Status of the SuperB Project

F.Forti, INFN and University, Pisa

Flavour Physics in the LHC Era

CERN, 9-11/10/2006

Outline

- Introduction and brief history
  - The SuperB Project Process
- The Physics Case
- The Accelerator
- The Detector
- Conclusion

Introduction

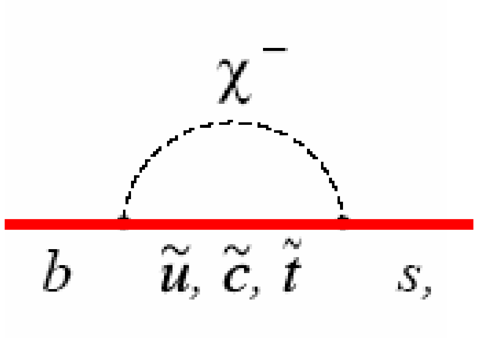
- Flavour physics is rich and promises sensitivity to NP
  - Physics case established and clear,
    ... but large statistics (50-100 ab^{-1}) is needed
- Increasing the current of PEP-II/KEKB is expensive
  - wall power and detector background explosion
  - effective limitation around $5x10^{35}$
- Linear SuperB concept presented at Hawaii workshop in March 2005 – exploit ILC R&D
  - Subsequently went through three phases
    - 5 GeV damping rings with high current and beam extraction, beam compression and final focus
    - 2 GeV damping rings with high currents, beam extraction and linacs, beam compression and final focus
    - 4 and 7 GeV DR with moderate currents with beam compression and final focus
  - By now, no linear part survives, although ILC synergy remains

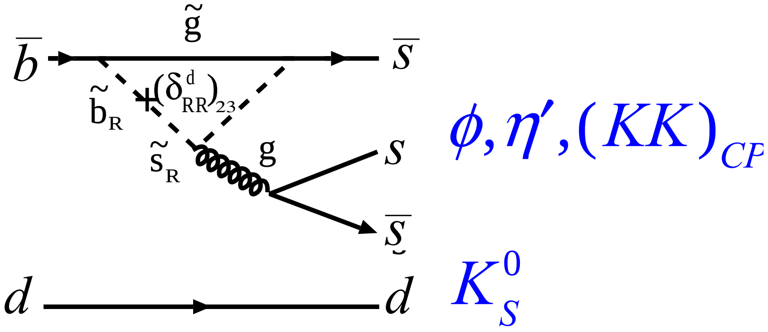
The SuperB Process

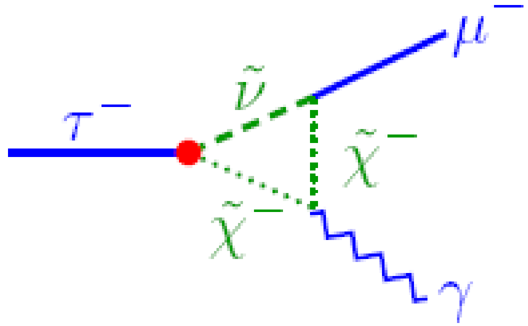
- International SuperB Study Group on
  - Physics case, Machine, Detector
- International steering committee established, chaired by M.A.Giorgi. Members from
  - Canada, France, Germany, Italy, Russia, Spain, UK, US
  - regular interaction with Japan, although not yet formalized
- Regular workshops
  - Three workshop held (2 in Frascati, 1 in SLAC)
  - SuperB Meeting at Daresbury
  - Next workshop in Monteporzio Catone (Rome) on Nov 13-15,2006.
- Conceptual Design Report
  - In preparation, to be delivered by February 20, 2007
  - Describe Physics case, Accelerator, Detector, including costing
  - International review in 2007

Physics case

The case for a high luminosity flavour factory

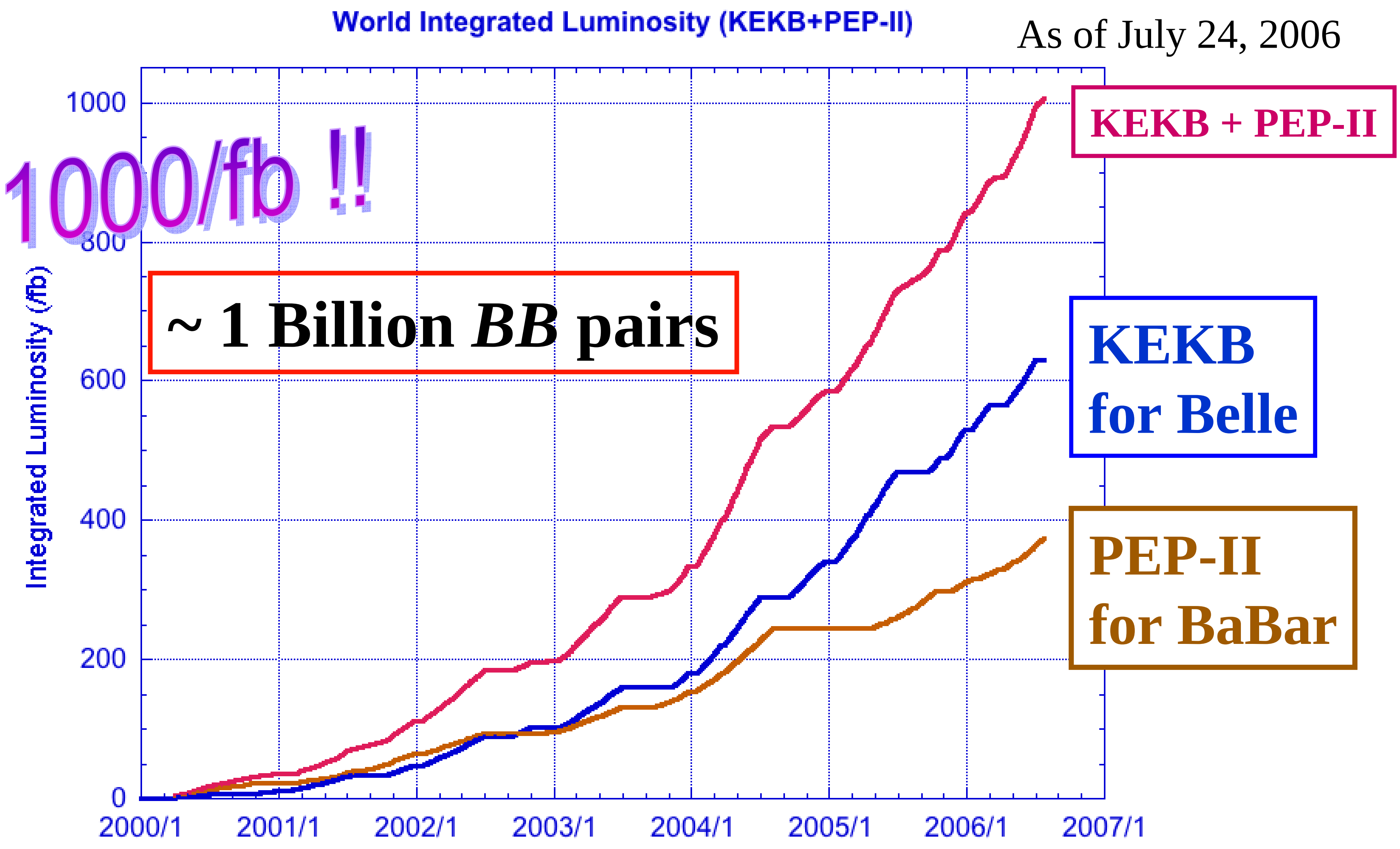






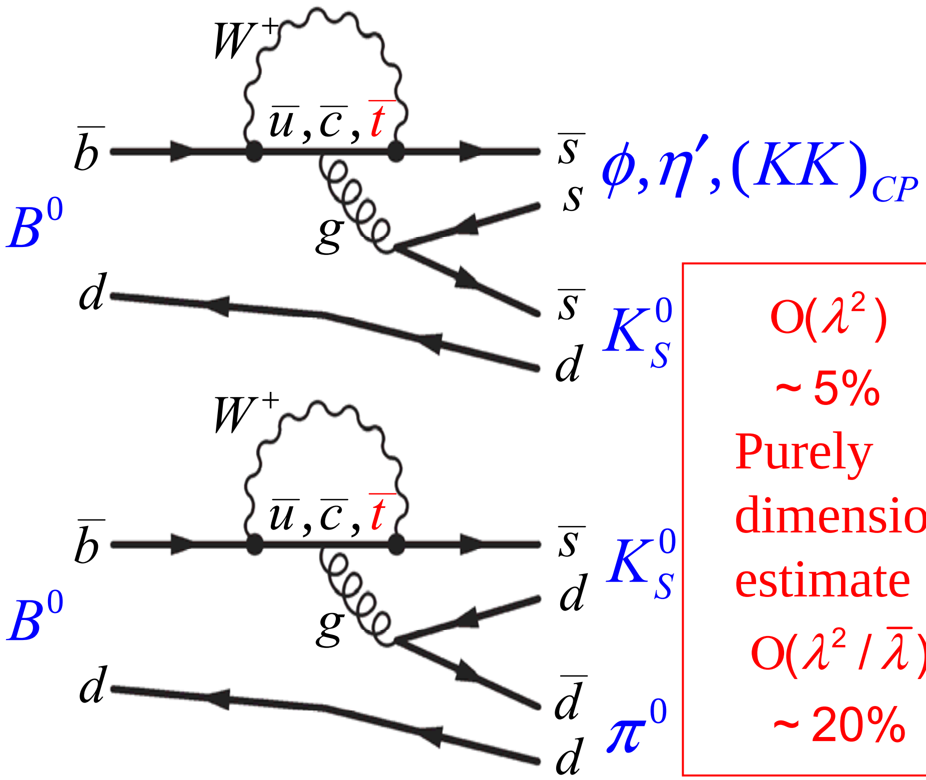
- Prejudice: if there is New Physics at the TeV scale it must have a flavor/CP structure
- New heavy quanta can be detected through precision measurement of processes involving loop diagrams
- Statistics of O(50 ab^{-1}) is necessary to reduce the experimental error below the theoretical uncertainty for the most sensitive analyses
- Physics reach is complementary to LHC-LHCb:
  - many rare decays are not accessible at LHC;
  - sensitivity to off-diagonal term of squark mixing matrix,
  - test of LFV in τ decays

What's new: Integrated Luminosity



sin2β and loops

In SM interference between B mixing, K mixing and Penguin $b \to s\bar{s}s$ or $b \to s\bar{d}d$ gives the same $e^{-2i\beta}$ as in tree process $b \to c\bar{c}s$. However loops can also be sensitive to New Physics!



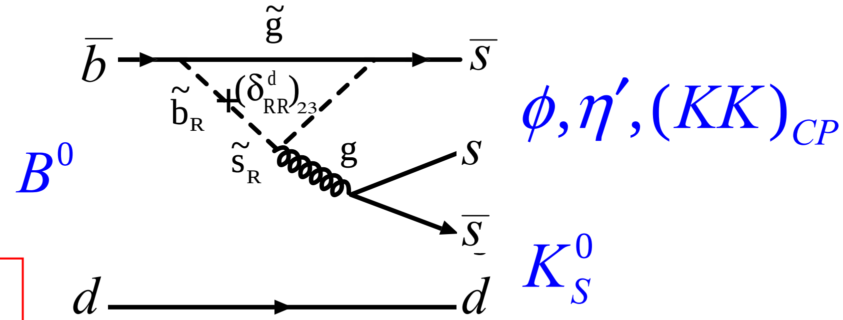
$O(\lambda^2)$

~ 5%

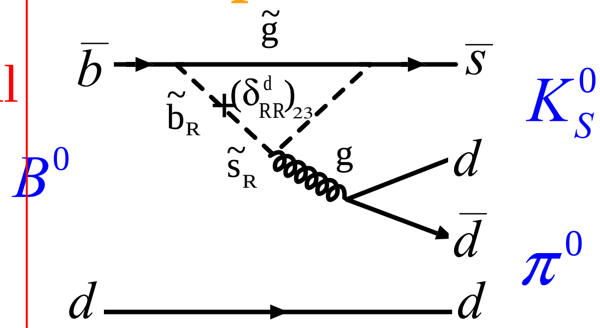
Purely dimensional estimate

$O(\lambda^2 / \bar{\lambda})$

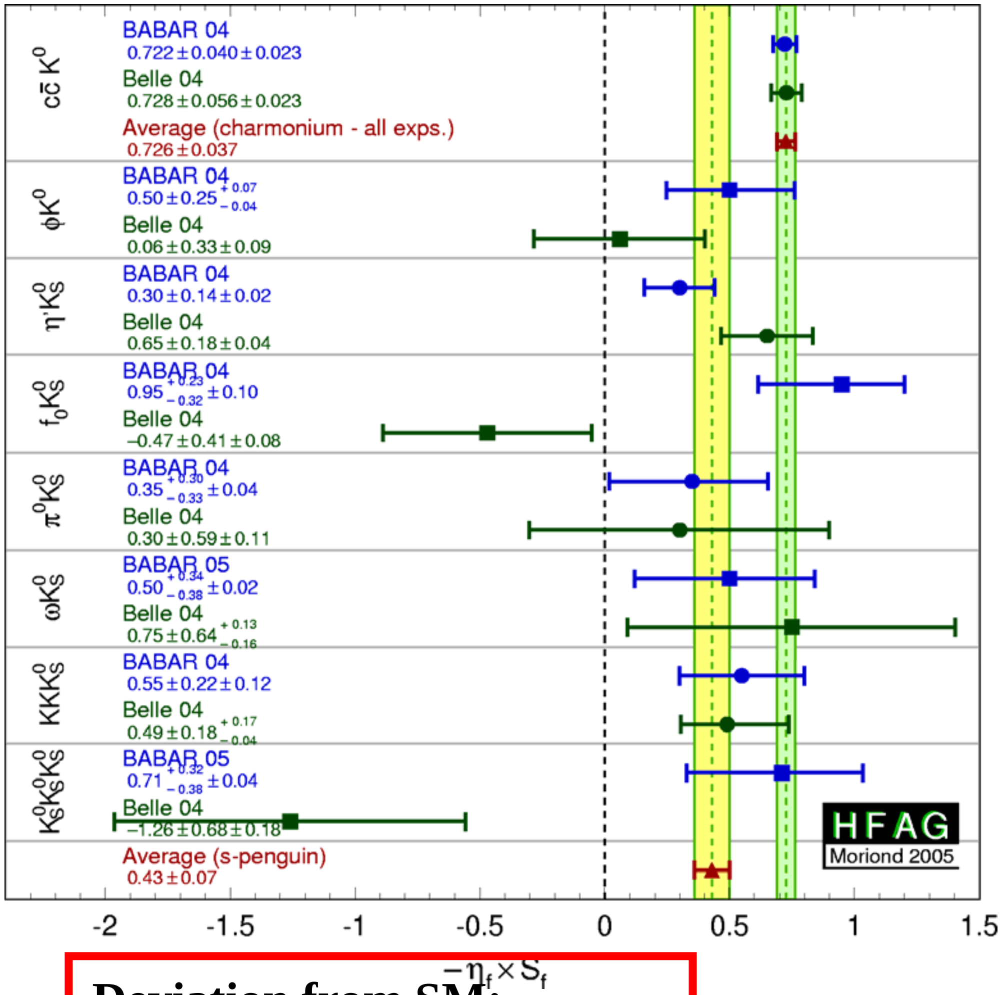
~ 20%

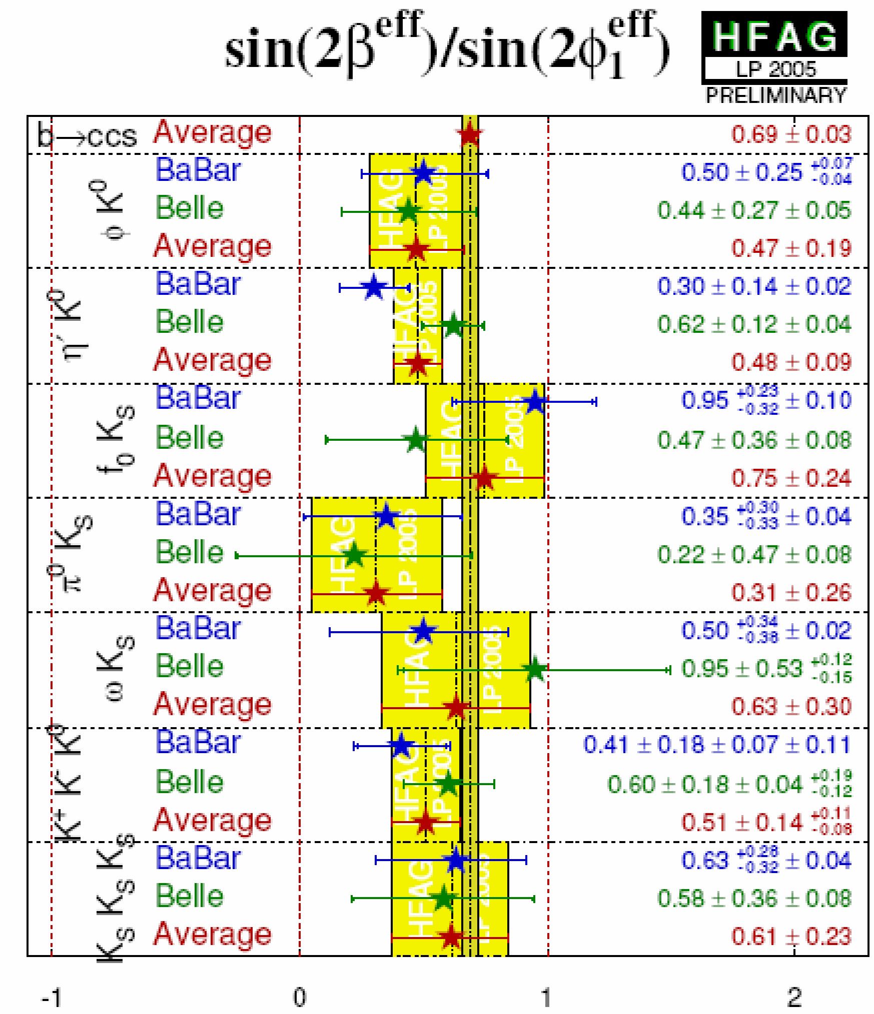


New phases from SUSY?



Winter vs. Summer 05



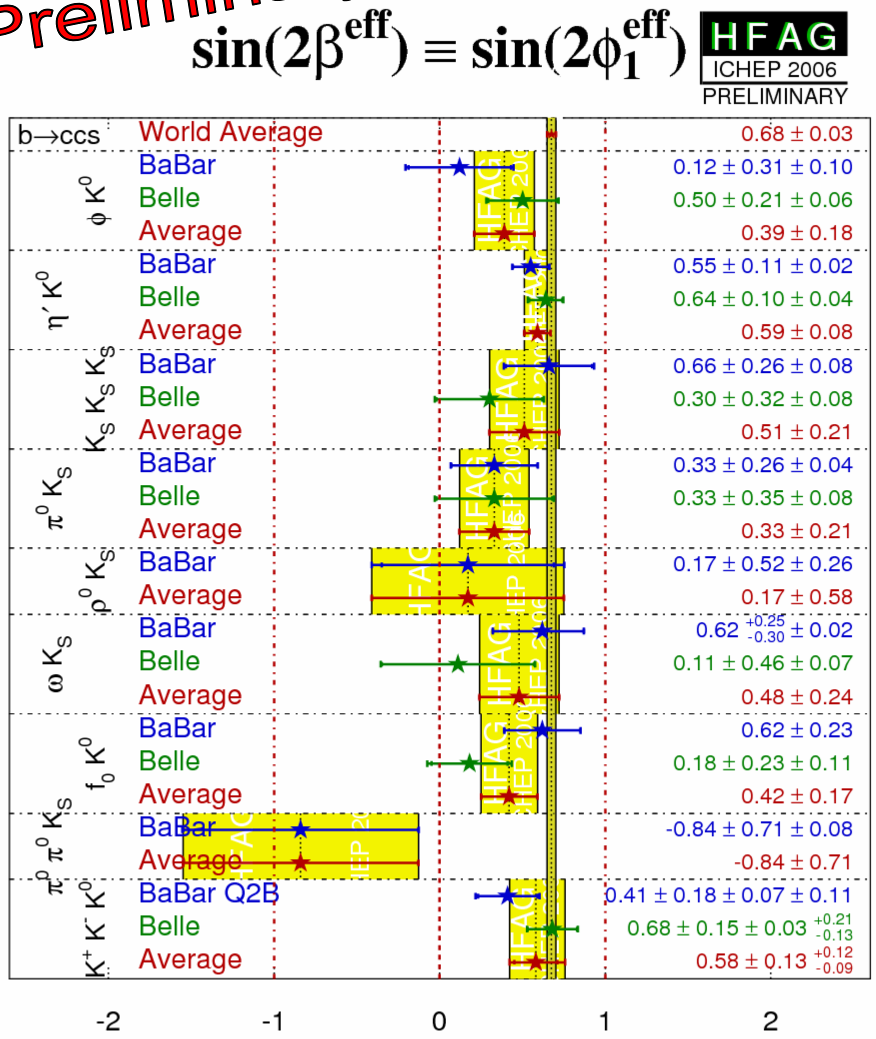


Deviation from SM:
No theory error: **3.7 s**
Naïve theory errors: **2.9 s**

- All except $\eta' K^0$ are within $\sim 1\sigma$
- All except $f_0 K^0_S$ have $\Delta S < 0$

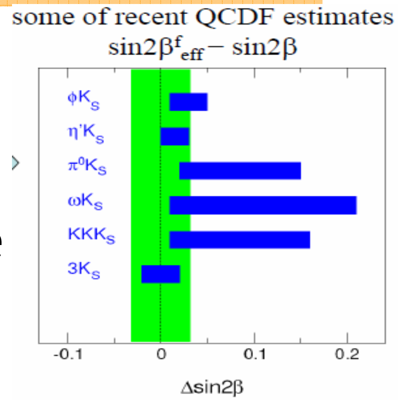
ICHEP06: β from $b \to s$ Penguins

Preliminary



Smaller than $b \to c\bar{c}s$ in all of 9 modes

Theory tends to predict positive shifts (originating from phase in Vts)



Naïve average of all $b \to s$ modes

$\sin 2\beta^{eff} = 0.52 \pm 0.05$

2.6 σ deviation between penguin and tree

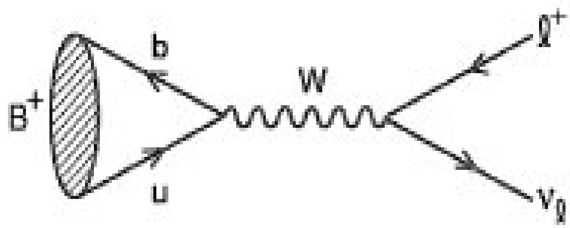
($b \to s$) ($b \to c$)

More statistics crucial for mode-by-mode studies!

$B^{\pm} \rightarrow \tau^{\pm} \nu$

ICHEP06
Browder (Belle)
Sekula (BaBar)

Important as W (suppressed by V_{ub}) can be replaced by charged Higgs, etc



$$B(B^+ \to l^+ \nu_l) = \frac{G_F^2 m_B m_l^2}{8\pi}\left(1 - \frac{m_l^2}{m_B^2}\right) f_B^2 |V_{ub}|^2 \tau_B$$

SM prediction
$(1.59 \pm 0.40) \times 10^{-4}$
(depends on f_B and V_{ub})

Difficult due to neutrinos in the final state

BELLE: tag with fully reconstructed B mesons (180 channels) (revised). 3.5 σ significance

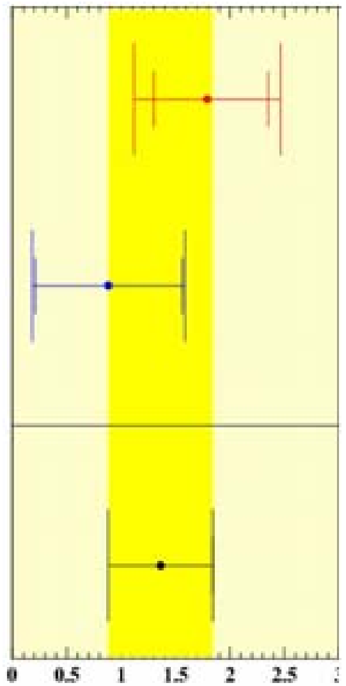
$$BF(B^+ \to \tau^+ \nu_\tau) = (1.79^{+0.56+0.39}_{-0.49-0.46}) \times 10^{-4}$$

BABAR (new) Tag with B→D(*)lν

$$BF(B^+ \to \tau^+ \nu_\tau) = (0.88^{+0.68}_{-0.67} \pm 0.11) \times 10^{-4}$$

BF<1.80@90%CL

Averaged (1.36 ± 0.48)x10-4



BF($B^+ \rightarrow \tau^+ \nu_\tau$)

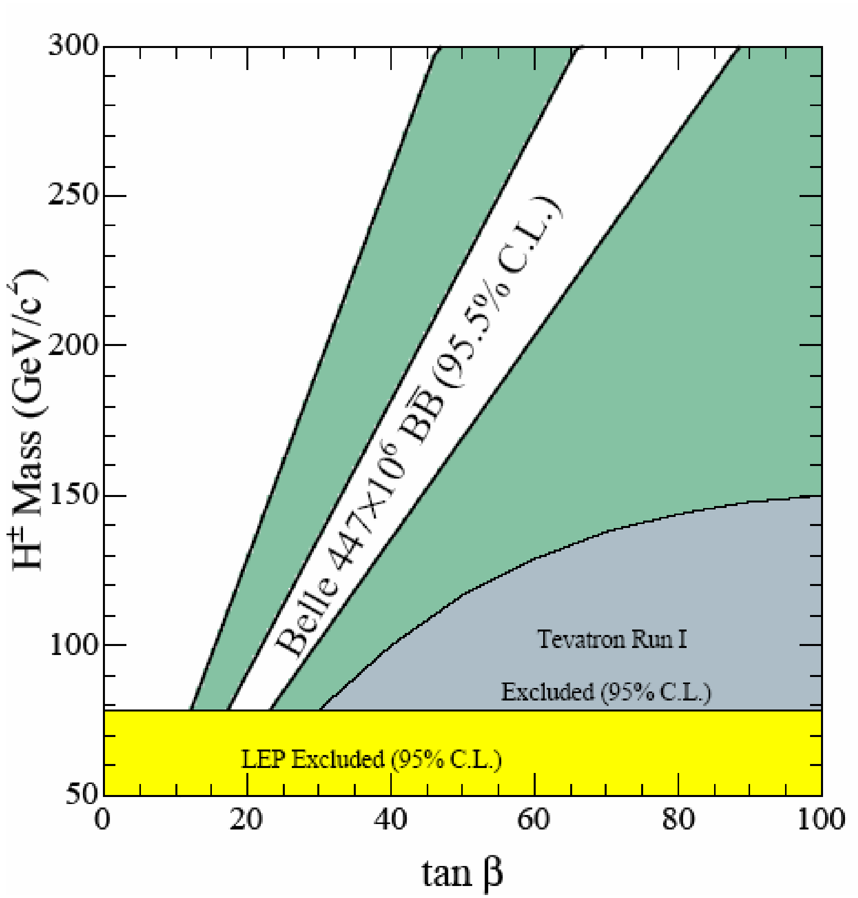
Impact of $B^{\pm} \rightarrow \tau^{\pm} \nu$

ICHEP06
Barlow

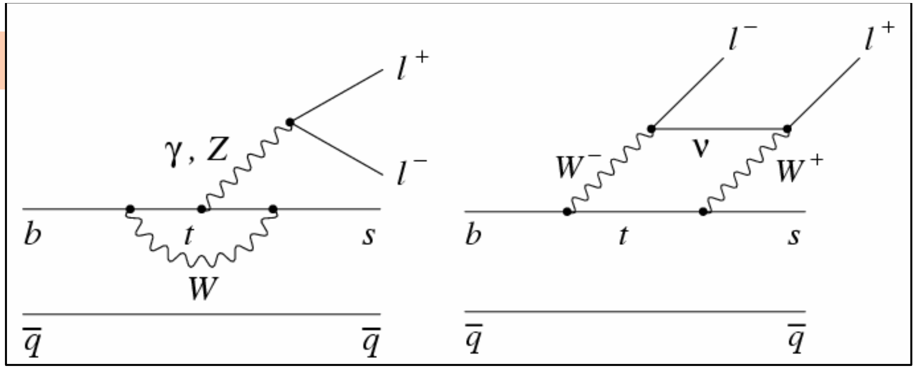
- Limits on e.g. 2 Higgs doublet model: *W.S.Hou, PRD 48, 2342 (1993)*
- SM prediction enhanced/reduced by factor r_H

$$r_H = \left(1 - \frac{m_B^2}{m_H^2} \tan^2 \beta\right)^2$$

Or: Within the SM, use the value of $BF(B^+ \rightarrow \tau^+ \nu_\tau)$ to give a measurement of f_B

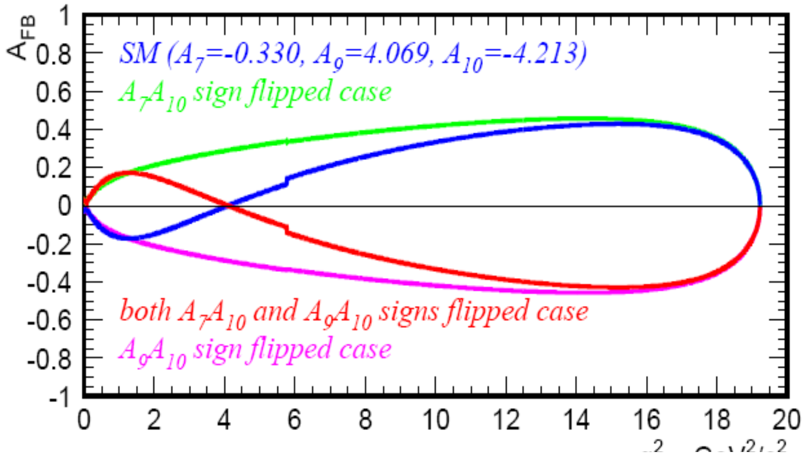


$K^{(*)}l^+l^-$ for NP

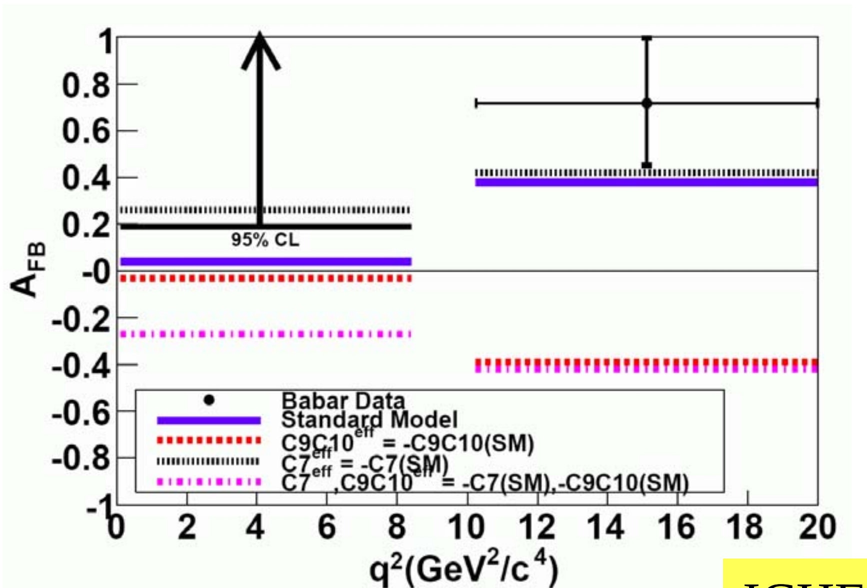


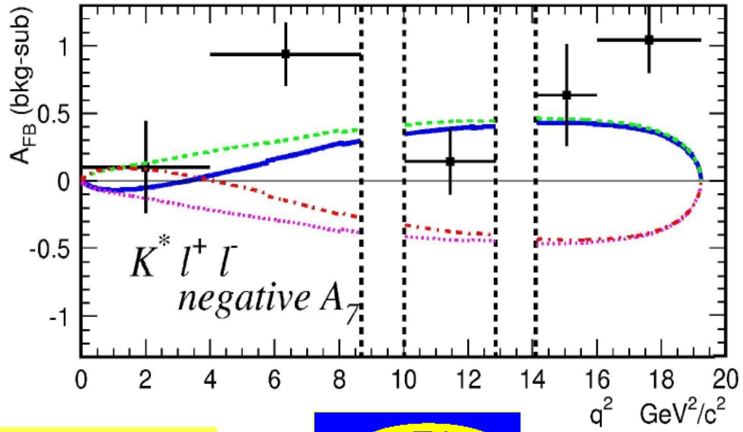
$\ell\ell$ pair forward-backward asymmetry vs q2 is sensitive to NP in the loop, altering the helicity structure

zero crossing predicted with very little theoretical uncertainties



BABAR





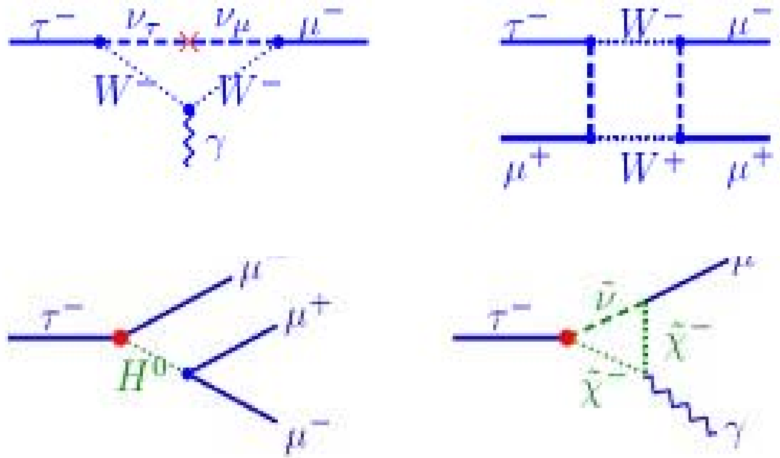
ICHEP06Kovalskyi

Lepton Flavour Violation

The B factories are also τ factories

$\sigma(\tau^+\tau^-) = 0.89$ nb at $\sqrt{s} = M(\Upsilon)$

Total sample of ~1.5 billion taus



90% CL limits

$Br(\tau^- \to e^-\gamma) < 12 \times 10^{-8}$

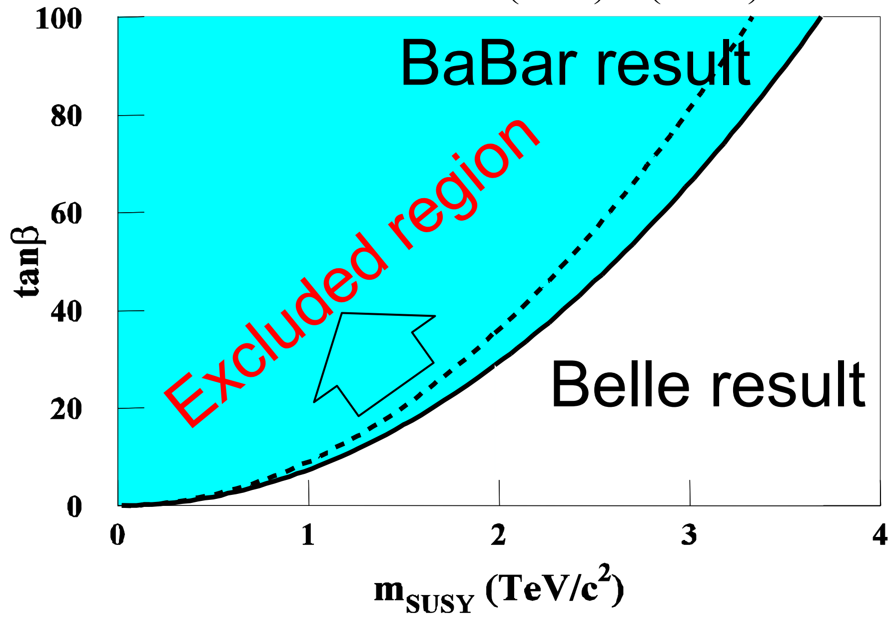
$Br(\tau^- \to \mu^-\gamma) < 4.1 \times 10^{-8}$

$Br(\tau^- \to e^-\gamma) < 11 \times 10^{-8}$

$Br(\tau^- \to \mu^-\gamma) < 6.7 \times 10^{-8}$

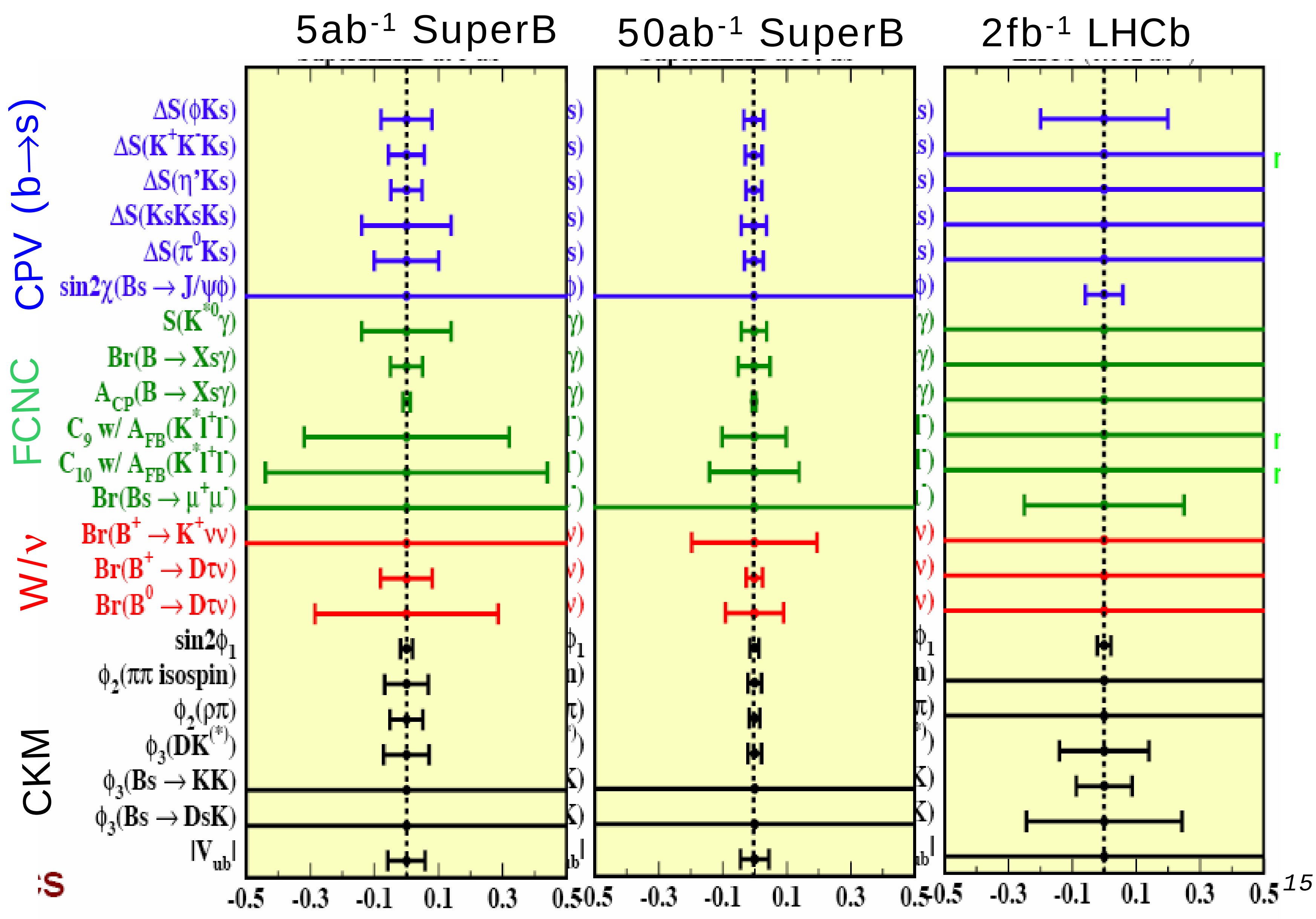
R.Barlow ICHEP06

$$Br(\tau \to \mu\gamma) = 3.0\times10^{-6} \times \left(\frac{\tan\beta}{60}\right)^2 \times \left(\frac{M_{SUSY}}{1\text{TeV}}\right)^{-4}$$



What's in store: Physics reach at SuperB

From T.Iijima talk



Estimate of some Theoretical Uncertainties

Ligeti, ICHEP 2004

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

SuperB Physics case

- There is a solid case for a SuperB collecting more than 50 ab-1:
  - Precision measurements allowing to detect discrepancies from the standard model
    - Theoretical precision allows (or will allow) this in many channels
  - Rare decay measurements
  - Lepton flavour violation
  - In addition: possibility to run at tau/charm threshold, polarized beam
- See for example:
  - Report from Roadmap committee (Slac.BABAR Analysis Doc#828 26July2004)
  - The Discovery Potential of a Super B Factory (Slac-R-709)
  - Letter of Intent for KEK Super B Factory (KEK Report 2004-4)
  - Physics at Super B Factory (hep-ex/0406071)
  - SuperB report (hep-ex/0512235)
  - Many documents available at the URL : www.pi.infn.it/SuperB

Accelerator

Summary from Oide's talk at 2005 2nd Hawaii SuperBF Workshop

- Present design of SuperKEKB (SAME CONSIDERATIONS FOR PEPII) hits fundamental limits in the beam-beam effect and the bunch length (HOM & CSR)[1]. Higher current is the only way to increase the luminosity .
- Many technical and cost issues are expected with a new RF system

We need a completely different collider scheme.....

"Just" increasing the current of PEP-II/KEKB is expensive

•wall power

•detector background explosion

•effective limitation around 5x1035

[1]High order modes, Coherent Synchrotron Radiation

SuperB new approach based on ILC Final Focus and Damping Ring

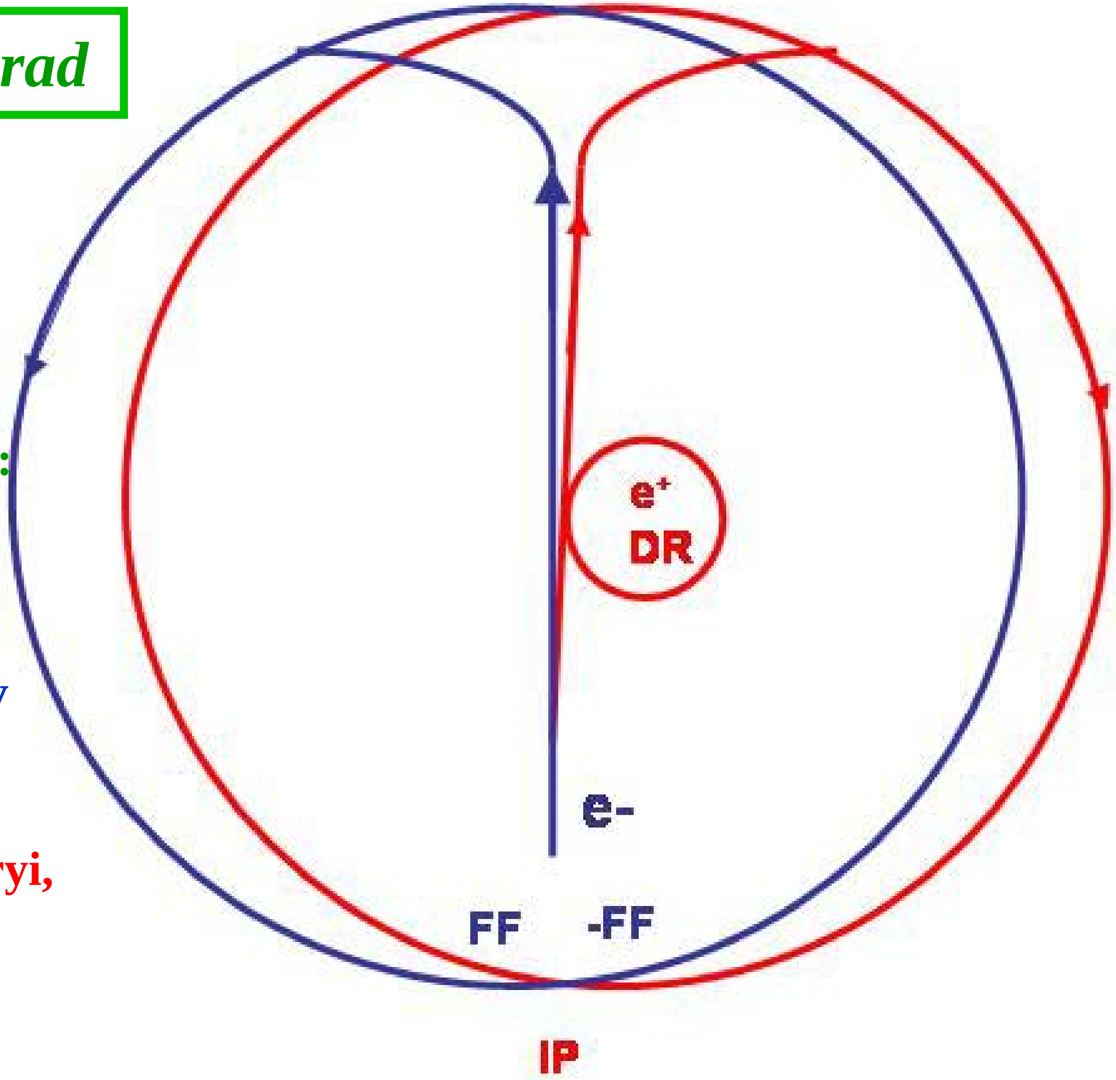
*Crossing angle = 2*15 mrad*

ILC rings &
ILC FF

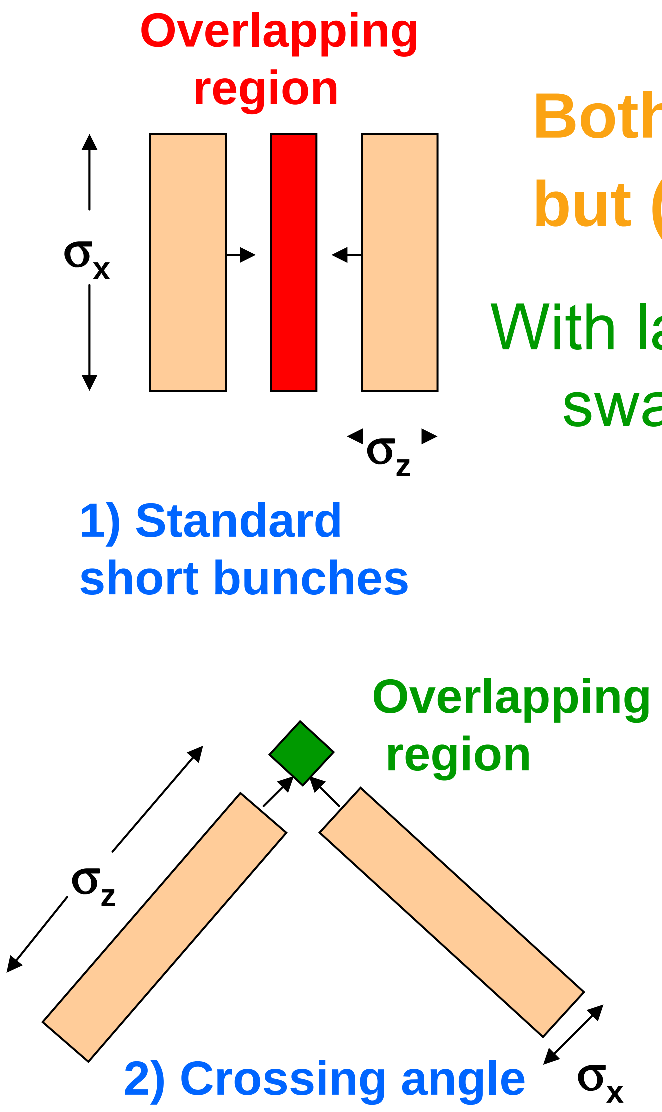
SuperB Contributors (Accelerator):
BINP: Koop, Levichev, Shatilov
KEKB: Ohmi

LNF: Biagini, Raimondi, Zobov

Pisa: Giorgi, Paoloni
SLAC: Novokhatski, Seeman, Seryi, Sullivan, Wienands

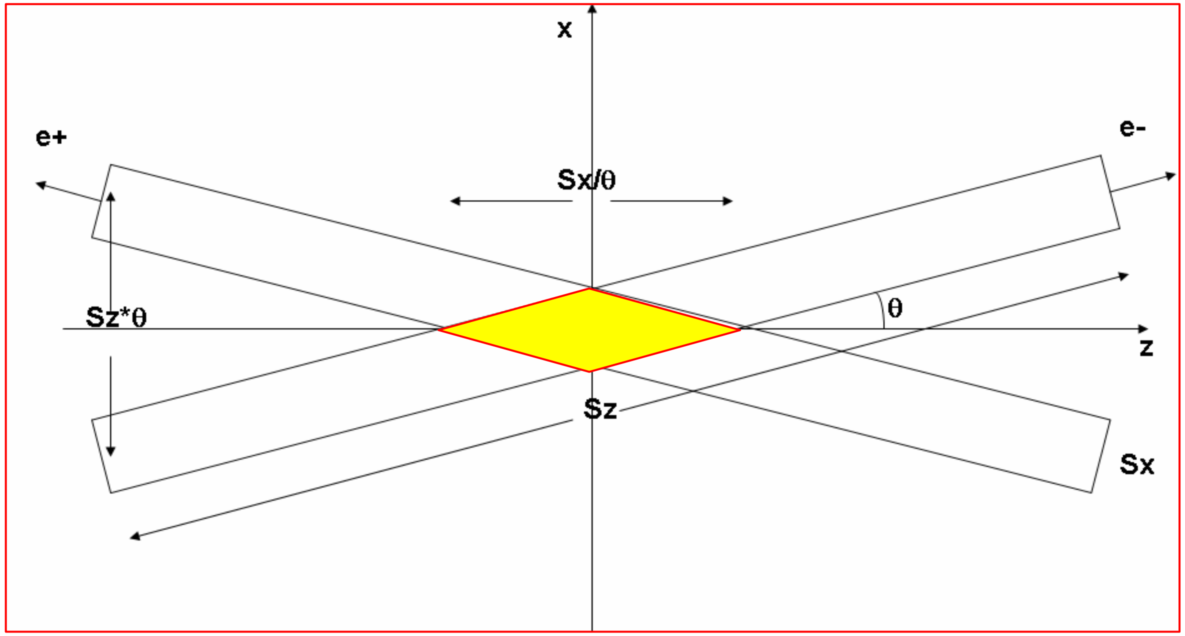


Crossing angle concepts

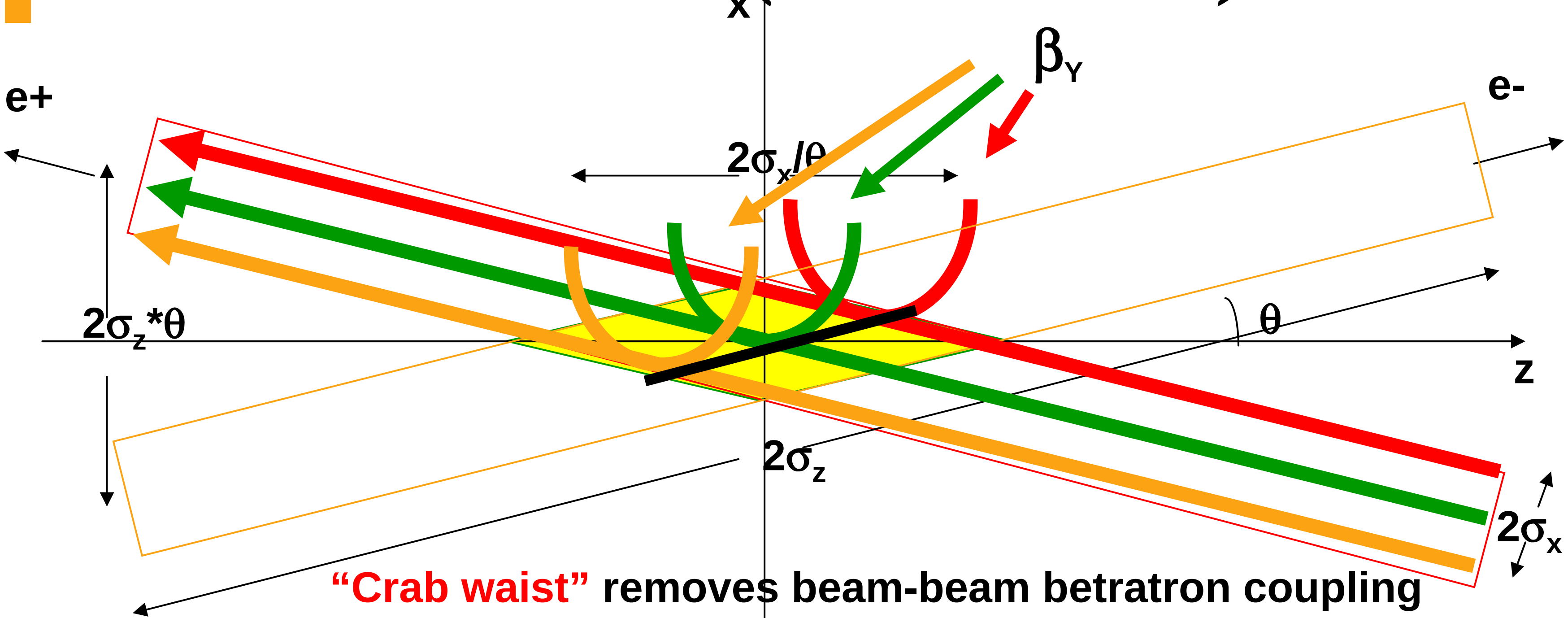


Both cases have the same luminosity, but (2) has longer bunch and smaller σ_x

With large crossing angle X and Z quantities are swapped: no need for short bunches



"Crab waist" (P. Raimondi)



"Crab waist" removes beam-beam betratron coupling Introduced by the crossing angle

Vertical waist has to be a function of x:

Z=0 for particles at $-\sigma_x$ ($-\sigma_x/2\theta$ at low current)

Z= σ_x/θ for particles at $+\sigma_x$ ($\sigma_x/2\theta$ at low current)

Crabbed waist realized with a sextupole in phase with the IP in X and at $\pi/2$ in Y

For a fixed longitudinal position, β_y does not depend on the horizontal motion anymore !
No vertical modulation due to the horizontal oscillations !

Relative Emittance growth per collision: $\Delta\varepsilon_y/\varepsilon_y$=1.5x10-3

Machine parameters

- Present parameter set based on ILCDR-like parameters 3.0 Km long rings studied with ILC OCS (Baseline) lattice scaled to 4 and 7 GeV
  - Same DR emittances
  - Same DR bunch length
  - 1.5 times DR bunch charges
  - Same ILC-IP betas
- Crossing angle and "crab waist" to minimize bb blowup
  - To be tested in 2007 on DAFNE.
- Use PEP-KEK DR damping time 17ms
- Fewer and lower field wigglers used
- Final Focus (ILC-like) included
- Design based on recycling all PEP hardware, Bends, Quads and Sexts, and RF system
  - Corresponds to a lot of money
- Maximize Luminosity keeping low ΔE and wall power.

Ring Parameters

Energy (GeV)	4	7
C (m)	2762	2762
B_w (T)	1.4	1.05
L_{bend}(m)	2.1	10.8
N. bends	96	96
B_{bend} (T)	0.439	0.144
Uo (MeV/turn)	2.3	4.1
Wiggler sections	4	4
σ_z (mm)	7.0	7.0
τ_s (ms)	17	17
ε_x (nm)	0.79	0.71
Emittance ratio	0.25%	0.25%
ΔE	1.0×10^{-3}	1.1×10^{-3}
Momentum compaction	1.85×10^{-4}	3.90×10^{-4}
ν_s	0.012	0.026
Vrf (MV)	5.5	19
N_{part} ($\times10^{10}$)	3.31	1.89
I_{beam} (A)	2.5	1.44
Tousheck lifetime (min)	95	1100
P_{beam}(MW)	5.7	5.9
Frf (MHz)	476	
$N_{bunches}$	4167	
Gap	5%	
P_{wall} (MW) (50% eff) 2 rings	23.2	

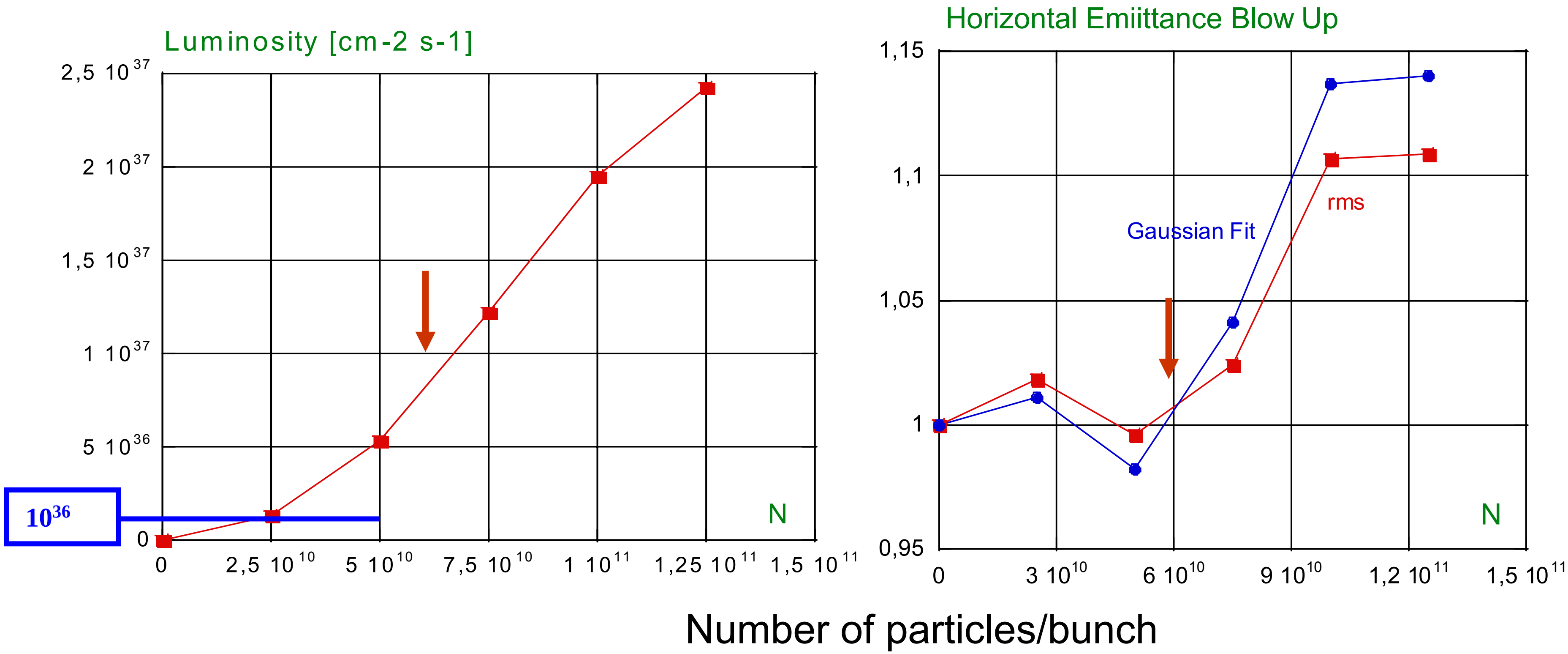
IP Parameters

βx	20mm
σx	4µm
σxp	200µrad
βy	200µm
σy	20nm
σyp	100µrad
σz	7mm
$2^*\theta$	30mrad

$L>10^{36}\ cm^{-2}\ s^{-1}$

POWER < 30MW

Upgradeable



M. Zobov, D. Shatilov

Detector

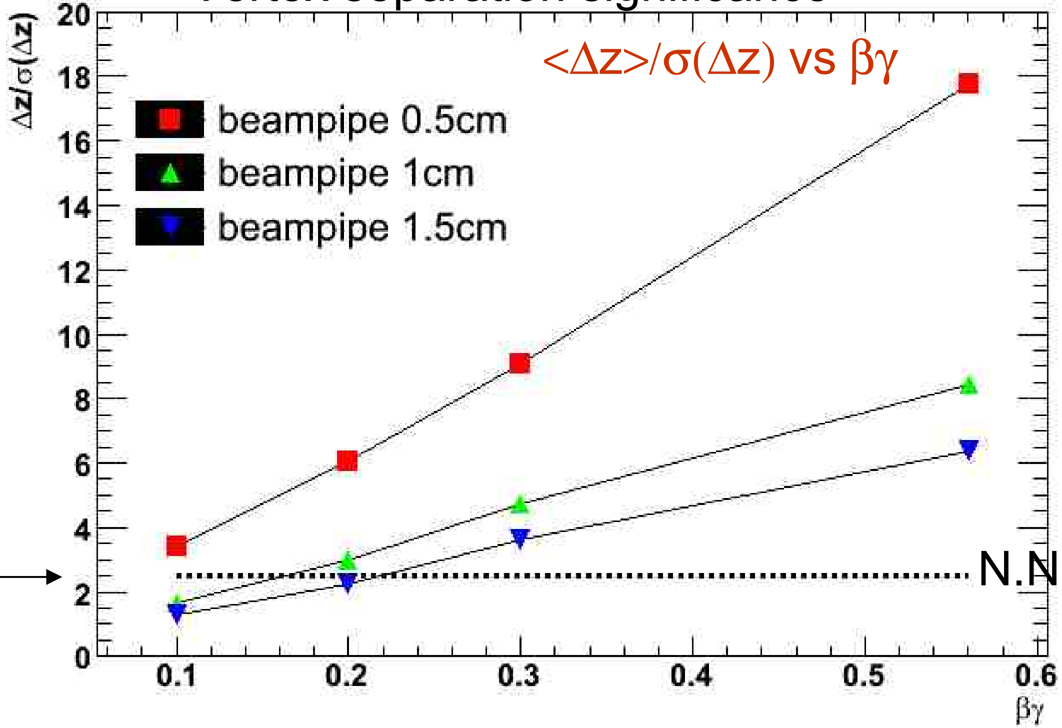
Backgrounds

- SuperB beam currents (2A) are similar to PEP-II/KEKB
- Reasonable to assume background is not larger than what with have today
  - Detailed simulations ongoing, especially for radiative Bhabhas and Touschek backgrounds
  - Need to design a robust detector with the enough segmentation and radiation hardness to withstand surprises (x5 safety margin)
- IR design is critical
  - Radiative Bhabhas
  - Syncrotron radiation shielding
  - Shielding from beam-beam blow up

Asymmetry

- Lower boost advantegeous for machine design
  - Babar: 9 + 3.1 βγ=0.56 , Belle: 8 + 3.5 βγ=0.45
  - SuperB: 7 + 4 βγ=0.28
- we can afford to have a lower boost only if the vertexing resolution is good:
  - small radius beam pipe
  - very little material in b.p. and first layer
- A b.p. with r<1cm is highly desirable

Vertex separation significance

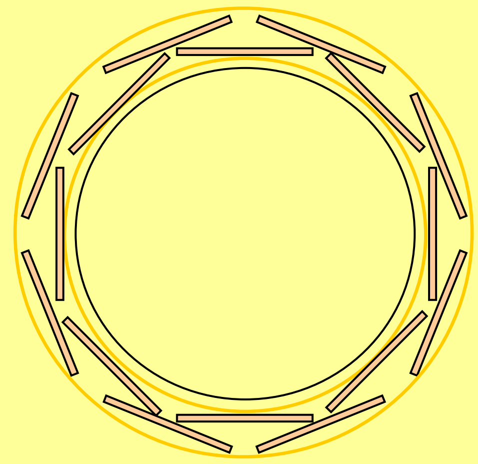


Present Babar value

N.Neri

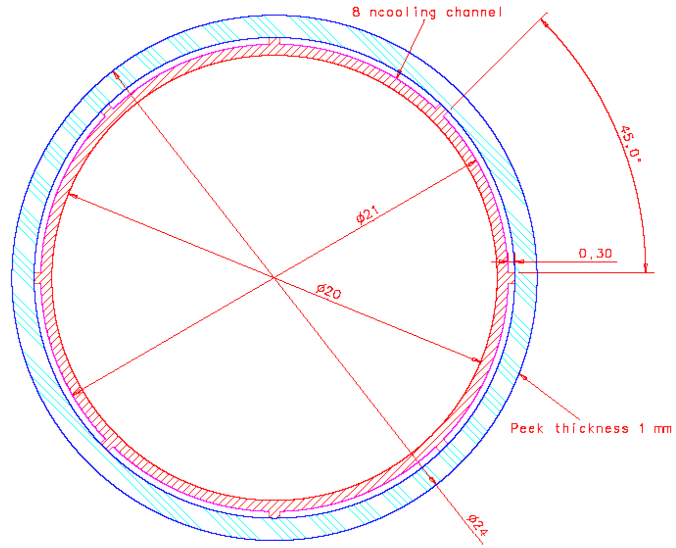
Detector components

- Vertexing
  - Thin pixel layer glued on beam pipe: needs R&D
- Intermediate tracking - Si Strip detectors
- Central tracking - Drift chamber
- Particle Identification
  - Čerenkov based PID – like DIRC
  - Need development on readout
  - Endcap region requires special study
- Calorimeter
  - Barrel part could be reused
  - In the endcaps require smaller Moliere radius and faster crystals Muon
  - It doesn't seem to be a problem

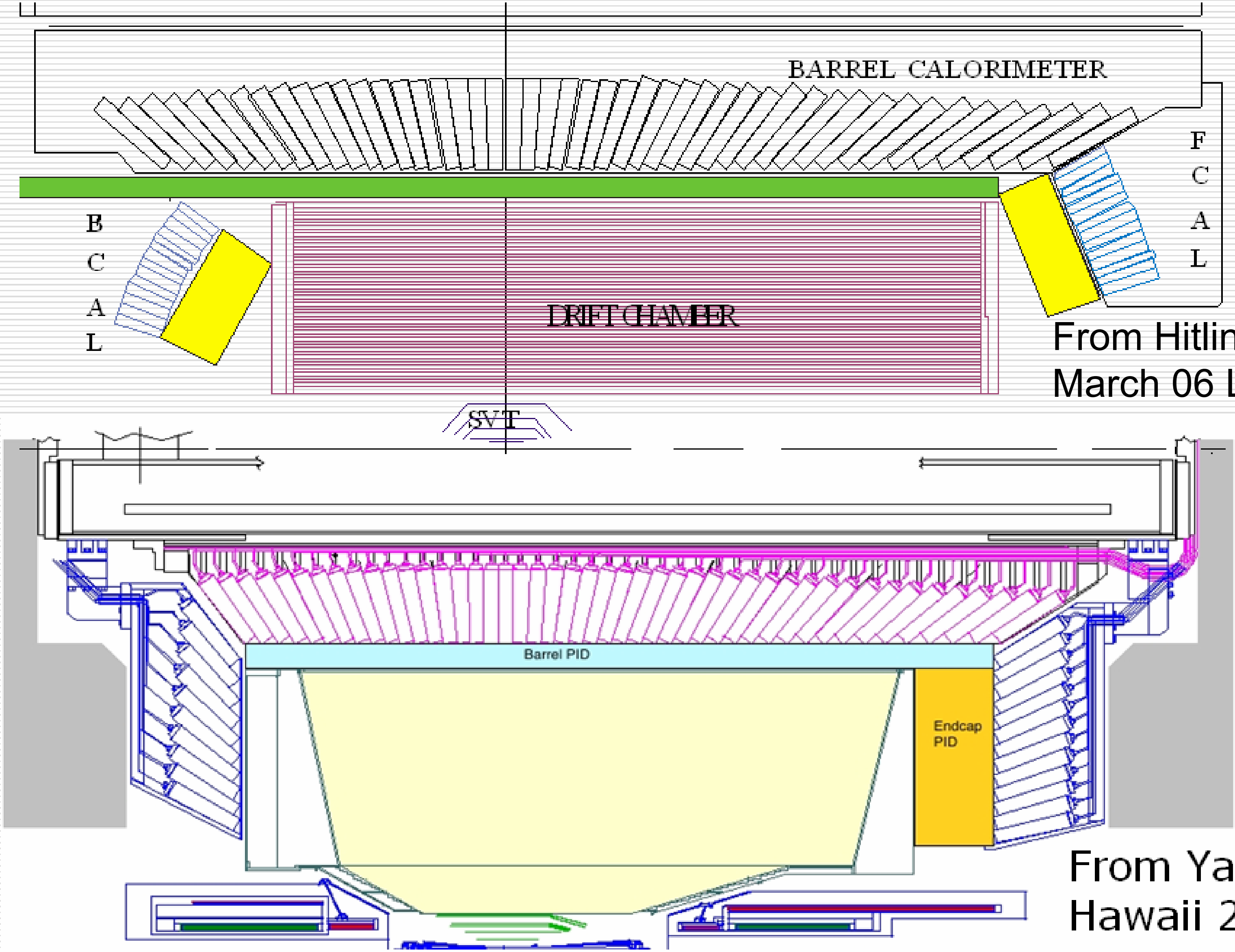


x10 scale with 5mm radius BP, 3mm pixel chip

Pipe Inner Radius 1 cm



Comparison – *BABAR* and Belle for *SuperB*



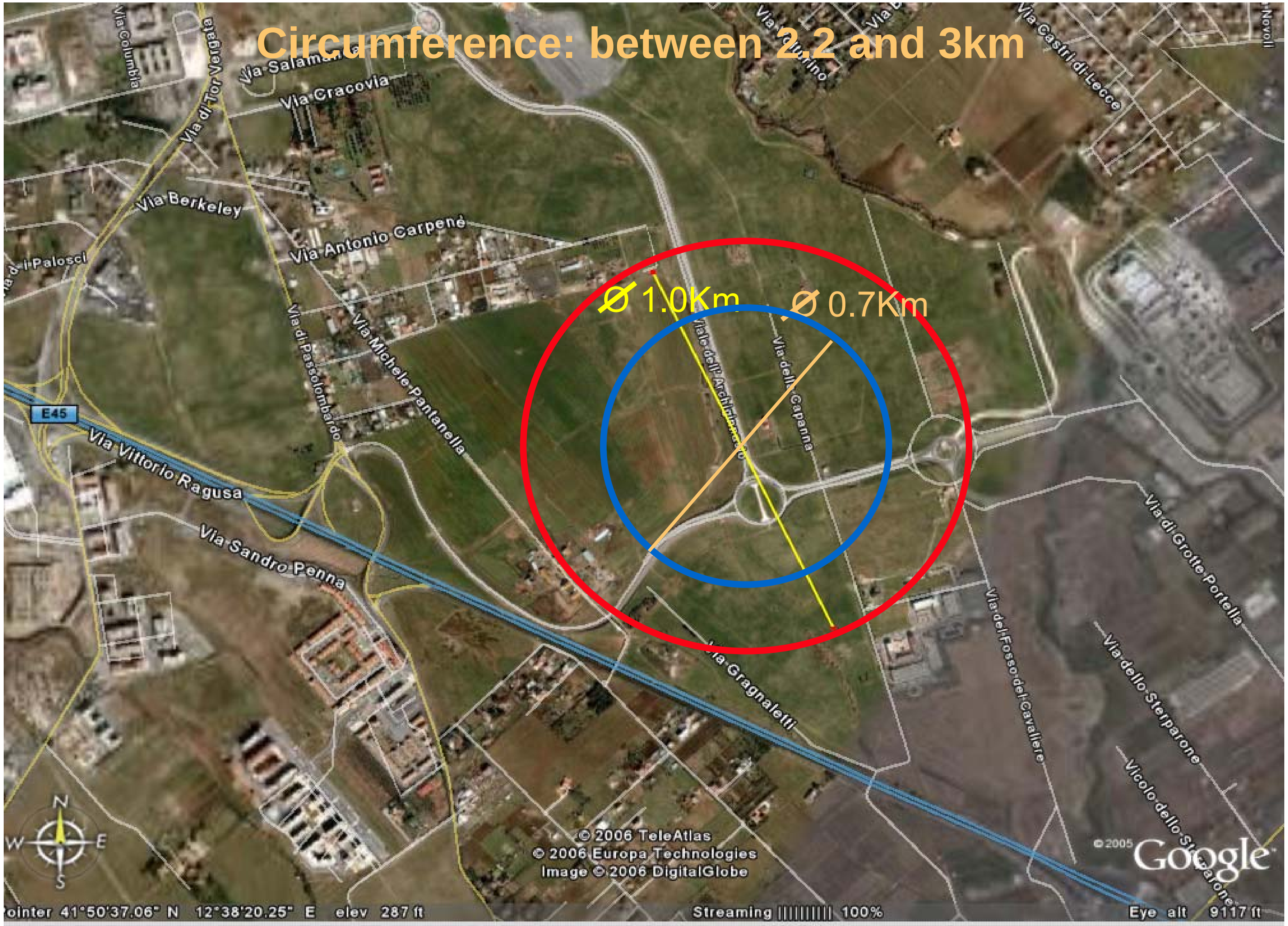
From Hitlin's talk at March 06 LNF

From Yamauchi's Hawaii 2005 talk

Conclusion

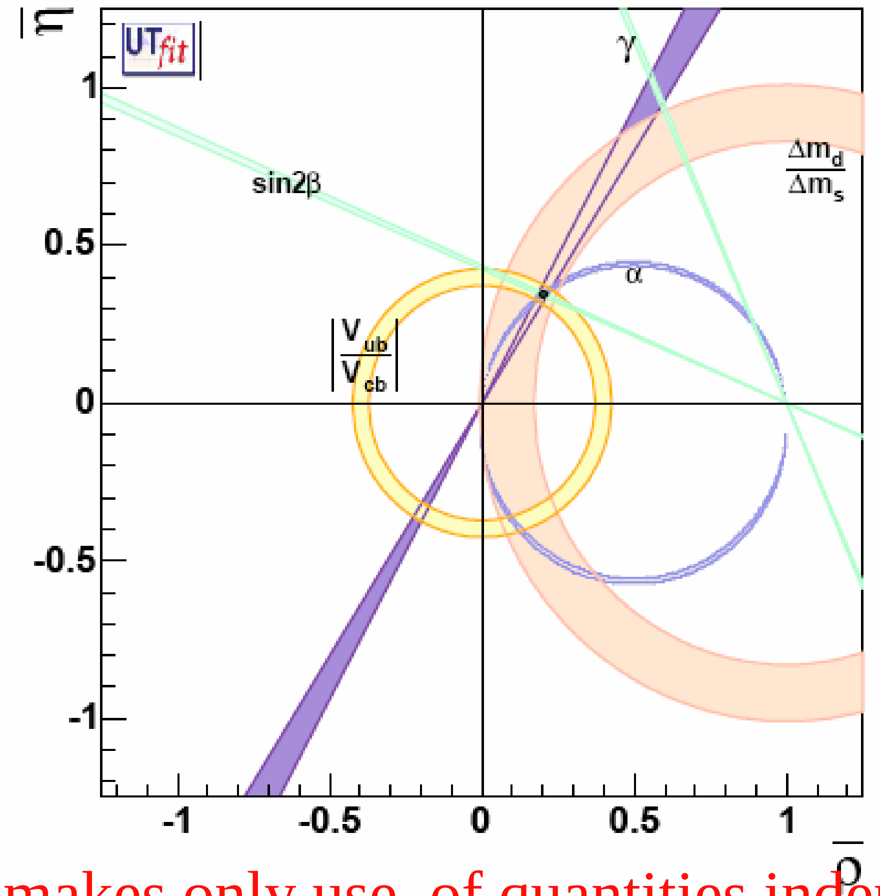
- The physics case for a high luminosity B Factory is clearly established
- The SuperB accelerator concept allows to reach and exceed the 10^{36} threshold
- There is a growing international interest and participation
- A conceptual design report will be available in early 2007 for review
- Next issues are: **site, money**

Possible site: Tor Vergata Campus



BACKUP

UNIVERSAL UT fit with 50 ab^{-1}



Universal fit makes only use of quantities independent of NP contributions within MFV

Extrapolation at high Lumi

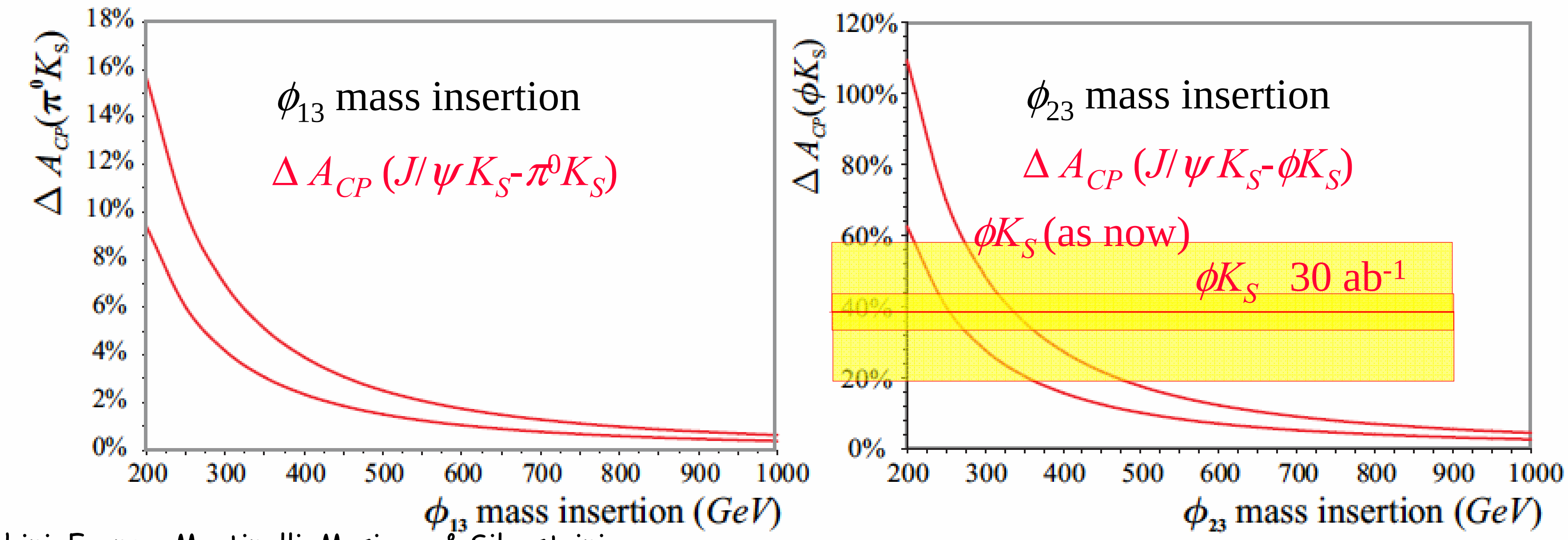
CPV in Rare Decays		e^+e^- Precision		
Measurement	Goal	3/ab	10/ab	50/ab
$S(B^0 \to \phi K_S^0)$	$\approx 5\%$	16%	8.7%	3.9%
$S(B^0 \to \eta' K_S^0)$	$\approx 5\%$	5.7%	3%	1%
$S(B^0 \to K_S^0 \pi^0)$		8.2%	5%	4%
$S(B^0 \to K_S^0 \pi^0 \gamma)$	SM: $\approx 2\%$	11%	6%	4%
$A_{CP}(b \to s\gamma)$	SM: $\approx 0.5\%$	1.0%	0.5%	0.5%
$A_{CP}(B \to K^* \gamma)$	SM: $\approx 0.5\%$	0.6%	0.3%	0.3%

CAVEAT on PENGUINS

Some effects seen in $b \rightarrow s s \bar{s}$ by Belle/*BABAR* could appear intriguing, but …

- Belle /*BABAR* results on specific modes are not in detailed agreement
- There are non-negligible SM theory uncertainties in many modes
- Vulnerability will remain even if results in the next few years reach 4+σ

Better look to some clean mode. Example:



Ciuchini, Franco, Martinelli, Masiero, & Silvestrini

$b \to s l^+ l^-$ precision measurements

New Physics – $K^{(*)}\ l^+l^-$, sl^+l^-		**e^+e^- Precision**			
Measurement	**Goal**	**3/ab**	**10/ab**	**50/ab**	**100/ab**
$\mathcal{B}(B \to K\mu^+\mu^-) / \mathcal{B}(B \to Ke^+e^-)$	SM: 1	~8%	~4%	~2%	~1.5%
$A_{CP}(B \to K^* l^+l^-)$ (all) (high mass)	SM: < 0.05%	~6% ~12%	~3% ~6%	~1.5% ~3%	~1.1% ~2%
$A^{FB}(B \to K^* l^+l^-) : \hat{s}_0$	SM: ±5%	~20%	~9%	9%	
$A^{FB}(B \to s l^+l^-) : \hat{s}_0$		27%	15%	6.7%	5.0%
$A_{FB}\ (B \to s l^+l^-) : C_9, C_{10}$		36-55%	20-30%	9-13%	7-10%

Rare Decays

MEASUREMENT	Goal	3/ab	10/ab	50/ab	100/ab
$\mathrm{B}(B \to D^* \tau\nu)$	SM: B: 8×10^{-3}	10.2%	5.6%	2.5%	
$\mathrm{B}(B \to s\,\nu\nu) K, K^*$	SM:Theory ~5% 1 excl: 4×10^{-6}	$\sim 1\sigma$	$>3\sigma$	$>4\sigma$	$>5\sigma$
$\mathrm{B}(B \to invisible)$		$<2 \times 10^{-6}$	$<1 \times 10^{-6}$	$<4 \times 10^{-7}$	$<2.5 \times 10^{-7}$
$\mathrm{B}(B_d \to \mu\mu)$	$\sim 8 \times 10^{-11}$	$<3 \times 10^{-8}$	$<1.6 \times 10^{-8}$	$<7 \times 10^{-9}$	$<5 \times 10^{-9}$
$\mathrm{B}(B_d \to \tau\tau)$	$\sim 1 \times 10^{-8}$	$<1 \times 10^{-3}$	$O(10^{-4})$	?	?
$\mathrm{B}(\tau \to \mu\gamma)$ now< 4.2 10^{-8} $\leq 1/\sqrt{\int L dt}$					<3.4 10^{-9}
$\mathrm{B}(\tau \to \mu Ks)$ now < 4.910^{-8}					<1.25 10^{-10}