CDF detector and trigger for B Physics

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Hyperons, Charm and Beauty Hadrons

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Outline

CDF detector elements crucial for B Physics

- Tracker
  - Silicon detectors (L00, SVXII, ISL)
  - Drift chamber (COT)
- Particle identification system
  - Time of Flight detector
  - dE/dx from the drift chamber
- Lepton detectors (muon chambers, CEM calorimeter)

CDF Trigger architecture

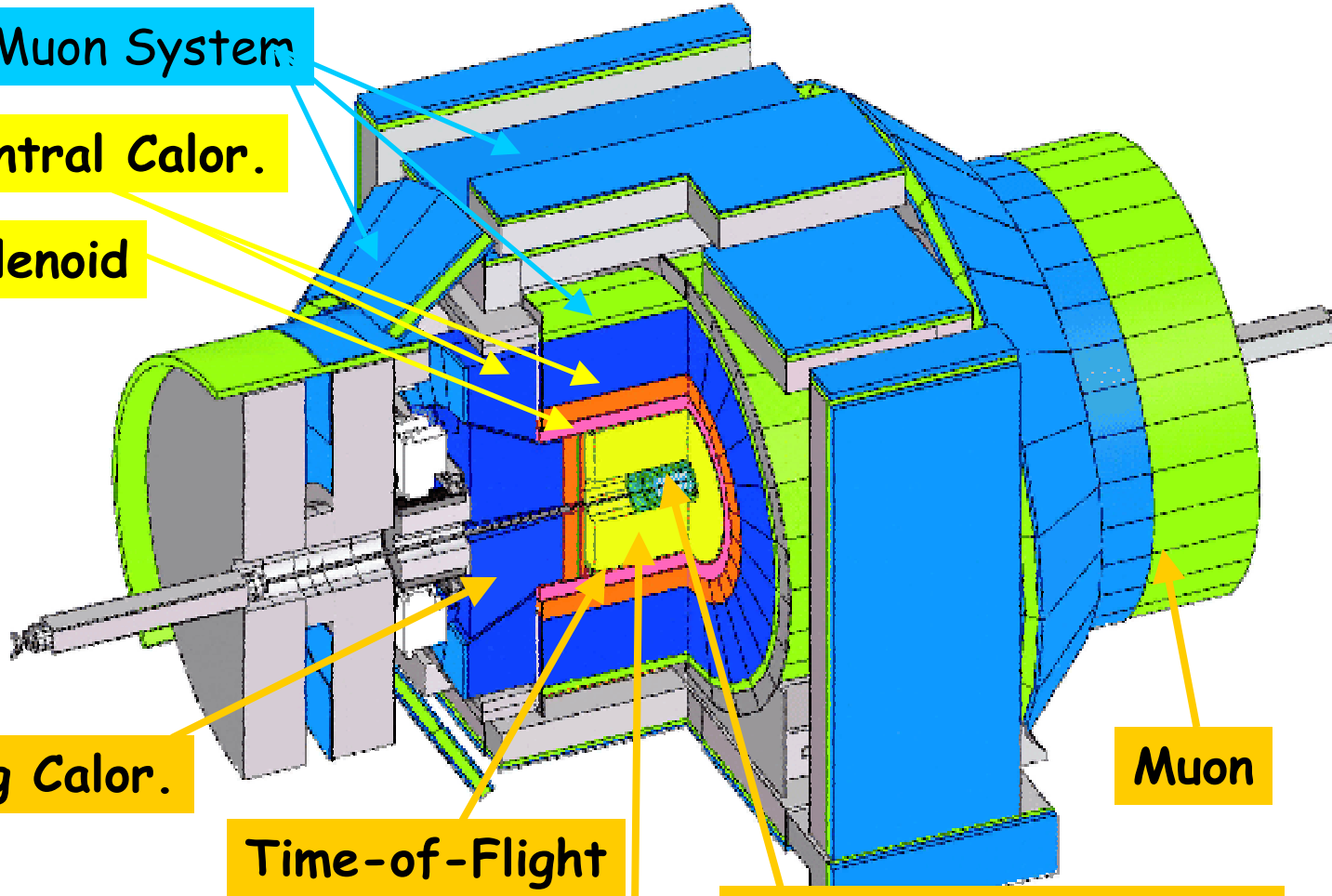
- XFT: Level 1 track trigger (lepton triggers)
- SVT: Level 2 silicon vertex trigger

CDF Trigger strategy for B Physics

- Problems at high luminosity (upgrades)

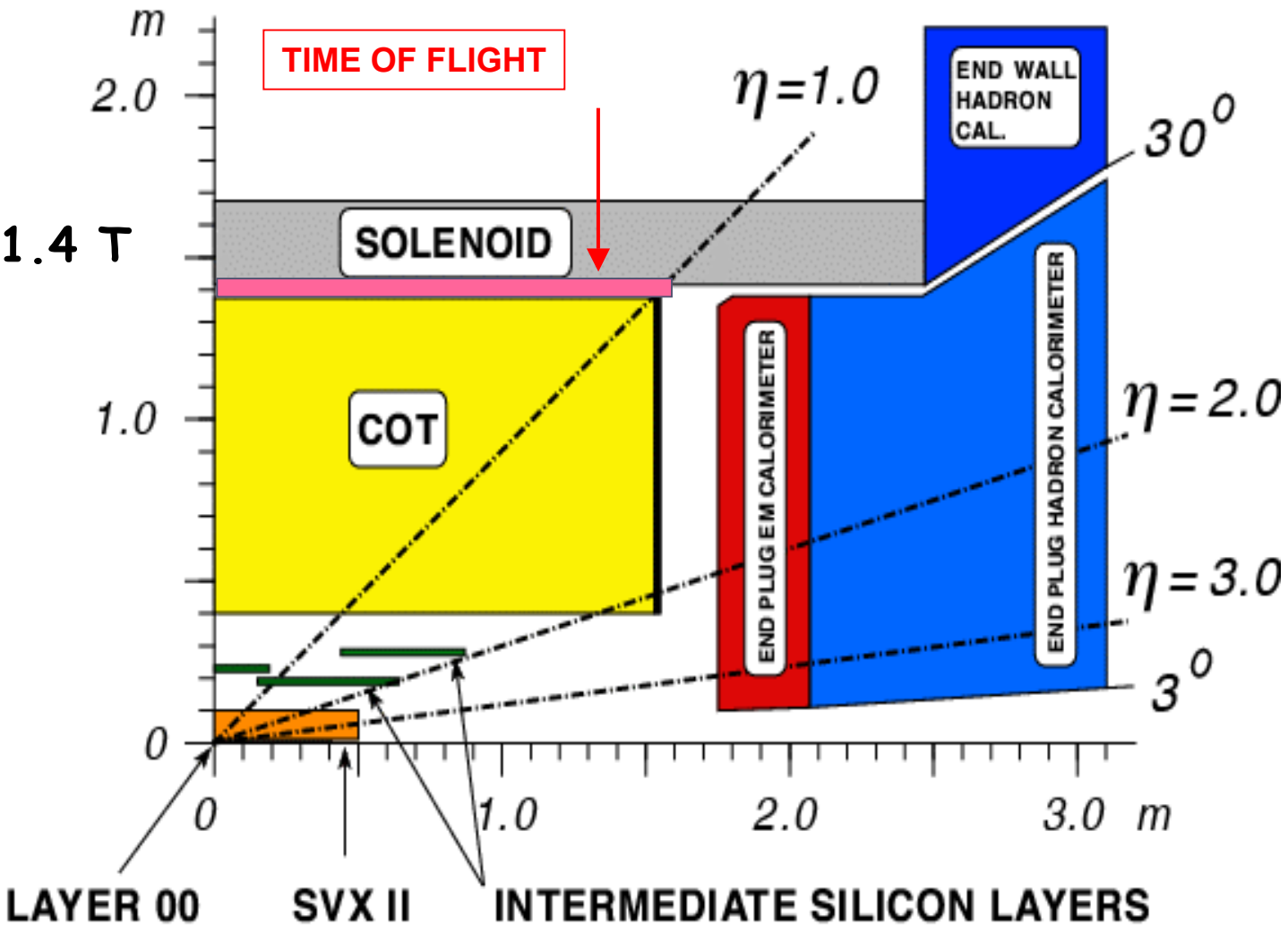
Conclusions

The CDF detector

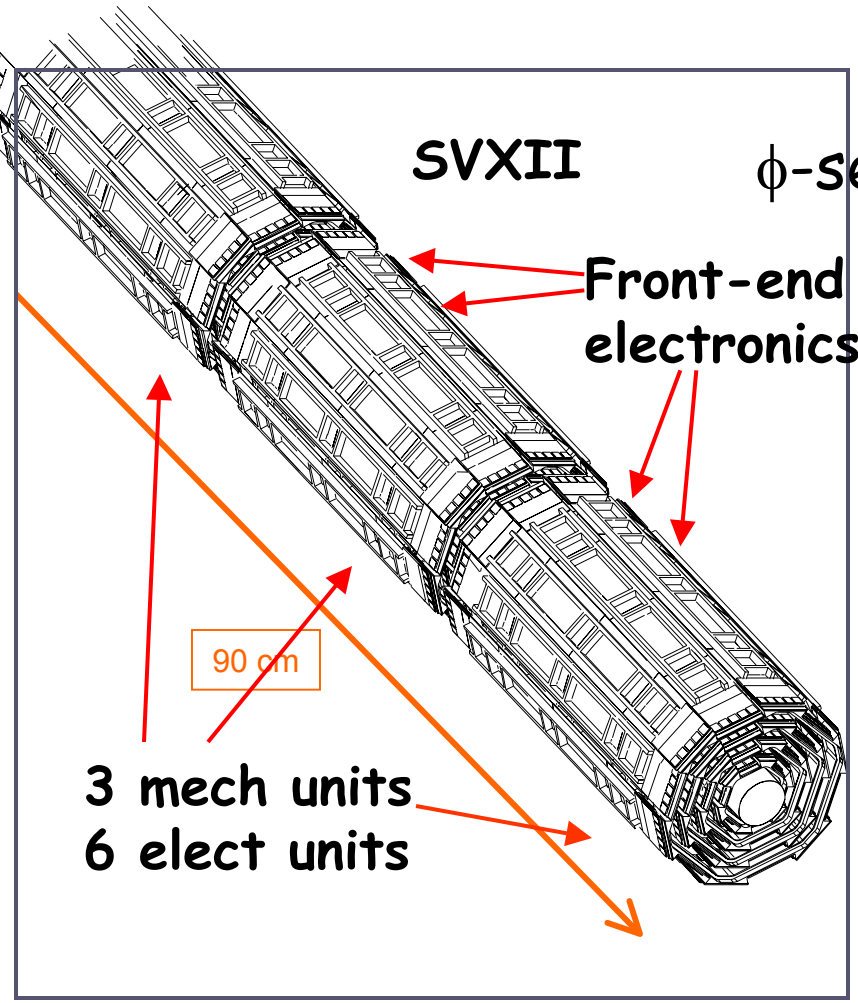


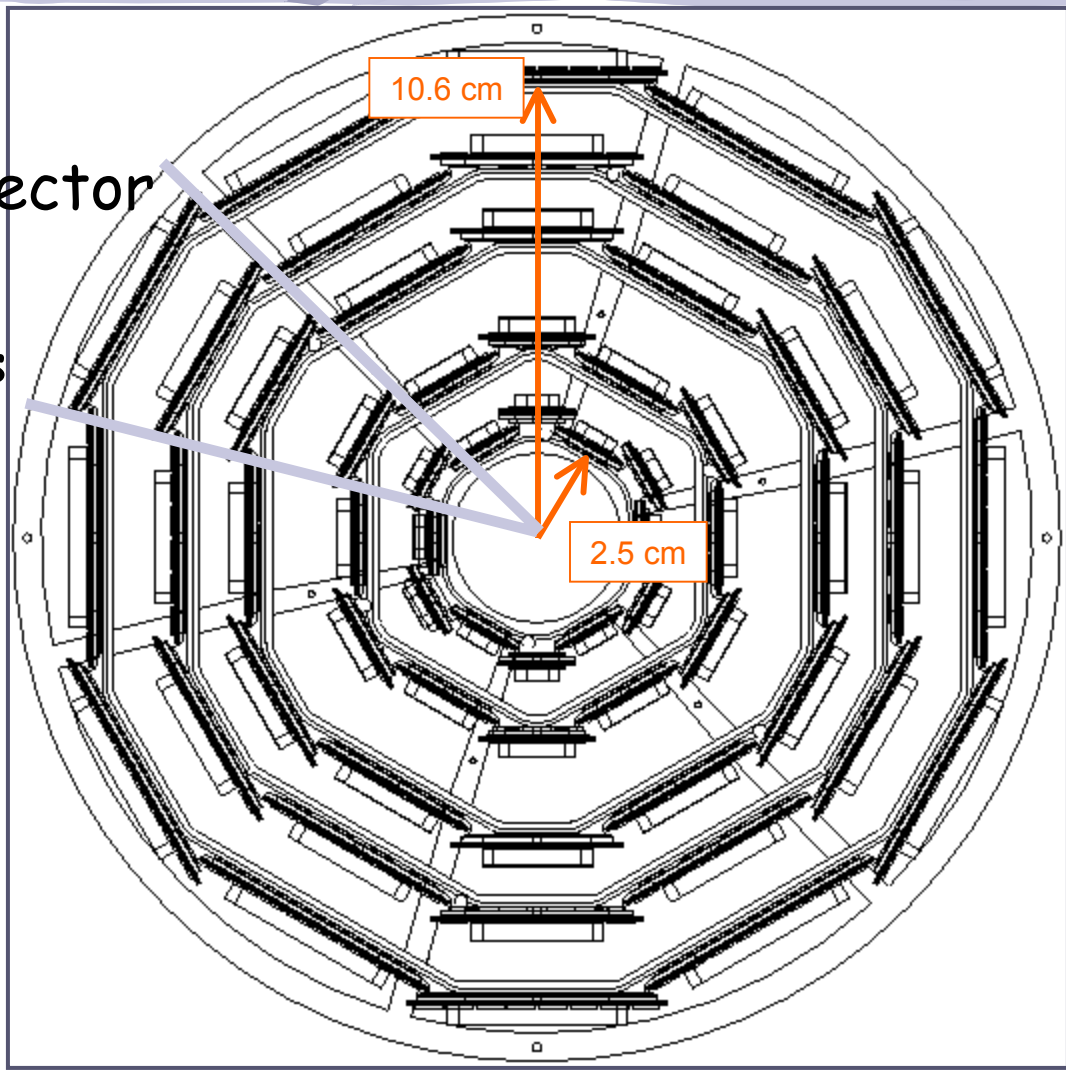
The CDF Tracker

B field = 1.4 T

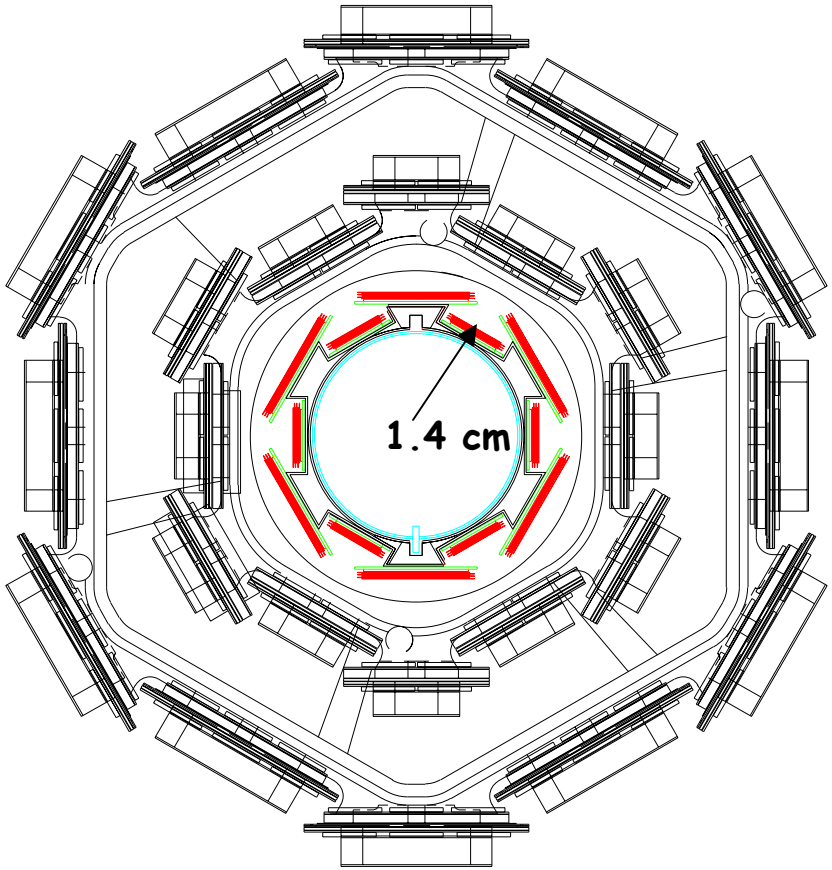


SVXII: silicon vertex detector





Layer 00



SVXII

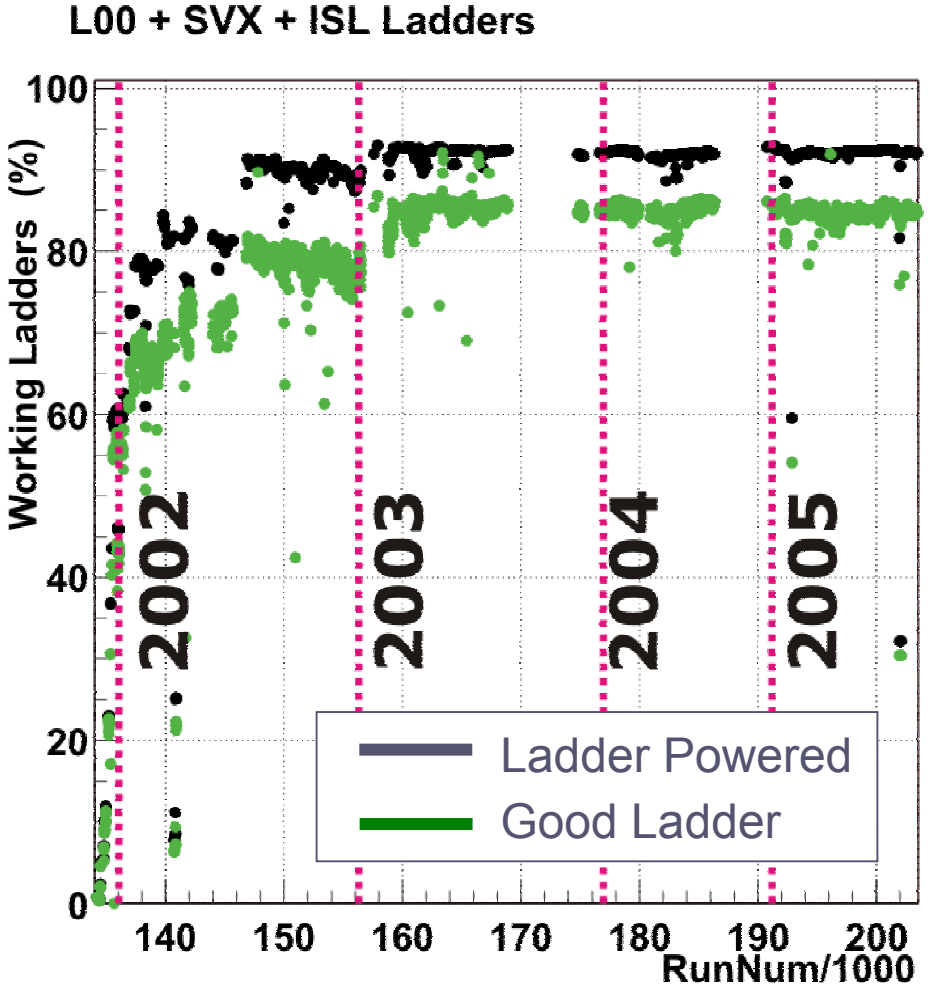
- 3 mech(6 electrical) barrels
- 72 electrical wedges
- r-ϕ strip pitch ~60 μm
- r-z strip pitch ~140 μm (90°)
- r-z strip pitch ~60 μm (stereo)
- total ~400,000 channels

L00

- 1 mech(1 electrical) barrel
- 12 electrical wedge
- r-ϕ strip pitch ~25 μm (floating)

σ_d ~35 μm @2 GeV/c (COT+silicon)

Current silicon status



Detector	Total	Powered	Good
L00	48	98%	96%
SVX	360	92%	84%
ISL	148	91%	82%

Charge Collection Efficiency > 99%

Single Hit Efficiency > 90%

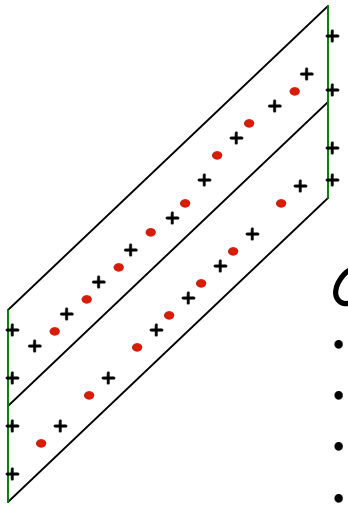
Resolution: 9 μm (2 strip cluster)

Signal-to-Noise Ratio:

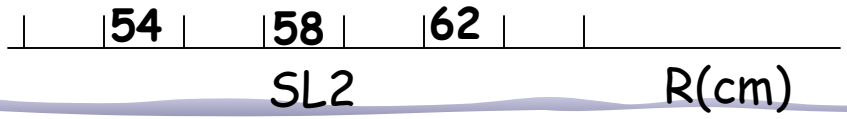
SNR	RΦ	Z
L00	10:1	-
SVX	14:1	12:1
ISL	12:1	12:1

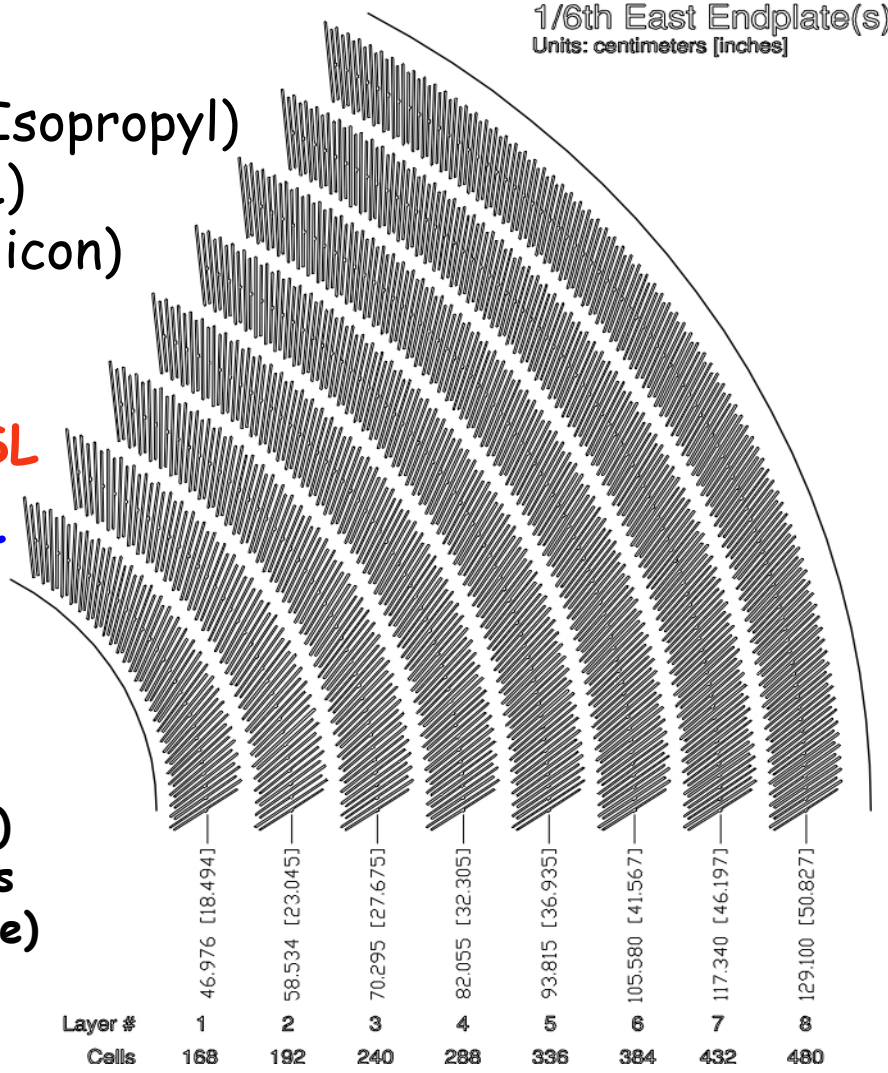
Central Outer Chamber

- Tevatron bunch crossing 396 ns:
  max drift time ~200 ns (50:50 Ar:Et+Isopropyl)
- Strong stereo tracking (4/8 stereo SL)
- $\sigma(pT)/pT^2$ = 0.15% [GeV/c]-1 (COT+silicon)
- Provides dE/dx (PID)



COT cell
- 12 sense/13 pot. wires
- 4 shaper wires (close cell)
- gold on mylar field sheets
- cell tilt 35° (Lorentz angle)

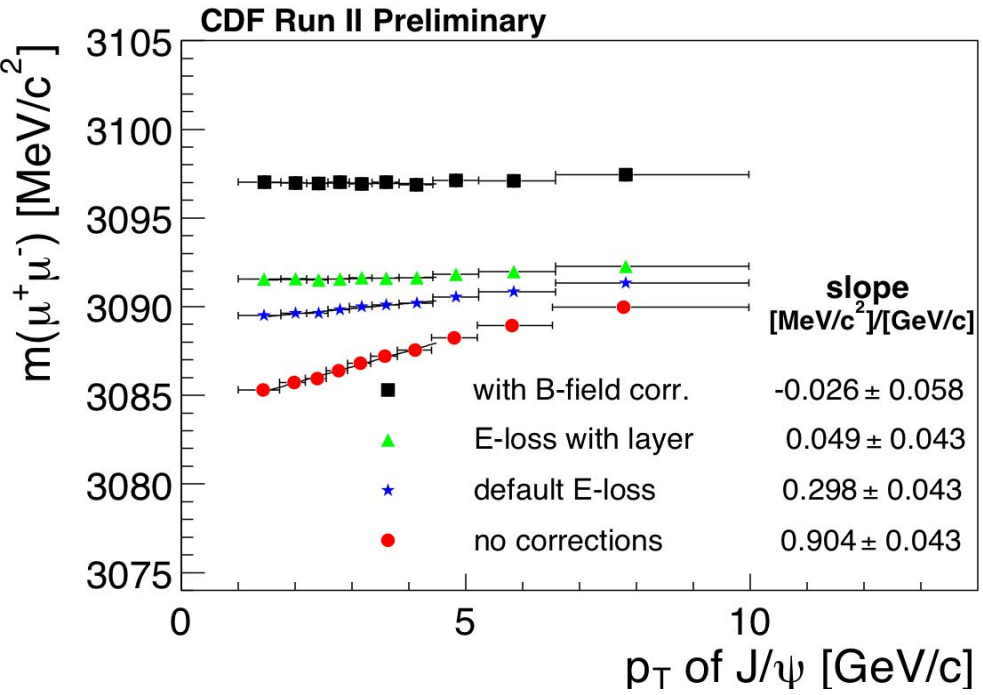




Integrated tracker performance

Mass measurements @sub-MeV level

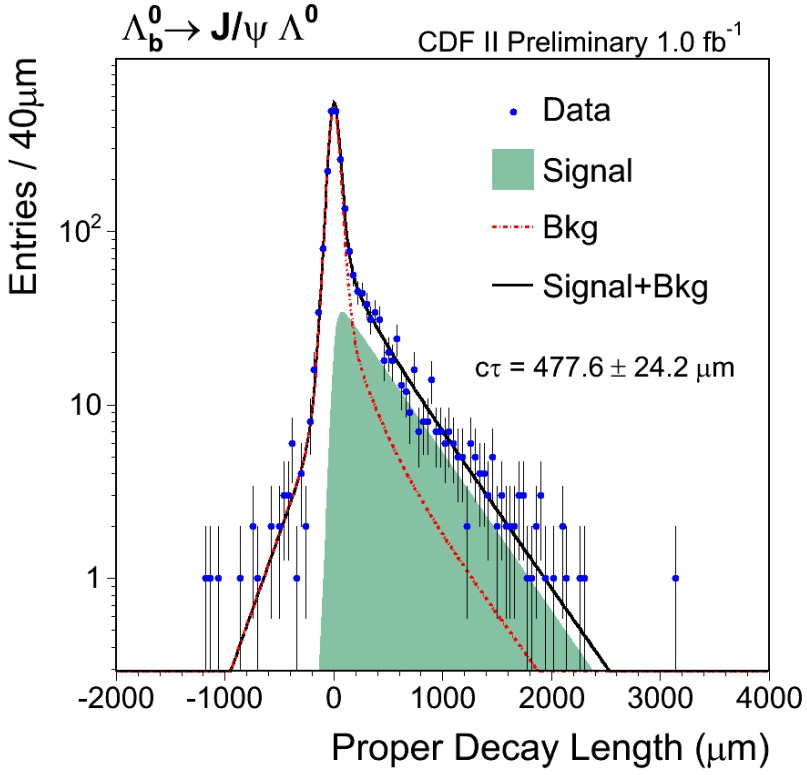
M(B+) = 5279.10 ± 0.41 ± 0.36 MeV
M(B0) = 5279.63 ± 0.53 ± 0.33 MeV
M(Bs) = 5366.01 ± 0.73 ± 0.33 MeV
M(Λb) = 5619.7 ± 1.2 ± 1.2 MeV



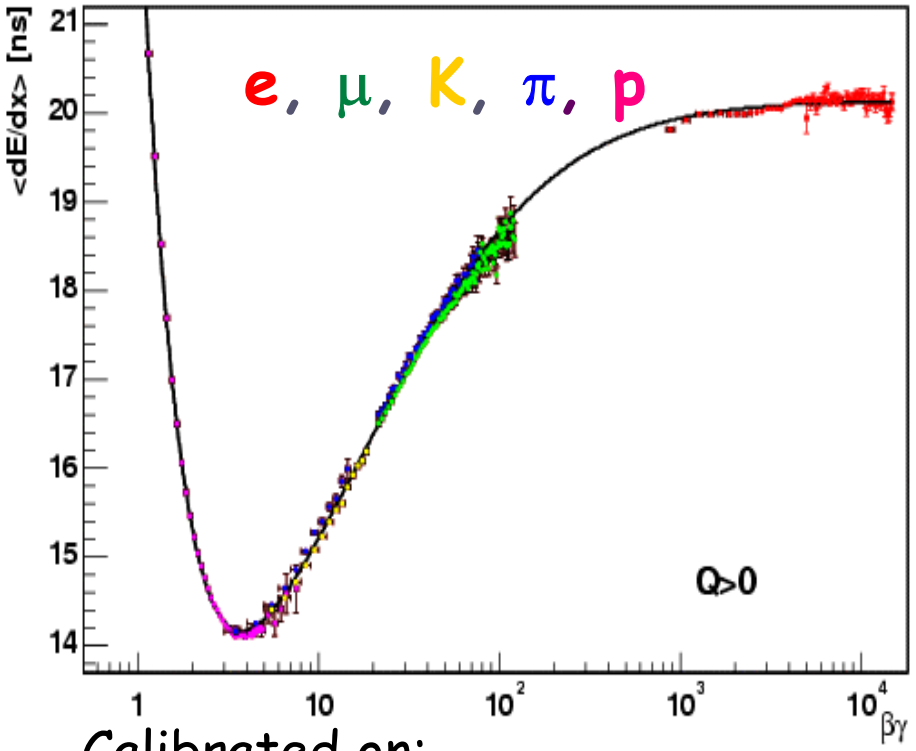
World class lifetimes

τ(Λb)= 1.524 ± 0.030 ± 0.016 ps

τ(Λb)/τ(B0) = 1.037 ± 0.058



Separation from PID (dE/dx in COT)



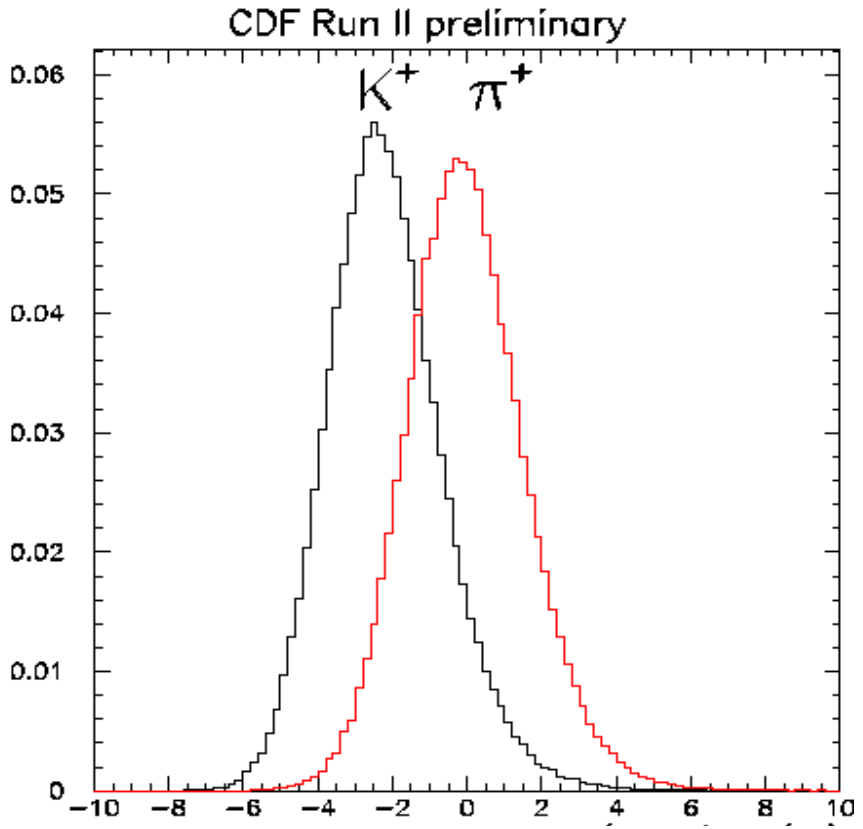
Calibrated on:

$D^* \rightarrow D^0 \pi_{soft} \rightarrow [K \pi] \pi_{soft}$

$J/\psi \rightarrow \mu\mu$

$J/\psi \rightarrow ee$ and conversions

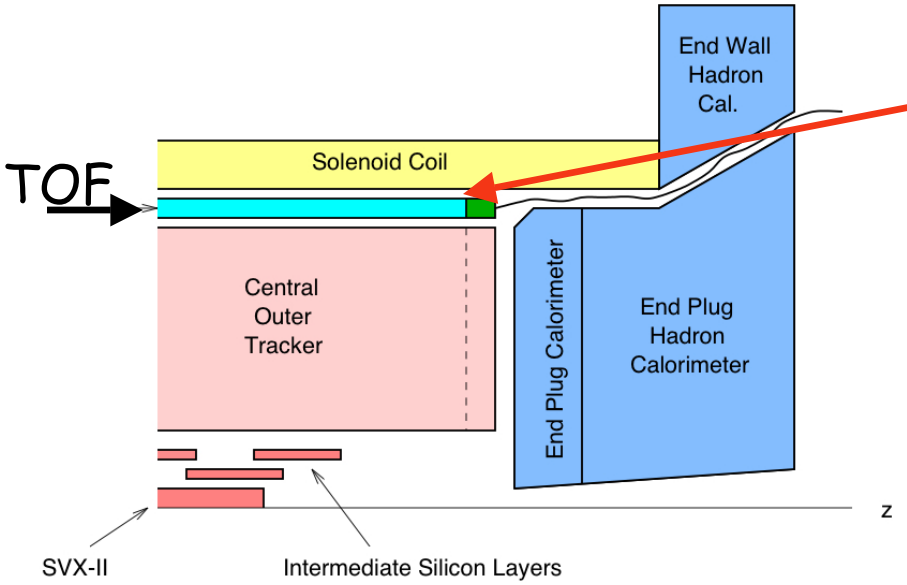
$\Lambda \rightarrow p \pi$



dE/dx residuals (ns)

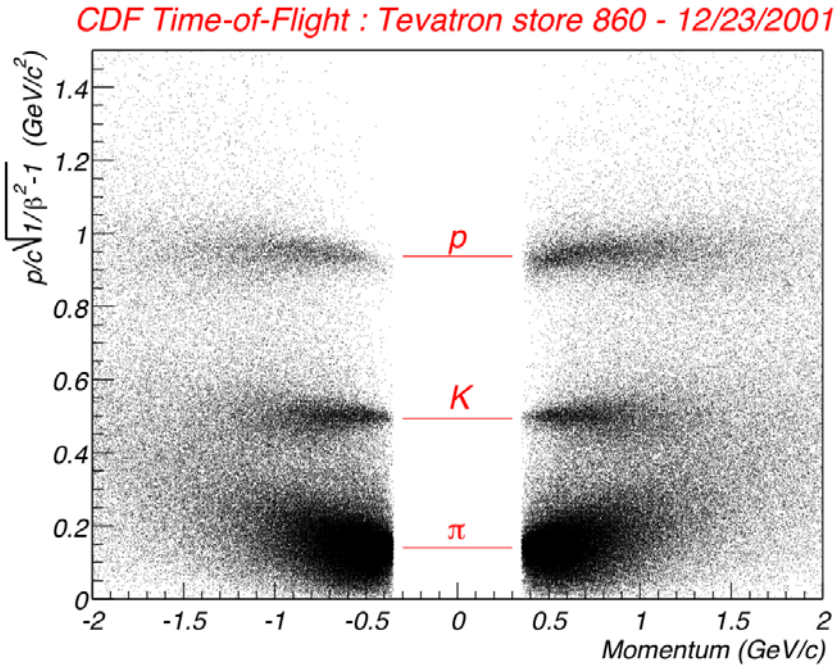
K/π separation: 1.4σ @P_T>2 GeV/c

Time Of Flight detector



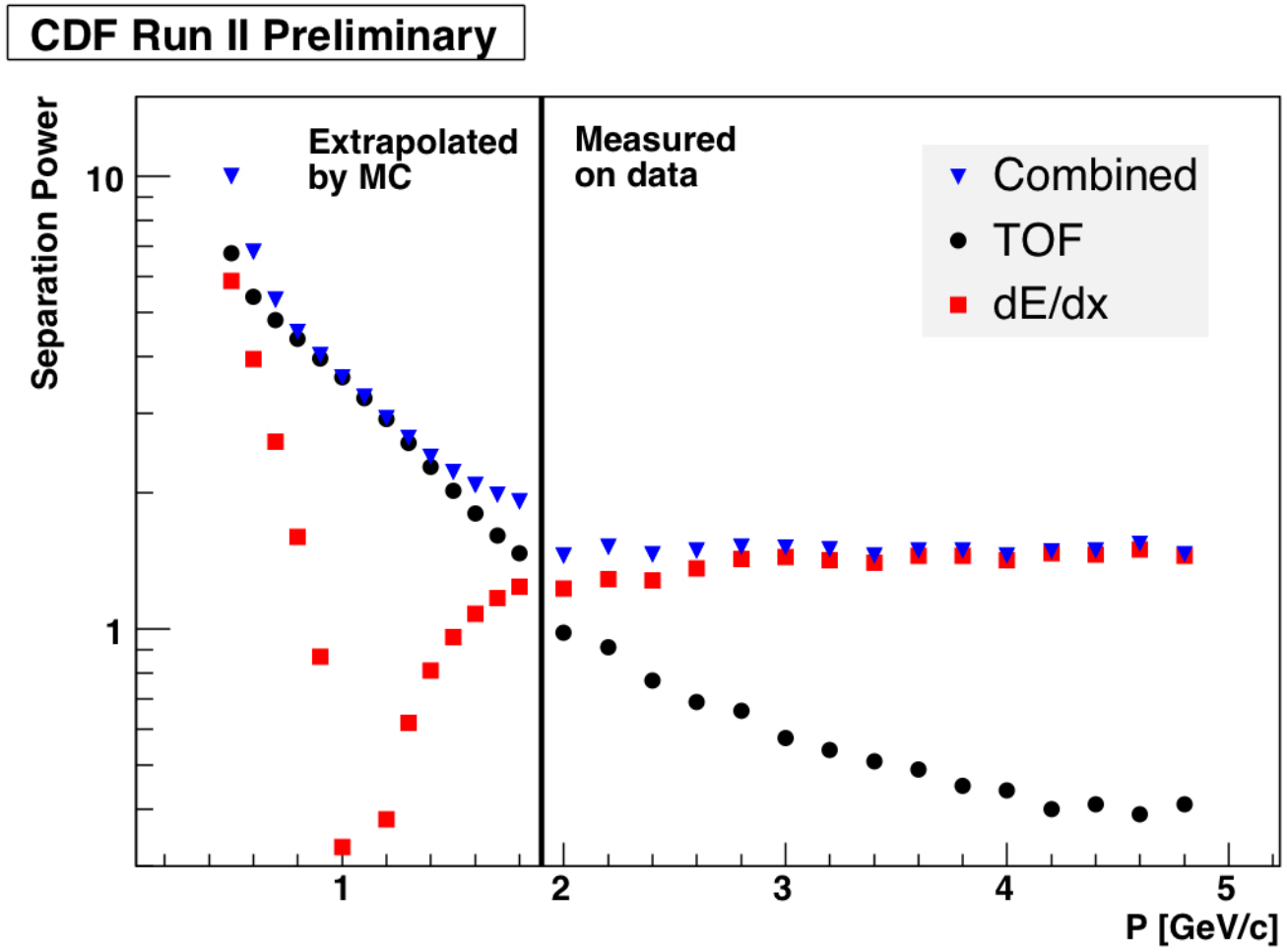
Radius (TOF) ~ 1.4 m (η<1)

σ_t ~ 110 ps

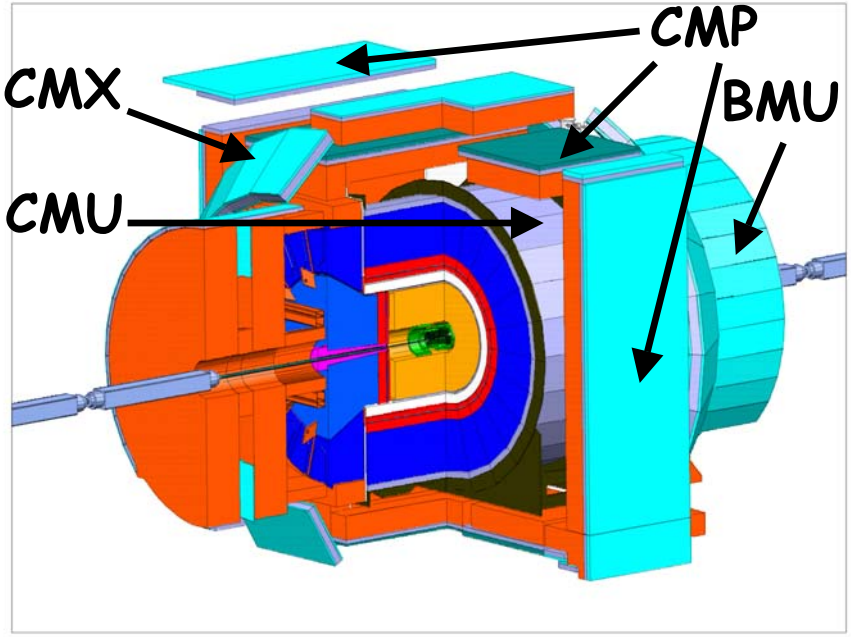


216 scintillator bars (Bicron BC-408)
2.8 m with ~ 4x4 cross section
Attenuation Length ~ 2.5 m
Fast rise time ~ 0.9 ps
Hamamstsu R7761 PMT on both ends

Separation from combined PID (TOF+dE/dx)

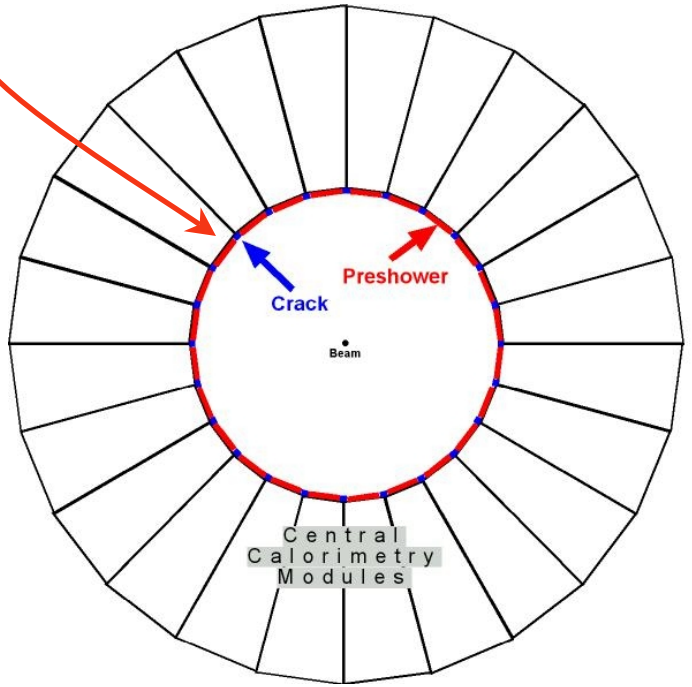


Lepton detectors (muons, electrons)

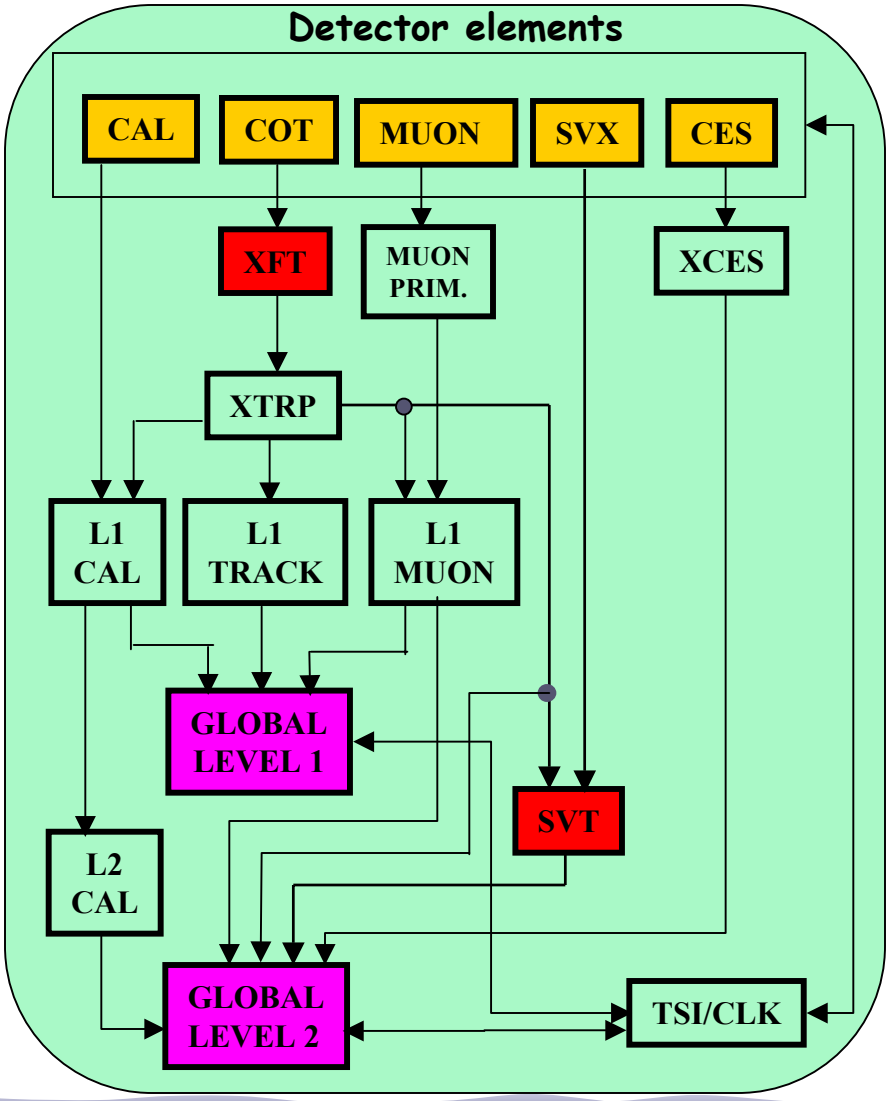


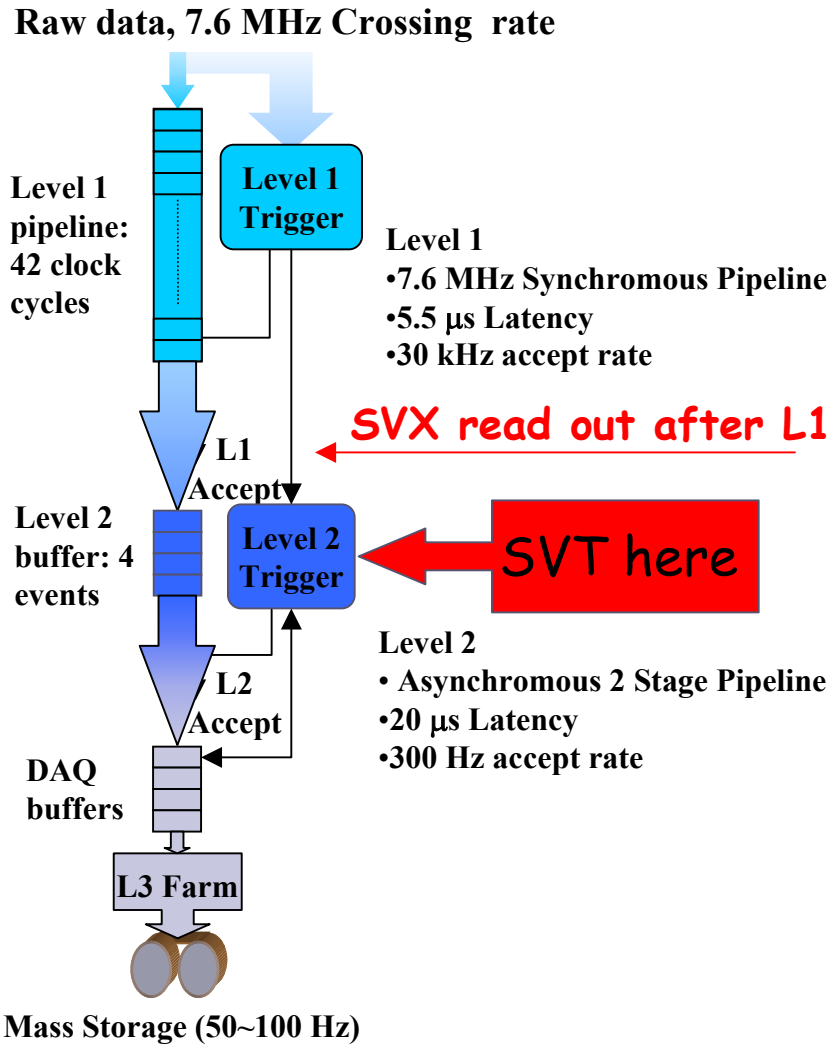
CMU/CMP $|\eta|<0.6$
CMX $0.6 < |\eta| < 1.0$
BMU $1.0 < |\eta| < 1.5$

CEM calorimeter: scintillator/lead
- $\eta \times \phi$ towers 0.11 x 0.26
- ~ 20 radiation length deep
- Position detector at shower max
- Preshower recently upgraded (gas chambers → scintillator bars)



CDF Trigger Architecture

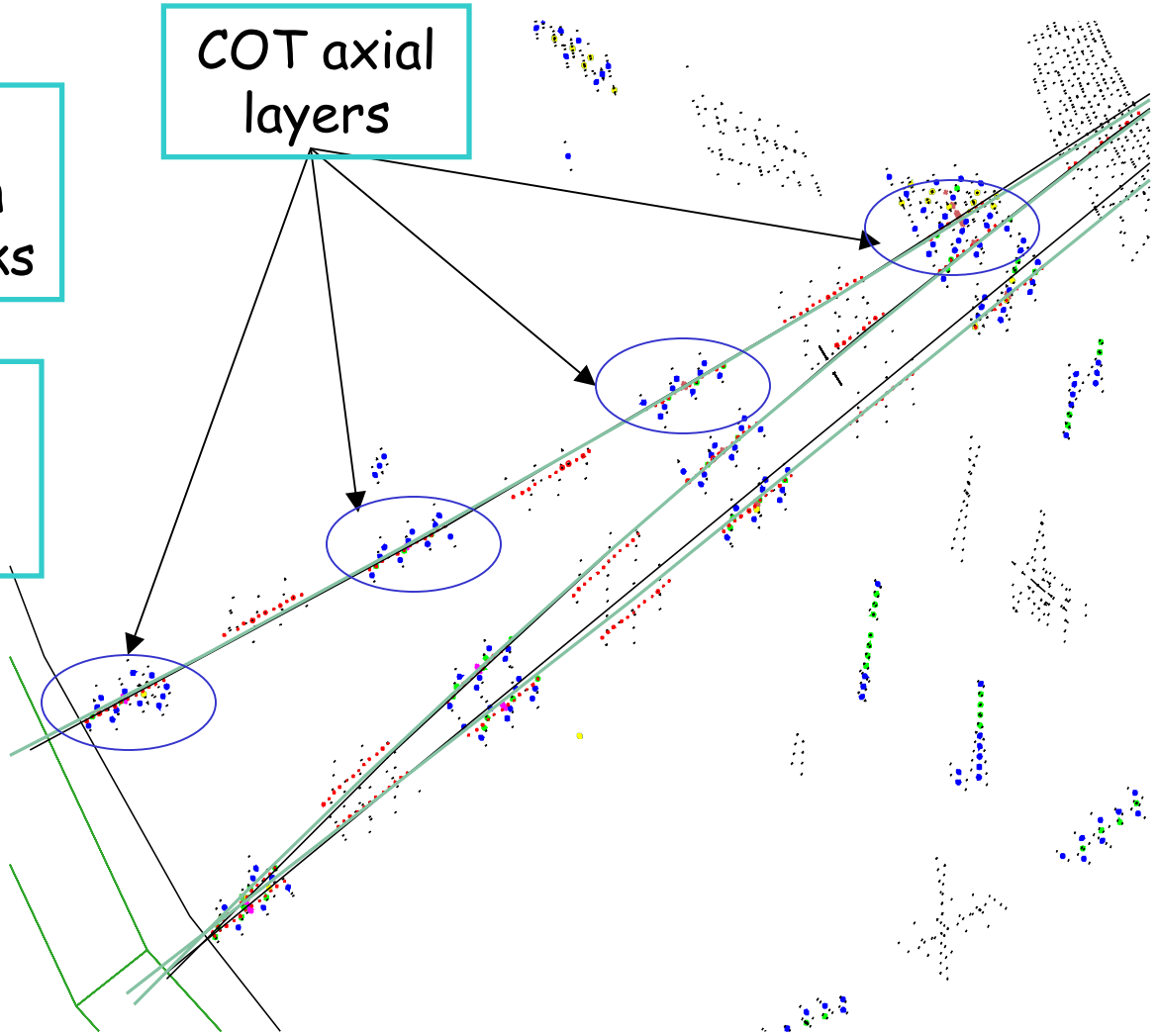




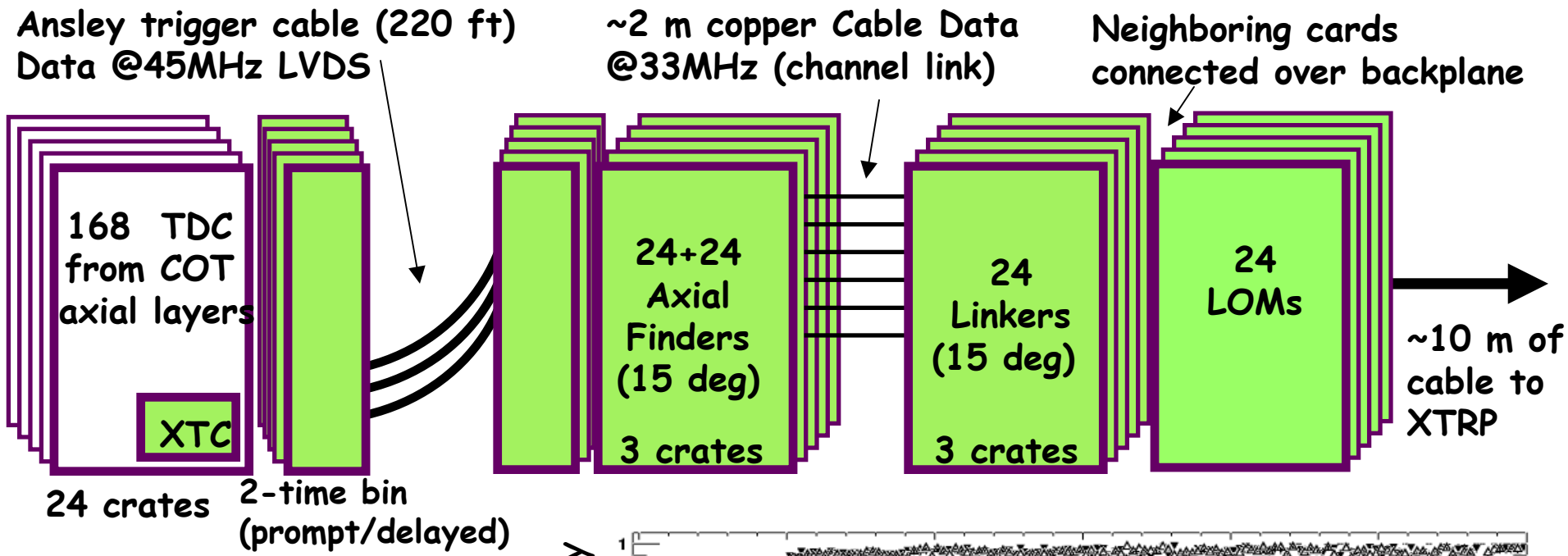
XFT working principle

Good hit patterns are identified as segments, then segments are linked as tracks

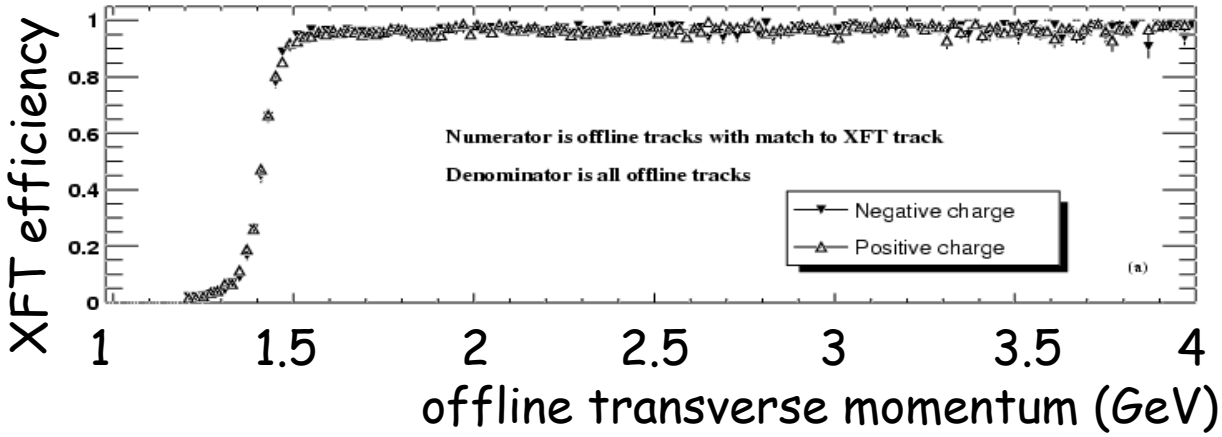
XFT uses only 4 axial layers
Upgrade to XFT3D (+stereo layers) in progress



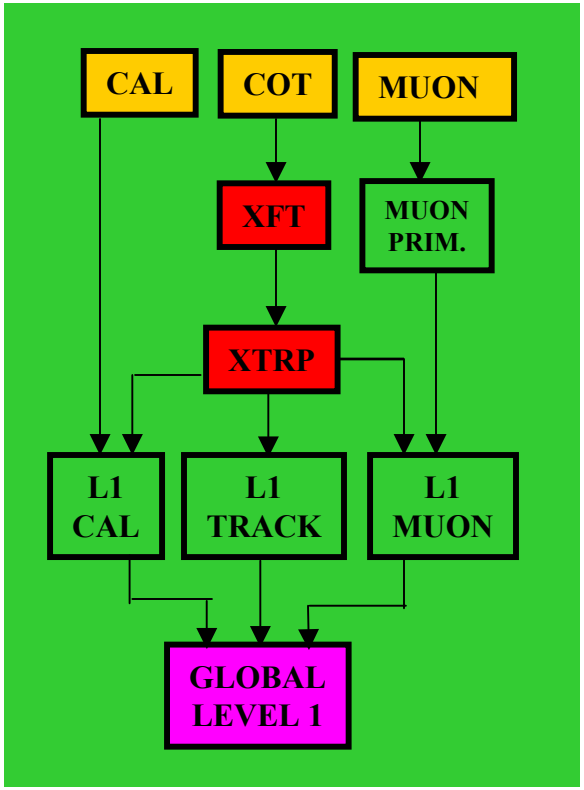
XFT Architecture

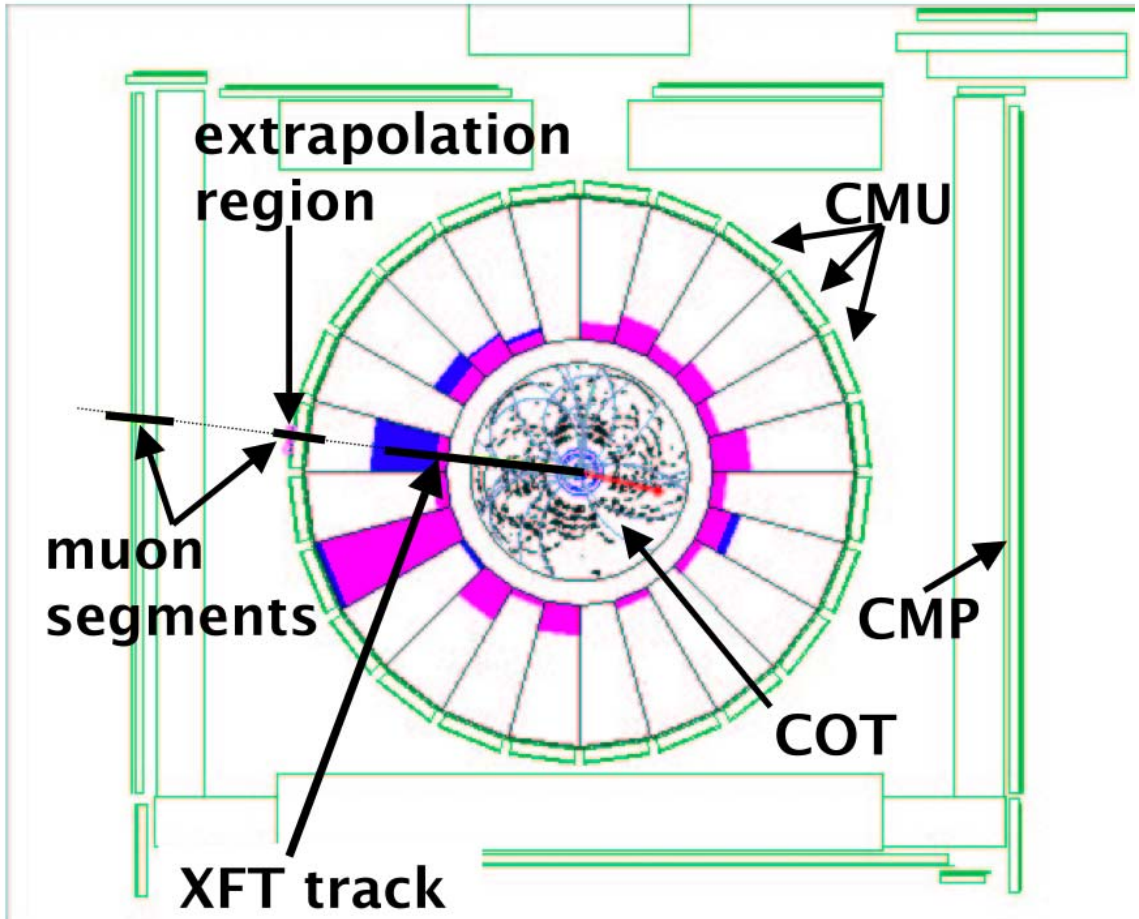


$\sigma(1/p_T) = 1.7\%/GeV$
$\sigma(\phi_0) = 5$ mrad
96% efficiency
($p_T > 1.5$ GeV)



Lepton triggers

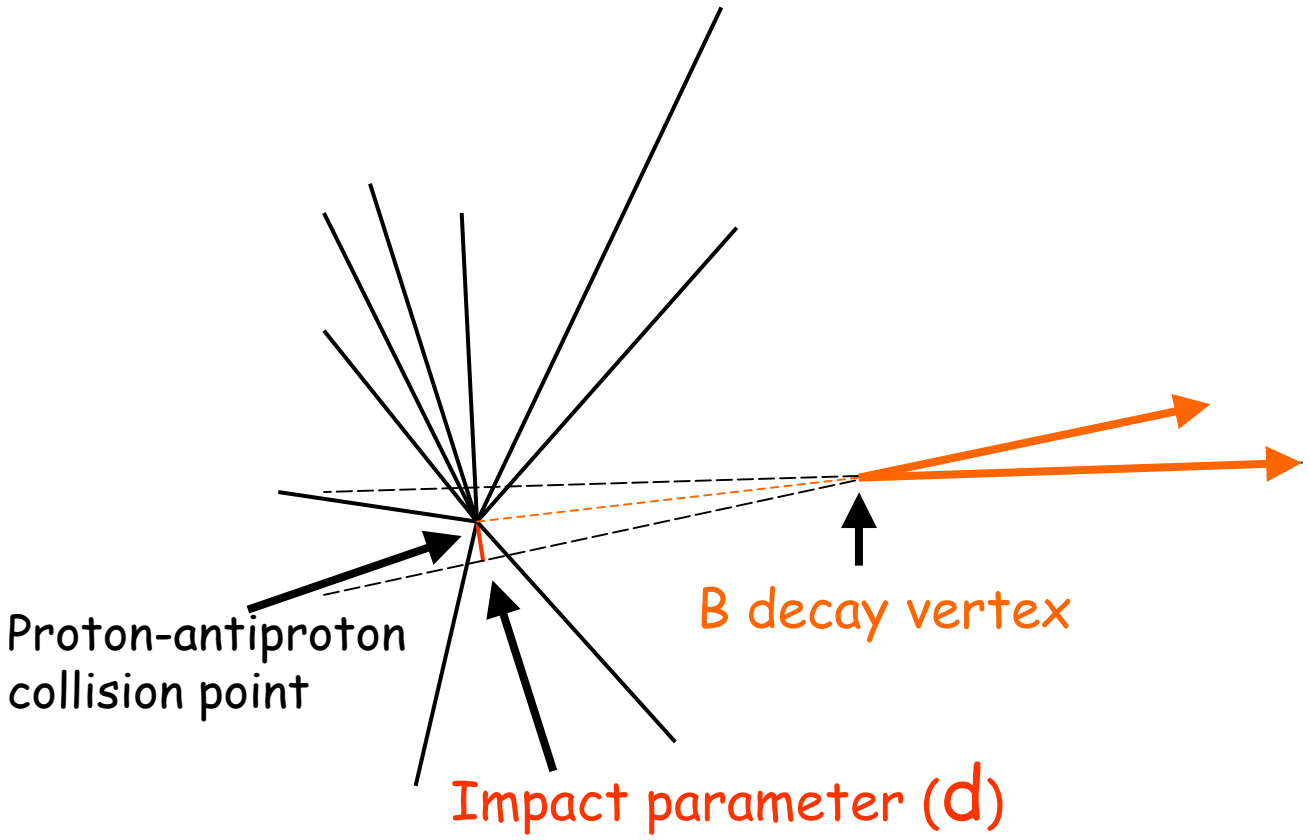




Lepton triggers

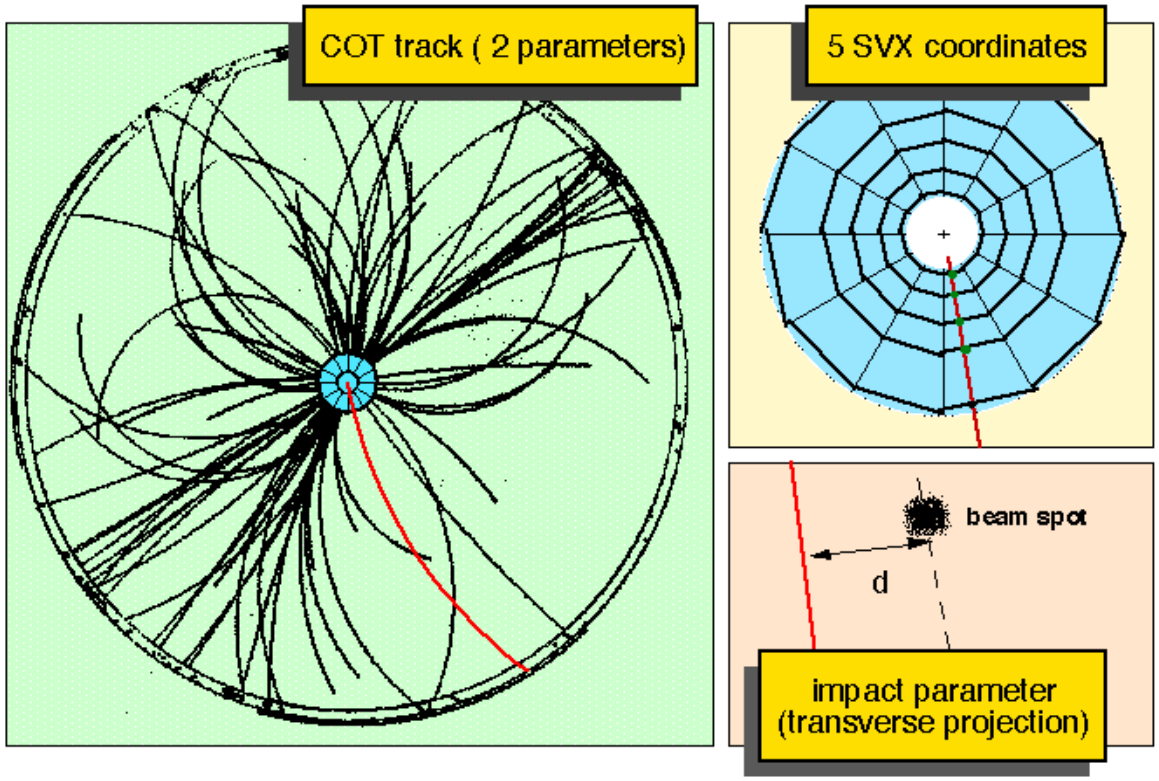
match between a muon stub or calorimeter signal with an XFT track extrapolated by the XTRP

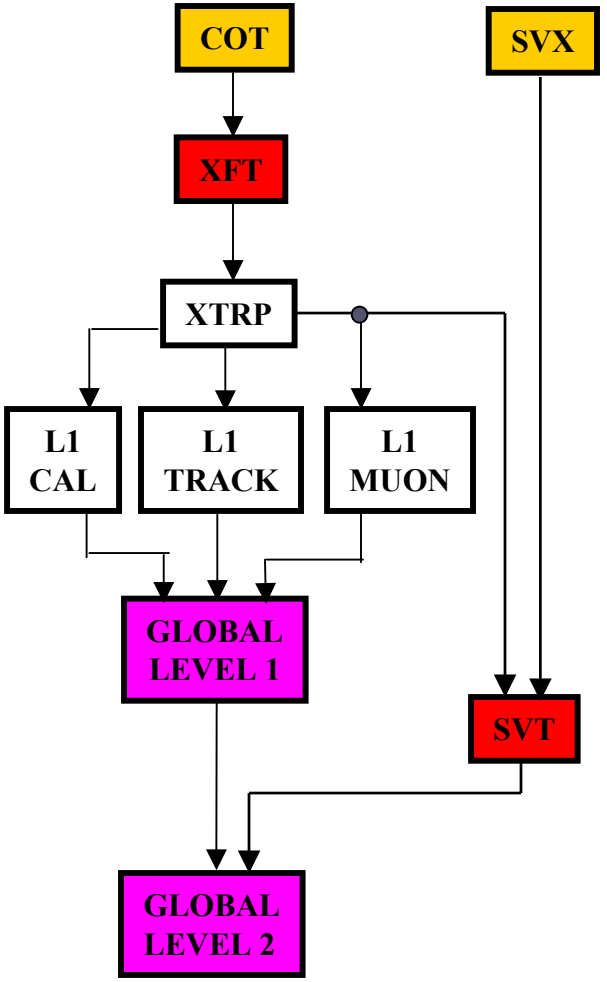
SVT: Exploit lifetime to select b,c



Transverse view

SVT: Input & Output





Inputs:

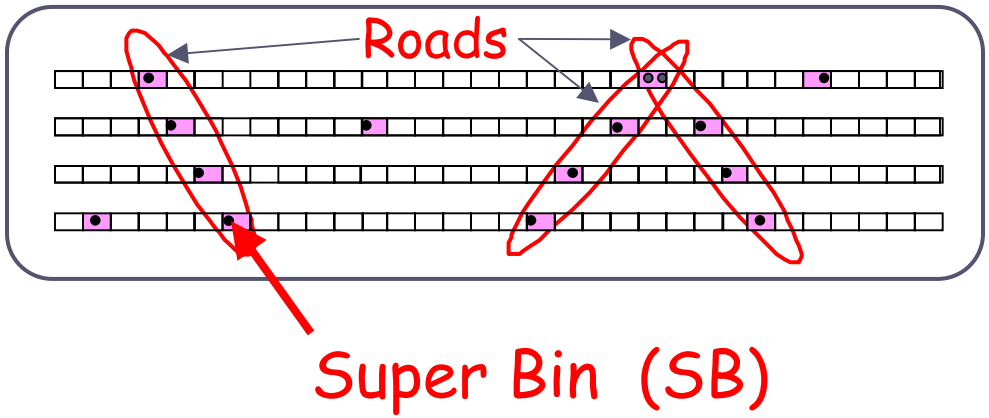
- L1 tracks from XFT (ϕ, pT)
- digitized pulse heights from SVX II

Outputs:

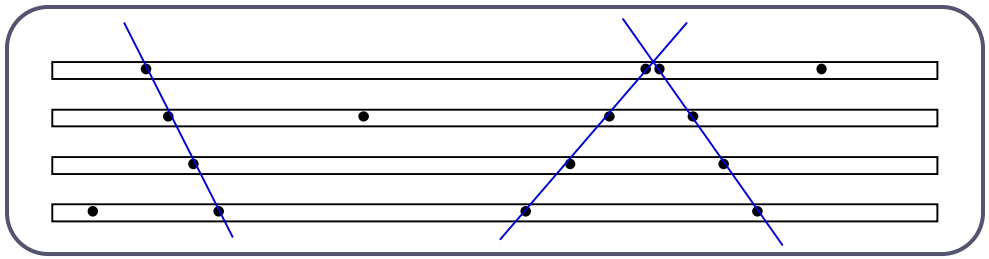
- reconstructed tracks (d, ϕ, pT)

Tracking in 2 steps

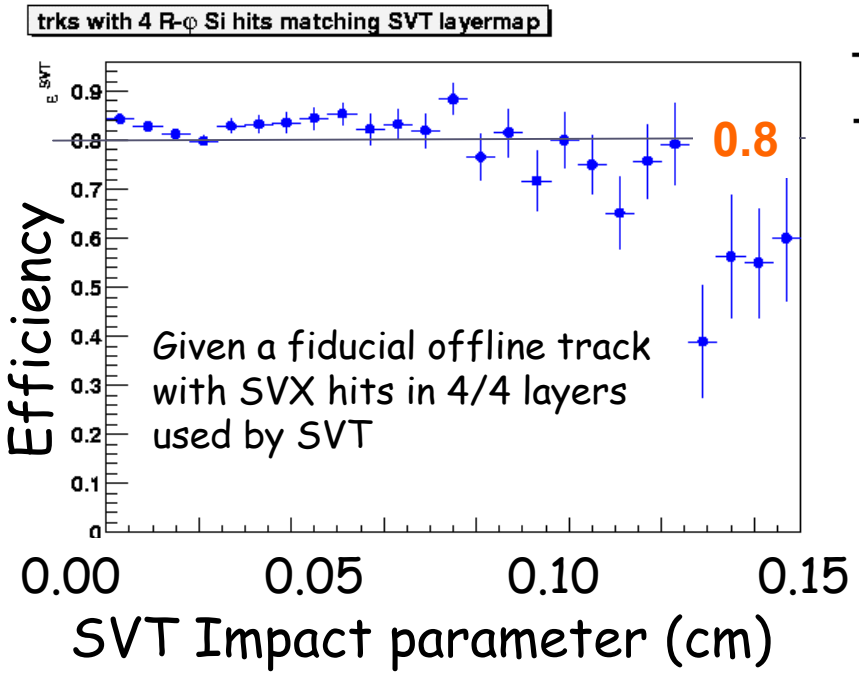
1. Find low resolution track candidates called "roads". Solve most of the pattern recognition

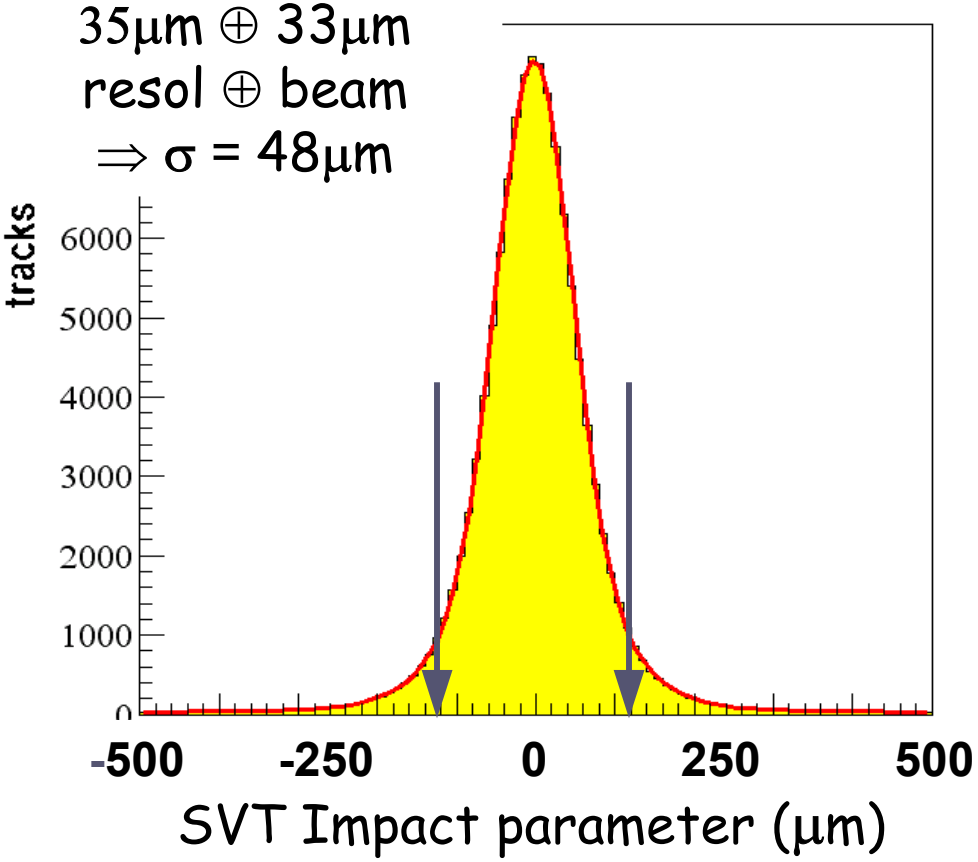


2. Then fit tracks inside roads. Thanks to 1st step it is much easier

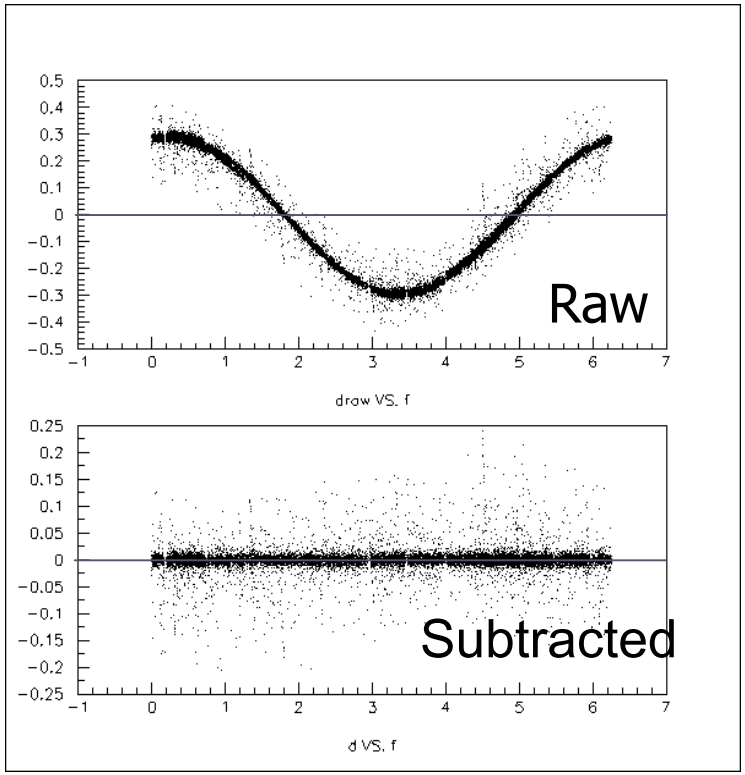


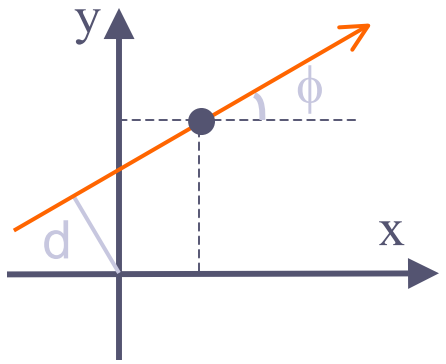
SVT Performance



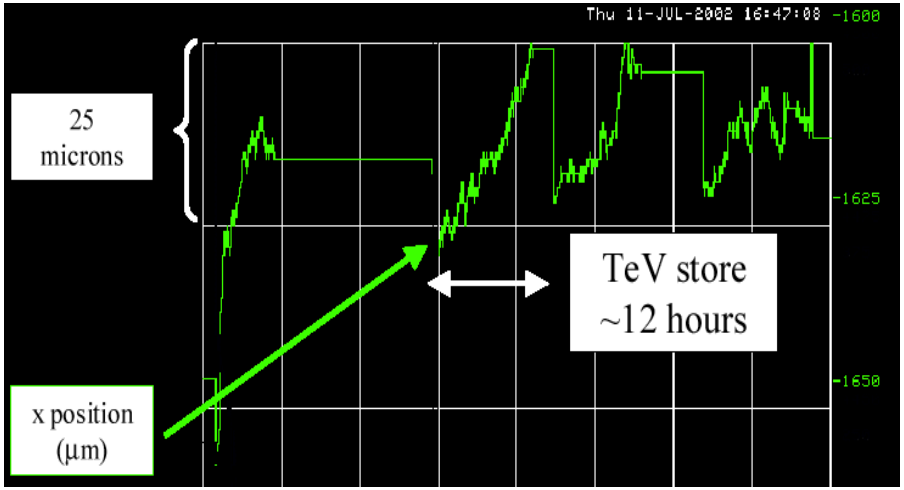


Online beamline fit & correction





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



Track Triggers and B Physics

Di-Muon (J/ψ)

Pt(μ) > 1.5 GeV

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

Displaced trk + lepton (e, μ)

IP(trk) > 120μm

Pt(lepton) > 4 GeV

Semileptonic modes

2-Track Trig.

Pt(trk) > 2 GeV

IP(trk) > 100 μm

Fully hadronic modes

$\psi(2S)$, $X(3872) \rightarrow J/\psi\pi\pi$ (quarkonia)

$B_s \rightarrow J/\psi\phi$, $B_{u,d} \rightarrow J/\psi K^{(*)}_s$

$\Lambda_b \rightarrow J/\psi\Lambda$ (masses, lifetimes, mix. calibration)

$B_{s,d} \rightarrow \mu\mu$ (rare decays)

$\Upsilon \rightarrow \mu\mu$

Bc (part.rec.$B \rightarrow J/\psi$lX)

High statistics lifetime

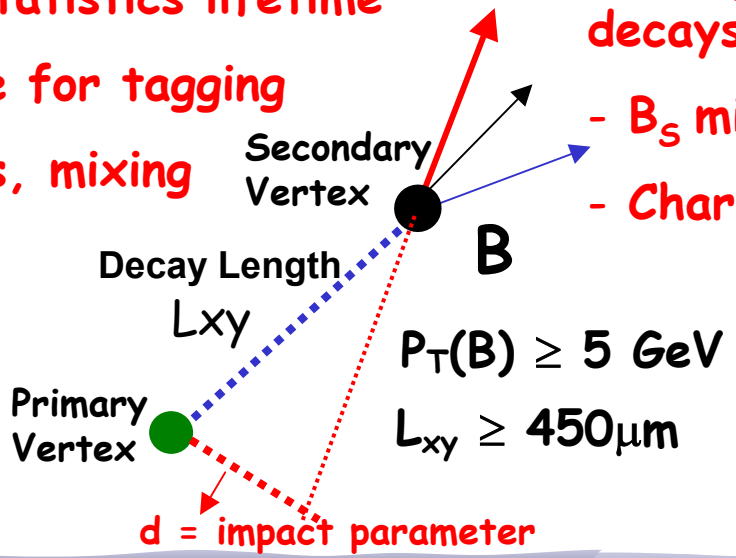
Sample for tagging

studies, mixing

- CP asymmetry in 2-body charmless decays

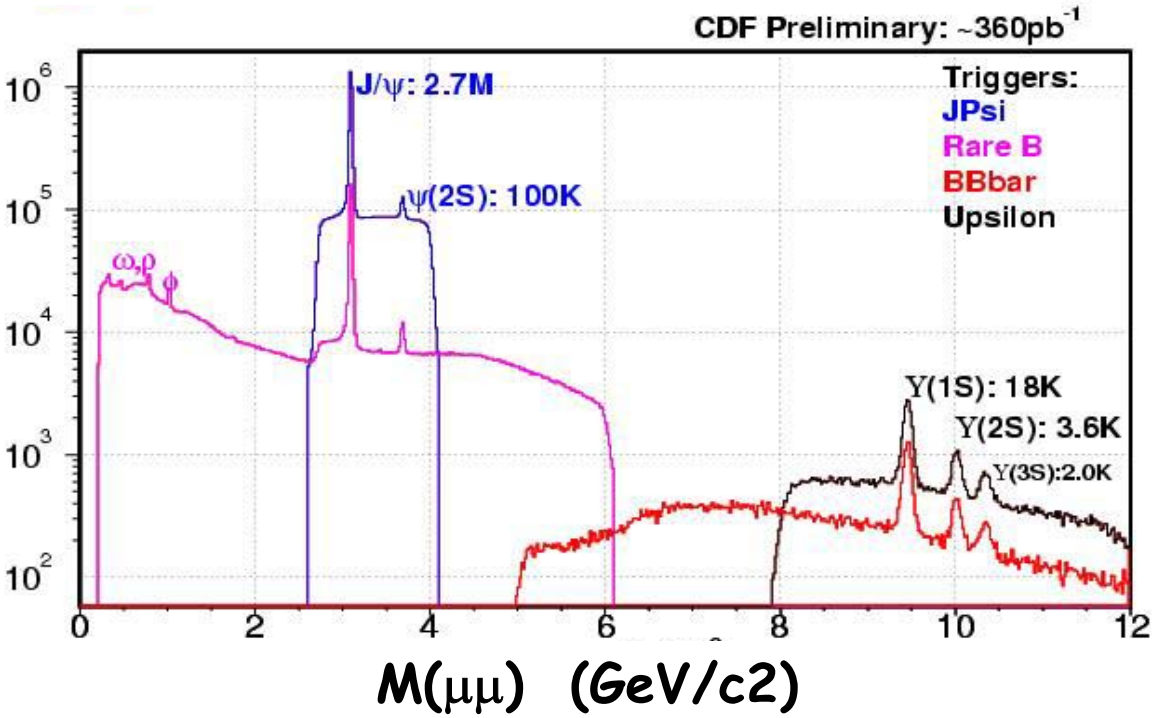
- B_S mixing

- Charm physics



Dimuon Trigger

Level 3 dimuon mass distribution for the several dimuon paths



Hadronic B decays with SVT

Two paths

L1:

Two XFT tracks

P_t > 2 GeV; $P_{t1} + P_{t2}$ > 5.5 GeV

$\Delta\phi$ < 135°

L2:

d_0>100 μm for both tracks

Validation of L1 cuts with $\Delta\phi$>20°

Lxy > 200 μm

d_0(B)<140 μm

Two body decays

L1:

Two XFT tracks

P_t > 2.0 GeV; $P_{t1} + P_{t2}$ > 5.5 GeV

$\Delta\phi$ < 135°

L2:

d_0>120 μm for both tracks

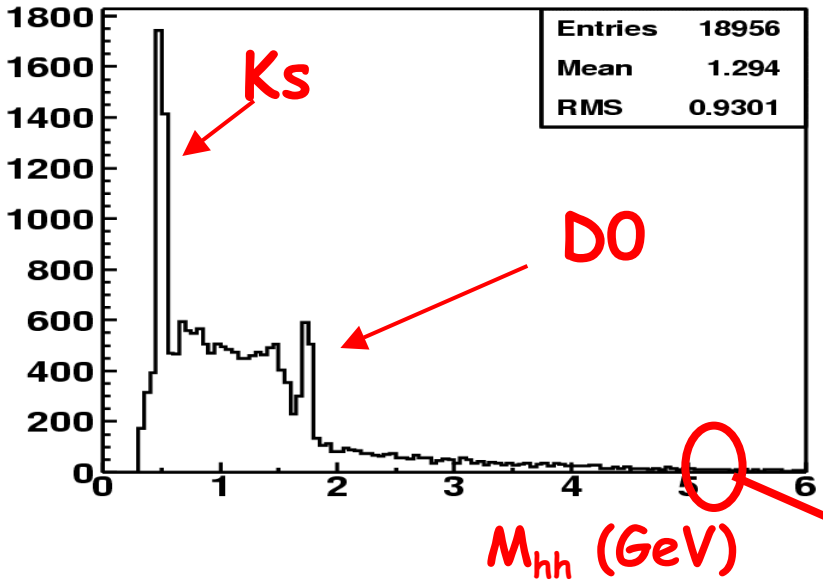
Validation of L1 cuts with $\Delta\phi$>2°

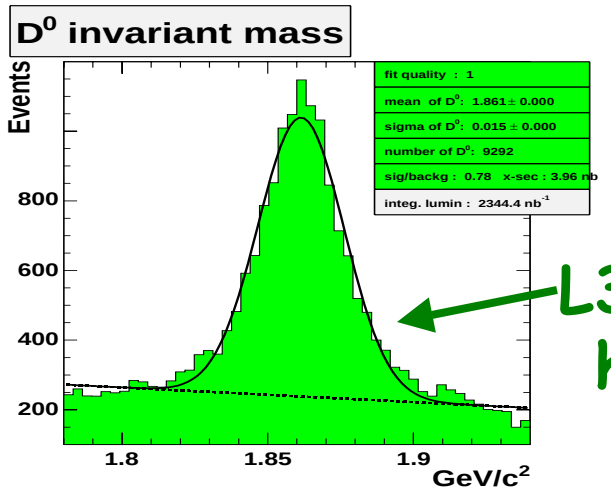
Lxy > 200 μm

~~d_0(B)<140 μm~~

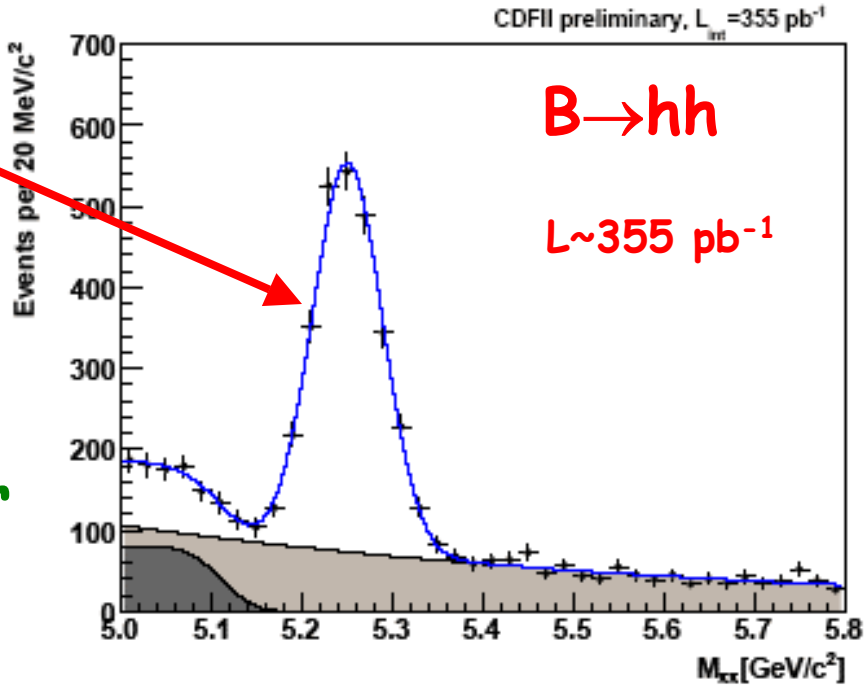
Many body decays

Hadron-hadron mass distribution





L3 monitor hadronic trigger



Triggering at high luminosity

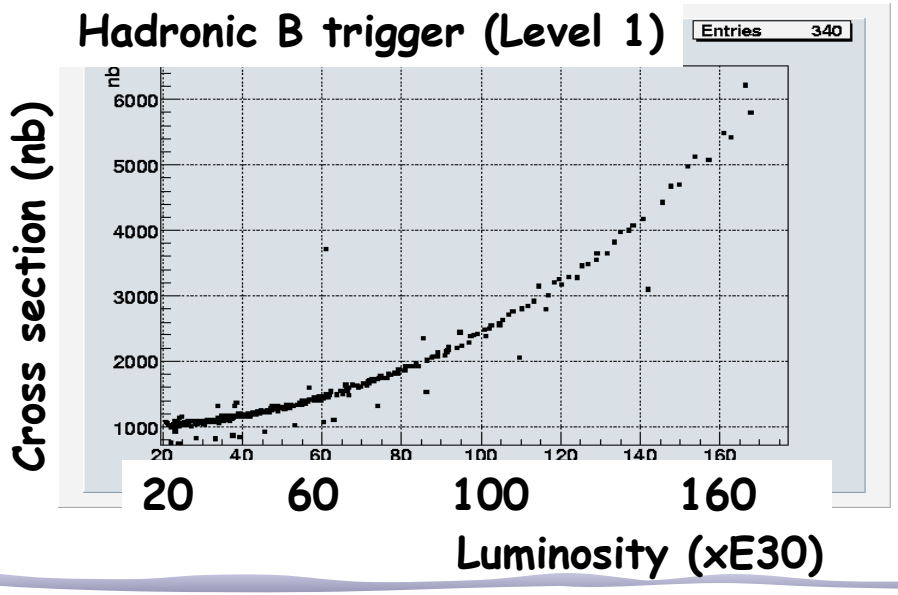
DAQ/trigger designed for L=1E32(@132ns)
now L=1.7E32(@396) and growing fast

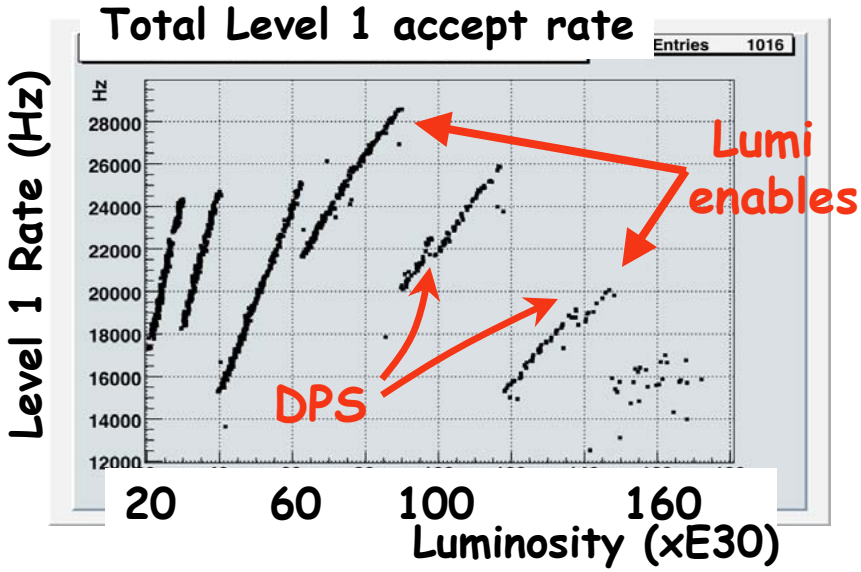
Harsh conditions:

-Overlapping events, larger COT occupancy, more XFT fakes, larger L1 trigger cross sections.

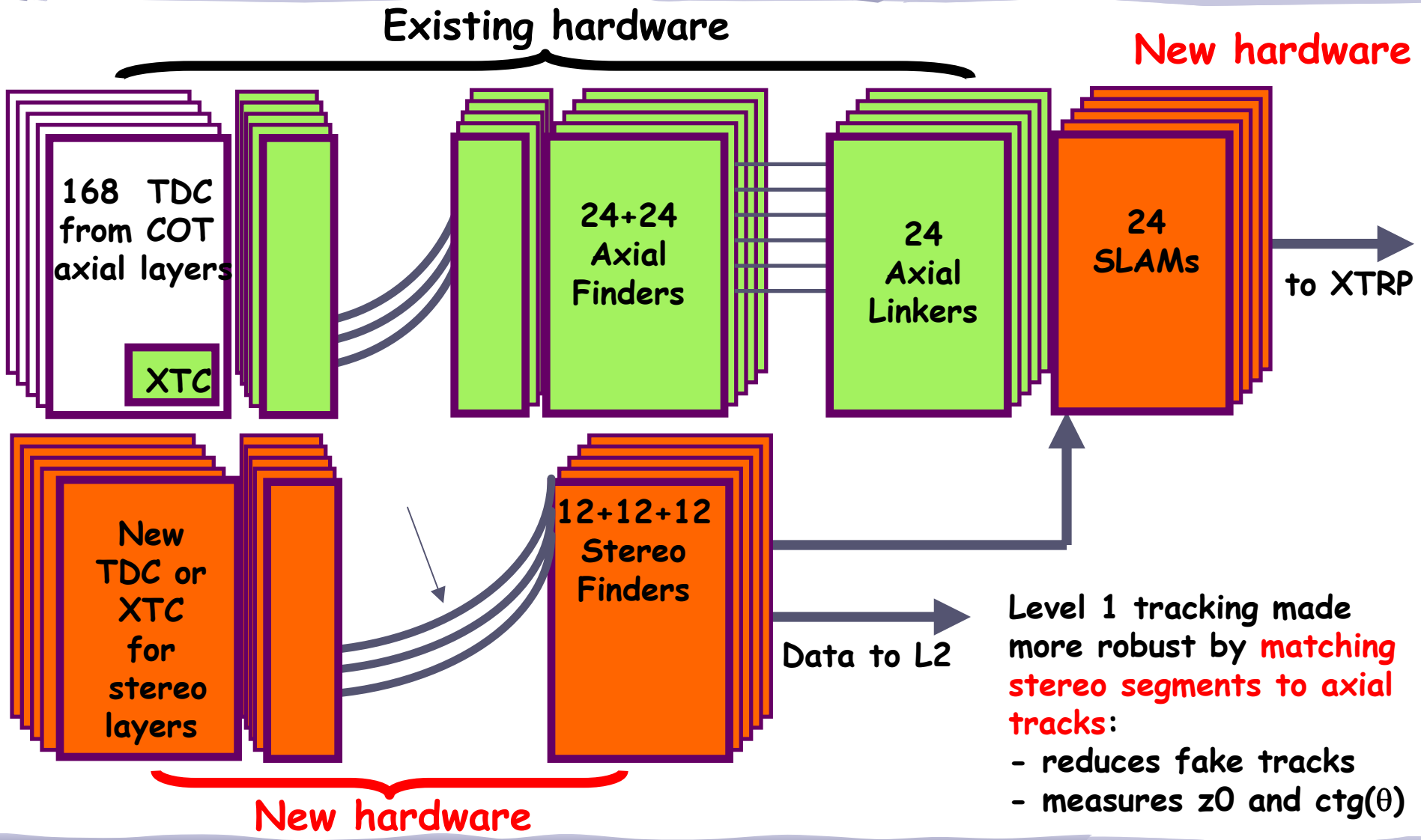
- More complex events, larger L2 processing time, more deadtime, will get worse.

Many clever ideas needed





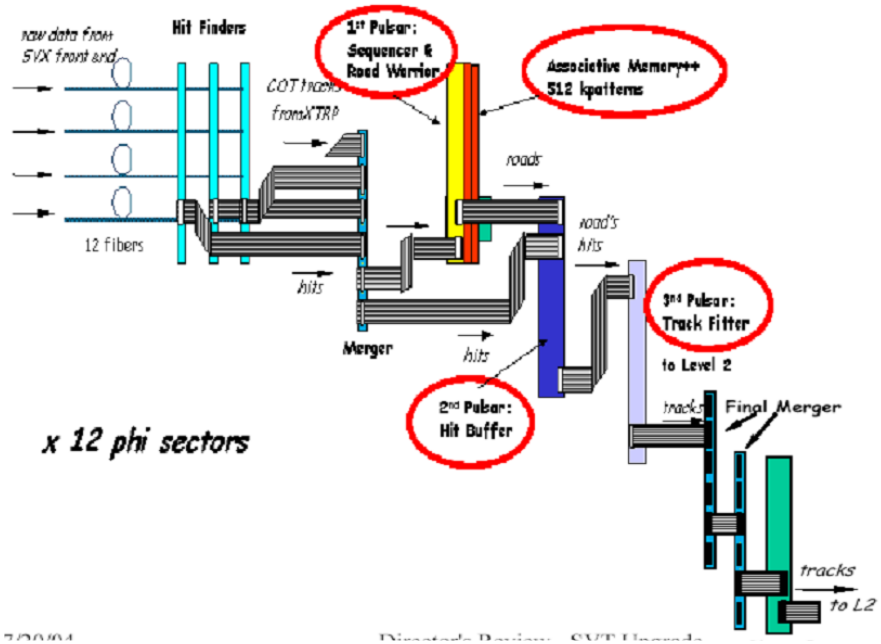
XFT Upgrade (within summer 2006)

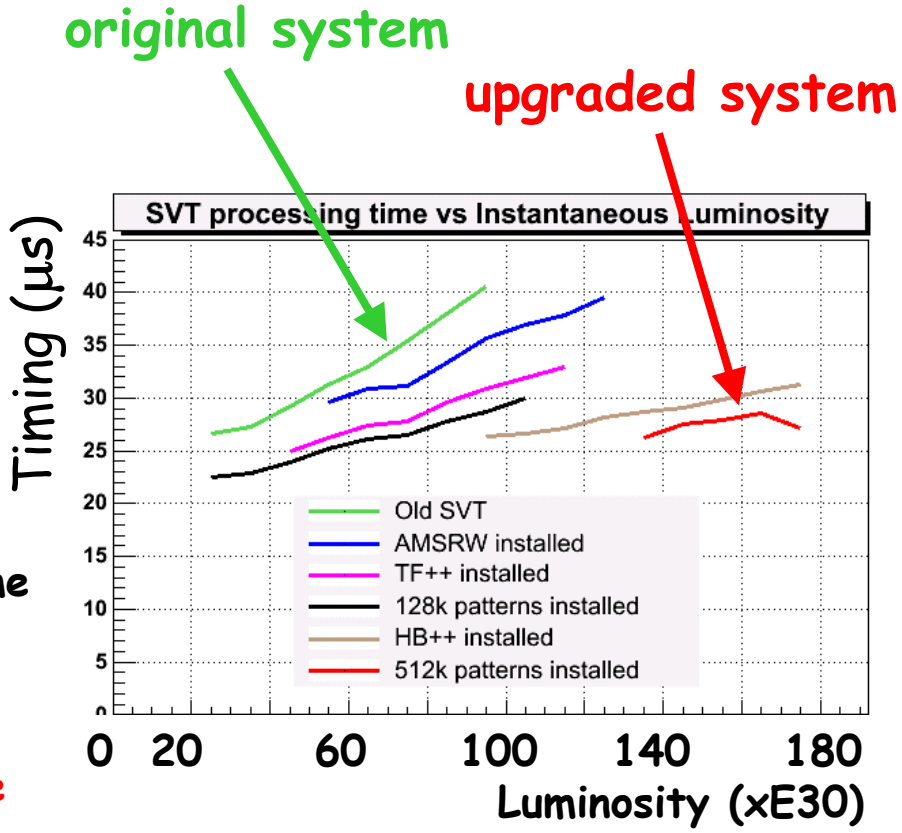


Level 1 tracking made more robust by matching stereo segments to axial tracks:

- reduces fake tracks
- measures z0 and ctg(θ)

SVT Upgrade (done, fall 2005)





SVT upgraded with faster components, same architecture as original system
New AM chip (32K→512K patterns/wedge)
- thinner roads: fewer combinations/road
More complex events processed in less time

Conclusions

We reviewed

The CDF detector elements crucial for B Physics

- Tracker
  - Silicon detectors (L00, SVXII, ISL)
  - Drift chamber (COT)
- Particle identification system
  - Time of Flight detector
  - dE/dx from the drift chamber
- Lepton detectors (muon chambers, CEM calorimeter)

The CDF Trigger architecture

- XFT: Level 1 track trigger (lepton triggers)
- SVT: Level 2 silicon vertex trigger

The CDF Trigger strategy for B Physics

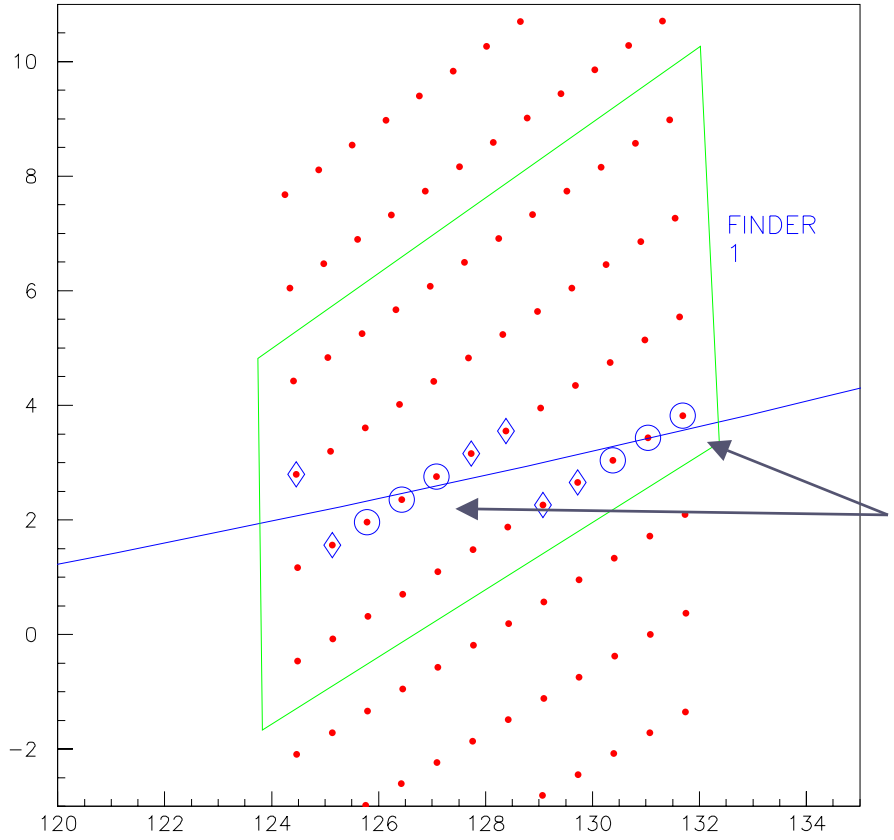
- Problems/solutions for high luminosity running

CDF can take good data for B analyses for all Run II

BACKUP

The Finder

Track segments are found by comparing hit patterns in a given layer to a list of valid patterns or "**masks**".



"Prompt" hit (T<64 ns)

"Delayed" hit (T> 64 ns)

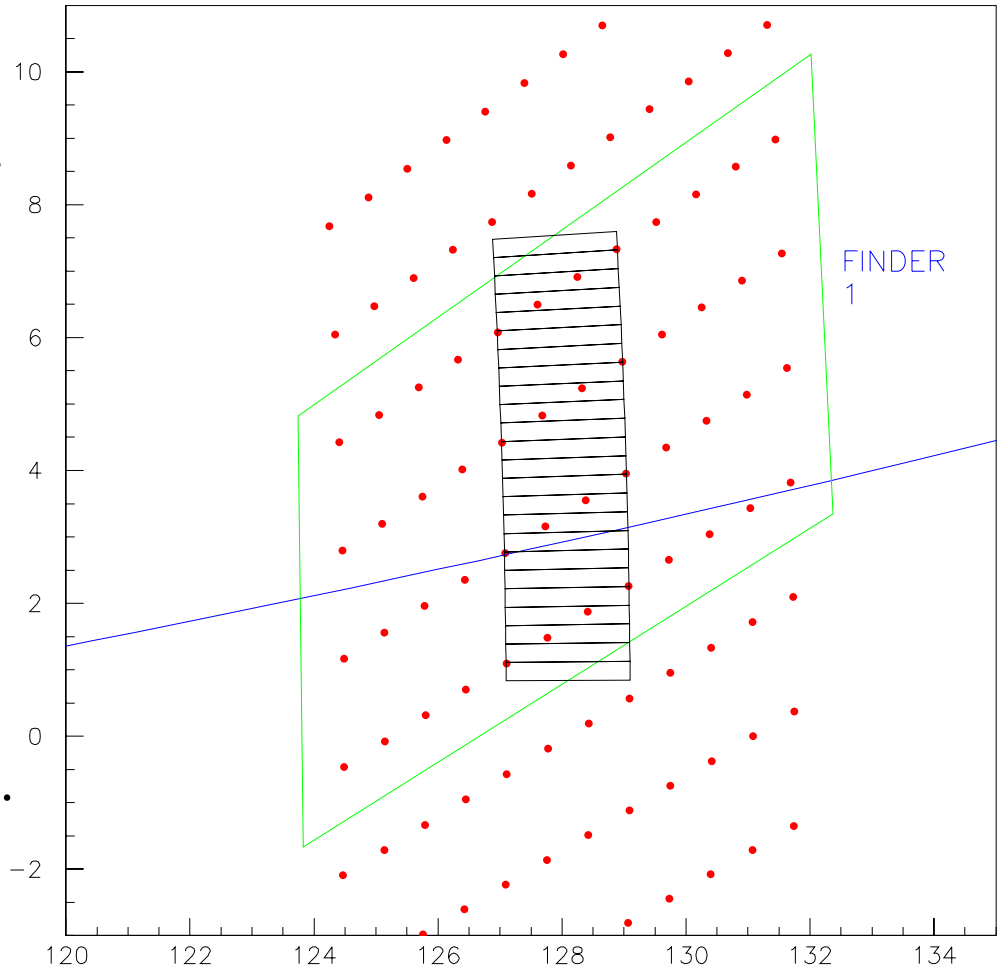
2 Bin Mask : A specific pattern of prompt and delayed hits on the 12 wires of an axial COT layer

Finder Output

2Bin Finder

- In the **inner** two layers, each **mask** corresponds to 1 of 12 **pixel** positions in the middle of the layer.
- In the **outer** 2 layers, each **mask** corresponds to 1 of 6 **pixel** positions and 1 of 3 **slopes**: (low pt +, low pt -, high pt).

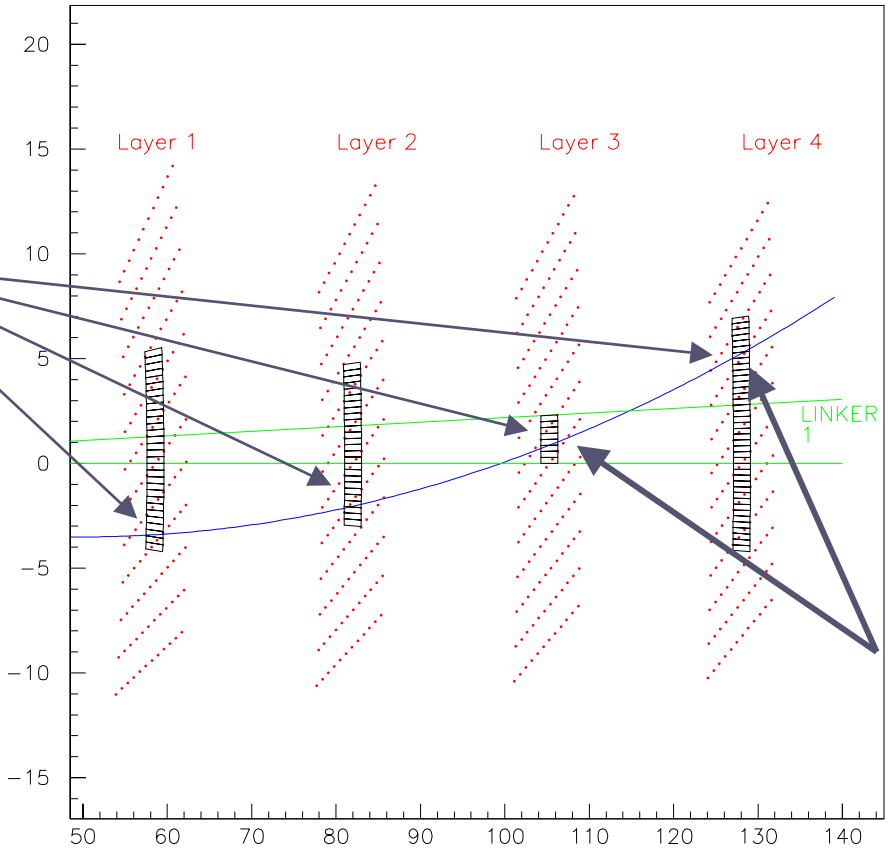
When a **mask** is located, the corresponding **pixel** is turned on.



The Linker

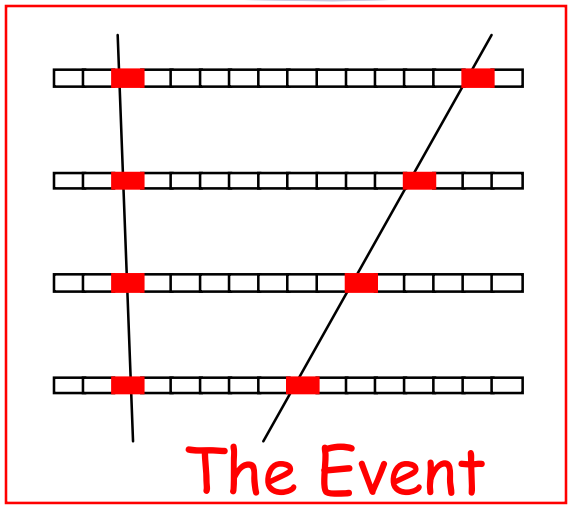
Tracks are found by comparing fired segments in all 4 layers to a list of valid segment patterns or "**roads**".

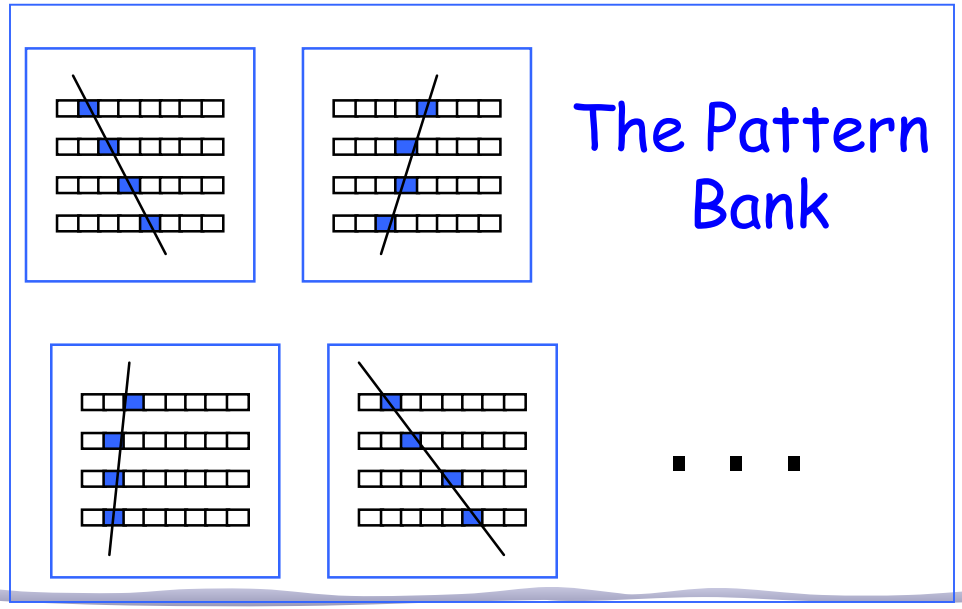
Pixels must match

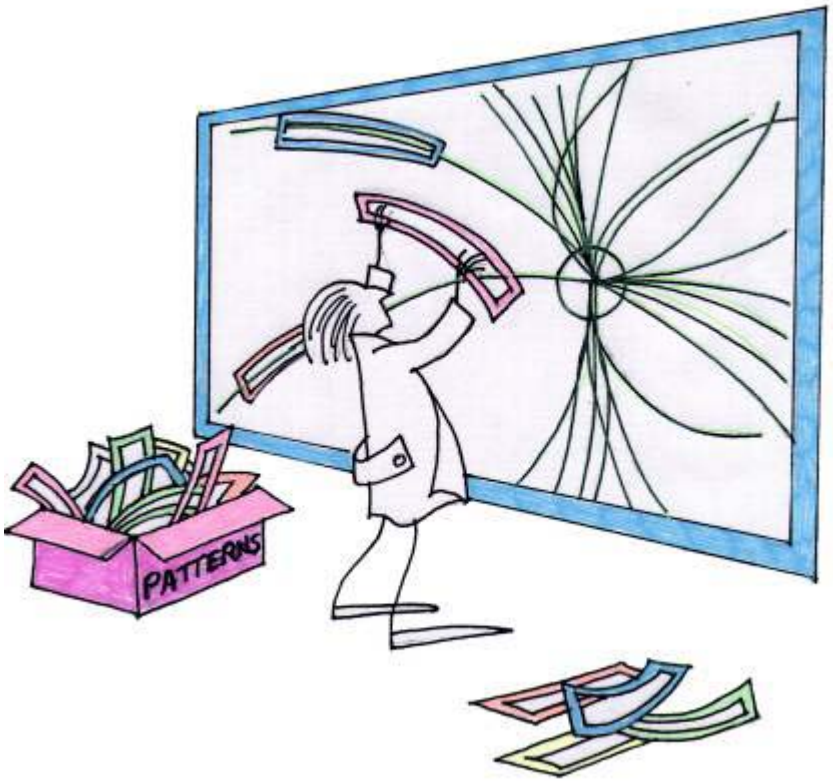


Slopes must match

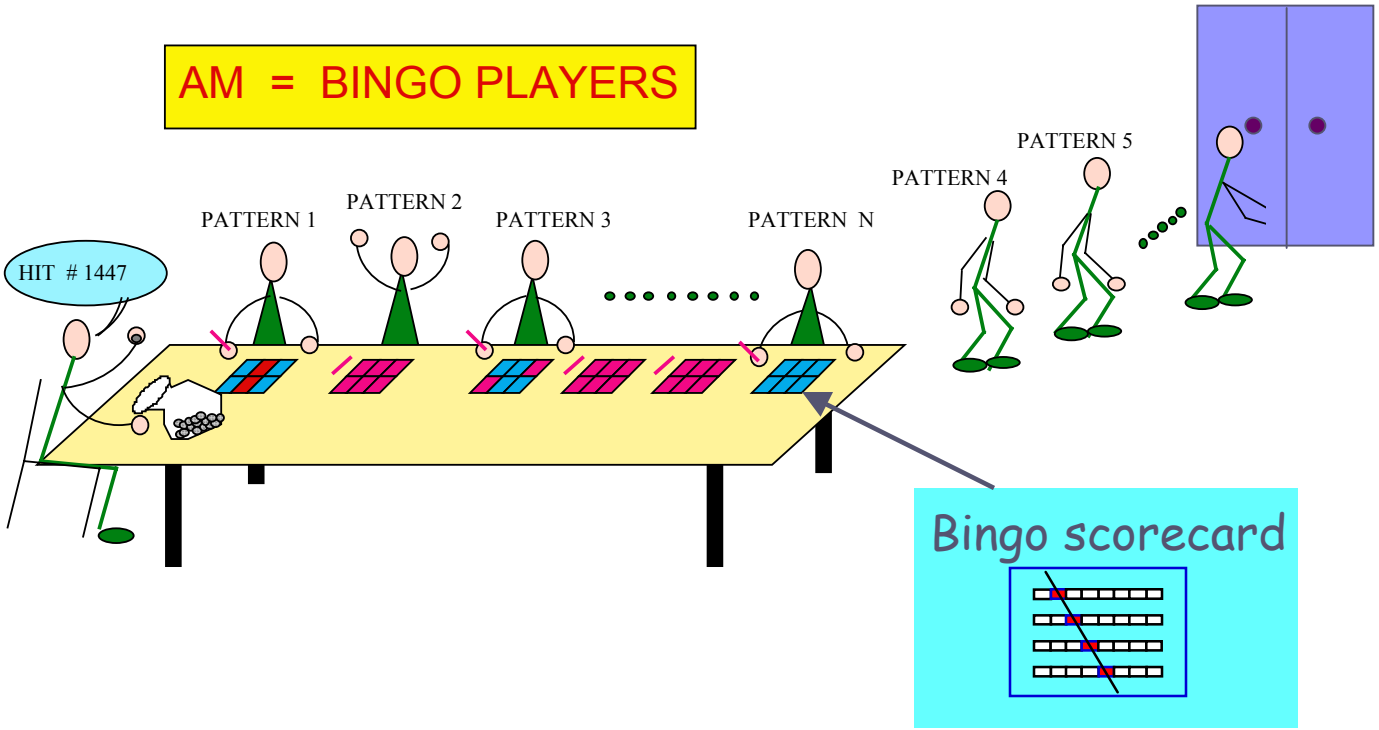
Pattern matching







AM: Associative Memory



- Dedicated device: maximum parallelism
- Each pattern with private comparator
- Track search during detector readout

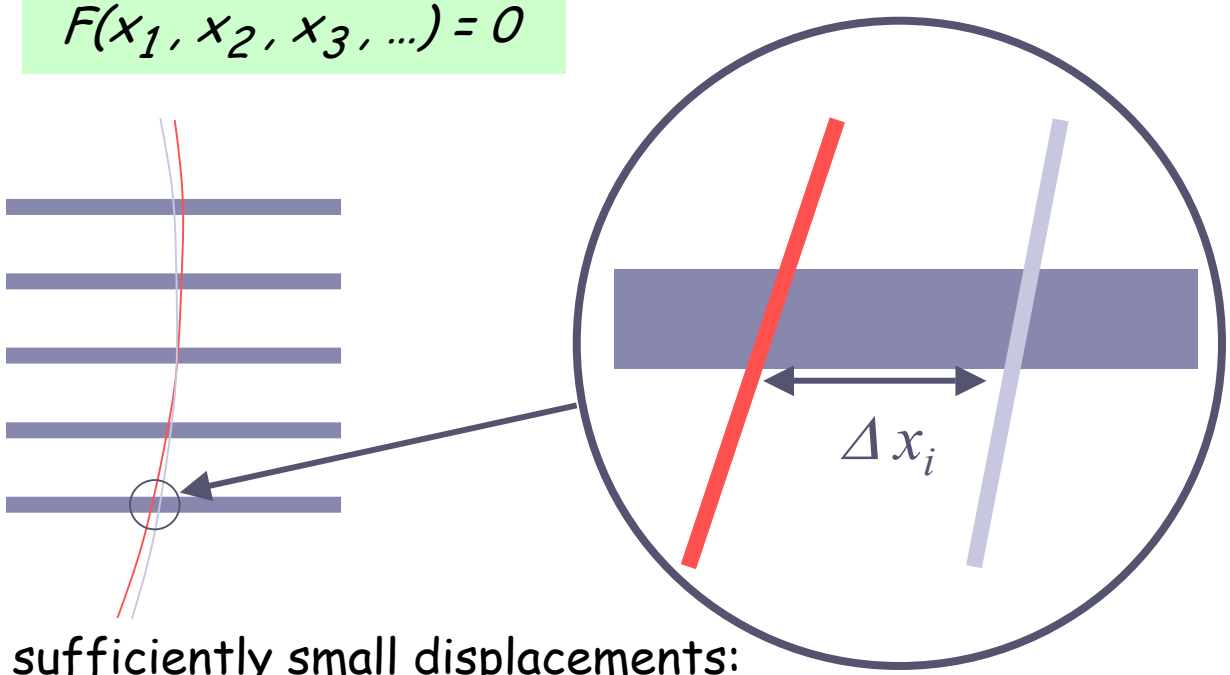
Track Fitting

- Track confined to a road: fitting becomes easy
- Linear expansion in the hit positions x_i:
  - $Chi2 = Sum_k ((c_{ik} x_i)^2)$
  - $d = d_0 + a_i x_i$; $phi = phi_0 + b_i x_i$; $Pt = ...$
- Fit reduces to a few scalar products: fast evaluation
  - (DSP, FPGA ...)
- Constants from detector geometry
  - Calculate in advance
  - Correction of mechanical alignments via linear algorithm
    - fast and stable
    - A tough problem made easy

From non-linear to linear constraints

Non-linear geometrical constraint for a circle:

$$F(x_1, x_2, x_3, \ldots) = 0$$



But for sufficiently small displacements:

$$F(x_1, x_2, x_3, \ldots) \sim a_0 + a_1\Delta x_1 + a_2\Delta x_2 + a_3\Delta x_3 + \ldots = 0$$

with constant a_i (first order expansion of F)