



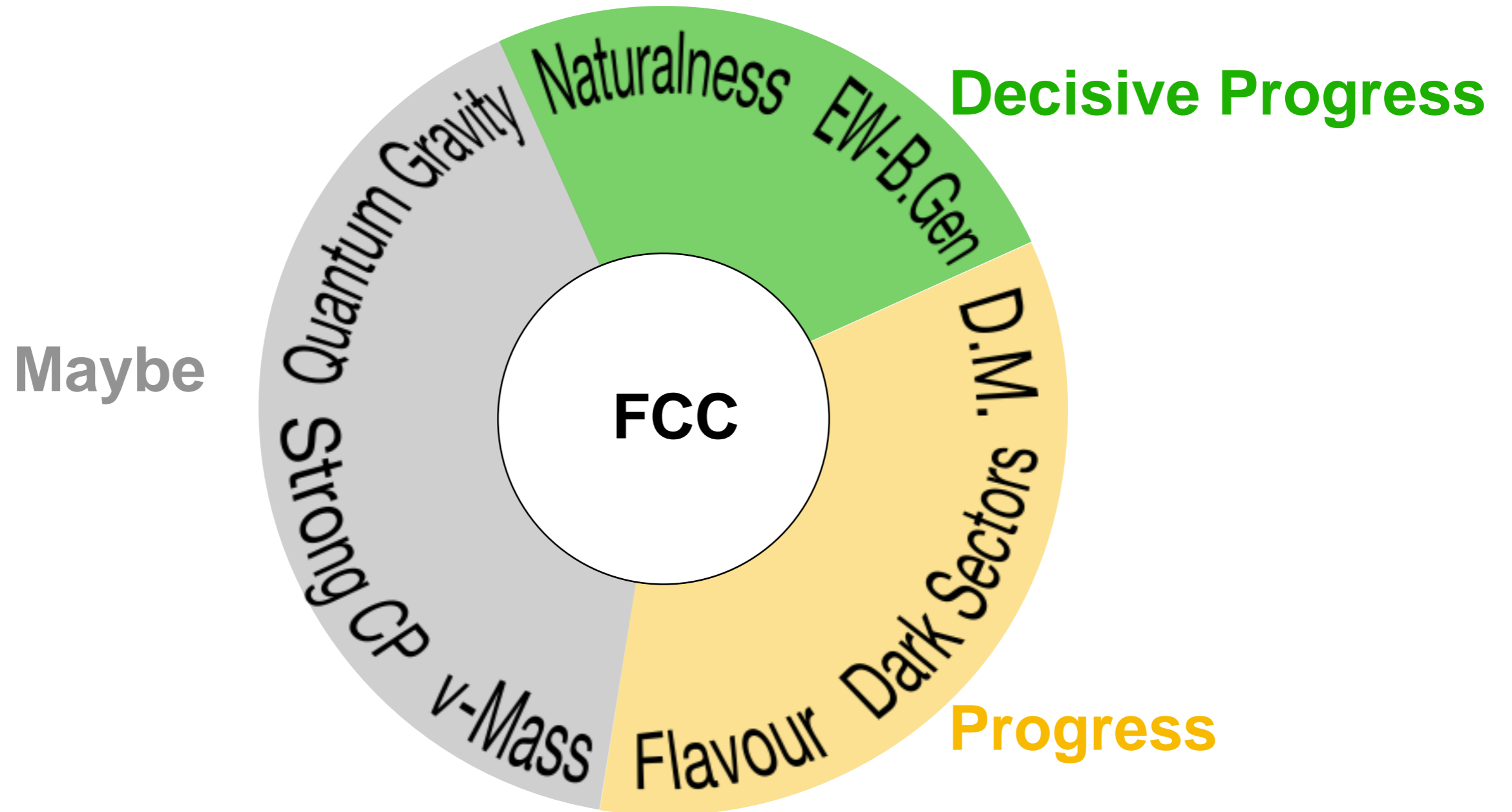
BSM-Part 2: Beyond the SM

FCC Week 2018 - Amsterdam - 11 April 2018

Riccardo Torre
CERN, INFN Genova



BSM @ FCC



BSM: Behind vs Beyond the SM

Behind the SM

New physics needed by the SM to explain its puzzles

- Hierarchy problem
- Origin of flavor
- Strong CP

Beyond the SM

New phenomena not explained by the SM that need physics beyond it

- Flavor anomalies
- Neutrino masses
- Dark Matter
- Axions
- EW phase transition/Baryogenesis

- Given the current absence of hints of new physics in neither of the BSM directions, future colliders are a crucial step to look for any possible answer to all the open questions
- No discovery/no answer is guaranteed, but **continuing exploration is absolutely mandatory**

BSM: Behind vs Beyond the SM

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Beyond the SM

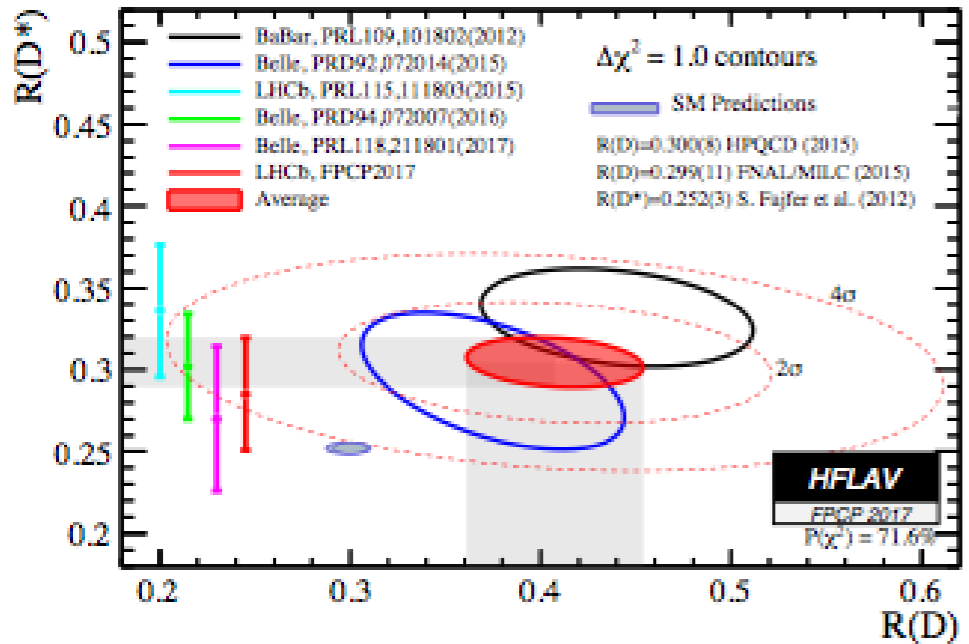
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Flavor anomalies

$$b \rightarrow cl\bar{\nu}$$

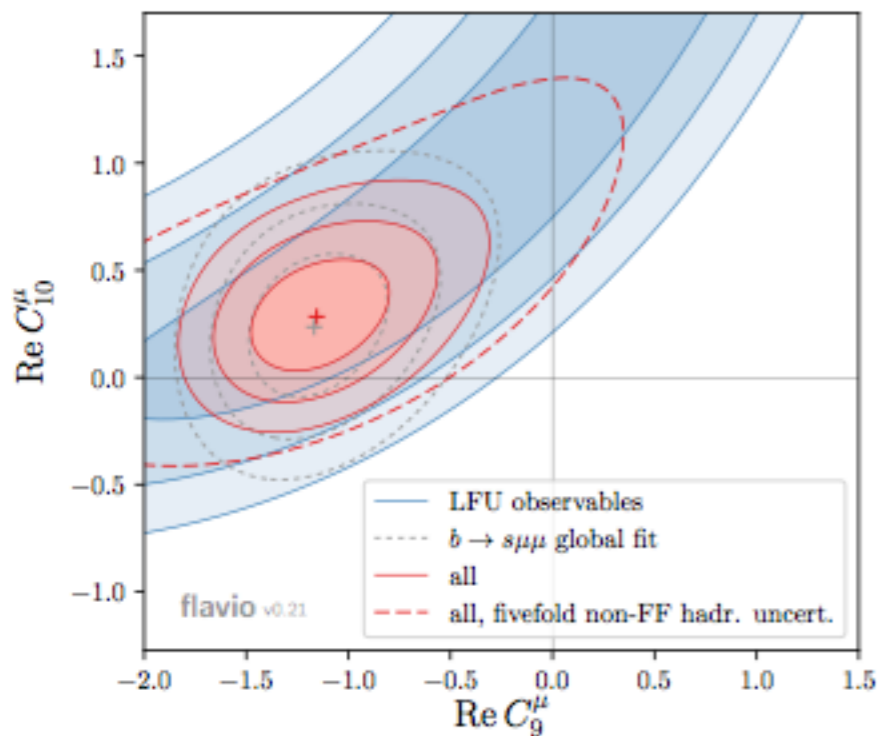


$M_{NP} < 9\text{TeV}$ [pert.unitarity]

Candidates:

- W', Z'
- EW scalars
- Leptoquarks

$$b \rightarrow sl\bar{l}$$



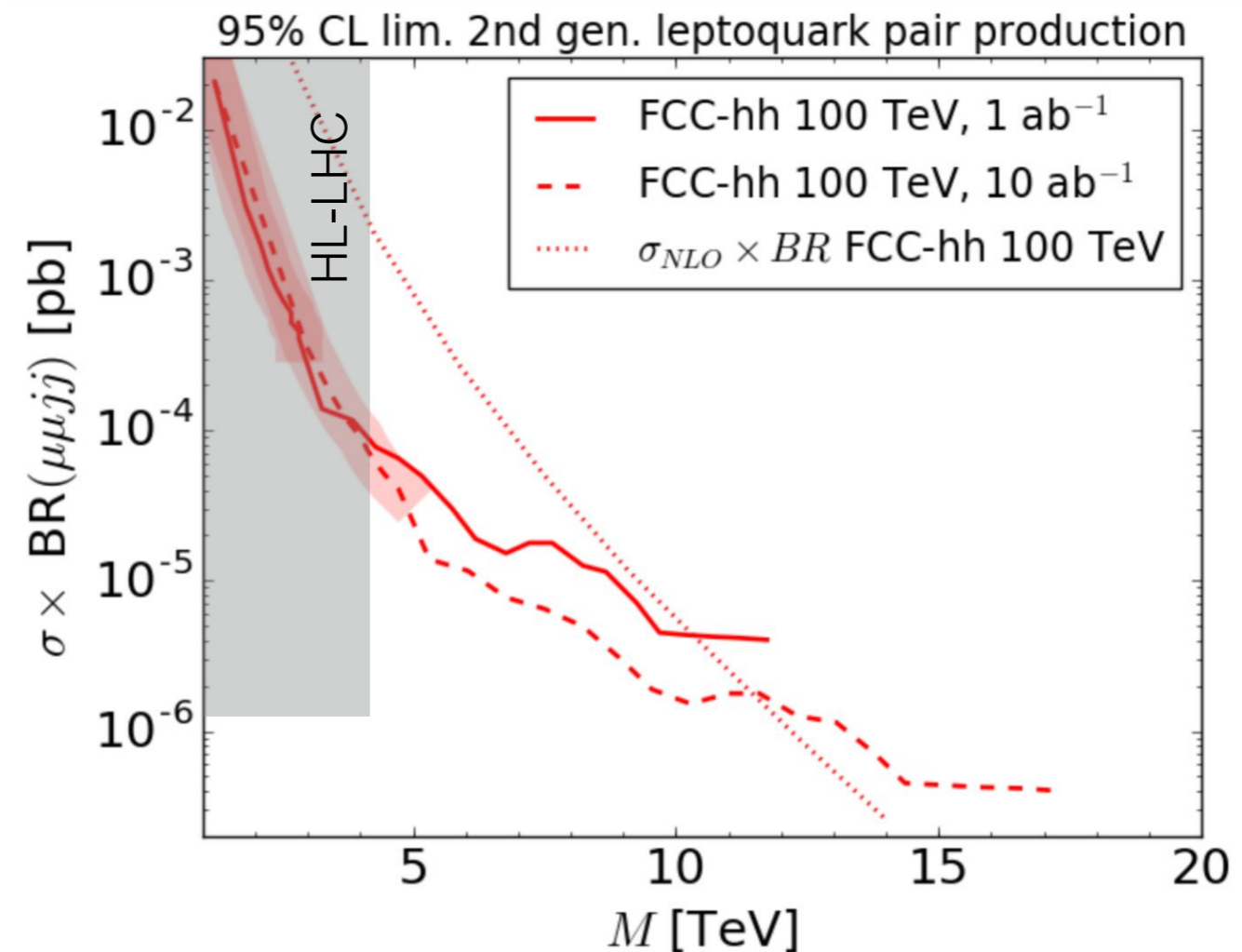
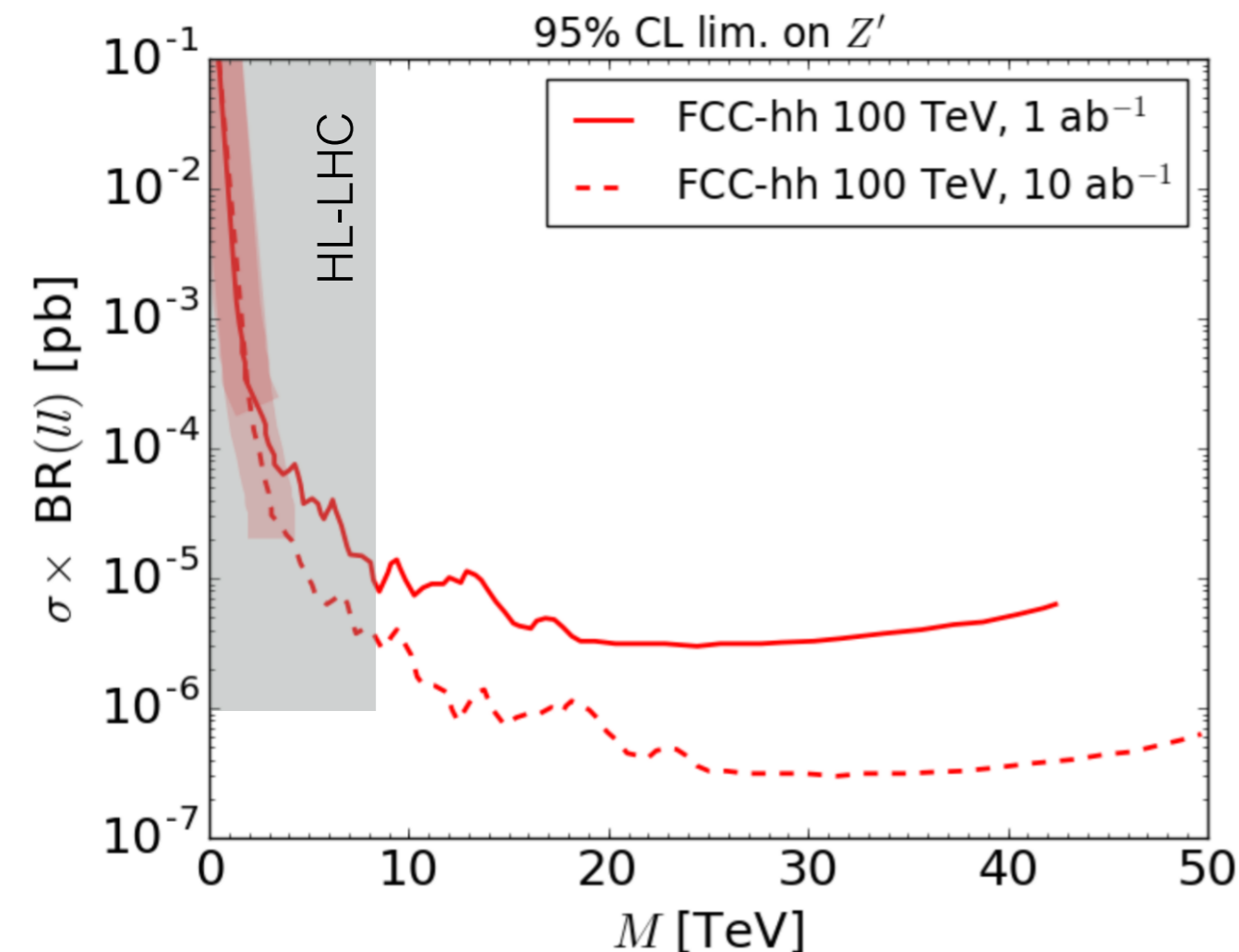
Combined explanation by
“Natural” μ suppression

[See talk by Greljo @ 2nd FCC Physics Workshop](#)

Flavor anomalies

- Several ongoing studies: [Di Luzio, Fuentes-Martin, Greljo, Nardecchia, Renner; Allanach, Gripaios, You; Robinson, Shakya, Zupan; Camalich; etc.]
- Final states with τ , and b pose challenges
- Indirect FCC-ee potential also under investigation
- Some prospects for high-pt searches already available

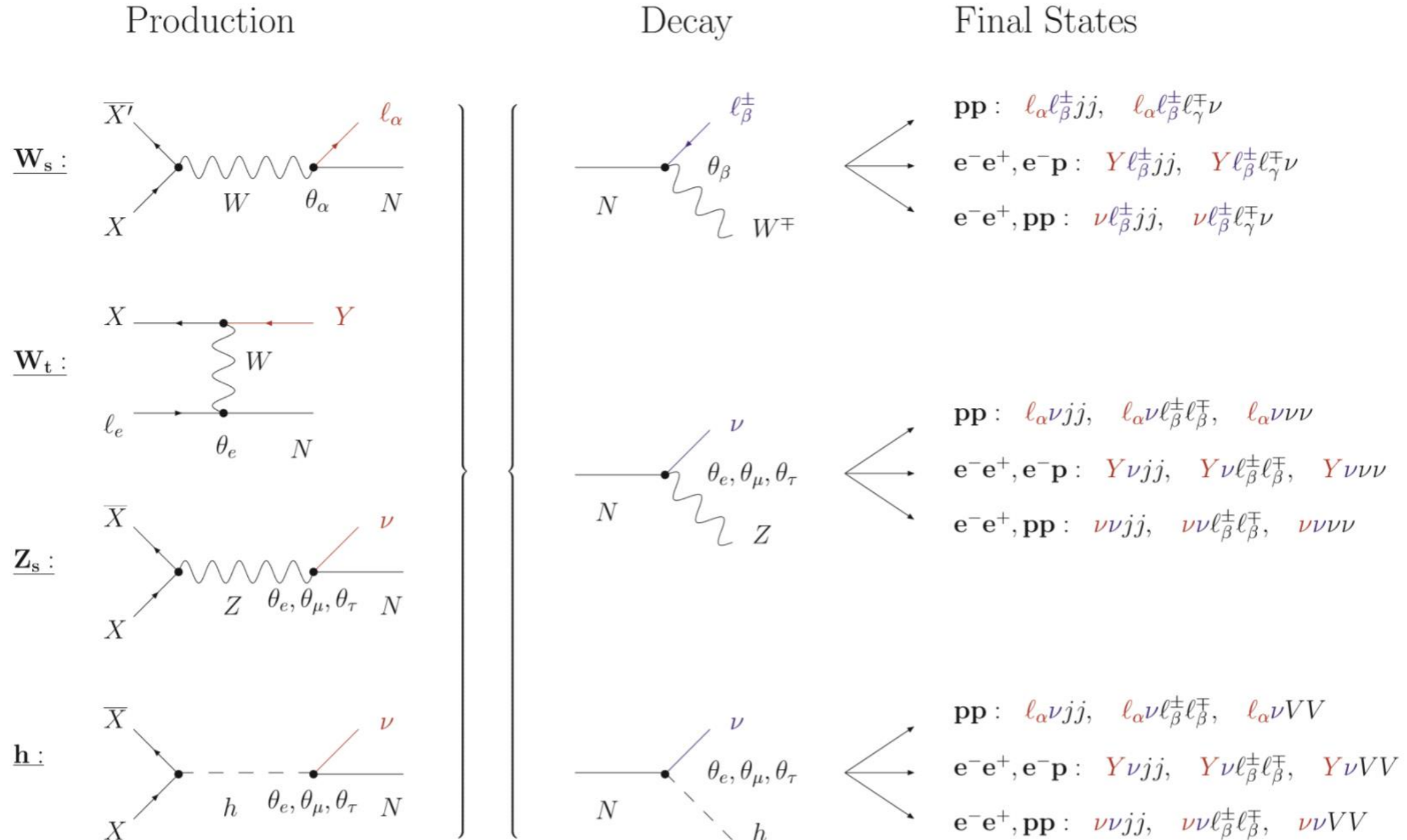
Allanach, Gripaios, You, 1710.06363 [hep-ph]



Sterile neutrinos @ FCC

➤ A simple way to generate neutrino masses is the seesaw mechanism

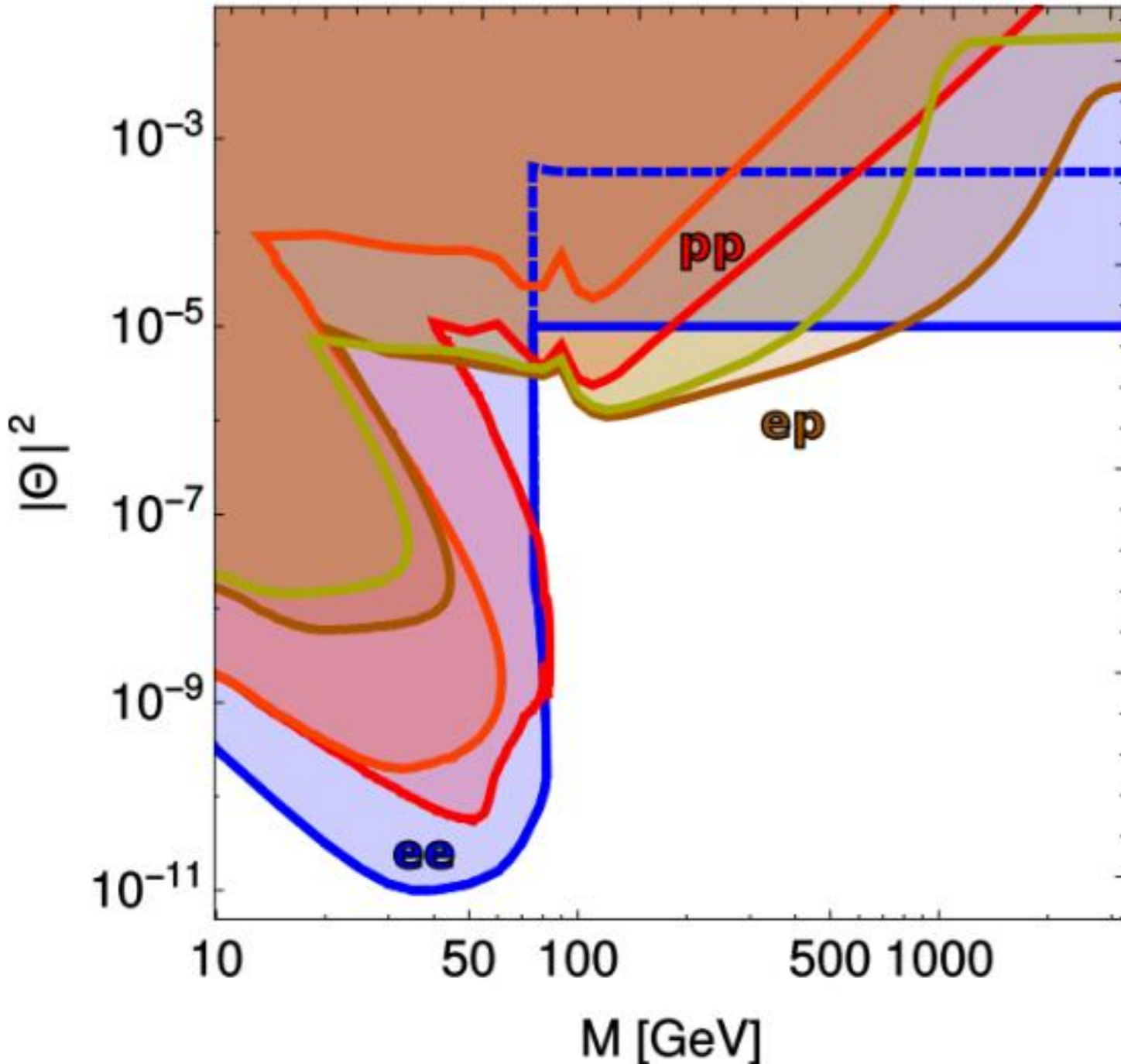
➤ New heavy “sterile” neutrinos mix with the active neutrinos $\theta_\alpha = y_{\nu_\alpha} \frac{v}{\sqrt{2}M}$



Sterile neutrinos @ FCC

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➤ New heavy “sterile” neutrinos mix with the active neutrinos $\theta_\alpha = y_{\nu_\alpha} \frac{v}{\sqrt{2}M}$



- For masses much above TeV best sensitivity from EWPT @ FCC-ee
- For intermediate masses good sensitivity from LFV (LNC) channels @ FCC-hh/eh
- For light masses best sensitivity from displaced vertices @ FCC-ee

[Antusch, Cazzato, Fischer, 1612.02728 \[hep-ph\]](#)

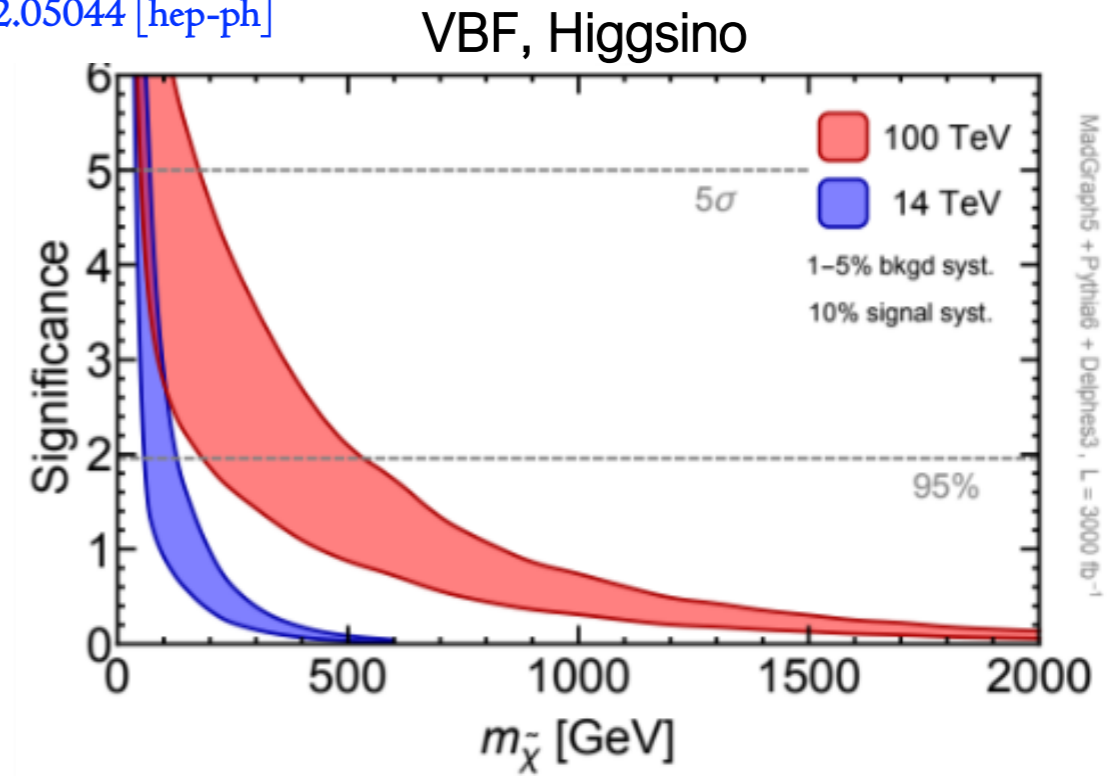
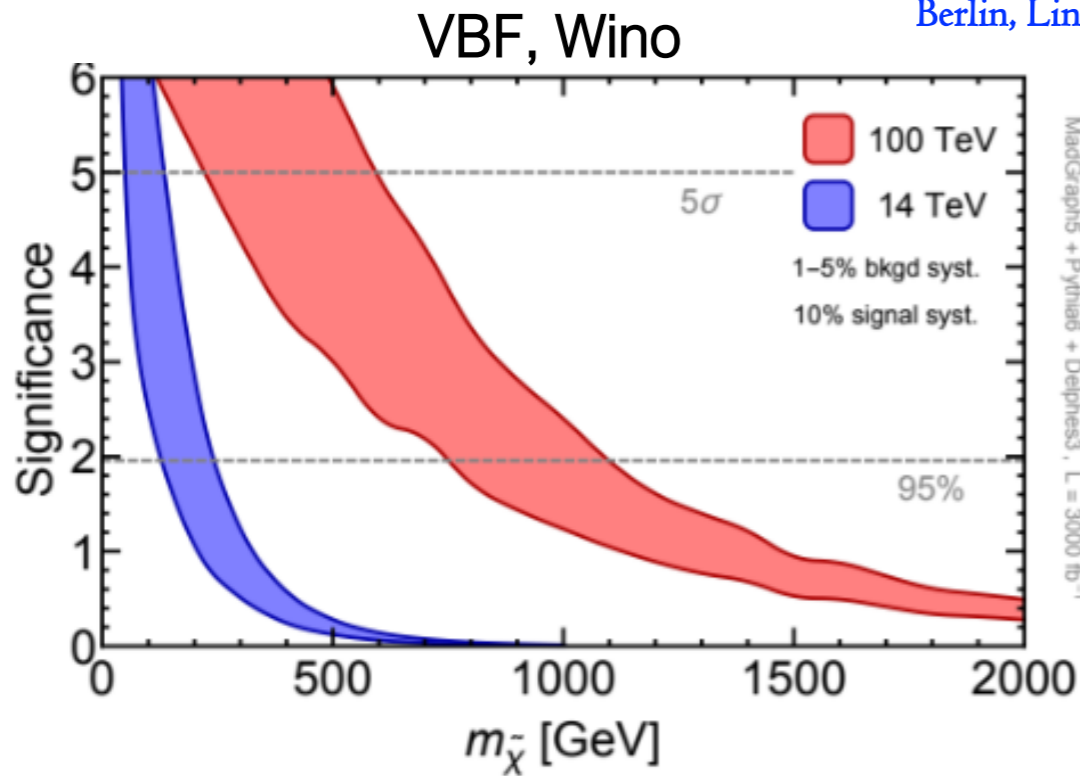
[See talk by Fischer @ 2nd FCC Physics Workshop](#)

Dark Matter

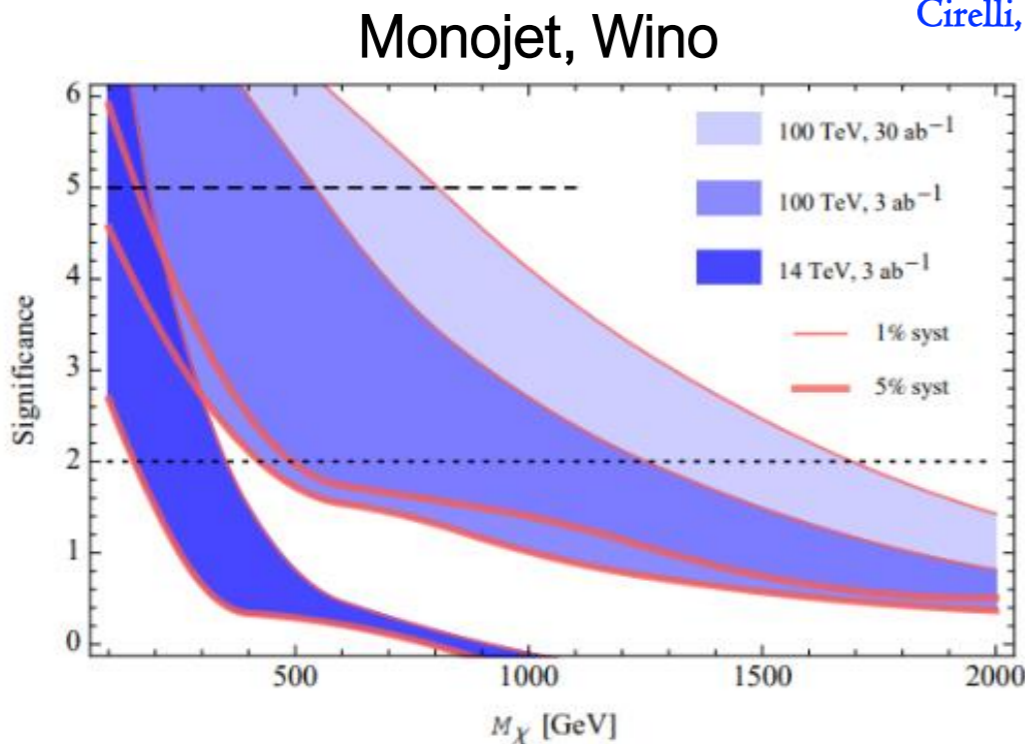
- FCC-hh allows to probe heavy WIMPs out of the reach of present and future Direct Detection experiments

[See talk by Bramante @ 2nd FCC Physics Workshop](#)

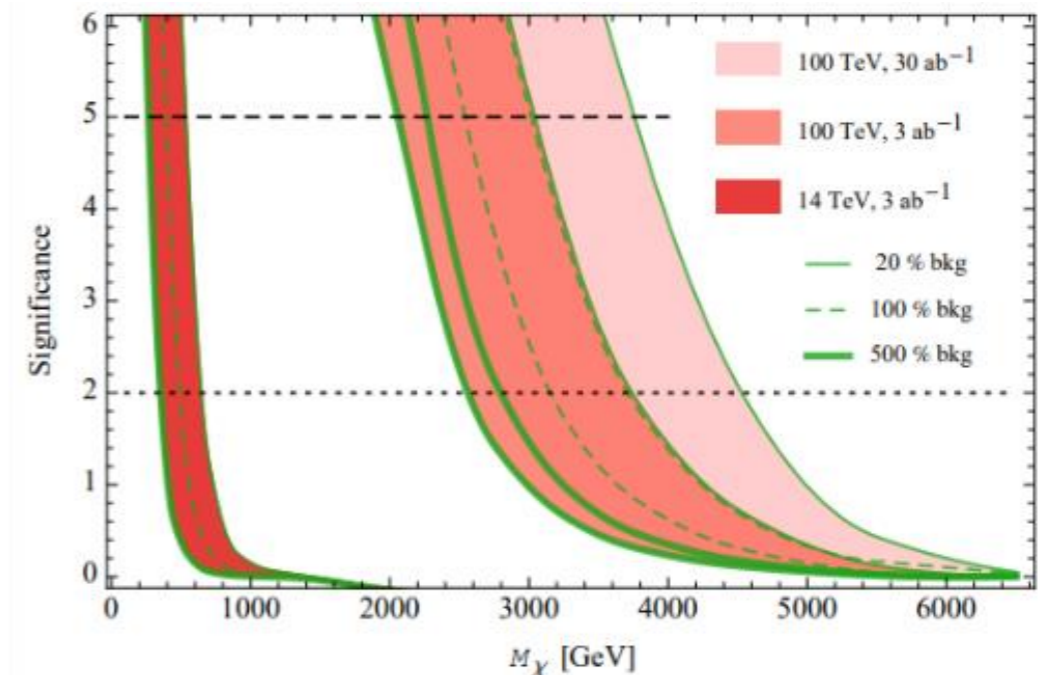
Berlin, Lin, Low, Wang, 1502.05044 [hep-ph]



Cirelli, Sala, Taoso, 1407.7058 [hep-ph]



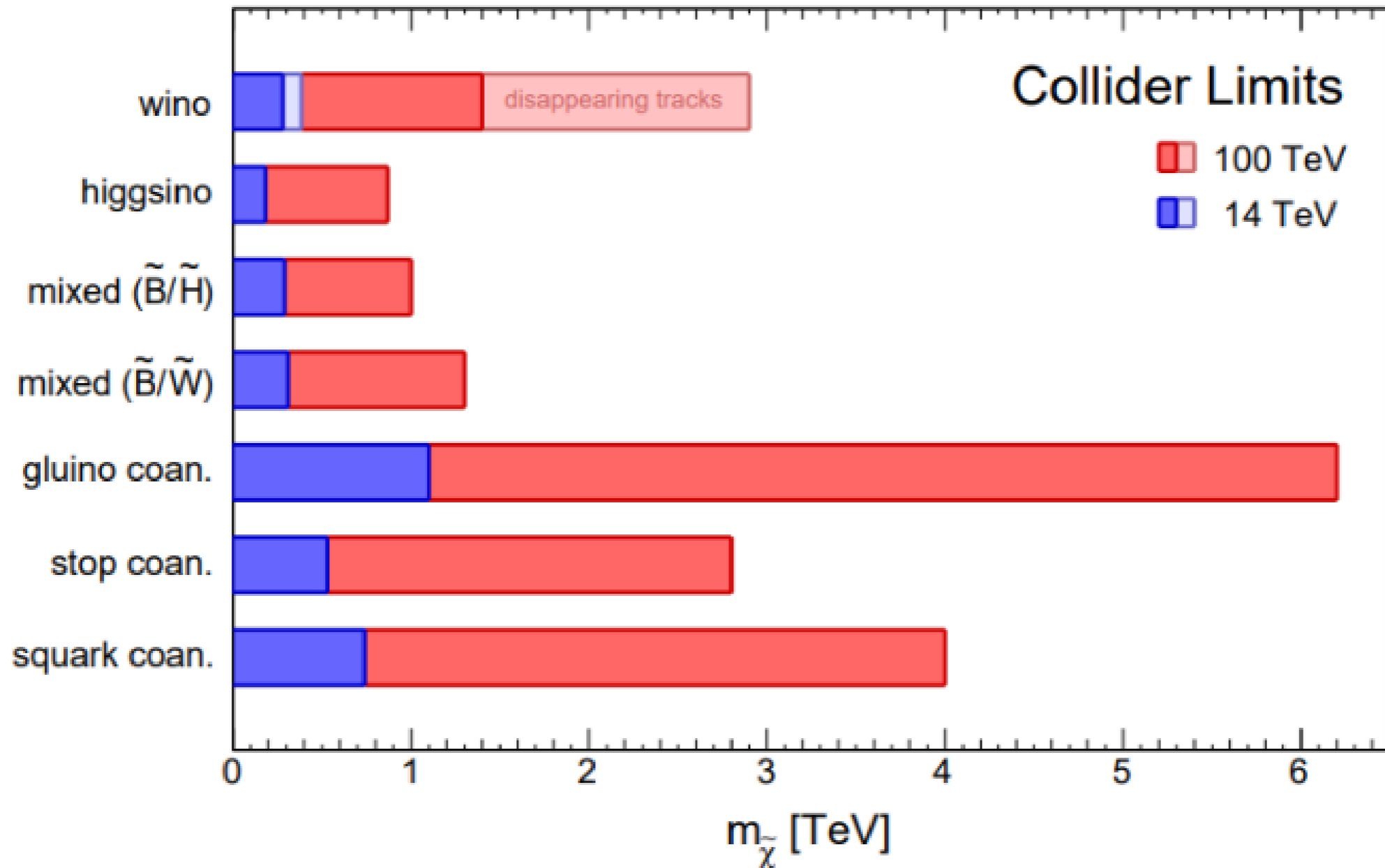
Disappearing Tracks, Wino



Dark Matter

- FCC-hh allows to probe heavy WIMP out of the reach of present and future Direct Detection experiments
- Reach improves by a factor 5/6 on most scenarios

FCC Yellow Report, CERN-2017-003-M



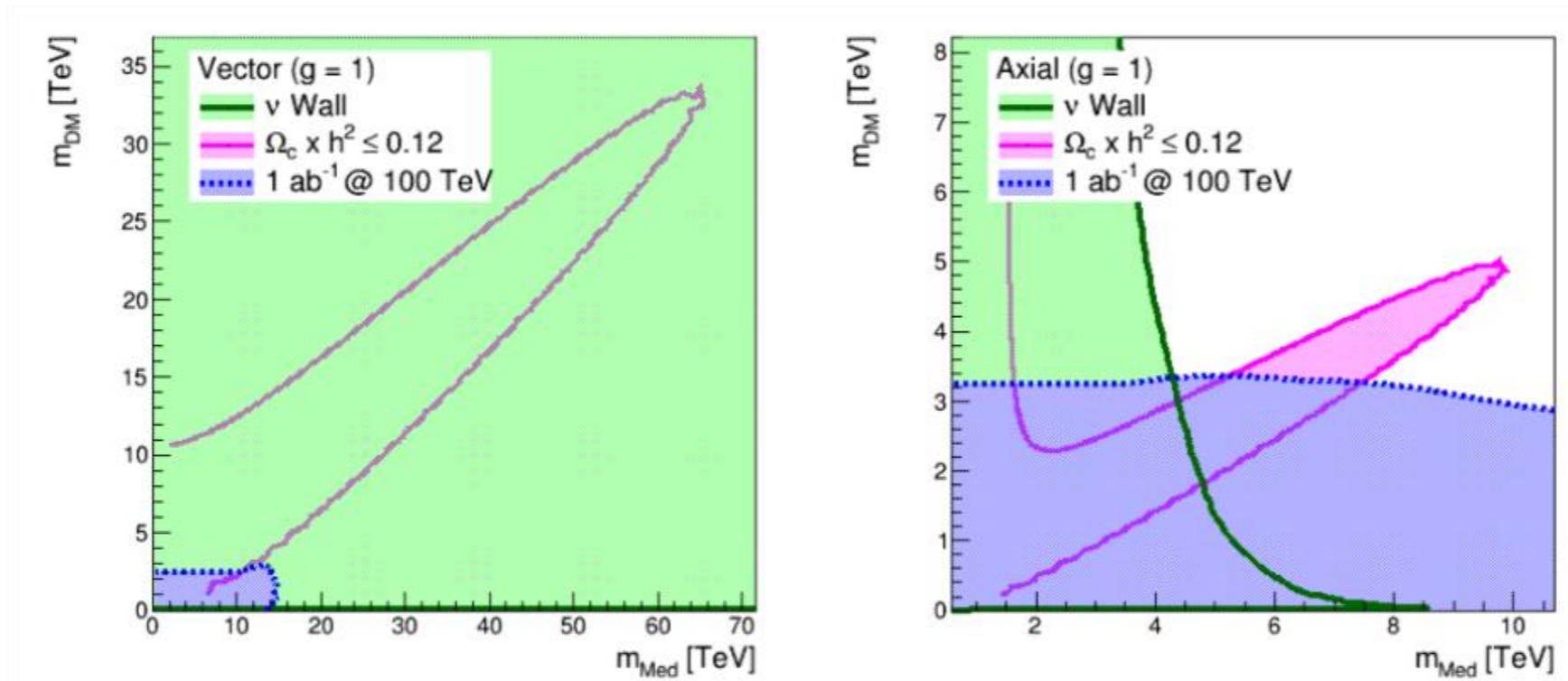
[See talk by Bramante @ 2nd FCC Physics Workshop](#)

Dark Matter

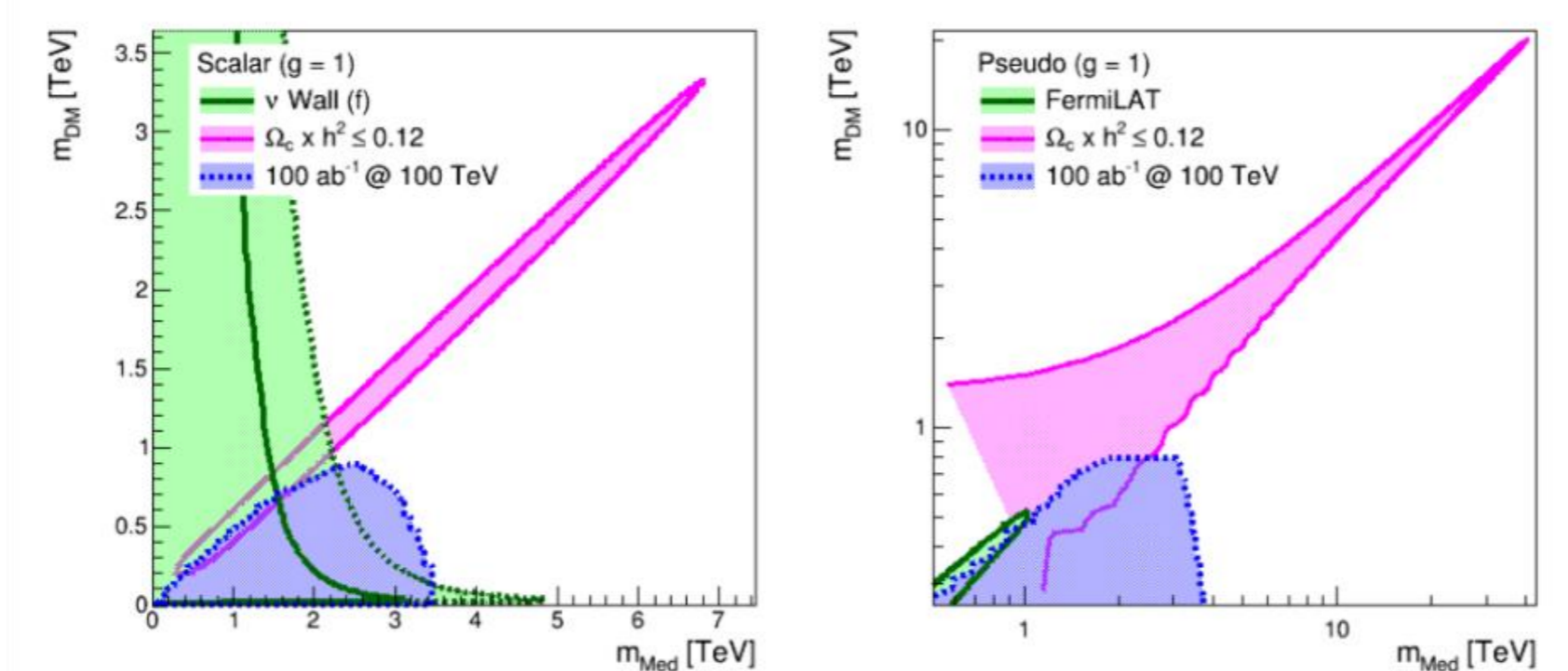
➤ Direct detection insensitive below the neutrino floor

[See talk by Bramante @ 2nd FCC Physics Workshop](#)

➤ FCC-hh can access a large part of that parameter space of simplified models



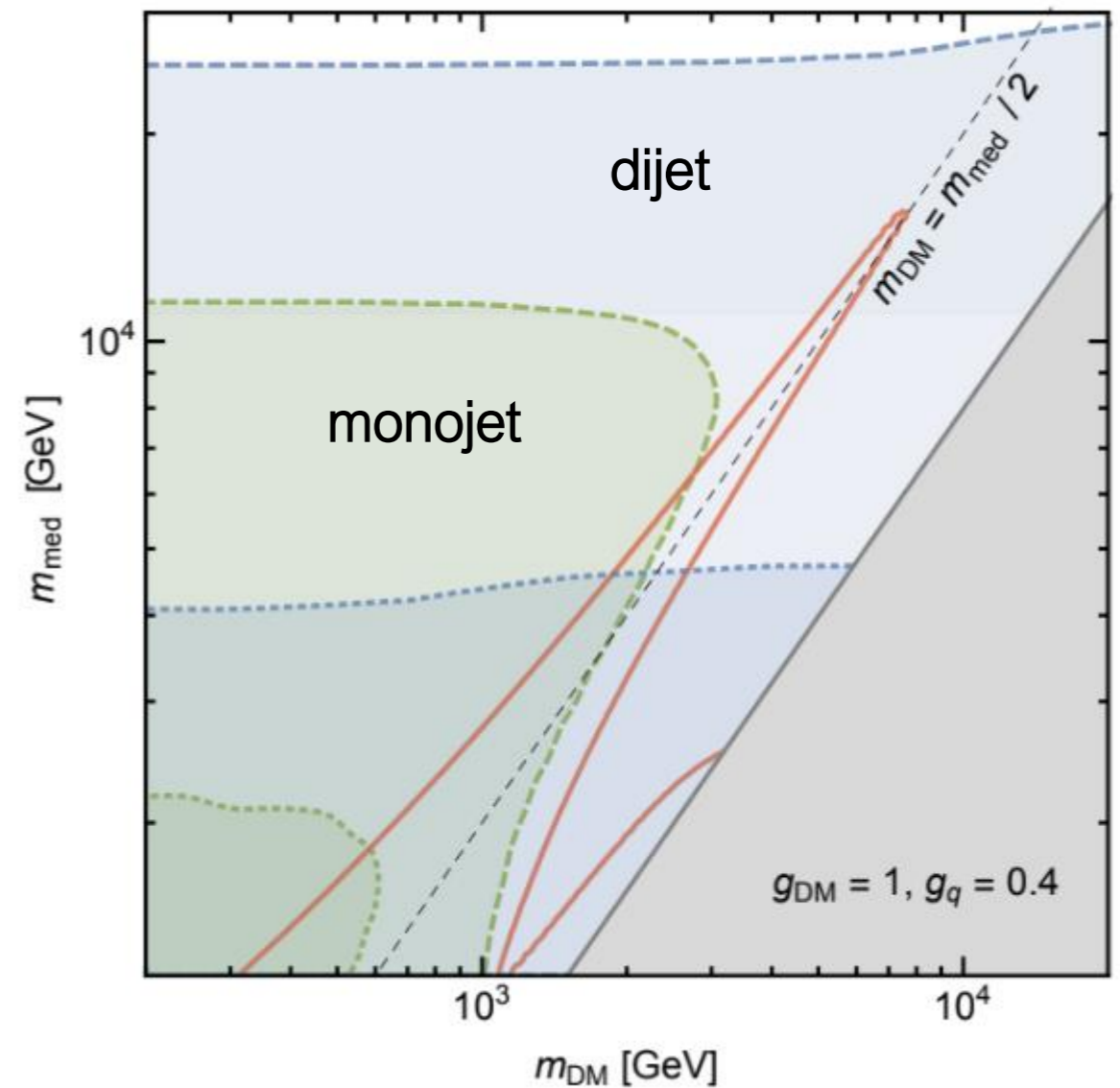
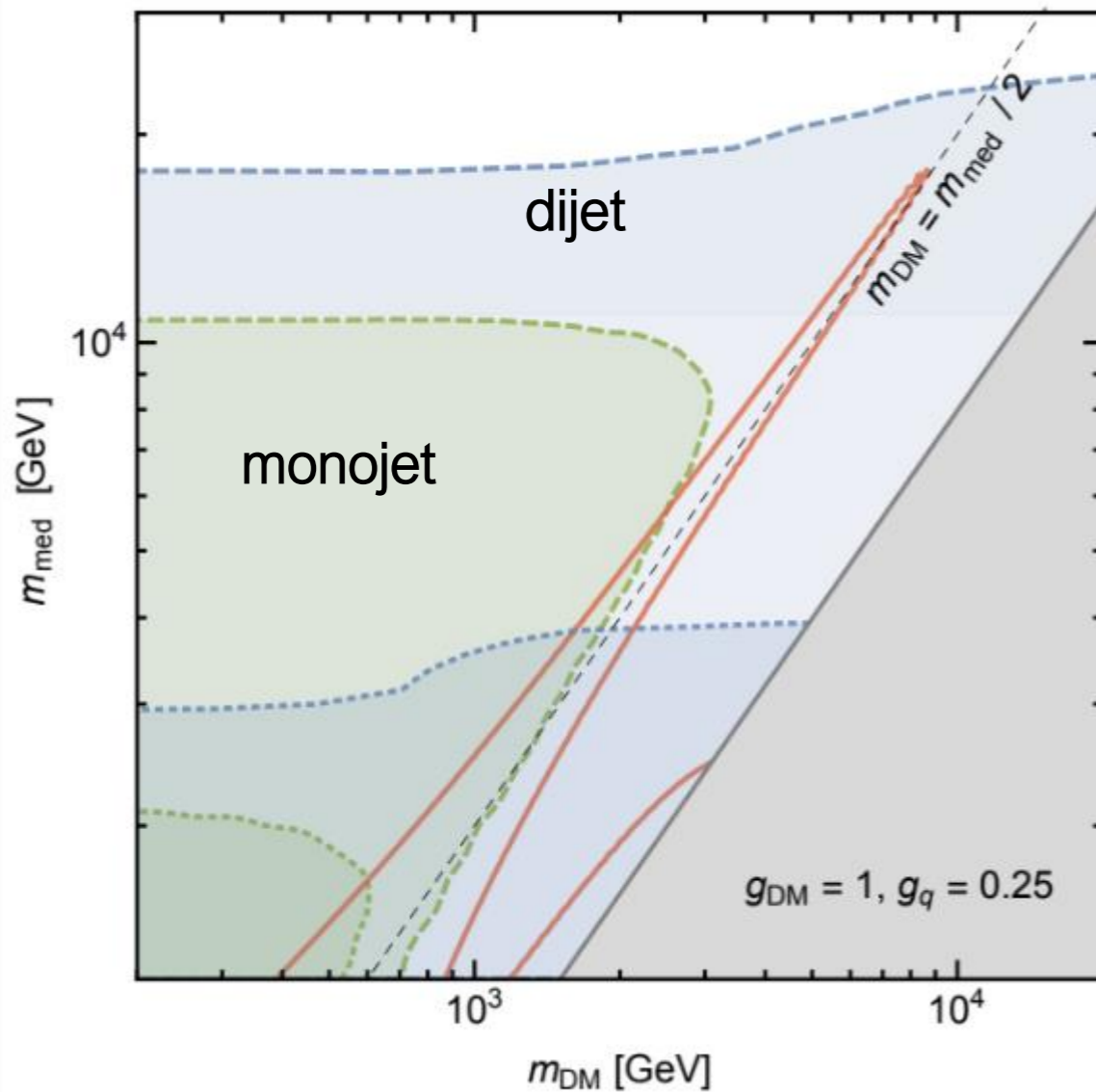
[du Pree, Hahn, Harris, Roskas, 1603.08525 \[hep-ph\]](#)



Dark Matter

- In some concrete models, e.g. Z' mediators, FCC-hh can cover a large fraction of the full parameter space
- For reasonable couplings FCC-hh reach extends to more than 10 TeV (DM and mediator mass)

FCC Yellow Report, CERN-2017-003-M



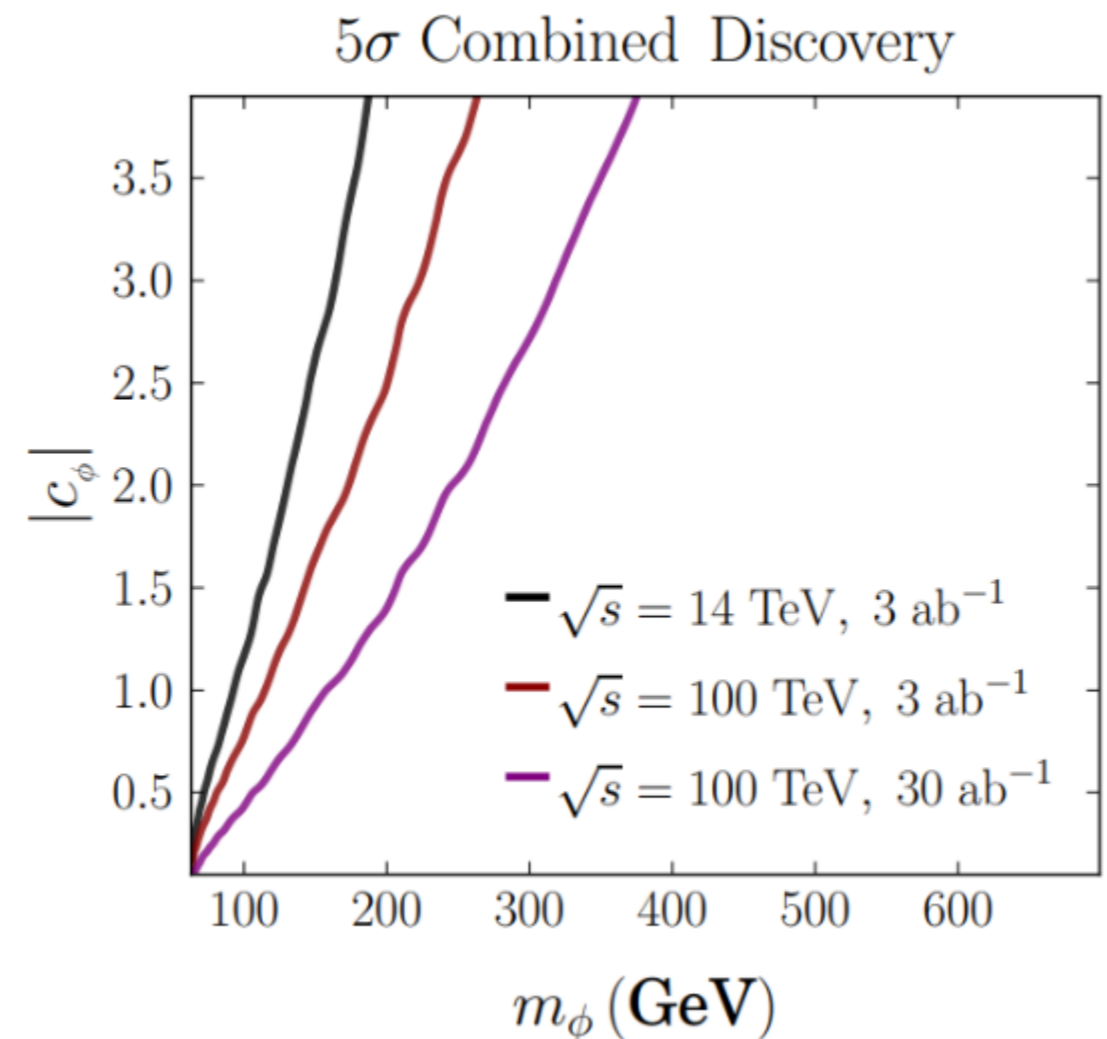
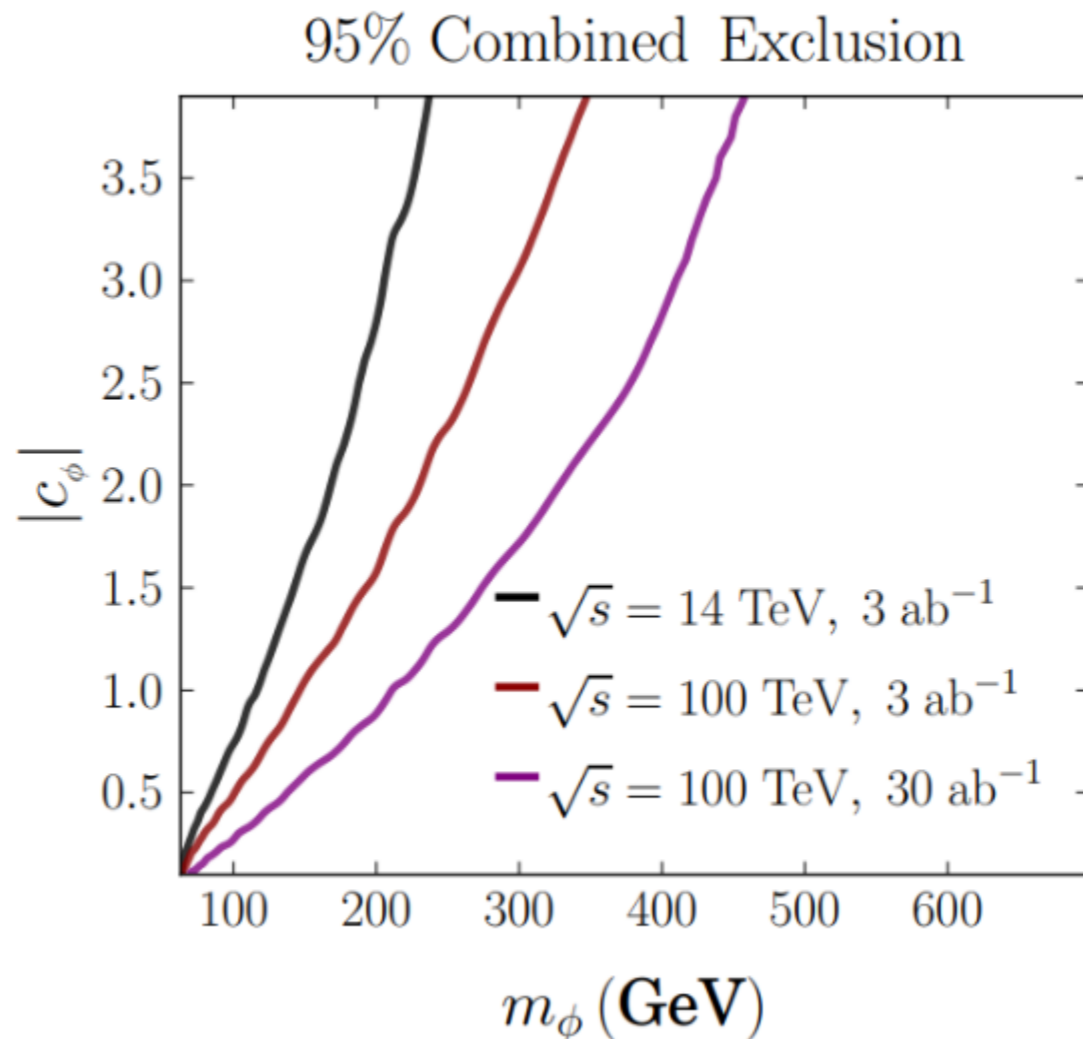
[See talk by Bramante @ 2nd FCC Physics Workshop](#)

Higgs portal

- Higgs portal models are relevant for different scenarios ranging from Dark Matter to Electroweak phase transition and Baryogenesis
- Simplest example: new EW singlet with Z_2 symmetry

$$\mathcal{L} = \mathcal{L}_{\text{SM}} - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}M^2\phi^2 - c_\phi|H|^2\phi^2$$

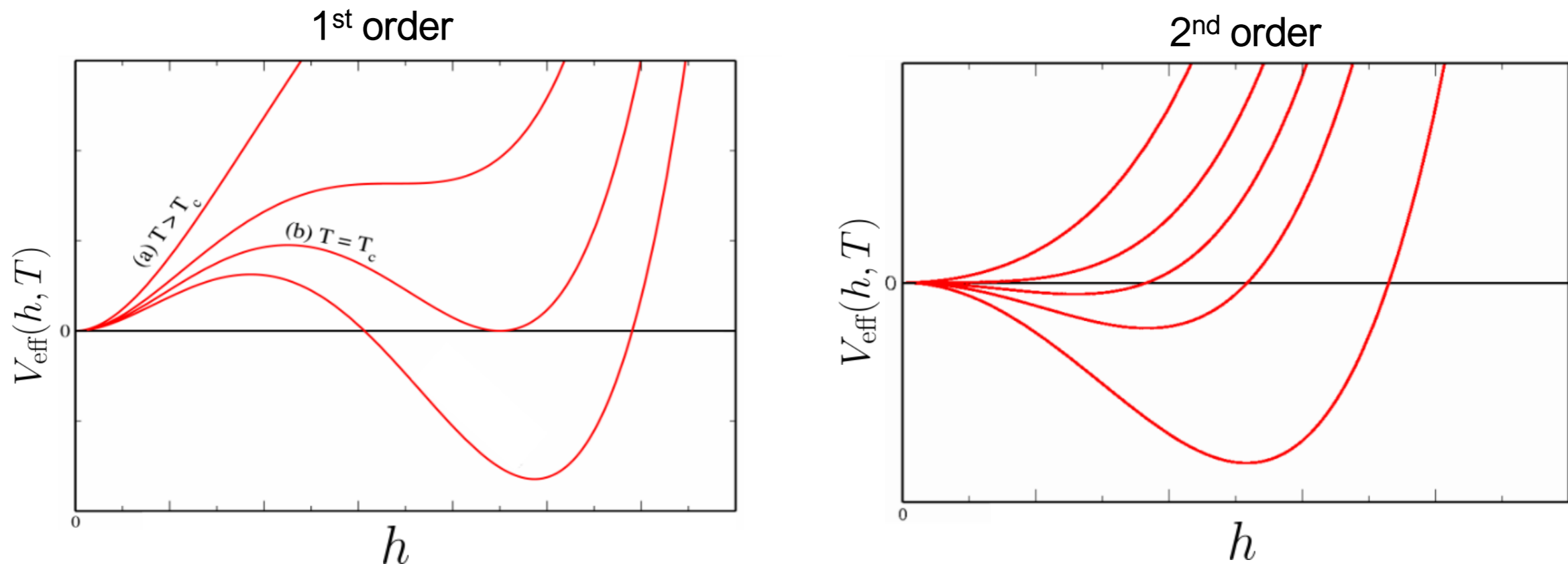
Craig, Lou, McCullough, Thalappilil 1412.0258 [hep-ph]



EW phase transition

- Describes EWSB in early universe
- Possible cosmological relics
- Possible mechanism to generate Baryon Asymmetry (Baryogenesis)

$$V_{\text{eff}}(h, T) = V_0(h) + V_0^{\text{CW}}(h) + V_T(h, T)$$



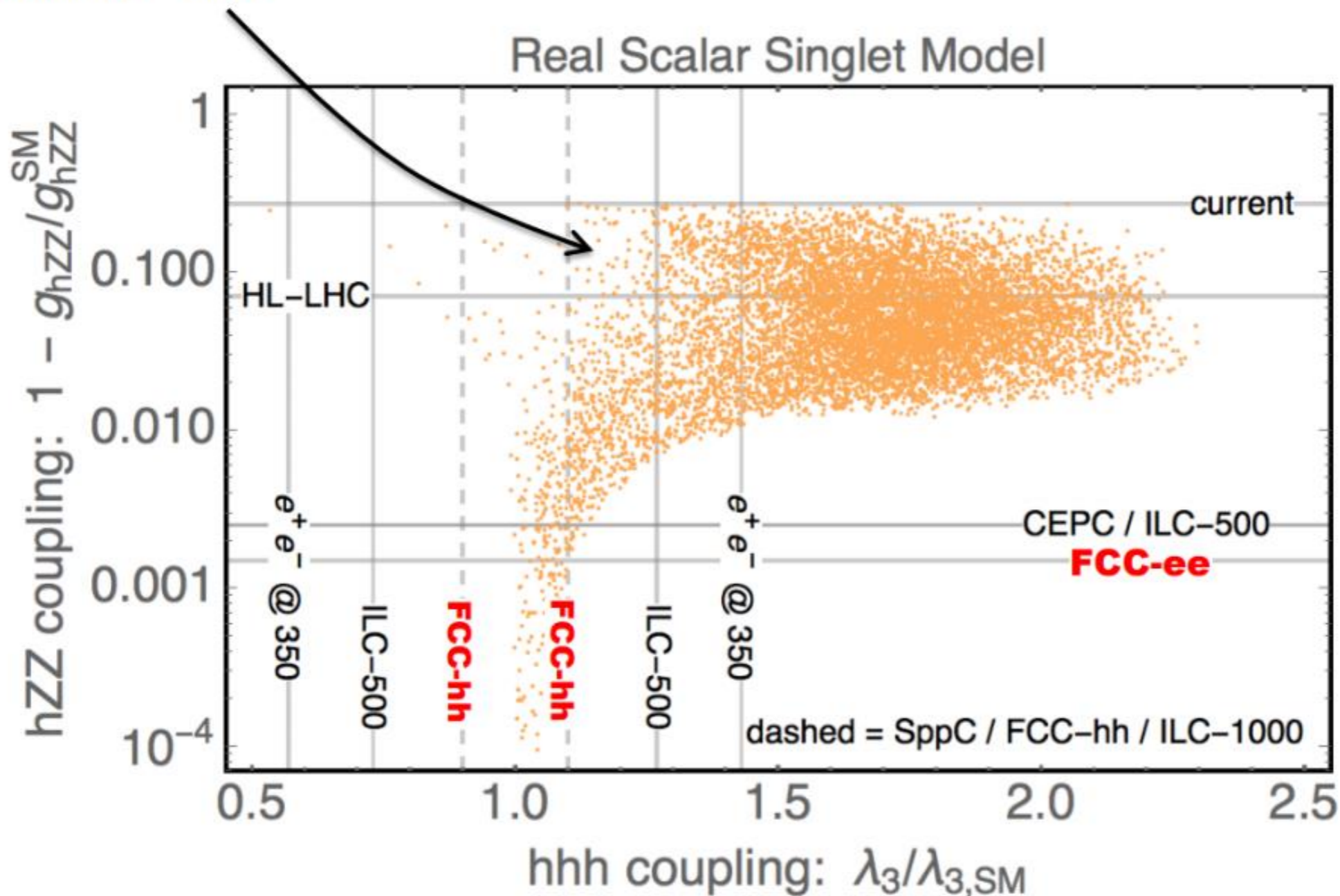
- In the SM the phase transition is smooth (2nd order)
- Need new physics that modifies the scalar potential to get a 1st order transition

EW phase transition

- The SM plus a real scalar singlet is the simplest scenario
- Viable parameter space can be tested at FCC-ee (hZZ) and FCC-hh (hhh)

Huang, Lou, Wang, I608.06619 [hep-ph]

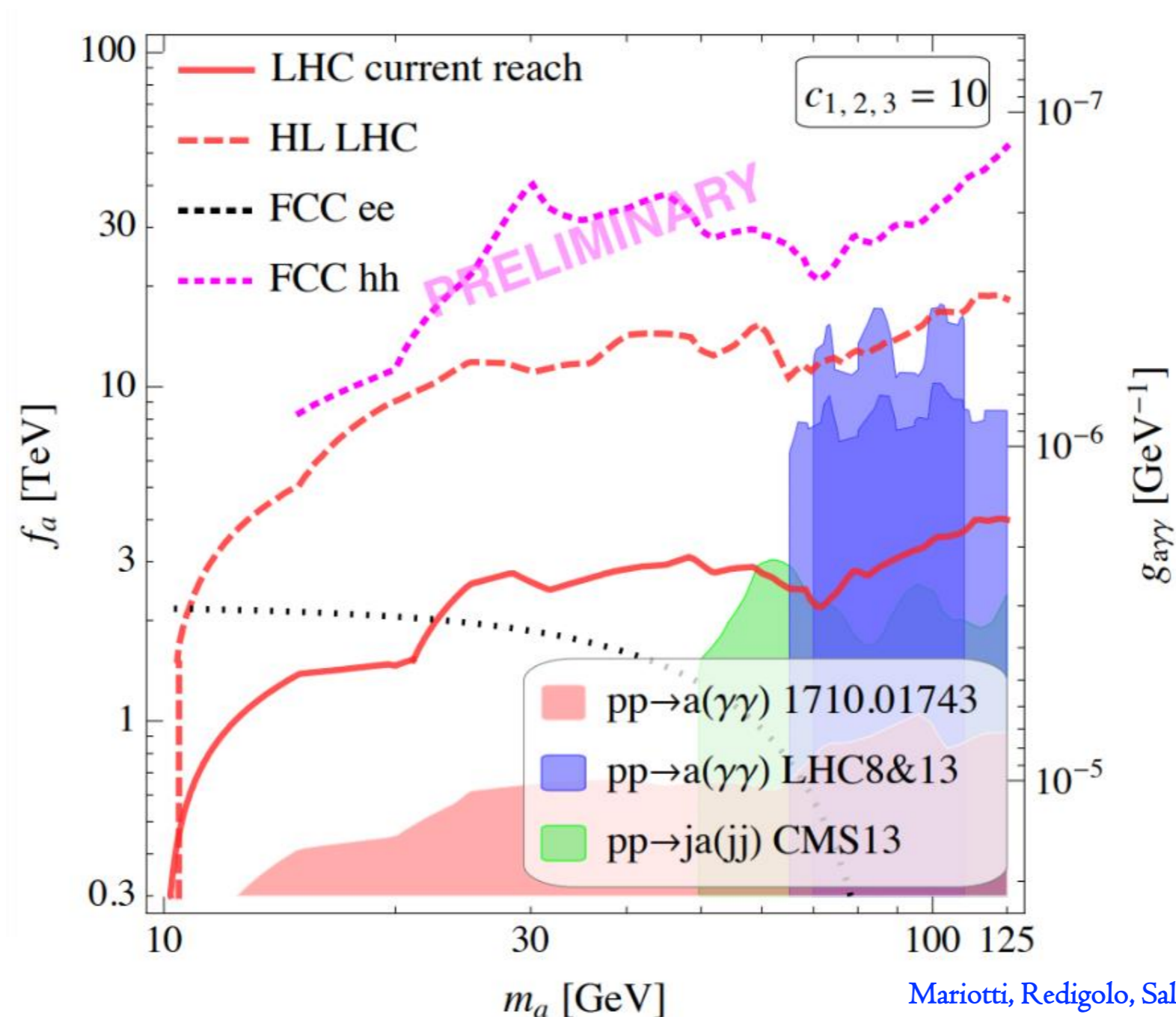
EWPT is 1st order



See talk by Long @ 2nd FCC Physics Workshop

Axion Like Particles

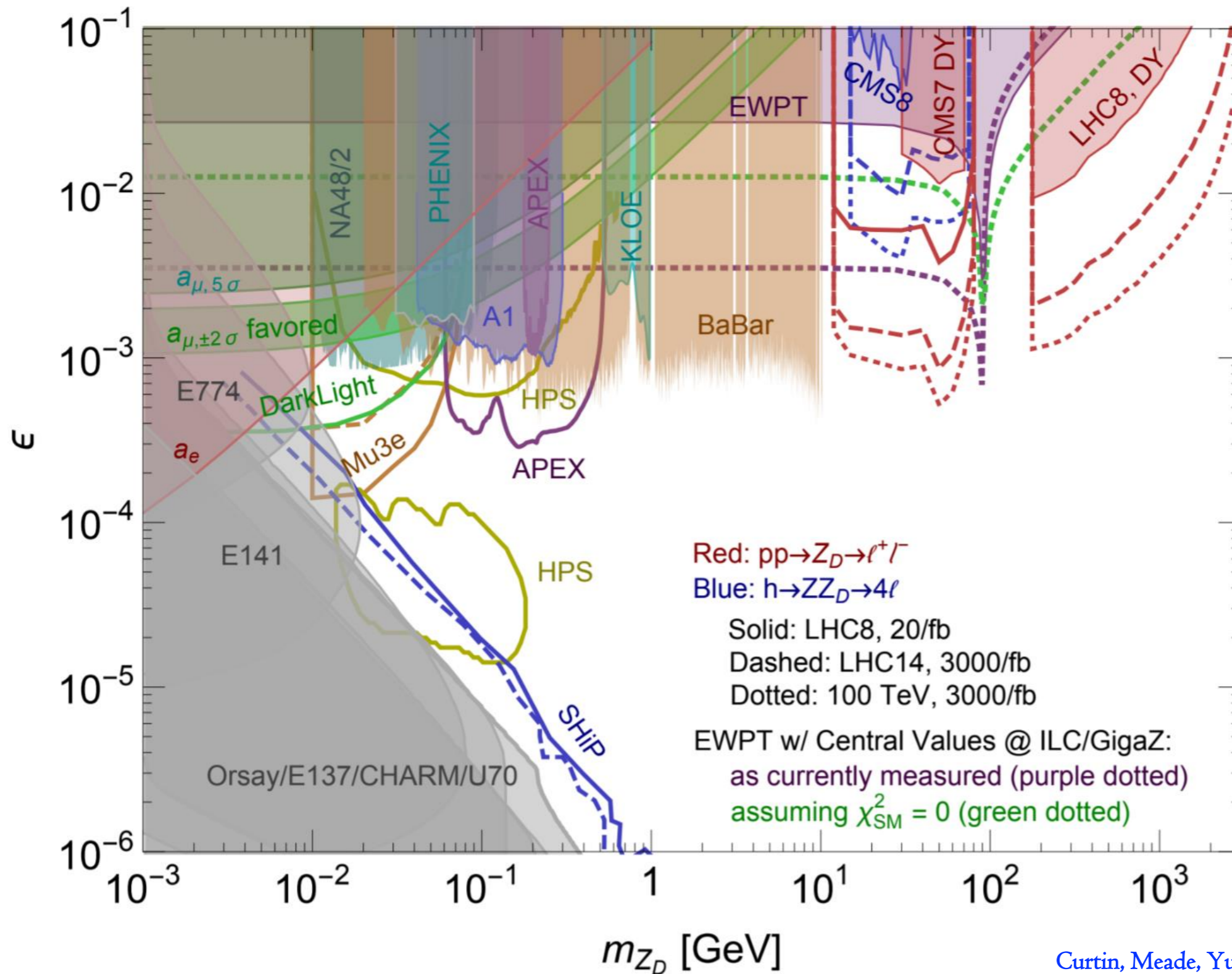
- Axion-like particles appear in many extensions of the SM
- They could have very different masses/couplings
- For instance ALPs can be constrained through di-photon searches



Mariotti, Redigolo, Sala, Tobioka, 1710.01743 [hep-ph]

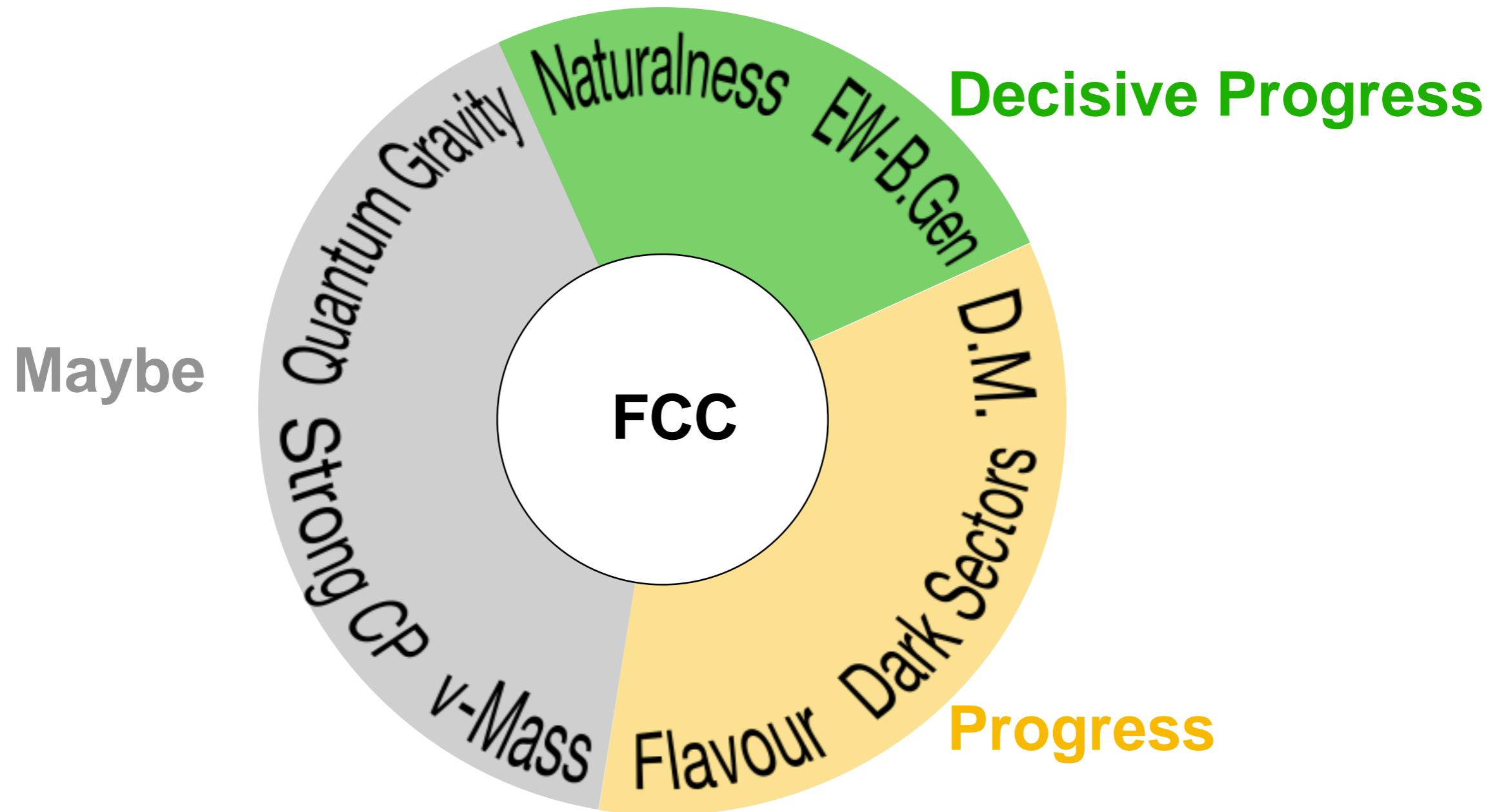
Dark photons

➤ Good interplay between FCC-ee and FCC-hh

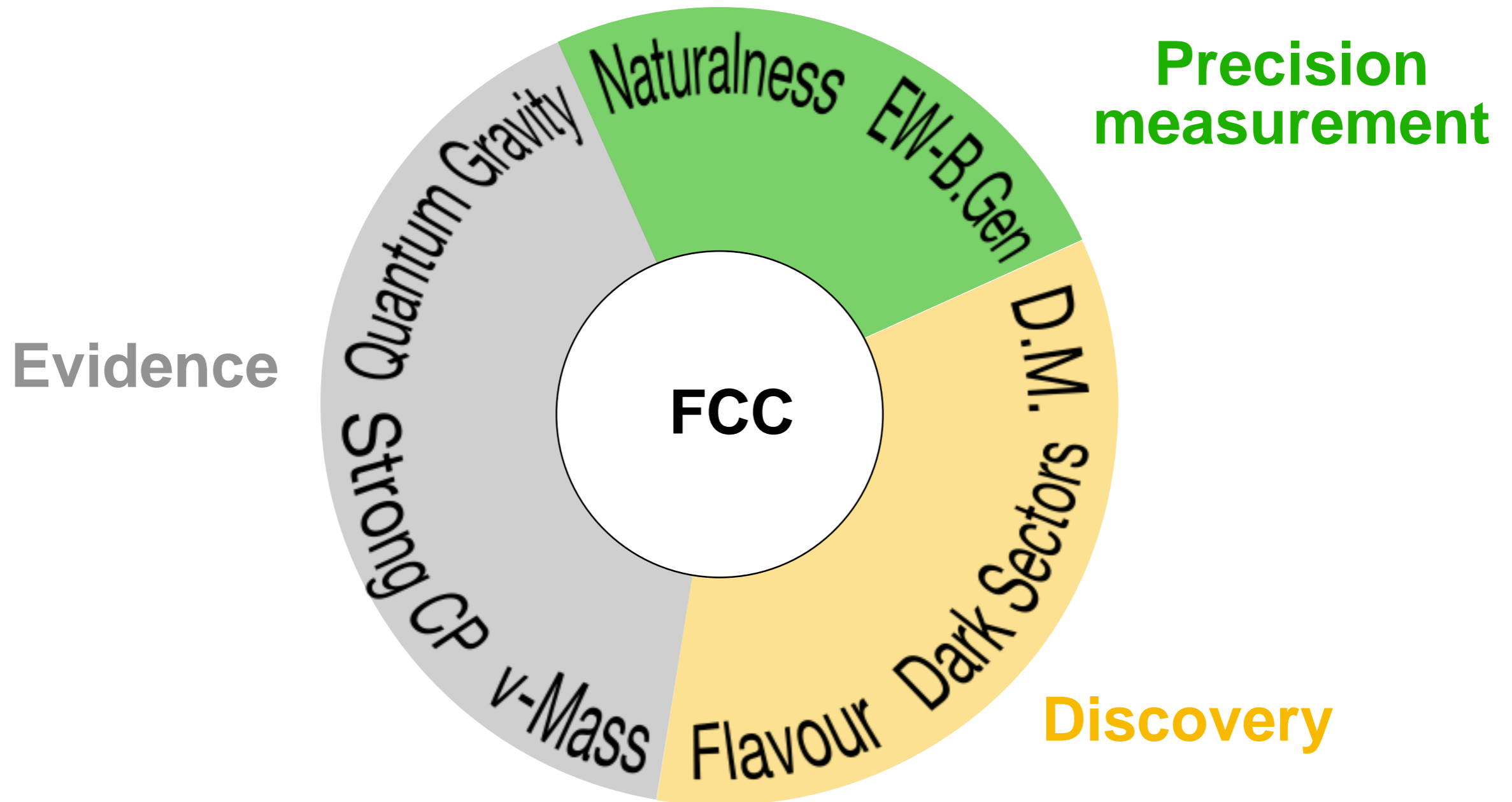


Curtin, Meade, Yu, 1409.0005 [hep-ph]

Summary...



... or, more optimistically



THANK YOU