DISCOVERY OPPORTUNITIES AT FUTURE COLLIDERS

Carleton University

DANIEL STOLARSKI

TRIUMF Science Week — August 20, 2020

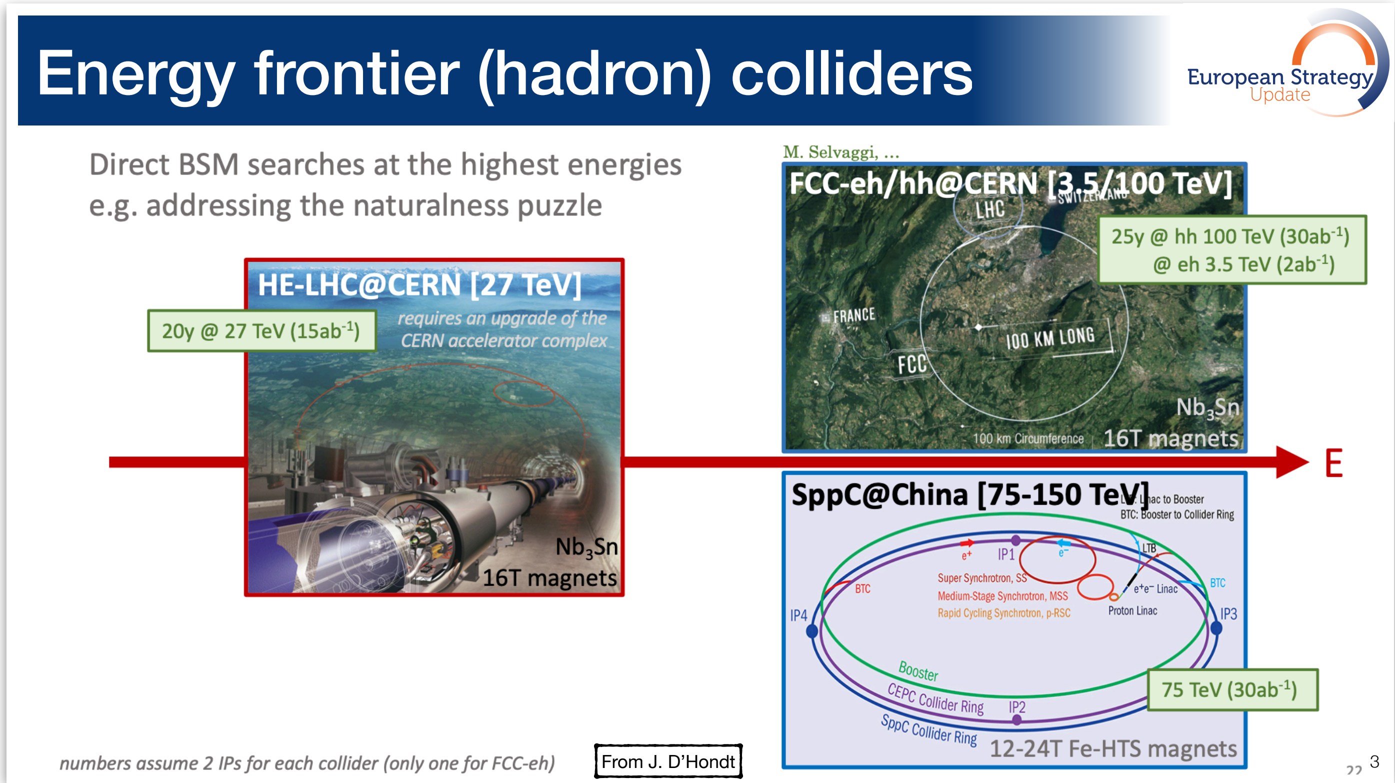
DISCLAIMERS

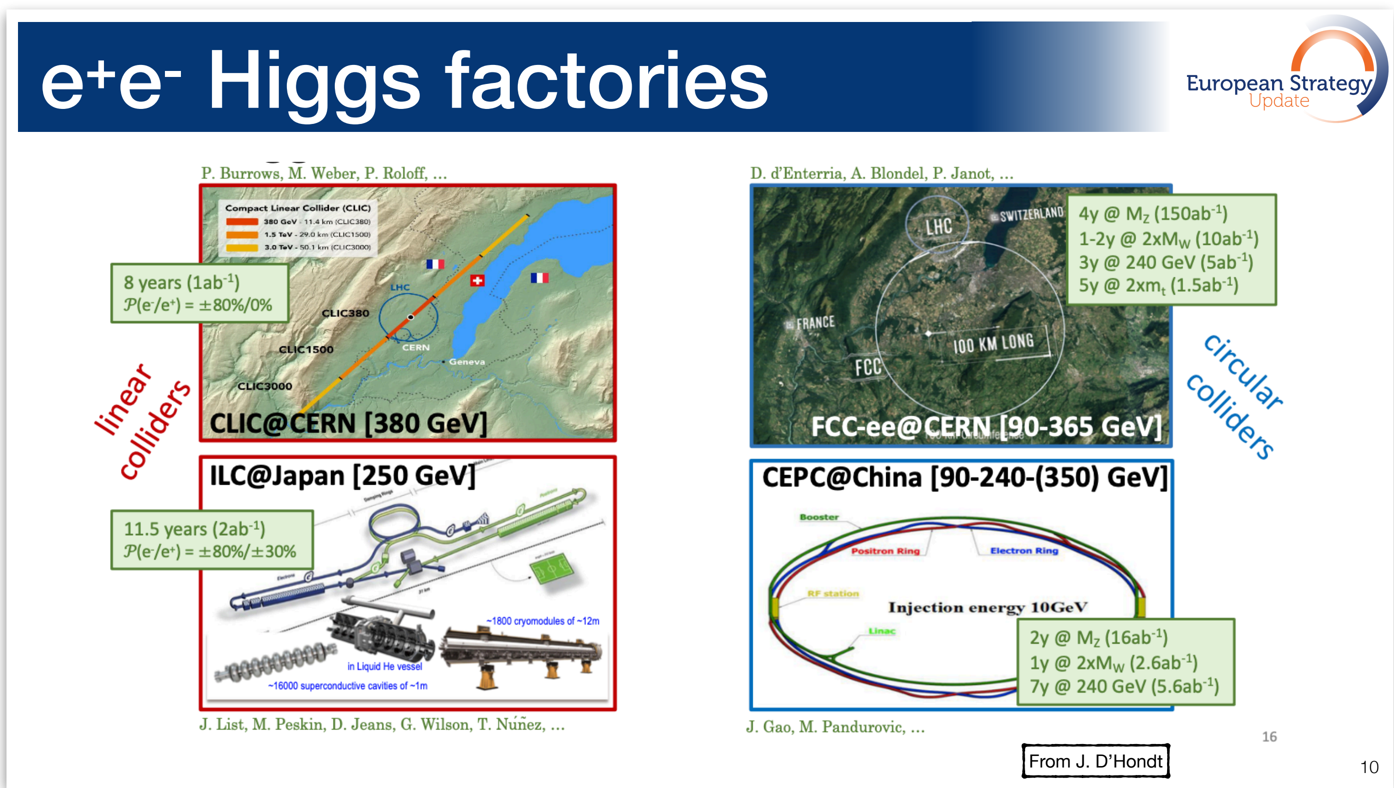
I am a BSM theorist giving a short talk:

- Will not compare different accelerator concepts.
- Will not discuss many interesting topics including QCD, heavy ions, etc.
- Incomplete list of BSM discovery opportunities.

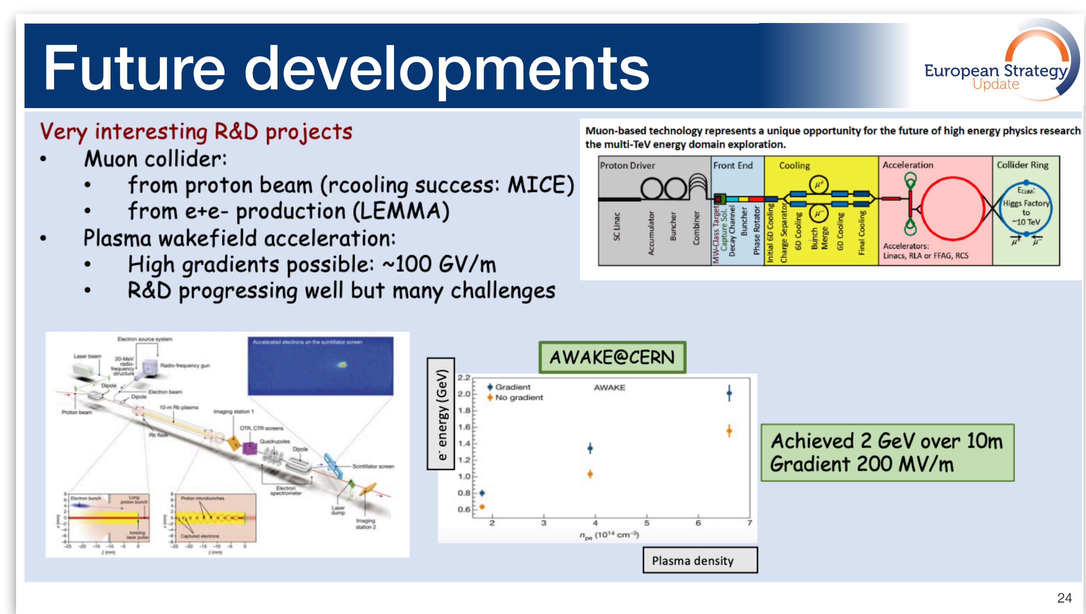
See references in backup slides for much more.

FUTURE ACCELERATORS





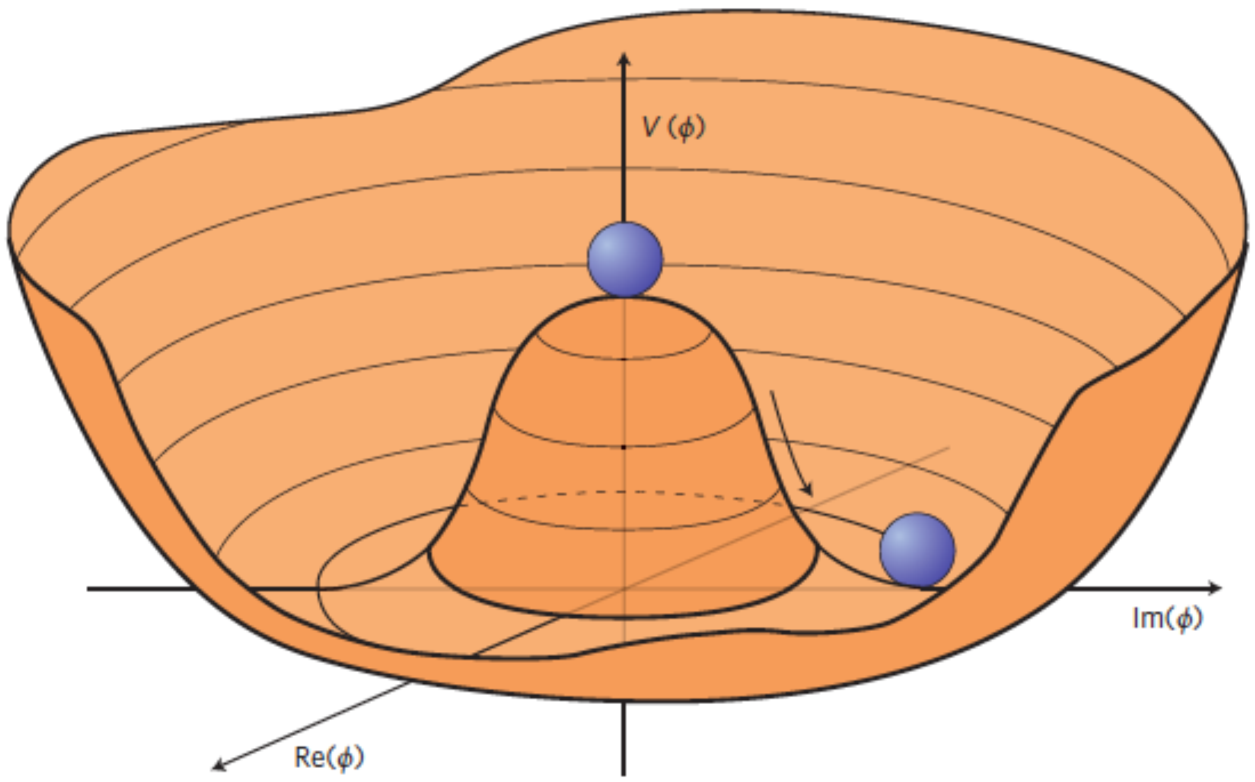
See talk by B. Vachon on Tuesday.



HIGGS POTENTIAL

SM says Higgs breaks electroweak symmetry with this potential.

No direct experimental evidence of this.

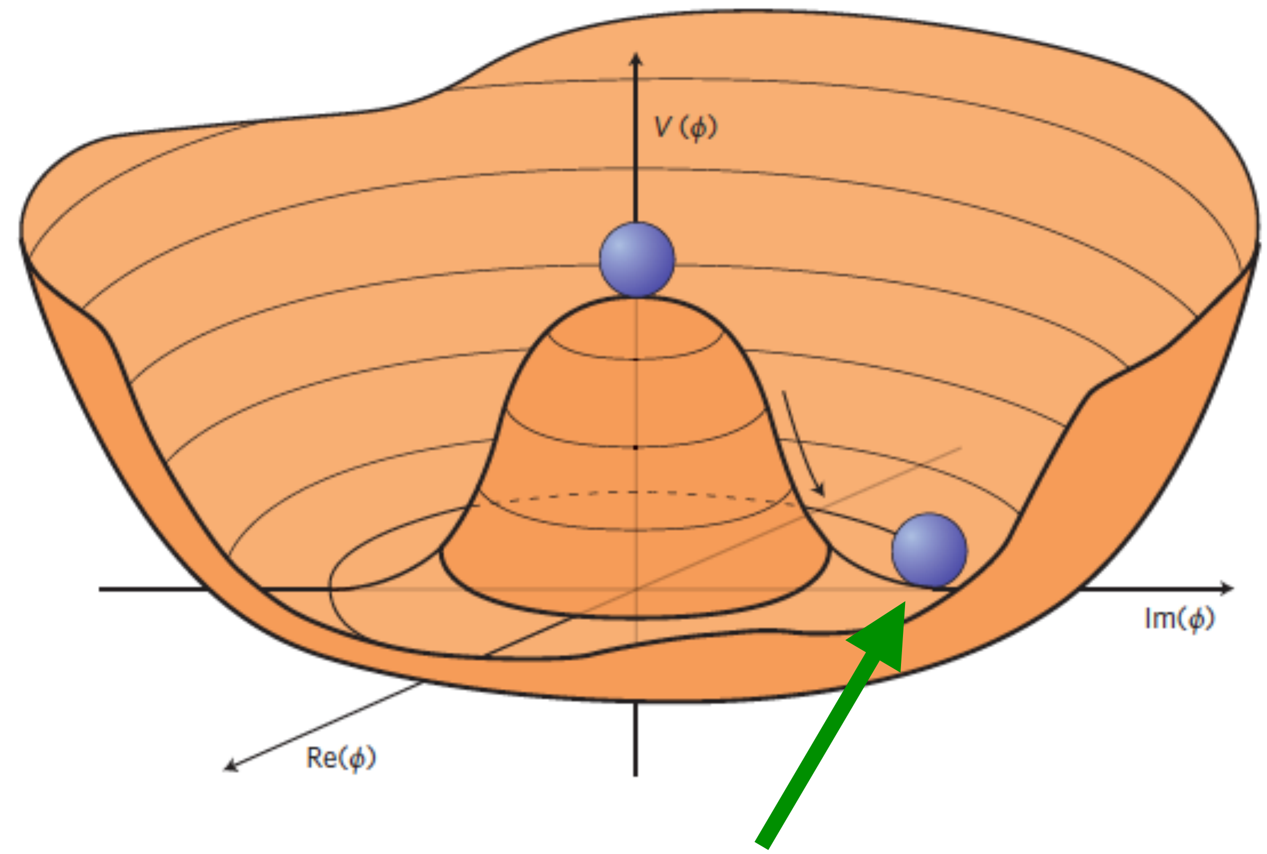


HIGGS POTENTIAL

SM says Higgs breaks electroweak symmetry with this potential.

No direct experimental evidence of this.

Can measure derivatives of potential.



Taylor series:

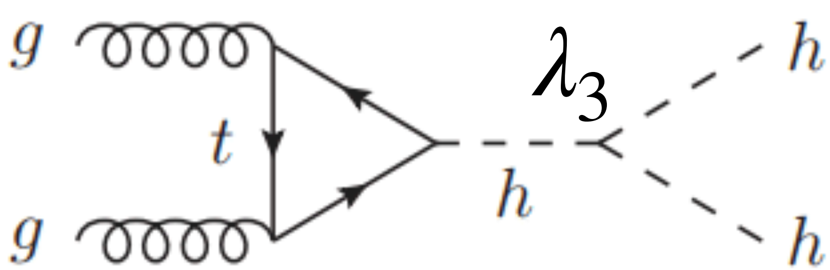
$$V(h) \sim \frac{1}{2} m_h^2 h^2 + \frac{1}{3!}\lambda_3 h^3 + \frac{1}{4!}\lambda_4 h^4 + \ldots$$

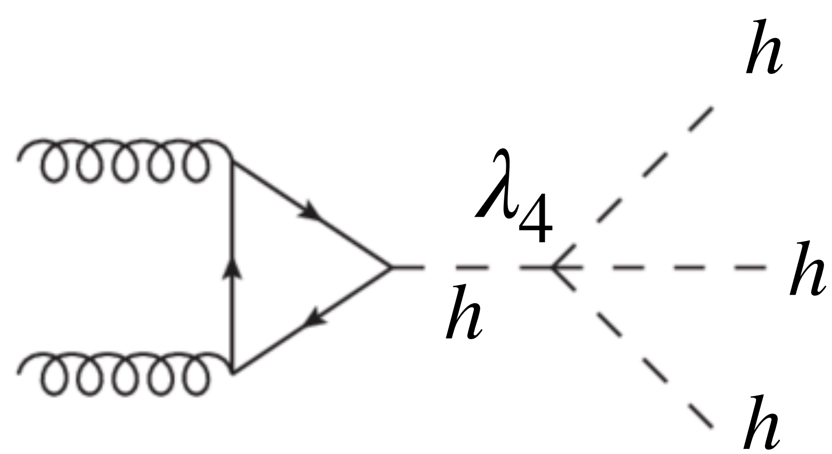
N-HIGGS PRODUCTION (hh)

SM makes definite predictions for these coefficients:

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

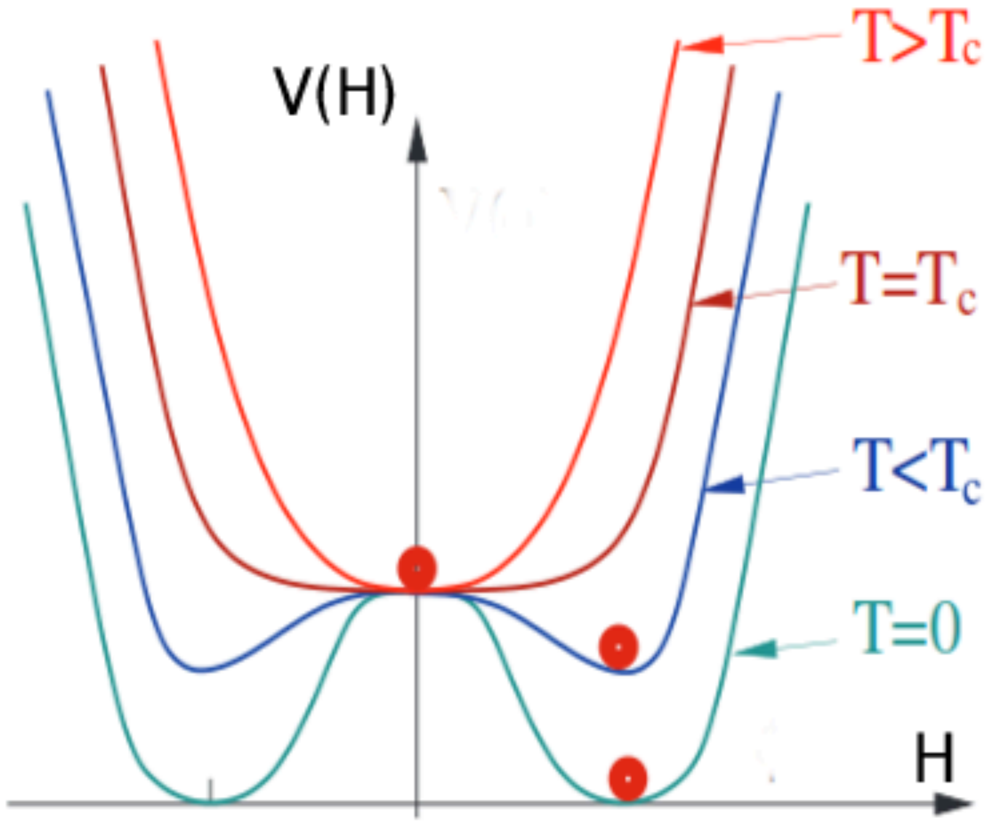
Can directly measure these couplings with multi-Higgs production (very hard at LHC).





ELECTROWEAK PHASE TRANSITION (hh)

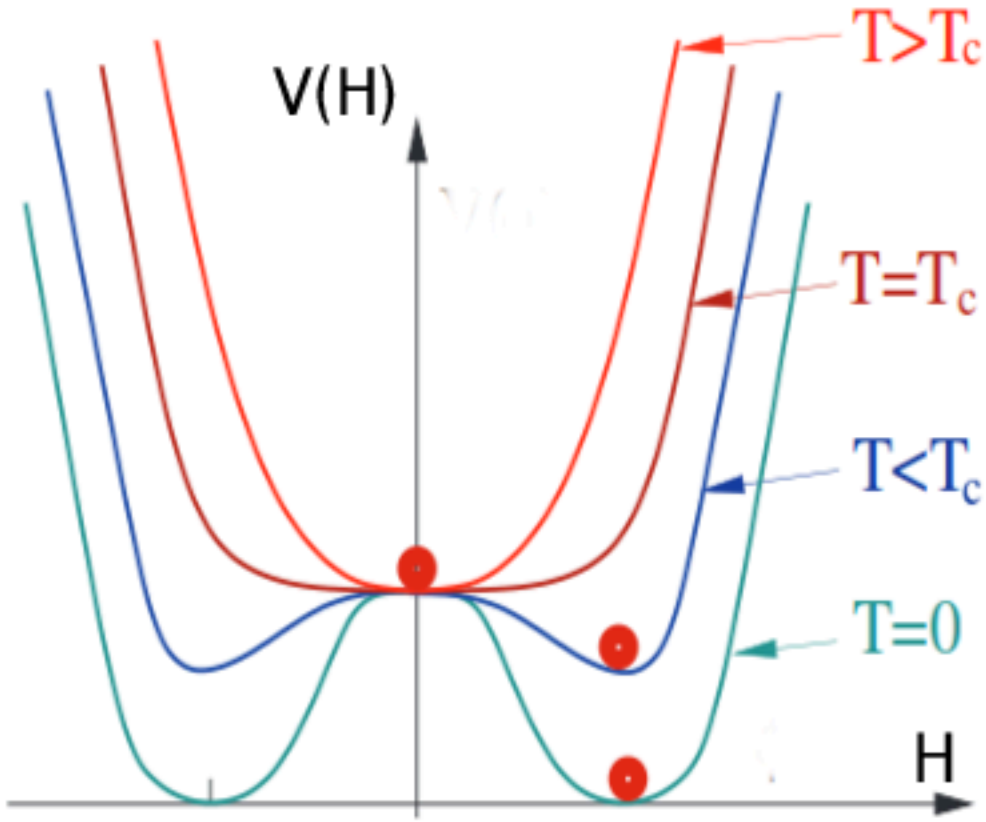
In the early universe, electroweak symmetry is restored.

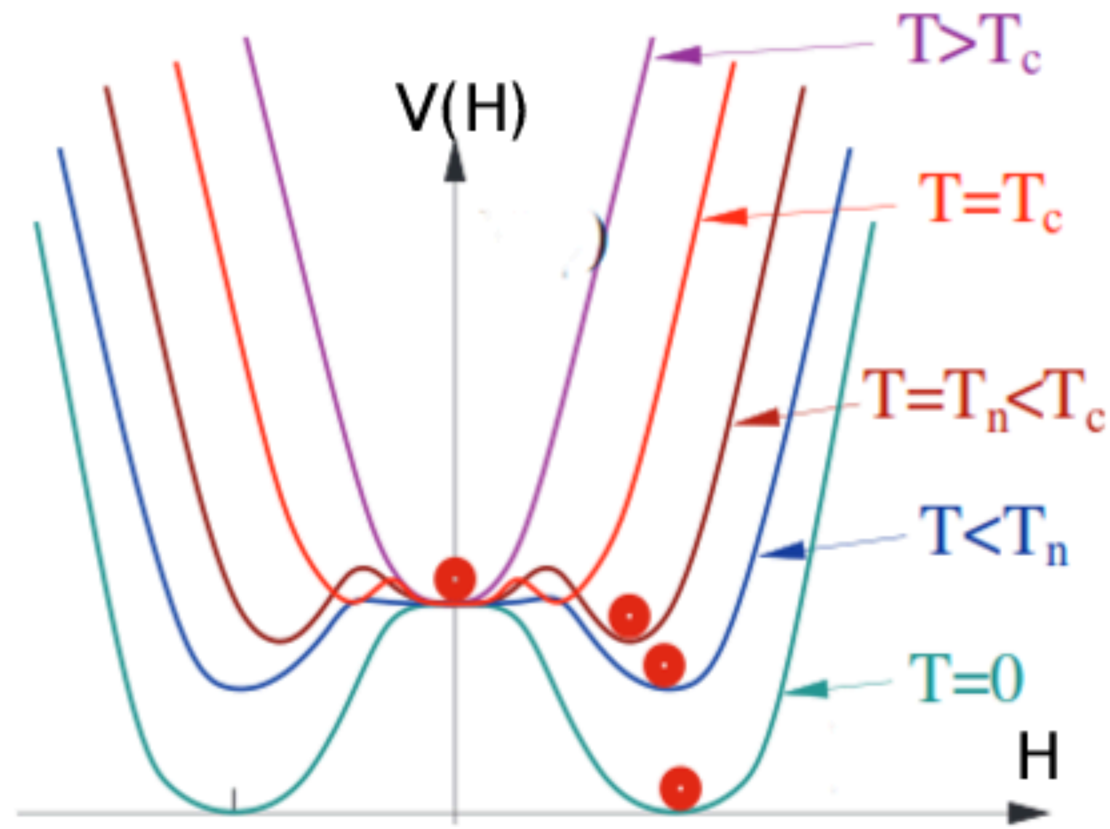


SM predicts smooth transition from unbroken to broken phase.

ELECTROWEAK PHASE TRANSITION (hh)

In the early universe, electroweak symmetry is restored.



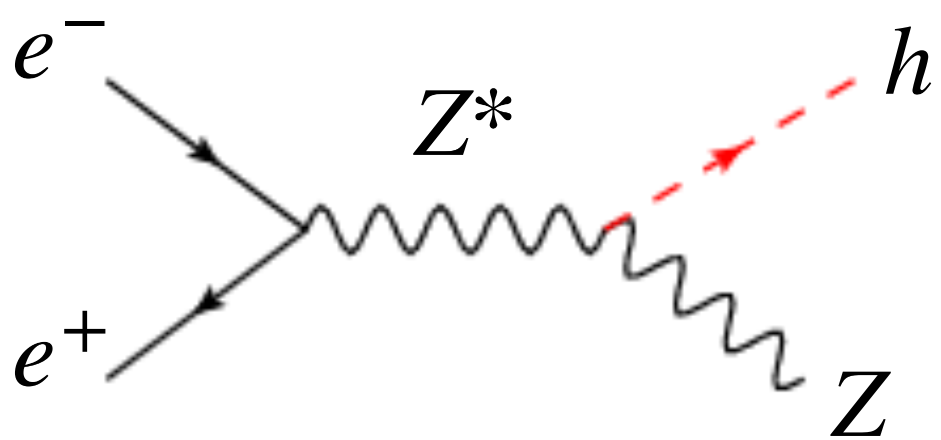


BSM theories (with new states) could have violent transition, possible baryogengesis mechanism.

Curtin, Meade, Yu, arXiv:1409.0005. See also talk by T. Tait on Wednesday.

NEW LIGHT PARTICLES (ee/he?)

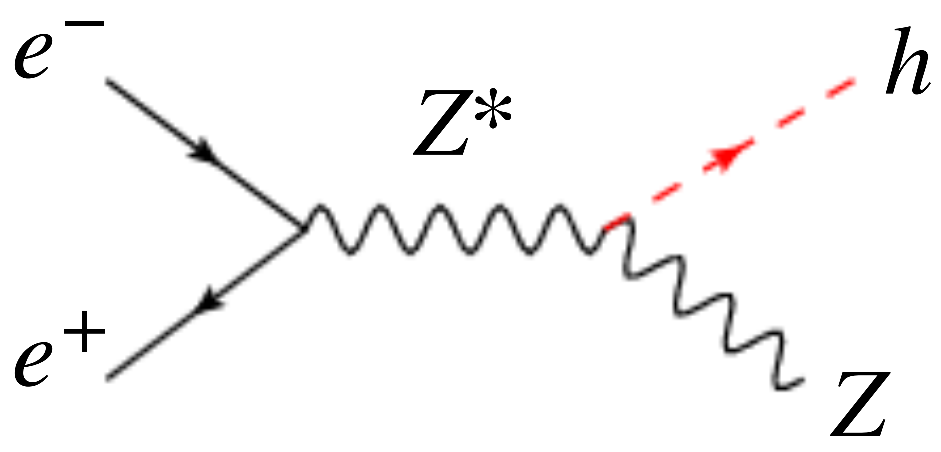
In lepton collider, can use knowledge of initial state to detect that a Higgs was created without seeing it.



Search for Higgs decays to new particles.

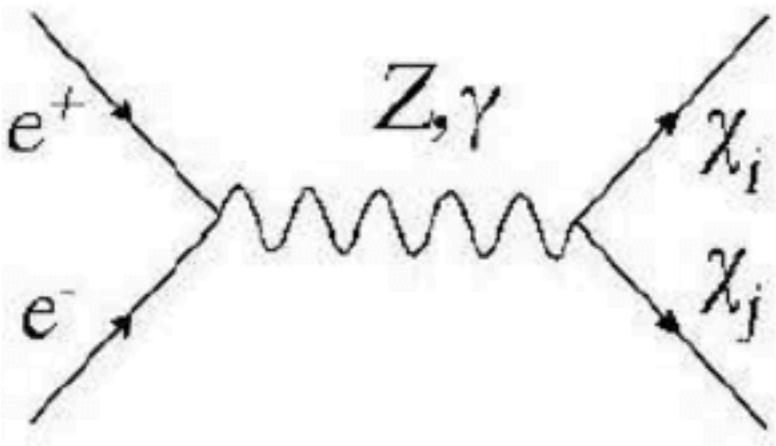
NEW LIGHT PARTICLES (ee/he?)

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 (hh/he?)

With 100 TeV CM, could discover:

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

NEW HEAVY PARTICLES (hh/he?)

With 100 TeV CM, could discover:

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

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

PROBING HIGH SCALES (ee/hh/he)

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

Parameterize via effective field theory (very general).

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

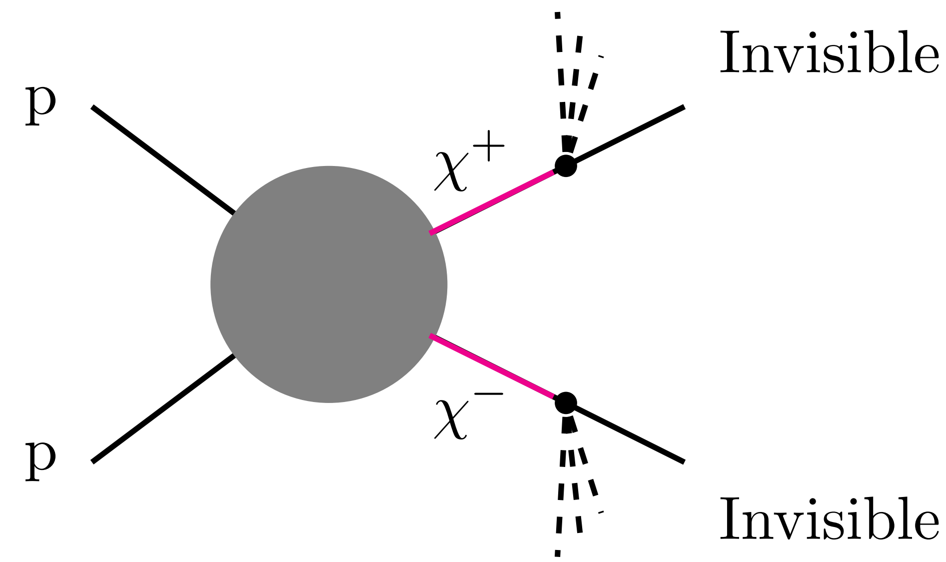
Can also do with W, Higgs, leptons, quarks...

DARK MATTER (hh)

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…

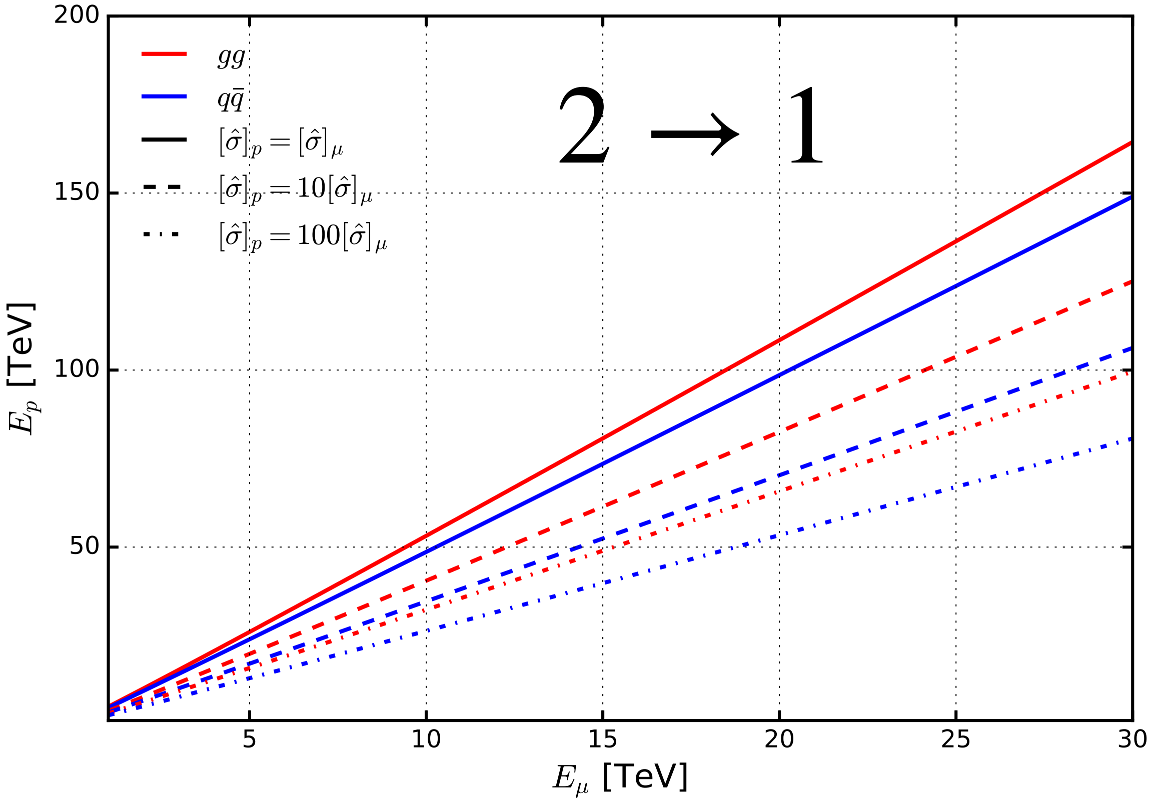


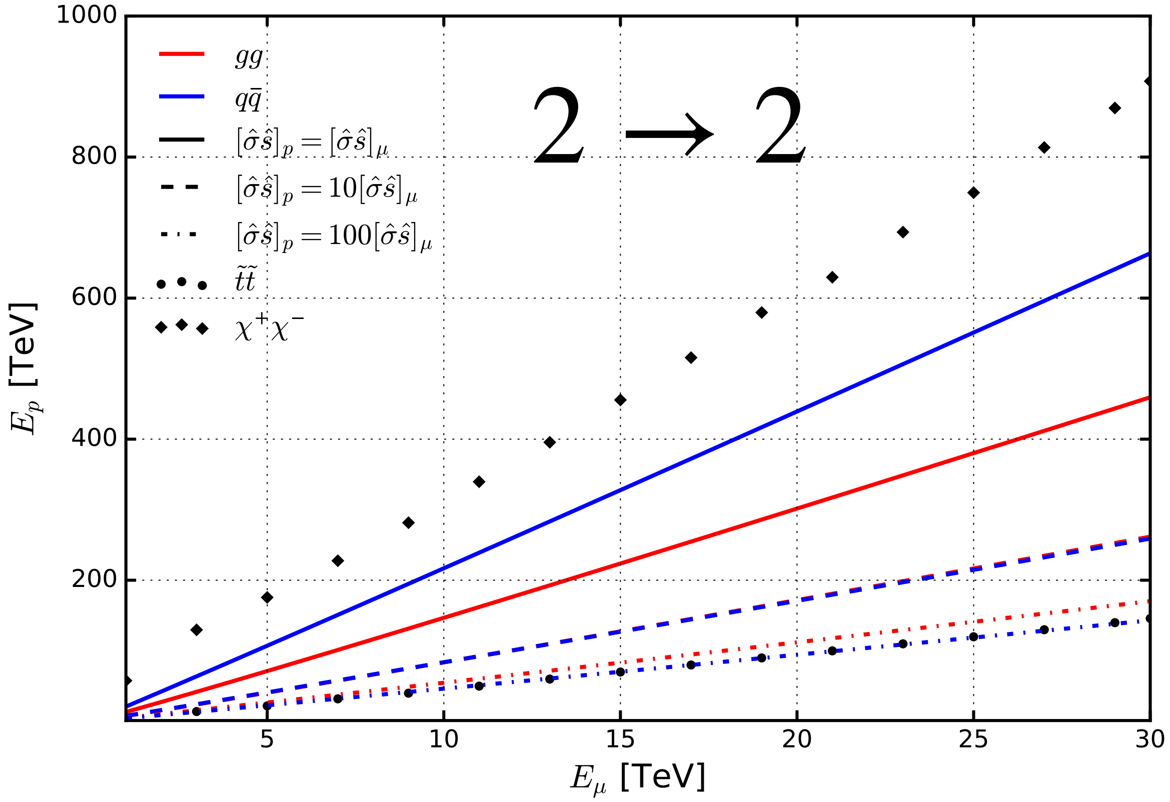
Mahbubani, Schwaller, Zurita, arXiv:1703.0532

MUON COLLIDERS

Muon collider will have potentially much higher energy than ee.

Effective energy much higher than pp.





Costantini et al. arXiv:2005.10289

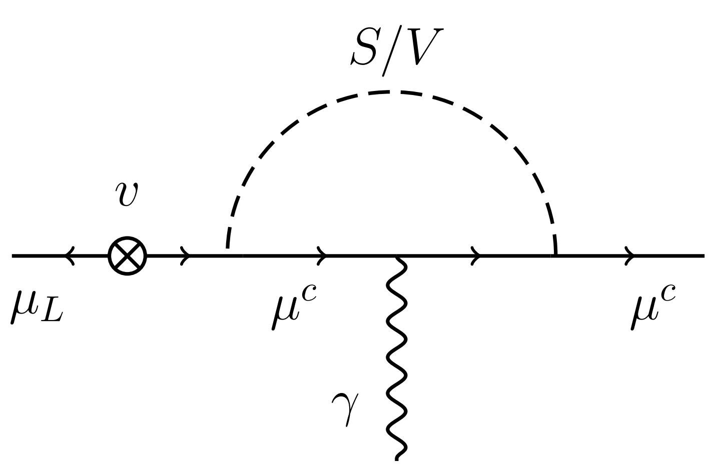
MUON COLLIDERS

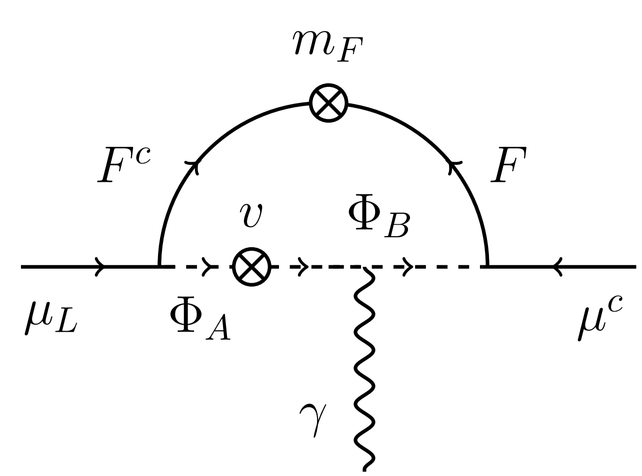
arXiv:2006.16277

A Guaranteed Discovery at Future Muon Colliders

Rodolfo Capdevilla[a,b],* David Curtin[a],† Yonatan Kahn[c],‡ and Gordan Krnjaic[d]§
[a] *Department of Physics, University of Toronto, Canada*
[b] *Perimeter Institute for Theoretical Physics, Waterloo, Ontario, Canada*
[c] *University of Illinois at Urbana-Champaign, Urbana, IL USA and*
[d] *Fermi National Accelerator Laboratory, Batavia, IL USA*
(Dated: July 1, 2020)

The longstanding muon $g-2$ anomaly may indicate the existence of new particles that couple to muons, which could either be light ($\lesssim$ GeV) and weakly coupled, or heavy ($\gg$ 100 GeV) with large couplings. If light new states are responsible, upcoming intensity frontier experiments will discover further evidence of new physics. However, if heavy particles are responsible, many candidates are beyond the reach of existing colliders. We show that, if the $(g-2)_\mu$ anomaly is confirmed and no explanation is found at low-energy experiments, a high-energy muon collider program is guaranteed to make fundamental discoveries about our universe. New physics scenarios that account for the





THANK YOU

REFERENCES

An incomplete list of references (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