Flavour Physics Technique at CDF and D0

FPCP 2009

Flavour Physics and CP Violation 2009

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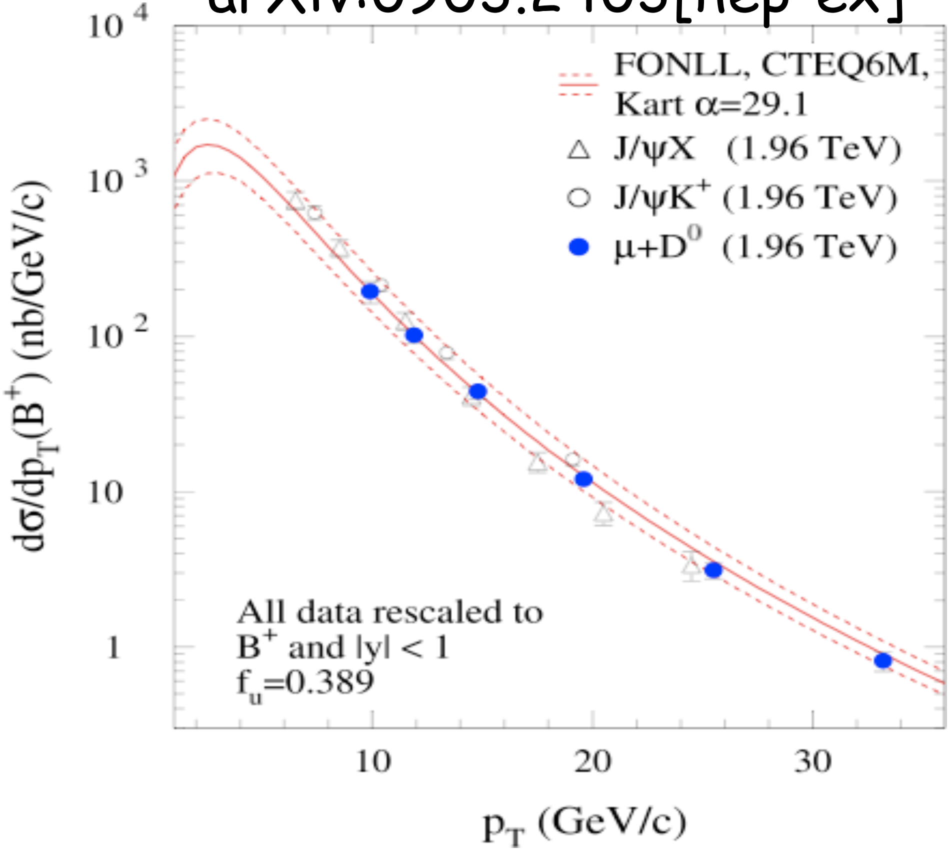
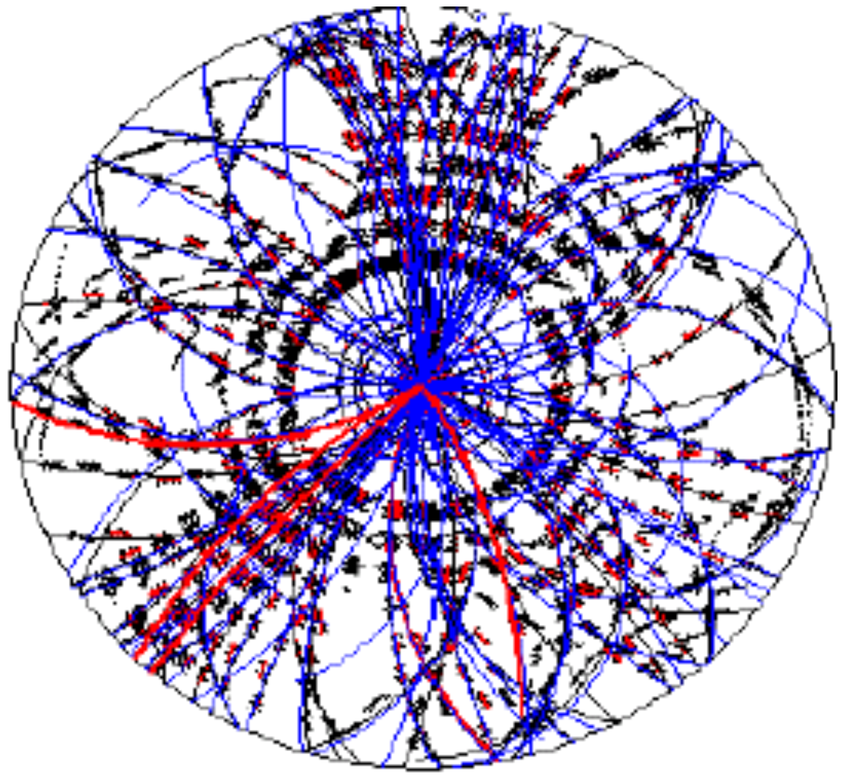
Outline

- **Detector elements crucial for B Physics at hadron colliders**
  - Integrated Tracking Systems
    - Silicon detectors, Drift chamber, Fiber Tracker
  - Lepton Detectors
- **Trigger architecture/strategies used for B Physics**
  - Lepton Triggers
  - Hadron Triggers (i.e. triggering on displaced vertices)
- **Clean reconstruction of complex topologies**
  - Precision mass, lifetime measurements
- **Particle identification from dE/dx, TOF**
  - Calibration, performance, use in analysis
- **Flavor tagging**
- **Conclusions**

Heavy Flavor Production at Tevatron

arXiv:0903.2403[hep-ex]





At Tevatron, b production cross section is much larger compared to B factories

→ CDF is enjoying a very rich B Physics program

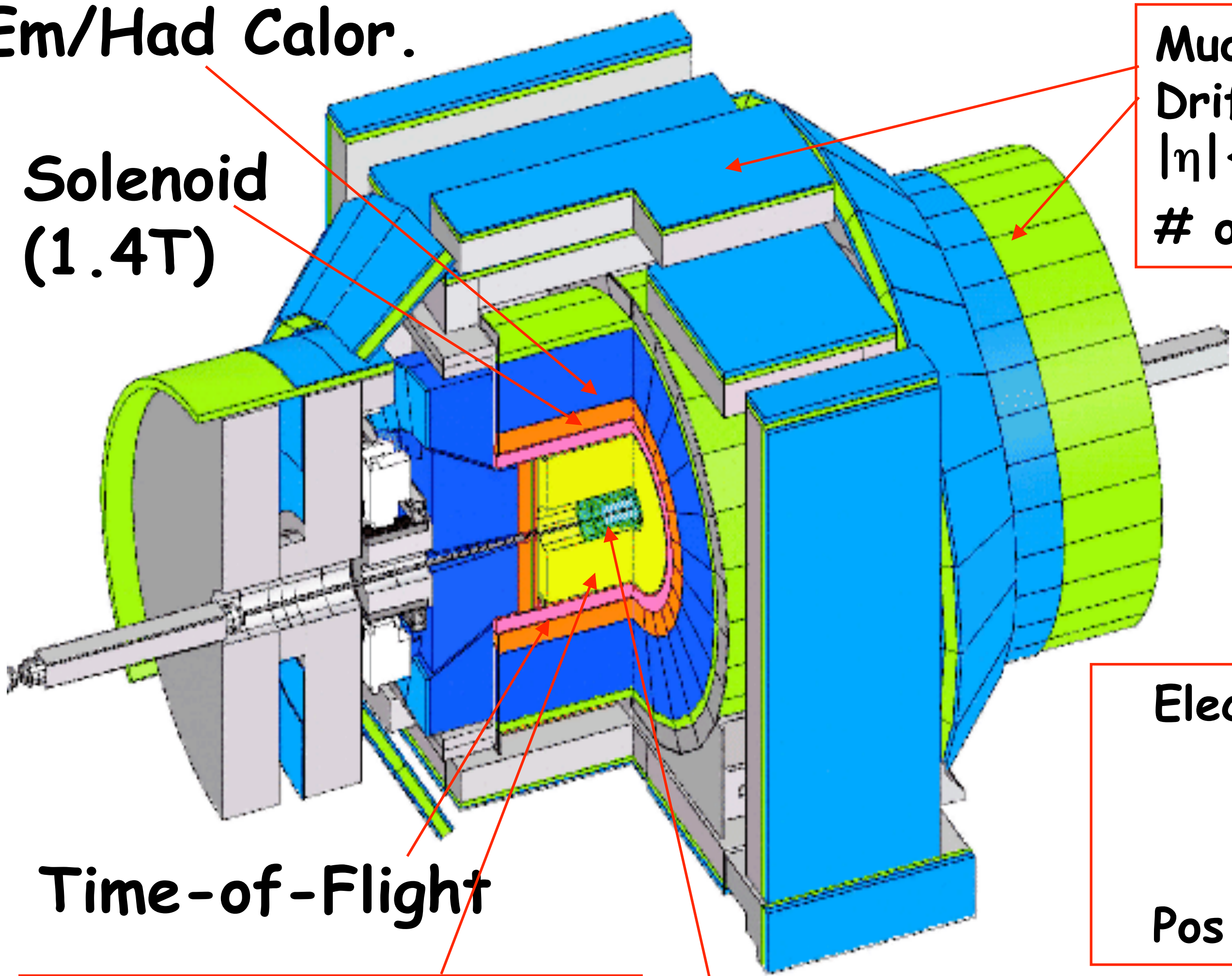
Plethora of states accessible at Tevatron (B_d, B_u, B_s, Λ_b, Ξ_b, Σ_b, Ω_b)

→ Complement the B factories physics program

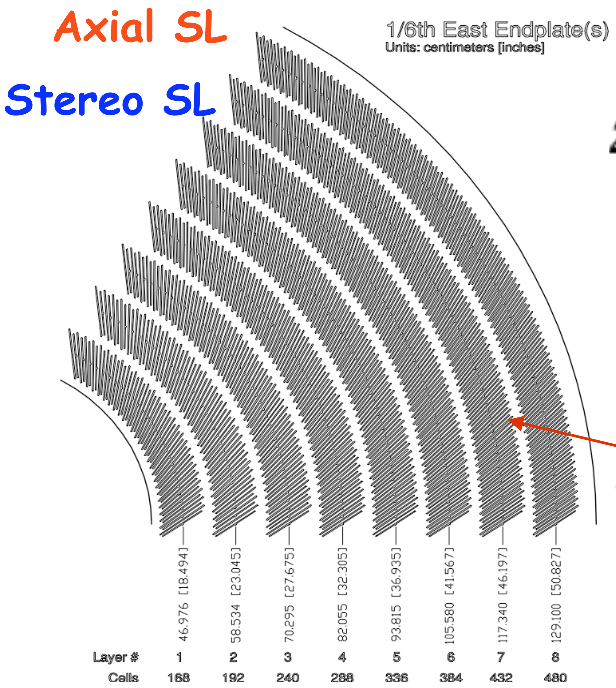
Total inelastic cross section at Tevatron is ~1000 larger than b cross section

→ Large backgrounds suppressed by triggers that target specific decays

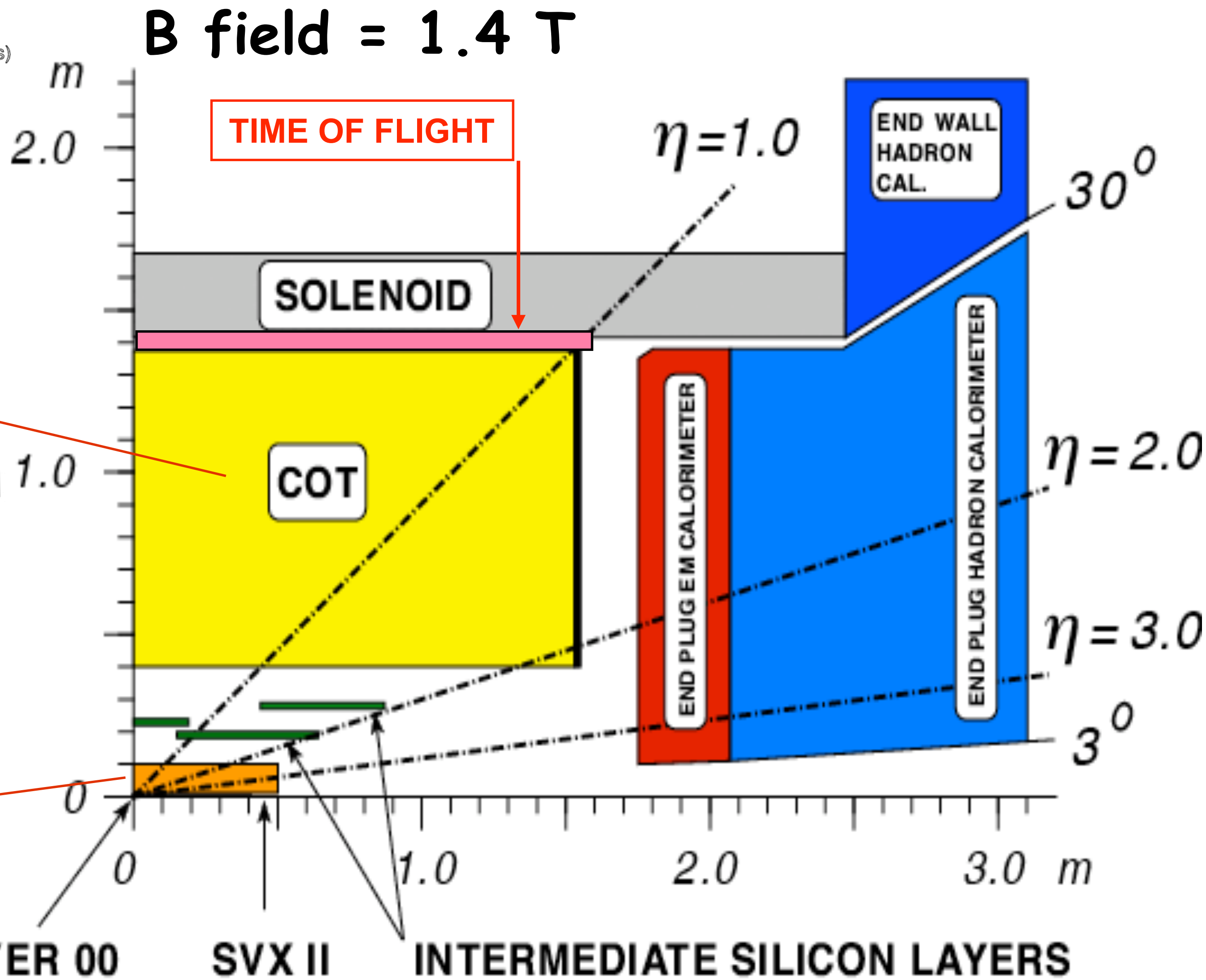
The CDF detector

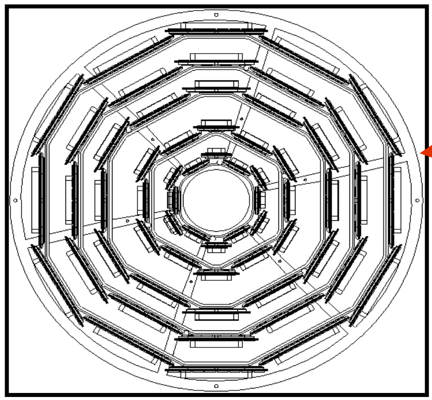


The CDF Tracker



B field = 1.4 T



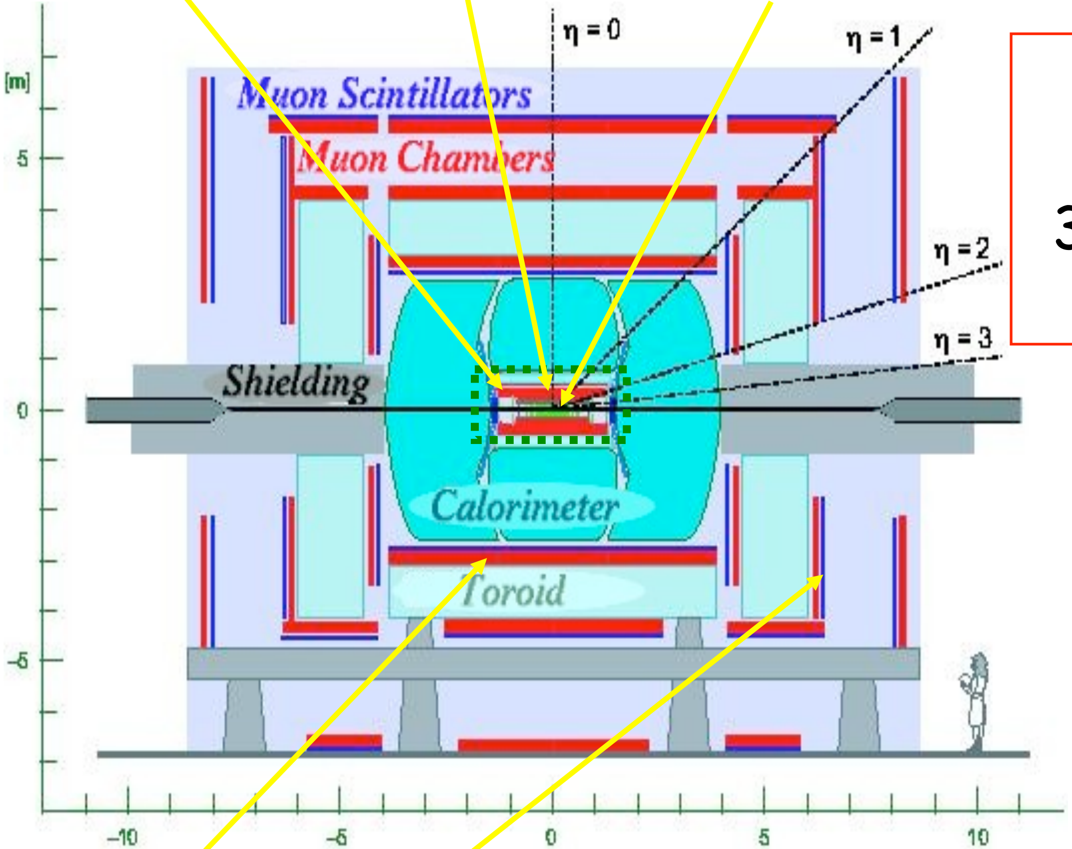


The D0 Detector

Fiber Tracker: 16 Layers, $|\eta|<2$, R ~0.5 m

2T Solenoid

Silicon Tracker: 5 Layers, $|\eta|<3$



Muon System $|\eta|<2$
Drift Tube/scintillator
3 layers of tubes (3-4 planes/layer)
Toroid between Layer 1-2

Electromagnetic Calorimeter
Liquid Argon/Uranium
0.1x0.1 (hxf), ~20 rad length
Preshow: scintillating strips
Shower max: 3rd layer

Central/Forward Muon Scintillators

CDF B Triggers

Di-Muon (J/ψ)

$Pt(\mu) > 1.5$ GeV

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

Displaced trk + lepton (e, μ)

$IP(trk) > 120\mu m$

$Pt(lepton) > 4$ GeV

Semileptonic modes

2-Track Trig.

$Pt(trk) > 2$ GeV

$IP(trk) > 100\ \mu m$

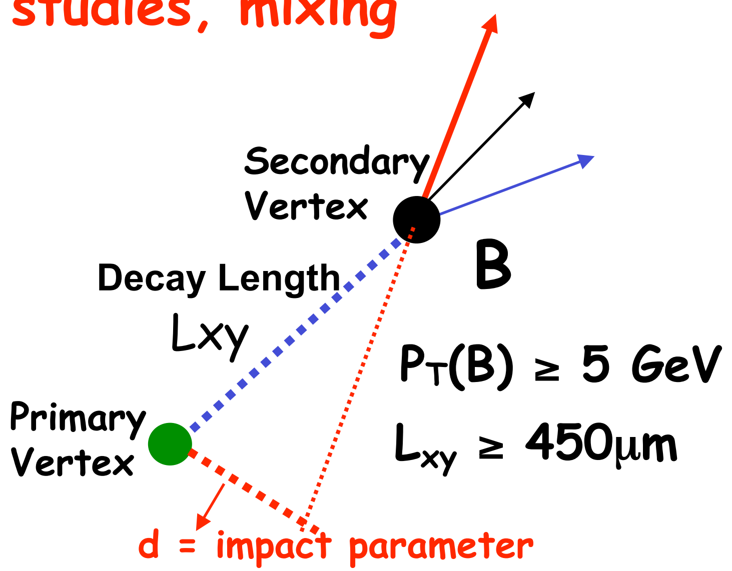
Fully hadronic modes

- $X(3872) \to J/\psi\pi\pi$
- β_s in $B_s \to J/\psi\,\phi$,
- Ξ_b, Ω_b Observation
- $\Lambda_b \to J/\psi\,\Lambda$ (masses, lifetimes)
- $B^0_{s,d} \to \mu\mu$ (rare decays)
- $Bc \to J/\psi\,\pi\ (J/\psi\, l X)$

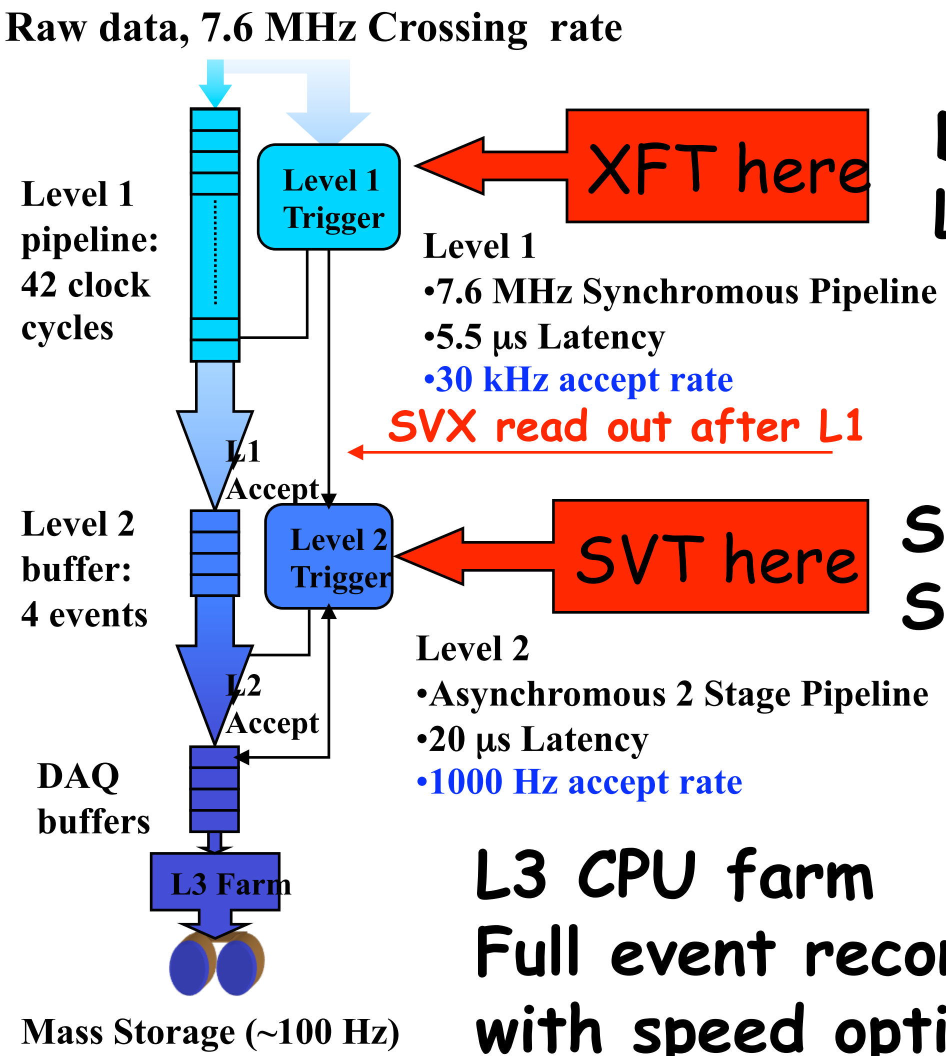
High statistics lifetime

Tagging studies, mixing

- $B \to hh$ (CP)
- B_s mixing
- D^0 mixing
- $\Sigma^{*+} \to \Lambda_b\,\pi$
- $\Lambda_b \to \Lambda_c\,\pi$



CDF Trigger Architecture



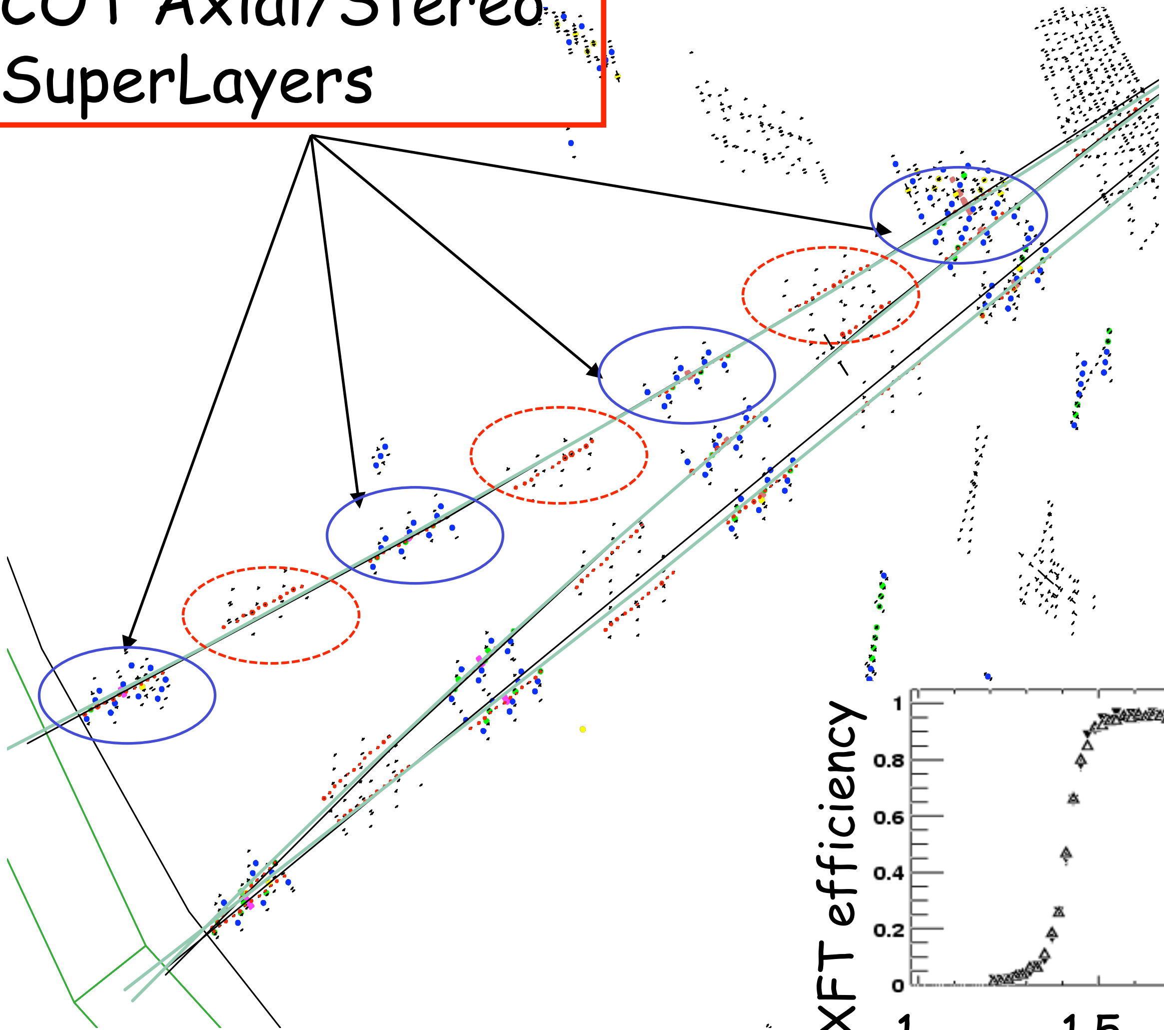
Drift chamber tracking
Lepton identification

Silicon tracking
Secondary vertex selection

L3 CPU farm
Full event reconstruction
with speed optimized offline code

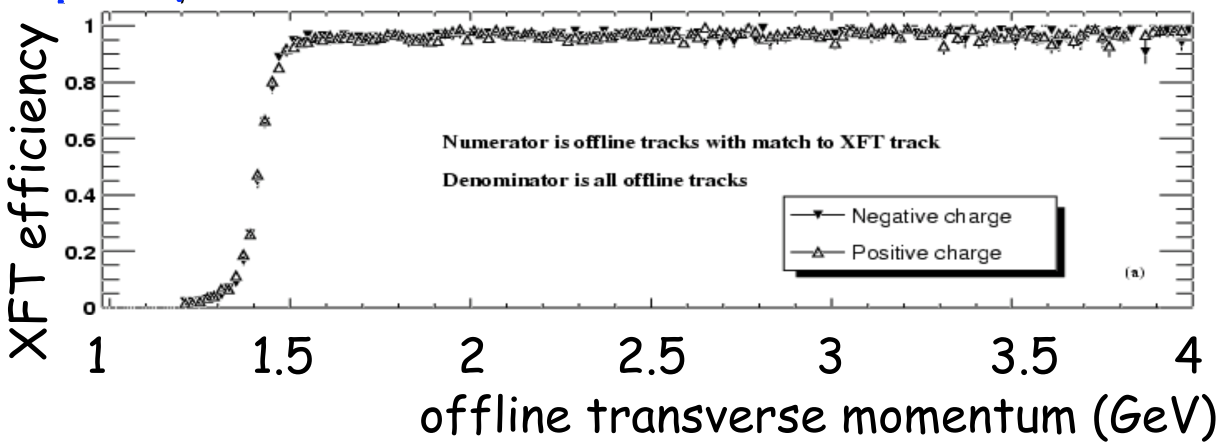
XFT working principle

COT Axial/Stereo SuperLayers

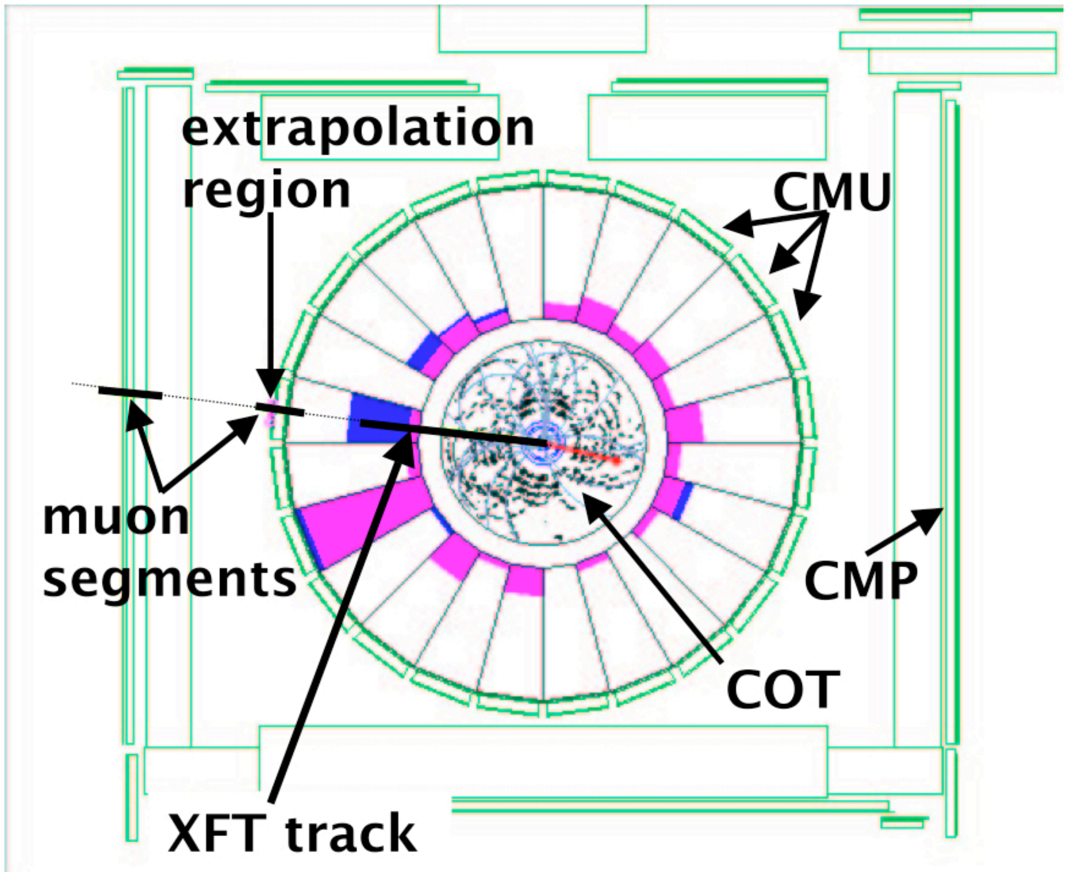


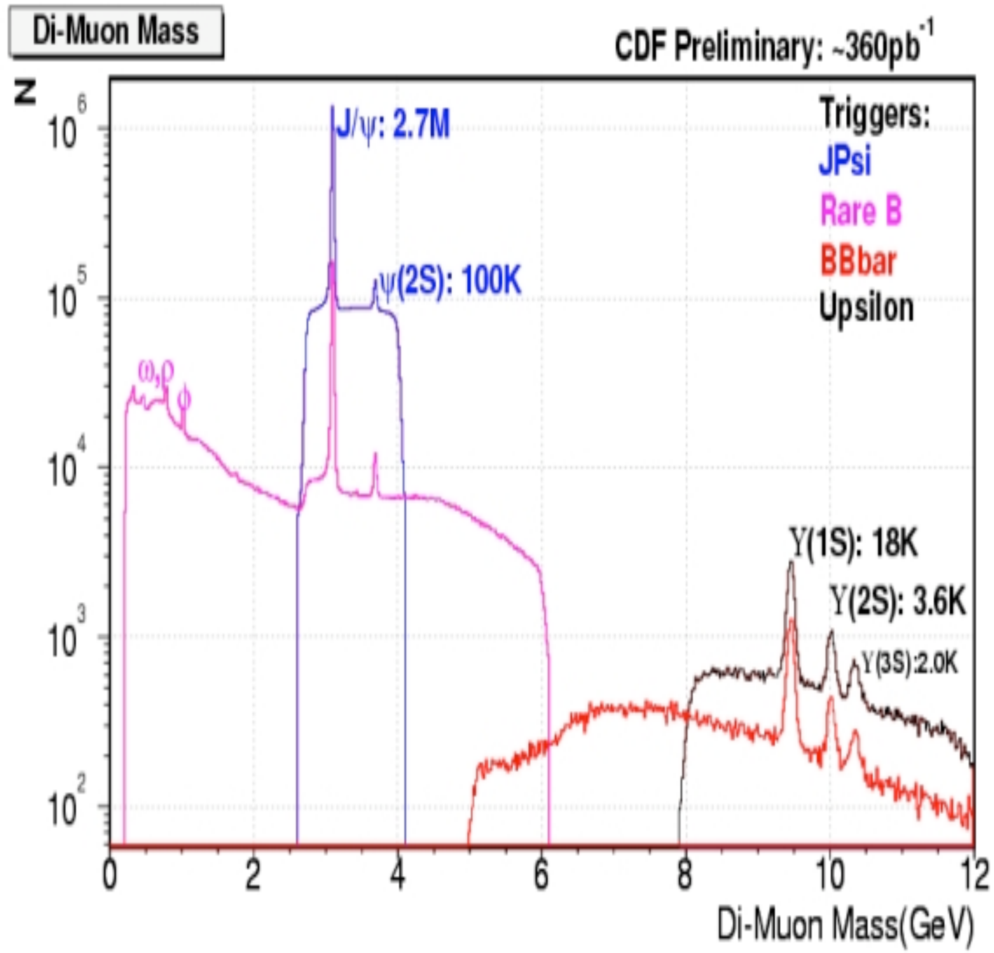
Good hit patterns identified as segments, segments linked as tracks

$\sigma(1/p_T)$ = 1.7%/GeV
$\sigma(\phi_0)$ = 5 mrad
96% efficiency
(p_T > 1.5 GeV)



Lepton triggers

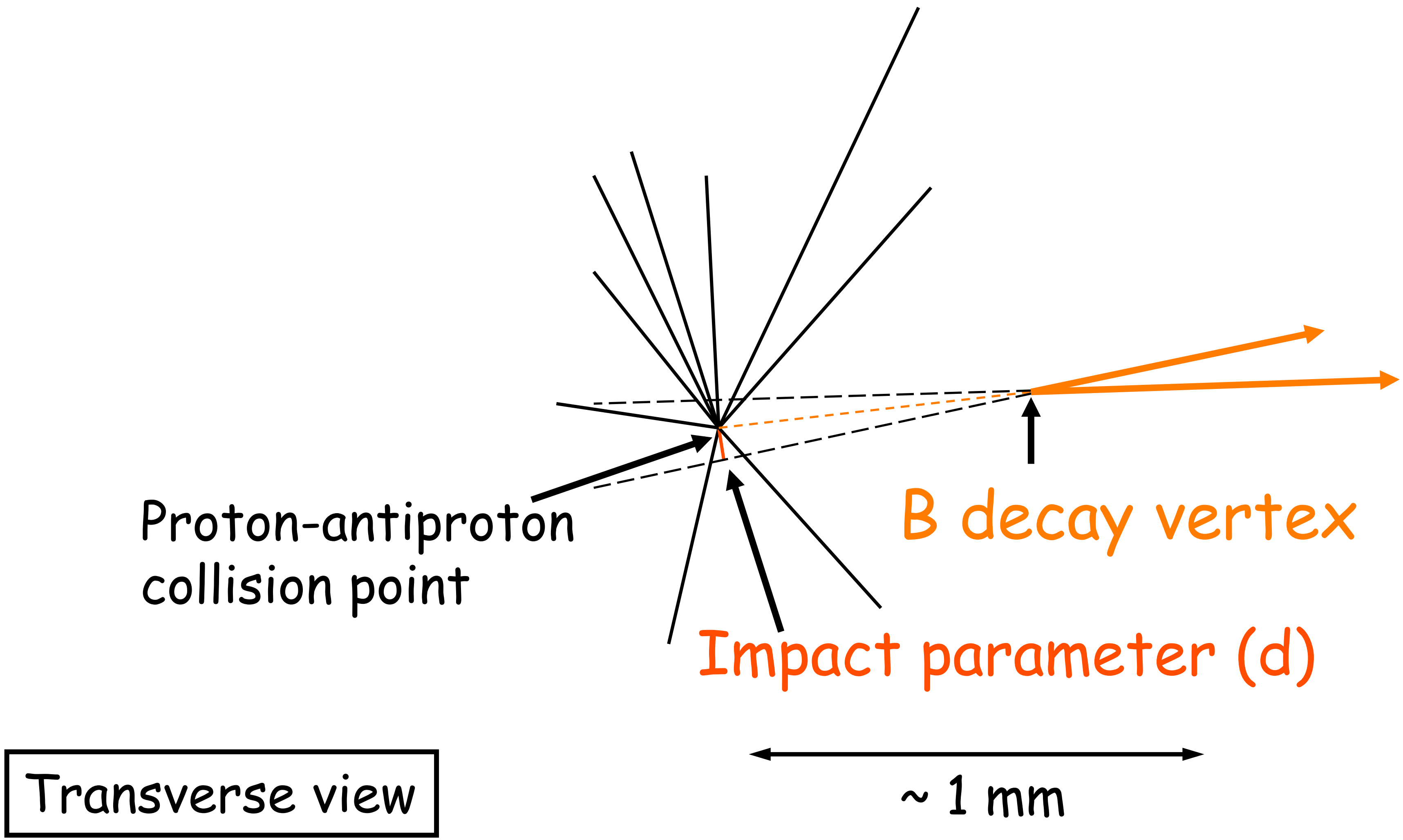




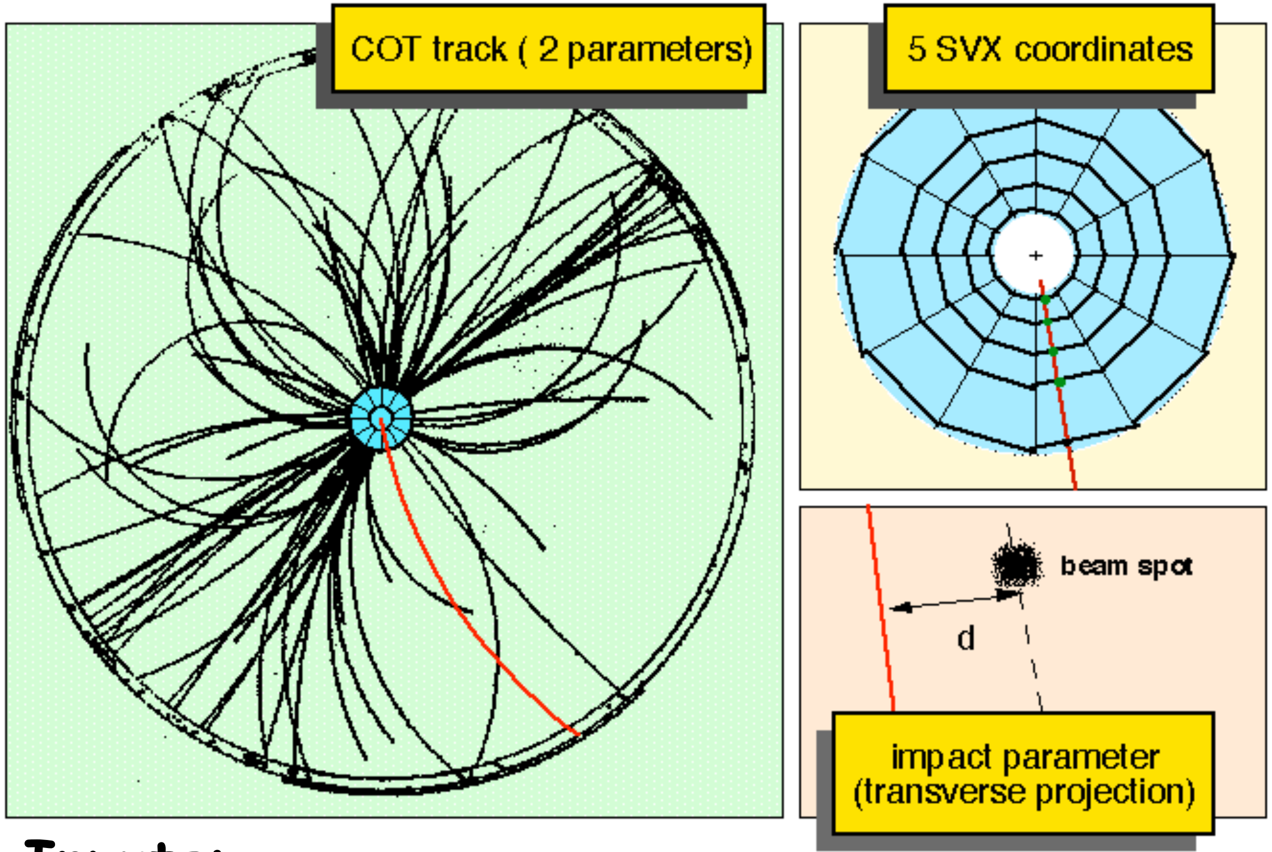
Lepton triggers

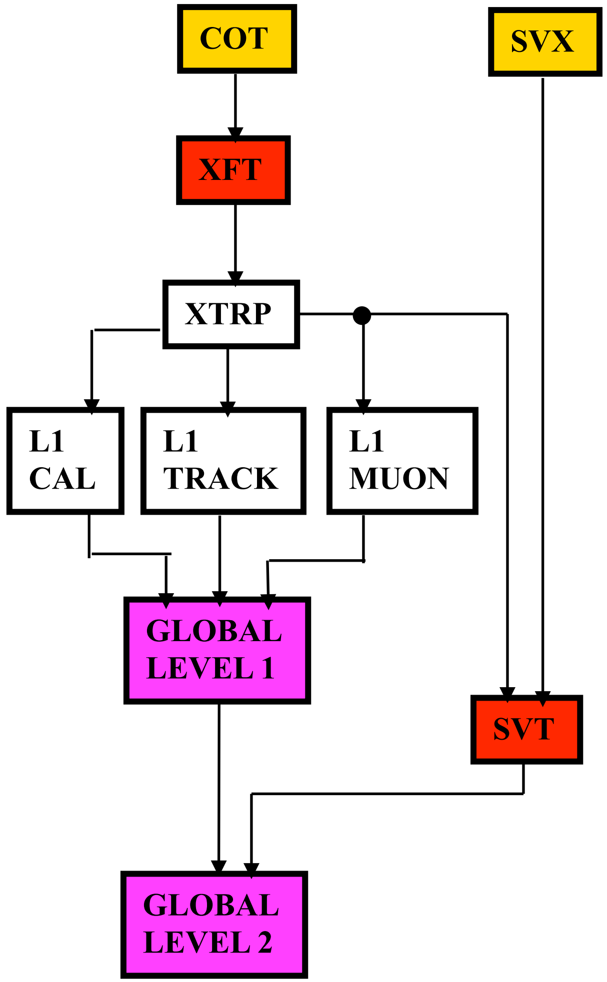
Match between a muon stub/calorimeter signal with an XFT track

Exploit lifetime to select b,c



SVT: Input & Output





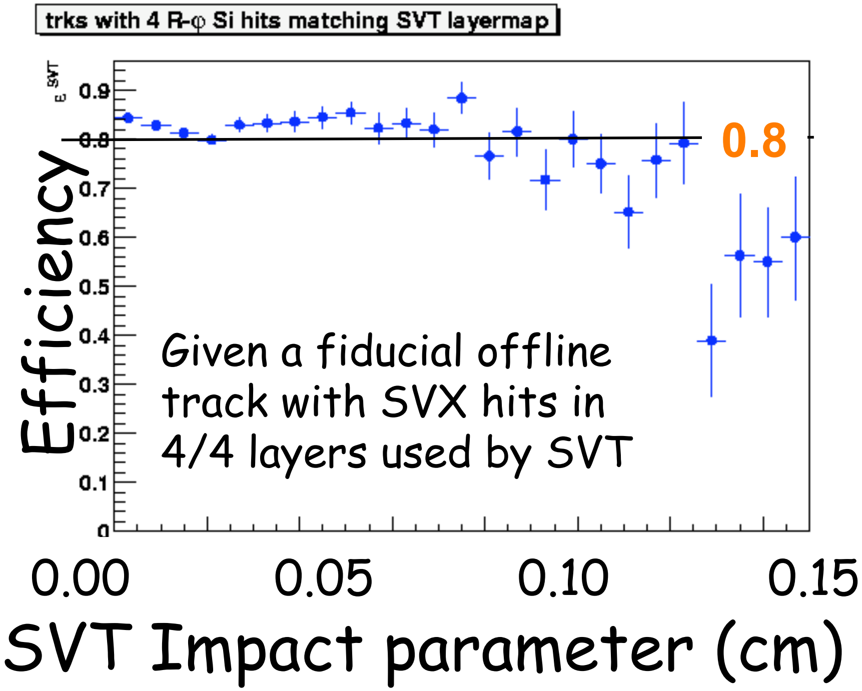
Inputs:

- L1 tracks from XFT (ϕ, pT)
- digitized pulse heights from SVX II

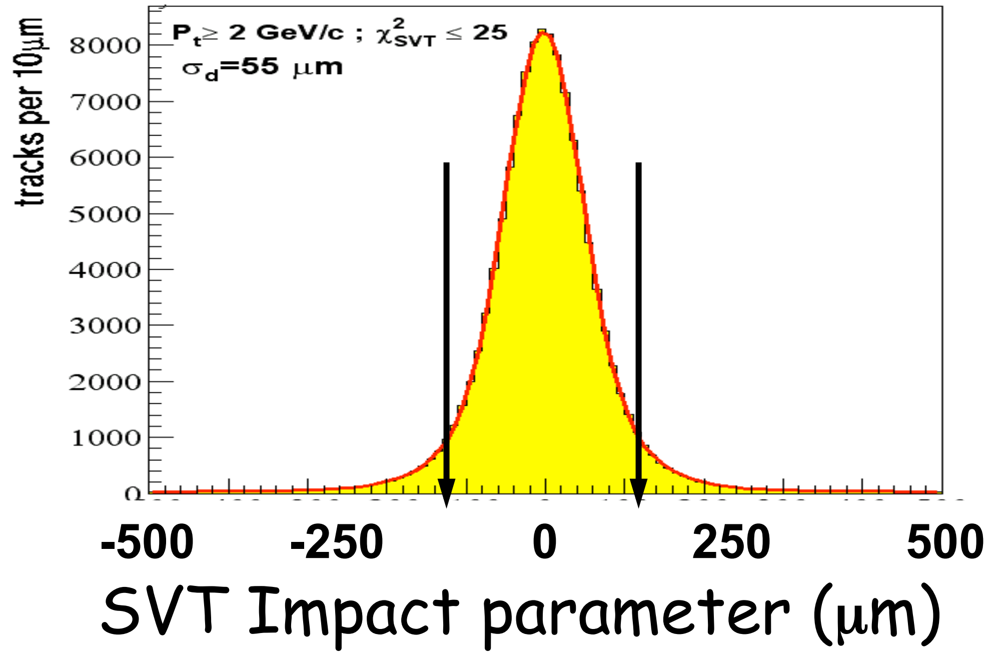
Outputs:

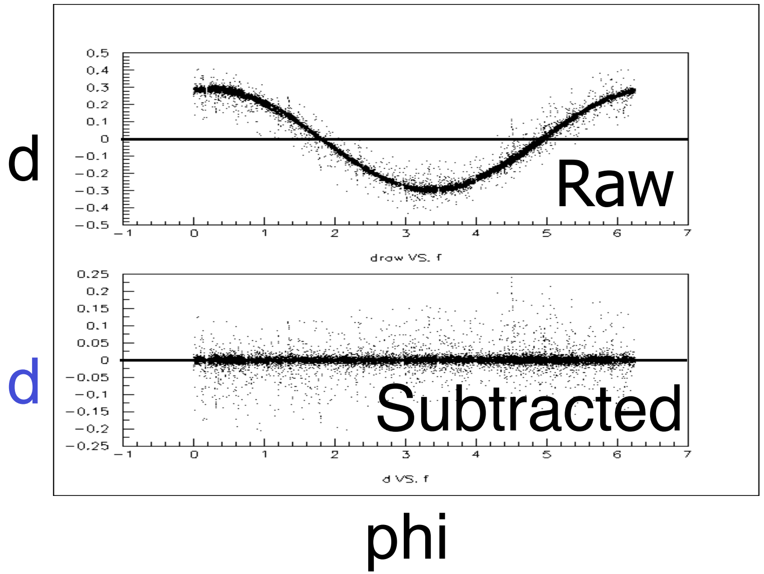
- reconstructed tracks (d, ϕ, pT)

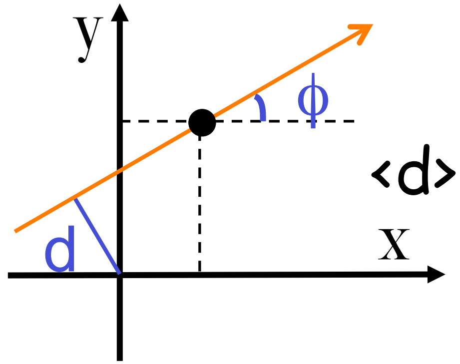
SVT Performance



σ = 48μm=35μm⊕33μm (res ⊕ beam)







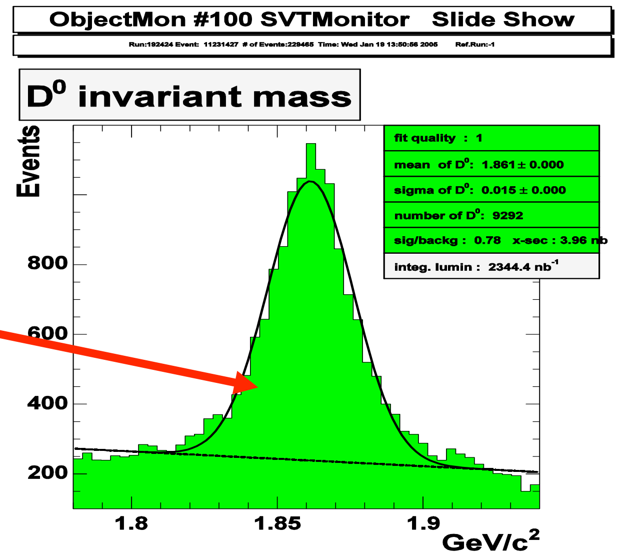
$\langle d \rangle = Y_{beam}\cos\phi - X_{beam}\sin\phi$

Online impact parameter measurement requires online beam position estimate

Hadronic B Trigger (I)

L1	Two XFT tracks: P_t > 2 GeV; $P_{t1}+P_{t2}$ >5.5 GeV; $\Delta\phi$ < 135°	
	Two-body decays	Multy-body decays
L2	100 µm<d_0<1mm for both tracks Validation of L1 cuts with $\Delta\phi$>20° Lxy > 200 µm d_0(B)<140 µm	120 µm<d_0<1mm for both tracks Validation of L1 cuts with $\Delta\phi$>2° Lxy > 200 µm ~~d_0(B)<140 µm~~
	B -> h h'	B_s mixing

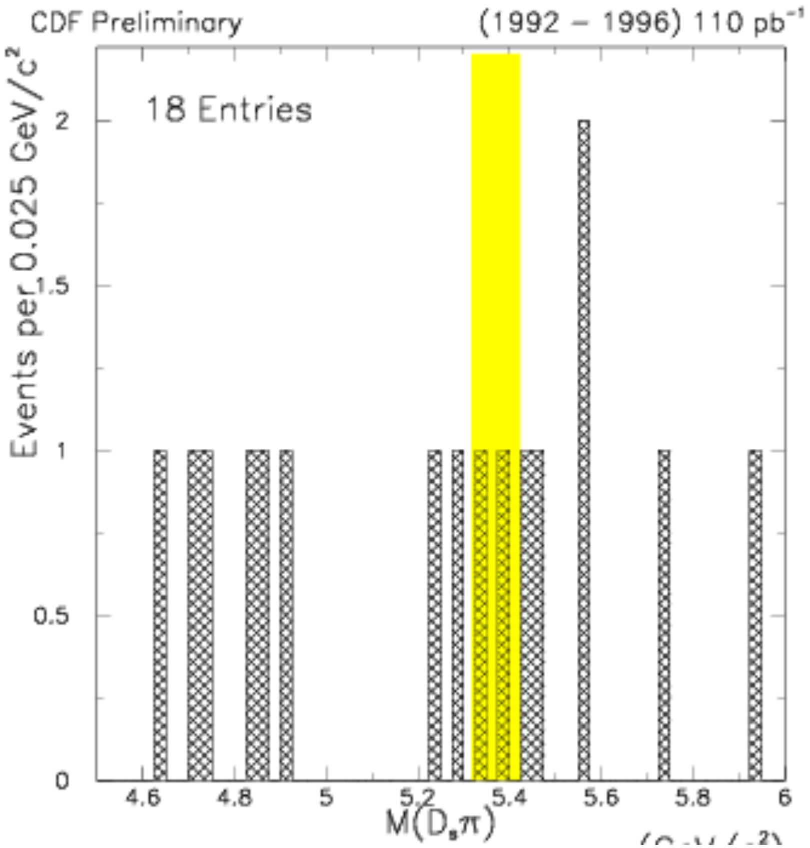
Trigger collects tons of $D^0 \rightarrow K^- \pi^+$
(use as online L3 monitor)



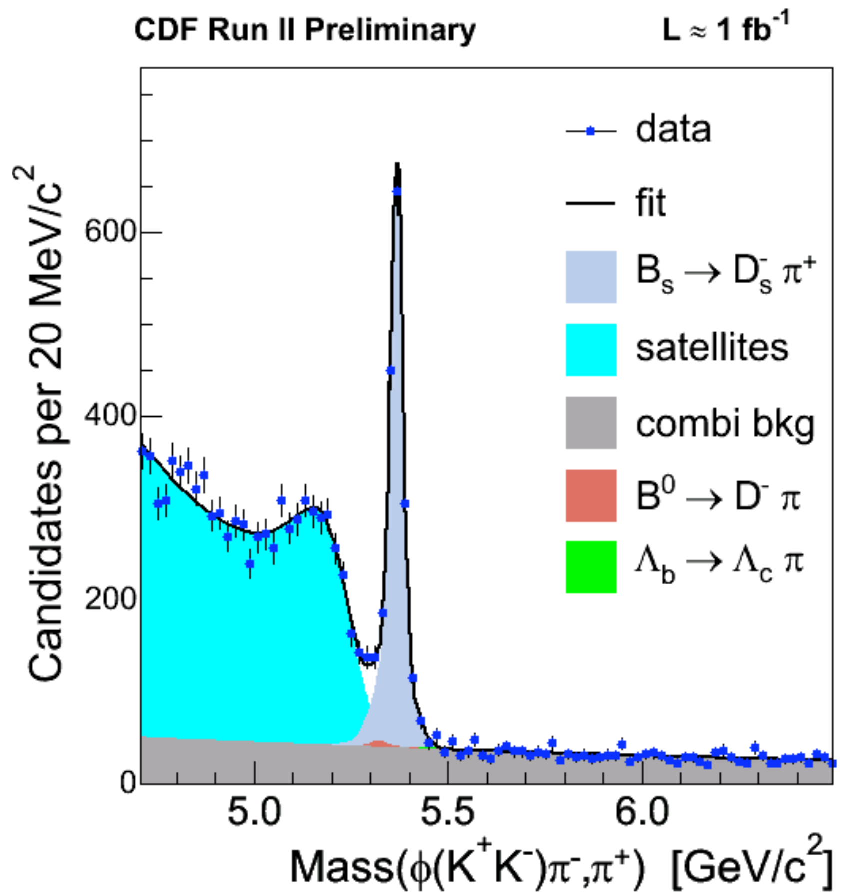
Hadronic B Trigger (II)

- Run I collected O(1) $B_s \to D_s\pi$ in 100 pb^{-1} (all D_s modes)
- Run II collected ~200/100 pb^{-1} $B_s \to D_s\pi$ (D_s--> $\phi[\to K^+K^-]\,\pi$)
- Compare with only 10x integrated luminosity!

Without SVT

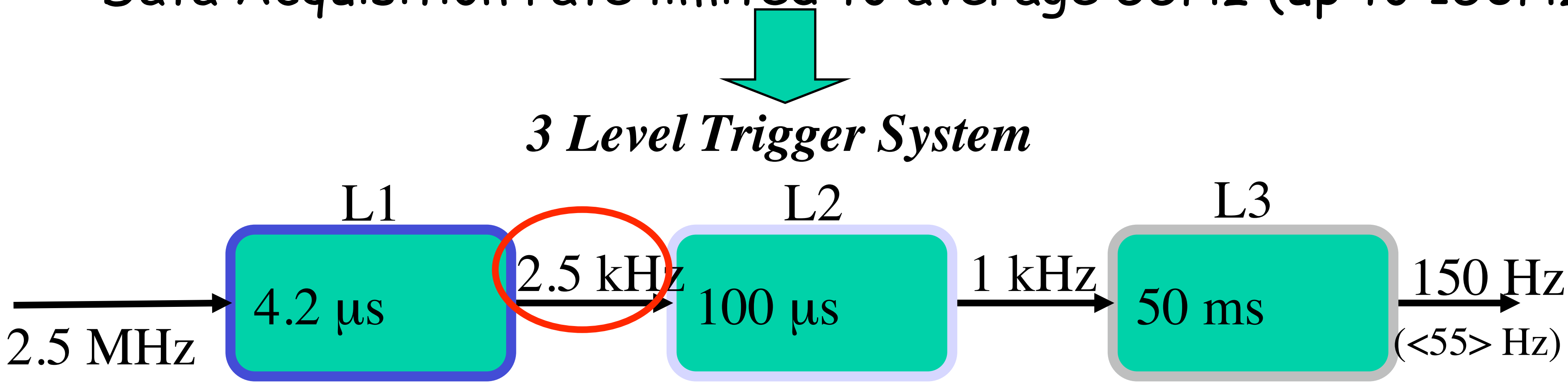


With SVT



D0 Trigger architecture

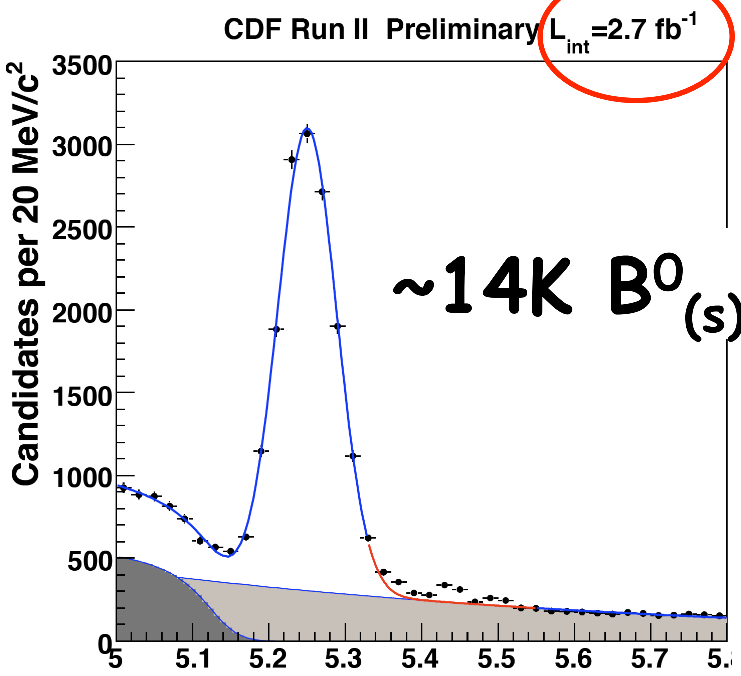
Data Acquisition rate limited to average 55Hz (up to 150Hz)



B Triggers

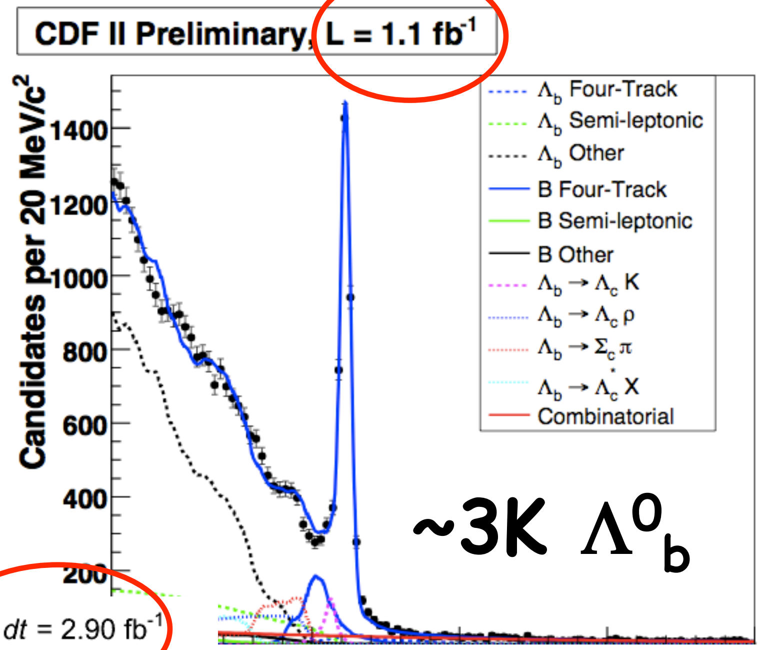
Di-Muon	Single Muon
$Pt1(\mu) > 3.0$ GeV, $\|\eta\|<2$	$Pt(\mu) > 3$ GeV, $\|\eta\|<1.5$
$Pt2(\mu) > 1.5(3.0)$ GeV, $\|\eta\|<2$	

Example Physics Signals



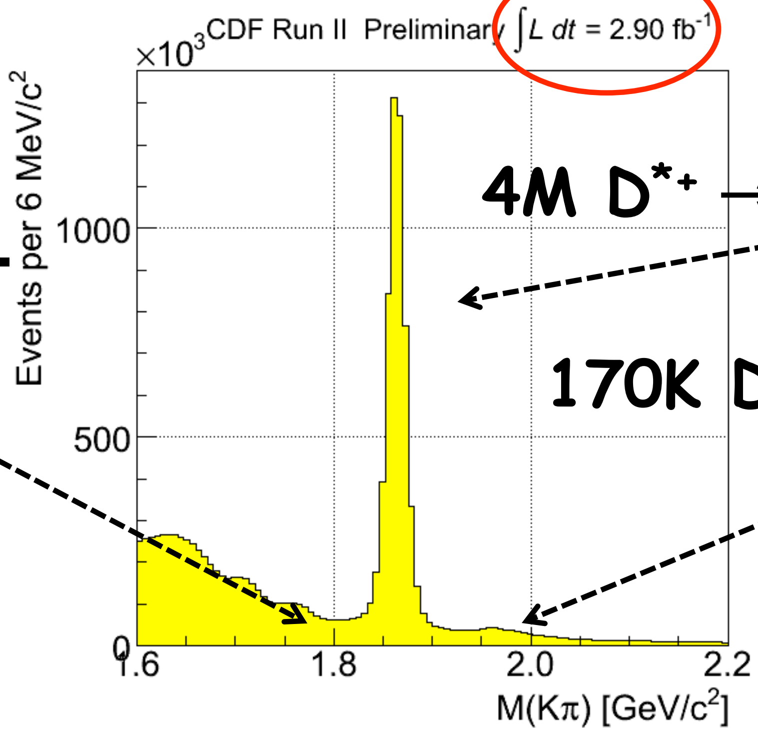
~14K $B^0_{(s)} \rightarrow h^+h'^-$

$M(\pi+\pi-)$



~3K Λ^0_b

$M(\Lambda^+_c \pi^-)$



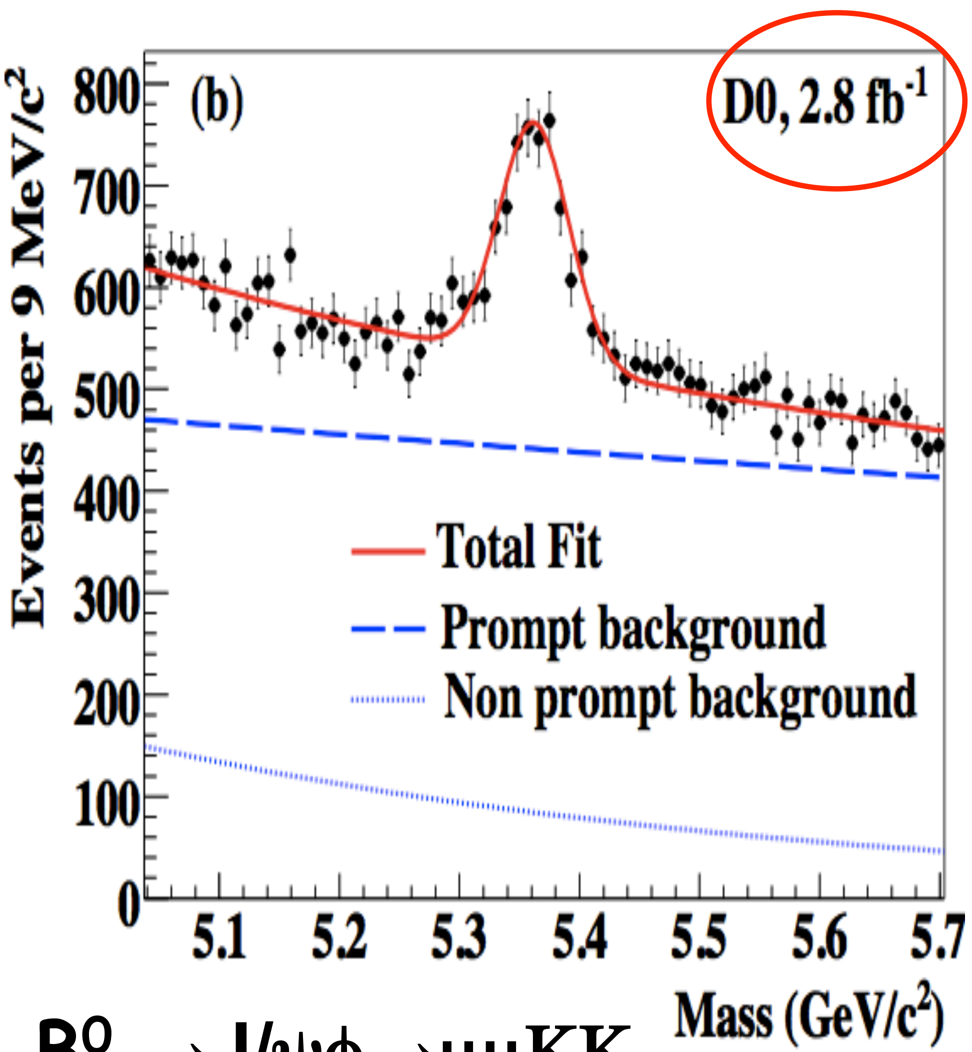
4M $D^{*+} \rightarrow D^0\pi^+ \rightarrow K-\pi+$

360K $D^{*+} \rightarrow D^0\pi^+ \rightarrow K+K-$

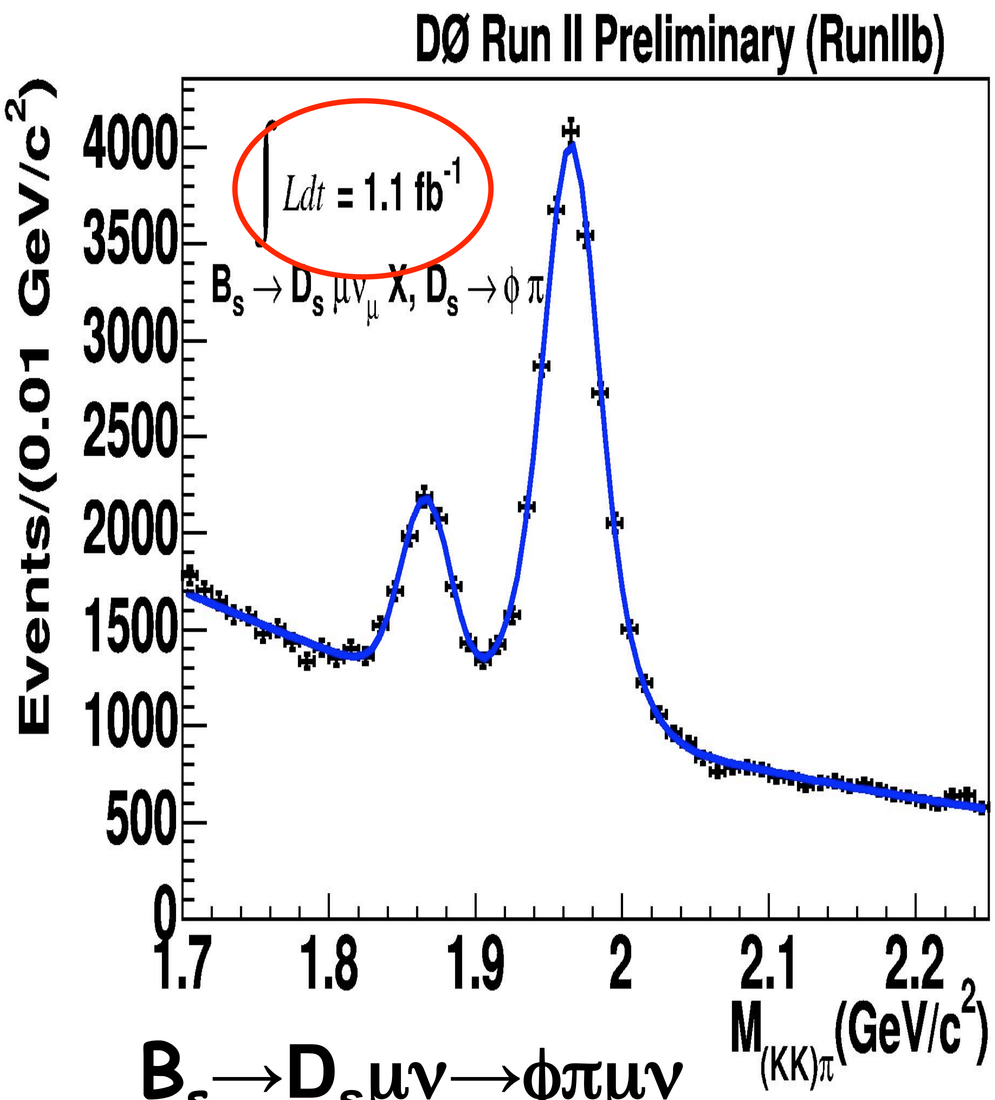
170K $D^{*+} \rightarrow D^0\pi^+ \rightarrow \pi+\pi-$

We already have ~5 fb^{-1} on tape

Example Physics Signals



$B^0_s \rightarrow J/\psi\phi \rightarrow \mu\mu KK$

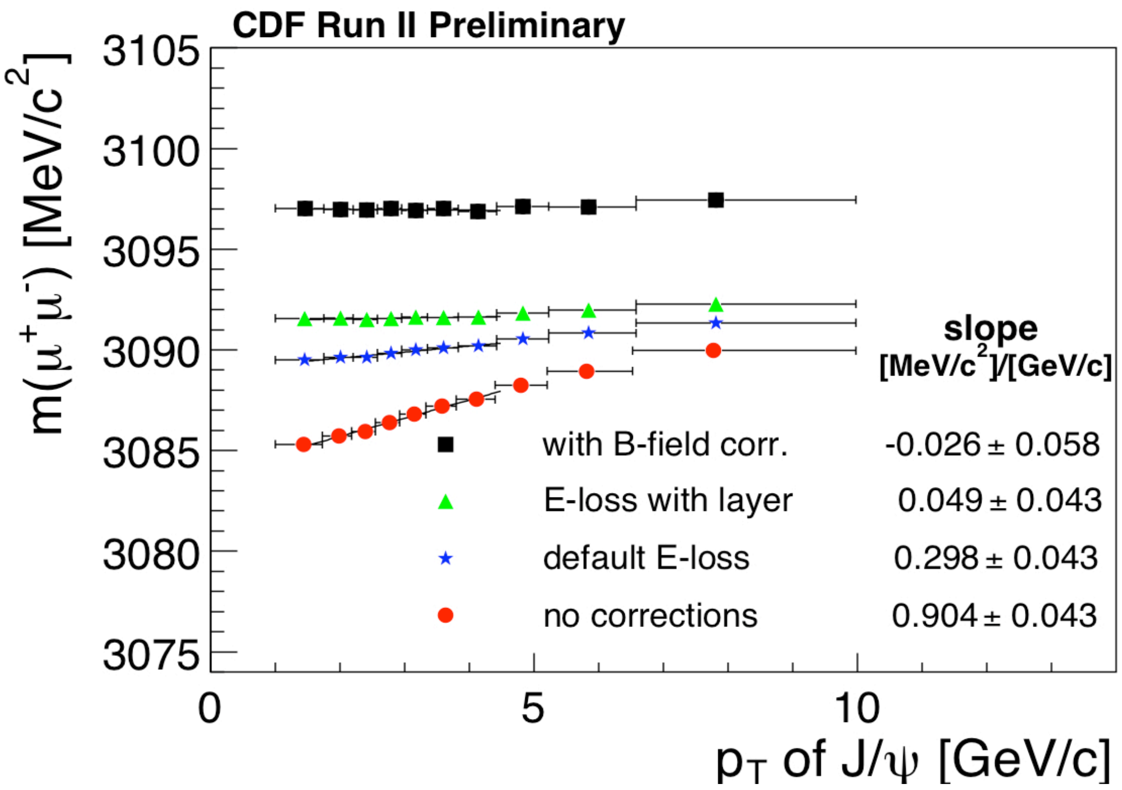


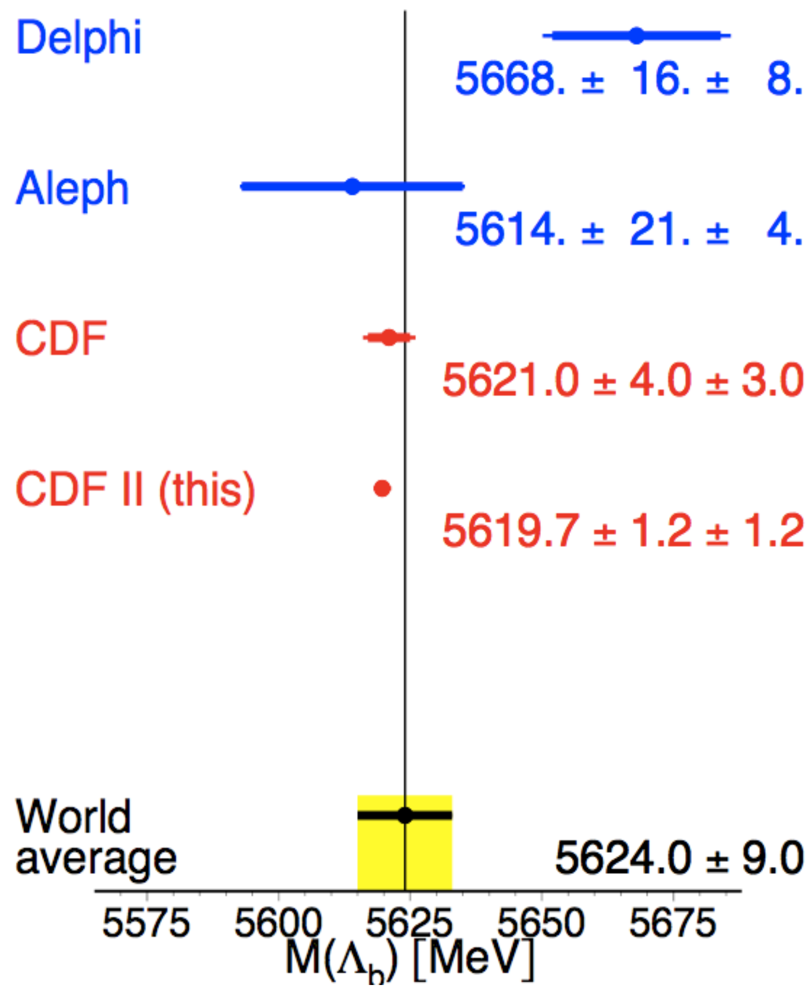
$B_s \rightarrow D_s\mu\nu \rightarrow \phi\pi\mu\nu$

We already have ~5 fb^{-1} on tape

Measure masses @sub-Mev level

Mass scale calibration with $J/\psi \rightarrow \mu\mu$





$M(B^+) = 5279.10 \pm 0.41 \pm 0.36$ MeV

$M(B^0) = 5279.63 \pm 0.53 \pm 0.33$ MeV

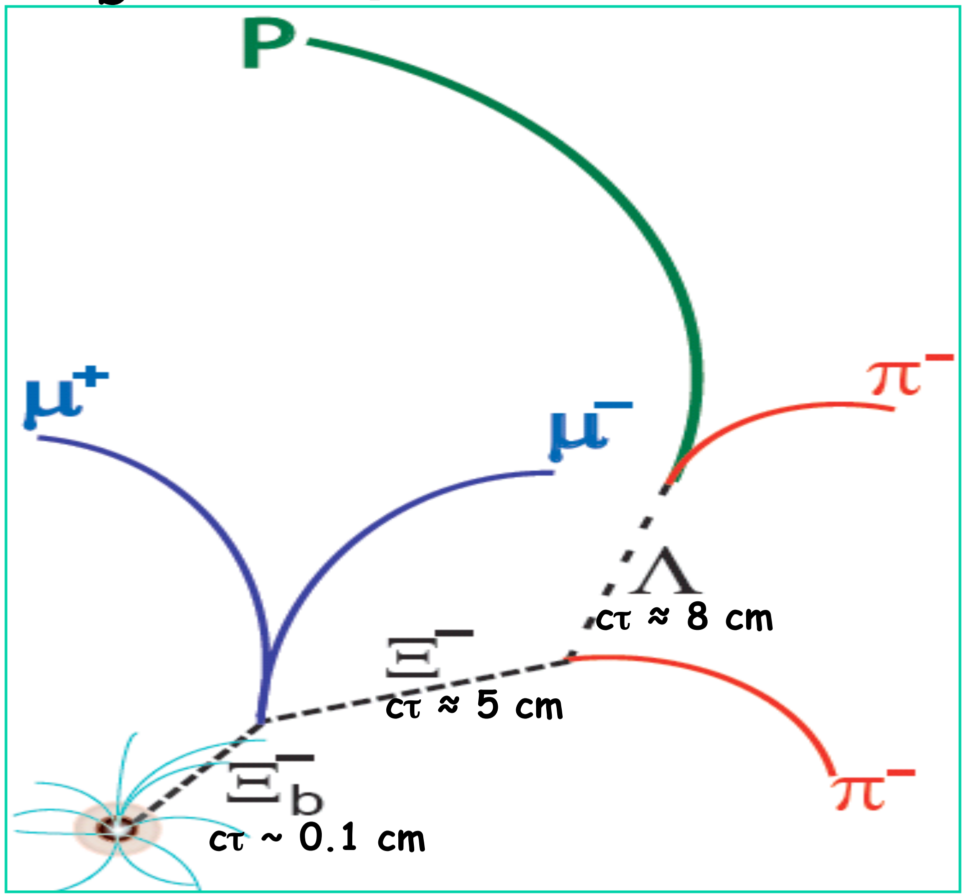
$M(B^0_s) = 5366.01 \pm 0.73 \pm 0.33$ MeV

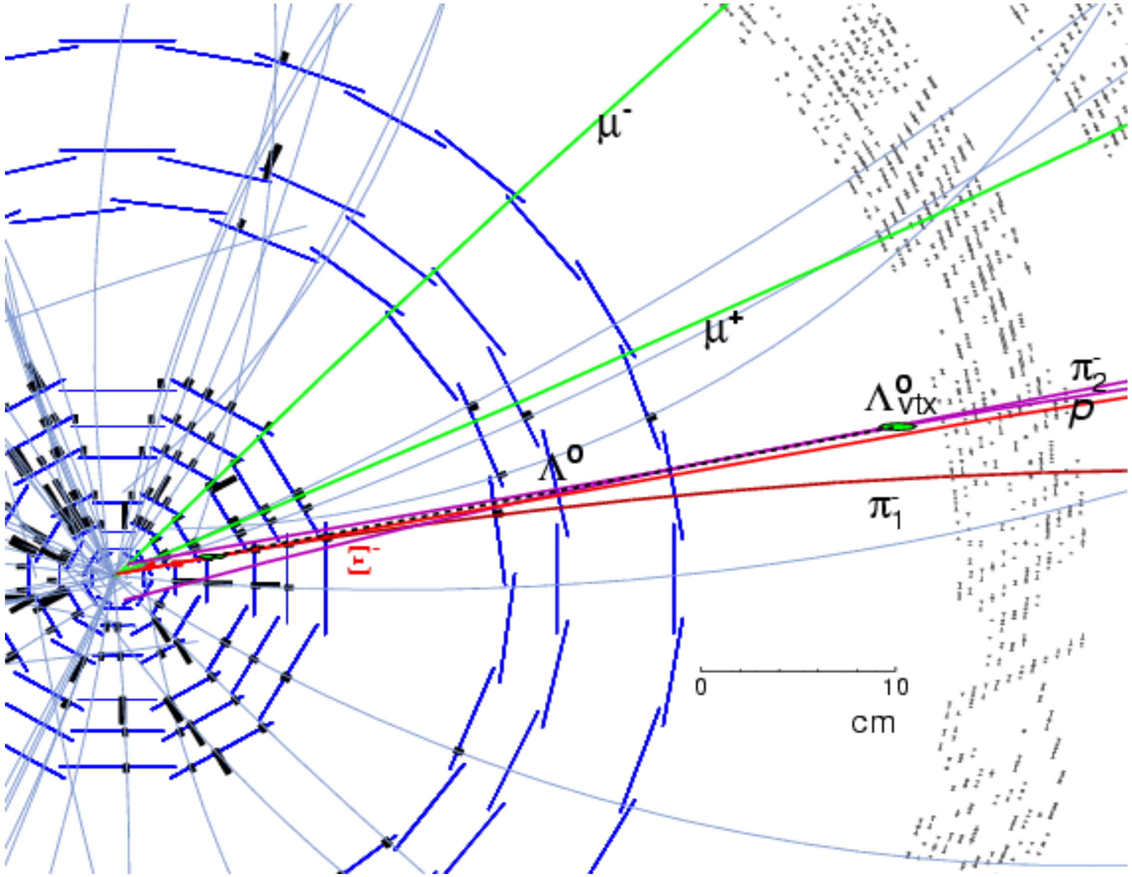
$M(\Lambda^0_b) = 5619.7 \pm 1.2 \pm 1.2$ MeV

Reconstruct most complex topologies

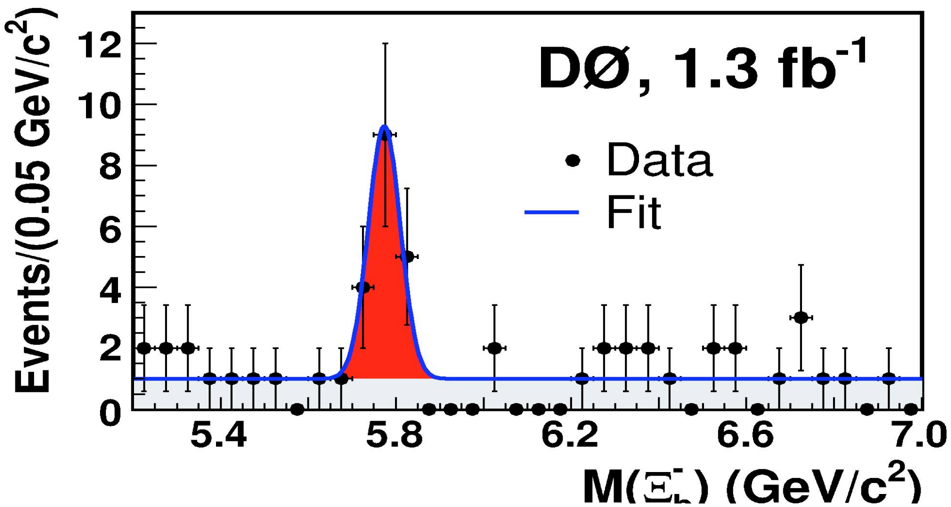
Reconstruct lots of b species: B^0, B^{**0}, B^+, B^0_s, B_c, Λ_b, Ξ_b, Ω_b

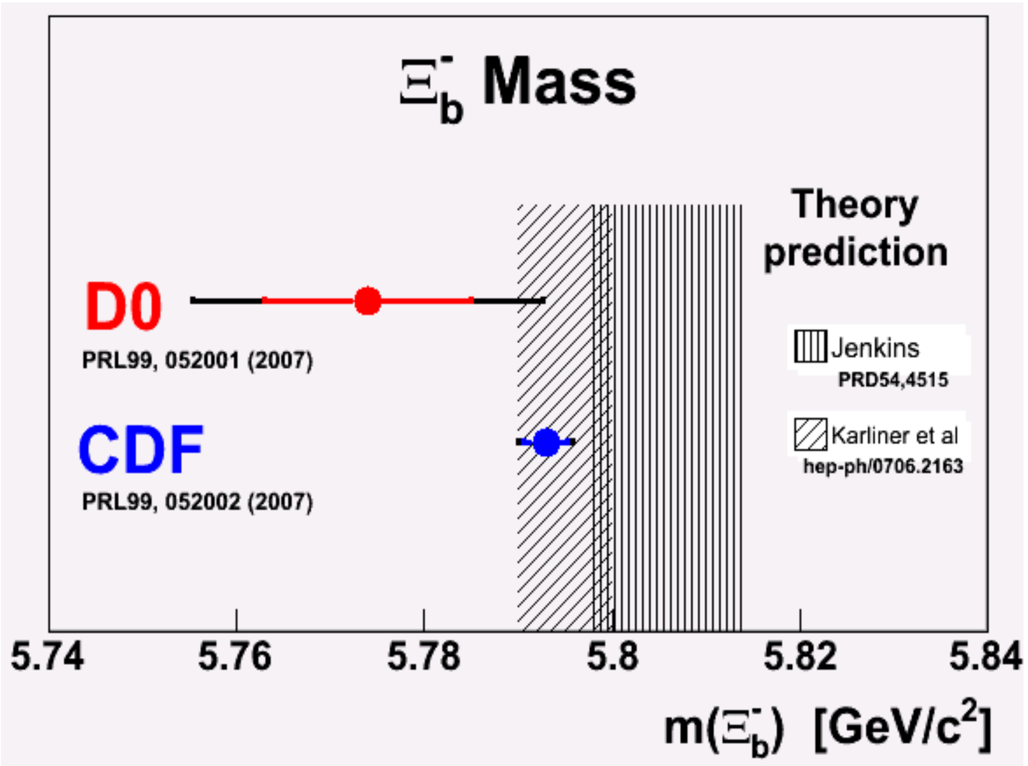
$\Xi^-_b \rightarrow J/\psi \Xi^-$

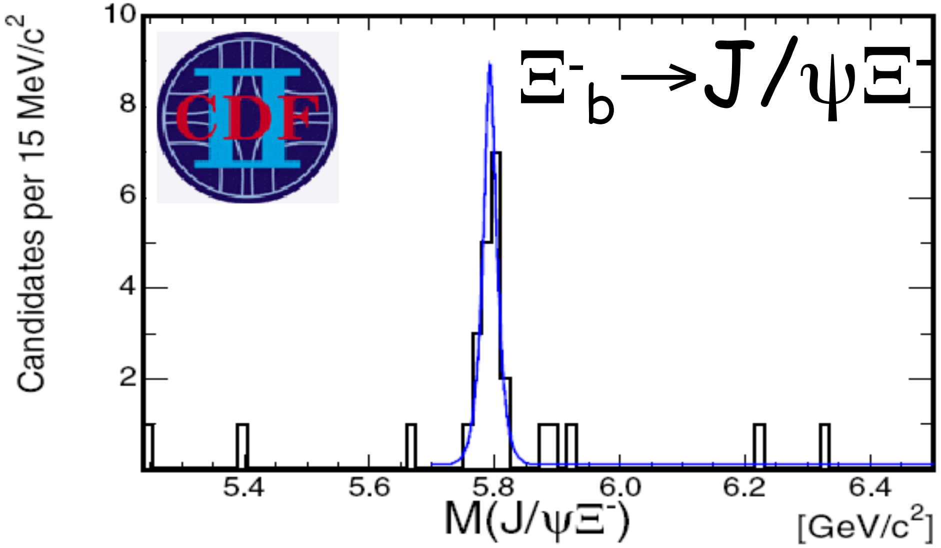




Measure Ξ^-_b mass @MeV level





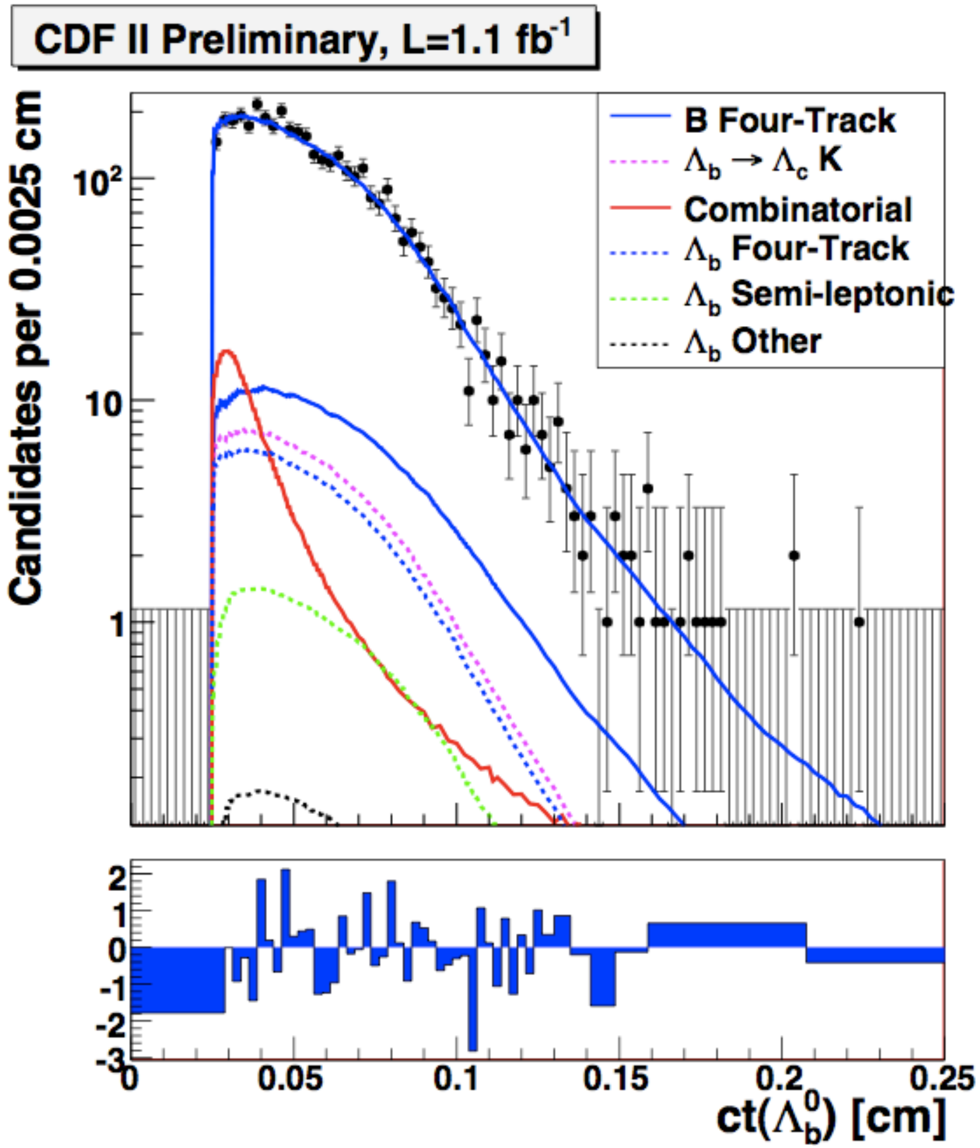


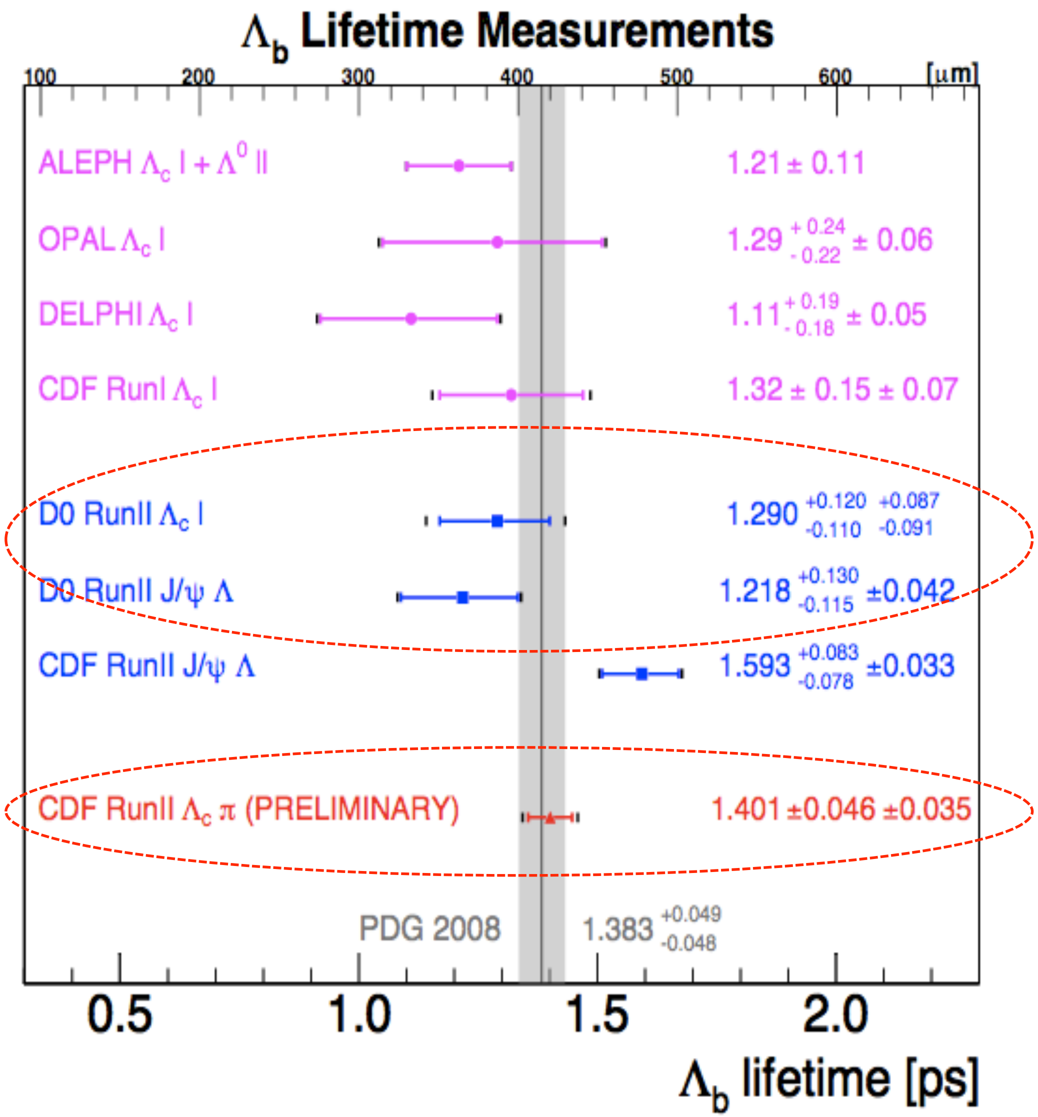
Exp	B[T]	Radii[cm]	|η| Cov	# points
CDF	1.4	1.5-137	<2.0	>100
D0	2.0	1.7-52	<3.0	20

CDF: $M(\Xi_b) = 5790.9 \pm 2.6 \pm 0.8$ MeV

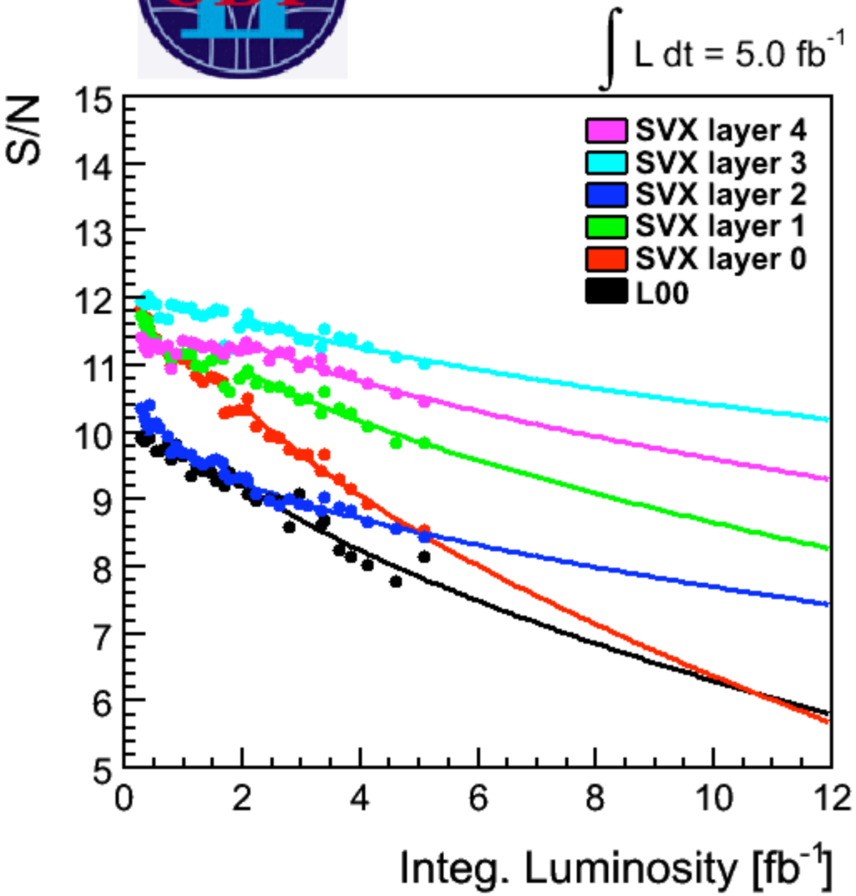
D0: $M(\Xi_b) = 5774 \pm 11 \pm 15$ MeV

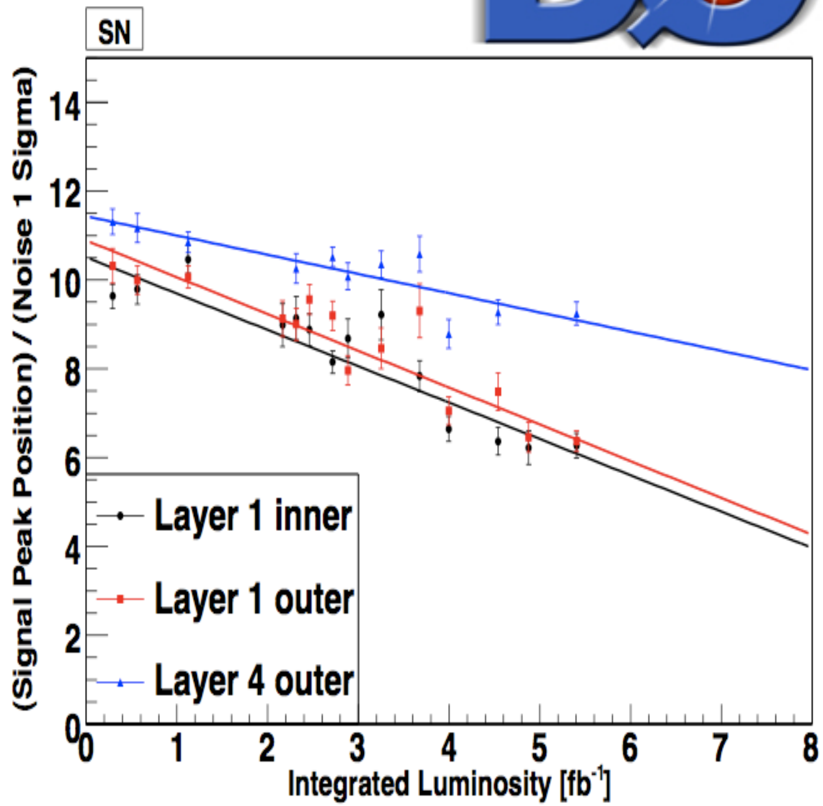
World class b-hadron lifetime measurements





Silicon Detectors status





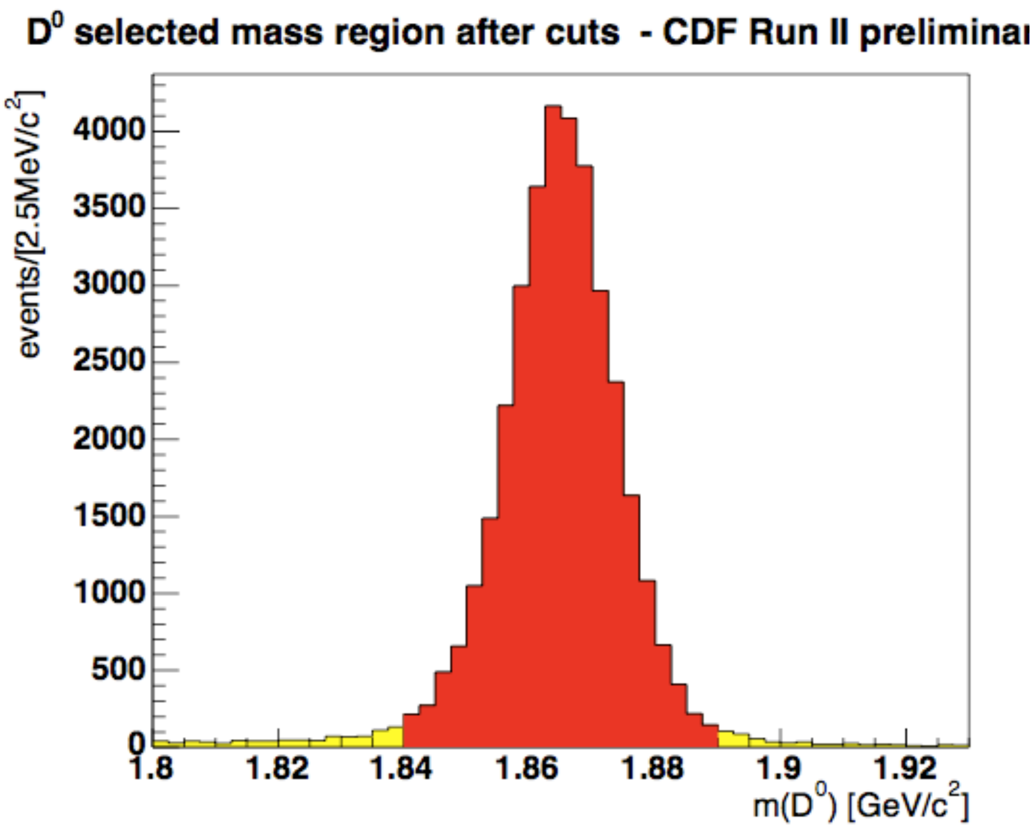
No significant degradation of offline(trigger) tracking performace expected if S/N > 3 (6)

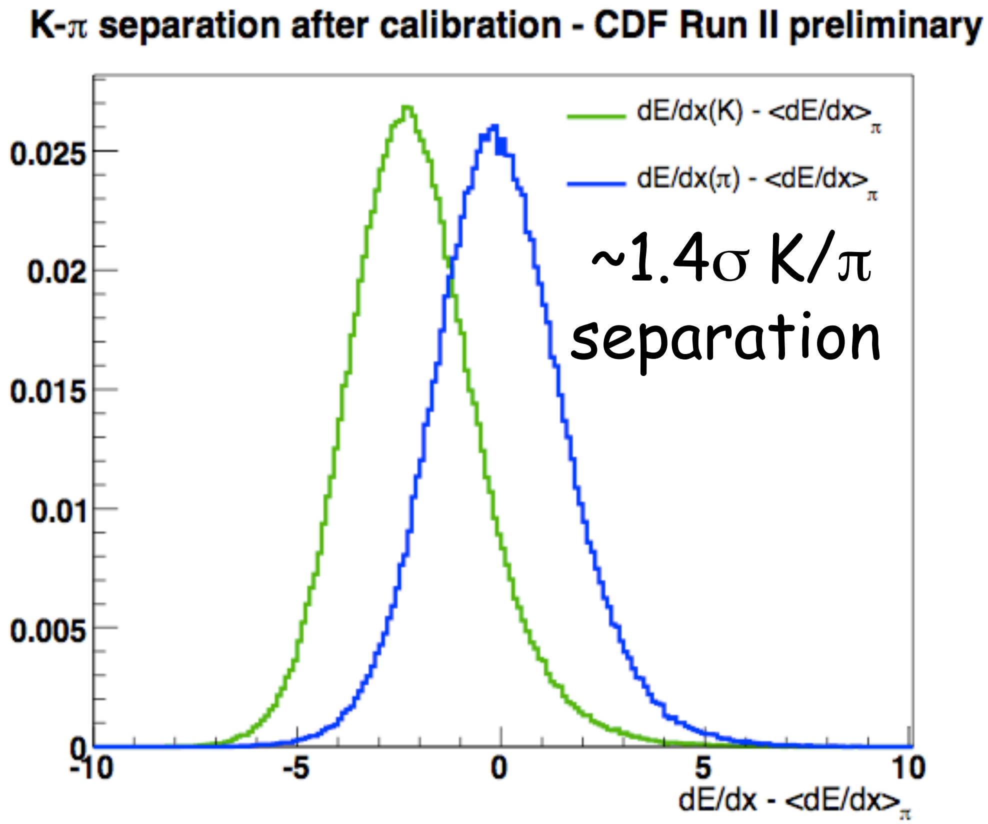
PID from dE/dx (Calibration)

Use large sample of $D^* \rightarrow D^0 \pi_{soft} \rightarrow [K\,\pi]\,\pi_{soft}$ (Hadronic Trigger)

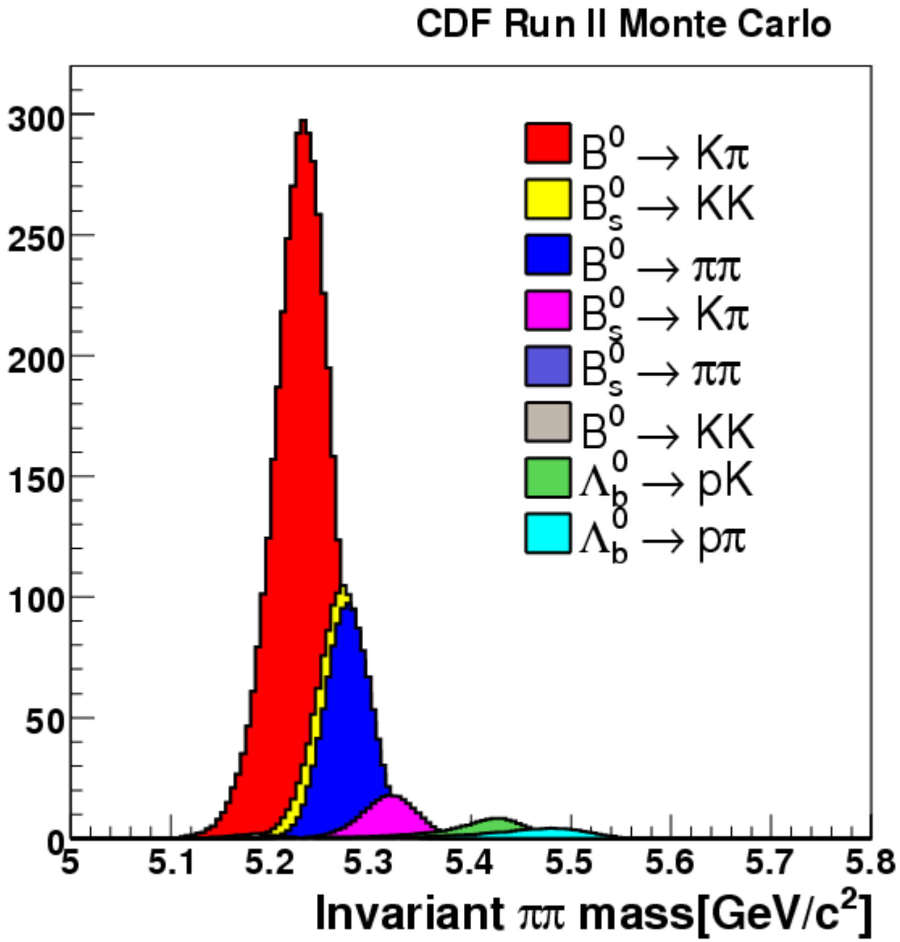
Tight mass cuts: $1.84 < m(D^0) < 1.89$ GeV, $5.3 < M(D^*) - m(D^0) - m(\pi) < 6.5$ MeV
Correct dE/dx dependencies on

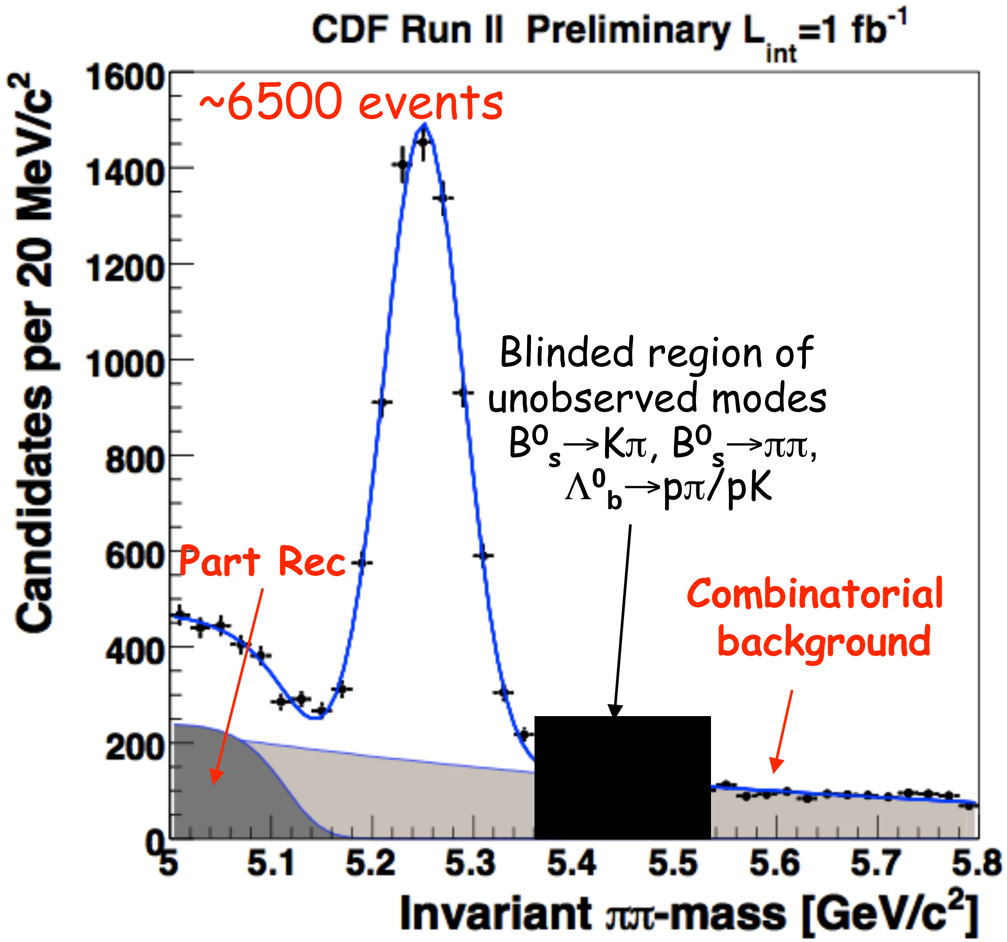
- time (run number)
- track parameters ϕ, η, n(hits), luminosity





Disentangle $B^0_{(s)} \to h^+h'^-$ with dE/dx





Despite good mass resolution (22 MeV/c²) $B^0 \to K\pi$, $B^0 \to \pi\pi$, $B^0_s \to KK$, $B^0_s \to K\pi$ overlap in a single peak (~35 MeV/c²)

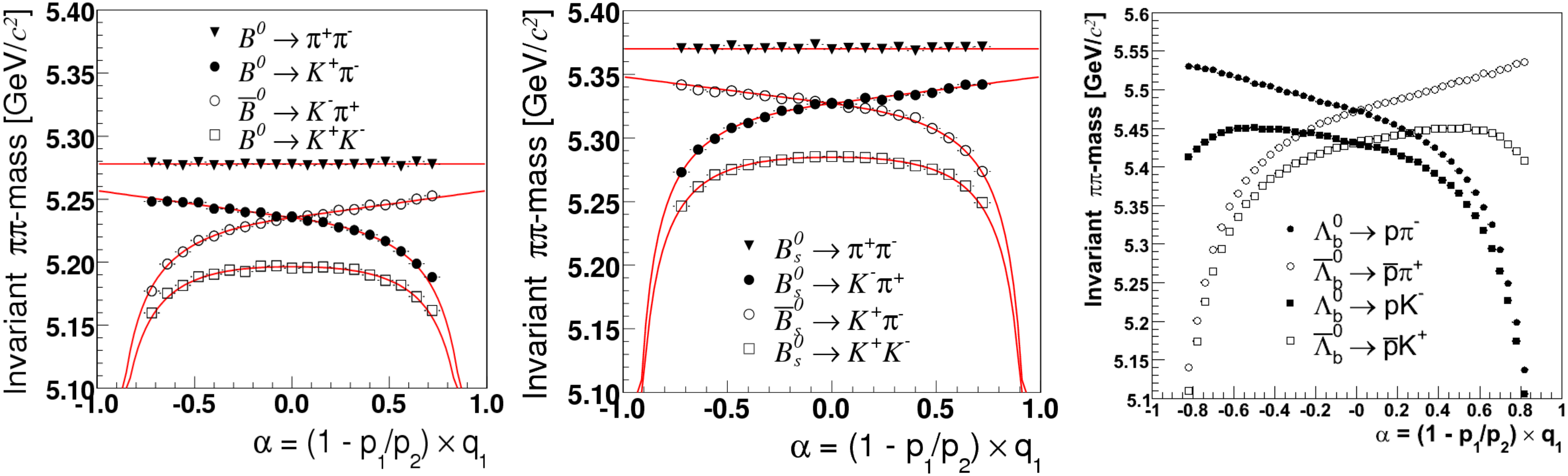
Single mass assignment (ππ) causes overlap even with perfect resolution

Determine signal composition using

- Kinematics (mass and momenta)
- Particle Identification (dE/dx).

Search for Handles (Kin+dE/dx)

CDFII Monte Carlo



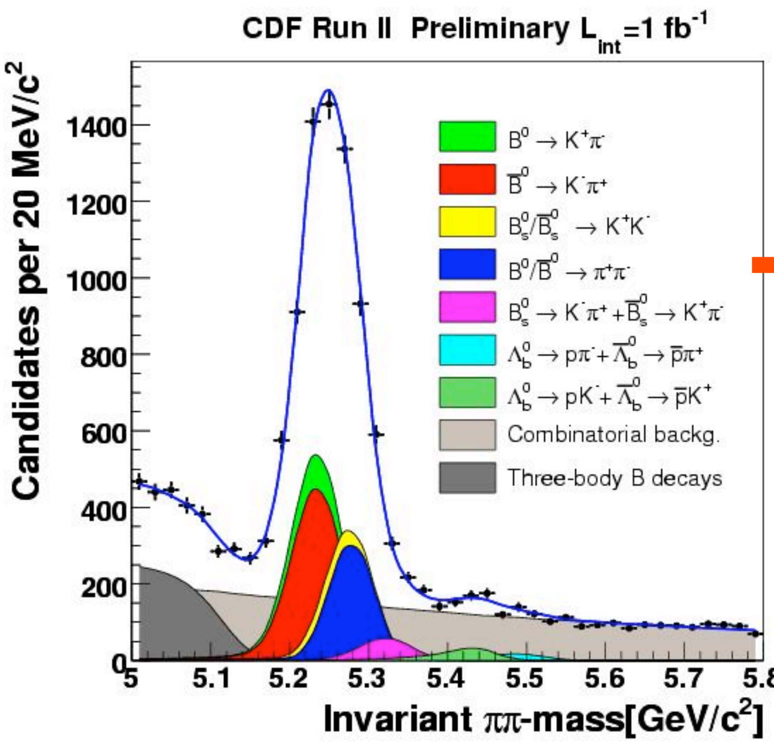
Kinematic variables:

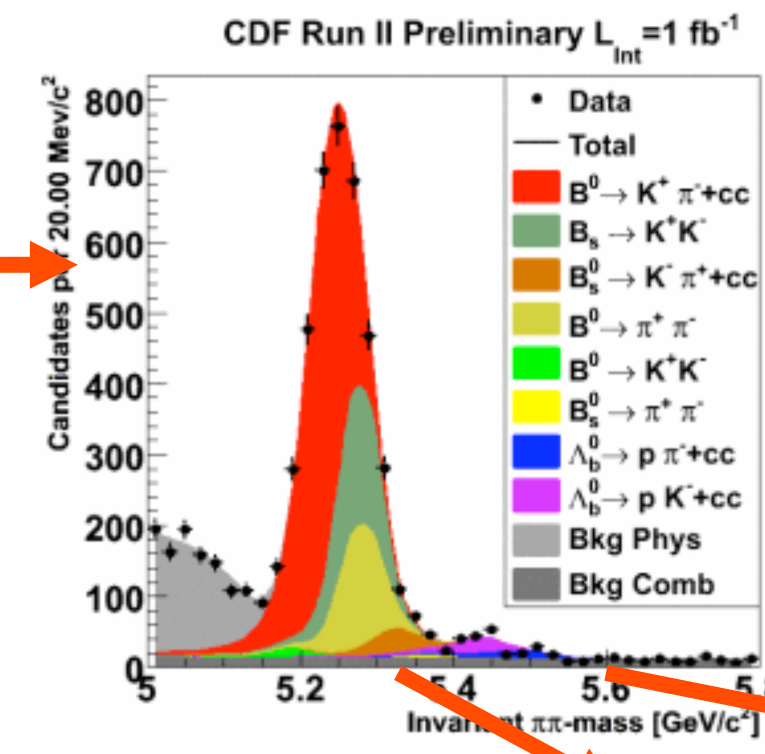
p_{min} (p_{max}) is the 3D track momentum with $p_{min} < p_{max}$

1) $M_{\pi\pi}$ invariant ππ-mass
2) $\alpha = (1 - p_{min}/p_{max}) q_{min}$ signed p-imbalance
3) $p_{tot} = p_{min} + p_{max}$ scalar sum of 3-momenta

This offers good discrimination amongst modes and between $K^+\pi^-/K^-\pi^+$

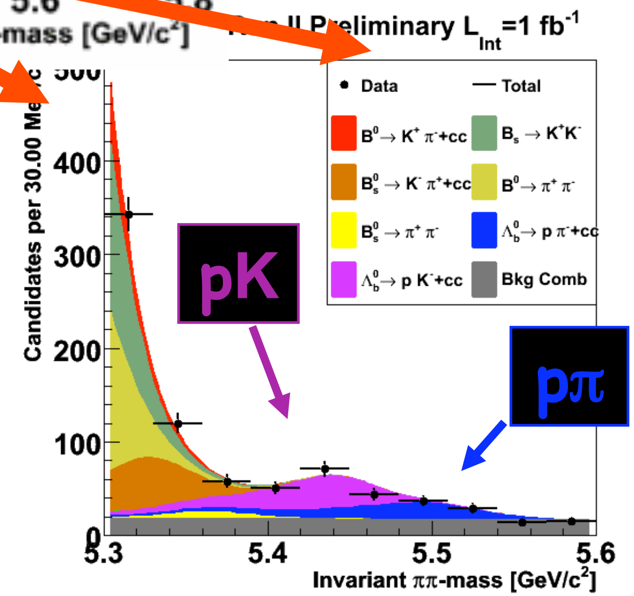
Observe new $B^0_{(s)} \to h^+h'^-$ decay modes





Tighter requirements optimized for Λ_b selection

Clear excess in Λ_b region



3 new rare modes observed

$$N_{\rm raw}(B^0_s \to K^-\pi^+) = 230 \pm 34\ (stat.) \pm 16\ (syst.)$$

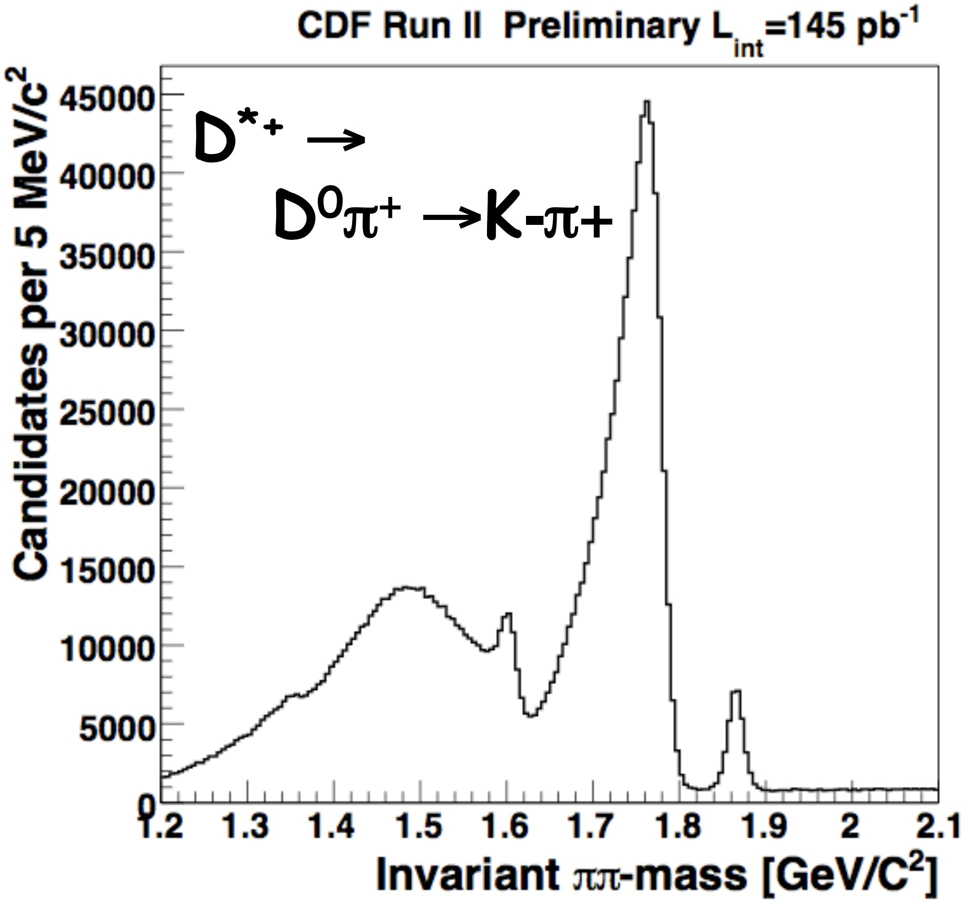
$$N_{\rm raw}(\Lambda^0_b \to p\pi^-) = 110 \pm 18\ (stat.) \pm 16\ (syst.)$$

$$N_{\rm raw}(\Lambda^0_b \to pK^-) = 156 \pm 20\ (stat.) \pm 11\ (syst.)$$

Direct CP in $B^0_{(s)} \rightarrow h^+h^{'-}$ decay modes

ACP measurements

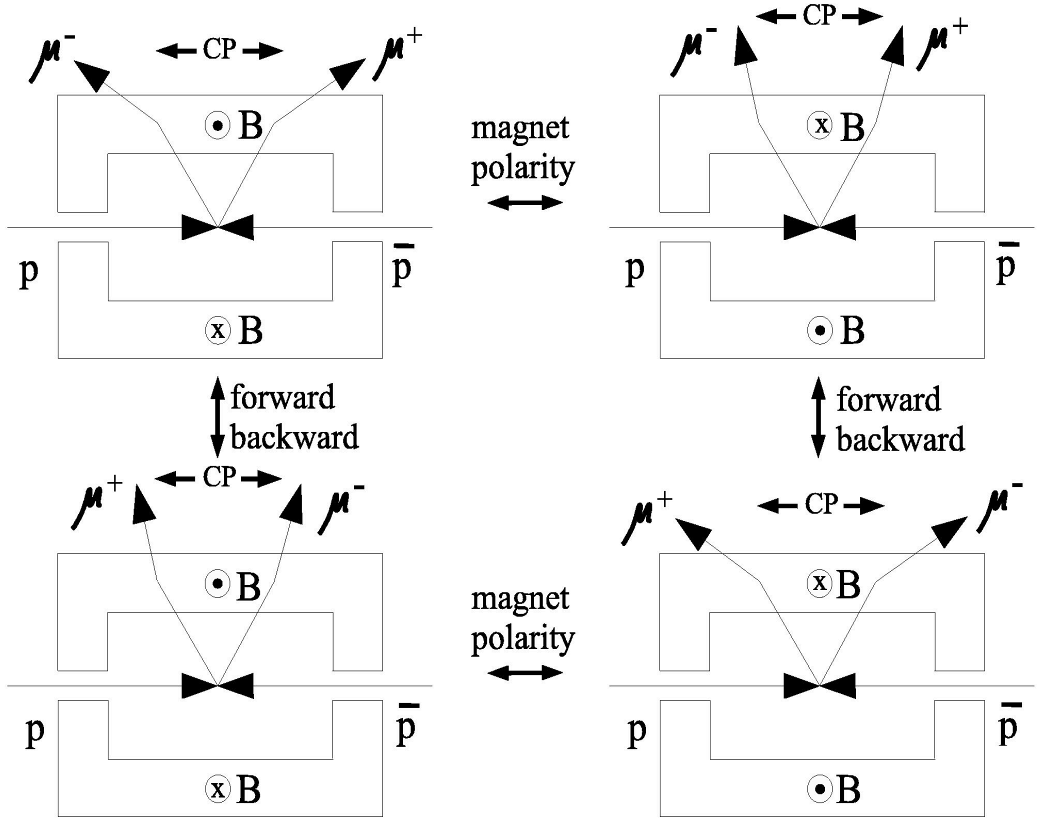
$Acp(B^0 \rightarrow K\pi) = -0.086 \pm .023 \pm .009$
$Acp(B^0_s \rightarrow K\pi) = 0.39 \pm 0.15 \pm 0.08$
$Acp(\Lambda^0_b \rightarrow p\pi) = 0.03 \pm 0.17 \pm 0.05$
$Acp(\Lambda^0_b \rightarrow pK) = 0.37 \pm 0.17 \pm 0.03$



Use large sample of $D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+$ and $\Lambda^0 \rightarrow p\pi^-$ to correct for asymmetric detector effects $\varepsilon(K^-\pi^+)/\varepsilon(K^+\pi^-)$ and $\varepsilon(p^-\pi^+)/\varepsilon(p\pi^-)$

D0 strategy for charge asymmetries

Asymmetric detector effects reduced by regular flipping of DØ's B fields.
(trk(q>0)=trk(q<0) if B reversed)



World class CP measurements in semileptonic B decays

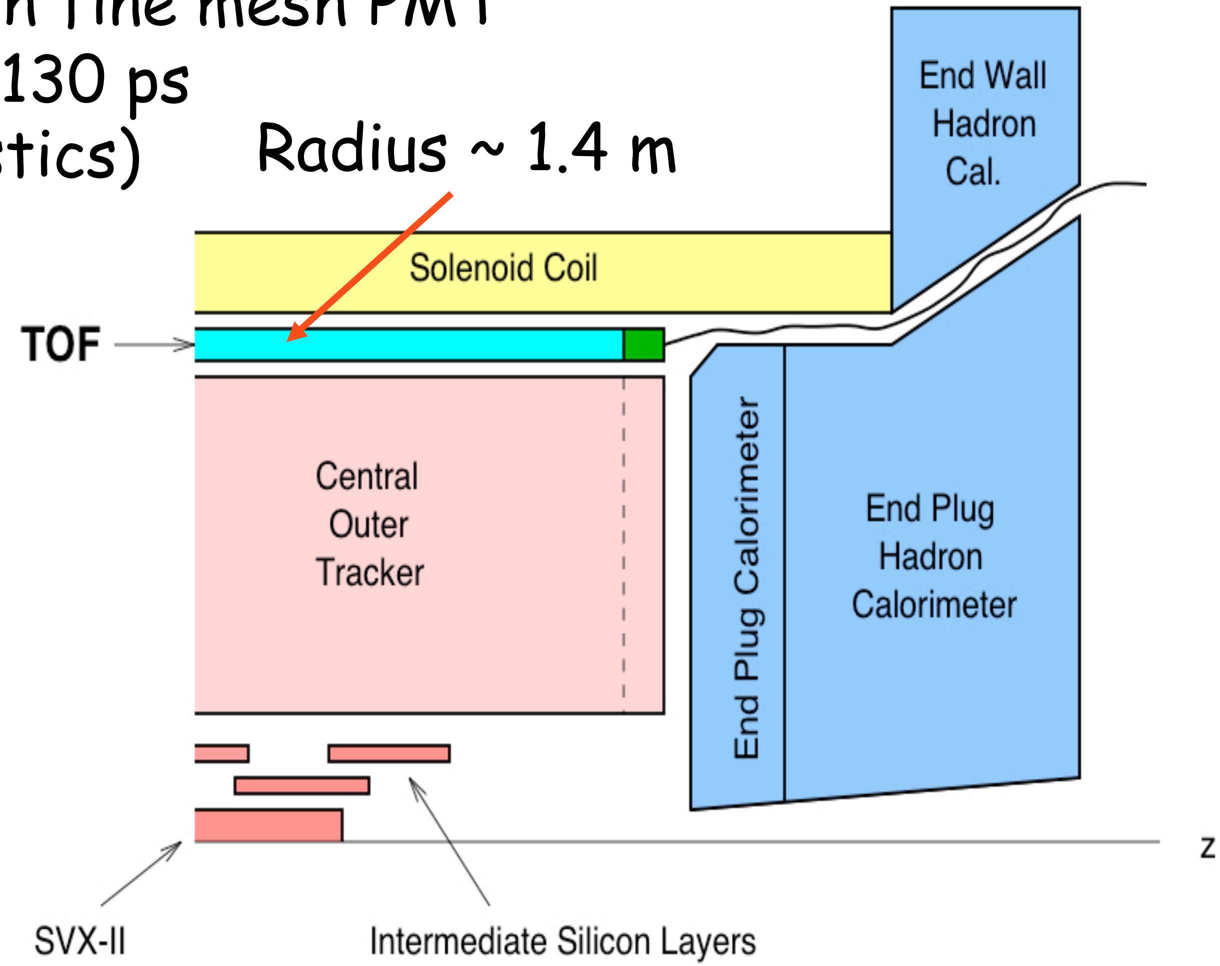
Most recent CP measurement in $B^0_s \rightarrow \mu^+ D^-_s X$
$a^s_{fs} = [-1.7 \pm 9.1^{+1.2}_{-2.3}] \times 10^{-3}$
(arXiv:0904.3907)

All details in Steve Beale's Talk

Time Of Flight Detector

216 Scintillator bars, 2.8 m long, 4x4 cm^2
read out both ends with fine mesh PMT
Measured σ_{TOF} = 100 - 130 ps
(limited by photostatistics)

Radius ~ 1.4 m



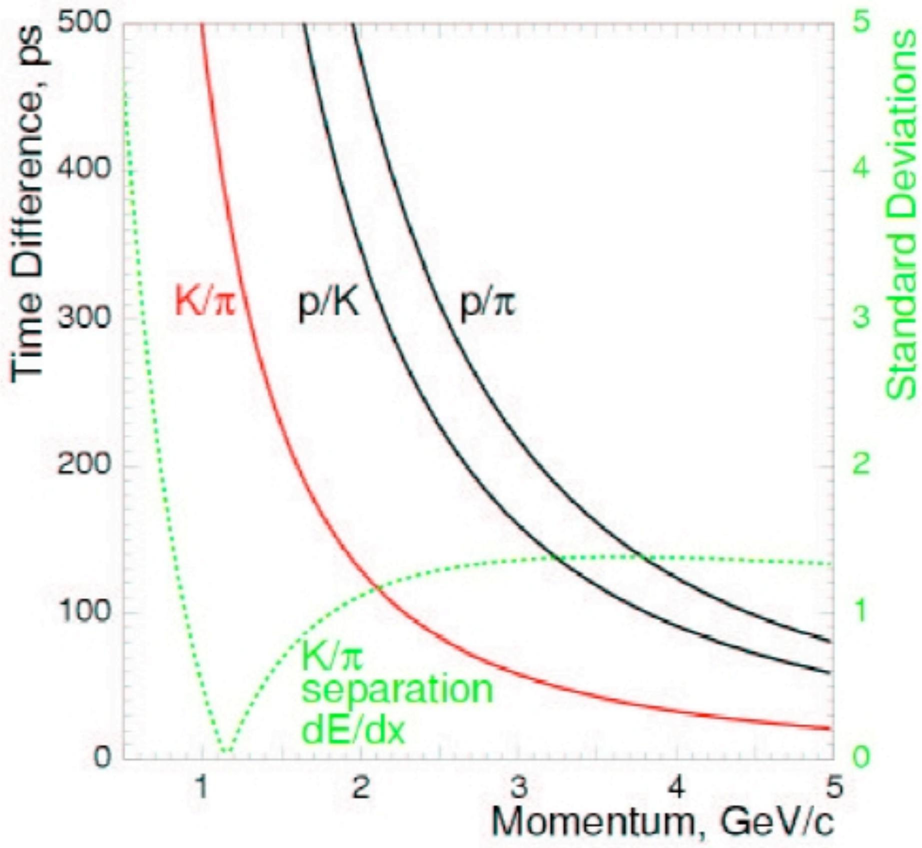
<u>Measured quantities:</u>

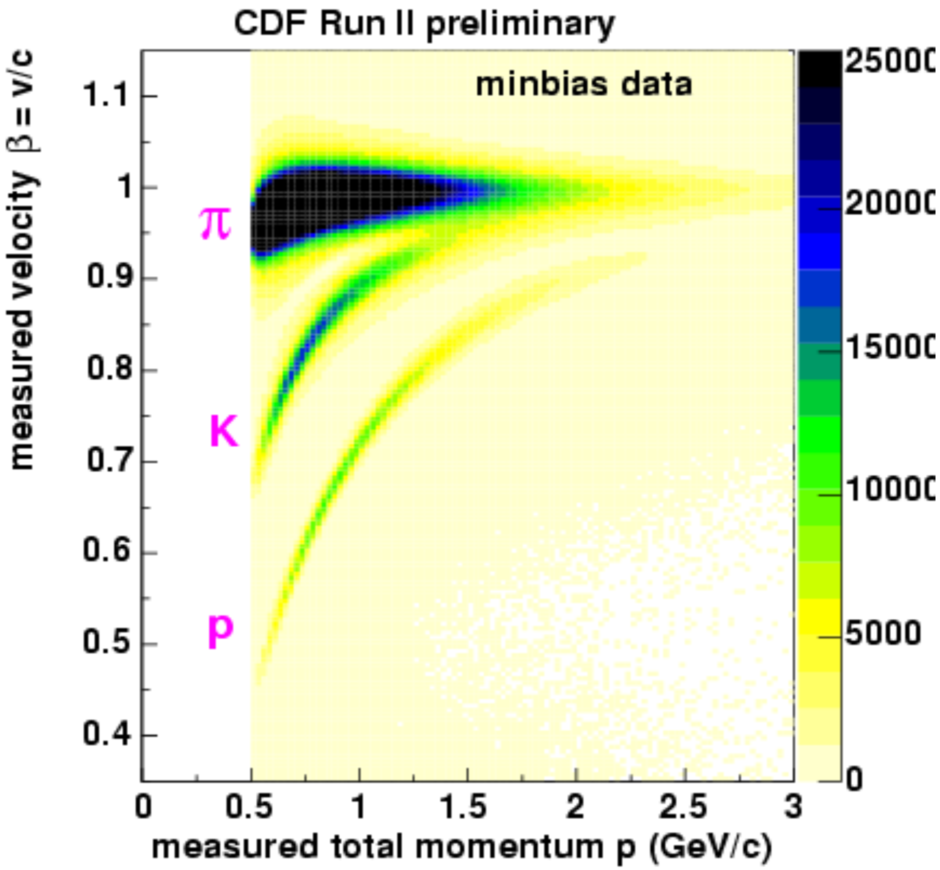
s = distance travelled
t = time of flight
p = momentum

<u>Derived quantities:</u>

$v = s/t$
$m = p/\gamma v$

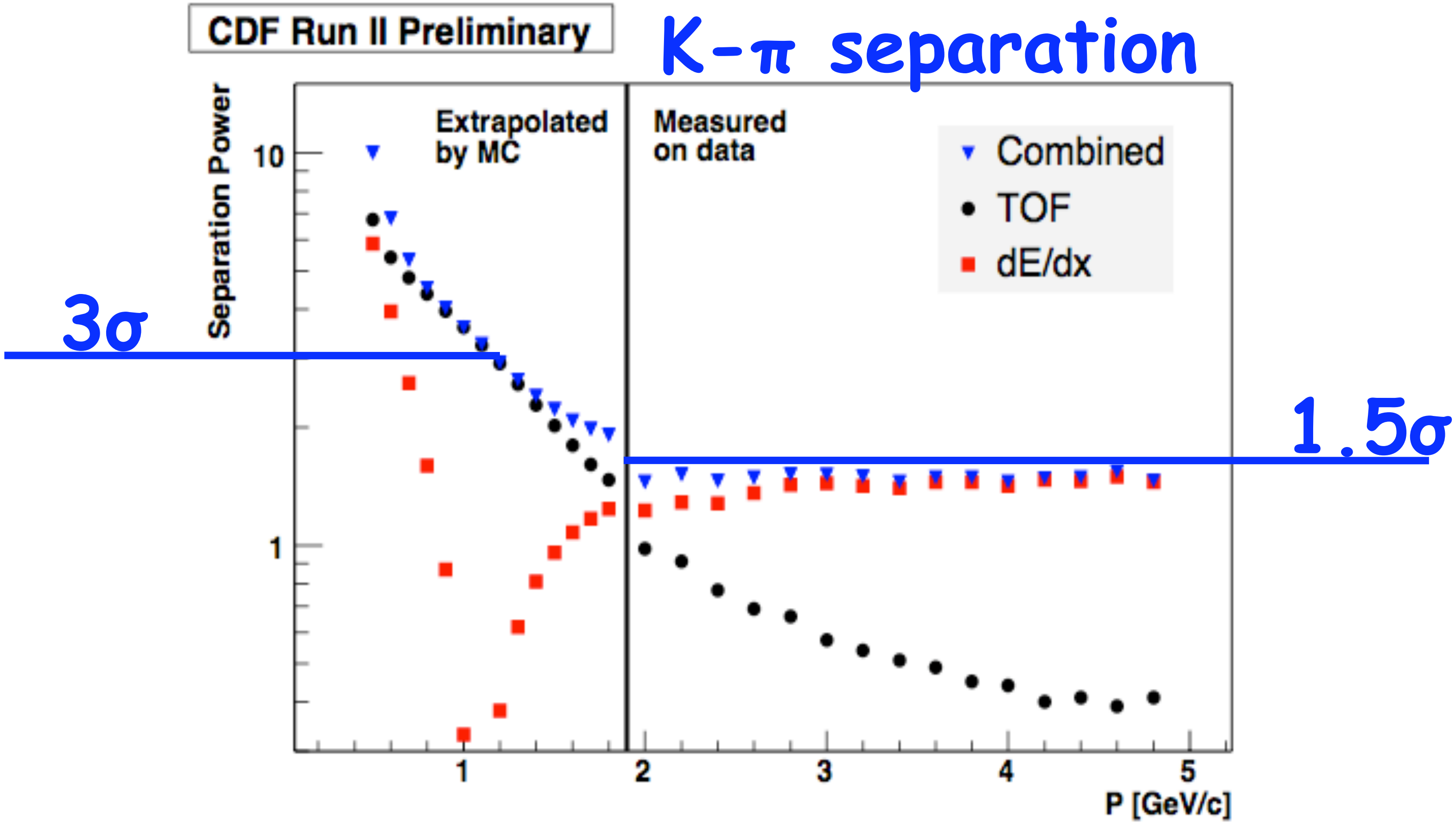
Time Of Flight Detector





Measured time resolution: σ_t ~ 110 ps

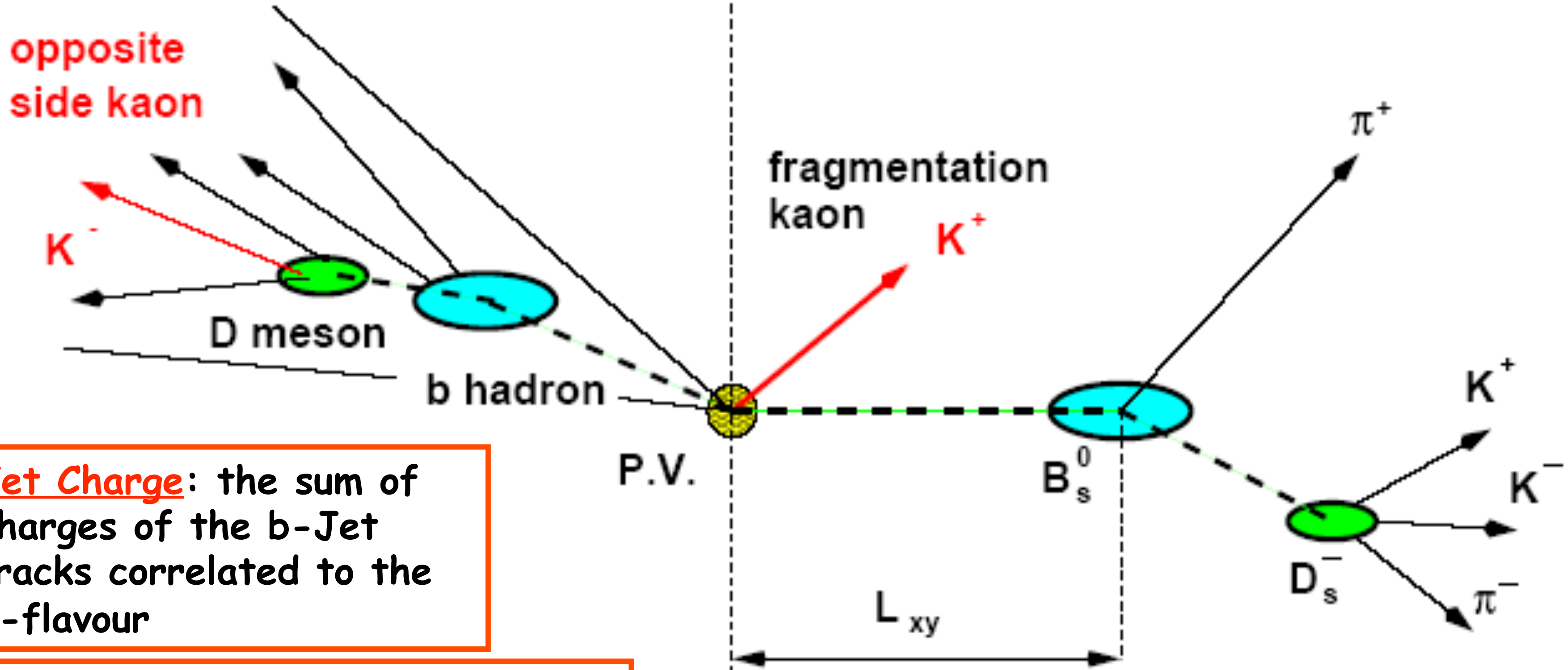
Combined PID (TOF+dE/dx)



Typical B decay daughter momentum ~GeV

More on tools: Flavour tagging

Opposite Side | **Same Side**



Jet Charge: the sum of charges of the b-Jet tracks correlated to the b-flavour

Soft Lepton (e,μ): due to $b \rightarrow \ell \nu X$
ℓ charge correlated to b-flavour

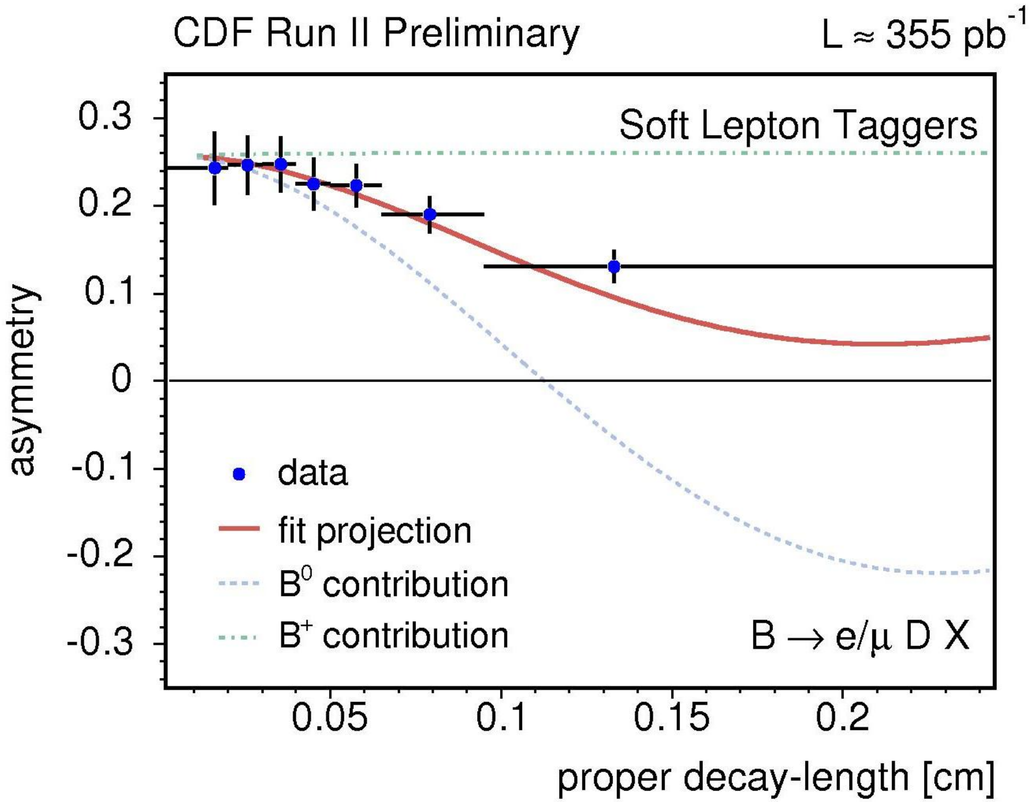
Opposite Side K: due to $b \rightarrow c \rightarrow s$
→search for secondary K (use PID)

Same Side Kaon: for B^0_s is likely to have close in ΔR a K+ from fragmentation (use PID)

Similar εD^2 for both CDF and DØ ~4.5% (~30% at B factories)
(Tevatron Yellow Book -year 2001- expected εD^2 ~11% at CDF)

Opposite Side Taggers

OST optimised by measuring B_d mixing



- Use exclusive combination of:
  - 2 SLT (μ, e)
  - 3 JQT categories
  - No OSKT

OST εD^2 =1.81±0.10 % (CDF)
OST εD^2 =2.48±0.21 % (D0)

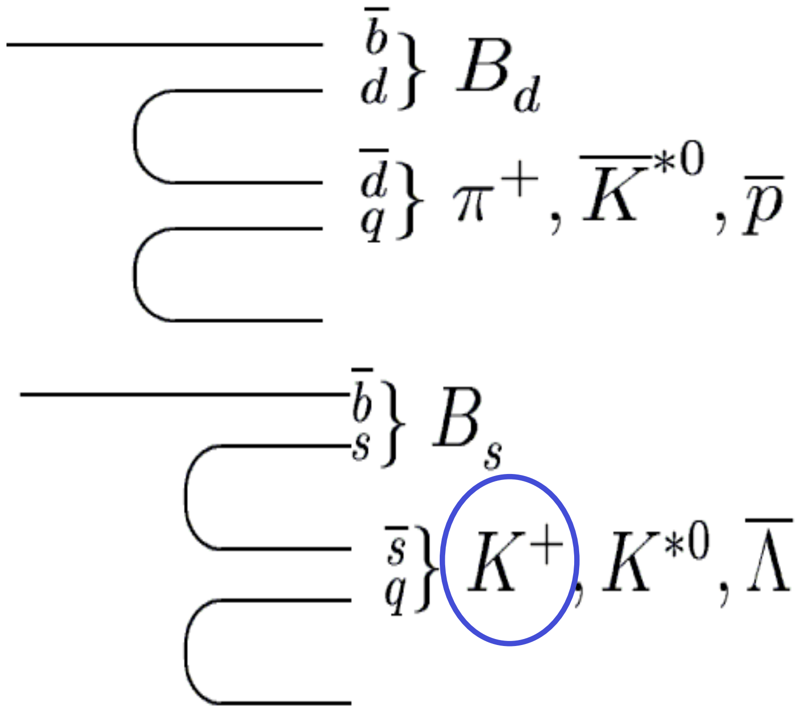
	HADRONIC (355 pb^{-1})	SEMILEPTONIC (1 fb^{-1})
Δm_d	(0.536±0.028±0.006) ps^{-1}	(0.509±0.010±0.016) ps^{-1}

Same Side Taggers

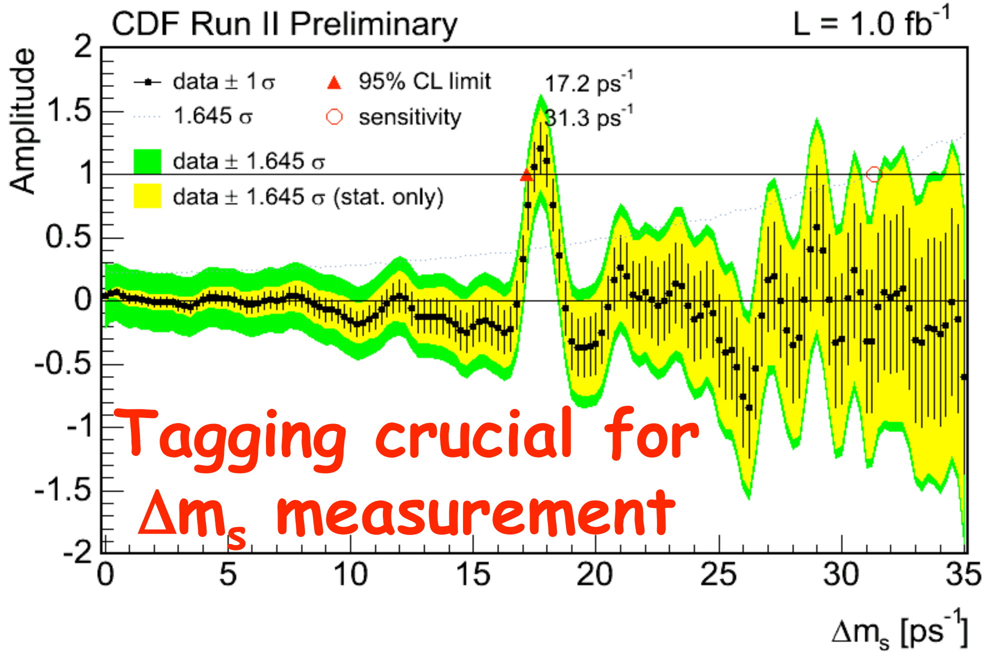
Look for the fragmentation track charge correlated with the B

Rely on MC prediction of SSKT performance for B_s mixing

- Choose the track in a cone of ΔR < 0.7 around B most likely to be a K
- Make use of PID based on dE/dx and TOF information (CDF)



SST $\varepsilon D^2 = 4.0^{+0.8}_{-1.2}$ % (CDF)
SST $\varepsilon D^2 = 1.7 \pm 0.6$ % (D0)



Conclusions

- CDF/D0 Detectors/Triggers are well understood and show stable performance with time
- Datasets increasing smoothly, as well as physics results