# BSM ~~Searches~~ Discoveries with FCC-ee

Chris Verhaaren

FCC Week

11 June 2024


# Some Theory Motivation

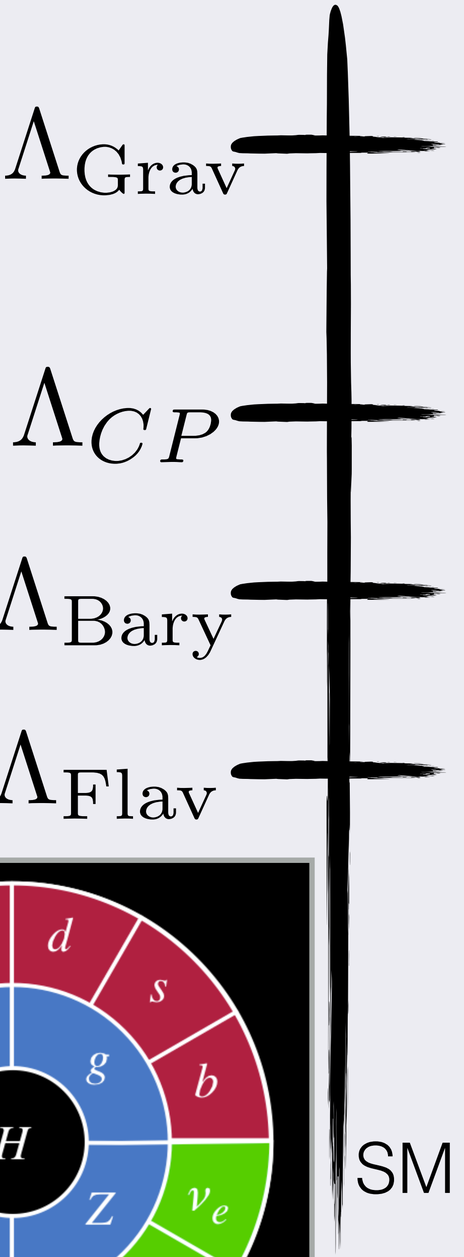
The Standard model is a triumph,
but must be extended

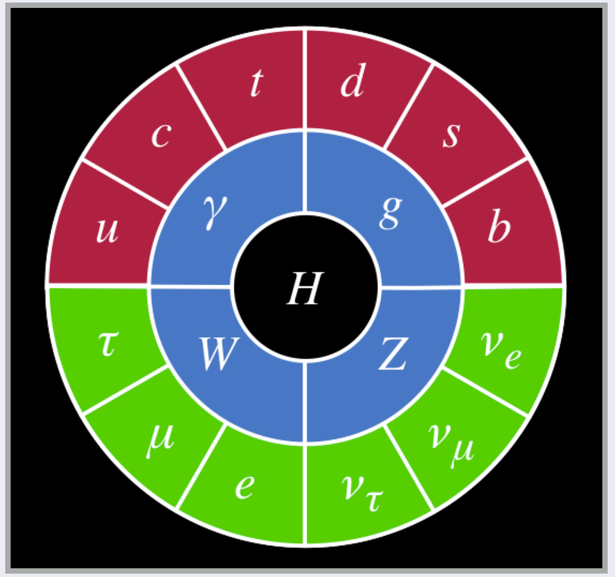
Extensions include new physics scales

Higgs appears insensitive to known
and likely BSM scales

If a symmetry protects the Higgs from these scales
then we should see symmetry partners of SM fields

Excellent Snowmass review: Craig 2205.05708

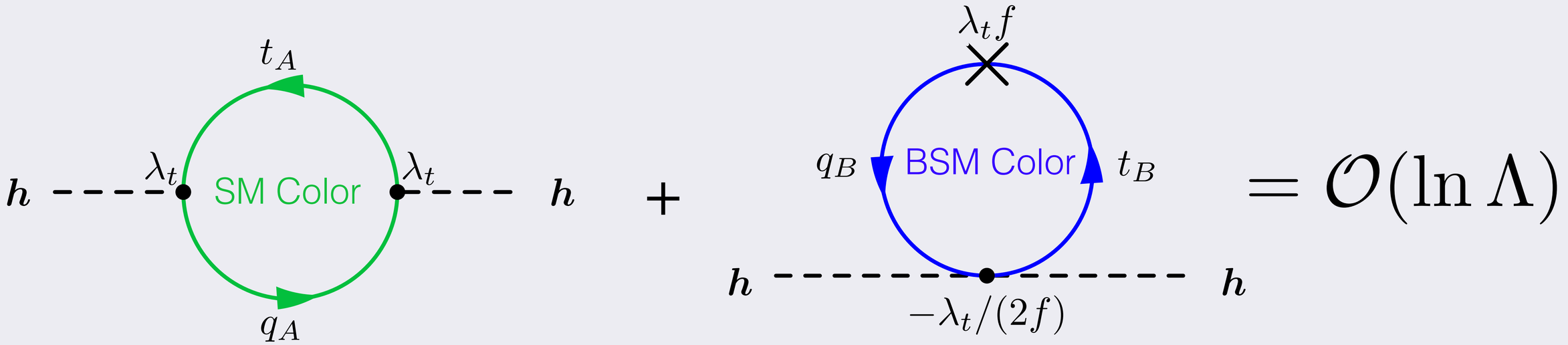


# Neutral Naturalness

Symmetry based solutions to ‘little’ Hierarchy puzzle

Quark symmetry partners do not carry SM color




Most collider searches for quark partners do not apply

Recent Snowmass Review: Batell, Low, Neil, CV 2203.05531

# Common Traits

Higgs couples to symmetry partners

**Guarantees** the Higgs is a portal to the new sector

Discrete symmetry relates SM fields and couplings to BSM counterparts

Often a twin symmetry (e.g. in Twin Higgs…)

Quark partners charged under “hidden” SU(3) color
with confinement $\gtrsim$ SM value

An EFT with cutoff of a few TeV

Many UV states with SM color accessible to FCC-hh

What can be done at FCC-ee?

# Z-portal Physics

Tripled top model Cheng, Li, Salvioni, CV 1803.03651 top partners are SM neutral scalars

New light matter below hidden confinement scale

Mostly SM neutral, small mixing with heavy EW charged states

Cheng, Li, Salvioni, CV 1906.02198

Light hadrons produced in rare Z and h decays

1906.02693

| Working point | Z, years 1-2 | Z, later | WW | HZ | $t\bar{t}$ | |
|---|---|---|---|---|---|---|
| $\sqrt{s}$ (GeV) | 88, 91, 94 | | 157, 163 | 240 | 340-350 | 365 |
| Lumi/IP ($10^{34}\,cm^{-2}s^{-1}$) | 115 | 230 | 28 | 8.5 | 0.95 | 1.55 |
| Lumi/year ($ab^{-1}$, 2 IP) | 24 | 48 | 6 | 1.7 | 0.2 | 0.34 |
| Physics Goal ($ab^{-1}$) | 150 | | 10 | 5 | 0.2 | 1.5 |
| Run time (year) | 2 | 2 | 2 | 3 | 1 | 4 |
| Number of events | $5 \times 10^{12}$ Z | | $10^8$ WW | $10^6$ HZ + 25k WW $\to$ H | $10^6 t\bar{t}$ +200k HZ +50k WW $\to$ H | |

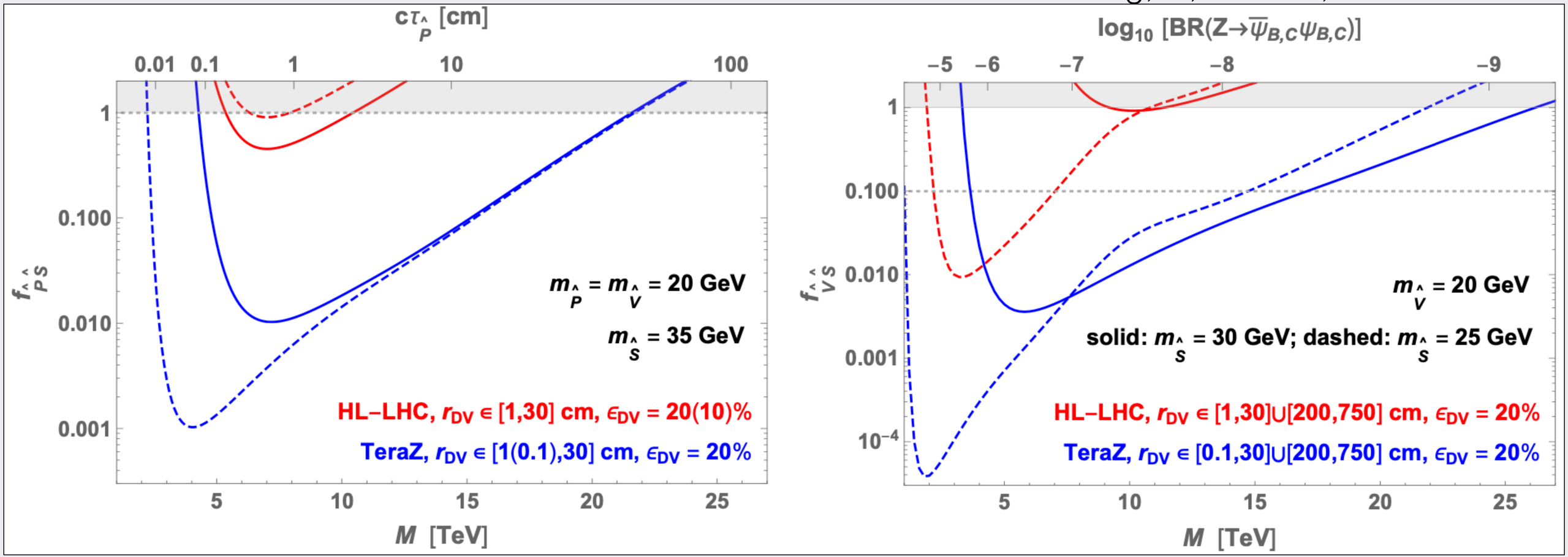
# Z-portal

Fraction of Z decays to hidden sector that are XY final state: $f_{XY}$

Grey lines motivated benchmarks

See that FCC-ee has impressive reach

Cheng, Li, Salvioni, CV 1906.02198

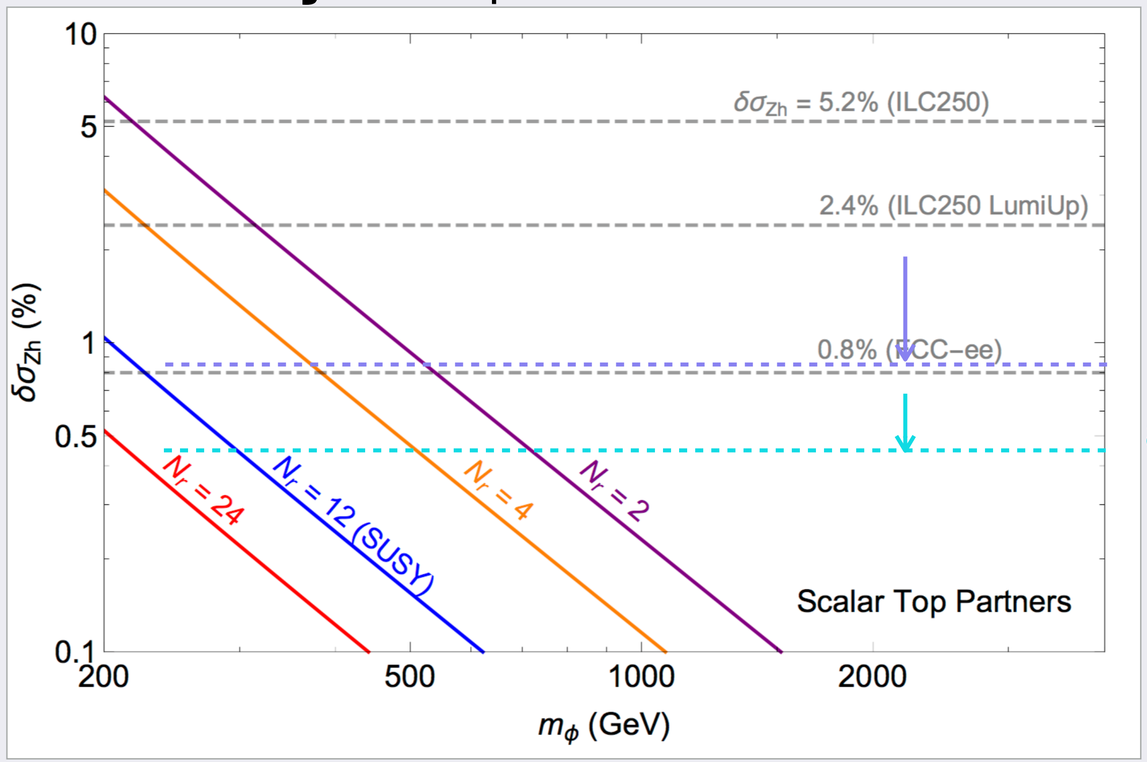


# Higgs Physics

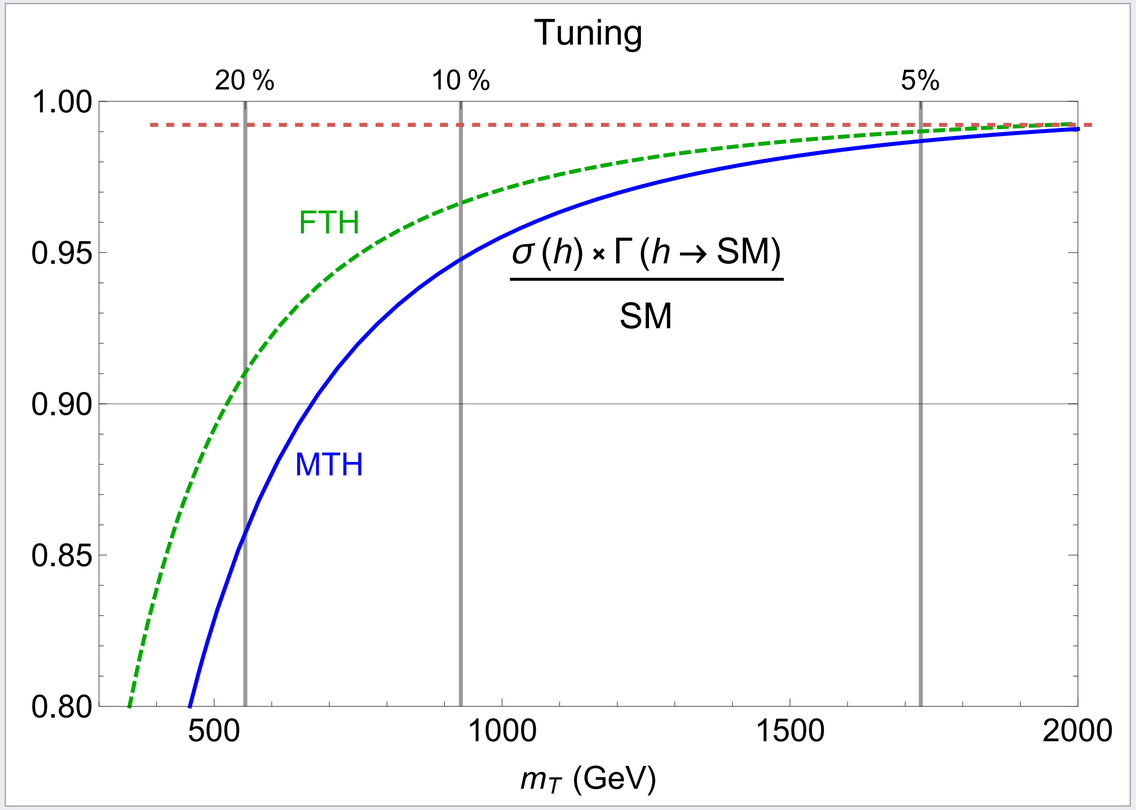
## Higgs Couplings

pNGB models predict tree level coupling deviations

**Always** loop level corrections

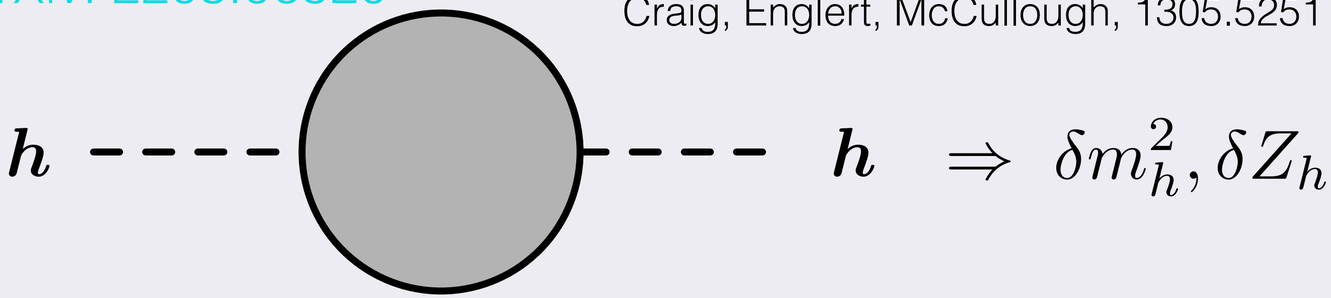



Curtin, Saraswat 1512.05782




arXiv: 2203.06520

Craig, Englert, McCullough, 1305.5251



# Higgs Physics

**Higgs Width**

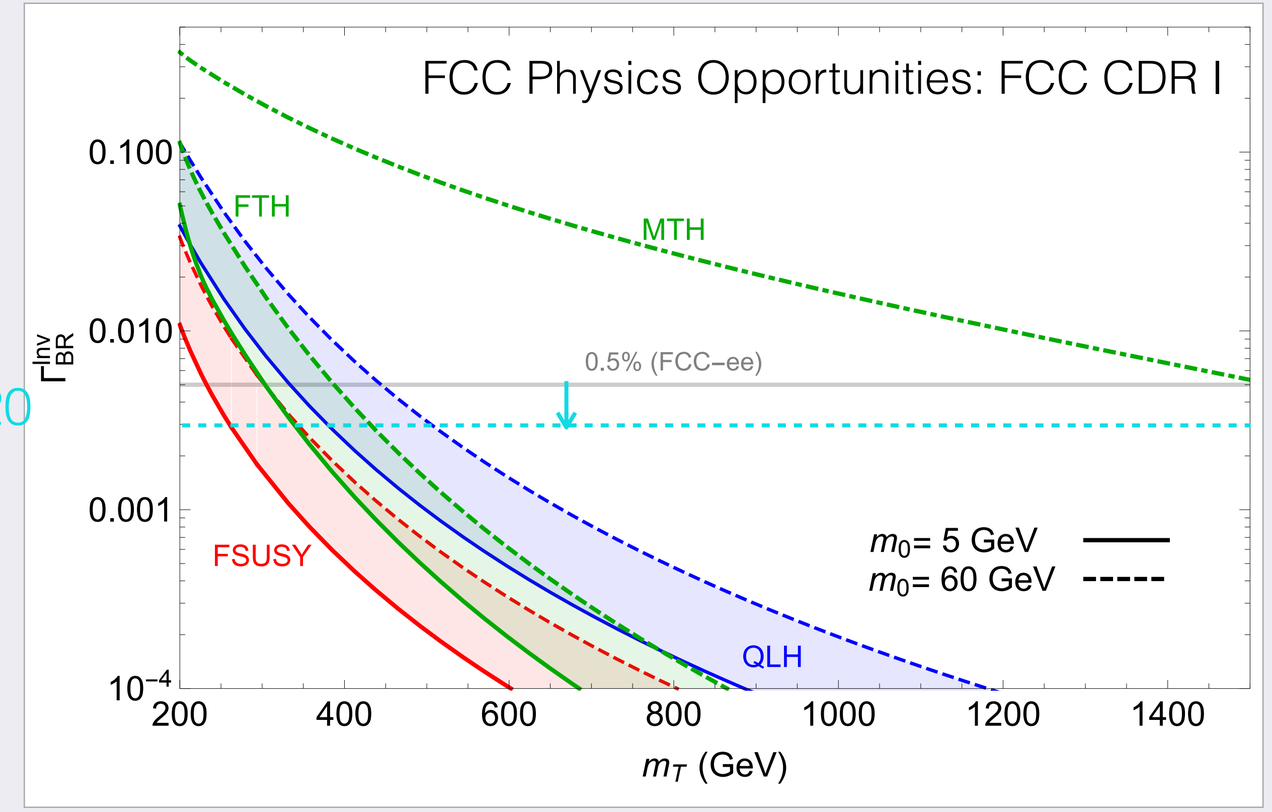
New states with EW charges often too heavy for Higgs decays (LEP)

Implies that bottom of hidden QCD spectrum are glueball states

Higgs develops loop-level decay to glueballs

arXiv: 2203.06520

Irreducible width of these scenarios



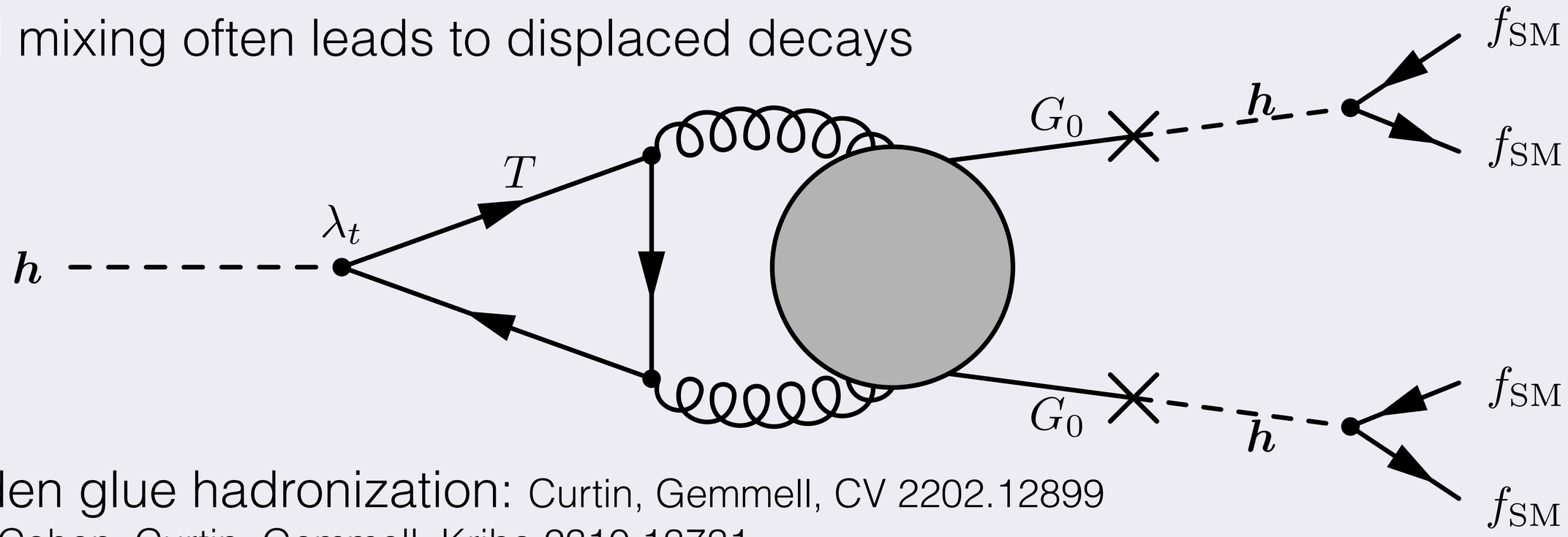
# Higgs Physics

**Exotic Higgs Decays**

Lightest hidden glueball mixes with the Higgs

$$h \to G_0 G_0 \to \bar{f} f \bar{f} f \qquad \text{(Mostly to b-quarks)}$$

Small mixing often leads to displaced decays




Hidden glue hadronization: Curtin, Gemmell, CV 2202.12899
Batz, Cohen, Curtin, Gemmell, Kribs 2310.13731

# Fractionally Charge Particles

Why the growing interest in fractionally charged particles?

Alonso, Dimakou, West 2404.03438, Li, Xu 2404.04229, Koren Martin 2406.?????

Even a neutral naturalness connection Batell, Cochran, Page, CV 2406.?????

The SM Lie **Algebra** is SU(3)xSU(2)xU(1)

The Lie **Group** may be $SU(3)xSU(2)xU(1)/Z_p$
with p={1,2,3,6}

Allow for states of electric charge that are multiples of $\frac{pe}{6}$

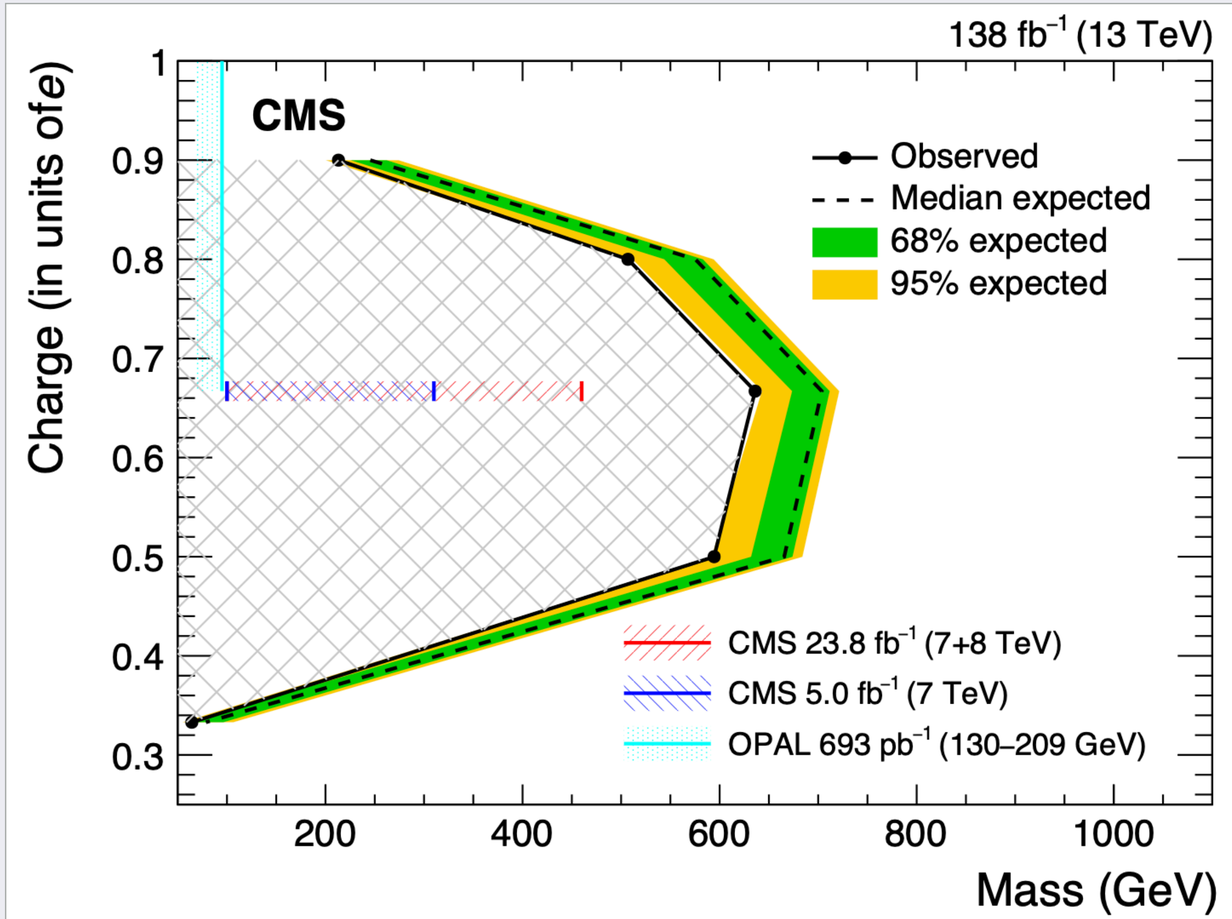
As emphasized by Koren Martin 2406.????? most popular GUTs do not allow particles of charge $\frac{e}{6}$

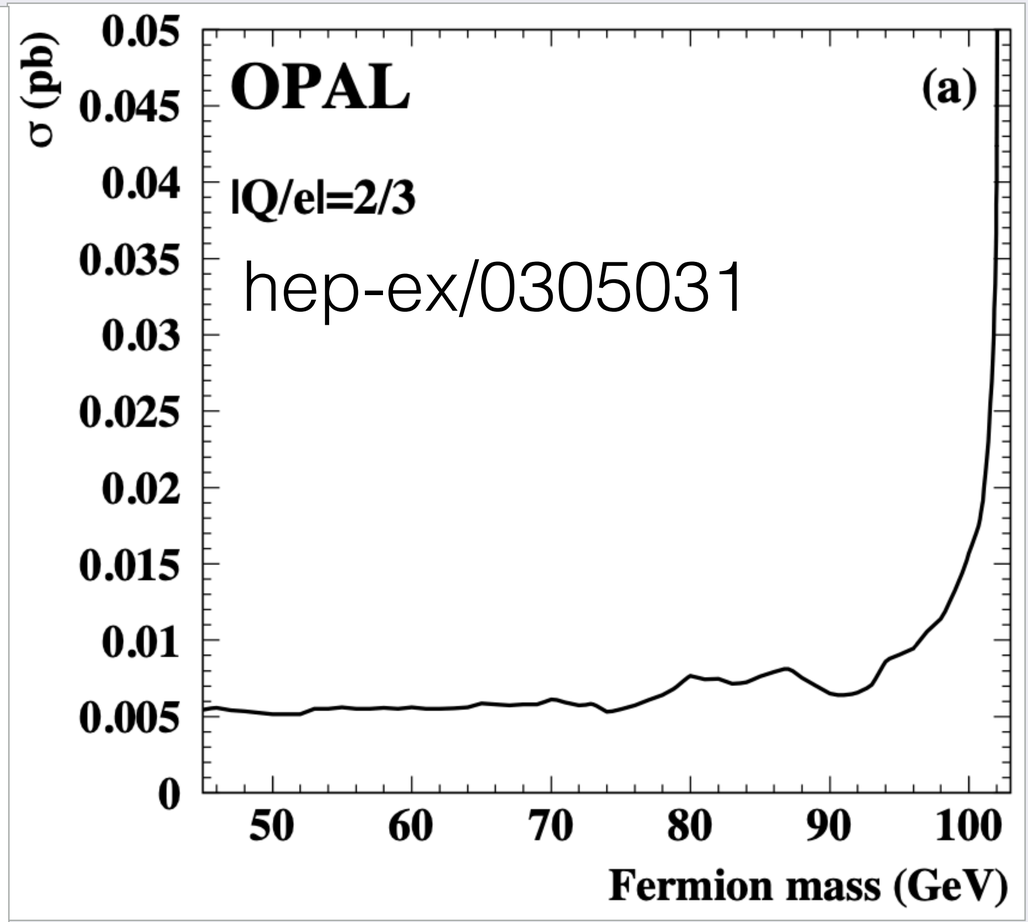
Detecting such a particles, of any mass, gives insight into high UV physics

# Fractionally Charge Particles

Not clear that the charge e/6 target can be probed at the LHC

Can the FCC-ee make a comprehensive search/discovery up to the top-quark mass?



# Summary

The hierarchy between the EW scale and other scales is puzzling

Models of Neutral Naturalness provide an explanation of hierarchies up to the few TeV range

Such models provide an intriguing target for FCC-ee **discoveries**

Rare Z decays

Higgs physics (couplings, width, exotic decays)

Fractionally charged particles (e/6) at low energies have ultra high energy implications