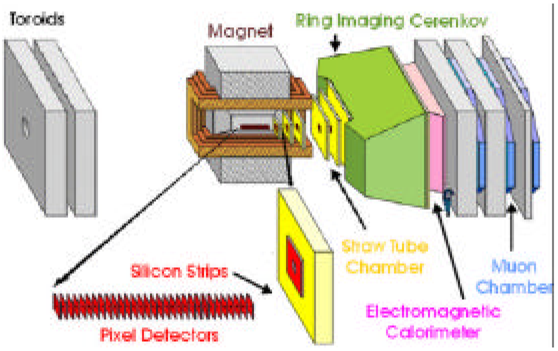

The BTeV Experiment

Jianchun Wang
Syracuse University
Representing the BTeV Collaboration
05/17/2002, FPCP Conference, Philadelphia, PA

Outline

- Physics Goal
- The one-arm spectrometer
- Physics sensitivities
- Status

BTeV—as of March 2002

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INFN - Pavia - G. Boca, G. Liguori, & P. Torre

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

Univ. of Virginia:

M. Arenton, S. Conetti, B. Cox, **A. Ledovskoy**

Wayne State University

G. Bonvicini, & D. Cinabro, A. Shreiner

University of Wisconsin

M. Sheaff

York University

S. Menary

Physics Goals

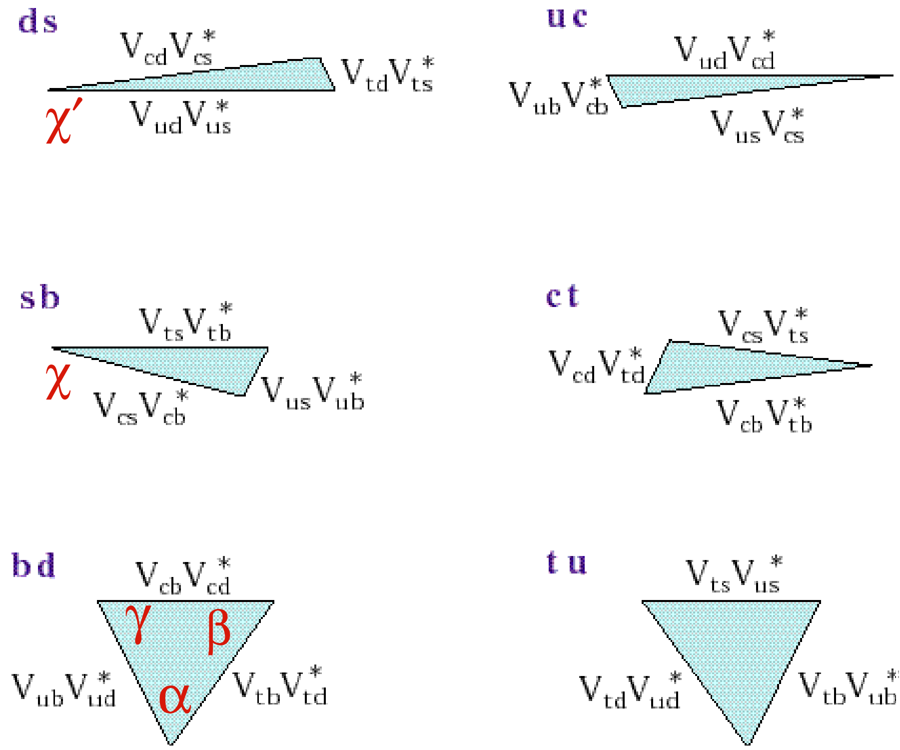
- BTeV is designed to search for physics beyond Standard Model and make precise measurements of SM parameters.
- The important measurements to make involve mixing, CP violation and rare decays of hadrons containing *b* or *c* quarks, especially:
  - CP violation in B^o , B_s and D^o mesons.
  - B_s mixing and $\Delta\Gamma_s$.
  - Rare b decays.

⇩

A window to new physics

The CKM Matrix and Phases

- The CP violation in the SM originates from quark mixing.
- The Unitarity of the CKM matrix allows us to construct 6 triangles, the most common beauty triangle is the bd triangle.
- The primary goal is to measure CKM phases: α, β, γ, χ.
- It is also important to measure the lengths of the sides (magnitudes).
- It is important to remove the 4-fold ambiguity generated by $\sin(2\phi) \rightarrow \phi$.



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

Required Measurements for CKM Tests

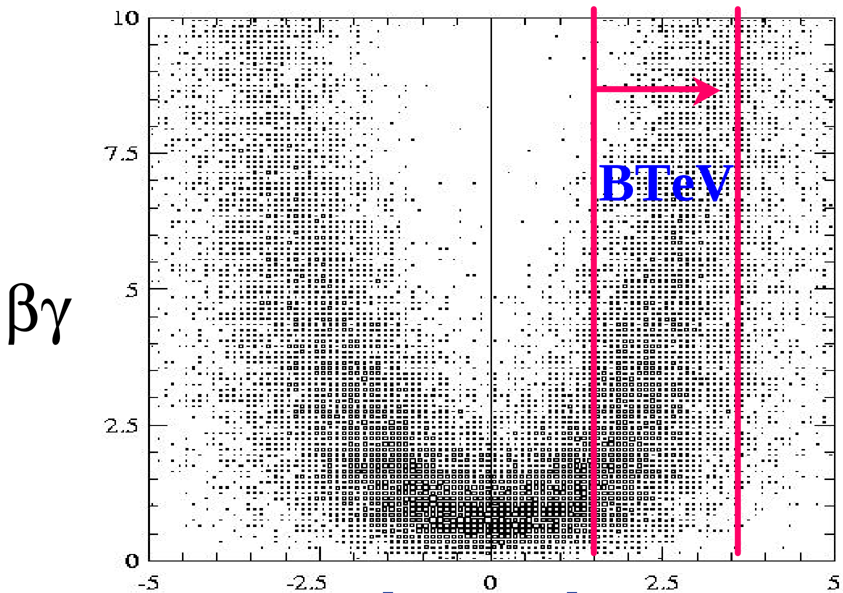
Physics Quantity	Decay Mode	Vertex Trigger	K/π sep	γ det	Decay time σ
$\sin(2\alpha)$	$B^o \to \rho\pi \to \pi^+\pi^-\pi^o$	✓	✓	✓	
$\sin(2\alpha)$	$B^o \to \pi^+\pi^-$ & $B_s \to K^+K^-$	✓	✓		✓
$\cos(2\alpha)$	$B^o \to \rho\pi \to \pi^+\pi^-\pi^o$	✓	✓	✓	
$\mathrm{sign}(\sin(2\alpha))$	$B^o \to \rho\pi$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

The BTeV detector is unique that satisfies all these requirements.

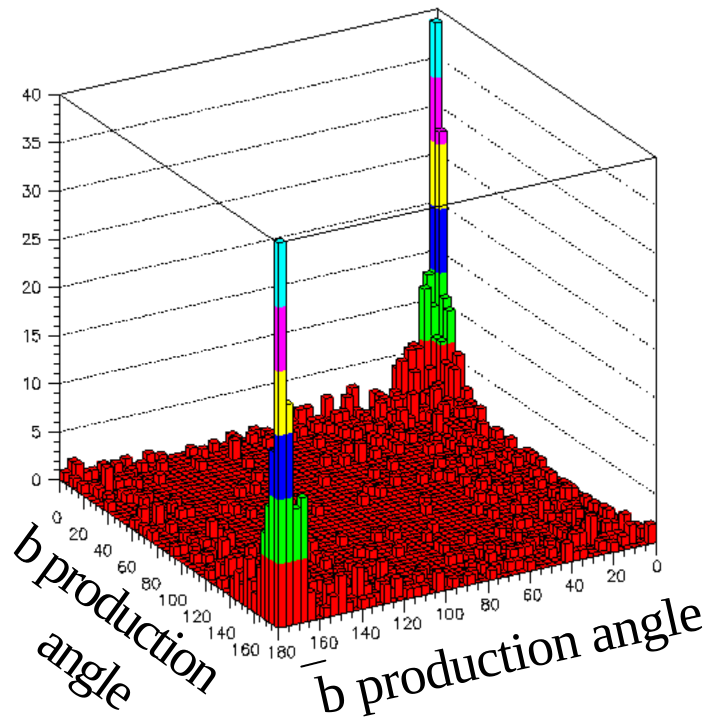
A Forward Detector at $p\bar{p}$ Collider

Forward region, 10 – 300 mrad, 1.5 <| η |<3.5

The higher momentum b are at larger η



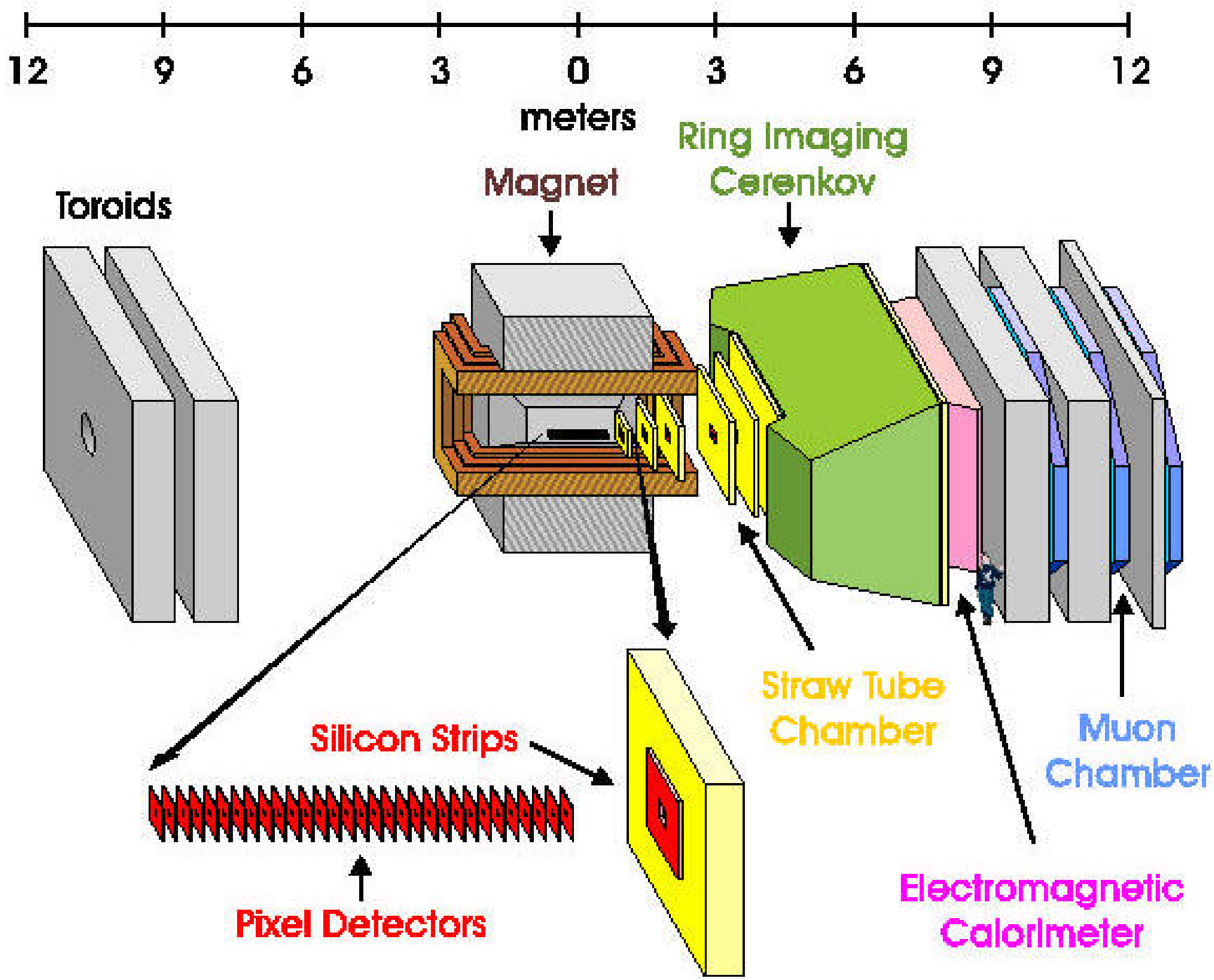
b production peaks at large angles with large $b\bar{b}$ correlation



The Tevatron as b & c Source

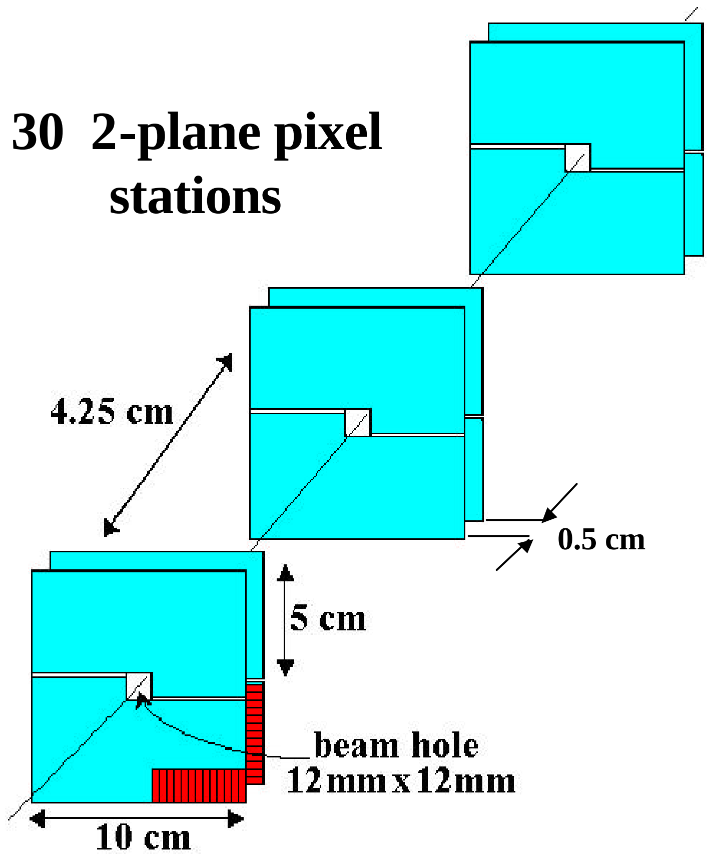
Luminosity	2×10^{32} cm^{-2}s^{-1}
b cross-section	100 μb
# of b-pairs per 10^7 sec	2×10^{11}
b fraction	1/500
c cross-section	>500 μb
Bunch Spacing	132 ns
Luminous region length	σ_z = 30 cm
Luminous region width	$\sigma_x \sim \sigma_y \sim$ 50 μm
Interactions/crossing	<2>

The BTeV Spectrometer



The BTeV Pixel Detector

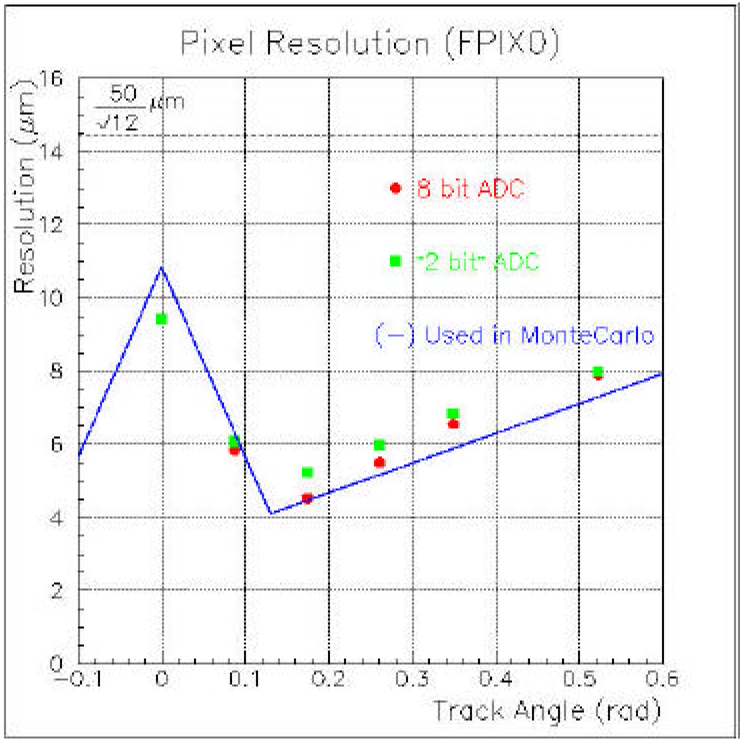
- Provides extremely high quality precision space points for vertex reconstruction, which are also used in the detached vertex trigger.
- Reasons for pixel detector:
  - Superior signal to noise.
  - Excellent spatial resolution (5-10 μm).
  - Very low occupancy.
  - Radiation hard.
  - Very fast.
- Special features:
  - Directly used in the level 1 trigger.
  - Pulse height is measured on every channel with a 3-bit FADC.
  - It is inside a dipole and gives a standalone momentum.



Pixels size: 50 μm × 400 μm

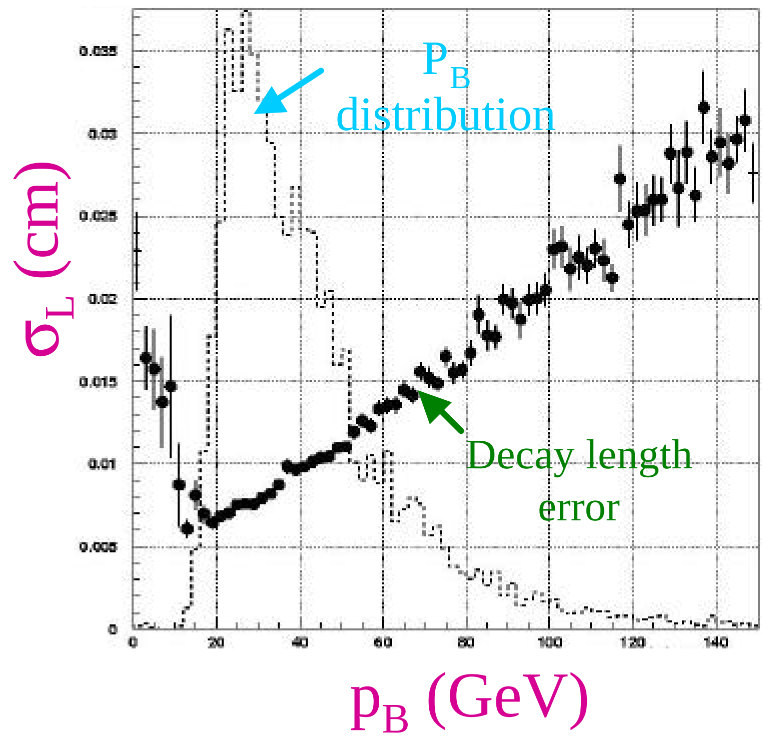
Performance of the Pixel Detector

Spatial Resolution from Beam Test 1999



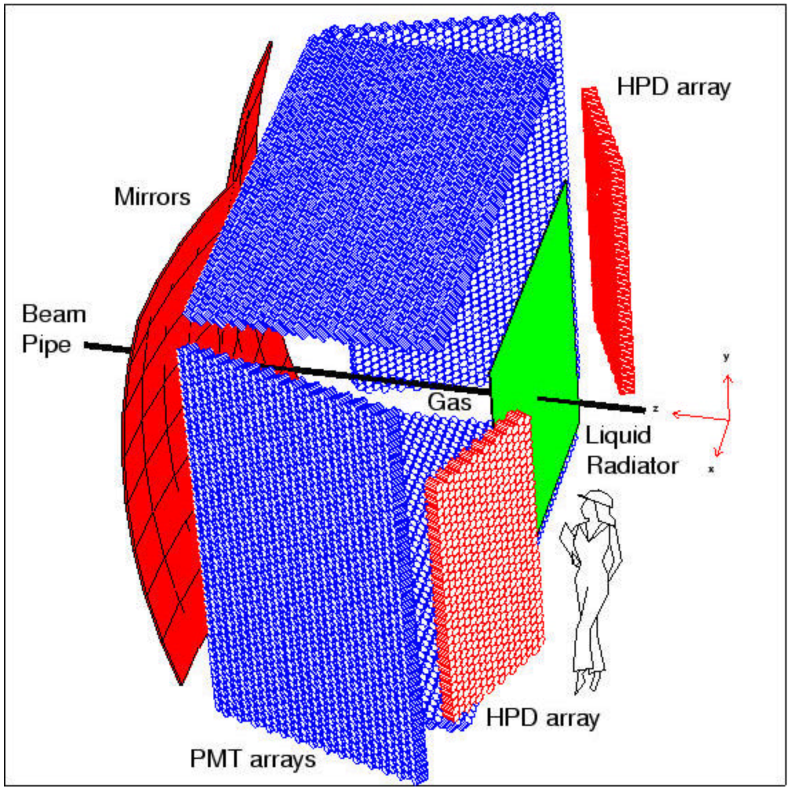
$B^\circ \rightarrow \pi^+\pi^-$

$\langle L\rangle/\sigma_L = 36$ at $p_B = 30$GeV

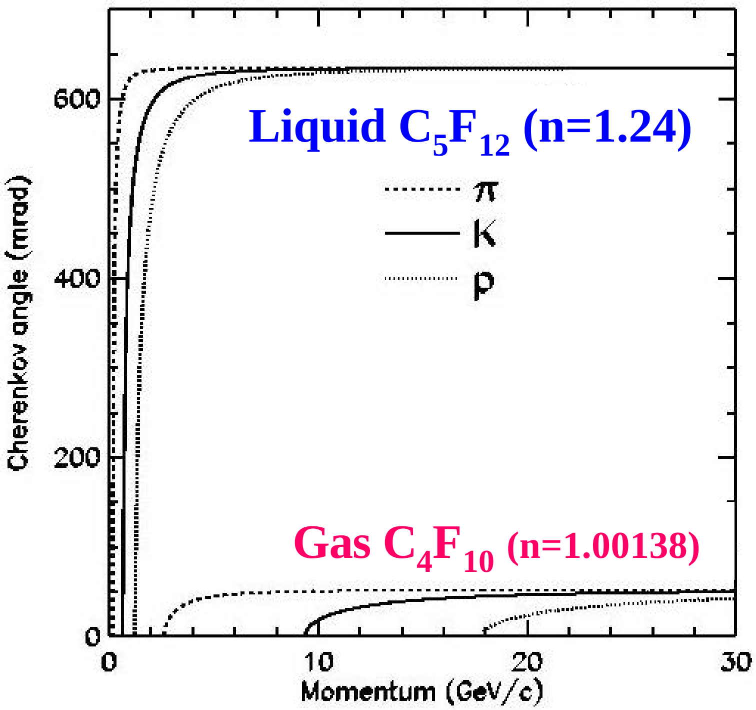


Large L_{decay} / σ_L is critical for b experiment

Ring Imaging Cherenkov Detector



Cherenkov angle vs P

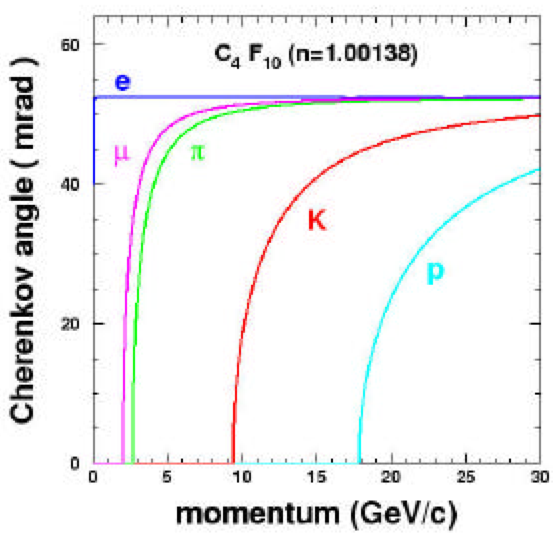


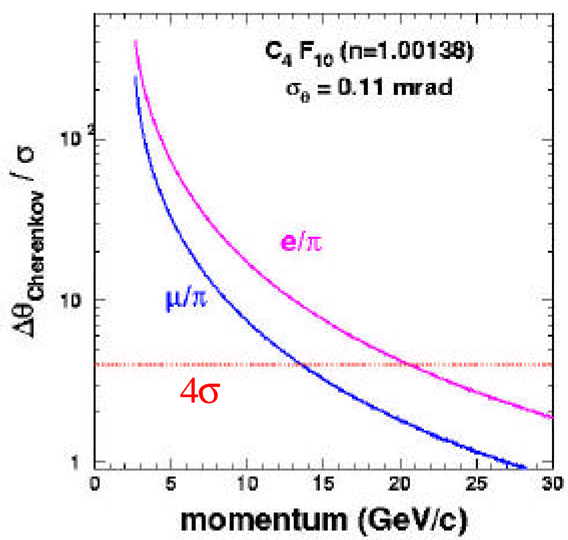
The RICH provides identification of kaons and pions.

It is essential to CP violation study

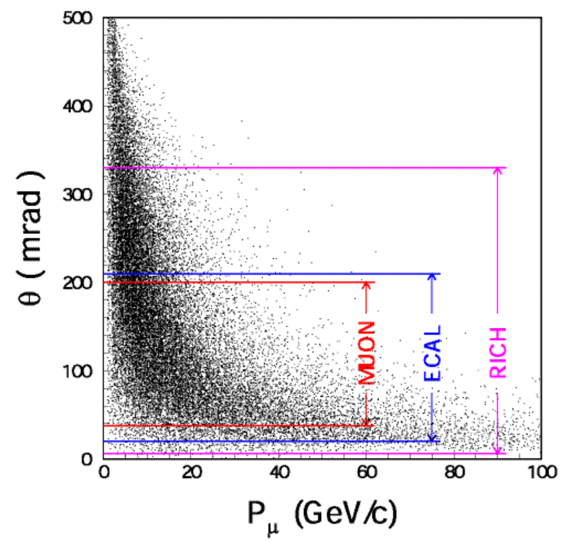
Lepton Identification Using RICH

- While the full detector aperture is 300 mr, the acceptance of the electromagnetic calorimeter and muon detector is only ~200 mr.
- The RICH, however, has both e/π and μ/π discrimination at low momentum. The wide angle particles are mostly at low momentum!



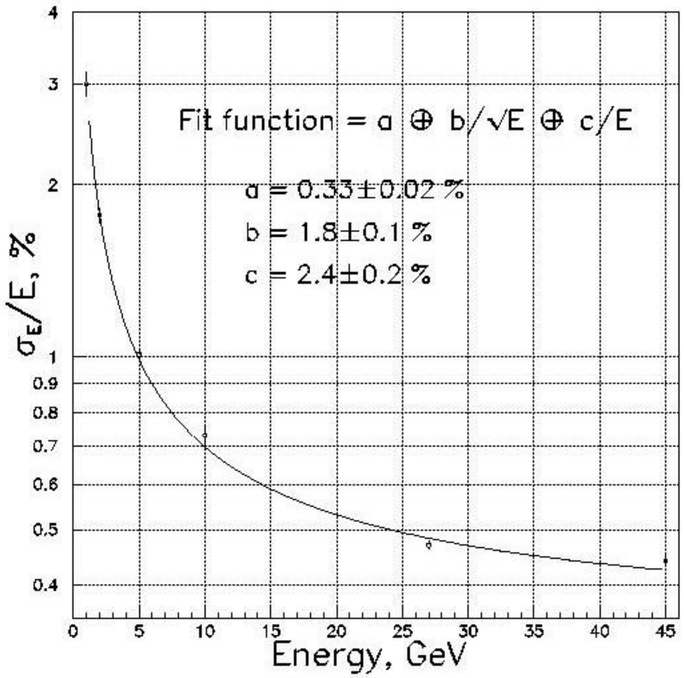


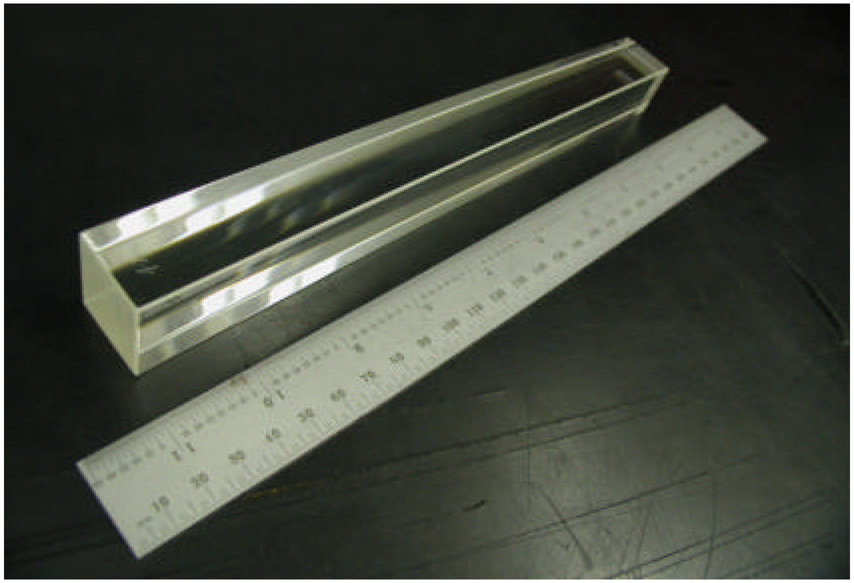
B→J/ψX



Electromagnetic Calorimeter

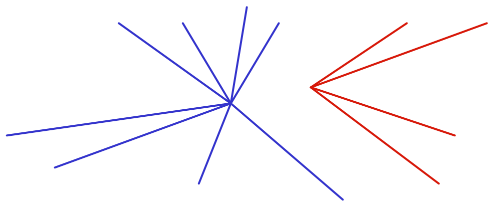
- EM calorimeter for γ/π° reconstruction and electron ID.
- 10,000 $PbWO_4$ crystal (rad hard) with PMT readout
- Lateral size: 27.2×27.2mm² (front), 28×28mm² (back), Length 22cm (25 X_0)
- Resolution: $\sigma_E/E = 0.8\%$ for γ in $B \to K^*\gamma$, $\sigma_M = 2.6$ MeV for 10 GeV π°.
- Sample crystals tested in a beam at Protvino.





Detached Vertex Trigger

- **Idea:** finds the primary vertex, selects events that have additional tracks miss it



- **Requirement:** at least 2 tracks detached by more than 6σ $\Rightarrow$ 1% minimum bias at level 1 trigger.
- Refined reconstruction at level 2 and 3.
- With 3-level trigger scheme, the event rate: 7.6 MHz $\Rightarrow$ 3 kHz
- **Efficiency:** (after the other analyses cuts)

State	efficiency(%)	State	efficiency(%)
$B \rightarrow \pi^+\pi^-$	63	$B^o \rightarrow K^+\pi^-$	63
$B_s \rightarrow D_s K$	71	$B^o \rightarrow J/\psi\ K_s$	50
$B^- \rightarrow D^o K^-$	70	$B_s \rightarrow J/\psi K^*$	68
$B^- \rightarrow K_s \pi^-$	27	$B^o \rightarrow \rho^o \pi^o$	56

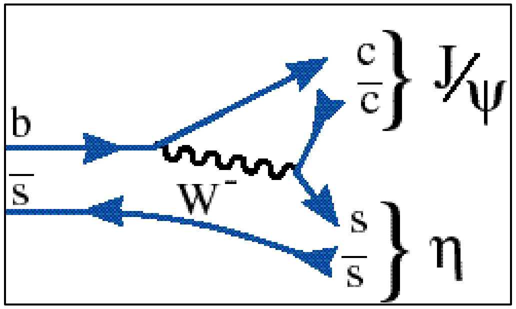
Physics Reach (CKM) in 10^7 s

Reaction	$\mathcal{B}$(B)($\times 10^{-6}$)	# of Events	S/B	Parameter	Error or (Value)
$B^o \to \pi^+\pi^-$	4.5	14,600	3	Asymmetry	0.030
$B_s \to D_s K^-$	300	7500	7	γ	8^o
$B^o \to J/\psi\, K_S$ $J/\psi \to l^+ l^-$	445	168,000	10	$\sin(2\beta)$	0.017
$B_s \to D_s \pi^-$	3000	59,000	3	x_s	(75)
$B^- \to \overline{D^o} (K^+\pi^-) K^-$ $B^- \to D^o (K^+K^-) K^-$	0.17 1.1	170 1,000	1 >10	γ	13^o
$B^- \to K_S \pi^-$ $B^o \to K^+\pi^-$	12.1 18.8	4,600 62,100	1 20	γ	$<4^o$ + theory errors
$B^o \to \rho^+\pi^-$ $B^o \to \rho^o\pi^o$	28 5	5,400 780	4.1 0.3	α	$\sim 4^o$
$B_s \to J/\psi\, \eta$, $B_s \to J/\psi\, \eta'$ $J/\psi \to l^+l^-$	330 670	2,800 9,800	15 30	$\sin(2\chi)$	0.024

Critical check to the SM

Critical Checks Using χ

- Silva & Wolfenstein (hep-ph/9610208), (Aleksan, Kayser & London), propose a test of the SM, that can reveal new physics; it relies on measuring the angle χ.
  - BTeV can use CP eigenstates in B_s decay to measure χ, for example $B_s \rightarrow J/\psi\eta^{(\prime)}$, $\eta \rightarrow \gamma\gamma$, $\eta' \rightarrow \rho\gamma$
  - Can also use $J/\psi\phi$, but need a complicated angular analysis
  - The critical check is

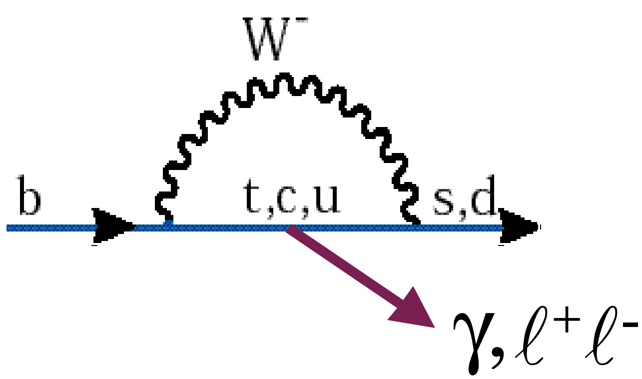


$$\sin ? = l^{2}\frac{\sin b \sin g}{\sin(b+g)}$$

  - Very sensitive since λ =0.2205±0.0018
  - Since χ ~ 0.03, need lots of data

Rare b Decays

- Sensitive to high mass gauge bosons and fermions. It is a good place to find new physics.
- Exclusive Rare Decays such as $B\to\rho\gamma$, $B\to K^*\ell^+\ell^-$: Dalitz plot & polarization
- Inclusive Rare Decays such as inclusive $b\to s\gamma$, $b\to d\gamma$, $b\to s\ell^+\ell^-$

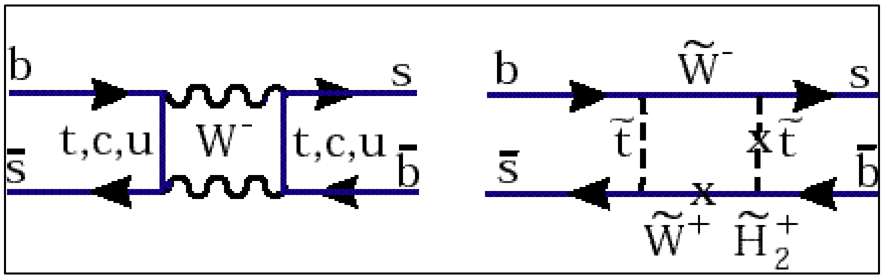


Reaction	$\mathcal{B}$ (10^{-6})	Signal /Year	S/B	Physics
$B^o\to K^{*o}\mu^+\mu^-$	1.5	2530	11	polarization & rate
$B^-\to K^-\mu^+\mu^-$	0.4	1470	3.2	rate
$b\to s\mu^+\mu^-$	5.7	4140	0.13	rate: Wilson coefficents

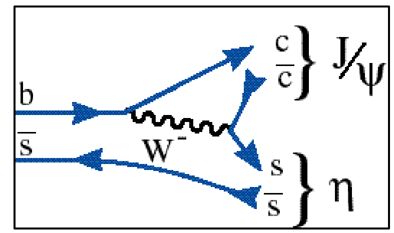
MSSM Measurements

(from Hinchcliff & Kersting hep-ph/0003090)

- Contributions to B_s mixing



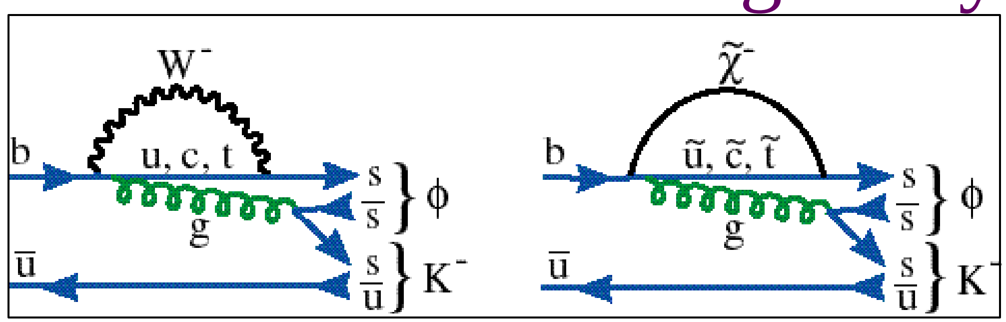
$B_s \rightarrow J/\psi\eta$



CP asymmetry ≈ $0.1\sin\phi_\mu\cos\phi_A\sin(\Delta m_s t)$, ~10 x SM

- Contributions to direct CP violating decay

$B^- \rightarrow \phi K^-$



Asym=$(M_W/m_{squark})^2\sin(\phi_\mu)$, ~0 in SM

Reconstructed Events in New Physics Modes: Comparison of BTeV with B-factories

Mode	BTeV (10^7s)			B-fact (500 fb^{-1})		
	Yield	Tagged	S/B	Yield	Tagged	S/B
$B_s \to J/\psi\eta^{(\prime)}$	12650	1645	>15	-	-	
$B^- \to \phi K^-$	6325	6325	>10	700	700	4
$B^o \to \phi K_s$	1150	115	5.2	250	75	4
$B^o \to K^* \mu^+\mu^-$	2530	2530	11	~50	~50	3
$B_s \to \mu^+\mu^-$	6	0.7	>15	0		
$B^o \to \mu^+\mu^-$	1	0.1	>10	0		
$D^{*+} \to \pi^+ D^o$, $D^o \to K\pi^+$	$\sim 10^8$	$\sim 10^8$	large	8×10^5	8×10^5	large

Specific Comparisons with LHC-b

Yields in two final states

Mode	BR	BTeV		LHC-b	
		Yield	S/B	Yield	S/B
$B_s \rightarrow D_s K^-$	$3.0x10^{-4}$	7530	7	7660	7
$B^o \rightarrow \rho^+ \pi^-$	$2.8x10^{-5}$	5400	4.1	2140	0.8
$B^o \rightarrow \rho^o \pi^o$	$0.5x10^{-5}$	776	0.3	880	not known

Status

- BTeV received a second unanimous approval by the Fermilab PAC (4/2002).

PAC Recommendation

“ … BTeV has designed and prototyped an ambitious trigger that will use B decay displaced vertices as its primary criterion. This capability, together with BTeV’s excellent electromagnetic calorimetry and particle ID and enormous yields, will allow this experiment to study a broad array of B and B_s decays. BTeV has a broader physics reach than LHCb and should provide definitive measurements of CKM parameters and the most sensitive tests for new physics in the flavor sector.”

- Detector costs have been reduced from ~180 M$ to ~110 M$ (includes G&A and 30% contingency). Full “Temple” review in 9/2002.
- P5 or equivalent review for DOE in Fall 2002.