Oblique Parameters, Mixing and BF(t’$\rightarrow$Wb)

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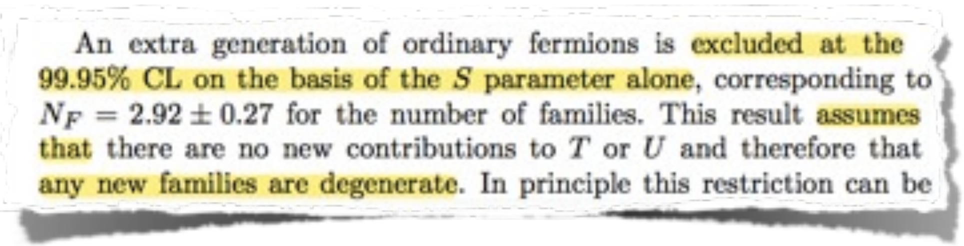
- Mixing for a degenerate 4th generation
- Mixing in a light-Higgs-”light”-neutrino scenario

Mixing - Not only w/3rd gen!

- In literature, most commonly studied case is 3-4 mixing.
  - ➡ Many experimental results reported assuming BF(t'->Wb)=100%.
    - This is partially because of the gains of using b-tagging etc.
  - ➡ Previous OPUCEM work (and work by many others) take into account 3-4 mixing only.
- However:
  - ➡ In general mixing is extremely important including mixing with light generations. Eberhardt, Lenz, Rohrwild showed that even fully-degenerate SM4 is possible with mixing (PRD 82, 095006 (2010)).

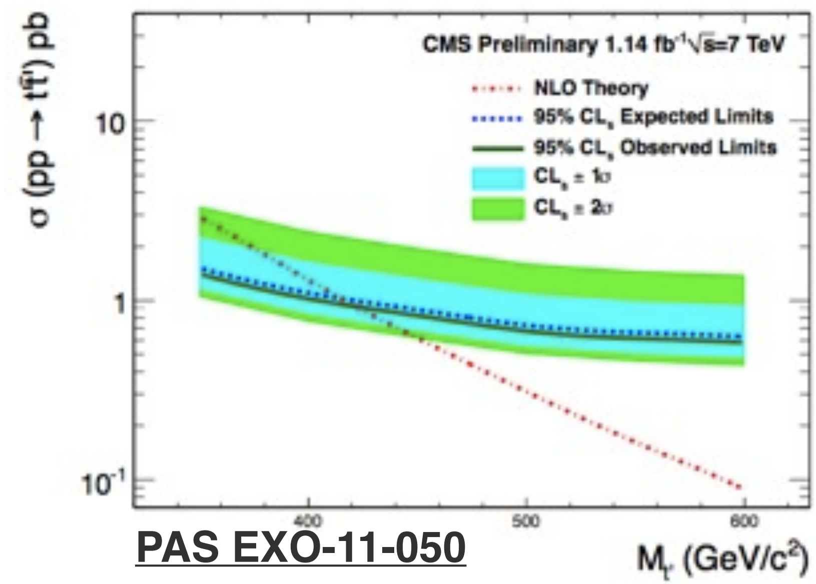
From PDG 2004



An extra generation of ordinary fermions is excluded at the 99.95% CL on the basis of the S parameter alone, corresponding to $N_F = 2.92 \pm 0.27$ for the number of families. This result assumes that there are no new contributions to T or U and therefore that any new families are degenerate. In principle this restriction can be

So PDG was not correct even for the degenerate families.

  - ➡ The amount of mixing with light generations is important to interpret the limits obtained by the LHC experiments.



PAS EXO-11-050

CMS t' results from fully-leptonic channel, assuming BF(t'->Wb)=100%.

Testing the Fully-degenerate 4G

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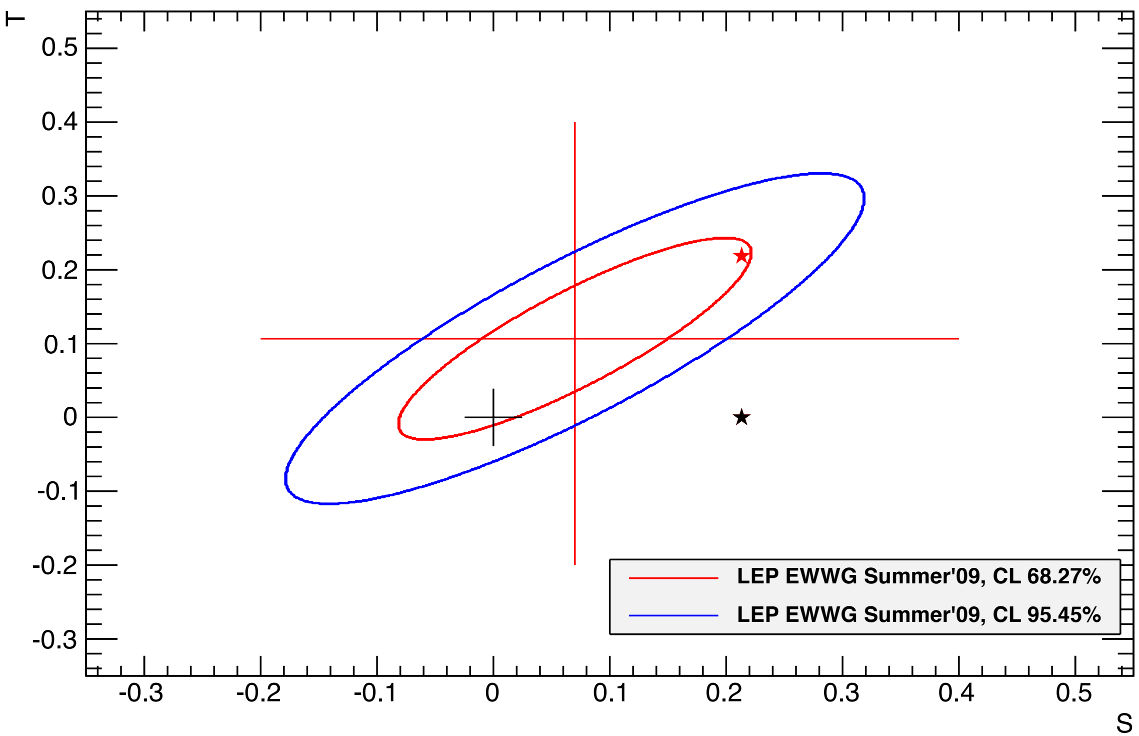


- Example fully-degenerate case:
- $m_{4G} = 400\text{GeV}$
- With no mixing: $\Delta\chi^2 = 22.1$.
- $|\sin\theta_{24}| = \sqrt{K_{24}} = 0.07$ $|\sin\theta_{34}| = \sqrt{K_{34}} = 0.14$, then $\Delta\chi^2{=}2.0$, ie. within 1σ error ellipse.

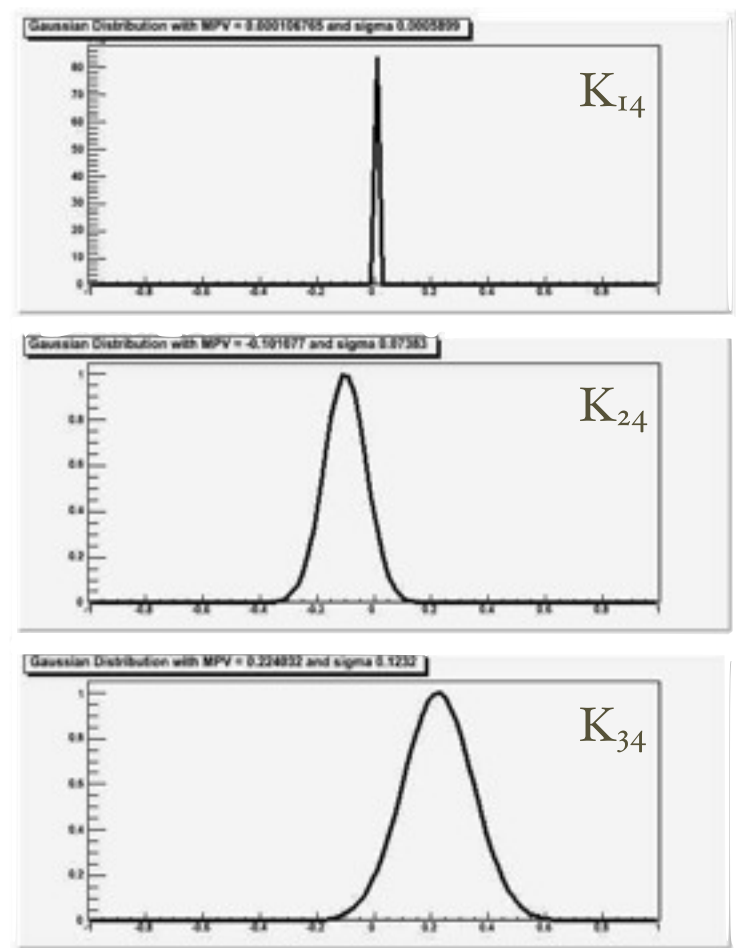
- So indeed fully-degenerate case is possible with mixing.
  - ➡ Question: What are the favoured values of $|s_{34}|$ and $|s_{24}|$?
  - ➡ Method: Start with current CKM measurements, generate random $|s_{i4}|$ values, determine weights using the ST ellipse.

Extending CKM

- Full treatment of 4x4 CKM with EW contraints is important for determining the overall allowed parameter space, ala. Lenz et al.
- However, to do a 1st order estimation of BF(t'->Wb), we simply take CKM 3x3 measurements from PDG, and using the unitarity condition, we determine the values of: $K_{i4} \equiv |V_{i4}|^2$, i=u,c,t.
  - ➡ Uncertainties obtained by simple error propagation, and assumed to be Gaussian.

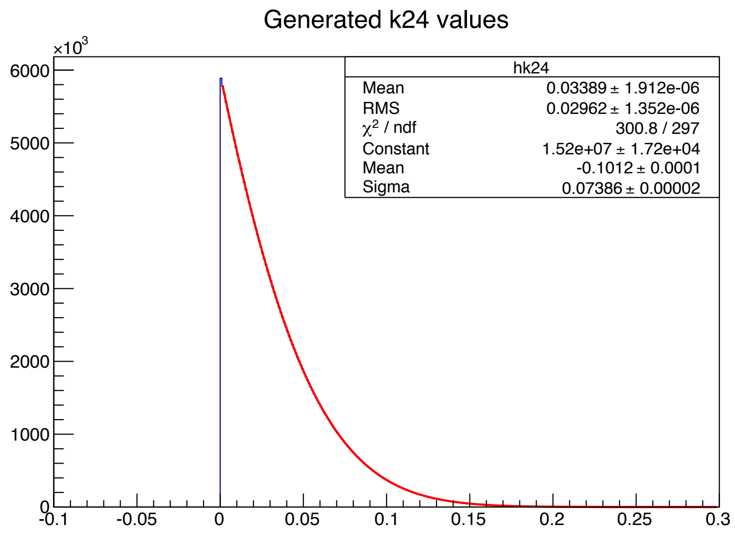
$$
\begin{aligned}
K_{14} &= 0.000106765 \pm 0.0005899 \\
K_{24} &= -0.101077 \pm 0.07383 \\
K_{34} &= 0.224032 \pm 0.1232
\end{aligned}
$$

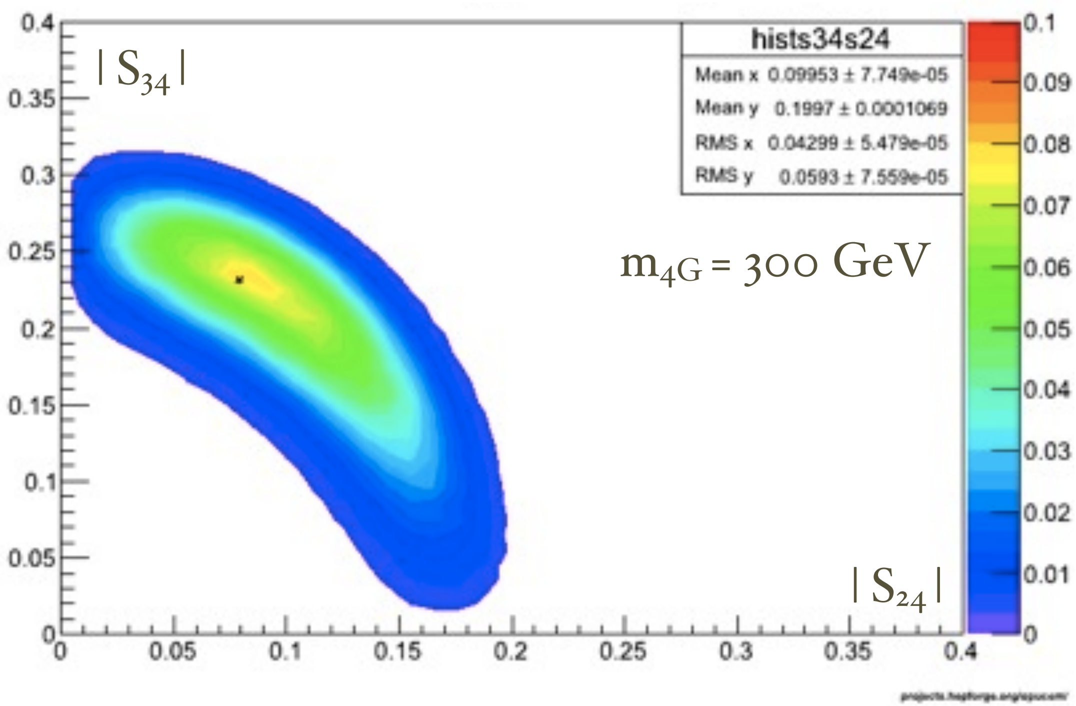
  - ➡ K_{14} is negligible.



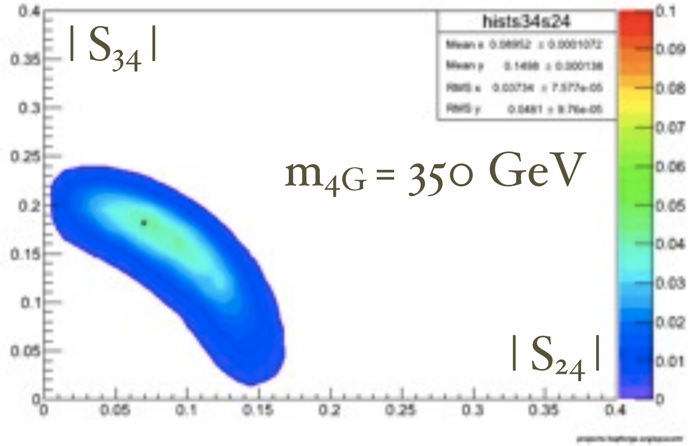
Generating…

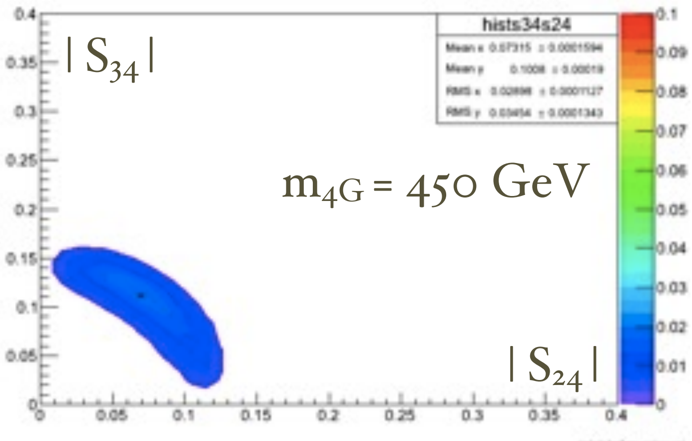
1. Generate Gaussian-distributed random $|K_{24}|$ & $|K_{34}|$, eliminate negative values.
2. For generated $|K_{24}|$ and $|K_{34}|$, compute S, T and $\Delta\chi^2$ from the center of the S-T ellipse.
   - m_H = 115 GeV
   - Dirac-type neutrino
3. Fill 2D histogram with S_{24} and S_{34} values, using χ^2 probability as weights.
   - Total weights are rather small, only 3.5% of points are within 2σ ellipse for m_{4G}=300GeV.
4. Determine the most favored S_{24}-S_{34} pair.

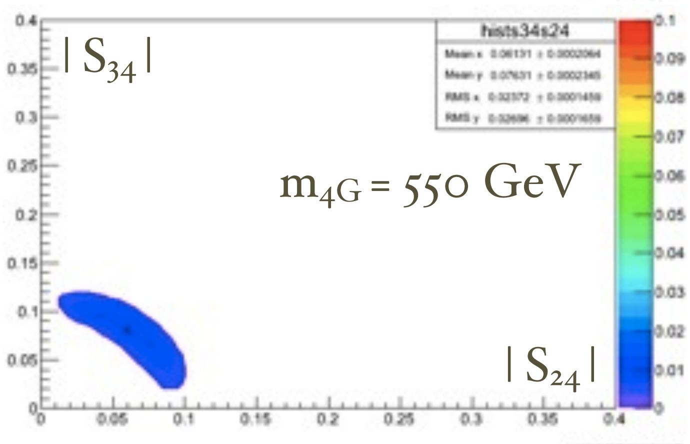




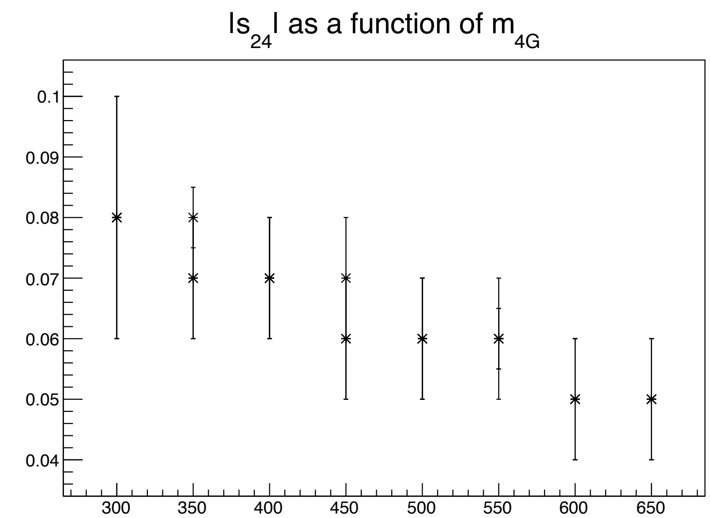
S_{24}-S_{34} versus m_{4G}

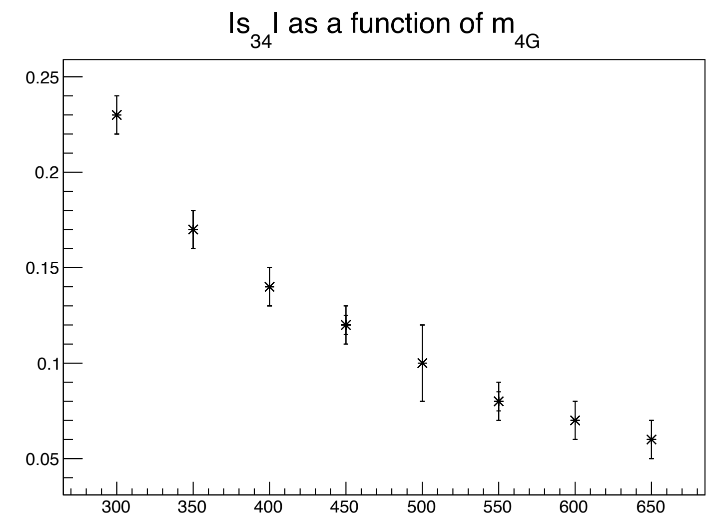






- Favoured S_{24} decreases slightly as degenerate mass increases, whereas S_{34} shows a much rapid decrease.
- Even at low masses, favoured S_{24} is not negligible compared to S_{34}.

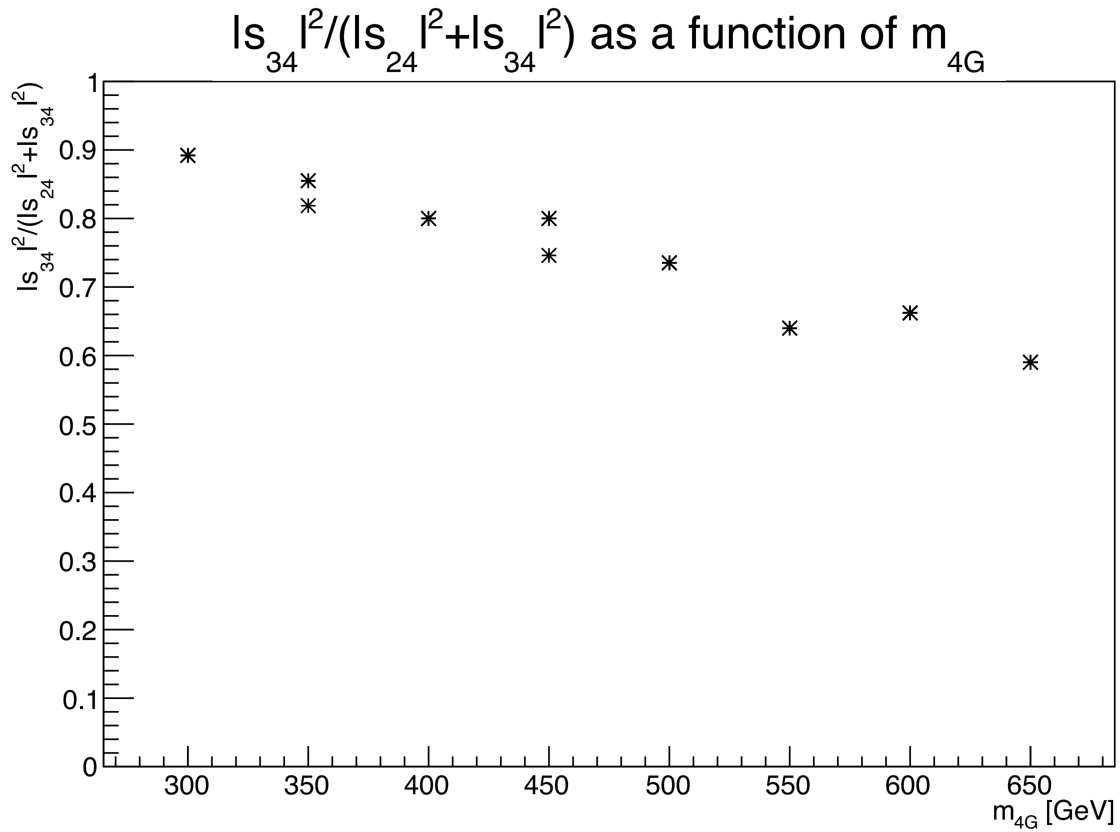




Error bars indicate estimated systematic errors due to binning effects.

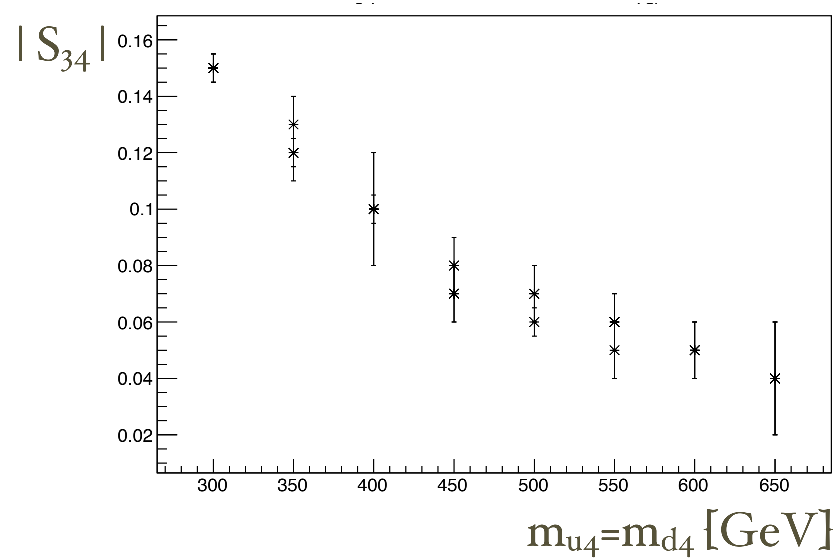
BF(t'->Wb)

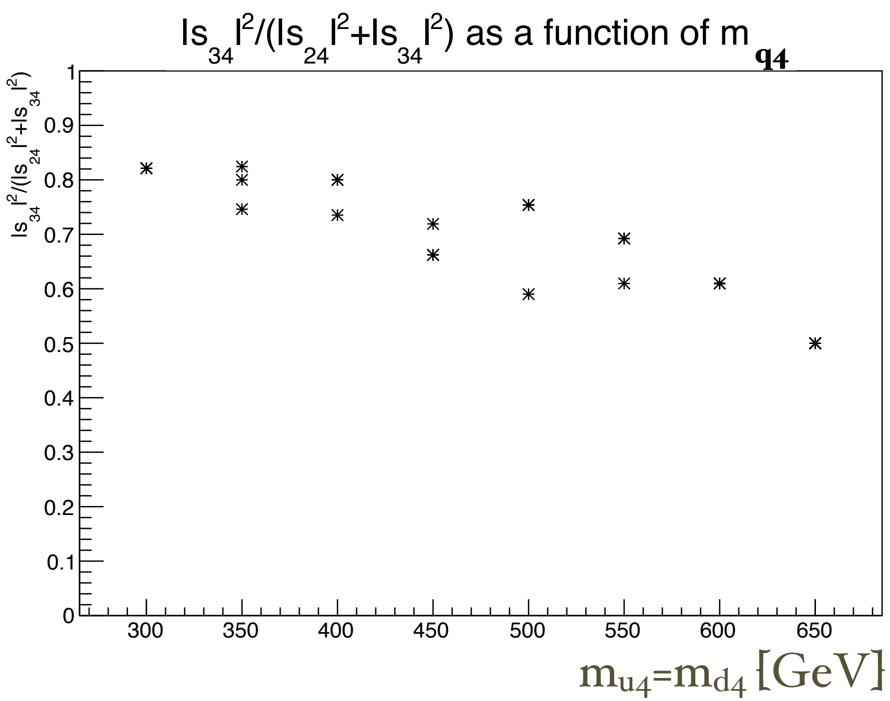
- Favored branching fraction varies between 90% to ~60% as the degenerate 4th generation mass increases.
  - ➡ Interpretation of the limits obtained from LHC experiments should be done carefully.



What about non-degenerate case?

- Considering a light Higgs scenario in which Higgs can decay into 4th generation neutrinos (to avoid current Higgs limits from the LHC experiments).
  - ➡ m_H = 130 GeV
    $m_{\nu 4}$ = 60 GeV
    m_{l4} = 120 GeV
    $m_{u4} = m_{d4}$
- Such a scenario is ok also without mixing (particularly when m_{l4}-$m_{\nu 4}$ gets large), but we still explore what happens with mixing.
- Favored S_{24}-S_{34} show similar behaviour to the fully-degenerate case.





Multiple markers per mass point roughly represent the uncertainty in determining the value. It includes statistical and binning effects.

Conclusion

- We checked that fully degenerate case is indeed allowed by EW precision data as long as the mixings are included.
- Favoured values of the mixing angles, S_{24} and S34 tend to imply a non-unity branching fraction for t'->Wb.
  - ➡ BF decreases from ~90% to ~60% with increasing degenerate fourth generation mass.
- Light Higgs scenarios with the Higgs decaying to 4th generation neutrinos are allowed by the EW precision data.
  - ➡ Since mixing increases the T parameter, for heavy charged lepton, low values of the mixing would be preferred.
  - ➡ However mixing can still play a role, with behaviour similar to the fully-degenerate case.

Backups

Lucky?

m_{4G}	fraction of points inside 2σ ellipse (%)
300	3.47
350	1.37
400	0.67
450	0.37
500	0.28
550	0.15
600	0.10
650	0.07

- For each degenerate mass, the fraction of generated (K_{24}, K_{34}) pairs for which the computed S and T lie within the 2σ error ellipse of the LEP EWWG 2009 results.

Light H, light nu

- Light Higgs, light neutrino scenarios are possible with or without mixing.
- If the mass difference between charged lepton and neutrino is small, and the difference between the two quarks are also small, then T can be slightly off the ellipse, in which case mixing can help.

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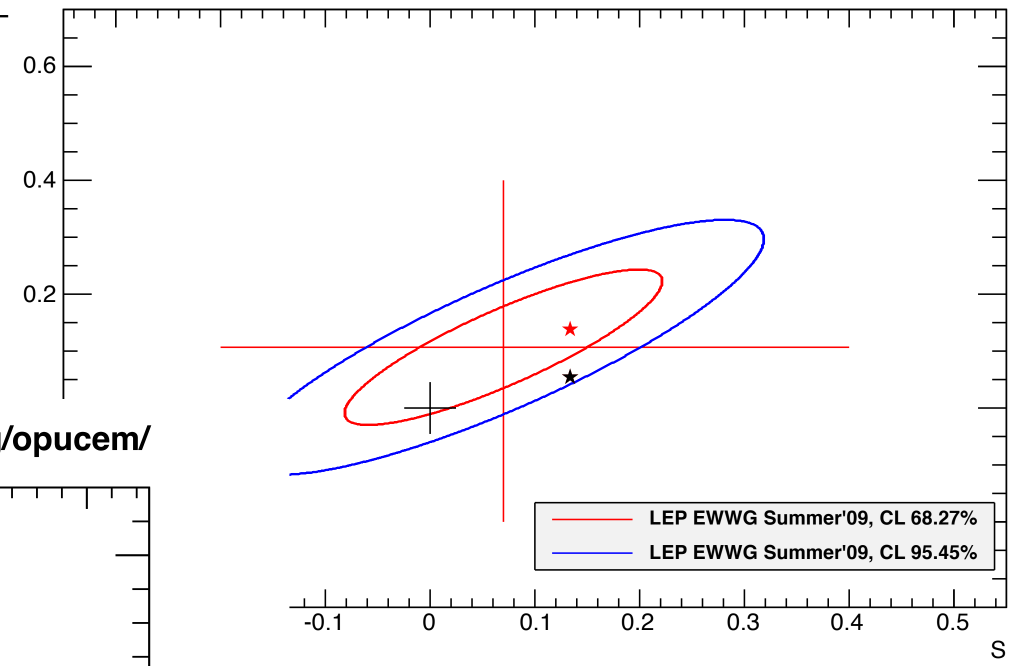

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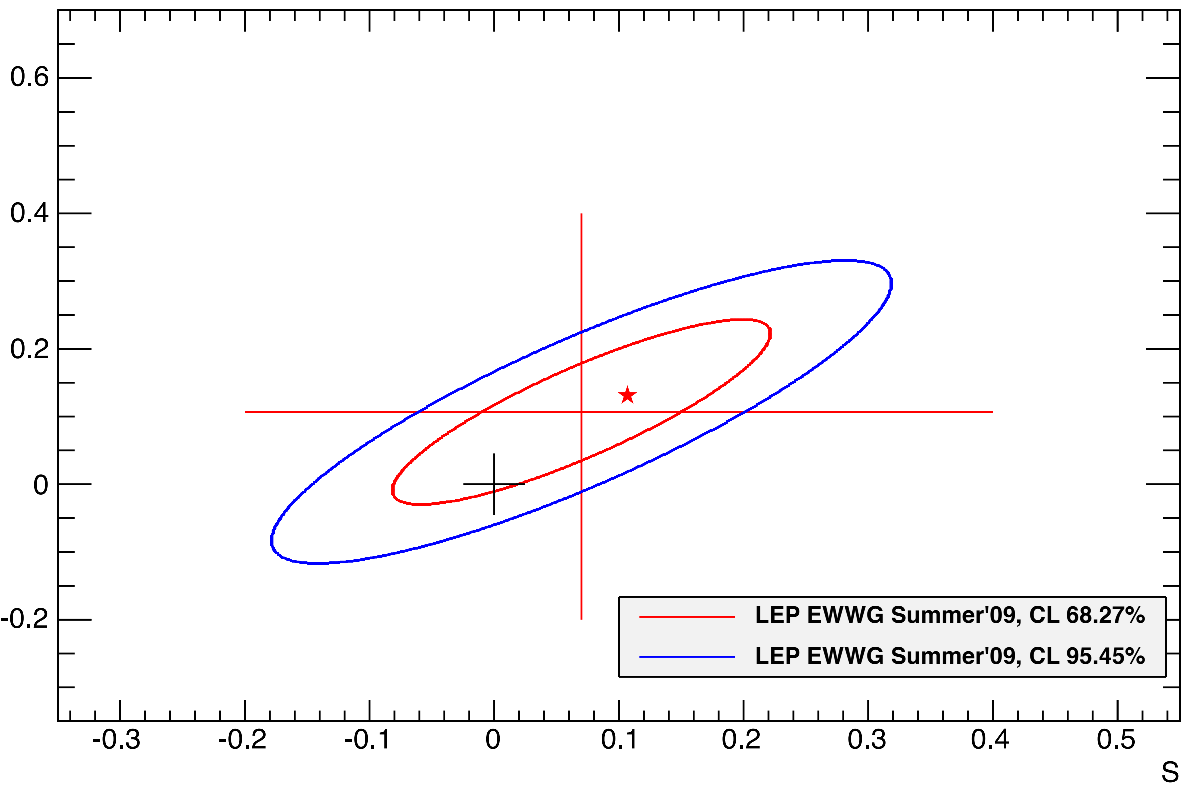
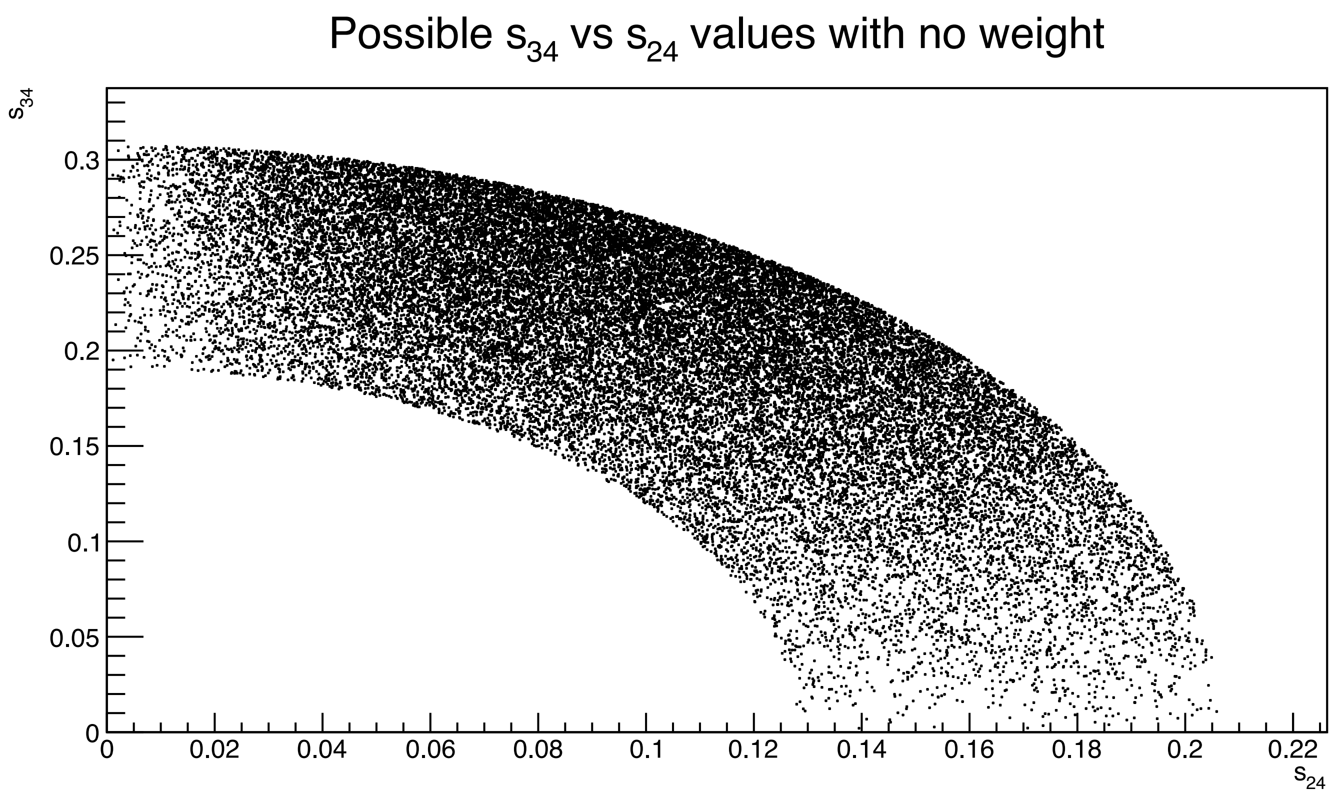


- Generated (S24, S34) pairs for which calculated S,T are within 2σ error ellipse.



CKM inputs

- From PDG:

$$|V_{ud}| = 0.97425 \pm 0.00022$$

$$|V_{us}| = 0.2252 \pm 0.0009$$

$$|V_{ub}| = (3.89 \pm 0.44) \times 10^{-3}$$

$$|V_{cs}| = 1.023 \pm 0.036$$

$$|V_{cd}| = 0.230 \pm 0.011$$

$$|V_{cb}| = (40.6 \pm 1.3) \times 10^{-3}$$

$$|V_{td}| = (8.4 \pm 0.6) \times 10^{-3}$$

$$|V_{tb}| = 0.88 \pm 0.07$$

$$|V_{ts}| = (38.7 \pm 2.1) \times 10^{-3}$$

$$\text{Given } X = f(a, b, c, \ldots)$$

$$\sigma_X^2 = (\tfrac{\partial f}{\partial a}\sigma_a)^2 + (\tfrac{\partial f}{\partial b}\sigma_b)^2 + (\tfrac{\partial f}{\partial c}\sigma_c)^2 + \ldots$$