The CDF-II Time-of-Flight Detector

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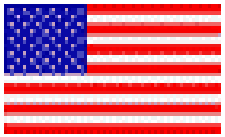
(on behalf of the CDF-II TOF group)

2002 IEEE NSS/MIC Norfolk, VA

ToF Group at CDF



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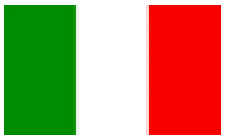

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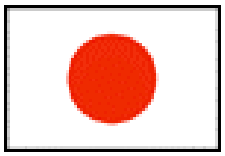

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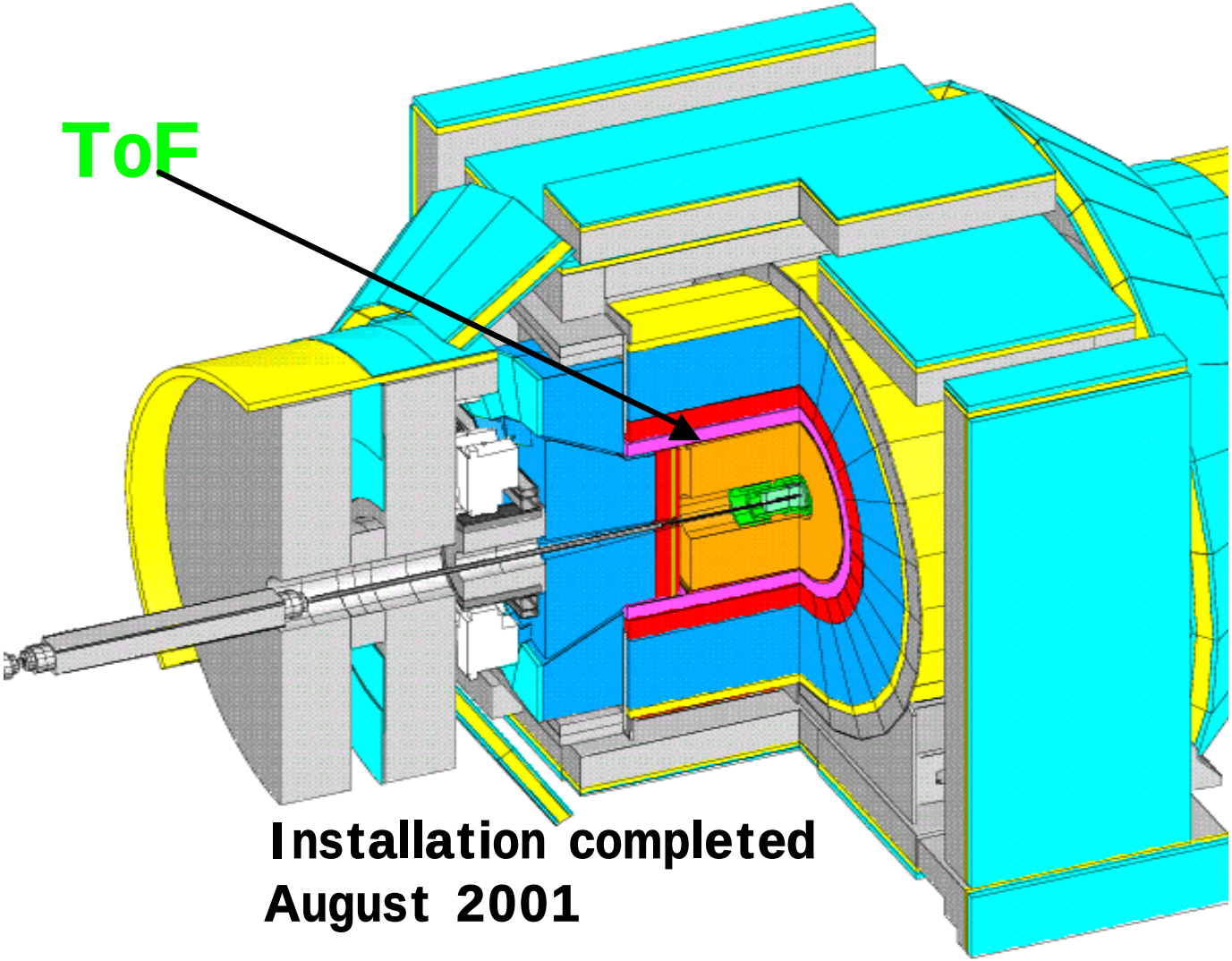
ToF in CDF-II

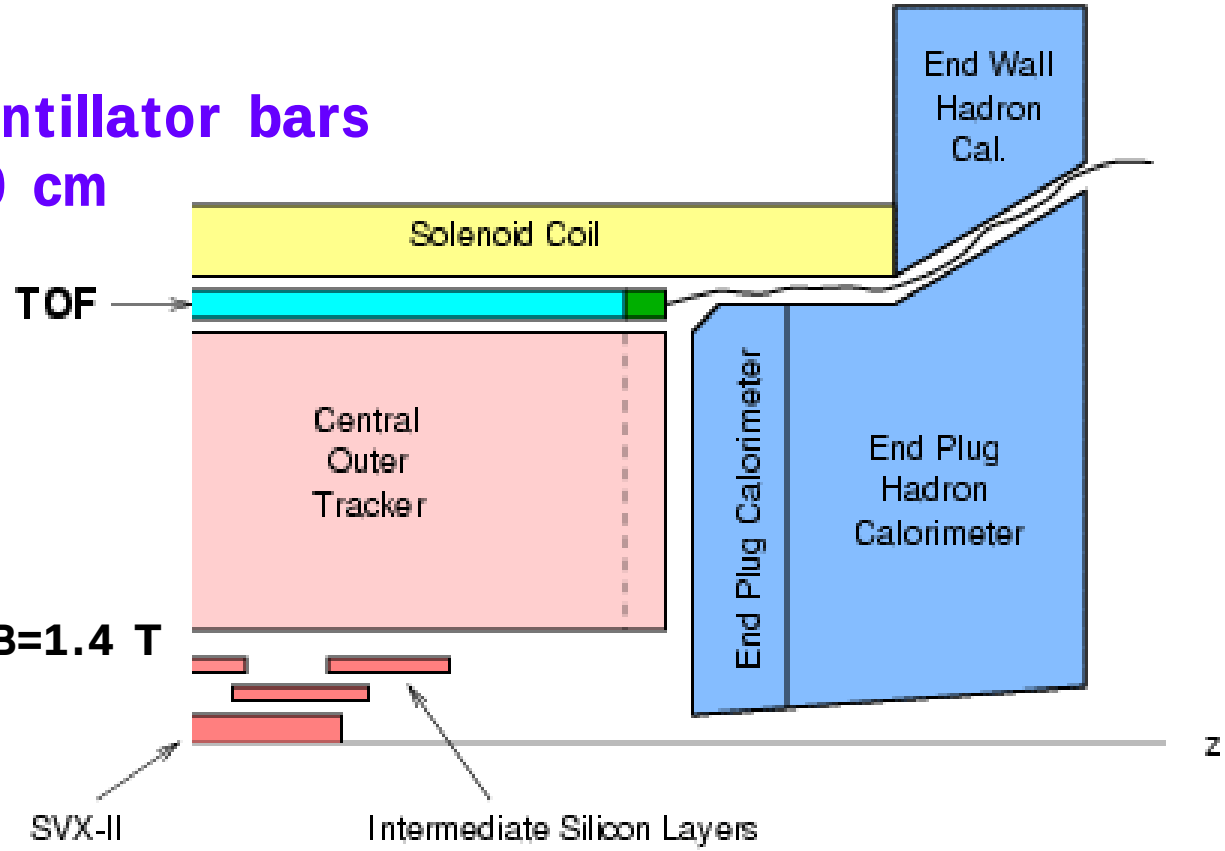


Installation completed August 2001

ToF in CDF-II

Barrel of 216 scintillator bars
4cm x 4cm x 280 cm
Bicron BC-408

PMT at each end
Hamamatsu R7761
Fine mesh, 19 stage
Gain reduction 500 @ B=1.4 T



Radial distance from beam pipe 1.4 m
tof ~ 5 ns for fastest particles

Particle ID with ToF

Tracking: **p, L**

ToF: **t**

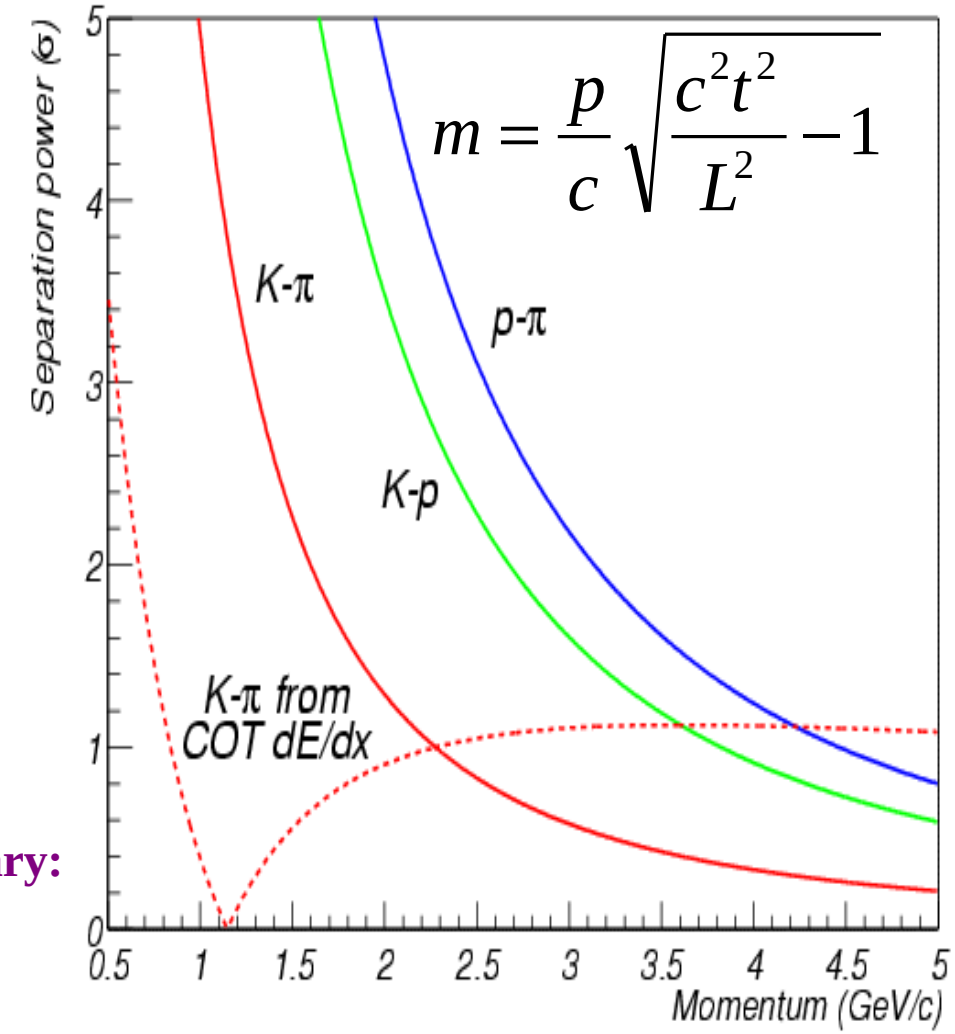
With ~ 100 ps resolution,
2s separation between:

K - p for p < 1.6 GeV/c

K - p for p < 2.7 GeV/c

p - p for p < 3.2 GeV/c

ToF and dE/dx are complementary:
enhanced pid at low p (< 2 GeV)



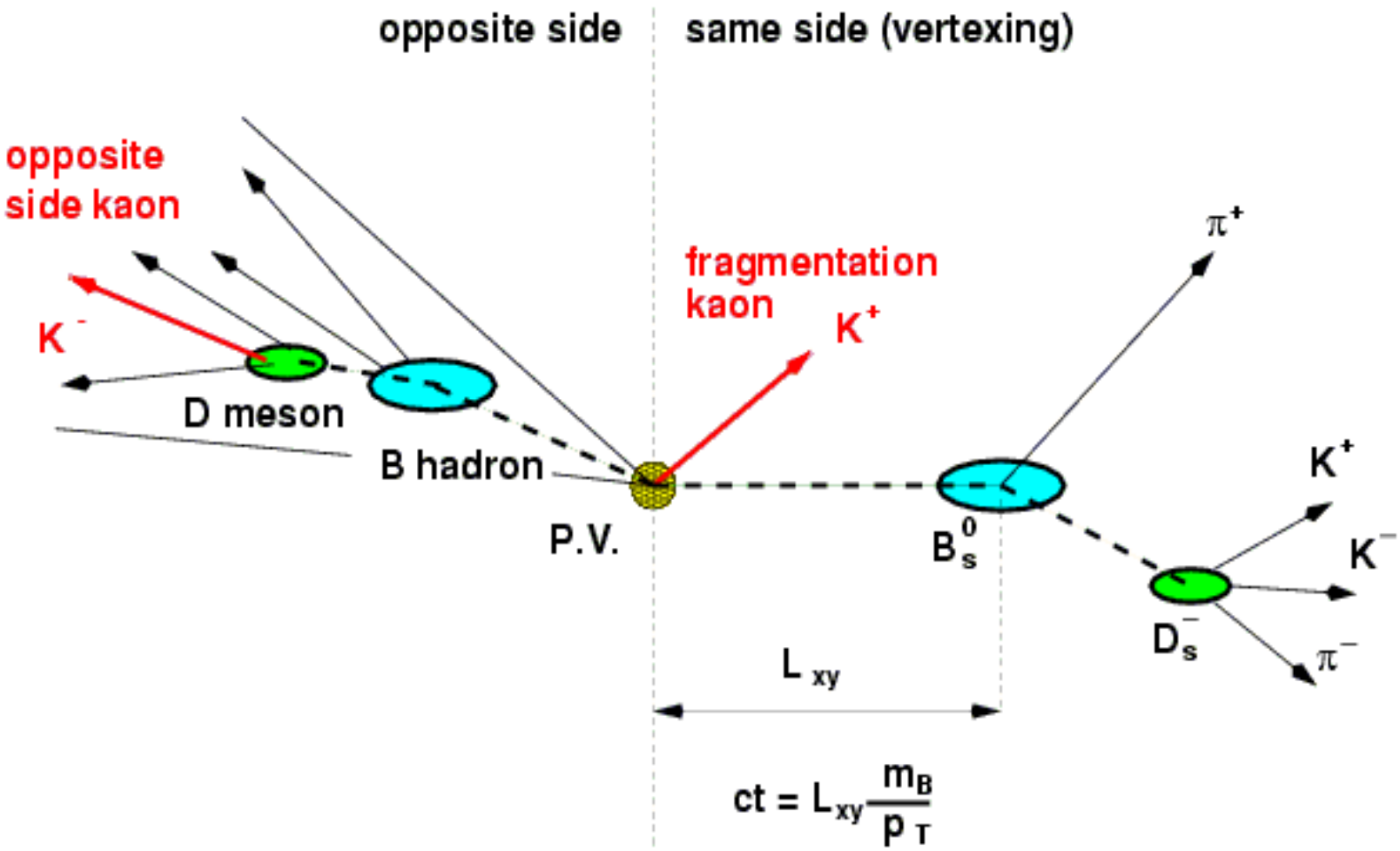
Physics Motivation

- **B flavor tag (via Kaon id)**
  - **ToF ⇨ B meson has b or $\bar{b}$ at production?**
  - **ToF ⇨ B meson has b or $\bar{b}$ at decay?**
- **B_s mixing is unique to Tevatron**

$$B_s^0(\bar{b}s) \Leftrightarrow \overline{B_s^0}(b\bar{s})$$

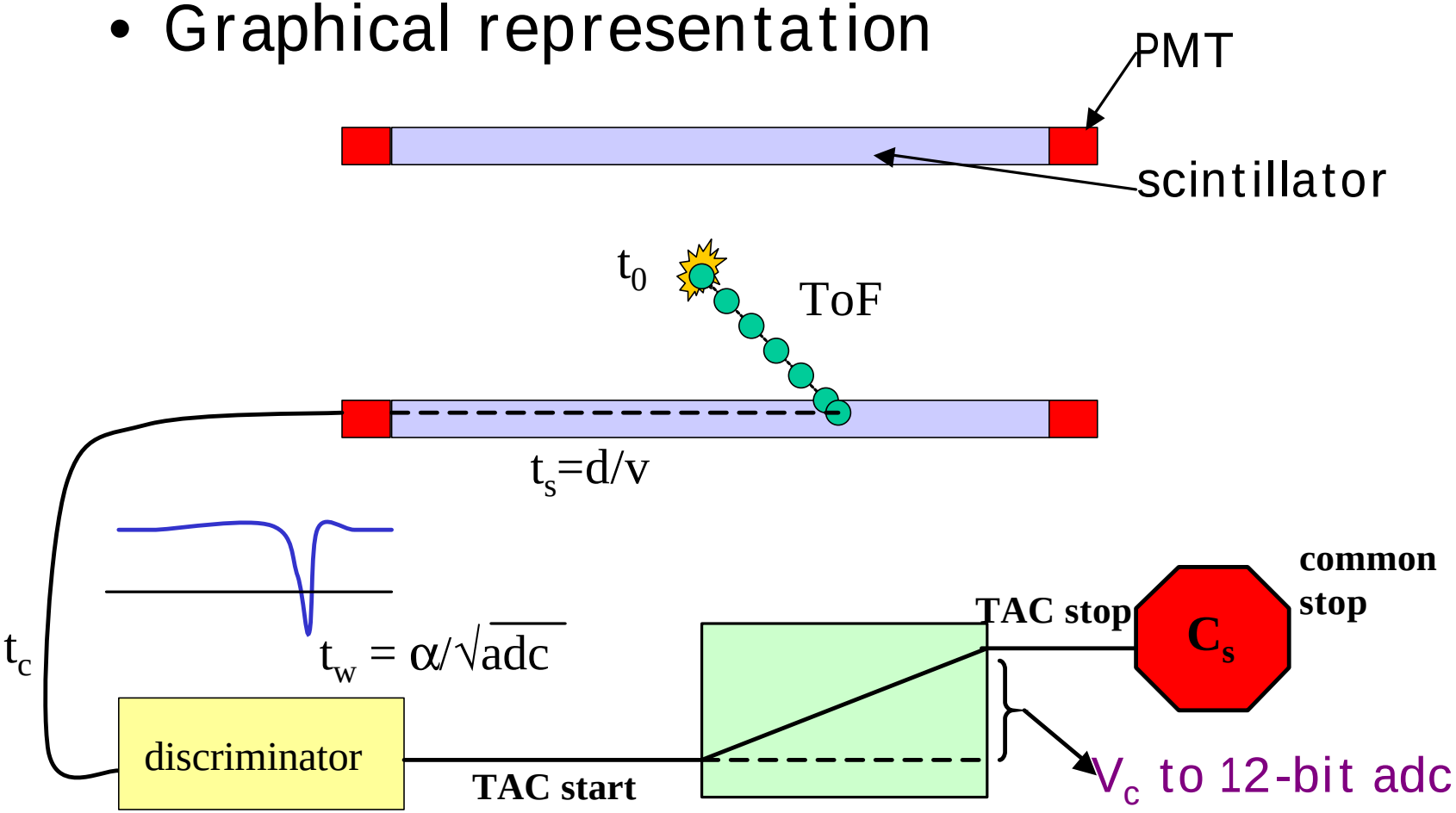
  - **B_s flavor oscillations ⇨ Δm_s**
  - **CP asymmetries in B_s decays**
- **Other applications**
  - **Cosmic ray rejection**
  - **HIP trigger for monopole searches**
  - **S/B enhancement in hadron reconstruction**

B flavor tagging using ToF



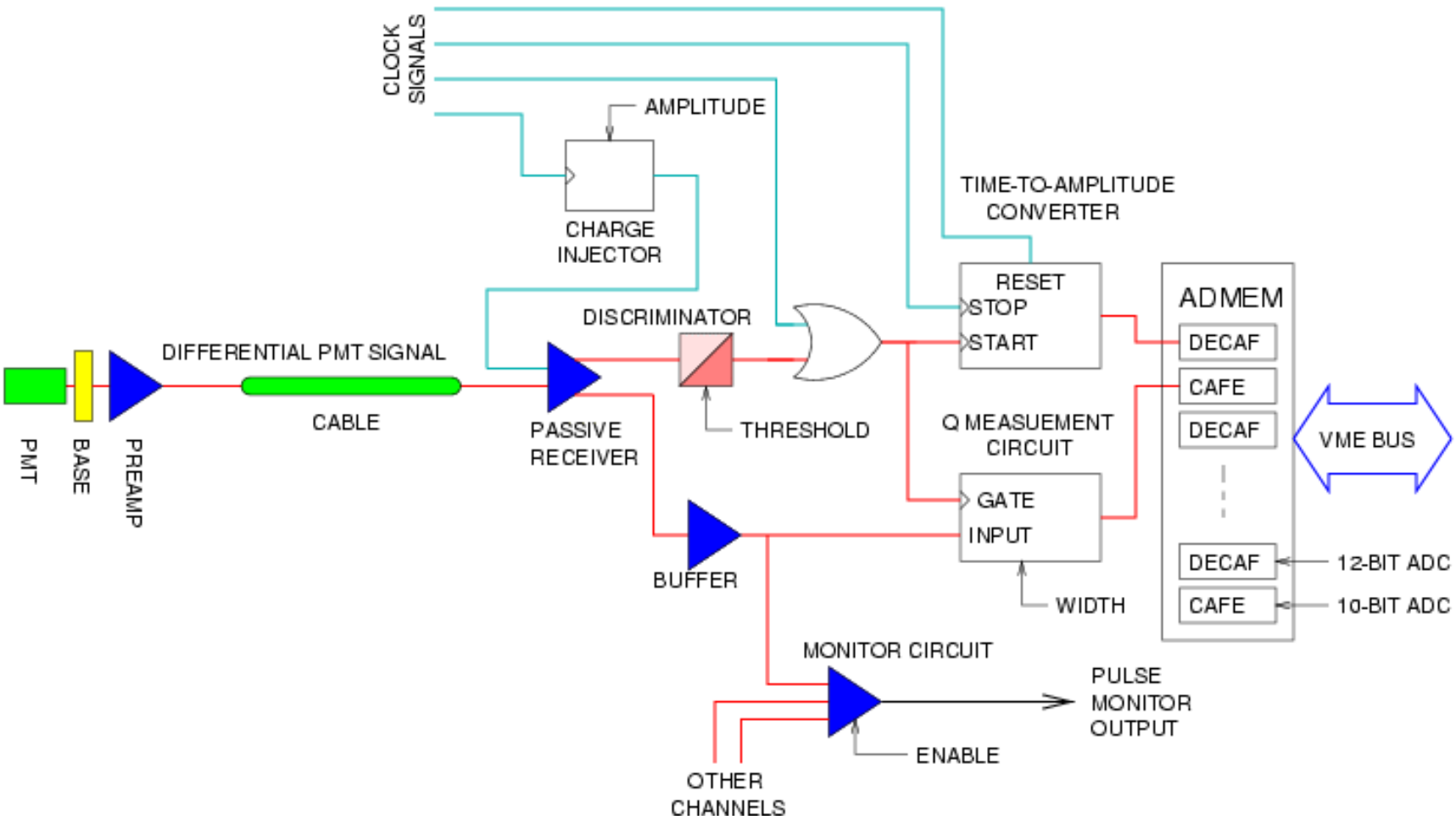
The CDFII Time of Flight Detector

- Graphical representation



$$adc=C_s-(t_0+ToF+t_s+t_c+t_w)$$

ToF Electronics



Electronics contribution to overall resolution < 25 ps

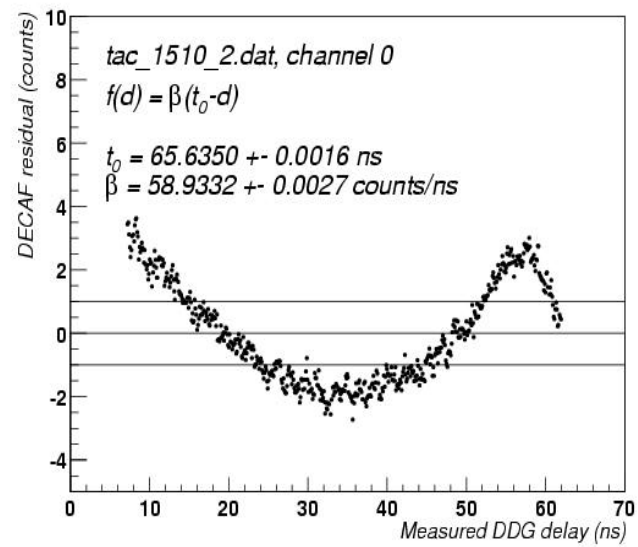
Online Calibration

Send known delays using a digital delay generator (DDG)

(DDG jitter < 25 ps)

Parameterize ADC response as:

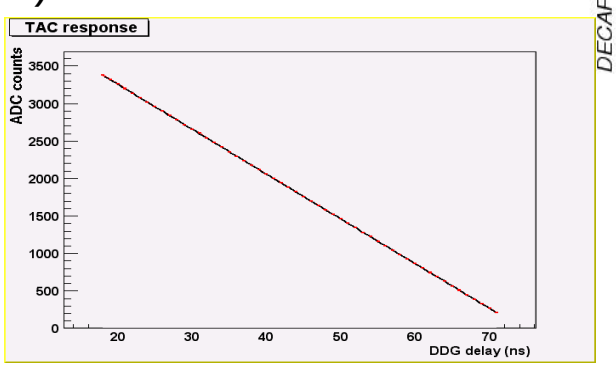
$$ADC = b(1 + ge^{-(t-t_0)/t})(t - t_0)$$

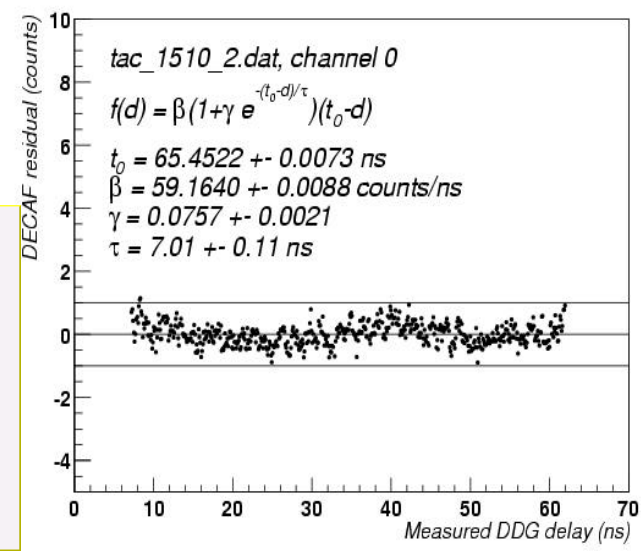


Almost linear response

(Non-linear behavior modeled within 17 ps by parameterization)

1 ADC count ~ 17 ps



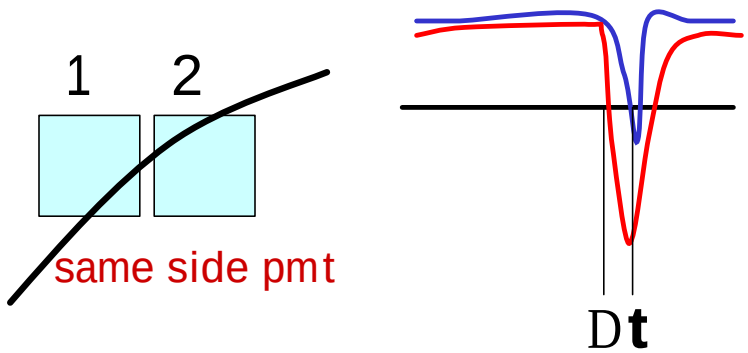


Off-line Calibrations

- Big challenge
- For ~100 ps resolution, must measure
  - Time walk effect
    - Due to dependence of discriminator time on pulse height
    - Of order ~ 2 ns
  - Speed of signal propagation in bars
    - Times depend on z-position of hit along bar
  - Differences in electronic path lengths
  - Attenuation length
  - t_0

Time Walk

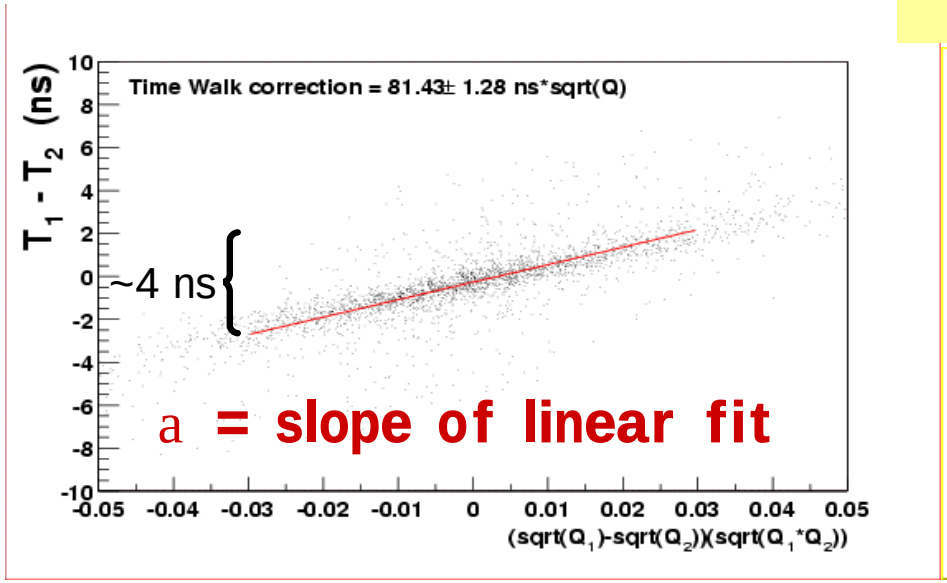
tracks hitting adjacent bars: $t_1 \sim t_2$

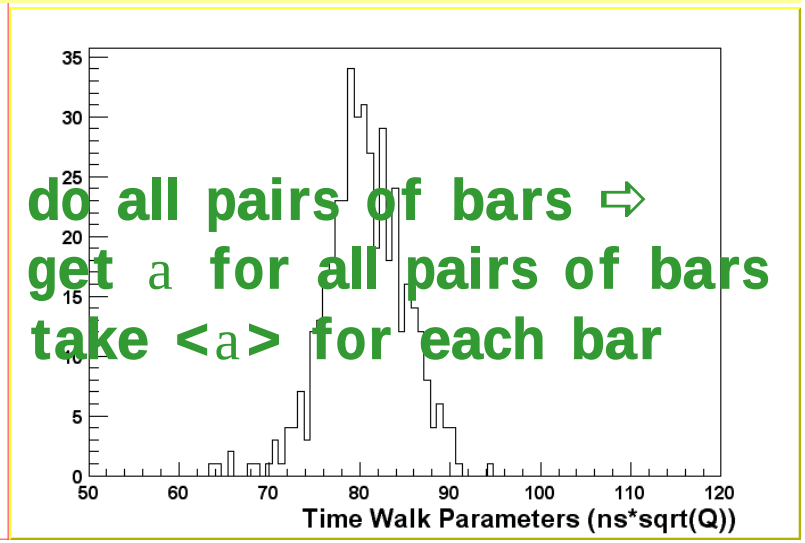


$$t_1 = c_1 - a \,/\, \sqrt{Q_1}$$

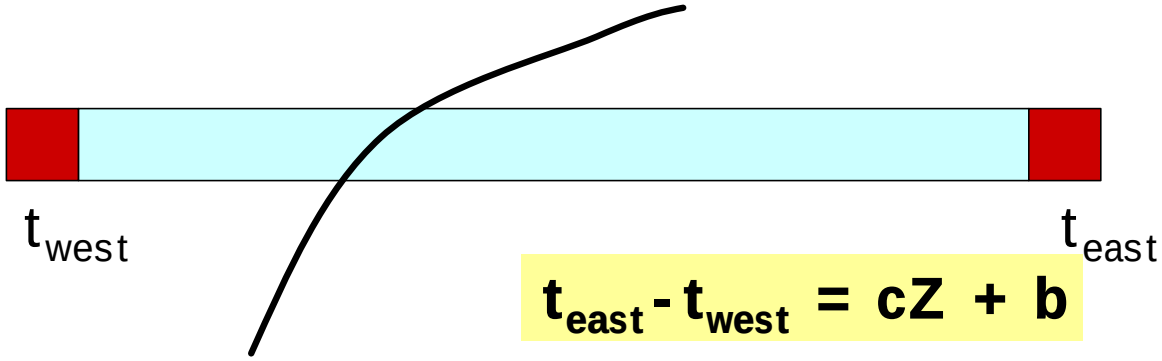
$$t_2 = c_2 - a \,/\, \sqrt{Q_2}$$

$$\Delta t = c + a \frac{\sqrt{Q_1} - \sqrt{Q_2}}{\sqrt{Q_1 Q_2}}$$





Speed of Light

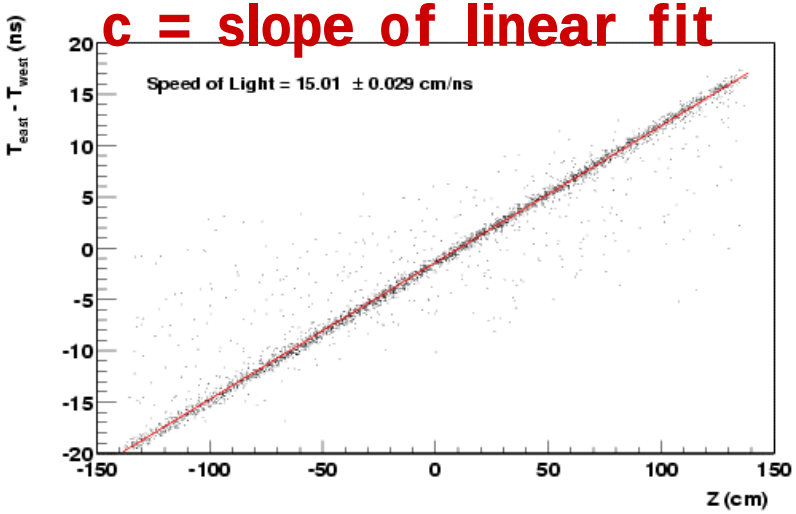


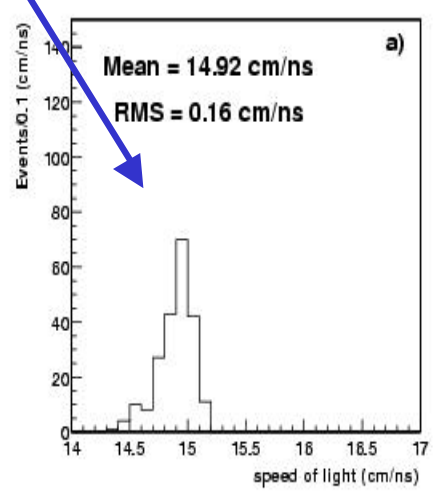
$$t_{east} - t_{west} = cZ + b$$

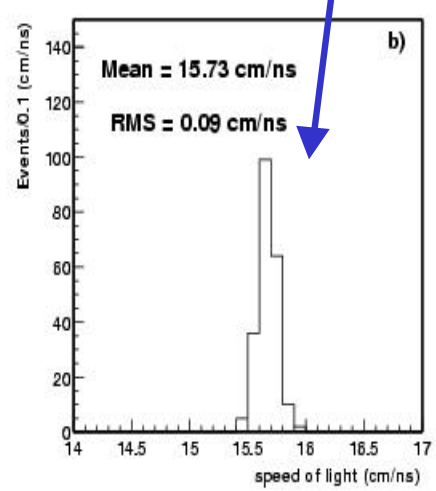
before t_w correction

c = slope of linear fit

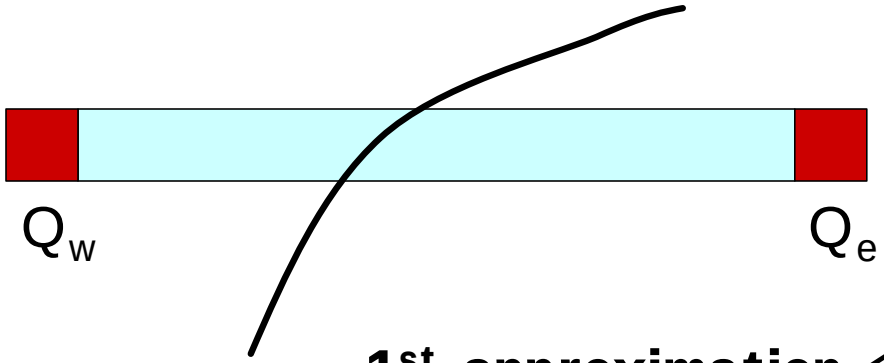
after t_w correction







Attenuation Length



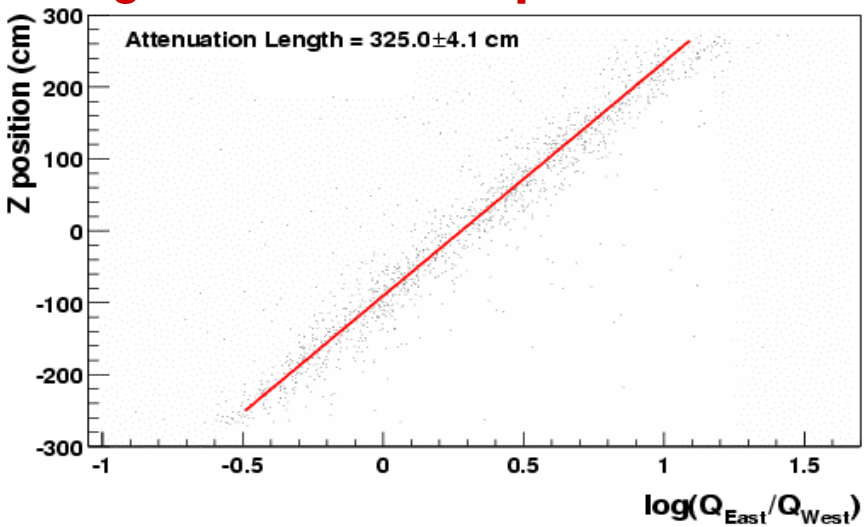
1st approximation

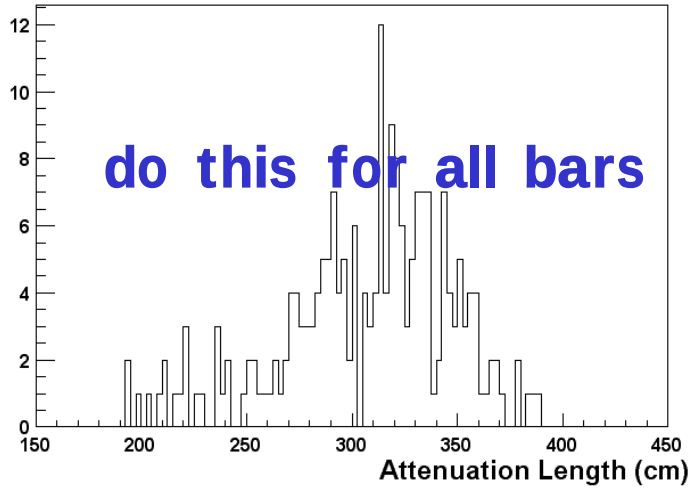
$$Q_e = Q_0 e^{-\frac{L/2-z}{l}}$$

$$Q_w = Q_0 e^{-\frac{L/2+z}{l}}$$

$$\ln(Q_e / Q_w) = \frac{2z}{l}$$

get l from slope of linear fit





T_0 Determination

- 3 tracks/event ⇨ t_0 over-constrained

Perform likelihood fit event by event:

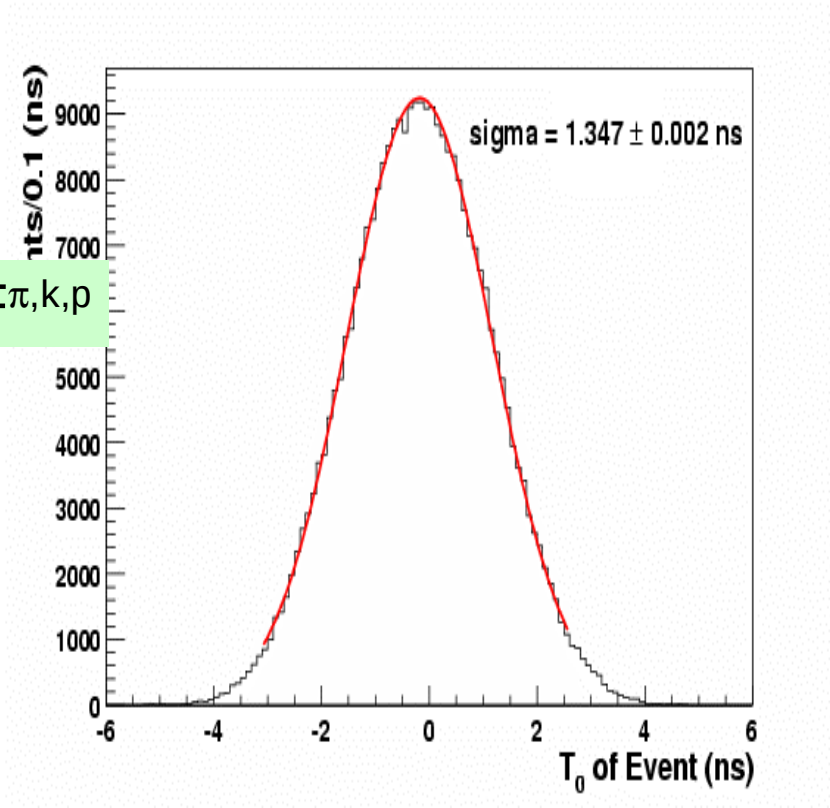
For each track hitting ToF:

$$t_0^{\pi,k,p} = t(adc) - t_c - t_w(Q) - t_s(z) - ToF^{\pi,k,p}$$

p,L,m ⇨ $$ToF = \frac{L}{c}\sqrt{\frac{m^2c^2}{p^2}+1}$$

Choose π,k,p with probabilities f_π, f_k, f_p ($\Sigma f_i = 1$)

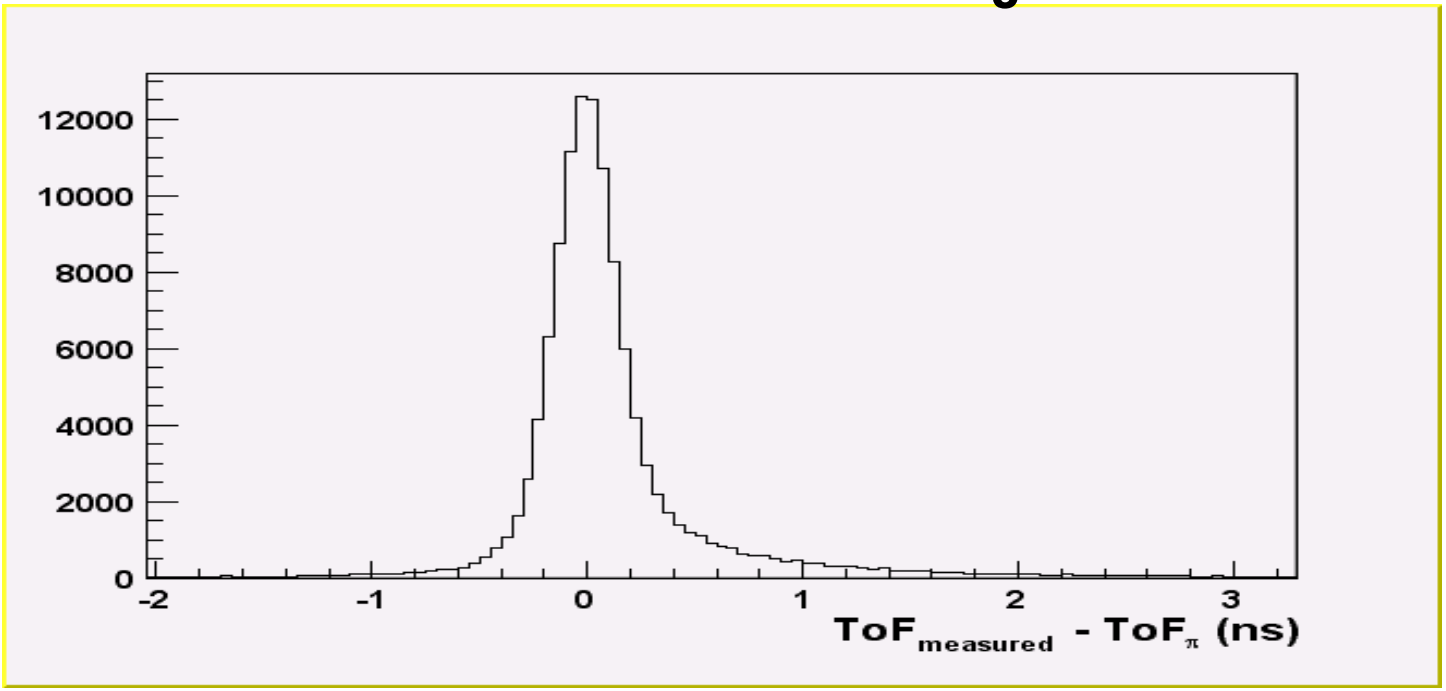
$$s(t_0) \sim 100 ps/\sqrt{N_{trk}}$$



Need to calculate t_0 event by event !

Current ToF Resolution

Naïve s determination:
- assume all tracks are p (mostly right)
- assume resolution is constant along bar



s ~ 150 ps. But:
- not all tracks are p
- resolution degrades farther from PMTs

Current ToF Resolution

Perform likelihood fit for tracks hitting ToF

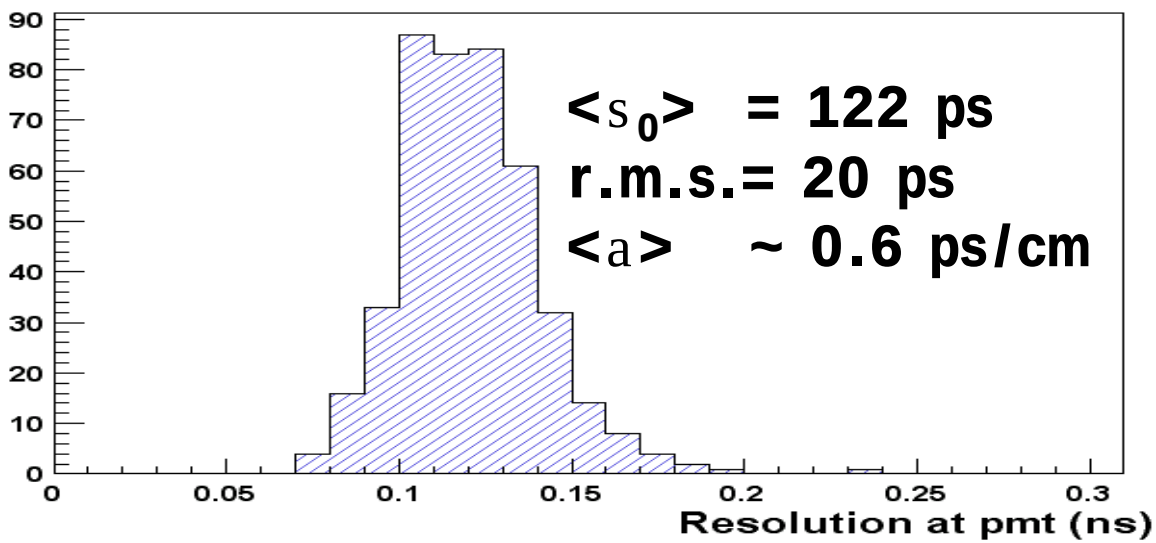
$$\Delta_{p,k,p} = ToF - ToF_{p,k,p}$$

Measured ToF minus predicted ToF for each particle hypothesis

$$s = s_0 + a \cdot z$$

Resolution degrades ~ linearly with distance from PMT

$$L \sim \sum_{tracks} \sum_{i=p,k,p} \frac{f_i}{\sqrt{2p}\, s} \cdot \exp(-\Delta_i^2 / 2s^2)$$



ToF: Particle ID

+ charge ⇨ p>0
- change ⇨ p<0

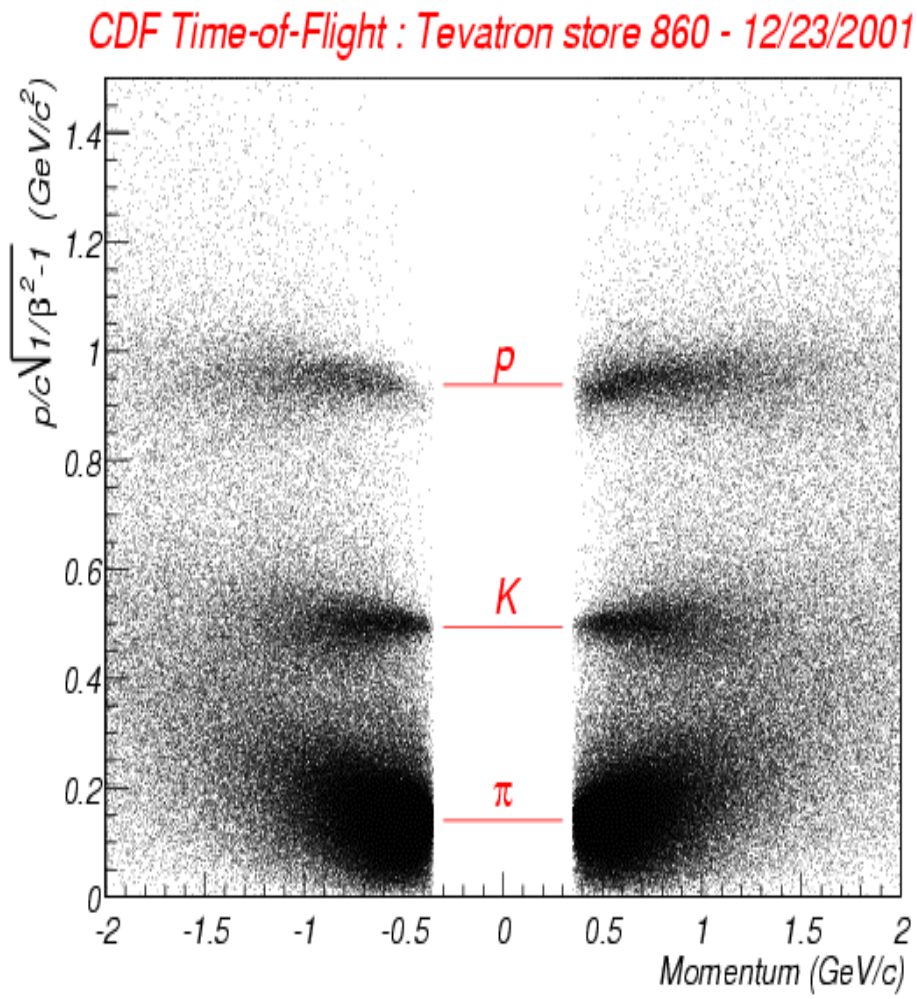
Loose track quality cuts:

- # COT hits > 48
- d_0 < 2s from beam
- z_0 < 2s from p.v.

Also:

- s_{t0} < 50 ps

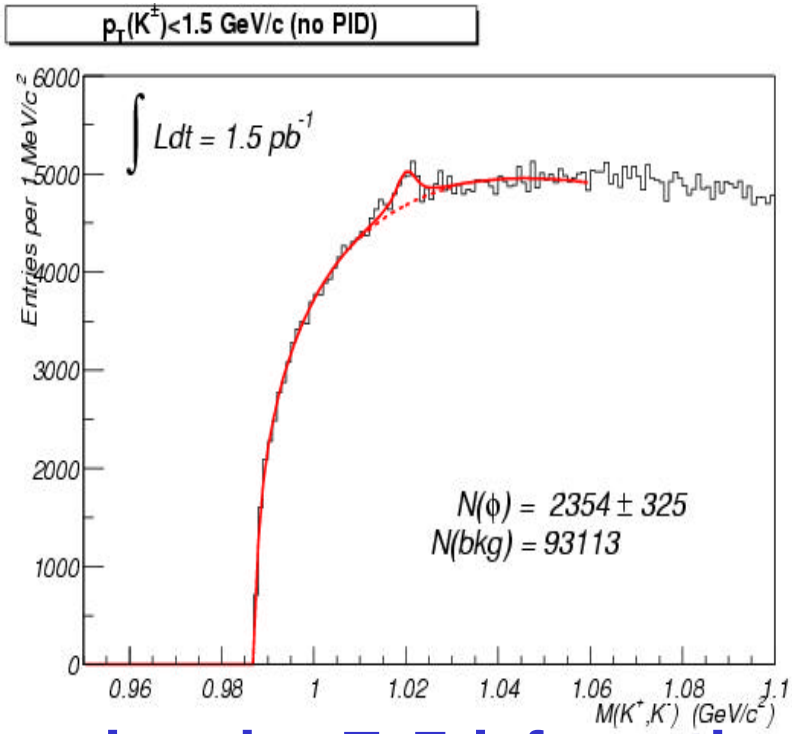
$$m = \frac{p}{c}\sqrt{\frac{c^2 t^2}{L^2} - 1}$$



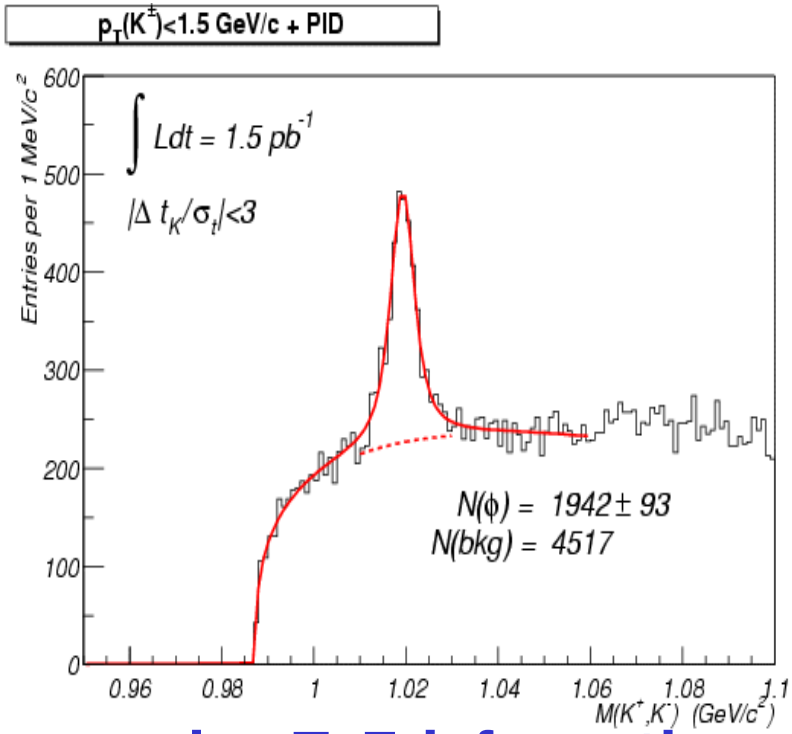
ToF: f(1020)⇨K⁺K⁻

Track selection:

- $0.4 < p_T(K) < 1.5$
- COT: ³ 20 stereo hits, ³ 20 axial hits
- Si: ³ 2 r-f hits
- $d_0 < 1$ mm from beamline



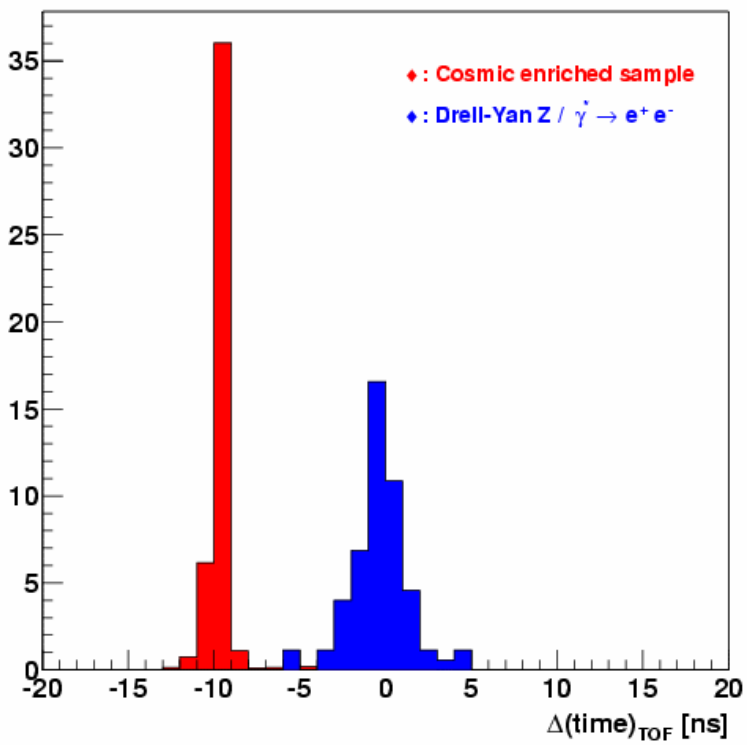
ignoring ToF information

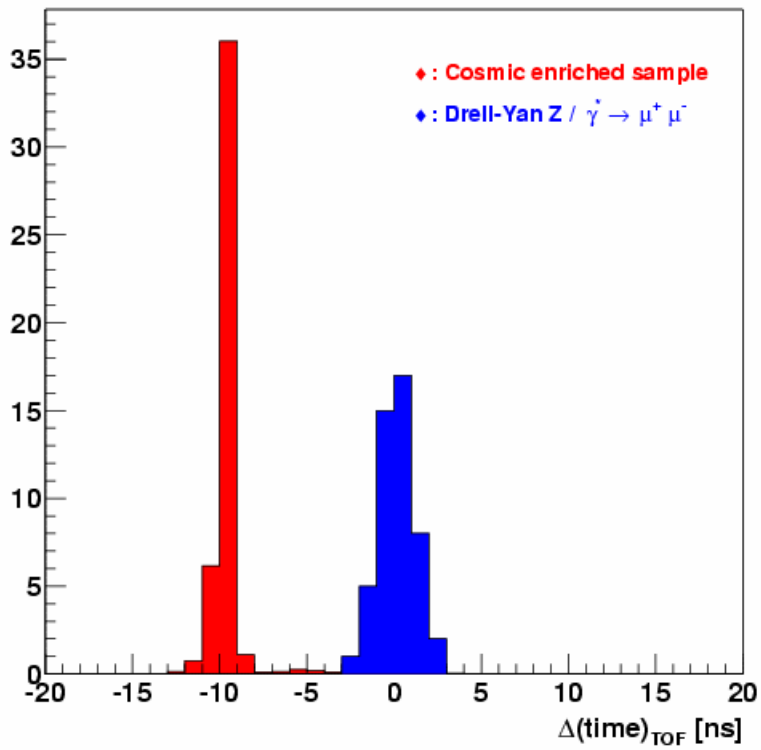


using ToF information

Cosmic Ray Rejection

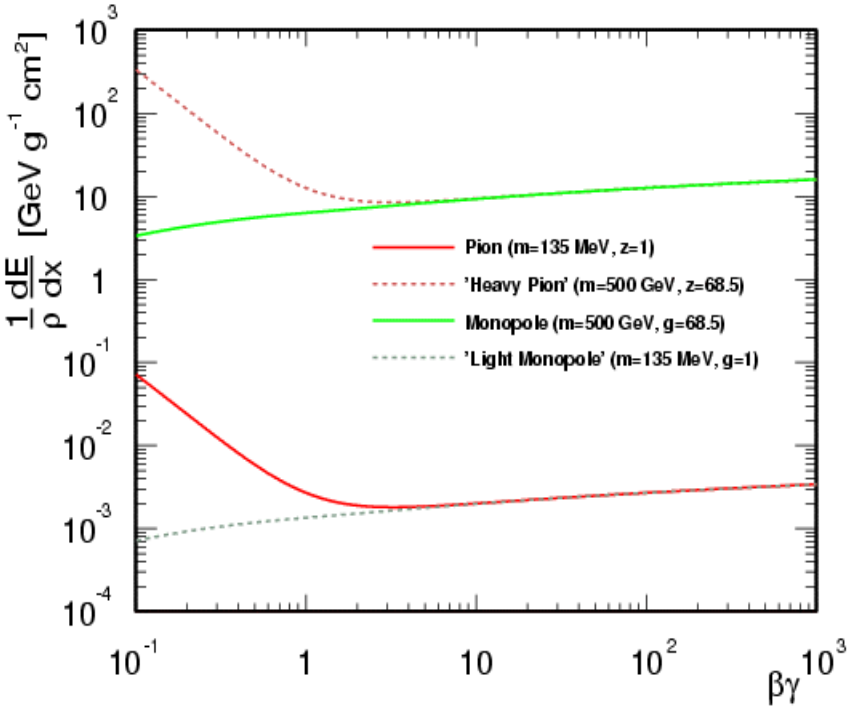
Significant background to Electroweak & Exotics physics (high P_T muon pairs)

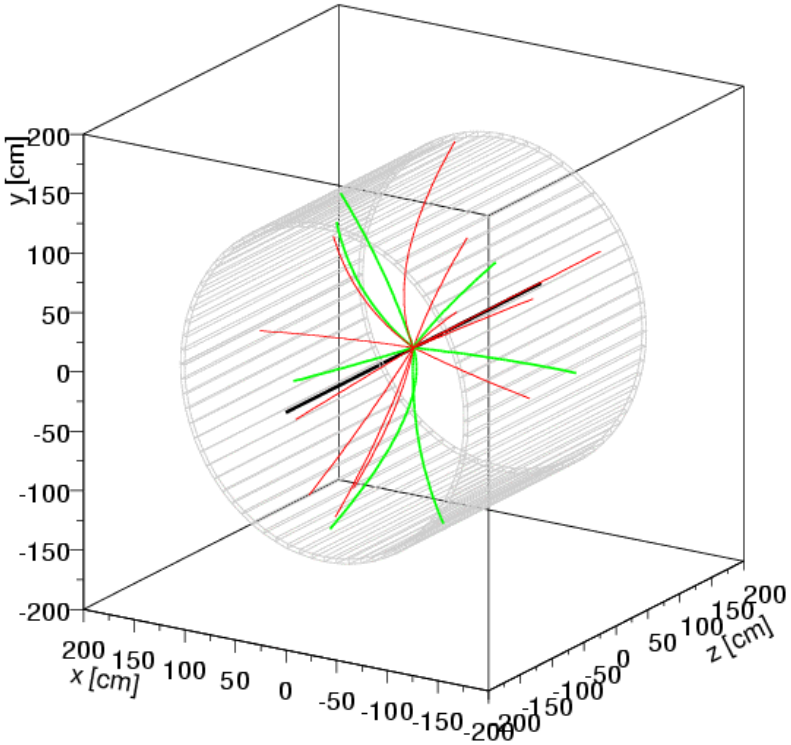




$T_{top} - T_{bottom} < t_1 - t_2$: excellent S/B separation

HIP Trigger & Monopole Search



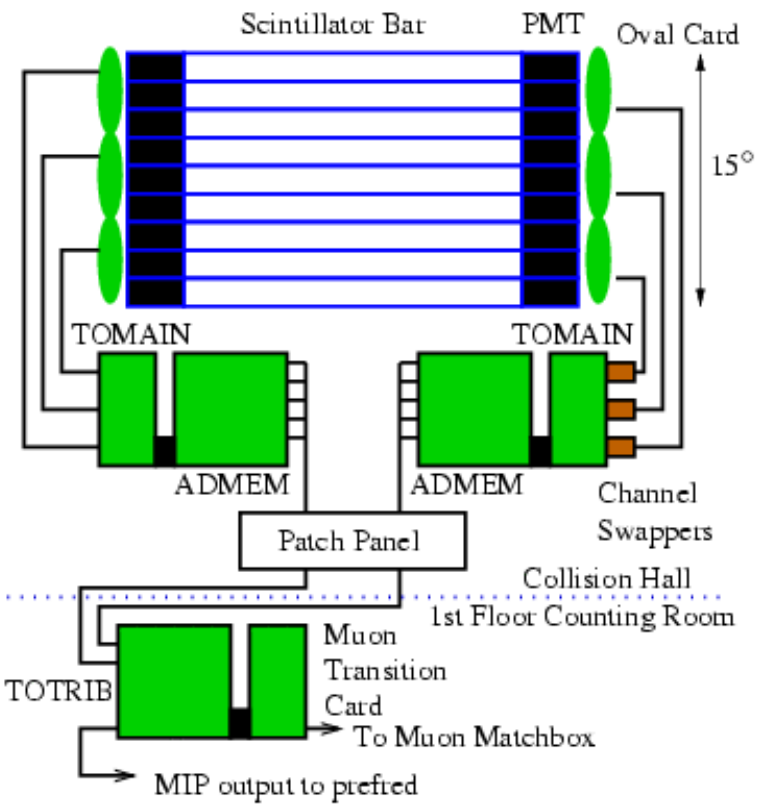


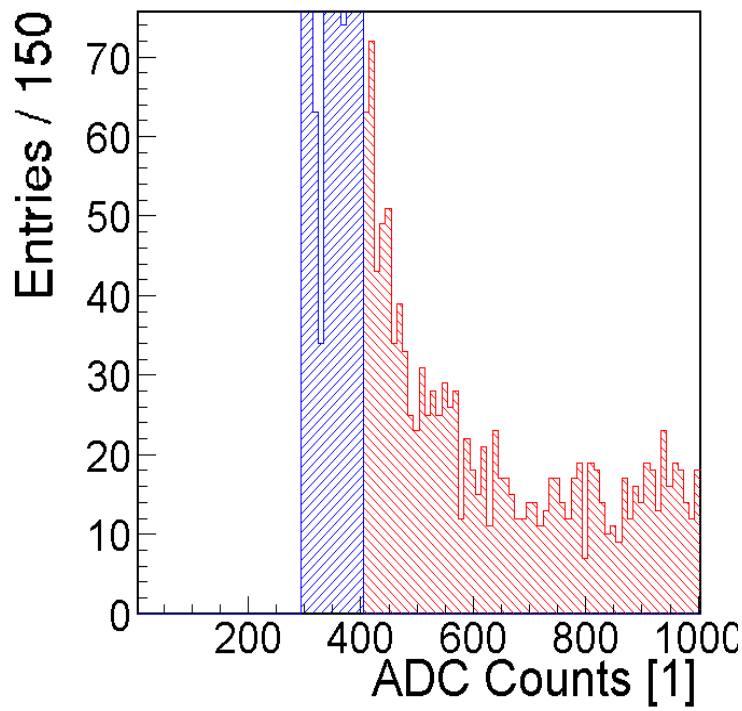
Magnetic Monopoles have 2 distinctive characteristics:

-very large dE/dx in ToF scintillator bars

-Tracks curved in z and straight in r-f

HIP Trigger & Monopole Search





Trigger for monopole search:

-single tracks with very large charge deposition in ToF

-Tracks curved in z and straight in r-f (COT)

Summary

- ToF installation complete: Aug-2001
- Fully integrated in CDF DAQ
- Electronics
  - Small (<25 ps) contribution to resolution
  - All channels performing well
- Calibrations
  - Online: use a DDG
  - Offline: use data
- Resolution at PMT: s ~ 122 ps
  - Will try to improve by refining calibrations
- Already used for physics
  - Cosmic rejection (EW/Exotic physics)
  - S/B enhancement in hadron reconstruction (b physics)
  - HIP, MIP,Cosmic trigger (near future)
    - Magnetic monopole search