HIGGS HUNTING FROM THE BOTTOM UP

COLLABORATIVE SEARCH STRATEGIES AT THE LHC

LHC2TSP: CERN - MARCH 2012

Jamison Galloway

based on work with A. Azatov and R. Contino

(arXiv:1202.3415 and in progress)

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*Or, a demonstration of principles described in yesterday's discussion of the Les Houches Recommendations

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- Focus on bridging any gaps between theory and experiment:
- Indentify the essential theory that is useful for experimentalists, and...
- The essential experiment (statistics) for theorists

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not just to make interpetation easier,
but to make it
**possible at all*
(examples to come)

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Which models are ruled out, which are still in play?
Answering accurately requires an understanding of essential statistics...

OUTLINE

It is in exploring the common ground between theory that one can isolate the important points regarding efficient communication of results

*inasmuch as one is interested in constructing likelihoods and exclusions in *general* parameter spaces*

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Three such items by our count
= emphasis of this talk...

Getting at answers with an obvious example: The Higgs

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Three massive vectors, triplet of approximate SU(2)

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&\mapsto LUR^\dagger
\end{aligned}
$$

described at leading order:

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&\quad -\frac{v}{\sqrt{2}}\,\psi_i^c\,U^\dagger\times\lambda_{ij}\psi_j+\mathrm{h.c.}
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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,
e.g. $\Lambda_{\mathrm{C.H.}} \sim 4\pi v/\sqrt{1-a^2} \ll M_{\mathrm{P}}$.

Likewise "*a*" tells us about other Higgses in the spectrum
e.g. $a = 1 \Rightarrow H^\pm, A^0$ completely decoupled in MSSM

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with theory predictions:

★ SM: $\begin{cases} a = b = 1 \\ c = 1 \end{cases}$

★ "MCHM4": $\begin{cases} \xi \equiv v^2/f^2 \\ a = c = \sqrt{1-\xi} \end{cases}$

★ "MCHM5": $\begin{cases} a = \sqrt{1-\xi} \\ c = \frac{1-2\xi}{\sqrt{1-\xi}} \end{cases}$

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A minimally-prejudiced question:

HOW CAN WE CONSTRAIN THIS SPACE?

Some "need to know" statistics

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

$$\begin{aligned} P(n|n_{\rm obs}) &= \frac{n^{n_{\rm obs}} e^{-n}}{n_{\rm obs}!} \times \pi(n) \\ &\xrightarrow{\rm A.L.} \exp\left[\frac{-(n-n_{\rm obs})^2}{2n_{\rm obs}}\right] \times \pi(n) \end{aligned}$$

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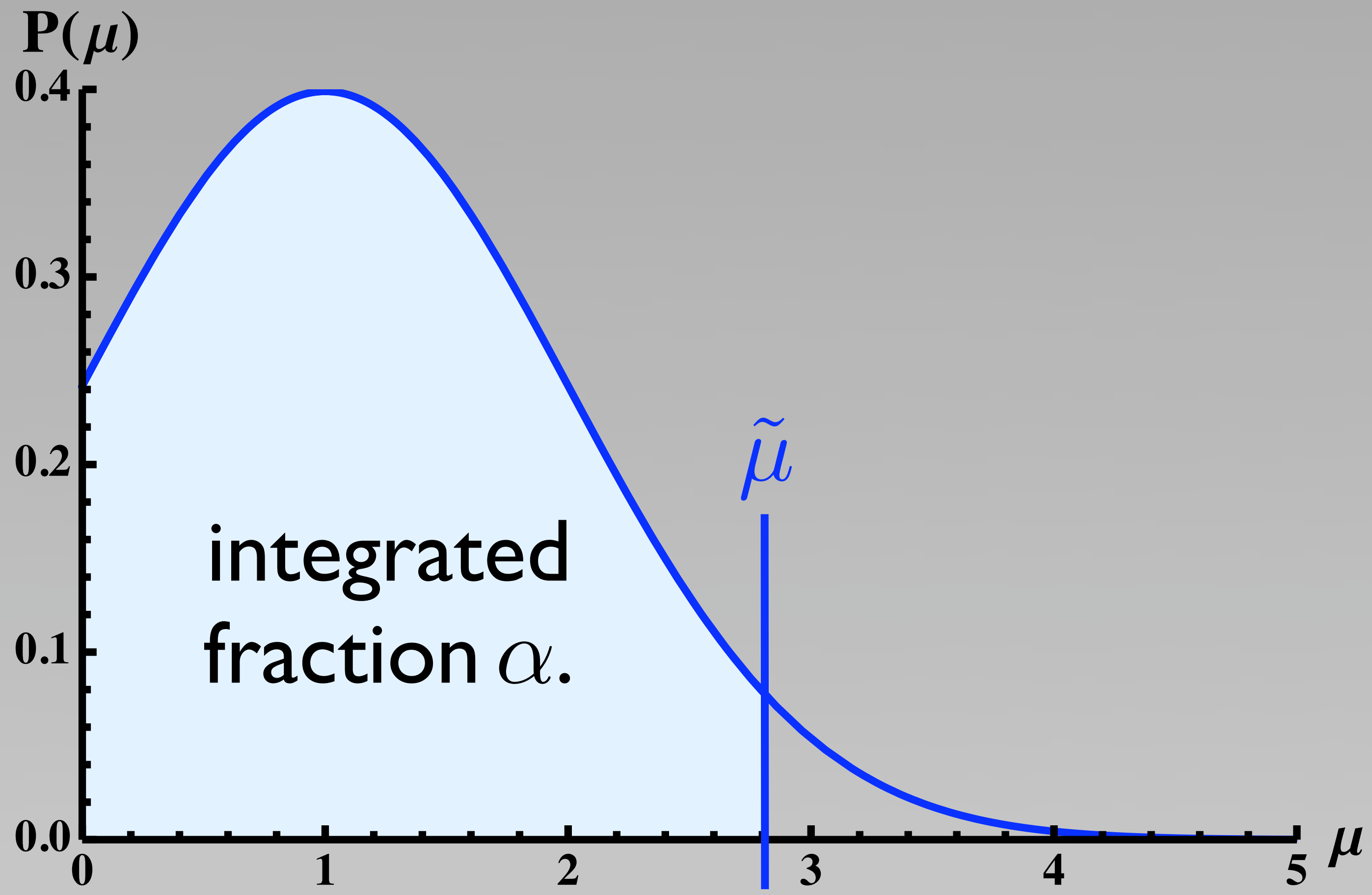

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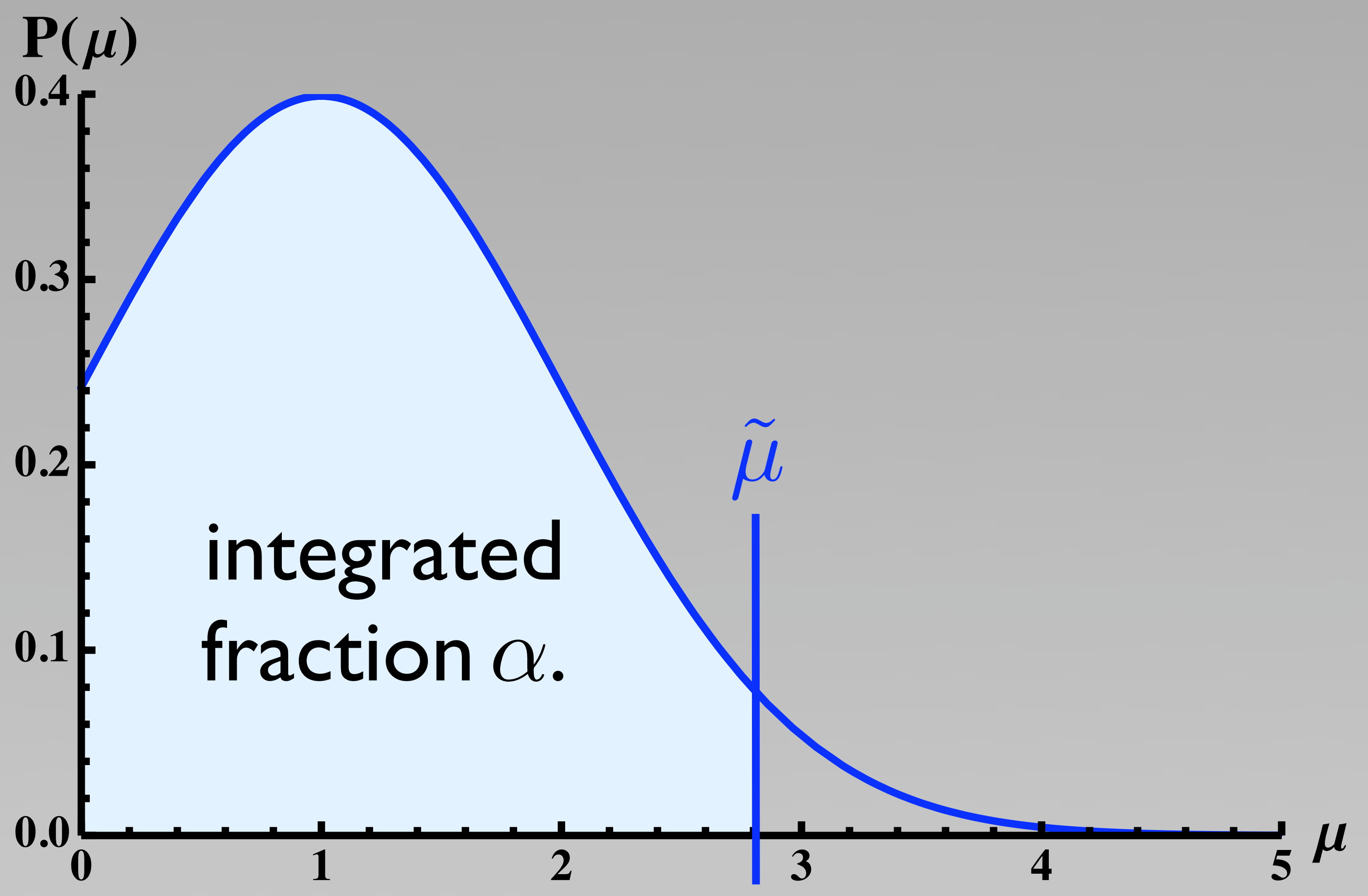

$\tilde{\mu}$: upper bound on signal strength modifier at CL = alpha.

Two versions:

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

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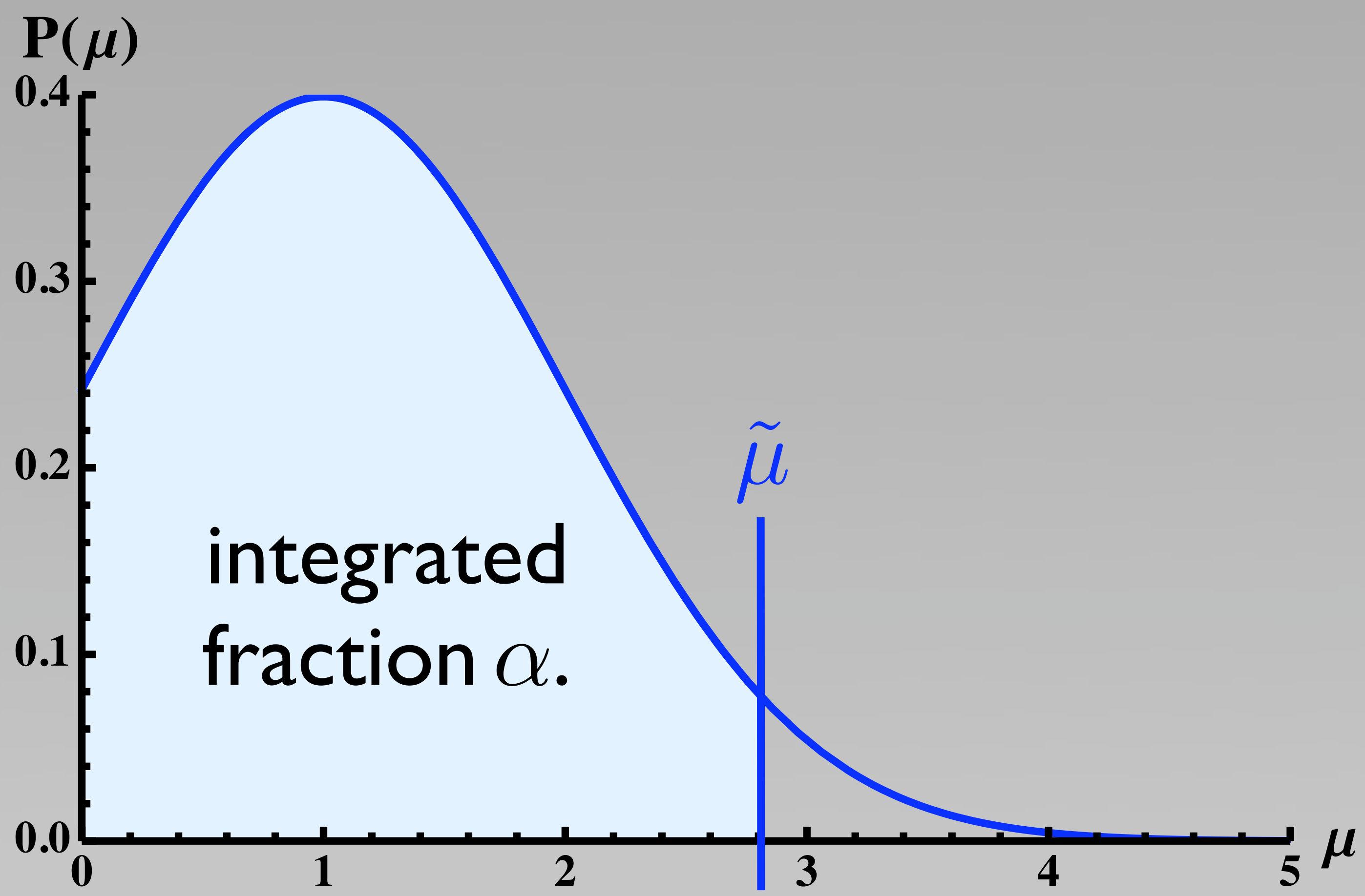

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Efficiencies not always provided, so unknown to theorists

Best we can do: *assume* that $\zeta_{p,i} = \zeta_i \ \forall\ p$.†

† Safely justified for SM and SM-like ($a = c$), but not in general.

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This *can* be related purely to theory, but it's only approximate

EFFICIENCIES NEEDED

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A closer look at “signal strength modifier”

IMPORTANT POINT NUMBER ONE

Tracing back from number of events to underlying theory
REQUIRES knowledge of efficiencies
when considering generalized spaces.

Moving on: Comparison to Likelihood

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

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NOT YET AVAILABLE *

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* but let's not despair
(although it would be nice to have)

Moving on: Comparison to Likelihood

IMPORTANTish POINT NUMBER TWO

Constructing exclusions for underlying theory
WOULD BE HELPED BY knowledge of likelihoods directly.

Moving on: Comparison to *RECONSTRUCTED* Likelihood

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

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

$$P(n_B + \mu n_S | n_{\rm obs}) = \pi(\mu) \times \exp\left[\frac{-(n_B + \mu n_S - n_{\rm obs})^2}{2n_{\rm obs}}\right]$$

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For observed exclusion, use a simple rewriting:

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Solve for remaining parameter using observed exclusion limit:

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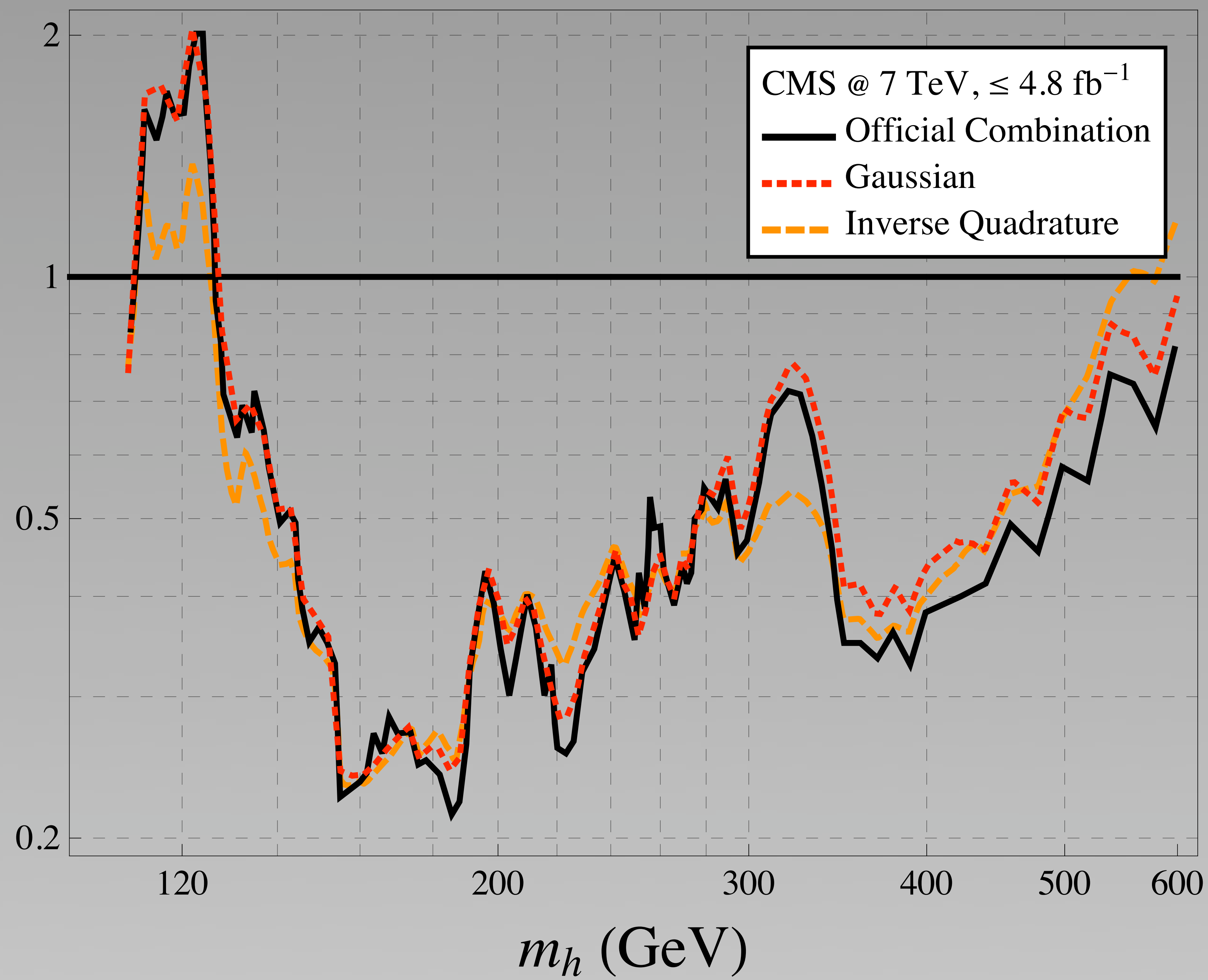
RECAP:

- o Expected exclusion tells us about s/b
- o Observed tells us delta, completes determination of (AL) likelihood
- o 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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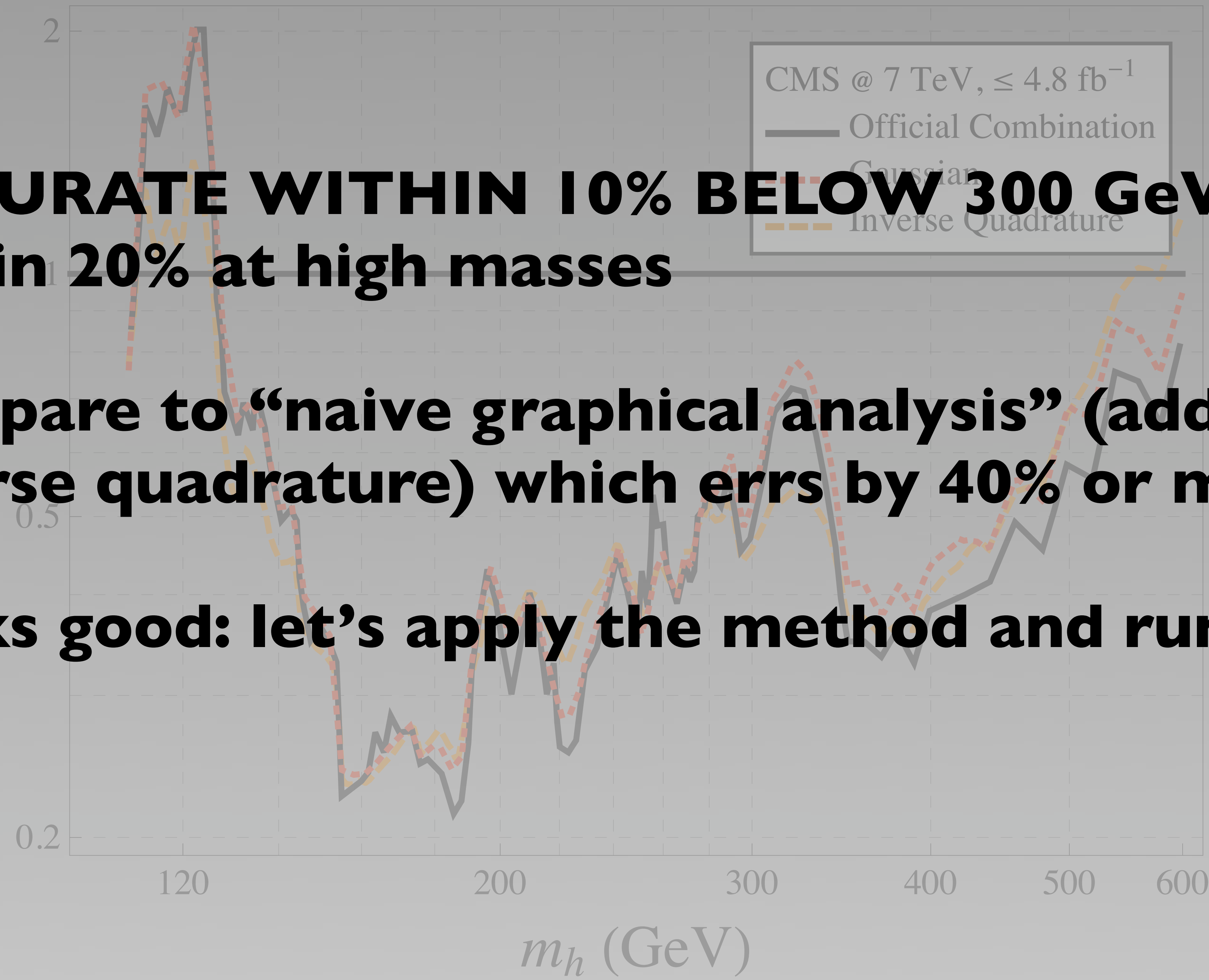
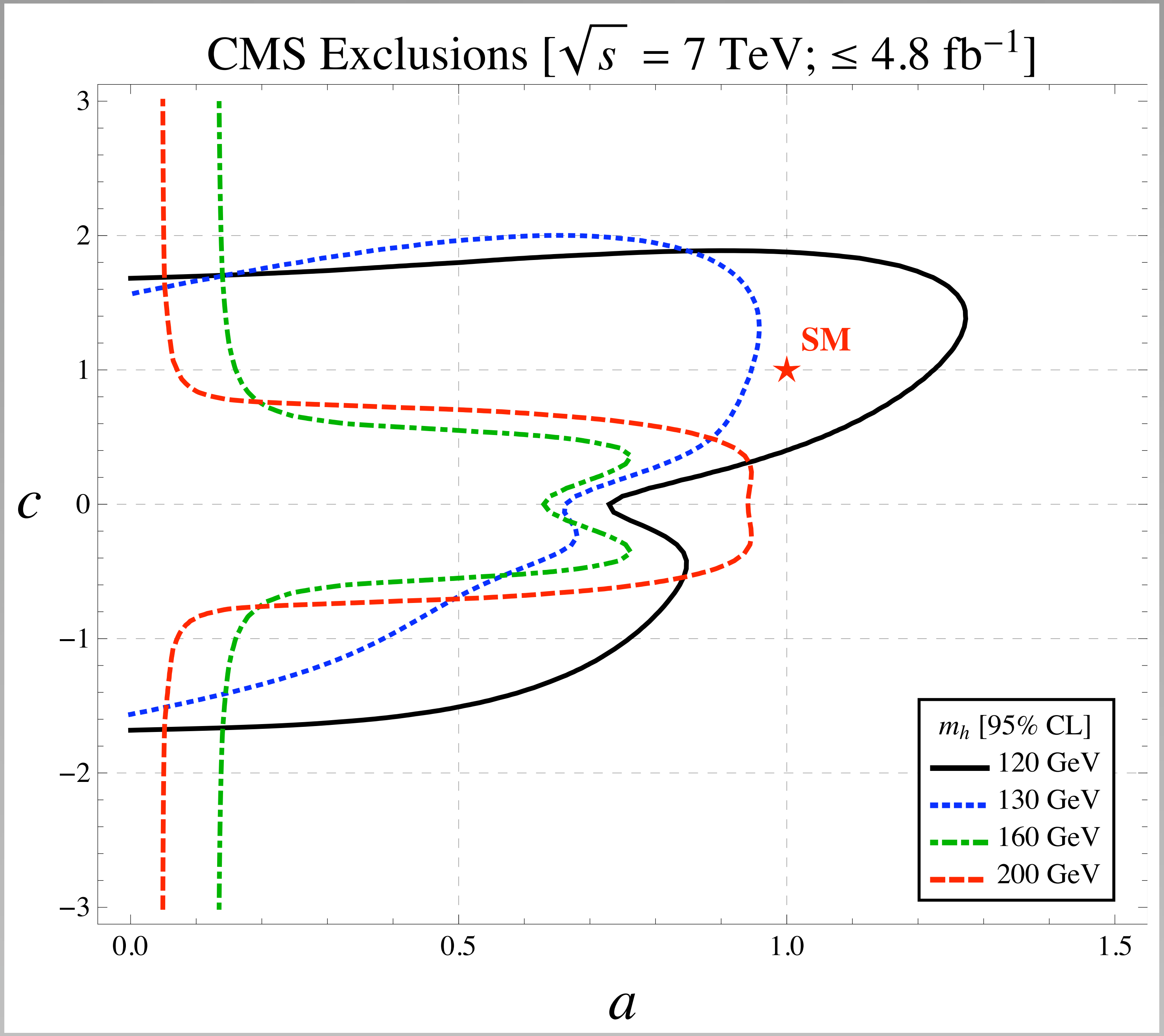


- **ACCURATE WITHIN 10% BELOW 300 GeV; within 20% at high masses**
- **Compare to "naive graphical analysis" (adding in inverse quadrature) which errs by 40% or more**
- **Looks good: let's apply the method and run with it**

Status report for unpopular mass points



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

Five channels for a light Higgs:

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$$\left.\begin{array}{ll} 1,2. & \text{Zero Jet, same/opposite flavor lepton} \\ 3,4. & \text{One Jet, same/opposite flavor lepton} \end{array}\right\} \longleftarrow \text{Inclusive}$$

$$\begin{array}{ll} 5. & \text{Two Jets} \end{array} \qquad \longleftarrow \text{VBF}$$

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1. Both in barrel, $\min(R9) > 0.94$
2. Both in barrel, $\min(R9) < 0.94$
3. $\geq$ One in endcap, $\min(R9) > 0.94$
4. $\geq$ One in endcap, $\min(R9) < 0.94$
5. Dijet tag

(1–4) ⟵ Inclusive

(5) ⟵ VBF

Photon candidates with high values of R_9 are mostly unconverted and have less background than those with lower values. Photon candidates in the barrel have less background than those in the endcap. For this reason it has been found useful to divide photon candidates into four categories and apply a different selection in each category, using more stringent requirements in categories with higher background and worse resolution.

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Five channels for a light Higgs:

$$1.\ WW \quad 2.\ \gamma\gamma \quad 3.\ ZZ \quad 4.\ \tau\tau \quad 5.\ bb$$

Inclusive

VBF + GF + “Boosted”
(combined limit given; event numbers for one mass)

Associated Production

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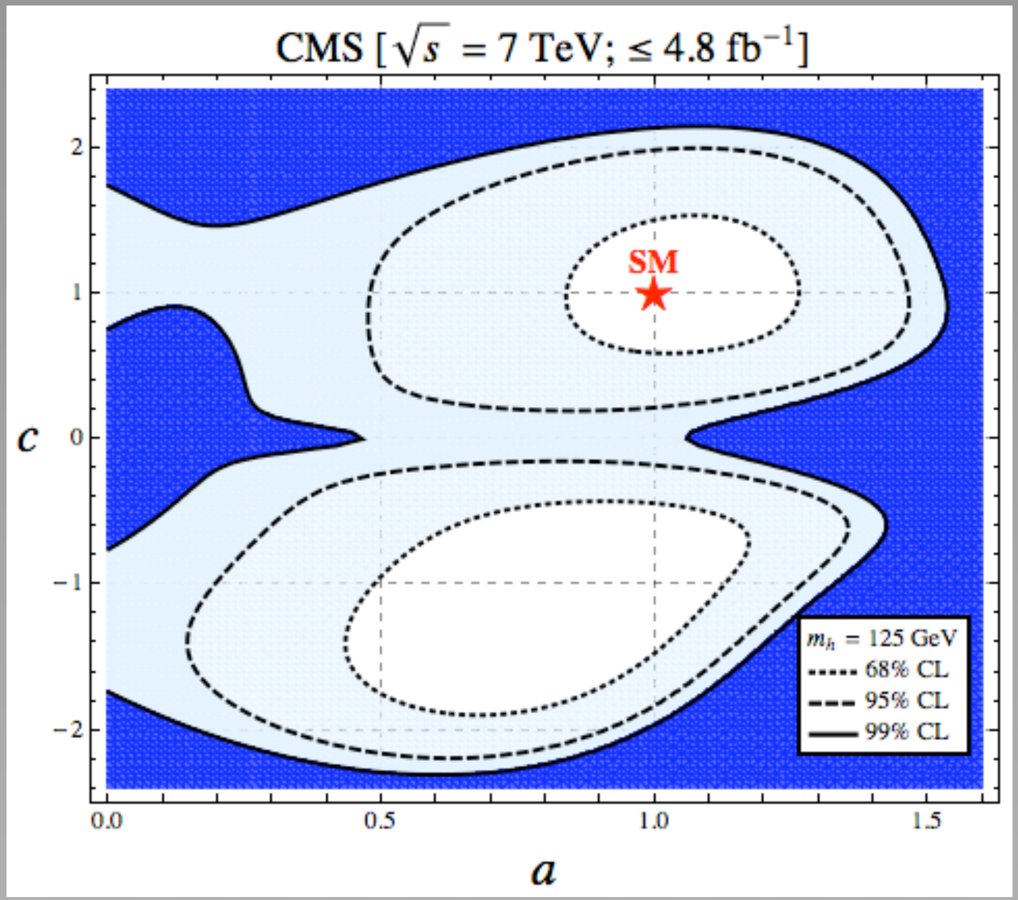

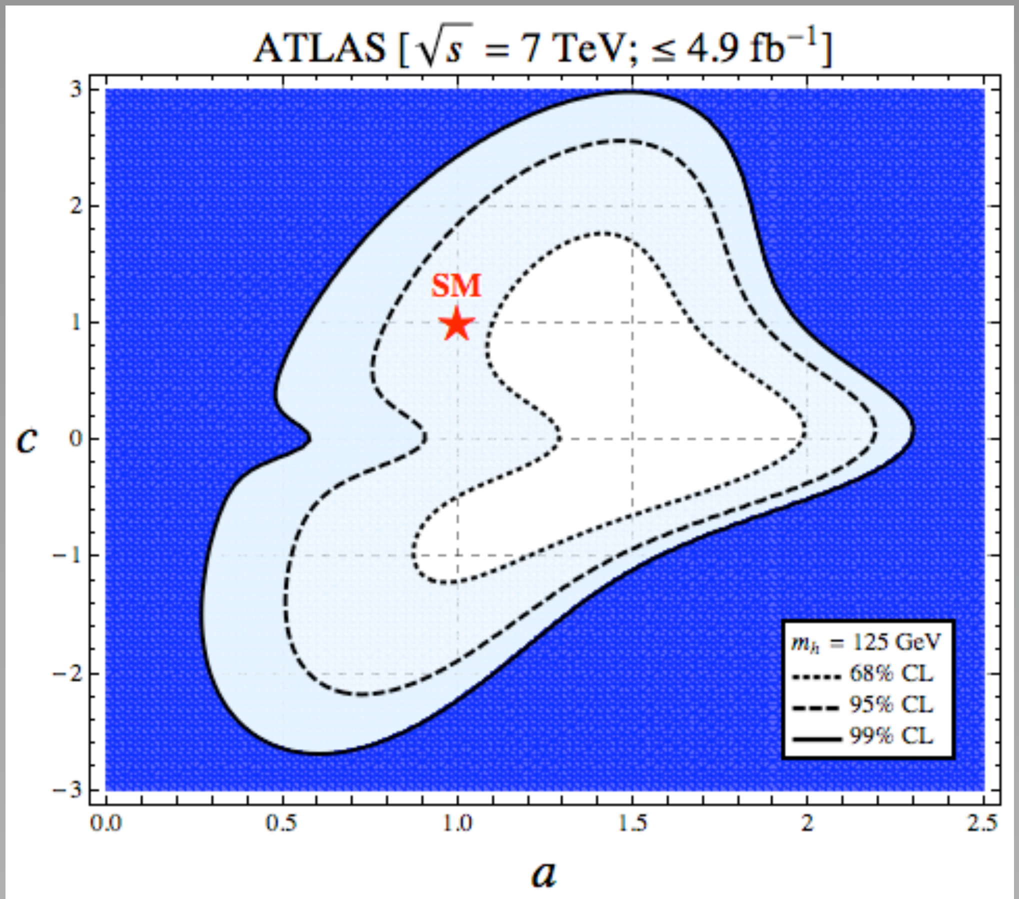

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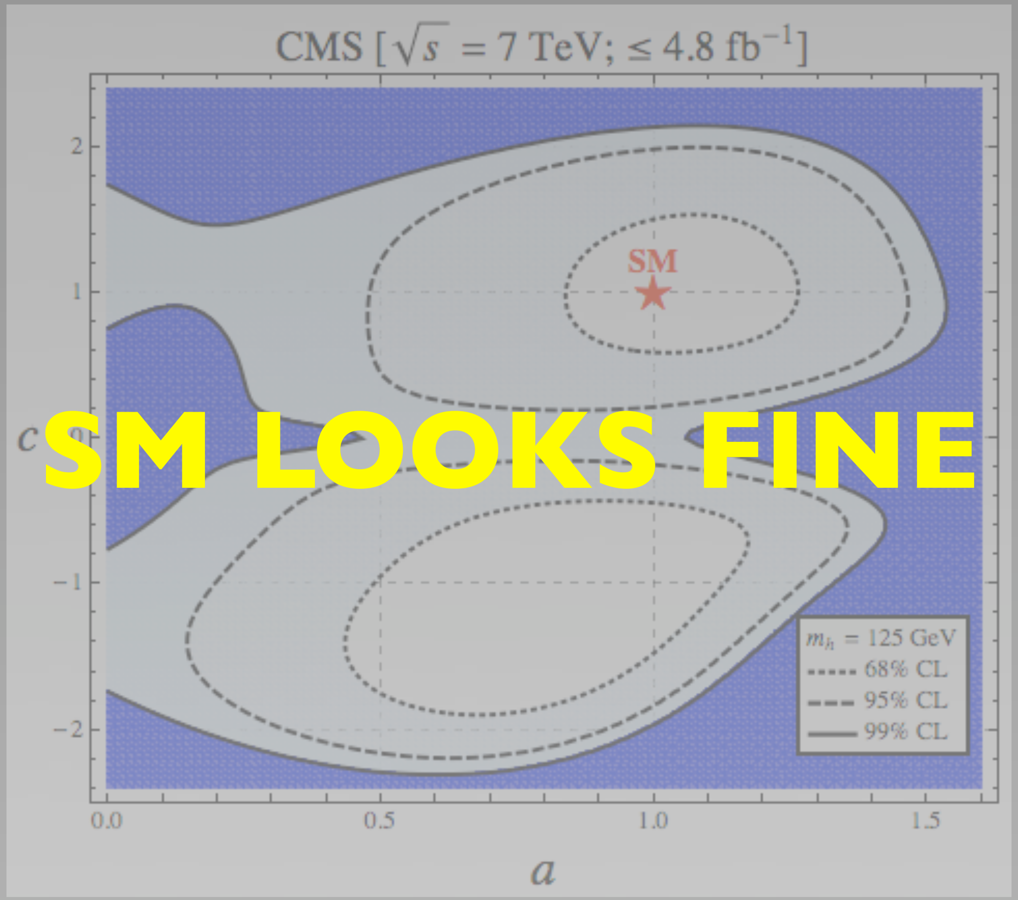

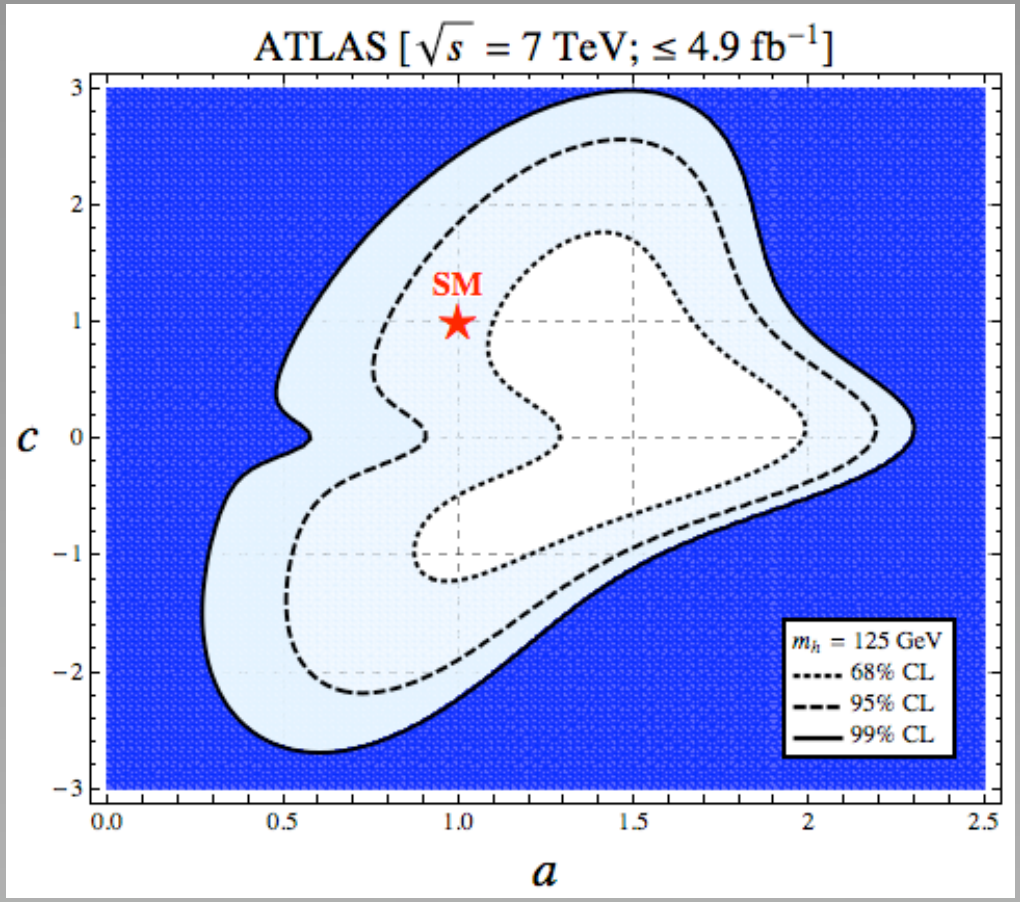

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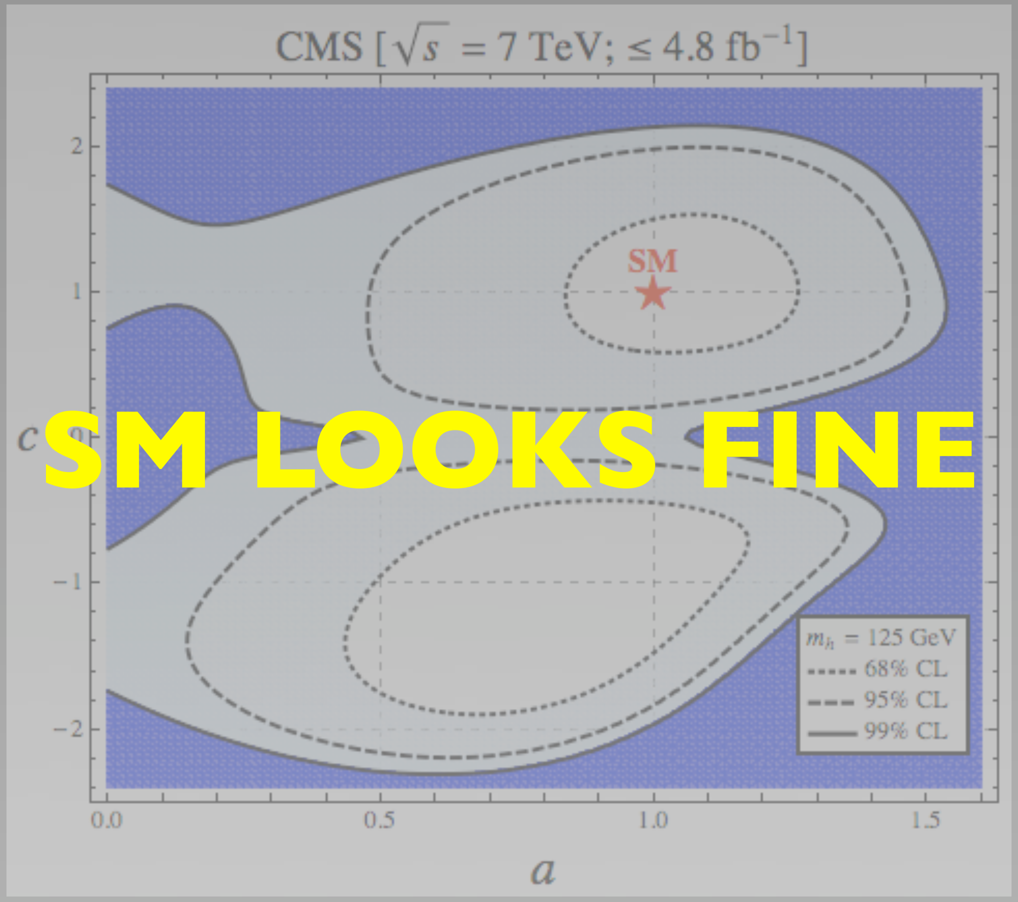

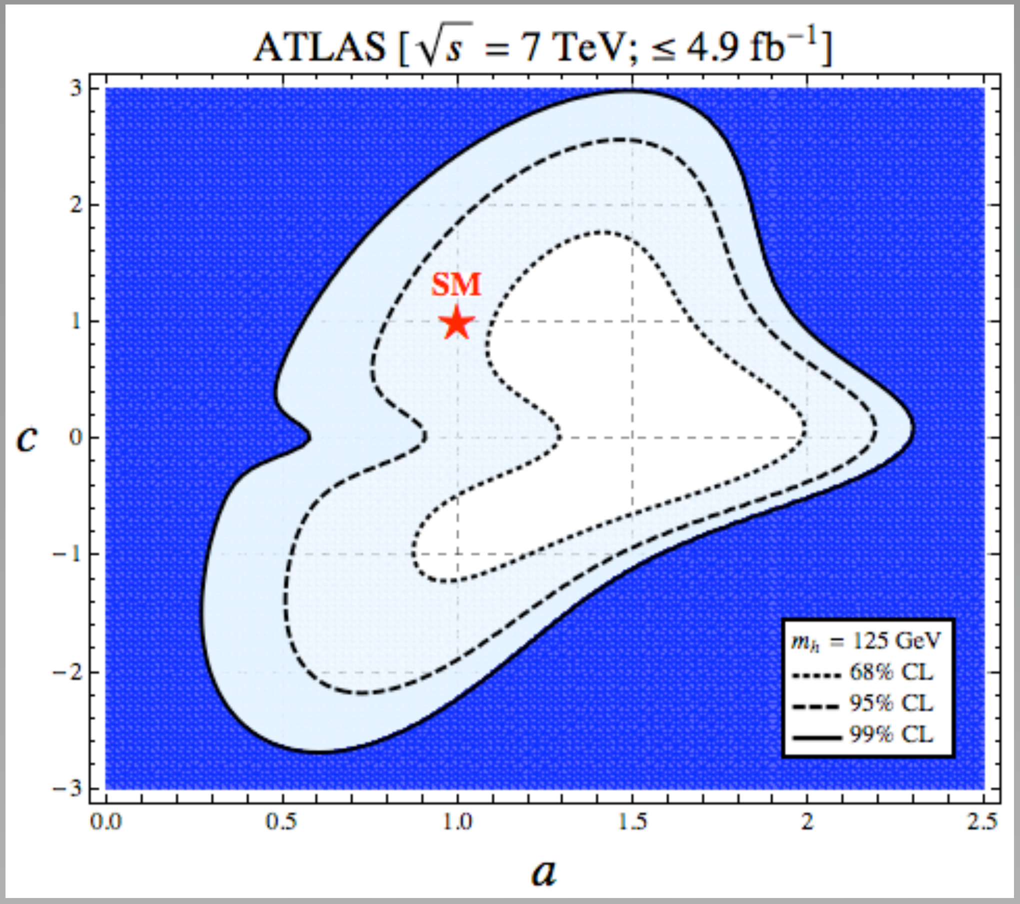

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how should we take this?

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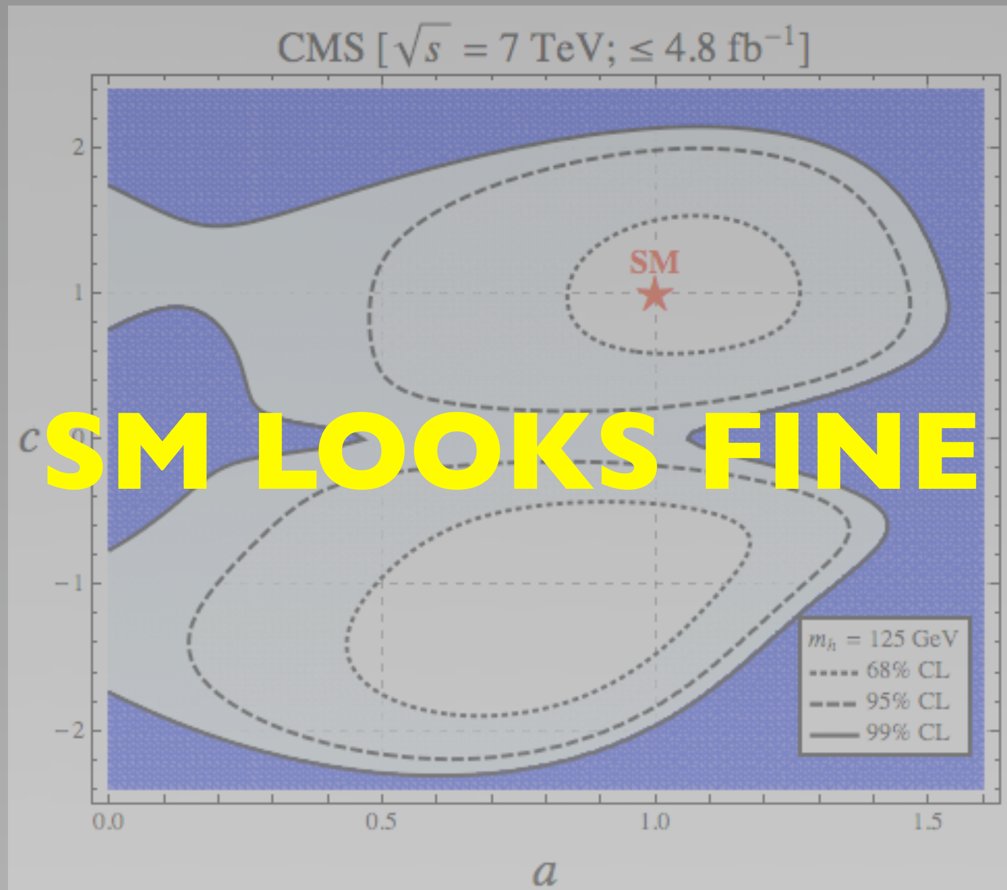

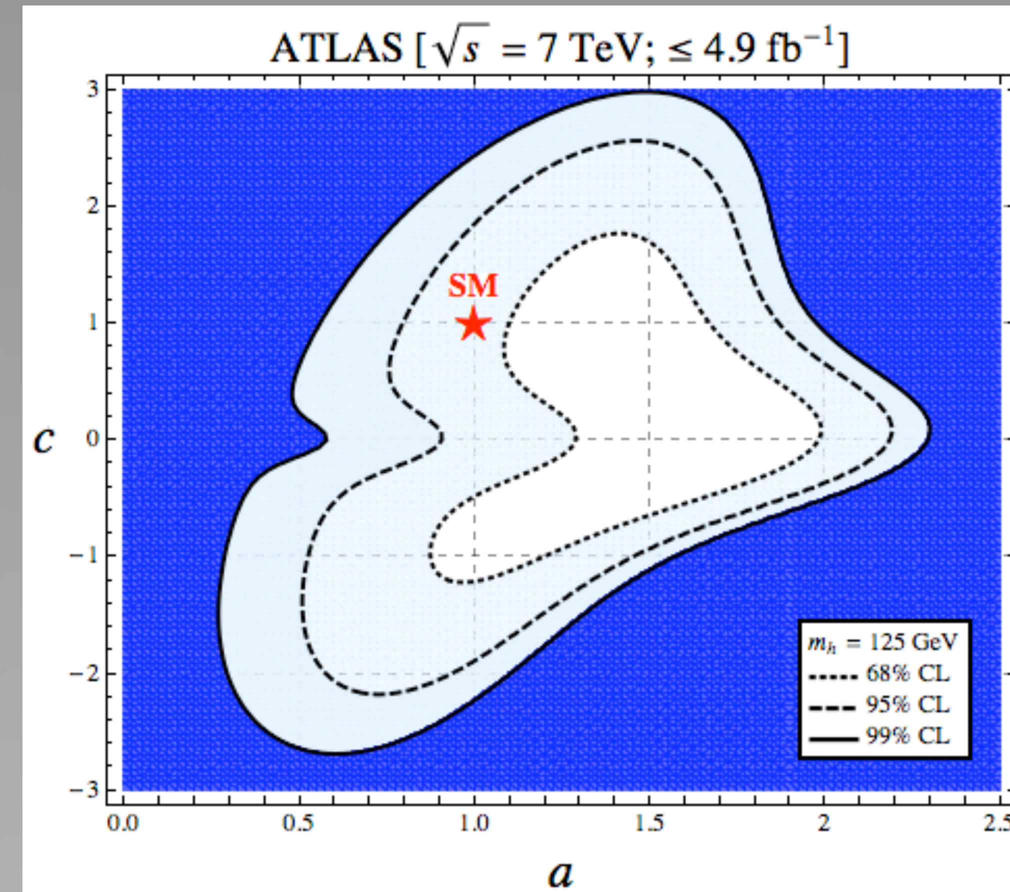

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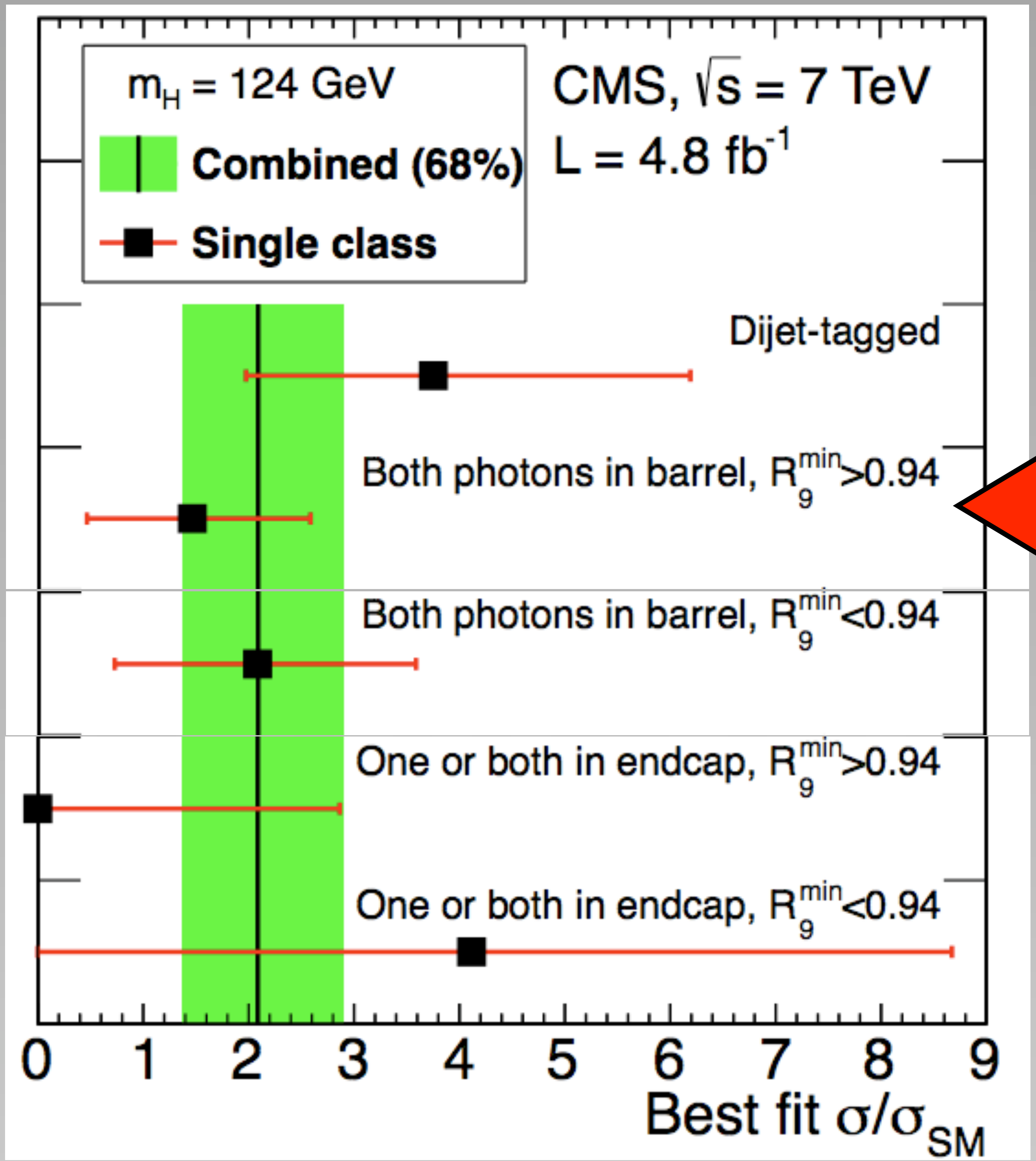
NOT VERY SERIOUSLY
stay tuned...

Final Point: The Need for Exclusive Searching and Reporting

About the displayed CMS results:

- o All WW subchannels treated individually
- o Others (except bb) treated inclusively
- o Can do better for gamma gamma exactly at peak

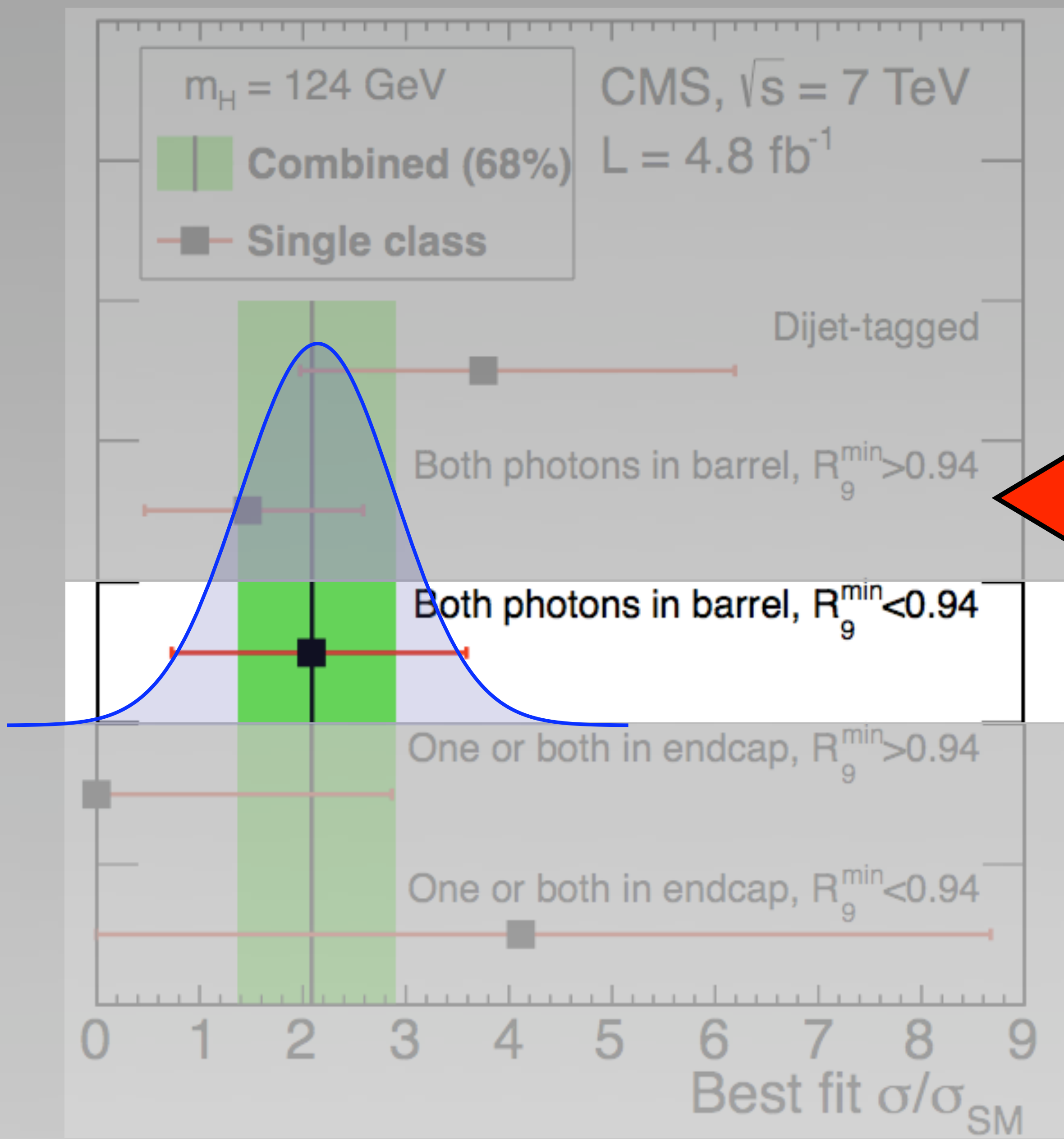


Different method:
Fit each band with
appropriate distribution
(approx. Gaussian)

Final Point: The Need for Exclusive Searching and Reporting

About the displayed CMS results:

- o All WW subchannels treated individually
- o Others (except bb) treated inclusively
- o Can do better for gamma gamma exactly at peak



e.g. ...

Final Point: The Need for Exclusive Searching and Reporting

About the displayed CMS results:

- All WW subchannels treated individually
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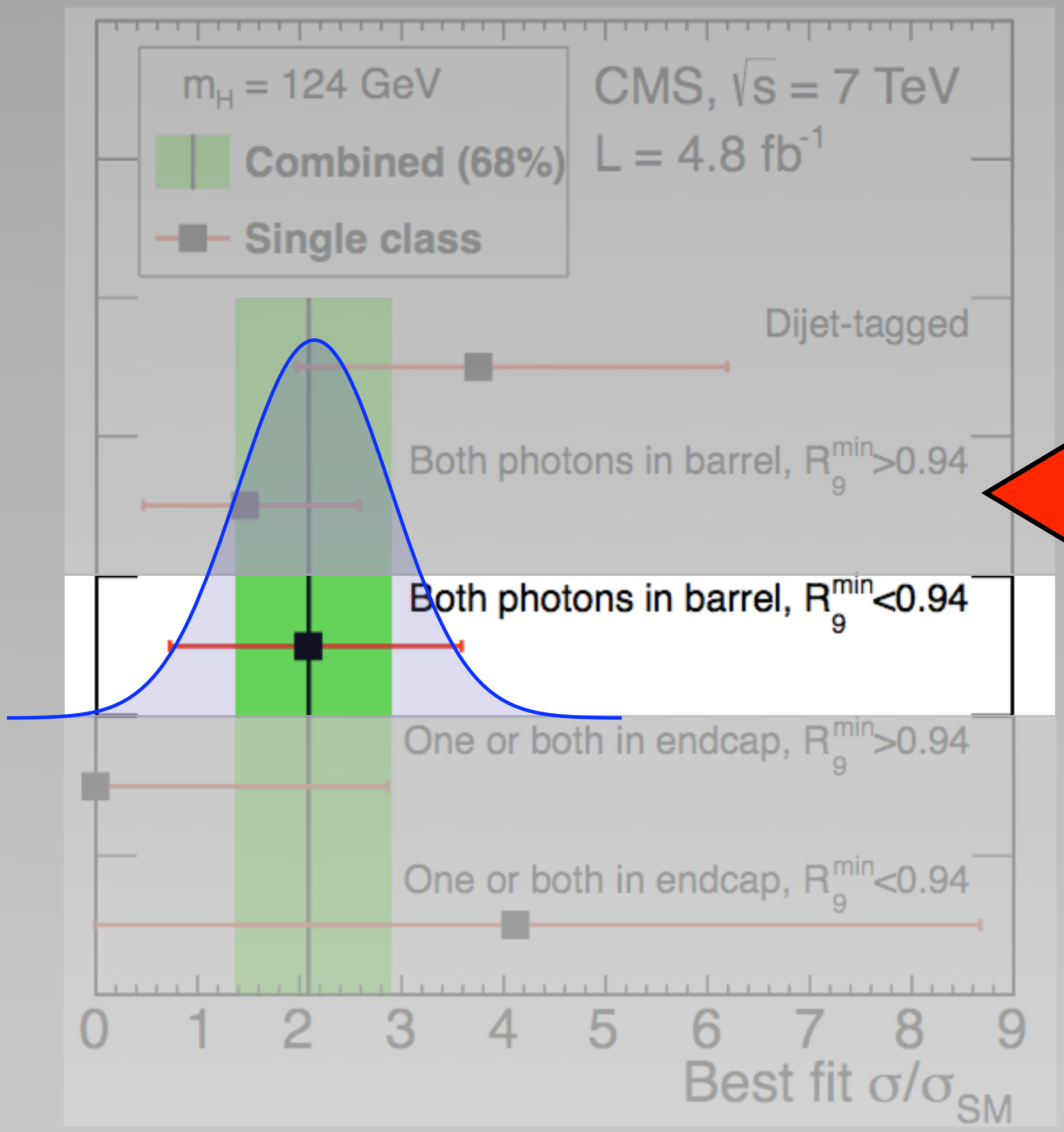
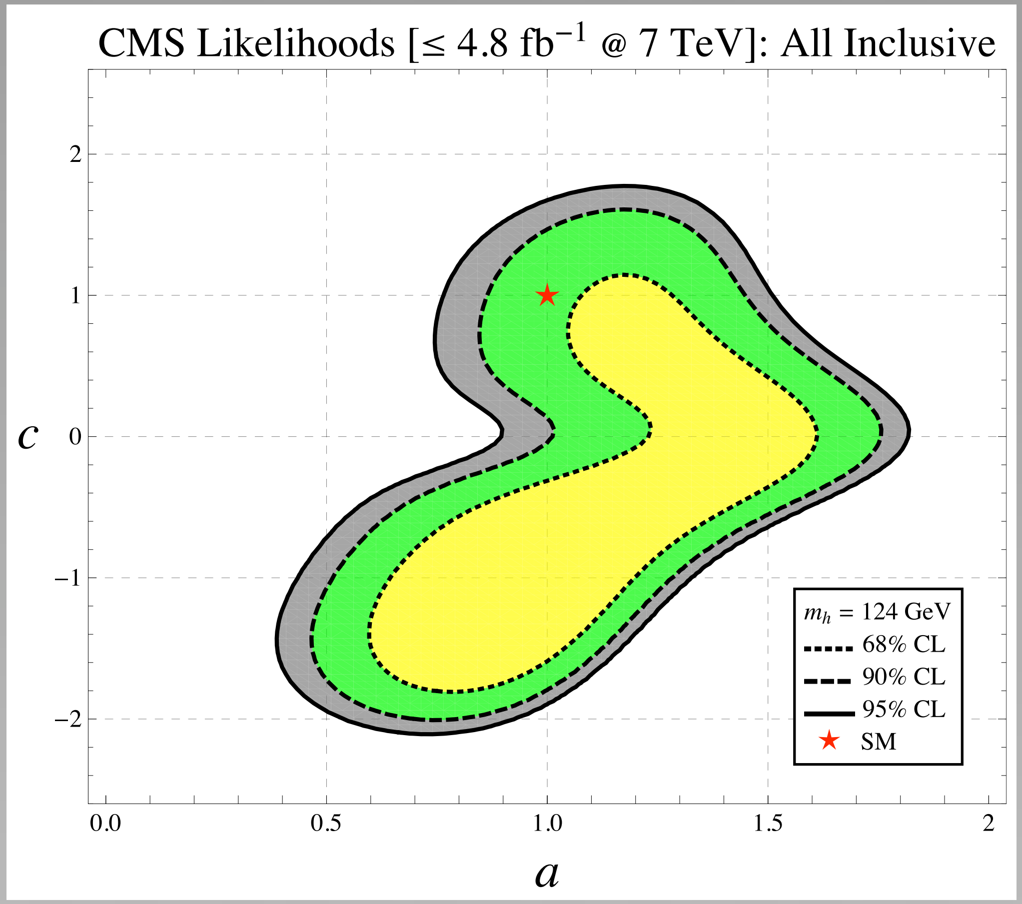
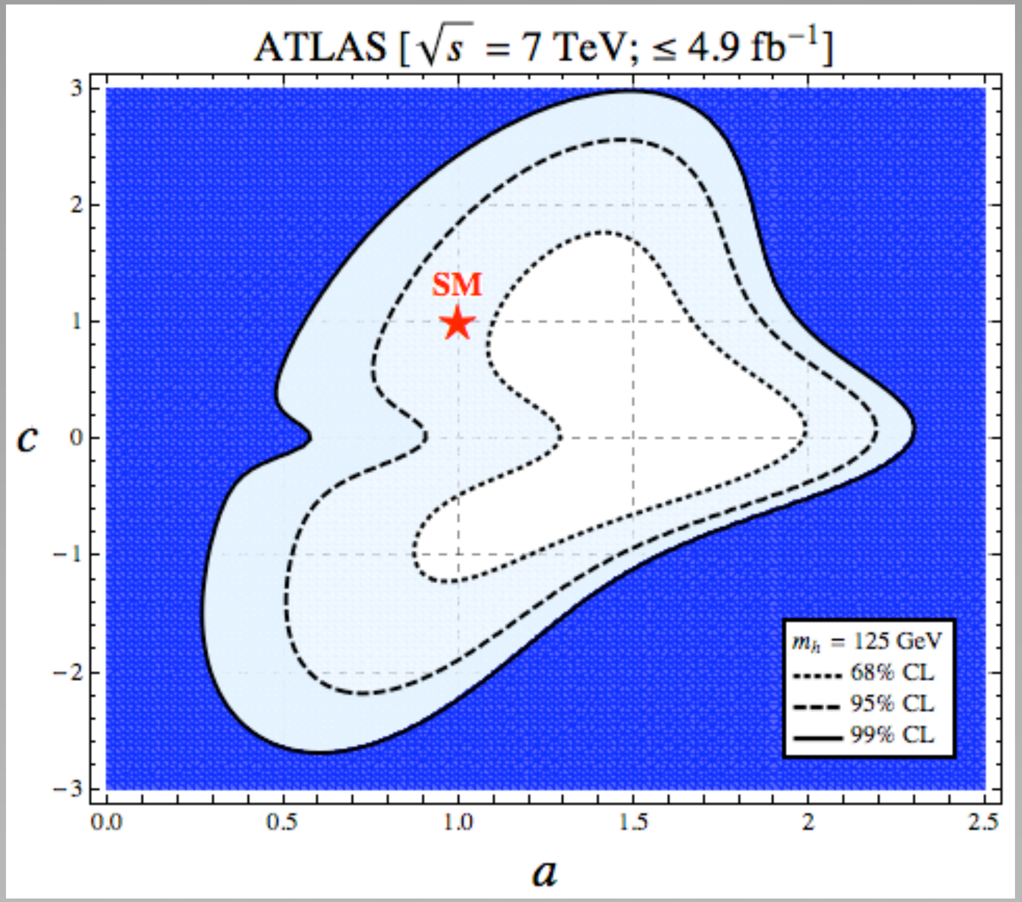


Total likelihood given by product of all

Final Point: The Need for Exclusive Searching and Reporting

Side-by-side comparison of INCLUSIVE results:

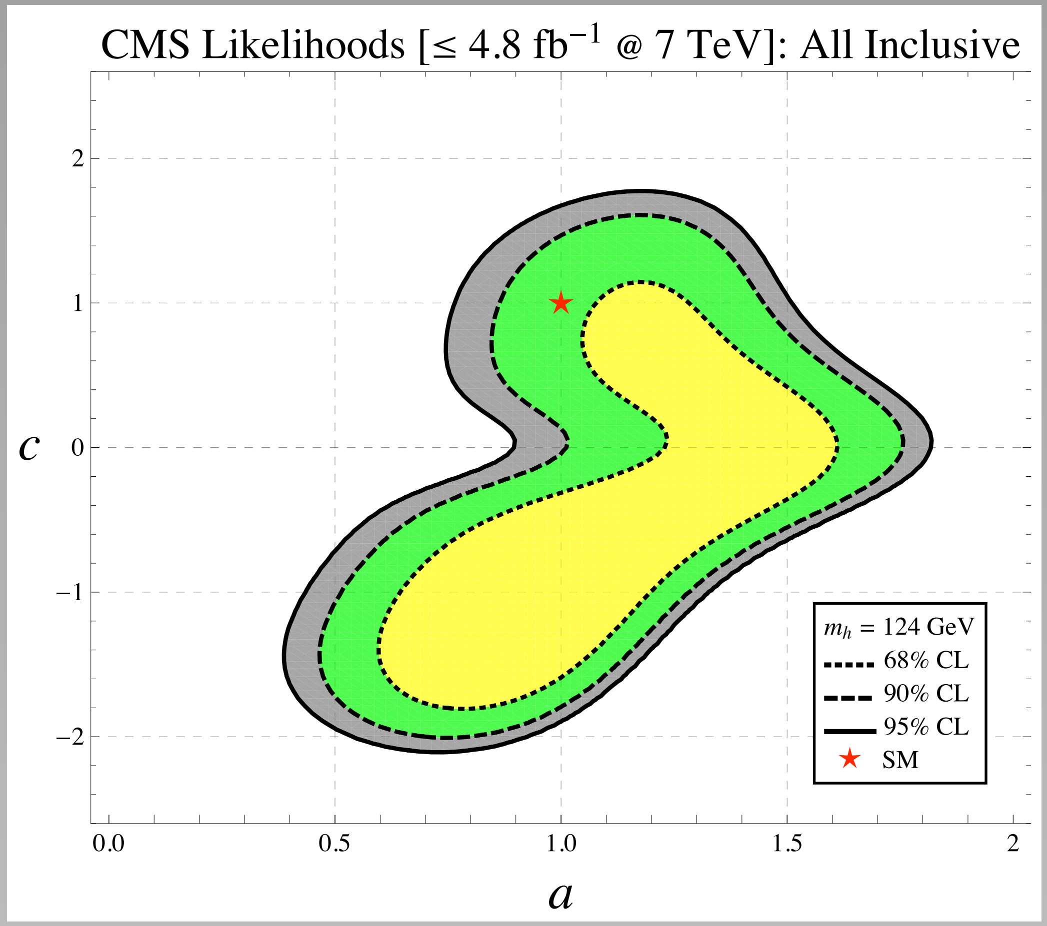


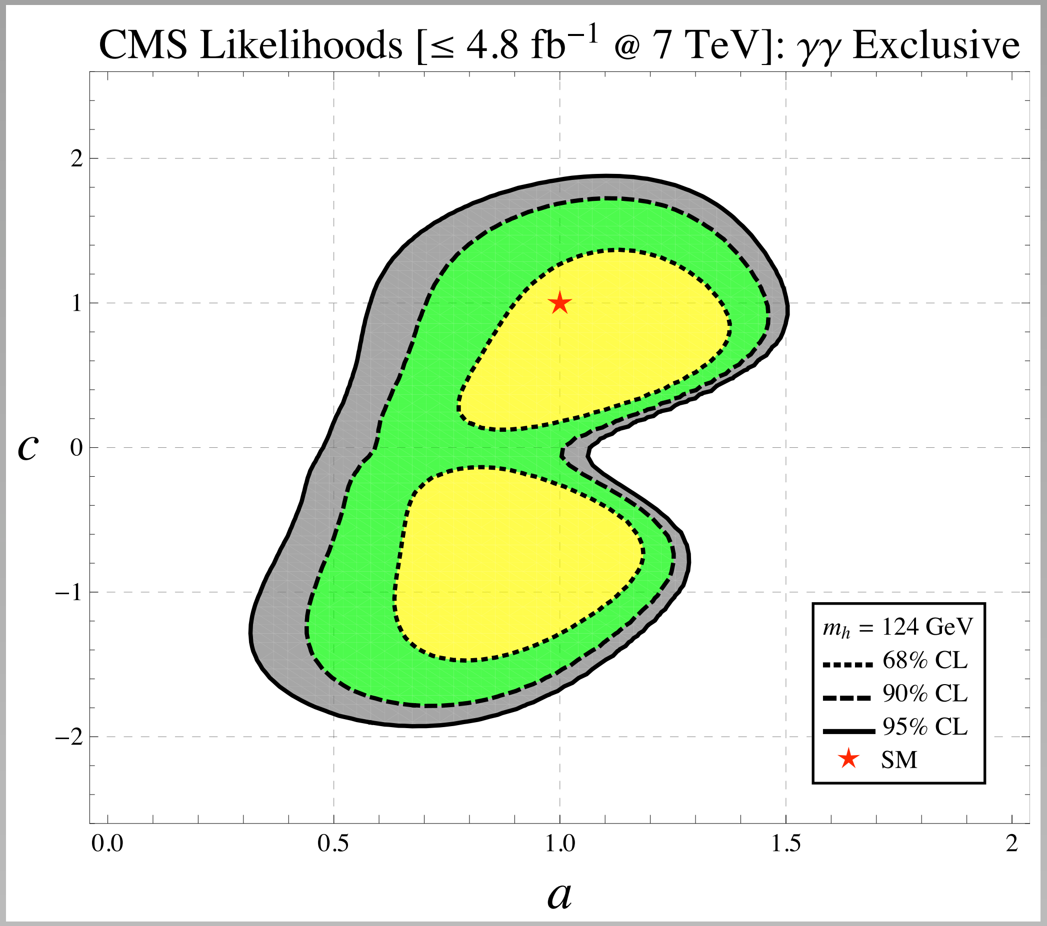


(There *are* real differences, but we see a distinctive -- qualitative -- similarity here)

Final Point: The Need for Exclusive Searching and Reporting

Now treat gamma gamma subchannels:





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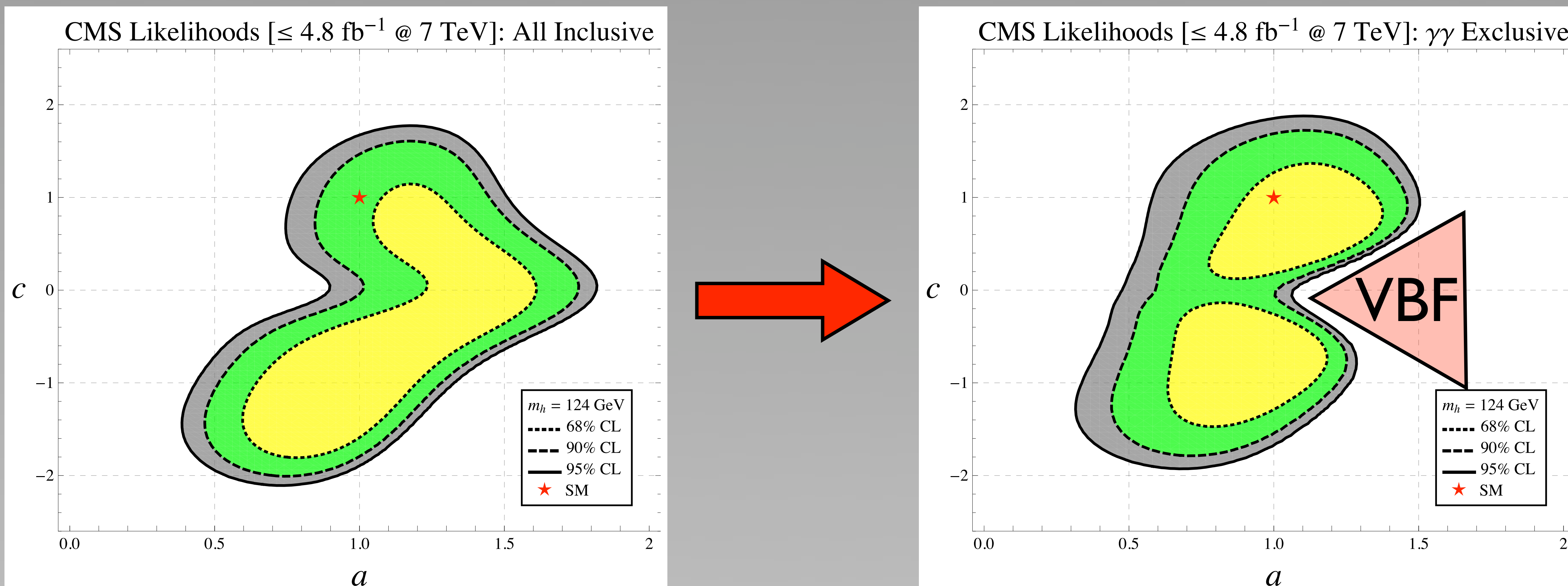

Final Point: The Need for Exclusive Searching and Reporting

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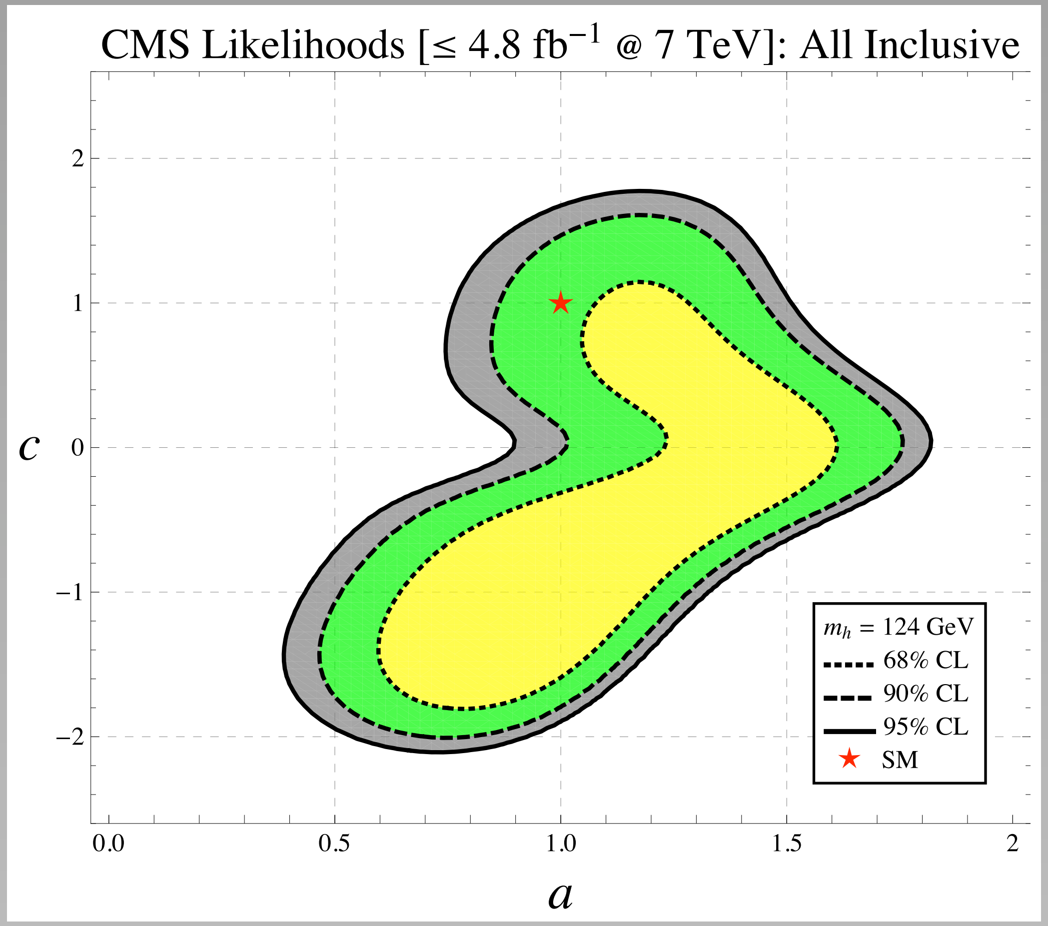
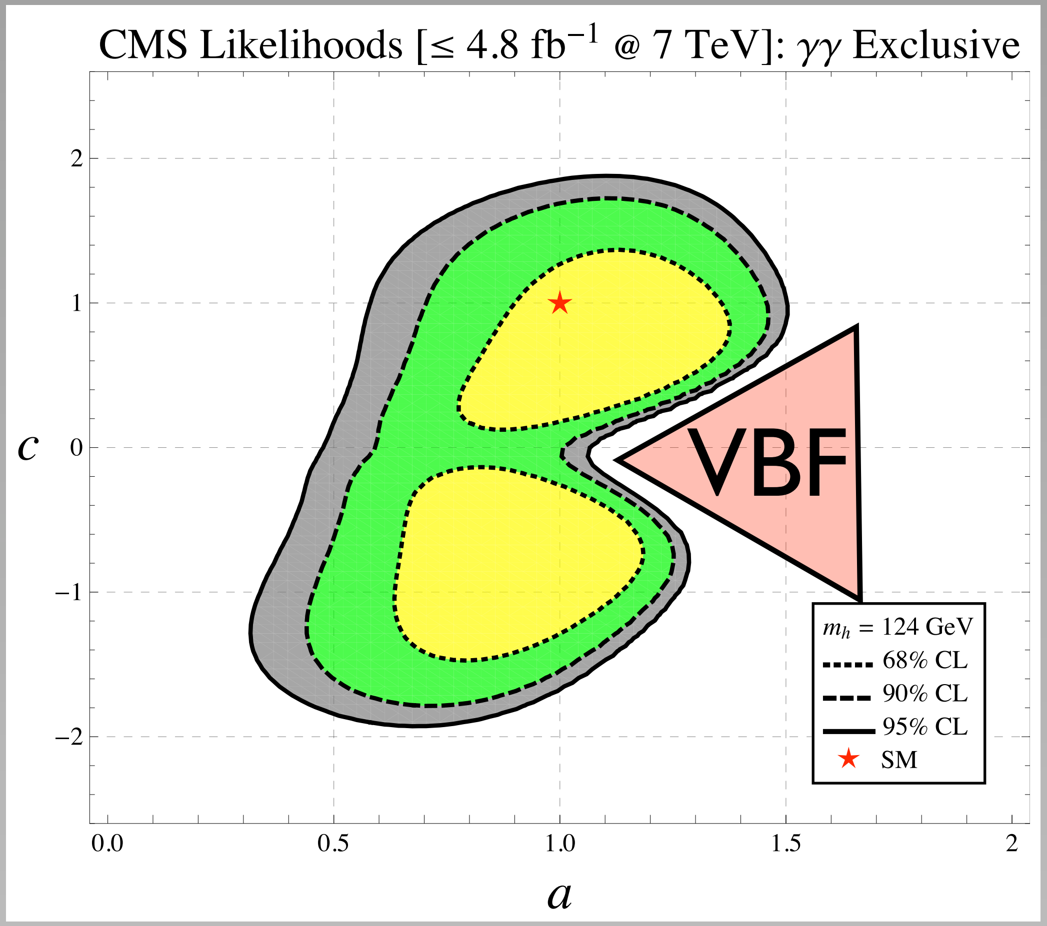
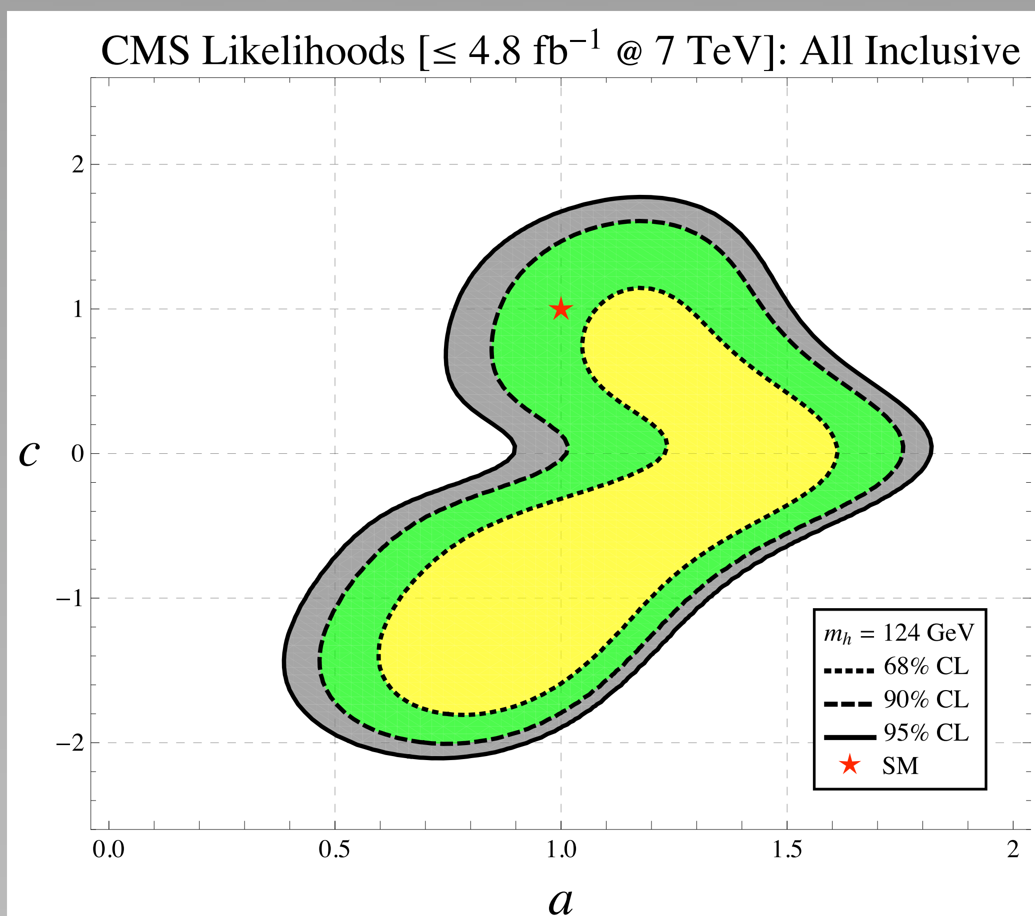


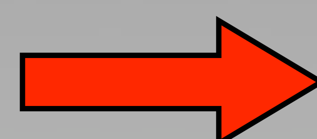


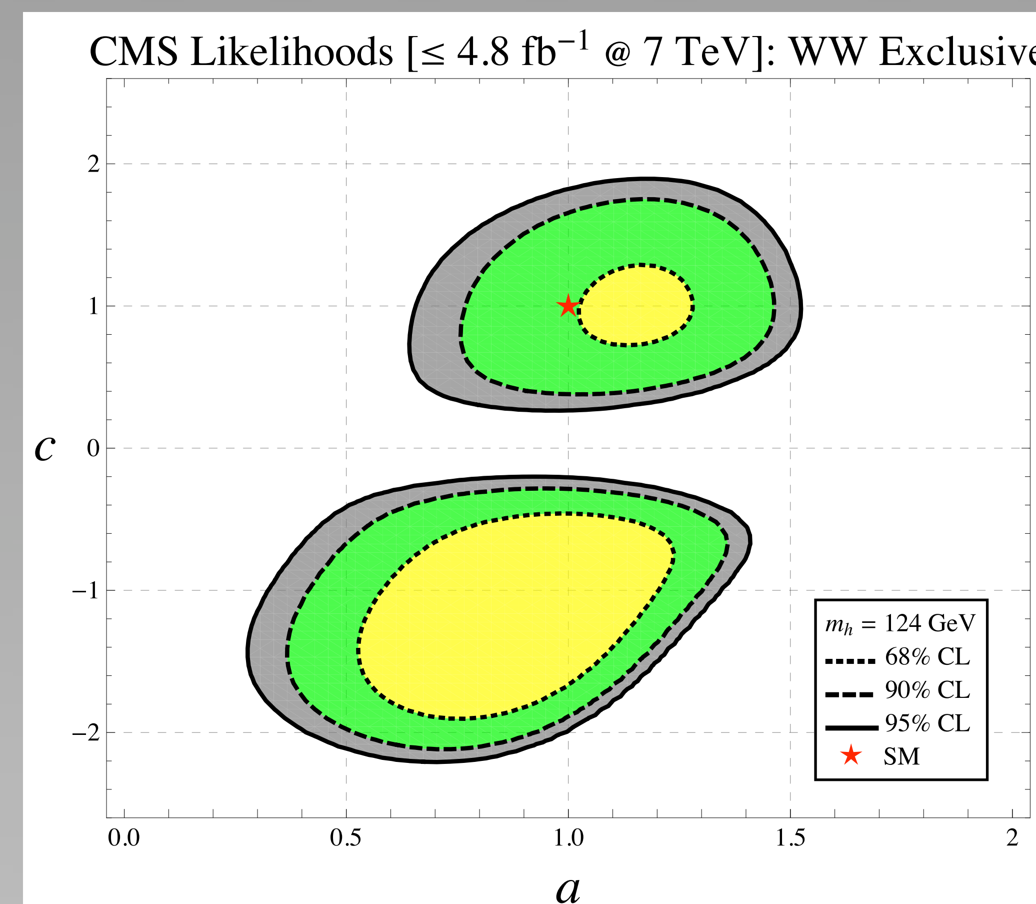
near $c = 0$ line, $R \sim a^2$ → Excess in dijet fit with gauge coupling

Final Point: The Need for Exclusive Searching and Reporting

WW subchannels:

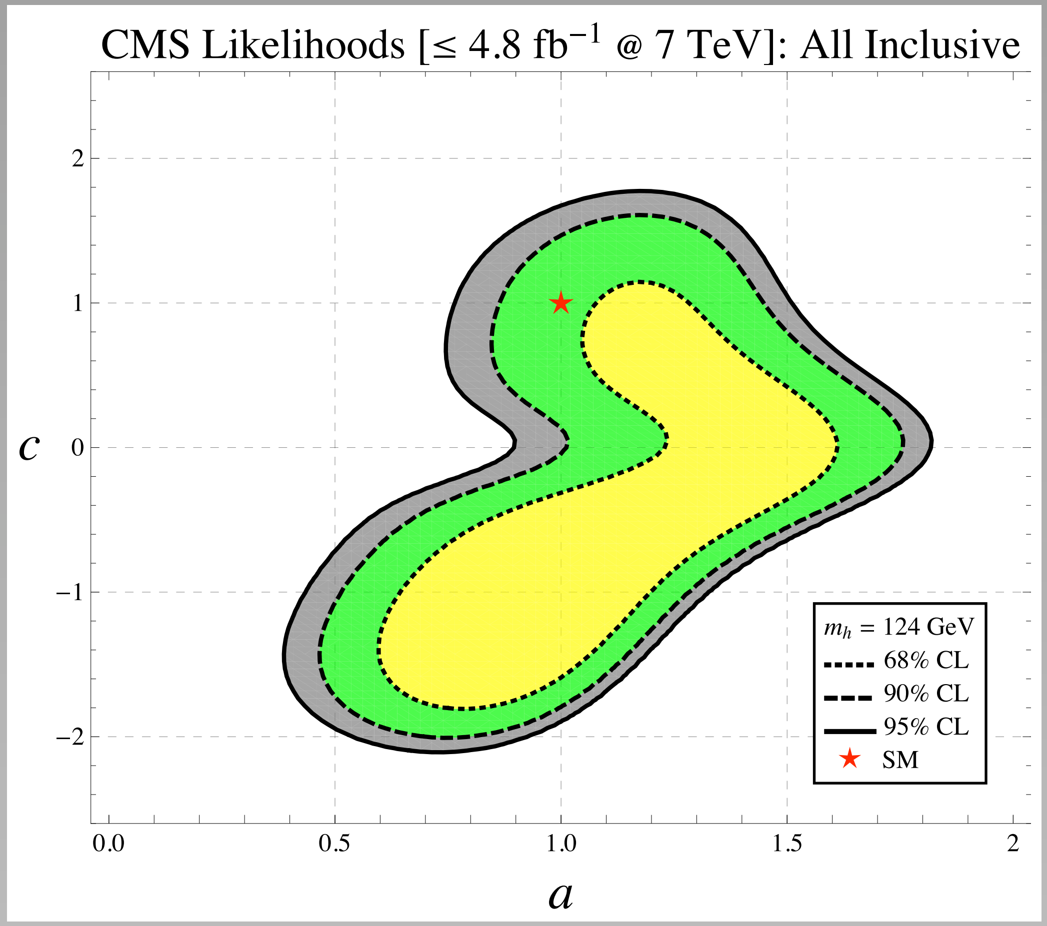


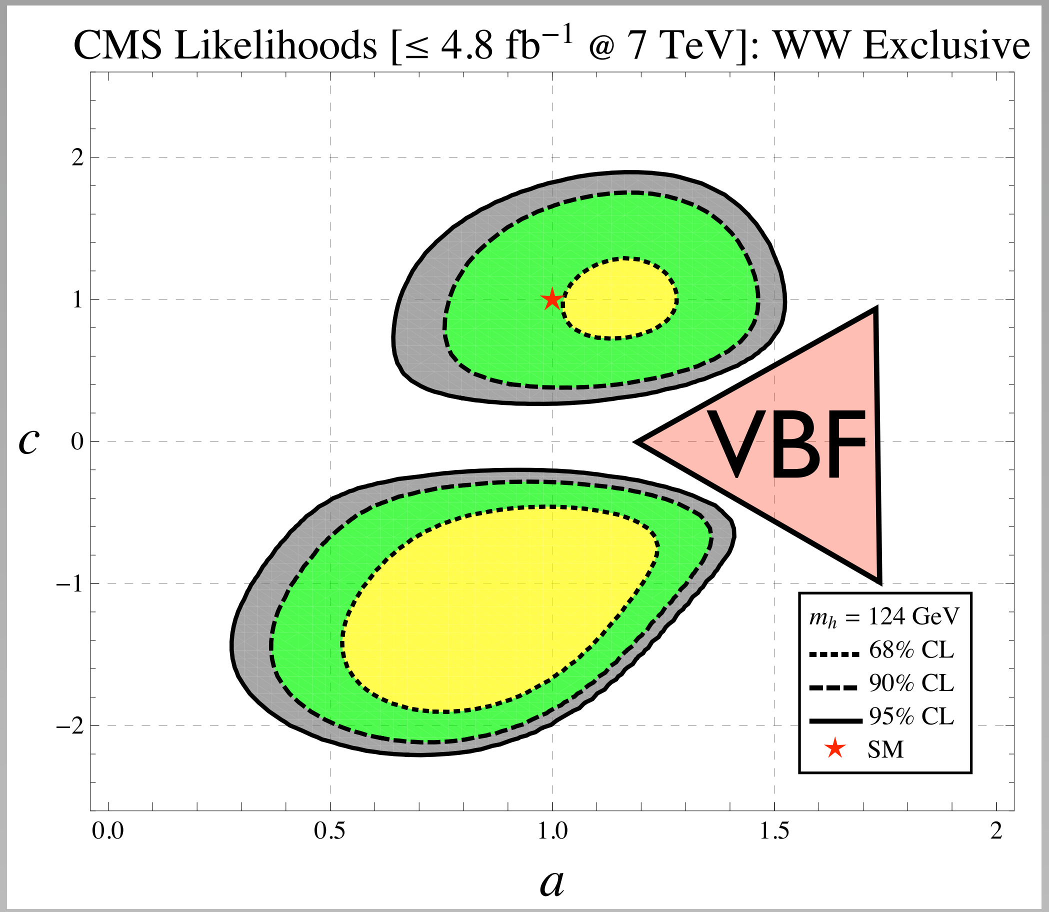




Final Point: The Need for Exclusive Searching and Reporting

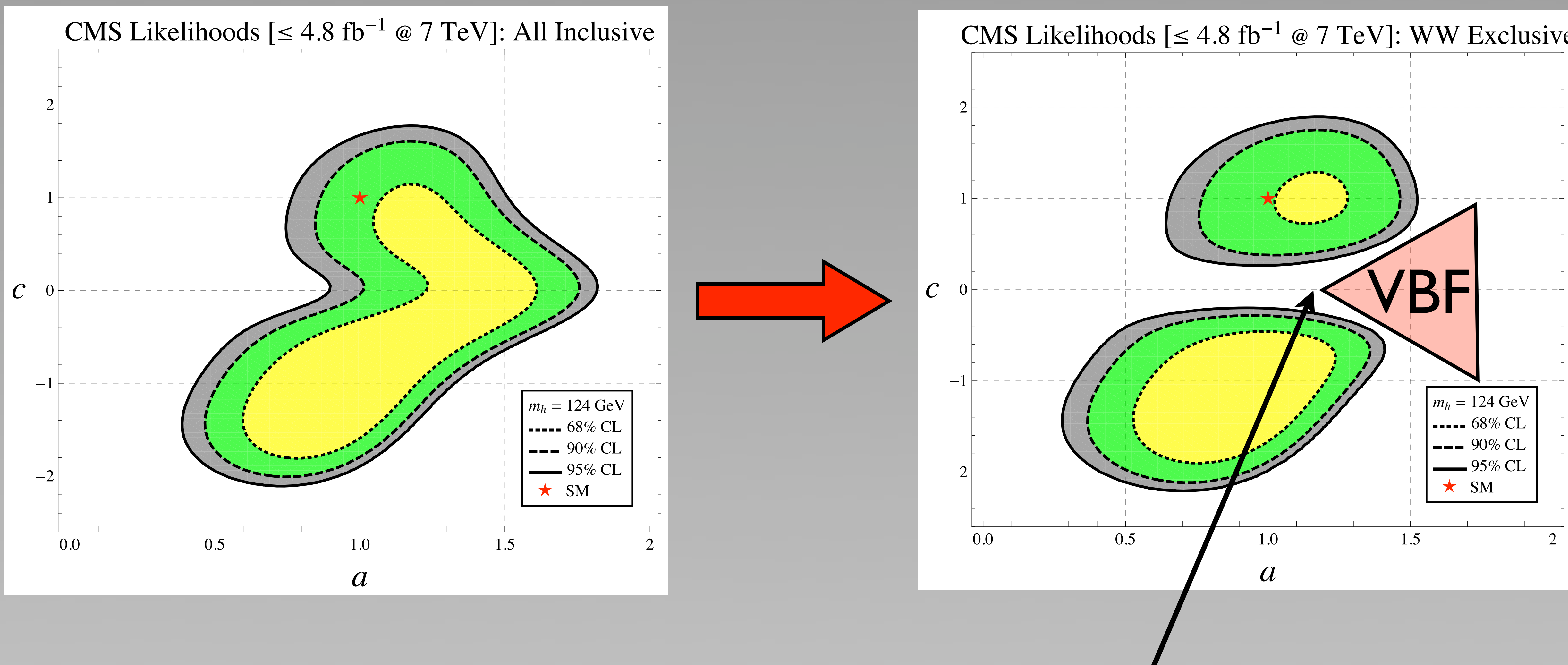
WW subchannels:





Final Point: The Need for Exclusive Searching and Reporting

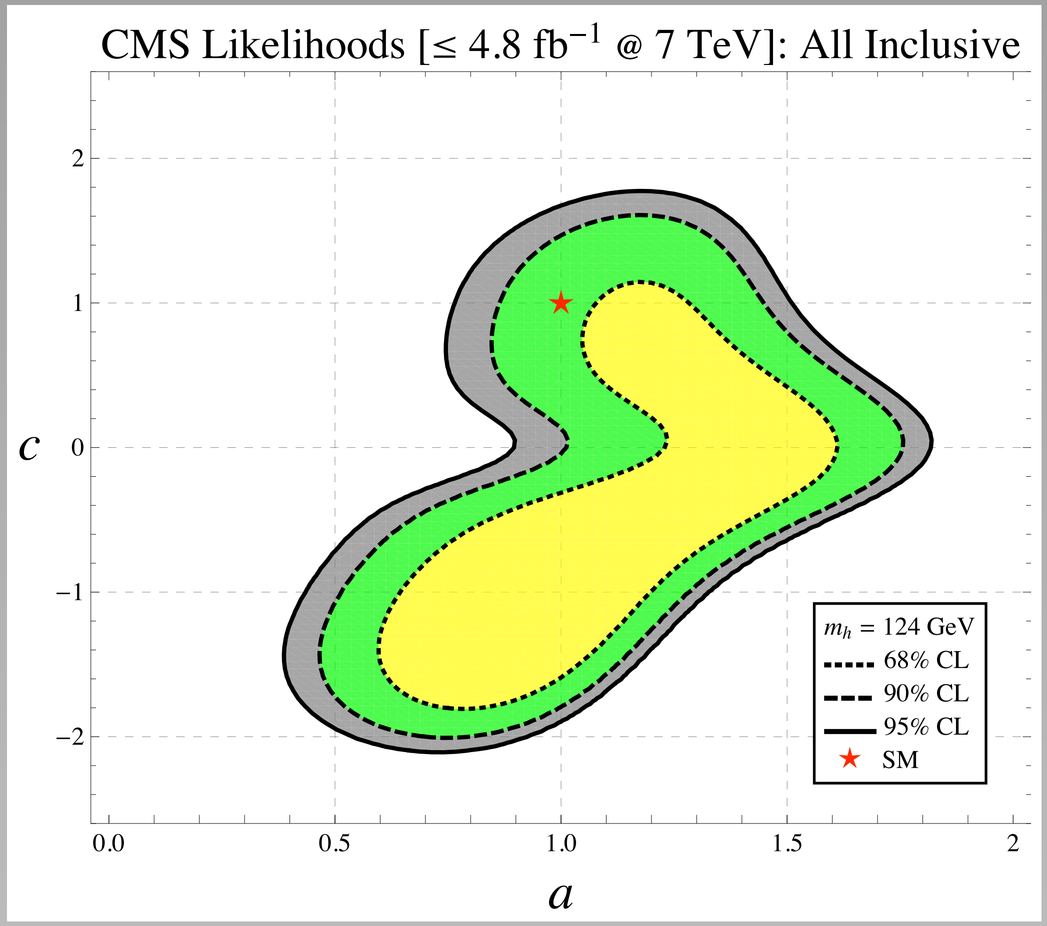
WW subchannels:

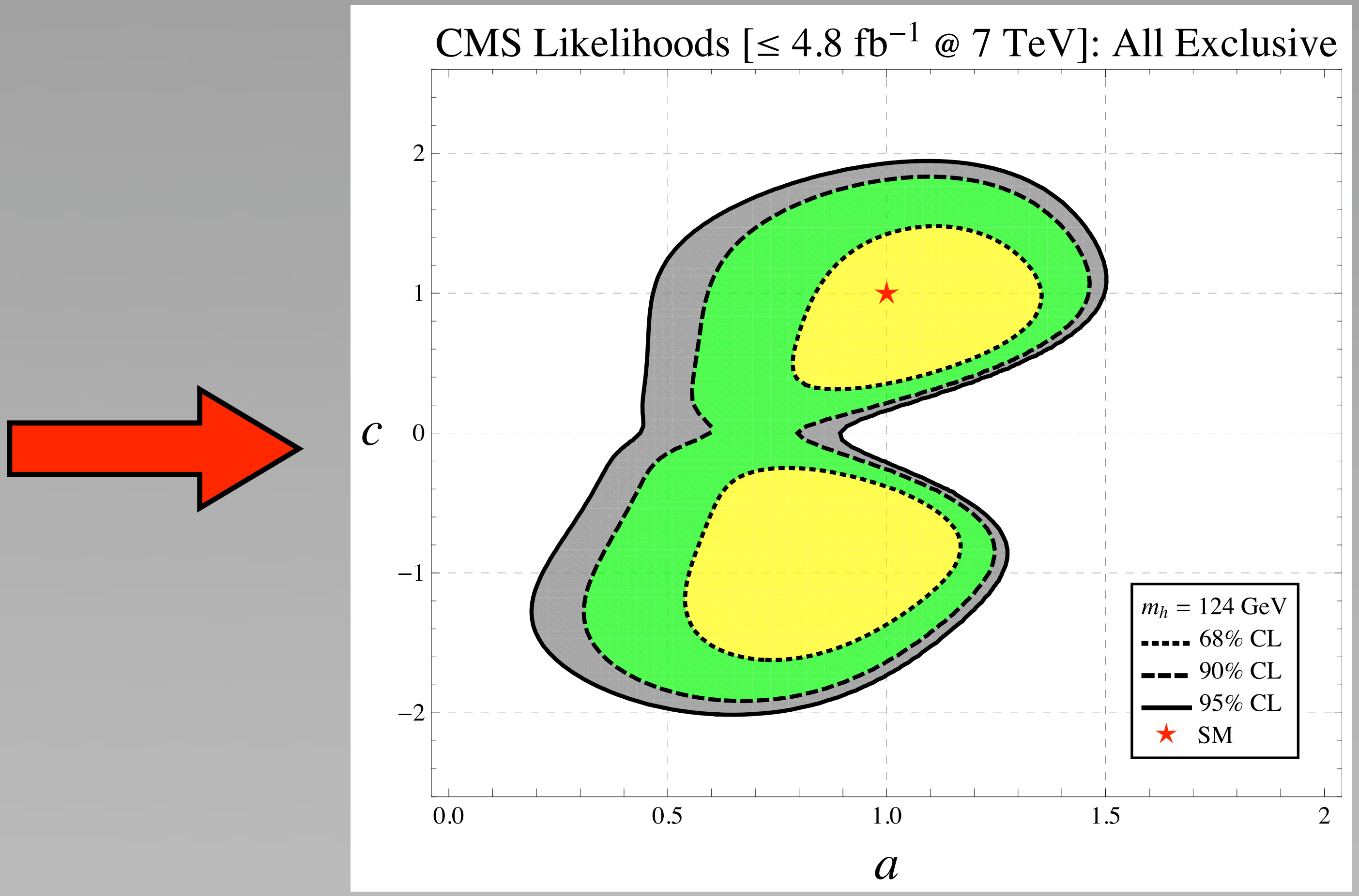


Note VBF cuts deeper in this case:
signal deficit in this subchannel
BG ~ 11, obs. ~ 8

Final Point: The Need for Exclusive Searching and Reporting

ALL subchannels:





Final Point: The Need for Exclusive Searching and Reporting

IMPORTANT POINT NUMBER THREE

Tracing back from events to underlying theory REQUIRES *separate* presentation of limits from each subchannel.

To Conclude

THREE IMPORTANT POINTS

I. Cut efficiencies truly *needed* for constraining generic spaces
II. Direct likelihoods would be *nice* to have
III. Exclusions in generic spaces *need* exclusive searches

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THREE IMPORTANT POINTS

I. Cut efficiencies truly *needed* for constraining generic spaces
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And some ‘incidentals’:

I. SM Higgs looking very good at 125 GeV
II. Other masses still in play, but very non-SM couplings
III. Time will tell us more, but we can already *tell ourselves* a LOT:
Well-tested techniques in place to explore
the parameter space of your choice...

Choose a space, any space...

Choose a space, any space...

Which has Nature chosen?

We're well on our way
to an answer...