

THEORY MOTIVATIONS FOR FUTURE COLLIDERS



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CAP Congress 2026 Future Collider Symposium — June 24, 2026

DISCLAIMERS

I am a **BSM** theorist giving a **short** talk:

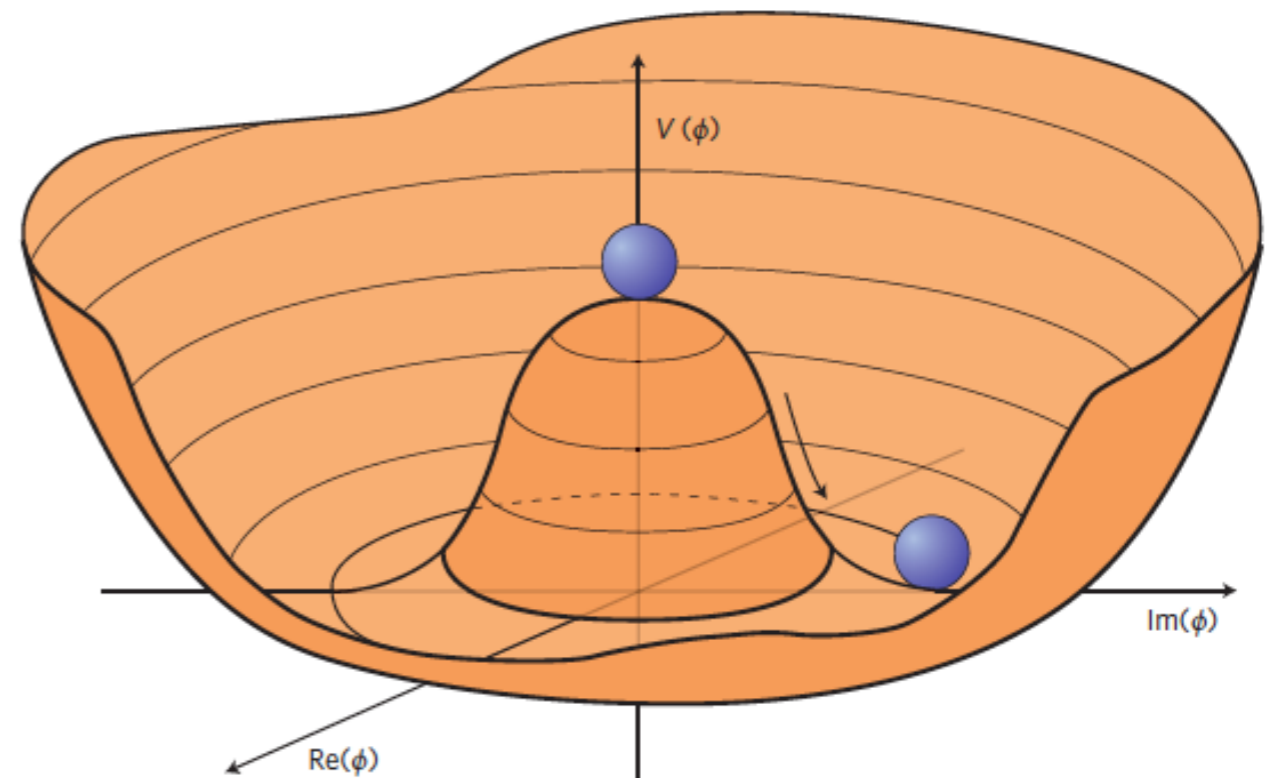
- Will not discuss flavour and neutrino experiments.
- Will not discuss many interesting topics including QCD, heavy ions, etc.
- These are the physics opportunities I find the most interesting.

See references in backup slides for much more.

HIGGS POTENTIAL

SM says Higgs breaks electroweak symmetry with this potential.

No direct experimental evidence of this.

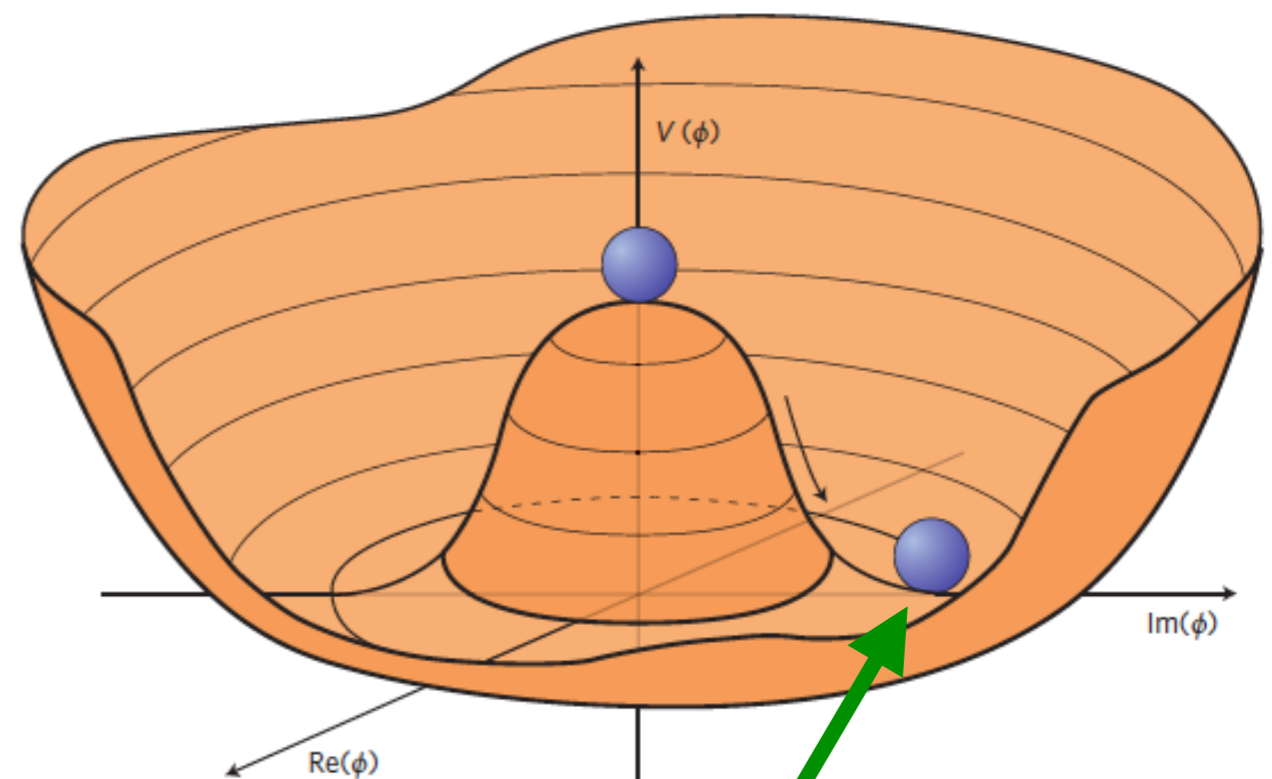


HIGGS POTENTIAL

SM says Higgs breaks electroweak symmetry with this potential.

No direct experimental evidence of this.

Can measure derivatives of potential.



Taylor series:

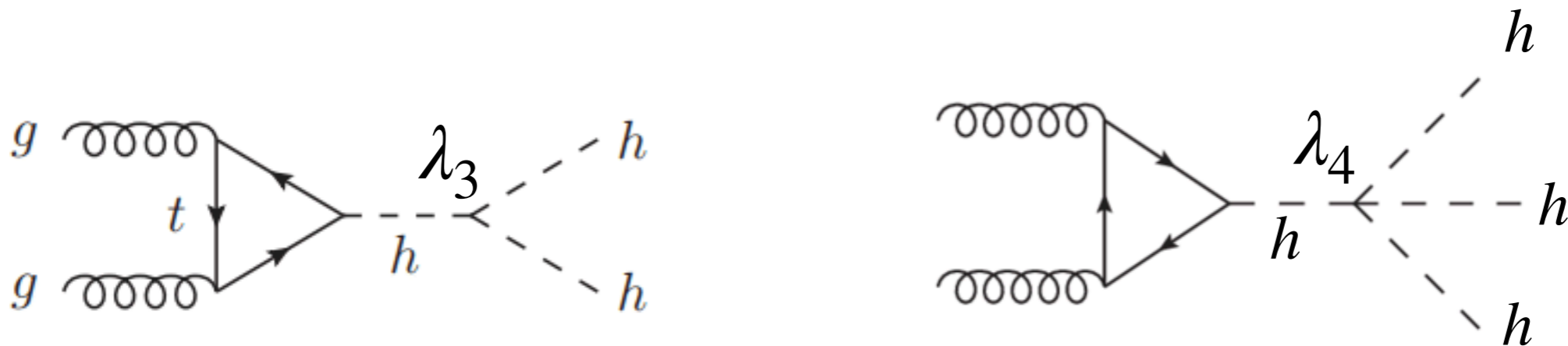
$$V(h) \sim \frac{1}{2}m_h^2 h^2 + \frac{1}{3!}\lambda_3 h^3 + \frac{1}{4!}\lambda_4 h^4 + \dots$$

N-HIGGS PRODUCTION

SM makes definite predictions for these coefficients:

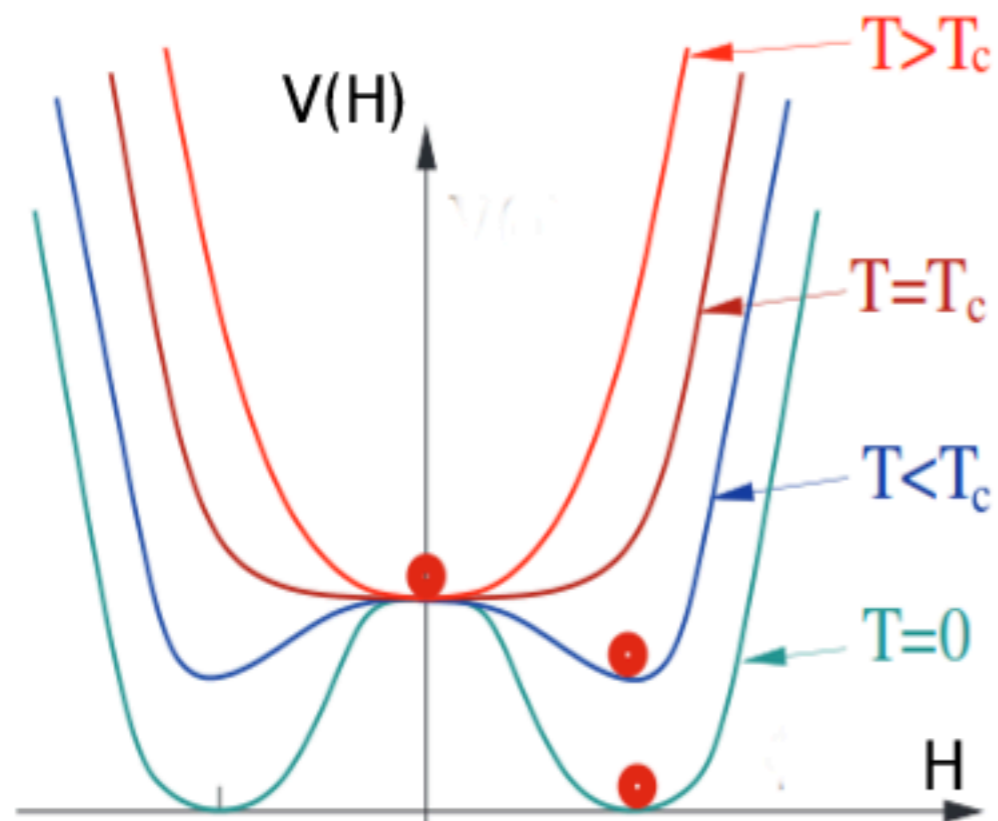
$$\lambda_3 \sim \frac{g m_h^2}{m_W} \quad \lambda_4 \sim \frac{g^2 m_h^2}{m_W^2}$$

Can directly measure these couplings with multi-Higgs production (very hard at LHC).



ELECTROWEAK PHASE TRANSITION

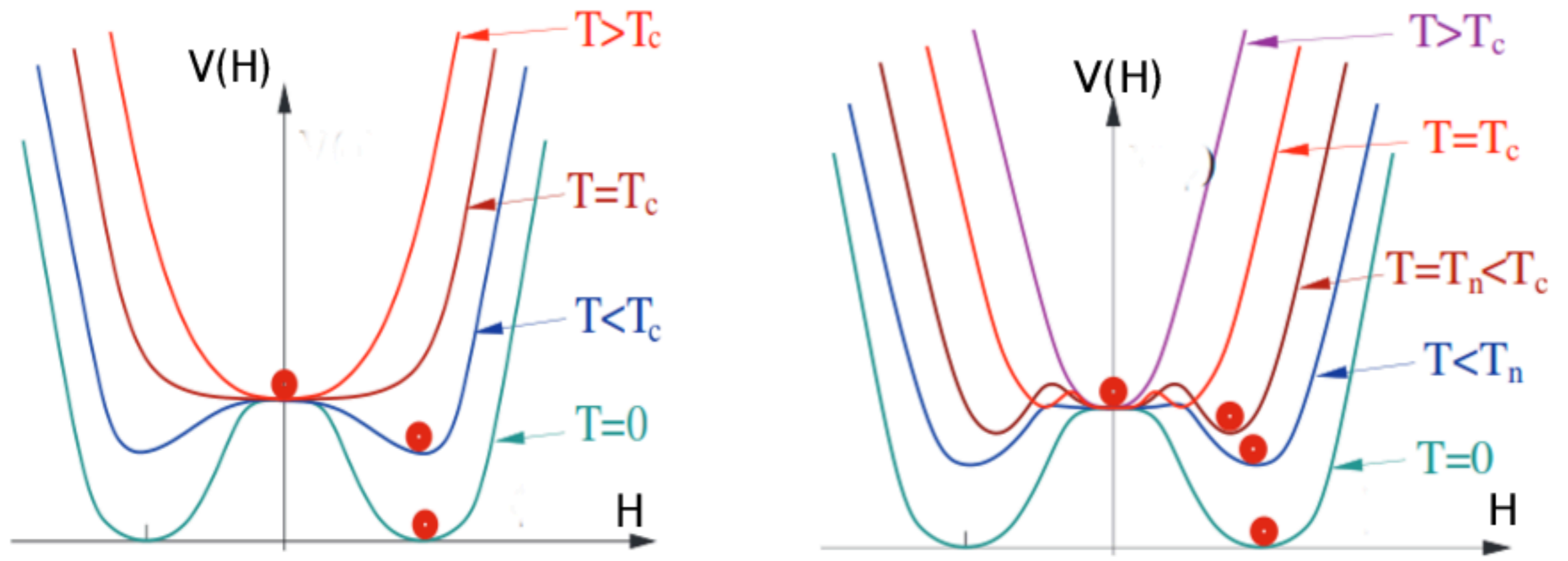
In the early universe, electroweak symmetry is restored.



SM predicts smooth transition from unbroken to broken phase.

ELECTROWEAK PHASE TRANSITION

In the early universe, electroweak symmetry is restored.

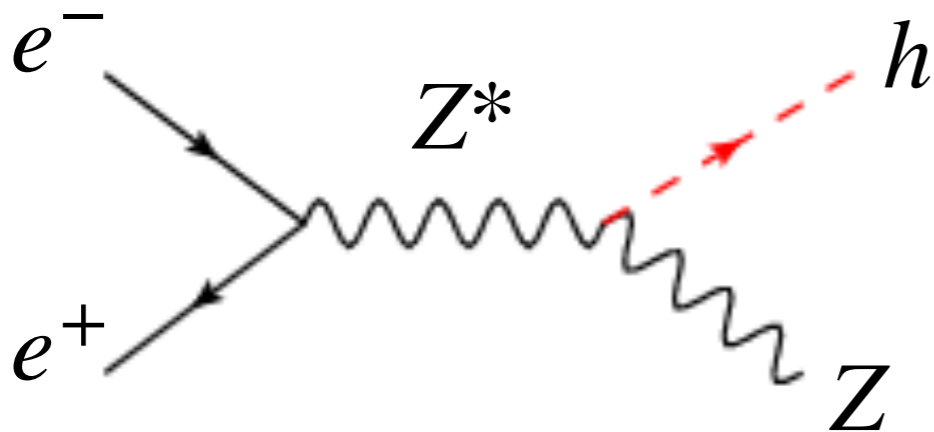


BSM theories (with new states) could have violent transition, possible baryogenesis mechanism.

[Curtin, Meade, Yu, arXiv:1409.0005.](#)

NEW LIGHT PARTICLES

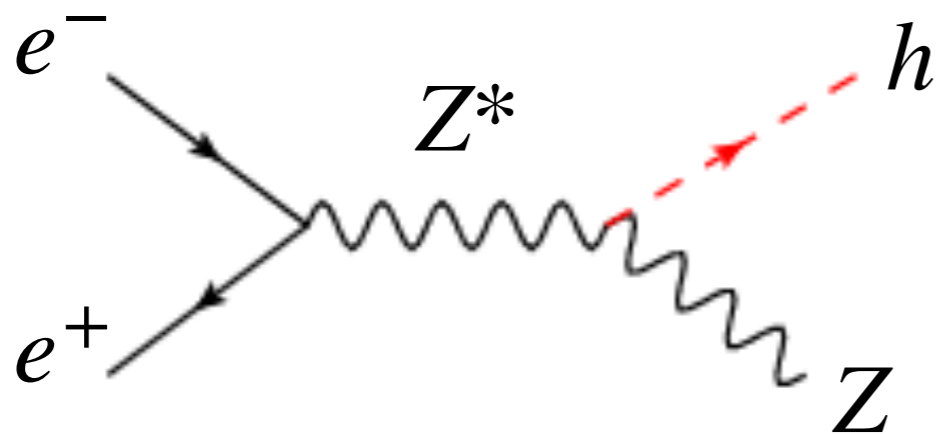
In lepton collider, can use knowledge of initial state to detect that a Higgs was created **without seeing it**.



Search for Higgs decays to new particles.

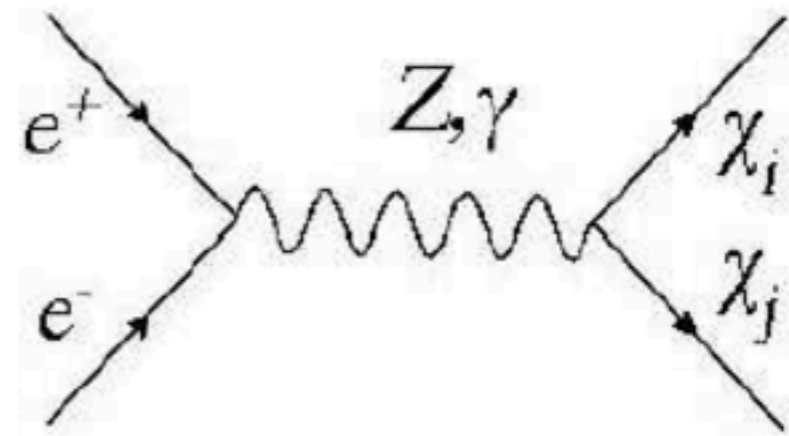
NEW LIGHT PARTICLES

In lepton collider, can use knowledge of initial state to detect that a Higgs was created **without seeing it**.



Search for Higgs decays to new particles.

Can also look for new electroweakly charged particles with difficult decays.



Could be connected to dark matter or SUSY.

NEW HEAVY PARTICLES

With 100 TeV CM, could discover:

- ~10 TeV coloured particles
- ~2 TeV electroweak particles
- ~20 TeV resonances

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Probing 10 TeV scale increases required tuning of weak scale from 1/100 to 1/10,000.



PROBING HIGH SCALES

Precise measurements can be translated to limits (or discoveries!) of new physics at high scales.

Parameterize via **effective field theory** (very general).

Example:
$$\frac{\delta\Gamma_Z}{\Gamma_Z} \sim \frac{1}{500,000} \Rightarrow \Lambda \sim 50 \text{ TeV}$$

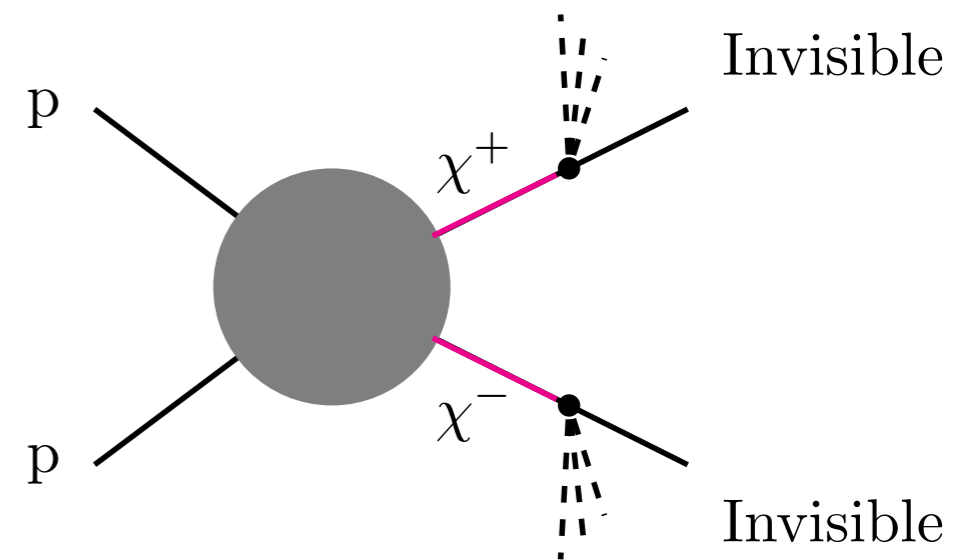
Can also do with W, Higgs, leptons, quarks...

DARK MATTER

WIMP classic (pure electroweak state) prefers a mass of 1-3 TeV.

Disappearing track search can probe cosmologically relevant parameters.

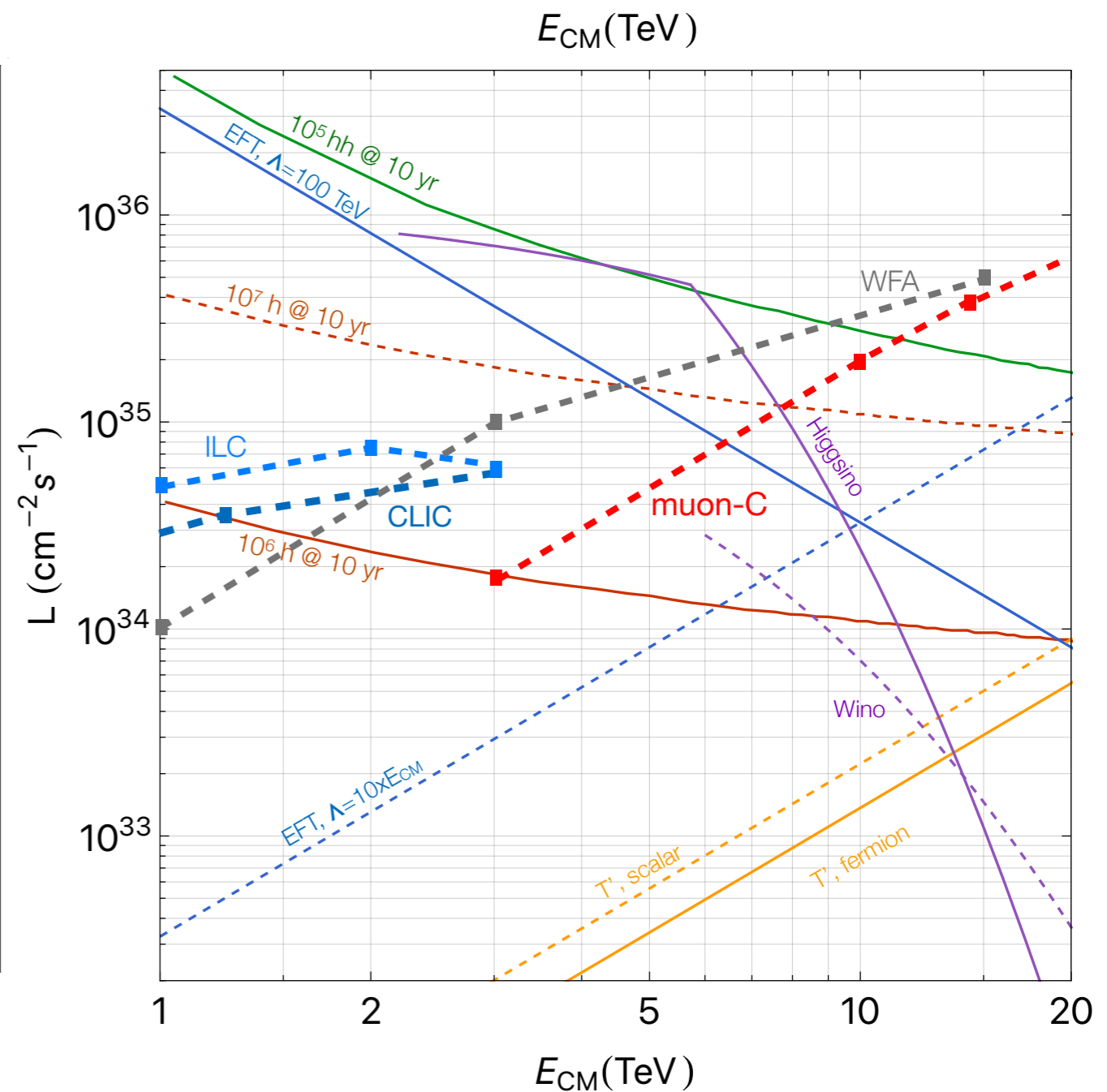
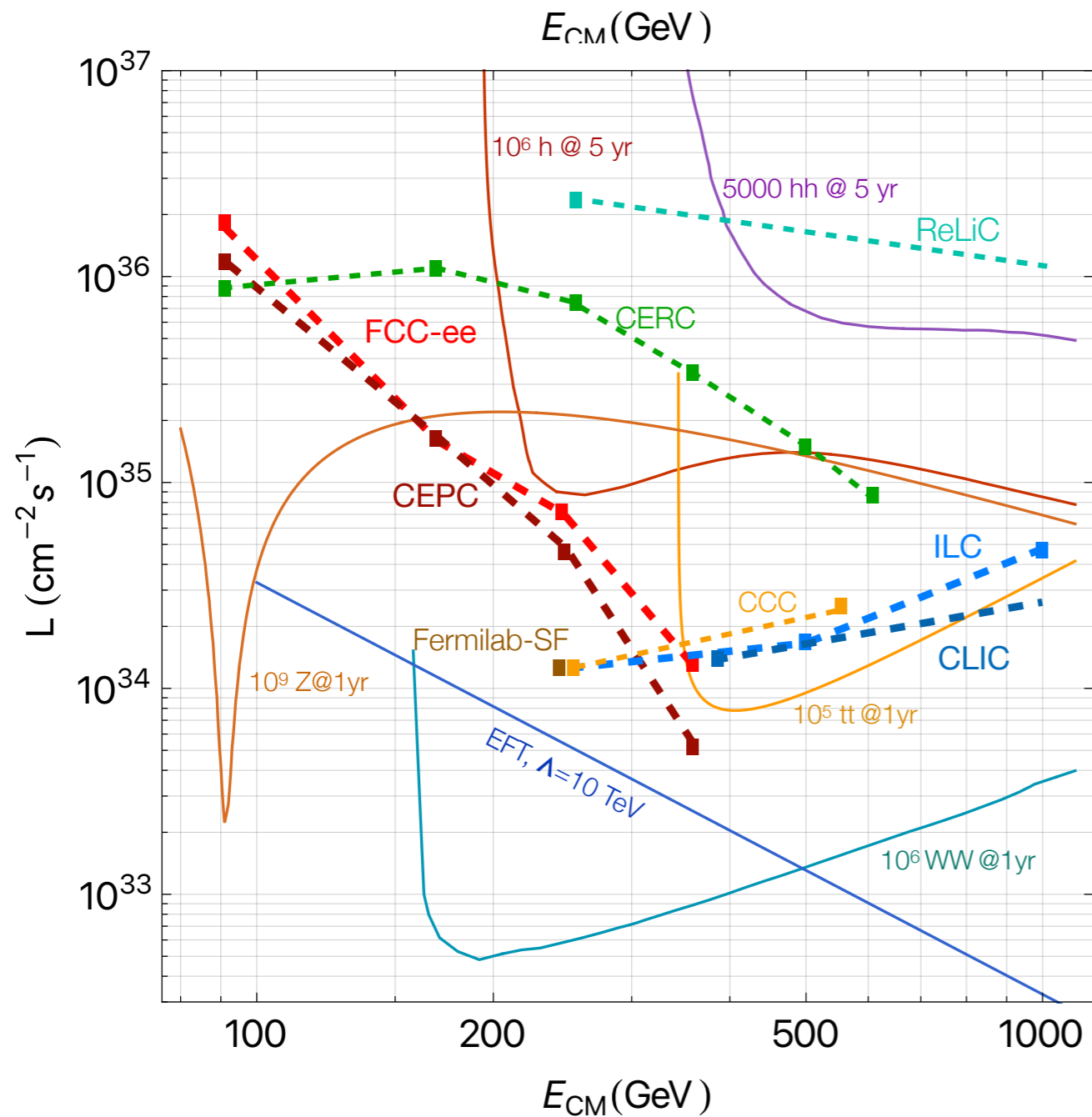
Also significant reach in mono-jets, mediator models, co-annihilation, asymmetric DM...



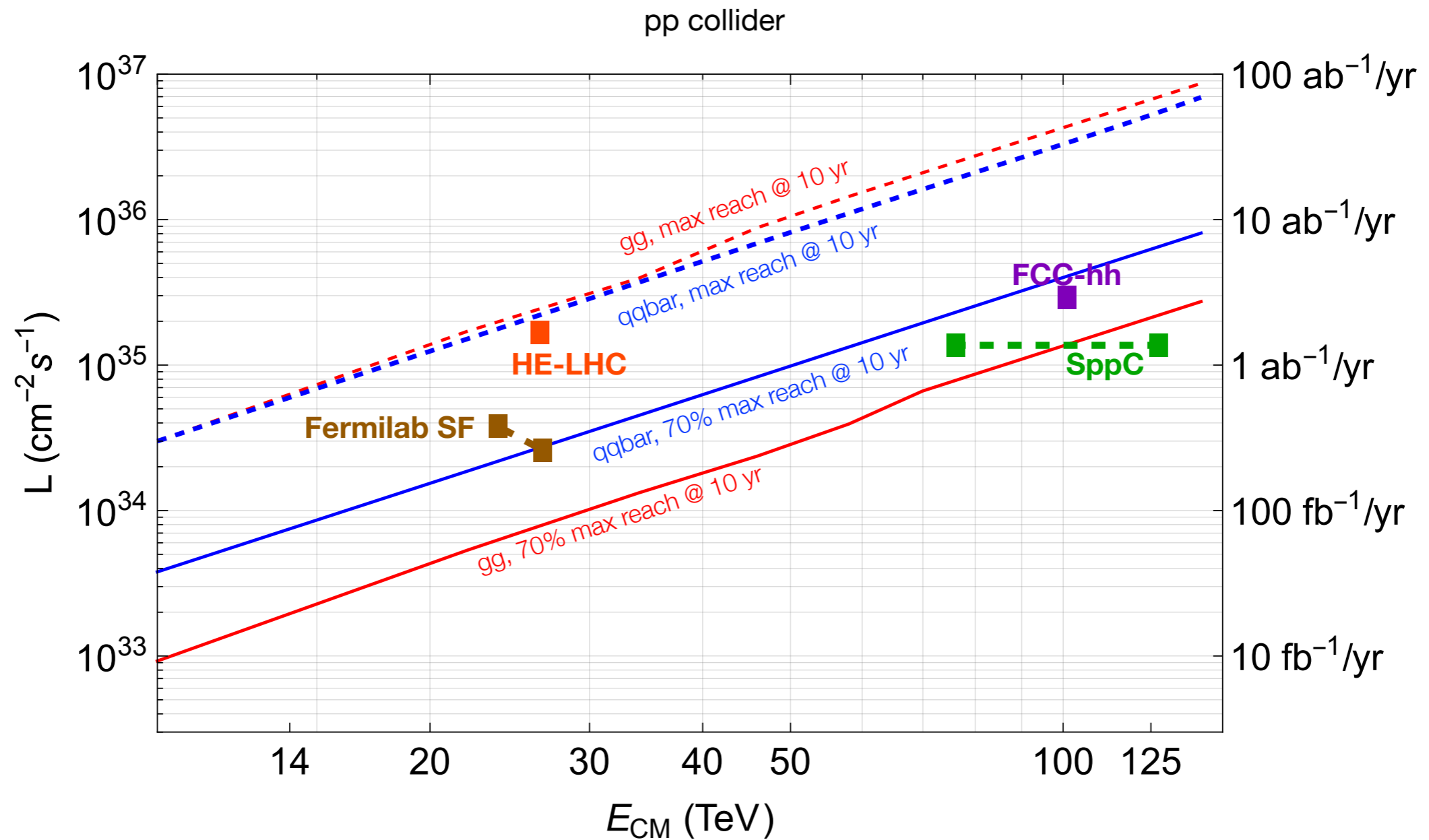
Mahbubani, Schwaller, Zurita,
arXiv:1703.0532

ENERGY VS LUMINOSITY

e^+e^- collider



E VS L HADRONS



Liu and Wang arXiv:2205.00031

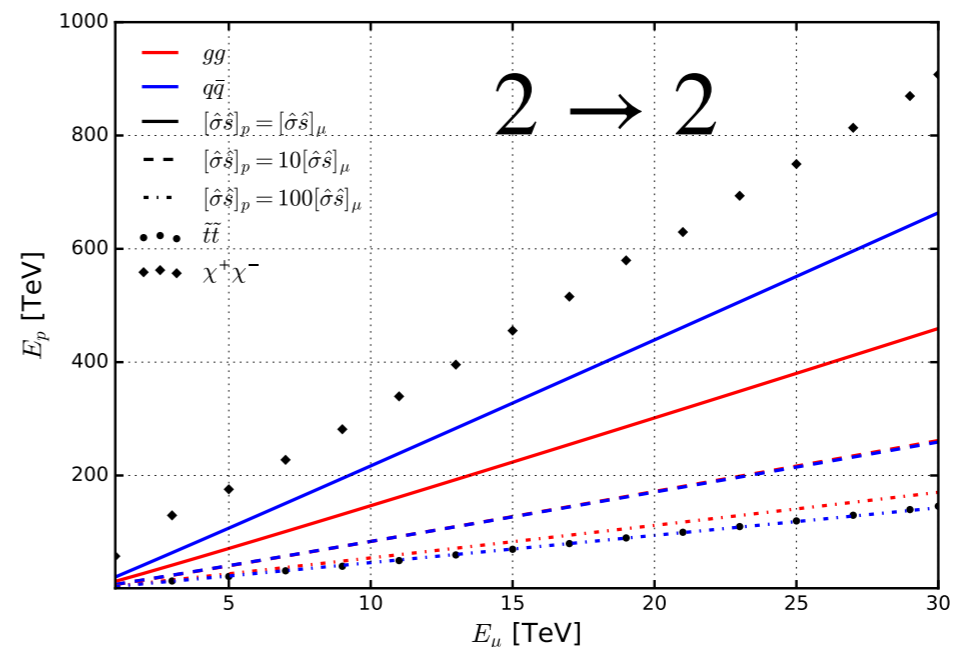
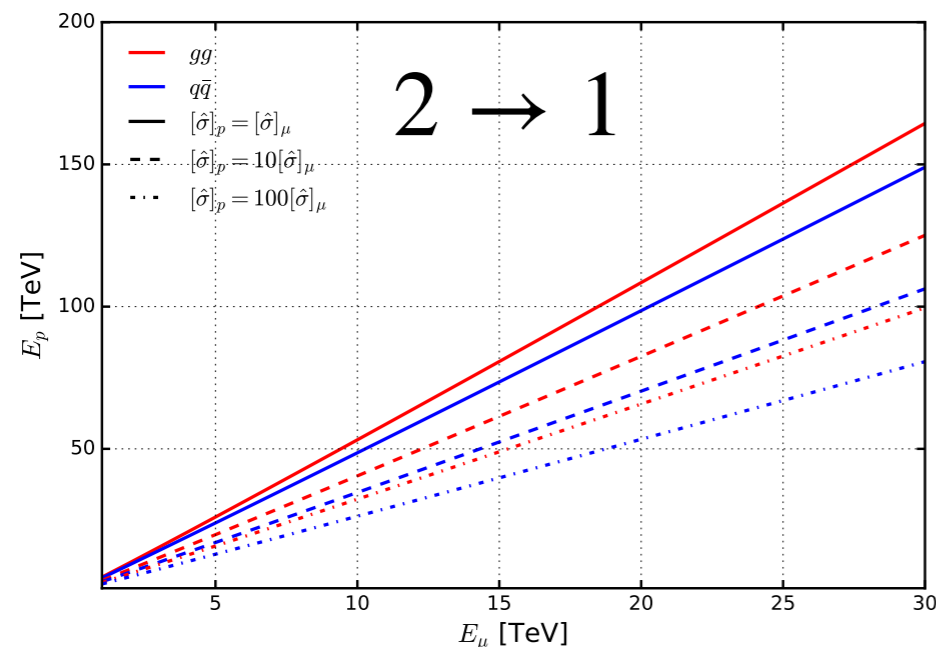
MUON COLLIDERS

Muon colliders can do it all!

Can reach much higher energies than electron collider.

Effective energy much higher than pp.

Costantini et al. arXiv:2005.10289



See slides from D. Curtin this morning.

GAUGE-HIGGS COUPLINGS

Higgs coupling to gauge bosons:

$$\mathcal{L} = h \left(\kappa_W g m_W W_\mu^+ W_\mu^- + \kappa_Z g \frac{m_Z^2}{2m_W} Z_\mu Z_\mu \right)$$

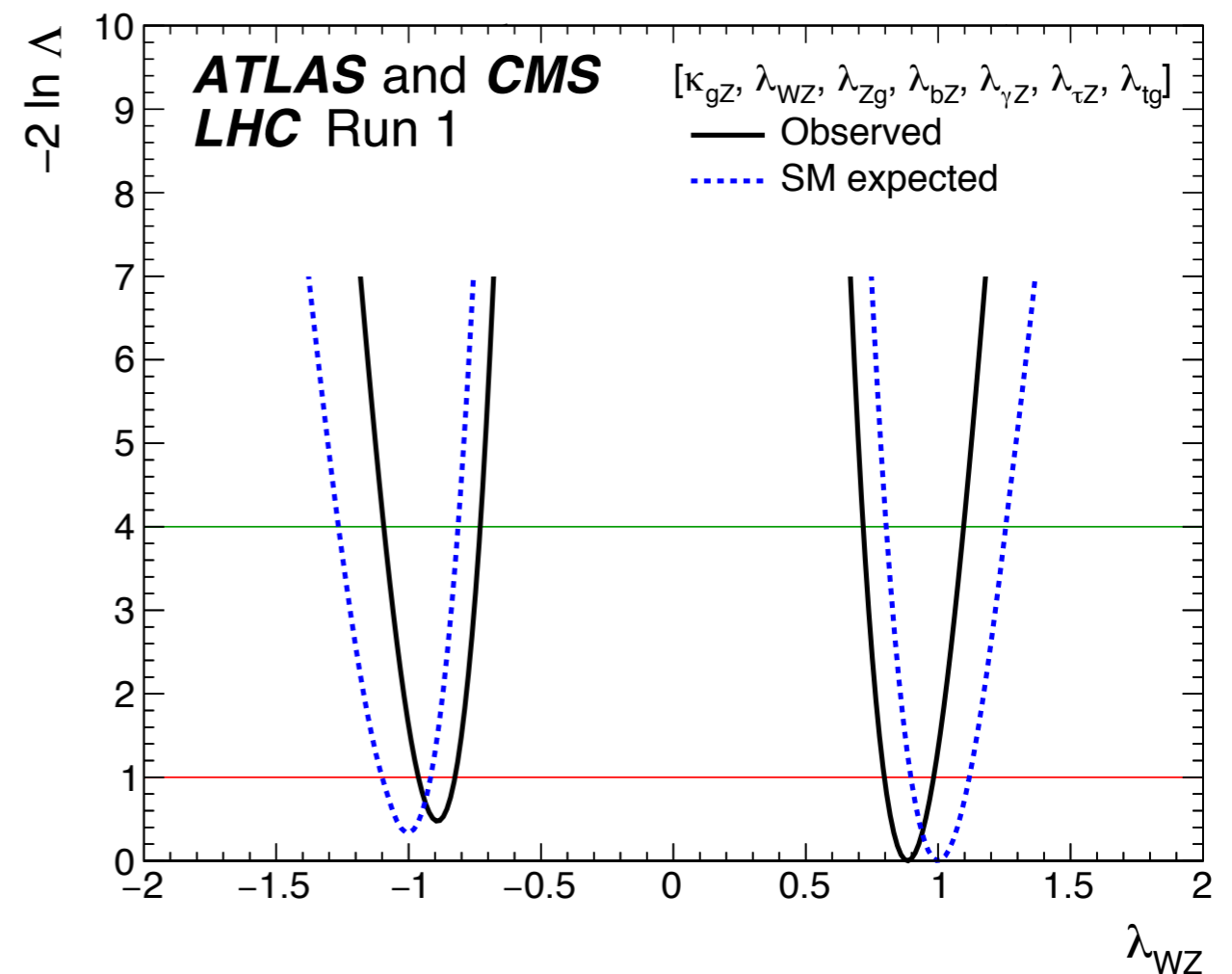
Parameterize deviation from SM with κ 's.

Also define: $\lambda_{WZ} = \frac{\kappa_W}{\kappa_Z}$

CONSISTENT WITH SM

λ_{WZ} also consistent with SM prediction.

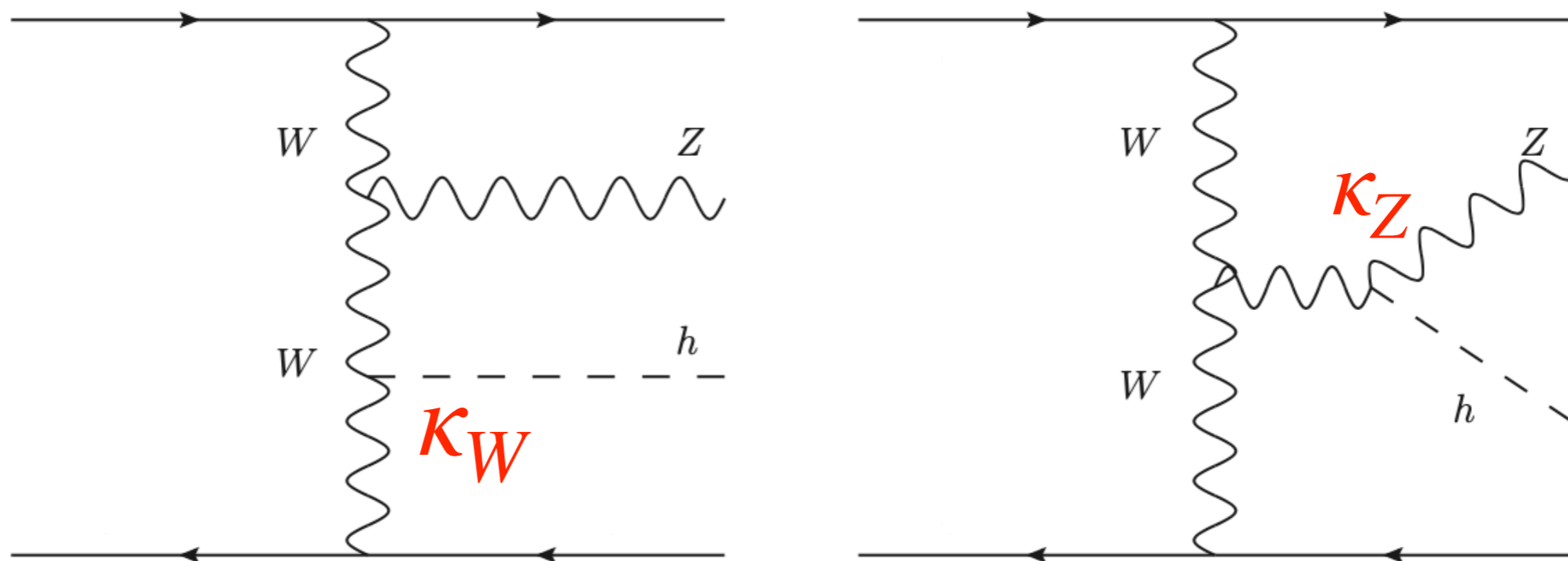
Very little sensitivity to the sign of λ_{WZ} !



ATLAS + CMS, arXiv:1606.02266.

VBF-VH PROCESS

Tree-level interference in VBF-VH very sensitive to relative sign of couplings.

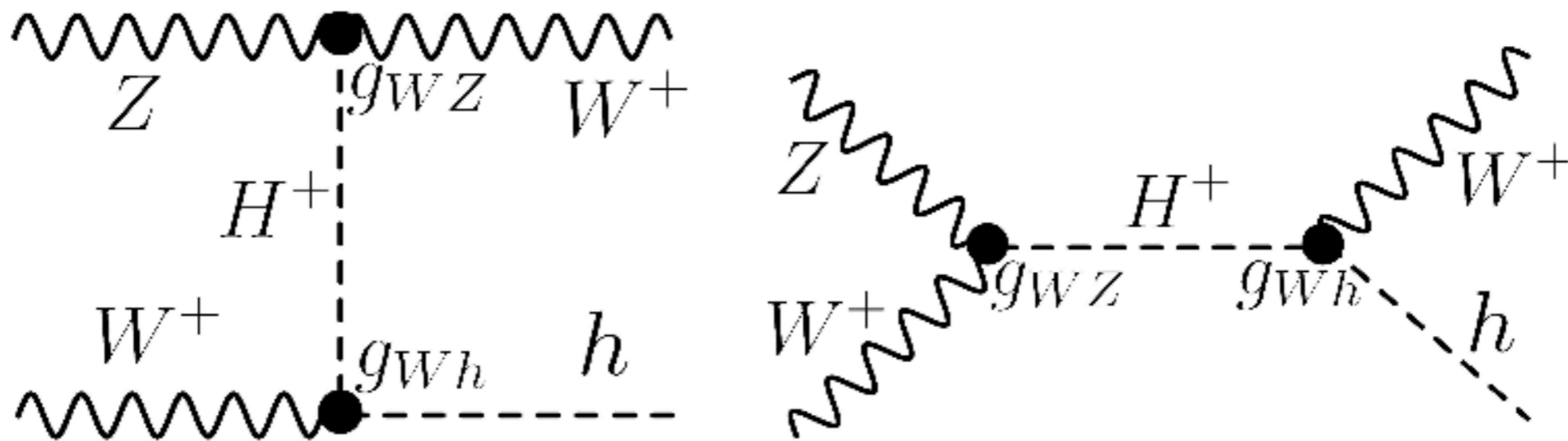


Very small cross section in SM, HL-LHC or future colliders can be valuable.

DS, Wu, 2006.09347.
de Lima, DS, 2404.10815.
de Lima, Tuckler, 2408.14536.

NEW STATES

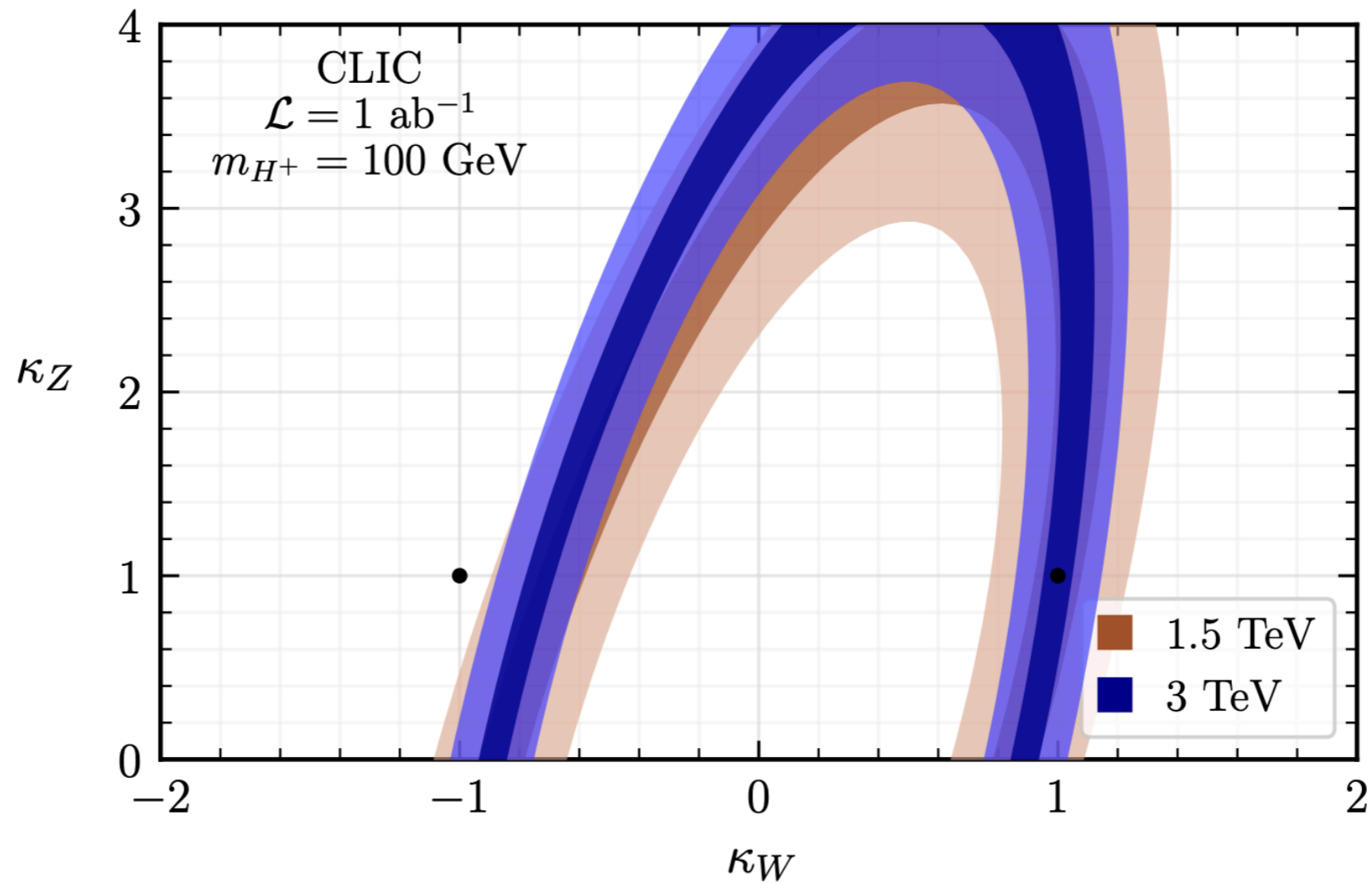
$\lambda_{WZ} = -1$ is definitionally beyond the SM and requires new light states.



Can model independently put bounds on these states independent of how they decay.

FUTURE COLLIDER RESULTS

VBF-ZH



de Lima, Tuckler, 2408.14536.

CHALLENGES

The physics case is the easy part!

Have to find funding for these machines.

Significant technology development is necessary:

- Better accelerator technology
- Better detector technology

**THANK
YOU**

REPORTS (ARXIV NUMBERS)

FCC Report: 2505.00272 and references therein.

Snowmass 2022 white papers:

- FCC-hh: 2204.10029
- FCC-ee: 2203.08310
- ILC: 2204.13627
- ReLiC: 2203.06476
- CERC: 2203.07358
- CEPC: 2205.08553
- CLIC: 2203.09186
- Electron ion: 2203.13199
- Muon collider: 2203.07361

MORE REPORTS

Some reports from earlier (arXiv numbers):

- 100 TeV pp BSM:
1606.00947
- 100 TeV pp Higgs:
1606.09408
- FCC-ee: 1308.6176
- ILC: 1306.6352
- CEPC: 1811.10545
- CLIC: 1812.07986
- LHeC and FCC-he:
2007.14491
- Muon Collider:
2005.10289