CKM workshop, Durham, April 8, 2003

Performance of CDF for B physics

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University of Pennsylvania

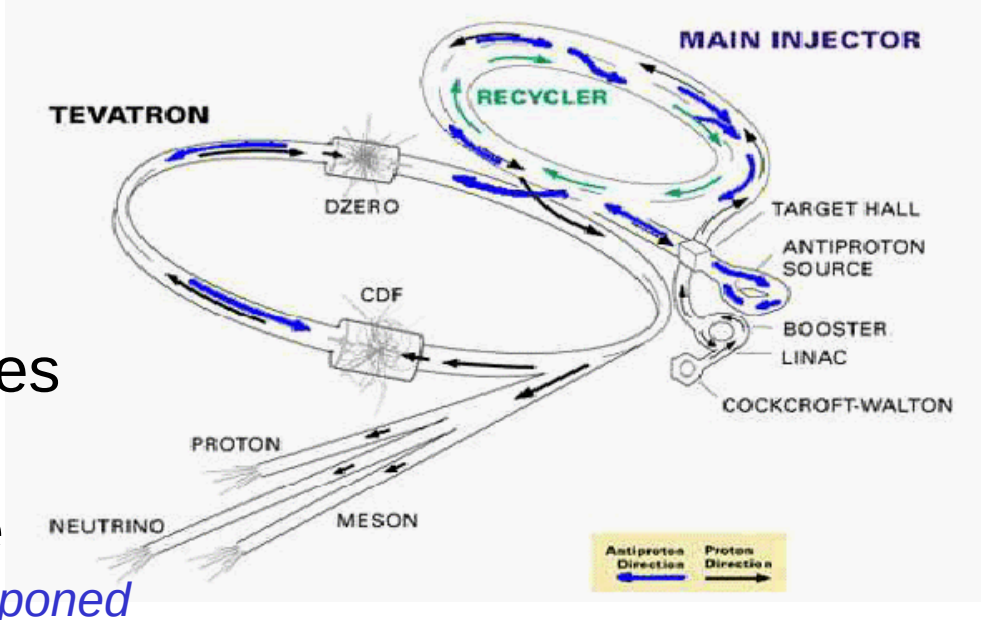
For the CDF collaboration

Outline

- Tevatron & CDF
- Trigger strategies
- Techniques for higher yields, lower rates
- B yields and results

Flavor tagging discussed yesterday in Donatella's talk

$p\bar{p}$ 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 ≈1 interaction/bunch crossing

Anticipate up to 10 in future

Interaction region:

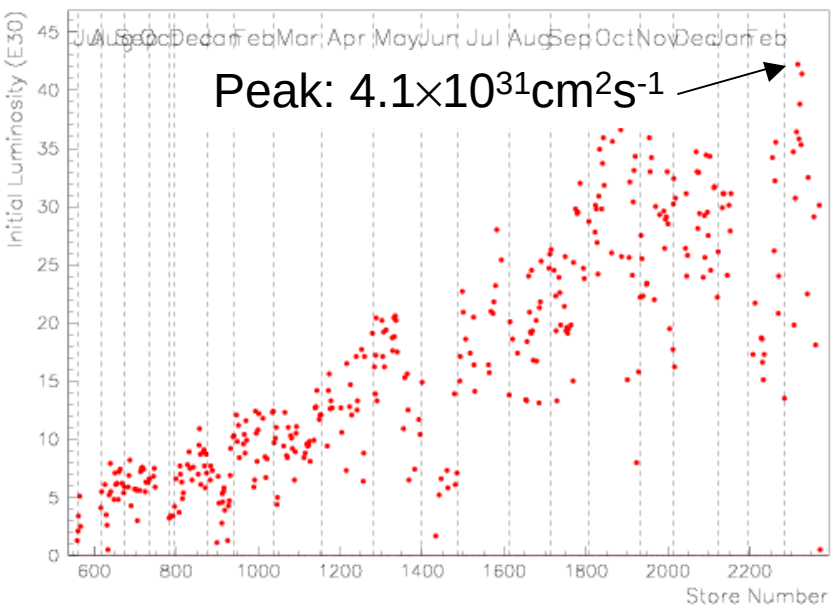
≈ 30 cm long

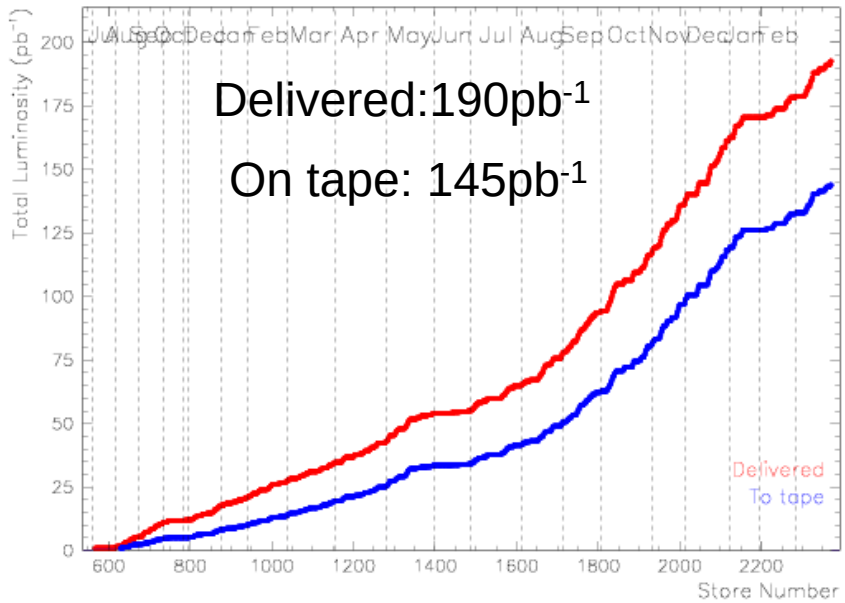
Need a long silicon detector

≈ 30 μm transverse size

Small compared to ct(B) » 450 mm

Tevatron performance





Still factor 2 below nominal

Present analyses use ≈70pb^{-1}

Compare to 110pb^{-1} in Run I

B physics at hadron colliders

Huge production rates: B^+ : 3.6±0.6μb *(Run I measurement)*

(For p_T³6GeV, |Y|£1)

D^+ : 4.3±0.7μb
D^0 : 9.3±1.1μb

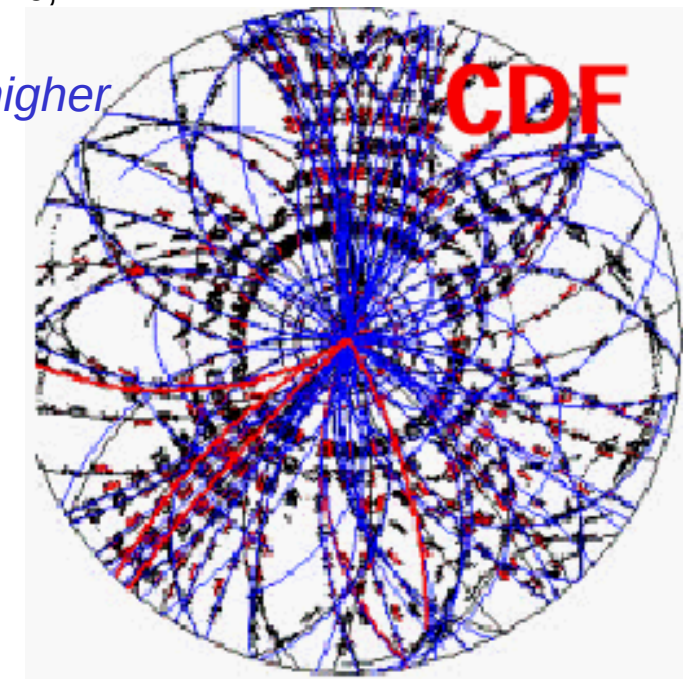
New Run II result!

3 orders of magnitude higher than at $e^+e^- \rightarrow \Upsilon(4S)$

Produce all B species: B^0, B^+, B_s, B_c, Λ_b,...

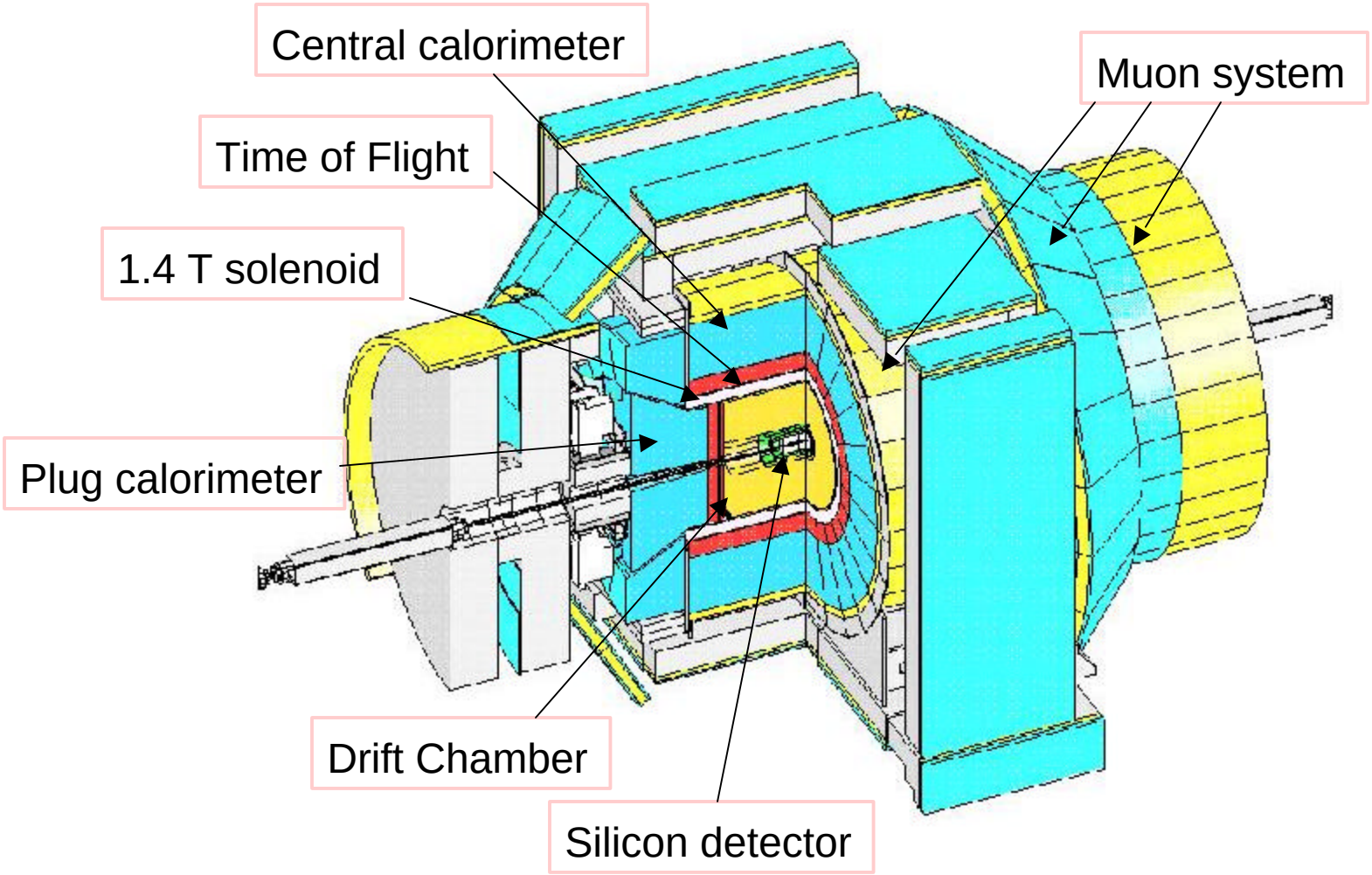
But backgrounds are also 3 orders of magnitude higher

Challenge: pick the 1 B decay from 10^4 QCD events



It's all about having a good trigger

The CDFII detector



The Central Outer Tracker (COT)

1.4 meter outer radius

Inside 1.4 Tesla solenoid

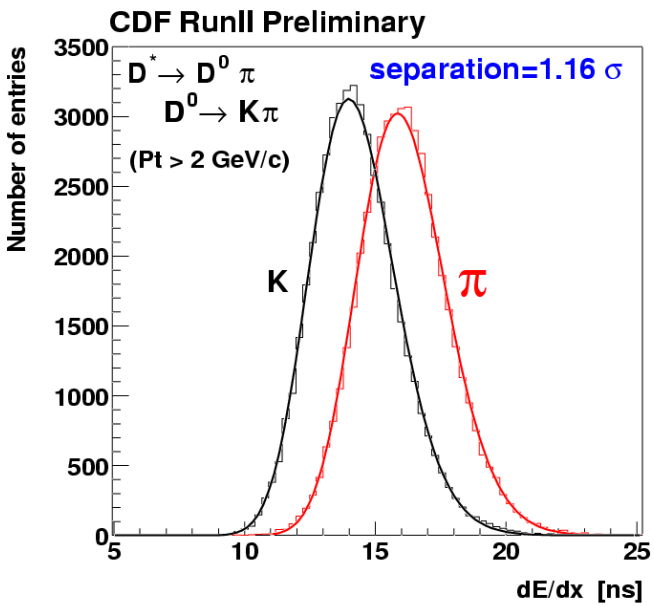
30,240 read out wires

4 axial superlayers (12 wires)
4 stereo superlayers (±50 mrad)

200 μm single wire resolution

$$\frac{\Delta p_T}{p_T} = (0.7 \oplus 0.1 \cdot p_T)\%$$

dE/dx: 1.2σ dE/dx π/K separation



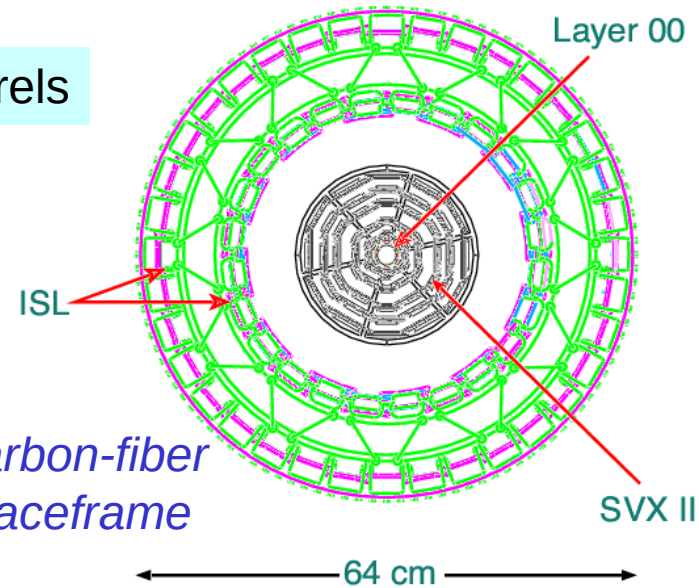
Very high tracking efficiency: >99.5%
(for high p_T,isolated tracks)

Very reliable operation
<1% dead channels

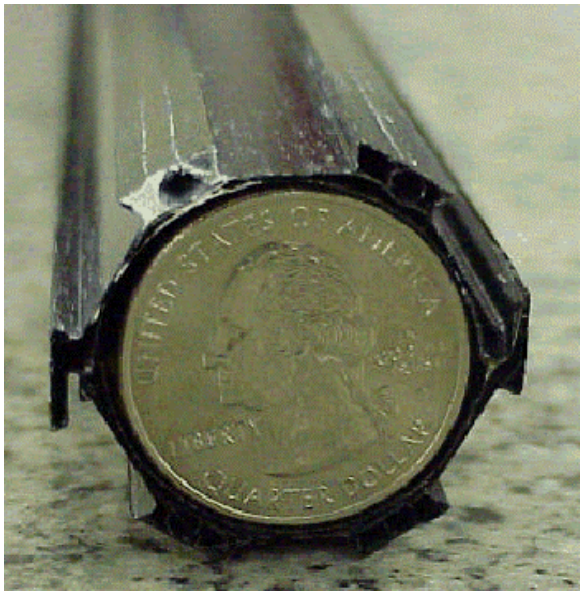
The CDF silicon system

750k channels total

SVXII	5 layers, double sided, 90cm long, 3 barrels
ISL	1.5 layer, double sided, 3.5m^2
	For high h tracking
Layer00:	Single-sided, radiation-hard, low mass



Carbon-fiber spaceframe



Impact parameter resolution:13+40/p_T μm

Analog pipeline

Deadtimeless operation

Optical readout

20 ms readout complete detector

Silicon trouble

SVXII

Beam incidents→broken chips

Very high instantaneous dose

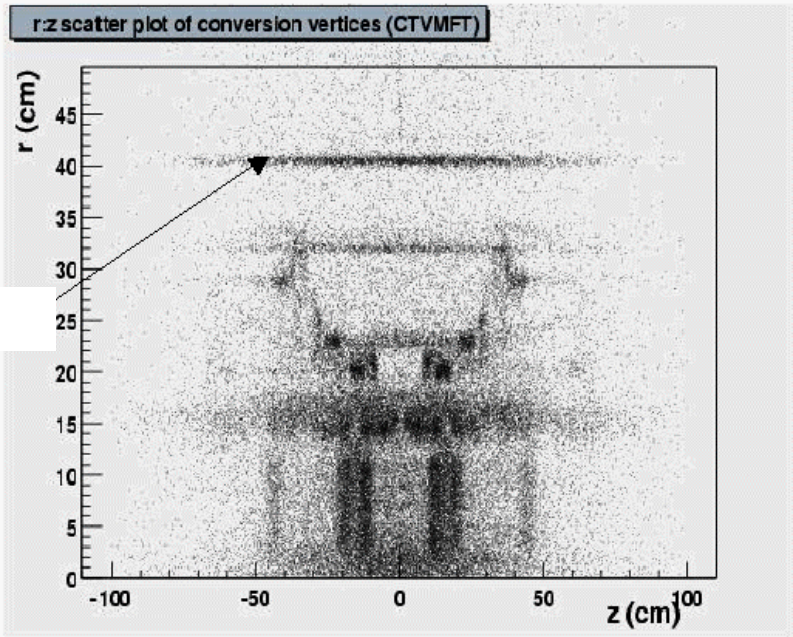
Wirebonds oscillate&break in Bfield

Avoid fixed-frequency readout

ISL

Cooling lines obstructed by epoxy

11/12 cleared with boroscope & 40W laser



So much material: » 0.15X_0

L00

Digital→analog cross-talk

Corrected in software, but cannot do sparsified readout

Since Jan, >90% works

Beam-related power supply failures

Replaced MOSFET voltage regulator by BJT

The Time-of-Flight detector (TOF)

4x4 cm scintillator bars, 3 m long (216)

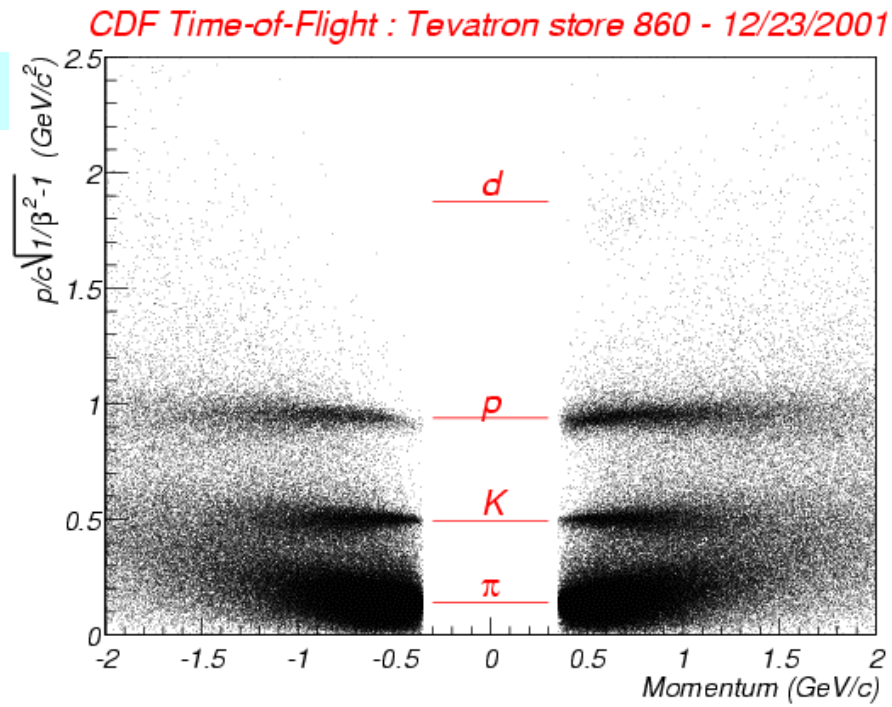
Between COT and solenoid

Readout on both sides of the bar

Compact, fine-mesh PMT
for operation inside B-field

110 ps timing resolution
2σ π /K separation for $p_T \leq 1.5$ GeV

Designed for flavor tagging



Very stable operation, all 432 channels work

Occupancy higher than expected

» 20% instead of 10%, affects the reconstruction efficiency

The three-level trigger

1.7 MHz bunch crossing rate

Dedicated hardware

42 L1 buffers

16 kHz L1 accept

Future: 25kHz

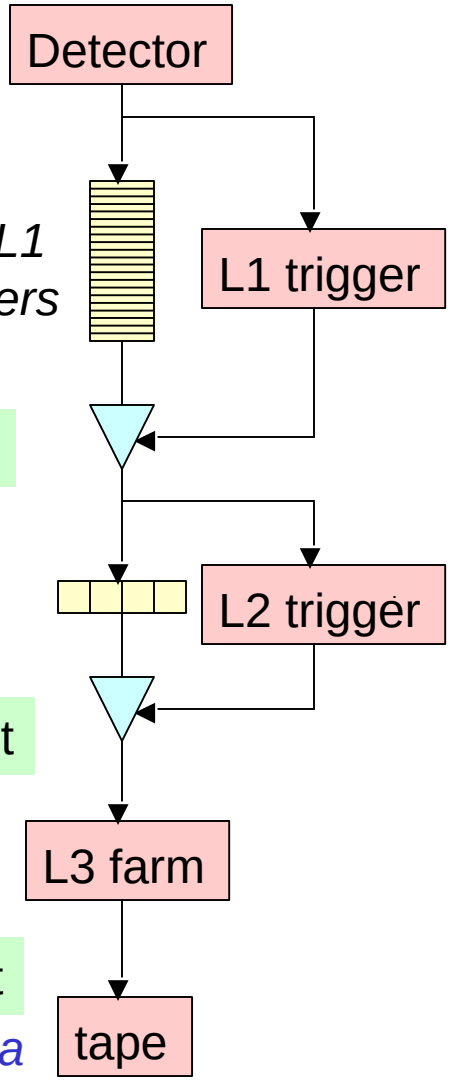
Design: 50kHz

250 Hz L2 accept

300 CPU's

50 Hz L3 accept

>100Hz with data compression



- Hardware tracking for $p_T \geq 1.5$ GeV
- Muon-track matching
- Electron-track matching
- Missing E_T, sum-E_T

- Silicon tracking
- Jet finding
- Refined electron/photon finding

- Full event reconstruction

The eXtremely Fast Tracker (XFT)

Every B-trigger needs it

Provides a list of tracks p_T>1.5GeV
Every (132ns) clock cycle

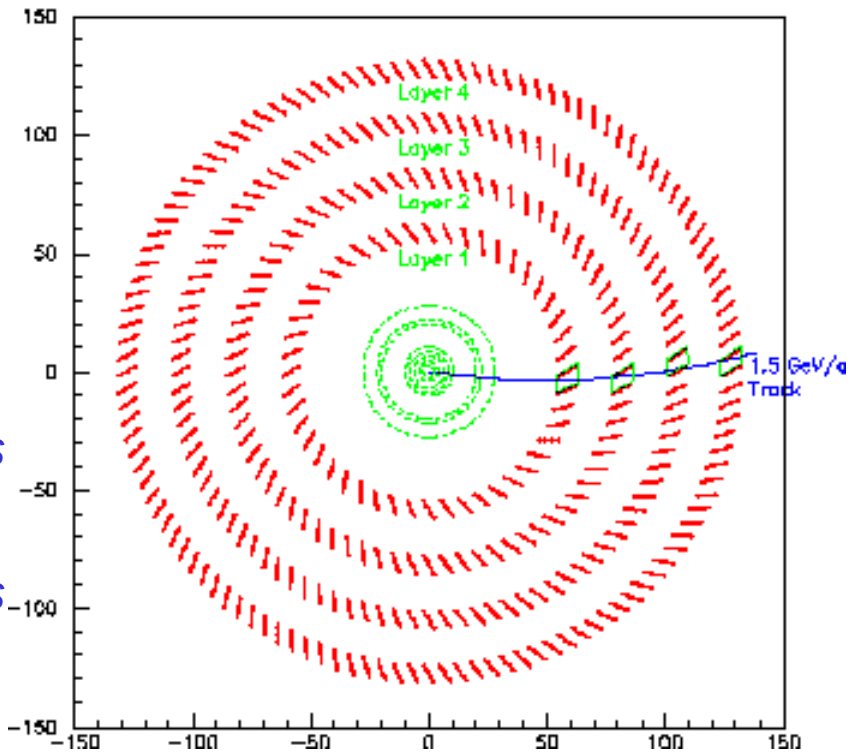
Finds segments in 4 axial SL

Compare to pre-programmed patterns

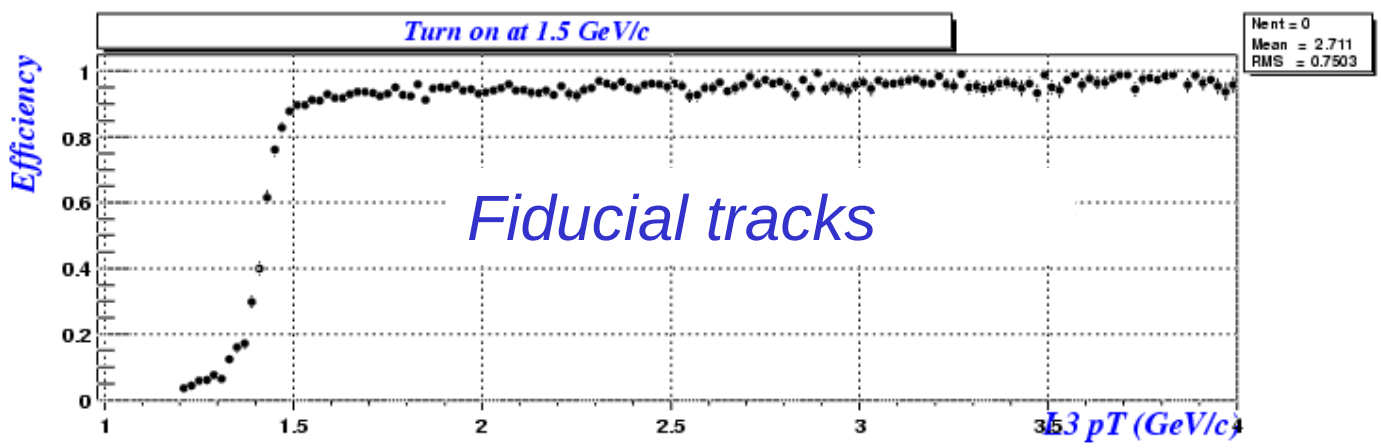
Links segments to tracks

Compare to pre-programmed patterns

Efficiency >95% for p_T>2GeV



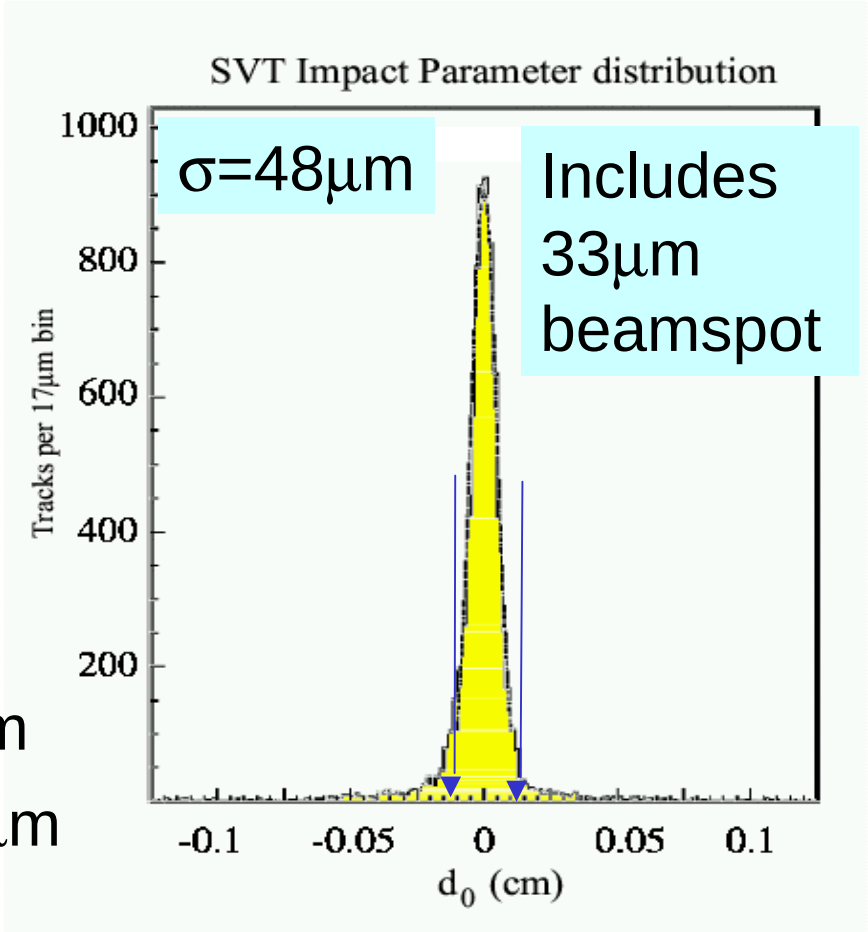
No stereo tracking



The Silicon Vertex Tracker (SVT)

Read out Silicon detector
& Reconstruct tracks at 10's of kHz!

Silicon Vertex Tracker (SVT)



Rate reduction:

$O(10^{-1})$ for 1 track d_0>120 μm

$O(10^{-2})$ for 2 tracks d_0>120 μm

More in parallel session by Ivan Vila

Trigger Strategies

2 leptons

B→charmonium

$B_d \to J/\psi\ K_S$

Rare decays

$B_s \to \mu\mu$

2 muons,
p_T>1.5GeV
(2GeV in Run I)

Lepton + displaced track

Semi-leptonic

$B_u \to l\nu D^0$

μ,e, p_T>4GeV
+
track p_T>2 GeV, d_0>120 μm

2 displaced tracks

2-body B-decays

$B_d \to \pi\pi$

Multi-body B-decays

$B_s \to D_s\pi$

2 tracks,
p_T>2GeV, Σp_T>5.5
d_0>120(100) μm

Trigger rates (in Hz)

At present peak lum (4.0×10^{31}):

	dimuon	leptonSVT		Two-track		bandwidth
Level 1: *Dominated by two-track trigger:*	40	e 800	μ 400	5000		16000
Level2: *SVT kicks in*	40	18	9	n-body 10	2-body 4	250
Level3: *Refined lepton identification*	1.8	2.3	1.3	7	0.8	50

Dynamic prescaling (DPS)

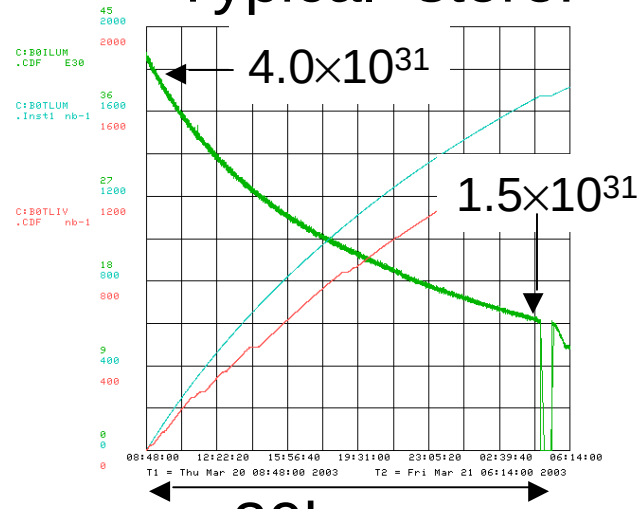
Implemented last August

Trigger is desiged for peak luminosity

Average luminosity ≈ 50% of peak

Fill the available L1 bandwidth with B physics!

"Typical" store:



3 versions of the two-track trigger:

High-p_T : $p_{T1}, p_{T2} > 2.5$GeV, $\Sigma p_T > 6.5$, $Q_1 \neq Q_2$

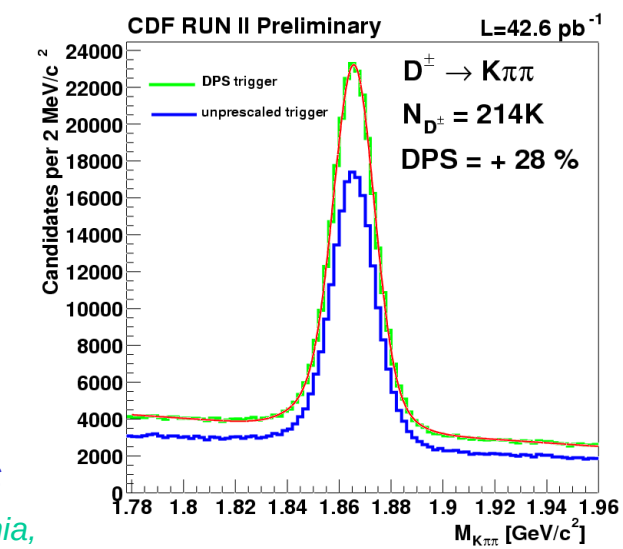
Never prescaled

Nominal: $p_{T1}, p_{T2} > 2.0$GeV, $\Sigma p_T > 5.5$, $Q_1 \neq Q_2$

Effective prescale >0.9

Low-p_T : $p_{T1}, p_{T2} > 2.0$GeV

Effective prescale » 0.22



28% gain in D^+ yield achieved

With these prescales

XFT 1-miss configuration

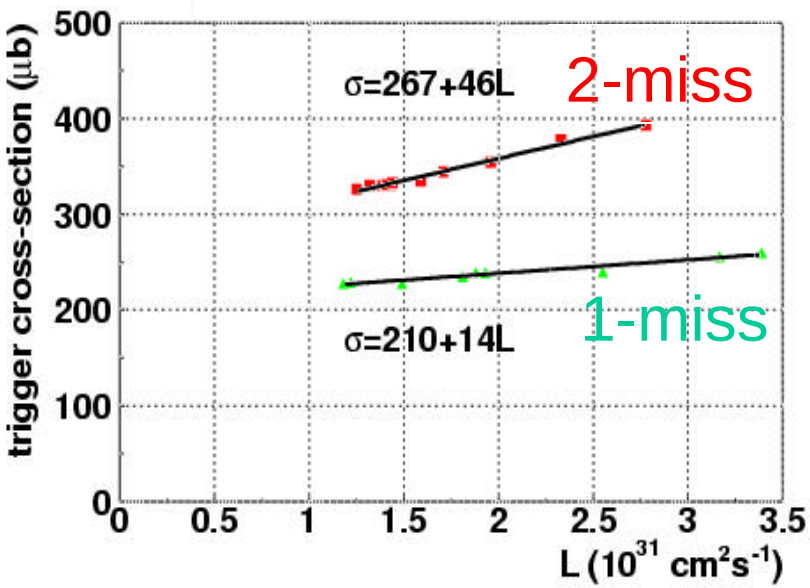
Implemented last October

Before, the XFT required 10/12 hits per SL

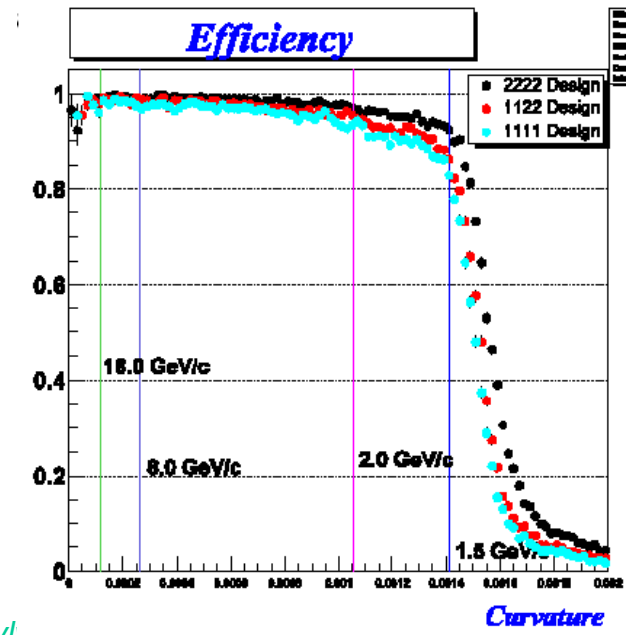
The two-track trigger reached the maximum L1 bandwidth

Tightened patters to require 11/12 hits

Big reduction in trigger rate



Small loss of efficiency



4/5 SVT tracking

Expected for April

Up to now, the SVT requires 4 Si hits on 4 layers

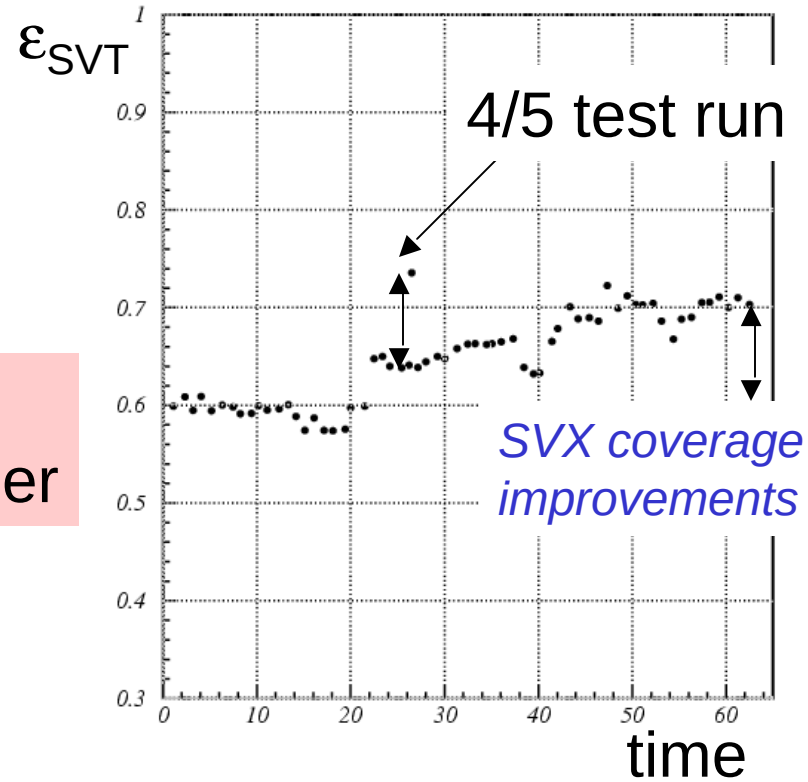
The 5th layer is not used

Efficiency scales as ε^4

SVT can be reprogrammed
To use all 5 layers
And allow 1 missing hit

15% single-track efficiency gain
⇒30% yield gain for 2-track trigger

Trigger rates go up by » 70%

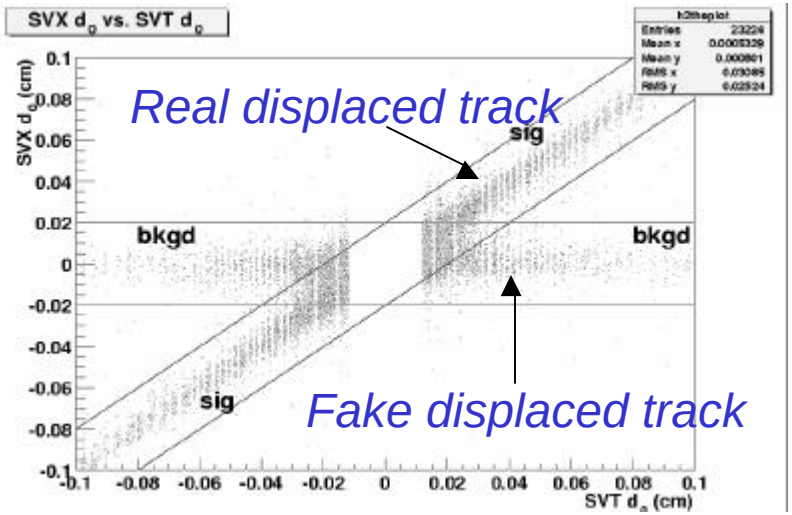


Si tracking at Level 3 trigger

Tracking since January, expect cutting in April

Online SVT tracks have non-Gaussian tail

Causes fake dispaced tracks



Confirm track displacement with software tracking

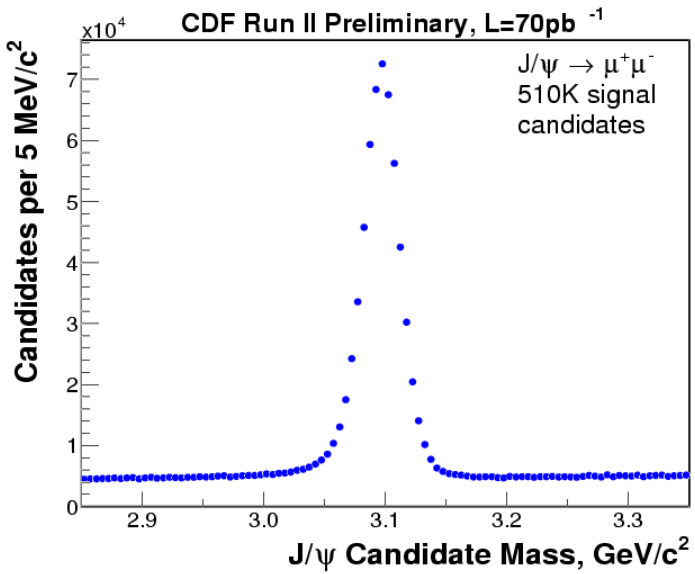
Fast version of Si tracking now runs online in L3 farms

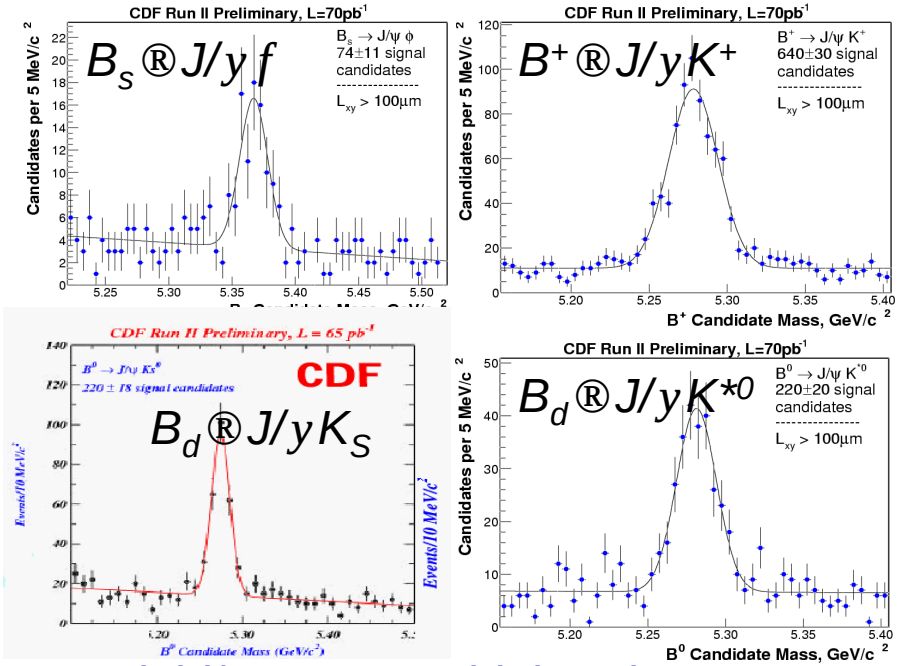
0.2s/event, no stereo tracking, simplified calibrations

More than factor 2 rate reduction for two-track triggers

Results from J/ψ trigger

510K $J/\psi \rightarrow \mu\mu$





Yield/Lum »70% higher than Run 1

Measure J/ψ down to p_T=0

$$\sigma(J/\psi)\times B(J/\psi\rightarrow\mu\mu)=240\pm1^{+35}_{-28}\,\text{nb}$$

(For |h|£0.6, all p_T)

New Run II result!

$\tau(B^+)$=1.57±0.07±0.02 ps

$\tau(B^0)$=1.42±0.09±0.02 ps

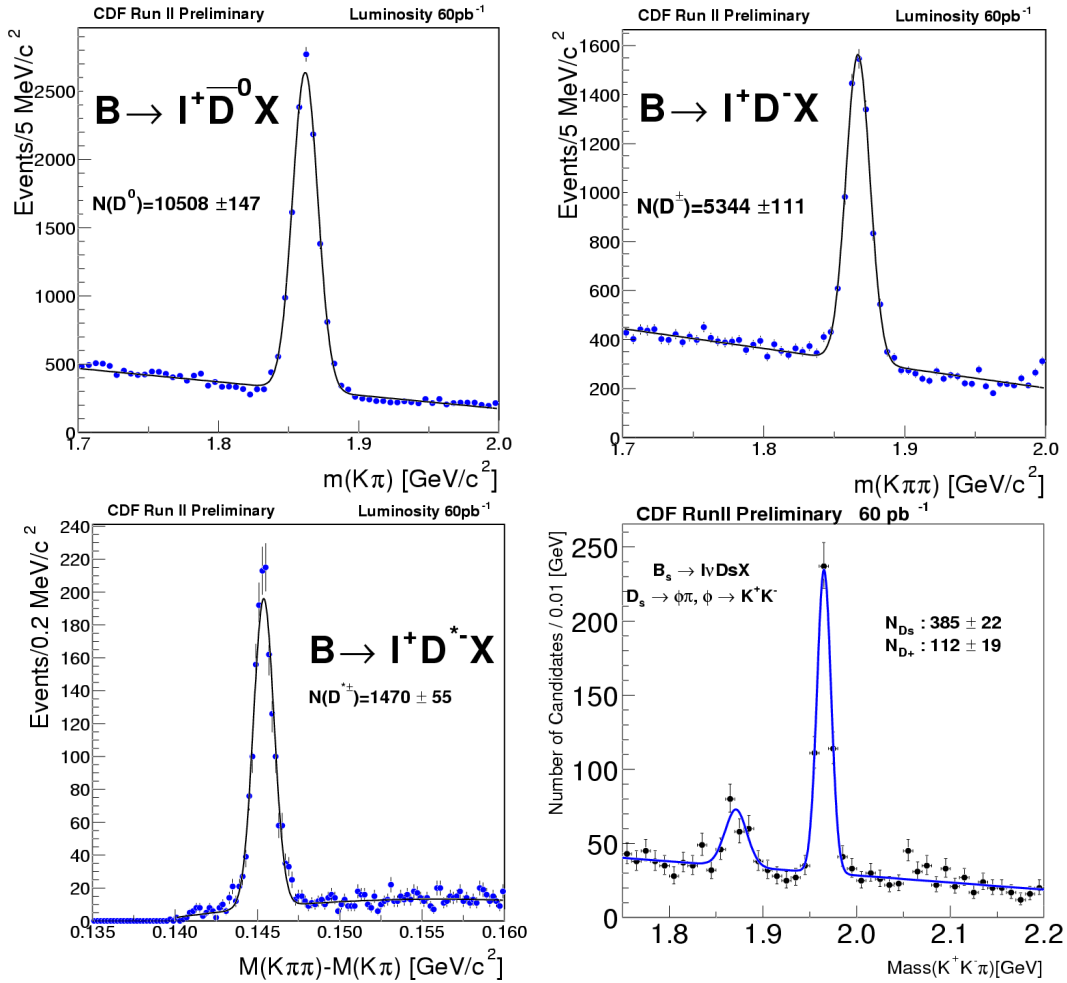
$\tau(B_s)$=1.25±0.20±0.02 ps

New Run II result!

Yields in the lepton+track trigger

Used for:

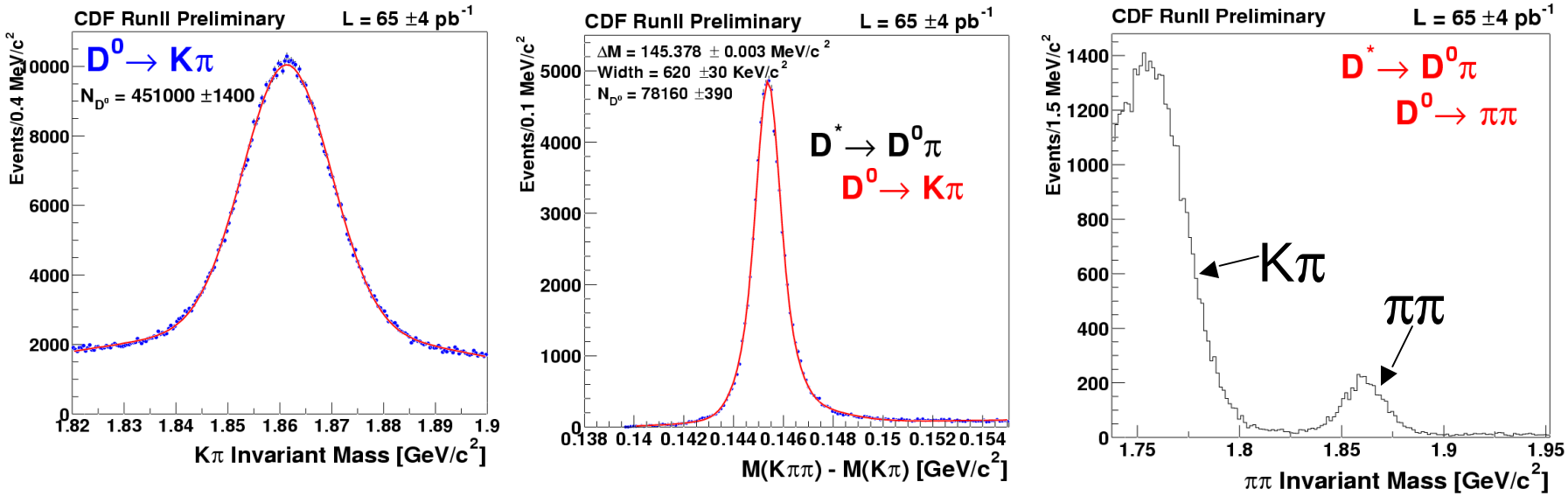
- Lifetime measurements
- Flavor tagging studies



Yields ≈ 5x higher than Run I:

(single 8GeV lepton)

Charm yields



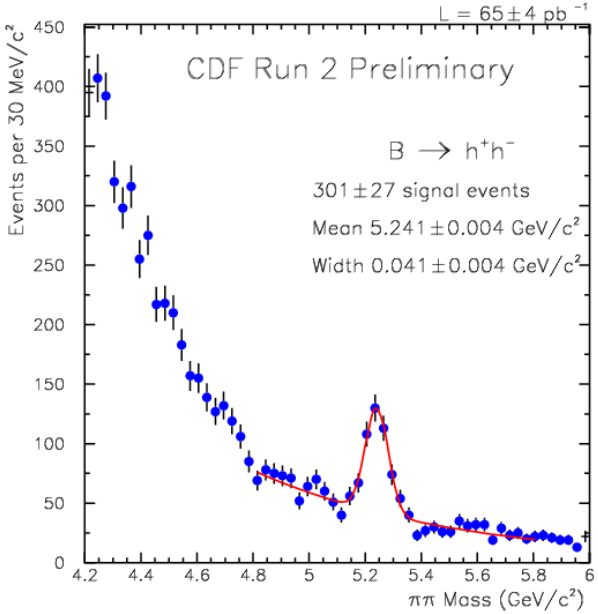
1pb^{-1} @CDF ≈ 1fb^{-1} @Y(4S)

Rare decays: $D^0 \to \mu\mu < 2.4\times10^{-6}$

New Run II result!

Direct $\not{C}P$ in D^0 decays: $$A_{CP} = \frac{\Gamma(D^0 \to \pi\pi) - \Gamma(\overline{D}^0 \to \pi\pi)}{\Gamma(D^0 \to \pi\pi) + \Gamma(\overline{D}^0 \to \pi\pi)}$$

Hadronic B yields

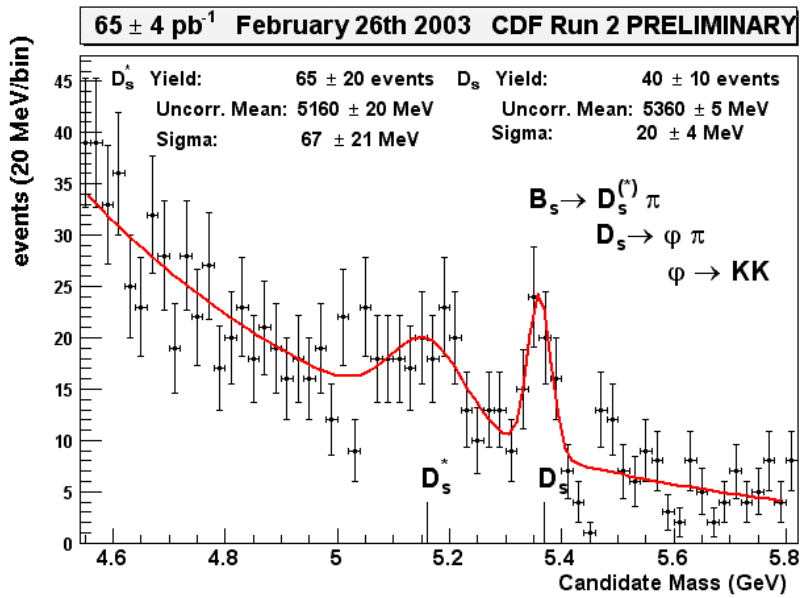


Clean $B \to hh$ signal established

Disentangle $B_d \to \pi\pi$ $B_d \to K\pi$

$B_s \to KK$ $B_d \to K\pi$

with kinematics & dEdx



$B_s \to D_s\pi$, $D_s \to \phi\pi$:
golden mode for B_s oscillations

Add additional modes

- $B_s \to D_s\, \pi\pi\pi, D^0 K\pi$
- $D_s \to K^*K$, $\pi\pi\pi$, $K_S K$

Need $O(10^3)$ events to observe SM B_s oscillations at 5σ

 May take a while…

Conclusion

CDF takes data, produces results

Some of our yield predictions were too optimistic

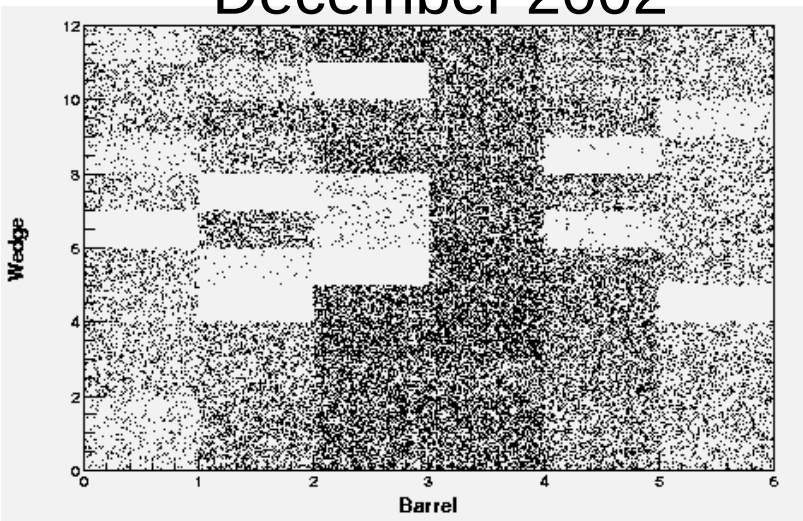
Nice surprise: competitive charm physics program

Keep improving trigger strategies for B physics

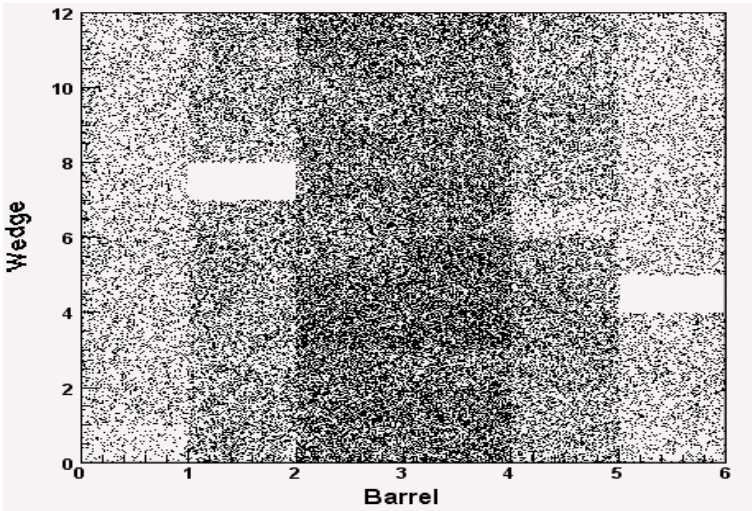
Recent efficiency improvements

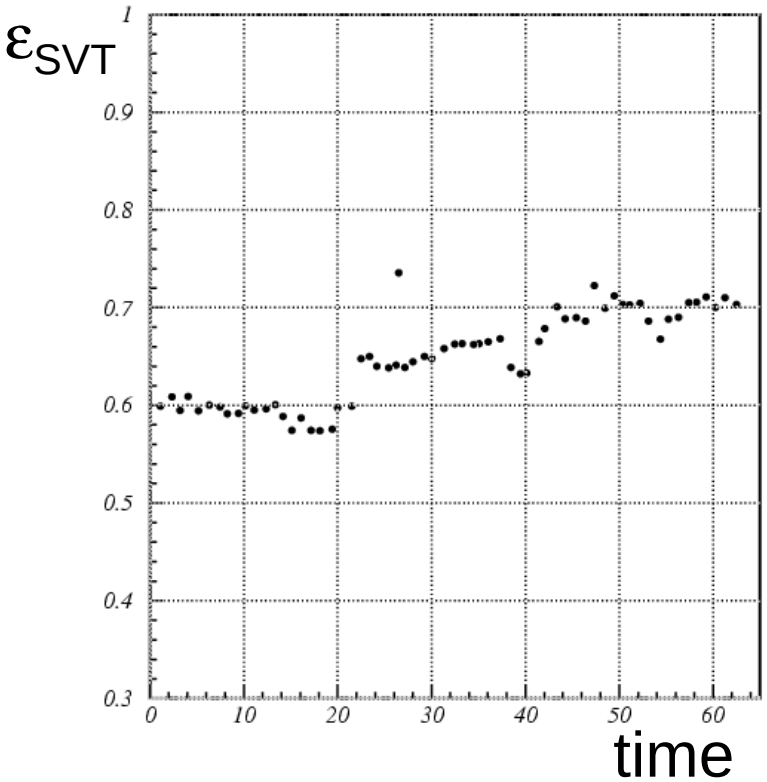
Lots of work and ingenuity to improve the Si coverage

December 2002

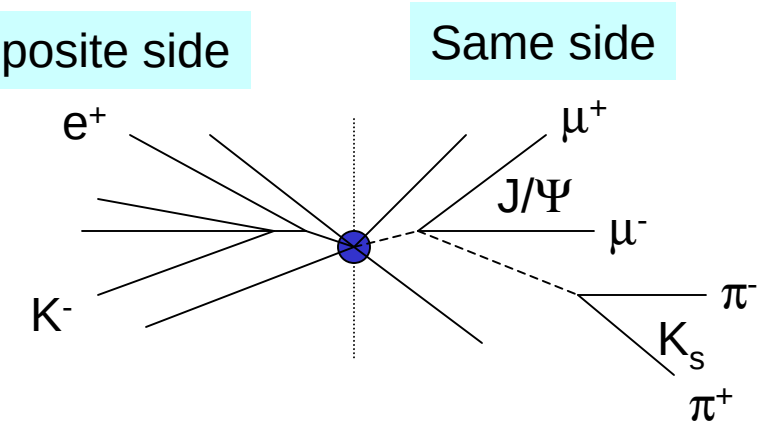


March 2003





Flavor tagging

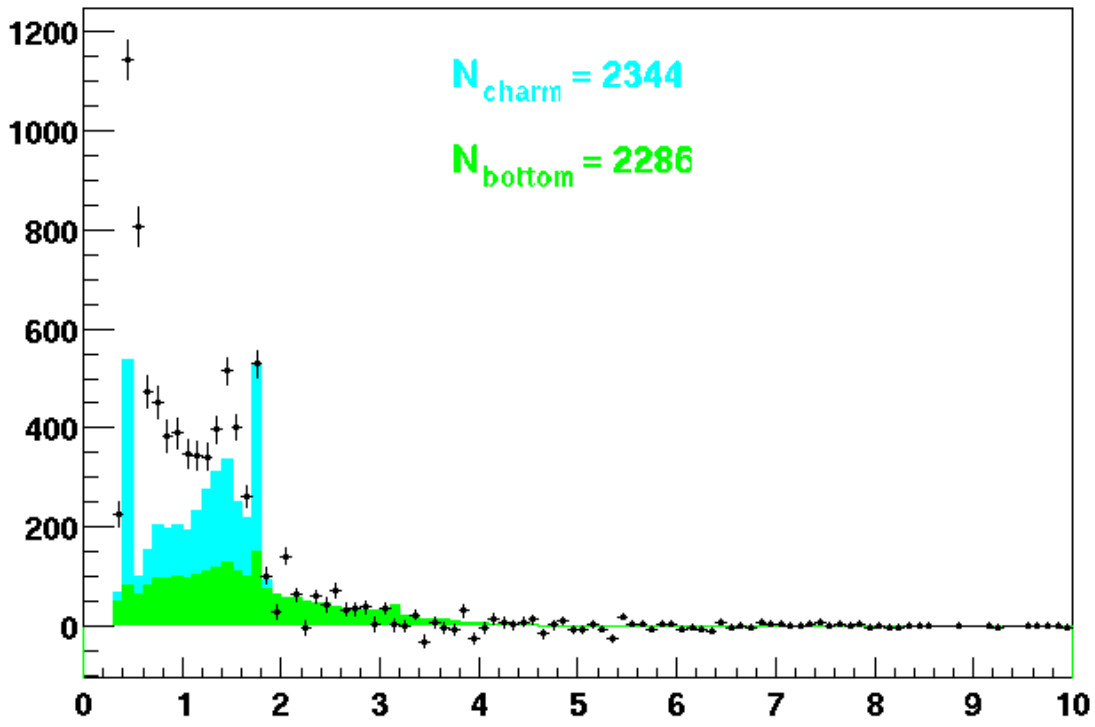


		ϵD^2
Opposite side:		
Lepton tag:	e or μ from $B \to l\nu_l X$	1.7%
Jet charge tag:	Sum of charges of all tracks: +1/3 for $\bar{b}$, -1/3 for b	3.0%
Kaon tag:	K from $B \to D \to K$. (Need TOF)	2.4%
Same side tag:		
Correlation between fragmentation particles and B		1.9%
		+
		9.0%

(Compare to BaBar/Belle : 29%)

BACKUP

Heavy flavor fraction of B_CHARM trigger



$\Rightarrow$ Heavy flavor fraction $\approx$ 70%

The Calorimeters and muon systems

Central calorimeterl for $|\eta| < 1$
Plug calorimeter up to $|\eta| < 3$

Electromagnetic (for electrons and photons)

Lead/scintillator $\sigma(E)/E = 2\% \oplus 14\% / \sqrt{E}$

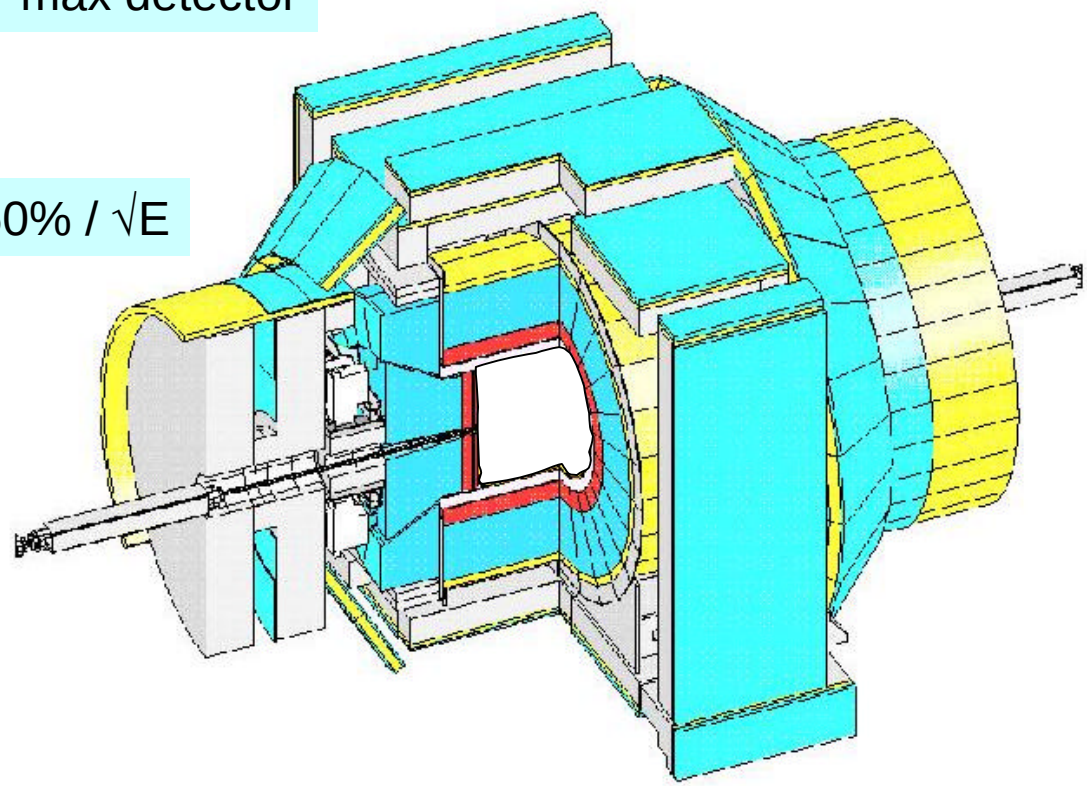
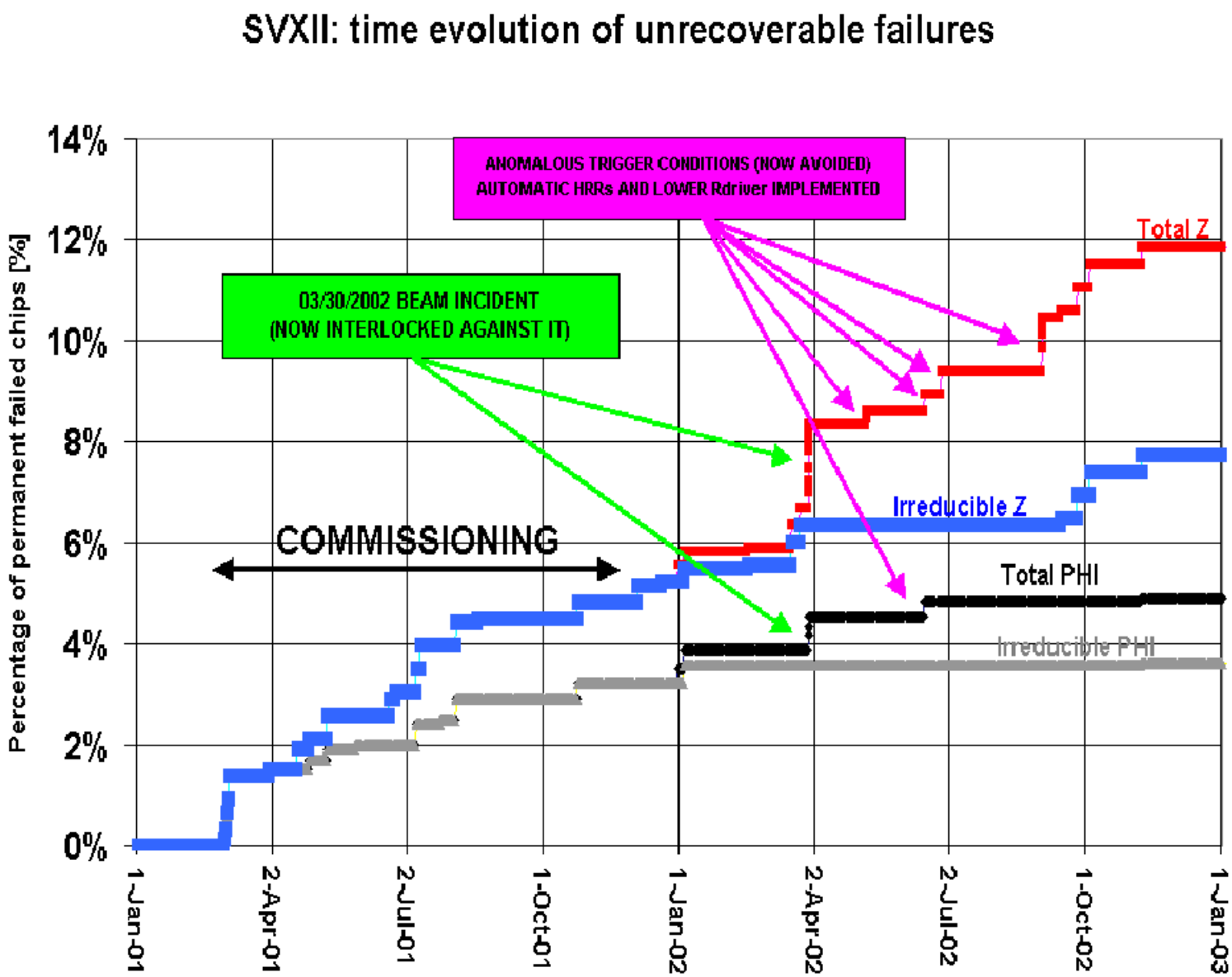
Pre-shower detector and shower-max detector

Hadronic (for jets)

Iron/scintillator $\sigma(E)/E = 4\% \oplus 60\% / \sqrt{E}$

Muon coverage for $|\eta| < 1.5$

Drift chambers and scintillators



Silicon damage