BTeV Physics Reach

LHC 2003 Symposium
K. Honscheid
Ohio State University

B Physics Today

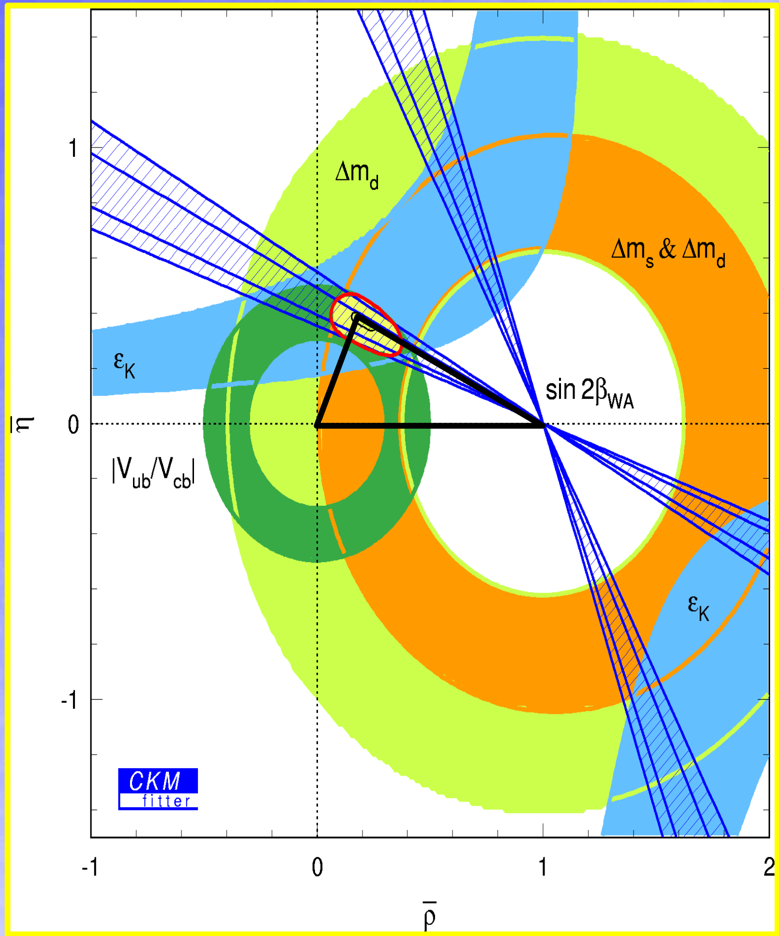
- CKM Picture okay

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

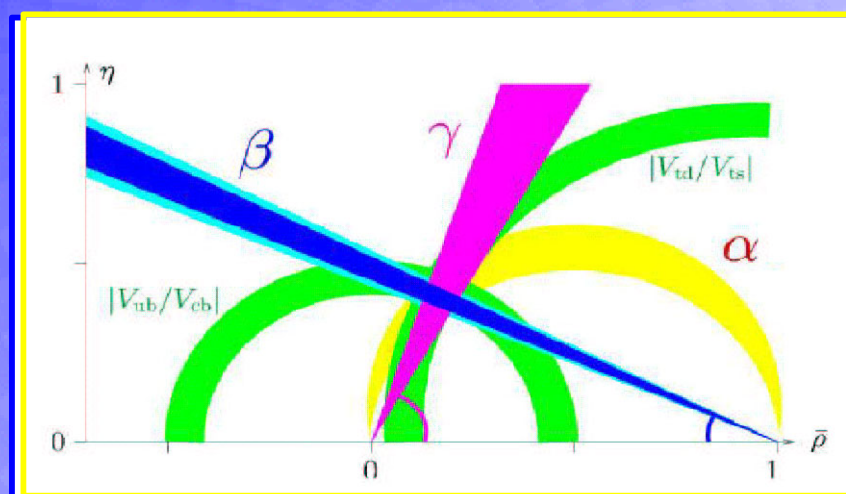
- CP Violation observed

$\sin(2\beta) = 0.734 +/- 0.054$

- No conflict with SM



Surprising B Physics

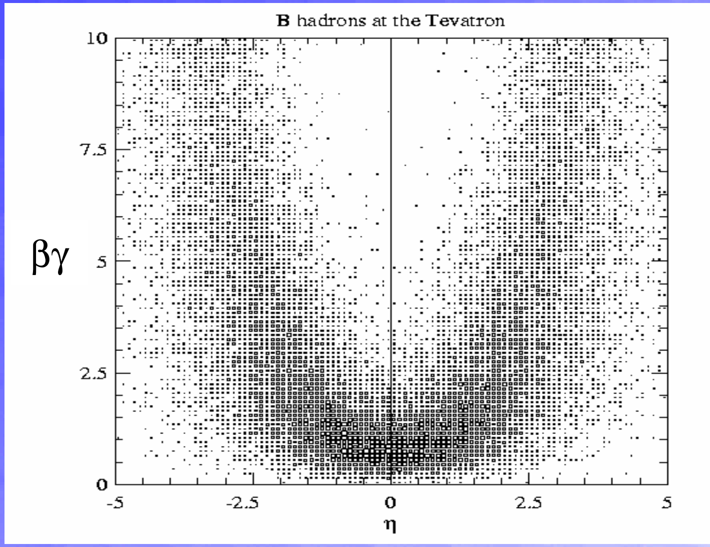
Year	Item	Theory Prediction	~Value	# B's
1983	τ_b	Too small to be observed ~ < 0.1ps	1 ps	2×10^4
1987	B^o-B^o mixing	Too small to see (~ < 1%) as m_{top} is believed to be ~30 GeV	20%	2×10^5
2001	$\sin(2\beta)$	No direct prediction, but consistent with other measurements	3/4	10^7
	α,β,γ		$>10^{11}$ b hadrons (including B_s)	

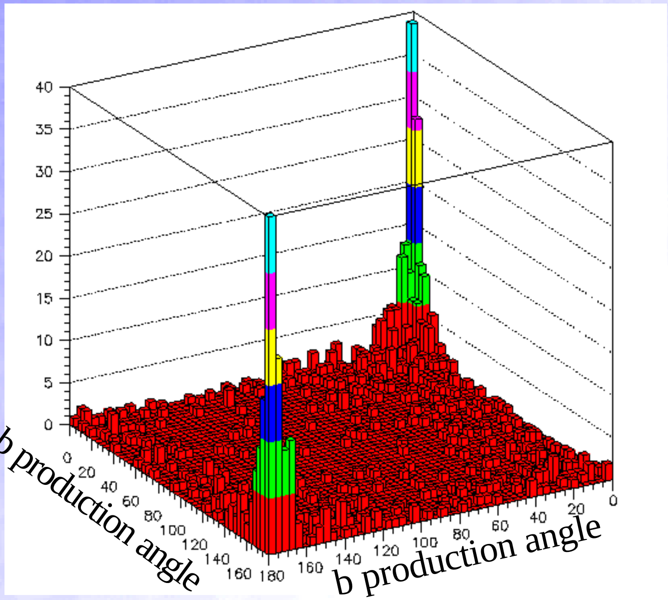
B Physics at Hadron Colliders

- The Tevatron as b (and c) source
  - b cross section ~100 μb, c cross section ~1000 μb
  - b fraction 2×10^{-3}
  - Inst. Luminosity 2×10^{32}
  - Bunch spacing 132 ns (396 ns)
  - Int./crossing <2> (<6>)
  - Luminous region σ_z = 30 cm

2×10^{11} b pairs/year

- Forward Geometry

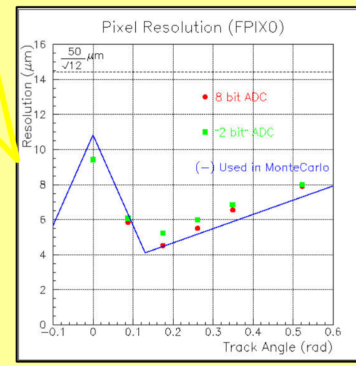




The BTeV Detector

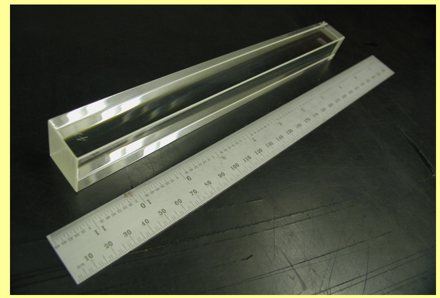
Pixel Detector

- 60 pixel planes
- inside magnet
- σ = 5-10 μm

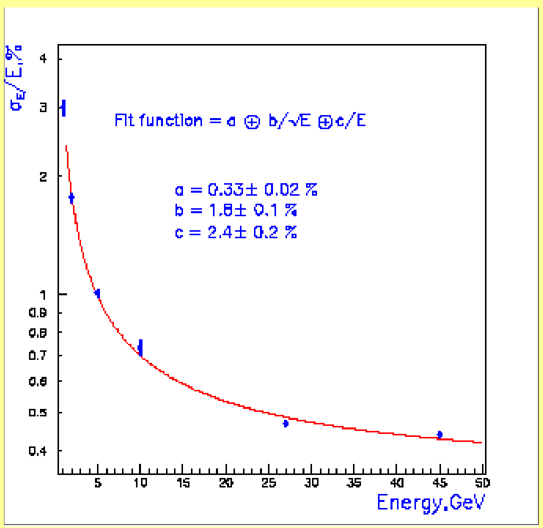


RICH Detector

$PbWO_4$ EM Calorimeter



10500 crystals
220 mm long, 28x28 mm^2



$\sigma(\eta \rightarrow \gamma\gamma) \sim 5$ MeV

$\sigma(\pi \rightarrow \gamma\gamma) \sim 3$ MeV

CLEO/BaBar/BELLE-like performance in a hadron Collider environment!

Muon Chamber

Electromagnetic Calorimeter

Efficiencies and Tagging

- For a requirement of at least 2 tracks detached by more than 6σ, we trigger on only 1% of the beam crossings and achieve the following trigger efficiencies for these states (<2> int. per crossing):

Decay	efficiency(%)	Decay	efficiency(%)
$B \rightarrow \pi^+\pi^-$	63	$B^o \rightarrow K^+\pi^-$	63
$B_s \rightarrow D_s K$	74	$B^o \rightarrow J/\psi\, K_s$	50
$B^- \rightarrow D^o K^-$	70	$B_s \rightarrow J/\psi K^*$	68
$B^- \rightarrow K_s \pi^-$	27	$B^o \rightarrow K^*\gamma$	40

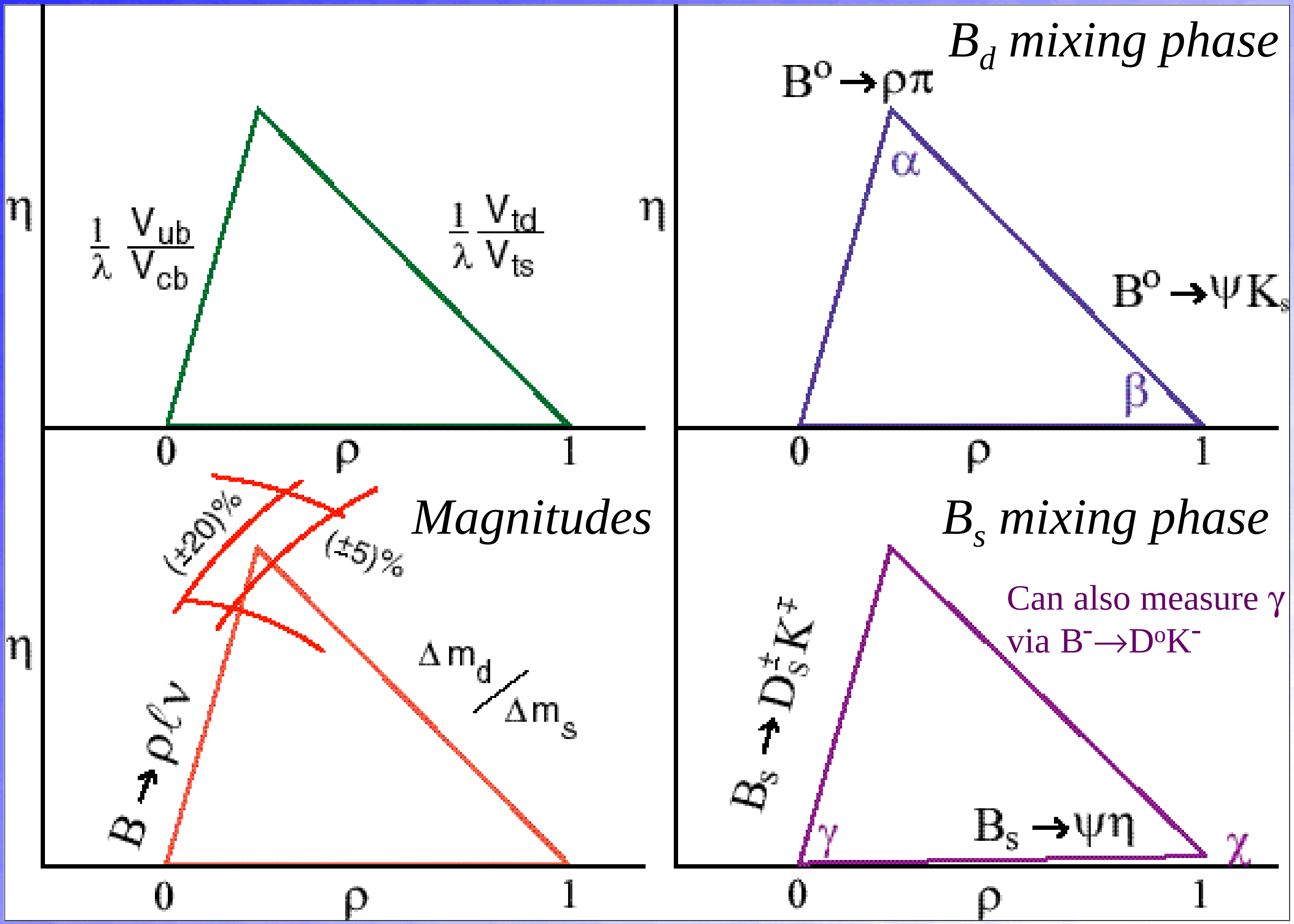
- $\varepsilon \equiv$ efficiency; $D \equiv$ Dilution or $(N_{right}-N_{wrong})/(N_{right}+N_{wrong})$
- Effective tagging efficiency $\equiv \varepsilon D^2$
- Extensive study for BTeV uses
  - Opposite sign $K^\pm$
  - Jet Charge
  - Same side $\pi^\pm$ (for B^o) or $K^\pm$ for (B_s)
  - Leptons
- Conclusion: $\varepsilon D^2 (B^o) = 0.10$, $\varepsilon D^2 (B_s) = 0.13$, difference due to same side tagging

The Physics Goals

- There is New Physics out there:
  - Baryon Asymmetry of Universe & by Dark Matter
  - Hierarchy problem
  - Plethora of fundamental parameters
  - …
- BTeV is in a unique position to:
  - Perform precision measurements of CKM Elements with small model dependence.
  - Search for New Physics via ~~CP~~ phases
  - Search for New Physics via Rare Decays
  - Help interpret new results found elsewhere (LHC, neutrinos)
  - Complete a broad program in heavy flavor physics
    - Weak decay processes, $\mathcal{B}$'s, polarization, Dalitz plots, QCD…
    - Semileptonic decays including Λ_b
    - b & c quark Production
    - Structure: B baryon states
    - B_c decays

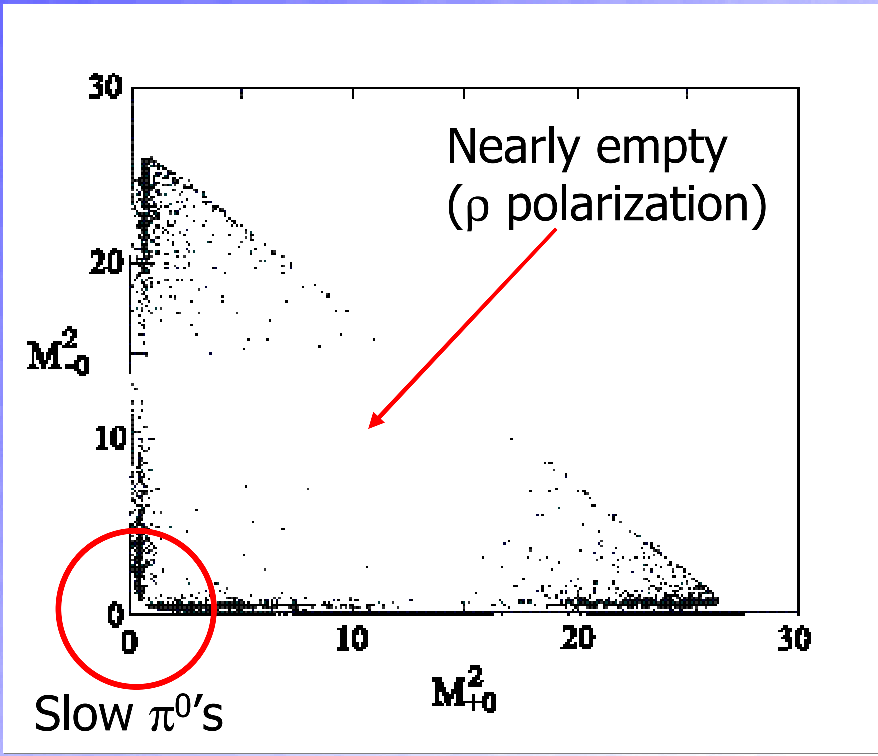
Part 1: Is the CKM Picture correct?

- Use different sets of measurements to define apex of triangle (adopted from Peskin)
- Also have ε_K (CP in K_L system)



Measuring a Using B^o ® rp ® $p^+p^-p^o$

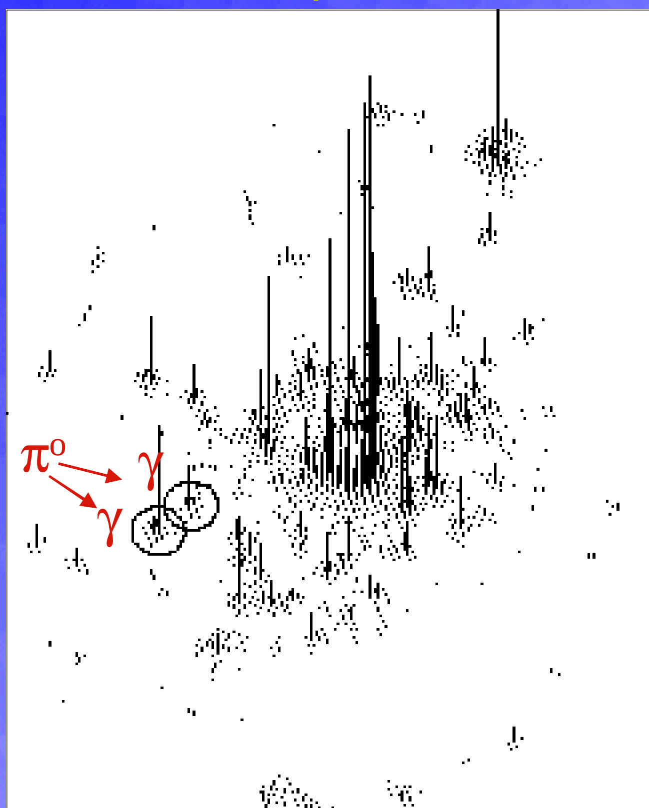
- A Dalitz Plot analysis gives **both** sin(2α) and cos(2α) (Snyder & Quinn)
- Measured branching ratios are:
  - $B(B^- \to \rho^o\pi^-) = \sim 10^{-5}$
  - $B(B^o \to \rho^-\pi^+ + \rho^+\pi^-) = \sim 3\text{x}10^{-5}$
  - $B(B^o \to \rho^o\pi^o) < 0.5\text{x}10^{-5}$
- Snyder & Quinn showed that 1000-2000 tagged events are sufficient
- Not easy to measure
  - π^0 reconstruction
- Not easy to analyze
  - 9 parameter likelihood fit

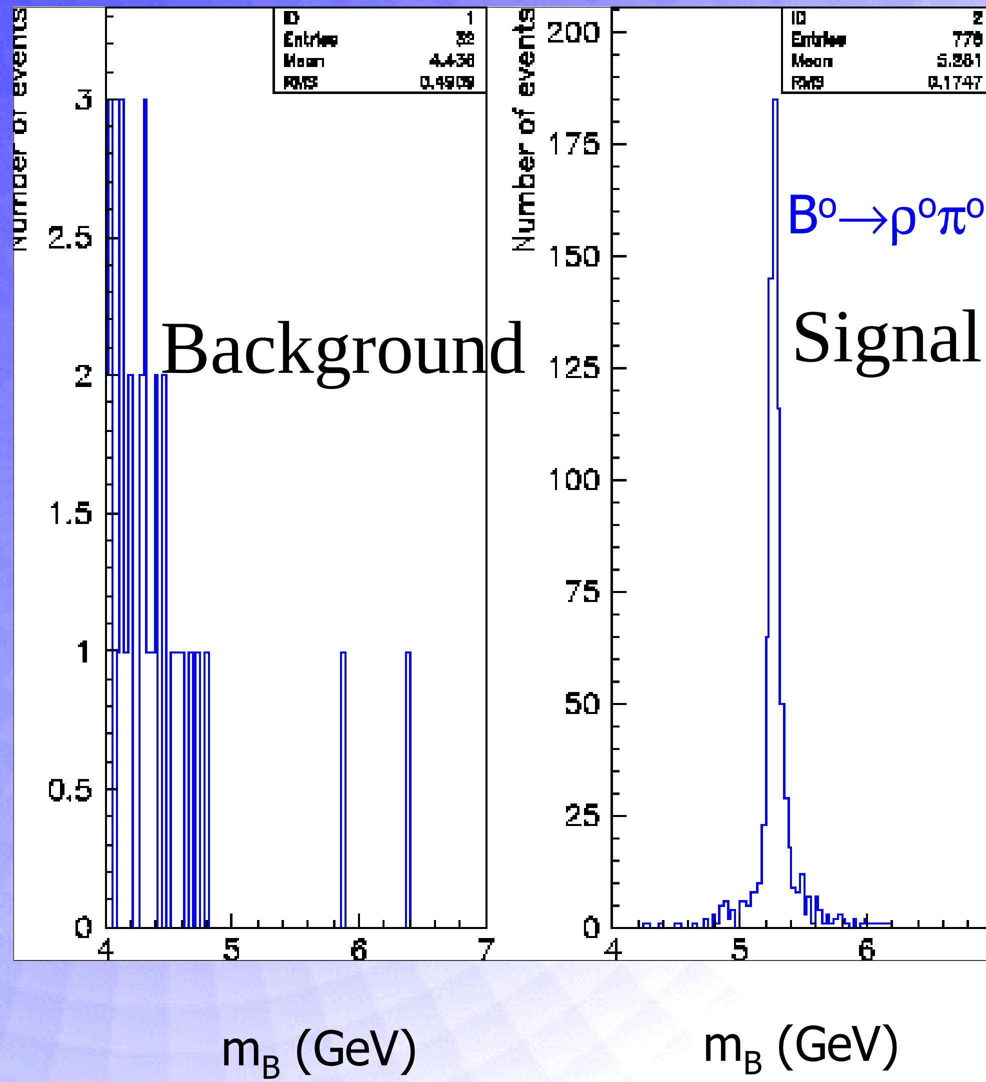


Dalitz Plot for $B^o \to \rho\pi$

Yields for Bº ® r p

- Based 9.9×10^6 background events
- $B^o \to \rho^+\pi^-$
  5400 events, S/B = 4.1
- $B^o \to \rho^o\pi^o$
  780 events, S/B = 0.3

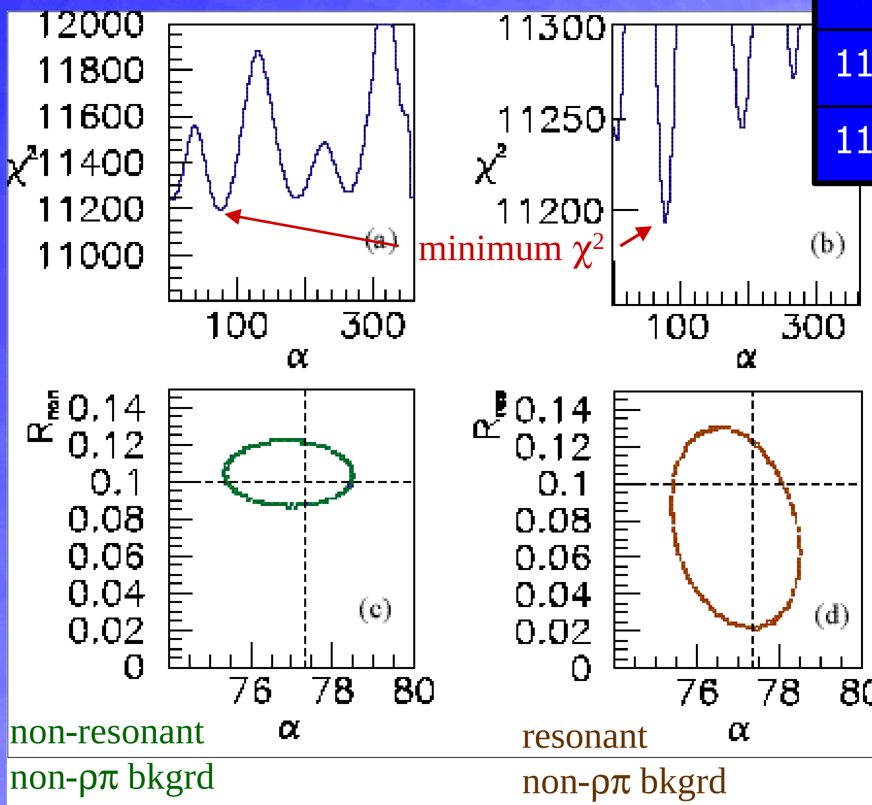




Our Estimate of Accuracy on a

- Geant simulation of $B^o \rightarrow \rho\pi$, (for $1.4\text{x}10^7$ s)

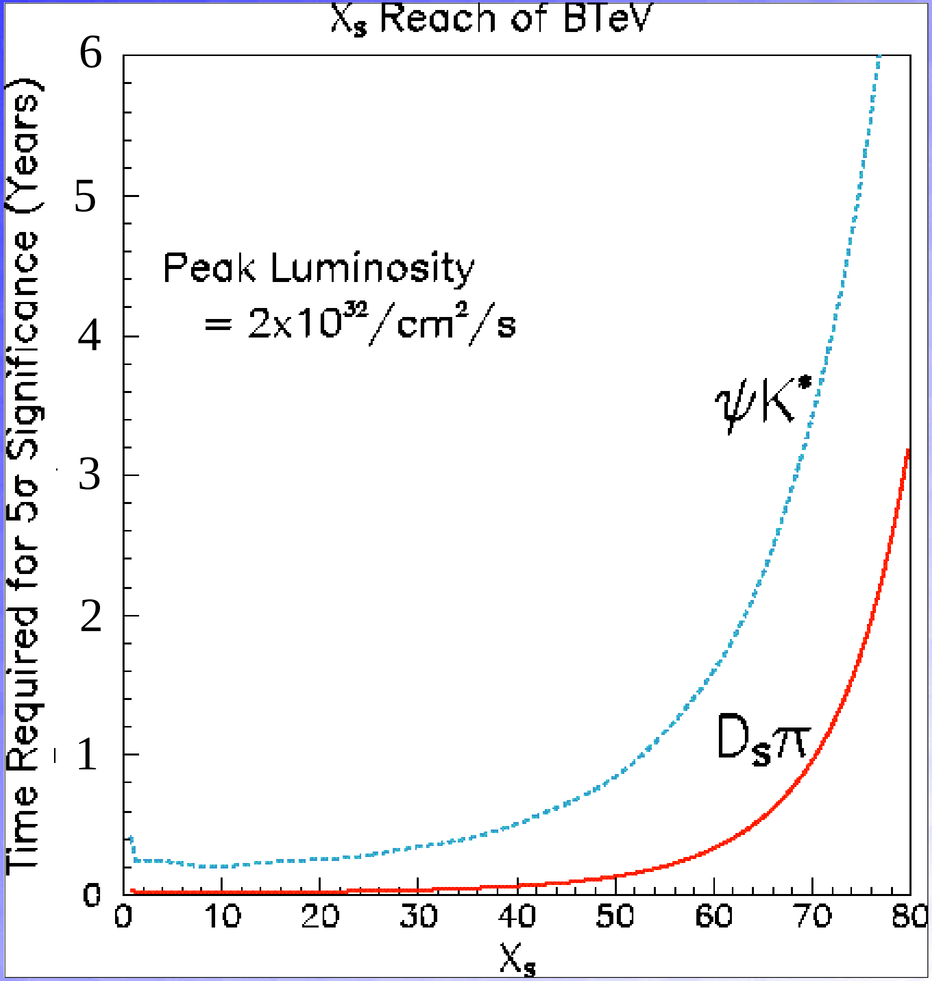
α (gen)	R_{res}	R_{non}	α (recon)	Δα
77.3°	0.2	0.2	77.2°	1.6°
77.3°	0.4	0	77.1°	1.8°
93.0°	0.2	0.2	93.3°	1.9°
93.0°	0.4	0	93.3°	2.1°
111.0°	0.2	0.2	111.7°	3.9°
111.0°	0.4	0.2	110.4°	4.3°



Example:
1000 $B^o \rightarrow \rho\pi$ signal + backgrounds
With input α=77.3°

B_s Mixing (V_{td}/V_{ts})

- BTeV reaches sensitivity to x_s of 80 in 3.2 years



Measuring c

- In the SM the phases and magnitudes are correlated:

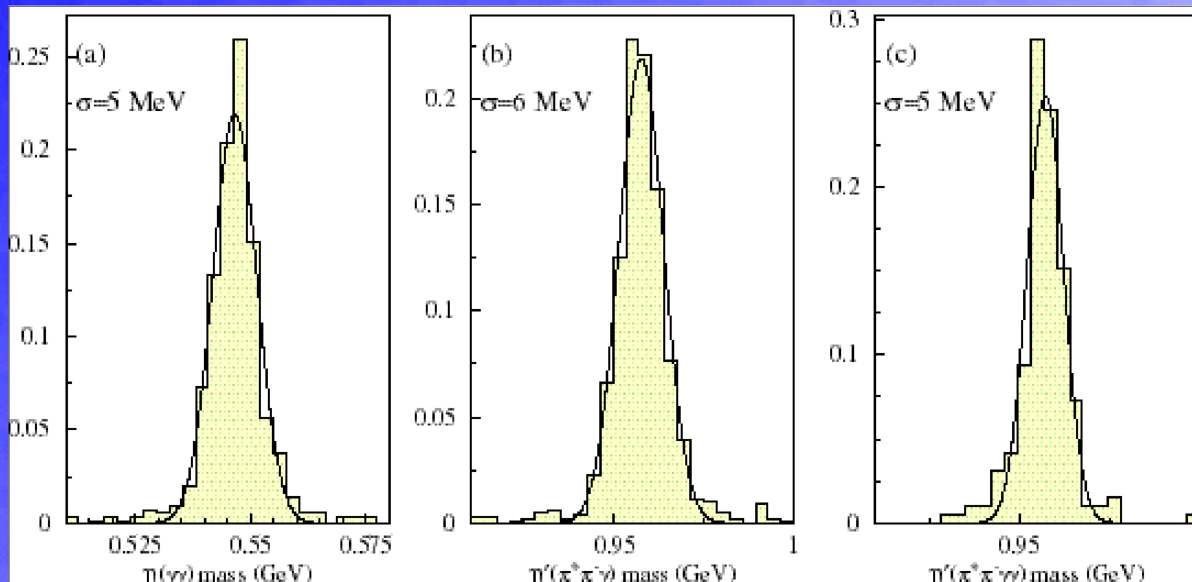
$$\sin\chi = \lambda^2 \frac{\sin\beta \sin\gamma}{\sin(\beta+\gamma)}$$

Silva & Wolfenstein (hep-ph/9610208)
Aleksan, Kayser & London

- $\lambda = |V_{us}| = 0.2205 \pm 0.0018$
- χ is the phase of V_{ts} -> B_s Mixing
- Good: B_s->$J/\psi\phi$ plus non-trivial angular analysis
- Better: B_s -> CP eigenstate such as $B_s \to J/\psi\eta^{(\prime)}$, $\eta \to \gamma\gamma$, $\eta' \to \rho\gamma$

Measuring c II

- BTeV can reconstruct η and η′



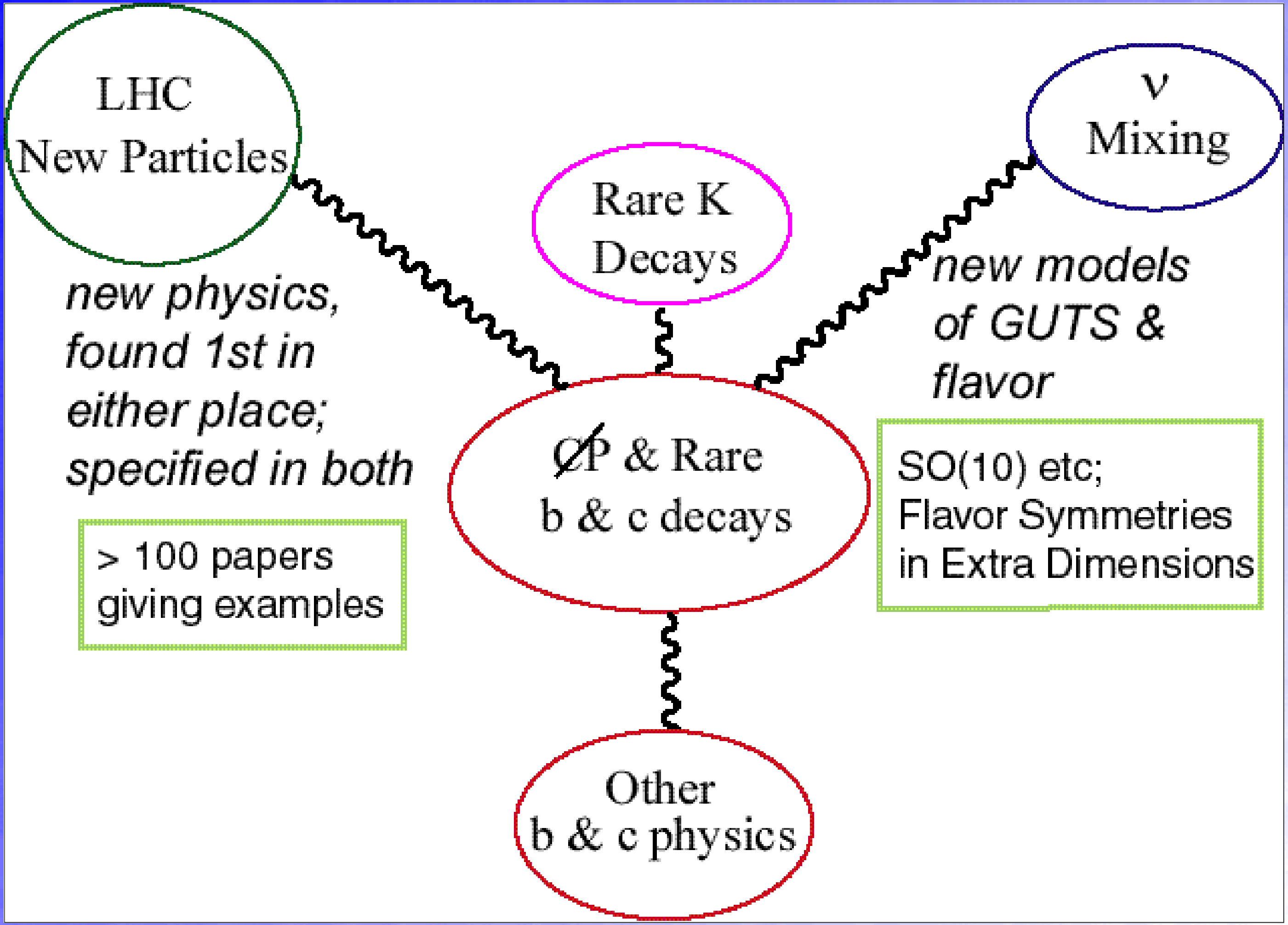
- Yield in one year
  - $B_s \to J/\psi\ \eta$: 2,800 events with S/B = 15
  - $B_s \to J/\psi\ \eta'$: 9,800 events with S/B = 30
  - Error on sin(2χ) = 0.024
  - With χ ~ 2° a precision measurement will require a few years.

Physics Reach (CKM) in 10^7 s

Reaction	$\mathcal{B}$(B) (x10^{-6})	# of 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)
$B^o \to J/\psi K_S$ $J/\psi \to \ell^+ \ell^-$	445	168,000	10	sin(2β)	0.017
$B^o \to J/\psi K^o$, $K^o \to \pi \ell \nu$	7	250	2.3	cos(2β)	~0.5
$B^- \to D^o (K^+\pi^-) K^-$	0.17	170	1		
$B^- \to D^o (K^+K^-) K^-$	1.1	1,000	>10	γ	13^o
$B_s \to J/\psi \eta$,	330	2,800	15		
$B_s \to J/\psi \eta'$	670	9,800	30	sin(2χ)	0.024
$B^o \to \rho^+\pi^-$	28	5,400	4.1		
$B^o \to \rho^o\pi^o$	5	780	0.3	α	~4^o

Reaction	$\mathcal{B}$(B) (x10^{-6})	# of Events	S/B	Parameter	Error
$B^- \to K_S \pi^-$	12.1	4,600	1		<4^o +
$B^o \to K^+\pi^-$	18.8	62,100	20	γ	Theory err.
$B^o \to \pi^+\pi^-$	4.5	14,600	3	Asymmetry	0.030
$B^o \to K^+ K^-$	17	18,900	6.6	Asymmetry	0.020

Part II: Search for New Physics



For a nice overview see: S. Stone "BTeV Physics" at http://doe-hep.hep.net/P5StoneMarch2003.pdf

First Example: Supersymmetry

- Supersymmetry: In general 80 constants & 43 phases
- MSSM: 2 phases (Nir, hep-ph/9911321)
- New Physics in B^o mixing: θ_D , B^o decay: θ_A, D^o mixing: $\phi_{K\pi}$

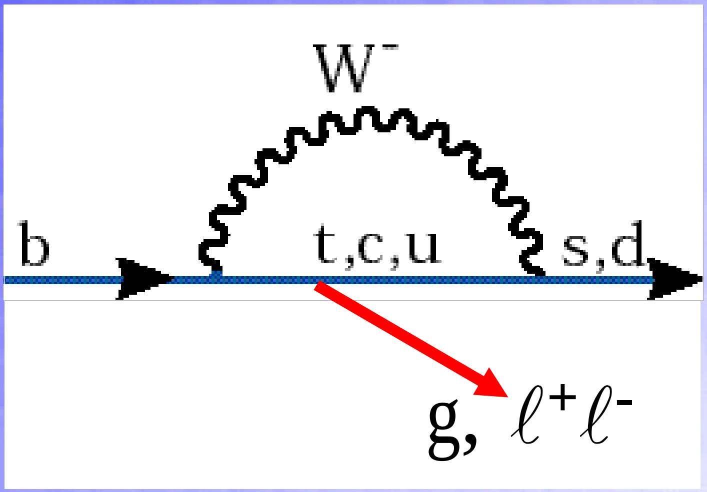
Process	Quantity	SM	New Physics
$B^o \rightarrow J/\psi K_s$	CP asym	$\sin(2\beta)$	$\sin 2(\beta+\theta_D)$
$B^o \rightarrow \phi K_s$	CP asym	$\sin(2\beta)$	$\sin 2(\beta+\theta_D+\theta_A)$
$D^o \rightarrow K^- \pi^+$	CP asym	0	$\sim\sin(\phi_{K\pi})$

Difference $\Rightarrow$ NP

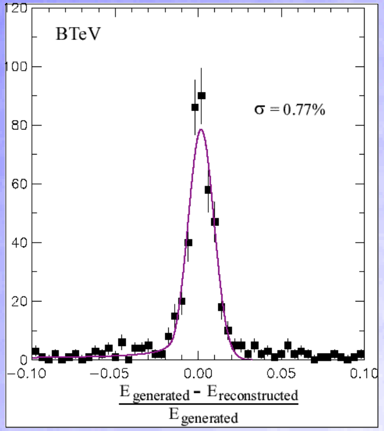
New Physics

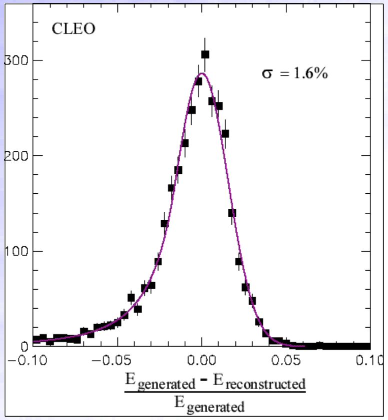
Rare b Decays

- Search for New Physics in Loop diagrams
  - New fermion like objects in addition to t, c or u
  - New Gauge-like objects in addition to W, Z or g



- Inclusive Rare Decays including
  - $b \to s\gamma$
  - $b \to d\gamma$
  - $b \to s\ell^+\ell^-$
- Exclusive Rare Decays such as
  - $B \to \rho\gamma$, $K^*\gamma$
  - $B \to K^*\ell^+\ell^-$ Dalitz plot & polarization





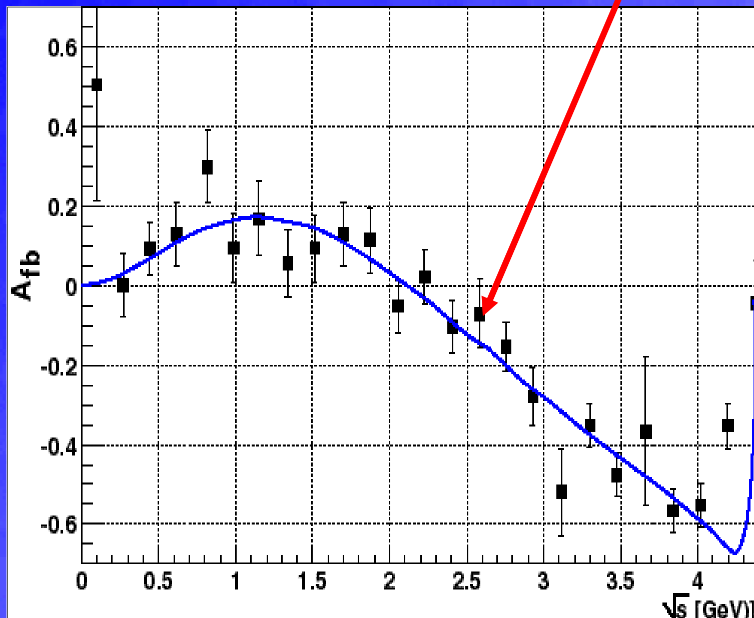
$B^o \to K^*\gamma$

Yield, S/B for Rare b Decays

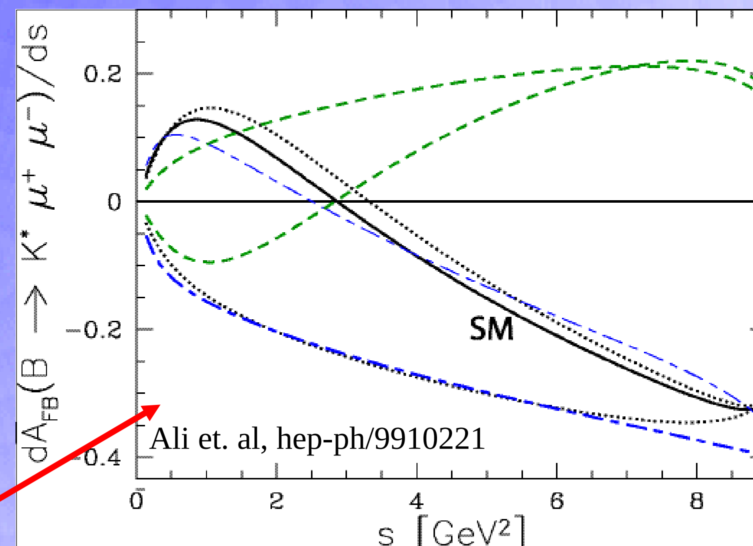
Reaction	$\mathcal{B}$ (10^{-6})	Signal	S/B	Physics
$B^o \rightarrow K^{*o}\mu^+\mu^-$	1.5	2530	11	Polarization; Rate
$B^- \rightarrow K^-\mu^+\mu^-$	0.4	1470	3.2	Rate
$b \rightarrow s\mu^+\mu^-$	5.7	4140	0.13	Rate; Wilson coefficents

Polarization in B^{o} ® $K^{*o}m^{+}m^{-}$

- BTeV data compared to Burdman et al calculation



- Dilepton invariant mass distributions, forward-backward asymmetry discriminate among the SM and various supersymmetric theories.
  (Ali, Lunghi, Greub & Hiller, hep-ph/0112300)

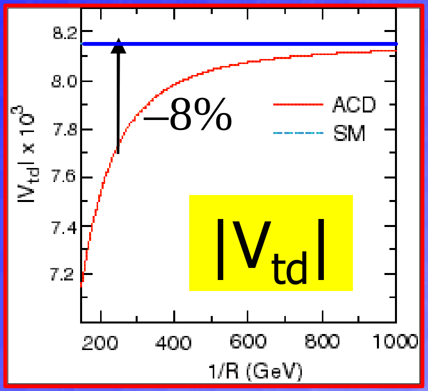


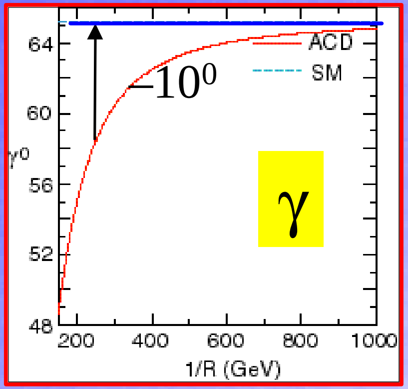
- One year for $K^{*}\ell^{+}\ell^{-}$, enough to determine if New Physics is present

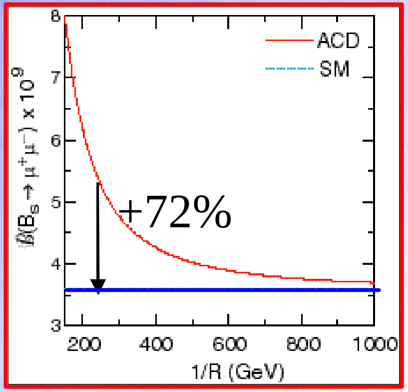
Second Example: Extra Dimensions

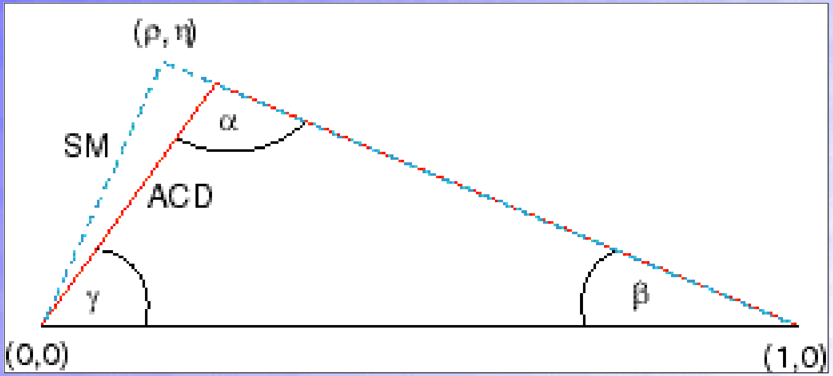
- Aranda & Lorenzo Diaz-Cruz, "Flavor Symmetries in Extra Dimensions" (hep-ph/0207059) (Buras et al. hep-ph/0212143)
- Extra spatial dimension is compactified at scale 1/R = 250 GeV on up
- No effect on $|V_{ub}/V_{cb}|$, $\Delta M_d/\Delta M_s$, $\sin(2\beta)$

$B_s \to \mu\mu$









Summary

- Heavy quark physics at hadron colliders provides a unique opportunity to
  - measure fundamental parameters of the Standard Model with no or only small model dependence
  - discover new physics in CP violating amplitudes or rare decays.
  - interpret new phenomena found elsewhere (e.g. LHC)
- Some scenarios are clear others will be a surprise

➡ This program requires a general purpose detector like BTeV with
  - an efficient, unbiased trigger and a high performance DAQ
  - a superb charged particle tracking system
  - good particle identification
  - excellent photon detection

Changes wrt Proposal in Event Yields & Sensitivities

- We lost one arm, factor = 0.5
- We gained on dileptons
  - From RICH ID
  - in proposal we used only $\mu^+\mu^-$, now we include e^+e^-
  - factor = 2.4 (or 3.9), depending on whether analysis used single (dilepton) id
- We gained on DAQ bandwidth, factor = 1.15
- Gained on εD^2 for B_s only, factor = 1.3

Mode	Yield proposal	Yield factor	Yield one-arm	Quantity Err(prop) (εD^2)	Quantity Err(1arm) (εD^2)
$B^o \to J/\psi\ K_s$	80,500	0.5*3.9*1.15=2.24	168,000	sin(2β) 0.025 (0.10)	sin(2β) 0.017 (0.10)
$B_s \to J/\psi \eta^{(\prime)}$	9,940	0.5*2.4*1.15=1.38	12,600	sin(2χ) 0.033 (0.10)	sin(2χ) 0.024 (0.13)
$B_s \to D_s\ K^-$	13,100	0.5*1.15 =0.58	7,500	γ 6^o (0.10)	γ 8^o (0.13)