Physics at a Super B Factory

Les Rencontres de Physique
de la Vallée d'Aoste

La Thuile, February 27- March 5, 2005

Francesco Forti, INFN-Pisa

Beauty of beauty factories

Impressive physics program achieved so far at B-Factories

- B mesons are a powerful laboratory
  - Sizable mixing and CP violation
  - HQET works and has predictive power
  - Many transitions probe different quantities
- e^+e^- machines are fantastic probes
  - Very clean environment: ½-track trigger
  - Coherent initial state allows true interference measurements and high tagging efficiency with low dilution
- Luminosity counts
  - Large samples allow precision measurements
  - Rare and very rare decays are becoming more and more crucial.

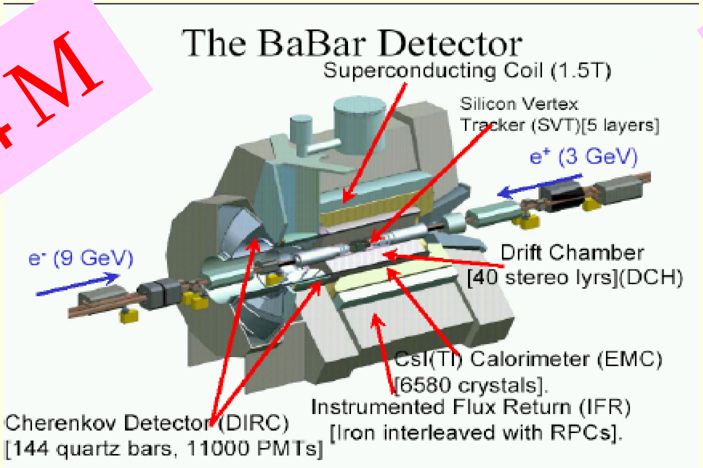
Yesterday

Experiments	Number of $b\bar{b}$ events ($\times 10^6$)	Environment	Characteristics
ALEPH, DELPHI OPAL, L3	$\sim$ 1 per expt.	Z^0 decays ($\sigma_{bb} \sim$ 6nb)	back-to-back 45 GeV b-jets all B hadrons produced
SLD	~ 0.1	Z^0 decays ($\sigma_{bb} \sim$ 6nb)	back-to-back 45 GeV b-jets all B hadrons produced beam polarized
ARGUS	~ 0.2	$\Upsilon(4S)$ decays ($\sigma_{bb} \sim$ 1.2nb)	mesons produced at rest B_d^0 and B^+
CLEO	~ 9	$\Upsilon(4S)$ decays ($\sigma_{bb} \sim$ 1.2nb)	mesons produced at rest B_d^0 and B^+
CDF	$\sim$ several	$p\bar{p}$ collisions $\sqrt{s} = 1.8$ TeV	events triggered with leptons all B hadrons produced

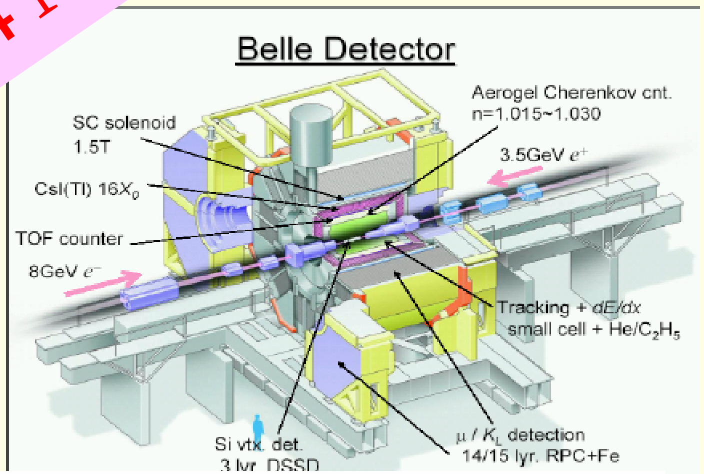
hep-ph0304132

Today

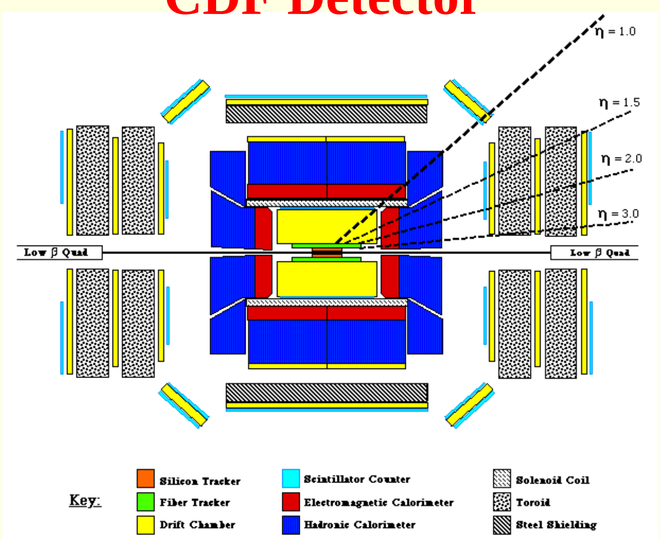
244 M



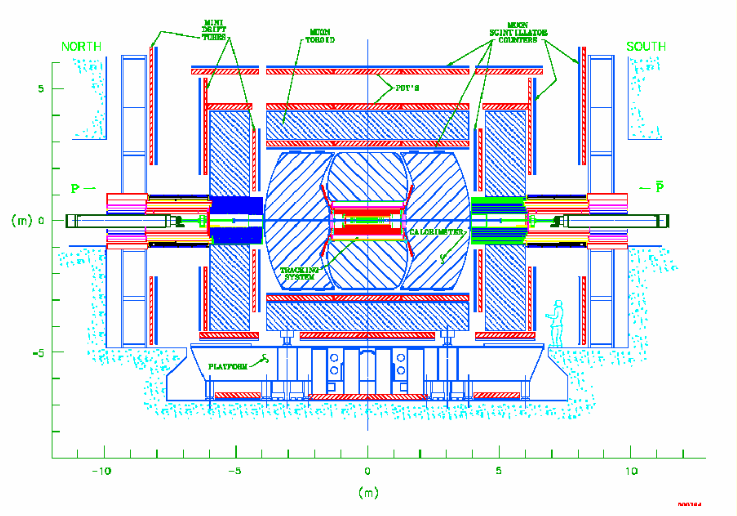
284 M



CDF Detector



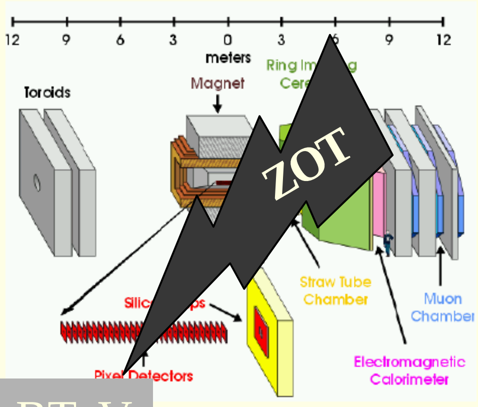
DØ Detector



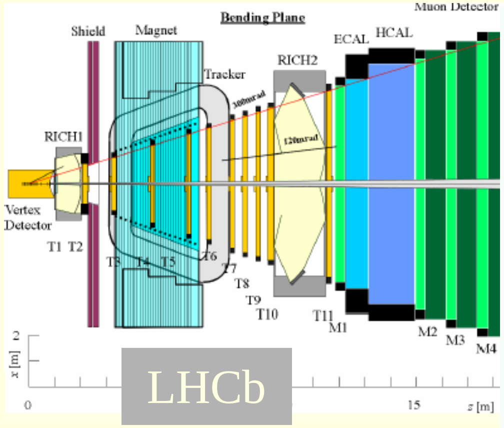
More B Physics ?

- What:
  - PEP-II/Babar & KEK-B/Belle currently at peak luminosity »10^{34} $cm^{-2}s^{-1}$
  - Integrated sample of about $1ab^{-1}$ for each machine by 2009
  - Upgrade ideas/proposals to increase luminosity by a factor 10 to 100, for a sample size of 5-50 ab^{-1}.
- Why:
  - High precision Standard Model Unitarity Triangle (UT) measurements
  - New Physics (NP) contributions to rare decays B.R. & Asymm.
  - Distinctive patterns may discriminate between models
- How:
  - Different upgrade scenarios are being considered
  - Detector and machine complexity/cost undergo a phase transition around a few x 10^{35} $cm^{-2}s^{-1}$
- When:
  - In the era of LHCb, (BTeV) and LHC experiments.
  - Competitiveness and complementarity with hadron machines

Tomorrow

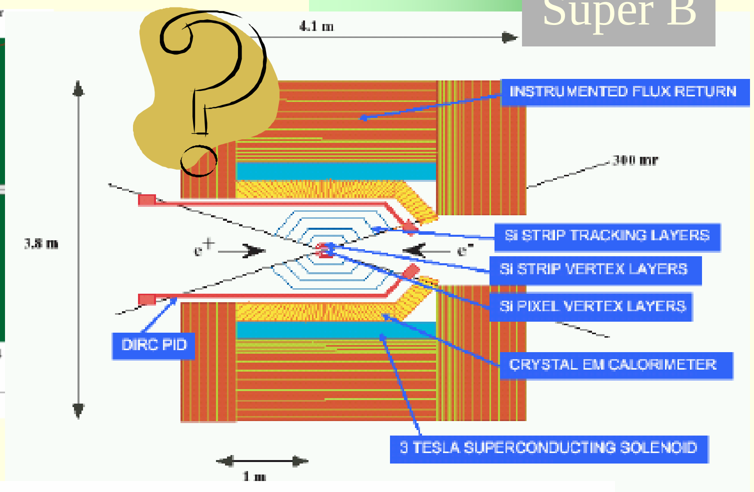


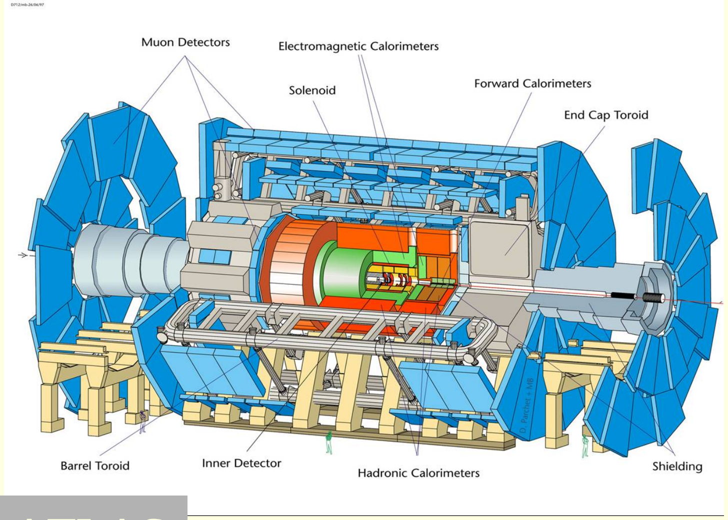
BTeV



LHCb

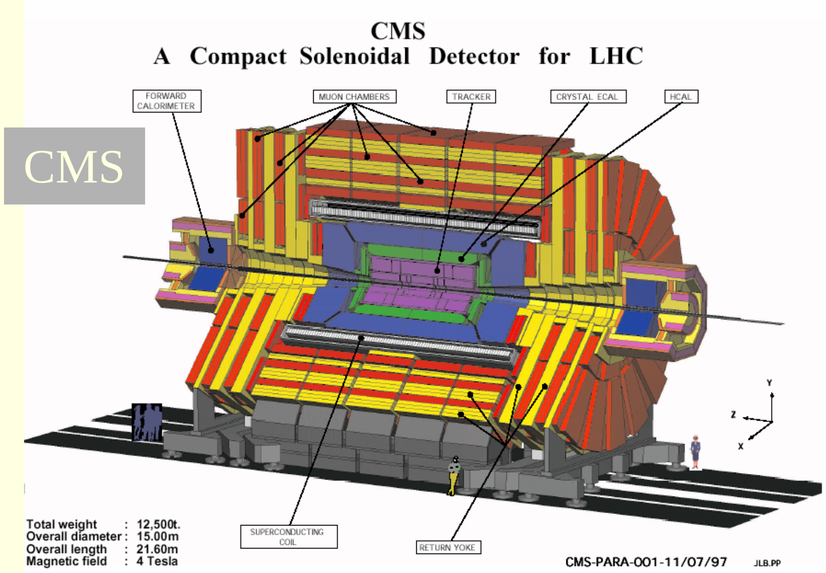
Super B





ATLAS

CMS

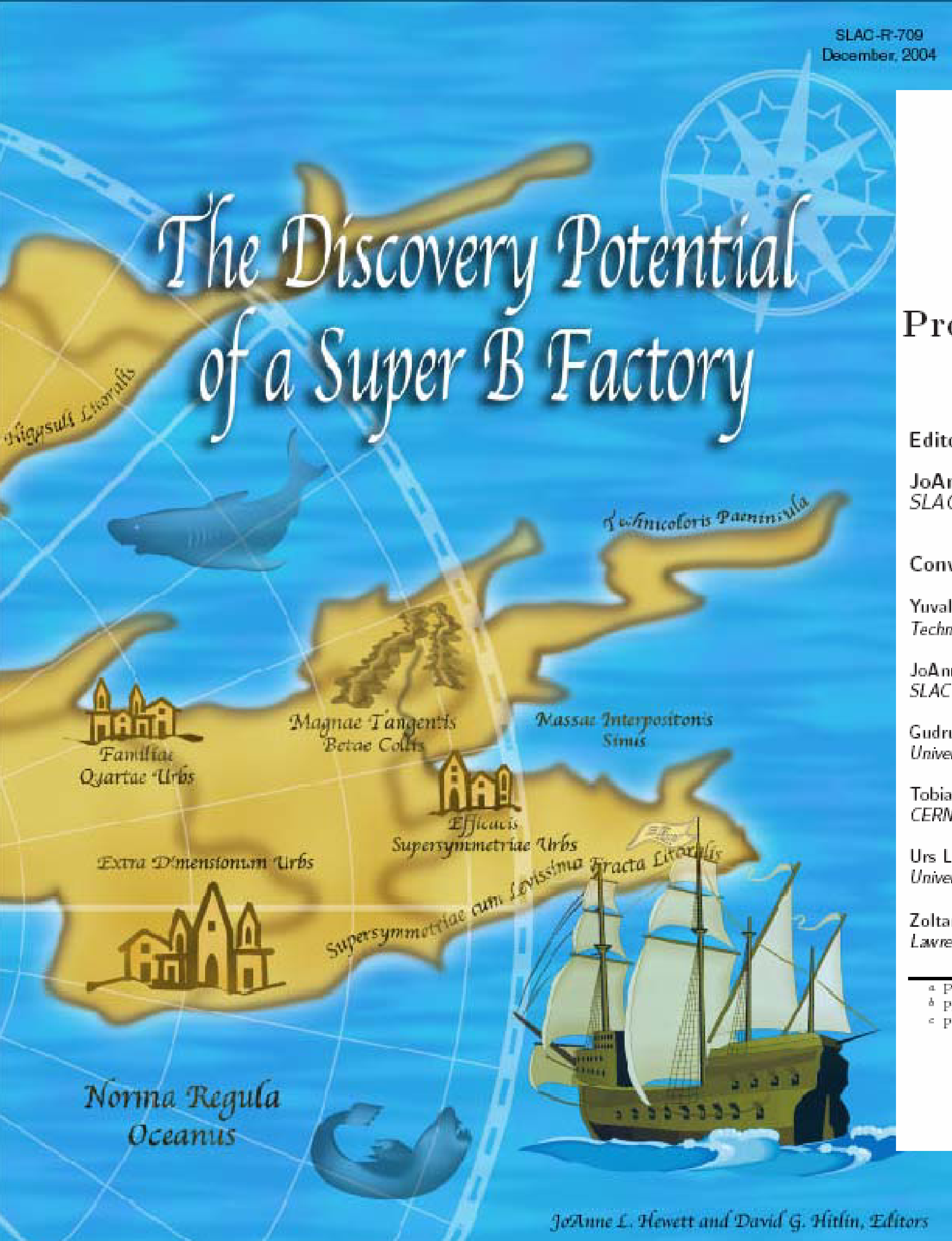


Yes, more B Physics !

- Unitarity Triangle sides measurements
  - From (semi)leptonic decays, inclusive or exclusive
  - $|V_{ub}|$, $|V_{cb}|$, $|V_{td}|$
- UT angles precision measurements
  - b→s penguin transitions very sensitive to new physics
  - CPV Asymmetries in $B \to \phi K_s$, $K_s \pi^0$ compared with sin2β.
  - α measurement with $B \to \pi\pi$ and ρρ; direct CPV
  - γ measurement with B→DK or similar channels.
- Rare decays
  - Exclusive and inclusive $b \to sg$ BFs, direct asymmetries, photon helicities
  - Exclusive and inclusive $b \to s l^+ l^-$ BFs, A_{FB}, CP asymmetries
  - B decays to states with large missing energy, such as $B_{(d,s)} \to \tau^+\tau^-$, $B \to K^{(*)} nn$, $b \to snn$, $B \to D^{(*)} tn_t$, $B \to X_C tn_t$

How to detect NP in B experiments.

- Experimental sensitivities for B experiments (2 to 50 ab^{-1})
  - Statistical and systematical
- Theoretical uncertainties of the reference points based on SM.
  - Given these uncertainties, is there still any sensitivity to NP?
    - $Q_{NP} - Q_{SM} > 3\ \sigma_{SM}(Q)$?
- Comparison with sensitivities from the planned hadron collider experiments.
  - Can the super-B measurements compete and/or provide better information than Hadron experiments?
  - Note that super B Factories cannot do B_s
    - mixing is too fast → no resolving power
    - Υ(5s) cross section smaller by a factor ~5 wrt Υ(4s)
    - decay itself mostly spectator: not competive with B_d



The Discovery Potential of a Super B Factory

Proceedings of the 2003 SLAC Workshops

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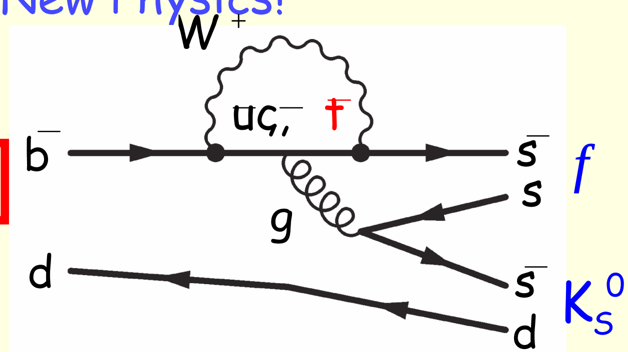
Available on the World Wide Web, with figures in full color, at
http://www.slac.stanford.edu/cgi-wrap/pubpage?slac-r-709

b→s penguin

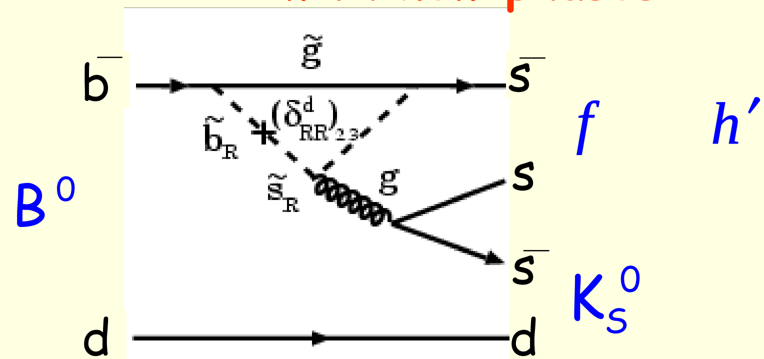
SM predicts for b→sss (almost) the same phase $e^{-2i\beta}$ as in tree process b→ccs. However loops can also be sensitive to New Physics!

SUSY contribution with new phases

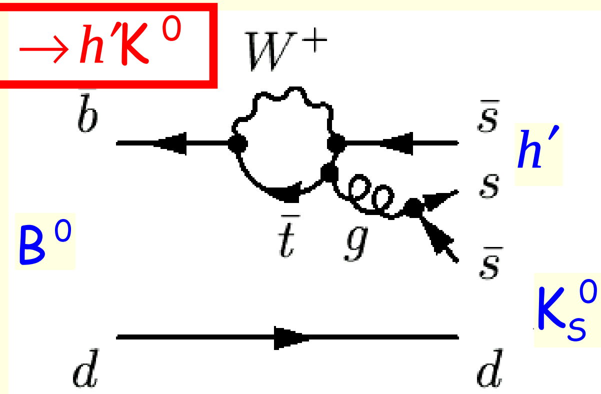
$B^0 \rightarrow fK^0$



$$BF = (7.6^{+1.3}_{-1.2} \pm 0.5) \times 10^{-6}$$

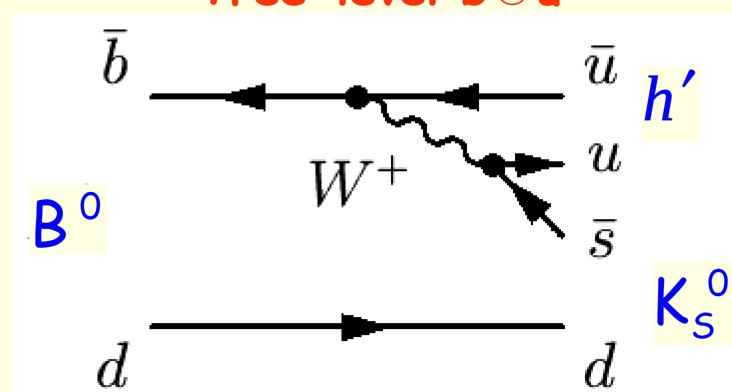


$B^0 \rightarrow h'K^0$



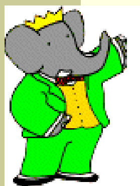
$$BF = (55.4 \pm 5.2 \pm 4.0) \times 10^{-6}$$

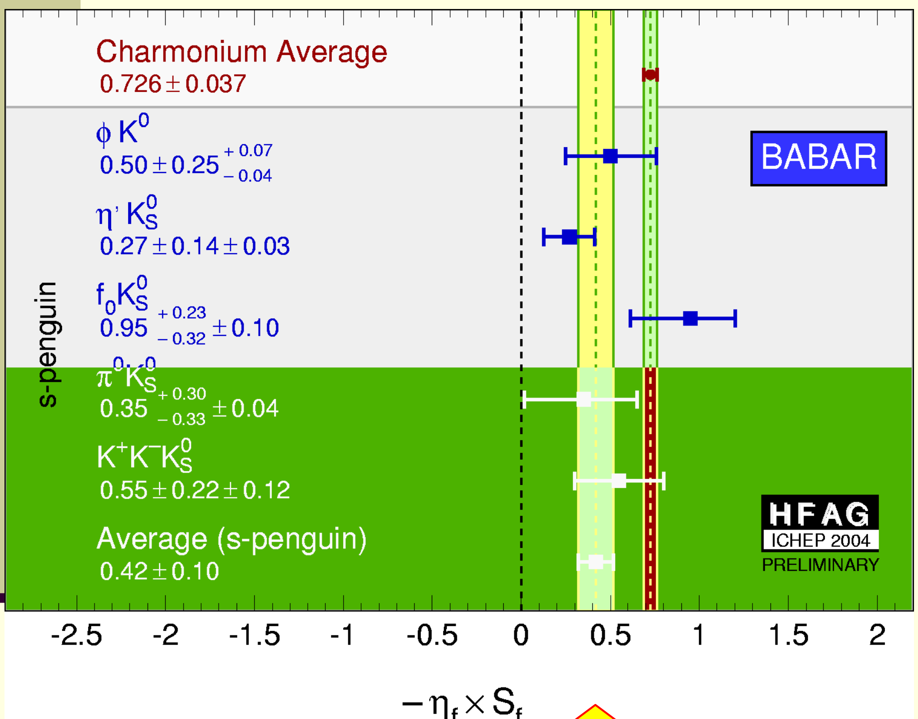
"Tree-level b®u"

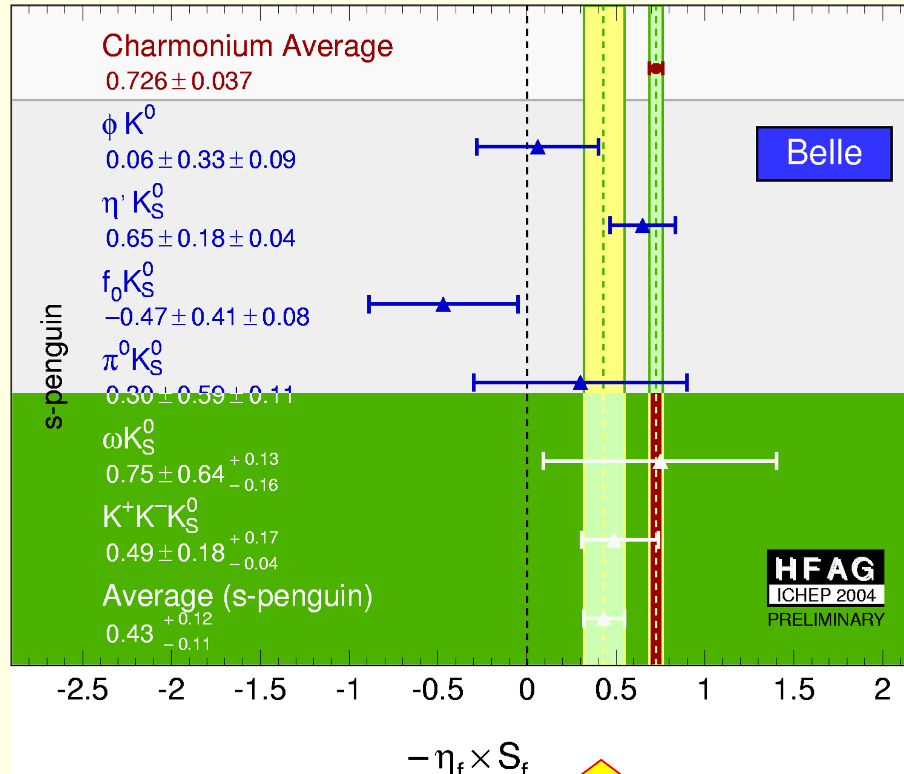


u-tree CKM suppressed T/P < 0.1

Intriguing hints from penguins







2.7σ from s-penguin to sin2β ($c\bar{c}$)

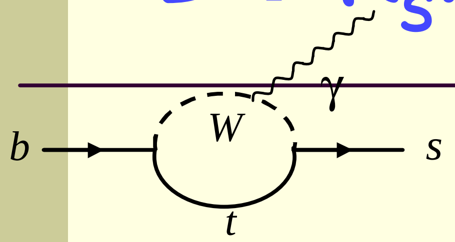
2.4σ from s-penguin to sin2β ($c\bar{c}$)

Strict I

Educated guess

Observable	SM: reference point	SM: Expected range
Time dependent CP Measurements b→sss(bar) & b→sdd(bar) & b→sγ		
$S(B\to\phi K_s)$	~Sin2β	|sin2β–S|<0.25 (0.05)
S(B→η′Ks)	~Sin2β	|sin2β–S|<0.3 (0.1)
$S(B\to K_s\,\pi^0)$	~Sin2β	|sin2β–S|<0.2 (0.15)
$S(B\to K^{*0}\,\gamma)$ (with $K^*\to K_s\,\pi^0$)	~2(m_s/m_b) Sin2β	|S|<0.1 (?)
b→s/dγ & b→s/d ($l^+ l^-$): Rates and $A_{cp(dir)}$		
Acp(b→s γ) [Acp(b→d γ)]		0.6% [-16%] (?)
[Γ(B→K*+ γ)–Γ(B→K*0 γ)]/(sum)	~0 (isospin breaking)	5 to 10% (?)
Γ(b→dγ)/ Γ(b→sγ)	|Vtd/Vts| (from mixing)	
$A_{cp}(B\to s\, l^+ l^-)$ $A_{cp}(B\to d\, l^+ l^-)$		<0.5% (0.05% for $K^*\, l^+ l^-$) ~(4.4+/-4)%
$B(B\to K\mu^+\mu^-)/B(B\to Ke^+e^-)$	1	1.0+/-0.0001
$A^{FB}(K^* l^+ l^-)$:s_0(zero crossing)		0.162+/-0.008 (5%)
$A^{FB}(K^* l^+ l^-)$:CP asymmetry	~0	
CPV in mixing: (|q/p|)	~1	
Very rare decays: $B\to\mu^+\mu^-$ $B\to\tau^+\tau^-$		
$B\to X\tau^+\nu$: Rate and τ polarization		~2%

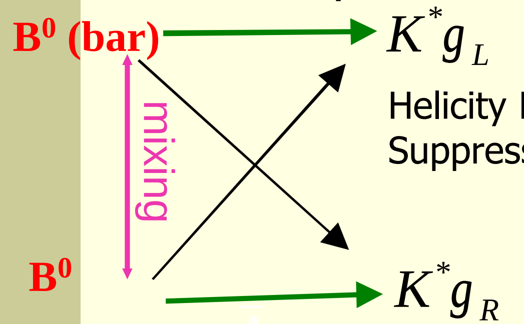
$B \rightarrow K_s \pi^0 \gamma$



The dominant SM amplitude gives: $b \rightarrow s g_{L}$, $b(bar) \rightarrow s g_{R}$

NP can modify helicity structure: e.g. LR symmetry, higgs in loops

Use TDCP to probe the helicity structure: (**but limited to $K^{*0} \rightarrow K_s\, p^0$** ~ 11%)



Helicity Flip
Suppressed by m_s/m_b

→ Expect:

$$S_{K^* g} = 2\frac{m_s}{m_b}\sin 2b \approx 0$$

~**0.042**

David Atwood, Michael Gronau, Amarjit Soni (1997)

PRL **79** ,185(1997)

	$0.1\ ab^{-1}$	$2\ ab^{-1}$	$5\ ab^{-1}$	$10\ ab^{-1}$	$50\ ab^{-1}$	LHCB	BTEV
$S(K_s \pi^0 \gamma)$	0.6	0.14	0.09 (0.12)	0.06	0.04(?)	X	X

Soni: m_s is the "current" mass: (m_s ~150 +/- 50 MeV), m_b ~5 GeV

→Theory error ~0.01 to 0.02 (??) (~30% of SM value of S)

CP Violation in b→s penguins

Rare Decays – New Physics – *CPV (?)*		e^+e^- Precision			1 Year Precision	
Measurement	**Goal**	**3/ab**	**10/ab**	**50/ab**	**LHC*b***	***B*TeV**
$S(B^0 \to \phi K_S)$	SM: <0.25 (0.05)	*0.08*	*0.05*	*0.02 (?)*	*0.08?*	*0.04?*
$S(B^0 \to \phi K_S + \phi K_L)$	SM:<0.25 (0.05)					
$S(B \to \eta' K_S)$	SM:<0.3 (0.1)	*0.06*	*0.03*	*0.01*		
$S(B \to K_S \pi^0)$	SM:<0.2 (0.15)	*0.08*	*0.05*	*0.04 (?)*		
$S(B \to K_S \pi^0 \gamma)$	SM:<0.1	*0.11*	*0.06*	*0.04 (?)*		
$A_{CP}(b \to s\gamma)$	SM: <0.6%	2.4%	1%	0.5% (?)		
$A_{CP}(B \to K^*\gamma)$	SM: <0.5%	0.59%	0.32%	0.14%	-	-
CPV in mixing ($\|q/p\|$)		<0.6%			X	X

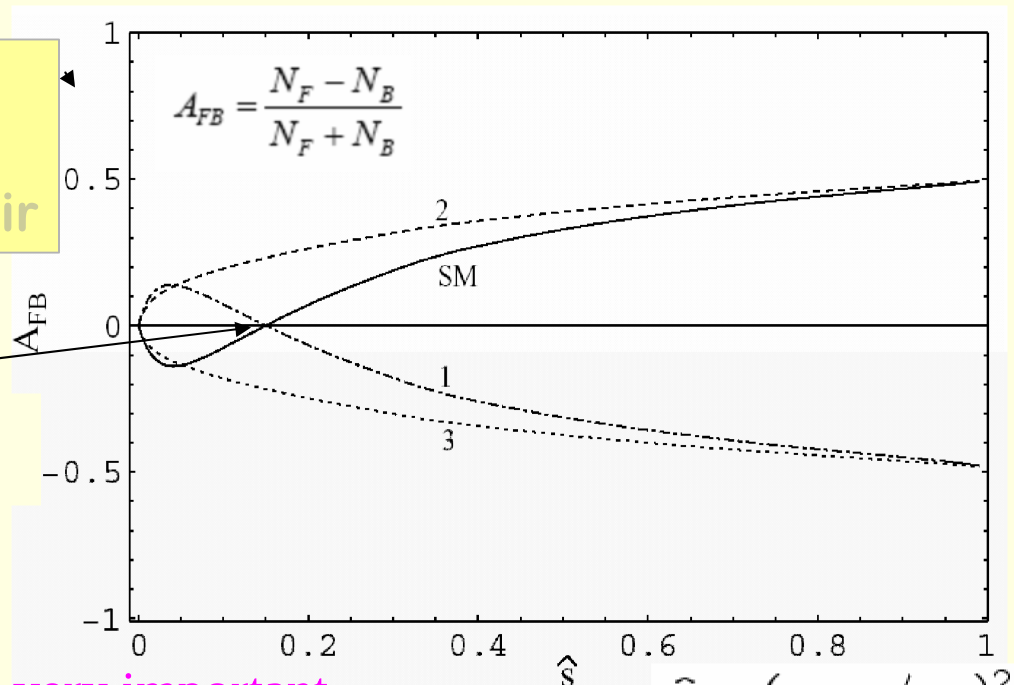
NP observables in s/d l+l- decay

A_{cp}(B→s $l^+ l^-$)	**SM:** <0.5% (0.05% for K* l^+ l)
A_{cp}(B→d $l^+ l^-$)	**SM:** $^-$~(4.4+/-4)%
B(B→sm^+m^-)/B(B→se^+e^-)	**SM:** ~1
A^{FB}(K*$l^+ l^-$):s_0(zero crossing)	SM predicts with ~5% accuracy
A^{FB}(K*$l^+ l^-$):CP asymmetry	Very small in SM

In dilepton rest frame
N_F = when l^+ along b dir
N_B = when l^+ opposite b dir

SM:
S_0 NNLO error = 5%

S_0 = 0.162+/-0.008 ~ C7/C9



$\hat{s} = (m_{l^+l^-}/m_b)^2$

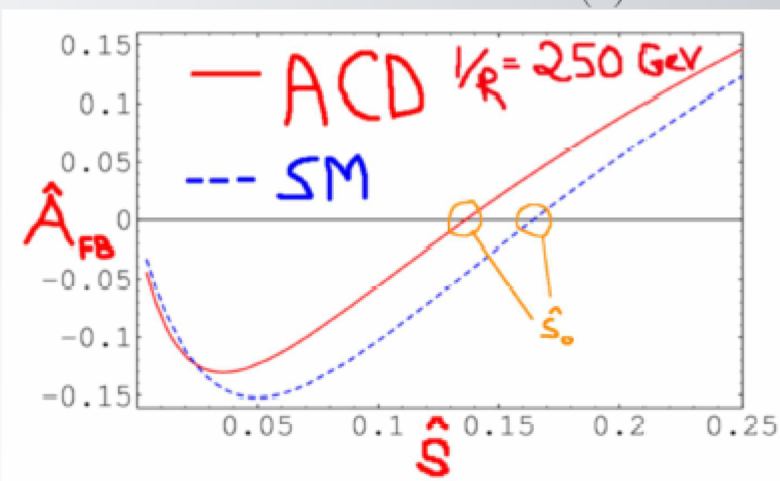
In SM: A^{CP}_{FB}~ 0
Determination of sign of AFB very important.

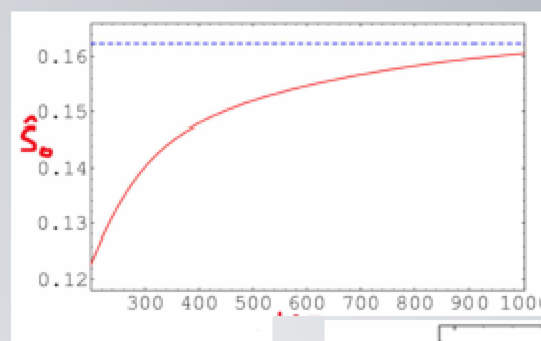
Universal extra dimension effects

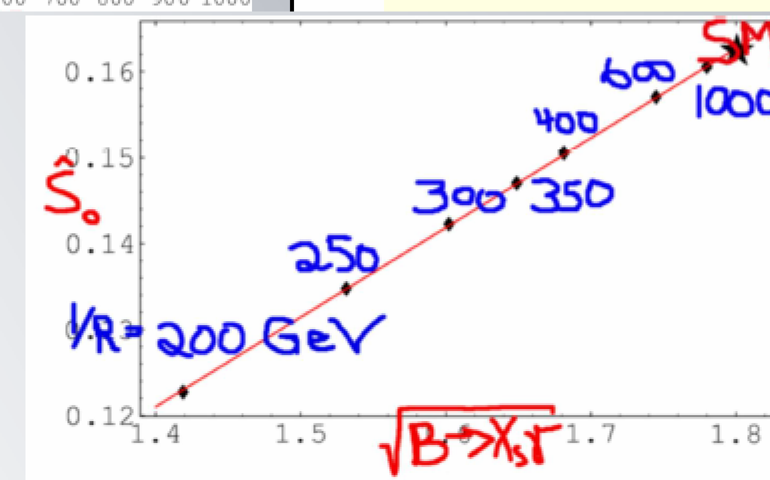
Forward Backward Asymmetry

$$A_{\rm FB}(\hat{s}) = \frac{1}{\Gamma(b\to ce\bar{\nu})} \int_{-1}^{1} d\cos\theta_l \frac{d^2\Gamma(b\to s\mu^+\mu^-)}{d\hat{s}d\cos\theta_l} {\rm sgn}(\cos\theta_l)$$

$$A_{\rm FB}(\hat{s}) \approx -3\tilde{C}_{10} \frac{\left[\hat{s}{\rm Re}\,\tilde{C}_9^{\rm eff}(\hat{s}) + 2C_{7\gamma}^{(0)\rm eff}\right]}{U(\hat{s})}$$







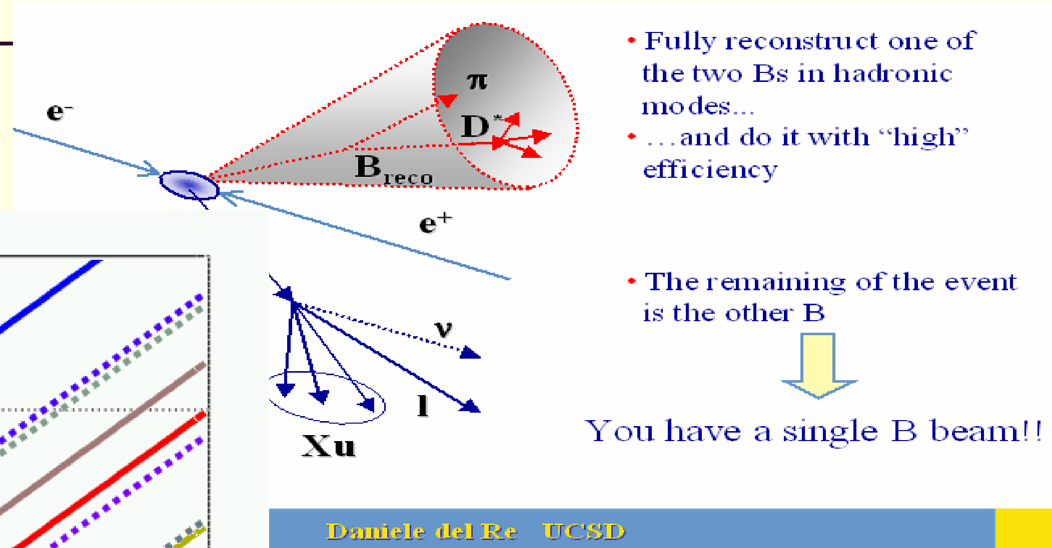
$\hat{s}_0^{NLO} = 0.142 \pm 0.02$ Ali,Mannel,Morozumi

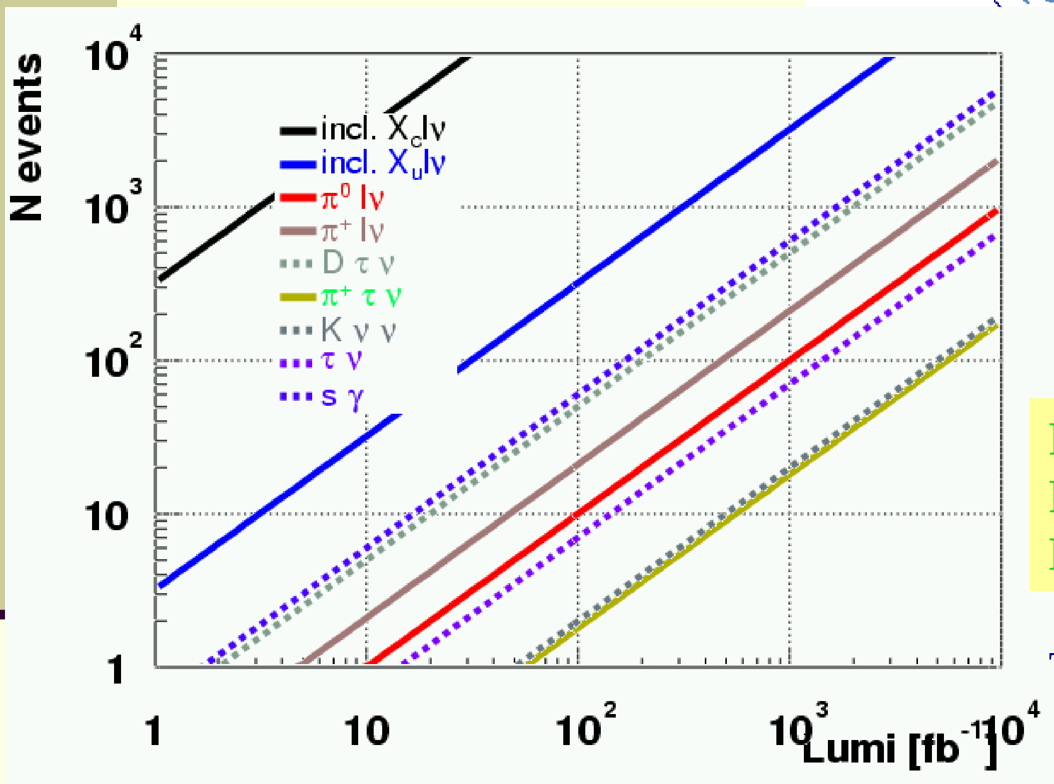
$\hat{s}_0^{NNLO} = 0.162 \pm 0.008$ Ghinculov,Hurth,Isidori,Ya
Asatrian,Greub,Walker,Bier

$\hat{s}_0^{ACD} = 0.146 \pm 0.01$ $1/R = 300\text{GeV}$

Andreas Weiler, 2nd

Recoil Physics





Recoil cinematics well known
Recoil flavor and charge is determined
Event closure needed with neutrinos

The final efficiency is ~0.4% (per bb_{bar} pair)

$\Rightarrow$ ~4000 B/fb^{-1} (at 30% purity)

$\Rightarrow$ 1500 B^0/fb^{-1}

$\Rightarrow$ 2500 B^+/fb^{-1}

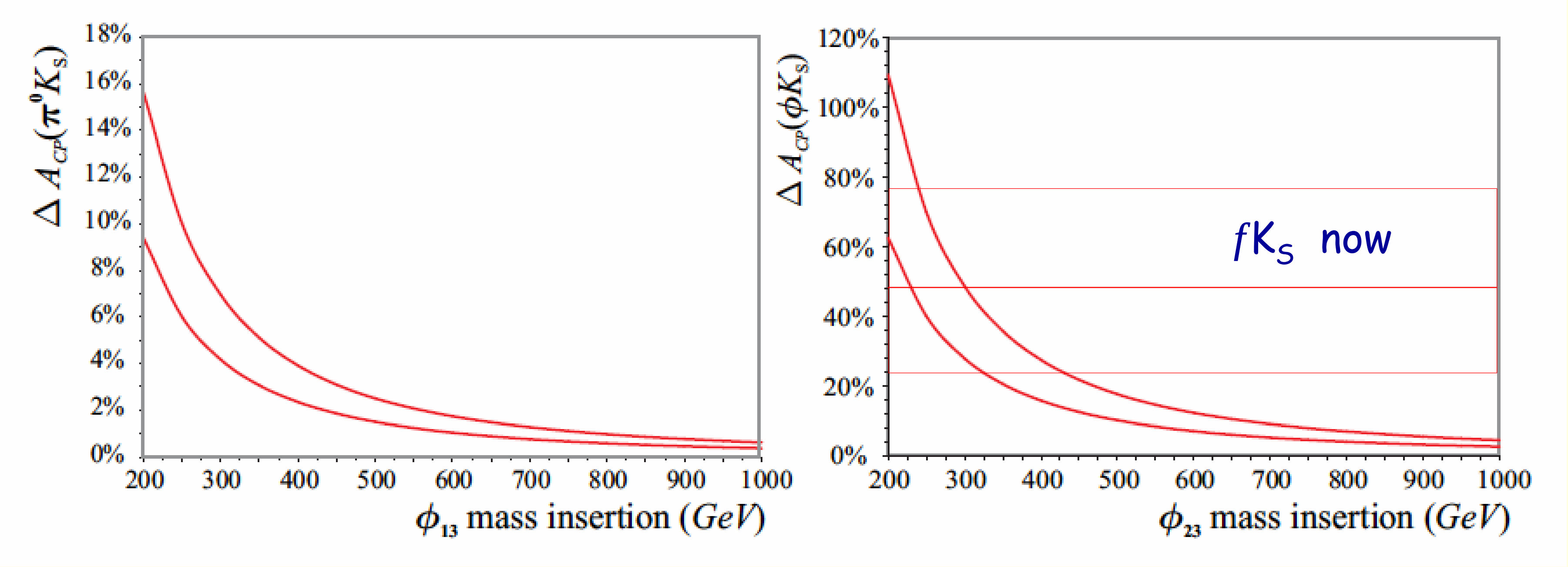
> 10^7 recoil Bs in 10ab^{-1}

My personal conclusions

- B Physics is far from over
  - Unitarity Triangle precision measurements mostly done by the end of the current program
    - At around 1-2 GB-pairs theoretical errors begin to dominate
  - NP will leave its marks in low energy processes:
    - although LHC will hopefully measure masses, the determination of couplings and phases will require clean, precise measurements at B Factories and LC
    - hadron machines do play an important role, but many channels are out of reach to them: B_s and very rare processes are their atout
    - large samples at e+e- machines (10-50 GB-pairs) are needed to reach the required sensitivity
- B Physics is not too popular these days (at least in the US) …
  - BTeV has been "terminated"
  - SLAC has decided to focus on the LC effort
  - but upgrade program still vigorously pursued at KEKB/BELLE
    - although KEKB/SuperBelle upgrade may not be ambitious enough
  - → Joint workshop at Hawaij, April 20-22
- … but in fact is still a very powerful laboratory.
  Strong endorsement of the Super B Factory by the community.

BACKUP

Sensibility to NP



Ciuchini, Franco, Martinelli, Masiero, & Silvestrini

Theoretical uncertainties

Measurement (in SM)	Theoretical limit	Present error
$B \to \psi K_S \ (\beta)$	$\sim 0.2^\circ$	1.6°
$B \to \phi K_S,\ \eta^{(\prime)} K_S, \ldots\ (\beta)$	$\sim 2^\circ$	$\sim 10^\circ$
$B \to \pi\pi,\ \rho\rho,\ \rho\pi \ (\alpha)$	$\sim 1^\circ$	$\sim 15^\circ$
$B \to DK \ (\gamma)$	$\ll 1^\circ$	$\sim 25^\circ$
$B_s \to \psi\phi \ (\beta_s)$	$\sim 0.2^\circ$	—
$B_s \to D_s K \ (\gamma - 2\beta_s)$	$\ll 1^\circ$	—
$\lvert V_{cb}\rvert$	$\sim 1\%$	$\sim 3\%$
$\lvert V_{ub}\rvert$	$\sim 5\%$	$\sim 15\%$
$B \to X \ell^+ \ell^-$	$\sim 5\%$	$\sim 25\%$
$B \to K^{(*)} \nu\bar{\nu}$	$\sim 5\%$	—

Ligeti, ICHEP 2004

Unitarity Triangle - Sides

Unitarity Triangle - Sides		e^+e^- Precision			1 Year Precision	
Measurement	**Goal**	**3/ab**	**10/ab**	**50/ab**	**LHC*b***	***B*TeV**
V_{ub} (inclusive)	syst =5-6%	2%	1.3%			
V_{ub} (exclusive) (π,ρ)	syst=3%	5.5%	3.2%			
V_{cb} (inclusive)						
V_{cb} (exclusive)						
f_b $\mathcal{B}(B\rightarrow\mu\nu)$	SM: $\mathcal{B}$~5×10^{-7}					
f_b $\mathcal{B}(B\rightarrow\tau\nu)$	SM: $\mathcal{B}$~5×10^{-5}	3.3 σ	6 σ	13σ f_b to ~10%		
V_{td}/V_{ts} ($\rho\gamma/K^*\gamma$)	Theory 12%	~3%	~1%			

Unitarity Triangle - Angles

Unitarity Triangle - Angles	e^+e^- Precision			1 Year Precision	
Measurement	**3/ab**	**10/ab**	**50/ab**	**LHC*b***	***B*TeV**
α (ππ) ($S_{\pi\pi}$, B→ ππ *BR*'s+ isospin)	6.7°	3.9°	2.1°	-	-
α (ρπ) (Isospin, Dalitz) (syst ≥3°)	3, 2.3°	1.6, 1.3°	1, 0.6°	2.5° -5°	4°
α (ρρ) (penguin, isospin, stat+syst)	2.9°	1.5°	0.72°		
β (*J*/ψ K_S) (all modes)	0.3°	0.17°	0.09°	0.57°	0.49°
γ (*B*→$D^{(*)}$*K*) (ADS)		2-3°		~10°	<13°
γ (all methods)		1.2-2°		7°	8°

Theory: α ~1° β ~ 0.2° γ <<1°

More Rare decays precision

Rare Decays – New Physics		e^+e^- Precision			1 Year Precision	
Measurement	**Goal**	**3/ab**	**10/ab**	**50/ab**	**LHC*b***	***B*TeV**
$\Gamma(b \to dg) / \Gamma(b \to sg)$					-	-
$\mathcal{B}(B \to D^{(*)}\tau\nu)$	SM: $\mathcal{B}$: 8x10^{-3}	10.2%	5.6%	2.5%	-	-
$\mathcal{B}(B \to s\nu\nu)$ $(K^{-,0}, K^{*-,0})$	SM:Theory ~5% 1 excl: 4x10^{-6}			~3σ	-	-
$\mathcal{B}(B \to invisible)$		<2x10^{-6}	<1x10^{-6}	<4x10^{-7}	-	-
$\mathcal{B}(B_d \to \mu\mu)$		-	-		1/2	1/2
$\mathcal{B}(B_d \to \tau\tau)$		-	-		-	-
$\mathcal{B}(\tau \to \mu\gamma)$			<10^{-8}		-	-

$b \rightarrow s l^+ l^-$ precision

New Physics – $K l^+ l^-$, $s l^+ l^-$		e^+e^- Precision			1 Year Precision	
Measurement	**Goal**	**3/ab**	**10/ab**	**50/ab**	**LHC*b***	***B*TeV**
$\mathcal{B}(B \longrightarrow K\mu^+\mu^-) / \mathcal{B}(B \longrightarrow K e^+ e^-)$	SM: 1	~8%	~4%	~2%	X	X
$A_{CP}(B \longrightarrow K^* l^+ l^-)$ (all) (high mass)	SM: < 0.05%	~6% ~12%	~3% ~6%	~1.5% ~3%	~1.5% ~3% (?)	~2% ~4% (?)
$A^{FB}(B \longrightarrow K^* l^+ l^-) : s_0$ $A^{FB}(B \longrightarrow K^* l^+ l^-) : A_{CP}$	SM: ±5%	~20%	~9%	5%	~12%	
$A^{FB}(B \rightarrow s l^+ l^-) : s_0$		27%	15%	6.7%		
$A_{FB}(B \rightarrow s l^+ l^-) : C_9, C_{10}$		36-55%	20-30%	9-13%		