Imperial College London

Physics Landscape

Nicholas Wardle
Imperial College London

ECR Future Collider Forum
4th November 2022
Cambridge University

Imperial College London

Physics Landscape

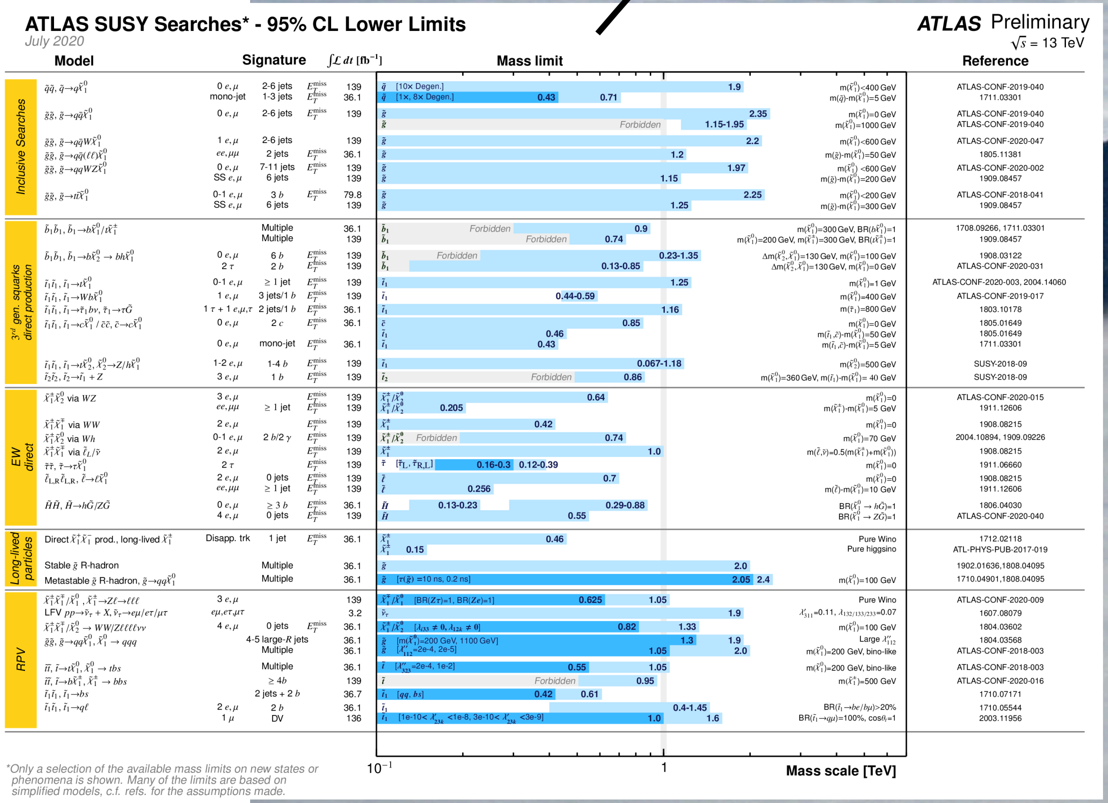
Nicholas Wardle
Imperial College London

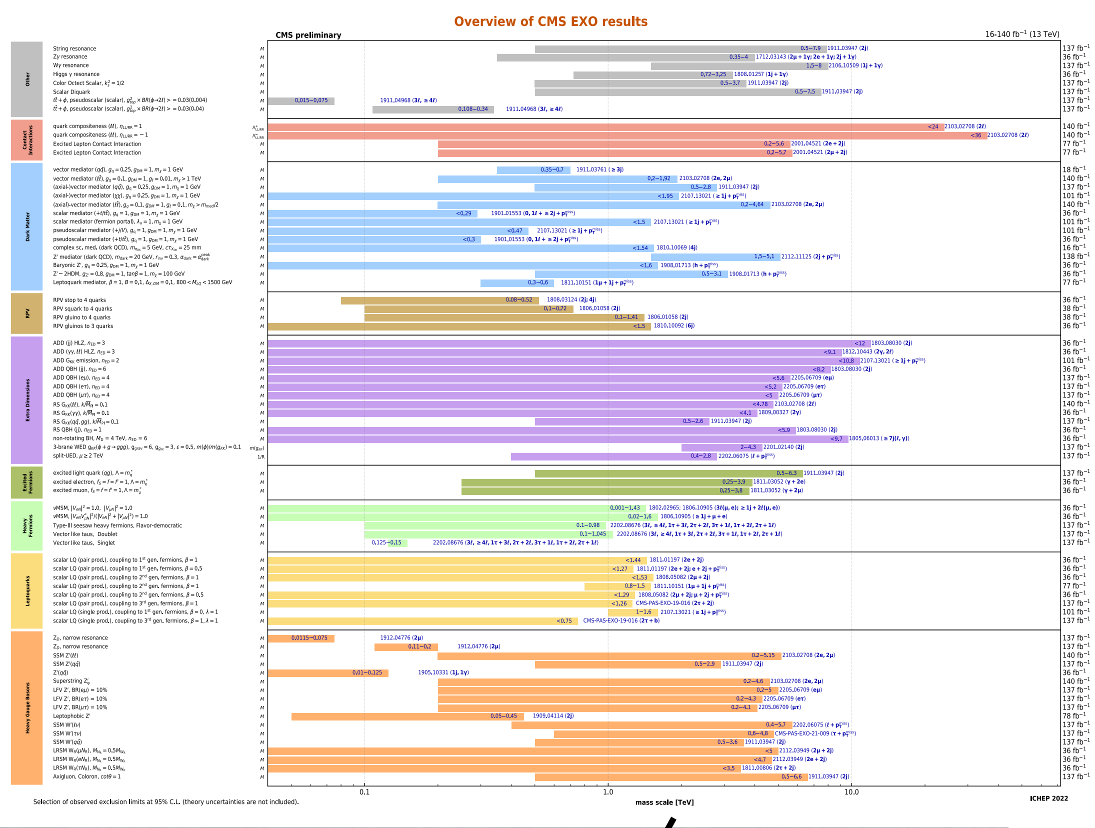
ECR Future Collider Forum
4th November 2022
Cambridge University

Describing the landscape

Describing the landscape

Somehow impossible to ignore the vast span of things that we haven’t seen so far …

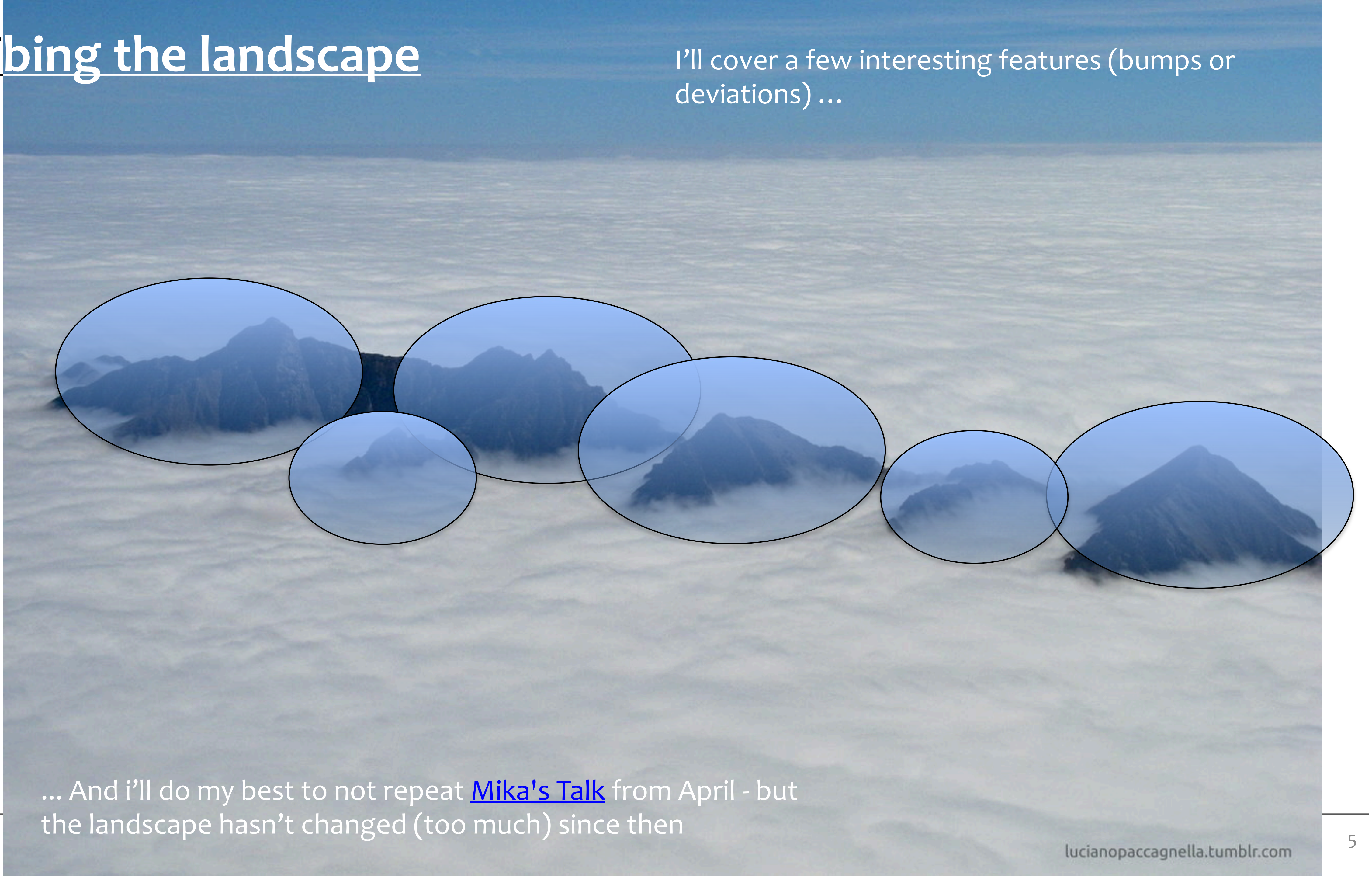




I’ll do my best to not repeat Mika's Talk from April but the landscape hasn’t changed (too much) since then

Describing the landscape

I'll cover a few interesting features (bumps or deviations) …

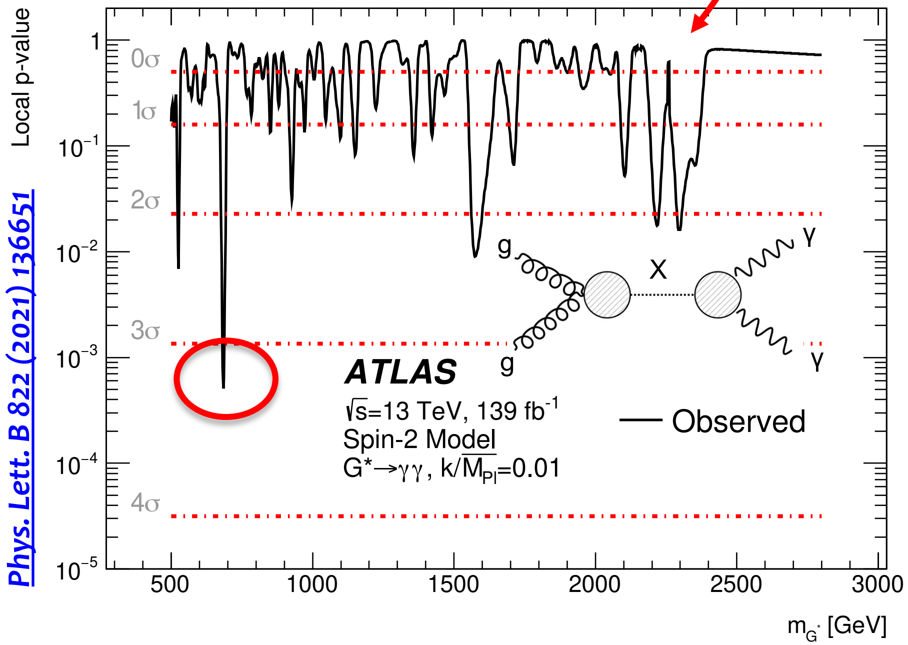


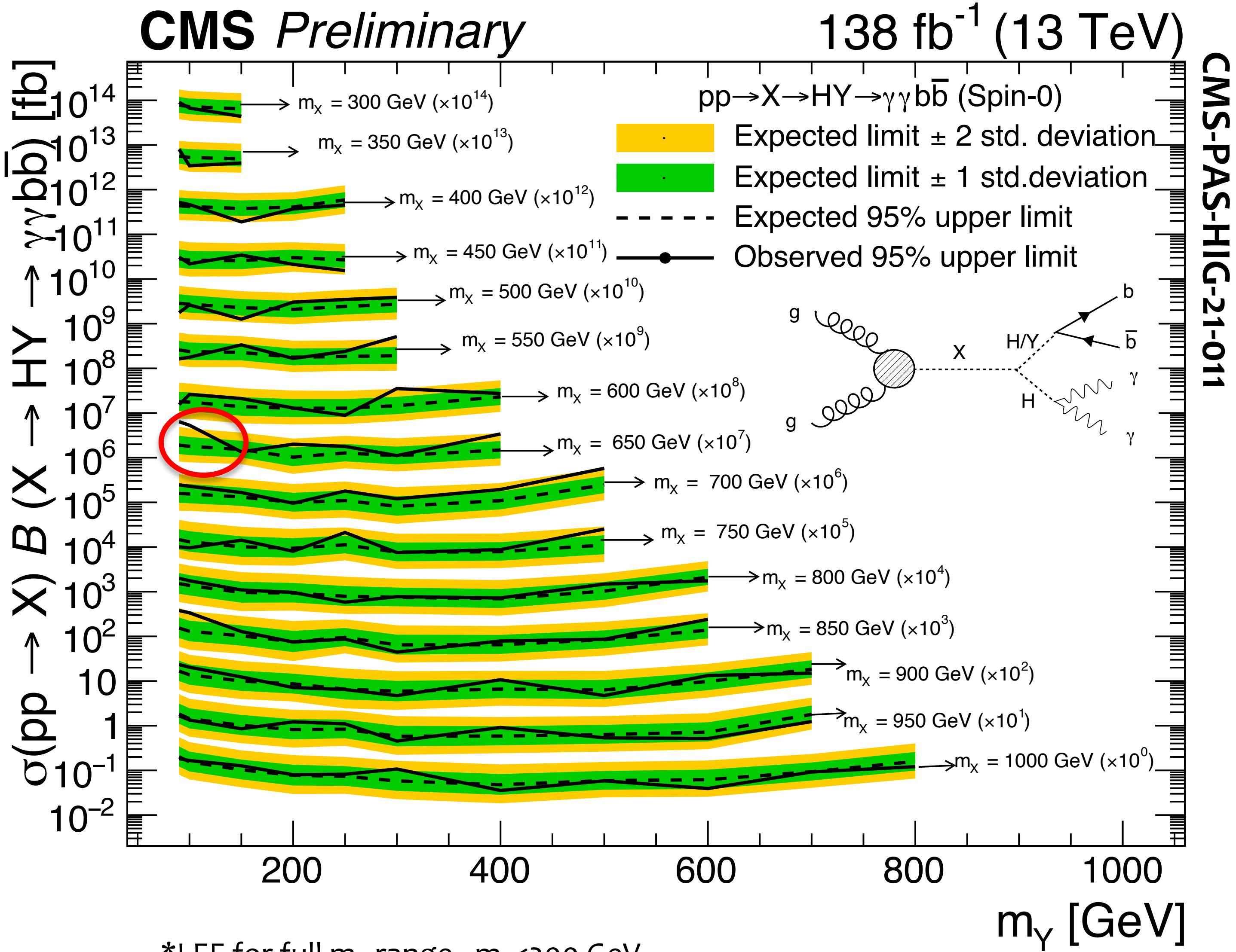
… And i'll do my best to not repeat Mika's Talk from April - but the landscape hasn't changed (too much) since then

Interesting Bumps

X→H(γγ)Y(bb) Excess for m_X=**650 GeV**, m_Y=**90 GeV** → **3.8σ** local (2.6σ global*)

X→γγ **3.29σ** (1.36σ) local (global) @m_X=**684 GeV**



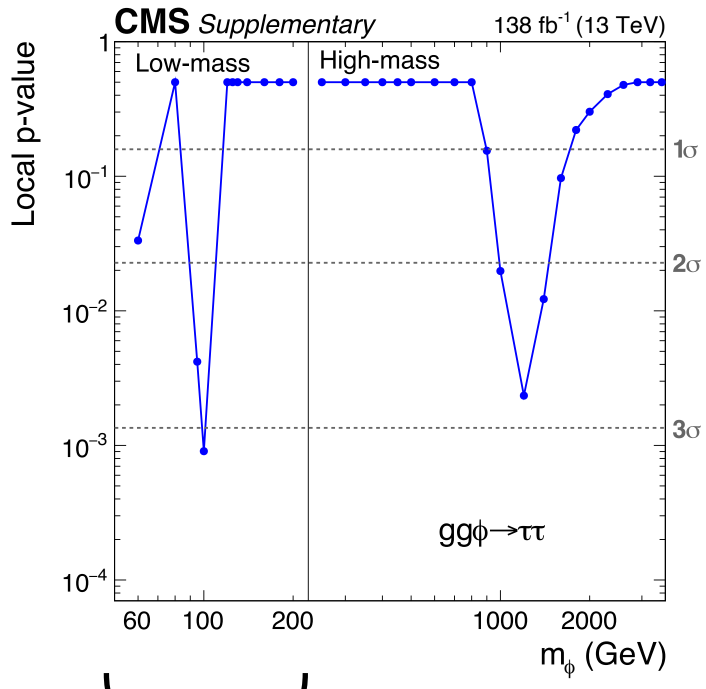


*LEE for full m_X range , m_Y<200 GeV

Related Bumps?

HIG-20-016: Search for high mass H→WW

HIG-21-001: Search for A/H→ττ

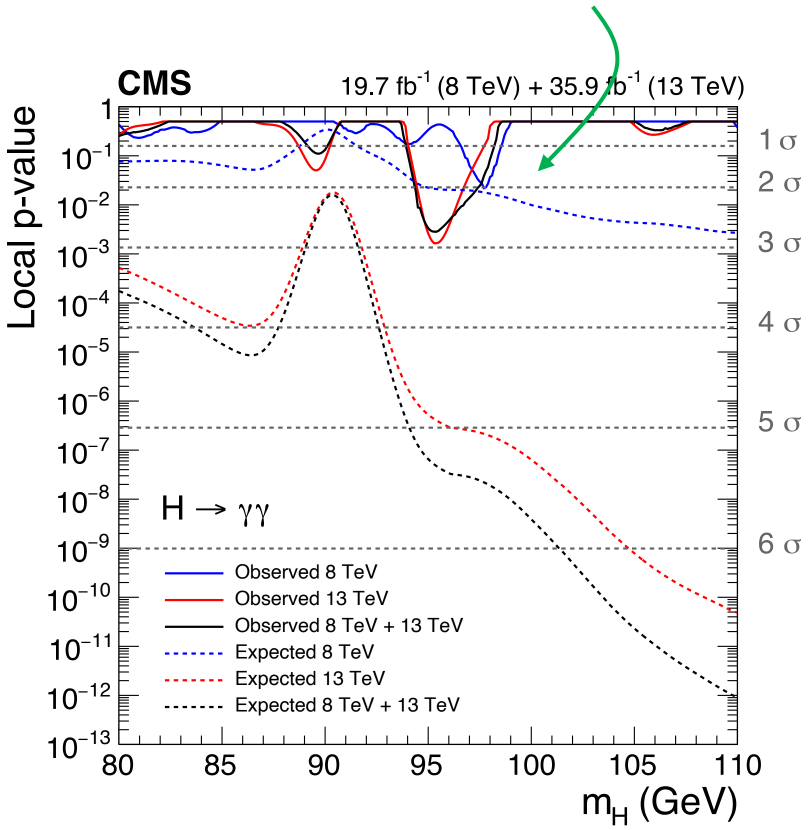


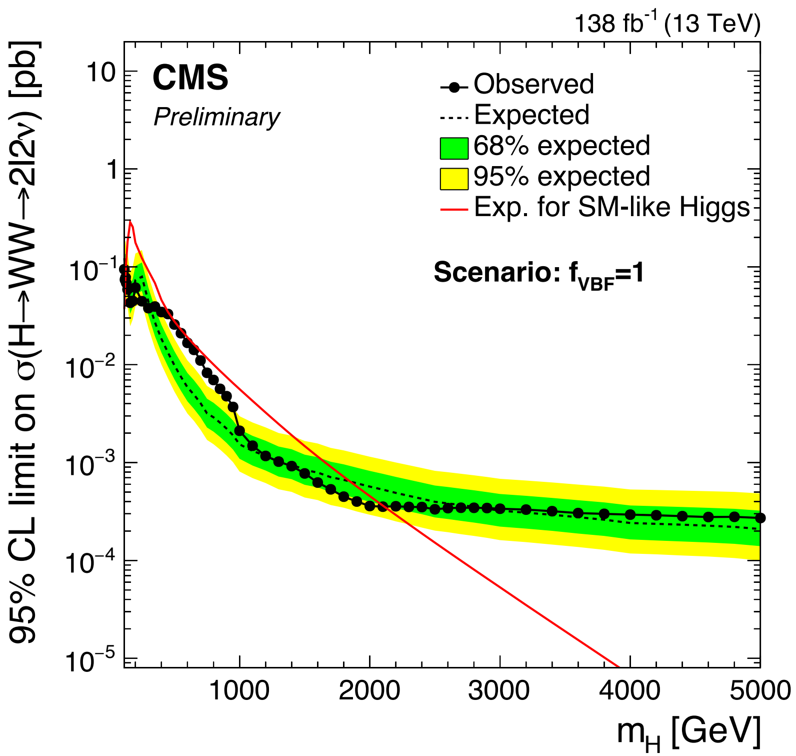
100 GeV: **3.1σ** (local) / 2.7σ (global)

1.2 TeV: **2.8σ** (local) / 2.4σ (global)

PLB 793 (2019) 320: Search for low mass h→γγ

95 GeV: **2.8σ** (local) / 1.3σ (global)



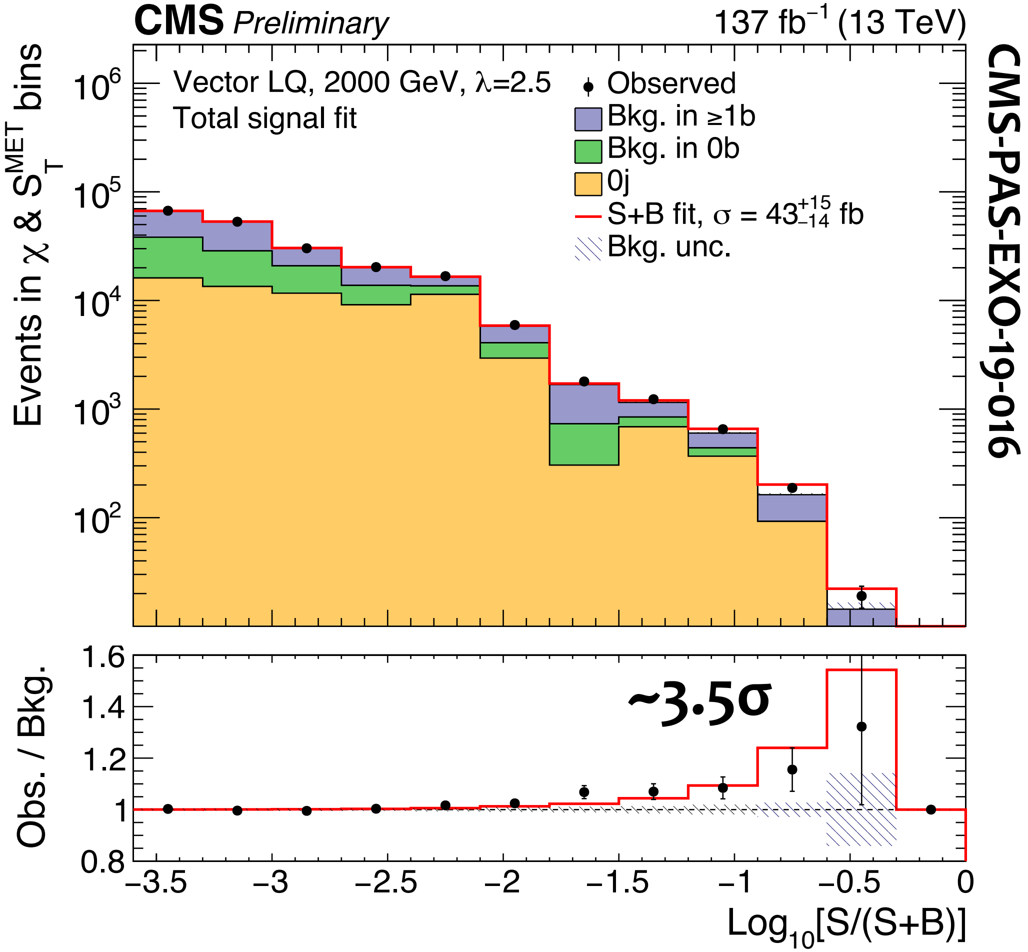


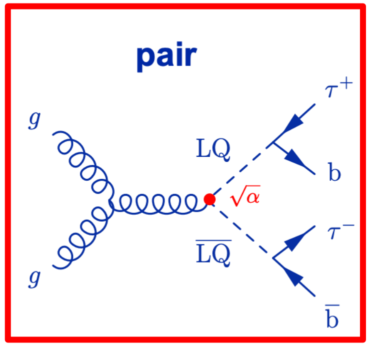
Excess (largely in VBF prod) at **650 GeV** – **3.8σ** (local) 2.6σ (global)

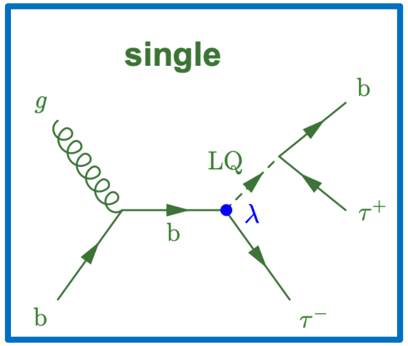
What's up with 650 & 90 GeV?

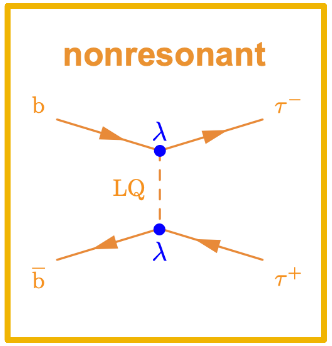
3rd Gen LQ bumps

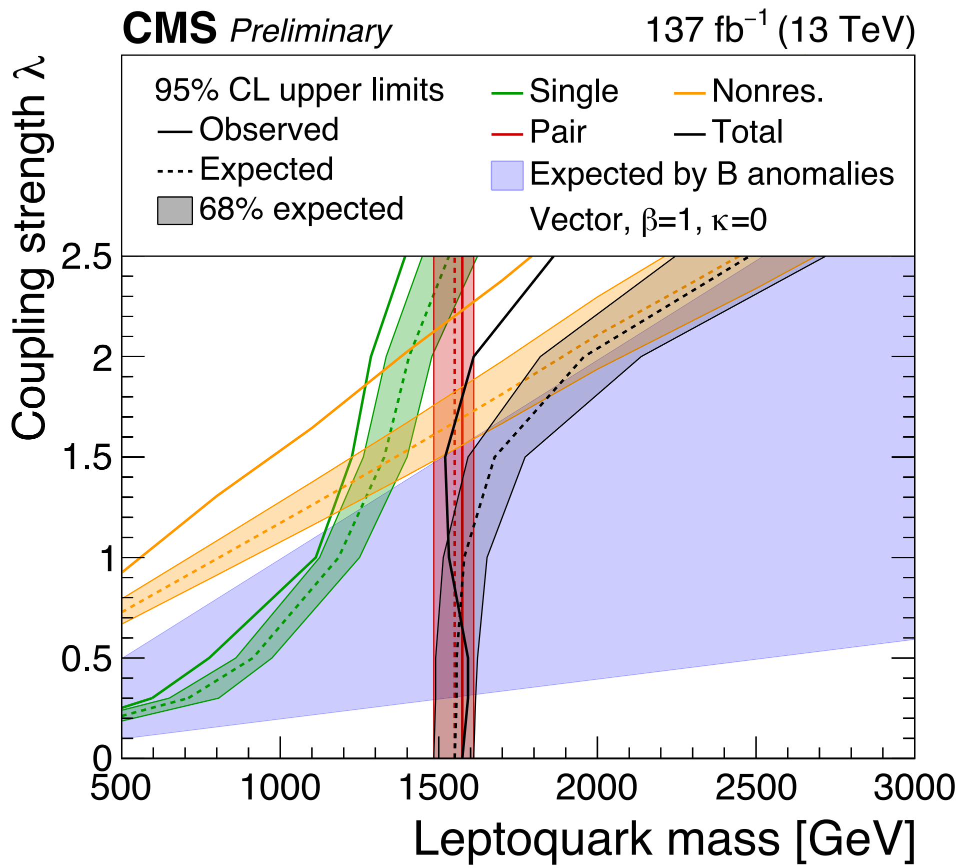
Searches for new physics with **large couplings to 3rd gen quarks and leptons** motivated by B-anomalies



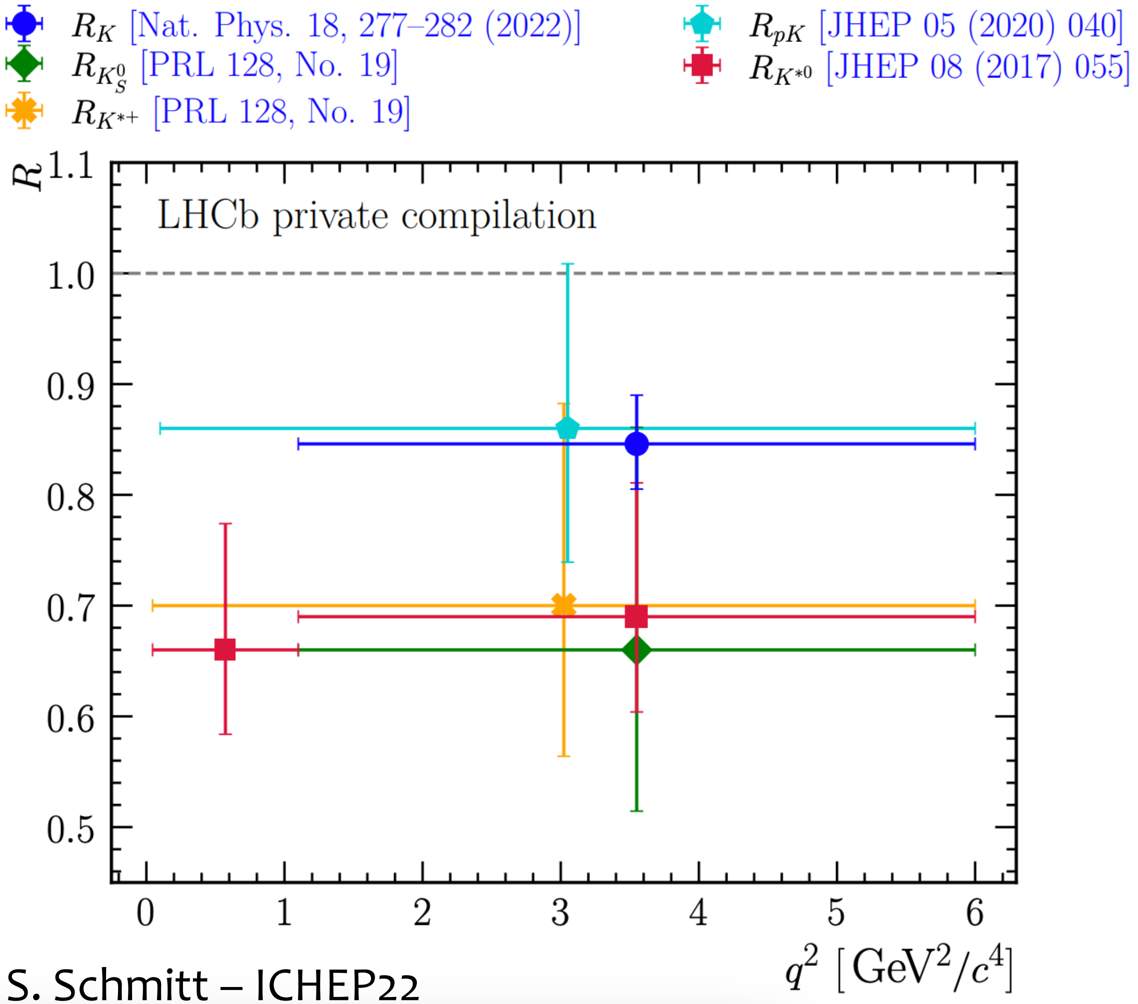




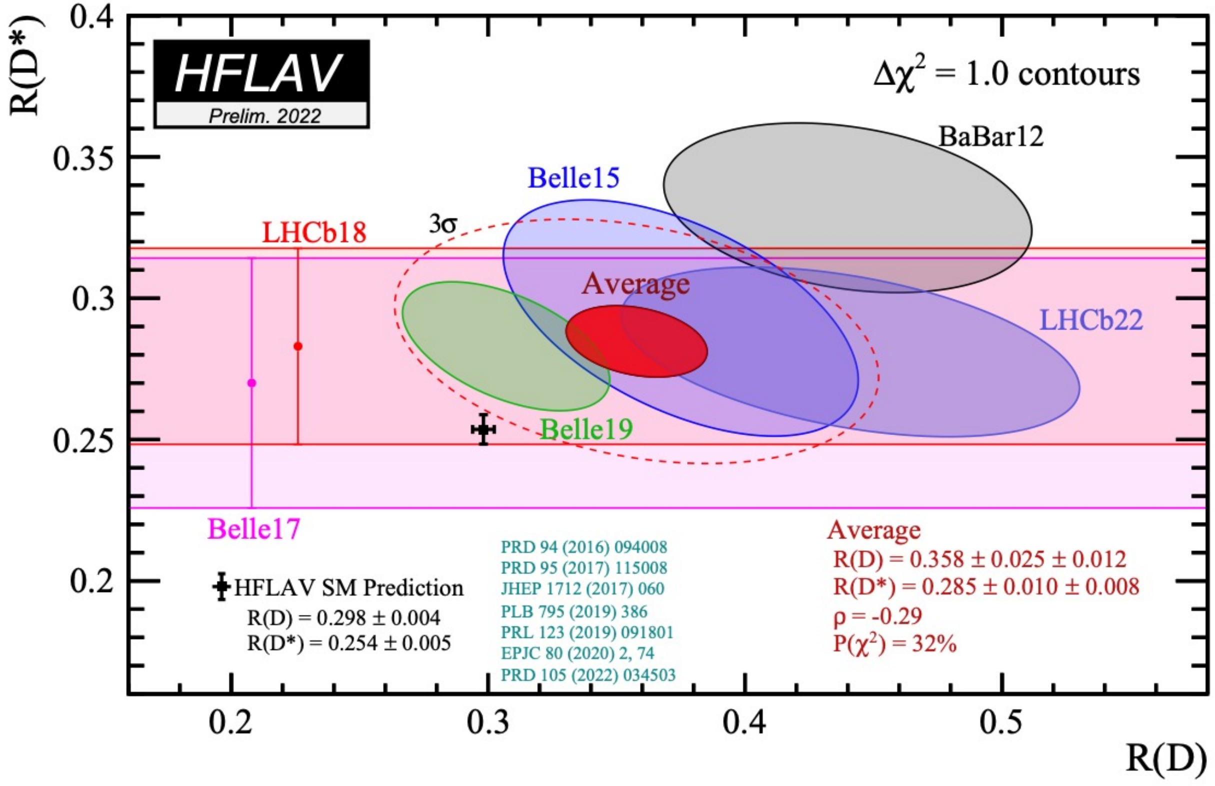




Speaking of anomalies



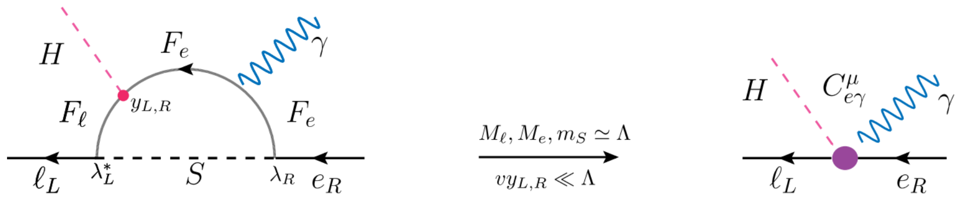
S. Schmitt – ICHEP22

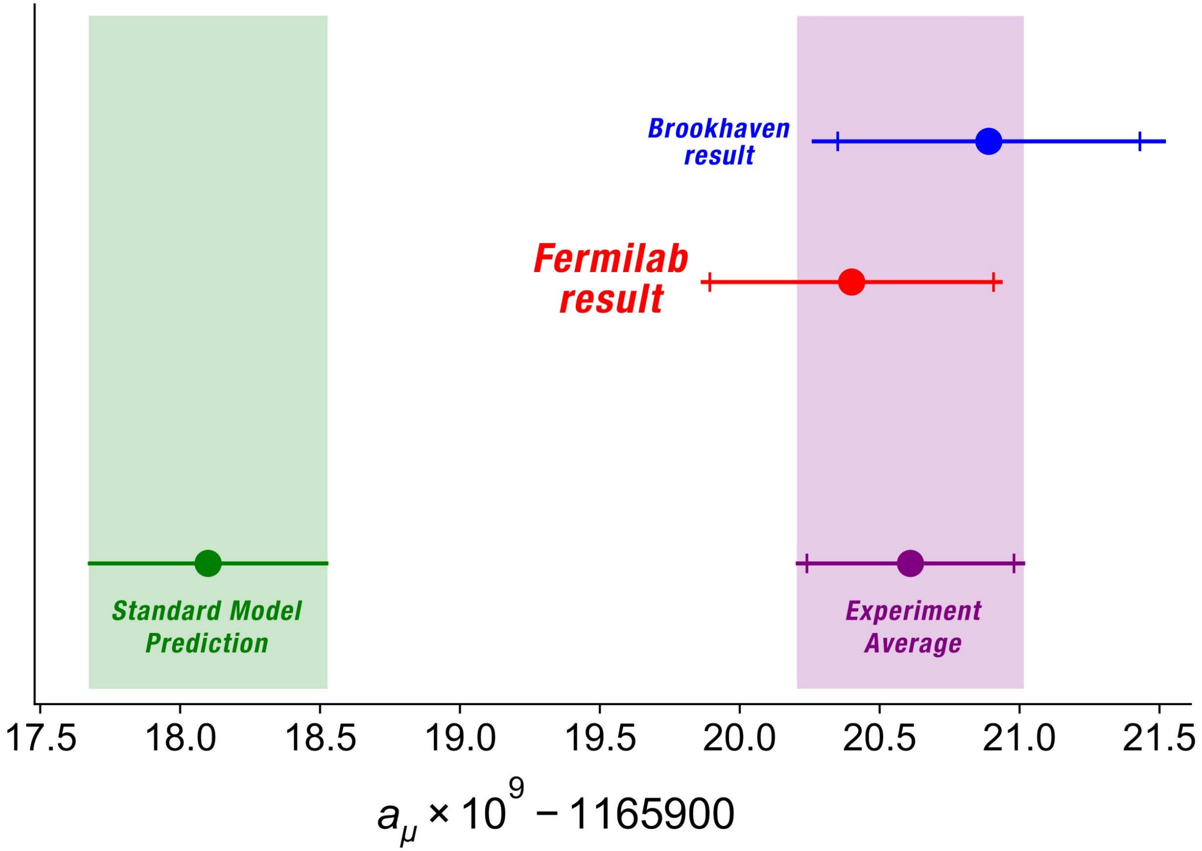


G. Ciezarek - LHC Seminar Oct 22

Setting the scale of NP?

One of the most striking results in our field is in the muon anomalous magnetic moment





FNAL news page

From perturbative unitarity constraints on NP interpretations of g-2 results (Phys. Rev. D 104, 055035 (2021))

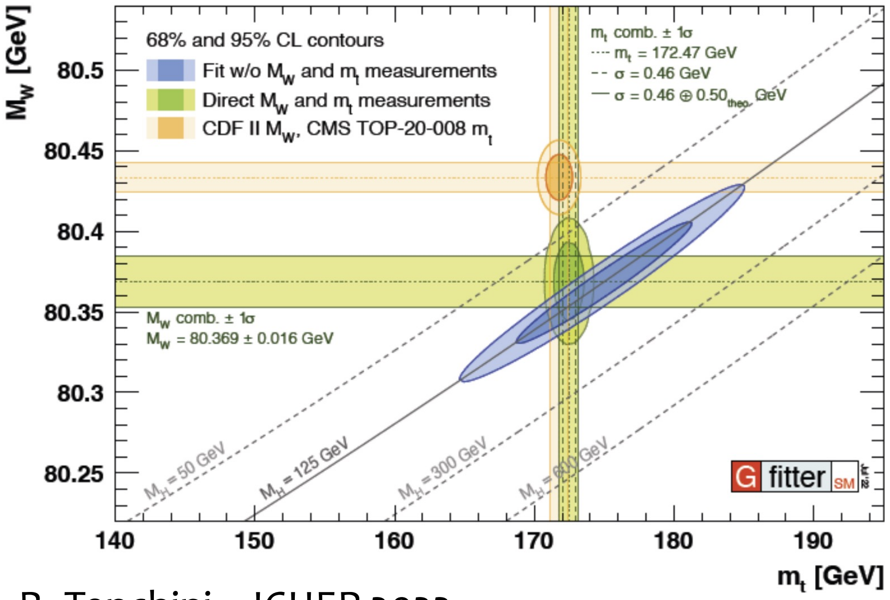
"… in order to resolve the new physics origin of the SMEFT operators behind Δaμ one would need to probe high-energy scales **up to the PeV**"

".. simplified models […] still imply new on-shell states below **200 TeV**"

Not everything is said and done yet

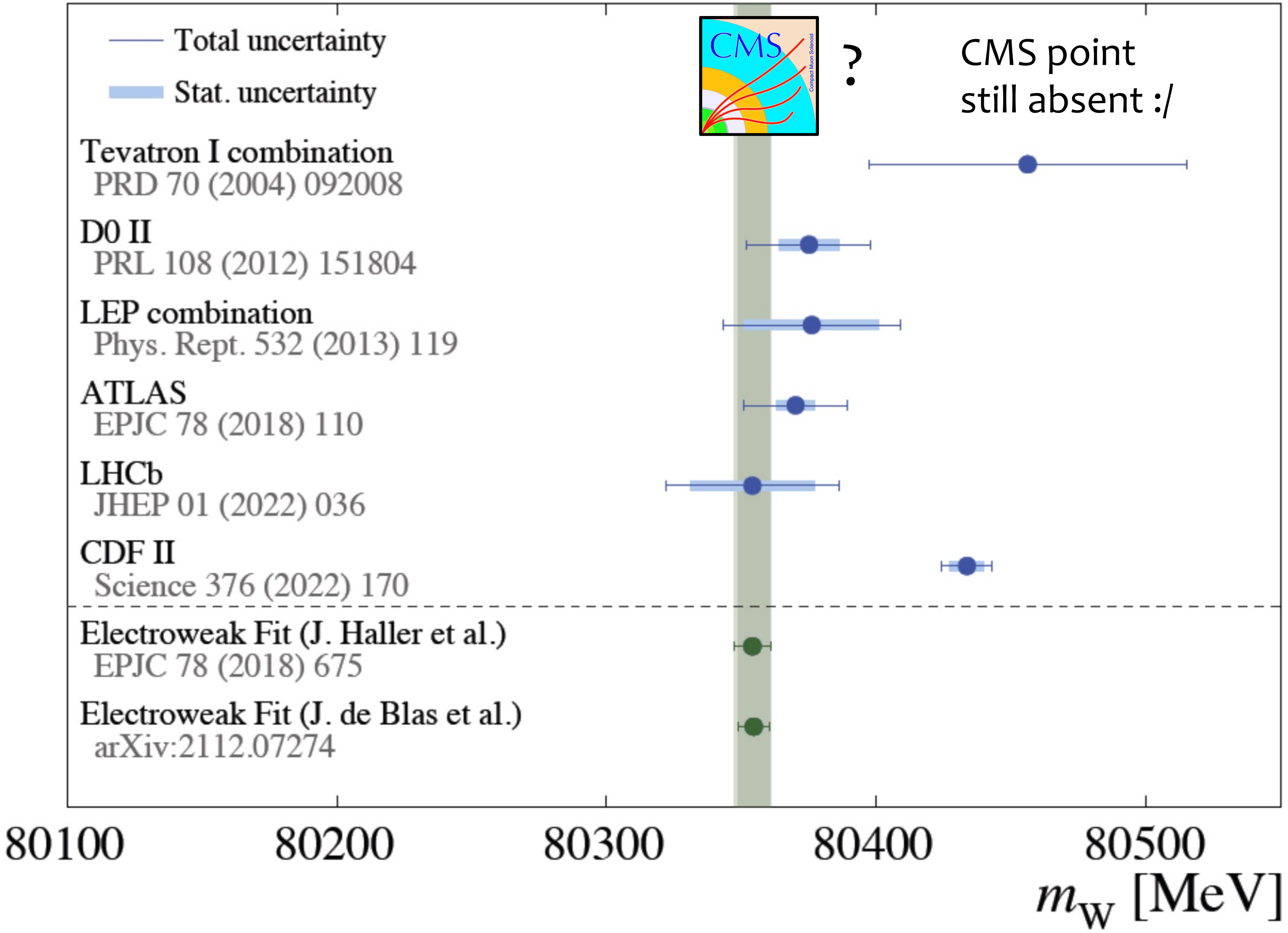
W mass

Understanding our precision W-mass measurements together will take **more data and more time** (exp-vs-exp & exp-vs-theory)



R. Tenchini – ICHEP 2022

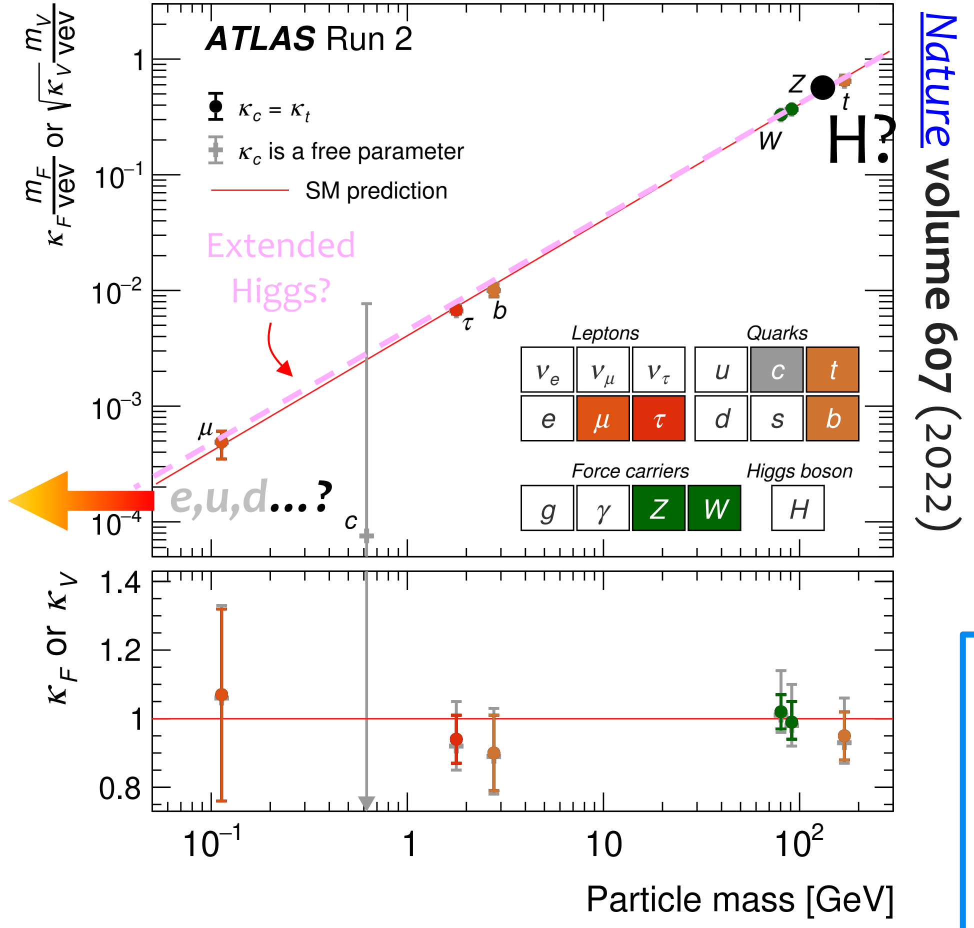
LHCB-FIGURE-2022-003

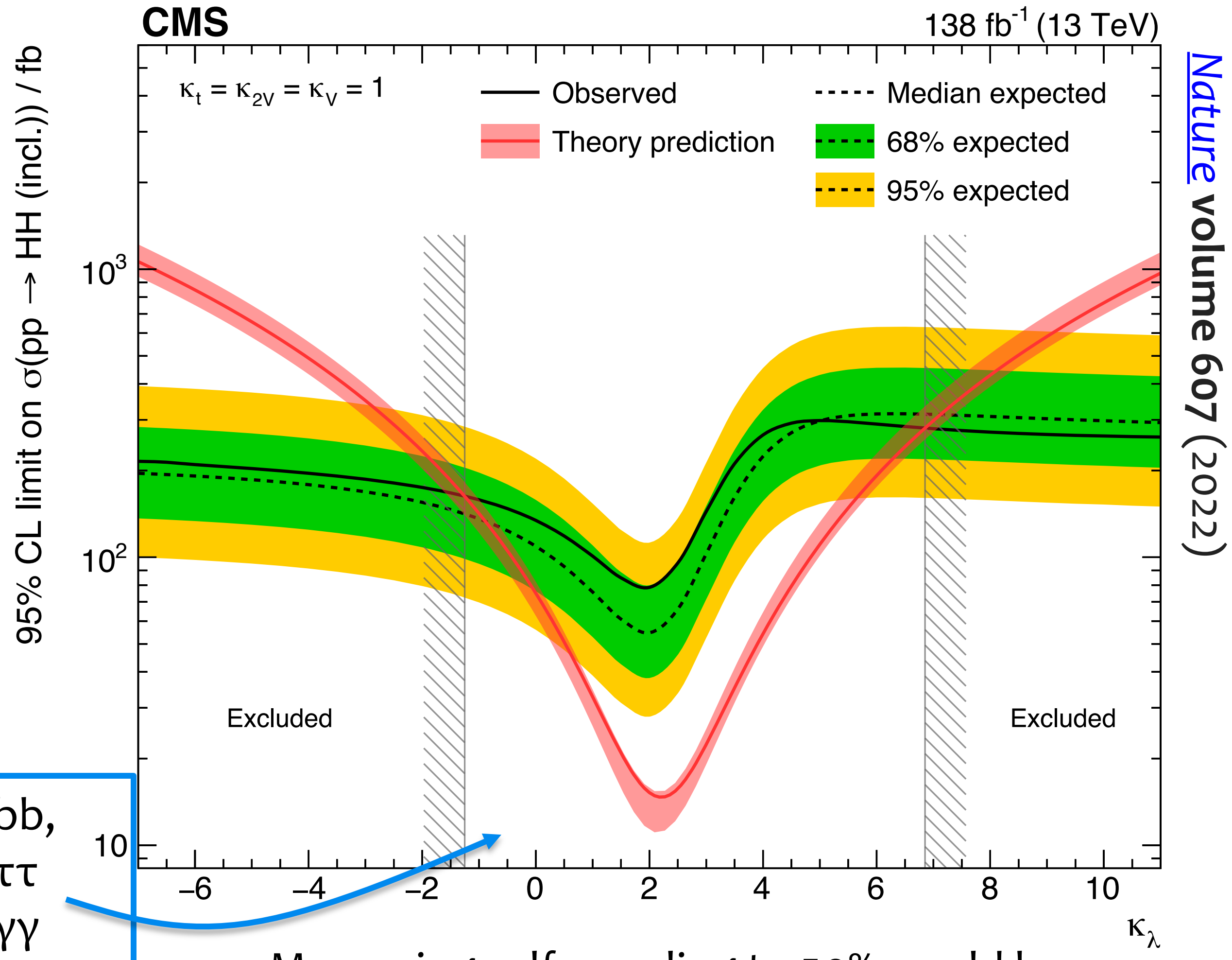


CMS point still absent :/

Higgs Physics

10 years of Higgs boson measurements still leave room for new physics!





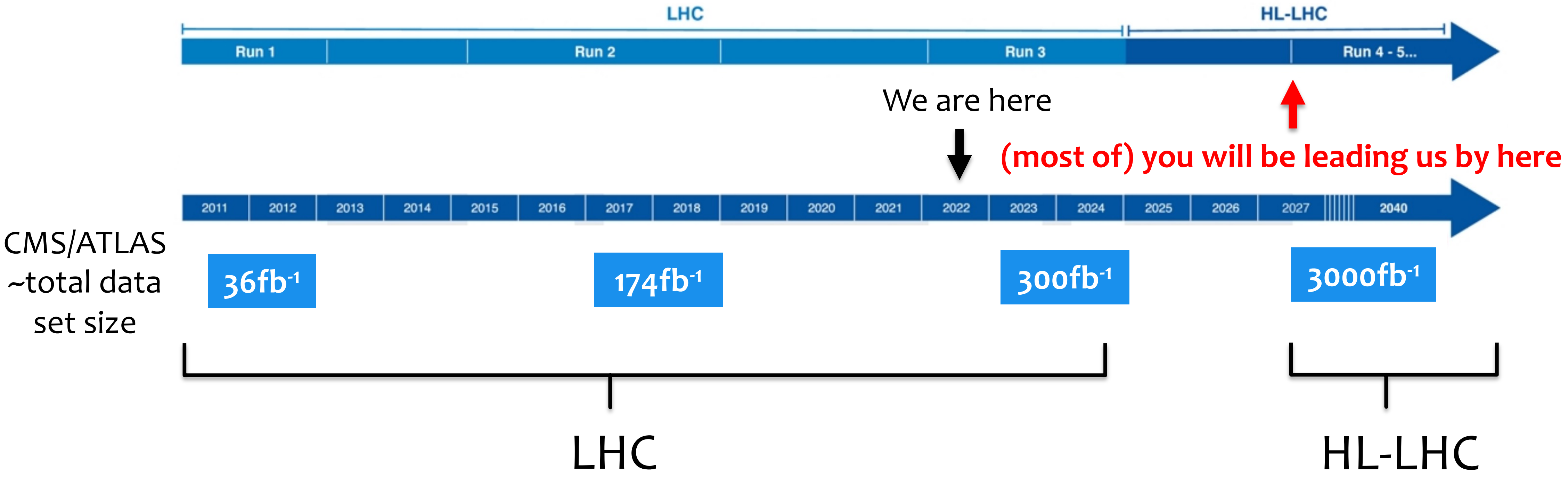
HH→bbbb,
HH→bbττ
HH→bbγγ
HH→bbZZ(4l)
HH→multilep.

Measuring self-coupling to 50% would be interesting for understanding early-universe evolution (Phys. Rev. D 97, 075008 (2018))

We've barely begun with the LHC

After Run-3 of the LHC, the next phase is the **high-luminosity** (HL)-LHC

~20x the data we have today!



Expect **> 160M H-bosons / 120k HH pairs** Per-expt by the end of the **HL-LHC** !

We've barely begun with the LHC

After Run-3 of the LHC, the next phase is the **high-luminosity** (HL)-LHC

~20x the data we have today!

We are he

CMS/ATLAS ~total data set size

36fb^{-1}

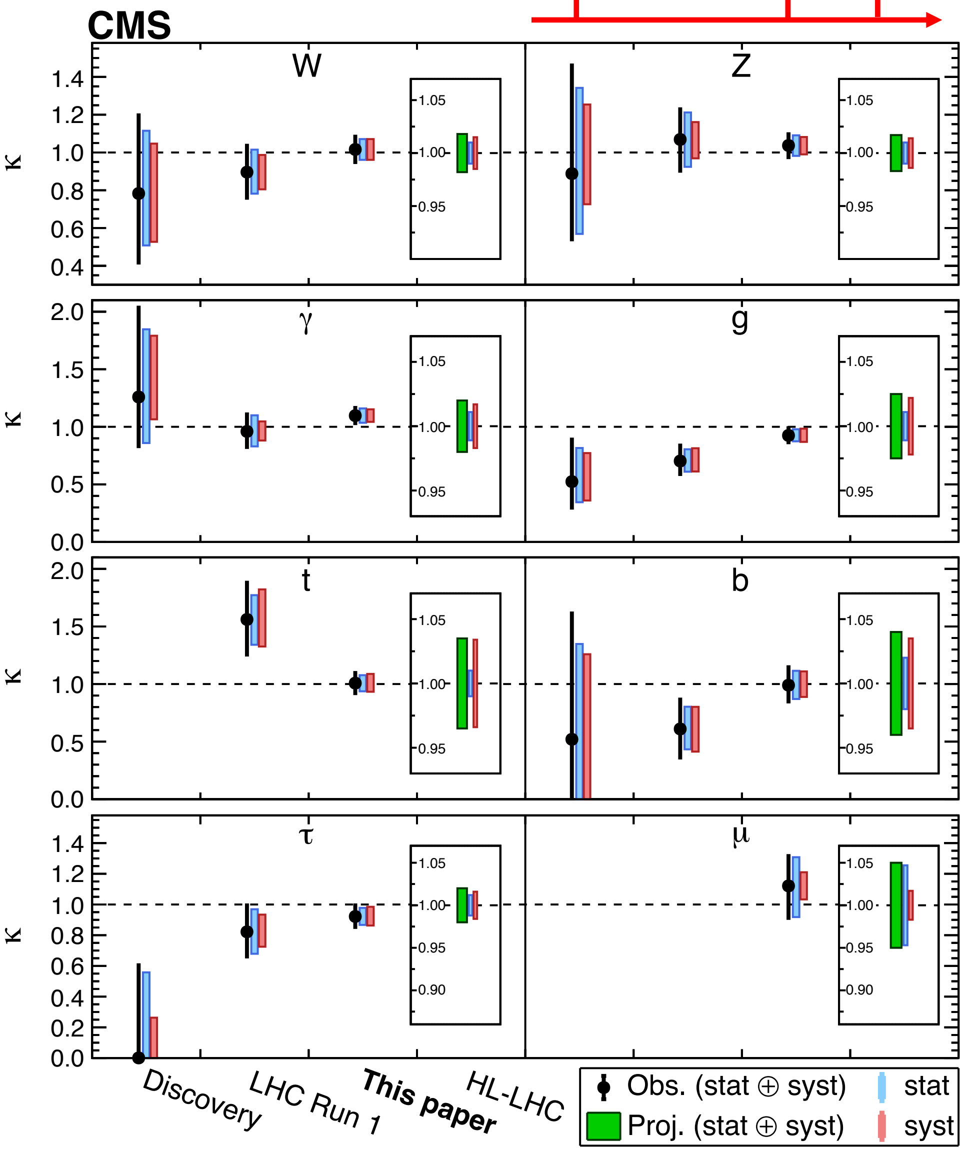
174fb^{-1}

LHC

0 yrs

10 yrs

~ 25yrs?



Nature publication

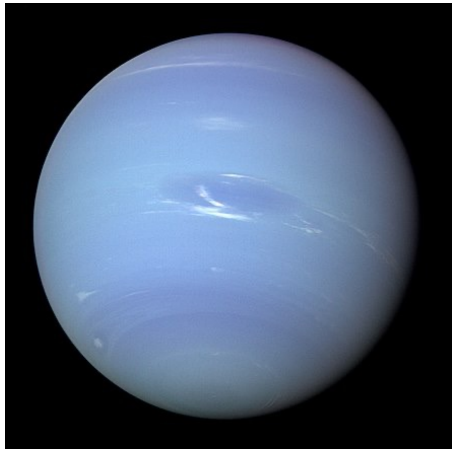
Expect **> 160M H-bosons / 120k HH pairs** Per-expt by the end of the **HL-LHC** !

Precision Measurements for Discovery

Examples from the past have taught us that precision measurements can lead to ***revolutionary discoveries…***

Herschel 1781

Le Verrier, Galle, d'Arrest 1846



?

Uranus discovery
"as a planet" (**1781**)

Neptune discovered with 1°
of predicted position (**1846**)

Precise measurements of position
revealed deviations from expected orbit
→ new planet predicted (**1845/46**)

Measurements of Mercury's orbit reveals
43 arcseconds/century anomaly
→ new planet (or body) predicted (**1859**)

Slide shamelessly stolen from excellent Jesse Liu (Cambridge) seminar

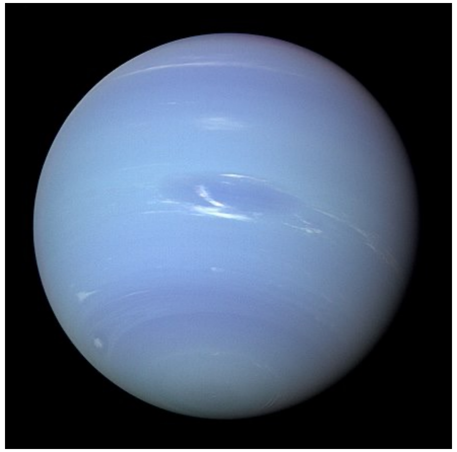
Precision Measurements for Discovery

Examples from the past have taught us that precision measurements can lead to ***revolutionary discoveries…***

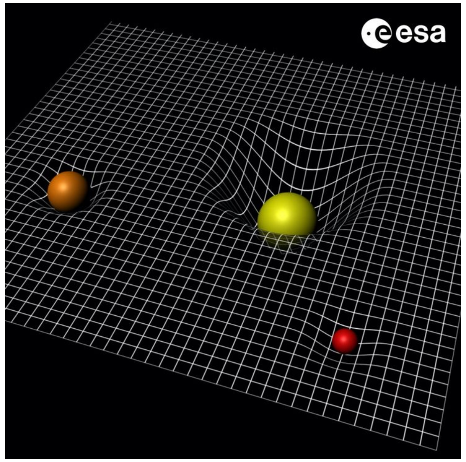
Herschel 1781

Uranus discovery
“as a planet” (**1781**)

Le Verrier, Galle, d'Arrest 1846



Neptune discovered with 1°
of predicted position (**1846**)



General relativity solves
anomaly and changes view
of space & time (**1915**)

Precise measurements of position
revealed deviations from expected orbit
→ new planet predicted (**1845/46**)

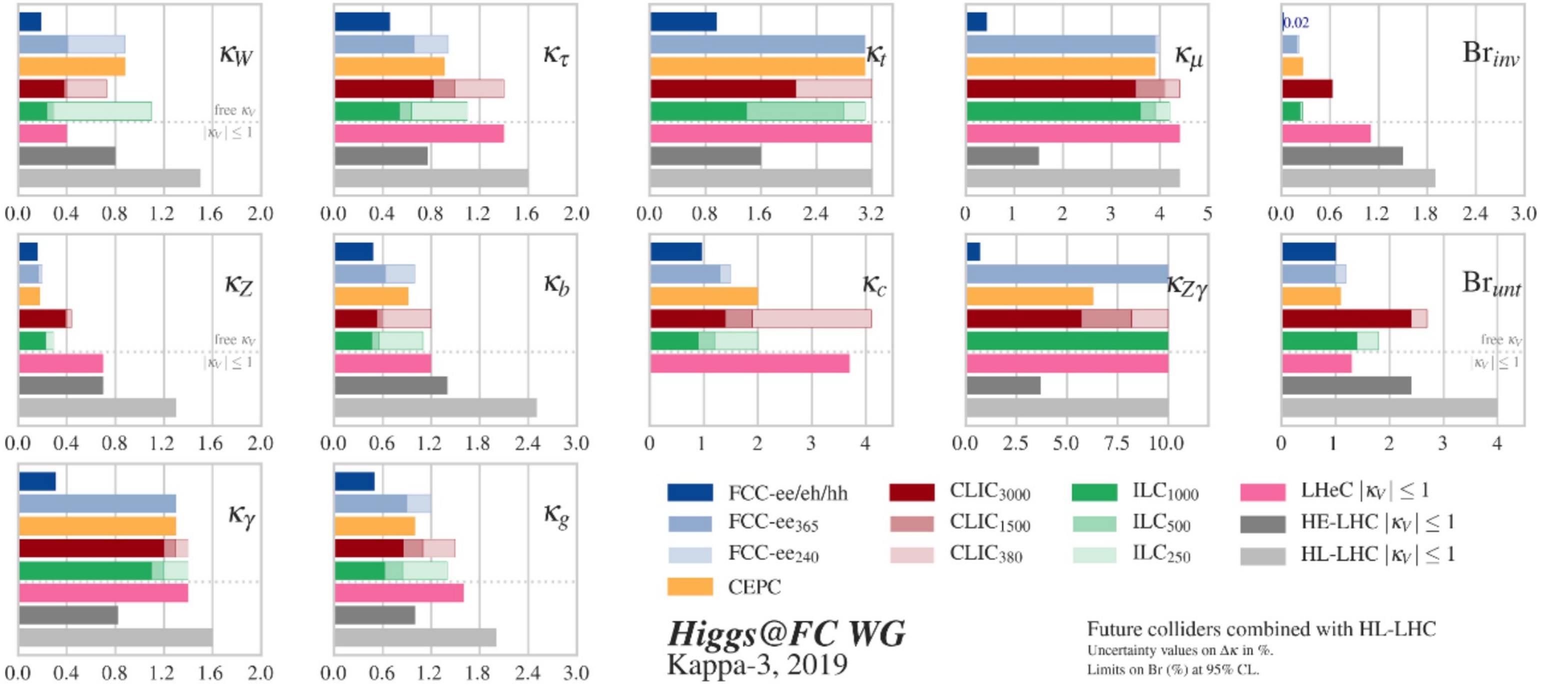
Measurements of Mercury’s orbit reveals
43 arcseconds/century anomaly
→ new planet (or body) predicted (**1859**)

Slide shamelessly stolen from excellent Jesse Liu (Cambridge) seminar

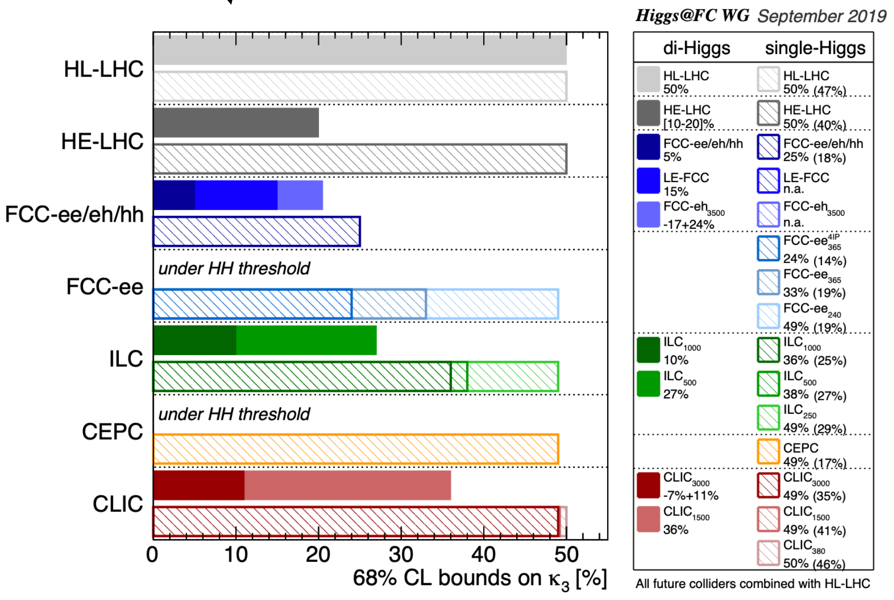
…History has a habit of repeating itself 🤞 …

FCC reach (there's more than just Higgs but…)

Many potential options but all lead to high **precision (O(%) level) characterization** of the Higgs boson couplings



Higgs boson **self-coupling** requires **high energy (O(100)TeV)** machine for % level measurement

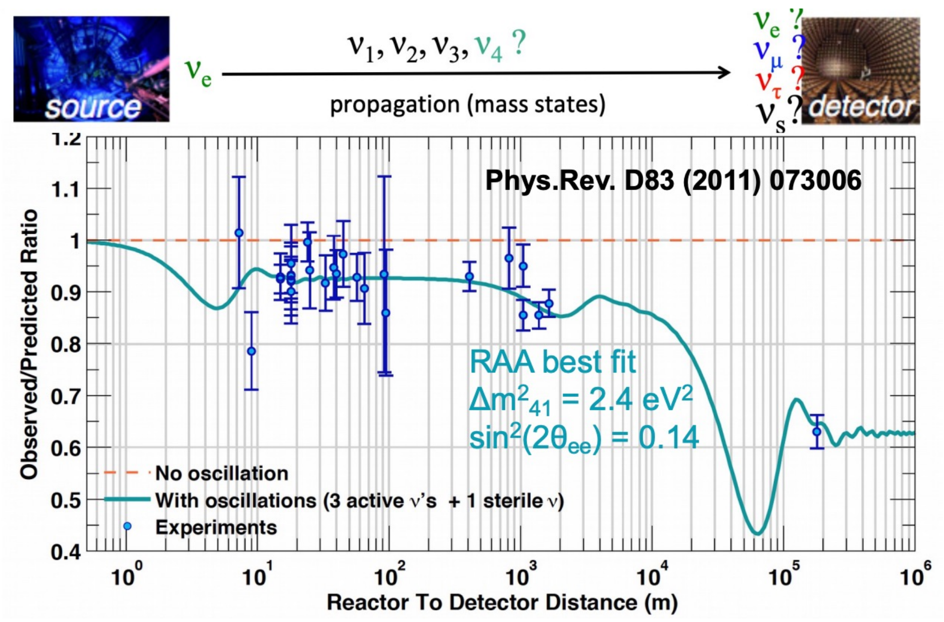


JHEP 139 (2020)

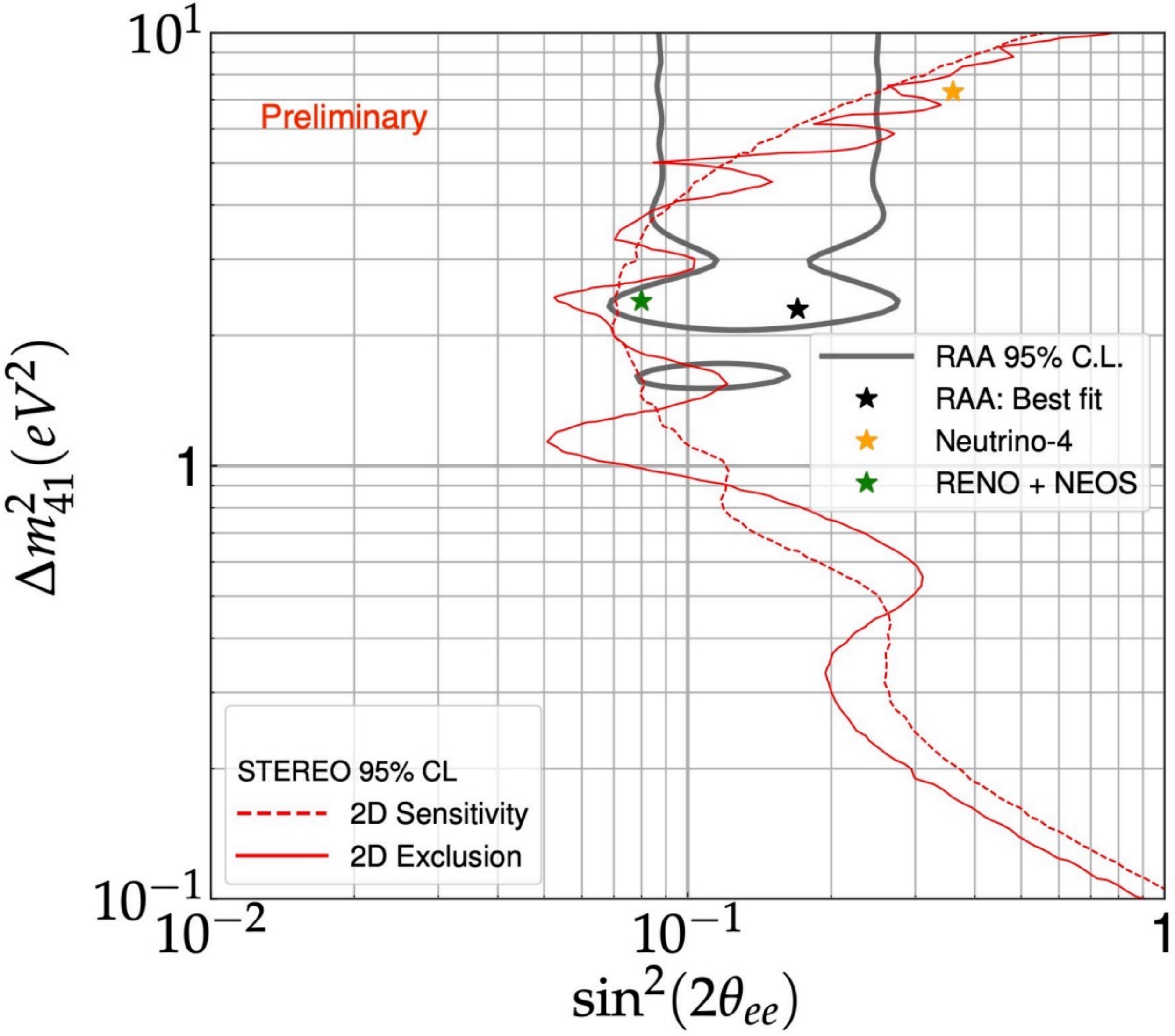
No Summary – time for discussion!

Backup Slides

Reactor Anomaly (STEREO)



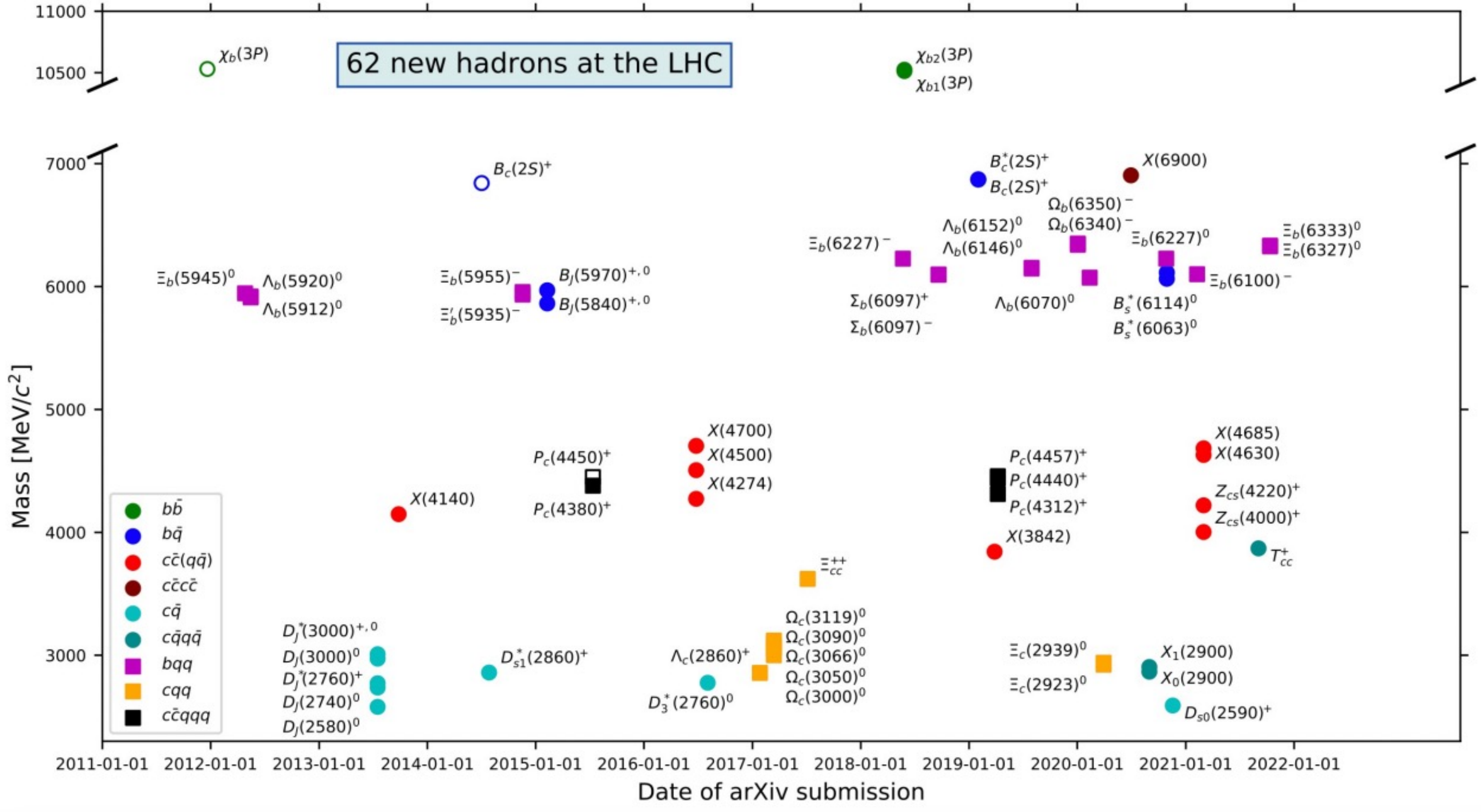
RAA : Reactor Antineutrino Anomaly (deficit in anti-neutrino flux from reactor)



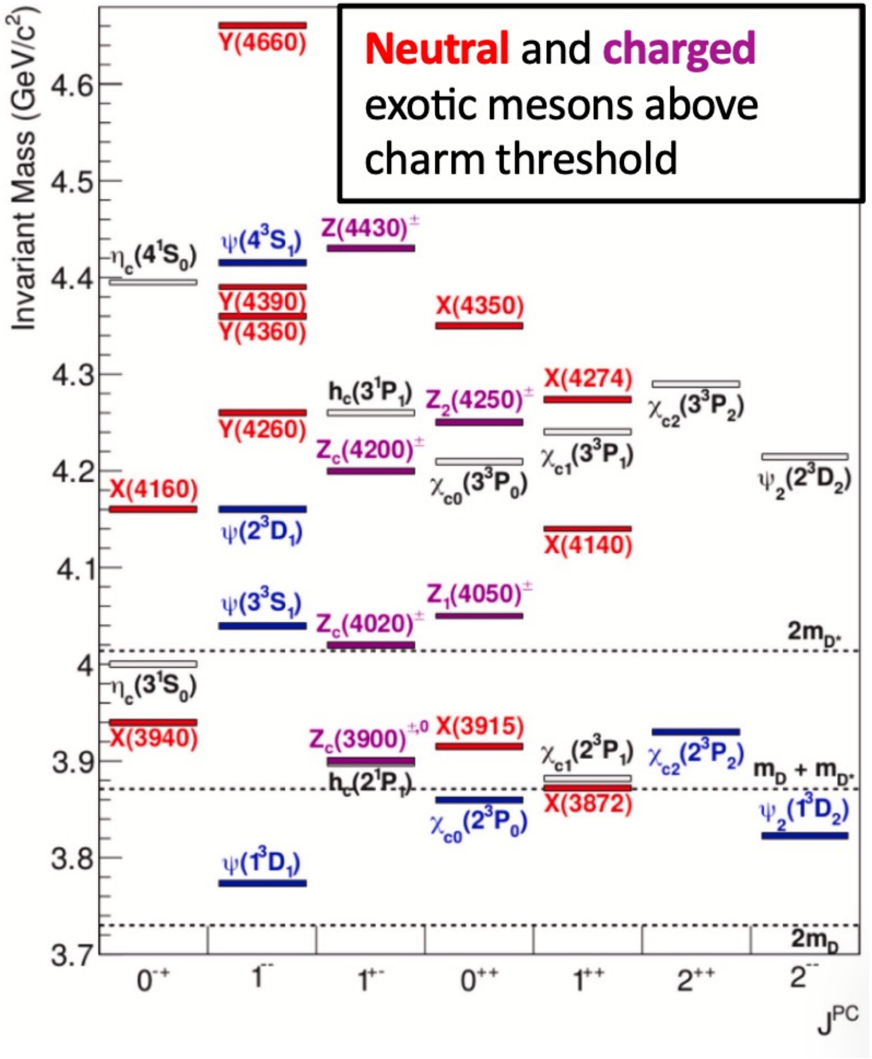
P. Del Amo Sanchez – ICHEP22

Spectroscopy

Many "new" states observed at the LHC & e^+e^- colliders



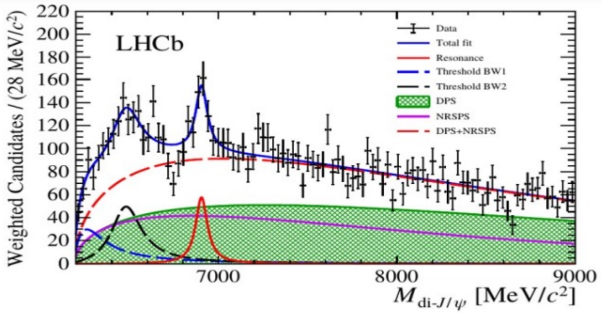
Includes e+e-, e.g. BES III, Belle

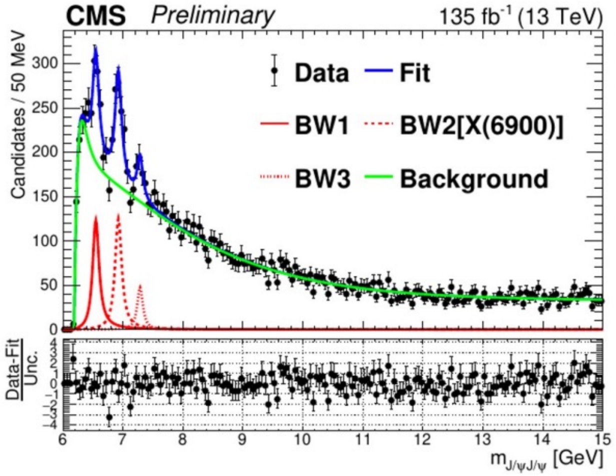


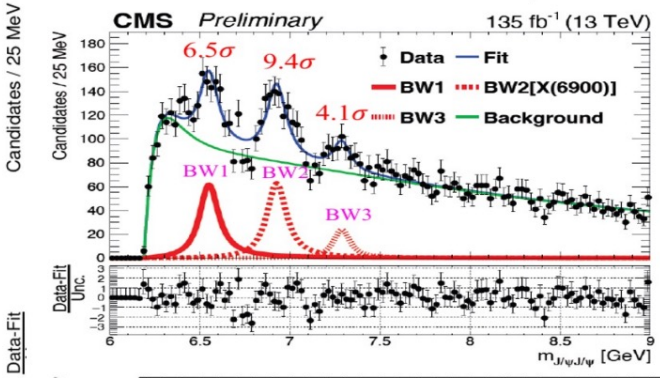
Spectroscopy

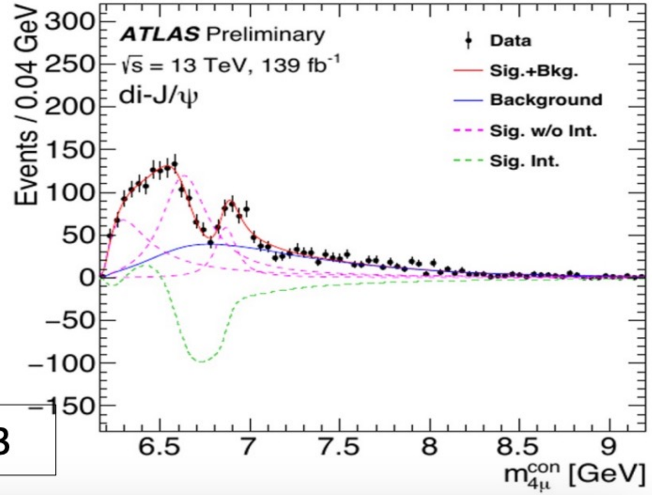
News about the X(6900) structure

CMS observed three J/ψ J/ψ resonances compatible with predictions of **cccc tetraquarks** states around the **X(6900)** observed by LHCb
ATLAS confirmed structure in the same region









	BW1	BW2	BW3
m	$6552 \pm 10 \pm 12$	$6927 \pm 9 \pm 5$	$7287 \pm 19 \pm 5$
Γ	$124 \pm 29 \pm 34$	$122 \pm 22 \pm 19$	$95 \pm 46 \pm 20$
N	474 ± 113	492 ± 75	156 ± 56

ATLAS-CONF-2022-040 | CMS-PAS-BPH-021-003 | LHCb Science Bulletin 65 (2020) 1983

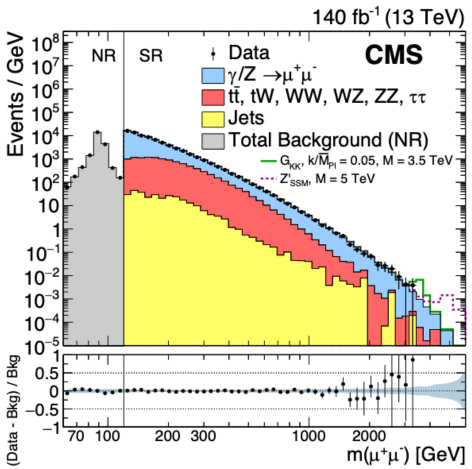
R. Tenchini – ICHEP 2022

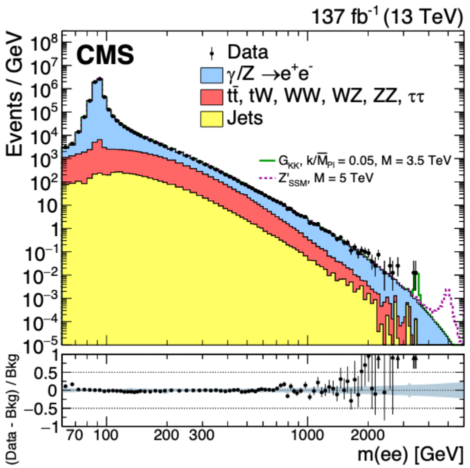
LFU test at TeV scale

Ration of searches for high mass dilepton resonances → Tests of LFU at the TeV scale

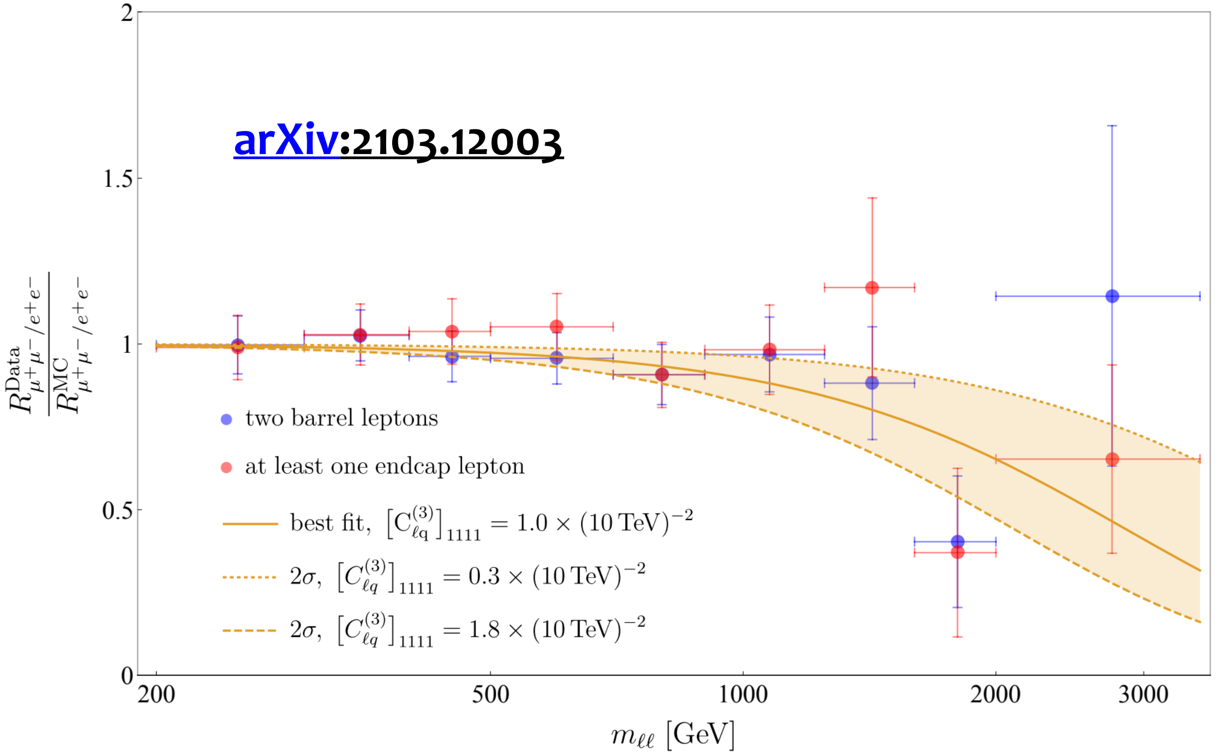
"combined preference for the new physics hypothesis of 4.5σ"

CMS-EXO-19-019



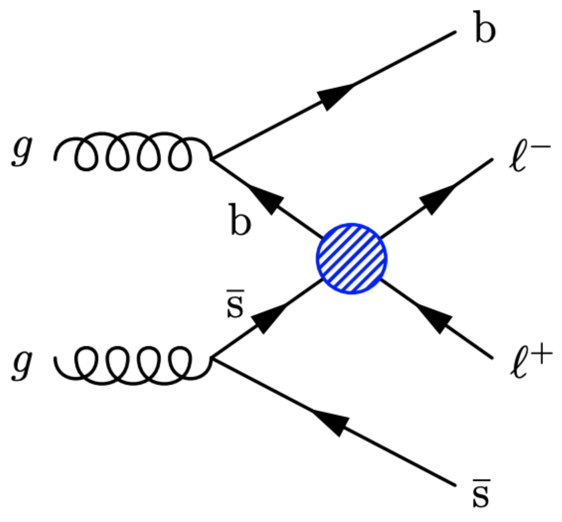


[arXiv:2103.12003](https://arxiv.org/abs/2103.12003)

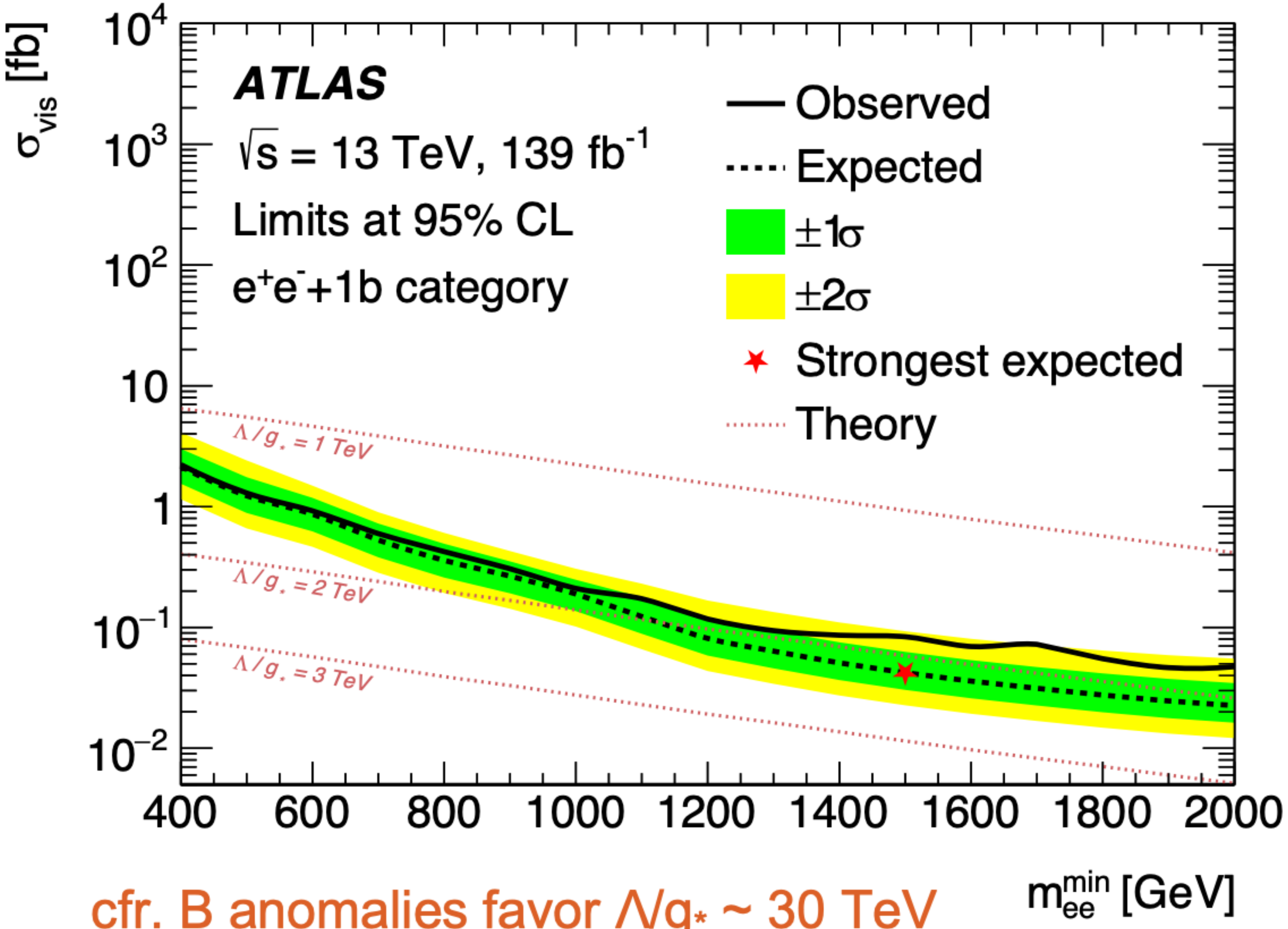


$$R_{\mu^+\mu^-/e^+e^-} = \frac{d\sigma(q\bar{q} \to \mu^+\mu^-)/dm_{\ell\ell}}{d\sigma(q\bar{q} \to e^+e^-)/dm_{\ell\ell}}$$

ATLAS 1st Gen LQ



ATLAS-EXOT-2018-16



cfr. B anomalies favor $\Lambda/g_{*} \sim 30$ TeV

Further 600-something evidence?

https://arxiv.org/abs/2111.08962 (acc by IJMP A)

Maurizio Consoli & Leonardo Cosmai

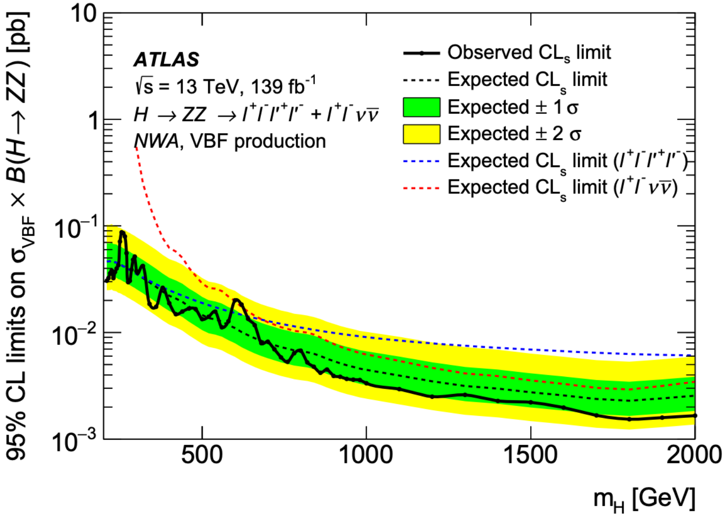
In the region of invariant mass 620÷740 GeV, we have analyzed the ATLAS sample of 4-lepton events that could indicate a new scalar resonance produced mainly via gluon-gluon fusion. These data suggest the existence of a new heavy state H whose mass 660 ÷ 680 GeV would fit well with the theoretical range $M_H = 690 \pm 10$ (stat) ± 20 (sys) GeV for the hypothetical second resonance of the Higgs field that has been recently proposed and which would couple to longitudinal W's with the same typical strength of the low-mass state at 125 GeV. Since the total width Γ_H is very poorly determined, to sharpen

prediction

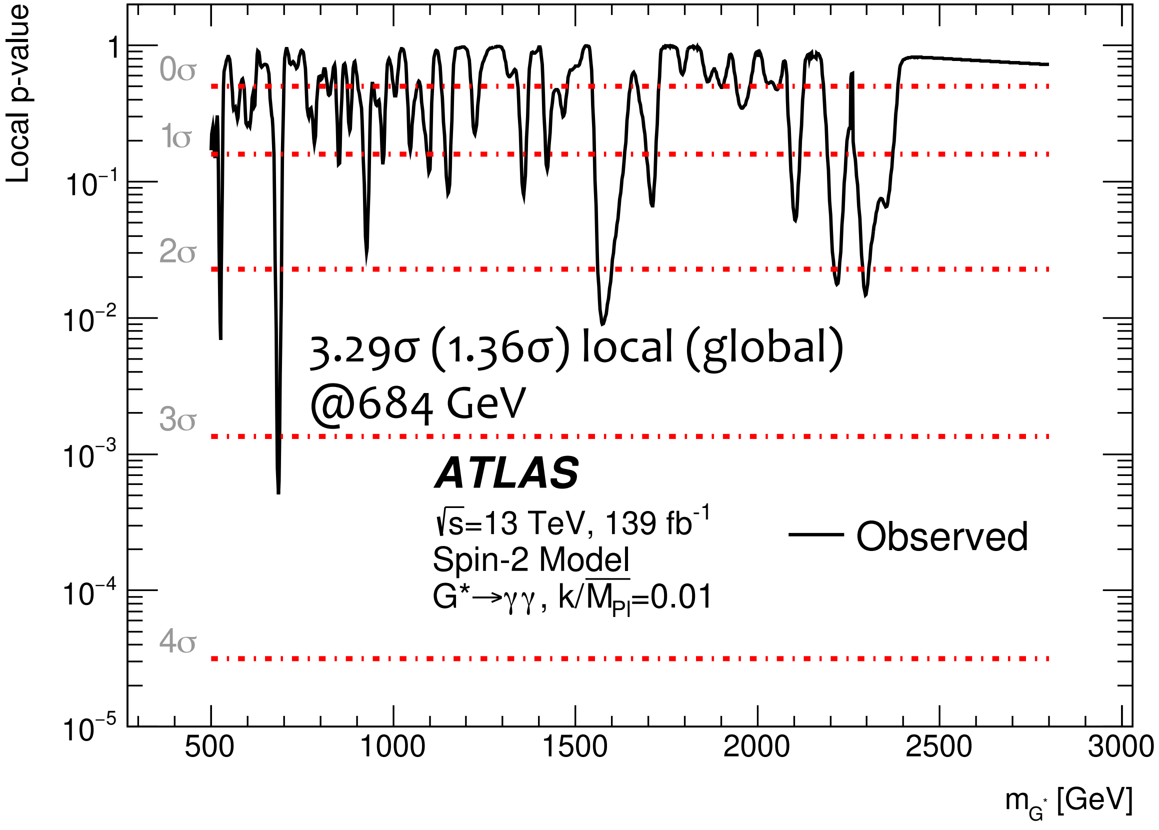
According to their estimate, 2.5σ local, 1.4σ global, from ATLAS H→ZZ search for M_X = 660-680 GeV

ATLAS search in H→ZZ→4l/2l2ν

Eur. Phys. J. C 81 (2021) 332

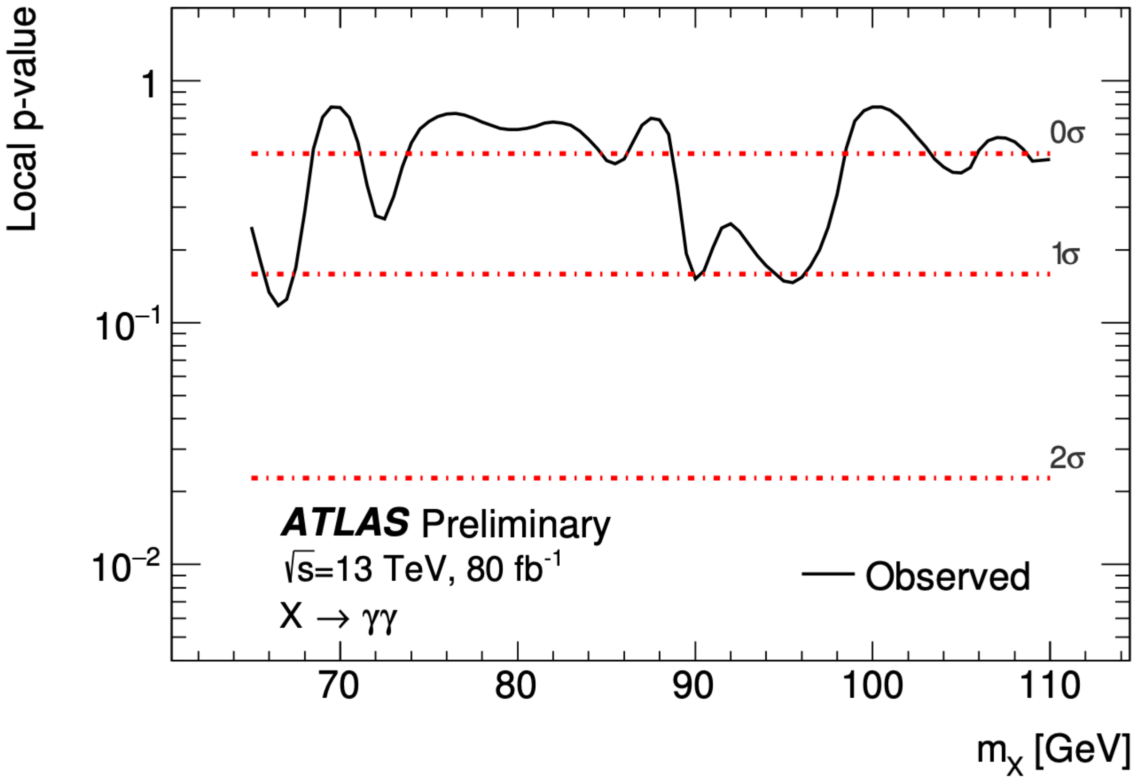


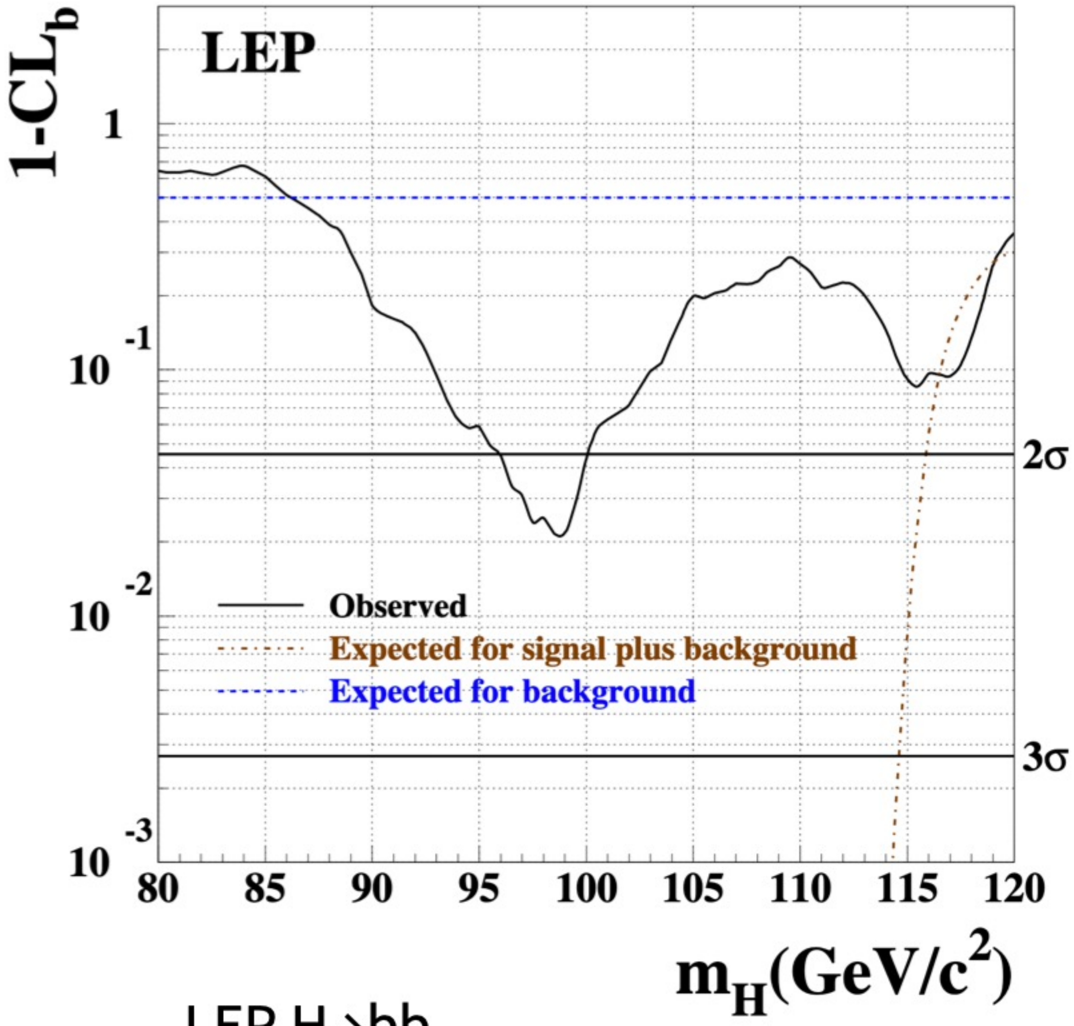
ATLAS X→γγ Phys. Lett. B 822 (2021) 136651



Further 90-something evidence?

ATLAS-CONF-2018-025



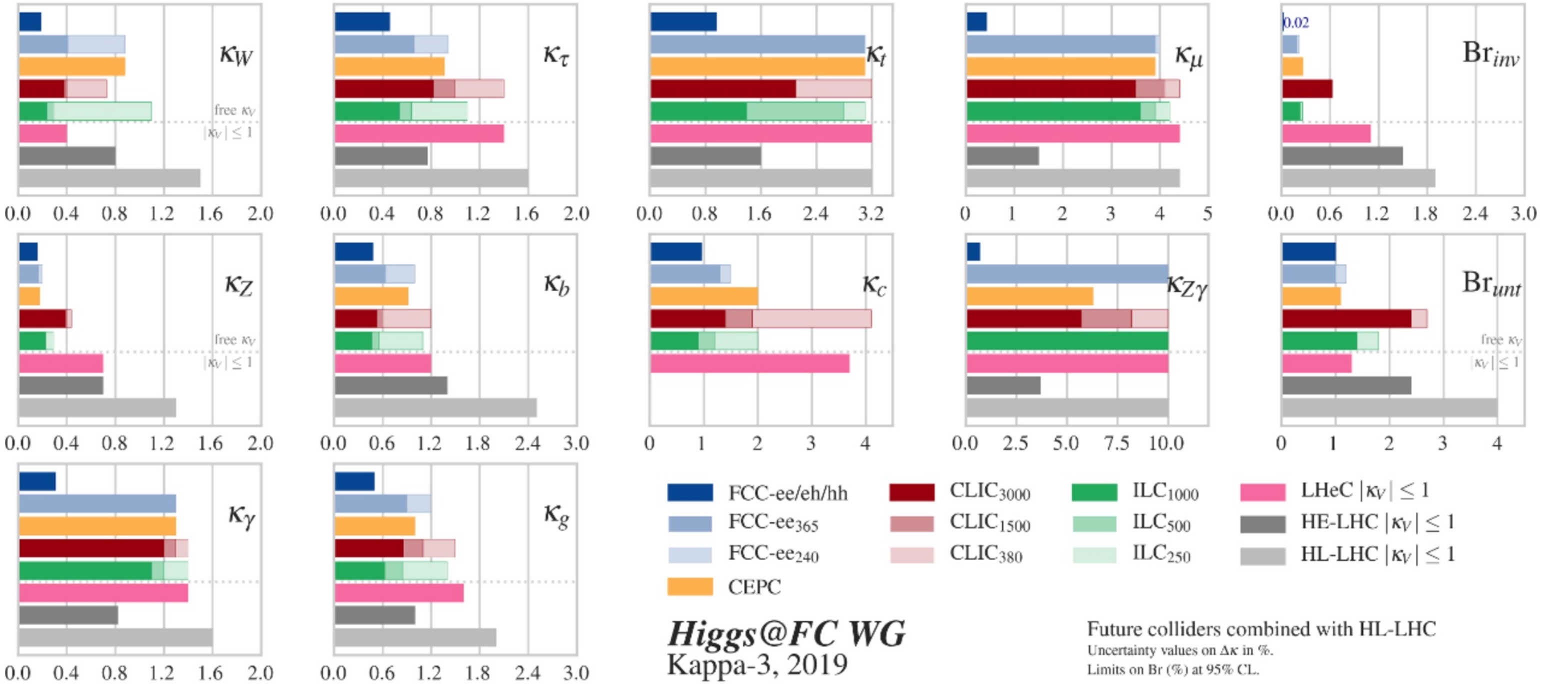


LEP H→bb

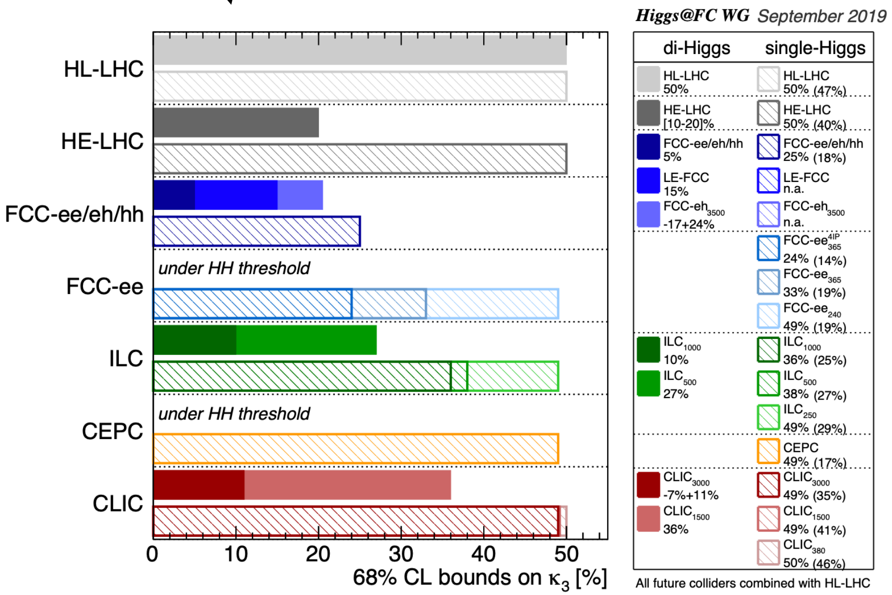
hep-ex/0306033

Higgs boson couplings beyond the HL-LHC

The **long road ahead** for the Higgs has many potential options but all lead to high **precision (~% level) characterization** of the Higgs boson couplings



Higgs boson **self-coupling** requires **high energy** machine for % level



JHEP 139 (2020)