BTeV experiment for CP violating measurements

- Philosophy of BTeV design
- Concentrate on those experimental aspects of BTeV which make it unique

C0 Interaction Region

Construction of new experimental hall is completed !

Opens a possibility of **dedicated** b experiment at Tevatron

Beyond Run II experiment (≥ 2005)

- **Want as broad exploration of b-physics as possible:**
  - detached vertex trigger at the lowest level to be able to study multi-hadron final states
  - tracking system with excellent efficiency, vertex, mass and decay time resolutions
  - lepton identification and triggering
  - best EM calorimeter for γ/π^0 detection
  - best particle identification for $\pi/K/p$ separation
- c-physics as a secondary goal

CP-approach to CKM matrix

- Four independent angles parametrizing CKM (instead of A, λ, ρ, η)

$$\beta = \arg\left(-\frac{V_{tb} V_{td}^*}{V_{cb} V_{cd}^*} \right) \qquad \gamma = \arg\left(-\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}} \right)$$

$$\chi = \arg\left(-\frac{V_{cs}^* V_{cb}}{V_{ts}^* V_{tb}} \right) \qquad \chi' = \arg\left(-\frac{V_{ud}^* V_{us}}{V_{cd}^* V_{cs}} \right)$$

($\alpha+\beta+\gamma=\pi$ not independent)

β & γ probably large, χ small ~0.02, χ' smaller

χ' too small to measure use $\lambda=|V_{us}/V_{ud}|$ instead

- Sensitive test of SM (Silva & Wolfenstein and Aleksan, Kayser & London)

$$\sin\chi = \lambda^2 \frac{\sin\beta \sin\gamma}{\sin(\beta+\gamma)}$$

It is not enough to test the standard unitarity triangle!

$\alpha+\beta+\gamma=\pi$

CP-approach to CKM matrix

- Similar tests

$$\sin\chi = \left|\frac{V_{ub}}{V_{cb}}\right|^2 \frac{\sin\gamma\sin(\beta+\gamma)}{\sin(\beta)} \qquad \sin\chi = \left|\frac{V_{td}}{V_{ts}}\right|^2 \frac{\sin\beta\sin(\beta+\gamma)}{\sin(\gamma)}$$

- Can be turned around to obtain perhaps the most accurate:

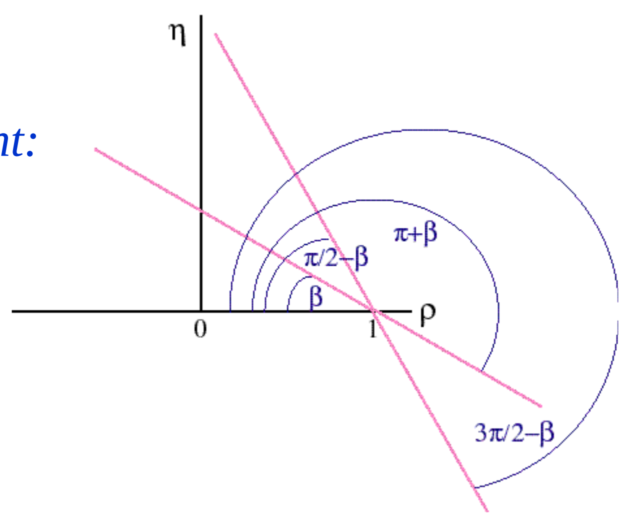
$$\left|\frac{V_{ub}}{V_{cb}}\right|^2 \qquad \left|\frac{V_{td}}{V_{ts}}\right|^2$$

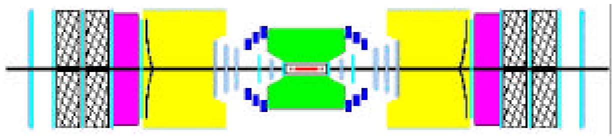
- Measurements of various CP asymmetries determines various sin(2 angle)

four fold ambiguity in determination of the angle !

Example- sin(2β) measurement:

β, $\pi/2-\beta$, $\pi+\beta$, $3\pi/2-\beta$





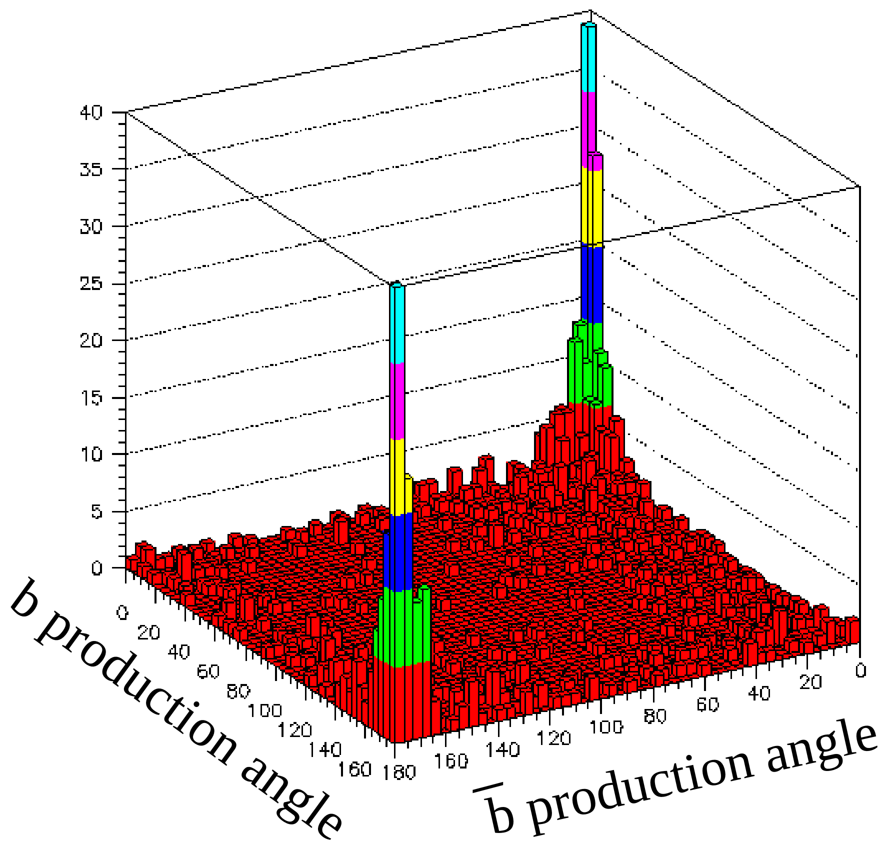
CP-approach to CKM matrix

- Need a lot of different measurements to determine all independent angles with their signs

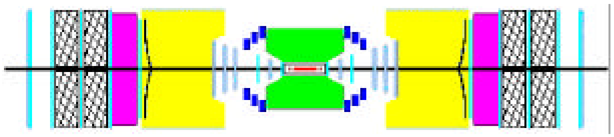
Physics Quantity	Decay Mode	Vertex Trigger	K/π sep	γ det	Decay time σ
$\sin(2\alpha)$	$B^o \to \rho\pi \to \pi^+\pi^-\pi^o$	✓	✓	✓	
$\sin(2\alpha)$	$B^o \to \pi^+\pi^-$ & $B_s \to K^+K^-$	✓	✓		✓
$\cos(2\alpha)$	$B^o \to \rho\pi \to \pi^+\pi^-\pi^o$	✓	✓	✓	
$\mathrm{sign}(\sin(2\alpha))$	$B^o \to \rho\pi$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

- BTeV experiment designed to carry out this program in full !

Forward Geometry



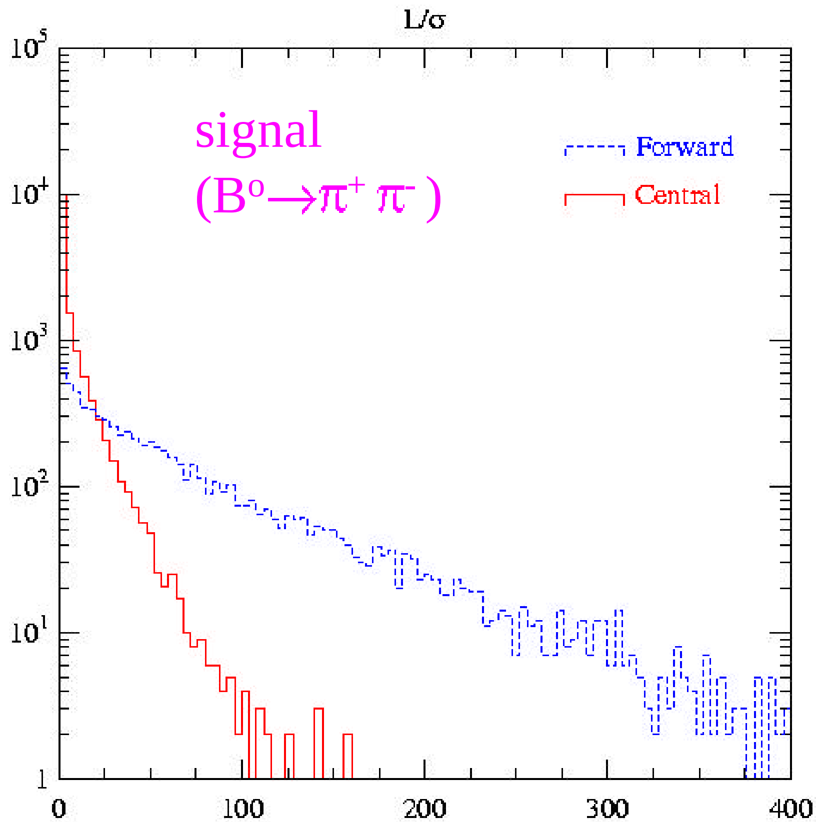
- b production peaks at large angles with large $b\bar{b}$ correlation
- Limited solid angle $\mapsto$ Limited cost



Forward Geometry

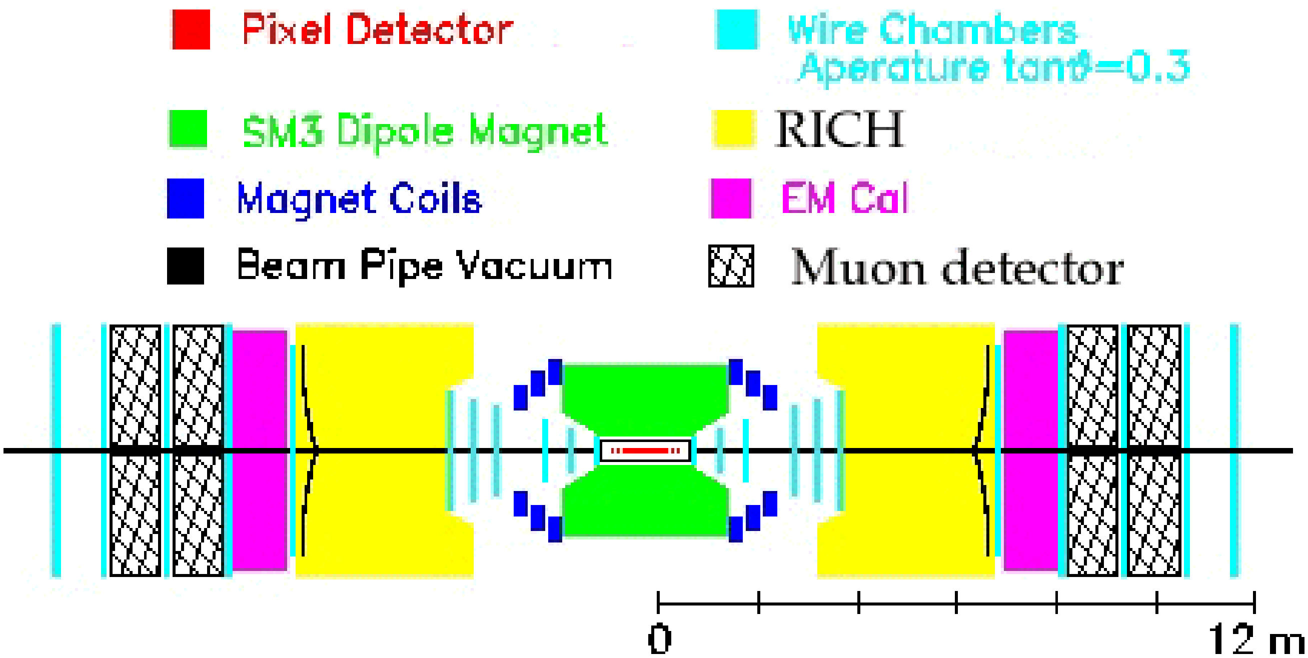
- The higher momentum b's:
  - the smaller the multiple scattering
  - the better background rejection via decay length/error cut - L/σ (in trigger and off-line)
  - the better decay time resolution

Backgrounds peak at $L/\sigma \cong 0$



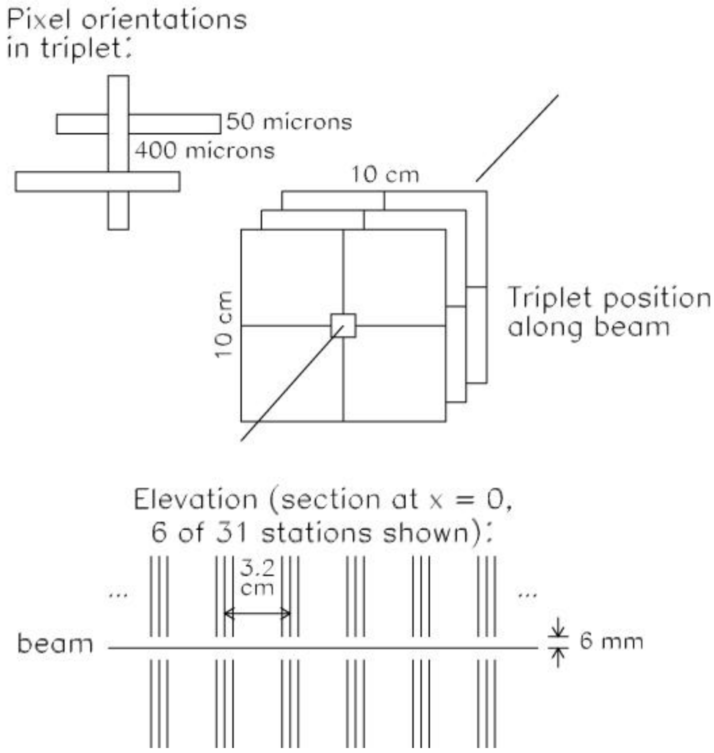
- Challenges:
  - the higher radiation dose
  - more particles to deal with

BTeV Detector



- Central pixel vertex detector in dipole magnetic field (1.6 T)
- Each of two arms:
  - tracking stations (silicon strips + straws)
  - hadron identification by RICH
  - γ/π^0 detection and e identification in lead-tungsten crystal calorimeter
  - μ triggering and identification in muon system with toroidal magnetic field
- Designed for luminosity 2×10^{32} cm^{-2}s^{-1}
(2×10^{11} $b\bar{b}$ events per 10^7 s)

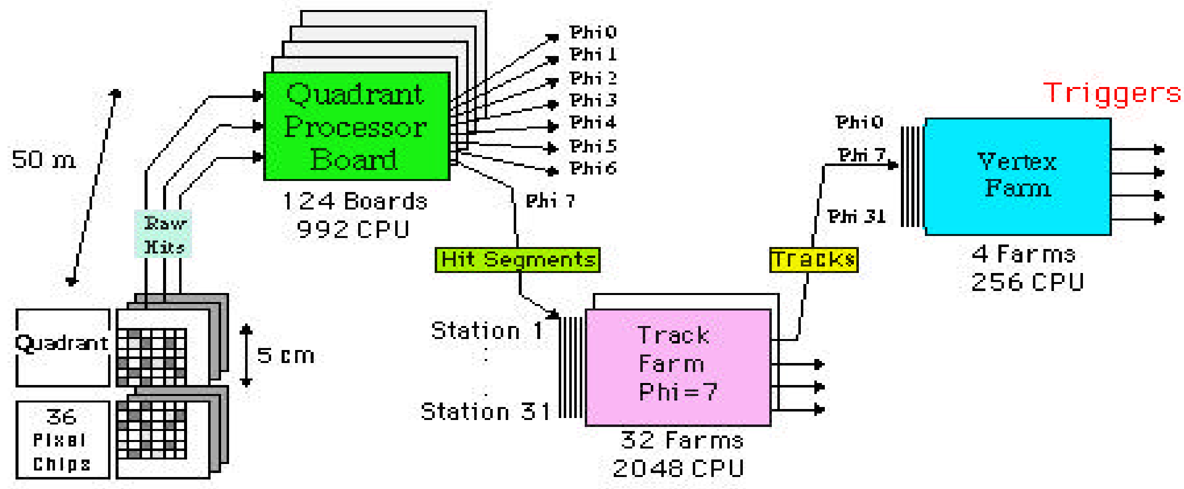
Pixel detector



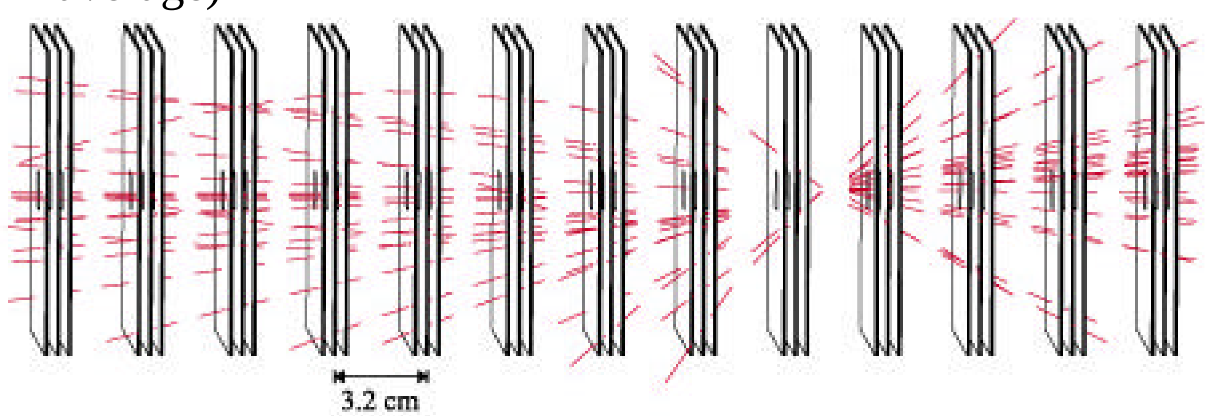
- inside the beam pipe
- inside magnetic field:
  - stand-alone P measurement possible (rejection of scattered low momentum tracks in the vertex trigger)

- Advantages over silicon strips
  - quasi 3D (5-10 μm resolution in narrow direction)
  - low occupancy ≤ 10^{-4}
  - low noise
  - very fast
  - radiation hard
- Essential for robust detached vertex trigger in the first trigger level
- Good vertex and decay time resolution in analysis

Detached vertex trigger



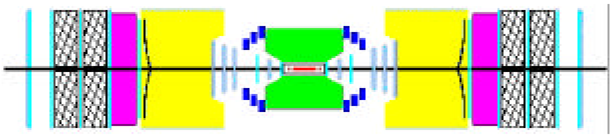
- Triplets used to get space point & mini-vector, called a ‘station hit’
- Station hits are organized into ϕ-slices
- Tracks are found in these ϕ-slices
  - full pattern recognition is performed
  - Minimum track p cuts are applied
- Event level processors then find primary vertices & detached tracks (can handle multiple interactions per crossing, 2 on average)



Overall Trigger System

Trigger Level	Input event rate kHz	Algorithm	Latency ms	Data reduction
1	7,600	Vertex or μ, e	0.05-1	100
2	70-100	Refined vertex, partial reconstruction	20	5-10
3	15-20	Full event reconstruction	200	5-10
Data logging	2-4			

- The only experiment with detached vertex trigger in the lowest level
  - LHC-b and CDF have vertex triggers in the second level
- hadron Pt threshold as low as 0.5 GeV $\mapsto$ good trigger efficiency for all kind of hadronic modes (the most open trigger)
  - LHC-b requires a high Pt hadron (>2.4 GeV)
  - CDF requires two high Pt hadrons (>2.2 GeV each)
- Data logging at rate 10-100 higher than in the other experiments
  - input rate from b's into detector is ~1 kHz !



Electromagnetic calorimeter

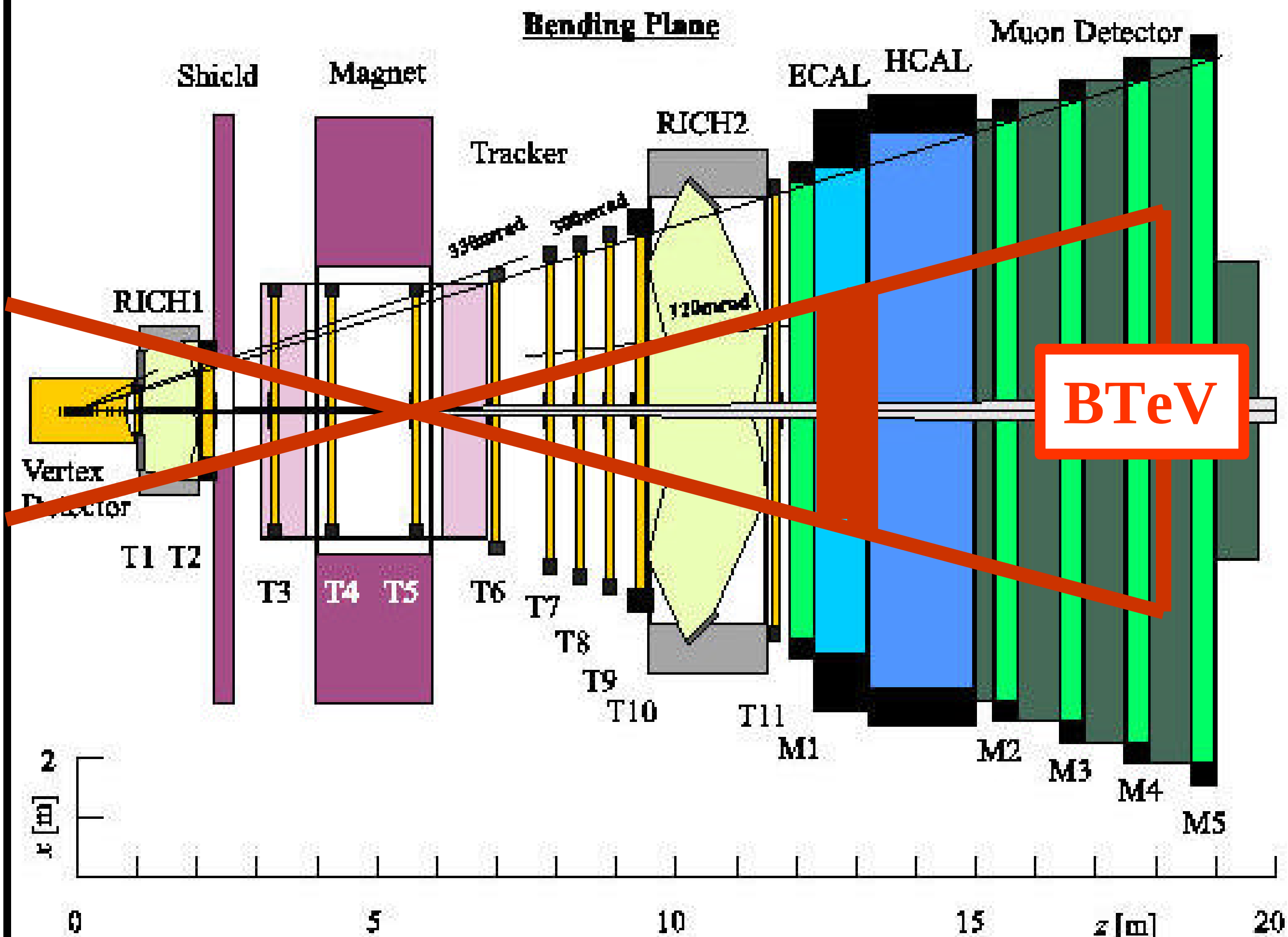
- Without modes with neutrals exploration of CP violation is incomplete ($B \rightarrow \rho\pi$!)
- Use ~40,000 lead-tungsten crystals ($PbWO_4$)
  - technology developed for LHC by CMS
  - radiation hard
  - fast scintillation (99% of light in <100 ns)
  - will use phototubes since outside the magnetic field
- Excellent energy and angular resolution:

BTeV	LHC-b (Pb-scintillating fiber sampling calorimeter with preshower detector)
Energy resolution	
$\sigma_E = \sqrt{\frac{(1.6\%)^2}{E} + (0.55\%)^2}$	$\sigma_E = \sqrt{\frac{(10\%)^2}{E} + (1.5\%)^2}$
Segmentation	
$(2.25\ \text{cm})^2$ at 7m	$(6 - 24\ \text{cm})^2$ at 13m

Electromagnetic calorimeter

- Why LHCb unlikely to afford $PbWO_4$

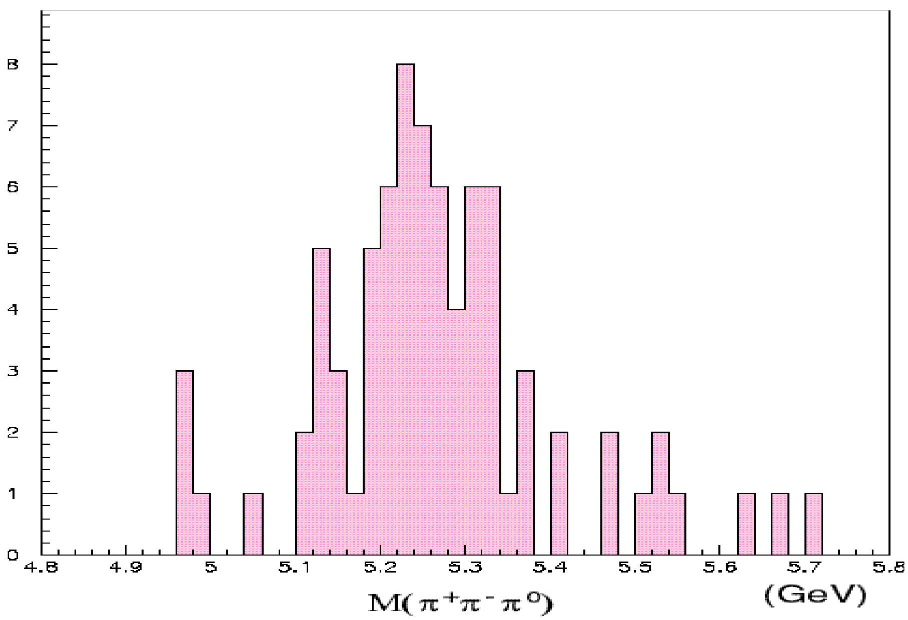
Higher CM energy $\mapsto$ *Higher particle momenta* $\mapsto$ *Longer spectrometer*



Also pre-shower detector needed for LHCb electron triggering and two RICH detectors are bad for γ detection

Key measurement for determination of α
$B^o \to \rho\,\pi \to \pi^+\pi^-\pi^o$

- Snyder&Quinn: need 1,000-2,000 to determine $\sin(2\alpha)$, $\cos(2\alpha)$ via Dalitz plot analysis
- BTeV expects ~2,450 tagged events at BR=3.5×10^{-5} (CLEO)
- Backgrounds not yet determined

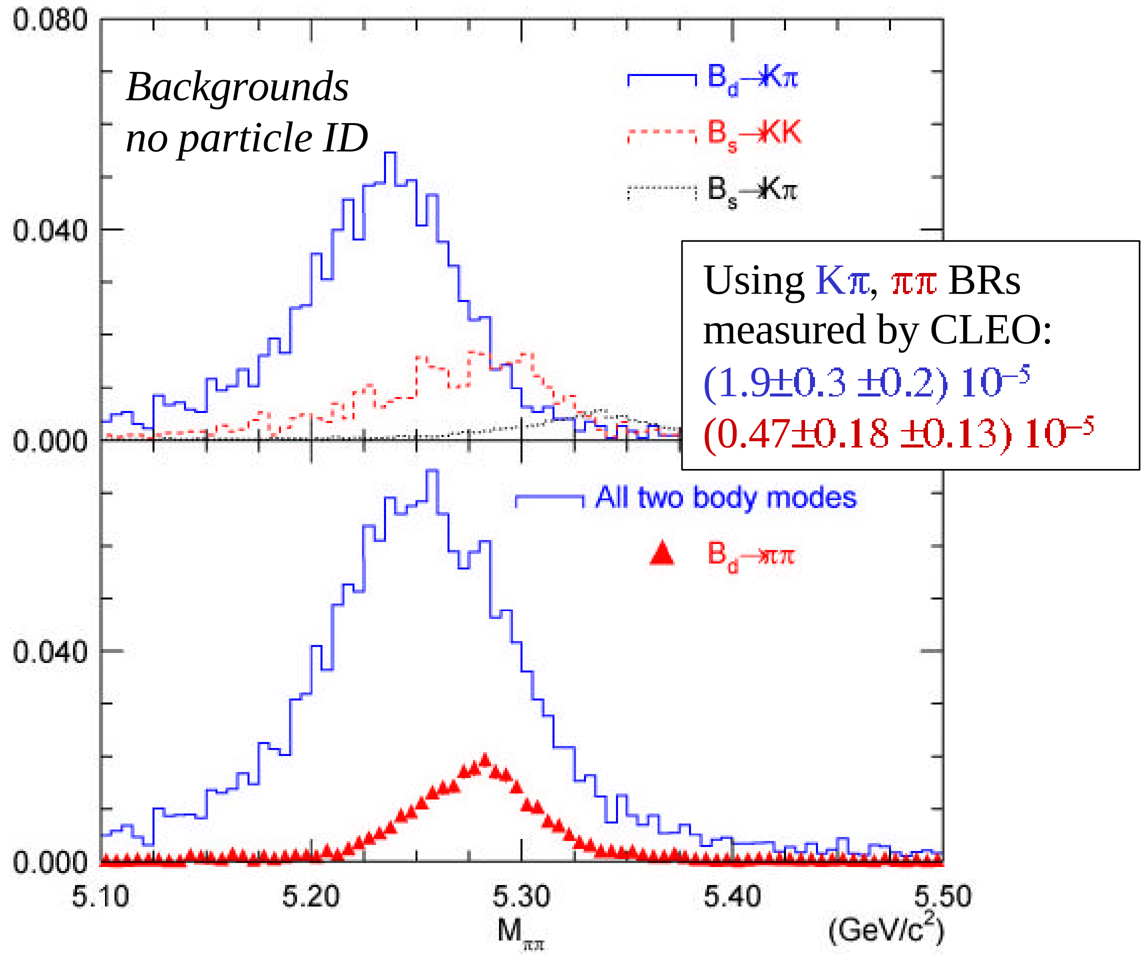


Other key measurement involving EM calorimeter

- determination of χ
  - $B_s \to J/\psi\ \eta', \eta' \to \rho\gamma$
  - $B_s \to J/\psi\ \eta\ , \eta \to \gamma\gamma$
- No simulations yet

π/K/p identification

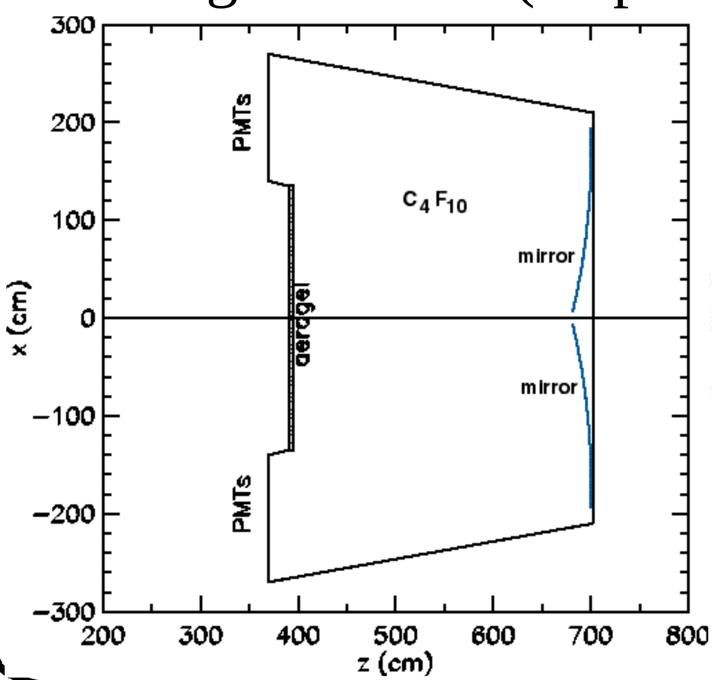
- Crucial for **many** measurements e.g. cannot separate $B^0 \to \pi^+\pi^-$ from other h^+h^-

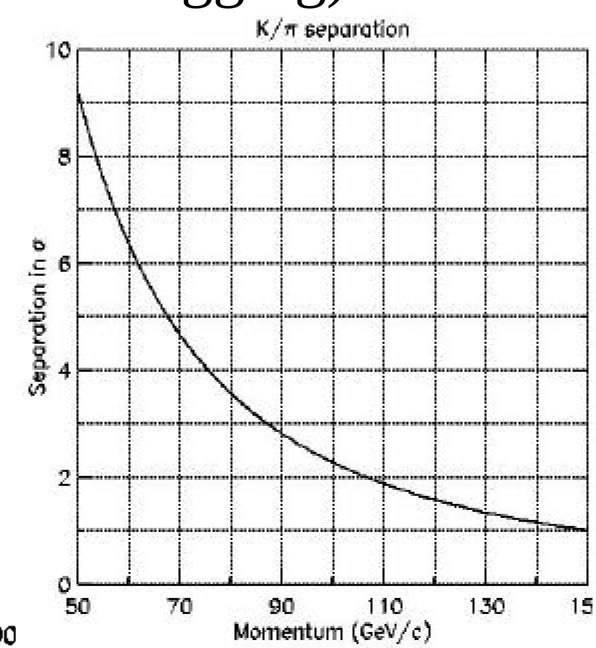


- Substantial contribution to tagging efficiency via “kaon tagging”

π/K/p identification

- Missing component in high Pt experiments
- Expensive to deploy in central geometry
  - CDF’s ToF helps tagging only (momentum coverage anti-correlated with the $\pi^+\pi^-$ trigger); only 1-1.5σ K/π separation from dE/dX
- Sufficient K/π separation can be achieved in BTeV with a single gaseous RICH (C_4F_{10})
  - LHCb needs two because of higher momenta
  - similar to HERA-B, and first LHCb RICH detectors
- Provide K/p separation at low momenta with aerogel radiator (helps kaon tagging)





A sample calculation for $B^0 \to \pi^+\pi^-$

	BTeV	LHCb	e+e-
$\sigma(bb)$ μm	100	500	0.001
Luminosity $cm^{-2}s^{-1}$	2×10^{32}	2×10^{32}	3×10^{33}
$BR(B^0 \to \pi^+\pi^-)$		0.47×10^{-5}	
Reconstruction efficiency	0.06	0.032	0.4
Trigger efficiency (after all cuts)	0.50	0.17	1.0
Number of $B^0 \to \pi^+\pi^-$ events in 10^7s	21,100	15,700	73
Tagging efficiency εD^2	0.1	0.1	0.3
Number of tagged events	2,100	1,570	22
Background/signal	1.7	1	2
Error in $\pi^+\pi^-$ asymmtery	± 0.027	± 0.023	± 0.370

Sensitivity to γ

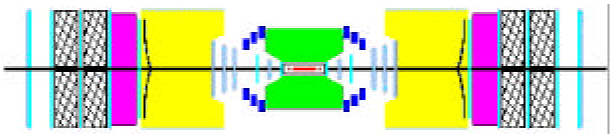
- Using $B_s \rightarrow D_s K^-$ $\pm 11^o$
- Using $B^- \rightarrow D^o K^-$ $\pm 13^o$
- Using $B \rightarrow K\pi$ $< \pm\ 5^o$

Sensitivity to $\sin(2\beta)$

- Using $B_d \rightarrow J/\psi\ K_s$ ± 0.02 (in $\mu+\mu-$)

All numbers in one year of running at design luminosity

Many more simulations to do !



Conclusions

- Tevatron is in unique position to thoroughly explore CP violation in b system
  - dedicated b detector is needed for a complete exploration (cannot do without PID and soft π^0 detection)
  - BTeV competitive with LHCb in all measurements with all charged track final states
  - BTeV much better than LHCb in modes with neutrals
  - With its inclusive trigger BTeV can explore the decays we have not thought of (new physics ?)