$B_{u,d}$ Physics WG Status

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Introduction

- The $B_{u,d}$ Working Group (convener: Adrian Bevan) has two sub-groups:
  - CPV and Mixing - sub-convener: Adrian Bevan
  - Rare, Radiative, Semi-leptonic Decays - John Walsh, Tobias Hurth
- Many of the Golden Modes fall into this WG, important work on some of these channels has been performed already in SuperB
- Summarize current status of various selected modes:
  - B-factory measurements
  - LHCb results that are relevant
  - SuperB studies

$B \to D^{(*)}\tau\nu$ (extracts from Luth @ FPCP)

Ratio of $B \to D^{(*)}\tau\nu$ vs $B \to D^{(*)}\ell\nu$ Decays

Z. Phys, C46, 93 (1990)

- S.L. decays involving a τ have an additional helicity amplitude (for $D^*\tau\nu$):

$$\frac{d\Gamma_\tau}{dq^2} = \frac{G_F^2 |V_{cb}|^2 |\mathbf{p}| q^2}{96\pi^3 m_B^2} \left(1 - \frac{m_\tau^2}{q^2}\right)^2 \left[\left(|H_{++}|^2 + |H_{--}|^2 + |H_{00}|^2\right)\left(1 + \frac{m_\tau^2}{2q^2}\right) + \frac{3}{2}\frac{m_\tau^2}{q^2}|H_t|^2 \right]$$

For $D\tau\nu$, only H_{00} and H_t contribute!

- To test the SM Prediction, we measure

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

Leptonic τ decays only

Several experimental and theoretical uncertainties cancel in the ratio!

- $B\bar{B}$ events are fully reconstructed:
  - hadronic B tag (tag efficiency improved 2x)
  - reconstruction of $D^{(*)}$ and e or μ (extend to lower momenta)
  - no additional charged particles
  - kinematic selections: $q^2 > 4$ GeV^2

  Background suppression by BDT (combinatorial and $D^{**}\ell\nu$)

- Full BABAR data sample, MC correction based on data control samples

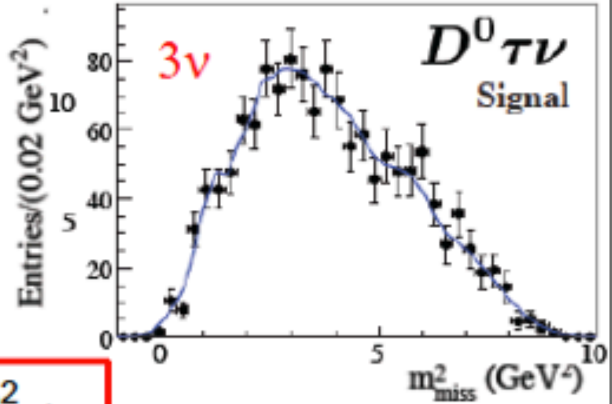
V. Lüth FPCP 2012 @ Hefei 2012 22

B→ $D^{(*)}$ τν: Extraction of Yields from M.L. Fit

- Unbinned M.L. fit
  - 2-D distributions:
  - 4 signal samples: $D^0\ell$, $D^{*0}\ell$, $D^+\ell$, $D^{*+}\ell$, (e or μ)
  - 4 $D^{(*)}\pi^0\ell\nu$ control samples

$m^2_{miss} = (P_{ee} - P_{Btag} - P_{D(*)} - P_\ell)^2$
Missing mass sq

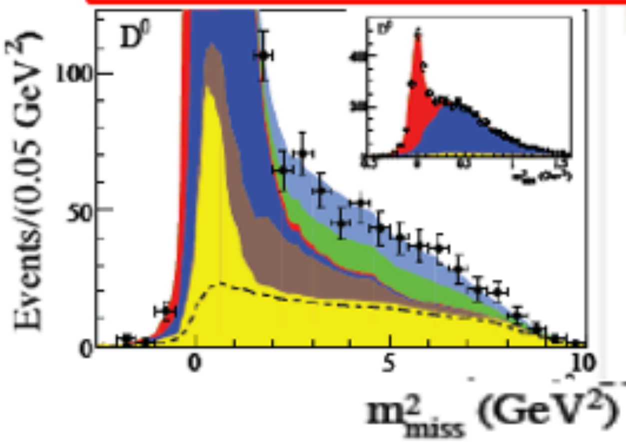
p^*_ℓ Lepton momentum in B rest frame

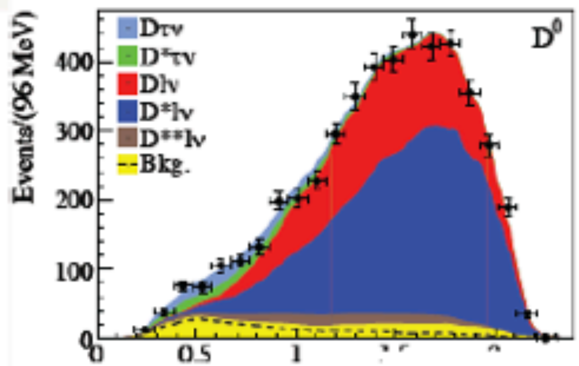


MC Simulation

- PDFs from MC (approximated using Keys fct.)
- Fitted Yields
  - 4 $D^{(*)}$ τν Signal
  - 4 $D^{(*)}$ ℓν Normalization
  - 4 D**ℓν Background
- Fixed Backgrounds
  - B^0–B^+ cross feed
  - $B\overline{B}$ combinatorial BG
  - Continuum $e^+e^-\to f\,\overline{f}(\gamma)$

$D^{(*)}\tau\nu$ Signal at larger m^2_{miss}





p^*_ℓ (GeV)

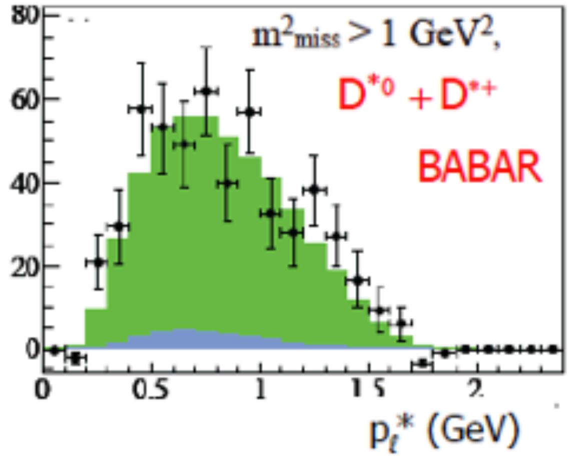
Results of Fit: $B \rightarrow D^*\tau\nu$

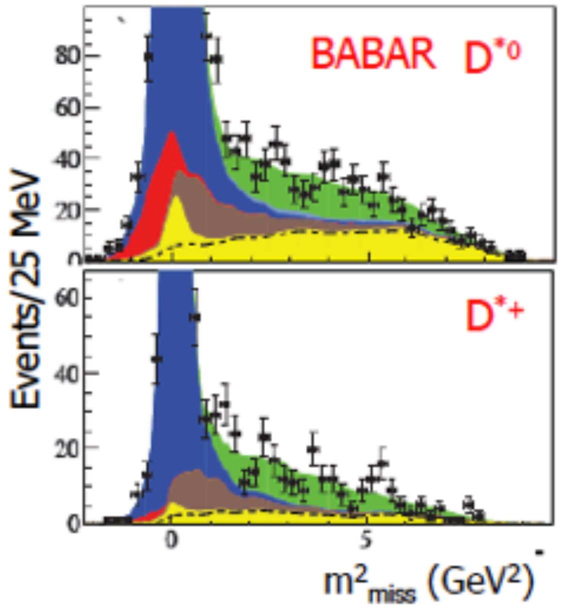
BABAR, to be submitted to PRL

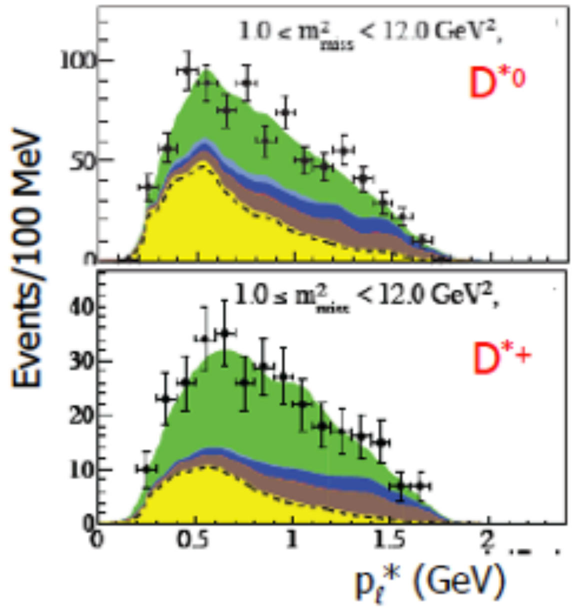
Statistical errors only

	$D^{*0}\tau\nu$	$D^{*+}\tau\nu$	$D^*\tau\nu$
$N_{\rm sig}$	639 ± 62	245 ± 27	888 ± 63
Significance (σ)	11.3	11.6	16.4
$R(D^*)$	0.322 ± 0.032	0.355 ± 0.039	0.332 ± 0.024

Isospin constrained







- $D^*\tau\nu$
- $D\tau\nu$
- $D^*l\nu$
- $Dl\nu$
- $D^{**}l\nu$

Free yields

- Bkg.

Fixed yield

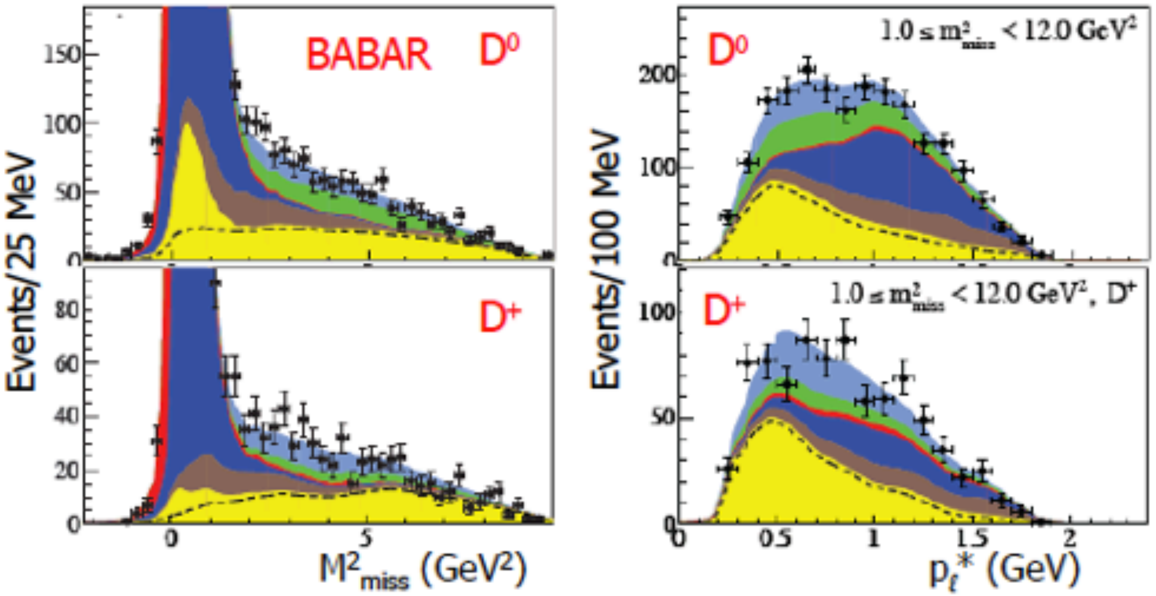
Results of Fit: $B \to D\tau\nu$

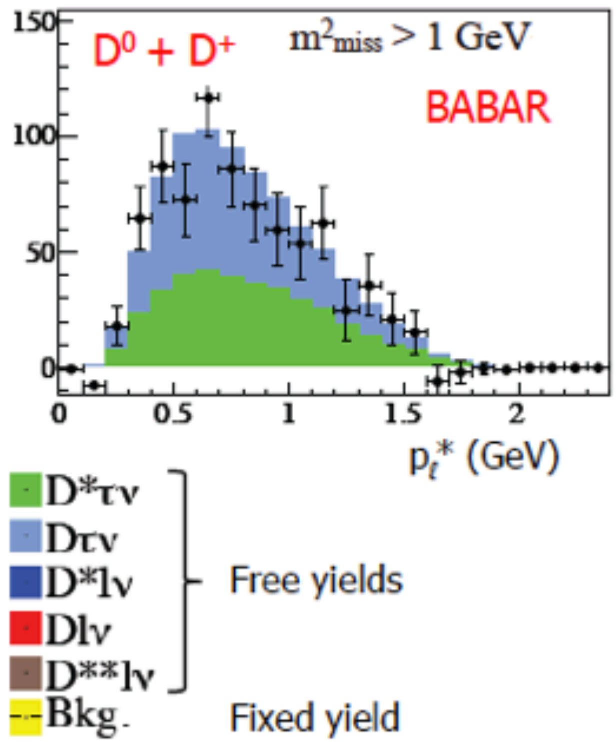
BABAR, to be submitted to PRL

Statistical errors only

	$D^0\tau\nu$	$D^+\tau\nu$	$D\tau\nu$
N_{sig}	314 ± 60	177 ± 31	489 ± 63
Significance (σ)	5.5	6.1	8.4
$R(D)$	0.429 ± 0.082	0.469 ± 0.084	0.440 ± 0.058

Isospin constrained





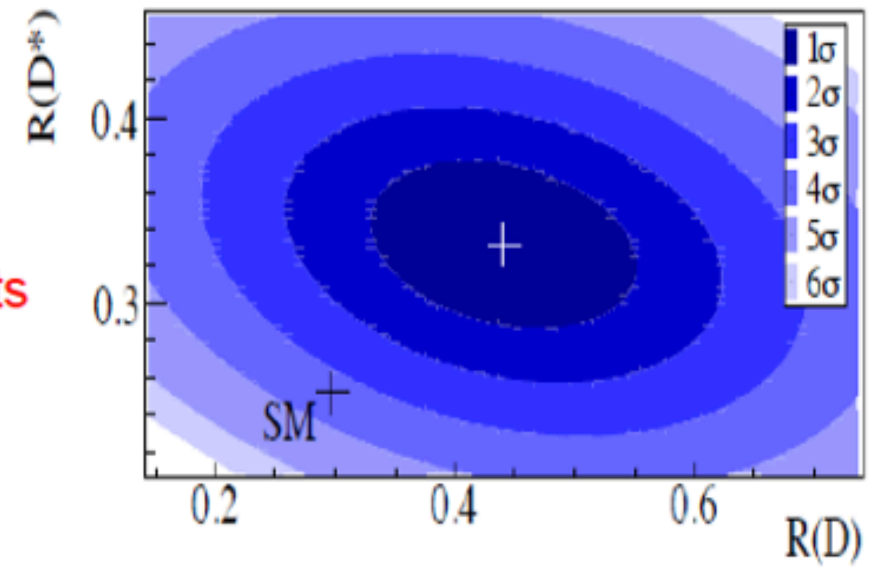
S.M. Predictions of R(D) and R(D*)

BABAR
to be submitted to PRL

Z. Phys, C46, 93 (1990)
PRD 82, 0340276 (2010)
PhD 85, 094025 (2012)
and recent updates

Comparison with S.M. calculation:

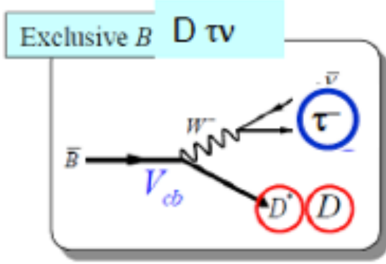
	R(D)	R(D*)
BABAR	0.440 ± 0.071	0.332 ± 0.029
SM	0.297 ± 0.017	0.252 ± 0.003
Difference	**2.0 σ**	**2.7 σ**



The combination of the two measurements (-0.27 correlation) yields $\chi^2/NDF=14.6/2$, i.e. Prob. = 6.9×10^{-4} !!

Thus the data are inconsistent with the SM prediction at 3.4 σ

Can we explain the excess events?



- A charged Higgs (2HDM type II) of spin 0 coupling to the τ will only affect H_t

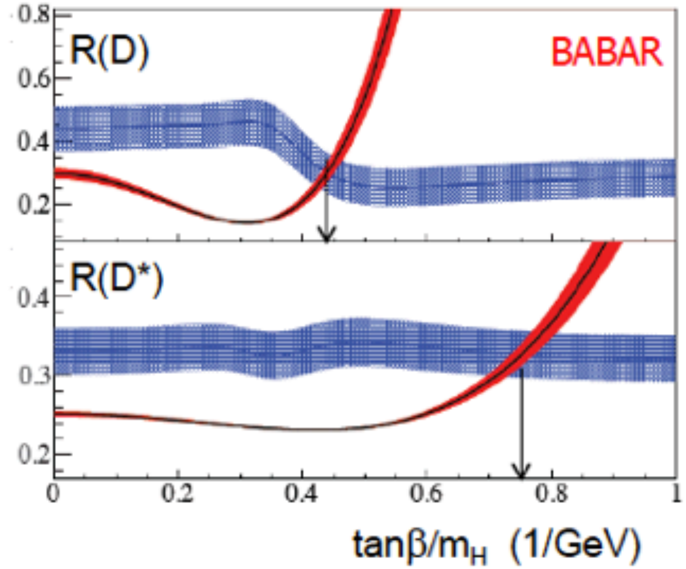
$$H_t^{2HDM} = H_t^{SM} \times \left(1 - \frac{\tan^2\beta}{m^2_{H\pm}} \frac{q^2}{1 \mp m_c/m_b}\right)$$

- for Dτν
+for D*τν

PRD 78, 015006 (2008)
PhD 85, 094025 (2012)

This could enhance or decrease the ratios R(D*) depending on $\tan\beta/m_H$

- We estimate the effect of 2DHM, accounting for difference in efficiency, and its uncertainty
- The data match 2DHM Type II at
  $\tan\beta/m_H = 0.44 \pm 0.02$ for R(D)
  $\tan\beta/m_H = 0.75 \pm 0.04$ for R(D*)
- The combination of R(D) and R(D*) excludes the Type II 2HDM in the full $\tan\beta$-m_H parameter space with a probability of >99.8%, provided M_H>10GeV !



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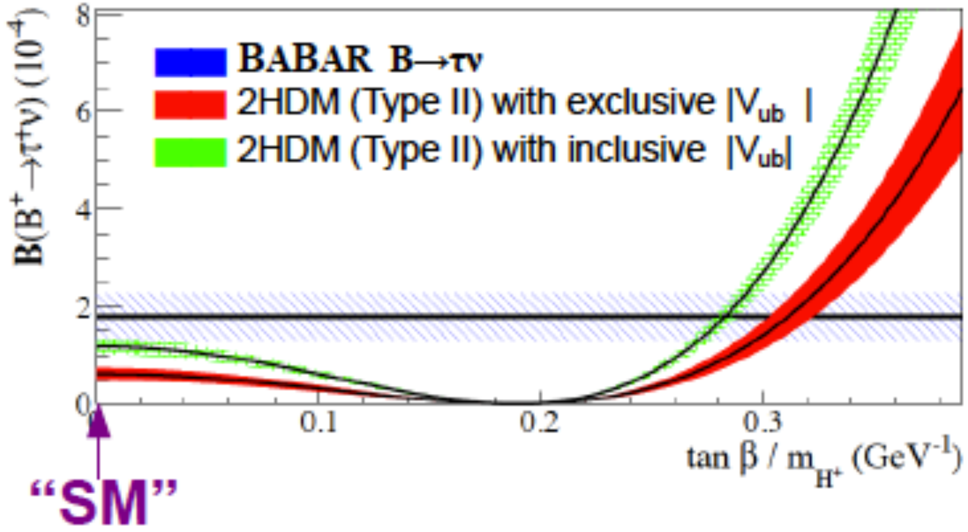
- SuperB: certainly can measure this channel.
- Little focus so far, but perhaps we should increase priority!
- Only at SuperB (Belle 2)

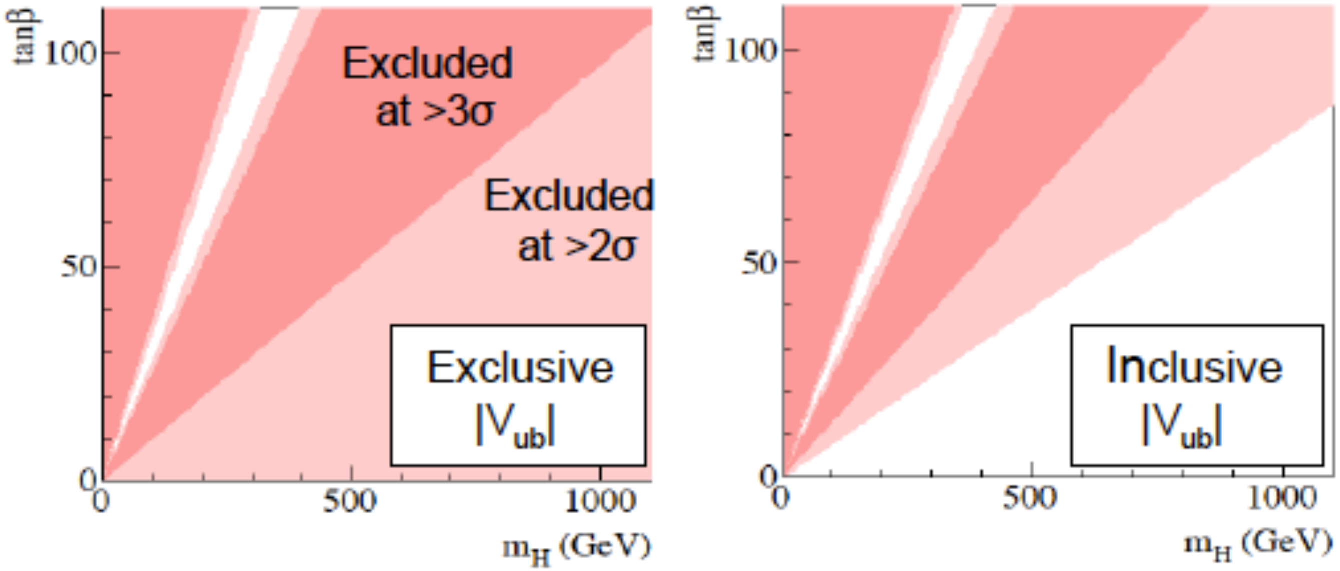
$B \to \tau\nu$

- Branching ratio affected by possible charged Higgs:
  - Exp: BF = (1.67 ± 30) x 10^{-4} (HFAG, 2011)
  - SM: BF = $\mathcal{B}(B \to \tau\nu)^{\text{SM}} = (0.79 \pm 0.07) \times 10^{-4}$ [UTfit] , $\mathcal{B}(B \to \tau\nu)^{\text{SM}} = (0.76\ ^{+\ 0.10}_{-\ 0.06}) \times 10^{-4}$ [CKMfit]
  - Mystery: most NP scenarios (2HDM-II, MSSM) ***reduce*** BF wrt SM
- Tension with V_{ub} and sin 2β
- Only can be measured in SuperB (and Belle 2)
  - still relevant even with measurement of $B_s \to \mu^+\mu^-$ from LHCb (see Blankenburg's talk from Thursday Physics Meeting)
- Estimated SuperB sensitivity: 3%
  - currently under study in SuperB (Guglielmo De Nardo)
- Related channel B→lν also under study (Marcello Rotondo, Valentina Santoro)

B → τν - latest BaBar result

$$\mathcal{B}(B^+ \to \tau^+ \nu) = (1.83^{+0.53}_{-0.49}(\text{stat.}) \pm 0.24(\text{syst.})) \times 10^{-4}$$

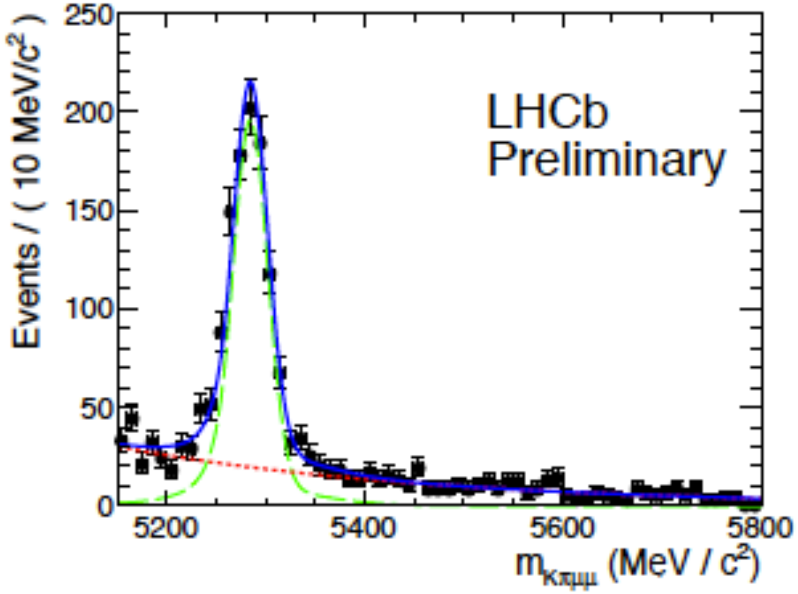


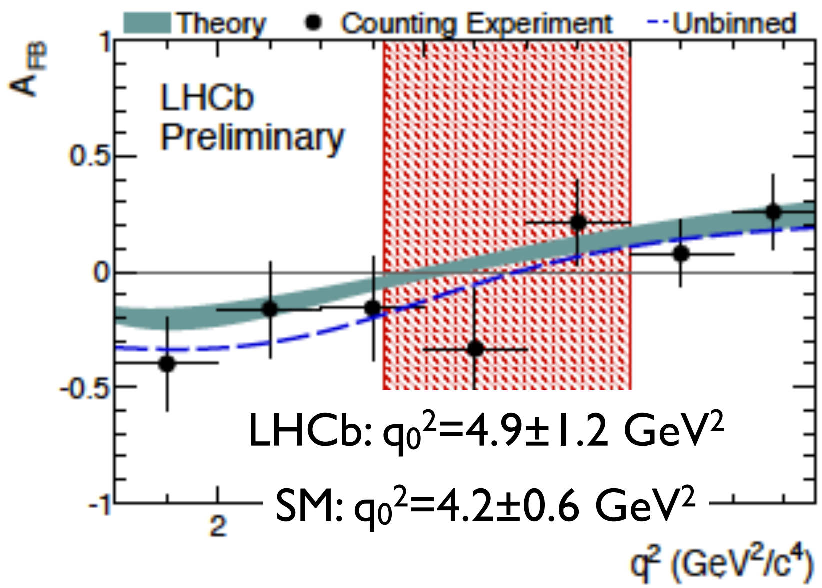


B → $X_s l^+ l^-$

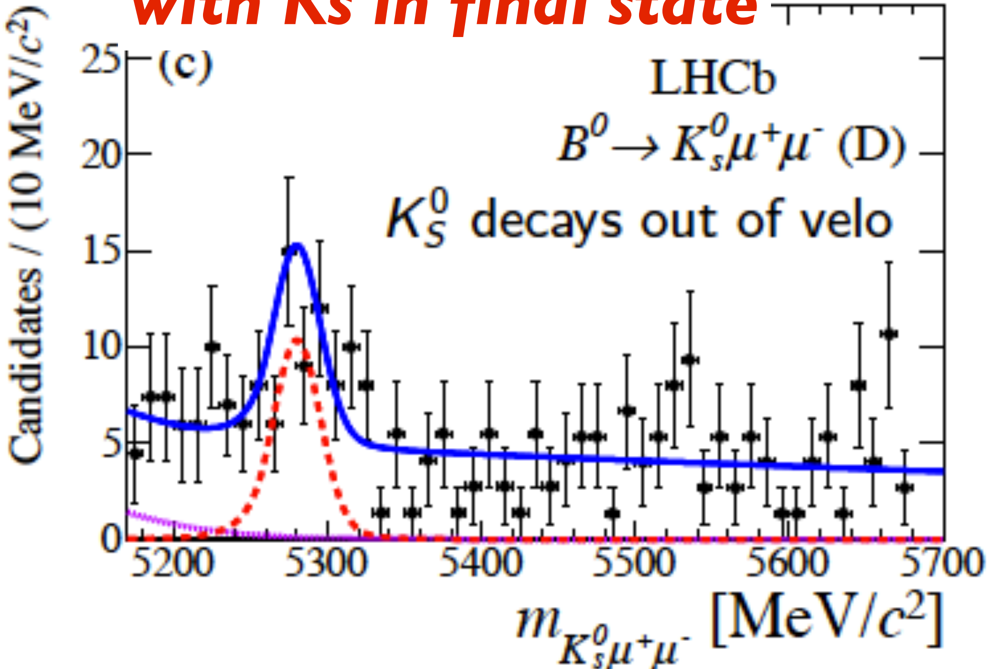
- Important part of SuperB rare decays program:
  - high sensitivity to NP
  - many observables
- LHCb can make very good measurements for a subset of the observables: $B^0 \to K^{*0}\mu^+\mu^-$
  - see next page
- However, much can only be done at e+e- (with high precision):
  - electron channel ⇒ μ/e ratio sensitive to NP (e.g. NMSSM)
  - Isospin asymmetry (requires reco of $K^{*+} \to K_s\pi^+, K^+\pi^0$
  - Inclusive channel: $B \to X_s\ell^+\ell^-$
- SuperB:
  - current sensitivities extrapolated from BaBar
  - identified interested analysts (Robertson, Walsh)

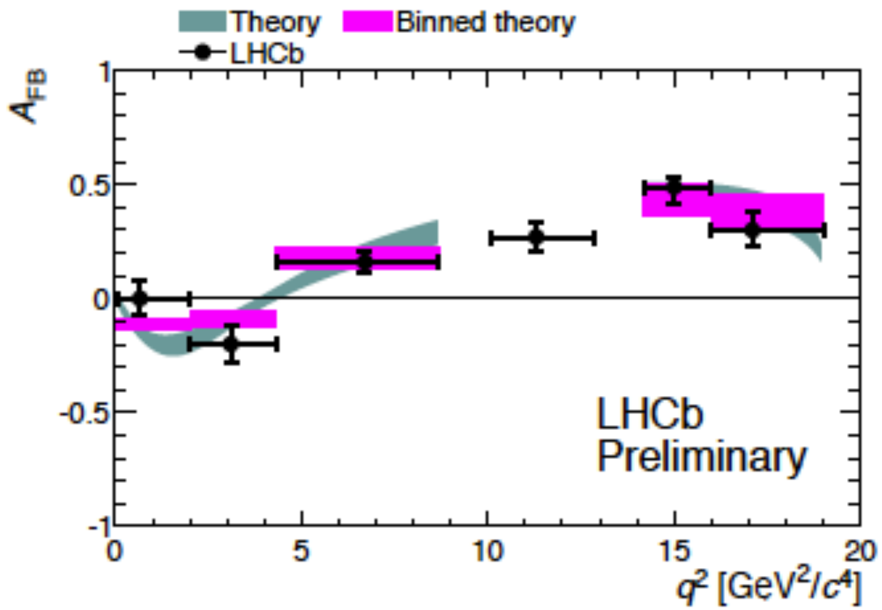
LHCb results on $B^0 \to K^{*0}\mu^+\mu^-$





with Ks in final state





$B \to X_s l^+ l^-$ sensitivities in SuperB

$B \to K^* l^+ l^-$

Observable	q^2 region [GeV^2/c^4]	*BABAR* (425 fb^{-1}) Stat.	*BABAR* (425 fb^{-1}) Sys.	Super*B* (75 ab^{-1}) Stat.	Super*B* (75 ab^{-1}) Sys.
$\sigma\mathcal{B}/\mathcal{B}$	all	0.162	0.063	0.01	0.032-0.048
$\sigma\mathcal{B}/\mathcal{B}$	0.1–7.02	0.23	0.070	0.014	0.035-0.053
$\sigma\mathcal{B}/\mathcal{B}$	10.24–12.96 and > 14.06	0.24	0.071	0.015	0.036-0.054
$\mathcal{R}_{K*}$	all	0.34	0.07	0.02	0.035-0.048
$\mathcal{A}_{CP}$	all	0.15	0.01	0.009	0.008-0.01
$\mathcal{A}_I$	0.1–7.02	0.17	0.03	0.01	0.015-0.023
$\mathcal{F}_L$	0.1–4	0.15	0.04	0.011	0.02-0.03
$\mathcal{F}_L$	4–7.84	0.14	0.04	0.011	0.02-0.03
$\mathcal{A}_{FB}$	0.1–4	0.14	0.05	0.011	0.025-0.038
$\mathcal{A}_{FB}$	4–7.84	0.14	0.05	0.011	0.025-0.038

- (Careful) extrapolations from BaBar
- Need SuperB simulation
  - Especially for fully inclusive analysis

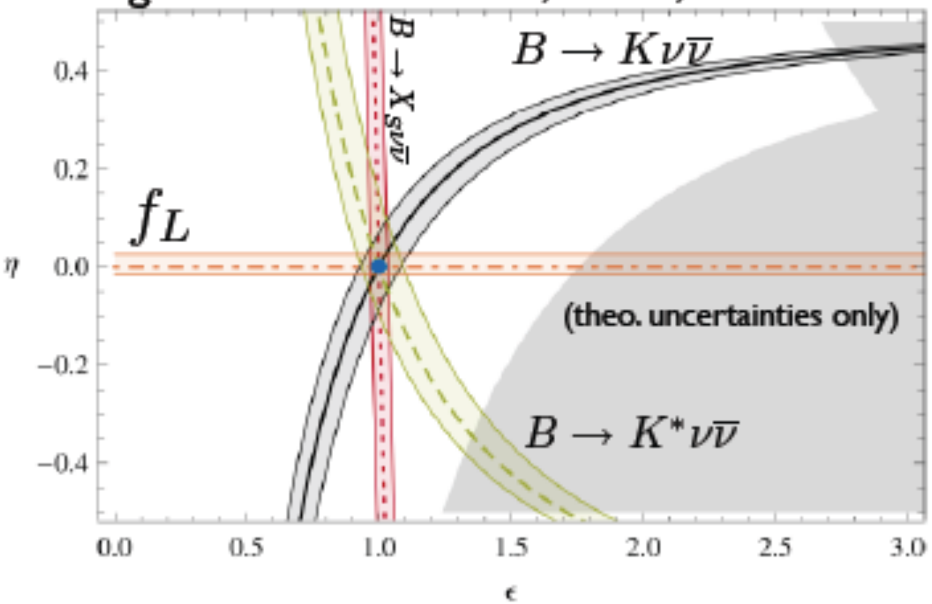
$B \to X_s l^+ l^-$

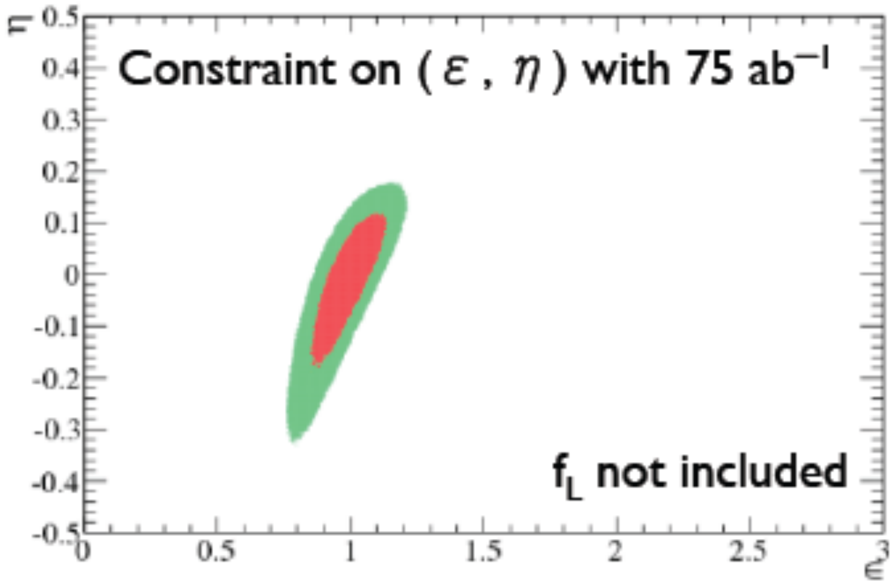
Observable	q^2 region [GeV^2/c^4]	*BABAR* (425 fb^{-1}) Stat. SE	*BABAR* Sys. SE	*BABAR* Stat. RM	*BABAR* Sys. RM	Super*B* (75 ab^{-1}) Stat. SE	Super*B* Sys. SE	Super*B* Stat. RM	Super*B* Sys. RM
$\sigma\mathcal{B}/\mathcal{B}$	all	0.11	0.056	0.26	0.06	0.008	0.03-0.05	0.019	0.03-0.05
$\sigma\mathcal{B}/\mathcal{B}$	0.1–1	0.29	0.07	0.69	0.07	0.022	0.04-0.06	0.052	0.04-0.06
$\sigma\mathcal{B}/\mathcal{B}$	1–4	0.23	0.06	0.53	0.06	0.017	0.03-0.05	0.040	0.03-0.05
$\sigma\mathcal{B}/\mathcal{B}$	4–7.84	0.18	0.06	0.43	0.06	0.014	0.03-0.05	0.032	0.03-0.05
$\sigma\mathcal{B}/\mathcal{B}$	10.24–12.96	0.31	0.07	0.73	0.07	0.024	0.04-0.06	0.055	0.04-0.06
$\sigma\mathcal{B}/\mathcal{B}$	>14.06	0.29	0.07	0.69	0.07	0.022	0.04-0.06	0.052	0.04-0.06
$\mathcal{R}_{X_s}$	all	0.21	0.06	0.50	0.06	0.016	0.03-0.05	0.038	0.03-0.05
$\mathcal{R}_{X_s}$	0.1–7.84	0.25	0.06	0.58	0.06	0.019	0.03-0.05	0.044	0.03-0.05
$\mathcal{A}_{CP}$	all	0.06	0.01	0.14	0.01	0.004	0.005-0.008	0.011	0.005-0.008
$\mathcal{A}_{CP}$	0.1–7,84	0.07	0.01	0.16	0.01	0.005	0.005-0.008	0.012	0.005-0.008
$\mathcal{A}_I$	all	0.05	0.06	0.12	0.06	0.004	0.03-0.05	0.009	0.03-0.05
$\mathcal{A}_I$	0.1–7.84	0.06	0.06	0.14	0.06	0.005	0.03-0.05	0.011	0.03-0.05
$\mathcal{H}_L$	0.1–1	0.17	0.04	0.40	0.04	0.013	0.02-0.03	0.030	0.02-0.03
$\mathcal{H}_L$	1–4	0.17	0.04	0.40	0.04	0.013	0.02-0.03	0.030	0.02-0.03
$\mathcal{H}_L$	4–7.84	0.13	0.04	0.27	0.04	0.009	0.02-0.03	0.021	0.02-0.03
$\mathcal{H}_A$	0.1–1	0.22	0.06	0.51	0.06	0.016	0.03-0.05	0.039	0.03-0.05
$\mathcal{H}_A$	1–4	0.22	0.06	0.51	0.06	0.016	0.03-0.05	0.039	0.03-0.05
$\mathcal{H}_A$	4–7.84	0.15	0.06	0.35	0.06	0.011	0.03-0.05	0.026	0.03-0.05

$B \to K^{(*)}\nu\nu$

- Sensitive to NP via Z^0 penguin
- Only weak limits imposed by current B-factories
- Can only be done at SuperB/Belle-2
- Probably most-studied channel thus far at SuperB: Elisa Manoni (Perugia)
  - hadronic tags in fastsim
  - currently performing some BG studies

e.g. see Altmannshofer, Buras, & Straub





$B \to X_s\gamma$

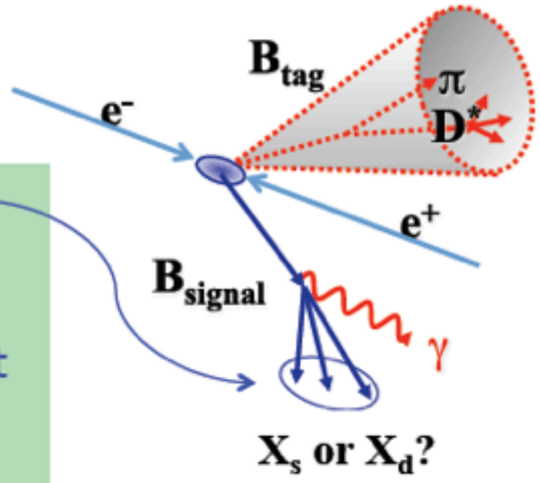
- Featured topic at SuperB Physics Workshop, Frascati, Dec 2011
  - Some optimism among theorists in reducing theoretical error on BF (currently at 7%, could go to 5% or lower) ⇒ provides impetus for SuperB analysis
  - Systematics-limited ⇒ careful study to estimate sensitivity
- Inclusive channel restricted to e+e- machines (LHCb can do $B \to K^*\gamma$)
- A_{CP}: very interesting observable at SuperB (many systematics cancel)
- Status in SuperB: not currently being worked on – group from Notre Dame (Jessop, Wang) has pulled out

Measuring $A_{CP}(B \to X_s \gamma)$

- SuperB/Belle-2 only experiments able to measure A_{CP} inclusively

$A_{CP}(B \to X_s\gamma)$ with Hadronic Tags

- Potentially quite powerful because X_s (or X_d) system is fully isolated
- Possible to separate on event-by-event basis $B \to X_s\gamma$ from $B \to X_d\gamma$ decays (which has never been done inclusively)



- Truly inclusive measurements of:
  - $A_{CP}(B \to X_s\gamma)$ and $A_{CP}(B \to X_d\gamma)$
- Isospin asymmetry
- Neubert, et al. (PRL 106 (141801) 2011) although they find a larger-than-thought theoretical uncertainty on $A_{CP}(B \to X_s\gamma)$, they note an expected difference in A_{CP} for B^0 and B^+ decays
  - this joint CP/isospin asymmetry could be measured at SuperB using hadronic tags

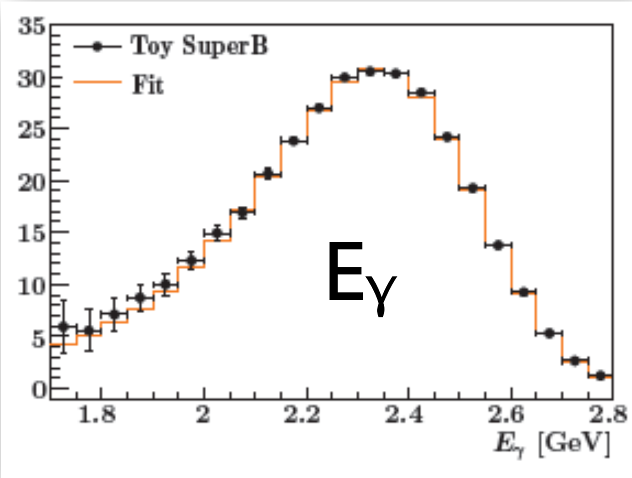
V_{ub} and semileptonic B decays

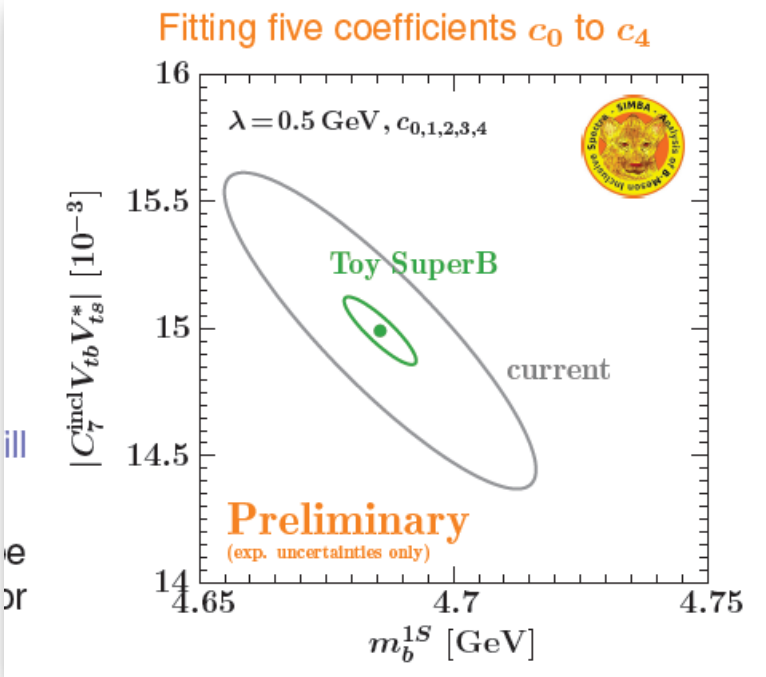
- We saw at the Physics Meeting on Thursday many interesting aspects of V_{ub}
  - discrepancy between ***inclusive*** and ***exclusive*** determinations of V_{ub} (2-3σ)
  - the current B-factories have completed these measurements, so this discrepancy will be there until resolved at SuperB/Belle 2
  - Gambino: efforts to improve precision of extraction of inclusive V_{ub}
  - Tackmann: extracting inclusive V_{ub} from simultaneous fits to $b \to u l \nu$ and $b \to s \gamma$ (see following)
  - Ciuchini: highlights of the role of V_{ub} in the CKM global fits and how SuperB will be able to severely constraint the parameters (ρ, η)
  - Rotondo: summary of experimental techniques and results
  - Crivellin: right-handed currents as a way to explain inclusive vs. exclusive Vub (and also large BF in $B \to \tau \nu$) (see following)

Global fits to b→ulν and b→sγ

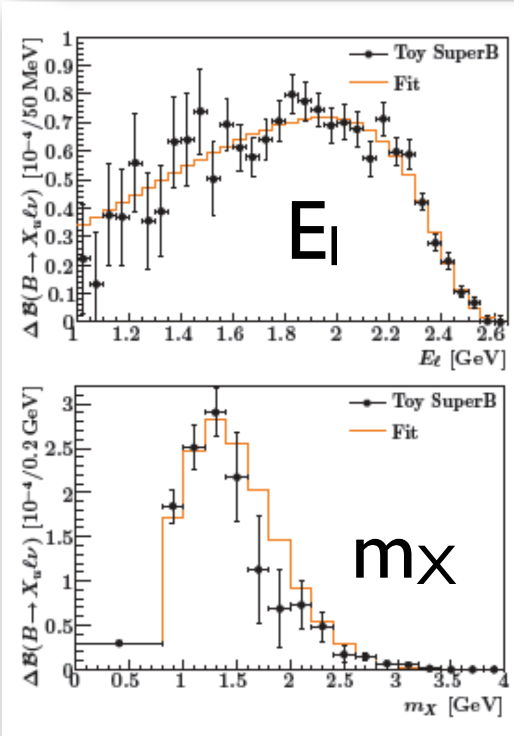
Tackman: Toy MC with SuperB stats

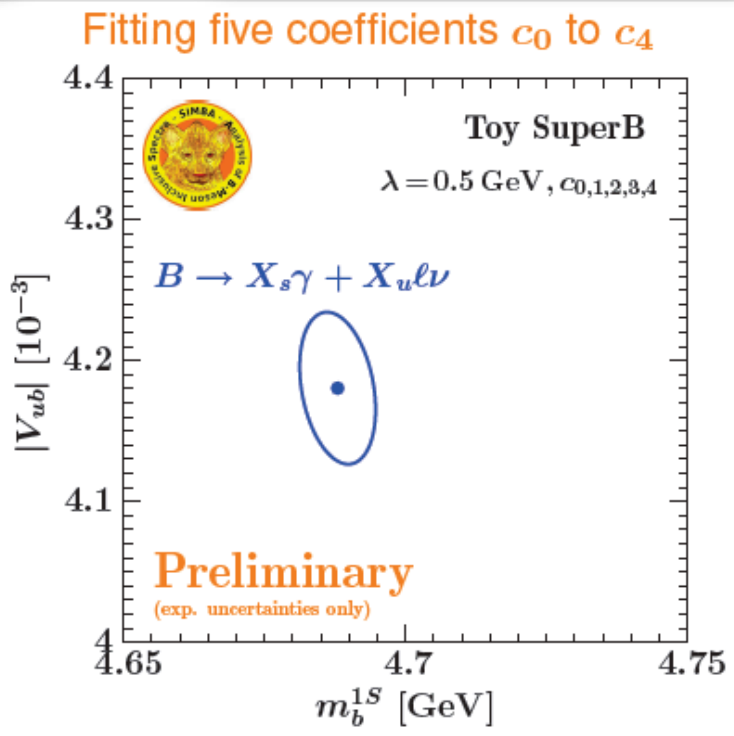
b→sγ





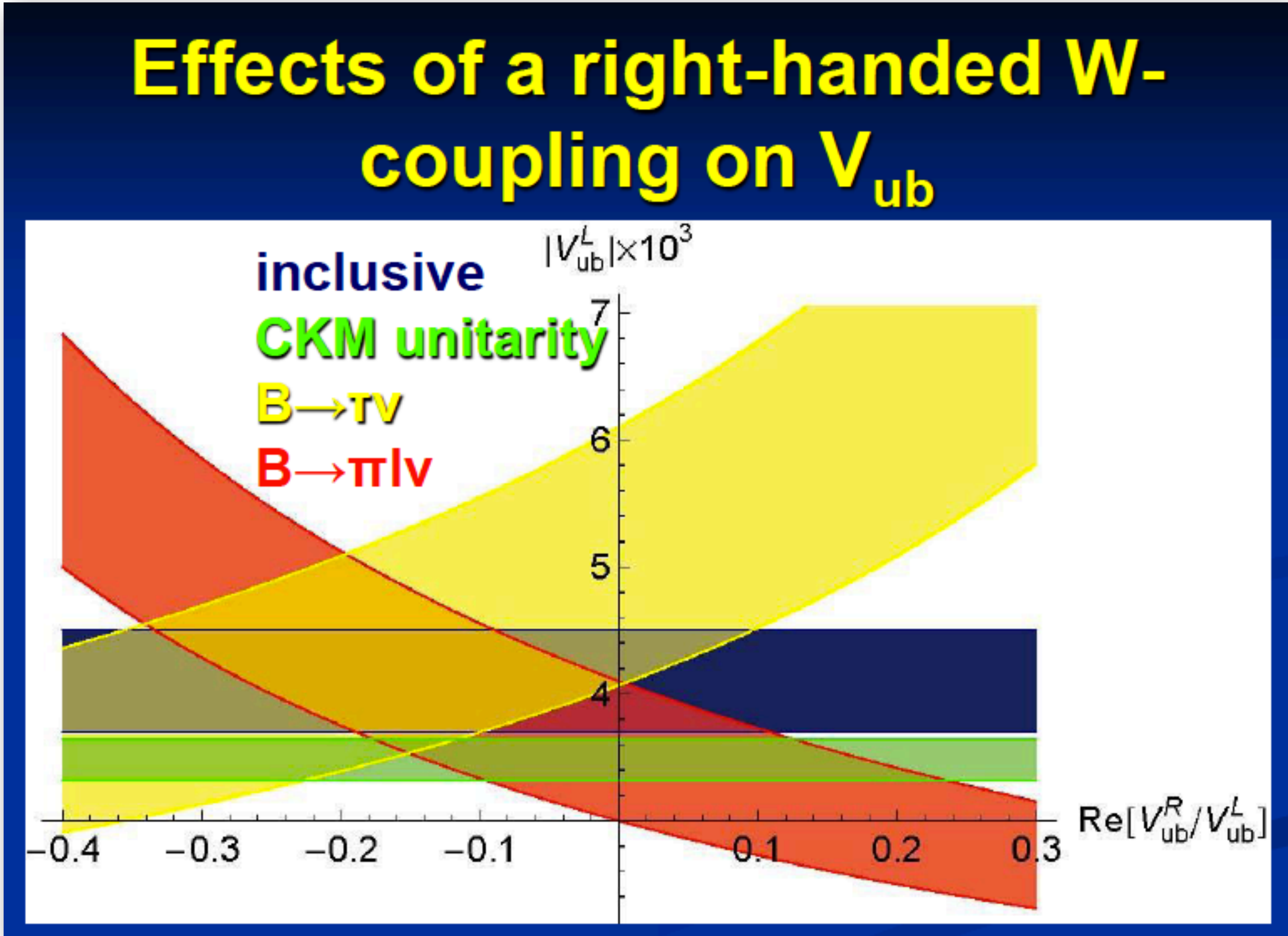
b→ulν





Right-handed currents?

Andreas Crivellin



V_{ub} in SuperB

- Last SuperB work on V_{ub} was at the *Valencia Workshop (2008)*
- Based on that, current experimental sensitivities are estimated at **2%** (inclusive technique) and **3%** (exclusive).
- Clearly, these need to be updated, along with estimates of expected theoretical uncertainties (which have already gotten smaller since Valencia)
- So, we are seeking people interested in working on this topic.

SuperB (Belle 2) only,
~~LHCb~~

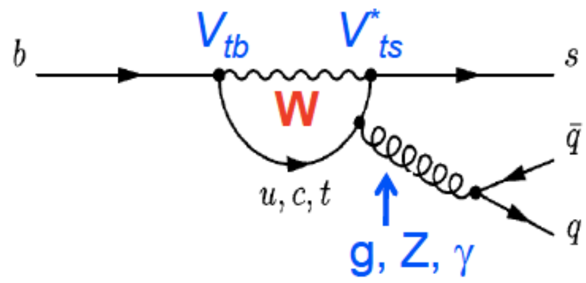
B→φφK

- Sensitive to CP and T violation
- Need angular analysis
- First simulations with SuperB fastsim started

- Currently being studied in SuperB: Marcin Chrzaszcz (Cracow)
- Computing power available in Poland for simulations

$B \to \eta' K^0$ and $B \to \varphi K^0$

- Gluonic penguin modes:

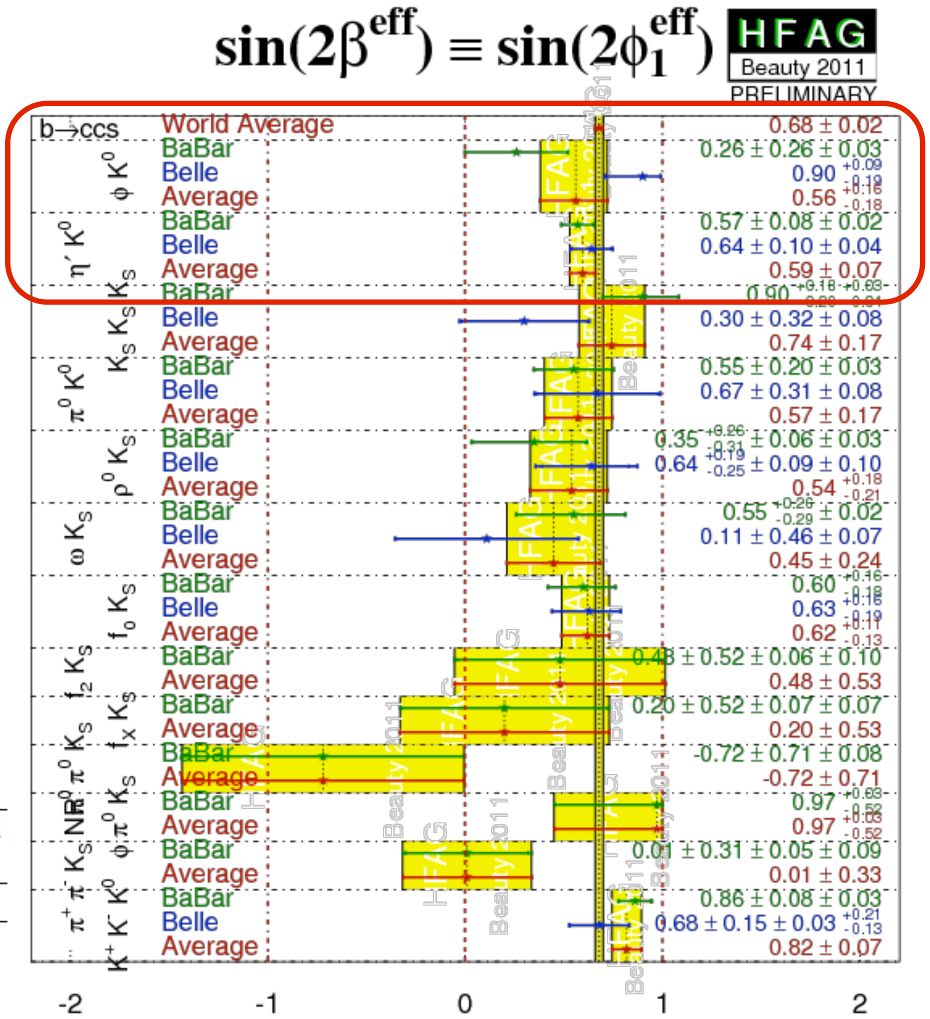


⇒ CP violation (CPV) by CKM phase (only)

- Sensitivity to NP via TDCPV – compare measured sin $2\beta_{eff}$ with $b \to c\underline{c}s$ value
- B-factory results are in agreement, but higher precision measurements needed
- SuperB sensitivity estimate $\sigma(S) \sim 0.01$ (for $B \to \eta' K^0$)
  - extrapolation from b-factory results
- Not currently under study in SuperB (although $B \to \varphi K^0$ used as benchmark channel in some SVT detector studies)

Gluonic penguins

- Many other gluonic penguins will be studied at SuperB as well



SuperB sensitivities

Mode	Current Precision			Predicted Precision (75 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	–	–	–

Precision modes

- In the SuperB Impact paper (arXiv:1109.5028) we divided the most important channels into "Golden Modes" and "Precision Modes"

Observable/mode	Current now	LHCb (2017)	Super$B$ (2021)	Belle II (2021)	LHCb upgrade (10 years of running)	theory now
		$5\,\text{fb}^{-1}$	$75\,\text{ab}^{-1}$	$50\,\text{ab}^{-1}$	$50\,\text{fb}^{-1}$	
α from $u\overline{u}d$	6.1°	$5^{\circ\,a}$	1°	1°	^{b}	$1-2^\circ$
β from $c\overline{c}s$ (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
$\lvert V_{cb}\rvert$ (inclusive) %	1.7		0.5%	0.6 (est.)		dominant
$\lvert V_{cb}\rvert$ (exclusive) %	2.2		1.0%	1.2 (est.)		dominant
$\lvert V_{ub}\rvert$ (inclusive) %	4.4		2.0%	3.0		dominant
$\lvert V_{ub}\rvert$ (exclusive) %	7.0		3.0%	5.0		dominant

- TDCP asymmetries to measure α, β, γ
  - Sensitivity estimates extrapolations from b-factories
- Not currently studied in SuperB
  - would like to choose one of these channels as a benchmark for detector and background studies

Tools for $B_{u,d}$ physics

- Hadronic tagging: used in $B \to K^{(*)}\nu\nu$ and $B \to \tau\nu$ analyses
  - maintained by Elisa Manoni
- Semileptonic tagging: currently not used by anybody, but looking for a client
  - maintained by Alejandro Perez
- Flavor tagging: imported from BaBar, but needs validation in SuperB fastsim

Analysis opportunities

- $B \rightarrow D^{(*)} \tau \nu$
- V_{ub}/Semileptonic decays
- $B \rightarrow X_s \gamma$, especially A_{CP}
- Precision mode for α, β or γ (benchmark)
- Inclusive $B \rightarrow K^{(*)} l^+ l^-$ modes
- Any analysis using SL tags
- Gluonic penguins