Beyond the Standard Model at Muon Collider

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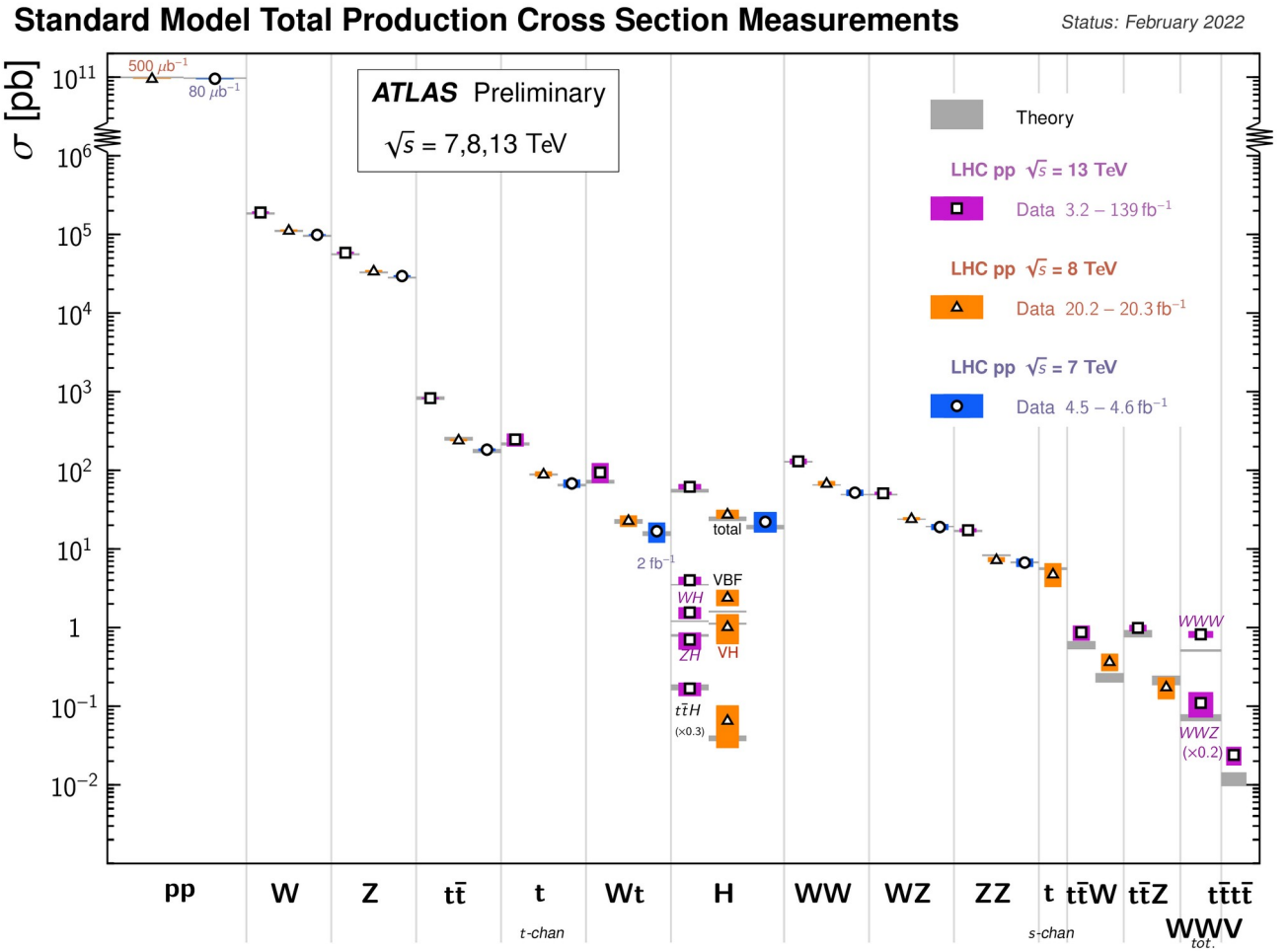
UK μC P&D

The Standard Model Measurements

The Standard Model is working very nicely! HEP experiments give values consistent with theorist's calculations.



But...

The Standard Model Problems

… not consistent with non-HEP observations

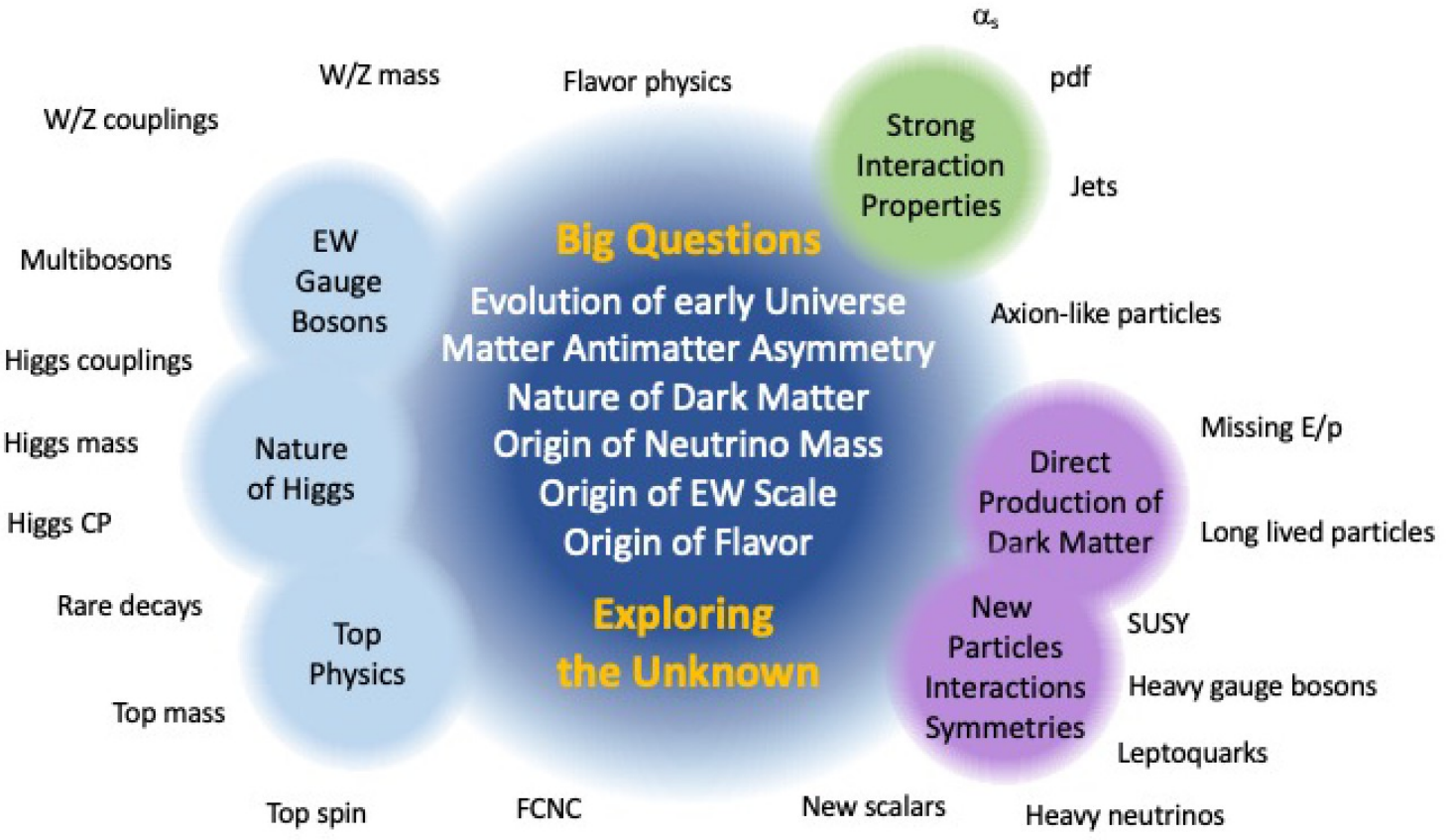
- **Dark Matter**
  - Cosmological observations show large blobs of unseen mass and SM cannot explain them
- **Matter/Antimatter asymmetry**
  - SM says matter/antimatter are almost the same, but world tells us that there is more matter
- **Hierarchy “problem”**
  - Higgs mass only correct if parameters are very precise for cancellations to occur
- **No gravity, Dark Energy, neutrino masses…**

More “solutions” than questions…

Credit: H. Murayama

Why collider experiments?

Collider experiments allow you to sample a **huge space of theories** with **one experimental setup**!



Very useful if you don't know **where to look**...

Predictions and Comparisons

Impossible to show Muon Collider is the best collider.

I don't know what your favourite (or "right") theory is.

Following Slides:

- How you can produce new physics.
- How you can search for BSM.
- A sampling of BSM to compare reach with other experiments.

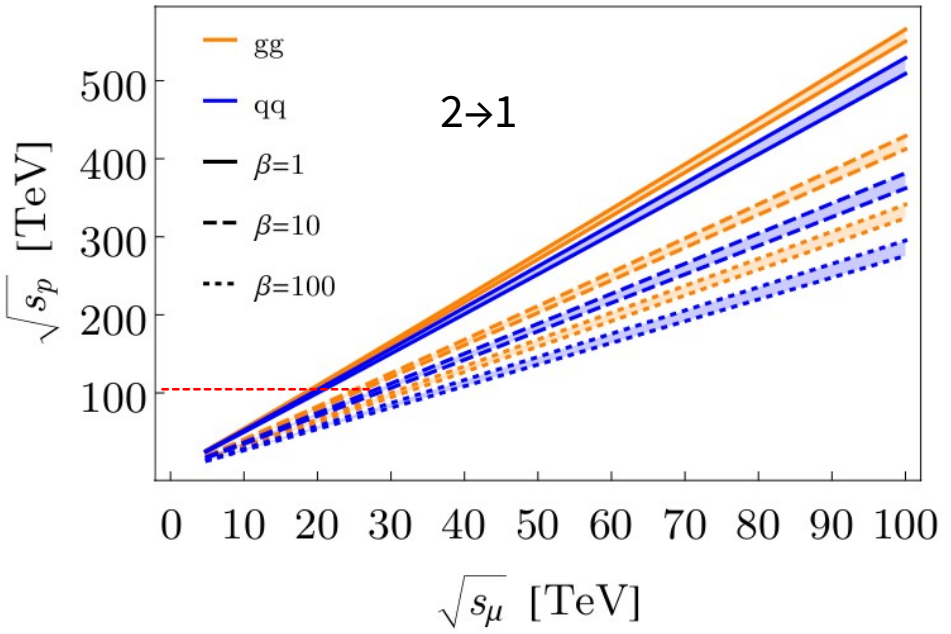
Goal is to show that a Muon Collider has the flexibility needed for the future.

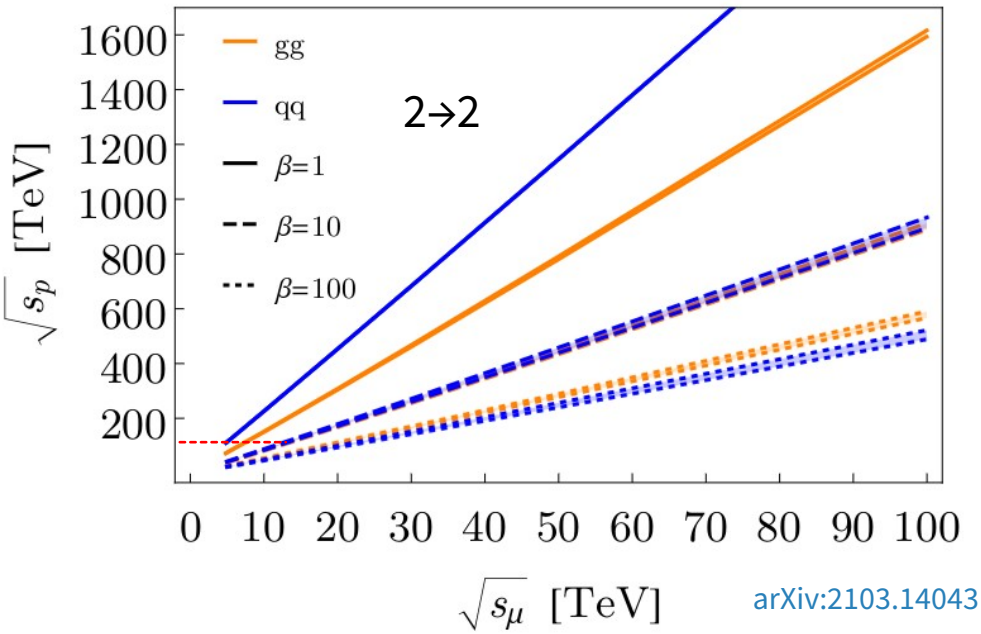
Annihilation (x~1)

Muons are elementary = full beam energy used in collision

$$\beta = \frac{[\hat{\sigma}]_p}{[\hat{\sigma}]_\mu}$$

~10 for QCD vs EW production.

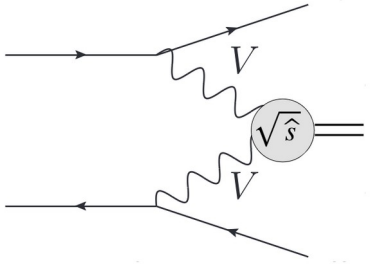




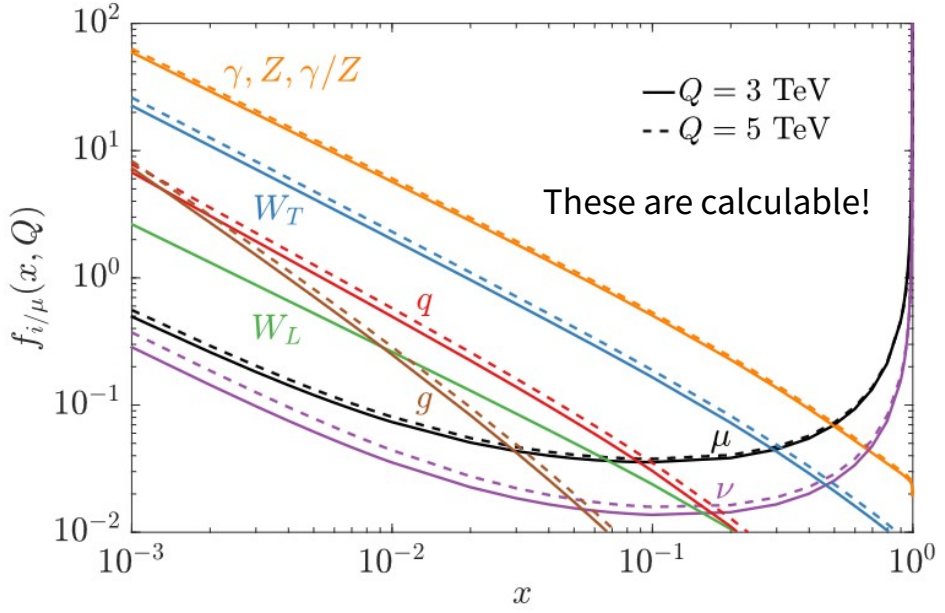
arXiv:2103.14043

100 TeV pp ≈ 10-30 TeV μμ

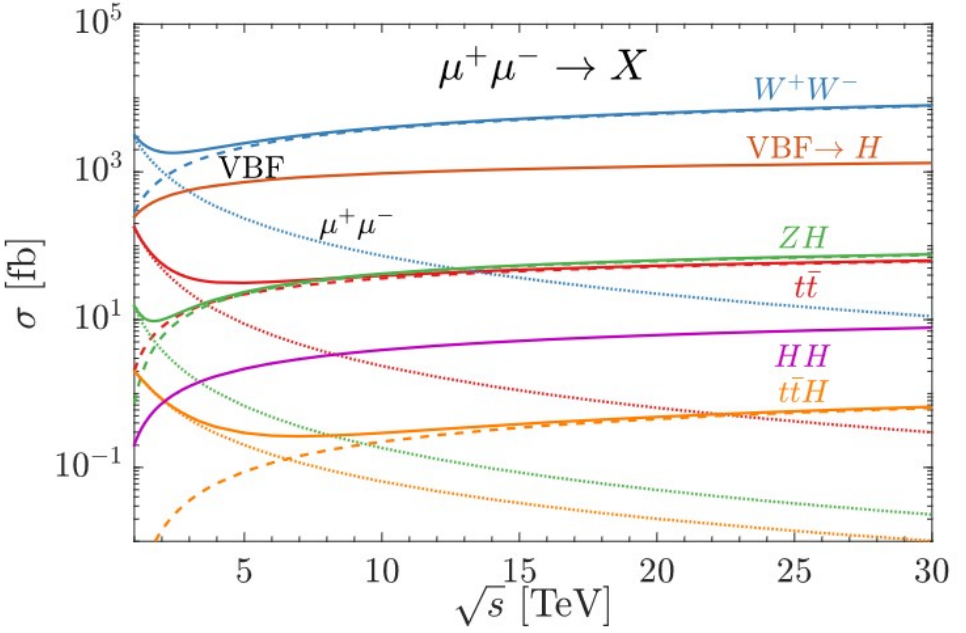
Vector Boson Fusion (x << 1)



Concept of **EW PDFs** useful for parametrizing productions.



Standard Model (background) cross-sections.
VBF (solid) dominates over annihilation (dashed).

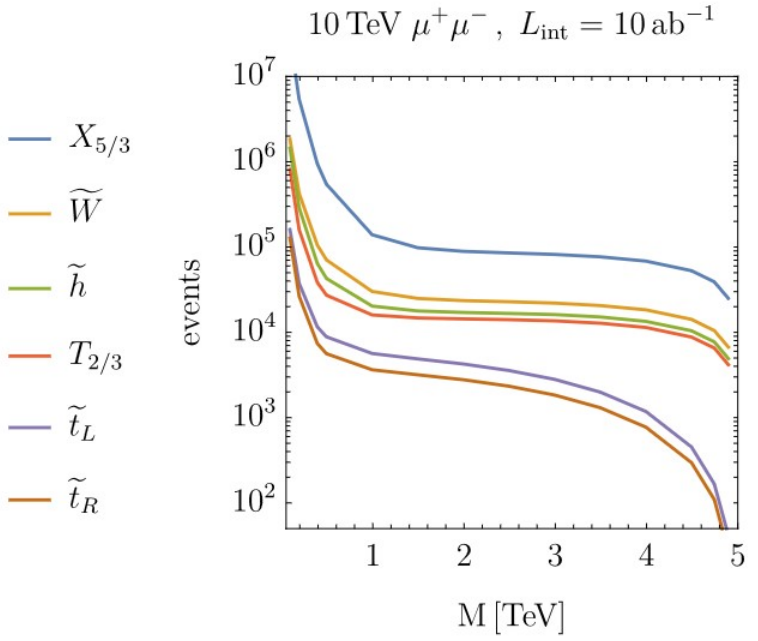


arXiv:2007.14300

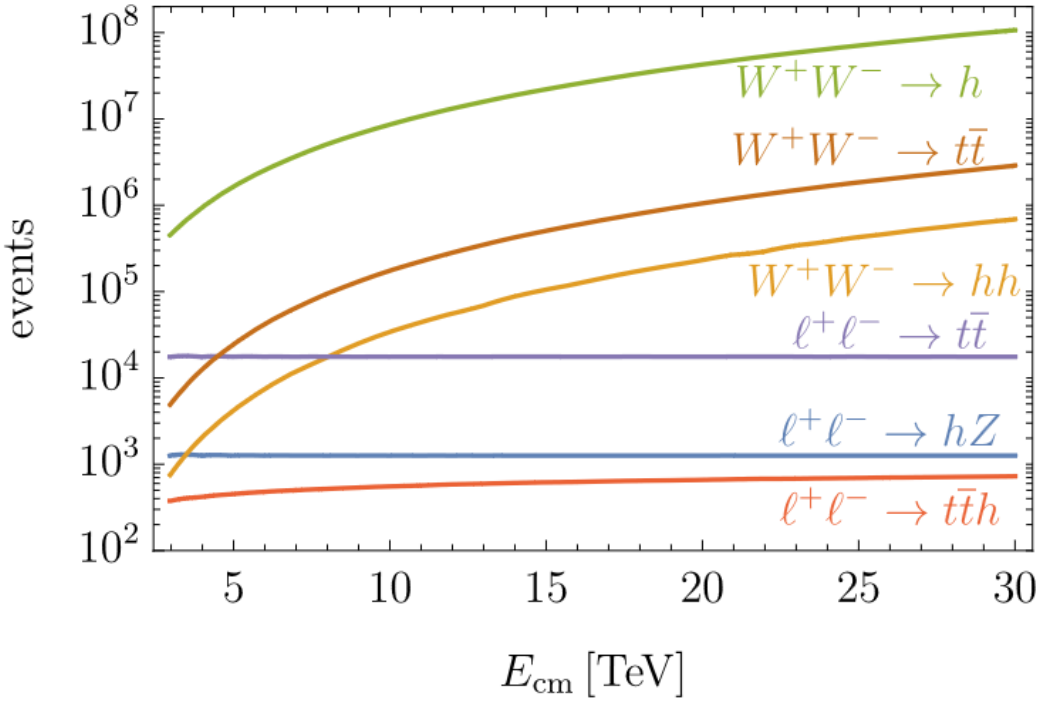
Muon collider is a vector-boson collider

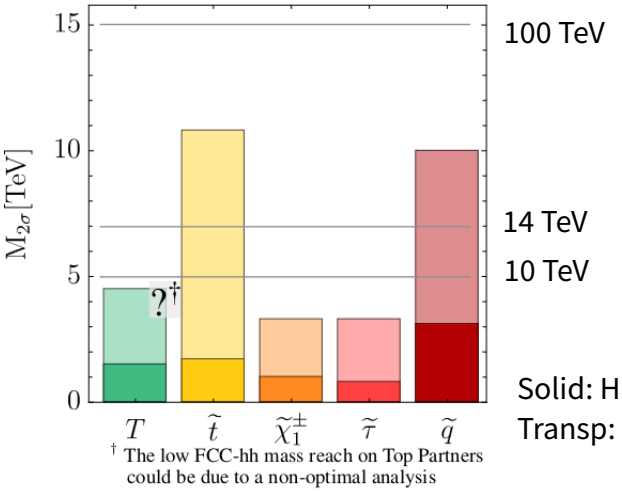
Event Counts

A few common BSM signals (left) and backgrounds (right).



Buttazzo, Franceschini, Wulzer





100 TeV

14 TeV

10 TeV

Tentative event reach *competitive* with FCChh for **EW states**.

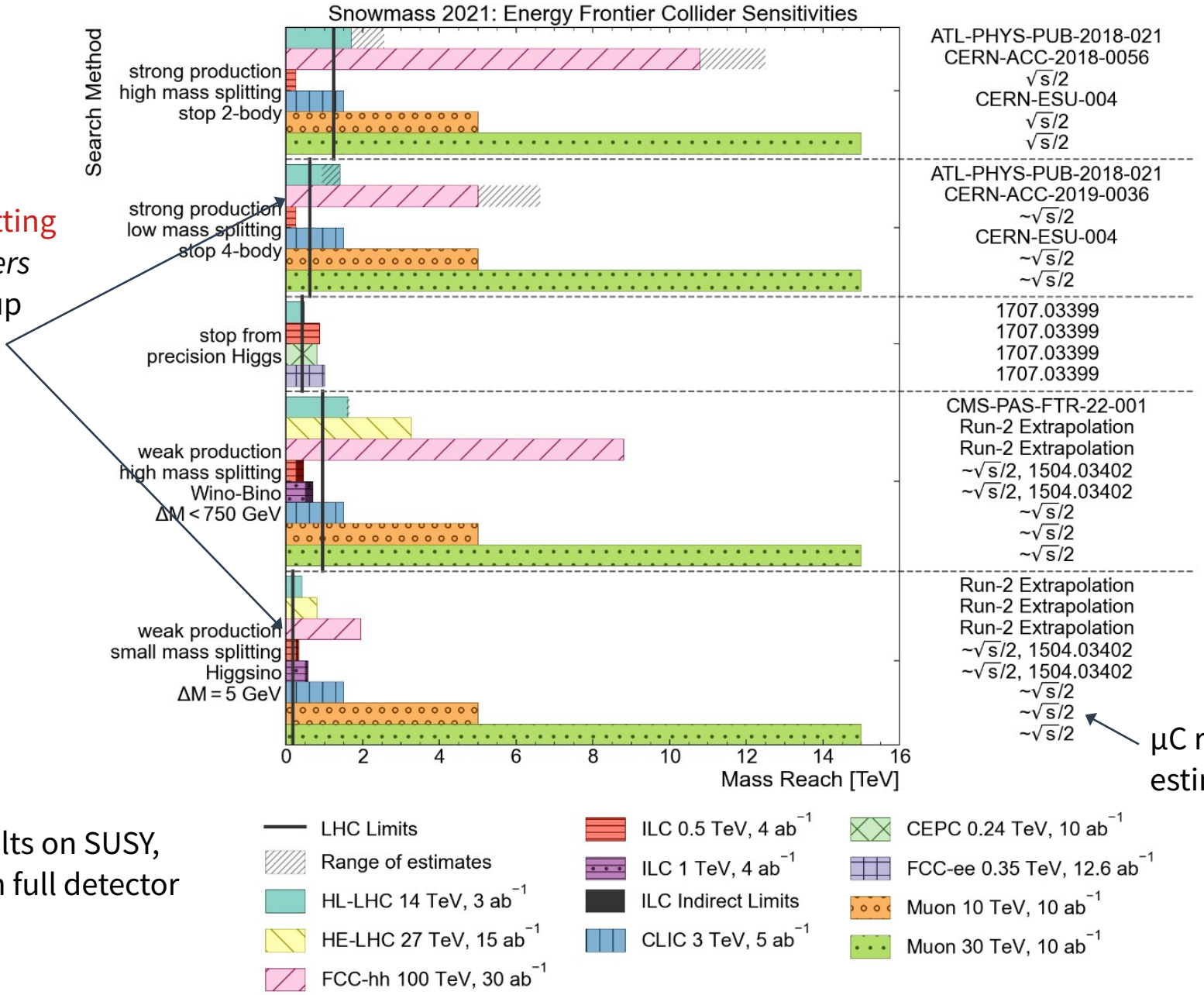
Reach is tenative as detector effects and more detailed analysis needed.

Solid: HL-LHC
Transp: FCChh

SUSY: Naturalness

Snowmass 2021 BSM Report

Small mass splitting at *hadron colliders* limited by pile-up

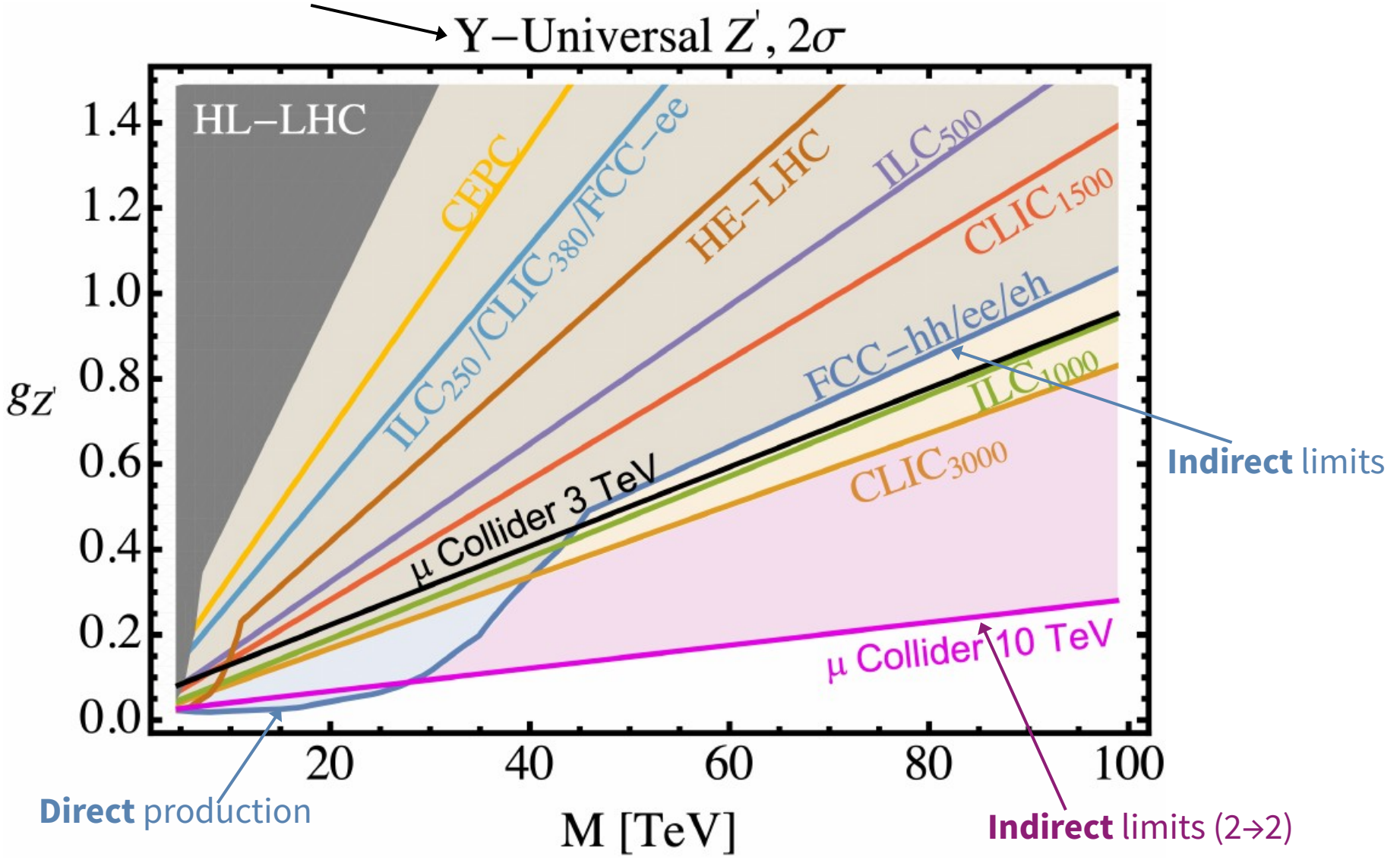


μC reach is estimated as √s/2

Not many results on SUSY, especially with full detector simulation.

Generic BSM: Z’

Compatible quark vs lepton couplings.

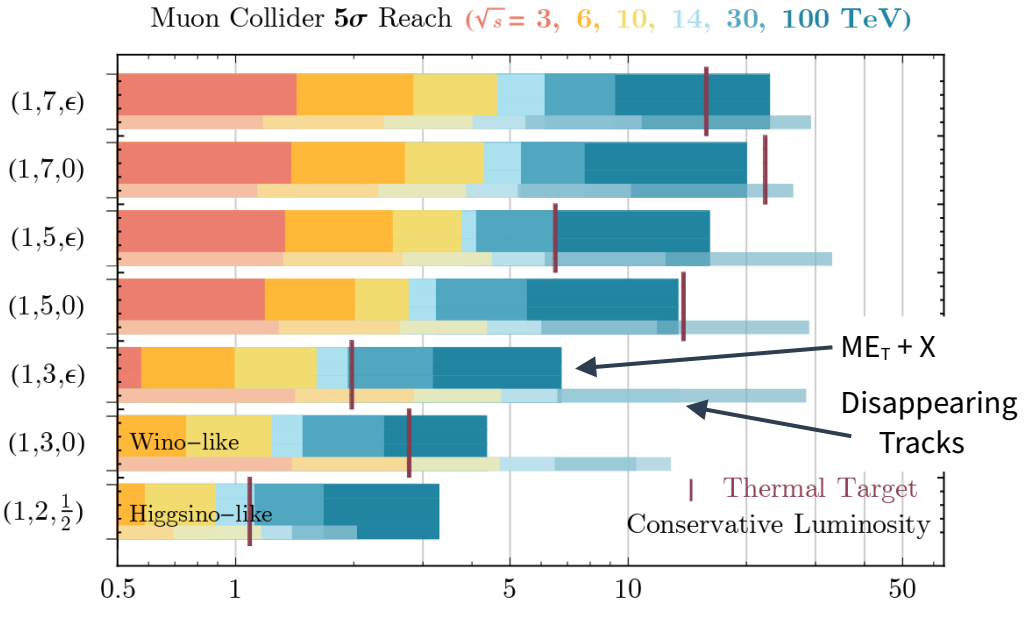


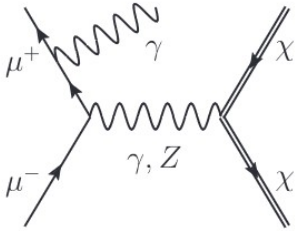
Dark Matter (WIMP)

“Minimal Dark Matter”

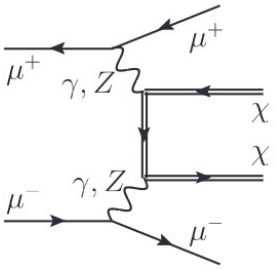
- Electroweak multiplet w/ neutral lighted particle.
- Thermal relic abundance fixes mass scale to 1-23 TeV.
- Small mass splittings make signature difficult.

Han, Liu, Wang, Wang

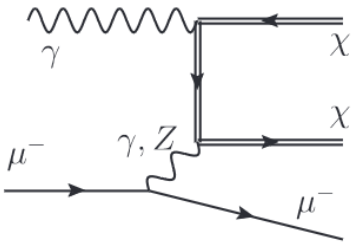




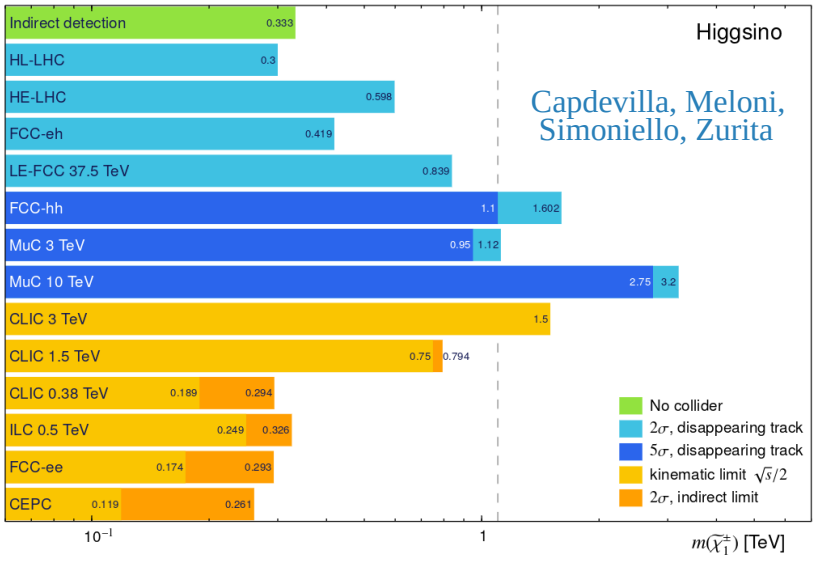
mono-photon



VBF



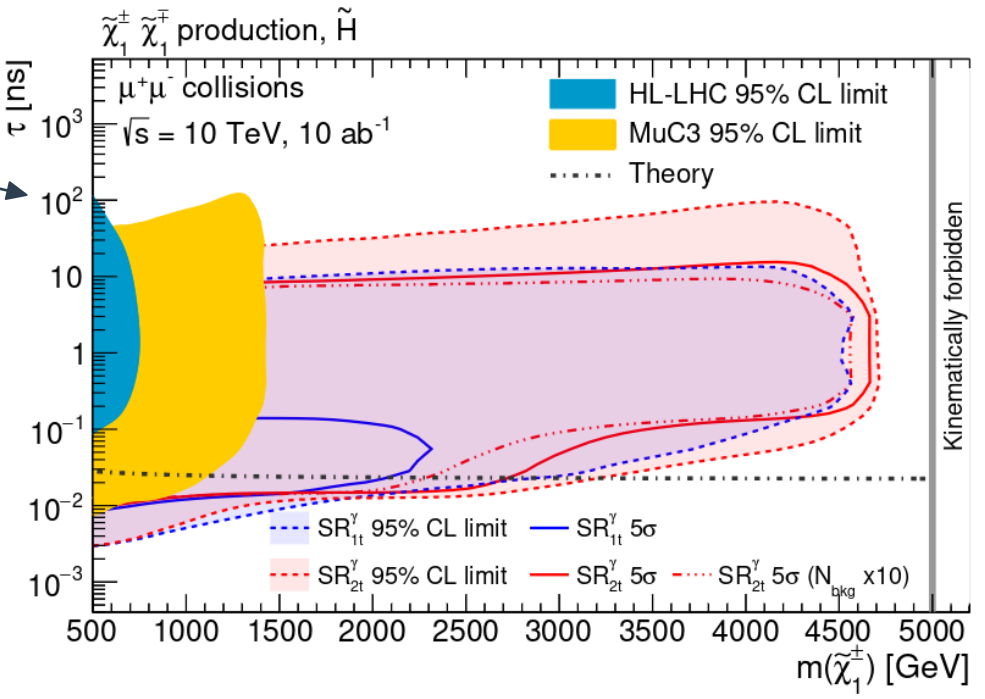
mono-muon

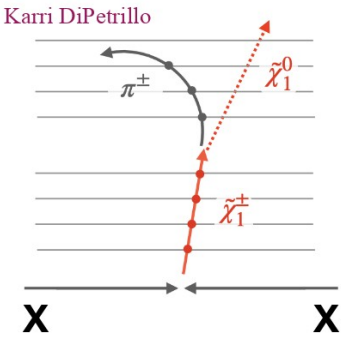


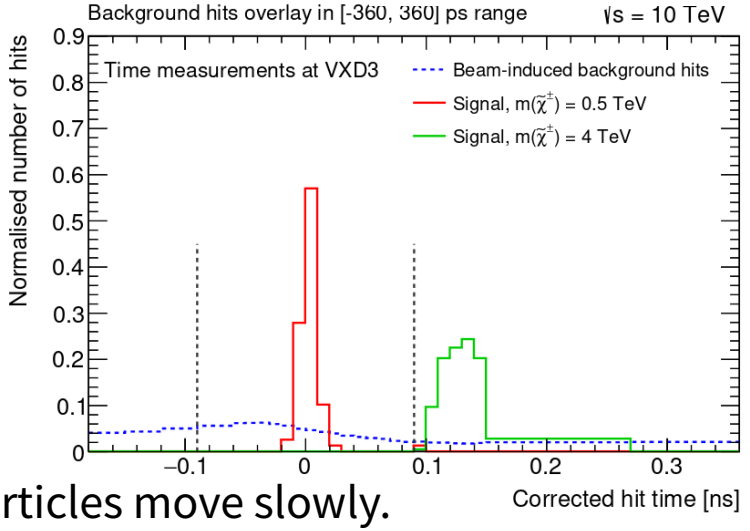
DM and Disappearing Tracks

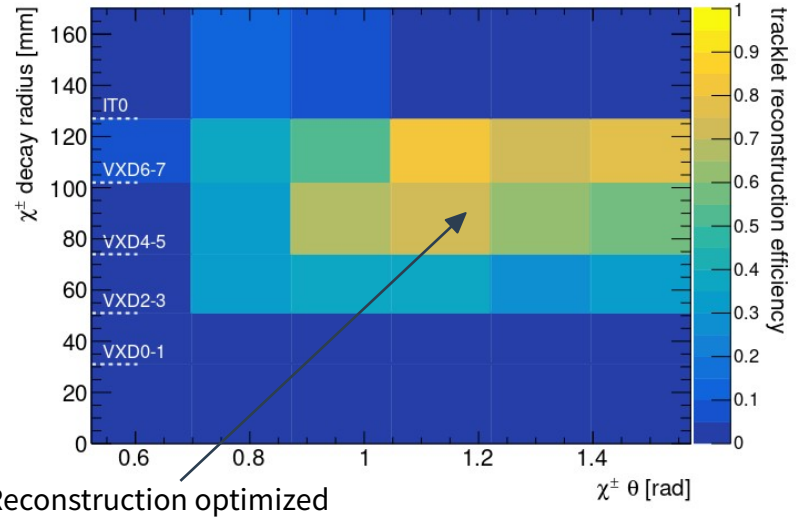
Capdevilla, Meloni, Simoniello, Zurita

Expected reach in the presence of BIB









Heavy particles move slowly.

- Cannot filter on detector...

Reconstruction optimized for *vertex barrel*.

Muon-specific Opportunities

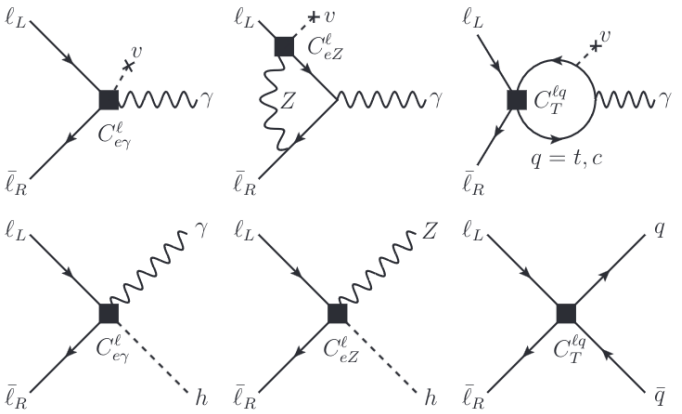
First time we would be colliding muons!

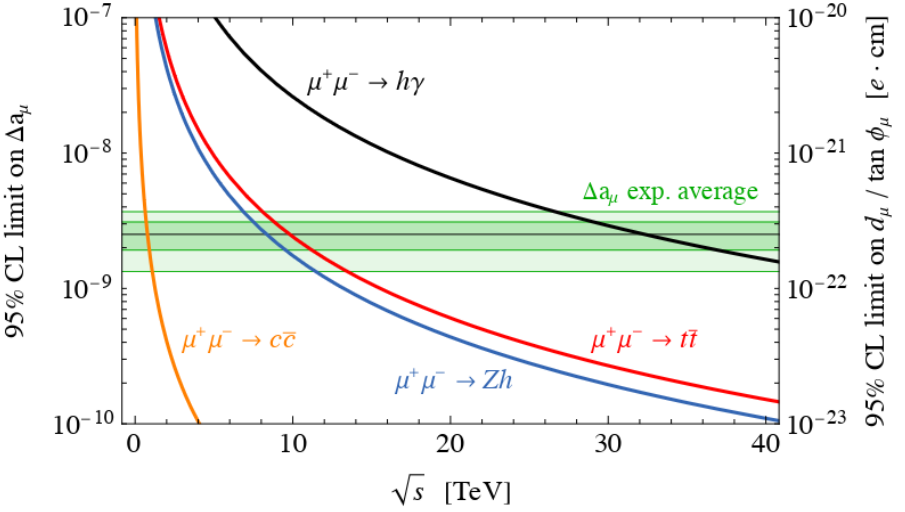
There are anomalies in this sector...

Cross-sections become sensitive to the same EFT operators as the g_μ-2 anomaly.

Contributions to g_l-2

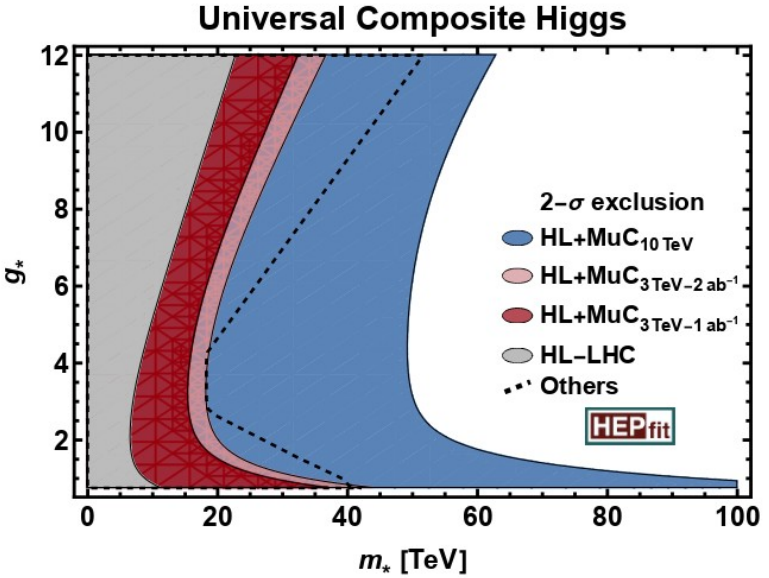
Corresponding scattering diagrams.

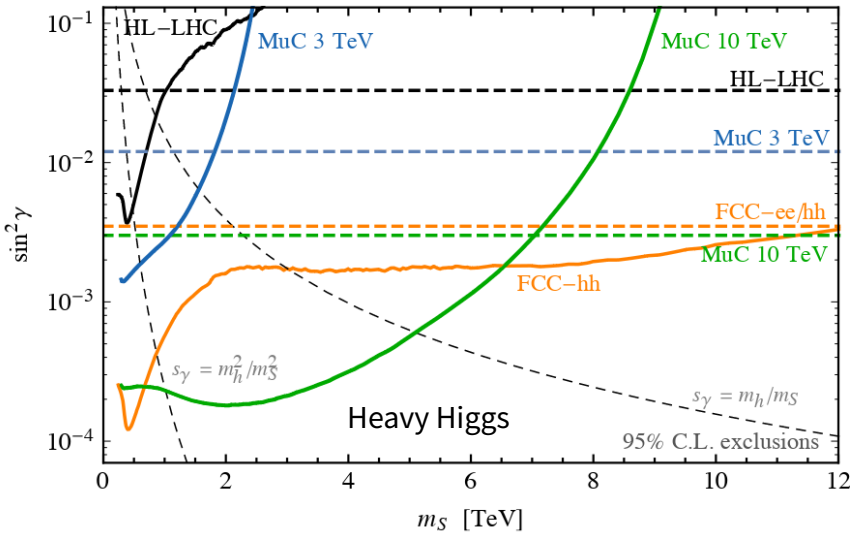


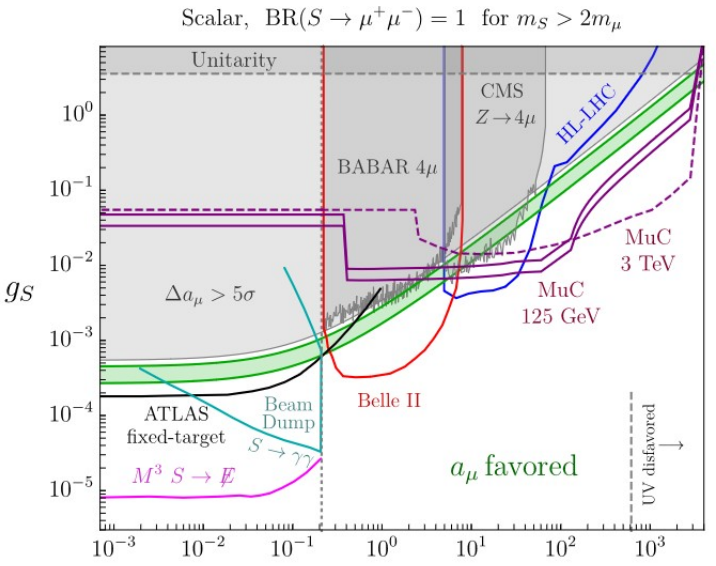


μC could confirm g_μ-2 anomaly and probe its form.

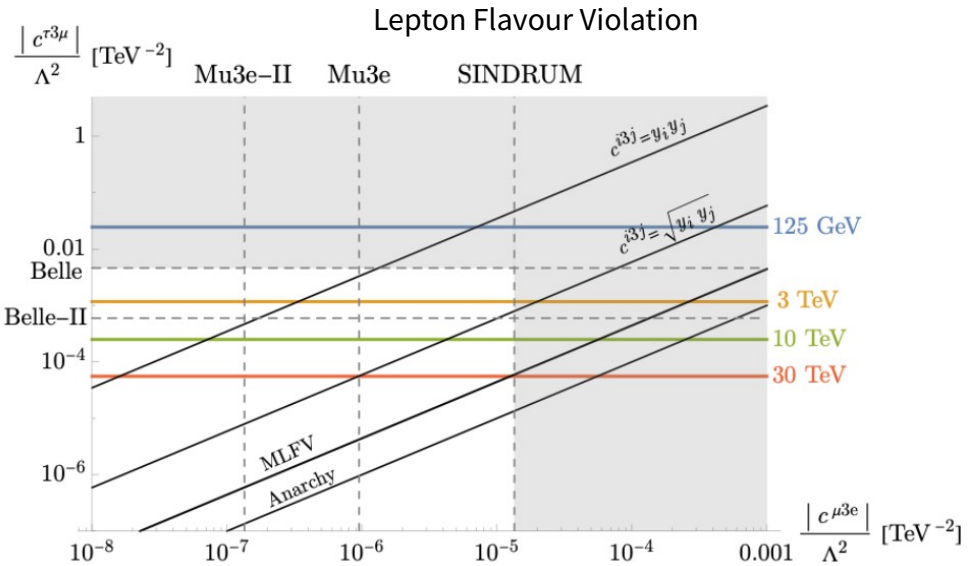
And many more…







g-2 inspired singled models m_S [GeV]



Conclusion

- **Muon Collider is good for Beyond the Standard Model!**
  - Energy reach of a proton collider.
  - Clean processes of a lepton collider.
- **Combination of muon and vector-boson colliders.**
  - Makes this a unique machine.
- **Reach comparable to FCChh.**
  - Hard to tell without getting into model specifics...
- **Missing: detector effects and precision measurements.**
  - Delphes card in preparation for ESPPU

BACKUP SLIDES

Sig vs Bkg for Higgs