Long-Lived Particles
Snowmass Energy Frontier 09

Snowmass Community Summer Study Meeting
Seattle, Washington
July 20, 2022

Juliette Alimena** (CERN)
Tulika Bose* (U Wisconsin)
Simon Knapen** (LBNL)
Zhen Liu* (U Minnesotta)
Simone Pagan Griso* (LBNL)

*   EF09 conveners
** LLP section editors

Long-Lived Particles in the Energy Frontier

LLPs fall (mostly) under **EF09**: "More general explorations"

• New bosons and heavy resonances (R. Harris, F. Yu)

• New fermions (I. Lewis, J. Hogan)

• Long lived particles (J. Alimena, S. Knapen)

Also see EF02, EF08, EF10, RF06, IF03, IF04

Long-Lived Particles in the Energy Frontier

Wrote **BSM report** covering EF08 (models), EF09, and EF10 (dark matter)

Version: 1.0; Date: June 23, 2022

Physics Beyond the Standard Model at Energy Frontier

(First Draft Prepared for Community Feedback)

Convenors: Tulika Bose,[1,*] Antonio Boveia,[2,†] Caterina Doglioni,[3,†] Simone Pagan Griso,[4,*] James Hirschauer,[5,‡] Elliot Lipeles,[6,‡] Zhen Liu,[7,*] Nausheen R. Shah,[8,‡] Lian-Tao Wang,[9,†] Kaustubh Agashe,[10] Juliette Alimena,[11] Sebastian Baum,[12] Kevin Black,[1] Gwen Gardner,[6] Tony Gherghetta,[7] Josh Greaves,[13] Maxx Haehn,[8] Phil C. Harris,[5] Robert Harris,[5] Julie Hogan,[14] Suneth Jayawardana,[8] Abraham Kahn,[6] Simon Knapen,[4,15] Ian M. Lewis,[16] Katherine Pachal,[17] Matthew Reece,[18] Carlos E.M. Wagner,[19,9] Riley Xu,[6] Felix Yu,[20] and
to be updated in accordance to Snowmass Energy Frontier policy/procedure/protocol

➡️ Input to the big Energy Frontier summary

3

Objectives

- Emphasize that LLPs are **important**

- Emphasize that LLPs **cannot be taken for granted**:

  ✦ **HL-LHC upgrades** are essential

  ✦ Strong physics case for one or more **auxiliary LLP detectors**

  ✦ **Future detectors/accelerators** must be designed with LLPs in mind

- Provide some **illustrative benchmarks** comparing existing and future facilities (non-exhaustive)

- **Summarize** LLP related Snowmass submissions

Outline

What makes a good LLP detector?

What are dedicated detectors and why do we need them?

Some example sensitivity plots

~ 12 pages

Strategies and detector R&D

Examples of things we highlighted:

- **Particle ID** capabilities are extremely valuable (e.g. dE/dx, time-of-flight etc)

- **Vertex resolution** near IP is a priority (e.g. VELO)

- **Dedicated triggers** for LLP's are essential, *especially* at hadron and muon machines

    - Hardware needs to be designed accordingly

- Aside from EW vs Strong production, not all colliders are born equal for LLPs: **Hadron and muon machines will be MUCH more challenging than e^+e^-**

Also see Cristián's talk next!

Dedicated detectors

- Important for **exhaustive coverage** of low mass LLPs in particular

- Emphasized **complementarity**:

  ✦ Forward vs central detectors

  ✦ Charged vs neutral LLPs
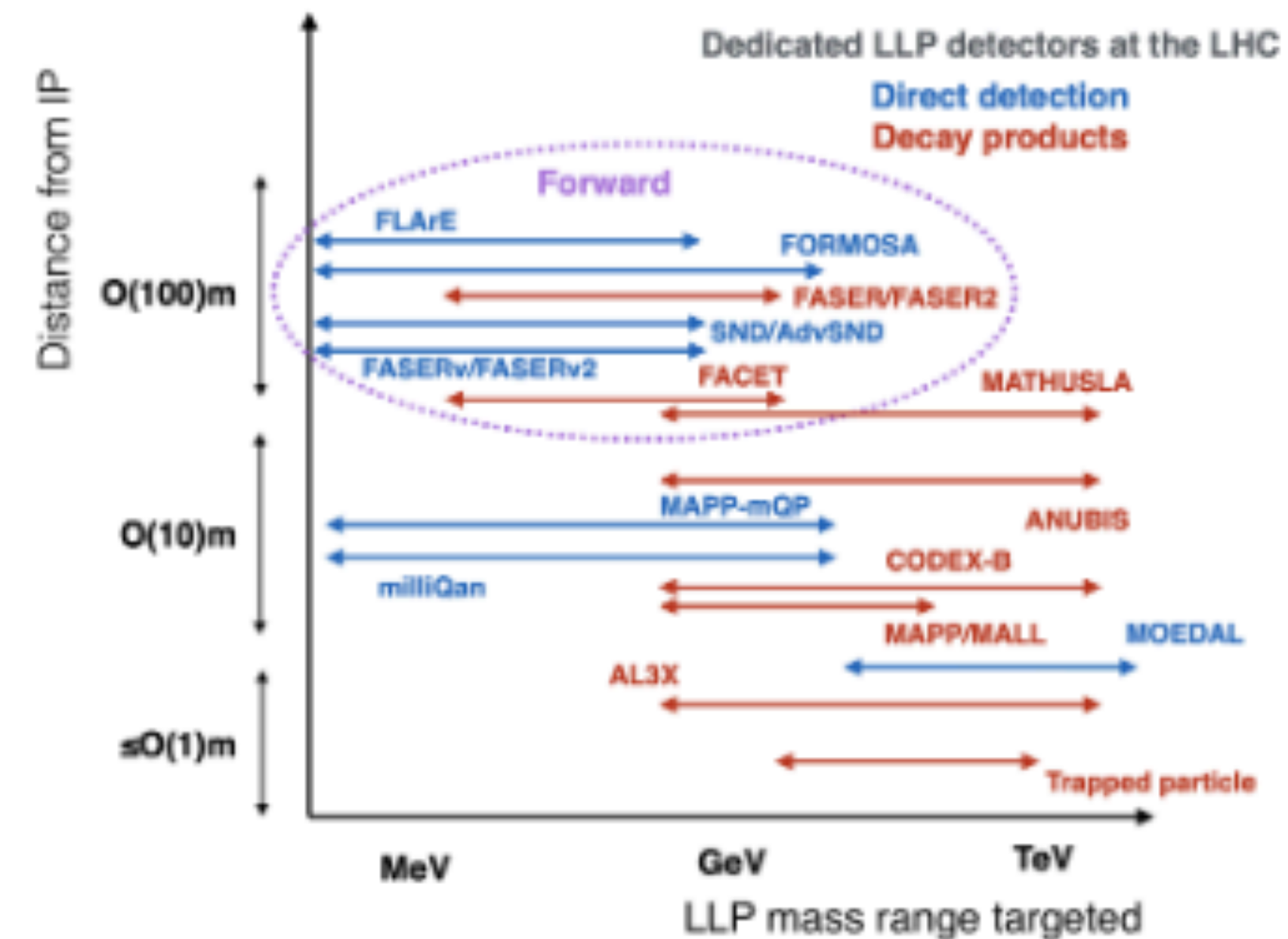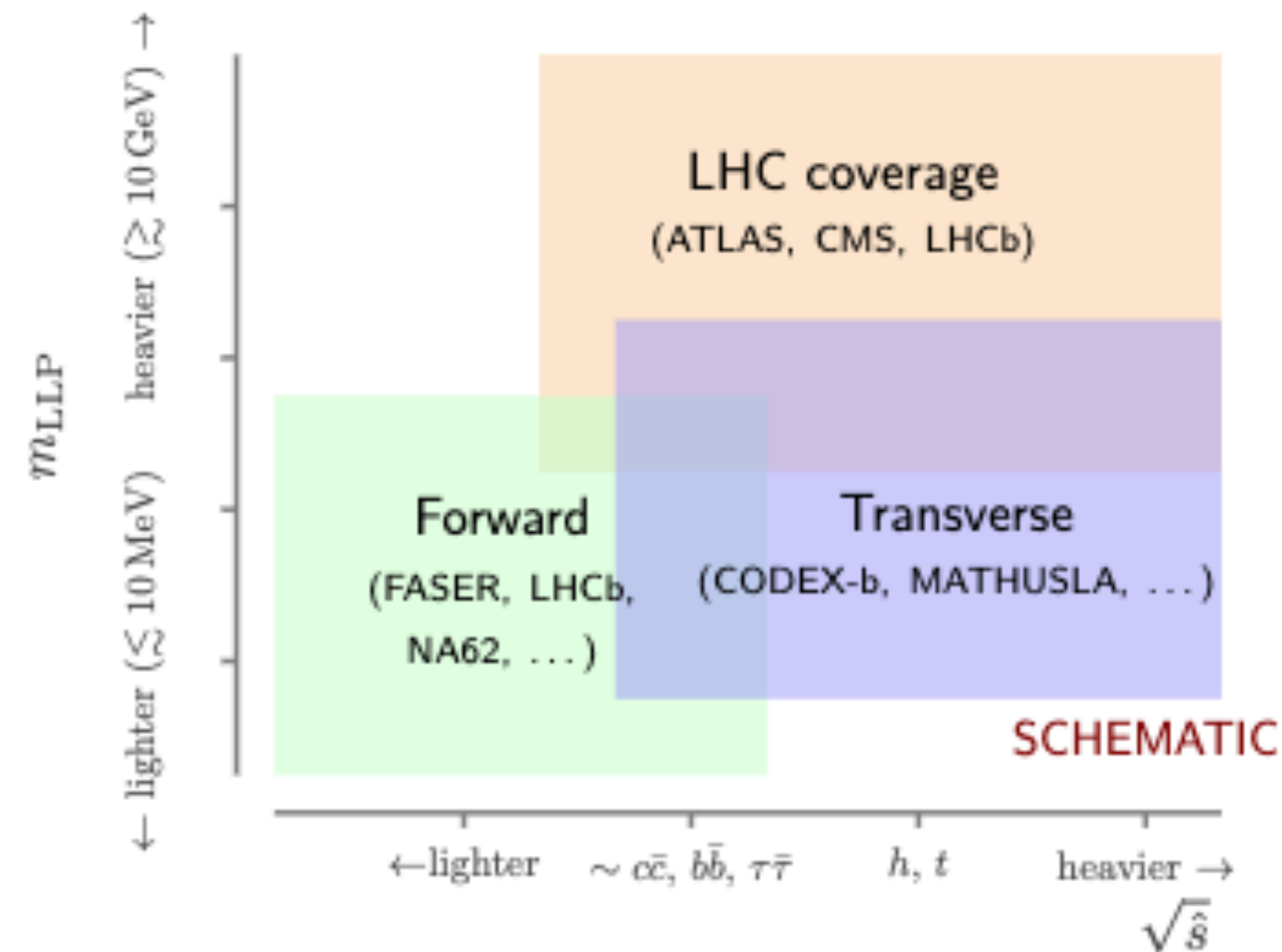
Dedicated detectors

- <u>Forward:</u> FASER, FPF, FACET, MOEDAL-MAPP

- <u>Central:</u> MATHUSLA, CODEX-b, ANUBIS, (AL3X)

- <u>Charged LLPs:</u> MOEDAL, milliQan, FORMOSA

- <u>At future colliders:</u> lepton & hadron colliders, some general thoughts

Roughly a paragraph per detector, space is limited…
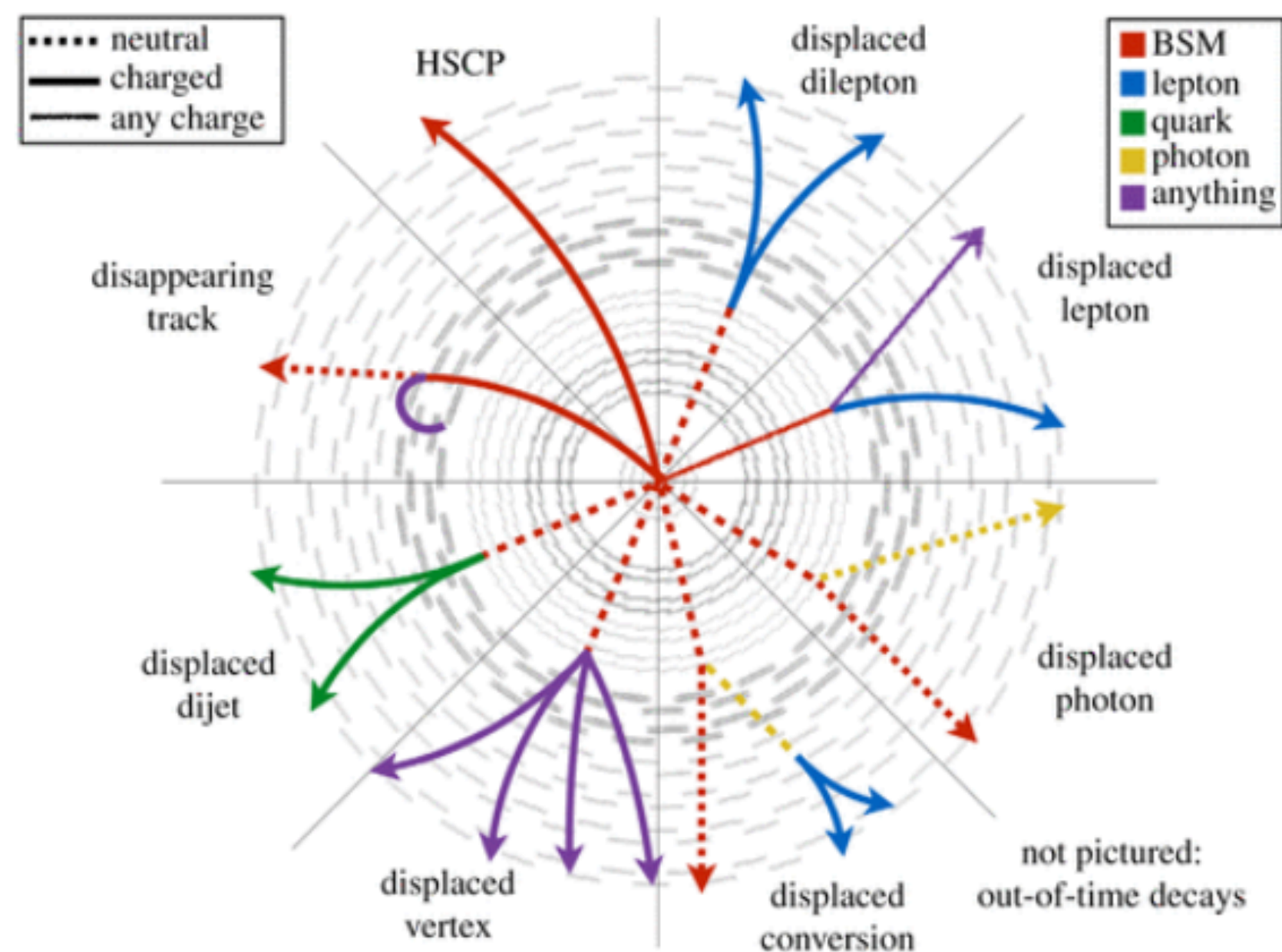
Signatures and Models

Really had to pick a handful of examples, sorry if your favorite model or search is not represented

E.g. For light LLPs, restricted to **Higgs decays to LLPs**
(Also featured in Higgs working group)

Dark photons, HNLs, etc. are mentioned, but sensitivity plots are featured in the New Fermions section and the RF06 report
(We cross reference)

C. Signatures & models
  1. Charged LLPs
  2. Low mass displaced vertices
  3. High mass displaced vertices
  4. Dark showers

Charged LLPs

Electrically charged LLPs can have two main signatures: disappearing tracks and heavy stable charged particles (HSCPs)

Focus on disappearing tracks, to show improvements at HL-LHC and future colliders
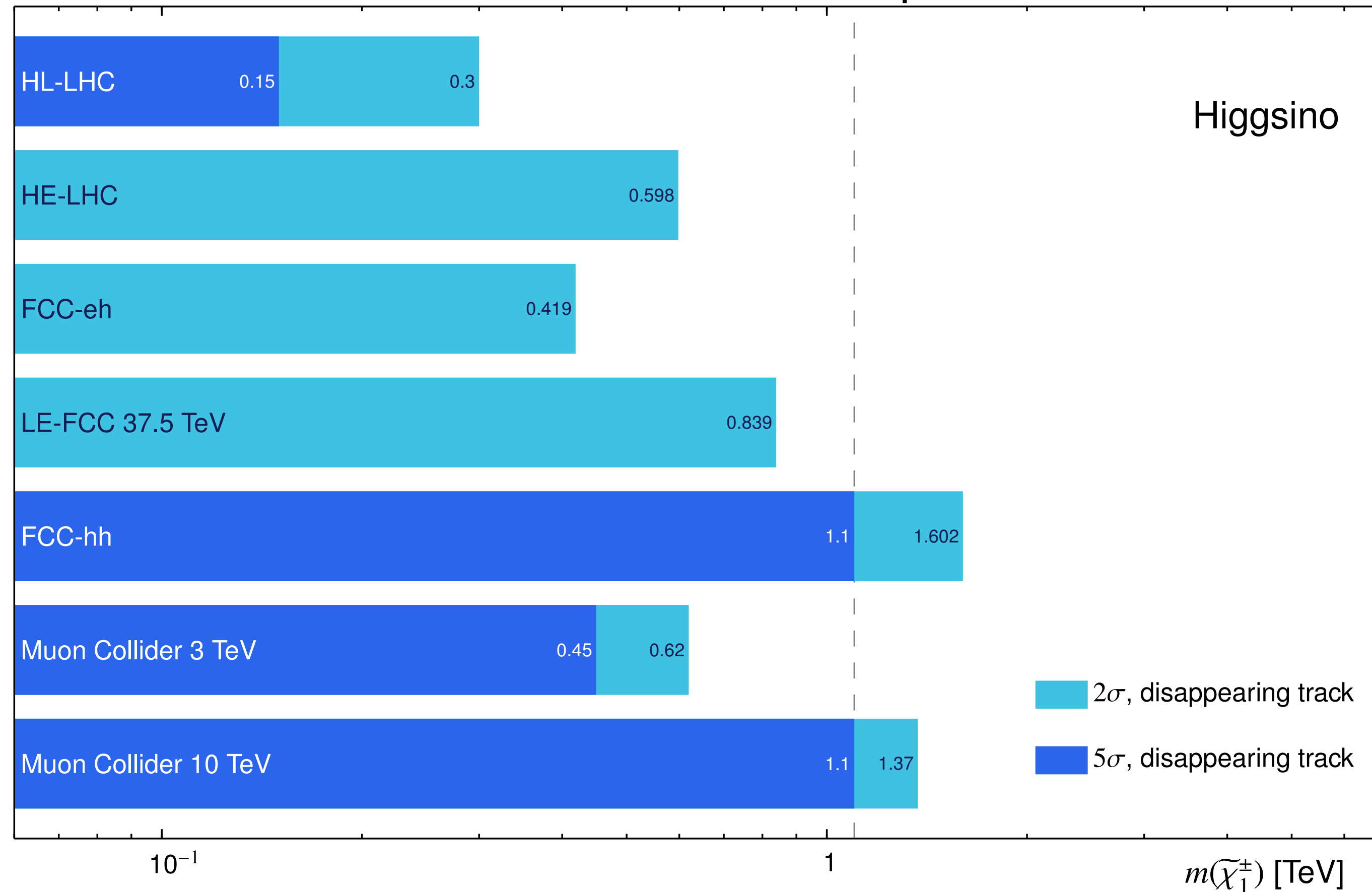
Disappearing track (Higgsino) sensitivity estimates, as function of mass and lifetime
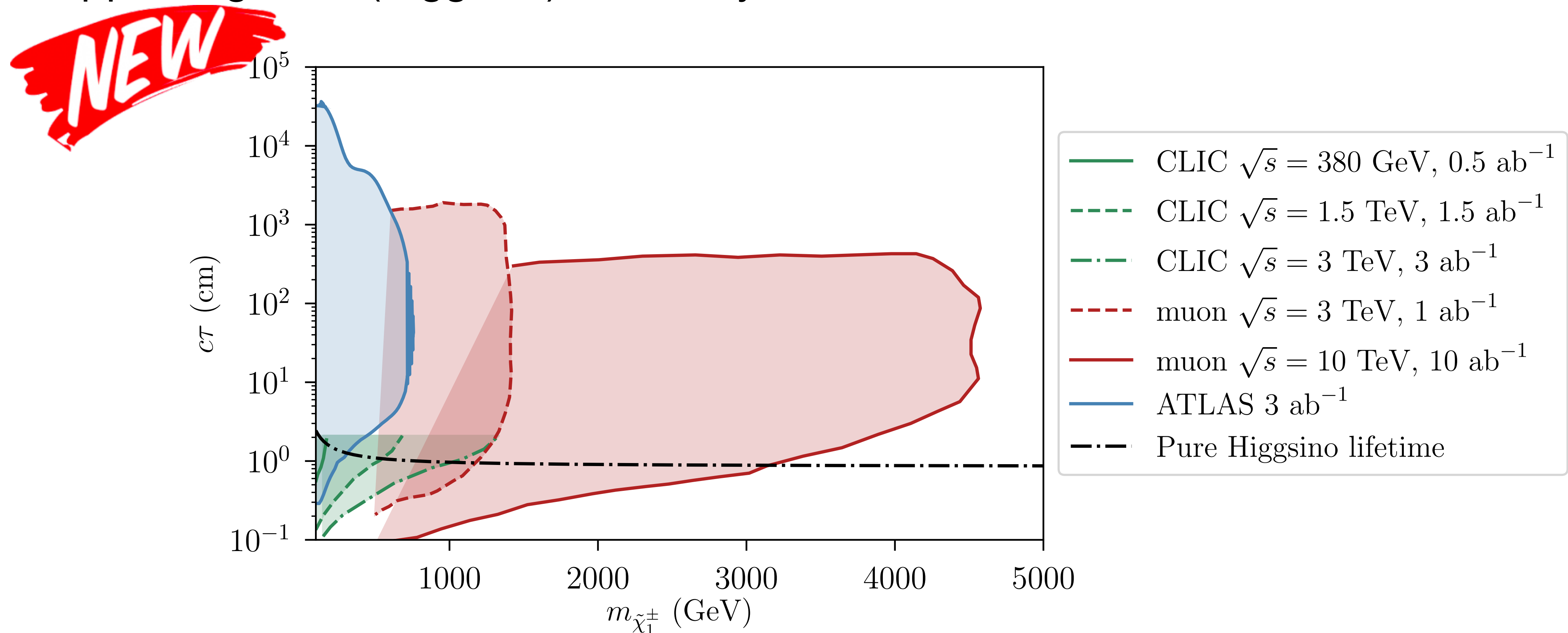
Charged LLPs

Disappearing track sensitivity estimates, assuming pure Higgsino
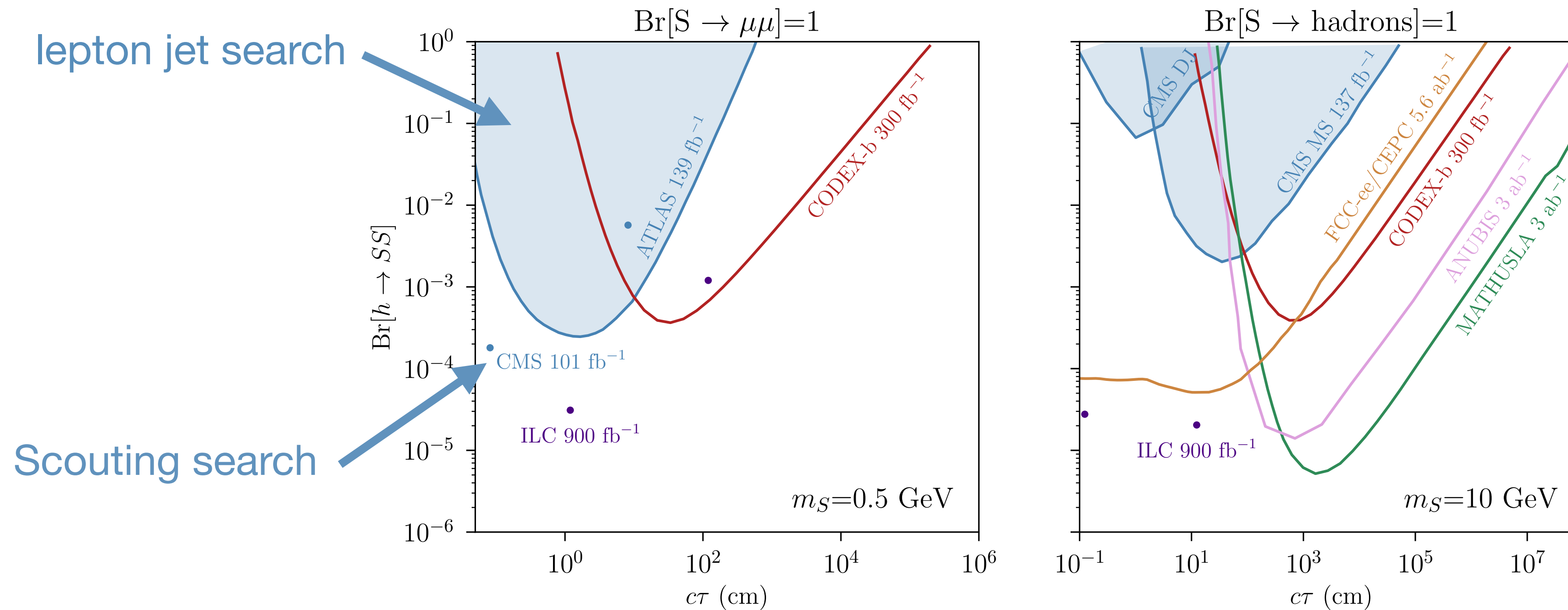
Capdevilla et al 2102.11292

Also briefly discuss HSCPs and mention the importance of timing and tracking detectors for this signature

Light LLPs

NEW

"Light" = hard to trigger on or need auxiliary detector

LLPs produced in Higgs decays (Higgs as window to new physics)

lepton jet search

Scouting search

$\text{Br}[S \to \mu\mu]=1$ $\text{Br}[S \to \text{hadrons}]=1$

ATLAS 139 fb^{-1} CODEX-b 300 fb^{-1} CMS 101 fb^{-1} ILC 900 fb^{-1} m_S=0.5 GeV

CMS DJ   CMS MS 137 fb^{-1} FCC-ee/CEPC 5.6 ab^{-1} CODEX-b 300 fb^{-1} ANUBIS 3 ab^{-1} MATHUSLA 3 ab^{-1} ILC 900 fb^{-1} m_S=10 GeV
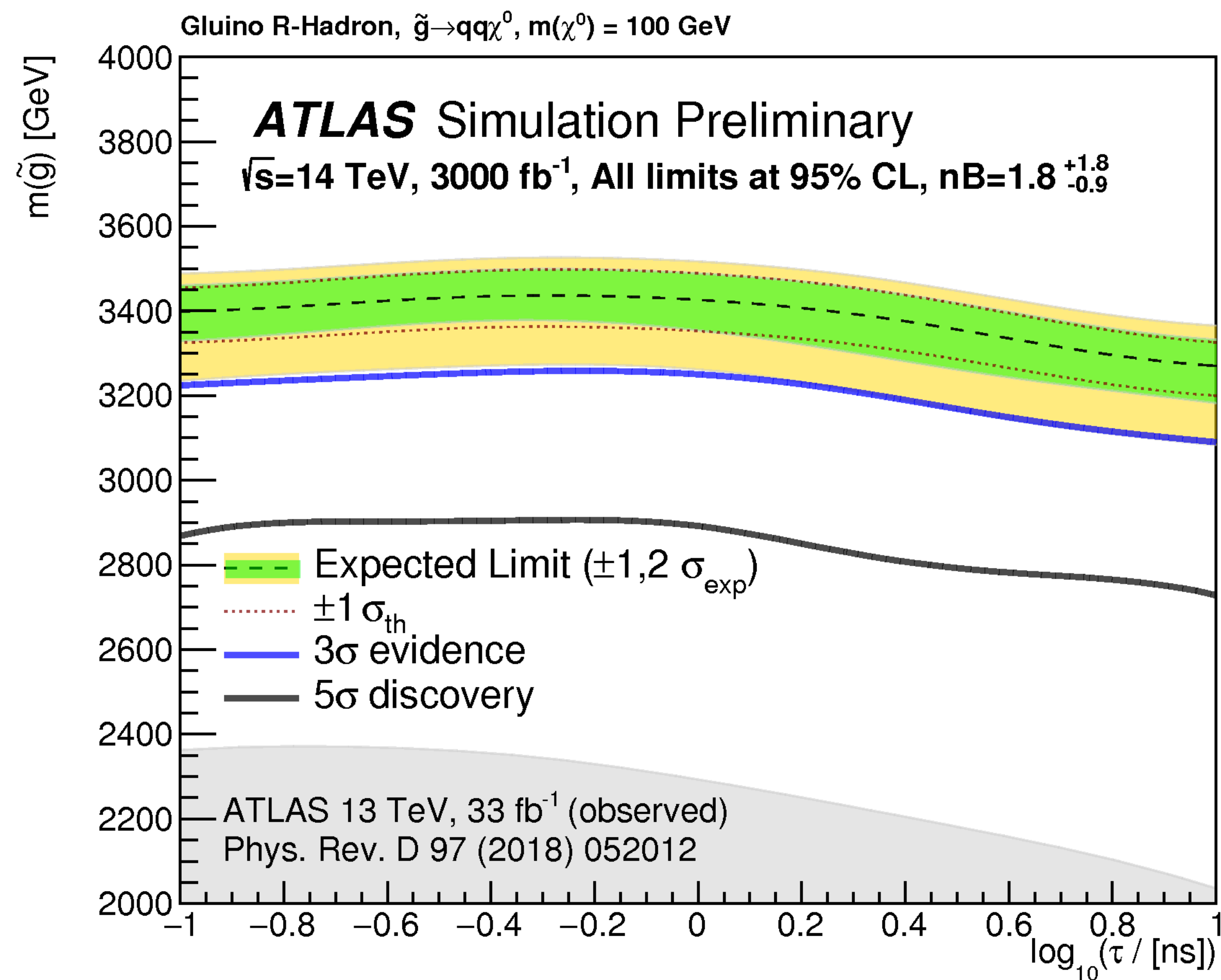
$\text{Br}[h \to SS]$ $c\tau$ (cm)

- Included strongest searches that we were comfortable extrapolating

- Sometimes only two lifetime points were available

- Mathusla study for left hand panel under way

- Several HL-LHC projections available, but already outperformed by existing analysis
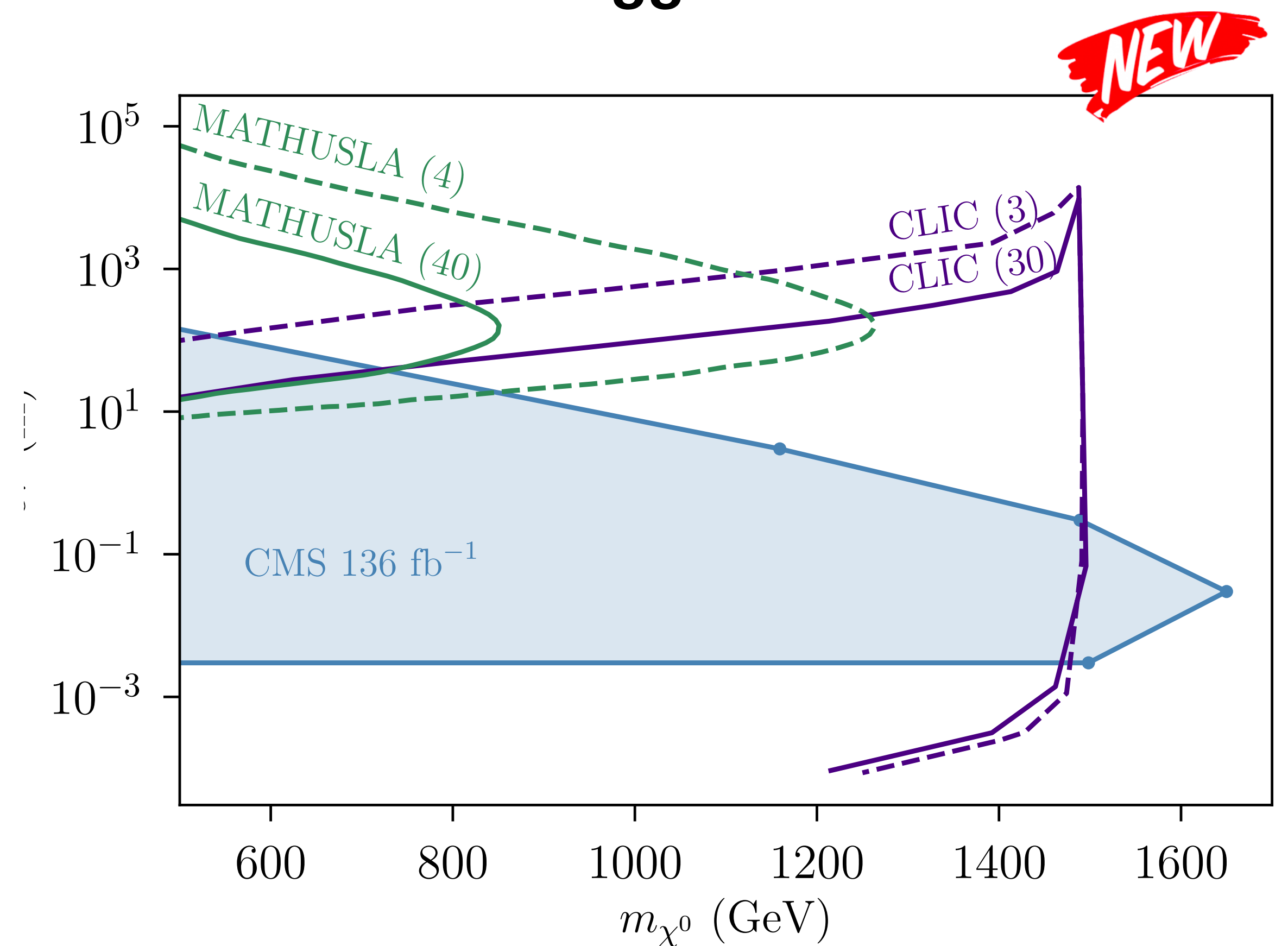
12

Heavy LLPs

"Heavy" = easier to trigger on at the (HL-)LHC

1 colored & 1 EW example

Gluinos

Gluino R-Hadron, $\tilde{g} \to qq\chi^0$, $m(\chi^0) = 100$ GeV

ATLAS Simulation Preliminary

$\sqrt{s}$=14 TeV, 3000 fb^{-1}, All limits at 95% CL, nB=1.8$^{+1.8}_{-0.9}$

Expected Limit (±1,2 σ_{exp})
±1 σ_{th}
3σ evidence
5σ discovery

ATLAS 13 TeV, 33 fb^{-1} (observed)
Phys. Rev. D 97 (2018) 052012

Higgsinos

MATHUSLA (4)
MATHUSLA (40)
CLIC (3)
CLIC (30)
CMS 136 fb^{-1}
NEW
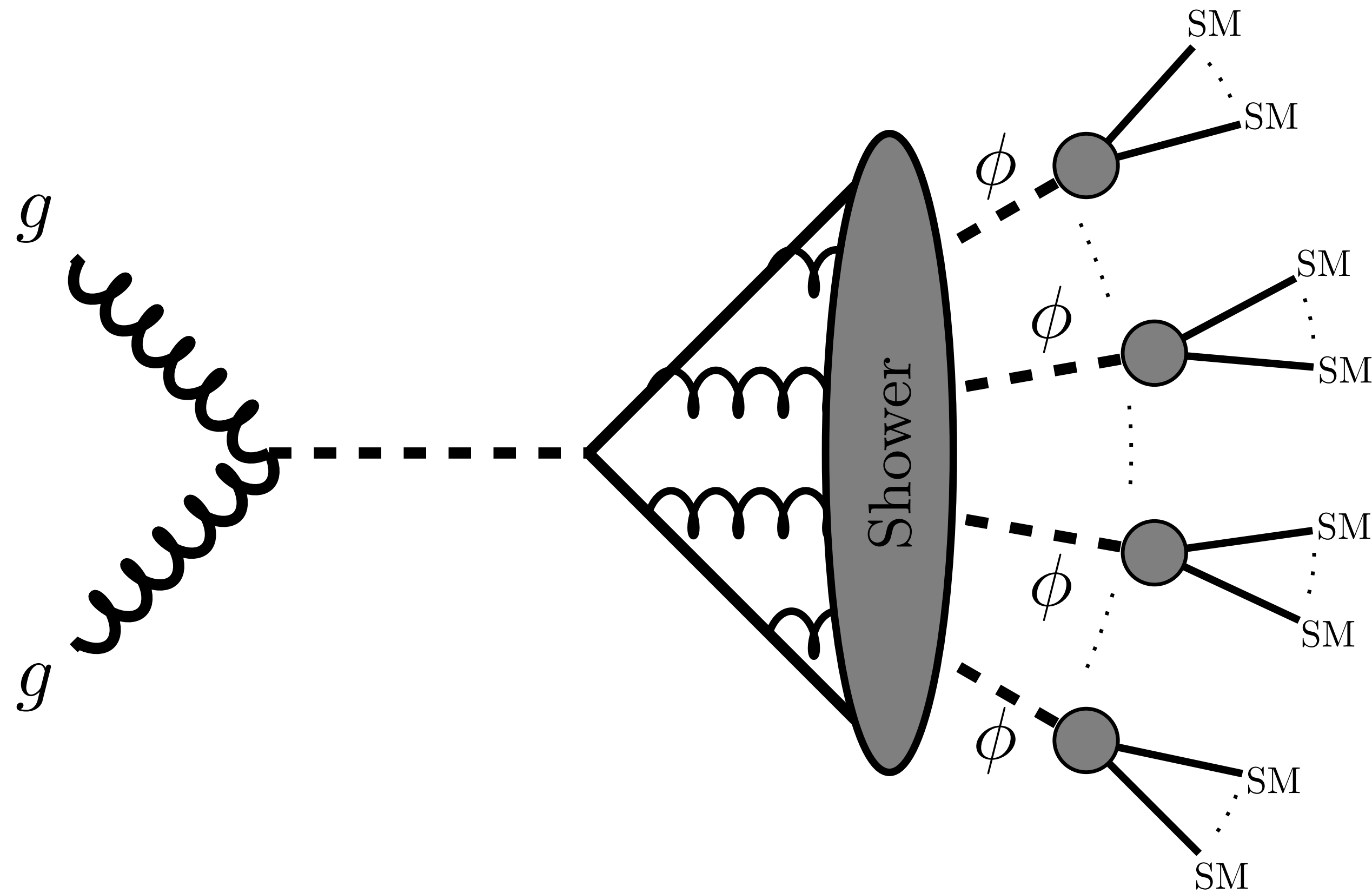
Dark Showers

Explains the challenges and motivation for dark showers
(Very brief, two paragraphs)

Summary

You can find the draft of the full BSM report (v2) and the overall EF report (v2.3) here:

https://snowmass21.org/energy/start#final_reports

We welcome suggestions, comments etc. Please bear in mind that we only have ~12 pages, an exhaustive summary is impossible.

You can leave your comments in the shared document linked on the webpage. Please identify yourself, so that we can get in touch if we have questions.

BSM report and EF summary reports will be finalized in the fall