The BTeV Experiment: Physics and Detector

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K. Honscheid
Ohio State University

B Physics Today

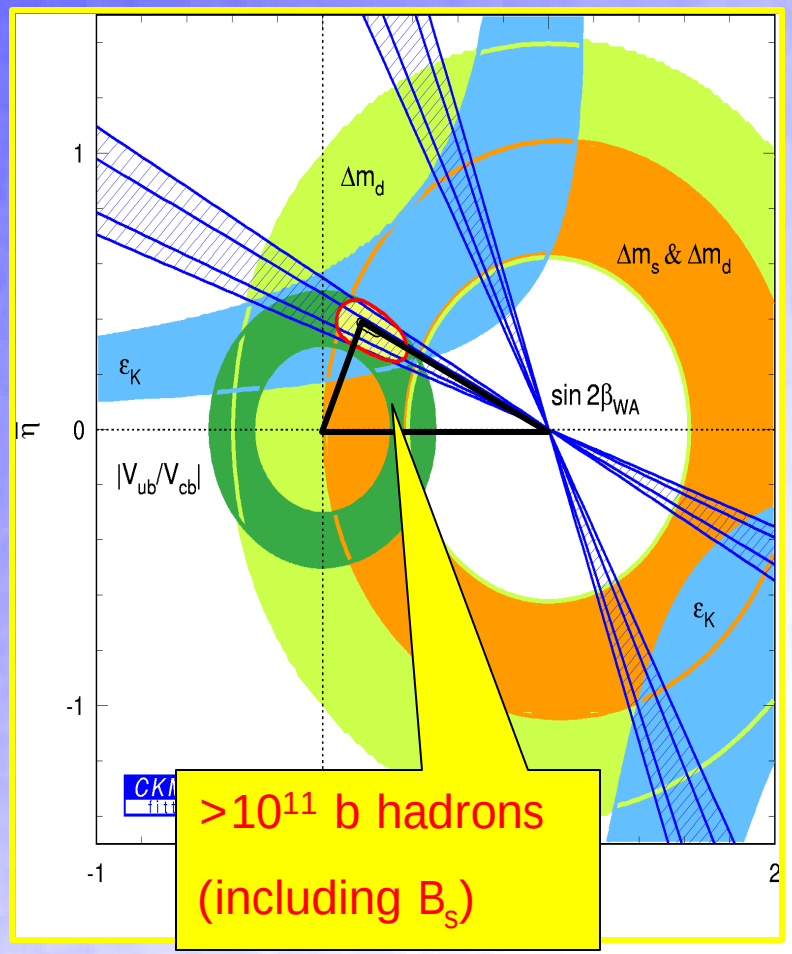
- CKM Picture okay

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- CP Violation observed

$\sin(2\beta) = 0.734 \pm 0.054$

- No conflict with SM

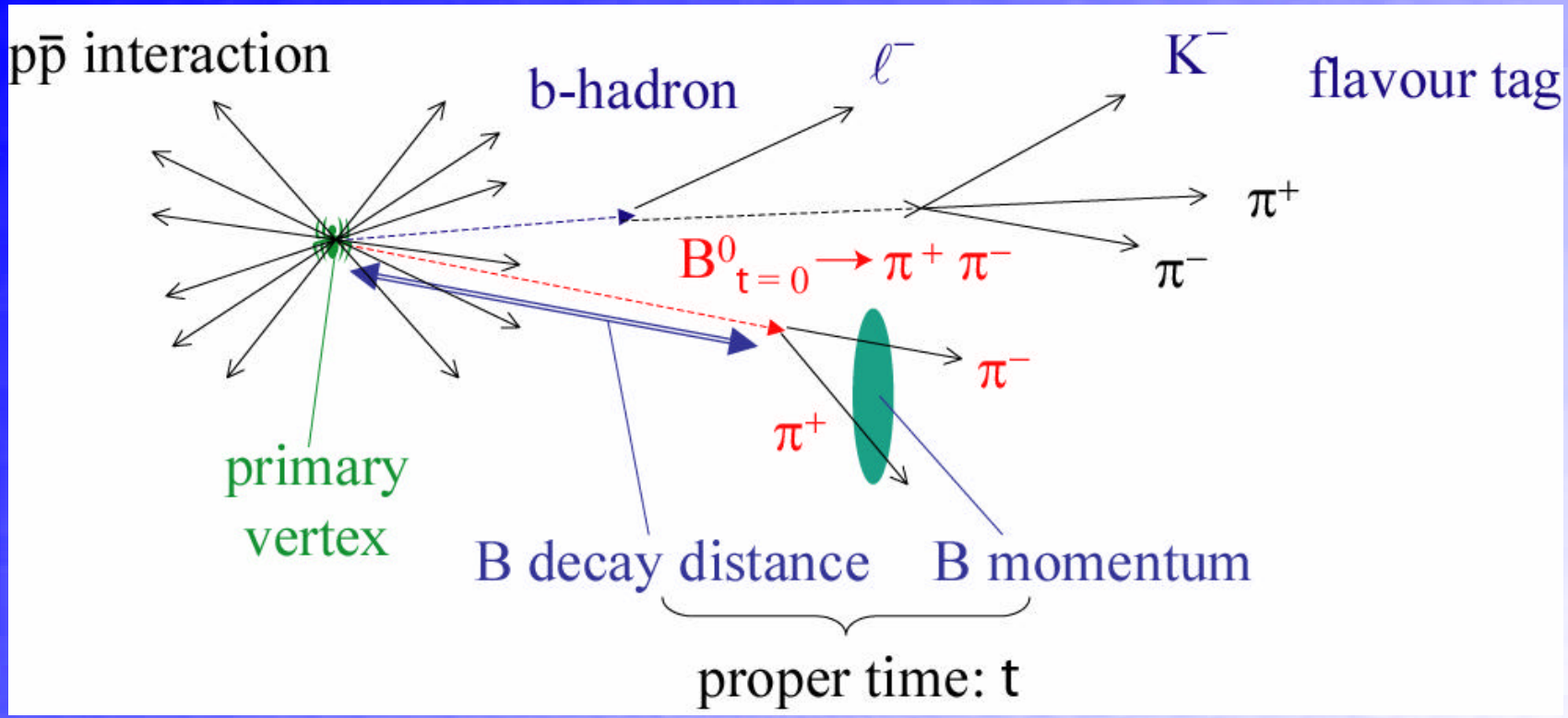


B Physics at Hadron Colliders

	Tevatron	LHC
Energy	2 TeV	14 TeV
b cross section	~100 mb	~500 mb
c cross section	~1000 mb	~3500 mb
b fraction	2×10^{-3}	6×10^{-3}
Inst. Luminosity	2×10^{32}	$> 2 \times 10^{32}$
Bunch spacing	132 ns (396 ns)	25 ns
Int./crossing	<2> (<6>)	<1>
Luminous region	30 cm	5.3 cm

- Large cross sections
- Triggering is an issue
- All b-hadrons produced (B, B_s, B_c, b-baryons)

Detector Requirements



- Trigger, trigger, trigger
- Vertex, decay distance
- Momentum
- PID
- Neutrals (γ, π^0)

From F. Teubert

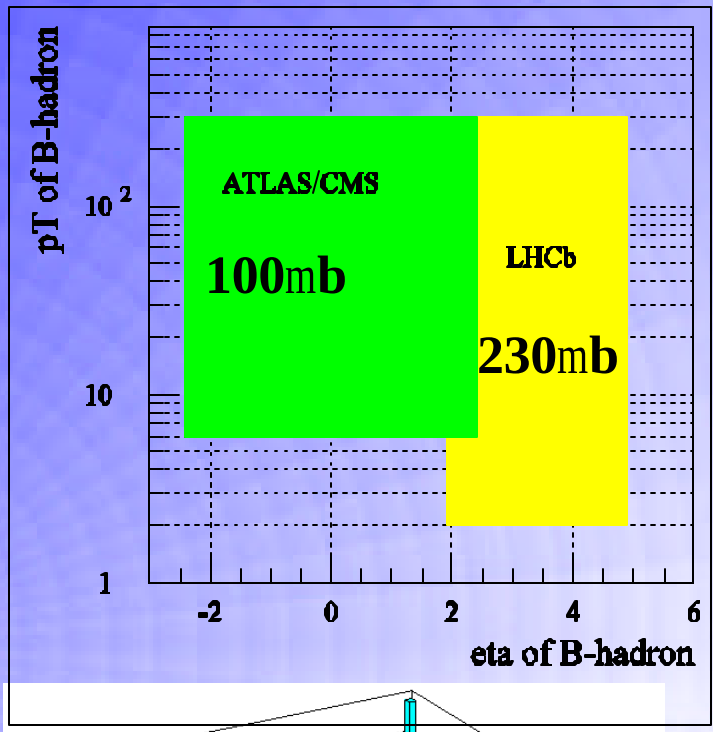
Forward vs. Central Geometry

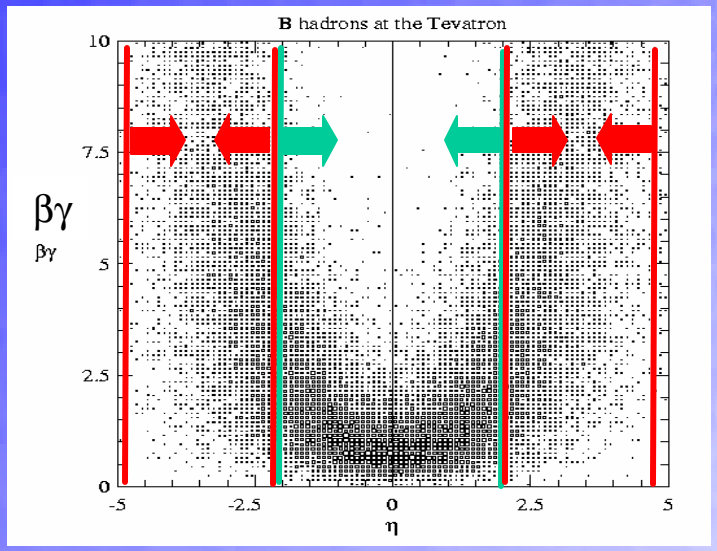
Multi-purpose experiments require large solid angle coverage.

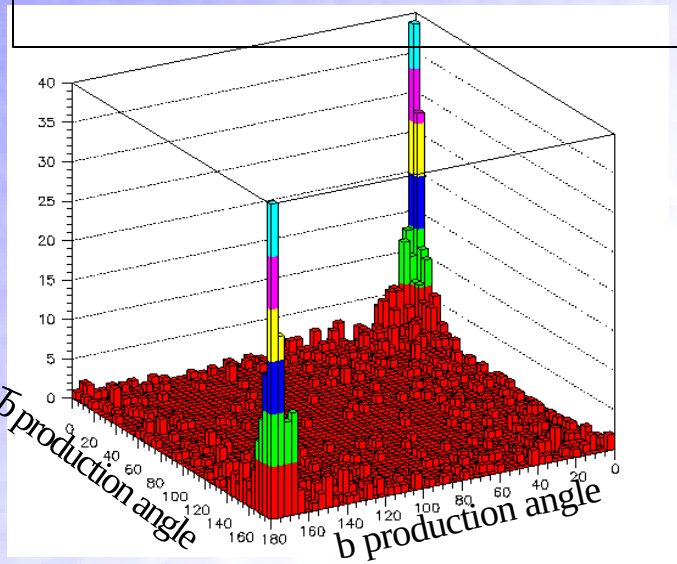
➡ Central Geometry (CDF, D0, Atlas, CMS)

Dedicated B experiments can take advantage of

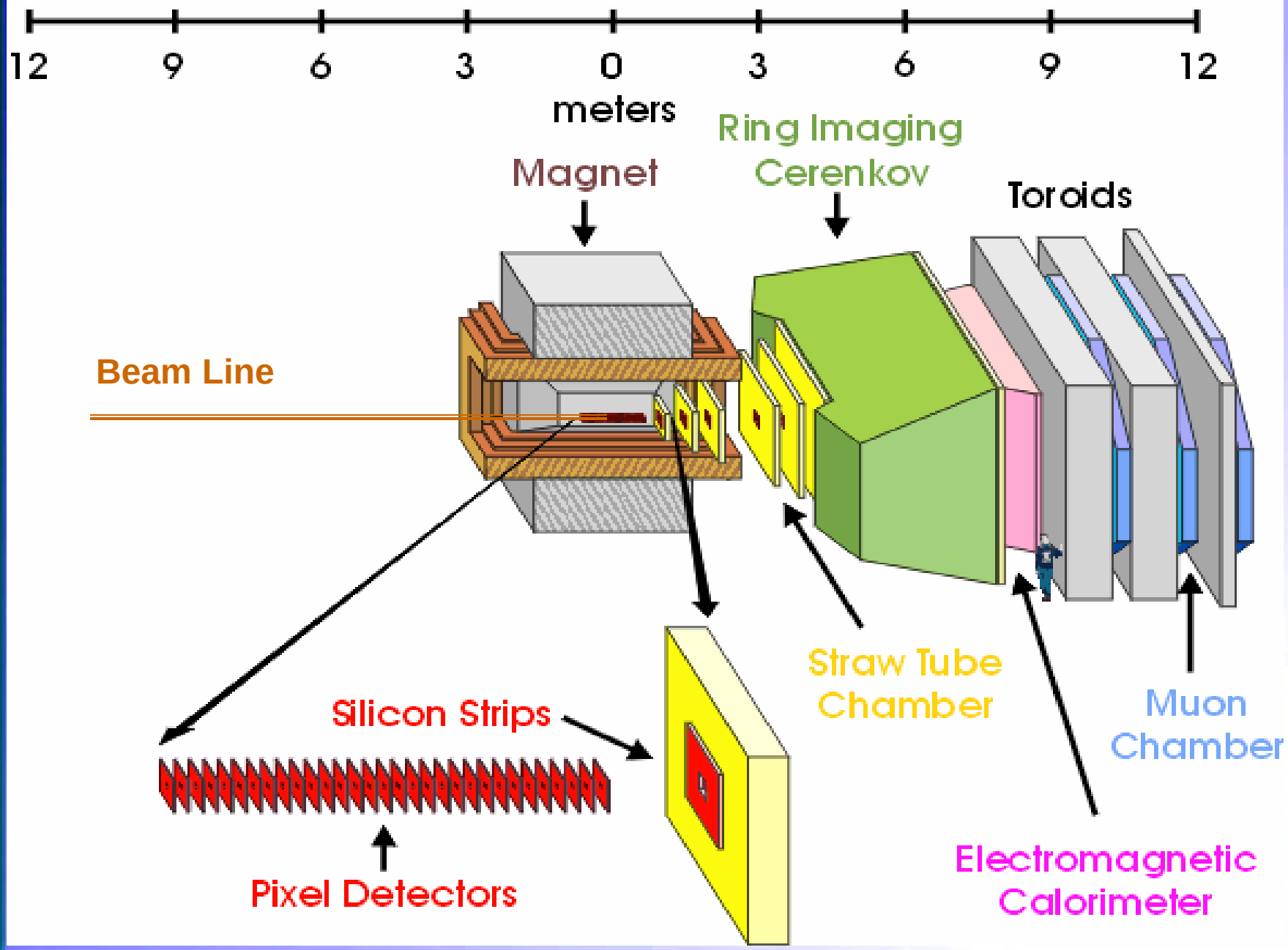
➡ Forward geometry (BTeV, LHCb)







The BTeV Detector



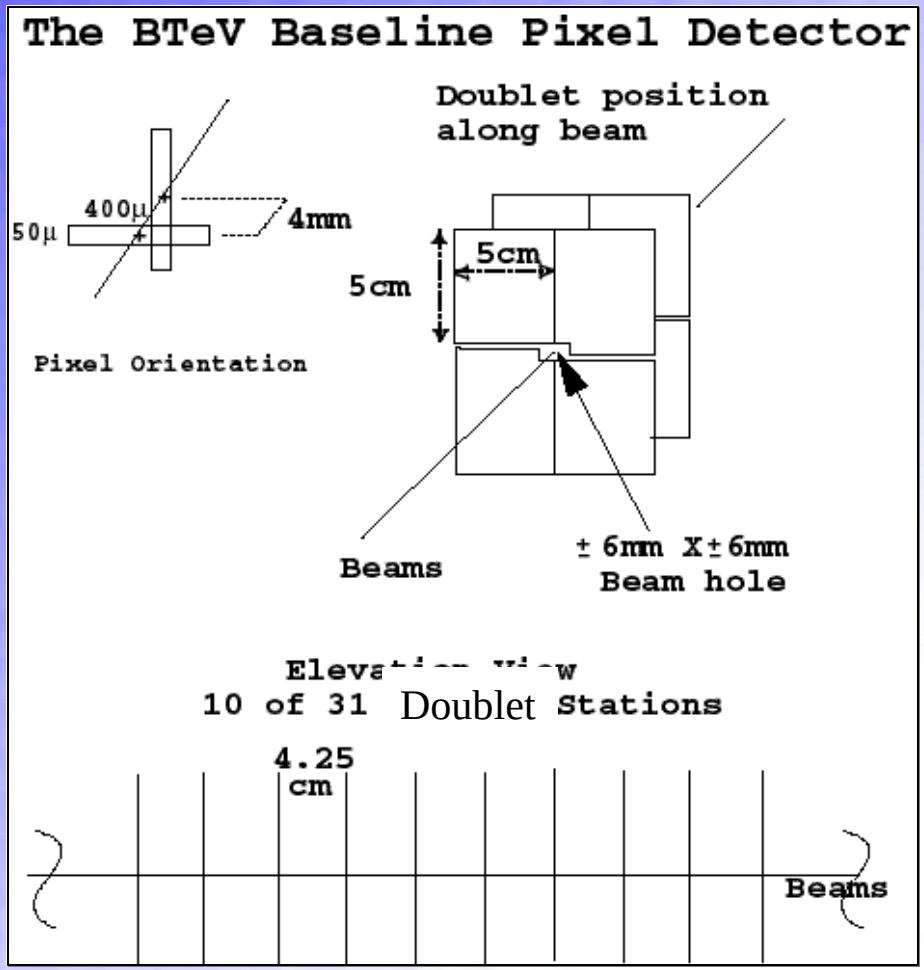
Pixel Vertex Detector

Reasons for Pixel Detector:

- Superior signal to noise
- Excellent spatial resolution -- 5-10 microns depending on angle, etc
- Very Low occupancy
- Very fast
- Radiation hard

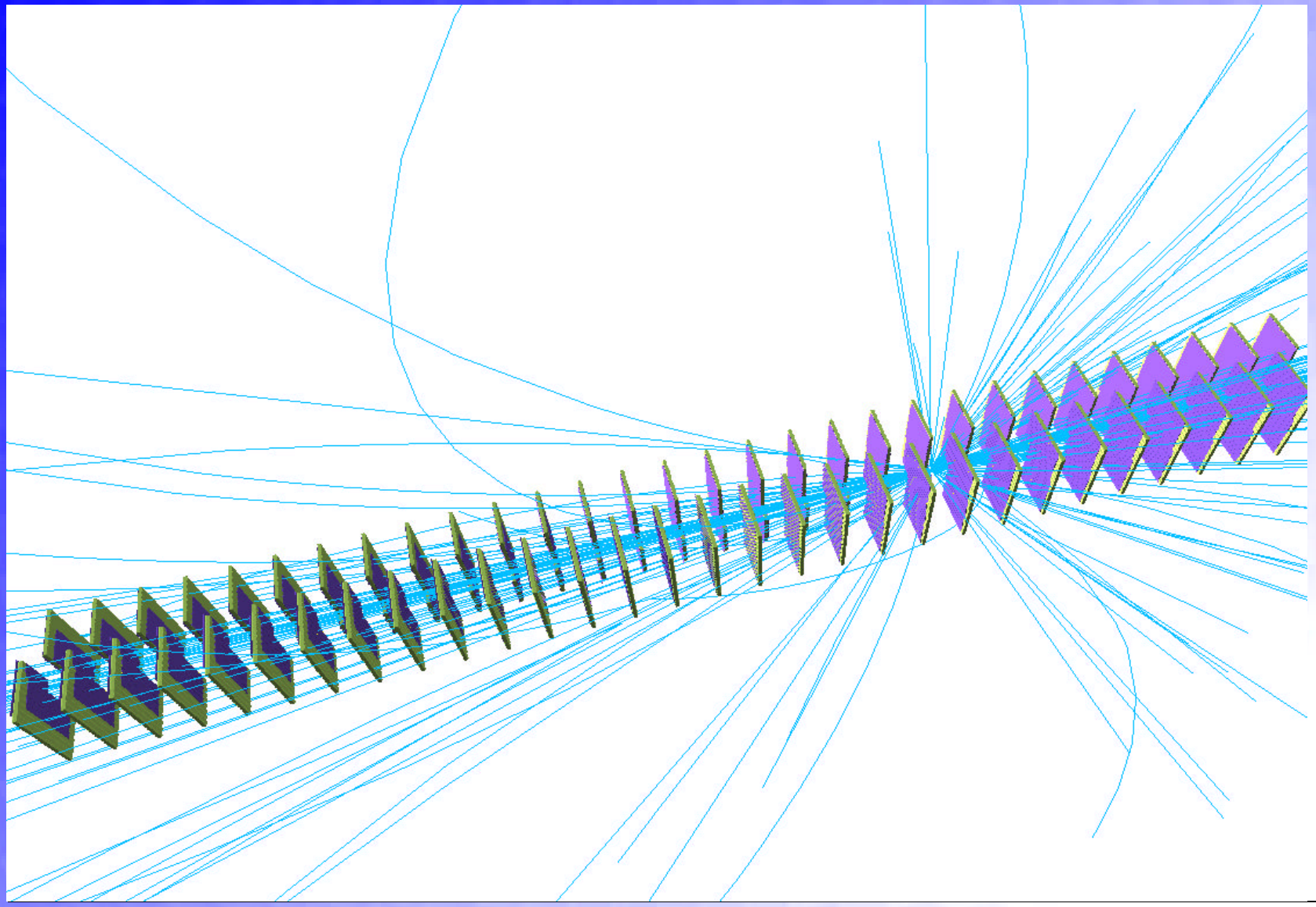
Special features:

- It is 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



The Pixel Detector II

Simulated B Bbar, Pixel Vertex Detector



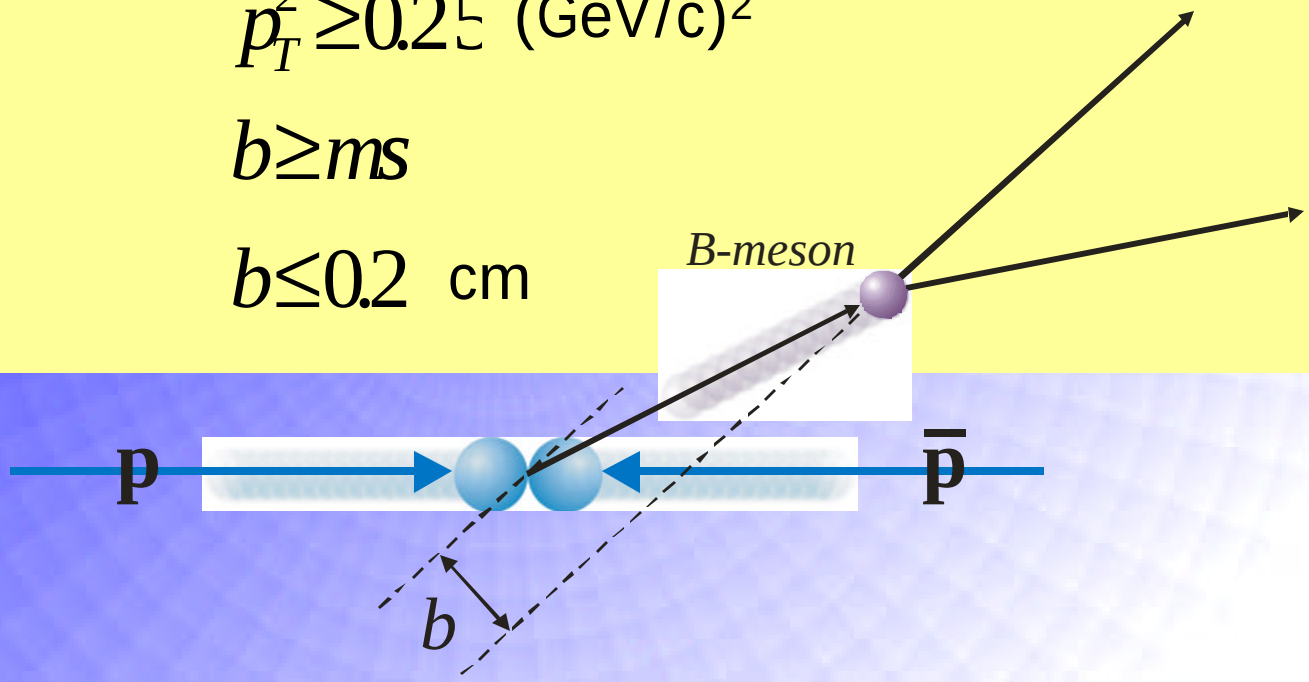
L1 vertex trigger algorithm

- Generate Level-1 accept if ≥ 2 "detached" tracks in the BTeV pixel detector satisfy:

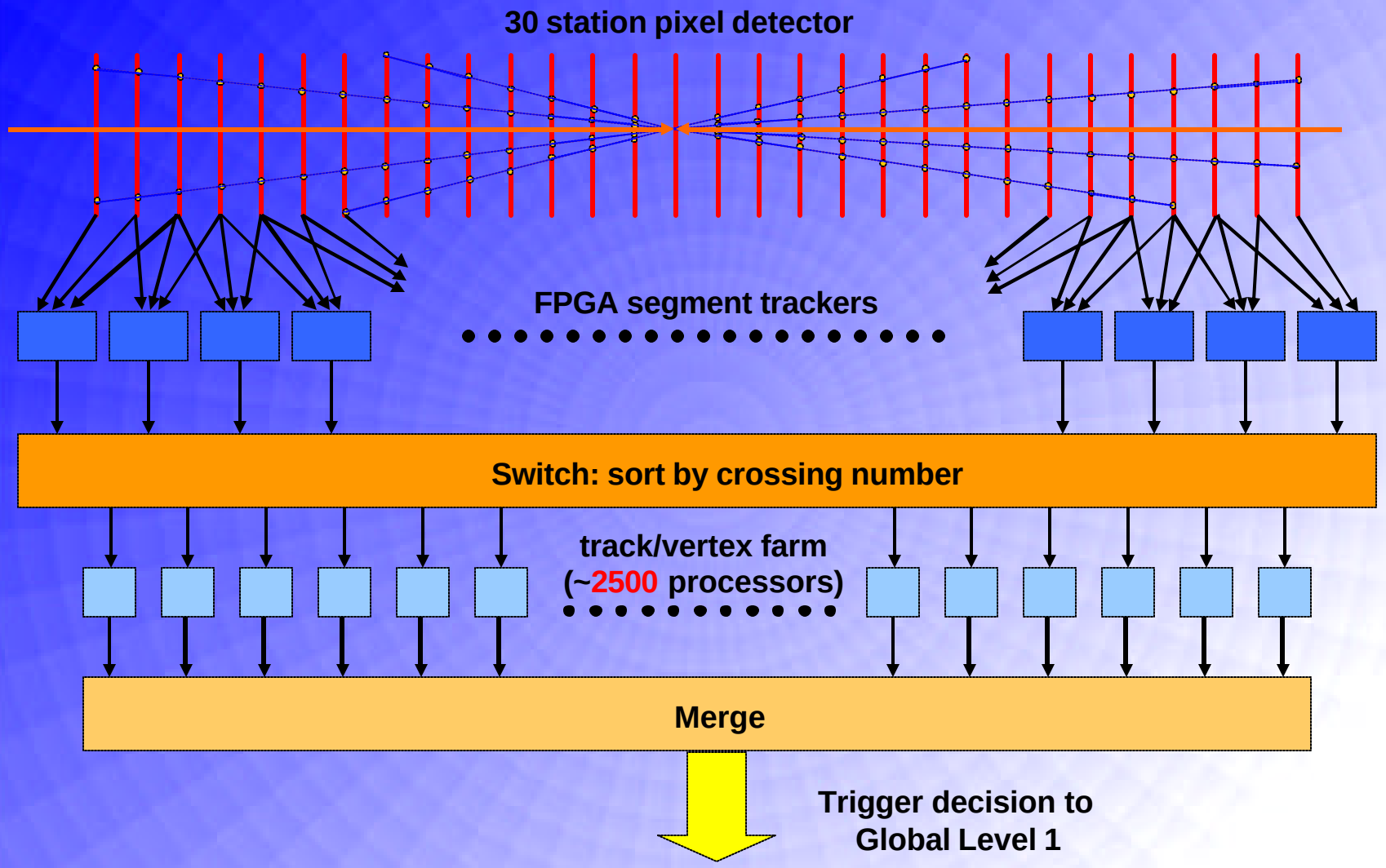
$$p_T^2 \geq 0.25 \text{ (GeV/c)}^2$$

$$b \geq ms$$

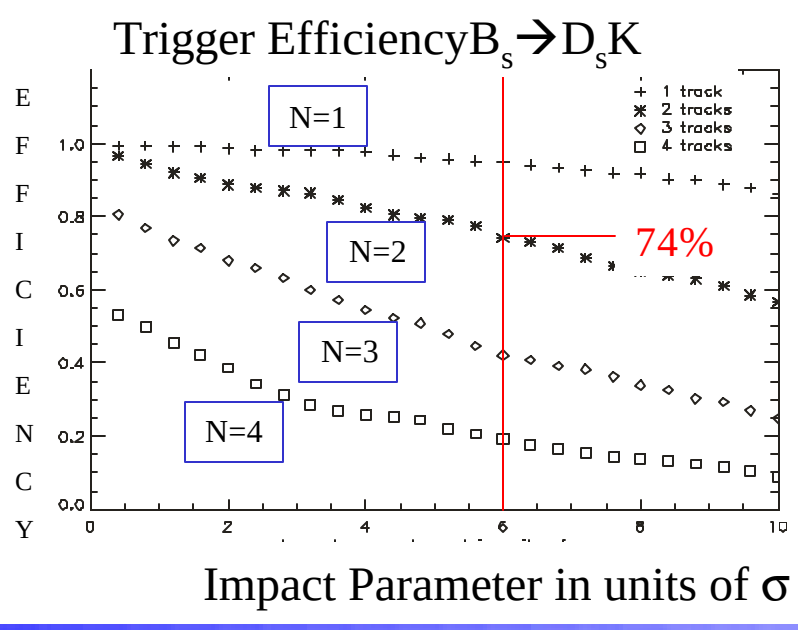
$$b \leq 0.2 \text{ cm}$$

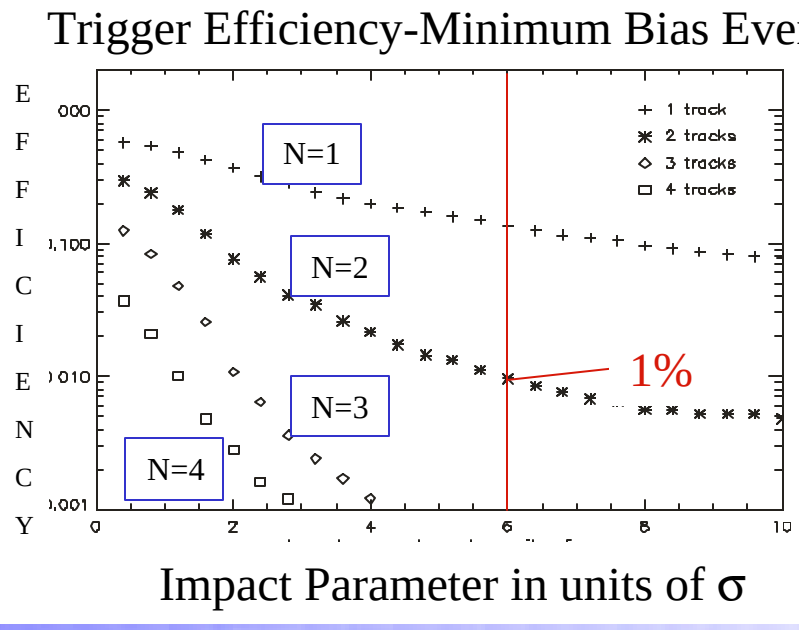


Level 1 vertex trigger architecture



Efficiencies and Tagging





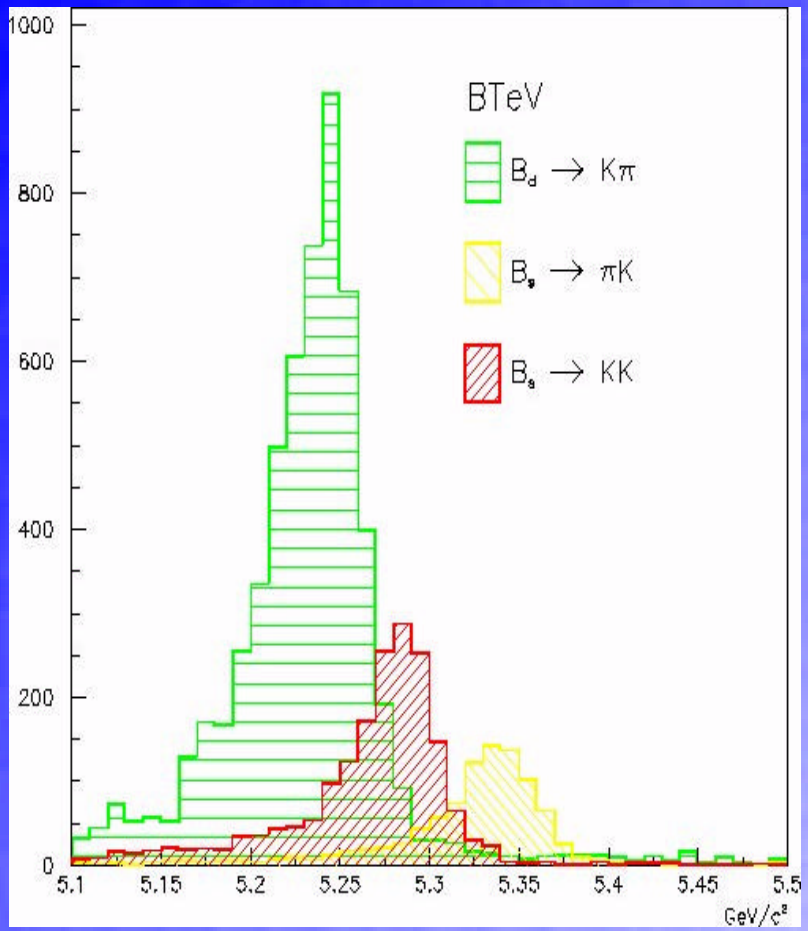
- For a requirement of at least 2 tracks detached by more than 6σ, we trigger on only 1% of the beam crossings and achieve the following trigger efficiencies for these states (<2> int. per crossing):

Decay	efficiency(%)	Decay	efficiency(%)
$B \rightarrow \pi^+\pi^-$	63	$B^o \rightarrow K^+\pi^-$	63
$B_s \rightarrow D_s K$	74	$B^o \rightarrow J/\psi\, K_s$	50
$B^- \rightarrow D^o K^-$	70	$B_s \rightarrow J/\psi K^*$	68
$B^- \rightarrow K_s \pi^-$	27	$B^o \rightarrow K^* \gamma$	40

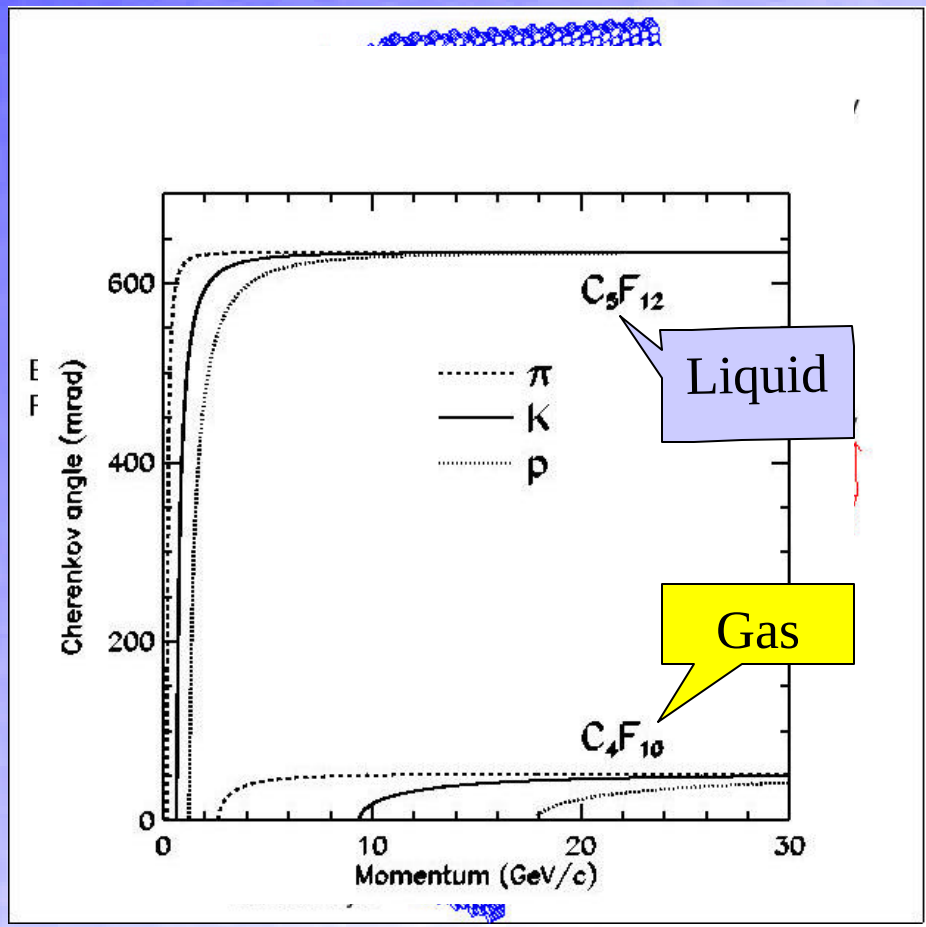
The Physics Goals

- There is New Physics out there:
  - Baryon Asymmetry of Universe & by Dark Matter
  - Hierarchy problem
  - Plethora of fundamental parameters
  - ...
- B Experiments at Hadron Colliders are well positioned to:
  - Perform precision measurements of CKM Elements with small model dependence.
  - Search for New Physics via ~~CP~~ phases
  - Search for New Physics via Rare Decays
  - Help interpret new results found elsewhere (LHC, neutrinos)
  - Complete a broad program in heavy flavor physics
    - Weak decay processes, *B*'s, polarization, Dalitz plots, QCD...
    - Semileptonic decays including Λ_b
    - b & c quark Production
    - Structure: B(s) spetroscopy, b-baryon states
    - B_c decays

Importance of Particle Identification

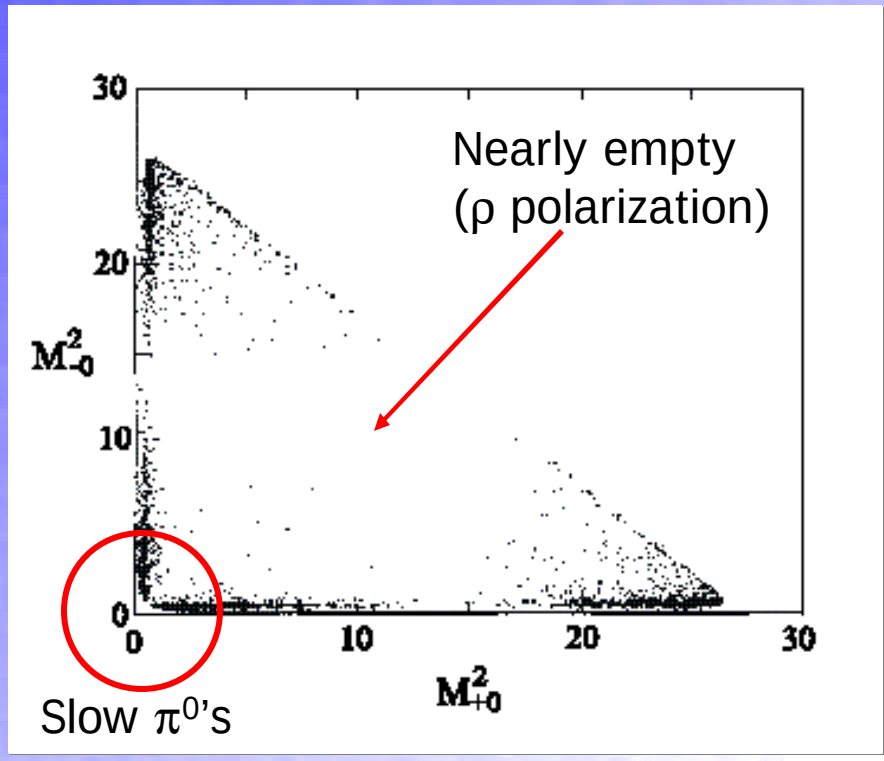


BTeV RICH Detector



Measuring a Using $B^0 \to \rho\pi \to \pi^+\pi^-\pi^0$

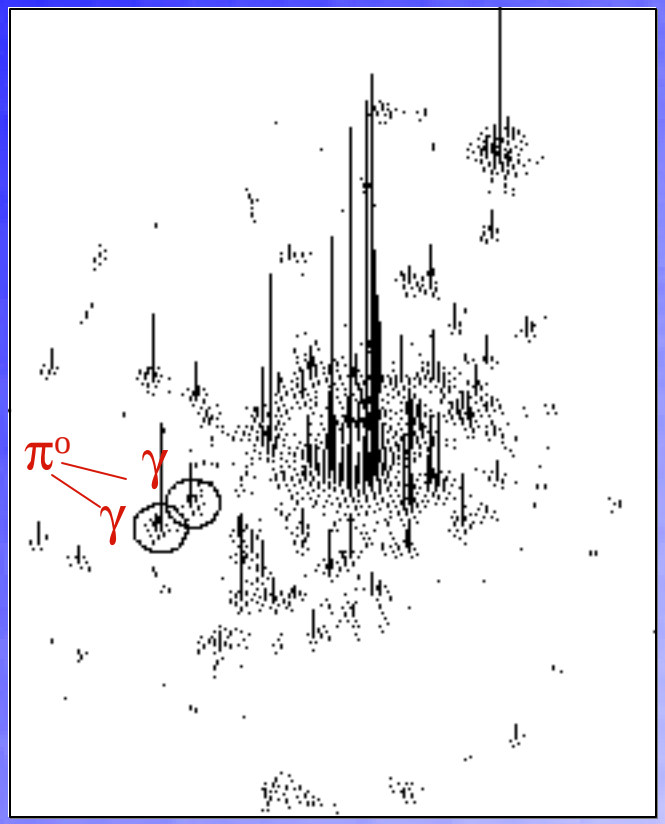
- A Dalitz Plot analysis gives **both** sin(2α) and cos(2α) (Snyder & Quinn)
- Measured branching ratios are:
  - $B(B^- \to \rho^0\pi^-) = \sim 10^{-5}$
  - $B(B^0 \to \rho^-\pi^+ + \rho^+\pi^-) = \sim 3\times10^{-5}$
  - $B(B^0 \to \rho^0\pi^0) < 0.5\times10^{-5}$
- Snyder & Quinn showed that 1000-2000 tagged events are sufficient
- Not easy to measure
  - π^0 reconstruction
- Not easy to analyze
  - 9 parameter likelihood fit

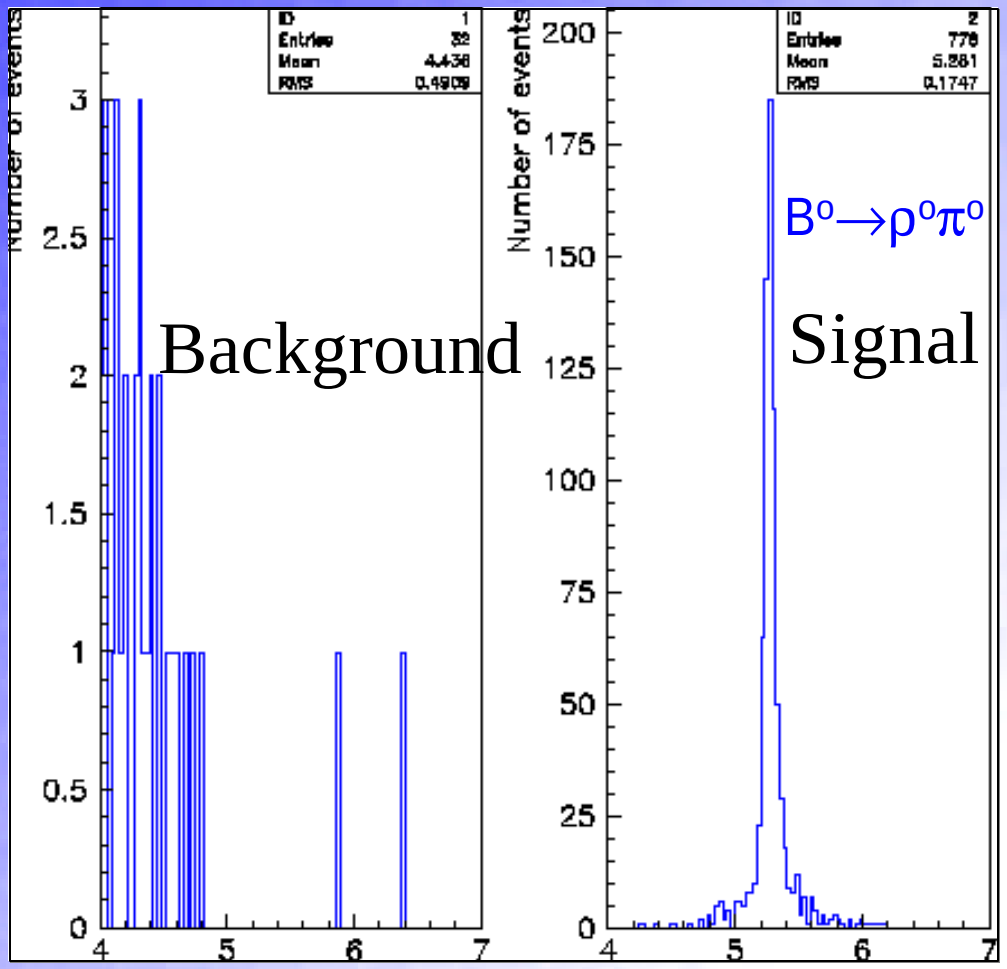


Dalitz Plot for $B^0 \to \rho\pi$

Yields for $B^o \to \rho\pi$

- Based 9.9×10^6 background events
- $B^o \to \rho^+\pi^-$
  5400 events, S/B = 4.1
- $B^o \to \rho^o\pi^o$
  780 events, S/B = 0.3

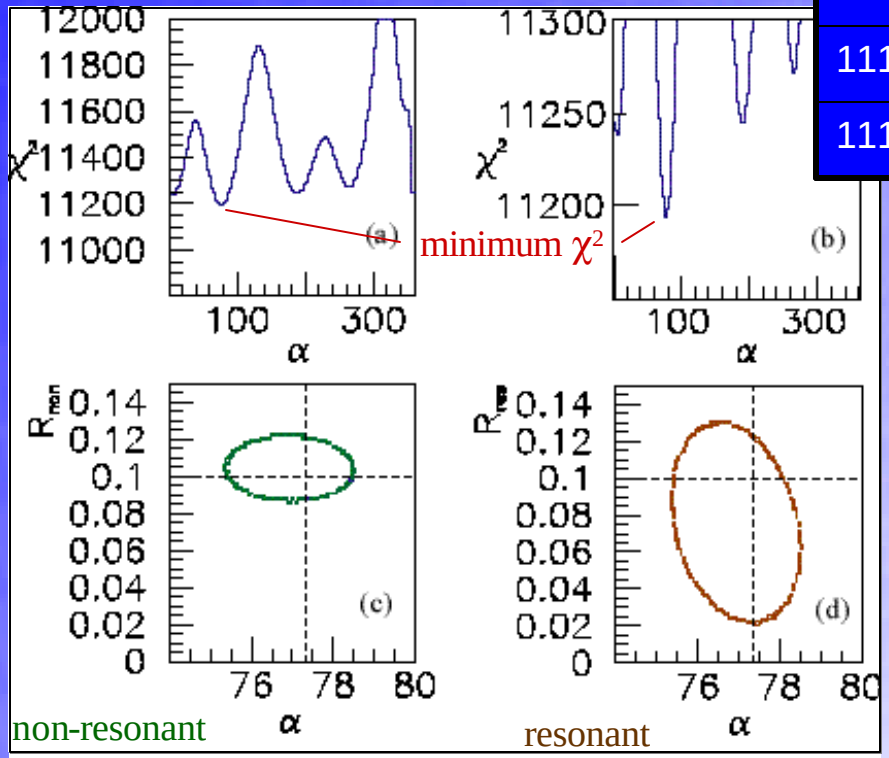




Our Estimate of Accuracy on a

- Geant simulation of $B^0 \to \rho\pi$, (for 1.4×10^7 s)

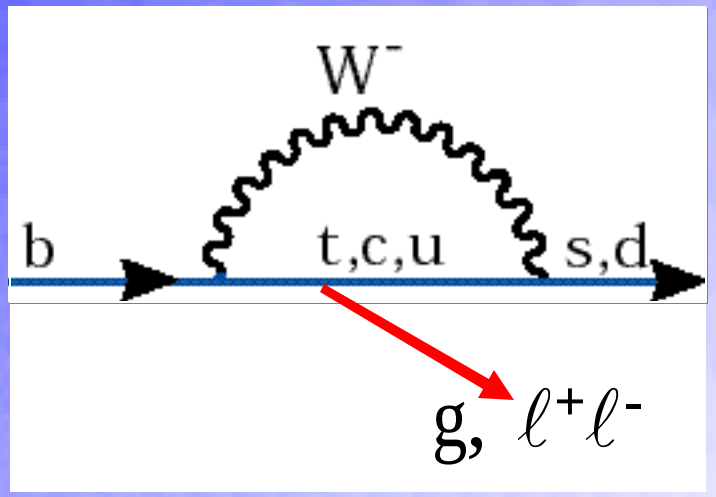
α (gen)	R_{res}	R_{non}	α (recon)	$\Delta\alpha$
77.3^o	0.2	0.2	77.2^o	1.6^o
77.3^o	0.4	0	77.1^o	1.8^o
93.0^o	0.2	0.2	93.3^o	1.9^o
93.0^o	0.4	0	93.3^o	2.1^o
111.0^o	0.2	0.2	111.7^o	3.9^o
111.0^o	0.4	0.2	110.4^o	4.3^o



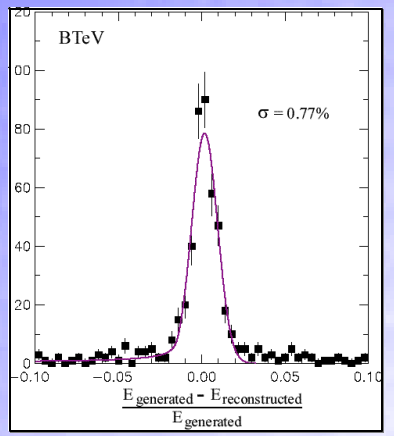
Example:
1000 $B^0 \to \rho\pi$ signal + backgrounds
With input $\alpha = 77.3^o$

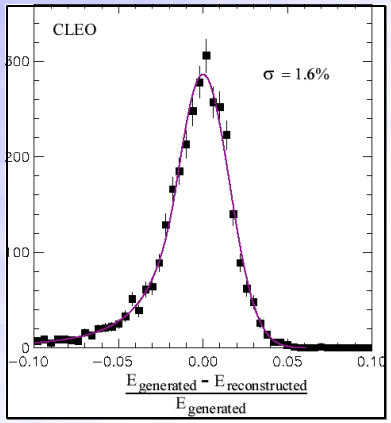
Rare b Decays

- Search for New Physics in Loop diagrams
  - New fermion like objects in addition to t, c or u
  - New Gauge-like objects in addition to W, Z or g



- Inclusive Rare Decays including
  - $b \to s\gamma$
  - $b \to d\gamma$
  - $b \to s\ell^+\ell^-$
- Exclusive Rare Decays such as
  - $B \to \rho\gamma$, $K^*\gamma$
  - $B \to K^*\ell^+\ell^-$ Dalitz plot & polarization





$B^o \to K^*\gamma$

Electromagnetic Calorimeter

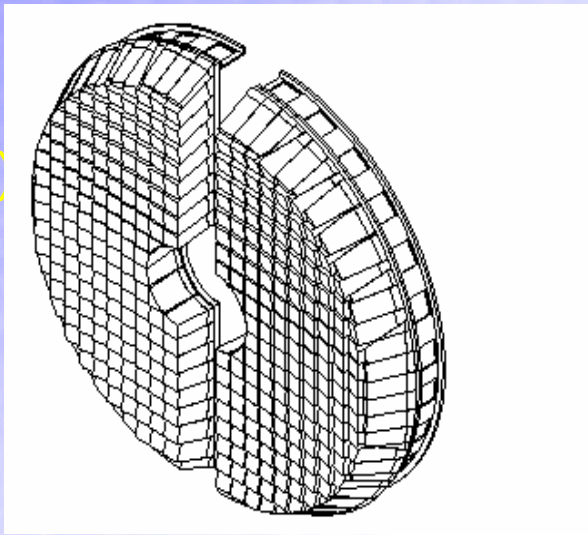
The main challenges include

- Can the detector survive the high radiation environment ?
- Can the detector handle the rate and occupancy ?
- Can the detector achieve adequate angle and energy resolution ?

BTeV will have a high resolution $PbWO_4$ calorimeter

- Developed by CMS for use at the LHC
- Large granularity
  - Block size 2.7 x 2.7 x 22 cm^3 (25 X_0)
  - ~23000 crystals
- Photomultiplier readout (no magnetic field)
- Pre-amp based on QIE chip (KTeV)
- Energy resolution
  - Stochastic term 1.6%
  - Constant term 0.55%
- Position resolution

$$s_x = 3526\,\mu\text{m}/\sqrt{E} \oplus 217\mu\text{m}$$

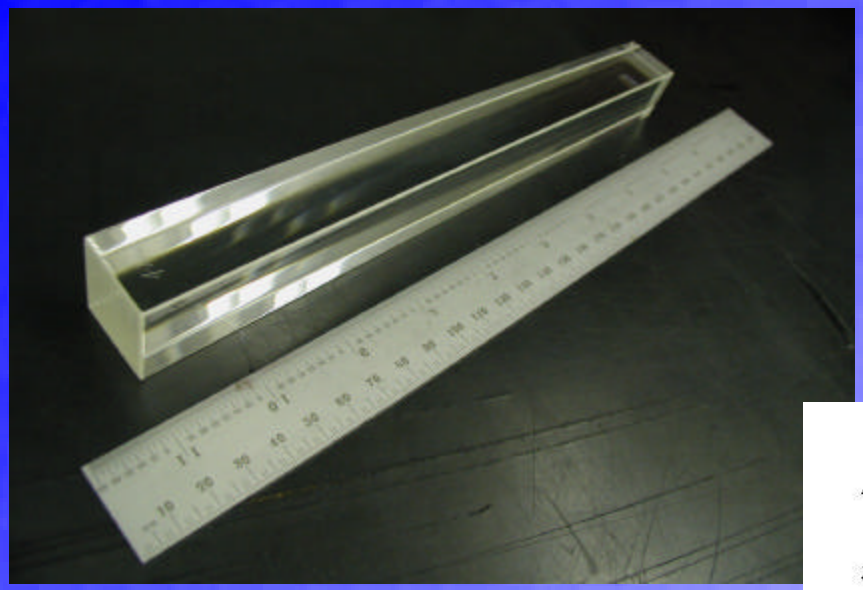


$PbWO_4$ Calorimeter Properties

Property	Value
Density(gm/cm^2)	8.28
Radiation Length(cm)	0.89
Interaction Length(cm)	22.4
Light Decay time(ns)	5(39%)
(3components)	15(60%)
	100(1%)
Refractive index	2.30
Max of light emission	440nm
Temperature	
Coefficient (%/°C)	-2
Light output/Na(Tl)(%)	1.3
Light output(pe/MeV)	
into 2" PMT	10

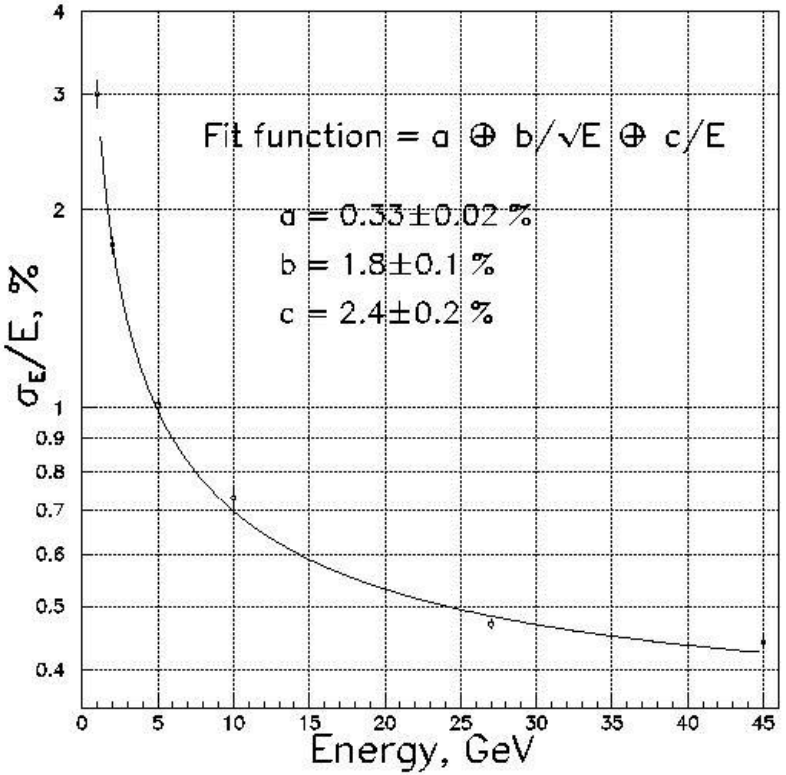
Property	Value
Transverse block size	2.7cm X 2.7 cm
Block Length	22 cm
Radiation Length	25
Front end Electronics	PMT
Inner dimension	+/-9.8cm (X,Y)
Energy Resolution:	
Stochastic term	1.6% (2.3%)
Constant term	0.55%
Spatial Resolution:	$s_x = 3526\,mm/\sqrt{E} \oplus 217mm$
Outer Radius	140 cm--215 cm
	$ driven
Total Blocks/arm	11,500

Electromagnetic Calorimeter Tests



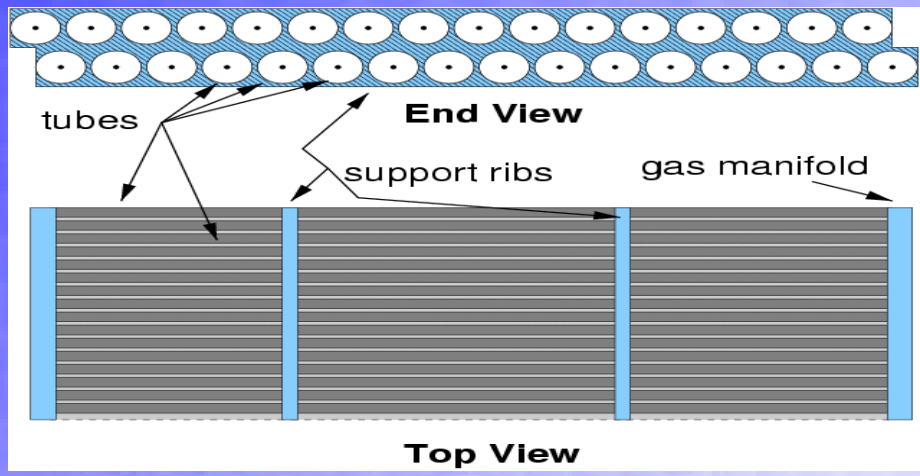
Block from China's Shanghai Institute

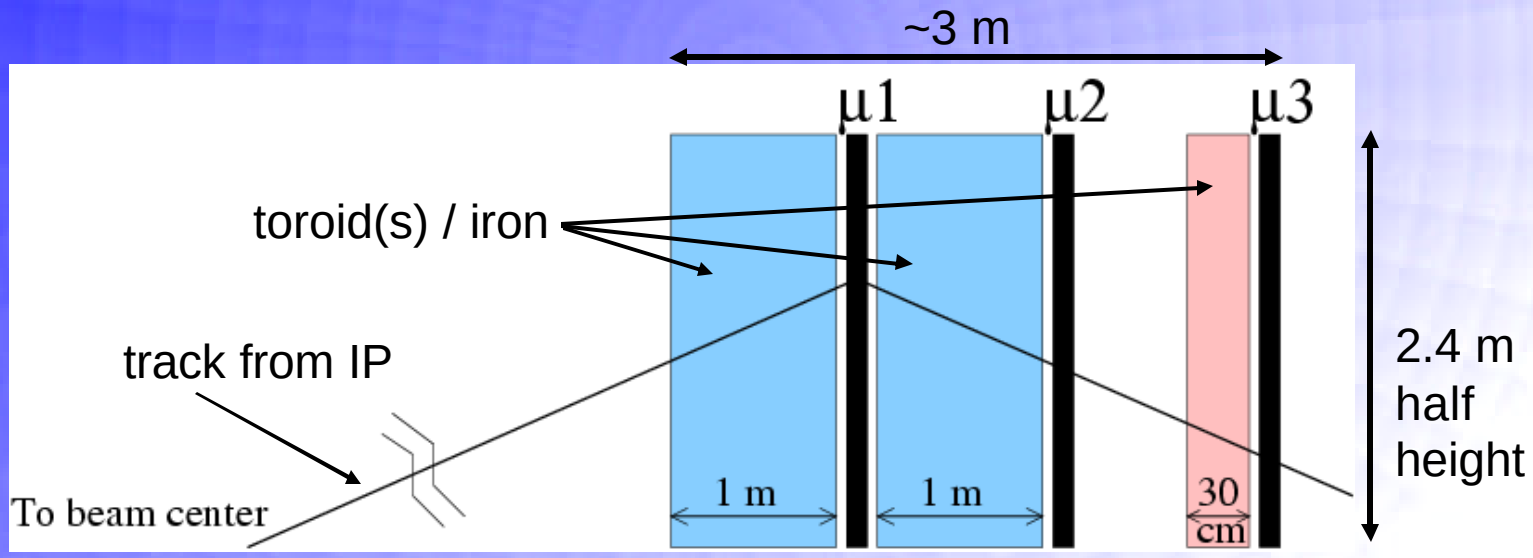
- Resolution (energy and position) close to expectations
- This system can achieve CLEO/BaBar/BELLE-like performance in a hadron Collider environment!



Muon System

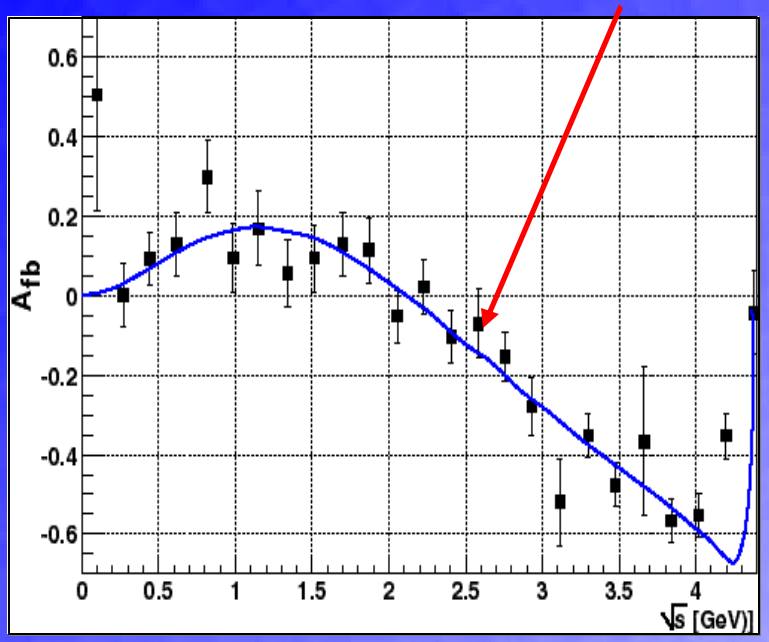
- Provides Muon ID and Trigger
  - Trigger for interesting physics states
  - Check/debug pixel trigger
- fine-grained tracking + toroid
  - Stand-alone mom./mass trig.
  - Momentum "confirmation"
- Basic building block: Proportional tube "Planks"

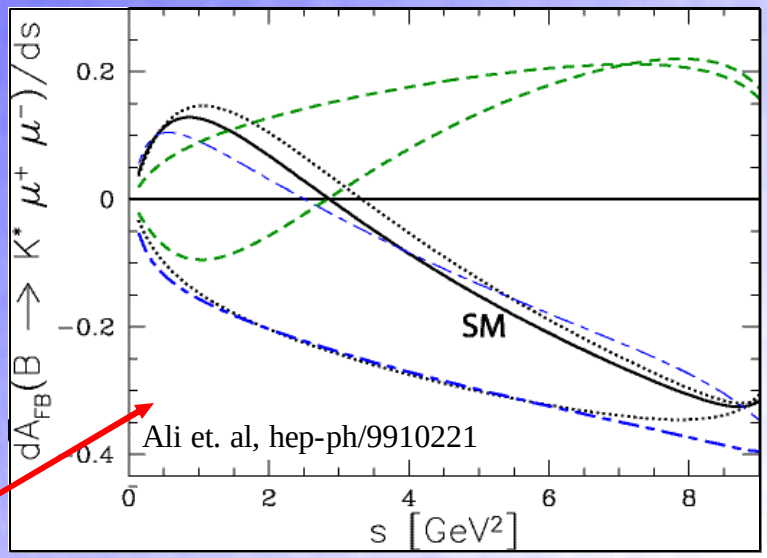




Polarization in B⁰ → K*⁰μ⁺μ⁻

- BTeV data compared to Burdman et al calculation





- Dilepton invariant mass distributions, forward-backward asymmetry discriminate among the SM and various supersymmetric theories.
  (Ali, Lunghi, Greub & Hiller, hep-ph/0112300)

- One year for $K^* \ell^+ \ell^-$, enough to determine if New Physics is present

Summary

- Heavy quark physics at hadron colliders provides a unique opportunity to
  - measure fundamental parameters of the Standard Model with no or only small model dependence
  - discover new physics in CP violating amplitudes or rare decays.
  - interpret new phenomena found elsewhere (e.g. LHC)
- Some scenarios are clear others will be a surprise

➡ This program requires a general purpose detector like BTeV with

- an efficient, unbiased trigger and a high performance DAQ
- a superb charged particle tracking system
- good particle identification
- excellent photon detection

Additional Transparencies

Physics Reach (CKM) in 10^7 s

Reaction	B(B) ($\times 10^{-6}$)	# of Events	S/B	Parameter	Error or (Value)
$B_s \to D_s K^-$	300	7500	7	$\gamma - 2\chi$	8^o
$B_s \to D_s \pi^-$	3000	59,000	3	x_s	(75)
$B^o \to J/\psi K_S$ $J/\psi \to \ell^+ \ell^-$	445	168,000	10	$\sin(2\beta)$	0.017
$B^o \to J/\psi K^o$, $K^o \to \pi \ell \nu$	7	250	2.3	$\cos(2\beta)$	~0.5
$B^- \to D^o (K^+\pi^-) K^-$	0.17	170	1		
$B^- \to D^o (K^+K^-) K^-$	1.1	1,000	>10	γ	13^o
$B_s \to J/\psi \eta$,	330	2,800	15		
$B_s \to J/\psi \eta'$	670	9,800	30	$\sin(2\chi)$	0.024
$B^o \to \rho^+\pi^-$	28	5,400	4.1		
$B^o \to \rho^o\pi^o$	5	780	0.3	α	~4^o

Reaction	B(B) ($\times 10^{-6}$)	# of Events	S/B	Parameter	Error
$B^- \to K_S \pi^-$	12.1	4,600	1		$<4^o$ +
$B^o \to K^+\pi^-$	18.8	62,100	20	γ	Theory err.
$B^o \to \pi^+\pi^-$	4.5	14,600	3	Asymmetry	0.030
$B^o \to K^+ K^-$	17	18,900	6.6	Asymmetry	0.020

A simplified trigger comparison

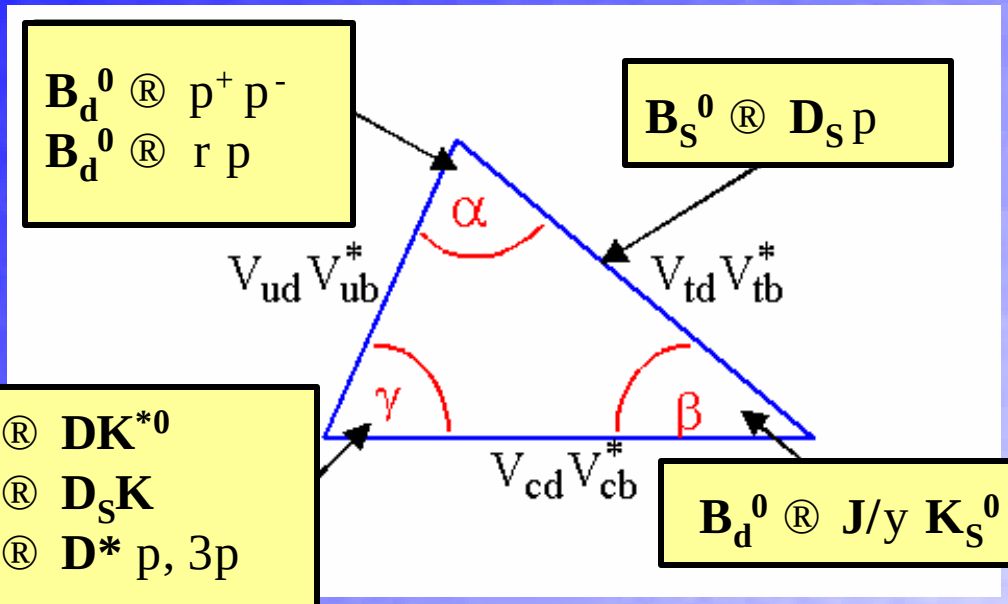
	LHCb	BTeV
High p_T, high E_T	10* MHz	
Impact parameter	1 MHz	7.6 MHz
Decay topology		80 kHz
Physics algorithms	40 kHz	
To tape	200 Hz	4 kHz

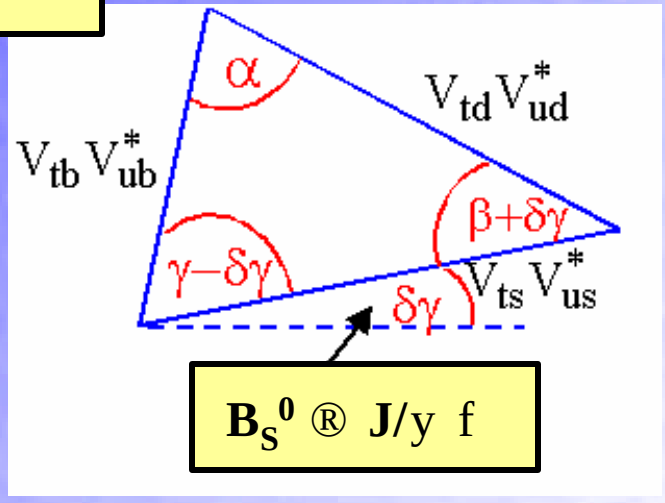
* Rate of events with visible collisions

	ATLAS	CMS
Muon trigger	40 MHz	40 MHz
$J/\psi \rightarrow l^+l^-$, $D_s \rightarrow \phi\pi$, $B \rightarrow \pi^+\pi^-$	23kHz	
Physics algorithms	1 kHz	4 kHz
To tape	10 Hz	10 Hz

From U. Egede

Unitarity Triangles

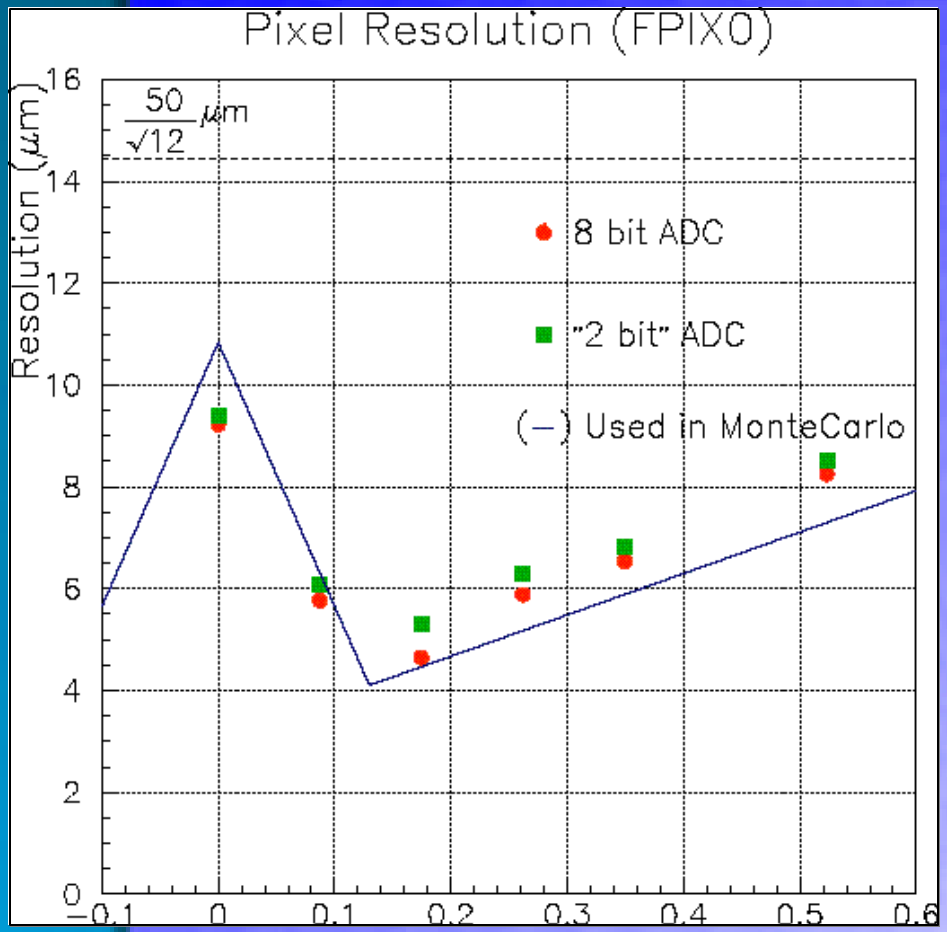




$\delta\gamma = \chi$

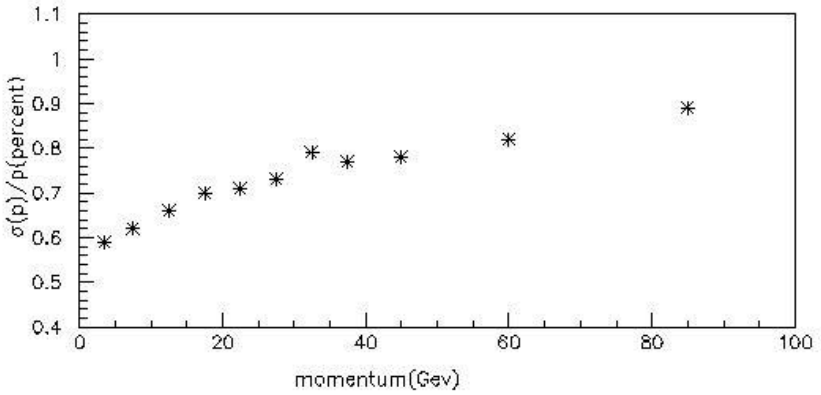
From N. Harnew

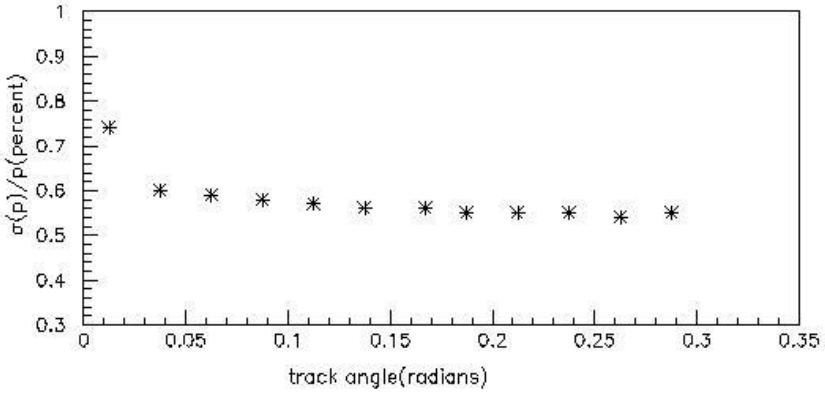
Pixel Test Beam Results



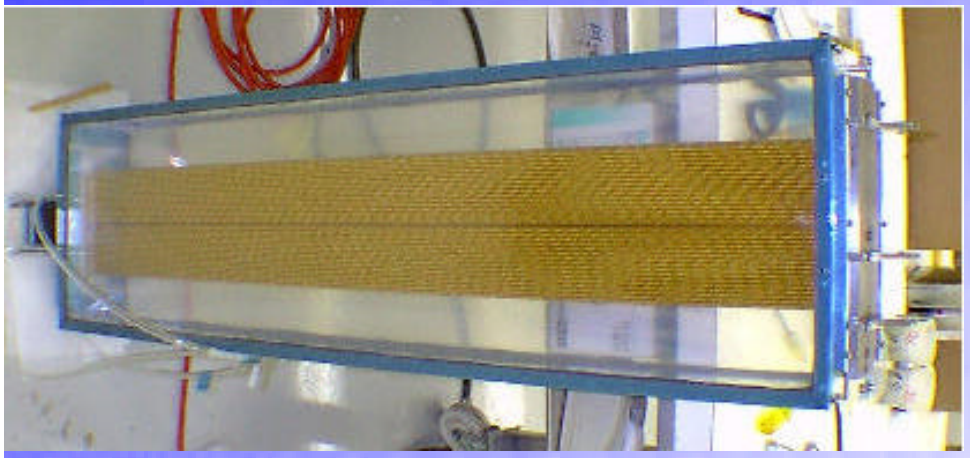
Analog output of pixel amplifier before and after 33 Mrad irradiation.
0.25μ CMOS design verified radiation hard with both γ and protons.

Forward Tracker

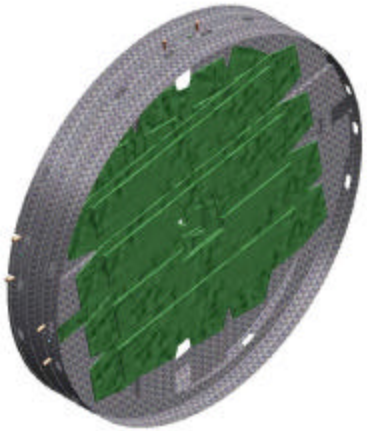




Predicted performance - Momentum resolution is better than 1% over full momentum and angle range



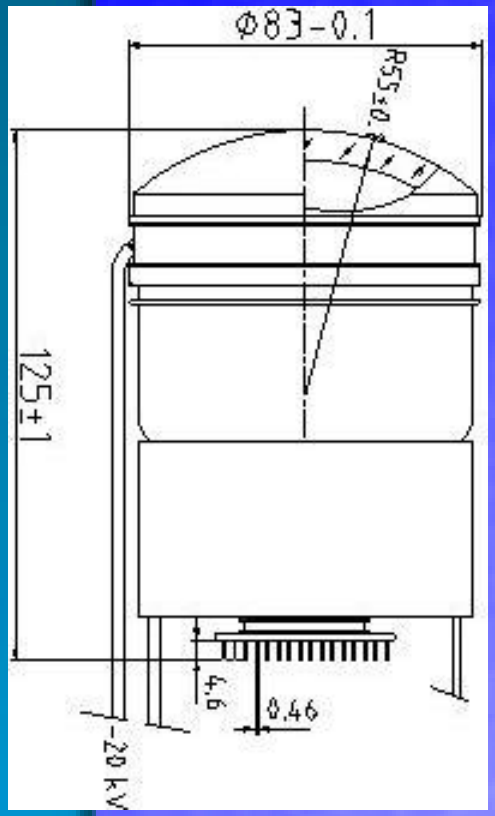
Prototype Straw tracker being constructed for FNAL beam test summer/fall 2002



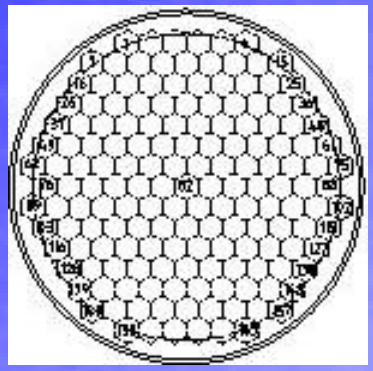
Drawing Of forward Microstrip tracker

HPD Schematic for BTeV RICH

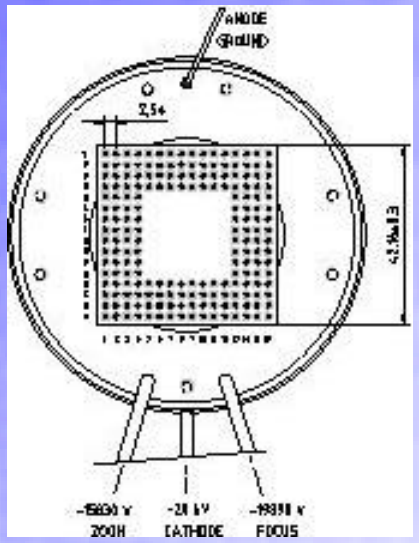
HPD Tube

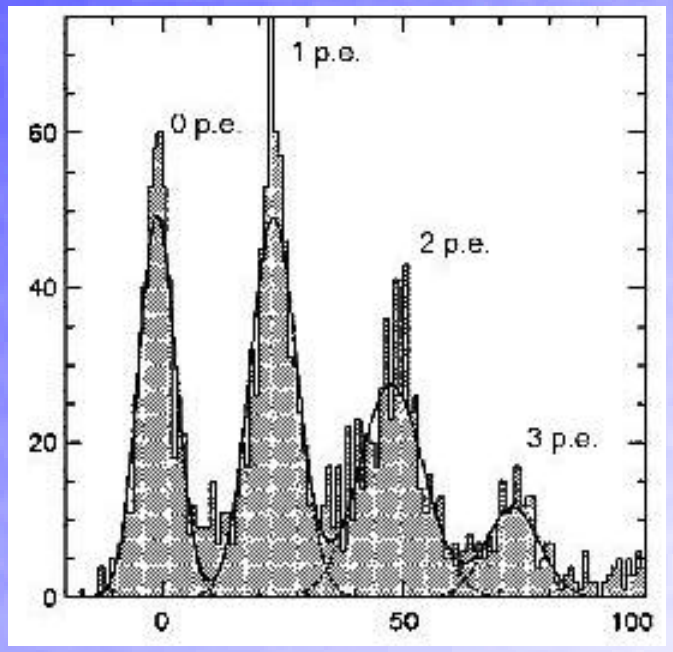


HPD Pixel array



HPD Pinout



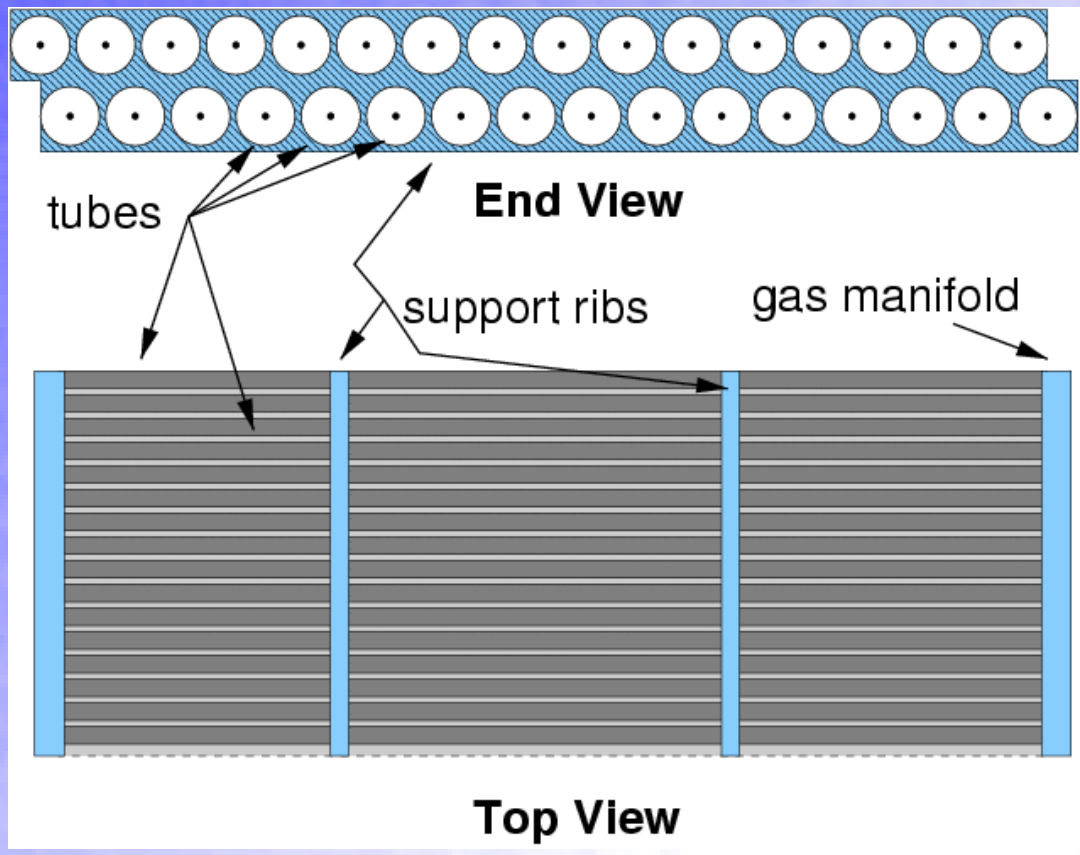


Pulse Height from 163 pixel prototype HPD. Note pedestal, 1, 2, 3 pe peaks

Prop Tube Planks

- Basic Building Block: Proportional Tube "Planks"

  - 3/8" diameter Stainless steel tubes (0.01" walls)
  - "picket fence" design
  - 30 μ (diameter) gold-plated tungsten wire
  - Manifolds are brass soldered to tubes (RF sheilding 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.



Plank Cosmic Ray Tests

BTeV Data Acquisition Architecture