SuperB Physics Workshop: Introduction

30th November – 4th December 2009
LNF Frascati

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The SuperB Physics Programme

Data Taking commences:

T_0+5yr (=2015?)

The Landscape in 2015

- Tevatron's era will have come to pass and the age of the LHC will be in full swing.

- LHC will have produced many interesting results.
  - Hopefully there will be some new physics.

  - LHCb will have measured:
    - Φ_s to
    - γ to
    - ... etc.

- MEG will have placed limits down to 10^{-13} on $\mu \longrightarrow e\gamma$

.... and so on.

Piecing together New Physics

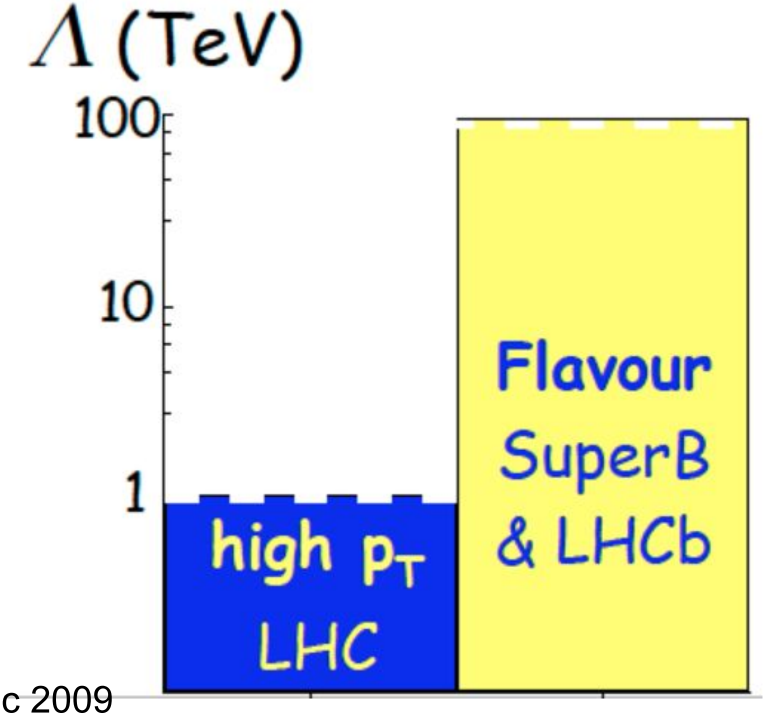
$$\mathcal{L}^{NP}_{eff} = \mathcal{L}_{SM} + \sum_k \left(\sum_i C_i^k\, Q_i^{(k+4)}\right)/\Lambda^k$$

NP flavour effects are governed by two players:

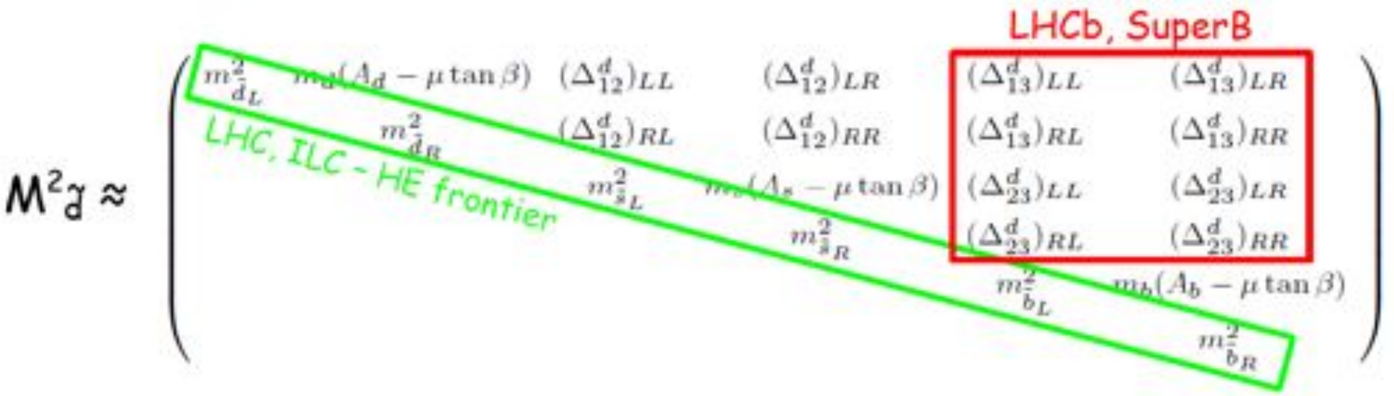
i) the new physics scale Λ

ii) the effective flavour-violating couplings C's

- NP could be flavour blind... but that would be fine tuning.
  - Wouldn't help us with the SUSY flavour problem.
  - unnatural given CKM and MSW.



SUSY CKM



LHCb, SuperB

LHC, ILC - HE frontier

$$M^2_{\tilde d} \approx \begin{pmatrix} m^2_{\tilde d_L} & m_d(A_d - \mu\tan\beta) & (\Delta^d_{12})_{LL} & (\Delta^d_{12})_{LR} & (\Delta^d_{13})_{LL} & (\Delta^d_{13})_{LR} \\ & m^2_{\tilde d_R} & (\Delta^d_{12})_{RL} & (\Delta^d_{12})_{RR} & (\Delta^d_{13})_{RL} & (\Delta^d_{13})_{RR} \\ & & m^2_{\tilde s_L} & m_s(A_s - \mu\tan\beta) & (\Delta^d_{23})_{LL} & (\Delta^d_{23})_{LR} \\ & & & m^2_{\tilde s_R} & (\Delta^d_{23})_{RL} & (\Delta^d_{23})_{RR} \\ & & & & m^2_{\tilde b_L} & m_b(A_b - \mu\tan\beta) \\ & & & & & m^2_{\tilde b_R} \end{pmatrix}$$

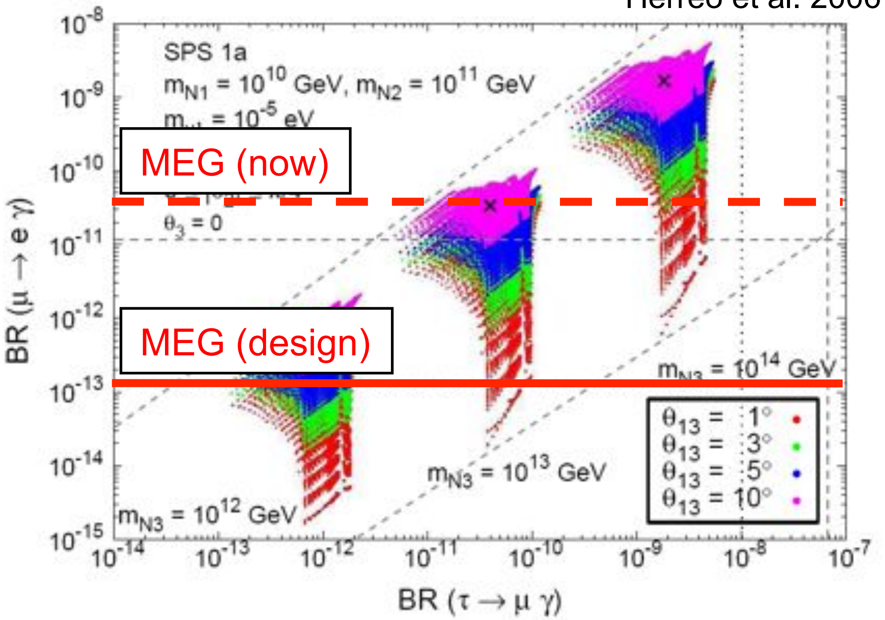
and similarly for $M^2_{\tilde u}$

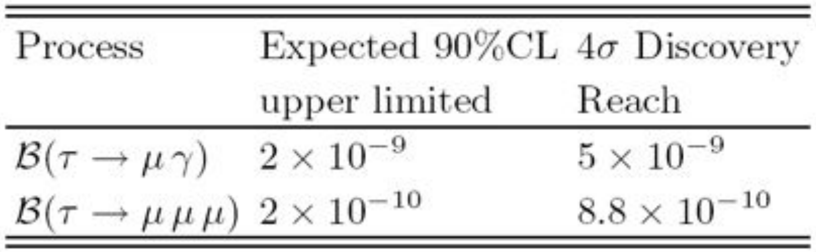
Lepton Flavour Violation (τ decay)

- $\tau \to \mu\gamma$ 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 may be 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) $\sim 2.4 \times 10^{-6}$ (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.

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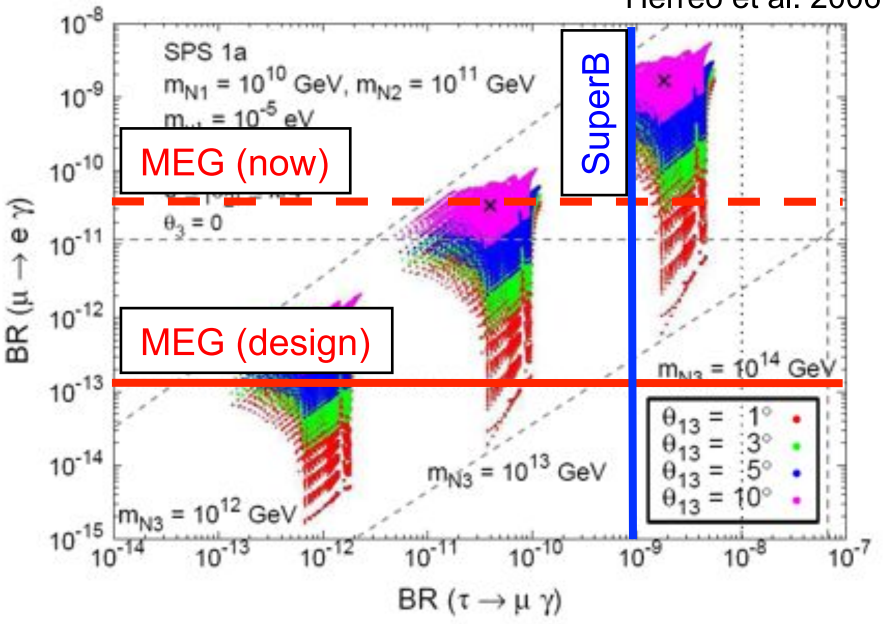

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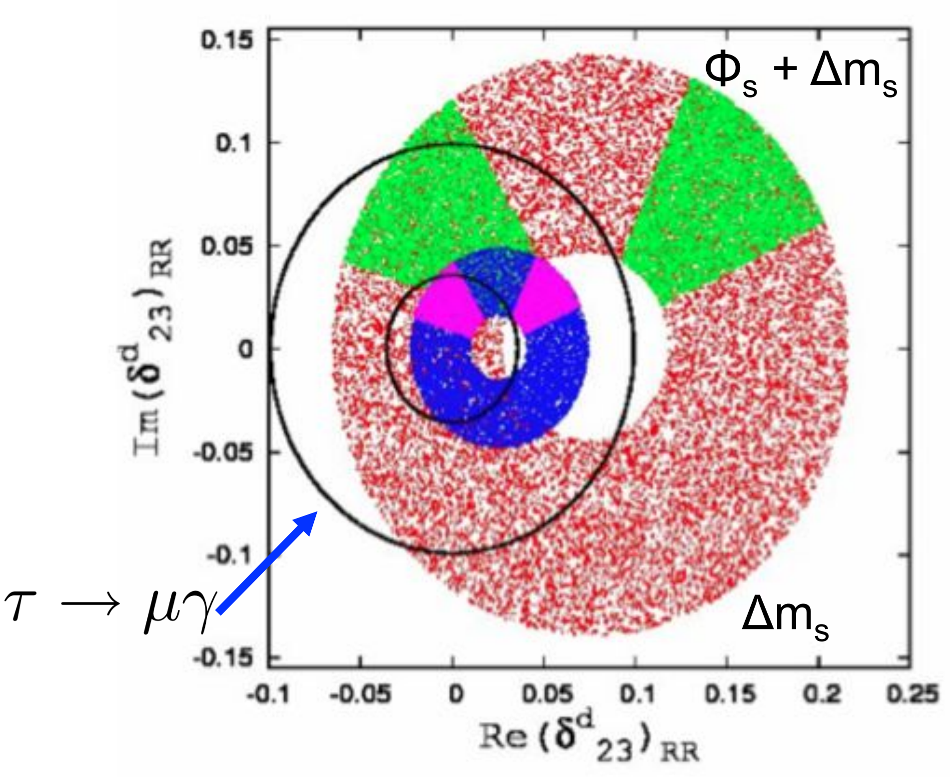
Use $\mu\ \gamma$/3l to distinguish SUSY vs. LHT.

Lepton Flavour Violation (τ decay)

$m_{\tilde{q}} = 300\,GeV$ BLUE

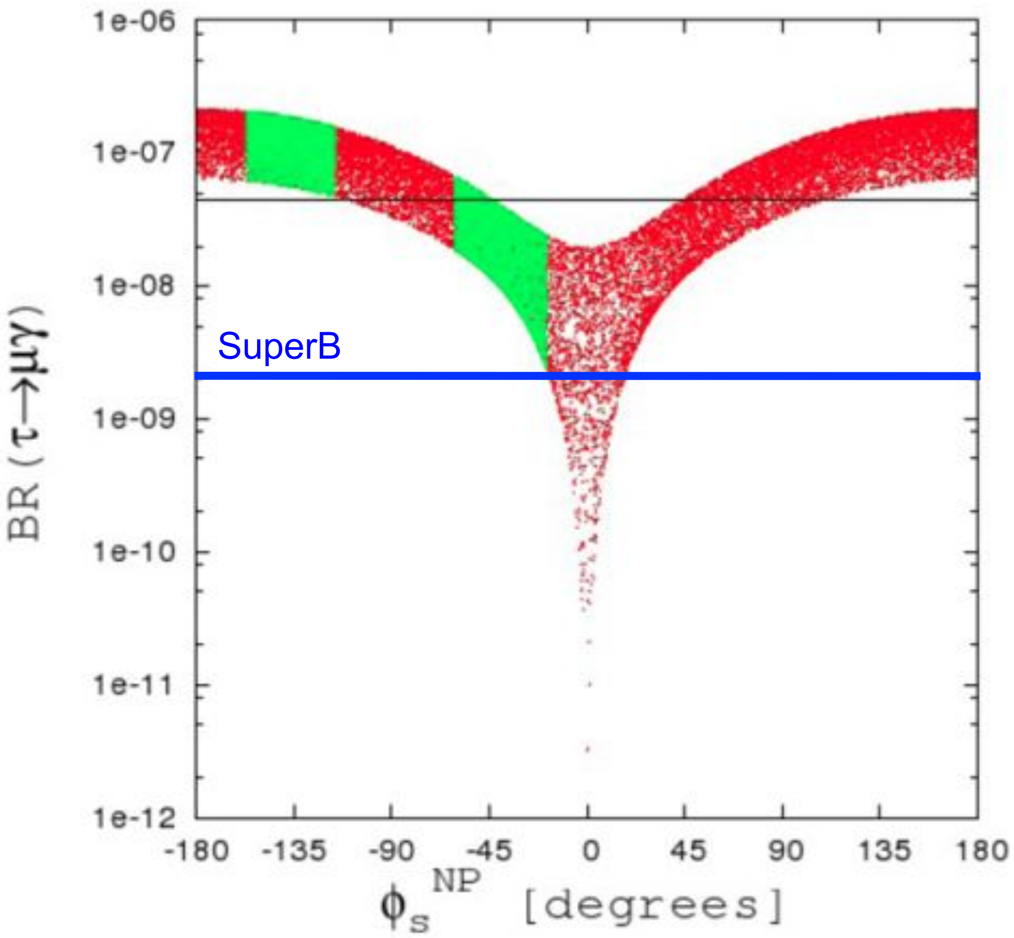
$m_{\tilde{q}} = 500\,GeV$ RED



- SU(5) SUSY GUT Model (arXiv :0710.5443, Parry and Zhang).
- Model has non-trivial SUSY squark couplings.
- Current B_S measurements favour $B(\tau \rightarrow \mu\gamma) > 3 \times 10^{-9}$.
- Need SuperB to probe to this sensitivity.

N.B. Different New Physics Models have different features, and different hierarchies!

Lepton Flavour Violation (τ decay)



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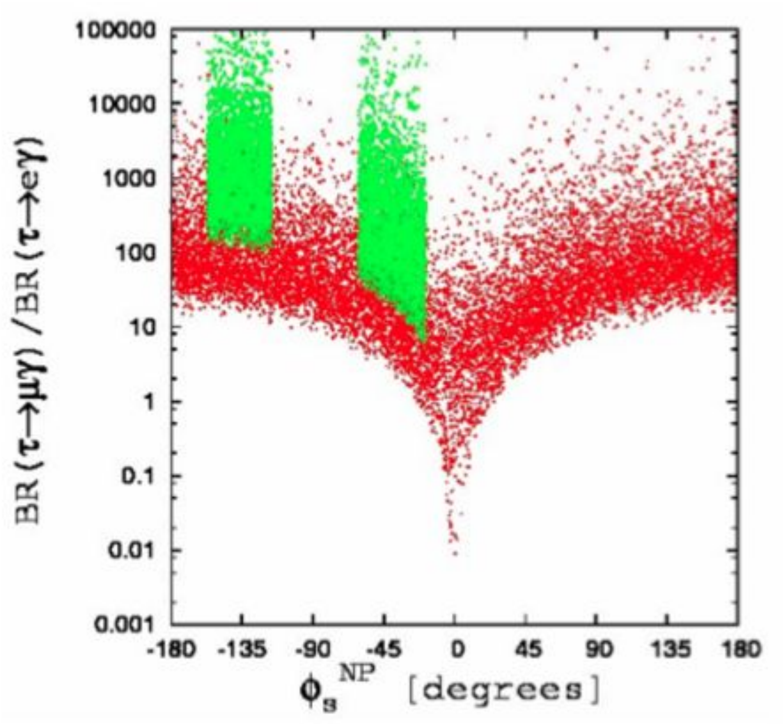

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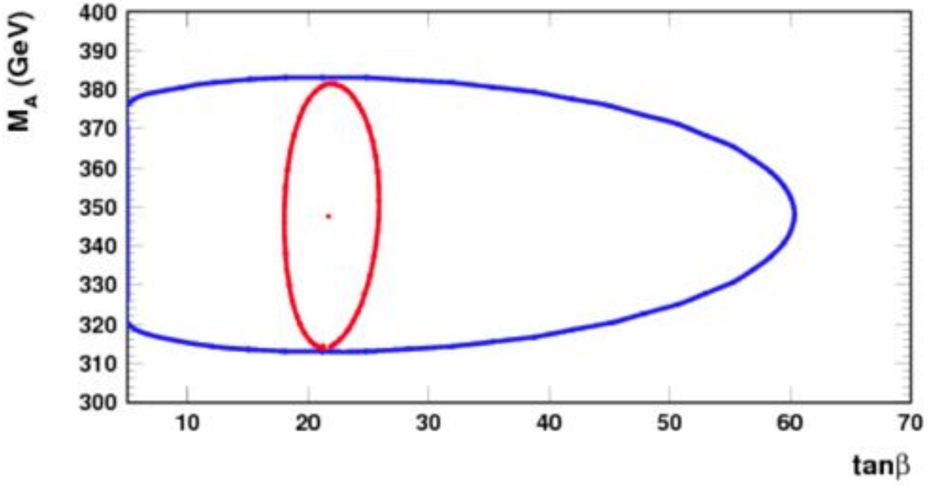
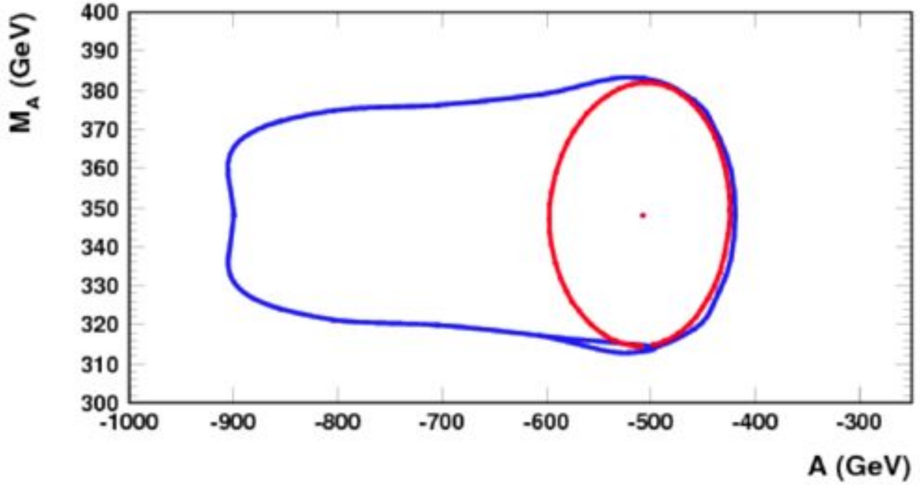
CMSSM: LHC/SuperB complementarity

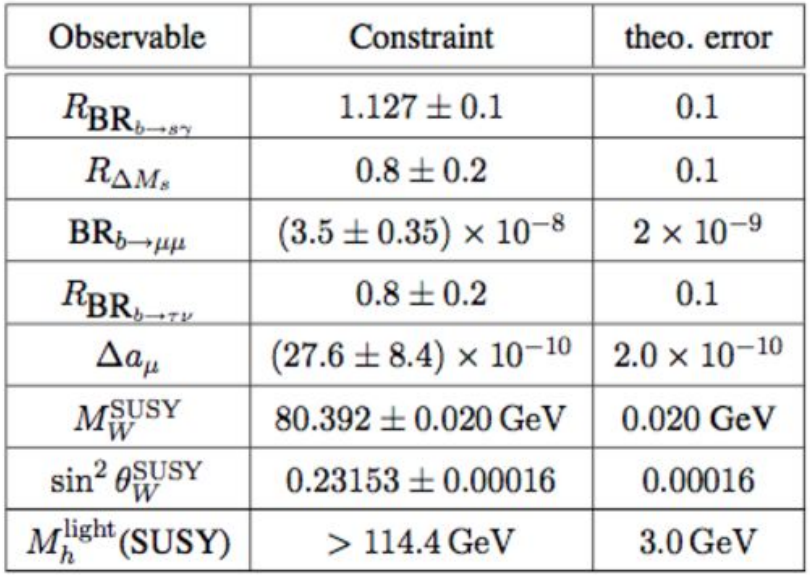


Blue = LHC:

- Will be able to measure m(A) [CP odd Higgs mass]
- Poor sensitivity to tanβ [ratio of Higgs vevs]
- Poor sensitivity to A [coupling]



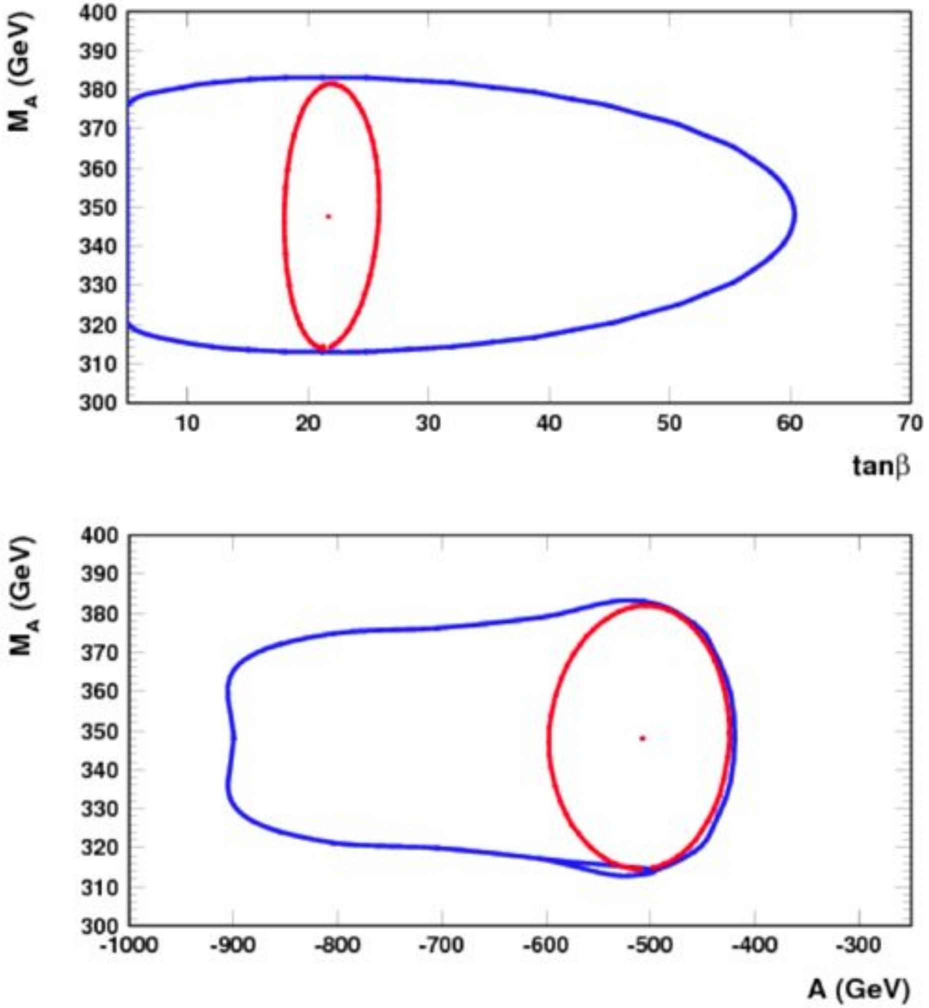
Red=LHC+EW/Low-energy constraints (includes SuperB):



Observable	Constraint	theo. error
$R_{\mathrm{BR}_{b\to s\gamma}}$	1.127 ± 0.1	0.1
$R_{\Delta M_s}$	0.8 ± 0.2	0.1
$\mathrm{BR}_{b\to\mu\mu}$	$(3.5 \pm 0.35) \times 10^{-8}$	2×10^{-9}
$R_{\mathrm{BR}_{b\to\tau\nu}}$	0.8 ± 0.2	0.1
Δa_μ	$(27.6 \pm 8.4) \times 10^{-10}$	2.0×10^{-10}
M_W^{SUSY}	$80.392 \pm 0.020\,\mathrm{GeV}$	$0.020\,\mathrm{GeV}$
$\sin^2\theta_W^{\mathrm{SUSY}}$	0.23153 ± 0.00016	0.00016
$M_h^{\mathrm{light}}(\mathrm{SUSY})$	$> 114.4\,\mathrm{GeV}$	$3.0\,\mathrm{GeV}$

Current analysis of data prefers tanβ~10.

CMSSM: LHC/SuperB complementarity



Blue = LHC:

- Will be able to measure m(A) [CP odd Higgs mass]
- Poor sensitivity to tanβ [ratio of Higgs vevs]
- Poor sensitivity to A [coupling]

Red=LHC+EW/Low-energy constraints (includes SuperB):

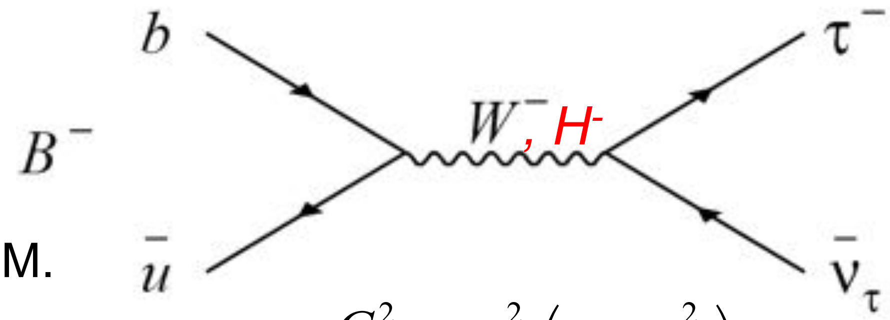
- Can build on the m(A) measurement to measure tanβ.

Again LHC and SuperB are complementary experiments. Each can contribute significantly to the knowledge of new physics.

Current analysis of data prefers tanβ~10.

Charged Higgs: $B^{\pm} \to \tau^{\pm} \nu$

- Within the SM, sensitive to f_B and $|V_{ub}|$: $\mathcal{B}_{SM}$~1.6×10^{-4}.

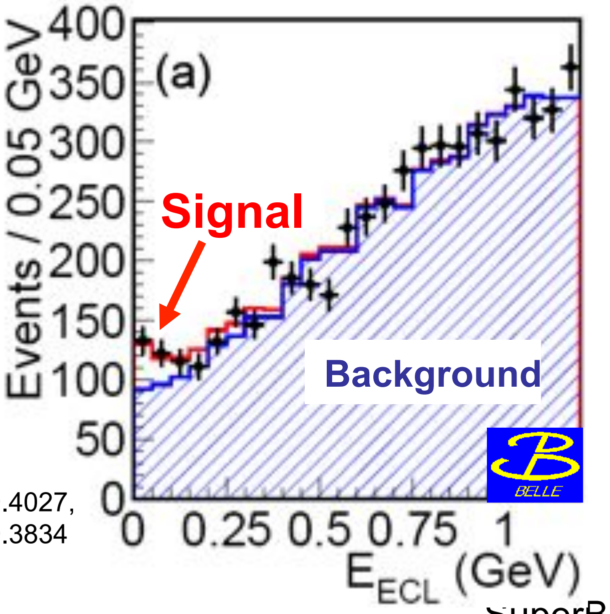


- $\mathcal{B}$ affected by new physics.
  - MFV models like 2HDM / MSSM.
  - Unparticles.

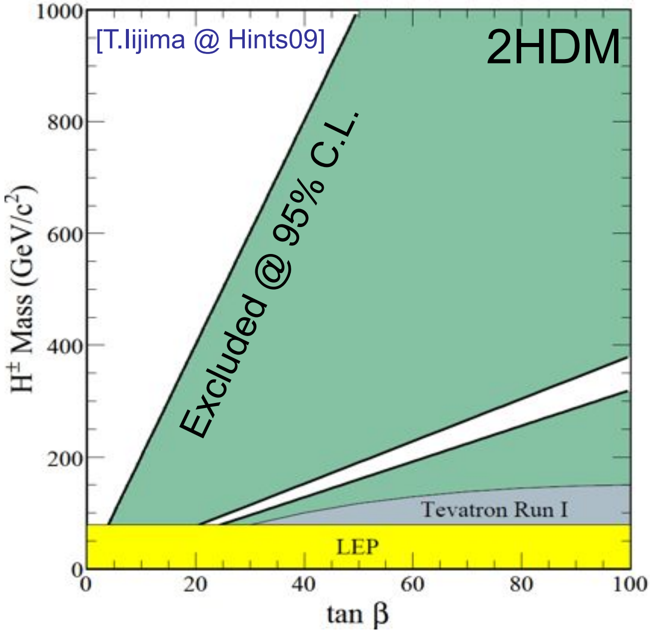
$$\mathcal{B}_{SM}(B^+ \to l^+\nu_l) = \frac{G_F^2 m_B m_l^2}{8\pi}\left(1-\frac{m_l^2}{m_B^2}\right) f_B^2 \,|V_{ub}|^2\, \tau_B$$

- Fully reconstruct the event (modulo ν).

$$\mathcal{B}_{\mathrm{WA}} = \left(1.73 \pm 0.35\right)\times10^{-4}$$



arXiv:0809.4027,
arXiv:0809.3834

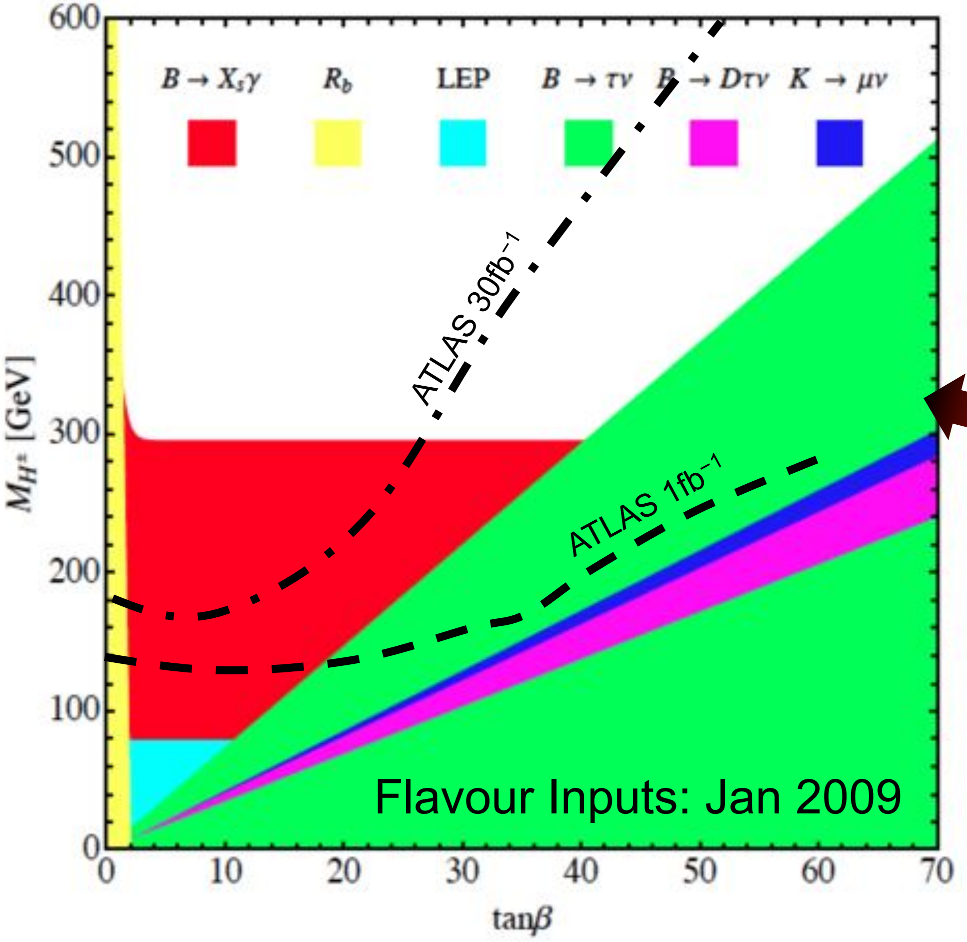


2HDM: W.-S Hou PRD **48** 2342 (1993)
MSSM: G. Isidori arXiv:0710.5377
Unparticles: R. Zwicky PRD**77** 036004 (2008)

Charged Higgs

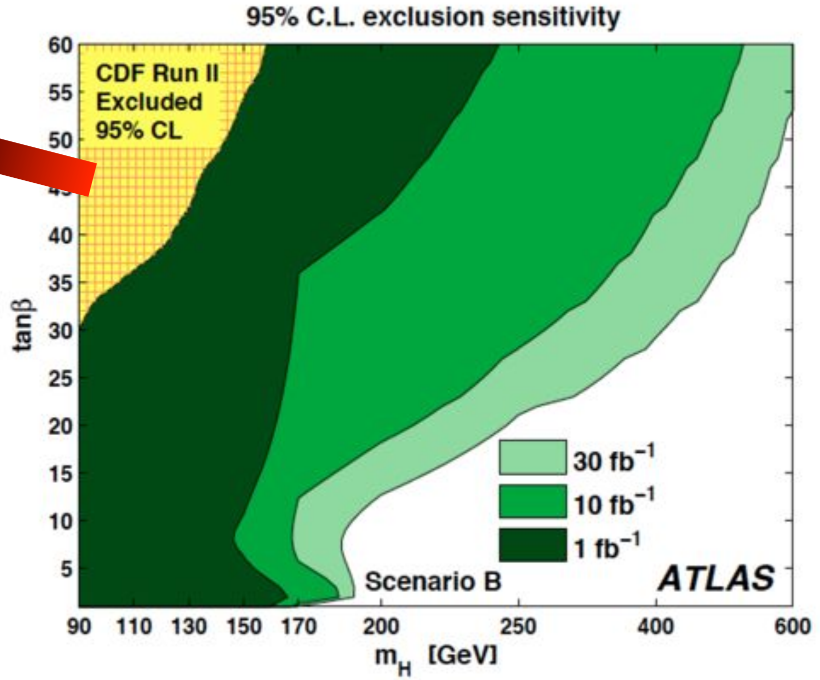
- B-factory searches competitive with LHC era: e.g. 2HDM

Existing Constraints from BaBar and Belle.
Combined Higgs search constraint from ATLAS: arXiv:0901.1502



U. Haisch 0805.2141

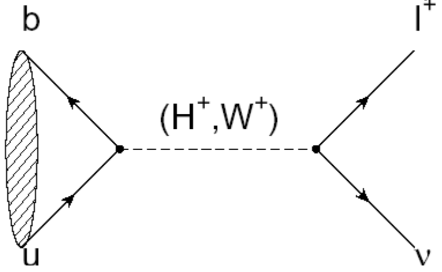
Converted constraints expected from
ATLAS onto the plot by hand.



Charged Higgs

Charm equivalent: $D_s^+ \to \mu^+\nu$, $\tau^+\nu$

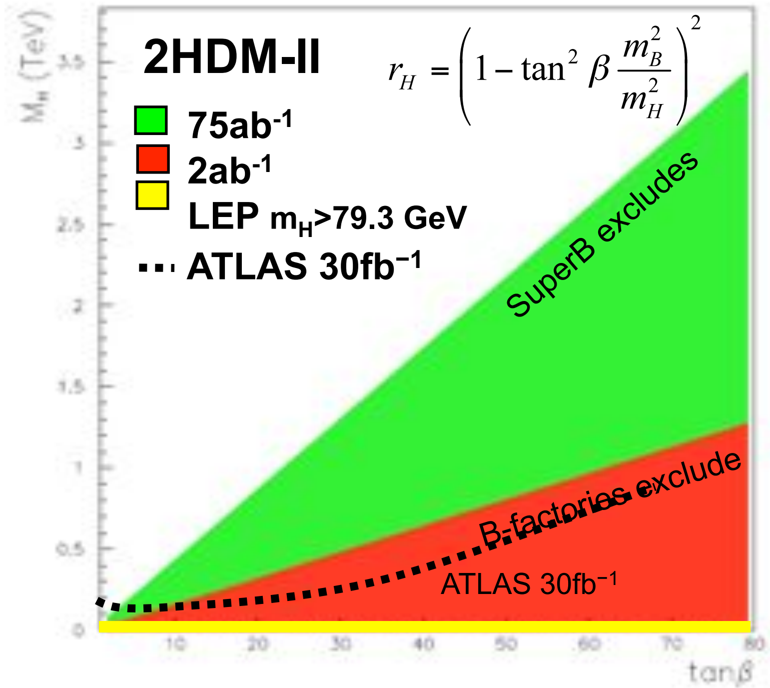
B-factories have 1.5ab^{-1} of data.
ATLAS sensitivity sketched from combined sensitivity plots in arXiv:0901.0512.

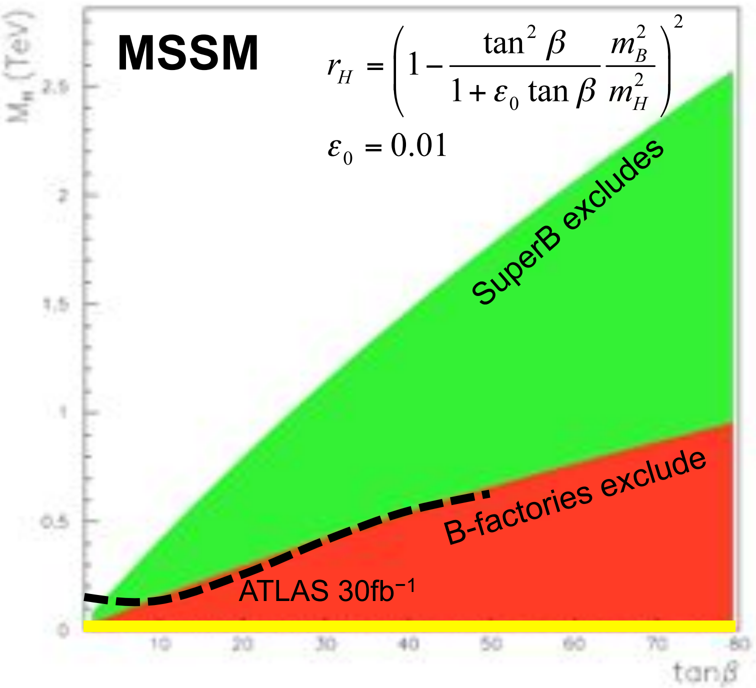


- Higgs mediated MFV:

$$r_H = \frac{\mathcal{B}_{SM+NP}}{\mathcal{B}_{SM}}$$

(Assuming SM branching fraction is measured)

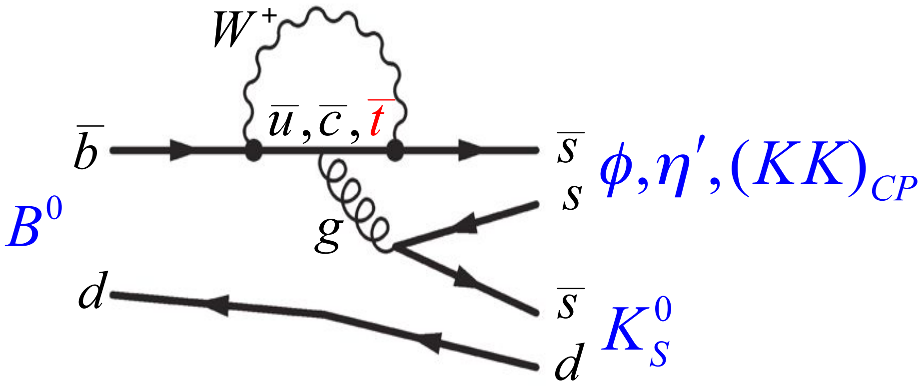




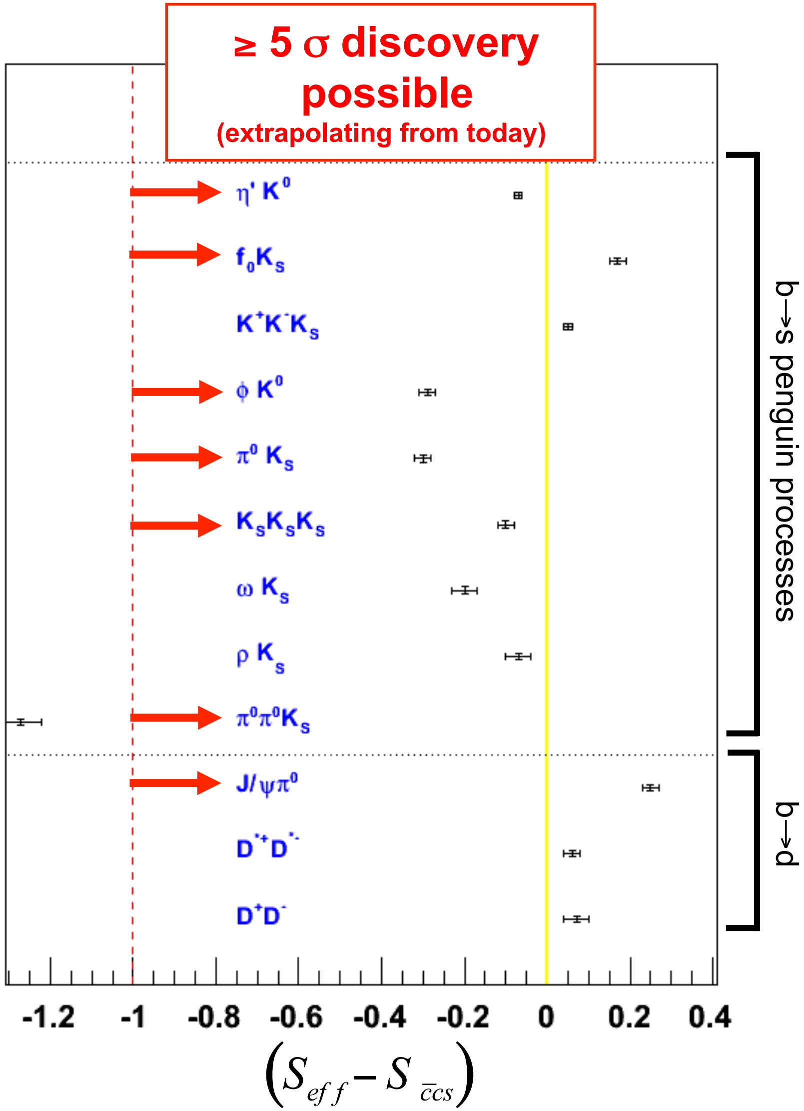
- Multi TeV search capability for large tanβ.
- Includes SM uncertainty ~20% from V_{ub} and f_B.

ΔS measurements

- $\beta=(21.1\pm0.9)°$ from Charmonium decays.
- Look in many different b→s and b→d decays for sin2β deviations from the SM:
- The golden channel is:

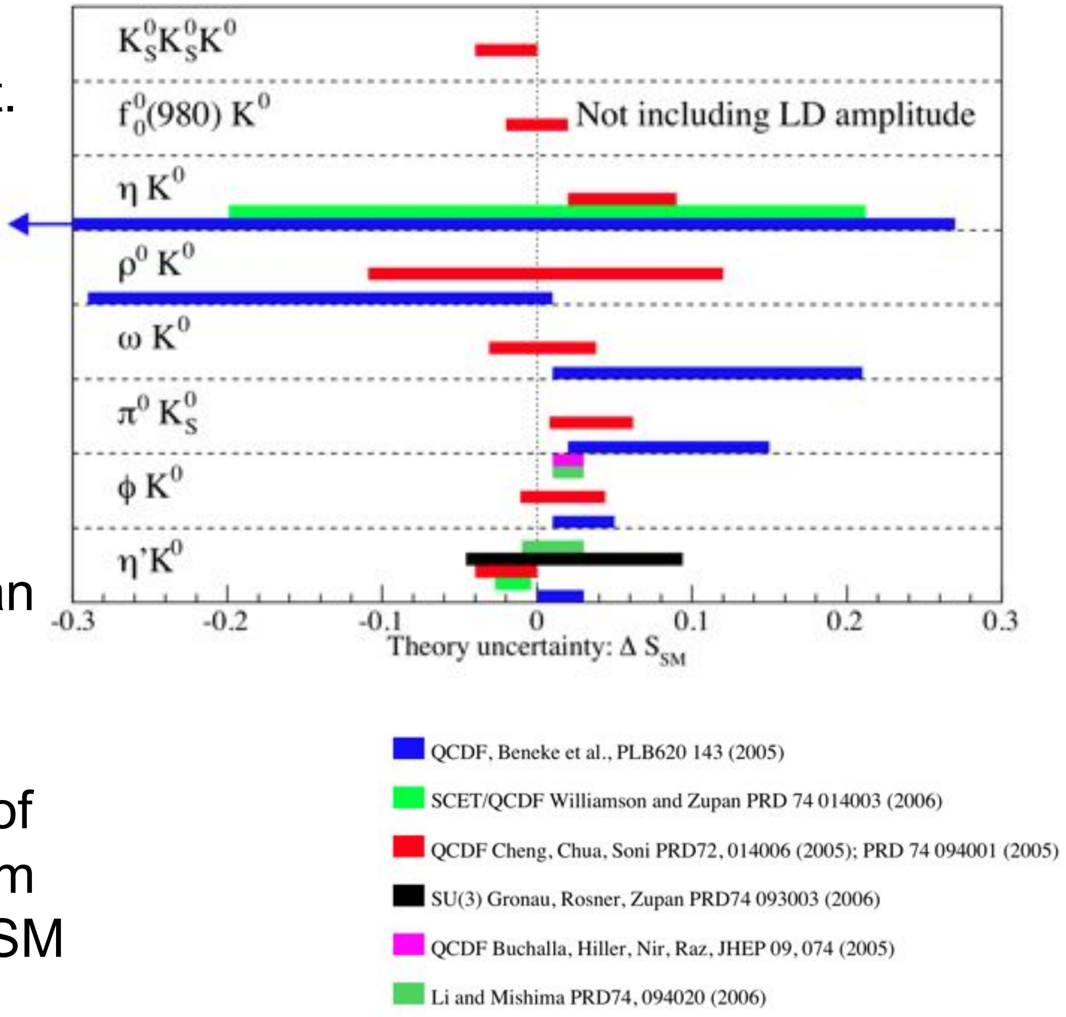


- Deviations would be from high mass particles in loops: H, χ, ...


≥ 5 σ discovery possible
(extrapolating from today)

ΔS measurements

- The SM uncertainty is strongly mode dependent.
- Golden modes have to be well measured and theoretically clean.
- Prefer to also have robust constraints from more than one theoretical approach.
- Precision measurements of the reference Charmonium decay also have a small SM uncertainty.



ΔS measurements

- We were reminded that we should be careful with what we compare:
  - NP could affect $c\bar{c}s$ sin2β.

1) Predict sin2β from indirect constraints.

$$[\sin(2\beta)]^{\text{prediction}}_{\text{no } V_{ub}} = 0.87 \pm 0.09\,.$$ 🟩

2) Compare to $\bar{c}cs$ measurement.

$$[\sin 2\beta]_{c\bar{c}s} = 0.672 \pm 0.023$$ 🟨

3) Compare to clean penguin measurements.

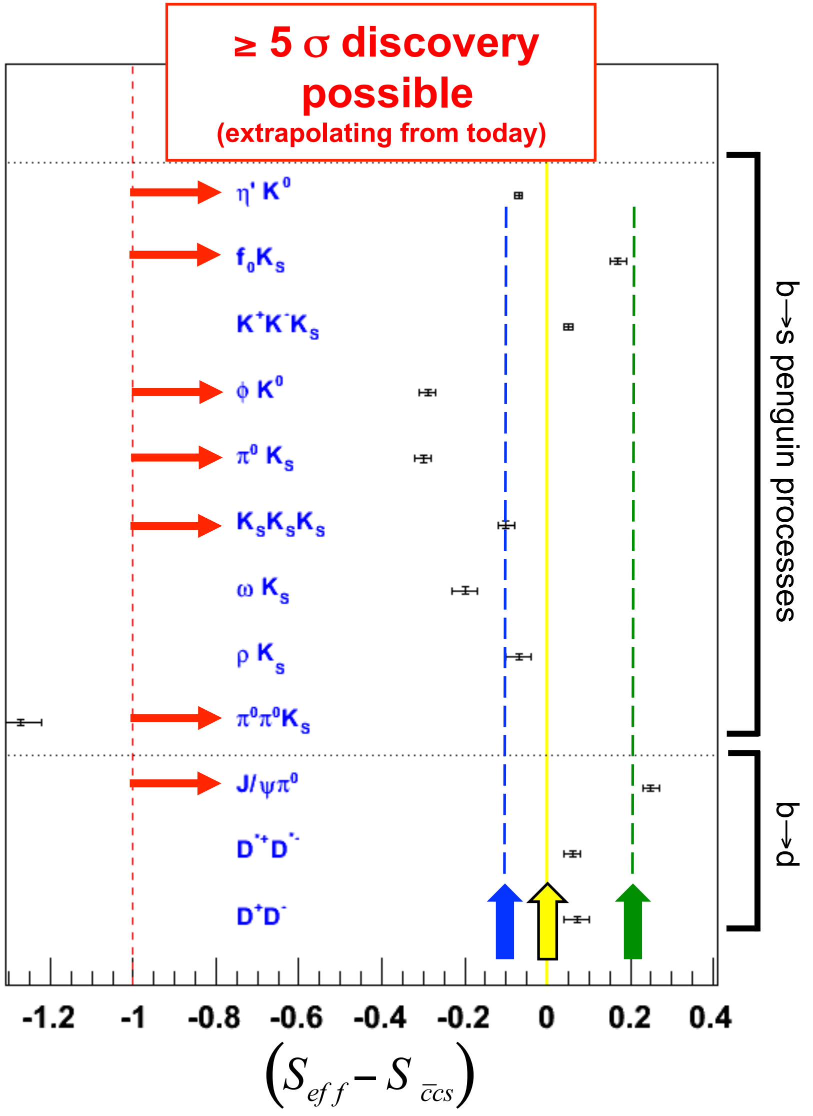
$$[\sin 2\beta]^{clean}_{b\to s-penguin} = 0.58 \pm 0.06$$ 🟦

(*or the average of the two*)

Are these 2.1-2.7σ hints for new physics?

Lunghi and Soni, Phys.Lett.B**666** 162-165 (2008).
Buras and Guadagnoli Phys Rev D **78** 033005 (2008).

- **Can theory error be reduced for other modes?**



≥ 5 σ discovery possible
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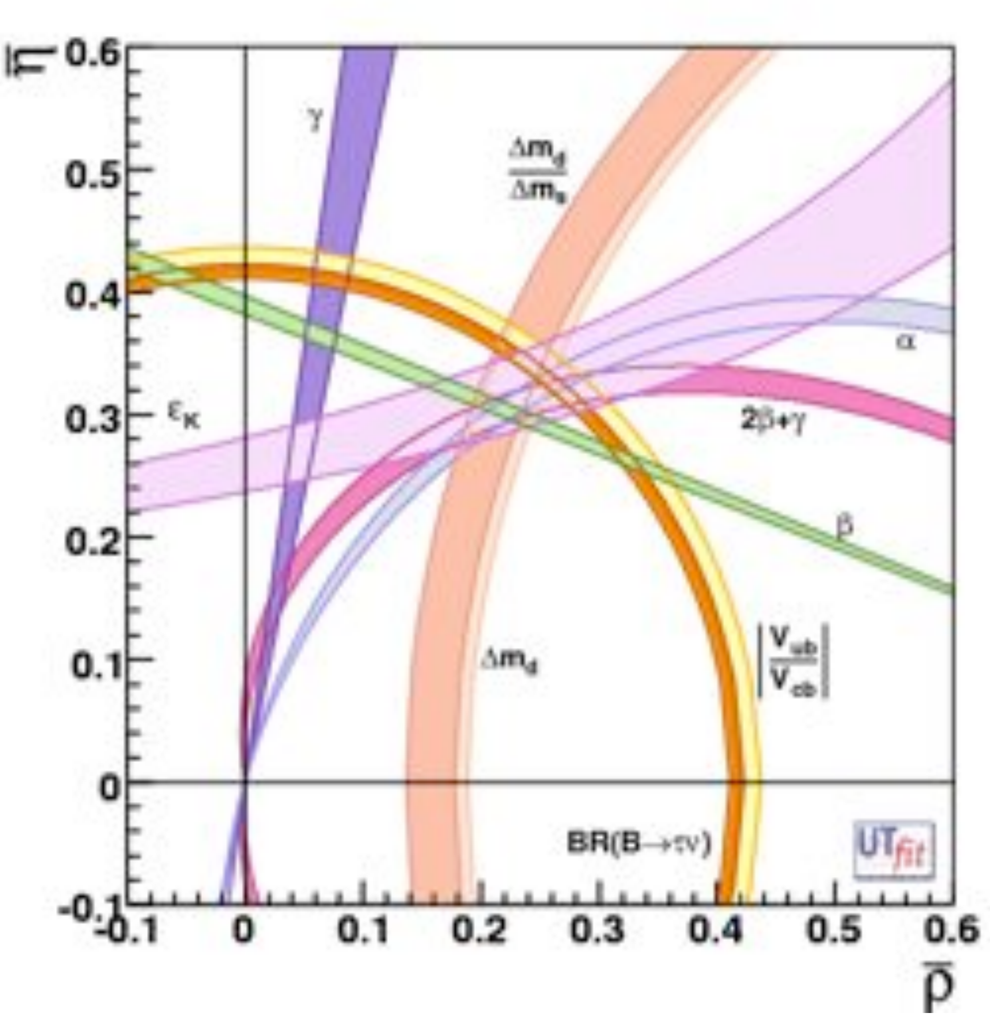
... and precision CKM



$$\sigma(\beta) < 0.5^\circ$$

$$\sigma(\alpha) \sim 1 - 2^\circ$$

$$\sigma(\gamma) \sim 1 - 2^\circ$$

$$etc.$$

Can we develop more insight into CKM?

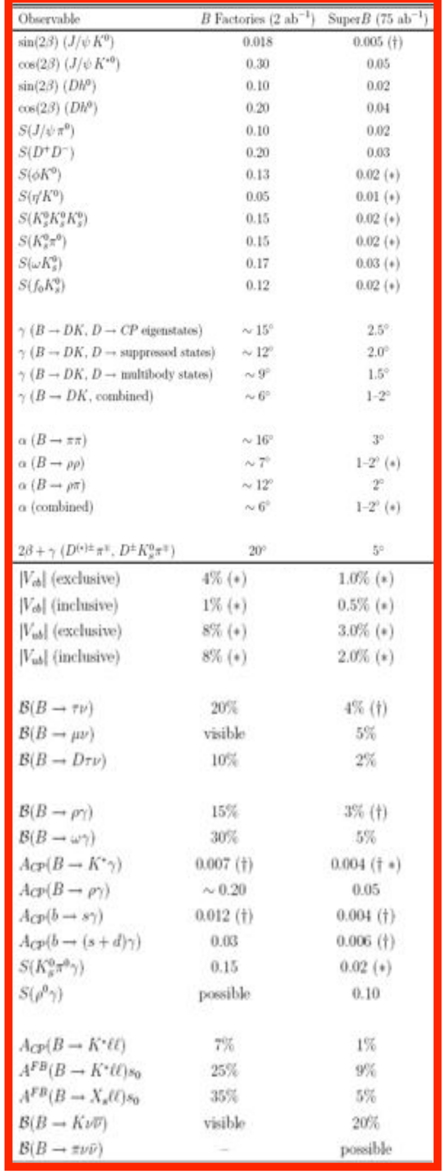
- does it work at the % level?

- what new physics probes become available with precision CKM?

[for SuperB and Other expt.]

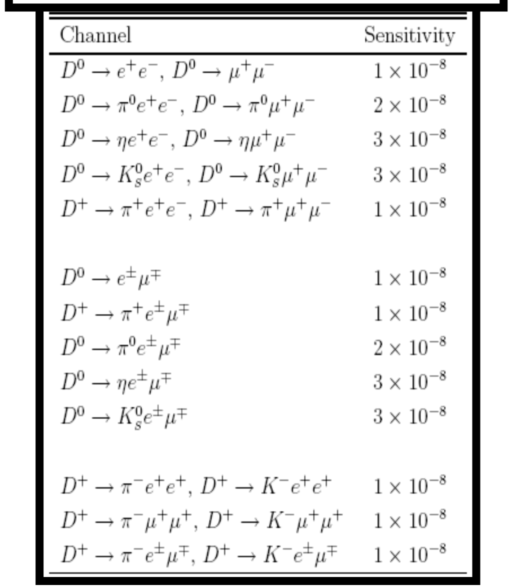
Standard Model measurements.

B Physics at Υ(4S)



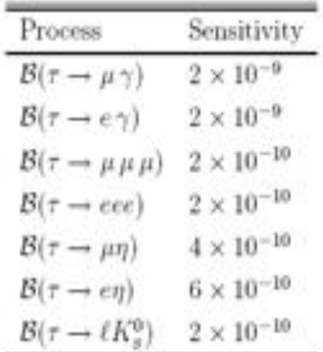
Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ $(J/\psi K^0)$	0.018	0.005 (†)
$\cos(2\beta)$ $(J/\psi K^{*0})$	0.30	0.05
$\sin(2\beta)$ (Dh^0)	0.10	0.02
$\cos(2\beta)$ (Dh^0)	0.20	0.04
$S(J/\psi\pi^0)$	0.10	0.02
$S(D^+D^-)$	0.20	0.03
$S(\phi K^0)$	0.13	0.02 (∗)
$S(\eta' K^0)$	0.05	0.01 (∗)
$S(K_s^0K_s^0K_s^0)$	0.15	0.02 (∗)
$S(K_s^0\pi^0)$	0.15	0.02 (∗)
$S(\omega K_s^0)$	0.17	0.03 (∗)
$S(f_0K_s^0)$	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°
$\lvert V_{cb}\rvert$ (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

Rare Charm Decays:
1 month at ψ(3770)



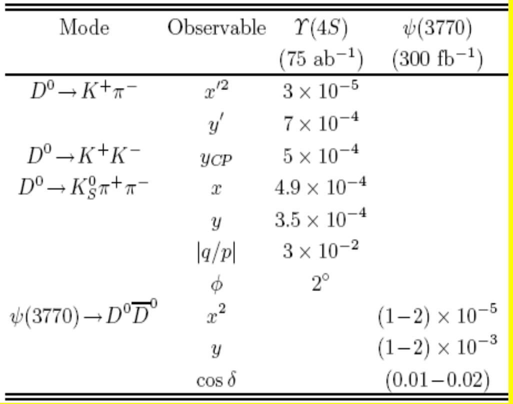
Channel	Sensitivity
$D^0\to e^+e^-$, $D^0\to\mu^+\mu^-$	1×10^{-8}
$D^0\to\pi^0e^+e^-$, $D^0\to\pi^0\mu^+\mu^-$	2×10^{-8}
$D^0\to\eta e^+e^-$, $D^0\to\eta\mu^+\mu^-$	3×10^{-8}
$D^0\to K_S^0e^+e^-$, $D^0\to K_S^0\mu^+\mu^-$	3×10^{-8}
$D^+\to\pi^+e^+e^-$, $D^+\to\pi^+\mu^+\mu^-$	1×10^{-8}
$D^0\to e^\pm\mu^\mp$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

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}
$\mathcal{B}(\tau\to\ell K_S^0)$	2×10^{-10}

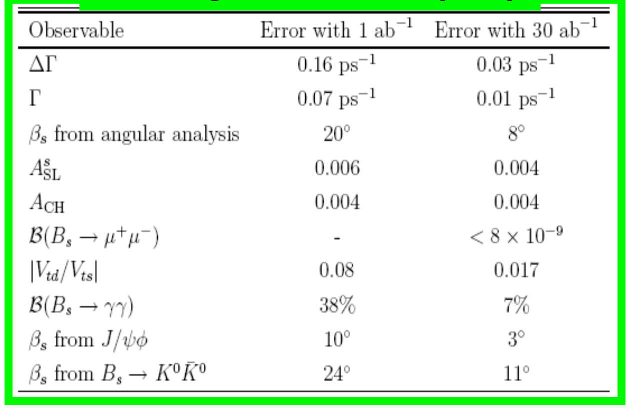
Charm Mixing



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}	
$D^0\to K_S^0\pi^+\pi^-$	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		$(1-2)\times10^{-3}$
	$\cos\delta$		$(0.01-0.02)$

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

B Physics at Υ(5S)



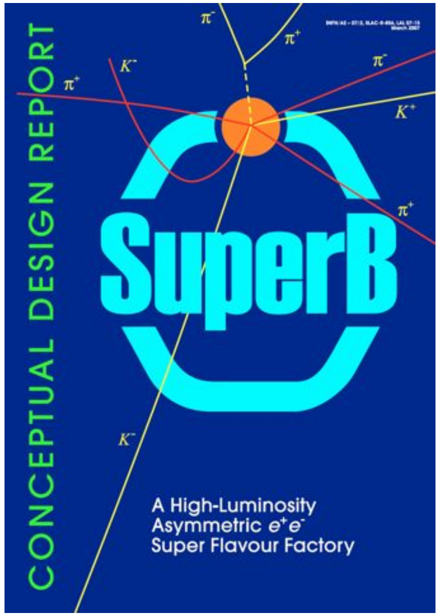
Observable	Error with 1 ab^{-1}	Error with 30 ab^{-1}
$\Delta\Gamma$	0.16 ps^{-1}	0.03 ps^{-1}
Γ	0.07 ps^{-1}	0.01 ps^{-1}
β_s from angular analysis	20°	8°
A_{SL}^s	0.006	0.004
A_{CH}	0.004	0.004
$\mathcal{B}(B_s\to\mu^+\mu^-)$	-	$<8\times10^{-9}$
$\lvert V_{td}/V_{ts}\rvert$	0.08	0.017
$\mathcal{B}(B_s\to\gamma\gamma)$	38%	7%
β_s from $J/\psi\phi$	10°	3°
β_s from $B_s\to K^0\bar{K}^0$	24°	11°

Other measurements of interest

- Let us not forget the other opportunities for searching for new physics at SuperB:
  - Charm decays: CPV and parallels of rare B decays.
  - LFV in light mesons
  - Light (few GeV) Higgs Searches
  - CPT Violation test / EPR correlation tests
  - Dark matter ... and Dark Forces

Recent (and imminent) milestones

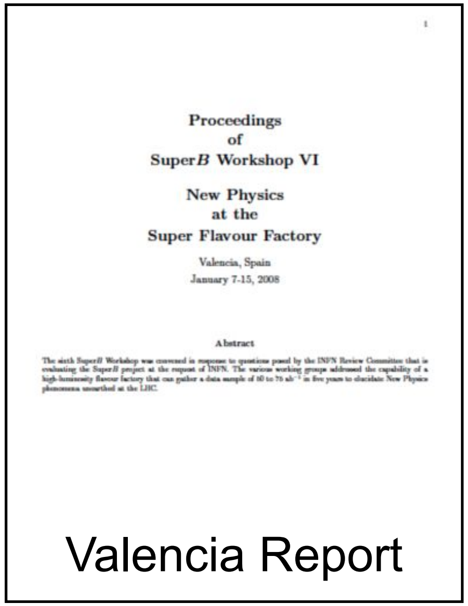
Milestones in the programme...


CONCEPTUAL DESIGN REPORT

SuperB

A High-Luminosity Asymmetric e^+e^- Super Flavour Factory

2007


Proceedings
of
Super*B* Workshop VI

New Physics
at the
Super Flavour Factory

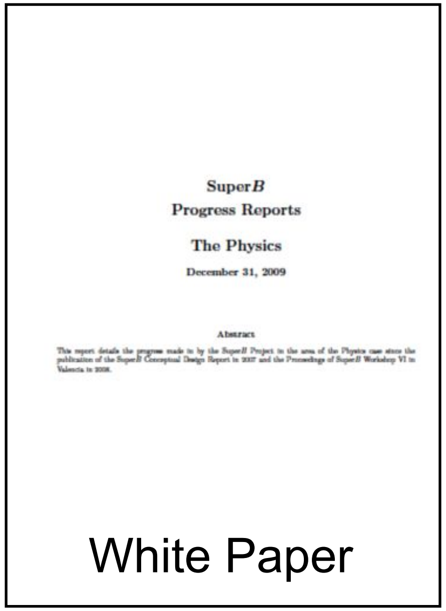
Valencia, Spain
January 7-15, 2008

Abstract

The sixth Super*B* Workshop was convened in response to questions posed by the INFN Review Committee that is evaluating the Super*B* project at the request of INFN. The various working groups addressed the capability of a high-luminosity flavour factory that can gather a data sample of 50 to 75 ab^{-1} in five years to elucidate New Physics phenomena unearthed at the LHC.

Valencia Report

2008


Super*B*
Progress Reports

The Physics

December 31, 2009

Abstract

This report details the progress made in by the Super*B* Project in the area of the Physics case since the publication of the Super*B* Conceptual Design Report in 2007 and the Proceedings of Super*B* Workshop VI in Valencia in 2008.

White Paper

2009/2010

- The white paper is a stepping stone toward the TDR (end of 2010).
- During this workshop we aim to review the state of the art in terms of flavour physics capabilities of SuperB.

Recent Progress

- A lot has happened since Warwick:
  - Dark Forces has gathered a lot of interest in the community (See F. Bossi).
  - First results from MEG (See F. Renga).
  - LHC data taking has re-started (See T. Hurth).
  - Full and Fast Sim. and a SuperB distributed computing model has come online (See the General Meeting).
    - We are now starting to optimize SuperB based on a few key benchmark channels.
- All of these factors are additional inputs to refine our goals.
- This work will continue through 2010 as we re-focus for the TDR.

Physics White Paper

Purpose

- Provide a coherent description of the physics case of the experiment:
  - New Physics Search Capability:
    - This is the reason why SuperB is relevant in 2015 (when we plan to go online).
    - What other inputs are necessary to decode the behaviour of new physics more comprehensively?
    - How the SuperB measurements push back our understanding of the viable models?
  - Standard Model Physics:
    - Precision CKM: as a test of the CKM anzatz.
    - As a control of SM uncertainties for other (non-)SuperB benchmark channels to search for new physics.

Scope

- Aim: 40-50 pages:
  - Have made a good start with the CDR & Valencia document.
  - Several key features have changed:
    - D mixing has been established, and CPV searches in charm are more mature.
    - NP probes in B and τ decays have advanced since last time.
    - Lattice QCD has matured: we can compare against CDR predictions.
    - Tevatron has measured Φ_s more precisely.
  - This document should be stand alone.

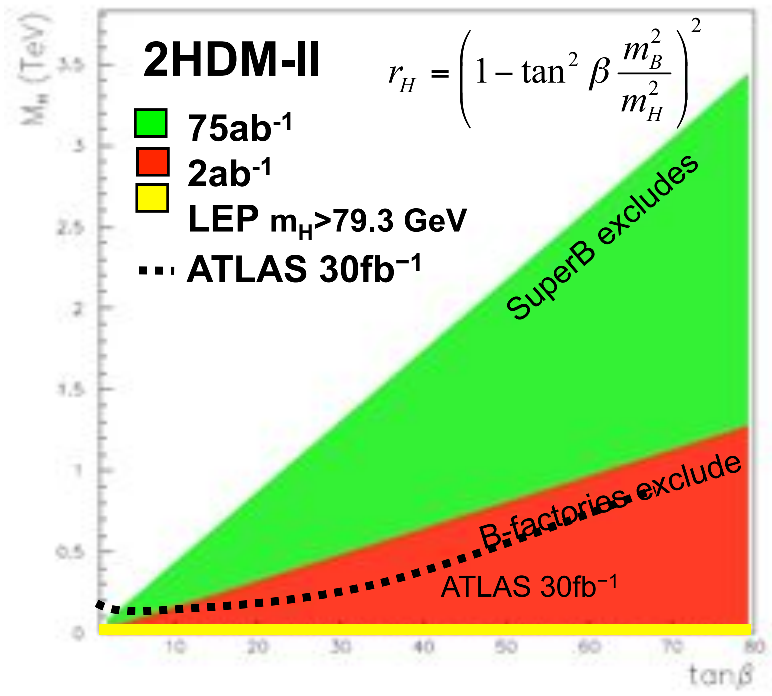
Content

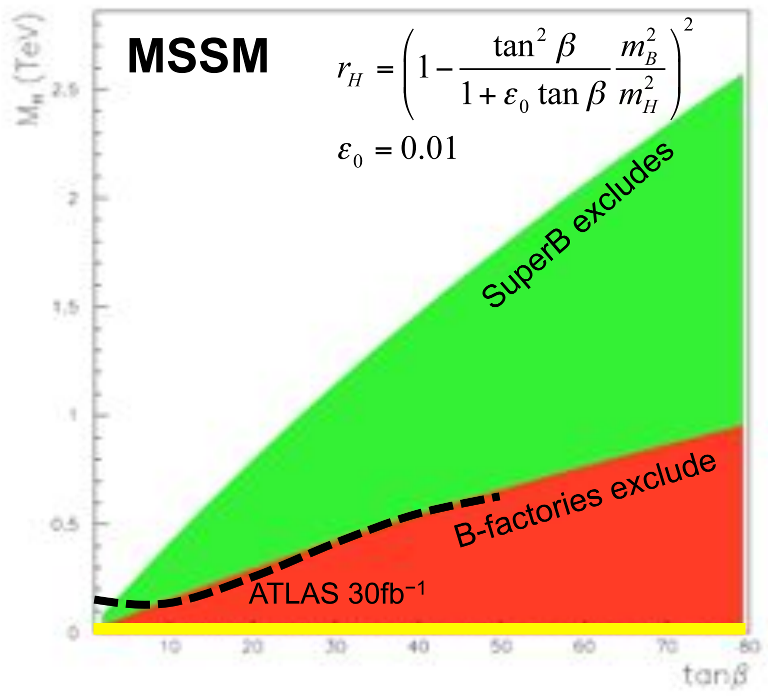
- Introduction
- B_u,d,s physics
- Charm physics
- τ physics
- Spectroscopy
- Role of Lattice QCD
- Interplay with other experiments
- Conclusion

The content is based on previous documents. If you think that a new section is needed – then propose it to the conveners in charge of that section.

Why have an interplay section?

- This is how we can show what SuperB will teach us about nature; in the context of existing and planned experimental programmes.





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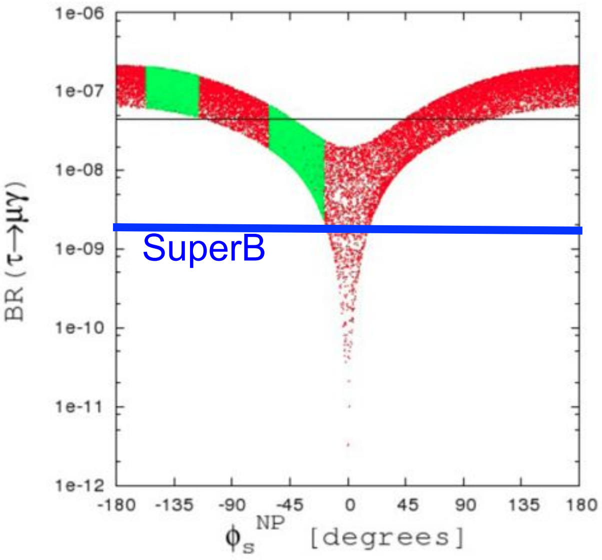

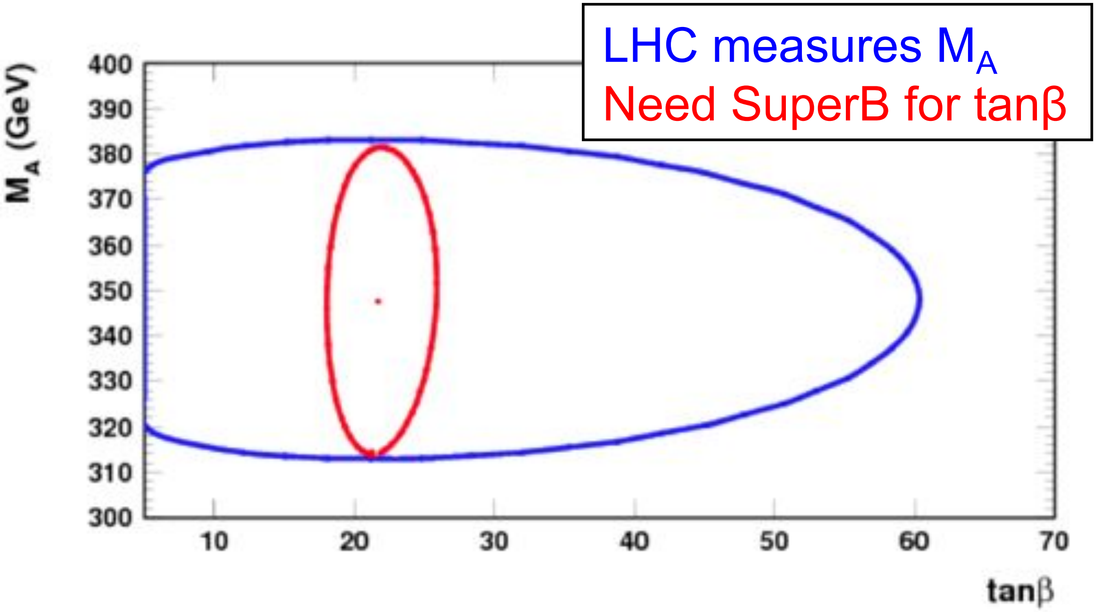
LHC measures M_A

Need SuperB for tanβ

Why have an interplay section?

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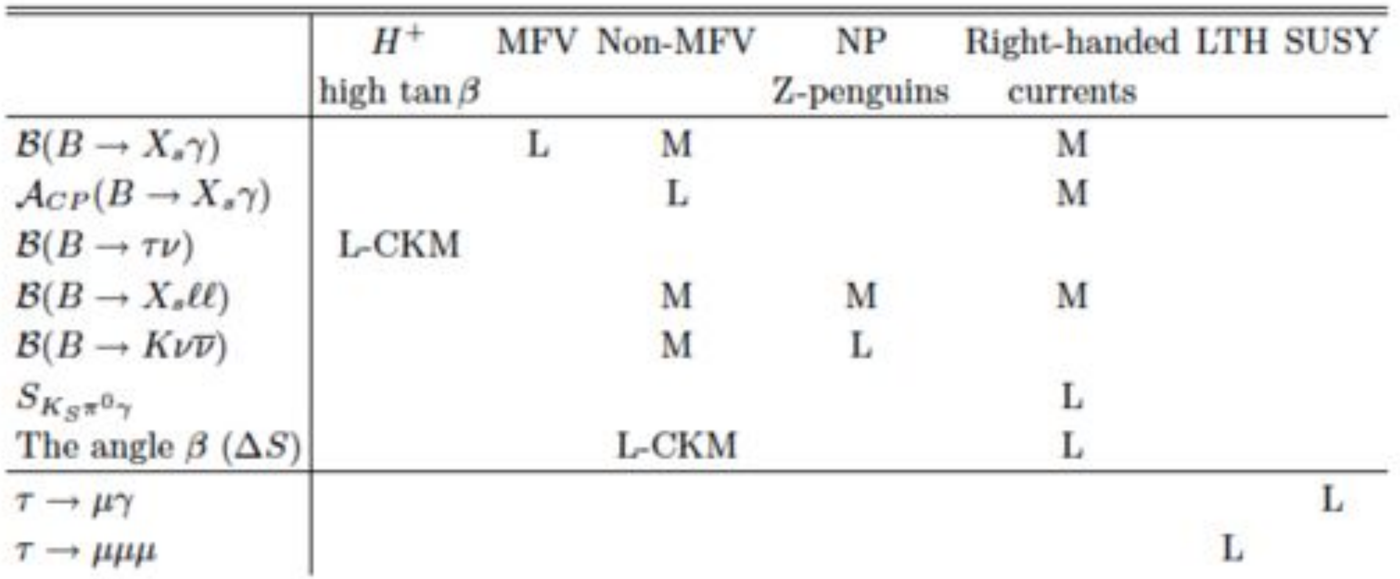


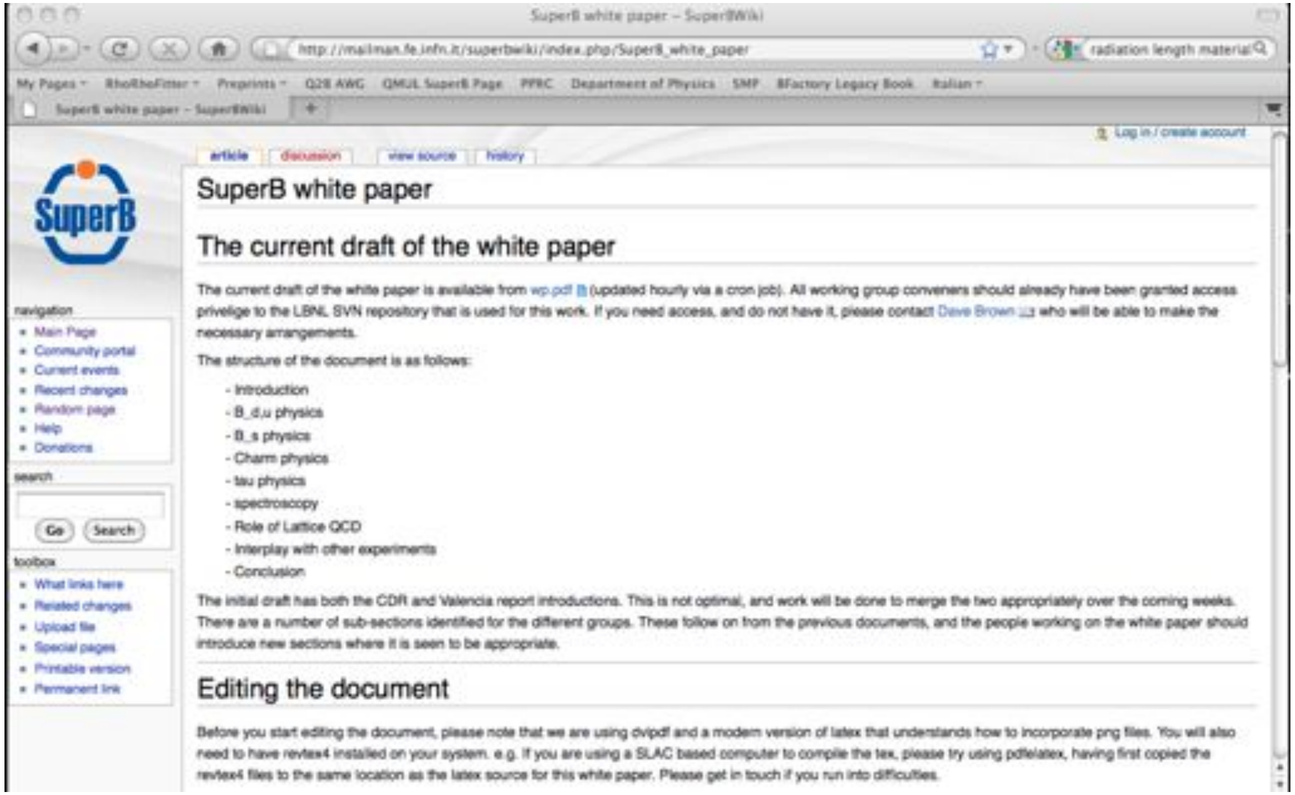
	H^+ high $\tan\beta$	MFV	Non-MFV	NP Z-penguins	Right-handed currents	LTH	SUSY
$\mathcal{B}(B \to X_s\gamma)$		L	M		M		
$\mathcal{A}_{CP}(B \to X_s\gamma)$			L		M		
$\mathcal{B}(B \to \tau\nu)$	L-CKM						
$\mathcal{B}(B \to X_s\ell\ell)$			M	M	M		
$\mathcal{B}(B \to K\nu\overline{\nu})$			M	L			
$S_{K_S\pi^0\gamma}$					L		
The angle β (ΔS)			L-CKM		L		
$\tau \to \mu\gamma$							L
$\tau \to \mu\mu\mu$						L	

Need to elaborate on the golden matrix of observables that can be used to decode new physics.

This is more than just rare B and τ decays... See the talks later this morning!

Where can I find the Tex source?

- The source is in an SVN repository at LBNL.
- Instructions for accessing this are on the Physics Wiki Page.
    - Physics Portal -> Documentation -> White Paper



SuperB white paper

The current draft of the white paper

The current draft of the white paper is available from wp.pdf (updated hourly via a cron job). All working group conveners should already have been granted access privelige to the LBNL SVN repository that is used for this work. If you need access, and do not have it, please contact Dave Brown who will be able to make the necessary arrangements.

The structure of the document is as follows:

- Introduction
- B_d,u physics
- B_s physics
- Charm physics
- tau physics
- spectroscopy
- Role of Lattice QCD
- Interplay with other experiments
- Conclusion

The initial draft has both the CDR and Valencia report introductions. This is not optimal, and work will be done to merge the two appropriately over the coming weeks. There are a number of sub-sections identified for the different groups. These follow on from the previous documents, and the people working on the white paper should introduce new sections where it is seen to be appropriate.

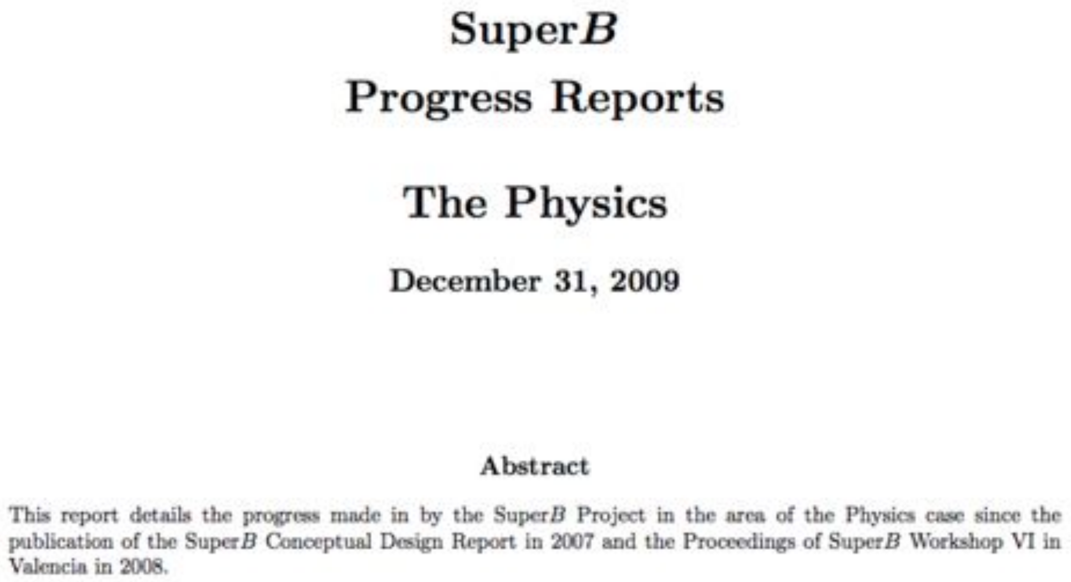
Editing the document

Before you start editing the document, please note that we are using dvipdf and a modern version of latex that understands how to incorporate png files. You will also need to have revtex4 installed on your system. e.g. If you are using a SLAC based computer to compile the tex, please try using pdflatex, having first copied the revtex4 files to the same location as the latex source for this white paper. Please get in touch if you run into difficulties.

How do I get to see the current version?

- A trscron job updates the pdf version of the white paper every hour.
  - Can download a current copy that corresponds to whatever has been committed.
  - Will always be up-to-date within 60min (*or broken*)

http://www.slac.stanford.edu/~bevan/superbID/wp.pdf



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How do I get an account to contribute?

- This work uses the original LBNL SuperB repository.
- Working group conveners and theorists have been given accounts to access this repository.
- If you have not already been informed of this and would like to access the Tex to contribute to the white paper, please see Dave Brown: Dave_Brown@lbl.gov.

Timescale

- We want to have the white paper finalized as soon as possible.
  - Get as much work done as possible this week.
  - Follow up with this work through the Christmas vacation.
  - Finish the document early next year at the latest: end Dec/Start Jan.
- *We can come back to the white paper at the end of the morning and take discussions through lunch!*

Summary

- Plenary talks this morning:
  - Dark Forces (F. Bossi)
  - MEG (F. Renga)
  - Interplay (T. Hurth)

- Parallel sessions this afternoon.

- Lattice plenary talk on Tuesday 11.14 (V. Lubicz).

- Parallel sessions on the remaining afternoons.