Status of BTeV

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Fermilab PAC Presentation
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OUTLINE

- Brief Overview of BTeV
- The BTeV R&D program
- Test Beam Preparation
- Running with 396ns BCO
- BTeV Cost Estimate

BTeV

Origins: Fnal FT CLEO Hera/HeraB

Massive expertise in pixels, trigger, electronics, tracking, crystal calorimetery, RICH, & Muon detection

Belarussian State- D .Drobychev, A. Lobko, A. Lopatrik, R. Zouversky

UC Davis - P. Yager

Univ. of Colorado-J. Cumalat, P. Rankin, K. Stenson

Fermi National Lab

J. Appel, E. Barsotti, C. N. Brown , J. Butler, H. Cheung, D. Christian, S. Cihangir, I. Gaines, P. Garbincius, L. Garren, E. Gottschalk, G. Jackson, A. Hahn, P. Kasper, P. Kasper, R. Kutschke, S. Kwan, P. Lebrun, P. McBride, J. Slaughter, M. Votava, M. Wang, J. Yarba

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P. Avery

University of Houston

A. Daniel, K. Lau, M. Ispiryan, B. W. Mayes, V. Rodriguez, S. Subramania, G. Xu

Illinois Institute of Technology

R. A. Burnstein, D. M. Kaplan, L. M. Lederman, H. A. Rubin, C. White

Univ. of Illinois- M. Haney, D. Kim, M. Selen, V. Simaitis, J. Wiss

Univ. of Insubria in Como-

P. Ratcliffe, M. Rovere

INFN - Frascati- M. Bertani, L. Benussi, S. Bianco, M. Caponero, F. Fabbri, F. Felli, M. Giardoni, A. La Monaca, E. Pace, M. Pallotta, A. Paolozzi

INFN - Milano - G. Alimonti, L. Edera, D. Lunesu, S. Magni, D. Menasce, L. Moroni, D. Pedrini, S.Sala, L. Uplegger

INFN - Pavia- G. Boca, G. Cosssali, G. Liguori, F.Manfredi, M. Manghisoni, M. Marengo, L. Ratti, V. Re, M. Santini, V. Speziali, P. Torre, G. Traversi

IHEP Protvino, Russia

A. Derevschikov, Y. Goncharenko, V. Khodyrev, V. Kravtsov, A. Meschanin, V. Mochalov, D. Morozov, L. Nogach, K. Shestermanov, L. Soloviev, A. Uzunian, A. Vasiliev

University of Iowa

C. Newsom, & R. Braunger

University of Minnesota

J. Hietala, Y. Kubota, B. Lang, R. Poling, & A. Smith

Nanjing Univ. (China)-

T. Y. Chen, D. Gao, S. Du, M. Qi, B. P. Zhang, Z. Xi Zhang, J. W. Zhao

Ohio State University-

K. Honscheid, & H. Kagan

Univ. of Pennsylvania

W. Selove

Univ. of Puerto Rico

A. Lopez, & W. Xiong

Univ. of Science & Tech. of China - G. Datao, L. Hao, Ge Jin, T. Yang, & X. Q. Yu

Shandong Univ. (China)-

C. F. Feng, Yu Fu, Mao He, J. Y. Li, L. Xue, N. Zhang, & X. Y. Zhang

Southern Methodist Univ - T. Coan, M. Hosack

SUNY Albany - M. Alam

Syracuse University

M. Artuso, S. Blusk, J. Butt, C. Boulahouache, O. Dorjkhaidav J. Haynes, N. Menaa, R. Mountain, N.Nadakumar, L. Redjimi, R. Sia, T. Skwarnicki, S. Stone, J. C. Wang, K. Zhang

Univ. of Tennessee -

T. Handler, R. Mitchell

Vanderbilt University -

W. Johns, P. Sheldon, E. Vaandering, & M. Webster

Univ. of Virginia: M. Arenton, S. Conetti, B. Cox, A. Ledovskoy, H. Powell, M. Ronquest, D. Smith, B. Stephens, Z. Zhe

Wayne State University

G. Bonvicini, D. Cinabro, A. Shreiner

University of Wisconsin

M. Sheaff

York University - S. Menary

Physics Goals

- Measure: CP violation in $B_{(uds)}$, B_s mixing, rare b decay rates, CP violation and rare decays in the charm sector.
- Look for rare/forbidden decays discover new physics.
- Measure Standard Model parameters precisely.
- Test for inconsistencies in the Standard Model: If found go beyond the SM and elucidate the new physics.
- If new physics found elsewhere, use b & c decays to help in its interpretation.

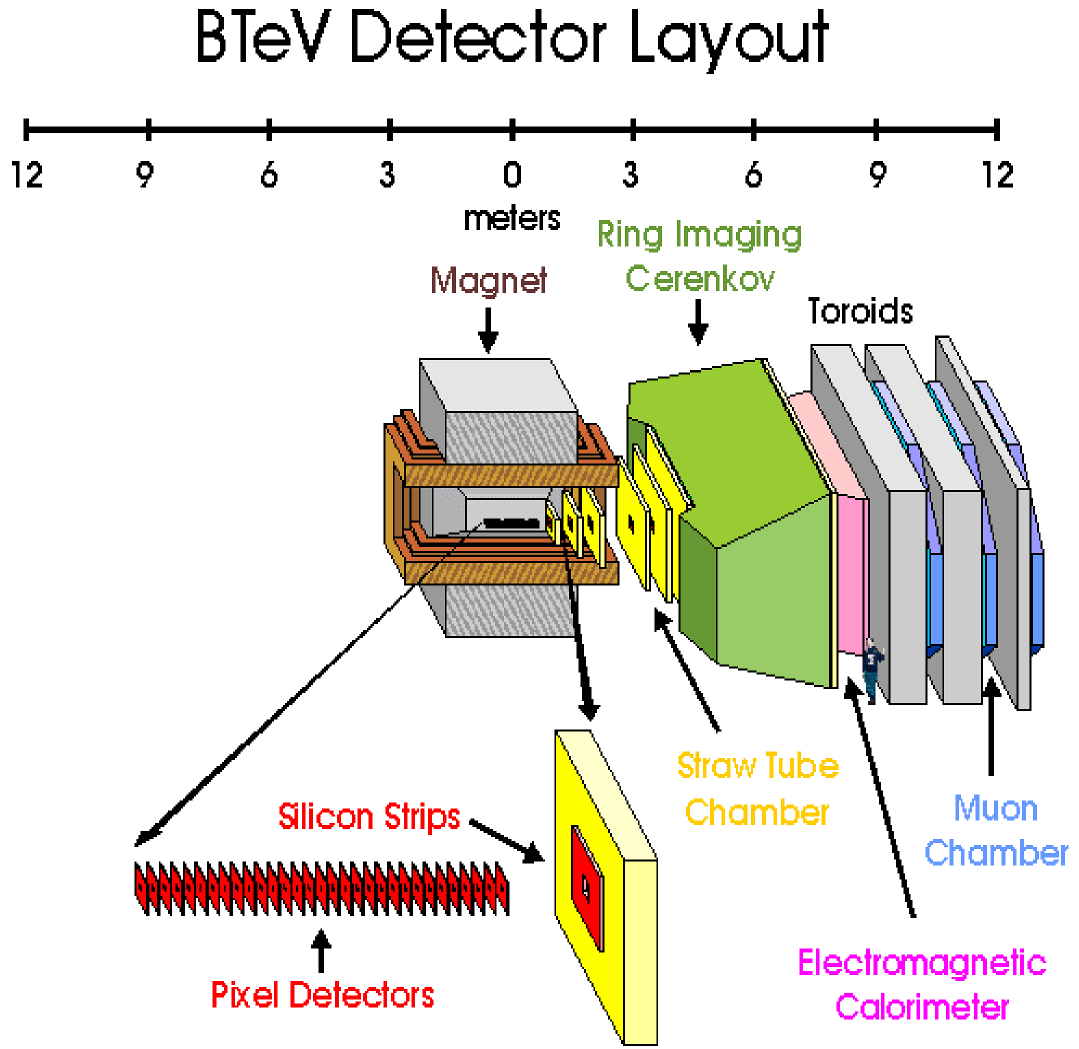
BTeV Physics Requirements

A range of physics, most requiring precision tracking near the beam and vertex triggering; e.g., in B decays.

Physics Quantity	Decay Mode	Vertex Trigger	K/π sep	γ det	Decay time σ
$\sin(2\alpha)$	$B^o \to \rho\pi \to \pi^+\pi^-\pi^o$	✓	✓	✓	
$\sin(2\alpha)$	$B^o \to \pi^+\pi^-$ & $B_s \to K^+K^-$	✓	✓		✓
$\cos(2\alpha)$	$B^o \to \rho\pi \to \pi^+\pi^-\pi^o$	✓	✓	✓	
$\mathrm{sign}(\sin(2\alpha))$	$B^o \to \rho\pi$ & $B^o \to \pi^+\pi^-$	✓	✓	✓	
$\sin(\gamma)$	$B_s \to D_s K^-$	✓	✓		✓
$\sin(\gamma)$	$B^o \to D^o K^-$	✓	✓		
$\sin(\gamma)$	$B \to K \pi$	✓	✓	✓	
$\sin(2\chi)$	$B_s \to J/\psi\eta'$, $J/\psi\eta$		✓	✓	✓
$\sin(2\beta)$	$B^o \to J/\psi K_s$				
$\cos(2\beta)$	$B^o \to J/\psi K^*$ & $B_s \to J/\psi\phi$		✓		
x_s	$B_s \to D_s\pi^-$	✓	✓		✓
$\Delta\Gamma$ for B_s	$B_s \to J/\psi\eta'$, K^+K^-, $D_s\pi^-$	✓	✓	✓	✓

Key Features of BTeV

- Precision vertex detector based on fast, rad-hard pixel arrays placed near beam
- High efficiency Level 1 detached vertex trigger using pixel information
- Forward tracking provided by Si strips (inner region) and straw tubes (outer)
- Good charged particle ID (RICH)
- Excellent photon and π^0 detection (EMCAL based on PWO)
- Muon detector based on Proportional tubes
- Fast, high capacity DAQ



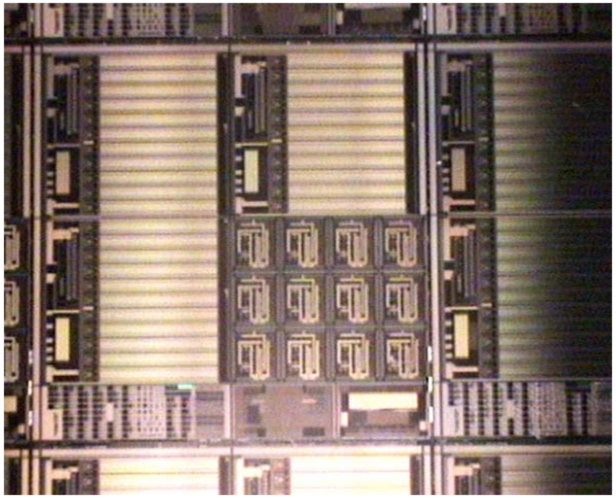
Technical Design Status

- **Our basic design has been stable since the original proposal in May 2000. The design has no show stoppers.**
- We have a highly efficient R&D program which solves a lot of the challenging technical issues and produces ~30 technical publications.
- The major issue over which we were unsure is now resolved: we will not use an aerogel radiator but a liquid radiator for the low momentum particle ID.
- We have eliminated three major criticisms:
  - **We will use commercial networking equipment in the DAQ rather than building a custom switch**
  - **We have received through the NSF, the funding required to develop a fault-tolerant, fault-adaptive, software system for the trigger farm**
  - **We have eliminated all liquid coolant joints in the pixel vaccum vessel in favor of thermal pyrolytic graphite (TPG) cold fingers to conduct heat away from the pixel detector**
- Many "plans" in 2000 are well on their way to realization today. A few choices among workable options still to be made (HPD vs MAPMT for RICH, choice of processors for trigger, optimization issues for forward tracker).
- We are ready to complete the Technical Design Report.

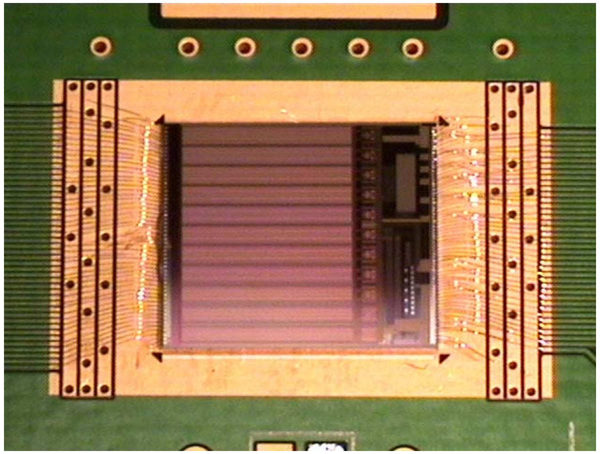
BTeV R&D Highlights and Plans

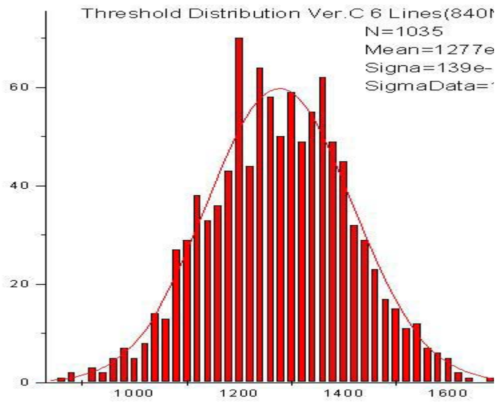
- Pixel Detector: achieved design (5-10 micron) resolution in 1999 FNAL test beam run. Demonstrated radiation hardness in exposures at IUCF. Readout chip and sensor meeting the BTeV specs have been bench tested and will be tested in FNAL test-beam in 2003
- Silicon strip electrical and mechanical design well underway. 1st readout chip submission in May.
- Straw Detector: prototype built, to be tested at FNAL in 2003
- RICH: HPD developed and has been bench tested. FE electronics prototype developed for HPD's. MAPMT now being tested and FE electronics for this option being developed. Full test vessel and gas system under development for beam test at FNAL in 2003
- EMCAL: four runs at IHEP/Protvino demonstrated resolution and radiation hardness,and effectiveness of calibration system. A fifth test will occur in April.
- Muon system tested in 1999 FNAL test beam run. Better shielding from noise implemented and bench-tested. Design to be finalized in FNAL test- beam in 2003
- Trigger code implemented on FPGA, Prototypes being constructed. NSF/RTES project to write fault tolerant software for massively parallel systems is well-along

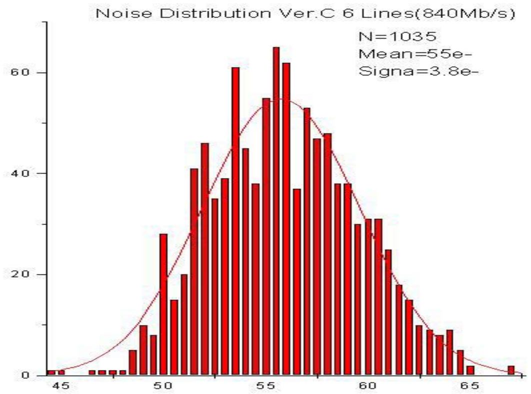
FPIX2 Pixel Readout chip



- 22 FPIX2 wafers received from TSMC last December
- Full size pixel ROC for BTeV
- All blocks tested before separately in prototypes. Tests included total dosage and Single event effects. All are included in this chip and if everything works, this is our production chip
- First test results show good performance
- Will assemble ~ 50 modules using these chips to understand assembly, testing and performance issues

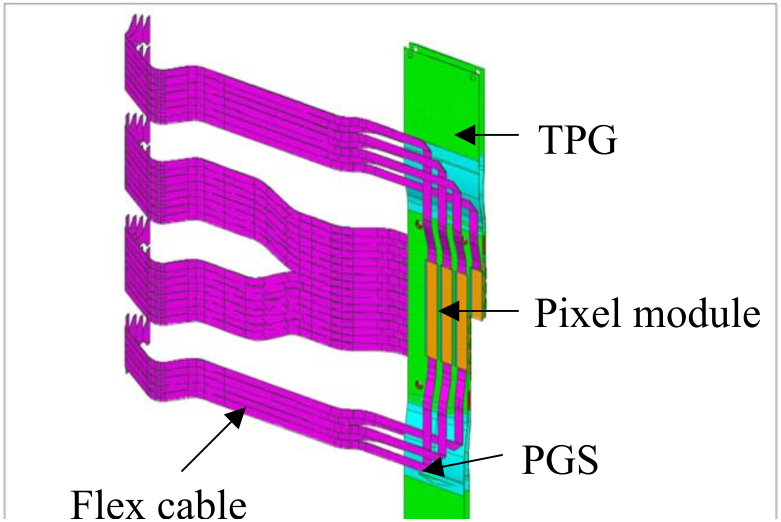


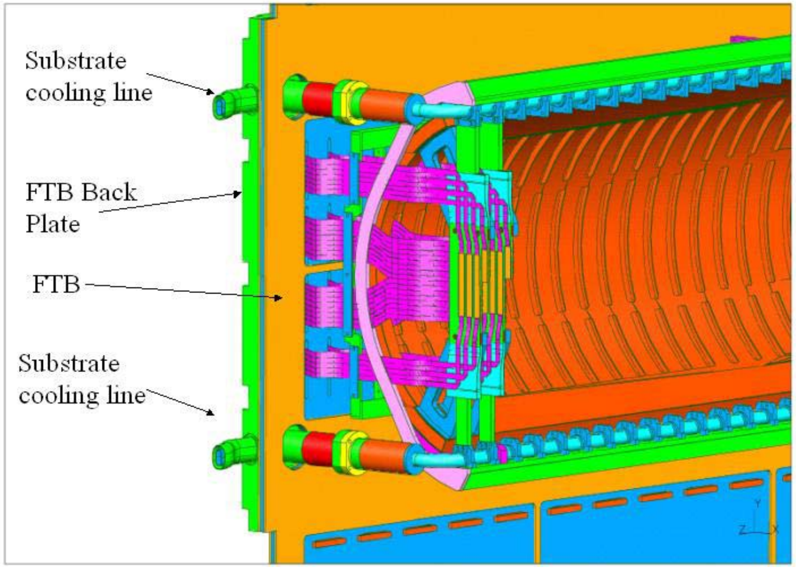




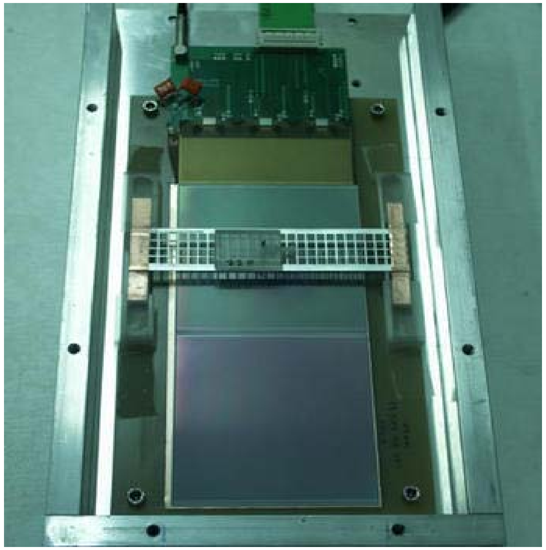
Pixel Substrate

- Pixel modules are mounted on the substrate which provides mechanical support & cooling
- Old baseline: light-weight fuzzy carbon with embedded glassy carbon tubes carrying water/glycol as coolant
- Major concern of the Temple Review: ensure that the water-glycol connections in the system are reliably leak-free (inside a vacuum system)
- A Pixel cooling system without joints in the vacuum vessel should be a priority feature for any substrate option.
- Our vacuum system will include cryopanels inside the vacuum vessel and LN_2 lines. We can use LN_2 to cool the pixel detector but we would still like to operate the detectors at around –5C to –10C.
- **This leads to to a different design : Thermal Pyrolytic Graphite (TPG) "cold-finger" substrate** – No cooling joint, uses conduction to carry away the heat generated in the pixel detector





Forward Tracker

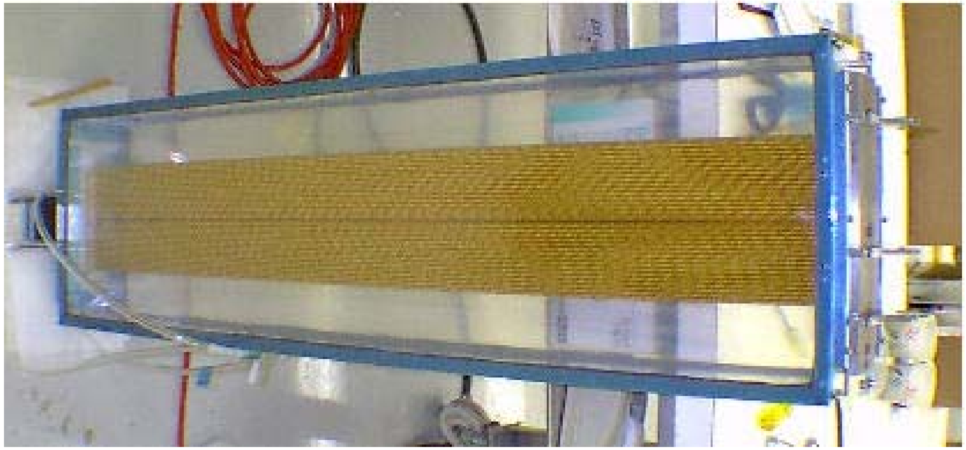


•Silicon Sensor

–Assembled 3 CMS HPK sensor suing IDE chips at Milano to characterize the sensors

–Study performance of long strips assembled in daisy chain configuration

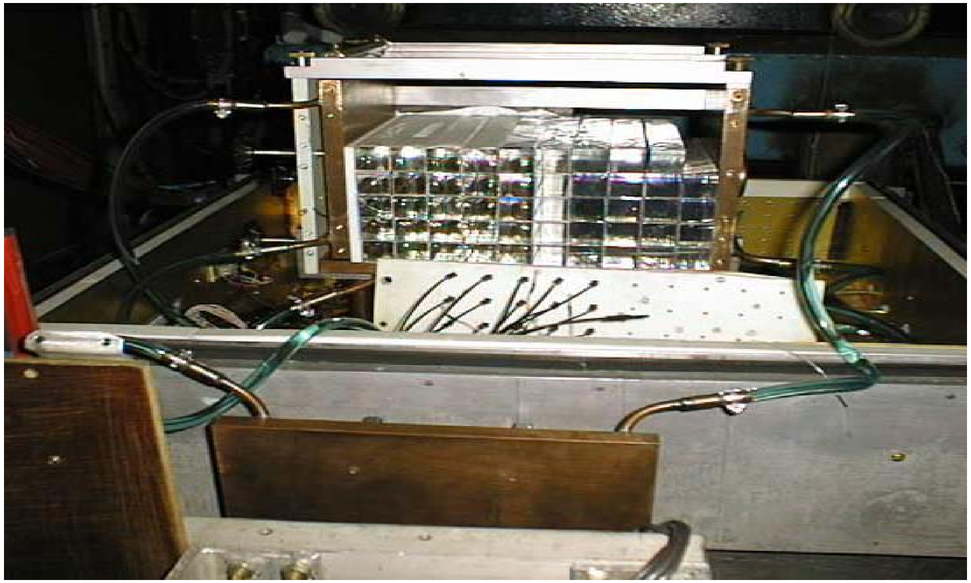
–Expose 2 of them to high doses of radiation at one end of the sensor and study effect of non-uniform irradiation on sensor operation at different temperatures



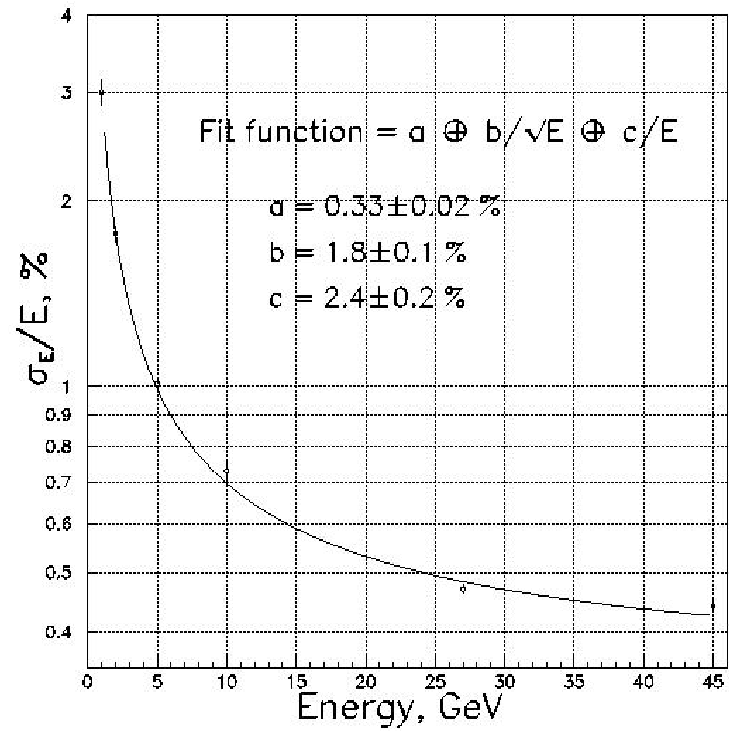
Prototype Straw tracker being constructed for FNAL Ready for beam test

3 views can be stacked to form a station. Reference pins guarantee a very precise relative alignment.

EMCal Test Beam Program



Stack of blocks from Bogoriditsk and SIC being installed in temperature controlled box for testing at Protvino in Mar'02

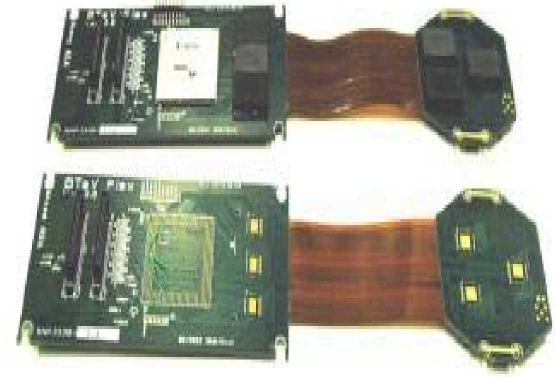


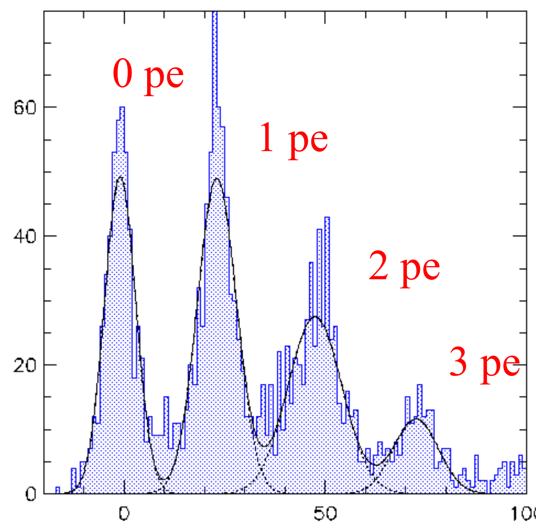
- IHEP Protvino: 5 test beam runs
  - Electron and pion beams (momentum measured).
- Study σ(E) vs incident energy, position and angle:
  - Time, temperature and rate stability.
  - Radiation hardness and recovery.
  - test of calibration scheme

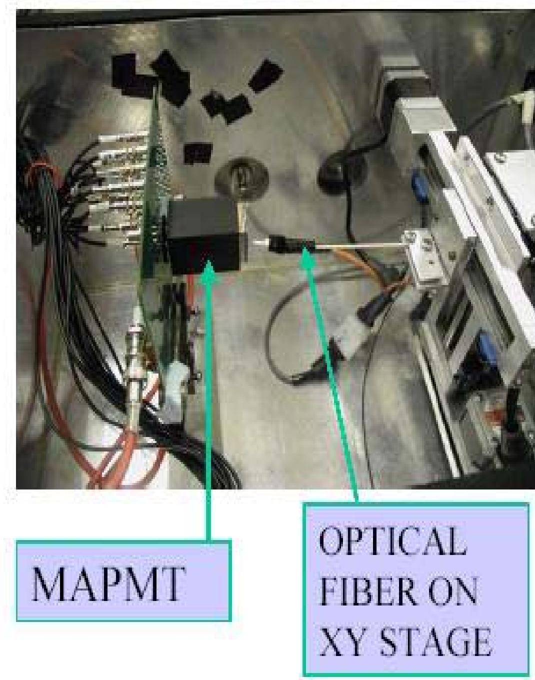
Resolution as measured in Test beam at IHEP/Protvino.
Stochastic term = 1.8%
$\sigma_{\pi 0} \rightarrow 3\%$!

RICH

- 163 channel HPD’s purchased (13 out of 15 delivered)
- HV and light response test in progress (8 tested so far and all look good)
- Electronics: prototype hybrids through 2nd generation
- Result on threshold scan of 1st hybrid agreed with simulation
- MAPMT option looks good also; active area and cost competitive with HPD system



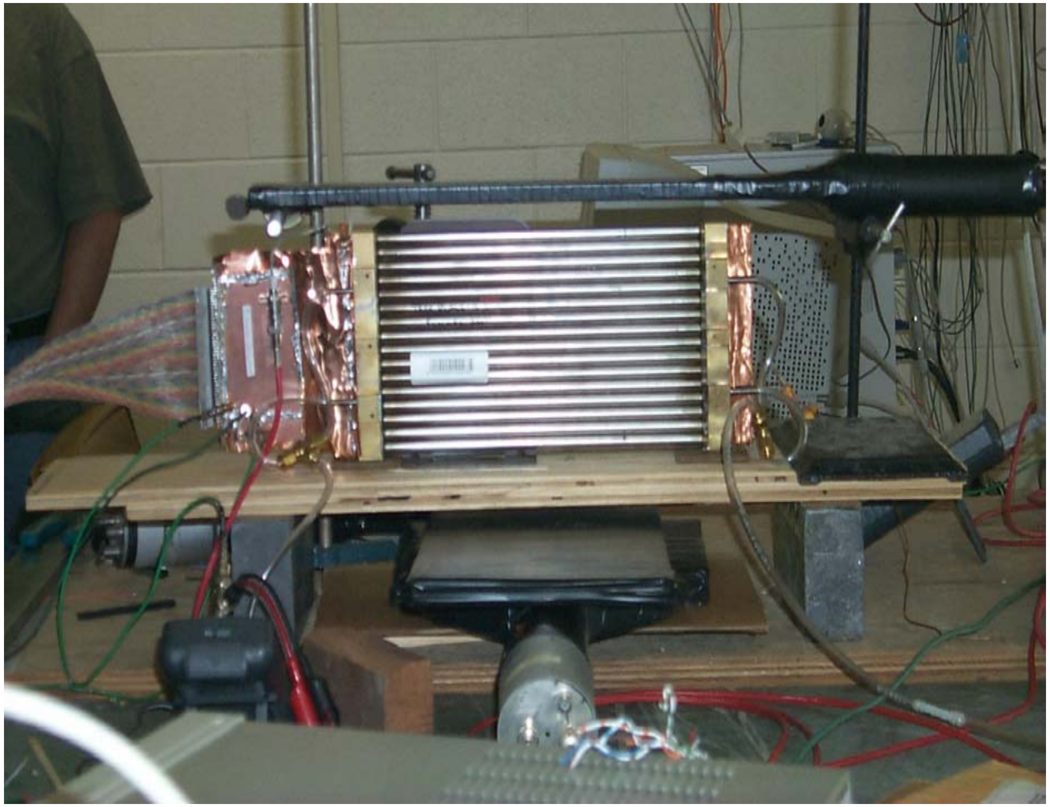




Muon System:Prop Tube Planks

- Basic Building Block: Proportional Tube "Planks"

- 3/8" diameter Stainless steel tubes (0.01" walls)
- 30 μ (diameter) gold-plated tungsten wire
- Manifolds are brass soldered to tubes (RF shielding important!)
- Front-end electronics: use Penn ASDQ chips, modified CDF COT card
- Try "D0 fast gas" 88% Ar - 10% CF_4 - CO_2 or 50% Ar – 50% Eth.



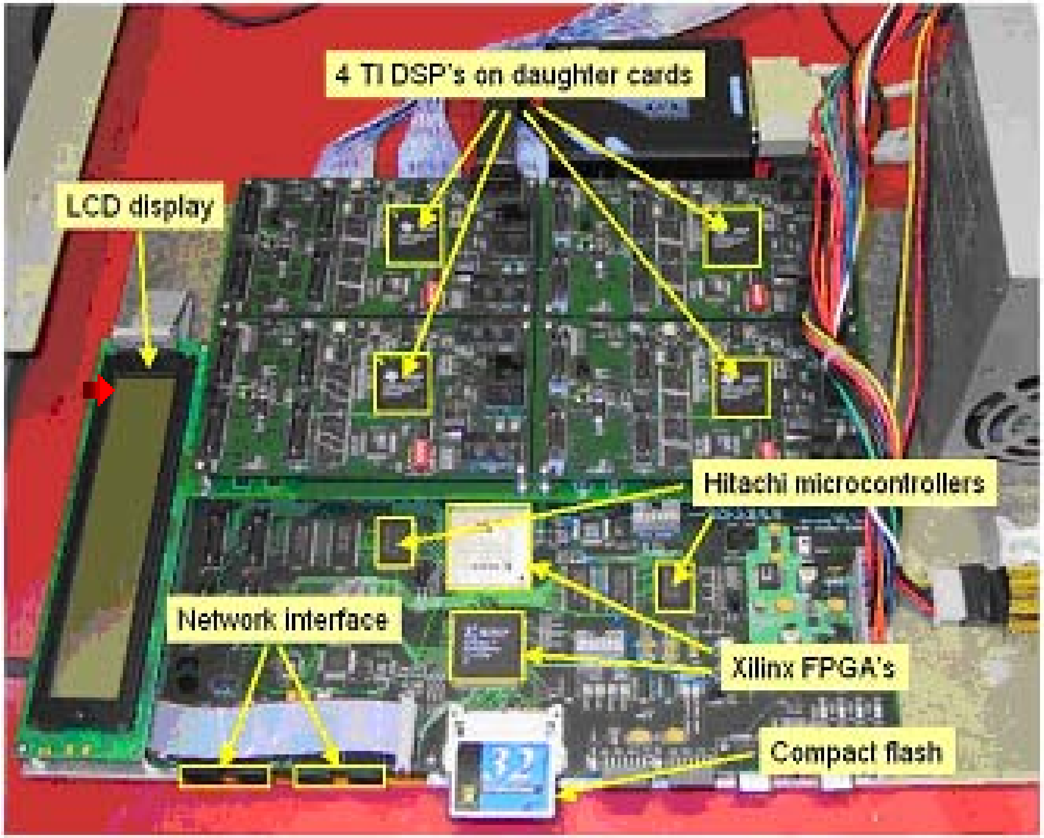
The BTeV Level I Vertex Trigger

The trigger will reconstruct every beam crossing and look for TOPOLOGICAL evidence of a B decaying downstream of the primary vertex. Runs at 7.6 MHz!

- **Key Points**
  - **This is made possible by a vertex detector with excellent spatial resolution, fast readout, low occupancy, and 3-d space points.**
  - **FPGA for pattern recognition**
  - **A heavily pipelined and parallel processing architecture using inexpensive processing nodes optimized for specific tasks ~ 2500 processors (DSPs).**
  - **Sufficient memory (~1 Terabyte) to buffer the event data while calculations are carried out.**
- **Number of conventional processors in Level 2/3 Farm is 2000**

L1 Trigger

- FPGA segment tracker algorithm (L1 pattern recognition) implemented on an Altera FPGA. Prototype being developed currently.
- 4-DSP pre-prototype built to validate the design of the L1 DSP farm
- Timing studies performed
- Also studied general purpose processors
  - Better timing performance
  - Higher power consumption
  - Needs other electronics



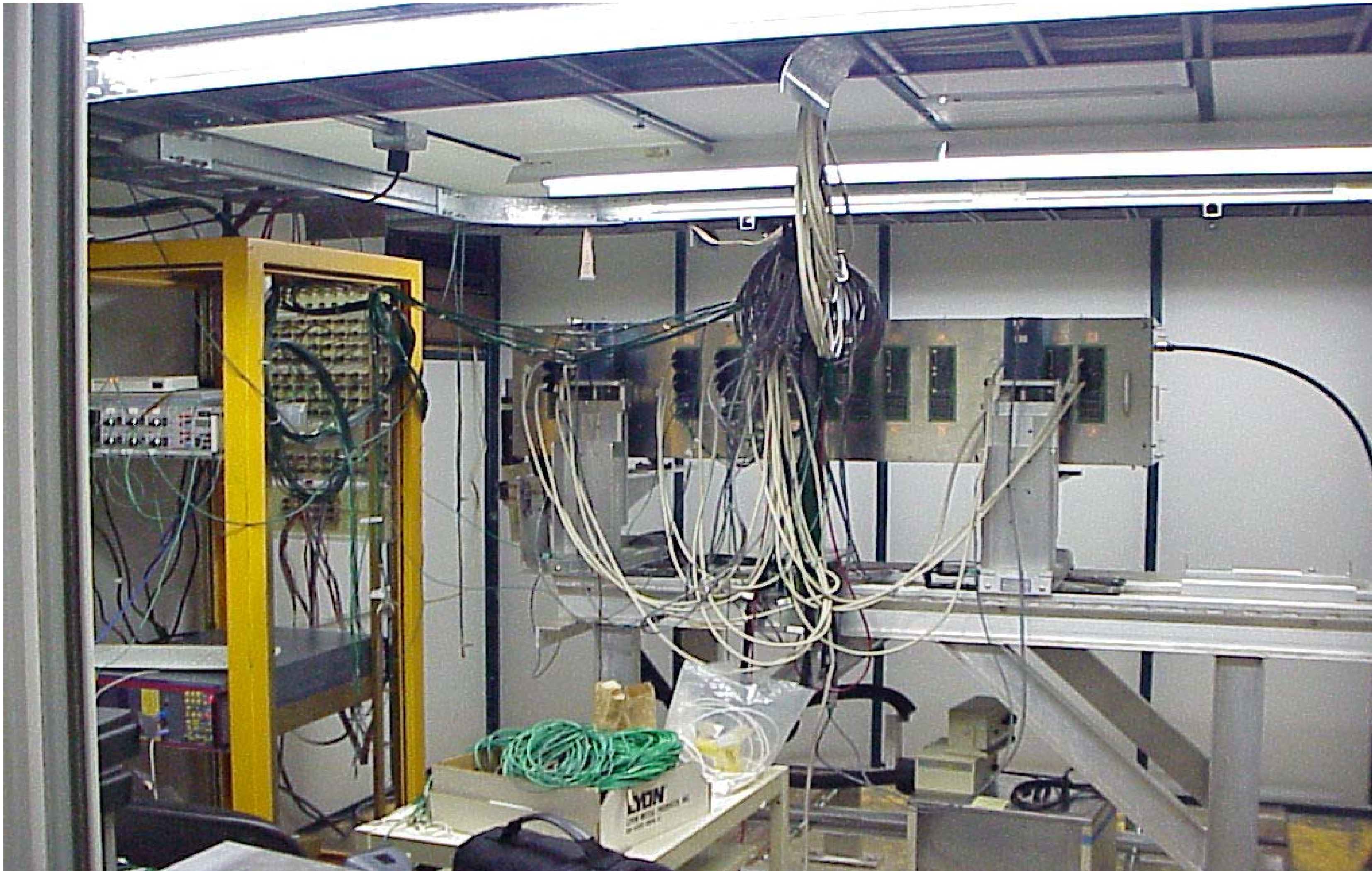
Fault Tolerance

- The trigger is working on many beam crossings at once. To achieve high utilization of all processors, it makes decisions as quickly as possible. There is no fixed latency and events are not emerging in the same time ordered sequence with which they enter the system.
- Keeping the trigger system going and being sure it is making the right decisions is a very demanding problem -- 6000-12,000 processing elements: FPGAs, DSPs. Commercial LINUX processors
- We have to write a lot of sophisticated fault tolerant, fault adaptive software
- We are joined by a team of computer scientists who specialize in fault-tolerant computing under an award of $5M over 5 years from the US NSF.

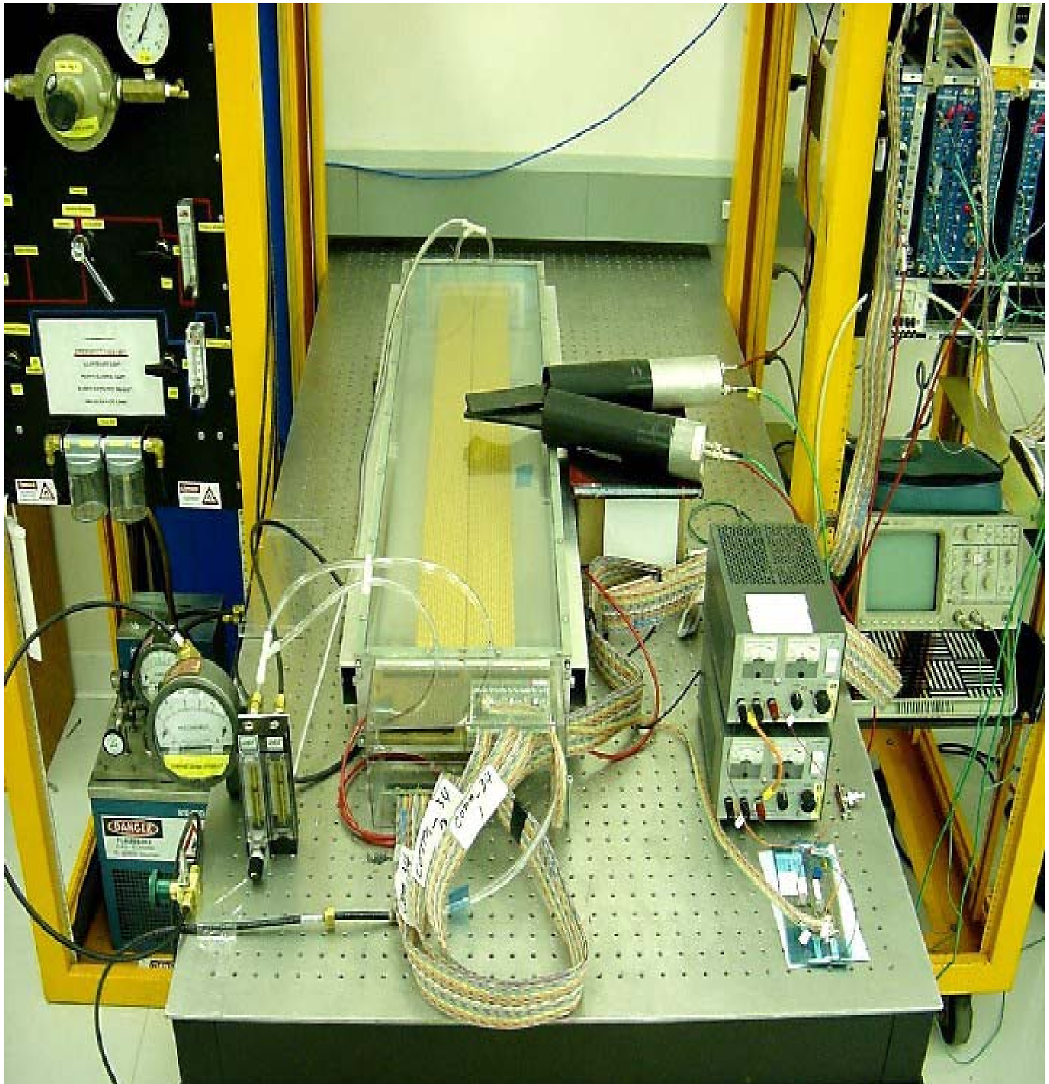
Preparation for Test Beam

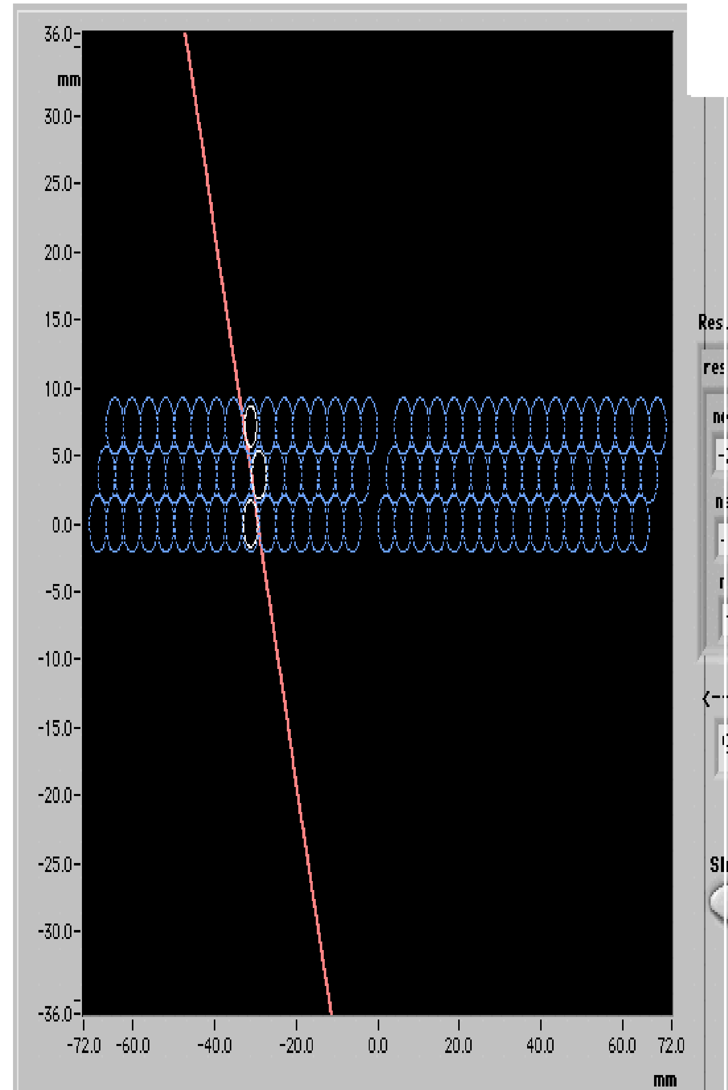
- **Pixel – ready for second run; will test detectors before and after irradiation; MOU signed (T927)**
- **Straws – ready for run to verify that it will hold up in high rate environment – well understood with cosmic ray test stand**
- **Strips – Tests at beginning of '04.**
- **RICH– ready for test beam in a few months – all parts designed and being assembled. Will test both HPD and MAPMT read out**
- **EMCAL – 4 test runs in Protvino completed– 5th in April. There will be a test beam setup at FNAL, mainly for quality assurance cross checks during production**
- **Muon– ready for second run, which will be final run before we are ready for production**
- **Will also test Control/Monitoring hardware/software**

Setup for Pixel Test Beam (T927)



Straw Prototype setup





Operation at 396 ns Bunch Crossing Interval

- BTeV was designed to operate at a peak luminosity of $2x10^{32}$ $cm^{-2}s^{-1}$ at 132 ns, i.e. <2> interactions/crossing (initial) unleveled
- We now expect to run at ~$2x10^{32}$ $cm^{-2}s^{-1}$ at 396 ns, i.e.<6> int/crossing (initial) unleveled OR ~$1.3x10^{32}$ at 396, i.e. <4> int/crossing, leveled
- To verify that we can do this, we have repeated many of our simulations but have run the code just as it was for two int/crossing– i.e. no retuning, so represents a worst case. We always used the peak rate, so our past estimates have been pessimistic.

Impact of 396 ns on BTeV

- Issues: occupancy, false triggers, more tracks.
- Pixels, Forward Silicon, Muon - OK
- Straws, EMCAL, RICH: Need to carefully study occupancy.
- Trigger:
  - Two nearby background collisions can look like a b.
- Key potential problem areas – RICH, EMCAL and trigger
  - **Studied with simulation on specific B decay modes on effect of changing # int/crossing from 2 to 6**
  - **RICH: ~13% loss of K ID efficiency using the same code**
  - **EMCAL: $B^0 \rightarrow \rho^+\pi^-$ study shows no significant loss of signal; estimate loss of signal < 20% (90% C.L.). Similar results from $B^0 \rightarrow D^{*-}\rho^+$.**

Trigger results for <2>, <4>, and <6> interactions per beam crossing

Avg. Ints./ BCO	Level 1 detachment cut (σ)	BCO (ns)	**Level 1 efficiency Bs**	**Level 1 efficiency min. bias**	Level 1 timing (ms)	**Number of TI C6713 DSPs**	Data/BCO into Level 1 (KBytes)	**Bandwidth into Level 1 (GB/s)**	Data/BCO into Level 2 (KBytes)	**Bandwidth into Level 2 (GB/s)**
< 2 >	1.9	132	**0.79**	**0.020**	0.540	**4091**	50	**379**	90	**13.6**
< 4 >	3.2	396	**0.75**	**0.020**	1.205	**3043**	100	**253**	150	**7.6**
< 4 >	2.3	396	**0.78**	**0.035**	1.205	**3043**	100	**253**	150	**13.3**
< 6 >	4.7	396	**0.66**	**0.020**	2.007	**5068**	150	**379**	180	**9.1**
< 6 >	3.6	396	**0.71**	**0.030**	2.007	**5068**	150	**379**	180	**13.6**

For L1 pixel trigger, results show that acceptable performance is achieved for different running conditions for trigger timing and bandwidth. Our baseline design is able to handle changes in running condition rather well, without requiring any significant changes in the design

BTeV Cost Estimate

- Cost estimate is derived from a complete, task-oriented WBS. Realistic assumptions are made about the production model. We have worked hard to include integration activities in a complete and consistent manner
- It includes cost and scheduling information.
- Extensive costing done & internal FNAL review led by Ed Temple
  - Multi-thousand line spreadsheets for each project
  - Each project required to fit into overall budget profile supplied by FNAL
- Base $89.6 M, Contingency 37%, Total $122.5 M in FY02 dollars, reflects a raise in our cost estimate by ~8%
- RTES $5M NSF grant for “fault tolerant, fault adaptive computing for the trigger”
- Foreign money may be available

Level 2 Cost Rollup

WBS #	WBS Activity Name	Construction (w.o. contingency) Million $ ('02)	Construction (with Contingency) Million $ ('02)
1	BTeV Construction	89.57	122.46
1.1	Vertex, Toroidal Magnet, Beam Pipe	1.34	1.88
1.2	Pixel Detector	11.80	17.08
1.3	RICH Detector	10.03	13.54
1.4	EM Calorimeter	11.30	14.51
1.5	Muon Detector	3.61	5.42
1.6	Forward Straw Tracker	5.93	8.36
1.7	Forward Silicon Microstrip Tracker	4.90	7.11
1.8	Trigger Electronics and Software	9.98	14.22
1.9	Event Readout and Controls	11.82	14.68
1.10	System Installation, Integration, etc	4.28	8.07
1.11	Project Management	6.46	7.43
	G&A estimate completion	8.14	10.18

Note: of the $78.1M base cost, 41% is labor, 59% is M&S. We estimate that inflation will result in a "then year" cost of $135 M

Concluding Remarks

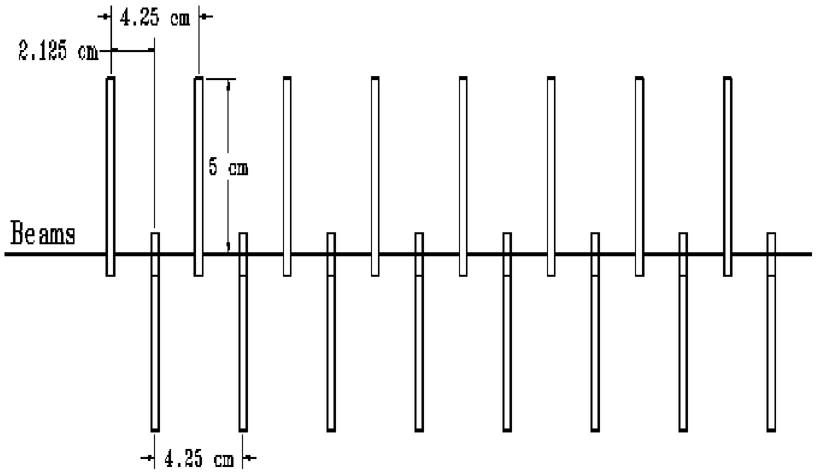
- BTeV will make critical contributions to our knowledge of CP Violation moving from initial observations to finding out if the Standard Model explanation is complete.
- Our technical design has been stable for two years and has only a few options still left to be decided. These would have little impact on the cost and schedule.
- Our R&D program has gone a long way to develop the technologies needed and reduce risks. The detector design has no show stoppers.
- BTeV will form a key part of a world class domestic flavor physics program after the LHC takes firm possession of the energy frontier.

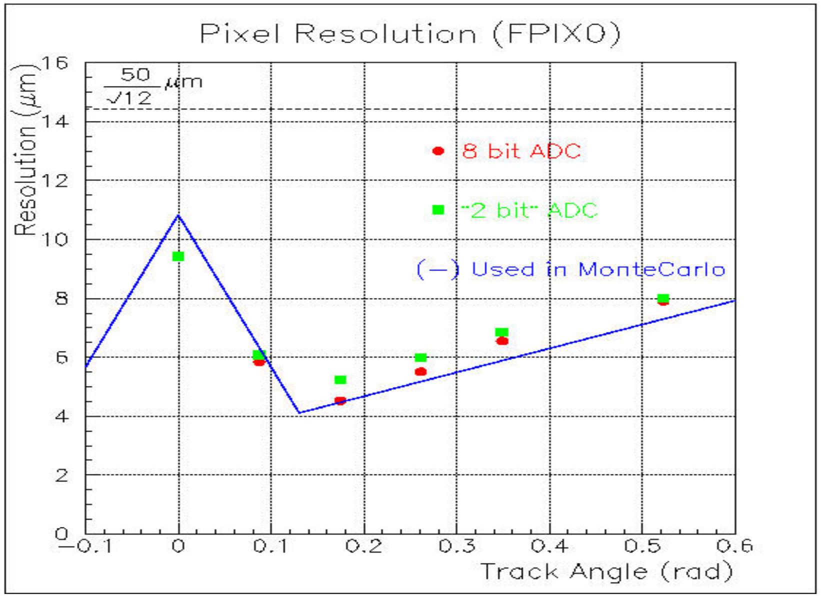
Appendix

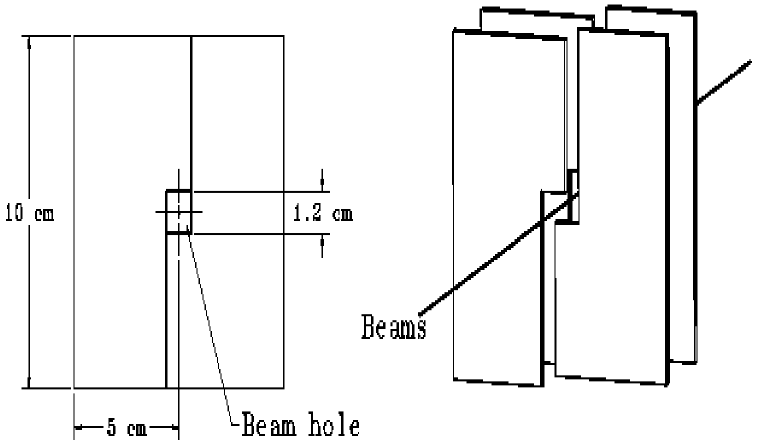
Pixel Vertex Detector

Special features:

- Info used directly in the L1 trigger.
- Pulse height is measured on every channel with a 3 bit FADC.
- It is inside a dipole and gives a crude standalone momentum measurement.
- Sitting close to beam and in vacuum
- 30 stations and 23 million pixels in total





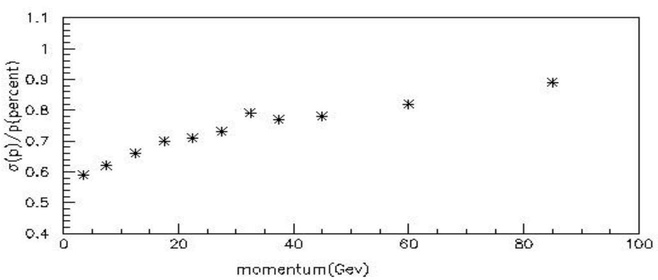


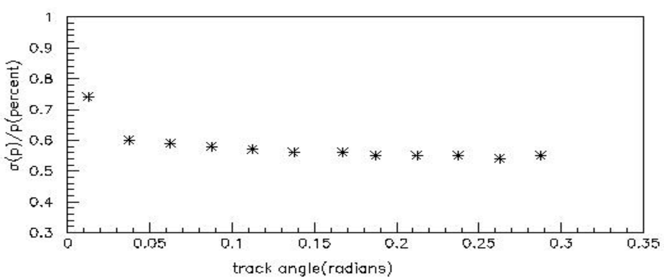
Forward Tracker

- Straws –uses Atlas design as basis
- Silicon Strips: simple single sided design,
- Expected performance: Momentum resolution better than 1% over full momentum and angle range

Straw size	4 mm, 8mm diameter
Central dead region	26 cm x 26 cm
Number of Stations	7
Z positions (cm)	96, 138, 196, 288, 332, 382, 725
Active Half size (cm)	27.2, 40.8, 61.2, 88.4, 102, 115.6, 197.2
Views per station	3
Layers per view	3
Total number of straws	26784
Total station thickness	0.8% X_0
Total channels	53568
Readout	ASDQ + TDC(8 bits), sparsified

Straws at large angles (low occupancy)

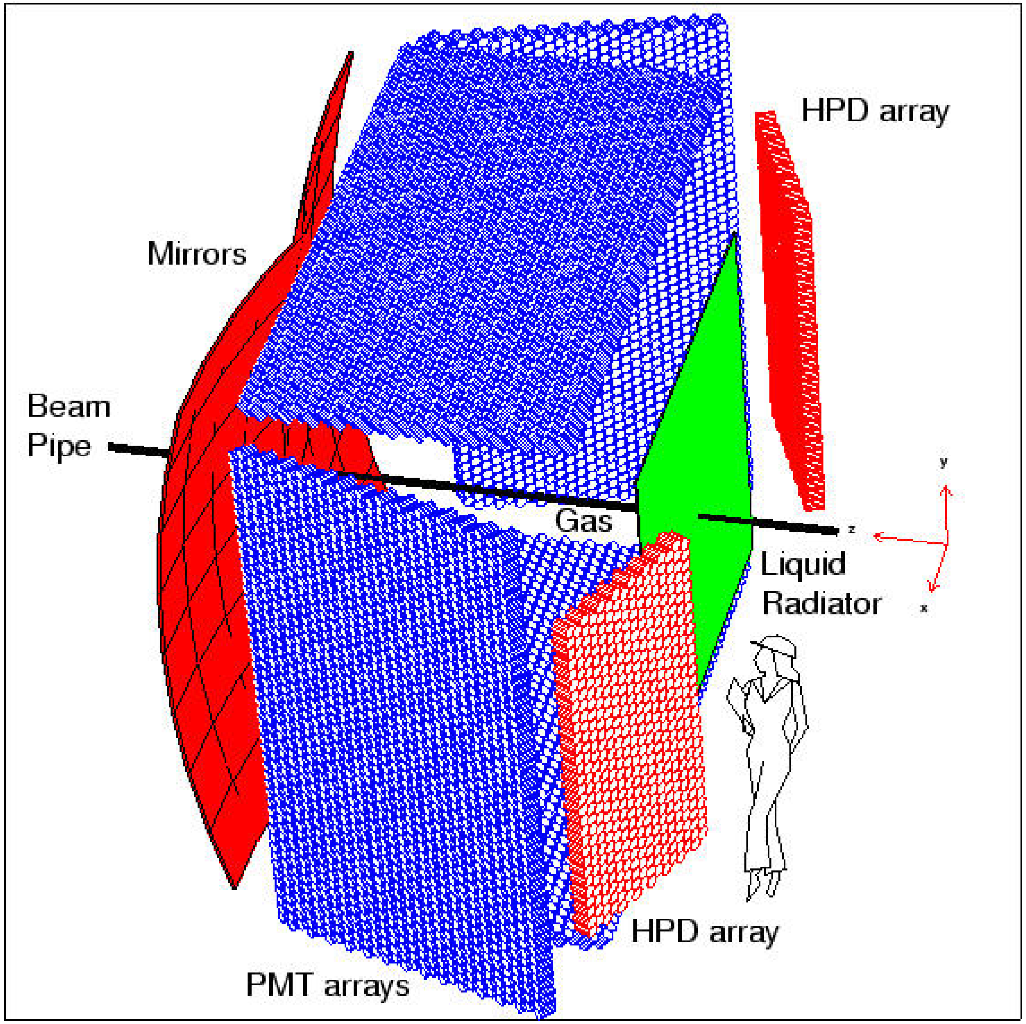




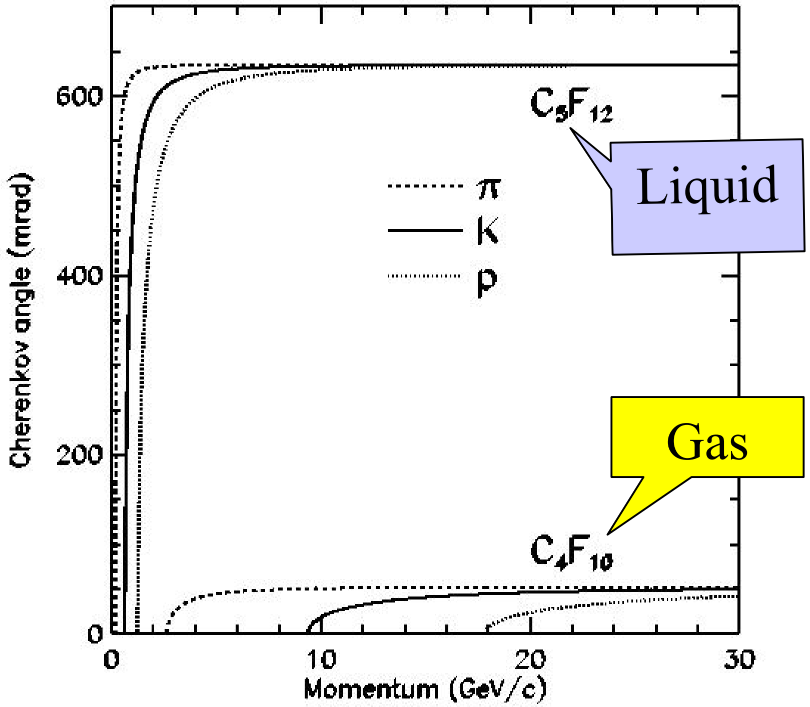
Property	Value
Sensors	~ 7 x 7 cm^2 p-on-n type
Pitch	100 μm
Thickness	300 μm
Sensor configuration	4 ladders of 4 sensors
Coverage	27 x 27 cm^2
Central Hole	5.4 x 5.4 cm^2 (7 x 7 cm^2 in last station)
Total stations	7
Z positions (cm)	99, 142, 200, 292, 336, 386, 729
Views per station	3 (X, U, V)
Readout	Sparsified binary
Total active area	~ 1.5 m^2
Channels per station	~ 5600
Total channels	~ 127600

Strips at small angles (high occupancy)

Layout of the New Particle Identifier showing the liquid radiator and its PMTs



Cherenkov angle vs P



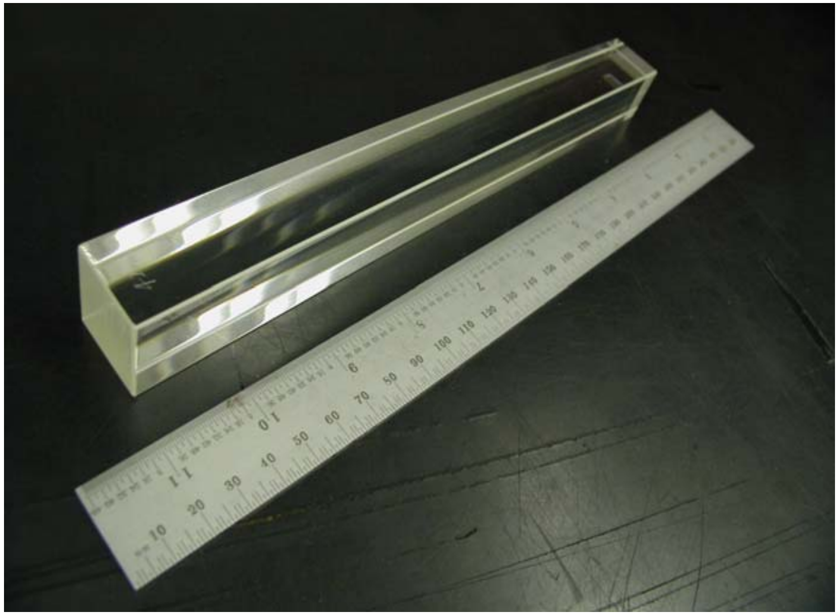
Electromagnetic Calorimeter

Table 4.8: Properties of $PbWO_4$

Property	Value
Density (g/cm^3)	8.28
Radiation Length (cm)	0.89
Interaction Length (cm)	22.4
Light Decay Time (ns):	5(39%) 15(60%) 100(1%)
Refractive Index	2.30
Maximum of emission (nm)	440
Temperature Coefficient (%/°C)	-2
Light output/NaI(Tl) (%)	1.3
Light output (pe/MeV into a 2" PMT)	10

Table 4.9: Properties of the BTeV electromagnetic Calorimeter

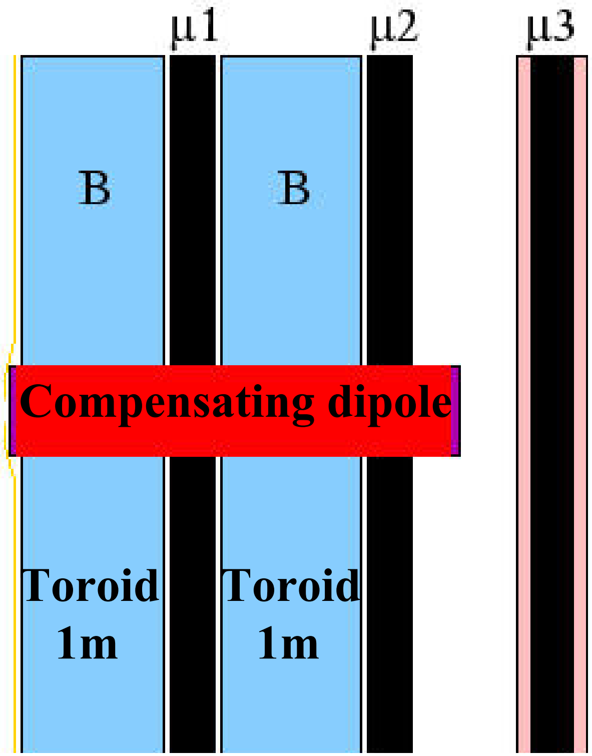
Property	Value
transverse block size, back	28.0 mm × 28.0 mm
tapered, smaller in front	27.2 mm× 27.2 mm
Block length	22 cm
Radiation Lengths	25
Front end electronics	PMT
Digitization/readout	QIE (FNAL)
Inner Dimension	± 9.88 cm × ± 9.88 cm
Outer Radius	160 cm
Total blocks per arm	10500

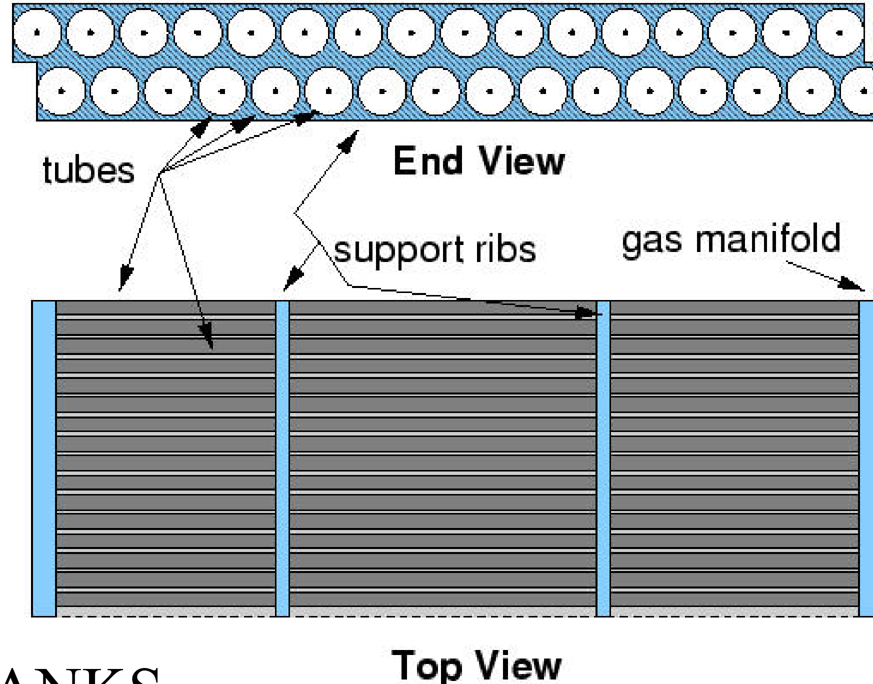


Block from China's Shanghai Institute of Ceramics

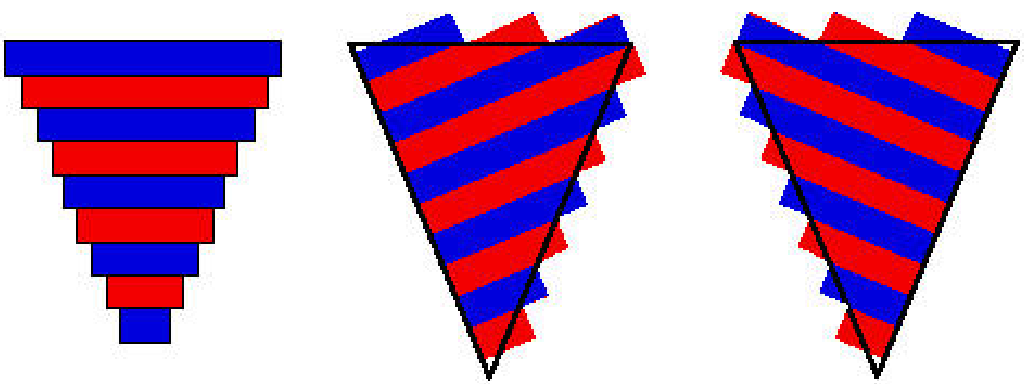
Lead Tungstate Crystals similar to CMS. Capable of excellent energy and spatial resolution. We will read them out with **PHOTOMULTIPLIER** tubes unlike CMS which uses avalanche photodiodes (and triodes for endcap) because of magnetic field. **This system can achieve CLEO/BaBar/BELLE-like performance in a hadron Collider environment!**

Muon Detector

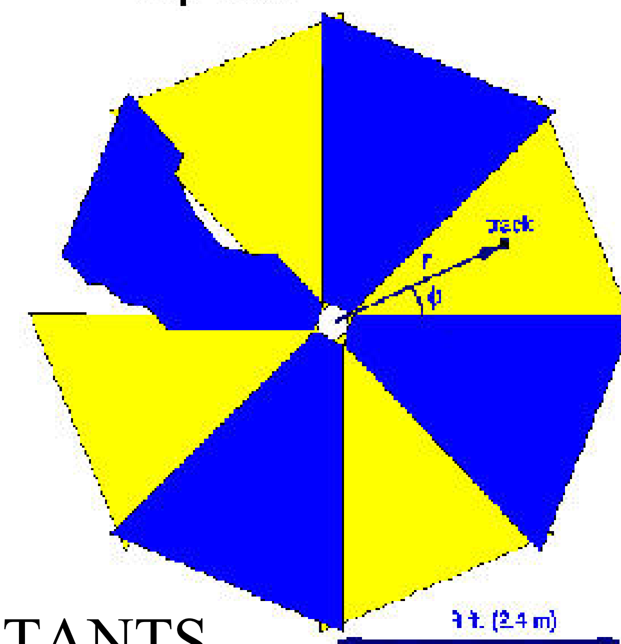




PLANKS

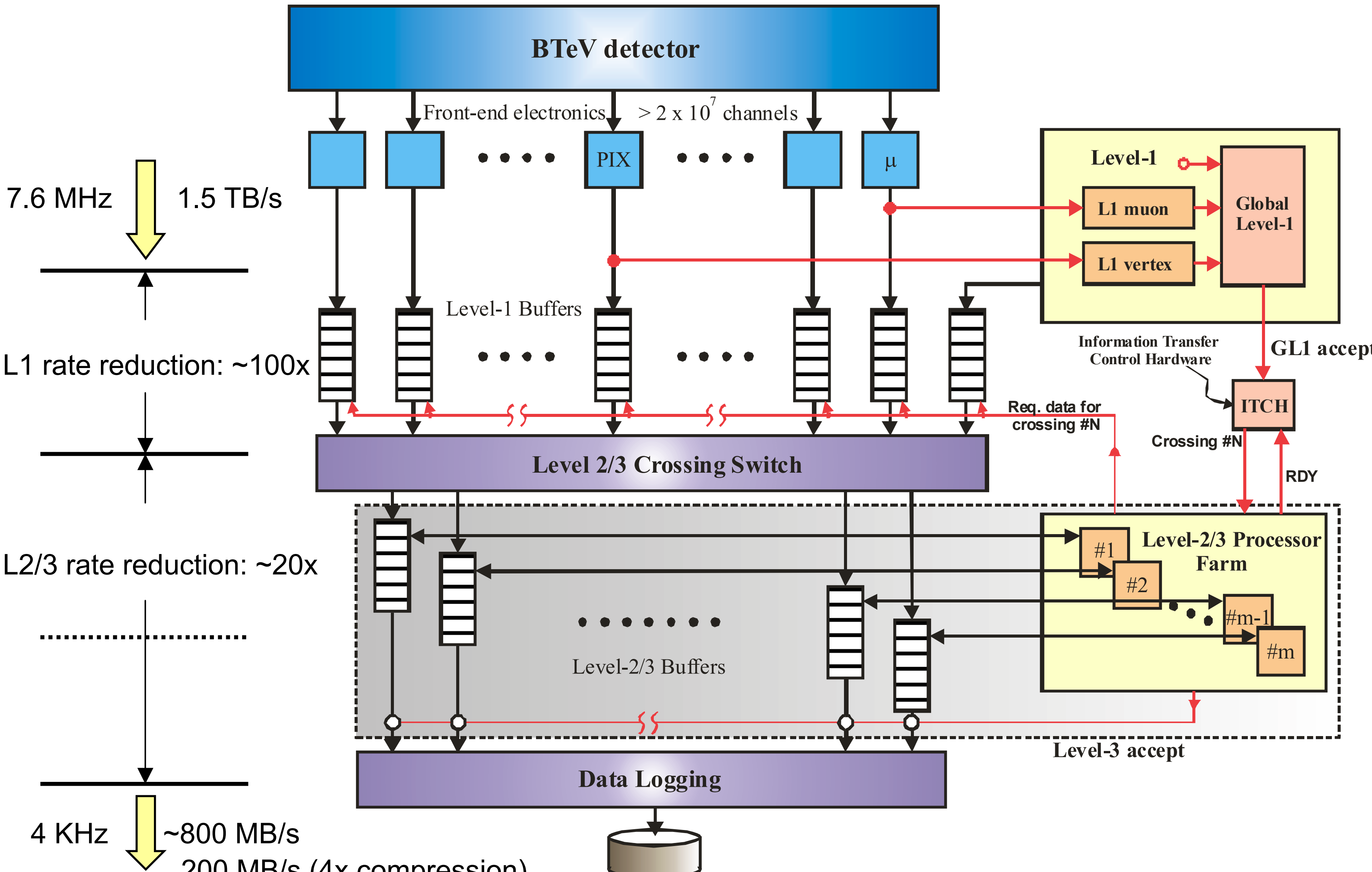


VIEWS

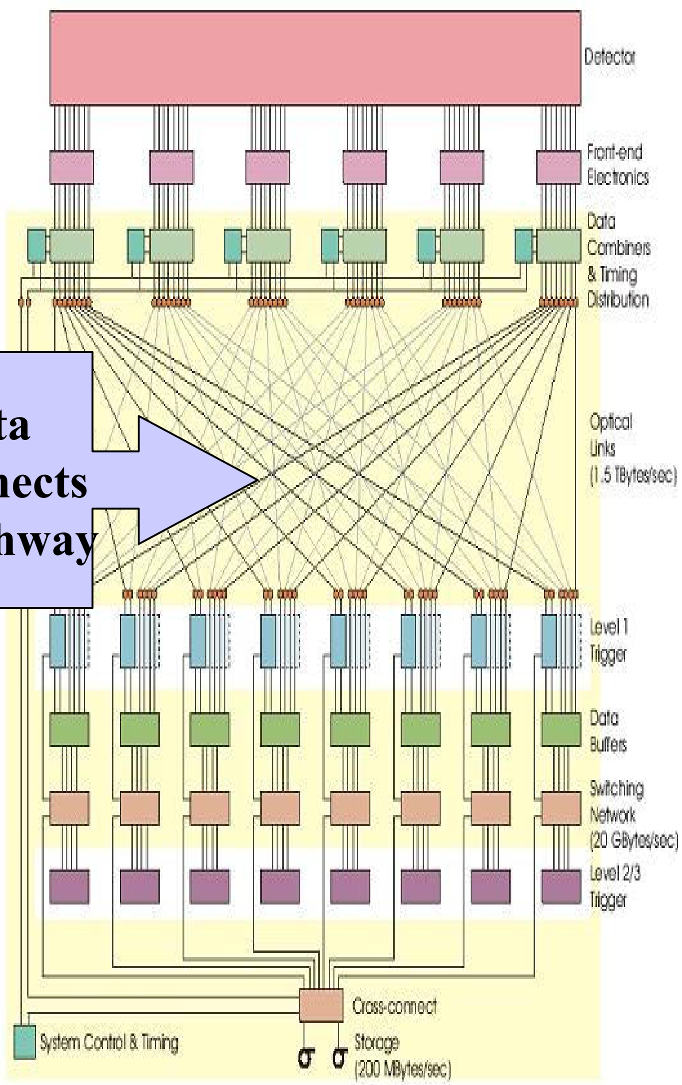


OCTANTS

BTeV trigger block diagram



Data Acquisition



Each data source connects to each highway

BTeV DAQ hardware is arranged in “8” independent “highways”.

- increases networking efficiency (larger packets are transmitted more efficiently with commercial switches)
- reduces the complexity of the event-builder fabric
- reduces the number of control messages

Each highway has a Global Level 1 Manager and an ITCH

From the viewpoint of a single highway, the crossing rate appears to be 1 microsecond (8 X 132nsec), with a corresponding 8X decrease in the packet processing overhead and index table size.