HIGGS HUNTING WITH MINIMAL PREJUDICE

PHENO 2012:

UNIVERSITY OF PITTSBURGH

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Based on arXiv:1202.3415 with A. Azatov and R. Contino;

in progress with A. Azatov, S. Chang, and N. Craig

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Outline:
Three Parts

I. Theory Input -- from models to data
II. Experimental Input -- from data to models
III. Application/Results -- Compositeness and SUSY

Part One: Theory Input

A simplified theory input: "The non-panacean Higgs"

The 'substandard model' has to be augmented (for renorm'ability):

Three massive vectors, triplet of approximate SU(2)

$$\begin{aligned} U &= \exp\left[2i\tau_a\pi_a(x)/v\right] \\ &\mapsto LUR^\dagger \end{aligned}$$

described at leading order:

$$\begin{aligned} \Delta\mathcal{L} &= \frac{v^2}{4}\mathrm{tr}\left[(D_\mu U)^\dagger(D^\mu U)\right] \\ &\quad -\frac{v}{\sqrt{2}}\,\psi_i^c\,U^\dagger \times \lambda_{ij}\psi_j + \mathrm{h.c.} \end{aligned}$$

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Assumption: the (custodial singlet) 'Higgs' might not be single-handedly responsible for unitarization, etc.
OTHER NEW PHYSICS enters at potentially low scales

Case studies to come: (minimal) compositeness and SUSY

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FOCUSING ON THESE GUYS

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WHY?

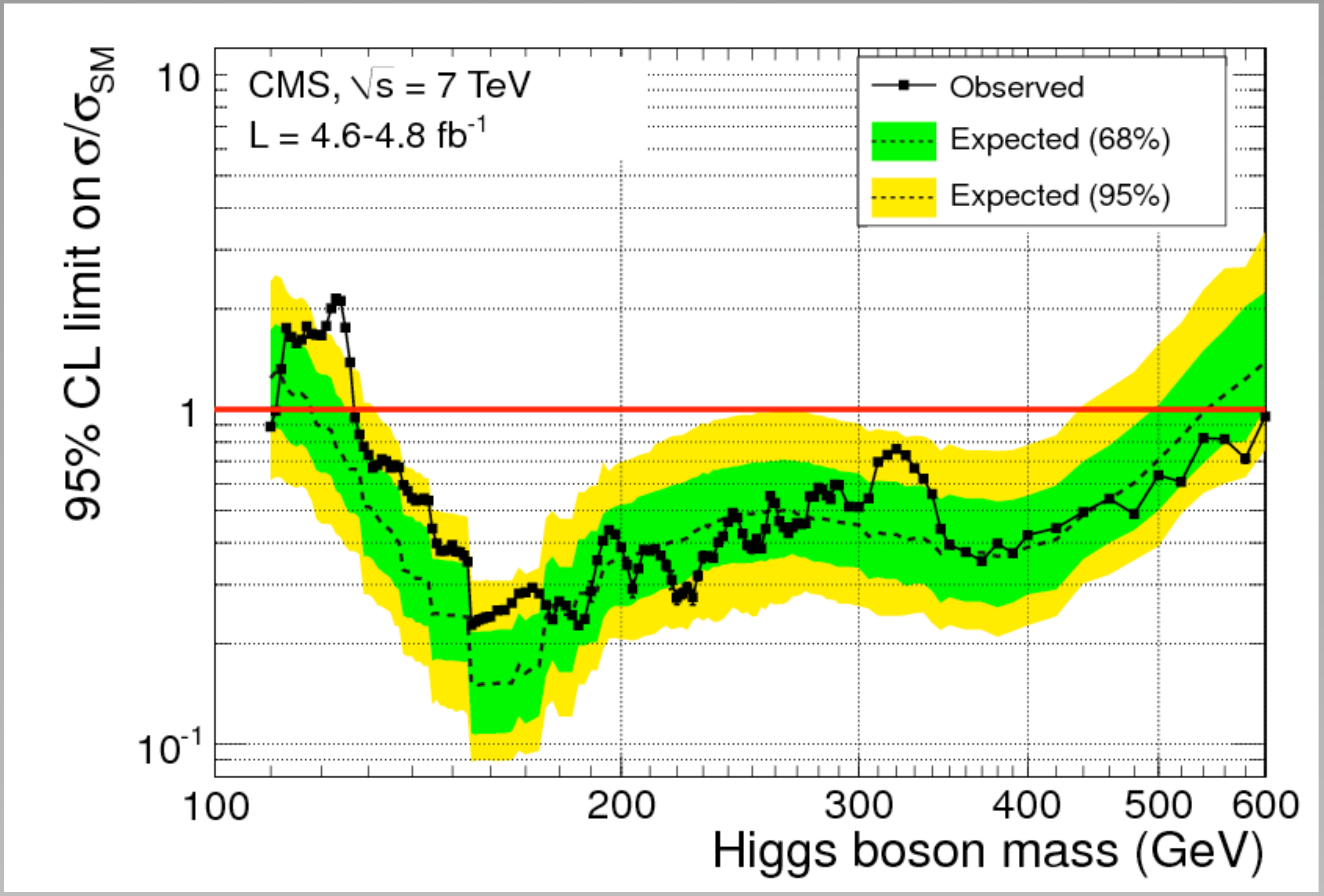
I. Naturalness ~ Couplings' deviation from SM

II. Consistency check if other low-mass EWSB states appear

III. Theorists need tools to construct (approximate) exclusions

Part Two: Experimental Input

Our handle: expected and observed exclusion limits (from each channel/subchannel)



- We have this certainly for each channel...
- ... and each subchannel when we're lucky
- Gives necessary information over whole mass range

What do we know (thanks to the LHC)?

Given background, signal, and observed events: construct likelihood:

$$P(n|n_{\rm obs}) = \frac{n^{n_{\rm obs}} e^{-n}}{n_{\rm obs}!} \times \pi(n)$$

$$\stackrel{\rm A.L.}{\longrightarrow} \exp\left[\frac{-(n-n_{\rm obs})^2}{2n_{\rm obs}}\right] \times \pi(n)$$

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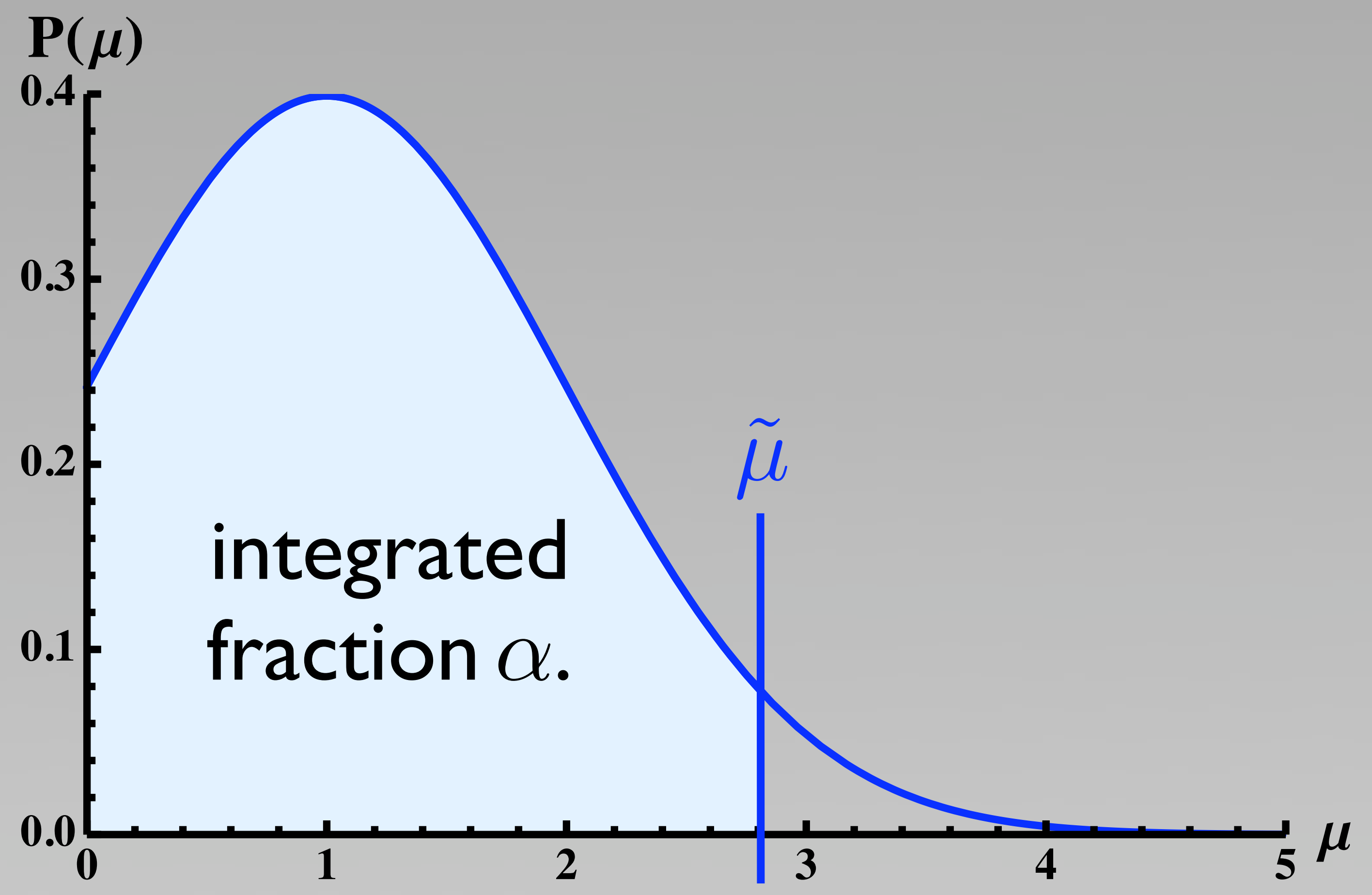

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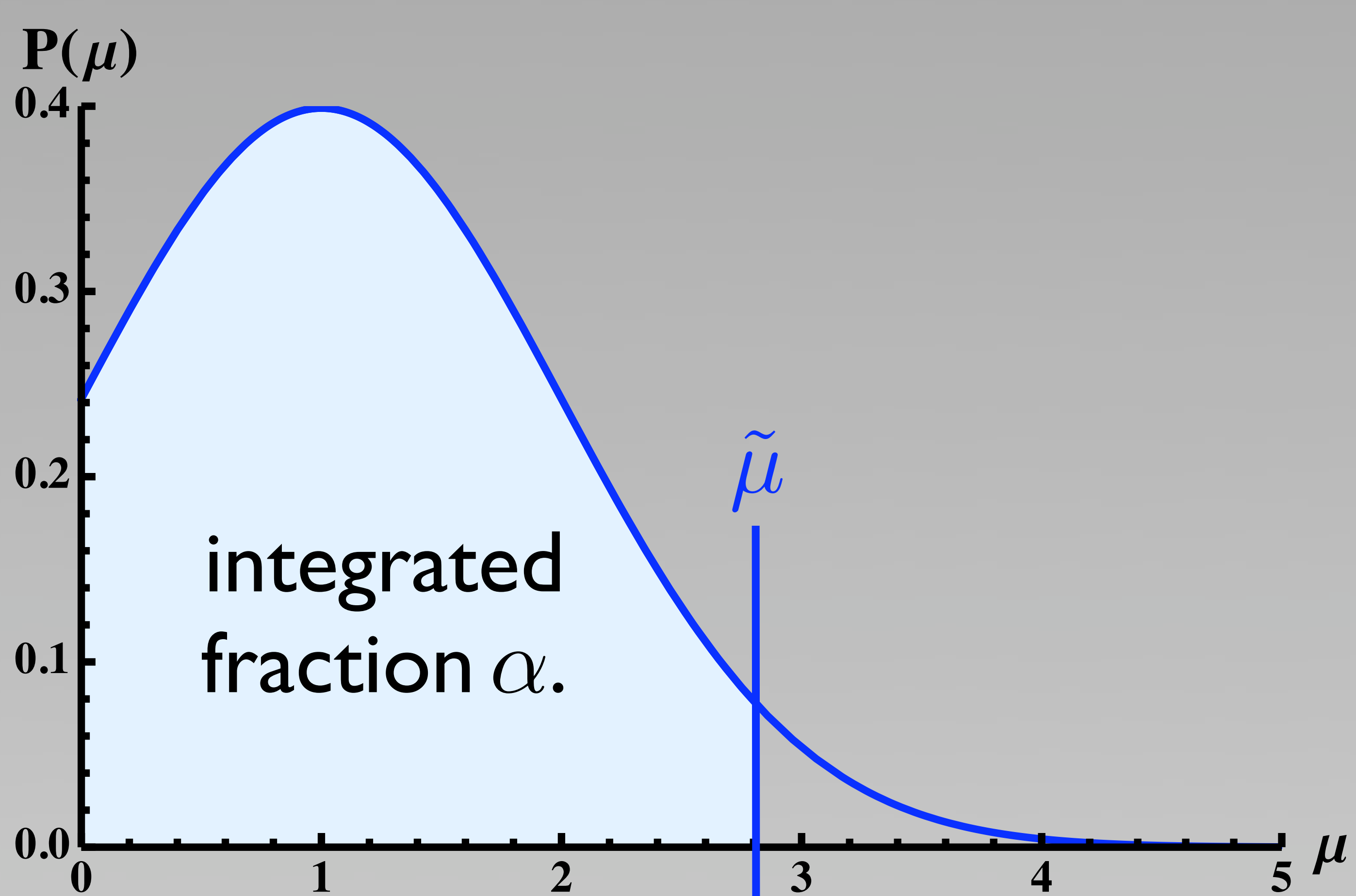

$\tilde{\mu}$: upper bound on signal strength modifier at CL = alpha.

Two versions:

1. Expected (background only hypothesis)
2. Observed (compared to data)

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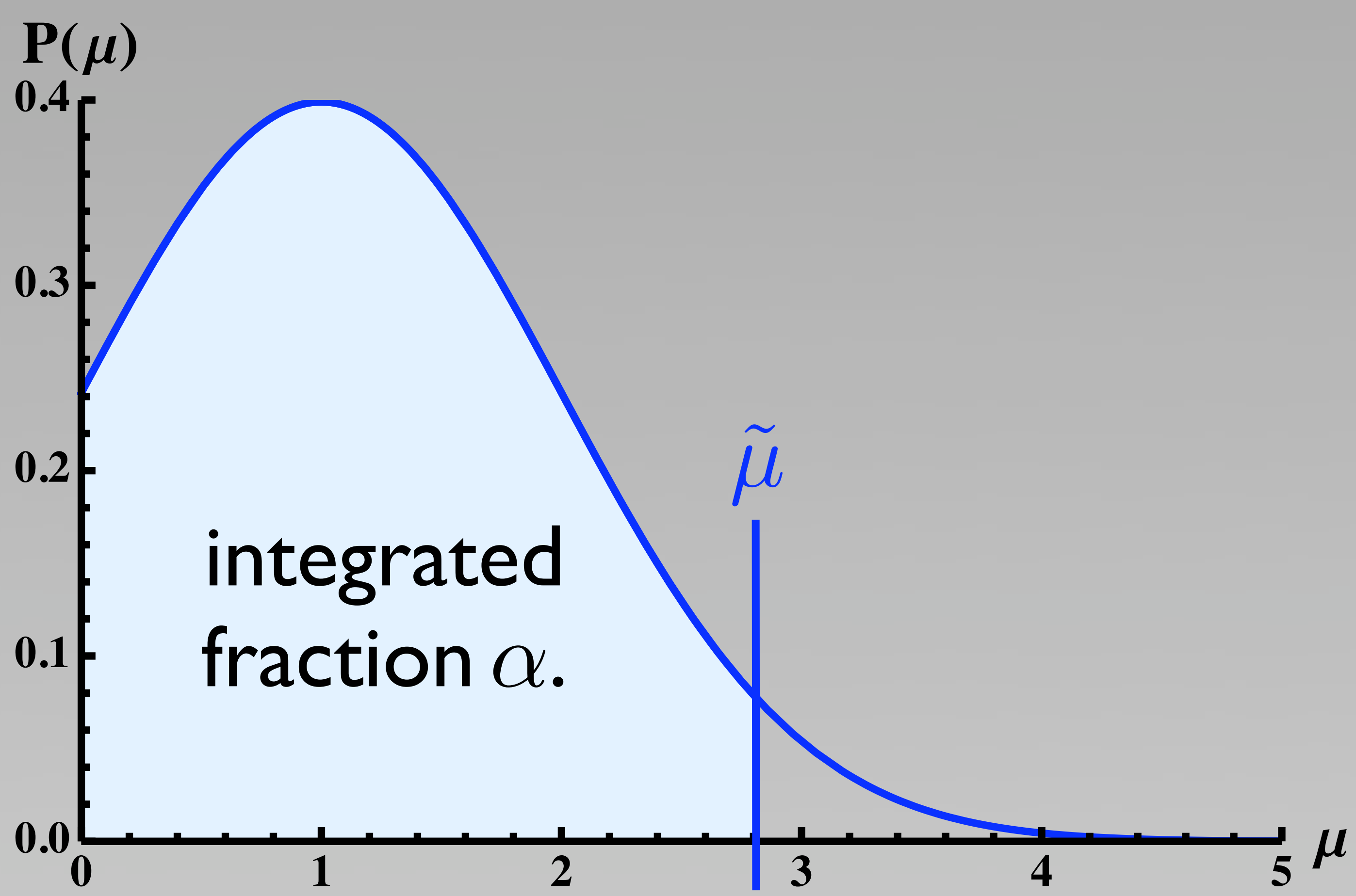

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Answer:
We know the amount by which we can rescale production/branching -- all in the same proportions -- and still be consistent with observation.

Said another way, we know what's going on in a one-dimensional parameter space: adequate in some cases, but in several others we'd like to push this information a bit further...

How do we proceed?

Moving on: Comparison to Likelihood

Now just map theory parameters to μ and compare to $P(\mu)$ ...

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... that we need to determine for ourselves at this point

Moving on: Comparison to *RECONSTRUCTED* Likelihood

(Three variables, only two constraints: we need to be slightly clever)

Assume asymptotic limit, i.e. Poisson ⟶ Gaussian:

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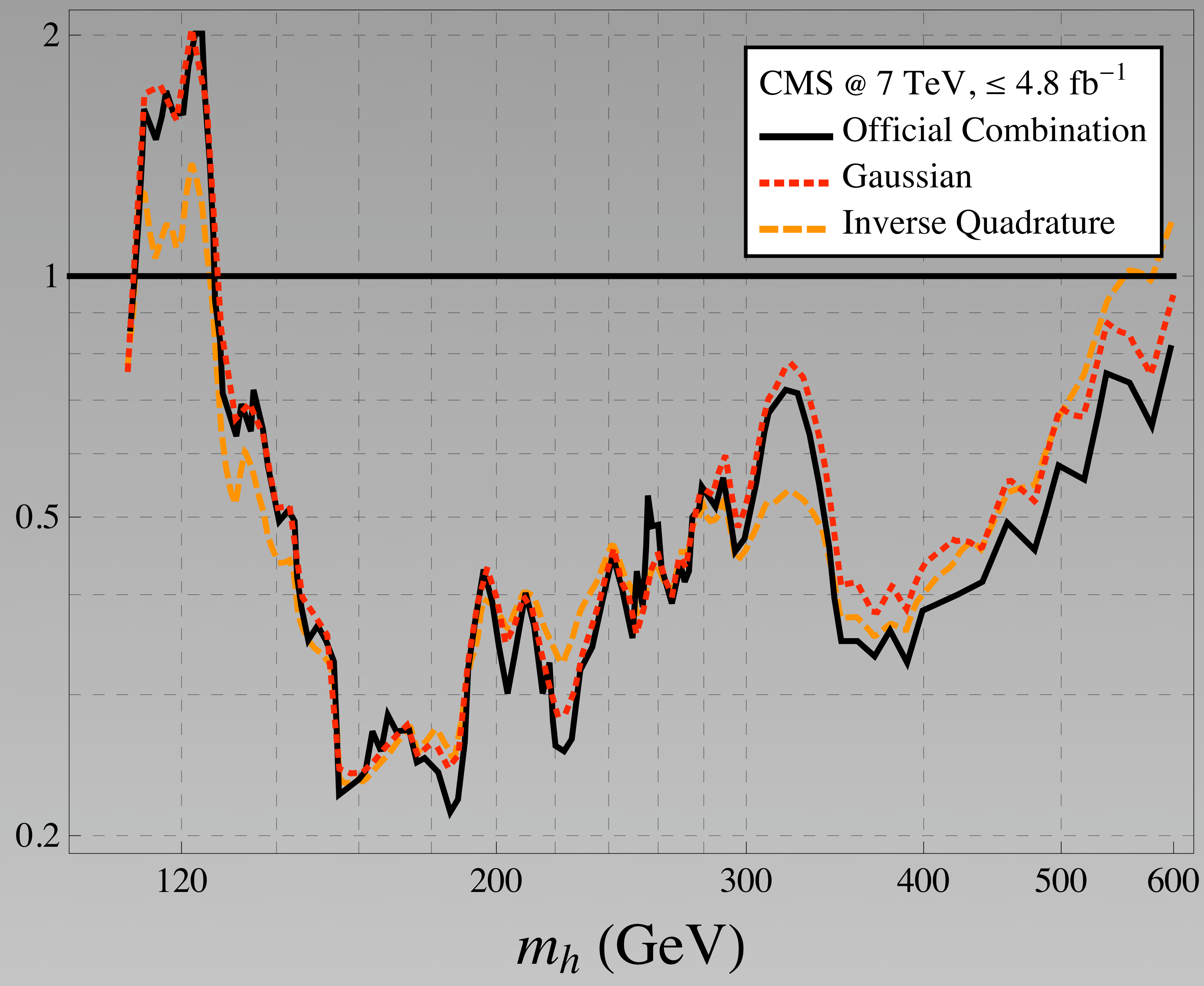
RECAP:

- Expected exclusion tells us about s/b
- Observed tells us delta, completes determination of (AL) likelihood
- Good news: can be done over whole mass range, not just at 'peaks' where information on best fit is available

How well does this method do?

One possible check: the total combination



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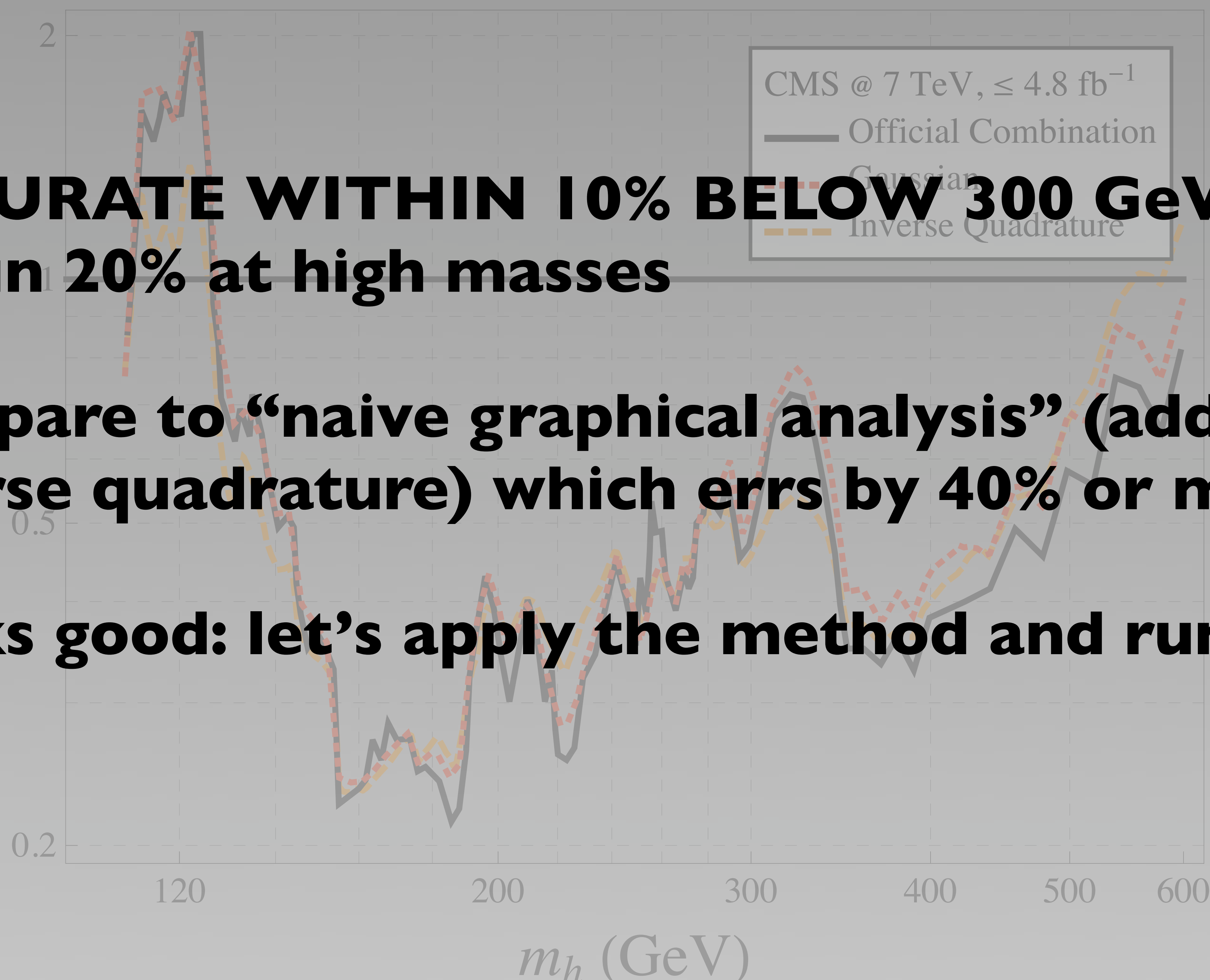
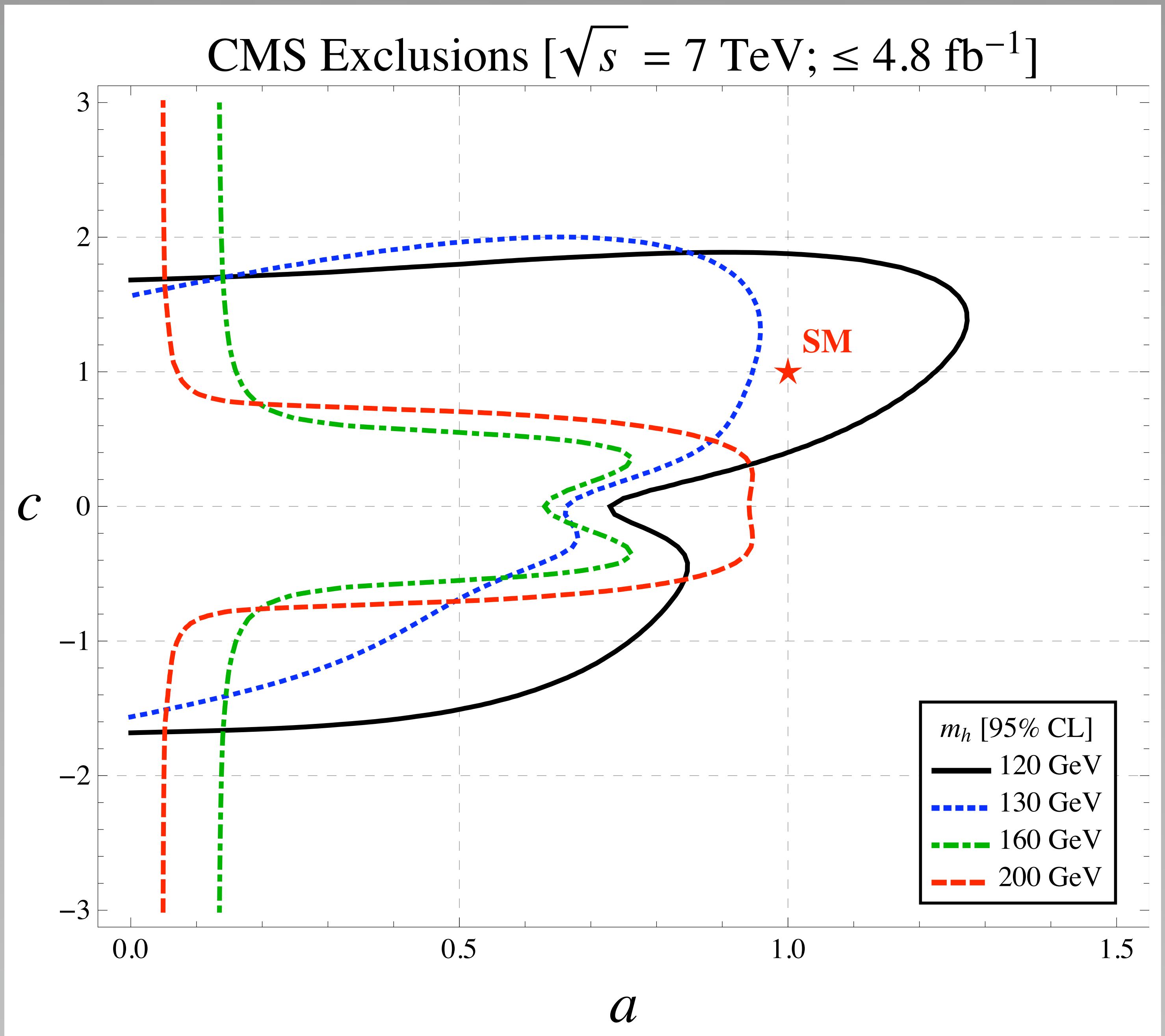


- **ACCURATE WITHIN 10% BELOW 300 GeV; within 20% at high masses**
- **Compare to "naive graphical analysis" (adding in inverse quadrature) which errs by 40% or more**
- **Looks good: let's apply the method and run with it**

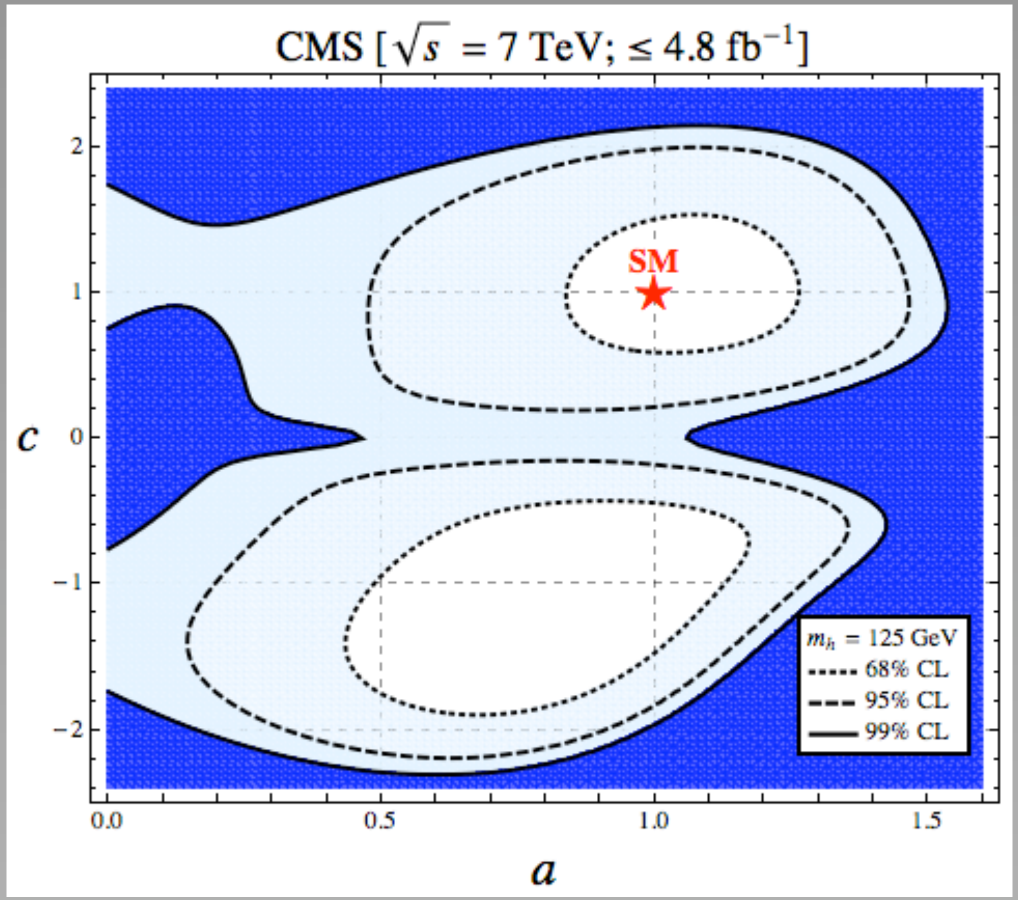
Part Three: Application

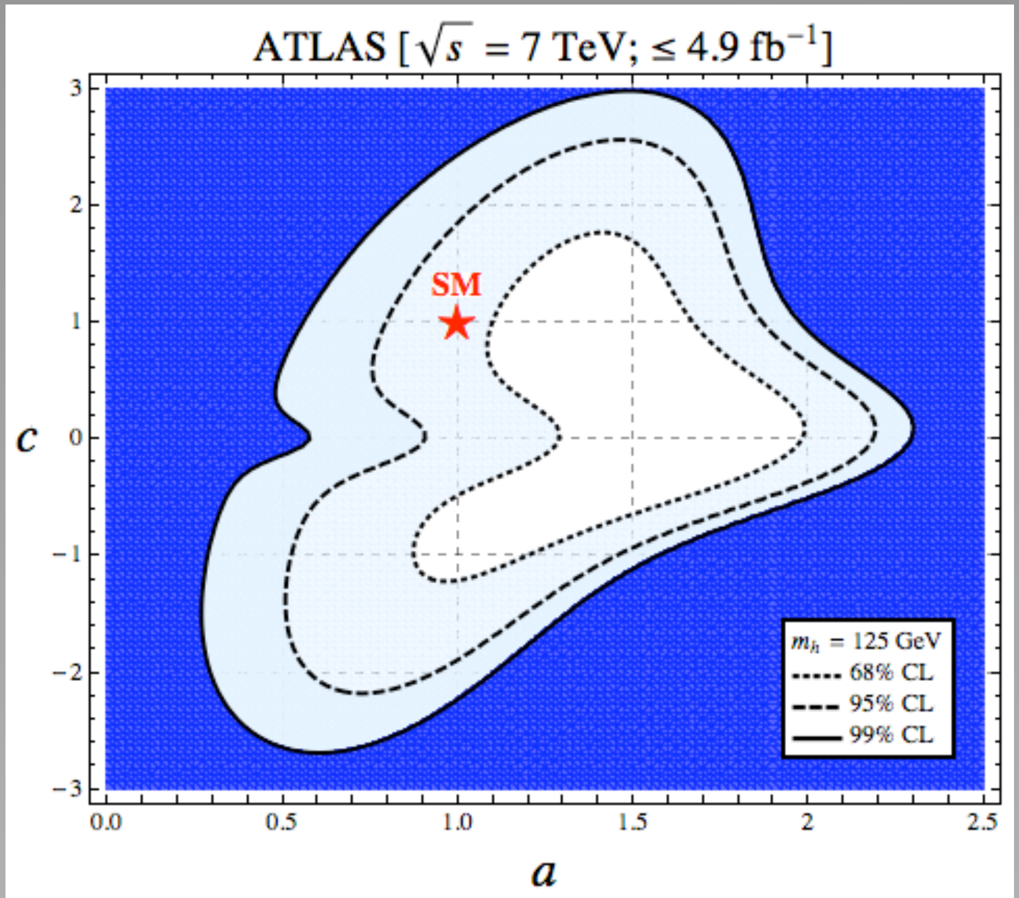
3A. Composite Higgs
with flavor-universal Yukawa rescalings
(cf. SO(5)/SO(4) with fermions in spinor or fundamental)

Status report for unpopular mass points



Status report for the Higgs at 125(?)(!)





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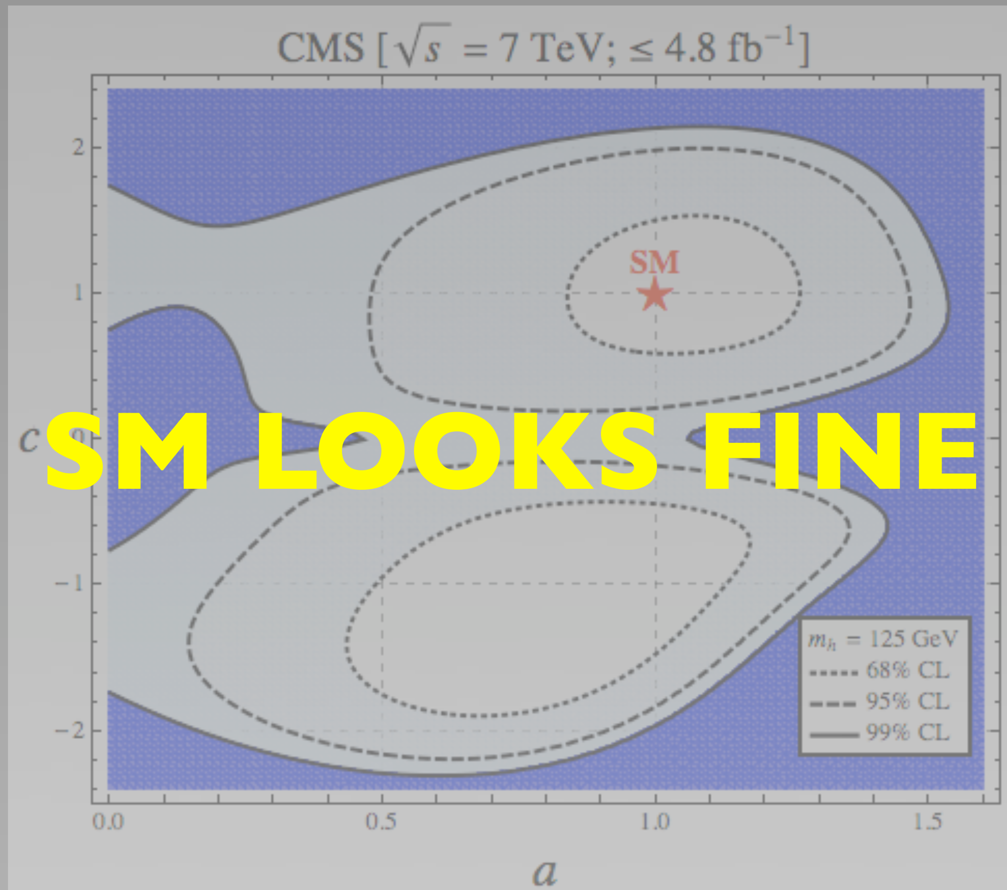

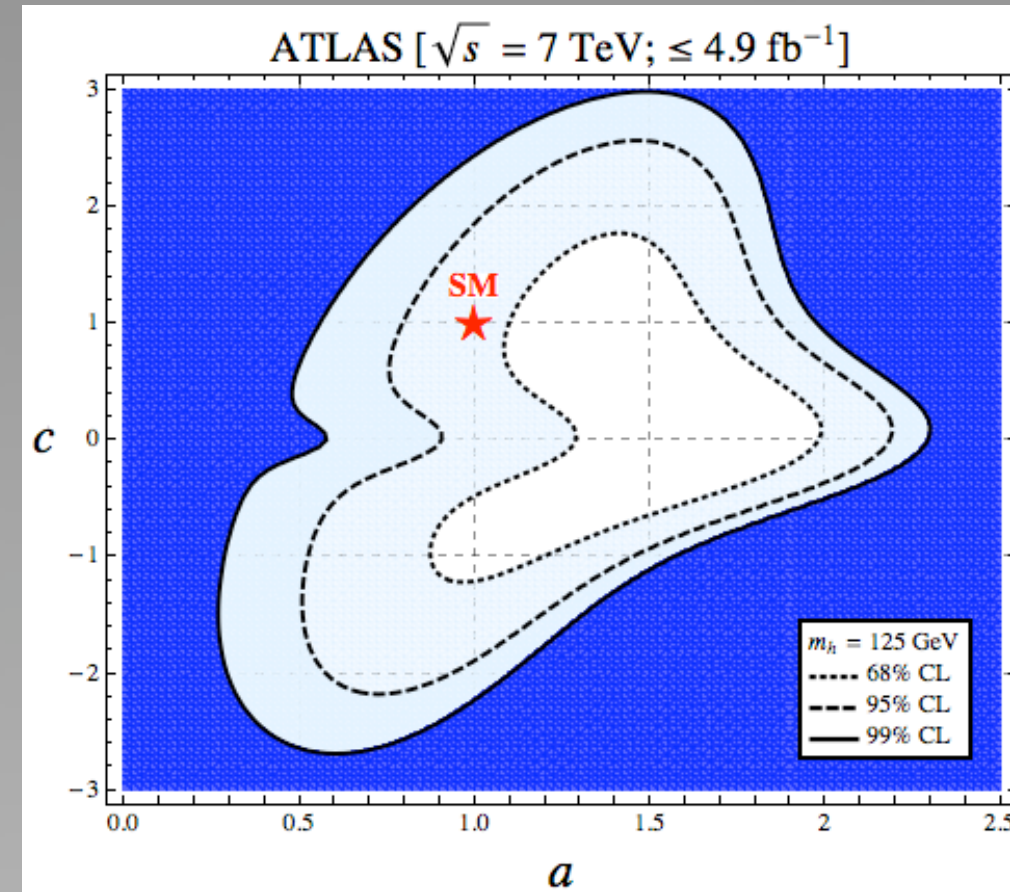

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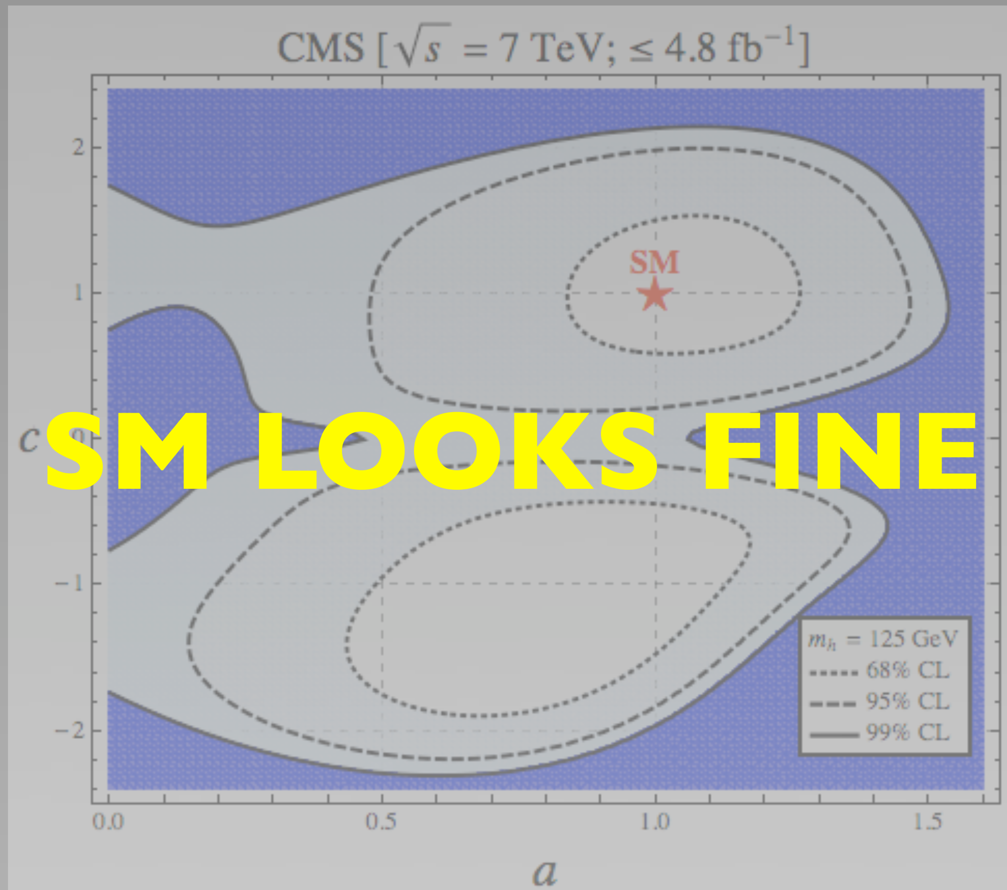

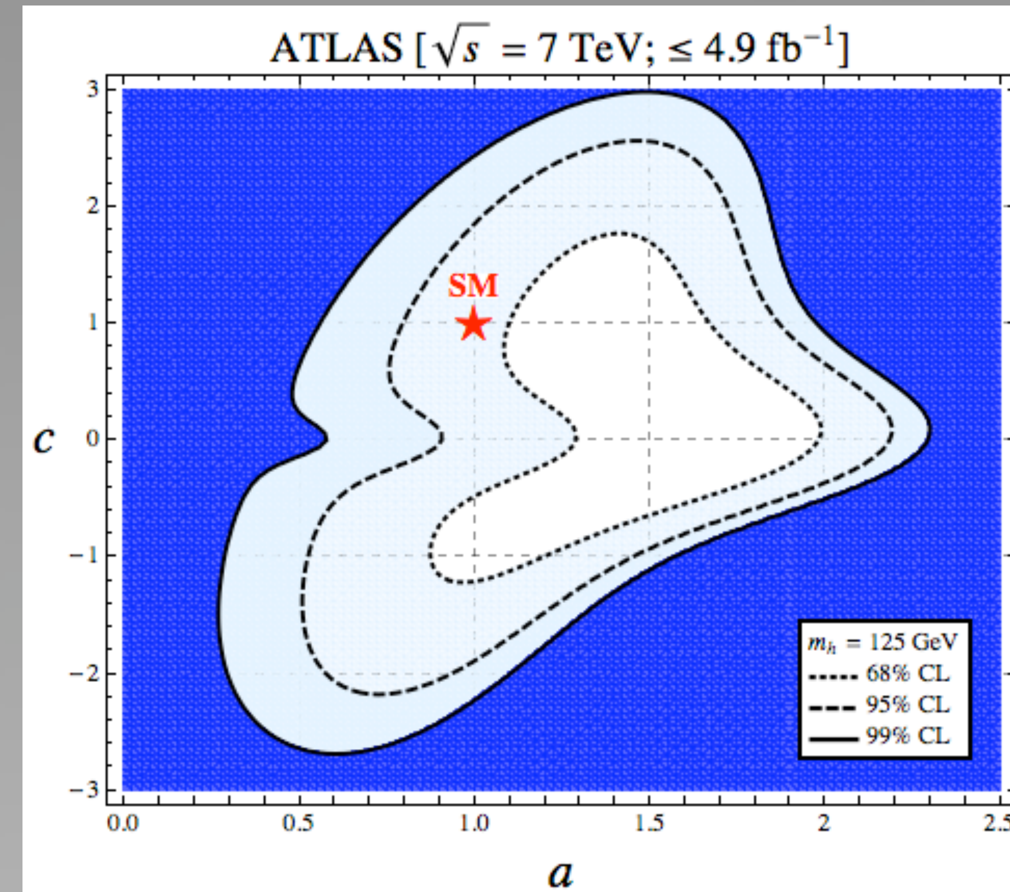

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how should we take this?

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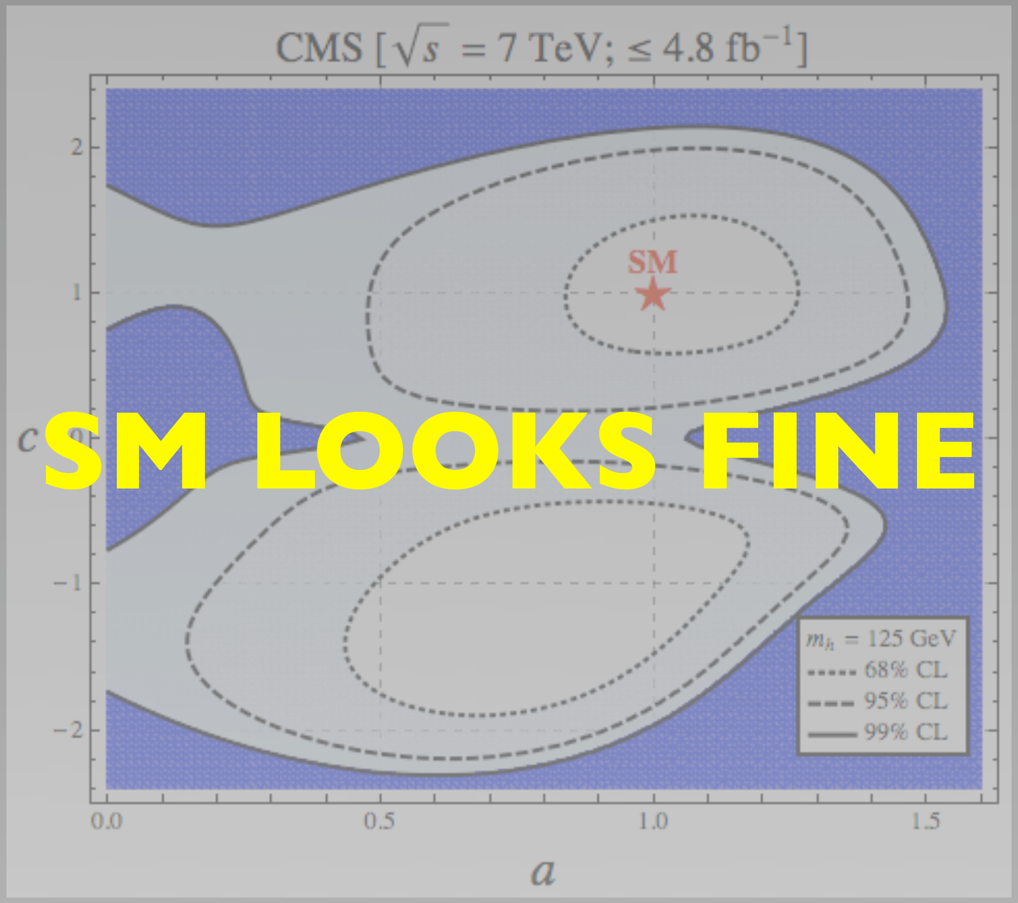

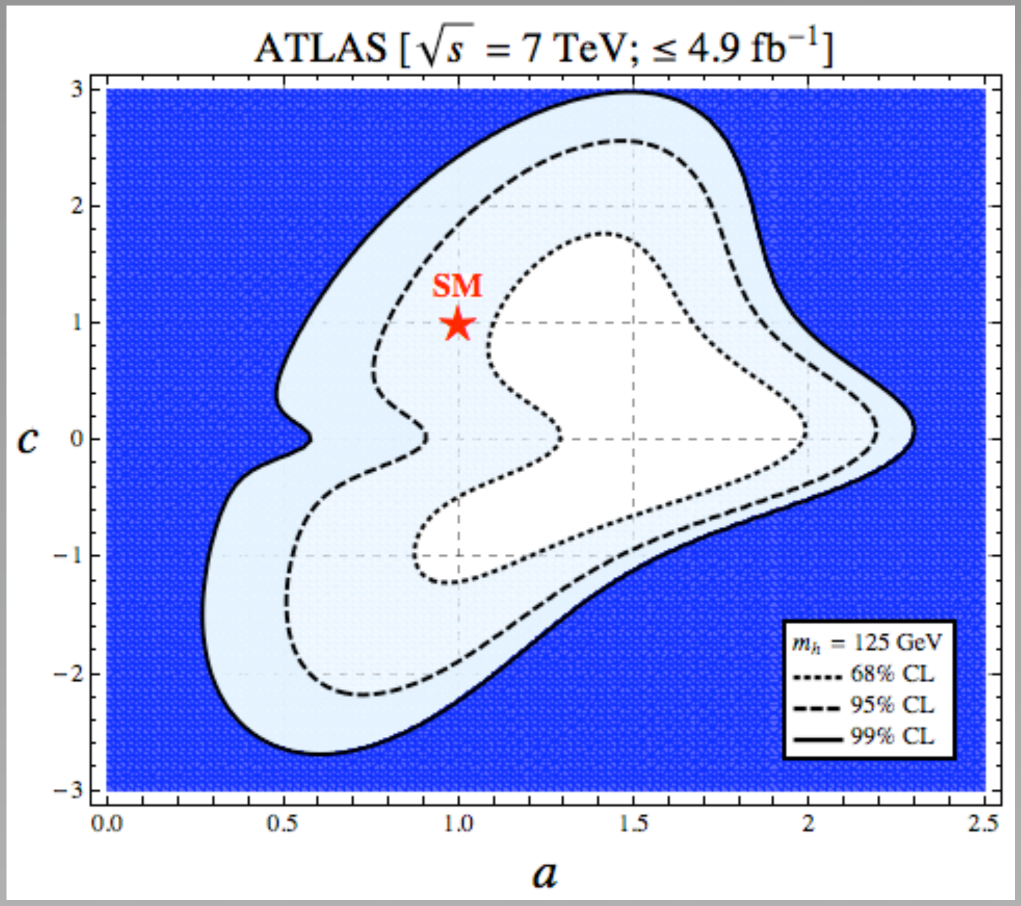

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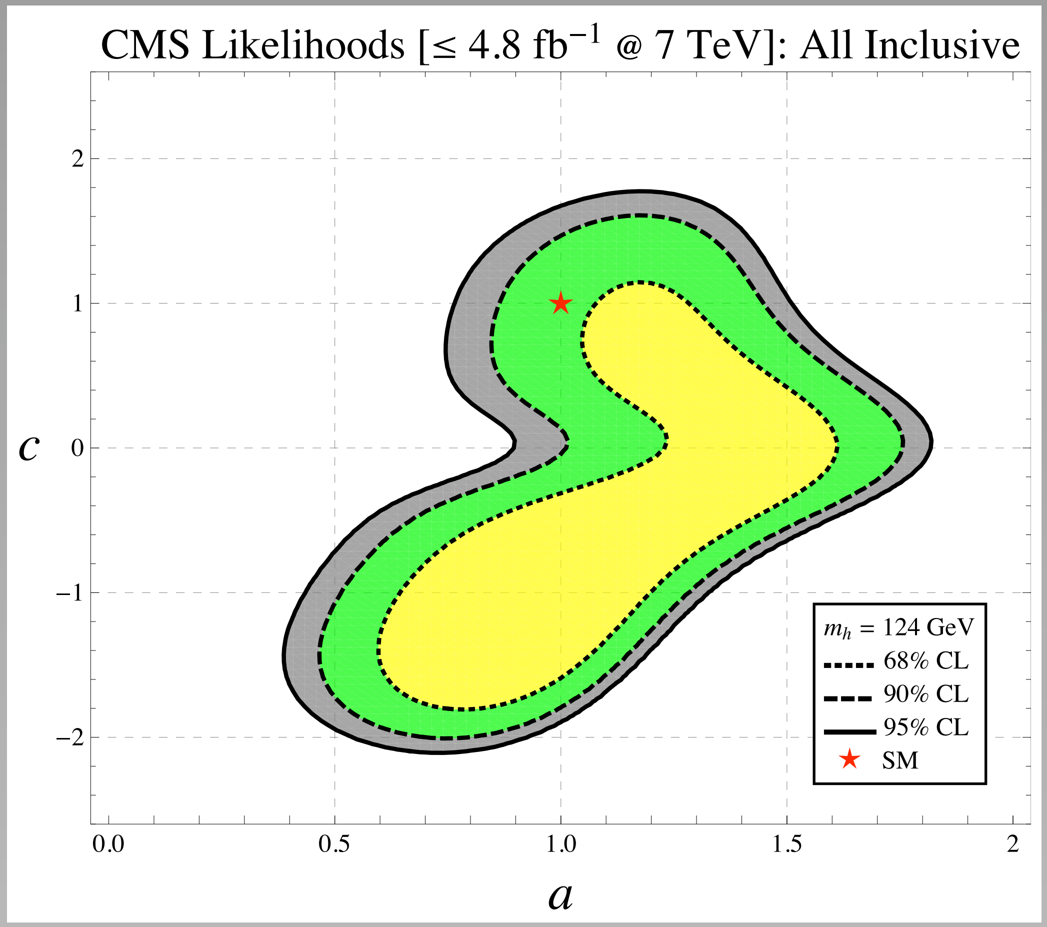
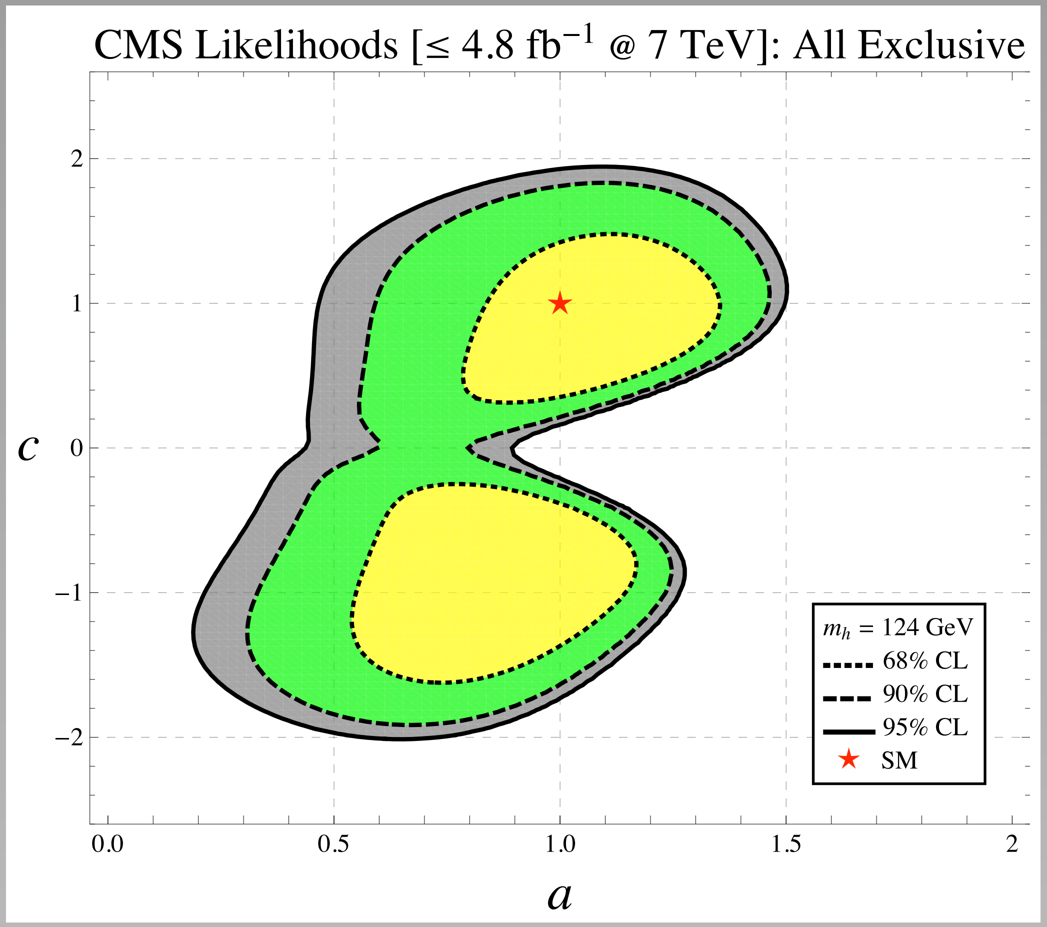
➡ Don't worry too much...

Cautionary tale: Need Exclusive Searching and Reporting

ALL INCLUSIVE vs. ALL EXCLUSIVE subchannels:





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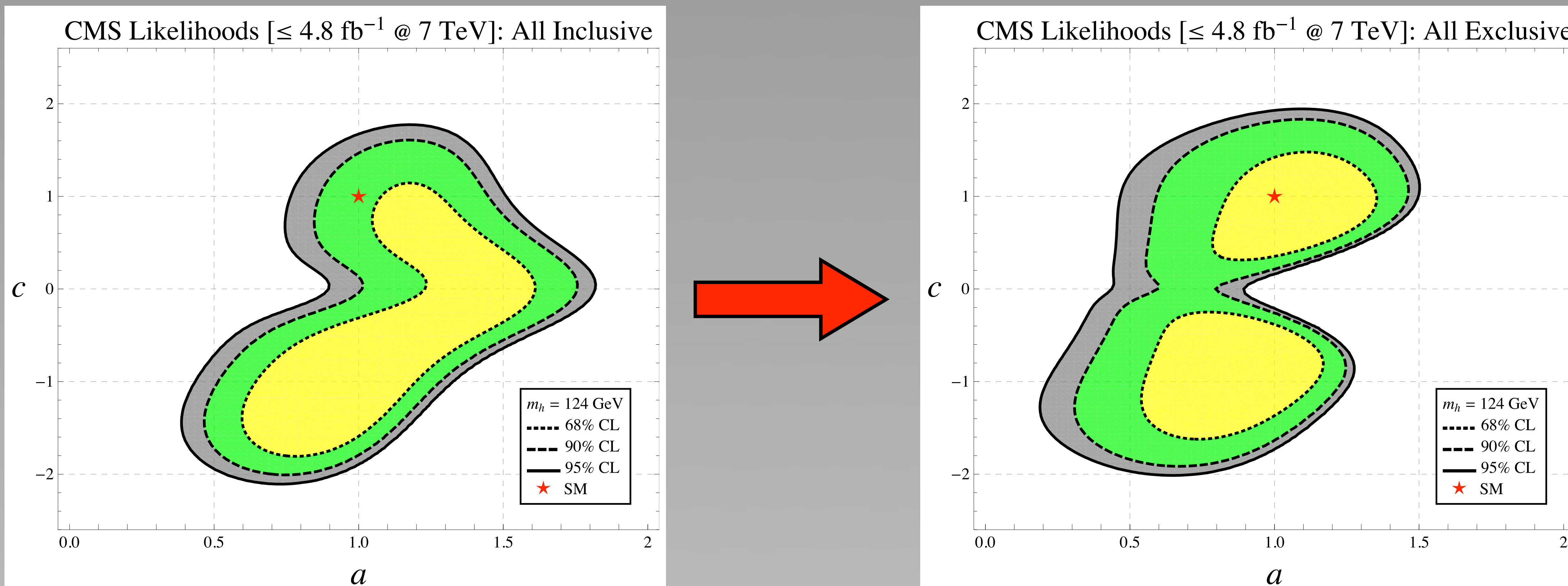

(Preliminary) Conclusions:

- o Exclusive anayses suggest that couplings in this framework ~ SM
- o Compositeness scale (4 pi f) quite high...
- o ...other states from EWSB (e.g. vectors) heavy unless large-N

Part Three: Application

3B. SUSY

in particular its minimal implementation

First: U and D Yukawas differ (Type-II 2HDM)

Conventions:

$$H_u = 2_{1/2},\ H_d = 2_{-1/2},\ \langle \mathrm{Re} H_u^0 \rangle / \langle \mathrm{Re} H_d^0 \rangle \equiv \tan\beta$$

$$\begin{pmatrix} h \\ H \end{pmatrix} = \sqrt{2} \begin{pmatrix} -\sin\alpha & \cos\alpha \\ \cos\alpha & \sin\alpha \end{pmatrix} \begin{pmatrix} \mathrm{Re} H_d^0 \\ \mathrm{Re} H_u^0 \end{pmatrix}$$

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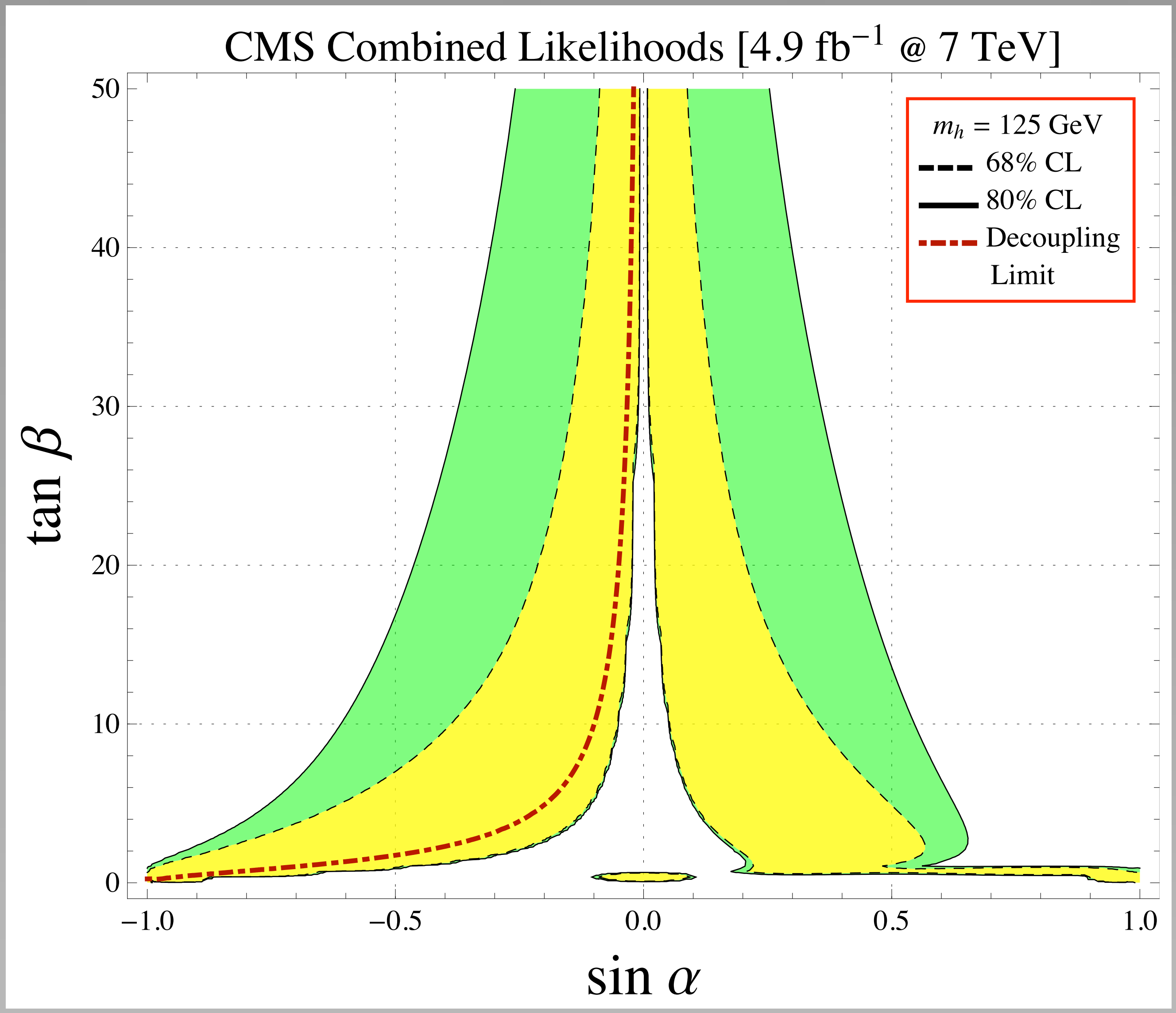
$$\left.\begin{aligned} c_u &\equiv g_{hQu^c}/\mathrm{SM} = \frac{\cos\alpha}{\sin\beta} \\ c_d &\equiv g_{hQd^c}/\mathrm{SM} = \frac{-\sin\alpha}{\cos\beta} \\ a &\equiv \mathrm{gauge}/\mathrm{SM} = \sin(\beta-\alpha) \end{aligned}\right\}$$

What is the data telling us about this space?

First look: *The* space of the MSSM Higgs



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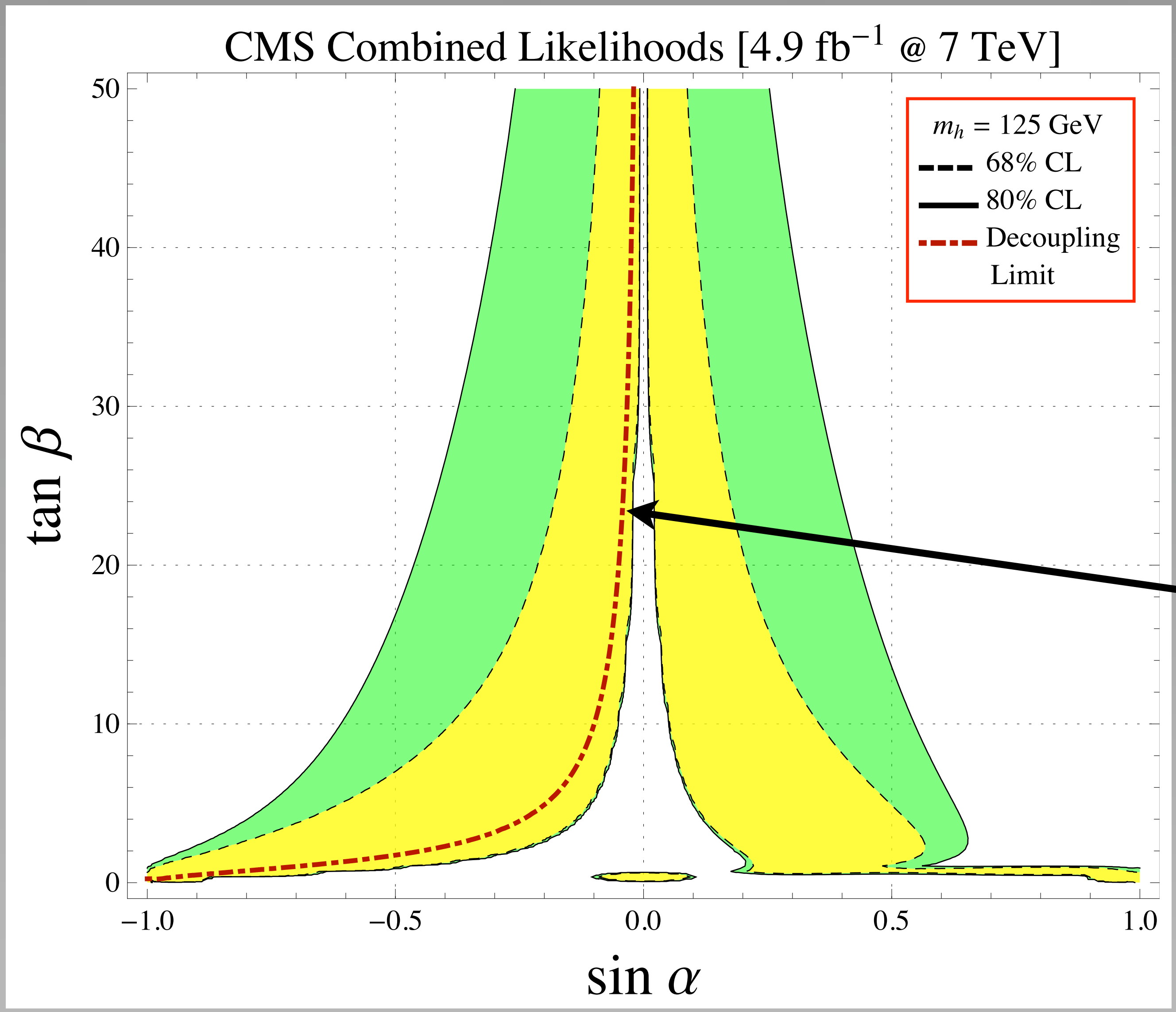

Decoupling:

$$H^0, H^\pm, A^0 \to \infty;$$

$$\Rightarrow a, c_u, c_d \to 1$$

Supported here by couplings, but also by Higgs mass!

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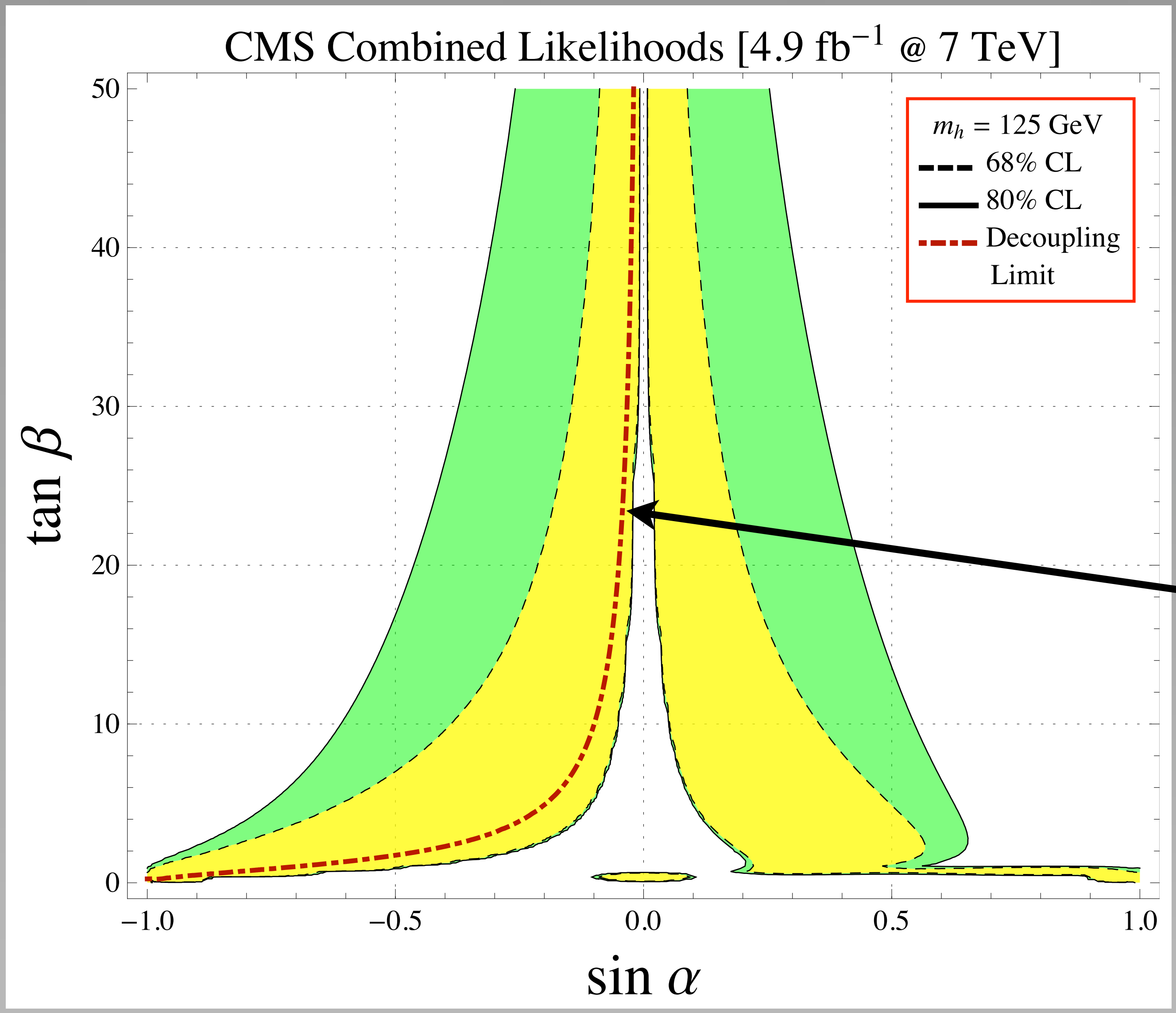

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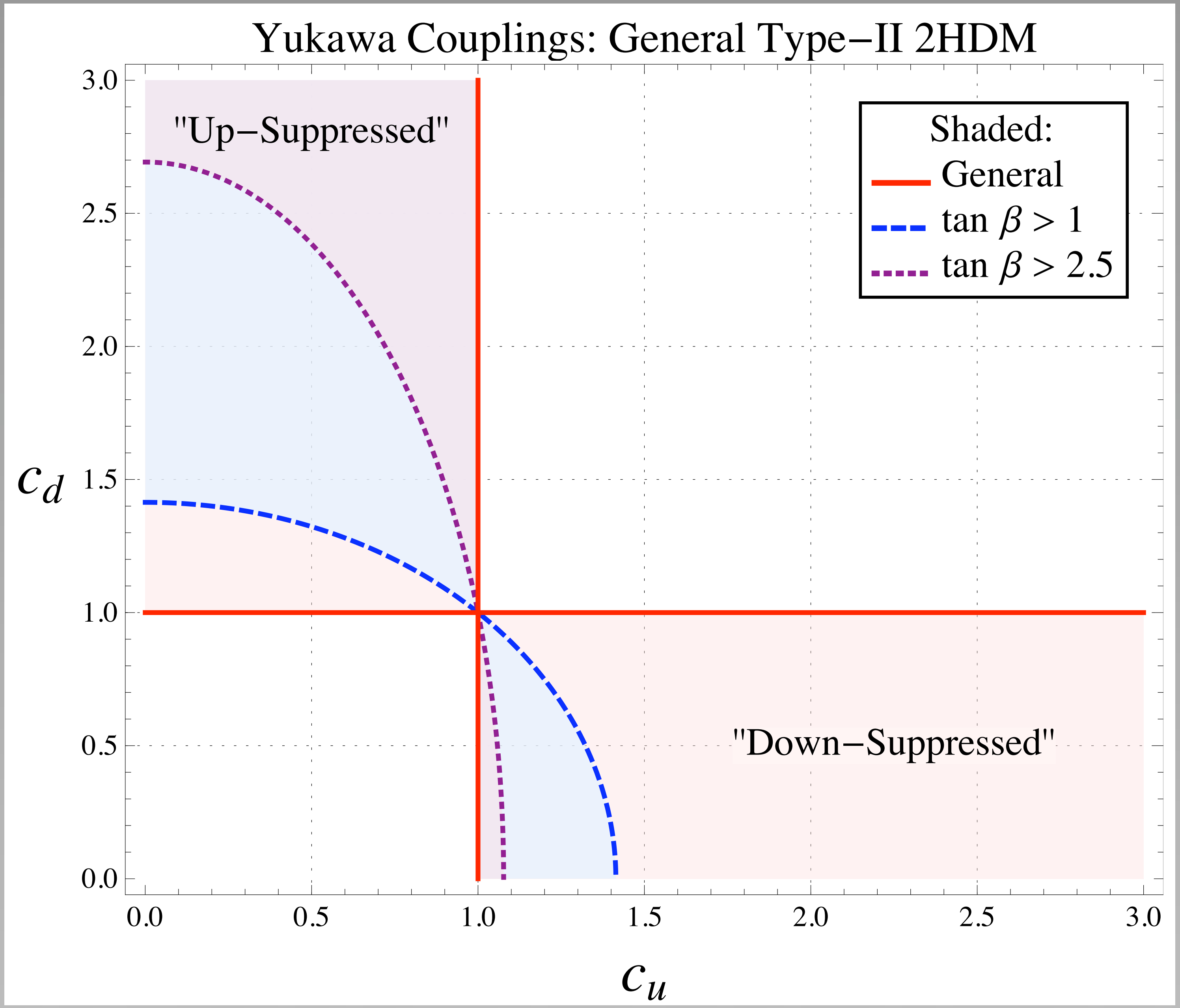
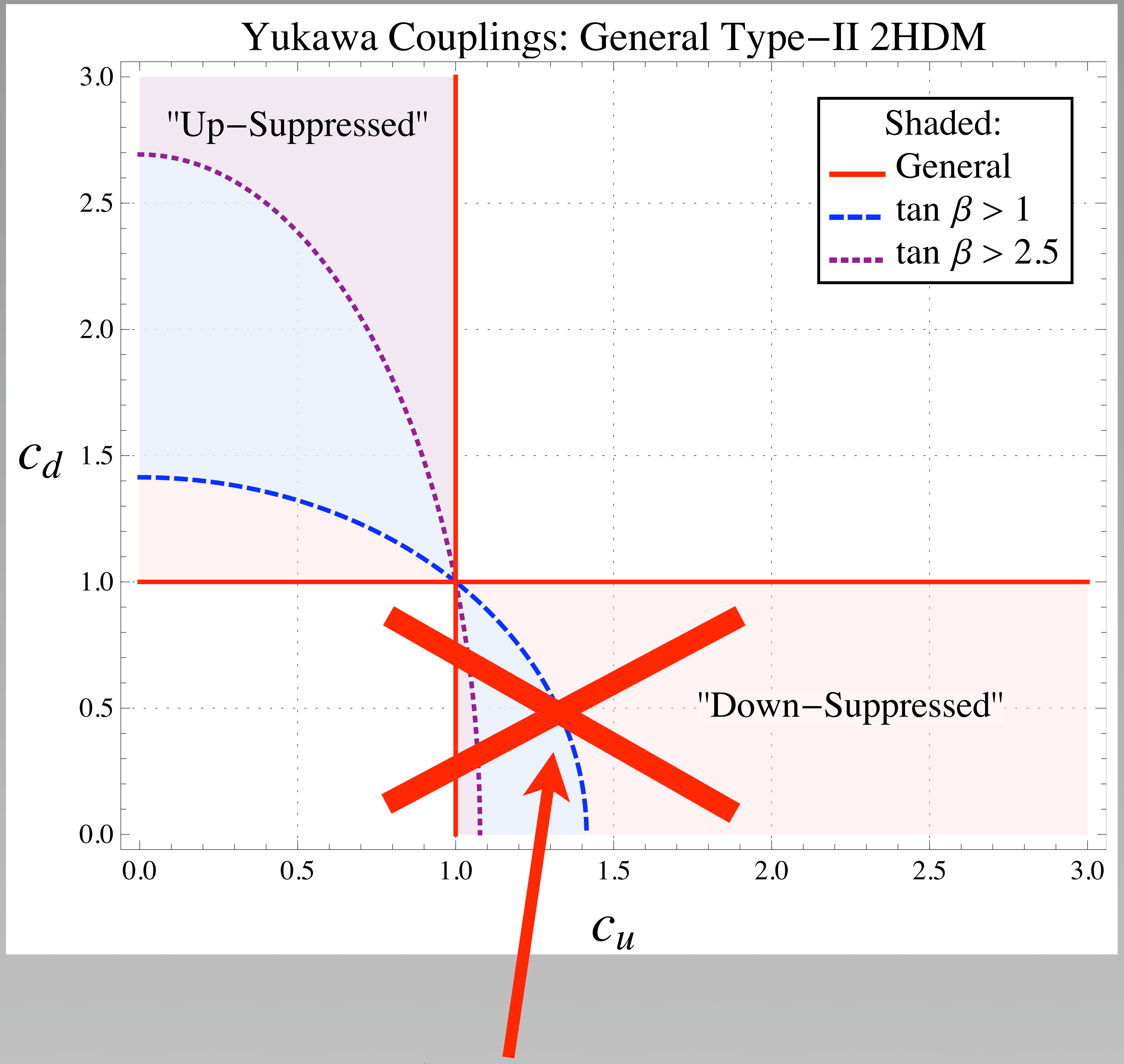
- Peak likelihood lies close to the deoupling limit contour
- Consistency of this requires ALL couplings to revert to SM
- To check this, we can examine a 3D space...

What does the accessible space of Yukawas look like?



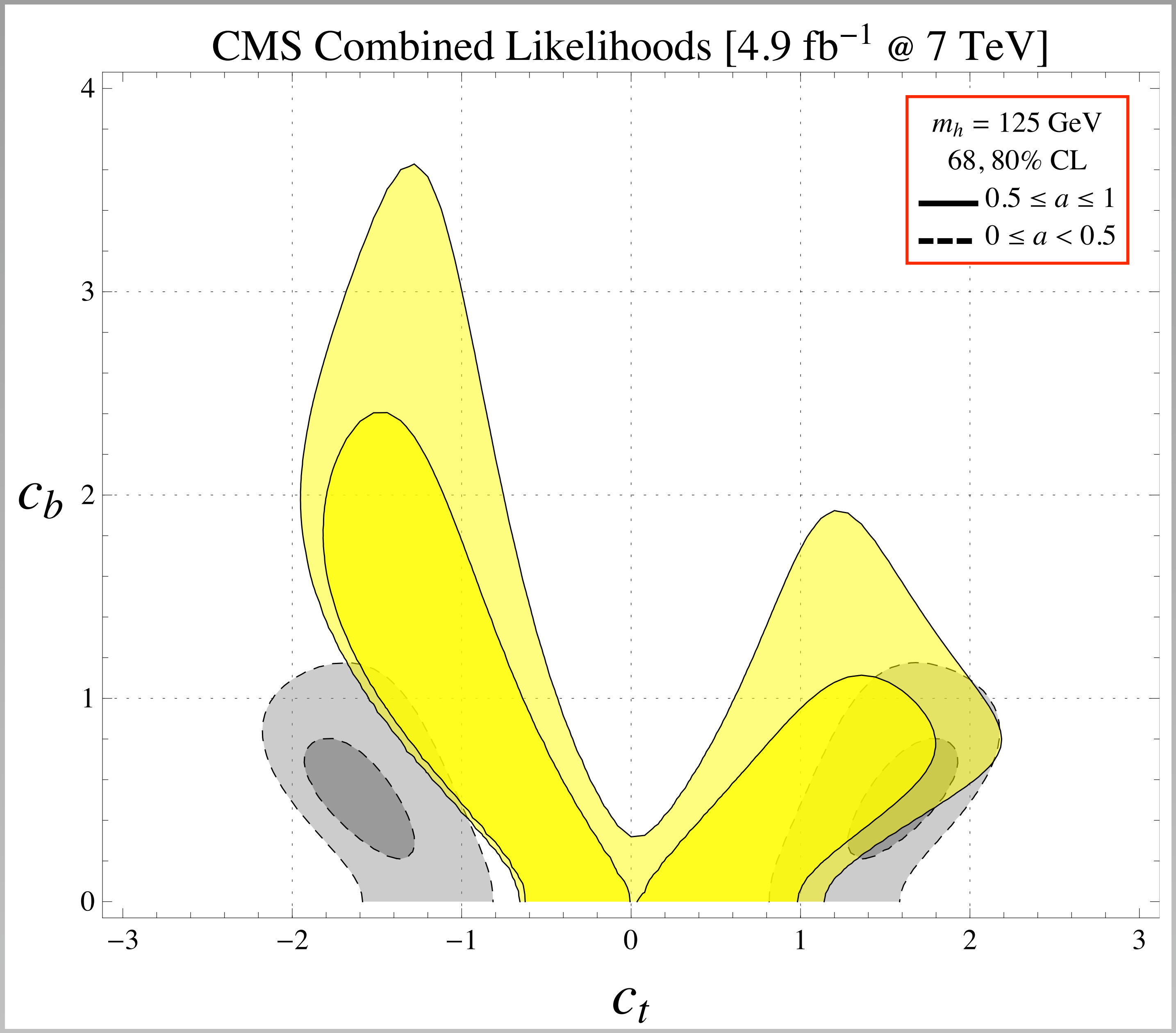
And for the MSSM?



The *very constrained* quartic structure of the MSSM (all coming from D terms) forbids it from entering the down-suppressed region whenever tan beta > 1.

Status...

We can construct the likelihood in the full 3D space, then project the gauge direction onto the 2D Yukawa plane:



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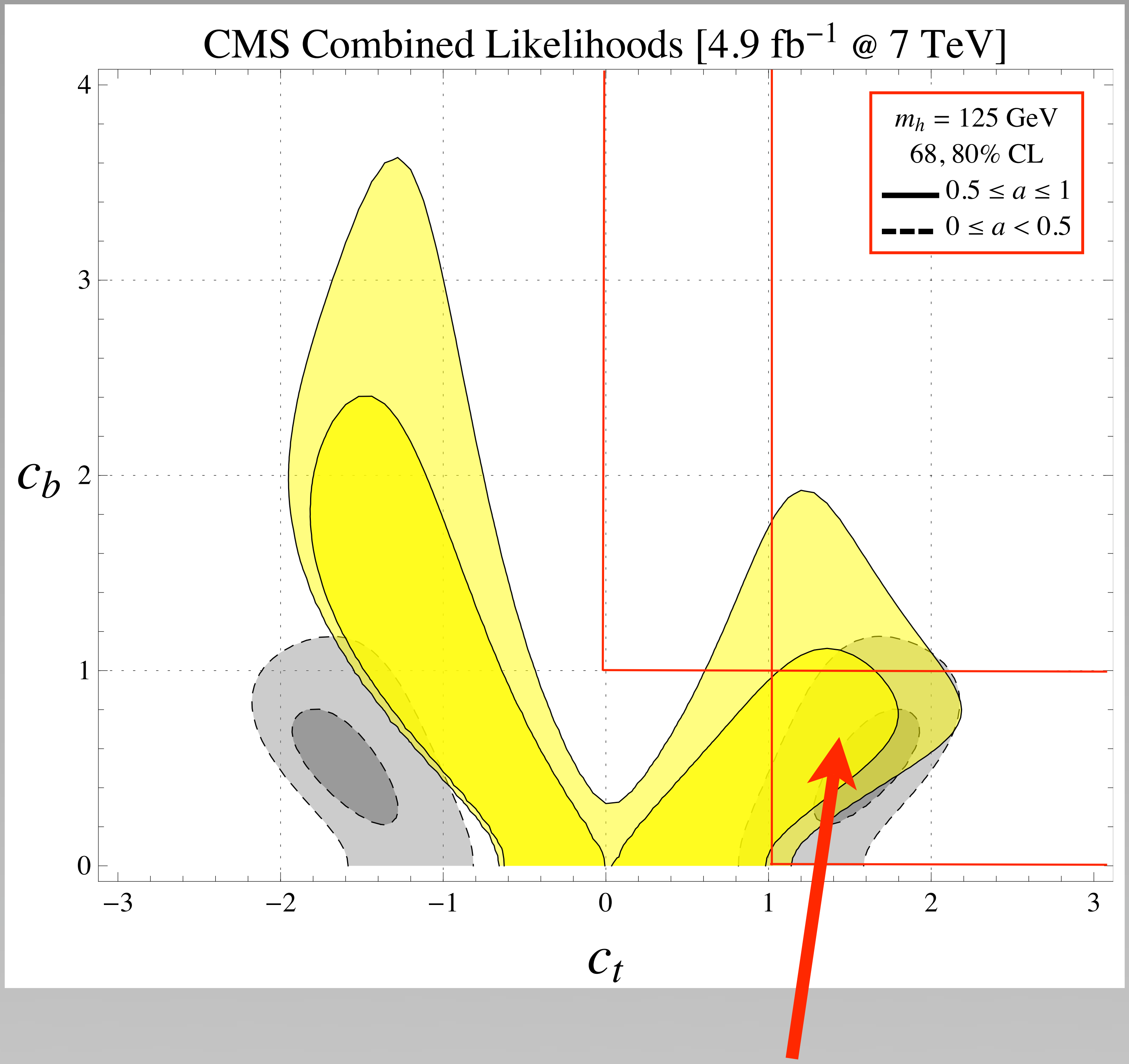

While gauge coupling currently prefers decoupling (couplings = SM), fermions seem to sing a slightly different tune: inaccessible for MSSM!

How does the MSSM fare?

$$\Delta V_{\text{generic}} \quad = \quad \lambda_1 \left|H_u\right|^4 + \lambda_2 \left|H_d\right|^4 - 2\lambda_3 \left|H_u\right|^2 \left|H_d\right|^2$$

$$(+ \text{ non-minimal terms})$$

MSSM for neutral CP-even fields: $\lambda_{1,2,3} = \frac{1}{8}(g^2 + g'^2)$

with potentially lifesaving quantum corrections to λ_1, but for "down-suppression" we need

$$v_u^2 \times (\lambda_1 + \lambda_3) < v_d^2 \times (\lambda_2 + \lambda_3)$$

i.e. big quantum-level correction to $\lambda_{2,3}$ when $\tan\beta > 1$

Natural thing to consider: new non-minimal dynamics -- new fields or compositeness...

Conclusions

I. Composite Higgs: Fairly SM-like couplings indicate strong dynamics at a high scale (so for instance would need large N for light resonances)

II. SUSY: Some hints of non-minimality so far; non-SM couplings indicate that some new states could show up soon

III. Generally: Couplings provide crucial indirect *hints* and *consistency checks* for BSM physics...

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III. Generally: Couplings provide crucial indirect *hints* and *consistency checks* for BSM physics...

...That model builders can themselves start to understand and apply

Each piece of the puzzle is important for consistency of the emerging picture; ultimately more data are needed, but we should be well-prepared to analyze things in as many ways as possible.