The SuperB Factory

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Outline

- The Physics Case.
- The Machine.
- The Detector.
- The SuperB Timeline.
- Conclusions.

Introduction

- Current flavor physics landscape is defined by BaBar, Belle, CDF, D0, and LHCb results.
  - Triumph of the CKM paradigm.
  - Indirect constraints on New Physics.

- First collision in SuperB will be in 2017 and the first full run is expected in 2018.
  - LHCb will have re-defined some areas of Flavor Physics.
  - LHC may (or may not) have found New Physics.
  - In both scenarios SuperB results can be used to constrain Flavor Dynamics at high energy

The Energy Scale of NP: Λ_{NP} (1)

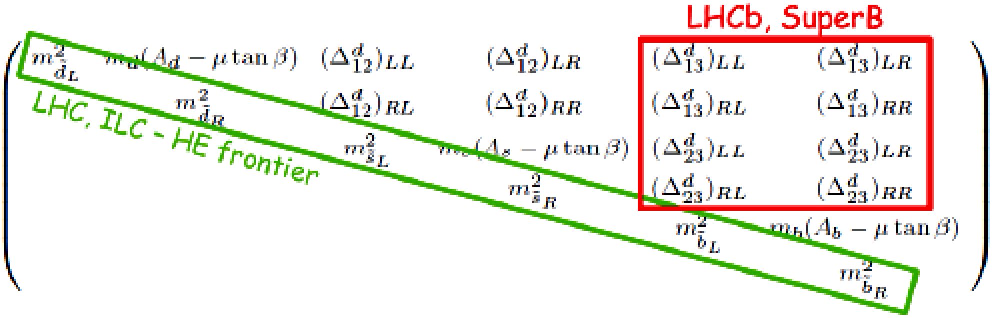
- SuperB does not operate at High Energy.
  - What's the point of having it ?
- Two paths in the quest for NP:
  - The relativistic path:
    - Increase the energy and look for direct production of new particles.
  - The quantum path:
    - Increase the luminosity and look for effects of physics beyond the standard model in loop diagrams.
- Model dependent indirect searches for NP at SuperB reach higher scales then can be attained at LHC.
  - B mixing and top: everyone knew the top was light until ARGUS found B mixing to be large.

The Energy Scale of NP: Λ_{NP} (2)

- Example: MSSM.
  - Simple, constrained by LHC data, but general enough to illustrate the issue:

e.g. MSSM: 124 (160 with ν_R) couplings, most are flavour related.

Δ's are related to NP mass scale.



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

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

- In many NP scenarios the energy frontier experiments will probe diagonal elements of mixing matrices.

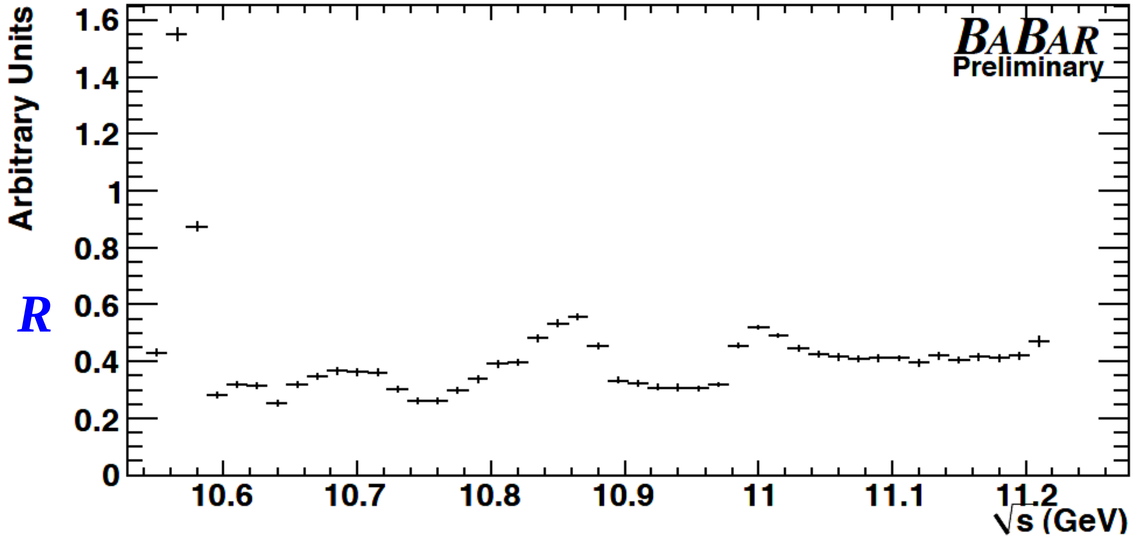
- Flavor experiments are required to probe off-diagonal ones.

Expected data sample for SuperB

- ϒ(4S) region:
  - 75ab^{-1} at the ϒ(4S)
  - Also run above / below the ϒ(4S)

  ~75 x10^9 B, D and τ pairs

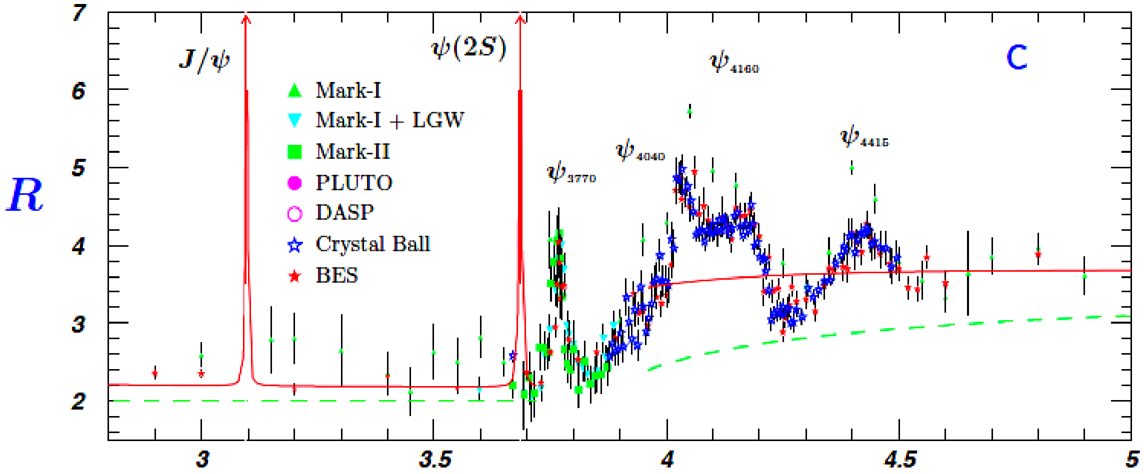
  (6 years run)



- ψ(3770) region:
  - 1 ab^{-1} at threshold
  - Also run at nearby resonances

  ~3.6 x 10^9 D pairs

  (< 1 year run)



Super B Physics Program in a Nutshell

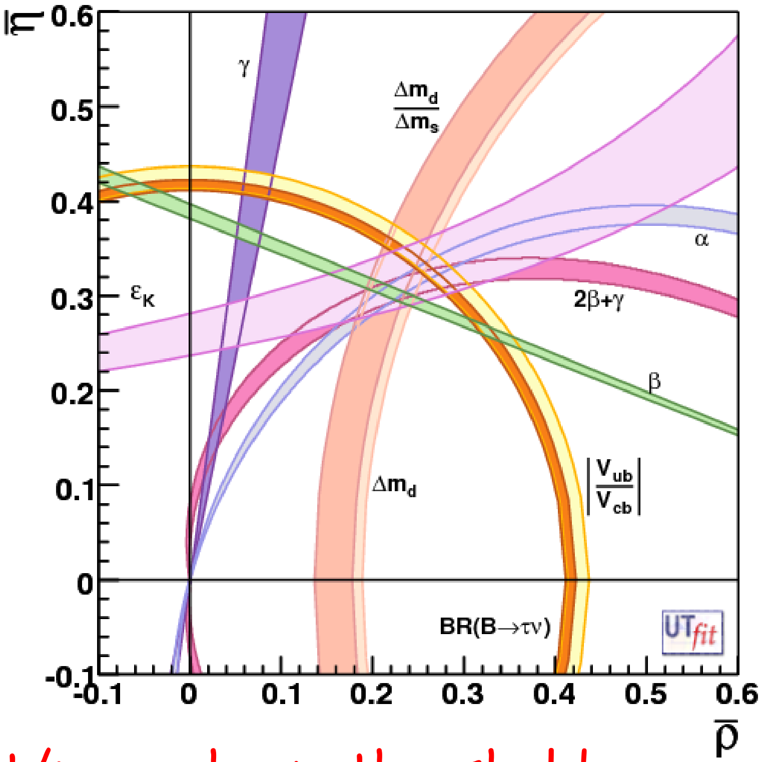
- Test of CKM Paradigm at 1% level.
- B rare decays
- Lepton Flavor Violation.
- B_s Physics.
- Electro-Weak measurements.
- Charm Physics.
- New hadrons (X, Y, Z States).
- …

Require Lattice QCD improvements

Test of CKM Paradigm

- Unitarity Triangle Angles
  - $\sigma(\alpha) = 1–2°$
  - $\sigma(\beta) = 0.1°$
  - $\sigma(\gamma) = 1–2°$
- Cabibbo-Kobayashi-Maskawa Matrix Elements
  - $|V_{ub}|$: Incl. σ = 2%; Excl. σ = 3%
  - $|V_{cb}|$: σ = 1%
  - $|V_{us}|$: Can be measured precisely using τ decays
  - $|V_{cd}|$ and $|V_{cs}|$: can be measured at/near charm threshold.
- SuperB measures the sides and angles of the Unitarity Triangle

The "dream" scenario with 75ab^{-1}

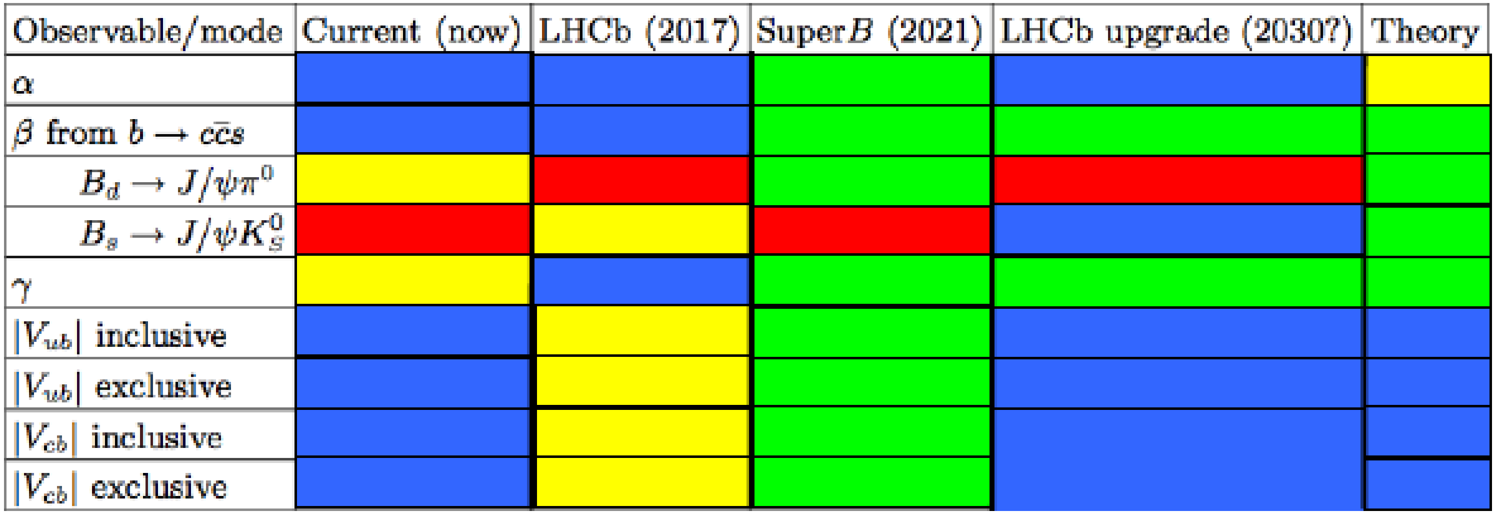


Time Dependent Analysis: BaBar vs SuperB

Changes in two main ingredients:

- Δt resolution: SuperB boost < BaBar boost -> smaller Δz, worst Δt.
  - To cure this:
    - Add SVT layer 0, reducing SVT inner radius from 3.32 cm to 1.60 cm.
    - Reduce beam spot size.
    - Lower material budget in the beam pipe.
  - Preliminary studies: Δt determined with comparable precision wrt BaBar
- Flavor tagging algorithm:
  - BaBar: Neural Network approach to isolate high momentum lepton and K and soft π (from D* decay)
    - Figure of merit: $Q = \varepsilon_{tag}(1-2\omega)^2$
    - ε_{tag} = tagging efficiency, ω=mistag probability
    - Resolution on S and C: $\sigma_{S,C} \propto \frac{1}{\sqrt{Q}}$
  - SuperB: expect to increase Q thanks to larger tracking coverage, improved PID, better vertexing

CKM measurements: SuperB vs. LHCb



Observable/mode	Current (now)	LHCb (2017)	Super$B$ (2021)	LHCb upgrade (2030?)	Theory
α	🟦	🟦	🟩	🟦	🟨
β from $b \to c\bar{c}s$	🟦	🟦	🟩	🟩	🟩
$B_d \to J/\psi\pi^0$	🟨	🟥	🟩	🟥	🟩
$B_s \to J/\psi K_S^0$	🟥	🟨	🟥	🟦	🟩
γ	🟨	🟦	🟩	🟩	🟩
$\lvert V_{ub}\rvert$ inclusive	🟦	🟨	🟩	🟦	🟦
$\lvert V_{ub}\rvert$ exclusive	🟦	🟨	🟩	🟦	🟦
$\lvert V_{cb}\rvert$ inclusive	🟦	🟨	🟩	🟦	🟦
$\lvert V_{cb}\rvert$ exclusive	🟦	🟨	🟩		🟦

LHCb can only use $\rho\pi$

βtheory error B_d

βtheory error B_s

Need an e^+e^- environment to do a precision measurement using semi-leptonic B decays.

Experiment: 🟥 No Result 🟨 Moderate Precision 🟦 Precise 🟩 Very Precise

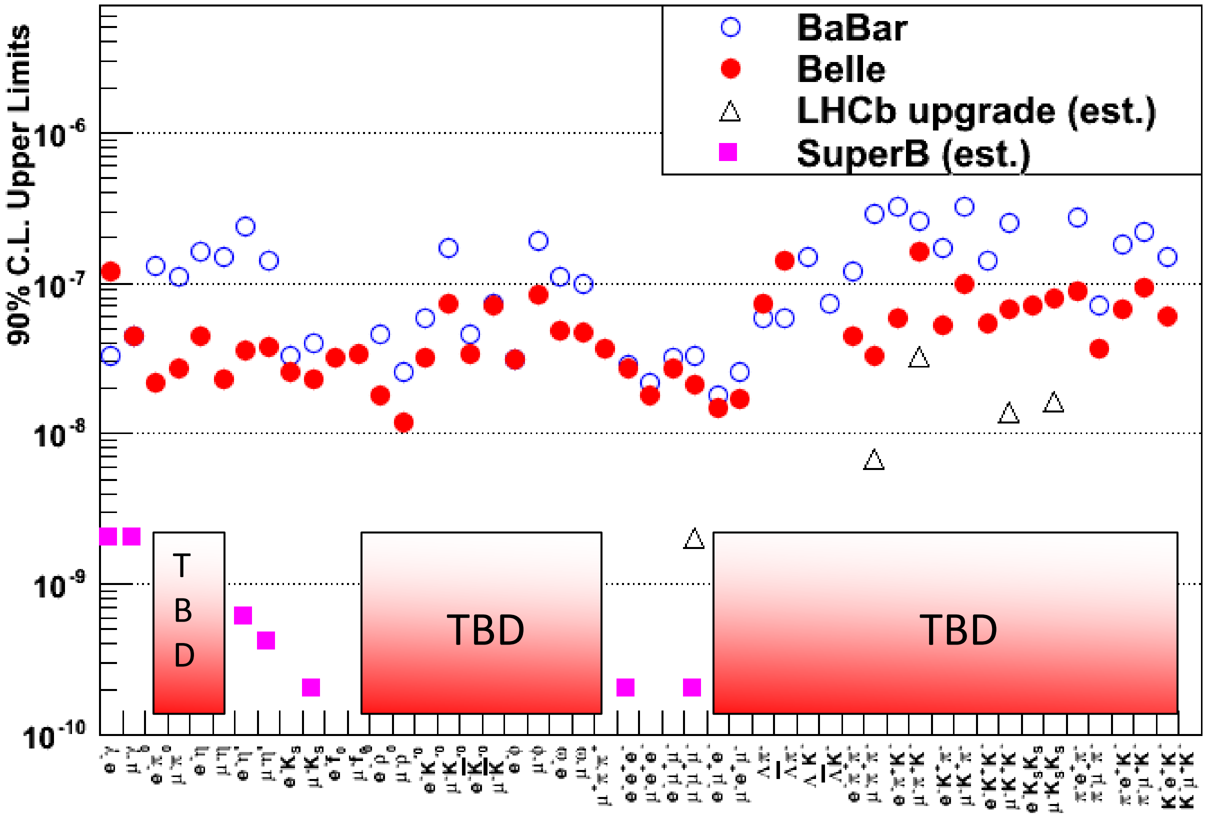
Theory: 🟨 Moderately clean 🟦 Clean Need lattice 🟩 Clean

See P. Seyfert & F. Renga's talks

Lepton Flavor Violation

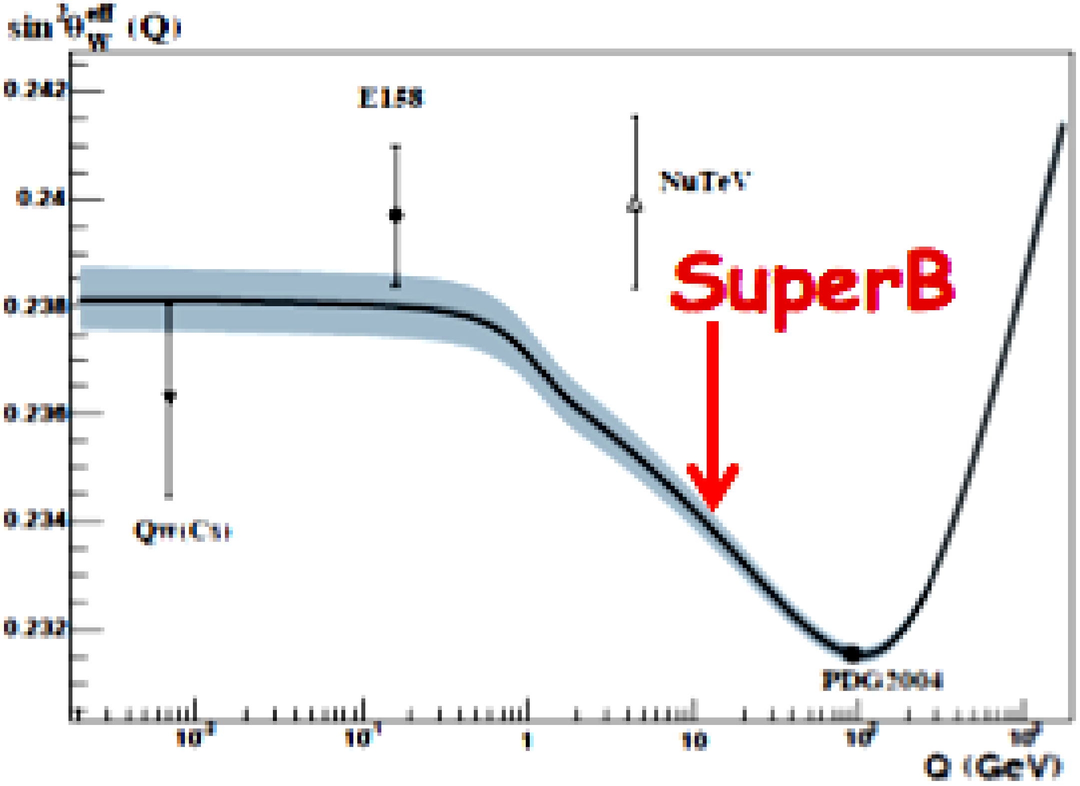
- ν mixing leads to a extremely low level of charged LFV (10^{-50}).
- Enhancements are possible in some new physics scenarios.

- Two orders of magnitude improvement over current limits.
- Hadron machines are not competitive with current methods.
    - Notable exception: $\tau \to 3\mu$ from LHCb
- Polarization helps in suppressing background.



EW Measurements

- $\sin^2\theta_W$ can be measured with polarised e^- beam:
  - $\sqrt{s}=\Upsilon(4S)$ is theoretically clean, c.f. b-fragmentation at Z pole.



Measure LR asymmetry in

$$\begin{aligned} e^+e^- &\rightarrow b\bar{b} \\ e^+e^- &\rightarrow c\bar{c} \\ e^+e^- &\rightarrow \tau^+\tau^- \\ e^+e^- &\rightarrow \mu^+\mu^- \end{aligned}$$

at the $\Upsilon(4S)$ to same precision as LEP/SLC at the Z-pole.

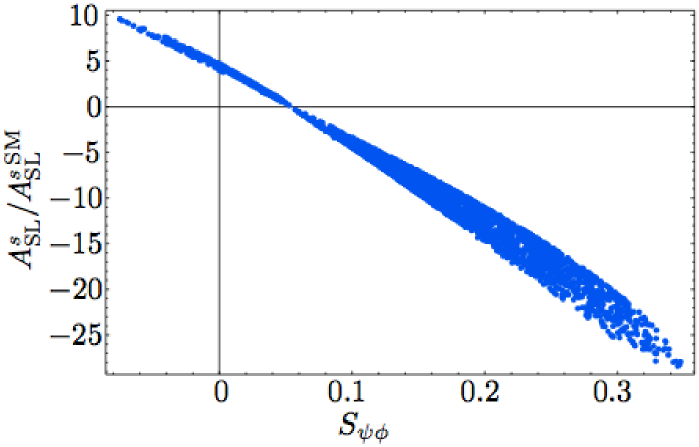
Complements measurements planned/ underway at lower energies (QWeak/MESA).

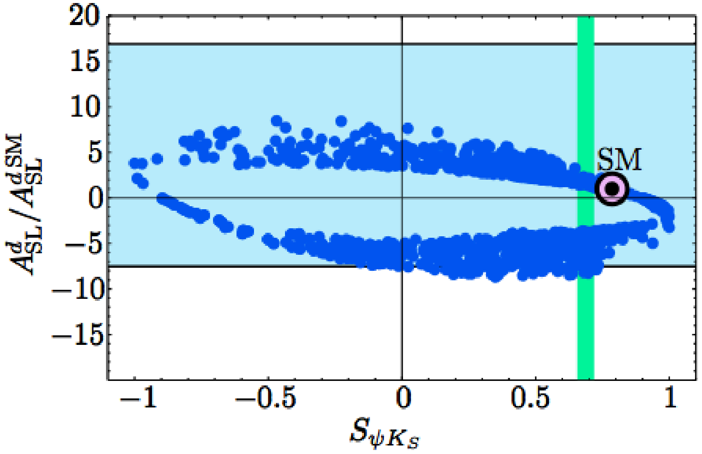
B_s Physics

- Can cleanly measure A^s_{SL} using $\Upsilon(5S)$ data

$$A^s_{\rm SL} = \frac{\mathcal{B}(B_s \to \overline{B}_s \to D_s^{(*)-} l^+ \nu_l) - \mathcal{B}(\overline{B}_s \to B_s \to D_s^{(*)+} l^- \nu_l)}{\mathcal{B}(B_s \to \overline{B}_s \to D_s^{(*)-} l^+ \nu_l) + \mathcal{B}(\overline{B}_s \to B_s \to D_s^{(*)+} l^- \nu_l)} = \frac{1-|q/p|^4}{1+|q/p|^4}\,.$$

$$\sigma(A^s_{SL}) \sim 0.004 \text{ with a few } ab^{-1}$$





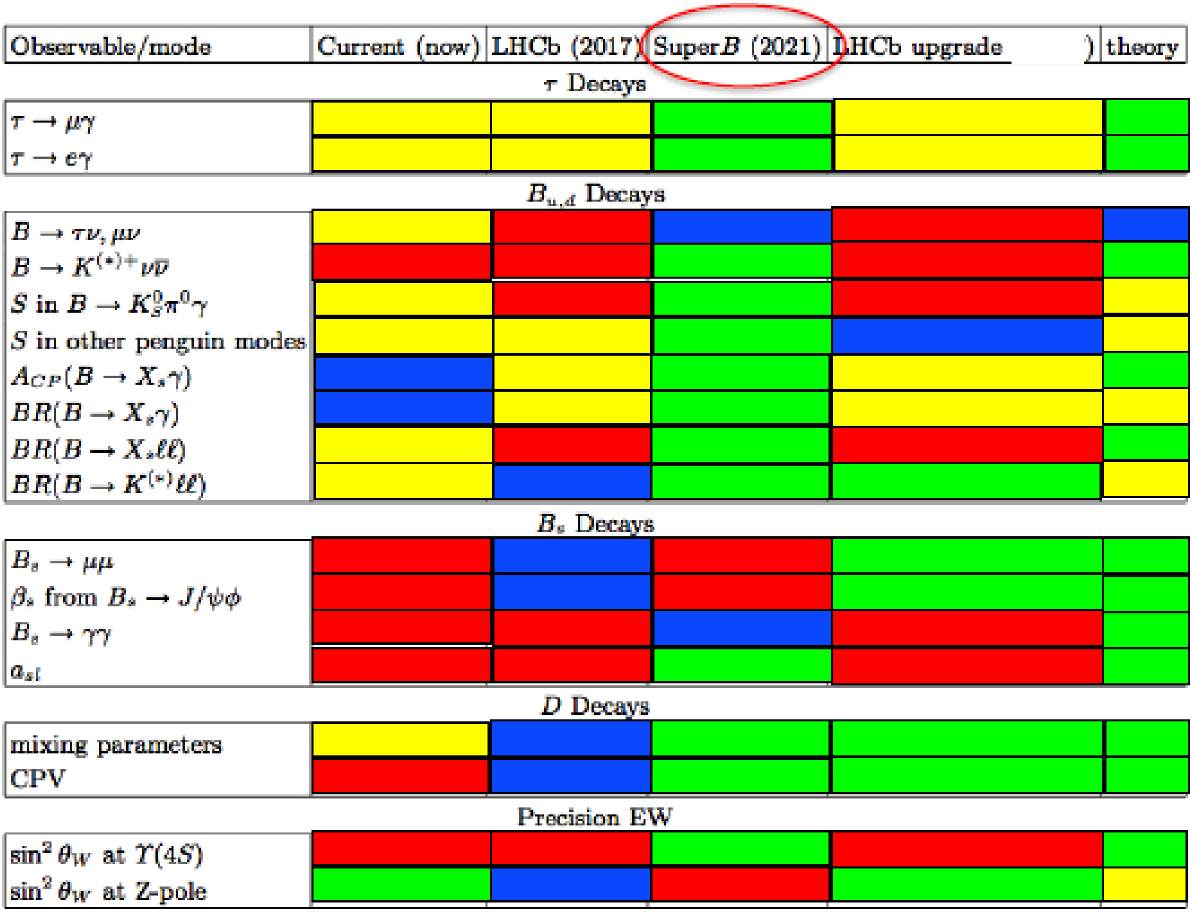
- SuperB can also study rare decays with many neutral particles, such as $B_s \to \gamma\gamma$, which can be enhanced by SUSY.

Golden Measurements: SuperB vs. LHCb

Experiment: 🟥 No Result 🟨 Moderate Precision 🟦 Precise 🟩 Very Precise

Theory: 🟨 Moderately clean 🟦 Clean Need lattice 🟩 Clean

Physics Group

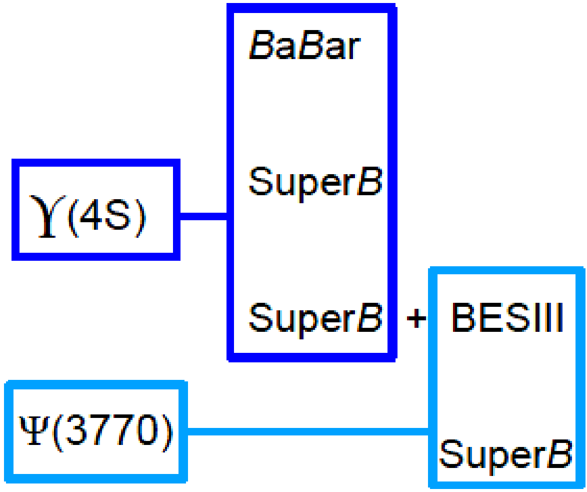


Observable/mode	Current (now)	LHCb (2017)	SuperB (2021)	LHCb upgrade)	theory	
τ Decays						
$\tau \to \mu\gamma$	🟨	🟨	🟩	🟨	🟩	Benefit from polarised e- beam
$\tau \to e\gamma$	🟨	🟨	🟩	🟨	🟩	
$B_{u,d}$ Decays						
$B \to \tau\nu, \mu\nu$	🟨	🟥	🟦	🟥	🟦	very precise with improved detector
$B \to K^{(*)+}\nu\overline{\nu}$	🟥	🟥	🟩	🟥	🟩	Statistically limited: Ang. analysis with >75ab-1
S in $B \to K_S^0\pi^0\gamma$	🟨	🟥	🟩	🟥	🟨	Right handed currents
S in other penguin modes	🟨	🟨	🟩	🟦	🟨	SuperB measures many more modes
$A_{CP}(B \to X_s\gamma)$	🟦	🟨	🟩	🟨	🟩	systematic error is main challenge
$BR(B \to X_s\gamma)$	🟦	🟨	🟩	🟨	🟨	control systematic error with data
$BR(B \to X_s\ell\ell)$	🟨	🟥	🟩	🟥	🟩	
$BR(B \to K^{(*)}\ell\ell)$	🟨	🟦	🟩	🟩	🟨	SuperB measures e mode well, LHCb does μ
B_s Decays						
$B_s \to \mu\mu$	🟥	🟦	🟥	🟩	🟩	
β_s from $B_s \to J/\psi\phi$	🟥	🟦	🟥	🟩	🟩	
$B_s \to \gamma\gamma$	🟥	🟥	🟦	🟥	🟩	
a_{sl}	🟥	🟥	🟩	🟥	🟩	
D Decays						
mixing parameters	🟨	🟦	🟩	🟩	🟩	
CPV	🟥	🟦	🟩	🟩	🟩	Clean NP search
Precision EW						
$\sin^2\theta_W$ at $\Upsilon(4S)$	🟥	🟥	🟩	🟥	🟩	Theoretically clean
$\sin^2\theta_W$ at Z-pole	🟩	🟦	🟥	🟩	🟨	b fragmentation limits interpretation

Charm at SuperB

- At the Υ(4S) with 75 ab^{-1}:
  - Large improvement in D^0 mixing and CPV: factor 12 improvement in statistical error wrt BaBar (0.5 ab^{-1}).
  - Time-dependent measurements will benefit also of an improved (2x) D^0 proper-time resolution.
- At the Ψ(3770) with 1 ab^{-1}:
  - $D\bar{D}$ coherent production with 100x BESIII data and CM boost up to βγ=0.56.
  - Almost zero background environment.
  - Possibility of time-dependent measurements exploiting quantum coherence.
  - Study CPV with Flavor and CP tagging.
  - Constrain Dalitz model and strong phases

Charm Mixing



Υ(4S)

BaBar

Super*B*

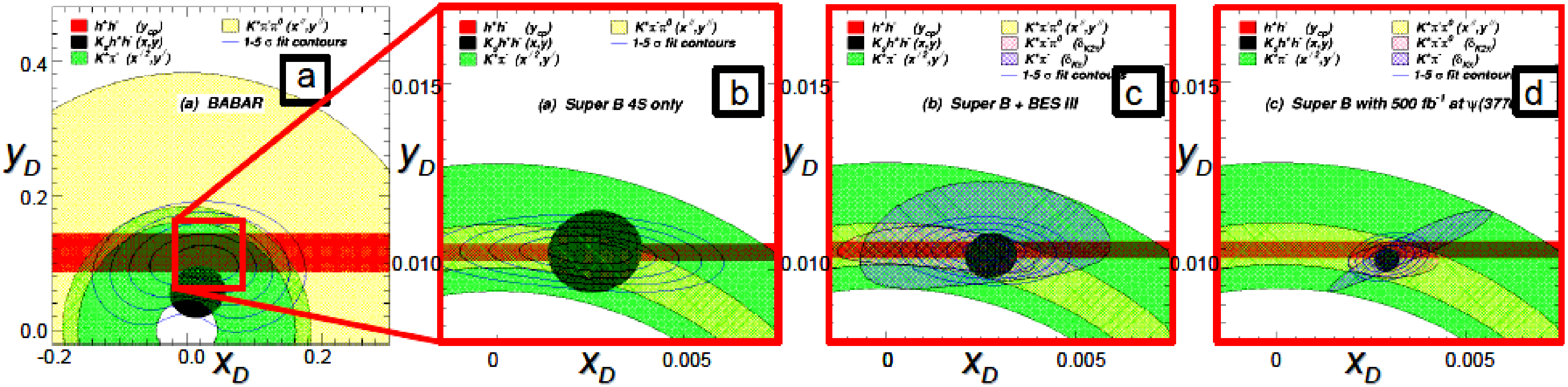
Super*B* + BESIII

Ψ(3770)

Super*B*

Fit	$x \times 10^3$	$y \times 10^3$	$\delta^{\circ}_{K^+\pi^-}$	$\delta^{\circ}_{K^+\pi^-\pi^0}$
(a)	$3.01^{+3.12}_{-3.39}$	$10.10^{+1.69}_{-1.72}$	$41.3^{+22.0}_{-24.0}$	43.8 ± 26.4
Stat.	(2.76)	(1.36)	(18.8)	(22.4)
(b)	$xxx^{+0.72}_{-0.75}$	$xxx \pm 0.19$	$xxx^{+3.7}_{-3.4}$	$xxx^{+4.6}_{-4.5}$
Stat.	(0.18)	(0.11)	(1.3)	(2.9)
(c)	$xxx \pm 0.42$	$xxx \pm 0.17$	$xxx \pm 2.2$	$xxx^{+3.3}_{-3.4}$
Stat.	(0.18)	(0.11)	(1.3)	(2.7)
(d)	$xxx \pm 0.20$	$xxx \pm 0.12$	$xxx \pm 1.0$	$xxx \pm 1.1$
Stat.	(0.17)	(0.10)	(0.9)	(1.1)

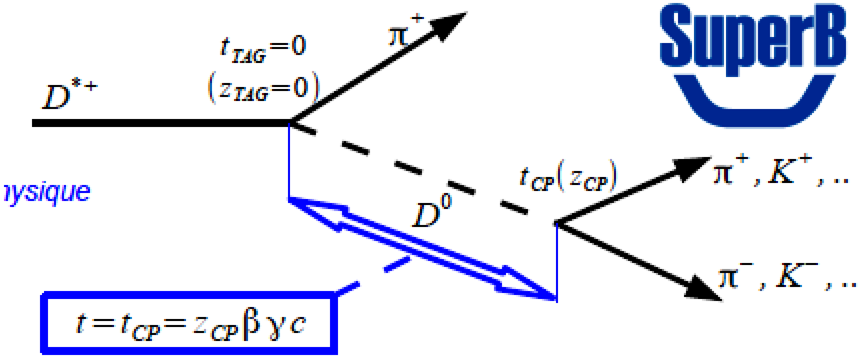
ArXiv: 1008.1541v1



A. Bevan- G. Inguglia- B. Meadows:
Phys. Rev. **D 84, 114009, arXiv:1106.5075**

Time Dependent CP Violation in Charm

A time-dependent analysis is a tool to look for *CPV in charm and will* open the door to measurements of the properties of the charm unitarity triangle.



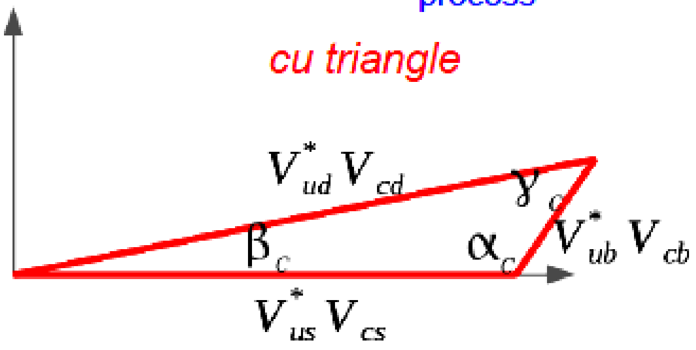
$$A_{CP}^{Phys}(t)=\frac{\overline{\Gamma}^{Phys}(t)-\Gamma^{Phys}(t)}{\overline{\Gamma}^{Phys}(t)+\Gamma^{Phys}(t)}=-\Delta\omega+\frac{(D+\Delta\omega)e^{\Delta\Gamma t/2}(|\lambda_f|^2-1)\cos\Delta M t+2\Im(\lambda_f)\sin\Delta M t}{(1+|\lambda_f|^2)h_+/2+h_-\Re(\lambda_f)}$$

$$\lambda_f=\left|\frac{q}{p}\right|e^{i\phi_{MIX}}\left|\frac{\overline{A}}{A}\right|e^{i\phi_{CP}}\underset{\text{if tree-dominated process}}{=}\left|\frac{q}{p}\right|e^{i\phi_{MIX}}e^{-2i\phi_T^W}$$

$$\boxed{\phi_{MIX}}\qquad\boxed{\beta_{c,eff}}$$

Parameter	SuperB $\Psi(3770)$ SL	$\Psi(3770)$ SL+K	$\Upsilon(4S)$ $\pi_s^{\pm}$
$\sigma_{\phi_{\pi\pi}}=\sigma_{arg(\lambda_{\pi\pi})}$	5.7°	2.4°	2.2°
$\sigma_{\phi_{KK}}=\sigma_{arg(\lambda_{KK})}$	3.5°	1.4°	$\boxed{1.6°}$
$\sigma_{\beta_{c,eff}}$	3.3°	1.4°	$\boxed{1.4°}$

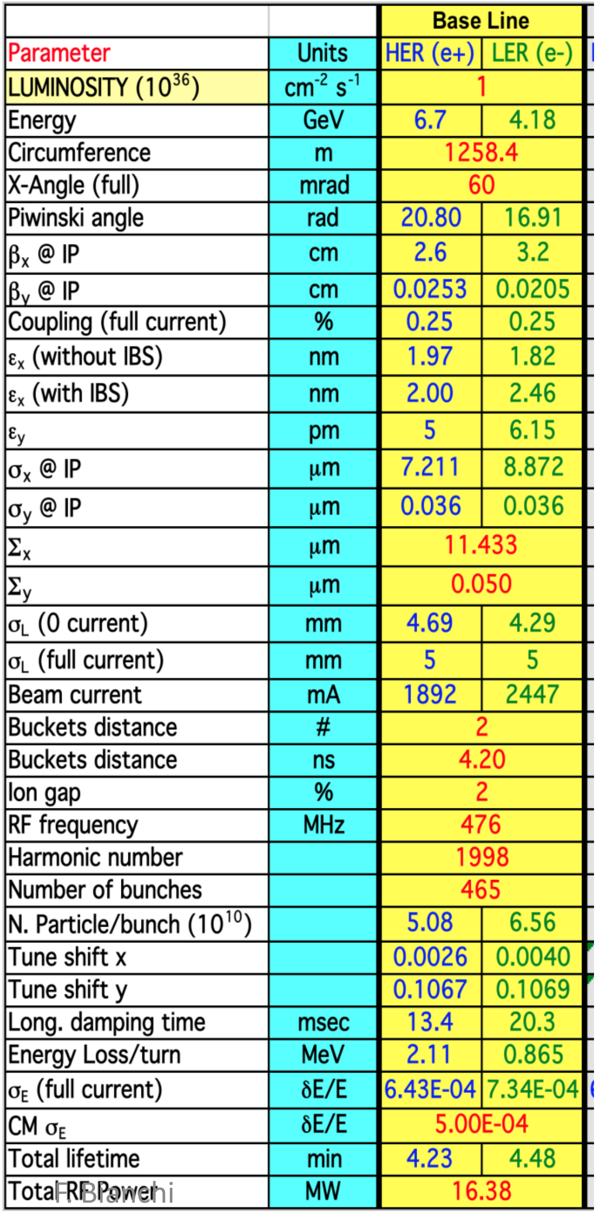
$$\boxed{\sigma_{\phi_{KK}}=\sigma_{arg(\lambda_{KK})}=\sigma_{\phi_{MIX}}}$$



The Machine

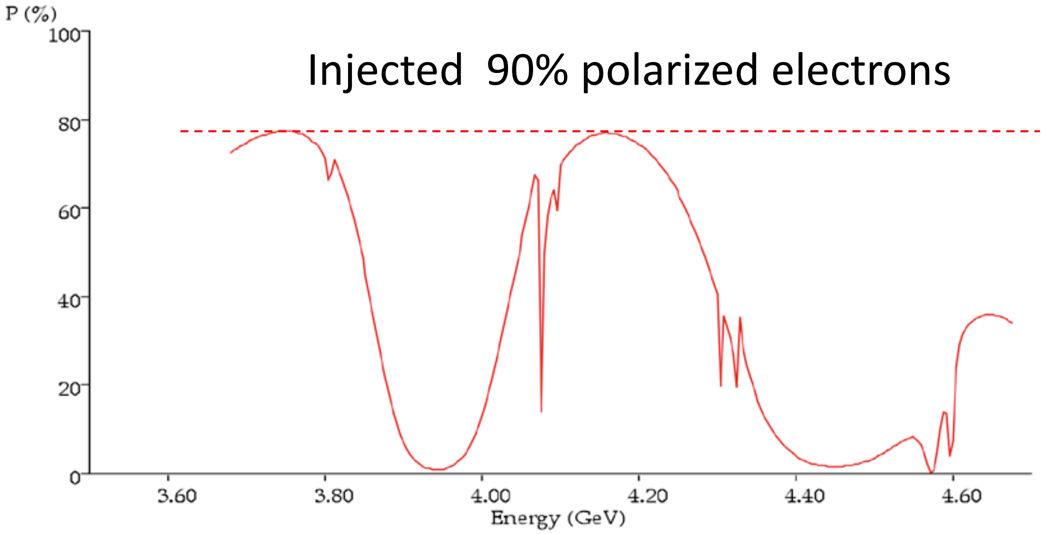
- SuperB is a 2 rings, asymmetric energies (e^- @ 4.18, e^+ @ 6.7 GeV, $\beta\gamma$=0.237) collider with:
  - large Piwinski angle and "crab waist" (LPA & CW) collision scheme
  - ultra low emittance lattices – ideas taken from ILC design
  - longitudinally polarized electron beam
  - target luminosity of 10^{36} cm^{-2} s^{-1} at the $\Upsilon(4S)$
  - possibility to run at τ/charm threshold still with polarized electron beam with $L = 10^{35}$ cm^{-2} s^{-1}
- Design criteria :
  - Minimize building costs
  - Minimize running costs (wall-plug power and water consumption)
  - Reuse of some PEP-II B-Factory hardware (magnets, RF)
- SuperB can also be a good "light source": work is in progress to design Synchrotron Radiation beamlines (collaboration with Italian Institute of Technology)

Baseline Collider parameters



		Base Line	
Parameter	Units	HER (e+)	LER (e-)
LUMINOSITY (10^{36})	cm^{-2} s^{-1}	1	
Energy	GeV	6.7	4.18
Circumference	m	1258.4	
X-Angle (full)	mrad	60	
Piwinski angle	rad	20.80	16.91
β_x @ IP	cm	2.6	3.2
β_y @ IP	cm	0.0253	0.0205
Coupling (full current)	%	0.25	0.25
ε_x (without IBS)	nm	1.97	1.82
ε_x (with IBS)	nm	2.00	2.46
ε_y	pm	5	6.15
σ_x @ IP	μm	7.211	8.872
σ_y @ IP	μm	0.036	0.036
Σ_x	μm	11.433	
Σ_y	μm	0.050	
σ_L (0 current)	mm	4.69	4.29
σ_L (full current)	mm	5	5
Beam current	mA	1892	2447
Buckets distance	#	2	
Buckets distance	ns	4.20	
Ion gap	%	2	
RF frequency	MHz	476	
Harmonic number		1998	
Number of bunches		465	
N. Particle/bunch (10^{10})		5.08	6.56
Tune shift x		0.0026	0.0040
Tune shift y		0.1067	0.1069
Long. damping time	msec	13.4	20.3
Energy Loss/turn	MeV	2.11	0.865
σ_E (full current)	δE/E	6.43E-04	7.34E-04
CM σ_E	δE/E	5.00E-04	
Total lifetime	min	4.23	4.48
Total RF Power	MW	16.38	

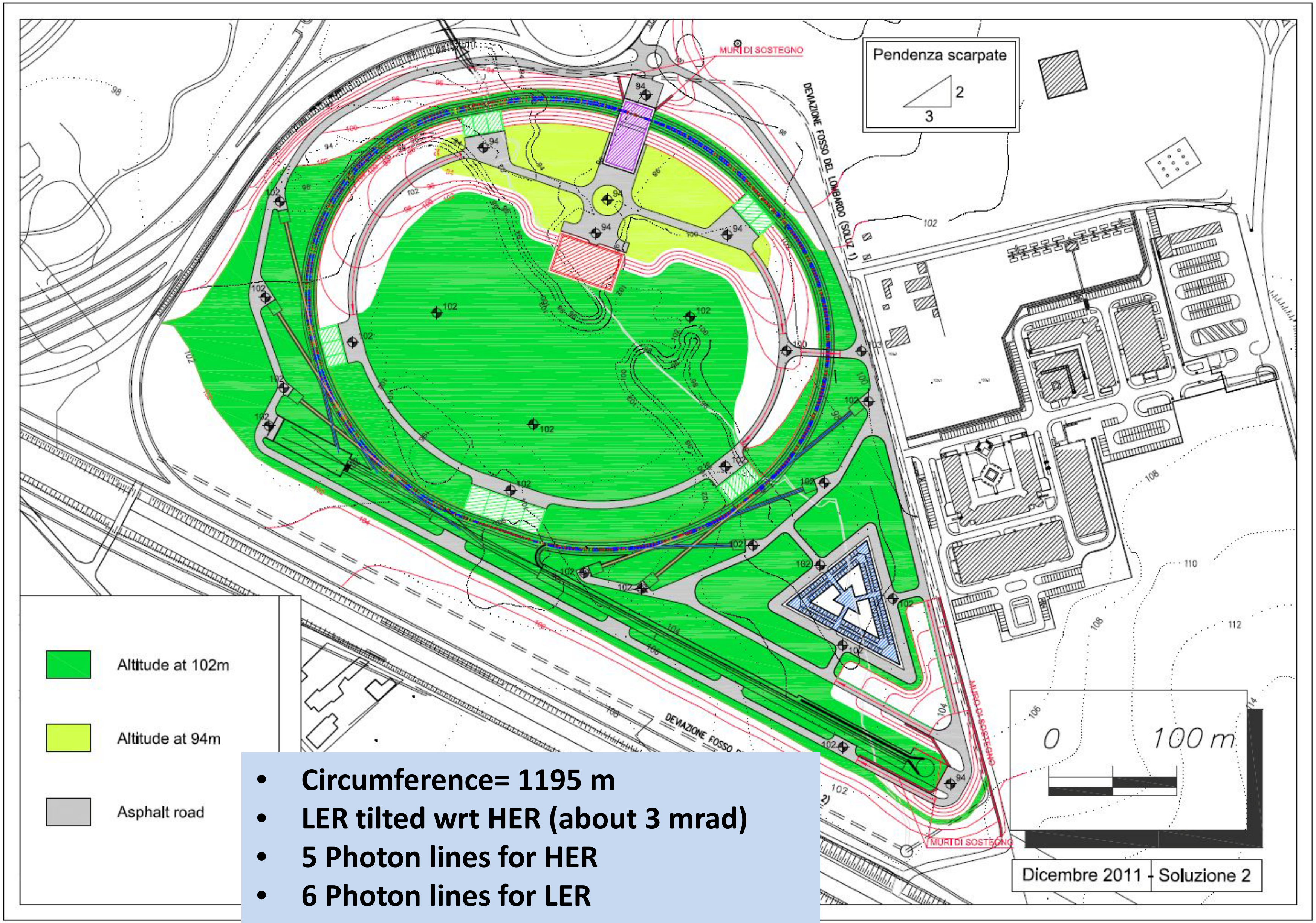
Baseline peak luminosity at Υ(4s) is 10^{36} cm^{-2} s^{-1} .
It can be increased by adding RF power up to a factor of 4.
The runs near charm threshold Ψ(3770) pay a factor O(10) in luminosity.
At charm threshold the boost(βγ) can be increased up to 0.5 for time dependent measurements.



Injected 90% polarized electrons

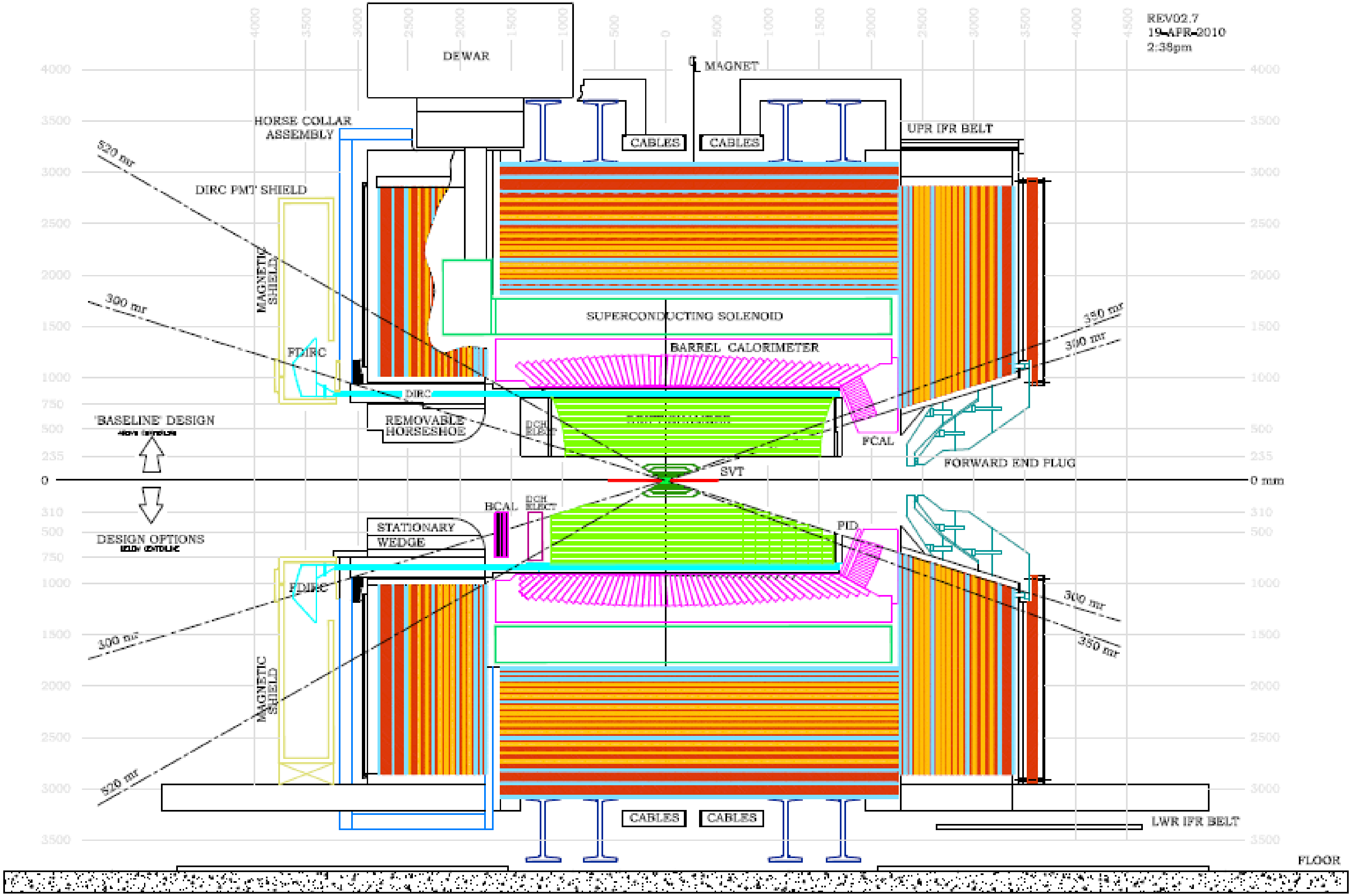
3.5 min beam lifetime . → CONTINUOUS INJECTION as in PEPII

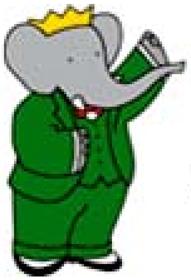
The Cabibbo Lab



- Circumference= 1195 m
- LER tilted wrt HER (about 3 mrad)
- 5 Photon lines for HER
- 6 Photon lines for LER

SuperB Detector Design



Detector Evolution: from  to SuperB

- Babar and Belle designs have proven to be very effective for B-Factory physics.
  - Follow the same ideas for SuperB detector.
  - Try to reuse same components as much as possible.

- Main issues:
  - Machine backgrounds – somewhat larger than in Babar/Belle.
  - Beam energy asymmetry – a bit smaller.
  - Strong interaction with machine design.

- A SuperB detector is possible with today's technology.
  - Baseline is reusing large (expensive) parts of Babar.
  - Quartz bars of the DIRC.
  - Barrel EMC CsI(Tl) crystal and mechanical structure.
  - Superconducting coil and flux return yoke.

- Some areas require moderate R&D and engineering developments to improve performance:
  - Small beam pipe technology.
  - Thin silicon pixel detector for first layer.
  - Drift chamber CF mechanical structure, gas and cell size.
  - Photon detection for DIRC quartz bars .
  - Forward PID system (TOF or focusing RICH).
  - Forward calorimeter crystals (LSO).
  - Minos-style scintillator for Instrumented flux return.
  - Electronics and trigger – need to revise Bfactory "½-track" trigger style.
  - Computing: has to handle a massive data amount.

SuperB Computing Model

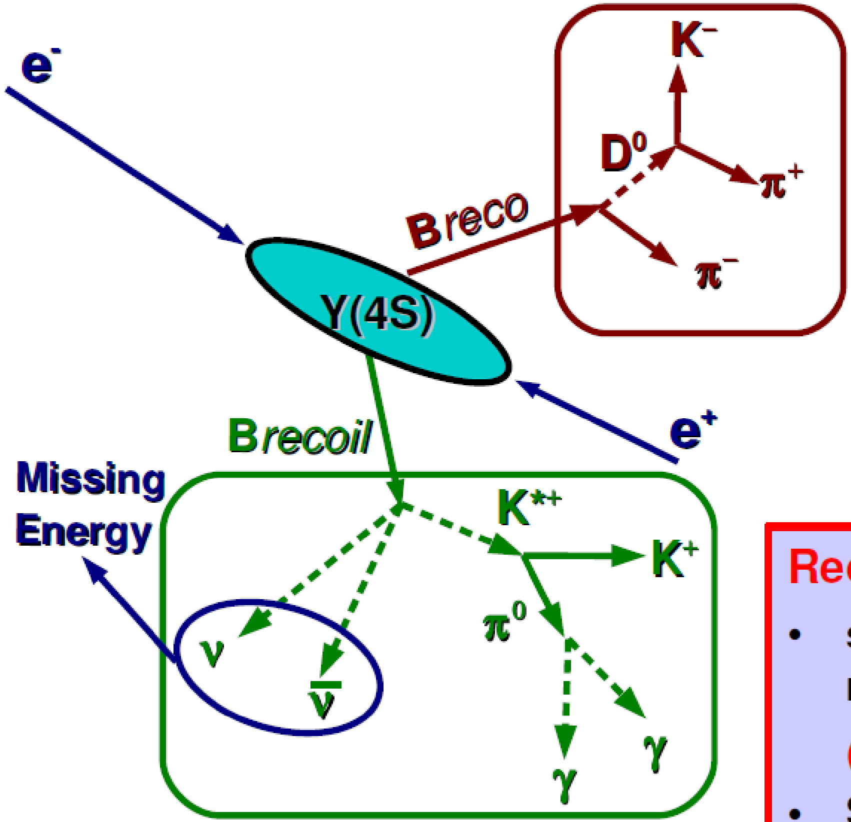
- Baseline is an extrapolation of BaBar computing model to a luminosity 100 times larger.
- Resource estimate:
  - Storage grows from O(50) PB to O(600) PB in 6 years.
  - CPU grows from 500 to 12,000 KHepSpec in 6 years.
- Question & challenges:
  - Is Moore's law still valid ?
    - Code must be optimized for running on multi/many core architectures.
  - How to access efficiently and reliably hundreds of PB of data ?
    - Identify a strategy to avoid I/O bottleneck.
    - How to share and replicate data among sites.
  - How use efficiently and reliably hardware resources widely dispersed ?
    - A resource management framework.
  - R&D program is in place to address these issues.

Conclusions

- SuperB project has been approved and funded by the Italian Government.
- The site has been selected. The construction preparatory work has started.
- The consortium "Nicola Cabibbo Laboratory" has been formed to manage the SuperB project.
- A very ambitious and innovative machine, state-of-the art detector, and an aggressive planning.
- First beams expected in 2017.

Backup

Recoil Analysis Technique



B*reco*: full (partial) reconstruction of one B into a hadronic (semi-leptonic) final state

B*recoil*: look for the signal signature, e.g. $K^{(*)}$ not accompanied by additional (charged+neutral) particles + **Missing Energy**

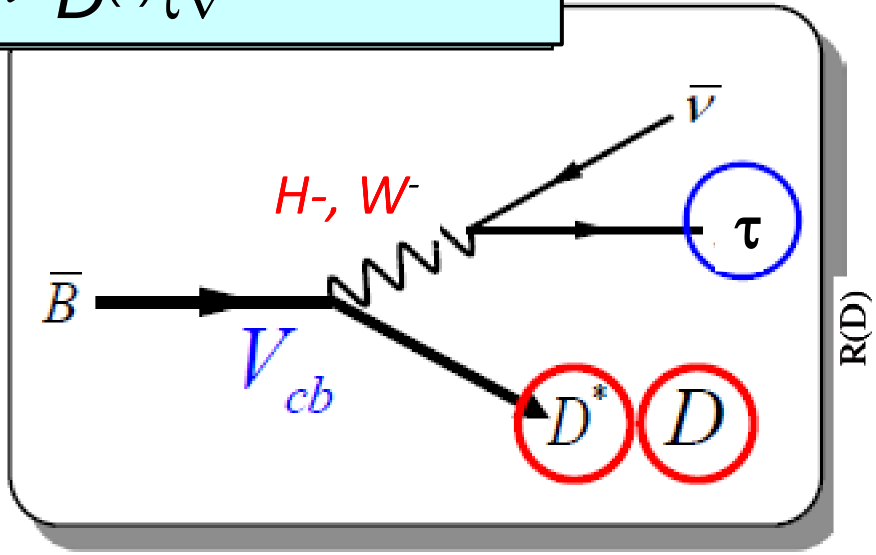
Recoil technique at B-Factories:

- search for rare decays ($\sim 10^{-5}$) with missing energy

  (Not possible at hadronic machines)
- Several benchmark channels at SuperB: $B \to \tau\nu$, $B \to K^{(*)}\nu\nu$, ...

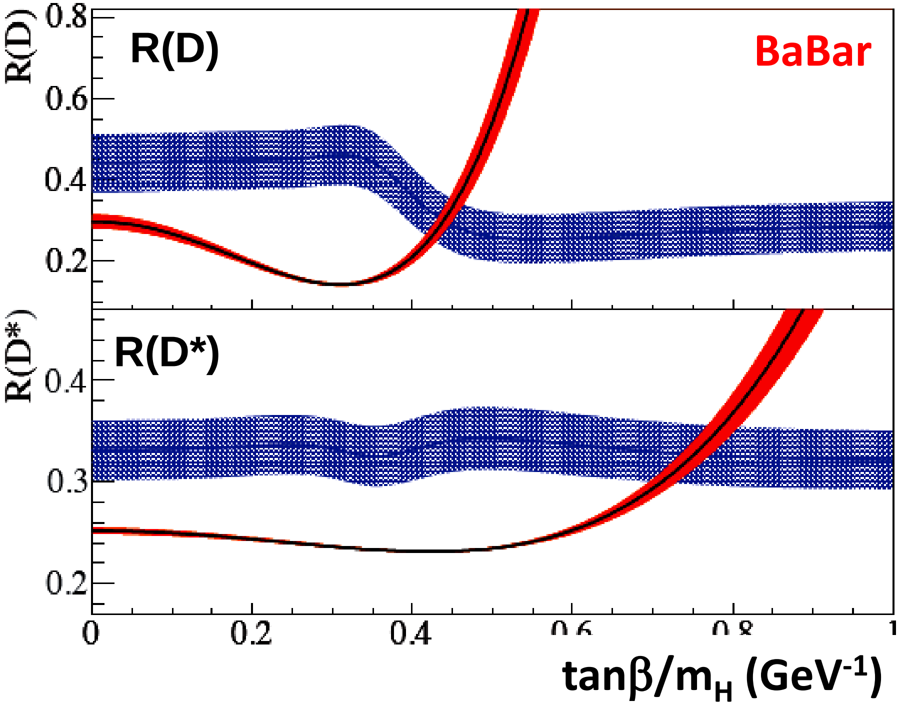
B Rare Decays

$B \rightarrow D^{(*)}\tau\nu$



$$R(D) = \frac{\Gamma(\bar{B} \rightarrow D\tau\nu)}{\Gamma(\bar{B} \rightarrow D\ell\nu)}$$

$$R(D^*) = \frac{\Gamma(\bar{B} \rightarrow D^*\tau\nu)}{\Gamma(\bar{B} \rightarrow D^*\ell\nu)}$$



$$H_t^{2\mathrm{HDM}} = H_t^{\mathrm{SM}} \times \left(1 - \frac{\tan^2\beta}{m^2_{H\pm}} \frac{q^2}{1 \mp m_c/m_b}\right)$$

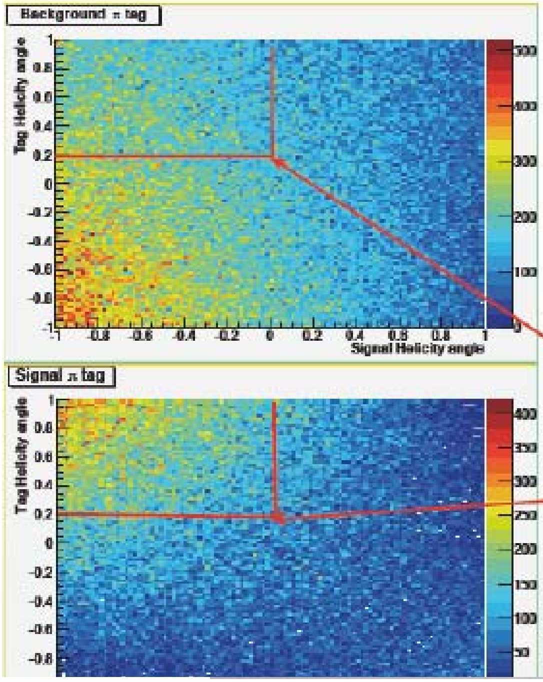
Type II 2HDM excluded in the full $\tan\beta$-m_H parameter space with a probability of >99.8%, provided M_H>10GeV

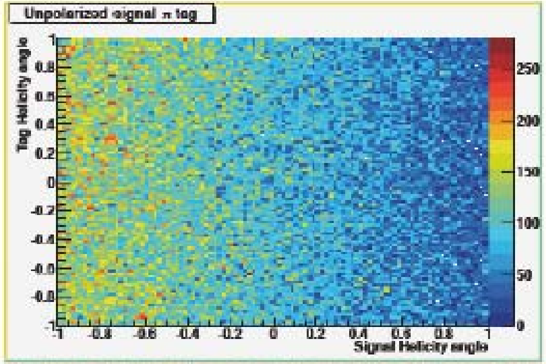
LFV in τ Decays with Polarization

τ-> μνν
background

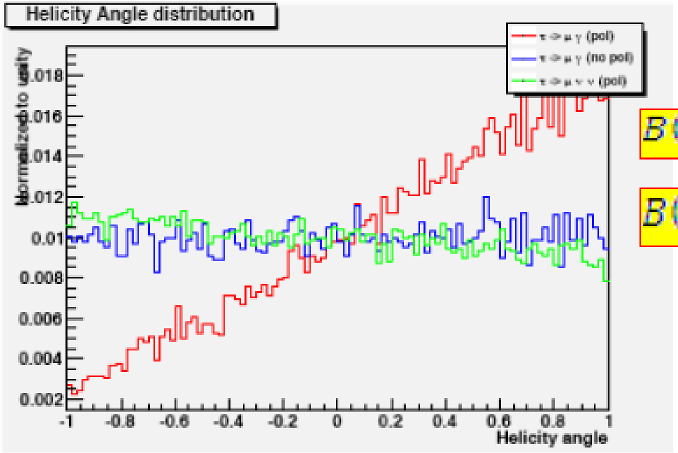
τ-> μγ vs τ->πν
cos(helicity)

signal





Applying a rectangular cut
eff. on signal ~40-45%
bkg retained ~ 10-15%



$B(\tau \rightarrow \mu\gamma)\ 2\times\ 10-9$

$B(\tau \rightarrow e\,\gamma)\ 2\times\ 10-9$

$B(\tau \rightarrow \mu\gamma)\ 1\times\ 10-9$

$B(\tau \rightarrow e\,\gamma)\ 1\times\ 10-9$

Sensitivity improves at least by a factor 2.
Equivalent to a factor 4 increase in luminosity.

How to get 100 times more luminosity ?

$$L = 2.17\times10^{34}\,\frac{n\xi_y E I_b}{\beta_y^*}$$

ξ_y	Vertical beam-beam parameter
I_b	Bunch current (A)
n	Number of bunches
β_y^*	IP vertical beta (cm)
E	Beam energy (GeV)

Present day B-factories

	PEP-II	KEKB
E(GeV)	9x3.1	8x3.5
I_b	1x1.6	0.75x1
n	1700	1600
I (A)	1.7x2.7	1.2x1.6
β_y^* (cm)	1.1	0.6
ξ_y	0.08	0.11
L ($\times10^{34}$)	1	2

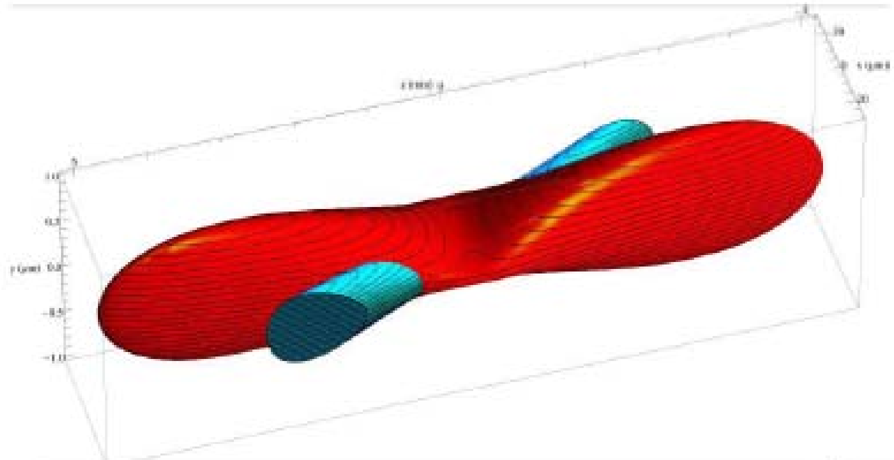
Answer:

Increase	I_b
Decrease	β_y^*
Increase	ξ_y
Increase	n

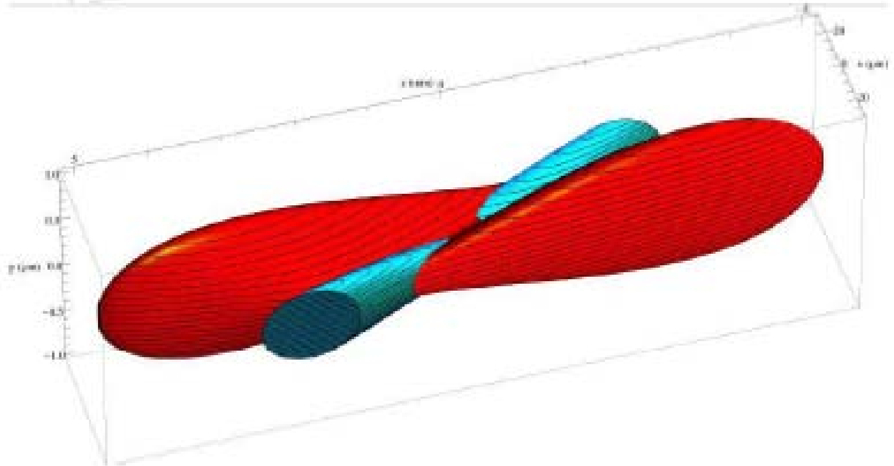
A New Idea

- Pantaleo Raimondi came up with a new scheme to attain high luminosity in a storage ring:
  - Change the collision so that only a small fraction of one bunch collides with the other bunch
    - Large crossing angle
    - Long bunch length
  - Due to the large crossing angle the effective bunch length (the colliding part) is now very short so we can lower β_y^* by a factor of 50
  - The beams must have very low emittance – like present day light sources
    - The x size at the IP now sets the effective bunch length
  - In addition, by crabbing the magnetic waist of the colliding beams we greatly reduce the tune plane resonances enabling greater tune shifts and better tune plane flexibility
    - This increases the luminosity performance by another factor of 2-3

How the Crabbed Waist Works



Crab-sextupoles off:
waist line is orthogonal to the axis of the beam



Crab-sextupoles on:
waist moves parallel to the axis of other beam: maximum particle density in the overlap between bunches

All particles in both beams collide in the minimum β_y region, with a net luminosity gain

SuperB Parameters Table

		Base Line		Low Emittance		High Current		τ/charm	
Parameter	Units	HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)
LUMINOSITY (10^{36})	$cm^{-2}\ s^{-1}$	1		1		1		1	
Energy	GeV	6.7	4.18	6.7	4.18	6.7	4.18	2.58	1.61
Circumference	m	1258.4		1258.4		1258.4		1258.4	
X-Angle (full)	mrad	60		60		60		60	
Piwinski angle	rad	20.80	16.91	29.42	23.91	13.12	10.67	8.00	6.50
β_x @ IP	cm	2.6	3.2	2.6	3.2	5.06	6.22	6.76	8.32
β_y @ IP	cm	0.0253	0.0205	0.0179	0.0145	0.0292	0.0237	0.0658	0.0533
Coupling (full current)	%	0.25	0.25	0.25	0.25	0.5	0.5	0.25	0.25
ε_x (without IBS)	nm	1.97	1.82	1.00	0.91	1.97	1.82	1.97	1.82
ε_x (with IBS)	nm	2.00	2.46	1.00	1.23	2.00	2.46	5.20	6.4
ε_y	pm	5	6.15	2.5	3.075	10	12.3	13	16
σ_x @ IP	μm	7.211	8.872	5.099	6.274	10.060	12.370	18.749	23.076
σ_y @ IP	μm	0.036	0.036	0.021	0.021	0.054	0.054	0.092	0.092
Σ_x	μm	11.433		8.085		15.944		29.732	
Σ_y	μm	0.050		0.030		0.076		0.131	
σ_L (0 current)	mm	4.69	4.29	4.73	4.34	4.03	3.65	4.75	4.36
σ_L (full current)	mm	5	5	5	5	4.4	4.4	5	5
Beam current	mA	1892	2447	1460	1888	3094	4000	1365	1766
Buckets distance	#	2		2		1		1	
Buckets distance	ns	4.20		4.20		2.10		2.10	
Ion gap	%	2		2		2		2	
RF frequency	MHz	476		476		476		476	
Harmonic number		1998		1998		1998		1998	
Number of bunches		465		465		931		931	
N. Particle/bunch (10^{10})		5.08	6.56	3.92	5.06	4.15	5.36	1.83	2.37
Tune shift x		0.0026	0.0040	0.0020	0.0031	0.0053	0.0081	0.0063	0.0096
Tune shift y		0.1067	0.1069	0.0980	0.0981	0.0752	0.0755	0.1000	0.1001
Long. damping time	msec	13.4	20.3	13.4	20.3	13.4	20.3	26.8	40.6
Energy Loss/turn	MeV	2.11	0.865	2.11	0.865	2.11	0.865	0.4	0.166
σ_E (full current)	δE/E	6.43E-04	7.34E-04	6.43E-04	7.34E-04	6.43E-04	7.34E-04	6.94E-04	7.34E-04
CM σ_E	δE/E	5.00E-04		5.00E-04		5.00E-04		5.26E-04	
Total lifetime	min	4.23	4.48	3.05	3.00	7.08	7.73	11.41	6.79
Total RF Power	MW	16.38		12.37		28.83		2.81	

Tau/charm threshold running at 10^{35}

Baseline + other 2 options:
- **Lower y-emittance**
- **Higher currents (twice bunches)**

Baseline:
- **Higher emittance due to IBS**
- **Asymmetric beam currents**

RF power includes SR and HOM