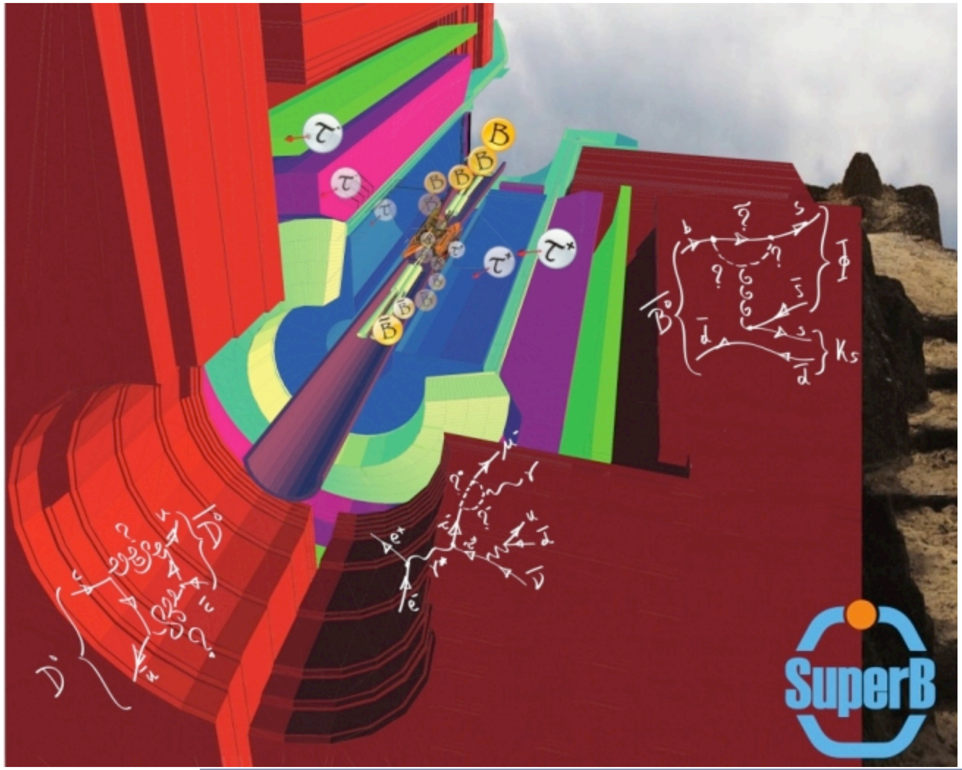


SuperB Physics Programme

Adrian Bevan
IHEP, Beijing, 21st October 2011

email: a.j.bevan@qmul.ac.uk

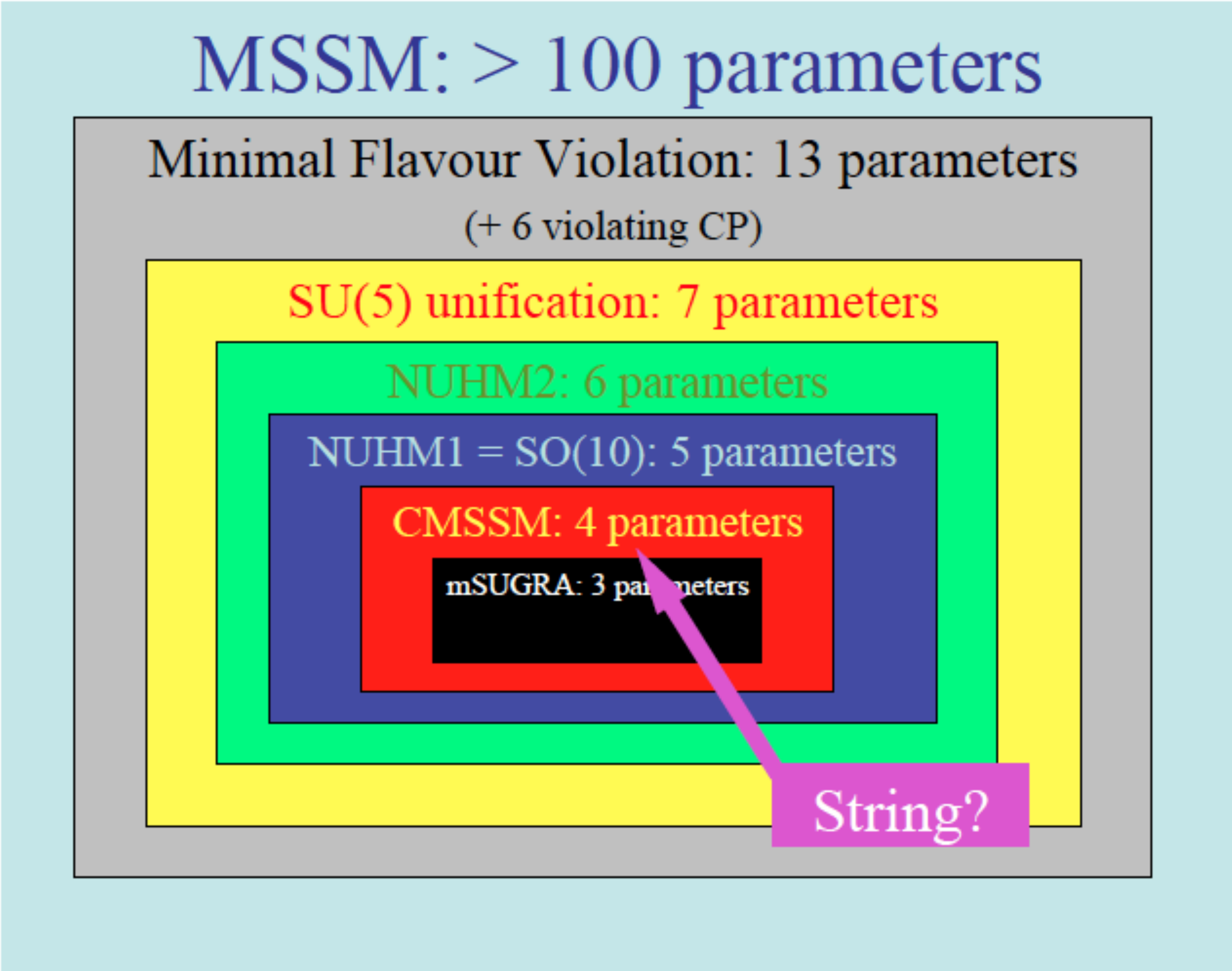
Queen Mary
University of London

Overview

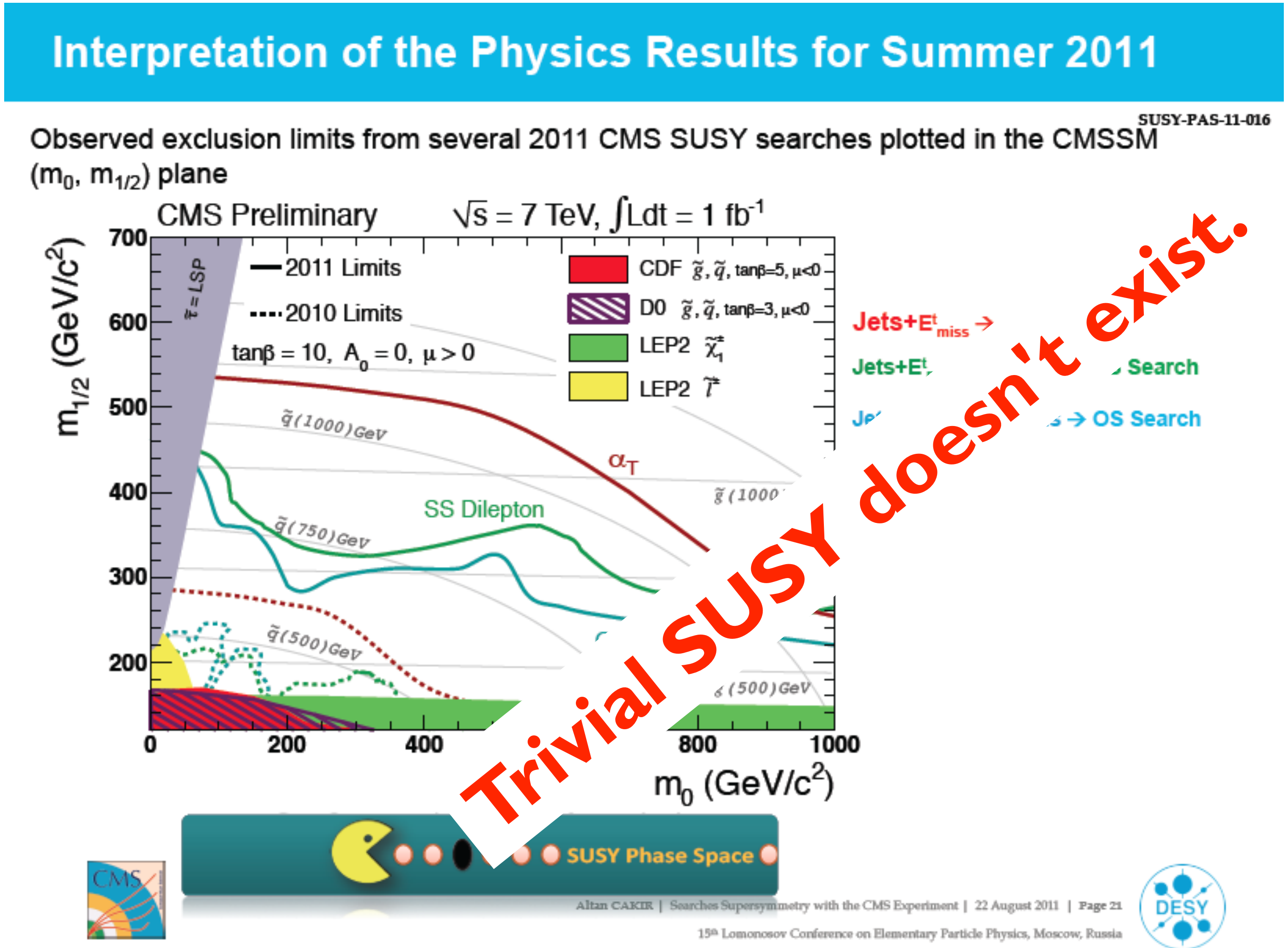
- Introduction
- Data samples available at SuperB
- Topics
  - τ physics
  - $B_{u,d,s}$ physics
  - D physics: a few highlights
    - See the other talks during this workshop (*AB, Giorgi, Meadows, Neri, Rama, Sokoloff*).
  - Precision EW
  - Spectroscopy
- Interplay
  - Precision CKM
  - Golden modes
- Summary

Introduction

- Current flavour physics landscape is defined by BaBar, Belle and the Tevatron.
  - We learned that CKM is correct at leading order.
  - Placed indirect constraints on NP that will last well into the LHC era. (e.g. H^+ searches).
- SuperB will start taking data in 2016, and the first full run is expected in 2017.
  - LHCb will have re-defined some areas of flavour physics on that timescale [and take data through to 2017 shutdown].
  - LHC may (or may not) have found new particles.
    - Existing mass scale exclusions are model dependent.
  - In both scenarios results from SuperB can be used to constrain flavour dynamics at high energy.


MSSM: > 100 parameters
Minimal Flavour Violation: 13 parameters
(+ 6 violating CP)
SU(5) unification: 7 parameters
NUHM2: 6 parameters
NUHM1 = SO(10): 5 parameters
CMSSM: 4 parameters
mSUGRA: 3 par meters
String?

LHC Results on SUSY (slide from A. Cakir, Lomonosov XV)



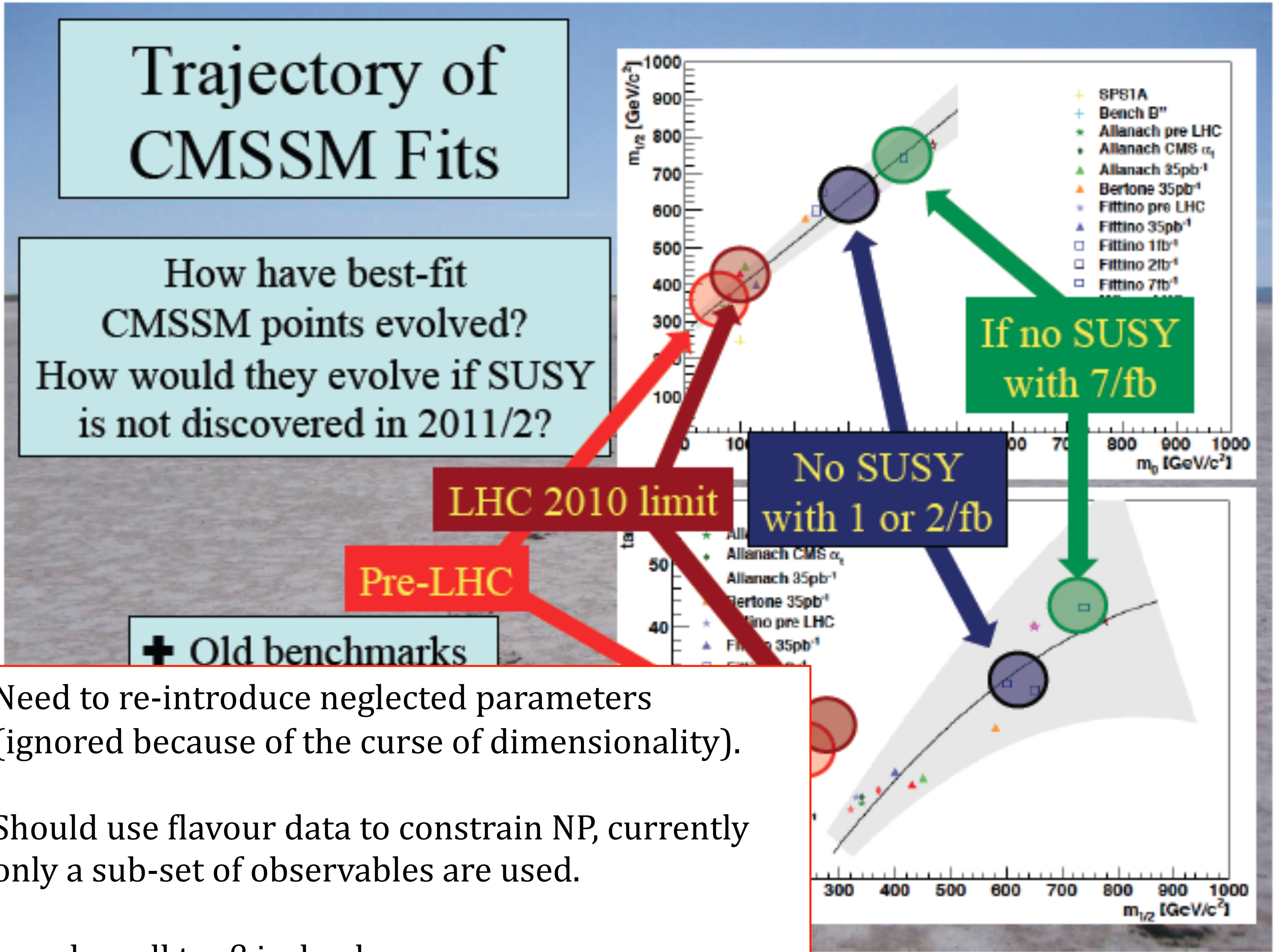
So far no evidence for SUSY.

The SUSY mass scale is now looking likely to be above 1TeV.

This has interesting implications for some of our measurements.

We need to make sure our benchmark processes and assumed scales are still valid as these contours are updated.

J. Ellis



Need to re-introduce neglected parameters (ignored because of the curse of dimensionality).

Should use flavour data to constrain NP, currently only a sub-set of observables are used.

... and small tanβ is dead.

Introduction

- Example: Consider MSSM as an illustration of SUSY
  - Simple, and being constrained by the LHC 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.

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

LHC, ILC - HE frontier

LHCb, SuperB

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

  - In many NP scenarios the energy frontier experiments will probe the diagonal elements of mixing matrices.
  - Flavour experiments are required to probe off-diagonal ones.

SUSY

- e.g. MSSM with generic squark mass matrices.

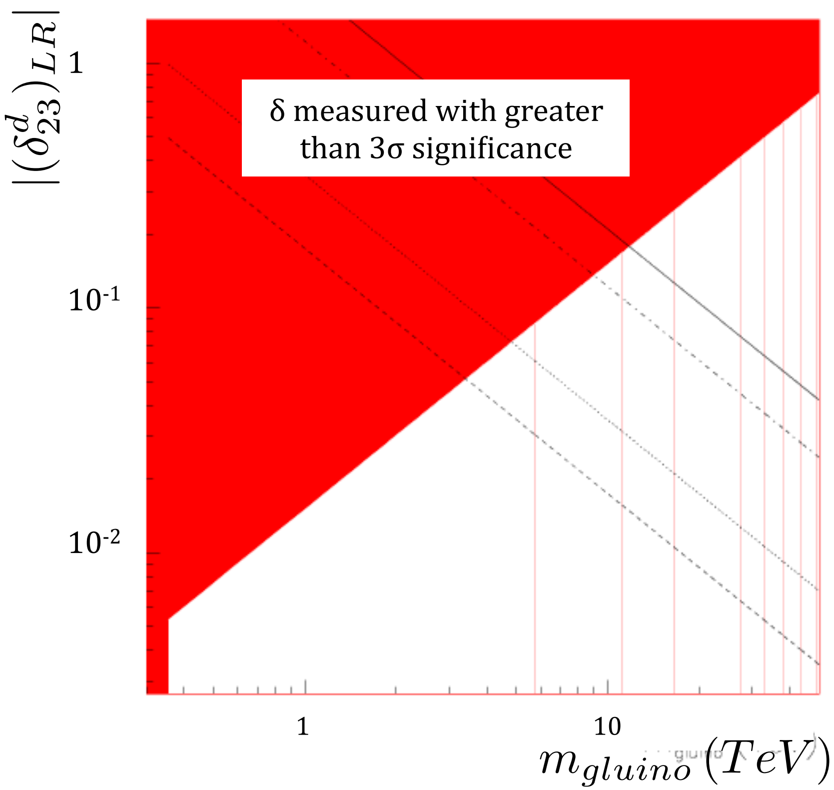
- Use Mass insertion approximation with $m_{\tilde{q}} \sim m_{\tilde{g}}$ to constrain couplings:

$$(\delta^q_{ij})_{AB} = \frac{(\Delta_{ij})^q_{AB}}{m^2_{\tilde{q}}}$$

- Can constrain the δ^d_{ij}'s using

$$\mathcal{B}(B \to X_s \gamma)$$
$$\mathcal{B}(B \to X_s \ell^+ \ell^-)$$
$$\mathcal{A}_{CP}(B \to X_s \gamma)$$

LHC constraints on the gluino mass, mean couplings are non-zero, and SuperB can provide an upper bound on Λ_{NP}.



e.g. see Hall et al., Nucl. Phys. B **267** 415-432 (1986)
Ciuchini et al., hep-ph/0212397

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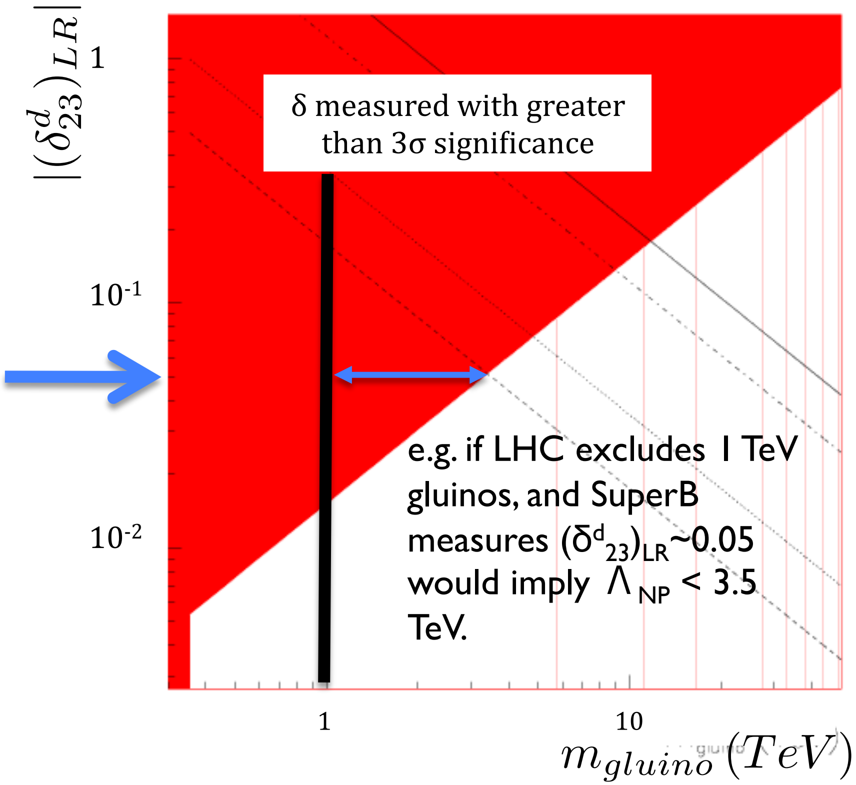

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Introduction

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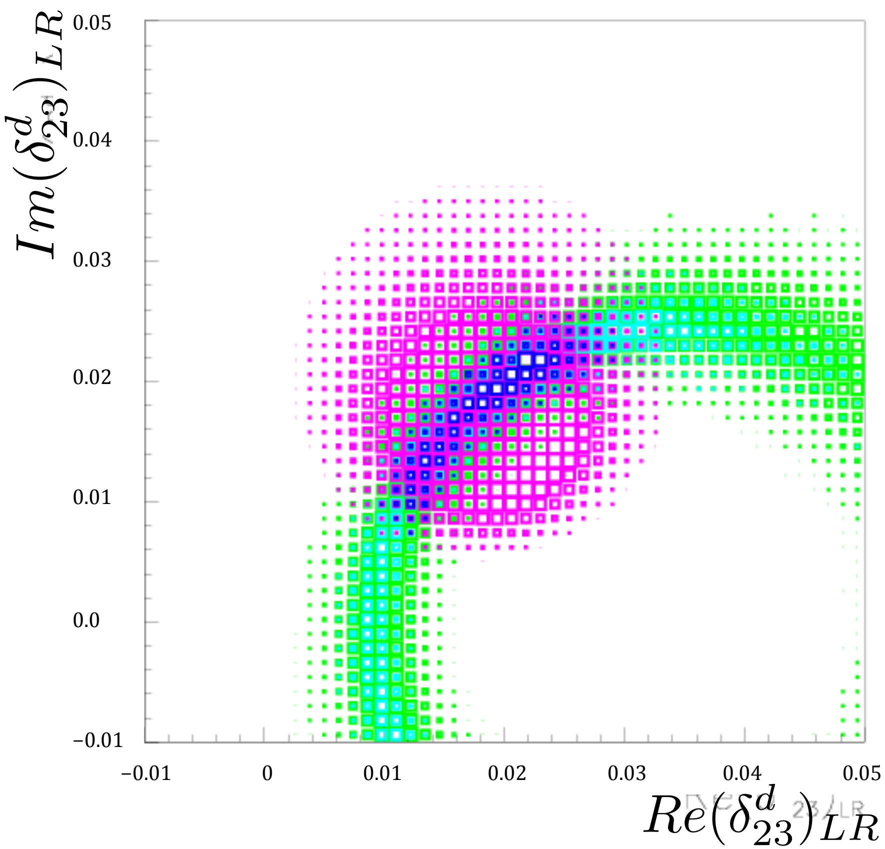
$$(\delta^q_{ij})_{AB} = \frac{(\Delta_{ij})^q_{AB}}{m^2_{\tilde{q}}}$$

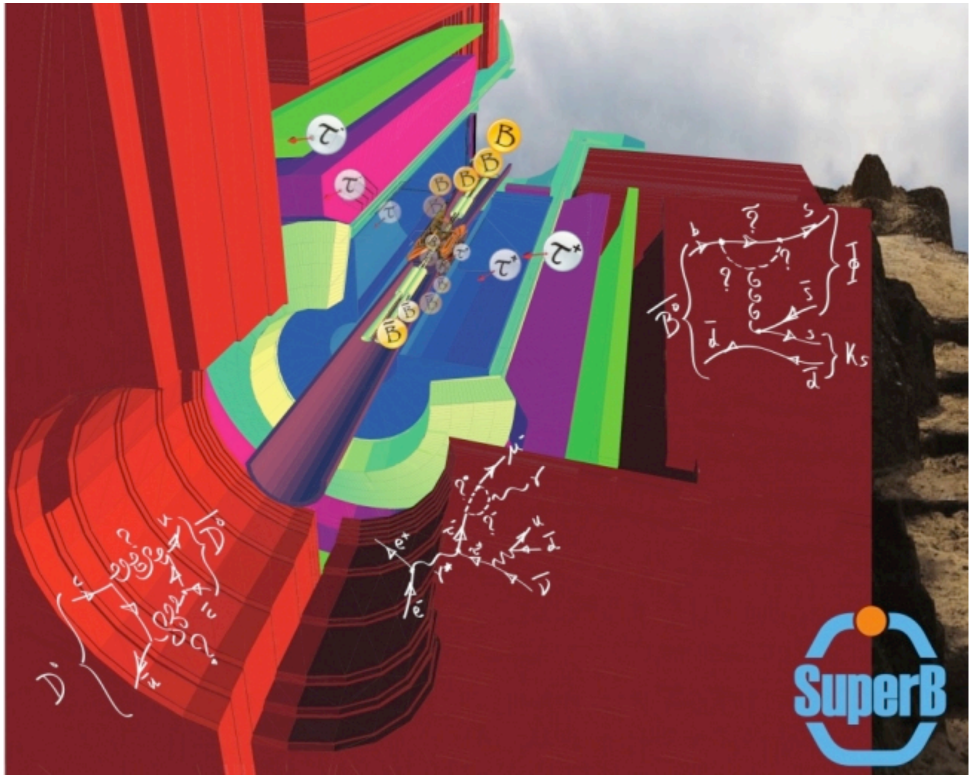
- Can constrain the δ^d_{ij}'s using
  - $\mathcal{B}(B \to X_s\gamma)$ (green)
  - $\mathcal{B}(B \to X_s\ell^+\ell^-)$ (cyan)
  - $\mathcal{A}_{CP}(B \to X_s\gamma)$ (magenta)



e.g. see Hall et al., Nucl. Phys. B **267** 415-432 (1986)
Ciuchini et al., hep-ph/0212397

The rest of this talk is an overview

- More details can be found in the following references:



Conceptual Design Report:
arXiv:0709.0451

Valencia Physics Workshop Report:
arXiv:0810.1312

Detector White Paper:
arXiv:1007.4241

Accelerator White Paper:
arXiv:1009.6178

Physics White Paper:
arXiv:1008.1541

Impact Document:
arXiv:1109.5028

Recently submitted to the archive

INFN/AE_11/1, LAL-11-200, SLAC-R-14548, MZ-TH/11-25

The impact of Super$B$ on flavour physics

July 1, 2011

Abstract

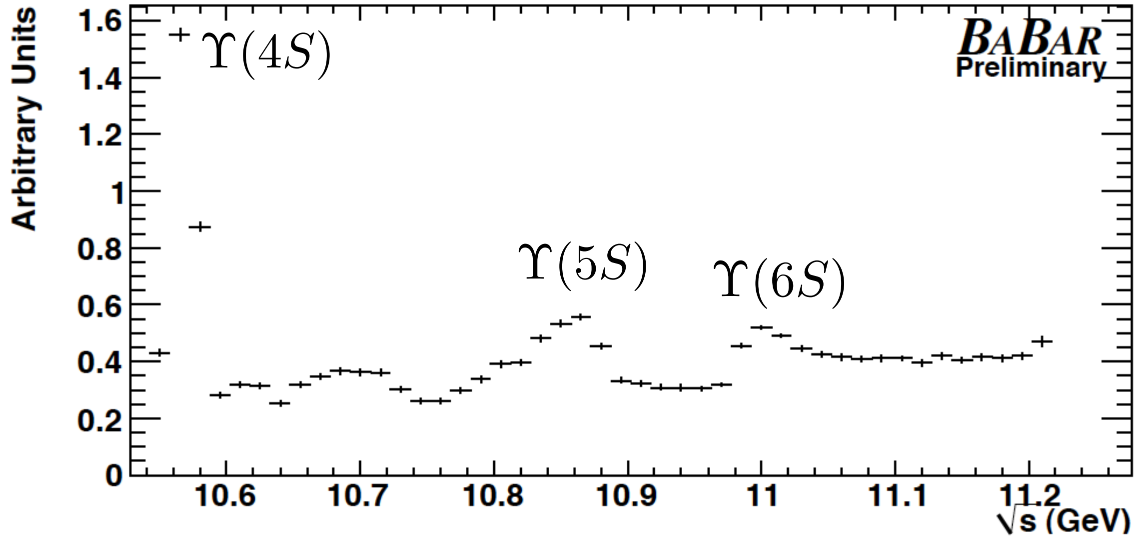
This report provides a succinct summary of the physics programme of Super$B$, and describes that potential in the context of experiments making measurements in flavour physics over the next 10 to 20 years. Detailed comparisons are made with Belle II and LHCb, the other B physics experiments that will run in this decade. SuperB will play a crucial role in defining the landscape of flavour physics over the next 20 years.

Data samples available at SuperB

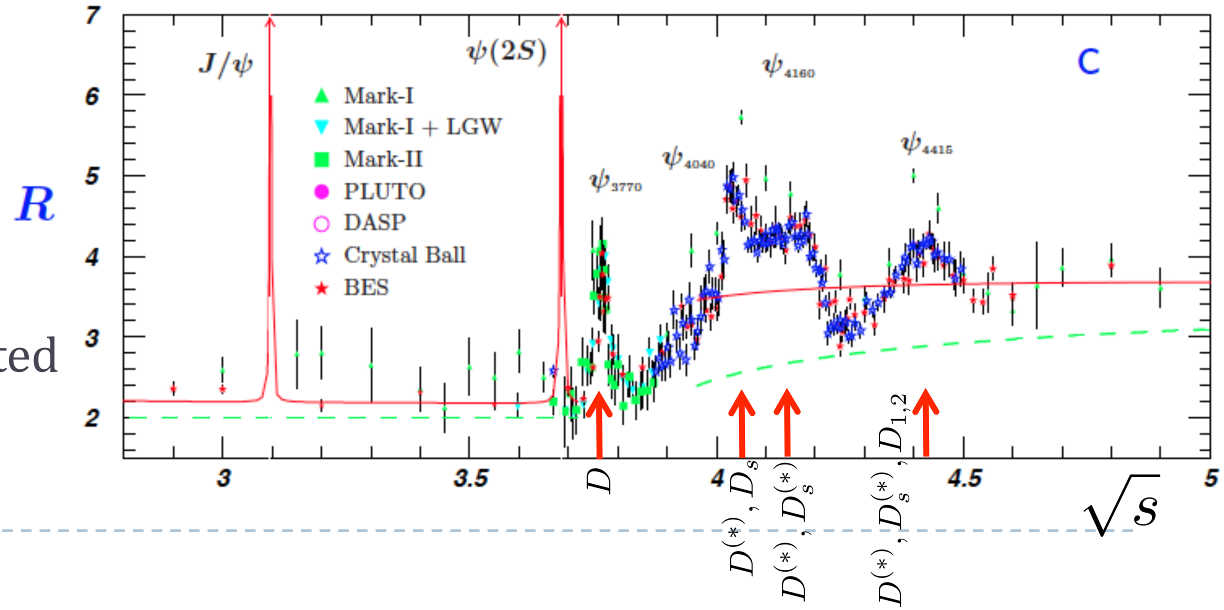
- Two distinct modes of operation:
  - 4S region: $\Upsilon(1S)$ – $\Upsilon(6S)$.
  - Charm threshold region: $\psi(3770)$ and nearby thresholds.

Data samples available at SuperB

- $\Upsilon(4S)$ region:
  - $75 ab^{-1}$ at the 4S.
  - Also run above / below the 4S.
  - $\sim 75 \times 10^9$ B, D and τ pairs.



- $\psi(3770)$ region:
  - $1ab^{-1}$ at threshold.
  - Also run at nearby resonances.
  - $\sim 4 \times 10^9$ D pairs at threshold in a dedicated one year run.



τ Physics

- The programme includes
  - Charged Lepton Flavour Violation [This talk]
  - CP Violation
  - τ EDM
  - τ g-2
  - Precision $|V_{us}|$ measurements

Lepton Flavour Violation (LFV)

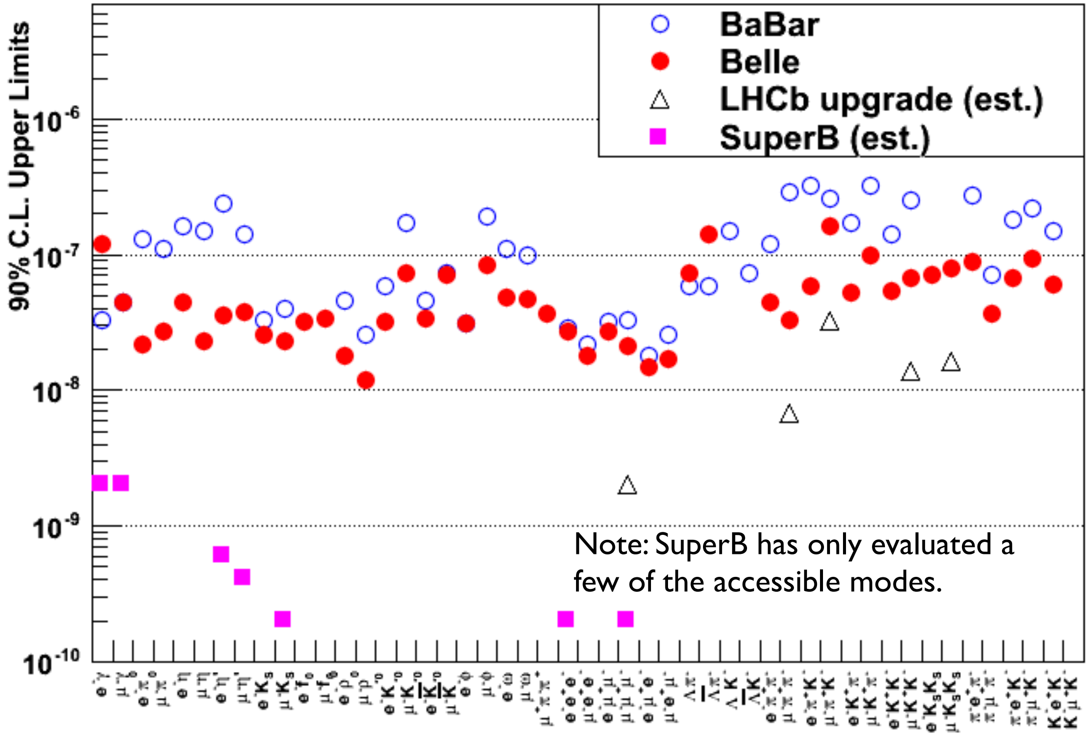
- ν mixing leads to a low level of charged LFV ($B \sim 10^{-54}$).
  - Enhancements to observable levels are possible with new physics scenarios.
  - Searching for transitions from 3rd generation to 2nd and 1st, i.e.

$$\tau \longrightarrow \mu \text{ and } \tau \longrightarrow e$$

➢Two orders of magnitude improvement at SuperB over current limits.

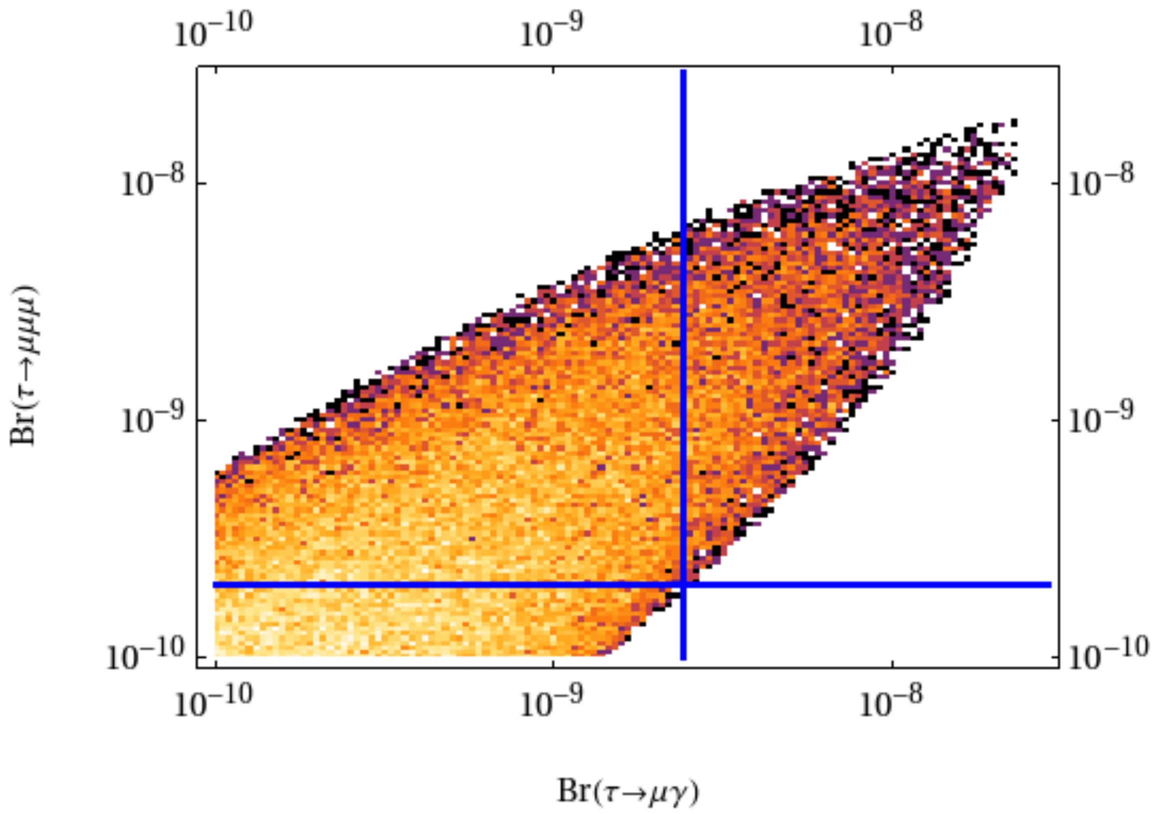
➢Hadron machines are not competitive with e^+e^- machines for this.

- N.B. e^- beam polarisation helps suppress background.



The golden LFV modes: $\tau \longrightarrow \mu\gamma, 3\mu$

- Symmetry breaking scale assumed: 500GeV.



NP scale assumed: 500GeV.

Current experimental limits are at the edges of the model parameter space

SuperB will be able to significantly constrain these models, and either find both channels, or constrain a large part of parameter space.

c/o M. Blanke

M. Blanke et al. arXiv:0906.5454

Specific example: $\tau \to \mu\gamma$

- Only cleanly accessible in e^+e^- (golden modes: $\mu\gamma$, 3 lepton).

Model dependent NP constraint.

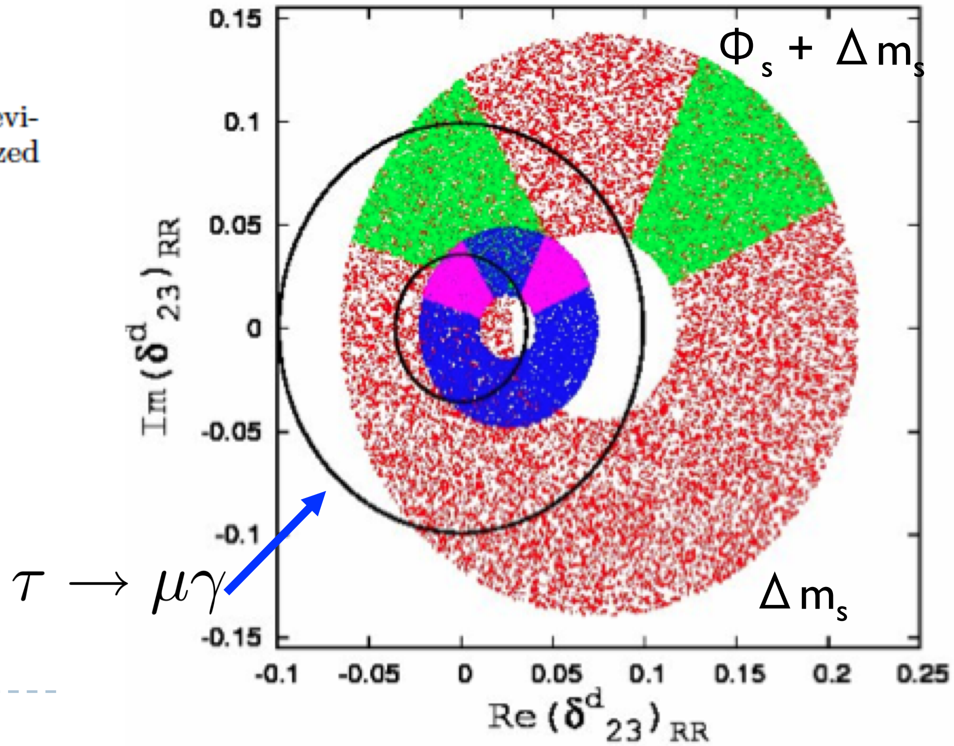
Correlated with other flavour observables: MEG, LHCb etc.

TABLE III: Expected 90% CL upper limits and 3σ evidence reach on LFV decays with 75 ab^{-1} with a polarized electron beam.

Process	Expected 90% CL upper limit	3σ evidence reach
$\mathcal{B}(\tau \to \mu\gamma)$	2.4×10^{-9}	5.4×10^{-9}
$\mathcal{B}(\tau \to e\gamma)$	3.0×10^{-9}	6.8×10^{-9}
$\mathcal{B}(\tau \to \ell\ell\ell)$	$2.3–8.2 \times 10^{-10}$	$1.2–4.0 \times 10^{-9}$

$m_{\tilde{q}} = 300\,GeV$ BLUE
$m_{\tilde{q}} = 500\,GeV$ RED

Not updated to latest results from LHCb



Parry and Zhang Nucl.Phys.B802:63-76,2008

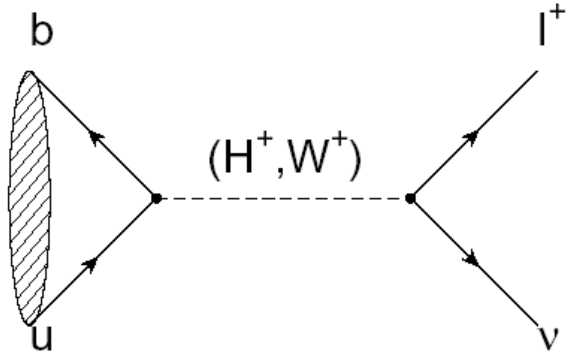
$B_{u,d,s}$ Physics

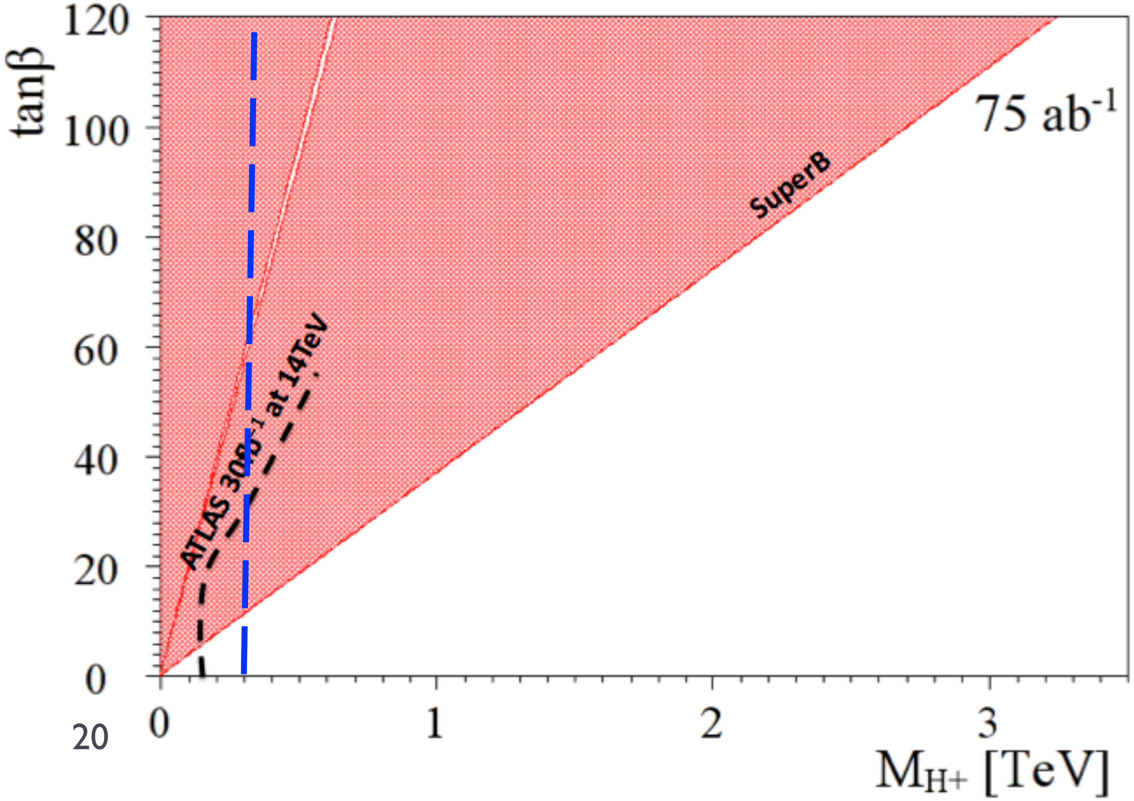
- The programme includes
  - Rare decays [This talk]
  - CKM angles and sides [This talk]
  - CPT

$B_{u,d}$ physics: Rare Decays

- Example: $B^{\pm} \rightarrow \ell^{\pm}\nu$
  - Rate modified by presence of H^{+}

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





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

Currently the inclusive b to sγ channel excludes $m_{H+} < 295$ GeV/c^2.

The current combined limit places a stronger constraint than direct searches from the LHC for the next few years.

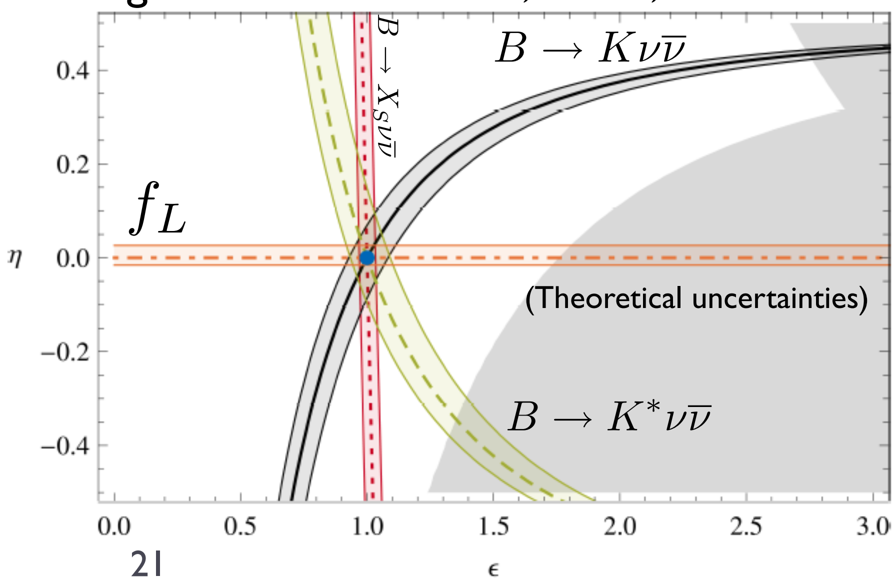
$B_{u,d}$ physics: Rare Decays

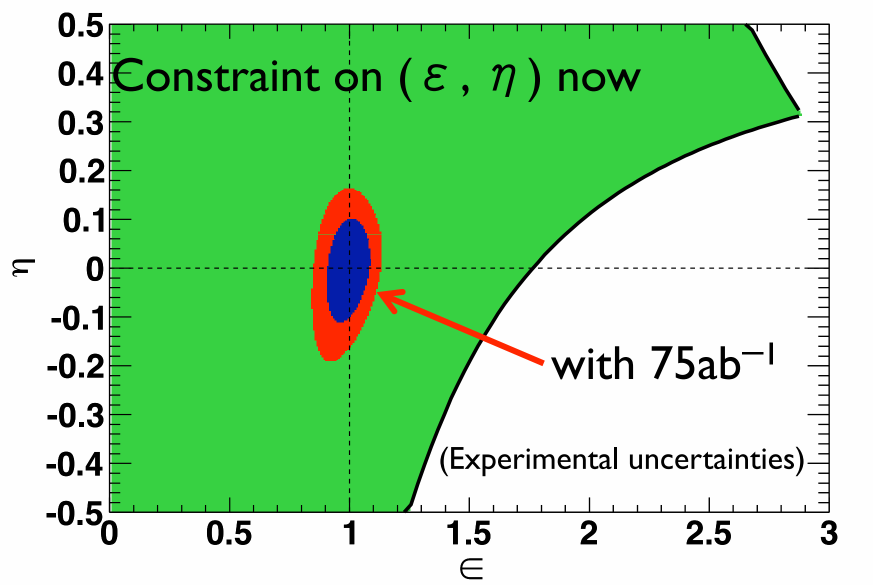
- Example: $B \to K^{(*)} \nu \bar{\nu}$
  - Need 75ab^{-1} to observe pseudoscalar and vector modes.
  - With more than 75ab^{-1} we could measure polarisation.

$$\epsilon = \frac{\sqrt{|C_L^\nu|^2 + |C_R^\nu|^2}}{|(C_L^\nu)^{\mathrm{SM}}|}, \qquad \eta = \frac{-\mathrm{Re}\,(C_L^\nu C_R^{\nu *})}{|C_L^\nu|^2 + |C_R^\nu|^2}$$

Sensitive to models with Z', RH currents and light scalar particles.

e.g. see Altmannshofer, Buras, & Straub





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

- SuperB can measure inclusive and exclusive modes:
  - Crosscheck results to understand source of NP.
  - Important as theory uncertainties differ.
  - Expect: 10-15,000 $K^*\mu\mu$ and 10-15,000 K^*ee events.

- SuperB can study all lepton flavours:
  - Equal amounts of μ and e final states can be measured.
    - Need both of these to measure all NP sensitive observables.
    - LHCb will accumulate slight more events in the $\mu\mu$ mode.
    - Expect superior statistics wrt LHCb for ee mode.
    - S/B~ 0.3, c.f. S/B~1.0 for LHCb.
  - Can also search for $K^{(*)}\tau^+\tau^-$ decay.
  - ... and constrain Majorana ν's using like sign final states.
    - Also of interest for D_s decays to $K^{(*)}ll$ final states near charm threshold.

TDCPV in B decays (i.e. CKM angles β & α)

- There are many redundant measurements of the CKM angles that are potential probes of NP.

Mode	Current Precision			Predicted Precision ($75\,\mathrm{ab}^{-1}$)			Discovery Potential	
	Stat.	Syst.	ΔS^f (Th.)	Stat.	Syst.	ΔS^f (Th.)	3σ	5σ
$J/\psi K^0_S$	0.022	0.010	0 ± 0.01	0.002	0.005	0 ± 0.001	0.02	0.03
$\eta' K^0_S$	0.08	0.02	0.015 ± 0.015	0.006	0.005	0.015 ± 0.015	0.05	0.08
$\phi K^0_S \pi^0$	0.28	0.01	–	0.020	0.010	–	–	–
$f_0 K^0_S$	0.18	0.04	0 ± 0.02	0.012	0.003	0 ± 0.02	0.07	0.12
$K^0_S K^0_S K^0_S$	0.19	0.03	0.02 ± 0.01	0.015	0.020	0.02 ± 0.01	0.08	0.14
ϕK^0_S	0.26	0.03	0.03 ± 0.02	0.020	0.005	0.03 ± 0.02	0.09	0.14
$\pi^0 K^0_S$	0.20	0.03	0.09 ± 0.07	0.015	0.015	0.09 ± 0.07	0.21	0.34
ωK^0_S	0.28	0.02	0.1 ± 0.1	0.020	0.005	0.1 ± 0.1	0.31	0.51
$K^+ K^- K^0_S$	0.08	0.03	0.05 ± 0.05	0.006	0.005	0.05 ± 0.05	0.15	0.26
$\pi^0 \pi^0 K^0_S$	0.71	0.08	–	0.038	0.045	–	–	–
ρK^0_S	0.28	0.07	-0.13 ± 0.16	0.020	0.017	-0.13 ± 0.16	0.41	0.69
$J/\psi \pi^0$	0.21	0.04	–	0.016	0.005			
$D^{*+} D^{*-}$	0.16	0.03	–	0.012	0.017			
$D^+ D^-$	0.36	0.05	–	0.027	0.008			

Current precision = BaBar to avoid having to worry about correlated errors in averages when performing extrapolations

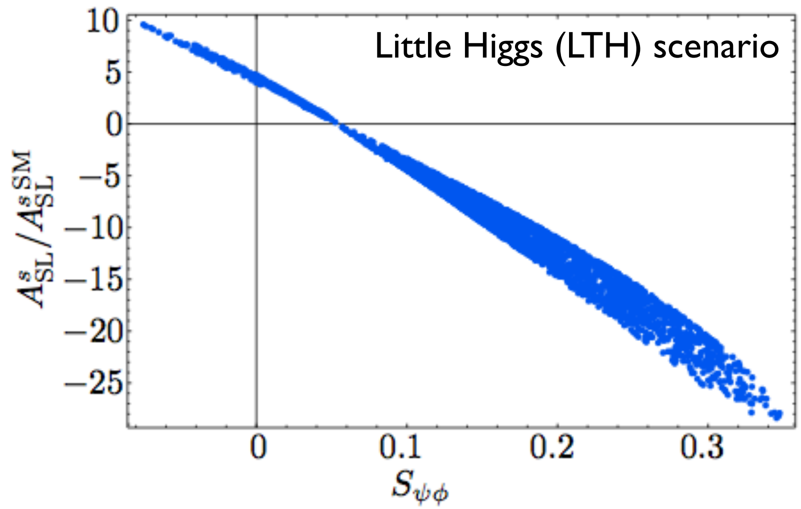
- Can also measure α using all modes: ππ, ρπ, ρρ, $a_1\pi$

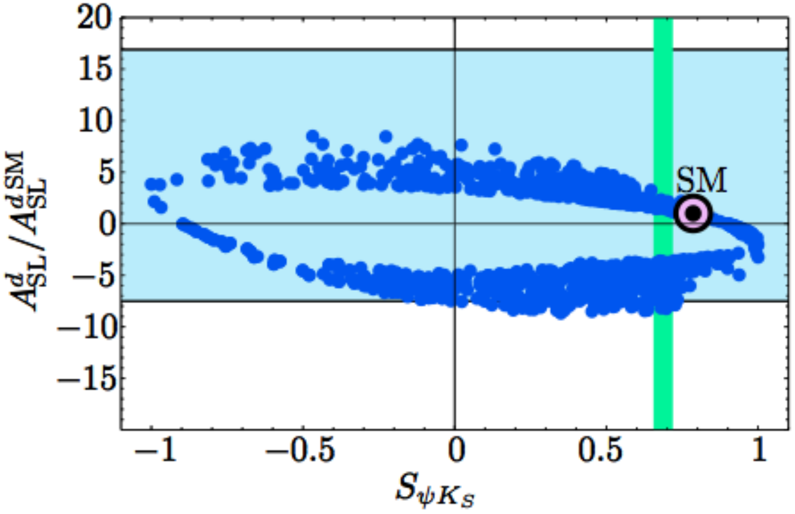
B_s physics

- Can cleanly measure A^s_{SL} using 5S data

$$A^s_{SL} = \frac{\mathcal{B}(B_s \to \overline{B}_s \to X^-\ell^+\nu_\ell) - \mathcal{B}(\overline{B}_s \to B_s \to X^-\ell^+\nu_\ell)}{\mathcal{B}(B_s \to \overline{B}_s \to X^-\ell^+\nu_\ell) + \mathcal{B}(\overline{B}_s \to B_s \to X^-\ell^+\nu_\ell)} = \frac{1-|q/p|^4}{1-|q/p|^4}$$

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





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

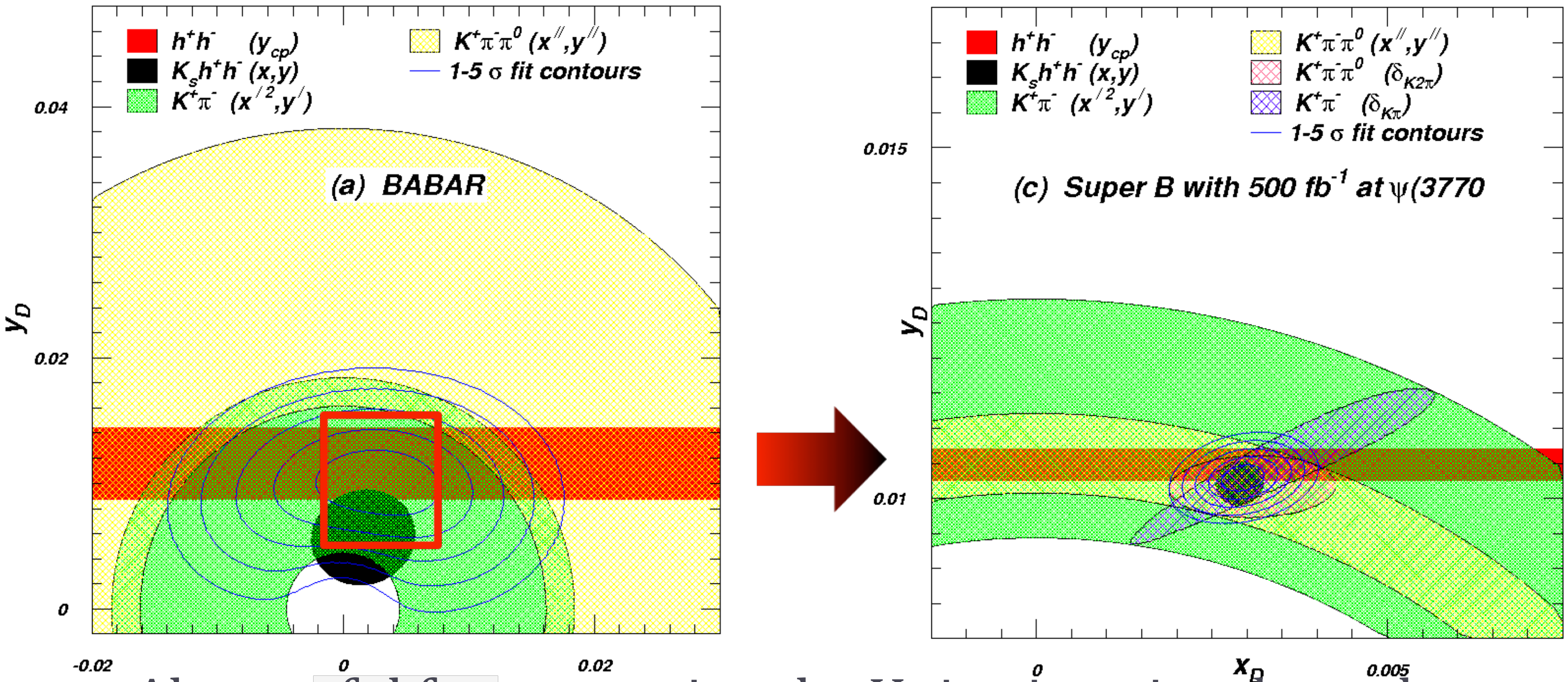
D Physics

- The programme includes
  - Mixing
  - CP Violation
  - Quantum Correlation based measurements
  - Rare decays

See the talks by AB, Brian, Matteo, Mike, Nicola for more details on the SuperB charm programme

Charm Mixing

- Collect data at threshold and at the 4S.
  - Benefit charm mixing and CPV measurements.

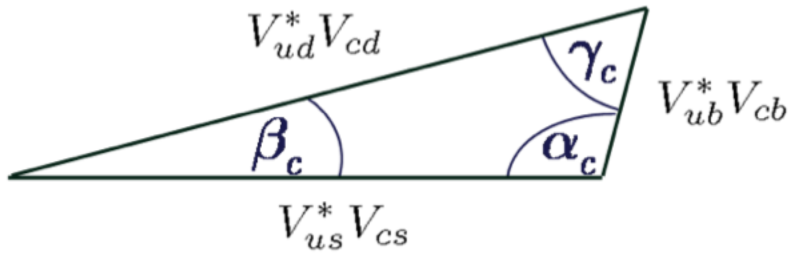


  - Also useful for measuring the Unitarity triangle angle γ (strong phase in D→Kππ Dalitz plot).

See the talk by Nicola Neri

The quest for the final angle of the CKM matrix: β_c

- The charm cu triangle has one unique element: β_c



$$V_{ud}^* V_{cd} + V_{us}^* V_{cs} + V_{ub}^* V_{cb} = 0$$

$$\begin{aligned}
\alpha_c &= \arg\left[-V_{ub}^* V_{cb}/V_{us}^* V_{cs}\right]. \\
\beta_c &= \arg\left[-V_{ud}^* V_{cd}/V_{us}^* V_{cs}\right], \\
\gamma_c &= \arg\left[-V_{ub}^* V_{cb}/V_{ud}^* V_{cd}\right],
\end{aligned}$$

$$\begin{aligned}
\alpha_c &= (111.5 \pm 4.2)^\circ \\
\beta_c &= (0.0350 \pm 0.0001)^\circ \\
\gamma_c &= (68.4 \pm 0.1)^\circ
\end{aligned}$$

- Precision measurement of mixing phase in many channels (<2°)
- Constrain $\beta_{c,eff}$ using a $D \to \pi\pi$ Isospin analysis
  - Search for NP and constrain $\beta_{c,eff} \sim 1°$.
  - Can only fully explore in an e^+e^- environment.
  - Data from the charm threshold region completes the set of 5 $|V_{ij}|$ to measure: needs SuperB to perform an indirect test of the triangle.

AB, Inguglia, Meadows, arXiv:1106.5075

See the talk by Brian Meadows

Charm Mixing: Summary

Strategy	Decay	$\sigma(\lvert q_D/p_D \rvert) \times 10^2$	$\sigma(\phi_M)^\circ$
HFAG (direct *CPV* allowed):			
Global χ^2 fit	<All modes>	± 18	± 9
Asymmetries a_z:			
x_D	<All modes>	± 1.8	–
y_D	<All modes>	± 1.1	–
y_{CP}	K^+K^-	± 3.8	–
y'	$K^+\pi^-$	± 4.9	–
x'^2	$K^+\pi^-$	± 4.9	–
x''	$K^+\pi^-\pi^0$	± 5.4	–
y''	$K^+\pi^-\pi^0$	± 5.0	–
TDDP (*CPV* allowed):			
Model-dependent	$K^0_S h^+ h^-$	± 8.4	± 3.3
BES III DP model	$K^0_S h^+ h^-$	± 3.7	± 1.9
Super*B* DP model	$K^0_S h^+ h^-$	± 2.7	± 1.4
SL Asymmetries a_{SL}:			
75 ab^{-1} at $\Upsilon(4S)$	$X\ell\nu_\ell$	± 10	
500 fb^{-1} at $\psi(3770)$	$K\pi$	± 10	
500 fb^{-1} at $\psi(3770)$	$X\ell\nu_\ell$	TBD	

- Can perform a precision measurement of charm mixing.
- TDCPV study of K^+K^- will provide a 1.3° measurement of the mixing phase (arXiv: 1109.4494).

Rare D Decays (some examples)

- Use 4S and ψ(3770) data to search for a number of important channels:

$D \to \gamma\gamma$

- Measure of the long distance contributions to the di-muon mode.

$$\mathcal{B}(D \to \mu^+\mu^-)_{LD} = 3.0 \times 10^{-5} \cdot \mathcal{B}(D^0 \to \gamma\gamma)$$

- Enables us to understand if μμ exhibits new physics or not.
- Expect to reach sensitivities $\sim 10^{-7}$.
- SM rate is $\sim 1 \times 10^{-8}$.
- Threshold running and D recoil techniques will play a role.

See arXiv:1008.1541

$D \to \nu\overline{\nu}(+\gamma)$

Work in progress

- Invisible final state is helicity suppressed in the SM.
- Sensitive to new scalar particles (e.g. Dark Matter etc).
- Experimentally need to use the D recoil technique to search for these states :
  - i.e. fully reconstruct one D meson, and search for the rare decay using whatever is left.
- two-neutrino final state will be hard, irreducible backgrounds going down the beam pipe).
- invisible+γ may be another story.

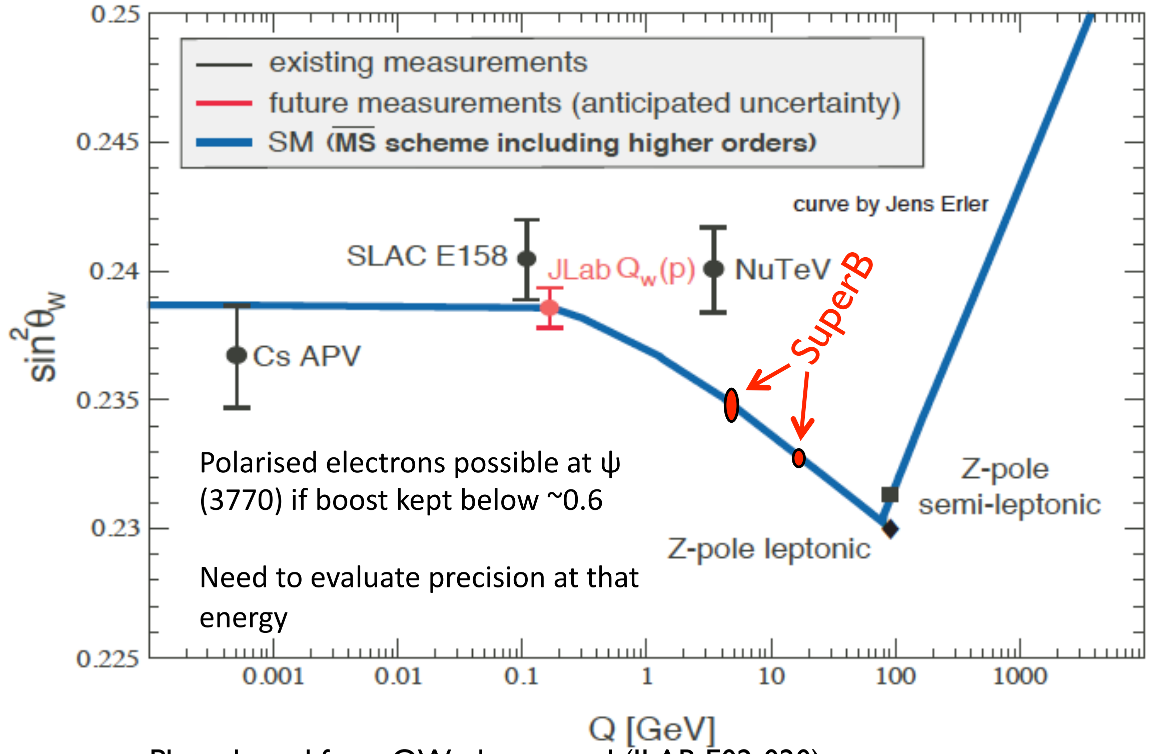
See PRD82:034005, 2010

See the talk by AB

Precision EW Physics

Precision Electroweak

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



Plot adapted from QWeak proposal (JLAB E02-020)

Measure LR asymmetry in

$$e^+e^- \to b\bar{b}$$
$$e^+e^- \to c\bar{c}$$
$$e^+e^- \to \tau^+\tau^-$$
$$e^+e^- \to \mu^+\mu^-$$

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

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

Spectroscopy

Spectroscopy

- Wide range of searches that can be made:
  - SM searches, and understanding the properties particles, e.g. of X, Y, Z (establishing quantum numbers and resolving issues in the field).
  - Searching for light scalar particles (Higgs and Dark Matter candidates).
  - Di-lepton and 4-lepton final states can be used to test:
    - lepton universality (c.f. NA62, many possible measurements in this area).
    - models of Dark Forces (few GeV scalar field in the dark sector).
  - Remember that BaBar's most cited paper is the discovery of the D_{sJ}.

Interplay

- Combine measurements to elucidate structure of new

	Observable/mode	H^+ high $\tan\beta$	MFV	non-MFV	NP Z penguins	Right-handed currents	LTH	SUSY AC	SUSY RVV2	SUSY AKM	SUSY δLL	SUSY FBMSSM
✓	$\tau \to \mu\gamma$							★★★	★★★	★	★★★	★★★
✓	$\tau \to \ell\ell\ell$						★★★					
✓	$B \to \tau\nu, \mu\nu$	★★★(CKM)										
✓	$B \to K^{(*)+}\nu\overline{\nu}$			★	★★★			★	★	★	★	★
✓	S in $B \to K_S^0\pi^0\gamma$					★★★						
✓	S in other penguin modes			★★★(CKM)		★★★		★★★	★★	★	★★★	★★★
✓	$A_{CP}(B \to X_s\gamma)$			★★★		★★		★	★	★	★★★	★★★
✓	$BR(B \to X_s\gamma)$		★★★	★		★						
✓	$BR(B \to X_s\ell\ell)$			★	★	★						
✓	$B \to K^{(*)}\ell\ell$ (FB Asym)							★	★	★	★★★	★★★
	$B_s \to \mu\mu$							★★★	★★★	★★★	★★★	★★★
	β_s from $B_s \to J/\psi\phi$							★★★	★★★	★★★	★	★
✓	a_{sl}						★★★					
✓	Charm mixing							★★★	★	★	★	★
✓	CPV in Charm	★★									★★★	

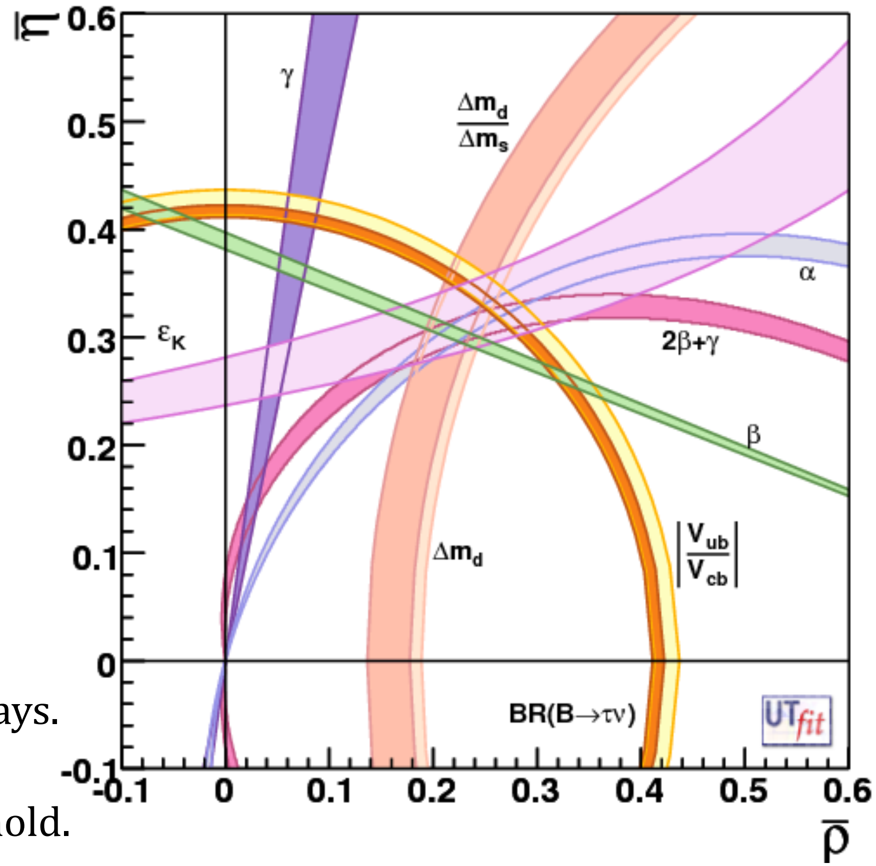
✓= SuperB can measure this

More information on the golden matrix can be found in arXiv:1008.1541, arXiv:0909.1333, and arXiv:0810.1312.

Precision CKM constraints

- Unitarity Triangle Angles
  - $\sigma(\alpha) = 1\text{–}2°$
  - $\sigma(\beta) = 0.1°$
  - $\sigma(\gamma) = 1\text{–}2°$
- CKM Matrix Elements
  - $|V_{ub}|$
    - Inclusive $\sigma = 2\%$
    - Exclusive $\sigma = 3\%$
  - $|V_{cb}|$
    - Inclusive $\sigma = 1\%$
    - Exclusive $\sigma = 1\%$
  - $|V_{us}|$
    - Can be measured precisely using τ decays.
  - $|V_{cd}|$ and $|V_{cs}|$
    - can be measured at/near charm threshold.

The "dream" scenario with 75ab-1



- SuperB Measures the sides and angles of the Unitarity Triangle.

Golden Measurements: General

	Red	Yellow	Blue	Green
Experiment:	No Result	Moderately precise	Precise	Very precise
Theory:		Moderately clean	Clean, needs Lattice	Clean

Observable/mode Luminosity	Current $\sim 1\,\mathrm{fb}^{-1}$	LHCb (2017) $5\,\mathrm{fb}^{-1}$	Super*B* (2022) $75\,\mathrm{ab}^{-1}$	LHCb upgrade $50\,\mathrm{fb}^{-1}$	Theory	
τ Decays						
$\tau \to \mu\gamma$	Yellow	Yellow	Green	Yellow	Green	Benefit from polarised e⁻ beam
$\tau \to e\gamma$	Yellow	Yellow	Green	Yellow	Green	
$B_{u,d}$ Decays						
$B \to \tau\nu, \mu\nu$	Yellow	Red	Blue	Red	Blue	very precise with improved detector
$B \to K^{(*)+}\nu\overline{\nu}$	Red	Red	Green	Red	Green	Statistically limited: Angular analysis with >75ab^{-1}
S in $B \to K^0_S\pi^0\gamma$	Yellow	Red	Green	Red	Yellow	Right handed currents
S (other penguin modes)	Yellow	Yellow	Green	Blue	Yellow	SuperB measures many more modes
A_{CP} $(B \to X_s\gamma)$	Blue	Yellow	Green	Yellow	Green	systematic error is main challenge
BR$(B \to X_s\gamma)$	Blue	Yellow	Green	Yellow	Yellow	control systematic error with data
BR$(B \to X_s ll)$	Yellow	Red	Green	Red	Green	
BR$(B \to K^{(*)} ll)$	Yellow	Blue	Green	Green	Yellow	SuperB measures e mode well, LHCb does μ
B_s Decays						
$B_s \to \mu\mu$	Red	Blue	Red	Green	Green	
β_S from $B_s \to J/\psi\,\phi$	Red	Blue	Red	Green	Green	
$B_s \to \gamma\gamma$	Red	Red	Blue	Red	Green	
a_{sl}	Red	Blue	Green	Green	Green	
D Decays						
Mixing parameters	Yellow	Blue	Green	Green	Green	
CP Violation	Red	Blue	Green	Green	Green	Clean NP search
Precision Electroweak						
$\sin^2\theta_W$ at $\Upsilon(4S)$	Red	Red	Green	Red	Green	Theoretically clean
$\sin^2\theta_W$ at Z-Pole	Red	Blue	Red	Green	Yellow	b fragmentation limits interpretation

Golden Measurements: CKM

- Comparison of relative benefits of SuperB ($75ab^{-1}$) vs. existing measurements and LHCb ($5fb^{-1}$) and the LHCb upgrade ($50fb^{-1}$).

Observable/mode Luminosity	Current $\sim 1\,\mathrm{fb}^{-1}$	LHCb (2017) $5\,\mathrm{fb}^{-1}$	Super$B$ (2022) $75\,\mathrm{ab}^{-1}$	LHCb upgrade $50\,\mathrm{fb}^{-1}$	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 $\rho\pi$

β theory error B_d
β theory error B_s

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

Experiment:	No Result	Moderately precise	Precise	Very precise
Theory:		Moderately clean	Clean, needs Lattice	Clean

Observable/mode	Current now	LHCb (2017) 5 fb^{-1}	Super$B$ (2021) 75 ab^{-1}	Belle II (2021) 50 ab^{-1}	LHCb upgrade (10 years of running) 50 fb^{-1}	theory now
			τ Decays			
$\tau \to \mu\gamma$ ($\times 10^{-9}$)	< 44		< 2.4	< 5.0		
$\tau \to e\gamma$ ($\times 10^{-9}$)	< 33		< 3.0	< 3.7 (est.)		
$\tau \to \ell\ell\ell$ ($\times 10^{-10}$)	$< 150 - 270$	< 244 [a]	$< 2.3 - 8.2$	< 10	< 24 [b]	
			$B_{u,d}$ Decays			
$\mathrm{BR}(B \to \tau\nu)$ ($\times 10^{-4}$)	1.64 ± 0.34		0.05	0.04		1.1 ± 0.2
$\mathrm{BR}(B \to \mu\nu)$ ($\times 10^{-6}$)	< 1.0		0.02	0.03		0.47 ± 0.08
$\mathrm{BR}(B \to K^{*+}\nu\bar{\nu})$ ($\times 10^{-6}$)	< 80		1.1	2.0		6.8 ± 1.1
$\mathrm{BR}(B \to K^{+}\nu\bar{\nu})$ ($\times 10^{-6}$)	< 160		0.7	1.6		3.6 ± 0.5
$\mathrm{BR}(B \to X_s\gamma)$ ($\times 10^{-4}$)	3.55 ± 0.26		0.11	0.13	0.23	3.15 ± 0.23
$A_{CP}(B \to X_{(s+d)}\gamma)$	0.060 ± 0.060		0.02	0.02		$\sim 10^{-6}$
$B \to K^*\mu^+\mu^-$ (events)	250[c]	8000	10-15k[d]	7-10k	100,000	-
$\mathrm{BR}(B \to K^*\mu^+\mu^-)$ ($\times 10^{-6}$)	1.15 ± 0.16		0.06	0.07		1.19 ± 0.39
$B \to K^*e^+e^-$ (events)	165	400	10-15k	7-10k	5,000	-
$\mathrm{BR}(B \to K^*e^+e^-)$ ($\times 10^{-6}$)	1.09 ± 0.17		0.05	0.07		1.19 ± 0.39
$A_{FB}(B \to K^*\ell^+\ell^-)$	0.27 ± 0.14[e]	[f]	0.040	0.03		-0.089 ± 0.020
$B \to X_s\ell^+\ell^-$ (events)	280		8,600	7,000		-
$\mathrm{BR}(B \to X_s\ell^+\ell^-)$ ($\times 10^{-6}$)[g]	3.66 ± 0.77[h]		0.08	0.10		1.59 ± 0.11
S in $B \to K^0_S\pi^0\gamma$	-0.15 ± 0.20		0.03	0.03		-0.1 to 0.1
S in $B \to \eta' K^0$	0.59 ± 0.07		0.01	0.02		± 0.015
S in $B \to \phi K^0$	0.56 ± 0.17	0.15	0.02	0.03	0.03	± 0.02
			B^0_s Decays			
$\mathrm{BR}(B^0_s \to \gamma\gamma)$ ($\times 10^{-6}$)	< 8.7		0.3	$0.2 - 0.3$		0.4 - 1.0
A^s_{SL} ($\times 10^{-3}$)	-7.87 ± 1.96 [i]	[j]	4.	5. (est.)		0.02 ± 0.01
			D Decays			
x	$(0.63 \pm 0.20\%$	0.06%	0.02%	0.04%	0.02%	$\sim 10^{-2}$ [k]
y	$(0.75 \pm 0.12)\%$	0.03%	0.01%	0.03%	0.01%	$\sim 10^{-2}$ (see above).
y_{CP}	$(1.11 \pm 0.22)\%$	0.02%	0.03%	0.05%	0.01%	$\sim 10^{-2}$ (see above).
$\lvert q/p \rvert$	$(0.91 \pm 0.17)\%$	8.5%	2.7%	3.0%	3%	$\sim 10^{-3}$ (see above).
$\arg\{q/p\}$ ($^\circ$)	-10.2 ± 9.2	4.4	1.4	1.4	2.0	$\sim 10^{-3}$ (see above).
			Other processes Decays			
$\sin^2\theta_W$ at $\sqrt{s} = 10.58\,\mathrm{GeV}/c^2$			0.0002	[l]		clean

Observable/mode	Current now	LHCb (2017) 5 fb^{-1}	Super$B$ (2021) 75 ab^{-1}	Belle II (2021) 50 ab^{-1}	LHCb upgrade (10 years of running) 50 fb^{-1}	theory now
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BR($B \to X_s\gamma$) ($\times 10^{-4}$)	3.55 ± 0.26		0.11	[illegible]	0.23	3.15 ± 0.23
$A_{CP}(B \to X_{(s+d)}\gamma)$	0.060 ± 0.060		0.02	[illegible]		$\sim 10^{-6}$
$B \to K^*\mu^+\mu^-$ (events)	250[c]	8000	[illegible]	[illegible]	100,000	-
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$B \to X_s\ell^+\ell^-$ (events)	28[illegible]		8,600	7,000		-
BR($B \to X_s\ell^+\ell^-$) ($\times 10^{-6}$)[g]	3.66 ± 0[illegible]		0.08	0.10		1.59 ± 0.11
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			Other processes Decays			
$\sin^2\theta_W$ at $\sqrt{s} = 10.58$ GeV/c^2			0.0002	[l]		clean

+ A number of charm decay analogues under investigation

Observable/mode	Current now	LHCb (2017)	Super$B$ (2021)	Belle II (2021)	LHCb upgrade (10 years of running)	theory now
		$5\,\mathrm{fb}^{-1}$	$75\,\mathrm{ab}^{-1}$	$50\,\mathrm{ab}^{-1}$	$50\,\mathrm{fb}^{-1}$	
α from $u\bar{u}d$	6.1°	$5^{\circ\,a}$	1°	1°	^{b}	$1-2^\circ$
β from $c\bar{c}s$ (S)	0.8° (0.020)	0.5° (0.008)	0.1° (0.002)	0.3° (0.007)	0.2° (0.003)	clean
S from $B_d \to J/\psi\pi^0$	0.21		0.014	0.021 (est.)		clean
S from $B_s \to J/\psi K^0_S$		?			?	clean
γ from $B \to DK$	11°	$\sim 4^\circ$	1°	1.5°	0.9°	clean
$\|V_{cb}\|$ (inclusive) %	1.7		0.5%	0.6 (est.)		dominant
$\|V_{cb}\|$ (exclusive) %	2.2		1.0%	1.2 (est.)		dominant
$\|V_{ub}\|$ (inclusive) %	4.4		2.0%	3.0		dominant
$\|V_{ub}\|$ (exclusive) %	7.0		3.0%	5.0		dominant

- With the exceptions of y_{CP} and K*μμ, there are no planned or existing experiments that will surpass SuperB precision in these modes for at least the next two decades.
- The best place to measure the other 33 golden modes is SuperB!

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		$5\,\mathrm{fb}^{-1}$	$75\,\mathrm{ab}^{-1}$	$50\,\mathrm{ab}^{-1}$	$50\,\mathrm{fb}^{-1}$	
α from $u\bar{u}d$	6.1°	$5^{\circ\,a}$	1°	1°	^{b}	$1-2^\circ$
β from $c\bar{c}s$ (S)	0.8° (				0.2° (0.003)	clean
S from $B_d \to J/\psi\pi^0$	0					clean
S from $B_s \to J/\psi K_S^0$					?	clean
γ from $B \to DK$	1				0.9°	clean
$\lvert V_{cb}\rvert$ (inclusive) %	1					dominant
$\lvert V_{cb}\rvert$ (exclusive) %	2					dominant
$\lvert V_{ub}\rvert$ (inclusive) %	4					dominant
$\lvert V_{ub}\rvert$ (exclusive) %	7					dominant

Of course, this summary is based on what we will be able to measure and is an important part of the bigger picture.

Globally the community has a strong flavour physics programme and many other inputs will help in elucidating the detailed nature of new physics.

- With the exceptions of y_{CP} and K*μμ, there are no planned or existing experiments that will surpass SuperB precision in these modes for at least the next two decades.
- The best place to measure the other 33 golden modes is SuperB!

Physics programme in a nutshell

- Versatile flavour physics experiment:
  - Probe new physics observables in wide range of decays.
    - Pattern of deviation from Standard Model can be used to identify structure of new physics.
    - Clean experimental environment means clean signals in many modes.
    - Polarised e^{-} beam benefit for τ LFV searches **(unique feature)**.
    - Charm threshold running adds many more observables, and improves potential of SuperB **(unique feature)**.
    - Measure angles and sides of the Unitarity triangle.
    - Measure other CKM matrix elements at threshold and using τ data.

- SuperB is working on a TDR for 2012.

- Will be followed by a physics book some time later.
  - Plenty of open areas for newcomers to work on!