudes



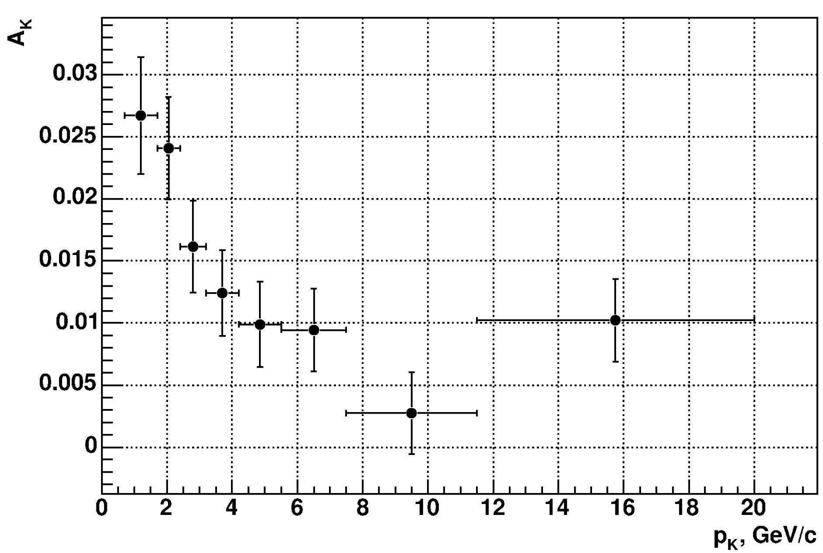
$$A_{CP}(B^+ \to J/\psi(1S)K^+) = \frac{\Gamma(B^- \to J/\psi K^-) - \Gamma(B^+ \to J/\psi K^+)}{\Gamma(B^- \to J/\psi K^-) + \Gamma(B^+ \to J/\psi K^+)}.$$



DATA	54,464
J/ψK	27,700±201
J/ψπ	1,073±97
J/ψKX	3,759±181
EXP BKG	21,932±351
TOT FIT	

Events easy to identify

$$B^- \to J/\psi\, K^-, \quad J/\psi \to \mu^+ \mu^-$$



A_K estimated independently:

$$A_K = 0.0139 \pm 0.0013(stat) \pm 0.0004(syst)$$

$$\boxed{A_{CP}(B^+ \to J/\psi(1S)\, K^+) = +\,0.0067 \pm 0.0074(stat) \pm 0.0026(syst)}$$ ***Best limit***

Bs Mixing sector
present conclusions

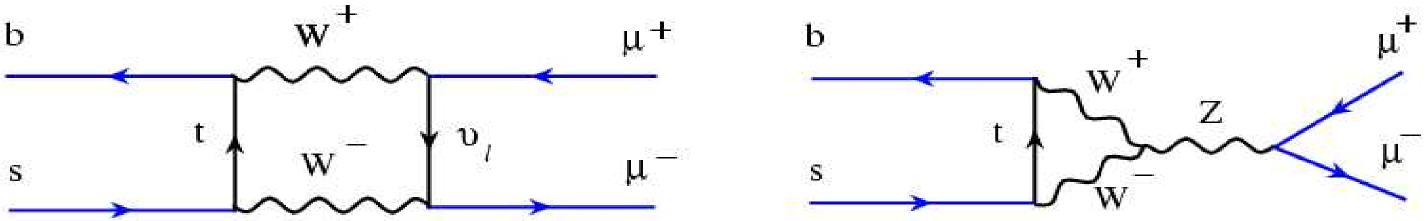
- Need for theoreticians to improve lattice calculations to be at the level of experimental accuracy of ΔM_s and work on the NP models
- Need for experimentalists to pursue and improve measurements accuracy on $\Delta\Gamma_s$ and Φ_s. More to come very soon (CDF) and also
- from both experiments with much more luminosity

Rare Decays and next steps in CPV

- $B_s \to \mu\mu$
- $B_s \to \mu\mu h$
- B_s in all-hadronic decays
- Direct CP Violation (DCPV)
- And a glance on the D^0 sector

$B_{s,d}\rightarrow\mu^+\mu$- rare decay search: motivation & strategy

In the Standard Model, the FCNC decay of $B_{s,d} \rightarrow \mu+\mu-$ is heavily suppressed



SM: BR($B \rightarrow\mu^+\mu^-$)= (3.42±0.54)x10^{-9} *(Buchalla, Buras)*

$B_d \rightarrow \mu+\mu-$ is further suppressed by CKM factor $(v_{td}/v_{ts})^2$

SM ⇒ Expect to see 0 events at the Tevatron (CDF + D0), BUT:

Sizeable New Physics enhancement (BR boosted by up to 100x) (ex:SUSY)

Strategy: Blind optimization using signal Monte Carlo and sideband data

Normalize to known ***B+ → J/ψ K+***

$$BR(B_s \rightarrow \mu^+\mu^-) = \frac{N_{B_s}}{N_{B^+}} \frac{\alpha_{B^+}\cdot\varepsilon_{B^+}^{total}}{\alpha_{B_s}\cdot\varepsilon_{B_s}^{total}} \frac{f_{b\rightarrow B^+}}{f_{b\rightarrow B_s}} BR(B^+ \rightarrow J/\psi K^+)BR(J/\psi \rightarrow \mu^+\mu^-)$$

Reconstruct normalization mode in the same data, applying same criteria

Evaluate expected background, open the box and calculate *BR* or limit

$B_{s,d} \rightarrow \mu^+ \mu^-$ event yield after optimization

Thanks to the good mass resolution CDF can resolve $B_s \rightarrow \mu\mu$ from $B_d \rightarrow \mu\mu$

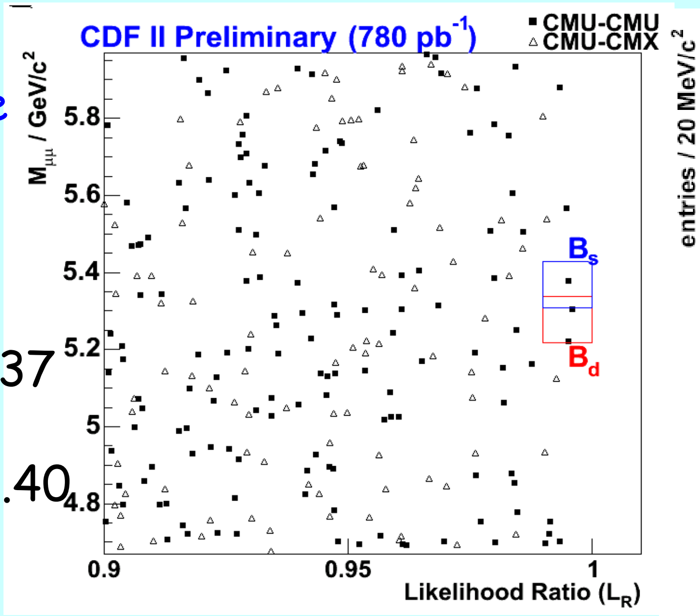
CDF (780 pb^{-1})

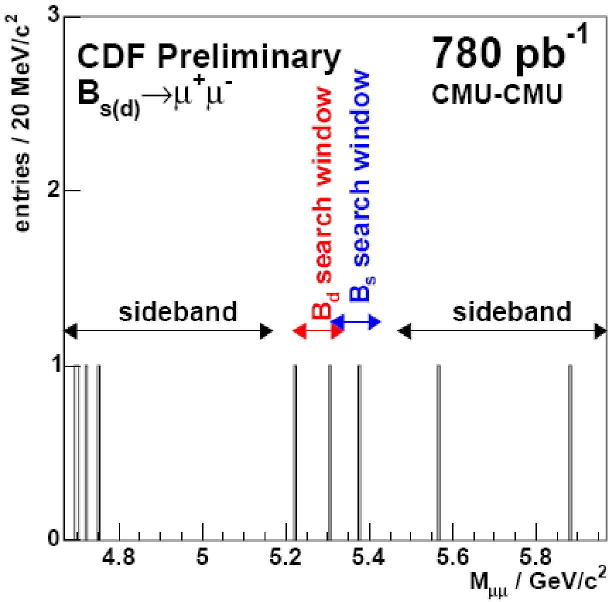
$B_s \rightarrow \mu\mu$

observe 1, expect 1.27 ± 0.37

$B_d \rightarrow \mu\mu$

observe 2, expect 2.45 ± 0.40





DØ (2 fb^{-1})

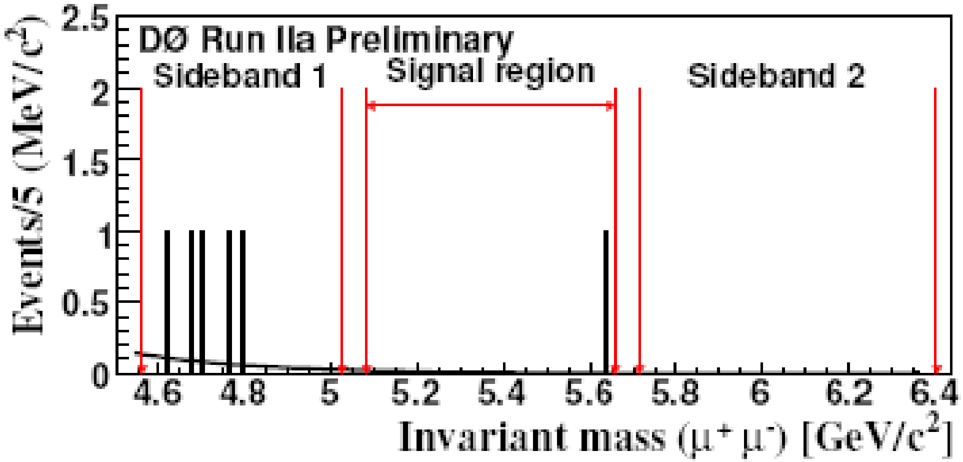
$B_s \rightarrow \mu\mu$

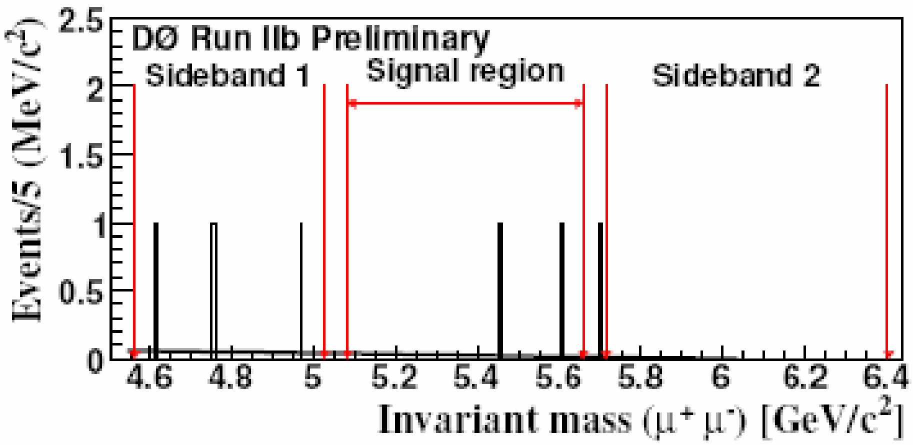
Run IIa (1250 pb^{-1})

observe 1, expect 0.8 ± 0.2

Run IIb (additional silicon layer, 750 pb^{-1})

observe 2, expect 1.5 ± 0.3





$B_{s,d}\to\mu^+\mu$- latest results

- No signal found
- CDF B_s limit (780 pb-1)
  - BR($Bs\to\mu+\mu-$)<8.0(10.)x10^{-8}@90%(95%)CL.

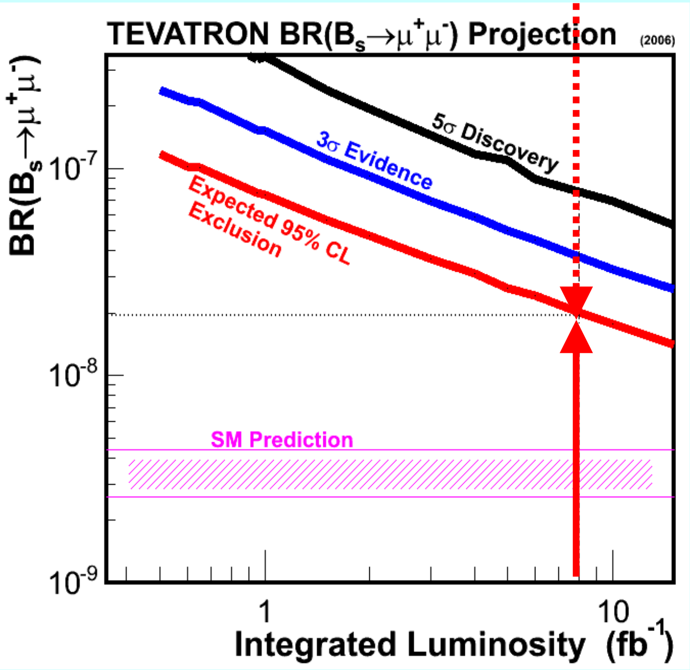
    (**8.0 x 10^{-8} / 3.42 x 10^{-9}(SM) ~ 30)**
- DØ B_s limit (2 fb-1)
  - BR($Bs\to\mu+\mu-$)<7.5(9.3)x10^{-8}@90%(95%)CL
- Tevatron combined (non official)
  - **BR($Bs\to\mu+\mu-$)<5.8x10^{-8}@(95%)CL**

    (x 17/SM with Tevatron combined)
- CDF B_d limit (780 pb-1)
  - BR($B_d\to\mu+\mu-$) < 2.3 (3.0) x 10^{-8} at 90% (95%) C.L.

    (**2.3 x 10^{-8}/1.0 x 10^{-10}(SM) ~ 230)**
  - Compare Babar BR($B_d\to\mu+\mu-$) < 8.3 x 10^{-8} at 90% C.L. (110 fb-1)

Tevatron expected reach

Full Run II: low 10^{-8} excluded



Current upper limits probe BR 20 to 200 times higher than SM prediction

(New results soon from CDF on full statistics)

Search for $B_{u,d,s}\rightarrow\mu+\mu$-h (K+/K*/Φ)

- Non-resonant decays B → μμh via box or penguin diagrams
- → new physics may be observable through interference with SM amplitudes
- Already observed (BaBar, Belle):
  - Bu → μμ K
  - Bd → μμ K*
- **Missing: Bs → μμ φ & prediction: BR(B_s → μμφ)=1.6x10^{-6}**

Goal: Re-establish $B_{u,d}$ signals in Tevatron data and 'discover' the unseen B_s

Experimental method: similar to the Bs → μμ analysis

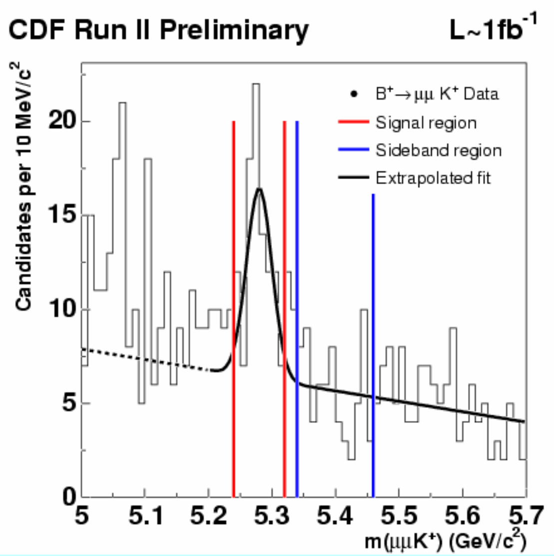
Normalize signal to analogous B → J/ψ h (J/ψ → μμ)

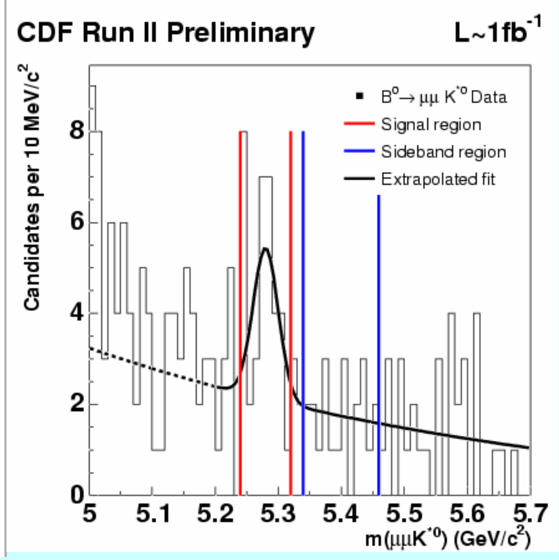
$$\frac{BR(B\rightarrow\mu^+\mu^-h)}{BR(B\rightarrow J/\psi h)}=\frac{N_{\mu\mu h}}{N_{J/\Psi h}}\frac{\varepsilon^{total}_{J/\Psi h}}{\varepsilon^{total}_{\mu\mu h}}BR(J/\psi\rightarrow\mu^+\mu^-)$$

Exclude J/ψ and ψ' regions in the (μμ) invariant mass spectrum

B^+ and B^0 yield (CDF)

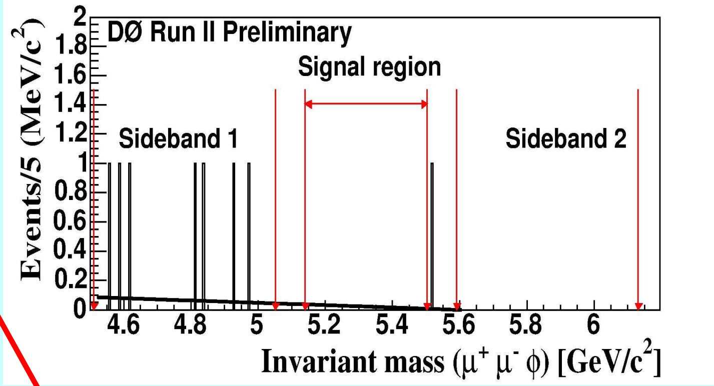
Mode	$B^+ \to \mu^+\mu^- K^+$	$B^0 \to \mu^+\mu^- K^{*0}$
$N_{sig.win.}$	90	35
N_{BG}	45.3 ± 5.8	16.5 ± 3.6
Significance	4.5	2.9

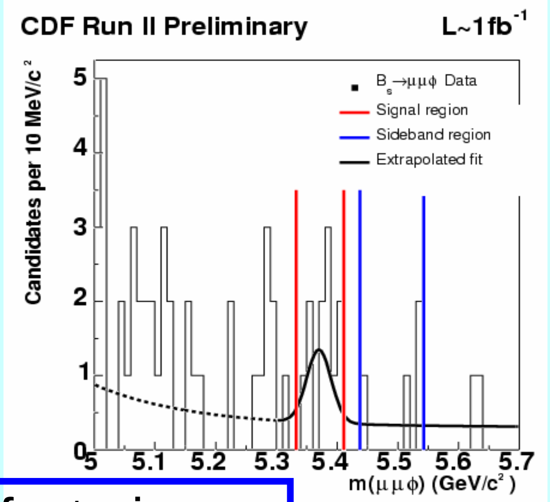




B_s yield

	DØ	CDF
Obs.	0	11
Exp.	1.6±0.6	3.5 ±1.5
pb^{-1}	450	920





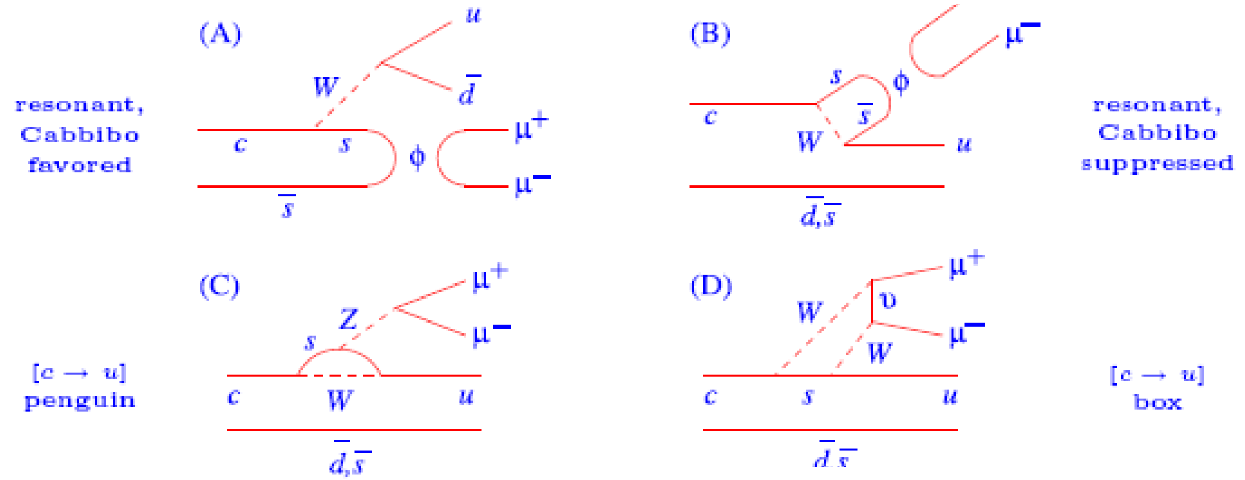
2.4 σ significance

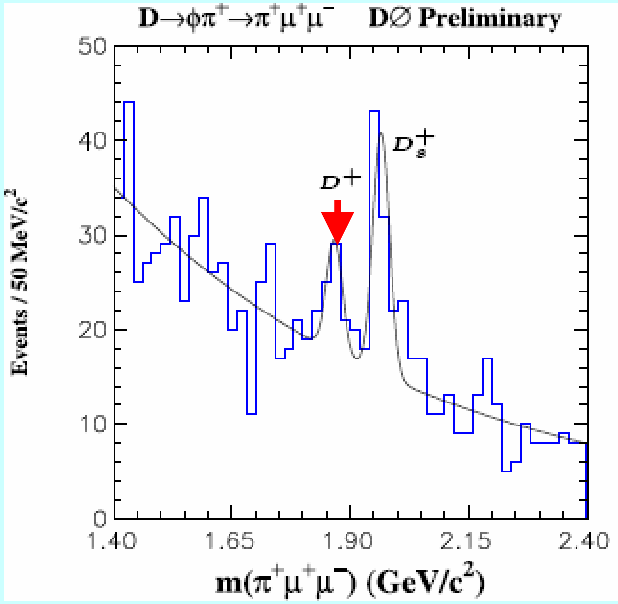
B^+, B^0: Good agreement & similar uncertainty to B-factories

- **BR($B^+ \to \mu\mu K+$) = [0.60 ± 0.15(stat.) ± 0.04(sys.)]x10^{-6} CDF, 45 ev.**
- **BR($B^0 \to \mu\mu K^{*0}$) = [0.82 ± 0.31(stat.) ± 0.10(sys.)]x10^{-6} CDF, 18 ev.**

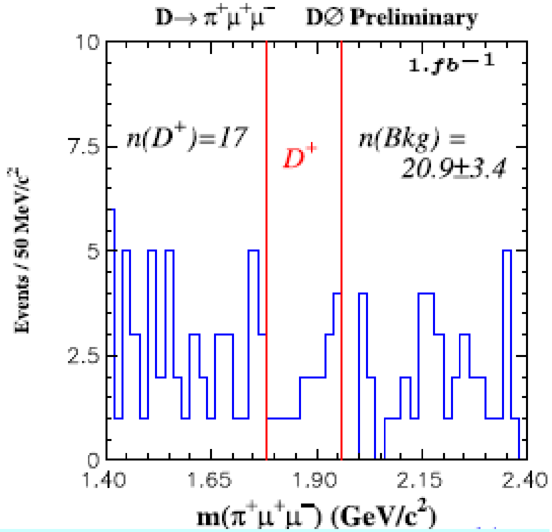
- **BR($B_s \to \mu\mu\phi$) < 2.4 x10^{-6} @ 90% C.L., CDF, 920 pb^{-1}, Bayesian approach**
  = [1.16 ± 0.56(stat.) ± 0.42(sys.)]x10^{-6}
- **BR($B_s \to \mu\mu\phi$) < 3.3 x 10^{-6} @ 90% C.L. DØ, 450 pb-1**

Good place to search for NP in up-type FCNC, enhanced in SUSY RPV or little Higgs models





$D^+ \to \mu^+\mu^-\pi^+$



BR upper limit obtained w.r.to normalizing channel $D_s^+\ \Phi\pi^+ \to \pi^+\mu^+\mu^-$

$$\frac{BR(D^+ \to \pi^+\mu^+\mu^-)}{BR(D_s^+ \to \Phi\pi^+) \text{ x } (\Phi \to \mu+\mu-)} < 0.46 \text{ (90\% CL)}$$

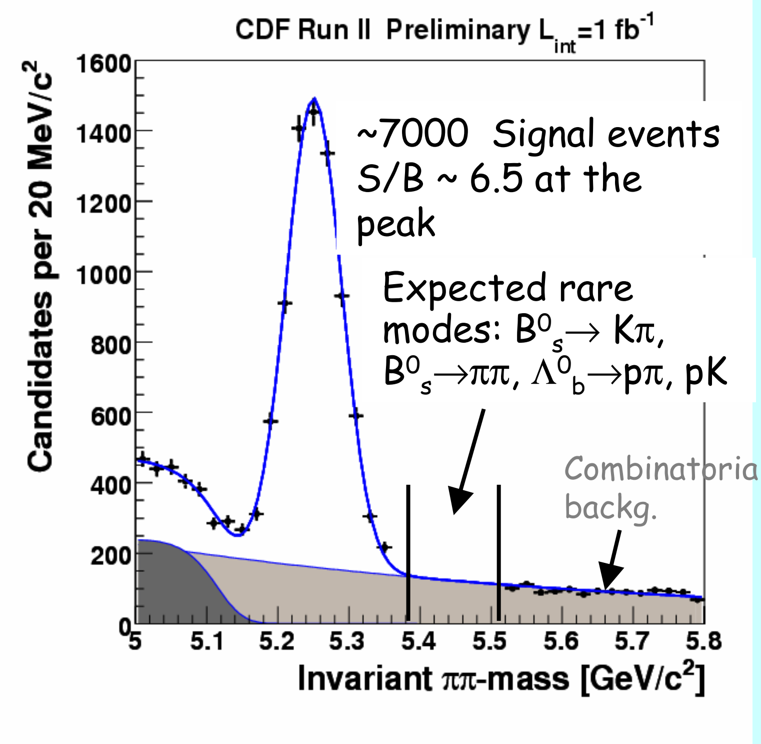
Using the central values for the normalizing fractions

$BR(D^+ \to \pi^+\mu^+\mu^-) < 4.7\text{x}10^{-6}$ (90%CL)

Previous searches:
FOCUS(03)<$8.8\text{x}10^{-6}$
CLEO(05)<$7.4\text{x}10^{-6}$
BaBar(06)<$24.4\text{x}10^{-6}$
(e+e-π+)

Search for $B^0,B_s^0 \rightarrow h^+h^-$

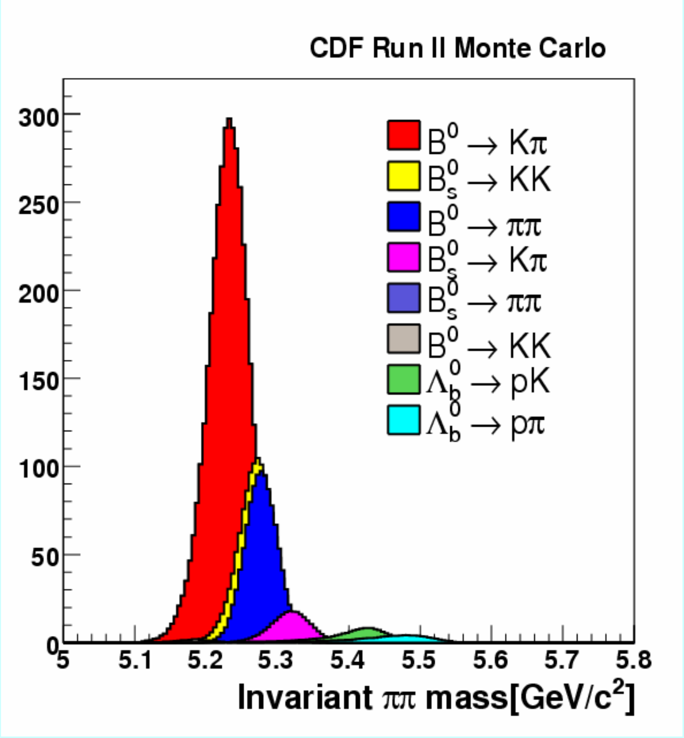
- an useful tool for probing CKM
- sensitive to the New Physics contributions in the Penguin diagrams
- sensitive to New Physics effects via anomalies in A_{CP}



~7000 Signal events S/B ~ 6.5 at the peak

Expected rare modes: $B^0_s \rightarrow K\pi$, $B^0_s \rightarrow \pi\pi$, $\Lambda^0_b \rightarrow p\pi$, pK

Combinatorial backg.



Despite excellent mass resolution (~22 MeV/c^2), modes overlap an unresolved peak, and PID resolution is insufficient for event-by-event separation.

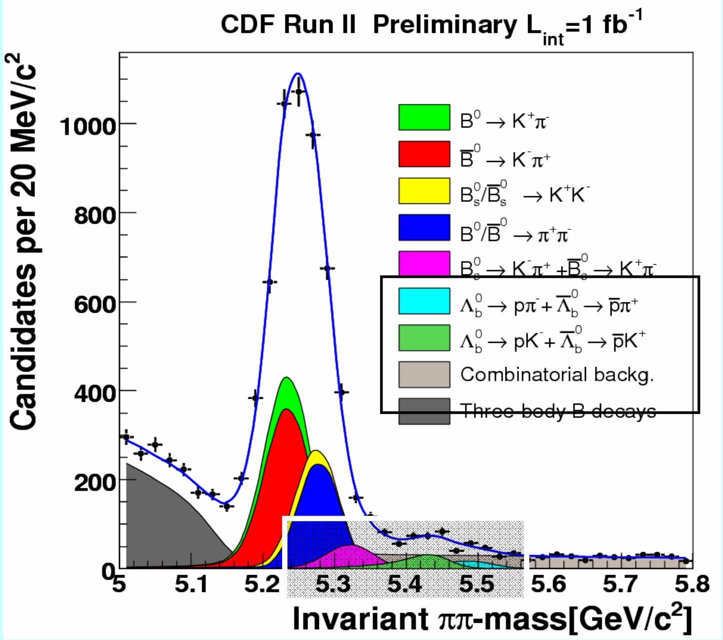
Hence, fit signal composition with a Likelihood that combines information from kinematics (mass and momenta) and particle ID (dE/dx).

➢3 new rare modes observed

$$N_{raw}(B_s^0 \to K^-\pi^+) = 230 \pm 34(stat.) \pm 16(syst.)$$ **8σ**

$$N_{raw}(\Lambda_b^0 \to p\pi^-) = 110 \pm 18(stat.) \pm 16(syst.)$$ **6σ**

$$N_{raw}(\Lambda_b^0 \to pK^-) = 156 \pm 20(stat.) \pm 11(syst.)$$ **11σ**



➢Upper limits on annihilation modes $B^0 \to \pi^+\pi^-$, $B_S^0 \to K^+K^-$

$$\frac{f_s}{f_d}\frac{BR(B_s^0 \to \pi^+\pi^-)}{BR(B^0 \to K^+\pi^-)} = 0.007 \pm 0.004(stat.) \pm 0.005(syst.)$$

$$\frac{BR(B^0 \to K^+K^-)}{BR(B^0 \to K^+\pi^-)} = 0.020 \pm 0.008(stat.) \pm 0.006(syst.)$$

$$BR(B^0 \to K^+K^-) = (0.39 \pm 0.16(stat.) \pm 0.12(syst)) \times 10^{-6}$$ **(<0.7x10^{-6}@90%CL)**

$$BR(B_s^0 \to \pi^+\pi^-) = (0.53 \pm 0.31(stat.) \pm 0.40(syst)) \times 10^{-6}$$ **(<1.36x10^{-6}@90%CL)**

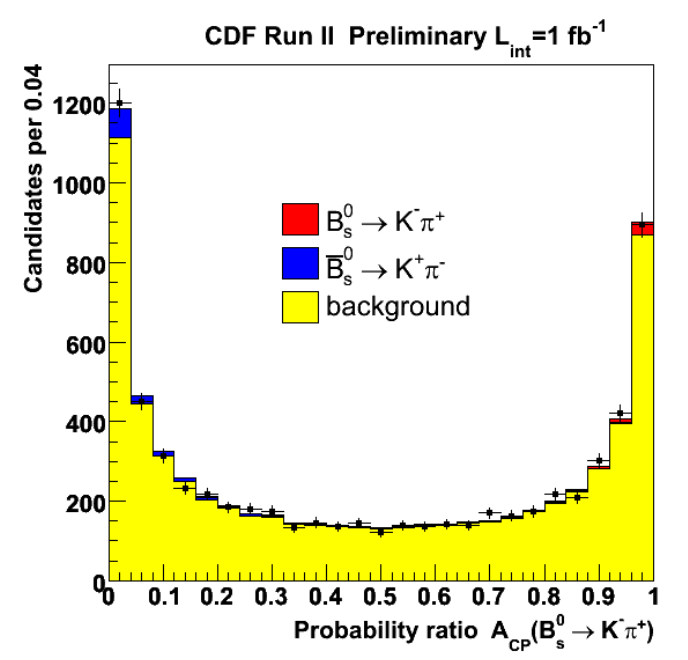
World's best upper limits for $B^0_s \to \pi^+\pi^-$ while same resolution of B-Fact. for $B^0 \to K^+K^-$. Both modes are annihilation-dominated decays and no observed yet – hard to predict exactly.

Direct CP Asymmetry

- “Is observed direct CP violation in $B^0 \to K^+\pi^-$ due to NP?

  Check SM prediction of equal violation in $B_s \to K^-\pi^+$”

Lipkin, Phys. Lett. B621:126 (2005)
Gronau & Rosner Phys.Rev. D71 074019 (2005)

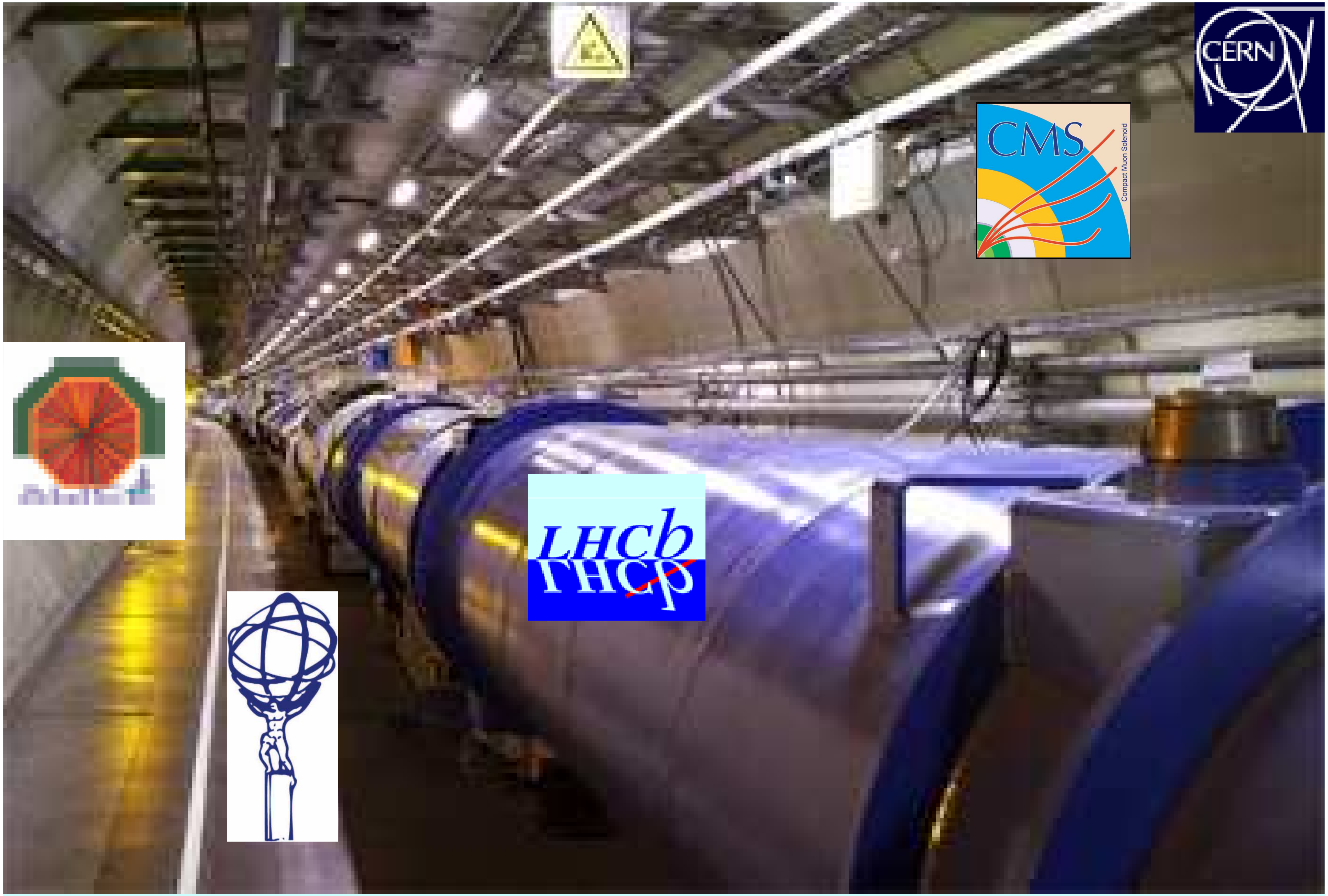


- Expect large $A_{CP}(B_s \to K^-\pi^+) \approx 0.37$
- Sign opposite to $A_{CP}(B^0 \to K^+\pi^-)$

$$A_{CP} = \frac{N\left(\bar{B}^0 \to K^-\pi^+\right) - N\left(B^0 \to K^+\pi^-\right)}{N\left(\bar{B}^0 \to K^-\pi^+\right) + N\left(B^0 \to K^+\pi^-\right)} = -0.086 \pm 0.023\,(\text{stat.}) \pm 0.009\,(\text{syst.})$$

$$A_{CP} = \frac{N\left(\bar{B}_s \to K^+\pi^-\right) - N\left(B_s \to K^-\pi^+\right)}{N\left(\bar{B}_s \to K^+\pi^-\right) + N\left(B_s \to K^-\pi^+\right)} = +0.39 \pm 0.15\,(\text{stat.}) \pm 0.08\,(\text{syst.})$$

First measurement of CP asymmetry in the B_s system



End of the journey & back to where we started: the LEP/LHC Tunnel

- HF Physics is **high precision Physics**
- Among **most promising way to explore BSM**.
- Important new HF results (B and D) at RHIC (PHENIX and STAR with upgraded detectors), HERA final (H1 and ZEUS) and CLEO-c and much more to come!
- Having proved **hadron colliders** can perform HF Physics = **Revolution** of the last 2 decades (UA1, CDF1), it means:
- Hadron colliders are **precision machines and 'not only' discovery machines.**
- The work achieved at Tevatron & 'other facilities' opens an **incredibly rich horizon** for the LHC .
- **HF Physics is technologically challenging** (*ex: innovation in Si tracking & related issues)*

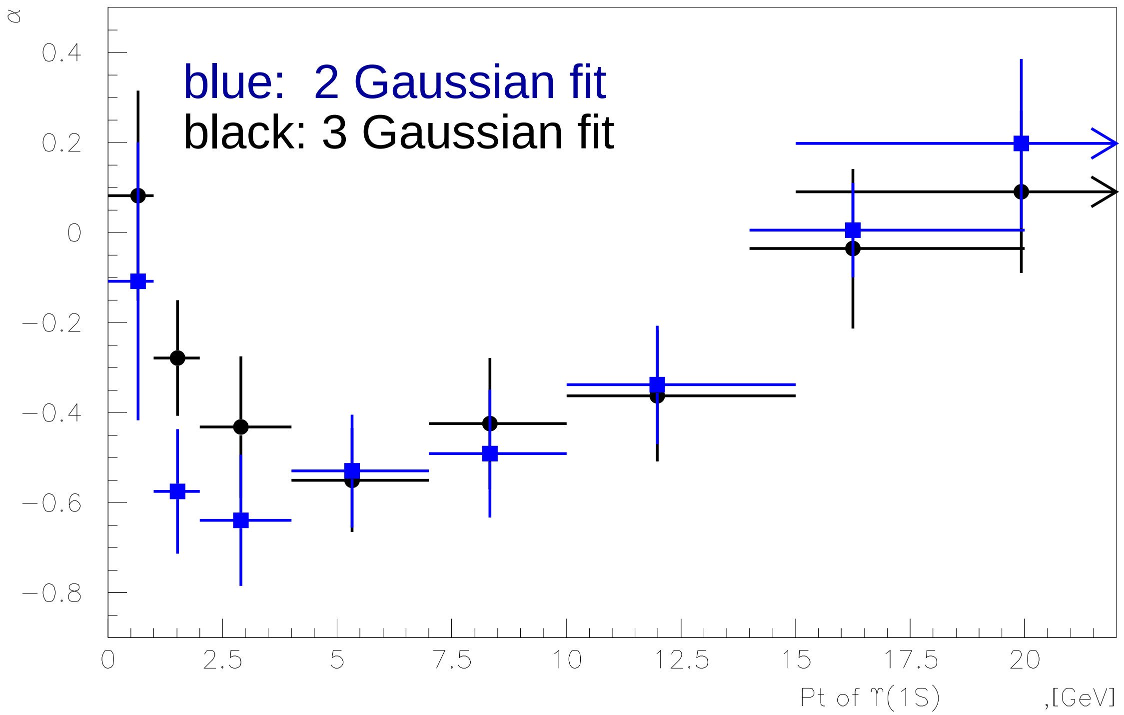
THIS IS JUST A BEGINNING WE MUST GO ON !

Backup slides

Polarization of Υ(1S)

NEW

DØ, Run2 Preliminary , 1.3 fb^{-1}



- **We have presented a measurement of the polarization of the Υ(1S) and Υ(2S) as a function of p_T from 0 to 20 GeV. Significant longitudinal polarization that is dependent on p_T is observed for the Υ(1S) that is inconsistent with QCD predictions.**

- **No contradictions to the NRQCD prediction for Υ(2S) are observed.**

Further improving the Bs oscillation frequency measurement

- Cleanest topology

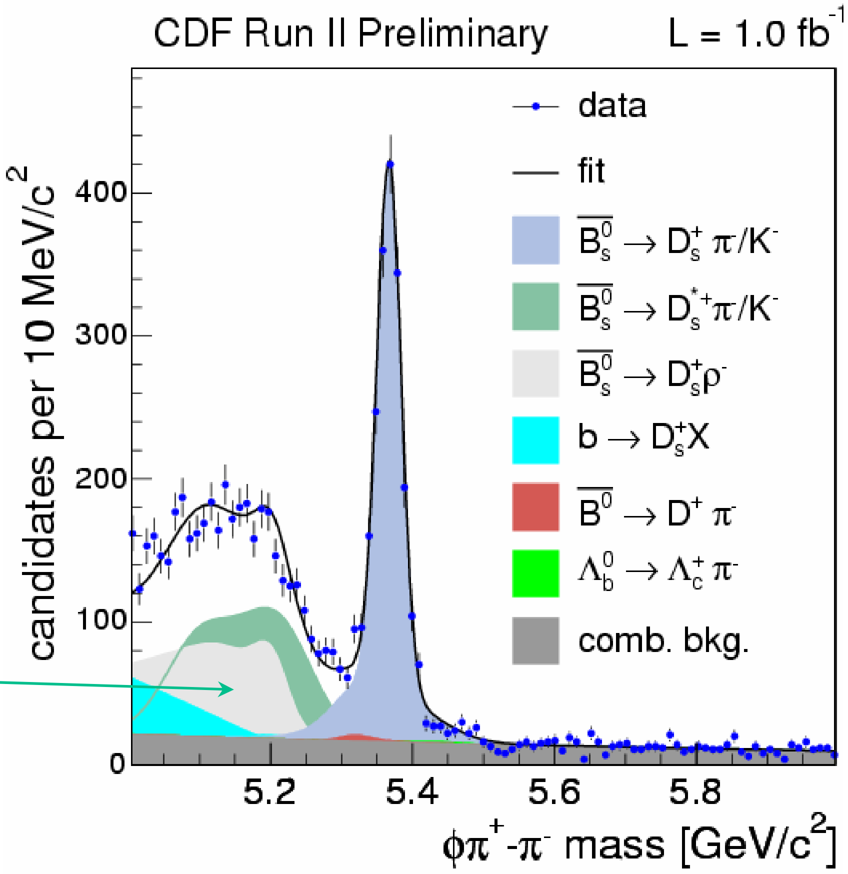
$$B_s^0 \to D_s^- \pi^+$$

$$D_s^- \to \phi \pi^-$$

$$\left(D_s^- \to \overline{K}^{*0} K^-, \pi^- \pi^+ \pi^-\right)$$

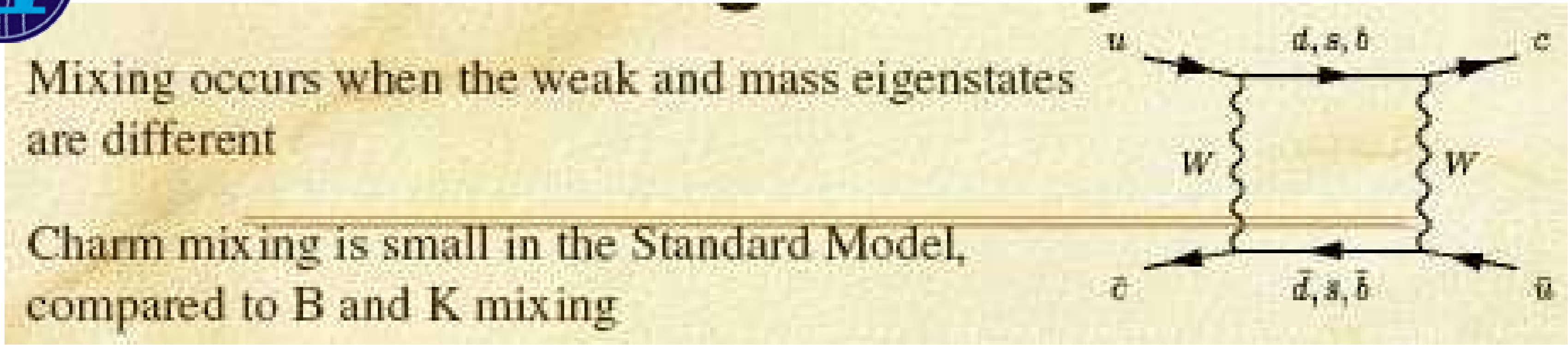
- Includes partially reconstructed decays

$$D_s^{*-}\pi^+, D_s^- \rho^+$$



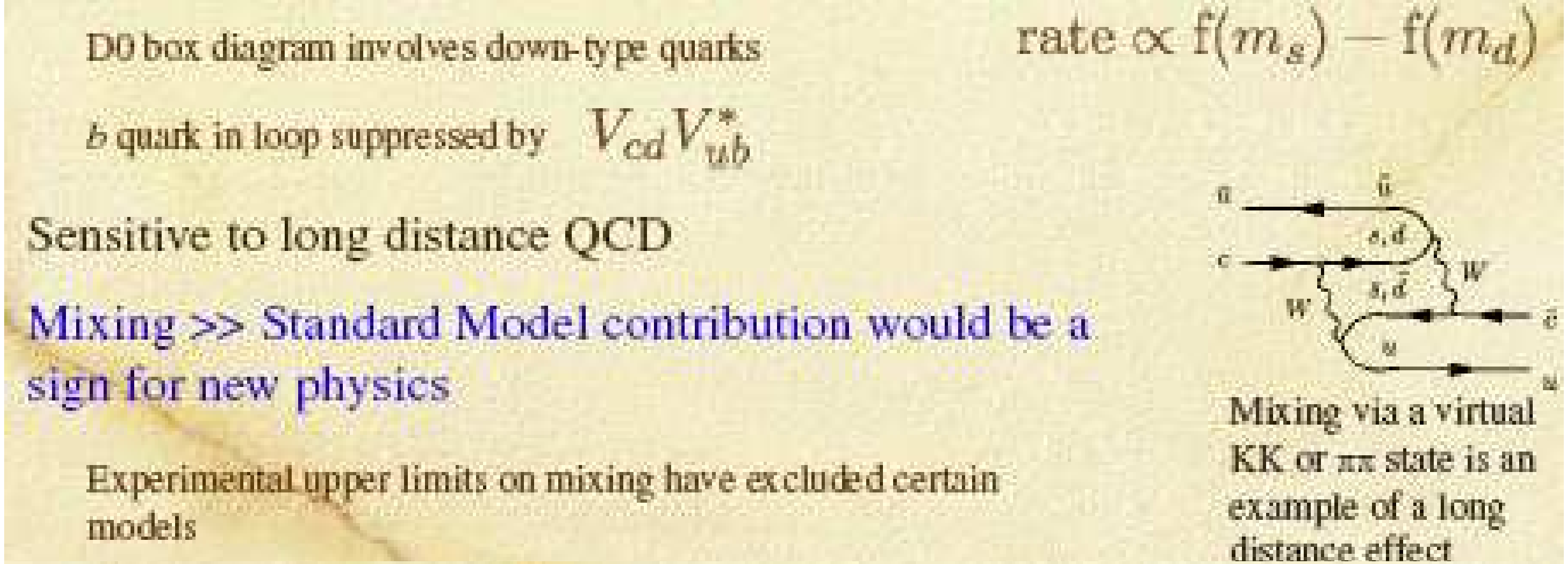
- Total signal
  - 8,800 fully reconstructed decays
  - 61,500 semileptonic decays

D0-D0bar Mixing



Mixing occurs when the weak and mass eigenstates are different

Charm mixing is small in the Standard Model, compared to B and K mixing



D0 box diagram involves down-type quarks

$$\text{rate} \propto f(m_s) - f(m_d)$$

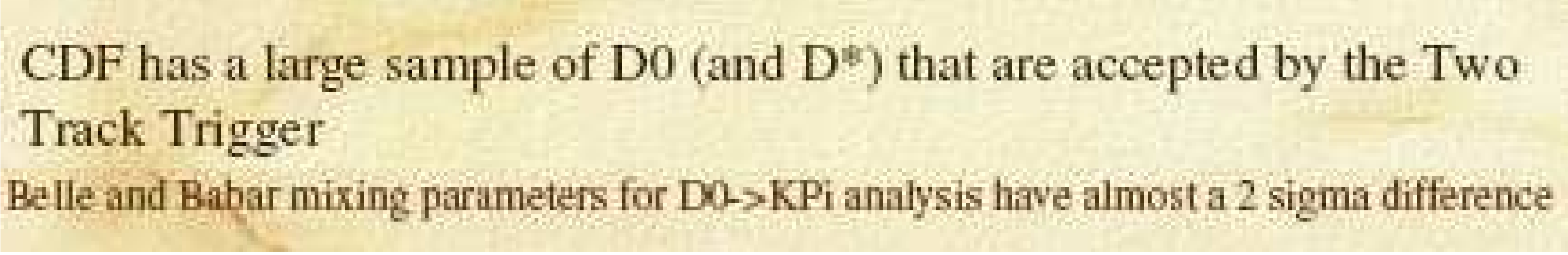
b quark in loop suppressed by $V_{cd}V^*_{ub}$

Sensitive to long distance QCD

Mixing >> Standard Model contribution would be a sign for new physics

Experimental upper limits on mixing have excluded certain models

Mixing via a virtual KK or ππ state is an example of a long distance effect



CDF has a large sample of D0 (and D*) that are accepted by the Two Track Trigger

Belle and Babar mixing parameters for D0->KPi analysis have almost a 2 sigma difference

- Mixing observed in *K0*, *Bd* and *Bs*, but not yet in *D0*

- Charm mixing is slower than *B* or *K* mixing

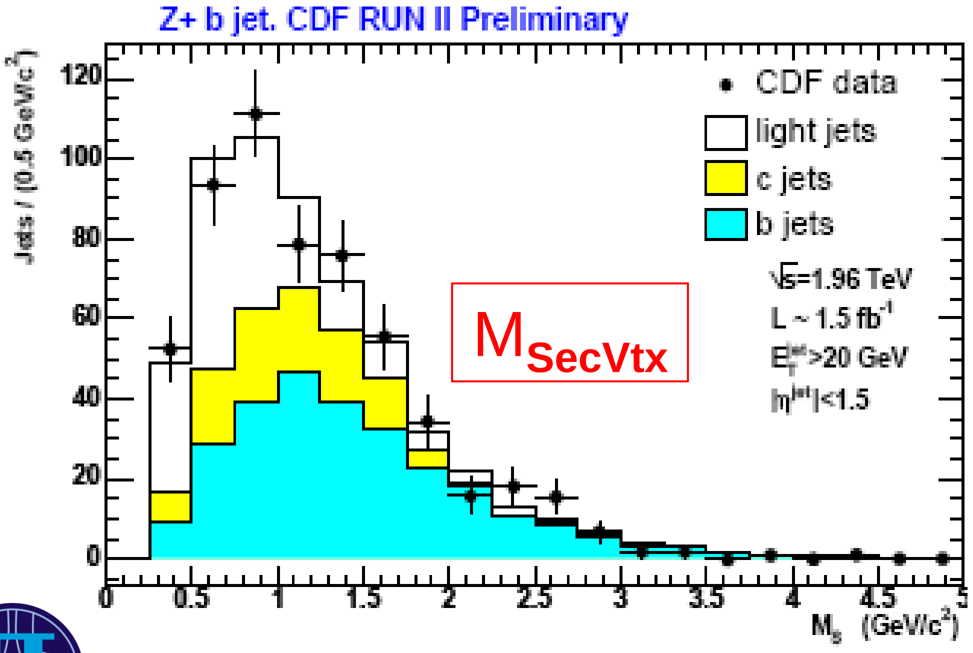
- Use *D** → *D0 p+* to tag the original flavor as *D0* or *anti-D0*

  - *D0* → *K- p* +, Cabibbo Favored (CF)
  - *D0* → *K+ p* -, Doubly Cabibbo Suppressed (DCS)

$$\begin{tikzcd}
D^0 \arrow[rr, bend left, "\text{DCS}"] \arrow[dr, "\text{MIX}"] & & K^+\pi^- \\
& \overline{D}^0 \arrow[ur, "\text{CF}"] &
\end{tikzcd}$$

Z+b jets new CDF result

Sec. Vtx mass fit in events with at least 1 tagged Jet:



Systematic table

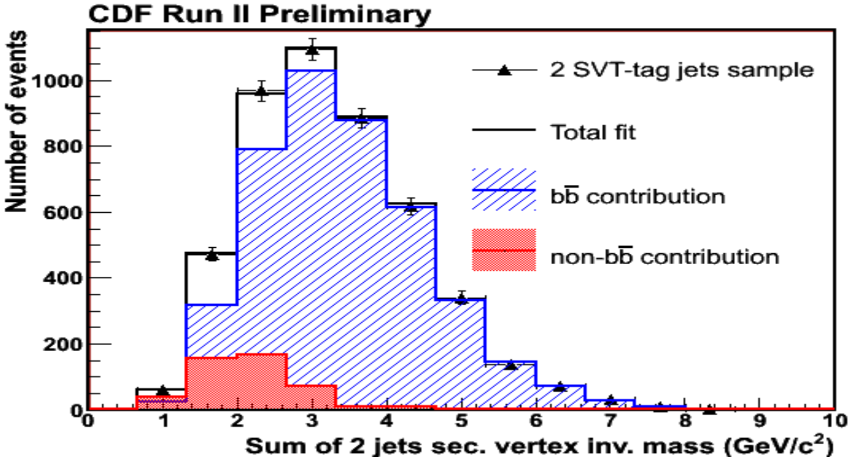
Systematic	Error [%]
energy scale	1.5
b energy scale	1.0
MC η^{jet} dependence	3.8
MC E_T^{jet} dependence	10
b tag efficiency	4.1
single/double c, b	4.6
track reconstruction	7.7
b multiplicity	0.8
Z efficiency	1.8
luminosity	5.8
background fake lepton	2.4
other backgrounds	0.4
total	16

	CDF Run II Preliminary Data	PYTHIA	MCFM NLO	MCFM NLO +ue +had
$\sigma(Z^0 + b\,\text{jet})$	$0.94 \pm 0.15 \pm 0.15$ pb	0.84	0.51	0.56
$\sigma(Z^0 + b\,\text{jet})/\sigma(Z^0)$	$0.00369 \pm 0.00057 \pm 0.00055$	0.0035	0.0021	0.0023
$\sigma(Z^0 + b\,\text{jet})/\sigma(Z^0 + \text{jet})$	$0.0235 \pm 0.0036 \pm 0.0045$	0.0218	0.0188	0.0177

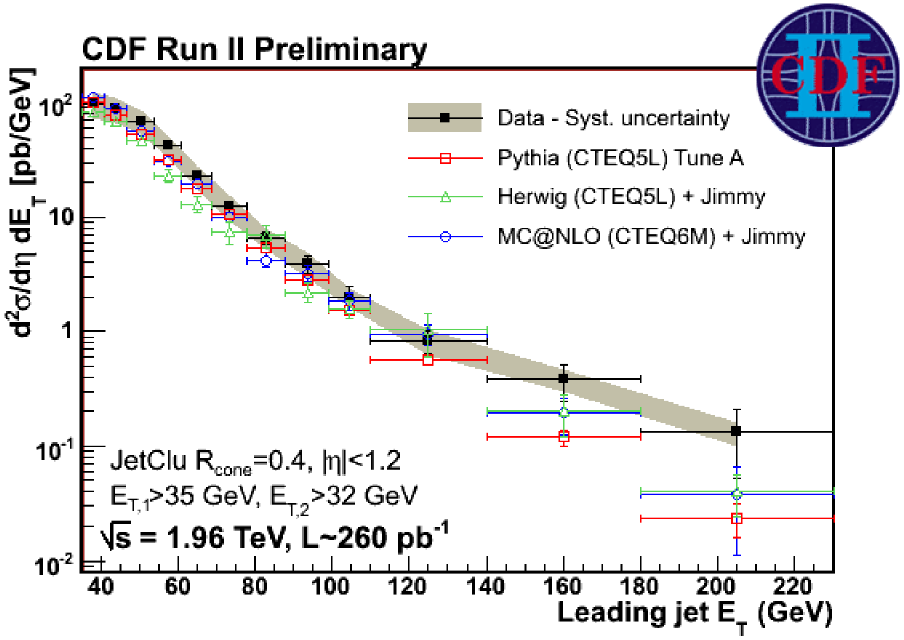
- Overall precision improved by almost a factor of 2.
- σ(Z+b) is 2σ away from MCFM NLO preliminary calculation by Campbell

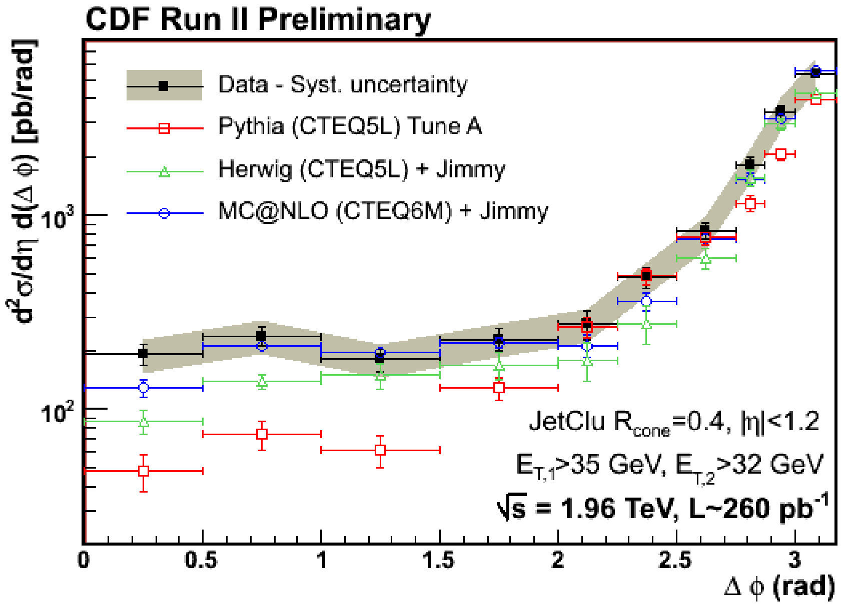
Inclusive bb di-jets production

- 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



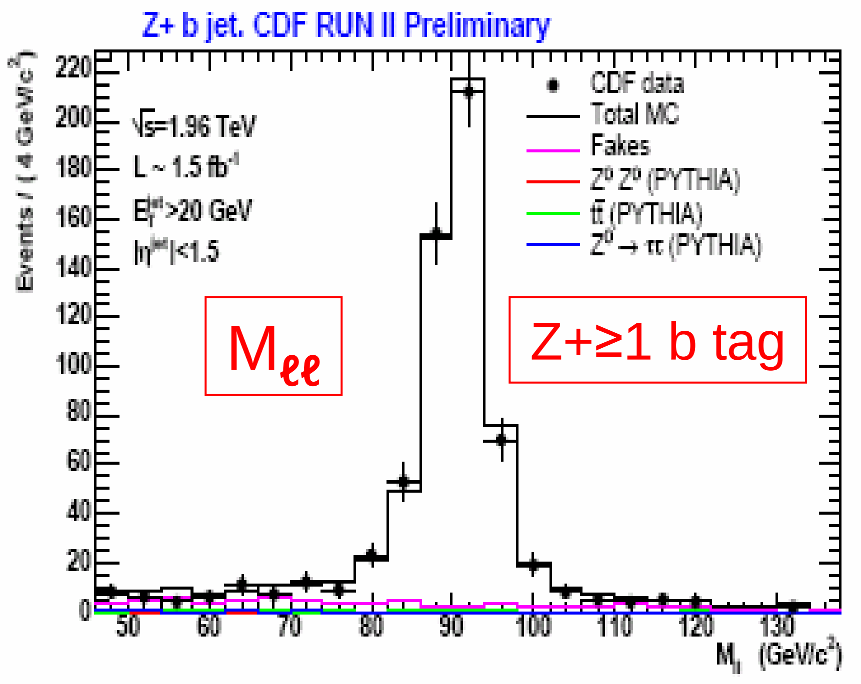


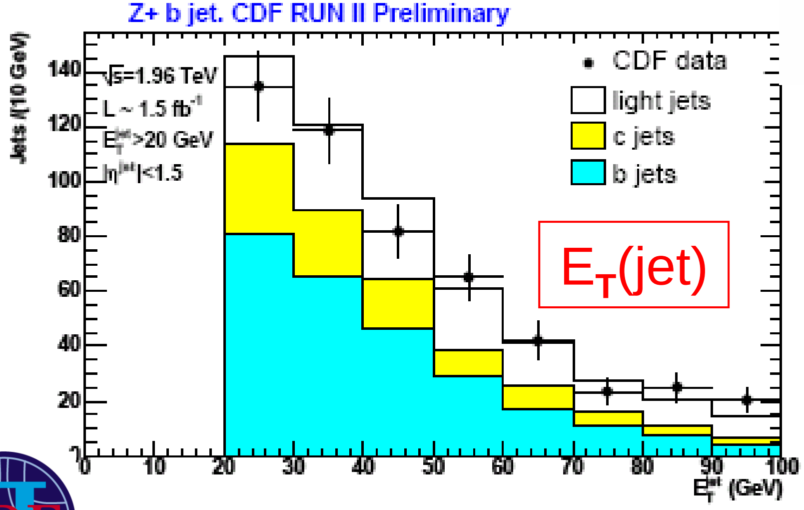
Z+b jets new CDF analysis

- Luminosity from 330 pb^{-1} → 1.5 fb^{-1}

- Improved selection, higher acceptance from 7.7% → 9.6%

- Improved systematics





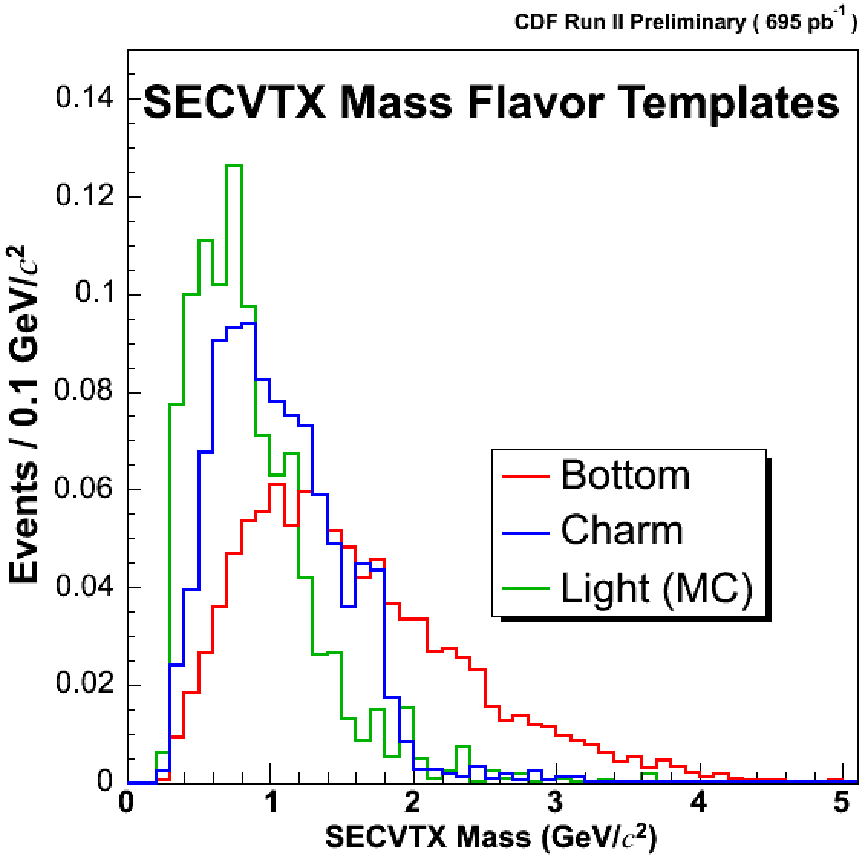
Inclusive Jets, Cone ΔR=0.7

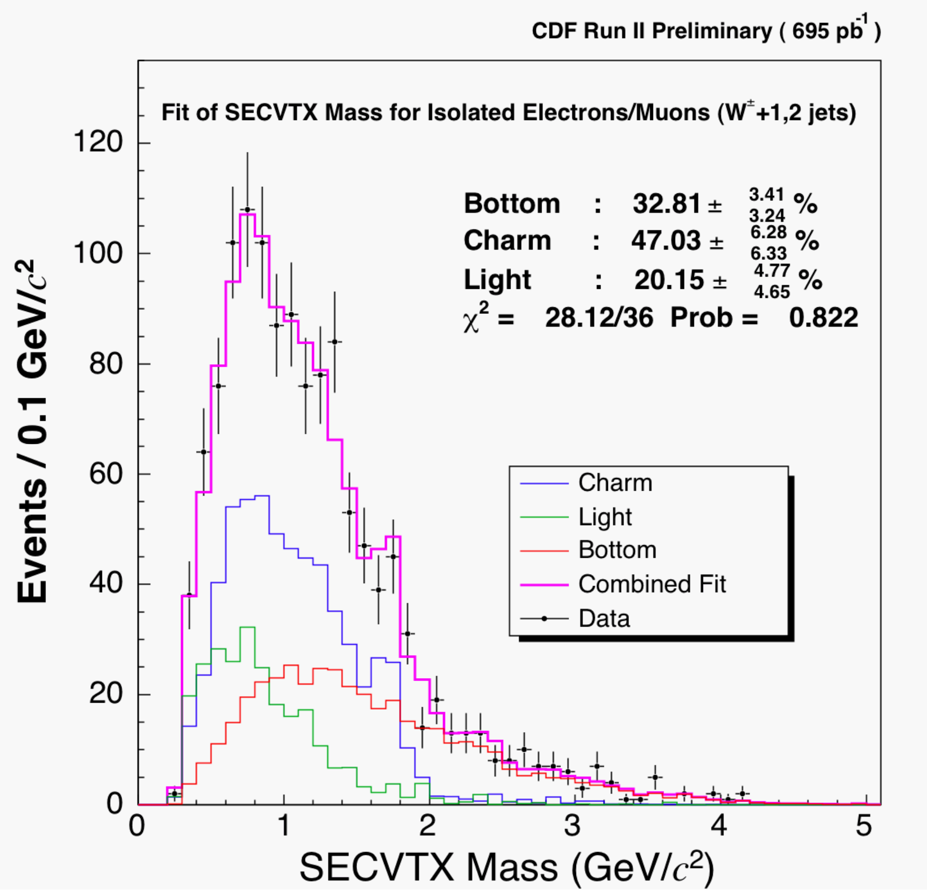
Ask for the Jet to have a Secondary Vertex Tag and

…exploit light,charm to b separation from sec.vtx. Mass →

W + bb production results

In secondary-vertex-tagged sample, fit for light, c, b contributions





measure: 0.90±0.32 pb for Wbb (E_T(j)>20 GeV, |η|<2.0

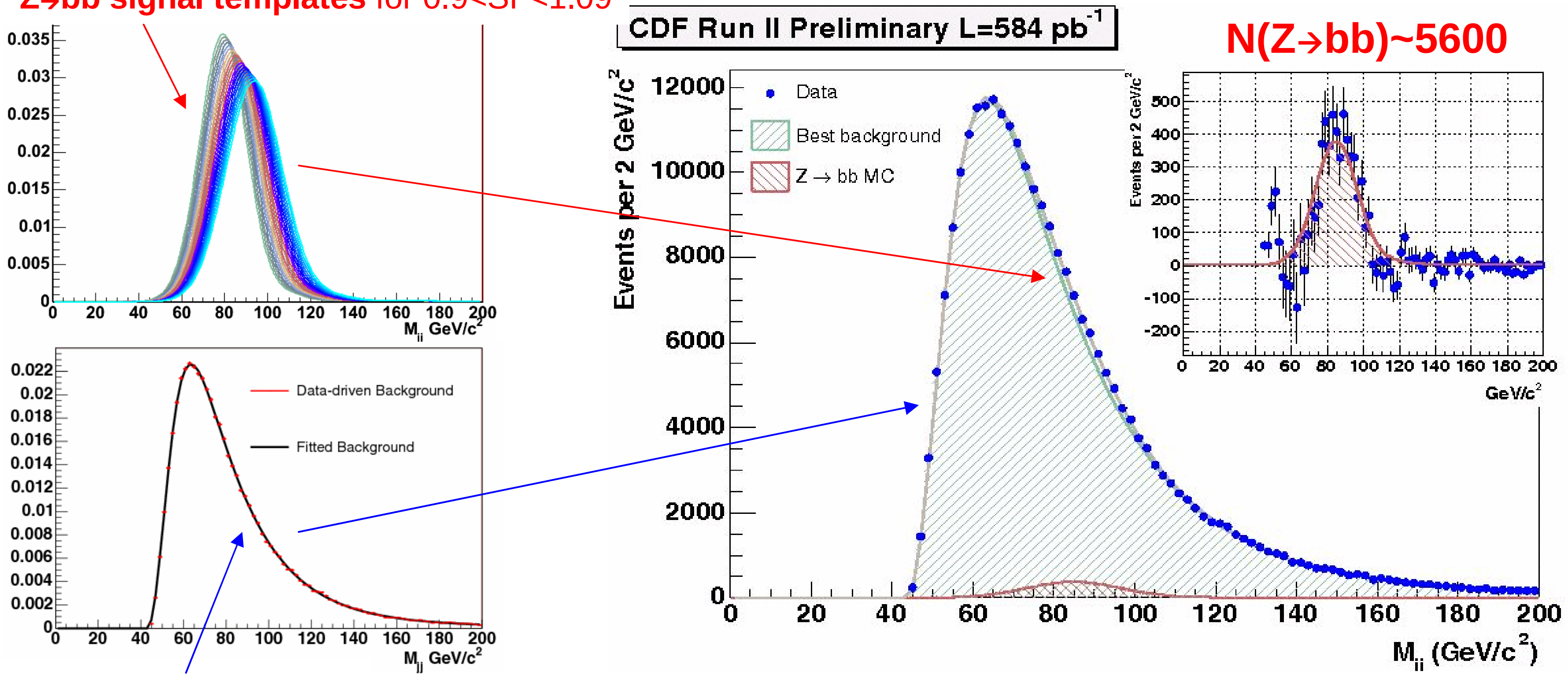
LO calculation (ALPGEN): 0.74±0.18 pb

b-Jets Energy Scale and Z→bb

- **Generic Jet Energy Calibration of the Detector needs specific correction for b-Jets**
- **Reduction of uncertainty in b-JES important for Top mass measurement**
- **Test algorithms to improve b-jet energy resolution is crucial for low mass Higgs search.**
- **Use of L2 SVT based b-tag di-jet trigger → Extract a signal, measure data/MC b-JES**

Result on 600 pb^{-1} → b-jet Data/MC Energy Scale Factor = 0.974 ± 0.020

Z→bb signal templates for 0.9<SF<1.09



N(Z→bb)~5600

Background template

Observation and mass measurement of Bc

B_c selection is unbiased based upon $B_u \to J/\Psi$ K:

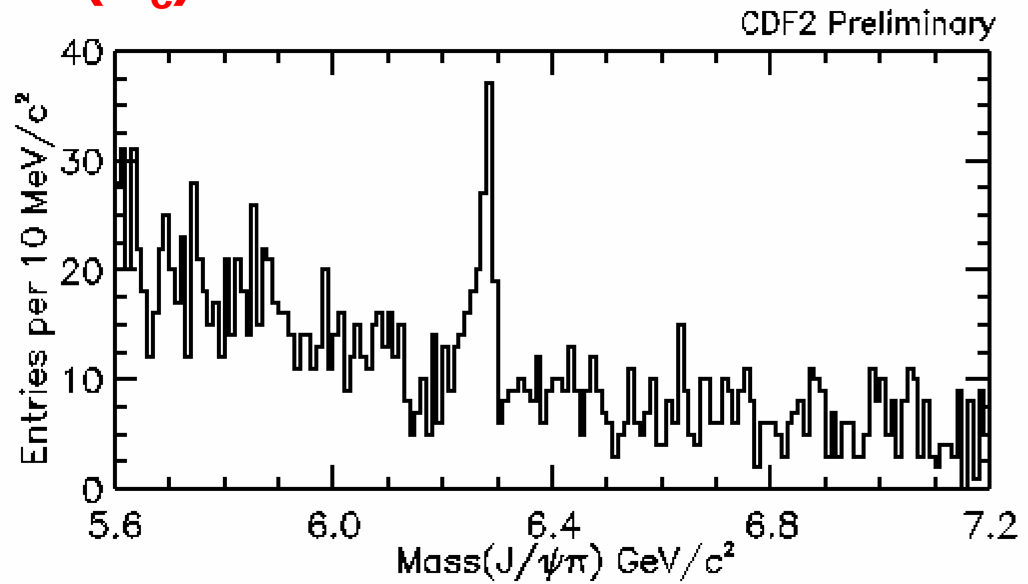
In 1.1 fb-1, CDF observe the decay at a significance > 6σ

and measure the mass:

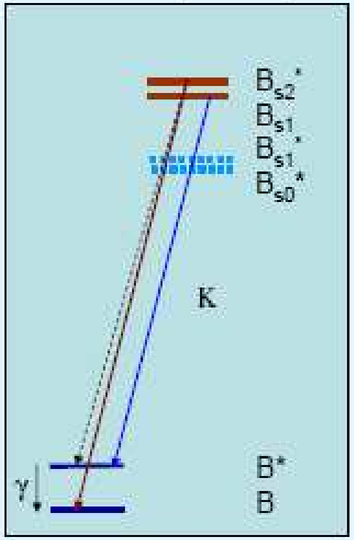
$$M(B_c) = 6276.5 \pm 4.0 \pm 2.7 \ \ \mathrm{MeV/C^2}$$

NOW with 2.2 fb-1, observation with > 8σ significance and:

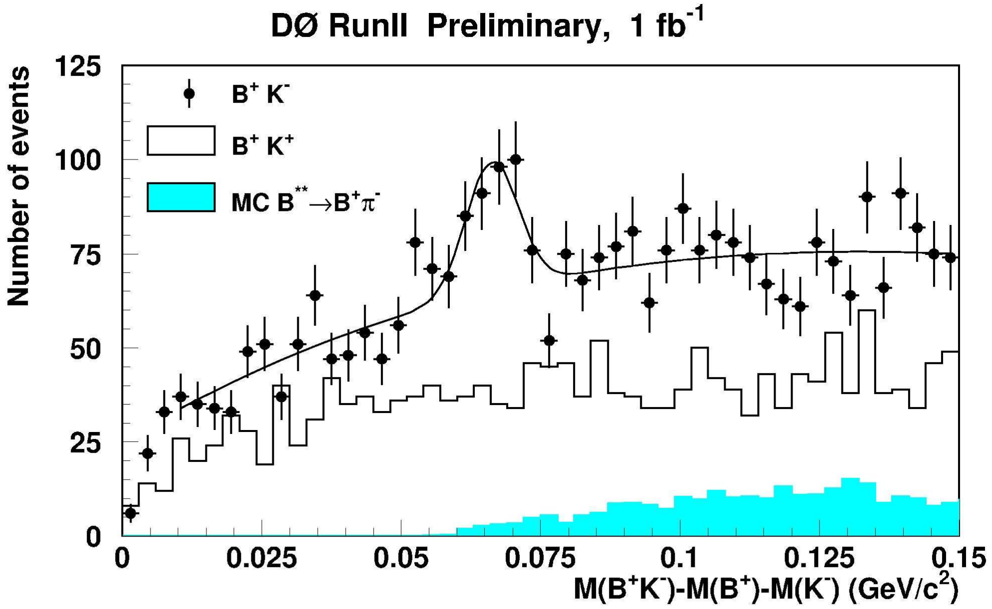
$$M(B_c) = 6274.1 \pm 3.2 \pm 2.6 \ \ \mathrm{MeV/C^2}$$



B_s^{**} : same transitions as for B^{0**} except substitute p→K. Expected:

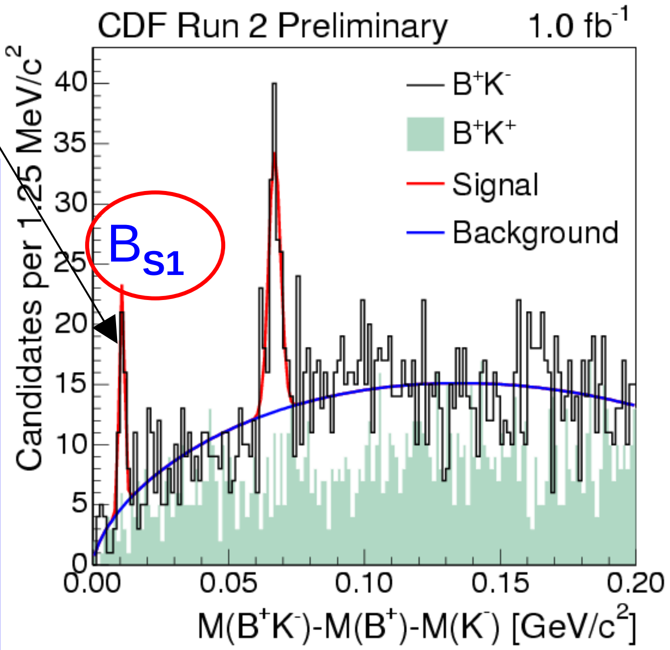


B_s^{**}



B_{s2}^* observed by both experiments. B_{s1} only by CDF, so, is it real? **(6.3σ significance)**

- Signals are observed in both channels with sharp well-defined likelihood curves.
- Significance evaluated using ratio L/L_0 (L_0 = likelihood with no signal in model)



CDF

$M(B_{s1}) = 5829.41 \pm 0.21$ (stat) ± 0.14 (syst) ± 0.6 (PDG) MeV/c²
$M(B_{s2}^*) = 5839.64 \pm 0.39$ (stat) ± 0.14 (syst) ± 0.5 (PDG) MeV/c²

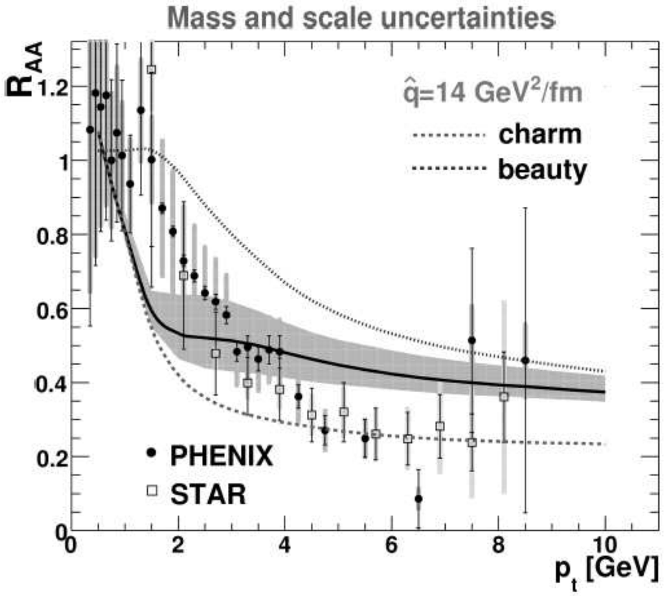
$DM(B_{s2}^*, B_{s1}) = 10.20 \pm 0.39$ (stat) ± 0.44 (syst) ± 0.35 (PDG) MeV/c²

D0

$M(B_{s2}^*) = 5839.1 \pm 1.4$(stat) ± 1.5 (syst) MeV/c²

HEAVY FLAVOUR PHYSICS AT HEAVY ION FACILITIES

The attenuation of heavy-flavoured particles in nucleus-nucleus collisions tests the microscopic dynamics of medium-induced parton energy loss and, in particular, its expected dependence on the identity (color charge and mass) of the parent parton.



Strong suppression of non Photonic e- high Pt in central AuAu collisions

Difficulty to describe it theoretically

Heavy-quark energy loss is presently studied at RHIC using measurements of the nuclear modification factor R_{AA} of ‘non photonic’(γ-conversion and π0 –Dalitz subtracted) single e-.

Charm dominating at low Pt and beauty at high Pt. Large perturbative uncertainty On Pt position of c-decay/b-decay.