Recent B Physics Results from the Tevatron

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For the CDF and D0 collaborations

Outline

- **B's at Hadron Colliders**
- **Tevatron Status**
- **CDF and D0**
- **Charm Physics**
- **B Physics**

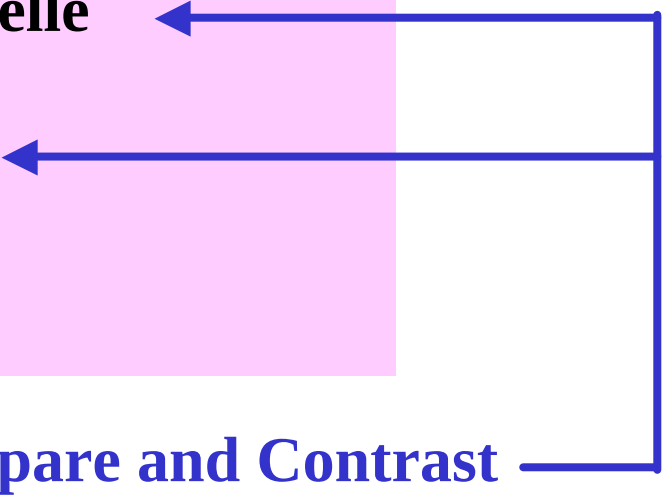
Physics at LHC 2004
Vienna
July 15, 2004



B Physics at Hadron Colliders

Recent and future B physics experiments:

$e^+ e^- \rightarrow Z^0$	SLC and LEP experiments
e p	Hera experiments
$e^+ e^-$ B factories	Babar and Belle
Hadron collider	
Central	CDF, D0,
	Atlas, CMS
Forward	TevB, LHCB



Pros and Cons at Tevatron

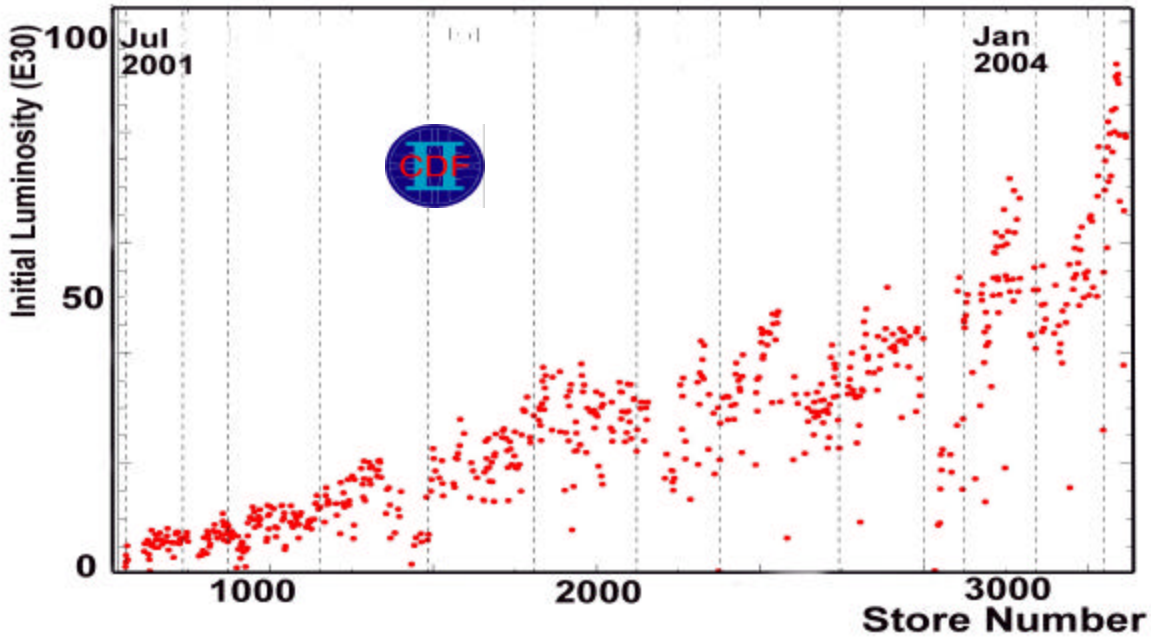
Pros:

- **Large cross section (~x1000 B factories)**
- **All B species ($B^{\pm}$, B^0, B_s, B_c, B^*, B^{**}, L_b, ...)**
- **Higher Pt Þ large boost Þ easier of measure lifetimes**
- **Incoherent production - easier for lifetimes and oscillation**

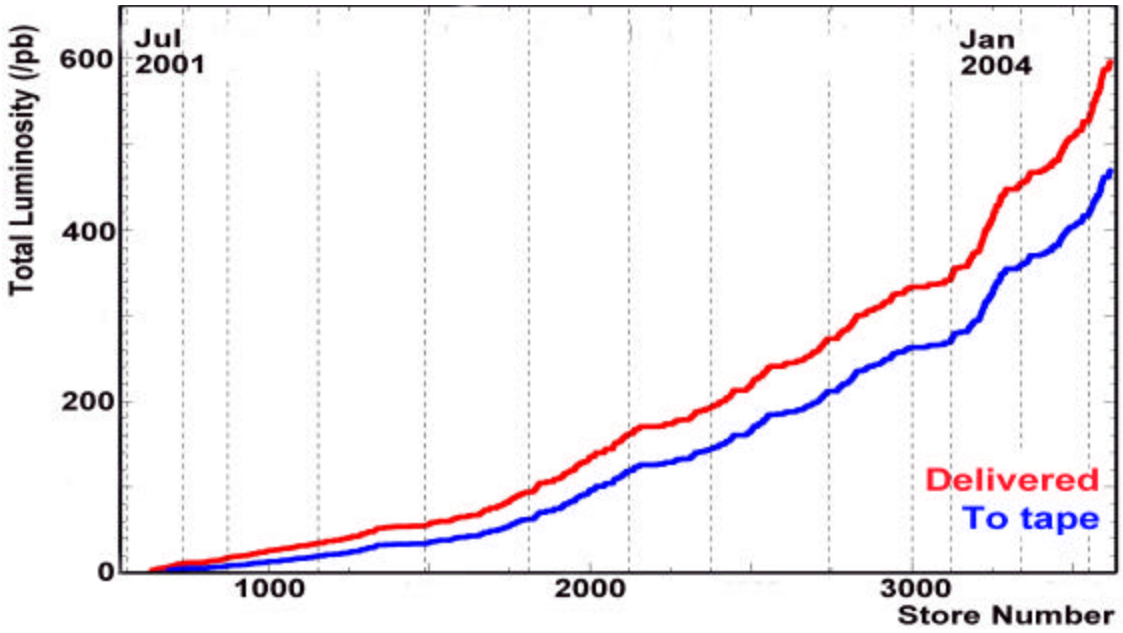
Cons:

- **Lower luminosity**
- **Very large backgrounds**
- **Events not as clean**
- **Tagging more difficult**
- **Photons difficult (calorimeters optimized for high P_t)**
- **Particle ID limited**
- **Must share resources with high P_t physics**

Run II Tevatron Performance



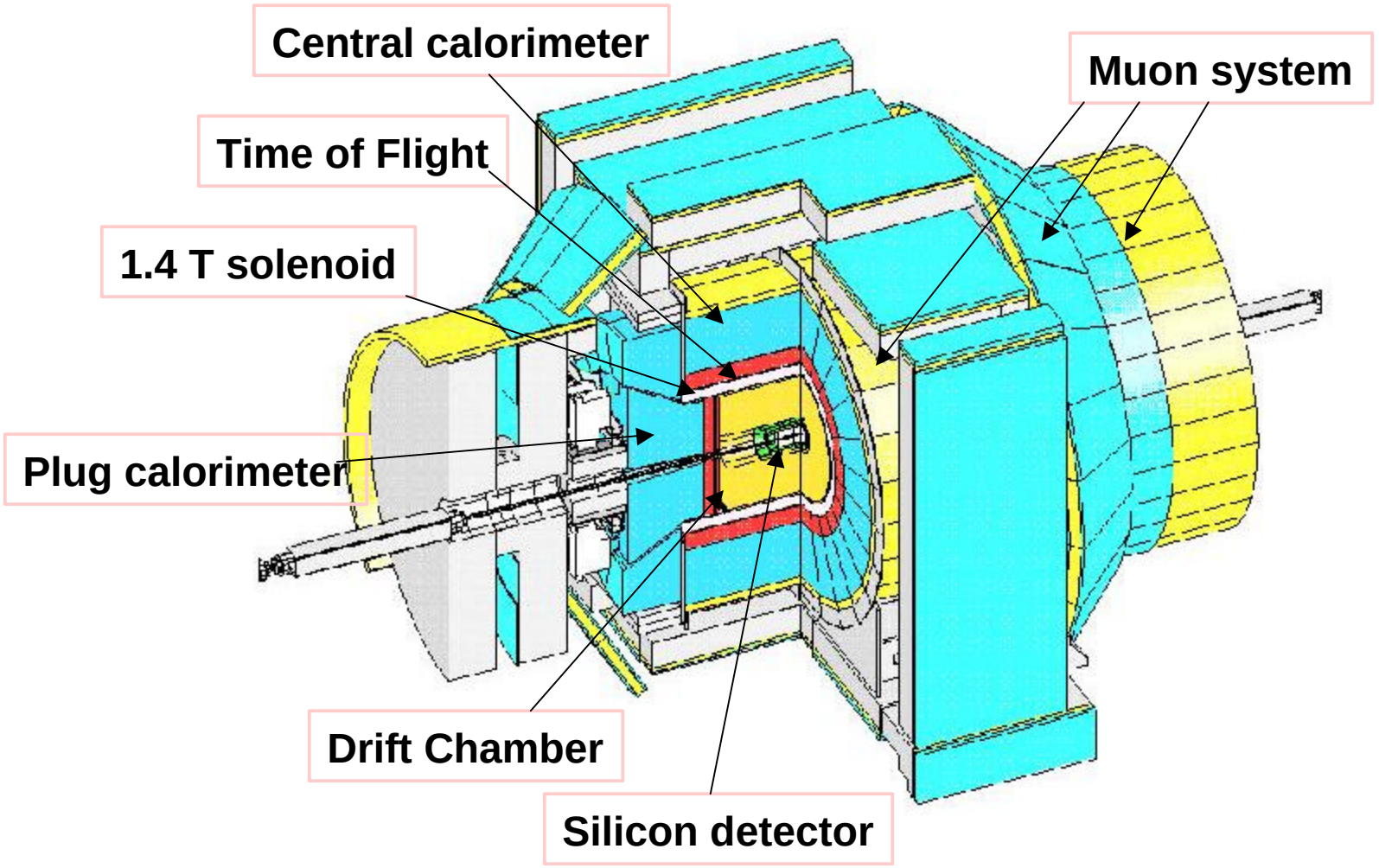
9.2×10^{31}



CDF and D0 each have ~400 pb $^{-1}$on tape.

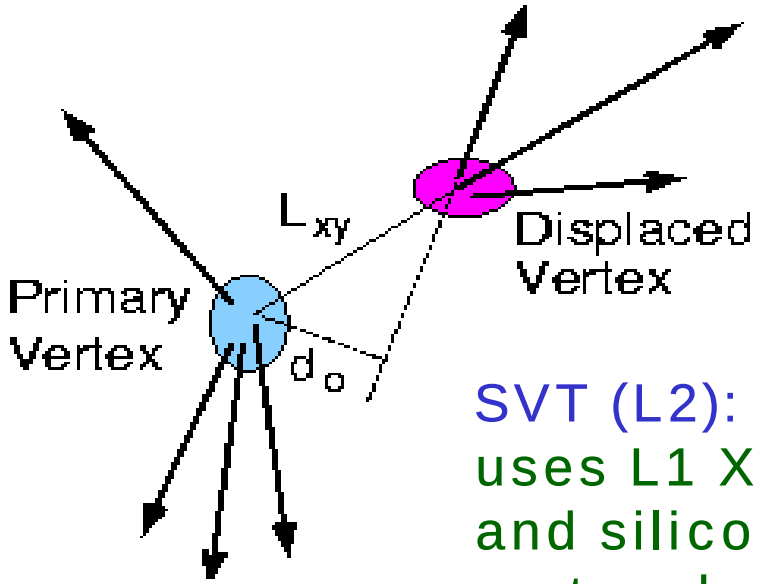
Analyses presented today include ~200 pb^{-1}.

The CDFII Detector

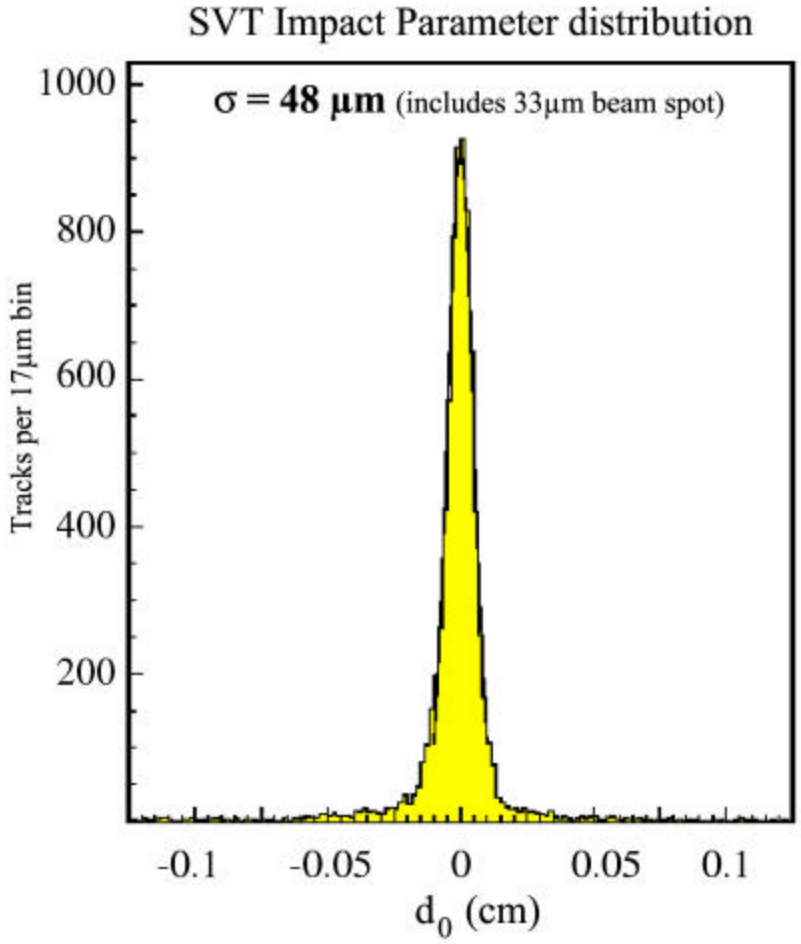


Track and Vertex Triggers

XFT:
uses drift chamber
axial layers to find
high pT tracks at L1



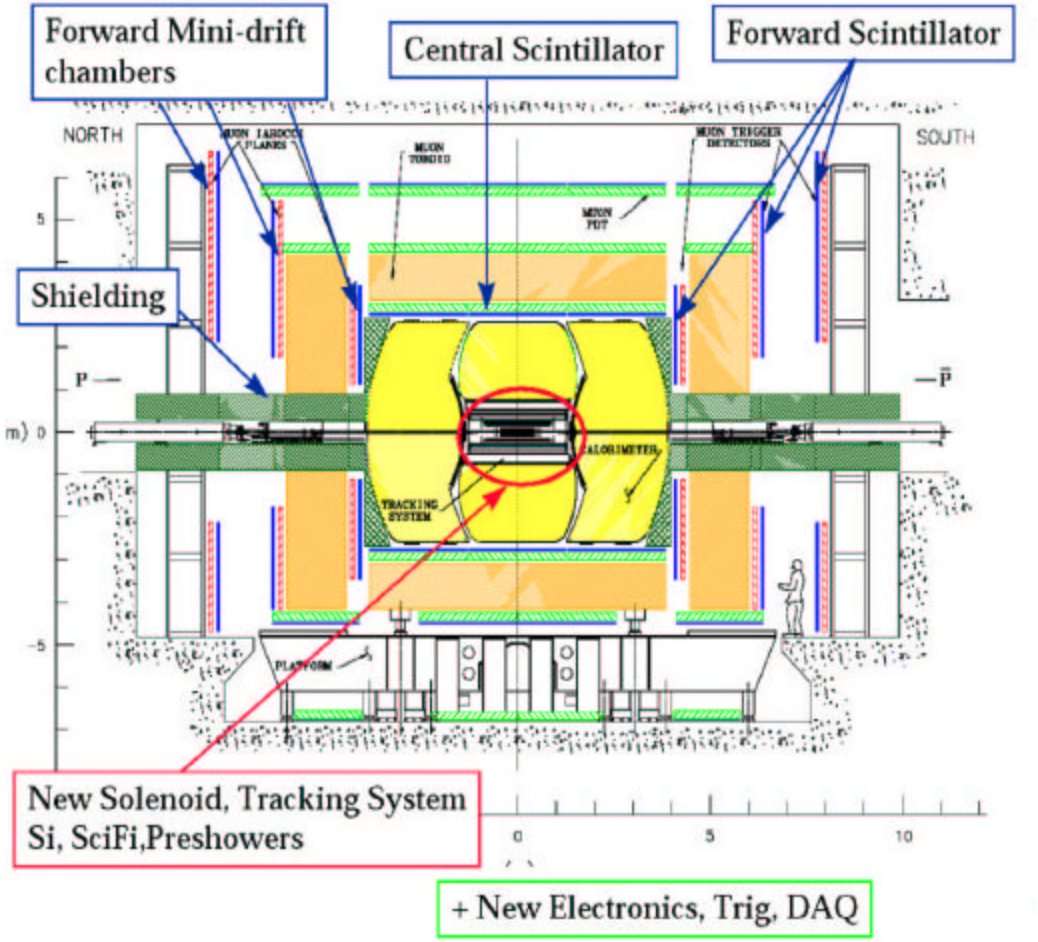
SVT (L2):
uses L1 XFT
and silicon
vertex detector



Two displaced tracks

Lepton + displaced track

DØ Run II Detector



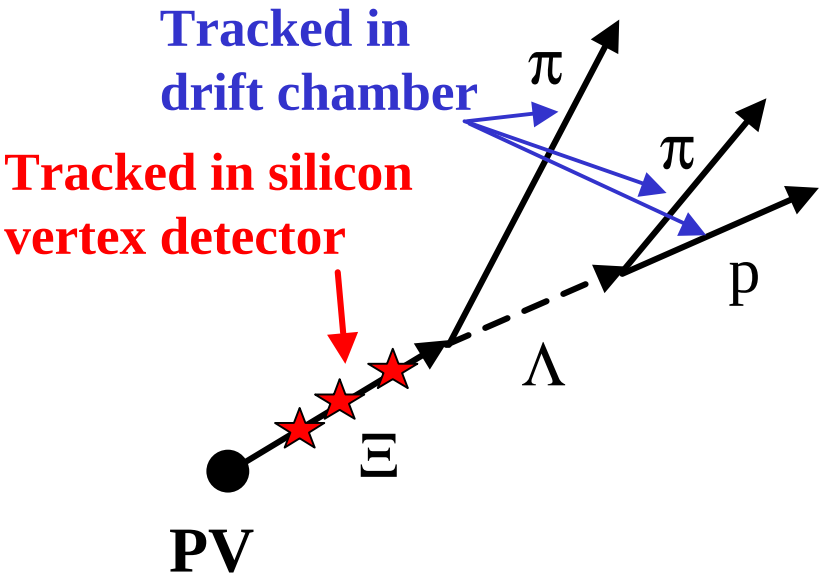
Retained from Run I

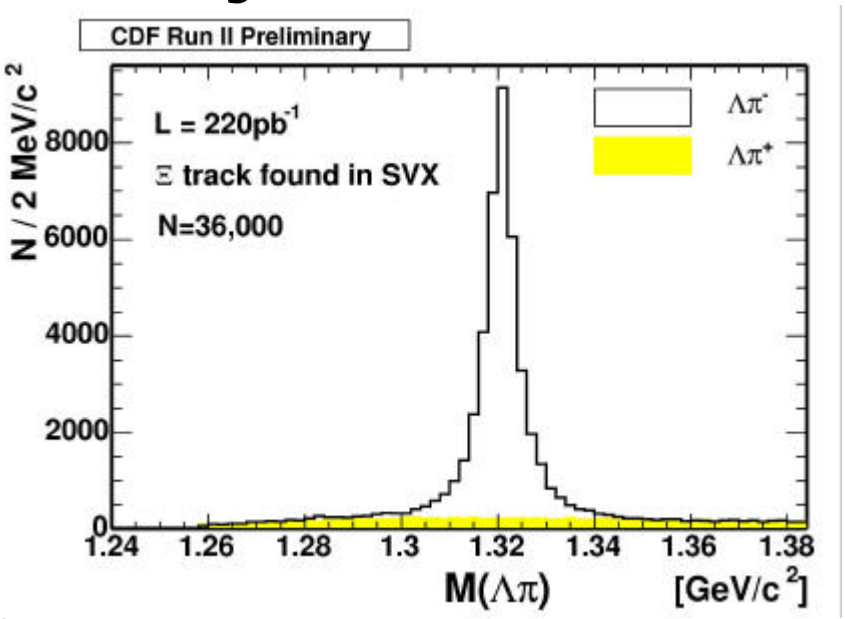
- LrAr Calorimeter
- Central muon detector
- Muon Toroid

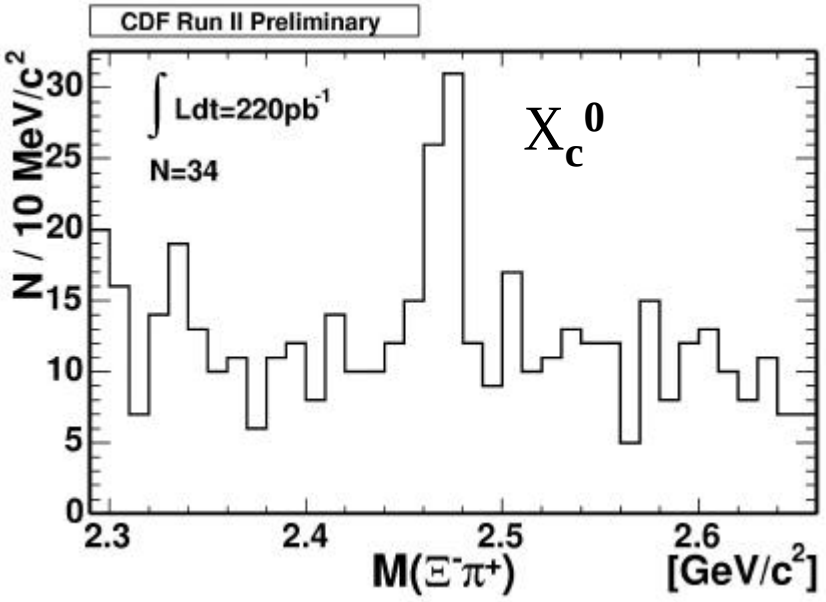
New for Run II

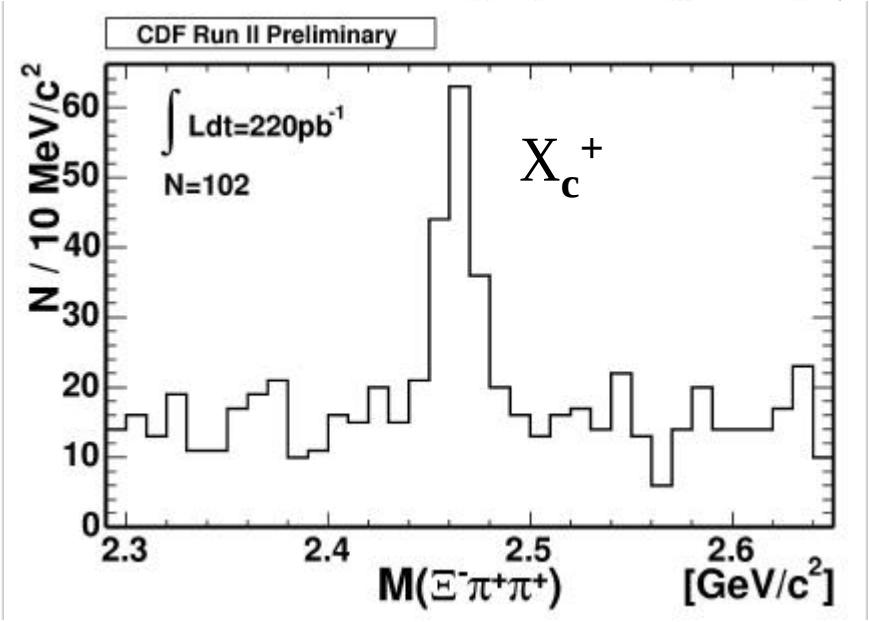
- Magnetic tracker
  - 2 Tesla solenoid
  - Silicon microvertex tracker
  - Scintillating fiber tracker
- Preshower detectors
- Forward muon detector
- Forward proton detector
- Front-end electronics
- Trigger and DAQ

Charmed Baryons



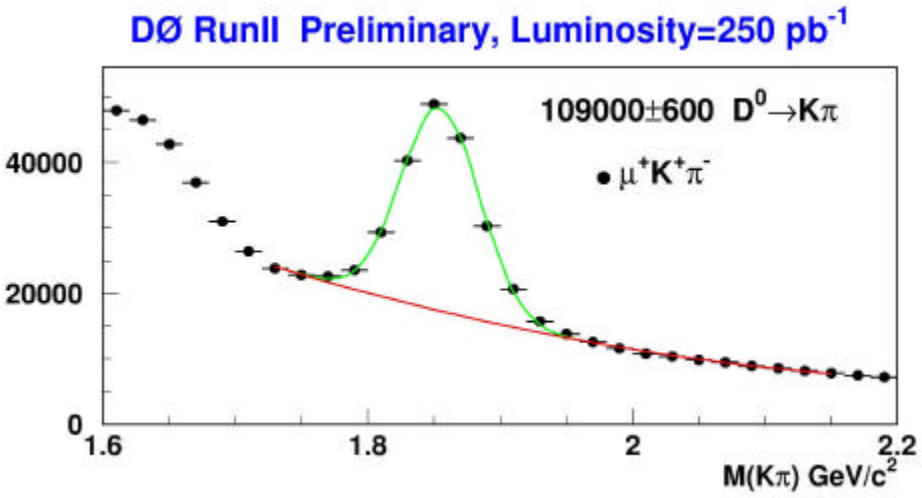




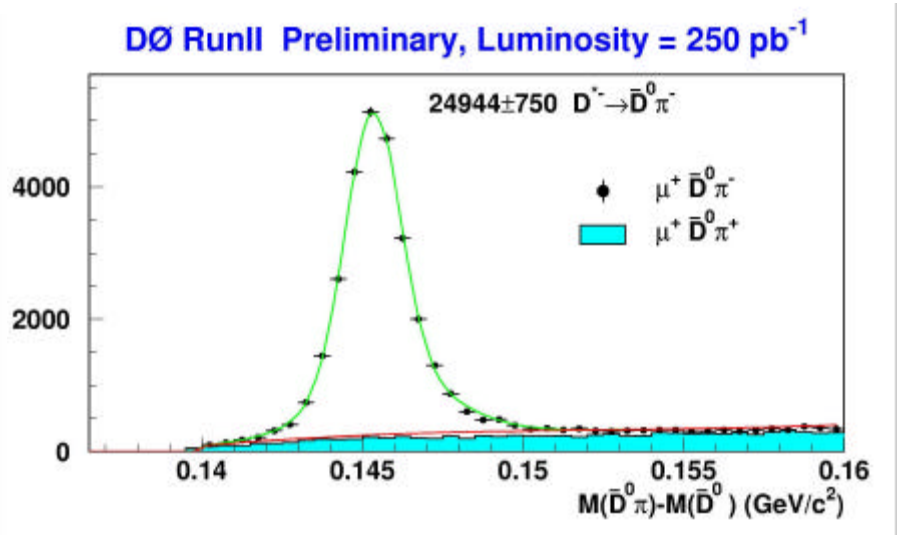


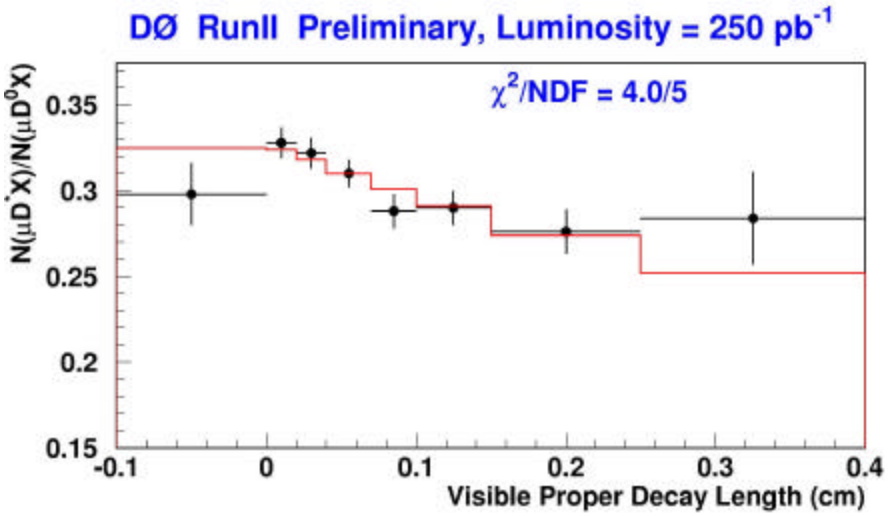
Lifetime Ratios

B ® D^0 m$^+$ n X



B ® D^{*-} m$^+$ n X

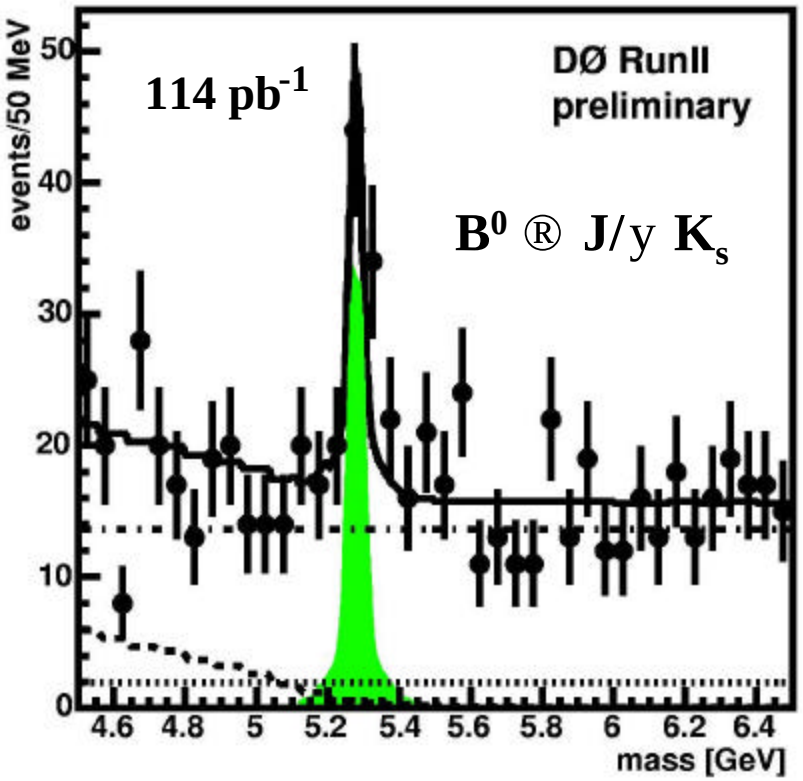


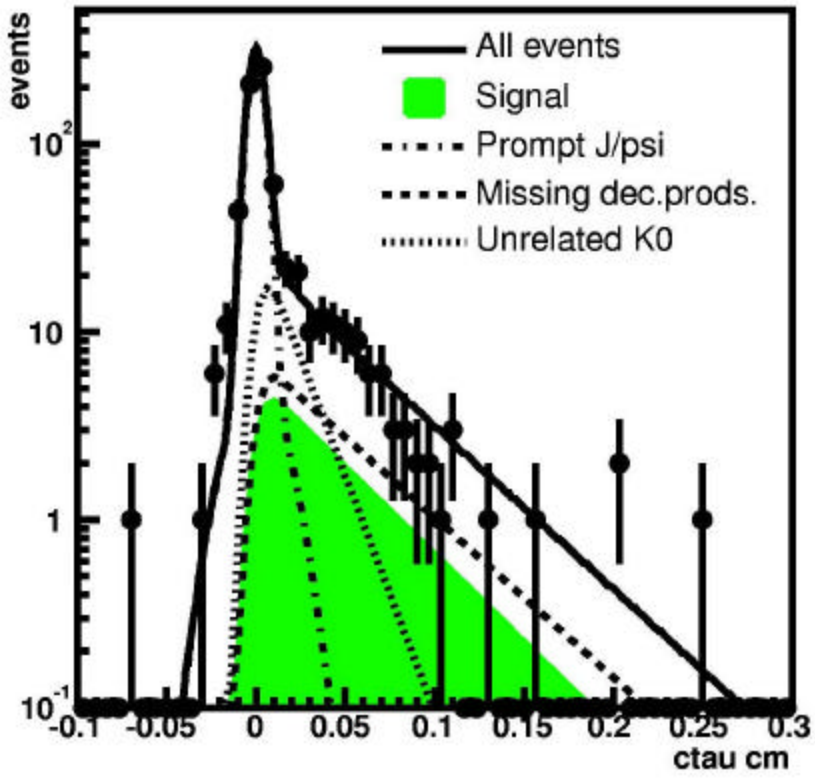


t^+/t^0 = **1.093 ± 0.021 ± 0.022**

2004 PDG: 1.086 ± 0.017

Lifetimes

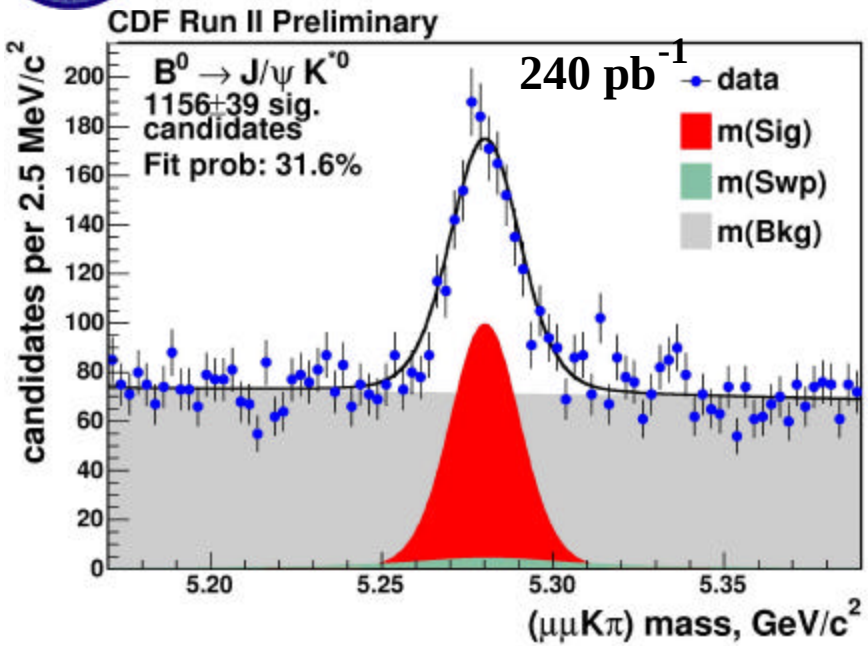


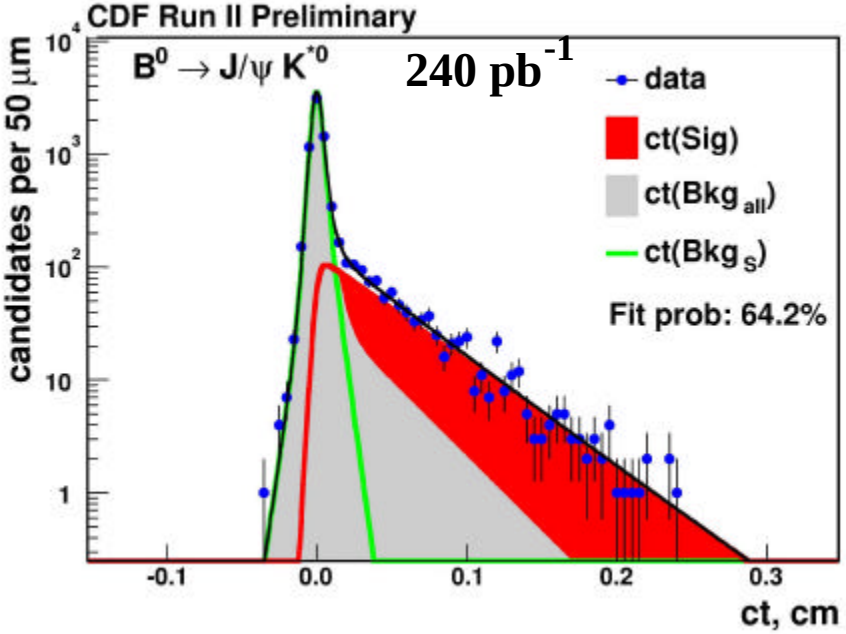


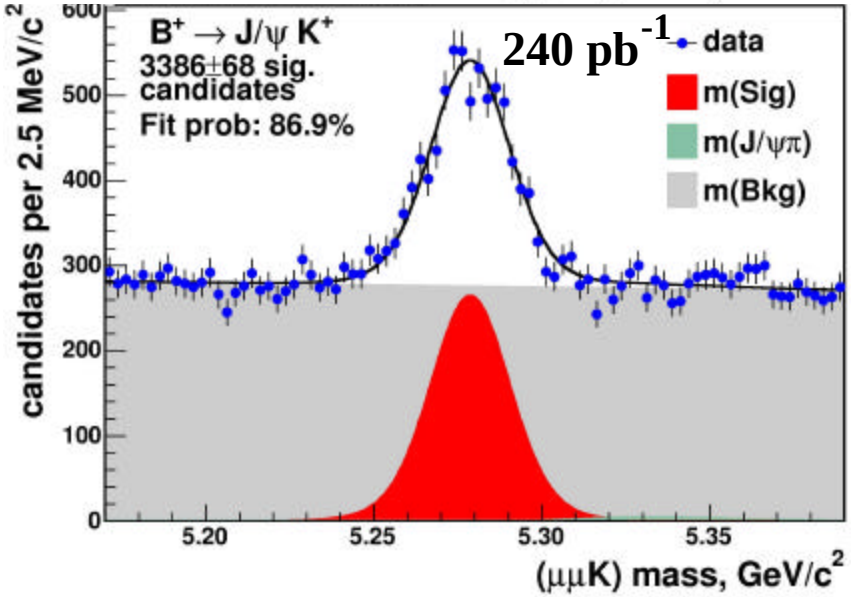
$$t_{B_d} = 1.56^{+0.32}_{-0.25} \pm 0.13 \text{ ps}$$

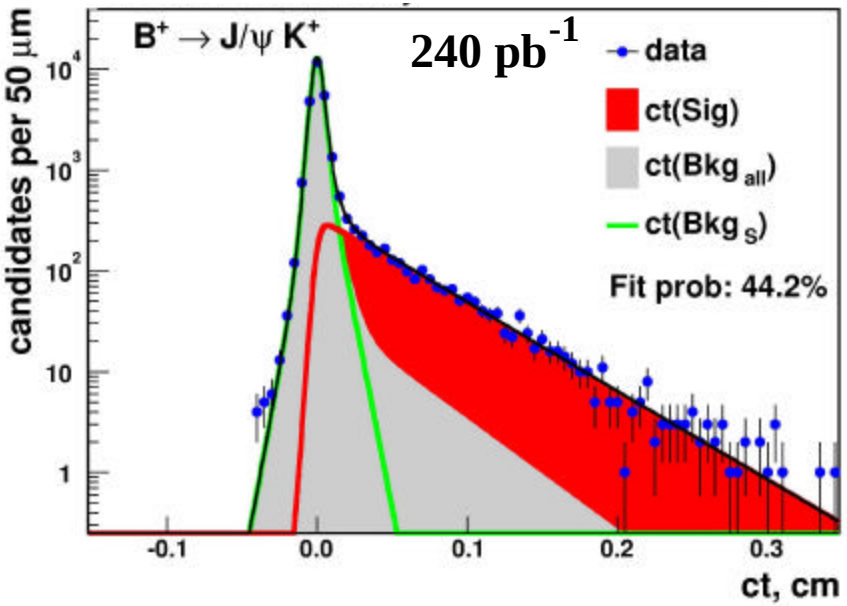
2004 PDG: 1.536 ± 0.014 ps

Lifetimes

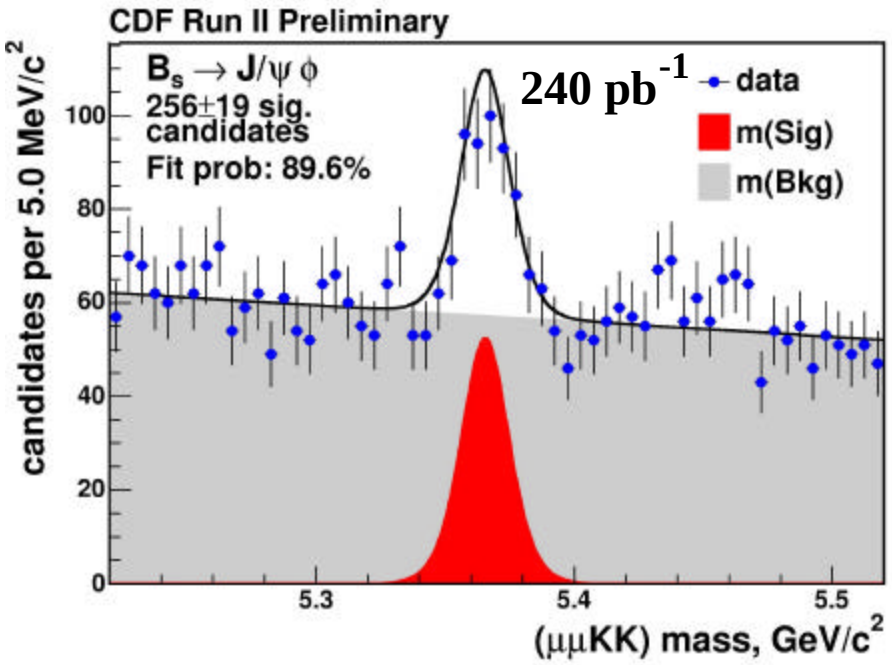

CDF Run II Preliminary
$B^0 \to J/\psi\, K^{*0}$
240 pb^{-1}
1156±39 sig. candidates
Fit prob: 31.6%
data
m(Sig)
m(Swp)
m(Bkg)
candidates per 2.5 MeV/c^2
($\mu\mu K\pi$) mass, GeV/c^2

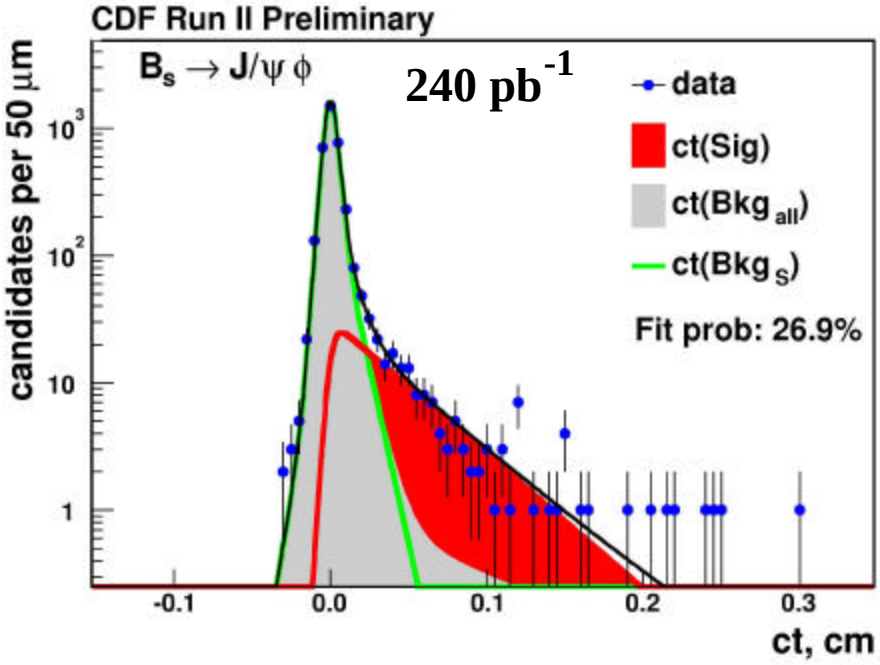

CDF Run II Preliminary
$B^0 \to J/\psi\, K^{*0}$
240 pb^{-1}
data
ct(Sig)
ct(Bkg$_{all}$)
ct(Bkg$_S$)
Fit prob: 64.2%
candidates per 50 μm
ct, cm


$B^+ \to J/\psi\, K^+$
240 pb^{-1}
3386±68 sig. candidates
Fit prob: 86.9%
data
m(Sig)
m(J/ψπ)
m(Bkg)
candidates per 2.5 MeV/c^2
($\mu\mu K$) mass, GeV/c^2


$B^+ \to J/\psi\, K^+$
240 pb^{-1}
data
ct(Sig)
ct(Bkg$_{all}$)
ct(Bkg$_S$)
Fit prob: 44.2%
candidates per 50 μm
ct, cm

Lifetimes



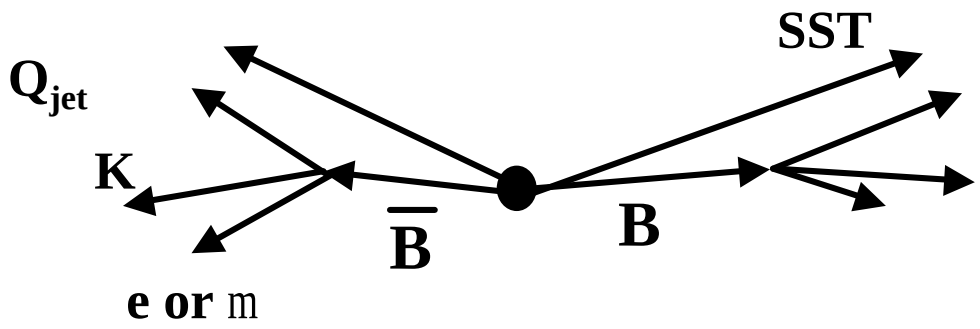


		2004 PDG
t^+	1.662 ± 0.033 ± 0.008 ps	1.671 ± 0.018 ps
t^0	1.539 ± 0.051 ± 0.008 ps	1.536 ± 0.014 ps
t_s	1.461 ± 0.100 ± 0.010 ps	1.461 ± 0.057 ps

Tagging

For many measurements (mixing and CP violation) it is necessary to tag the B meson type (B or $\overline{B}$) at production.

Most taggers based on B-hadron pair production at Tevatron.

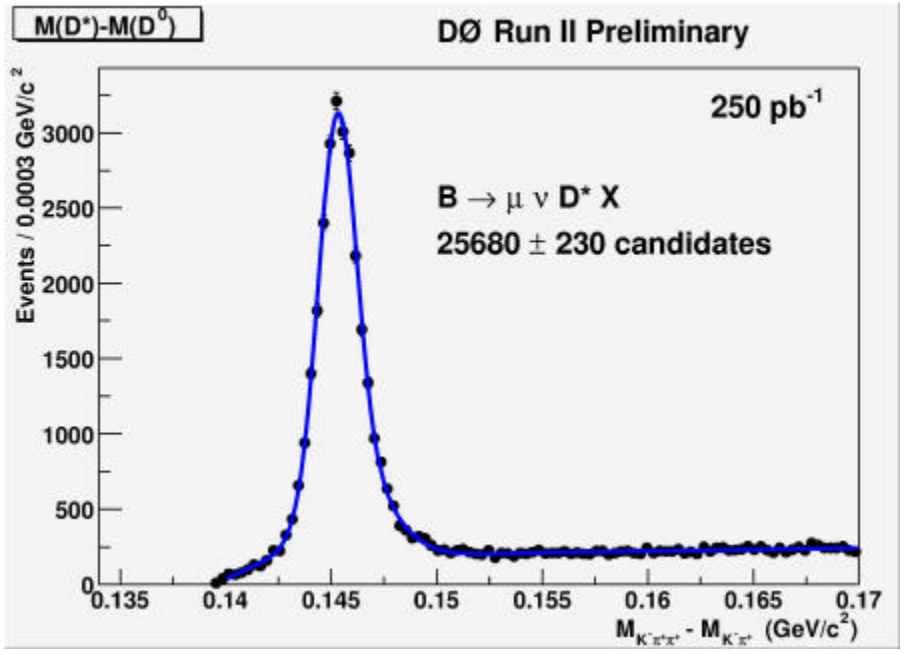


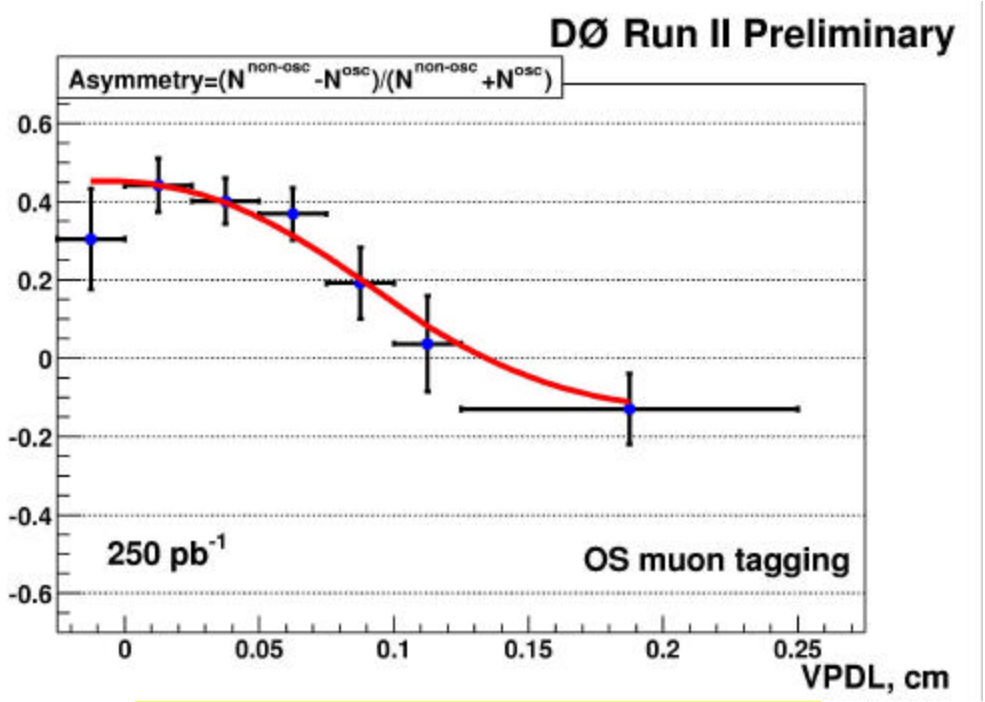
Taggers:

- **Opposite side lepton (e or μ)**
- **Jet charge (P_t weight charge of opposite jet)**
- **Opposite side K**
- **Same side tag (charge of track near B)**

Efficiency ε
Dilution $D = 1 - 2f_{mistag}$
$N_{effective} = \varepsilon D^2 N_0$

Opposite Side MuonTagging





$\Delta m_d = 0.506 \pm 0.055 \pm 0.049\ ps^{-1}$

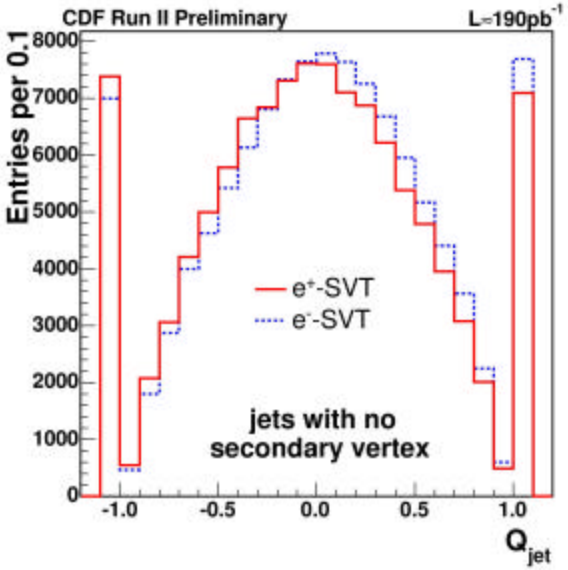
2004 PDG: $0.502 \pm 0.007\ ps^{-1}$

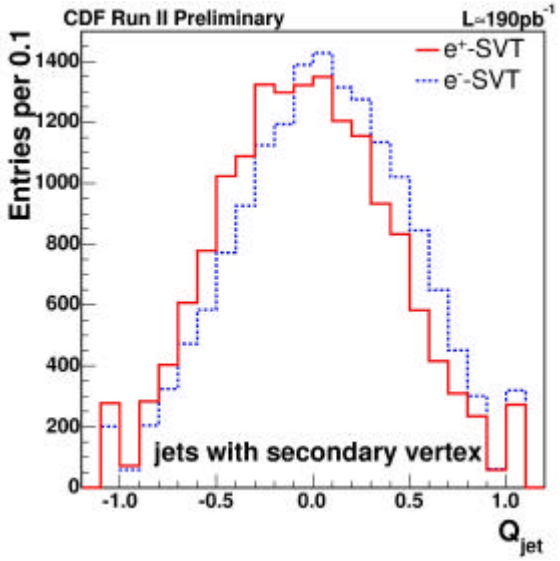
$\varepsilon D^2 \sim 1.0\%$

Measure asymmetry in number of B's that have "correct" correlation versus "incorrect".

Amplitude is proportional to D. There is an offset due to $B^{\pm}$.

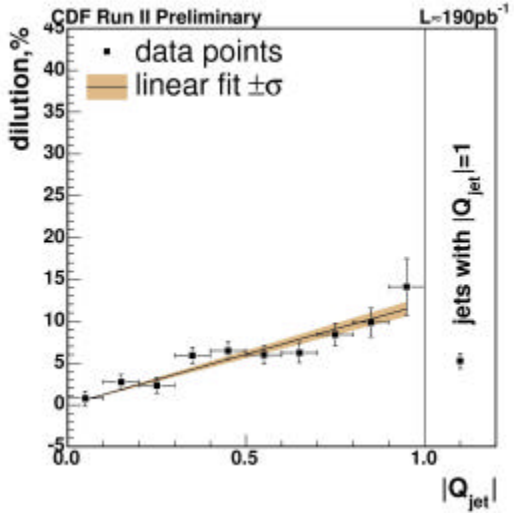
Jet Charge Tagging

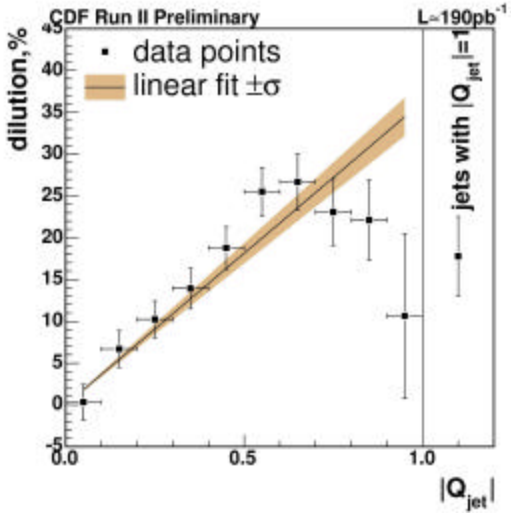




$eD^2 \sim 0.42\%$

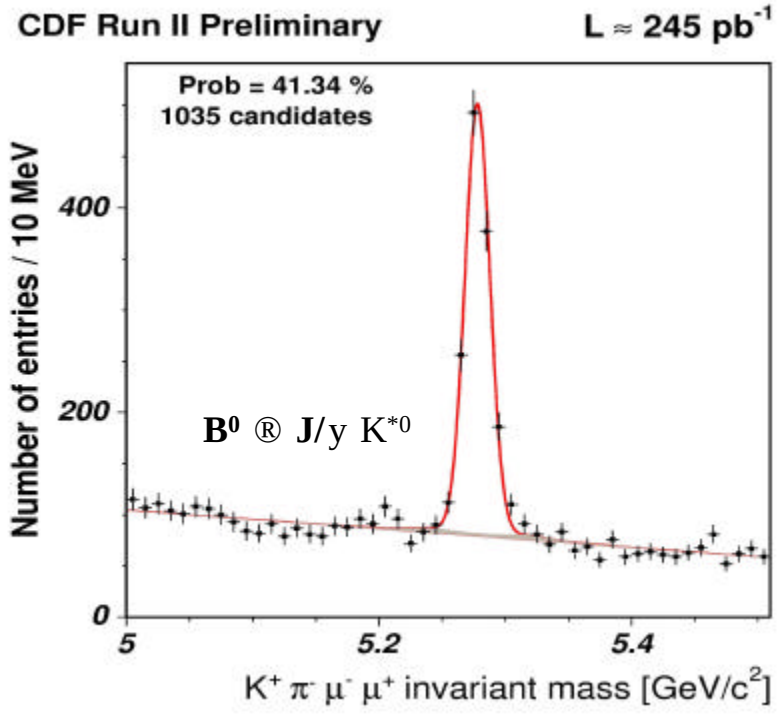
Working on improvements. Expect ~1% soon.

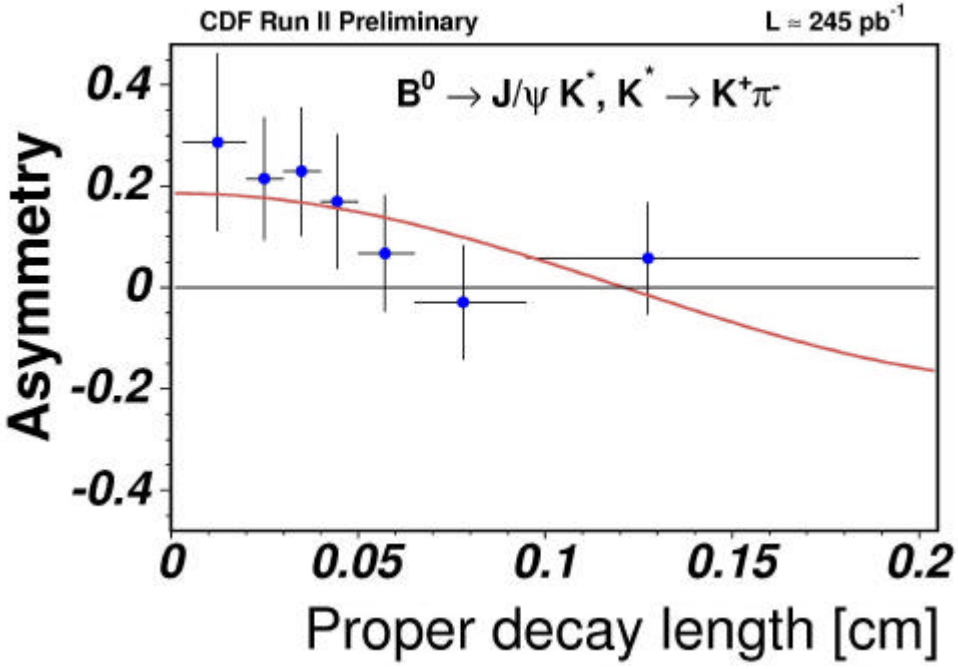




Use Q_{jet} dependence to weight events with better dilution

Same Side Tagging





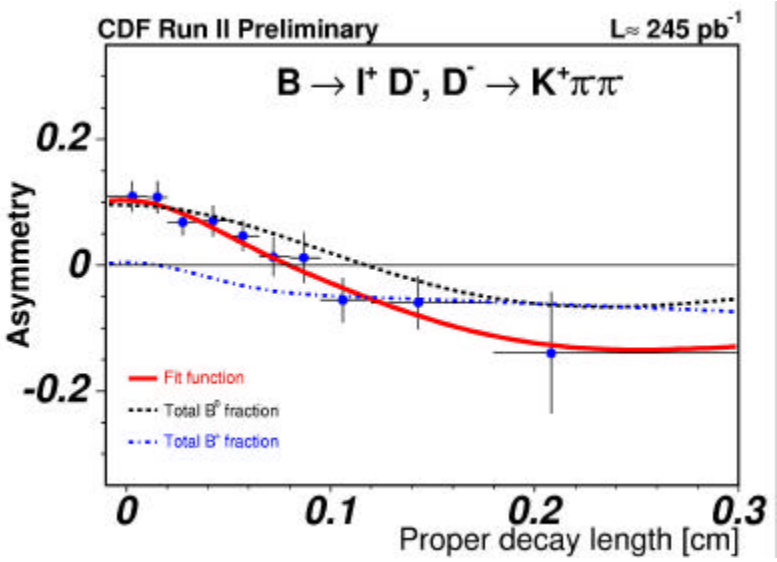
$\Delta m_d = 0.55 \pm 0.10 \pm 0.01\ ps^{-1}$

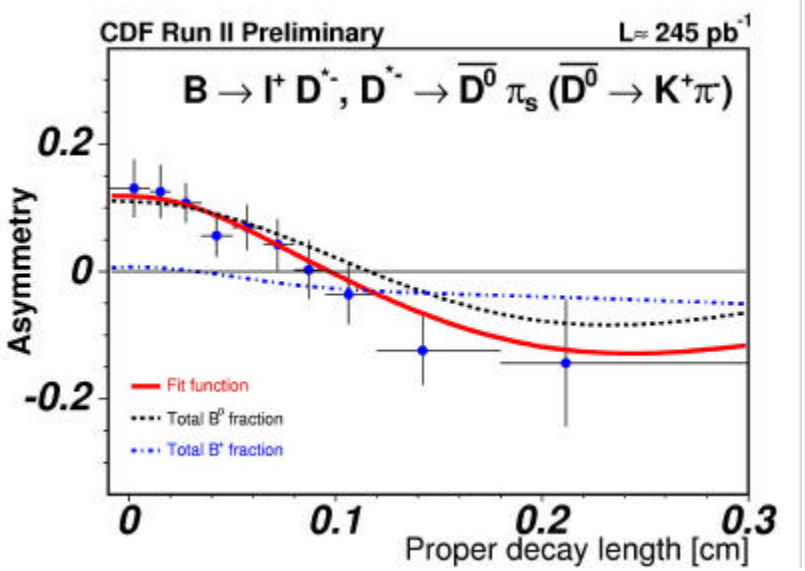
2004 PDG: 0.502 ± 0.007 ps^{-1}

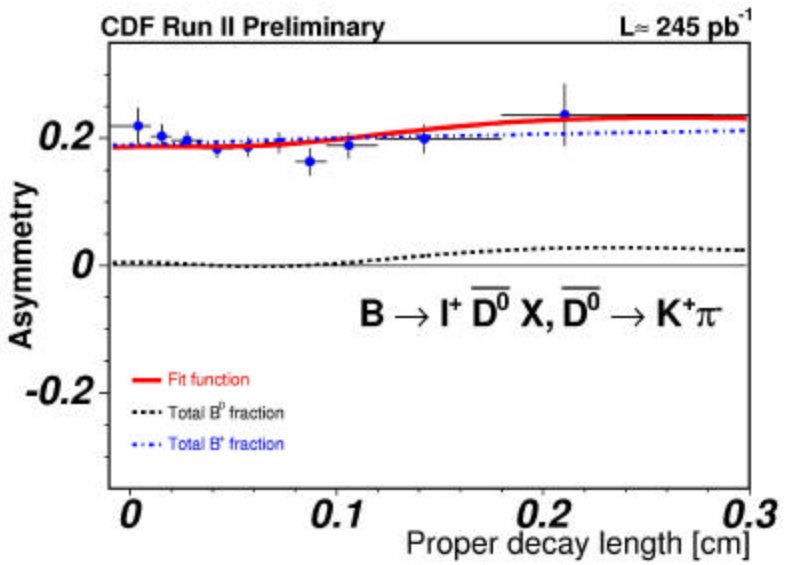
$\varepsilon D^2(B^0) \sim 1.0\%$

$\varepsilon D^2(B^+) \sim 2.8\%$

Same Side Tagging







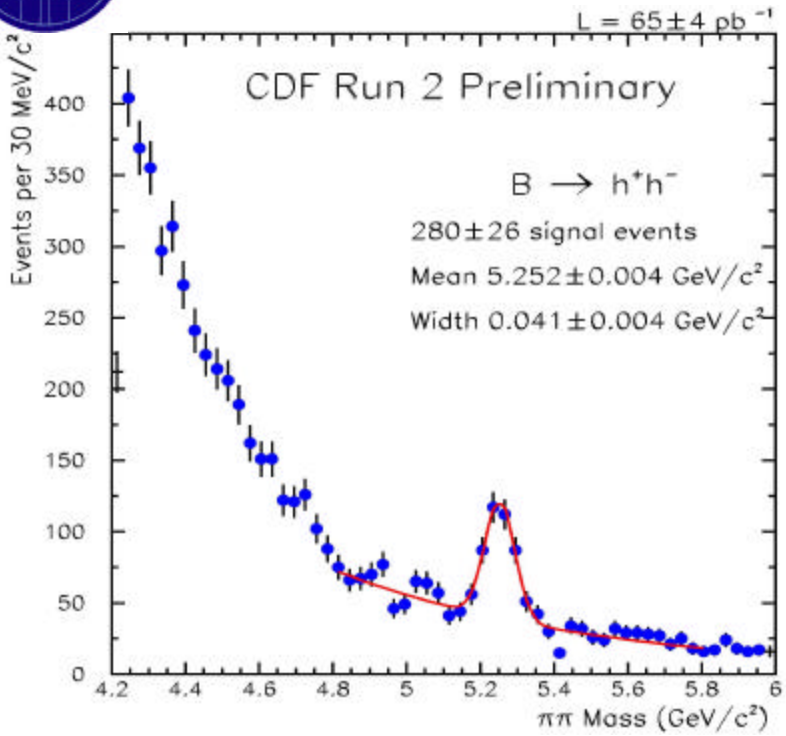
$\Delta m_d = 0.443 \pm 0.052 \pm 0.030(sc) \pm 0.012\ ps^{-1}$

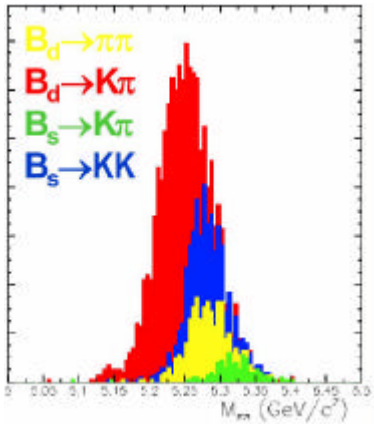
2004 PDG: $0.502 \pm 0.007\ ps^{-1}$

$D_0 = (12.8 \pm 2.0)\%$

$D_+ = (28.3 \pm 2.0)\%$

B ® h h





Signal contribution from

B^0 ® $K^+ p^-$

B^0 ® $p^+ p^-$

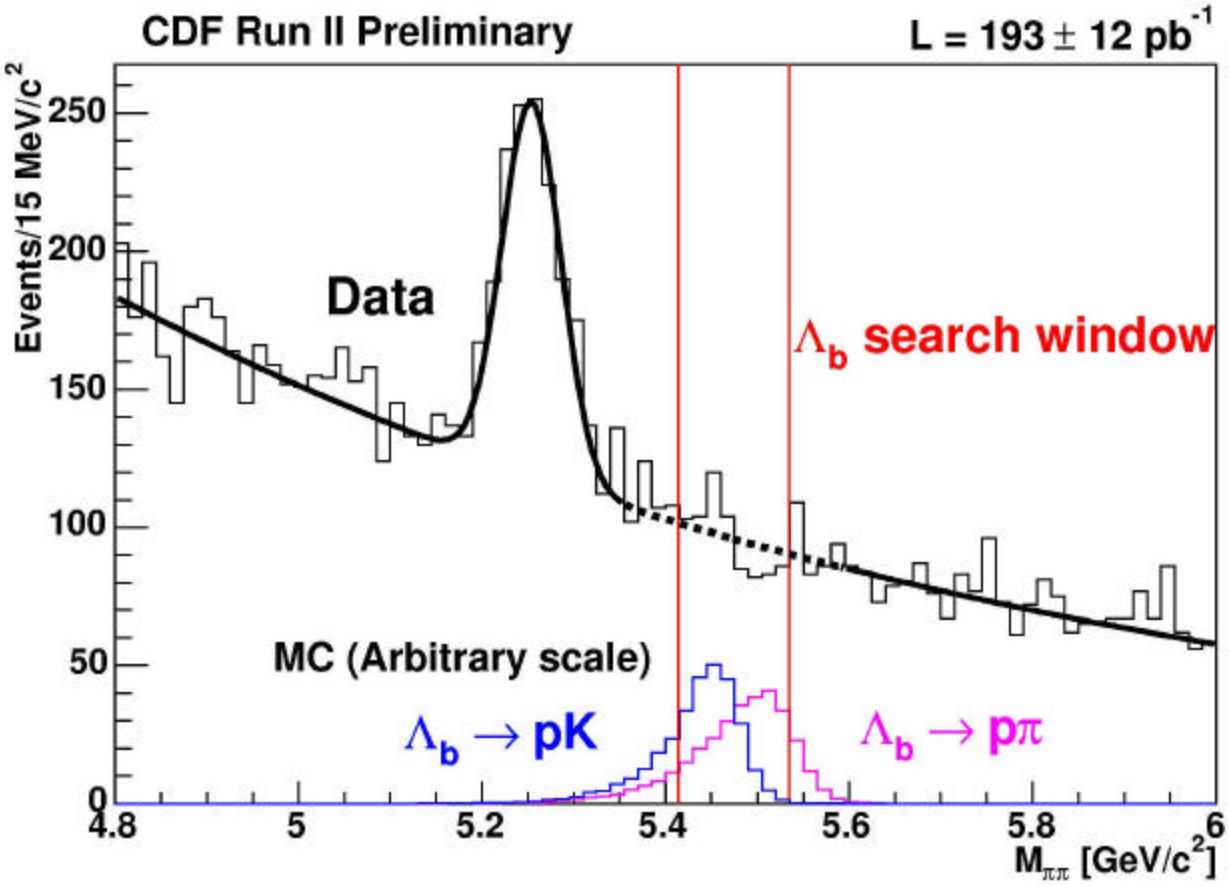
B_s ® $K^+ K^-$

B_s ® $p^+ K^-$

Separate using kinematics and dE/dx (1.2 s here, has improved to 1.38 s).

		2004 PDG
$\frac{BR(B^0 \to p^+ p^-)}{BR(B^0 \to K^+ p^-)}$	$= 0.26 \pm 0.11 \pm 0.06$	0.26 ± 0.03
$A_{CP} = \frac{\bar{B}^0 \to K^+ p^- - B^0 \to K^+ p^-}{\bar{B}^0 \to K^+ p^- + B^0 \to K^+ p^-}$	$= 0.02 \pm 0.15 \pm 0.02$	-0.09 ± 0.04
$\frac{BR(B_s \to K^+ K^-)}{BR(B^0 \to K^+ p^-)}$	$= 2.71 \pm 0.73 \pm 0.35(fs/fd) \pm 0.81$	

$\Lambda_b \to p\,h$



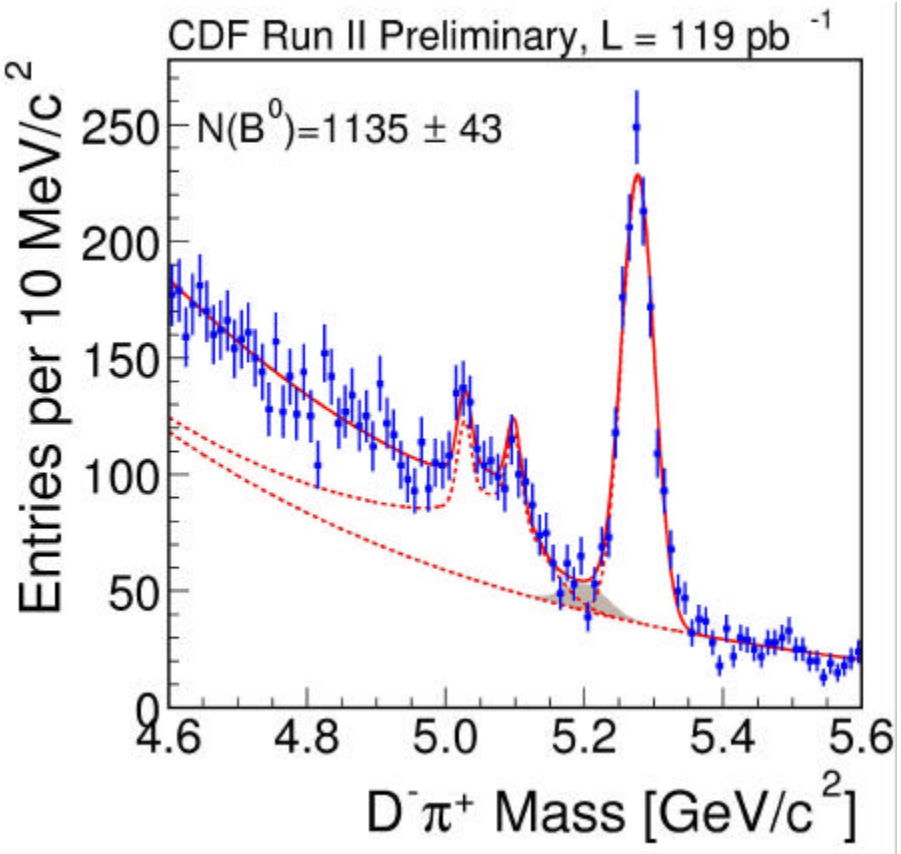
Blind Analysis

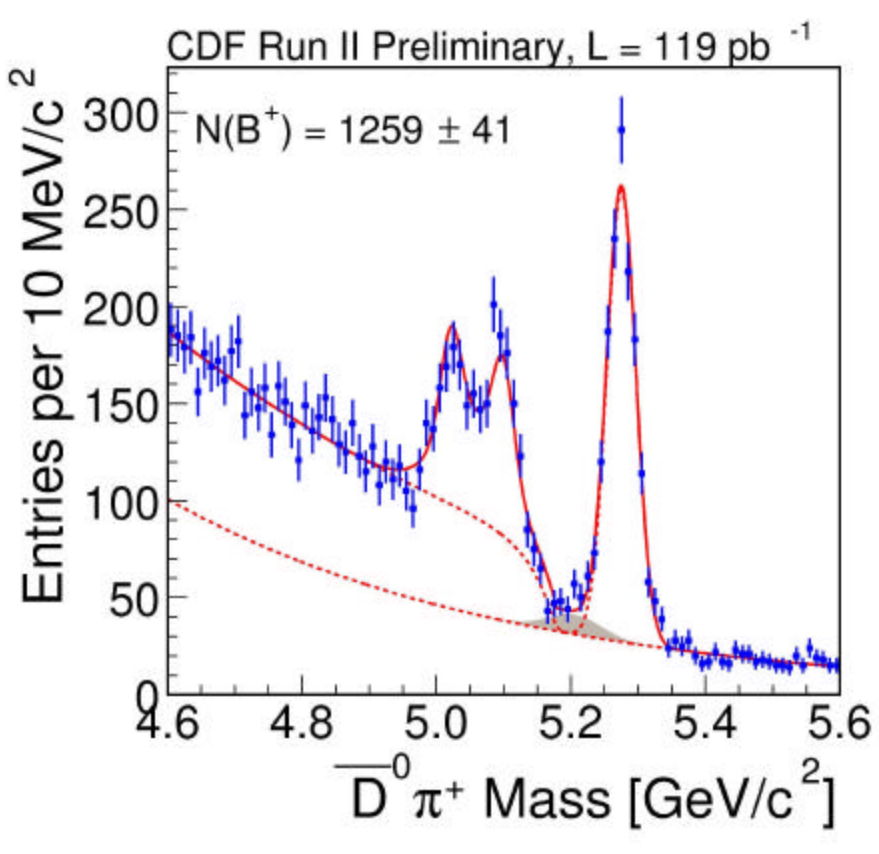
2004 PDG:
BR($\Lambda_b \to p\,K$) < 5x10^{-5}
BR($\Lambda_b \to p\,p$) < 5x10^{-5}

Expect 772 ± 31 background events in search window.
Observe 767 events Þ no evidence of signal.
Limit: BR($\Lambda_b \to p\,K$) + BR($\Lambda_b \to p\,p$) < 2.2 x 10^{-5} (90% CL)

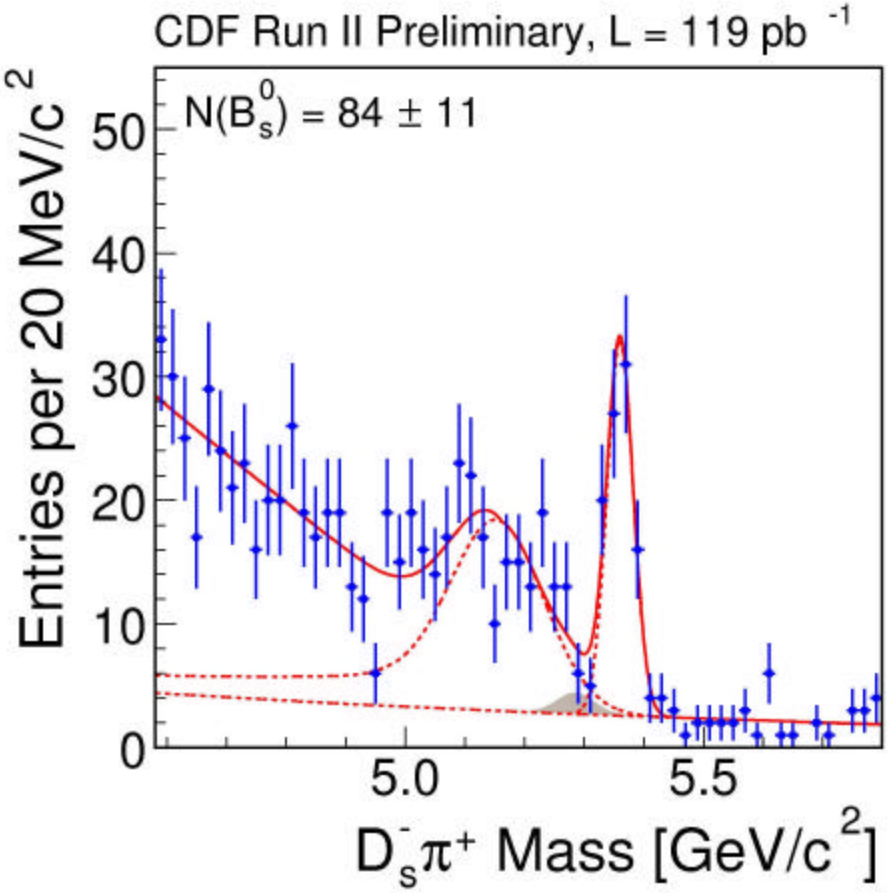
B ® D p

From 2 track trigger





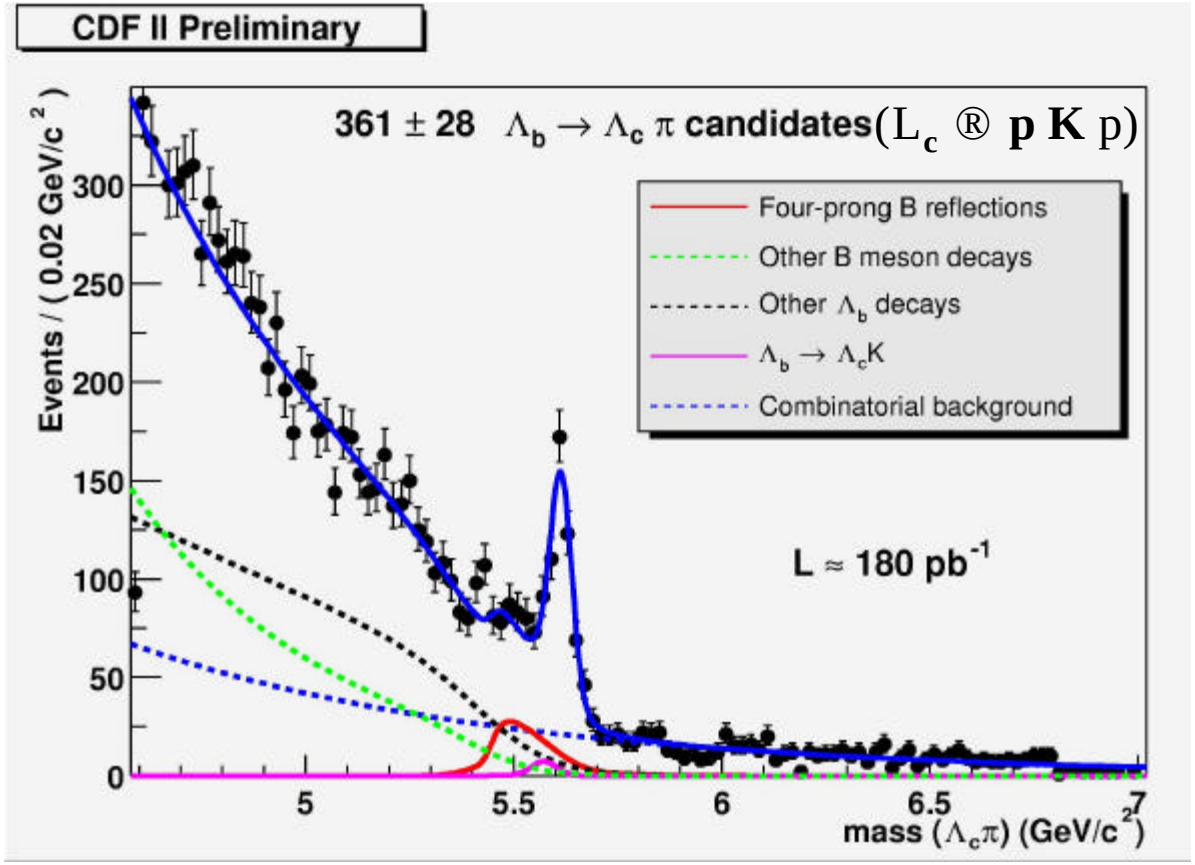
$B_s \to D_s \pi$



$$\frac{f_s}{f_d}\frac{BR(B_s \to D_s^- \pi^+)}{BR(B^0 \to D^- \pi^+)} = 0.35 \pm 0.05 \pm 0.04 \pm 0.09(BR)$$

$$\frac{BR(B_s \to D_s^- \pi^+)}{BR(B^0 \to D^- \pi^+)} = 1.4 \pm 0.2 \pm 0.2 \pm 0.4(BR) \pm 0.5(PR)$$

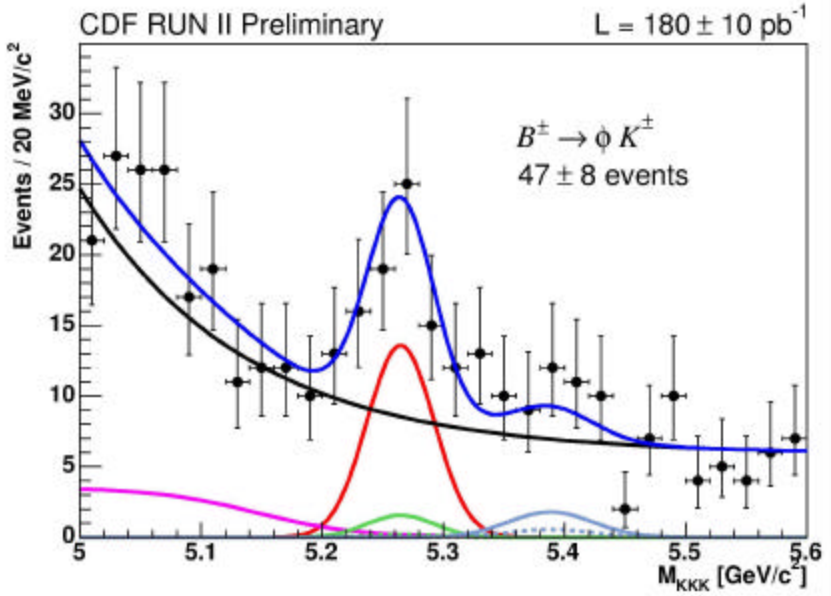
$L_b \to L_c p$

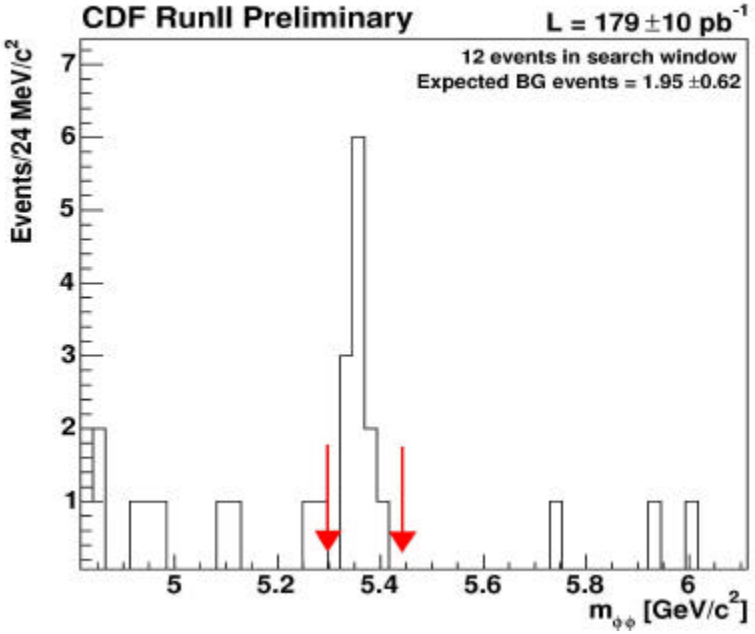


$$\frac{f_{\Lambda b}}{f_d}\frac{BR(\Lambda_b \to \Lambda_c^- \pi^+)}{BR(B^0 \to D^- \pi^+)} = 0.66 \pm 0.11 \pm 0.09 \pm 0.18(BR)$$

$$\frac{BR(\Lambda_b \to \Lambda_c^- \pi^+)}{BR(B^0 \to D^- \pi^+)} = 2.2 \pm 0.4 \pm 0.3 \pm 0.7(BR+PR)$$

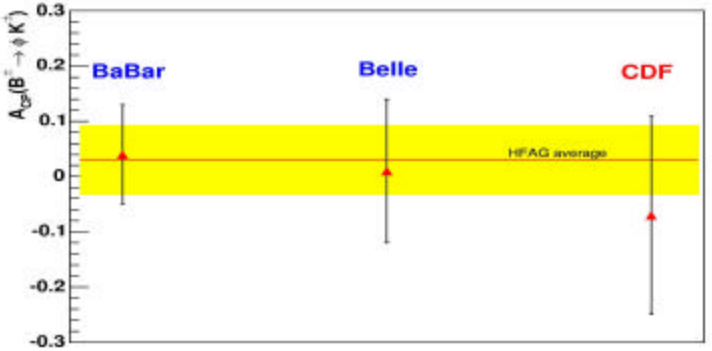
$B^+ \to f K^+$, $B_s \to f f$



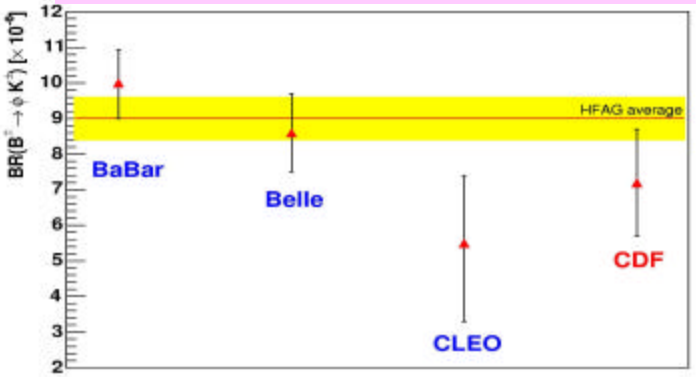


Dominated by Penguin diagrams.
Sensitive to new physics?

A_{CP} = -0.07 ± 0.17 ± 0.06



BR = (7.2 ± 1.3 ± 0.7) x 10^{-6}



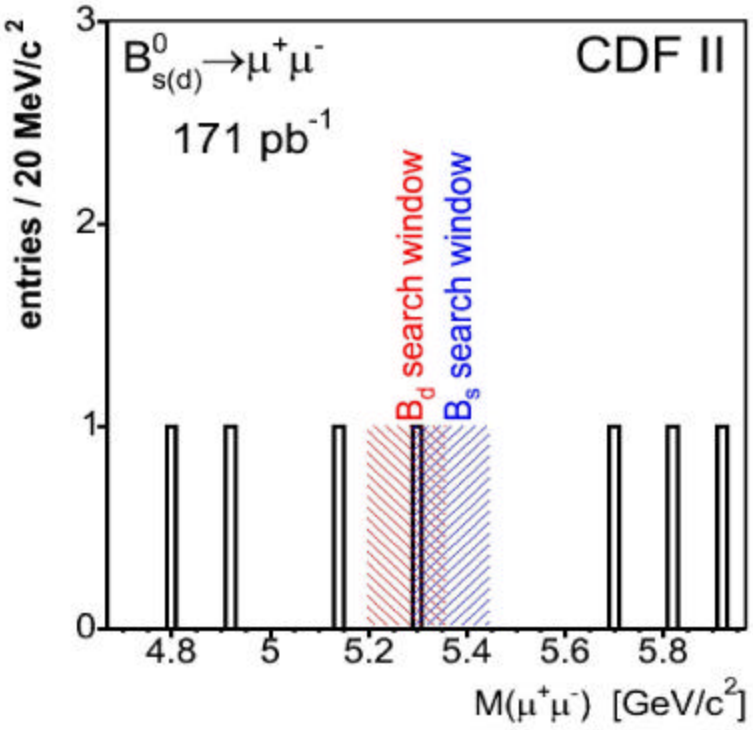
BR(B → f f) = (1.4±0.6 ± 0.2 ± 0.5)x10^{-5}

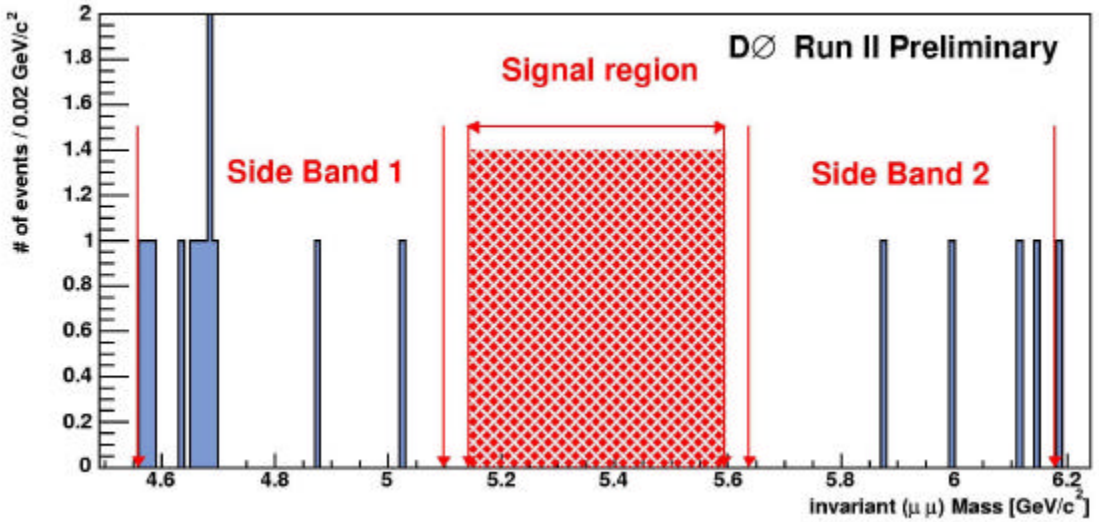
$B_{d,s} \to \mu^+ \mu^-$

BR($B_s \to \mu^+ \mu^-$) < 5.8 x 10^{-7}

BR($B_d \to \mu^+ \mu^-$) < 1.5 x 10^{-7}

90% CL





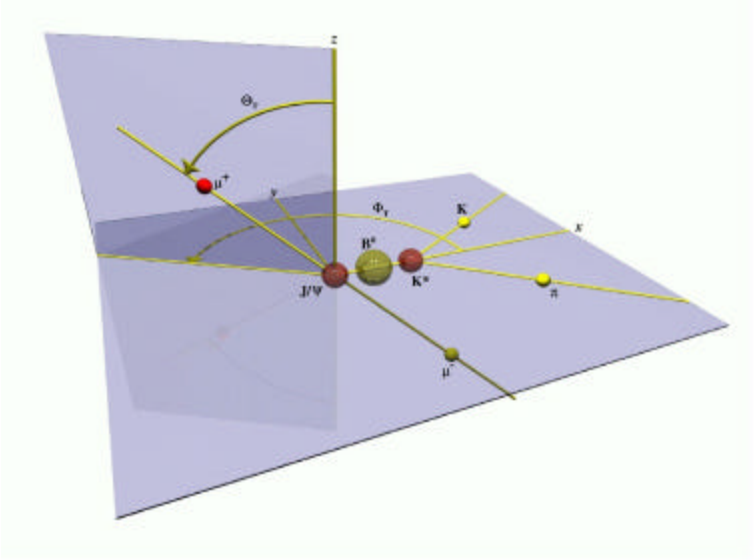
Normalize to $B^+ \to J/\psi K^+$
Expected Sensitivity (180 pb^{-1}):
~1 x 10^{-6} 95%CL

B_s ® J/y f, B_d ® J/y K^*

VV decay
3 amplitudes:

A_0, $A_\parallel$	CP even
$A_\wedge$	CP odd

B_s mass eigenstates (B_L and B_H) are expected to be nearly CP eigenstates. A combined angular and time analysis can separate these.



$\vec{\rho} = (\cos\theta,\ \phi,\ \cos\psi)$

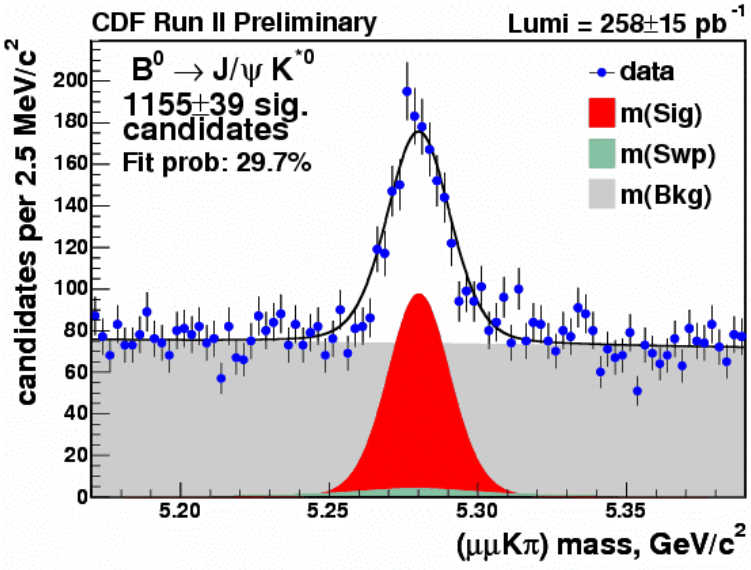
B_s:

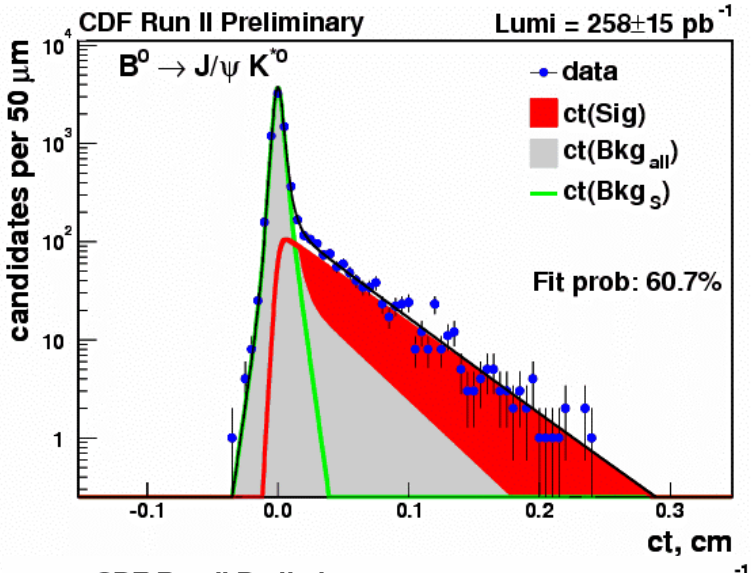
$$\frac{\mathcal{P}}{dt} \propto |A_0|^2 \cdot e^{-\Gamma_L t} \cdot f_1(\vec{\rho}) + |A_\parallel|^2 \cdot e^{-\Gamma_L t} \cdot f_2(\vec{\rho}) + |A_\perp|^2 \cdot e^{-\Gamma_H t} \cdot f_3(\vec{\rho}) + Re(A_0^* A_\parallel) \cdot e^{-\Gamma_L t} \cdot f_5(\vec{\rho})$$

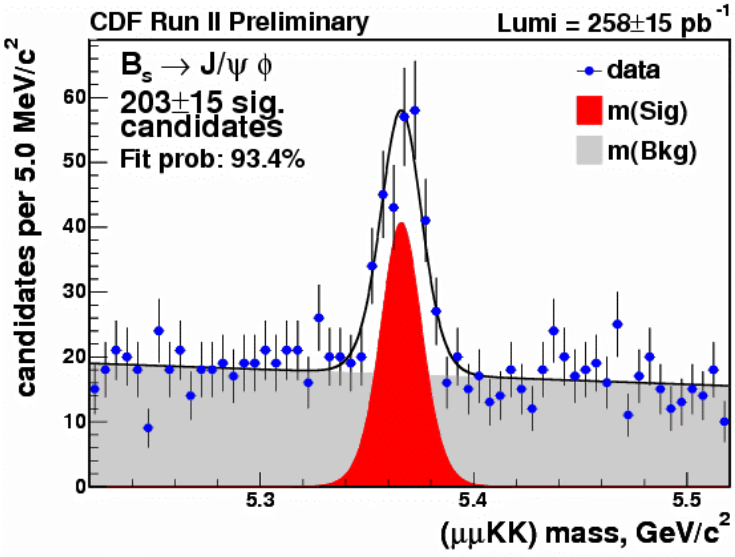
B_d:

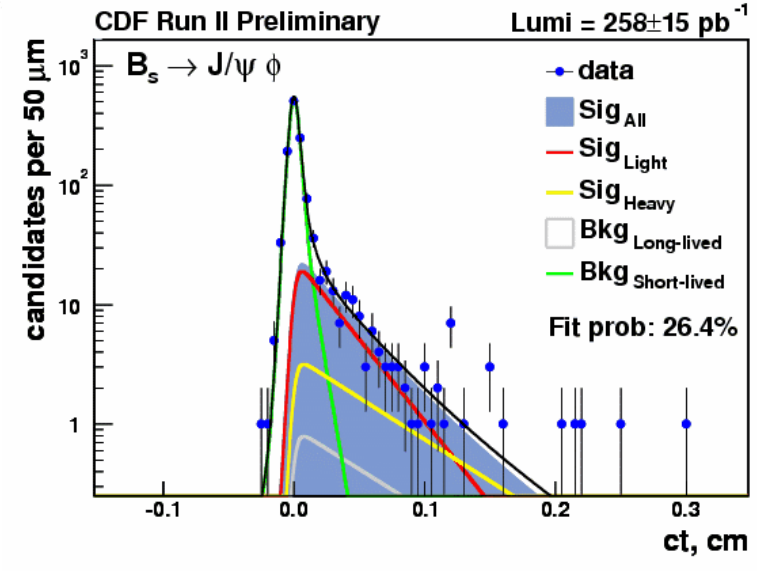
$$\frac{d^4\mathcal{P}}{d\vec{\rho}\,dt} \propto \left\{ |A_0|^2 \cdot f_1(\vec{\rho}) + |A_\parallel|^2 \cdot f_2(\vec{\rho}) + |A_\perp|^2 \cdot f_3(\vec{\rho}) \pm Im(A_\parallel^* A_\perp) \cdot f_4(\vec{\rho}) + Re(A_0^* A_\parallel) \cdot f_5(\vec{\rho}) \pm Im(A_0^* A_\perp) \cdot f_6(\vec{\rho}) \right\} \cdot e^{-\Gamma_d t}$$

B_s ® J/y f, B_d ® J/y K^*

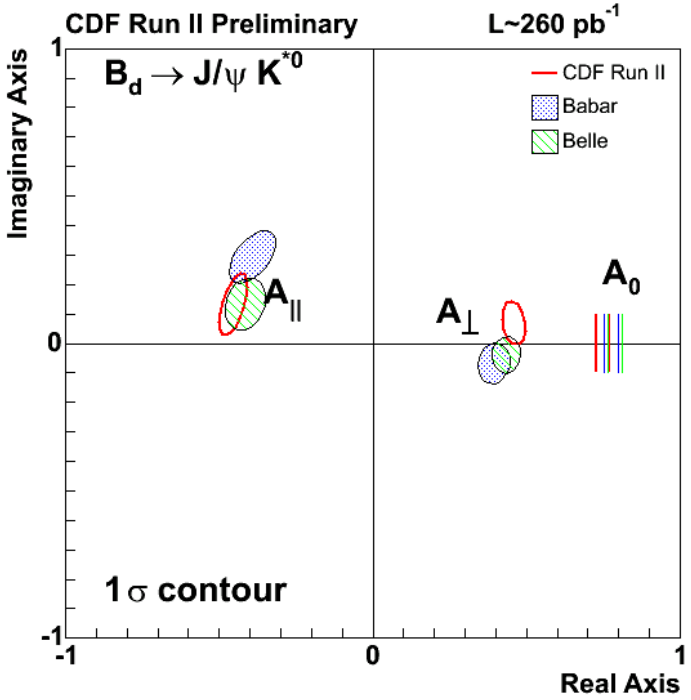

CDF Run II Preliminary
Lumi = 258±15 pb-1
B0 → J/ψ K*0
1155±39 sig. candidates
Fit prob: 29.7%
data
m(Sig)
m(Swp)
m(Bkg)
candidates per 2.5 MeV/c2
(μμKπ) mass, GeV/c2

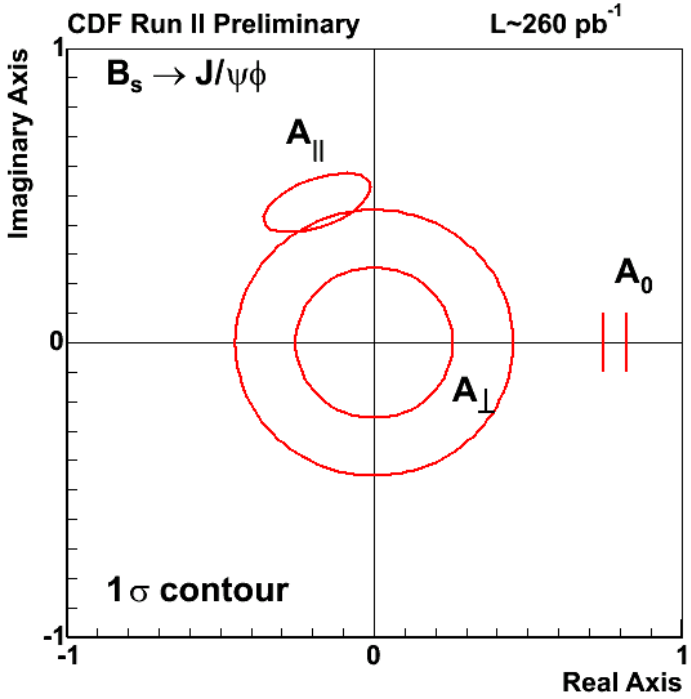

CDF Run II Preliminary
Lumi = 258±15 pb-1
B0 → J/ψ K*0
data
ct(Sig)
ct(Bkg all)
ct(Bkg S)
Fit prob: 60.7%
candidates per 50 μm
ct, cm


CDF Run II Preliminary
Lumi = 258±15 pb-1
Bs → J/ψ φ
203±15 sig. candidates
Fit prob: 93.4%
data
m(Sig)
m(Bkg)
candidates per 5.0 MeV/c2
(μμKK) mass, GeV/c2


CDF Run II Preliminary
Lumi = 258±15 pb-1
Bs → J/ψ φ
data
Sig All
Sig Light
Sig Heavy
Bkg Long-lived
Bkg Short-lived
Fit prob: 26.4%
candidates per 50 μm
ct, cm

$B_s \to J/\psi f$, $B_d \to J/\psi K^*$





B_s ® J/y f, B_d ® J/y K^*

	B_d	B_s Unconstrained Fit	B_s Constrained Fit	unit
M_B	5280.2 ± 0.8	5366.1 ± 0.8	5366.0 ± 0.8	MeV/c^2
A_0	0.750 ± 0.017	0.784 ± 0.039	0.783 ± 0.038	
$A_\parallel$	0.473 ± 0.034	0.510 ± 0.082	0.539 ± 0.070	
$A_\perp$	0.464 ± 0.035	0.354 ± 0.098	0.308 ± 0.087	
$\delta_\parallel$	2.86 ± 0.22	1.94 ± 0.36	1.91 ± 0.32	
$\delta_\perp$	0.15 ± 0.15			
$c\tau_B$	462 ± 15	**2004 PDG: 460.2 ± 4.2**		μm
$c\tau_L$		$316 \left(^{+48}_{-40}\right)$	$340 \left(^{+46}_{-28}\right)$	μm
$c\tau_H$		$622 \left(^{+175}_{-138}\right)$	$713 \left(^{+167}_{-129}\right)$	μm
$c\tau_s$		$419 \left(^{+45}_{-38}\right)$	460 ± 6.2	μm
$\Delta\Gamma_s/\Gamma_s$		$65 \left(^{+25}_{-33}\right)$	$71 \left(^{+24}_{-28}\right)$	%
$\Delta\Gamma_s$		$0.47 \left(^{+0.19}_{-0.24}\right)$	$0.46 \left(^{+0.17}_{-0.18}\right)$	ps^{-1}
N_{sig}	1155 ± 39	203 ± 15	201 ± 15	

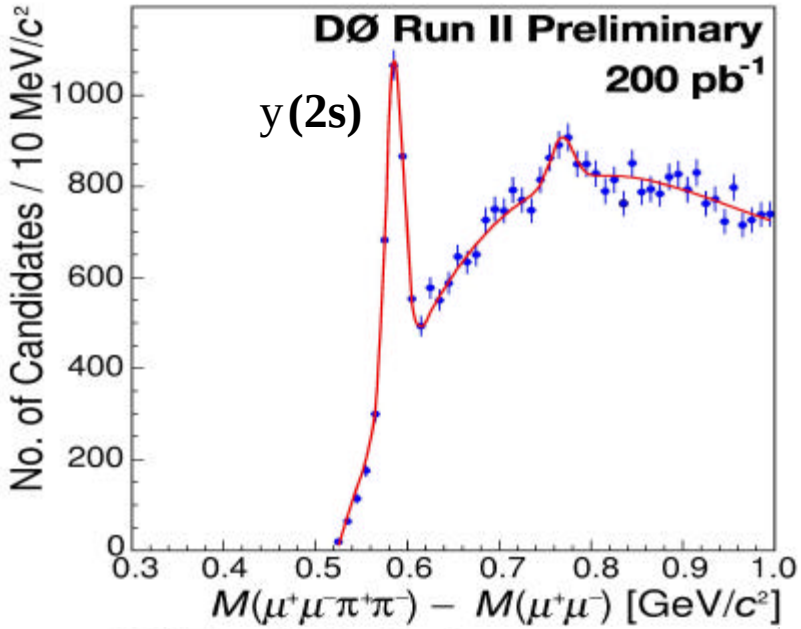
SM: $\Delta\Gamma_s/\Gamma_s \sim (12 \pm 6)\%$

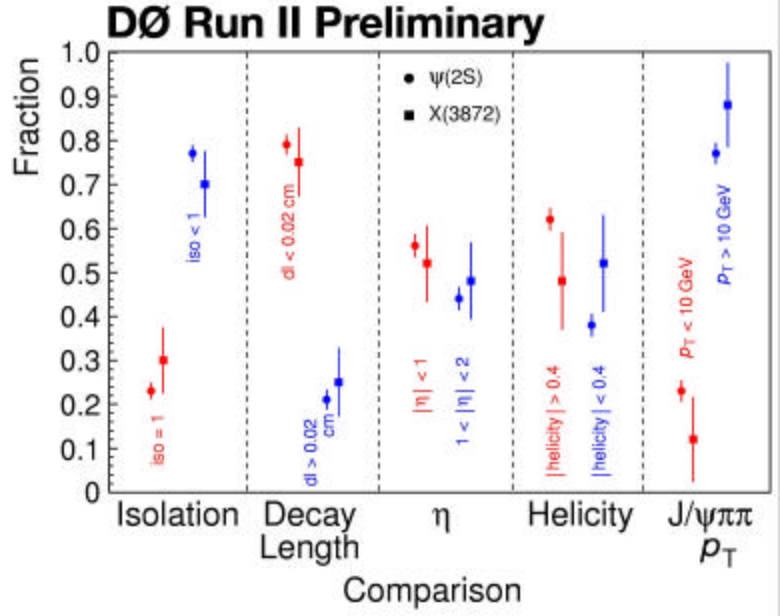
This measurement predicts
Δm_s = ~125 ± 65 ps^{-1}

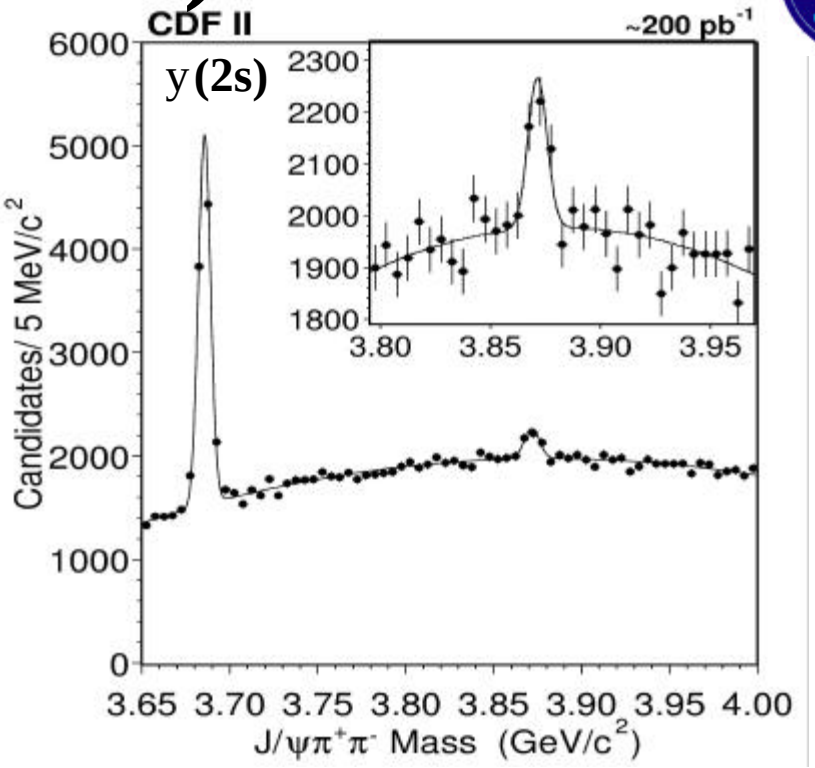
From MC, probability of > measurement:

$\Delta\Gamma/\Gamma$	0	12%
Unconstrained	0.3%	1.2%
Constrained	0.1%	0.5%

X(3872)





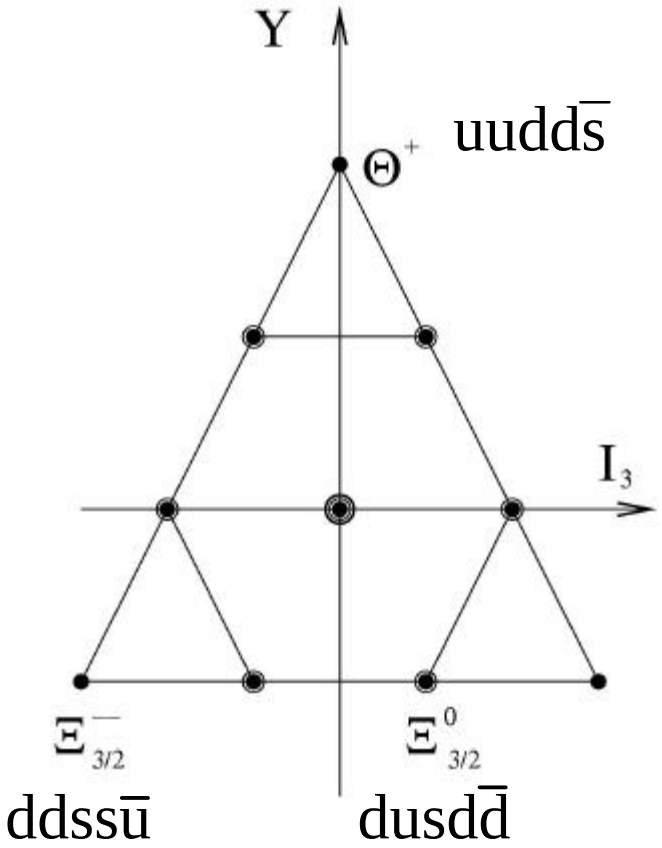


CDF fit to lifetime:

X long-lived fraction (16.8 ± 4.9)%
y(2S) long-lived fraction (28.3 ± 1.1)%

Pentaquarks

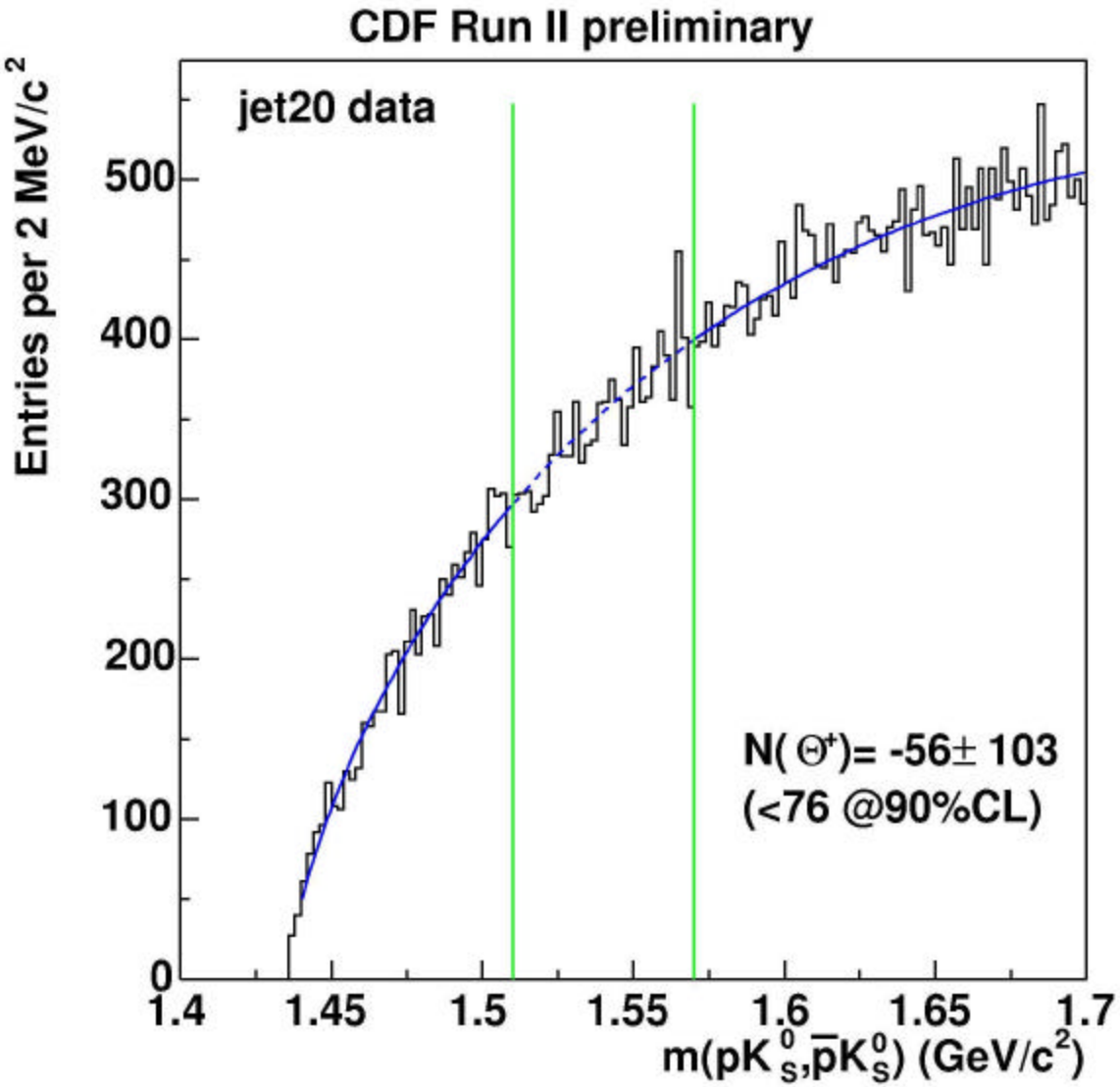
Several experiments have reported evidence for pentaquarks (baryons with 4 quarks and an antiquark)



Experiment	State	Mass (MeV/c^2)
Many	Q^+	1530
NA49	X^{--}, X^0	1860
H1	Q_c^+	3099

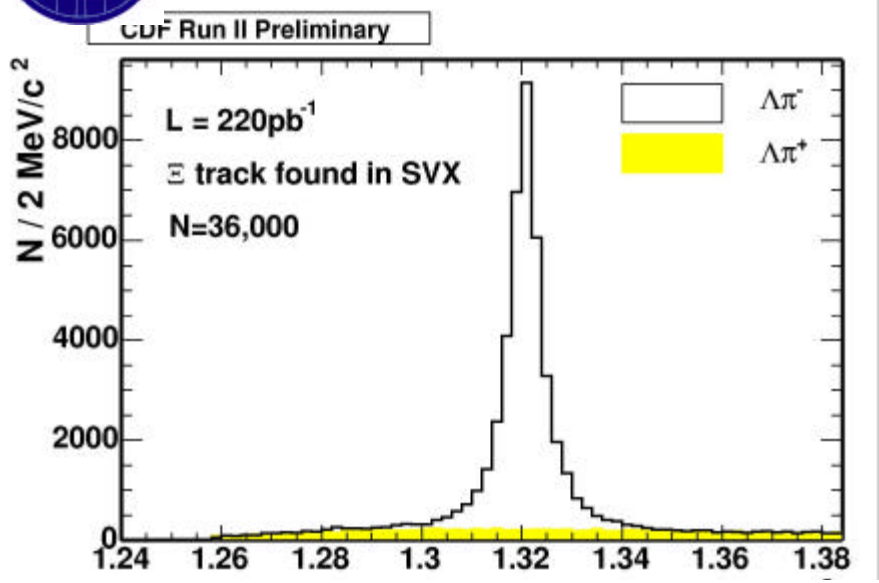
CDF has capability of seeing all these states, has a large sample of data, and has excellent tracking.
We don't see any of them.

Pentaquarks

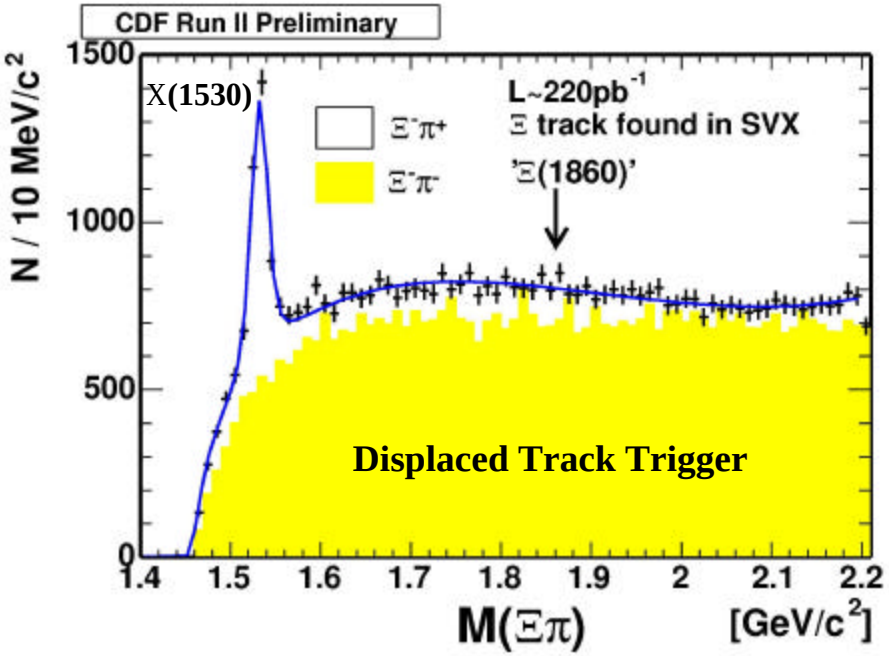


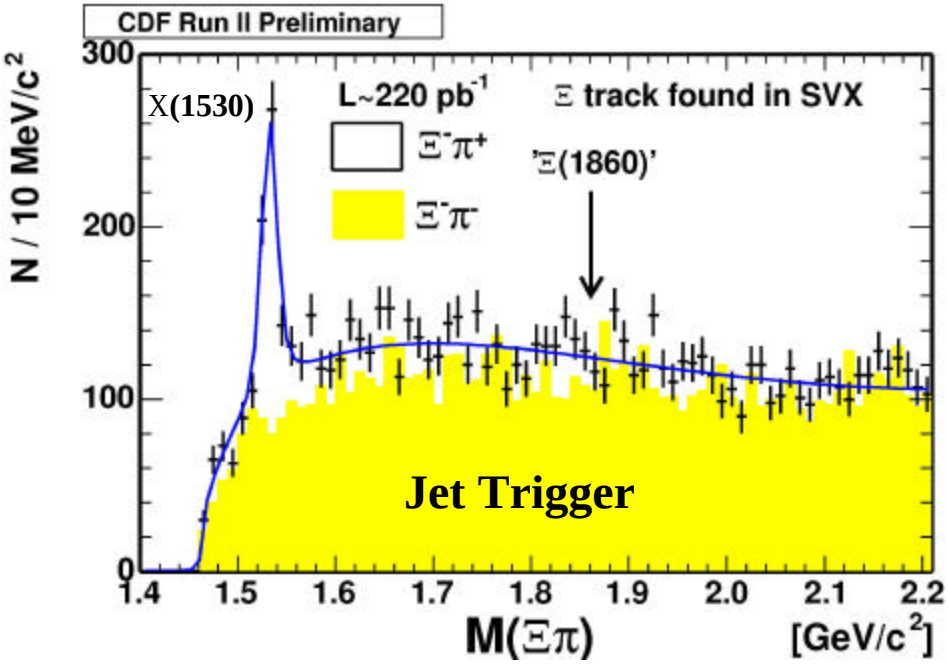
$Q^+ \rightarrow p K_S$

Pentaquarks



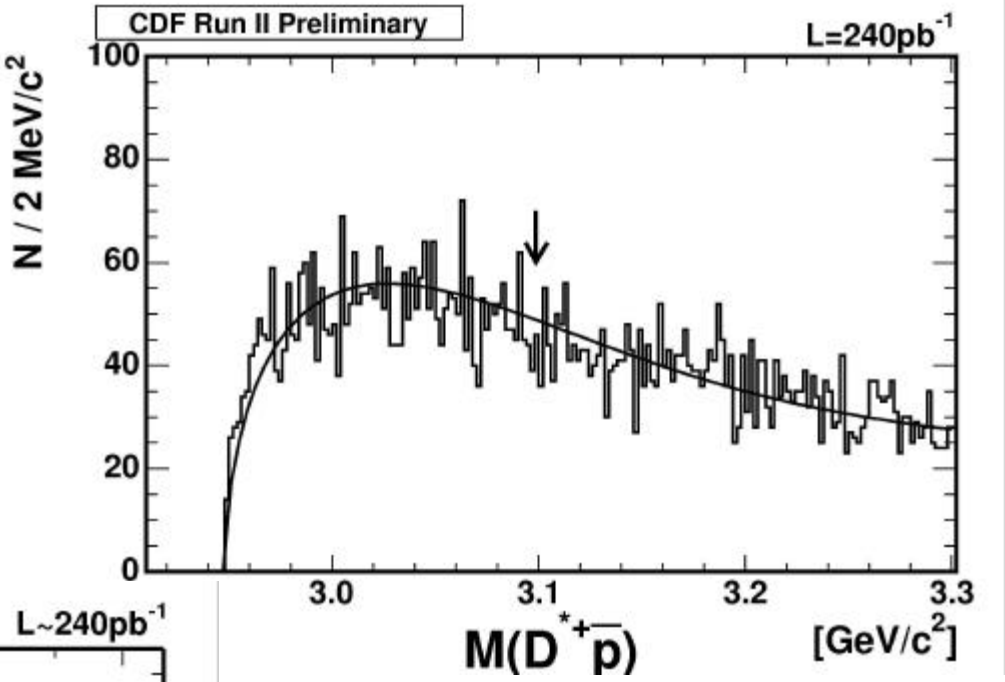
$X(1860) \rightarrow X^{-} p^{\pm}$

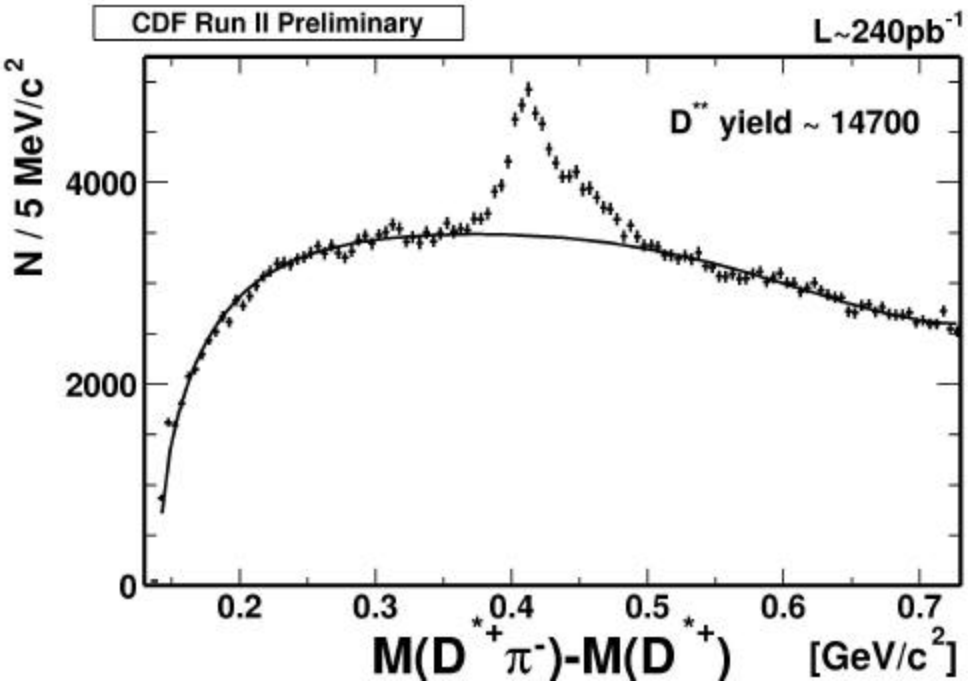




Pentaquarks

$Q_c \rightarrow D^{*-} p$





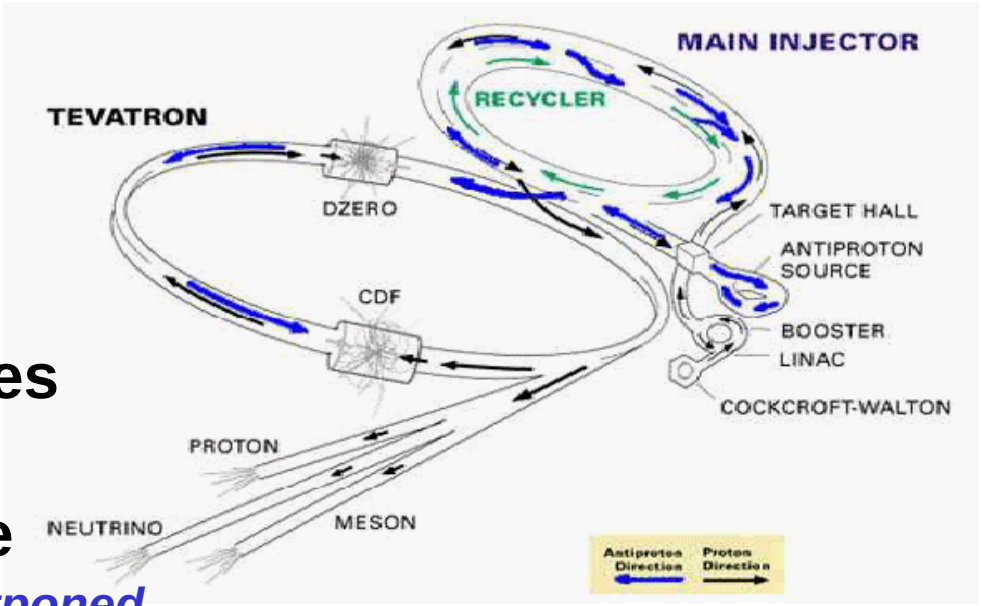
Summary

B Physics at a hadron collider is a challenging but rewarding field.

Precision measurements are possible in many cases, including some unique and rare signatures.

Backup Slides

$\bar{p}p$ Collisions at the Tevatron



980+980GeV collisions

was 900+900 GeV in RunI

36 p bunches x 36 $\bar{p}$ bunches

396 ns bunch crossing time

132 ns upgrade indefinitely postponed

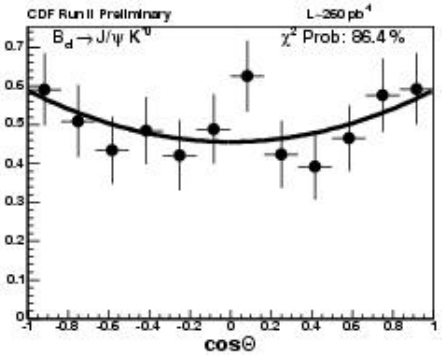
At present luminosities »2 interactions/bunch crossing

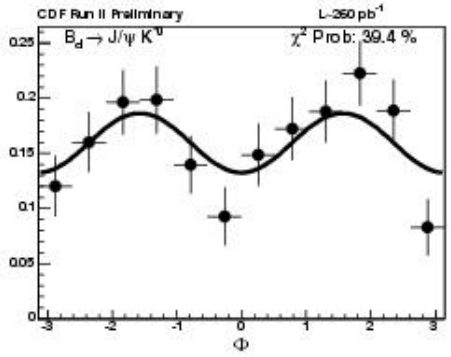
Anticipate up to 10 in future

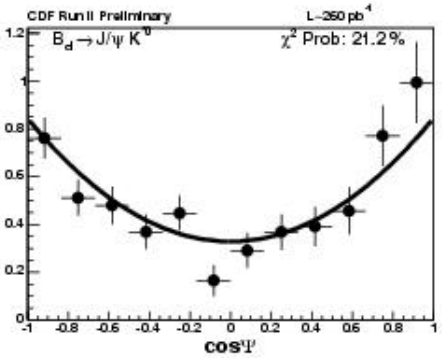
Interaction region:

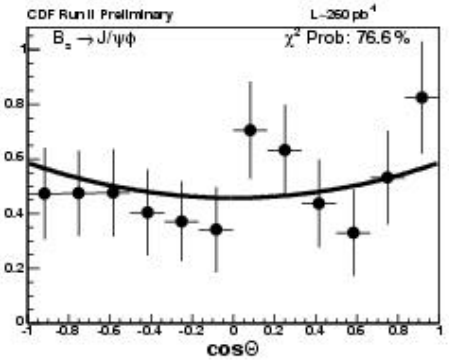
- **» 30 cm long**
  Need a long silicon detector
- **» 30 mm transverse size**
  Small compared to ct(B) » 450 mm

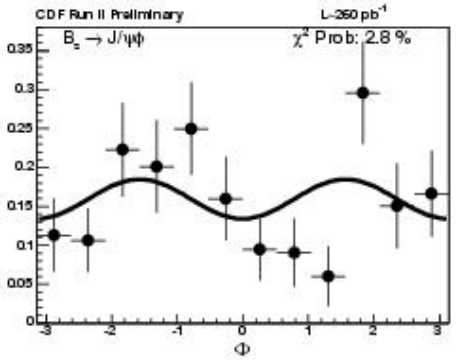
B_s ® J/y f, B_d ® J/y K^*

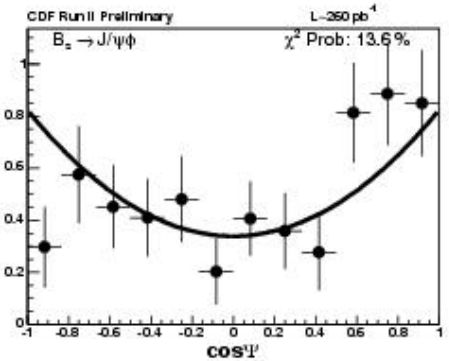

CDF Run II Preliminary
L~260 pb-1
Bd → J/ψ K0
χ2 Prob: 86.4 %
cosΘ


CDF Run II Preliminary
L~260 pb-1
Bd → J/ψ K0
χ2 Prob: 39.4 %
Φ

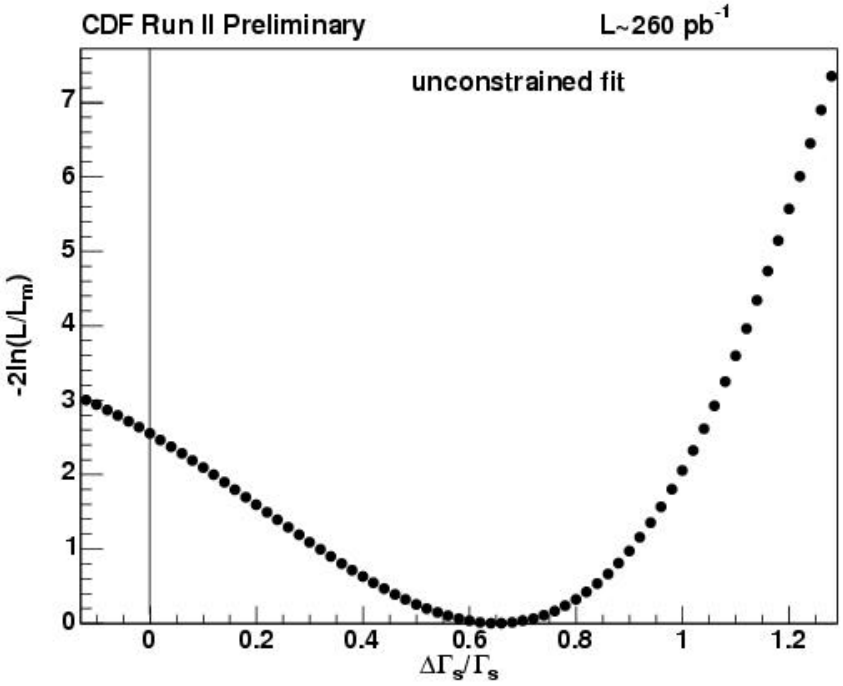

CDF Run II Preliminary
L~260 pb-1
Bd → J/ψ K0
χ2 Prob: 21.2 %
cosΨ

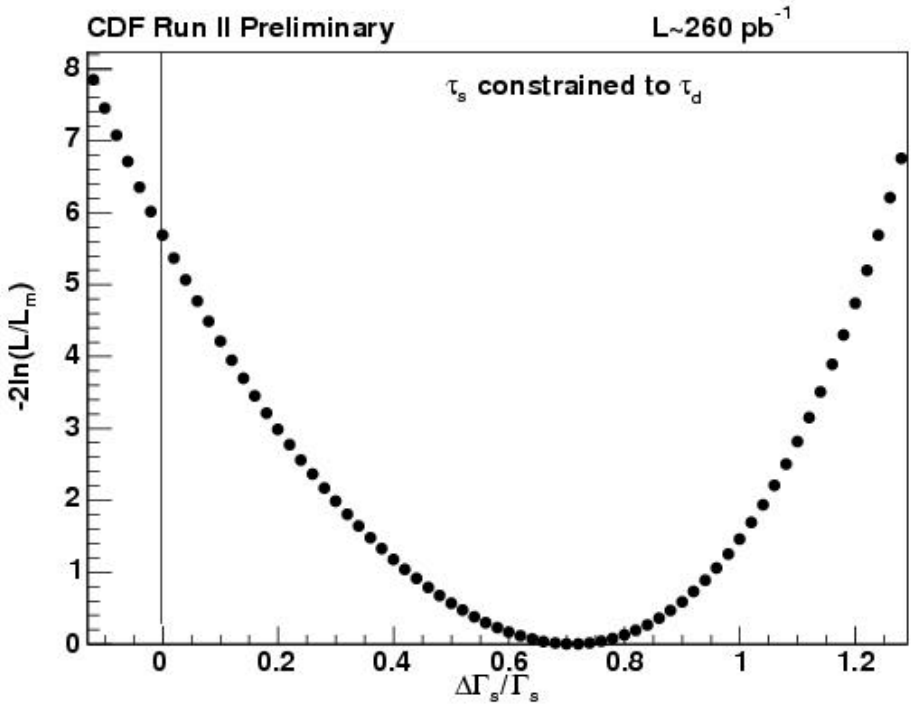

CDF Run II Preliminary
L~260 pb-1
Bs → J/ψφ
χ2 Prob: 76.6 %
cosΘ


CDF Run II Preliminary
L~260 pb-1
Bs → J/ψφ
χ2 Prob: 2.8 %
Φ

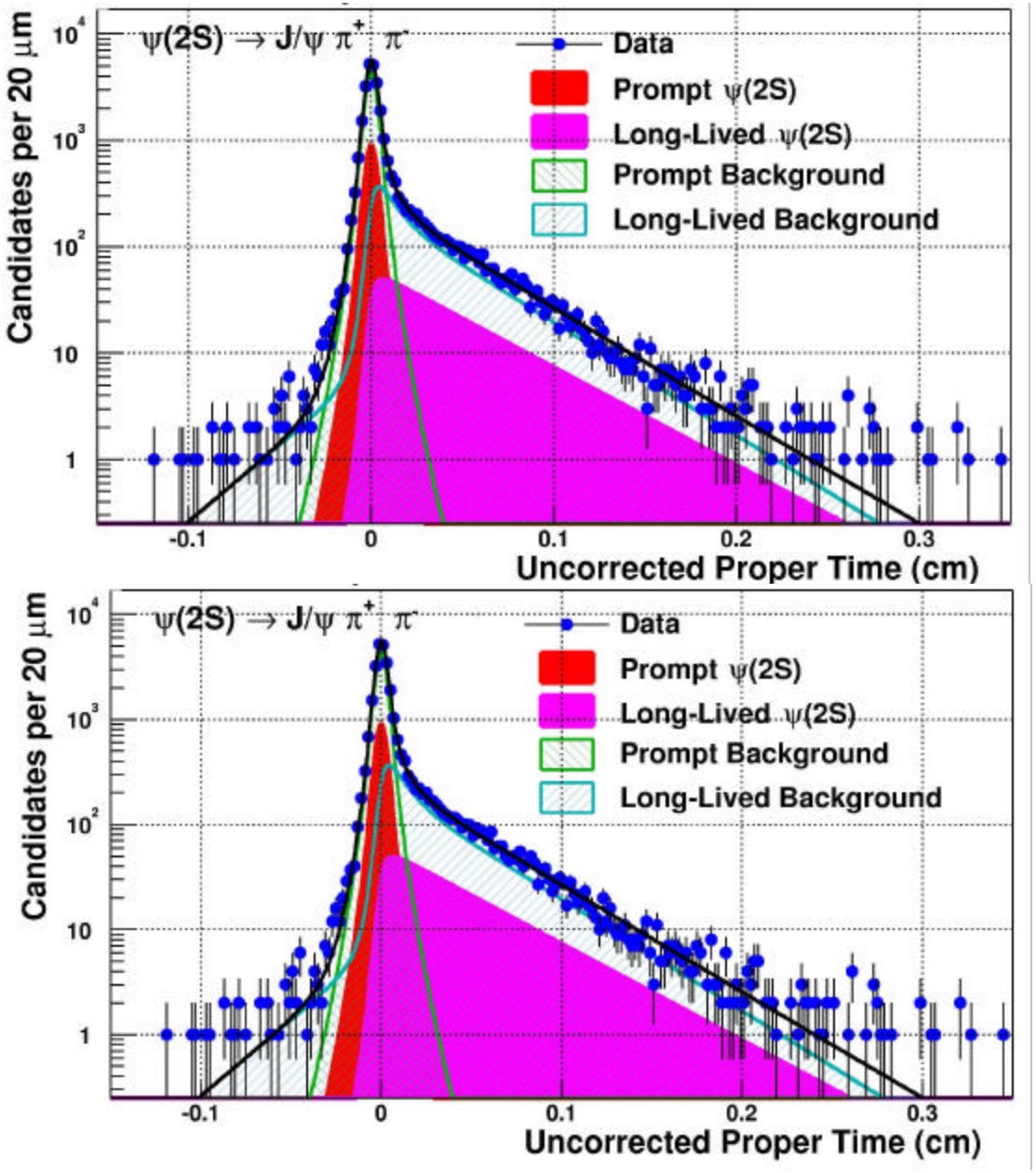

CDF Run II Preliminary
L~260 pb-1
Bs → J/ψφ
χ2 Prob: 13.6 %
cosΨ

$B_s \to J/\psi\, f, B_d \to J/\psi\, K^*$

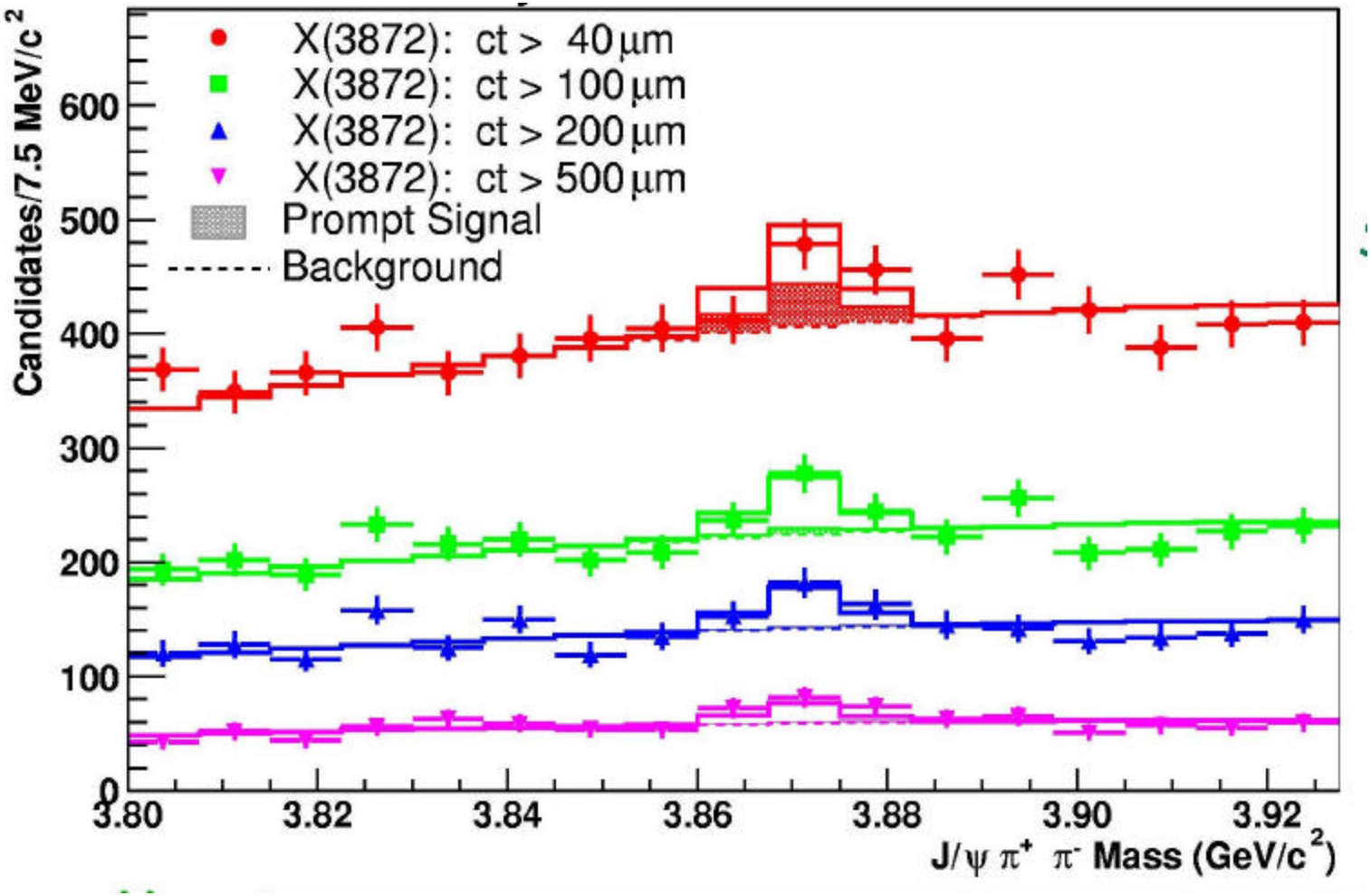




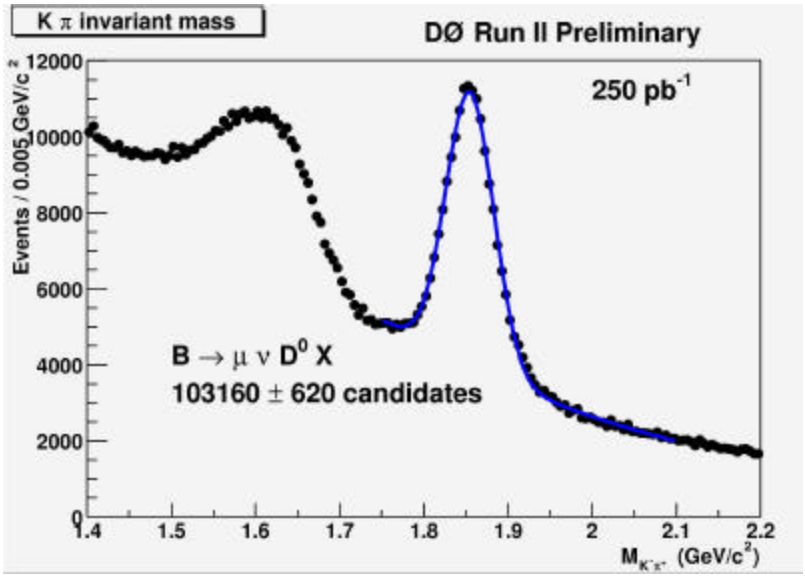
X(3872)

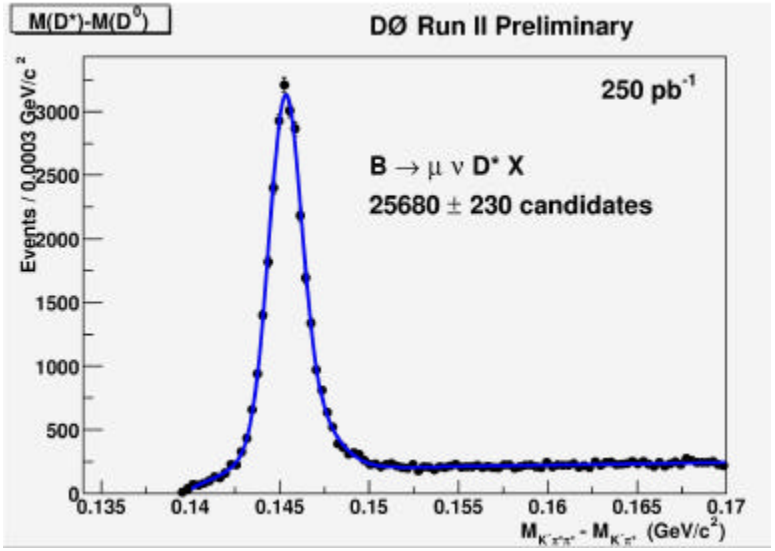

ψ(2S) → J/ψ π+ π-
Data
Prompt ψ(2S)
Long-Lived ψ(2S)
Prompt Background
Long-Lived Background
Candidates per 20 μm
Uncorrected Proper Time (cm)
ψ(2S) → J/ψ π+ π-
Data
Prompt ψ(2S)
Long-Lived ψ(2S)
Prompt Background
Long-Lived Background
Candidates per 20 μm
Uncorrected Proper Time (cm)

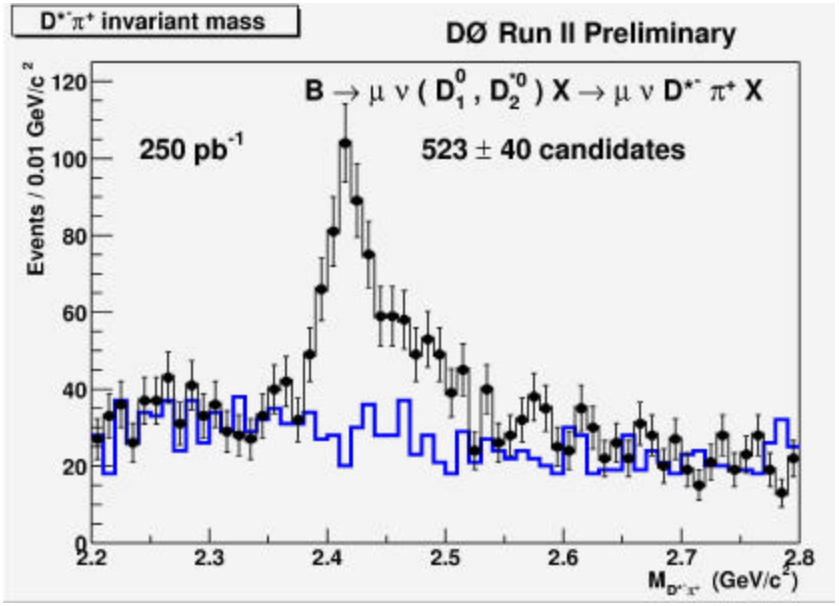
X(3872)


X(3872): ct > 40 μm
X(3872): ct > 100 μm
X(3872): ct > 200 μm
X(3872): ct > 500 μm
Prompt Signal
Background
Candidates/7.5 MeV/c²
0
100
200
300
400
500
600
3.80
3.82
3.84
3.86
3.88
3.90
3.92
J/ψ π⁺ π⁻ Mass (GeV/c²)

B ® D** m n X

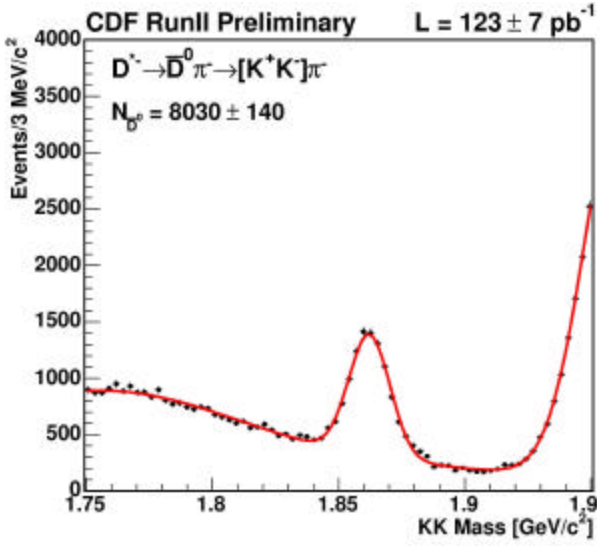


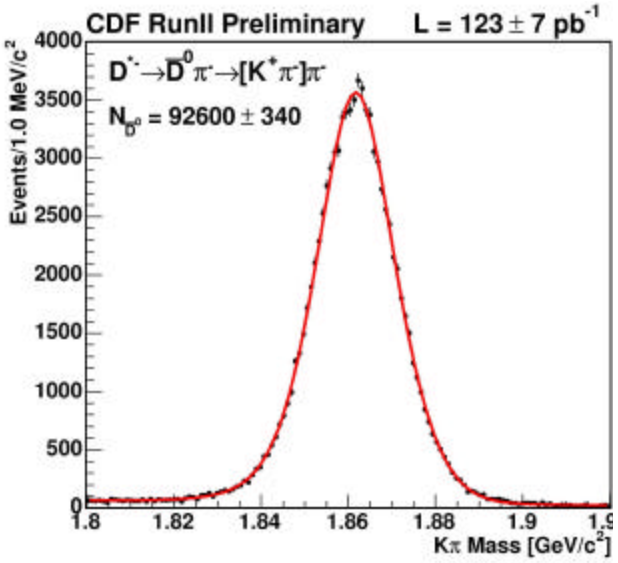


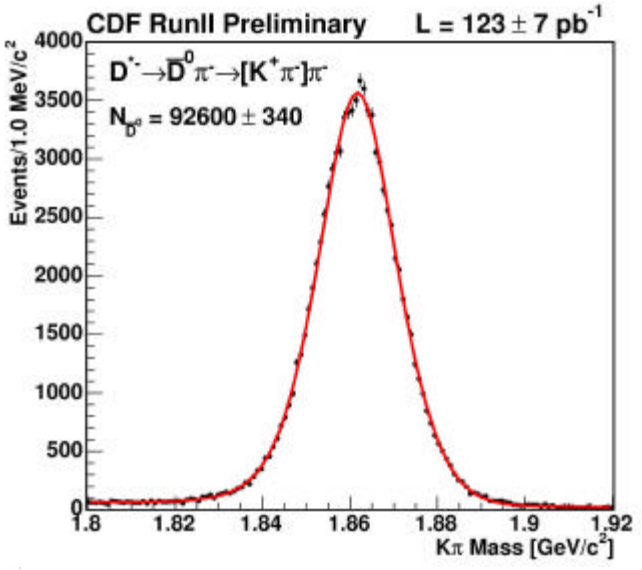


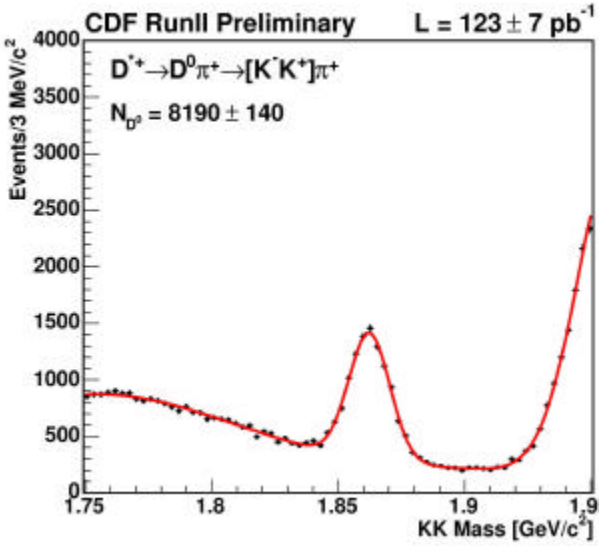
BR(B ® m n [D_1,D_2] X) x BR([D_1,D_2] ® D^* p)
= (0.280 ± 0.021 ± 0.088)%

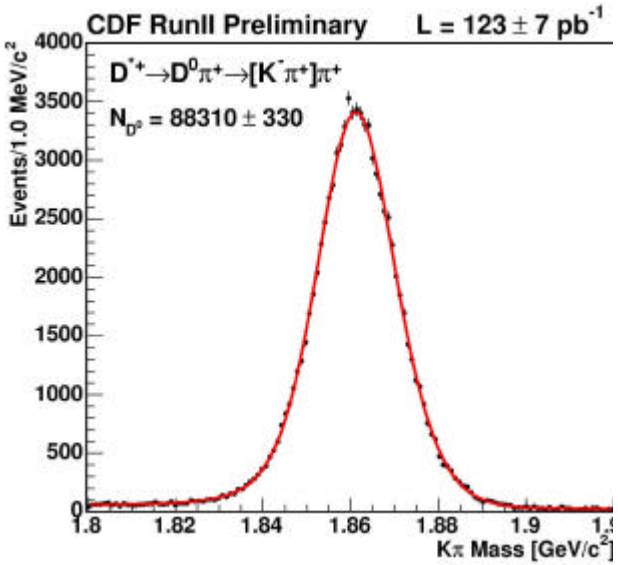
D^0 ® Kp, KK, pp

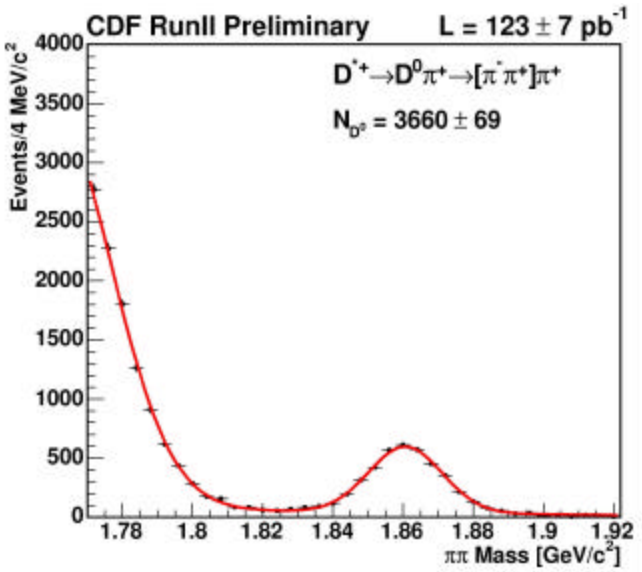

CDF RunII Preliminary
L = 123 ± 7 pb-1
D*-→D0π-→[K+K-]π-
N = 8030 ± 140
Events/3 MeV/c2
KK Mass [GeV/c2]


CDF RunII Preliminary
L = 123 ± 7 pb-1
D*-→D0π-→[K+π-]π-
N = 92600 ± 340
Events/1.0 MeV/c2
Kπ Mass [GeV/c2]

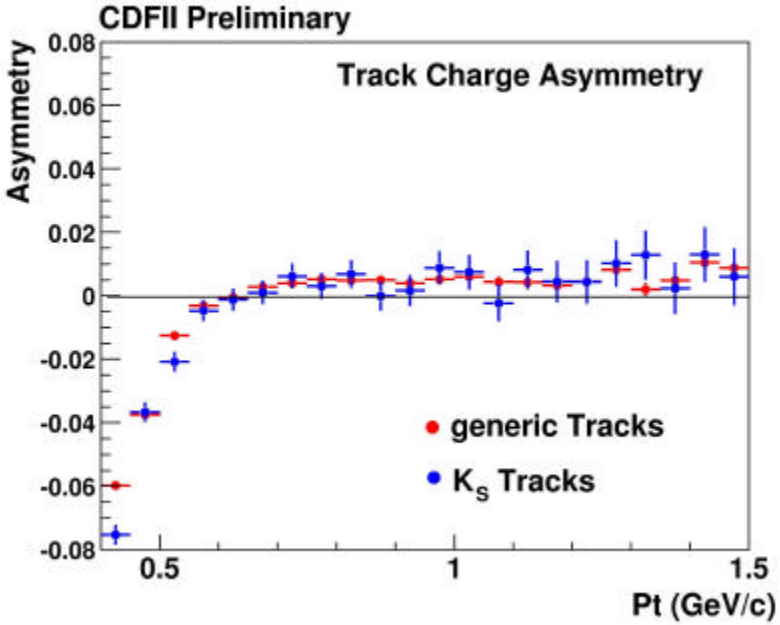

CDF RunII Preliminary
L = 123 ± 7 pb-1
D*-→D0π-→[K+π-]π-
N = 92600 ± 340
Events/1.0 MeV/c2
Kπ Mass [GeV/c2]

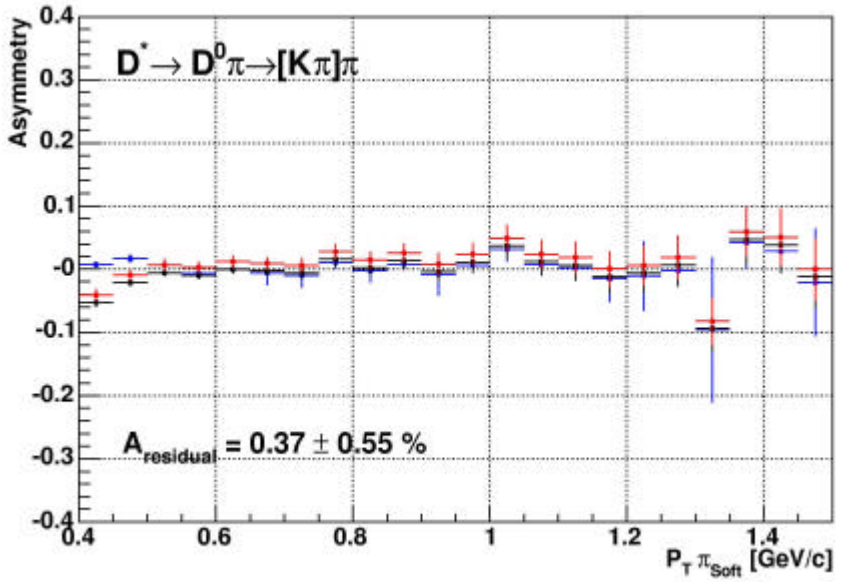

CDF RunII Preliminary
L = 123 ± 7 pb-1
D*+→D0π+→[K-K+]π+
N = 8190 ± 140
Events/3 MeV/c2
KK Mass [GeV/c2]


CDF RunII Preliminary
L = 123 ± 7 pb-1
D*+→D0π+→[K-π+]π+
N = 88310 ± 330
Events/1.0 MeV/c2
Kπ Mass [GeV/c2]


CDF RunII Preliminary
L = 123 ± 7 pb-1
D*+→D0π+→[π-π+]π+
N = 3660 ± 69
Events/4 MeV/c2
ππ Mass [GeV/c2]

D^0 ® Kp, KK, pp





$$\frac{G(D^0 \to KK)}{G(D^0 \to Kp)} = (9.96 \pm 0.11 \pm 0.12)\%$$

$$\frac{G(D^0 \to pp)}{G(D^0 \to Kp)} = (3.608 \pm 0.054 \pm 0.040)\%$$

$A_{CP}(KK) = (2.0 \pm 1.2 \pm 0.6)\%$

$A_{CP}(pp) = (2.0 \pm 1.2 \pm 0.6)\%$

2004 PDG

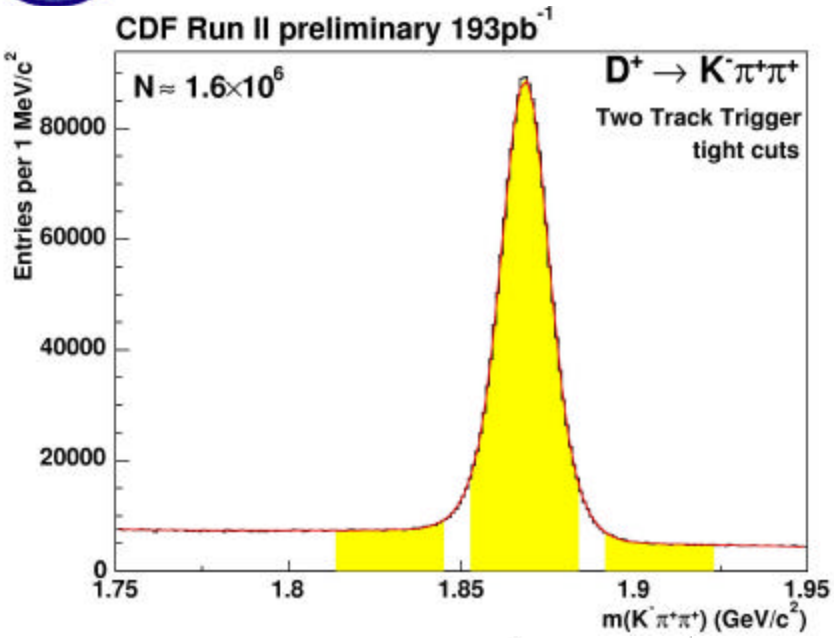
$(10.23 \pm 0.21)\%$

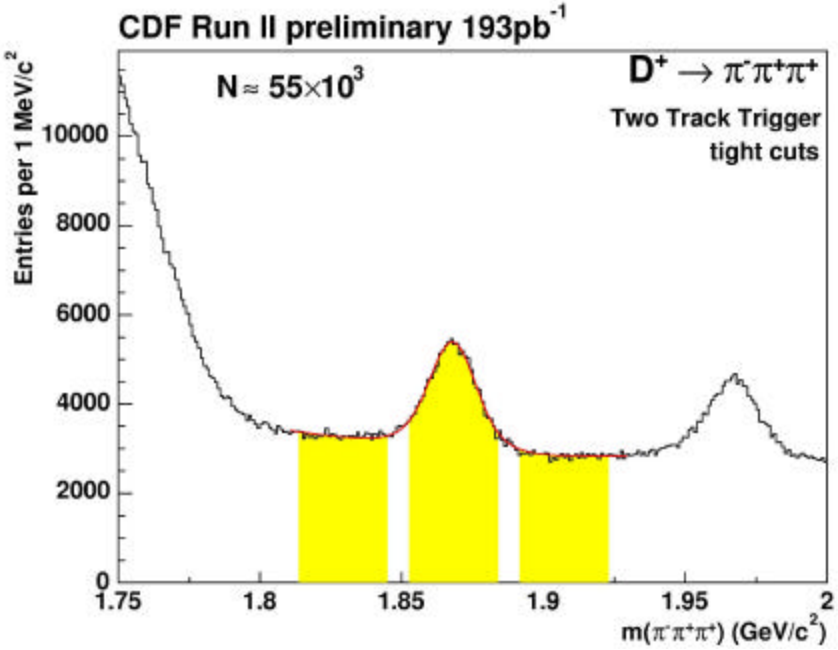
$(3.63 \pm 0.10)\%$

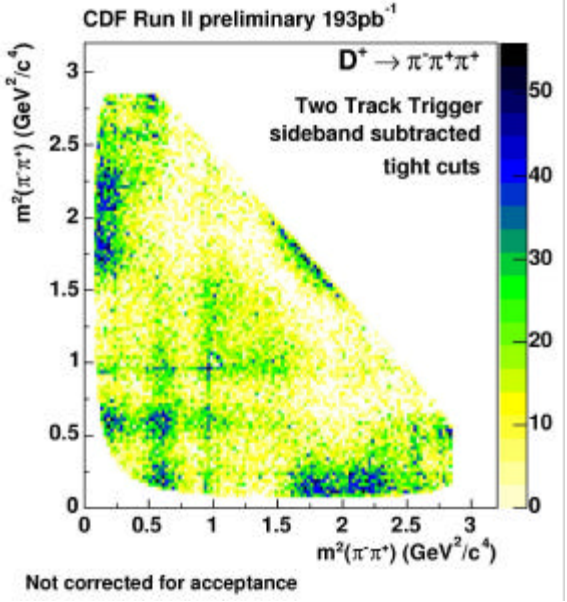
$(0.5 \pm 1.6)\%$

$(2.1 \pm 2.6)\%$

$D^+ \to p^+ p^- p^+$

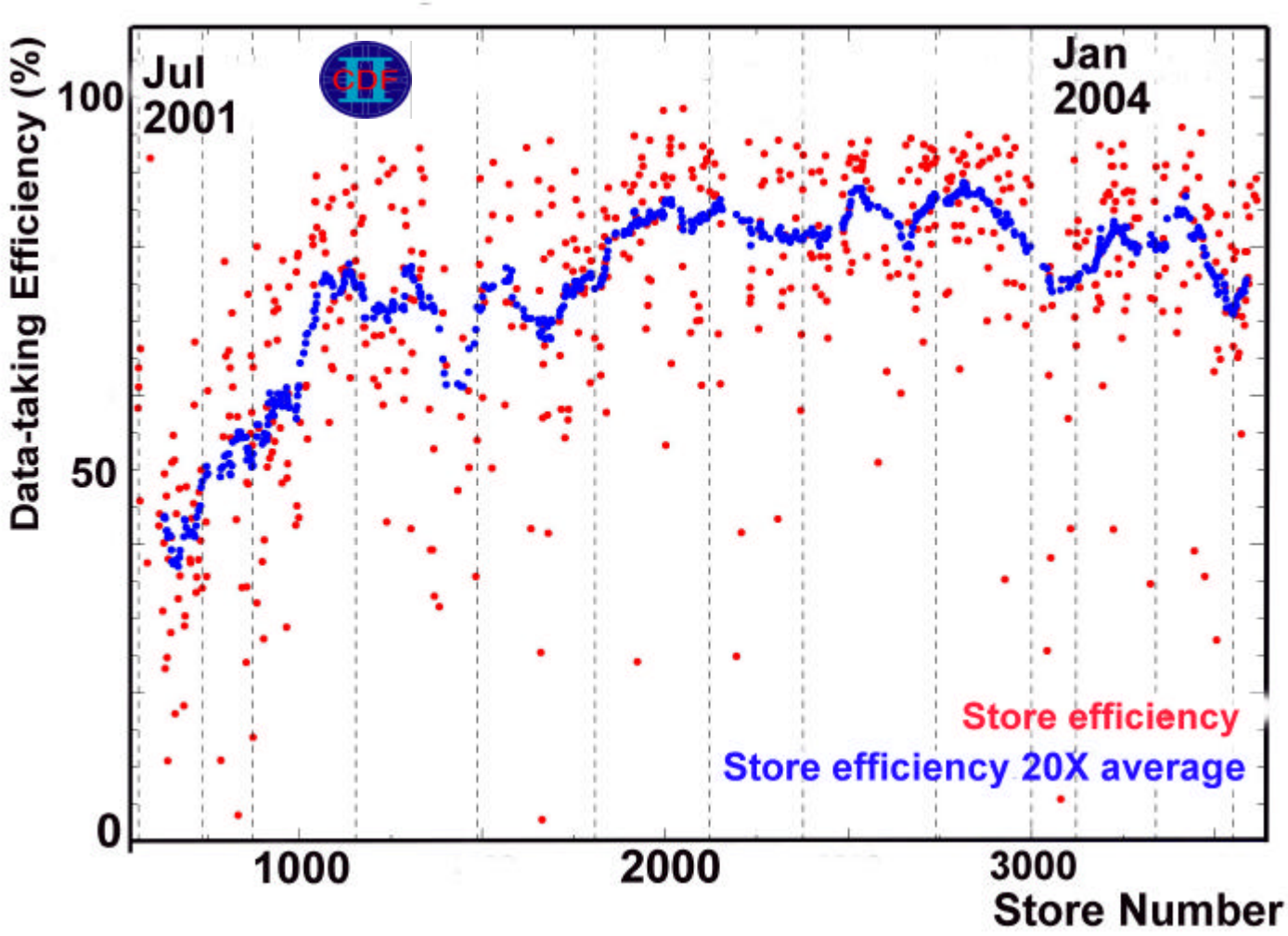




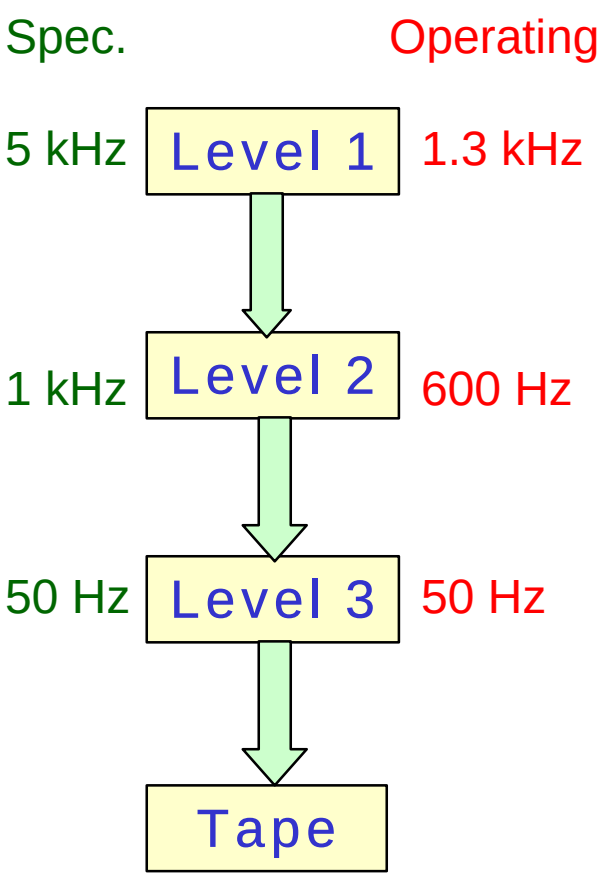


Look for direct CP violation is full sample and in regions of Dalitz plot.

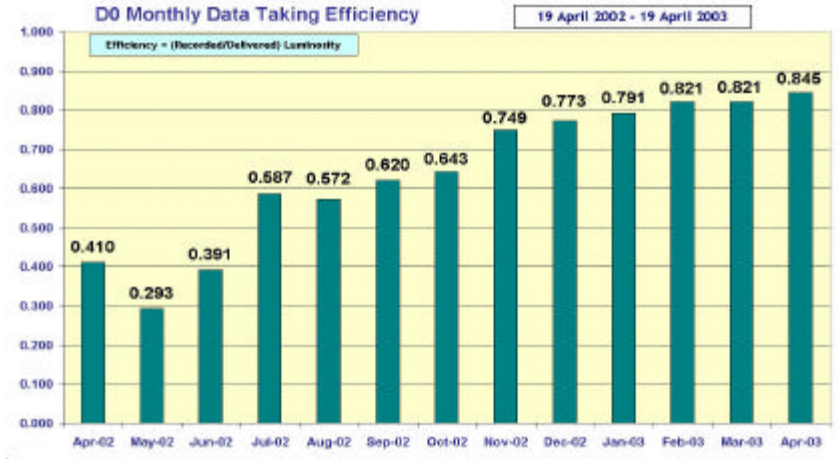
CDF Data Taking Efficiency

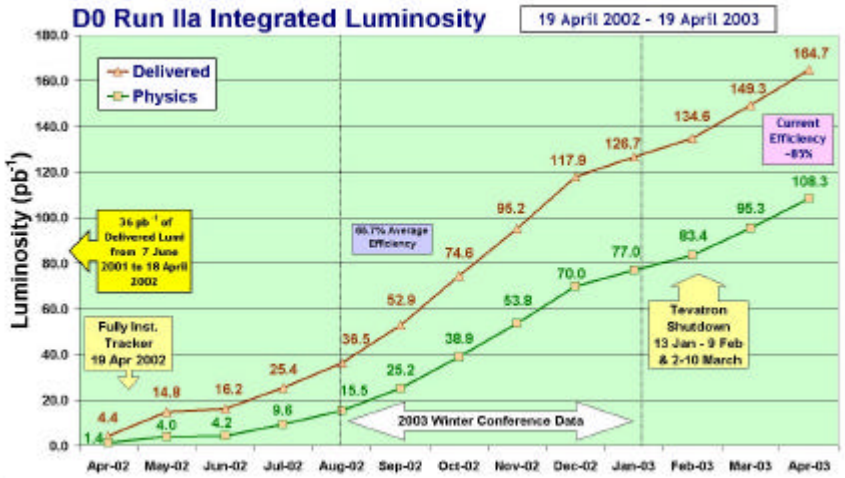


Trigger and DAQ



Tracker and silicon-based triggers integration underway





DAQ efficiency improved significantly, running routinely at ~85% now...