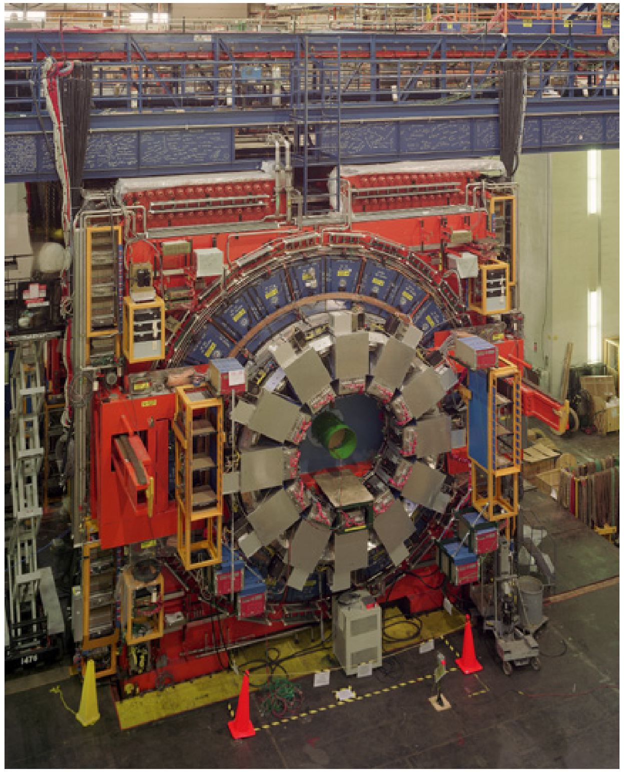
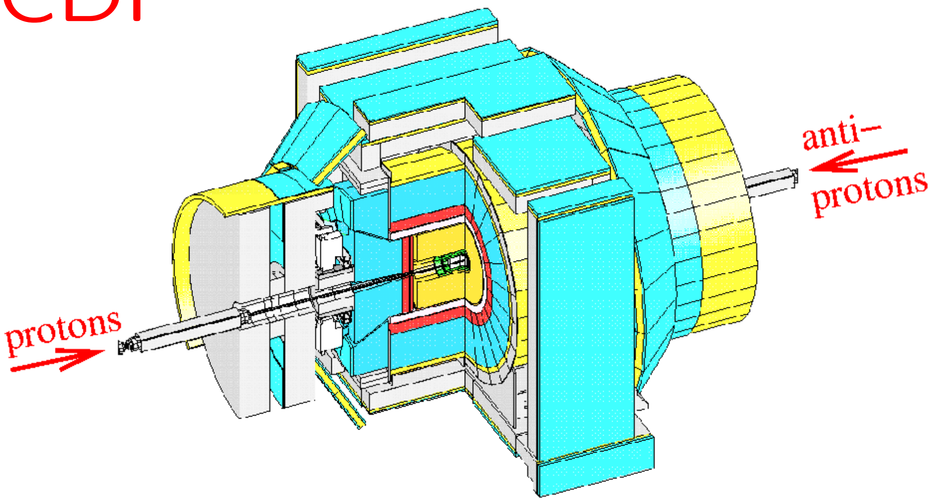
B Physics at CDF

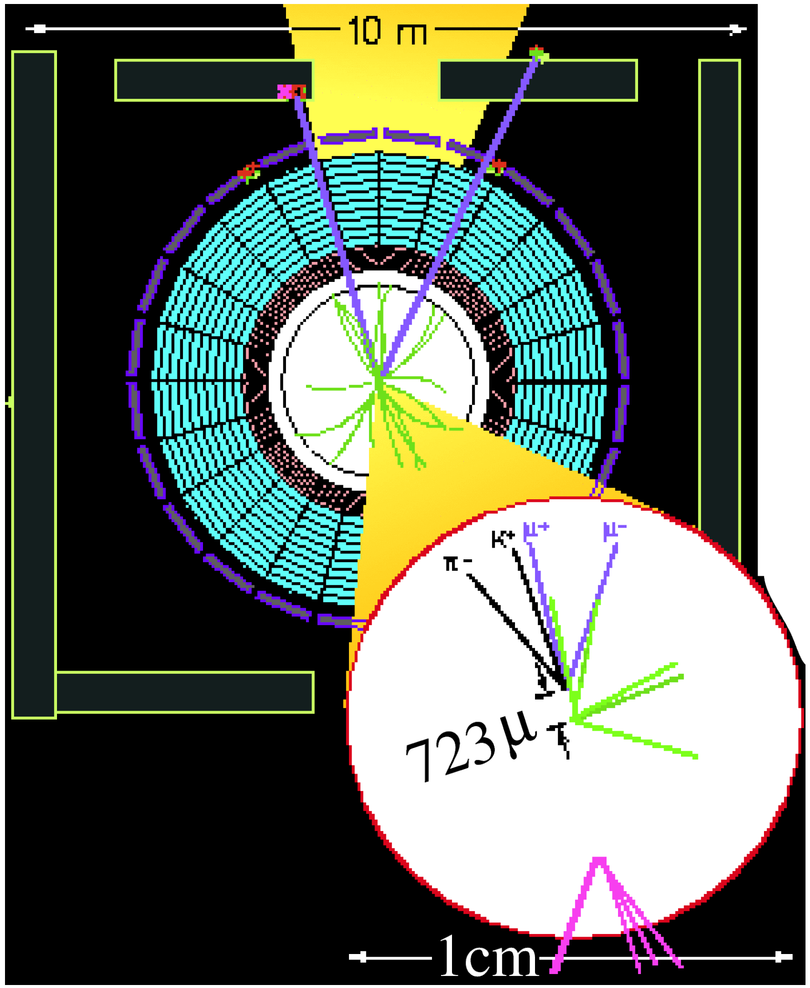
- Decays with 2 muons
- Hadronic B decays
- Something completely different: Pentaquarks



CDF



- New Si microstrip detector
  $\rightarrow$ excellent time resolution
- B triggers include
  - $\mu\mu$ Trigger: finds $B \rightarrow J/\psi X$
  - Displaced Track Trigger: finds B's (and charm)!

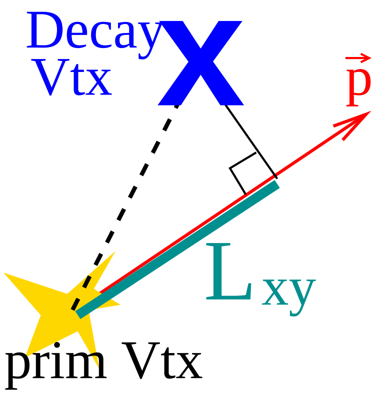


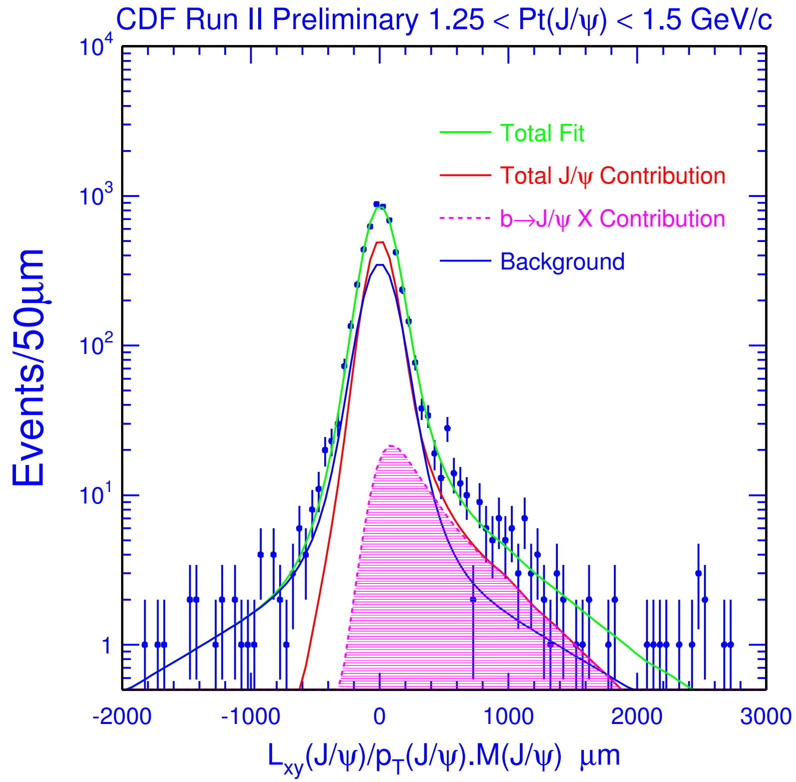
$B_d \rightarrow J/\psi K^*$ event at CDF

Measured b X-sections at CDF:

Extract b-fraction in J/$\psi(\mu\mu)$ data from fit to L_{xy}

L_{xy} = projection of decay distance onto $\vec{p}$.





J/ψ from B's have long, positive L_{xy}, prompt J/ψ symmetric, centered on 0.

$$\sigma(p\bar{p} \rightarrow \bar{b}X|y| < 1.0) = 29.4 \pm 0.6 \pm 6.2\,\mu b$$

Lifetime (ratios) and Heavy Quark Expansion

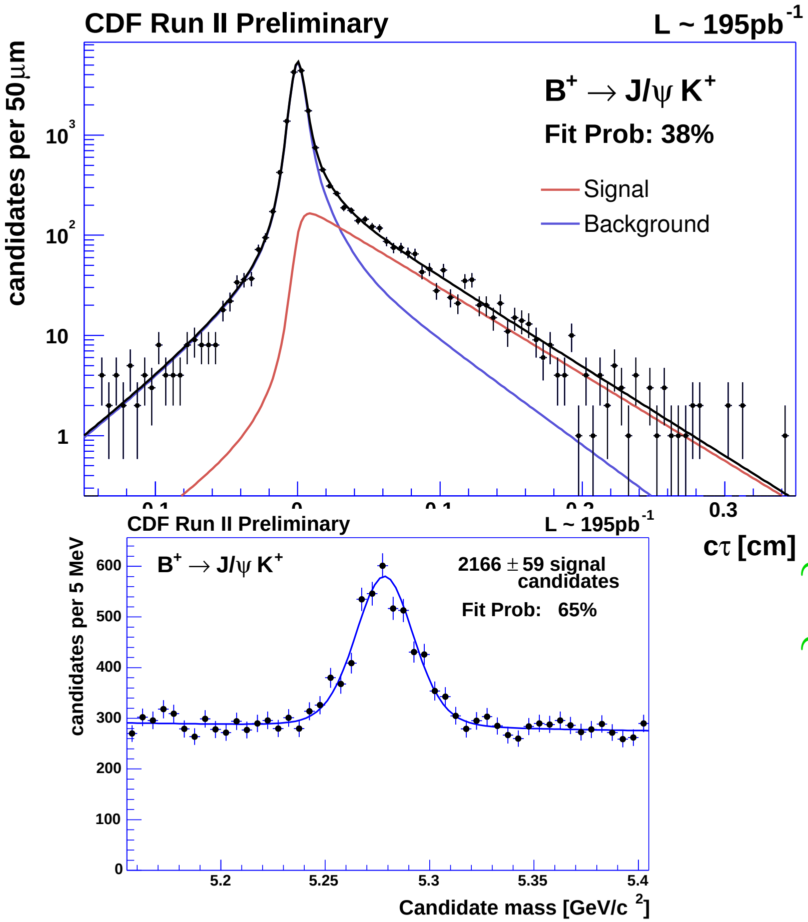
- HQE frequently used to relate measurements to CKM parameters e.g. B.R. of $B \to \ell\nu X$ to $|V_{cb}|$, $|V_{ub}|$ (see talks this morning).
- Need to be sure this tool works!
- HQE gives precise predictions for B-hadron lifetime ratios - good testing ground.

HQE predictions for B lifetimes

$$\tau(\mathrm{B_c}) \ll \tau(\Xi_b^0)$$
$$\sim \tau(\Lambda_\mathrm{b}) < \tau(\mathrm{B_d^0}) \sim \tau(\mathrm{B_s^0}) < \tau(\mathrm{B^-})$$
$$< \tau(\Xi_\mathrm{b}^-) < \tau(\Omega_\mathrm{b})$$

- $\tau(\mathrm{B^-})/\tau(\mathrm{B_d^0}) = 1.067 \pm 0.027$
- $\tau(\mathrm{B_s})/\tau(\mathrm{B_d^0}) = 0.998 \pm 0.015$
- $\tau(\Lambda_\mathrm{b})/\tau(\mathrm{B_d^0}) = 0.9 \pm 0.05$

Lifetimes in $\mu\mu$ Trigger $B \to J/\psi(\mu\mu)X$ *fully reco'ed*



- Resolution: Evt-by-evt Gauss.
- Signal: exp $\otimes$ Gauss.
- Bckg model: (prompt + 1 negative and 2 positive exp) $\otimes$ Gauss.
- Use mass fit for evt-by-evt S/B.
- Unbinned fit with $\mathcal{L} = \mathcal{L}(\tau, \text{mass})$

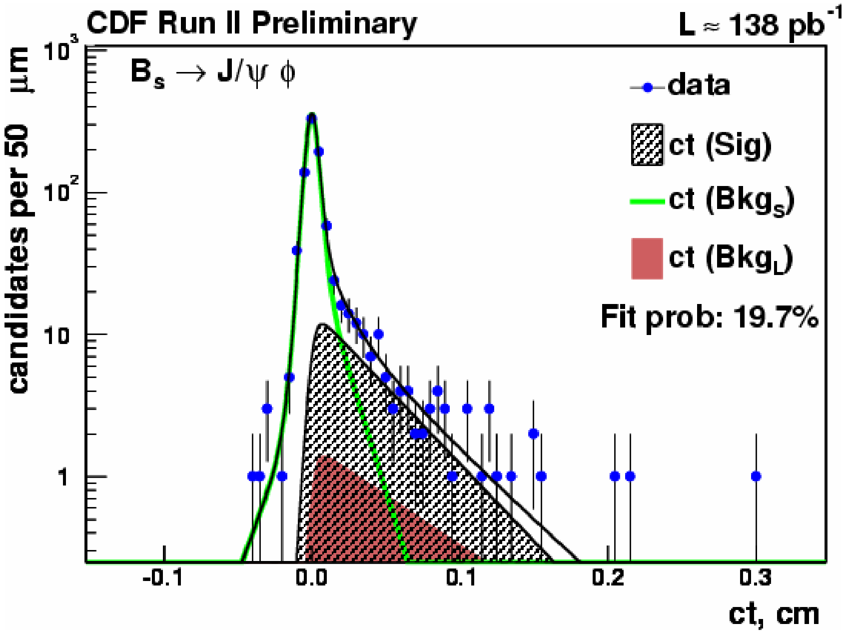
$\sim 2.4\,\text{k}\ B^+ \to J/\psi K^{(*)+}$

$\sim 1.6\,\text{k}\ B^0 \to J/\psi K^{(*)0}$, $195\,\text{pb}^{-1}$

- $\tau_{B+} = 1.66 \pm 0.04 \pm 0.02\,\text{ps}$
- $\tau_{B^0} = 1.49 \pm 0.05 \pm 0.03\,\text{ps}$
- $\tau_{B+}/\tau_{B^0} = 1.12 \pm 0.046 \pm 0.014$

Lifetime $B_s \to J/\psi\phi$ B $\to J/\psi(\mu\mu)X$ *fully reco'ed*

Result for $138\,\text{pb}^{-1}$

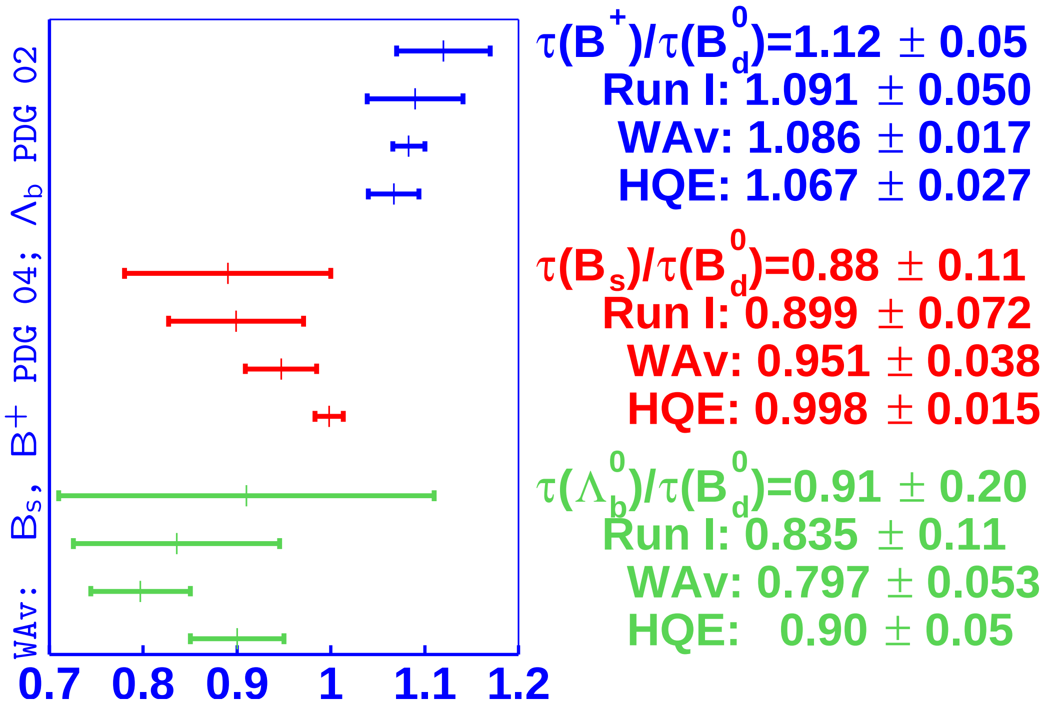


- $\tau_{B_s} = 1.33 \pm 0.14 \pm 0.02\,\text{ps}$
- $\tau_{B_s}/\tau_{B^0} = 0.88 \pm 0.11(\text{stat})$
- `Note: Measurement dominated by CP-even component`

- Comes in 3 angular momentum states, 2 CP-even, 1 CP-odd.
- Can be disantangled by angular analysis. $\Rightarrow$ measure $\Delta\Gamma_s$.
- ...with more statistics.

CDF Run II Results: Lifetime Ratios (prelim)

$B_u^+ \to J/\psi(\mu^+\mu^-)K^{(*)+}$, $B_d^0 \to J/\psi(\mu^+\mu^-)K^{(*)0}$, $B_s^0 \to J/\psi(\mu^+\mu^-)\phi$, $\Lambda_b \to J/\psi(\mu^+\mu^-)\Lambda$



Run II B^+/B_d from $195\,pb^{-1}$

Run II B_s/B_d from $138\,pb^{-1}$

Run II Λ_b/B_d from $65\,pb^{-1}$

Run I results: all channels combined. Run II (here): fully reconstructd $J/\psi(\mu\mu)X$ only.

Approaching Run I precision. Tevatron-specific: B_s and Λ_b llifetimes.

Run IIa will provide real test of HQE.

Search For $B_s \to \mu^+\mu^-$, $B_d \to \mu^+\mu^-$

High Sensitivity to New Physics

SM BR $\sim 10^{-9}$

Many extension of SM (mSUGRA, SO(10)) predict enhancements by several orders of magnitude.

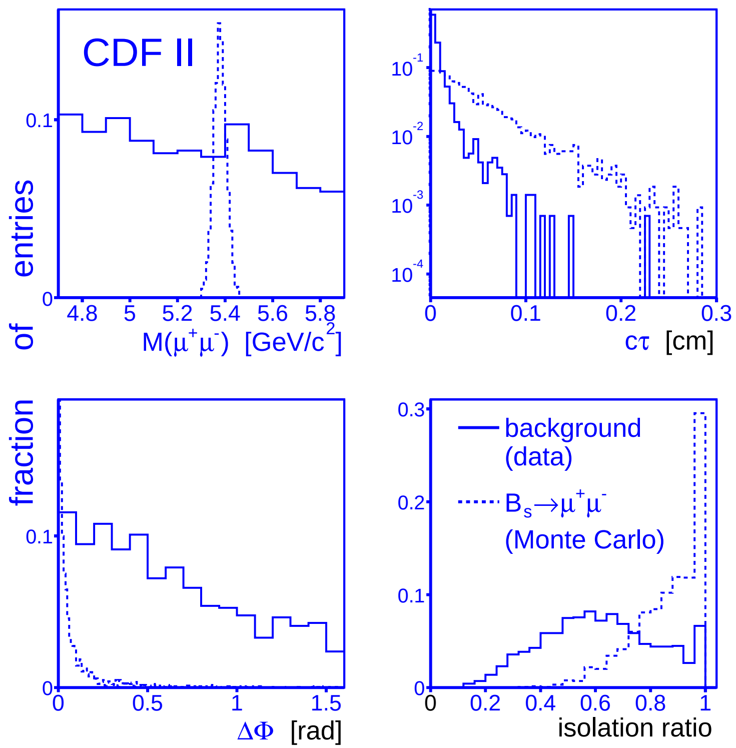
- Observation $\Rightarrow$ New Physics.
- Else: Exclude some theories.

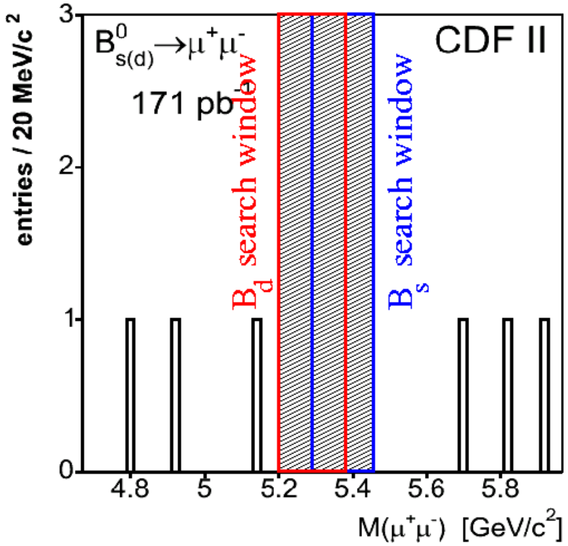
For example mSUGRA

- $\mathrm{BR}(B_s \to \mu^+\mu^-)$
  $\approx 10^{-6} \tan^6 \beta \frac{M_{1/2}^2 \mathrm{GeV}^4}{(M_{1/2}^2 + M_0^2)^3}$
- Connection to $a_\mu = \frac{(g-2)_\mu}{2}$:
  $\delta a_\mu \mathrm{SUSY} = a_\mu \mathrm{SUSY} - a_\mu \mathrm{SM}$
  $\propto \tan \beta \frac{f(M_0)}{M_{1/2}^2}$

`Dedes, Dreiner, Nierste, 2001, hep-ph/010827`

Search For $\mathrm{B_s} \to \mu^+\mu^-$, $\mathrm{B_d} \to \mu^+\mu^-$





Predicted Bg in search windows:

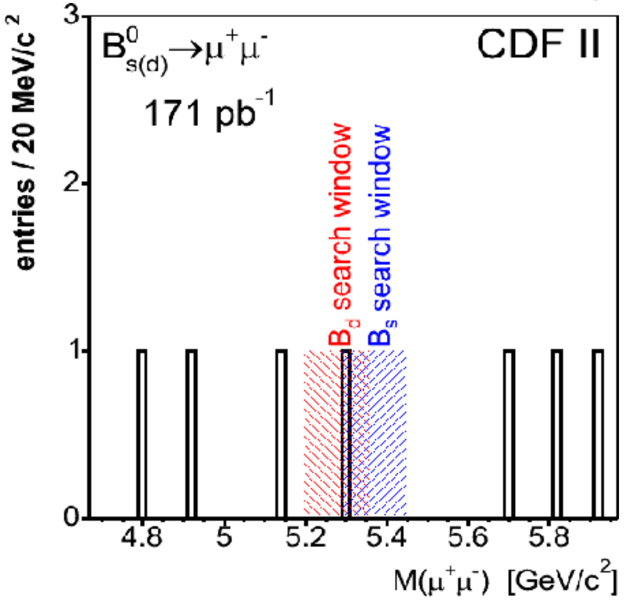
$\mathrm{B_d}$: 1.05 ± 0.30
$\mathrm{B_s}$: 1.07 ± 0.31
$\Big\}$ 1.75 ± 0.34

$\mathrm{Bkg} = N(c\tau, \Delta\Phi) \cdot R(\mathrm{Iso}) \cdot R(\mathrm{mass})$

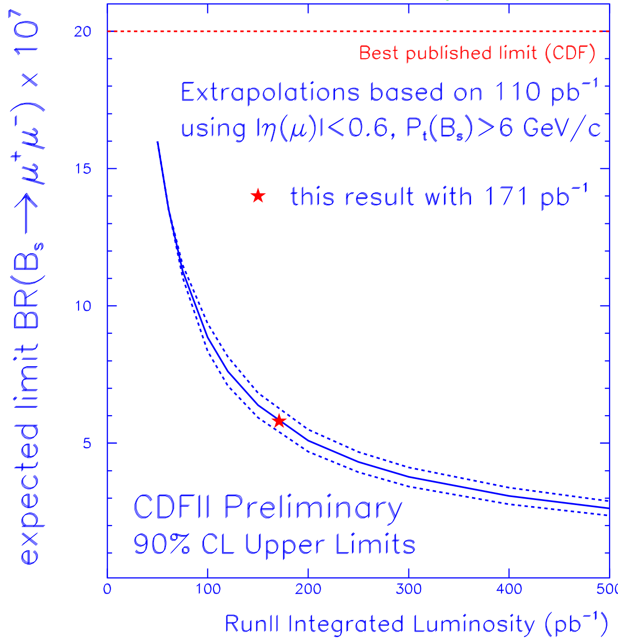
X-check Bg-predictions in $\mu^+\mu^+$, $\mu^-\mu^-$ and ($\mu^+\mu^-$ with $c\tau < 0$). Then unblind.

Search For $B_s \to \mu^+\mu^-$, $B_d \to \mu^+\mu^-$ in $171\,\mathrm{pb}^{-1}$

Result: 1evt in overlap region



Limit vs Lumi up to $0.5\,\mathrm{fb}^{-1}$



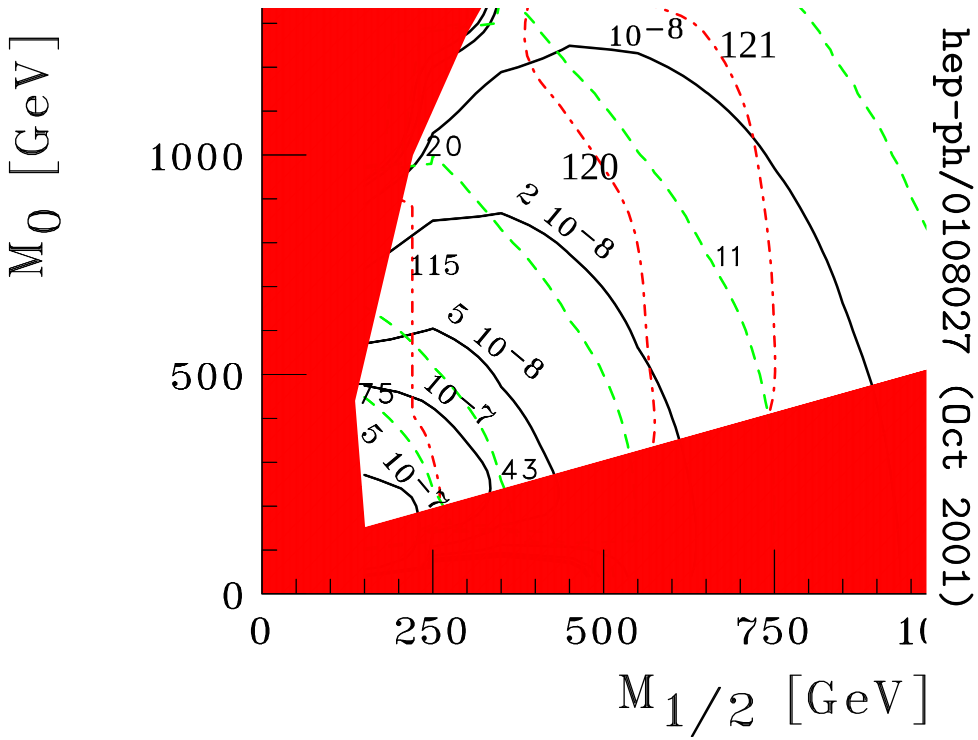
Projection without anticipated improvement in μ coverage.

$\mathrm{BR}(B_d \to \mu^+\mu^-) < 1.5 \cdot 10^{-7}$ (90%CL)

$\mathrm{BR}(B_s \to \mu^+\mu^-) < 5.8 \cdot 10^{-7}$ (90%CL)

Prev. best limits: B_d: $1.6 \cdot 10^{-7}$ (BELLE 2003) B_s: $2 \cdot 10^{-6}$ (CDF Run I)

$B_s \to \mu\mu$, $(g-2)_\mu$, and mSUGRA.



Black BR($B_s \to \mu\mu$).
Green $\delta a_\mu / 10^{-10}$
Red Mass of (lightest) Higgs (GeV)

For $\tan\beta = 50$ $A_0 = 0$, $\mu > 0$,
$m_t = 175$ GeV

Inching into the allowed parameter space of mSUGRA.

Displaced Track Trigger

Trigger

- 3 Level Trigger: 2.5 MHz$\rightarrow$ L1 $\rightarrow$ 15 kHz $\rightarrow$ L2 $\rightarrow$ 300 Hz $\rightarrow$ L3$\rightarrow$ 50 Hz $\Rightarrow$ throw away 99.998% of all events.

- Need to make sure that those 0.002% we keep are carefully selected.

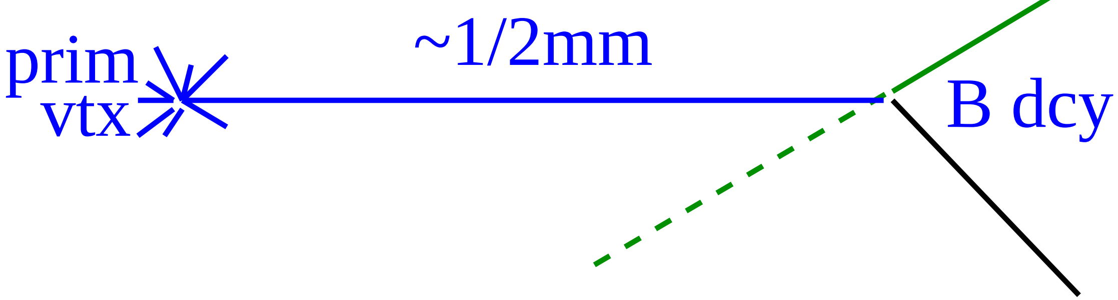
B Trigger

- Traditionally: Trigger on $\ell(e, \mu)$. Works well - see results on previous slides.

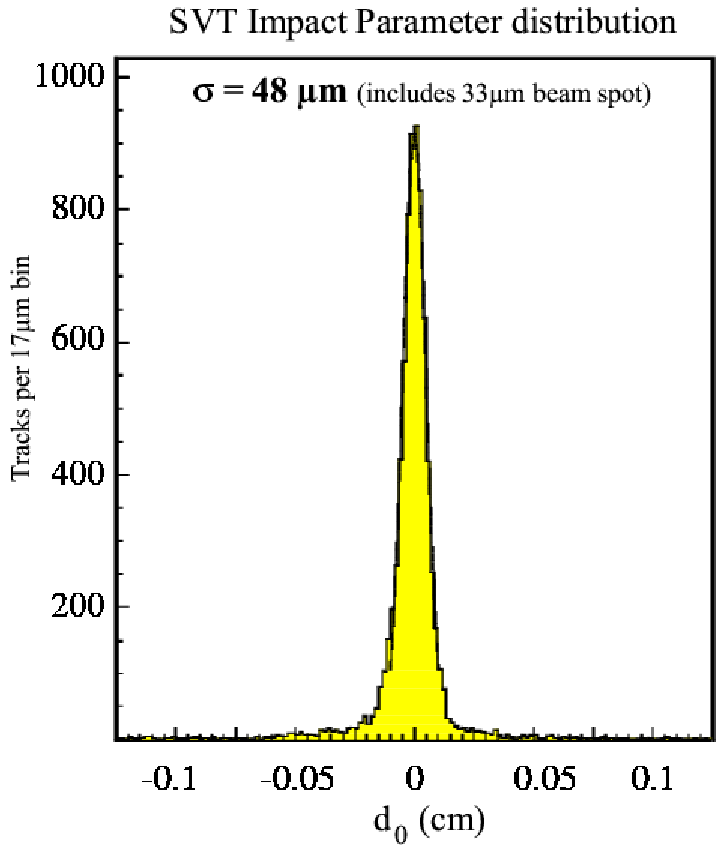
- Excludes important B decays, like $B_d^0 \rightarrow \pi^+\pi^-$.

- Run 2: First time in a hadron collider: Use "long" B lifetime.

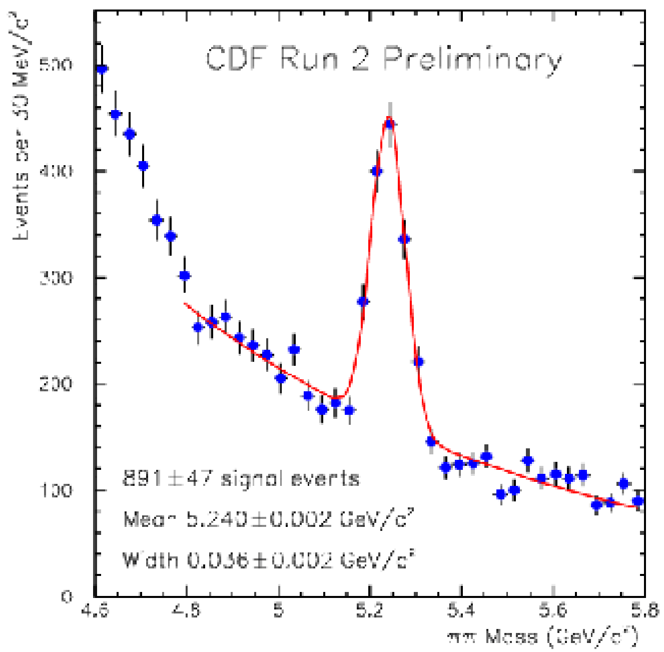
  Trigger on Impact Parameter at L 2 (2 tracks, IP $> 100\,\mu$).



Displaced Track Trigger

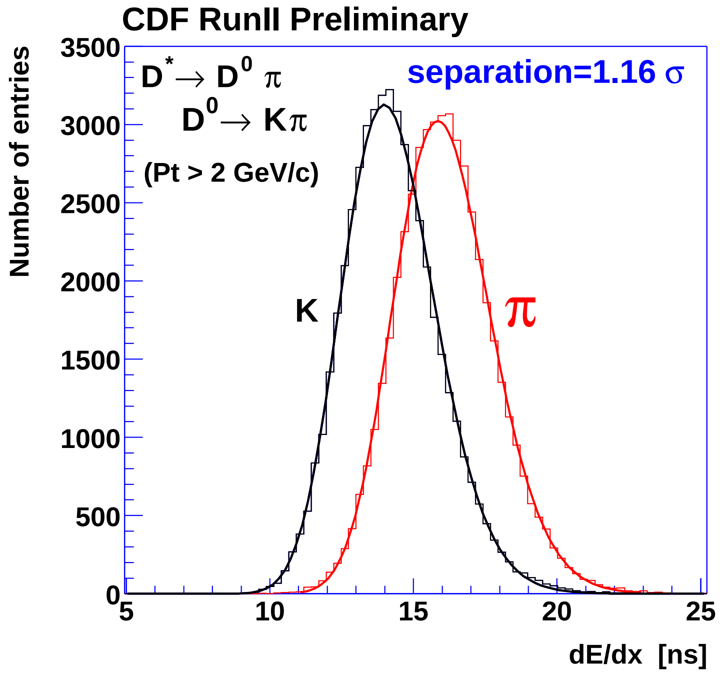


900 B → hh events for 190 pb^{-1}
($B_d^0 \to \pi\pi$, $B_s^0 \to KK$, etc)

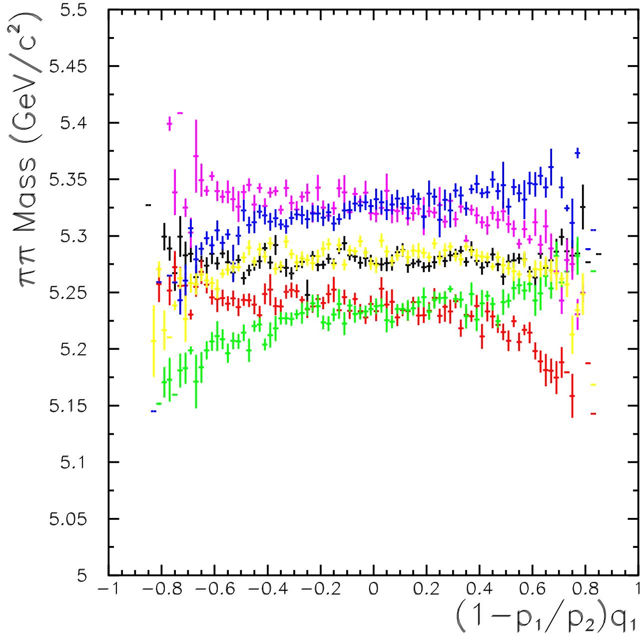


Disentangling $B \to hh$

Challange: Separate $B_d^0 \to \pi\pi$, $B_s^0 \to KK$ *and other* $B \to hh$



1.16σ K/π sep. from $\frac{dE}{dx}$ (Data)



$B_d \to \pi\pi$

$B_s \to KK$

$B_d \to K\pi$

$\bar{B}_d \to K\pi$

$B_s \to K\pi$

$\bar{B}_s \to K\pi$

Mass vs $(1 - p_1/p_2) \cdot Q_1$.
(Monte Carlo)

$B^0_d \to$ hh Results for 65 pb^{-1}, and prospects

- First observation of $B_s \to KK$: 90 ± 24 out of 300 $B \to hh$ events (65 pb^{-1}).

- Search for $C\!\!\!/P$ in time-integr. rates
$$A_{CP} = \frac{\Gamma(\bar{B}^0_d \to K^-\pi^+) - \Gamma(B^0_d \to K^+\pi^-)}{\Gamma(\bar{B}^0_d \to K^-\pi^+) + \Gamma(B^0_d \to K^+\pi^-)}$$
$$= 0.02 \pm 0.15 \pm 0.017$$

- $\frac{\Gamma(B^0_d \to \pi^+\pi^-)}{\Gamma(B^0_d \to K^\pm\pi^\mp)} = 0.26 \pm 0.11 \pm 0.06$
$\frac{\Gamma(B^0_s \to K^+K^-)}{\Gamma(B^0_s \to K^\pm\pi^\mp)}$
$= 2.71 \pm 0.73 \pm 0.35(f_s/f_d) \pm 0.81$

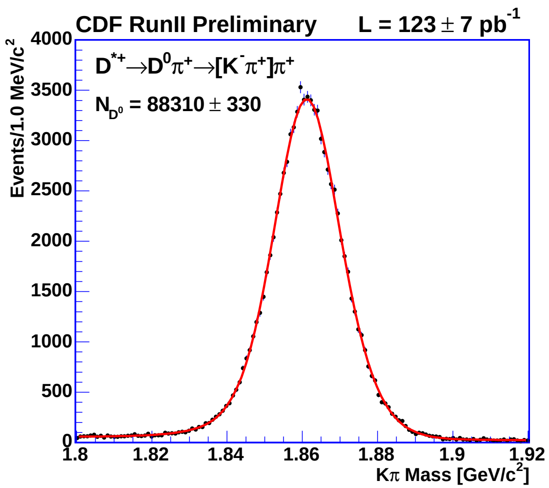
- Analysed $\sim$ 3$\times$ as much data $\to$ Improved results, soon.

- Long term: Time dependent decay rate asymmetries in $B_d \to \pi\pi$ and $B_s \to KK$ allow extraction of $C\!\!\!/P$ phase γ.

Loads of Charm - $D^0 \to hh$

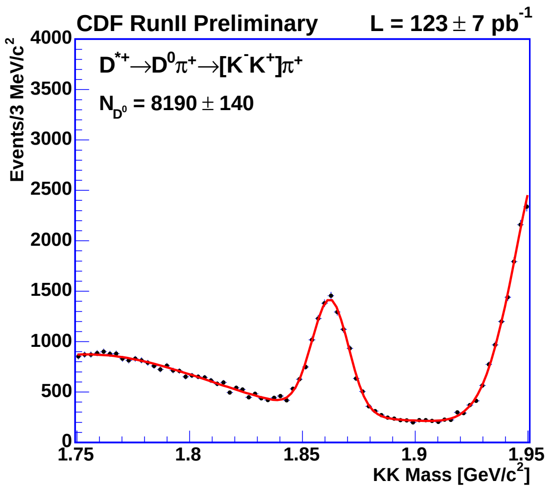
D^0 *from* $D^{*+} \to D^0\pi$*: Clean signal, distinguish* D^0, $\bar{D}^0$. For 123 pb^{-1}

$D^{*+} \to D^0(K^-\pi^+)\pi^+$



$88.3\,\mathrm{k} \pm 0.3\,\mathrm{k}$

$D^{*+} \to D^0(K^+K^-)\pi^+$



$8.19\,\mathrm{k} \pm 0.14\,\mathrm{k}$

- $A_{CP\,KK} = \dfrac{\Gamma(\bar{D}^0 \to K^+K-) - \Gamma(D^0 \to K^+K^-)}{\Gamma(\bar{D}^0 \to K^-K^+) + \Gamma(D^0 \to K^+K^-)}$

  $= 2.0\% \pm 1.2\% \pm 0.6\%$

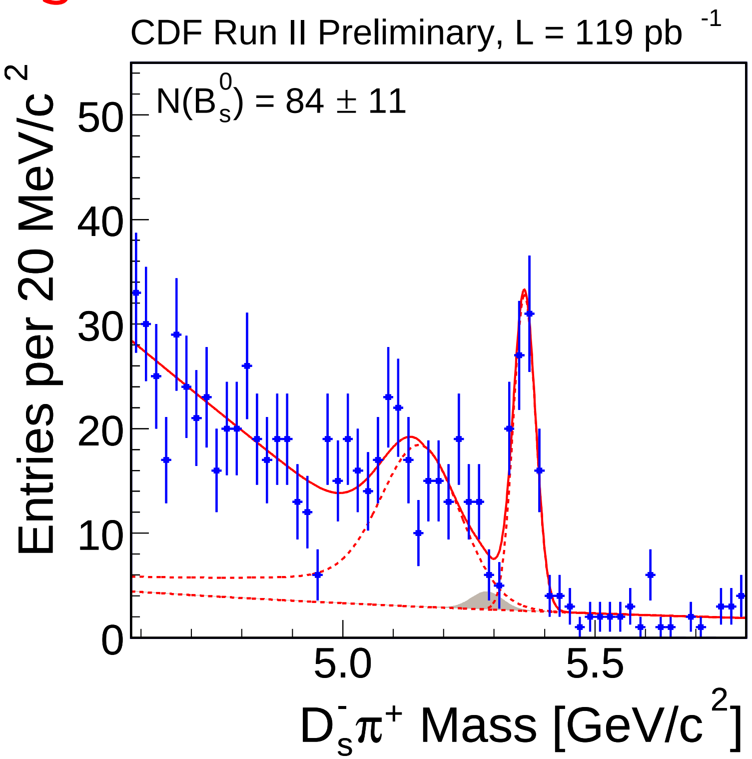
- $A_{CP\,\pi\pi} = \dfrac{\Gamma(\bar{D}^0 \to \pi^+\pi-) - \Gamma(D^0 \to \pi^+\pi^-)}{\Gamma(\bar{D}^0 \to \pi^-\pi^+) + \Gamma(D^0 \to \pi^+\pi^-)}$

  $= 1.0\% \pm 1.2\% \pm 0.6\%$

$\dfrac{\Gamma(D^0 \to K^+K^-)}{\Gamma(D^0 \to K^\pm\pi^\mp)} = 9.96\% \pm 0.11\% \pm 0.12\%$ $\quad \dfrac{\Gamma(D^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to K^\pm\pi^\mp)} = 3.608\% \pm 0.054\% \pm 0.12\%$

$\dfrac{\Gamma(D^0 \to K^+K^-)}{\Gamma(D^0 \to \pi^+\pi^-)} = 2.762\% \pm 0.040\% \pm 0.034\%$

$B_s^0 \to D_s\pi$



- Flavour eigenstate
- No missing momentum (unlike $B_s^0 \to D_s \ell\nu$), good time resolution ($\sigma(\tau)$ in topol. similar decays: 67 fs). Needs hadron trigger.
- CDF's "golden mode" for mixing.
- 80 $B_s^0 \to D_s(\phi\pi)\pi$ evt for $119\,\mathrm{pb}^{-1}$, $S/B \sim 2$. Note: efficiency improved. Now $\sim 1.6\,\mathrm{evts/pb}^{-1}$.

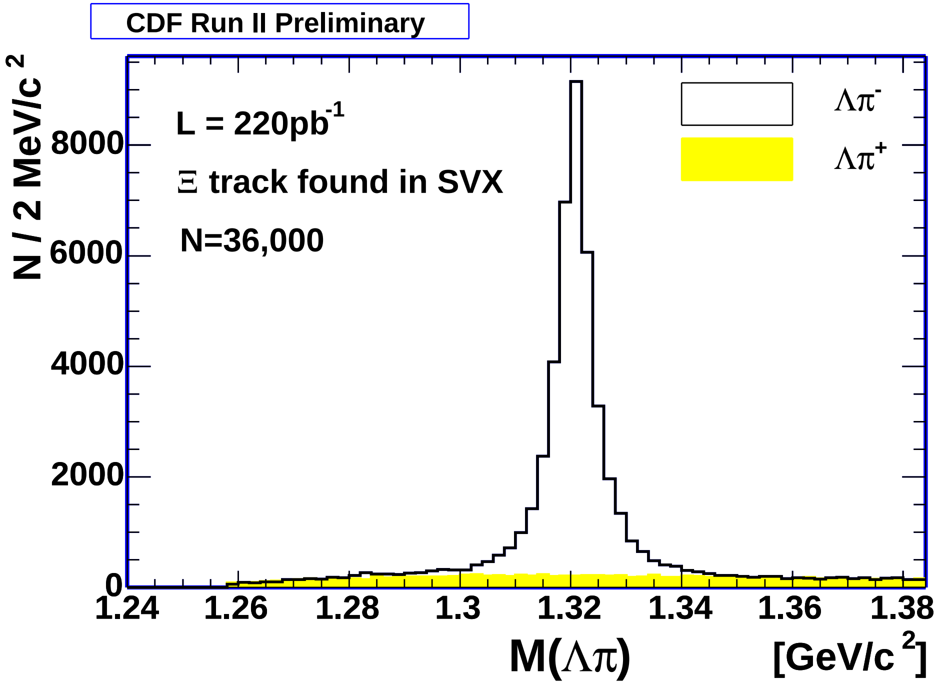
No B_s mixing result, yet. B.R. instead:

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

Pentaquarks

Looking for $\Xi^0(1860) \rightarrow \Xi^-\pi^+$ and $\Xi^{--} \rightarrow \Xi^-\pi^-$ with $\Xi^- \rightarrow \Lambda(p\pi)\pi^-$, found by NA49 (hep-ex/0310014)

1^{st} Step: Ξ^- reconstruction



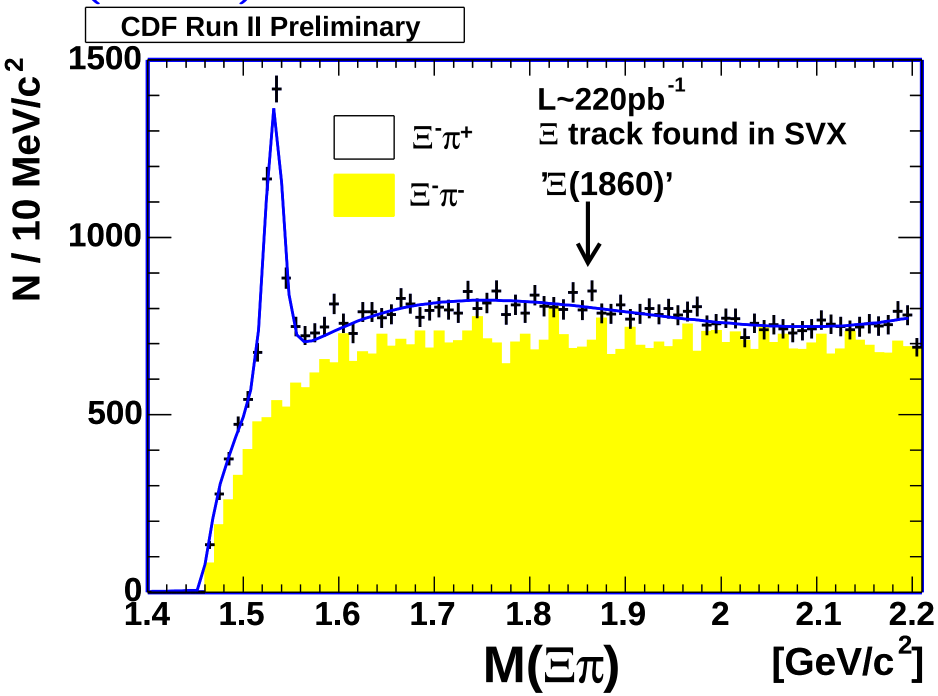
- Ξ^- is very long lived - yet another job for the displaced track trigger. Find 36,000 Ξ^-.

- Ξ^- lives long enough to leave hits in Si Detector. Requiring hits from the Ξ^- in the Si provides extremely clean Ξ^- signal.

Pentaquarks Looking for $\Xi(1860) \to \Xi^-\pi^\pm$

2^{nd} Step: Combine Ξ^- with $\pi^\pm$

Normalise by known $\Xi^0(1530) \to \Xi^-\pi^+$.



- Don't see any $\Xi(1860)$
- It's not statistics: ($18\times$ as many Ξ^- as NA49).
- Unknown bias due to Trigger? Re-check with Jet20 data ($2\times$ NA49). Still no $\Xi(1860)$

95% UL relativ to $\Xi(1530)$:

$\Xi^-\pi^+$ (search) / $\Xi(1530)$	0.07
$\Xi^-\pi^-$ (control) / $\Xi(1530)$	0.04

Summary

Plenty of B at Tevatron. Only source of B_s, Λ_b.

Lepton Trigger

- $\sigma(p\bar{p} \to bX)$
- Precise τ_B in $B \to J/\psi X$. 1^{st} step towards $\Delta\Gamma_s$, test HQE.
- Best limits for $B_{d,s} \to \mu\mu$. Highly sensitive probe of New Physics.

Hadron Trigger

- Unique sample of $B \to hh$, $B \to D\pi$
- 1^{st} observation of $B_s \to KK$.
- Lots of Charm.
- Future: $\Delta\Gamma_s$, Δm_s, C̸P with $B_s \to KK$ & $B_d \to \pi\pi$

- Pentaquarks: Didn't see $\Xi(1840)$

  ... will look for others, especially D or J/ψ + Baryon.

Summary B Physics at DØ and CDF

Lepton Trigger

- Plenty B $\rightarrow$ J/ψX, B $\rightarrow \ell\nu$X, for $\sigma(p\bar{p} \rightarrow bX)$, B.R. B $\rightarrow$ D**, precise τ for B$^+$, B$_d$, B$_s$, Λ_b.
- Best limits for B$_{d,s} \rightarrow \mu\mu$ from CDF, DØ result with similar precision, soon. Highly sensitive probe of New Physics.
- Flavour tagging and B$_d$ mixing results from DØ.

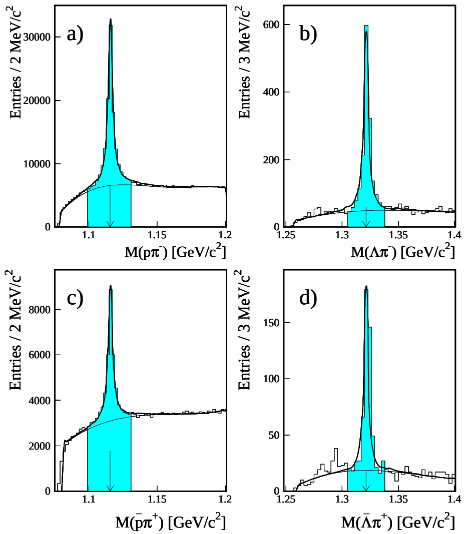
Hadron Trigger

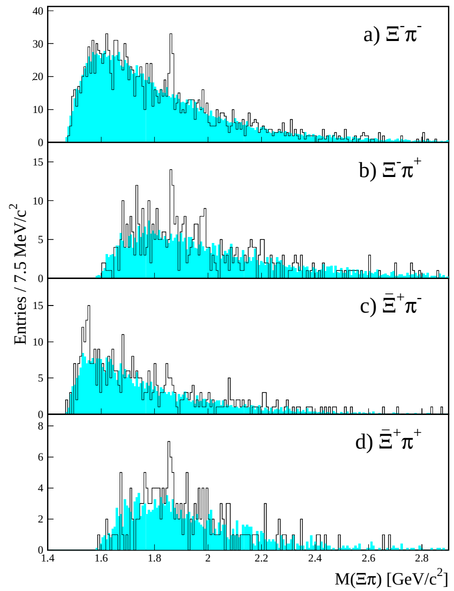
- Unique sample of B $\rightarrow$ hh, B $\rightarrow$ Dπ. 1st observation of B$_s$ $\rightarrow$ KK, Lots of Charm.
- DØ's displaced track trigger is being comissioned.
- Pentaquarks: Didn't see Ξ(1840). Will look for others, especially D or J/ψ + Baryon.

Penty of B results at both experiments. Beginning to seriously probe SM. More B physics of all flavours, soon.

BACKUP SLIDES

NA49 Digest

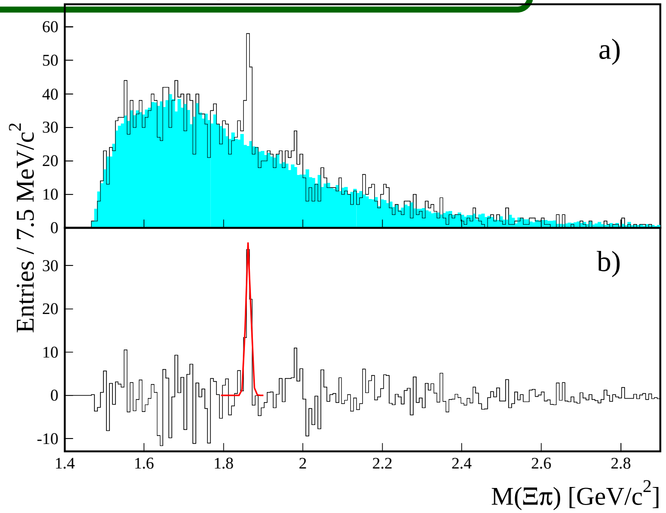




- two cuts:
  - $p(\pi^+) > 3$ GeV/c
  - opening angle between Ξ and π greater than $4.5°$

NA49 Digest

$$N(\Xi^-) = 1,640$$
$$N(\bar{\Xi}^+) = 551$$
$$N(\Xi(1530)^0) \sim 150$$
$$N(\Xi(1860)) = 67.5$$
$$N(\Xi(1860)^{--}) = 36$$
$$N(\Xi(1860)^0) = 31.5$$



$$r^0_{\mathrm{NA49}} = \frac{\#\Xi(1860)}{\#\Xi(1530)} = \frac{\sigma(pp \to \Xi(1860)) \cdot Br(\Xi(1860) \to \Xi^-\pi^+) \cdot a(\Xi(1860))}{\sigma(pp \to \Xi(1530)) \cdot a(\Xi(1530))} \sim 0.21, \quad (1)$$

$$r^{--}_{\mathrm{NA49}} = \frac{\#\Xi(1860)}{\#\Xi(1530)} = \frac{\sigma(pp \to \Xi(1860)) \cdot Br(\Xi(1860) \to \Xi^-\pi^-) \cdot a(\Xi(1860))}{\sigma(pp \to \Xi(1530)) \cdot a(\Xi(1530))} \sim 0.24, \quad (2)$$

$$r_{\mathrm{NA49}} = \frac{\#\Xi(1860)}{\#\Xi(1530)} = \frac{\sigma(pp \to \Xi(1860)) \cdot Br(\Xi(1860) \to \Xi^-\pi^\pm) \cdot a(\Xi(1860))}{\sigma(pp \to \Xi(1530)) \cdot a(\Xi(1530))} \sim 0.45 \quad (3)$$

$$\frac{\sigma(pp \to \Xi(1530)) \cdot a(\Xi(1530))}{\sigma(pp \to \Xi) \cdot a(\Xi)} \sim 0.068 \quad (4)$$

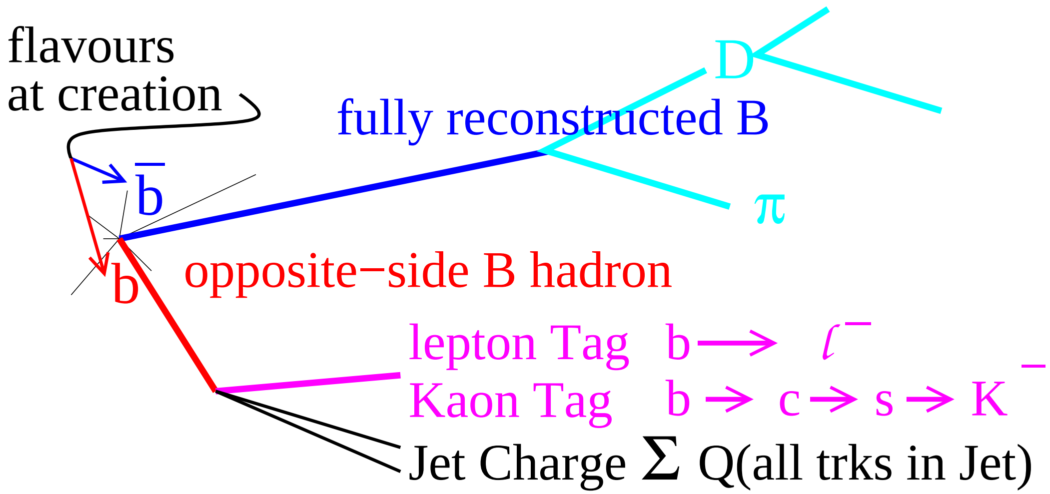
The B_s System

- Two CP-eigenstates with different mass and lifetime. Measure both $\Delta\Gamma_s$ and Δm_s at CDF.
- $\Delta\Gamma_s$ from lifetimes in $B_s^0 \to D_s D_s$, $B_s^0 \to KK$, $B_s^0 \to J/\psi\phi$
- 1^{st} step towards $\Delta\Gamma_s$: Average τ in $J/\psi\phi$ $1.33 \pm 0.14\,\text{ps}$
- Δm_s from B_s oscillations.

Status

- $\Delta m_s = 15 - 30\,\text{ps}^{-1}$, 95% CL (Direct limit + Unitarity Triangle, from CKMFitter).
- Theory: $\frac{\Delta\Gamma_s}{\Gamma_s} = 7\% \pm 4\%$
- Exp: $\frac{\Delta\Gamma_s}{\Gamma_s} < 0.31$, 95% CL
- $\frac{\Delta\Gamma_s}{\Delta m_s} = \frac{\pi}{2}\frac{m_b^2}{m_W^2}\left|\frac{V_{cb}V_{cs}}{V_{ts}V_{tb}}\right|^2 \times \text{QCD} \sim 2 \cdot 10^{-3}$
- Sensitive to CKM and New Physics.

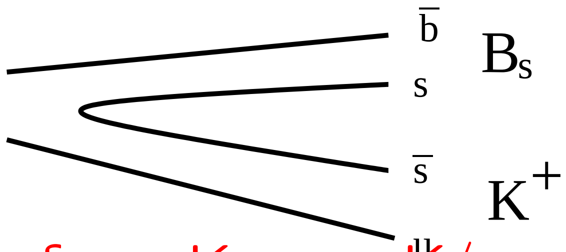
Tagging Strategies and Status



Measured Performances in Run II.
ε = efficiency, ω = wrong-tag
$D = 1 - 2\omega$

Tag	εD^2 (%)
μ	0.66 ± 0.09
e	in progress
K_{opp}	in progress
Q_{Jet}	in progress
$B_d{:}\pi_{same}$	1.9 ± 0.9
$B_s{:}K_{same}$	in progress

Same Side Tag:



N events before tagging $\sim \varepsilon D^2 \cdot N$ perfectly tagged events.

Expect great things from Kaons: K/π sep. in Time Of Flight.

Δm_s with $B_s^0 \to D_s\pi$

Significance =

$$\sqrt{\frac{1}{2} S \varepsilon D^2} \sqrt{\frac{S}{S+B}} \exp\left((\Delta m_s \sigma_\tau)^2\right)$$

Performance

	Now	Expected Improvements
$\frac{Evts}{lumi}$	1.6 pb	more D_s modes
S/B	$\sim$ 2.	
εD^2	being studied	
$\sigma(\tau)$	67 fs	L00,PV $\Rightarrow$ 50 fs

Most important improvement: Better $\sigma(\tau)$ using innermost Si layer, and evt-by-evt prim. Vtx.

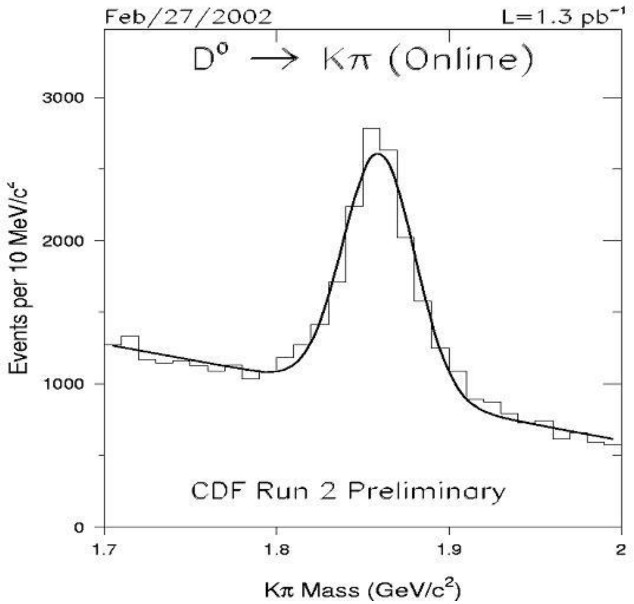
B production at Tevatron Run II

- $\mathrm{p\bar{p}}$ collisions @ 1.96 TeV, $\sigma_{\mathrm{b\bar{b}}} \sim$ 0.05 mb
- Produce many $\mathrm{B^0, B_s, \Lambda_b}, \ldots.$ some picture
- Challanging: Messy environment ($\sigma(\mathrm{p\bar{p}}\ inel) \sim$ 100 mb)

Silicon Vertex Trigger *Impact Parameter trigger at L2*

Combines L1-tracks with Si-info to calculate IP.

$\sigma_{IP} = 48\,\mu\text{m} = 0.35\,\mu\text{m(intrinsic)} \oplus 0.33\,\mu\text{m(beam-size)}$



Finds lots of charm. Use $D^0 \to K\pi$ as online monitor for SVT.

2-Track Hadron Trigger

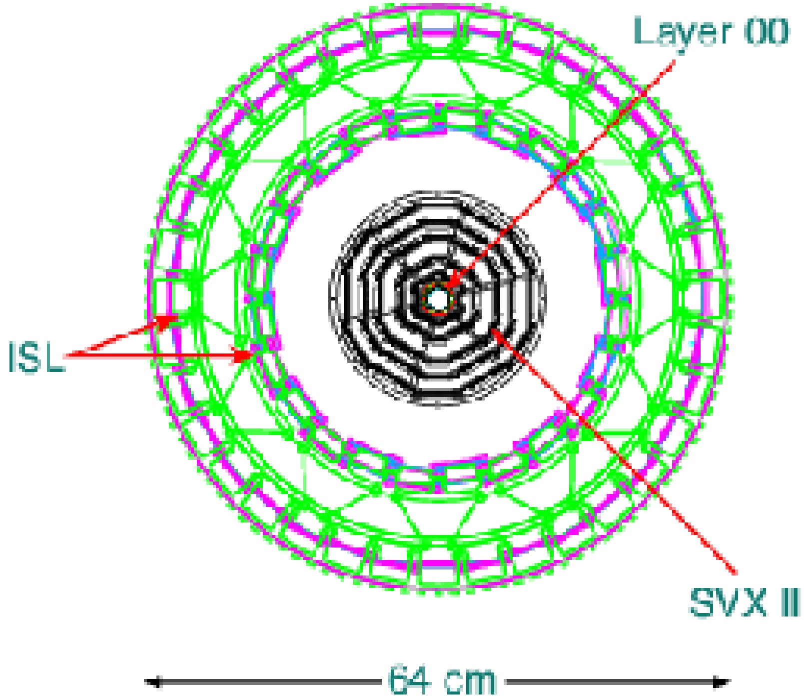
L1: 2 XFT tracks, $p_t > 2\,\text{GeV}$, $\Delta\phi < 135^\circ$, $p_{t1} + p_{t2} > 5.5\,\text{GeV}$.

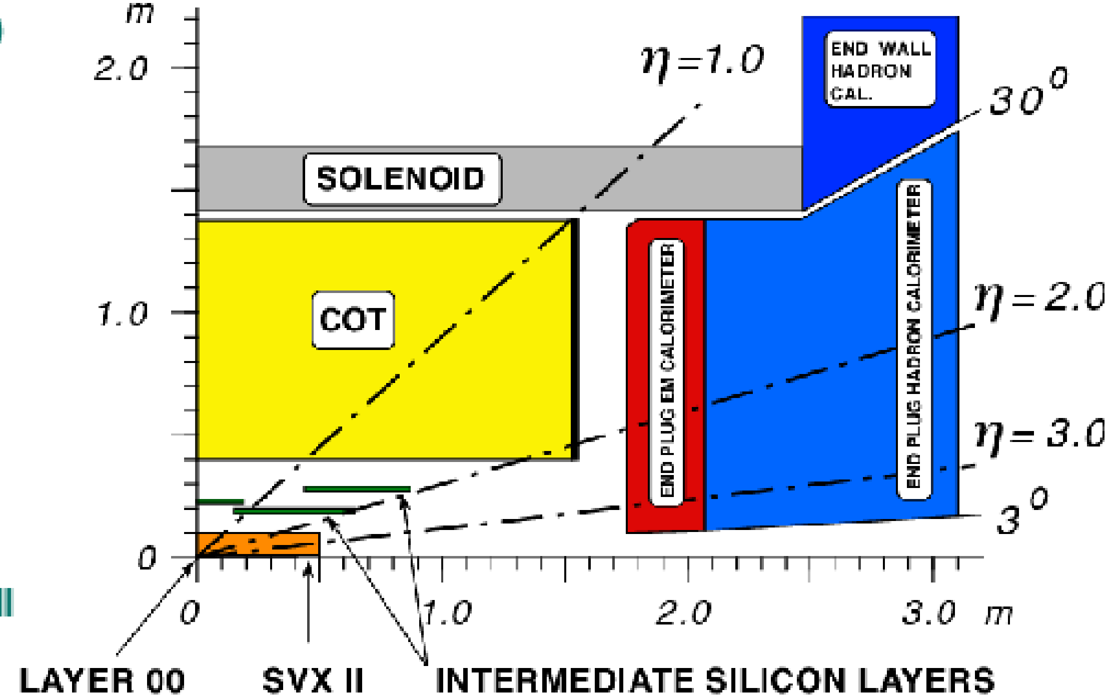
L2:

2-body: e.g. $B_d^0 \to \pi\pi$	Multi-body: e.g. $B_s^0 \to D_s\pi$
IP$> 100\,\mu$m	IP$> 120\,\mu$m
$20^\circ < \Delta\phi < 135^\circ$	$2^\circ < \Delta\phi < 90^\circ$
$L_{xy} > 200\,\mu$m	$L_{xy} > 200\,\mu$m
IP of B $< 140\,\mu$m	–

L3: Same with refined tracks & mass cuts.

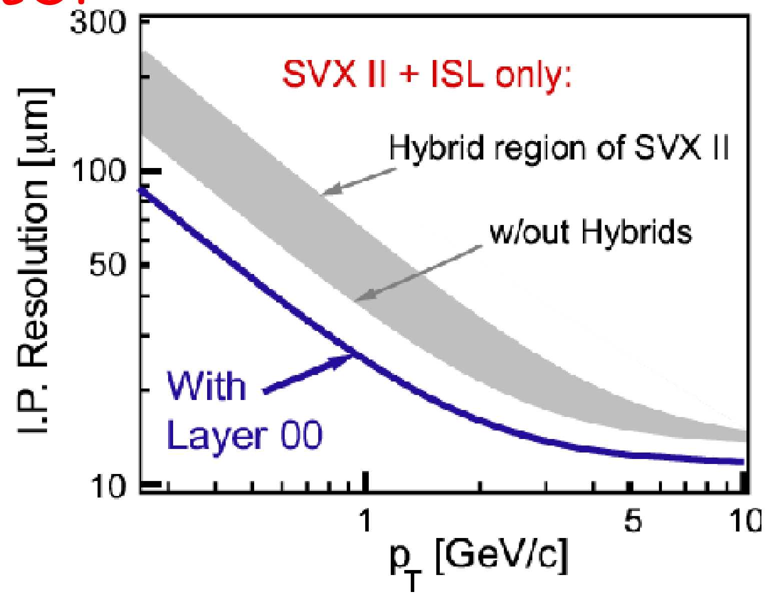
Silicon Vertex Detector





Silicon Vertex Detector

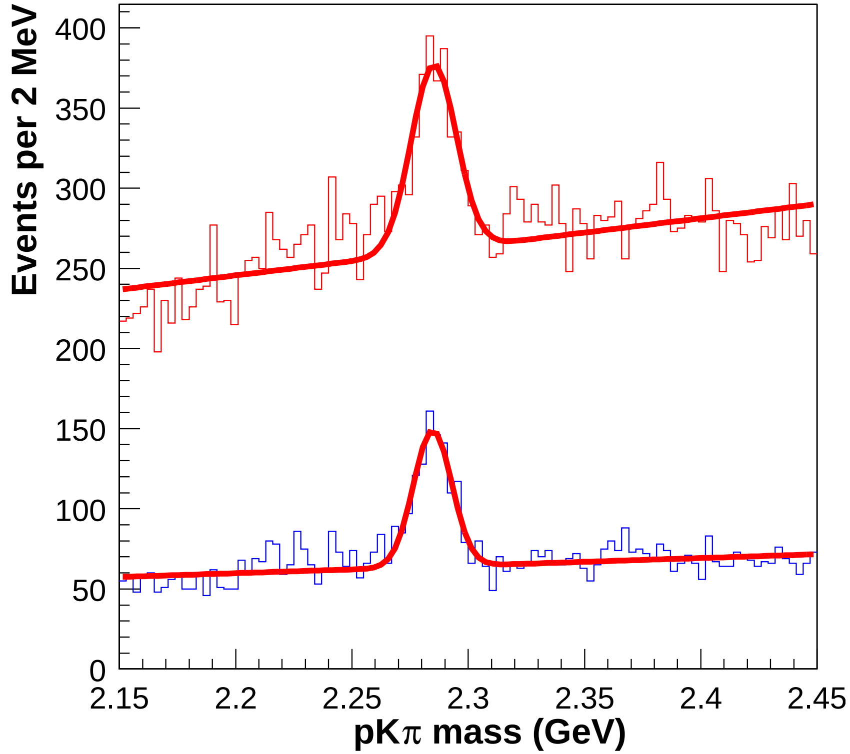
- Layer 00 fully functional
- Cooling problem solved.
- Chip-failures in z-layers understood, can be prevented in future (no problems since Nov).
- Need to finalise Alignment: For now, ISL, Layer 00 and z-information not used (coming soon).



For "simple" τ measurements, SVX II in 2-D fully adequate. Improvement from L00, ISL, and z available soon, esp. for Δm_s, and to improve acceptance.

CDF Run II Semileptonic: $\tau(\Lambda_b)$ *from* $\Lambda_b \to \Lambda_c^+(pK^+\pi^-)\ell^-\nu$

- Use combined particle ID from time of flight and $\frac{dE}{dx}$ to identify protons and reduce background (see Figure).
- Find $590 \pm 50\ \Lambda_c$.
- Combine Λ_c with ℓ, accept masses between $M(\Lambda_c)$ and $M(\Lambda_b)$
- Statistical precision of current sample: $\sigma(\tau_{\Lambda_b}) = 0.13\,\text{ps}$



Λ_c mass with and without proton ID from TOF and $\frac{dE}{dx}$.