The Central Fiber Tracker for the DØ Upgrade

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Outline

- The DØ upgrade for Tevatron Run II
- The Central Fiber Tracker (CFT)
  - Mechanical construction
  - Readout (light-guides, Visible Light Photon Counters, integrator/digitizer chip)
  - Cosmic ray test
  - Test of light-guides and VLPC readout cassettes in the DØ setup
- The Central Track Trigger
- Track reconstruction performance

The DØ Upgrade: Motivation

- Enhance physics capabilities for RunII
  - Tracking in magnetic field (Central Fiber Tracker)
  - High-resolution tracking in vertex region (Silicon Microstrip Tracker)
  - Improved acceptance (forward muon system, forward silicon disks)
- Luminosity increase
  - 'old' DØ designed for operation at 10^{30} cm^{-2} s^{-1}
  - Run II designed to ultimately achieve $5x10^{32}$ cm^{-2} s^{-1}
- Bunch structure change
  - Run I: minimum bunch spacing 3.5 μs
  - Run II: 396 ns at start, reaching eventually 132 ns (challenge for readout and trigger)

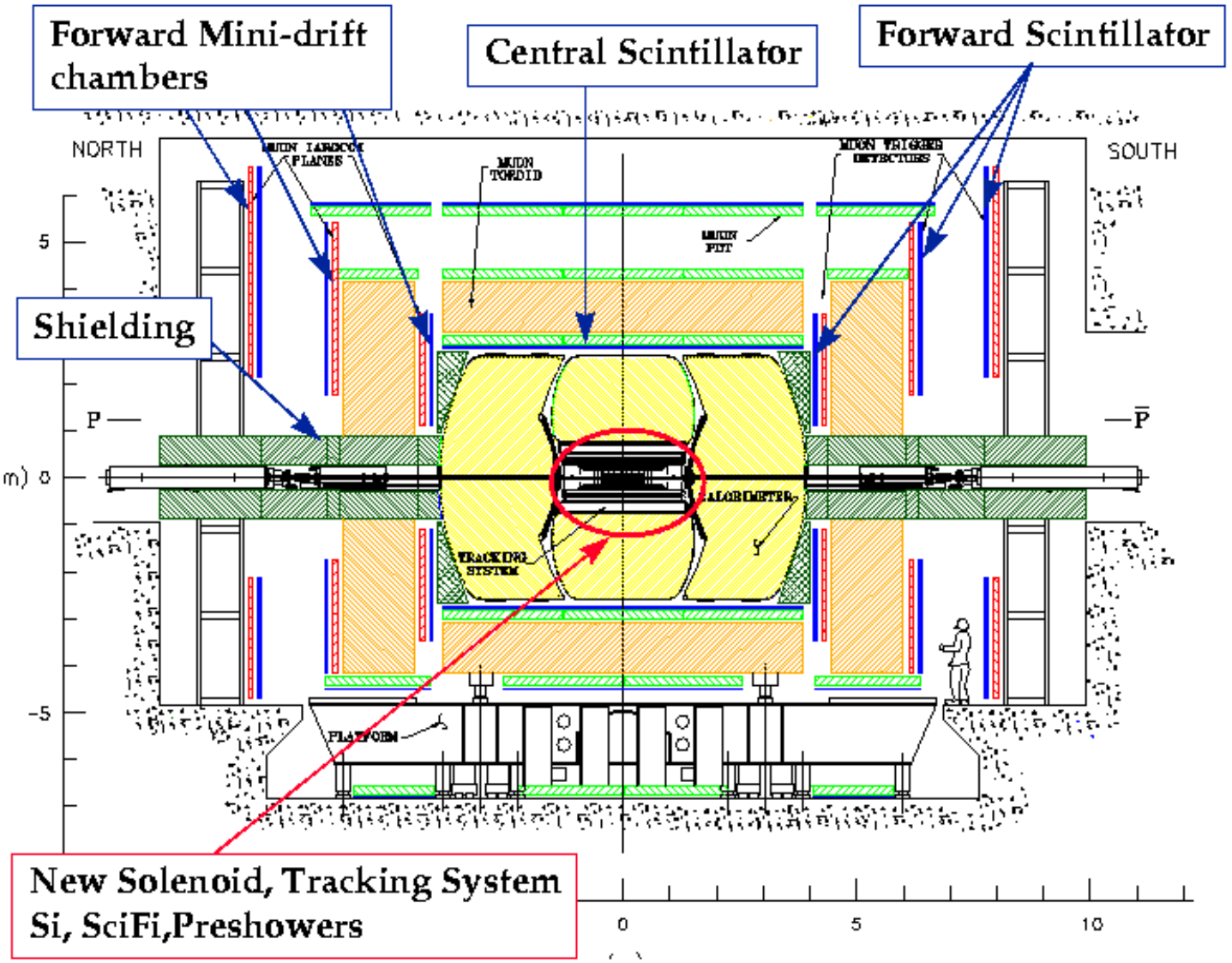
Tevatron Upgrades

Tevatron improvements
- -Linac upgrade
- -Main injector
- -New p-bar storage ring
- -p-bar source improvm.

	Ib (93-95)	IIa	IIa	IIb
Bunches	6x6	36x36	140x108	140x108
Typ. Lum. ($\times 10^{32}$ cm^{-2} s^{-1})	0.16	0.86	2.1	5.2
Int. Lum. (pb^{-1} / week)	3.2	17.3	42	105
Energy (GeV)	900	1000	1000	1000
Bunch spacing (ns)	3500	396	132	132
Interactions / crossing	2.6	2.3	1.9	4.8

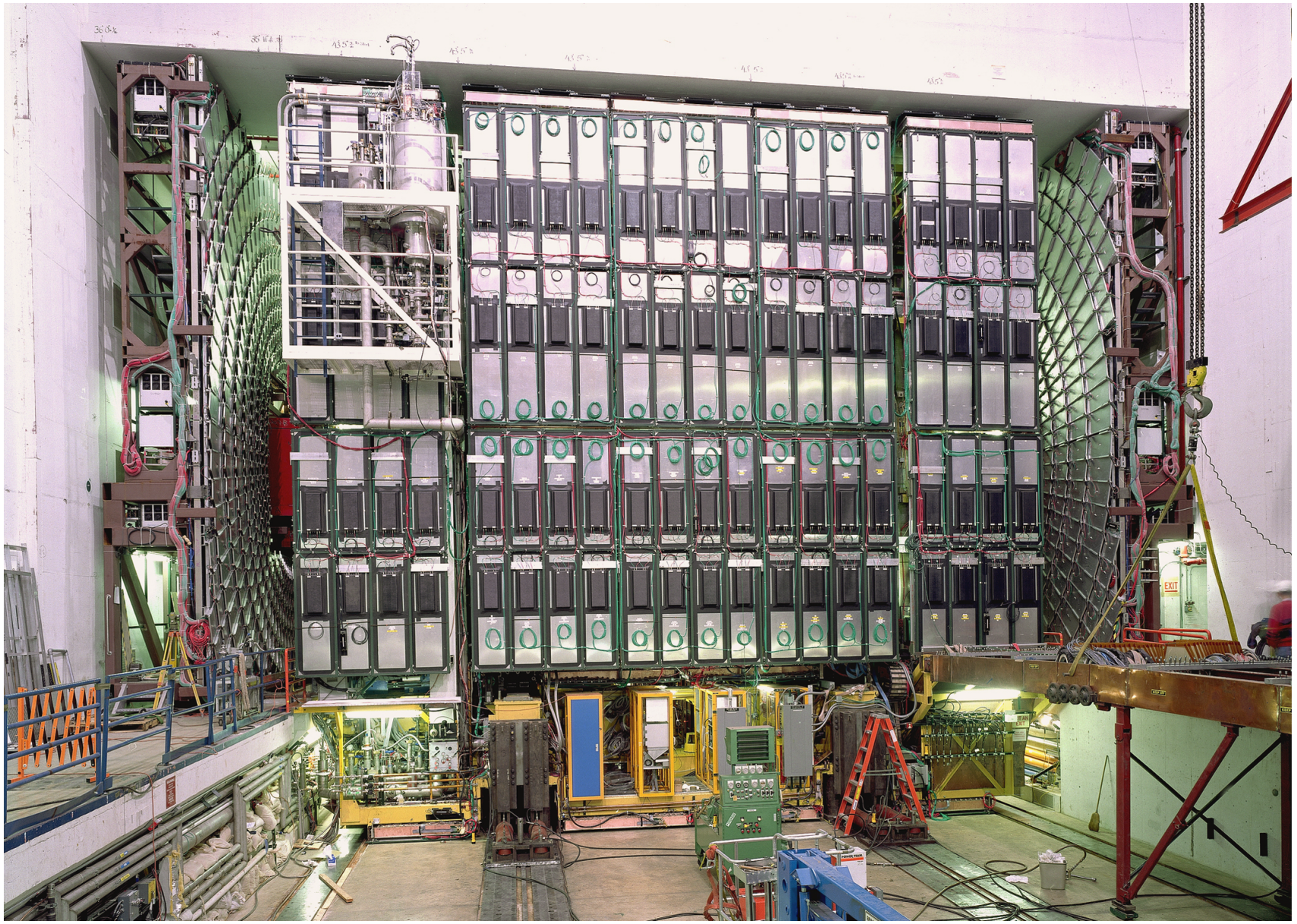
- Detector challenges
  - Large occupancies and event pile-up (multiple interactions and from previous bunch crossings)
  - Radiation damage
  - Complex trigger system (3 levels)
    - L1 decision time 4.2 μs (32 bunch crossings at 132 ns)
- Increased physics potential
  - High statistic sample for precision measurements at large p-T and searches (m-top, m-W, di-bosons)
  - Increased cms-energy (parton luminosity): σ(t t-bar) by 40% larger
  - Spectroscopy at low p-T (B-physics)

The Upgraded DØ Detector



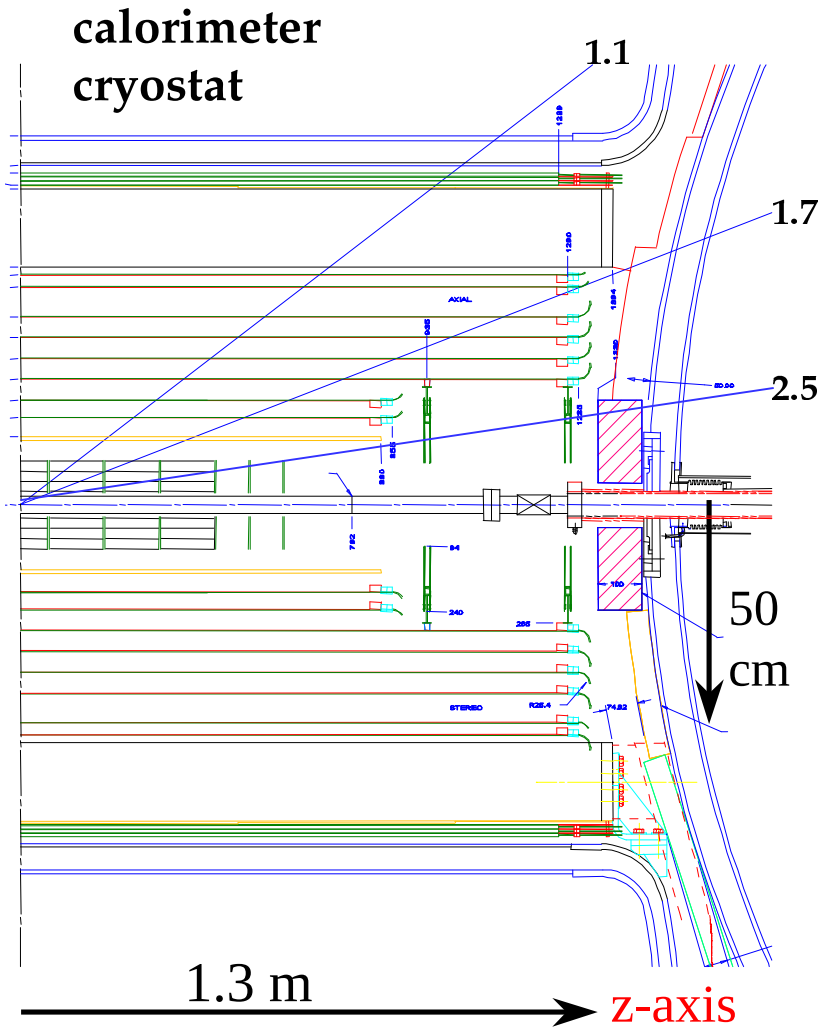
DØ's Roll-In on January 25th

DØ in Collision Hall



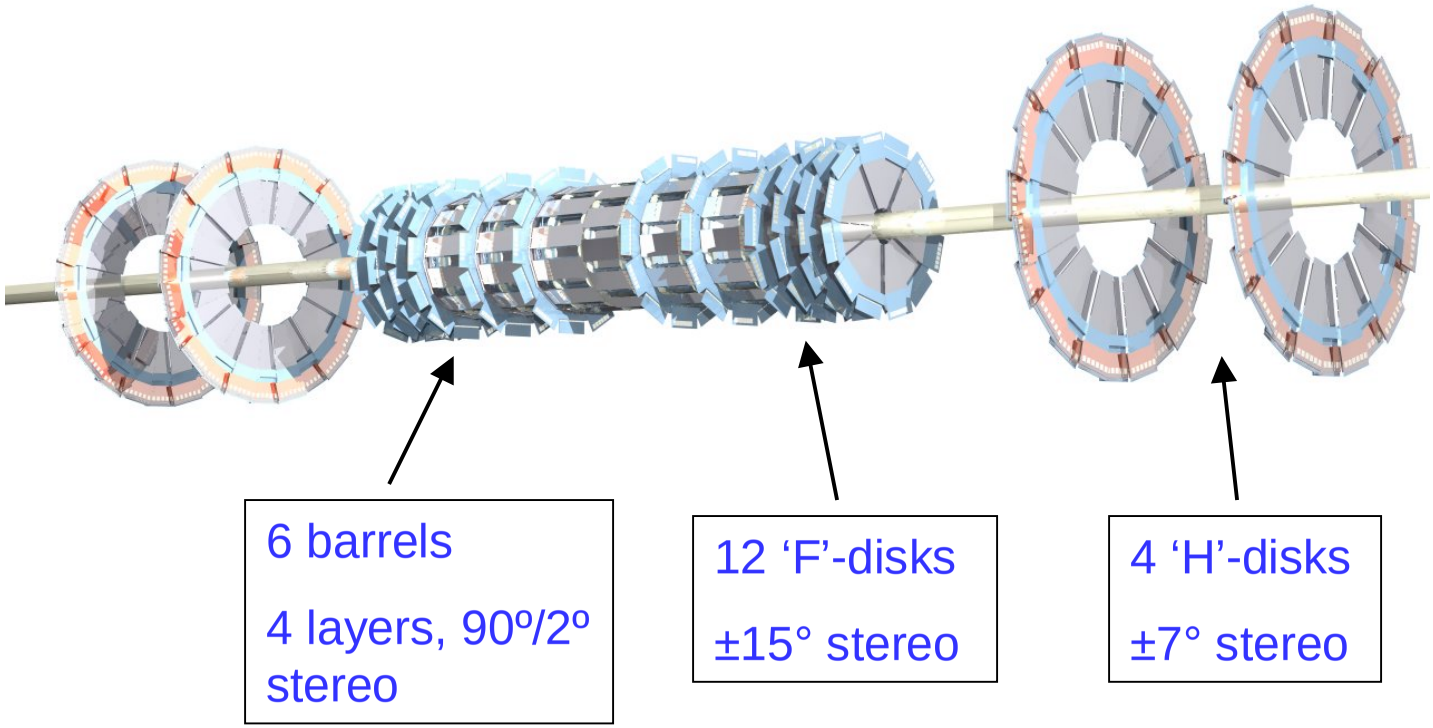
Upgraded DØ Tracking

- Silicon Microstrip Tracker
  - 4 layer barrels (double/single sided)
  - Disks (in between and forward reg.)
  - 793,000 channels
- Central Fiber Tracker
  - 8 cylinders with axial and stereo doublet layers of scintillating fibers
  - 76,800 channels with VLPC readout
- 2T Super-Conducting Solenoid
- Central Preshower
  - 3 layers triangular strips behind solenoid and 1 $\mathbf{X}_0$ Pb
  - 8,000 channels
- Forward Preshower
  - 4 layers triangular strips, in front of and behind 2 $\mathbf{X}_0$ Pb
  - 16,000 channels

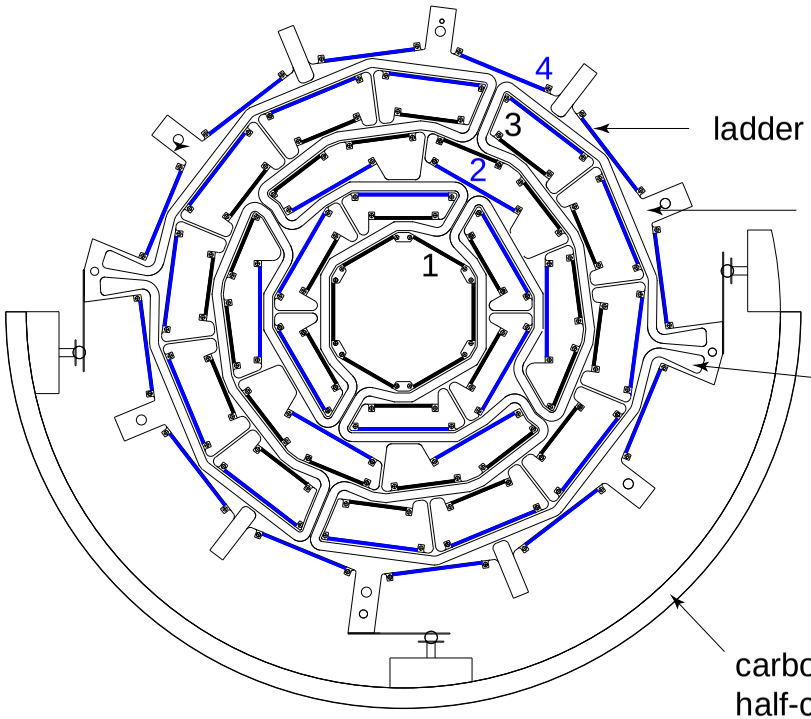


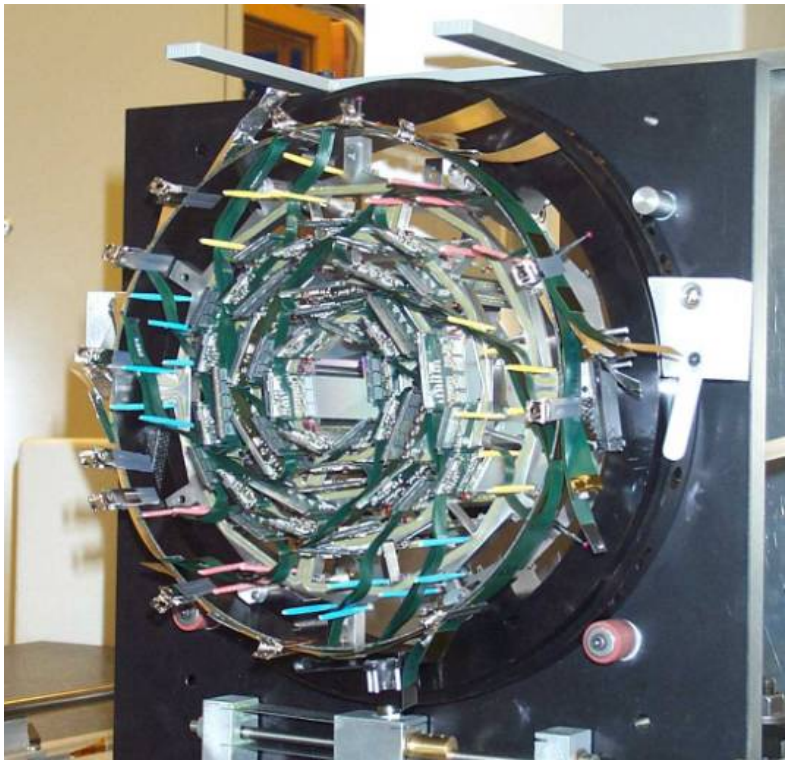
Silicon Microstrip Tracker

- Very high resolution measurements of particle tracks near beam pipe (point resolution: 10 μm)
- Track reconstruction to η = 3
- Track impact parameter trigger (STT)



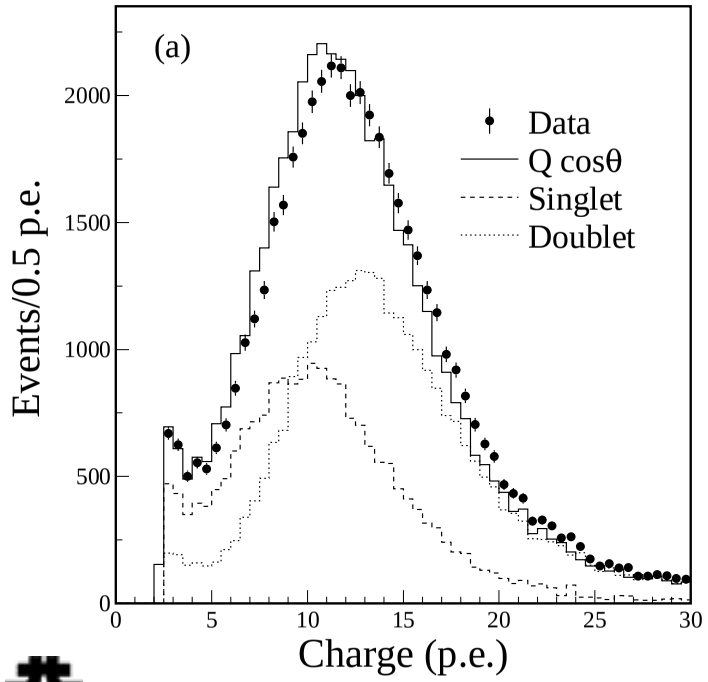
Silicon Tracker: Barrel Assembly



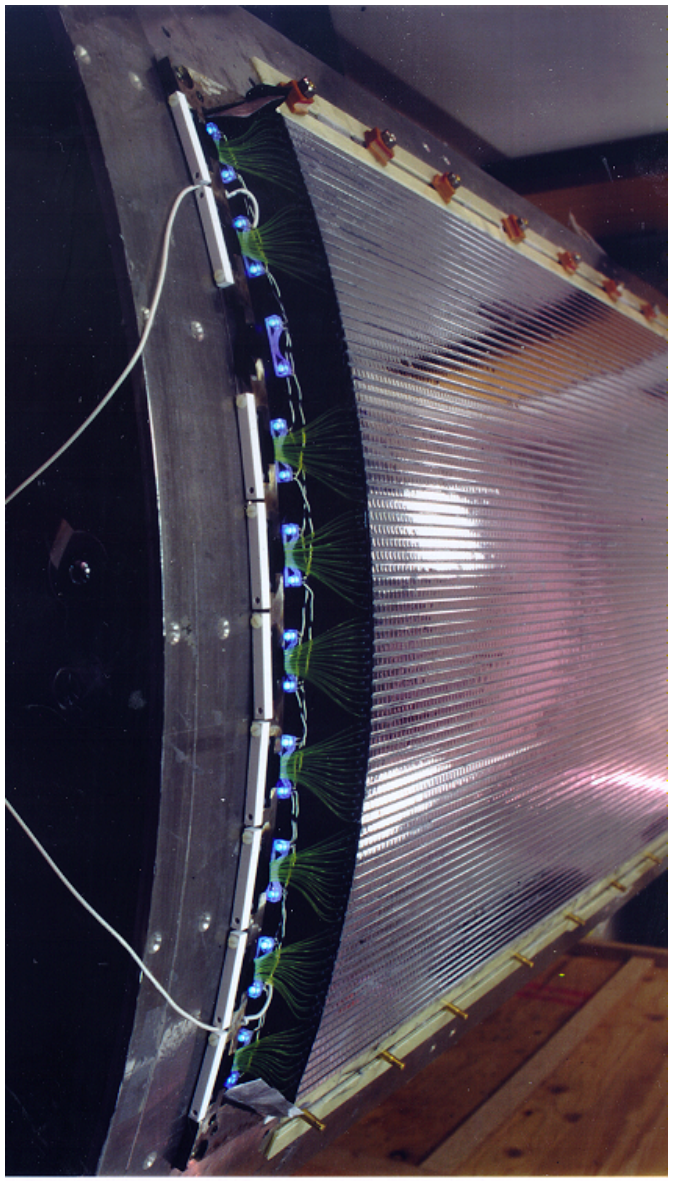


Central Preshower

- Specifications:
  - Triangular scintillator strips
    - Axial used in L1 trigger
    - Stereo ±20º
  - $2X_0$ preradiator (solenoid+Pb)
  - Coverage: $|\eta|<1.5$
  - VLPC readout (same as CFT)
  - position and energy correction for electron trigger and offline electron id

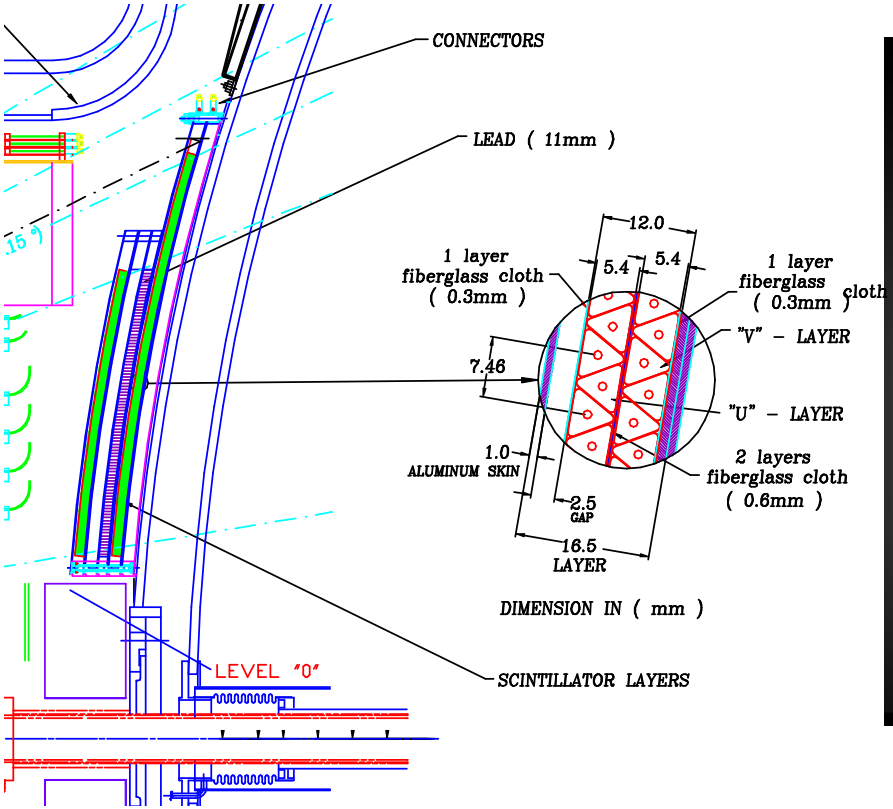


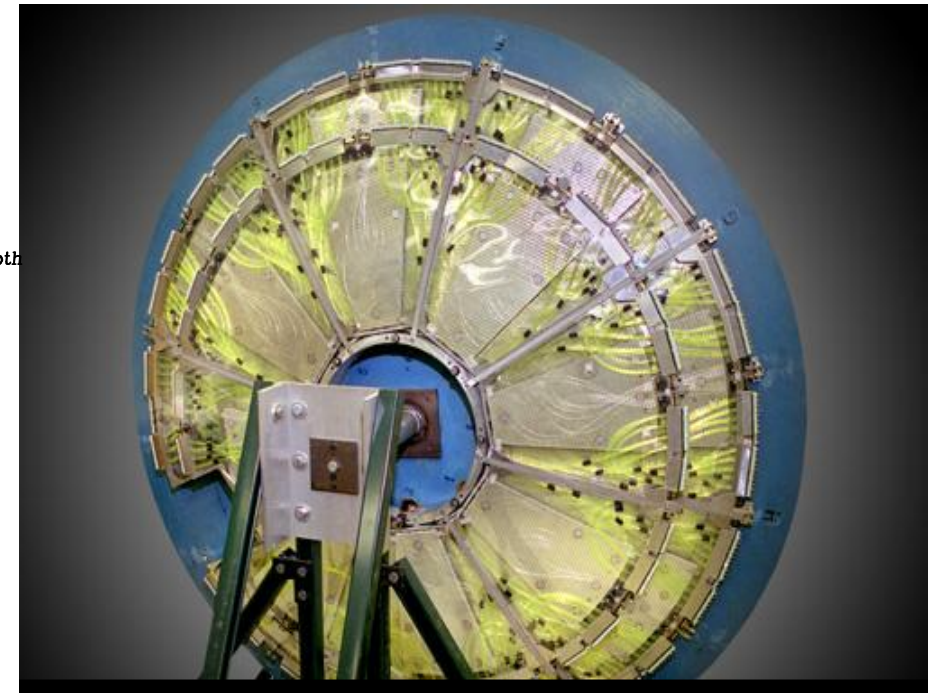
Cosmic ray test result



Forward Preshower

- Mounted on outer calorimeter cryostats
- 4 layers triangular strips, in front of and behind 2 X_0 Pb
- Provides a factor of 2-4 rejection for electron trigger for $1.4<|\eta|<2.5$
- VLPC readout (same as CFT)

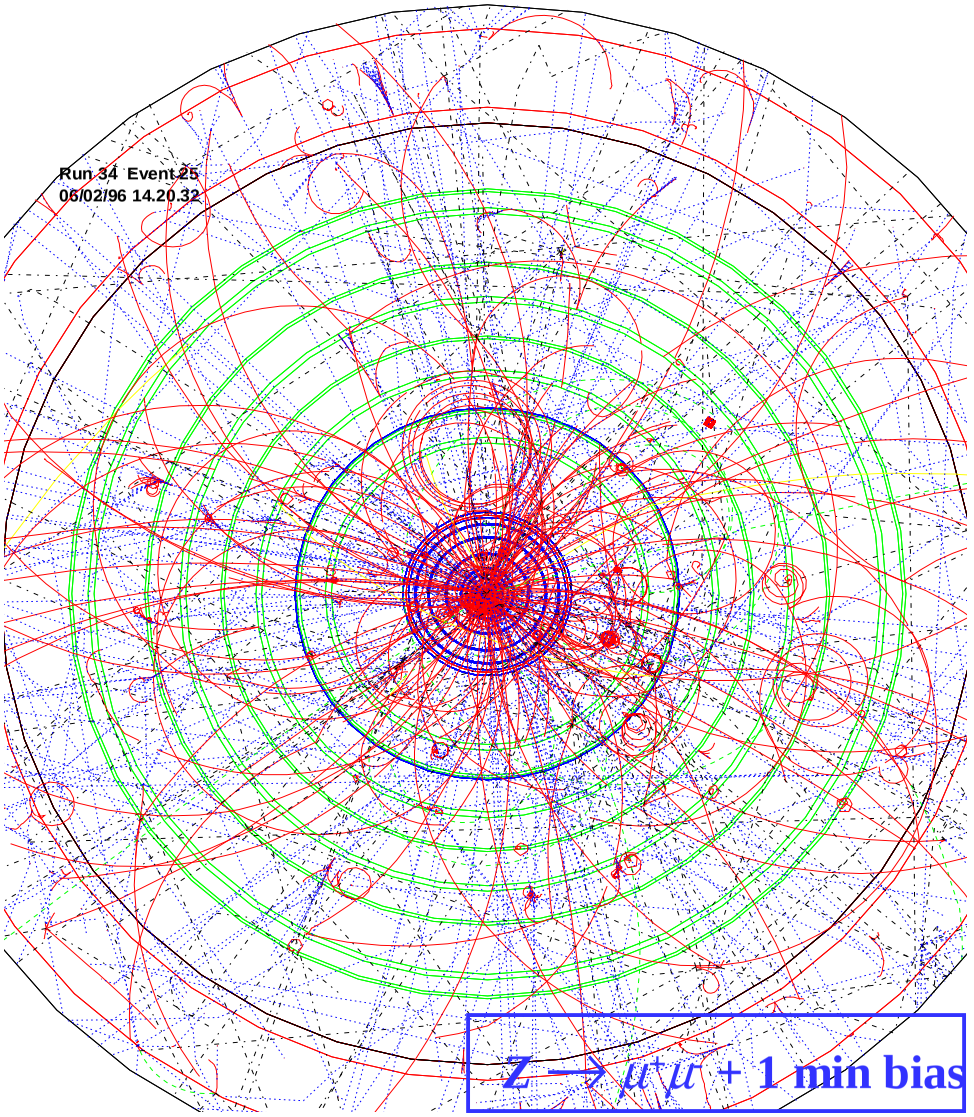




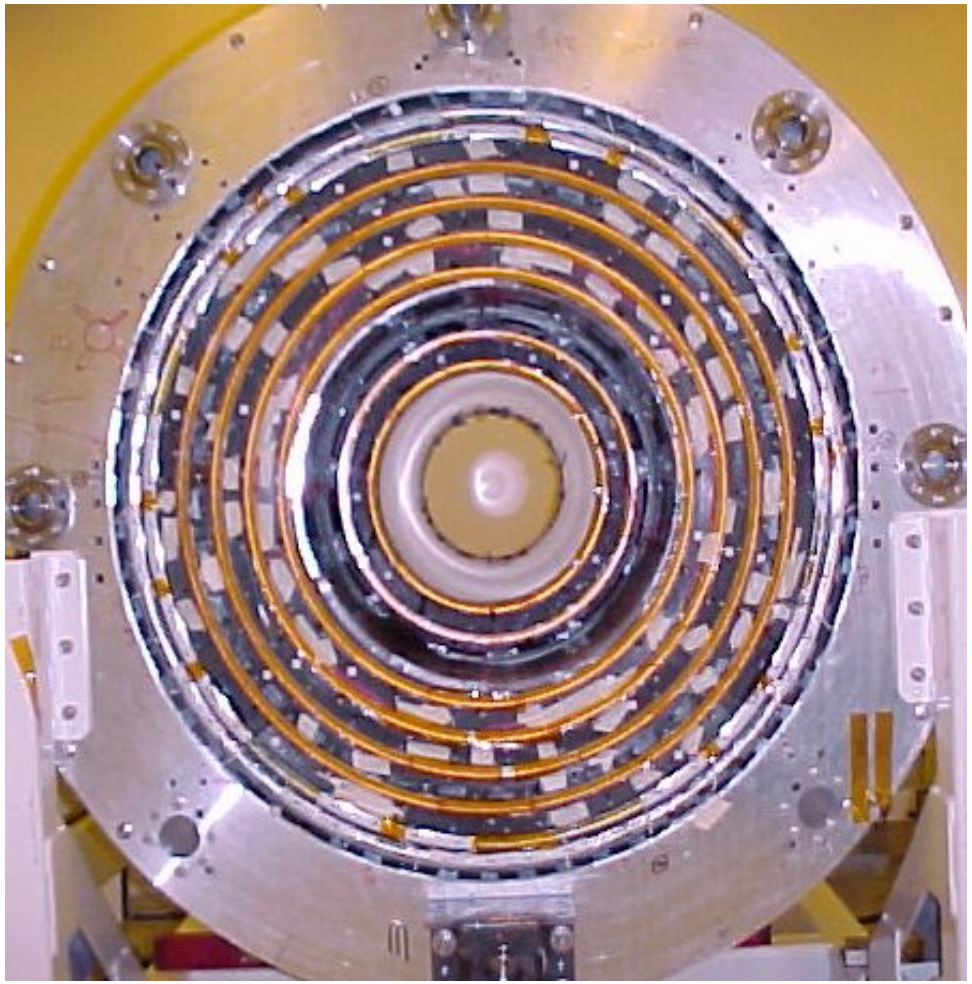
Central Fiber Tracker

Two main Functions:

1. Together with Silicon Tracker: Track reconstruction and momentum measurement for |η|<1.7 (up to |η|<2 with limited hit layers), CFT provides roads for hit search in SMT
2. Fast Level 1 triggering: combined with information from preshower and muon systems: single e, μ triggers; precise fiber alignment prerequisite (only axial fibers used in L1 trigger)

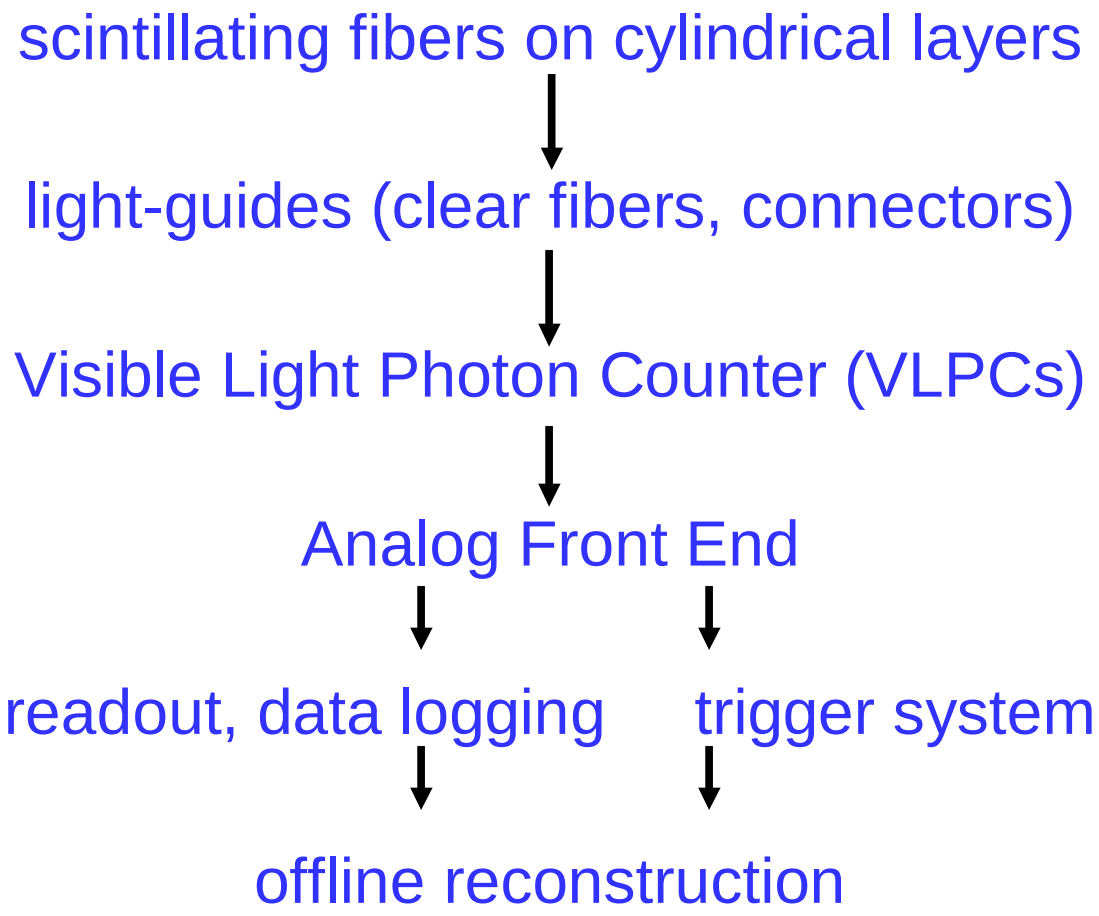


CFT Construction Design

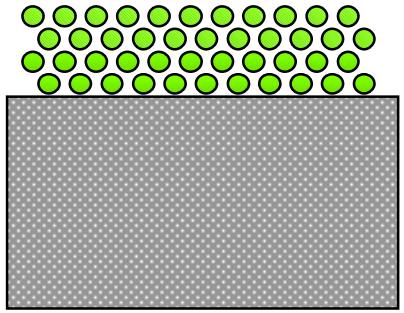


- 8 cylinders
  - Carbon fibers with Rohacel core
  - Axial and stereo double layers of scintillating fibers
  - Stereo angle: ±3º
  - 76,800 channels
  - Length:
    - outer 6 (cyl. 3-8): 2.52 m
    - inner 2 (cyl. 1-2): 1.66 m
  - Radius: 20 cm – 51 cm
- 300 wave guides
  - à 256 fibers
  - Length 8 m – 11.5 m
- readout with VLPCs
  - Visible Light Photon Counter

From Scintillation to Reconstructed Tracks

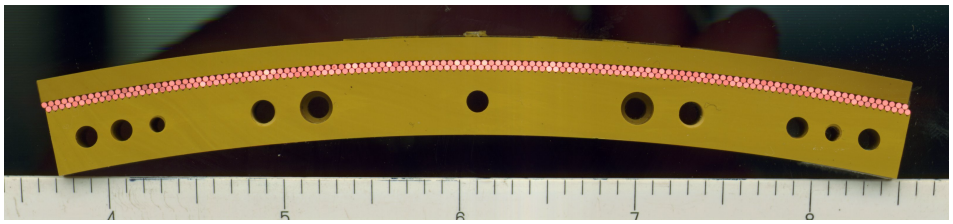


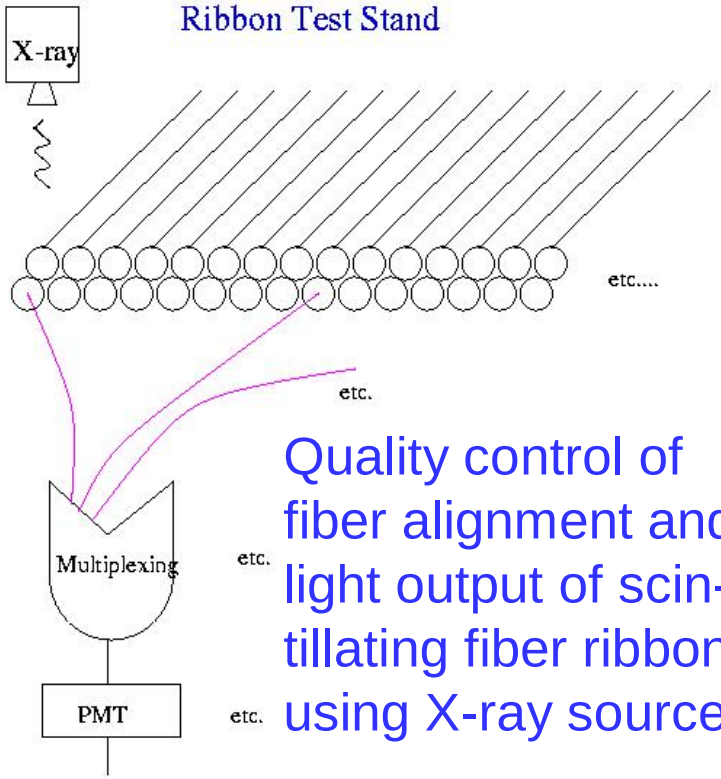
Scintillating Fiber Ribbons



- 256 fibers (in doublet) each are grouped into ribbons which are glued on carbon cylinders
- Each super-layer consist of axial doublet and stereo doublet (alternating u-v)

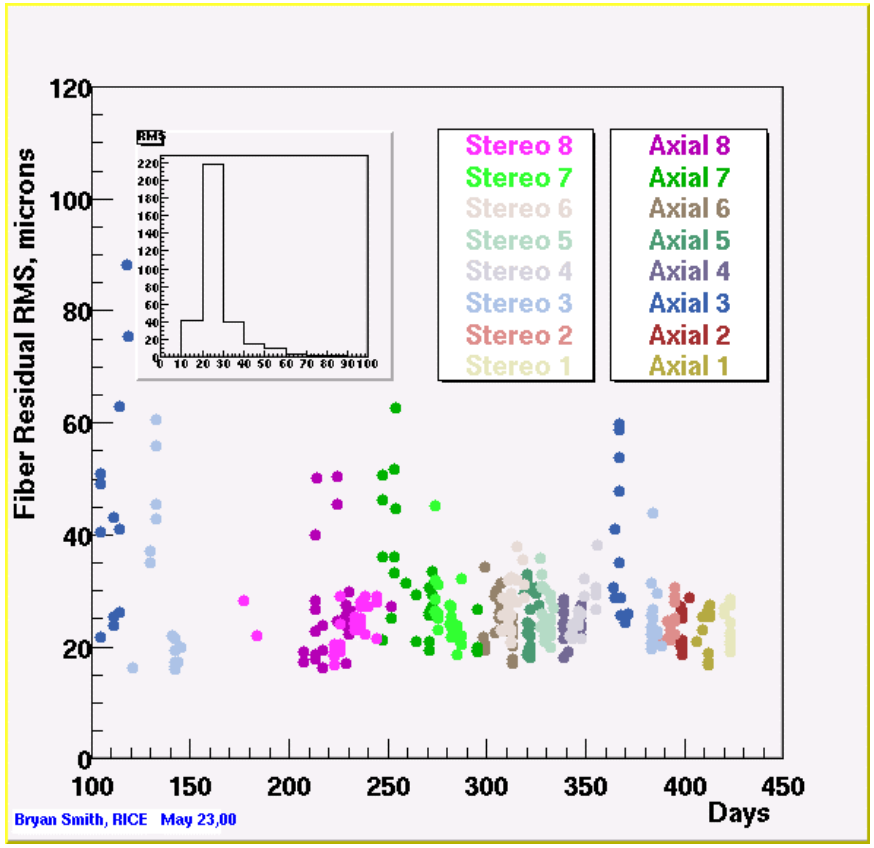
- Multi-clad fibers with 830 µm diameter (Kuraray)
- Far-end mirrored (sputtered aluminum)
- Coupled to clear fibers using curved connectors

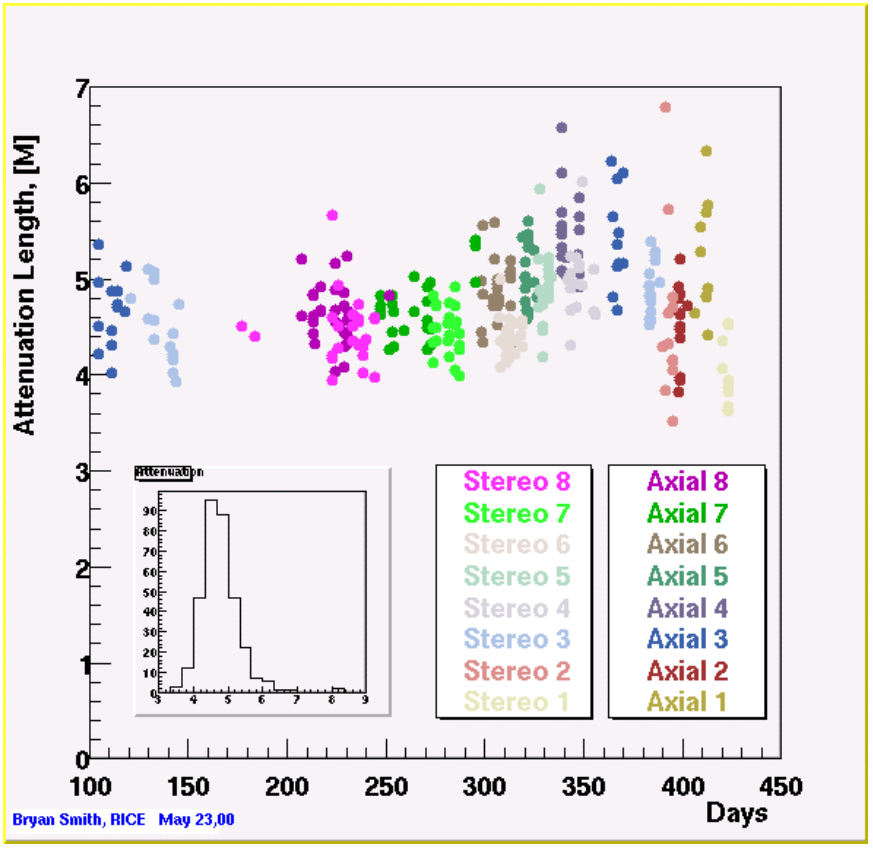




Quality control of fiber alignment and light output of scintillating fiber ribbons using X-ray source

Fiber Ribbons: QC results



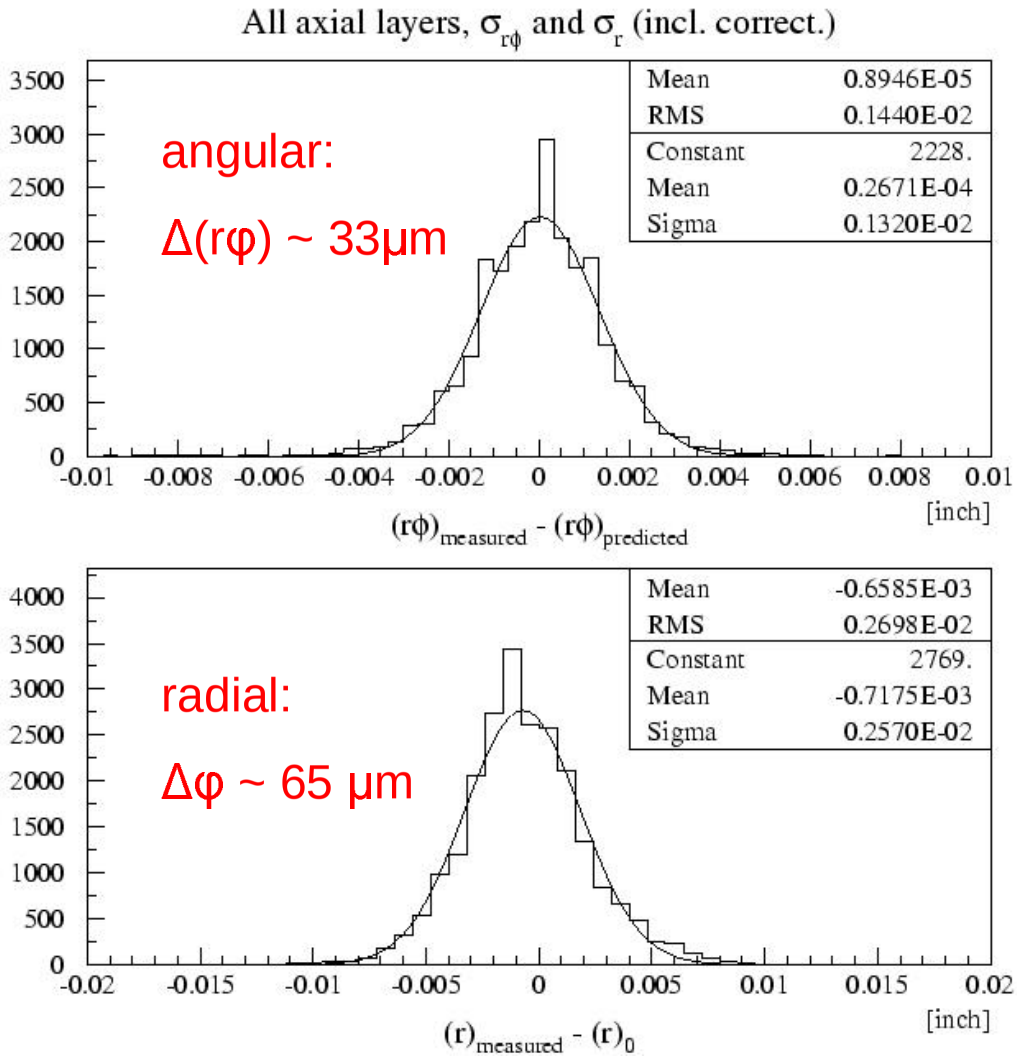


- Fiber positioning resolution: approx. 25 µm

- Attenuation length of scintillating fibers: 4-6 m
- Reflectivity: approx. 95%

Fiber Positioning on Tracker

- Fiber position survey
  - Measured on cylinder
  - Using large-volume CMM
- Global precision of fiber positions
  - Measured – desired in DØ coordinate system shown
  - Angular: Δ(rφ) ~ 33 μm
  - Radial: Δφ ~ 65 μm
  - Incl. corrections for angular offset, pitch, residual stereo angl



Fiber Alignment (Axial Layers)

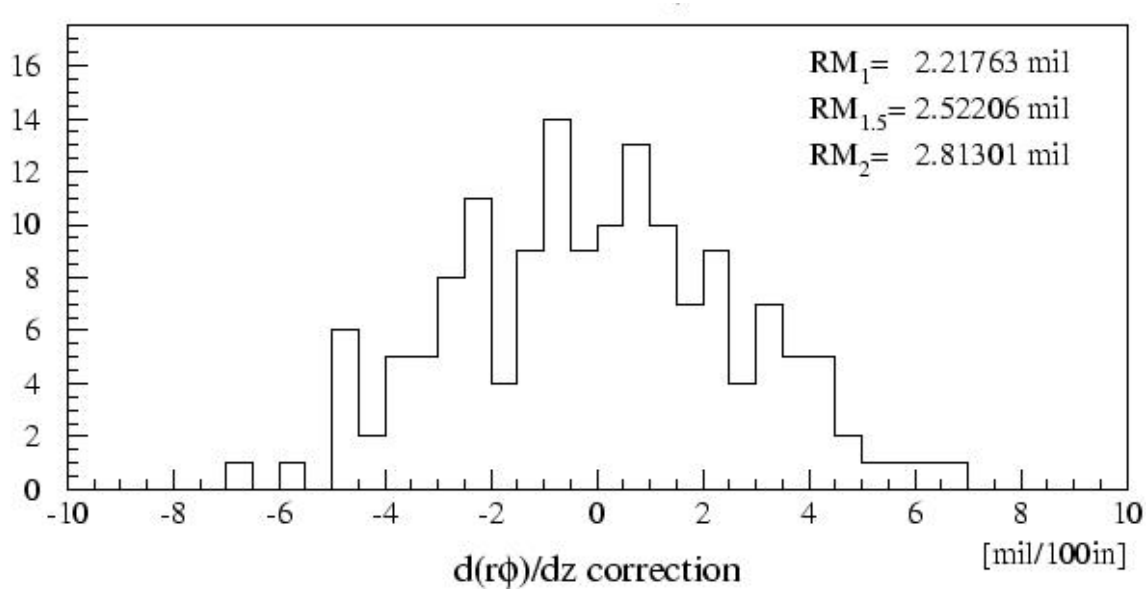
- Parallel alignment of fibers is demanded by track trigger
  - Online correction of residual stereo angle not possible
- Sources of misalignment:
  - Ribbon production, ribbon mounting, nesting position of cylinders
- Nesting position was optimized based on fiber survey
  - Desired position was obtained by ~0.5 mil
- CMM measurements provide start-point for offline analysis based on reconstructed tracks

stereo slope in rφ in mil/100”

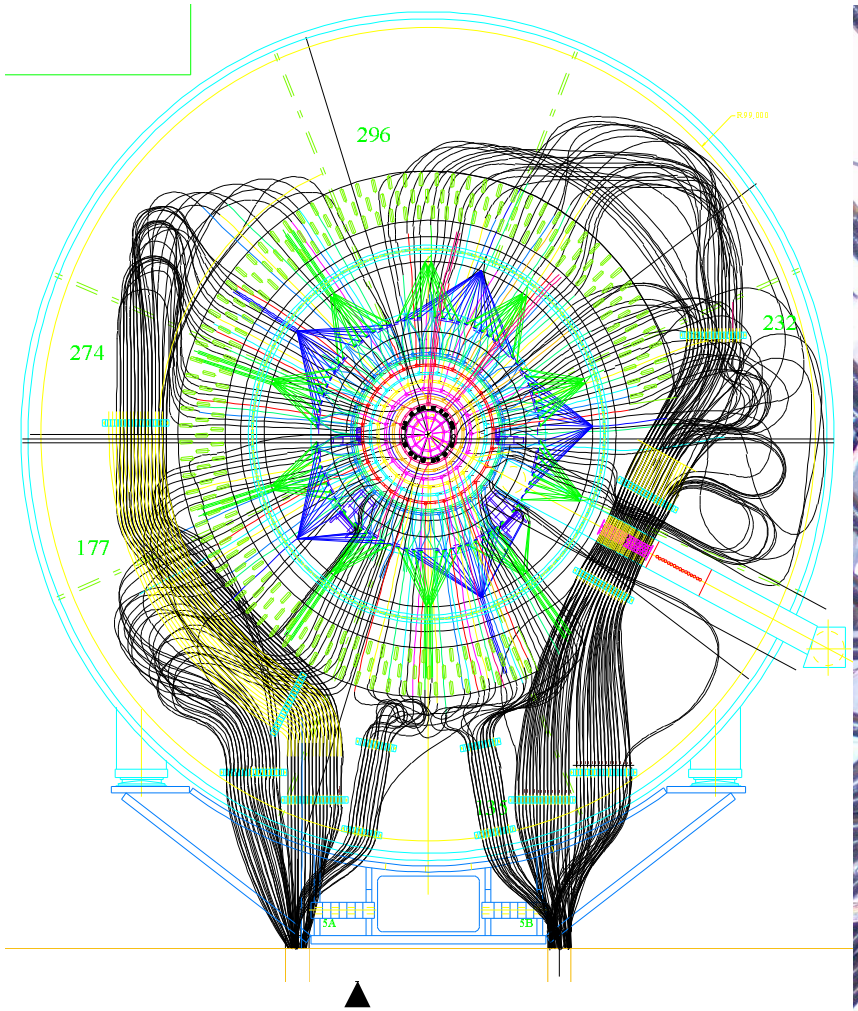
average abs. slope: 2.2

slope RMS: 2.8

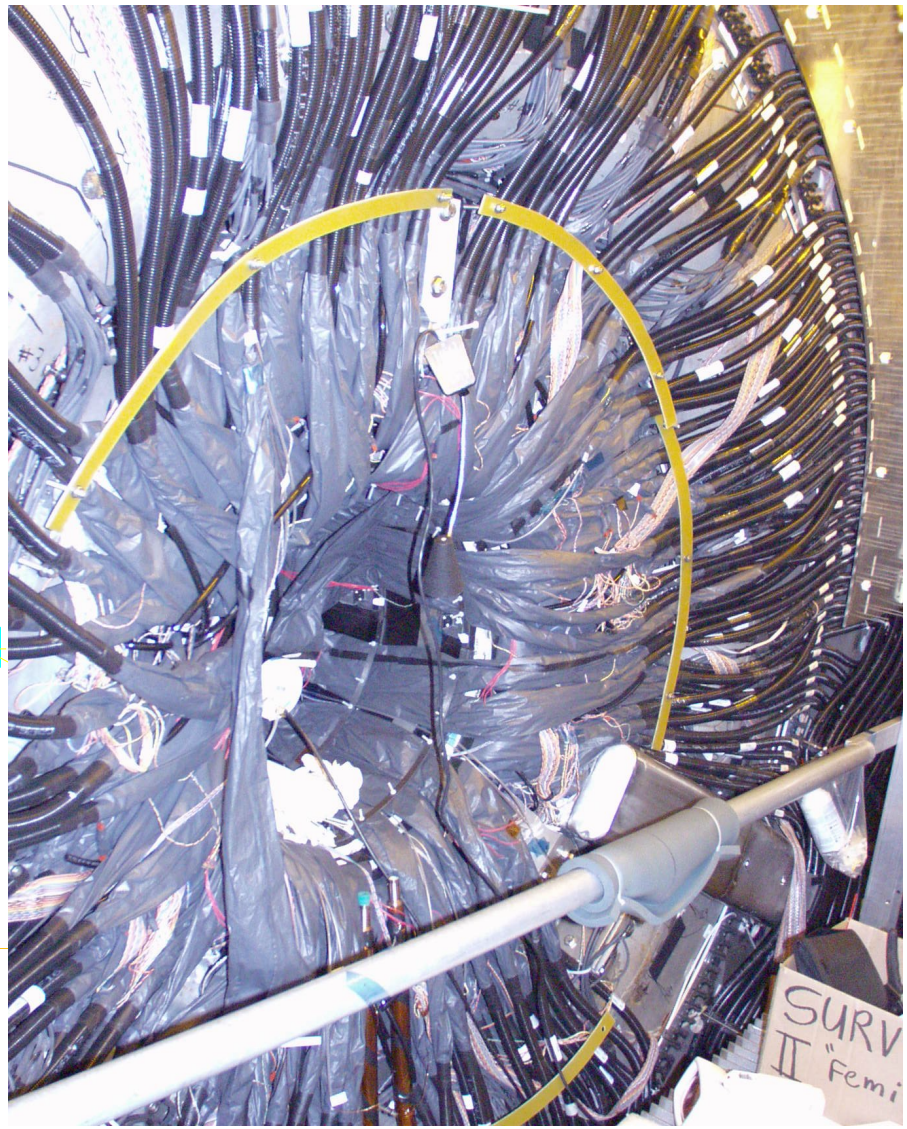
specification: 4 mils (end-to-end, i.e. 100”



Routing of Clear Fiber Light Guides

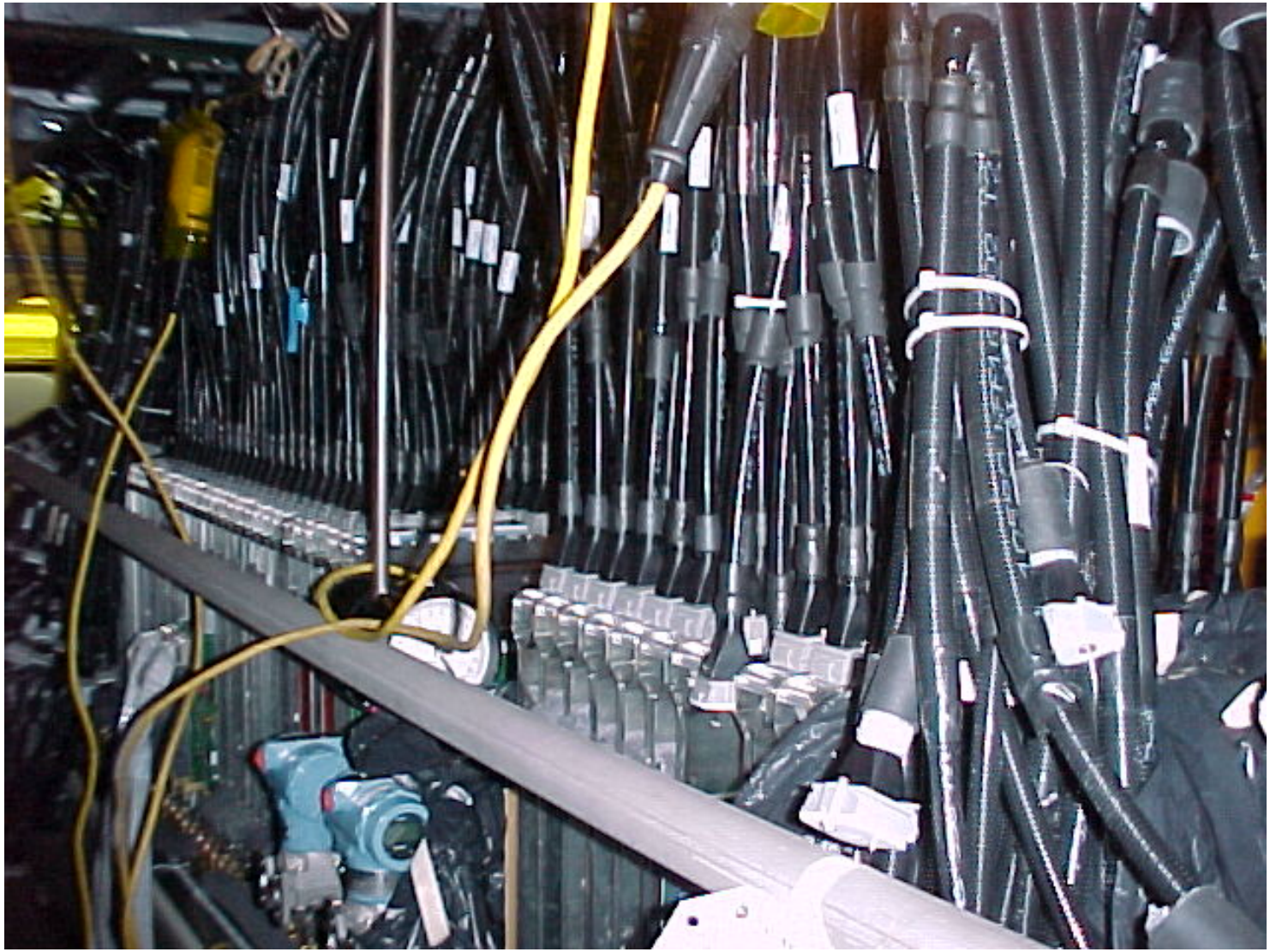


~200 light guides on each side



Installation completed

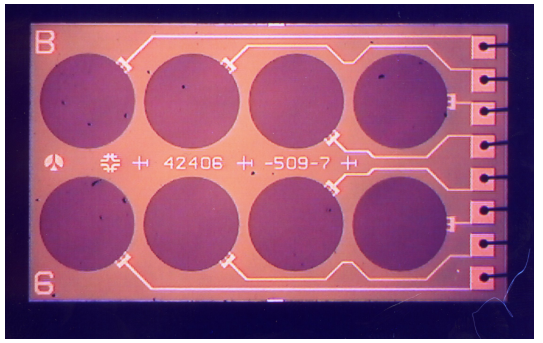
Light-Guide Connection to VLPC Cassettes

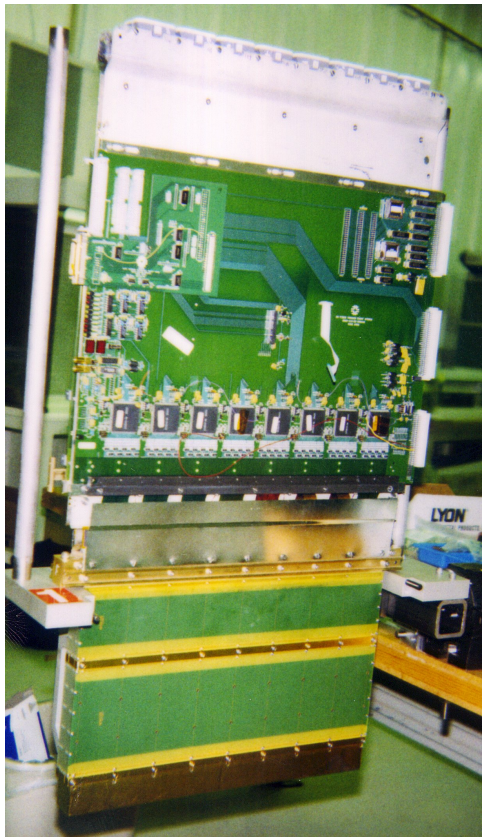


- On the ‘platform’ below calorimeter cryostat

VLPC Readout

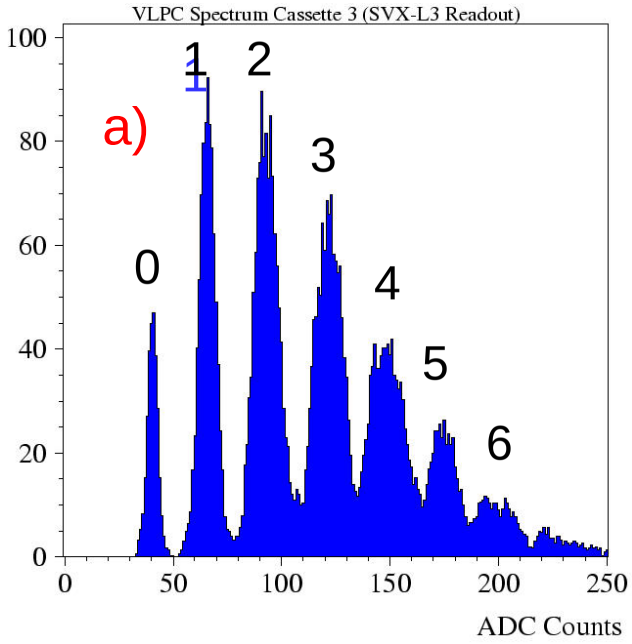
- Optical readout of fibers with Visual Light Photon Counters (VLPC)
  - SiAs chip (Boeing)
  - Excellent performance:
    - High quantum efficiency: ~ 80%
    - High gain: ~ 40,000
    - Low noise
- VLPC chips assembled in cassettes
- challenges:
  - fiber to pixel alignment: 10 μm
  - operation at 9K (cryogenic system, liquid helium)
- ~ 100 cassettes with each 1024 channels needed

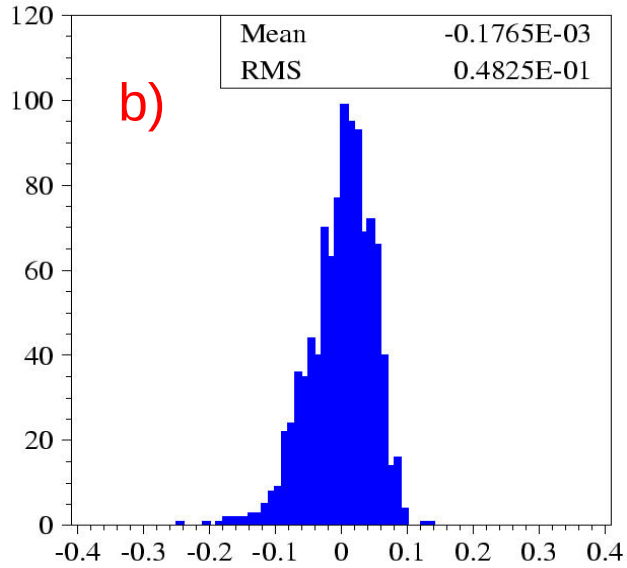




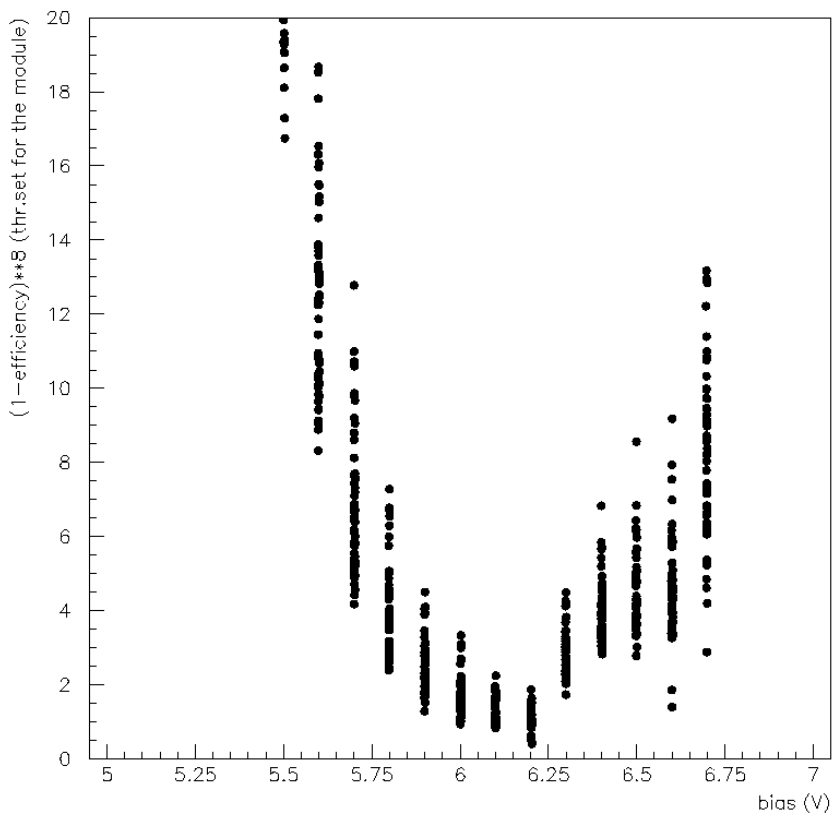
VLPC Readout: Cassette Test with LEDs

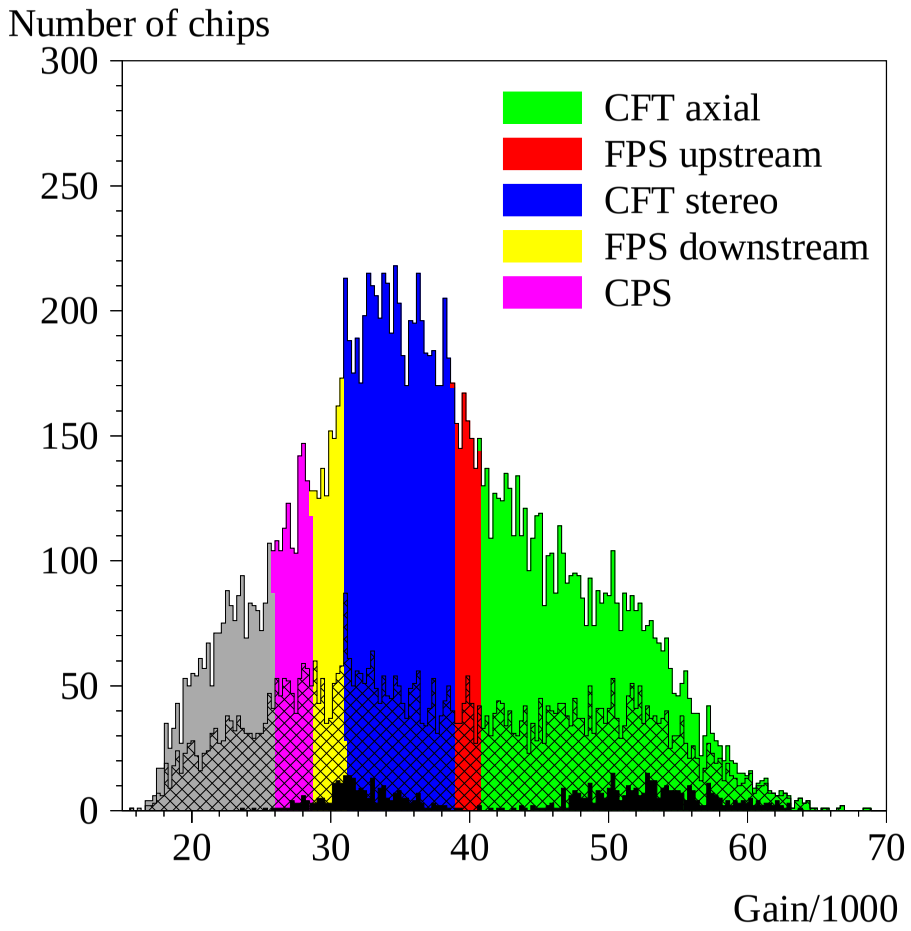
- Full characterization of cassettes in test cryostat
  - Gain, quantum efficiency and noise level are measured as a function of bias voltage and background rate
  - Determination of individual operation points for 64 channels resp.
- single photo peaks visible (LED pulser), c.f. a)
- good uniformity
  - Gain variation within cassette ~5%, c.f. b)
  - Q.e. uniformity: ~ 15%
  - Noise level uniformity (set to 0.5% occupancy): ~15%





VLPC Characterization

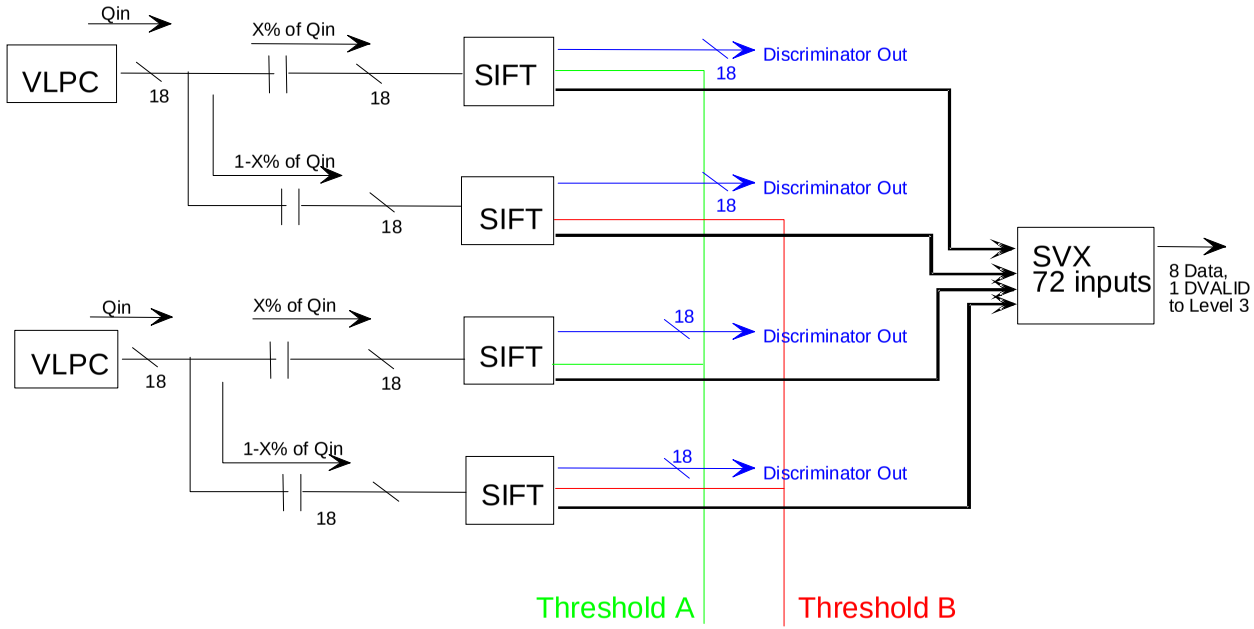




- Optimal VLPC bias voltages are determined by minimizing inefficiency at fixed noise level (0.5%)
- Classification based on gain: VLPC with highest gain used for CFT axial (L1 trigger efficiency)

Analog Front End Readout

- VLPC signal is discriminated (SIFT) and digitized (SVX II)
- Production of AFE boards delayed



SIFT chip:

- ~1 p.e. trigger threshold anticipated
- Two discriminator levels for Preshower detectors
- Currently only operational at 396 ns
- Fast discriminator for trigger signal (Level 1 track trigger)

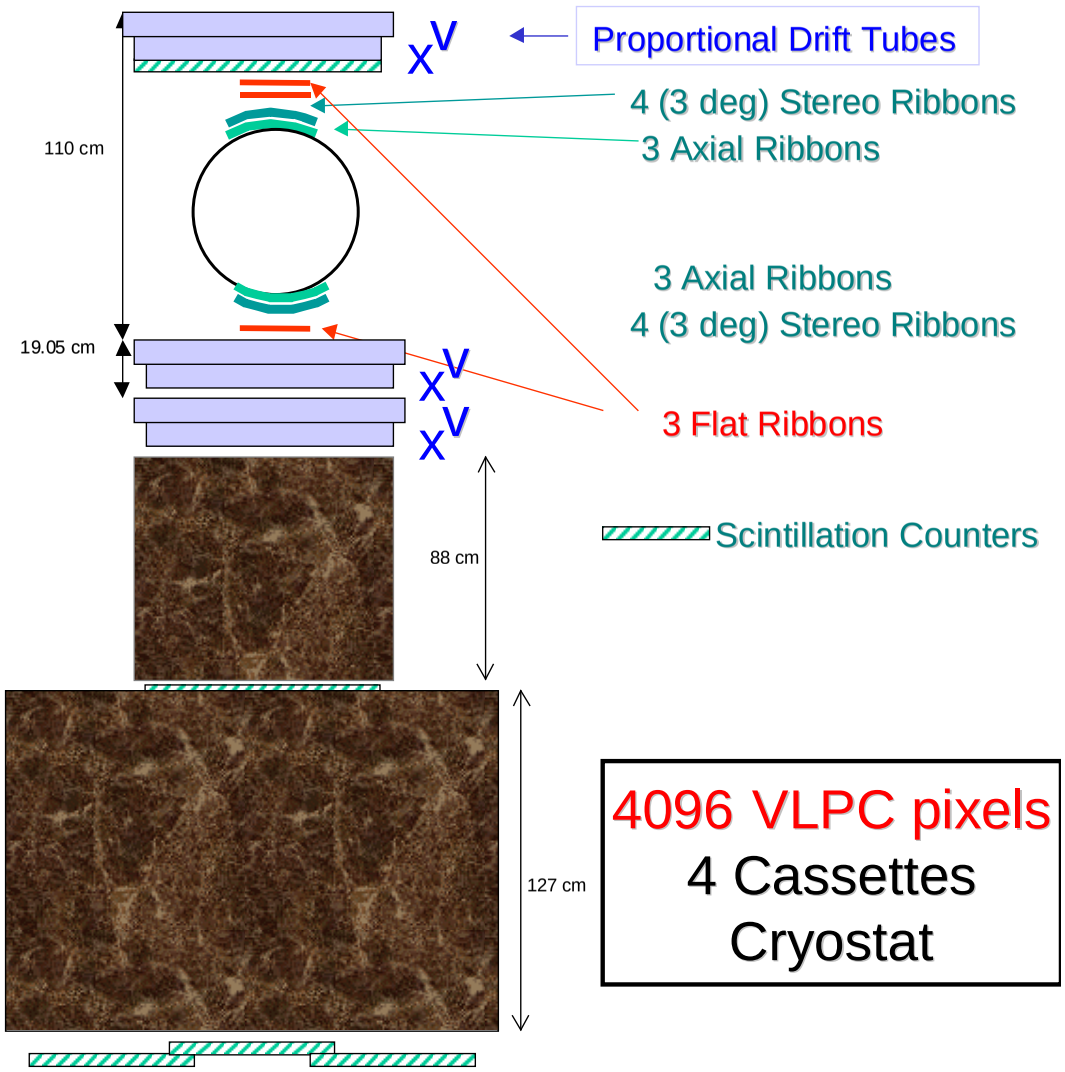
SVX II chip

- Similar to SMT readout
- Integrator: rise time adjustable
- 32 cell analog pipe-line (L1 buffer)
- 8-bit ADC on chip
- Sparse and next-nghbr readout
- Power: 3 mW /channel

Cosmic Ray Test

Cosmic ray test used to study:

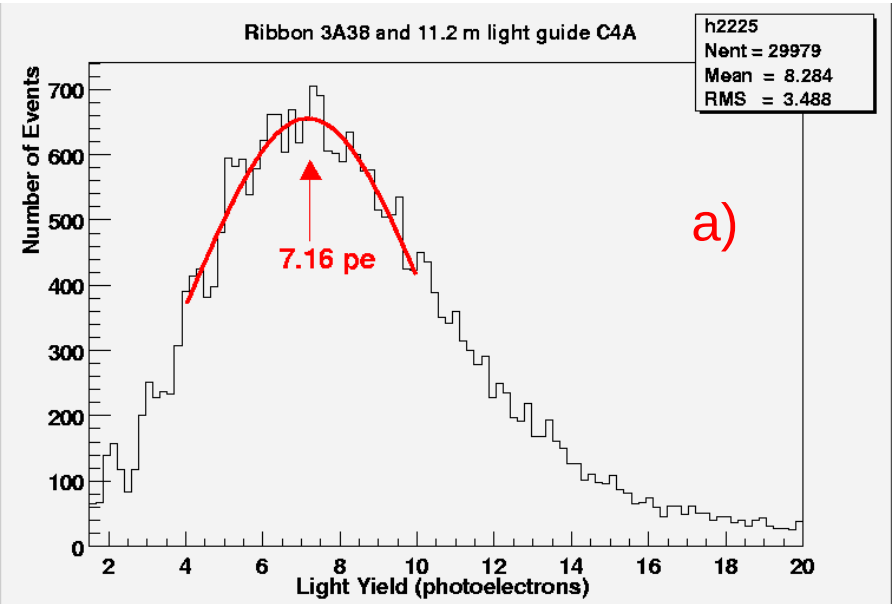
- Light-yields from scintillating fibers
- Quality of optical readout (light guides, connectors)
- Readout system
- Aging
- Position resolution

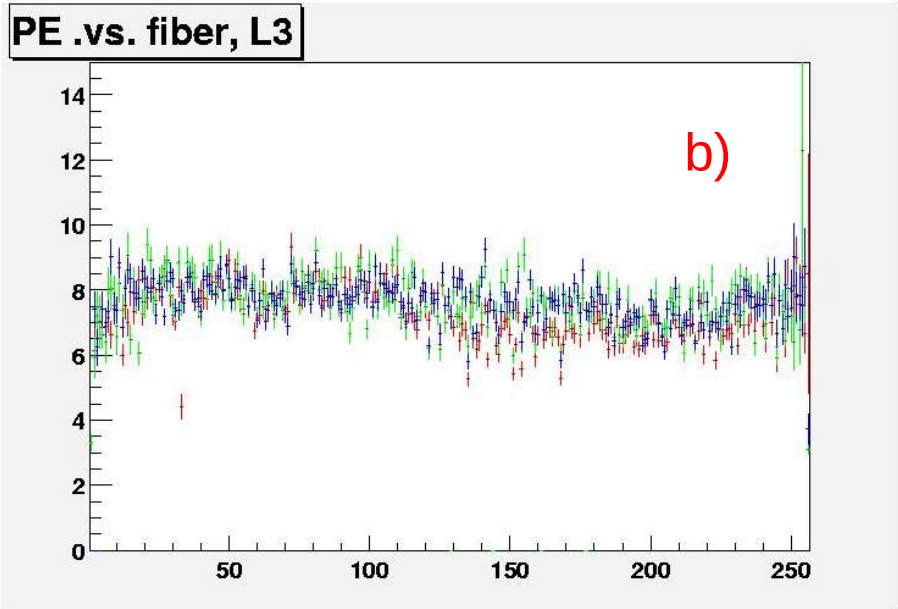


4096 VLPC pixels
4 Cassettes
Cryostat

Results from the Cosmic Ray Run

- Photo electron yields
  - Average p.e. yield for vertical tracks (with 11 m light-guide): approx. 7-8 p.e., c.f. a)
  - P.e. yield uniform over individual fibers, c.f. b)
- Also measured:
  - Doublet position resolution: ~ 100 μm
  - Doublet efficiency: ~ 99.9%
  - Fiber position shifts (>25 μm) due to changes in air humidity





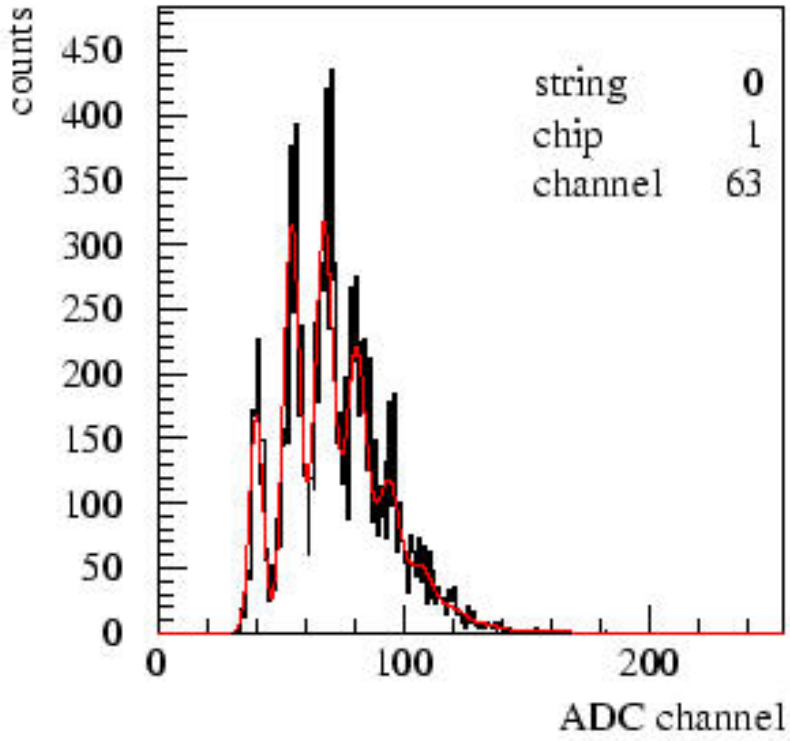
Light-Guide and Optical Readout Test

- Test of complete fiber readout in DØ setup
- Scintillating fibers can be illuminated with LED panels
  - Each ribbon (256 fibers) is covered by 3 panels on both ends respectively.
  - Provides a measurement of light attenuation (LG quality)

Photo peaks in the ADC spectrum of single fibers:

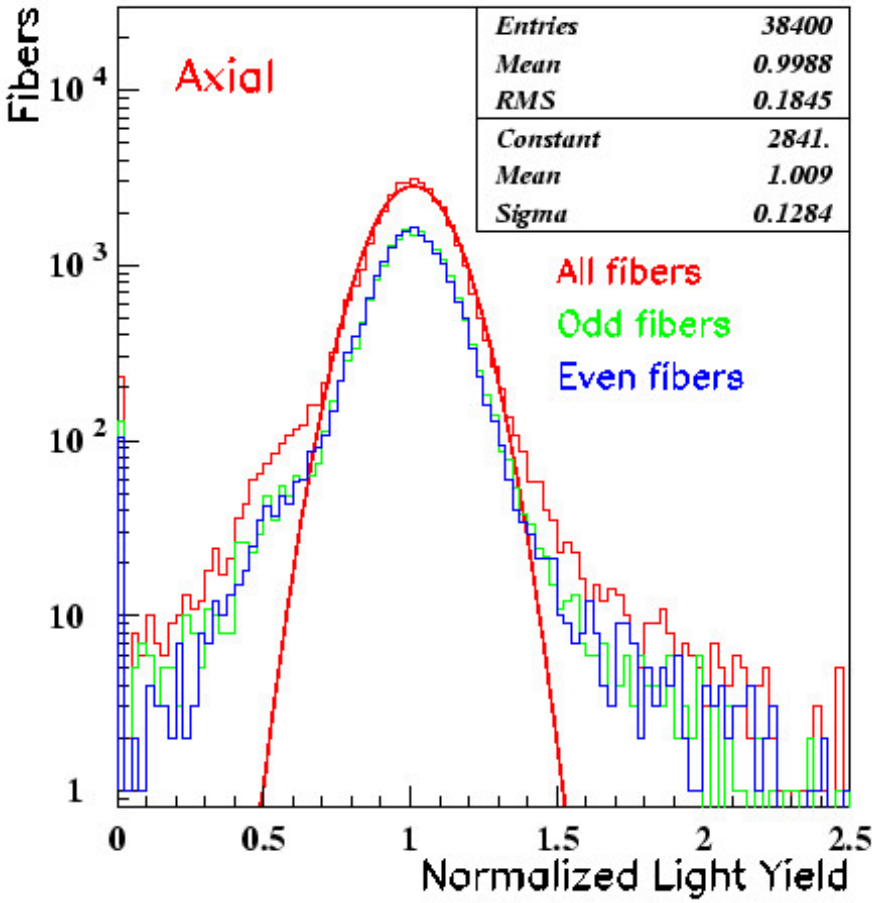
Poisson fit (smeared by Gaussians) provides a measure of the average p.e. yield for a fiber channel (scintillating fiber + clear fiber + VLPC chip [quantum efficiency]).

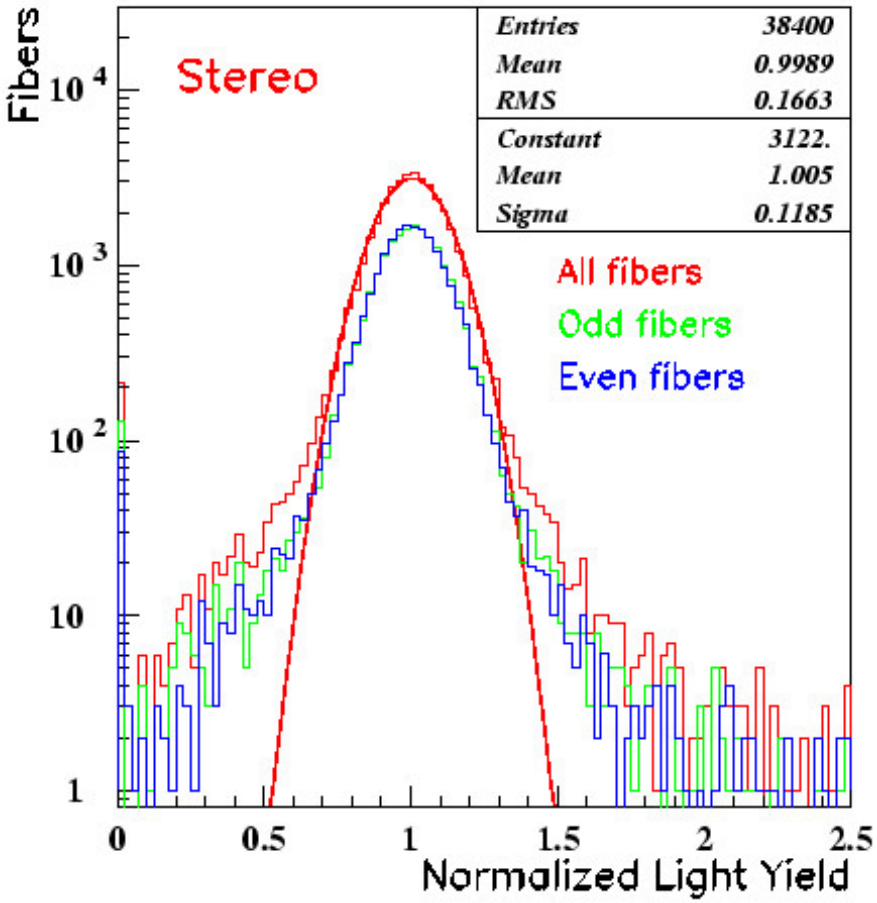
p.e. yield with LED system: 0.5–2.5 p.e.
depends on light coupling into scint. fibers



Light Yield Uniformity

- Spread in light yield across fibers: ~ 12%
  - System of scintillating fibers + clear fiber light guide
  - Obtained using LED calibration system

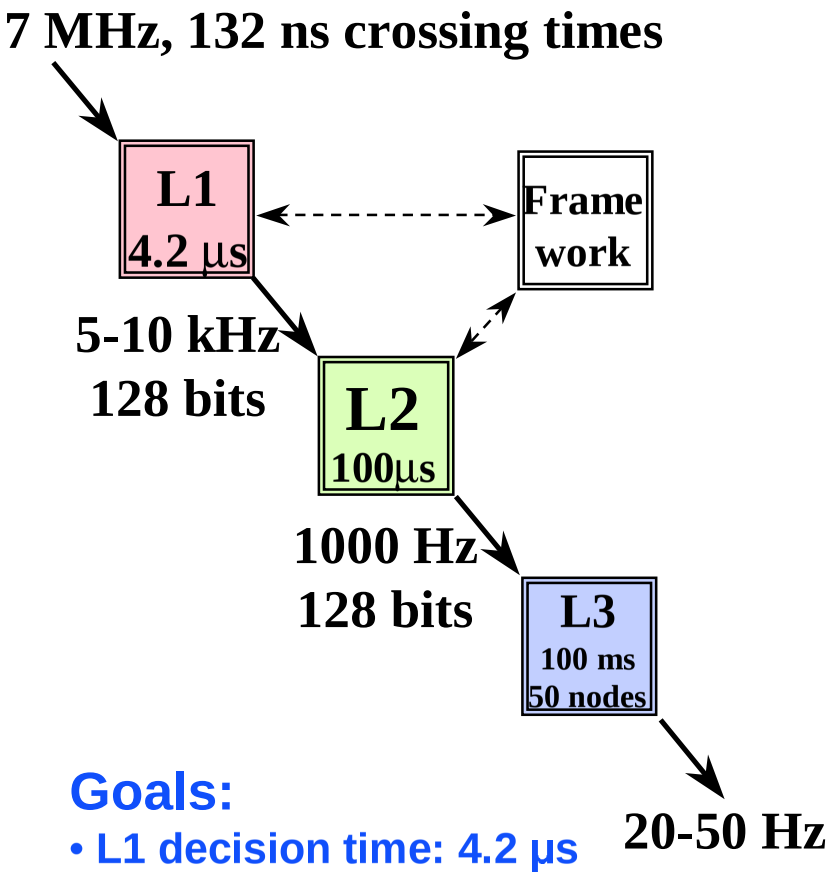


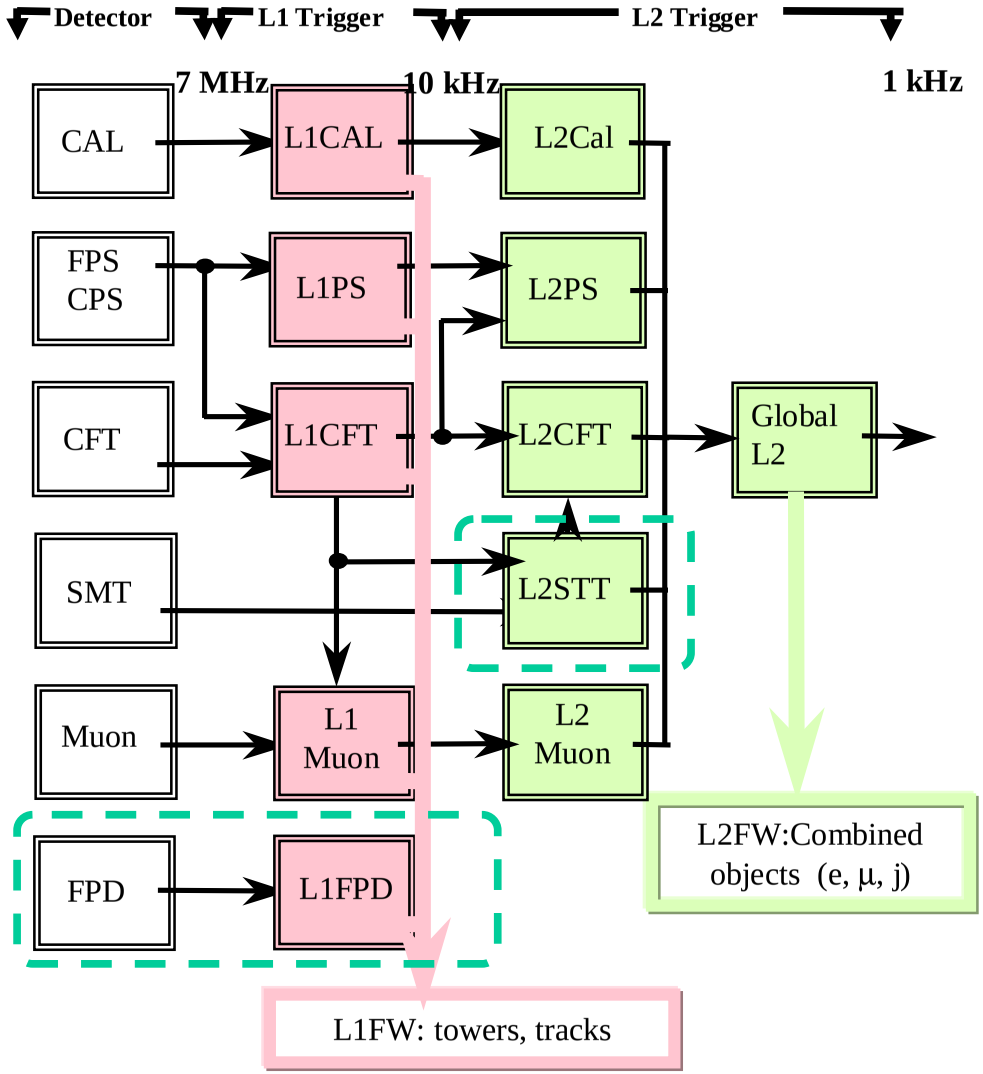


Trigger: Example Cross-Sections and Rates

Process	X-Section	Rate ($L=2\times10^{32}$ cm^{-2}s^{-1})
Inelastic $p\bar{p}$	50 mb	10 MHz
$b\bar{b}$ ($\|y\|<1$)	50 μb	10 kHz
$p\bar{p} \rightarrow WX$	22 nb	4.4 Hz
$p\bar{p} \rightarrow ZX \rightarrow b\bar{b}X$	1 nb	0.2 Hz
$p\bar{p} \rightarrow tX$	11 pb	8 / hour
$p\bar{p} \rightarrow W/Z\ H$	0.5 pb	8 / day

DØ's 3 Level Trigger System





Goals:

- L1 decision time: 4.2 μs
  - SXV: 32 cell analog pipeline
- Accommodate :
  - $L=2x10^{32}cm^{-2}\ s^{-1}$ &
  - Bunch Crossings 132 ns
- Maintain Run I e, mu,jet acceptance
- Dead-time: <5%

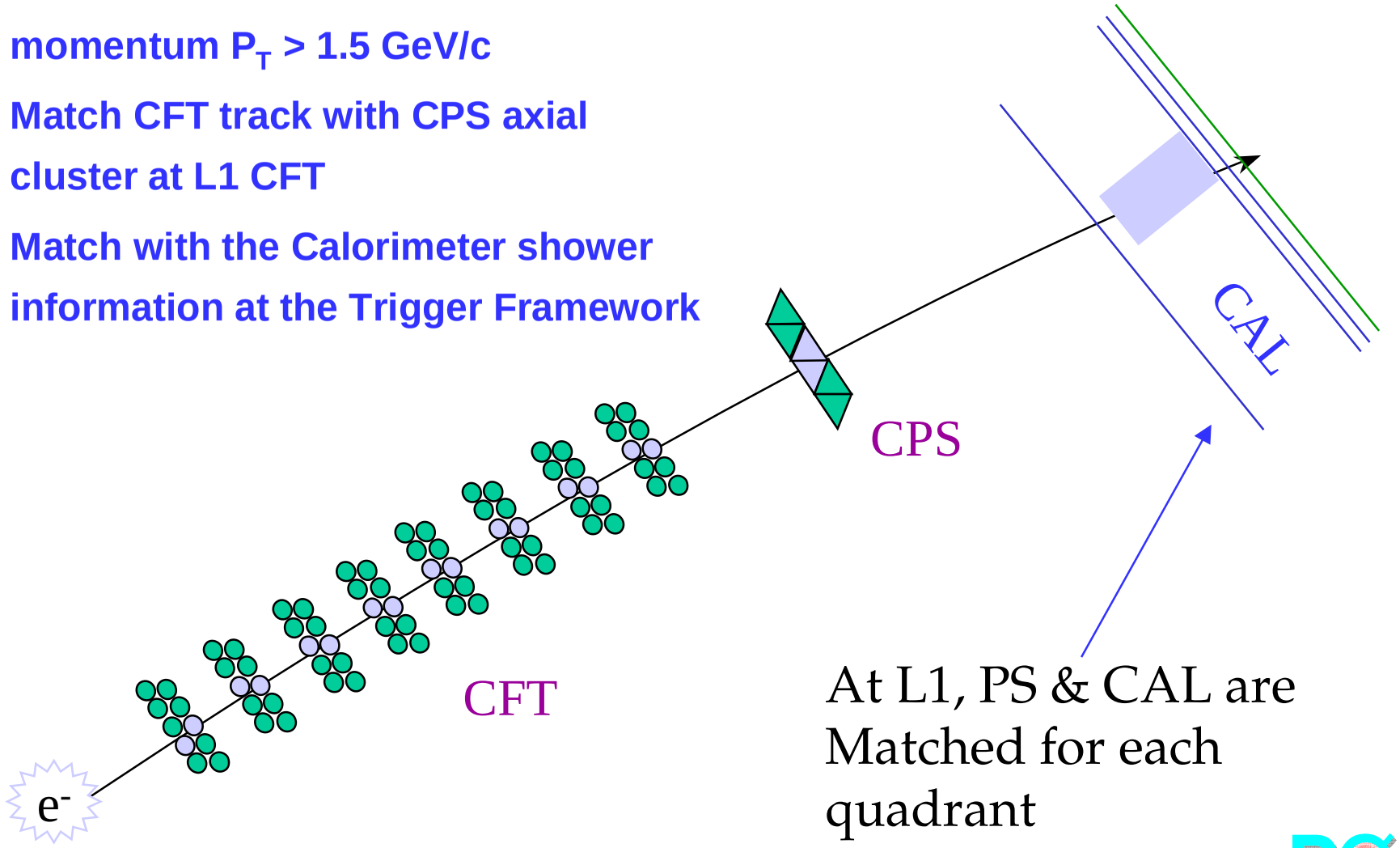
Trigger: Improvements comp. to Run II

		Run I	Run II
Rates	In	300 kHz	7 MHz
	L1	150 Hz	10 kHz
	L2	—	1 kHz
	L3	4 Hz	50 Hz
Terms	L1	32	128
	L2	—	128
	L3	128	arbitrary
Inputs	L1	calorim,muons	cal,mu,trk,ps
	L2	—	corr's,phys objs
	L3	vax farm	pc farm

- Trigger systems only partly available at Run start

L1 Central Electron Trigger Example

1. Fiber hit pattern recognition in the CFT for tracks consistent with momentum P_T > 1.5 GeV/c
2. Match CFT track with CPS axial cluster at L1 CFT
3. Match with the Calorimeter shower information at the Trigger Framework



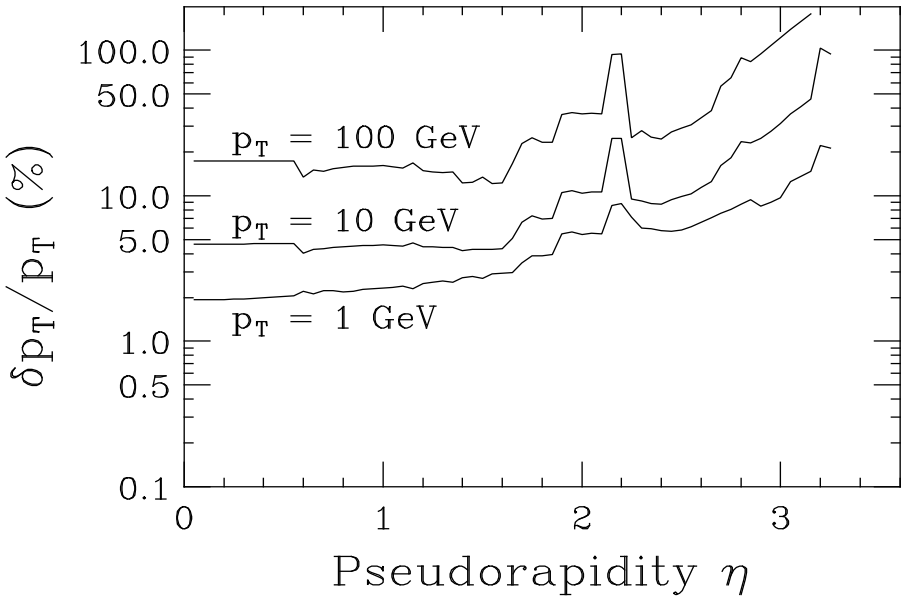
At L1, PS & CAL are Matched for each quadrant

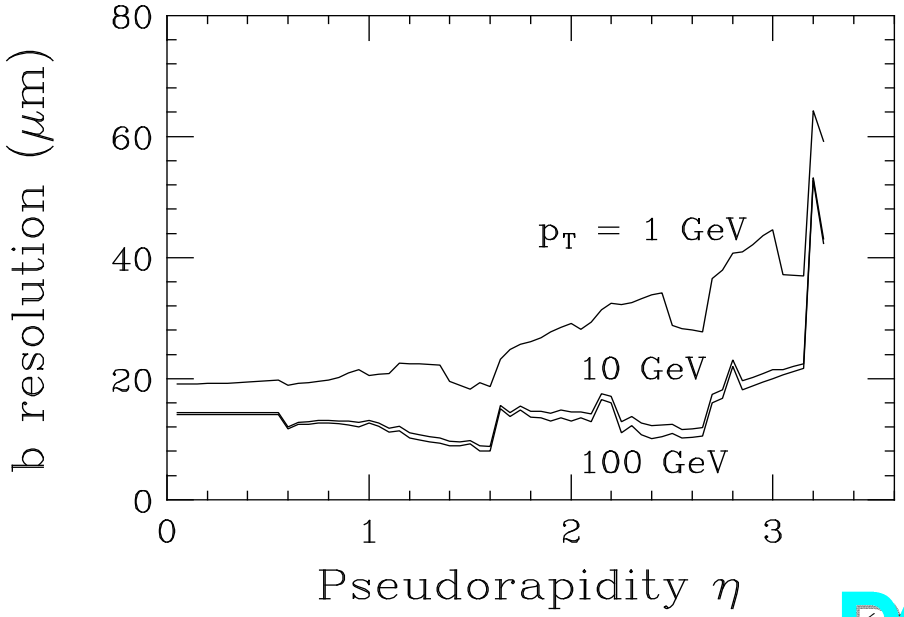
Track Reconstruction on Level 1

- Compute trajectories (equations) analytically (in each as built sector) in 2T field for all possible tracks with p_T >1.5GeV and download resulting 16000 equations to FPGAs
  - FPGAs each with ~ 3-600,000 logic gates
  - Find all doublets (layer eff>99.5%)
  - 8^{th} layer (44 fibers/H sector) used as anchor (reference) layer.
  - Uses 8 out of 8 layers low p_T, and 7 out of 8 for highest p_T bin..
  - VHDL to implement tracking logic 8 of 8,example: T101317222732394 5 = A[10] AND B[13] AND C[17] AND D[22] AND E[27] AND F[32] AND G[39] AND H[45]
- Equations sorted into 4p_T threshold bins 10,5,3, and 1.5 GeV
  - 1.5 to 3 GeV have 50% of the track equations!

Offline Tracking Performance

- p_T resolution vs. rapidity:
  $\delta p_T/p_T$=8% for p_T = 45 GeV at η=0
- Important addition to DØ physics capabilities:
  - *E/p* matching for electron identification
  - Muon momentum resolution
  - Charge sign determination
  - Calorimeter calibration
- 2-d (*r*-ϕ) impact parameter resolution vs. pseudorapidity
  - Enables b-quark tagging





Outlook

- Run II will start in about 1 week. Proton beam scheduled for March 1st.
- Fiber tracker is mechanically completed including installation of light-guides.
- Optical readout system thoroughfully commissioned.
- Front-End electronics needs to be completed yet.
- DØ's Central Fiber Tracker will provide a high resolution and high granularity tracking system capable of issuing a fast trigger decision and precise track reconstruction.
- There will be lots of high precision data to come in Run II.