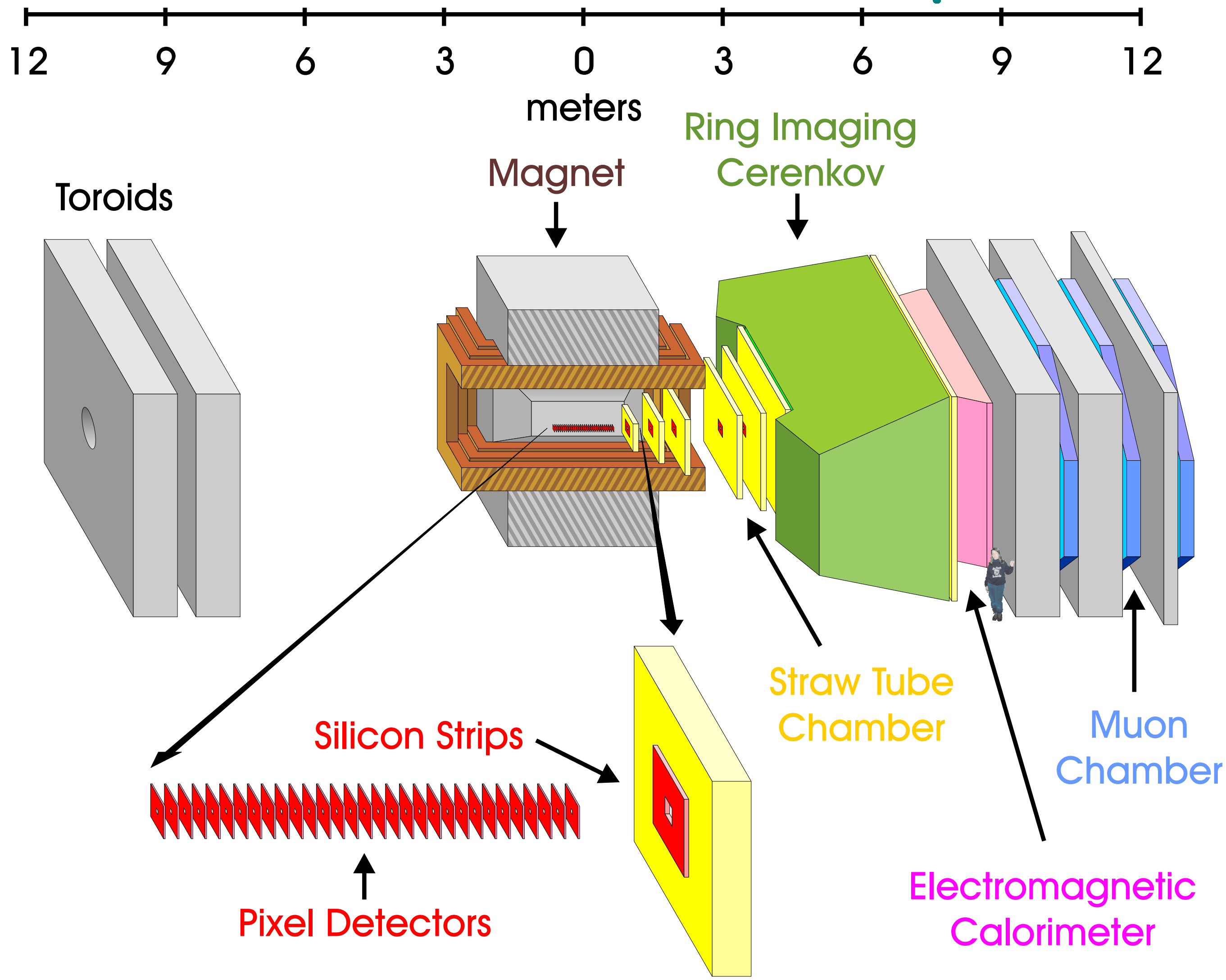
BTeV Detector Update



David Cinabro
Wayne State University
Beauty 2003, 15 October

BTeV Update

I Latest News: Strong Endorsement from P5 and HEPAP!

II BTeV Design Drivers

- A $p\bar{p}$ Heavy Flavor Production
- B B Decay Characteristics
- C TeVatron Environment

III Detector Components

- A Vertex Magnet
- B Pixel Detector
- C Silicon and Straws
- D RICH
- E $PbWO_4$ (PWO) EM Calorimeter
- F Muon System

IV Notes on Schedules and Plans

V Summary

NOTE: Trigger covered by Mike Wang tomorrow, Physics by Brad Cox on Saturday.

Strong Endorsement from P5 and HEPAP!

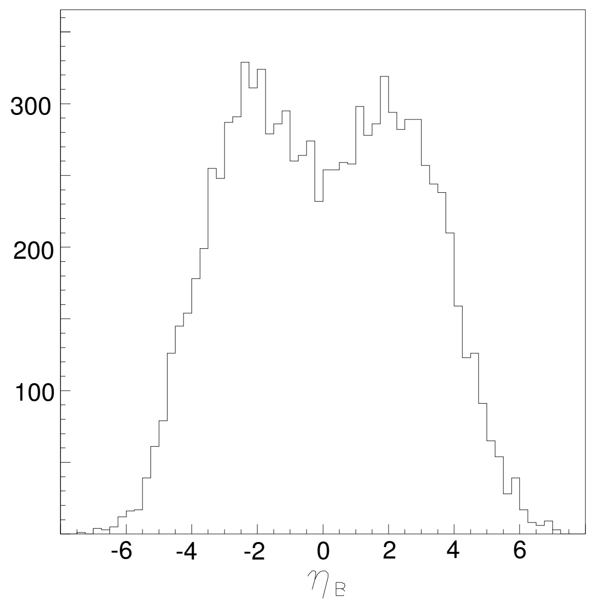
Quoting from P5 Draft Report, posted by HEPAP on 1 October 2003:

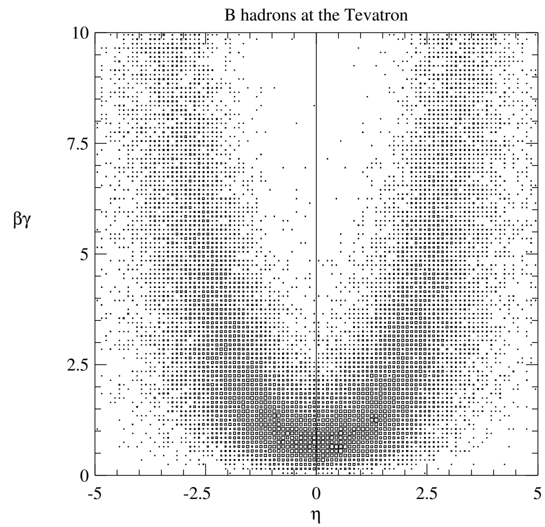
> *P5 supports the construction of BTeV as an important project in the world-wide quark flavor physics area. Subject to constraints within the HEP budget, we strongly recommend an earlier BTeV construction profile, and enhanced C0 optics.*

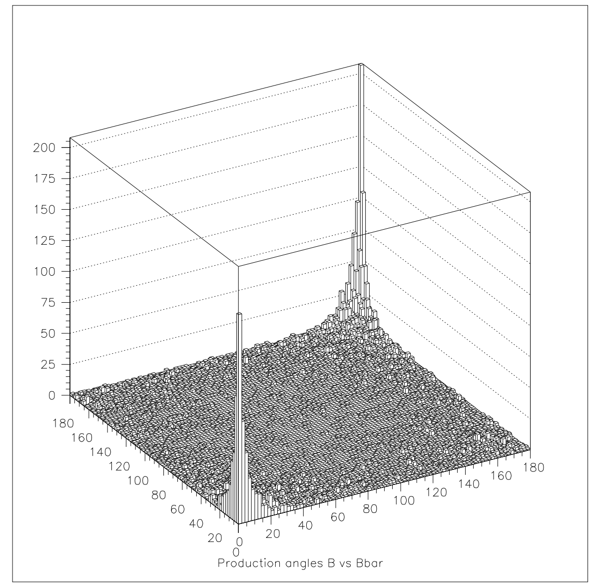
Speaks for itself. Strongest endorsement yet of BTeV beyond Fermilab. My thoughts on what this means at the end.

Design Driver: $p\bar{p}$ Heavy Flavor Production

Primary production mechanism is gluon-gluon fusion implying:







Production is flat out to large rapidity, large rapidity corresponds to high momentum B's, and large fraction of B and $\bar{B}$ correlated production is collinear. These imply that a detector with a single arm in the forward direction has good acceptance for fast, co-produced B-$\bar{B}$.

B cross section is 1/500 of total. See BTeV Trigger talk by Mike Wang tomorrow.

BTEV/CO

Design Driver: B Decay Characteristics

Decay Mode	Detector Property				
	Vertex Trigger	K/π Separation	γ Detection	Superb τ Resolution	Lepton ID
$B^0 \to \rho\pi \to \pi^+\pi^-\pi^0$	$\surd$	$\surd$	$\surd$		
$B_s \to D_s K^-$	$\surd$	$\surd$		$\surd$	
$B^+ \to D^0 K^+$	$\surd$	$\surd$			
$B^0 \to K\pi$	$\surd$	$\surd$	$\surd$		
$B \to \pi^+\pi^-, B_s \to K^+K^-$	$\surd$	$\surd$		$\surd$	
$B_s \to J/\psi\eta', J/\psi\eta$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$
$B^0 \to J/\psi K_s$					$\surd$
$B_s \to \phi K_s, \eta' K_s, J/\psi\phi$	$\surd$	$\surd$	$\surd$		$\surd$
$B^0 \to J/\psi K^*, B_s \to J/\psi\phi$					$\surd$
$B_s \to D_s\pi^-$	$\surd$	$\surd$		$\surd$	
$B_s \to J/\psi\eta', K^+K^-, D_s\pi^-$	$\surd$	$\surd$	$\surd$		$\surd$

Not comprehensive, but focuses on CP-Violation in B Decay. All capabilities needed for flavor tagging the other B. Implies a general purpose detector with wide ranging capabilities.

Design Driver: TeVatron Environment

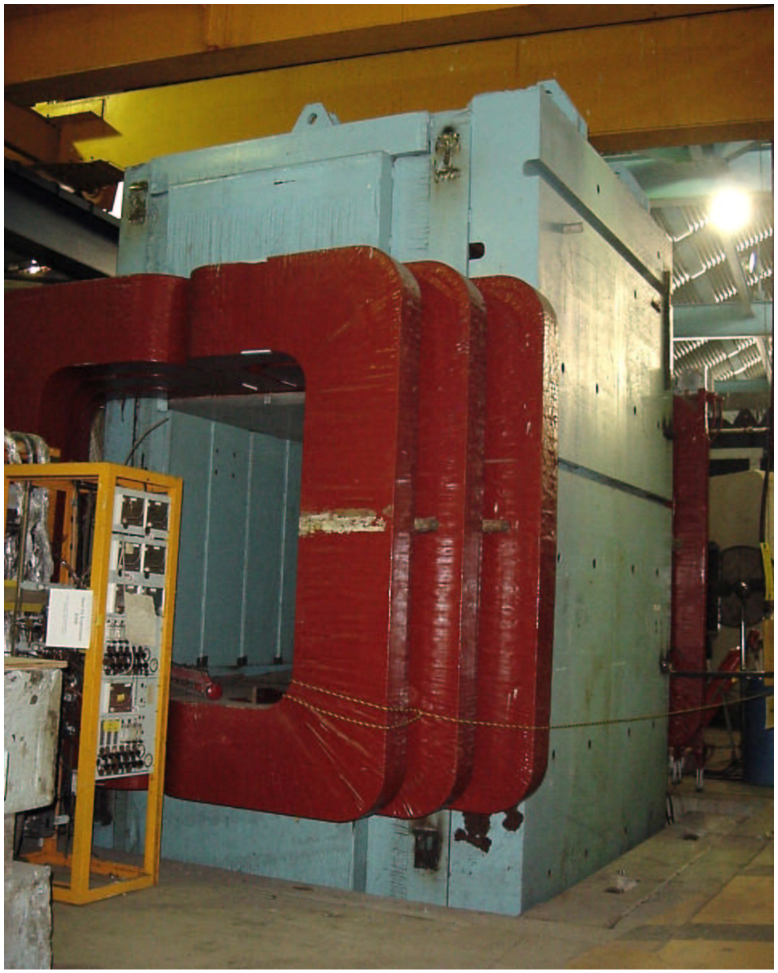
Characteristics of the TeVatron and our assumptions about cross sections, etc. define an environment that has implications for the detector:

Luminosity	$2 \times 10^{32}\text{cm}^{-2}\text{sec}^{-1}$
$b\bar{b}$ Cross Section	100 μb
b's in 10^7 sec	4×10^{11}
$\sigma(b\bar{b})/\sigma(\text{Total})$	$\sim 0.15\%$
$\sigma(c\bar{c})$	$> 500\mu$b
Bunch Spacing	132 ns
Length of Luminous Region	10-20 cm
Transverse Width of Luminous Region	$\sigma_x \approx \sigma_y \approx 50\mu$m
Interactions/crossing	$< 2.0 >$

Assumptions are conservative. Designed to handle up to double this luminosity. TeVatron now runs with a bunch spacing of 396 ns. This is not likely to change and Interactions/crossing would go to 6.0 at start of run and $< 3-4 >$, and our design assumes this.

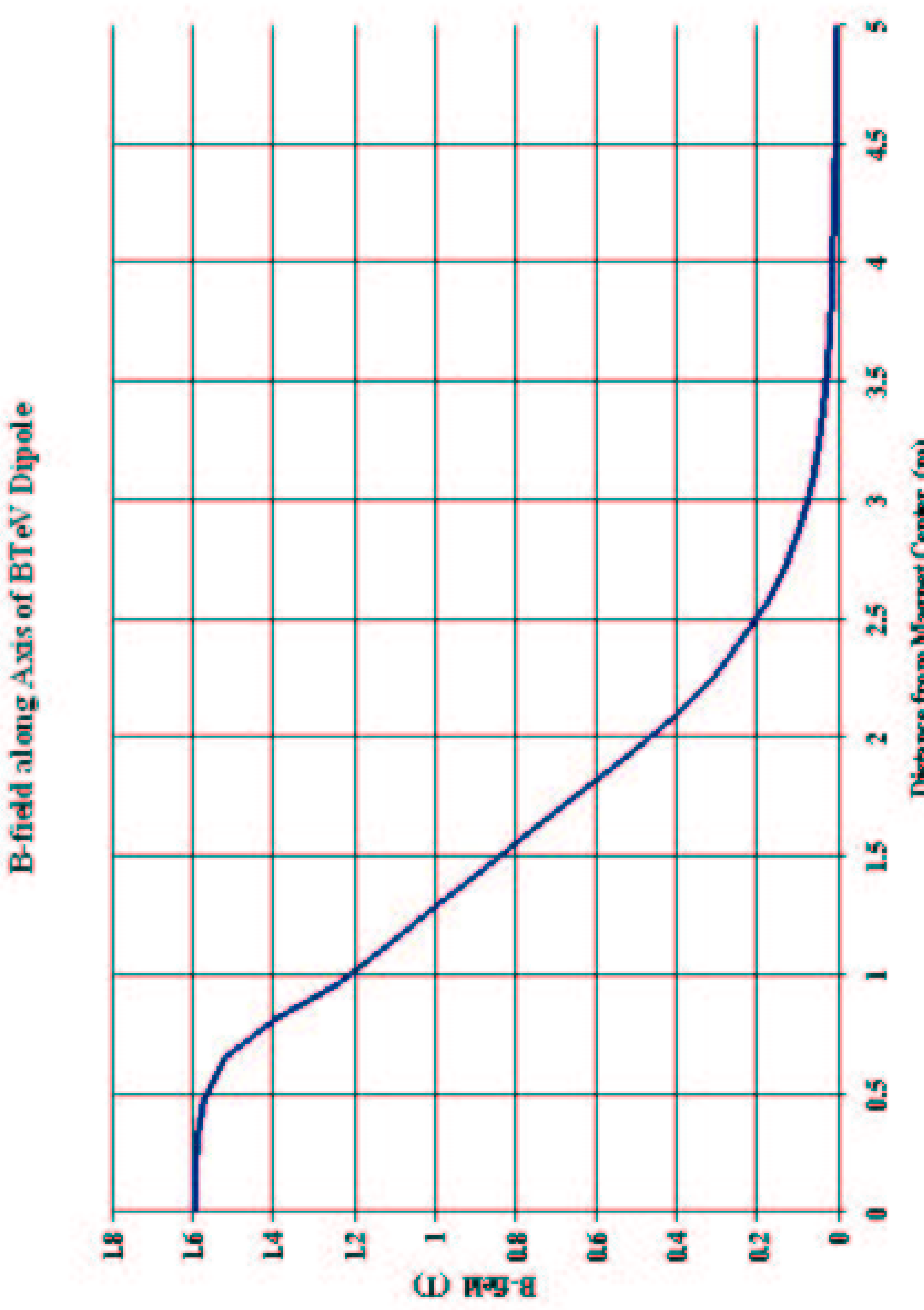
The size of the C0 hall is a physical limitation which has some impact on the muon system.

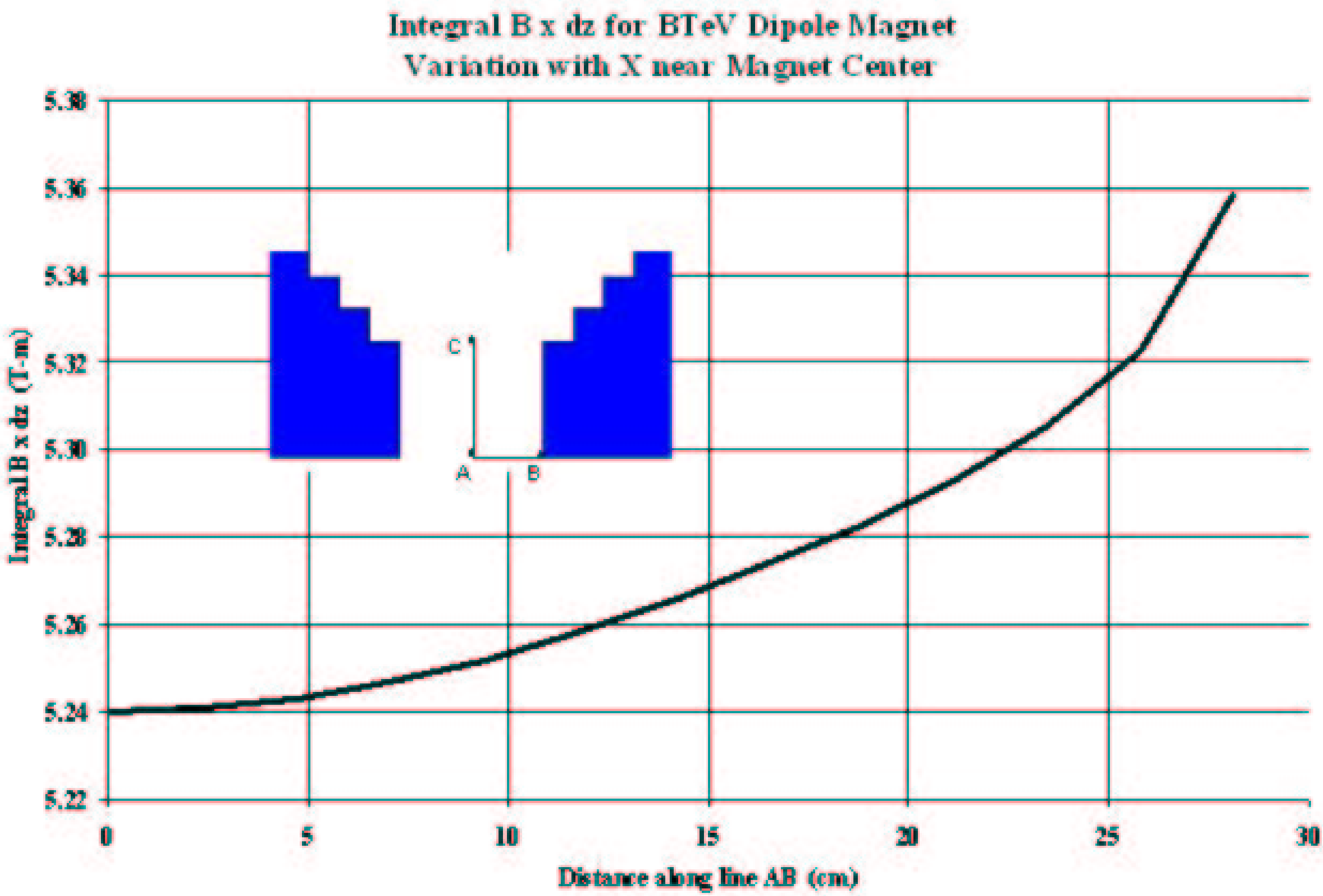
Vertex Magnet

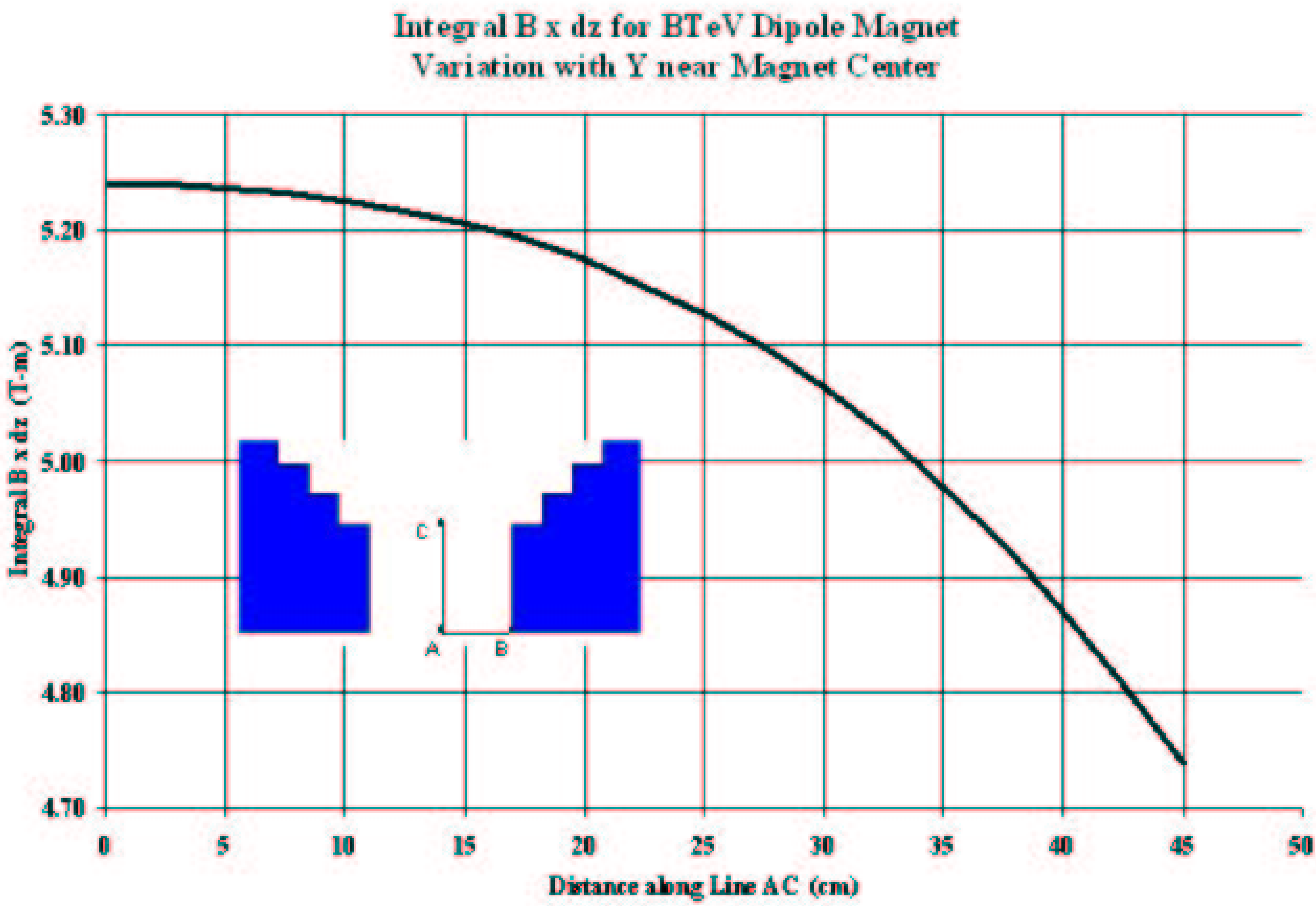


Existing SM3 magnet:

- Design complete for new pole inserts
- Central Field of 1.6 T, integrated 5.2 T-m, 1.5 GeV kick
- Vertical deflection compensated by dipoles at ends of collision hall
- Field uniform to 1% in region of pixel detector
- 500 metric tons

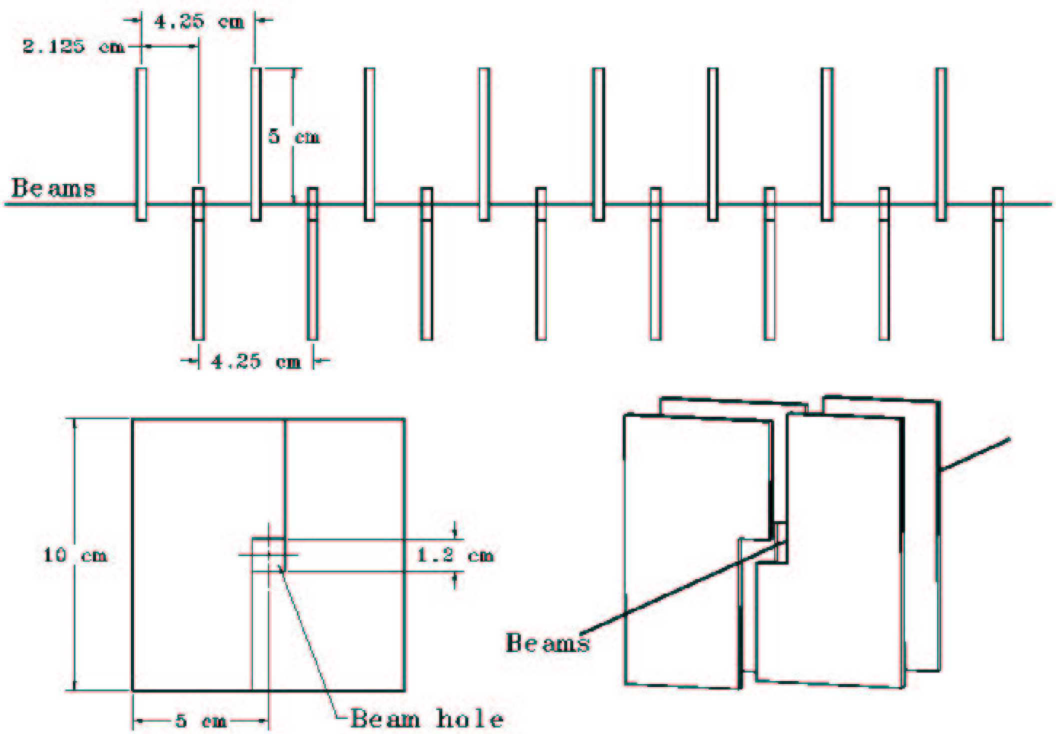

B-field along Axis of BTeV Dipole
B-field (T)
Distance from Magnet Center (m)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Integral B x dz for BTeV Dipole Magnet
Variation with X near Magnet Center
5.38
5.36
5.34
5.32
5.30
5.28
5.26
5.24
5.22
Integral B x dz (T-m)
C
A
B
0
5
10
15
20
25
30
Distance along line AB (cm)



Integral B x dz for BTeV Dipole Magnet
Variation with Y near Magnet Center
Integral B x dz (T-m)
5.30
5.20
5.10
5.00
4.90
4.80
4.70
0
5
10
15
20
25
30
35
40
45
50
Distance along Line AC (cm)
C
A
B

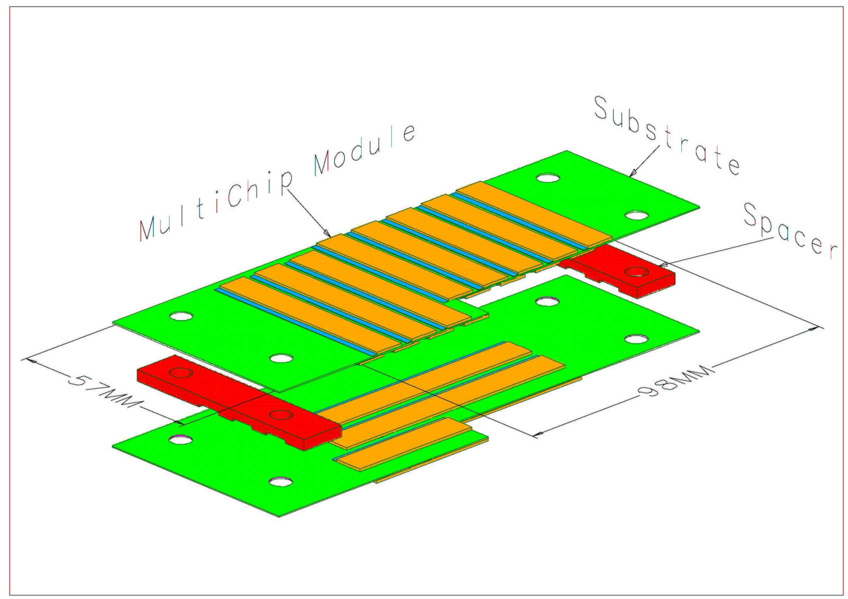
Pixel Detector General



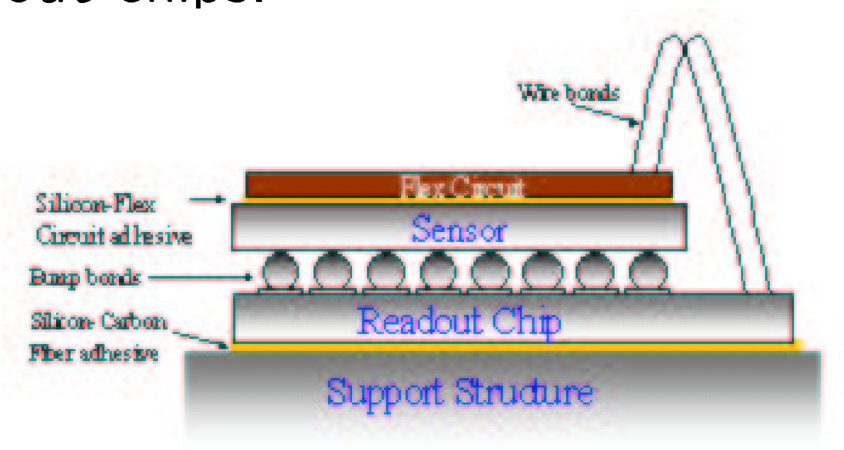
- Key sub-detector
- Feeds vertex trigger
- In beam vacuum to get close and get best possible resolution
- 30 Stations, 23 million pixels
- In dipole field; measures momentum
- Runs at -5°C to minimize radiation damage

Pixel Detector Sensor

Grouped into Multi-Chip Modules (MCM) which are formed into half stations:



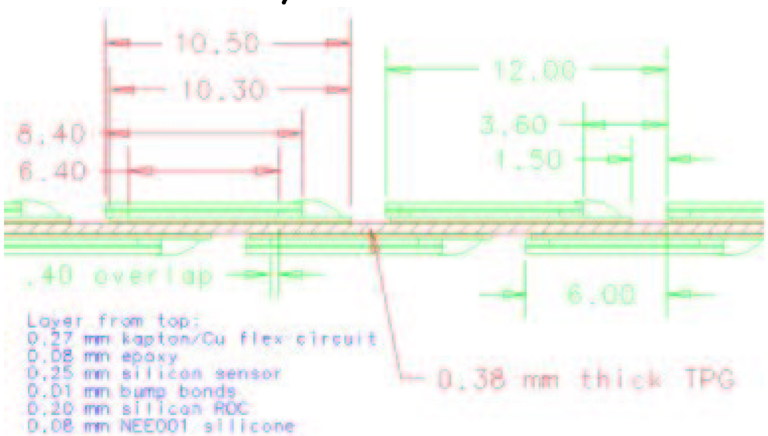
Sensors bump bonded to read-out chips:

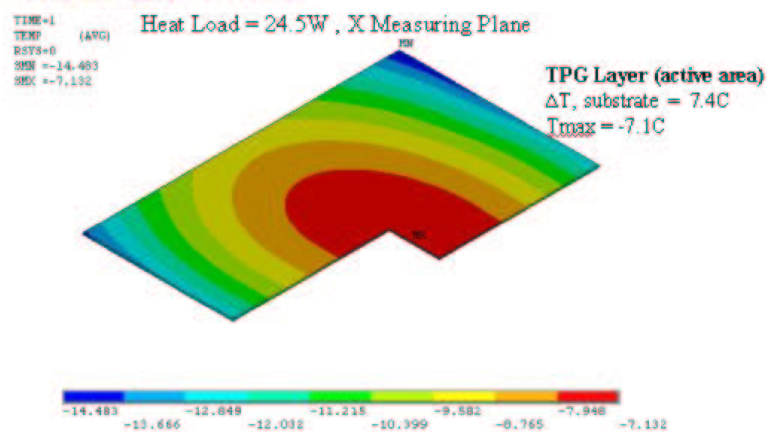


Two sets of Modules on each half station to minimize dead area.

Pixel Detector Substrate and Mechanics

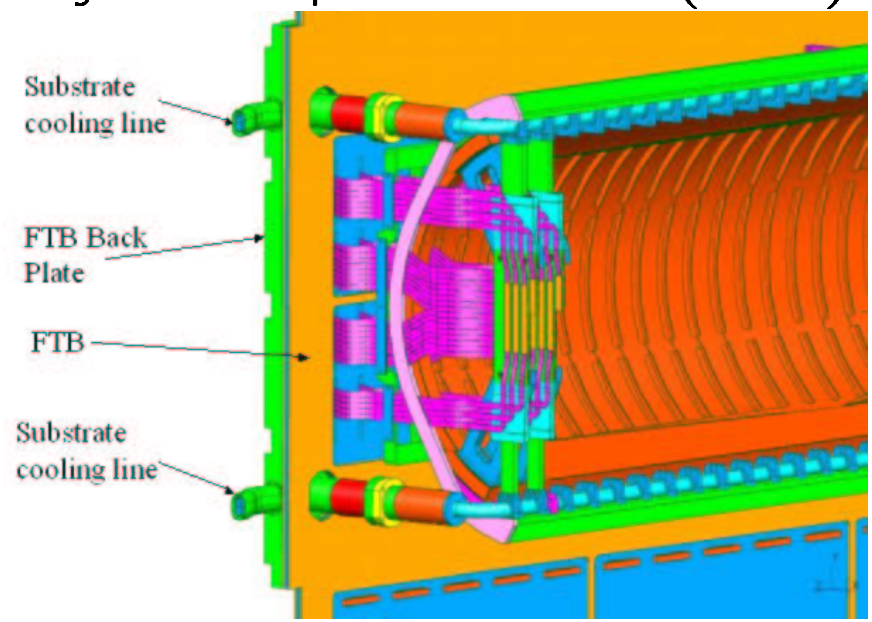
Substrate is Thermal Pyrolytic Graphite (TPG), which has Thermal Conductivity of ~ 2000 W/K-m:





Each station has $\chi/\chi_0 = 1.3\%$.

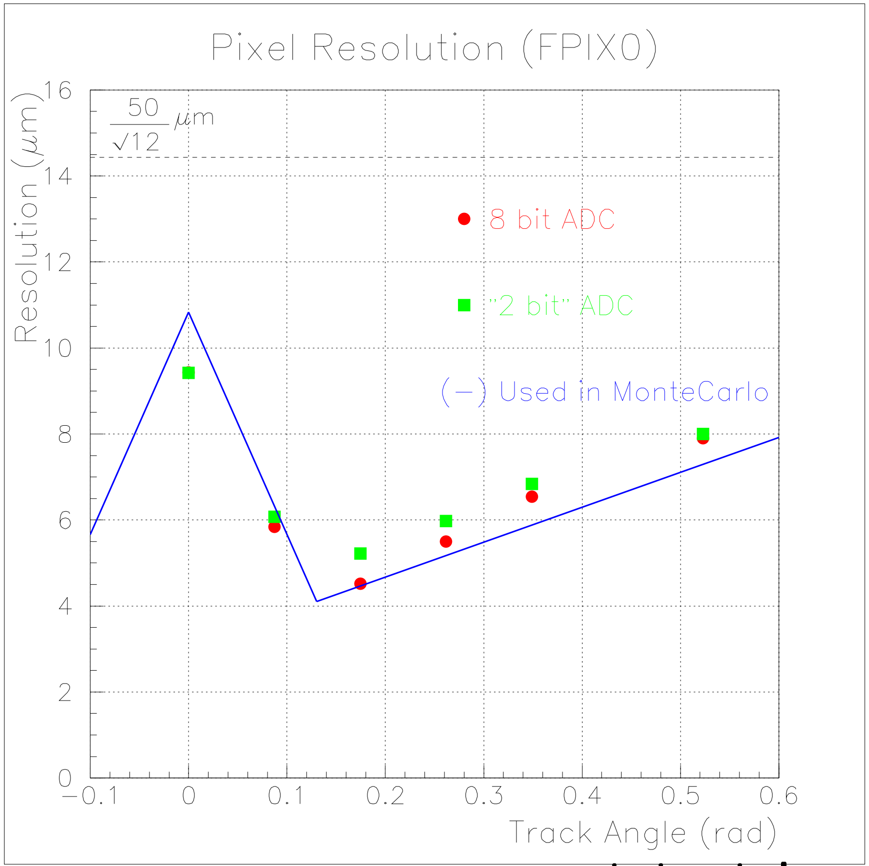
Connection via flex circuits to feed-through boards. Connection to liquid nitrogen coolant line by Pyrolytic Graphite Sheet (PGS).



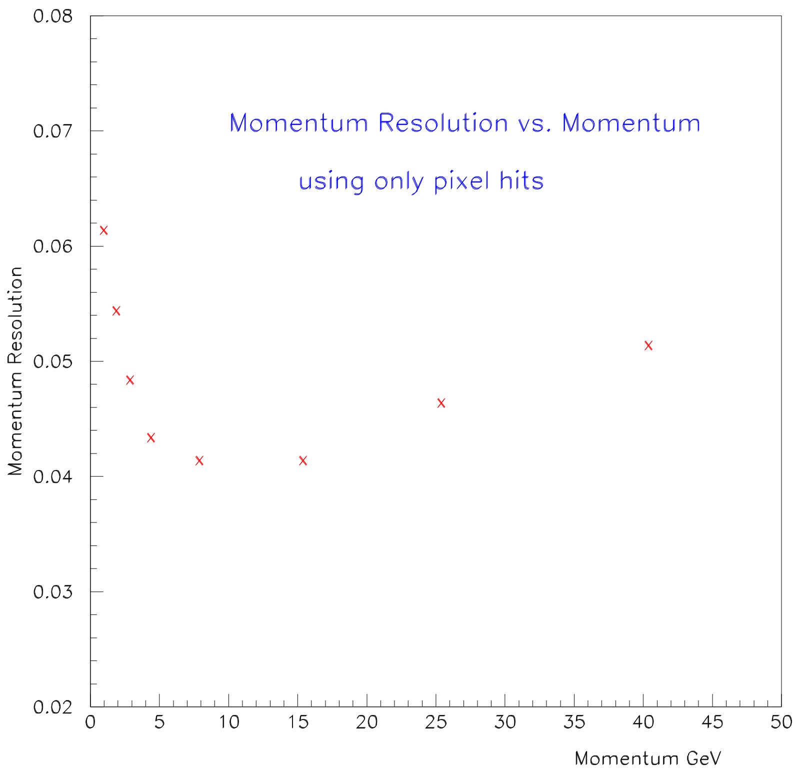
Whole side of detector moves away from beam during injection via mechanical actuator.

Pixel Detector Resolution

Spatial resolution from prototypes in testbeam:



Momentum resolution $(\delta p/p)$ from simulations:



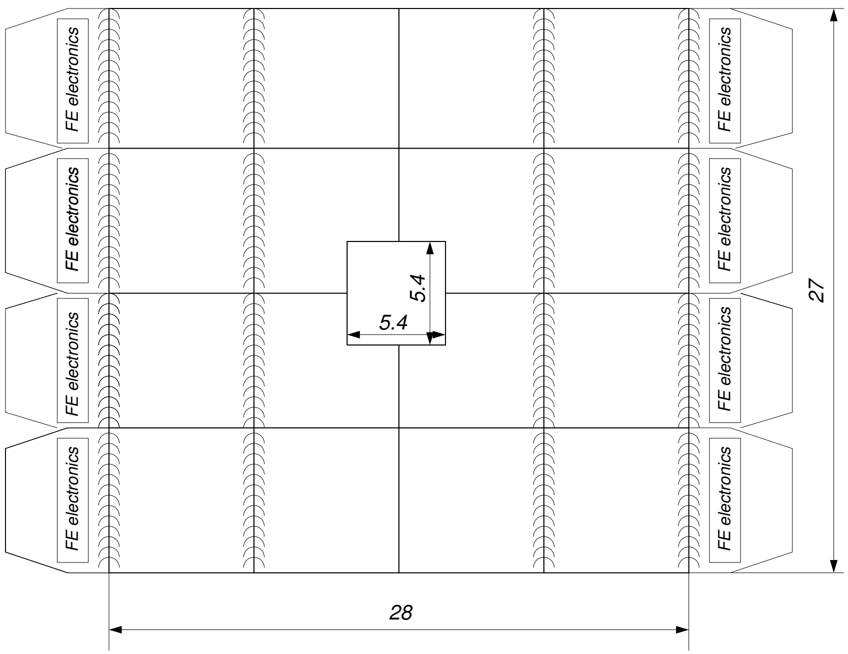
Both are vital for input to trigger simulation.

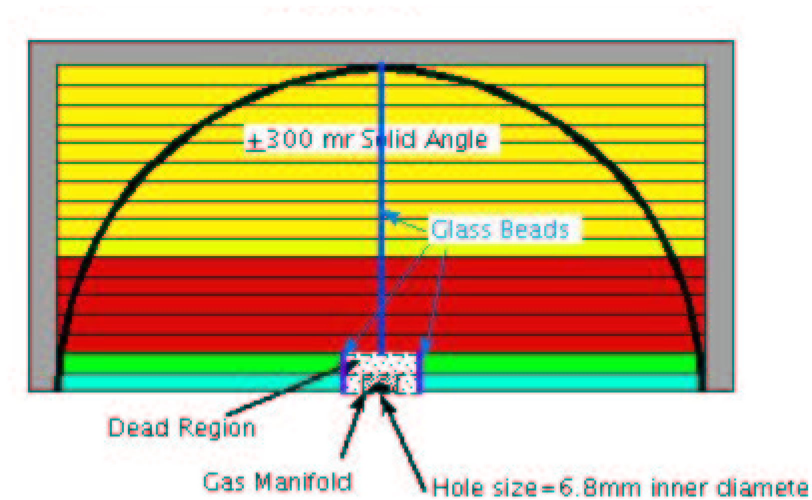
Pixel Ongoing R&D

- Test beam results on 2 and 5 chip MCM
- Running chips at cryogenic temperatures
- Effect on TeVatron vacuum. Cryopumping.
- RF and other EM effects.
- Systems issues. 10% Prototype.
- Assembly and Installation

Silicon and Straws

Seven planes, three in vertex magnet, silicon strips close to beam pipe, straws outside.





Improves momentum and connects pixel tracks to downstream detectors. Occupancy and radiation hardness are the major challenges.

Silicon and Straws Ongoing R&D

- Development of rad hard silicon readout chip (FSSR)

- Prototype silicon performance

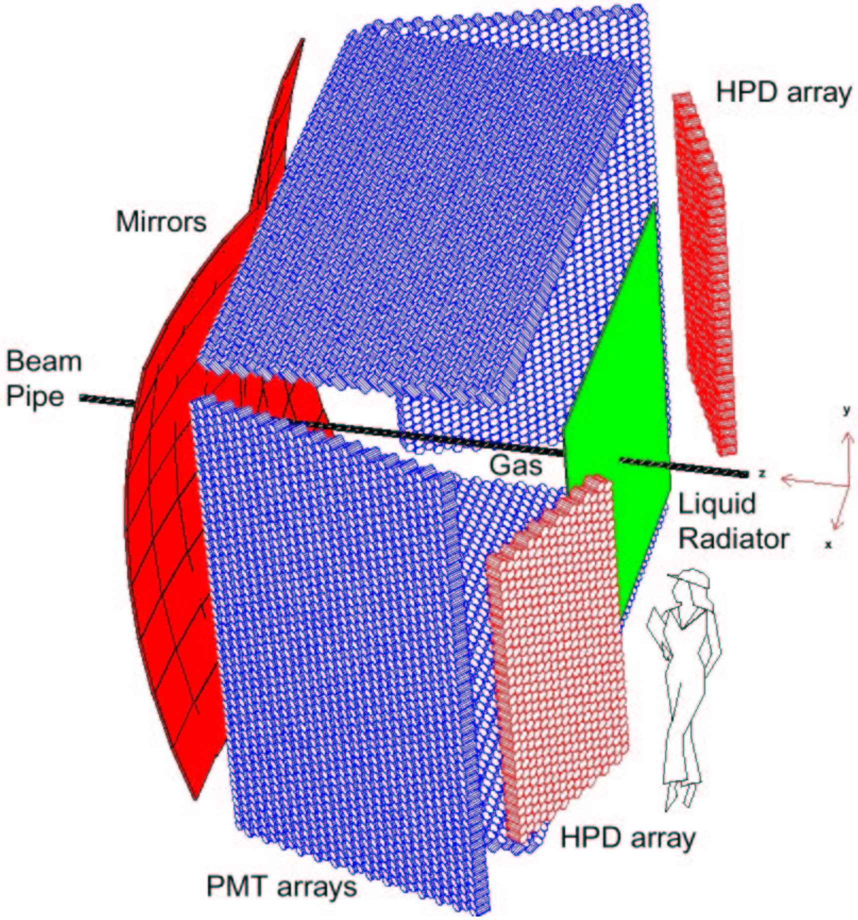
- Studies of copper coated straws to reduce gas permeability

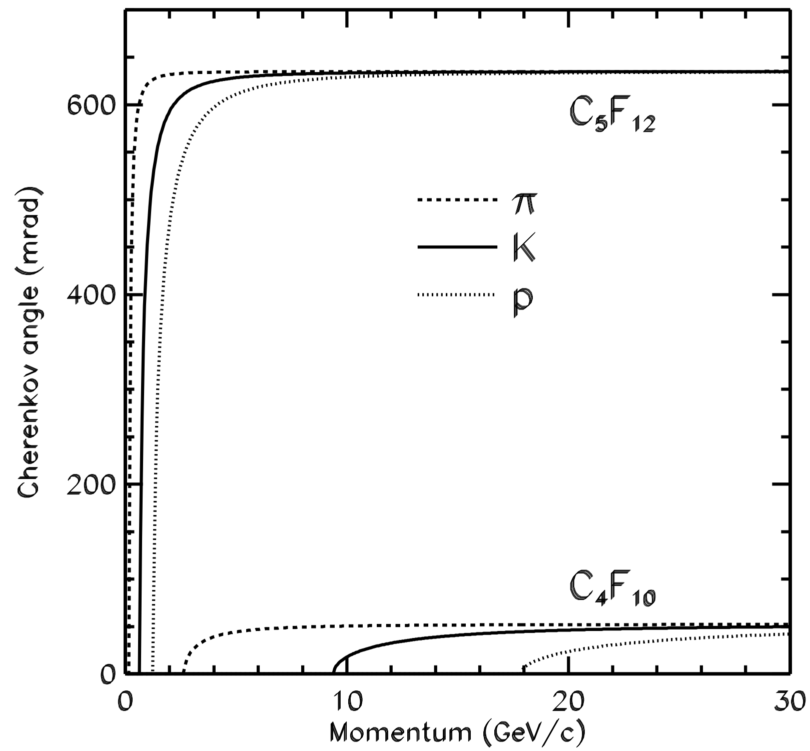
- Gas choice. Kapton, better rad hardness than mylar, but stretches with ethanol. $ArCO_2$ mixtures under study. Aging carefully studied.

- Glass capillary to divide wires.

RICH

Two part system with a liquid (C_5F_{12}, $n = 1.24$) radiator for low momentum, and gas (C_4F_{10}, $n = 1.00138$) for high momentum. Low momentum is very beneficial for flavor tagging.

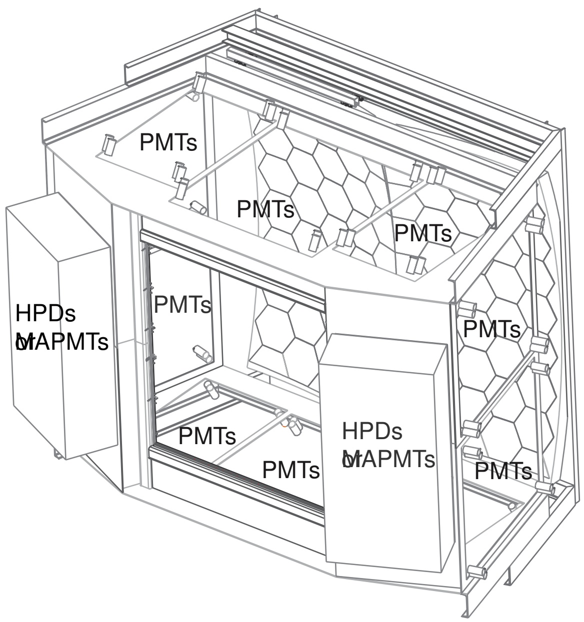


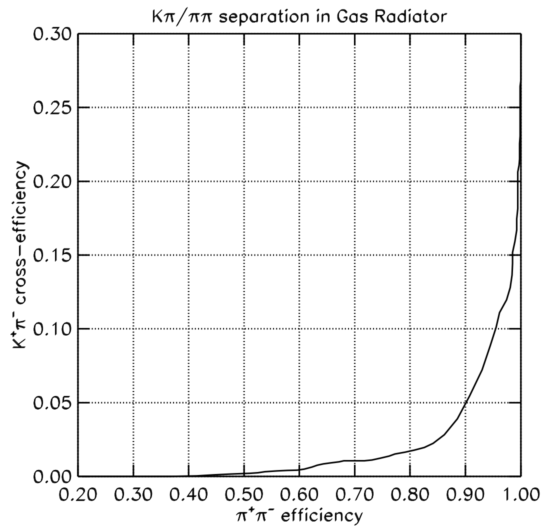


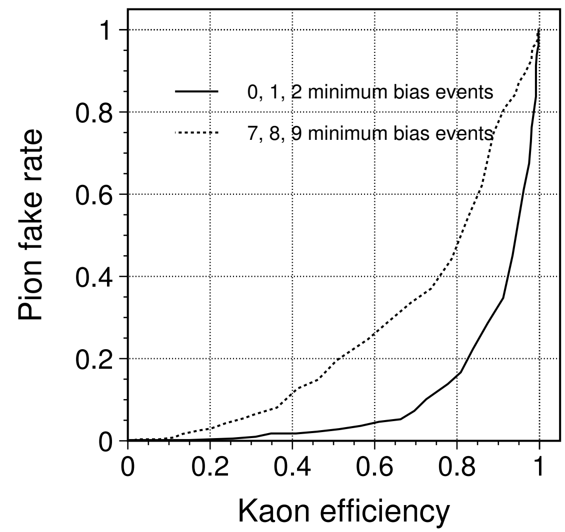
Cerenkov photons from the liquid directly to the side and detected with PMT's; from gas bounce off mirrors and detected with HPD or MAPMT.

RICH Performance

The detector has been extensively simulated based on R&D results on mirrors, photon detectors, engineering plans, and backgrounds:







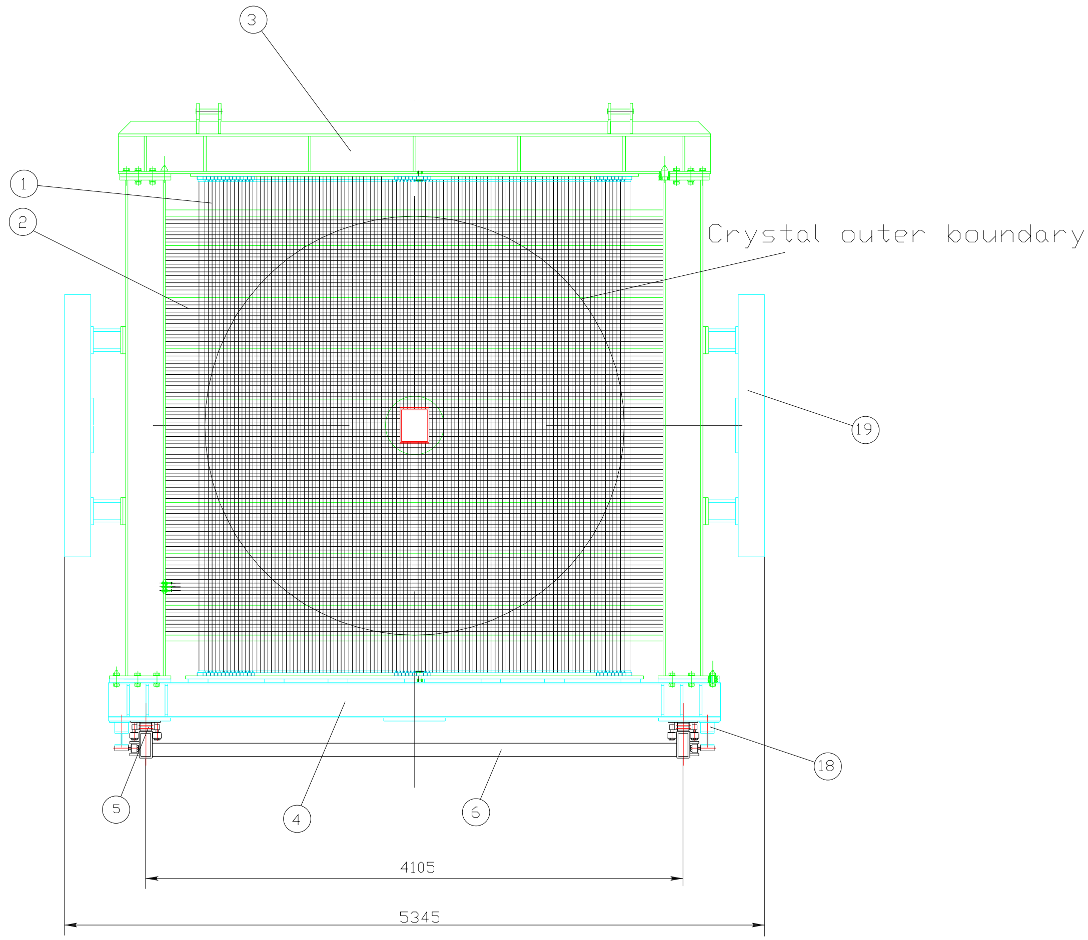
Large number of interactions/crossing noticeably degrades performance (loss of 25% at $< 8.0 >$, expect $< 3.5 >$). Taken into account when assessing physics reach.

RICH Ongoing R&D

- Beam test of photodetectors and liquid radiator
- Carbon Fiber mirrors
- Alignment
- Plans for component quality assurance
- Choice between HPD and MAPMT

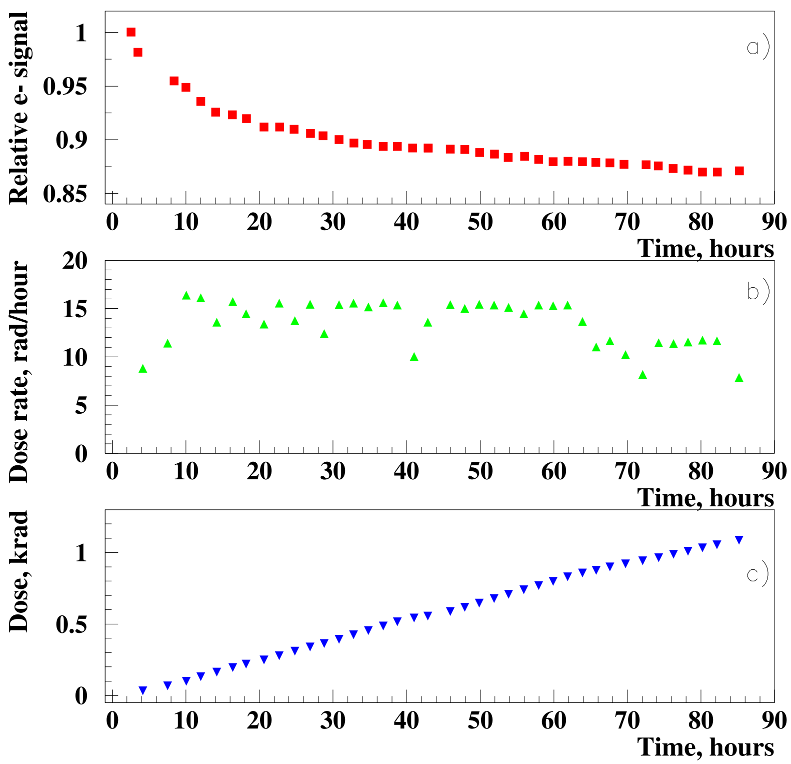
PWO EM Calorimeter

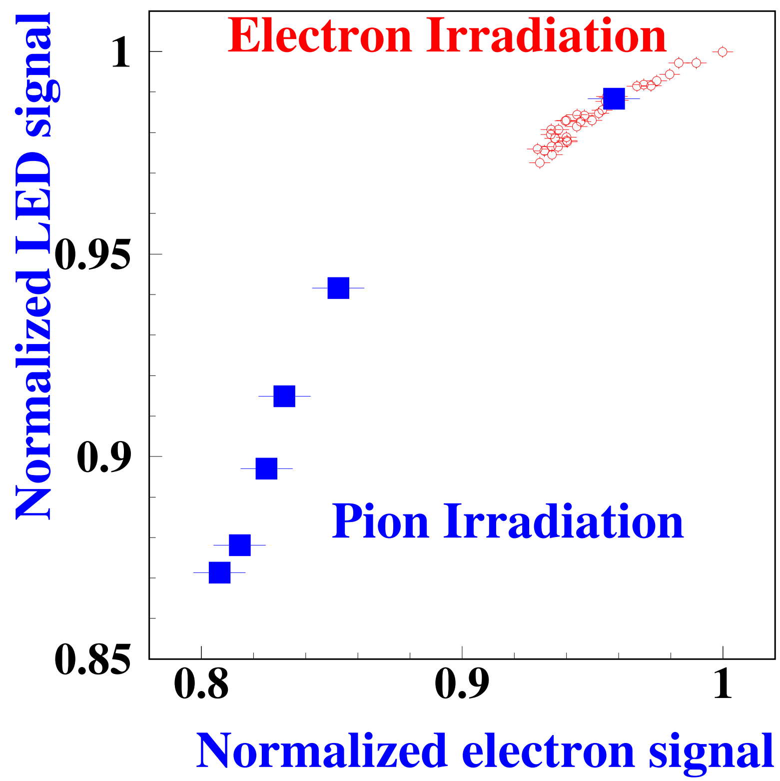
- Unique feature.
- 10,000, 2.8x2.8x22cm tapering PWO Crystals
- PMT readout since beyond vertex magnet field
- Crystals supported by frame with lattice of 0.3mm thick Al strips
- Crystals taper and point off vertex to minimize dead material



PWO EM Calorimeter Radiation Hardness

Extensive studies of the radiation hardness for many PWO sources

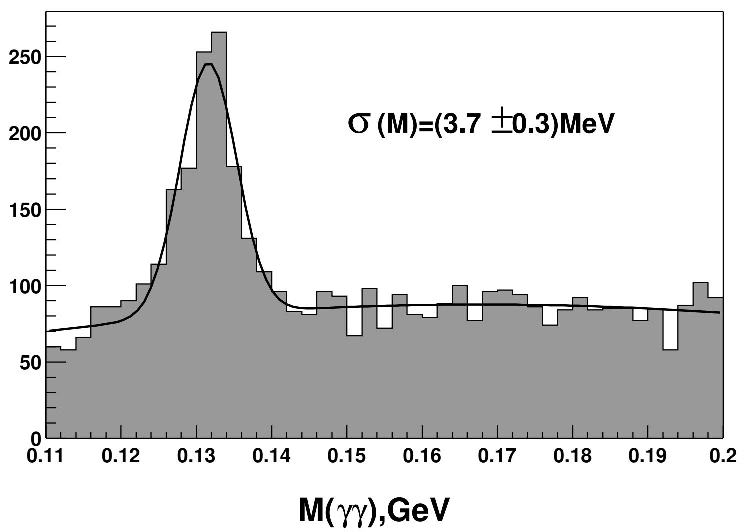


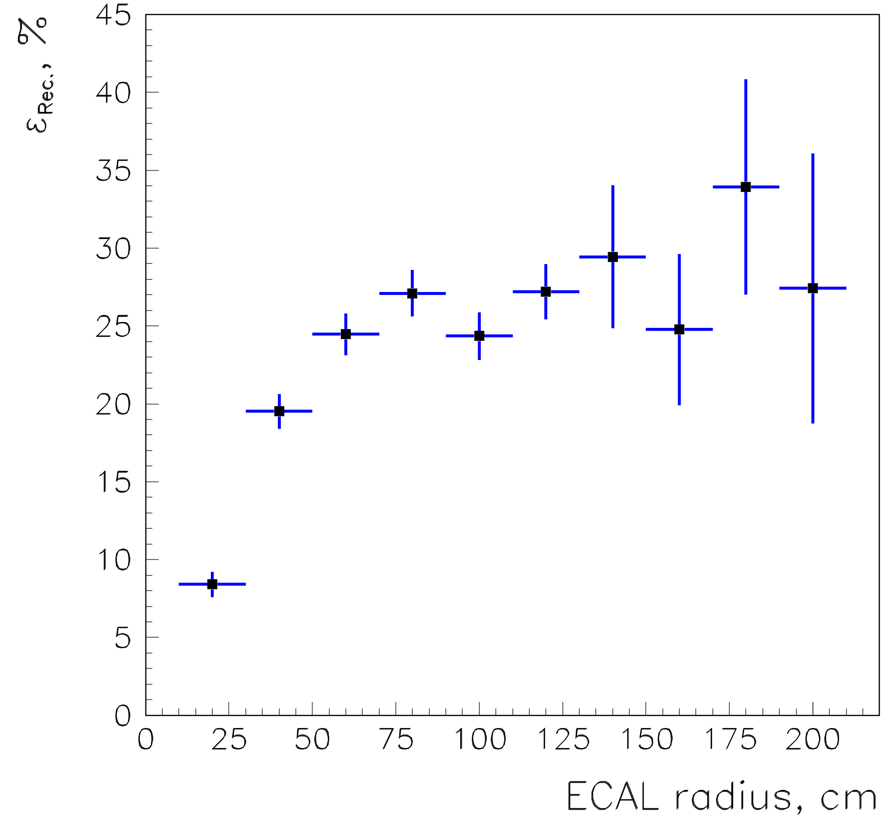


Leads to strict requirements and testing regime for crystals and a rigorous calibration and monitoring light pulsar system.

PWO EM Calorimeter Performance

Simulation of $B \rightarrow \rho^{+}\pi^{-}$ based on observed crystal energy resolution and variation plus expected backgrounds:





Performance is excellent allowing analysis of the $B \rightarrow \pi\pi\pi$ Dalitz plots.

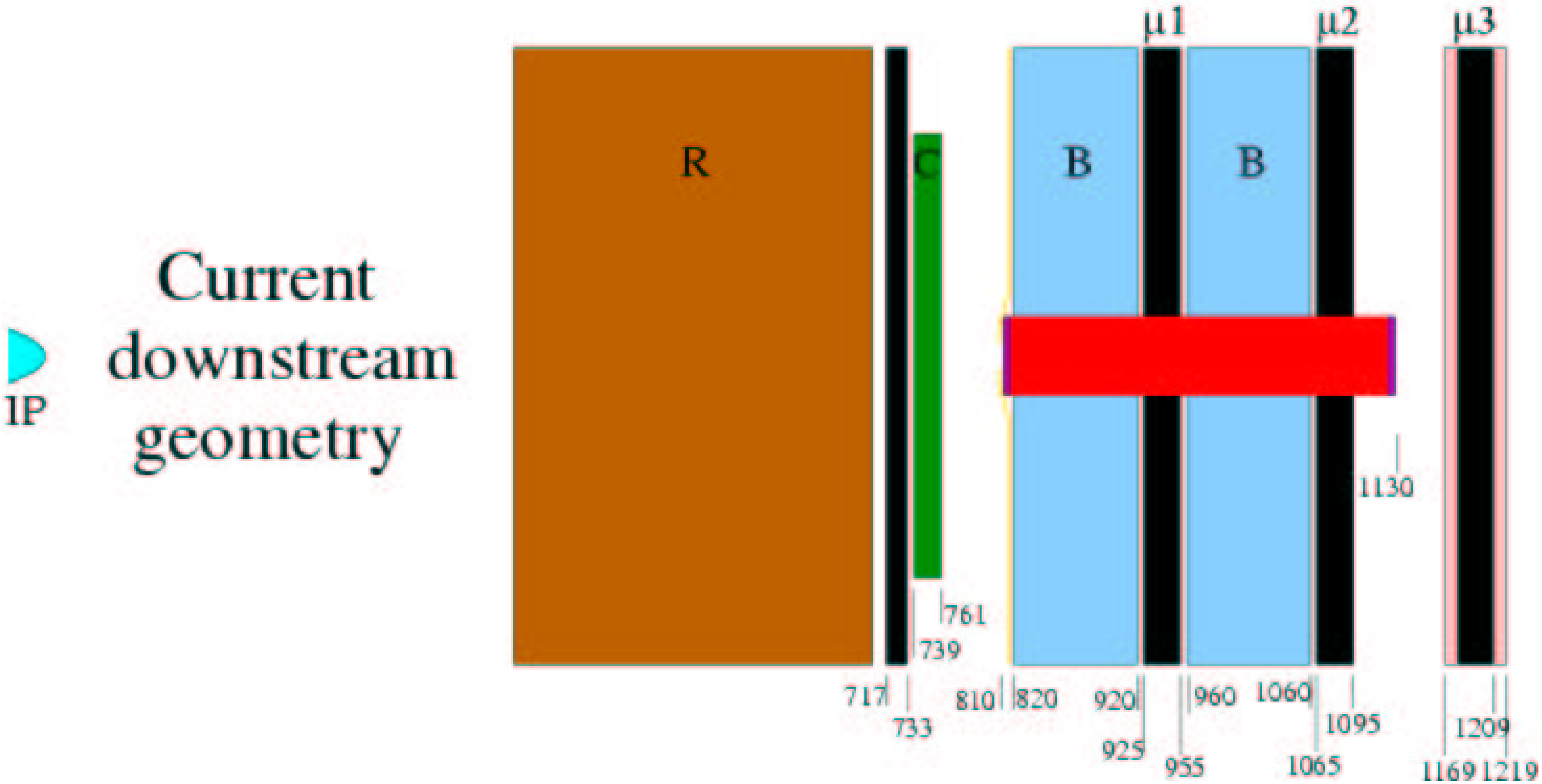
EM Calorimeter Ongoing R&D

- More testbeam radiation studies
- Quality assurance studies
- LED calibration and monitoring system

BTEV/Co

Muon System

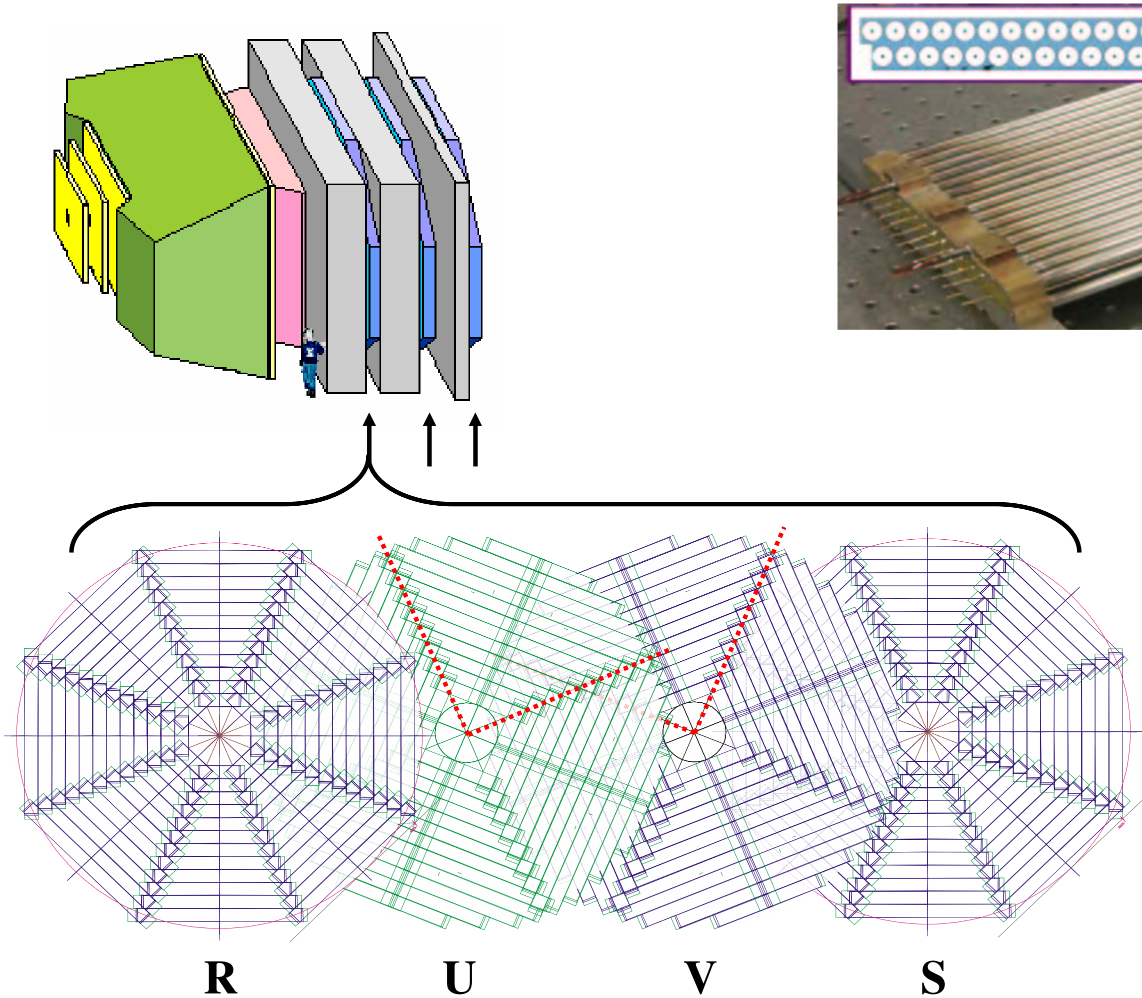
Two toroids and three Ar-CO_2 proportional tube tracking stations. Measures muon momentum to give a muon trigger:

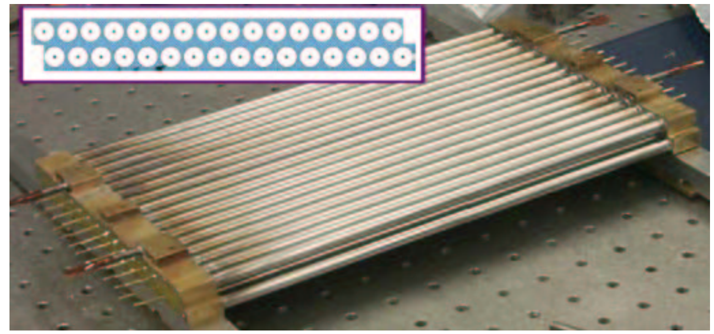


Compensating dipoles within muon system. Uninstrumented arm also has toroids and compensating dipoles.

Muon System Modules

Building block is a two layer plank, that is formed into a four layer octant:





37,000 channels and gives momentum resolution = $(19 \oplus 0.6p)\%$ based on beam test measurements.

Muon System Ongoing R&D

- Testbeam with production planks
- High radiation dose lifetime tests
- Front end electronics
- Mechanical octant test
- Mass production
- Gas System prototype
- In situ background measurement

Plans and Schedule

- Undergoing our second Temple review next week. This talk based on our TDR being prepared for this review.
- Expect a Lehman review in December.
- Should lead to swift approval which would imply start of construction in late 2004.
- TDR assumes 5 year construction period.
- P5 report could imply speed up of this plan.
- Start of experiment probably in mid-2009.

Summary

- Since 1 October, the happiest collaboration in the world
- A complete TDR; no large technical hurdles
- Two reviews to pass before the end of the year
- We are eager and ready to begin construction next year
- Will lead to a running experiment in 2009

Detector Performance Summary

Angular Acceptance	10-300 mrad
Charged Particle Momentum Acceptance	$>$ 3 GeV
Mass Resolution (all charged B decay)	$<$ 50 MeV
Tracking Efficiency	$>$ 98%
Primary Vertex Resolution	10 μm
Proper Time Resolution	$<$ 50 fs
Trigger Efficiency (vertexable B decay)	$>$ 50%
Trigger Efficiency (single prong B decay)	$>$ 20%
Rejection of Light Quark Events	$>$ 99.8%
Data Rate	$<$ 200 Mbytes/sec
$K-\pi$ Separation (3-70 GeV)	$> 4\sigma$
$p-K$ Separation (3-70 GeV)	$> 4\sigma$
EM Resolution	$< 2\%/\sqrt{E}$
EM Energy Range	$>$ 1 GeV
EM Acceptance	10-200 mrad
Muon ID	5-100 GeV
Muon mis-ID	$<$ 0.1%
Muon Momentum Resolution	$< 20 \oplus 0.6p\%$
Time Response	100 ns
Radiation Hardness	$>$ 10 years