S. Stone
Oct. 16, 2013

Workshop Summary & Outlook

Thanks to the organizers: John Ellis, Tim Gershon, Gino Isidori, Patrick Koppenburg, Gilad Perez, Frederic Teubert, Andreas Weiler, Guy Wilkinson etc…

*Apologies if I did not mention your talk

Prime Objective

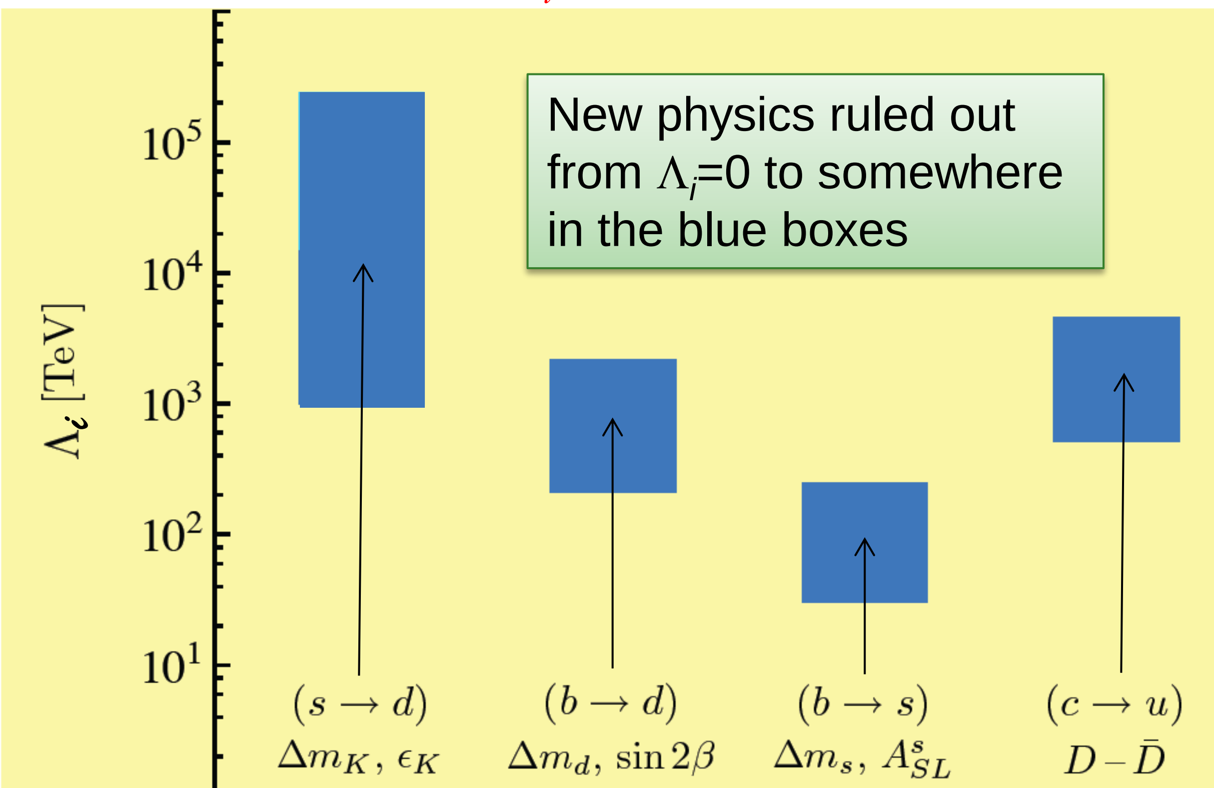
- Dictates that physics beyond the Standard Model must be found
- “The success of the LHCb experiment has so far been a nightmare for all flavour physicists…” Gauld, Goetz and Haisch

1 TeV Scale New Particles

- Naturalness
  - Higgs is most sensitive to physics of order M=125 GeV, has been pushed to ~1 TeV due to absence of signals. Can be pushed higher. (Soni suggests 10 TeV for KK)
  - But corrections to Higgs mass go as M^2, so can't push M too high without getting into fine tuning problem (see Zupan's talk)
  - Need New Physics to cut off quantum corrections
- Suggested NP mechanisms: SUSY, Higgs compositeness, and extra dimensions. Each predicts a rich spectrum of new states

Flavor as a High Mass Probe

- Already excluded ranges if c_i~1
  - $\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \frac{c_i}{\Lambda_i^2} O_i$, take $c_i = 1$



New physics ruled out from Λ_i=0 to somewhere in the blue boxes

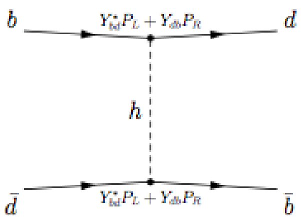
Ways out

1. New particles have large masses >>1 TeV
2. New particles have degenerate masses (or alignment, see Shadmi's talk)
3. Mixing angles in new sector are small, same as in SM (MFV)
4. The above already implies strong constrains on NP

See: Isidori, Nir & Perez arXiv:1002.0900; Neubert EPS 2011 talk

Harink: Limits on NP Higgs Yukawa's

Meson Mixing



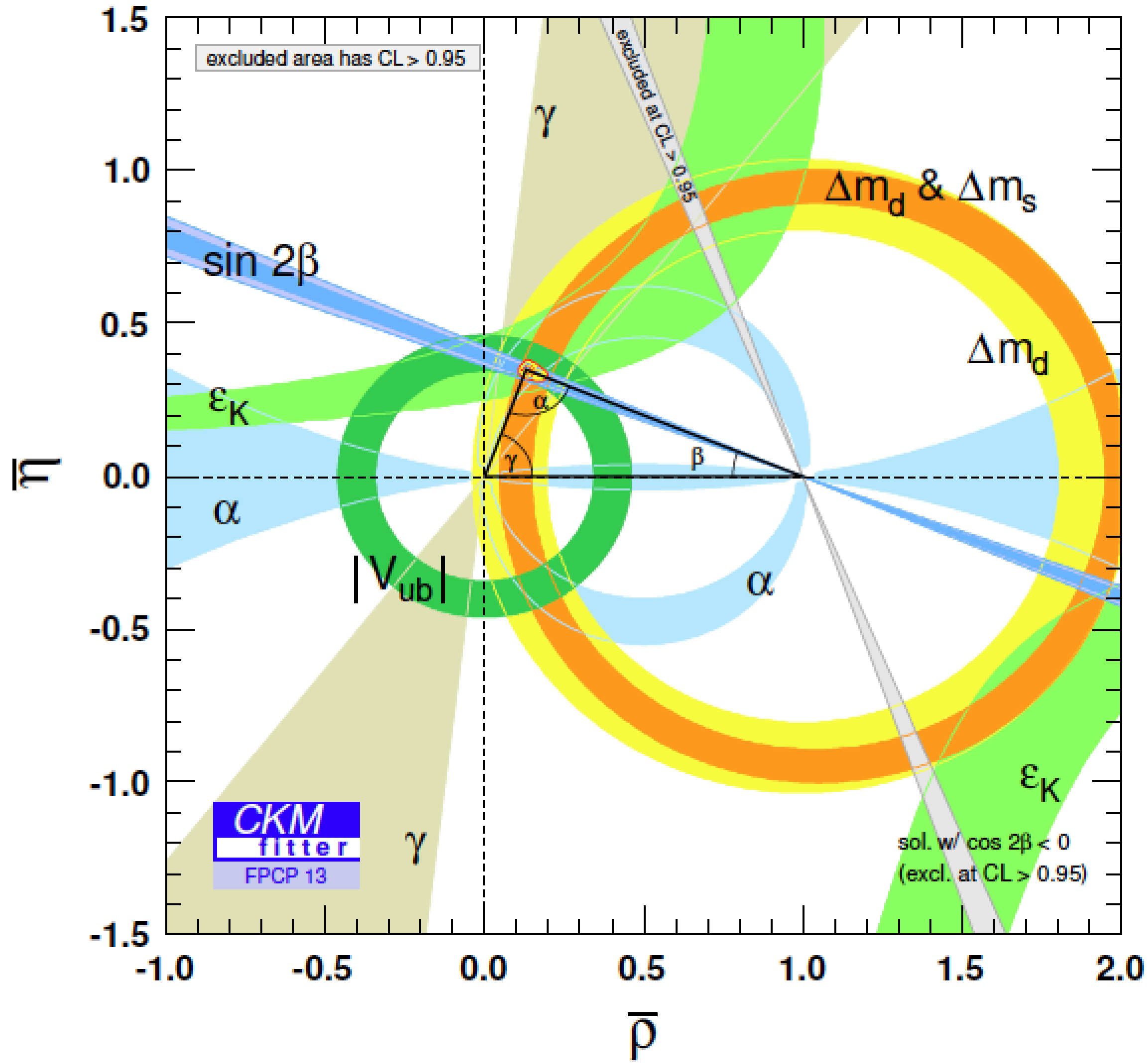
* Meson mixing's powerful:

Technique	Coupling	Constraint	$m_i m_j / v^2$
D^0 oscillations [48]	$\lvert Y_{uc}\rvert^2$, $\lvert Y_{cu}\rvert^2$	$< 5.0 \times 10^{-9}$	5×10^{-8}
	$\lvert Y_{uc} Y_{cu}\rvert$	$< 7.5 \times 10^{-10}$	
B_d^0 oscillations [48]	$\lvert Y_{db}\rvert^2$, $\lvert Y_{bd}\rvert^2$	$< 2.3 \times 10^{-8}$	3×10^{-7}
	$\lvert Y_{db} Y_{bd}\rvert$	$< 3.3 \times 10^{-9}$	
B_s^0 oscillations [48]	$\lvert Y_{sb}\rvert^2$, $\lvert Y_{bs}\rvert^2$	$< 1.8 \times 10^{-6}$	7×10^{-6}
	$\lvert Y_{sb} Y_{bs}\rvert$	$< 2.5 \times 10^{-7}$	
K^0 oscillations [48]	$\mathrm{Re}(Y_{ds}^2)$, $\mathrm{Re}(Y_{sd}^2)$	$[-5.9 \ldots 5.6] \times 10^{-10}$	8×10^{-9}
	$\mathrm{Im}(Y_{ds}^2)$, $\mathrm{Im}(Y_{sd}^2)$	$[-2.9 \ldots 1.6] \times 10^{-12}$	
	$\mathrm{Re}(Y_{ds}^* Y_{sd})$	$[-5.6 \ldots 5.6] \times 10^{-11}$	
	$\mathrm{Im}(Y_{ds}^* Y_{sd})$	$[-1.4 \ldots 2.8] \times 10^{-13}$	

"Natural" models are constrained!

Generic Analyses

- Compare measurements look for discrepancies



NP via ΔF=2 processes

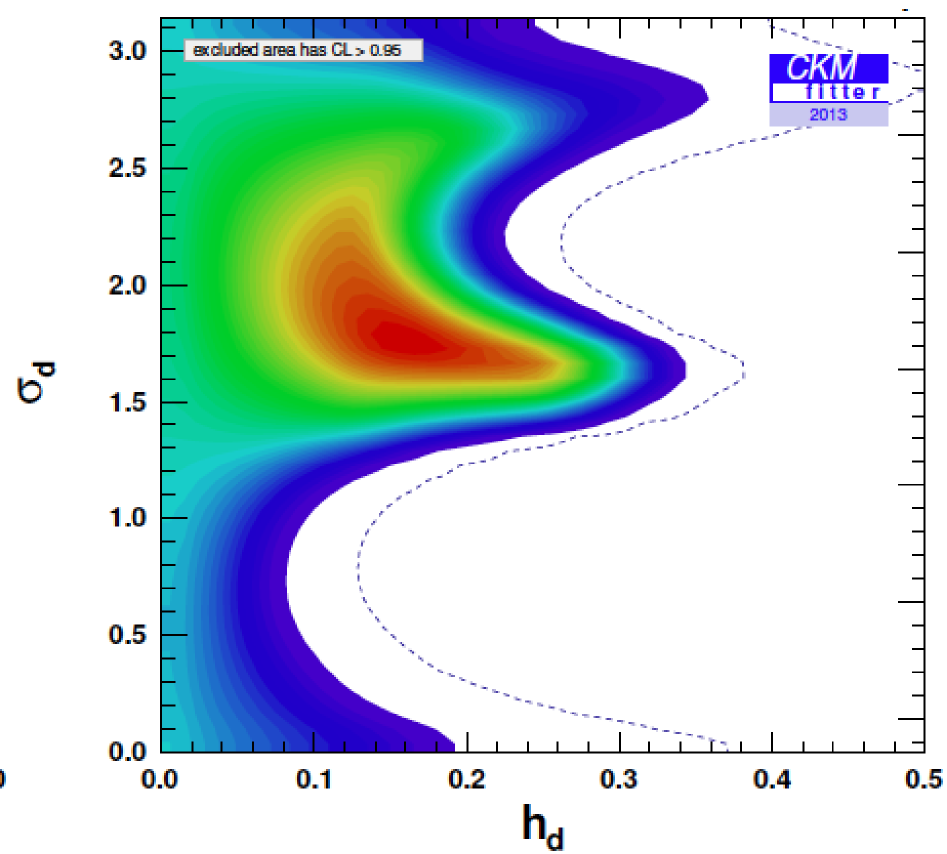
- $B^o_{(s)}$ mixing and CP. Parameterize NP as h & σ

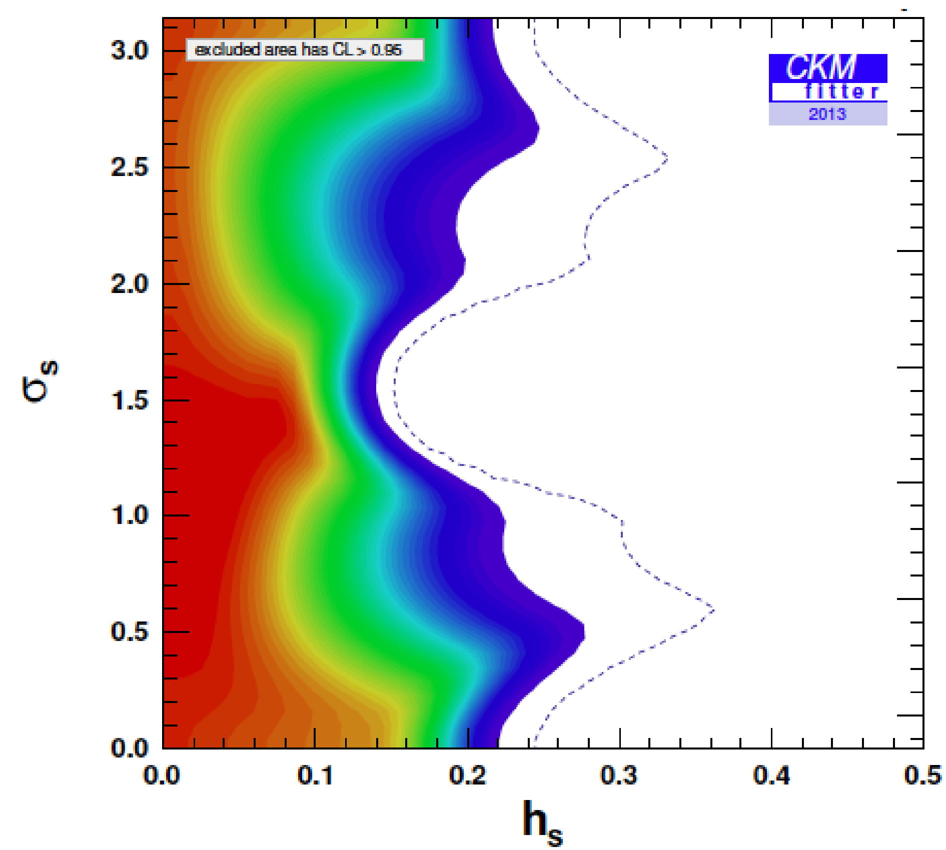
$$M_{12} = M_{12}^{\rm SM} \times \left(1 + h\, e^{2i\sigma}\right)$$

- Tree level processes are assumed not to contain NP, so measure well, especially V_{ub} γ

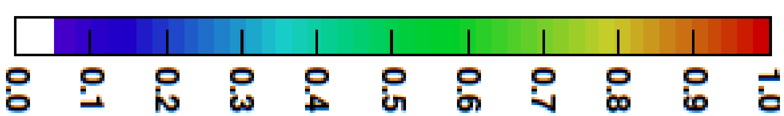
- From Zoltan's talk, now and future

95% cl Limits

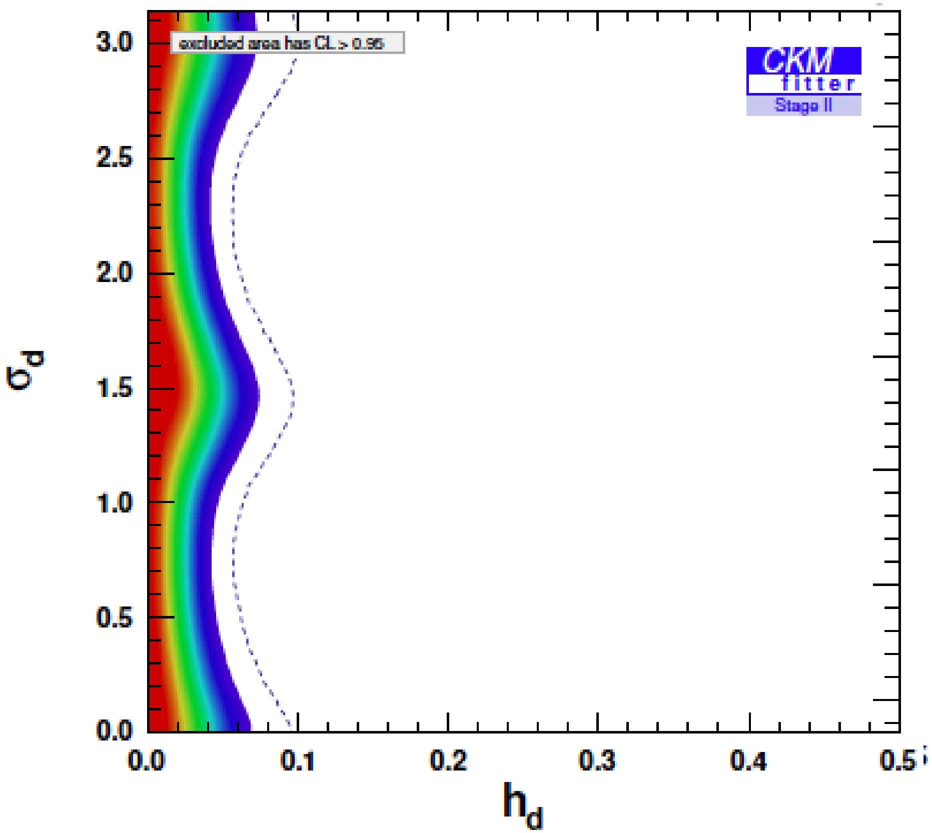


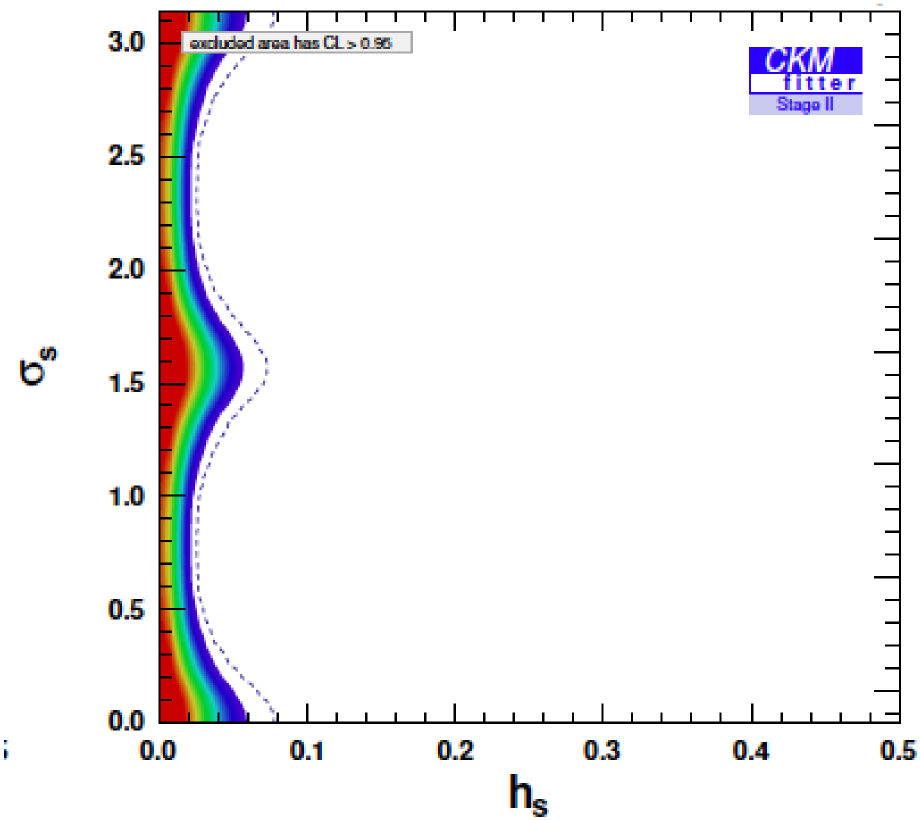


Current

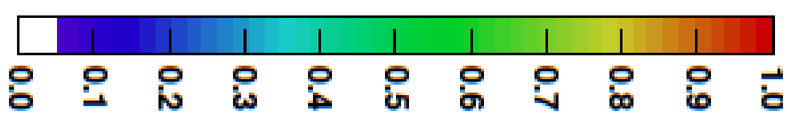


Future





- Belle II, LHCb Upgrade
- Assuming no NP



V_{ub} & Right Handed Currents

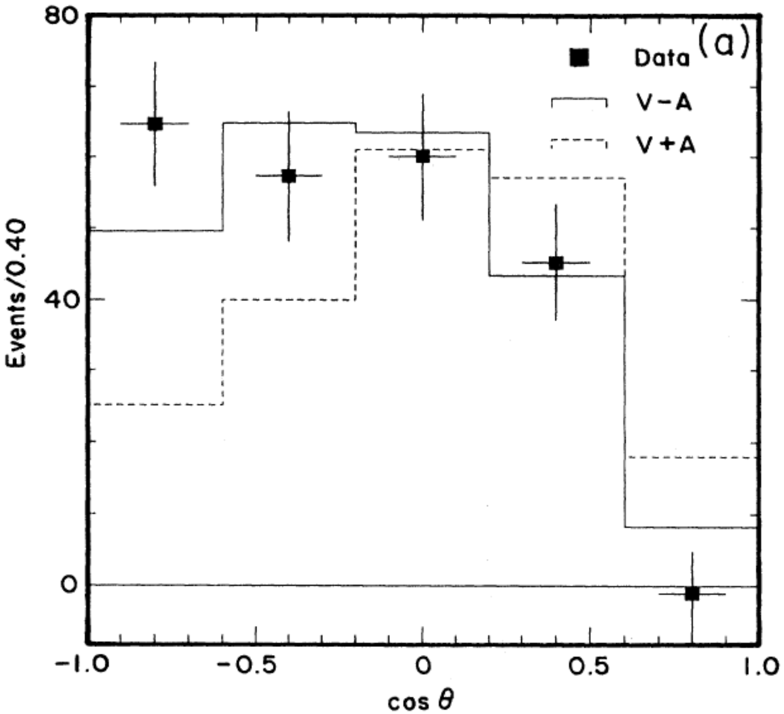
- Although we assumed before that there was no NP in tree level diagrams, here we revoke that criteria
- What do we know about right-handed currents in b decays?
- CLEO result from ~1/fb

PHYSICAL REVIEW D VOLUME 47, NUMBER 3 1 FEBRUARY 1993

Lepton asymmetry measurements in $\bar{B} \to D^* l^- \bar{\nu}_l$ and implications for $V-A$ and the form factors

S. Sanghera,[a] T. Skwarnicki,[a] R. Stroynowski,[a] M. Artuso,[b] M. Goldberg,[b] N. Horwitz,[b]
R. Kennett,[b] G. C. Moneti,[b] F. Muheim,[b] S. Playfer,[b] Y. Rozen,[b] P. Rubin,[b] S. Stone,[b] ....

CLEO V-A



- cosθ is D^{*+} decay angle

TABLE III. The χ^2/N_{DF} for $N_{DF}=4$ for the fits to the cosΘ distribution and 95% C.L. limits for allowed amount of $V+A$ hadronic current.

Model	$\bar{B}^0 \to D^{*+} l^- \bar{\nu}_l$ $V-A$	$V+A$	$B^- \to D^{*0} l^- \bar{\nu}_l$ $V-A$	$V+A$	Simultaneous fit $(V+A)/(V-A)$
ISGW	1.6	9.0	1.3	6.8	$<19\%$
KS	0.9	15.7	0.9	7.3	$<30\%$
WSB	2.3	12.0	1.8	5.5	$<24\%$

FIG. 3. $dN/d\cos\Theta$ distribution: (a) in the decay $\bar{B}^0 \to D^{*+} l^- \bar{\nu}_l$ and (b) in the decay $B^- \to D^{*0} l^- \bar{\nu}_l$. Overlaid are the results of the fits of the ISGW model assuming pure $V-A$ or $V+A$ currents for the $b \to c$ transition.

This needs to be done much better

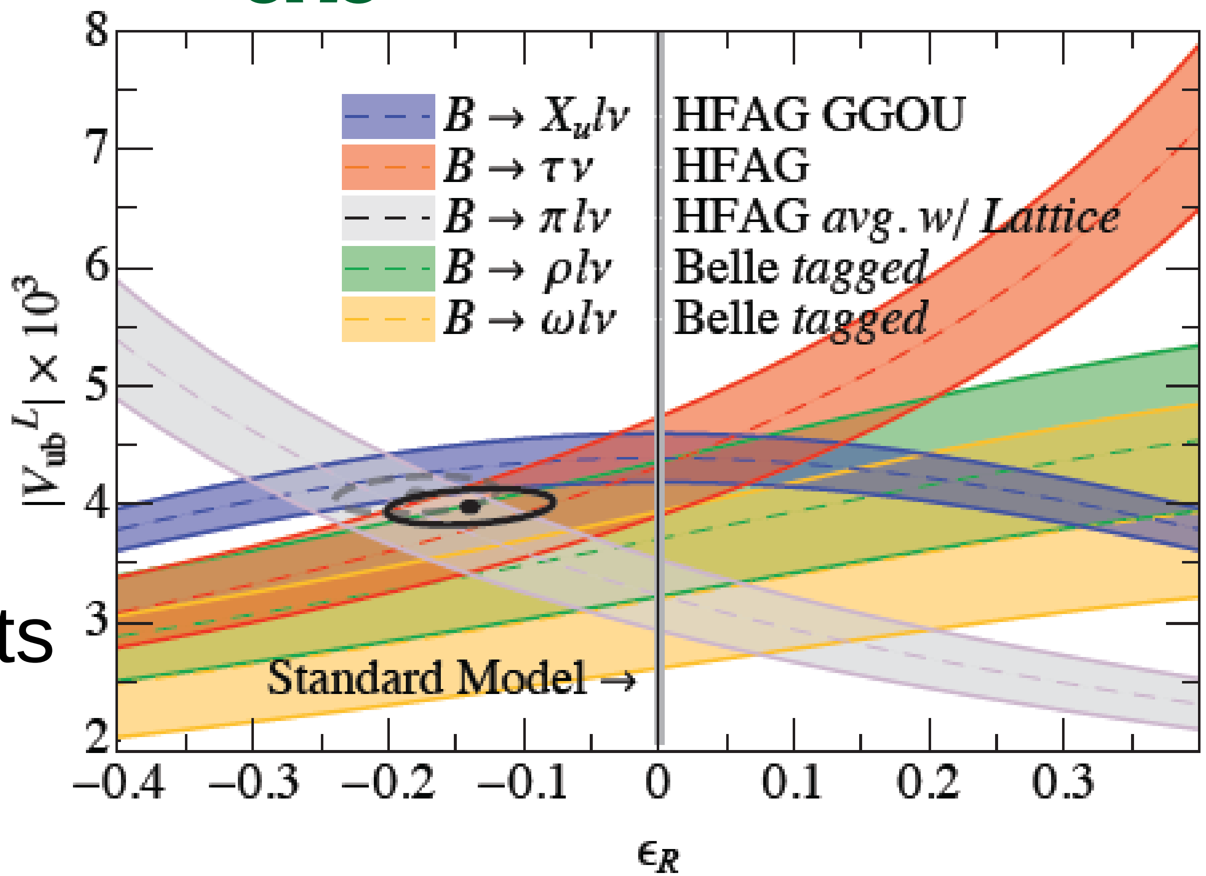
A fix for V_{ub}?

- Conflicts among V_{ub} measurements
- Different processes have different sensitivities to right-handed currents

Decay	$\lvert V_{ub}\rvert \times 10^4$	add right-handed current	current
$B \to \pi \ell \bar{\nu}_\ell$	3.23 ± 0.30	$(1+\epsilon_R)$	axial
$B \to X_u \ell \bar{\nu}_\ell$	4.39 ± 0.21	$(1+\epsilon_R^2)$	vector & axial
$B \to \tau \bar{\nu}_\tau$	4.32 ± 0.42	$(1-\epsilon_R)$	vector

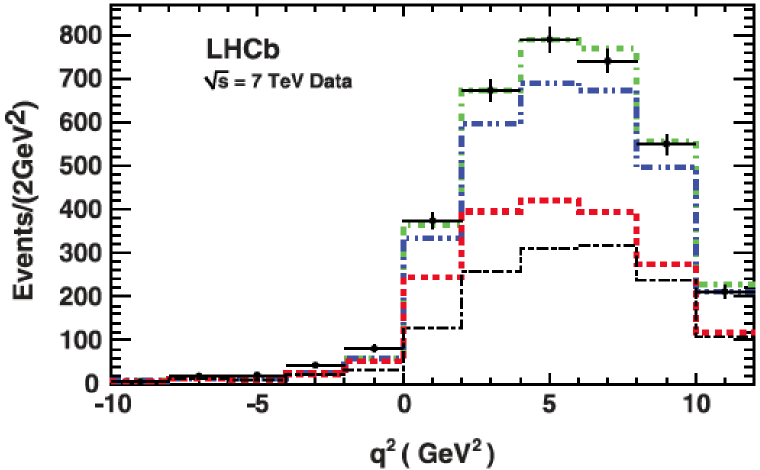
V_{ub} Data

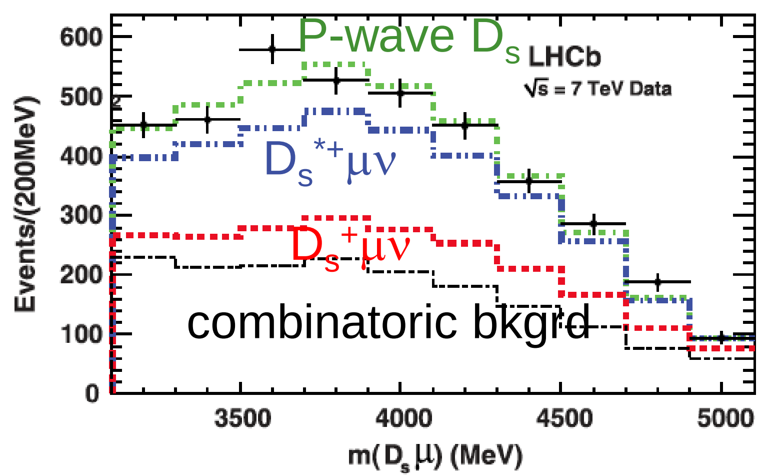
- V_{ub} values as functions of ε_R
- First done by: Crivellin, arXiv:0907.2461
- Ligeti suggests using $\rho\ell\nu$ to measure ε_R



LHCb does semileptonic decays

- Used to measure f_s/f_d, otherwise $B_s \to \mu^+\mu^-$ is only half a measurement (inclusive e.g. $D_s\mu X\nu$; also used for A^s_{sl})
- Exclusive semileptonic can also be done using constraint of knowing b-decay direction (ala' FNAL fixed target experiments)
- Projections of 2-D fit to $D_s\mu X\nu$



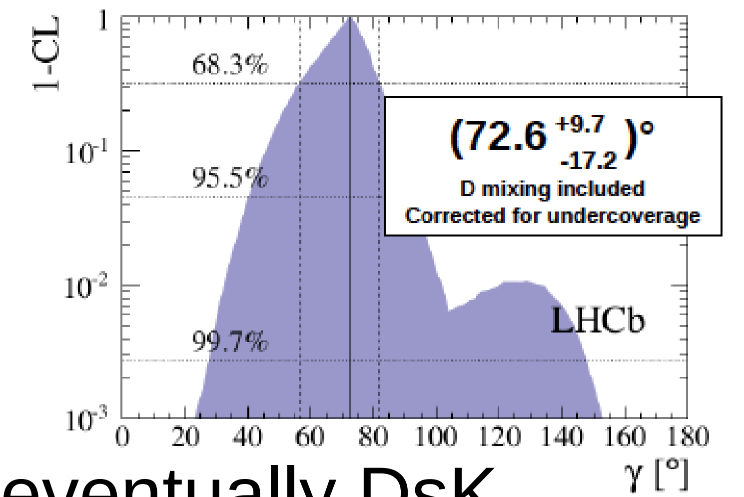


Shopping list

- $B_s \rightarrow K^{(*)}\mu\nu$
- $B_s \rightarrow D_s^{(*)}\mu\nu$ these & above used to provide an independent measure of V_{ub}/V_{cb}
- $B^o \rightarrow \rho^o\mu\nu$ including right-handed current measurements
- $B^o \rightarrow D^{*+}\mu\nu$ including right-handed current measurements
- $B \rightarrow D^{**}\mu\nu$ needed to understand
- $B^o \rightarrow D^{*+}\tau\nu$, see talk of *Ciezarek*

Comments on γ

Paper Phys Lett B 726 (2013) 151

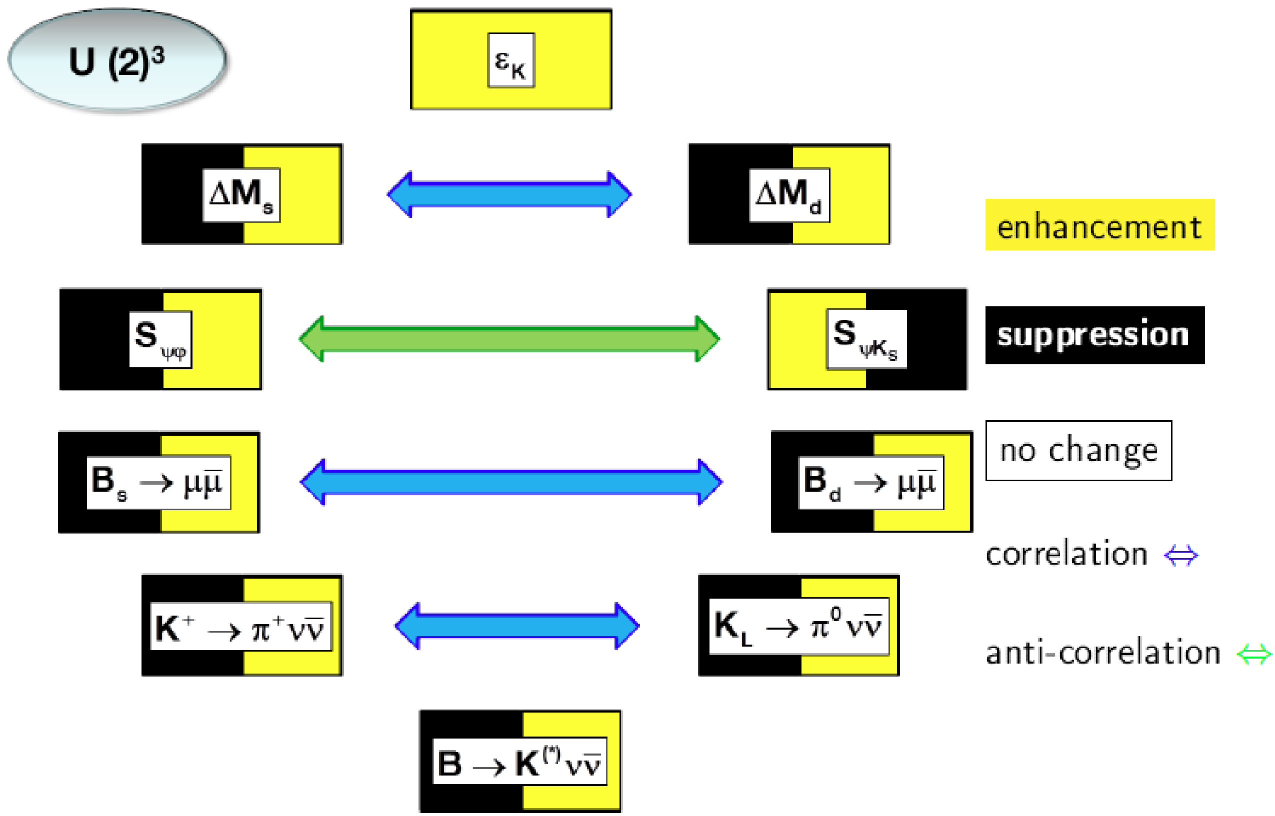


- See talk of Gandini
- Use clean methods only
- Don't use $B^-\rightarrow D^o\pi^-$, due to possible contamination from D^o CPV. Use $B^-\rightarrow D^oK^-$ & eventually DsK
- Don't use $B^o\rightarrow\pi^+\pi^-$, with $B^o\rightarrow K^+K^-$ assuming U-spin symmetry, but use this to measure the U-spin breaking, so we may be able to use U-spin for something else (e.g. limiting Penguins in ϕ_s)

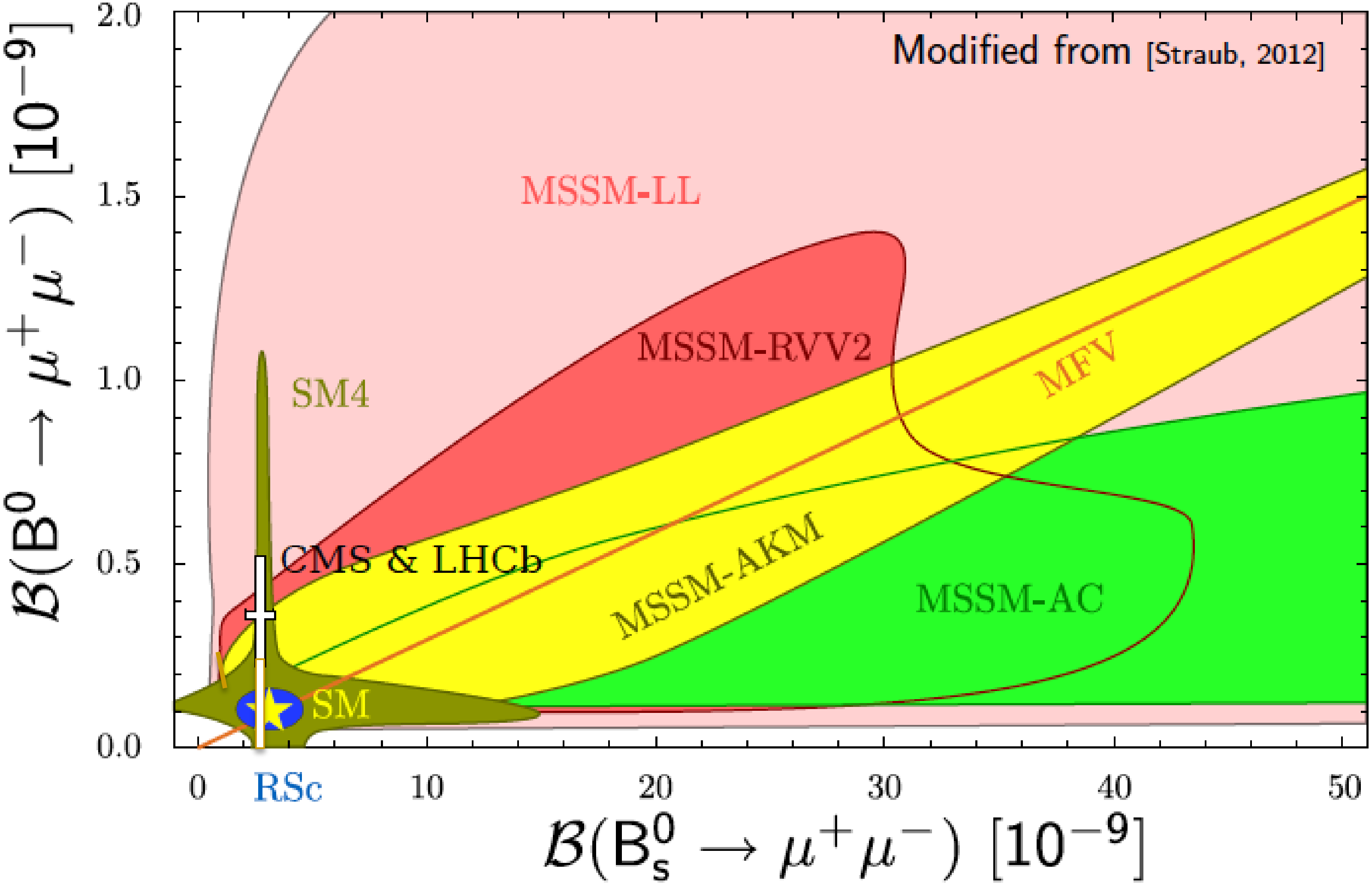
Top Down Analyses

- Here we pick a model and work out its consequences in many modes
- Example

Girrbach

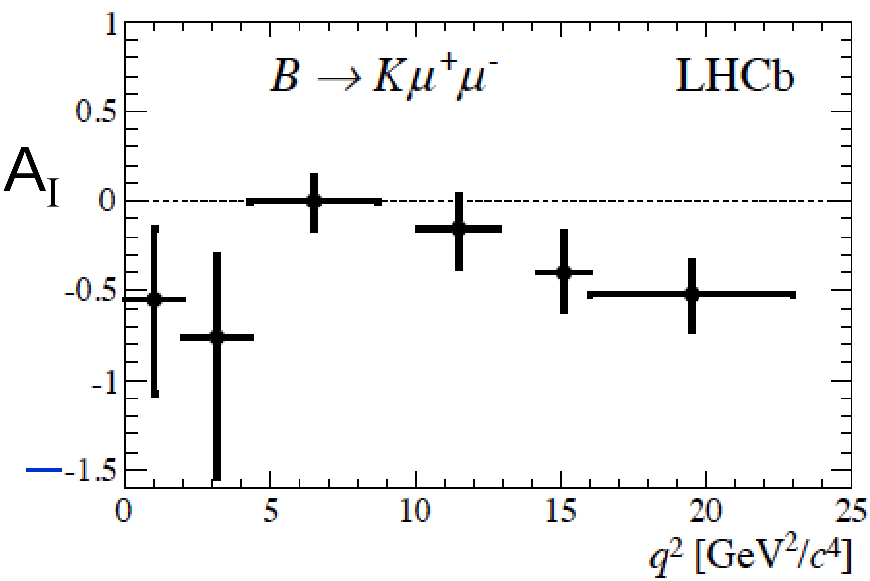


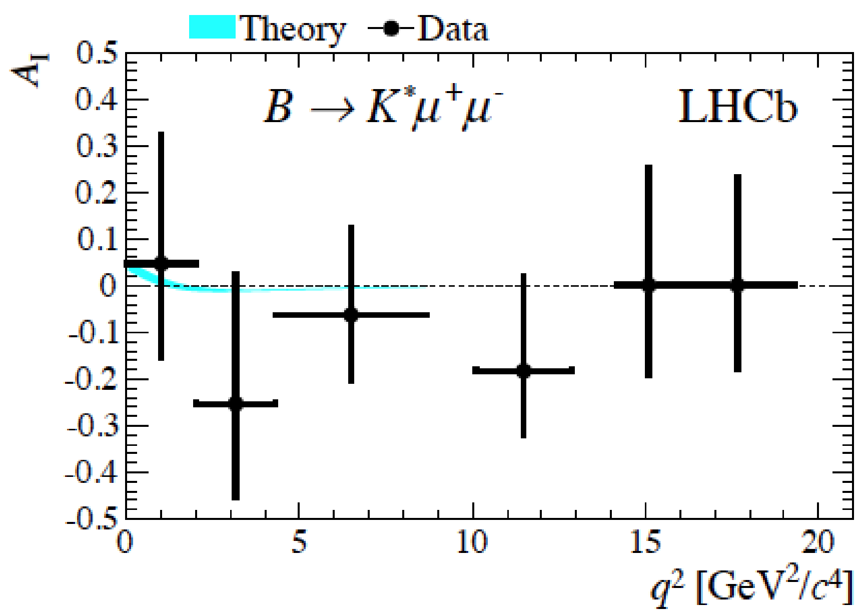
Another Top Down Ex.



B→K$^{(*)}\ell^+\ell^-$ I

- I find K$\ell^+\ell^-$ very interesting (*Langenbruch talk*)
- (1) Isospin asymmetry at 4.4 σ level & doesn't look like experimental effect as not seen in K*$\ell^+\ell^-$. No model can reproduce effect. A real hint at NP or long distance effects that we do not understand? (*Zwicky talk*)

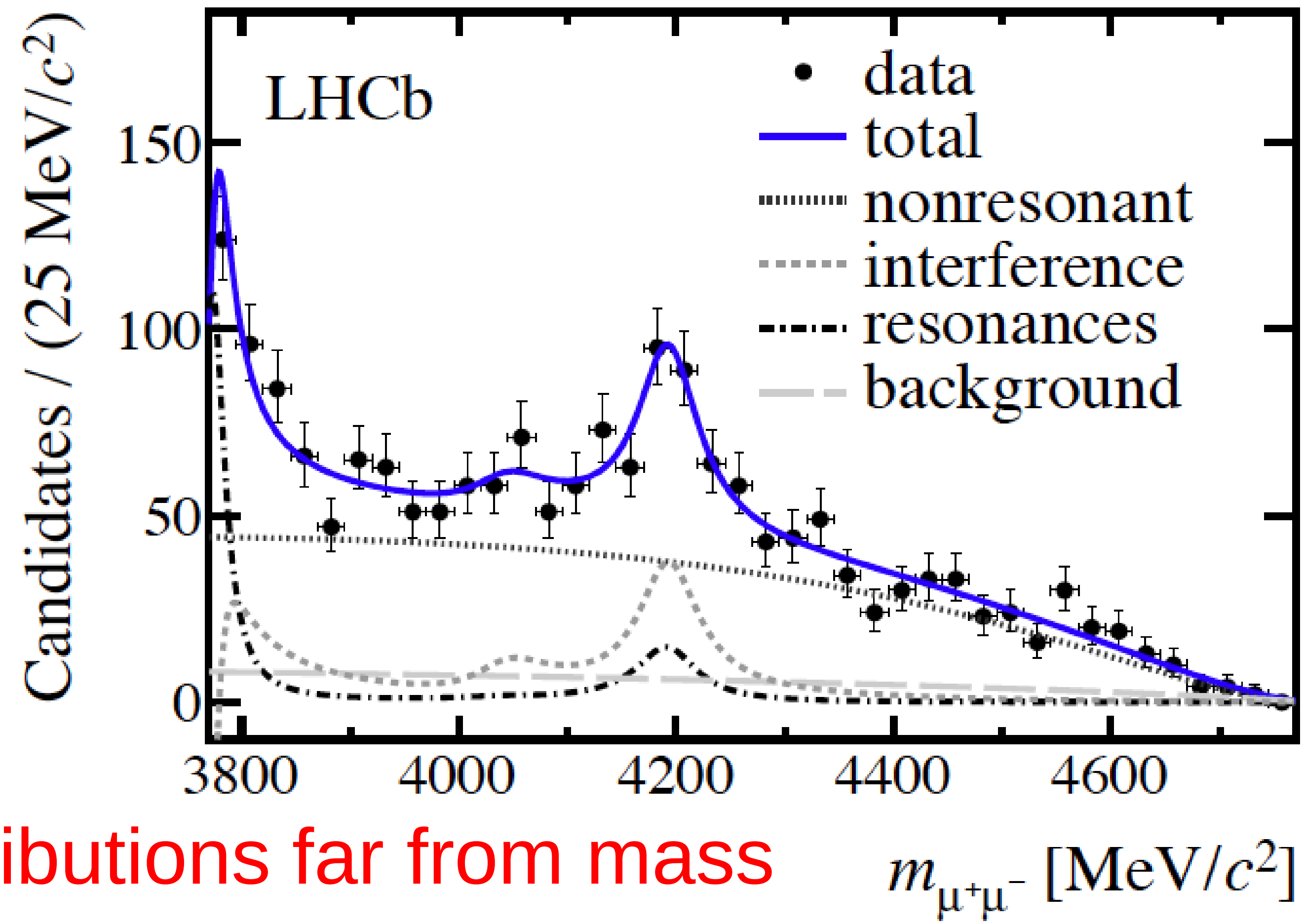




$B \to K^{(*)}\ell^+\ell^-$ II

- (2) Resonant substructure in $\ell^+\ell^-$. Should be present in $K^{(*)}\ell^+\ell^-$. Why hasn't it been seen?
- Are there more states?
- Need to put in K* calculations.

Can affect angular distributions far from mass peaks as states are wide



$K^*\ell^+\ell^-$ déjà vu ΔA_{cp}?

- 1st ΔA_{cp} then P_5' in one q^2 bin. Theory input…

$B \rightarrow K^{(*)}\ell^+\ell^-$ III

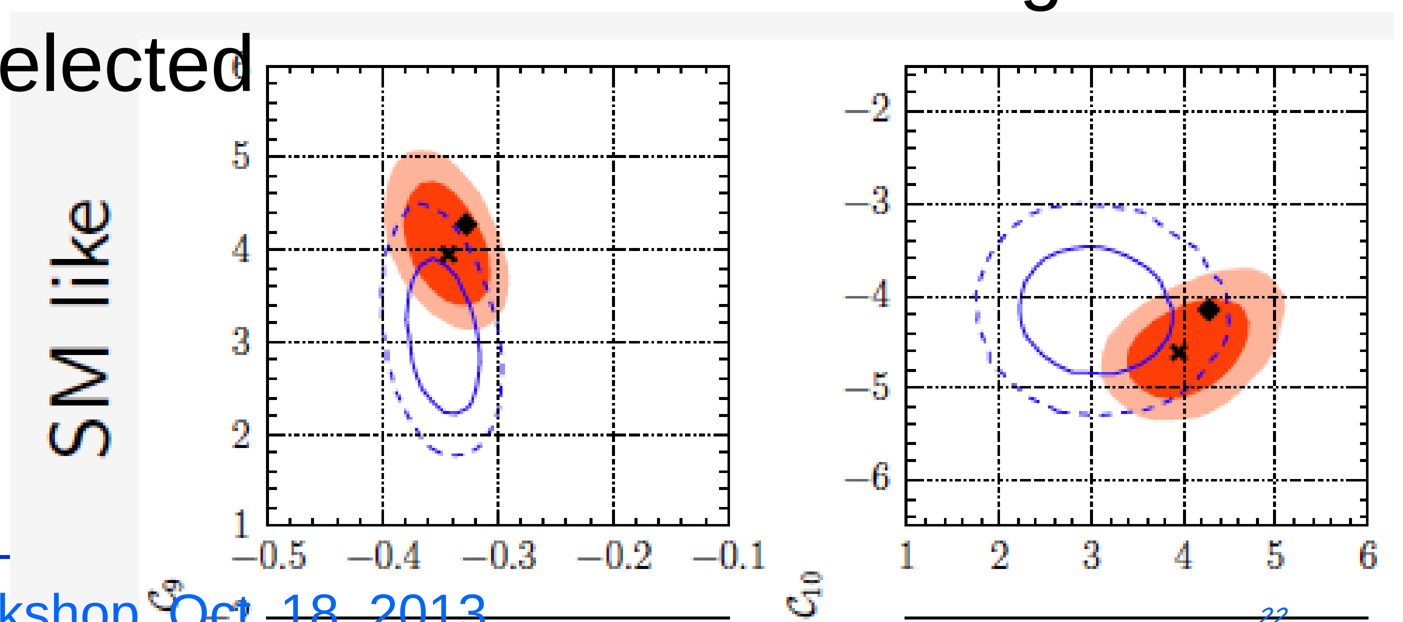
- Much ado about discrepancy in one q^2 bin with some SM predictions
- In order to see NP must see more than one effect. Need to establish a pattern
- van Dyk: some difference between using all data and selected

red(all)

blue(sel)

68%, & 95%

cl intervals



$B \to K^{(*)}\ell^+\ell^-$ IV

- Straub: top down model with multi-TeV Z´ can explain data
- PS: some disagreement in theoretical prediction uncertainty (see talks of van Dyk and Mahoudi) & relatively large errors. Wingate: lattice QCD can help

Null Test From Charm

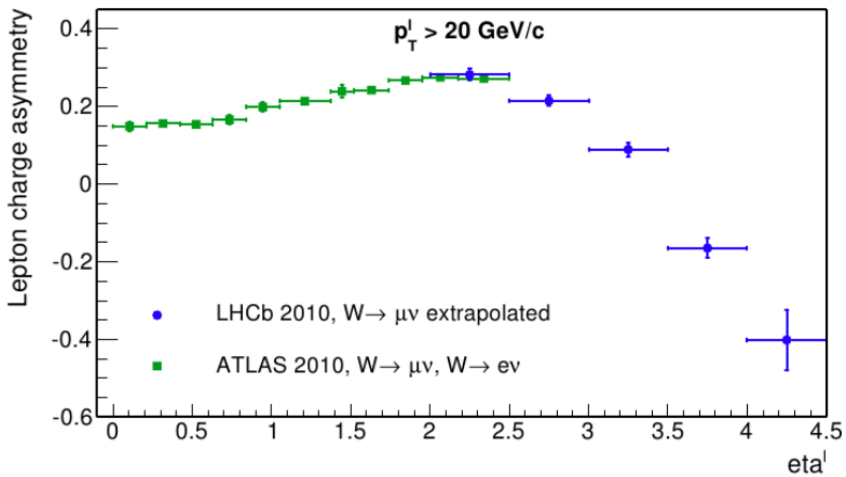
- Charm CPV not established. ΔA_{cp}
  - HFAG = (0.33±0.12)%
  - LHCb $\pi^{\pm}$ tags (-0.34±0.18)%, $\mu^{\pm}$ tags (0.49±0.37)%
  - My view $|\Delta A_{cp}|<(1-\varepsilon)\%$, where $\varepsilon \sim 0.5$ (more data needed)
  - A very useful constraint on NP models
- Not a null test: Charm mixing firmly established at 1% level, likely long distance effect $D^0 \Rightarrow \pi\pi(KK)(...) \Rightarrow \bar{D}^0$, but x´ & y´ parameters not yet well measured

Null Tests from B CPV

- ϕ_s: 0.01±0.07±0.01 rad
  - potential use of all the $B_s \to J/\psi\ K^+K^-$ rate (see Van Leerdam's talk)
- A_{SL}^s x3 statistics available
- Both important to search for NP

Seeking NP at higher masses (Coco)

- Since Higgs couples to mass we should do what we can on top quarks especially where we can do better than ATLAS & CMS despite the factor of 10 less ∫L
- Strassler points out other searches for new Higgs decays or new long lived particles



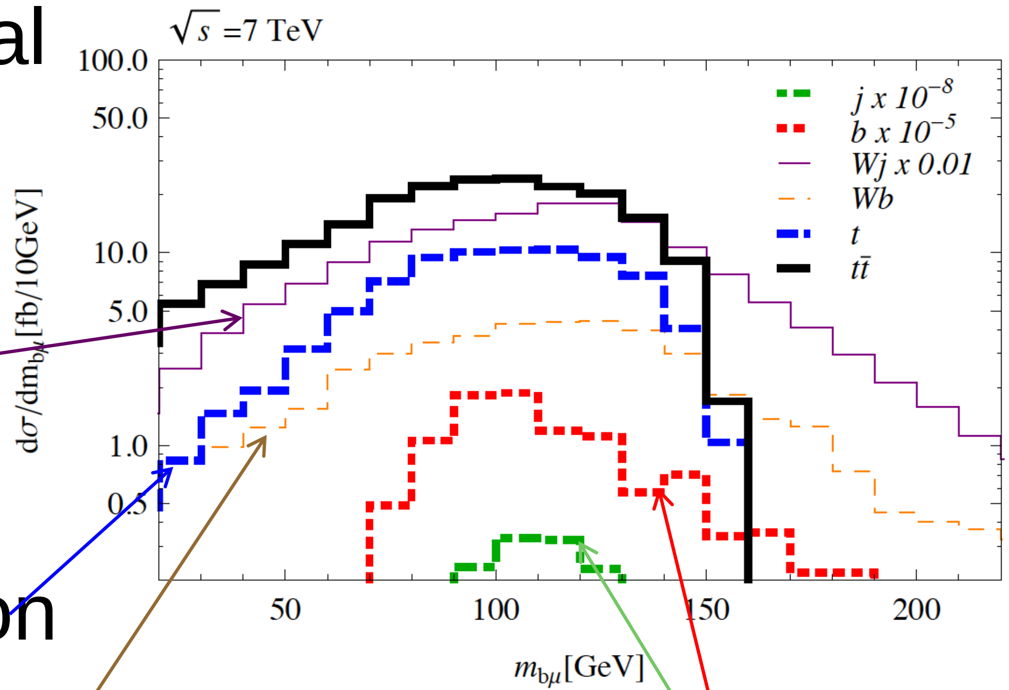
- Can also search for Majorana neutrinos from D, B or even W decays

$t\bar{t}$ asymmetry

- Seen in CDF & D0
- (By the way getting fed up with disproving CDF/D0 results hinting at NP, e.g. ϕ_s, A_{sl})
- Because LHC is at larger η asymmetry is larger than in ATLAS/CMS due to more $q\bar{q}$ and qg scattering
- Use $t\rightarrow Wb$, $W\rightarrow\mu\nu$,
- Predictions of signal & background from Kagan, Kamenik, Perez & Stone arXiv:1103.3747

Predictions for LHCb

- $t \to Wb$, $W \to \mu\nu$ signal
- W+light quark jet including charm scaled to ATLAS measured σ.
- Single top production
- W+$\bar{b}$ jet (not from top)
- $b\bar{b}$ with one $b \to \mu$, reduced by jet isolation (anti-kt jet algorithm used)
- light dijet's reduced by b tagging, jet isolation & μ id

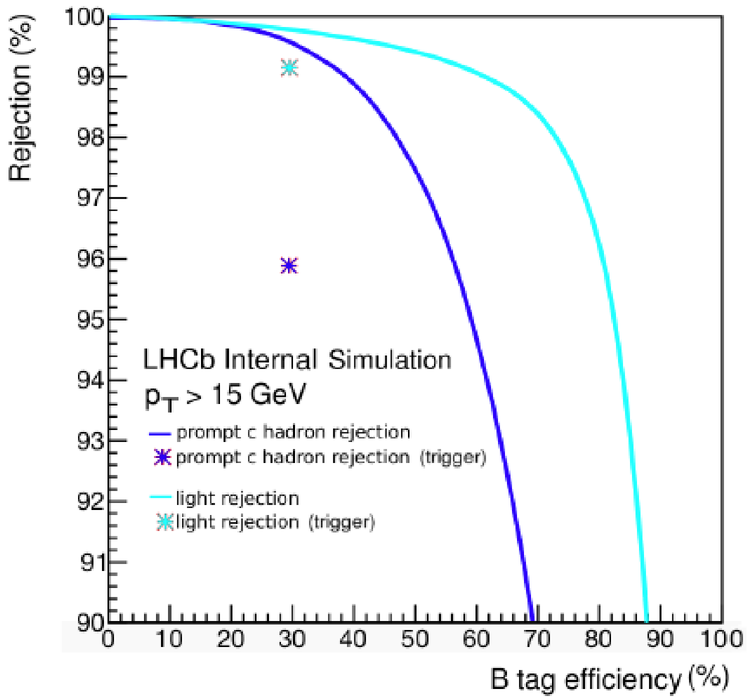


Necessary Ingredients for $t \rightarrow bW$

- $W^{\pm} \rightarrow \mu^{\pm}\nu$ detection
- Jet reconstruction and energy measurement
  - Require large efficiency for high p_T, and energy resolution so that $\sigma_{m(\mu\text{-jet})} \sim 20$ GeV
- Algorithm for b-jet tagging
  - Measurement of tagging efficiency (ε)
  - Measurement of light quark rejection (R)
  - Requirement is $R > 100:1$ for $\varepsilon > 50\%$

Current LHCb (Barter)

- Jet energy scale determined to 1% from Z+1 jet events
- For p_T>10 GeV jet energy resolution is 10-15%
- b-jet tagging: for 50% eff have 99.5% light quark rejection. $b\bar{b}$ asymmetry already measured
- $t\bar{t}$ asymmetry measurement is ready for prime time

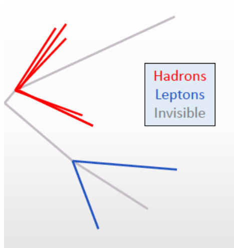


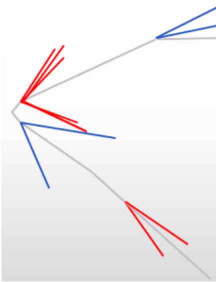
Much other physics (Strassler)

My view -- Highest priority for LHCb for Long-Lived Particles: Higgs boson decays

- We know at least one exists!
- The Higgs decays via weak couplings/loops/off-shell W/Z and is very sensitive to new particles.
- Must develop comprehensive knowledge of this particle
- Tough Target: Many final states difficult for ATLAS/CMS
- But if you can do it, many Higgs-related searches will exclude other models too

- For long-lived particles, LHCb has a niche
  - Low masses (0.1? – 100? GeV)
  - Short lifetimes (ps – 100 ps)
  - Complex final states with multiple (possibly clustered) vertices
  - Final states with 1 or 0 leptons and many hadrons





- Fortunately this is an extremely interesting niche because it is where the Higgs boson sits

Conclusions

- Recall Prime Objective: to seek out and find new physics wherever it may be hiding
- We have a great deal to do even with current data: many areas not discussed in this workshop, e.g. CPV in B^o, B_s etc…light meson spectroscopy: $q\bar{q}$ versus tetraquark, etc..
- Much to do with jets, right-handed currents, γ, V_{ub}, $K^{(*)}\mu\mu$, even charm
- It will be fun!
- Much thanks to our theory friends for coming

For Yuval

Pleasant Dreams!

- LHCb discovers New Physics

The End

Signal example

- Predicted cross-section difference between t and t̄ in the Z′ model of Jung et al. [arXiv:0907.4112]