Summary & Outlook

15th International Conference on B-Physics at Frontier Machines
Edinburgh, UK
July 14-18, 2013

Hassan Jawahery
University of Maryland

Apologies:

- No good jokes
- Not a comprehensive summary of this very rich conference (61 talks).
- Fortunately several excellent overview talks cover some of the key areas:
  - Heavy Flavor production (M. Cacciari)
  - Spectroscopy and Exotica (A. Polosa)
  - Kaon Physics (M. Sozzi)
  - Lepton Flavor Violation (V. Cirigliano)

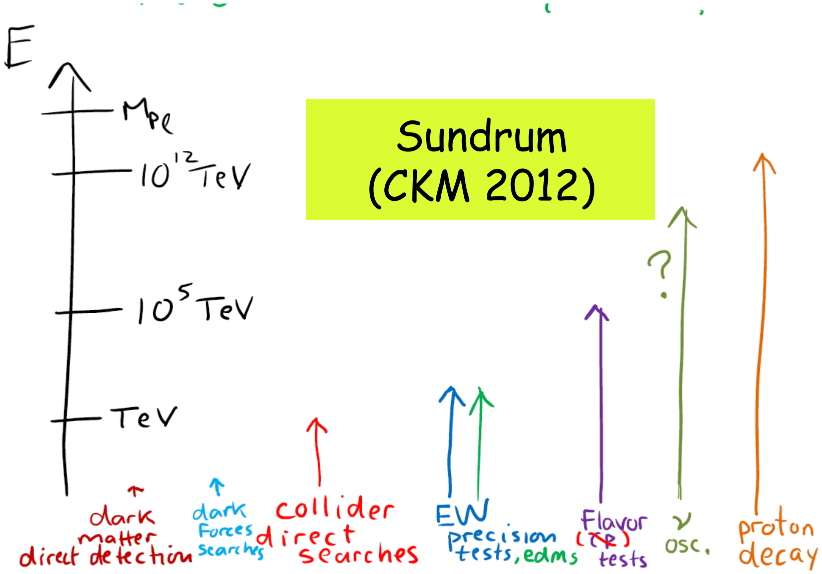
Summary from a narrow perspective:

Personal take on how are we advancing on our Flavor-New Physics project.

According to famous theorists:

Flavor's great physics power rests in its current exclusive access to CPV & NP reach of FCNC processes.

➔ Potential access to very high energy scales.

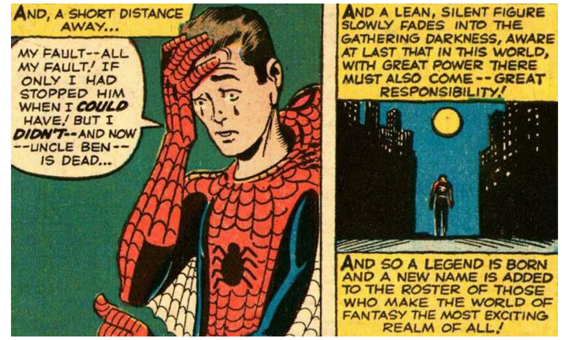


Isidori, Nir, Perez

Operator	Bounds on Λ [TeV] ($C = 1$) Re	Bounds on Λ [TeV] ($C = 1$) Im	Bounds on C ($\Lambda = 1$ TeV) Re	Bounds on C ($\Lambda = 1$ 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; $\lvert q/p \rvert, \phi_D$
$(\bar{c}_R u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	Δm_D; $\lvert q/p \rvert, \phi_D$
$(\bar{b}_L \gamma^\mu d_L)^2$	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}; $S_{\psi\phi}$

“With great power comes great responsibility”

Uncle Ben/Spiderman



Like it or not, the successful CKM-project of the past two decades has morphed into the Flavor-NP project- our main responsibility now.

Outline:

- Highlight of the recent results on some of the key parameters of this project.
- Preparation for the precision era.

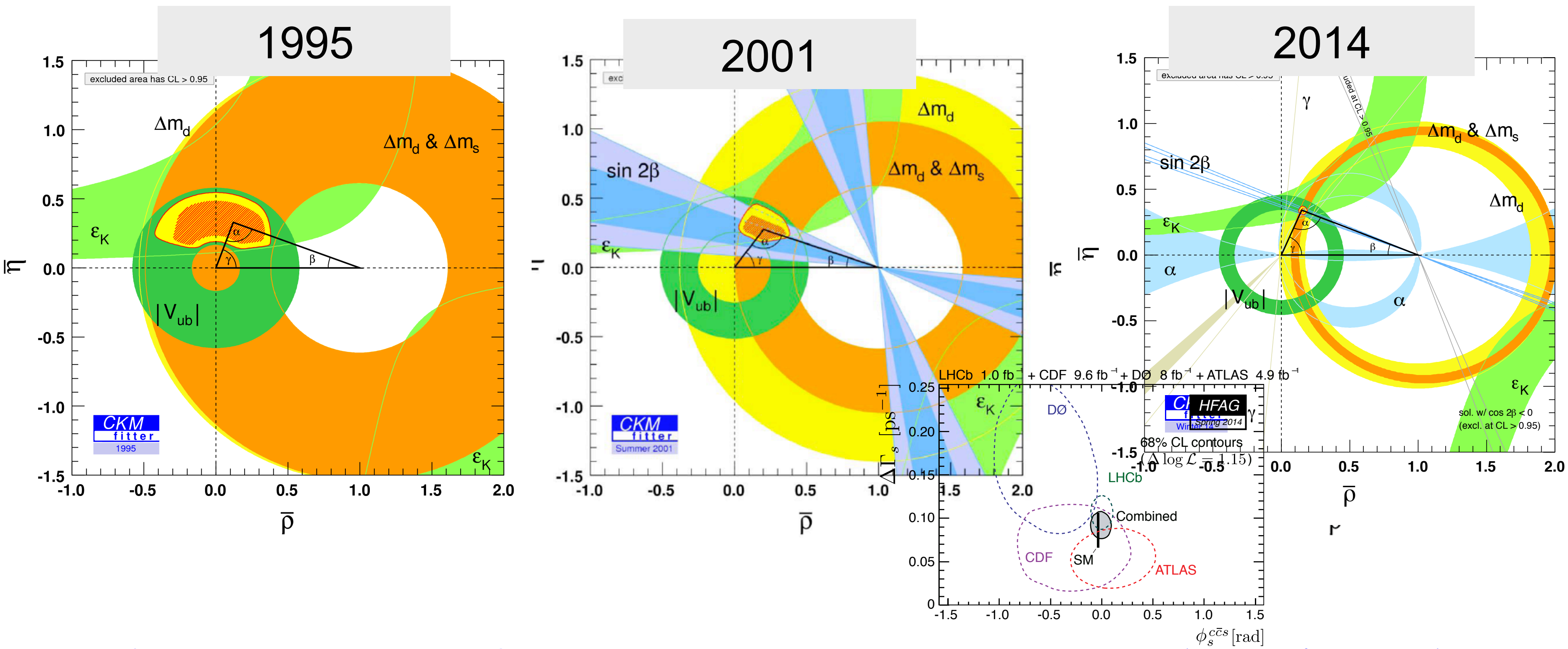
Conclusions:

✓Flavor Physics seems in excellent health

- LHCb, with CMS & ATLAS in certain areas, is now dominating the new findings:
  - B factories and Tevatron, in their legacy state, and BESS-III still producing consequential physics results.

- Future looks great: Flavor physics remains one of the key drivers – (in US P5 language)- of the search for New Physics beyond SM.
  - Experimental outlook seems bright, and includes: two Super Flavor experiments, two cLFV experiments, and two rare kaon experiments.

The CKM-project has been extremely successful
Thanks to the B factories, Tevatron , LHC, theory insights & LQCD



- The CKM picture of CPV in SM seems to be correct (Nobel 2008)
- Flavor remains the only source of observed CP & T-violations
- Precisions of rare FCNC processes have significantly improved

→ Severe constraints on possible scenarios of New Physics
Still leaving plenty of room for NP

Assessing the task: How much NP is allowed?

- Example: NP constraints from Meson Mixing

Charles et al (arXiv: 1309.2293).

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

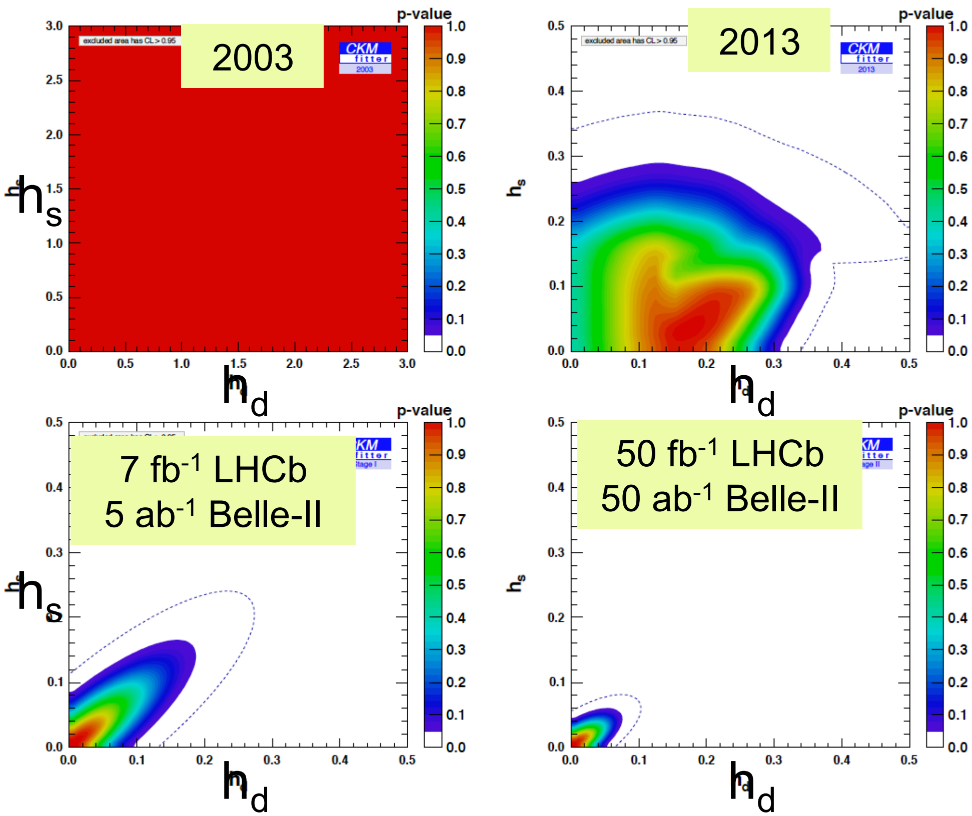
➢Current data:

◆B_s is now on equal ground as B_d system (Thanks to LHCb results).

◆Data allows NP at 20-30% SM

➢Future:

If consistency with SM persists- LHCb and Belle-II measurements- combined with improved LQCD errors- will constrain the magnitude of NP contribution to ~5% of SM



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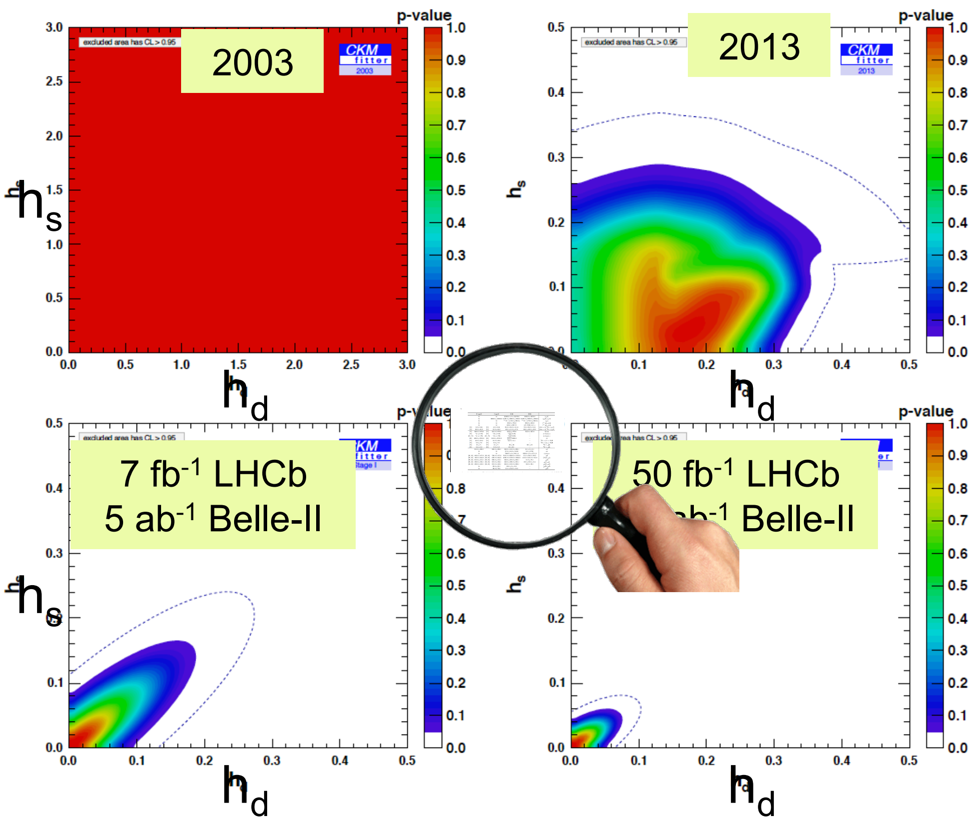

A closer look at the numbers reveals some of the challenges ahead

	2003	2013	Stage I		Stage II	
$\|V_{ud}\|$	0.9738 ± 0.0004	$0.97425 \pm 0 \pm 0.00022$	id		id	
$\|V_{us}\|$ $(K_{\ell 3})$	$0.2228 \pm 0.0039 \pm 0.0018$	$0.2258 \pm 0.0008 \pm 0.0012$	0.22494 ± 0.0006		id	
$\|\epsilon_K\|$	$(2.282 \pm 0.017) \times 10^{-3}$	$(2.228 \pm 0.011) \times 10^{-3}$	id		id	
Δm_d [ps^{-1}]	0.502 ± 0.006	0.507 ± 0.004	id		id	
Δm_s [ps^{-1}]	> 14.5 [95% CL]	17.768 ± 0.024	id		id	
$\|V_{cb}\| \times 10^3$ $(b \to c\ell\bar{\nu})$	$41.6 \pm 0.58 \pm 0.8$	$41.15 \pm 0.33 \pm 0.59$	42.3 ± 0.4	[17]	42.3 ± 0.3	[17]
$\|V_{ub}\| \times 10^3$ $(b \to u\ell\bar{\nu})$	$3.90 \pm 0.08 \pm 0.68$	$3.75 \pm 0.14 \pm 0.26$	3.56 ± 0.10	[17]	3.56 ± 0.08	[17]
$\sin 2\beta$	0.726 ± 0.037	0.679 ± 0.020	0.679 ± 0.016	[17]	0.679 ± 0.008	[17]
α (mod π)	—	$(85.4^{+4.0}_{-3.8})^\circ$	$(91.5 \pm 2)^\circ$	[17]	$(91.5 \pm 1)^\circ$	[17]
γ (mod π)	—	$(68.0^{+8.0}_{-8.5})^\circ$	$(67.1 \pm 4)^\circ$	[17, 18]	$(67.1 \pm 1)^\circ$	[17, 18]
β_s	—	$0.0065^{+0.0450}_{-0.0415}$	0.0178 ± 0.012	[18]	0.0178 ± 0.004	[18]
$\mathcal{B}(B \to \tau\nu) \times 10^4$	—	1.15 ± 0.23	0.83 ± 0.10	[17]	0.83 ± 0.05	[17]
$\mathcal{B}(B \to \mu\nu) \times 10^7$	—	—	3.7 ± 0.9	[17]	3.7 ± 0.2	[17]
$A^{d}_{SL} \times 10^4$	10 ± 140	23 ± 26	-7 ± 15	[17]	-7 ± 10	[17]
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$\bar{m}_c$	$1.2 \pm 0 \pm 0.2$	$1.286 \pm 0.013 \pm 0.040$	1.286 ± 0.020		1.286 ± 0.010	
$\bar{m}_t$	167.0 ± 5.0	$165.8 \pm 0.54 \pm 0.72$	id		id	
$\alpha_s(m_Z)$	$0.1172 \pm 0 \pm 0.0020$	$0.1184 \pm 0 \pm 0.0007$	id		id	
B_K	$0.86 \pm 0.06 \pm 0.14$	$0.7615 \pm 0.0026 \pm 0.0137$	0.774 ± 0.007	[19, 20]	0.774 ± 0.004	[19, 20]
f_{B_s} [GeV]	$0.217 \pm 0.012 \pm 0.011$	$0.2256 \pm 0.0012 \pm 0.0054$	0.232 ± 0.002	[19, 20]	0.232 ± 0.001	[19, 20]
B_{B_s}	1.37 ± 0.14	$1.326 \pm 0.016 \pm 0.040$	1.214 ± 0.060	[19, 20]	1.214 ± 0.010	[19, 20]
f_{B_s}/f_{B_d}	$1.21 \pm 0.05 \pm 0.01$	$1.198 \pm 0.008 \pm 0.025$	1.205 ± 0.010	[19, 20]	1.205 ± 0.005	[19, 20]
B_{B_s}/B_{B_d}	1.00 ± 0.02	$1.036 \pm 0.013 \pm 0.023$	1.055 ± 0.010	[19, 20]	1.055 ± 0.005	[19, 20]
$\tilde{B}_{B_s}/\tilde{B}_{B_d}$	—	$1.01 \pm 0 \pm 0.03$	1.03 ± 0.02		id	
$\tilde{B}_{B_s}$	—	$0.91 \pm 0.03 \pm 0.12$	0.87 ± 0.06		id	

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Stage II: ~2% Vub
~1% Vcb

Stage II: γ at 1° – & α at 1°
where is the limit of isospin analysis for α

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Sin2β & ϕ_s ultimately limited by knowledge of color suppressed penguins- (R. Fleisher)

Stage II is counting on ~0.5% accuracy on lattice inputs

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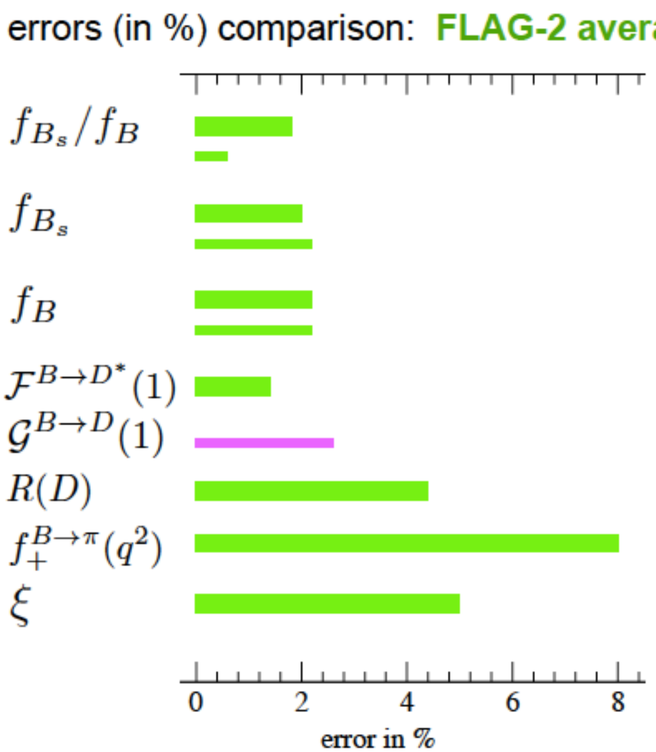
➢ Progress on this program rests on significant improvement on knowledge of theoretical inputs.

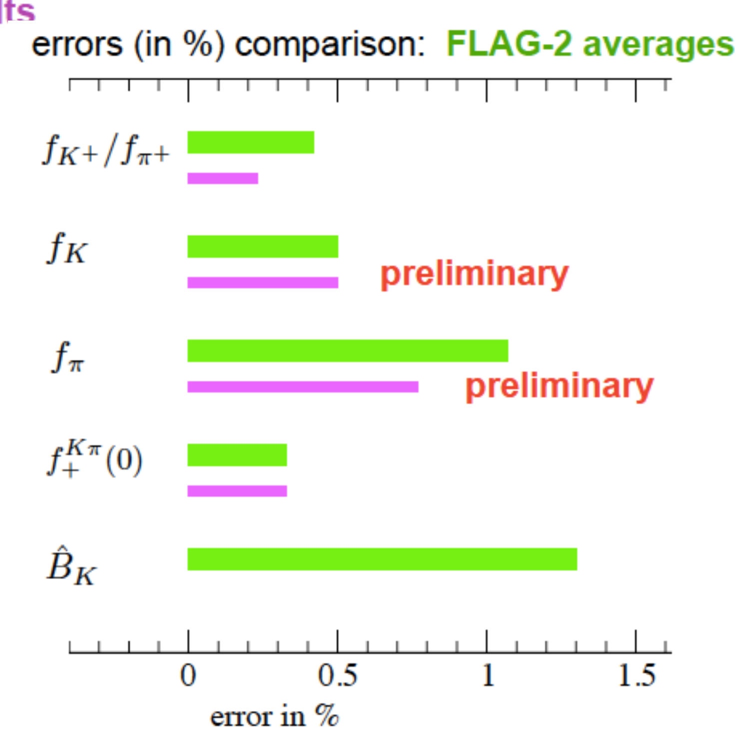
➢In many cases, the past approaches, including data driven methods, wont work for some of the key measurements. Pressure is mounting on LQCD to deliver validated precision results.

See the talk on status of LQCD by Aida El-Khadra

- Significant progress made over the past decade both in precision and in validation approach- now predictions are available to be tested with data.

- Can we reach sub-percent accuracy? (This is beyond my pay-grade to say- but given recent advances, it seems promising.)





Of course, Flavor-NP program is much broader than mixing: Example of theorist vision: *"DNA of flavor physics effects"*

by W. Altmannshofer, A.J. Buras, S. Gori, P. Paradisi D.M. Straub,

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{\rm CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

★★★ large effects
★★ visible but small effects
★ unobservable effects

In practice, data itself may set the direction if some of the current tensions survive:

- puzzles & areas of tension with SM slowly growing; all in need of plausible SM explanations ..or (NP?)
  - Inclusive vs exclusive Vub and Vcb
  - Sin2β tension (direct vs CKM fit)
  - Di-muon Asymmetry
  - Lepton universality tests (e.g. B->$D^{(*)}\tau\nu$,..)
  - Tensions in radiative decays
  - Kp-puzzle
  - large direct CPV in B
  - …

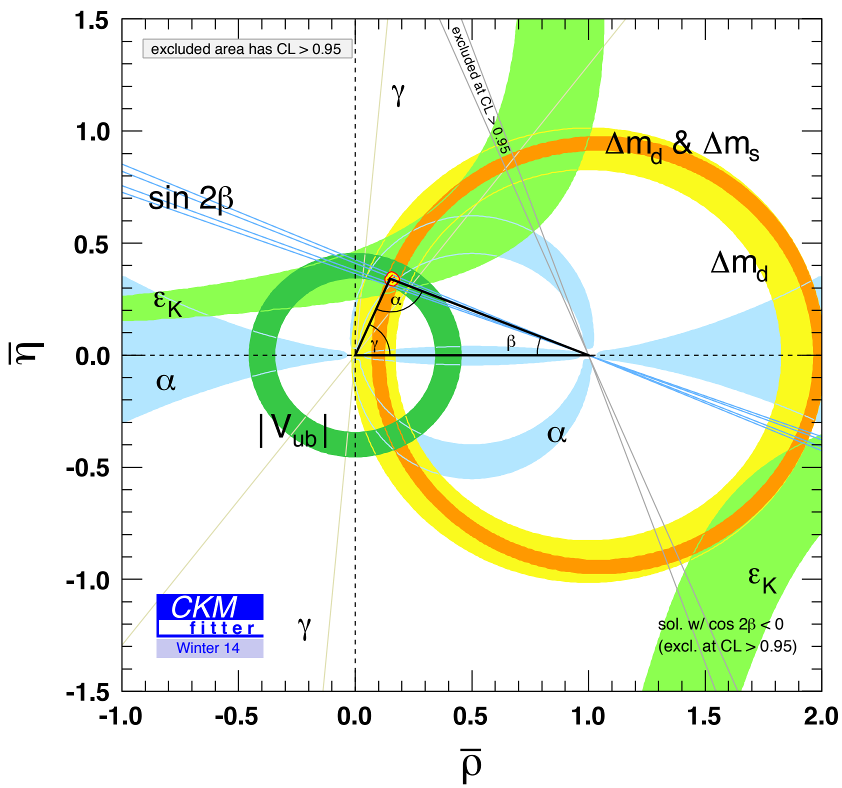
……

The view from Beauty 2014

Beauty 2014: Status of CKM

All is well with the CKM picture at O(10%) level:

$$\alpha + \beta + \gamma = (175.2 \pm 9.3)^o$$



	Direct	CKM fit
α	$= \left(88.8^{+4.5}_{-4.3}\right)^o$	$\left(93.6^{+3.2}_{-2.9}\right)^o$
β	$= \left(21.5^{+0.8}_{-0.7}\right)^o$	$\left(25.38^{+0.80}_{-1.57}\right)^o$
γ	$= \left(70^{+7.7}_{-9.0}\right)^o$	$\left(66.4^{+1.2}_{-3.3}\right)^o$
$-2\beta_s$	$= +0.00 \pm 0.07$	$-0.0363^{+0.0014}_{-0.0012}$

Sin2β tension (driven by B→τν) eased

$\sin 2\beta = 0.682 \pm 0.019(meas) \qquad 0.774^{+0.017}_{-0.036}(fit) \quad (< 2.3\sigma)$

|Vub| and |Vcb| :
Exclusive vs Inclusive results still don't agree (~3 σ effects)

Beauty 2014: Status of CKM

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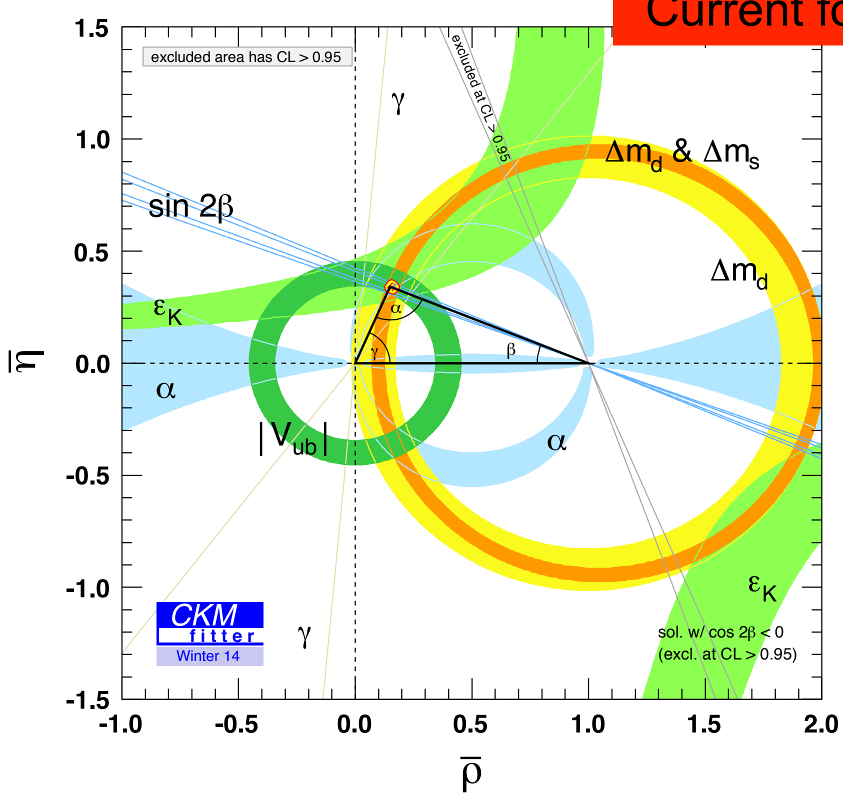

Current focus

	Direct	CKM fit
α	$= \left(88.8^{+4.5}_{-4.3}\right)^o$	$\left(93.6^{+3.2}_{-2.9}\right)^o$
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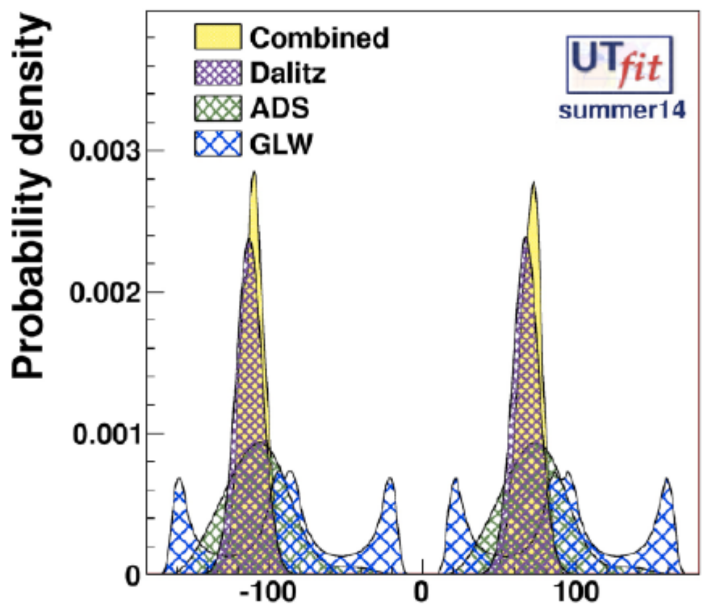
Beauty 2014: Status of CKM
New results on gamma (from tree processes)

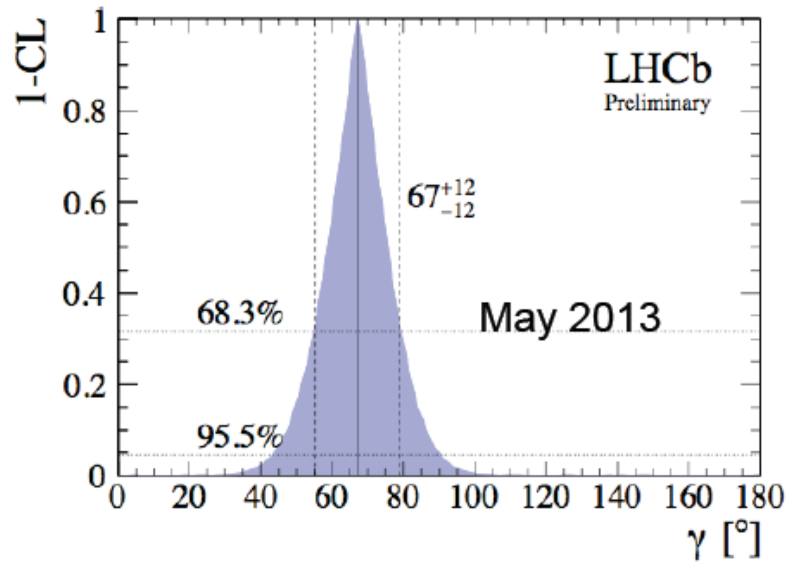
Sneha Malde 15th July 2014

LHCb measurement from B->DK (combined GLW, ADS, GGSZ) is already as precise as BaBar/Belle



$$\gamma\,(combined) = 68.3 \pm 7.5^{o} \quad UTFit$$

$$\gamma\,(combined) = 70.0^{+7.7\,o}_{-9.0} \quad CKMfitter$$



With little theoretical pollution, the road is clear for 1-2 degree precision. Aim of LHCb-Upgrade and Belle-II

γ from Time-Dependent analysis of $B_s^0 \to D_s^{\mp} K^{\pm}$

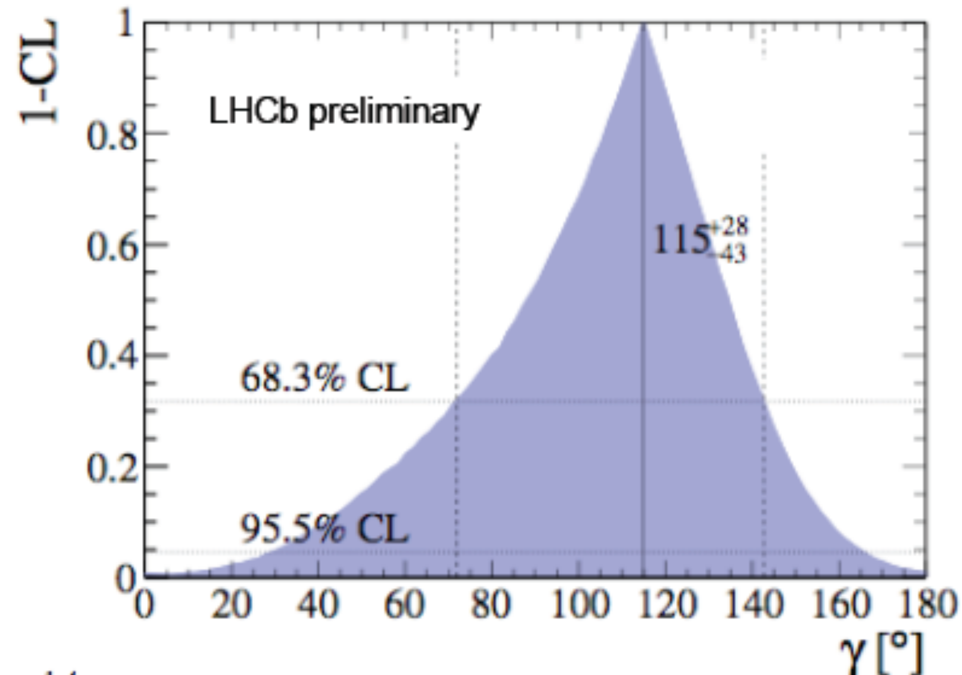
$$\frac{d\Gamma_{B_s^0\to f}(t)}{dt} = \frac{1}{2}|A_f|^2(1+|\lambda_f|^2)e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + C_f\cos(\Delta m_s t) - S_f\sin(\Delta m_s t)\right],$$

Sneha Malde 15th July 2014

$$\gamma = (115^{+28}_{-43})^\circ$$

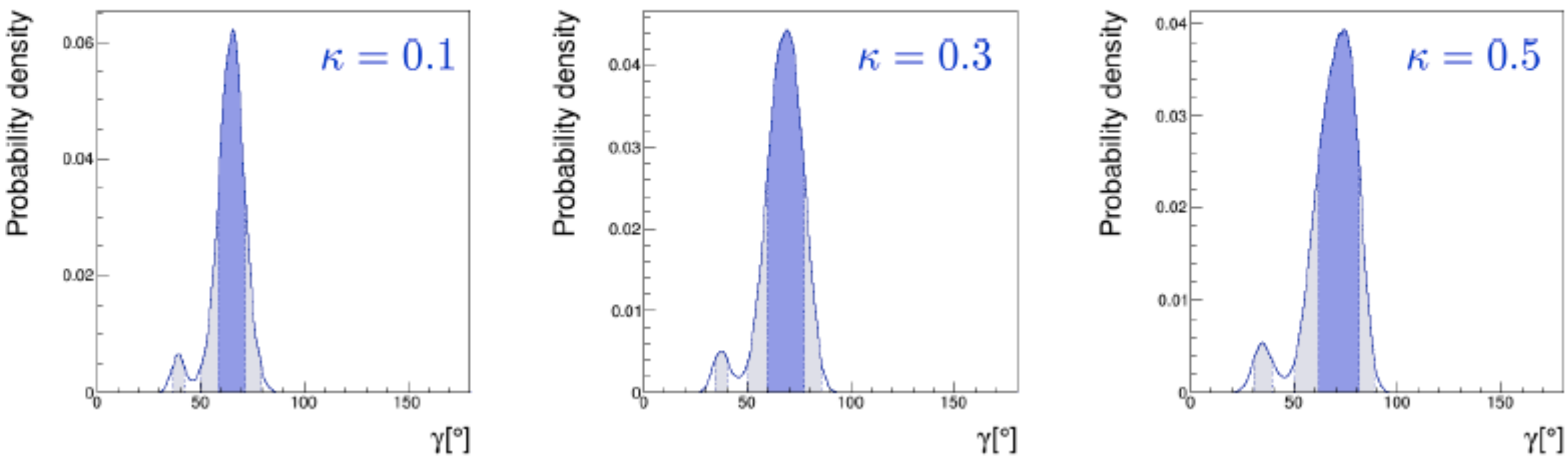
$$r_{D_sK} = (0.53^{+0.17}_{-0.16})$$

$$\delta_{D_sK} = (3^{+19}_{-20})^\circ$$



Beauty 2014: Status of CKM
gamma from B→ππ & KK

M. Ciuchini on γ using Fleischer Method:
U-spin to connect B→π+π− and B→K+K-
Add in Gronau-London Isospin analysis – stable vs U-spin breaking



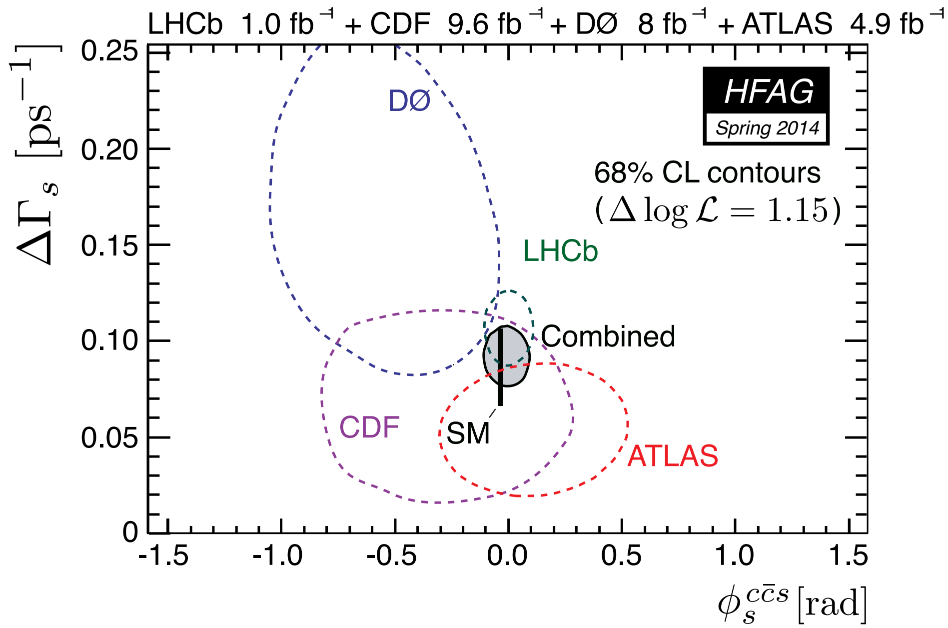
$$\gamma = (68 \pm 15)^\circ \;\; [25^\circ, 87^\circ]$$

Impressive agreement with measurement from Tree processes
Mostly redundant with α measurement from B→ππ

B^0_s system is now an equal player on NP field

ϕ_s=0.00±0.07 (rad)

Γ_s=0.6564±0.0031 (ps^{-1})
$\Delta\Gamma_s$=0.083 ±0.008 (ps^{-1})



Most precise meas. (3/fb)

$$\phi_s(J/\psi\pi^+\pi^-) = 0.070 \pm 0.068 \pm 0.008 \text{ rad}$$

Combining LHCb results:

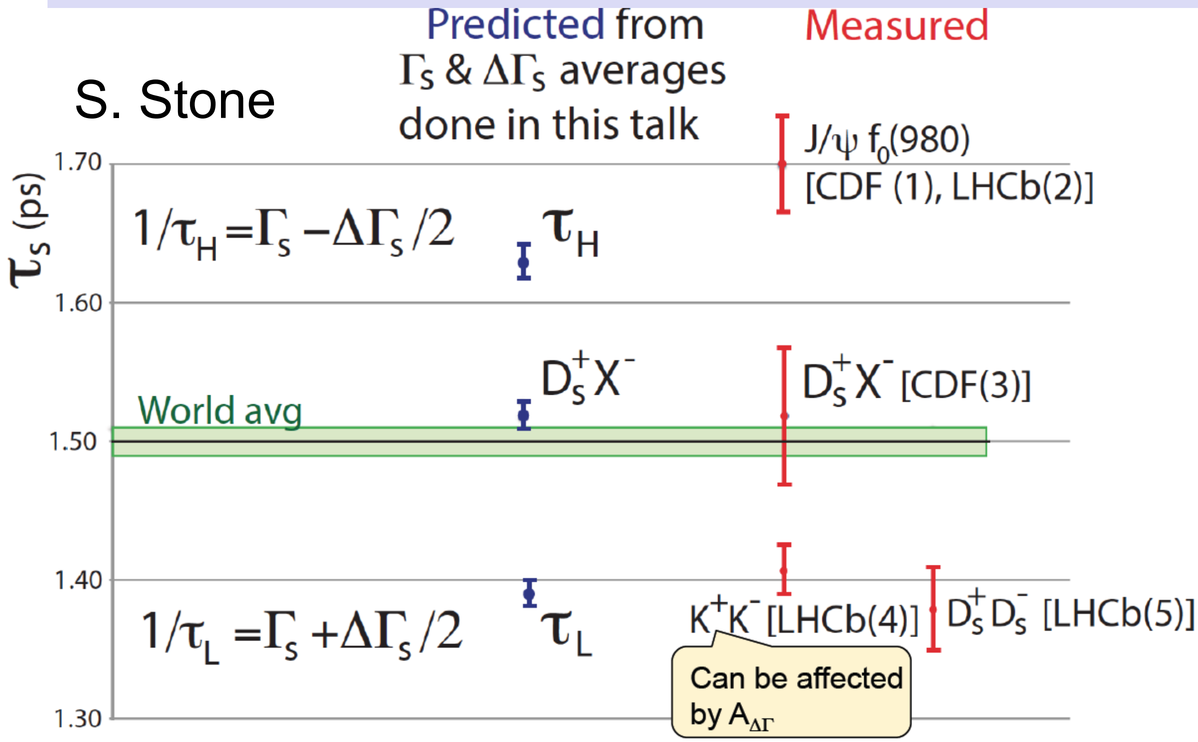
Φ_s=0.07±0.054±0.008 rad

ϕ_s from a $B_s \rightarrow \phi\phi$
(penguin decay)
ϕ_s=-0.17±0.19 ±0.03 (rad)
λ=1.04±0.15±0.03
Consistent with no direct CPV
& SM ϕ_s

Effective Bs lifetime measurements

S. Stone

P. Gandini



1-arXiv:1106.3682, 2-arXiv:1207.0878, 3-arXiv:1103.1864,4-LHCB-PAPER-2014-011,5-arXiv:1312.1217

$$\Delta\Gamma_s = 0.106 \pm 0.013 \quad ps^{-1}$$

$$A_{\Delta\Gamma} = \frac{-2\,\mathrm{Re}(\lambda_f)}{(1+|\lambda_f|^2)} = -0.87 \pm 0.17 \pm 0.13$$

$$(\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f})$$

B^0_s system internally consistent &
All consistent with SM and no evidence for CPV
Except for D0's Di-Muon asymmetry

Semileptonic asymmetry A^s_{sl}

$$A^b_{sl}(D0) = C_d a^d_{sl} + C_s a^s_{sl} + C\frac{\Delta\Gamma}{\Gamma}$$

With $B_s \to D_s \mu\nu$ (with $1fb^{-1}$)

LHCb finds $A^s_{sl} = \left(-0.06 \pm 0.50 \pm 0.36\right)\%$

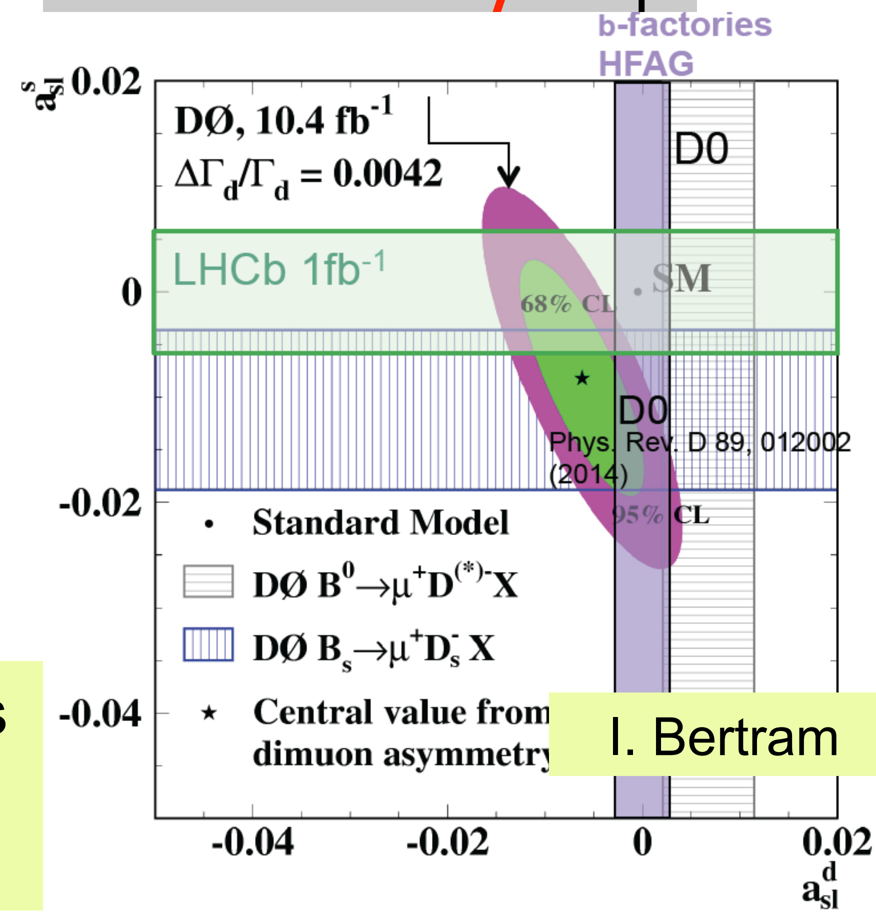
In good agreement with SM

A. Lenz

$$A^d_{fs} = (-4.1 \pm 0.6) \times 10^{-4}$$

$$A^s_{fs} = (1.9 \pm 0.3) \times 10^{-5}$$

D0's anomalous A_{sl} with di-muons persists with the new analysis including the effect of $\Delta\Gamma$.



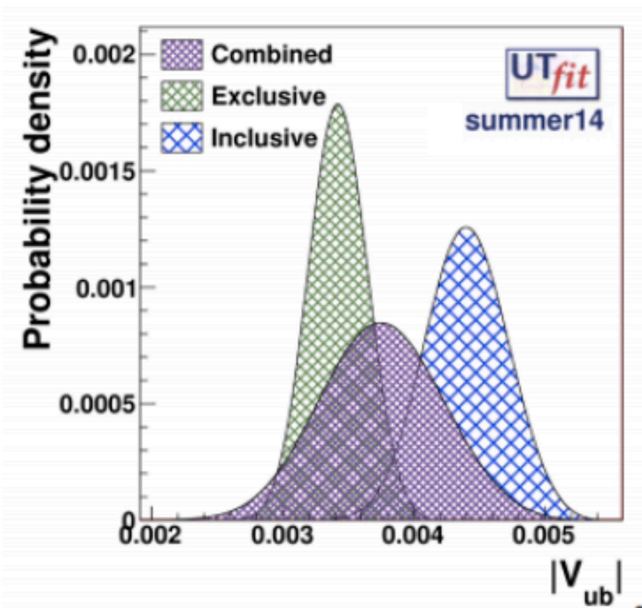
I. Bertram

Vub and Vcb

•Non-zero $|V_{ub}|$ established by CLEO & ARGUS >2 decades ago

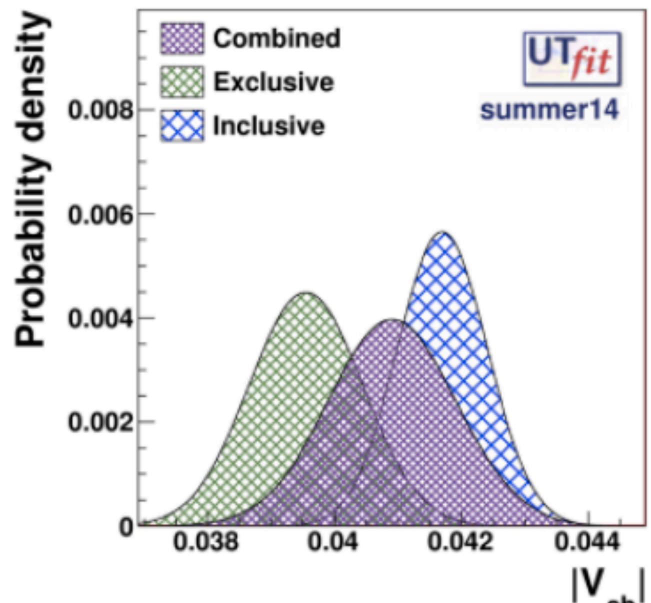
•The magnitude and phases are now measured- but precision measurement (1% for $|V_{cb}|$ and 2% $|V_{ub}|$) remains elusive.

See overview talk by Aoife Bharucha



$V_{ub}(excl) = (3.42 \pm 0.22)\ 10^{-3}$
$V_{ub}(incl) = (4.40 \pm 0.31)\ 10^{-3}$
$V_{ub} = (3.75 \pm 0.46)\ 10^{-3}$

~1.9 σ discrepancy



$V_{cb}(excl) = (39.55 \pm 0.88)\ 10^{-3}$
$V_{cb}(incl) = (41.7 \pm 0.7)\ 10^{-3}$
$V_{cb} = (40.9 \pm 1.0)\ 10^{-3}$

~2.5 σ discrepancy

D. Derkach UTFIT@ICHEP2014

Vub and Vcb

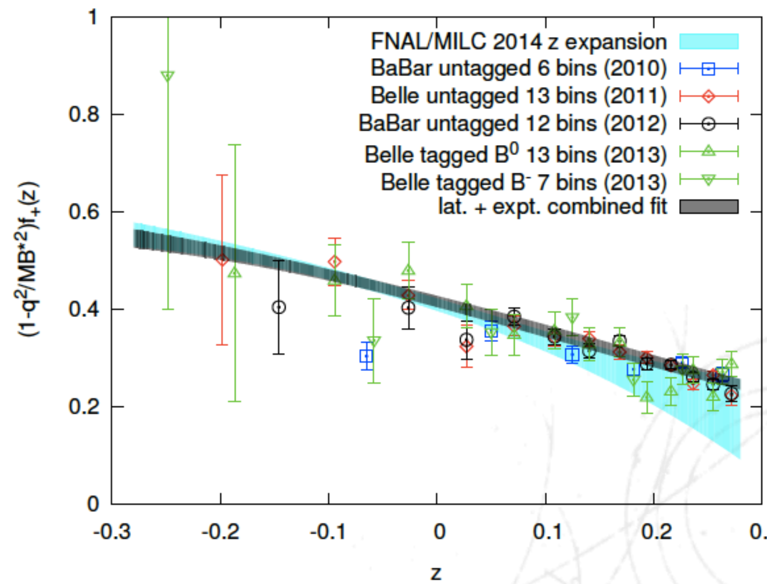
- Both $|V_{cb}|$ and $|V_{ub}|$ are critical to future flavor physics measurements and the search for New Physics in flavor processes.
    - |Vcb| is the dominant source of uncertainty in calculation of rare kaon decays: $K \rightarrow \pi\nu\nu$
    - |Vub| is a key to constraining the CKM parameters free of NP contributions.
    - Both are now dominated by theoretical uncertainties.

- Do we have a way of checking the validity of the theoretical (systematic) uncertainties?
    - Will exclusive vs inclusive approach remain a viable method?
    - Can (validated) Lattice QCD meet the challenge in the era of CKM[O(1%)]?

Vub and Vcb

Talk by Daping Du (FNAL/MILC) at Lattice 2014

See talks by A. Bharucha and A. El-Khadra:
New lattice calculations of $B \rightarrow \pi$ form factors & simultaneous fits to data may reduce the errors by 50% (aiming for ~4% Vub error).



There may be hope for validation of predictions too: some important tests coming up:

$B_s \rightarrow K l \nu$

$\Lambda_b \rightarrow p l \nu$

Will provide very useful checks on form-factor predictions from LQCD and validation of other exclusive meas.

Vub and Vcb

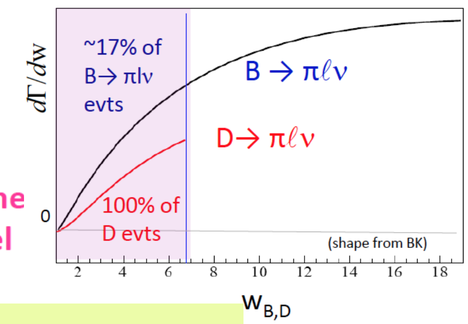
A new approach (BaBar) (A. Oyanguren/ICHEP2014)- see Bill Gary's talk
Simultaneous fits to D and B →πlν

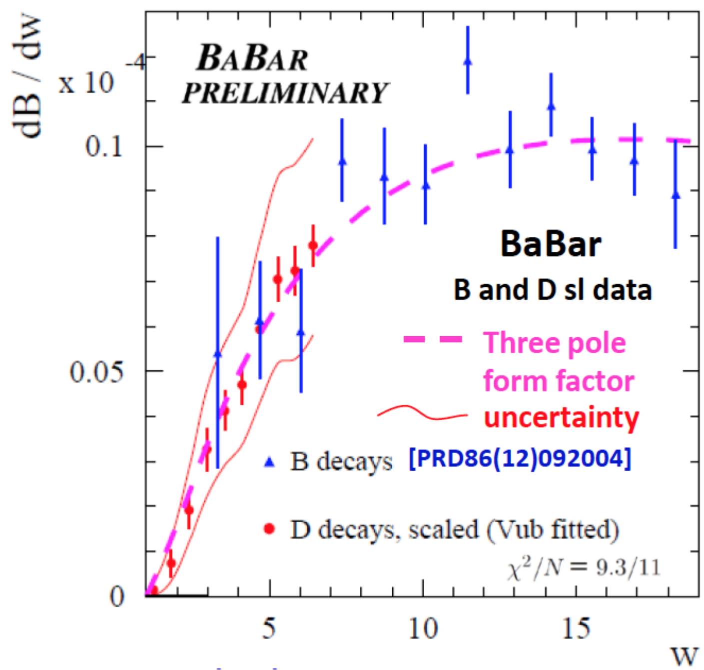
Using $w_{B,D}$ instead of q^2 $$w_{B,D} = \frac{M_{B,D}{}^2 + m_\pi^2 - q^2}{2M_{B,D} m_\pi}$$

At $w_B = w_D$: $$\frac{d\Gamma(B \to \pi \ell \nu)/dw_B}{d\Gamma(D \to \pi \ell \nu)/dw_D} = \left|\frac{V_{ub}}{V_{cd}}\right|^2 \left(\frac{M_B}{M_D}\right) \left|\frac{f_+^{B\to\pi}}{f_+^{D\to\pi}}\right|^2$$

1) From Lattice

2) From a phenomenological model





With lattice form-factors

$$|V_{ub}| = (3.65 \pm 0.18 \pm 0.40) \times 10^{-3}$$

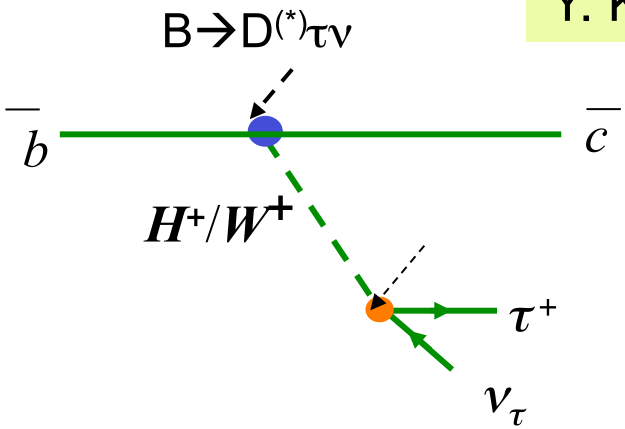
With 3-pole model for form-factors

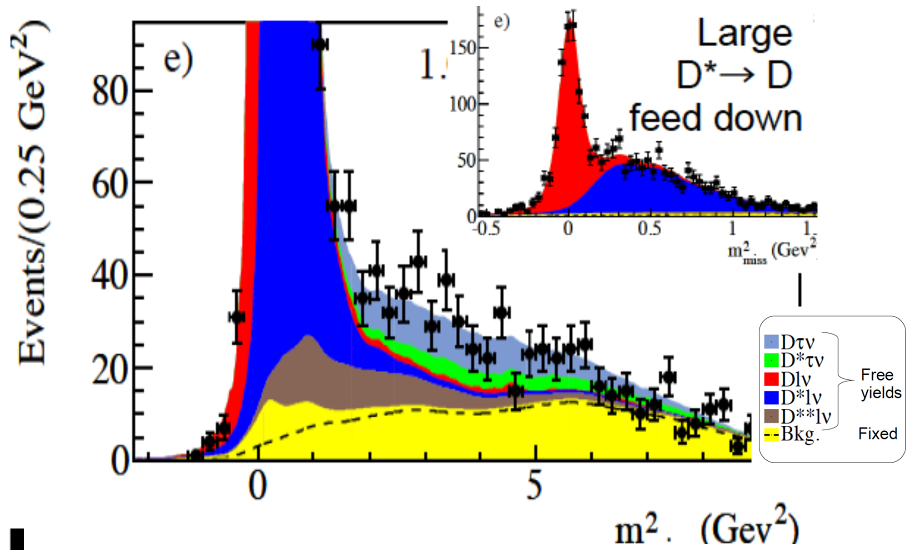
$$|V_{ub}| = (2.6 \pm 0.2 \pm 0.4) \times 10^{-3}$$

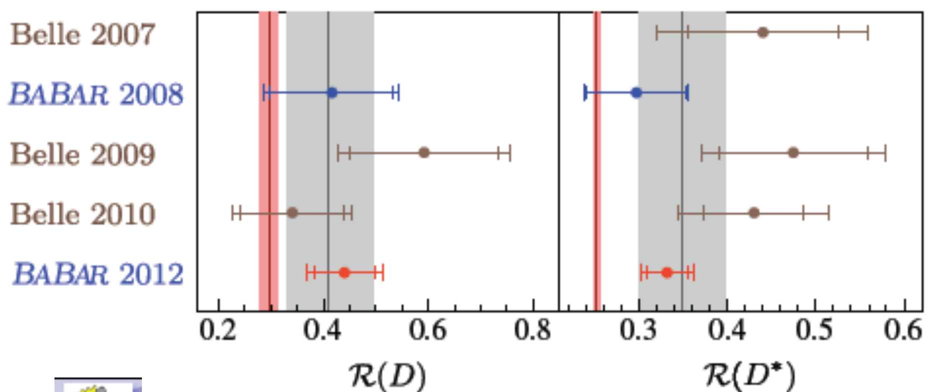
~10% measurement, still dominated by knowledge of FF
But now depends on ratio of FF's
Is this easier for LQCD?

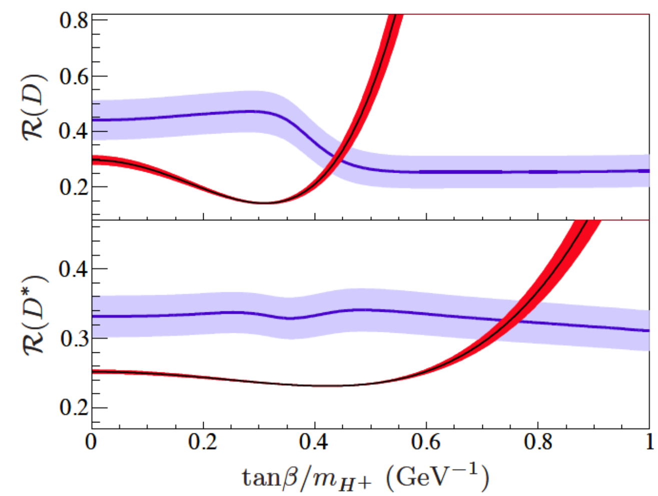
Lepton Univsersality test via B→D$^{(*)}$τν

Y. Kwon





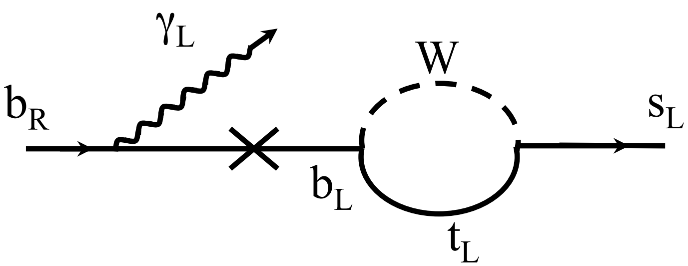


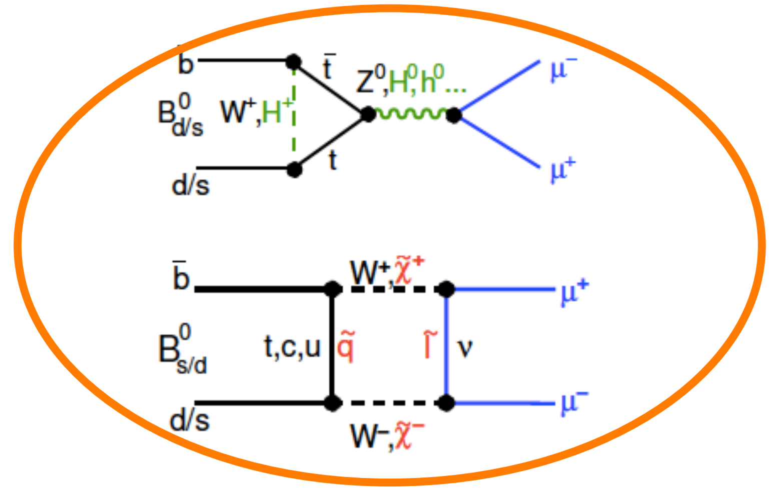


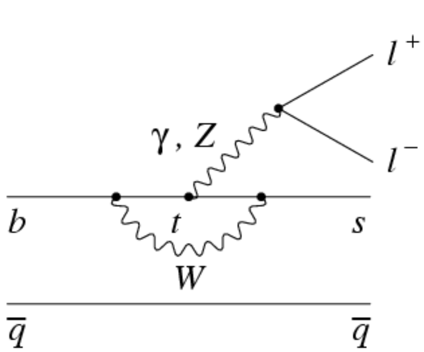
3.4σ from SM

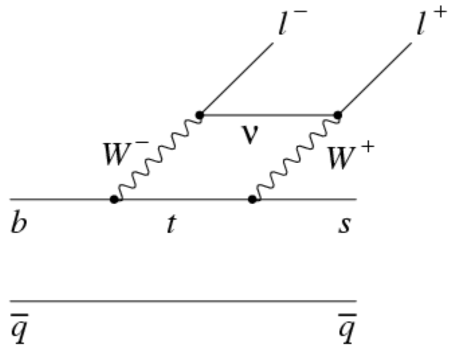
2HDM-II is challenged to fit in both R(D) and R(D*)

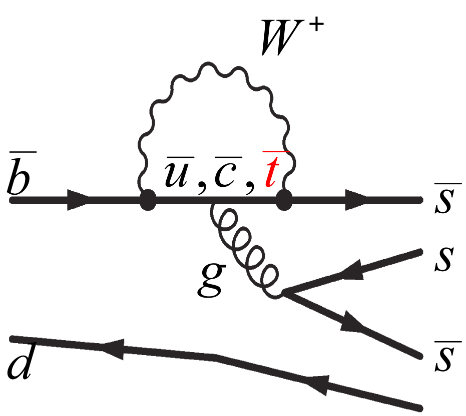
Rare and very Rare decays

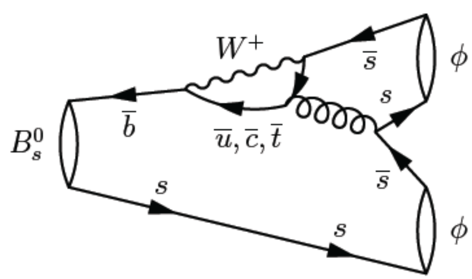


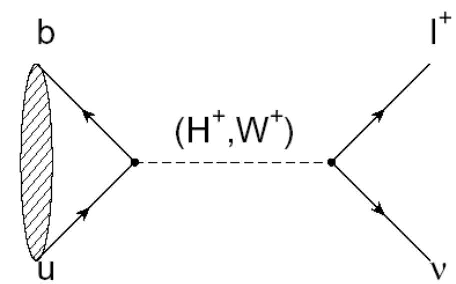






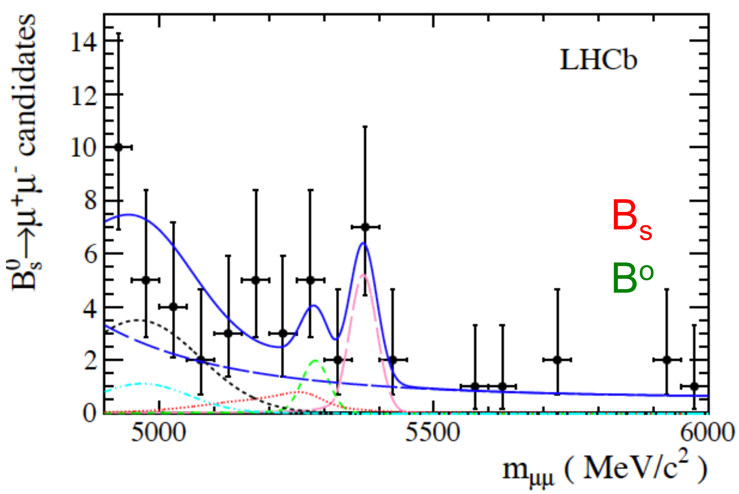


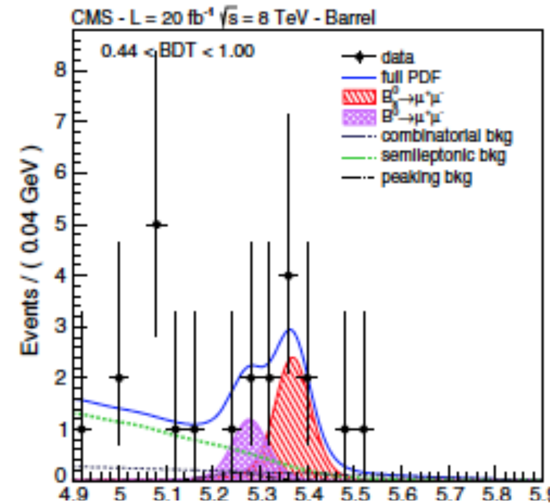


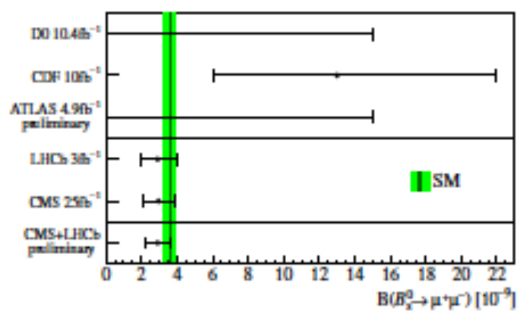


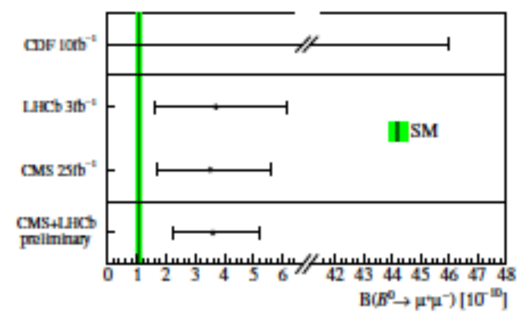
A. Heister
B. M. Rama
W. Walkowiak

$B^0_s \rightarrow \mu^+\mu^-$ Long awaited- finally seen



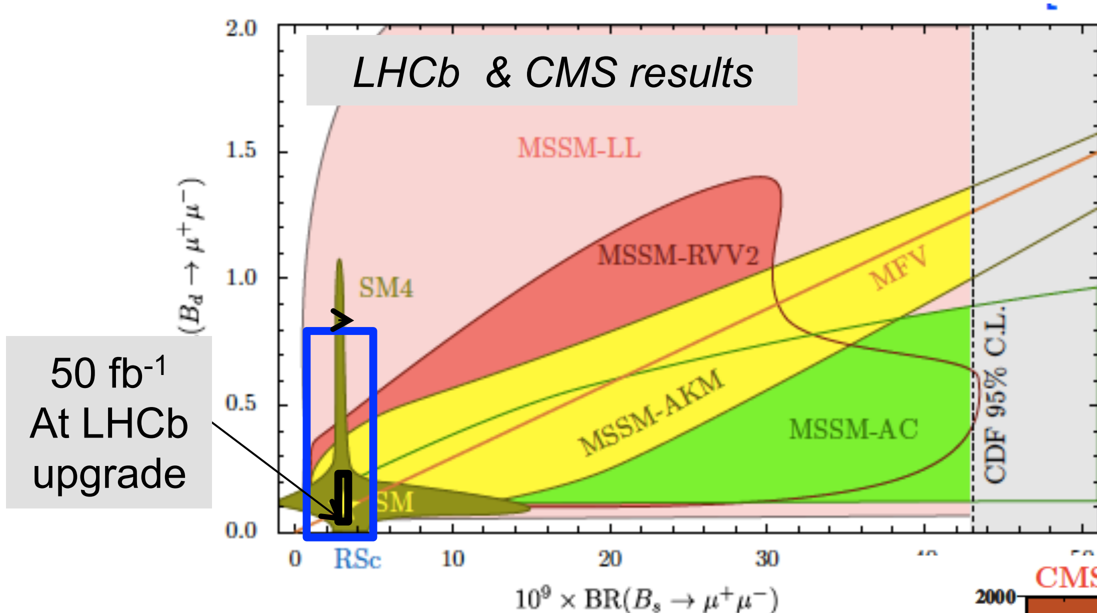






•SM is triumphant -- Precision measurement is a goal of next run and LHC upgrade along with: (further in future) $B_d \rightarrow \mu\mu / B_s \rightarrow \mu\mu$ (key to testing MFV) & $B_s \rightarrow \tau\tau$

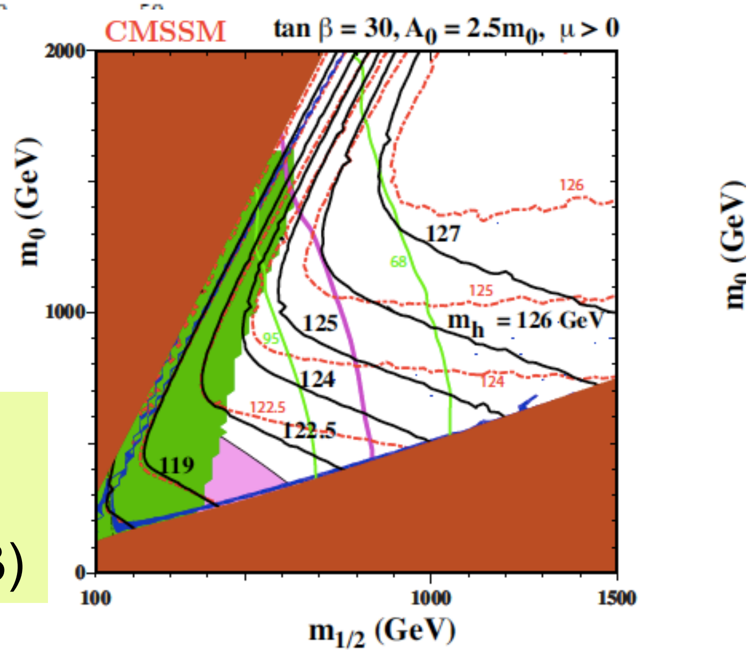
Major impact on SUSY parameter space



Most constraining at large tanβ

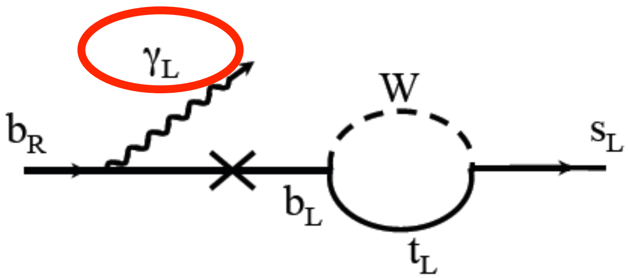
$$B(B_{s,d} \to \mu^+\mu^-) \propto m_\mu^2 \tan^6 \beta$$

From M. Misiak
No all of SUSY is excluded
Only the left of green line (for this tanβ)



Figs. 1 and 7 from arXiv:1312.5426 by John Ellis.

Evolution of an old friend: b→sγ



Very slow progress

Initial observation at CLEO- 1995

$$Br(b \to s\gamma) = (2.32 \pm 0.57 \pm 0.35) \times 10^{-4} (Exp)$$

$$= \quad (3.28 \pm 0.33) \times 10^{-4} (SM\ /\ Th)$$

2011: Measurements at the B factories

$$B(B \to X_s\gamma)[E_\gamma > 1.6 GeV) = (3.52 \pm 0.23 \pm 0.09) \times 10^{-4}$$

$$B(B \to X_s\gamma)_{NNLL}[E_\gamma > 1.6 GeV) = (3.15 \pm 0.23) \times 10^{-4}$$

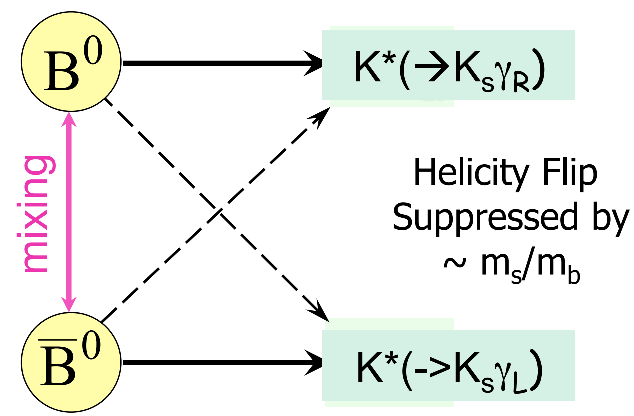
First attempt at measuring photon polarization at B factories:

via time-dependent CPV in $B \to K^0_s \pi^0 \gamma$

(Gronau, Soni, Atwood)

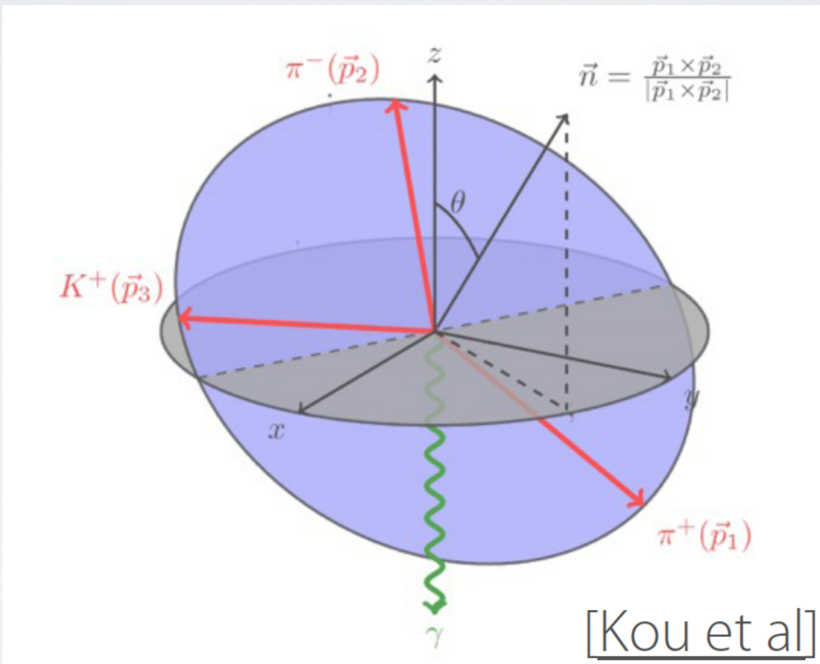
$$\mathbf{S_{K^*\gamma}} = -0.16 \pm 0.22$$

SM: S <0.04 (probably not the final word)
Major item on menu of Belle-II and LHCb-upgrade($B_s \to \phi\gamma$)



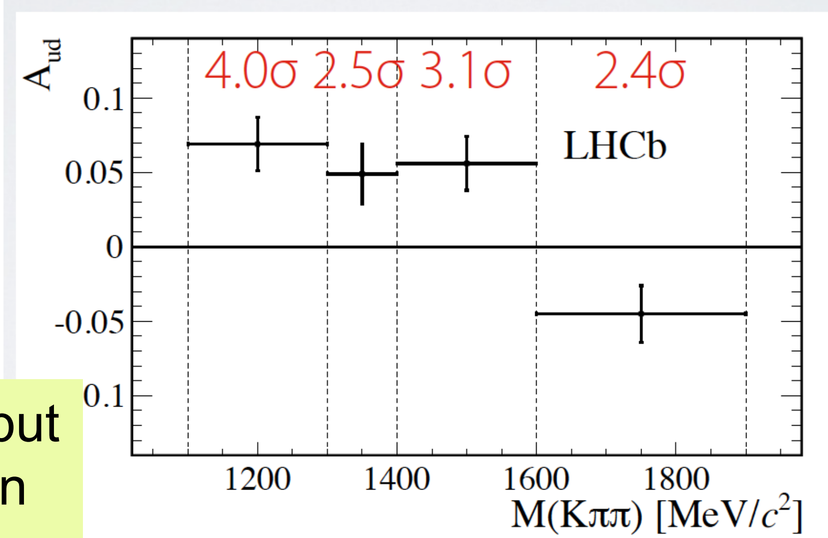
Photon polarization results from LHCb

$B \to K^+\pi^+\pi^-\gamma$ Up-Down Asymmetry related to polarization of FS photon



Talk by A. Puig

$$\mathcal{A}_{\mathrm{UD}} \equiv \frac{\int_0^1 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta} - \int_{-1}^0 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta}}{\int_{-1}^1 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta}} = C\lambda_\gamma$$



5.2 σ in favor of Photon polarization– but this measurement doesn't tell the sign and the magnitude of the polarization.

$b \to s l^+ l^-$ is providing many tests and some anomalies

- New results from B factories on the inclusive front $B \to X_s l^+ l^-$ P. Chang's talk
- The exclusive channels: $B \to K(^*) l^+ l^-$ now dominated by LHCb, as well as results from CMS and ATLAS.

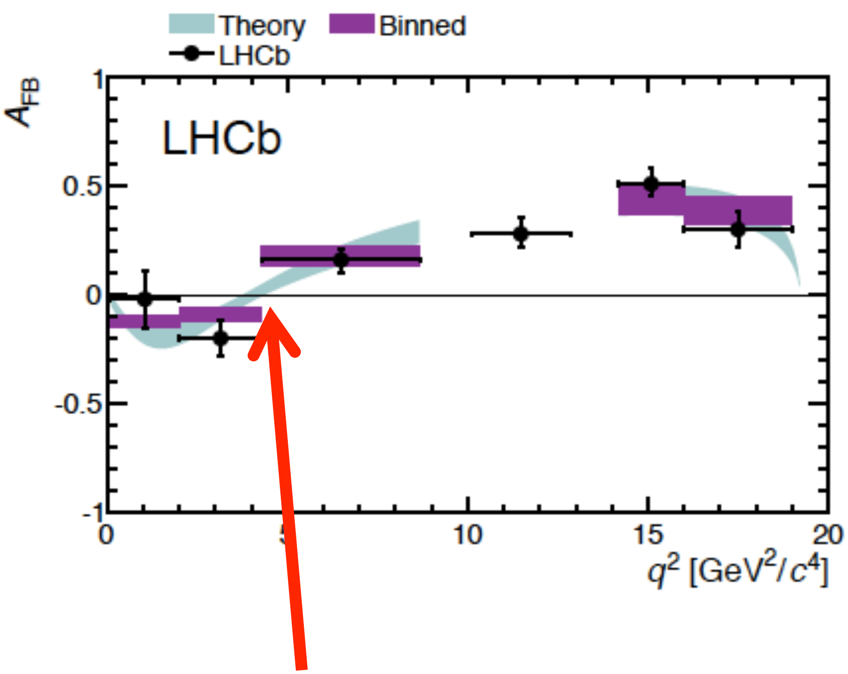
overview of theory by C. Bobeth)

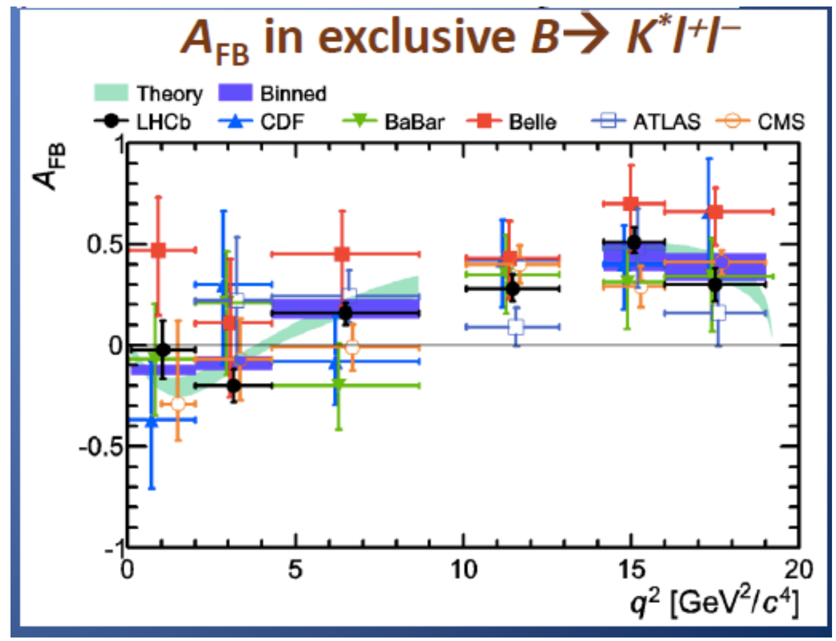
Experimental data: $b \to s(d)\,\bar{\ell}\ell$ – number of events

# of evts	BaBar 2012 471 M $\bar{B}B$	Belle 2009 605 fb^{-1}	CDF 2011 9.6 fb^{-1}	LHCb 2011 (+2012) 1 (+2) fb^{-1}	CMS 2011 (+2012) 5 (+20) fb^{-1}	ATLAS 2011 5 fb^{-1}
$B^0 \to K^{*0}\bar{\ell}\ell$	$137 \pm 44^\dagger$	$247 \pm 54^\dagger$	288 ± 20	2361 ± 56	415 ± 70	426 ± 94
$B^+ \to K^{*+}\bar{\ell}\ell$			24 ± 6	162 ± 16		
$B^+ \to K^+\bar{\ell}\ell$	$153 \pm 41^\dagger$	$162 \pm 38^\dagger$	319 ± 23	4746 ± 81	not yet	not yet
$B^0 \to K^0_S\bar{\ell}\ell$			32 ± 8	176 ± 17		
$B_s \to \phi\bar{\ell}\ell$			62 ± 9	174 ± 15		
$B_s \to \bar{\mu}\mu$				emerging	emerging	limit
$\Lambda_b \to \Lambda\bar{\ell}\ell$			51 ± 7	78 ± 12		
$B^+ \to \pi^+\bar{\ell}\ell$		limit		25 ± 7		
$B_d \to \bar{\mu}\mu$			limit	limit	limit	limit

b→sl⁺l⁻ is providing many tests and some anomalies

Data mostly Consistent with SM- with a few exceptions



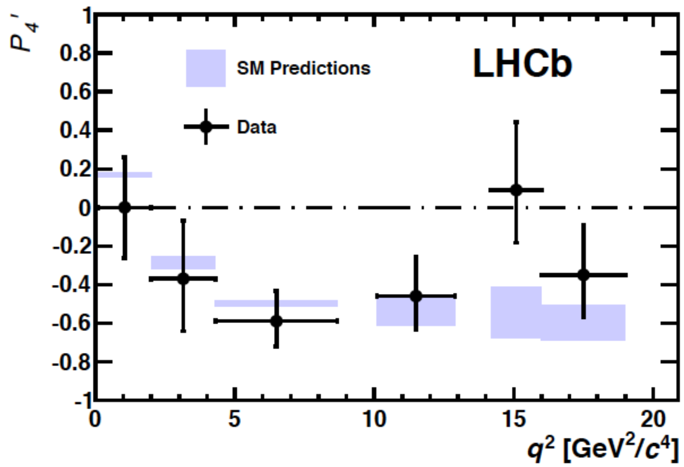


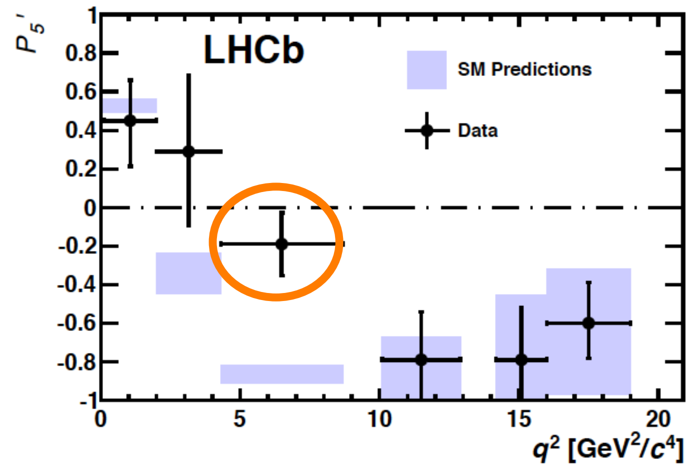
- Result $q_0^2 = 4.9 \pm 0.9\,\mathrm{GeV}^2$ consistent with SM prediction $q^2_{0,\mathrm{SM}} = 4.36^{+0.33}_{-0.31}\,\mathrm{GeV}^2$ [EPJ C41 (2005) 173-188]

Was considered highly sensitive to NP effects

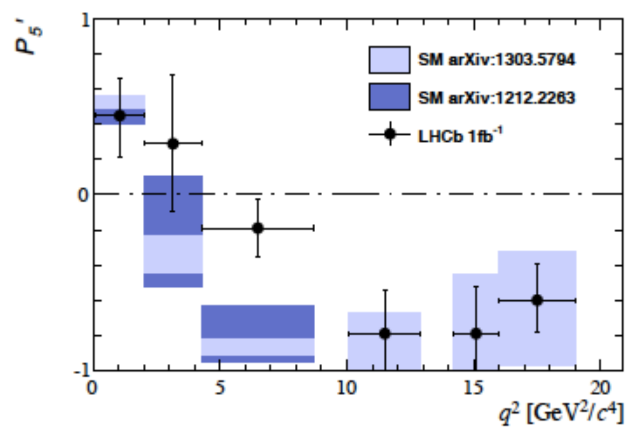
C. Langenbruch on LHCb
P.Chang on B factories

$B^0 \rightarrow K^{(*0)}\mu^+\mu^-$:New Variables w less FF dependence



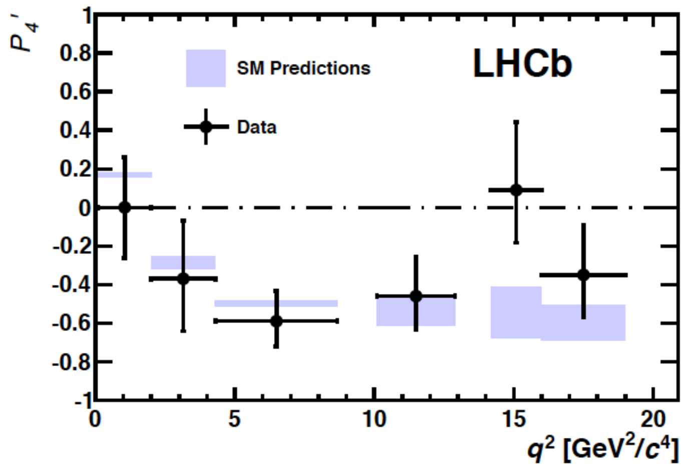


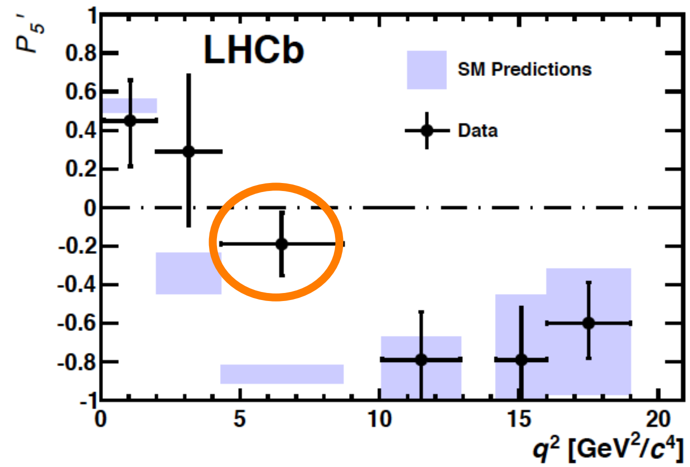
3.7 σ deviation but caution: there is substantial room in theory predictions

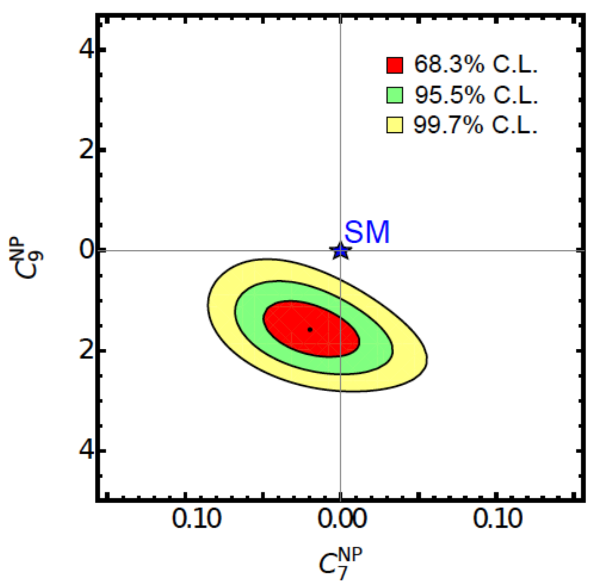


[Jäger et al., JHEP 1305 (2013) 043]

$B^0 \rightarrow K^{(*0)}\mu^+\mu^-$:New Variables less FF dependent

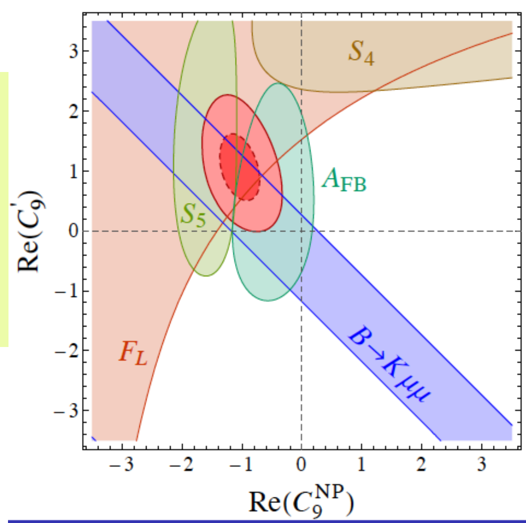






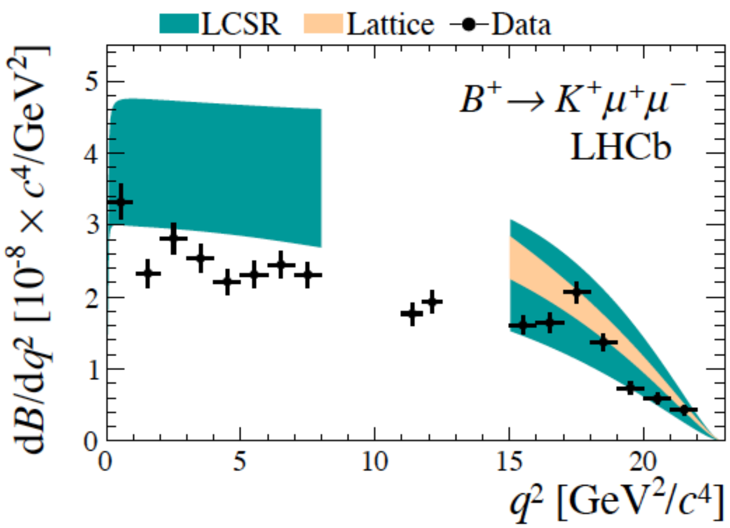
Decotes-Genon, Matias & Virto

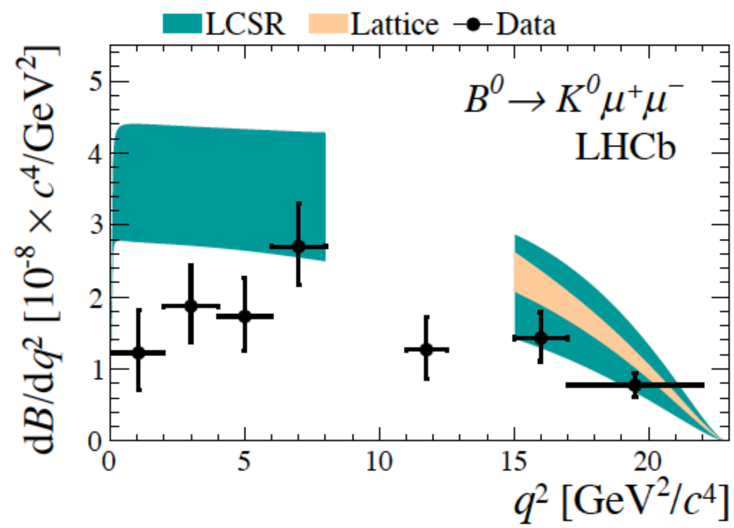
If taken seriously-
Global fits to data favor modifying C_9, $C`_9$,
Introducing a FC Z`

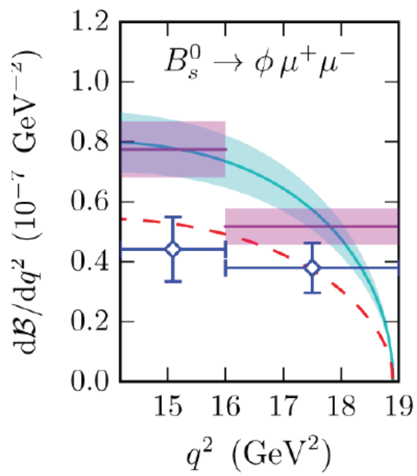


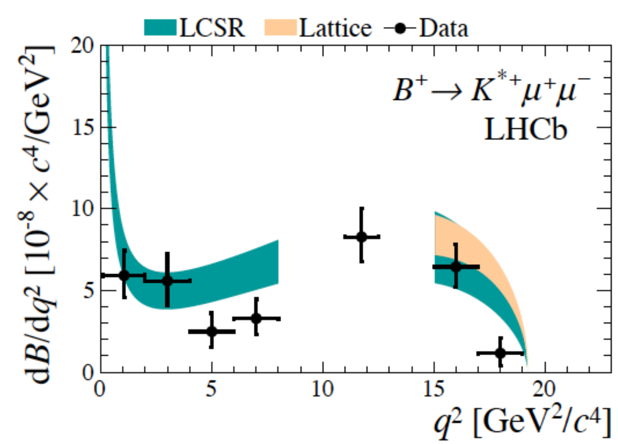
Altmannshofer & Straub

Differential rates also favor C9 modification- all rates tend to be lower than “predicted” SM rates.





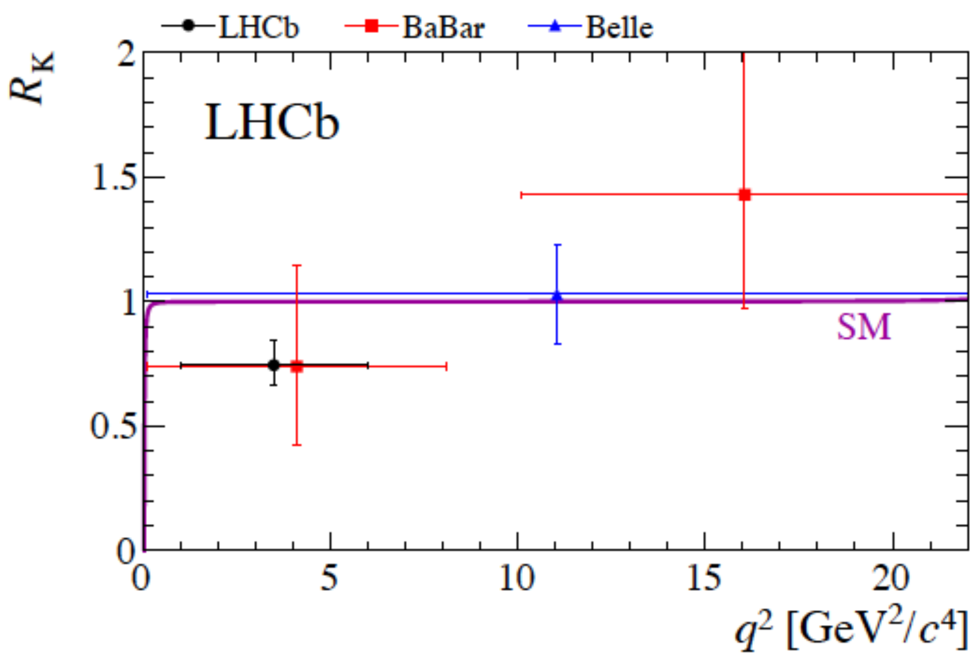




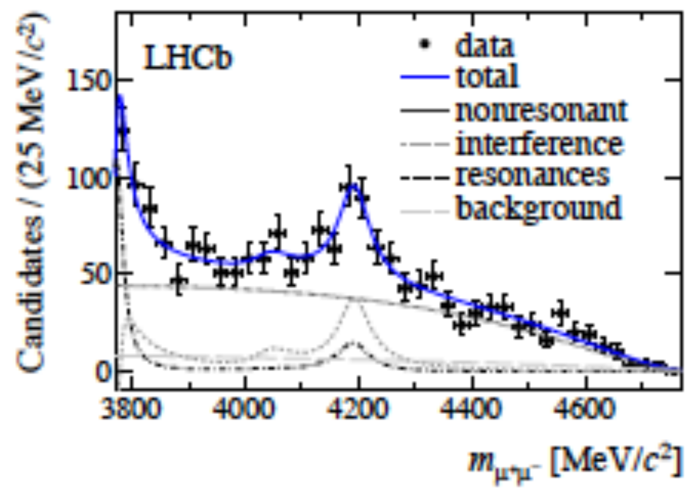
More from $B^o \to K\mu^+\mu^-$

Lepton Universality Test- 2-3 sigma effect

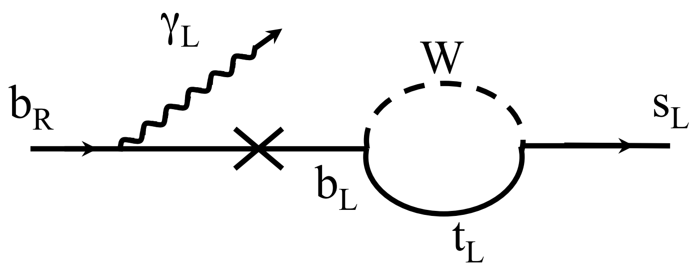
$$R_K = \frac{\Gamma(B^+ \to K^+\mu^+\mu^-)}{\Gamma(B^+ \to K^+e^+e^-)}$$

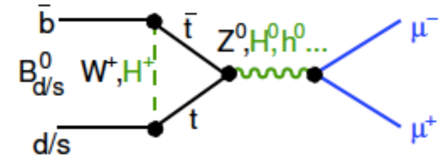


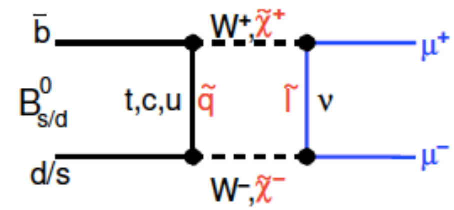
More excited charmonium present than predicted

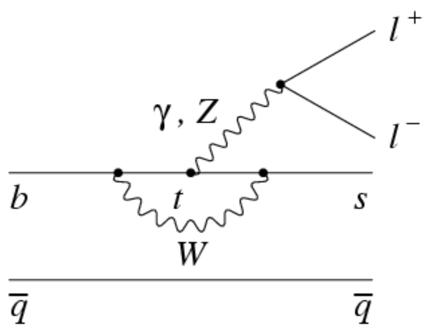


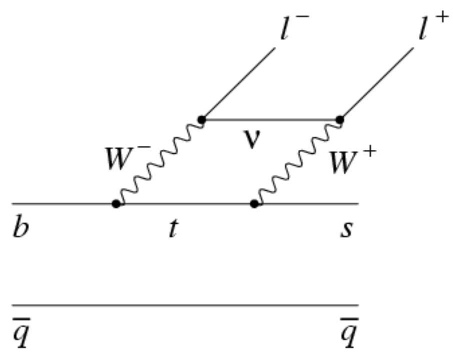
Rare and very Rare decays

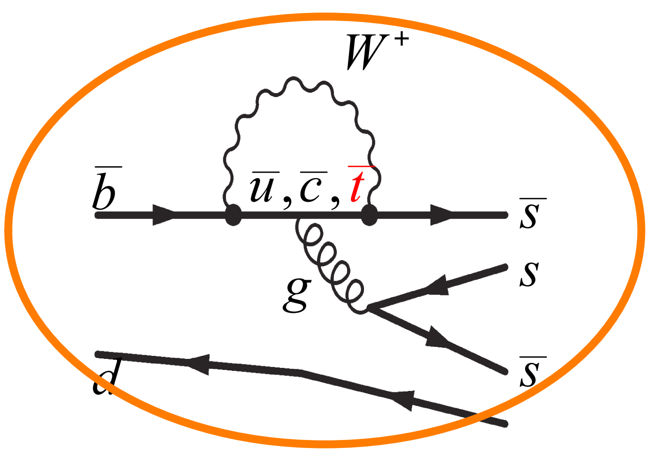


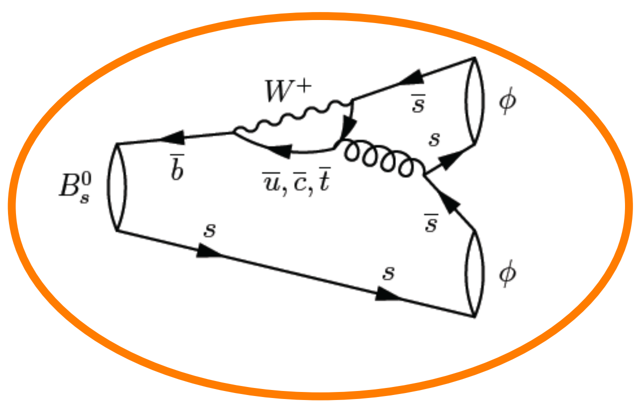


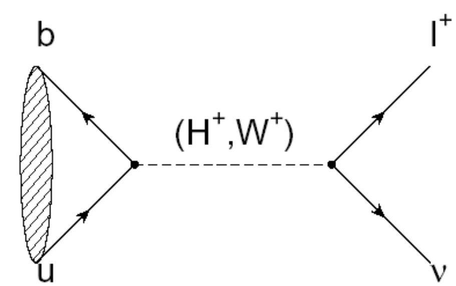












Penguin dominated B^0 decays measurements of "sin2β", "ϕ_s"

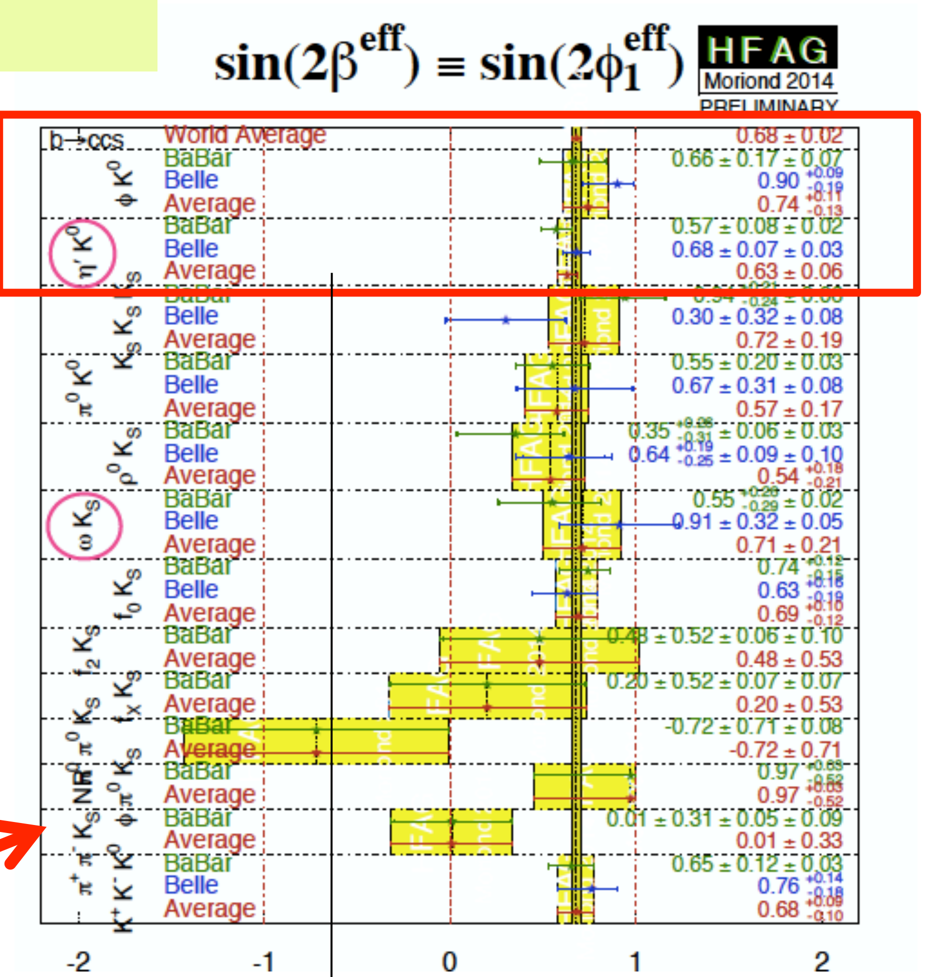
New B^0_s addition to this program

ϕ_s from a $B_s \to \phi\phi$ (penguin dominated process)-Analog of $B^0 \to \phi K_s$

$\phi_s = -0.17 \pm 0.19 \pm 0.03$ (rad)

$\lambda = 1.04 \pm 0.15 \pm 0.03$

Consistent with no CPV & SM ϕ_s



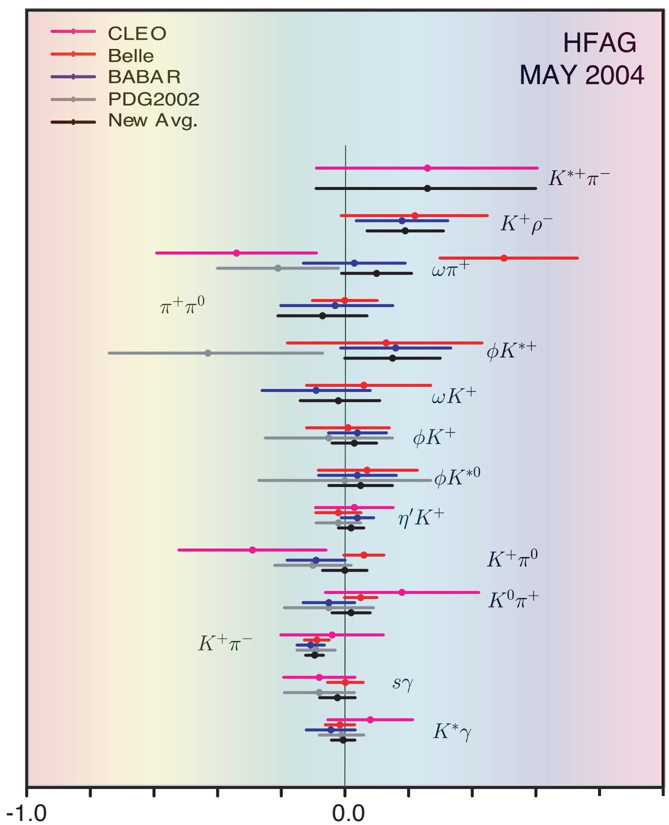
New updates (B. Golob)

current results are consistent with SM. But theoretical uncertainties unknown (range of 0.02→0.1 was suggested in the past)

Non-leptonic charmless B decays

Land of penguins & Puzzles

CP Asymmetry



$$A_{CP} = \frac{\Gamma(b \quad f) - \Gamma(\bar{b} \quad \bar{f})}{\Gamma(b \quad f) + \Gamma(\bar{b} \quad \bar{f})}$$

Cibrán Santamarina

We still have the "Kπ puzzle":

Large Direct CP observed in Bs (LHCB & CDF):

$$A_{cp}(B_s^0 \to K^-\pi^+) = 0.27 \pm 0.08 \pm 0.02$$

Consistent with expected value applying U-spin to B^0_d measurements (Fleischer)

Large (local) CPV in Dalitz Plane of B→hh'h"

Source of these large strong phases?

Pattern of polarization in B→VV

Decay Mode	$B^0 \to \rho^+\rho^-$ BaBar arXiv0607098	$B^0 \to \rho^0 K^{*0}$ BaBar PRD 85 072005	$B^0 \to \phi\phi$ LHCb arXiv 1407.2222	$B_s^0 \to K^{0*}\bar{K}^{0*}$ LHCb PLB709 50	$B^0 \to K^{0*}\bar{K}^{*0}$ BaBar PRL 100 081801	$B^0 \to \phi K^{*0}$ LHCb JHEP 1405 069	$B_s^0 \to \phi\bar{K}^{*0}$ LHCb JHEP 1311 092
	0.977 ±0.028	0.40 ±0.14	0.364 ± 0.015	0.31 ± 0.13	0.80 ± 0.13	0.497 ± 0.024	0.51 ± 0.16

Direct CP Violation in B decays- the "Kπ" puzzle

B. Golob:
And now we have

$$A_{CP}(B^+ \to K^+\pi^0) - A_{CP}(B^0 \to K^+\pi^-) = 0.123 \pm 0.020$$

$$A_{CP}(K^{*+}\pi^-) - A_{CP}(K^{*+}\pi^0) = +0.16 \pm 0.14$$

Before invoking NP- a more accurate test of SM processes is in order – proposed sum rule by (Gronau) & (Atwood, Soni), also suggestions by Rosner, Lipkin,..

$$A_{cp}(K^+\pi^-) + A_{cp}(K^0\pi^+)\frac{B(K^0\pi^+)}{B(K^+\pi^-)}\frac{\tau_0}{\tau_+} \approx A_{cp}(K^+\pi^0)\frac{2B(K^+\pi^0)}{B(K^+\pi^-)}\frac{\tau_0}{\tau_+} + A_{cp}(K^0\pi^0)\frac{2B(K^0\pi^0)}{B(K^+\pi^-)}\frac{\tau_0}{\tau_+}$$

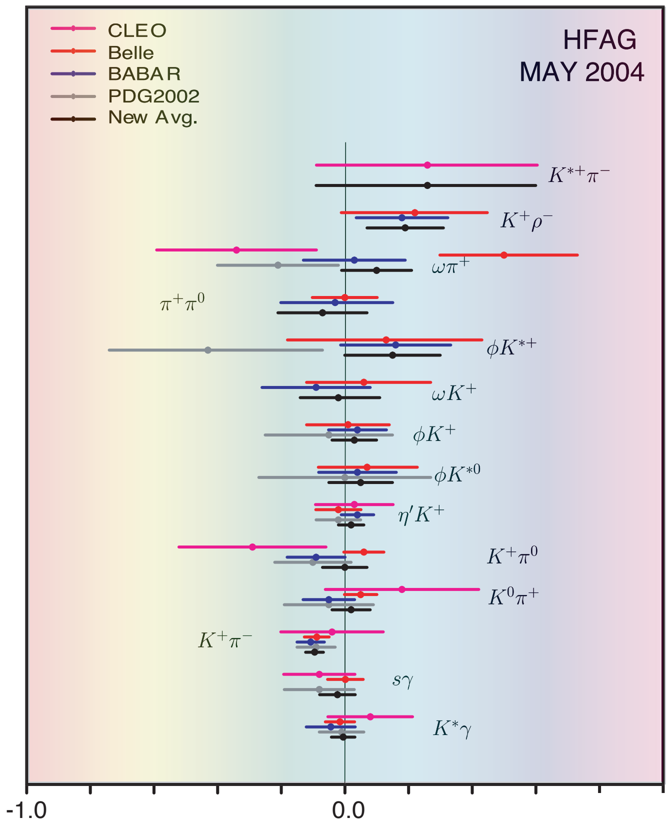
$$A_{cp}(B^+ \to K^+\pi^0) = +0.038 \pm 0.018 \qquad A_{cp}(B^+ \to K^0\pi^+) = -0.009 \pm 0.025$$

$$A_{cp}(B^0 \to K^+\pi^-) = -0.085 \pm 0.010 \qquad A_{cp}(B^0 \to K^0\pi^0) = +0.01 \pm 0.10$$

- The current data satisfies the sum rule
- The precision of the test is limited by measurement of CPV in $B^0 \to K^0\pi^0$
- A lot more to do on experimental meas. & on the QCD side as well.

Non-leptonic charmless B decays
Land of penguins & Puzzles

CP Asymmetry



$$A_{CP} = \frac{\Gamma(b \quad f) - \Gamma(\bar{b} \quad \bar{f})}{\Gamma(b \quad f) + \Gamma(\bar{b} \quad \bar{f})}$$

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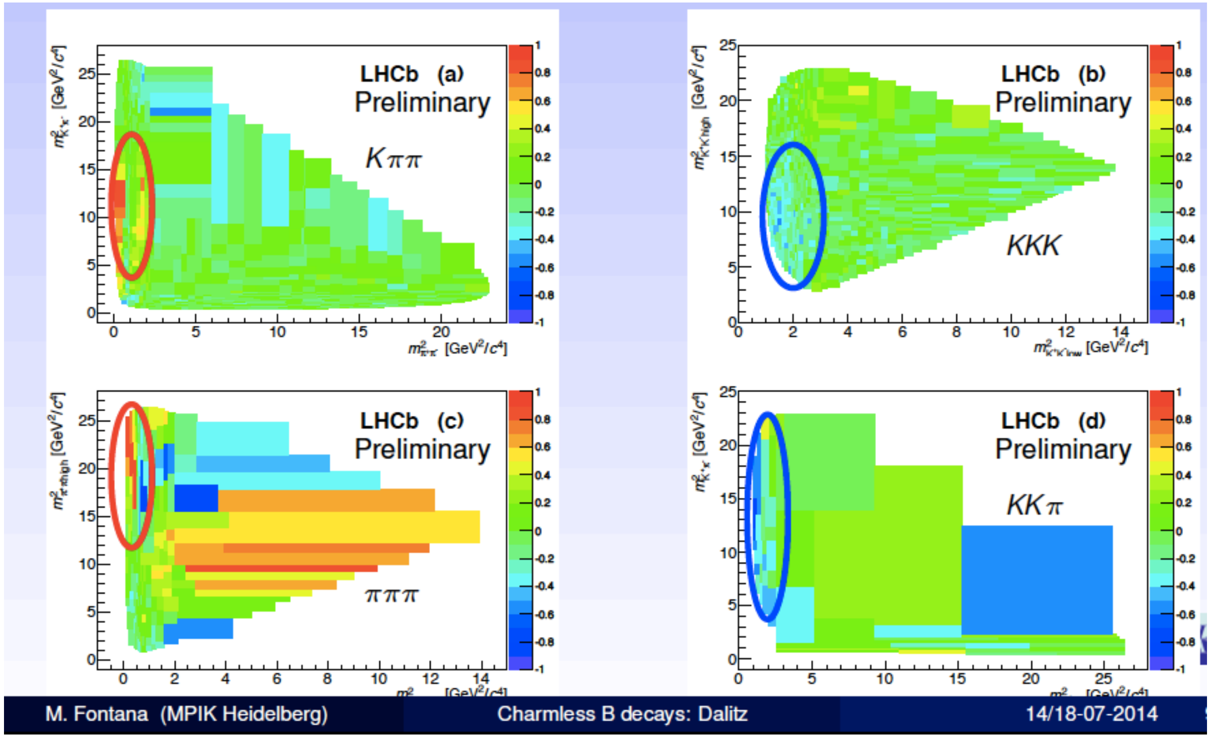
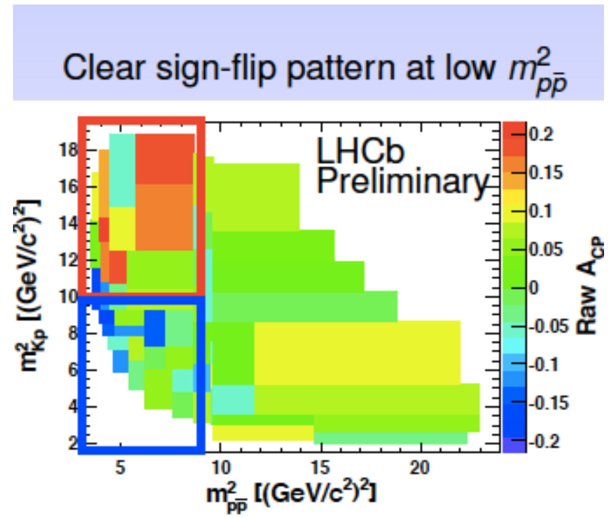
	0.977 ±0.028	0.40 ±0.14	0.364 ± 0.015	0.31 ± 0.13	0.80 ± 0.13	0.497 ± 0.024	0.51 ± 0.16

Large (local) direct CPV in B→hh'h" decays

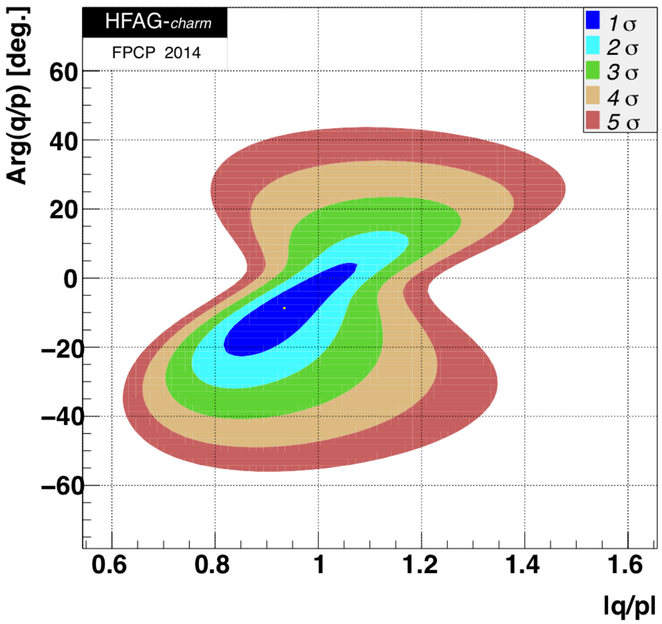




- These effects seen in regions not associated to resonances
- Ultimately, will need amplitude analysis
- final state re-scattering may have a role; how do we reconcile with 2-body decays (no evidence for large re-scattering)

Mixing & CP Violation in the Charm System

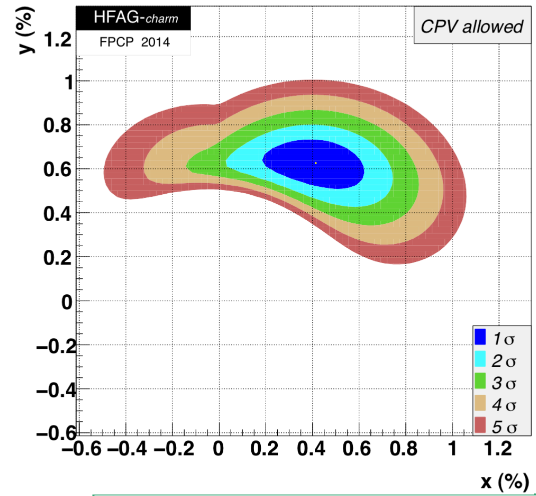
- Mixing in D^0 system is now firmly established via many observables:
- Time evolution of doubly-cabibbo-suppressed $D^0 \to K^+\pi^-$
- Lifetime difference in CP-odd and CP-even modes
- Dalitz analysis of $D^0 \to K_s\pi^+\pi^-$ $K_sK^+K^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+\pi^-$, ...
- Simultaneously fit for CPV:



$$\left|\frac{q}{p}\right| = 1.007^{+0.09}_{-0.08}$$

$$\varphi(\mathrm{deg}) = -8.7^{+8.7}_{-9.1}$$

SM : ϕ <0.6 (deg)



$$x = \frac{\Delta M}{\Gamma} = (0.43^{+0.14}_{-0.15})\%$$

$$y = \frac{\Delta\Gamma}{2\Gamma} = (0.60 \pm 0.07)\%$$

$$A_D = -0.71^{+0.92}_{-0.95}$$

D^0 mixing is now on firm ground

Zero mixing is excluded at >10 σ

No evidence for
CPV in the charm system

No Evidence for Direct CPV in the charm system

$$A_{cp} = \frac{\Gamma(D \to f) - \Gamma(\bar{D} \to \bar{f})}{\Gamma(D \to f) + \Gamma(\bar{D} \to \bar{f})}$$

The most sensitive channels:

Channel	A_{cp} (%)
$D^0 \to \pi^+\pi^-$	$+0.05 \pm 0.15$
$D^0 \to K^0_s\pi^0$	-0.27 ± 0.21
$D^0 \to K^+K^-$	-0.16 ± 0.12
$D^+ \to K^0_s\pi^+$	-0.41 ± 0.09
$D^+ \to K^0_s K^+$	-0.03 ± 0.17
$D^+_s \to K^0_s K^+$	$+0.08 \pm 0.26$
$D^+_s \to K^0_s\pi^+$	-0.63 ± 0.47

No evidence found for Direct CPV in charm decays
Sensitivities in many channels approaching ~10^{-3}

R. Zwicky

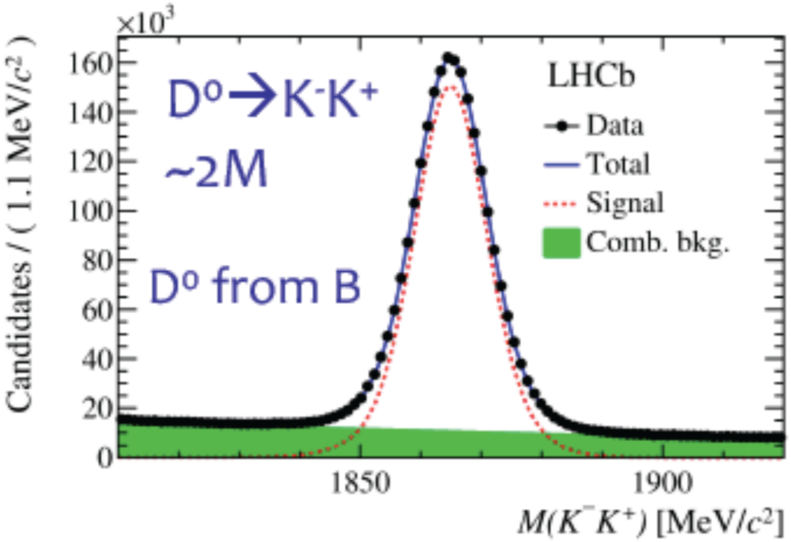
SCS benchmark value: $A_{CP} < 10^{-3}$
$D^0 \to K^+K^-, \pi^+, \pi^-, D_S^+ \to K_S, \pi + ..$

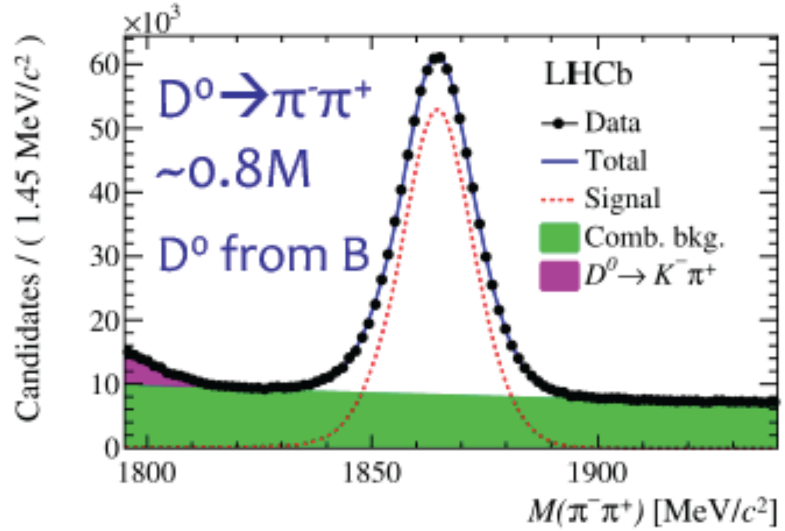
$>3\sigma$ Expect $A_{cp} \sim -0.33\%$
induced by indirect CPV in K^0

New results from LHCb

LHCb results on direct CPV from D's selected from Semileptonic B decays

A. Carbone





$$\Delta A_{CP} = (+0.14 \pm 0.16\,(\text{stat}) \pm 0.08\,(\text{syst}))\%$$
$$A_{CP}(K^-K^+) = (-0.06 \pm 0.15\,(\text{stat}) \pm 0.10\,(\text{syst}))\%$$

$$A_{CP}(\pi^-\pi^+) = (-0.20 \pm 0.19\,(\text{stat}) \pm 0.10\,(\text{syst}))\%$$

Future

The past decade saw major advances on possibilities for future flavor experiments

- A new novel accelerator concept emerged for realization of an e+e- Super Flavor factory (at ~10^36/cm2/s)

- Heavy flavor physics at hadron colliders successfully demonstrated by Tevatron & LHC experiments.

  LHCb detector & trigger concepts proved very successful with spectacular results.

- Experimental concepts revived and proposed for measuring CLFV: m→eg (at ~10^{-13}) with ME, μN→eN (at 10^{-16} level) with Mu2e @FNAL and COMET@Jparc.

- Kaon experiments moving forward; soon to operate: NA62@CERN and Koto@Jparc

Super Flavor Experiments

At LHC: Endowed with large production xsection: its mostly about trigger & pile-up

σ_{cc}~6 mb (7 TeV) σ_{τ}~80 μb (7 TeV)
σ_{bb}~280 μb(7 TeV) (~500 at 13 TeV)

LHCb at L~2-4x10^{32}/cm^2/s
Expect ~8/fb by 2018
B_d, B_u, B_s, B_c, Λ_b,...
LHCb upgrade aimed for 2018
To operate at L~2x10^{33}/cm^2/s
expect ~5/fb/year (total of ~50/fb)

- CMS and ATLAS players in some key area

- e+e- Super B factory
- Small x-section; its mostly about luminosity (xsection ~1 nb)

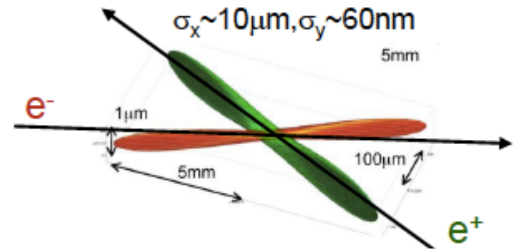
Asymmetric energy $e^+ + e^-$ colliders to operate in the $\Upsilon(4S)$ region as well as in the charm threshold region.

- SuperB, Italy (originated the concept – but failed to be funded)
- Super KEKB in Japan- well underway
- At L ~8x10^{35} /cm^2/s

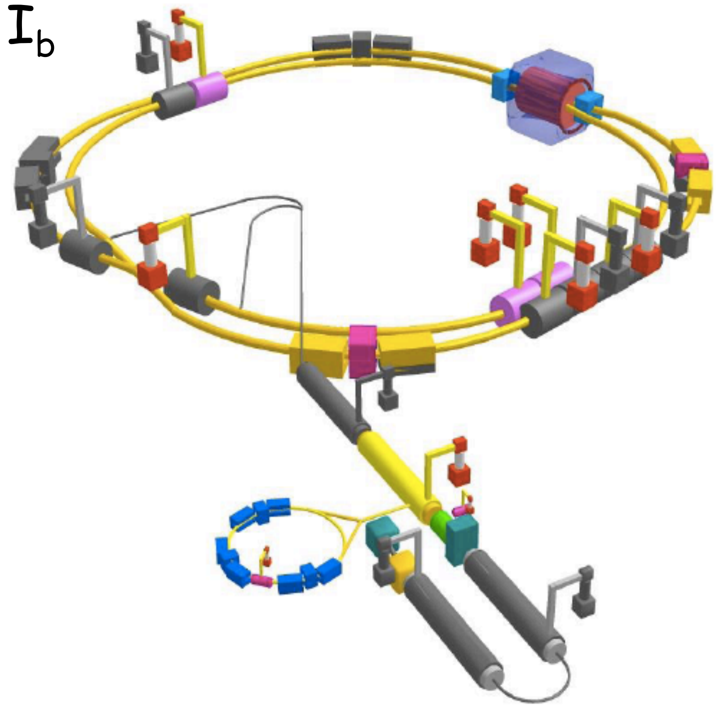
  Aiming for a data set of ~ 50 /ab
  - ~10^{11} B decays
  - ~10^{11} tau decays
  - ~10^{11} charm decays

Belle-II at SuperKEKB

Asymmetric Energy e+e- collider at goal peak Luminosity 8×10^{35} /cm^2/s aiming for 50 ab^{-1}



Design based on Nano-beam scheme proposed by P. Raimondi (Frascati), tight focusing, larger crossing angle & higher I_b



Accelerator Upgrade

- low emittance electron injector
- New positron damping ring
- New vacuum chambers
- New HER and LER lattice and long dipoles for low emittance
- New IR for low β^*
- Modified and additional RF for higher currents

The LHCb upgrade

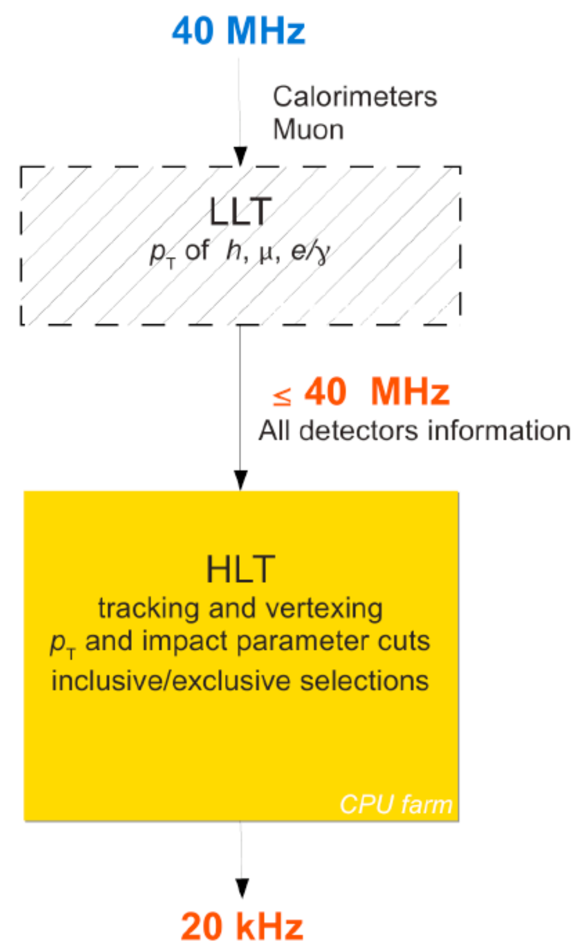
The upgrade is designed to run at luminosity of $(1\text{-}2)\times10^{33}$ $cm^{-2}s^{-1}$; Aiming for 50 fb^{-1}

- Requires new approach to the LHCb trigger scheme to overcome L0 (1MHz) limitation.

➔ New Trigger Apporach:

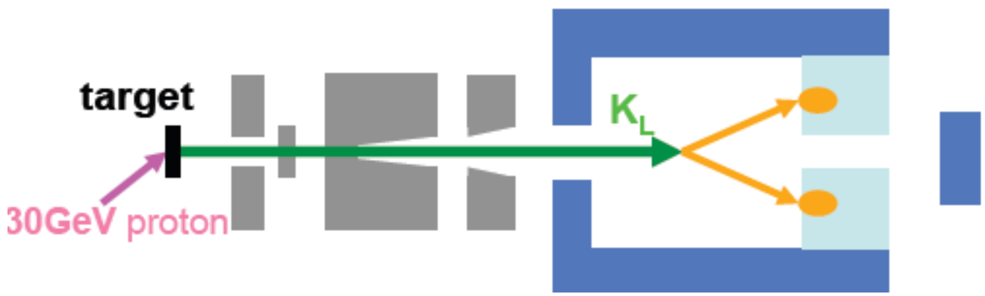
- Remove L0 (hardware) trigger
- Readout the detector at the 40 MHz LHC clock rate
- Move to a fully flexible software trigger

=>>Major upgrade of LHCb detector required : to cope with increase occupancy, data rate and radiation dose, & to preserve efficiency and low ghost rate: Replace all readout electronics, entire tracking system (Vertex locator, upstream & downstream tracking detectors) & upgrade Particle ID system



Rare Kaon Physics: Ultimate goal is measurements of $K^+ \rightarrow \pi^+ \nu\nu$ & $K_L \rightarrow \pi^0 \nu\nu$: very clean/dominated by short distance effects

- Near future:
  - NA62 CERN/SPS aim at 10% meas. of $K^+ \rightarrow \pi^+ \nu\nu$ @Br~10^{-10} (SM)
  - KOTO at JPARC aims at 1st signal of $K_L \rightarrow \pi^0 \nu\nu$ @BR~$0.2.10^{-10}$ (SM)



•An improved design over BNL E391: aims for 1000x better sensitivity- to below the Grossman-Nir limit ; Next step for ~100 events

- •higher power beam (100 KW) & highly collimated (pencil) neutral beam. 40 times the K_L rate in E391 and lower n/K_L
- •Unique DAQ for extremely high hit rates in detector elements

- OKRA no longer part of the FNAL program

Conclusions:

✓ Flavor Physics is in excellent health

- Precision era is already here and the findings are mostly consistent with SM, but areas of tensions are growing.

- Future looks great: Flavor physics remains one of the key drivers of the search for New Physics beyond SM.
  - The planned strong experimental program together with advances on theory front will challenge the SM with tremendous precision.

Thank you!

for this great conference at this beautiful location