To SuperB or not to SuperB ?

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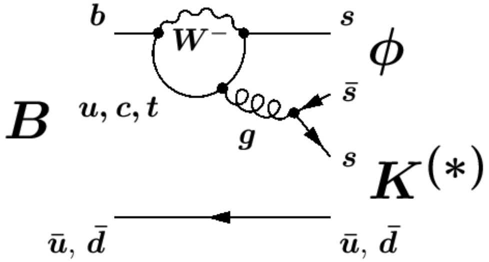
IFAE, Torino,
14-16 Aprile 2004

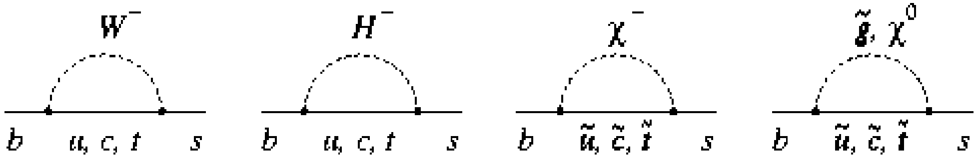
That is the SuperQuestion !

- What:
  - PEP-II/Babar and KEK-B/Belle operate currently at a luminosity $\approx 10^{34}$ cm^{-2}s^{-1} with
  - 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. & A_{CP}
  - 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} mainly because of backgrounds
- When:
  - in the era of LHCb, BTeV and LHC experiments.
  - Competitiveness and complementarity with hadron machines is a real issue.

The Physics Menu

- UT 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





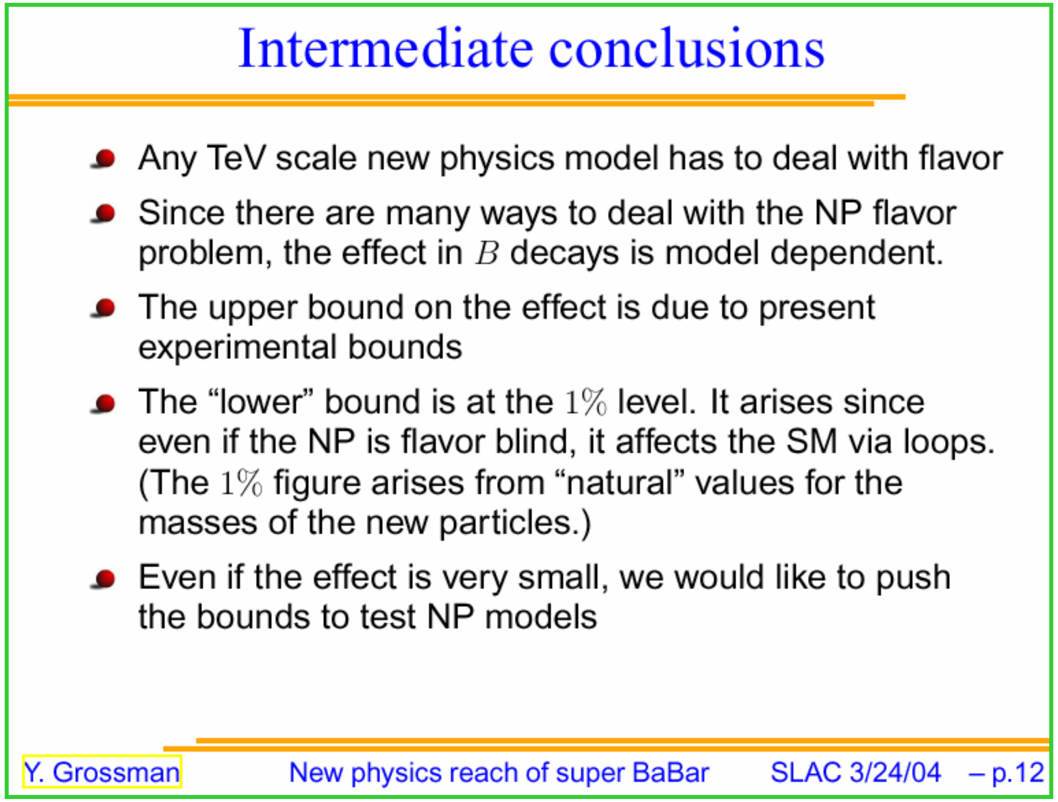
  - CPV Asymmetries in $B \to \phi K_s$, $K_s\pi^0$ compared with $\sin 2\beta$.
  - $\sin 2\alpha$ measurement with $B \to \pi\pi$ and $\rho\rho$; direct CPV
  - γ measurement with $B \to DK$ or similar channels.
- Rare decays
  - Exclusive and inclusive $b \to s\gamma$ BFs, direct asymmetries, photon helicities
  - Exclusive and inclusive $b \to s l^+ l^-$ BFs, A_T, A_L, A_{FB}, *CP* asymmetries
  - *B* decays to states with large missing energy, such as $B_{(d,s)} \to \tau^+\tau^-$, $B \to K^{(*)}\nu\nu$, $b \to s\nu\nu$, $B \to D^{(*)}\tau\nu_\tau$, $B \to X_C\tau\nu_\tau$

NP in B physics

- In most cases the rates, particularly in hadronic decays, suffer from large theory uncertainties and not considered suitable for NP studies.
- The best NP observables in B physics seem to be:
  - Time-dependent CPV asymmetries in b→sss(bar), b→s dd(bar), and b→sγ
  - Direct CP asymmetries in some cases (e.g. b->s/dγ -maybe)
  - Ratio of rates (maybe)
  - b→sl+l-: CP asym., Forward-Backward asymmetry & its CP asym.
  - Rate of very rare decays B→l+l-
  - B→X$\tau\nu$:rate and polarization
  - Other near zeros: e.g. CPV in mixing

Why – The Physics Case

- Find NP effects in flavour physics.
  - Strong endorsement from the B experts in the theory community for the potential of direct NP studies with super b-factories.
  - What is the scale of NP ?
    - Λ_{NP} is 1 TeV from hierarchy problem.
    - …But Λ_{NP} >1000TeV from flavor bounds.
  - Model dependance is unavoidable.
  - Theoretical uncertainty can be crucial.



Intermediate conclusions

- Any TeV scale new physics model has to deal with flavor
- Since there are many ways to deal with the NP flavor problem, the effect in B decays is model dependent.
- The upper bound on the effect is due to present experimental bounds
- The “lower” bound is at the 1% level. It arises since even if the NP is flavor blind, it affects the SM via loops. (The 1% figure arises from “natural” values for the masses of the new particles.)
- Even if the effect is very small, we would like to push the bounds to test NP models

Y. Grossman New physics reach of super BaBar SLAC 3/24/04 – p.12

From Matthias Neubert at the Hawaii Workshop

- UT physics is hard
- Consider how difficult is has been (and still is) to determine the 4 parameters of the CKM matrix, for which there is no background
- With New Physics there is a SM background, whose subtraction in general introduces large hadronic uncertainties

- In some cases, one can directly probe certain types of New Physics operators (e.g., “electroweak” or trojan penguins)
  - $B \rightarrow \Phi K_s$ and $B \rightarrow \pi K_s$ are examples
- In other cases such as $B \rightarrow VV$ or $B \rightarrow K^* \gamma$, one probes specific operators with non-standard chirality

- Precisely why we don’t know what to expect and what to look for, the breadth of the Super-B program will guarantee success
- Discovery of new particles at the LHC would help to interpret these finding and guide further studies
- Even finding no effect in some studies would provide important clues

Ingredients of the physics case

- 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?
- Comparison with sensitivities from the planned hadron collider experiments.
  - Can the super-B measurements compete and/or provide better information than Hadron experiments?
- If possible, range of expected (NP-SM) values for these observables given the physics landscape in the LHC era (2010-2012?).
  - Very hard to do. What changes if NP is (or is not) discovered at LHC ?

Sources

- A lot of activity has been going on in the past couple of years
  - Study groups, Workshops, Theorists involvement
  - Many detailed, in-depth studies.
- Try to summarize numbers and conclusions from
  - Several Belle workshops
    `belle.kek.jp/workshops`
  - Two Babar workshops
    `www.slac.stanford.edu/BFROOT/www/Organization/1036_Study_Group`
  - Hawaii joint workshop
    `www.phys.hawaii.edu/~superb04`
- In the following tables:
  - several empty spaces
    - Different assumptions, missing studies, etc.
  - LHCb and BTeV numbers always come from their presentations
  - Updating…

Observable	SM: reference point	SM: Expected range
Time dependent CP Measurements $b \rightarrow sss(bar)$ & $b \rightarrow sdd(bar)$ & $b \rightarrow s\gamma$		
$S(B \rightarrow \phi K_s)$	$\sim \mathrm{Sin}2\beta$	$\|\sin 2\beta - S\| < 0.25$
$S(B \rightarrow \eta' Ks)$	$\sim \mathrm{Sin}2\beta$	$\|\sin 2\beta - S\| < 0.3$
$S(B \rightarrow K_s \pi^0)$	$\sim \mathrm{Sin}2\beta$	$\|\sin 2\beta - S\| < 0.2$
$S(B \rightarrow K^{*0} \gamma)$ (with $K^* \rightarrow K_s \pi^0$)	$\sim 2(m_{s/}m_b)\ \mathrm{Sin}2\beta$	$\|S\| < 0.1$ (?)
$b \rightarrow s/d\gamma$ & $b \rightarrow s/d$ $(l^+ l^-)$: Rates and $A_{cp(dir)}$		
$Acp(b \text{->} s\ \gamma)$ $[Acp(b \text{->} d\ \gamma)]$		0.6% [-16%] (?)
$[\Gamma(B \rightarrow K^{*}+\ \gamma) - \Gamma(B \rightarrow K^{*}0\ \gamma)]/(\mathrm{sum})$	~0 (isospin breaking)	5 to 10% (?)
$\Gamma(b \rightarrow d\gamma)/\ \Gamma(b \rightarrow s\gamma)$	|Vtd/Vts| (from mixing)	
$A_{cp}(B \rightarrow s\ l^+ l^-)$ $A_{cp}(B \rightarrow d\ l^+ l^-)$		<0.5% (0.05% for $K^*\ l^+ l^-$) ~(4.4+/-4)%
$B(B \rightarrow K\mu^+\mu^-)/B(B \rightarrow Ke^+e^-)$	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: $B \rightarrow \mu^+\mu^-$ $B \rightarrow \tau^+\tau^-$		
$B \rightarrow X\tau^+\nu$: Rate and τ polarization		~2%

Theoretical uncertainties

Measurement	Theoretical error
$B \to \psi K_S\ (\beta)$	$< 1\%$
$B \to \phi K_S,\ B \to \eta' K_S,\ \ldots\ (\beta)$	$\sim 5\%$
$B \to DK\ (\gamma)$	$\sim 10^{-3}$
$B \to \pi\pi,\ B \to \rho\pi,\ B \to \rho\rho\ (\alpha)$	$\sim 5\%$
V_{cb}	$\sim 1\%$
V_{ub}	$\sim 5\%$
$b \to s\gamma$	$\sim 5\%$
$B \to X\ell^+\ell^-$	$\sim 5\%$
$B \to K^*\nu\bar{\nu}$	$\sim 5\%$

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 B($B\to\mu\nu$)	SM: B~5x10^{-7}					
f_b B($B\to\tau\nu$)	SM: B~5x10^{-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**
$\alpha\,(\pi\pi)$ ($S_{\pi\pi}$, $B\to\pi\pi$ BR's+ isospin)	6.7°	3.9°	2.1°	-	-
$\alpha\,(\rho\pi)$ (Isospin, Dalitz) (syst ≥3°)	3, 2.3°	1.6, 1.3°	1, 0.6°	2.5° -5°	4°
$\alpha\,(\rho\rho)$ (penguin, isospin, stat+syst)	2.9°	1.5°	0.72°		
$\beta\,(J/\psi K_S)$ (all modes)	0.3°	0.17°	0.09°	0.57°	0.49°
$\gamma(B\to D^{(*)}K)$ (ADS)		2-3°		~10°	<13°
γ(all methods)		1.2-2°			

Theory: α~5%, β~ 1%, γ~0.1%

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**
$S(B^0\rightarrow\phi K_S)$	SM: <0.25	16%	8.7%	3.9%	16%?	7%?
$S(B^0\rightarrow\phi K_S+\phi K_L)$	SM:<0.25					
$S(B\rightarrow\eta' K_S)$	SM:<0.3	5.7%	3%	1%		
$S(B\rightarrow K_S\pi^0)$	SM:<0.2	8.2%	5%	4% (?)		
$S(B\rightarrow K_S\pi^0\gamma)$	SM:<0.1	11.4%	6%	4% (?)		
$A_{CP}(b\rightarrow s\gamma)$	SM: <0.6%	2.4%	1%	0.5% (?)		
$A_{CP}(B\rightarrow K^*\gamma)$	SM: <0.5%	0.59%	0.32%	0.14%	-	-
CPV in mixing ($\lvert q/p\rvert$)		<0.6%			X	X

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**
$\Gamma(b\to d\gamma)$ / $\Gamma(b\to s\gamma)$					-	-
$B(B\to D^{(*)}\tau\nu)$	SM: B: $8x10^{-3}$	10.2%	5.6%	2.5%	-	-
$B(B\to s\nu\nu)$ $(K^{-,0}, K^{*-,0})$	SM:Theory ~5% 1 excl: $4x10^{-6}$			~3σ	-	-
$B(B\to invisible)$		$<2x10^{-6}$	$<1x10^{-6}$	$<4x10^{-7}$	-	-
$B(B_d\to\mu\mu)$		-	-		1/2	1/2
$B(B_d\to\tau\tau)$		-	-		-	-
$B(\tau\to\mu\gamma)$			$<10^{-8}$		-	-

b→sl$^+$l$^-$ precision

New Physics – Kl$^+$l$^-$, sl$^+$l$^-$		e^+e^- **Precision**			**1 Year Precision**	
Measurement	**Goal**	**3/ab**	**10/ab**	**50/ab**	**LHC*b***	***B*TeV**
B($B \longrightarrow K\mu^+\mu^-$) /B($B \longrightarrow Ke^+e^-$)	SM: 1	~8%	~4%	~2%	X	X
$A_{CP}(B \longrightarrow K^* \lambda^+\lambda^-)$ (all) (high mass)	SM: < 0.05%	~6% ~12%	~3% ~6%	~1.5% ~3%	~1.5% ~3% (?)	~2% ~4% (?)
$A^{FB}(B \longrightarrow K^*\lambda^+\lambda^-) : s_0$ $A^{FB}(B \longrightarrow K^*\lambda^+\lambda^-) : A_{CP}$	SM: ±5%	~20%	~9%	9%	~12%	
$A^{FB}(B \rightarrow s\lambda^+\lambda^-) : \hat{s}_0$		27%	15%	6.7%		
$A_{FB}\,(B \rightarrow s\lambda^+\lambda^-) : C_9\,,\,C_{10}$		36-55%	20-30%	9-13%		

Pattern of Deviation from SM Predictions

Unitarity triangle Rare decay

	B_d- unitarity	ε_K	Δ m(Bs)	B->ϕKs	B->Msγ indirect CP	b->sγ direct CP
mSUGRA	closed	small	small	small	small	small
SU(5) SUSY, GUT + ν_R (degenerate)	closed	large	small	small	small	small
SU(5) SUSY, GUT + ν_R (nondegenerate)	closed	small	large	large	large	small
U(2) Flavor symmetry	large	large	large	large	large	sizable

Y.Okada

- In most cases SM predictions are sufficiently under control as to motivate these highly sensitive measurements
- NP effects on B and τ physics are model-dependent
  - In this context, model-dependent is not a dirty word
  - In fact, the pattern of New Physics effects in the flavor sector is diagnostic of the type of SUSY-breaking

The international scene

- KEK-B/Belle: A letter of intent has been put forward in February 2004 for a Super KEK-B machine and a Super Belle detector.
  - Luminosity ranges from 1×10^{35} to 5×10^{35}
  - Detector upgrades include:

•Silicon striplets
•Small cell drift chamber
•Pure CsI calorimeter endcap

- PEP-II/Babar: A “Roadmap committee” is preparing a report summarizing discussions and studies done over the past couple of years.
  - Current direction is to propose a “upgradable platform”:
    - Start with 2×10^{35} machine and detector, but already include an upgrade path to $7\text{-}8\times10^{35}$ for the $10\,\mathrm{ab}^{-1}$/year goal.
  - Detector upgrades include

•Silicon striplets → thin pixels
•Small cell drift chamber → all silicon tracker
•Pure CsI calorimeter endcap → Liquid Xenon or LSO xtals

  - Base detector possible with current technology, while full upgrade will require significant R&D

The OSBF Principle

- a.k.a. “One Super B Factory”
- It is unlikely that the HEP community has enough resources to build more than one Super B Factory
  - Encourage collaboration between Babar and Belle communities (and others) to join efforts
  - Joint workshop in January 2004 (Hawaii), second of a series, more to come
    http://www.phys.hawaii.edu/~superb04/
- Approval process lengthy
  - Connected to global funding political decisions:
    - ITER, NLC
  - Unlikely to have serious funds before 2008
  - Only if there is overall community agreement and support

Conclusion and outlook

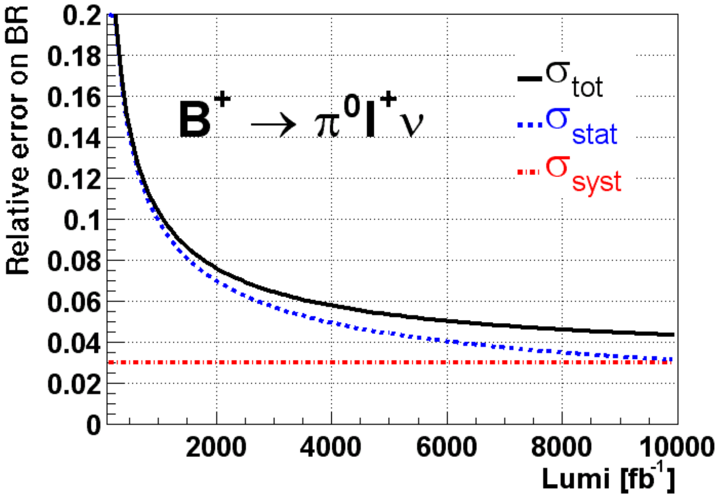
- A $10ab^{-1}$/year Super B Factory has a real discovery potential
  - NP effects in loops are significant and accessible
  - In the LHC era
    - The LHC experiments will measure the NP masses
    - The B experiments will measure couplings
  - Precision UT measurements can help sort out things
- It is fully competitive with LHCB/BTeV
  - No B_s, but same or better precision with almost anything else
  - Very clean sample (including recoil technique)
  - Accessibility of channels with γ, ν, π^0
- Are there enough resources ?
  - Need to design new collaboration form between Belle and Babar
  - External input/additions are welcome

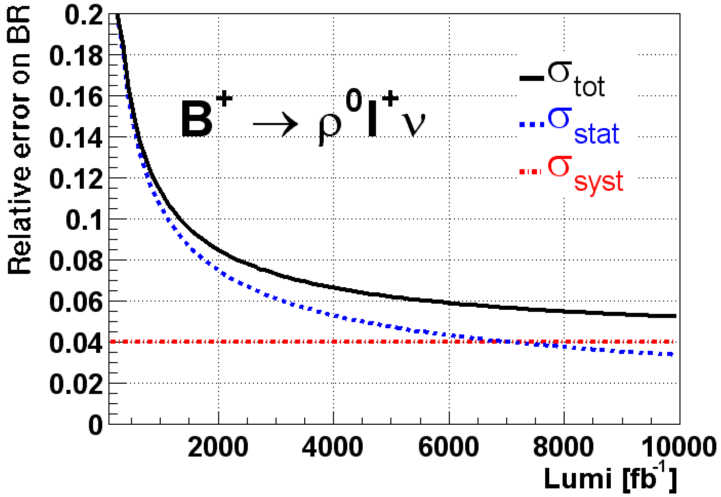
--- Detailed slides on physics processes ---

Exclusive Charmless Decays

BF measurement	S/B	σ(tot) $500 fb^{-1}$	σ(tot) $10 ab^{-1}$
$B \to \pi^0 l\nu$	>10	~14%	~4%
$B \to \rho^0 l\nu$	~4	~15%	~5%
$B \to \omega l\nu$	~2.5	~16%	~6%
$B \to \pi^+ l\nu$	>10	~11%	~3%
$B \to \rho^+ l\nu$	~2	~15%	~6%

*Assumes negligible systematic error from FF and uses rough estimate of exp. syst. error





$B^+ \to \tau^+\nu_\tau$

Datta

- Measurement of $|V_{ub}|$ with $B^+ \to \ell^+\nu_\ell$
  - ▷ Take lQCD for f_B, then

$$\mathcal{B}(B^+ \to \mu^+\nu_\mu) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

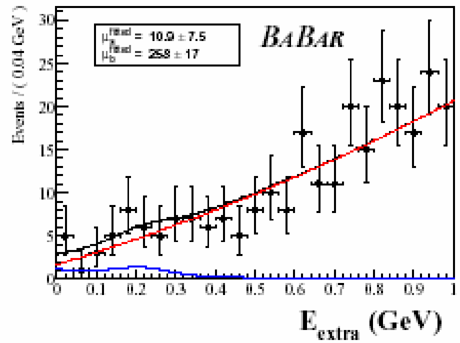
  - ▷ SM: $\sim 10^{-4}$ (for τ)
  - ▷ Recoil
  - ▷ Measure E_{extra}
- SuperBABAR:
  - ▷ tighten cuts
  - ▷ better tag

Expect at 2 ab^{-1}:

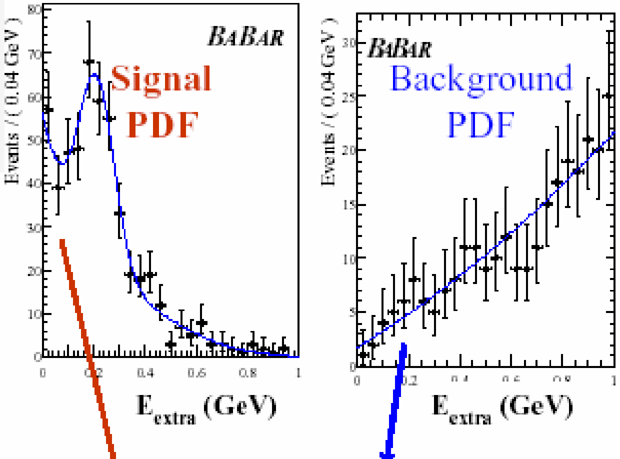
$S/B \sim 120/1000$

significance $> 4\sigma$

Physics Results: Semi-Leptonic Tag



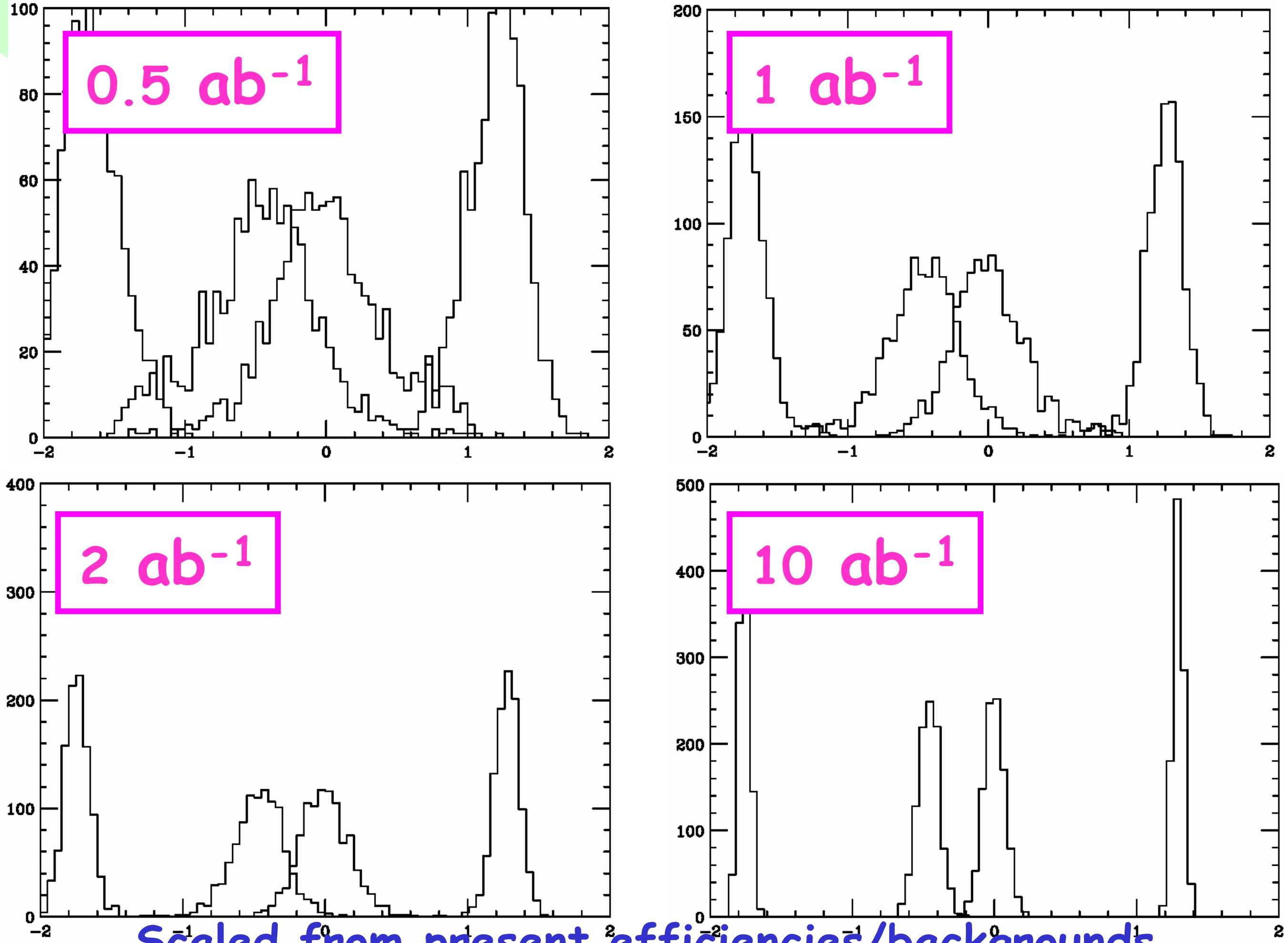
Fit Parameter	Fitted Value
Signal	10.9±7.5
Background	258.1±17.4



Signal input	Signal fitted	Bkg. Input	Bkg. fitted
0	0.05±7.30	269	268.96 ±7.30
5	5.13 ±7.89	269	268.88 ±7.90
10	10.10 ±8.29	269	260.90 ±8.28
20	19.93 ±9.04	269	269.08 ±9.03
30	30.11 ±9.48	269	268.88 ±9.49
40	40.06 ±10.14	269	268.95 ±10.14

10/22/2003 Mousumi Datta, UW-Madison 10

Toy MC Study for α/ϕ_2



Scaled from present efficiencies/backgrounds

***BABAR* Long-Range Task Force**

Assumes

$$BF\left(B^0,\bar{B}^0 \rightarrow \pi^0\pi^0\right)$$

$$= 2.5, 1.5 \times 10^{-6}$$

***BABAR* meas**

$BF(B0 \rightarrow \pi^0\ \pi^0) =$
$2.1 \pm 0.6 \pm 0.3 \times 10^{-6}$

Isospin analysis in $\pi\pi$ channel

γ/ϕ_3 Measurement

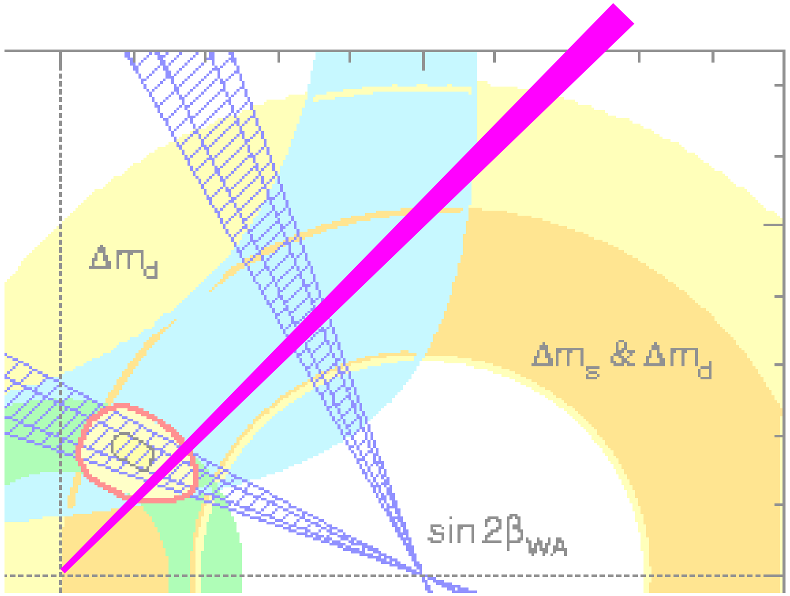
$\sin^2\gamma$ in $B \to D^0K$ (GW, ADS)

Recent developments

- $B \to D^0_{(CP)}K$
- $B \to D^0_{(non\text{-}CP)}K$, $D^0K\pi$

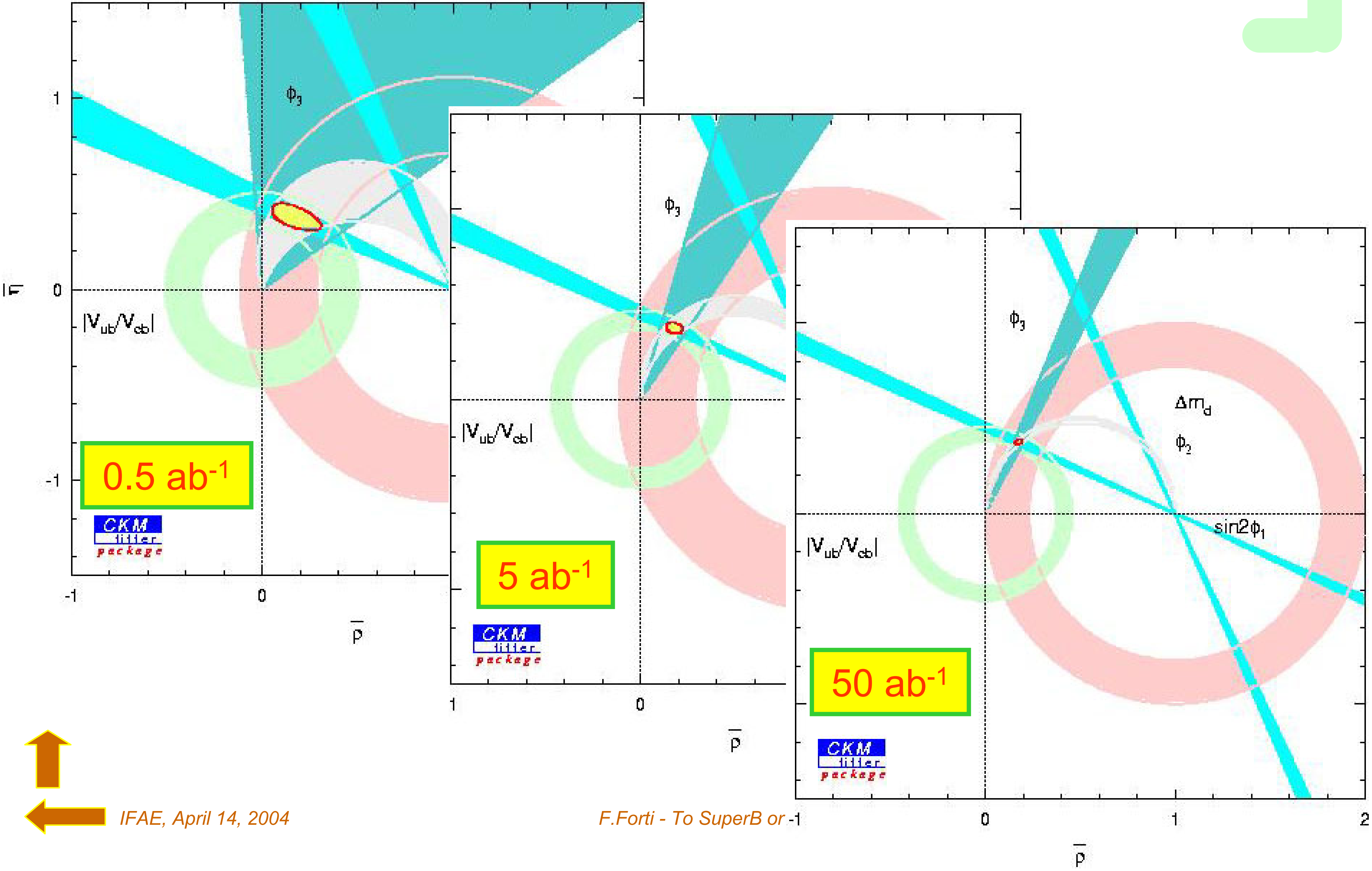
$\sin(2\beta+\gamma)$

- $B^0 \to D^{(*(*))}\pi^{(*)}$
- $B^0 \to DK\pi$
- D^0K^0

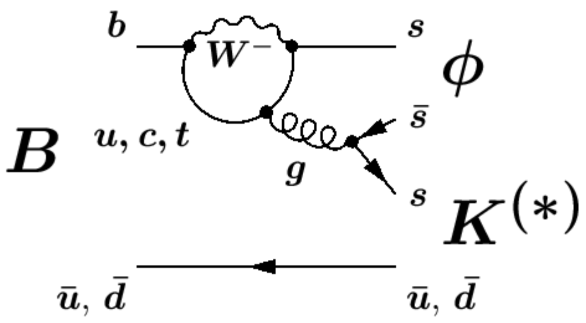


- Use all methods
  - Will measure γ to ~ 2° (%) (stat) or less at 10 ab^{-1}
  - Only $\gamma \to \gamma+\pi$ ambiguity is left
    - Excluded theoretically?
  - The error is so small that ambiguities won't matter

Error on angles



Intriguing Hint from Penguins?

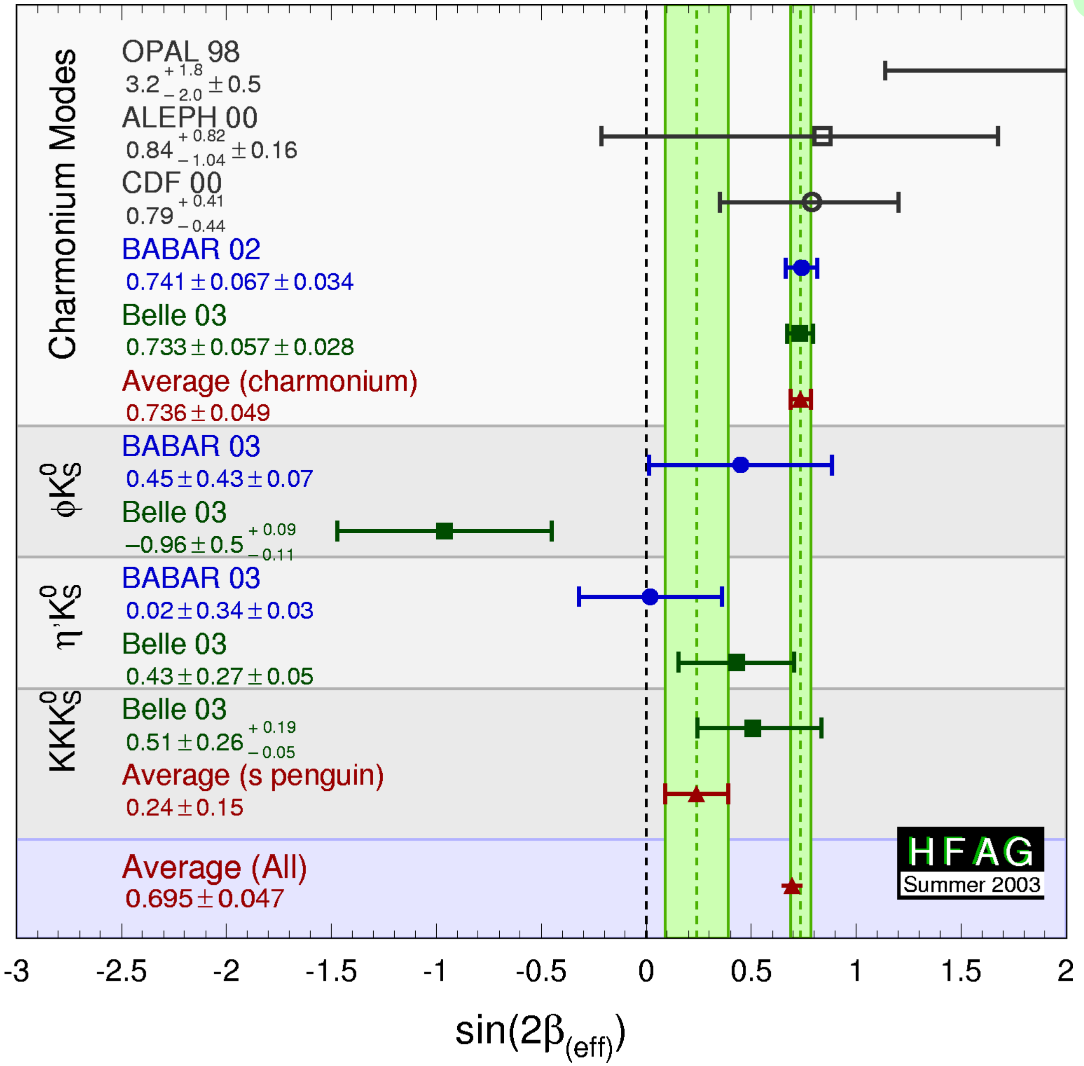


Present average for $b \to s\bar{s}s$

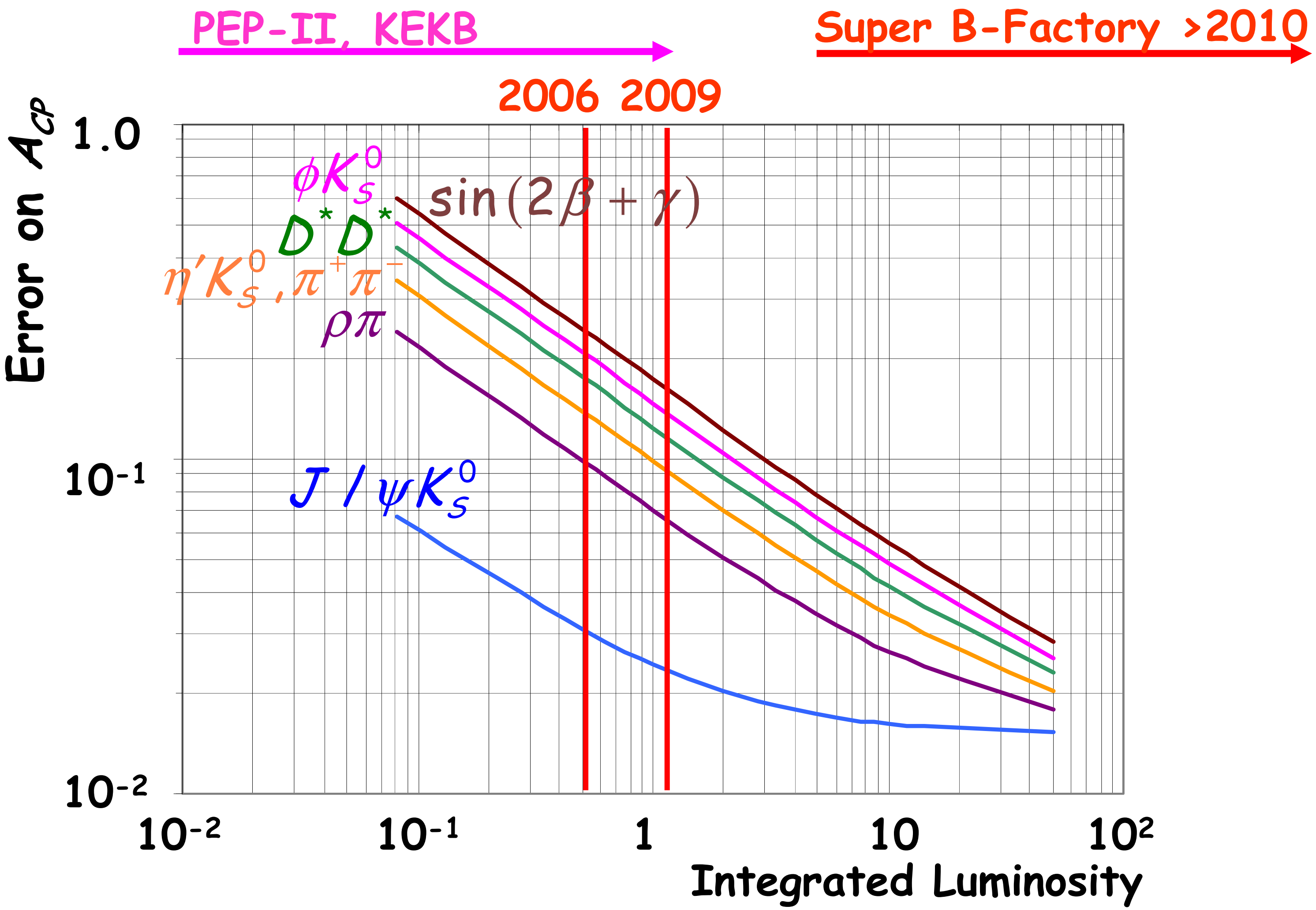
0.24 ± 0.15

~3.1 sigma below charmonium modes

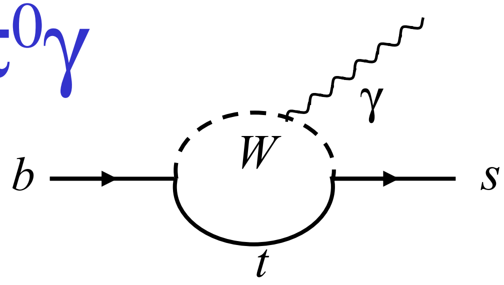
If central value remains as is, this would become ~5 sigma by 2005



Error projection for A_{CP}



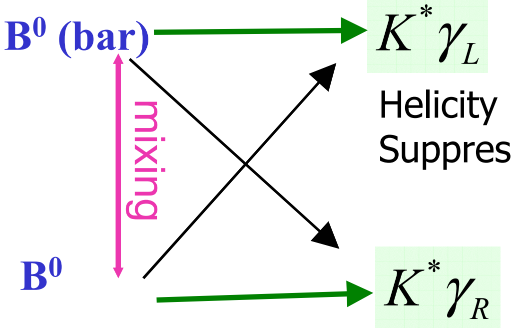
B→$K_s\pi^0\gamma$



The dominant SM amplitude gives: b→sγ_{L}, b(bar)→sγ_{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}→$K_s\pi^0 \sim 11\%$**)



Helicity Flip
Suppressed by m_s/m_b

→ Expect:

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

$\boxed{\sim 0.042}$

David Atwood, Michael Gronau, Amarjit Soni (1997)

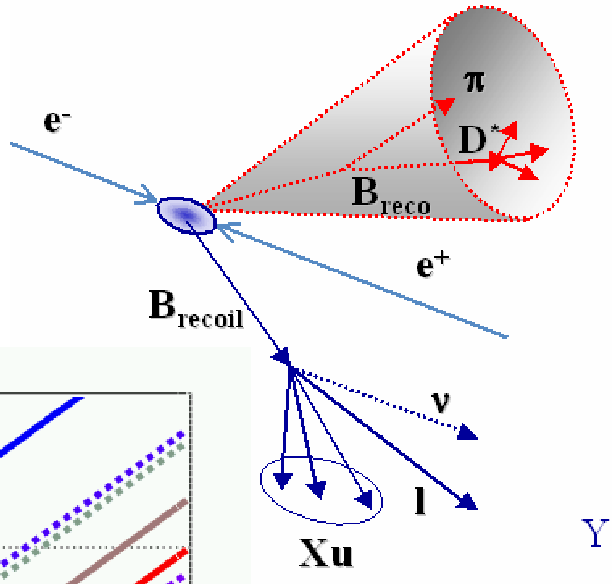
PRL **79** ,185(1997)

	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)

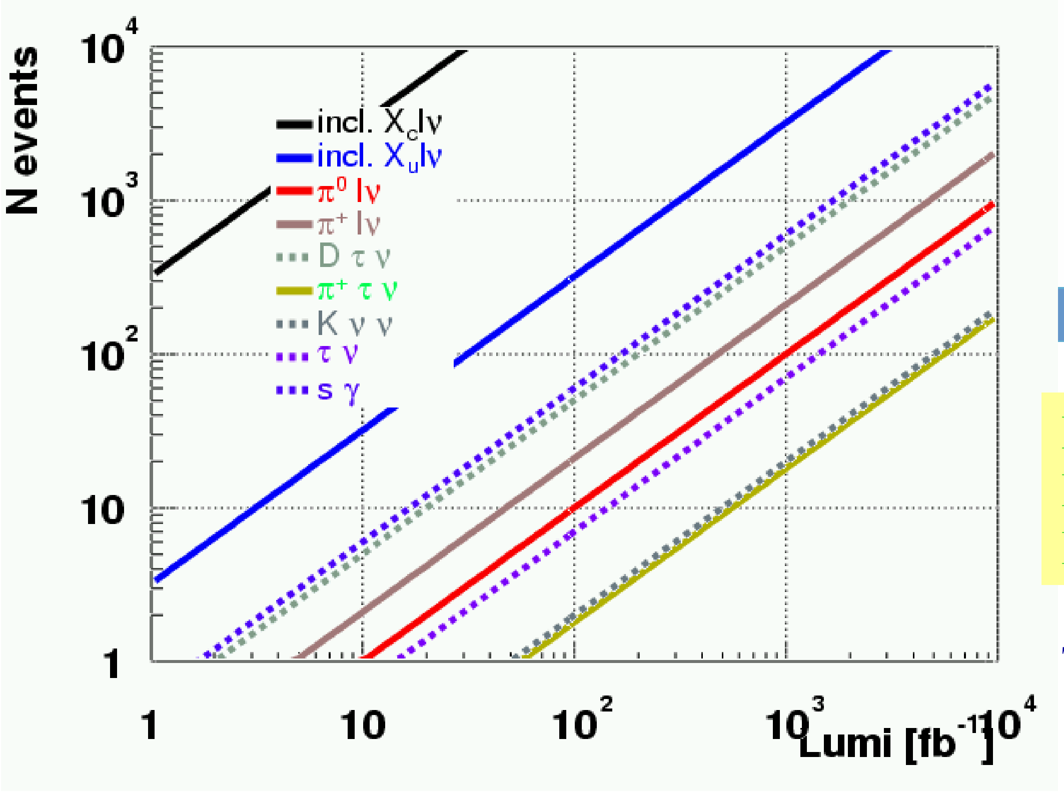
Recoil Physics



- Fully reconstruct one of the two Bs in hadronic modes…
- …and do it with "high" efficiency

- The remaining of the event is the other B

You have a single B beam!!



Daniele del Re UCSD

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

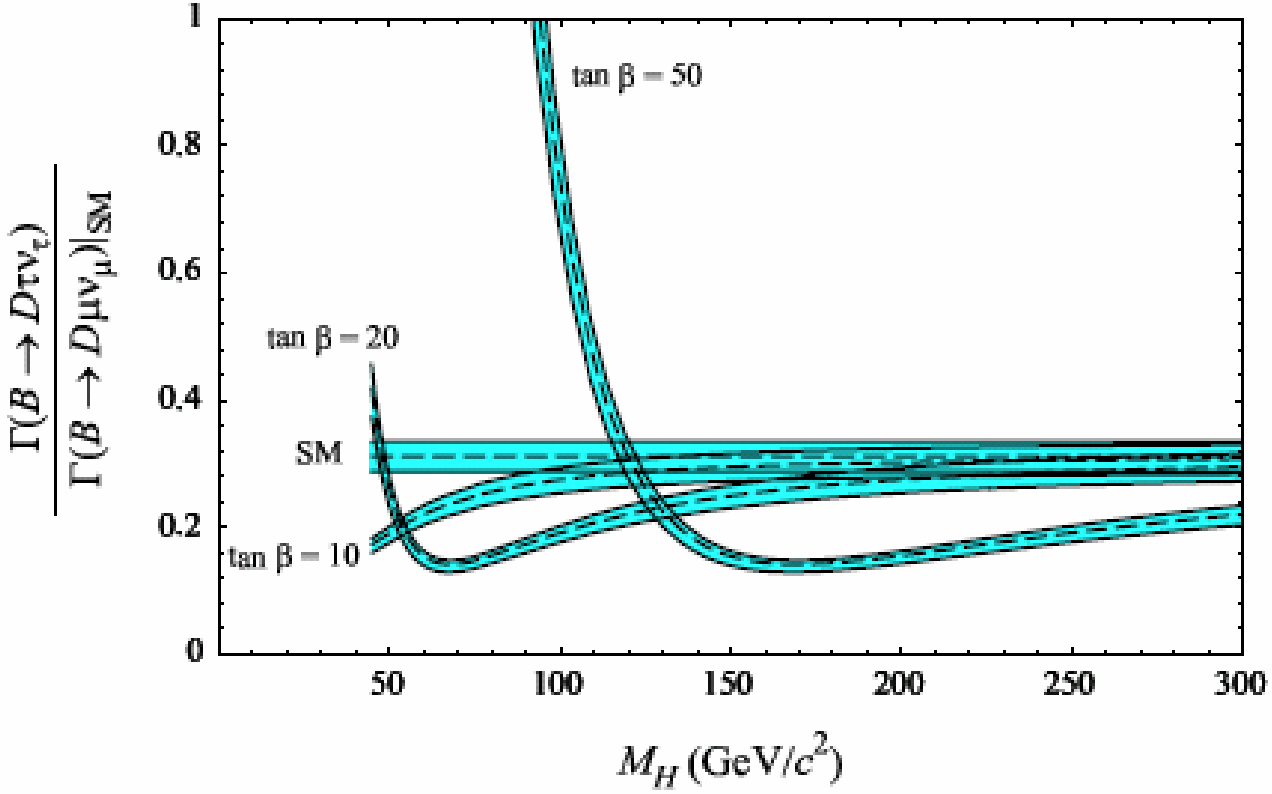
The final efficiency is ~0.4% (per bb_{bar} pair)

⇒ ~4000 B/fb^{-1} (at 30% purity)
⇒ 1500 B^0/fb^{-1}
⇒ 2500 B^+/fb^{-1}

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

$B \rightarrow D\tau\nu_\tau$

- Sensitive to NP



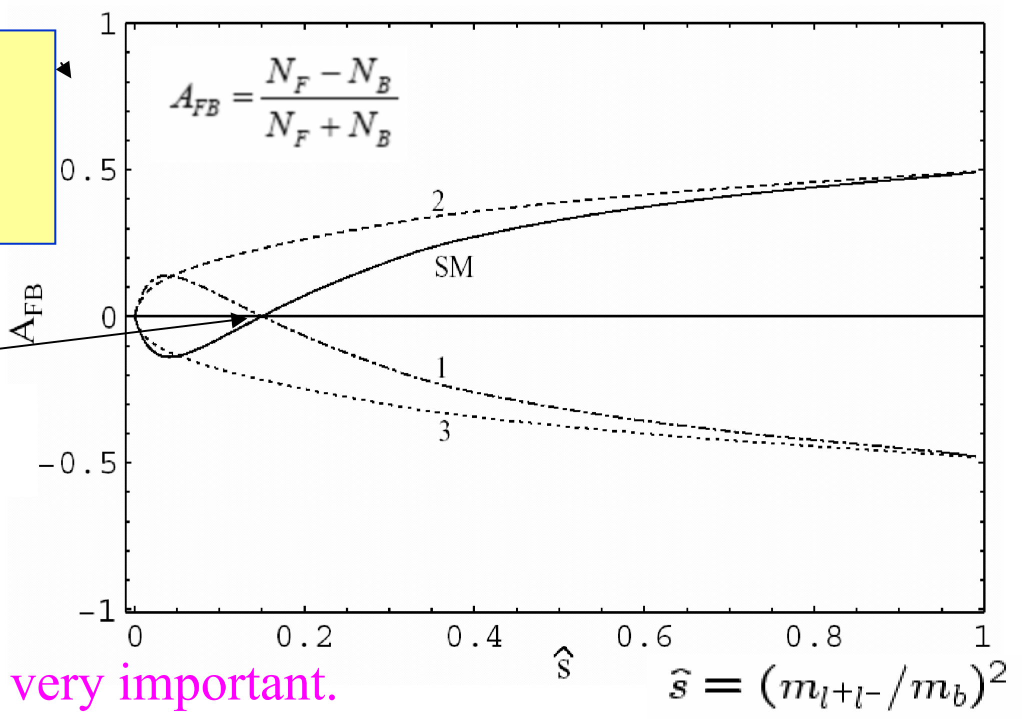
NP observables in s/d l+l- decay

$A_{cp}(B \to s\, l^+ l^-)$	**SM:** <0.5% (0.05% for $K^* l^+ l$)
$A_{cp}(B \to d\, l^+ l^-)$	**SM:** -~(4.4+/-4)%
$B(B \to s\mu^+\mu^-)/B(B \to s e^+ e^-)$	**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



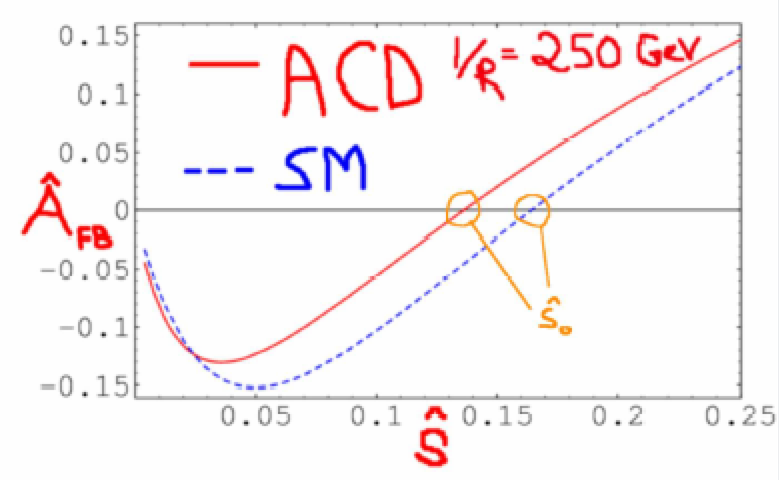
In SM: $A^{CP}{}_{FB}$~ 0
Determination of sign of AFB very important.

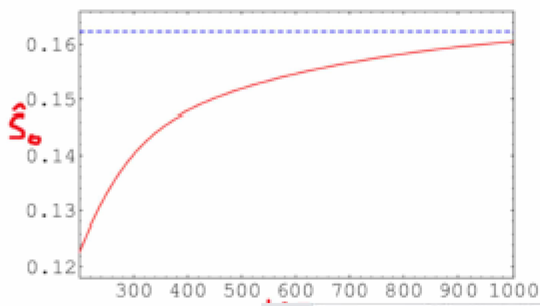
Universal extra dimension effects

Forward Backward Asymmetry

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

$$A_{\rm FB}(\hat s) \approx -3\tilde C_{10} \frac{\left[\hat s \mathrm{Re}\, \tilde C_9^{\rm eff}(\hat s) + 2C_{7\gamma}^{(0)\rm eff}\right]}{U(\hat s)}$$



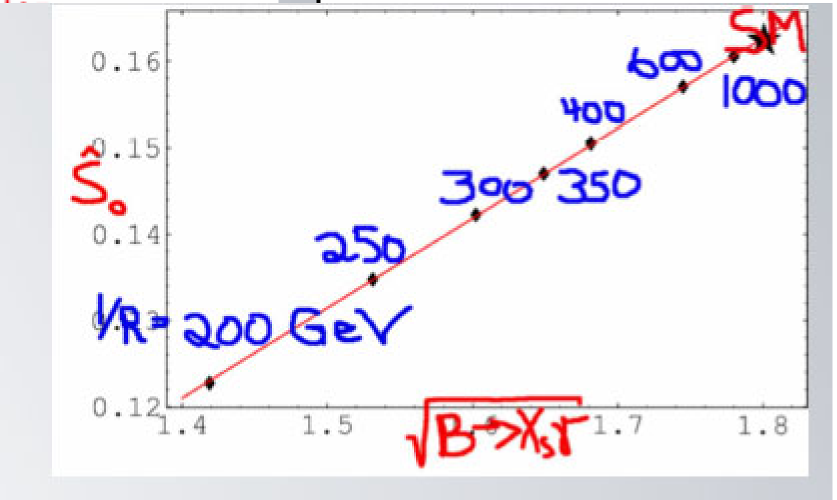


$$\left\{ \begin{array}{ll} \hat s_0^{NLO} & = 0.142 \pm 0.02 \\ \hat s_0^{NNLO} & = 0.162 \pm 0.008 \\ \hat s_0^{ACD} & = 0.146 \pm 0.01 \end{array} \right.$$

Ali,Mannel,Morozumi

Ghinculov,Hurth,Isidori,Yao
Asatrian,Greub,Walker,Bier

$1/R = 300\mathrm{GeV}$



Andreas Weiler, 2nd

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