BTeV Physics Reach

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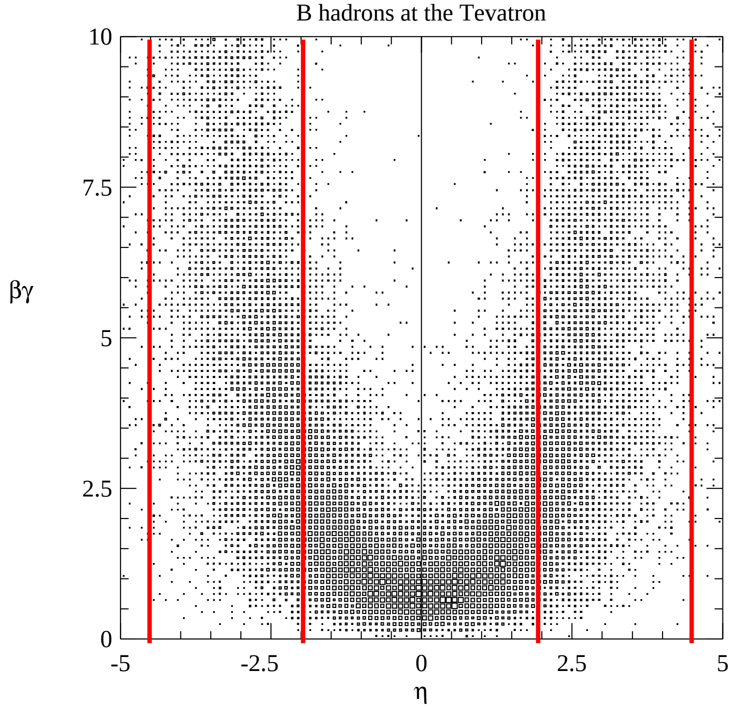
Outline

- The BTeV Detector
- Physics and Sensitivities
- Comparisons with Other Experiments
- BTeV Status
- Conclusion

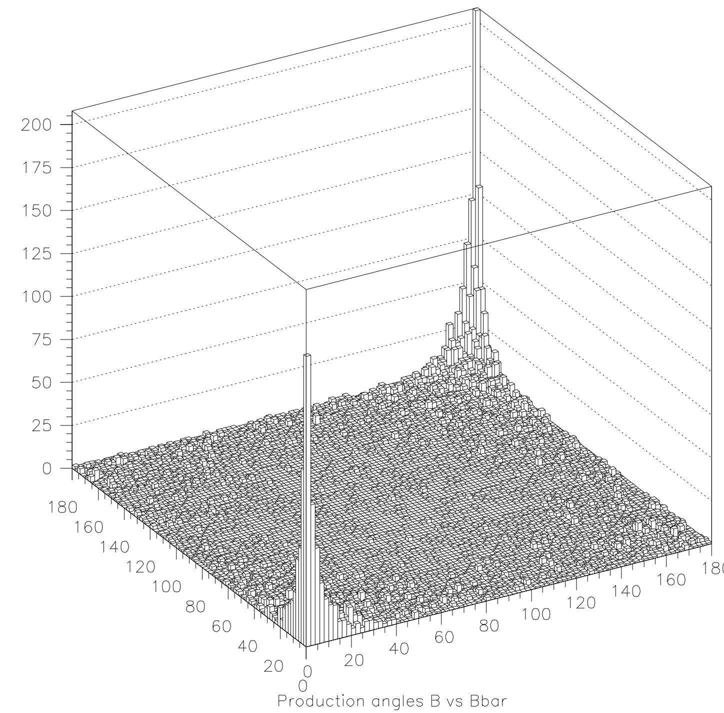
B's in the Forward Direction

- $\sigma(b\overline{b}) \sim 100\ \mu$b, $\sigma(c\overline{c}) \sim 1000\ \mu$b
- Luminosity 2×10^{32}, 132/396 ns spacing $\rightarrow \langle 2/6 \rangle$ int/cross
- $B\bar{B}$ fraction $\approx 2 \times 10^{-3} \rightarrow 2 \times 10^{11}$ $B\bar{B}$ pairs/year
- Interaction region $\sigma_z = 30$ cm



BTeV: $1.9 < \eta < 4.5$

Better decay length separation

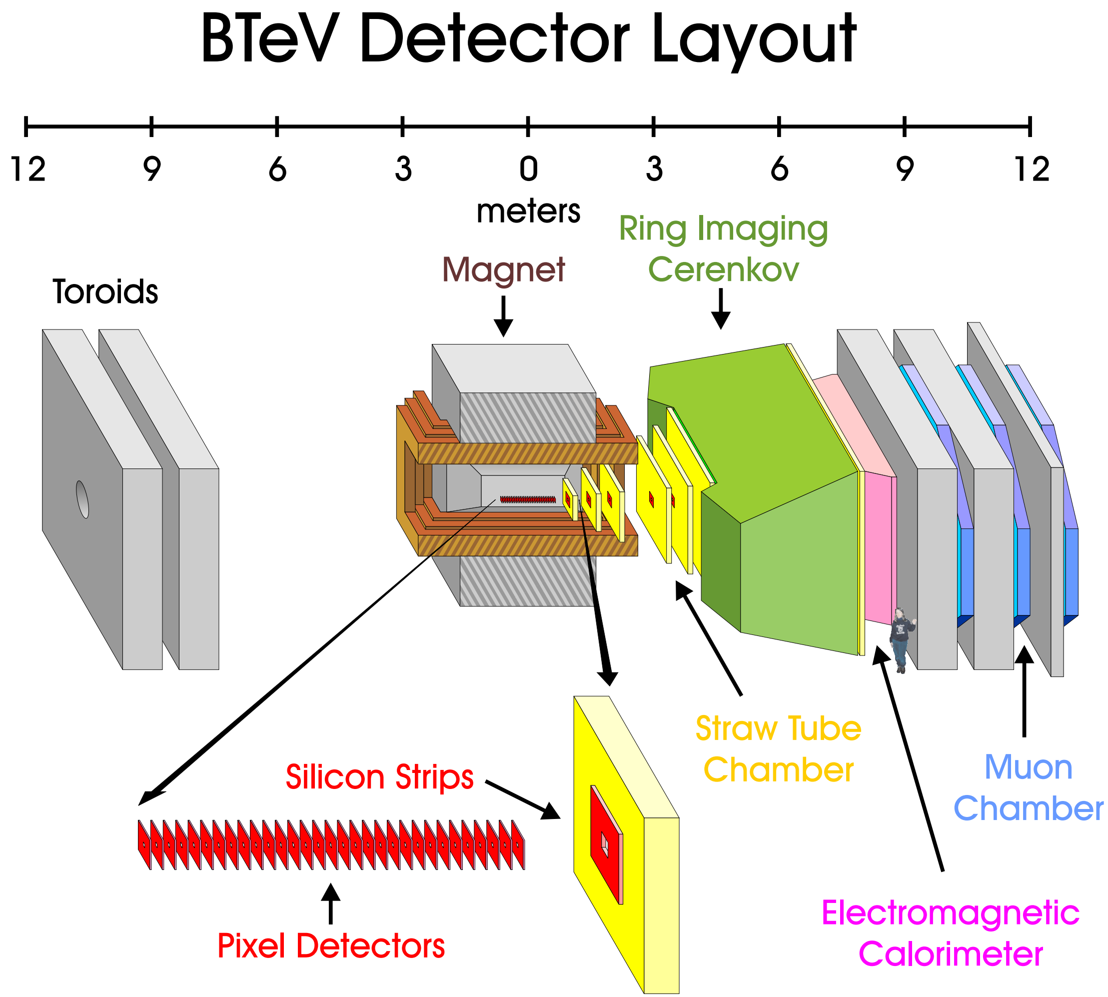


More $B\bar{B}$ in detector

Better opp. side tagging

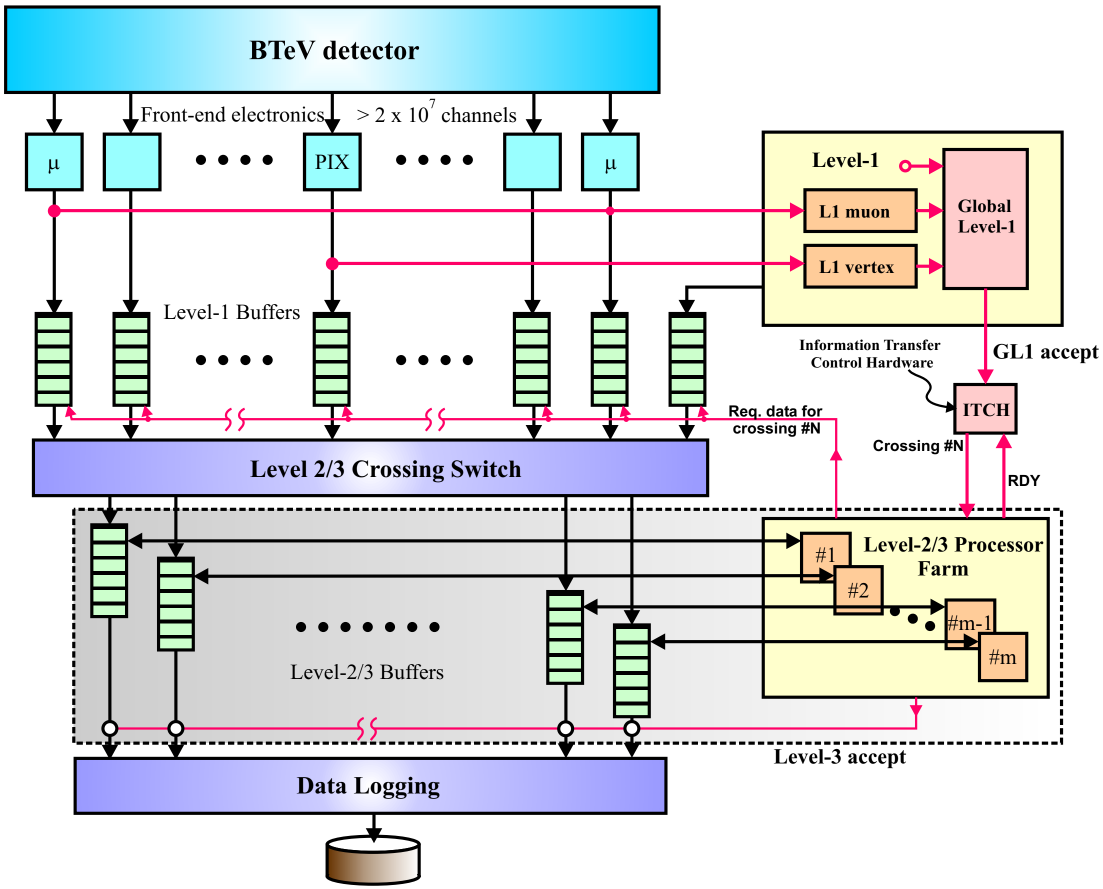
The BTeV Spectrometer

- Collider experiment, but fixed-target-like configuration
- Pixels in magnet, forward tracking with silicon & straws
- RICH particle ID, $PbWO_4$ EM Cal., muon detection



BTeV Trigger & DAQ

Applies computation to every crossing (up to 7.6 MHz)



- Made possible by 3D pixel space-points, low occupancy
- Pipelined with 1 TB buffer, no fixed latency
- Level 1: FPGAs and 2500 DSPs find detached vertices, p_T
- Level 2/3: Farm of 2000 PCs does fast version of reconstruction
- Output rate: 4 KHz, 200 MB/s
- Data rate: 1–2 Petabytes/yr
- Considering *not* using tape

Efficiencies and Tagging

Triggering on ≥ 2 tracks detached by $> 6\sigma$, we select 1% of crossings and have these efficiencies ($\langle 2 \rangle$ int./crossing):

Decay	ϵ(%)	Decay	ϵ(%)
$B^0 \to \pi^+\pi^-$	63	$B^0 \to K^+\pi^-$	63
$B_s^0 \to D_s^+ K^-$	74	$B^0 \to J/\psi K_S^0$	50
$B^- \to D^0 K^-$	70	$B_s^0 \to J/\psi K^*$	68
$B^- \to K_S^0 \pi^-$	27	$B^0 \to K^* \gamma$	63

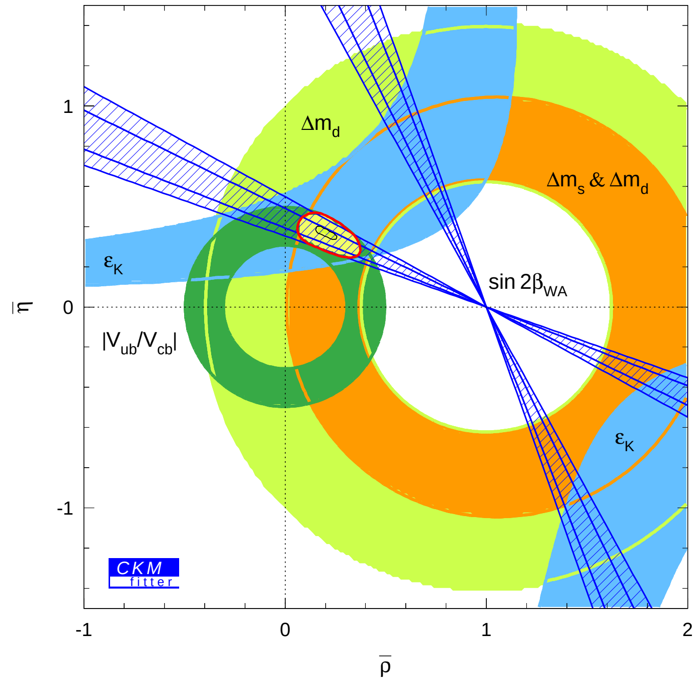
- Dilution $D \equiv (N_{\text{right}} - N_{\text{wrong}})/(N_{\text{right}} + N_{\text{wrong}})$
- Effective tagging efficiency $= \epsilon D^2$
- BTeV studies use
  - Opposite side $K^\pm$
  - Opposite side leptons & jet charge
  - Same side $\pi^\pm$ (for B^0), $K^\pm$ (for B_s^0)
- Conclusion $\epsilon D^2(B^0) = 0.10$, $\epsilon D^2(B_s^0) = 0.13$, diff. from same side tagging

SM Description of $\not{CP}$

So far the Standard Model description of $\not{CP}$ has held up well. No discrepancies have emerged.

Assume in 2008–9:

- $\Delta m(B_d)/\Delta m(B_s)$ to 5% from CDF & DØ
- $\sin 2\beta$ to 0.02 from 1000 fb^{-1} from BABAR & Belle



Except $\sin 2\beta$, theory errors dominate

But, we know there is "New Physics:" Dark matter, baryon asymmetry, ν mixing. May have visible effects in b sector

BTeV's challenge will be to test New Physics as an additional source of $\not{CP}$.

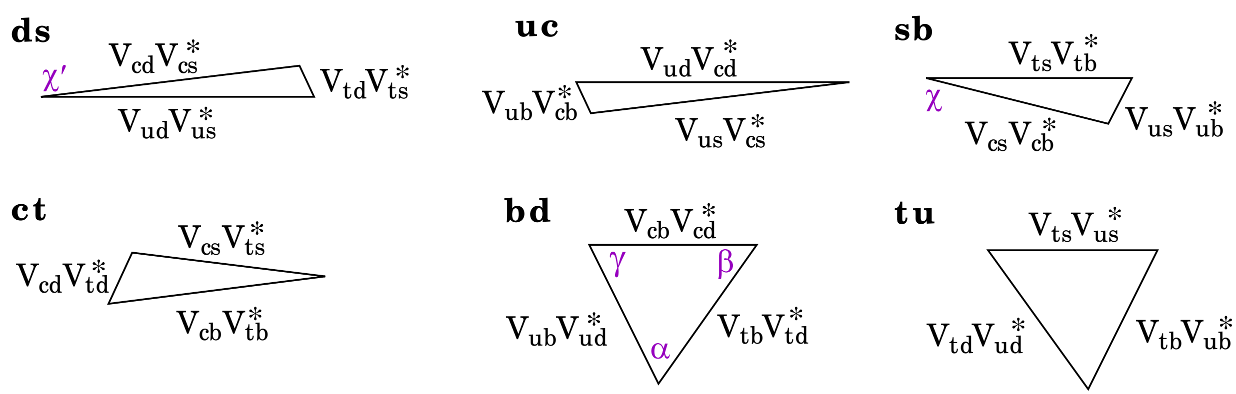
Unitarity and CKM triangles

Unitarity constraints of the CKM matrix allow us to create 6 triangles with equal areas; defined by only four angles: β, γ, χ, and χ' instead of A, λ, ρ, and η.

$$\beta = \arg\left[-\frac{V_{tb}V_{td}^*}{V_{cb}V_{cd}^*}\right]$$

$$\gamma = \arg\left[-\frac{V_{ub}^*V_{ud}}{V_{cb}^*V_{cd}}\right]$$

etc.



- β well measured in B decays, α and γ more difficult $(\alpha + \beta + \gamma = \pi)$
- χ small, *CP* violation in B_s^0 decays
- χ' very small, *CP* violation in K's

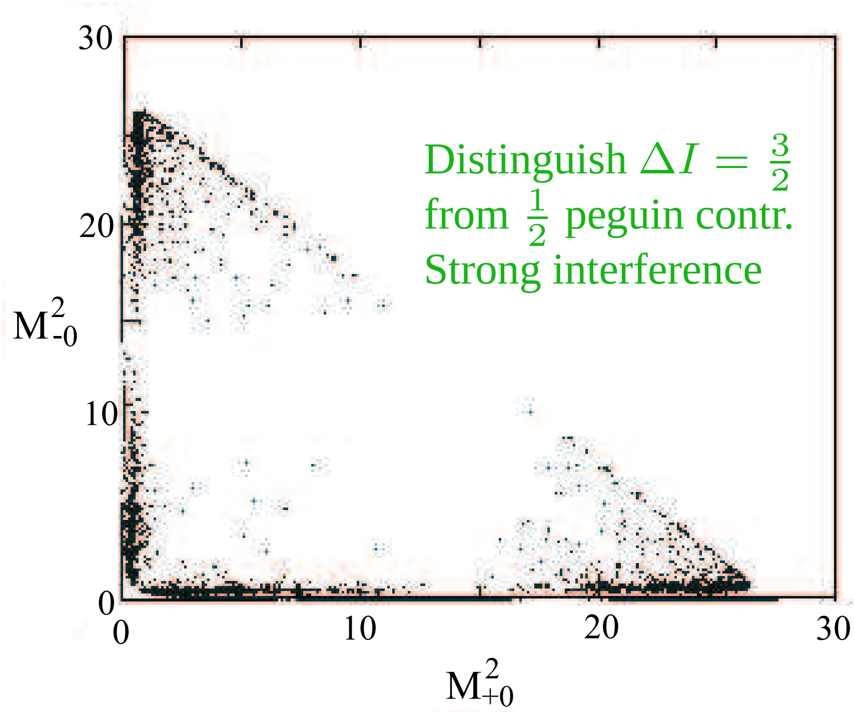
Measuring α

Most accessible in $B^0 \to \pi^+\pi^-$

- Problem: Penguin contamination is $\sim 40\%$
- Can salvage by also measuring $B^+ \to \pi^+\pi^0$ and $B^0 \to \pi^0\pi^0$ (very difficult)

Model indep. with $B^0 \to \rho\pi$ Dalitz gives $\sin 2\alpha$, $\cos 2\alpha$

- Measured BRs:
  - $B^0 \to \rho^\pm\pi^\pm$: $\approx 3 \times 10^{-5}$
  - $B^0 \to \rho^0\pi^0$: $< 0.5 \times 10^{-5}$
  - $\gtrsim B^0 \to \pi^+\pi^-$
- Challenging analysis, 9 parameter fit

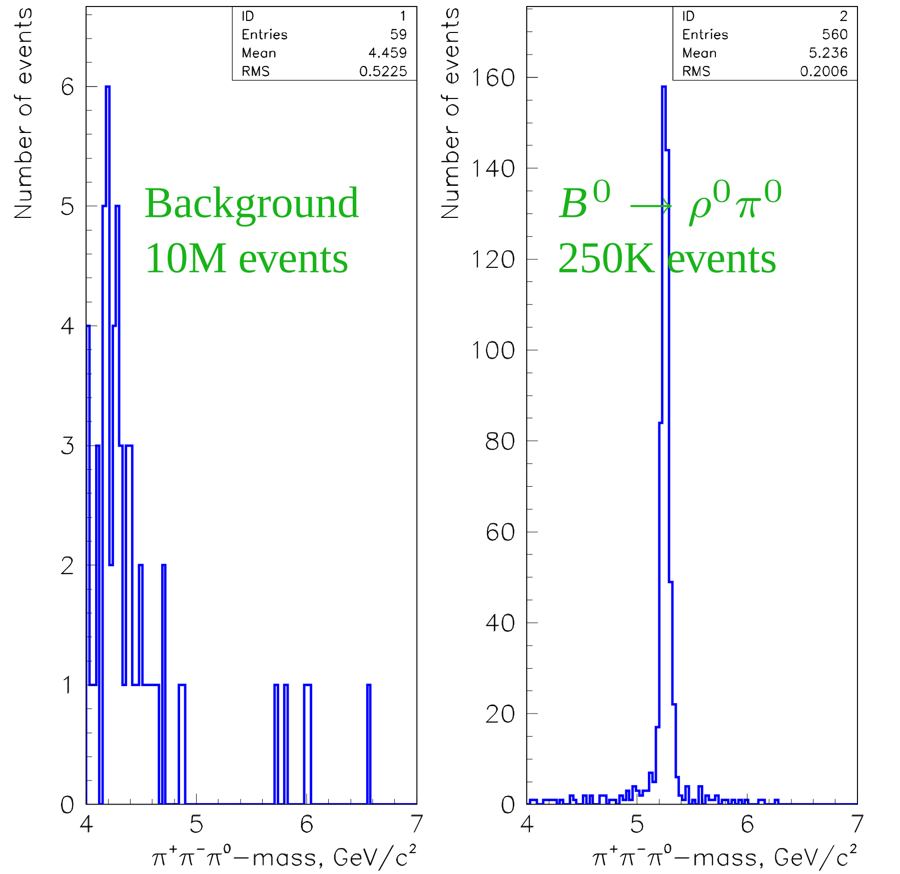


$B^0 \to \rho\pi$ in BTeV

For one yr of running:

	$\rho^\pm\pi^\mp$	$\rho^0\pi^0$
BR ($\times 10^{-5}$)	2.8	0.5
ϵ	0.0014	0.0011
Sig./10^7 s	5400	776
ϵD^2	0.10	0.10
Tagged/yr	540	78
Sig/BG	4.1	0.3

Depending on value of α, measured to 1.4–4.3° in 1.4×10^7 s



Also includes various assumptions of BG composition, Penguin amplitudes

Measuring χ

$\sin 2\chi$ is the *CP* asymmetry of B_s^0 decays

In the Standard model, phases and magnitudes are correlated:

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

where $\lambda \equiv \left|\frac{V_{us}}{V_{ud}}\right| = 0.2205 \pm 0.0018$

Analysis:

- $B_s^0 \to J/\psi\phi$
  - Mixed *CP* final state, needs angular analysis
- $B_s^0 \to J/\psi\eta^{(\prime)}$
  - Definite *CP* final state
  - Less data, simpler analysis, more difficult recon.

B_s^0 Mixing, measurement of x_s

$$x_{d/s} \equiv \frac{\Delta m_{d/s}}{\Gamma_{d/s}}$$

$$= \frac{G_F^2}{6\pi^2} B_{B_{d/s}} f^2_{B_{d/s}} m_{B_{d/s}} \tau_{B_{d/s}} \left| V_{tb}^* V_{t(d/s)} \right|^2 m_t^2 F\left(\frac{m_t^2}{m_W^2}\right) \eta_{\mathrm{QCD}}$$

Combined with x_d, x_s is a measure of $|V_{td}/V_{ts}|$. Many theoretical uncertainties cancel $\longrightarrow$ better measurement in (ρ, η) plane

$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{B_s}}{m_{B_d}} \xi^2 \left| \frac{V_{ts}}{V_{td}} \right|^2$$

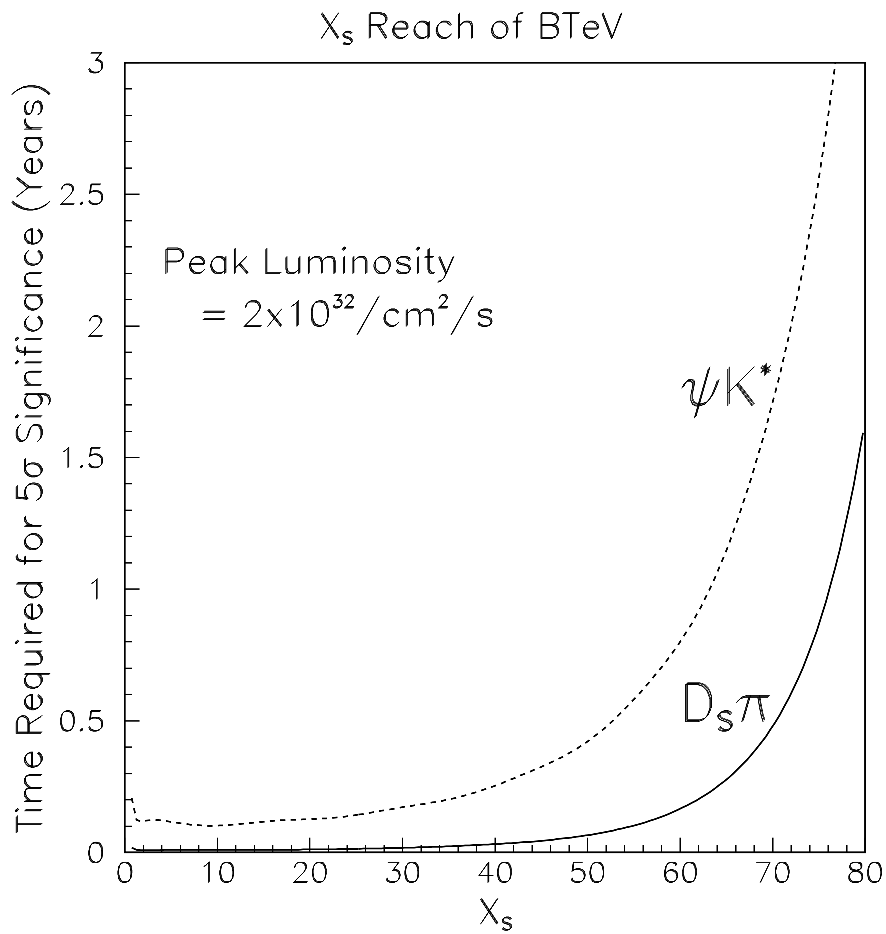
$$\xi = \frac{f_{B_s}}{f_{B_d}} \sqrt{\frac{B_{B_s}}{B_{B_d}}} = 1.24 \pm 0.04 \pm 0.06$$ (lattice best value)

BTeV's x_s sensitivity

In the SM, x_s should be $\lesssim 40$.

BTeV's best channel is $B_s^0 \to D_s^+\pi^-$ and gives us sensitivity up to $x_s = 80$ in about three years running.

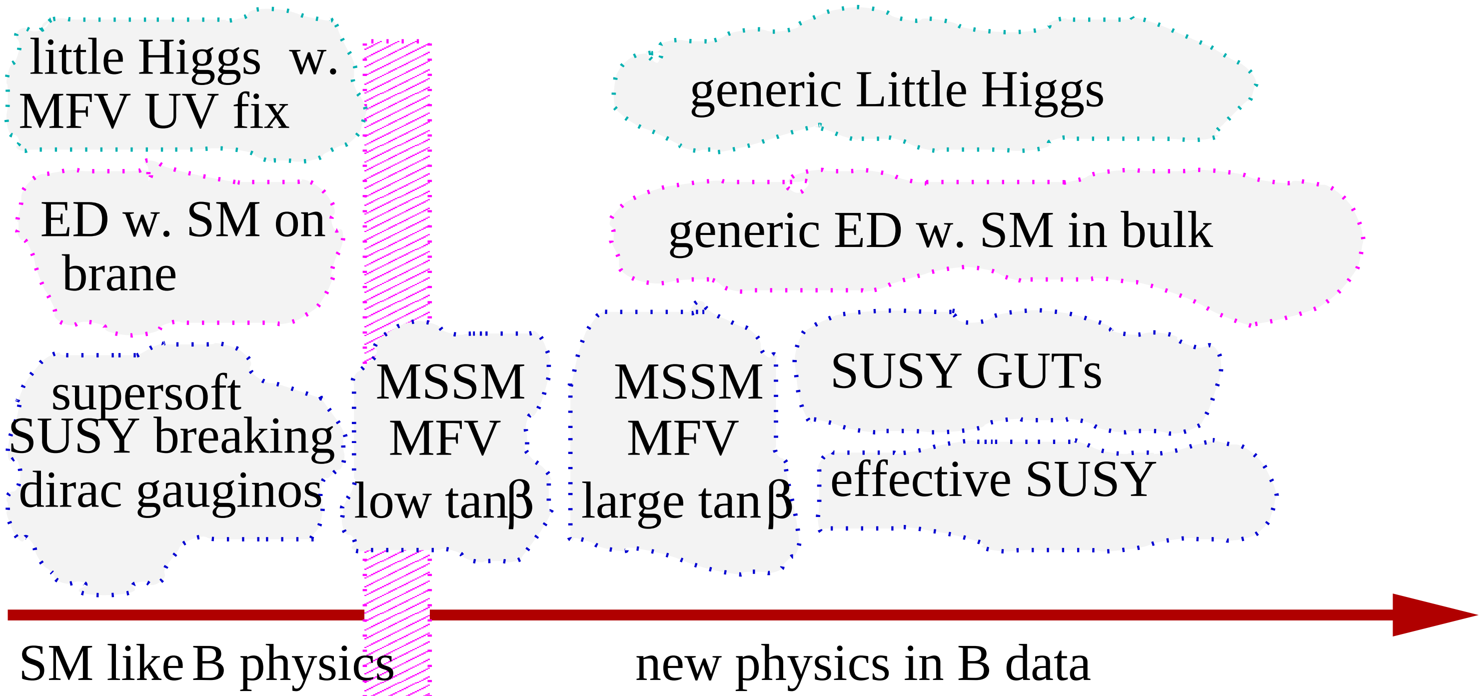
"Discovery" is 5σ significance.



2-arm sensitivity, $\sim \frac{1}{2}$ for 1-arm

New Physics

From Masiero & Vives (hep-ex/0104027): *"the relevance of SUSY searches in rare processes is not confined to the usually quoted possibility that indirect searches can arrive 'first' ... in signaling the presence of SUSY. Even after the possible direct production and observation of SUSY particles, the importance of FCNC and CP violation in testing SUSY remains of utmost relevance. They are and will be complementary to the Tevatron and LHC establishing low energy supersymmetry as the response to the electroweak breaking puzzle."*
We would replace "SUSY" with "New Physics"



From Hiller–hep/ph/0207121

Example: MSSM

- In general, SUSY adds 80 constants, 43 new phases
- In MSSM, two new phases (hep-ph/9911321):
- θ_D (B^0 mixing), θ_A (B^0 decay)
- $\phi_{K\pi}$ (combination $\rightarrow$ $\not{CP}$ in D^0 mixing)
- Predictions of θ_D, θ_A vary, $\mathcal{O}(0.1\text{–}1)$

Decay	SM	MSSM
$B^0 \rightarrow J/\psi K^0_S$	$\sin 2\beta$	$\sin 2(\beta + \theta_D)$
$B^0 \rightarrow \phi K^0_S$	$\sin 2\beta$	$\sin 2(\beta + \theta_D + \theta_A)$
$D^0 \rightarrow K^-\pi^+$	0	$\sim \sin \phi_{K\pi}$

Two obvious signatures: Different *CP* asymmetries in $B^0 \rightarrow J/\psi K^0_S$ and $B^0 \rightarrow \phi K^0_S$ and $\not{CP}$ in $D^0 \rightarrow K^-\pi^+$.

Sensitivities in One Year

Decay Mode	BR (10^{-6})	# Events	S/B	Parameter	Error (Value)
$B_s^0 \to D_s^+ K^-$	300	7 500	7	$\gamma - 2\chi$	8°
$B_s^0 \to D_s^+ \pi^-$	3000	59 000	3	x_s	(75)
$B^0 \to J/\psi K_S^0, J/\psi \to \ell^+\ell^-$	445	168 000	10	$\sin 2\beta$	0.017
$B^0 \to J/\psi K^0, K^0 \to \pi \ell \nu$	7	250	2.3	$\cos 2\beta$	~ 0.5
$B^- \to D^0(K^+\pi^-)K^-$	0.17	170	1		
$B^- \to D^0(K^+K^-)K^-$	1.1	1 000	> 10	γ	13°
$B_s^0 \to J/\psi \eta$	330	2 800	15		
$B_s^0 \to J/\psi \eta'$	670	9 800	30	$\sin 2\chi$	0.024
$B^0 \to \rho^+\pi^-$	28	5 400	4.1		
$B^0 \to \rho^0\pi^0$	5	780	0.3	α	$\sim 4^\circ$
$B^- \to K_S^0 \pi^-$	12.1	4 600	1		$< 4^\circ +$
$B^0 \to K^+\pi^-$	18.8	62 100	20	γ	theory err.
$B^0 \to \pi^+\pi^-$	4.5	14 600	3		0.03
$B_s^0 \to K^+K^-$	17	18 900	3	α, γ	0.02

Model dependent checks may be useful for resolving ambiguities

Measurement Requirements

BTeV provides:

- Large samples of tagged B^+, B^0, B_s^0 decays, unbiased b and c decays
- Efficient trigger, well understood acceptance and reconstruction
- Excellent vertex and momentum resolutions
- Excellent particle ID and γ, π^0 reconstruction

Quantity	Decay Mode	Vertex Trigger	K π Sep.	γ Det.	Decay Time σ
$\sin 2\alpha$	$B^0 \to \rho\pi \to \pi^+\pi^-\pi^0$	✓	✓	✓	
$\cos 2\alpha$	$B^0 \to \rho\pi \to \pi^+\pi^-\pi^0$	✓	✓	✓	
$\sin\gamma$	$B_s^0 \to D_s^+ K^-$	✓	✓		✓
$\sin\gamma$	$B^0 \to D^0 K^-$	✓	✓		
$\sin 2\chi$	$B_s^0 \to J/\psi\eta, J/\psi\eta'$		✓	✓	✓
$\sin 2\beta$	$B^0 \to J/\psi K_S^0$				
$\cos 2\beta$	$B^0 \to J/\psi K^0, K^0 \to \pi\ell\nu$		✓		
x_s	$B_s^0 \to D_s^+ \pi^-$	✓	✓		✓
$\Delta\Gamma$ for B_s^0	$B_s^0 \to J/\psi\eta^{(\prime)}, K^+K^-, D_s^+\pi^-$	✓	✓	✓	✓

BTeV Compared to B-factories

- No B_s^0, B_c^+, Λ_b^0 at B-factories
- Tevatron σ 10^5 higher than e^-e^+
  - B-factory: $\mathcal{L} = 10^{34} \rightarrow 1.1 \times 10^8\ B^0/10^7$ s
  - BTeV: $\mathcal{L} = 2 \times 10^{32} \rightarrow 1.5 \times 10^{11}\ B^0/10^7$ s
- Reconstruction and tagging efficiency is sometimes $50\times$ better at e^+e^-
- BTeV is able to overcome this with high cross section
- Many modes BTeV collects $30\times$ e^+e^- statistics/yr
- Assume B-factories reach > 500 fb^{-1}, currently ~ 130
- Super-KEK: Plan to upgrade to $\mathcal{L} = 10^{35}$ in 2007, still not competitive with BTeV in $B\bar{B}$

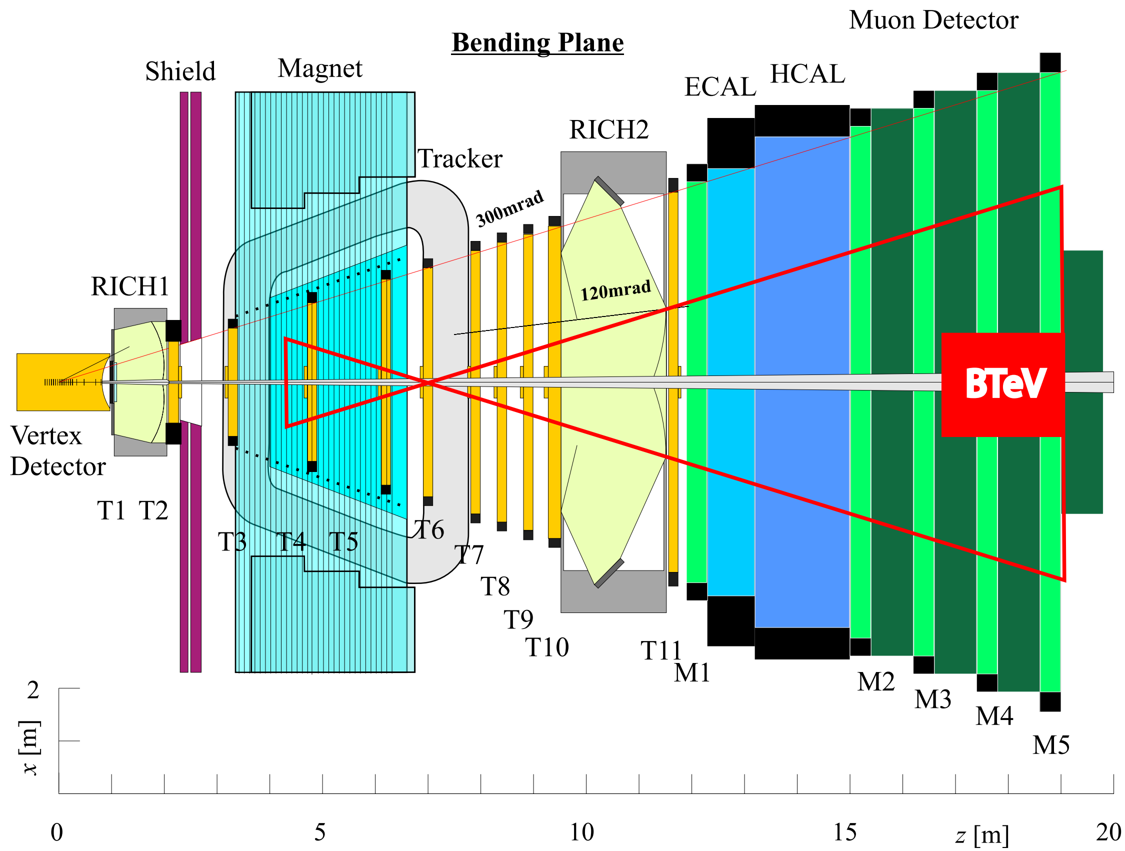
Comparison to LHCb

Strongest competitor to BTeV. Recently re-optimized to reduce material in spectrometer.

LHCb advantages:

- $\sigma_{b\overline{b}} = 5 \times \text{BTeV}$
- $\sigma_{\text{tot}} = 1.6 \times \text{BTeV}$
- $\langle \text{Int./Cross} \rangle < 1$

But, BTeV has many advantages too.



LHCb before re-optimization

BTeV Advantages over LHCb

- 132 or 396 ns crossing time vs. 25 ns
- Lower BTeV $p \rightarrow$ shorter detector (hall length $\sim$same)
  - Only one RICH needed, less B-field
  - Smaller size $\rightarrow$ better detectors/$$
- Better EM calorimeter — more comprehensive studies
- DAQ has $20\times$ rate, $5\times$ more *b* decays to “tape”
- Pixel detector allows vertexing at L1
  - Unbiased selection of *b* and *c* decays
  - Will have physics that becomes interesting “on tape”
- Multiple interactions per crossing OK
  - Longer interaction region, pixel vertexing
- Vertex detector in B-field can reject low-momentum tracks

Comparisons with LHCb

Comparisons with prelim. (April 2003) LHCb-light #s. BTeV #s scaled to LHCb BR's.

Mode	BR (10^{-5})	LHCb Untagged		BTeV
		TDR	Light	
$B_s^0 \to D_s^+ \pi^- \quad (x_s)$	300	86 000	72 000	59 000
$B_s^0 \to D_s^+ K^- \quad (\gamma - 2\chi)$	23	6 000	8 000	5 900

Comparisons with LHCb TDR #s. (Light #s will be similar)

Mode	BR	LHCb		BTeV	
		Yield	S/B	Yield	S/B
$B_s^0 \to J/\psi \eta^{(\prime)} \quad (\chi)$	1.0×10^{-3}	—	—	12 650	> 15
$B^0 \to \rho^+ \pi^- \quad (\alpha)$	2.8×10^{-5}	2 140	0.8	5 400	4.1
$B^0 \to \rho^0 \pi^0 \quad (\alpha)$	0.5×10^{-5}	880	0.05?	776	0.3

BTeV does better with γ, π^0, more comprehensive data set

History and Status of BTeV

- December 1997: BTeV becomes R&D project
- May 1999: Preliminary TDR
- May 2000: Proposal for 2-arm BTeV, $130M + $50M
  - Unanimously approved by PAC, June 2000
- March 2002: One arm descoped detector proposed, offline computing supplied by universities: $122M + $0M
  - Unanimously approved by PAC
- October 2002: Fermilab (Temple) cost review
- March 2003: Review by P5
- Assuming a positive P5 report, a Temple (internal) and Lehman review will follow
- Construction, commissioning 2007–8, data taking 2009

Conclusions

- Plenty of physics not covered
  - Other non-SM tests: Extra dimensions, SO(10)
  - FCNC decays
  - b baryons, B_c mesons
  - Copious amounts of charm
- We will make key measurements in B_s^0 decays and states with γ's; our ability to record all b states gives us the broadest possible scope and significant advantages over other experiments
- BTeV will make critical contributions to our knowledge of $\not{C}\not{P}$ and move from initial observations to determining if the SM description is complete. BTeV is not just doing SM physics; it can reveal or help explain new phenomena
- Part of a high precision flavor program to complement and interpret any NP discoveries at Tevatron or LHC

Backup Slides

396 ns Bunch Crossing

- BTeV was designed for $\mathcal{L} = 2 \times 10^{32}$ cm^{-2}s^{-1} at 132 ns $\rightarrow \langle 2 \rangle$ interactions/crossing
- Now expect $\mathcal{L} \sim 2 \times 10^{32}$ cm^{-2}s^{-1} at 396 ns ($\langle 6 \rangle$ int./cross) or $\mathcal{L} \sim 1.3 \times 10^{32}$ cm^{-2}s^{-1} at 396 ns ($\langle 4 \rangle$ int./cross)
- Verified performance by repeating many simulations at $\langle 4 \rangle$ and $\langle 6 \rangle$ int./cross (without re-optimizing code)
- Key potential problem areas (trigger, EMCAL, RICH) all hold up well based on simulations
- On going work to fully understand the impact of a change to 396 ns, *e.g.* optimizing charge collection for pixel readout

Change from Two Arms to One

Between our first and second PAC approvals, BTeV was rescoped. However, we also found better ways to do physics, so the effect was not as drastic on our ability to achieve our physics goals:

- Loss of one arm: factor = 0.5
- Gains in dileptons:
  - RICH ID of μ's
  - Proposal: $\mu^+\mu^-$ only, now e^+e^- too
  - Factor = 2.4 (or 3.9) for (di)lepton ID
- DAQ retains full bandwidth, loosen triggers: factor = 1.15
- Same-side $K^{\pm}$ tagging for B_s^0 only: factor = 1.3
- Bottom line: w.r.t. proposal, factors from 0.58–2.9, most physics is same or better with new assumptions