Collider searches for DM and weakly coupled (LLP & ALP) particles

Vladimir V Gligorov

LPNHE Paris

CNRS

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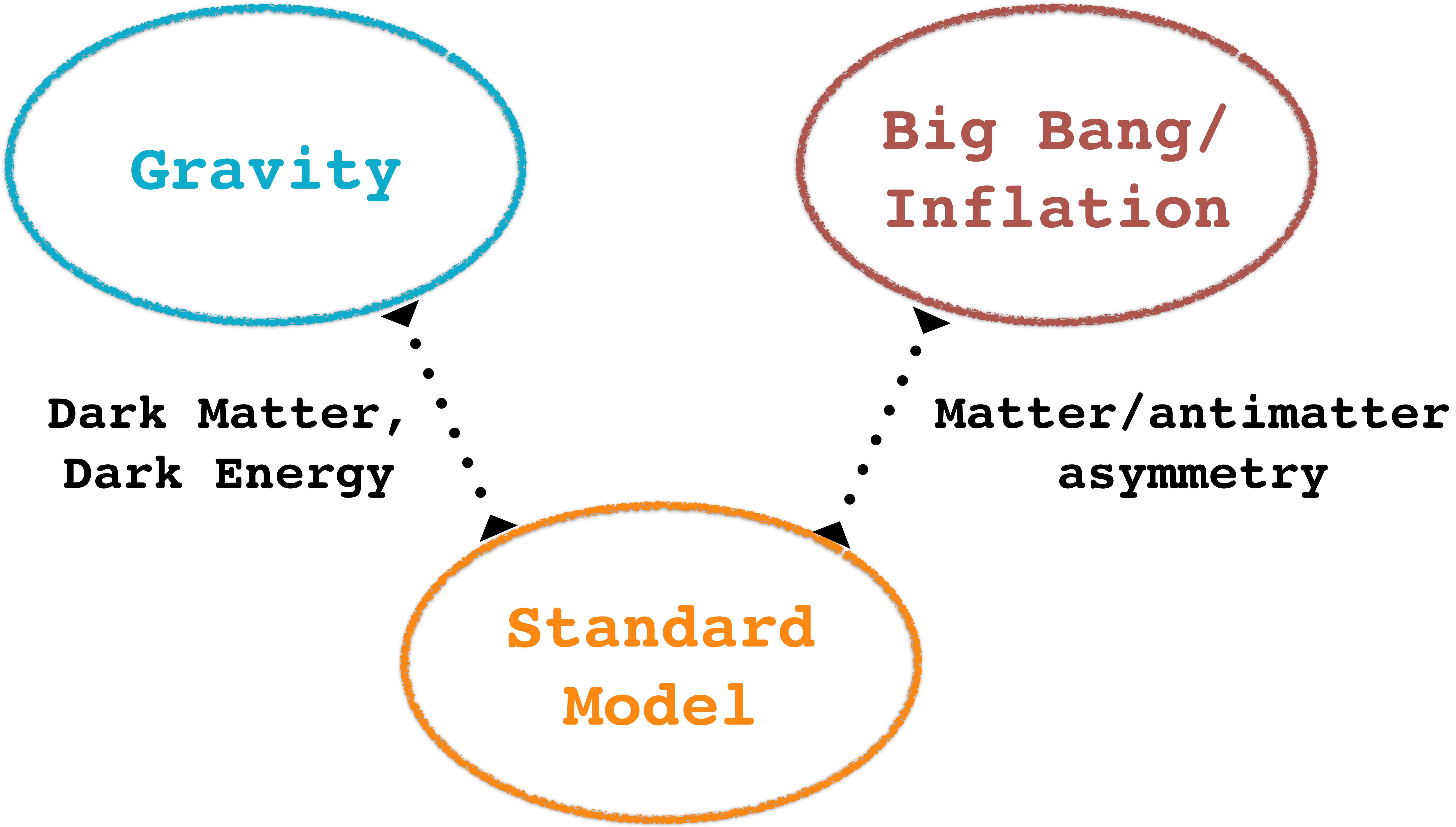
Why are we here?

And the really big bad ghoul… nonlocality. But let’s not go there.



Our theories of nature are inconsistent with each other => new physics!

Possibilities

&

Capabilities

Why long lived particle searches?

Long lifetimes arise from a hierarchy of scales or a small coupling*

Three mechanisms:

- Off-shell decay
- Small splitting (phase space)
- Small coupling

Lessons from the SM:

- generic if there is more than one scale
- Often 3 body decays
- Weak theory prior on lifetime

(e.g. proton decay!)

$$\Gamma \sim y^2 \left(\frac{m}{M}\right)^n m$$

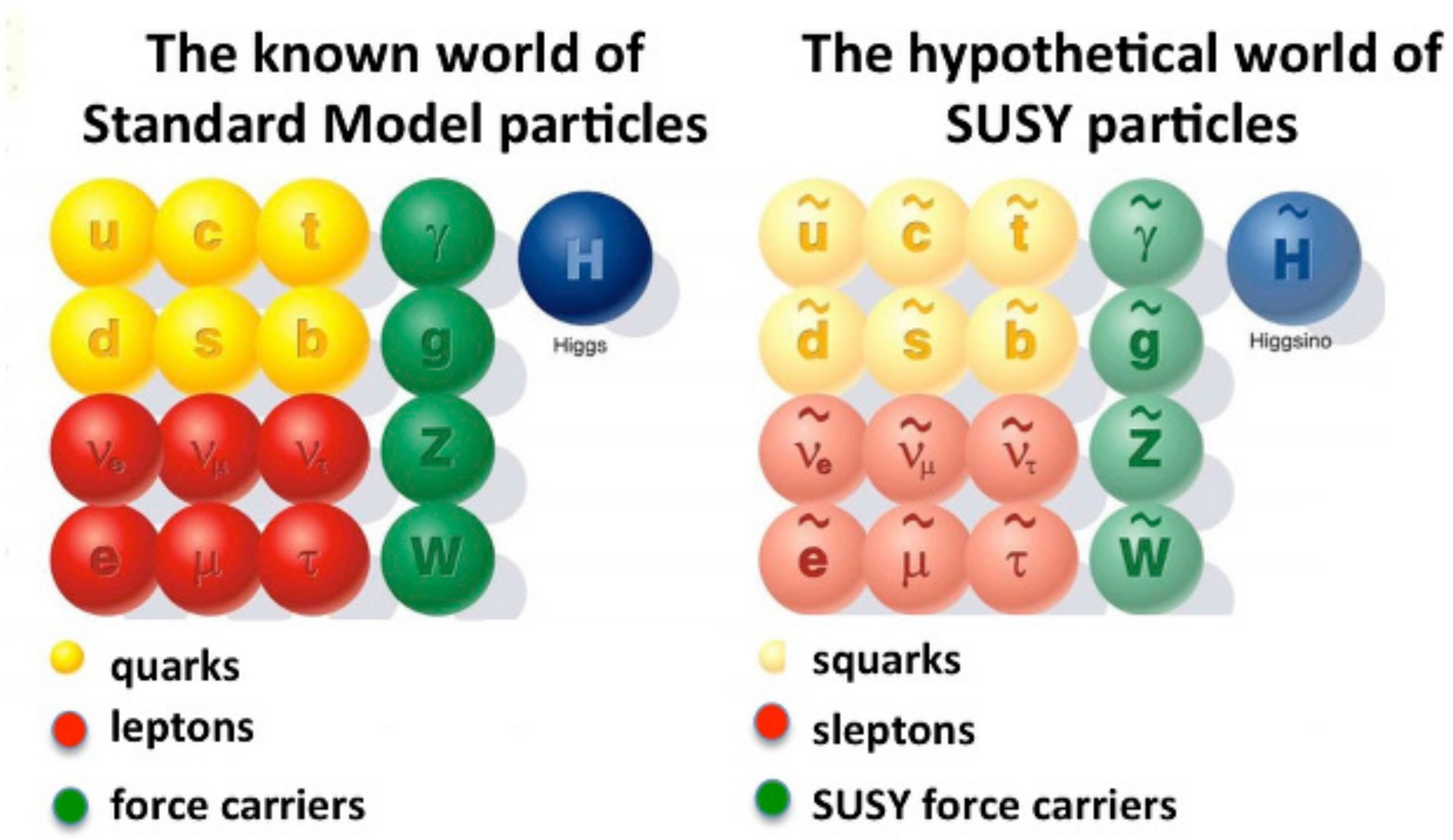
small coupling (y^2)

hierarchy of scales (m/M)

n: Set by symmetry structure, typically $n \geq 4$

* could either be a hierarchy or loop suppression

Long-lived particles are generic



R-parity violation
Gauge mediation
(mini-)split SUSY
stealth SUSY

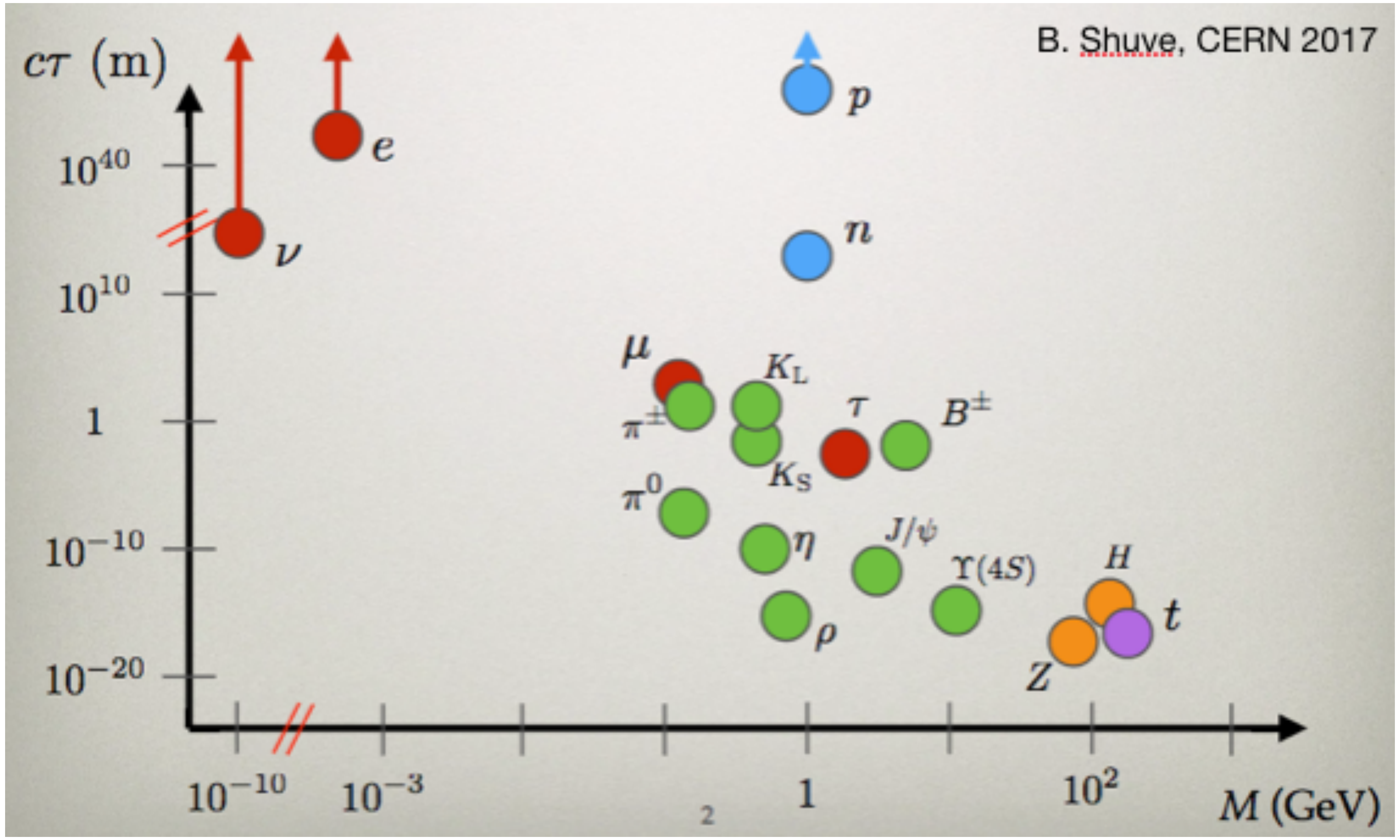
Asymmetric Dark Matter
Freeze-in
composite Dark Matter
…

Other

Baryogenesis
Neutrino masses
Neutral Naturalness
Hidden Valleys

A very wide range of BSM models introduce long-lived and/or weakly coupled particles

LLP mass vs lifetime vs production



The bigger the mass, the smaller in general the coupling you have to impose to get a narrow width (long lifetime)

The details linking production and decay in this heavily depend on the specific LLP and the portal used to access it.

Collider vs. fixed target mode

	Fixed target	Collider
Advantages	Production rate Collimated production & decay	Access to higher mass LLPs via e.g. Higgs portal
Disadvantages	No access to very heavy LLPs Big shielding required for bkg	Uncollimated production Hard to instrument Hard to shield

Collider vs. fixed target mode

To put the production argument in some context, consider the SPS vs. HL-LHC, each over 5 years

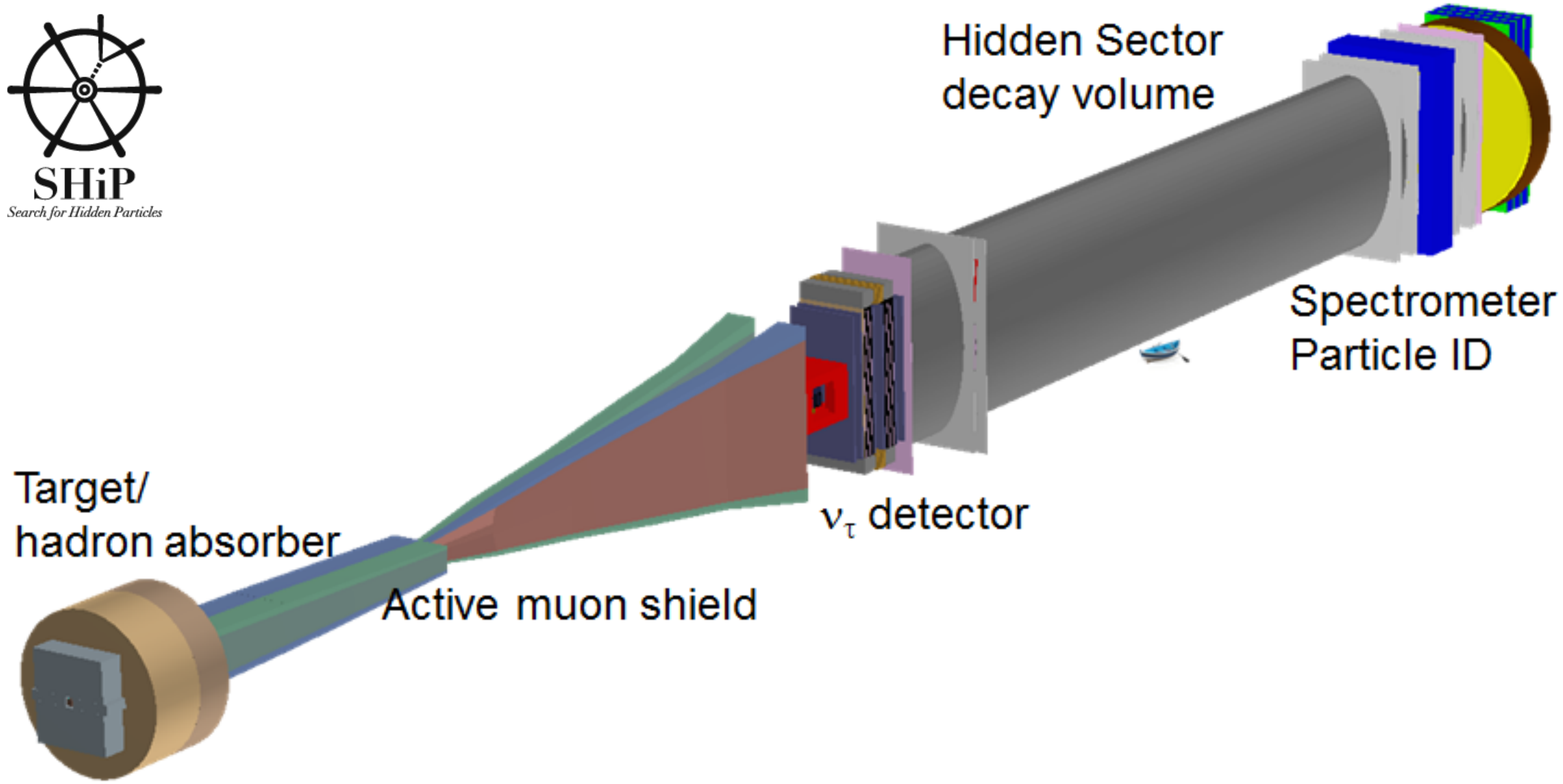
Charm Hadrons @ SPS : $O(10^{18})$
Charm Hadrons @ HL-LHC : $O(10^{16})$

Beauty Hadrons @ SPS : $O(10^{14})$
Beauty Hadrons @ HL-LHC : $O(10^{15})$

This is why SHIP is so great at LLPs produced in charm decays, while HL-LHC can compete for beauty and dominates for anything heavier

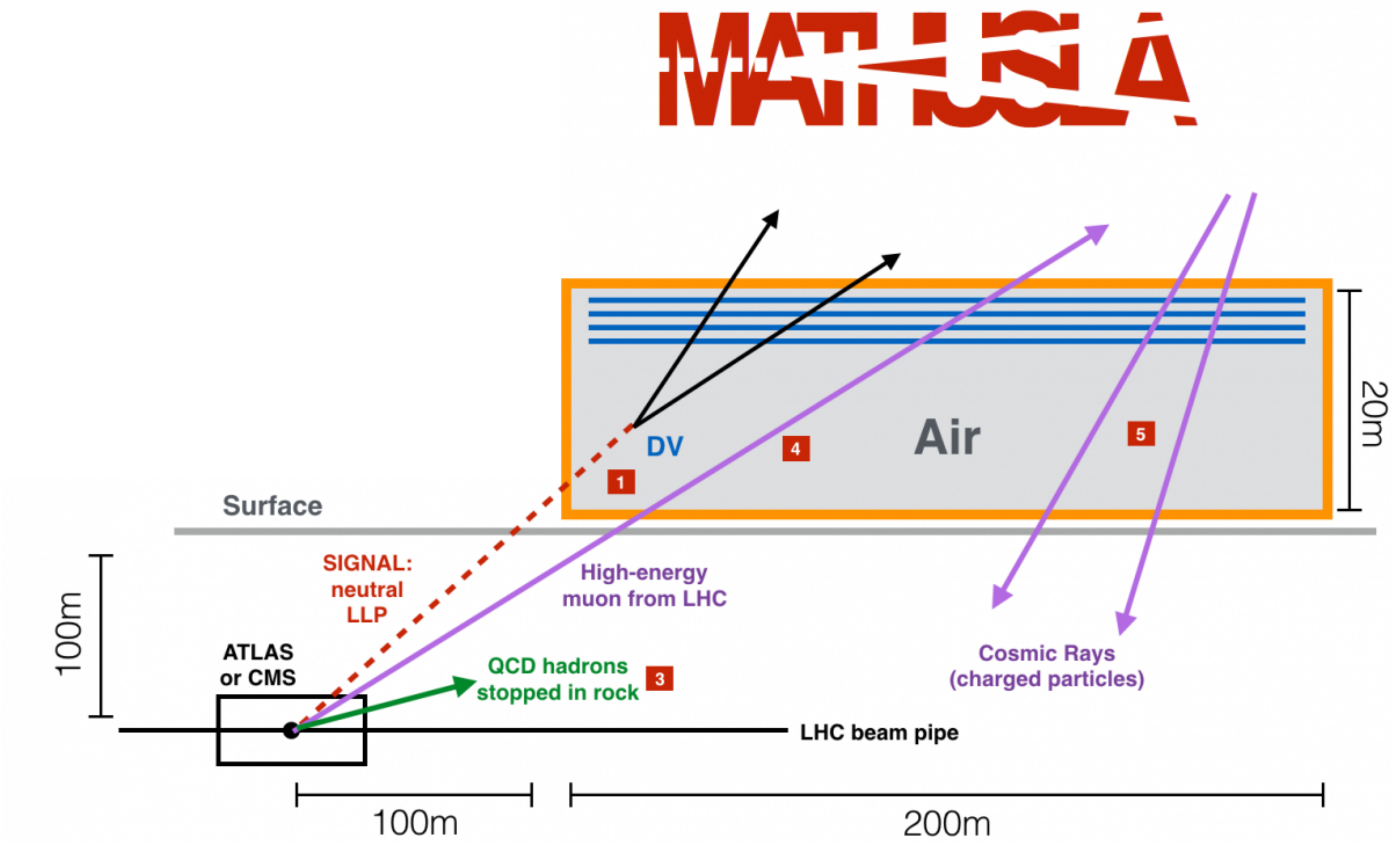
Distance versus solid angle coverage

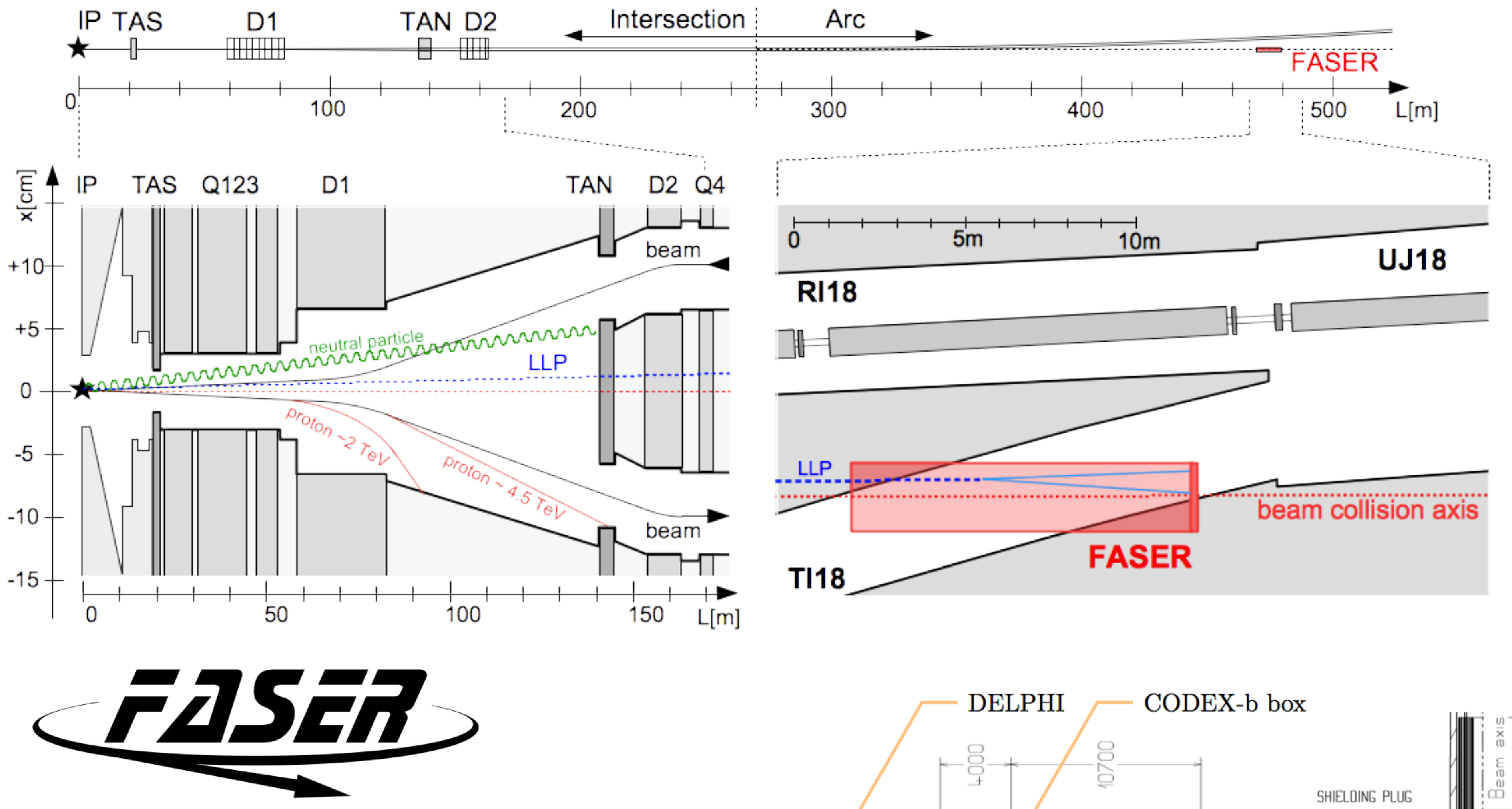
Fixed target : collimated production

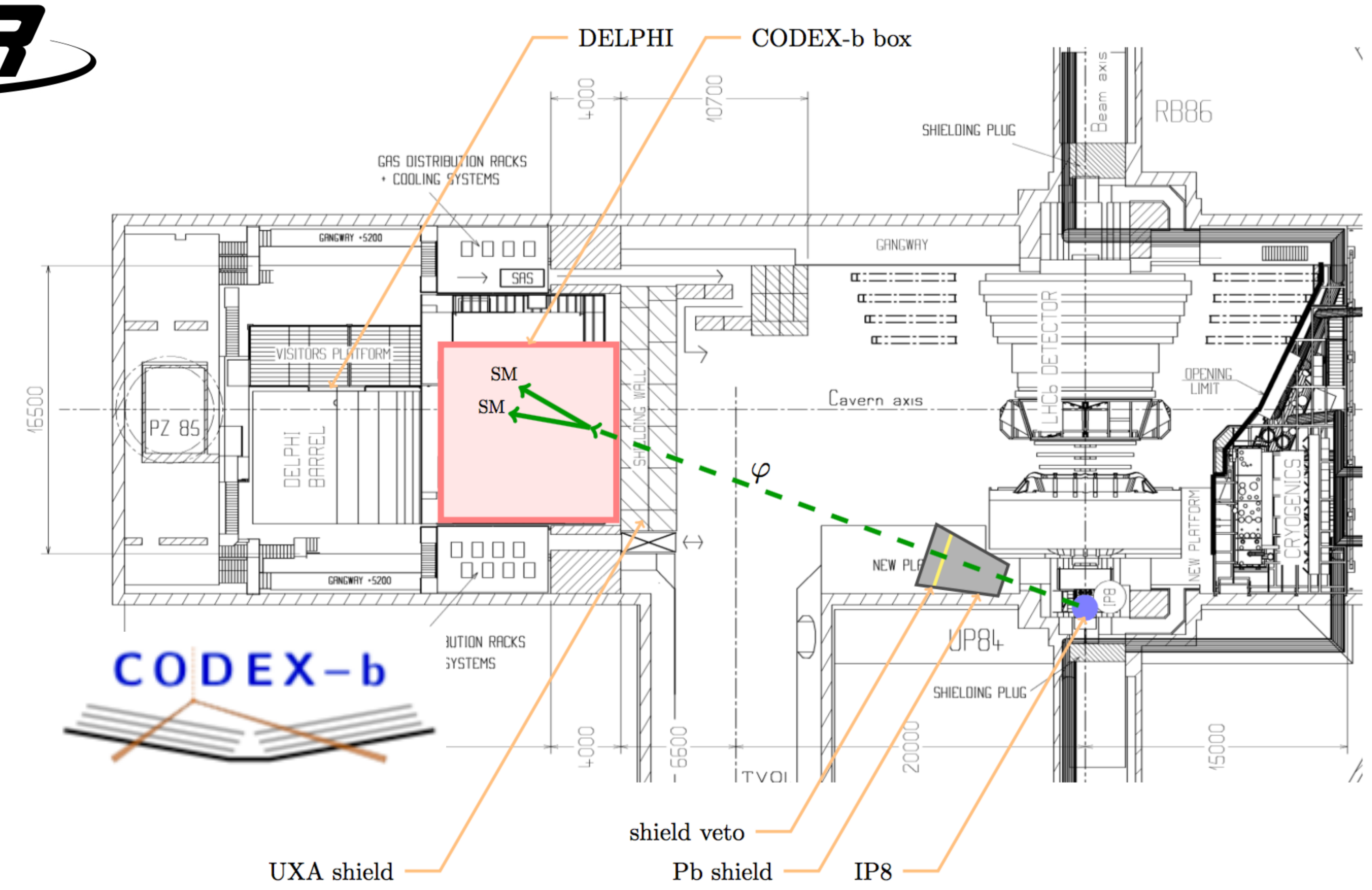


Collimated production and decay mean that solid angle coverage is largely independent of optimal decay volume. The geometry is dominated more by the required size of shield.

Distance versus solid angle coverage

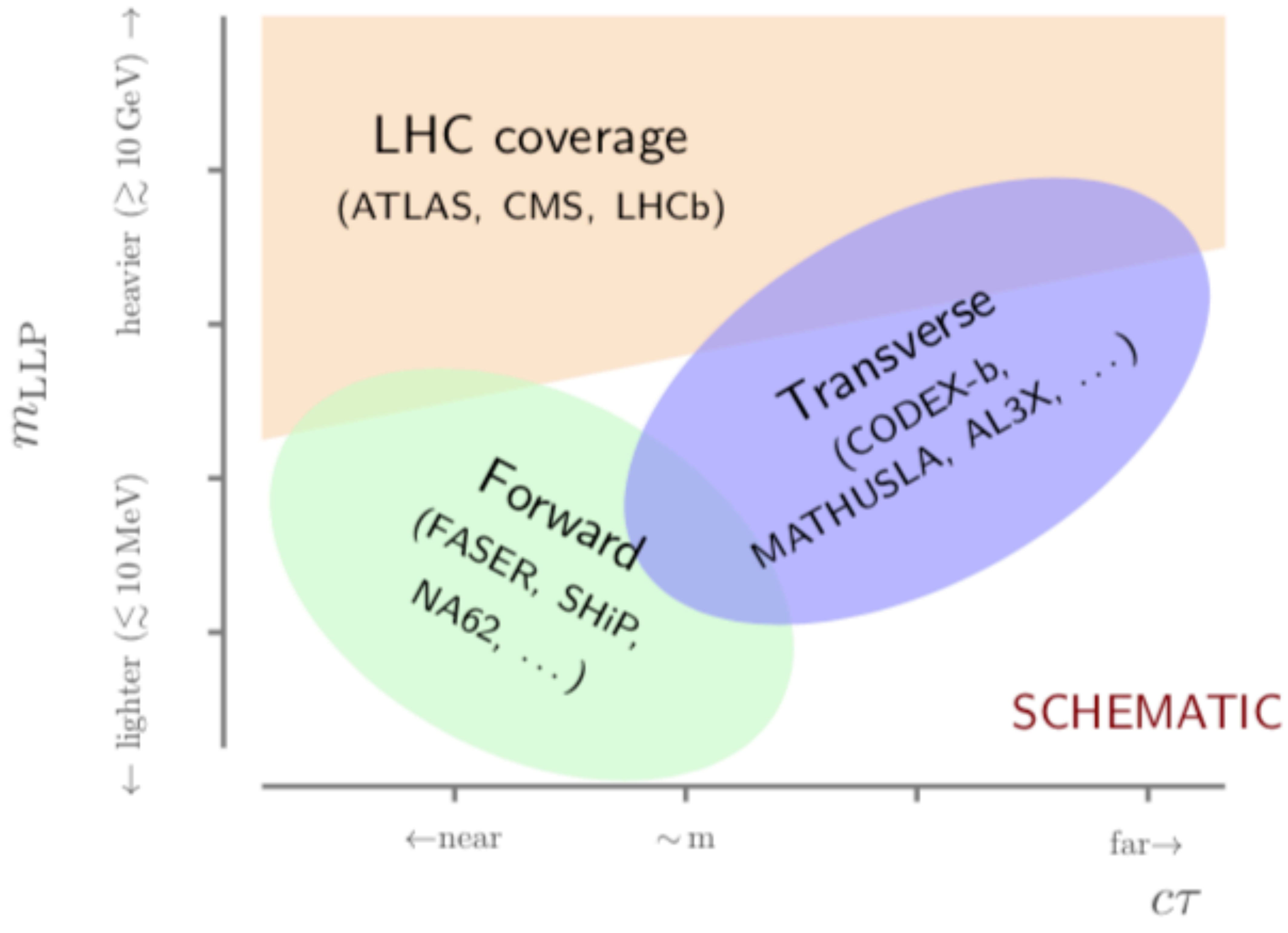


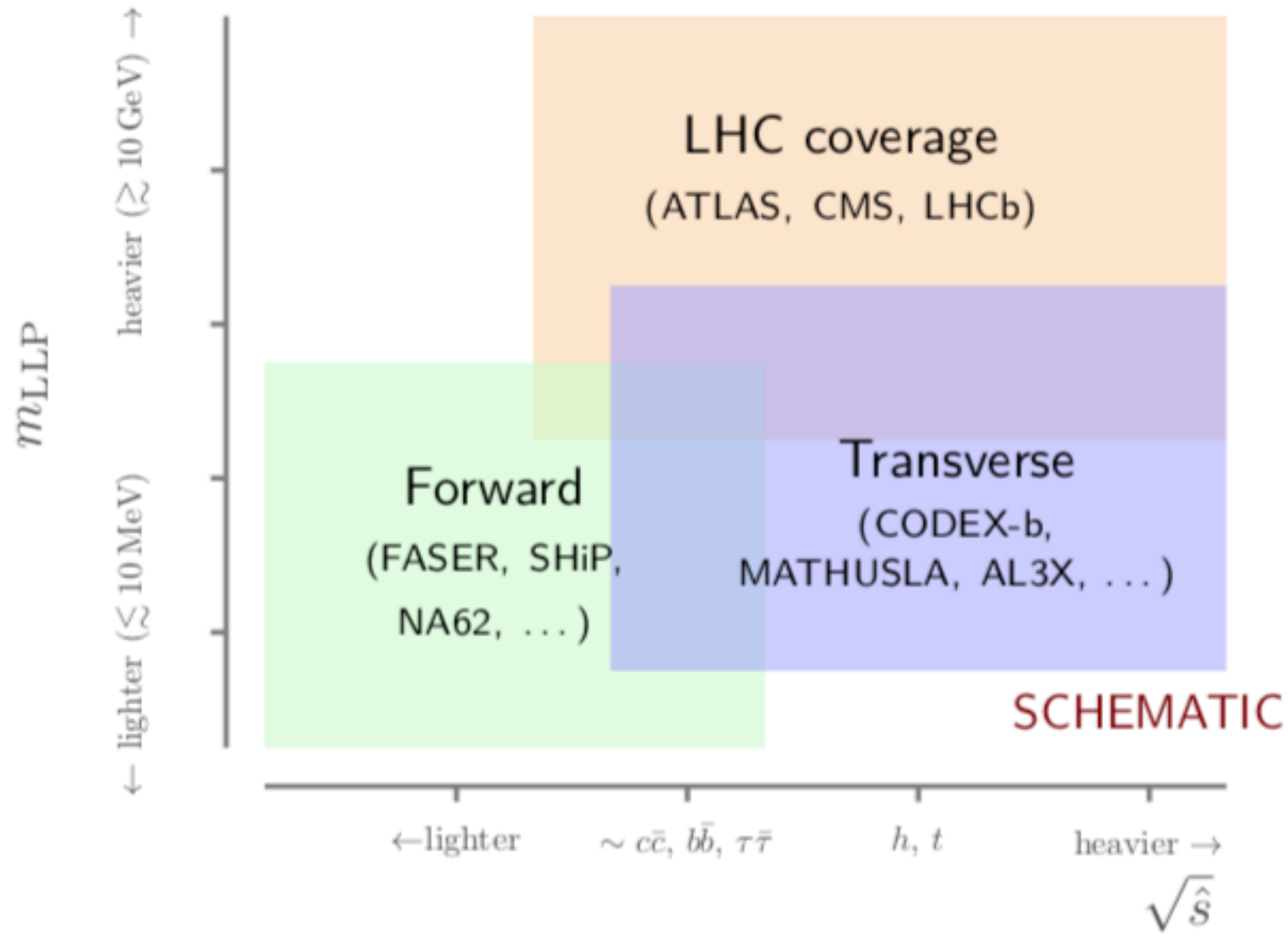




Uncollimated production means that (unless you go very forward) the size of your detector goes quadratically with the distance from collision point. Hence MATHUSLA's 200x200 m^2…

Reach complementarity

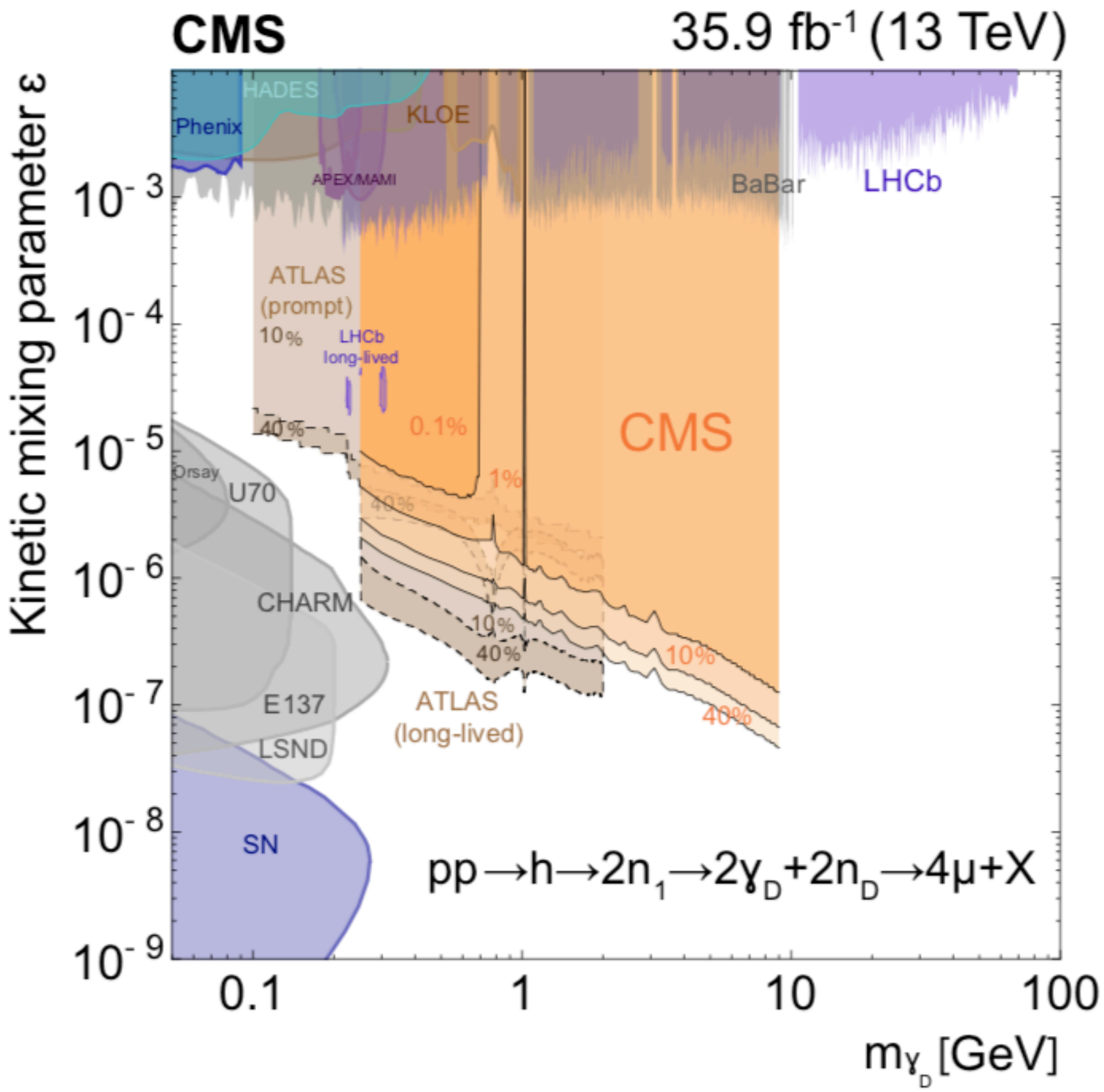


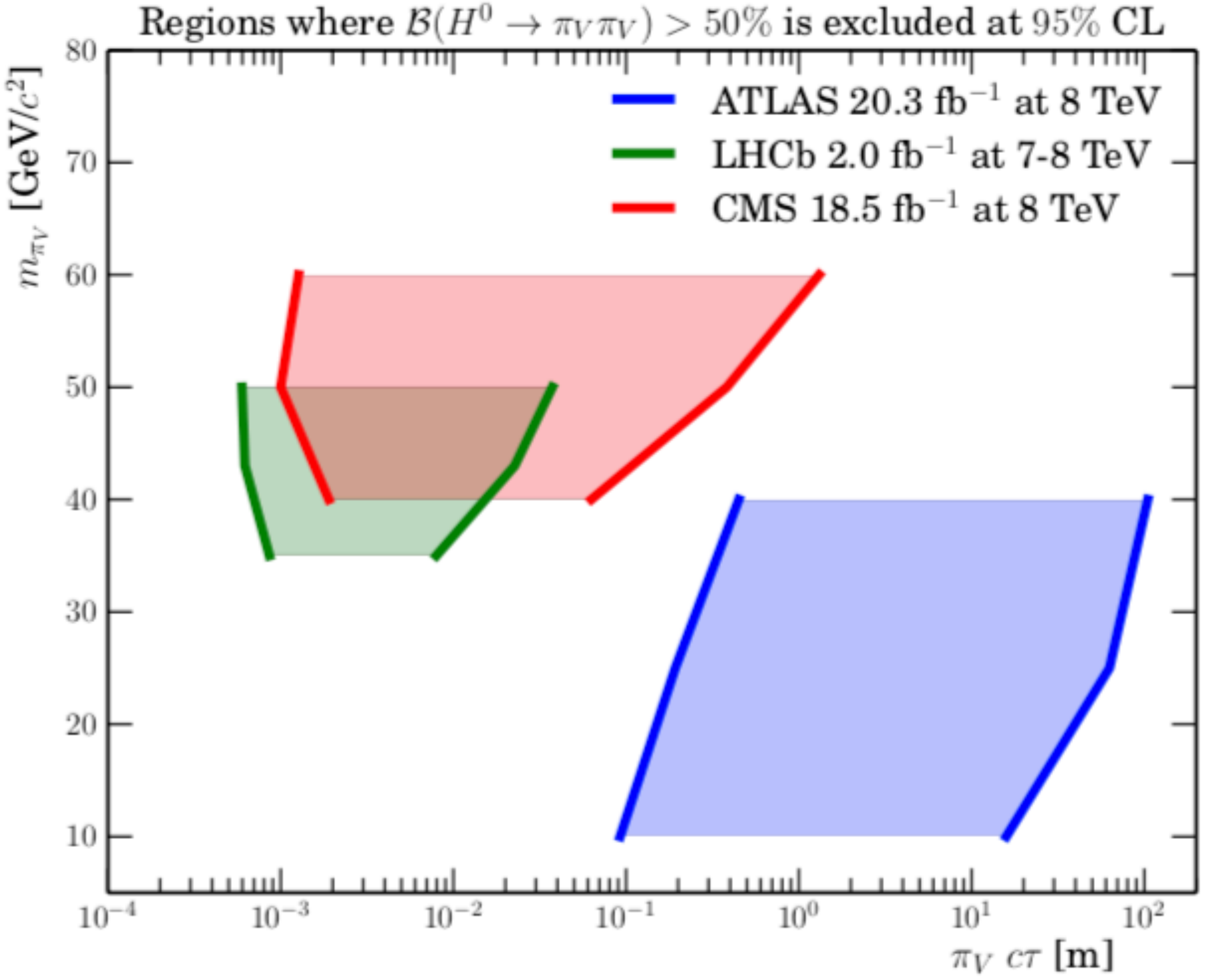


Forward or transverse dedicated experiments add significant complementary coverage to direct (HL)-LHC searches

Reach examples from LLP WP

[Link to white paper]





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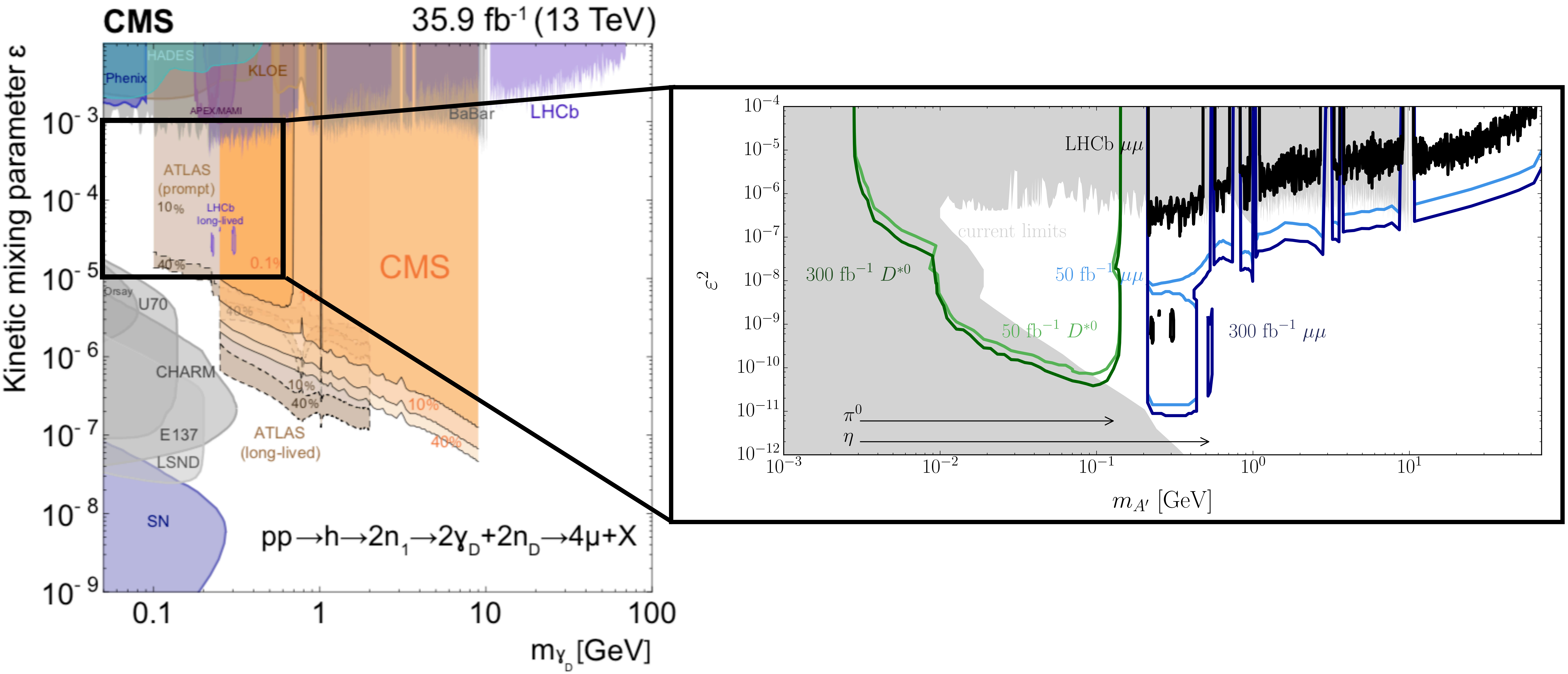
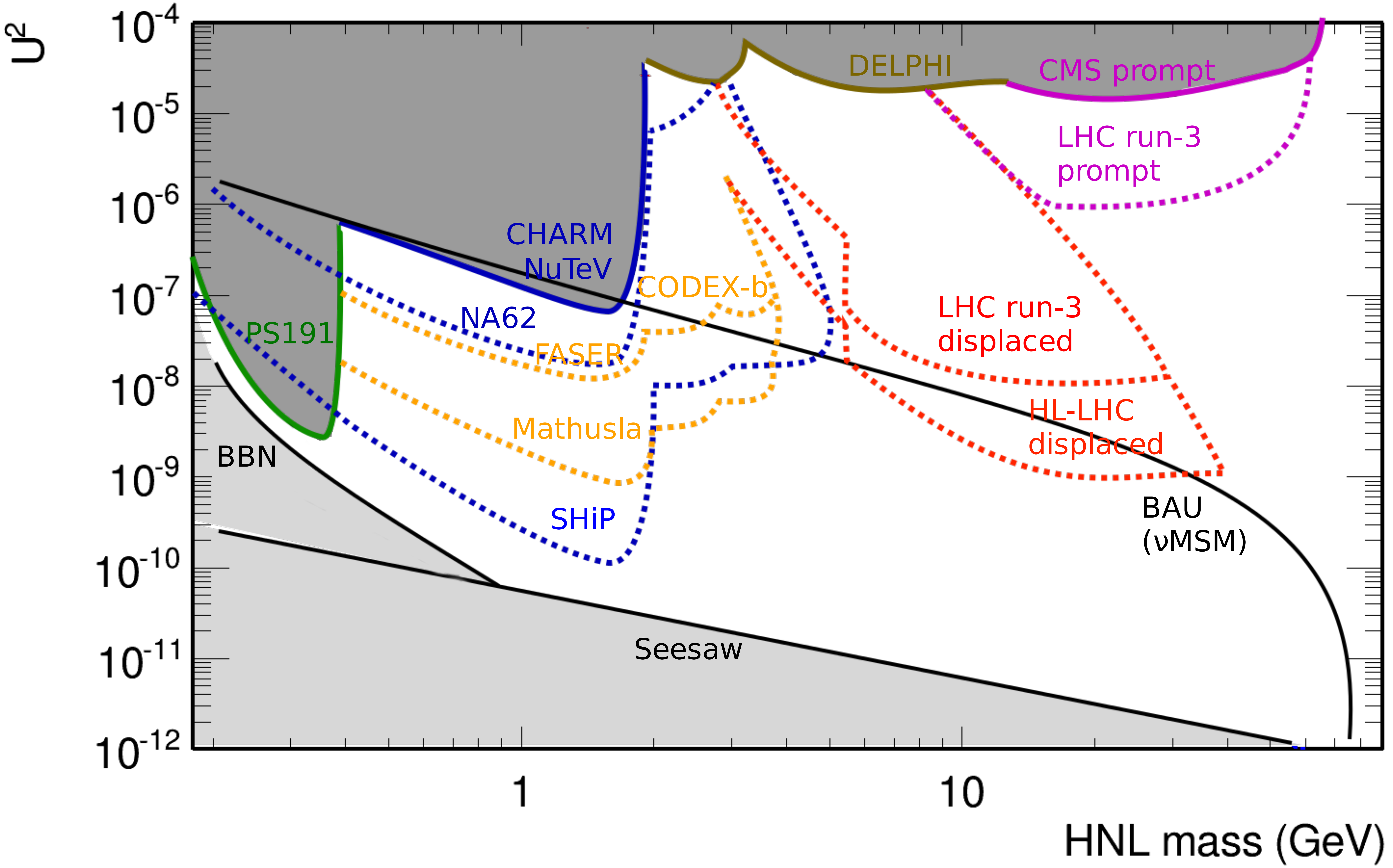


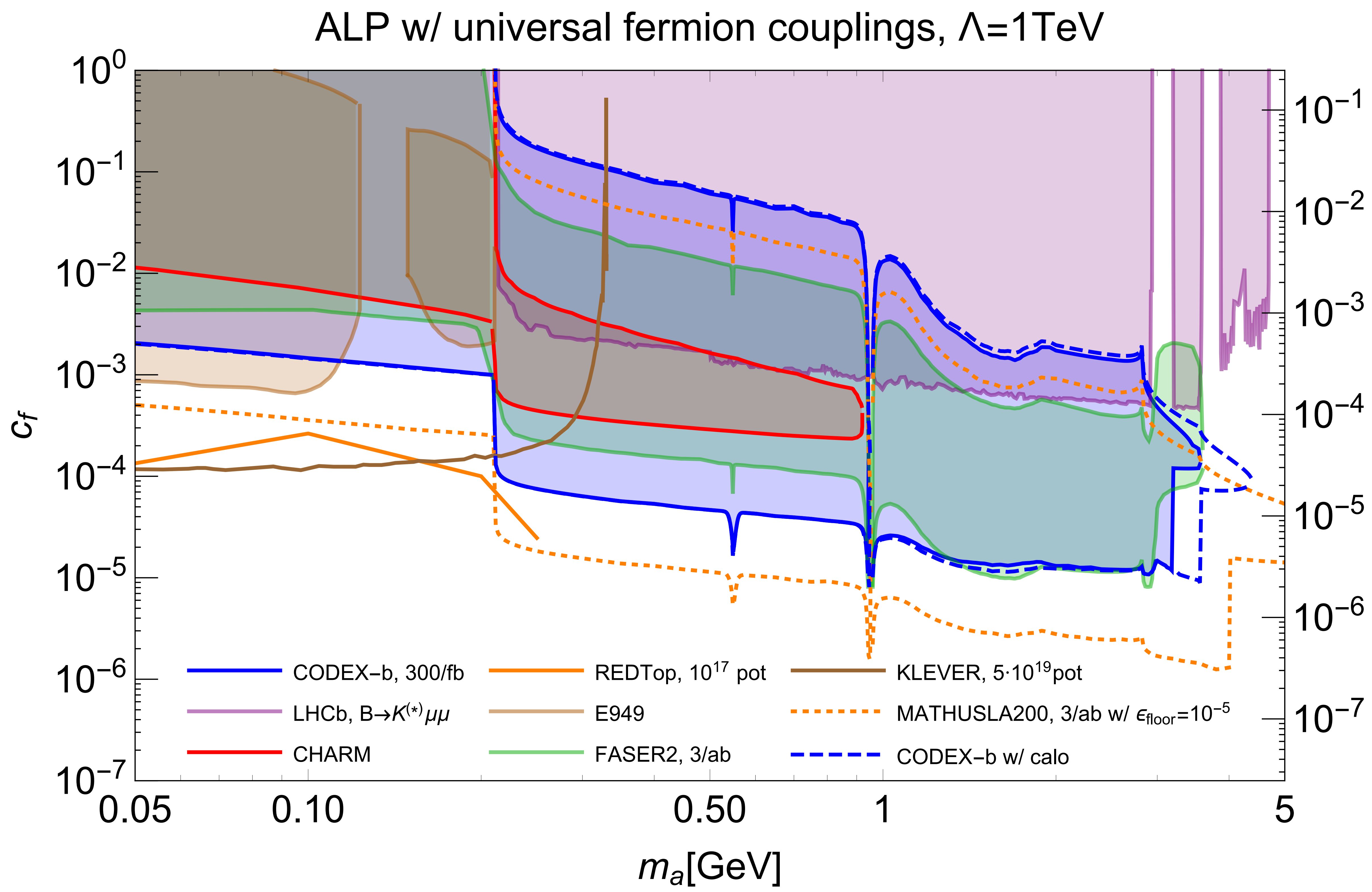
Reach projections for HNL

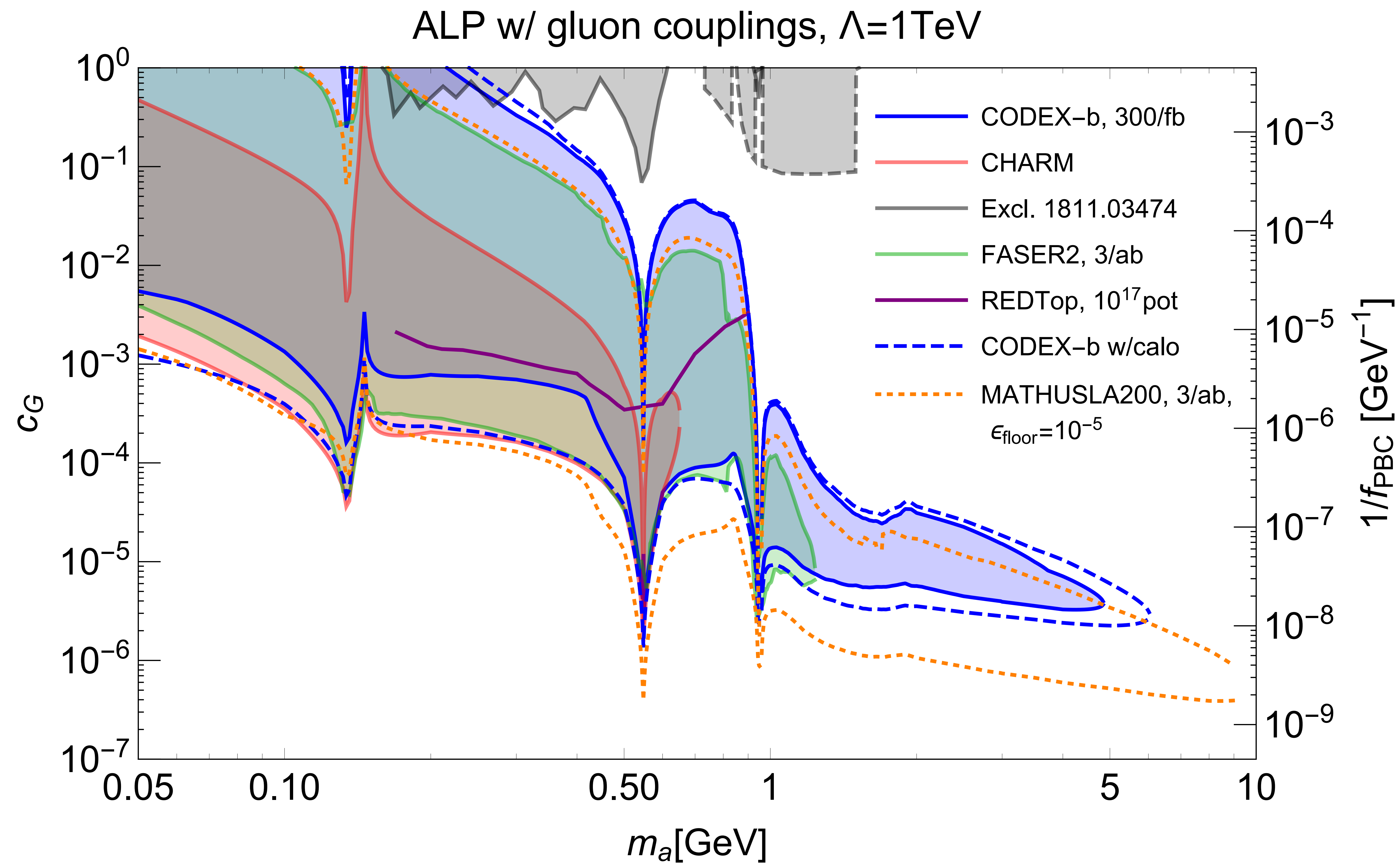
[Link to white paper]



Reach for ALPs

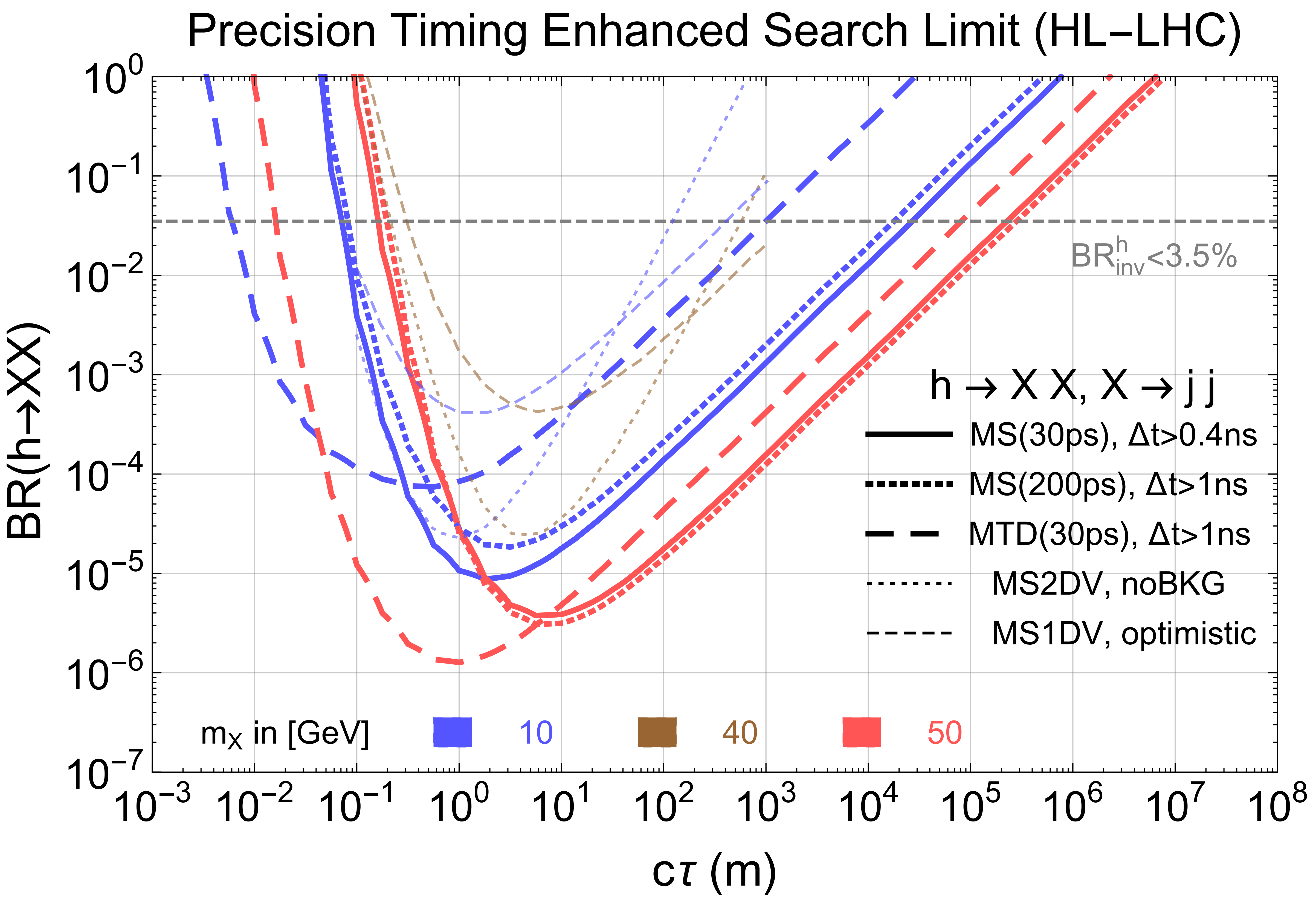
Link to CODEX-b EOI

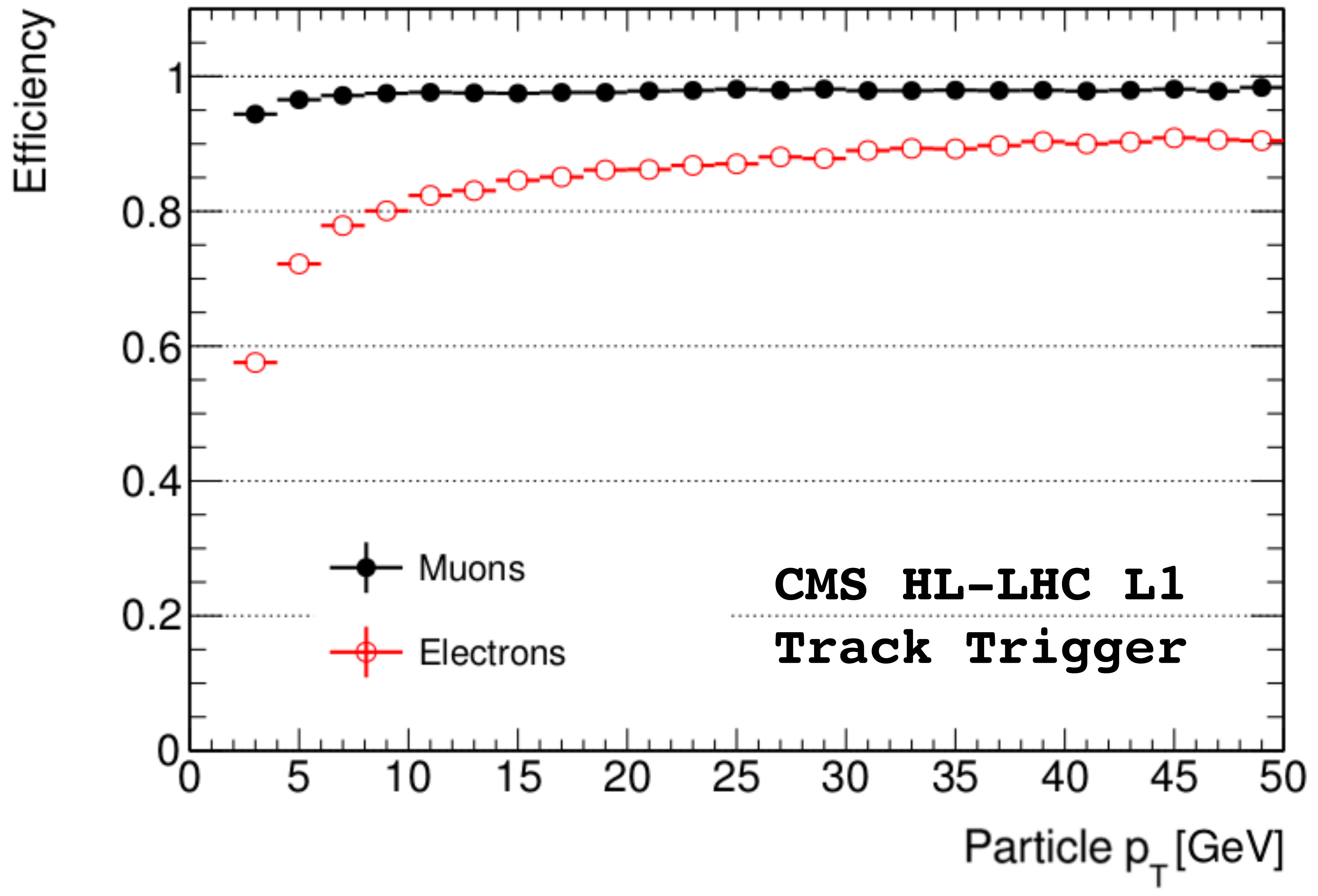




Improved detectors at HL-LHC

Link to white paper

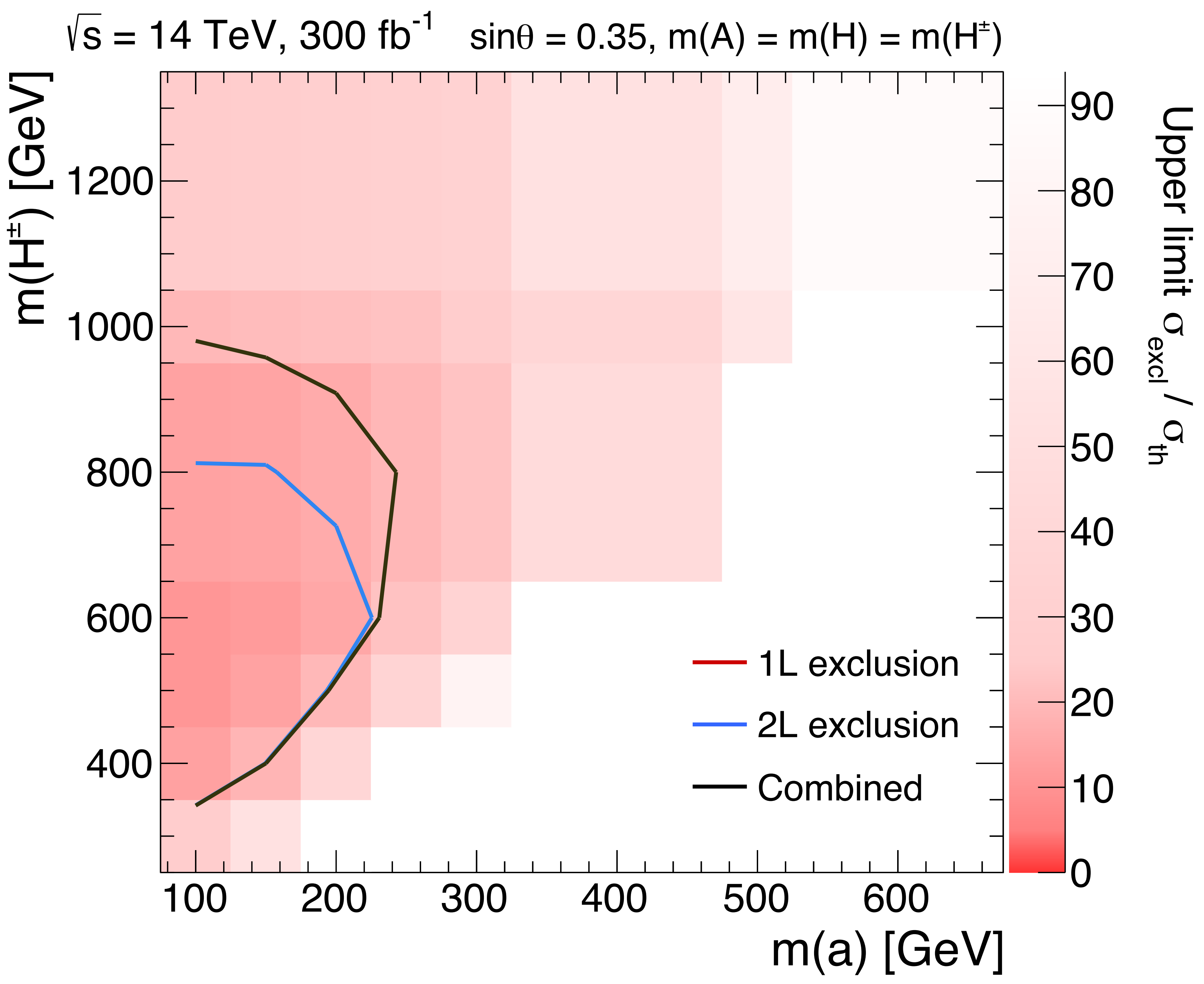


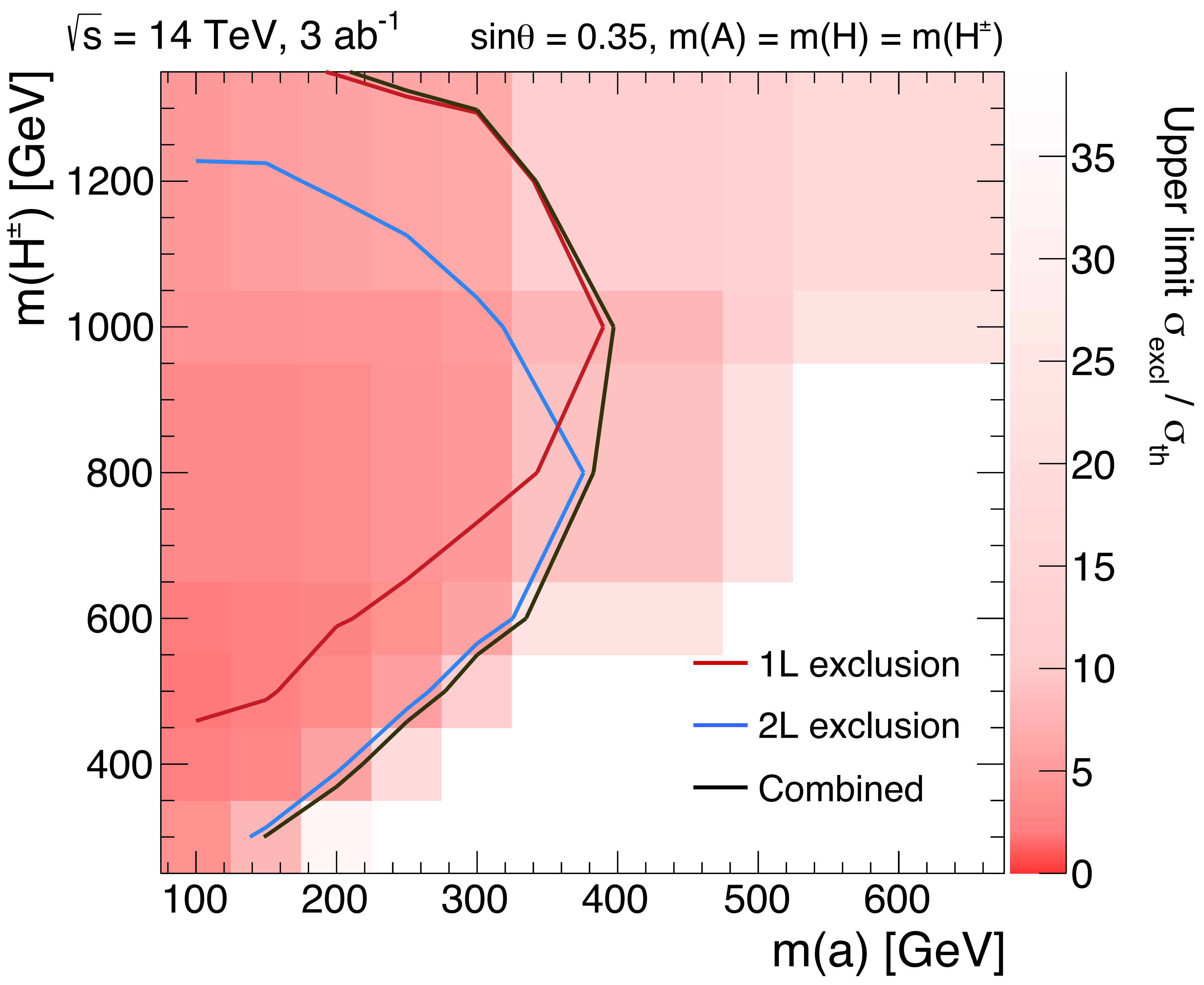


Expect significant improvement in reach per luminosity!

Dark matter and top quarks

BSM at HL-LHC yellow report

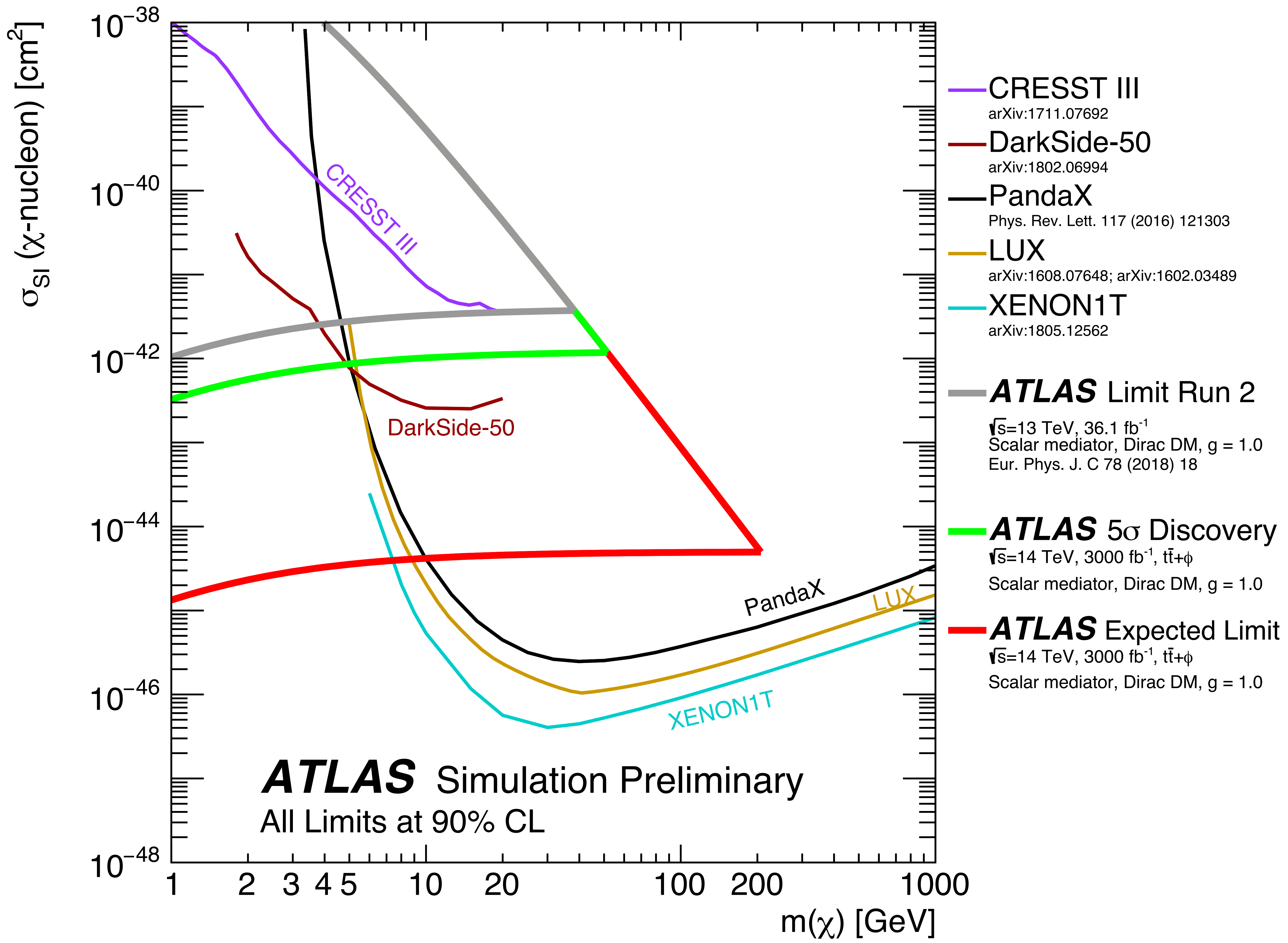




Many, particularly scalar, models favour interactions with top quarks; a rich variety of searches exists and is planned

Collider vs direct DM

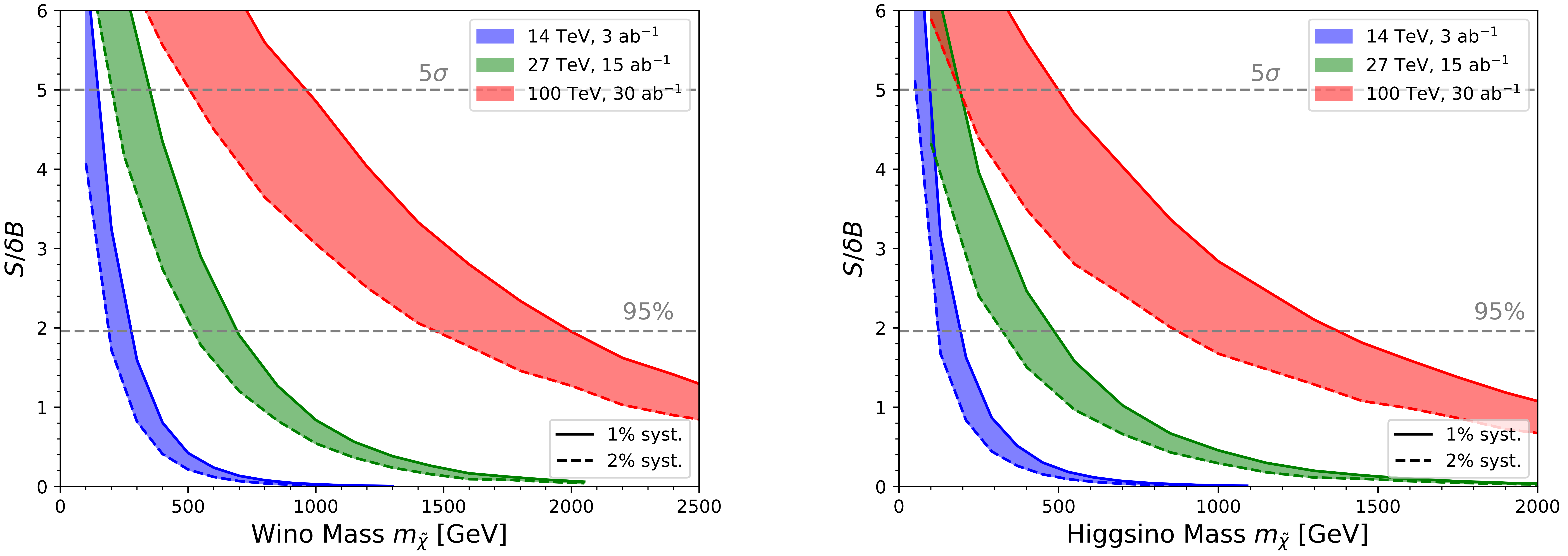
BSM at HL-LHC yellow report



Plot is for ATLAS but similar for CMS. Adds particular value at low masses, although note that this plot is made for DM-SM couplings of O(1) so must be interpereted with care.

Towards future colliders

BSM at HL-LHC yellow report



Benefit from FCC-hh in these searches is clear

French institutes interests & plans

ATLAS

Existing involvement in SUSY and direct, simplified-model-based DM searches by LPSC group.

Involvement now extending to dark QCD searches, in which dark quarks hadronize into dark hadrons. Results in unusual, for example displaced, hadronic jets.

Analysis work complemented by work on jet performance, and general effort on the upgrade of the ATLAS inner tracker by French ATLAS groups.

CMS

Existing work by IPHC group on stop pair and inclusive mono-top searches is now being expanded to LLPs.

One interesting analysis is searching for low β-factor high-p_T tracks with a large energy deposit in the tracker and a large TOF in the muon layers. This almost-stable charged LLP is generic in many BSM models. HL-LHC detector upgrades will help, in particular charge measuring tracker layers, timing layers, and the L1 track trigger.

Analysis complemented by work on tracking, particularly for highly displaced tracks, and using machine learning techniques.

Disclaimer: based on contributions to the GT1 document…

LHCb

Proposal by LPNHE group to build CODEX-b, beginning with a 2x2x2 metre prototype, called CODEX-β, in Run 3.

Informal green light from LHCb subject to engineering drawings (in course of preparation) and sufficient people to assure maintenance.

Prototype based on RPCs for ATLAS upgrade, collaboration with the Tor Vergata group. Calorimetry options are being studied for an eventual full detector.

Phenomenology & reinterpretation

Because DM and LLPs are so generic in BSM models, new models constantly emerging. The French community is strongly involved in the conception of simplified models used by the experiments.

Critical to reinterpret existing searches! Heavy involvement by the French community in tools for reinterpretation and recasting, notably MadAnalysis5, SmodelS, and the LHCiTools project.

Fast detector simulation for LLP searches and a unified treatment of long-lived and prompt signatures are key areas of work for the future. Automatising the description of simplified model topologies, and efficiently interpolating multidimensional efficiency maps will also be very important in this.

Disclaimer: based on contributions to the GT1 document…

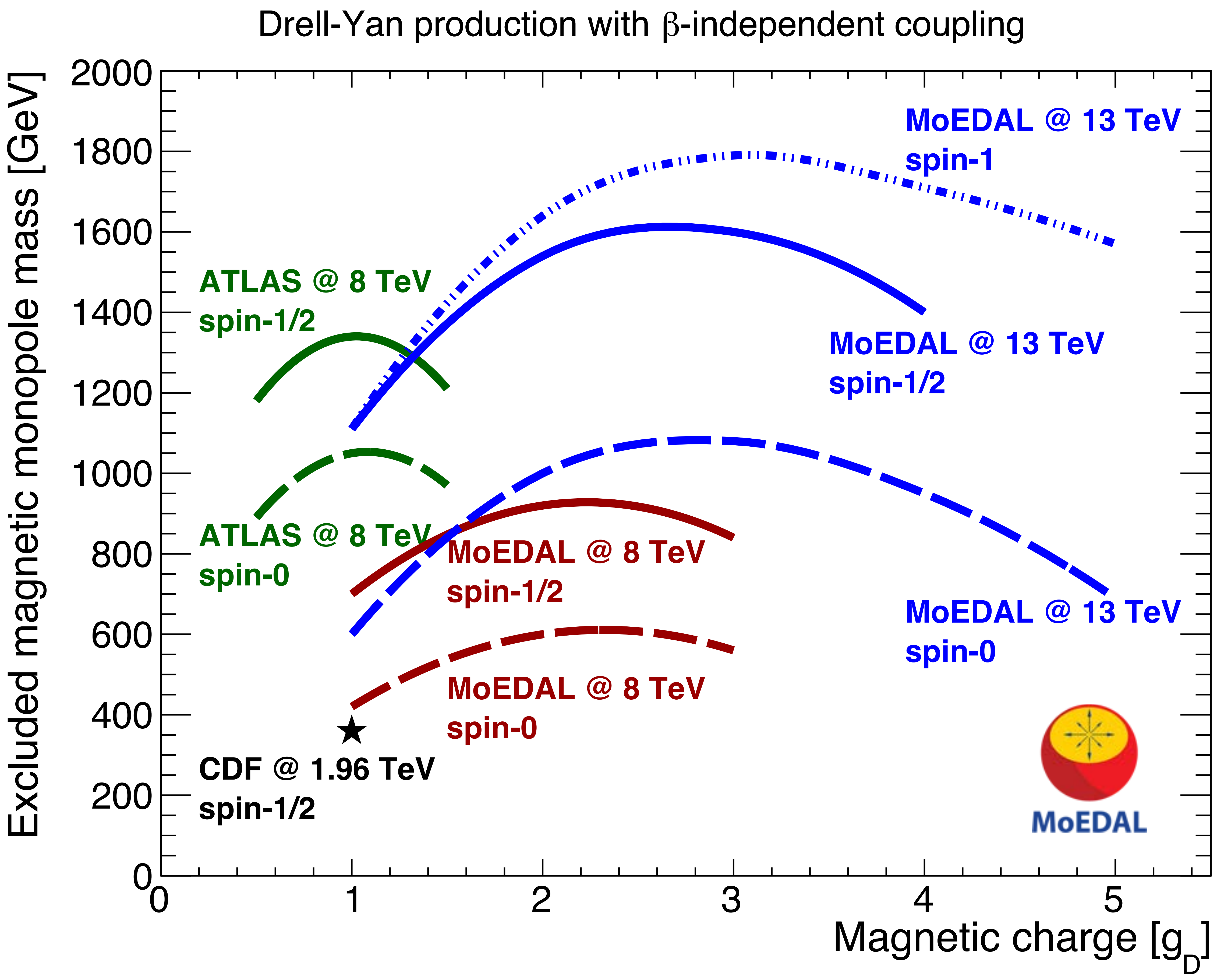
Conclusion

Conclusion

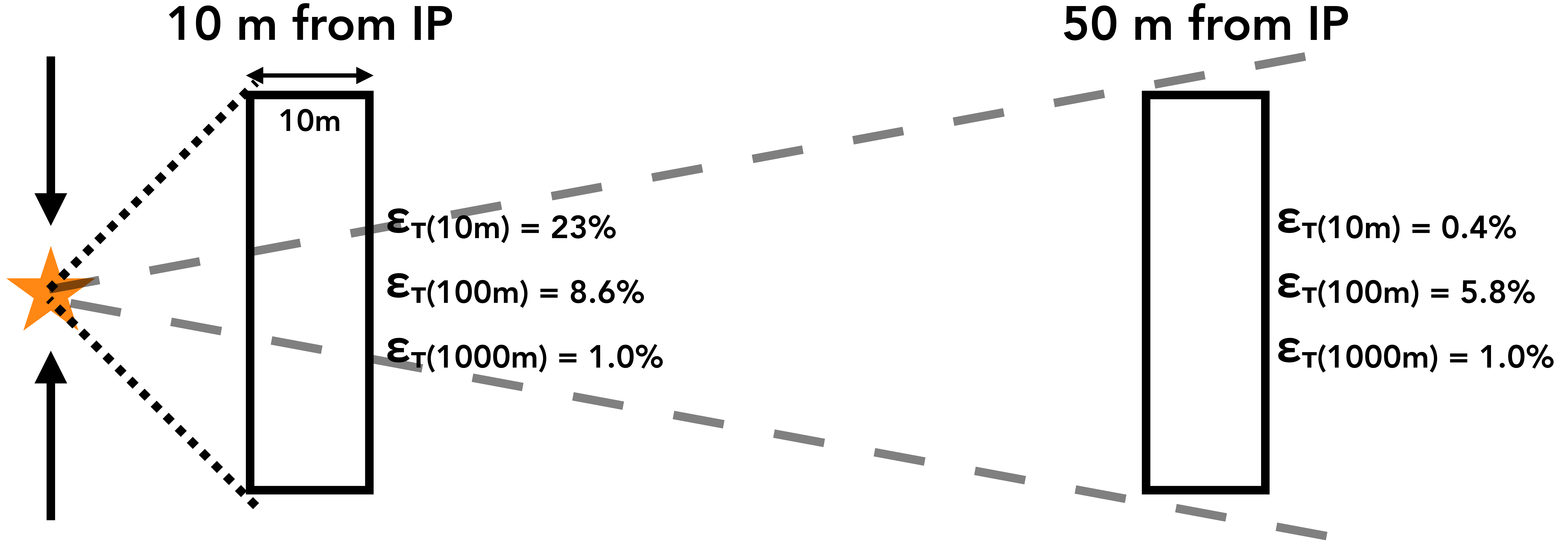
Backups

Reach for magnetic monopoles

Link to white paper



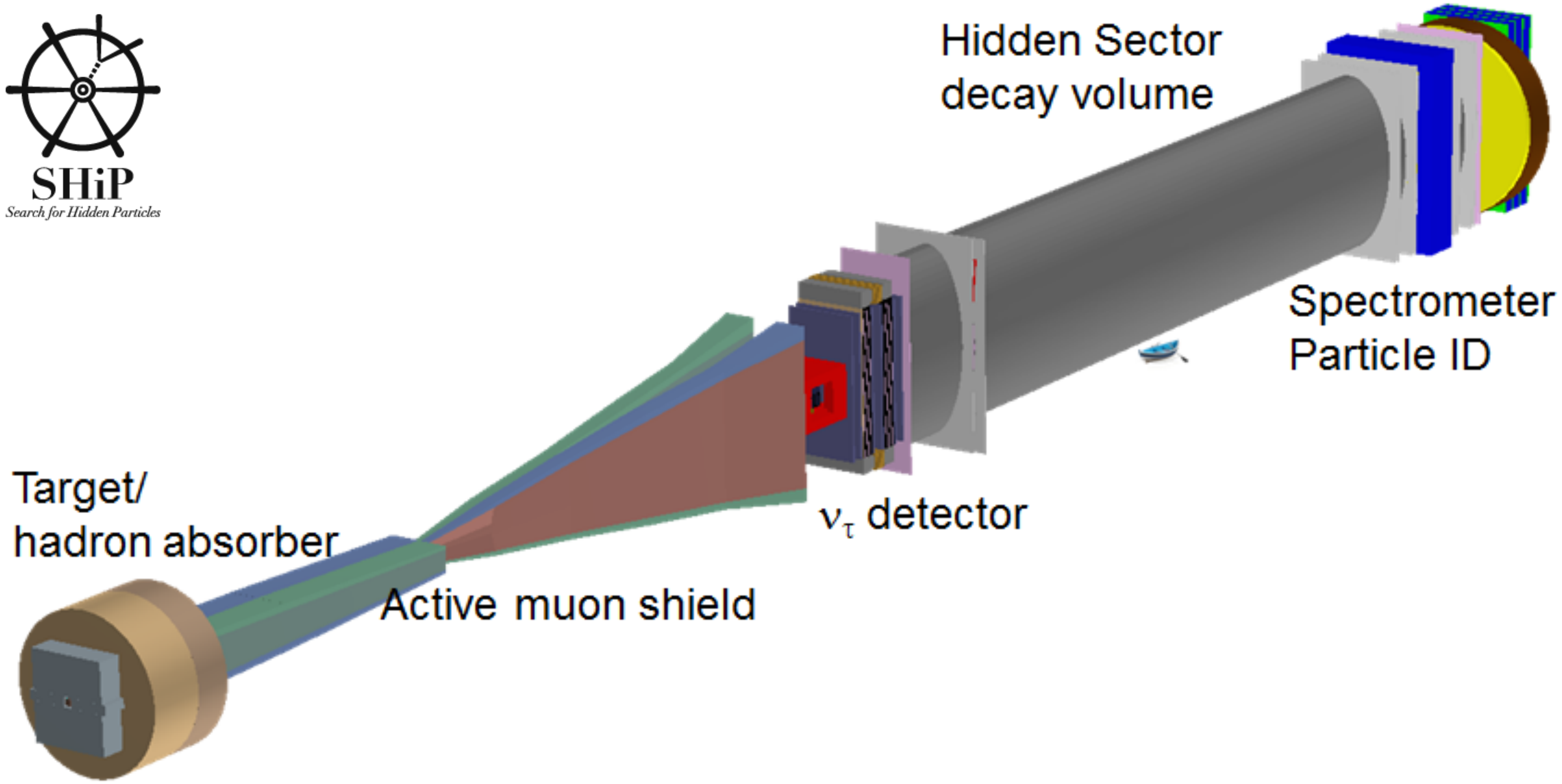
Distance versus lifetime coverage



Being far away isn't even really helpful for probing longer lifetimes, since for very long lifetimes the exponential looks almost flat anyway. What really matters is your volume/lumi. Of course if you see a signal, you'll struggle to measure its lifetime without a deep detector or precise timing…

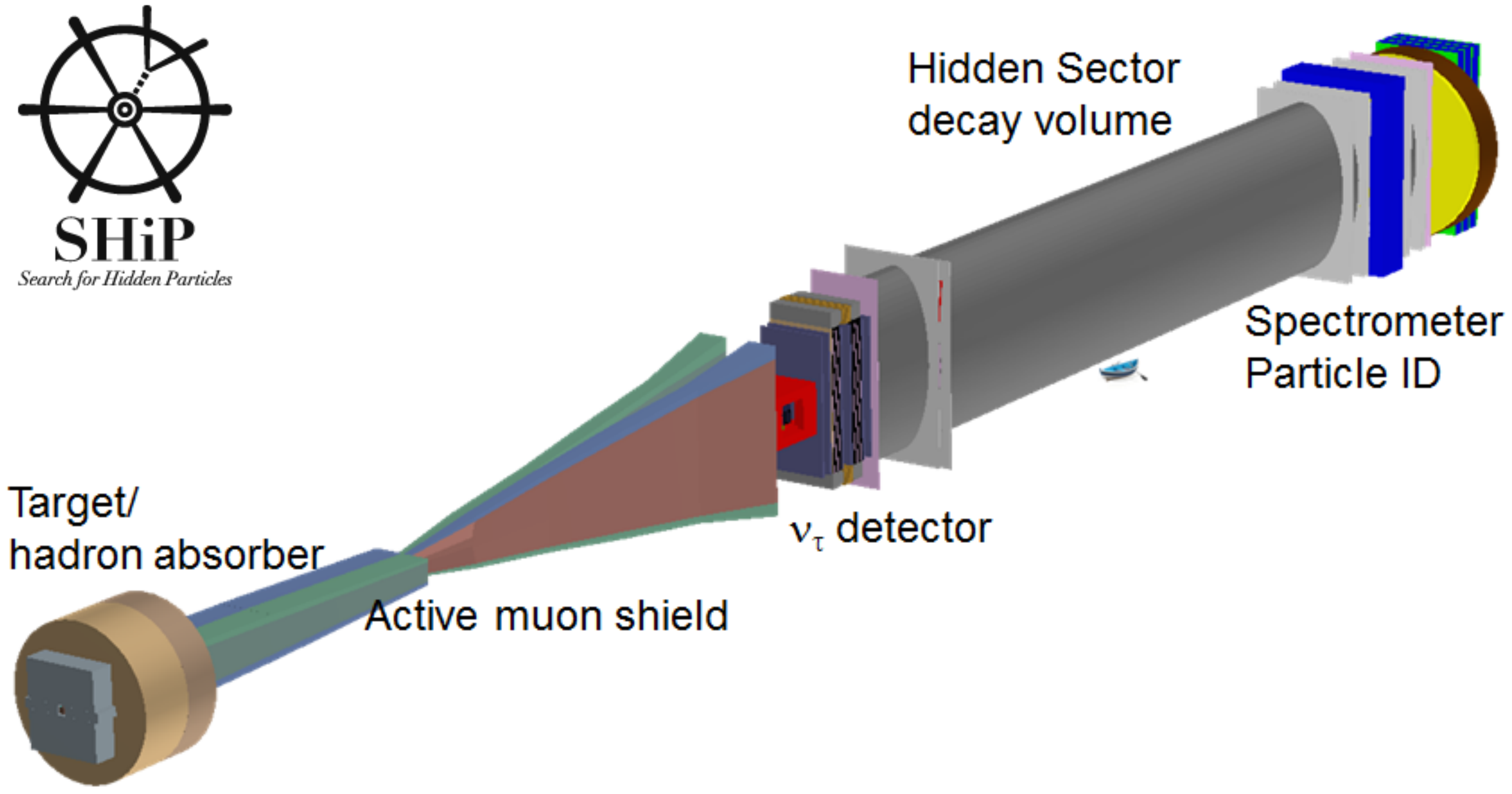
A kingdom for a magnet

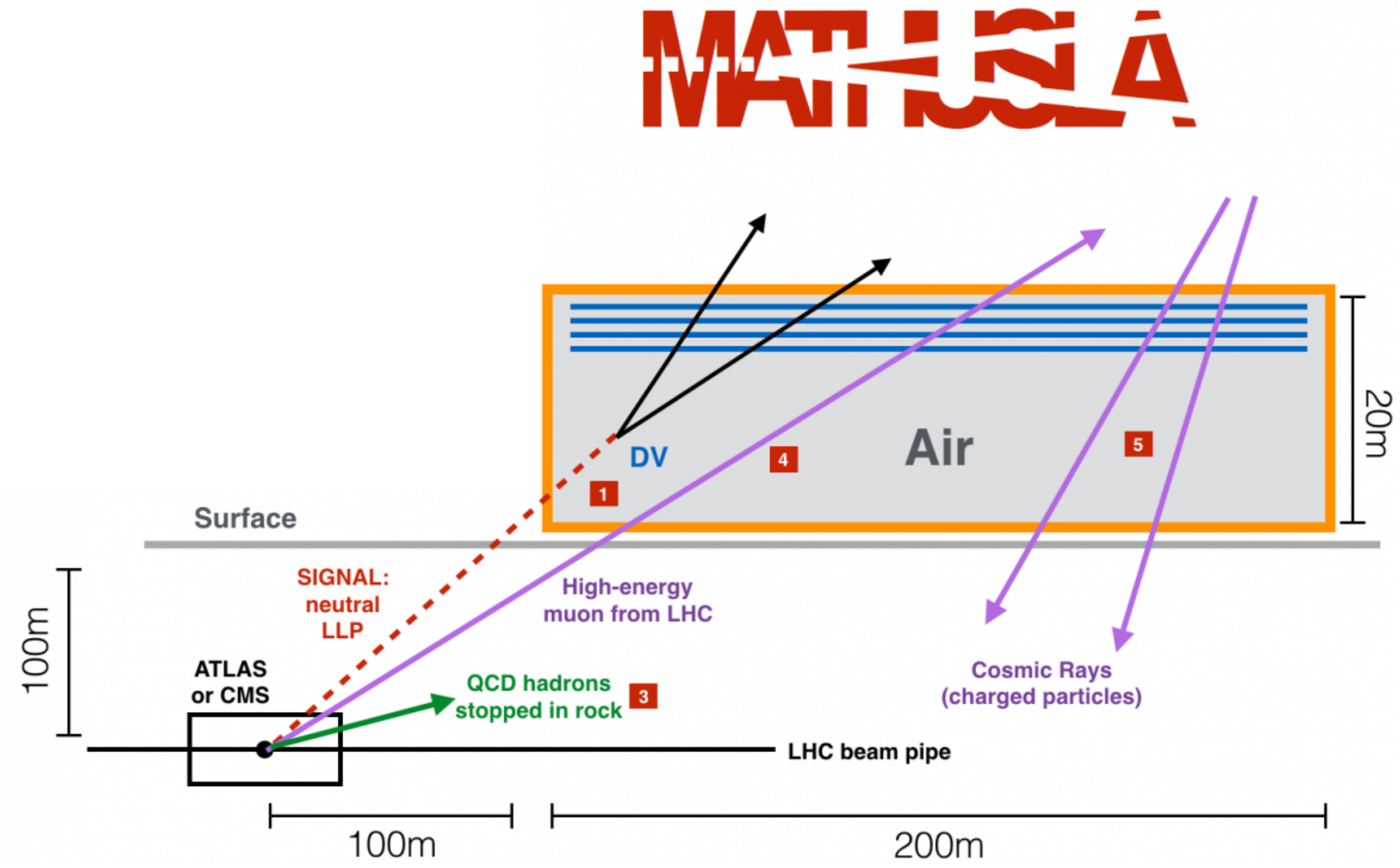
Fixed target : easy!



In fixed target mode on the other hand, even if your distance to the first measured point is large, all decay products go in a small geometrical cone, so quite possible to add a magnet

The quest for zero background





Considerations : size of shield, active layer for in-shield secondary production, vacuum decay vessel or calorimeter style detector (?), magnet or timing/calorimetry for reconstruction?