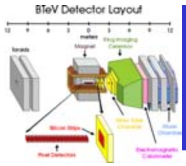
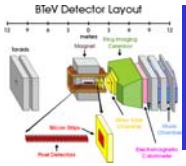


Status of BTeV experiment at the Fermilab Tevatron

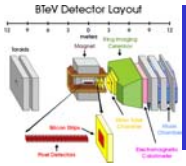
Stefano Bianco
Laboratori Nazionali di Frascati dell'INFN
For the BTeV Collaboration



Outline

1. Physics
2. Detector
3. Status and Schedule

Due to limited time I shall only provide overview of the main features. Lots more details in recent talks by Sheldon Stone (DOE CD-1 Review April 2004), Joel Butler (Fermilab PAC June 2004), Penny Kasper (BEACH04, Chicago), Harry Cheung (WIN 2003), Rob Kutschke (Aspen Winter 2004).



BTeV Collaboration

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New Mexico State -
V. Papavassiliou
Northwestern Univ. -
J. Rosen
Ohio State University-
K. Honscheid, & H. Kagan
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Shandong Univ. (China)-
C. F. Feng, Yu Fu, Mao He, J. Y. Li, L. Xue, N. Zhang, & X. Y. Zhang
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T. Coan, M. Hosack

Syracuse University-
M. Artuso, C. Boulahouache, S. Blusk, J. Butt, O. Dorjkhaidav, J. Haynes, N. Menaa, R. Mountain, H. Muramatsu, R. Nandakumar, L. Redjimi, R. Sia,
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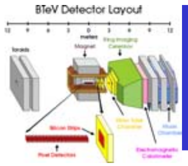
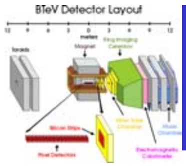
Vanderbilt University
W. Johns, P. Sheldon, E. Vaandering, & M. Webster
University of Virginia M. Arenton, S. Conetti, B. Cox, A. Ledovskoy, H. Powell, M. Ronquest, D. Smith, B. Stephens, Z. Zhe
Wayne State University
G. Bonvicini, D. Cinabro, A. Schreiner
University of Wisconsin
M. Sheaff
York University - S. Menary

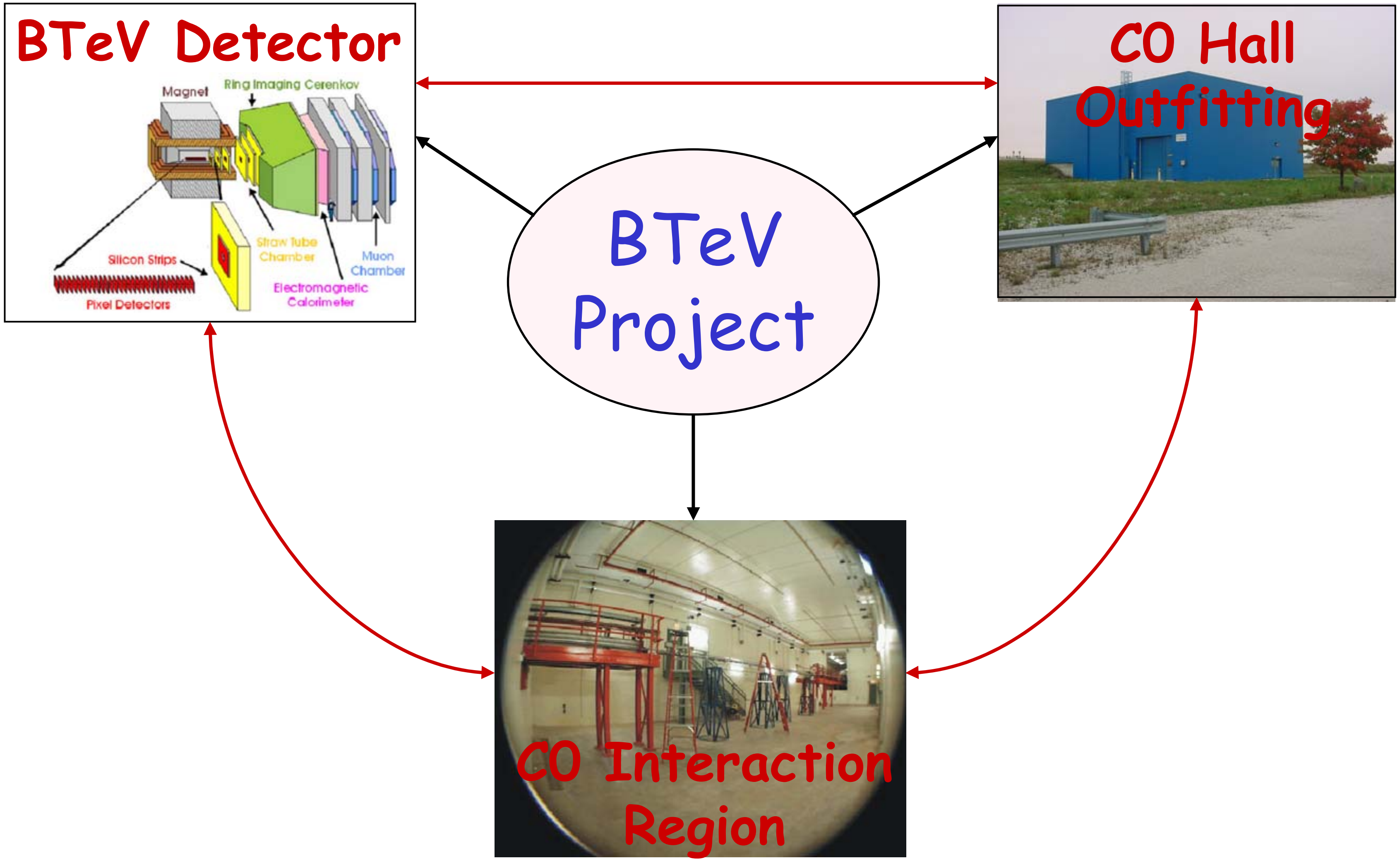


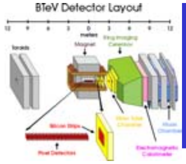
What is BTeV?

- Tevatron $\mathbf{p\text{-}\bar{p}}$ collider experiment, at Fermilab:
  - Forward spectrometer @ C0 interaction region
  - Beauty and charm physics:
    - Precision measurements of SM parameters
    - Exhaustive search for new physics.
- BTeV is a part of broad program to address fundamental questions in flavor physics.
- Details at: http://www-btev.fnal.gov.



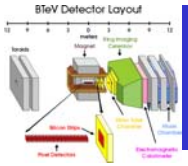
Project Scope





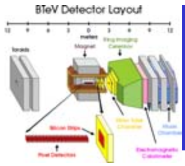
A Brief History of BTeV

- June 2000: Stage I approval from lab.
- Concerns raise about budget.
- May 2002: Stage I approval for descoped (2 arms→ 1 arm) detector.
- October 2003: "P5 supports the construction of BTeV as an important project in the world-wide quark flavor physics area."
- Office of Science – "Facilities for the Future of Science, a 20 year Outlook" – BTeV given priority 1 among HEP med-term projects
- 2004: DOE – approval process
  - Completed reviews for first 2 stages with positive recommendations
  - Final schedule and budget profile in the fall.
  - DOE requires very conservative schedule – BTeV is still competitive in decay modes with all charged tracks and dominant in modes with neutrals. (PAC June 2004, P5 July 2004)
- June 2004: Italy's INFN approves participation to BTeV(~5M Euro for M&S)
- Get CD-2/3 (~Jan 2005) and Start Construction (in President's FY05 budget)
- Start data taking 2009

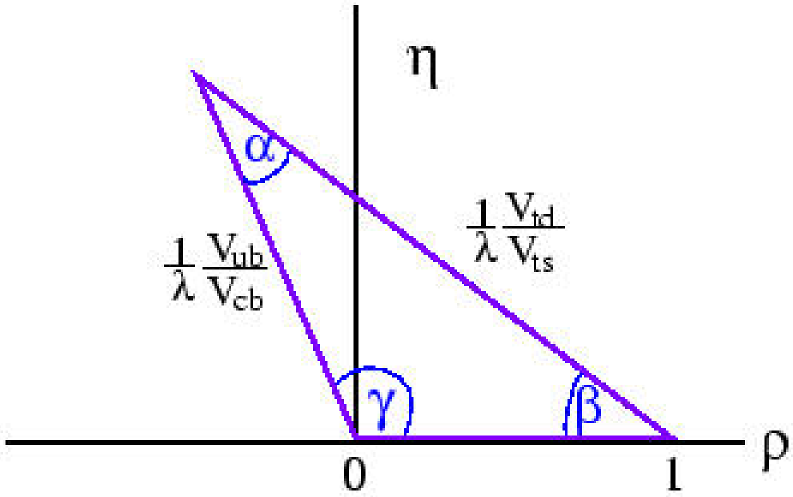


Physics Goals

- CP violation in SM is unique, predictive and testable
- Almost any extension of SM has new sources of CPV
- Measure
  - CP violation in $B_{(uds)}$, B_s mixing, rare b decay rates;
  - CP violation and rare decays in the charm sector.
    - *→Recent review on charm physics incl.CPV*
      - *SB,F.L.Fabbri,D.Benson,I.Bigi, Riv.Nuovo Cim.* ***26*** *n.7-8 (2003)*
- Precise measurement of SM parameters
- Make an exhaustive search for physics beyond SM
  - Look for rare/forbidden decays
  - Test for inconsistencies in the Standard Model: If found, go beyond the SM and elucidate the new physics.
- If/when new physics is found elsewhere, at the Tevatron or LHC, BTeV can contribute to its interpretation by looking for impact in B physics. BTeV is sensitive to phases of amplitudes.



Key Measurements of the CKM matrix in B Decays

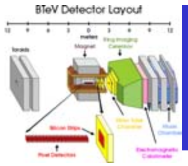


$$\chi = \arg\left(-\frac{V_{cs}^{*}V_{cb}}{V_{ts}^{*}V_{tb}} \right)$$

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

About 1/2 of the key measurements are in B_s decays. About 1/2 of the key measurements have π^o's or γ's in the final state!

BTeV addresses these issues.

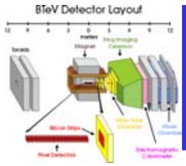


Why do b and c Physics at Tevatron?

- Large samples of b quarks
  - Get ~ 4×10^{11} b hadrons per 10^7s at L = 2×10^{32} $cm^{-2}s^{-1}$
  - e^+e^- $\Upsilon(4S)$ 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 for study at the Tevatron
- Charm rates are ~ 10× larger than b rates

Nominal Tevatron parameters :

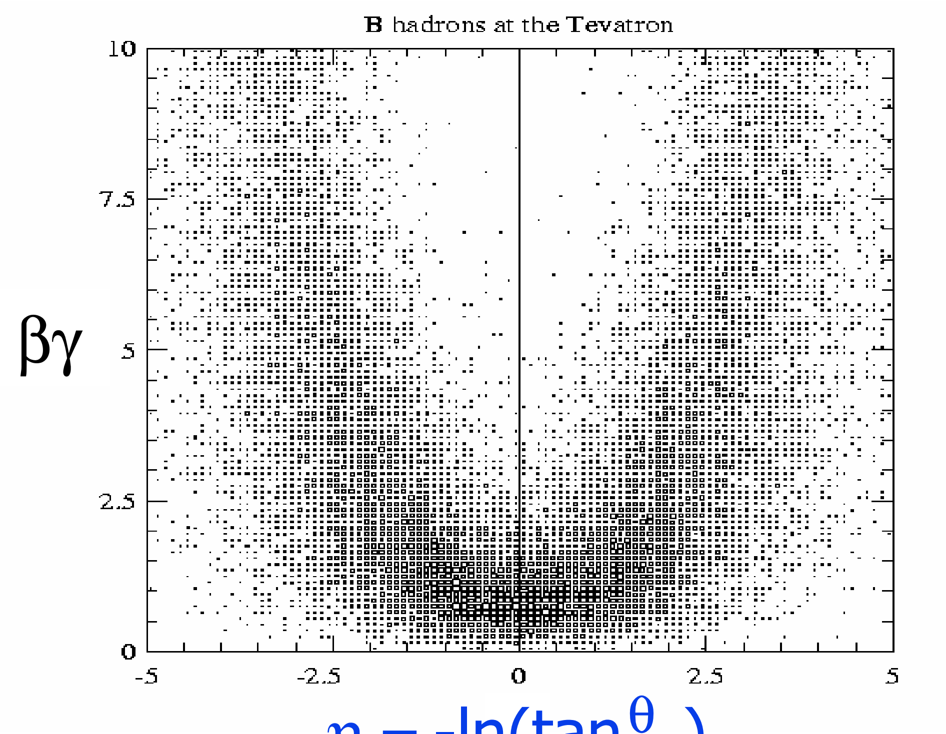
- CMS energy = 2 TeV
- Peak Luminosity L = 2×10^{32} $cm^{-2}s^{-1}$
- Integrated luminosity 1.6 fb^{-1}/year
- Time/crossing = 396 ns
- Interaction region σ_z= 30cm and $\sigma_{x,y}$= 50μm
- bb cross section = 100 μb



Characteristics of hadronic b production

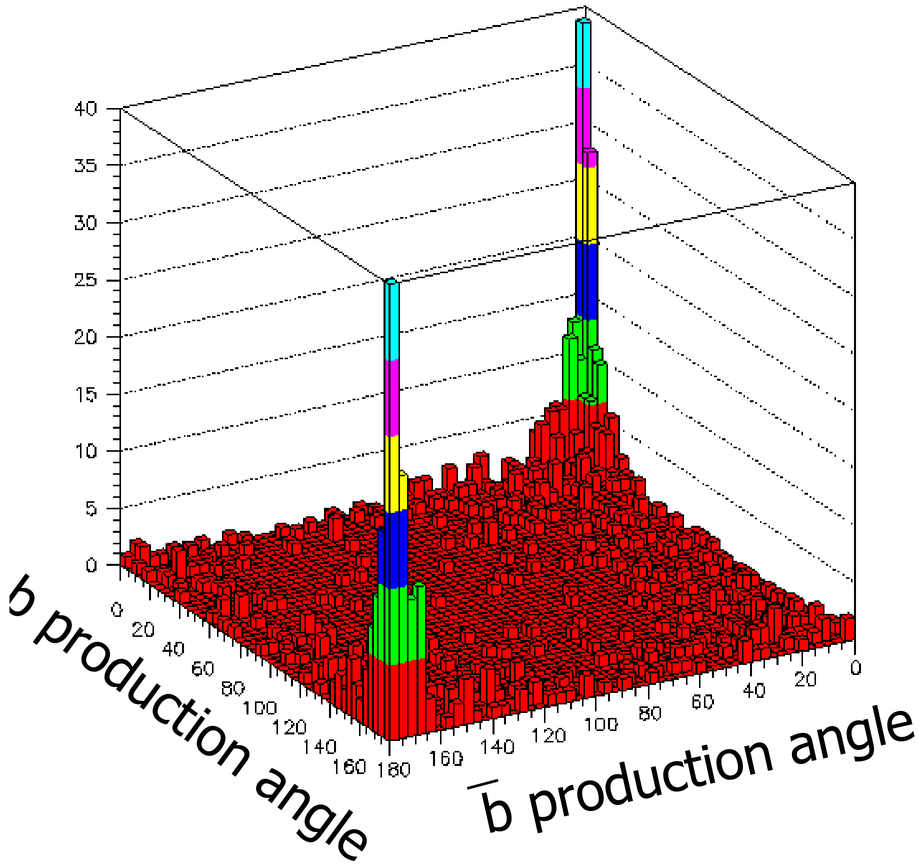
$$p\bar{p} \rightarrow b\bar{b} + X$$

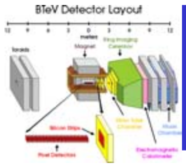
The higher momentum b's are at larger η's



$$\eta = -\ln(\tan\frac{\theta}{2})$$

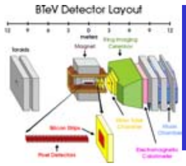
b production peaks at large angles with large $b\bar{b}$ correlation





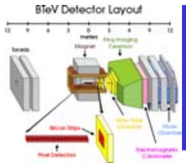
Requirements: General

- Intimately tied to Physics Goals
- In general, within the acceptance of the spectrometer (10 – 300 mr with respect to beam) we need to:
  - Detect charged tracks & measure their 3-momenta
  - Measure the point of origin of the charged tracks (vertices)
  - Detect neutrals & measure their 3-momenta
  - Reveal the identity of charged tracks (e, μ, π, K, p)
  - Trigger & acquire the data (DAQ)
- Detector we designed meets the requirements



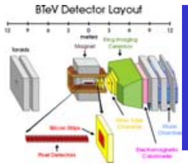
Basics Reasons for the Requirements

- B's (& D's) are long lived, ~1.5 ps, so if they are moving with reasonable velocity they go ~3 mm before they decay. This allows us to Trigger on the the presence of a B decay (*detached vertex*).
- B's are produced in pairs $p\bar{p} \rightarrow b\bar{b}+X$, and for many crucial measurements we must detect one b fully and some parts of the other: "flavor tagging"
- Physics states of great interest now are varied and contain both charged modes and neutrals, B_d & B_s

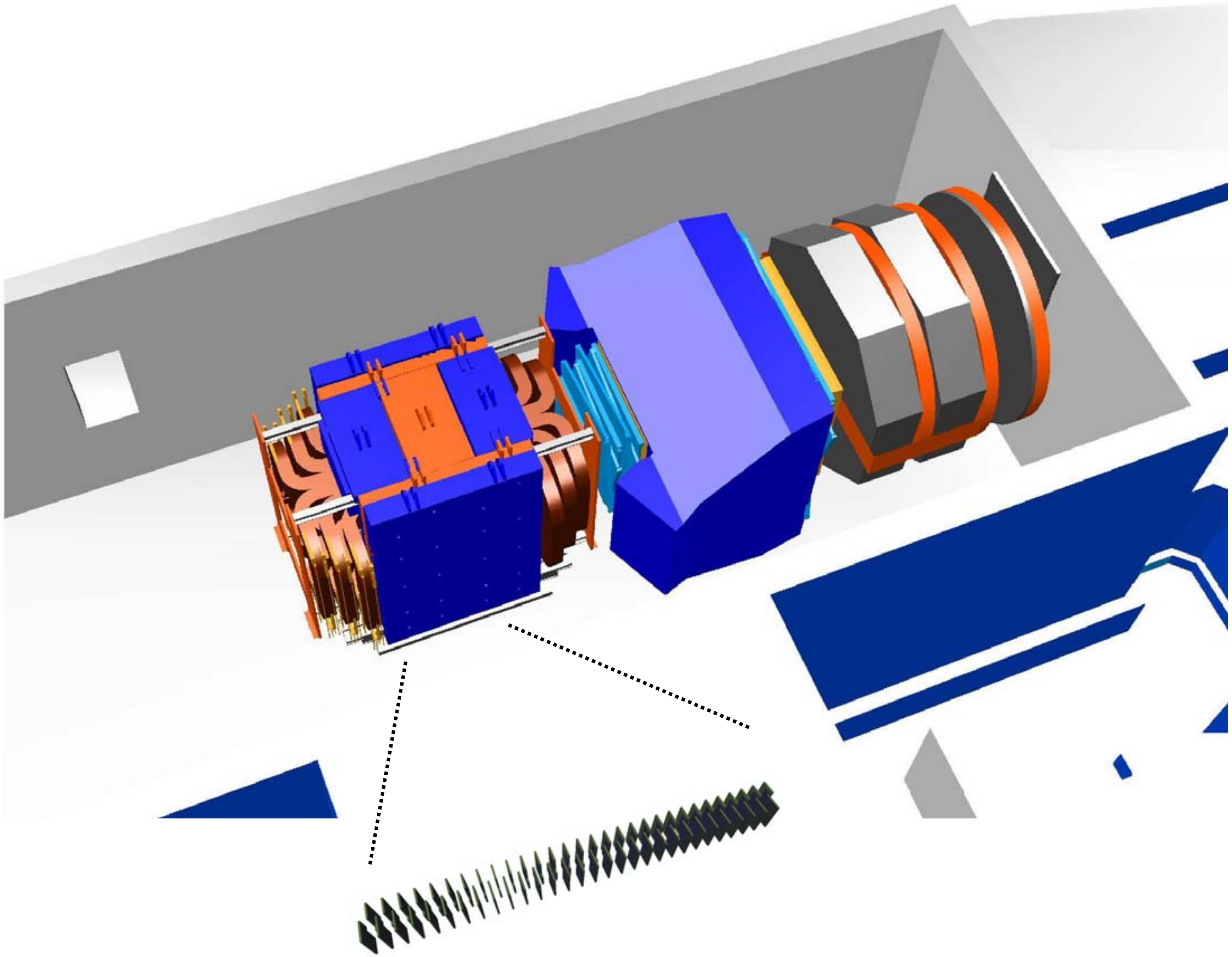


More Basic Reasons

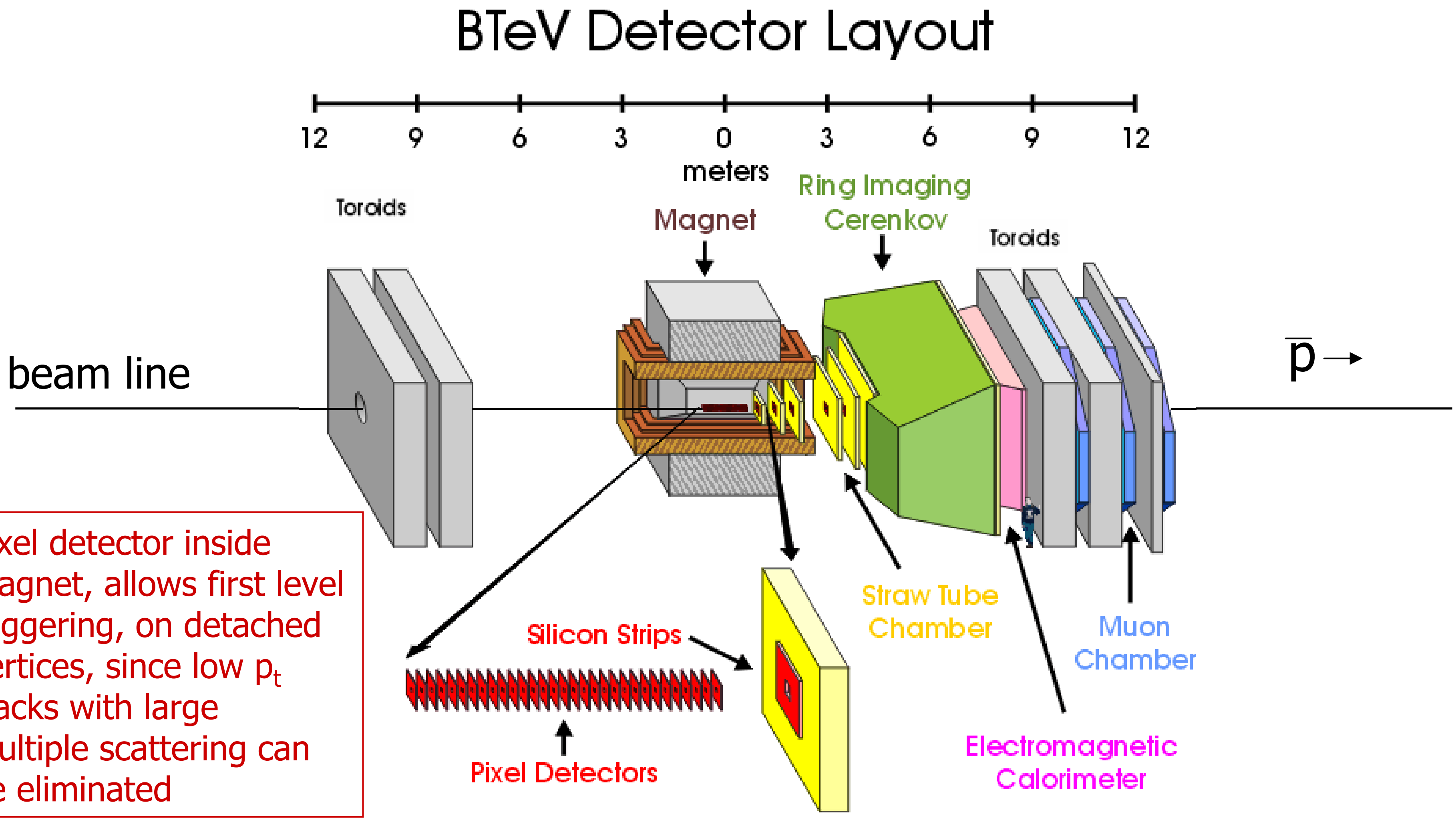
- Many modes contain γ, π^o & η, so need excellent electromagnetic calorimetery
- B_s oscillations are fast, so need excellent time resolution ~<50 fs, compared to ~1500 fs lifetime. Also very useful to reduce backgrounds in reconstructed states
- Physics Backgrounds from $\pi \Leftrightarrow K$ can be lethal
  - $B_s \to D_s\, \pi^-$ is 15X $B_s \to D_s\, K^-$
  - $B^o \to K^* \pi \to K^{\mp} \pi^{\pm} \pi^o$ is 2X $B^o \to \rho\pi \to \pi^+ \pi^- \pi^o$
  - Bs $\to$KX coincides with Bd $\to \pi$X if K $\Leftrightarrow \pi$
  - Bd $\to$ Kπ overlaps Bd $\to \pi\pi$
  - So excellent charged hadron identification is a must



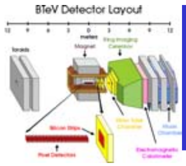
The BTeV detector in the C0 collision hall



The BTeV Detector

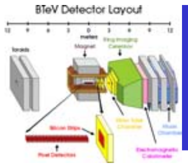


Pixel detector inside magnet, allows first level triggering, on detached vertices, since low p_t tracks with large multiple scattering can be eliminated



Summary of Required Measurements for CKM Tests

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

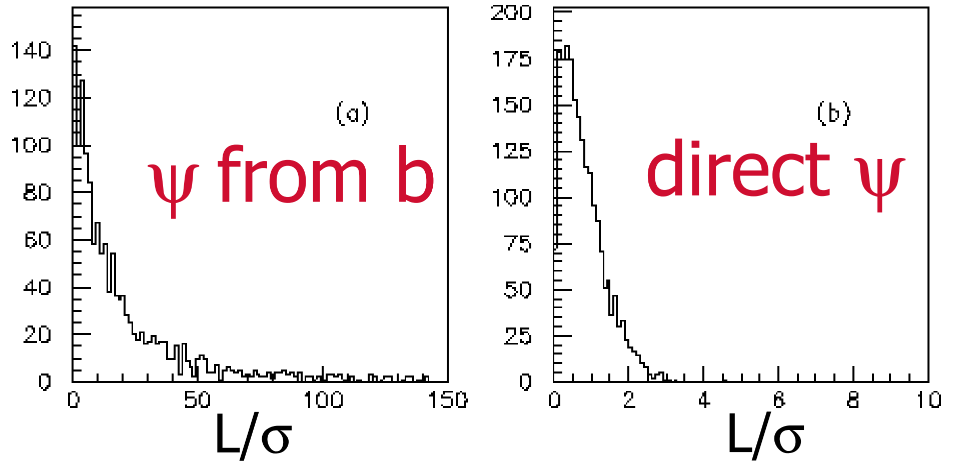


Fundamentals: Decay Time Resolution

- Excellent decay time resolution
  - ➢ Reduces background
  - ➢ Allows detached vertex trigger
- The average decay distance and the uncertainty in the average decay distance are functions of B momentum:

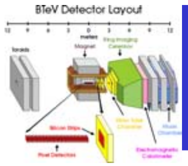
$<L> = \gamma\beta c\tau_B$

$= 480\ \mu m \times p_B/m_B$



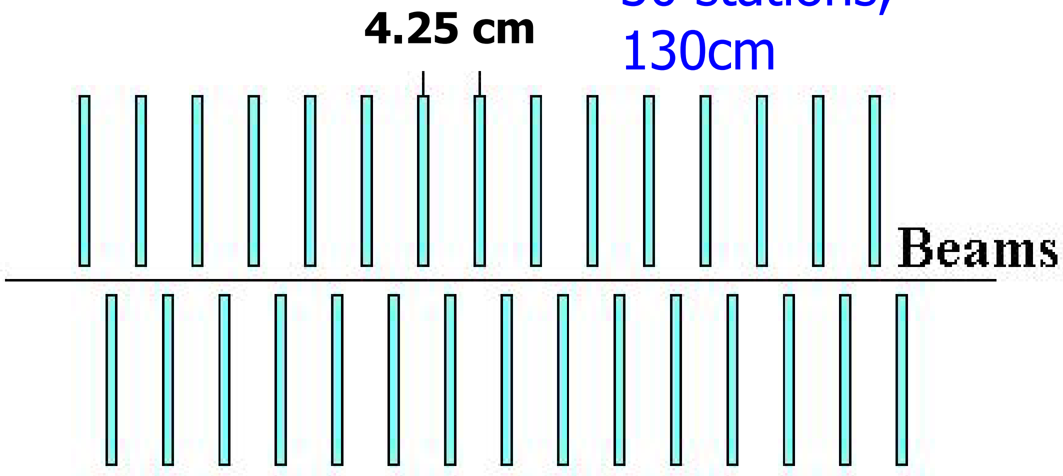
CDF/D0 region →

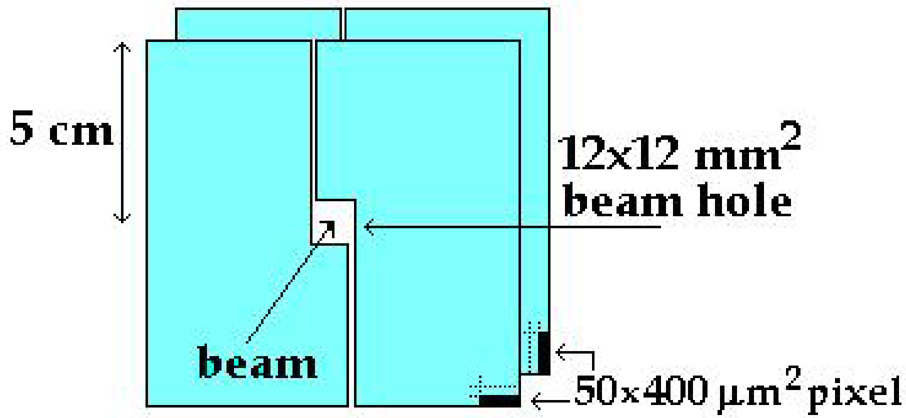
LHC-b region

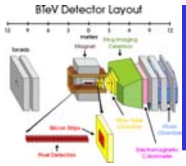


Pixel Vertex Detector

- **Low occupancy**
- **Excellent signal/noise**
- **Fast readout**
- **Excellent resolution (5-10 μm in 1999 FNAL test beam run)**
- **radiation hard sensors and readout chips (demonstrated in exposures at IUCF)**
- **Used in lowest level trigger**

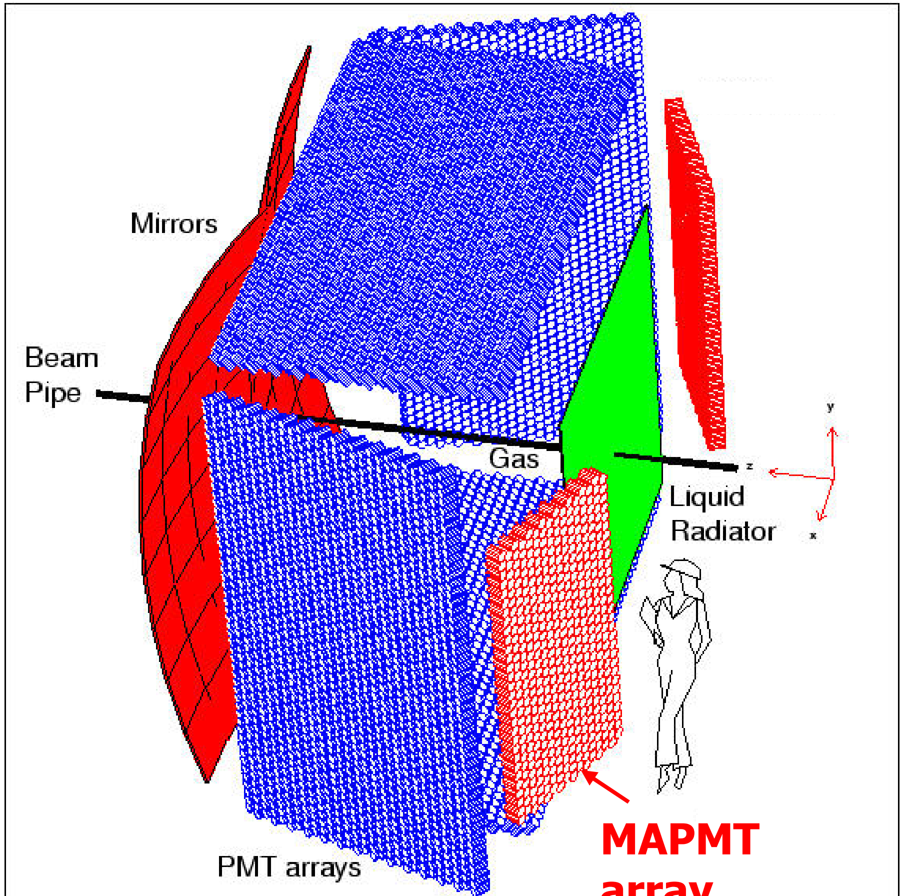






Ring Imaging Cerenkov Counter

- Gas radiator (C_4F_8O) detected on planes of Multi-Anode PMTs
- Liquid radiator (C_5F_{12}) detected on array of side mounted PMTs

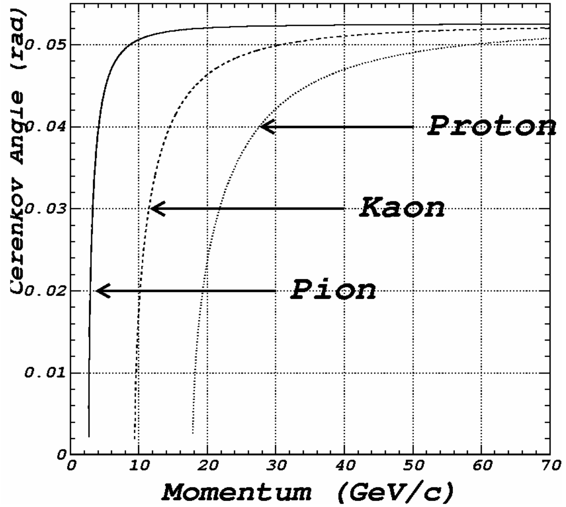


MAPMT array

Gas

C_4F_8O

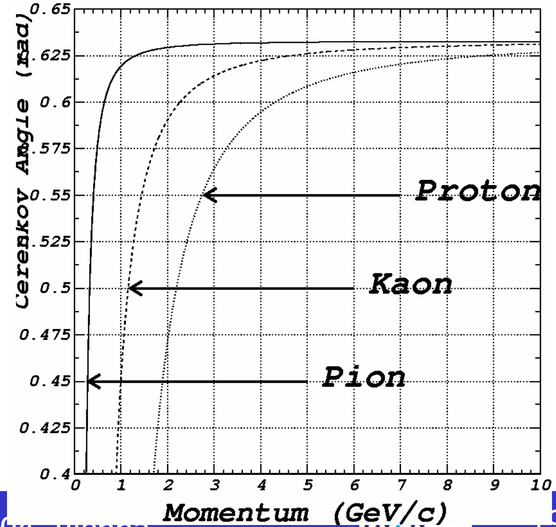
n=1.00138

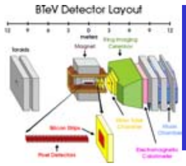


Liquid

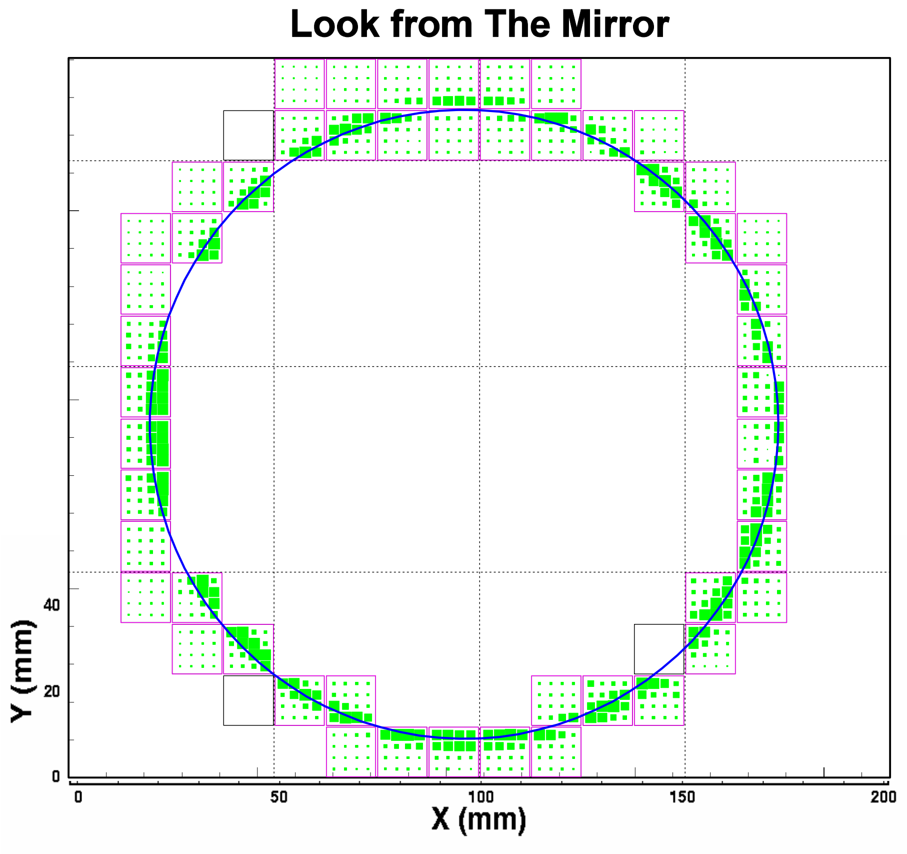
C_5F_{12}

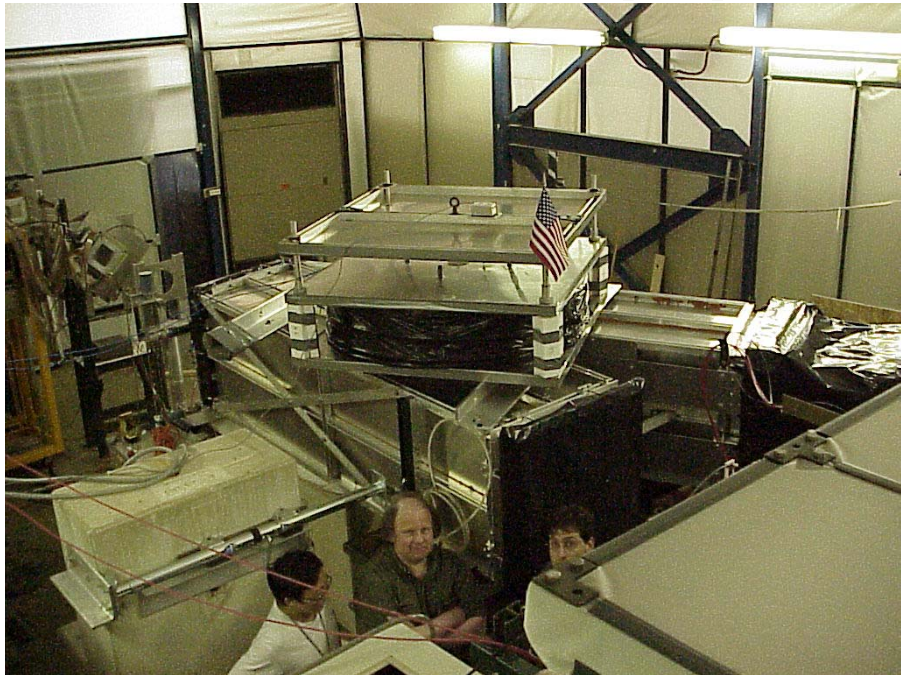
N=1.29



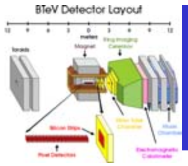


Rich Detector – beam test (II)





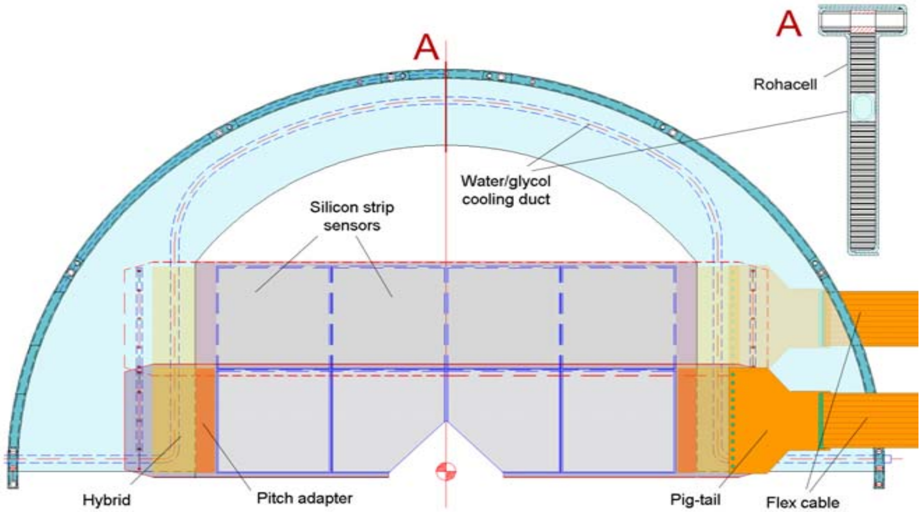
First Ring in Freon

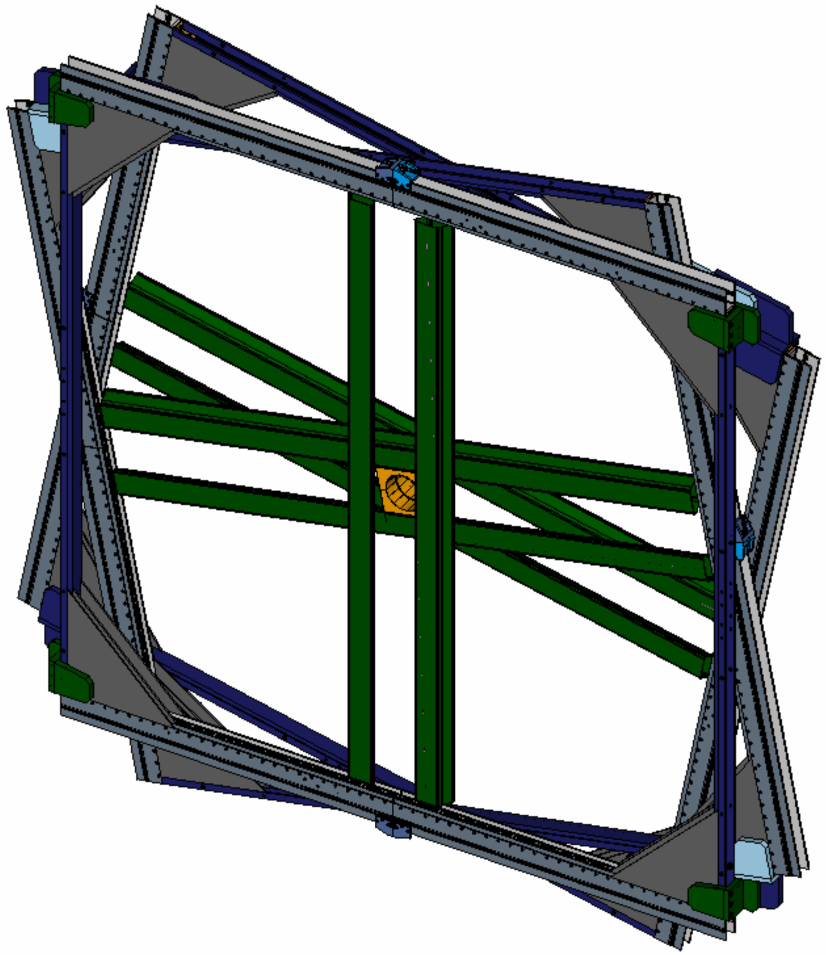


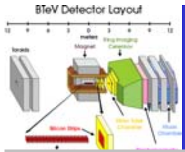
Forward Tracking

7 Stations – Silicon strips and straws

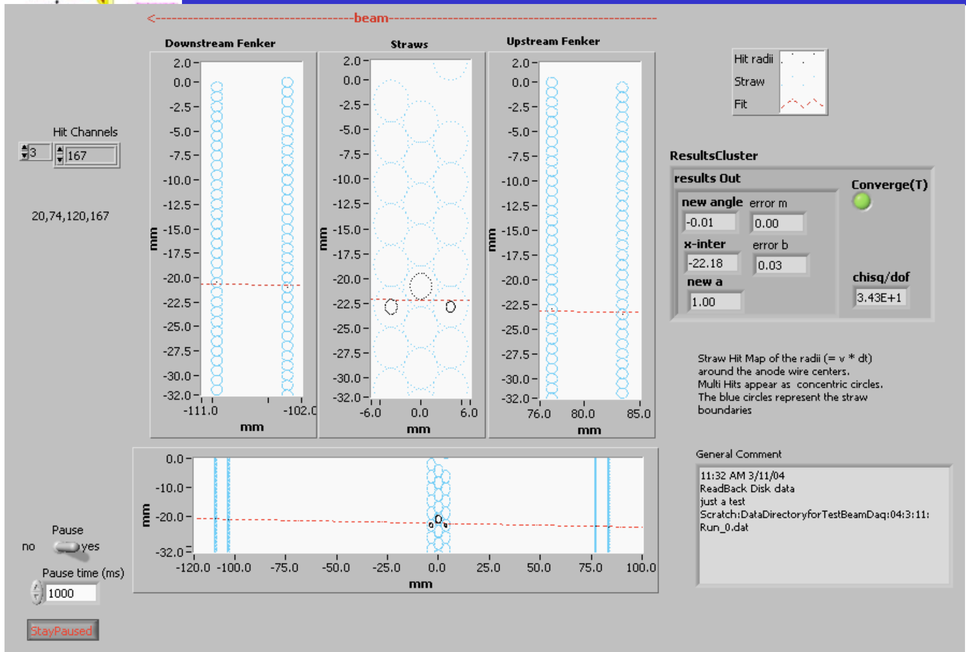
3 views
Momentum resolution <1%

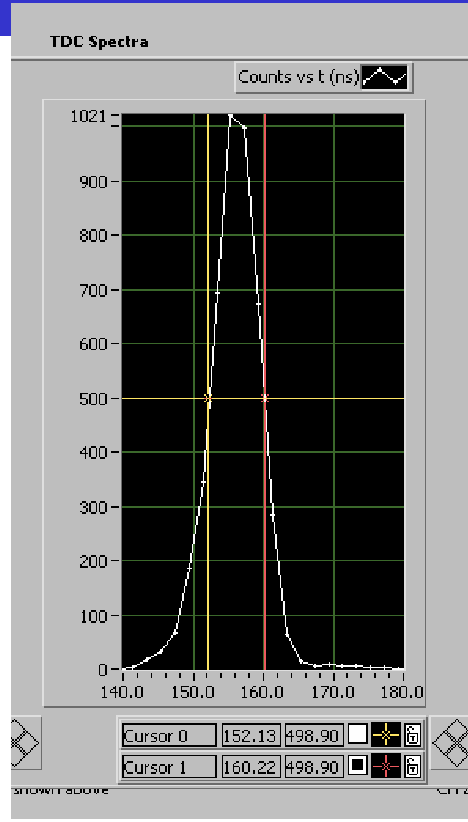






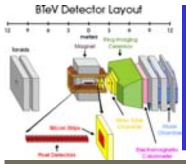
Straw Detector – beam test



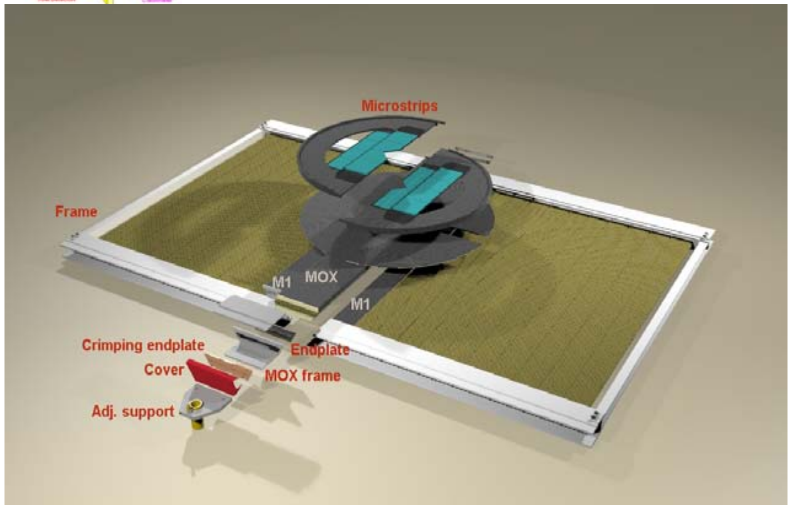


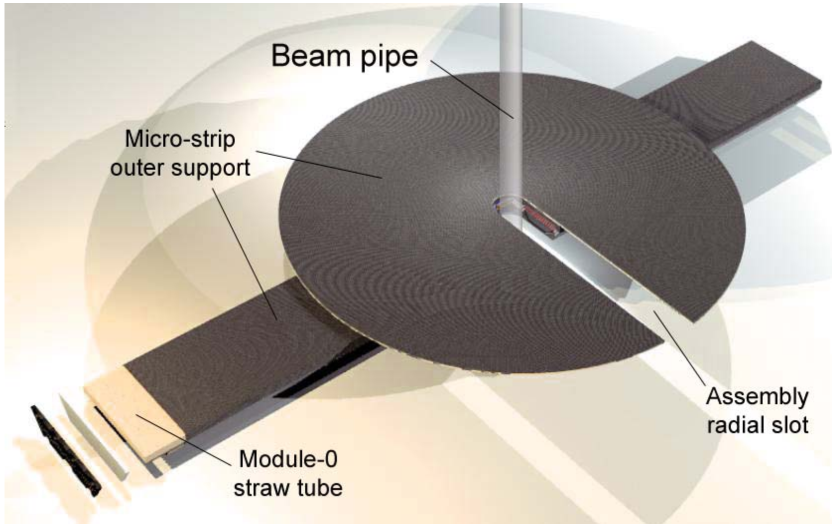
TDC Spectrum
FWHM = 8.1 ns => 486 μ.
RMS = 206 μ.
MWPC position resolution =144 μ.
Quadrature Subtraction gives
<u>Straw Resolution =148 μ</u>.

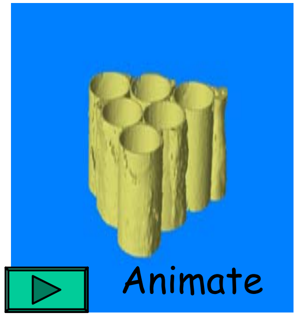
This meets the needs for BTeV Forward Tracking



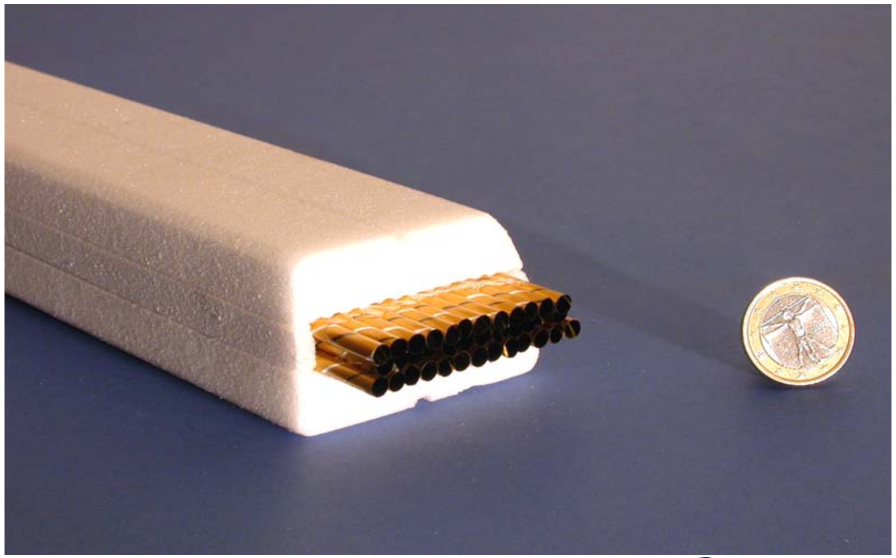
X view station: straws and microstrips integration

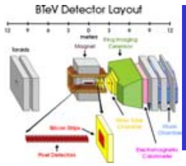






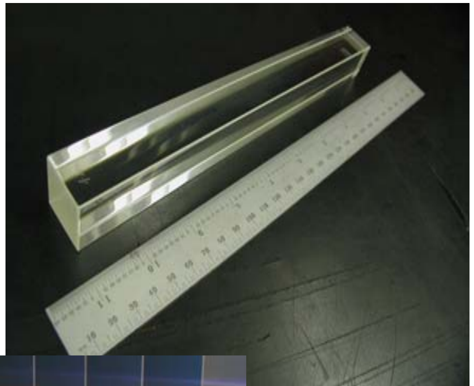
A special straw module MOX holds microstrips. In MOX, straws are not mechanically tensioned but glued inside a rohacell lattice.
X-ray tomography verifies the straws circularity.

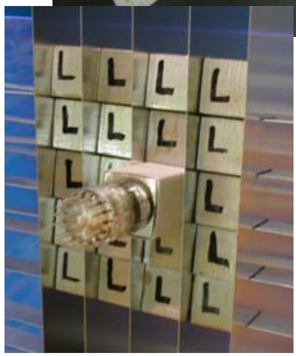


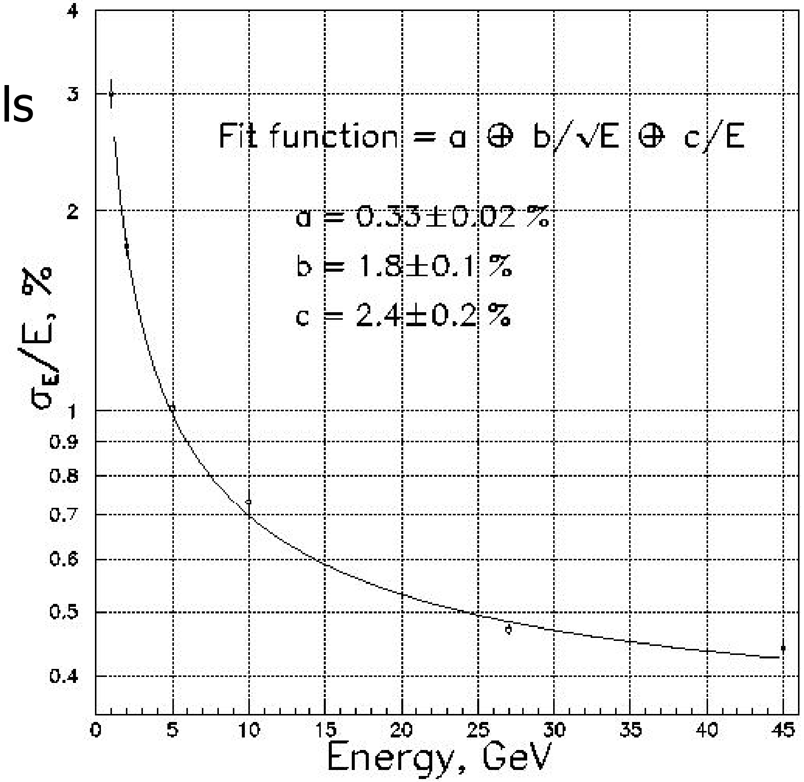


Lead Tungstate EM Calorimeter

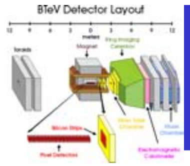
- $PbWO_4$ 28×28mm^2 × 22cm tapered crystals
- Excellent energy and spatial resolution
- Fast, compact, radiation hard





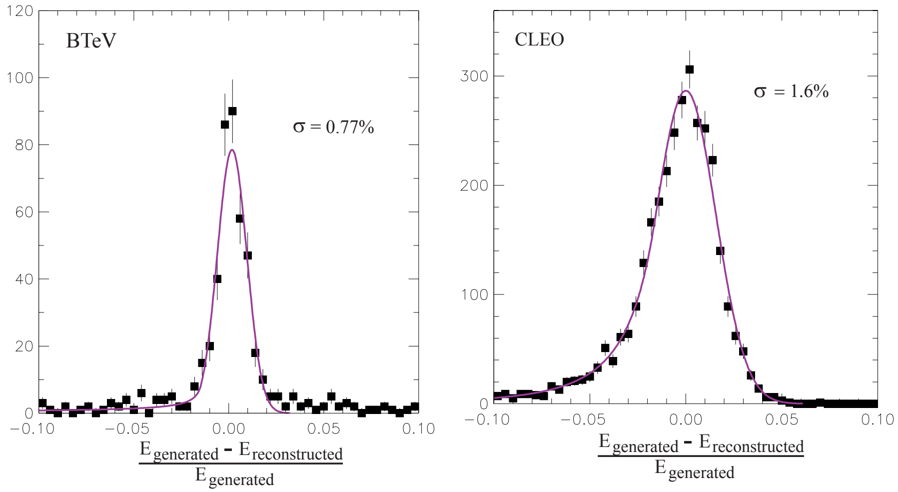


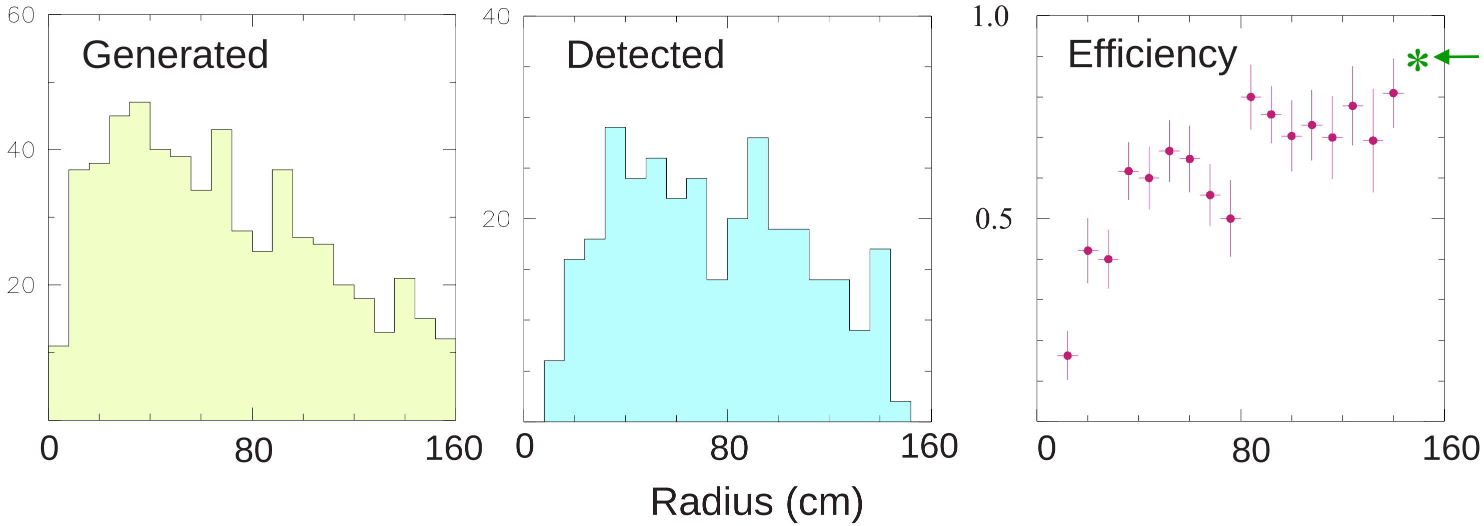
Beam tests (Protvino):
- established energy and position resolution
- Studied radiation damage and recovery
- Calibration methods.
- Crystals from 4 vendors



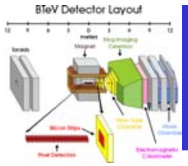
EM cal using $PbWO_4$ Crystals

- GEANT simulation of $B^o \rightarrow K^*\gamma$, for BTeV & CLEO
- Isolation & shower shape cuts on both





CLEO
barrel
ε=89%

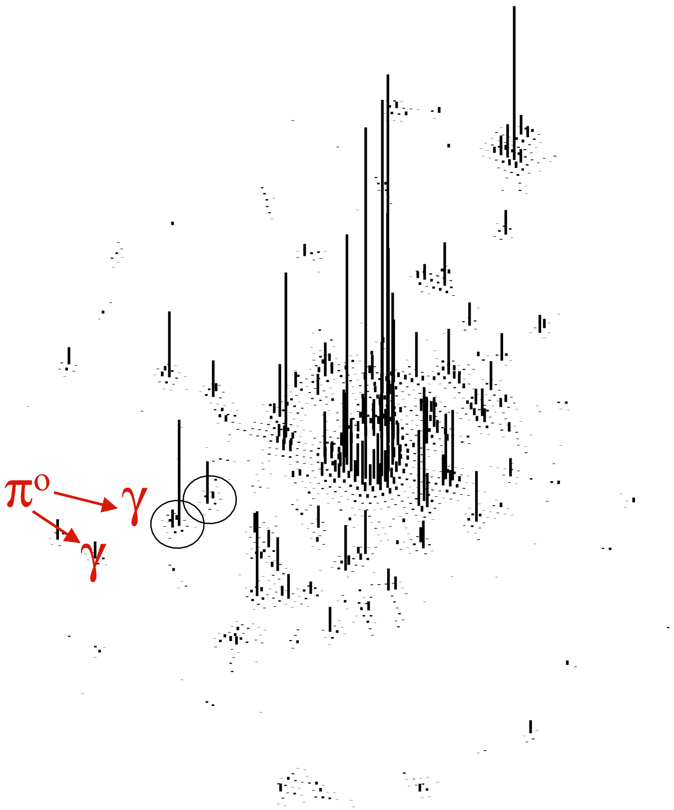


$B^o \to \rho\pi$

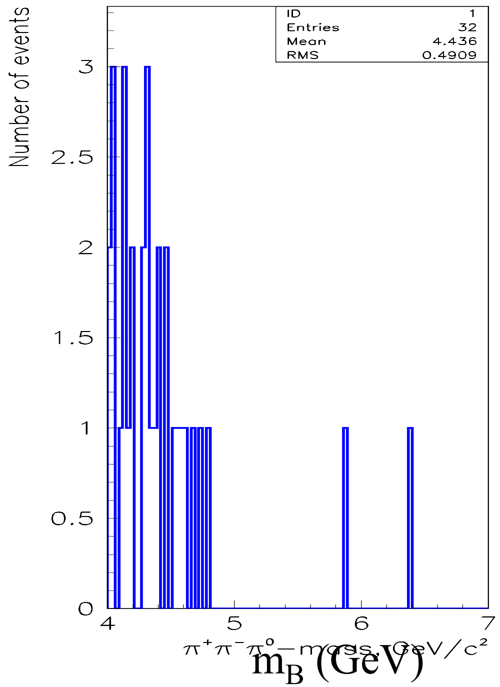
Based 9.9×10^6 bkgrnd events

$B^o \to \rho^+\pi^-$ S/B = 4.1

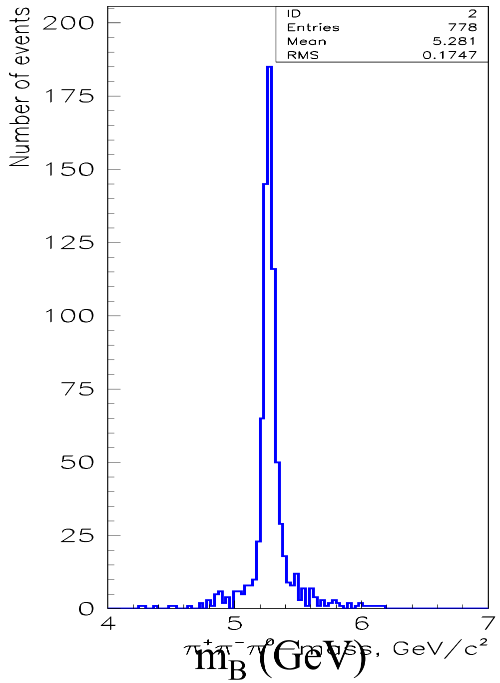
$B^o \to \rho^o\pi^o$ S/B = 0.3

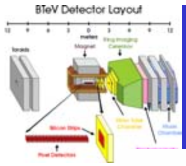


bkgrnd

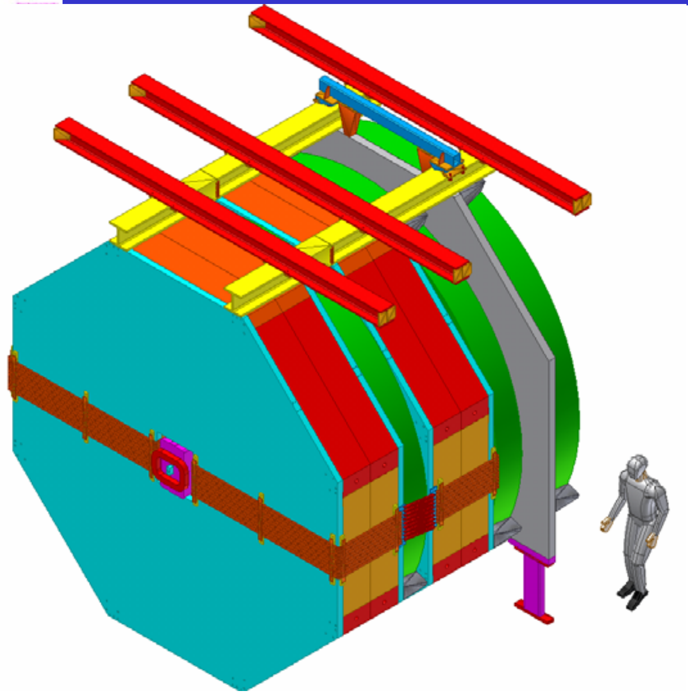


signal



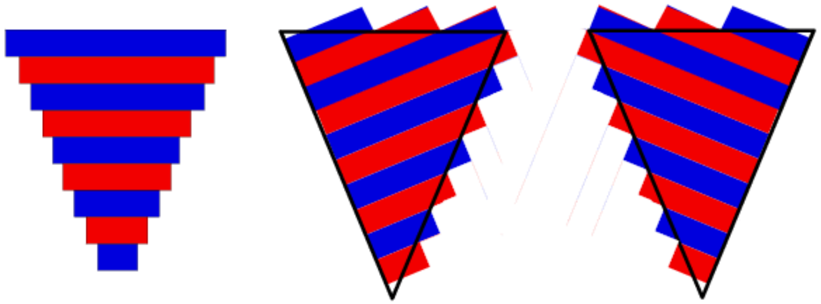


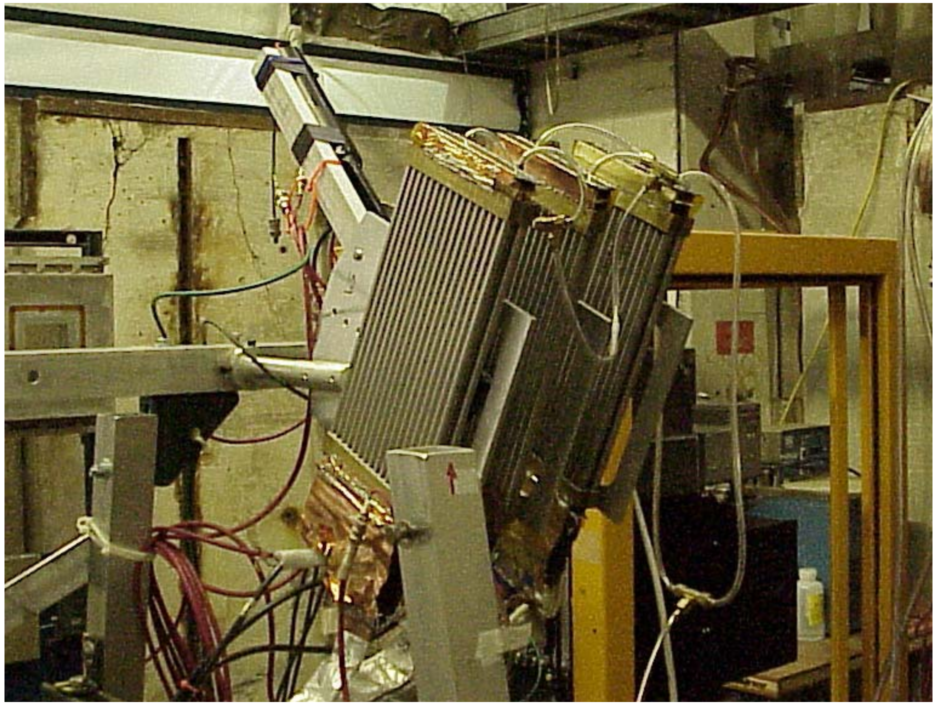
Muon Detector



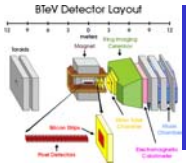
3 stations of steel proportional tubes

2 toroids – independent momentum measurement





Prototype Planks in test beam



BTeV Trigger

- 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

- Level 1: accepts >50% B events that pass analysis cuts, rejects 98% light quark background.
- Level 2: accepts 90% of B events from Level 1, rejects 90% background from Level 1
- Level 3: rejects another factor of 2 in background, does full offline reconstruction

50 kHz

↓

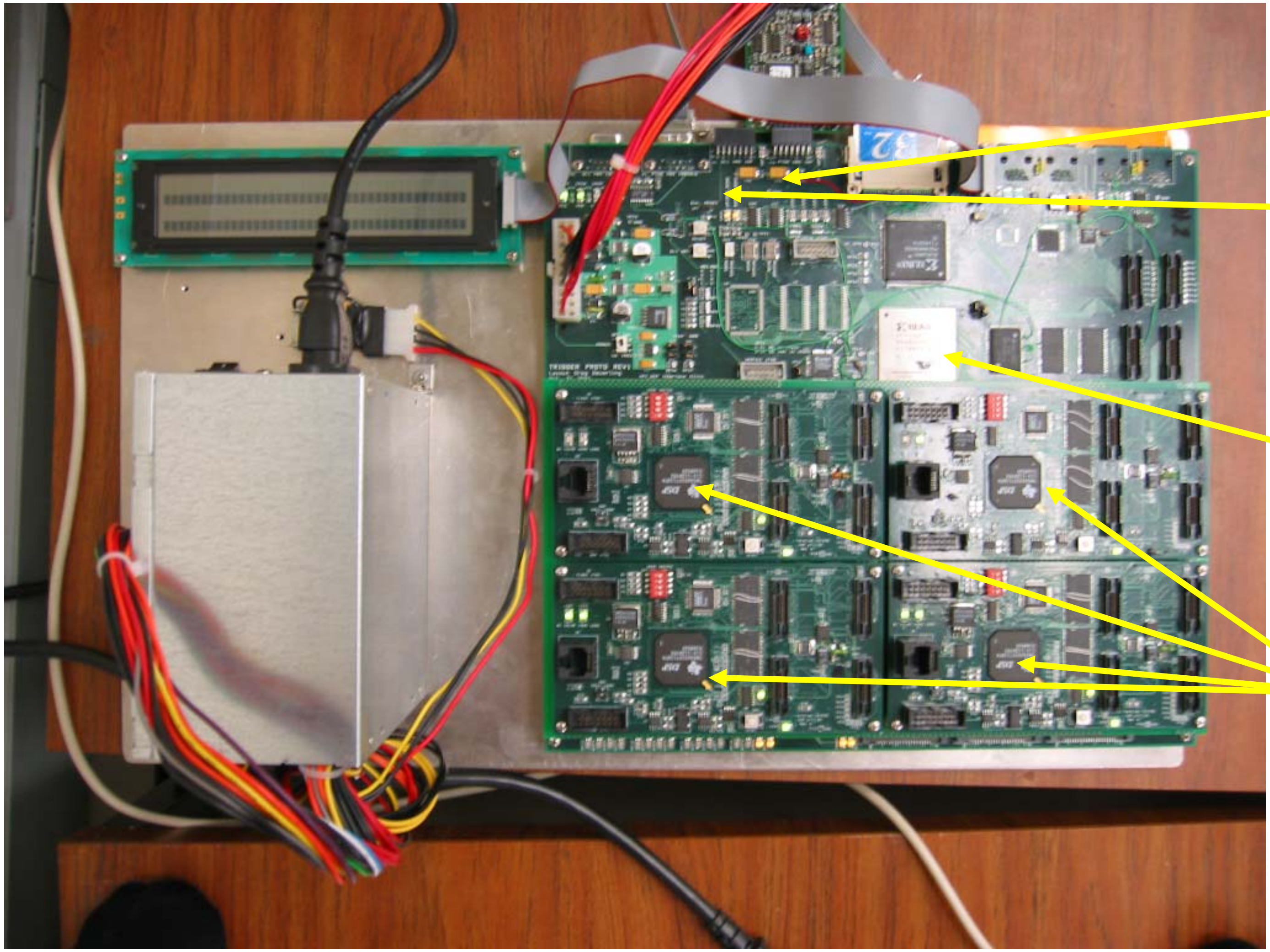
5 kHz

↓

2.5 – 4 kHz

200MB/s on “tape”

Trigger R&D : Farm pre-prototype

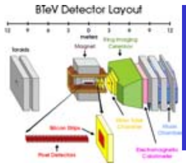


PTSM interface

GL1 interface

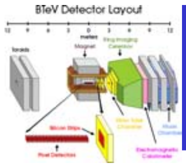
High speed Data I/O controller (Buffer Manager)

4 DSPs



Summary of CKM Physics Reach 2 fb^{-1}

Reaction	$\mathcal{B}$(B)(x10^{-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	$\gamma - 2\chi$	8^o
$B^o \to J/\psi K_S$, $J/\psi \to l^+ l^-$	445	168,000	10	sin(2β)	0.017
$B_s \to D_s \pi^-$	3000	59,000	3	x_s	(75)
$B^- \to D^o (K^+\pi^-) K^-$	0.17	170	1		
$B^- \to D^o (K^+K^-) K^-$	1.1	1,000	>10	γ	13^o
$B^- \to K_S \pi^-$	12.1	4,600	1		<4^o +
$B^o \to K^+\pi^-$	18.8	62,100	20	γ	theory errors
$B^o \to \rho^+\pi^-$	28	5,400	4.1		
$B^o \to \rho^o\pi^o$	5	780	0.3	α	~4^o
$B_s \to J/\psi \eta$, $J/\psi \to l^+l^-$	330	2,800	15		
$B_s \to J/\psi \eta'$	670	9,800	30	sin(2χ)	0.024



Comparisons to Belle/BaBar

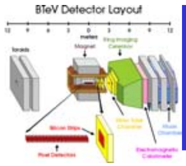
- No B_s, B_c and Λ_b at B-factories

- Number of flavor tagged $B^0 \to \pi^+\pi^-$ (BR=0.45×10^{-5})

	L($cm^{-2}s^{-1}$)	σ	#$B^0/10^7$s	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 $B^- \to D^0K^-$ (Full product BR=1.7×10^{-7})

	L($cm^{-2}s^{-1}$)	σ	#$B^0/10^7$s	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



New Physics (1)

- Decays that occur in the SM only through loops are particularly sensitive to “new physics”
- The leptonic decay $b \to s\ell^+\ell^-$ is sensitive to the actual form of the new interactions as one can measure $M(\ell^+\ell^-)$ and Dalitz plot as well as total rate

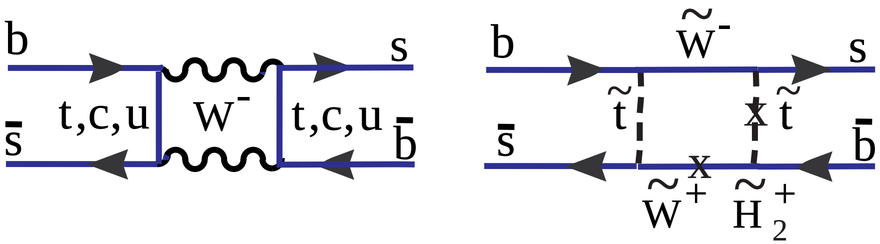
Reaction	$B(10^{-6})$	Yield/year	S/B
$B \to K^*\mu^+\mu^-$	1.5	2530	11
$B \to K\mu^+\mu^-$	0.4	1470	3.2

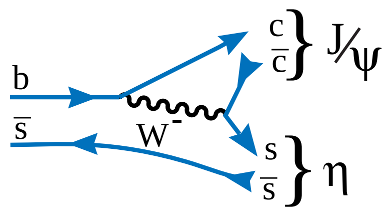
New Physics (2) SSM Measurements from Hinchcliff & Kersting

(hep-ph/0003090)

- Contributions to B_s mixing

$B_s \rightarrow J/\psi\eta$

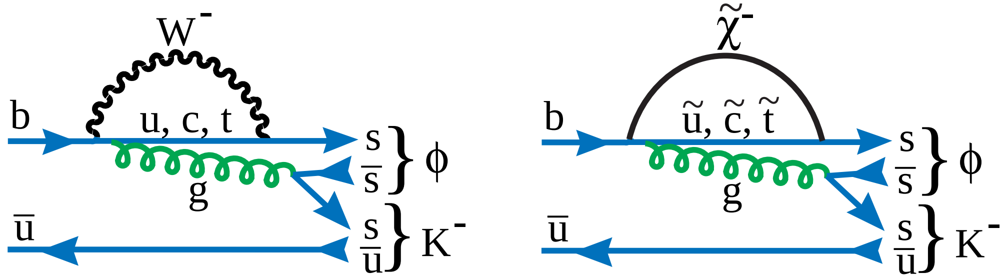




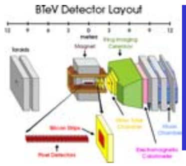
CP asymmetry $\approx 0.1\sin\phi_\mu\cos\phi_A\sin(\Delta m_s t)$, ~10 x SM

- Contributions to direct CP violating decay

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



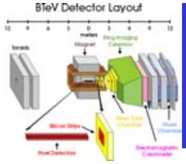
Asym=$(M_W/m_{squark})^2\sin(\phi_\mu)$, ~0 in SM



Summary of New Physics

- Using b and c decays mediated by loop diagrams BTeV is sensitive to mass scales of up to few TeV.
- The New Physics effects in these loops may be the only way to distinguish among models.

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	1000	n/a	4
$B^0 \to \phi K_s$	2000	200	5.2	350	90	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



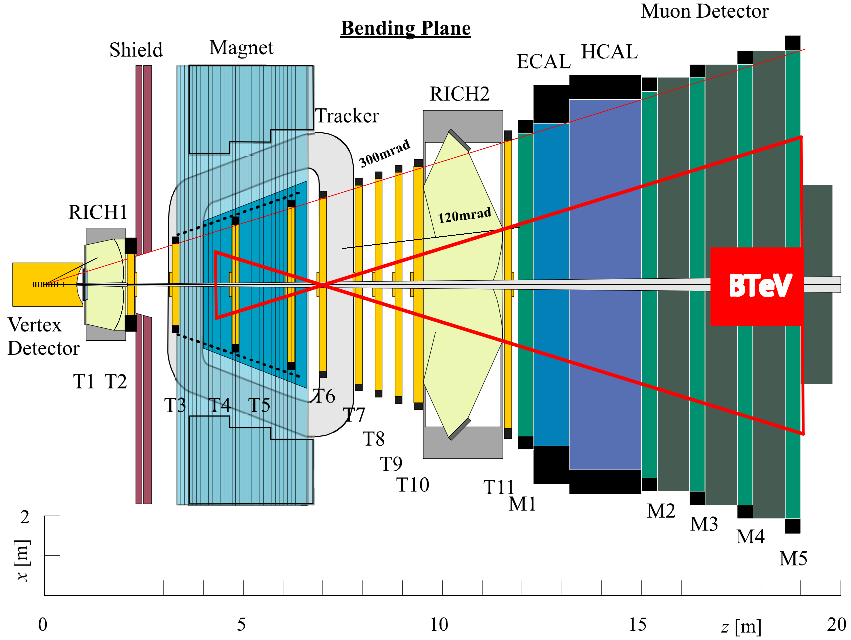
Comparison to LHCb

LHCb advantages:

- σ_{bb}(LHCb) = $5\times\sigma_{bb}$(BTeV)
  σ_{tot}(LHCb) = $1.6\times\sigma_{tot}$(BTeV)
- ⟨Interactions/Crossing⟩ ~ 3× lower than BTeV

BTeV advantages:

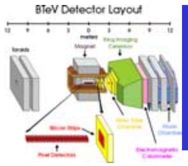
- Detached vertex trigger at lowest level
- Higher rate DAQ
- Better resolution EMCAL



	LHCb	BTeV
$\sqrt{s}$	14 TeV	2 TeV
σ_{bb}	500 μb	100 μb
$\sigma_{inelelastic}$	80 mb	50 mb
L ($cm^{-2}s^{-1}$)	2×10^{32}	2×10^{32}
$N_{bb}/10^7 s$	10^{12}	2×10^{11}
$t_{\text{bunch spacing}}$	25 ns	(132) 396 ns
$\omega_{\text{bunch crossing}}$	40 MHz	(7.6) 2.5 MHz
σ_z	5 cm	30 cm
$<N_{\text{pp int./bco}}>$	0.4	(2) 6

BTeV and LHCb have comparable sensitivites in charged modes, BTeV is superior in modes with γ's and π^0's

For a great comparison review see:
Marta Calvi, DAΦNE04, June 2004 Frascati



Conclusions

- Tevatron has recently made significant improvements in luminosity and overall performance.
- BTeV will make critical contributions to our knowledge of CP violation as attention turns from initial observations to the work of finding out if the Standard Model explanation is correct and complete.
- B-quark physics is an essential ingredient to the understanding of NP which will be possibly discovered by ATLAS and CMS
- Bs, Bc, b-baryons are uniquely studied at hadron machines
- BTeV and LHC-b are equivalent for charged modes, BTeV is superior for neutrals
- Positive recommendations from DOE reviews. Still a long ordeal but can start construction at beginning of 2005. Start running in 2009.