Summary

- 4G extensions of SM3 should be seriously considered
- It is highly unlikely to be just SM4
- Heavier 4G quarks can trigger DEWSB and consequently can be a simpler solution to hierarchy problem w/o the need for multitude of new parameters
- It facilitates significantly baryogenesis over SM3
- Opens up new avenues for DM
- Unlike almost all BSM models, 4G extension need not cause flavor or CP problem
- (Sin2beta)tree less than SM3 and (sin2beta)penguin less than both, may be hints of 4G
- AFB (tt) may be a hint of a strongly coupled 4G
- Experimental searches for t' -> t h, b'->t h+- should be given a high priority [in addition to conventional modes]

Tension Between a 4^{th} Generation and the LHC Higgs Searches

There seems a tension between a 4^{th} generation and the current LHC Higgs, a large range of Higgs mass has been excluded.

Is it possible to evade the exclusion range of Higgs mass to leave more room for the 4^{th} generation?

Yes, if there are new physics beyond SM to modify

1. gg -> h production
2. h -> WW*, ZZ* decay modes
3. h decays with a large invisible branching ratio

…

1. A model which can modify gg-> h production

If there is new physics which contributes significantly to gg -> h and cancels the SM3(SM4) contribution, the production of h can be reduce which leads to event number reduction.

Example: Color octet Higgs doublet S = (8,2,1/2). (Manohar&Wise)

Being colored particle, may contribute to g g-> h.

Colored

$$\mathcal{L} = (\sqrt{2}G_F)^{1/2}\frac{\alpha_s}{12\pi}\, G^A_{\mu\nu}G^{A\mu\nu}h\left(n_{hf} + \frac{v^2}{m_S^2}\frac{3}{8}(2\lambda_1+\lambda_2)\right)$$

fied.

$\lambda_{1,2}$ coupling of S to usual Higgs doublet H. If $\lambda_{1,2}$ is negative, S contribution can cancel the heavy quark contribution resulting in a smaller event number to analyze at the LHC.

2. A model where gg-> h and h -> WW*, ZZ* are modified

Two Higgs, H1,2, one couple to the first 3 and another to the 4th generation.

There are two physical Higgs, h and H.

$$\frac{\sigma_h}{\sigma_{SM}} \equiv \frac{\sigma(pp \to h \to VV)}{\sigma(pp \to H_{SM} \to VV)} \sim \left[\left(2\frac{\sin\alpha}{\sin\beta} + \frac{\cos\alpha}{\cos\beta}\right)\cos(\beta-\alpha)\right]^2$$

$$\frac{\sigma_H}{\sigma_{SM}} \equiv \frac{\sigma(pp \to H \to VV)}{\sigma(pp \to H_{SM} \to VV)} \sim \left[\left(2\frac{\cos\alpha}{\sin\beta} - \frac{\sin\alpha}{\cos\beta}\right)\sin(\beta-\alpha)\right]^2$$

where $V = W$ or Z.

If h is SM-like Higgs with coupling to W-pairs the same as that in the SM: $\beta = \alpha$,

h couplings to the fermions are the same as those for the SM4 and $\sigma_h/\sigma_{SM4} \sim 1$.

h can be the heavier Higgs and have a mass outside the range of current searches.

But H is actually the lighter one which can be produced at the LHC, the search requires a different strategy as it does not couple to W-pairs, $\sigma_H/\sigma_{SM} << 1$.

3. A model for large than expected invisible Higgs decay width

If there is a new invisible width Γ_{inv} beside SM decay width ΓSM,

One can define: R = $\Gamma_{SM}/(\Gamma_{SM}+\Gamma_{inv})$. Visible event number is reduced by R.

A model to realize this: SM+D

SM3(SM4) + a real SM singlet D darkon field (plays the role of dark matter).

$$\mathcal{L}_D = \frac{1}{2}\partial^\mu D\,\partial_\mu D - \frac{1}{4}\lambda_D D^4 - \frac{1}{2}m_0^2 D^2 - \lambda D^2 H^\dagger H$$

D is stable due to a D-> - D Z_2 symmetry.

After H develops VEV, there is a term: λ v DD h.

This term is important for annihilation of D D -> h -> SM particle

This term also induce h -> DD if DM mass is less than half of the Higgs mass increasing the invisible decay width and make the LHC detection harder!

Visible decay modes and gg -> h are the same as SM3 (SM4)

Data allow two region of DM mass, a few GeV and about half of the Higgs mass.

H -> DD can happen. Higgs can have much larger invisible branching ratio.

Summary

- 4SM with SM Higgs only possible for

  a) very large m_H (600 GeV and above)

  => electroweak precision constraints still valid?

  b) small m_H window: 115 GeV (LEP2) – O(145 GeV)

  => Window size depends on $m_{\nu 4}$ (the heavier $m_{\nu 4}$ the smaller the window)

  => Current Tevatron and LHC limits are not conservative

  Need to re-calculate combined limit for $m_{\nu 4}$ = 46.7 GeV

- 4SM: If m_H close to LEP2 limit and $m_{\nu 4}$ close to $m_Z/2$

  the Higgs search can take quite some time

- Signal size in H-->WW and H-->$\gamma\gamma$ can be used <u>either to constrain $m_{\nu 4}$</u>

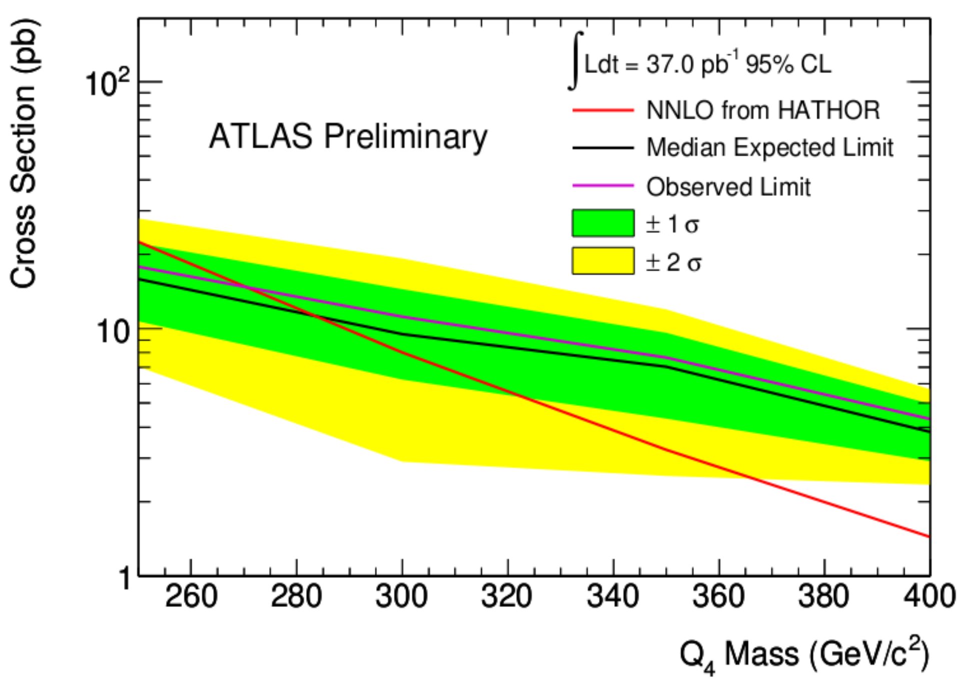
  <u>or to exclude 4SM</u>: a) if lower limit hits LEP2 bound or

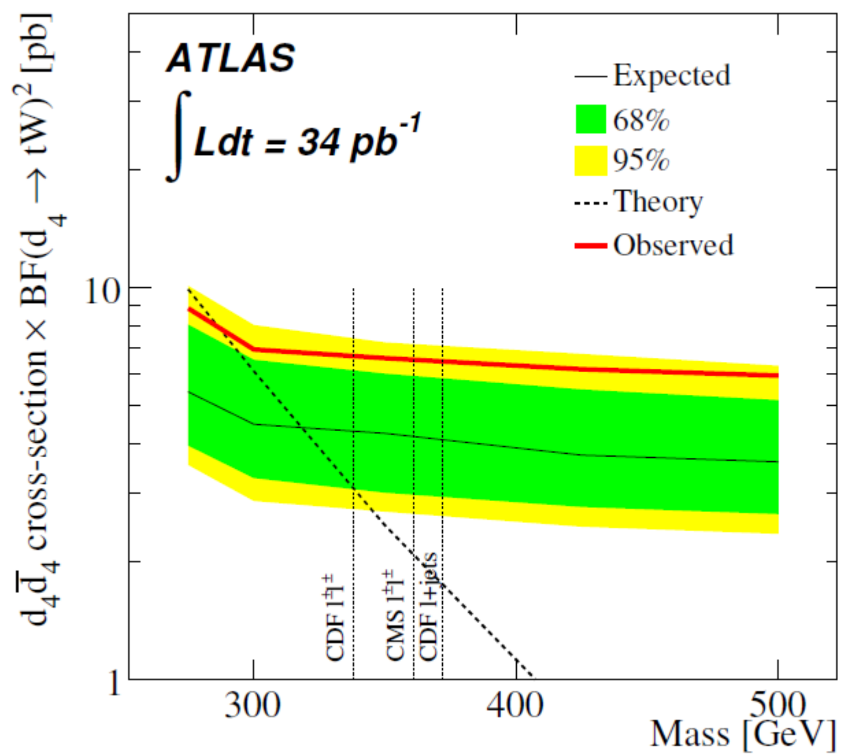
  b) if positive Higgs signal does not fit 4SM expectation

ATLAS 4GQ Search Summary

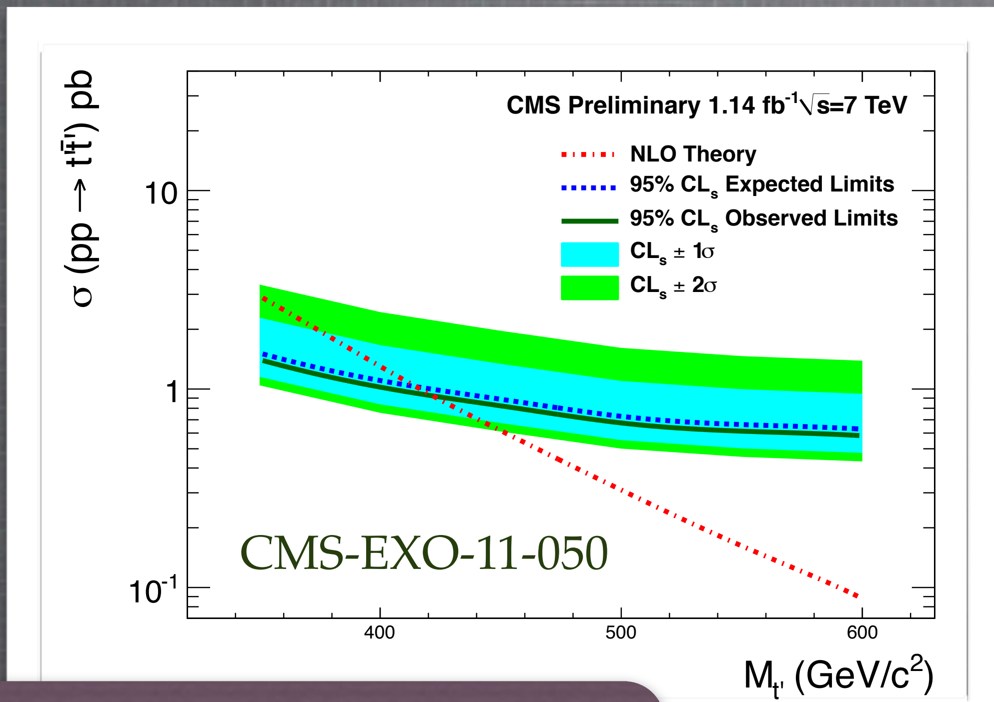
- Exclude Q4 < 270 GeV
  - Q4 → Wq
    (Top-like decay)
  - Opposite-sign dilepton search

- Exclude d4 < 290 GeV
  - d4 → tW
  - Same-sign dilepton search

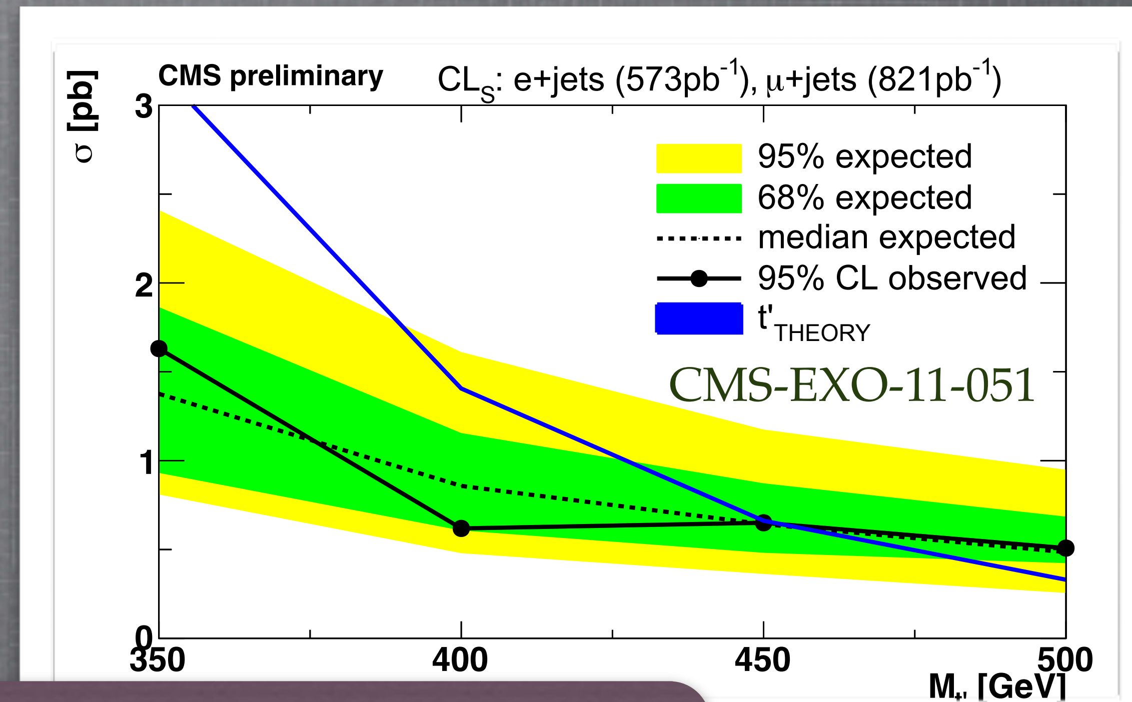




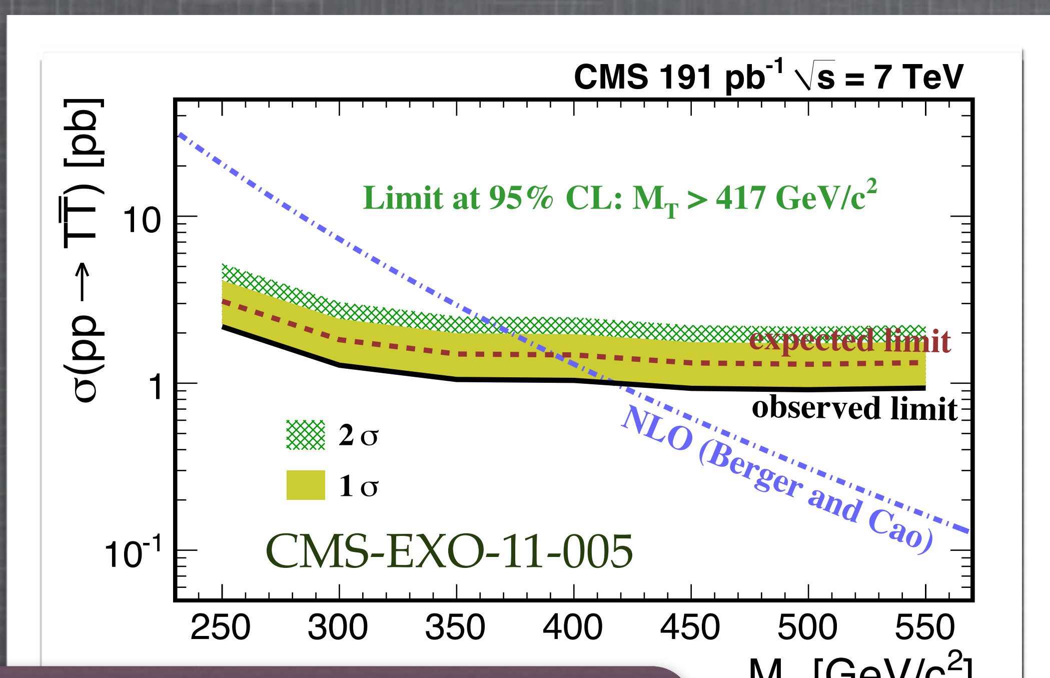
CMS DIRECT SEARCHES



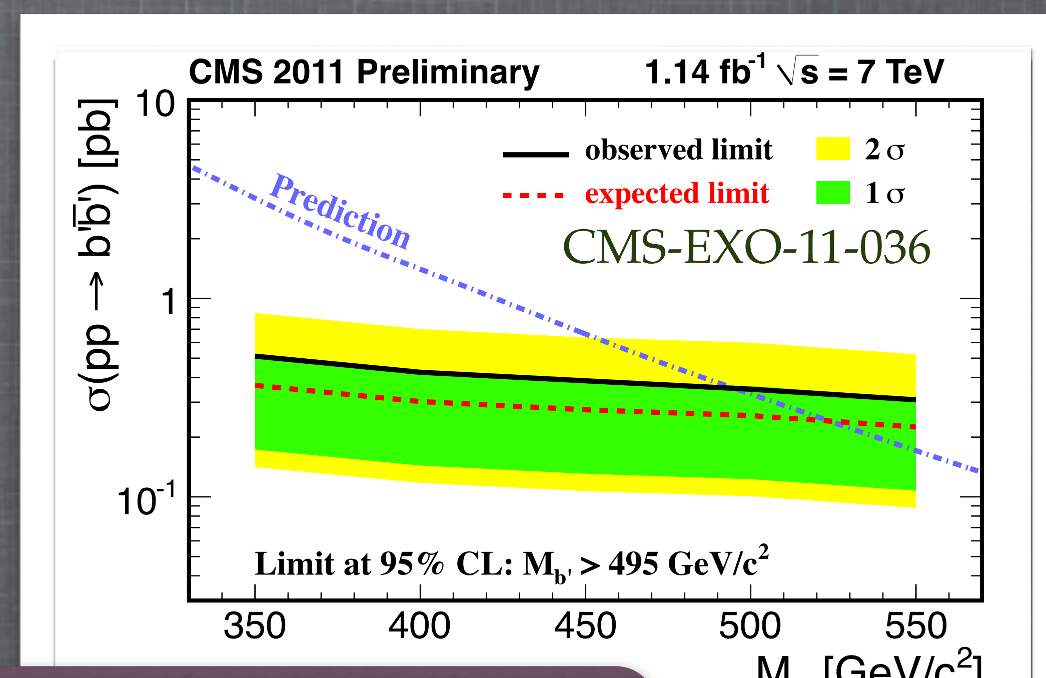
For **t′→bW** dilepton decays,
M(t′) > 422 GeV at 95% C.L.



For **t′→bW** lep+jets,
M(t′) > 450 GeV at 95% C.L.



For **T→tZ** decays,
M(T) > 417 GeV at 95% C.L.



For **b′→tW** decays,
M(b′) > 495 GeV at 95% C.L.

Key Observables in the Flavour Sector

Soumitra Nandi

Univ. of Montreal,
Montreal, Canada

Results: Scan and Fit

Elements	Allowed ranges		
	Scan	Fitting (at 1σ)	
	$m_{t'}$ (GeV) = [375,575]	$m_{t'}$ = 400 GeV	$m_{t'}$= 575 GeV
$\lvert\lambda^{t'}_{db}\rvert\times 10^4$	< 21.0	0.26 ± 0.50	0.13 ± 0.24
$\lvert\lambda^{t'}_{sb}\rvert\times 10^2$	< 1.5	0.85 ± 0.64	0.37 ± 0.47
$\lvert\lambda^{t'}_{ds}\rvert\times 10^4$	< 37.4	0.48 ± 0.70	0.27 ± 0.39
$\delta^s_{t'}$ (rad)	Fig.	1.39 ± 0.30 4.93 ± 0.30	1.41 ± 0.48 4.91 ± 0.48
$\delta^d_{t'}$ (rad)	[0,2π]	4.53 ± 0.46 1.79 ± 0.44	4.42 ± 0.78 1.65 ± 0.75
$\chi^2/d.o.f$	N.A.	3.57/5	3.81/5

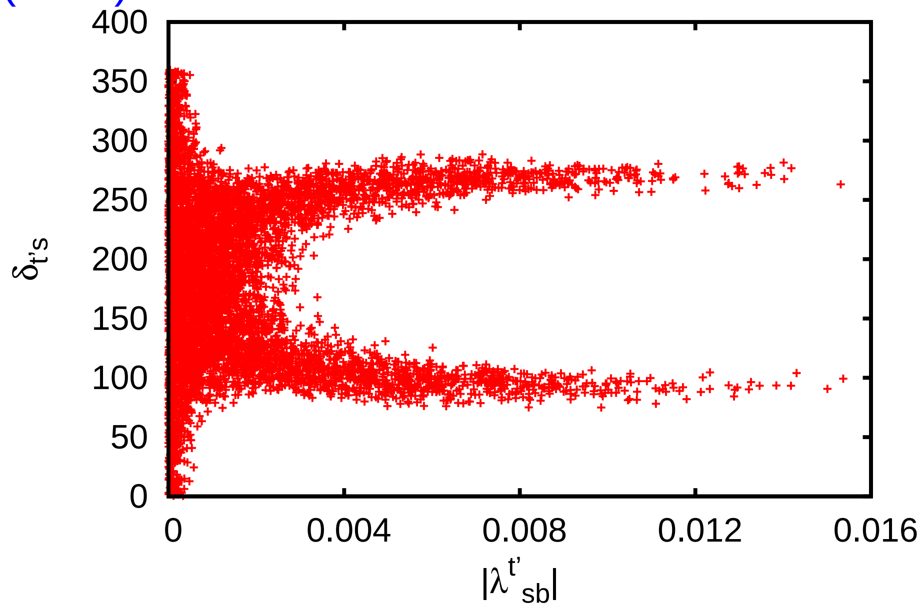
Indirect Constraint:

$|V_{t'b}| = 0.07 \pm 0.09$ for $m_{t'} = 400$ GeV, 0.04 ± 0.06 for $m_{t'} = 575$ GeV

$|V_{t's}| = 0.13 \pm 0.16$ for $m_{t'} = 400$ GeV, 0.09 ± 0.12 for $m_{t'} = 575$ GeV

$\lambda^{t'}_{sb}$: Magnitude vs Phase

Nandi & Soni, PRD83 (2011) ..



Here $m_{t'} = [375\mathrm{GeV}, 575\mathrm{GeV}]$..

- The magnitude of different SM4 product couplings reduce with the increase of $m_{t'}$
- For slightly higher values of $|\lambda^{t'}_{sb}|$, $\delta^{s}_{t'}$ has two distinct solutions...
- Due to the constrain from $|\epsilon_K|$, along with $\delta^{s}_{t'}$, $\delta^{d}_{t'}$ has two distinct solutions..

Although the SM predictions of all the input observables are consistent with the measured values, the theoretical errors still allow a large 4G effect in $b \to s$....

SM4 predictions

Observables	Predictions		
	SM	SM4 (at 1σ)	
		$m_{t'}$ = 400 GeV	$m_{t'}$ = 575 GeV
$\phi_s^{\Delta_s}$	≈ 0	$\pm(0.29 \pm 0.23)$	$\pm(0.18 \pm 0.23)$
$\lvert\Delta_s\rvert$	1	0.92 ± 0.11	0.95 ± 0.12
$a_{sl}^s \times 10^2$	$(2.04 \pm 0.55) \times 10^{-3}$	$\pm(0.2 \pm 0.1)$	$\pm(0.1 \pm 0.1)$
$A_{CP}^{B \to X_s \gamma}$ (%)	0.57 ± 0.08	1.23 ± 0.51	0.89 ± 0.41
		-0.05 ± 0.50	0.27 ± 0.40
$Br(B_s \to \mu^+ \mu^+) \times 10^9$	3.2 ± 0.2	3.47 ± 1.92	3.32 ± 2.76
$Br(B \to X_s \nu \bar{\nu}) \times 10^5$	2.7 ± 0.2	2.04 ± 0.66	2.04 ± 0.95
$Br(K_L \to \pi^0 \nu \bar{\nu}) \times 10^{11}$	2.8 ± 0.6	2.44 ± 3.21	3.22 ± 6.04
$(q^2)_0^{\mathrm{incl}}$ GeV^2	3.49 ± 0.26	3.41 ± 0.30	3.41 ± 0.36

A_{CP} and A_{FB} in $b \to s\ell^+\ell^-$

Soni et.al., PRD82 (2010)

- Direct CP asymmetry in $B \to X_s \ell^+\ell^-$:
  - In the SM, $A_{CP}(B \to X_s \ell^+\ell^- \approx 0$ in the high-q^2 region
  - In SM4, $A_{CP}(B \to X_s \ell^+\ell^-)$ can be enhanced up to 1% and it is highly correlated with $S_{\psi\phi}$
  - Super-B can measure $A_{CP}(B \to X_s \ell^+\ell^-$ with an $\approx (1 \to 2)$% accuracy
  - No significant deviations from SM in the low-q^2 region..
- The Forward-Backward asymmetry $A_{FB}(q^2)$ in inclusive or exclusive $b \to s\ell^+\ell^-$ decay:
  - No significant deviations from SM....
  - Zero crossing of $A_{FB}(q^2)$ is also consistent with SM....

Buras et.al. JHEP1009 (2010)

- In the SM4, $S_{\psi\phi} > 0.5$ disfavoured the measured direct CP violation in $K \to \pi\pi$, ϵ'/ϵ $\Rightarrow$ Therefore the present data on $S_{\psi\phi}$ is also consistent with the measured ϵ'/ϵ

Data allow a linear relationship between $\lambda^{t'}_{sb}$ and $\lambda^{b'}_{uc}$ $\Rightarrow$ Large effect in $b \to s$ is correlated with a large effect in $D - \bar{D}$ mixing and decays

...........see Buras et.al, JHEP 1007 (2010) and Nandi & Soni, PRD83 (2011)

Conclusions

- From the perspective of flavour physics, 4G Models remain an interesting option for new physics effects in B and K Observables.
- Certain Tensions and Anomalies can be resolved.
- Qualitative difference to LHT, RSc, SUSY flavour scenarios:
  - relatively low masses for $m_{t'}$,
  - non-decoupling of heavy 4G quarks.
- Prominent effects and correlations in Rare Kaon Decays are still possible (even with small deviations in the B_s sector)
  - Inclusion of ϵ'/ϵ actually disfavours large (positive) values of $S_{\psi\phi}$.
- Correlations among Precision Flavour Observables can distinguish between different scenarios for the Wolfenstein Scaling of the CKM Matrix in 4G.

Evidence against 4th generation

CAN NOT BE JUST SM4

- **Simple SM4 light higgs seems strongly disfavored by data** (Amarjit Soni)

$\sigma_{SM4}/\sigma_{SM3} \sim 9$ (the reason why a wider range for SM4 has been excluded compared with SM3) (Xiao-Gang He)

If with SM3 like cross section, 4th generation is ruled out?

ill not find the Higgs in the whole expected mass range up to

ot exist? Also SM4 is not favored.

There seems to be a lot of evidence against a "straightforward" 4th generation - are the solutions contrived workarounds?

- PMNS matrix is really close to 3×3 unitarity

Andreas Menzel

SM benchmarks

- With 2011 data LHCb will be in a position to measure tree-level γ from B→DK decays to about 5° to 10° - that's of course just the beginning. CLEO-c and BES III input will play an important role in high-precision γ measurements - principle proven by BaBar (coherence factor) and BELLE (Dalitz analysis).

implies a precision of
a few degrees after
5/fb at 14TeV

→How precisely do you need to know γ?

Determination of V_{ub}

(Ulrik Egede)

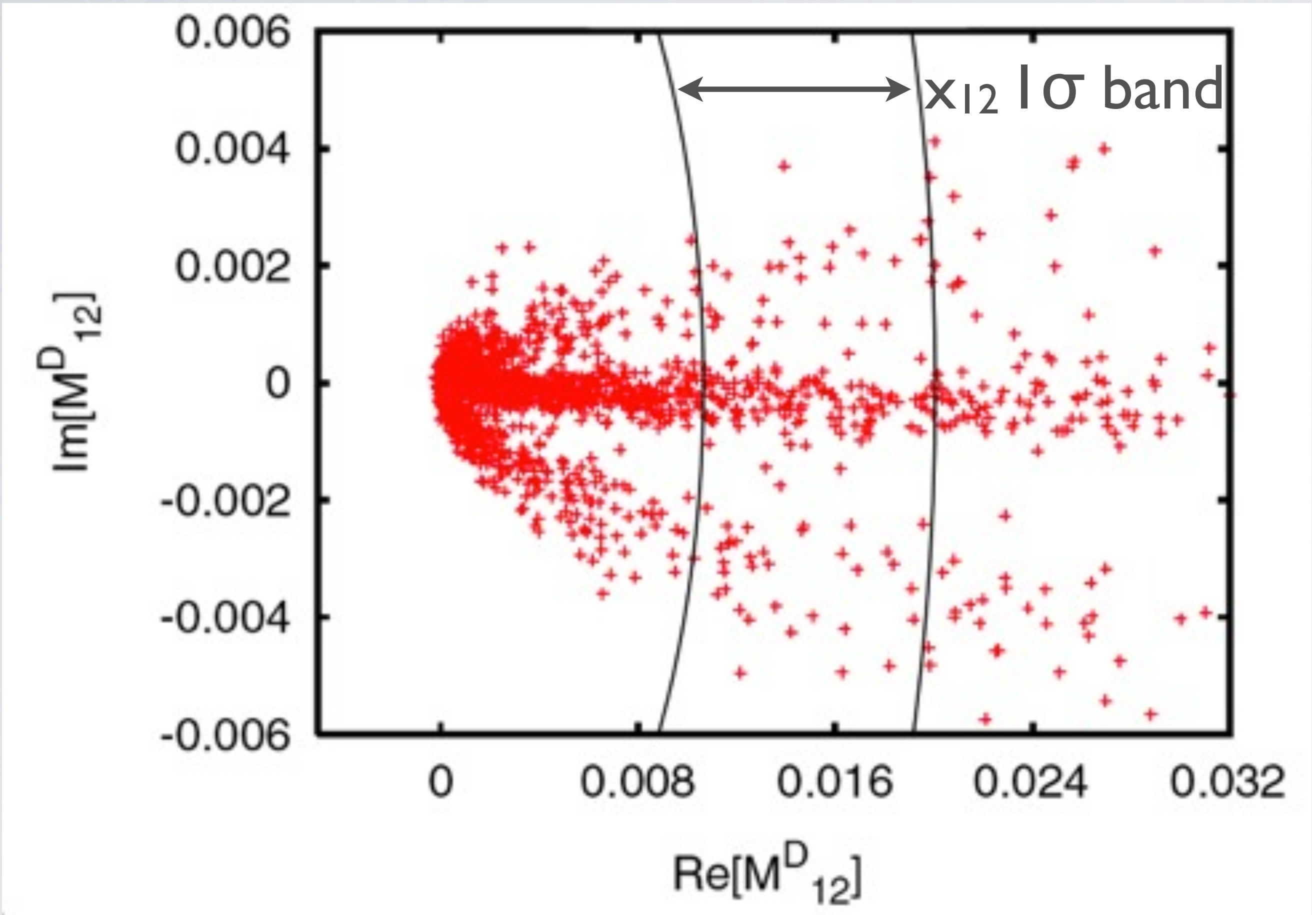
Use BFs of $B\to K^*\mu\mu$, $B\to\rho\mu\nu$, $D\to K^*\mu\nu$, $D\to\rho\mu\nu$

Pirjol, Grinstein PRD**70** (2004) 114005

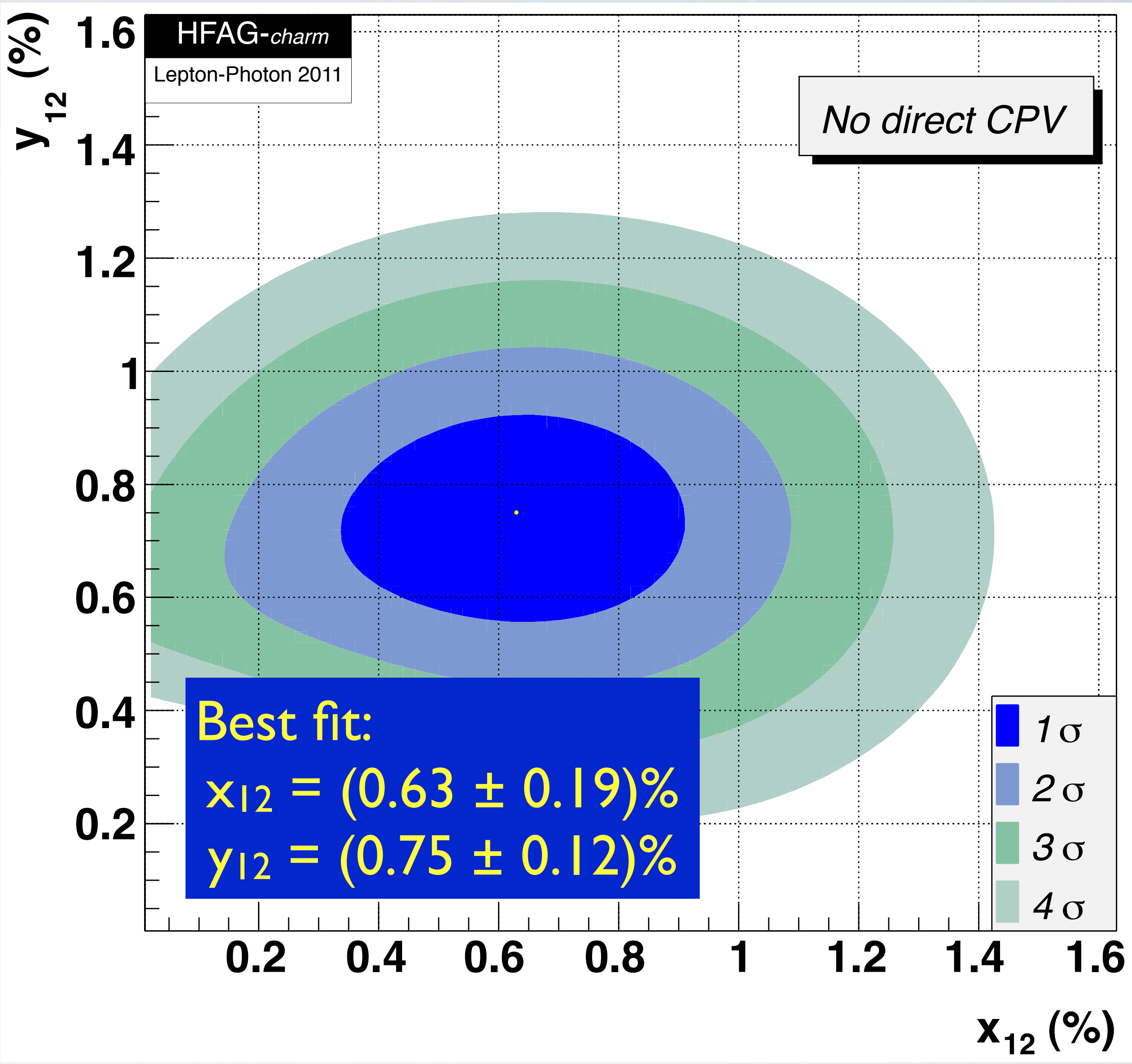
→Any ideas what other cans of worms to be thrown at V_{ub} by LHCb?

⇒How is any of this relevant to 4th generation physics?

CHARM MIXING



Nandi, Soni, PRD 83 114510 (2011)



- Example neglecting LD contributions
- Entering the region of precision measurements
- LHCb will significantly improve precision of charm mixing observables
- Need precise prediction to interpret these results

Discussion points concerning

Neutral meson mixing (Beauty)

IPPP workshop on
Flavour and the Fourth Family

Wouter Hulsbergen

summary of experimental sensitivity

- B_d system

	now	end 2012
ΔM [%]	$\mathbf{0.08}$	$< \mathbf{0.08}?$
$\Delta\Gamma/\Gamma$	$\mathbf{0.02}$	$< \mathbf{0.02}?$
$\lvert q/p\rvert$	$\mathbf{0.003}$ (HFAG)	$\mathbf{0.001}$ (?)
ϕ [rad]	$\mathbf{0.03}$	$\mathbf{0.03}$

- B_s system

	now	end 2012
ΔM [%]	$\mathbf{0.03}$	$\sim \mathbf{0.02}$
$\Delta\Gamma/\Gamma$	$\mathbf{0.04}$	$\sim \mathbf{0.02}$
$q/p\rvert$	$\mathbf{0.001 - 0.005}$	$\mathbf{0.001}?$
ϕ [rad.]	$\mathbf{0.16}$	$\sim \mathbf{0.06}$

Q: what are theoretical bounds on 'penguin' pollutions to ϕ from observation of suppressed decays?

Di-muon charge asymmetry at D0

- D0 (arXiv:1106.6308, subm. to PRD):

$$A^b_{sl} = (-0.787 \pm 0.172 \pm 0.093)\%$$

SM: $$A^b_{sl}(SM) = (-0.023^{+0.005}_{-0.006})\%$$

3.9 sigma

- a bit hard to explain theoretically,even beyond SM

- splitting sample by IP, gives

$$a^d_{sl} = (-0.12 \pm 0.52)\%$$
$$a^s_{sl} = (-1.81 \pm 1.06)\%$$

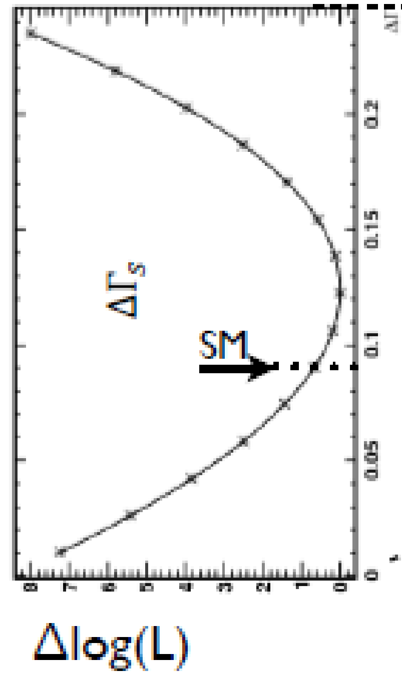
too little stats to say anything

<u>remarked yesterday:</u>
sample with which a^d is estimated is much purer than sample with which a^s is estimated

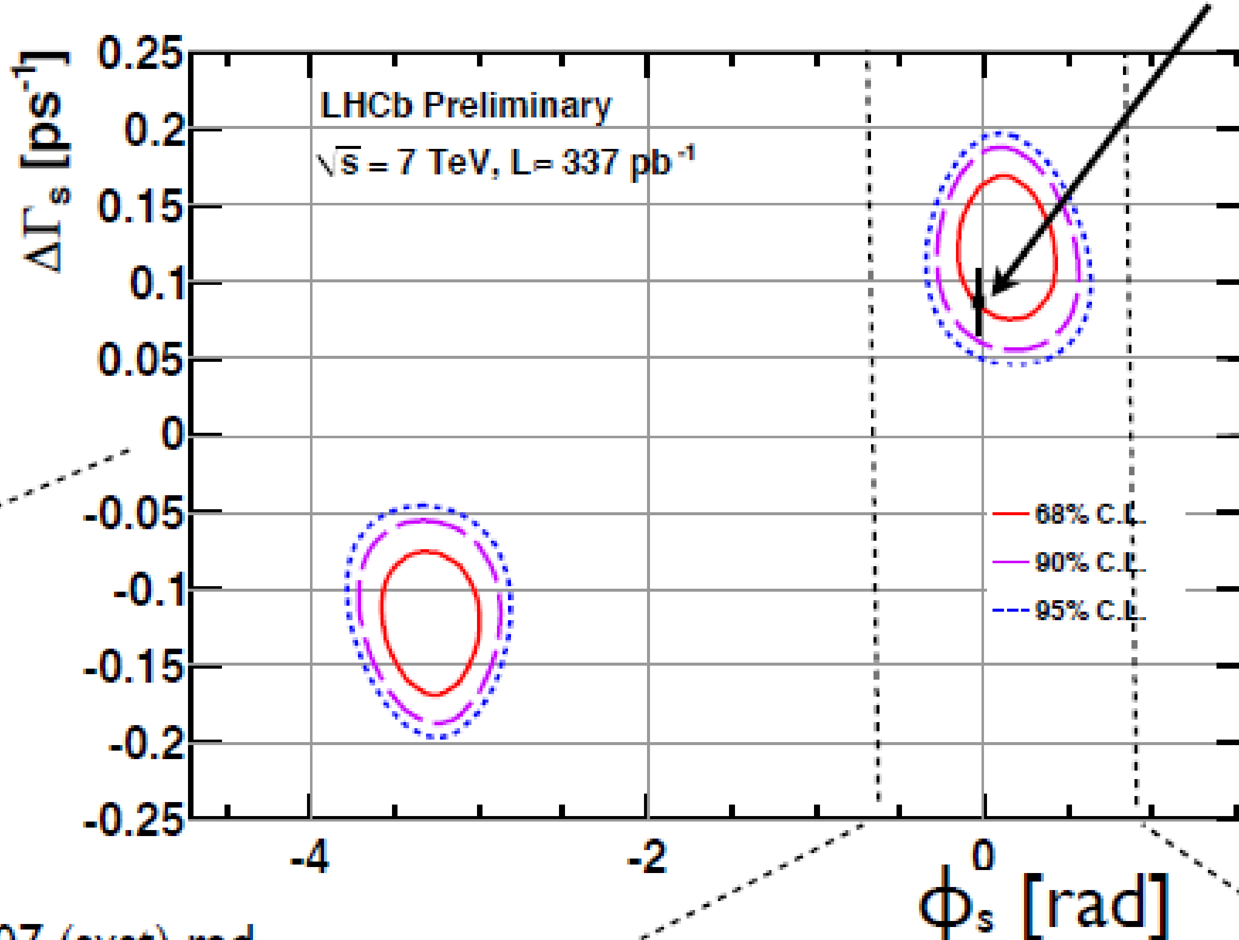
- LHCb working hard to provide measurement of a^s_sl by winter 2012

$B_s \to J/\psi\varphi$: $\Delta\Gamma_s$ vs. ϕ_s

LHCb-CONF-2011-49



Standard Model
(Lenz, Nierste: arXiv:1102.4274)



Most precise measurement of ϕ_s

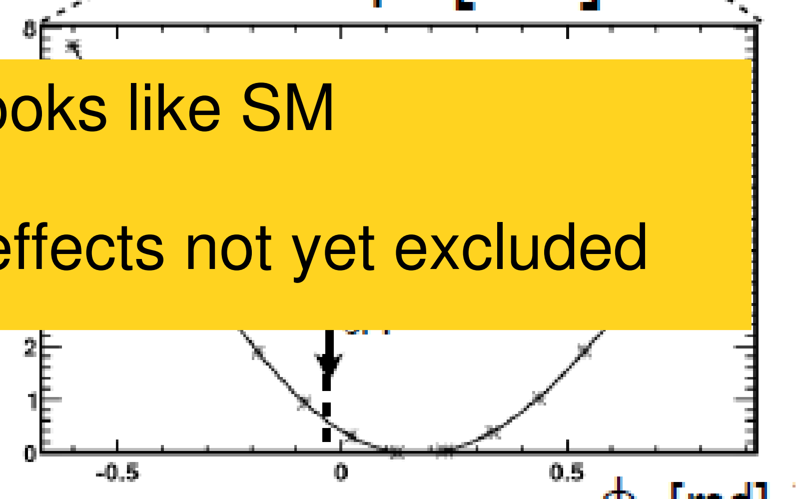
- $\phi_s = 0.13 \pm 0.18$ (stat) ± 0.07 (syst) rad
- Consistent with SM

4 σ Evidence for $\Delta\Gamma_s \neq 0$:

- $\Delta\Gamma_s = 0.123 \pm 0.029$ (stat) ± 0.008 (syst) ps^{-1}
- $\Gamma_s = 0.656 \pm 0.009$ (stat) ± 0.008 (syst) ps^{-1}

LHCb result looks like SM

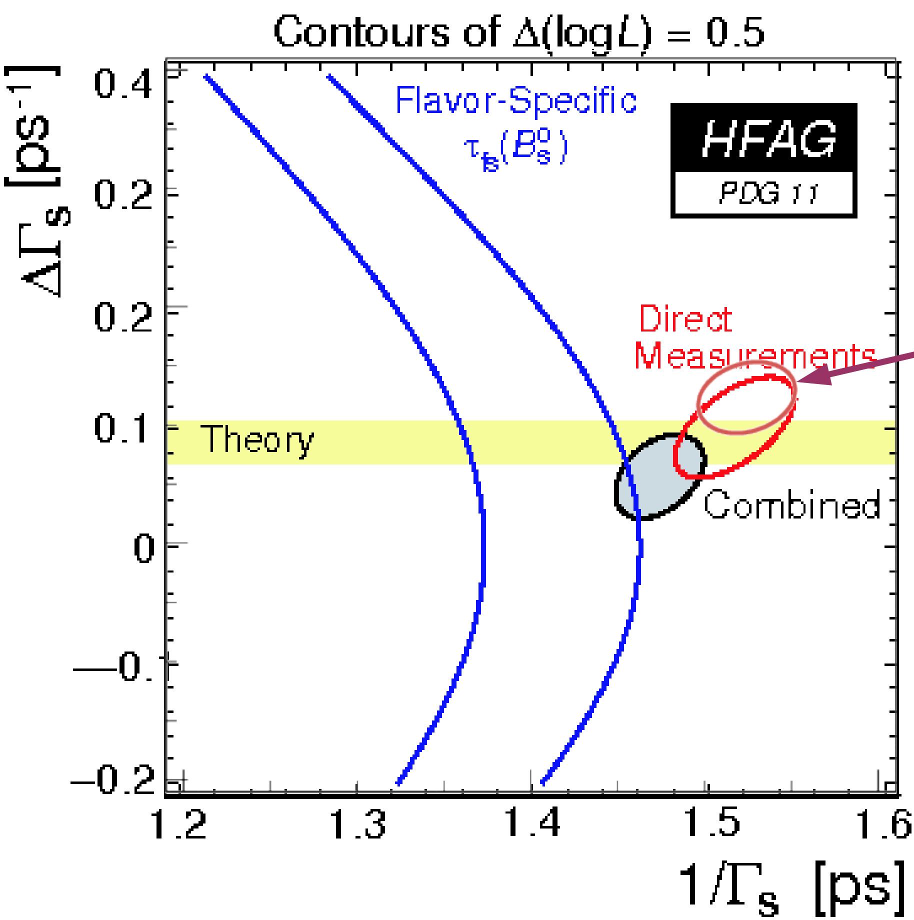
but large NP effects not yet excluded



(slide by Gerhard Raven at LP2011)

$\Delta\Gamma_s$

- J/psi phi analysis also gives most precise single measurement of Γ_s and $\Delta\Gamma_s$



LHCb in J/psi phi (341/pb)

$$\tau(B_s^0)_{\mathrm{fs}} = \frac{1}{\Gamma_s} \frac{1 + \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1 - \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$$

slight inconsistency in Γ between direct measurement and measurement with flavour specific decays?

Q: any wise comments from theory side?
(like “impossible in any NP model”)

Discussion

Boštjan Golob
University of Ljubljana/Jožef Stefan Institute & Belle/Belle II Collaboration

University of Ljubljana

"Jožef Stefan" Institute

Flavour and the Fourth Family, Durham, September 14-16, 2011

- $B \to \tau\nu$
- $B \to K\pi$ *puzzle*
- *summary of incl. rare B decays*

$$\Gamma(P^+ \to \ell^+\nu) = \frac{G_F^2}{8\pi}\left|V_{Qq}\right|^2 f_P^2 m_P m_\ell^2 \left(1 - \frac{m_\ell^2}{m_P^2}\right)$$

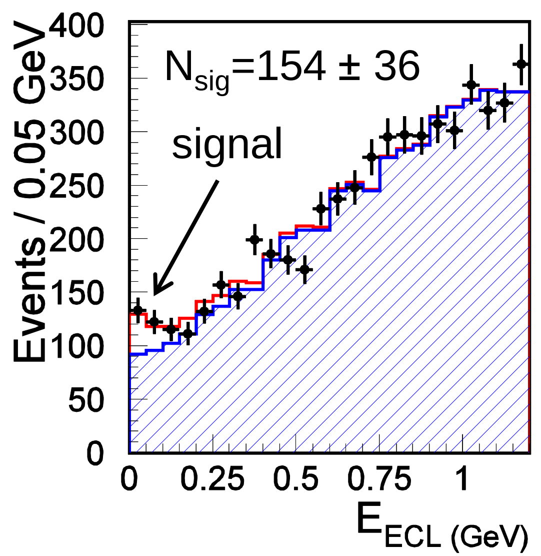
$B^+ \to \tau^+\nu$

fully (partially) reconstruct B_{tag};
search for 1/3 tracks from $B_{sig} \to \tau\nu$;
no additional energy in EM calorim.;
signal at $E_{ECL} \sim 0$;

semil. tagging:

Belle, arXiv: 0809.3834, 600 fb^{-1}

$$Br(B^+ \to \tau\nu) = (1.65 \pm {}^{0.38}_{0.37} \pm {}^{0.35}_{0.37}) \cdot 10^{-4}$$



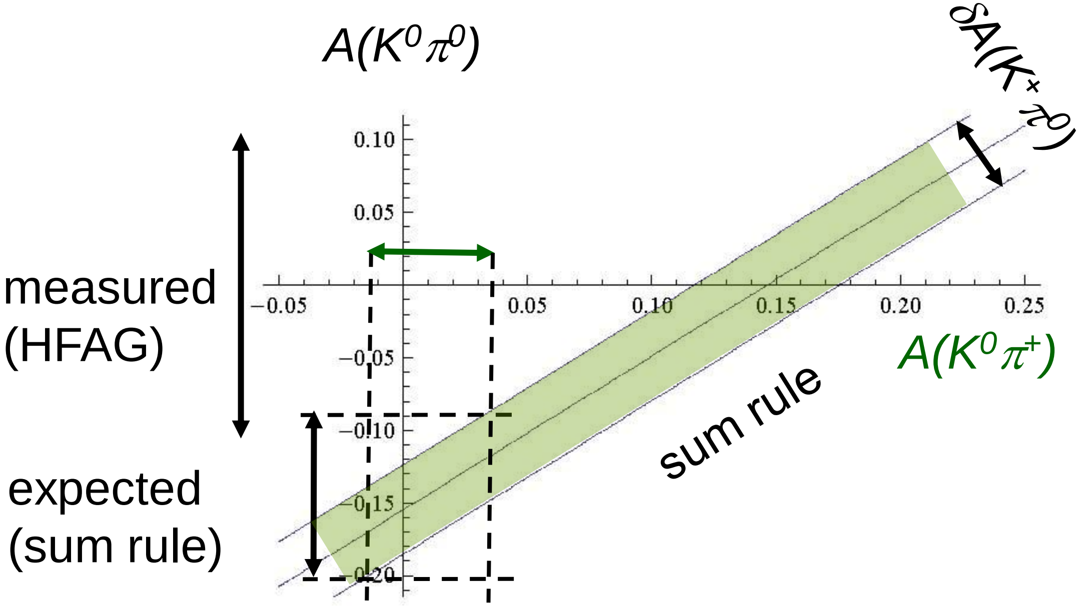
Belle 50 ab^{-1}; current W.A. central value;
semil. + hadr. tag;
total Br error scaled
(main syst. is reducible: bkg. ECL shape, ε B_{tag});
for G/GSM:
V_{ub}, currently 5% from CKM fit;
f_B, currently 10% from LQCD;
both expected 3%;

$$\sigma(Br(B^+ \to \tau\nu)) \approx 0.05 \cdot 10^{-4}$$
$$\sigma(\Gamma / \Gamma^{SM}) \approx 0.08$$

$$\mathcal{A}_f(K^+\pi^-) + \mathcal{A}_f(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)\tau_{B^0}}{\mathcal{B}(K^+\pi^-)\tau_{B^+}} = \mathcal{A}_f(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)\tau_{B^0}}{\mathcal{B}(K^+\pi^-)\tau_{B^+}} + \mathcal{A}_f(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}.$$

Direct CPV puzzle:

$A(K^0\pi^+)=0.009 \pm 0.025$
$A(K^+\pi^0)=0.050 \pm 0.025$
$A(K^+\pi^-)=-0.098 \pm 0.012$
$A(K^0\pi^0)=-0.01 \pm 0.10$



$$\mathcal{A}_f(K^+\pi^-) + \mathcal{A}_f(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)\tau_{B^0}}{\mathcal{B}(K^+\pi^-)\tau_{B+}} = \mathcal{A}_f(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)\tau_{B^0}}{\mathcal{B}(K^+\pi^-)\tau_{B+}} + \mathcal{A}_f(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}.$$

Direct CPV puzzle:

$A(K^0\pi^+)=0.009 \pm 0.025$
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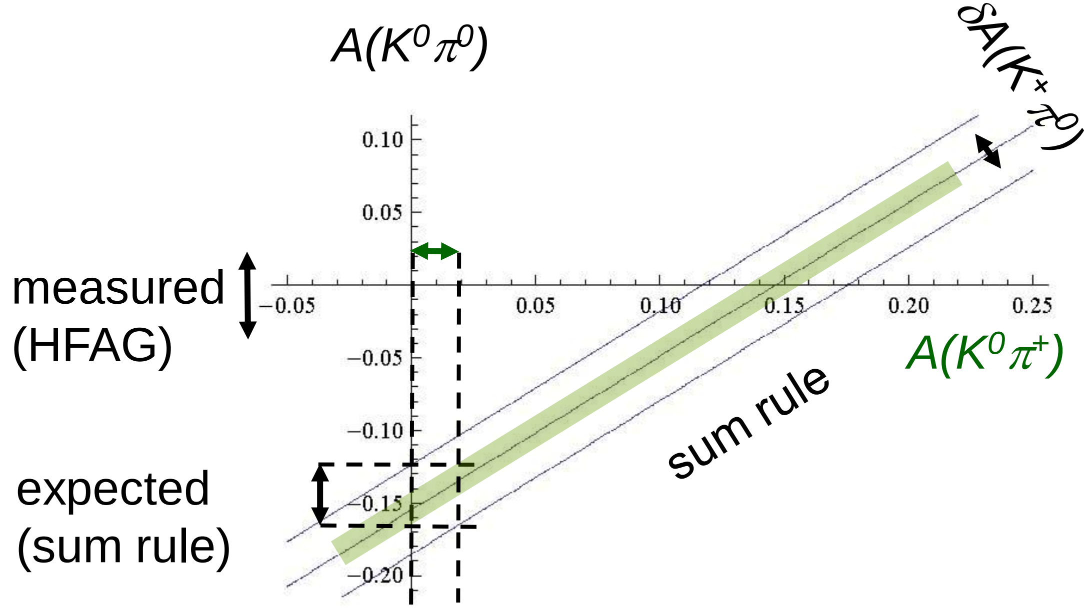
$A(K^0\pi^0)=-0.01 \pm 0.10$



50 ab^{-1}:

B →$K^0\pi^0$: main syst. uncertainty from tag side interf.;
can be reduced by measuring Δt with semil. B_{sig} decays
B → $K^0\pi^+$, $K^+\pi^0$: full systematics treated as non-scaling

Summary of incl. rare decays

observable	accuracy	comment	sensitivity to SM4
$\mathcal{B}(b \to s\gamma)$	3%		**
$A_{CP}(b \to s\gamma)$	0.2%		****
$\mathcal{B}(b \to s\ell\ell)$	10^{-7}	$0 < q^2 < 6$ GeV^2	?
$A_{FB}(b \to s\ell\ell)$	0.03	$0 < q^2 < 4$ GeV^2	***
$A_{CP}(b \to s\ell\ell)$	$5 \cdot 10^{-3}$		*
$\mathcal{B}(b \to s\nu\nu)$	25%		

questions: theory accuracy (e.g. for $B \to s\gamma$)?
Relation between fully inclusive / sum of exclusives (e.g. for $B \to s \ell \ell$ / $B \to s \nu \nu$)?

Summary/Discussion

- Kaon decays can give several constraints on 4th generation
- BR(K+,L→$\pi\nu\nu$) about to be measured
- RK reached record precision, and will improve in the future
- search for ν_H just started
- Possible to have strong effects in K and B at the same time
- Even for SM-like $S_{\varphi\phi}$ and Bs→$\mu\mu$, possible large effects and correlations in K

- Interplay between rare decays and RK when 4G lepton mixing is not negligible
- If 4G lepton mixing is large, but RM is SM (Ue4=Uμ4), how do rare decays change
- Is there a combination of kaon variables that could rule out SM4
- How $\pi\nu\nu$ change for various 4G quark mixing matrix scenarios
- If $\pi\nu\nu$ deviates from SM, how critical is to build an experiment for πll