The scientific case for Super Flavor Factories

XXXVII International Meeting on Fundamental Physics
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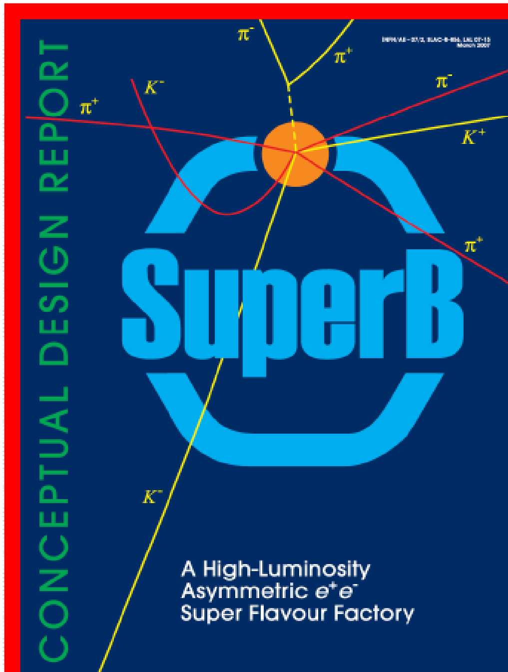
Outline

- The Physics Case
- Accelerator aspects
- Detector design
- The SuperB collaboration

Master references for this talk



3 main Chapters:
Physics case
Detector
Machine
444 pages 320 signers
~80 institutions

Special specific workshop
to answer the IRC questions on physics and sharpen the physics case

Proceedings
of
Super$B$ Workshop VI

New Physics
at the
Super Flavor Factory

Valencia, Spain
January 7-15, 2008

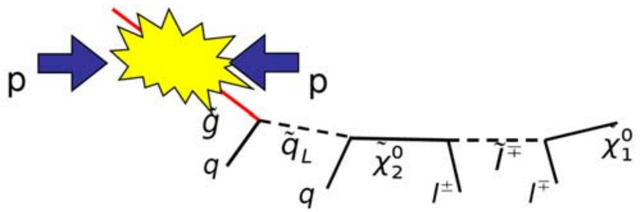
49 signers
~24 institutions

…and references therein

The *SuperB* programme in one slide

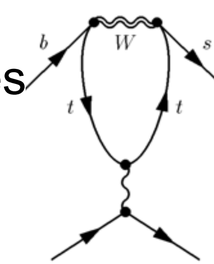
- New Physics (NP) is expected beyond the Standard Model
  - at what scale Λ? 0.5,1, 10…10^{16} TeV?
  - quantum stabilization of the Electroweak Scale suggests $\Lambda \sim 1$ TeV
    - same motivation as the LHC!

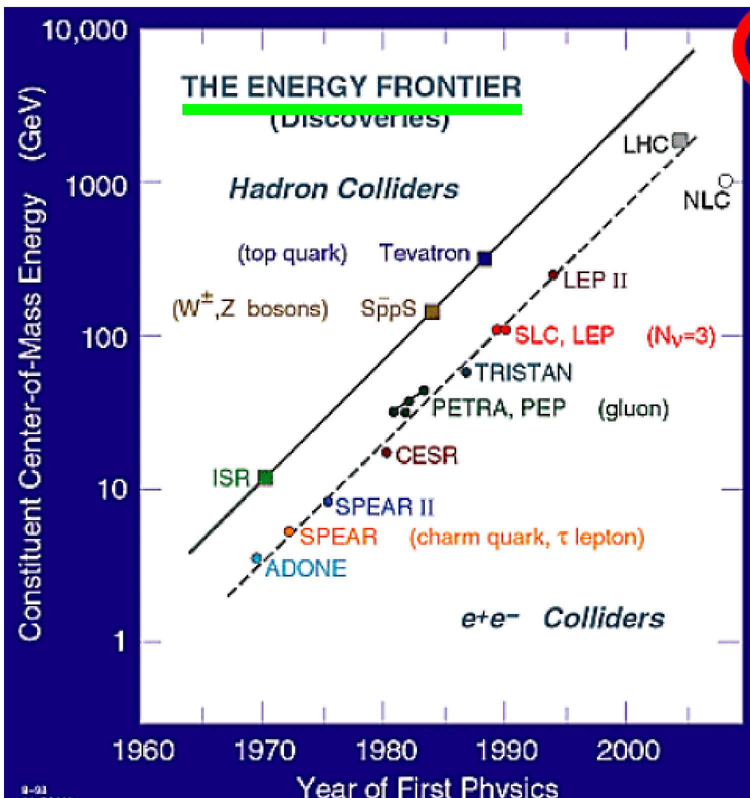
The quest for New Physics: two paths

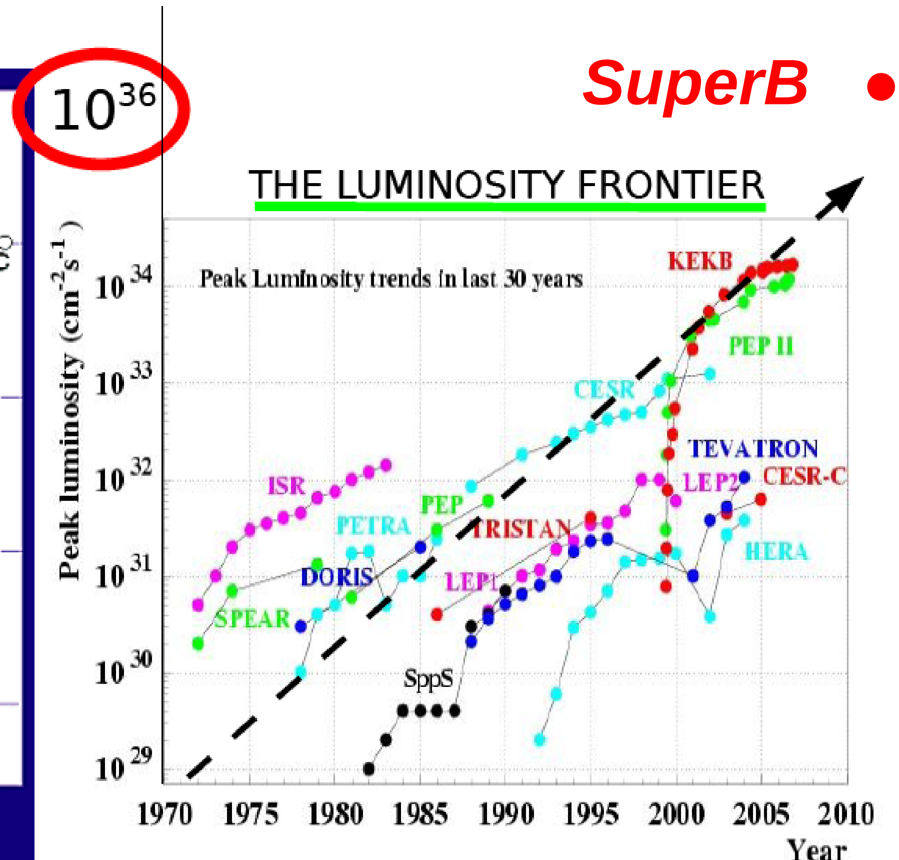


Produce new ***real*** heavy particles
Crucial is CoM energy

Reveal new ***virtual*** heavy particles
via their effect in quantum loops
Crucial is precision ➔ luminosity







The *SuperB* programme in one slide

- New Physics (NP) is expected beyond the Standard Model
  - at what scale Λ? 0.5,1, 10…10^{16} TeV?
  - quantum stabilization of the Electroweak Scale suggests $\Lambda \sim 1$ TeV
    - same motivation as the LHC!
- Two scenarios:
  - LHC finds New Physics (Λ is known)
    - SuperB can measure the flavour couplings, study the flavour structure of NP, search for still heavier states
  - The NP scale is above the LHC reach
    - look for indirect NP signals, understand where they may come from, exclude regions in parameter space, up to $\Lambda \sim 10$TeV, or more
- *Complementary* to LHC
  - Many rare decay final states are only accessible to SuperB
  - Sensitive to off-diagonal terms in the squark mixing matrix.
  - Test *CP*, *CPT*, and Lepton Flavour Violation (LFV) in τ decay, τ anomalous magnetic moment.
  - Search for *CP* (and *CPT*) violation in *D* decays.

Data sample

- The above is feasible with a dataset *two order of magnitudes* larger than current *B* factories
  - i.e., 55-110 Billion $B\bar{B}$ pairs
    - similar numbers of D mesons and τ leptons
- i.e., 75 ab^{-1} collected at the Υ(4S) in 5 years at design lumi ***if***:
  - $\mathcal{L}=10^{36}cm^{-2}s^{-1}$, 100x today's best
  - efficiency as high as in present *B* factories (new Snowmass year ~$1.4\cdot10^{7}$s)
- machine backgrounds similar to *B* factories (or lower)
- ability to run at
  - lower energies (τ, charm)
  - higher energies (B_s)
  - with polarized beams
- All of this with reasonable electricity bill

In fact, a **Super Flavour Factory**!

B Physics @ Υ(4S)

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ $(J/\psi K^0)$	0.018	0.005 (†)
$\cos(2\beta)$ $(J/\psi K^{*0})$	0.30	0.05
$\sin(2\beta)$ (Dh^0)	0.10	0.02
$\cos(2\beta)$ (Dh^0)	0.20	0.04
$S(J/\psi \pi^0)$	0.10	0.02
$S(D^+D^-)$	0.20	0.03
$S(\phi K^0)$	0.13	0.02 (∗)
$S(\eta' K^0)$	0.05	0.01 (∗)
$S(K_S^0 K_S^0 K_S^0)$	0.15	0.02 (∗)
$S(K_S^0 \pi^0)$	0.15	0.02 (∗)
$S(\omega K_S^0)$	0.17	0.03 (∗)
$S(f_0 K_S^0)$	0.12	0.02 (∗)
γ $(B \to DK,\ D \to CP$ eigenstates)	$\sim 15^\circ$	2.5°
γ $(B \to DK,\ D \to$ suppressed states)	$\sim 12^\circ$	2.0°
γ $(B \to DK,\ D \to$ multibody states)	$\sim 9^\circ$	1.5°
γ $(B \to DK$, combined)	$\sim 6^\circ$	1–2°
α $(B \to \pi\pi)$	$\sim 16^\circ$	3°
α $(B \to \rho\rho)$	$\sim 7^\circ$	1–2° (∗)
α $(B \to \rho\pi)$	$\sim 12^\circ$	2°
α (combined)	$\sim 6^\circ$	1–2° (∗)
$2\beta + \gamma$ $(D^{(*)\pm}\pi^\mp,\ D^\pm K_S^0 \pi^\mp)$	20°	5°

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\lvert V_{cb}\rvert$ (exclusive)	4% (∗)	1.0% (∗)
$\lvert V_{cb}\rvert$ (inclusive)	1% (∗)	0.5% (∗)
$\lvert V_{ub}\rvert$ (exclusive)	8% (∗)	3.0% (∗)
$\lvert V_{ub}\rvert$ (inclusive)	8% (∗)	2.0% (∗)
$\mathcal{B}(B \to \tau\nu)$	20%	4% (†)
$\mathcal{B}(B \to \mu\nu)$	visible	5%
$\mathcal{B}(B \to D\tau\nu)$	10%	2%
$\mathcal{B}(B \to \rho\gamma)$	15%	3% (†)
$\mathcal{B}(B \to \omega\gamma)$	30%	5%
$A_{CP}(B \to K^*\gamma)$	0.007 (†)	0.004 († ∗)
$A_{CP}(B \to \rho\gamma)$	~ 0.20	0.05
$A_{CP}(b \to s\gamma)$	0.012 (†)	0.004 (†)
$A_{CP}(b \to (s+d)\gamma)$	0.03	0.006 (†)
$S(K_S^0 \pi^0 \gamma)$	0.15	0.02 (∗)
$S(\rho^0 \gamma)$	possible	0.10
$A_{CP}(B \to K^*\ell\ell)$	7%	1%
$A^{FB}(B \to K^*\ell\ell)s_0$	25%	9%
$A^{FB}(B \to X_s\ell\ell)s_0$	35%	5%
$\mathcal{B}(B \to K\nu\bar{\nu})$	visible	20%
$\mathcal{B}(B \to \pi\nu\bar{\nu})$	–	possible

Very small number of systematics (†) or theoretically (*) limited measurements

B_s @ Υ(5S), τ and charm Physics

B_s Physics @ Υ(5S)

	with 1 ab^{-1}	Error with 30 ab^{-1}
$\Delta\Gamma$	0.16 ps^{-1}	0.03 ps^{-1}
Γ	0.07 ps^{-1}	0.01 ps^{-1}
β_s from angular analysis	20°	8°
A^s_{SL}	0.006	0.004
A_{CH}	0.004	0.004
$\mathcal{B}(B_s \to \mu^+\mu^-)$	-	$< 8 \times 10^{-9}$
$\lvert V_{td}/V_{ts} \rvert$	0.08	0.017
$\mathcal{B}(B_s \to \gamma\gamma)$	38%	7%
β_s from $J/\psi\phi$	10°	3°
β_s from $B_s \to K^0\bar{K}^0$	24°	11°

τ Physics

	Sensitivity
$\mathcal{B}(\tau \to \mu\,\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to e\,\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to \mu\,\mu\,\mu)$	2×10^{-10}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \to e\eta)$	6×10^{-10}
$\mathcal{B}(\tau \to \ell K^0_S)$	2×10^{-10}

Charm mixing and CPV

Mode	Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$D^0 \to K^+K^-$	y_{CP}	$2\text{–}3 \times 10^{-3}$	5×10^{-4}
$D^0 \to K^+\pi^-$	y'_D	$2\text{–}3 \times 10^{-3}$	7×10^{-4}
	x'^2_D	$1\text{–}2 \times 10^{-4}$	3×10^{-5}
$D^0 \to K^0_S\pi^+\pi^-$	y_D	$2\text{–}3 \times 10^{-3}$	5×10^{-4}
	x_D	$2\text{–}3 \times 10^{-3}$	5×10^{-4}
Average	y_D	$1\text{–}2 \times 10^{-3}$	3×10^{-4}

Charm FCNC

	Sensitivity
$D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$	1×10^{-8}
$D^0 \to \pi^0e^+e^-$, $D^0 \to \pi^0\mu^+\mu^-$	2×10^{-8}
$D^0 \to \eta e^+e^-$, $D^0 \to \eta\mu^+\mu^-$	3×10^{-8}
$D^0 \to K^0_S e^+e^-$, $D^0 \to K^0_S\mu^+\mu^-$	3×10^{-8}
$D^+ \to \pi^+e^+e^-$, $D^+ \to \pi^+\mu^+\mu^-$	1×10^{-8}
$D^0 \to e^\pm\mu^\mp$	1×10^{-8}
$D^+ \to \pi^+e^\pm\mu^\mp$	1×10^{-8}
$D^0 \to \pi^0e^\pm\mu^\mp$	2×10^{-8}
$D^0 \to \eta e^\pm\mu^\mp$	3×10^{-8}
$D^0 \to K^0_S e^\pm\mu^\mp$	3×10^{-8}
$D^+ \to \pi^-e^+e^+$, $D^+ \to K^-e^+e^+$	1×10^{-8}
$D^+ \to \pi^-\mu^+\mu^+$, $D^+ \to K^-\mu^+\mu^+$	1×10^{-8}
$D^+ \to \pi^-e^\pm\mu^\mp$, $D^+ \to K^-e^\pm\mu^\mp$	1×10^{-8}

Any Golden channels for NP?

- As shown by the *B* factories, a *huge* number of measurements can be performed in the clean environment of $e^+e^-\rightarrow\Upsilon(4S)\rightarrow B\bar{B}$
- Most are statistics-limited, and worth to be studied with 75ab^{-1}
  - in most cases, large control samples can further reduce syst./theor. errors
- We do not know what NP is out there
  - having many observables is a feature!

Illustrative example of golden channels in different scenarios

	H^+ high tanβ	Minimal FV	Non-Minimal FV (1-3)	Non-Minimal FV (2-3)	NP Z-penguins	Right-Handed currents
$\mathcal{B}(B\rightarrow X_s\gamma)$		■		●		●
$A_{CP}(B\rightarrow X_s\gamma)$				■		●
$\mathcal{B}(B\rightarrow \tau\nu)$	■-CKM					
$\mathcal{B}(B\rightarrow X_s l^+l^-)$				●	●	●
$\mathcal{B}(B\rightarrow K\nu\overline{\nu})$				●	■	
$S(K_S\pi^0\gamma)$						■
β			■-CKM			●

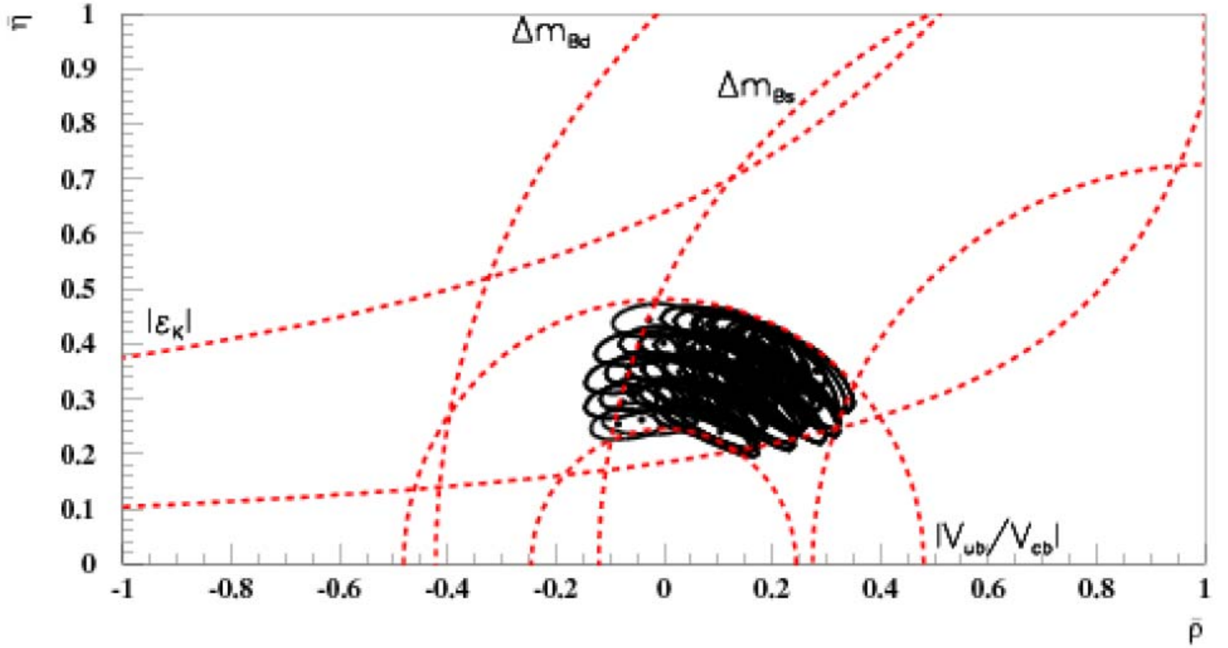
■ Golden mode for a given scenario

● Non-golden, but still sensitive to deviations from the SM

-CKM requires high precision on CKM parameters (obtainable with SuperB)

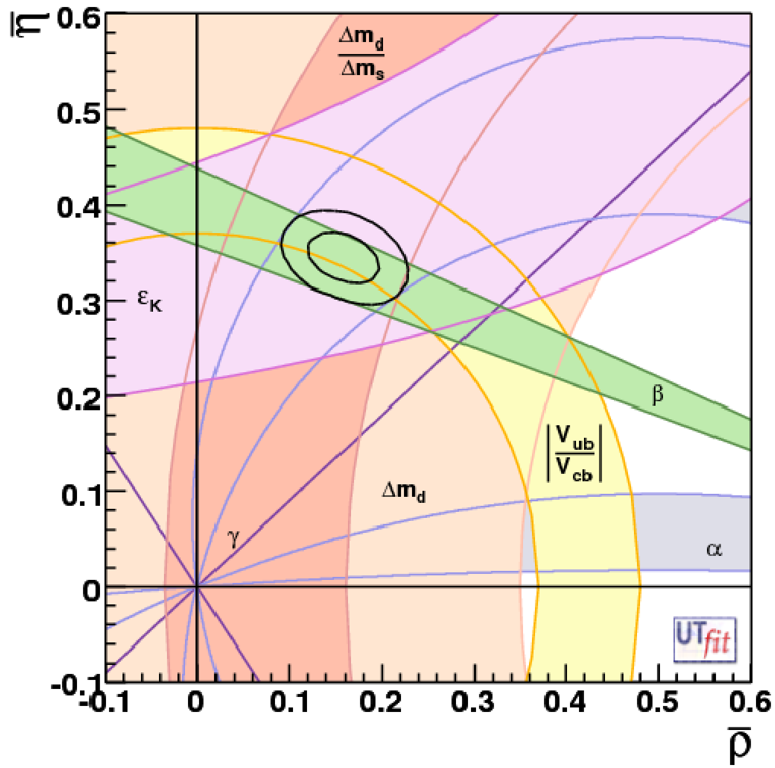
Prelude: CKM at 1%

The UT before the B factories



Prelude: CKM at 1%

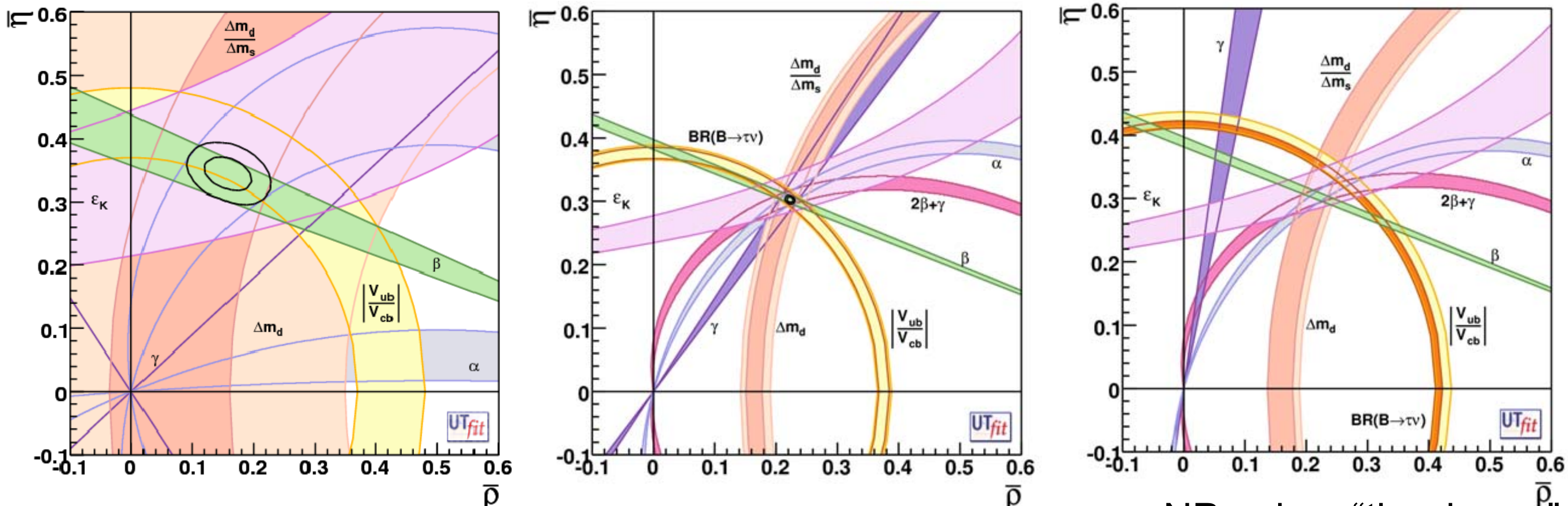
The UT now…



Prelude: CKM at 1%

Today

SuperB ($50ab^{-1}$)+lattice improvements

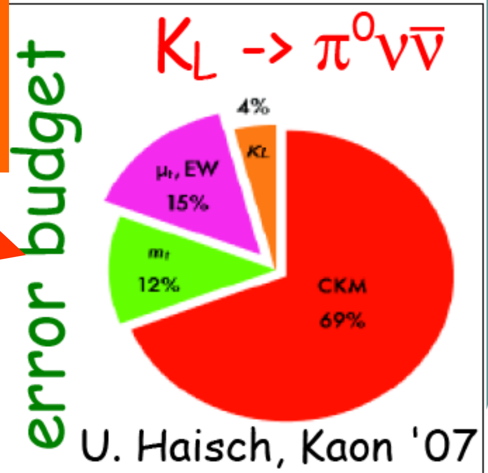


SM, a.k.a. “the nightmare”

NP, a.k.a. “the dream”

Parameter	SM Fit today	SM Fit at Super$B$
$\bar{\rho}$	0.163 ± 0.028	± 0.0028
$\bar{\eta}$	0.344 ± 0.016	± 0.0024
α (°)	92.7 ± 4.2	± 0.45
β (°)	22.2 ± 0.9	± 0.17
γ (°)	64.6 ± 4.2	± 0.38

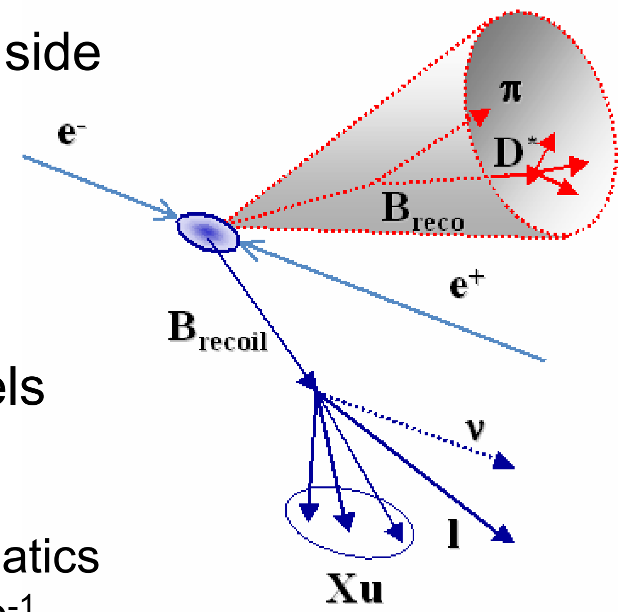
Improving CKM crucial for NP searches, not only in the B sector



BEWARE: in some cases (e.g., V_{ub}) a consistent reduction of the theoretical error is needed (and should be possible)

Digression: *B* Beams at the Υ(4S)

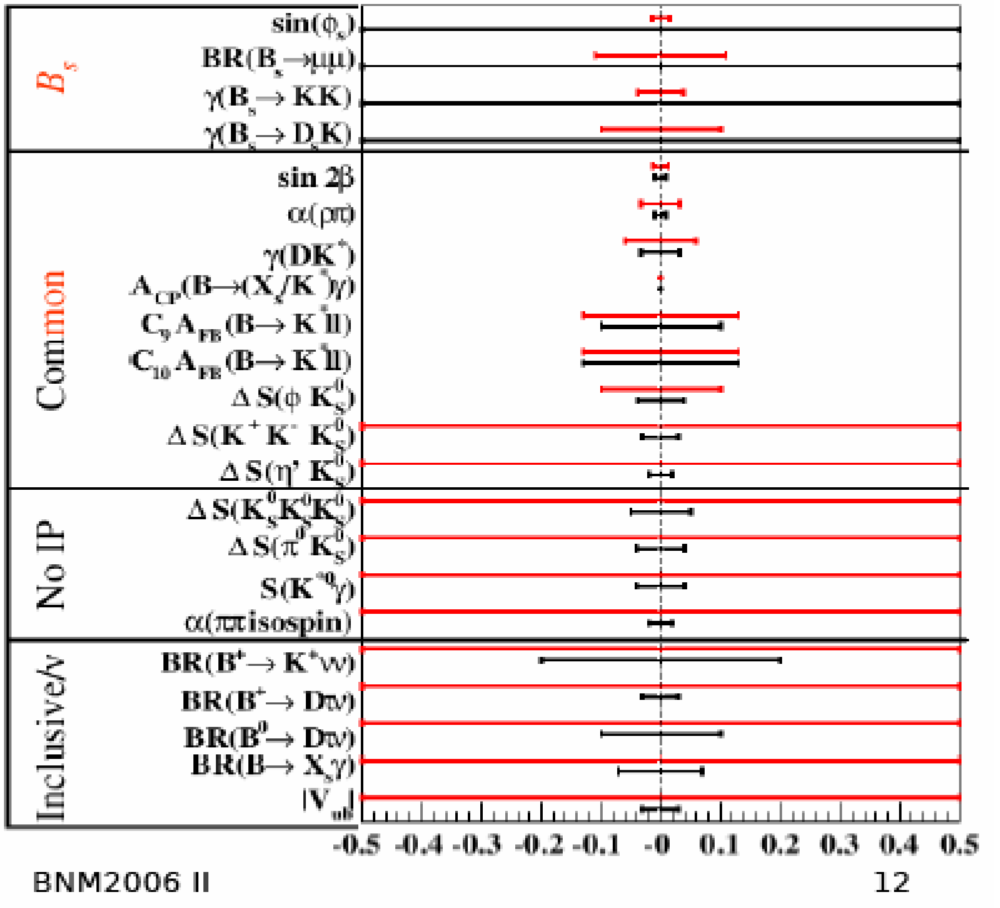
- A technique already used at the *B* factories
  - exploit clean environment at e^+e^- collider and quantum correlation of $\Upsilon(4S)\to B\bar{B}$
- Fully reconstruct one the two *B*'s in hadronic modes
- Obtain a high purity *B* beam on the opposite side
  - (almost) completely eliminate continuum background
  - *B* tracks already assigned
    - much reduced combinatorics in recoil
  - known kinematics, charge and flavour
- *Unique tool* to study rare decays and channels with missing energy
  - few per mille efficiency
  - trade loss in statistics with reduction in systematics
  - perfect tool for SuperB: > 10^7 recoil Bs in $10ab^{-1}$
  - V_{ub}, $B\to\tau\nu$, $B\to K^{(*)}\nu\nu$, $b\to s\gamma$ ...



SuperB vs. LHCb

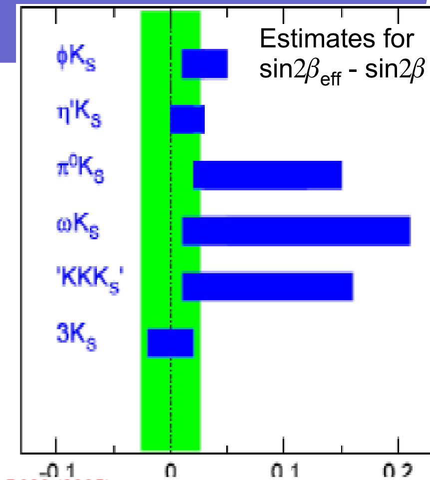
SuperB (3 years, 50 ab^{-1}) and LHCb (5 year, 10 fb^{-1})

- SuperB
  - has no handle on B_s time-dependent measurements
  - is much better in modes with neutrals
  - has no competition in channels with missing energy
- Programs are largely complementary



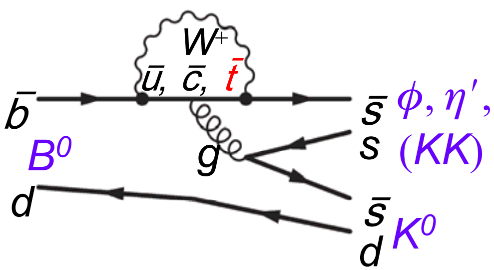
NP in $|\Delta F|=1$ transitions

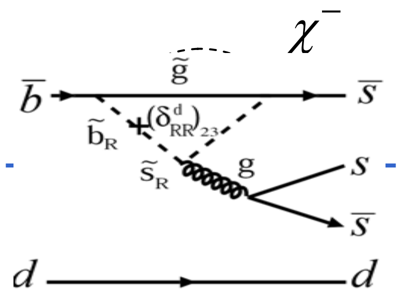
- Rare FCNC processes mediated in the SM by loops can receive significant contributions from NP diagrams of the same order
- NP can modify the expected SM amplitudes and asymmetries
- Need to look in as many different modes (and observables) as possible

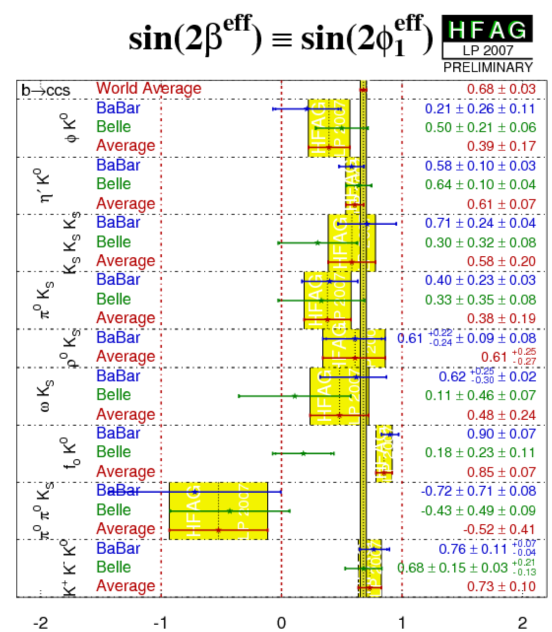


QCDF: (Beneke, PLB620 (2005), 143-150, Cheng et al., PRD72 (2005) 094003 etc.
SCET: (Williamson & Zupan, hep-ph/0601214)

SU(3): Grossman *et al*, PRD68 (2003) 015004; Gronau *et al*, PRD71 (2005) 074019; …).



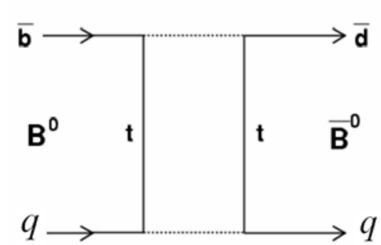


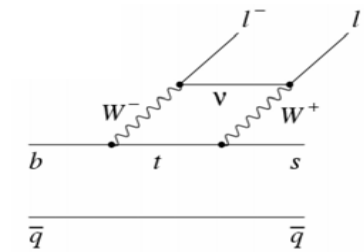


- e.g. β_{eff} measured in $b \to s$ penguin decays can be different from b in $b \to c\bar{c}s$
- SM corrections to the dominant loop diagram must be carefully considered
  - O(0.01) uncertainties for $\eta' K_s$ and $3K_s$
  - SM corrections tend to prefer $\sin 2\beta_{eff}$ - $\sin 2\beta$
  - Data show opposite trend (but discrepancy almost vanished now)
- With SuperB @75/ab exp. error at level of current theor. prediction (or below)

NP in |ΔF|=2 transitions

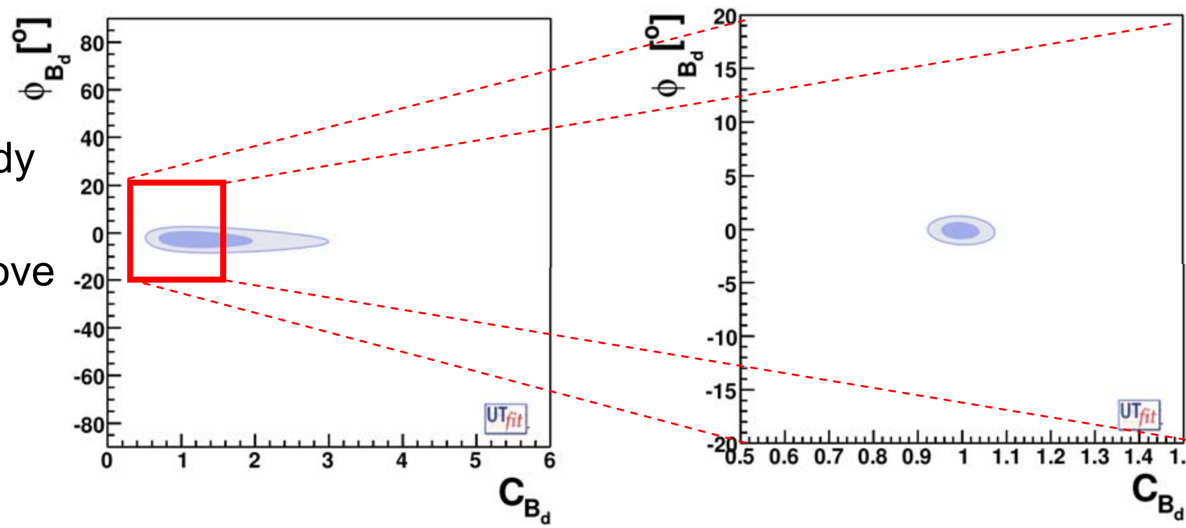
- ΔF=2 transition mediated by box diagrams (mixing or FCNC)
- again, NP can contribute to these processes
  - parameterize NP as:





$$C_q e^{i\phi_q} = \frac{\langle B_q^0 \mid H_{SM+NP} \mid \overline{B}_q^0 \rangle}{\langle B_q^0 \mid H_{SM} \mid \overline{B}_q^0 \rangle}$$

- In the SM $C_q=1$, $\phi_q=0$
- present measurements already constrain NP in B_d mixing
- SuperB will significantly improve such constraint
  - note the different scales…



Same-sign dilepton asymmetry

Minimal Flavour Violation

- All existing measurements are consistent with the SM predictions
  - absence of FCNC, absence of lepton/baryon number violations, CP asymmetries …
- Extensions of the SM at the weak scale -needed to address the hierarchy problem- must incorporate this evidence
- Generic NP models couple to flavour differently than the SM
- One attractive approach to prevent large new flavour signals is to require that the model be

MINIMALLY FLAVOUR VIOLATING (MFV)

Gabrielli, Giudice, NPB433
Buras et al, NPB500
D'Ambrosio et al., NPB645

- Allow only operators already in the SM, and suppress new contributions to them by the same CKM factors that suppress the SM contributions
  - In this way, new MFV physics changes SM predictions for FCNC processes by O(1) at most
- Only certain classes of the minimal SUSY Standard Model (MSSM) are MFV theories.
  - mSUGRA, 1HDM/2HDM …

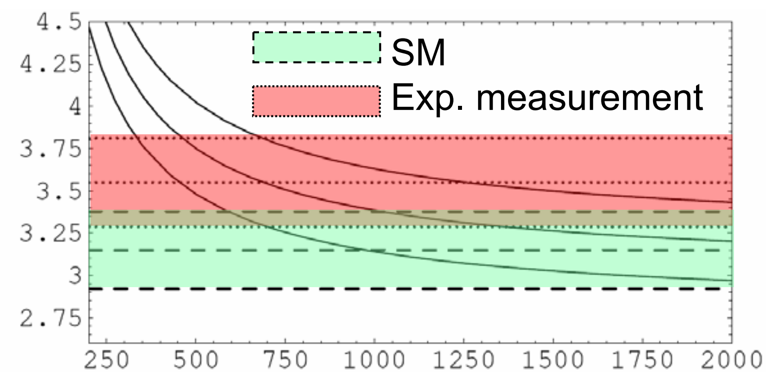
Definitely, a “worst case” scenario for NP searches

A FEW EXAMPLES

Rare radiative decays: $\mathcal{B}(B\to X_s\gamma)$

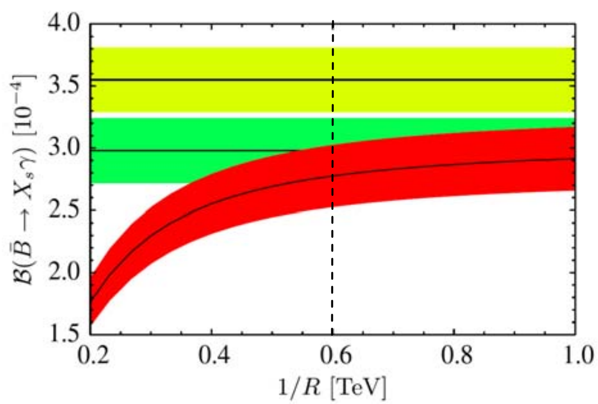
- Today's WA: $\mathcal{B}(B\to X_s\gamma)|_{E_\gamma>1.6\mathrm{GeV}} = (3.55\pm0.26)10^{-4}$
  - recoil analysis (both from semileptonic and hadronic B_{reco}) to control experimental uncertainties ➔ ~3% combined systematic error
  - theory error mainly from extrapolation of minimum E_γ (1.9→1.6GeV)
    - improved measurement of photon spectrum will reduce uncertainty
- Stringent constraints from SuperB

- $\mathcal{B}(B\to X_s\gamma)$ vs. Higgs mass in 2HDM



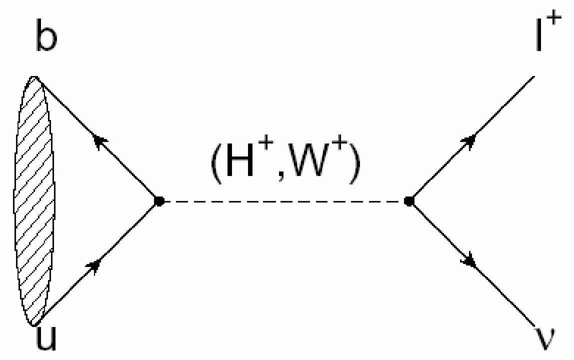
- In fact, already most stringent bound: M_{H+}>295GeV @95%CL

- $\mathcal{B}(B\to X_s\gamma)$ vs. "compactification radius" of minimal universal extra-dimension model (mACD)



- 1/R>600GeV@95%CL

Higgs-mediated NP in MFV at large tanβ: $\mathcal{B}(B\to\ell\nu)$

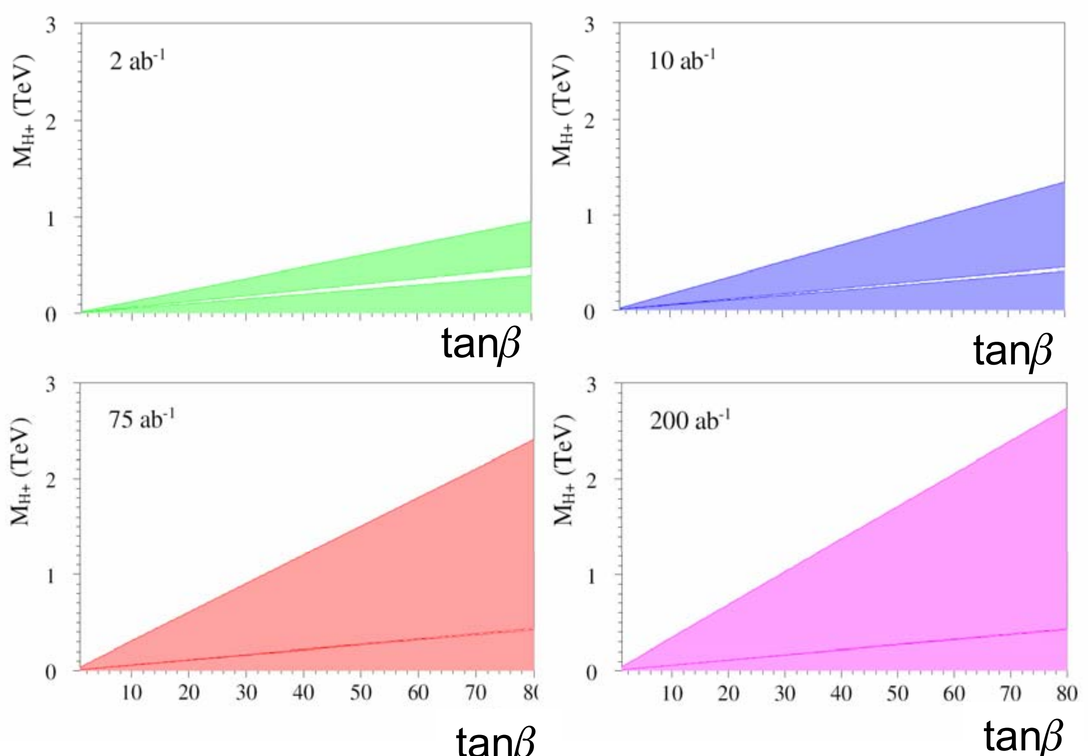


SUSY Higgs contribution in 2HDM

$$r_H \equiv \frac{\mathcal{B}_{SM+NP}}{\mathcal{B}_{SM}} = \left(1-\frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

Similar expression holds for MSSM

- $B\to\mu\nu$ *starts contributing @75ab^{-1}*
- $B\to\tau\nu$ systematically limited beyond *75ab^{-1}*
- search capability for large tanβ up to >2TeV

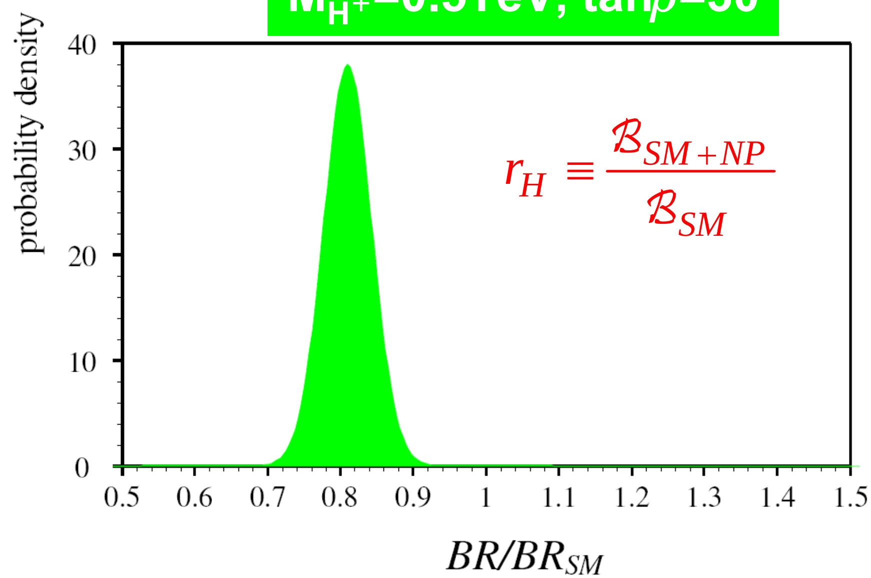


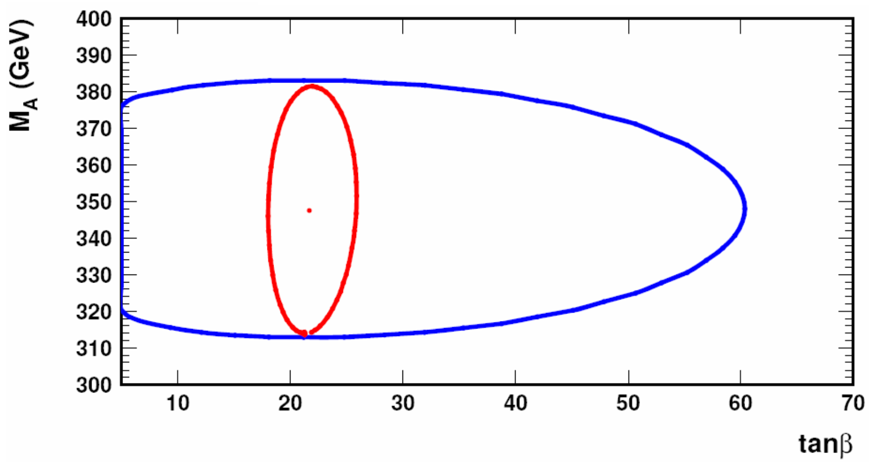
IMPORTANCE OF HAVING LARGE SAMPLES

Or, if LHC discovers SuperSymmetry:

…SuperB can measure the couplings

M_{H^+}=0.5TeV, tanβ=30



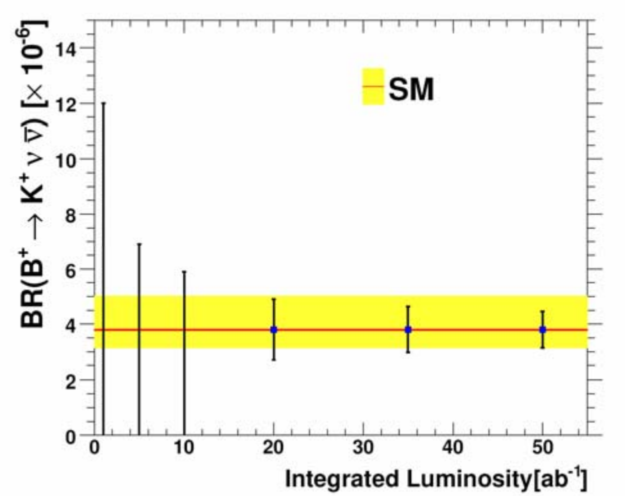


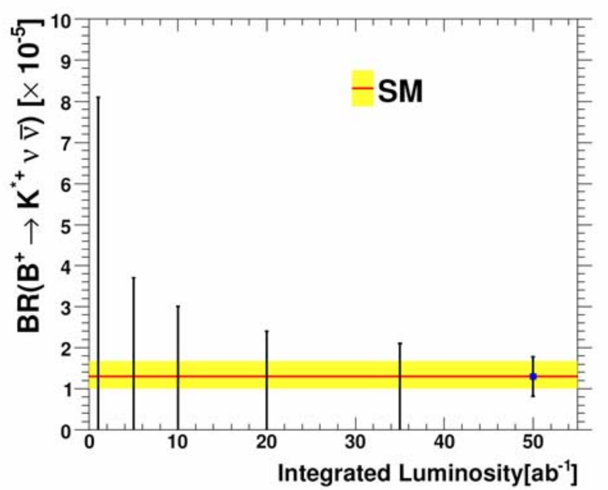
- LHC ALONE
- LHC+EW constraints + SuperB

$b \rightarrow s$ invisible: NP reach vs. luminosity

G. Isidori, arXiv:hep-ph/0009024

- $B \to K^{(*)} \nu\bar{\nu}$ can probe NP in Z^0 penguins
- Best exp. bound: $BF(B^+ \to K^+ \nu\bar{\nu}) < 14 \cdot 10^{-6}$
- SM prediction: $4 \cdot 10^{-6}$
- as usual, recoil analysis
  - improved *SuperB* hermeticity crucial
  - 30% bkg. reduction corresponds to 1/0.7, or ~40% more luminosity





IMPORTANCE OF HAVING LARGE SAMPLES

A non-MFV model: MSSM + Mass Insertions

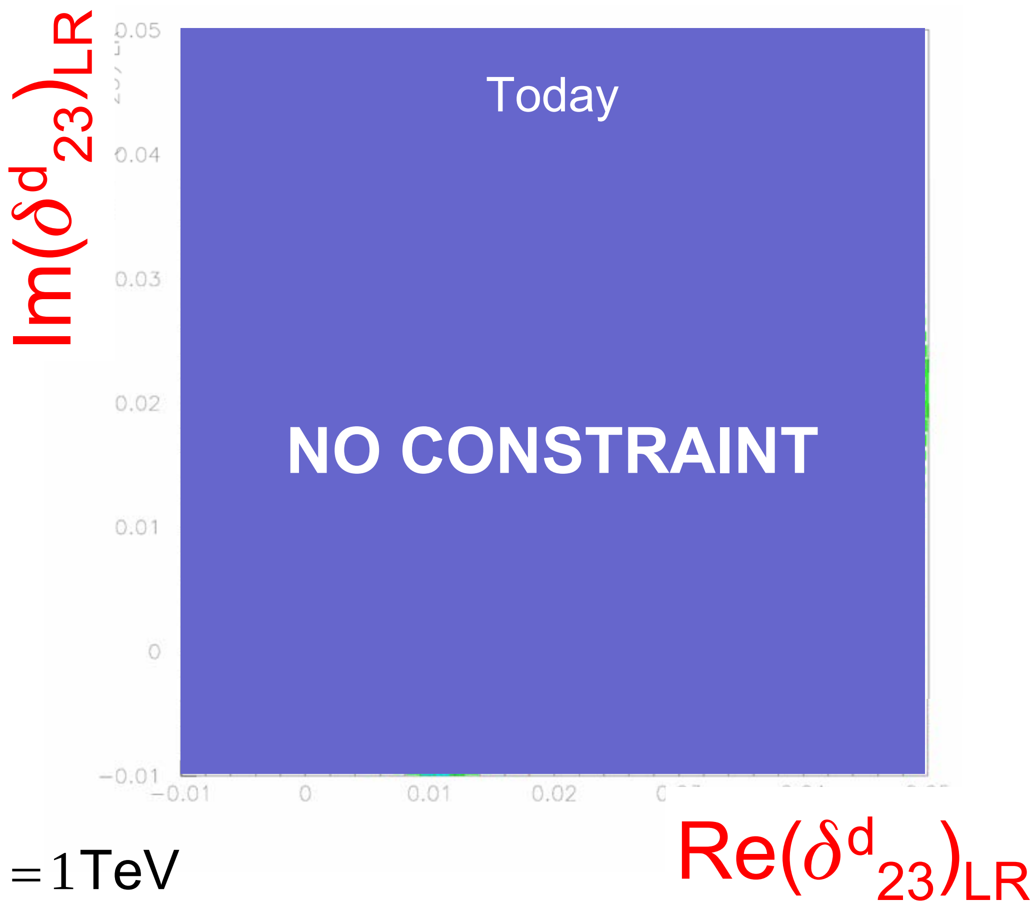
- The SM encodes quark mixing in the CKM matrix, ν mixing in the PNMS matrix, SUSY… in the SCKM matrix, V_{SCKM}
  - LHC measures diagonal elements of V_{SCKM}
  - SuperB can measure off-diagonal elements
- MSSM with generic soft SUSY-breaking terms, but dominant gluino contributions only

$$(\tilde{q}_i)_A \; - - - \overset{(\delta^q_{ij})_{AB}}{\times} - - - \; (\tilde{q}_j)_B$$

$$q = \{u, d\}, \quad (A, B) = \{L, R\}$$
$$(i, j) = \{1, 2, 3\}$$

  - All flavour-changing NP effects in the squark propagators (“Mass Insertions”)
    - NP scale SUSY mass: $\Lambda \sim \tilde{m} \sim m_{\tilde{g}}$
    - flavour-violating coupling: $(\delta^q_{ij})_{AB} \equiv \dfrac{(M^2_{ij})^q_{AB}}{\tilde{m}^2}$

Example: $(\delta^d_{23})_{LR}$ when Λ=1TeV



$A_{CP}(B \to X_s \gamma)$

$BF(B \to X_s \gamma)$

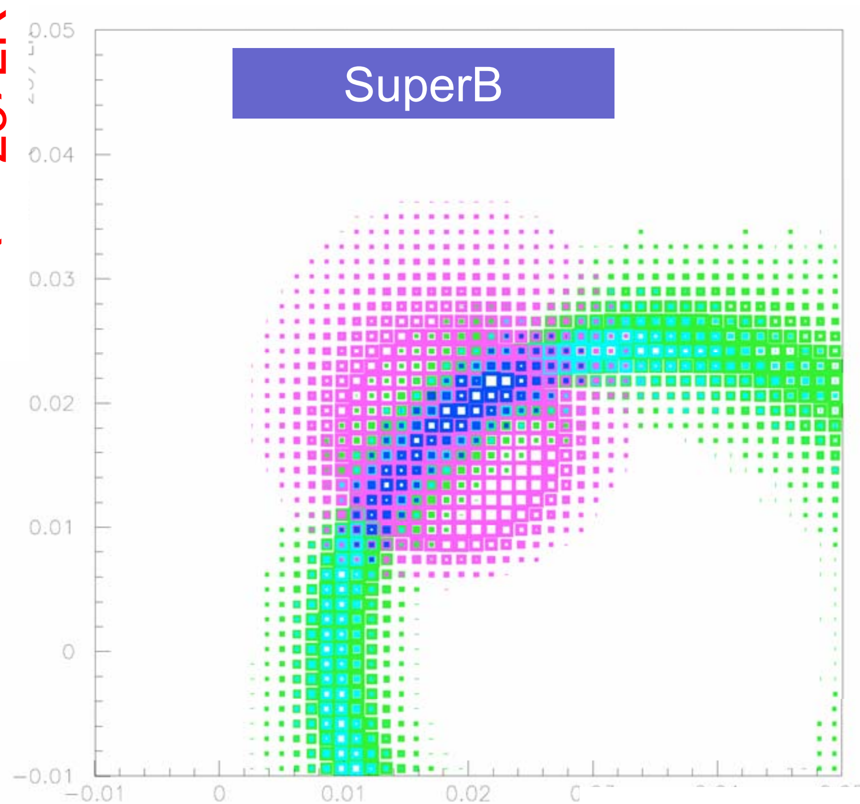
$A_{CP}(B \to X_s \ell^+ \ell^-)$

All together

$\Lambda = m_{\tilde{g}} = m_{\tilde{q}} = 1\mathrm{TeV}$

Example: $(\delta^d_{23})_{LR}$ when Λ=1TeV

$\mathrm{Im}(\delta^d_{23})_{LR}$



$\mathrm{Re}(\delta^d_{23})_{LR}$

$A_{CP}(B \to X_s \gamma)$

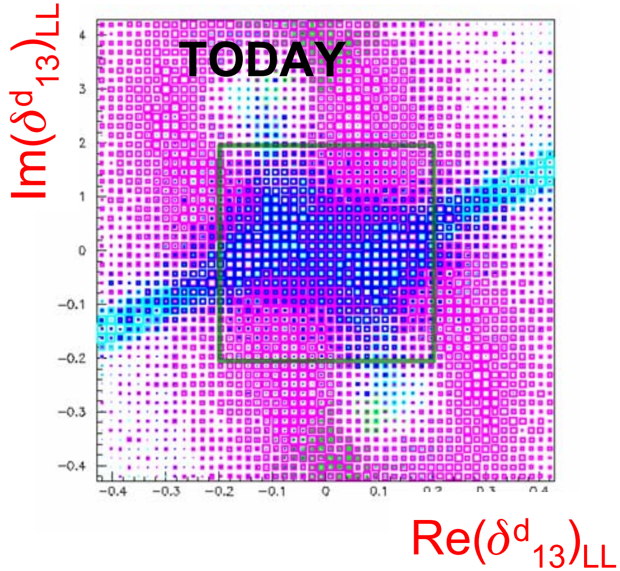
$BF(B \to X_s \gamma)$

$A_{CP}(B \to X_s \ell^+ \ell^-)$

All together

$\Lambda = m_{\tilde{g}} = m_{\tilde{q}} = 1\text{TeV}$

Example: $(\delta^d{}_{13})_{LL}$ when Λ=1TeV

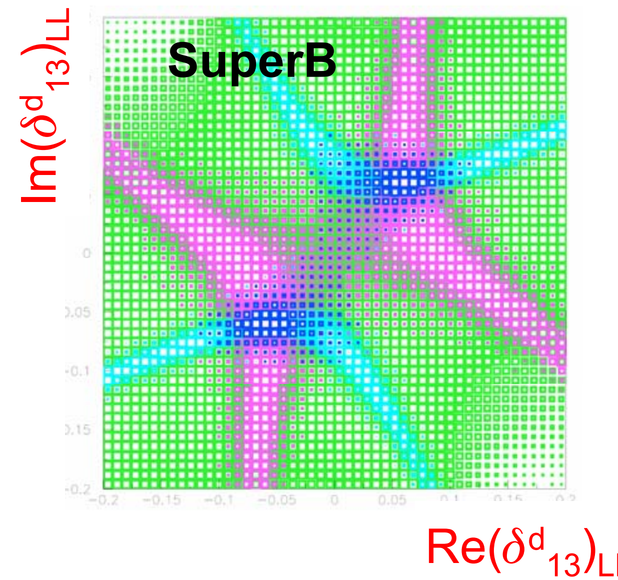


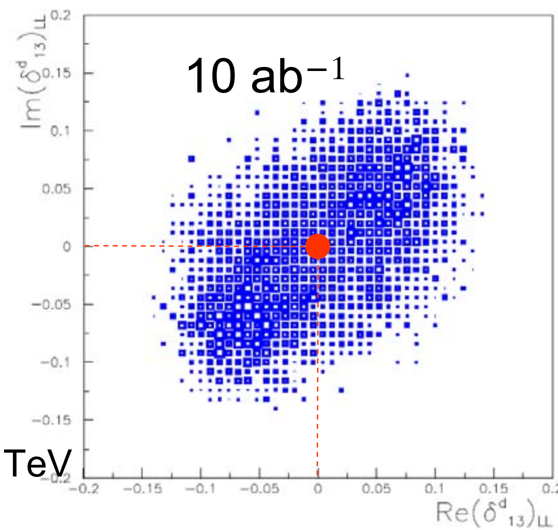
Δ_{m_d} only

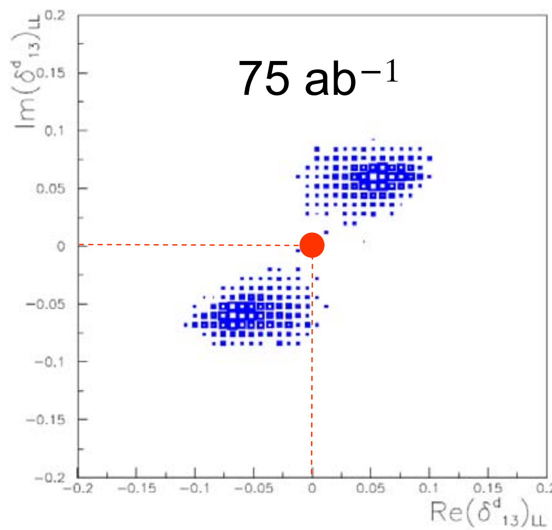
A_{SL} only

β only

All together





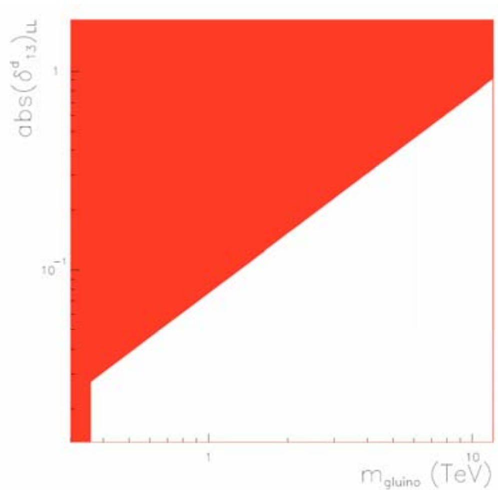


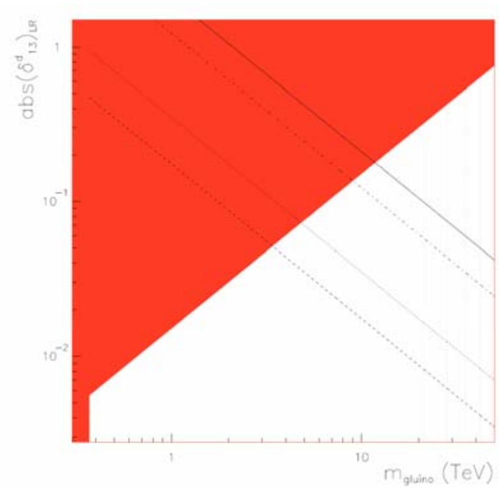
$\Lambda = m_{\tilde{g}} = m_{\tilde{q}} = 1$TeV

SM ➔ (0,0)

IMPORTANCE OF HAVING LARGE SAMPLES

Or, measuring Λ if δ is (O(1))





- Question: if LCH does NOT find NP, *and* the MFV SUSY coupling are "natural" i.e., O(1), what energy scale SuperB is sensitive to?
  - the red area shows regions where the reconstructed MI (δ) is at least 3σ away from 0.
  - If $|\delta|$~1, gluino masses of ~10 TeV can be probed.

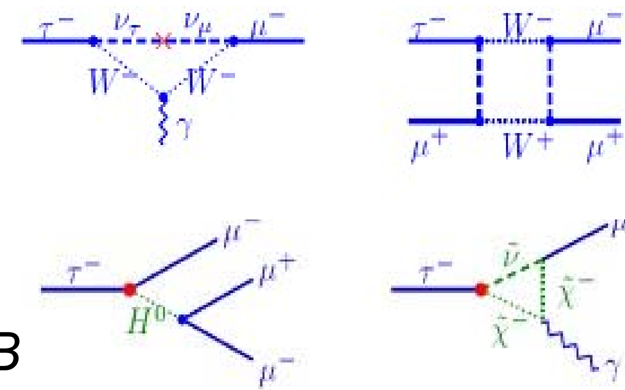
Summary: 75ab^{-1} is the right data sample

- Solid physics case showing that 75ab^{-1} are instrumental in reaching much higher NP sensitivity than 10ab^{-1} (i.e., SuperKEKB)

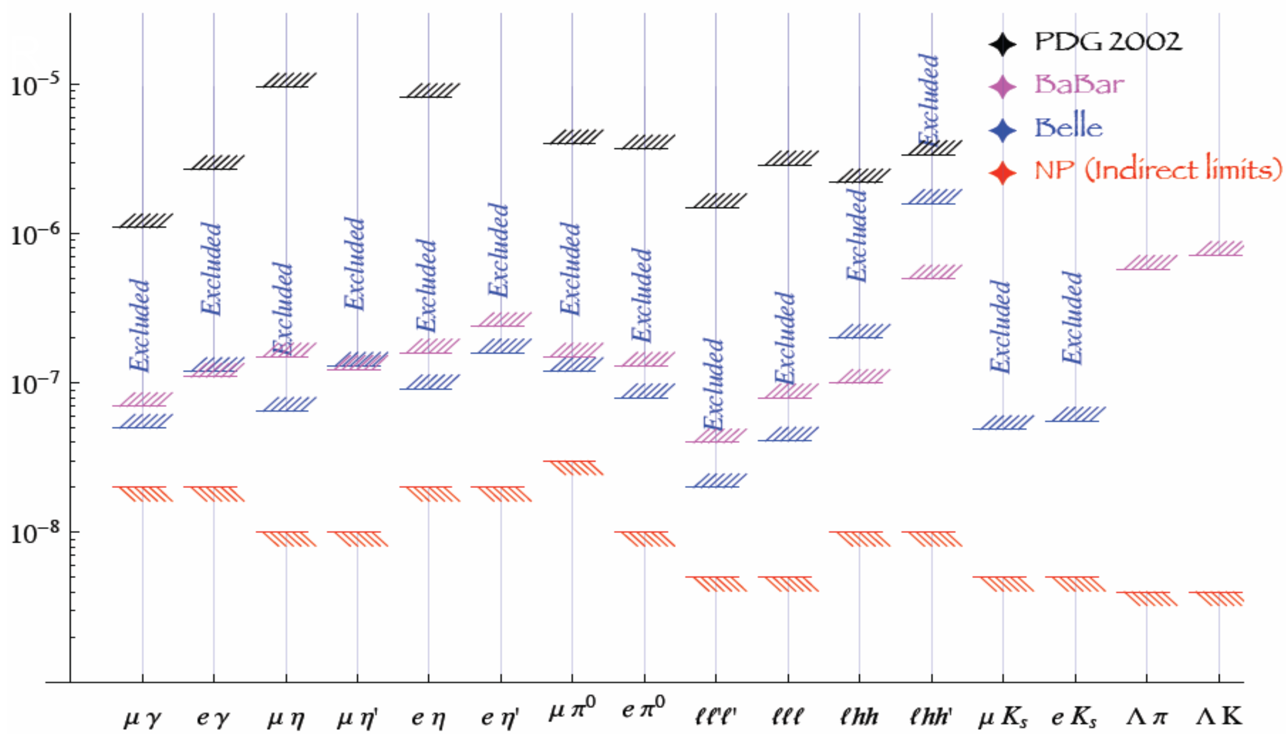
Mode	Sensitivity		
	Current	10 ab^{-1}	75 ab^{-1}
$\mathcal{B}(B \to X_s\gamma)$	7%	5%	3%
$A_{CP}(B \to X_s\gamma)$	0.037	0.01	0.004–0.005
$\mathcal{B}(B^+ \to \tau^+\nu)$	30%	10%	3–4%
$\mathcal{B}(B^+ \to \mu^+\nu)$	X	20%	5–6%
$\mathcal{B}(B \to X_s l^+l^-)$	23%	15%	4–6%
$A_{\rm FB}(B \to X_s l^+l^-)_{s_0}$	X	30%	4–6%
$\mathcal{B}(B \to K\nu\overline{\nu})$	X	X	16–20%
$S(K_S^0\pi^0\gamma)$	0.24	0.08	0.02–0.03

SFF as a τ factory: LFV in τ decays

- LVF negligeably small in the SM
- Could be larger in several SM extensions



- Many limits already pushed down by the *B* factories



SFF as a τ factory: LFV in τ decays

- SuperB sensitivities extrapolated from current *B* factories allow to probe an interesting region
- e.g. exclude MFV predictions

decay	$f = 500$ GeV
$\tau \to e\gamma$	$1 \cdot 10^{-8}$
$\boxed{\tau \to \mu\gamma}$	$\boxed{2 \cdot 10^{-8}}$
$\tau^- \to e^-e^+e^-$	$2 \cdot 10^{-8}$
$\tau^- \to \mu^-\mu^+\mu^-$	$3 \cdot 10^{-8}$

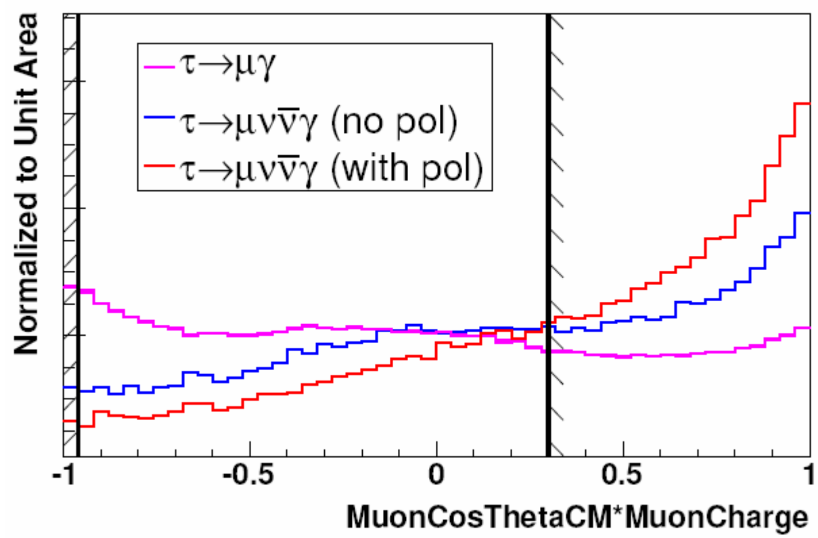
LFV BR upper limit in LHT model

Process	Sensitivity @75 ab^{-1}
$\mathcal{B}(\tau \to \mu\,\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to e\,\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to \mu\,\mu\,\mu)$	2×10^{-10}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \to e\eta)$	6×10^{-10}
$\mathcal{B}(\tau \to \ell K_s^0)$	2×10^{-10}

- Ratio of BR's also sensitive to the NP model

ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{\mathcal{B}(\tau^- \to \mu^-\mu^+\mu^-)}{\mathcal{B}(\tau \to \mu\gamma)}$	$0.4 \ldots 2.3$	$\sim 2 \cdot 10^{-3}$	$0.06 \ldots 0.1$

- Furher improvements possible including beam polarization



Charm Physics

- At the $\Upsilon(4S)$
- at DD threshold
  - in 4months ~0.3ab^{-1} ←→ 1000xCLEO-c, 10 x BESIII

Strong dynamics and CKM measurements @threshold(4GeV)

D decay form factor and decay constant @ 1%
Dalitz structure useful for γ measurement

exclusive V_{ub} ~ few %
syst. error on γ from Dalitz Model <1°

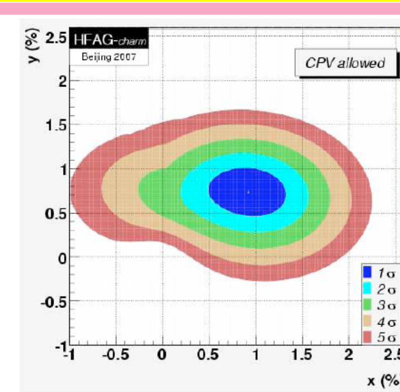
Rare decays FCNC down to 10^{-8}

@threshold(4GeV)

Channel	Sensitivity
$D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$	1×10^{-8}
$D^0 \to \pi^0 e^+e^-$, $D^0 \to \pi^0\mu^+\mu^-$	2×10^{-8}
$D^0 \to \eta e^+e^-$, $D^0 \to \eta\mu^+\mu^-$	3×10^{-8}
$D^0 \to K^0_s e^+e^-$, $D^0 \to K^0_s\mu^+\mu^-$	3×10^{-8}
$D^+ \to \pi^+ e^+e^-$, $D^+ \to \pi^+\mu^+\mu^-$	1×10^{-8}
$D^0 \to e^\pm\mu^\mp$	1×10^{-8}
$D^+ \to \pi^+ e^\pm\mu^\mp$	1×10^{-8}
$D^0 \to \pi^0 e^\pm\mu^\mp$	2×10^{-8}
$D^0 \to \eta e^\pm\mu^\mp$	3×10^{-8}
$D^0 \to K^0_s e^\pm\mu^\mp$	3×10^{-8}
$D^+ \to \pi^- e^+e^+$, $D^+ \to K^- e^+e^+$	1×10^{-8}
$D^+ \to \pi^- \mu^+\mu^+$, $D^+ \to K^-\mu^+\mu^+$	1×10^{-8}
$D^+ \to \pi^- e^\pm\mu^\mp$, $D^+ \to K^- e^\pm\mu^\mp$	1×10^{-8}

D mixing

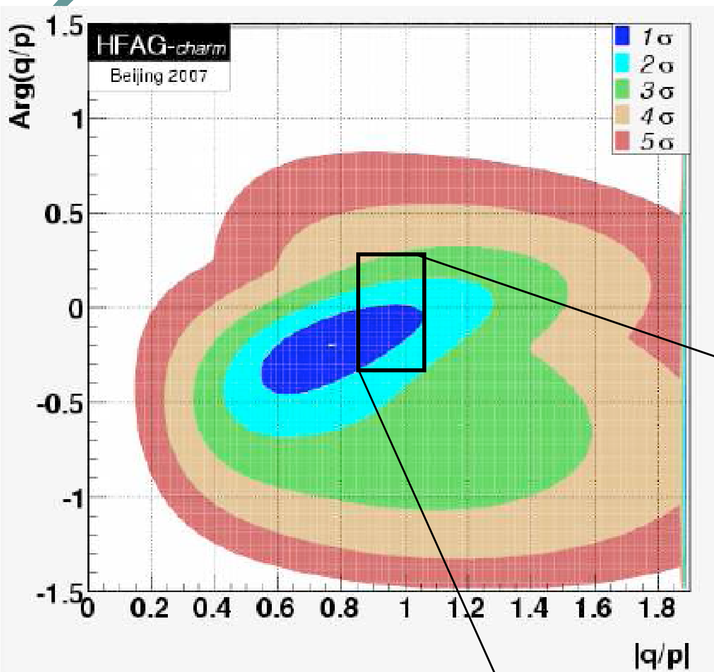
Better studied using the high statistics collected at $\Upsilon(4S)$



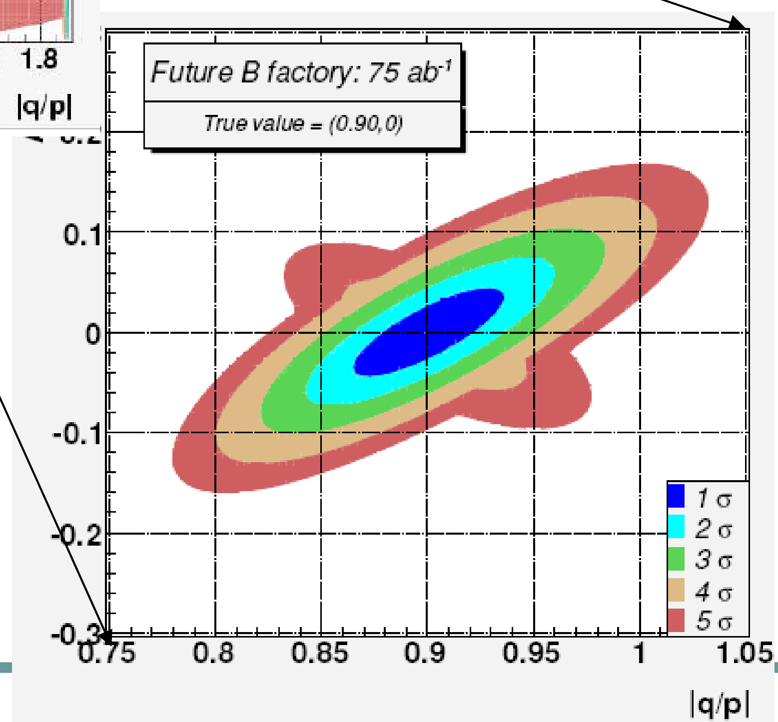
Mode	Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$D^0 \to K^+K^-$	y_{CP}	2–3×10^{-3}	5×10^{-4}
$D^0 \to K^+\pi^-$	y'_D	2–3×10^{-3}	7×10^{-4}
	x'^2_D	1–2×10^{-4}	3×10^{-5}
$D^0 \to K^0_S\pi^+\pi^-$	y_D	2–3×10^{-3}	5×10^{-4}
	x_D	2–3×10^{-3}	5×10^{-4}
Average	y_D	1–2×10^{-3}	3×10^{-4}
	x_D	2–3×10^{-3}	5×10^{-4}

CP Violation in mixing could now addressed

CP Violation in charm



Mode	Observable	$\Upsilon(4S)$ ($75\ \text{ab}^{-1}$)	$\psi(3770)$ ($300\ \text{fb}^{-1}$)
$D^0 \to K^+\pi^-$	x'^2	3×10^{-5}	
	y'	7×10^{-4}	
$D^0 \to K^+K^-$	y_{CP}	5×10^{-4}	
$D^0 \to K^0_S\pi^+\pi^-$	x	4.9×10^{-4}	
	y	3.5×10^{-4}	
	$\lvert q/p\rvert$	3×10^{-2}	
	ϕ	2°	
$\psi(3770)\to D^0\overline{D}^0$	x^2		$(1-2)\times10^{-5}$
	y		$(1-2)\times10^{-3}$
	$\cos\delta$		$(0.01-0.02)$



More topics in the CDR

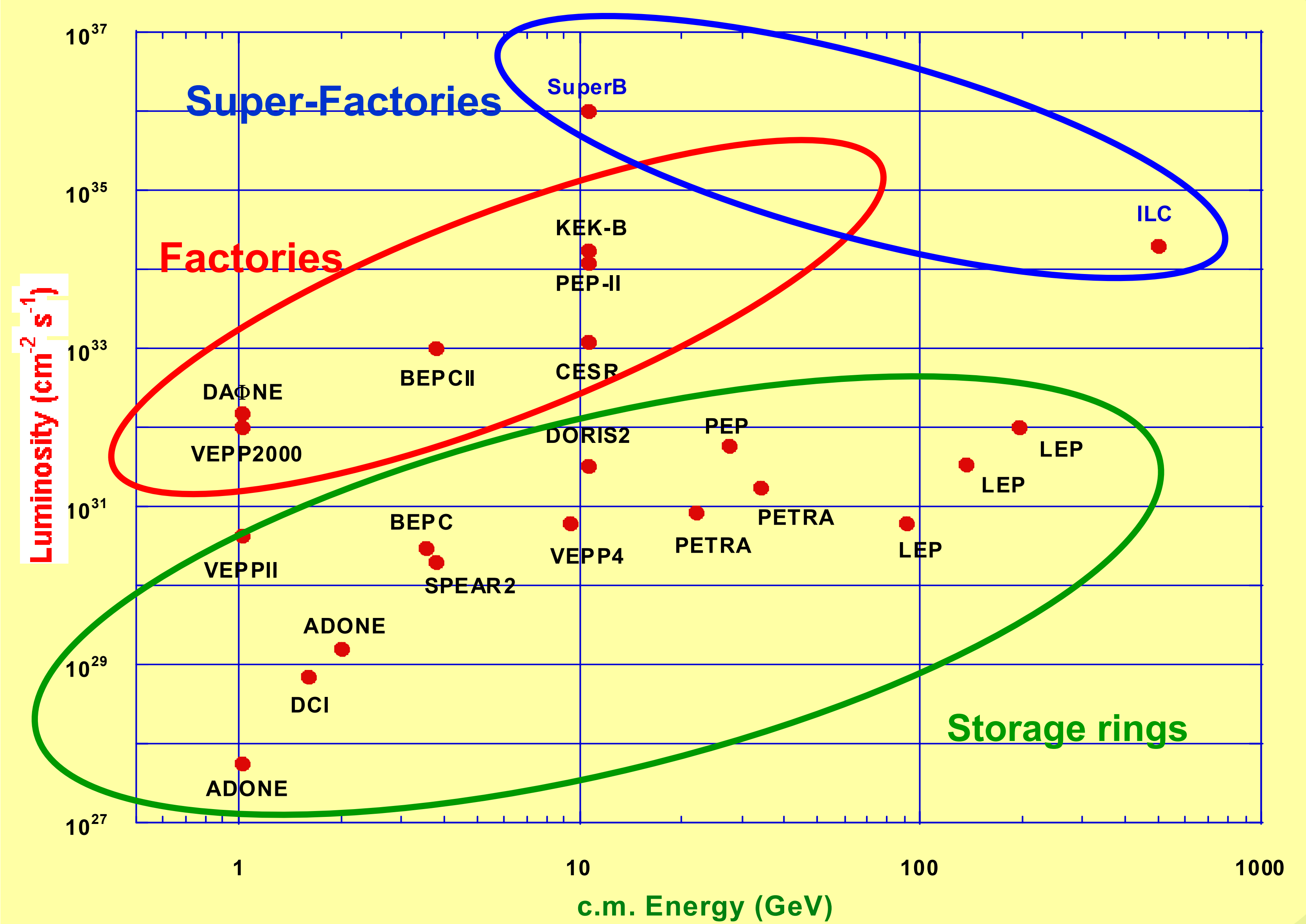
- Physics at Y(5S)
  - machine can run at same lumi as Y(4S)
- Spectroscopy
  - many new, puzzling states discovered at the B factories
  - SuperB ideal to clear up the picture
- Light quark studies using ISR (e.g., measurement of hadronic cross section, input for a_{μ})
- Finally, there can always be surprises!
  - we had several at the B factories…

The SuperB Accelerator

or, how to increase the peak luminosity by a factor

100!

Past, present, (and future) $e^+ e^-$ colliders



Luminosity…

For Gaussian bunches with N particles each and transverse dimension σ_x / σ_y

$$\mathcal{L} = f_{coll} \times \frac{N^+ N^-}{4\pi \sigma_x \sigma_y}$$

Can also be written as:

$$\mathcal{L} = \frac{\gamma_\pm}{2 e r_e} \left(1 + \frac{\sigma_y^*}{\sigma_x^*} \right) \left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*} \right) R_l$$

Lorentz factor, classical e± radius and ratio of beam sizes

Beam current: I
beam-beam parameter: ξ
vertical β function at IP

Reduction factor from crossing angle and the hourglass effect

How to increase the Luminosity?

$$L \propto \frac{I_{\pm}\xi_{\pm y}}{\beta_y^*} R_l$$

P. Raimondi, ca. 2006

"Classic" method (SuperKEKB)

1. Increase beam current
   - 1A/2A ➔ up to 4.1A/9.4A
2. Decrease β_y*
3. Increase beam-beam parameter ξ (reduce bunch length)
4. Crab crossing to increase R_l and optimize beam dynamics

- High wall-plug power
- HOM in beam pipe
  - overheating, instabilities, power cost
- Smaller dynamic aperture
- Shorter LER Touschek lifetime

hard to surpass 5×10^{35} $cm^{2}s^{-1}$

SuperB

A sinergy between *B*-factory and ILC-type concepts:

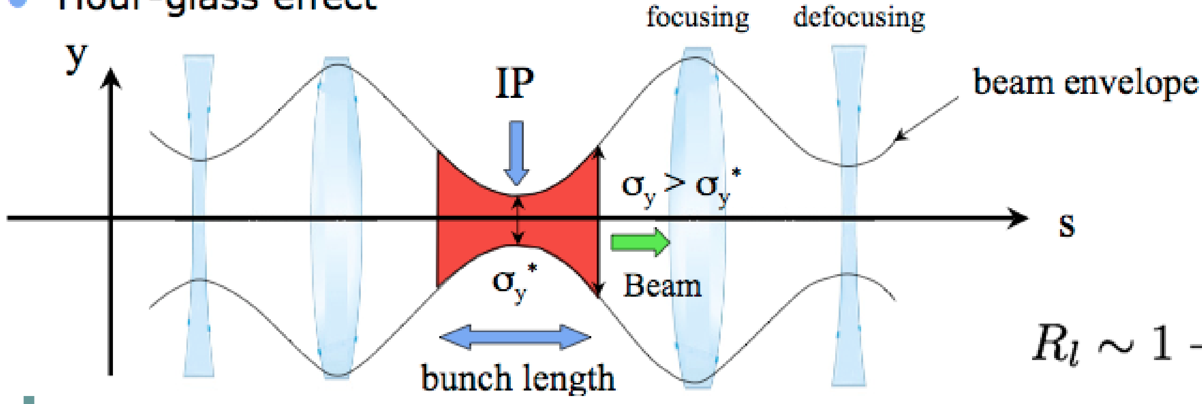
1. Focus beams at IP
   - very small β_y*
   - σ_y from 3μm down to 40nm
2. Same currents as in PEP-II
3. Retain longer bunch lengths
4. Large Piwinski angle and Crab Waist and to optimize beam dynamics

Lumi: 10^{36} $cm^{2}s^{-1}$ (baseline).

The hourglass effect

$$L \propto \frac{I_{\pm}\xi_{\pm y}}{\beta_y^*} R_l$$

- Hour-glass effect



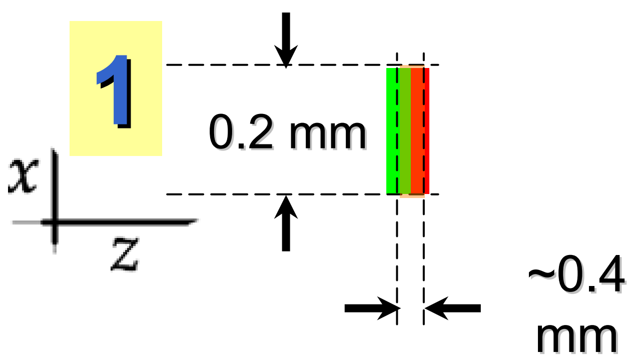
Angular Divergence @ IP
x
Transverse Size @ IP
=
Emittance (Ring Constant)

$$R_l \sim 1 - \left(\frac{\sigma_z}{2\beta_y}\right)^2 + \mathcal{O}\left(\frac{\sigma_z}{\beta_y}\right)^4$$

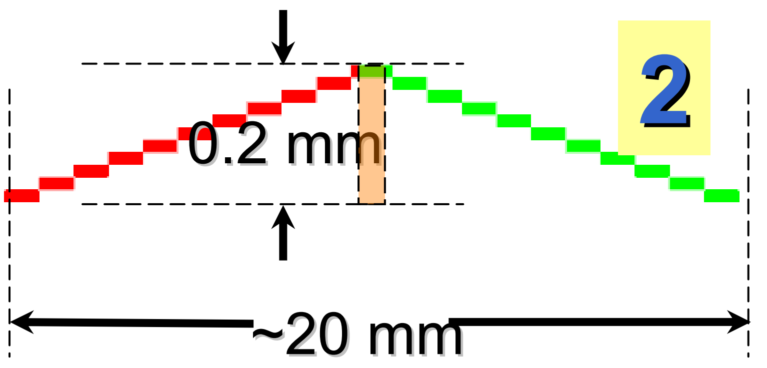
- Small amplitude @ IP not efficient with long bunches
  - particles in the head and tail of the bunch will see a larger β_y
  - ➔ "β_y^* should be comparable to the *overlapping area*"
- In a storage ring
  - it is comparably easier to achieve small horizontal size and emittance than to make short bunches
  - vertical emittance/size scale with the horizontal ones

Large crossing angle, long bunches, small x-size

- "β_y should be comparable to the overlapping area"
- Configurations 1 and 2 have same overlap, and yield same luminosity

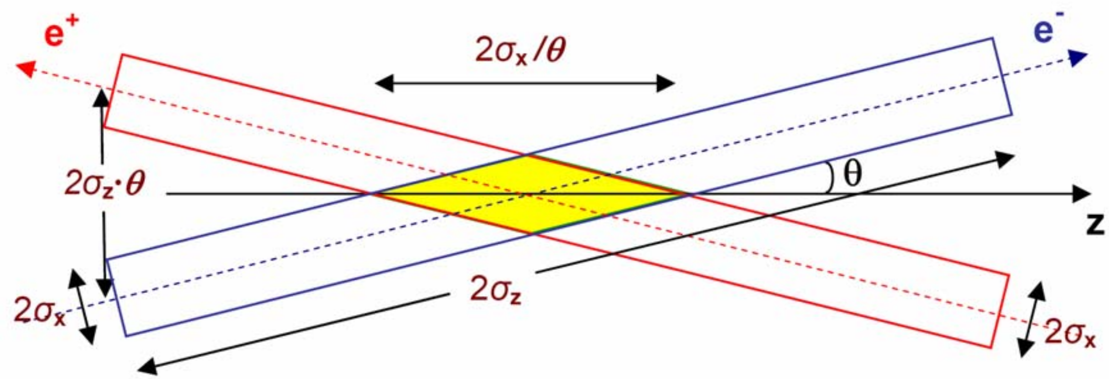


- Short bunches
- aspect ratio $\sigma_y / \sigma_x \sim 1/3000$



- Long bunches
- aspect ratio $\sigma_y/\sigma_x \sim 1/300$

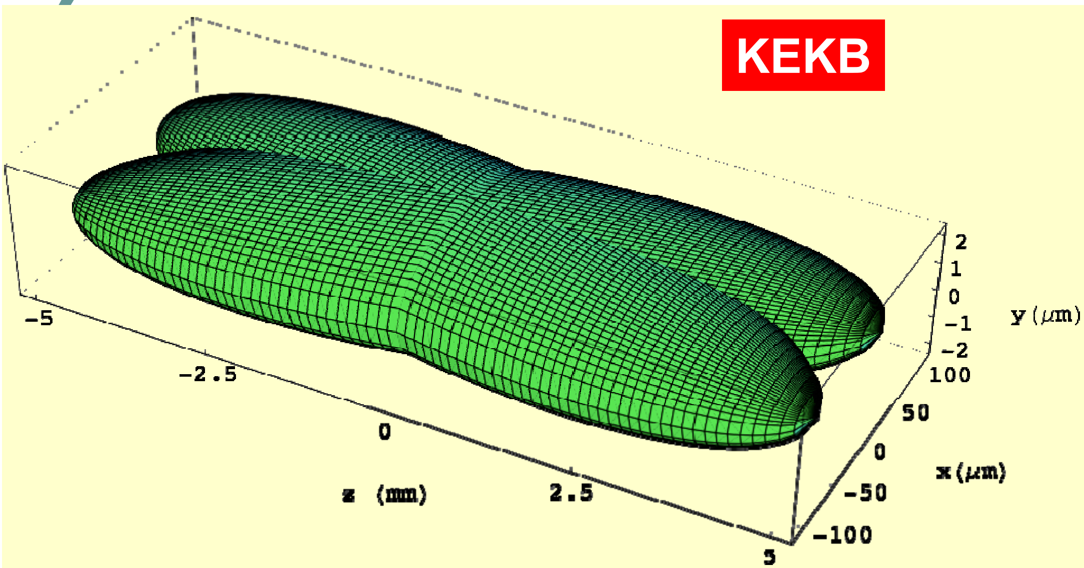
The large crossing angle swaps the x and z planes

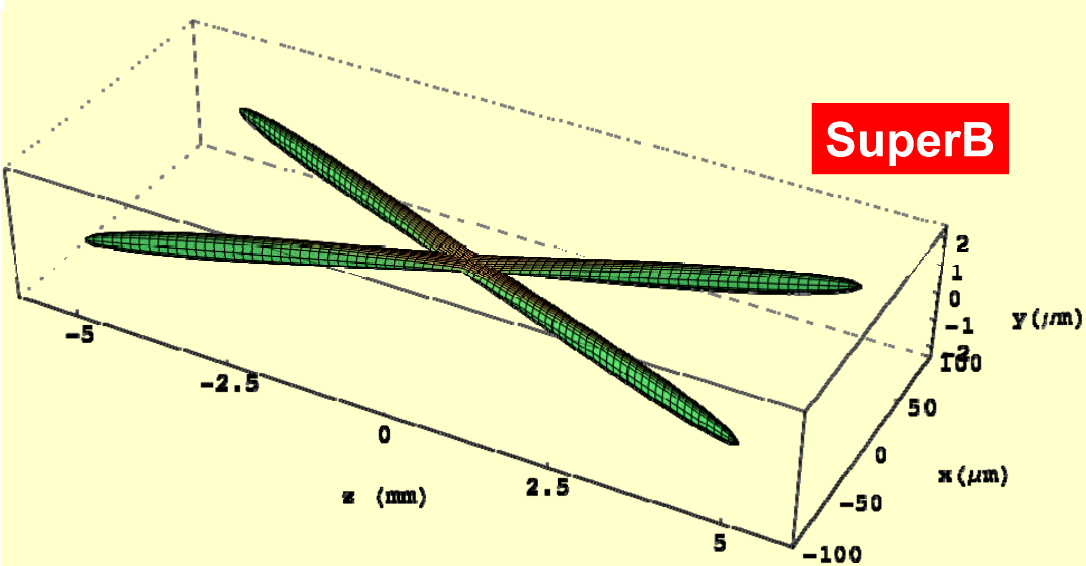


Large Piwinski angle:

$$\phi = tg(\theta)\sigma_z/\sigma_x$$

IP beam distributions



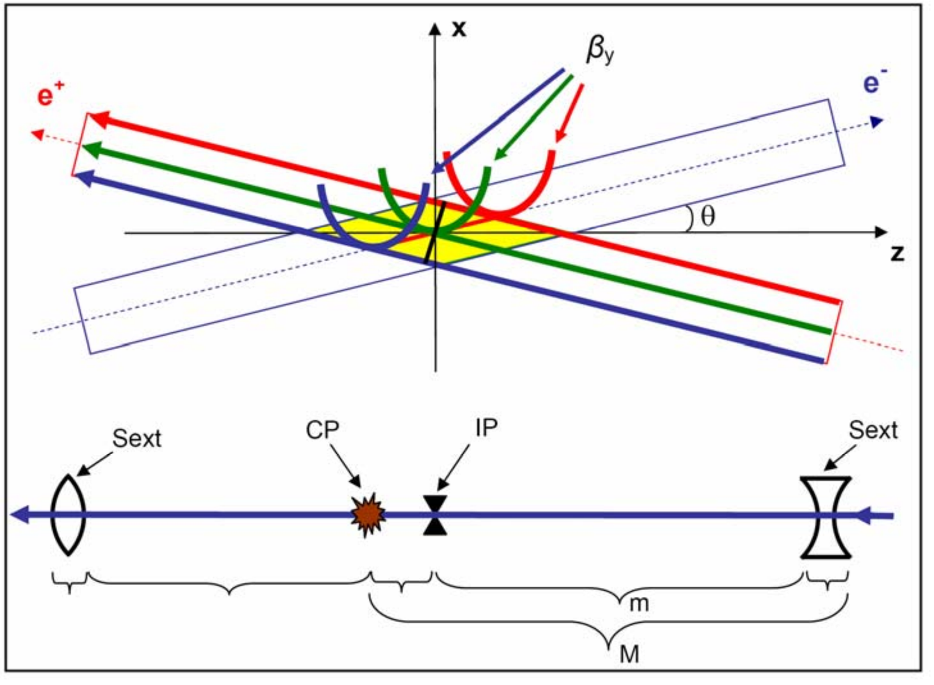


	KEKB	SuperB
I (A)	1.7	2.
β_y^* (mm)	6	0.3
β_x^* (mm)	300	20
σ_y^* (μm)	3	0.035
σ_x^* (μm)	80	6
σ_z (mm)	6	5
L ($cm^{-2}s^{-1}$)	1.7×10^{34}	$1.\times10^{36}$

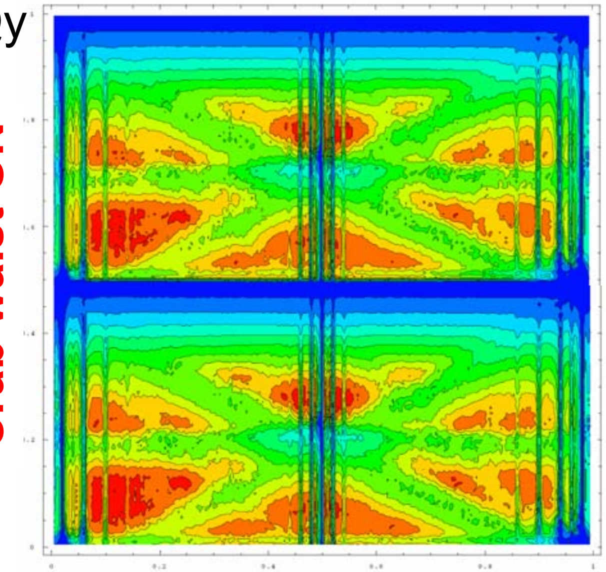
Here is Luminosity gain

One further step

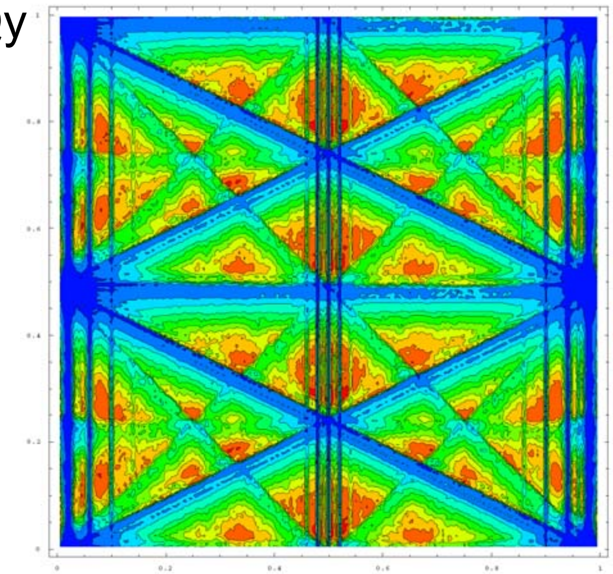
- By analogy to the "crab crossing"
  - bunches rotated in crossing-angle collisions to make them collide head-on
- crab waist
  - the minimum of β_y is shifted to correspond to the axis of the other beam
    - requires one pair of sextupoles per beam
    - collisions always happen at the waist ➔ *luminosity is maximized*
    - *beam-beam resonances greatly reduced*



Lumi scans in the tunes plane @ SuperB



RED is good
BLUE is bad



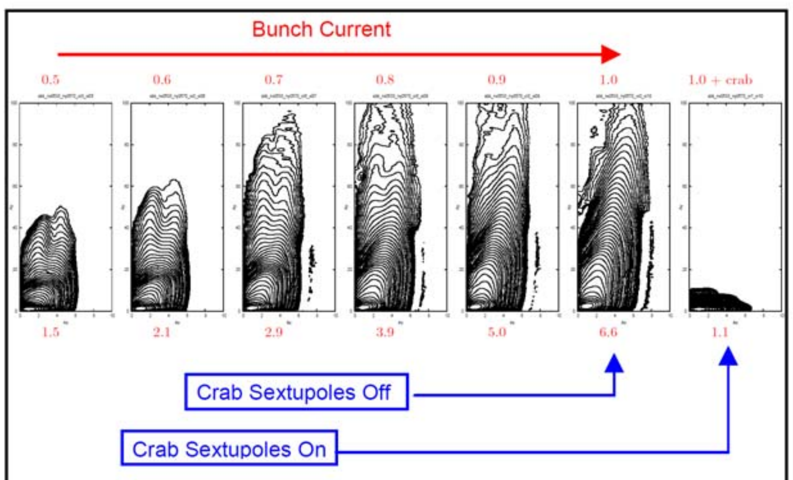


Figure 6: Beam tails and vertical blowup (numbers at the bottom) vs. bunch current and Crab Waist.

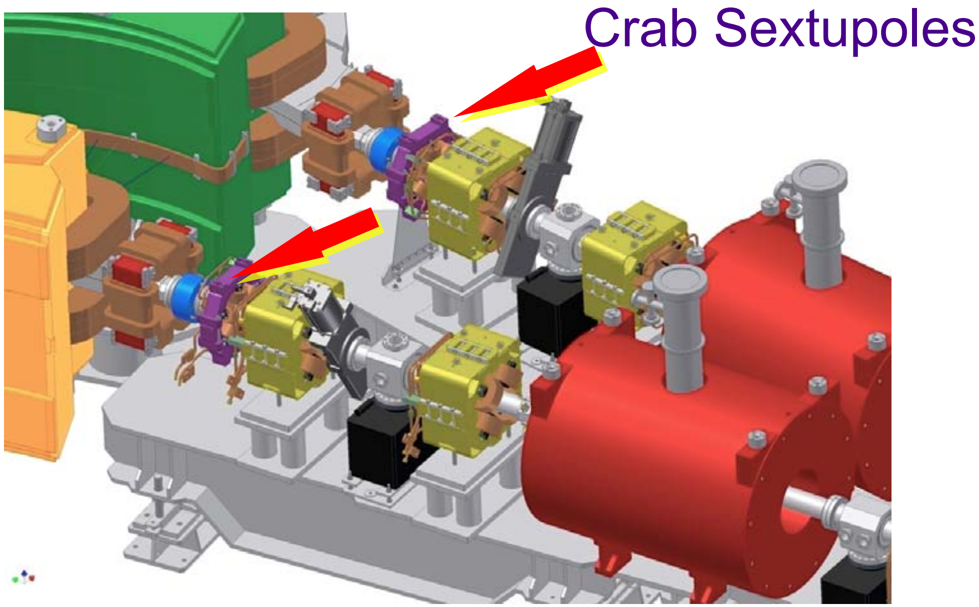
Area of good working points *expands a lot* with crab waist (*)

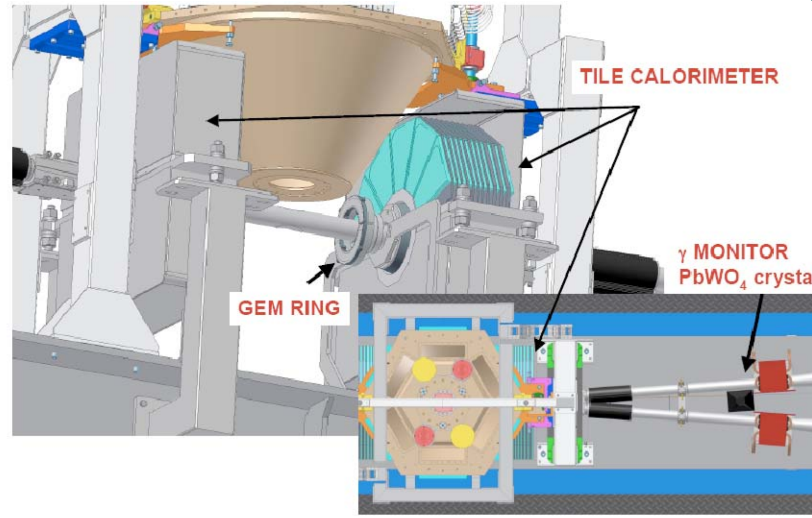
- possibility to increase the beam-beam tune shift!

(*) even with 2.5 x bunch current!

$$L \propto \frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}$$

Demonstration of the crab waist concept

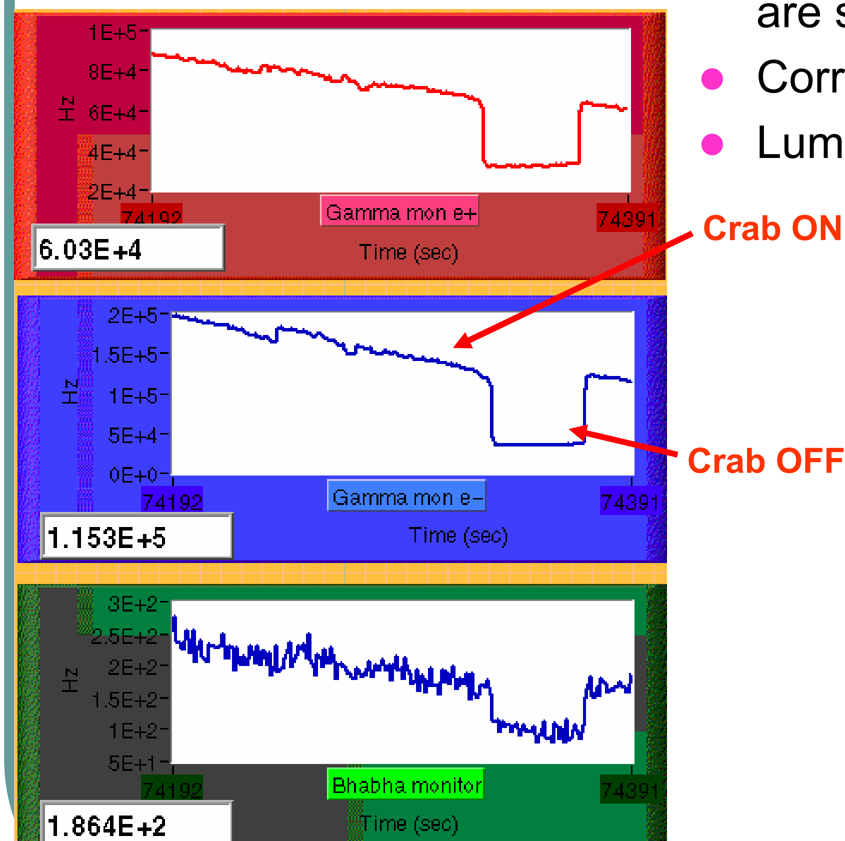




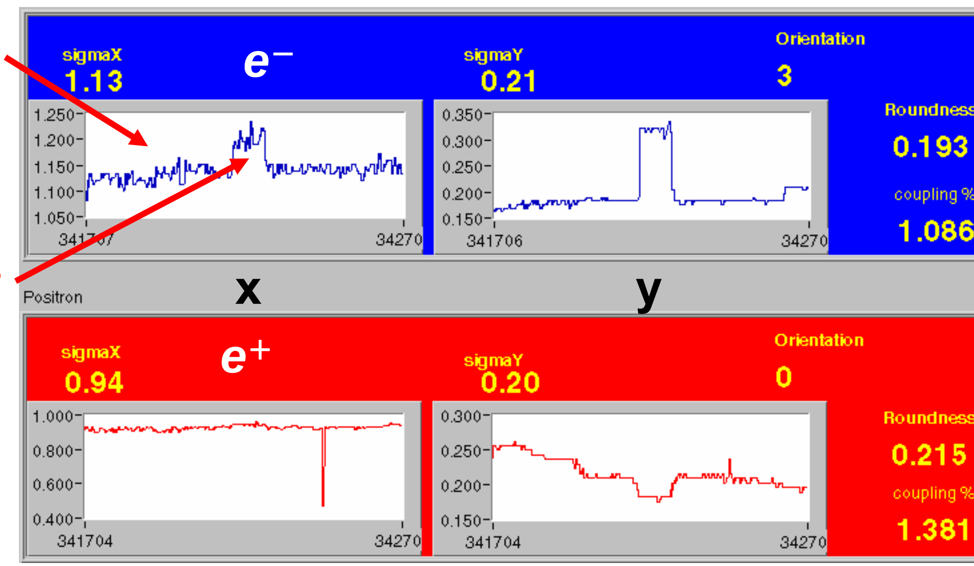
- The innovative crab waist concept experimentally demonstrated at DAFNE in 2008
- Tests continuing also this year
- Small angle EMC as luminosity monitor
- Beam crab waist obtained with 2 pairs of sextupoles

DAΦNE: First Crab Waist Test

- Luminosity and beam sizes measured in collision with crab-waist sextupoles switched ON/OFF/ON
- Blow-up in beam sizes and decrease in Bhabha rates observed when crab sextupoles in one ring are switched OFF (other ring ON)
- Correspondingly measure decrease in lifetime
- Luminosity vs product of currents linear

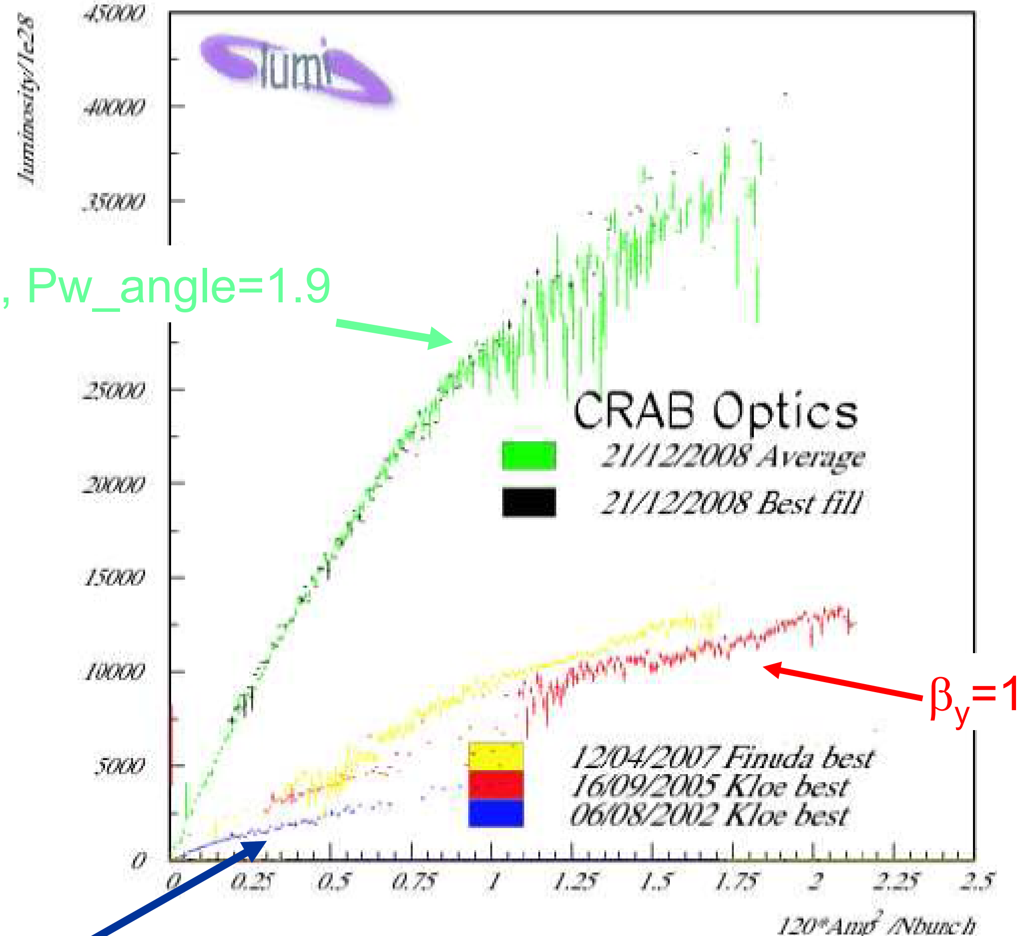


Luminometers



Transverse beam dimensions at the Synchrotron Light Monitor

Luminosity vs. product of currents



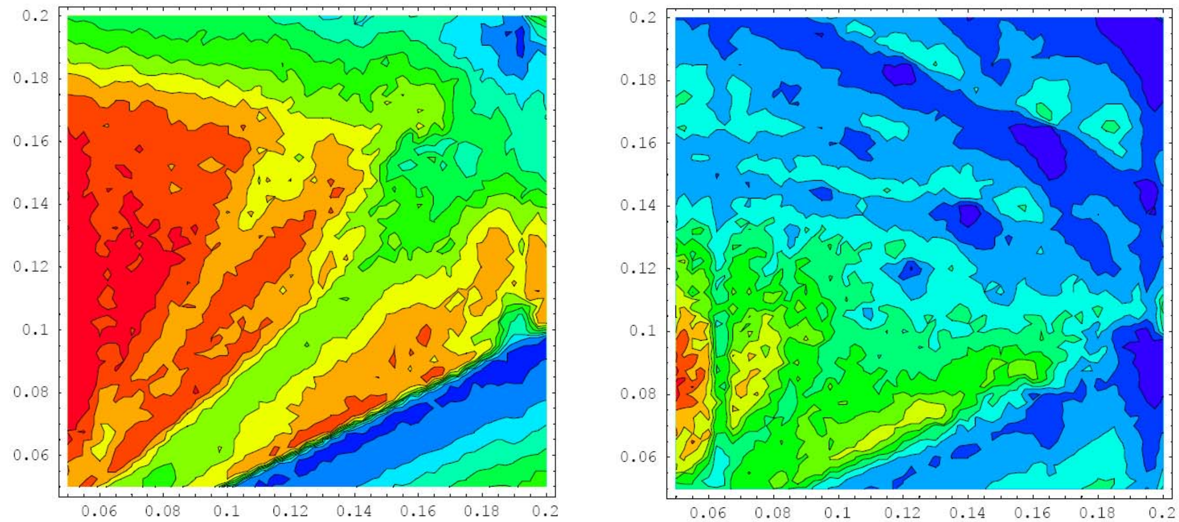
β_y=9mm, Pw_angle=1.9

β_y=18mm, Pw_angle=0.6

β_y=25mm, Pw_angle=0.3

Lumi scan in the tunes plane

RED is good
BLUE is bad



Crab ON => 0.6/θ
$L_{max} = 2.97 \times 10^{33}\ cm^{-2}s^{-1}$
$L_{min} = 2.52 \times 10^{32}\ cm^{-2}s^{-1}$

Crab OFF
$L_{max} = 1.74 \times 10^{33}\ cm^{-2}s^{-1}$
$L_{min} = 2.78 \times 10^{31}\ cm^{-2}s^{-1}$

FIG. 11: SIDDHARTA luminosity scan[3)]. Red colour corresponds to the maximum luminosity, blue – to the minimum.

- *X-Y betatron resonances significantly reduced with crab waist*
  - higher lumi
  - much wider working point area

The SuperB Detector

General considerations for *B* physics

- *CP* sensitivity from:
  - Observing many exclusive final states with high efficiency and low backgrounds
    - need large solid angle coverage
  - Tag flavor with high efficiency
    - good lepton ID, particle ID over large momentum range: good π/K separation to over 4 GeV(dE/dx; Cherenkov counter)
  - Measure the relative decay times of the B mesons
    - z position of the vertex depends on the amount of material (beam pipe) between the IP and first layer of silicon sensors, radius of beam pipe
    - resolution of z separation between B vertices is the key
- *B* decays: many modes with low BRs
  - many particles, many low momentum
    - require good low momentum resolution (little material, 'high'B)
  - soft γ's from soft π^0's, as well as high energy electrons and photons
    - require good low energy photon energy measurement with low noise and minimum material in front of the calorimeter, as well as calorimeter depth to contain higher E photons and electrons

Well, this is *BABAR*! (or Belle…)

Main differences:

- Machine: lower boost (smaller longitudinal separation of secondary vertices)
  - Need vertex detector with higher resolution
- Much higher luminosity (bkg.rates?)
  - Faster & more robust detectors
  - KEEP AN OPEN, 100% EFFICIENT TRIGGER

Common sense: costs

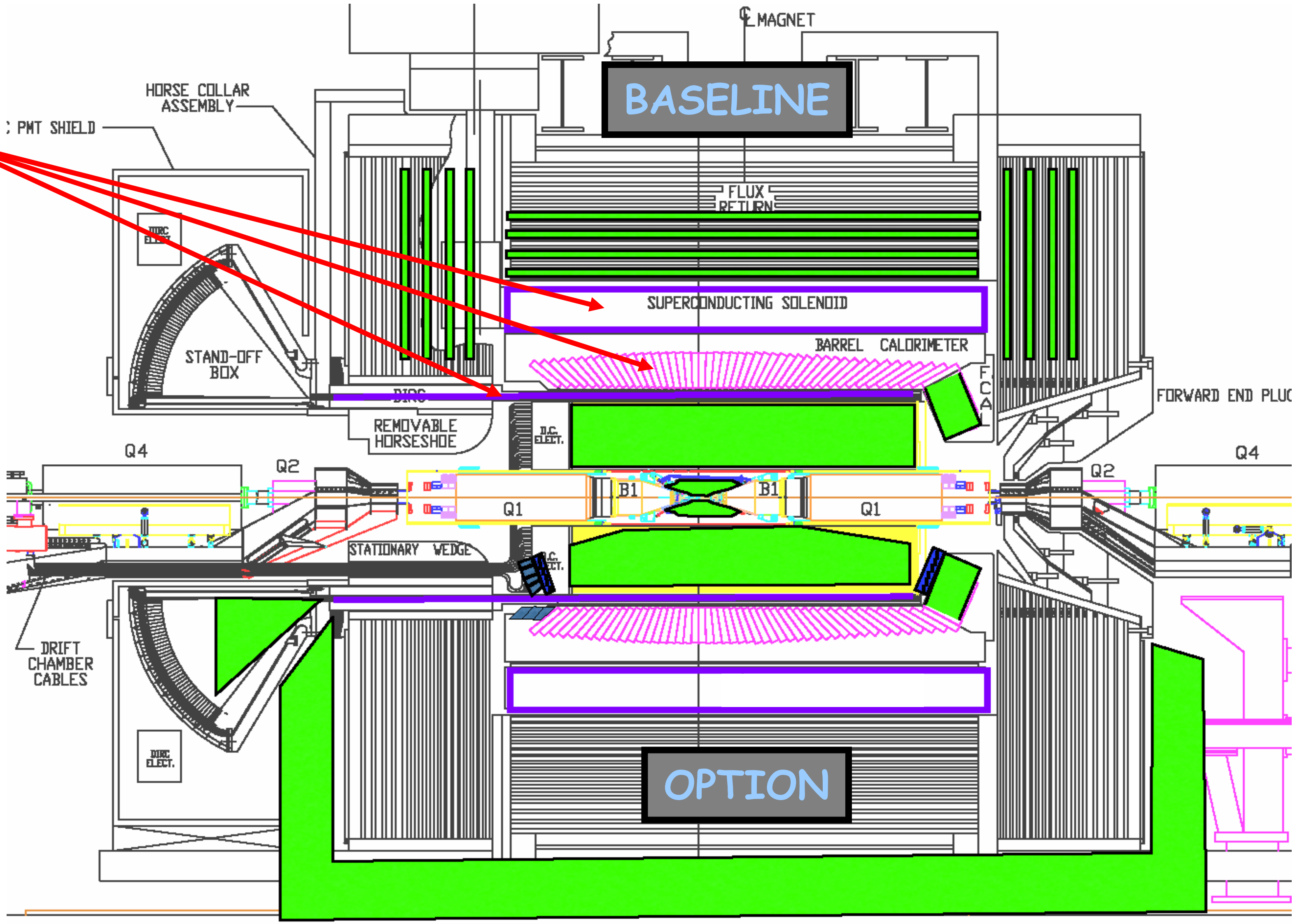
- Reuse as much as possible & reasonable
  - thankfully, this includes the more expensive parts

- *BaBar/Belle will fit the requirements*

  ➔ *Improve performances where needed & feasible, to (try and) match the improved statistical accuracy*

BABAR reuse

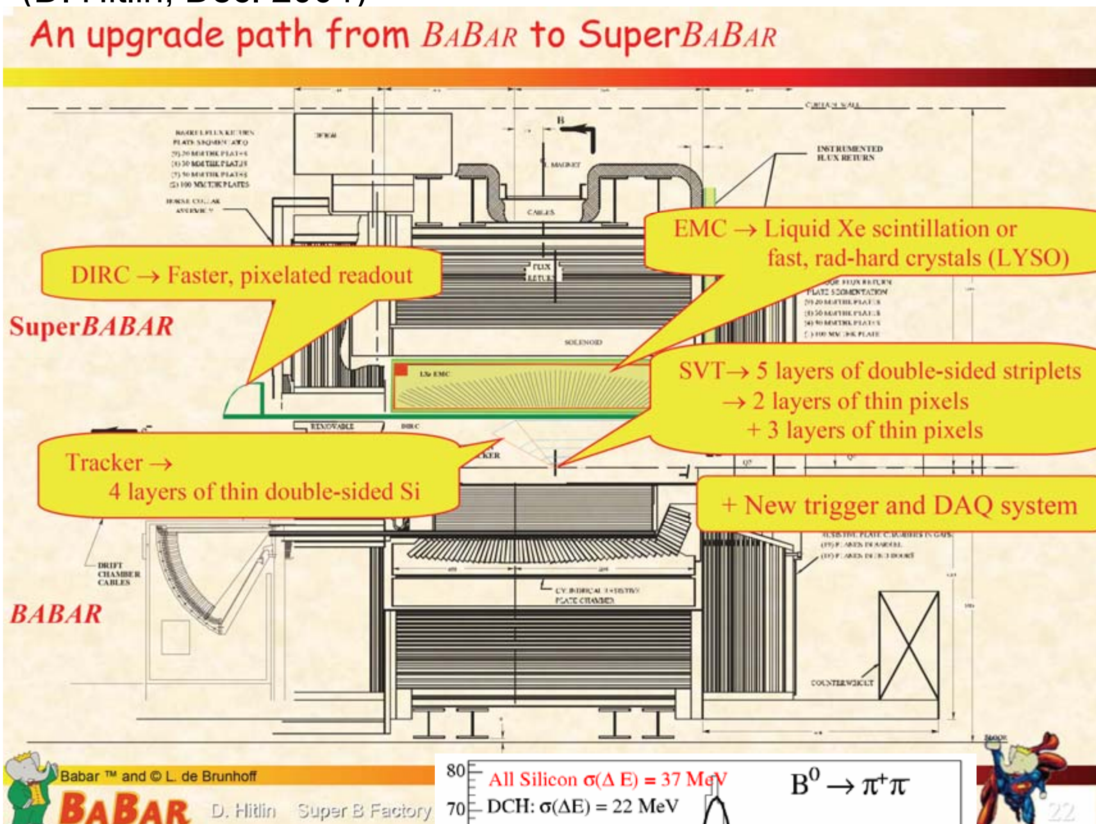
Reuse from *BABAR*

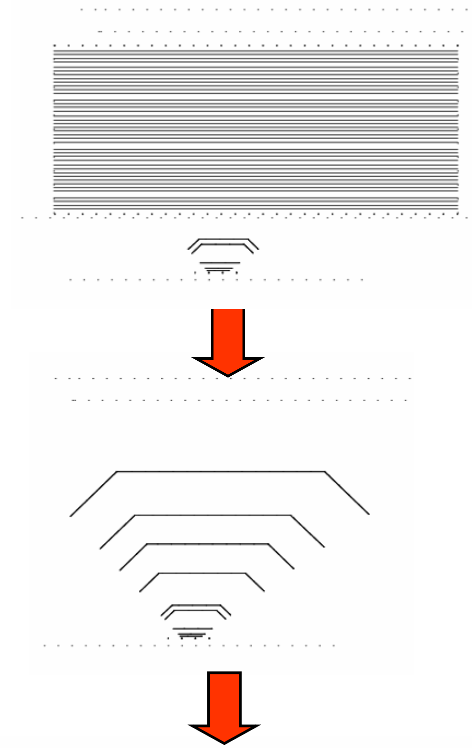


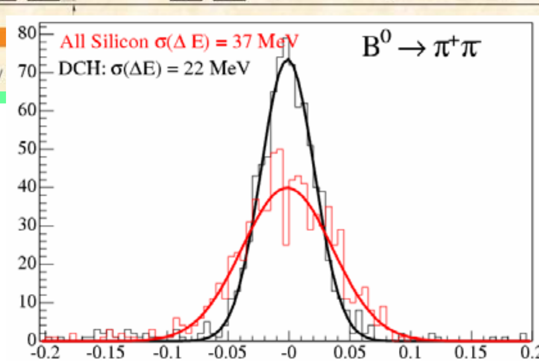
Note: this is only possible because of low beam currents!

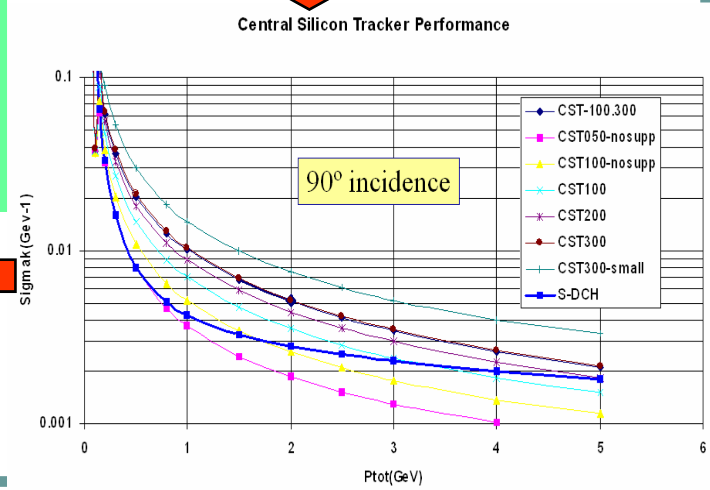
In 2004, the prospects were quite different

(D. Hitlin, Dec. 2004)





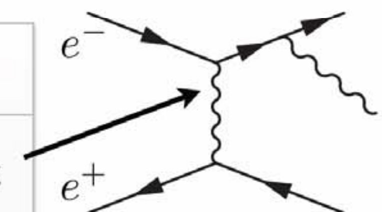


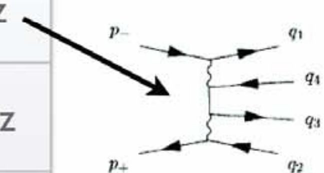


Backgrounds must be considered, anyway

- Luminosity-scaling backgrounds are the main issue
- Huge QED cross sections at the IP
  - Low currents / high luminosity
    - Beam-gas backgrounds are not a problem
    - Synchrotron radiation light from the Final Focus can be shielded

	Cross section	Evt/bunch xing	Rate
Radiative Bhabha	~340 mbarn ($E\gamma/E_{beam}$ > 1%)	~680	0.3THz
e^+e^- pair production	~7.3 mbarn	~15	7GHz
Elastic Bhabha	$O(10^{-5})$ mbarn (Det. acceptance)	~20/Million	10KHz
$\Upsilon(4S)$	$O(10^{-6})$ mbarn	~2/million	1 KHz





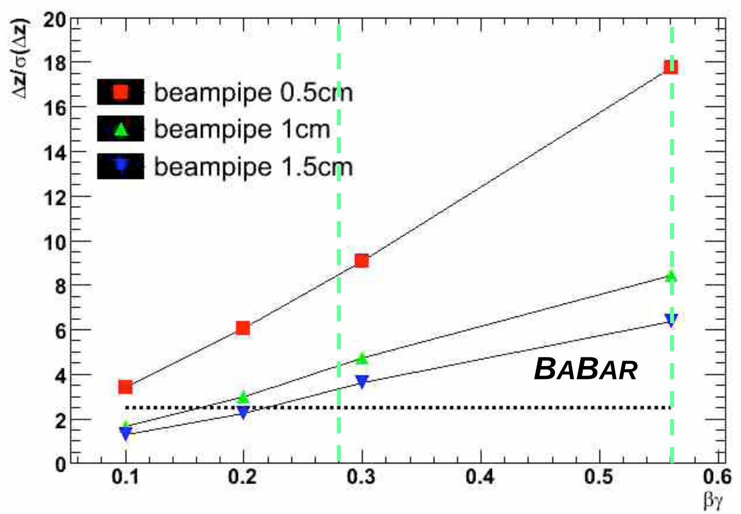
HADRON 07: FRASCATI, 12 OCT

EUGENIO PAOLONI

Energy asymmetry, vertexing

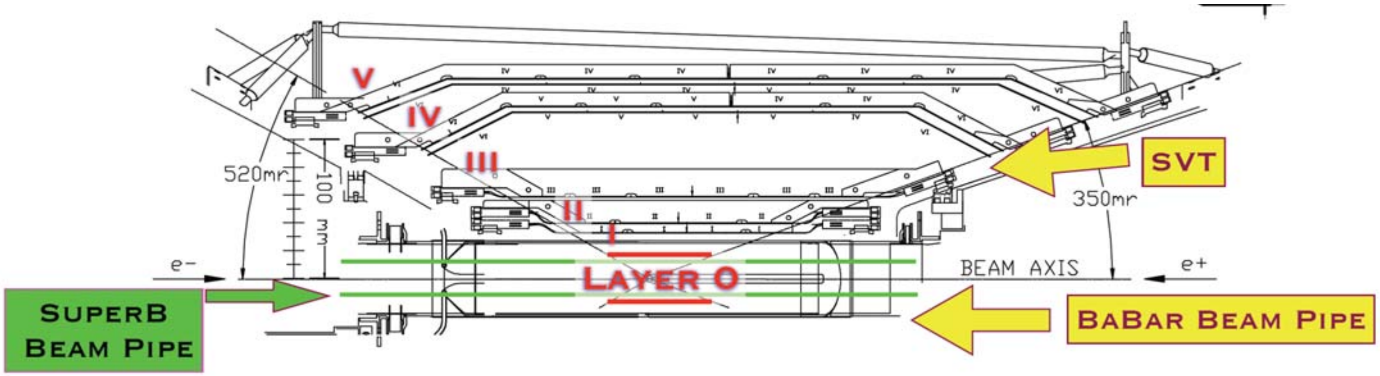
- In SuperB, reduced energy aymmetry (**7 on 4 GeV, $\beta\gamma$=0.28**)
  - Compare *BABAR*: 9 on 3.1 GeV, $\beta\gamma$=0.56, and Belle: 8 on 3.5 GeV, $\beta\gamma$=0.45
  - Easier to obtain very low horizontal emittances, easier IR design
  - Increased angular coverage of decay products ➔ better hermeticity!
- Time-dependent analyses need to separate the two B decay vertices:
  - small radius beam pipe possible thanks to the ultra-small beams
  - very little material in beam pipe and first layer

Impact of boost, and radius of 1st layer, on vertex separation in ($B \to \pi\pi$)
• Rest of tracking as in *BABAR*

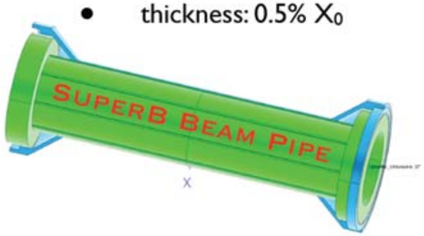


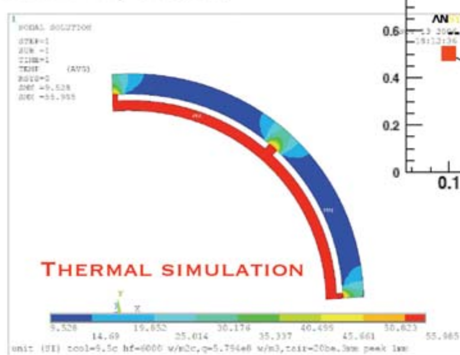
• despite lower boost, vtx separation can be better than in *BABAR*

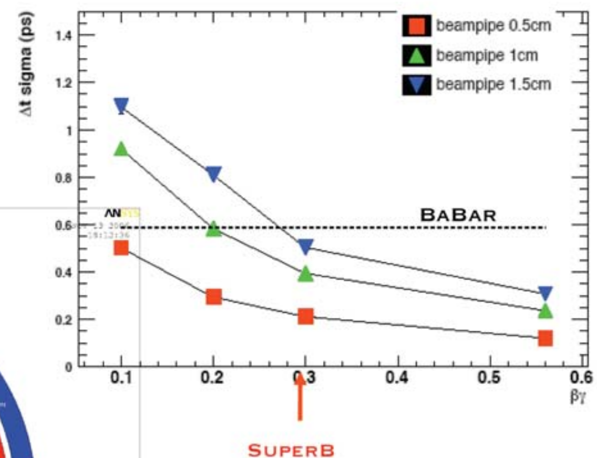
Silicon Vertex Tracker



- Baseline: use an SVT similar to the Babar one, complemented by one or two inner layers.
  - Cannot reuse because of radiation damage
- Beam pipe radius is of paramount importance
  - inner radius: 1.0cm,
  - layer0 radius: 1.2cm,
  - thickness: 0.5% X_0





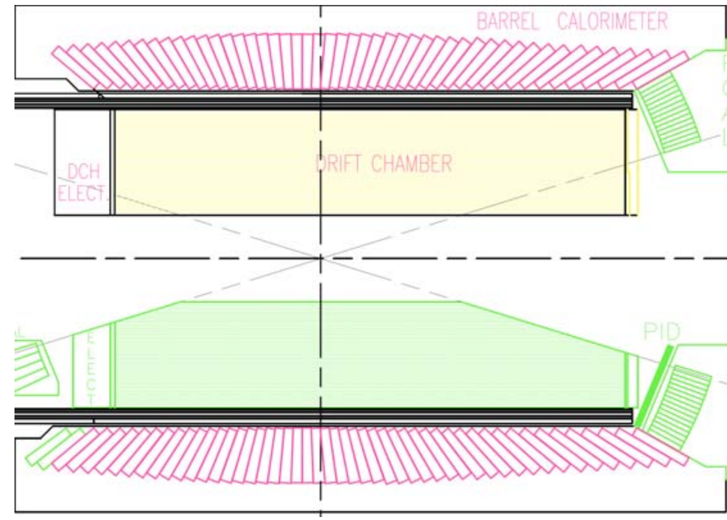


HADRON 07: FRASCATI, 12 OCT

EUGENIO PAOLONI

Use striplet or pixel detector (MAPS) on layer 0 to cope with high expected occupancies

Drift Chamber

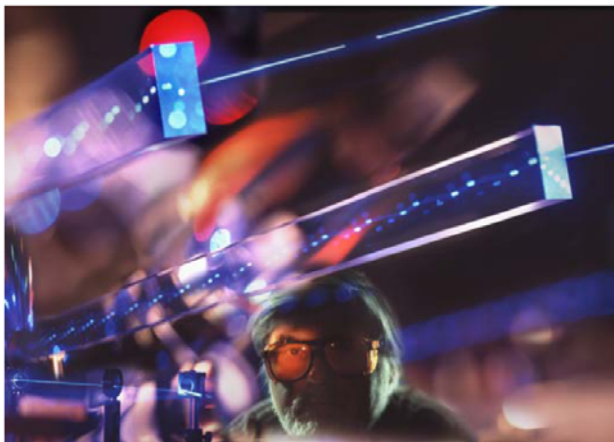


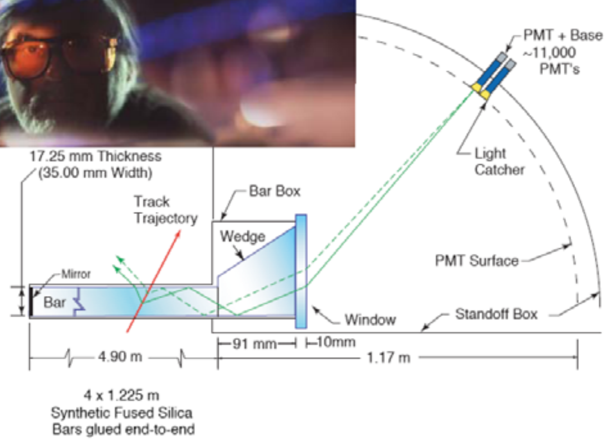
Build on *BABAR* drift chamber concept: no major R&D effort needed, but:

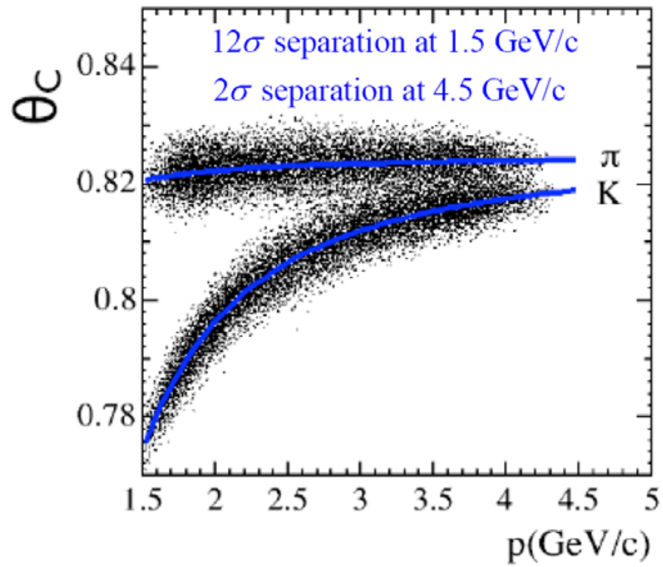
- Lighter structure, all in Carbon Fiber (CF)
  - Preliminary studies show that dome-shaped CF end-plates with X_0 ~2% seem achievable (compare 13-26% in BABAR DCH)
- Design faster, lighter electronics (possibly taking into account detectors being considered now to be installed behind backward end-plates)
- To control expected increase in occupancy:
  - studying faster gas mixtures
  - considering smaller cells
  - Tapered shape of end-plates
    - alternative solutions being explored

Particle ID

- Detector of internally reflected Cherenkov light (DIRC) works expremely well
  - ✓ reuse same principle (and quartz bars) with state of the art readout
- forward PID device under consideration





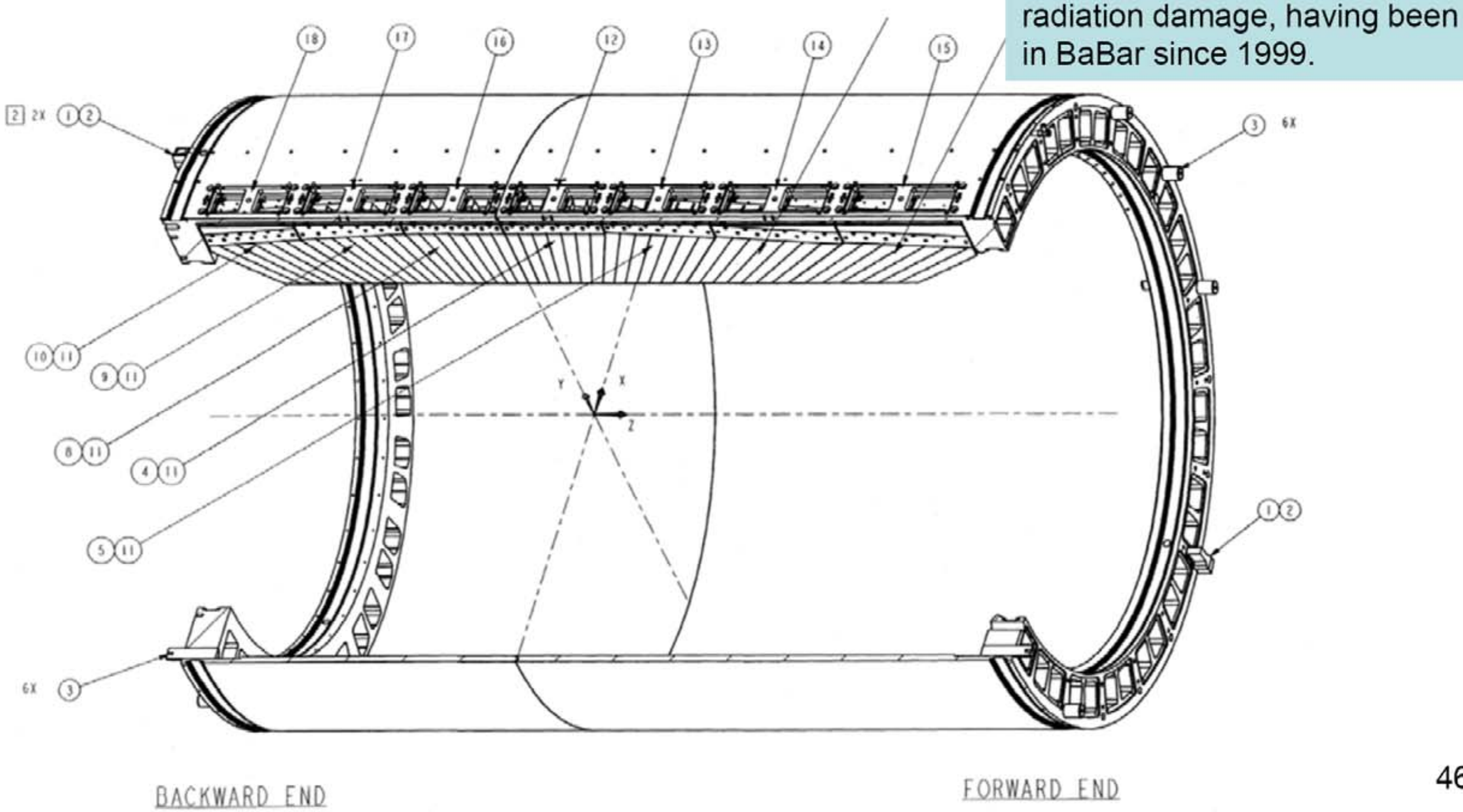


Can benefit from reducing the volume of water between the end of the quartz bars and the photodetectors (PMTs) at SuperB.

EM calorimeter (barrel)

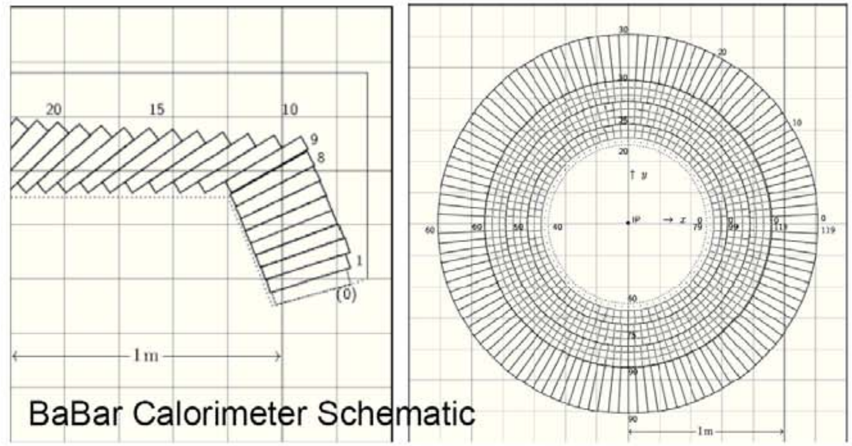
- Calorimeter Barrel is more than sufficient for our needs.

•Fast enough signal output for the expected rates at SuperB
•Not suffering from any signs of radiation damage, having been used in BaBar since 1999.



EM calorimeter (endcap)

- BaBar End-Cap doesn't have a fine enough granularity for rates at SuperB.
  - Need a finer segmentation.
  - Similar total X_0.
  - Faster readout electronics.
  - Several candidate materials for End-Cap replacement.
    - LYSO is baseline
      - expensive at the moment (~$40/cc).
      - Aim for $15/cc.
  - Need to integrate into the existing Barrel, and optimise segmentation.
  - R&D underway toward a LYSO Calorimeter test-beam in ~2009.



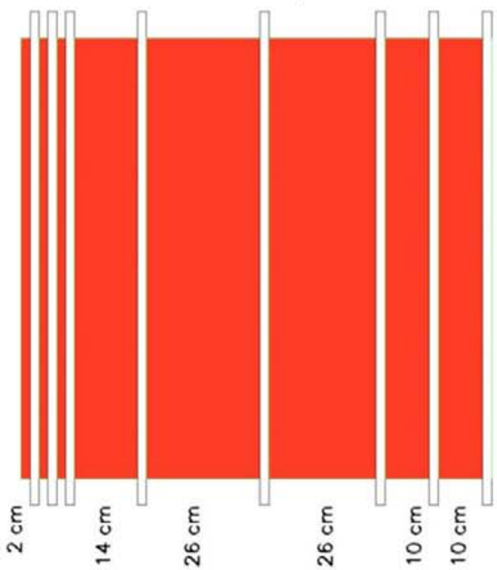
BaBar Calorimeter Schematic

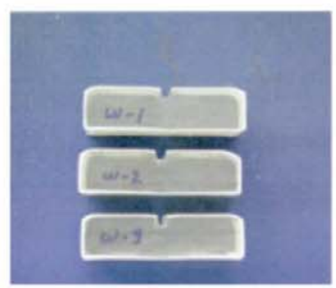
2.5 x 2.5 x 20 cm (18 X_0) Bar

Backward endcap (veto counter?) under consideration

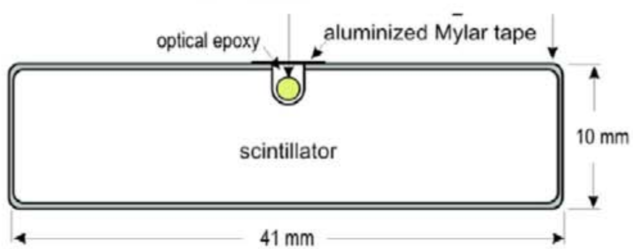
Instrumented Flux Return

- BaBar has 5 radiation lengths of material for μ identification in the flux return.
  - This is not optimal.
  - SuperB will have more iron.
- The segmentation of active regions of the flux return will remain the same as BaBar (3.7cm pitch).
- 7-8 layers of MINOS style scintillator bars.

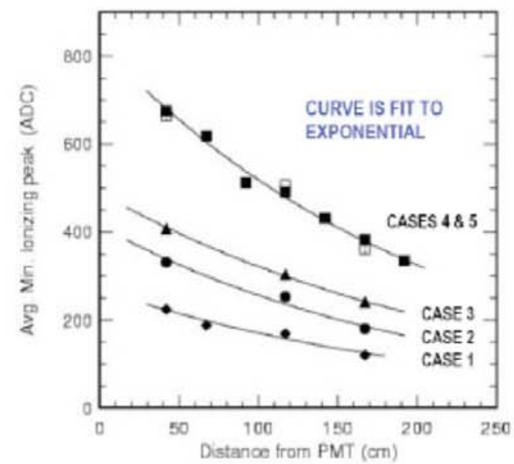




MINOS PRODUCTION BARS SHOWING 4 x 1 cm² CROSS SECTION WITH CO-EXTRUDED TIO₂ AND GROOVE FOR WLS FIBER



ATTENUATION LENGTH MEASUREMENTS FOR 5 CASES



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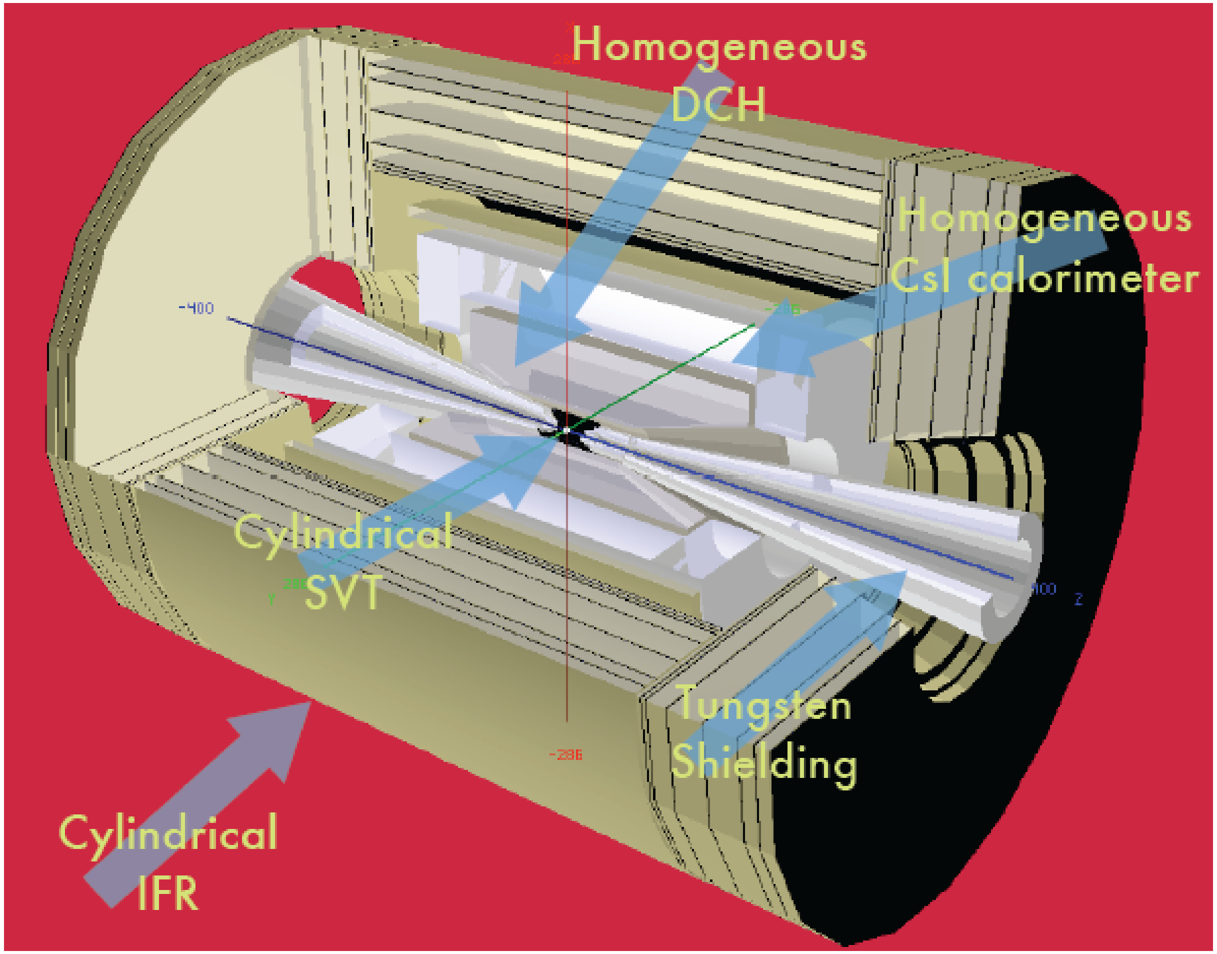
The SuperB Detector

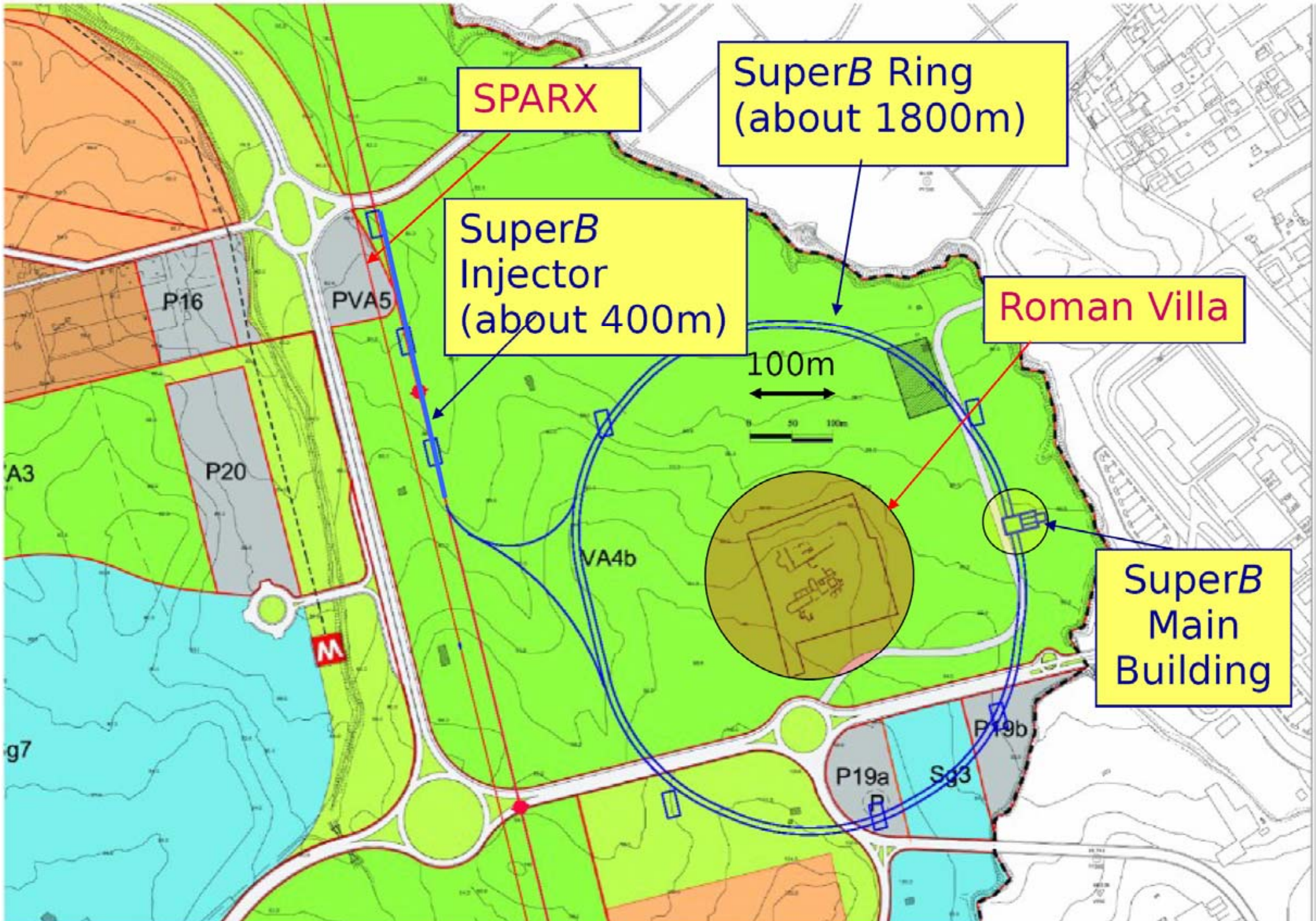


The SuperB detector is coming to life (in the simulation, for now)

Potential SuperB site

- On the University of Rome Tor Vergata campus

Footprint



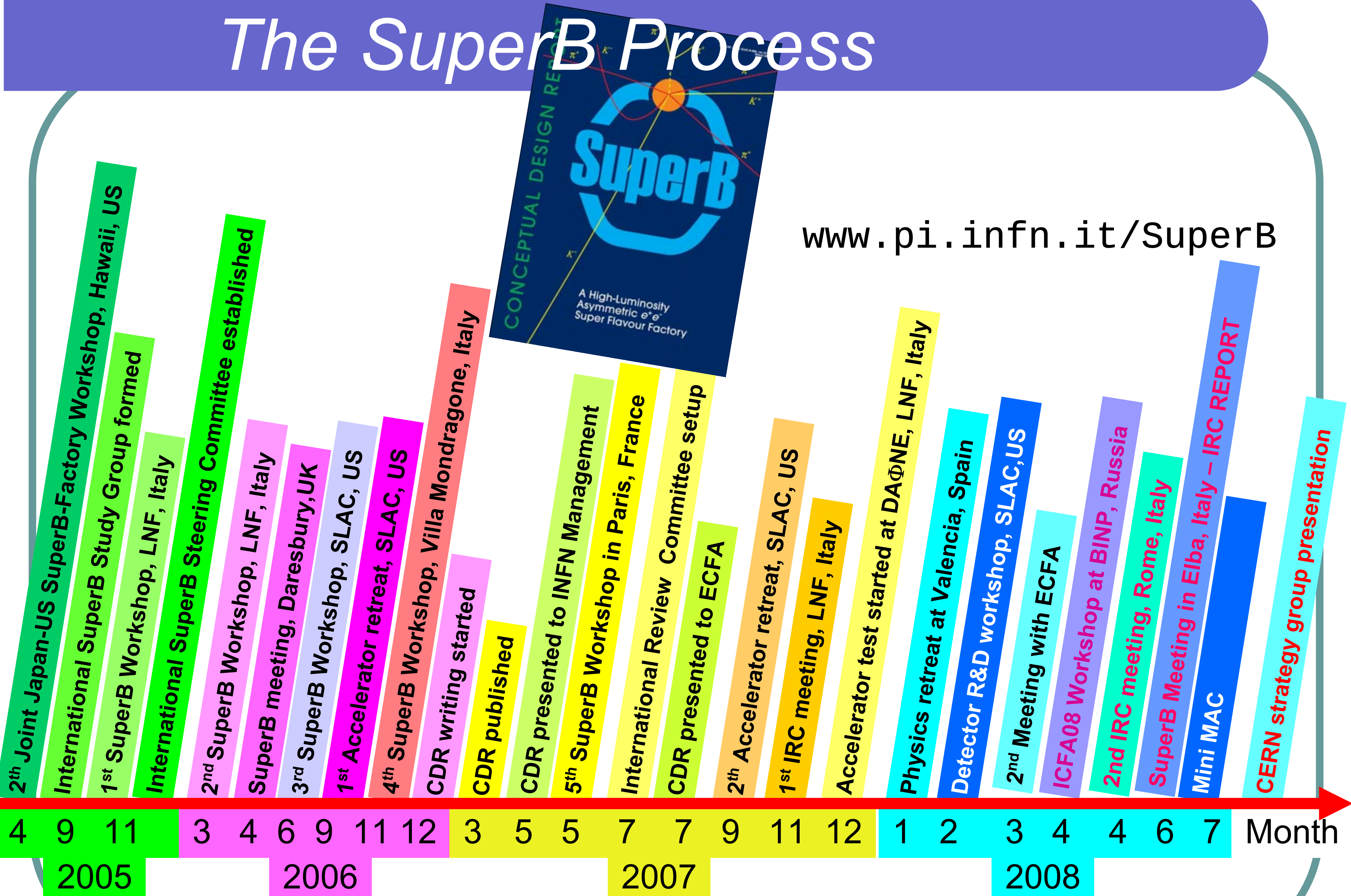
by F.Forti

Conclusions & outlook

- Solid physics case for Super Flavour Factory with $L>10^{36}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.
  - strongly complementary with the energy frontier
- The machine is challenging and based on radically new accelerator ideas
  - experimentally validated by the test at DAFNE
- The proposed detector is based on *BABAR* concept, and further improved
- Substantial savings allowed by reuse of PEP-II and *BABAR* parts

The SuperB Process

www.pi.infn.it/SuperB



(Courtesy of M. Biagini)

1st IRC report

The International Review Committee setup up by the INFN president to evaluate the SuperB CDR reported very favourably

First Report of the International Review Committee[1] (IRC) for the Super*B* Project

Hiroaki Aihara, John Dainton, Young Kee Kim, Jacques Lefrançois, Antonio Masiero, Steve Myers, Tatsuya Nakada[2], Daniel Schulte, Abe Seiden

Roma, May 21st 2008

5. Conclusion

We recommend strongly that work towards the realisation of a Super*B*, taken to be an asymmetric e^+e^- collider with luminosity at least 10^{36} cm^{-2} s^{-1}, continues.

The Super*B* concept is at an important stage. The significance of the physics programme at such a machine continues to be developed, increasing in both scope and importance. It motivates an even more concerted effort to meet many technical challenges, in particular concerned with the design of storage rings which meet the physics specification.

So far there has been no "showstopper"; rather there has emerged a number of innovative and noteworthy developments at the cutting-edge of contemporary technique in accelerator physics and of detector technology. There still remains the possibility of insurmountable technical challenges, in particular in establishing the physics of machine performance which, in some aspects, address fundamental issues of accelerator physics. Beginning as soon as possible, these challenges must be addressed if progress is to continue with the aim of realising Super*B* on the proposed time schedule. To this end, it is now both timely and highly appropriate that a Machine Advisory Committee be established to oversee progress in the many critical issues faced in the design of the Super*B* asymmetric collider.

It is clear from the above that it is essential at this time to ensure appropriate conservation and preservation of detector and machine components from PEP2 and *B*A*B*AR which could be incorporated into Super*B*.

ECFA report

Report on the INFN Super Flavour Factory Project

Working Group set up by the restricted meeting of ECFA

Y. Karyotakis (LAPP, France), F. Linde (Nikhef, the Netherlands),
B. Spaan (Uni. Dortmund, Germany)
Chaired by T. Nakada (EPFL, Switzerland)

Introduction

INFN requested European Committee for Future Accelerator (ECFA) to form an opinion on their Super Flavour Factory project during its restricted meeting (RECFA) in Lisbon on 29th of March 2008. Following a proposal by the ECFA chair, K. Meier, RECFA asked one of its members, T. Nakada, to form and chair an internal working group who should prepare a report, which should then be endorsed by ECFA. The working group consists of the four authors of this report. The report consists of a physics section describing the current status of flavour physics and the significance of a future Super Flavour Factory, a short description of the INFN project as understood by the working group, consideration of the global situation, and finally a summary.

- We consider that **flavour physics should be seen as an important part of the European research programme of elementary particle physics**, complementary to physics provided by the energy frontier experiments. For the coming ~5 years, LHCb will do this job in the b and c quark sectors. To follow-up this progress, **collecting 50 ab^{-1} or more at** Υ**(4S) energy with e^+e^- storage rings by the end of the next decade would be a significant milestone, if this can be realised at a moderate cost**.
- The INFN Super Flavour Factory project team proposes a novel scheme […]. This idea of obtaining a high luminosity with tiny beam spots at the collision point based on very small emittance beams and crab waist collisions could revolutionize the design of the future colliders. **Therefore, westrongly support the R&D effort to see if such a machine can really be built.**
- The current tests at DAFNE are promising and we would like to congratulate the team for this impressive achievement. **However, a substantial amount of work is still required for producing a Technical Design Report**, […]
- Given the complexity of the project, we feel that **a clear plan containing realistic technical milestones and resource requirements together with a strategy how to obtain them is needed as a necessary condition for an approval of the project**.
- Such a plan should aim at **obtaining an integrated luminosity of significantly more than 50 ab^{-1} by not much later than the end of the next decade**. Given the very ambitious time scale, a clear decision taking process must be established soon.

Latest News 19th Dec 2008

from Marcello Giorgi

"…It is a great pleasure to annonce you that INFN Board of Directors has endorsed the SuperB as a special project. The consensus was unanimously expressed after a long and exhausting discussion. The implications are that thereb is no obstacle to proceed with the TDR and to move to the construction of the strong organization that we need.
The project will receive the financial support ain a very generous way by the Lazio Regional governement. Roberto Petronzio after the vote of the Board was authorized by the Lazio government to officially announce this contribution that could fully cover the cost of the project preparation,
In addition INFN will give extra money through the Gruppo I. Nando Ferroni, chair of Gruppo I, confirmed in front of the Board. INFN will ask us periodical reports to the Board of Directors, to monitor the process.
Roberto Petronzio has also communicated that the funding process for construction with the National Italian Governement has started and in good shape

TDR definition and schedule

- TDR definition and schedule
  - Document requested for approval by the italian governement by end 2009. As complete as possible for the machine and the site and with a snapshot for the Physics,Detector and Computing
  - Final TDR document by the end 2010
  - Official TDR launch in February 2009 in Orsay (worskhop 15th-18th Feb)
- Next
  - Physics workshop in Warwick, April 15-18
  - MiniMAC in April as well

Many thanks!

- To the organizers of this really interesting Workshop
- For discussions and material used in the preparation of this talk to my SuperB colleagues, in particular:
  - A. Bevan, M. Biagini, M. Boscolo, M. Ciuchini, F. Forti, E. Paoloni, M. Giorgi, A. Stocchi