Overview of BTeV Pixel Detector

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Unique Features of BTeV Pixel Detector

Data driven readout, for use of the pixel detector in secondary vertex trigger at first (lowest) level

Better than 9 μ spatial resolution within 300 mrad θ_x, θ_y

Situated in vacuum, within 6 mm of beams

Designed for 132 nsec crossing times

Future Pixel Detector Specifications

Experiment Property	ALICE Pb-Pb Collider	ATLAS p-p Collider	BTeV $\overline{p}$-p Collider	CMS p-p Collider
Pixel Size	50 x 425 microns sq.	50 x 300/400 microns sq.	50 x 400 microns sq.	150 x 150 microns sq.
Size of Largest Subassembly	1. 7 x 7.1 cm sq.	1.6 x 6.1 cm sq.	0.9 x 7.6 cm sq.	1.7 x 6.6 cm sq.
Min.dist. to beam	41 mm	50 mm (B) 98 mm	6 mm	41 mm, barr. 60 mm, disk
Number of Pixels	~ 10 x 10^6	80 x 10^6	23 x 10^6	35 x 10^6
Total Active Area	0.26 m^2	~ 1.5 m^2	0.5 m^2	~ 0.8 m^2
Material X_0 per plane	~1 %	1.80 % (B) 1.62 %	1.25 %	1.65 % 2.3 %
Special Features	90 tracks/cm^2	4 bit TOT ADC	Level 1 Trig 3 bit ADC	4 T Field

BTeV Physics Requirements

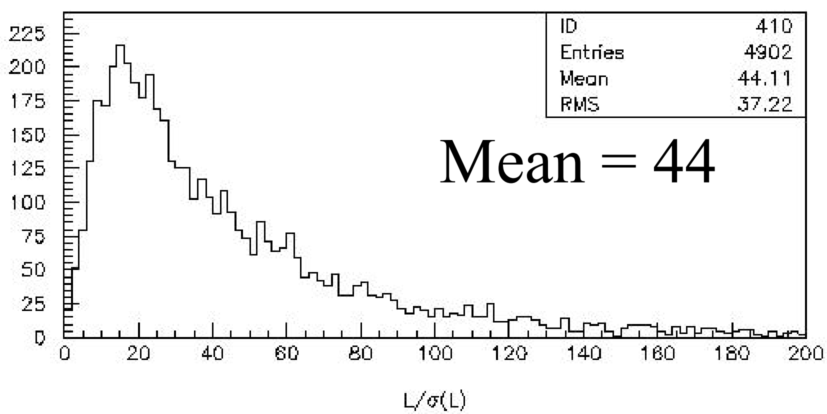
A range of physics, most requiring precision tracking near the beam and vertex triggering; e.g., in B decays.

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^-, $D_s\pi^-$	✓	✓	✓	✓

Physics Performance

An example: $B_s \rightarrow D_s\ K^+$

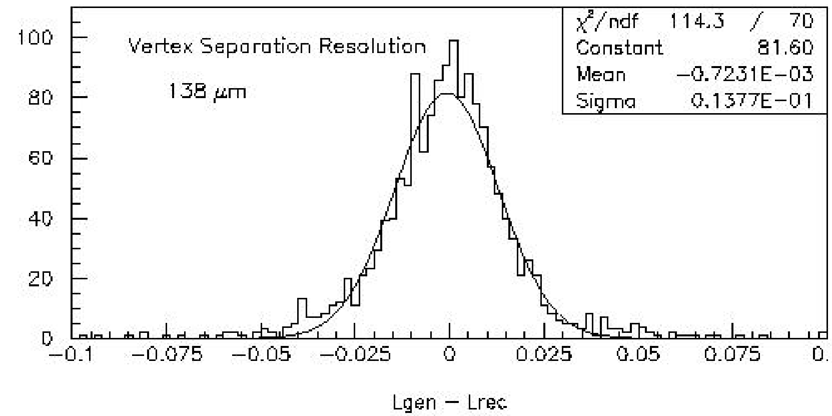
Distribution in L/σ of Reconstructed B_s

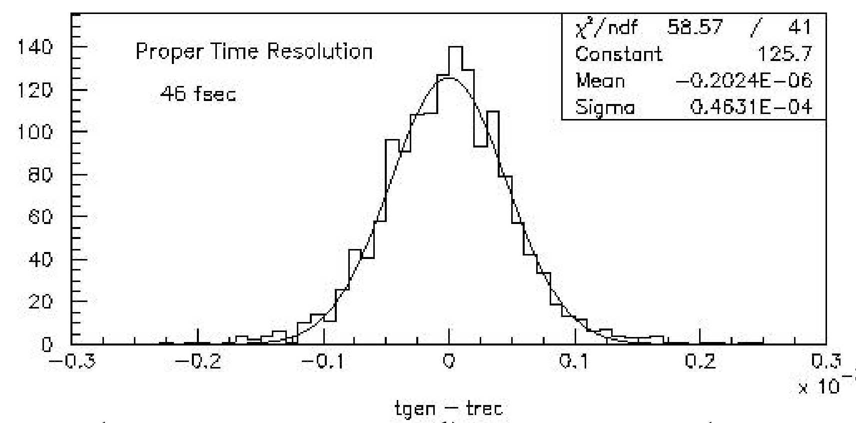


BTeV Geant3 simulation

Note $x_s = 25 \rightarrow 400$ fsec mixing period

Primary-secondary vertex separation Minus generated. σ = 138μ

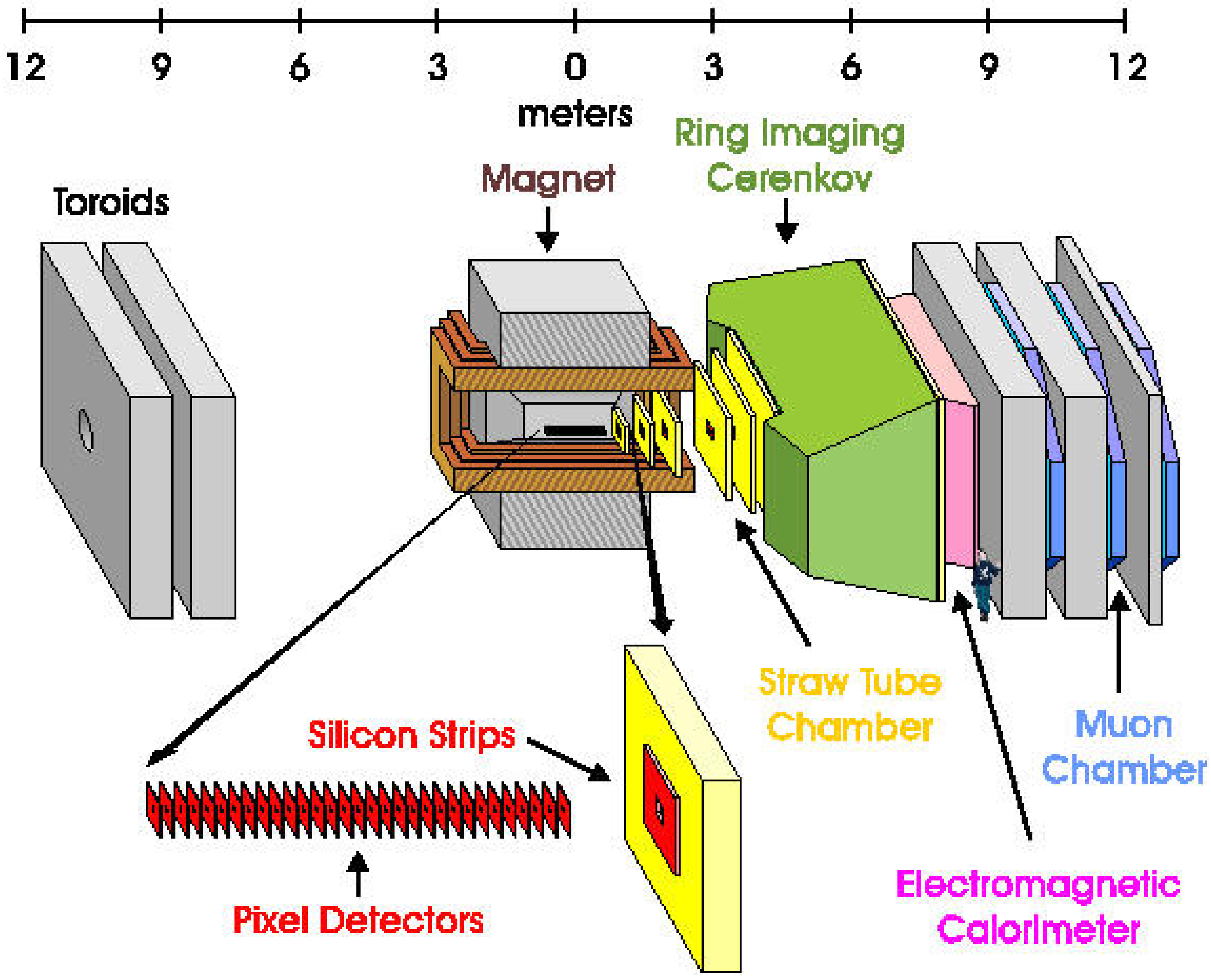




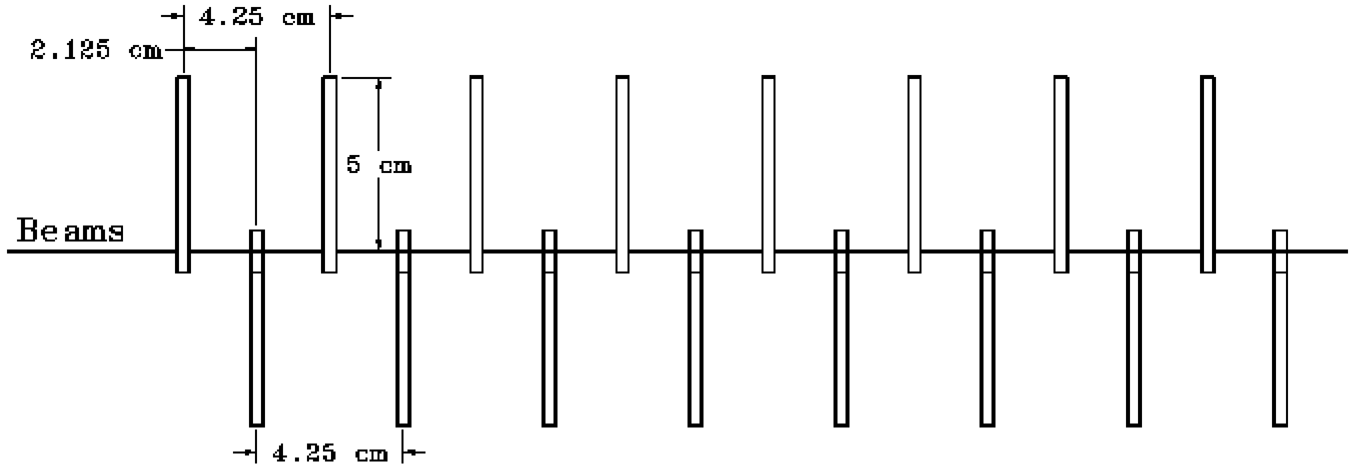
τ_{proper} (reconstructed) - τ_{proper} (generated)

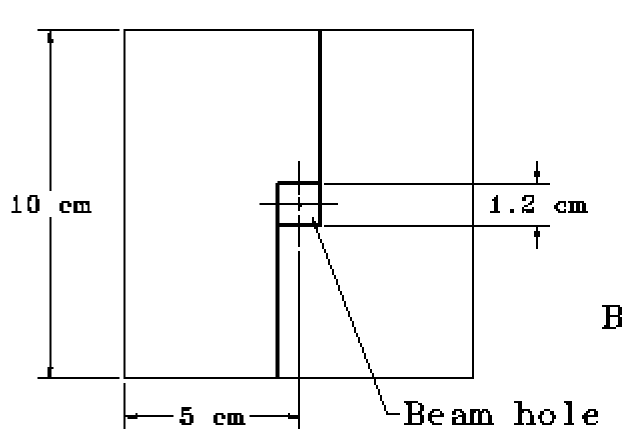
σ = 46 fsec

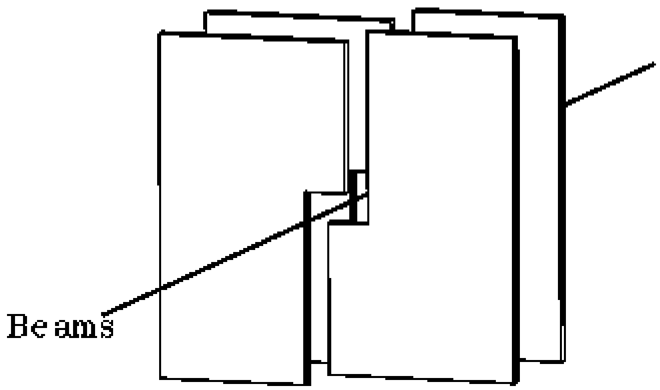
The Full BTeV Detector



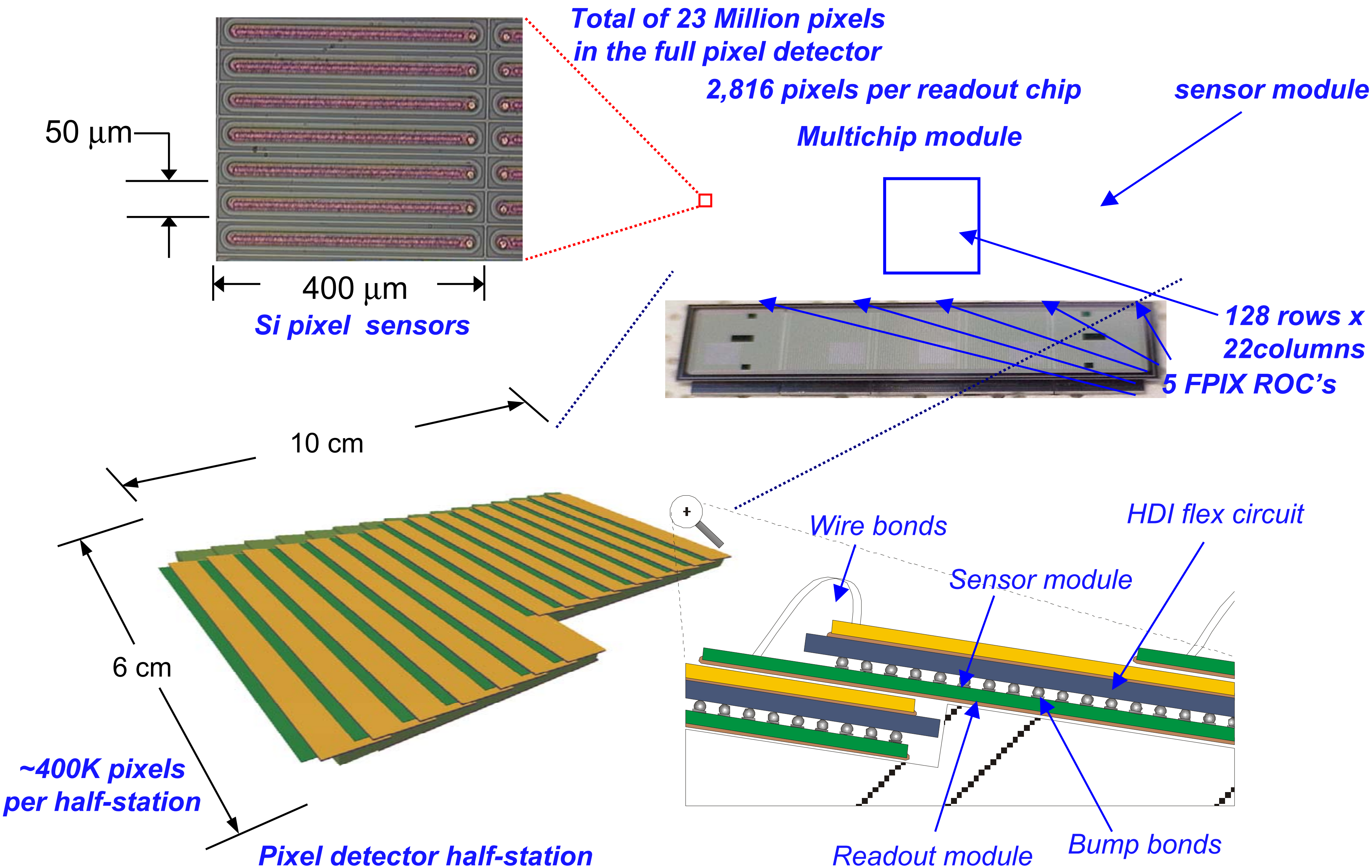
Layout of Pixel Stations/Planes



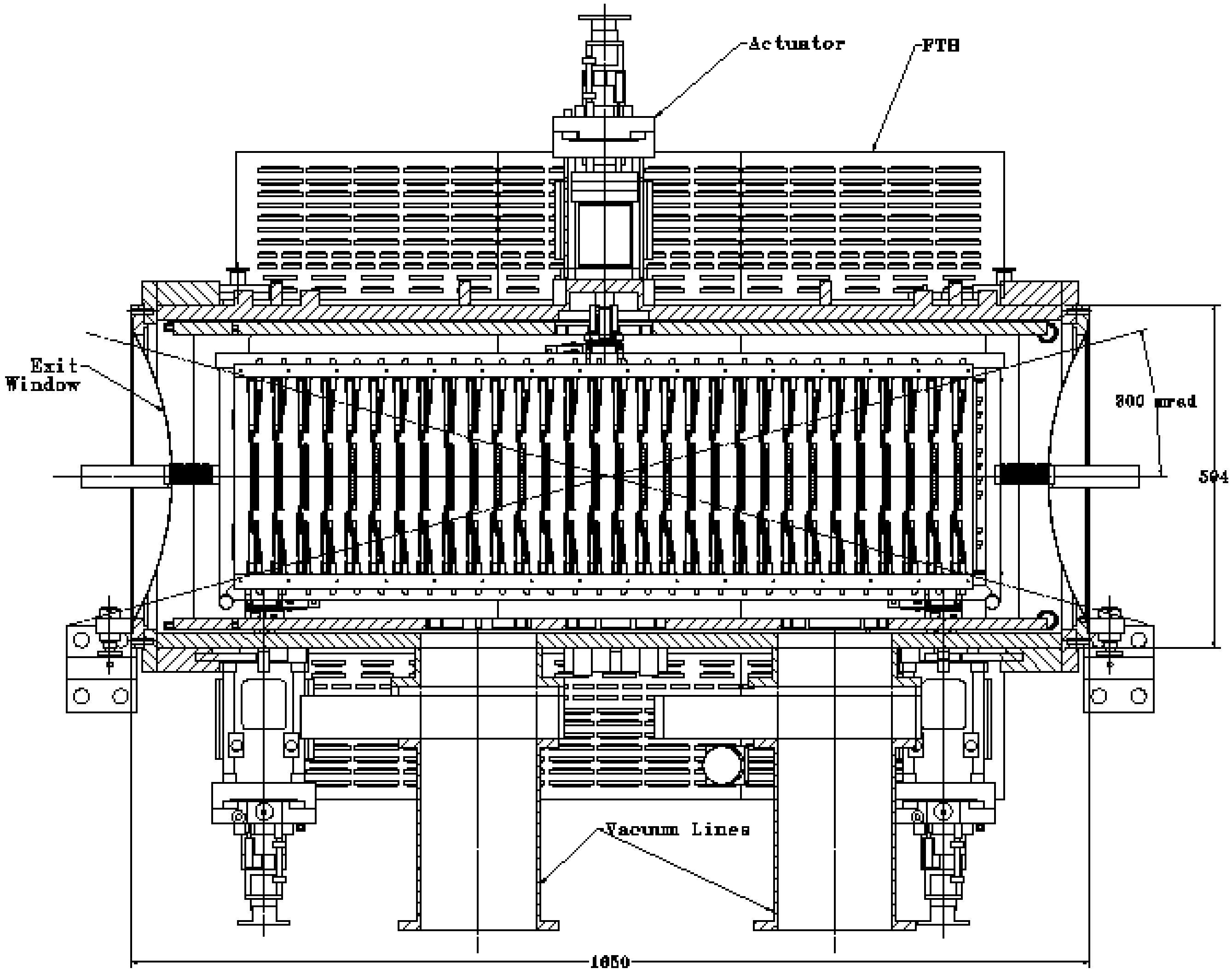




Half-Station Assembly



Moving the Half-Detectors



Estimated Material in BTeV Pixel Detector

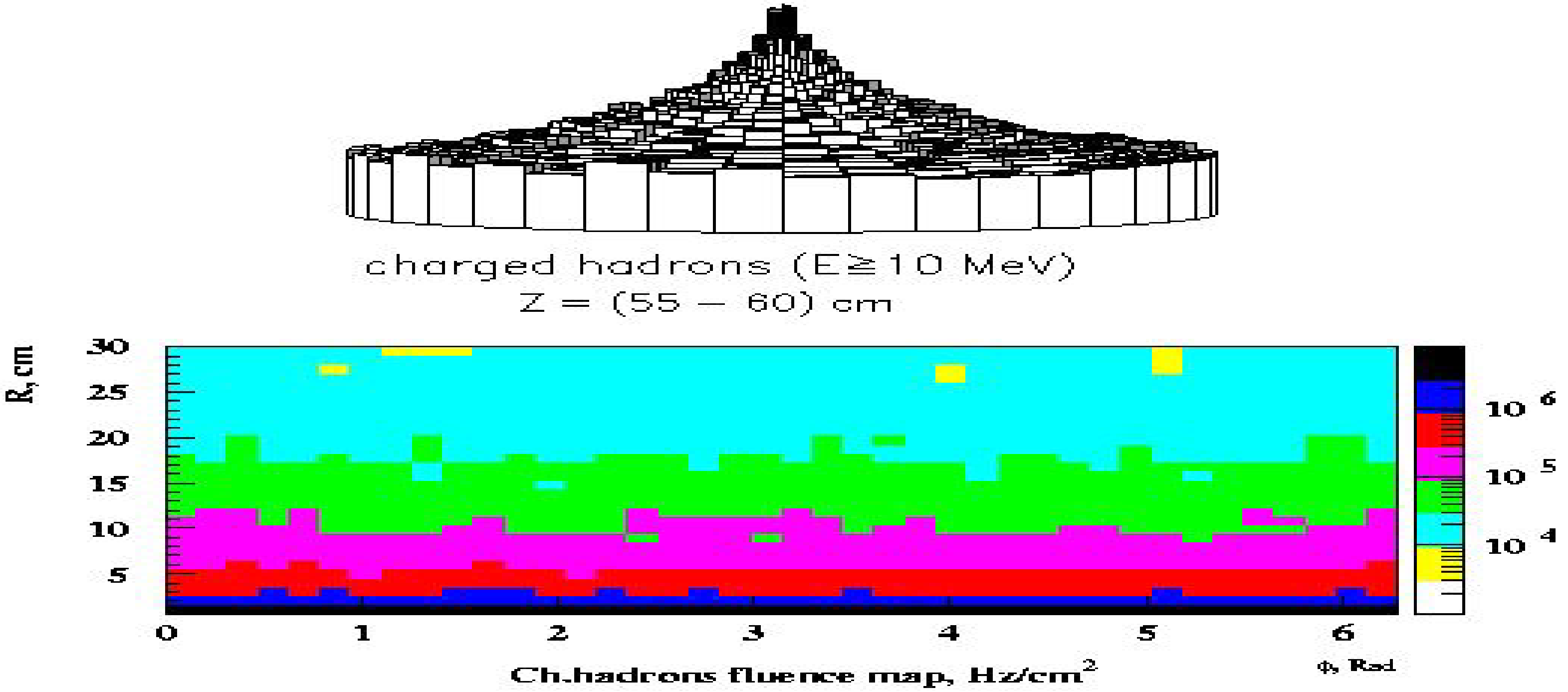
Item	Thickness, X per plane (μ)	Xo (mm)	Coverage	X/Xo per plane (%)
Sensor	250	93.6	1.46	0.39
Readout Chip	200	93.6	1.47	0.31
Bump and Wire Bonds	20	10.0	0.02	0.004
HDI and Components				0.19
Adhesive				0.02
Substrate and Cooling	675			0.17
rf Shielding (Al)	150	89.0	1.00	0.17
TOTAL				1.25

BTeV Pixel Radiation Environment

(L=2·10^{32} cm^{-2} sec^{-1})

Charged hadrons dominate.

Pixel detector at Z = (55 – 60) cm



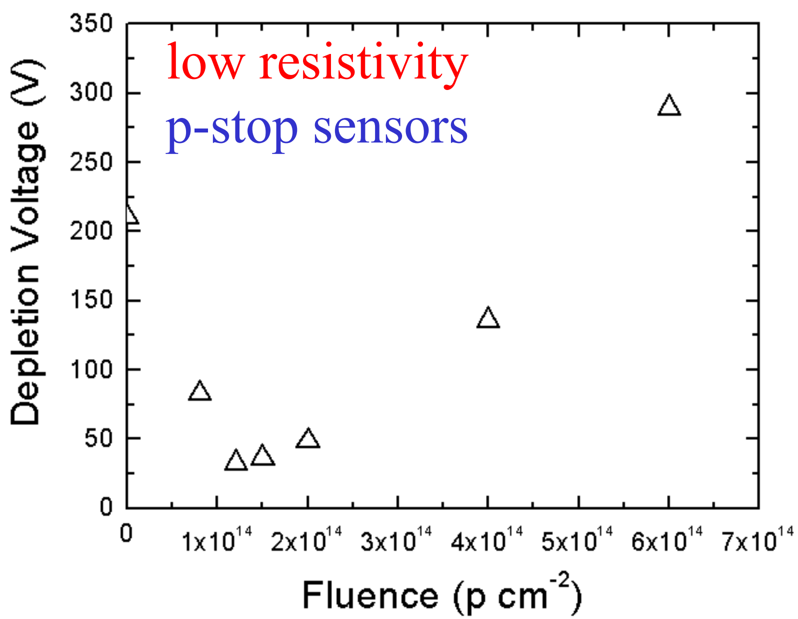
BTeV Sensor Overview

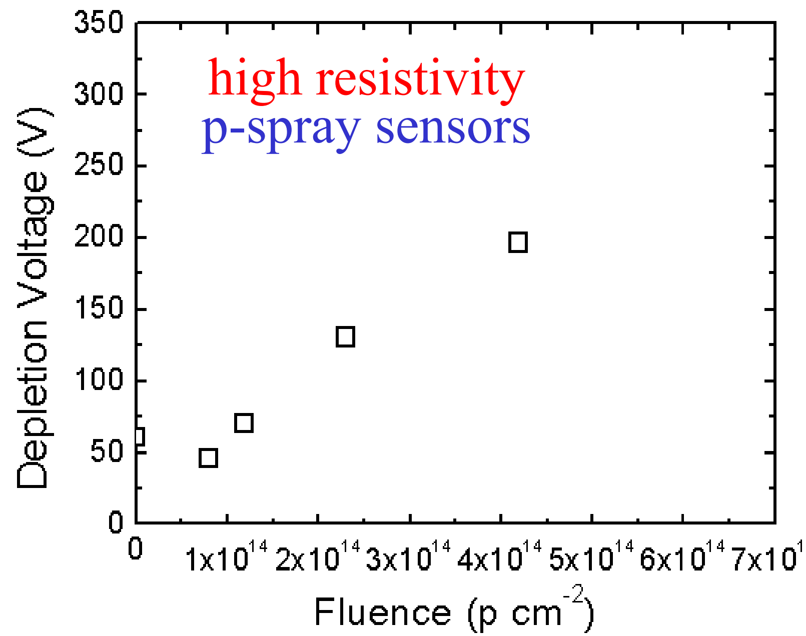
n+/n/p type, low resistivity, ~ 250 μ silicon

Undecided so far on p-spray or p-stop isolation

> 10 guard rings on p-side

Operating Temp. ~ -5° C





BTeV Readout Chip Overview

(See talk by David Christian)

3-bit FADC in each cell using multiple comparators.

Fast token passing (0.125 nsec per row, all columns in parallel)

Data-driven architecture, with in-cell data sparsification (with one setable threshold per chip).

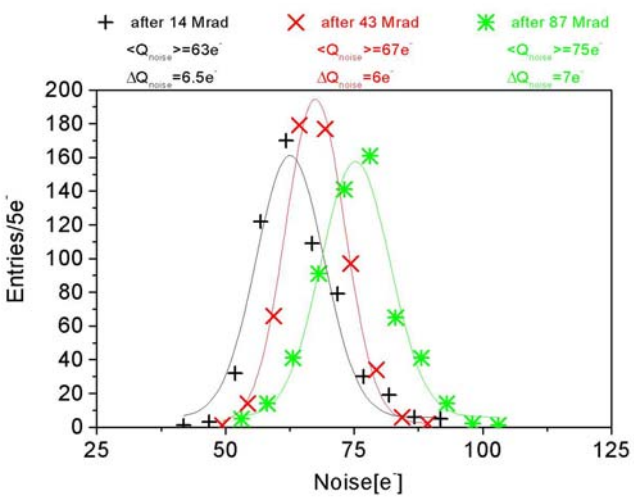
Chips closest to beam use 6 serial 140 Mbps lines (840 Mbps total), most only require 1 serial line. Total bandwidth of full pixel detector 2 Tbps.

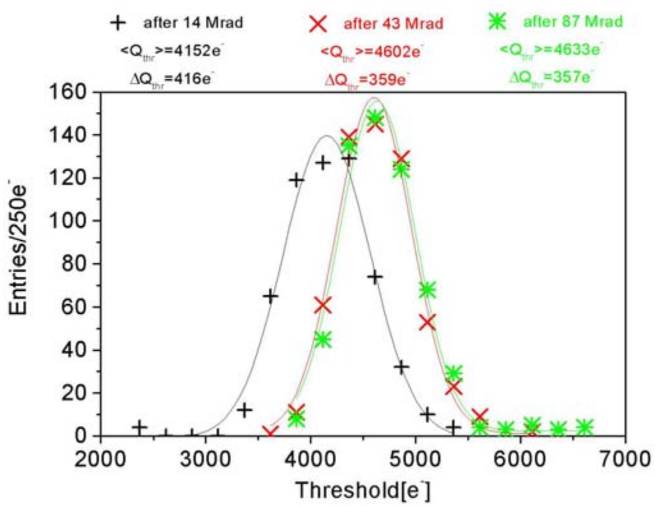
Negligible loss of data, even at 3 x nominal luminosity. Nominal luminosity = $2 \times 10^{32}\ (\mathrm{cm}^2\text{-sec})^{-1}$

Implemented in 0.25 μ CMOS technology.

Radiation Hardness of RO Chip

Measurements at 14, 43, and 87 Mrad by 200 MeV p's



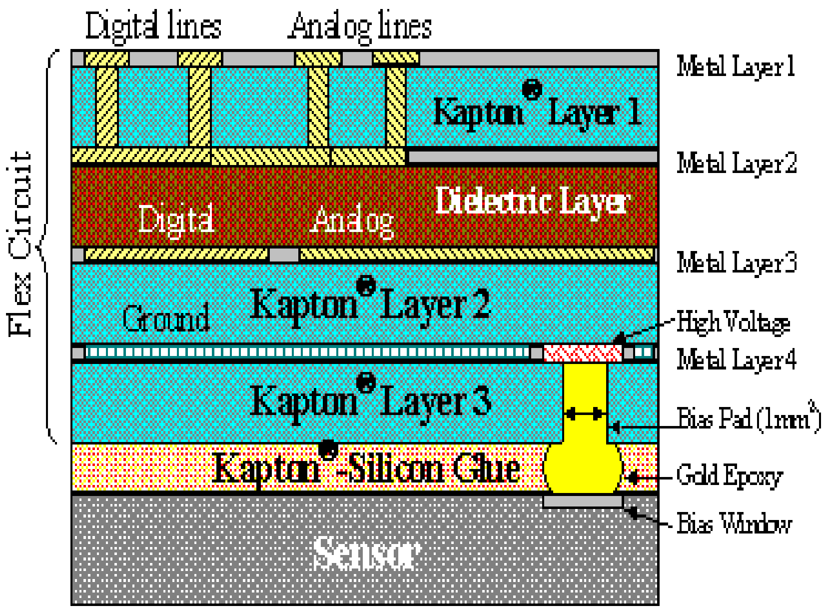


Noise Distribution

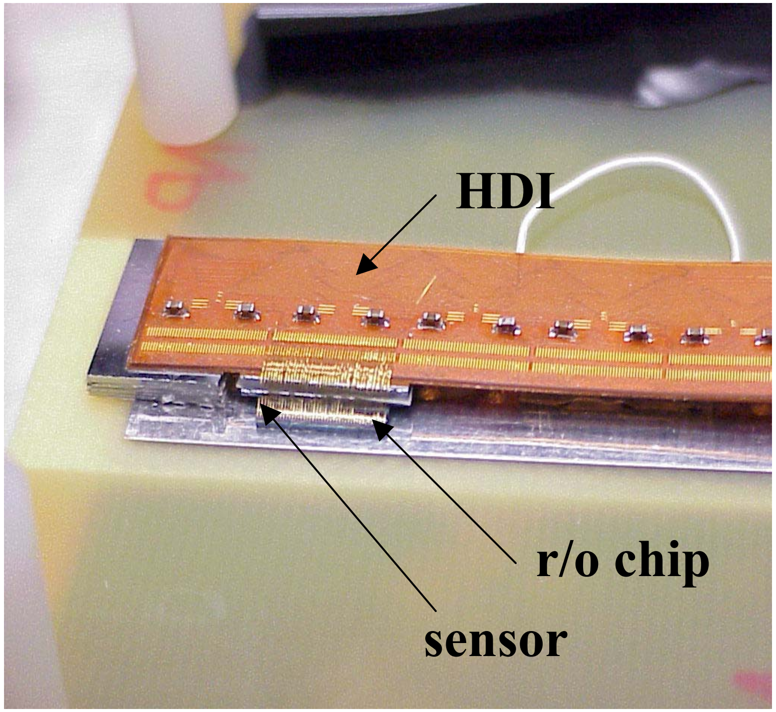
Threshold Distribution

Readout Chip Interconnections

(See talk by Sergio Zimmermann)



HDI for FPIX1



- 15 HDI delivered from CERN; only 4 without defects
- Preliminary performance assessment very satisfactory $\Rightarrow$ design validation
- We need to simplify the design for FPIX2, and find a commercial vendor for large scale production

Vacuum/Mechanical System Progress

Given the good progress on the electronic components of the system, recently turning attention more to the mechanical and cooling issues of the system.

Support substrate – "fuzzy carbon" baseline, but also looking at Be, pocofoam, pyrolytic graphite.

Getting signals out of vacuum using pc feed-through board.

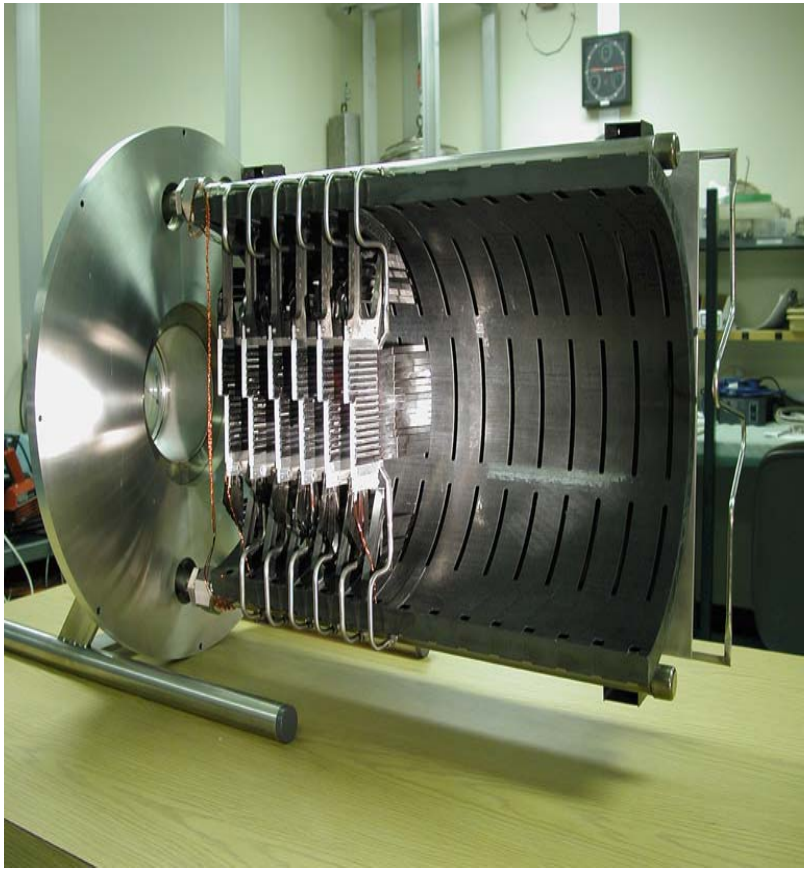
Final vacuum level using cryopanel for water pumping

Air-actuated prototype mover tested.

Vacuum: Outgassing Tests

on a 5% of full size system

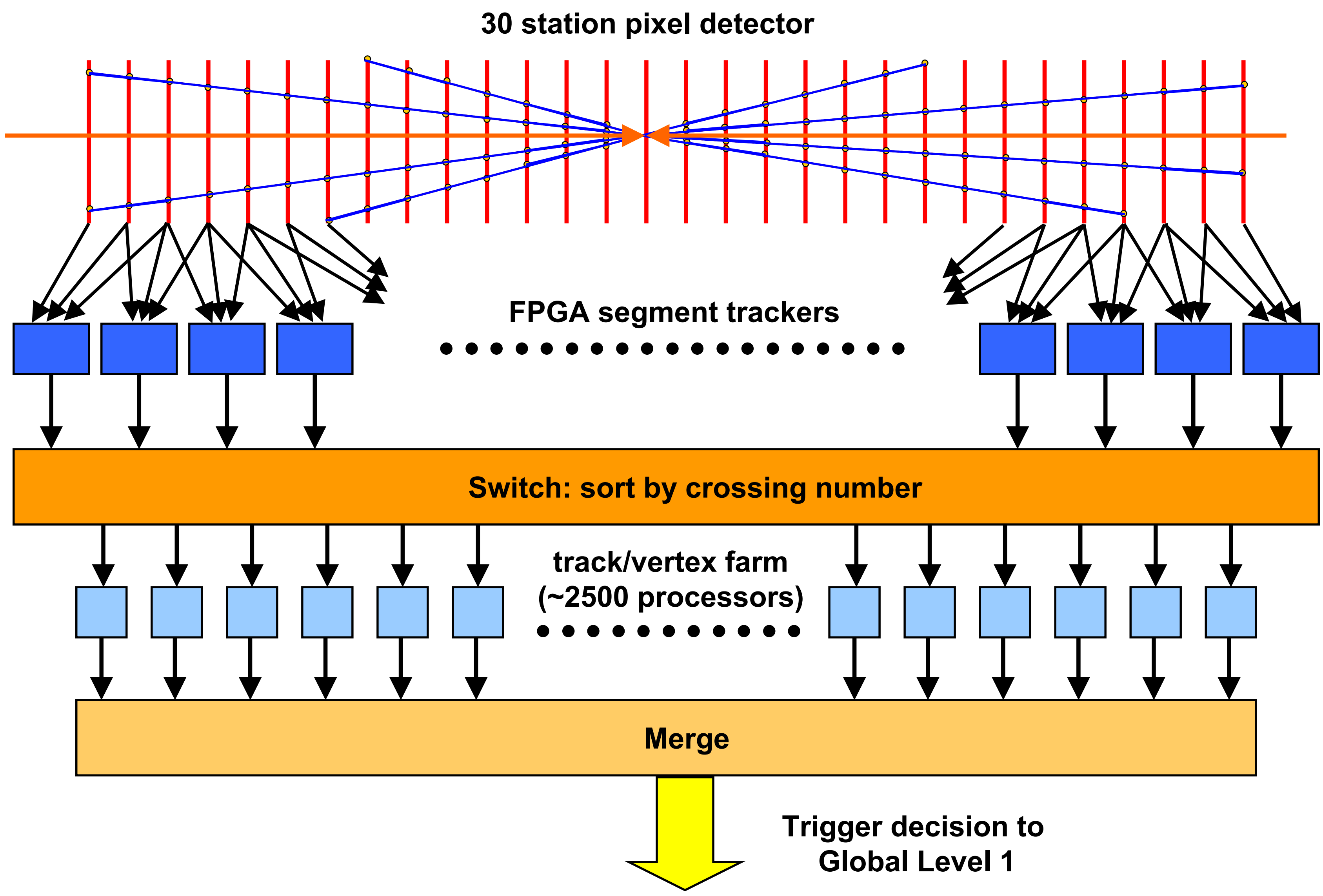
(See talk by Mayling Wong)



Chip Control and Data to the Trigger/DAQ

- Programmable interface on chip.
  - 14 DACs on chip control bias currents, thresholds, etc.
  - Each cell has kill (disable) and inject (test) control bits.
  - Four independent reset levels (2 hardware, 2 software).
  - Configuration read-back.
  - No daisy-chain between chips.
  - Wire bond chip ID on chip.
- Point to point connection between pixel readout chips and Data Combiner Board (DCB).
  - Digital I/O through LVDS signals.
  - DCB located behind the magnet (30 foot cable).
- Information for each hit pixel cell:
  - Row and column of hit cell (chip ID added by DCB)
  - 8 bit timestamp extended by DCB.
  - 3 bit ADC on each cell for pulse height

Level 1 Vertex Trigger Architecture



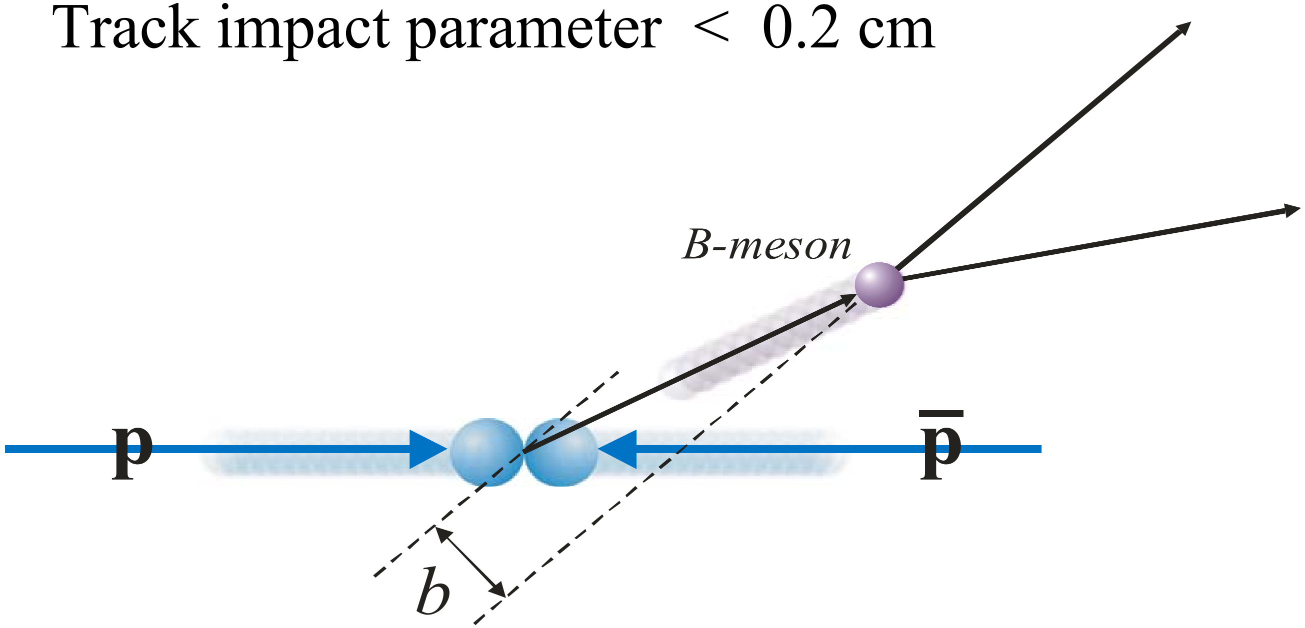
Simplified Overview of Trigger Algorithm

Generate Level-1 Trigger accept if >2 “detached” tracks in the BTeV pixel detector satisfy:

$$p_T^2 > 0.25 \ (\mathrm{GeV}/c)^2$$

Track impact parameter $> m\,\sigma$

Track impact parameter < 0.2 cm

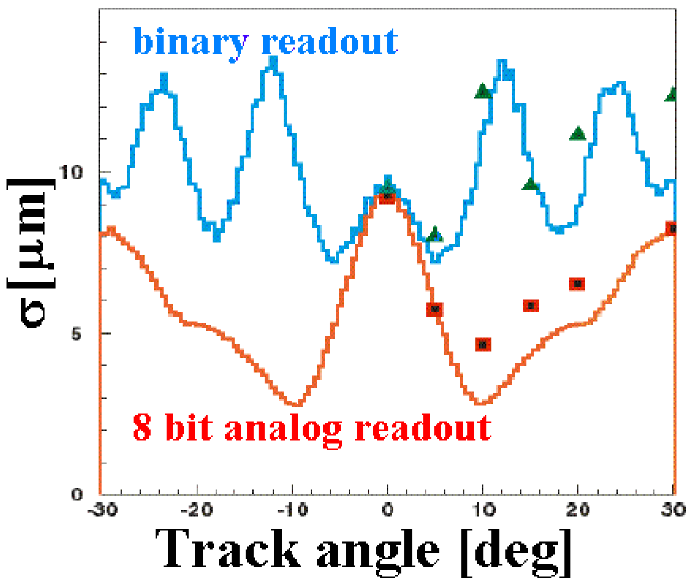


Level 1 Trigger Efficiencies

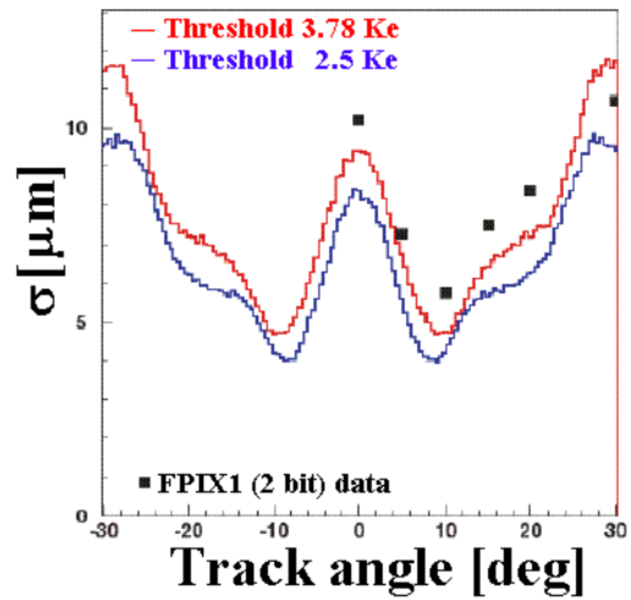
Process	Eff. (%)	Monte Carlo
Minimum bias	1	BTeVGeant
$B_s \rightarrow D^+_s K^-$	74	BTeVGeant
$B^0 \rightarrow D^{*+} \rho^-$	64	BTeVGeant
$B^0 \rightarrow \rho^0 \pi^0$	56	BTeVGeant
$B^0 \rightarrow J/\psi K_s$	50	BTeVGeant
$B_s \rightarrow J/\psi K^{*0}$	68	MCFast
$B^- \rightarrow D^0 K^-$	70	MCFast
$B^- \rightarrow K_s \pi^-$	27	MCFast
B^0 2-body modes $(\pi^+\pi^-, K^+\pi^-, K^+K^-)$	63	MCFast

Previous Test Beam Results

Good agreement between data and BTeV pixel detector simulation package with input parameters describing the detector properties (such as V_{bias}, V_{dep}, threshold, noise, …) corresponding to the sensors used in the test beam.

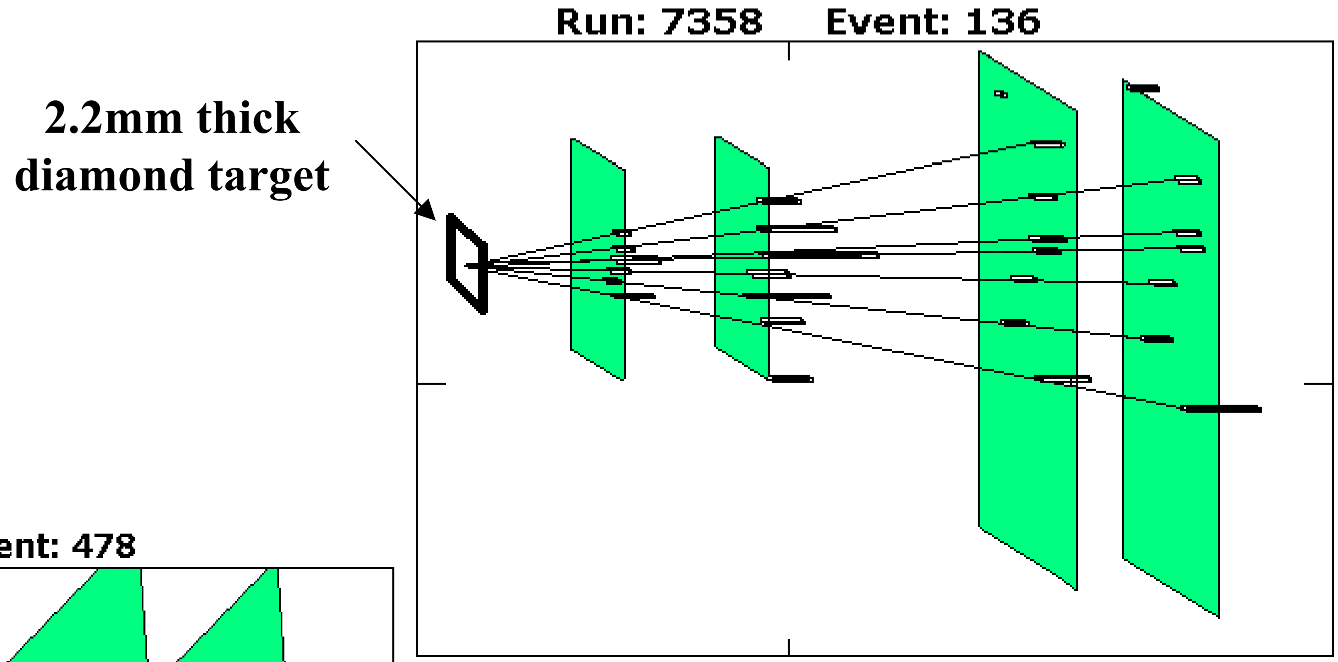


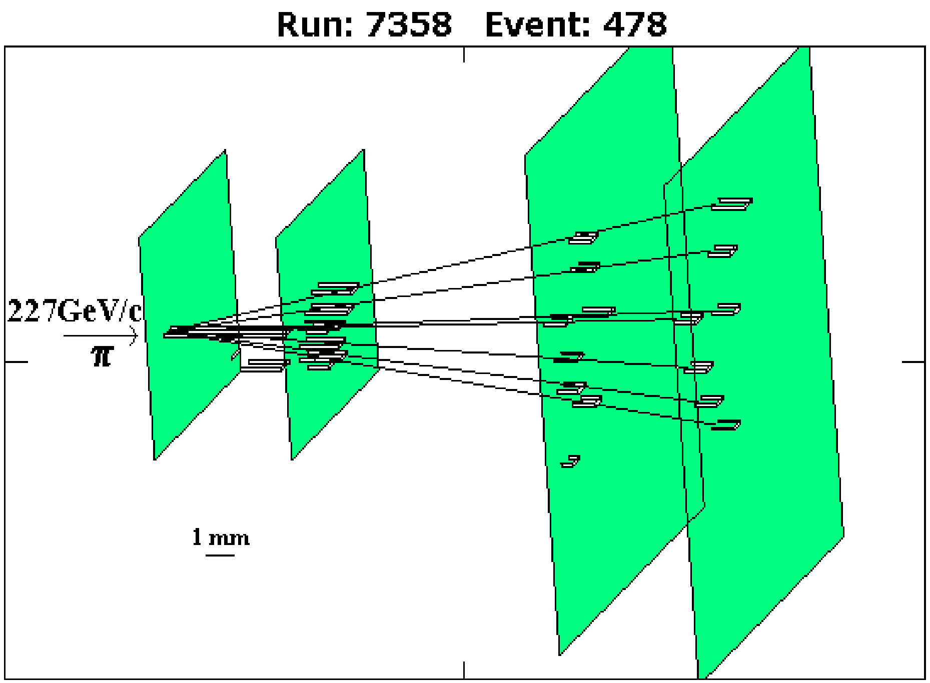
Comparison of FPIX0 test-beam data and simulation for binary and 8 bit analog readout. Threshold 2.5 Ke$^-$.



Comparison of FPIX1 test-beam data and simulation for 2 bit analog readout and 2 values of threshold

Examples from BTeV Test Beam





Excellent tracking capability, even in high track environments.

Goals for Autumn Test Beam Run

Use previous generation BTeV pixel detectors for beam telescope.

Study charge collection in irradiated detectors, for both p-spray and p-stop isolation.

Study operation of multi-chip module, including region between readout chips.

Study operation of multi-chip module with big variation in radiation level across module.

Other R&D Efforts

Full size (22 column by 128 row) FPIX2

Simulation of charge collection in p-stop and p-spray sensors to help settle final choice

Prototype substrates

Test idea of using cryo-pump cooling for detector cooling to – 5^{o} C

Test various rf shield techniques from Al sheet to screen to wires parallel to beam pipe

Aim at a 10% test of final system

Who's Working on the BTeV Pixel System?

Fermilab: J. A. Appel, G. Chiodini, D. C. Christian, S. Cihangir, M. R. Coluccia, R. Kutschke, S. Kwan, M. Marinelli, M. Wang, G. Cardoso, H. Cease, C. Gingu, B. K. Hall, J. Hoff, A. Mekkaoui, T. Tope, M. Turqueti, R. Yarema, S. Zimmermann, J. Howell, C. Kendziora, C.M. Lei, A. Shenai, A. Toukhtarov, M.L. Wong , D. Slimmer, D. Zhang, S. Austin, S. Jakubowski, R. Jones, G. Sellberg

Iowa: C. Newsom, T. Nguyen, J. Morgan

Milano: G. Alimonti, S. Magni, D. Menasce, L. Moroni, D. Pedrini, S. Sala, L. Uplegger

Syracuse: M. Artuso, P. Gelling, C. Boulahouache, J.C. Wang

Wayne State: D. Cinabro, G. Bonvicini, A. Schriener, A. Guiterrez, G. Gallay, S. LaPointe

Wisconsin: M. Sheaff