SuperB

http://www.pi.infn.it/SuperB/

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CIPANP '09,
San Diego, May 2009.

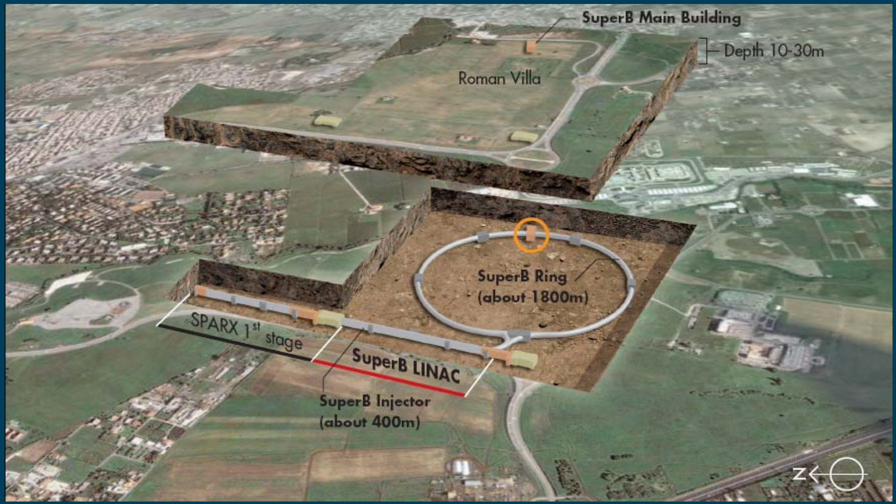
Overview

- SuperB in a nutshell
- Physics potential of SuperB
  - New Physics Search Capabilities
    - Lepton Flavour & CP Violation in τ decay
    - Rare Decays
    - Fundamental Symmetries & Higgs/dark matter
  - Standard Model measurements.
- Current Status
- Conclusion

SuperB (In a Nutshell)

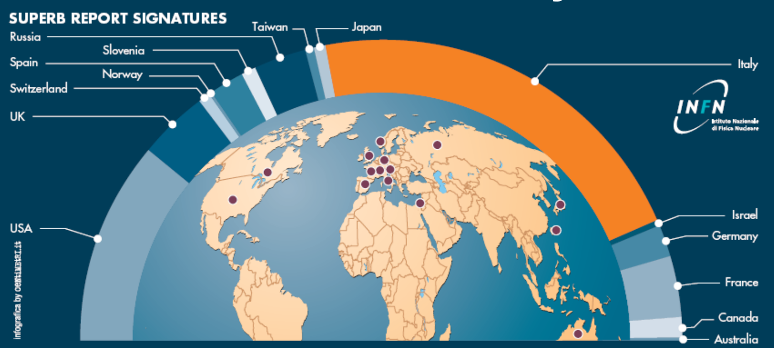
Site: Tor Vergata Campus (Rome II)

- Asymmetric energy e^+e^- collider
- Low emittance operation (like LC)
- Polarised beams
- Luminosity $10^{36}\ cm^{-2}s^{-1}$
  - $75ab^{-1}$ data at the $\Upsilon(4S)$
  - Collect data at other $\sqrt{s}$
  - Start data taking as early as 2015



- Crab Waist technique developed to achieve these goals

- International Community



Geographical distribution of CDR signatories.

Precision B, D and τ decay studies and spectroscopy

- New Physics in loops
  - 10 TeV reach at $75ab^{-1}$
  - Rare decays
  - ΔS CP violation measurements
- Lepton Flavour & CP Violation in τ decay
- Light Higgs searches
- Dark Matter searches

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Physics Potential of SuperB

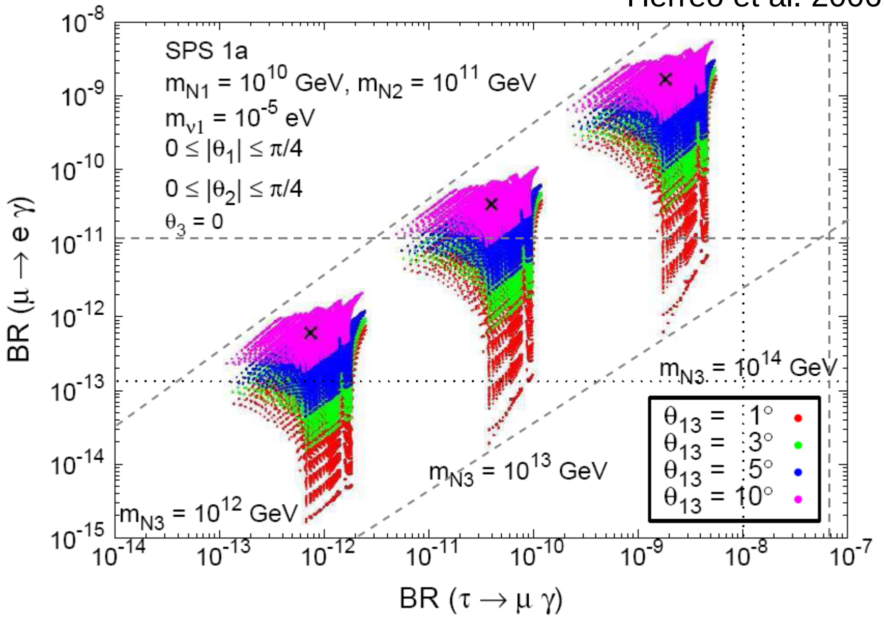
- SuperB is a super flavour factory!
  - Hundreds of billions of B_u, B_d, D, τ decays with 5 years of data taking:
    - $75ab^{-1}$ at the $\Upsilon(4S)$.
    - Running at charm threshold: $\psi(3770)$.
    - And at other Υ resonances.
- Lepton Flavour & CP Violation in τ decay.
- Rare Decay constraints on new physics.
- Fundamental symmetries & Higgs/dark matter constraints:
  - Lepton Universality, CP, T, CPT.
- + Standard Model B, D and τ physics.

Lepton Flavor Violation in τ decay

- $\tau \to \mu\gamma$ upper limit can be correlated to θ_{13} (neutrino mixing/CPV, T2K etc.) and also to $\mu \to e\gamma$.
- Complementary to flavour mixing in quarks.
- Golden modes:
  - $\tau \to \mu\gamma$ and 3μ.
- e^- beam polarization:
  - Lower background
  - Better sensitivity than competition!
- e+ polarization used later in programme.
- CPV in $\tau \to K_S \pi \nu$ at the level of $\sim 10^{-5}$.
- Bonus:
  - Can also measure τ g-2 (polarization is crucial).
  - σ(g-2) ~2.4×10^{-6} (statistically dominated error).

SUSY seasaw = CMSSM + $3\nu_R$ + $\tilde{\nu}$

Herreo et al. 2006

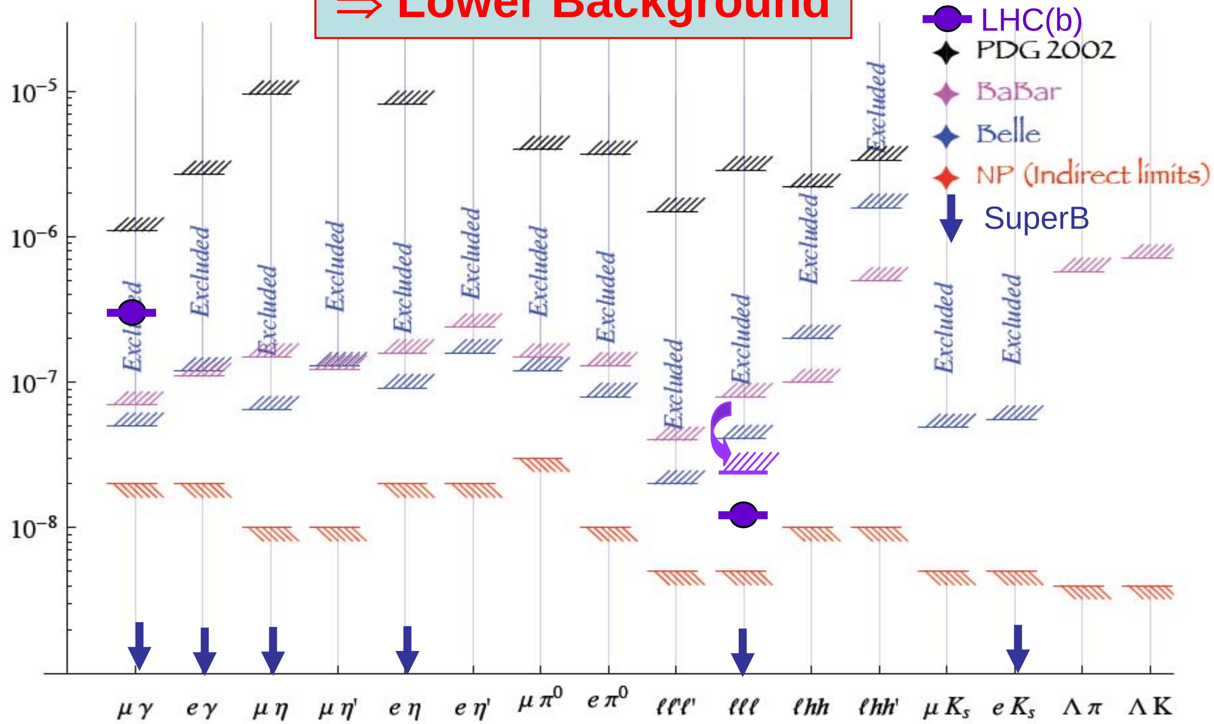


Process	Expected 90%CL upper limited	4σ Discovery Reach
$\mathcal{B}(\tau \to \mu\gamma)$	2×10^{-9}	5×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$	2×10^{-10}	8.8×10^{-10}

Use $\mu\,\gamma$/3l to distinguish SUSY vs. LHT.

Lepton Flavor Violation in τ decay

e⁻ beam polarization
⇒ Lower Background



SuperB Sensitivity ($75ab^{-1}$)

Process	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}

- LHC is ***not*** competitive (Re: both GPDs and LHCb).
- SuperB sensitivity ~10 – 50× better than NP allowed branching fractions.

Rare Decays

- No one smoking gun… rather a '***golden matrix***'.

X = Golden Channel o = Observable effect	H^+ high $\tan\beta$	Minimal FV	Non-Minimal FV (1-3)	Non-Minimal FV (2-3)	NP Z-penguins	Right-Handed currents
$\mathrm{BR}(B \to X_s\gamma)$		X		o		o
$A_{CP}(B \to X_s\gamma)$				X		o
$\mathrm{BR}(B \to \tau\nu)$	X-CKM					
$\mathrm{BR}(B \to X_s l^+ l^-)$				o	o	o
$\mathrm{BR}(B \to K\nu\overline{\nu})$				o	X	
$S(K_S\pi^0\gamma)$						X
β (ΔS)			X-CKM			X

- Need to measure all observables in order to select/eliminate new physics scenarios!

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%
$A_{FB}(B \to X_s l^+ l^-)_{s0}$	X	30%	4–6%
$\mathcal{B}(B \to K\nu\overline{\nu})$	X	X	16–20%
$S(K^0_S\pi^0\gamma)$	0.24	0.08	0.02–0.03

- **The golden modes**
  - **will be measured by SuperB.**
  - **`smoking guns' for their models.**
- **Measurements not yet made are denoted by X.**
- **With 75ab^{-1} we can**
  - **Reach above a TeV with $B \to \tau\nu$**
  - **See $B \to K\nu\overline{\nu}$**

Rare Decays : SUSY CKM

- Flavour couplings in squark sector (like CKM)

LHCb, SuperB

LHC, ILC - HE frontier

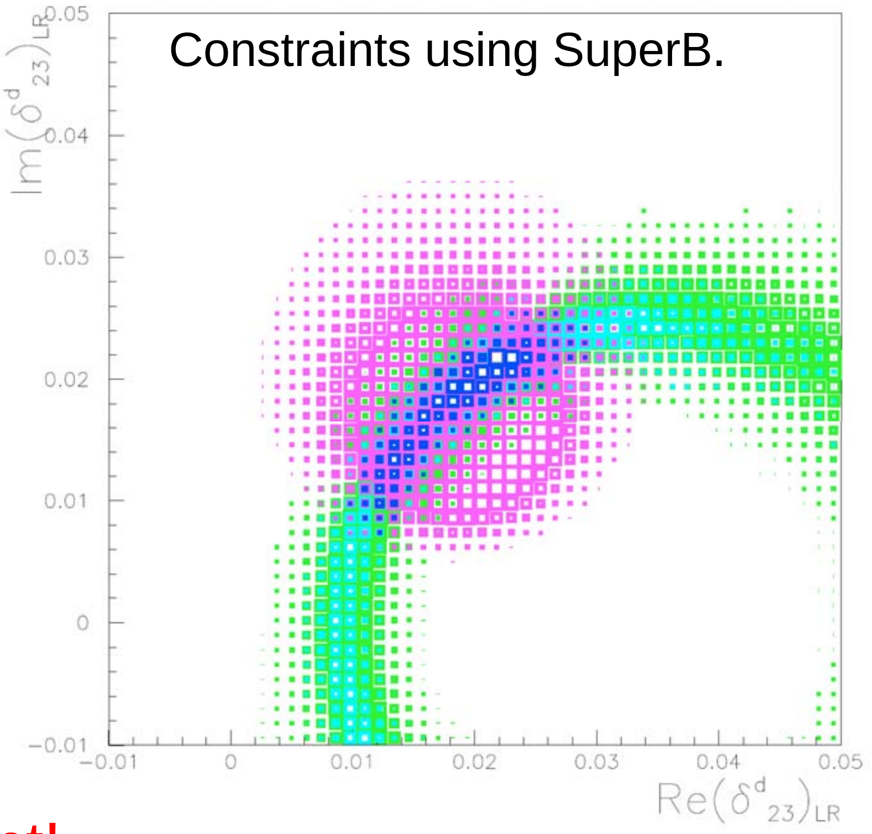
$$M^2_{\tilde{d}} \approx \begin{pmatrix} m^2_{\tilde{d}_L} & m_d(A_d-\mu\tan\beta) & (\Delta^d_{12})_{LL} & (\Delta^d_{12})_{LR} & (\Delta^d_{13})_{LL} & (\Delta^d_{13})_{LR} \\ & m^2_{\tilde{d}_R} & (\Delta^d_{12})_{RL} & (\Delta^d_{12})_{RR} & (\Delta^d_{13})_{RL} & (\Delta^d_{13})_{RR} \\ & & m^2_{\tilde{s}_L} & m_s(A_s-\mu\tan\beta) & (\Delta^d_{23})_{LL} & (\Delta^d_{23})_{LR} \\ & & & m^2_{\tilde{s}_R} & (\Delta^d_{23})_{RL} & (\Delta^d_{23})_{RR} \\ & & & & m^2_{\tilde{b}_L} & m_b(A_b-\mu\tan\beta) \\ & & & & & m^2_{\tilde{b}_R} \end{pmatrix}$$

and similarly for $M^2_{\tilde{u}}$

- NP scale: $m_{\tilde{q}}$
- Flavour and CP violation coupling: $(\Delta_{ij}^d)_{AB}/m_{\tilde{q}}^2$
- Why?
  - Non trivial CKM & MSW, so it is natural for squarks to mix!
  - Unnatural to have couplings ~0 and a low mass scale.
- e.g. MSSM: 124 parameters (160 with ν_R).
  - Most are flavour couplings!

Rare Decays : SUSY CKM

- Couplings are $\left(\delta_{ij}^{q}\right)_{AB} = \left(\Delta_{ij}^{q}\right)_{AB} / m_{\tilde{q}}^{2}$
  where *A*,*B*=*L*,*R*, and *i*,*j* are squark generations.
- e.g. Constraint on $(\delta_{23}^{d})_{LR}$ using:



- $\mathcal{B}(B\to X_s\,\gamma)$ [green]
- $\mathcal{B}(B\to X_s\,l^+l^-)$ [cyan]
- $A_{CP}(B\to X_s\,\gamma)$ [magenta]
- Combined [blue]

SuperB probes new physics in SUSY larger than 20TeV (and up to 300TeV in some scenarios)

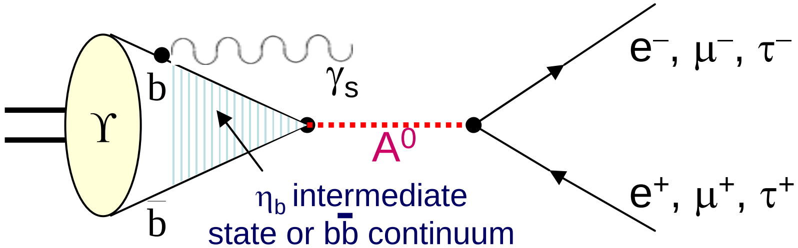
Now: Whole Range allowed.

SuperB: % level measurement!

See (or rule out) a sparticle signal at TeV scale with 75ab^{-1}.

Searching for a Light Higgs & Dark Matter

- Many NP scenarios have a possible light Higgs Boson (e.g. 2HDM).
- Can use $\Upsilon(nS) \to l^+ l^-$ to search for this.
  - Contribution from A^0 would break lepton universality



M. A. Sanchis-Lozano, hep-ph/0510374,
Int. J. Mod. Phys. A19 (2004) 2183

- Can expect to record at least $300 fb^{-1}$ recorded at the $\Upsilon(3S)$ in SuperB.
- This is 10 × the BaBar data sample at the $\Upsilon(3S)$.

- NMSSM Model with 7 Higgs Bosons

Physical Higgs bosons: (seven)

2 neutral CP-odd Higgs bosons ($A_{1,2}$)
3 neutral CP-even Higgs bosons ($H_{1,2,3}$)
2 charged Higgs bosons ($H^{\pm}$)

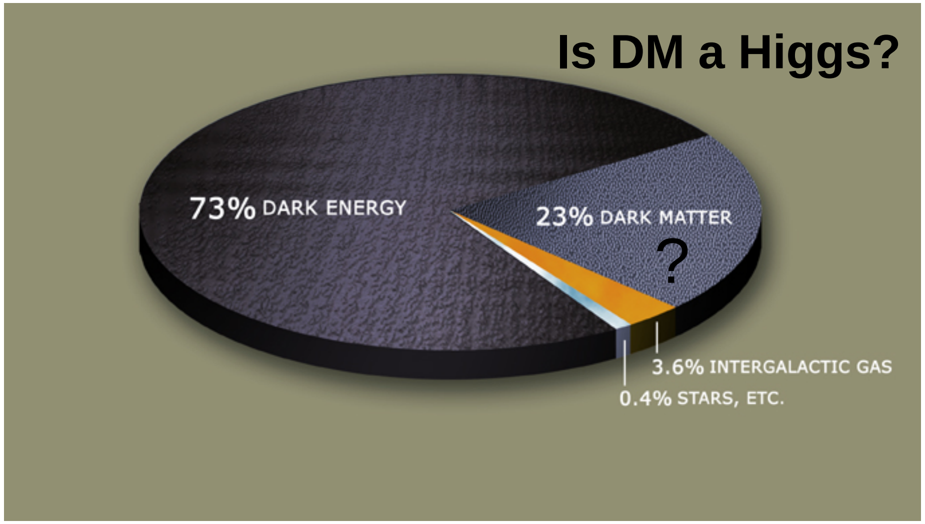
Possible NMSSM Scenario

A_1 ~ 10 GeV
H_1 ~ 100 GeV (SM-like)
Others ~300 GeV (almost degenerate)

- A_1 could be a light DM candidate.

Gunion, Hooper, McElrath [hep-ph:0509024]
McElrath [hep-ph/0506151], [arXiv:0712.0016]

Searching for Dark Matter

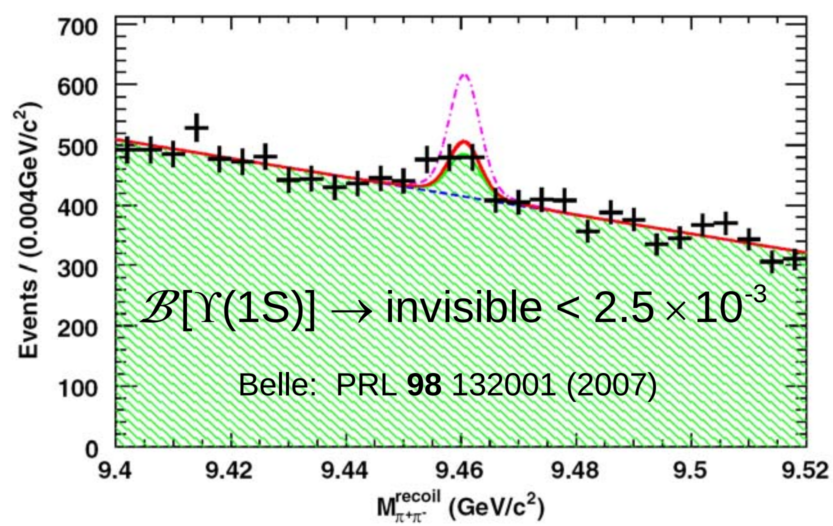


- Possible to search for the effect of DM at the B-factories for most modes:

$$\Upsilon \to invisible \qquad J/\Psi \to invisible$$
$$\eta \to invisible \qquad \Upsilon \to \gamma + invisible$$
$$B^+ \to K^+ + invisible \qquad \Upsilon \to \gamma A_1, A_1 \to \tau^+\tau^-$$
$$K^+ \to \pi^+ + invisible \qquad J/\Psi \to \gamma A_1$$

hep-ph/0506151, hep-ph/0509024, hep-ph/0401195, hep-ph/0601090, hep-ph/0509024, hep-ex/0403036 ...

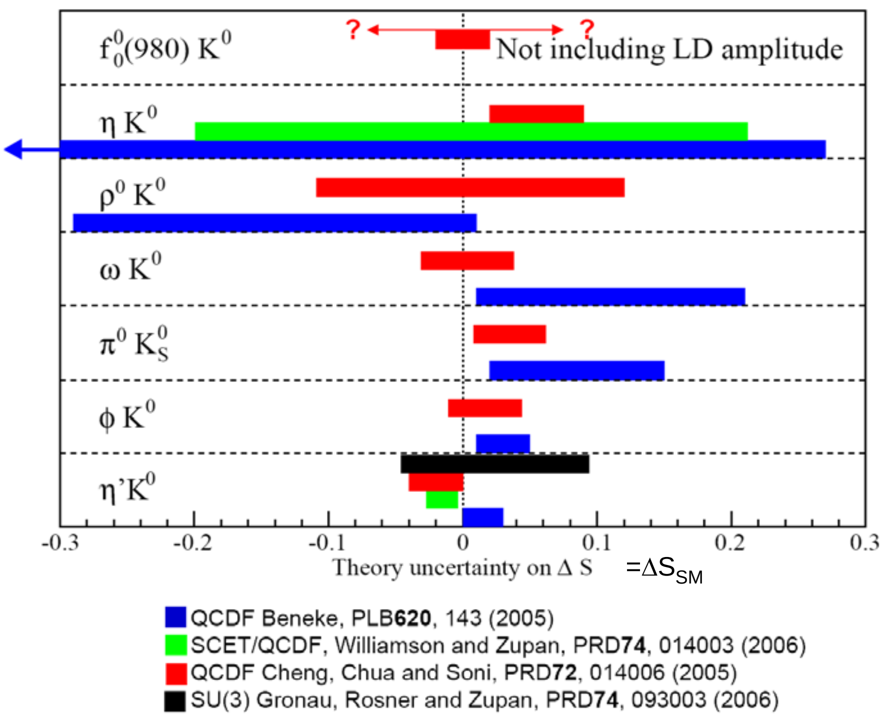
- SM Expectation: $\mathcal{B}(\Upsilon(1S) \to \nu\overline{\nu}) = (9.9 \pm 0.5) \times 10^{-6}$
- NP extension: $\mathcal{B}(\Upsilon(1S) \to \chi\chi)$ up to 6×10^{-3}
- SuperB should be able to provide a precision constraint on this channel.
- Belle has 7fb-1 at the $\Upsilon(1S)$, SuperB will have hundreds of fb^{-1}.

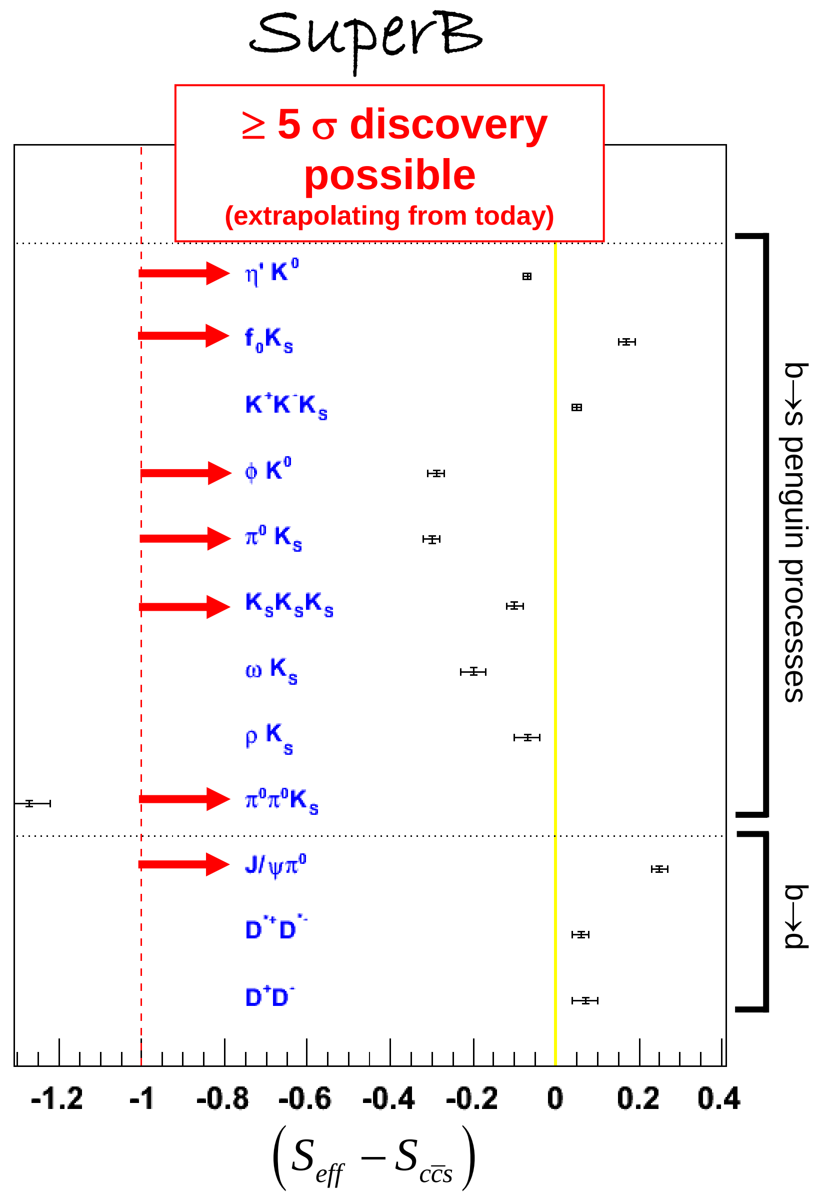


ΔS measurements (CPV)

- $\beta=(21.1\pm0.9)^\circ$ from Charmonium decays.
- Look in many different $b\to s$ and $b\to d$ decays for $\sin 2\beta$ deviations from the SM:

$$\Delta S_{\rm NP} = S_{eff} - S_{c\bar{c}s} - \Delta S_{\rm SM}$$





Standard Model measurements.

B Physics at 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 (∗)
$S(K^0_s K^0_s K^0_s)$	0.15	0.02 (∗)
$S(K^0_s \pi^0)$	0.15	0.02 (∗)
$S(\omega K^0_s)$	0.17	0.03 (∗)
$S(f_0 K^0_s)$	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° (∗)
$2\beta+\gamma$ $(D^{(*)\pm}\pi^\mp, D^\pm K^0_s \pi^\mp)$	20°	5°
$\lvert V_{cb}\rvert$ (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 (†)
$S(K^0_S \pi^0 \gamma)$	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%
$\mathcal{B}(B \to K\nu\overline{\nu})$	visible	20%
$\mathcal{B}(B \to \pi\nu\bar{\nu})$	–	possible

Rare Charm Decays: 1 month at ψ(3770)

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}

Charm Mixing

Mode	Observable	$\Upsilon(4S)$ (75 ab^{-1})	$\psi(3770)$ (300 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		$(1-2) \times 10^{-5}$
	y		$(1-2) \times 10^{-3}$
	$\cos\delta$		$(0.01-0.02)$

See CDR and Valencia report for details of the SM measurements and other possible NP searches.

τ: LFV / CPV / …

Process	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}

B Physics at Υ(5S)

Observable	Error 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°

Current Status

- Work toward realizing the experiment is starting!
  - Prepare Technical Design Reports *now - end 2010*.
  - Construct experiment *2011-2015*.

… then start to take data!

- Just started work toward Technical Design Reports.
  - Fast and GEANT simulations available to optimize detector studies for physics goals!
  - Detector and accelerator R&D ongoing.
  - Preparing
    - A Technical Proposal for end of 2009.
    - A Technical Design Report for end of 2010/start 2011.
  - Physics workshop at Warwick April 2009.
  - Plenty of work to do…

- You're welcome to join the effort!
  - contact giorgi.superb@pi.infn.it for more information.

Conclusion

- SuperB measures a unique set of new physics observables to high precision.
  - Measure a ***golden matrix*** to test new physics signatures.

Scenario 1

  - LHC finds new physics after 2010…
    - But what exactly has it found…? ⇒ **SuperB pins it down**!

Conclusion

- SuperB measures a unique set of new physics observables to high precision.
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Scenario 1

  - LHC finds new physics after 2010…
    - But what exactly has it found…? $\Rightarrow$ **SuperB pins it down**!

Scenario II

  - LHC doesn't find new physics!
    - $\Rightarrow$SuperB indirectly searches far beyond the reach of LHC: ~ 100TeV.
      - c.f. 1970: GIM mechanism and $K_L \to \mu^+\mu^-$.
      - c.f. 1973: 3^{rd} generation from CKM matrix.
      - c.f. 90s $\Rightarrow$ heavy top quark mass from Δm_d.
      - Z^0 width constraints on the SM Higgs …?

Conclusion

- SuperB measures a unique set of new physics observables to high precision.
  - Measure a ***golden matrix*** to test new physics signatures.

Scenario I

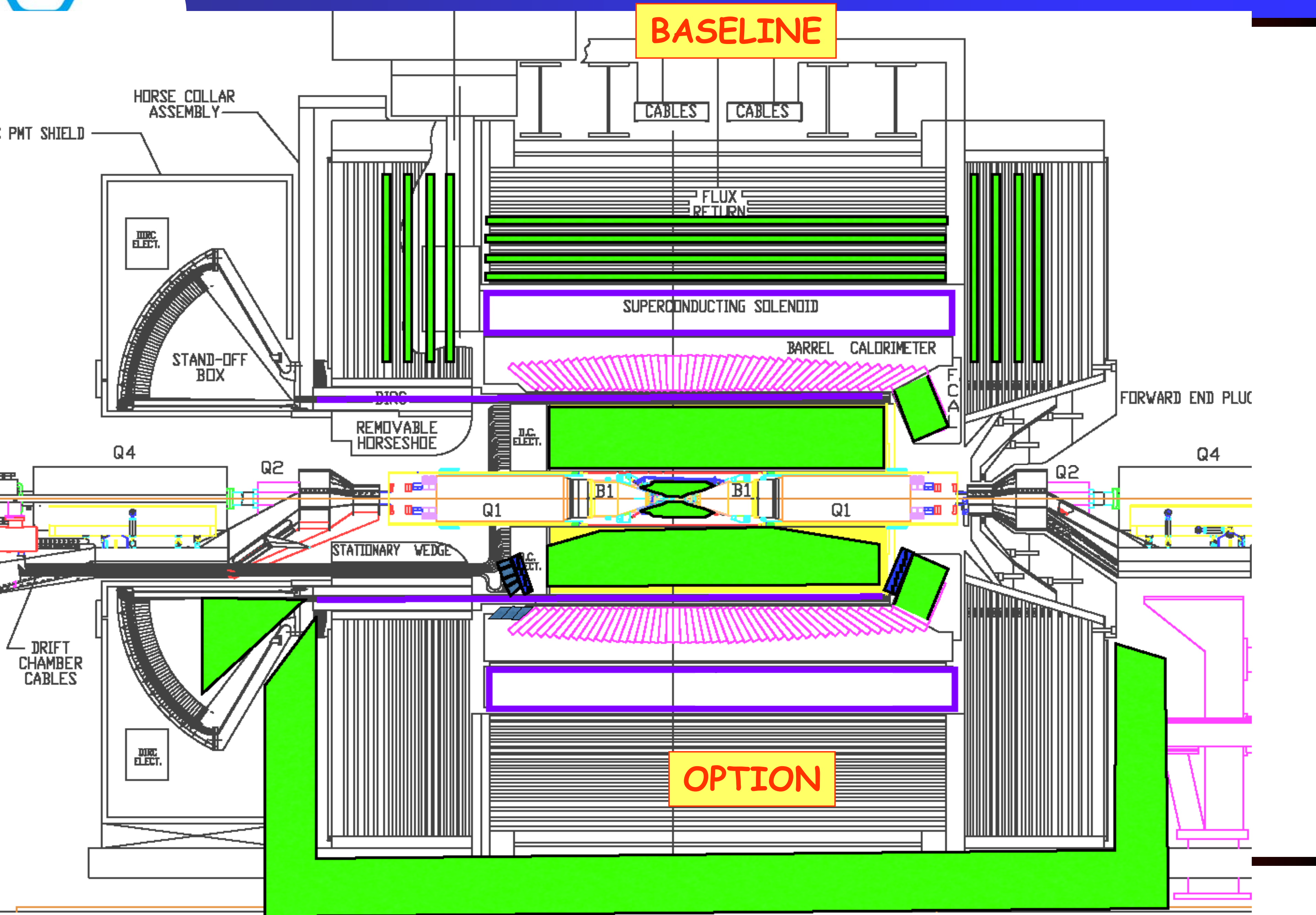
  - LHC finds new physics after 2010…
    - But what exactly has it found…? ⇒ **SuperB pins it down**!

Scenario II

  - LHC doesn't find new physics!
    - ⇒SuperB indirectly searches far beyond the reach of LHC: ~ 100TeV.
      - c.f. 1970: GIM mechanism and $K_L \to \mu^+\mu^-$.
      - c.f. 1973: 3rd generation from CKM matrix.
      - c.f. 90s ⇒ heavy top quark mass from Δm_d.
      - Z^0 width constraints on the SM Higgs …?
  - Either way round we need SuperB to unravel the mysteries of nature.
- + SuperB does all of the Standard Model measurements you'd expect.
  - and … constrains SM errors for other NP searches; e.g. $K^0_L \to \pi^0 \nu\bar{\nu}$.
- See http://www.pi.infn.it/SuperB/, CDR, and physics workshop report for more details: arXiv:0810.1312 and 0709.0451.

Additional Material

Detector Layout – Reuse parts of Babar



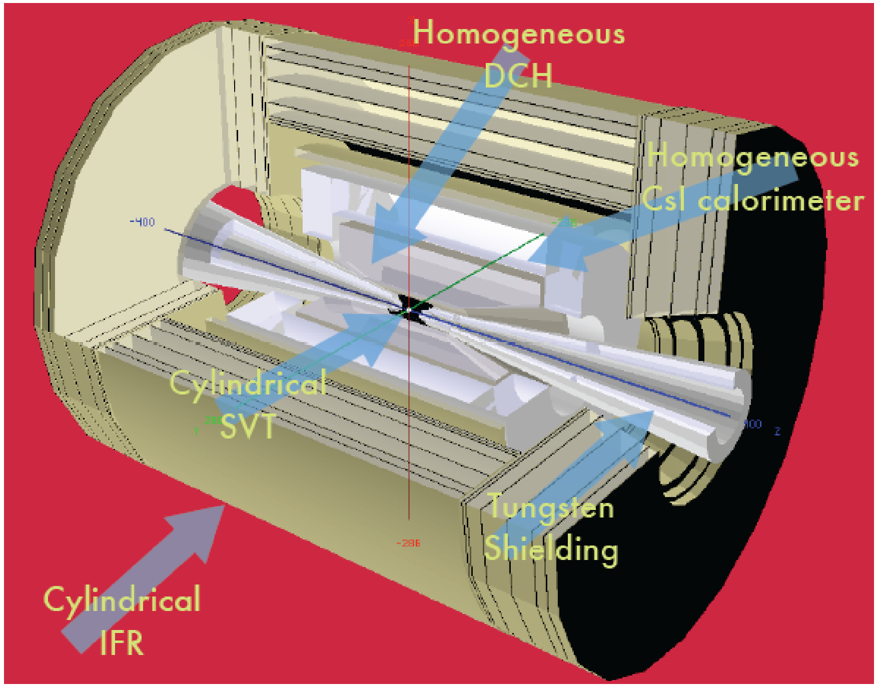
Detector

- Simulation:
  - FastSim (validated on using geometry for BaBar)
    - Reproduces BaBar resolutions etc.
    - Change to SuperB geometry and boost for development of benchmark studies.
    - Then move to GEANT 4 for more detailed work.

  - GEANT 4 model of SuperB shown.

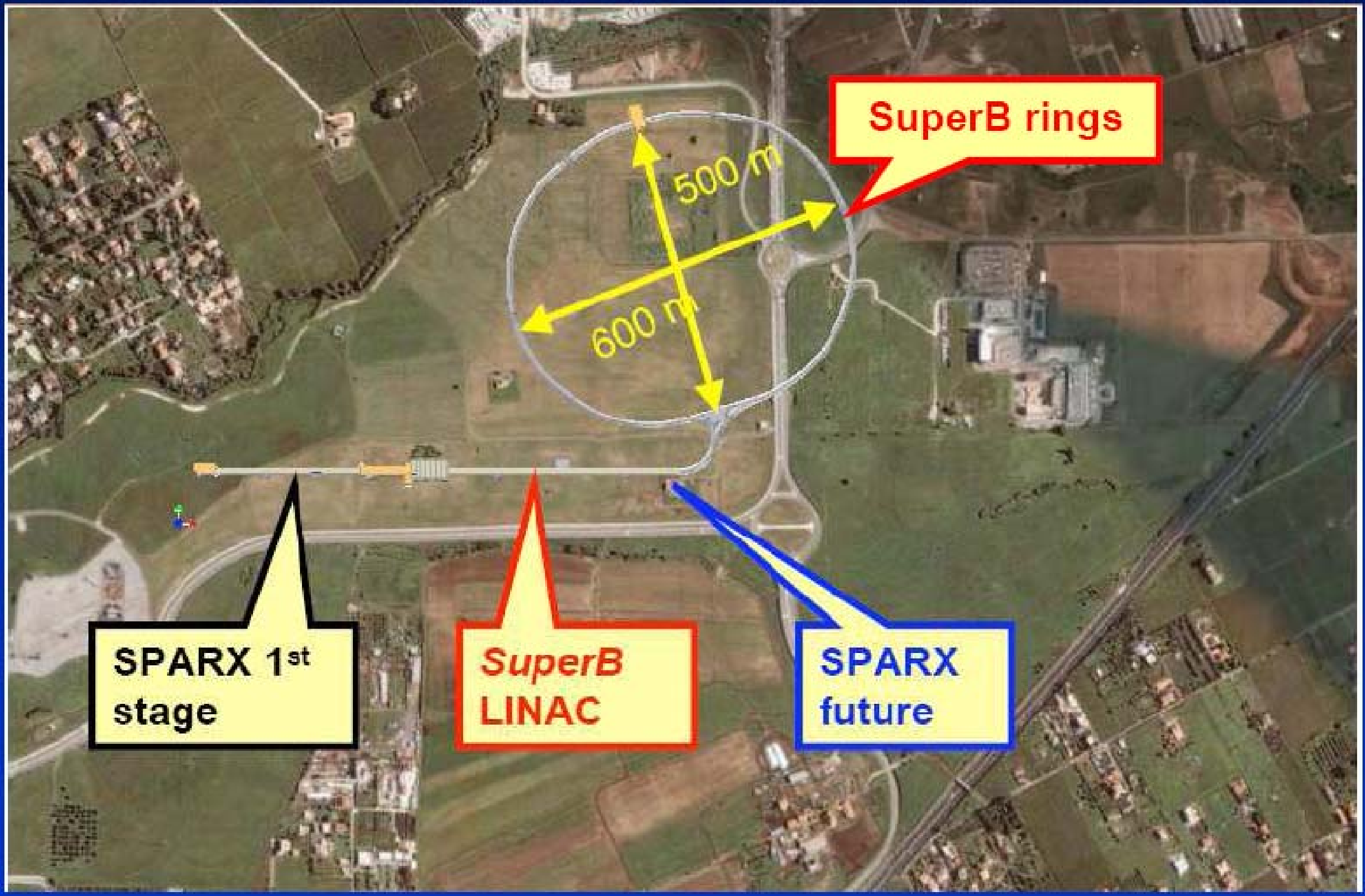
  - Using BaBar framework.

  - Draw on a decade of analysis experience from BaBar and Belle to optimize an already good design.



From M. Biagini @ ICFA 2008 meeting

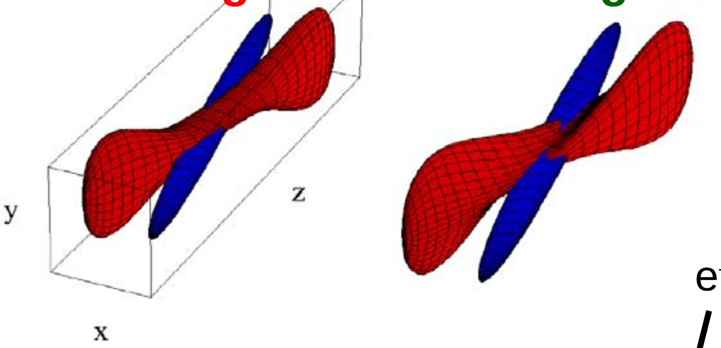
SuperB footprint on Tor Vergata site



21

Crab waist tests at DAΦNE

Crabbing off **Crabbing on**

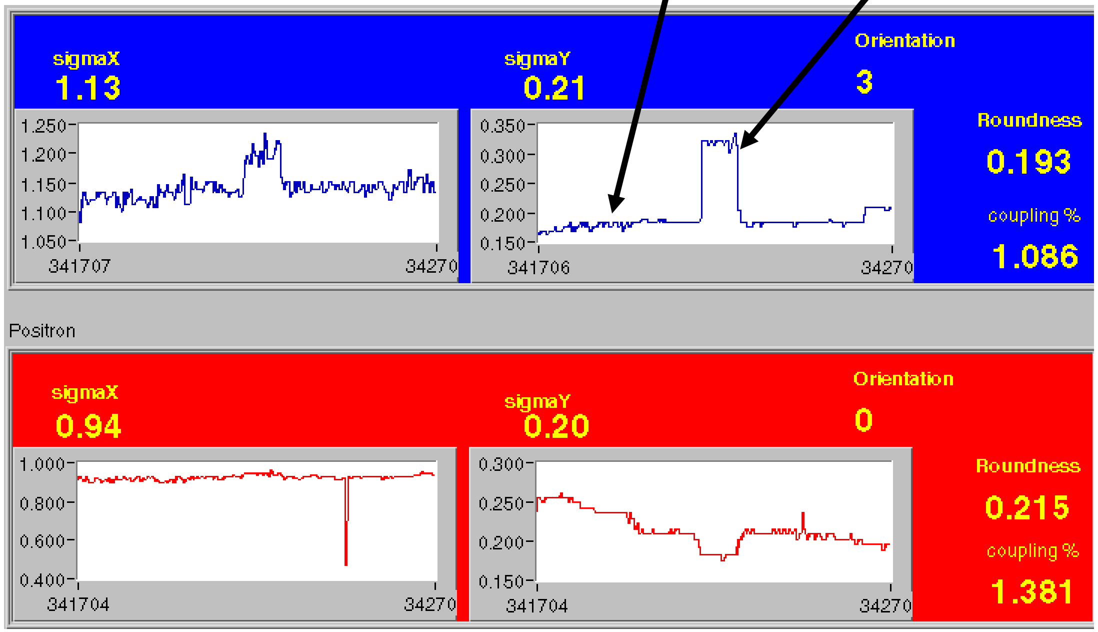


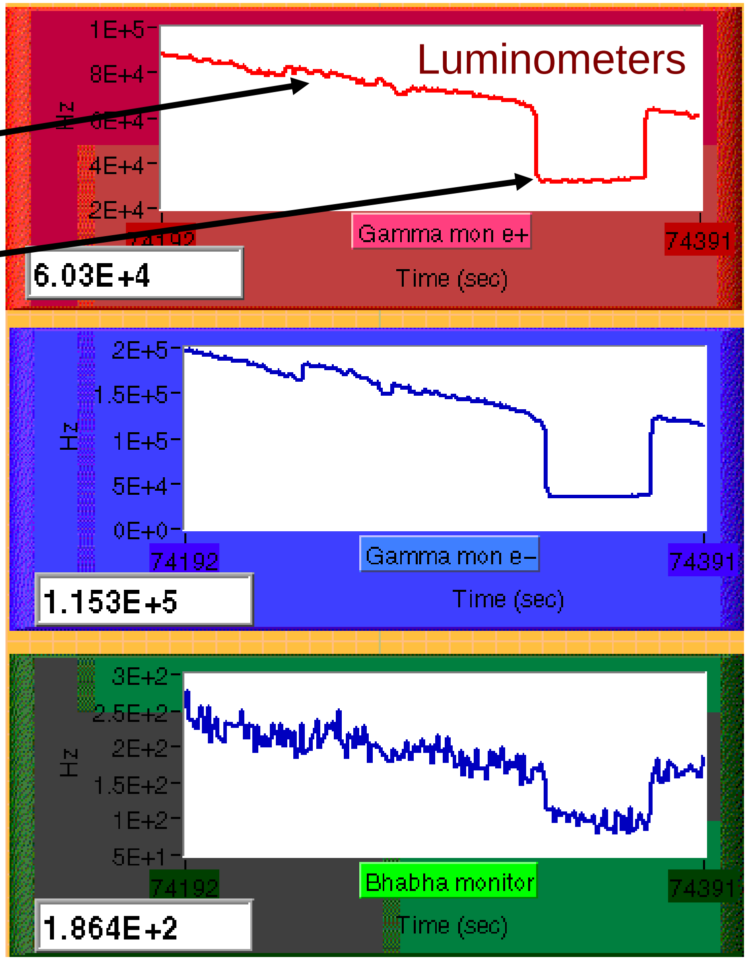
Crab sextupoles give luminosity improvement of roughly factor 2.
(Factor of 4 achieved in latest run!)

e⁻ sextupoles on

e⁻ sextupoles off

Transverse beam sizes at Synchrotron Light Monitors



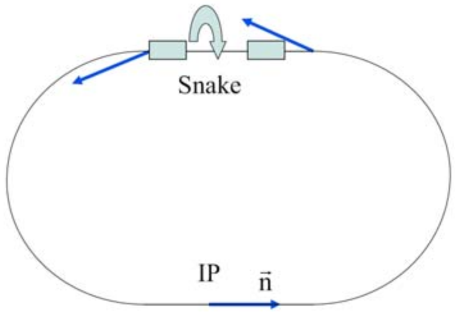


P. Raimondi (INFN-LNF)

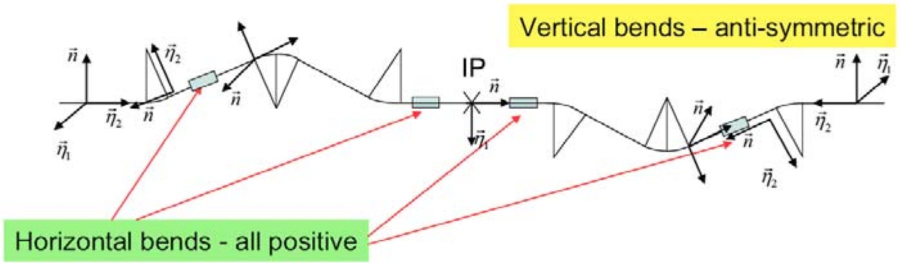
Polarisation

- In a storage ring, particle spins naturally precess around the vertical fields of the arc dipoles, at a rate determined by the particle energy.
  - This means that vertical polarisation is naturally preserved, but longitudinal polarisation can be lost without preventive measures.

- For SuperB, there are two options to maintain longitudinal polarisation in the beam at the IP:
  1. Use solenoids opposite the IP, to rotate the spin by π around the longitudinal axis.
  2. Use solenoids or vertical bends to rotate between vertical and longitudinal spin before and after the IP.



- Option 2 will probably work best for the multi-GeV SuperB rings, but more studies are needed.



- With a source providing ~ 90% polarisation, it is expected that an average polarisation of 80% can be achieved for the e^- beam. e^+ polarisation would be an upgrade…