Fourth family parameter fits

SM4 and single-top workshop in Leinsweiler, 27 March 2012

Otto Eberhardt[1], G. Herbert, H. Lacker, A. Lenz, A. Menzel[2], U. Nierste, & M. Wiebusch, using CKMfitter

[1]Karlsruhe Institute of Technology, [2]HU Berlin

Outline

- Direct searches
  - Fermion mixing
  - Fermion masses
  - Higgs searches
- Loop observables
  - Electroweak precision observables
  - Combining direct searches and EWPOs
  - Flavour constraints
  - Outlook

The fourth family model

SM fit parameters: m_H, θ_{12}^{CKM}, θ_{13}^{CKM}, θ_{23}^{CKM}, ϕ_1^{CKM}, $\theta_{12}^{\text{PMNS}}$, $\theta_{13}^{\text{PMNS}}$, $\theta_{23}^{\text{PMNS}}$, ϕ_1^{PMNS}

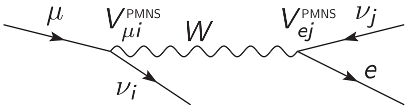
New in the SM4: $m_{t'}$, $m_{b'}$, m_{ν_4}, m_{ℓ_4},

θ_{14}^{CKM}, θ_{24}^{CKM}, θ_{34}^{CKM}, ϕ_2^{CKM}, ϕ_3^{CKM},

$\theta_{14}^{\text{PMNS}}$, $\theta_{24}^{\text{PMNS}}$, $\theta_{34}^{\text{PMNS}}$, ϕ_2^{PMNS}, ϕ_3^{PMNS}

Lepton mixing and G_F

G_F is determined from τ_μ:



If we use 4×4 unitarity of V^{PMNS},

$G_F = 1.16637 \cdot 10^{-5} GeV^{-2}$ is only a lower limit. [Lacker, Menzel '10]

Its extraction in an SM4 consistent combined fit yields

$G_F = 1.1678^{+0.00089}_{-0.00120}$

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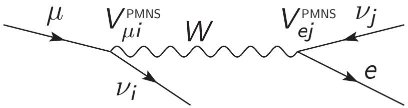

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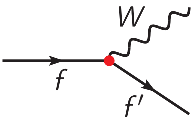
But let's neglect lepton mixing for the moment.

Tree-level constraints to the CKM matrix

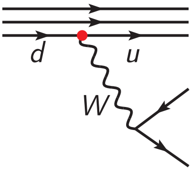


$$V_{CKM4} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{ub'} \\ V_{cd} & V_{cs} & V_{cb} & V_{cb'} \\ V_{td} & V_{ts} & V_{tb} & V_{tb'} \\ V_{t'd} & V_{t's} & V_{t'b} & V_{t'b'} \end{pmatrix}$$

Tree-level constraints to the CKM matrix

β decays $\longrightarrow$

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{ub'} \\ V_{cd} & V_{cs} & V_{cb} & V_{cb'} \\ V_{td} & V_{ts} & V_{tb} & V_{tb'} \\ V_{t'd} & V_{t's} & V_{t'b} & V_{t'b'} \end{pmatrix}$$

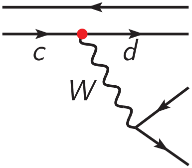


Tree-level constraints to the CKM matrix

β decays

semileptonic meson decays & ν scattering

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{ub'} \\ V_{cd} & V_{cs} & V_{cb} & V_{cb'} \\ V_{td} & V_{ts} & V_{tb} & V_{tb'} \\ V_{t'd} & V_{t's} & V_{t'b} & V_{t'b'} \end{pmatrix}$$



Tree-level constraints to the CKM matrix

β decays

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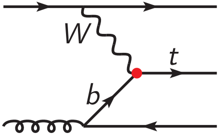
semileptonic
meson decays
& ν scattering

(single) top production



Tree-level constraints to the CKM matrix

β decays → V_{ud}

semileptonic meson decays & ν scattering → $V_{us}, V_{ub}, V_{cd}, V_{cs}, V_{cb}$

(single) top production → V_{tb}

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{ub'} \\ V_{cd} & V_{cs} & V_{cb} & V_{cb'} \\ V_{td} & V_{ts} & V_{tb} & V_{tb'} \\ V_{t'd} & V_{t's} & V_{t'b} & V_{t'b'} \end{pmatrix}$$

$$\gamma \equiv \arg\left(\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$ from CKMfitter fits

Direct fermion searches

Most search limits are subject to assumptions:

- BF=100% in search channel
- Lifetime

Particle	Signature	m_{min} [GeV]	Experiment
ℓ_4 (short & long τ)	$\ell_4 \to \nu + W$	100	L3 (PRL B 517, 75 (2001))
ν_4 (Dirac short τ)	$\nu_4 \to \ell + W$	90.3	L3 (PRL B 517, 75 (2001))
ν_4 (Majorana short τ)	$\nu_4 \to \ell + W$	62.1	Carpenter, 1005.0628
t', short τ	$t' \to bW$	552	CMS (CMS-EXO-11-050)
b', short τ	$b' \to tW$	600	CMS (CMS-EXO-11-036)

$\to$ Geoffrey Herbert's talk

Direct Higgs searches

Signal strength

$$\frac{\text{signal strength(SM4)}}{\text{signal strength(SM3)}} = \frac{\sigma(4)}{\sigma(3)} \cdot \frac{\mathrm{BR}(4)}{\mathrm{BR}(3)}$$

We have analysed four channels: $\gamma\gamma$, WW, ZZ from LHC and $b\bar{b}$ from TeVatron, assuming $m_H = 125$ GeV.

Direct Higgs searches

Signal strength

$$\frac{\text{signal strength(SM4)}}{\text{signal strength(SM3)}} = \frac{\sigma(4)}{\sigma(3)} \cdot \frac{\mathrm{BR}(4)}{\mathrm{BR}(3)}$$

We take the colliders' best fit values for the SM3 signal strength.

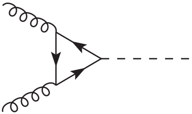
Direct Higgs searches

Signal strength

$$\frac{\text{signal strength(SM4)}}{\text{signal strength(SM3)}} = \frac{\sigma(4)}{\sigma(3)} \cdot \frac{\mathrm{BR}(4)}{\mathrm{BR}(3)}$$

Rescale the main production channels:

$$\sigma_{\mathrm{gg}}(4) = \sigma_{\mathrm{gg}}(3) \cdot \frac{\Gamma_{\mathrm{SM4}}}{\Gamma_{\mathrm{SM3}}} \cdot \frac{\mathrm{BR}(4)}{\mathrm{BR}(3)}$$



Direct Higgs searches

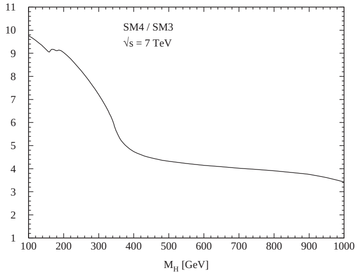
Signal strength

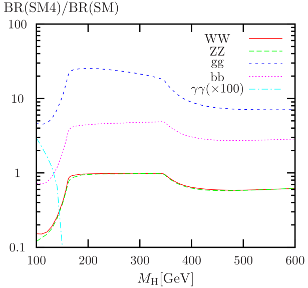
$$\frac{\text{signal strength(SM4)}}{\text{signal strength(SM3)}} = \frac{\sigma(4)}{\sigma(3)} \cdot \frac{\text{BR}(4)}{\text{BR}(3)}$$

Redo BR calculation for the SM4 using HDecay

Direct Higgs searches

Cross section and branching ratios for fermion masses of around 600 GeV:



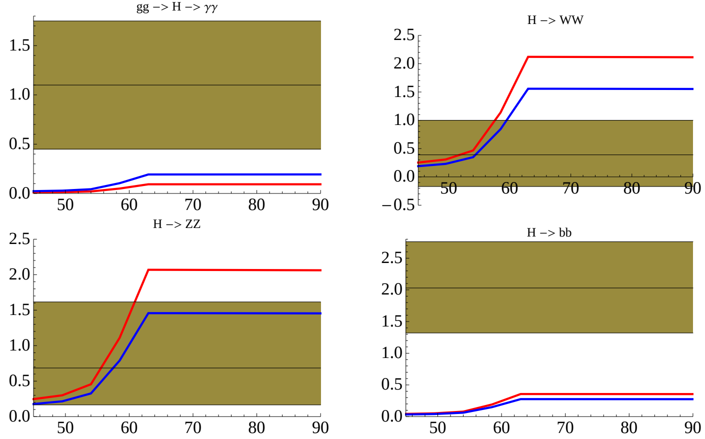


[Denner et al. '11]

We have to pay attention to the channel hierarchy!
It is also crucial whether we have a "light" fourth neutrino.
(I. e. 45.6 GeV $< m_{\nu_4} < \frac{m_H}{2}$)

Direct Higgs searches

m_{ν_4} [GeV] vs. $\frac{\text{signal strength(SM4)}}{\text{signal strength(SM3)}}$ in the single channels:



$m_H = 125$ GeV

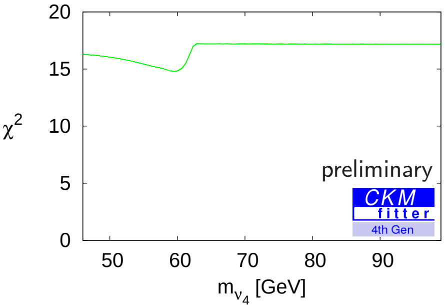
$m_{\ell_4} = 100$ GeV

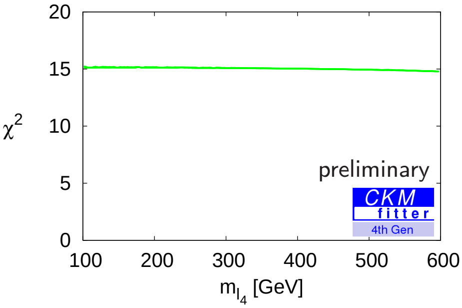
$m_{\ell_4} = 600$ GeV

→Fit with free m_{ℓ_4} and m_{ν_4} (quark masses are fixed to around 600 GeV here)

Direct Higgs searches

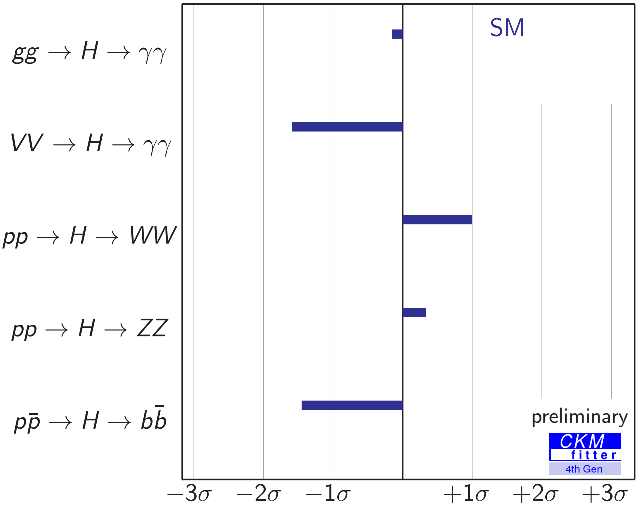
$m_H = 125$ GeV





Direct Higgs searches

Pulls on the single Higgs decay channels



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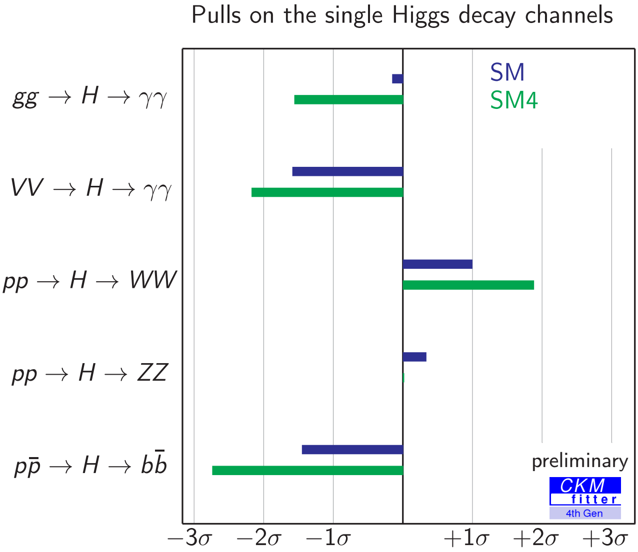

$m_H = 125$ GeV

Electroweak precision data

Direct LEP bounds => STU

good approximation for $\theta_{i4} \approx 0$ and $m_{\mathrm{SM4}} > m_Z$

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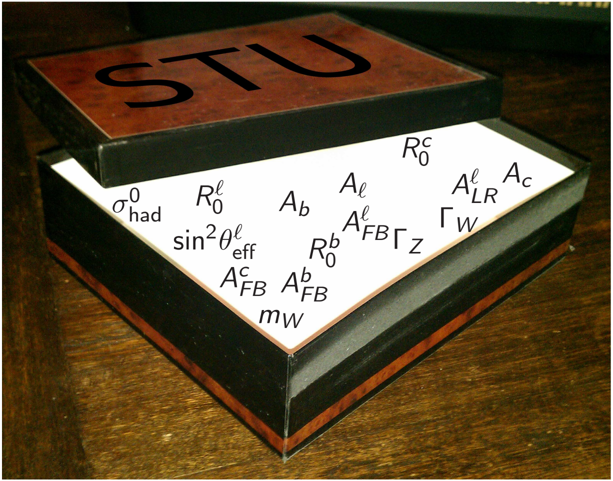
Electroweak precision data

Direct LEP bounds => STU?



no approximation

$$\mathcal{O}^{\text{SM4}} = \mathcal{O}^{\text{SM3}} \cdot \Delta\mathcal{O}$$

[Gonzalez, Rohrwild, Wiebusch '11]

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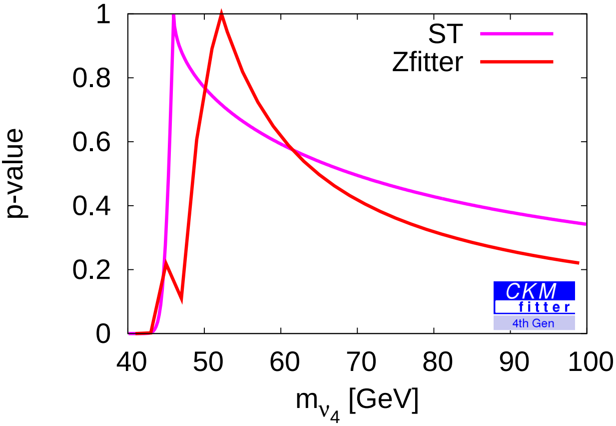
Electroweak constraints

→ Martin Goebel's talk

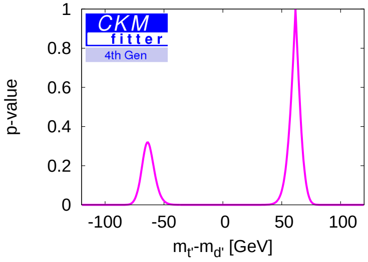
Compare the difference between *ST* and the EWPOs for a Dirac neutrino mass:



Electroweak constraints

$m_H = 120$ GeV

Fermion mass difference, neglecting the leptons:



$(V^{\text{CKM}} = \mathbb{1})$

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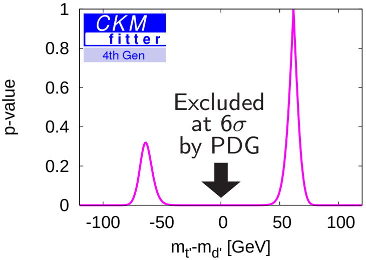

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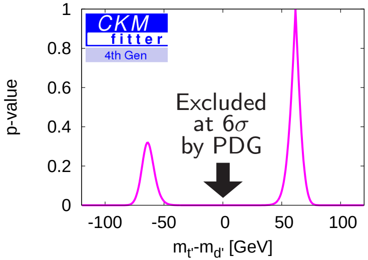

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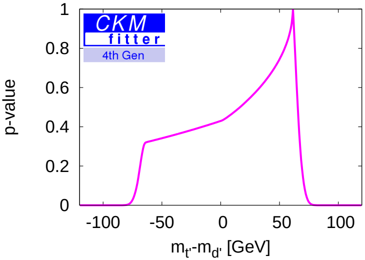

$(V^{\mathrm{CKM}} \neq \mathbb{1})$

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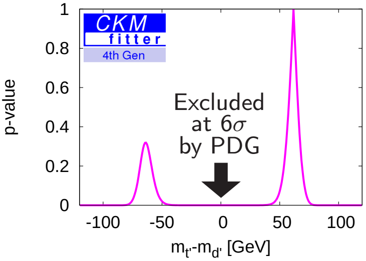

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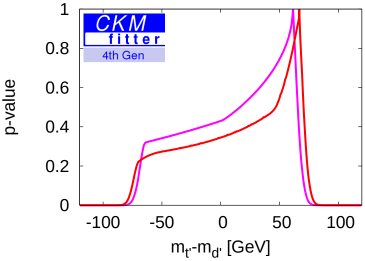

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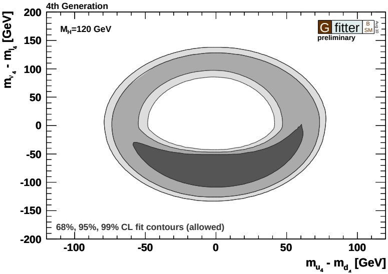
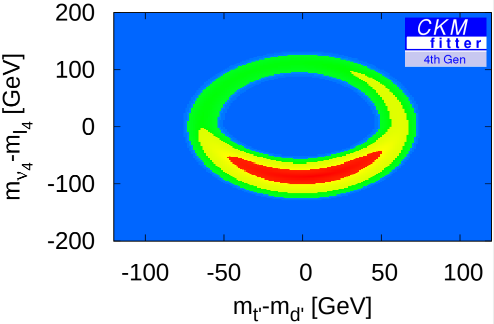
Electroweak constraints

$m_H = 120$ GeV

Mass splitting of the fermion doublets:





Electroweak constraints

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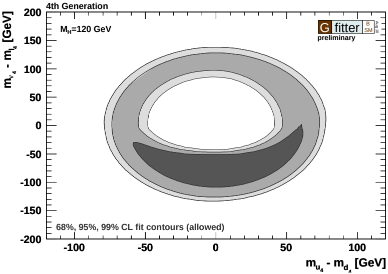

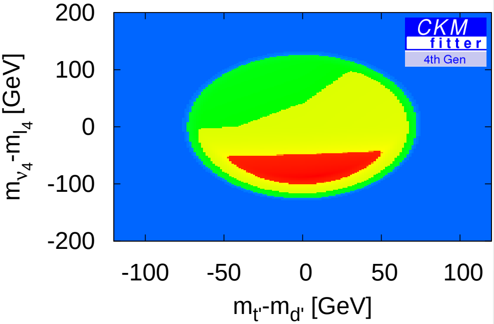

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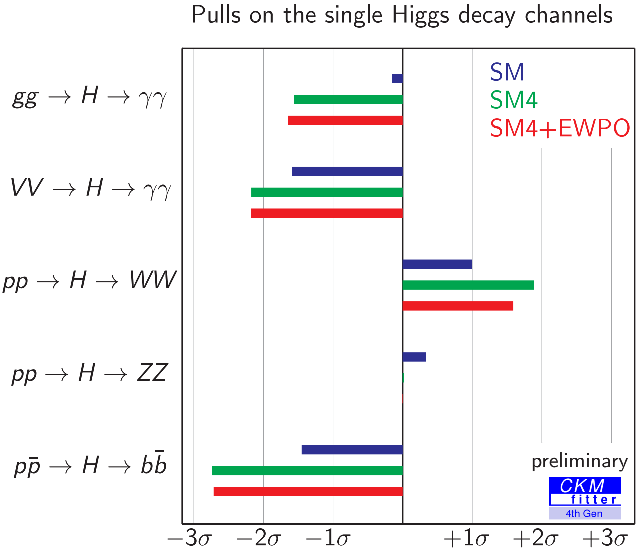
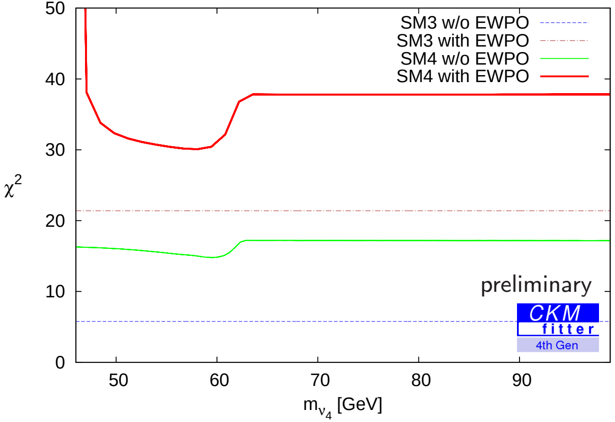


$m_H = 125$ GeV

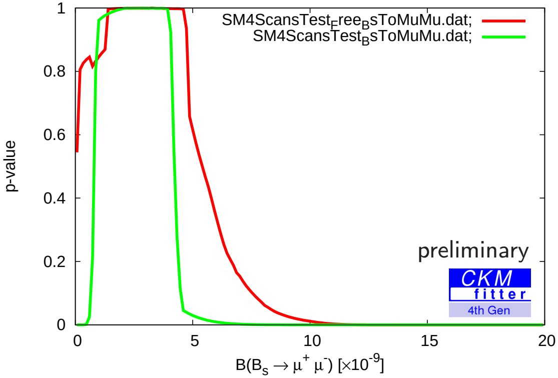
Direct Higgs searches and EWPOs

$m_H = 125$ GeV



Flavour constraints

- $B_s \to \mu^+\mu^-$



Flavour constraints

- $B_s \to \mu^+\mu^-$
- ϵ_K
- A_{sl}, ΔM_{B_d}, ΔM_{B_s}
- $R(b \to s\gamma)$

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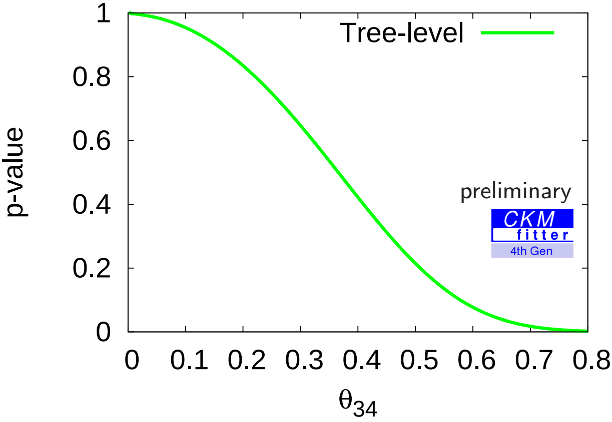
Flavour constraints

Mixing angle between 4th and 3rd generation:



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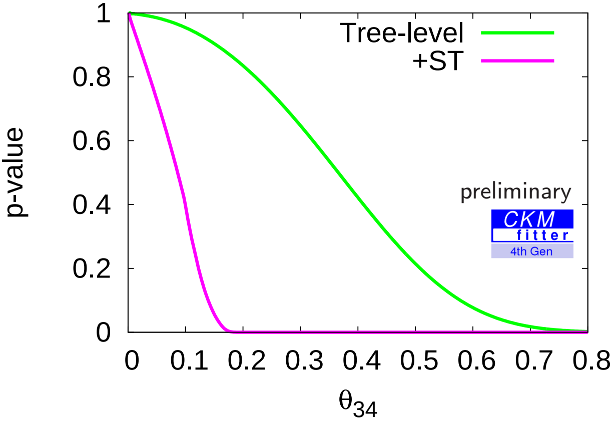

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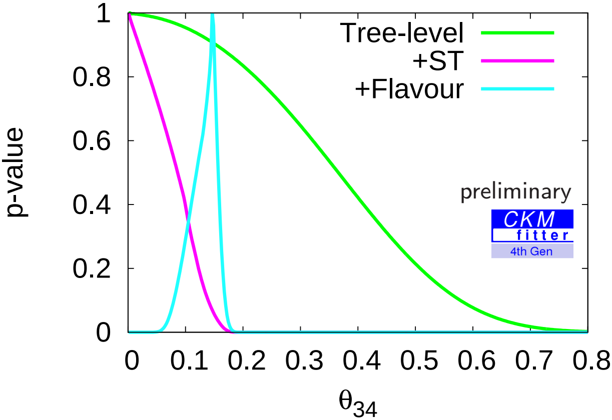

Outlook

All the constraints have to be combined in a global fit.
We are working on it.

CKM fitter 4th Gen

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Back-Ups

Inputs I

$m_{t'} \in [450, 900]$ GeV
$m_{b'} = 600$ GeV
$m_{\nu_4} \in [45, 100]$ GeV
$m_{\ell_4} \in [100, 600]$ GeV

$m_H = 125$ GeV

$\theta_{14} = \theta_{24} = \theta_{34} = \phi_2 = \phi_3 = 0$
$|V_{ud}| = 0.97421^{+0.00034}_{-0.00029}$
$|V_{us}| = 0.2254 \pm 0.0013$
$|V_{ub}| = \left(3.92 \pm 0.09\ _{(\text{stat})}\ \pm 0.45\ _{(\text{sys})}\right) \cdot 10^{-3}$
$|V_{cd}| = 0.230 \pm 0.011$
$|V_{cs}| = 0.98 \pm 0.01\ _{(\text{stat})}\ \pm 0.1\ _{(\text{sys})}$
$|V_{cb}| = \left(40.89 \pm 0.38\ _{(\text{stat})}\ \pm 0.59\ _{(\text{sys})}\right) \cdot 10^{-3}$
$|V_{tb}| = 1.0 \pm 0.099$

γ CKMfitter fit

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Inputs II

$\sigma^{\mathrm{LHC}}(W* \to WH)$	0.5729	$\mathrm{BR}_{\mathrm{SM3}}(H \to WW)$	0.2317
$\sigma^{\mathrm{LHC}}(Z* \to ZH)$	0.3158	$\mathrm{BR}_{\mathrm{SM3}}(H \to ZZ)$	0.02836
$\sigma^{\mathrm{LHC}}(VBF)$	1.211	$\mathrm{BR}_{\mathrm{SM3}}(H \to gg)$	0.09157
$\sigma^{\mathrm{LHC}}(ttH)$	0.08634	Γ_{SM3}	0.003807
$\sigma^{\mathrm{LHC}}(gg \to H)$	15.31	Γ_{SM4}	LUT
$\sigma^{\mathrm{TeV}}(W* \to WH)$	129.5	$\frac{\mathrm{ss}_{\mathrm{SM4}}}{\mathrm{ss}_{\mathrm{SM3}}}(p\bar{p} \to H \to bb)$	$2.03^{+0.73}_{-0.71}$
$\sigma^{\mathrm{TeV}}(Z* \to ZH)$	78.5	$\frac{\mathrm{ss}_{\mathrm{SM4}}}{\mathrm{ss}_{\mathrm{SM3}}}(gg \to H \to \gamma\gamma)$	1.10 ± 0.65
$\mathrm{BR}_{\mathrm{SM3}}(H \to bb)$	0.553	$\frac{\mathrm{ss}_{\mathrm{SM4}}}{\mathrm{ss}_{\mathrm{SM3}}}(pp \to H \to WW)$	$0.39^{+0.61}_{-0.56}$
$\mathrm{BR}_{\mathrm{SM3}}(H \to \gamma\gamma)$	0.002434	$\frac{\mathrm{ss}_{\mathrm{SM4}}}{\mathrm{ss}_{\mathrm{SM3}}}(pp \to H \to ZZ)$	$0.69^{+0.93}_{-0.52}$
		$\frac{\mathrm{ss}_{\mathrm{SM4}}}{\mathrm{ss}_{\mathrm{SM3}}}(VV \to H \to \gamma\gamma)$	$3.70^{+2.02}_{-1.70}$

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Inputs III

S	0.03 ± 0.09	0.867	0
T		0.07 ± 0.08	0
U			0

A_{FB}^{ℓ}	0.0171 ± 0.001	m_W	80.387 ± 0.017 GeV
A_{FB}^{b}	0.0992 ± 0.0016	Γ_W	2.085 ± 0.042
A_{FB}^{c}	0.0707 ± 0.0035	σ_{had}^0	41.54 ± 0.037
A_ℓ	0.1499 ± 0.0018	R_0^b	0.21629 ± 0.00066
A_c	0.670 ± 0.027	R_0^c	0.1721 ± 0.003
A_b	0.923 ± 0.02	R_0^{ℓ}	20.767 ± 0.025
$\sin^2\theta_{\text{eff}}^{\ell}$	0.2324 ± 0.0012	Λ_{QCD}	0.226264 ± 0.002
m_Z	91.1875 ± 0.0021	$\Delta\alpha^{(5)}$	0.02749 ± 0.0001
Γ_Z	2.4952 ± 0.0023		

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