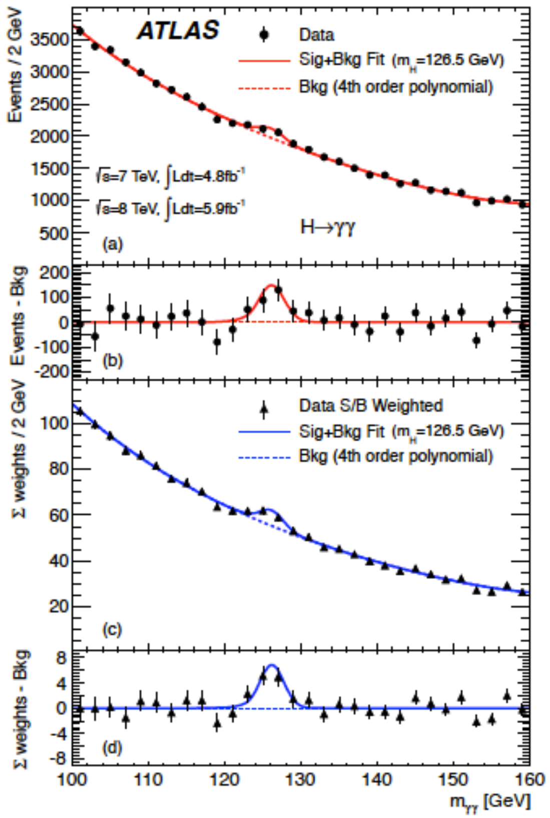
Physics Progress and Plans

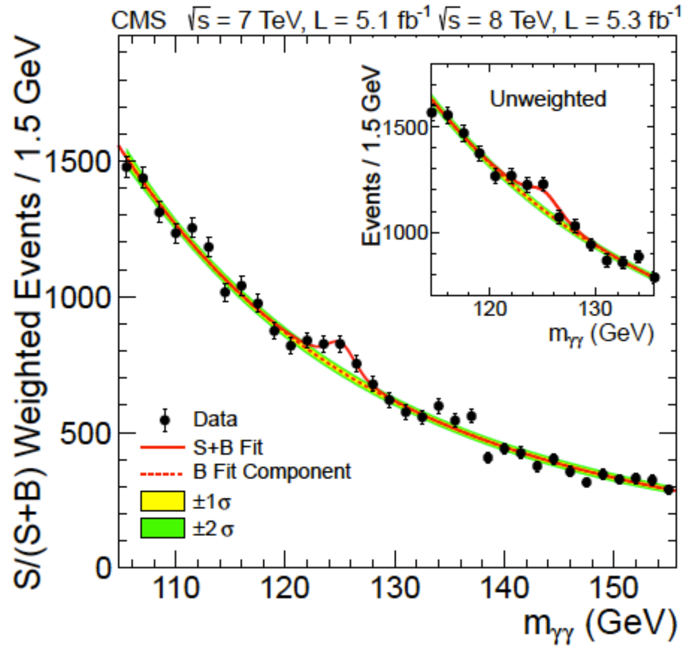
Adrian Bevan

Overview:
- Summary of European Strategy Group contribution.
- Planning for the December workshop
- Updating sensitivity comparisons

Higgs like boson discovered at CERN

- We should revisit old studies to see what we can learn about the Higgs:
  - We know it is relevant to NP dynamics in $B \to K^* \ell\ell$ decays
  - The Higgs mass pins down the EW sector pretty well (much better than the LEP plot): $\sin^2\theta_W$ is now a NP search parameter.





arXiv:1207.7214,
arXiv:1207.7235

m_H ~125-126 GeV/c^2

ESG Contribution

- A number of people helped prepare a brief summary of the programme:

Super*B* Physics Programme

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(Dated: July 30, 2012)

On the behalf of the Super*B* Collaboration

- Brian Meadows also contributed to this, but is acknowledged by his request so as not to interfere with his sabbatical this year.

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On the behalf of the SuperB Collaboration

Many thanks for help from the contributors and comments from the community!

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Future prospects

"Minimalistic" list of the key (low-energy) quark flavor-violating observables:

✔	γ from tree ($B \to DK, \ldots$)	S-LHCb S-Bfactory
✔	$\lvert V_{ub} \rvert$ from exclusive semi-leptonic B decays	S-Bfactory [SuperKEKB & SuperB]
	$B_{s,d} \to l^+l^-$	S-LHCb + ATLAS & CMS
	CPV in B_s mix. [ϕ_s]	S-LHCb + ATLAS & CMS
✔	$B \to K^{(*)}\, l^+l^-, \nu\nu$	S-LHCb / S-Bfactory
✔	$B \to \tau\nu, \mu\nu$ (+D)	S-Bfactory
	$K \to \pi\nu\nu$	Kaon beams [NA62, KOTO, ORKA]
✔	CPV in charm	S-LHCb / S-Bfactory

Future prospects

"Minimalistic" list of the key (low-energy) quark flavor-violating observables:

✔ • γ fr

✔ • $|V_{ub}$ … & SuperB]

• $B_{s,d}$

• CPV

✔ • B →

✔ • B →

• $K \rightarrow \pi\nu\nu$ Kaon beams [NA62, KOTO, ORKA]

✔ • CPV in charm S-LHCb / S-Bfactory

My interpretation:

Complementarity between hadron, e+e- and kaon experiments.

To cover all eventualities, we need all areas supported.

Additional material

Top-10 list of key flavor-changing measurements [a (motivated) personal choice]

	• $B(\mu \to e\gamma)$	SES $< 10^{-13}$
	• $B(\mu N \to eN)$	SES $< 10^{-16}$
✔	• $B(\tau \to \mu\gamma)$	SES $< 10^{-9}$
	• $B(B_s \to \mu^+\mu^-)$	$\sigma_{rel} < 5\%$
	• ϕ_s	$\sigma < 0.01$
	• $B(K^+ \to \pi^+\nu\nu)$ or $B(K_L \to \pi^0\nu\nu)$	$\sigma_{rel} < 5\%$
✔	• $B(B^+ \to l^+\nu)$	$\sigma_{rel} < 5\%$
✔	• $a_{CP}(D \to \pi\pi\gamma)$	$\sigma < 0.005$
✔	• $\lvert V_{ub} \rvert$	$\sigma_{rel} < 5\%$
✔	• γ_{CKM}	$\sigma < 1^o$

N.B.: the observables are not listed in order of importance

THE FLAVOUR PROBLEMS

FERMION MASSES

What is the rationale hiding behind the spectrum of fermion masses and mixing angles (our "**Balmer lines**" problem)

→ **LACK OF A FLAVOUR "THEORY"**

(new flavour – horizontal symmetry, radiatively induced lighter fermion masses, dynamical or geometrical determination of the Yukawa couplings, …?)

FCNC

Flavour changing neutral current (FCNC) processes are suppressed.

In the SM two nice mechanisms are at work: the **GIM mechanism** and the structure of the **CKM mixing matrix.**

How to cope with such delicate suppression if the there is new physics at the electroweak scale?

From a closer look

From the UTA (excluding its exp. constraint) → Prediction

	Prediction	Measurement	Pull
$\sin 2\beta$	0.81±0.05	0.680±0.023	2.4 ←
γ	68°±3°	76°±11°	<1
α	88°±4°	91°±6°	<1
$\lvert V_{cb}\rvert \cdot 10^3$	42.3±0.9	41.0±1.0	<1
$\lvert V_{ub}\rvert \cdot 10^3$	3.62±0.14	3.82±0.56	<1
$\varepsilon_K \cdot 10^3$	1.96±0.20	2.23±0.01	1.4 ←
$BR(B\to \tau \nu)\cdot 10^4$	0.82±0.08	1.67±0.30	-2.7 ←

TARANTINO 2012

Which are the sources of flavor symmetry breaking accessible at low energies?

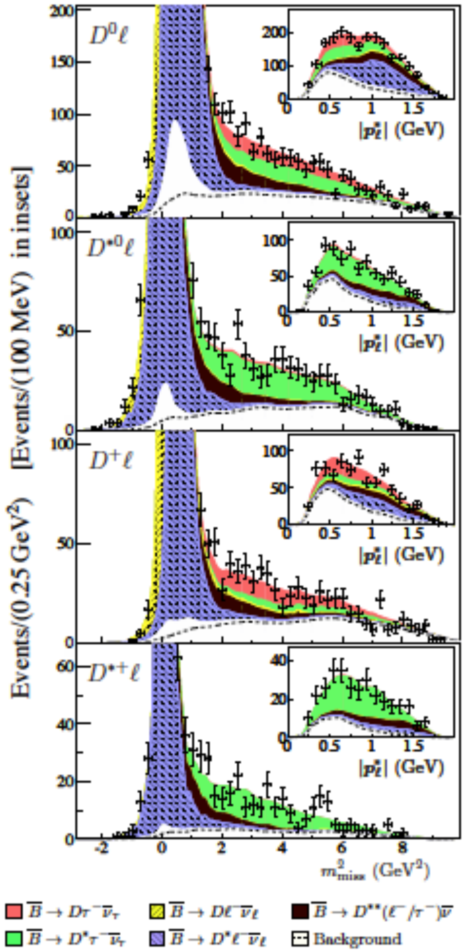
$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM+v}} + \frac{c_{NP}}{\Lambda^2} O_{ij}^{(6)}$$

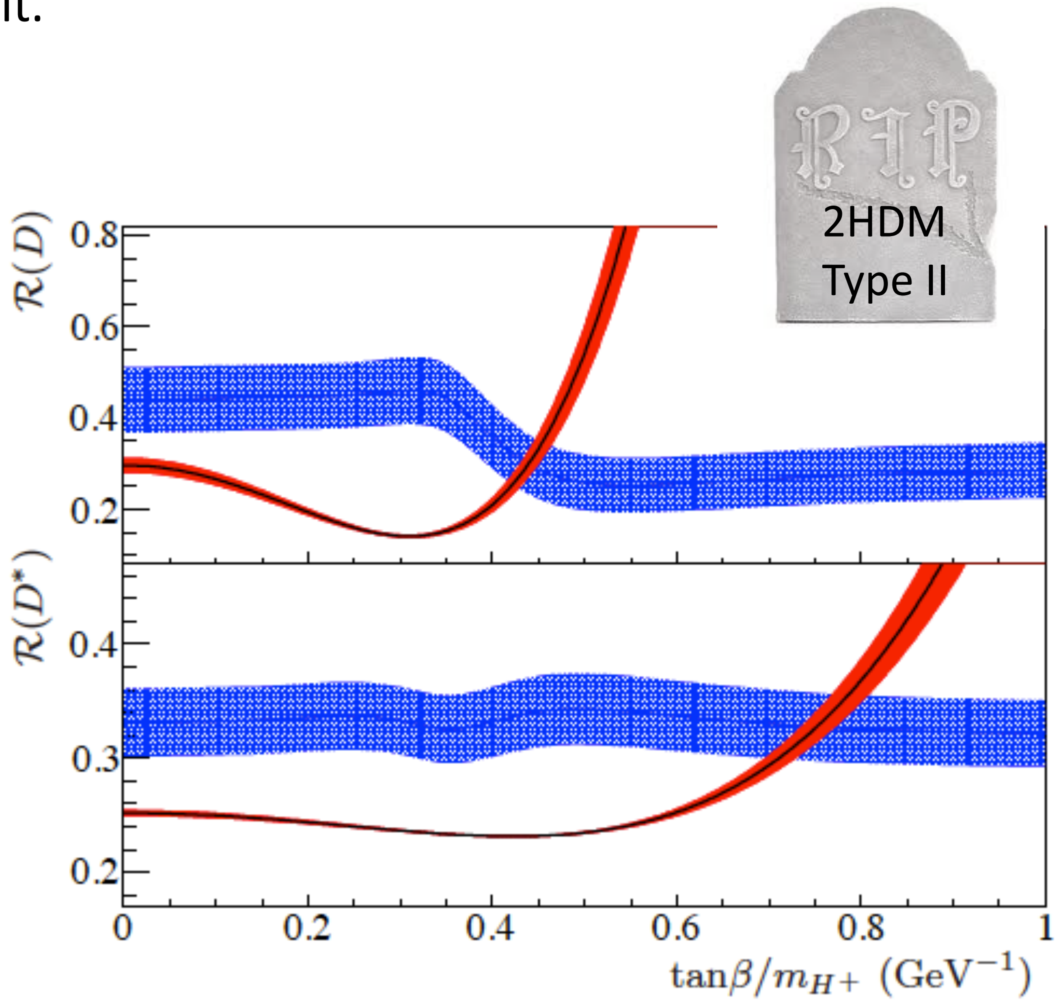
Operator	Bounds on Λ in TeV ($c_{NP}=1$) Re	Bounds on Λ in TeV ($c_{NP}=1$) Im	Bounds on c_{NP} ($\Lambda = 1$ TeV) Re	Bounds on c_{NP} ($\Lambda = 1$ TeV) Im	Observables
$(\bar{s}_L\gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ϵ_K
$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	Δm_K; ϵ_K
$(\bar{c}_L\gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\|q/p\|, \phi_D$
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	Δm_D; $\|q/p\|, \phi_D$
$(\bar{b}_L\gamma^\mu d_L)^2$	6.6×10^2	9.3×10^2	2.3×10^{-6}	1.1×10^{-6}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$	2.5×10^3	3.6×10^3	3.9×10^{-7}	1.9×10^{-7}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_L\gamma^\mu s_L)^2$	1.4×10^2	2.5×10^2	5.0×10^{-5}	1.7×10^{-5}	Δm_{B_s}; $S_{\psi\phi}$
$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	4.8×10^2	8.3×10^2	8.8×10^{-6}	2.9×10^{-6}	Δm_{B_s}; $S_{\psi\phi}$

New flavor-breaking sources at the TeV scale (if any) are highly tuned arXiv:1205.5442 (BaBar)

B→D*τν

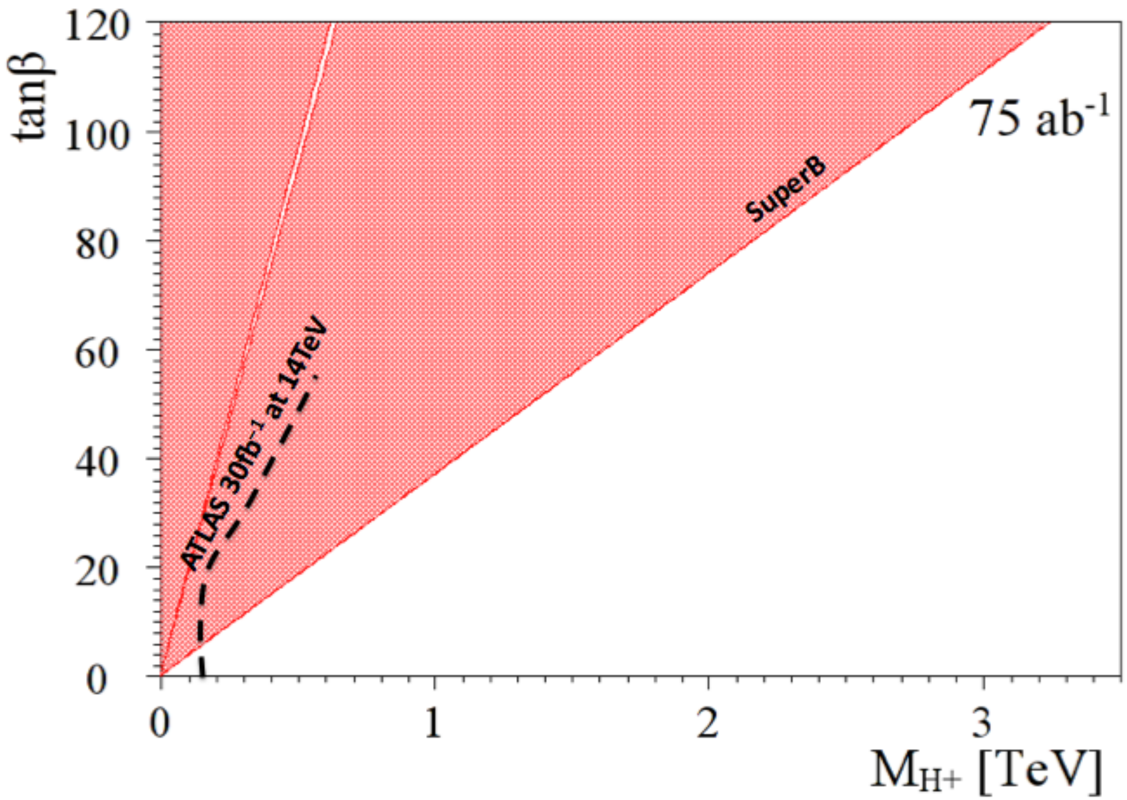
- Measure a ratio of modes to reduce theoretical dependence of constraint.
- 2D fit, using E_{extra} in an MVA that has a loose cut on it to minimise systematic impact on result.





B→τν, μν

- Belle and BaBar updated τν results at ICHEP.
  - Belle consistent with SM
  - BaBar is not...



Longer term issue:

Are we using the most experimentally robust ways to measure this branching fraction?

Will E_{extra} ultimately limit our ability to do the measurement?

c.f. the D*τν result from BaBar.

T Violation

- Wouldn't it be nice to actually test T violation using T-conjugate pairs?

- Would be possible to compare CP violation with CPT tests to close the loop on testing T, CP and CPT.

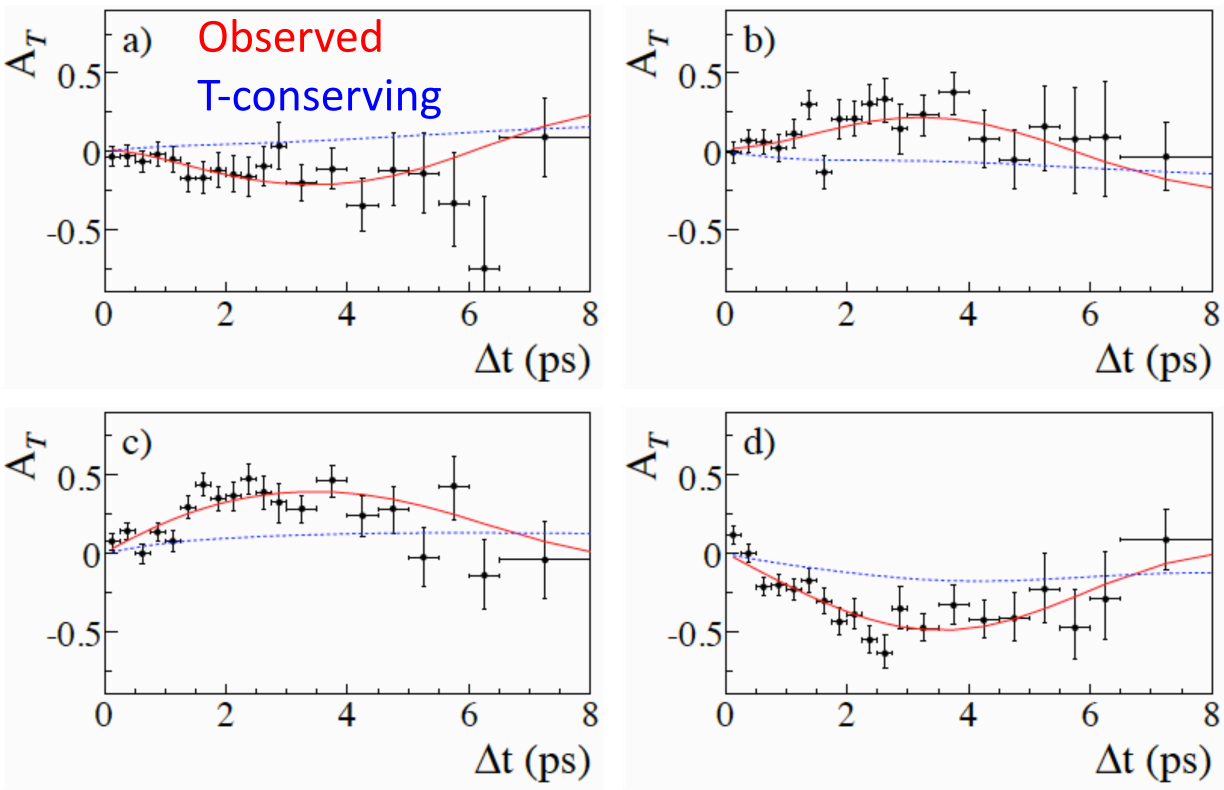
- Need to identify T conjugate pairs of decays to construct:

$$|A\rangle \rightarrow |B\rangle$$

$$|B\rangle \rightarrow |A\rangle$$

T Violation

- BaBar showed results at FPCP



Compatible with sin2β results on CPV and with CPT

- 14σ significance for this result: SuperB should confirm this measurement with high precision.
  - Part of our symmetry testing programme.

DIRECT CPV IN $D^0 \rightarrow \pi^+\pi^-, K^+K^-$

2011: LHCb, 620 pb^{-1} first evidence (3.5 σ) of CPV in charm

$$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = (-0.82 \pm 0.21 \pm 0.11)\%$$

2012: fom CDF, 9.6 fb^{-1}, + LHCb + BELLE

$$\Delta A_{CP} \equiv A_{CP}\left(K^+K^-\right) - A_{CP}\left(\pi^+\pi^-\right) = \left(-0.74 \pm 0.15\right)\%$$

This result demands an enhancement of the suppressed CKM amplitudes of the SM of a factor approx. 5 – 10 Isidori, Kamenik, Ligeti, Perez 2011

But the charm quark is ***TOO HEAVY*** to apply the ChPT, while, at the same time, it is ***TOO LIGHT*** to trust the Heavy Quark Effective approach : ***HENCE IT IS NOT IMPOSSIBLE THAT THE SM IS ONCE AGAIN FINDING A WAYOUT TO SURVIVE!*** Golden, Grinstein 1989; Brod, Kagan, Zupan 2011

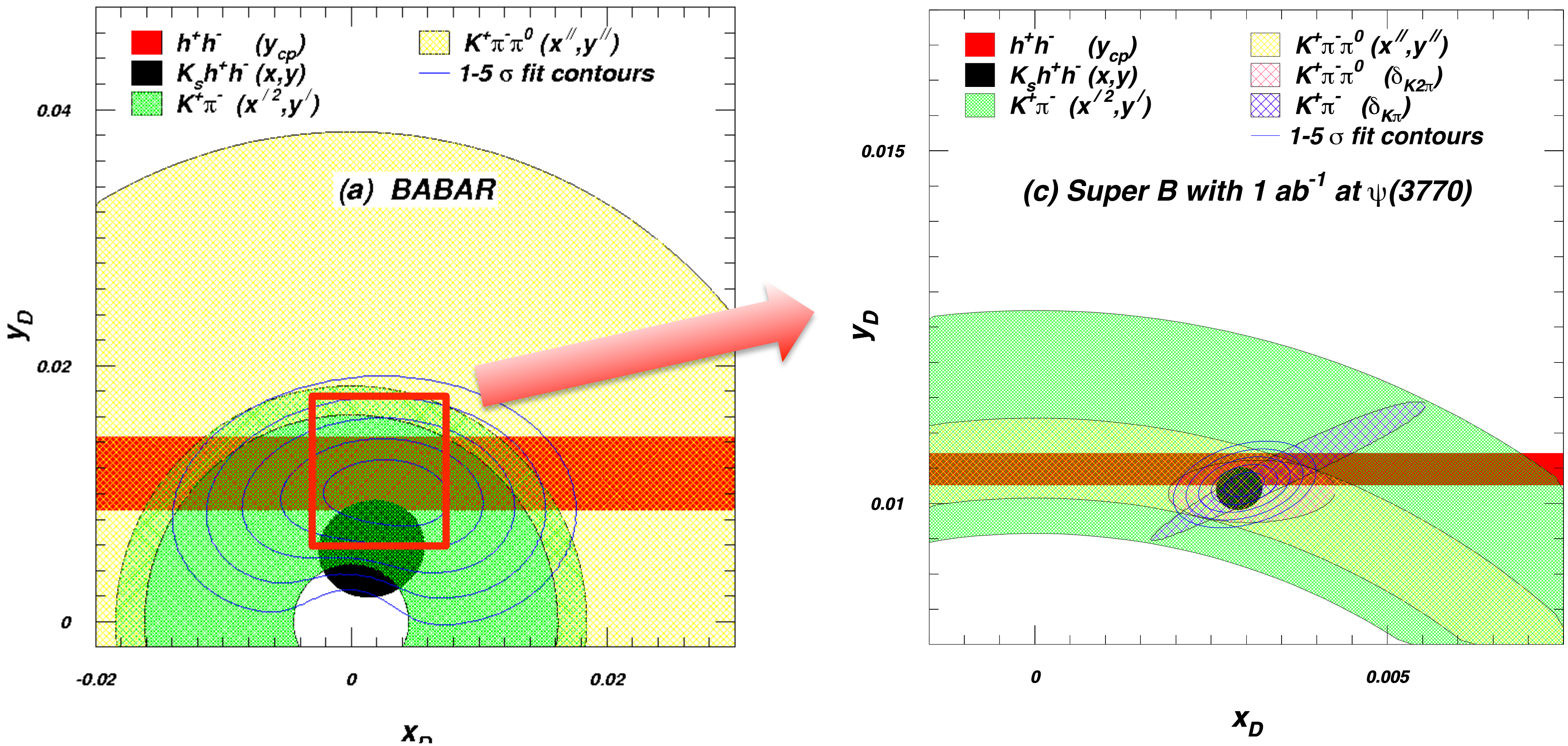
ON THE OTHER IT REMAINS POSSIBLE THAT NEW PHYSICS IS SHOWING UP... Giudice, Isidori, Paradisi 2012; Barbieri, Buttazzo, Sala e Straub 2012

POSSIBLE SURPRISES FROM THE KAON TOO → NA62 ?

- Ikaros Bigi has told us many times that we need to test CP violation in the up-quark sector.
  - LHCb have paved the way with a deviation from expectation ($D^0 \rightarrow KK/\pi\pi$).
  - Belle also see a CP effect ($D^+ \rightarrow K_S pi^+$).
  - These are direct CPV measurements. "*Binary test of the SM*"
- The experimental community is slowly coming round to the fact that hadronic uncertainties are important.
- We need to:
  - Do time-dependent measurements (indirect CPV is clean[ish])
  - Measure sets of channels to constrain hadronic uncertainties.
  - e.g. a long list of things to do here: $D^0 \rightarrow \pi^+\pi^0$, ...

Charm Mixing Update

- Now assume $1ab^{-1}$ at ψ(3770).



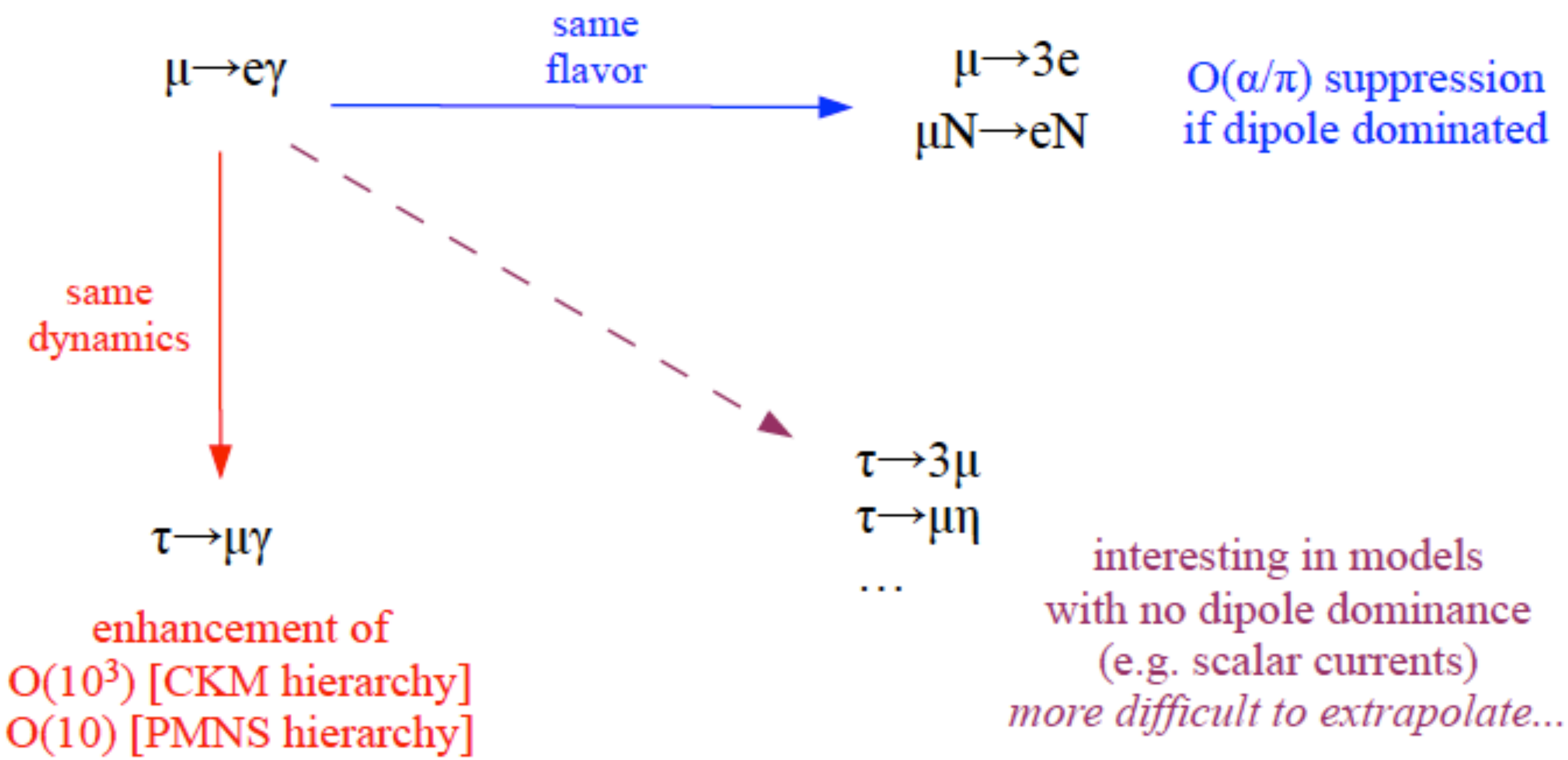
- Updated plots now available in the TDR.
- $K_S$hh Dalitz plot contribution helps shrink overall syst. error

Other charm physics of interest

- Many rare decays to explore:
  - Pretty good idea of how well we can measure a number of final states.
  - Need to look at multi-body states (i.e. amplitude analyses).
    - 3 body modes should be explored in general: probably current configurations are good enough.
    - 4 body states are a concern:
      - We expect that at charm threshold these will be problematic to reconstruct (based on discussion with CLEO-c and BES III collaborators).
      - Their solution was: 1T magnetic field, and remove detector X_0 at the centre of the detector.
      - Should be studied for the physics book.

* The key role of LFV and EDMs

The recent MEG bound, $BR(\mu\to e\gamma) < 2.4\times10^{-12}$, and its final sensitivity ($\sim10^{-13}$), can be taken as reference values to estimate potentially interesting levels for future LFV searches in different channels:



⋆ *The key role of LFV and EDMs*

The recent MEG bound, $BR(\mu\to e\gamma) < 2.4\times10^{-12}$, and its final sensitivity ($\sim10^{-13}$), can be taken as reference values to estimate potentially interesting levels for future LFV searches in different channels:

$\mu\to e\gamma$: $< 2\times10^{-12}$

→ same flavor → $\mu\to 3e$, $\mu N\to eN$: $\lesssim 10^{-14}$ — $O(\alpha/\pi)$ suppression if dipole dominated

↓ same dynamics ↓ $\tau\to\mu\gamma$: $\lesssim 4\times10^{-9}$

enhancement of
$O(10^3)$ [CKM hierarchy]
$O(10)$ [PMNS hierarchy]

Key observables & planned exp. Limits:

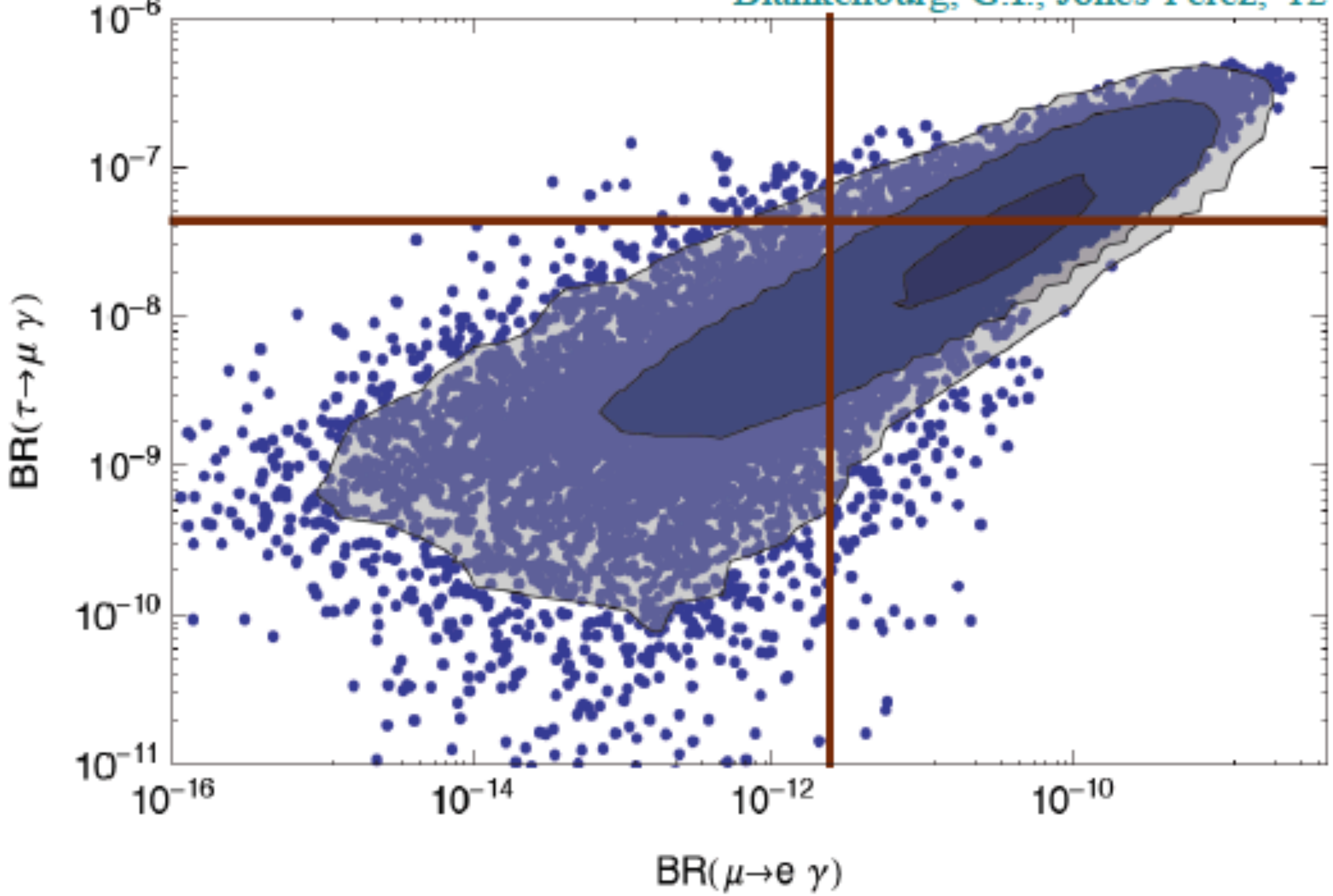
• $\mu\to e\gamma$	5×10^{-14} [PSI/MEG-II]
• $\mu\to 3e$	10^{-16} [PSI/μ3e]
• $\mu N\to eN$	$10^{-15}\to10^{-18}$ [JPARC/COMET] $10^{-15}\to10^{-18}$ [FNAL/Mu2e]
• $\tau\to\mu\gamma$	2×10^{-9} [S-Bfactory ($50ab^{-1}$)]
• $\tau\to 3\mu$	10^{-9}-10^{-10} [S-Bfact., S-LHCb]

* *The key role of LFV and EDMs*

...and there is no doubt that if MEG will see a positive signal, then all other LFV searches would be extremely important to understand the nature of the effect.

E.g.: SUSY with minimally broken $U(3)^5$

Blankenburg, G.I., Jones-Perez, '12

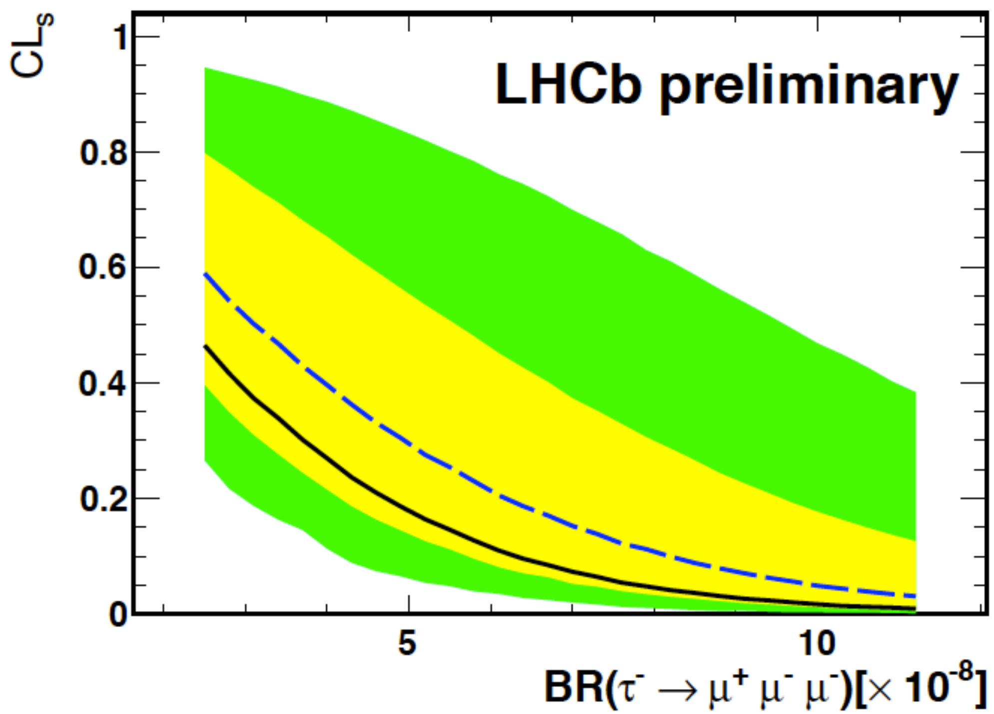


Tau physics from a hadron machine

- LHCb showed some nice preliminary results on $\tau \rightarrow 3\mu$

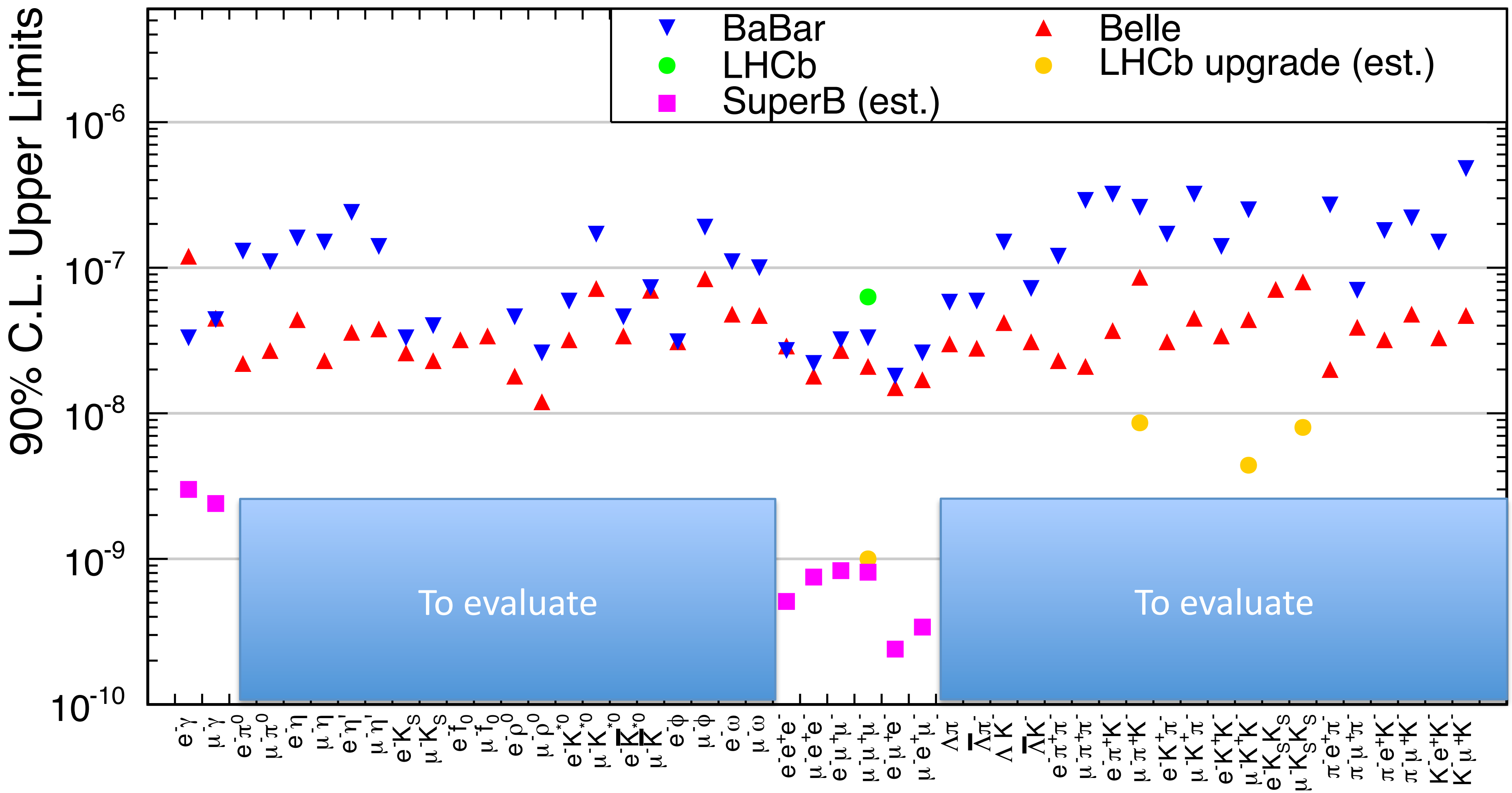
$$\mathcal{B}(\tau^- \rightarrow \mu^+\mu^-\mu^-) \quad < \quad 6.3 \times 10^{-8} \text{ at } 90\% \text{ CL},$$
$$\mathcal{B}(\tau^- \rightarrow \mu^+\mu^-\mu^-) \quad < \quad 7.8 \times 10^{-8} \text{ at } 95\% \text{ CL}.$$

- 3 times worse limit than the B Factories using 1fb-1 of data.
- Background plays a role, so one has to take care extrapolating limits.
- Expect some improvement in method when extrapolating beyond this level.
- See LHCb-CONF-2012-015

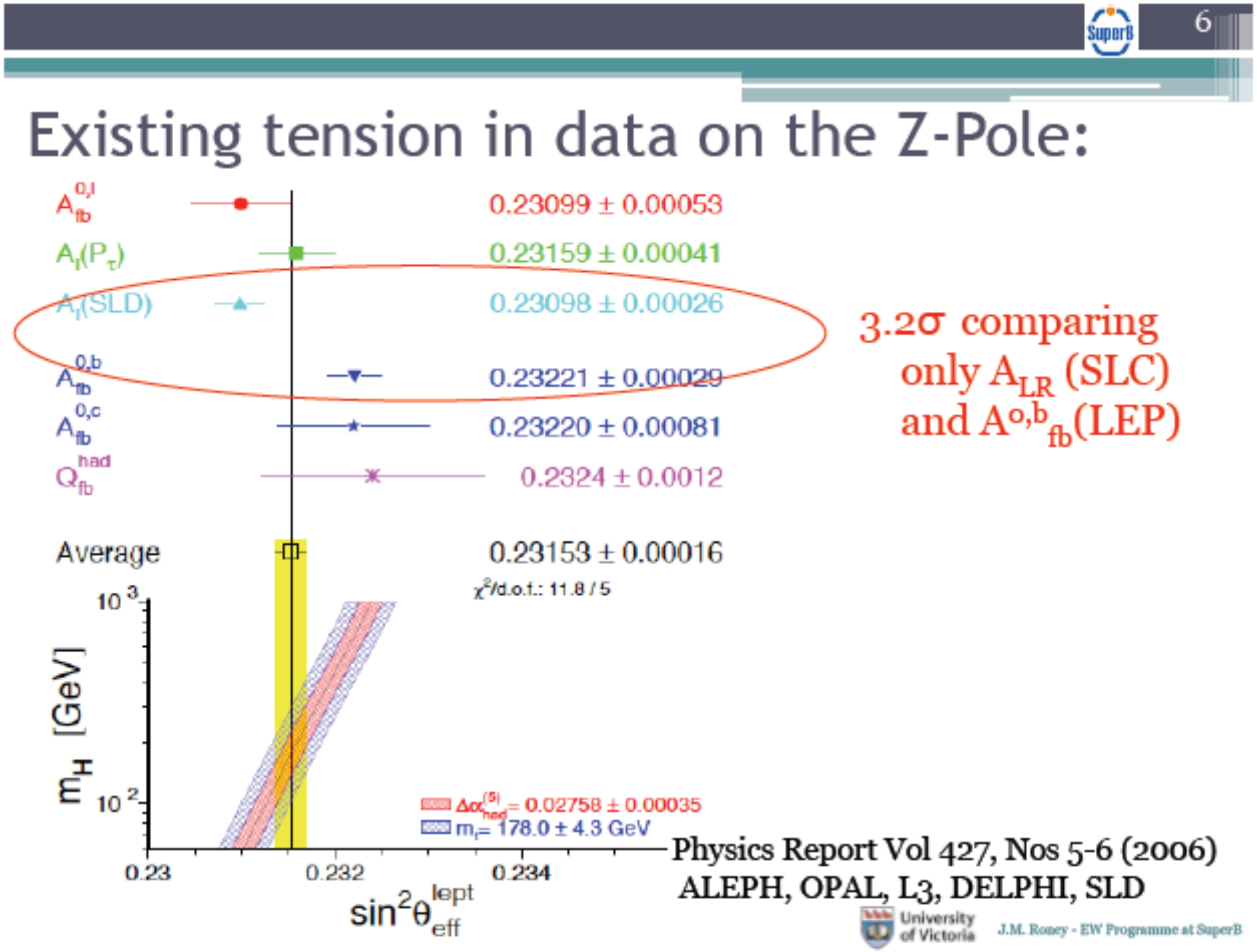


(personal opinion: Unfortunately LHCb succumbed to using CLs)

τ LFV


BaBar
Belle
LHCb
LHCb upgrade (est.)
SuperB (est.)
90% C.L. Upper Limits
10^-6
10^-7
10^-8
10^-9
10^-10
To evaluate
To evaluate

Precision EW programme



Mike Roney, ICHEP

SuperB Left-Right Asymmetries

Fermion flavour	σ (nb) eff %	Number Selected events (billions)	SM g_V^f (M_Z)	A_{LR} 70% Pol	g_V^f Total Error (%)	$Sin^2\theta_W(M_Z)$ Total Error
beauty	1.1 (95%)	38	-0.3437 ± .0001	-0.013	0.5	0.0026
charm	1.3 (30%)	29	+0.1920 ±.0002	-0.003	0.5	0.00076
tau	0.92 (25%)	17	-0.0371 ±.0003	$-3x10^{-4}$	2.3	0.00043
muon	1.15 (54%)	46	-0.0371 ±.0003	$-3x10^{-4}$	1.5	0.00027

Now we know the Higgs mass, reverse the precision EW constraint to predict weak angle running.

Measure this at the 4S to remove the need to worry about hadronization uncertainties.

Requires machine to have polarised electrons.

This table concentrates on observables that SFFs can measure, with a few of the prime examples from hadron experiments to highlight that there are many things that need to be measured well.

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 $\sim 1\,\text{ab}^{-1}$	LHCb (2017) $5\,\text{fb}^{-1}$	Super*B* (2022) $75\,\text{ab}^{-1}$	LHCb upgrade $50\,\text{fb}^{-1}$	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 $>75\text{ab}^{-1}$
S in $B \to K_S^0\pi^0\gamma$	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	Green	Blue	Red	Green	Yellow	b fragmentation limits interpretation

This table concentrates on observables that SFFs can measure, with a few of the prime examples from hadron experiments to highlight that there are many things that need to be measured well.

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 $\sim 1\,\text{fb}^{-1}$	LHCb (2017) $5\,\text{fb}^{-1}$	Super*B* (2022) $75\,\text{ab}^{-1}$	LHCb upgrade $50\,\text{fb}^{-1}$	Theory
α	Blue	Blue	Green	Blue	Yellow
β from $b \to c\bar{c}s$	Blue	Blue	Green	Green	Green
$B_d \to J/\psi \pi^0$	Yellow	Red	Green	Red	Green
$B_s \to J/\psi K^0_S$	Red	Yellow	Red	Blue	Green
γ	Yellow	Blue	Green	Green	Green
$\lvert V_{ub}\rvert$ inclusive	Blue	Yellow	Green	Blue	Blue
$\lvert V_{ub}\rvert$ exclusive	Blue	Yellow	Green	Blue	Blue
$\lvert V_{cb}\rvert$ inclusive	Blue	Yellow	Green	Blue	Blue
$\lvert V_{cb}\rvert$ exclusive	Blue	Yellow	Green	Blue	Blue

LHCb can only use ρπ

βtheory error B_d
βtheory error B_s

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

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

TDR

- The European Strategy Group documentation consolidated our previous work.
  - Largely re-used this text for the TDR physics overview.
  - Charm mixing potential updated for $1ab^{-1}$ at threshold.
  - A good snapshot of where we are today, and refers back to other documents that we have written in the past few years.

Updating comparisons

- The complementarity of SuperB with other experiments assumes experimental sensitivities as stated at a given point in time.
  - We know a lot more about the potential of some of the complementary experiments now that we did last year.
  - After both ICHEP and the CKM workshop we expect that there will be a number of results that will need updating for our standard speaker material.
  - We will systematically update these expectations post-CKM.

December Meeting

- We plan to have a physics workshop at the December meeting.
  - Details to be discussed over the next few days
  - Plan to follow the same format as the December 2011 meeting.
  - Will start to discuss the physics book timeline, once we have the approved schedule of the project in hand.
  - Will also take stock of areas that we have not thought much about: (e.g. multi-body charm decays at threshold and the 4S).