BTeV - Status and Perspectives

- Physics Goals - My Perspective
- Detector Description and R&D
- Comparisons to other experiments
- Status

Fermilab

Harry W.K. Cheung

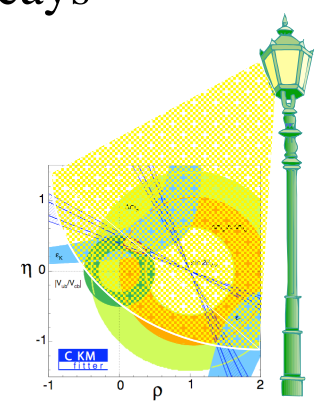
Physics Goals:
My perspective on one slide

- The Standard Model CKM matrix is very predictive

e.g. all quark CP-violation is described by □ (i.e. 1 parameter)

- To discover new physics (or help interpret new physics discovered elsewhere) we need a comprehensive study of quark flavour physics

  - Need to measure "□", □, □ □ in many modes/decays
  - Look at rare b decays and mixing
  - Look at CP-violation and rare decays in charm
  - Check flavour independence with kaon decays



- Compare to the comprehensive tests of EW at LEP and SLD - repeat for quark flavour physics!

So don't just look under one lamp post!

Requirements for Measurements

- Precision: Large samples of decays, flavour tagged for CP-violation
- Comprehensive: B^+, B_d, B_s, B_c, b-baryon and charm decays
  Efficient reconstruction for "all" decays, including □and □^{0}'s
  Excellent flavour tagging

Physics Quantity	Decay Mode	Vertex Trigger	K/□ Sep	□Det	Decay Time □
sin(2□)	B^0 □ □□ □ □$^+$□$^-$□^{0}	✓	✓	✓	
cos(2□)	B^0 □ □□ □ □$^+$□$^-$□^{0}	✓	✓	✓	
sin(□)	B_s □ D_sK^-	✓	✓		✓
sin(□)	B^0 □ D^0K^-	✓	✓		
sin(2□)	B_s □ J/□□, J/□□□		✓	✓	✓
sin(2□)	B^0 □ J/□ K_s				
cos(2□)	B^0 □ J/□ K^0, K^0 □ □l□		✓		
x_s	B_s □ D_s □$^-$	✓	✓		✓
□□ for B_s	B_s □ J/□□$^{(\prime)}$, K^+K^-, D_s□	✓	✓	✓	✓

BTeV Collaboration

Origins: Fnal FT CLEO Hera/HeraB

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Univ. of Tennessee: T. Handler, R. Mitchell

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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

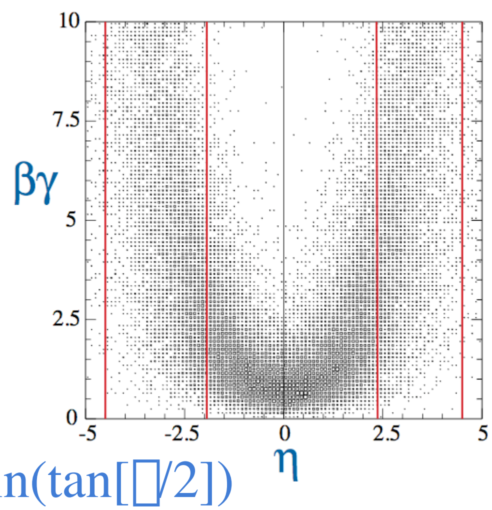
University of Wisconsin: M. Sheaff

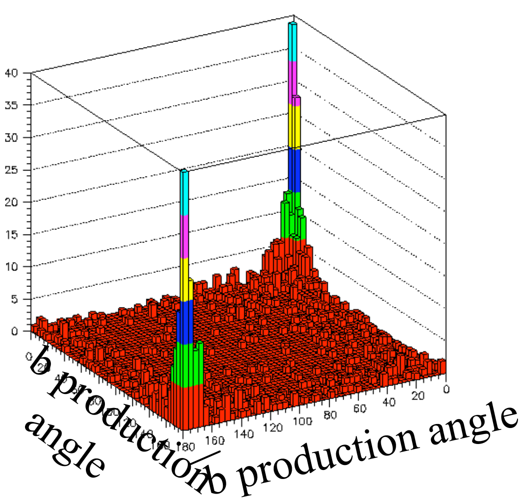
York University: S. Menary

Why do b and c Physics at Tevatron?

- Large samples of b quarks
  - Get ~ 4×10^{11} b hadrons per 10^7s at $L = 2\times10^{32}$ $cm^{-2}s^{-1}$
  - For e^+e^- at Υ(4S) get 2×10^8 B hadrons per 10^7s at 10^{34} $cm^{-2}s^{-1}$
- B_s, Λ_b and other b-flavored hadrons are accessible at the Tevatron
- Charm rates are ~ 10× larger than b rates

Why look in the Forward Region?



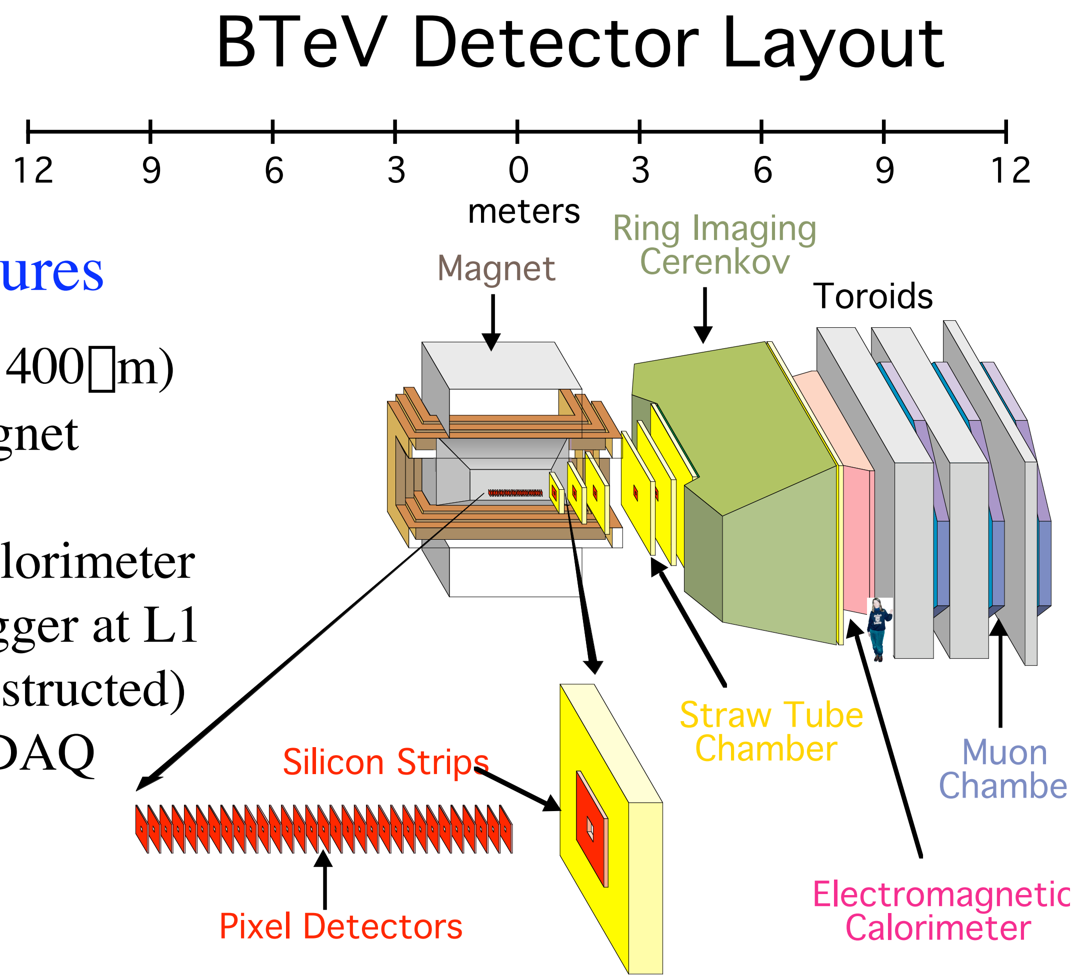


- Decay length separation
- Less MCS
- More BB in detector
- Better away-side tagging

The BTeV Detector

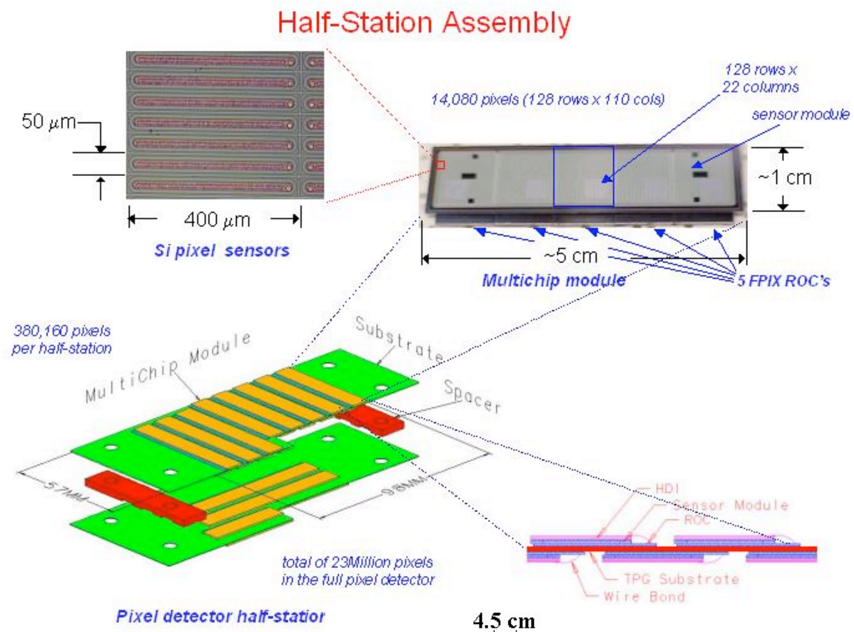
Main/Unique Features

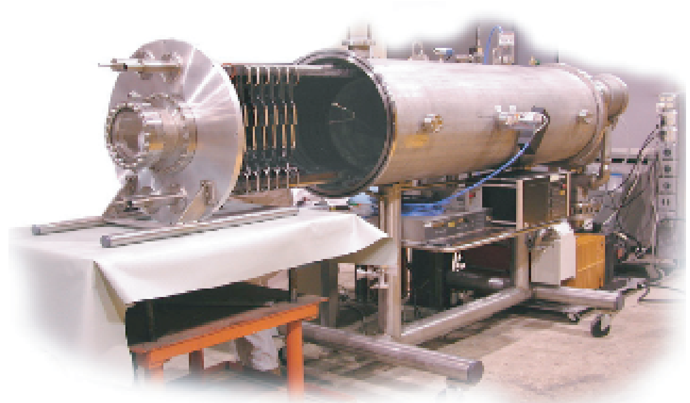
- Vertex pixel ($50\mu m \times 400\mu m$) detector in dipole magnet
- RICH for particle ID
- $PbWO_4$ crystal EM calorimeter
- Vertex separation Trigger at L1 (primary vertex reconstructed)
- Powerful high speed DAQ (output rate at 4KHz)

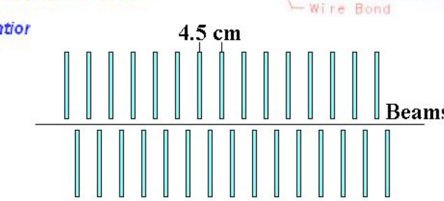


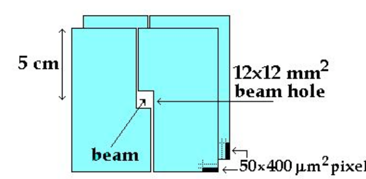
Pixel Vertex Detector

- **Achieved design (5-10 micron) resolution in 1999 FNAL test beam run.**
- **Demonstrated radiation hardness in exposures at IUCF.**
- **The final readout chip has been bench tested and will undergo final testing in FNAL test-beam in 2003.**





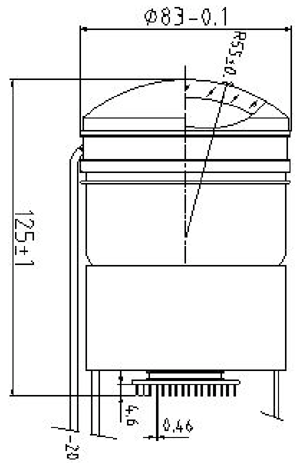


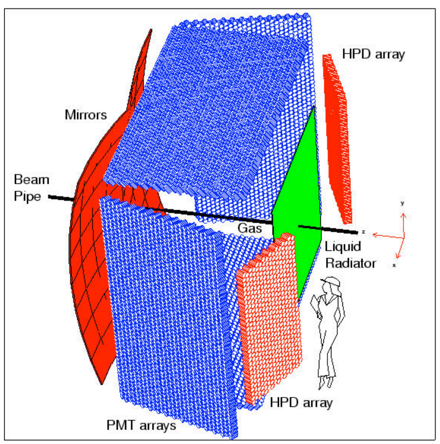


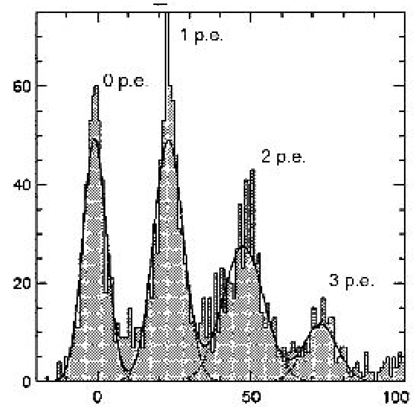
Ring Imaging Cerenkov Counter

- Gas radiator (C_4F_{10}) detected on planes of Hybrid Photodiodes
- Liquid radiator (C_5F_{12}) detected on array of side mounted PMTs

- Developing a 163 pixel HPD
- Bench test at Syracuse showing pulse height distribution from prototype







HPD Enclosure will be here

Enclosure for RICH beam test

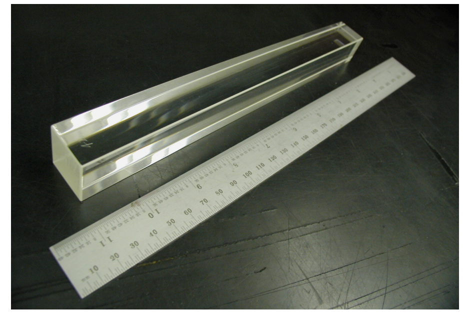
Beam

Mirror at back end

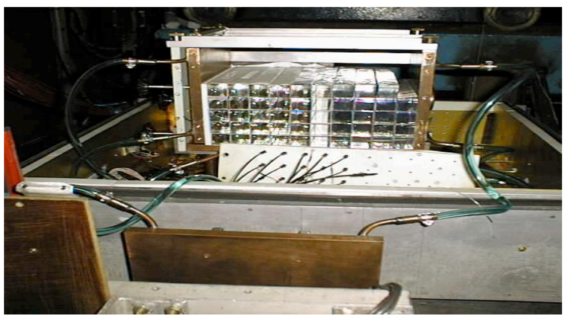
- Also testing MAPMTs

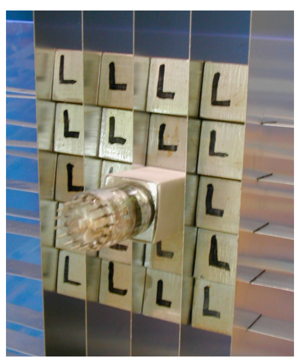
Lead Tungstate EM Calorimeter

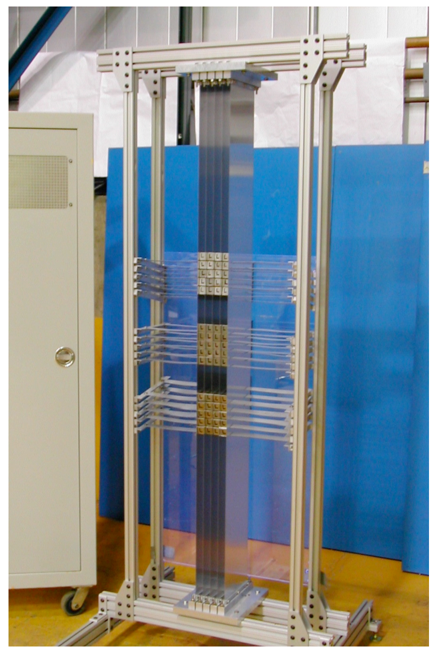
- $PbWO_4$ 28×28mm^2 × 22cm crystals pioneered by CMS, but BTeV uses PMTs
- Excellent energy and spatial resolution
- Resolution measured at IHEP/Protvino beam tests (Stochastic term = 1.8%)

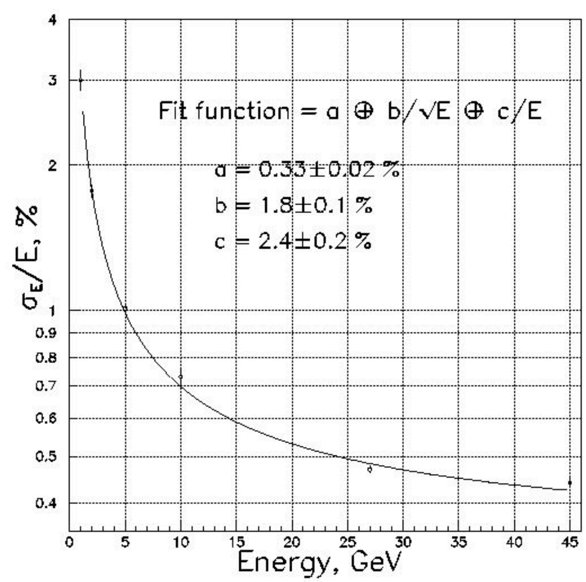


Multiple vendors (Bogoriditsk, Russia and Shanghai, China)

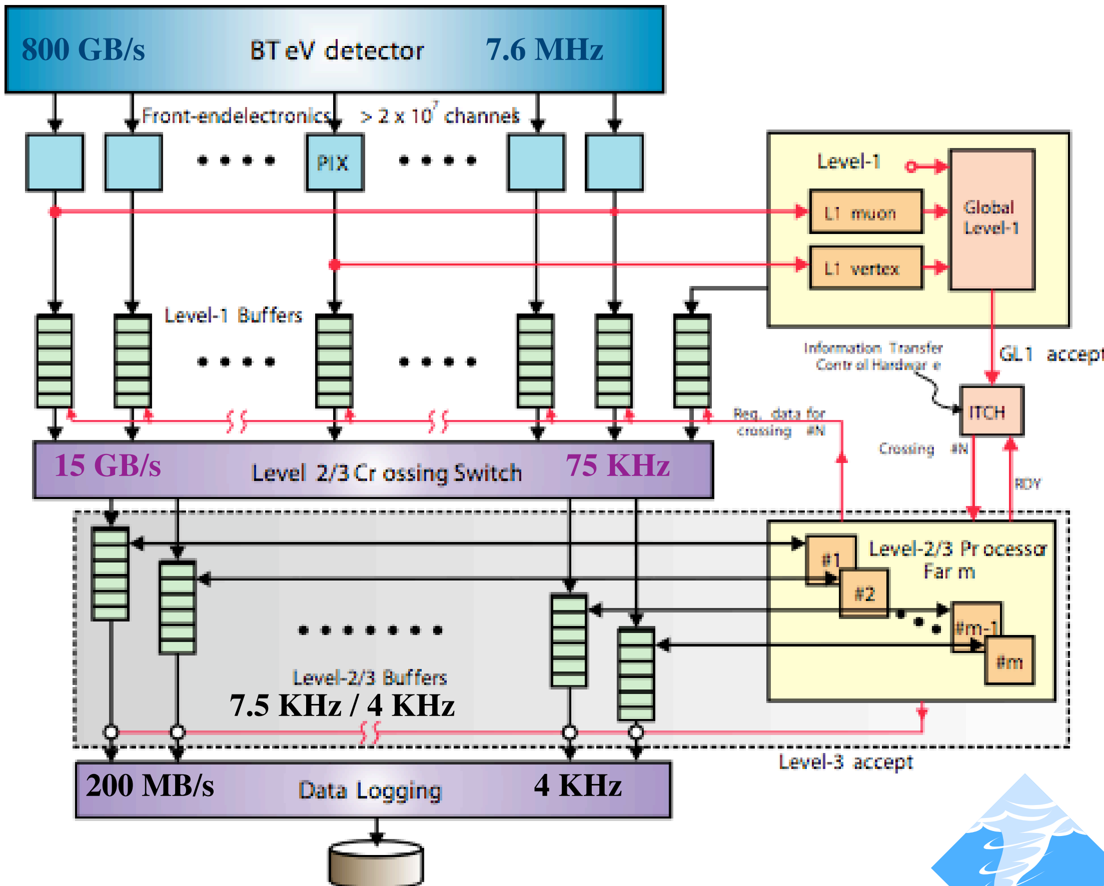








BTeV Trigger



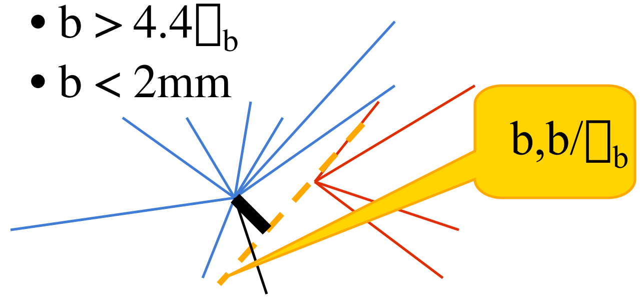
1-2 Petabytes per year

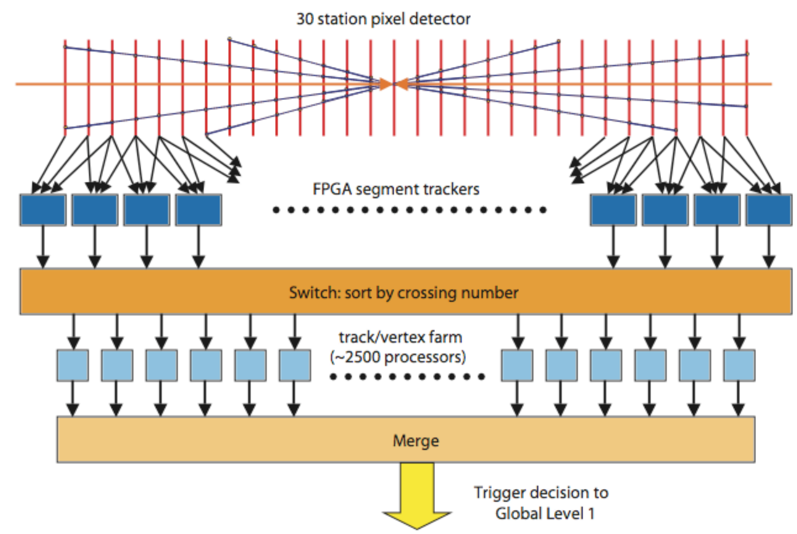
- Reconstructs primary vertex and looks for detached decays every crossing
- Made possible by vertex detector (3D space points with excellent resolution and low occupancy)
- Pipelined and parallel processing with 1 TB of buffer
- 3 Stage Trigger
  - L1:FPGAs and DSPs
  - L2/L3: Linux PCs

BTeV L1 Pixel Trigger

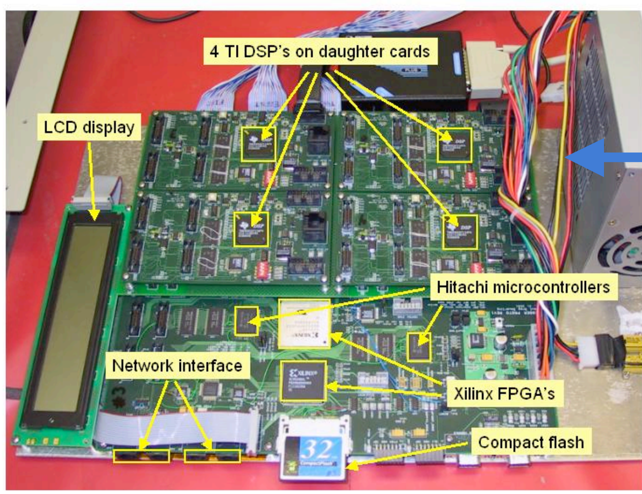
Finds primary vertex and looks for
At least 2 tracks that miss it with:

- $p_T^2 > 0.25\ (\mathrm{GeV}/c)^2$
- $b > 4.4\sigma_b$
- $b < 2\mathrm{mm}$





100/1 rejection of min-bias events

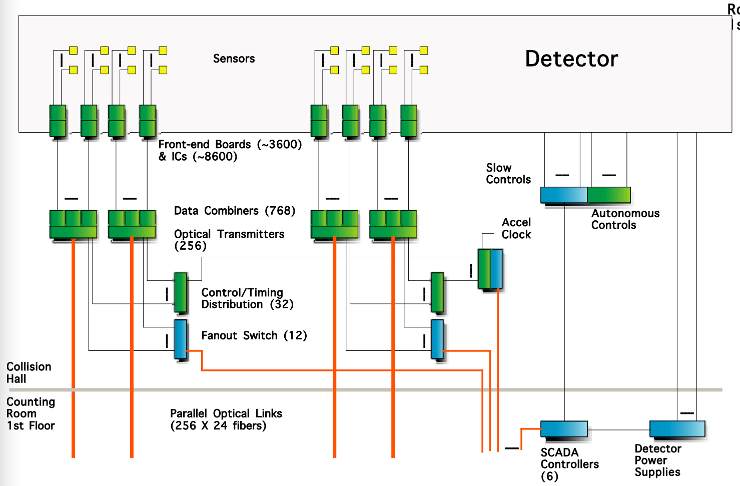


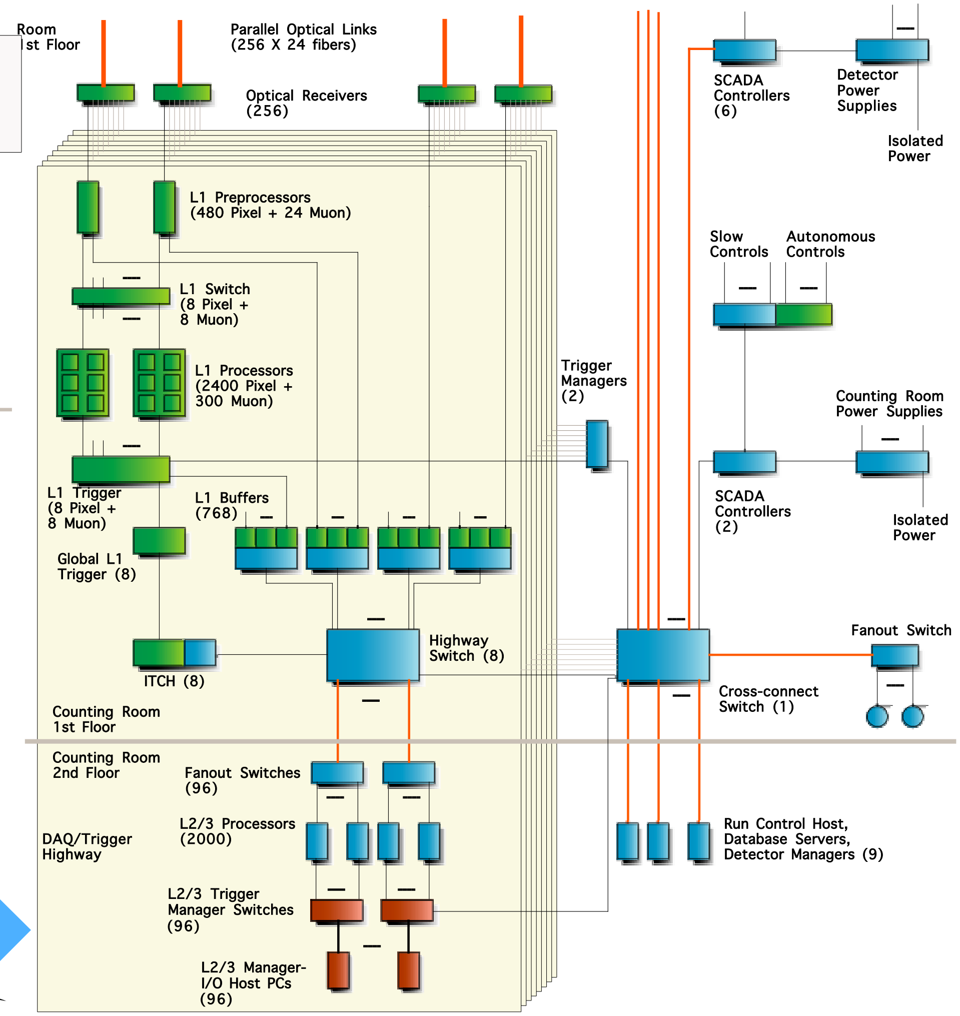
L1 Vertex Trigger prototype

- Timing tests show we are already close to the required < 350 μs L1 latency
- Speed is low by 2.7× w/old DSP
  1.8× w/new DSP

No need for hand optimized assembly code!

BTeV DAQ





- Changed custom switch to a commercial one to lower risk.
- DAQ is divided into 8 “Highways”
- Output data is DST and saved on disk (with duplication)

Fault Tolerance in Trigger and DAQ

- Outcome of BTeV's response to an early review on complexity of system is a research program on Real Time Embedded Systems Research (RTES)
- A collaborative effort between computer scientists and BTeV physicists funded by the NSF ($5M over five years)

Illinois **Pittsburgh** **Syracuse** **Vanderbilt** **Fermilab** **NSF**

- Researching the design and implementation of high-performance, heterogeneous, fault-tolerant and fault-adaptive real-time systems that are embedded (*i.e.* are an integral part of the hardware they serve)
- Contains an educational outreach program where high school teachers take part in the research and develop WEB lessons for their students (Summer programs at Fermilab and Pittsburgh, integrated with QuarkNet, Link-to-Learn and College in High School programs)

Physics Reach CKM in 10^7 s

(Model Independent)

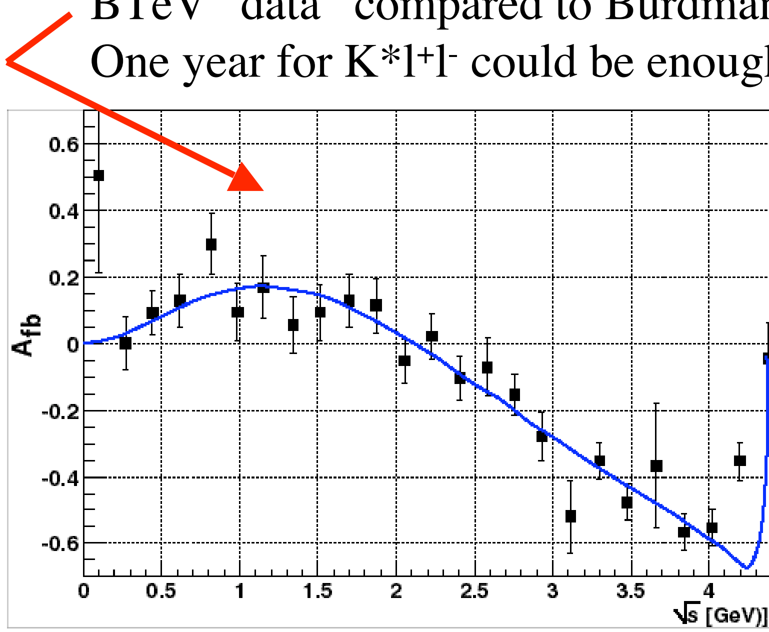
Decay	$\mathcal{B}$(B) (x10^{-6})	# Events	S/B	Parameter	Error or (Value)
$B_s \to D_s K^-$	300	7500	7	$\gamma - 2\chi$	8^o
$B_s \to D_s \pi^-$	3000	59,000	3	x_s	(75)
$B^0 \to J/\psi K_S$ $J/\psi \to \ell^+ \ell^-$	445	168,000	10	sin(2β)	0.017
$B^0 \to J/\psi K^0$, $K^0 \to \pi \ell \nu$	7	250	2.3	cos(2β)	~0.5
$B^- \to D^0 (K^+\pi^-) K^-$	0.17	170	1	γ	13^o
$B^- \to D^0 (K^+K^-) K^-$	1.1	1,000	>10		
$B_s \to J/\psi \eta$	330	2,800	15	sin(2χ)	0.024
$B_s \to J/\psi \eta'$	670	9,800	30		
$B^0 \to \rho^+\pi^-$	28	5,400	4.1	α	~ 4^o
$B^0 \to \rho^0\pi^0$	5	780	0.3		

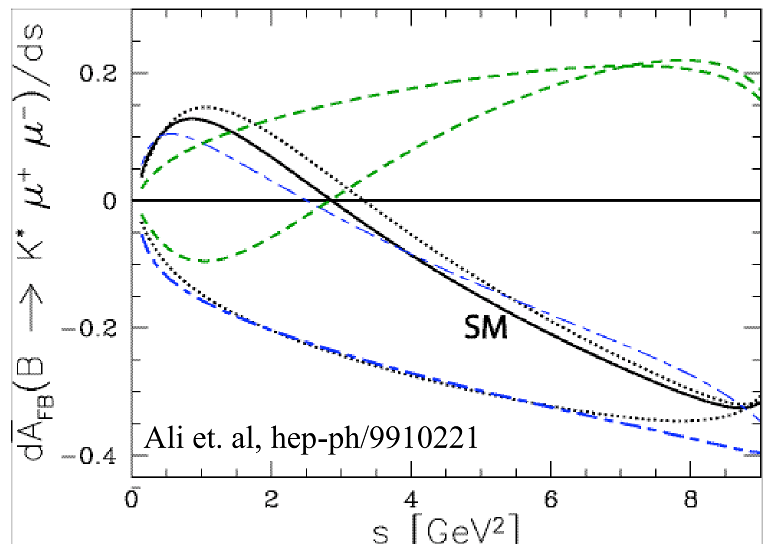
Physics Reach Rare Decays

Decay	$\mathcal{B}$ (10^{-6})	Signal	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 coefficients

BTeV "data" compared to Burdman et al. Calculation for $K^*l^+l^-$

One year for $K^*l^+l^-$ could be enough to determine if New Physics is present





Operation at 396 ns Bunch Crossing

- BTeV was designed for $L = 2\times10^{32}\ cm^{-2}s^{-1}$ at 132 ns
  i.e. $\langle 2 \rangle$ interactions/crossing
- Now expect $L \sim 2\times10^{32}\ cm^{-2}s^{-1}$ at 396 ns, i.e. $\langle 6 \rangle$ int/crossing
  or $L \sim 1.3\times10^{32}\ cm^{-2}s^{-1}$ at 396 ns, i.e. $\langle 4 \rangle$ int/crossing
- Verified performance by repeating many of the simulations
  at $\langle 4 \rangle$ and $\langle 6 \rangle$ int/crossing (without re-optimizing the code)
  Average impact across store is ~10%
- Key potential problems areas - trigger, EMCAL and RICH all
  hold up well based on simulations
- Ongoing work to understand fully the impact of a change to
  396 ns bunch spacing, a "396 ns impact" document is being prepared.

Charm Physics Potential

Flexible trigger and high rate DAQ - potential to find New Physics

- D^0-$\overline{D}^0$ Mixing: Box diagram: □m_D^{SD}/□ < 1□10^{-4}
  LD Dispersive: □m_D^{LD}/□ ~ 2□10^{-4}
  LD HQET: □m_D^{LD}/□ ~ (1 to 2)□10^{-5}
  SM Contribution: □m_D^{SM}/□ < 1□10^{-4}
  Current experimental limit □m_D/□ < 0.1 Lots of Discovery room!

- CP Violation: Possibly observe SM CP violation in charm!
  SM: A_{CP} □ 2.8□10^{-3} for D^+ □ $\overline{K}^{*0}K^+$
  A_{CP} □ -8.1□10^{-3} for D_s^+ □ K^{*+}□□
  Expect □(A_{CP}) = 1□10^{-3} for 10^6 background-free events
  Excellent D* tag (efficiency □ 25%)
  Geant simulation gives # reconstructed D^0□ K□ > 10^8

BTeV has the necessary detectors, trigger and DAQ for charm

Comparisons to Belle/BaBar

- No B_s, B_c and Λ_b at B-factories (no comprehensive study)
- Number of flavor tagged $B^0 \to \pi^+\pi^-$ (BR=0.45×10^{-5})

	$L(cm^{-2}s^{-1})$	σ	$\#B^0/10^7s$	ϵ_{rec}	ϵD^2	#tagged
e^+e^-	10^{34}	1.1nb	1.1×10^8	0.45	0.26	56
BTeV	2×10^{32}	100μb	1.5×10^{11}	0.021	0.1	1426

- Number of $B^- \to \overline{D}^0K^-$ (Full product BR=1.7×10^{-7})

	$L(cm^{-2}s^{-1})$	σ	$\#B^0/10^7s$	ϵ_{rec}	#
e^+e^-	10^{34}	1.1nb	1.1×10^8	0.4	5
BTeV	2×10^{32}	100μb	1.5×10^{11}	0.007	176

Events in New Physics Modes: Comparison with B-Factories

Mode	BTeV (10^7s)			B-Factory (500 fb^{-1})		
	Yield	Tagged	S/B	Yield	Tagged	S/B
$B_s \to J/\psi\, \eta^{(\prime)}$	12650	1645	>15	-	-	-
$B^- \to \phi K^-$	11000	n/a	>10	700	700	4
$B^0 \to \phi K_s$	2000	200	5.2	250	75	4
$B^0 \to K^* \mu^+ \mu^-$	2530	n/a	11	~50	~50	3
$B_s \to \mu^+ \mu^-$	6	0.7	>15	-	-	-
$B^0 \to \mu^+ \mu^-$	1	0.1	>10	0	-	-
$D^{*+} \to D^0 \pi^+, D^0 \to K \pi^+$	$\sim 10^8$	$\sim 10^8$	large	8×10^5	8×10^5	large

Comparison to Super-KEK

- KEK-B plans for $L=10^{35}$ $cm^{-2}s^{-1}$ in 2007, (10× original design)
- Numbers in previous tables still not competitive with BTeV
- Problems for detectors (See E2 report at Snowmass)

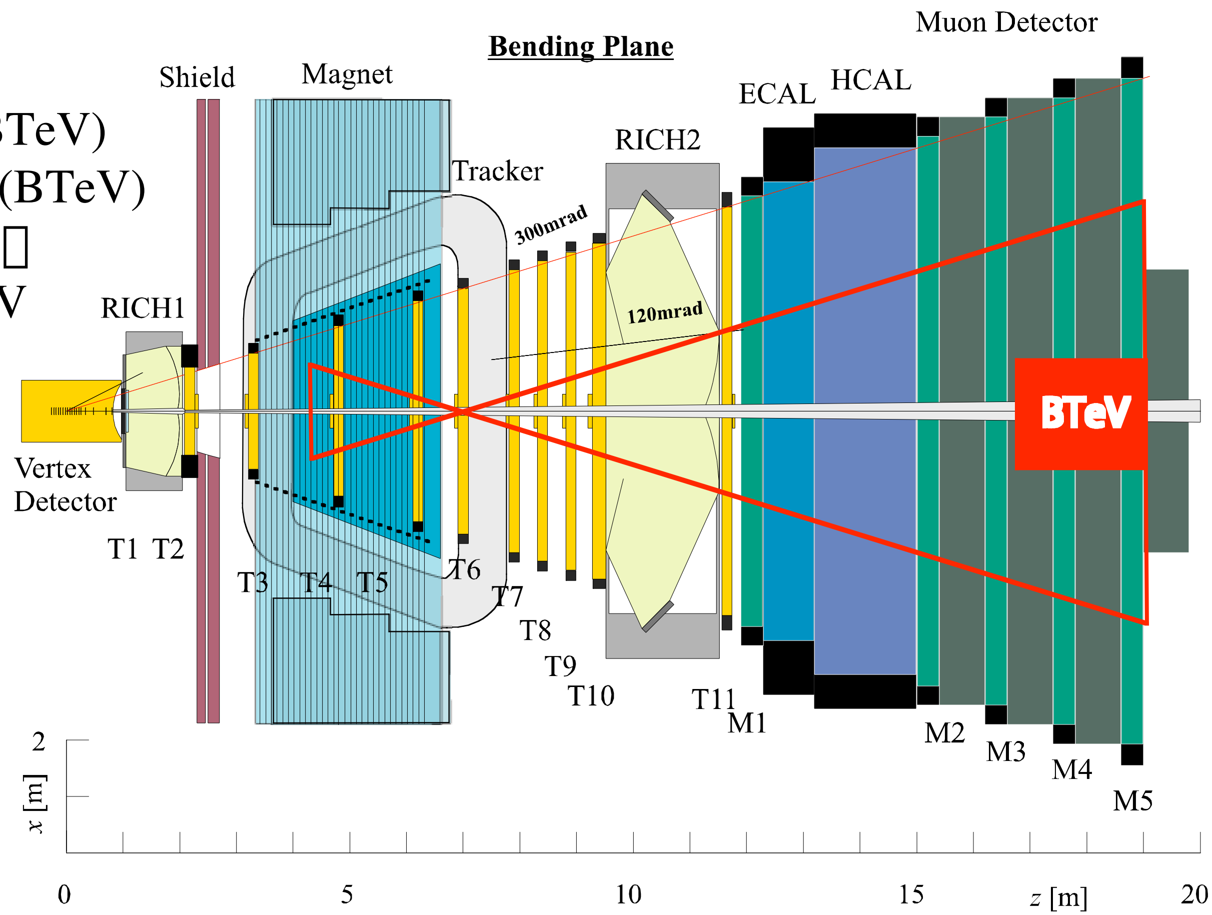
Comparison to Super-BaBar

- Proposal for $L=10^{36}cm^{-2}s^{-1}$ (>100× original design)
- Would be competitive with BTeV in B^0 and B^+ Physics
- Still could not do B_s, B_c and Λ_b
- Serious technical problems to overcome for both the machine and detector
- We believe the cost will far exceed that of BTeV (Recent HEPAP subpanel mentions $500M)

Comparison to LHCb

- Competition is LHCb
  □$_{bb}$(LHCb) = 5□□$_{bb}$(BTeV)
  □$_{tot}$(LHCb) = 1.6□□$_{tot}$(BTeV)
- □Interactions/Crossing□
  □ 3□ lower than BTeV

However BTeV has Many Advantages!



Comparison to LHCb II

- BTeV is designed around a pixel detector with less occupancy, allows for a detached vertex trigger at the first level trigger
  - Large samples of rare hadronic and charm decays
  - BTeV can run with multiple interactions per crossing
- BTeV vertex detector in magnetic field allows rejection of low momentum (high MCS) tracks in the trigger
- BTeV has a (20$\times$) higher rate DAQ - more b and c decays
- BTeV will have a much better EM calorimeter - more comprehensive study of decays
- LHCb are currently extensively changing their design beyond TDR:
  - Reduced # silicon planes and thickness, # tracking stations
  - Put magnetic field in interaction region (remove shield-RICH)
  - Added high p_T only trigger (for $B \to h^+h^-$)
  - Allow multiple interactions per crossing

Comparison to LHCb III

- Compare to preliminary (April 2003) LHCb light #s

Mode	BR (10^{-5})	LHCb Untag Yield		BTeV (Yield scaled to BR)
		TDR	Light	
$B_s \to D_s \pi^-$	300	86000	72000	59000
$B_s \to D_s K^-$	23	6000	8000	5900

- Compare to LHCb TDR #s (LHCb light #s ready in fall $\Rightarrow$TDR #s)

Mode	BR	LHCb		BTeV	
		Yield	S/B	Yield	S/B
$B_s \to J/\psi \eta^{(\prime)}$	1.0×10^{-3}	-	-	12650	>15
$B^0 \to \pi^+ \pi^-$	2.8×10^{-5}	2140	0.8	5400	4.1
$B^0 \to \pi^0 \pi^0$	0.5×10^{-5}	880	unknown	776	0.3

- BTeV superior for photons/π^0 and more comprehensive data set

Brief History and Status of BTeV

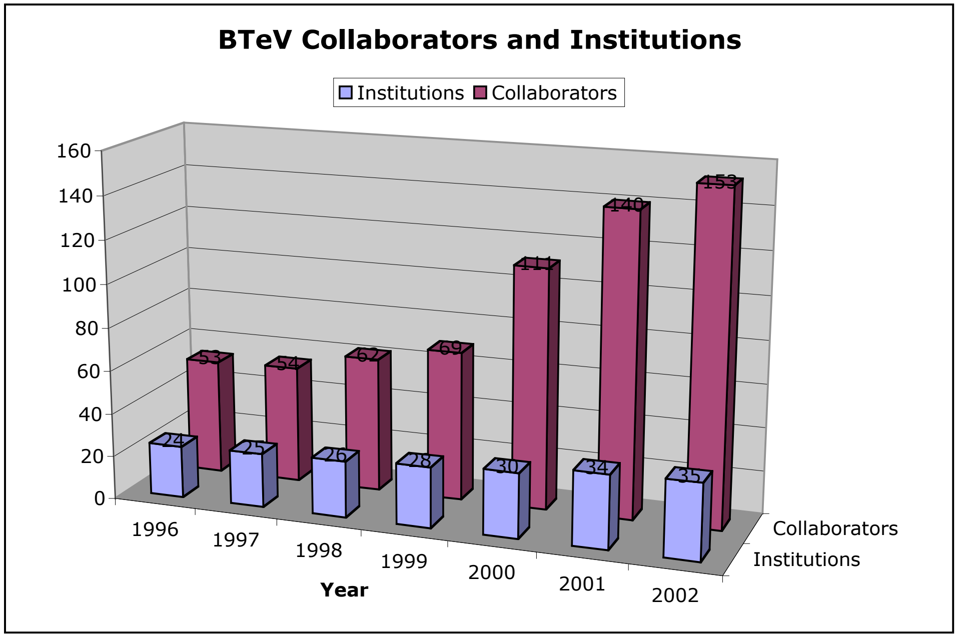
What it takes to get an experiment approved “now”

- May 1997 - EOI, 161 pages
- Dec. 1997 - Addendum, 62 pages - address PAC concerns
  □ BTeV becomes a R&D project
- May 1999 - Preliminary TDR, 373 pages (full BTeV)
- May 2000 - Proposal, 429 pages, submitted to Fermilab
  June 2000 □ PAC unanimously recommends Stage 1 approval
  □ Approval from Director (2-arms)
- Mar. 2002 - Proposal update, 126 pages (request from Lab, 1-arm)
  □ PAC unanimously recommends approval of descoped BTeV
  □ Approval from Director
- Oct. 2002 - Fermilab conducts cost review of BTeV (Temple)
- Mar. 2003 - Review of BTeV by P5

□ Oct. 2003 - P5 supports building BTeV and recommends earliest construction

Continual interest in BTeV

- Despite long review and approval process and problems for universities getting funding (e.g. for R&D):



- Shows there is a very strong interest in the physics and technology of BTeV

Summary I

- From the PAC report of June 2000 on 2-arm BTeV:

  "The Committee believes that BTeV has the potential to be central part of an excellent Fermilab physics program in the era of the LHC. With excitement about the science and enthusiasm for the elegant and challenging detector, the Committee unanimously recommends Stage I approval for BTeV"

- From the April 2002 PAC recommendations on updated BTeV:

  "The Committee once again recommends Stage I approval for BTeV. Although the composition of the committee has changed substantially since 2000, this recommendation is again unanimous."

- From the September 2003 P5 report to HEPAP:

  "P5 supports the construction of BTeV as an important project in the world-wide quark flavor physics area. Subject to constraints within the HEP budget, we strongly recommend an earlier BTeV construction profile and enhanced C0 optics."

Summary II

- If we get DOE approval and funding:

Year		2003	2004	2005	2006	2007
Tevatron Collider						BTeV
		CDF & DZero	CDF & DZero	CDF & DZero	CDF & Dzero	CDF & Dzero
Neutrino Program	B	MiniBoone	MiniBooNE	MiniB OPEN	OPEN	OPEN
	MI			MINOS	MINOS	MINOS
Meson 120	MT	Test Beam	Test Beam	Test Beam	Test Beam	Test Beam
	MC	E907/MIPP	E907/MIPP	E907/MIPP	OPEN	OPEN

Year		2008	2009	2010	2011	2012
Tevatron Collider		BTeV	BTeV	BTeV	BTeV	BTeV
		CDF & DZero	CDF & DZero	OPEN	OPEN	OPEN
Neutrino Program	B	OPEN	OPEN	OPEN	OPEN	OPEN
	MI	MINOS	MINOS	OPEN	OPEN	OPEN
Meson 120	MT	Test Beam	Test Beam	Test Beam	Test Beam	Test Beam
	MC	E906	E906-DrellYan	E906-DrellYan	E906-DrellYan	OPEN
	ME/P	OPEN	CKM	CKM	CKM	CKM OPEN

We are excited about BTeV and eager to get construction funded and started!