The DØ Silicon Track Trigger

Ken Herner
SUNY Stony Brook
for the DØ Collaboration

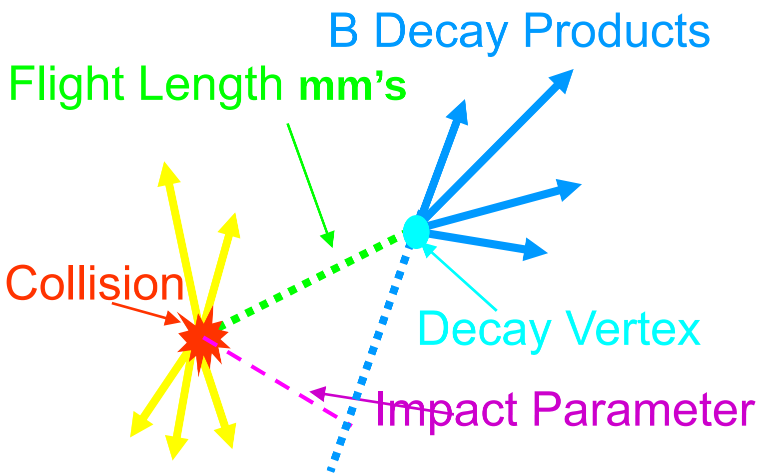
17th International Workshop on Vertex Detectors
30 July 2008

Outline

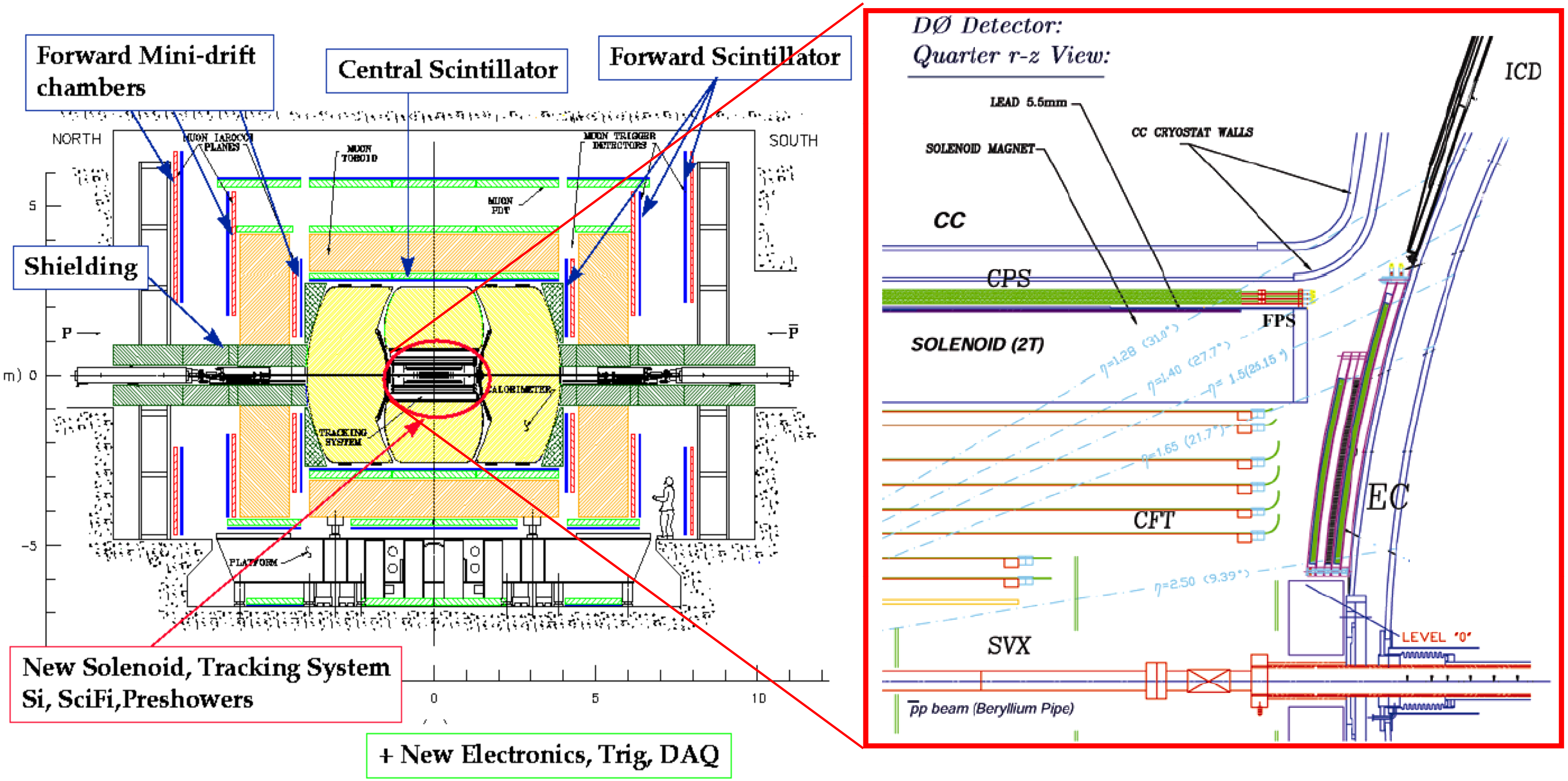
- Introduction and Design Goals
- Technical layout
- Data flow
- Physics Performance
- Use in DØ trigger system

Introduction

- Physics motivation:
  - Select events with high impact parameter (long-lived) tracks, consistent with *b*-quarks
  - Advantageous for:
    - Z->bb (increased bb production leads to better understanding of b-quarks in detector)
    - Top physics (reduce HF/LF systematics)
    - Higgs searches (H->bb dominant decay below 160 GeV)
    - B-physics: $B_d^o \rightarrow J/\Psi\ K_S$ yield / CP violation
- Challenges
  - Hundreds of tracks per event
  - Multiple scattering
  - Trigger decisions must be fast (50 μs)
  - A dedicated processor could do this



The DØ Detector

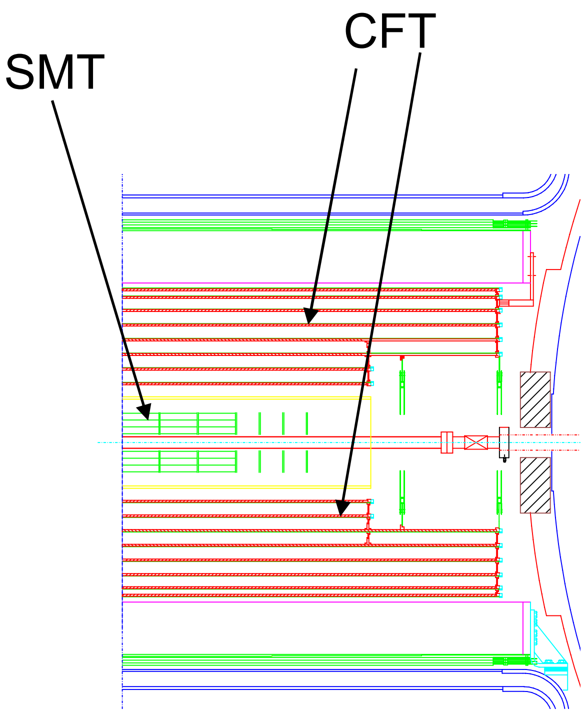


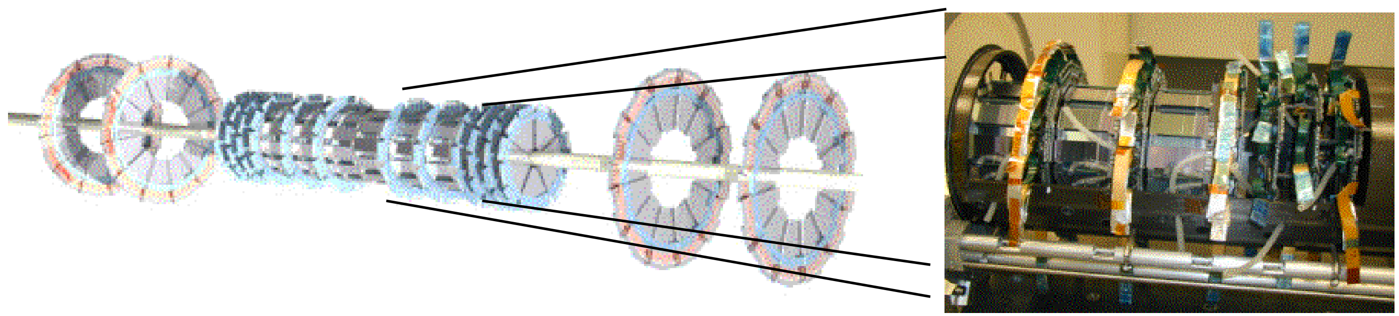
Focus today on tracking systems

STT Input Sub detectors

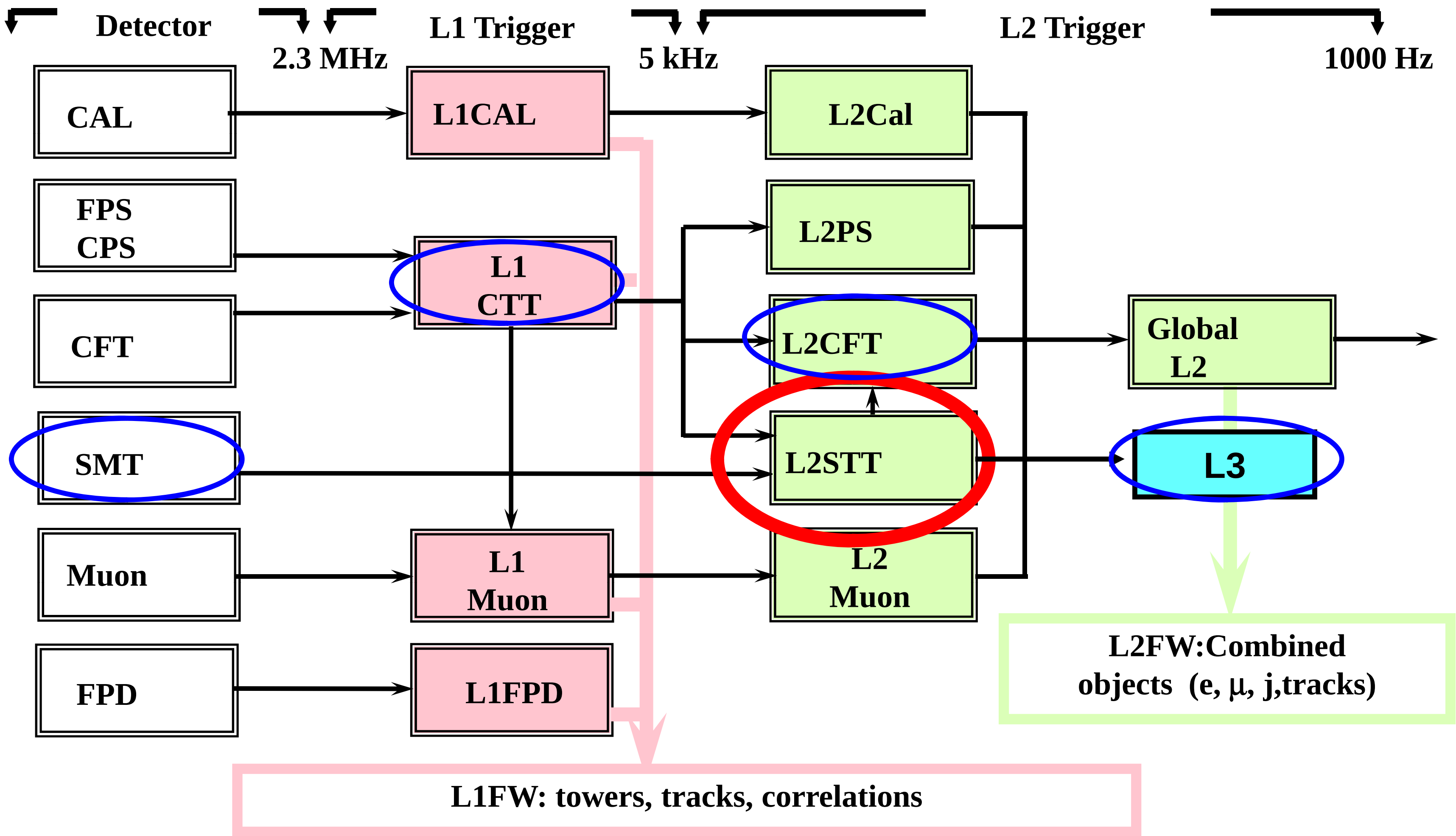
- Central Fiber Tracker (CFT)
- Outside silicon
- 8 layers scintillating fibers
  - Axial and stereo, offset 3 deg.
- |η| < ~1.6
- ~77,000 channels

- Silicon Microstrip Tracker (SMT)
- Innermost sub detector
- 15 micron position resolution
- ~800,000 channels
- 6 barrel detectors
- 12 F-disks
- 2 (in RunIIb) H-disks



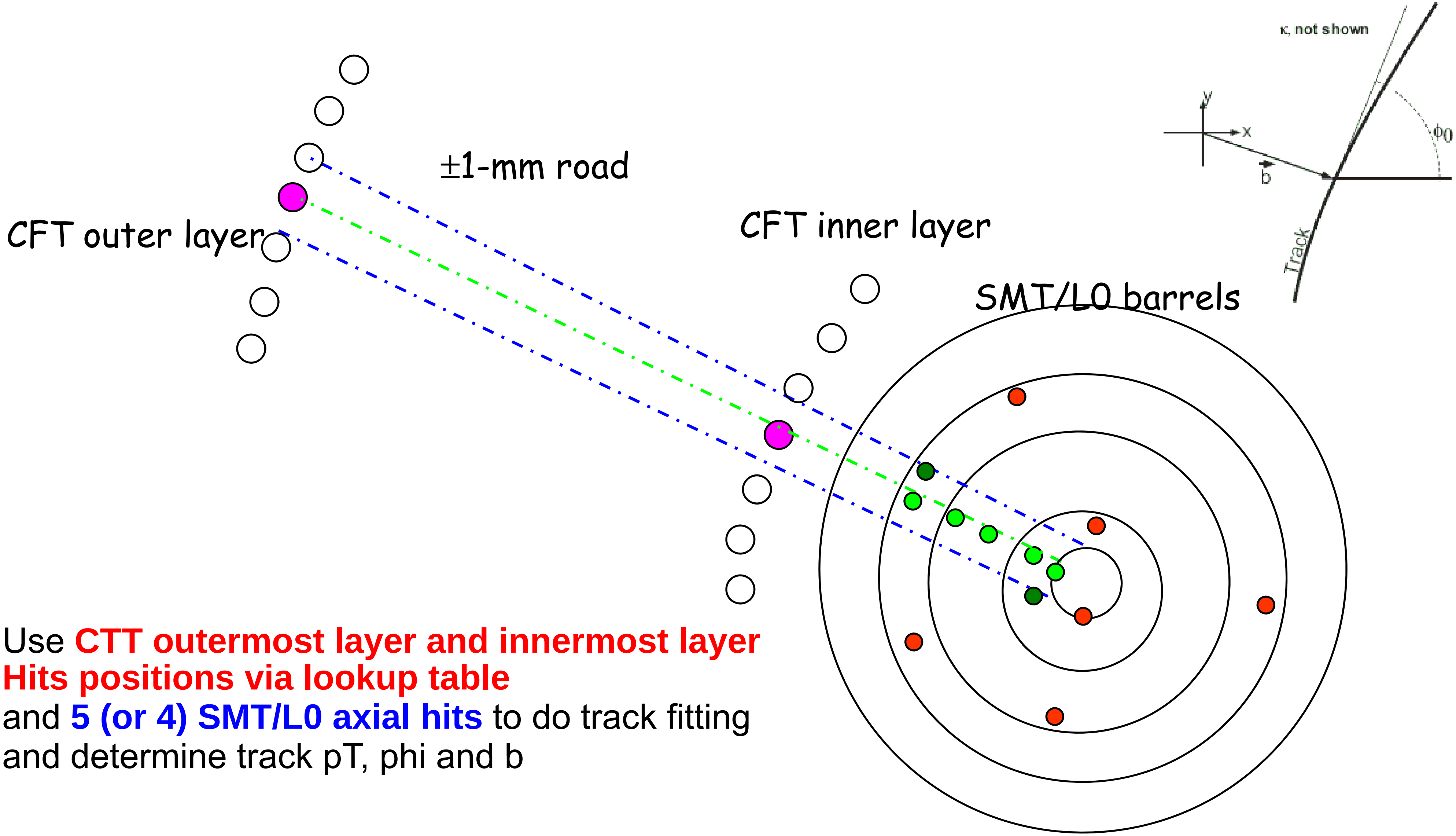


L1/L2 DØ Trigger System



- CTT: central track trigger, takes CFT and Preshower as input, 80 ϕ sectors
- ~800,000 SMT readout channels, unavailableL1

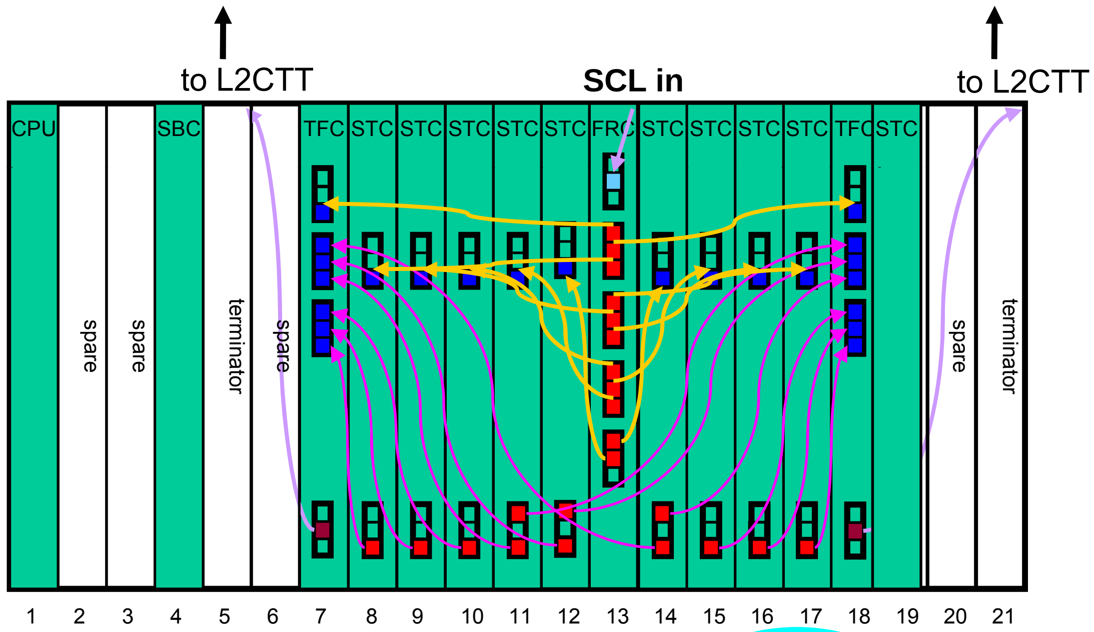
STT Pattern Recognition

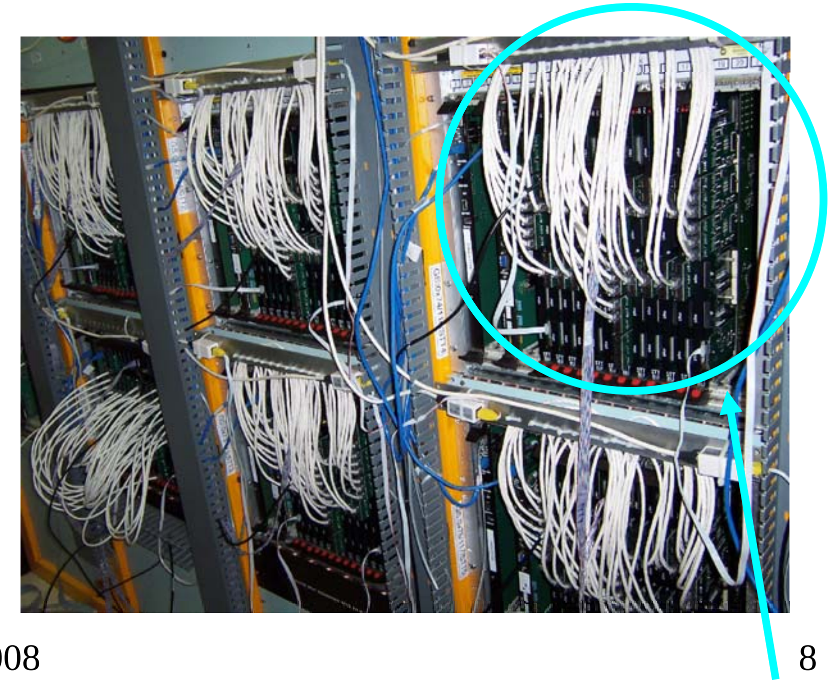


Use **CTT outermost layer and innermost layer**
Hits positions via lookup table
and **5 (or 4) SMT/L0 axial hits** to do track fitting
and determine track pT, phi and b

STT Layout

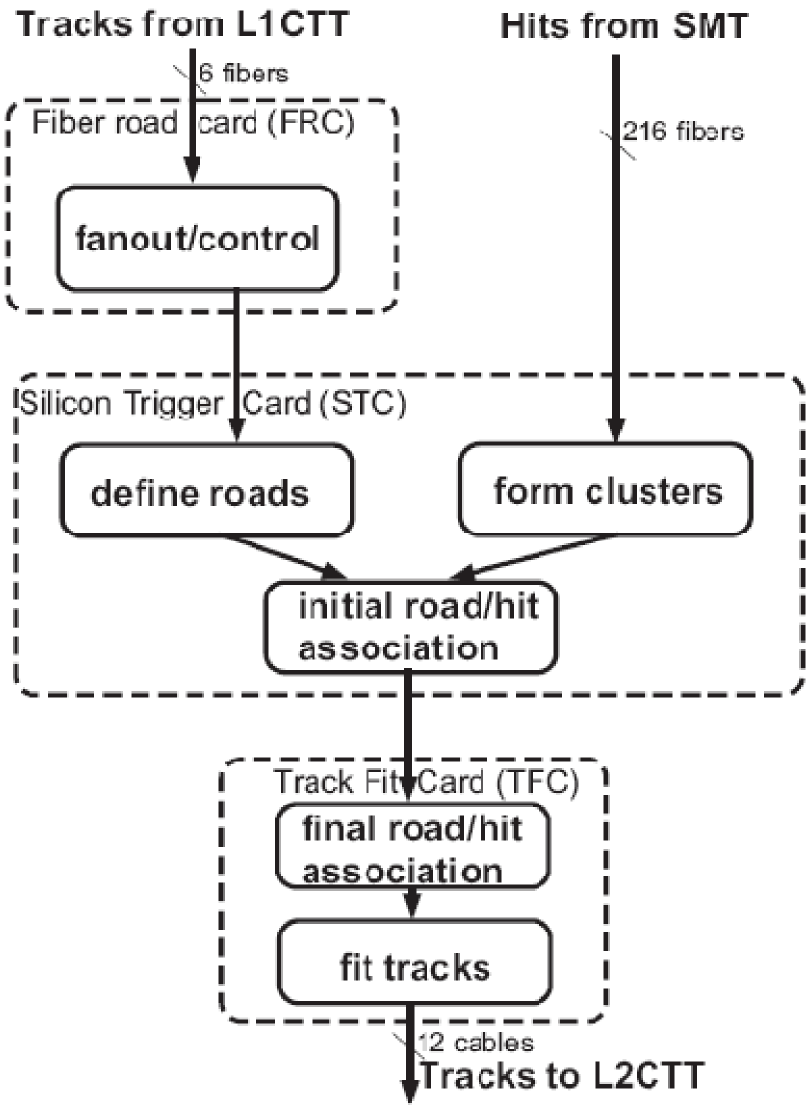
- 6 crates (separate modules in phi, slight overlap)
- Within a crate
  - 1 Fiber Road Card (FRC)
    - Reads L1 CTT tracks, communicates with trigger framework
  - 10 Silicon Trigger Cards (STC)
    - associate L1CTT tracks and SMT hits (barrel detectors only)
  - 2 Track Fit Cards (TFC)
    - Final track fitting
  - 12 phi sectors





Installed crate

Dataflow within STT

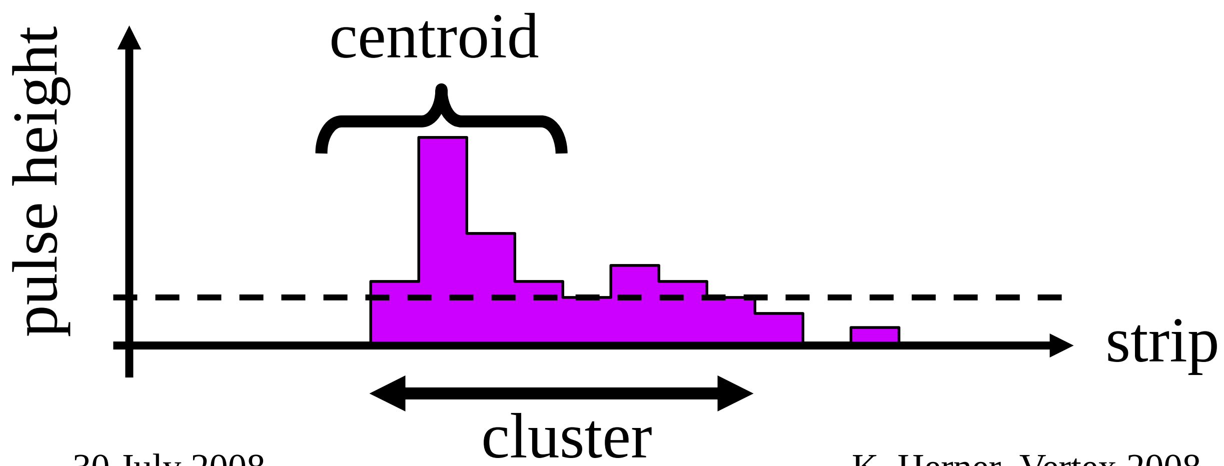


Fiber Road Card (FRC)

- Functions as link to rest of trigger system
- Receives L1CTT tracks
- Send L1CTT tracks to TFCs and STCs
- Control transmission of fitted tracks to L3 on L2 accepted events

Silicon Trigger Card (STC)

- Function: associate SMT data to CTT tracks
  - Receives raw SMT data (optical fiber, HP G-link protocol)
  - Performs pedestal subtraction
  - Removes noisy/disabled SMT channels
    - Checked for changes before every Tevatron store, or ~once/day
  - Clusters SMT hits (only SMT barrel detectors)
  - Associate hits to L1CTT tracks (roads) if within 2mm

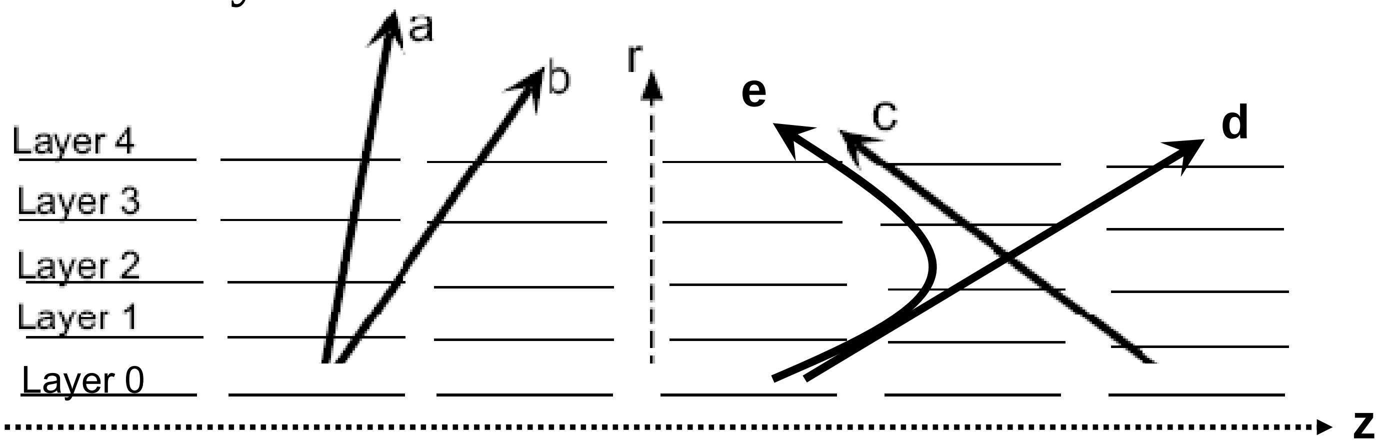


Track Fit Card (TFC)

- Final track fitting
- Chooses hits from 5 or 4 SMT layers to match to CTT road
  - Fit with clusters from 5 layers if possible; if not, fit with 4 layers (one-pass fit)
  - if 5-layer fit possible but fails, drop hit with worst chi2 and refit (two-pass fit)
  - Always prefer 5-layer fits
- Calculation is performed in digital signal processors (DSPs),
  - integerized for speed
    - Extensively tested, differences smaller that output precision required
  - results computed offline
  - stored in Lookup tables

Track Fitting

- Linearized track fit formula: $$\phi(r) = \frac{b}{r} + \kappa r + \phi_0$$
- b: impact parameter, k: curvature, ϕ_0 : track phi at point of closest approach
- Formulate track equation in terms of hits (4 or 5 SMT hits + 2 CFT hits)
- Track cannot change SMT barrel more than once, and not by more than one



Tracks a, b, c allowed; d, e not allowed

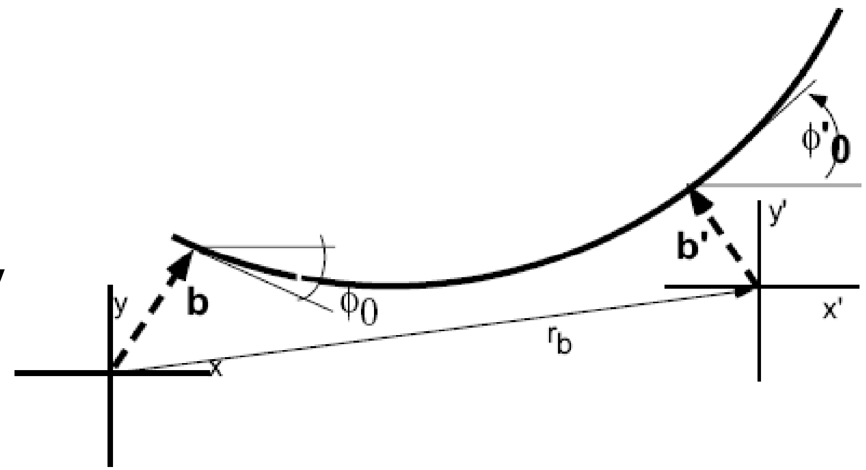
Track Fitting (2)

- With ϕ_1 as reference, use ϕ residuals in computation
- Inverse Matrices computed offline, Stored in LUTs
- TFC returns fit χ^2
  - Need to approximate multiple scattering:
  - Rescale by $\chi^2 = 2\chi^{2\prime}\sqrt{4+64/p_T^2}$

$$\begin{pmatrix} b \\ \kappa \\ \phi_0 \end{pmatrix} = \begin{pmatrix} \text{Inverse Matrix} \\ 3\times(N_{hits}-1) \end{pmatrix} \times \begin{pmatrix} \Delta\varphi_0 \\ \Delta\varphi_2 \\ \Delta\varphi_3 \\ \Delta\varphi_4 \\ \Delta\varphi_A \\ \Delta\varphi_H \end{pmatrix}$$

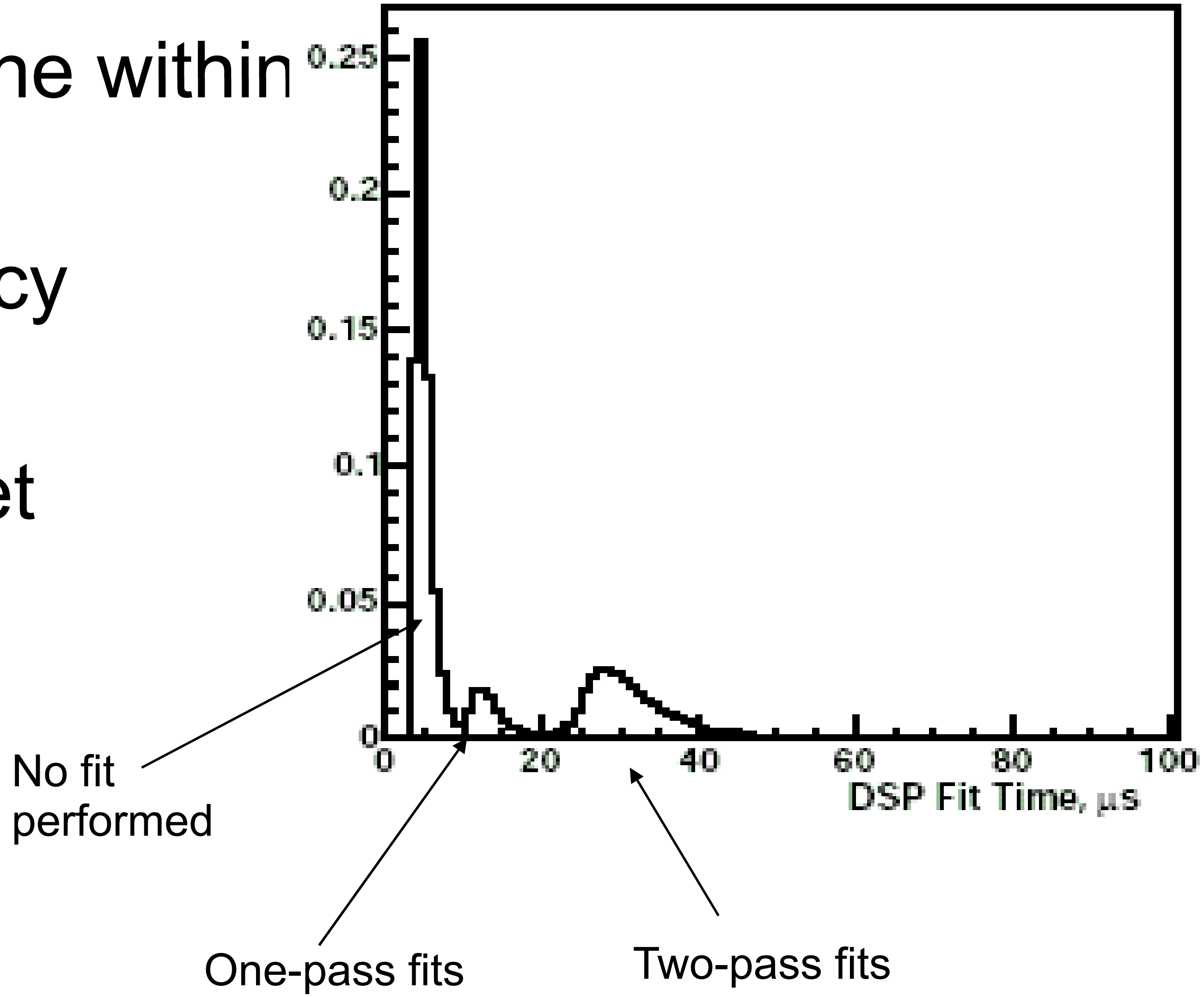
Beam Spot Correction

- Critical impact parameter is not w.r.t. origin, but w.r.t. interaction point
- STT corrects *b* and ϕ to coordinate system with beam x,y as origin
  - TFC picks up latest beamspot at the start of each run
  - Alarm triggered on large move (~10 microns)
- STT can tolerate about 400 microns of beam tilt (angle w.r.t. *z*-axis)

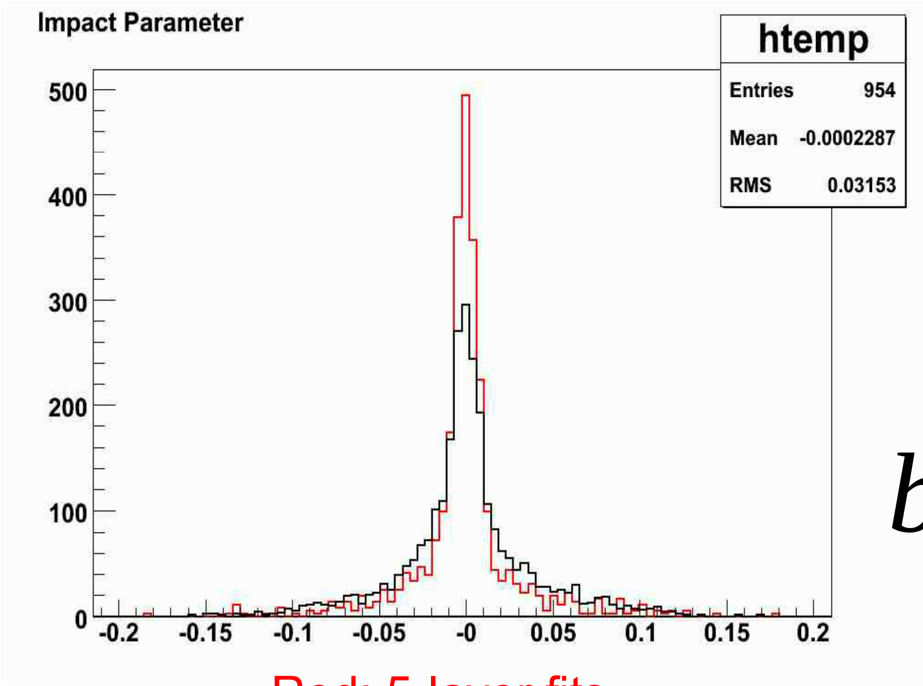


Fit Time Performance

- Nearly all fits done within 50 μs
- Also 50 μs latency allowed
- Design goals met

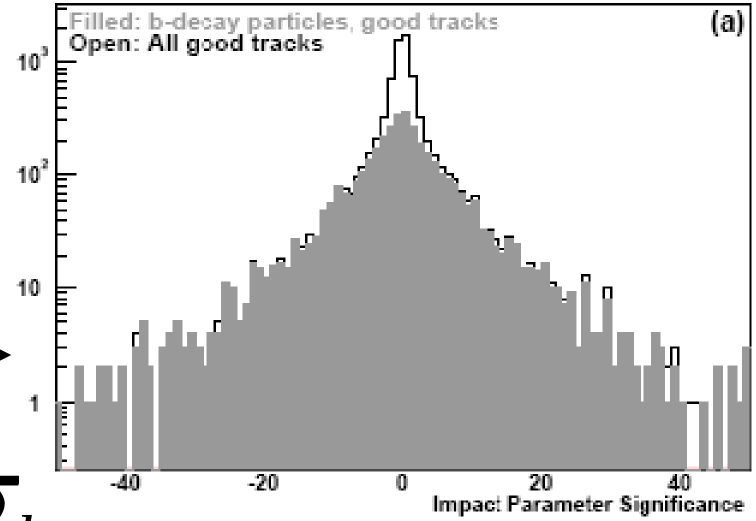


Physics Performance



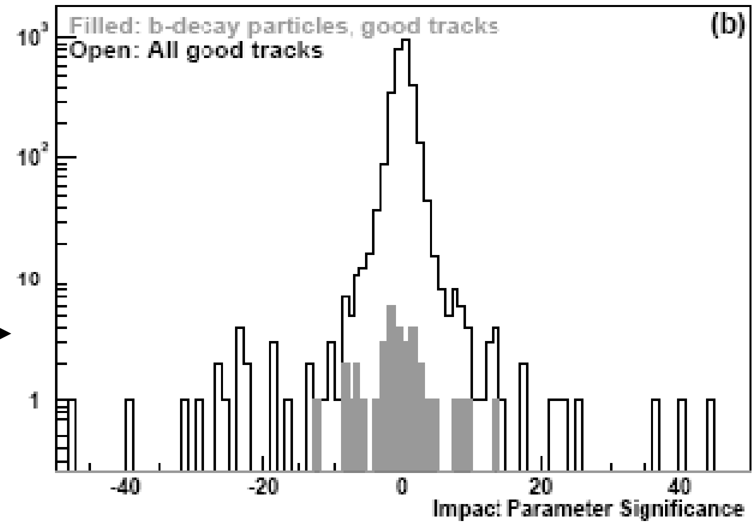
Red: 5-layer fits
Blue: 4-layer fits

IP Significance, b_{sig}
ZH->ννbb MC



$$b_{sig} = b / \sigma_b$$

IP Significance, b_{sig}
Multijet Events



IP resolution:

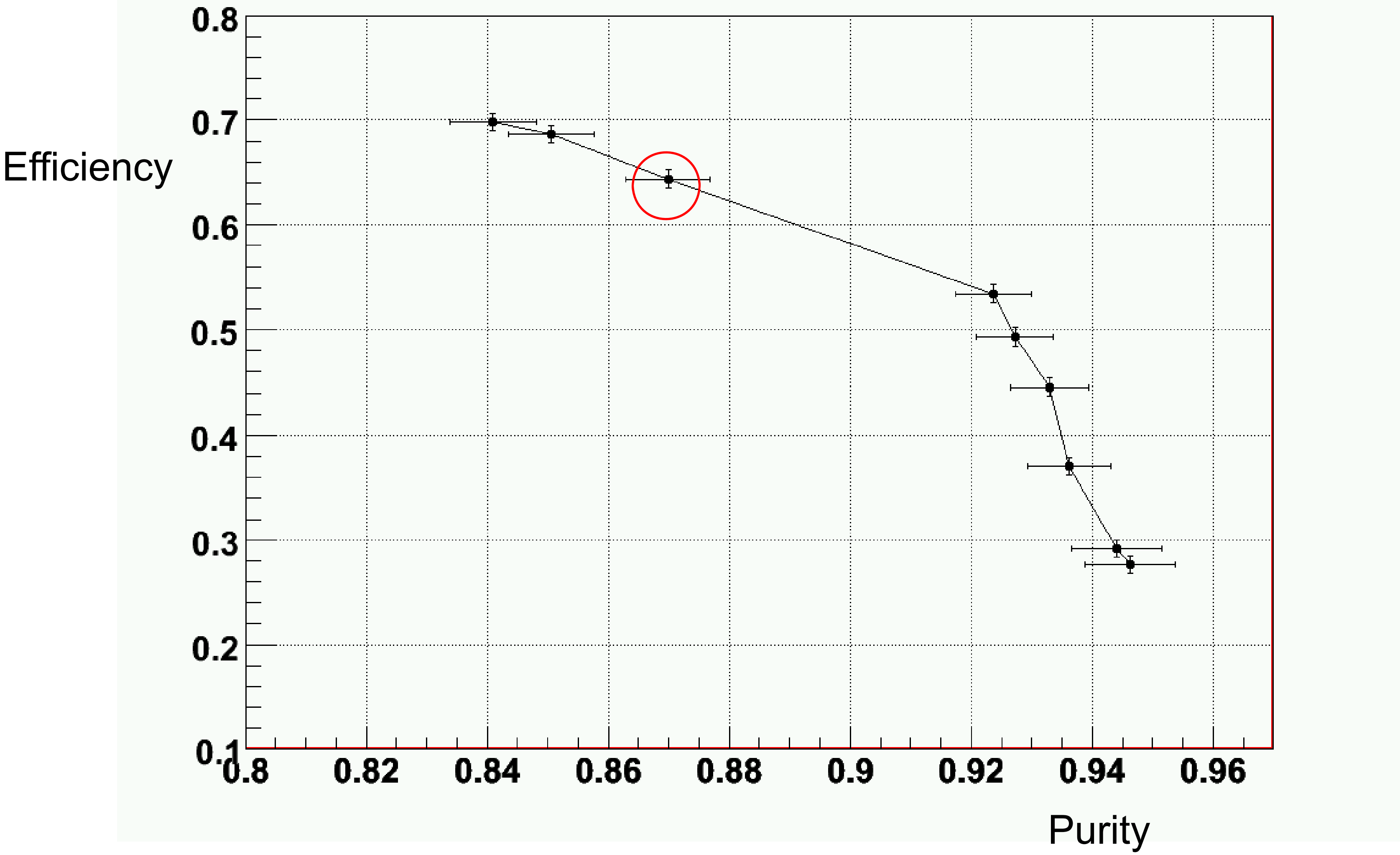
$$\sigma_b = \sqrt{35^2 + 19^2 + \left(\frac{54\ \mathrm{GeV}/c}{p_T}\right)^2}\ \mu\mathrm{m} = \sqrt{40^2 + \left(\frac{54\ \mathrm{GeV}/c}{p_T}\right)^2}\ \mu\mathrm{m}.$$

5 GeV: σ_b = 41 microns 50 GeV: σ_b = 40 microns

Physics Performance (2)

- Match STT tracks to Reconstructed tracks, counting good quality Reco. Tracks as the benchmark
  - Good STT track: $p_T > 1.5$ GeV, $\chi^2 <$ cut value (typically 5.5)
  - Good Reco track: $p_T > 1.5$ GeV, |h| < 1.6, c2 < 4, hits in 4 SMT layers, hits in innermost and outermost CFT layers (mimic STT points used)
- Definitions
  - Efficiency: $$\frac{N_{STT-Reco\ matches}}{N_{Good\ Reco}}$$
  - Purity: $$\frac{N_{STT-Reco\ matches}}{N_{Good\ STT}}$$

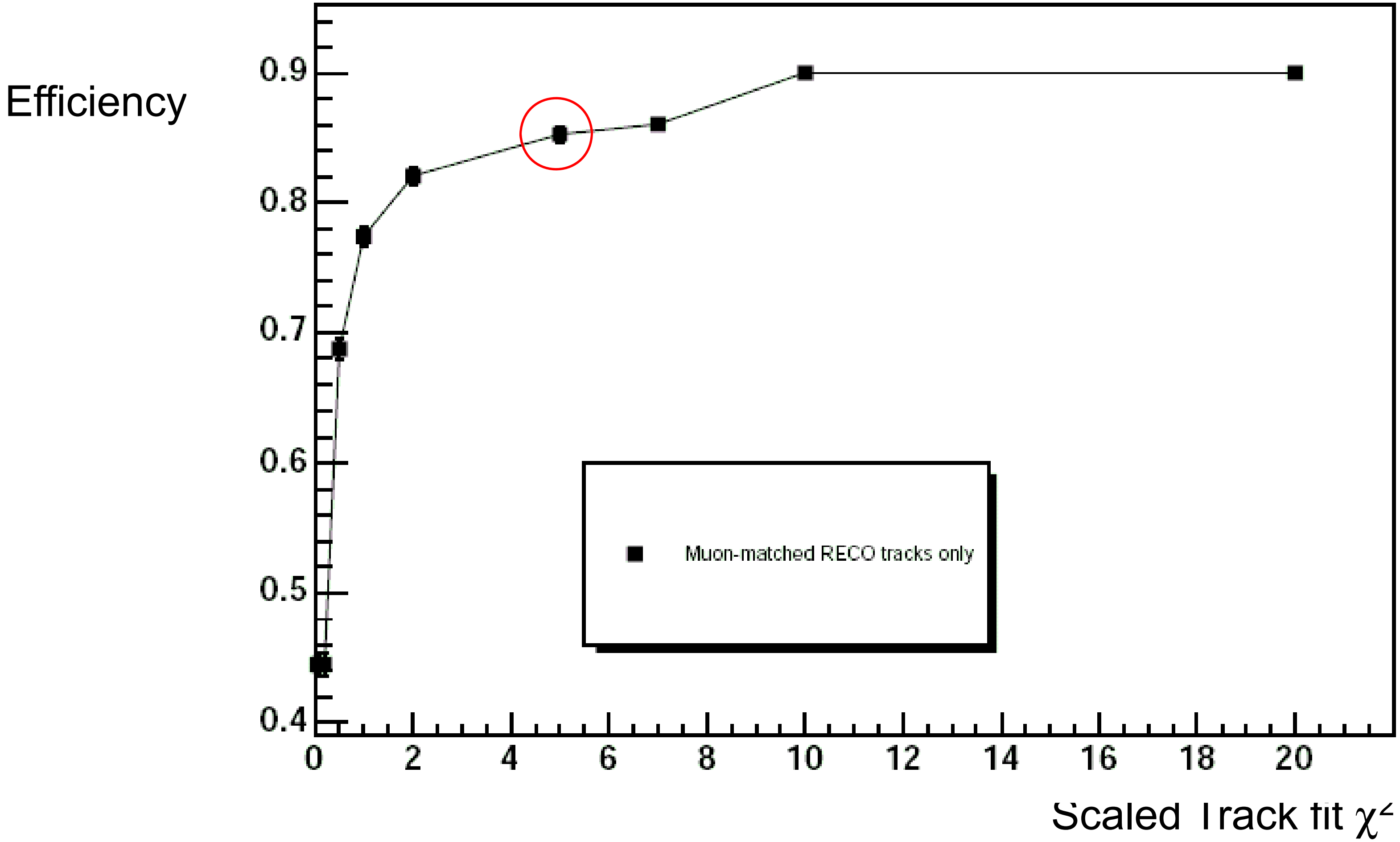
Physics Performance (2)



Each point represents a different cut on the scaled fit χ^2 , red is a typical cut value in trigger

Physics Performance (3)

Efficiency



STT Efficiency for Z->μμ Events vs. muon-matched reconstructed tracks
75 < Mμμ < 105 GeV

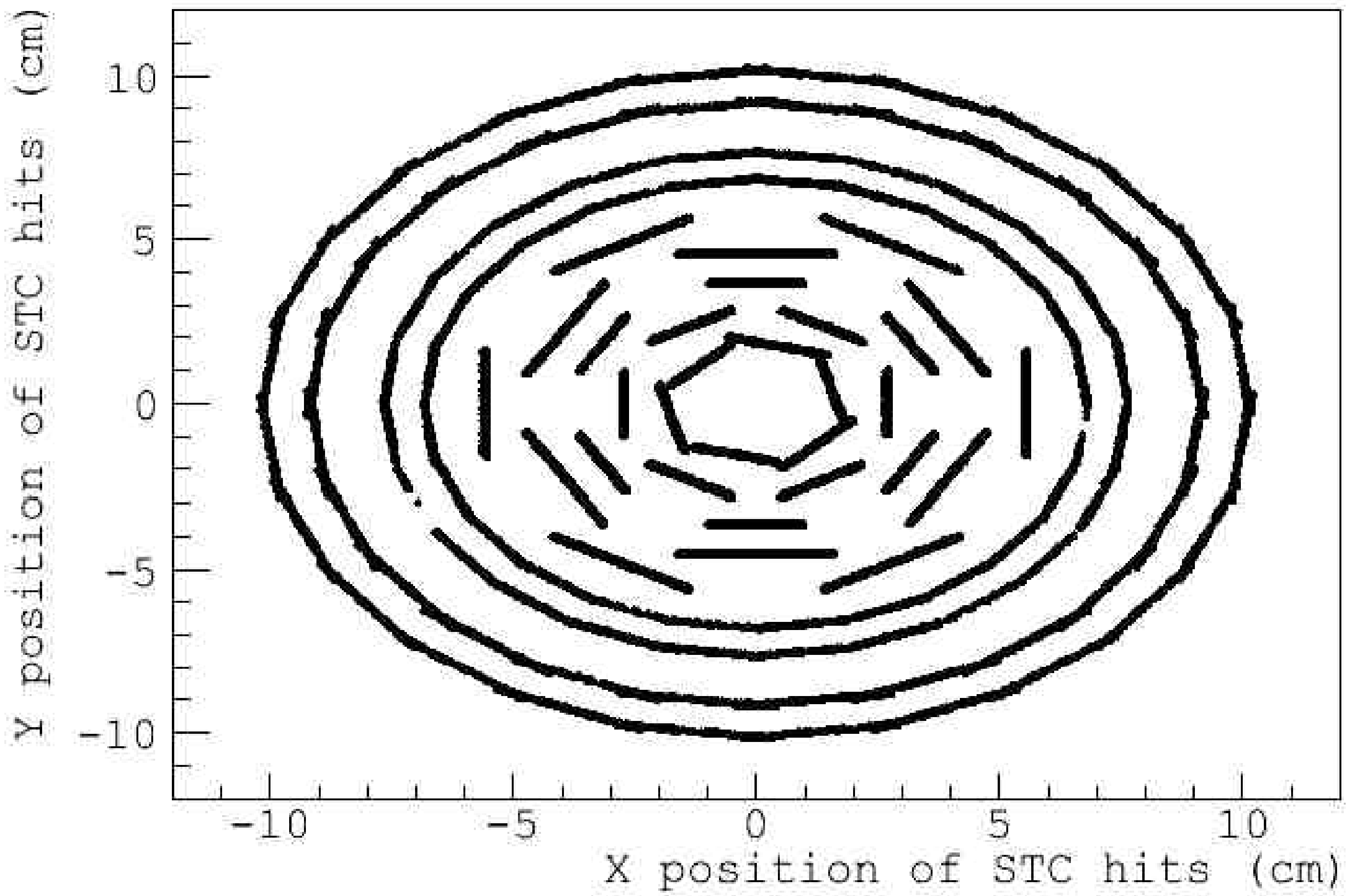
Use in the DØ Trigger

- STT can be used to select high-IP tracks in jets
  - useful for trigger on events containing b-jets
- An example- a multijet trigger on DØ
  - Designed for top, Higgs, b physics
  - At Level 2 this trigger is an OR of four conditions
  - Two require an STT track
    - $\chi 2 < 5.5$
    - IP significance > 3
  - Can maintain a low trigger rate while relaxing jet kinematic cuts *and* enhancing b-quark composition of triggered events
- Other uses
  - Track matches in muon, tau triggers- more precise pT information with silicon hits

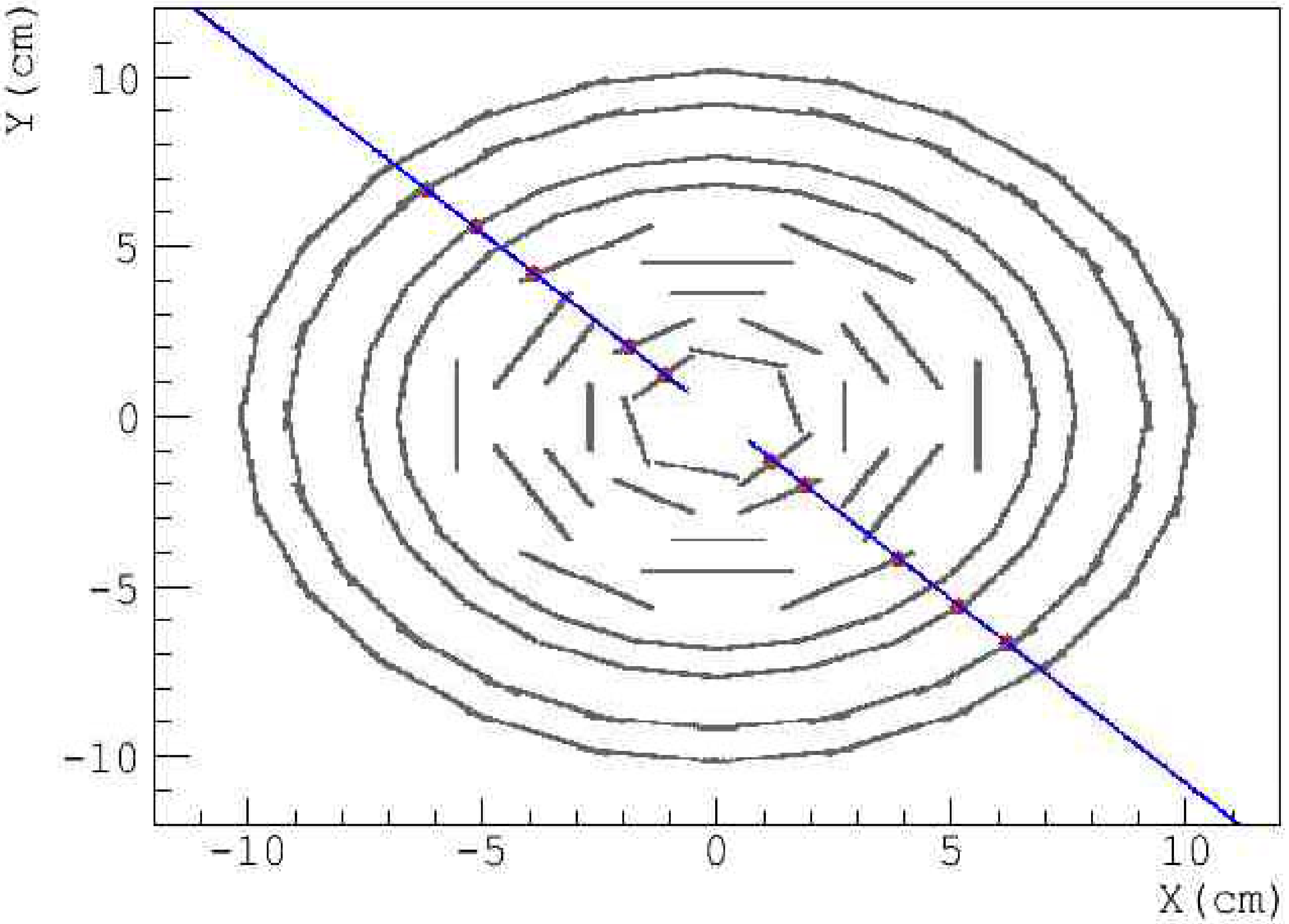
Summary

- The DØ Silicon Track Trigger is a dedicated processor designed to use tracks and silicon hits to identify high impact parameter tracks
- Contributing to event selection since 2004
- 70% efficient in multijet events, 90% in $Z \to \mu\mu$ events
- Fast processing time and good IP resolution
- Negligible addition to overall latency at L2

STC Hit Positions

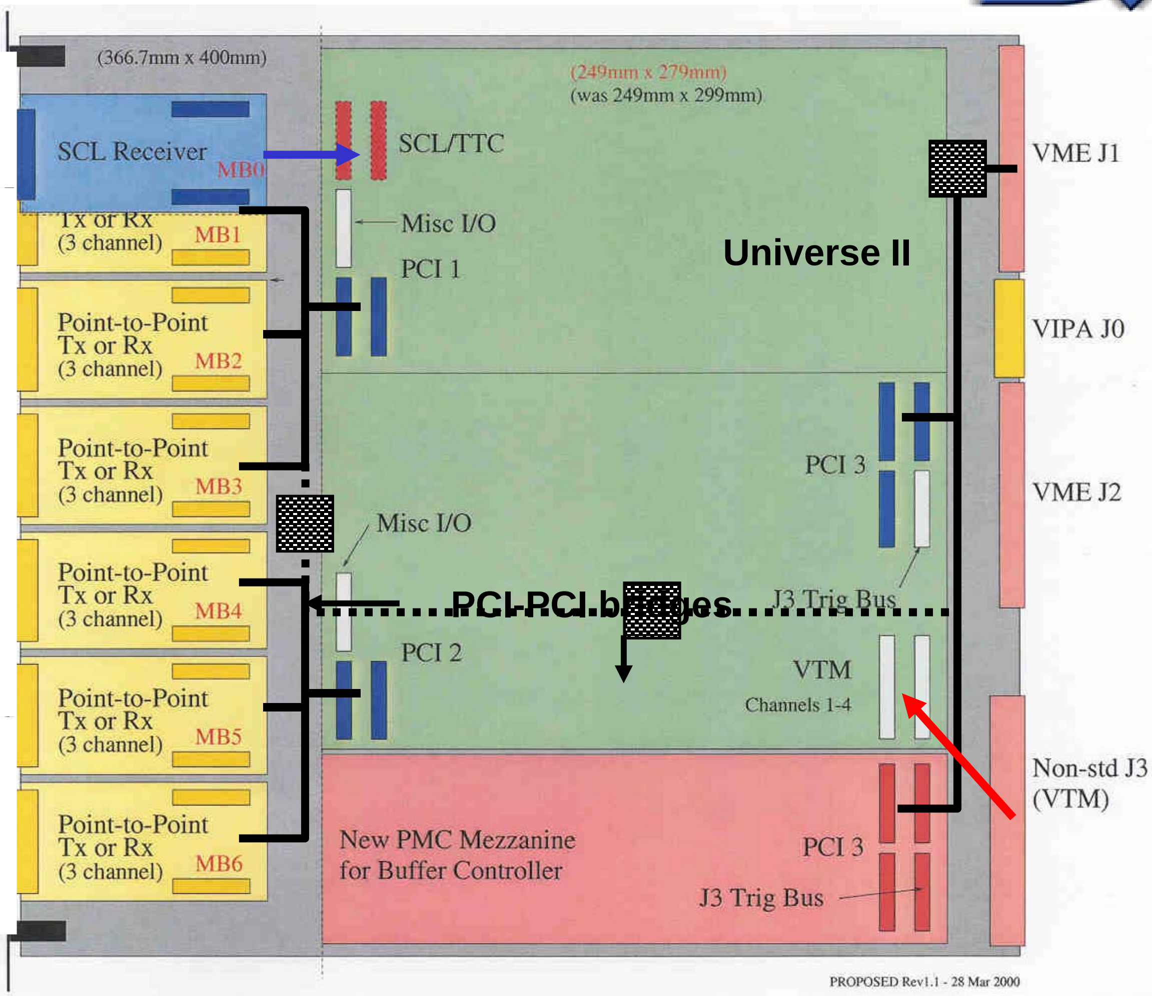


A Cosmic Muon In STT

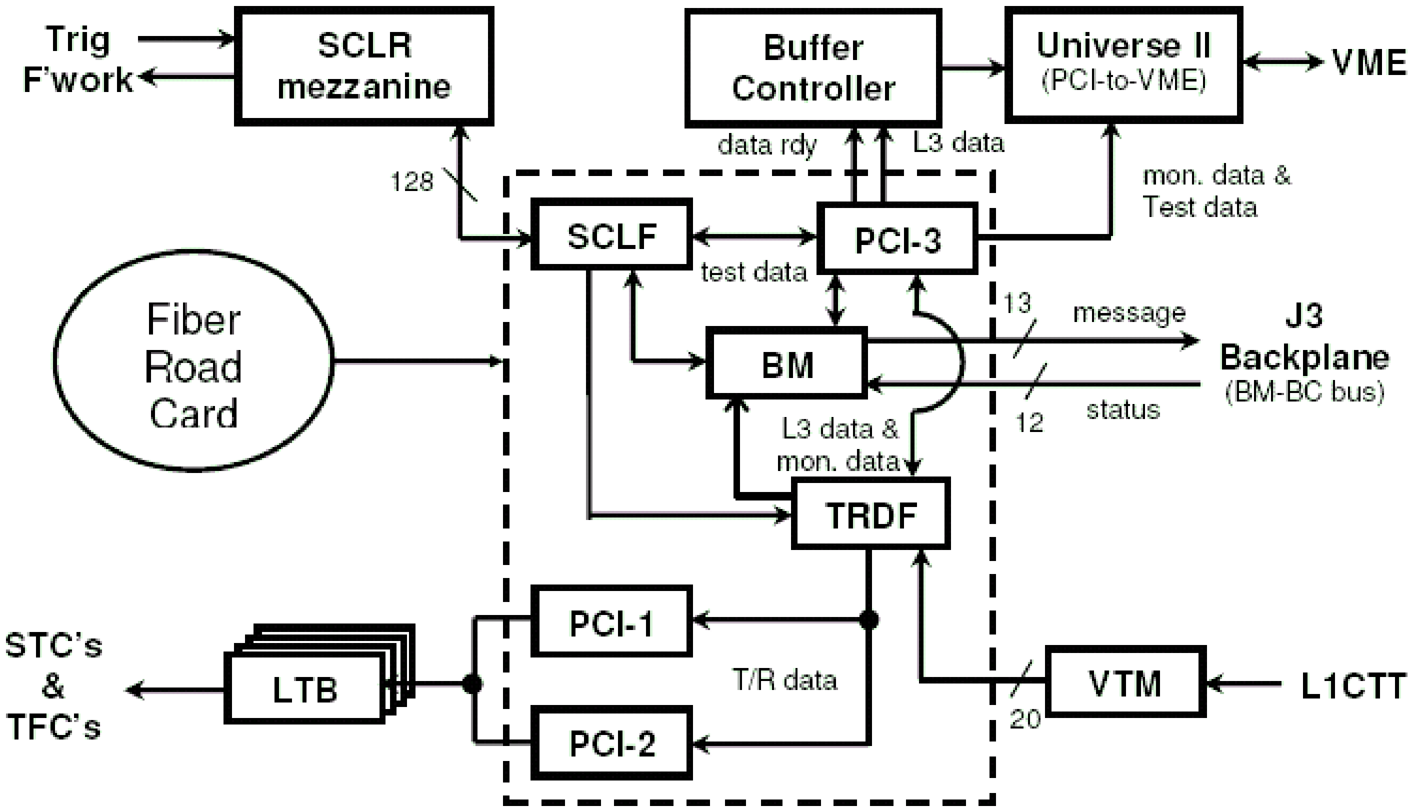


STT Motherboards

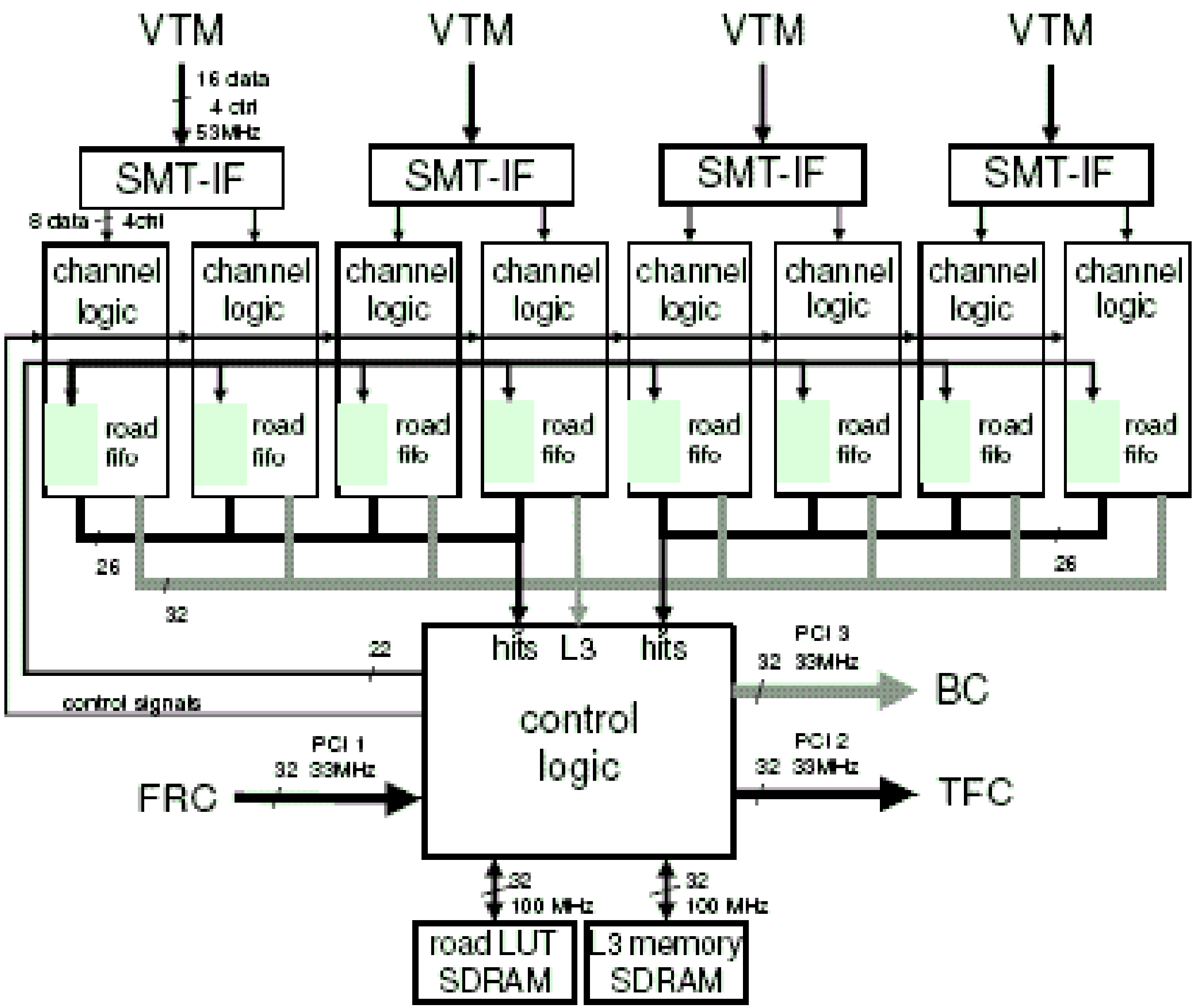
- FRC, STC and TFC share requirements for internal and external interfaces
- Mount daughter cards on common motherboard
- 9Ux400 mm VME64x -compatible
- Three 33-MHz PCI busses for on-board communications
- Data communicated between cards via point-to-point links (LVDS cables, LRB and LTB)
- VME bus used for Level 3 readout, initialization and monitoring



Fiber Road Card Block Diagram



Silicon Trigger Card Block Diagram



Track Fit Card Block Diagram