Beauty and Charm Physics at CDF Run II

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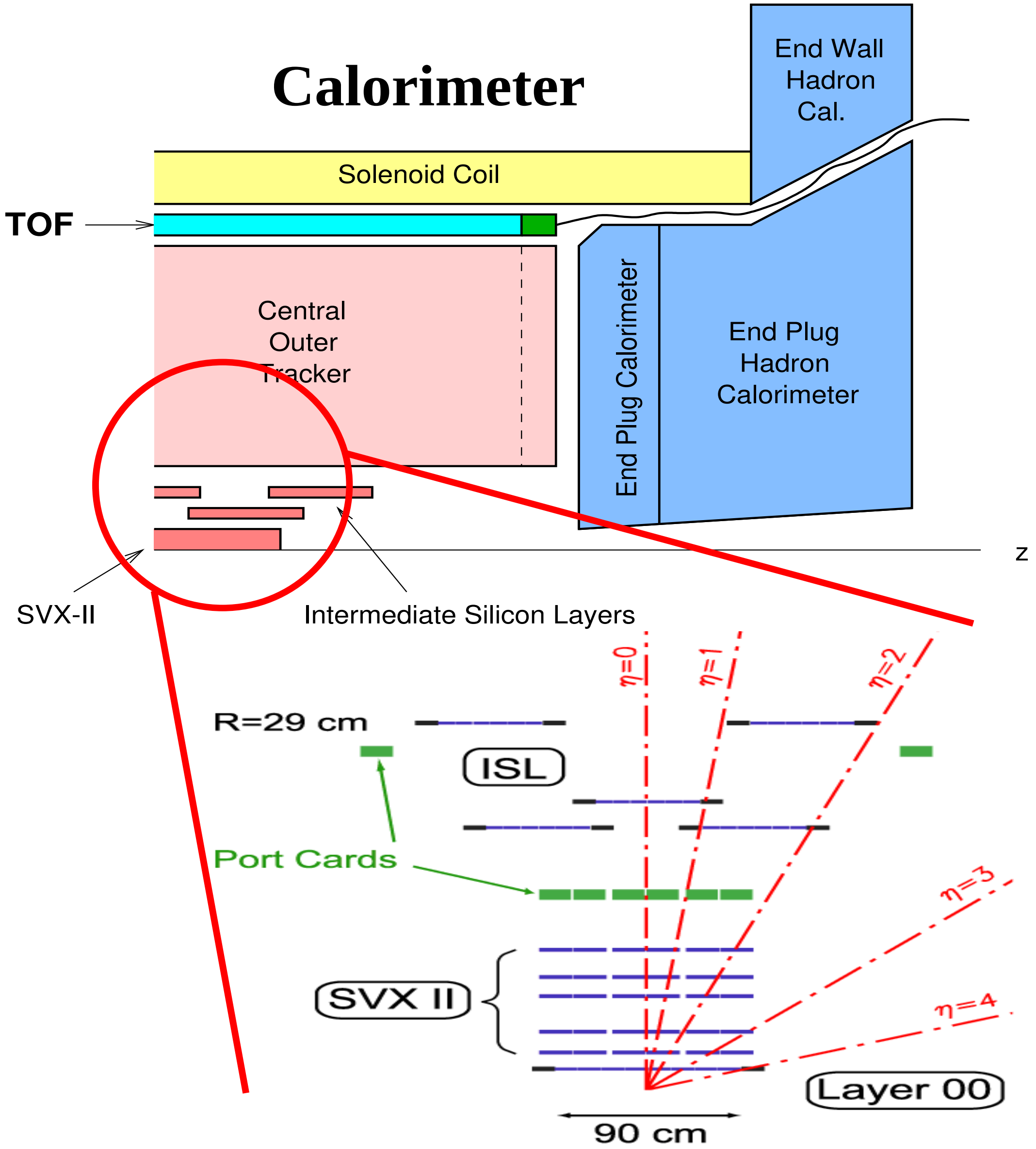
(for the CDF II collaboration)

IV International Symposium on LHC Physics and Detectors FERMILAB, May 1-3 , 2003

Topics

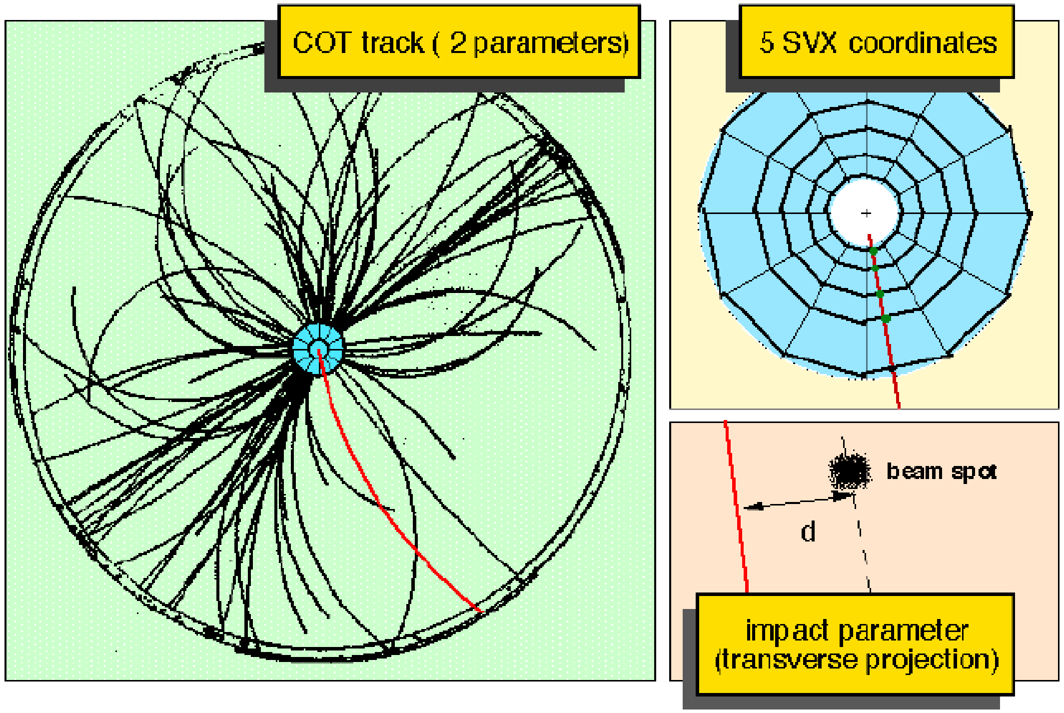
- b and c production - Run II
- Masses, lifetimes, branching fractions of b/c hadrons.
- CKM matrix physics at CDF

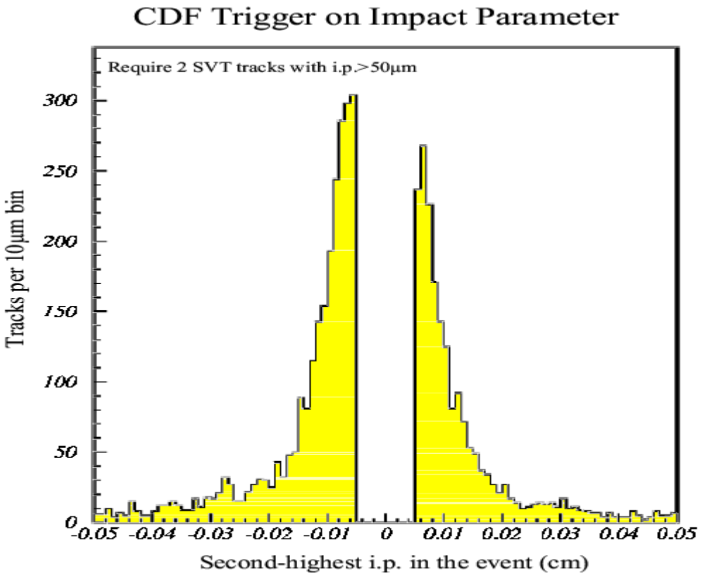
The CDF Run II Detector

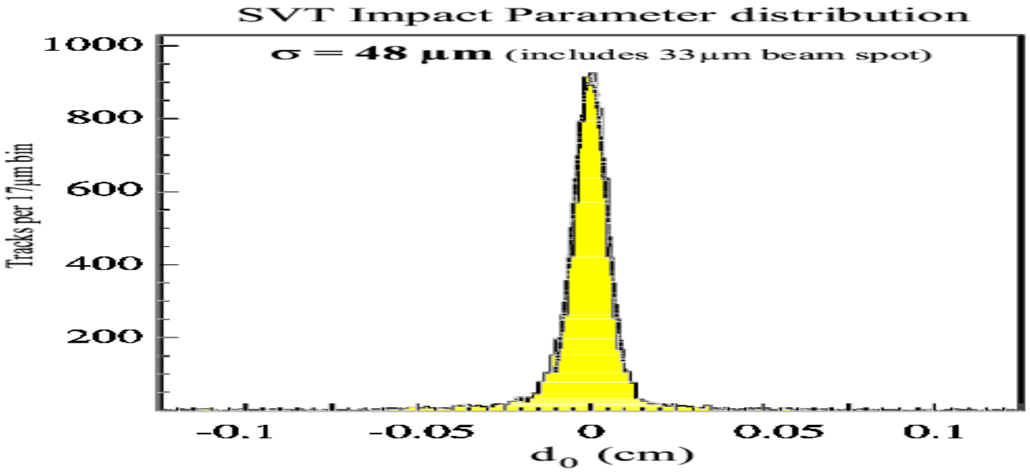


- New central tracker w/ 96 layers
- *8 Layers of 3-D Silicon up to* $|\eta| = 2$, $\sigma(d_0) \sim 20\mu m$
- New TOF system
- *Track Triggers at Level 1 (Central tracking) and Level 2 (Si tracking) with* $p_t > 1.5\ GeV/c$ $|\eta| < 1.0$

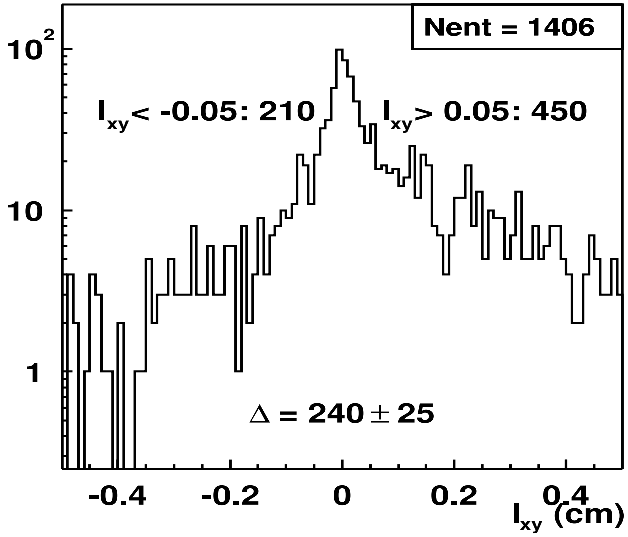
Run II Secondary Vertex Trigger



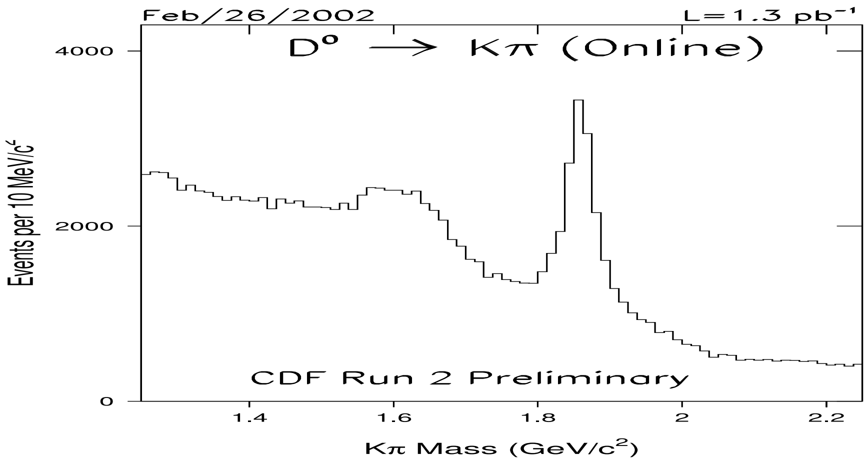


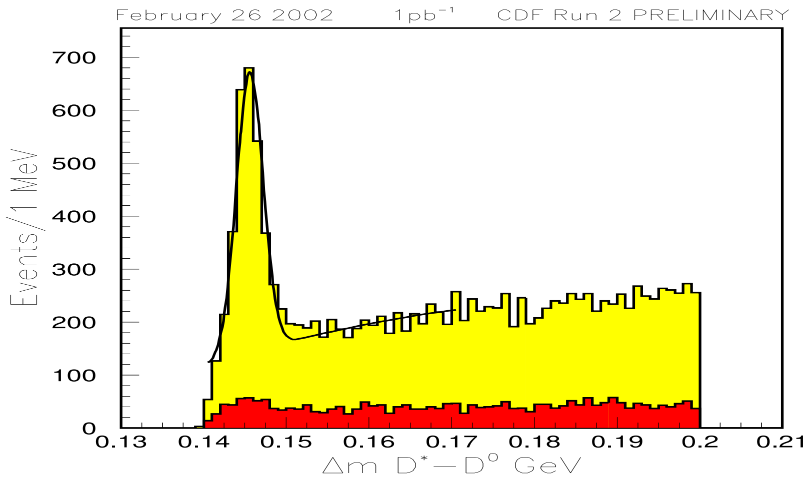


$150\mu m \leq d_0 \leq 1mm \quad 2^\circ \leq \Delta\phi \leq 90^\circ$

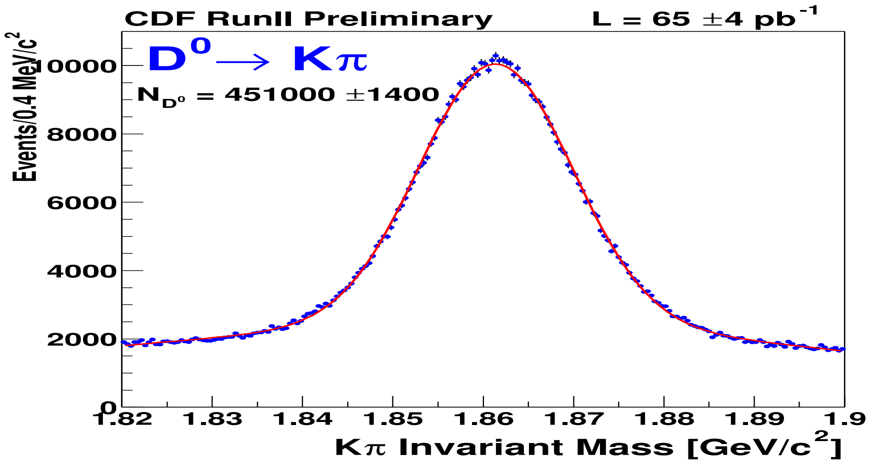


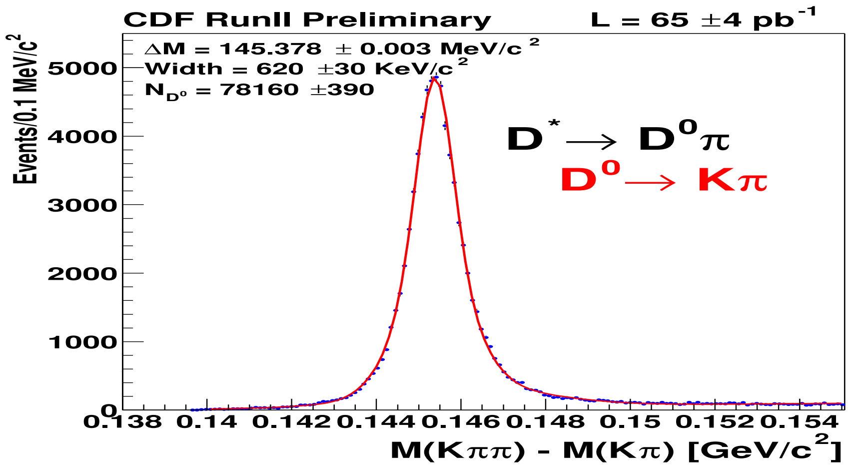
Charm in Run II





Feb'-02 charm signals reconstructed with online SVT tracks.

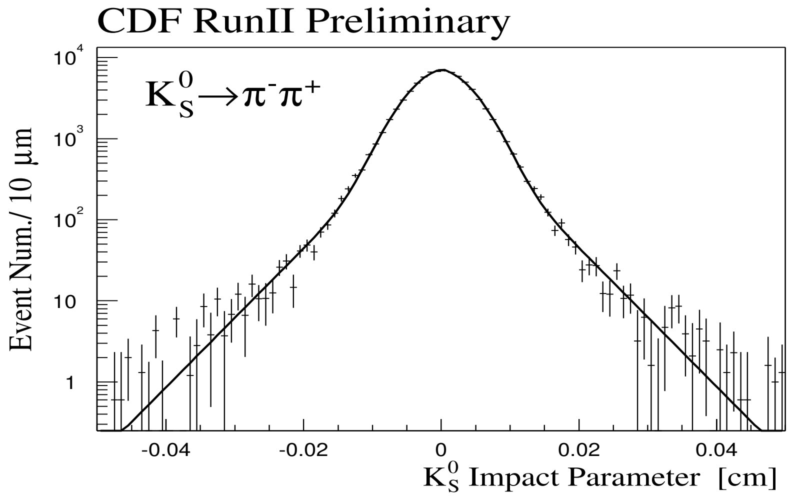




450K $D^0 \rightarrow K\pi$ fully reconstructed 78K D^* fully reconstructed

Direct Charm Production Run II

Use impact parameter of reconstructed charm mesons $F_D(d_0)$ *to distinguish directly produced charm from* $B \to DX$, $F_B(d_0)$

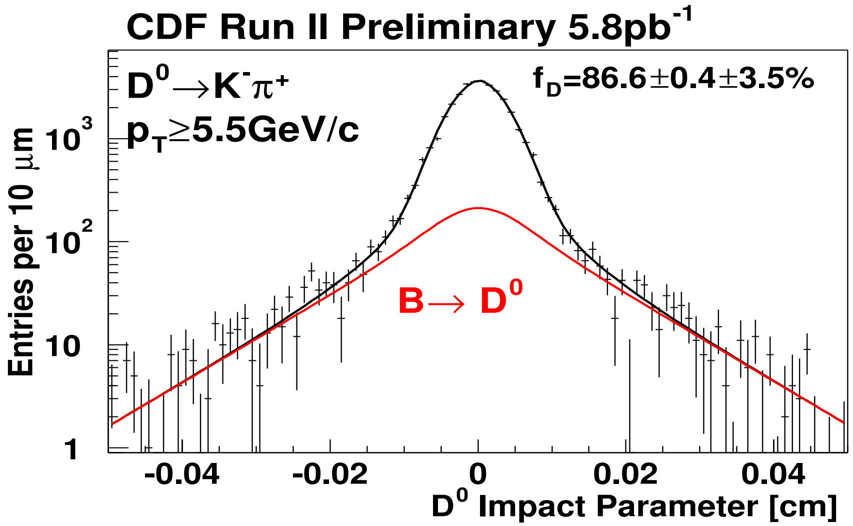


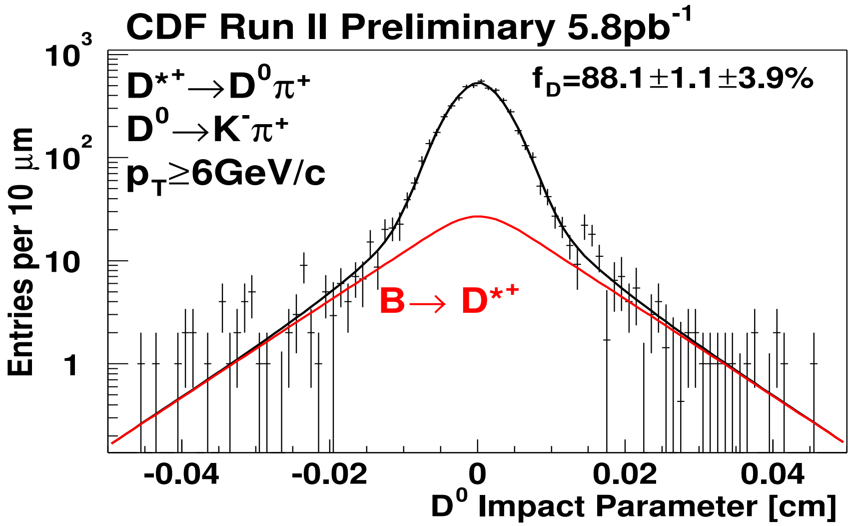
From $K_s \to \pi\pi$ data we find

$F_D(d_0)$ = Gaussian + exp tails.

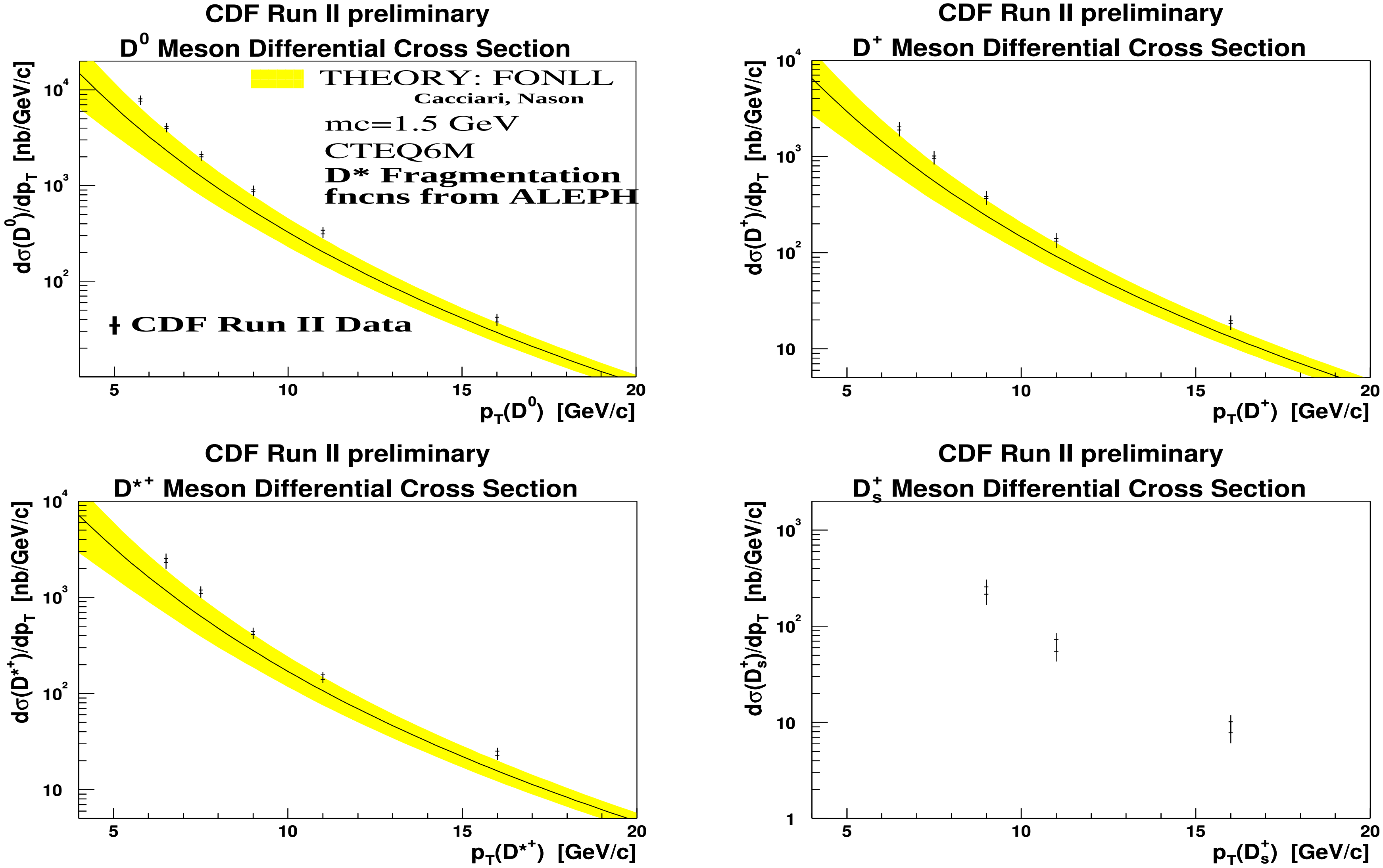
From $B \to DX$ MC :

$F_B(d_0)$ = a double exponential.





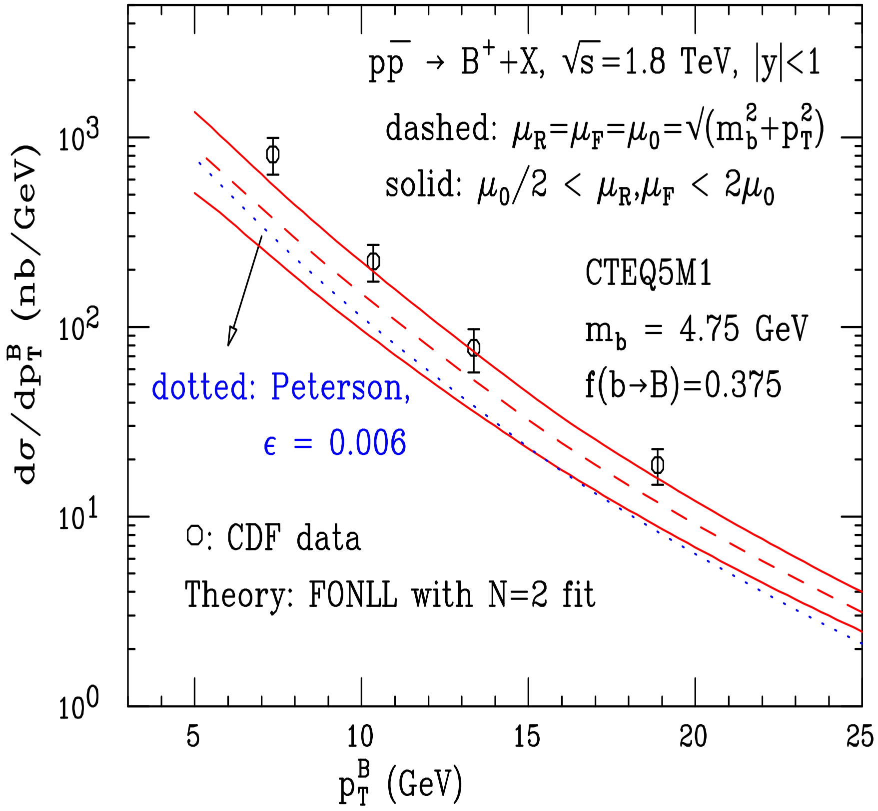
Direct Charm Production X-Sec.



$$E/T = 1.7 - 1.9(low\ p_t) \text{ and } E/T = 1.3 - 1.4(high\ p_t)$$

Theory update: B production

When $p_T >> m_b$, large logarithms of the ratio p_T/m_b arise in the coefficients of the perturbative expansion. Resummation of next-to-leading logs merged with the QCD NLO using a retuned fragmentation function from more recent e^+e^- data with NLL applied



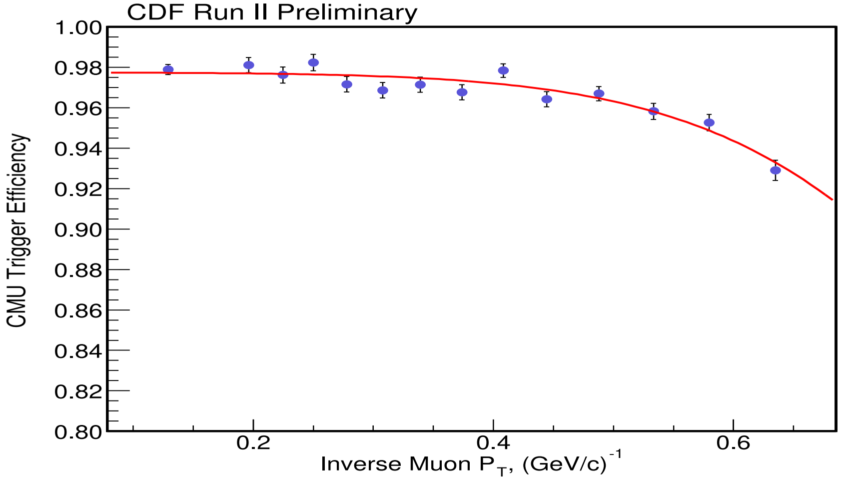
Cacciari, Nason hep-ph/0204025 (Run I Data)

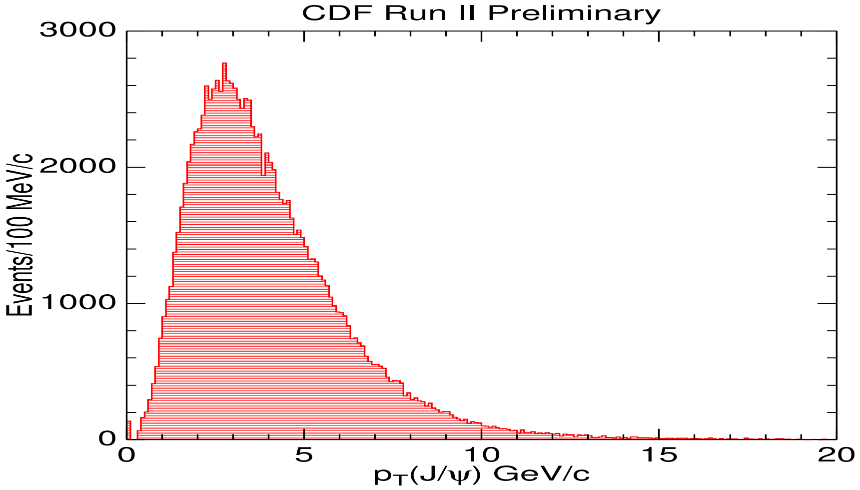
$$E/T = 1.7 \pm 0.5(theory) \pm 0.5(expt)$$

Run II: test current theory predictions at $p_t^{min} < 5$ GeV

Run II Muon Triggers

Run II dimuon trigger has been optimized and running stably at a rate of 12 $J/\psi s$ / nb^{-1} ($|\eta| < 1.0$) since Jan. 2002



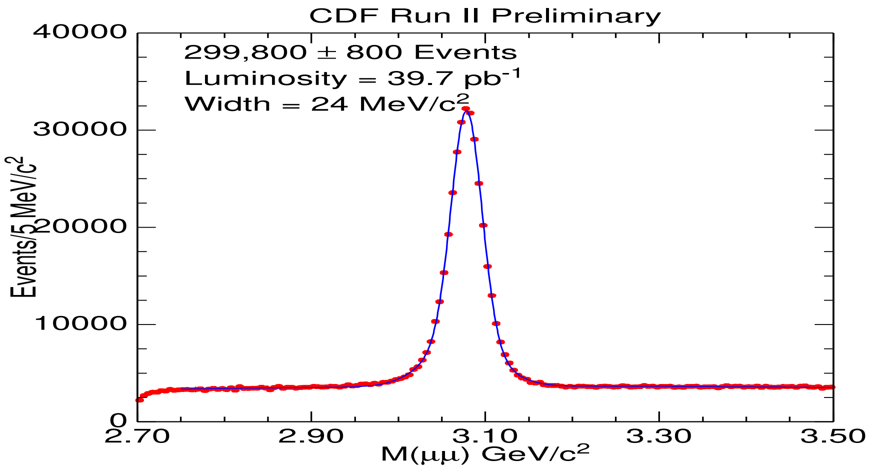


L1 μ trigger efficiency J/ψ transverse momentum

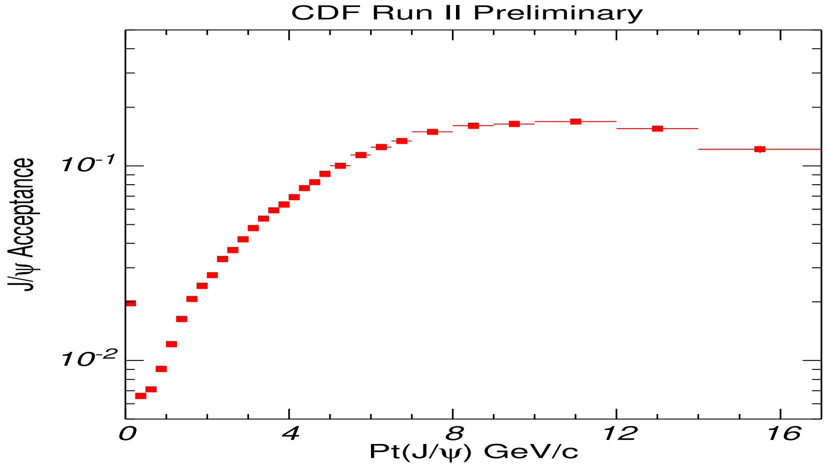
Run II di-muon trigger features:

- *lower p_t reach:* $p_t(\mu) > 1.5(|\eta| < 0.6), 2.0(0.6 < |\eta| < 1.0)$ $\rightarrow p_t(J\psi) = 0\ GeV/c \rightarrow$ TOTAL cross-sections
- *Opening angle* $\Delta\phi > 5^0$ *(was* 15^0*)* $\rightarrow$ *polarization.*

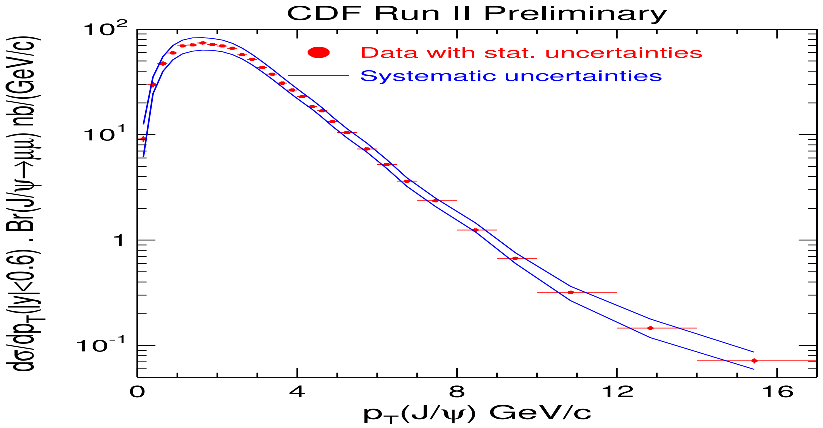
Run II inclusive $J/\psi X$ x-sec



300K J/ψ from 37 pb^{-1}



Detector acceptance



J/ψ inclusive x-sec

First at a hadron collider !: Total J/ψ cross-section:

$$\sigma(p\bar{p} \rightarrow J/\psi X, |\, y(J/\psi)\,| < 0.6)$$
$$\times Br(J/\psi \rightarrow \mu\mu)$$
$$= 240 \pm 1(stat)^{+35}_{-28}(syst) \text{ nb}$$

HVQ production - summary

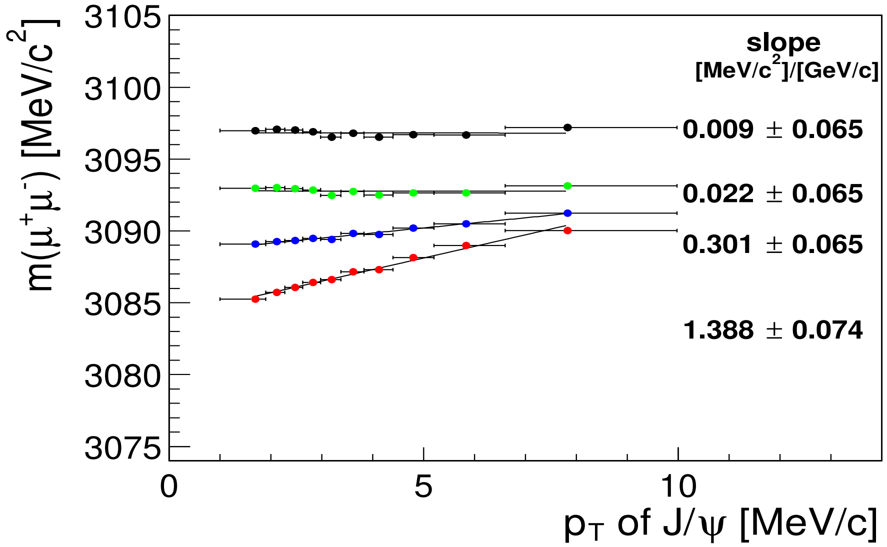
Run II new and improved triggers ! Larger kinematic coverage of the dimuon triggers, $|\eta| < 1$, $p_t(\mu) < 1.5$ GeV/c ($|\eta| < 0.6$). Track triggers $\Rightarrow$ large SVT b/c yields at $p_t(l) < 6GeV/c$ and $p_t(track) > 2GeV/c$. *Test theory predictions in a different kinematic region.*

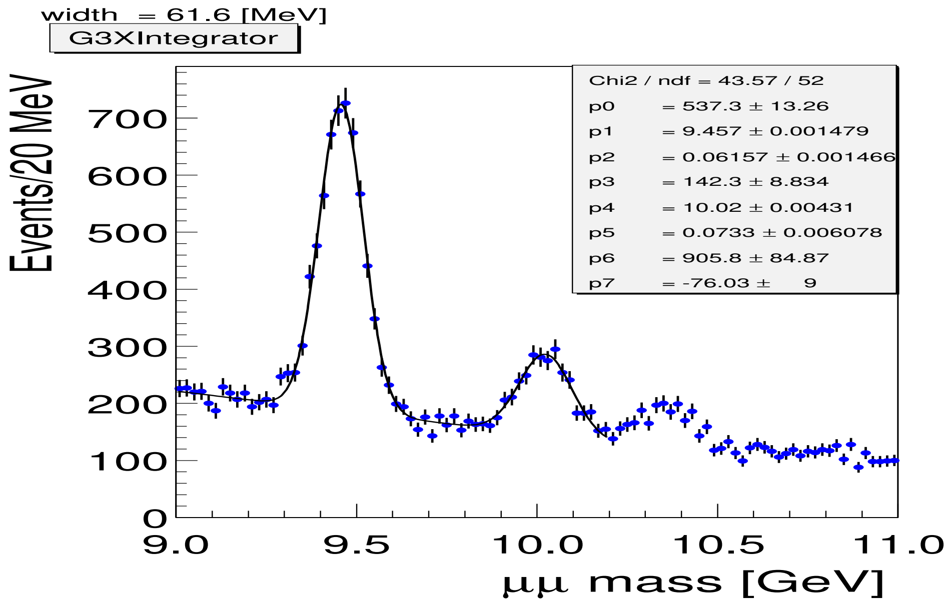
Milestones on the road to HVQ production: Preliminary measurements of total inclusive J/ψ and open charm x-secs. Exclusive B mesons reconstructed. methods for seperation of prompt J/ψ and D from bs developed. *Preliminary measurements of b production x-secs underway.*

Masses, Lifetimes, Branching fractions

SVXII Material calibration

J/ψ mass ⇒ ∼ 10% *of SVXII material unaccounted for.* Need B-Field correction of ≈ 0.1% .

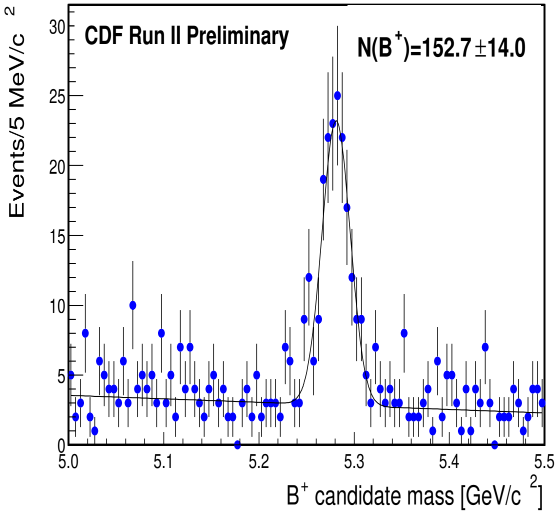


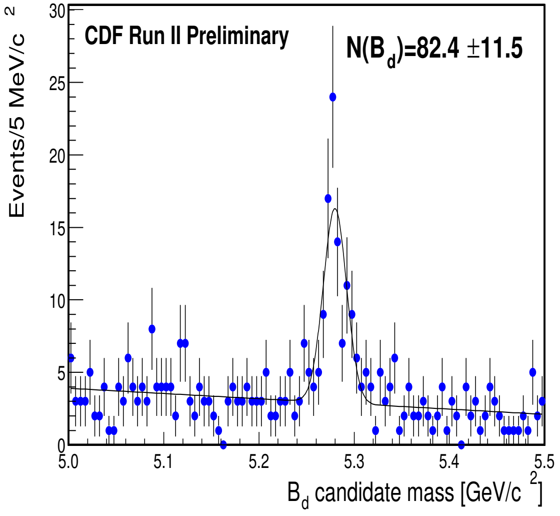


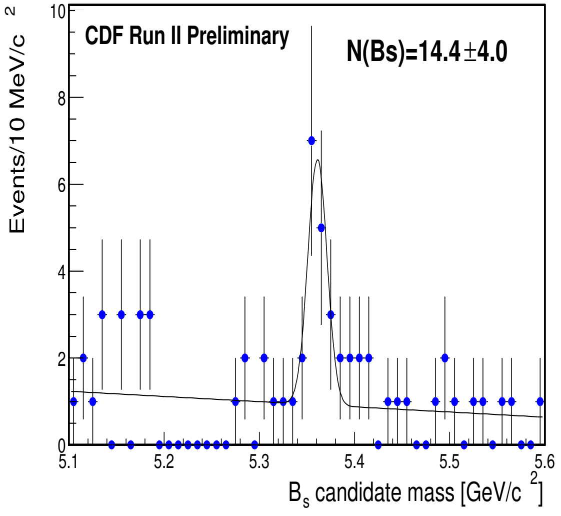
Particle	Measured mass	PDG 2002 mass
K_s	$497.36 \pm 0.05(stat)$	497.672 ± 0.031
D^0	$1864.25 \pm 0.06(stat)$	1864.6 ± 0.5
$\Upsilon(1S)$	$9458 \pm 1(stat)$	9460.37 ± 0.21

B meson masses ***

Run I B_s and Λ_b worlds best. *Competitive measurements early.*







$B^+ \to J/\psi K+$ $\quad$ $B^0 \to J/\psi K^{*0}$ $\quad$ $B^0_s \to J/\psi \phi$

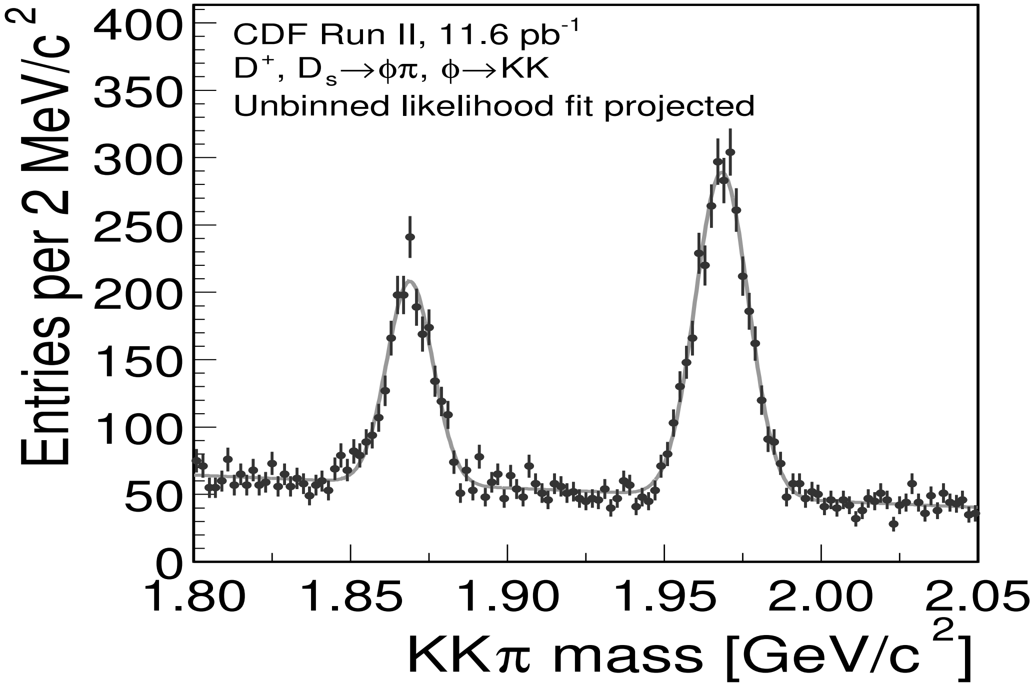
Particle	Measured mass (Summer'02)	PDG 2002 mass
B^+	$5280.6 \pm 1.7(stat) \pm 1.1(syst)$	5279.0 ± 0.5
B^0	$5279.8 \pm 1.9(stat) \pm 1.4(syst)$	5279.4 ± 0.5
B^0_s	$5360.3 \pm 3.8(stat)^{+2.1}_{-2.9}(syst)$	5369.6 ± 2.4

Mass Difference $D_s^+ - D^+$

Measurement of $\Delta M(D_s^+ - D^+)$ is input to the overall PDG fit for all the charmed mesons. Predicted by HQET and Lattice QCD. $D_s^\pm, D^\pm \to \phi\pi,\ \phi \to KK$

First CDF Run II Publication!!

Effect	Syst.[MeV/c^2]
fitting	0.14
event selection	0.11
momentum scale	0.10
Tracker effects	0.06
Calibration procedure	0.03
Total	0.21

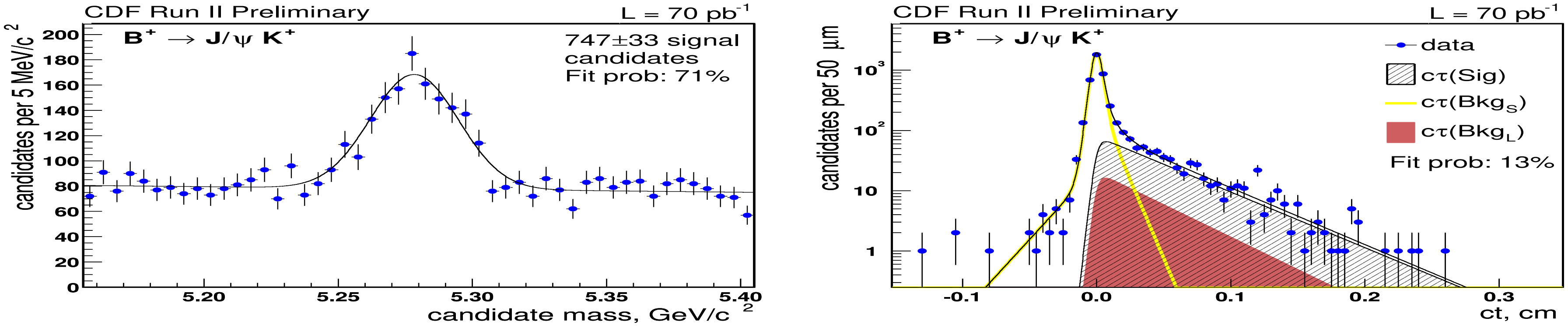


$$m(D_s^\pm) - m(D^\pm) = 99.41 \pm 0.38(stat) \pm 0.21(syst)\ \mathrm{MeV/c^2}$$

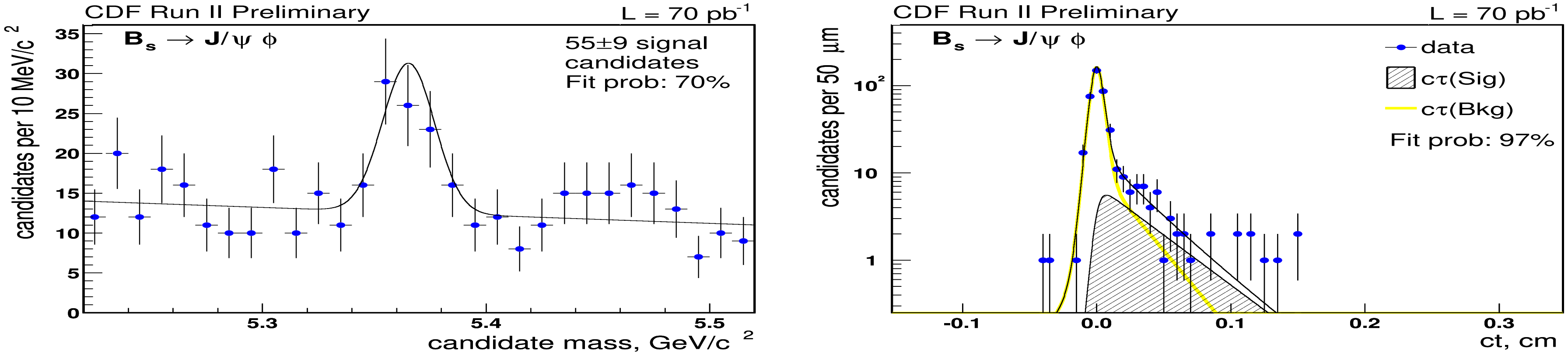
$$m(D_s^\pm) - m(D^\pm) = 99.2 \pm 0.5\ \mathrm{MeV/c^2}\ \text{-PDG2002}$$

B_s lifetime using $B_s \to J/\psi\phi$

The ratio $\frac{\tau(B_s)}{\tau(B_d)}$ *tests Heavy Quark Expansion theory predictions.*



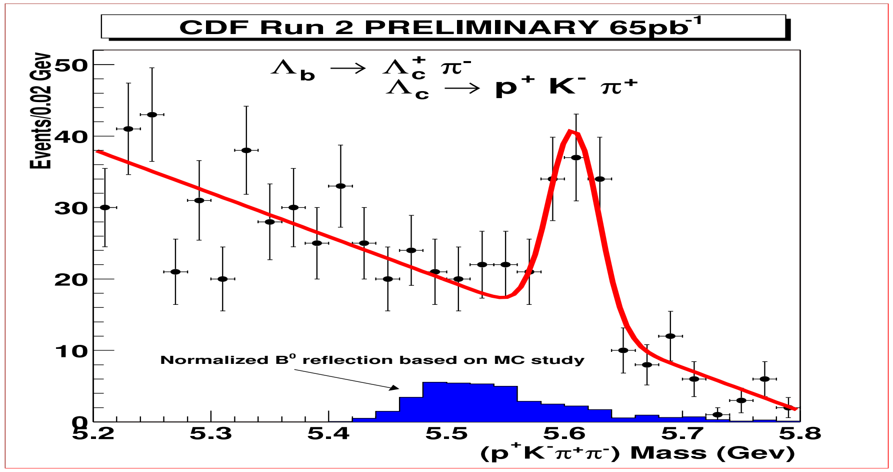
$B_u^+ \to J/\psi K^+$ control sample. $\tau(B^+) = 1.57 \pm 0.07(stat) \pm 0.02(syst)$ ps

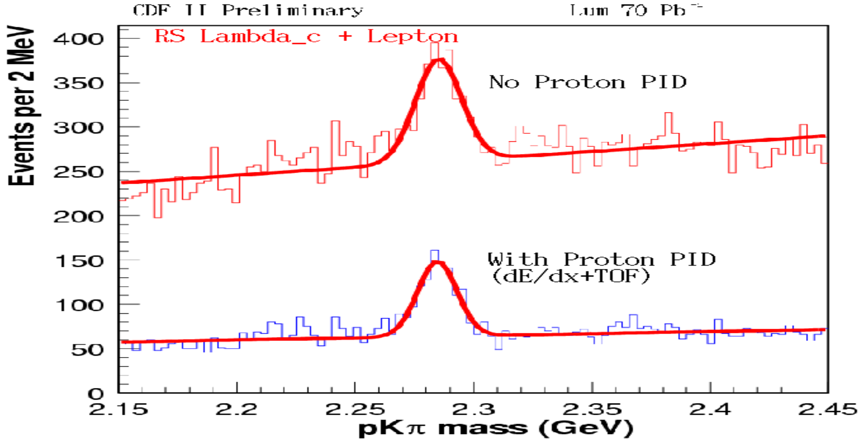


$\tau(B_s) = 1.26 \pm 0.20(stat) \pm 0.02(syst)$ ps

$\tau(B_s) = 1.34 \pm 0.23(stat) \pm 0.05(syst)$ ps - CDF Run I

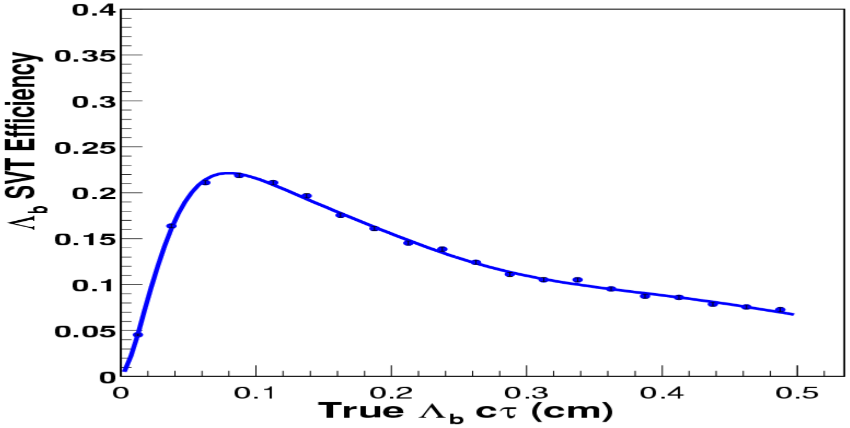
Beauty Baryons

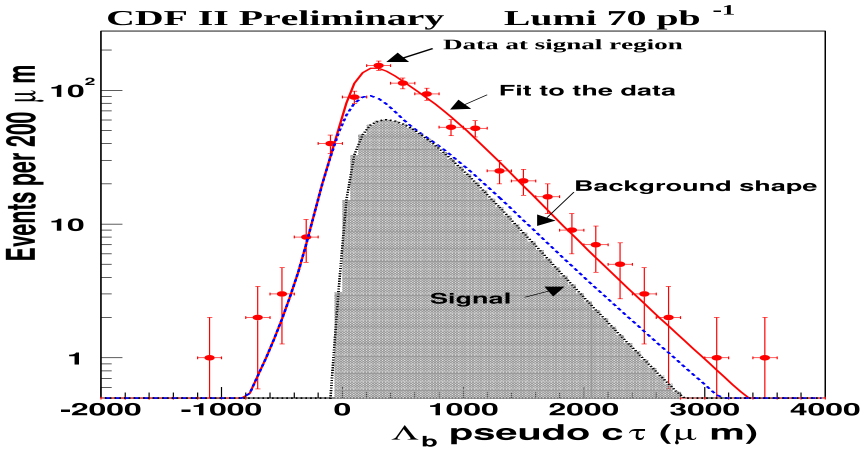




$\Lambda_b \to \Lambda_c \pi \approx 73$ *events* (measure Br)

$\Lambda_b \to \Lambda_c \ell X \approx 600$ events



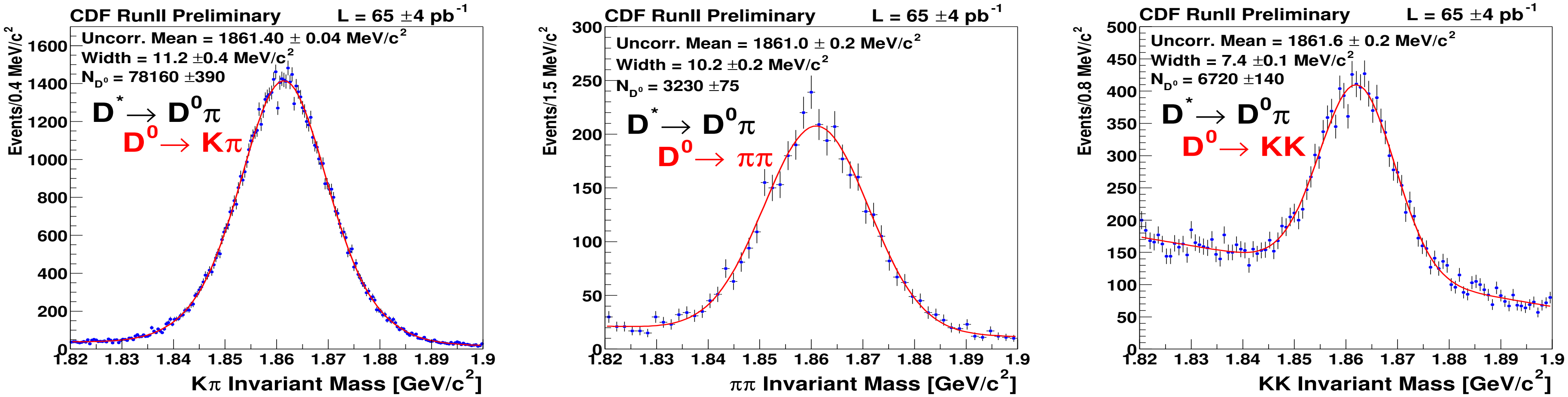


$$\tau_{\Lambda_b}(\Lambda_c \mu X) = xxx \pm 0.13(stat) \pm 0.07(syst) ps$$

$$\tau_{\Lambda_b}(\Lambda_c \ell X) = 1.32 \pm 0.15(stat) \pm 0.07(syst) \text{ ps - CDF Run I}$$

Cabbibo suppressed D decays ***

Decays of D^0 to CP eigenstates K^+K^- and $\pi^+\pi^-$ are important for D^0 mixing and CP violation.



$$\frac{\Gamma(D^0 \to K^+K^-)}{\Gamma(D^0 \to K\pi)} = 9.41 \pm 0.18(stat) \pm 0.13(syst)\% \text{ CDF Run II}$$

$$\Gamma(D^0 \to K^+K^-)/\Gamma(D^0 \to K\pi) = 9.93 \pm 0.14 \pm 0.14\% \text{ FOCUS2003}$$

$$\frac{\Gamma(D^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to K\pi)} = 3.686 \pm 0.076(stat) \pm 0.084(syst)\% \text{ CDF Run II}$$

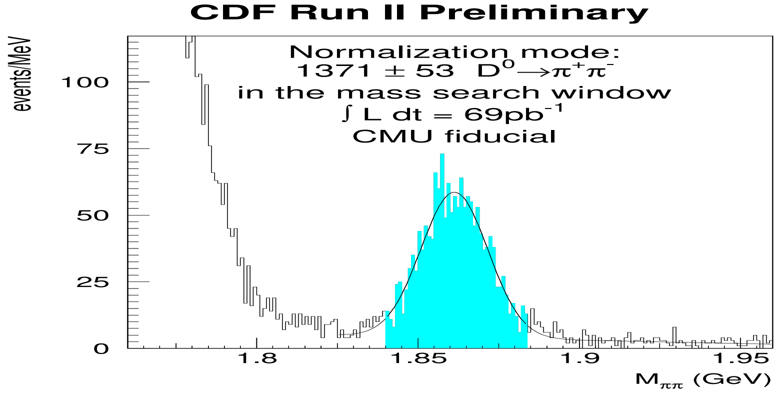
$$\Gamma(D^0 \to \pi^+\pi^-)/\Gamma(D^0 \to K\pi) = 3.53 \pm 0.12 \pm 0.06\% \text{ FOCUS2003}$$

$$\mathcal{A}_{cp}(D^0 \to KK) = 2.0 \pm 1.9(stat) \pm 0.7(syst)\%$$

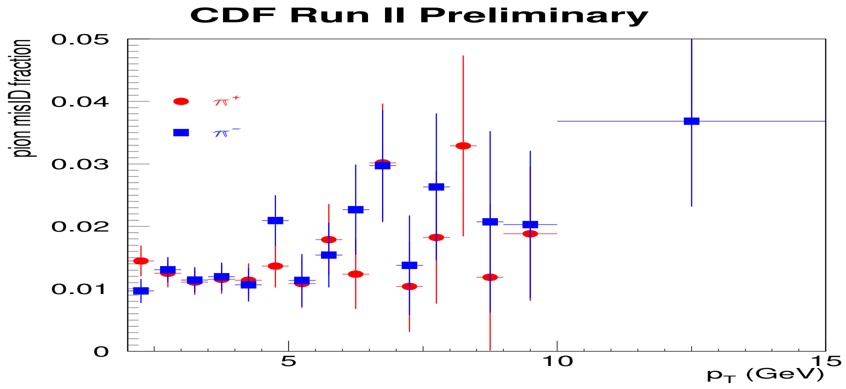
$$\mathcal{A}_{cp}(D^0 \to \pi\pi) = 2.0 \pm 1.9(stat) \pm 0.7(syst)\%$$

Rare FCNC $D^0 \to \mu\mu$

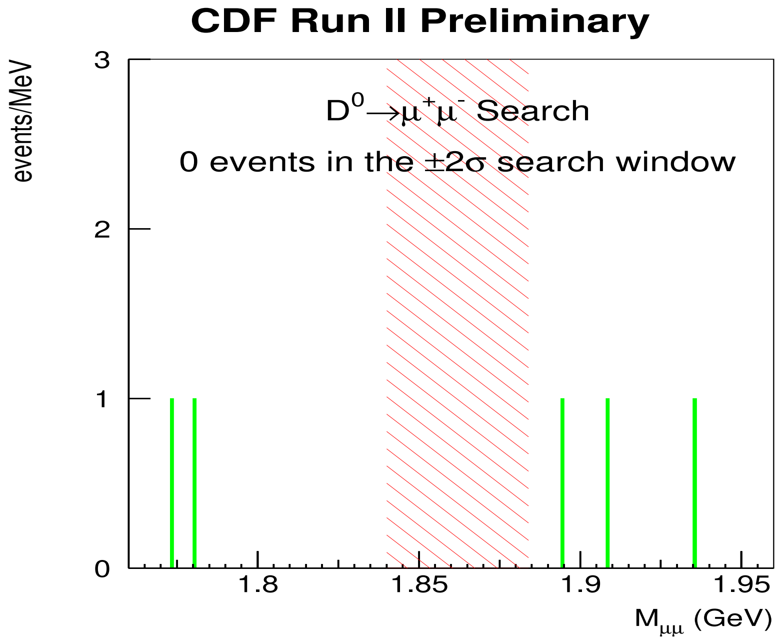
Sensitive to physics beyond the SM (3×10^{-13}). *SUSY models with R-Parity violation predict up to* 3.5×10^{-6}



Normalize to $D \to \pi\pi$



Pion misid rate



$Br(D^0 \to \mu^+\mu^-) \leq 2.4 \times 10^{-6}$

@ 90% C.L.

Previous limit $\leq 4.1 \times 10^{-6}$

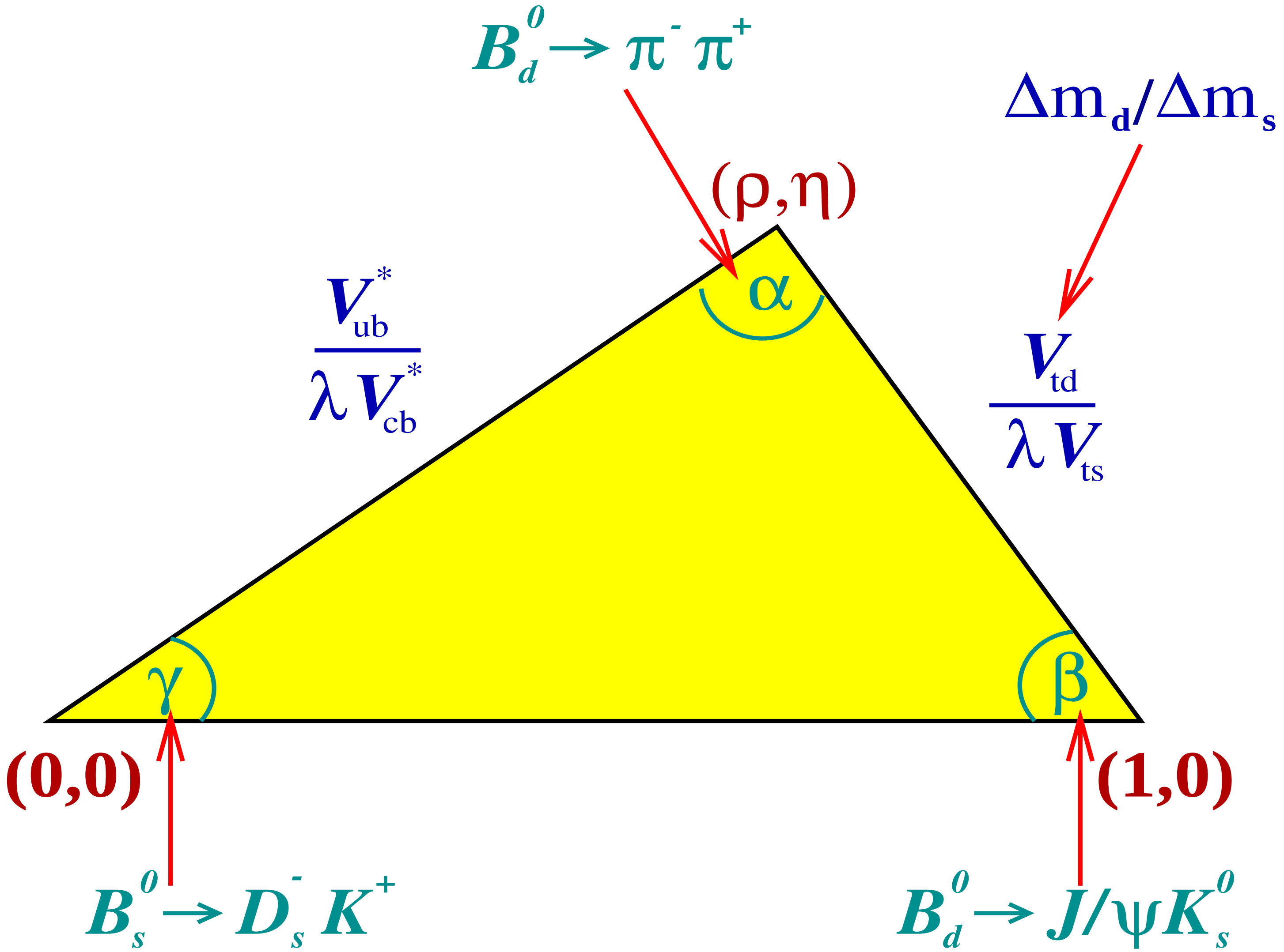
b/c-hadron properties

Particle	Measured mass MeV/c^2
B^+	$5280.6 \pm 1.7(stat) \pm 1.1(syst)$
B^0	$5279.8 \pm 1.9(stat) \pm 1.4(syst)$
B_s^0	$5360.3 \pm 3.8(stat)^{+2.1}_{-2.9}(syst)$
$m(D_s^\pm) - m(D^\pm)$	$99.41 \pm 0.38(stat) \pm 0.21(syst)$

Particle	Lifetime
B_s	$1.26 \pm 0.20(stat) \pm 0.02(syst)ps$
Λ_b	$xxx \pm 0.13(stat) \pm 0.07(syst)ps$

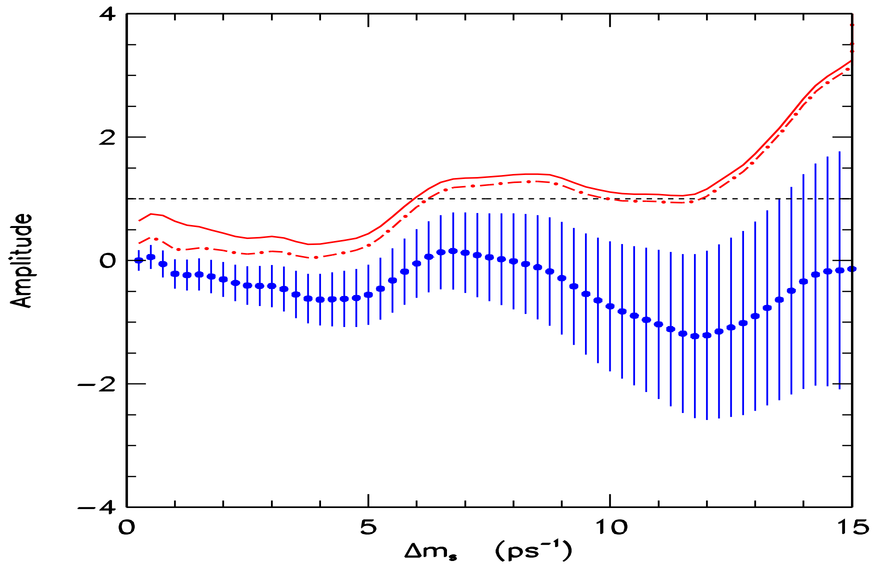
Decay	Branching fraction
$Br(D^0 \to \mu^+\mu^-)$	$\leq 2.4 \times 10^{-6}$ @ 90% $C.L.$

Studying the α, β, γ of B Physics



B_s mixing ($\Delta m_s >> \Delta m_d$)

$$P^{B_s^0}_{SS(OS)} = 1/2\tau \exp(-t/\tau) \times[1 \mp \mathcal{A}(\Delta m_s)\cos(\Delta m_s t)]$$



Run I limit :

$\Delta(m_s) > 5.8\text{ps}^{-1}$@ 95% CL.

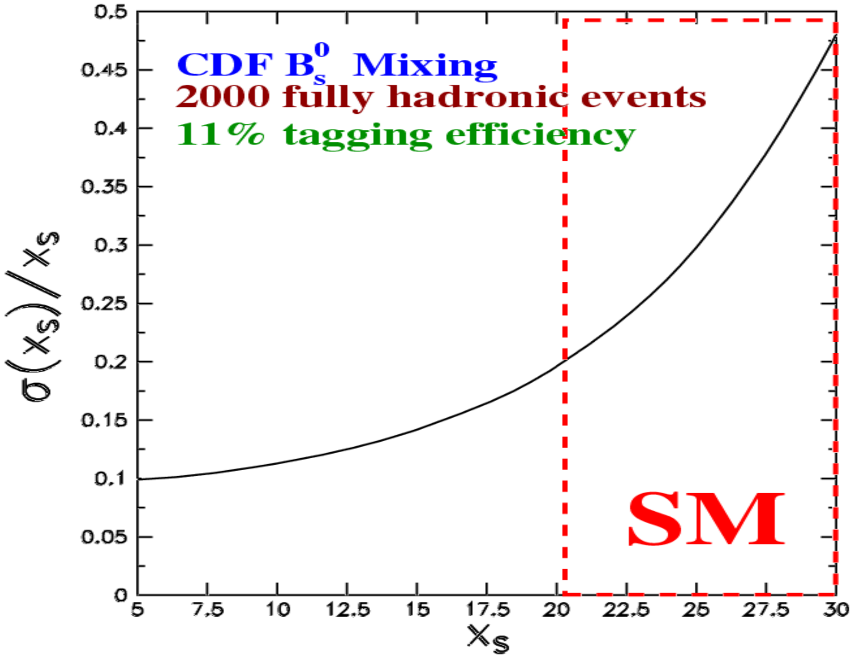
From $B_s \to \phi\, l \underbrace{X\nu}_{direction?}$

Run II

Hadronic trigger

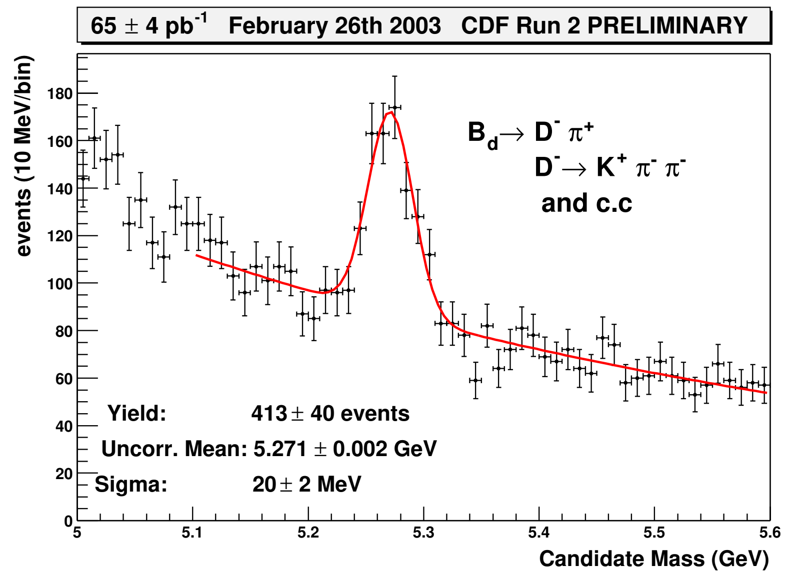
L00 and TOF

Use $B_s \to D_s^{(*)+} \underbrace{n\pi}_{tag}$

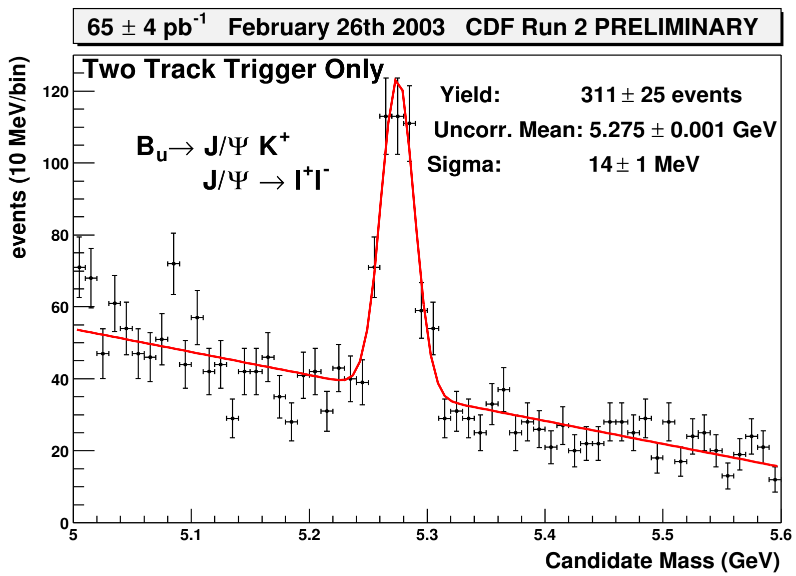


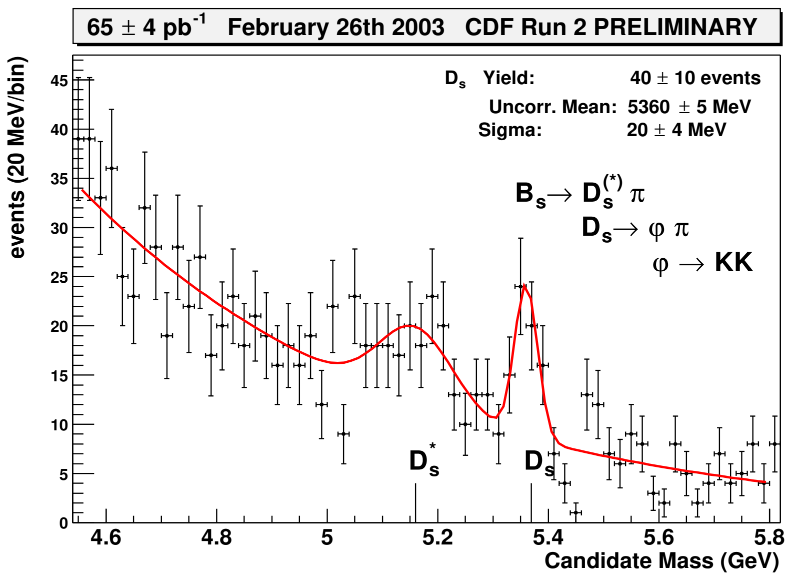
$X_s = \Delta m_s/\tau(B_s)$

B_s hadronic - Run II



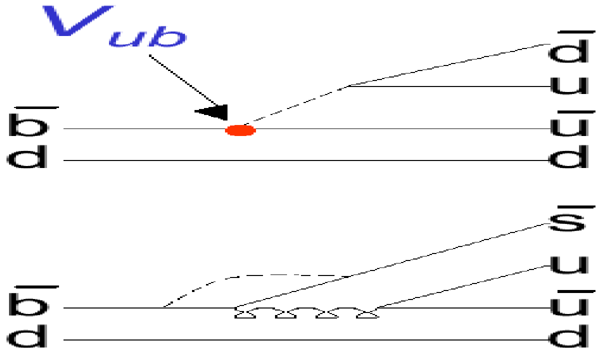
Compare $B_d \to D^-\pi$ and $B_u \to J/\psi K^+$ in TTT $\Rightarrow$ trigger eff. understood. Normalize B_s to $B_d \to D^-\pi$, $D^- \to K\pi\pi$. B_s yield $= 40 \pm 10$ events - much lower than expected but mostly understood.

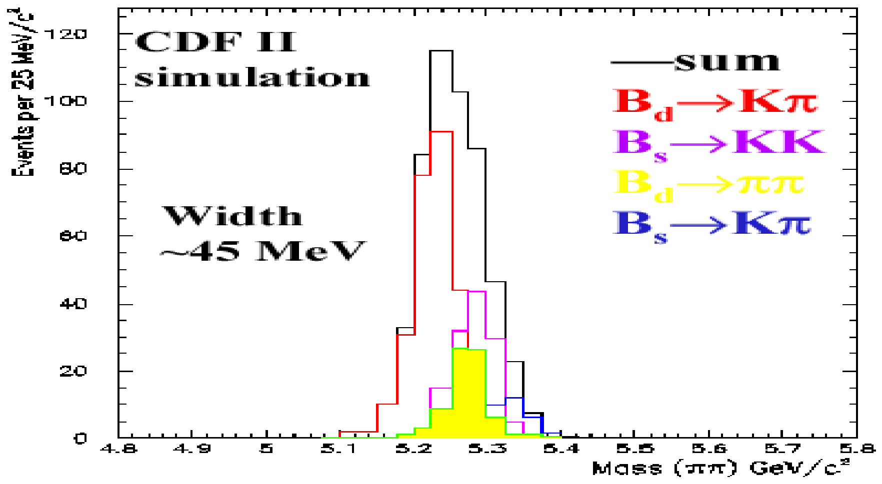


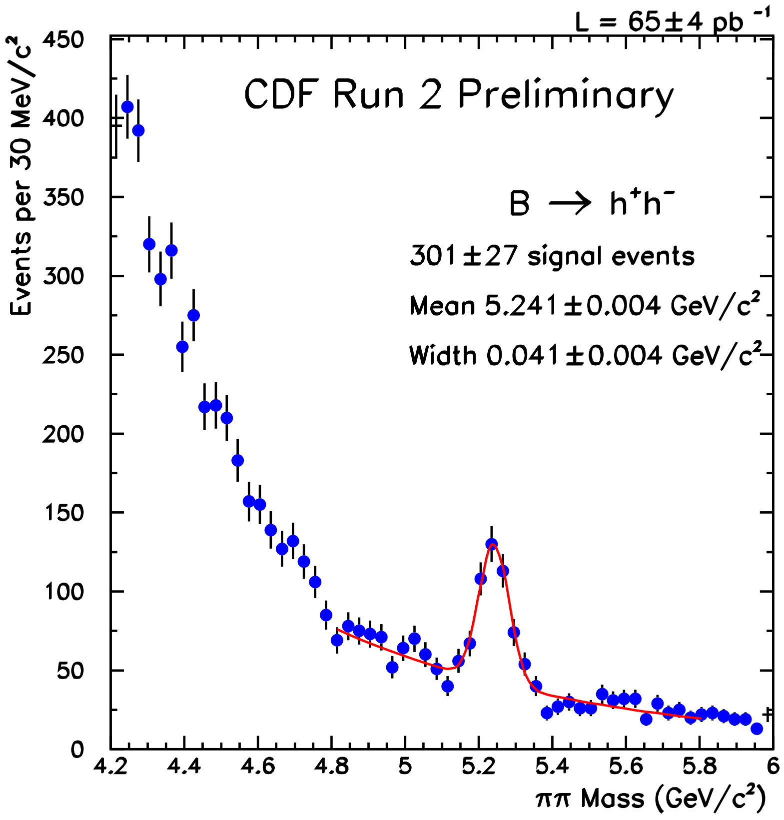


Direct CPV in $b \to hh \to \alpha, \gamma$

Direct CP violation in $B^0 \to \pi^+\pi^-$ *Penguin "pollution" need* $B \to K^+K^-$. *Expect 500* $B \to hh/100pb^{-1}$. *Goal is to measure* $\mathcal{A}_{cp}(B_d \to \pi^+\pi^-, K^+\pi^-/B_s \to KK, K^-\pi^+/\Lambda_b^0 \to p^+\pi^-, p^+K^-)$

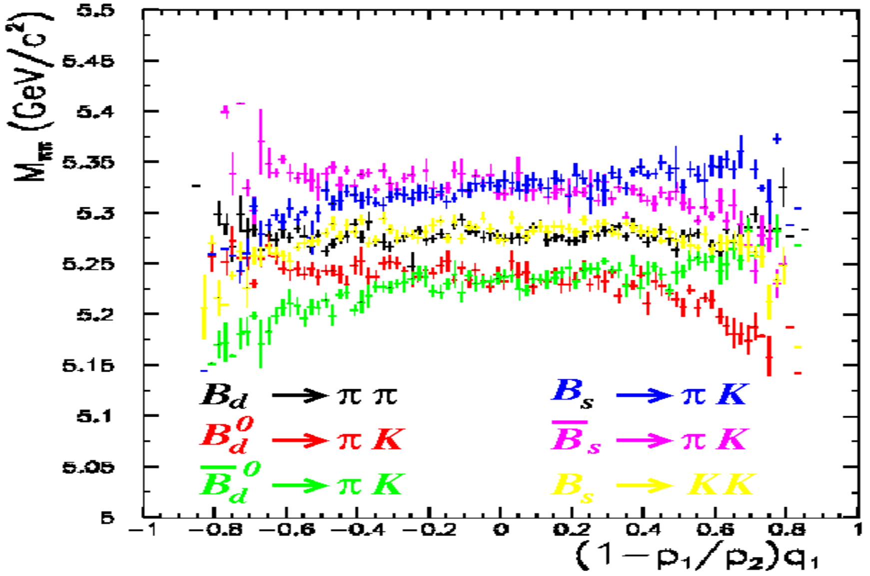


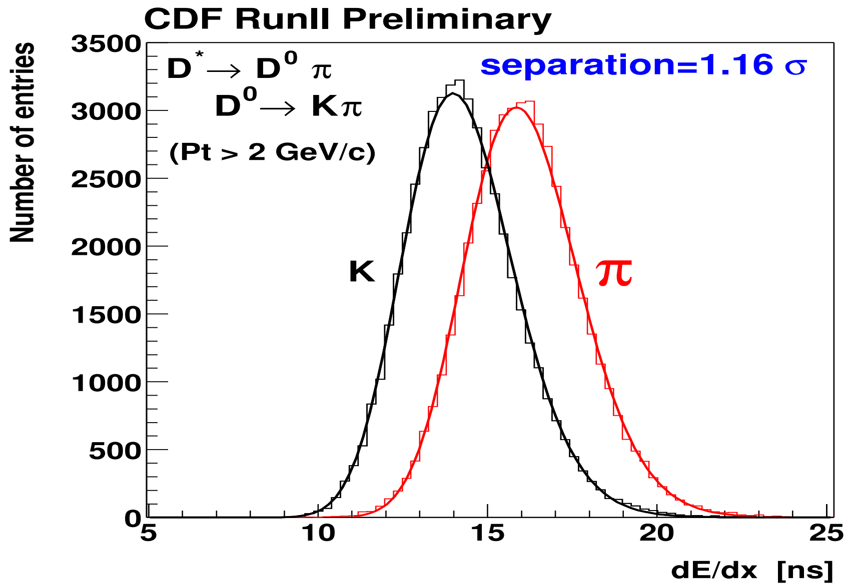




Disentangling $B \to h^+h^-$

Differences in $\pi - K$ kinematics seperate $K\pi/\pi K$ from $\pi\pi/KK$ decays. Particle ID seperates $\pi\pi$ from KK and πK from $K\pi$





$M_{\pi\pi}$ versus $\alpha = (1 - \frac{p_1}{p_2}).q_1$ $\quad id_{1,2} = \frac{dE/dX(trk_{1,2}) - dE/dX(\pi)}{dE/dX(K) - dE/dX(\pi)}$

$$\mathcal{F} = G(M_{\pi\pi} - \mathcal{M}(\alpha), \sigma_M).\underbrace{P(\alpha)}_{MC}.G(id_1 - Eid_1, 1).G(id_2 - Eid_2, 1)$$

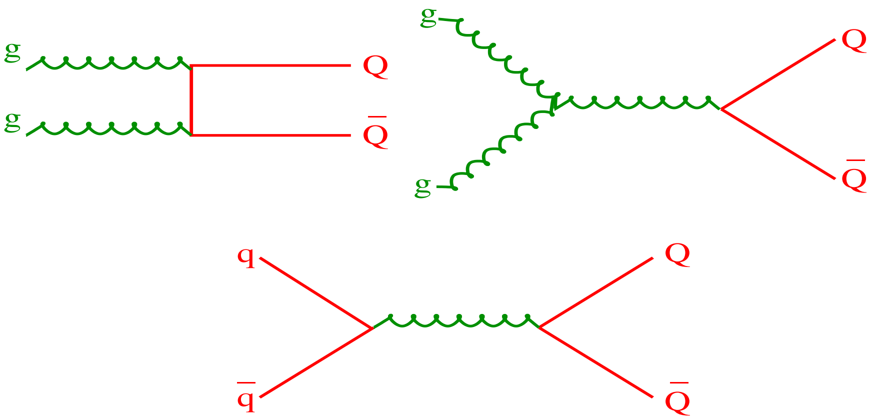
Total likelihood function : $\mathcal{L} = \sum_{i=1}^{6} f_i \cdot \mathcal{F}_i(\alpha, M_{\pi\pi})$

CONCLUSION

Run II Heavy flavor results first publications - summer/winter '03

Backup slides

Basics of HVQ Production in $p\bar{p}$



LO HVQ PRODUCTION

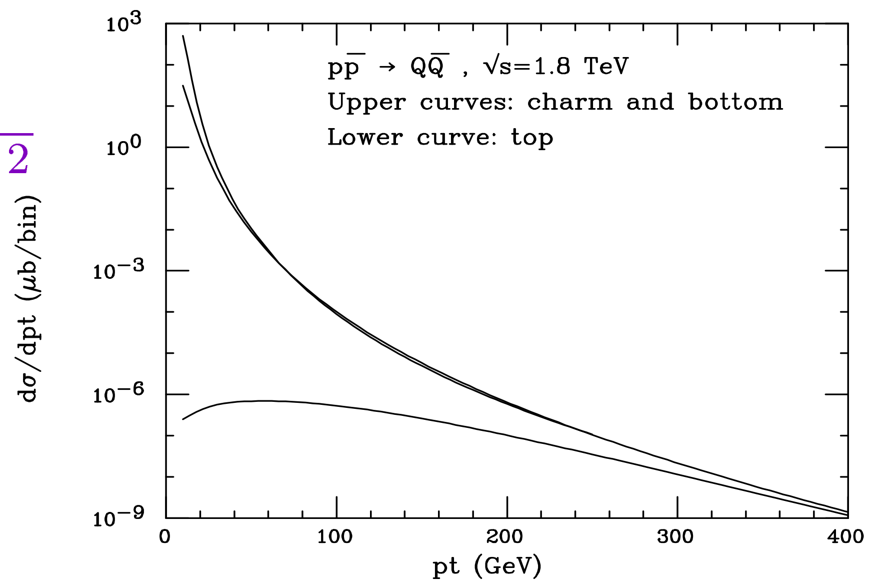
Two leading order perturbative processes:

$$\frac{\hat{\sigma}(gg \to Q_1\bar{Q}_1)}{\hat{\sigma}(gg \to Q_2\bar{Q}_2)} \overset{s\to\infty}{\to} 1 - \frac{log(m_1^2/m_2^2)}{log(s/m_2^2)}$$

$$\frac{\hat{\sigma}(q\bar{q} \to Q_1\bar{Q}_1)}{\hat{\sigma}(q\bar{q} \to Q_2\bar{Q}_2)} \overset{s\to\infty}{\to} 1 - \mathcal{O}(m_1^4/\hat{s}^2)$$

Hadronic states need PDFs:

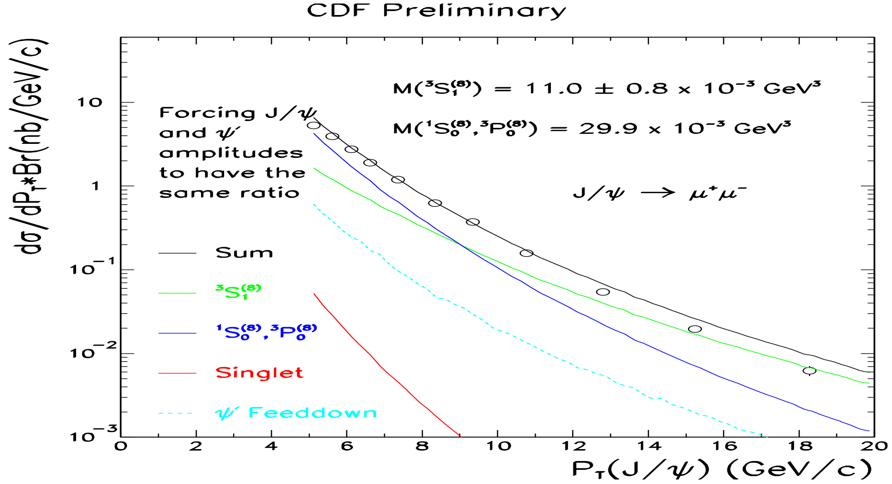
$$\frac{d\sigma}{dy\,d\bar{y}\,dp_T^2} \propto \frac{1}{m_T^4}\frac{1}{[1+\cosh(y-\bar{y})]^2} \times \sum_{i,j} x_1 f_i(x_1) x_2 f_j(x_2) \times \bar{\sum}|M(ij \to Q\bar{Q})|^2$$

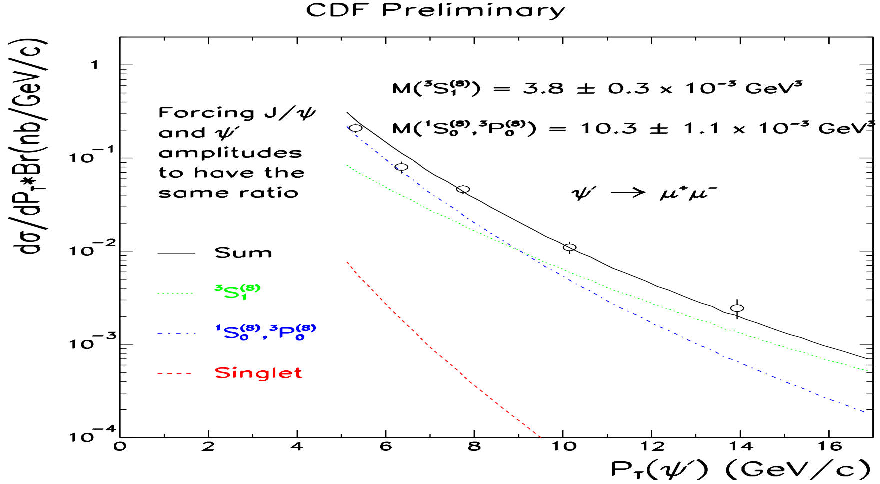


Fragmentation $\Rightarrow$ FS hadrons

Quarkonia production - Theory

Quarkonia bound states are non-relativistic. NRQCD LO perturbative expansion is $\mathcal{O}(\alpha_s^3 v^0)$ as in the color singlet model (CSM) + higher order $\mathcal{O}(\alpha_s^3 v^4)$. Fragmentation processes $\propto$ color octet matrix element dominate.





Direct J/ψ production (Run I) $\qquad$ ψ' production (Run I)

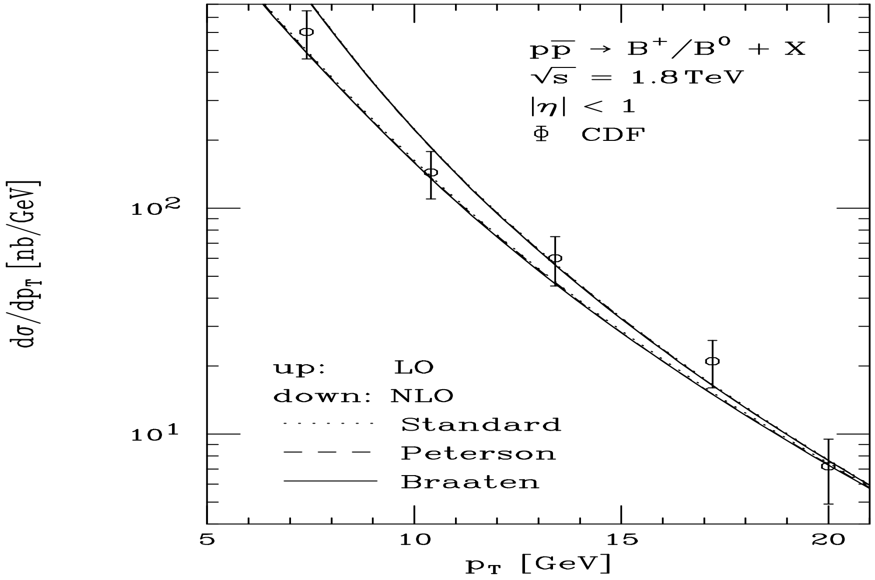
At low p_t, non-fragmentation diagrams from other octet matrix elements are important, soft gluon effects cause rates to diverge.

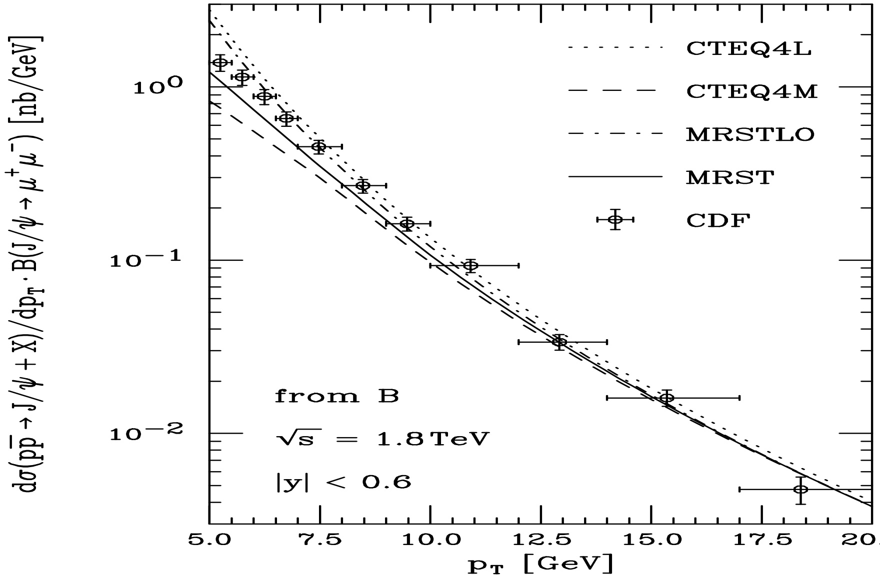
Theory: B Fragmentation functions

Non-perturbative fragmentation functions for B mesons are extracted from LEP data using 3 different parameterizations.

Applied to LO and NLO QCD with $\bar{M}S$ factorization. $\Rightarrow$ *good agreement with CDF Run I data on B meson cross-section.*

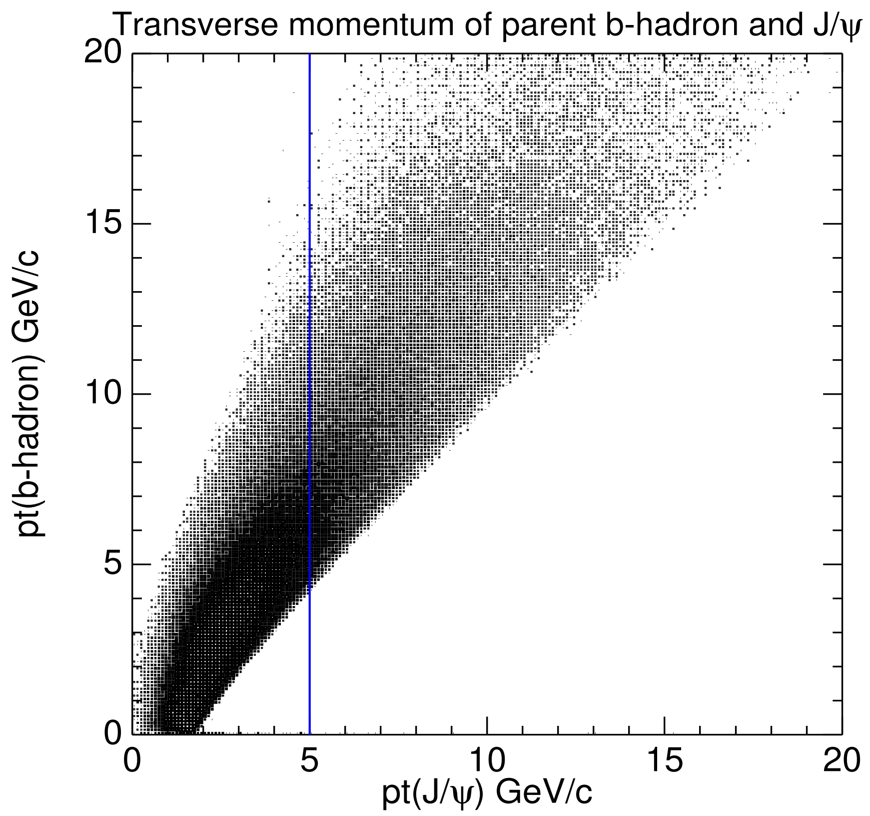
Using the NRQCD factorization scheme: $\Rightarrow$ *good agreement with CDF Run I measurement of J/ψ cross-section from B.*

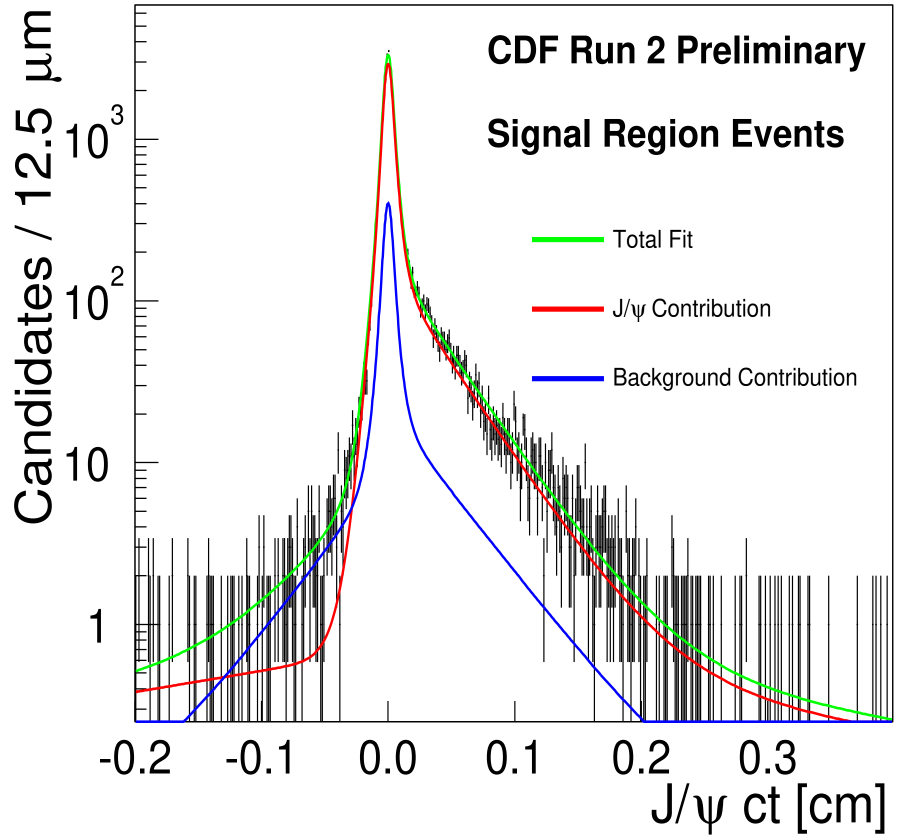




Binnewies, Kniehl, Kramer hep-ph/9802231 (Run I) hep-ph/9901348 (Run I)

b Production - Run II

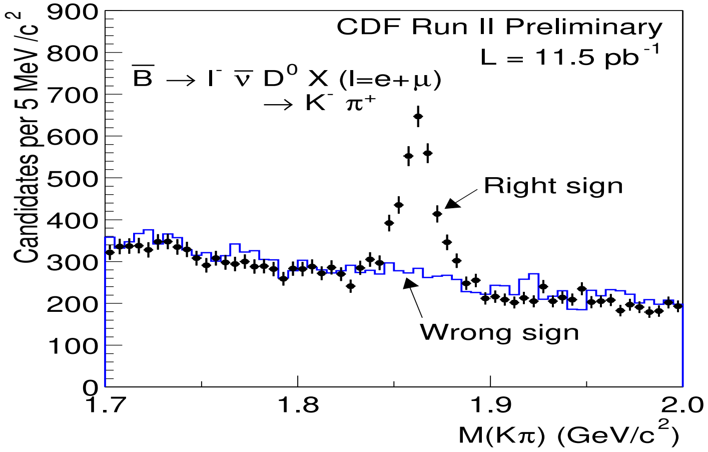


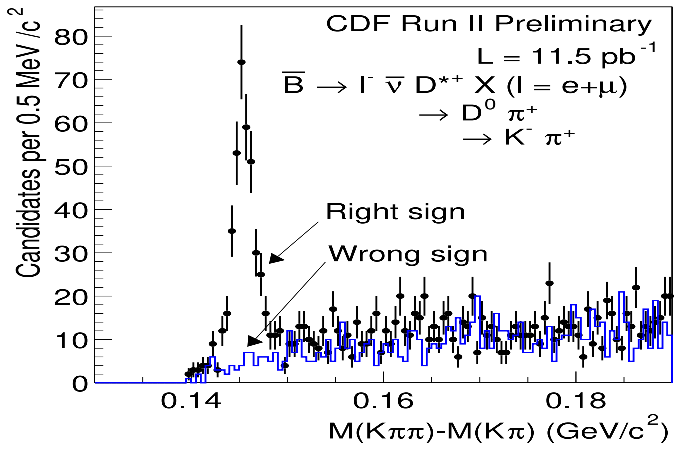


Run II: $p_t(J/\psi) \sim 1.5\text{GeV} \Rightarrow p_t(B) \sim 0!$ *Extract inclusive b-hadron cross-section from* $b \to J/\psi X$ *using long b lifetime*

Lepton+SVT Track trigger Yields

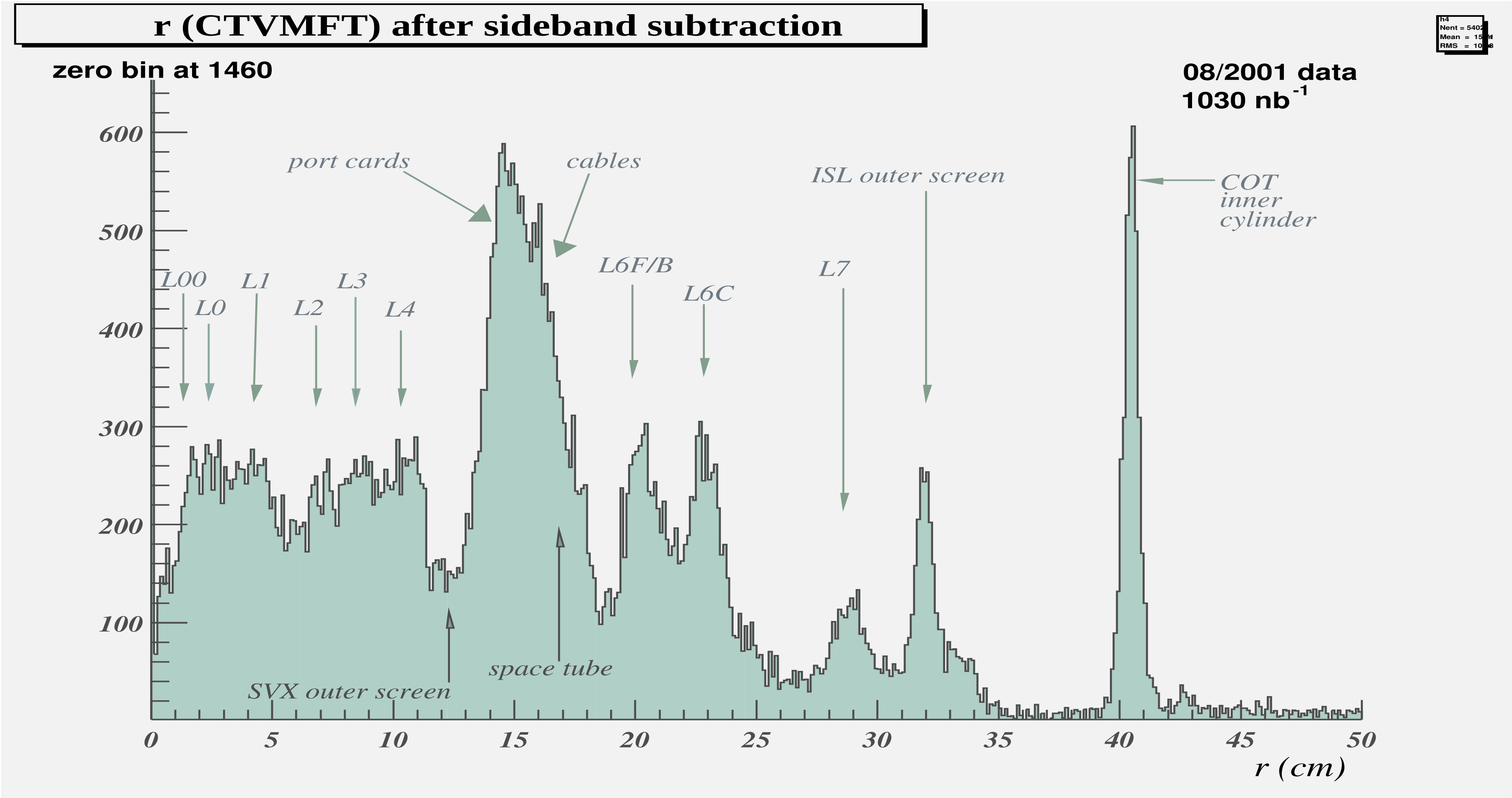
By spring (100 pb^{-1}) CDF will have one of the worlds largest semileptonic B samples from the inclusive Lepton + SVT.





b decay	Expected yield
$b \to \ell + track$	3M
	(> 90% b-purity)
$B \to \ell D^0 X$	20K
	($B^{\pm}$ enhanced)
$B \to \ell D^{*\pm} X$	10 K
	(B^0 enhanced)
$B_s \to \ell D_s X$	1 K
$\Lambda_b \to \Lambda_c \ell \nu$	1 K

SVXII = Lots of Material



From comparison to GEANT MC, we find we are still missing $\sim$ 10% of the SVXII material in the simulation.

Λ_b and heavy baryon lifetimes

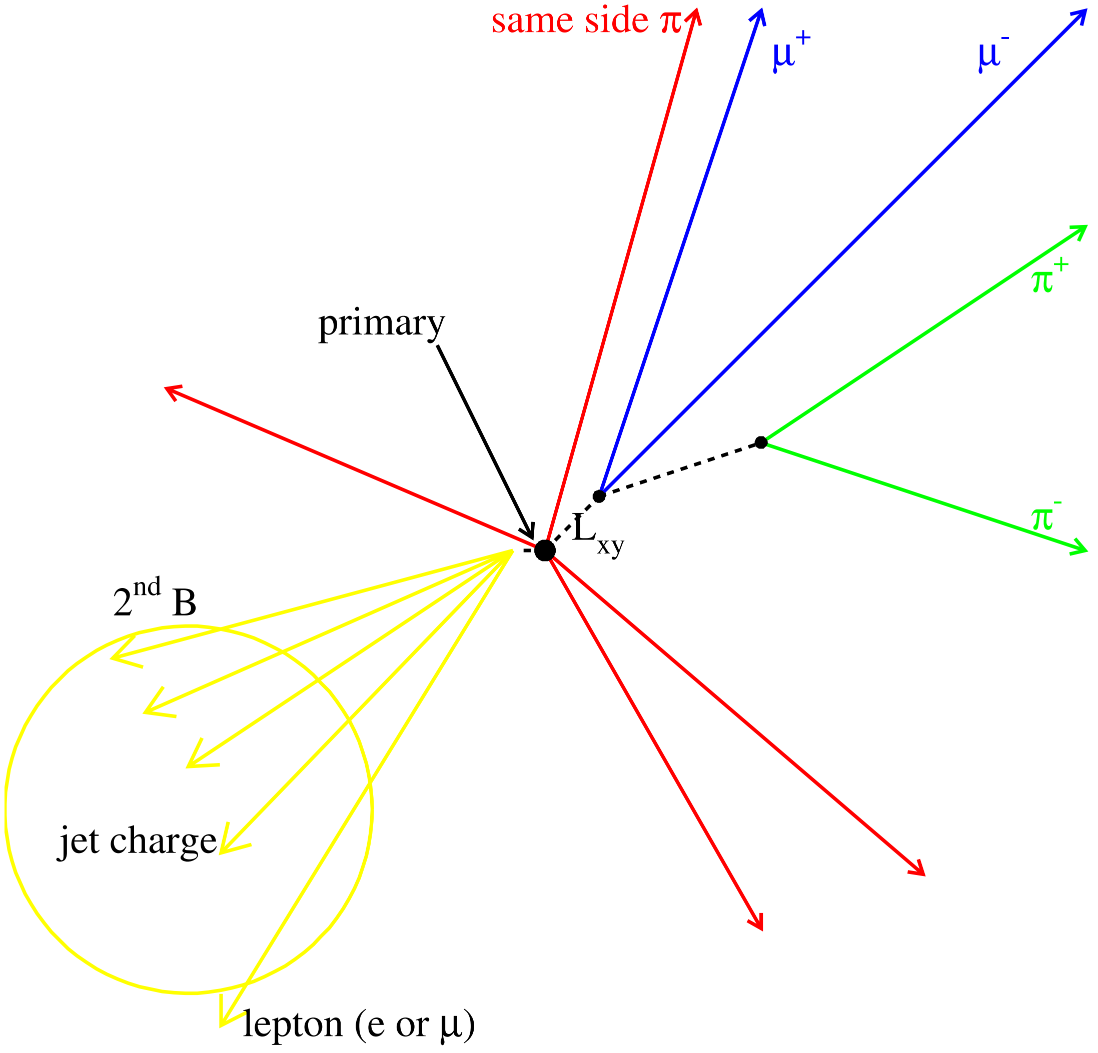
The dominant source of lifetime differences between b-flavored hadrons are weak interactions between the b-quark and the light valence quark of the order $16\pi^2(\bar{\Lambda}/m_b)^3 = \mathcal{O}(5-10\%)$ *in HQET expansions where* $\bar{\Lambda} = M_{H_b} - m_b$. *The lifetime difference of b-hadrons therefore tests HQET expansions at the third order.*

Expect $\frac{\tau(\Lambda_b)}{\tau(B_d)} \sim 0.9$ but measure $\frac{\tau(\Lambda_b)}{\tau(B_d)} = 0.78 \pm 0.05$.

Will new NLO QCD calculations explain the difference between theory and expt.?

Flavor Tagging

Tag B flavor at production:.



RUN II $\sin 2\beta$

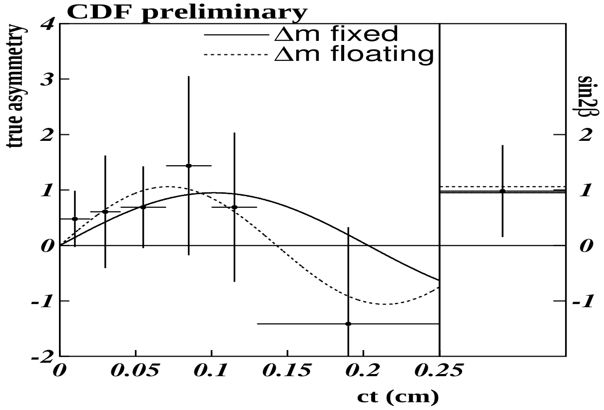
$$D_{ilution} = \frac{N_{Right\ tags} - N_{wrong\ tags}}{N_{Right\ tags} + N_{wrong\ tags}}$$

$$A_{cp}^{observed} = D A_{cp}^{true}$$

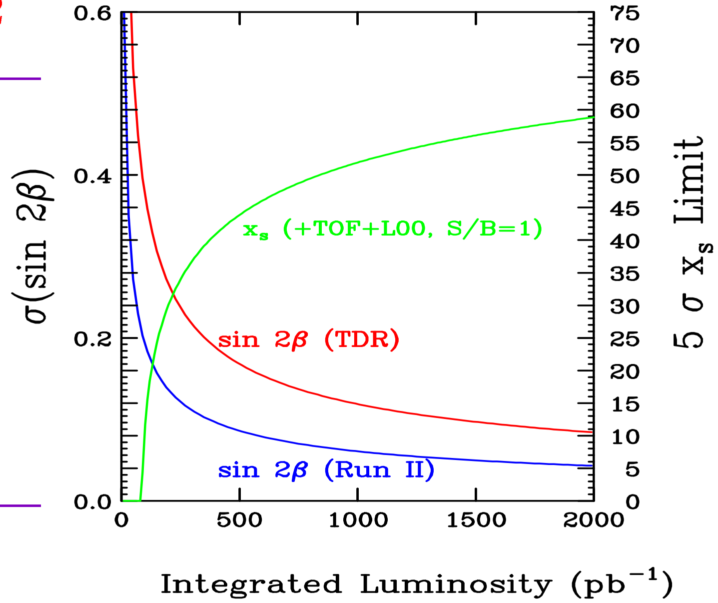
$$\sigma(\sin 2\beta) \sim 1/\sqrt{\underbrace{\epsilon}_{tag\ efficiency} D^2 N_{tot}}$$

Tag	RUN I ϵD^2	RUN II ϵD^2
JetQ	3.0%	3.0%
SLT	1.7%	1.7%
SST(π,K)	(1.4%,1.0%)	(1.9%,4.2%)
OS(K)	-	2.4%
Total (B_d)	6.1%	9.0%

RUN I

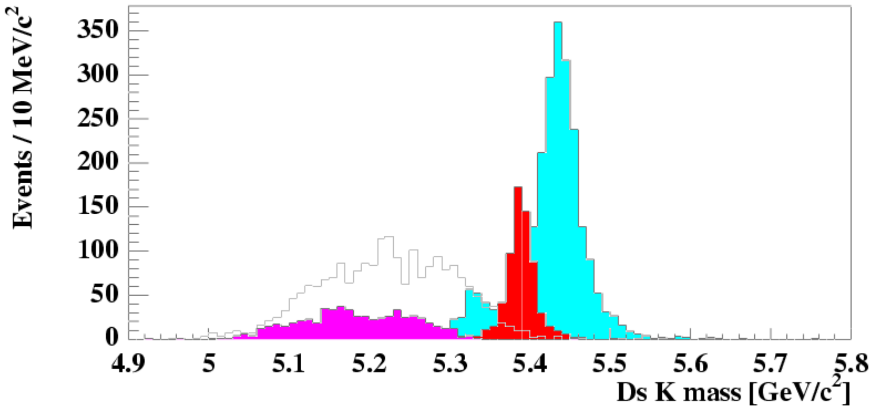


$\sin(2\beta) = 0.91^{+0.37}_{-0.36}$



Measuring $\sin\gamma$

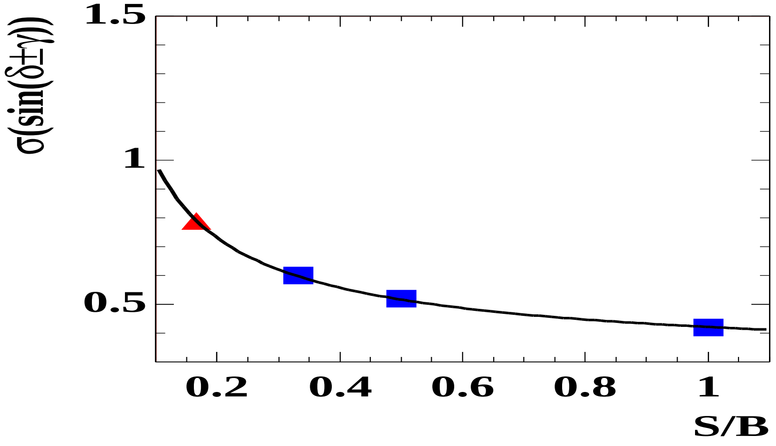
$$\Gamma_{B_s^0 \to D_s^{\mp} K^{\pm}}(t) = A e^{-t}[1 \pm R\cos x_s t \pm \sqrt{1-R^2}\sin(x_s t)\sin(\delta+\gamma)]$$

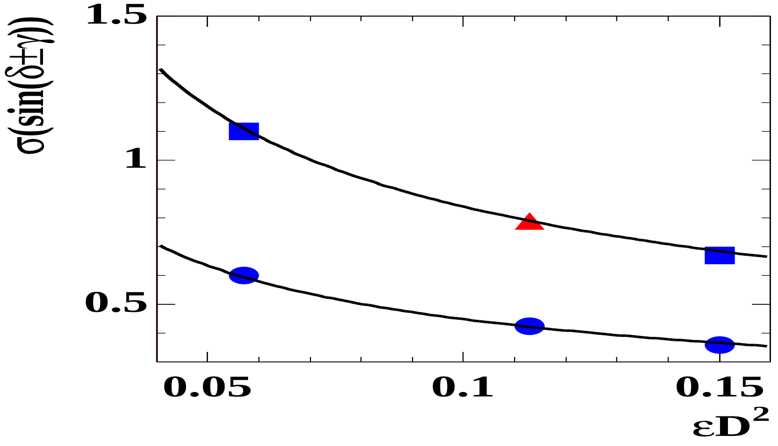


$B_s^0 \to D_s^{\mp} K^{\pm}$ expected yield

and backgrounds:

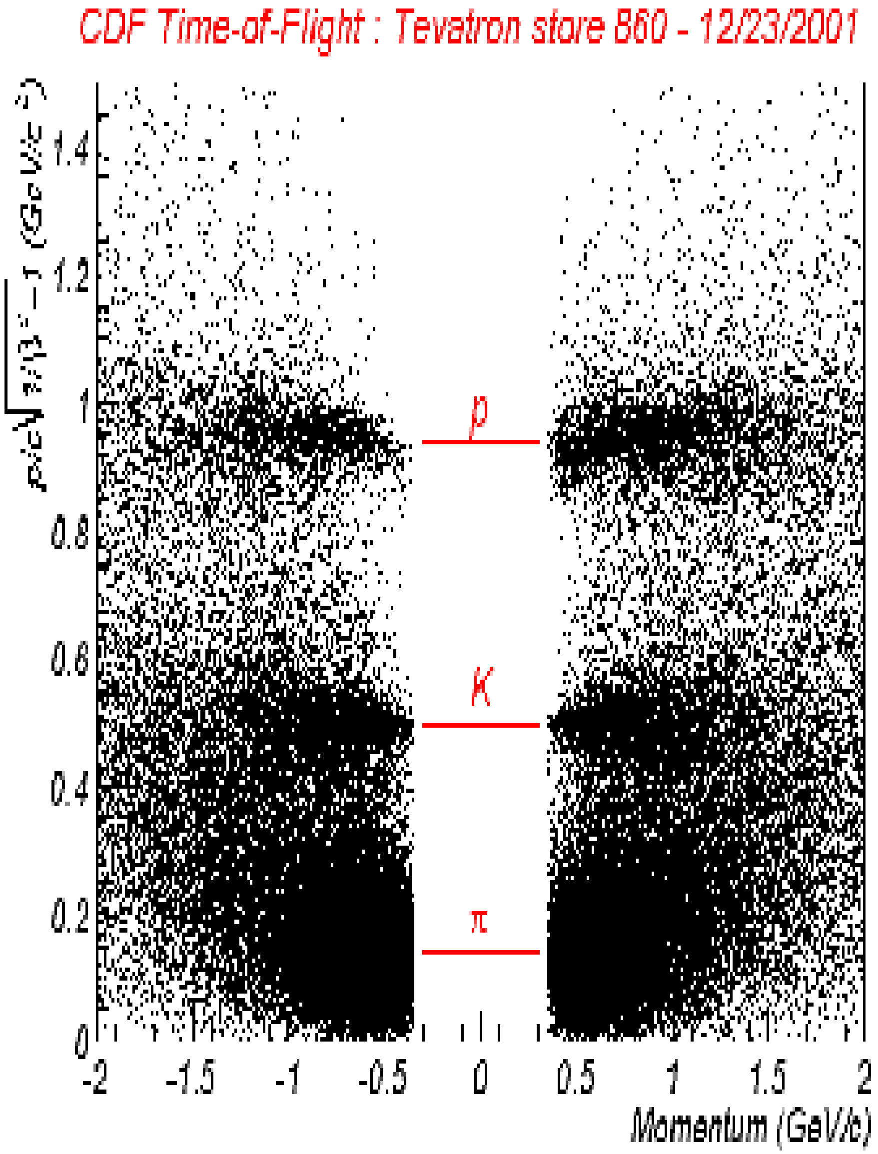
$D_s\pi$ $D_s^* K$ $D_s^*\pi$

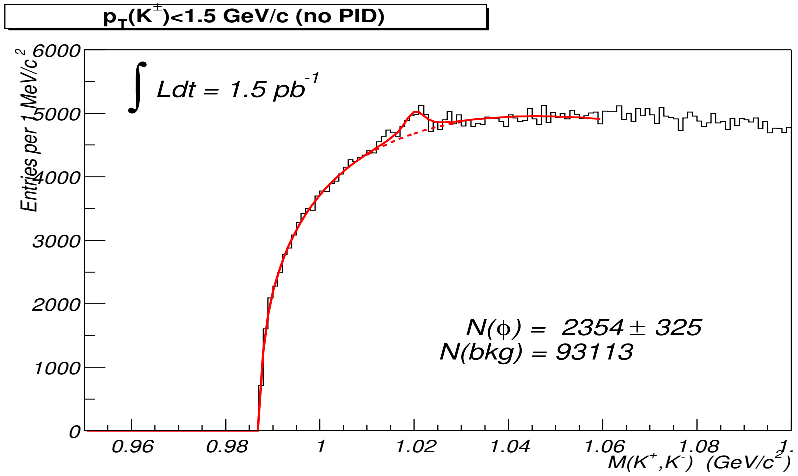




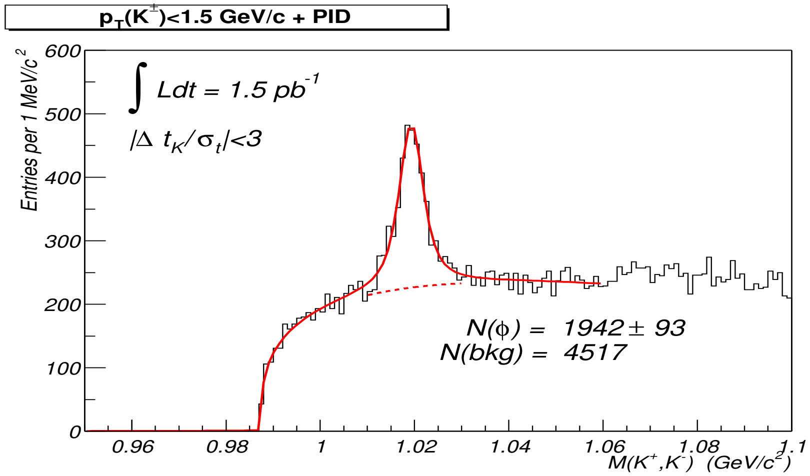
Expected error on $\sin(\delta+\gamma)$

Particle ID: TOF performance



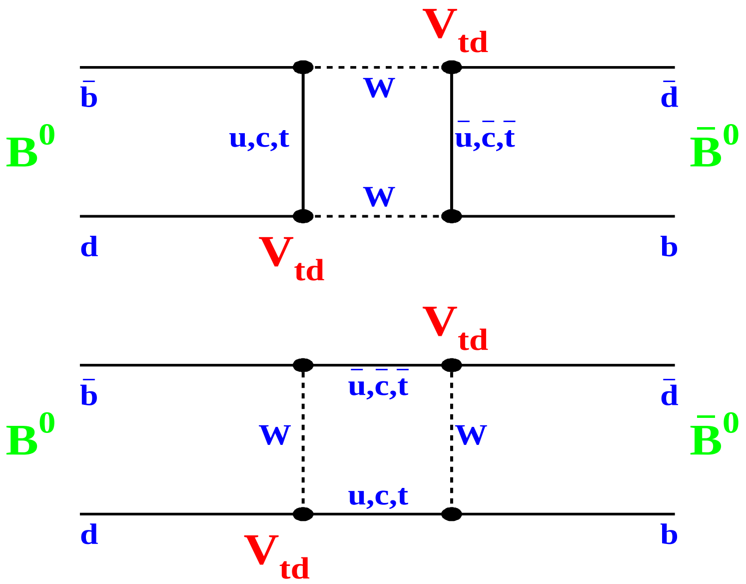


Raw $\phi \to K^+K^-$



$\phi \to K^+K^- +$ TOF

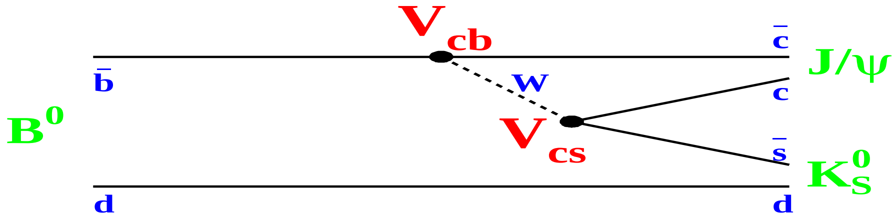
B_d mixing and measuring $\sin 2\beta$

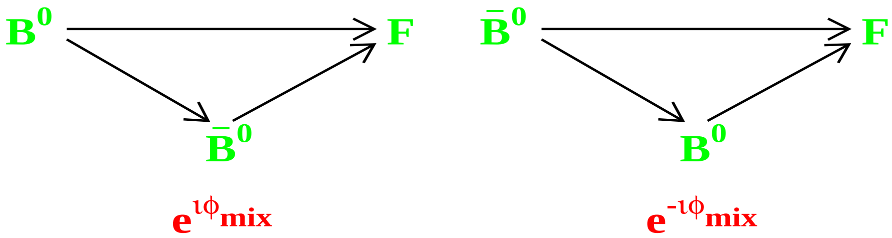


$$B(\bar{B}) \to l^{\pm}X,\ D^{*\mp}l^{\pm}\nu,\ l^{\pm} + jet$$

$$\begin{aligned} A(t) &= \frac{\mathrm{Unmixed}(t) - \mathrm{Mixed}(t)}{\mathrm{Unmixed}(t) - \mathrm{Mixed}(t)} \\ &= \cos(\underbrace{\Delta m_d}_{\mathrm{M_{heavy}} - \mathrm{M_{light}}}\ t) \end{aligned}$$

If $B\bar{B}$ mix AND decay to the same final state $\Rightarrow \not{C}\mathrm{P}$





$$A_{CP} = \frac{\mathrm{N}(\bar{B} \to f) - \mathrm{N}(B \to f)}{\mathrm{N}(\bar{B} \to f) + \mathrm{N}(B \to f)} = \sin(2\beta)\sin(\Delta m_d t)$$

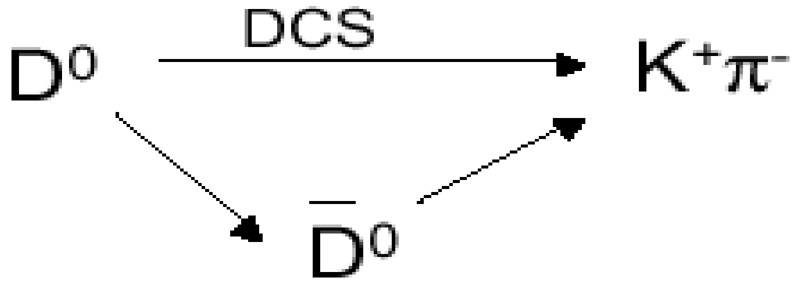
D^0 Mixing

(a) Lifetime difference between CP and non-CP final states

$$y \equiv \frac{\Delta\Gamma}{2\Gamma} = \frac{\tau_{K\pi}}{\tau_{KK,\pi\pi}} - 1$$

$y < 10^{-5}$

(b) Mixing in wrong sign hadronic decays = oscillations.



Expectation for 100 pb^{-1}. Belle/BaBar yield $= 1M/100fb^{-1}$:

Mode	Yield
$D^0 \to K^-\pi^+$	1M
$D^0 \to K^+K^-$	100K
$D^0 \to \pi^+\pi^-$	30K
$D^0 \to K^+\pi^-$ (DCS)	1 K

A_{cp} in $B_s \to J/\psi\phi$ and $B_s \to D_s^+ D_s^-$

Measures weak phase of V_{ts} which is very small in SM. Evidence for anomalous $\not{C}$P *phases if asymmetry is observed.* $B_s \to D_s^- \pi^+$ is $\sim (50:50)$ CP even and odd, $B_s \to J/\psi\phi$ is mixed, $B_s \to D_s^+ D_s^-$ is CP even.