

Neutrino/Beam-Dump Complementarity for New Physics

Kevin Kelly, Texas A&M University

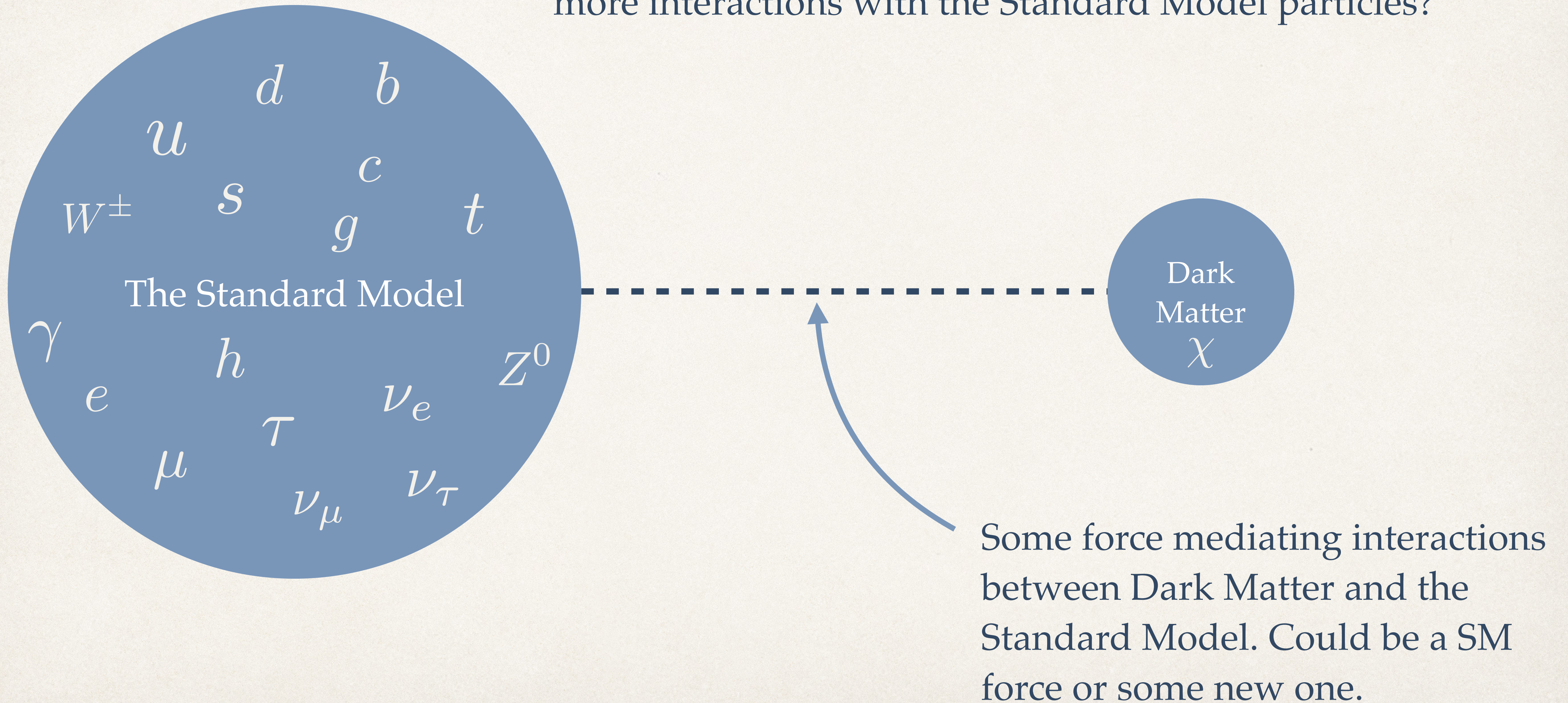
PHENO 2026 — University of Pittsburgh — 12th May, 2026



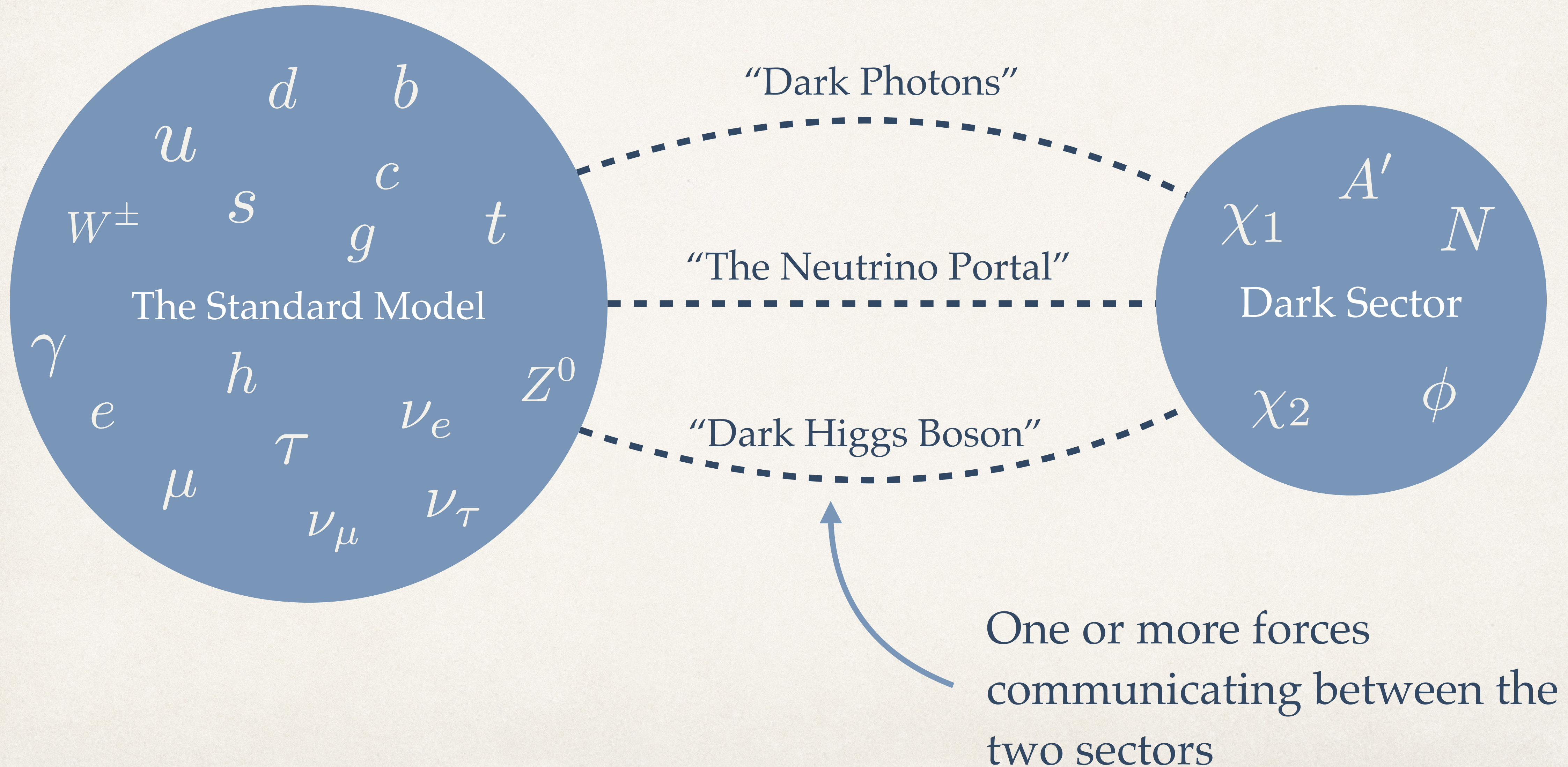
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Dark Matter

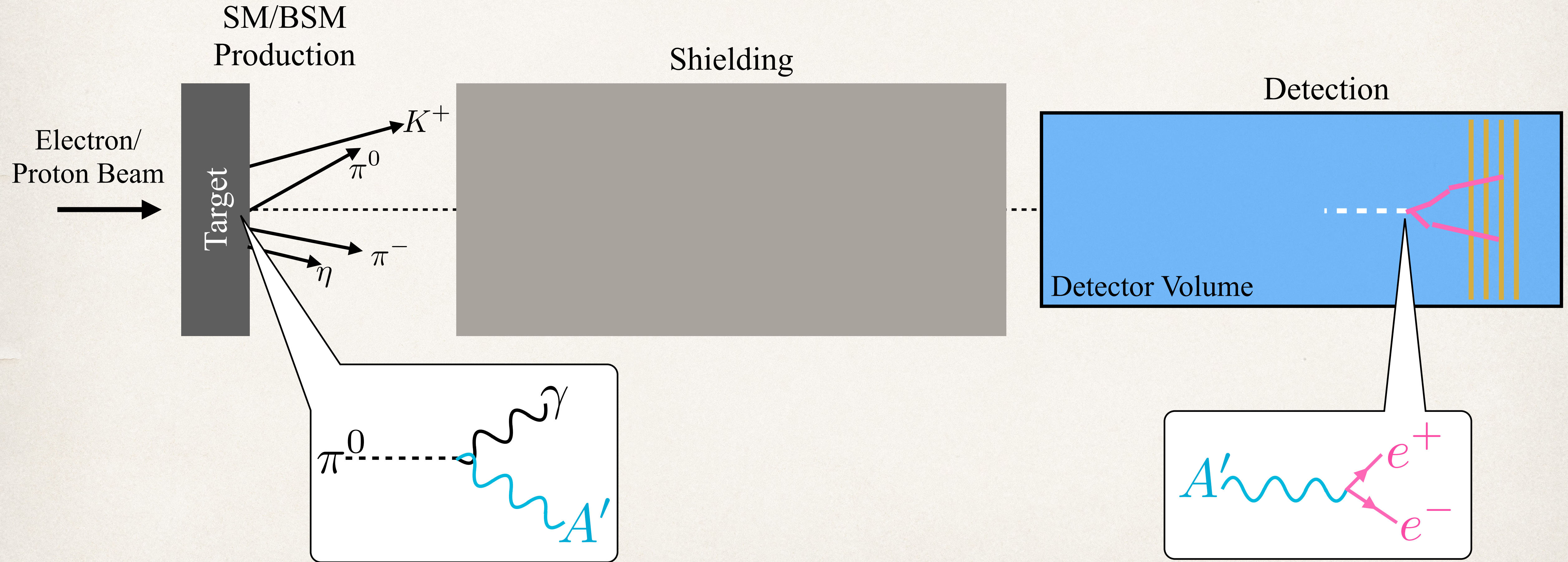
All evidence for dark matter is gravitational... could it have more interactions with the Standard Model particles?



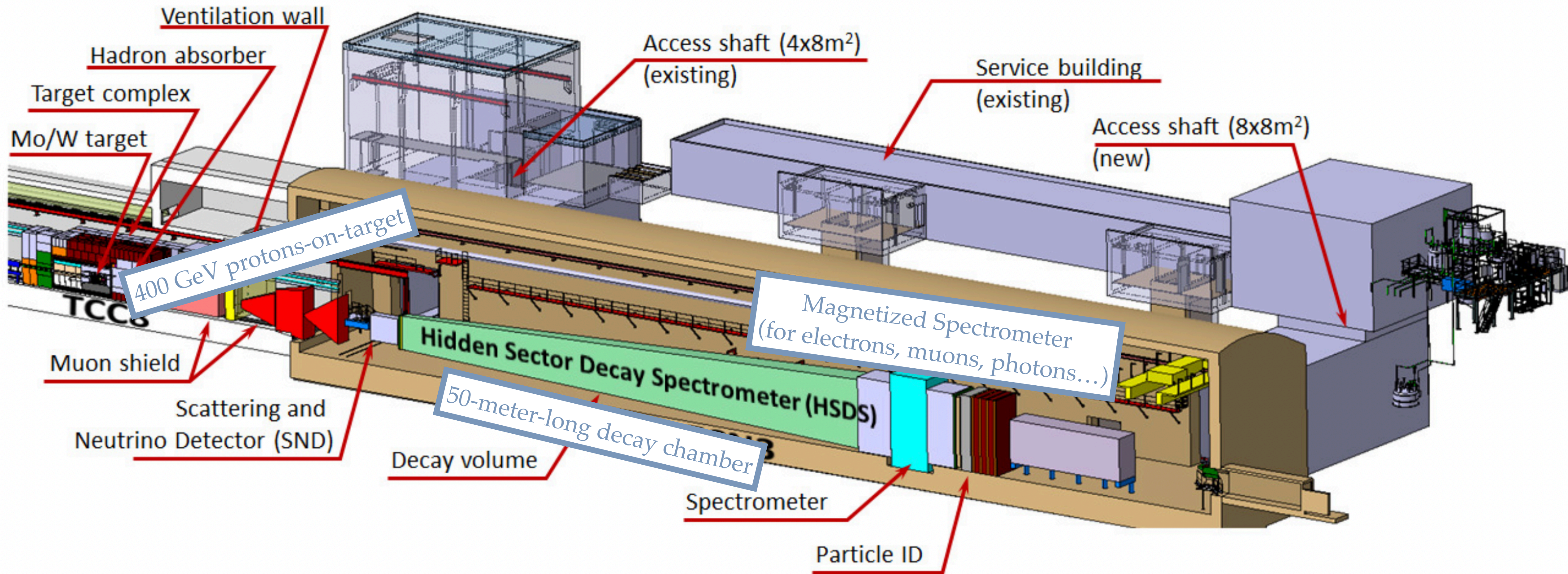
Dark Matter & Dark Sectors



Schematic View of a Beam-Dump Facility



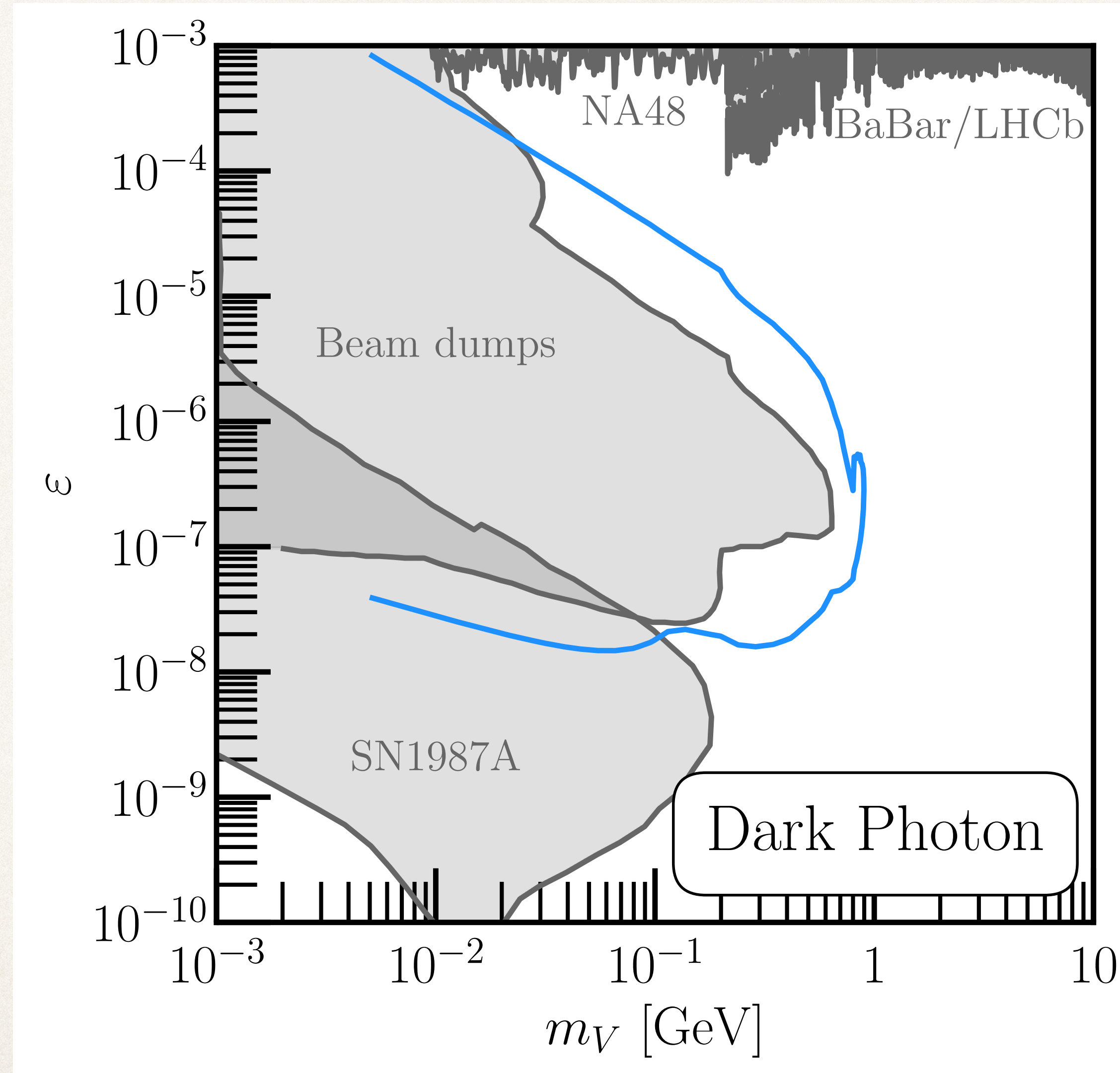
SHiP: Search for Hidden Particles



Approved for operation CERN — the “ultimate” dark sector experiment?

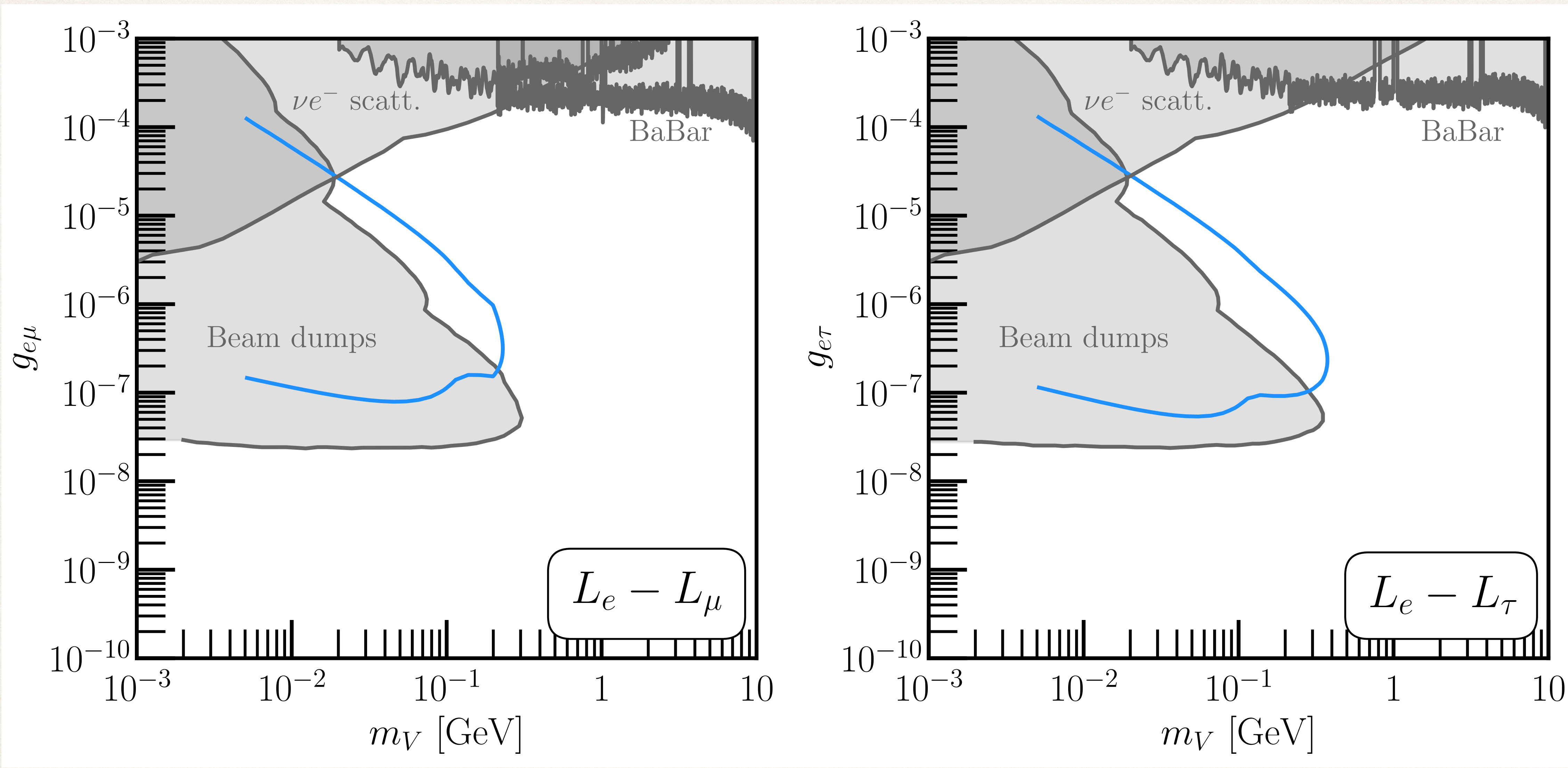
SHiP Dark-Photon Sensitivity

Blue: “traditional” production through neutral meson decay



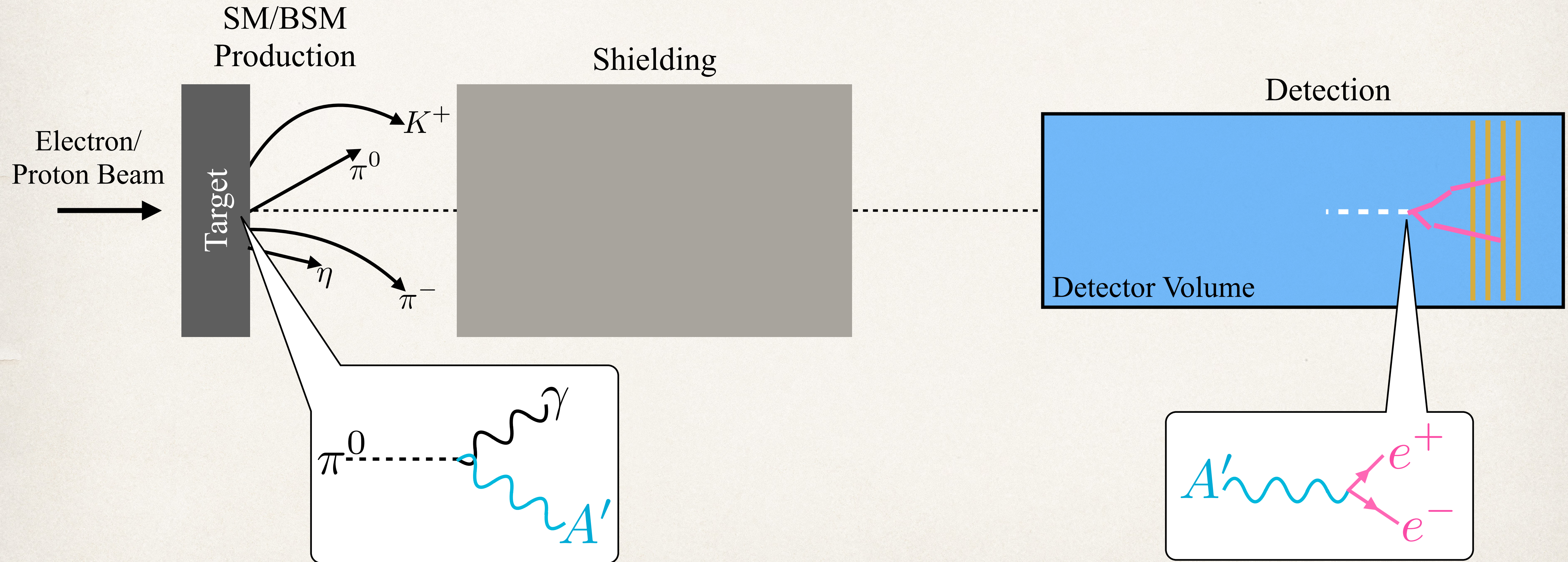
SHiP & Leptophilic Gauge Bosons

Blue: "traditional" production through neutral meson decay



Alternative production mechanisms?

Previously, we just considered SM particles that subsequently decay into BSM ones

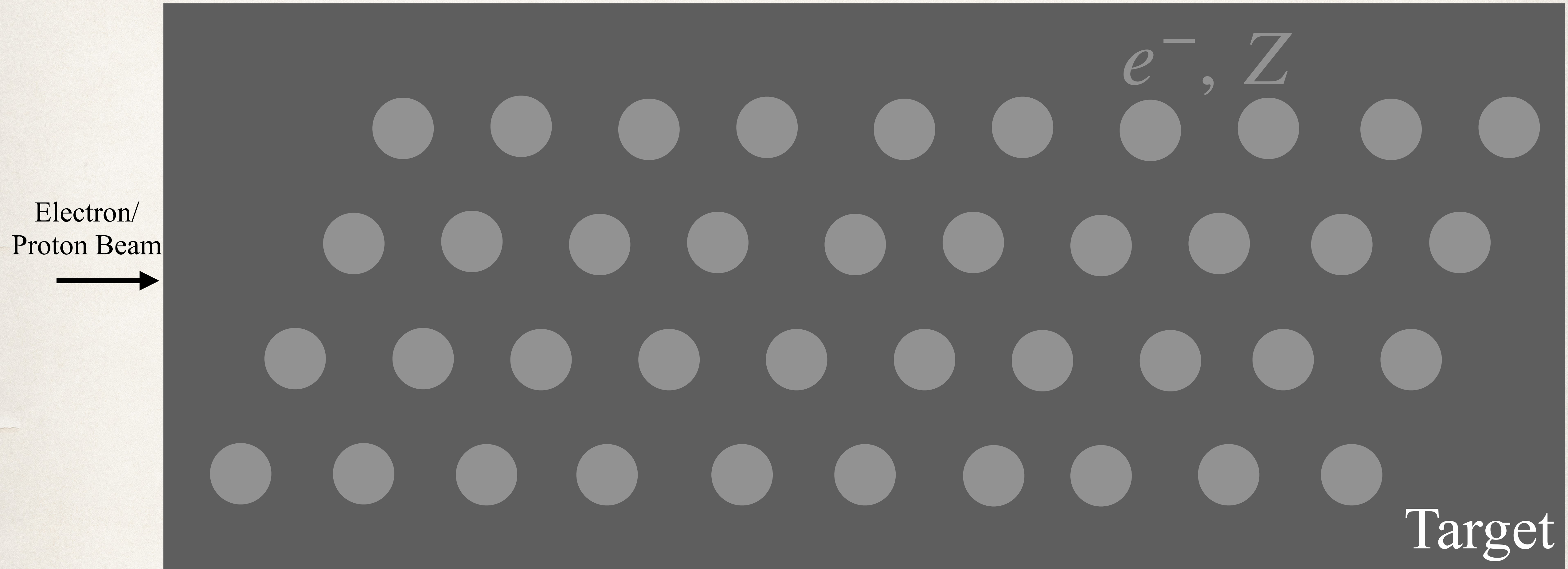


Alternative production mechanisms?

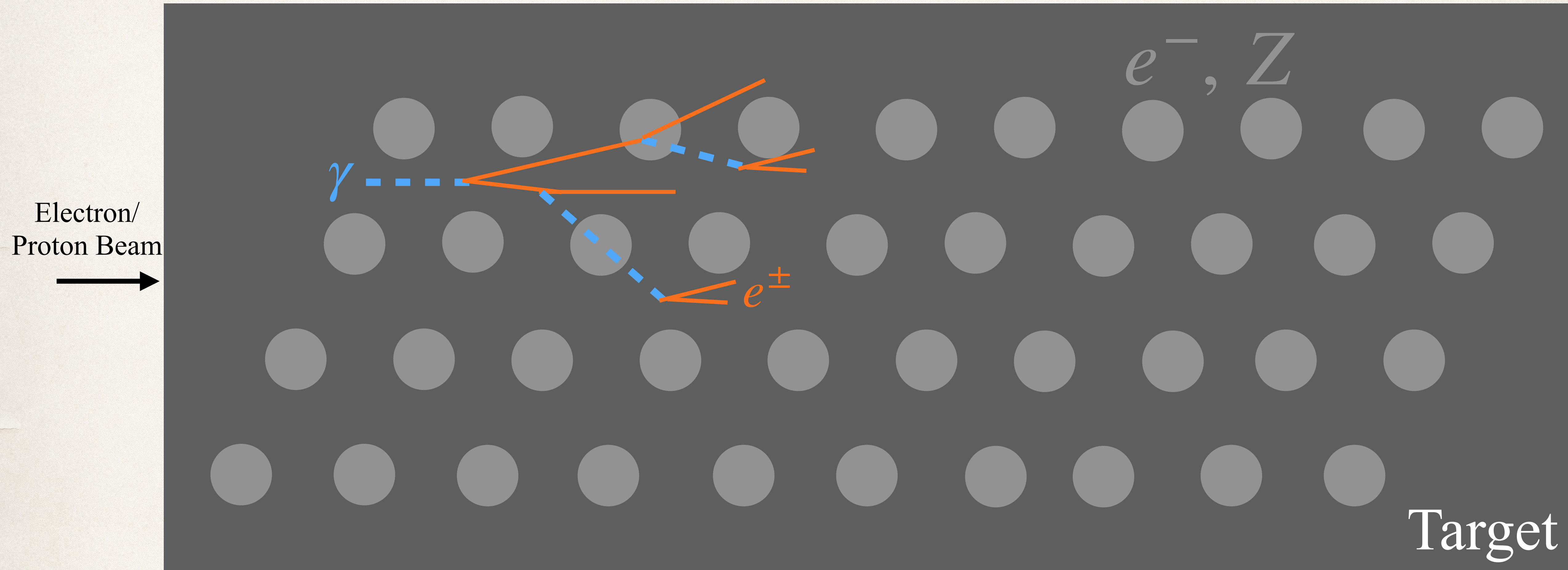
Electron/
Proton Beam
→

Target

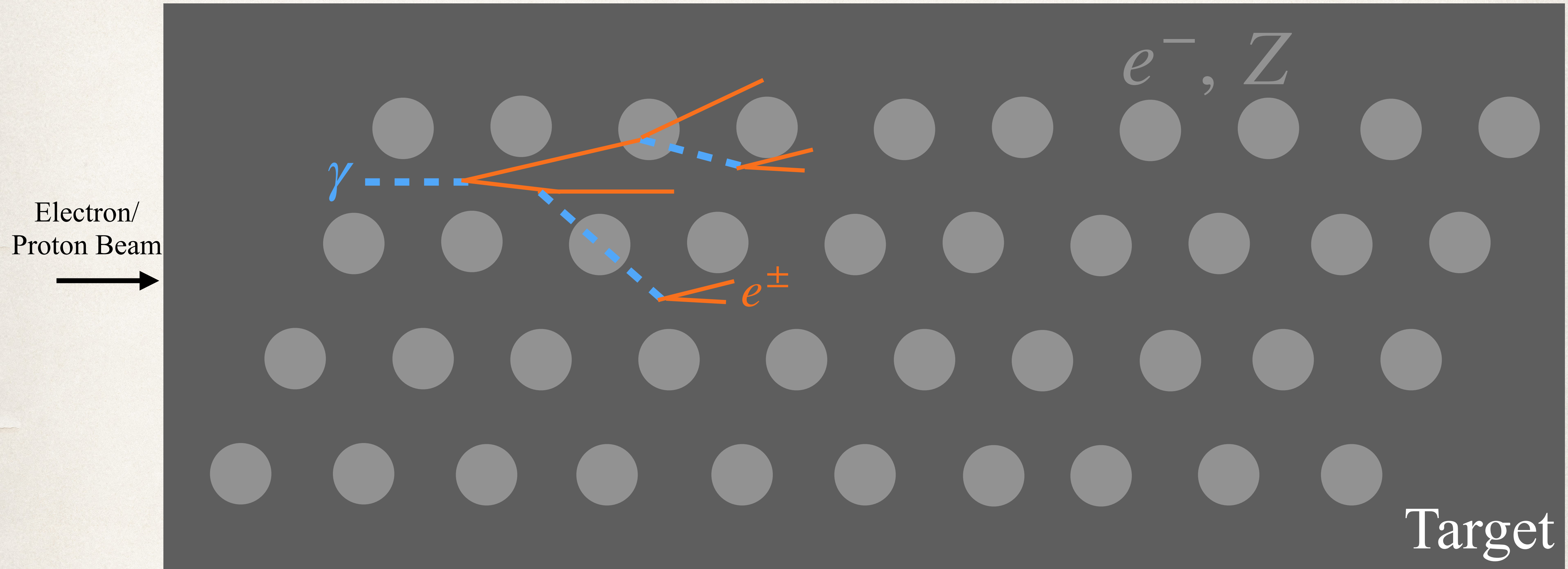
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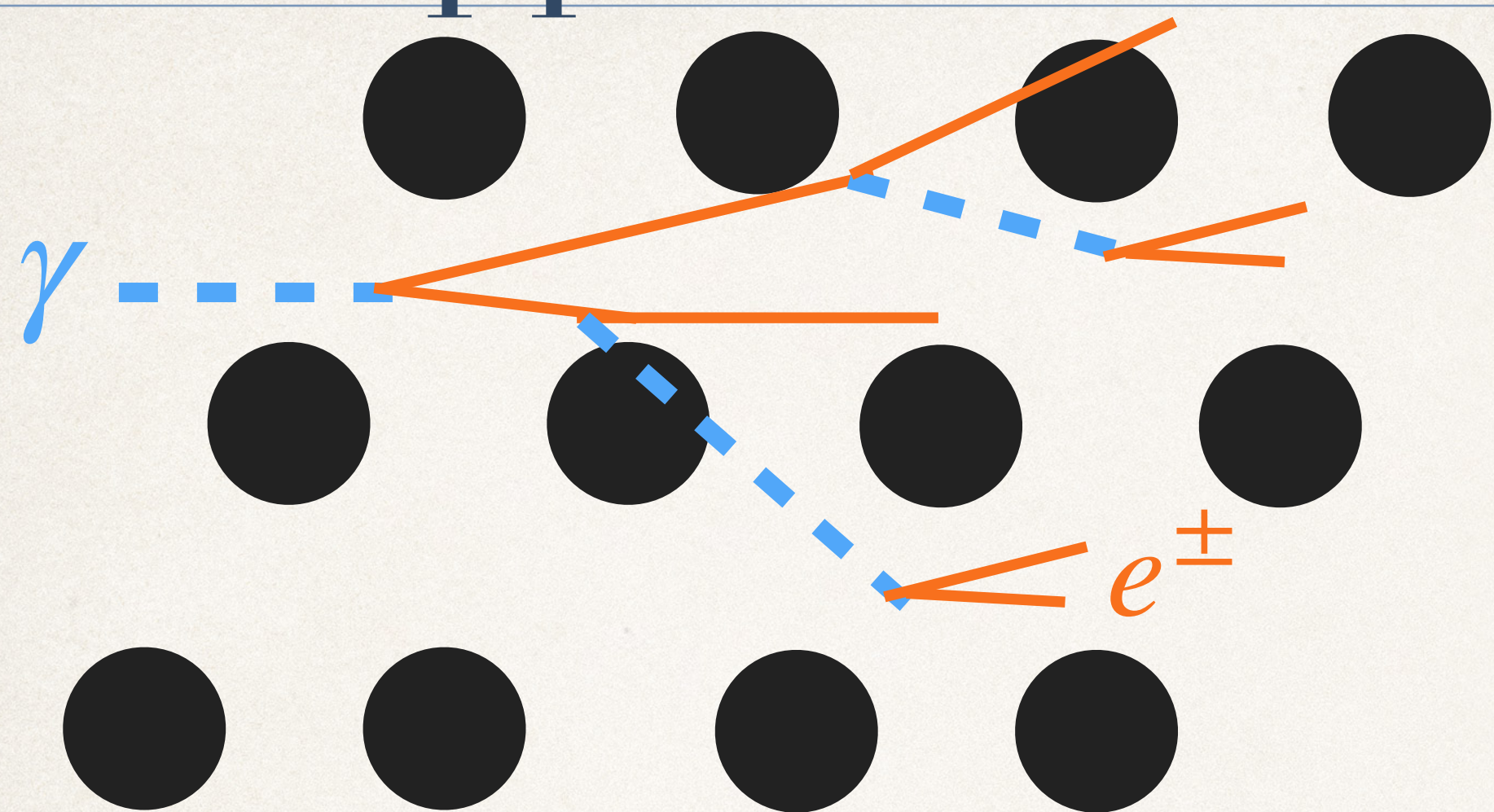


Alternative production mechanisms?

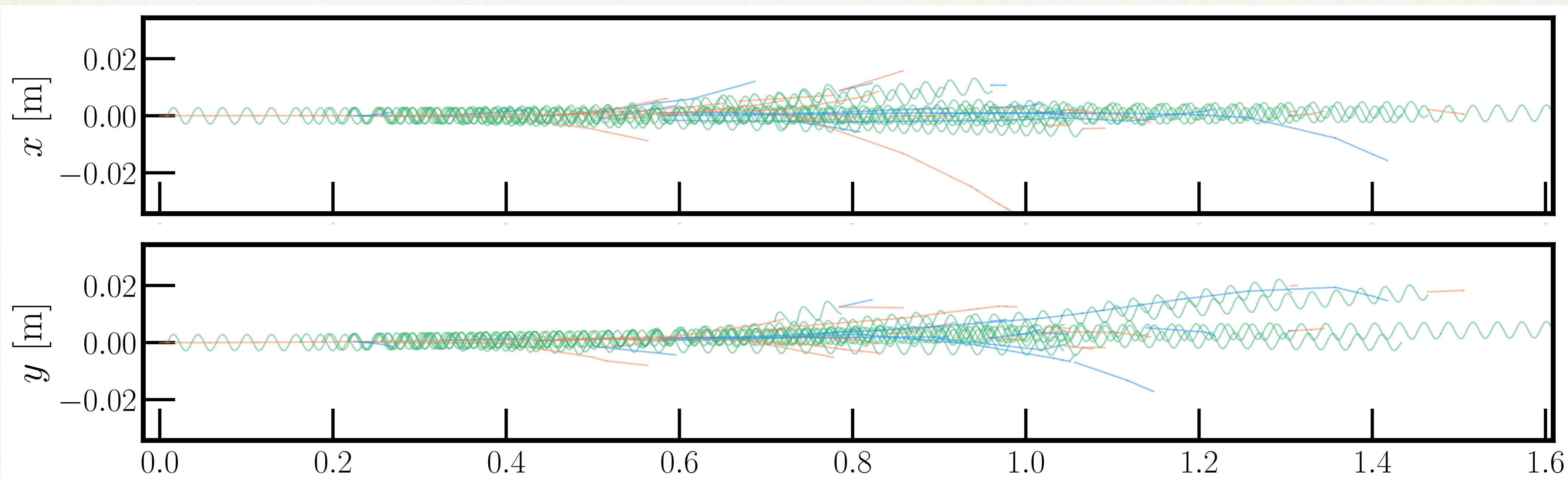


Every Hadronic / Electromagnetic interaction in the target is a potential for BSM production!
many interactions = many opportunities for production

Our approach? PETITE <https://github.com/kjkellyphys/PETITE>



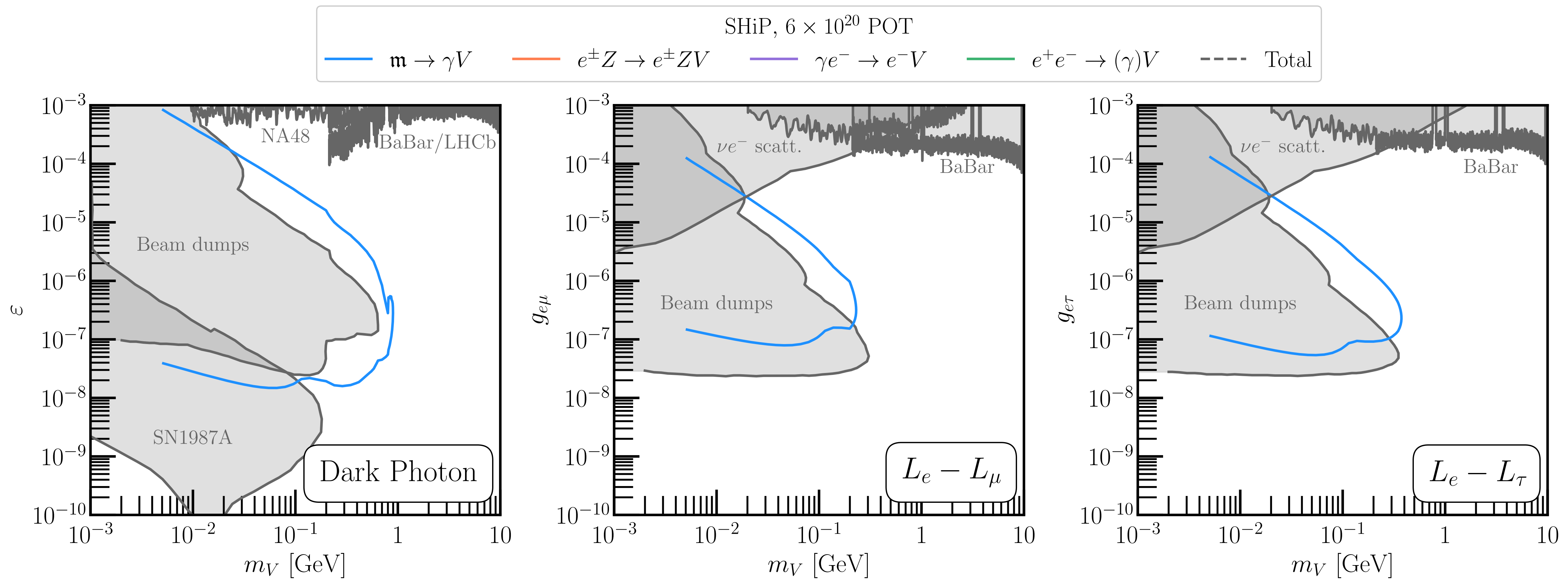
Originally developed for neutrino environments, PETITE allows for rapid simulation of EM cascades in thick targets that can be processed for determination of BSM flux predictions



Blinov, Fox, KJK, Machado, Plestid [\[2401.06843\]](https://arxiv.org/abs/2401.06843) z [m]

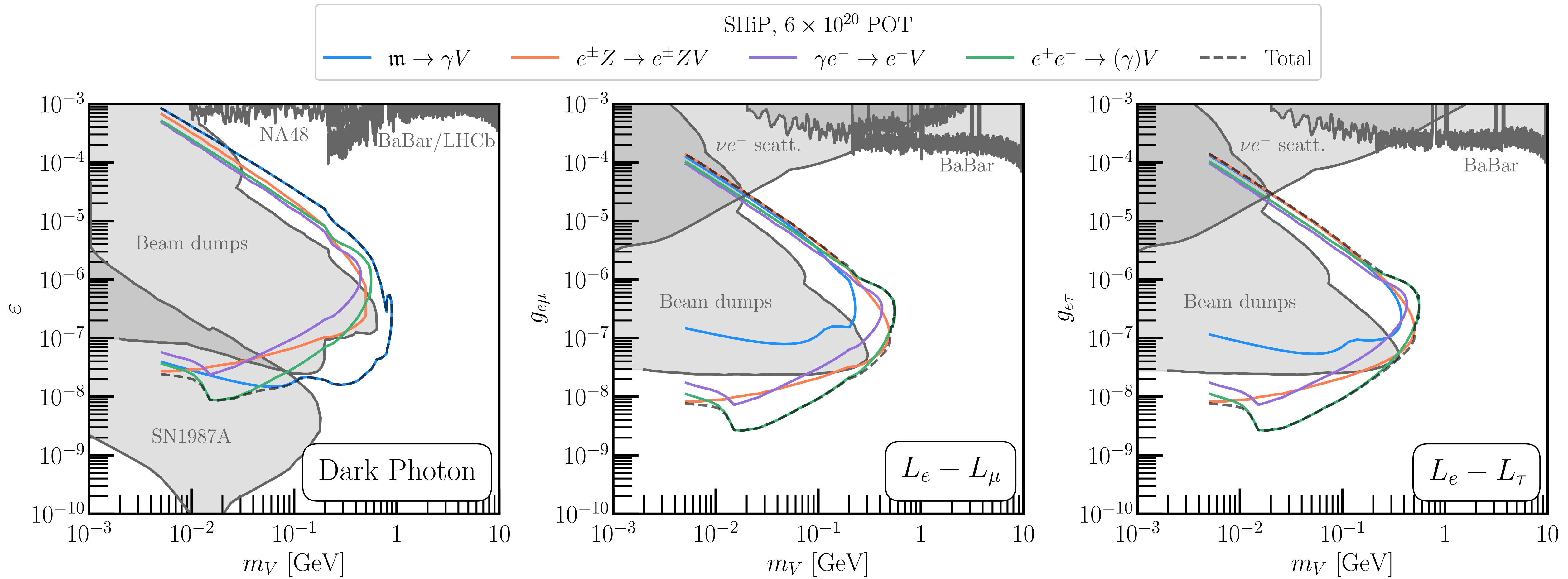
Updating SHiP's sensitivity

Blue: "traditional" production mechanisms



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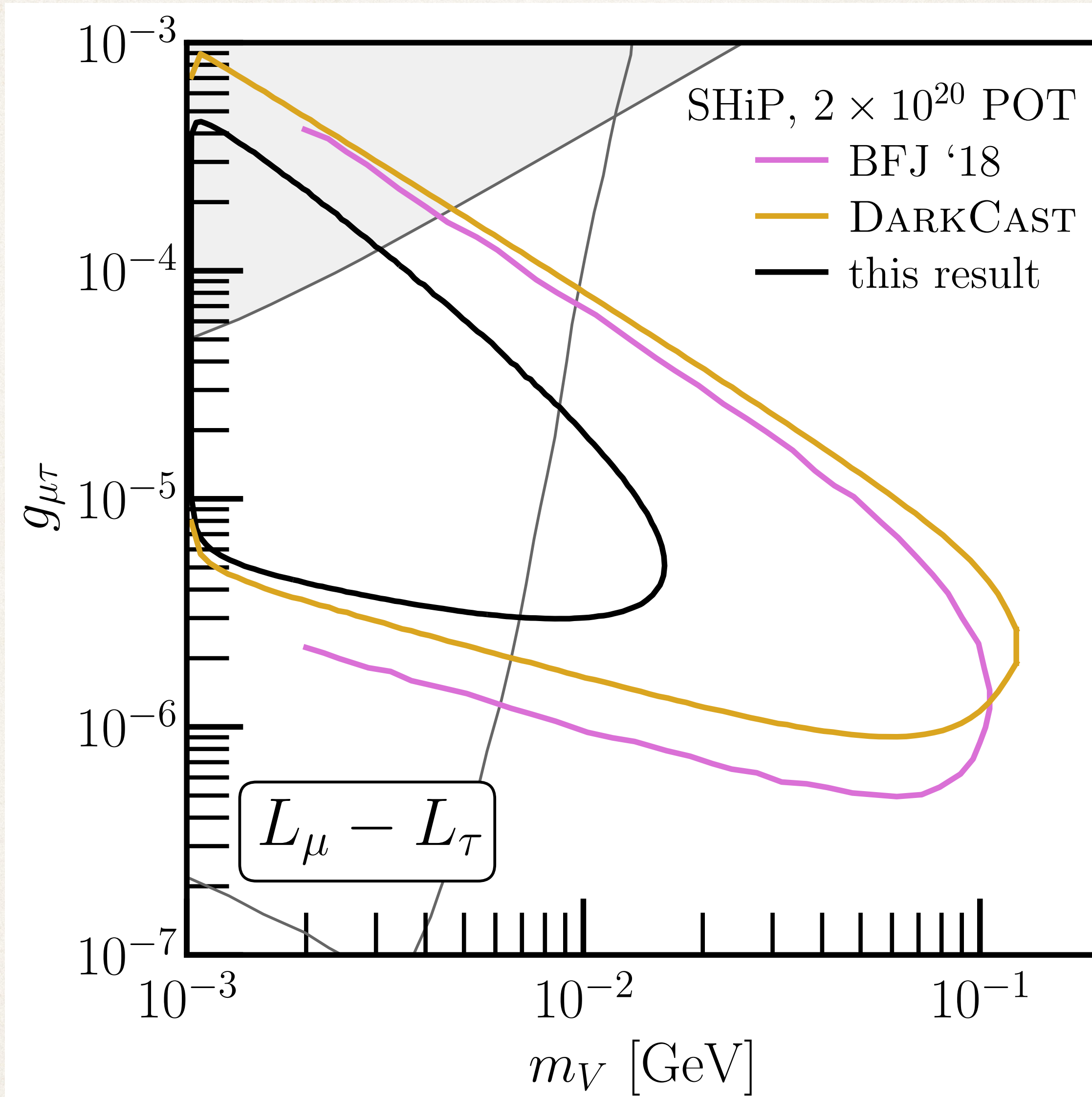


Orange / Purple / Green: Our additions

Orders-of-magnitude sensitivity improvement!

Aside: $L_\mu - L_\tau$ Gauge Bosons

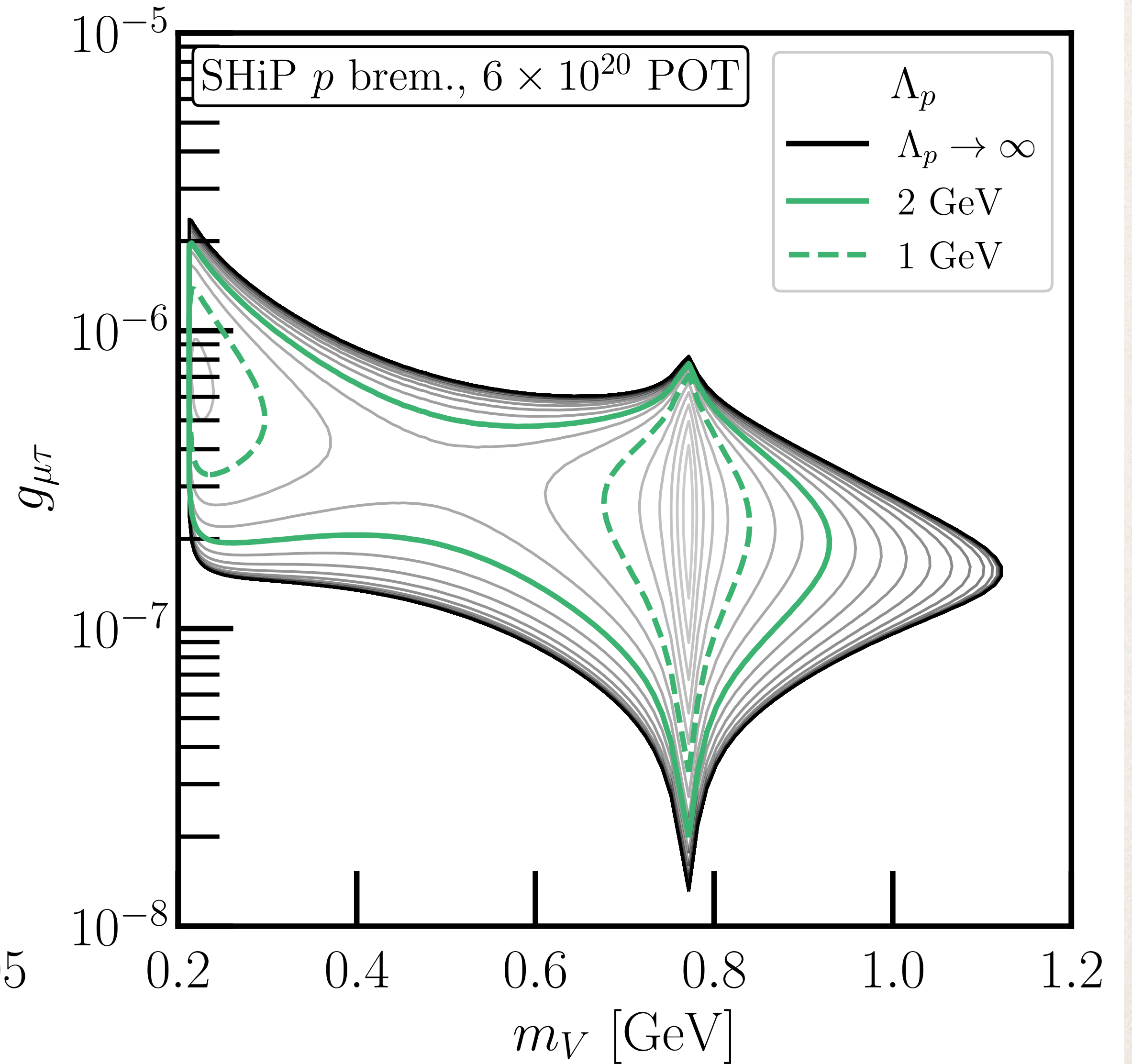
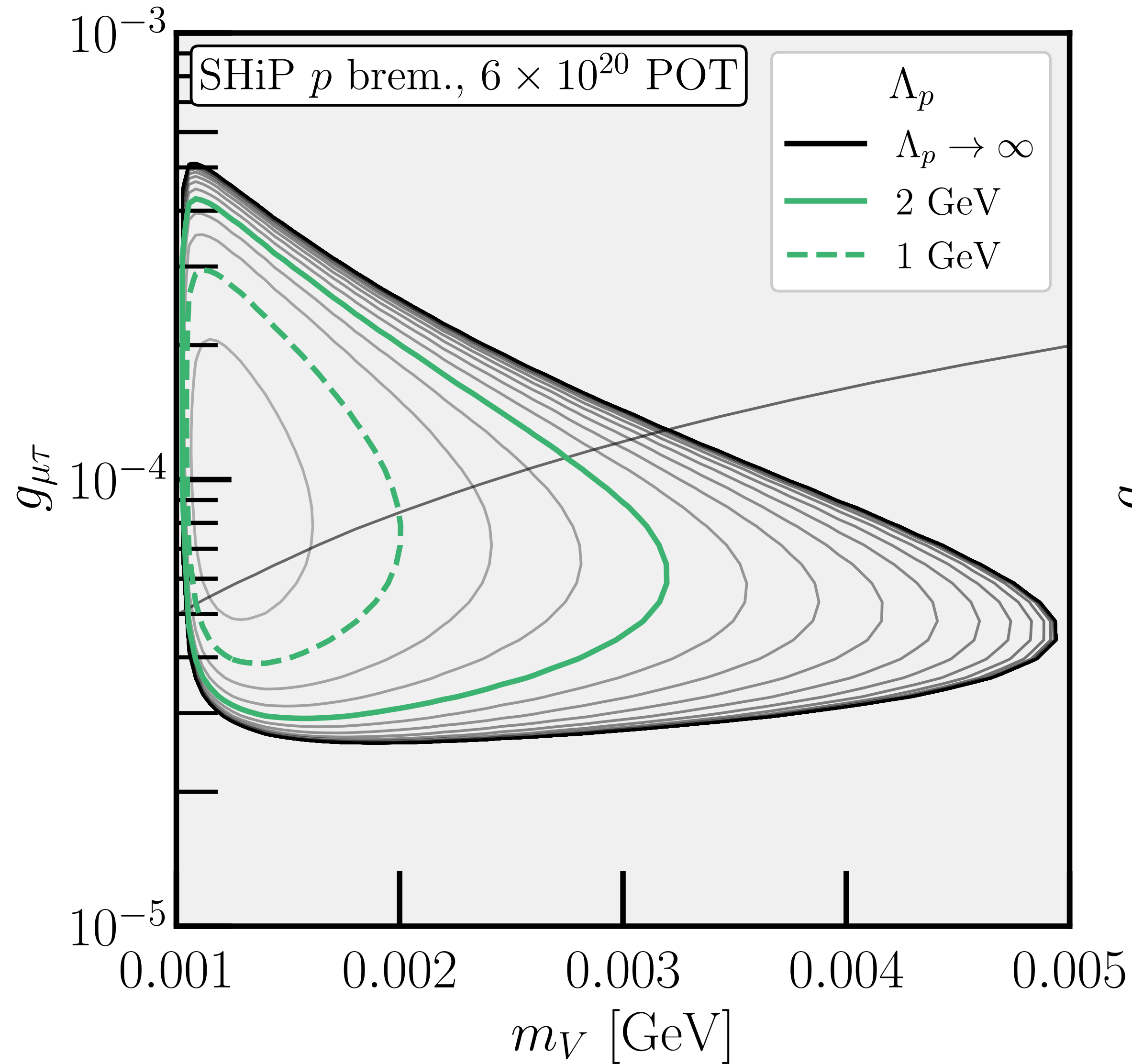
SHiP + $L_\mu - L_\tau$



Previous estimates of SHiP Sensitivity to this model dramatically overstated experimental sensitivity

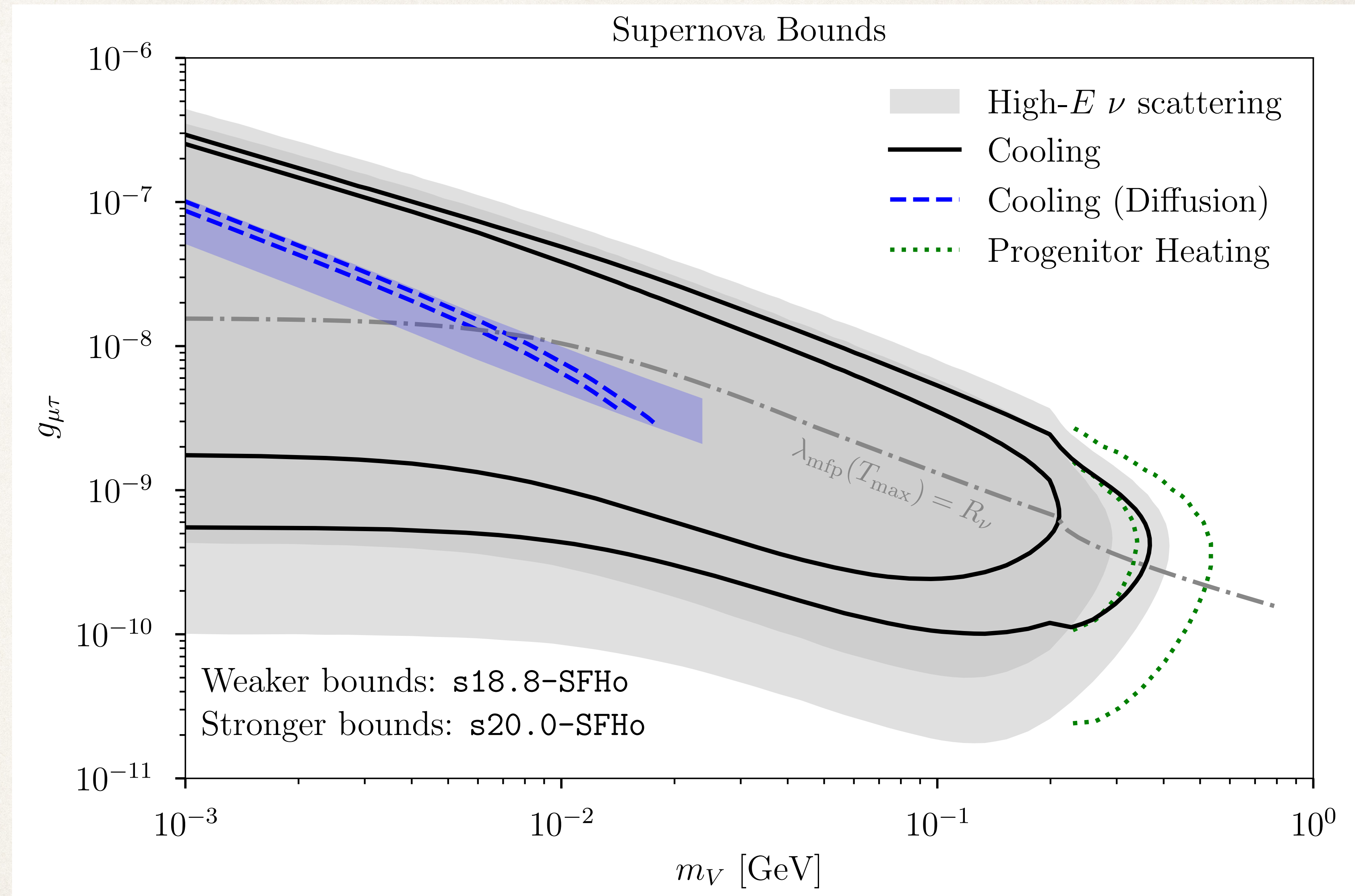
SHiP + $L_\mu - L_\tau$

Sensitivity depends strongly on theoretical pp scattering treatment.



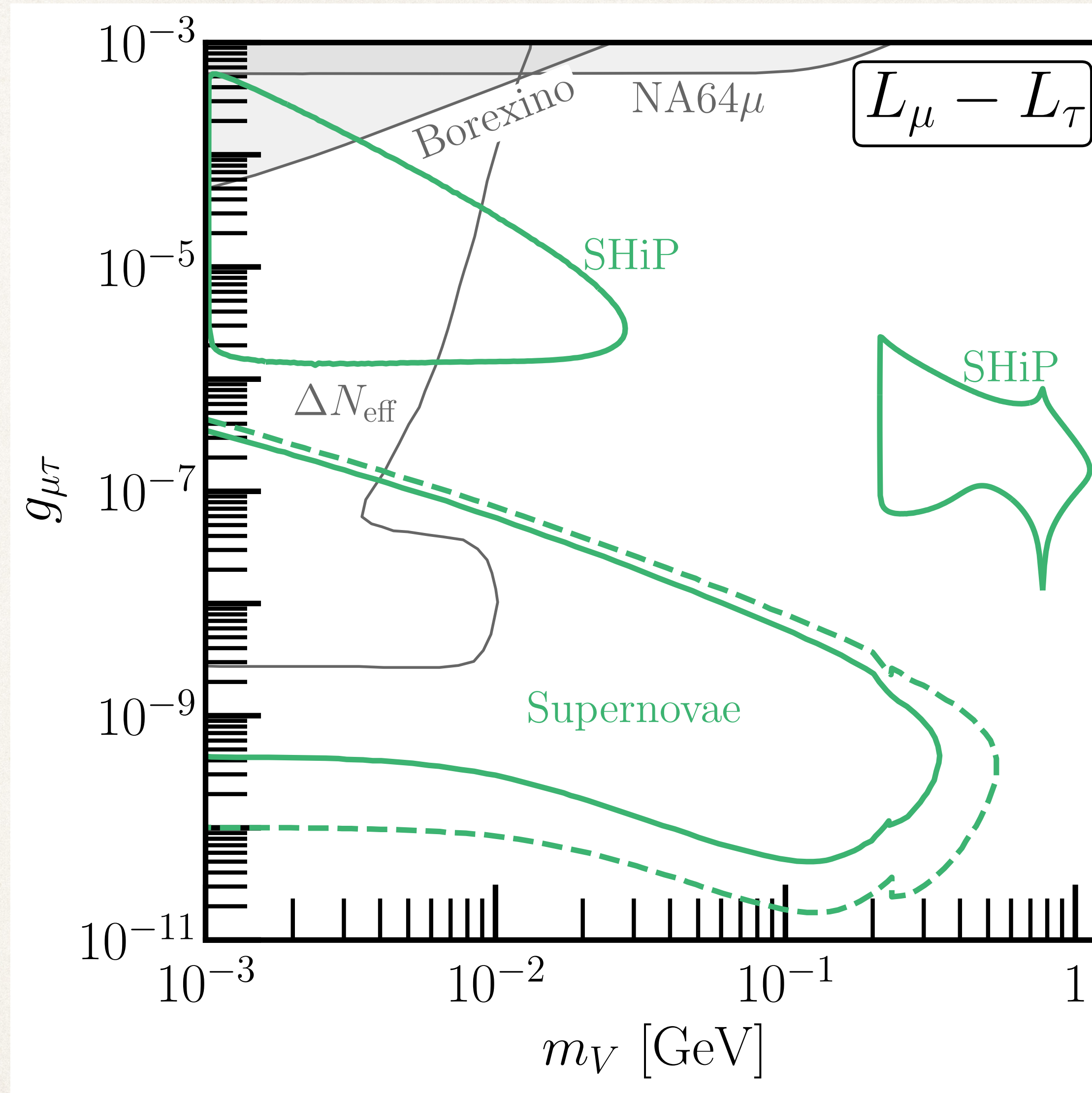
Supernovae + $L_\mu - L_\tau$

Also took advantage of this opportunity to revisit supernovae-based constraints on this model.



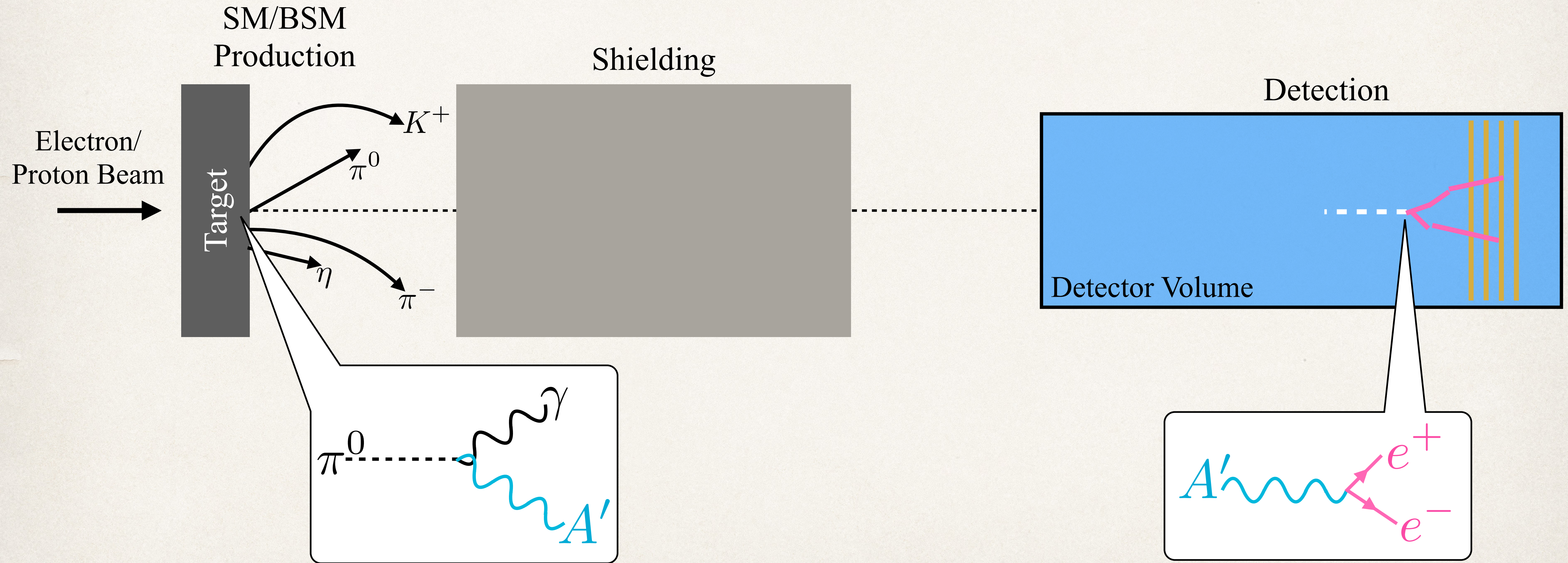
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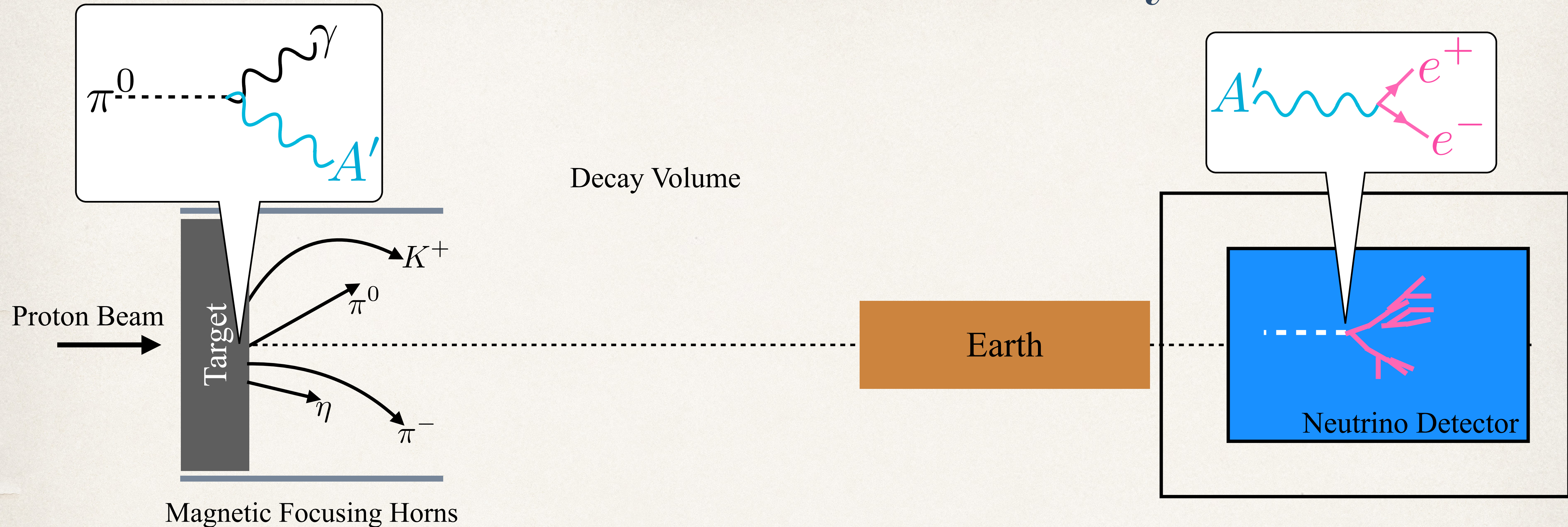


What about Neutrino Facilities?

Schematic View of a Beam-Dump Facility



Schematic View of a Neutrino Facility

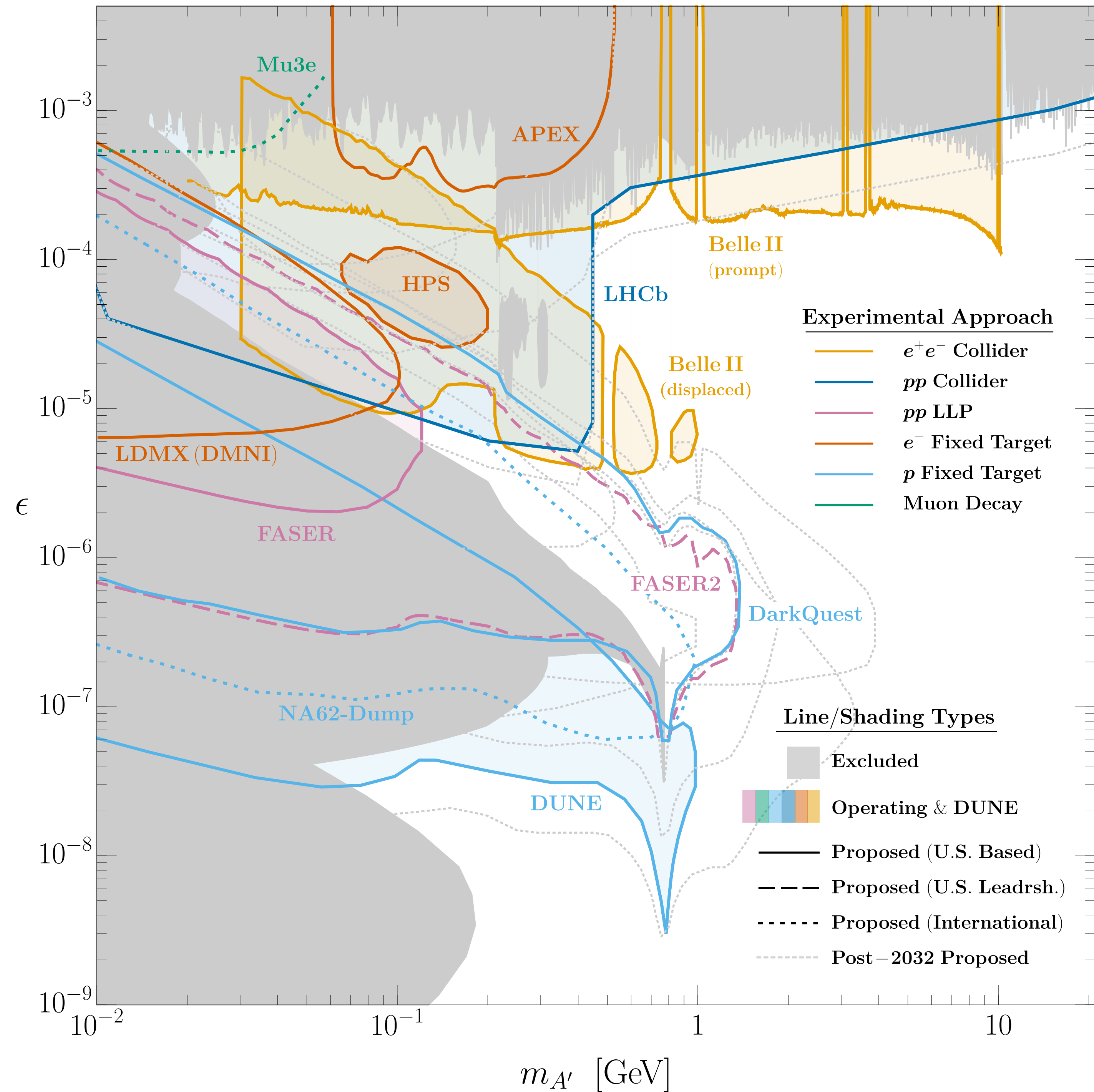


Neutrino facilities are designed to *focus* the SM neutrino flux in the forward direction, but BSM production is still feasible!

Now, we need to contend with backgrounds.

A global effort

Neutrino experiments
complement dedicated dark-
sector facilities



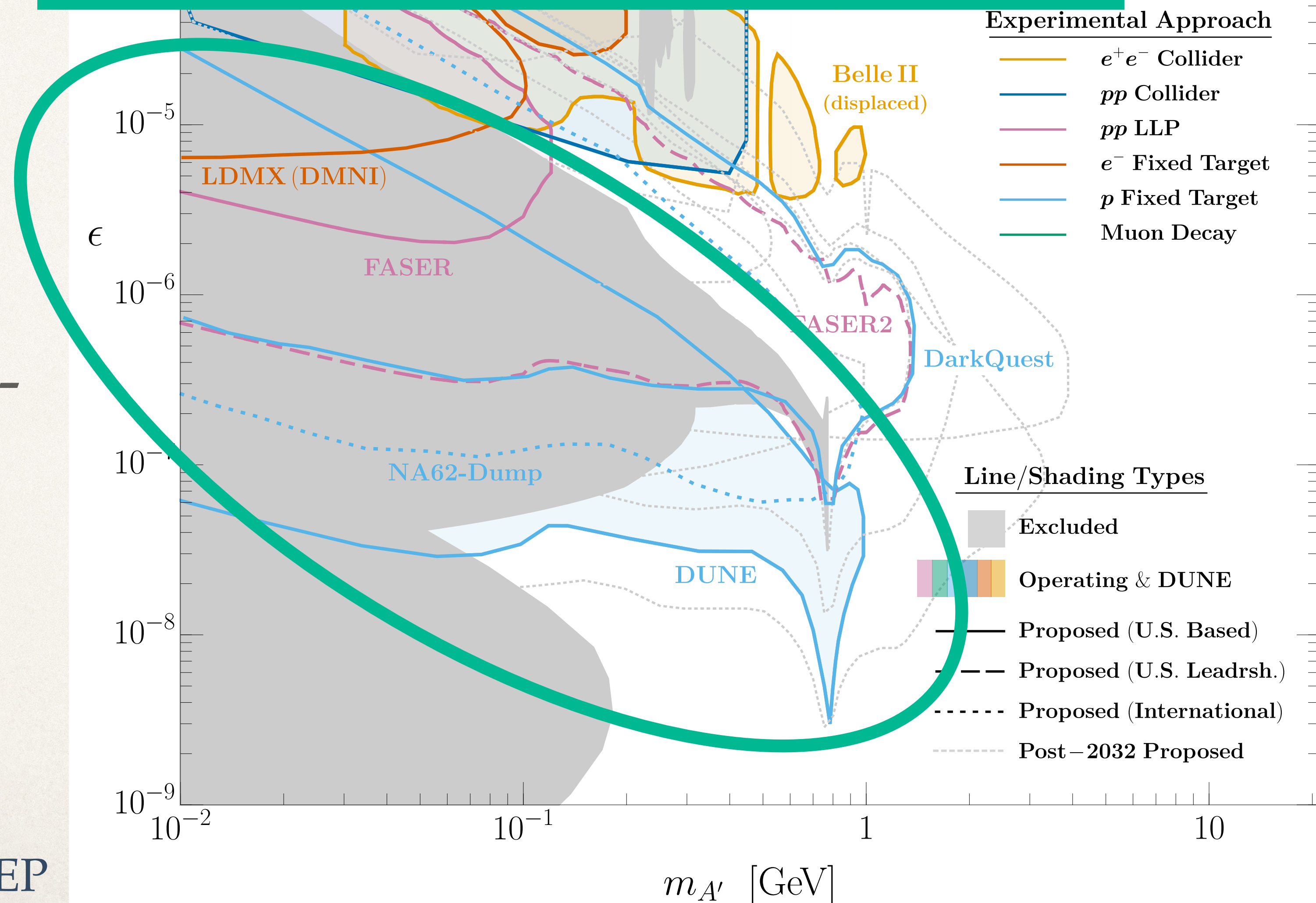
Gori et al (Snowmass) [[2209.04671](#)]

Berryman et al (incl. KJK), [[1912.07662](#)] JHEP

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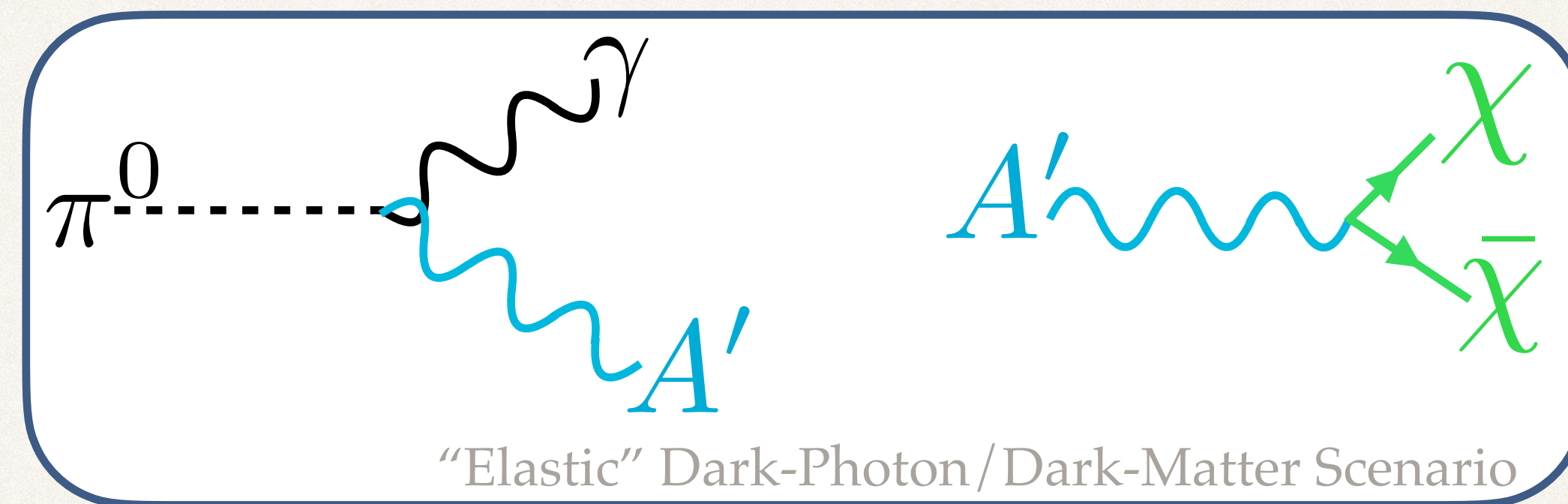
Parameter space that can't be accessed by
dedicated experiments that *will* be explored
by DUNE.



Gori et al (Snowmass) [\[2209.04671\]](#)

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Instead of long-lived-particle production, what about if that particle decays into dark matter?

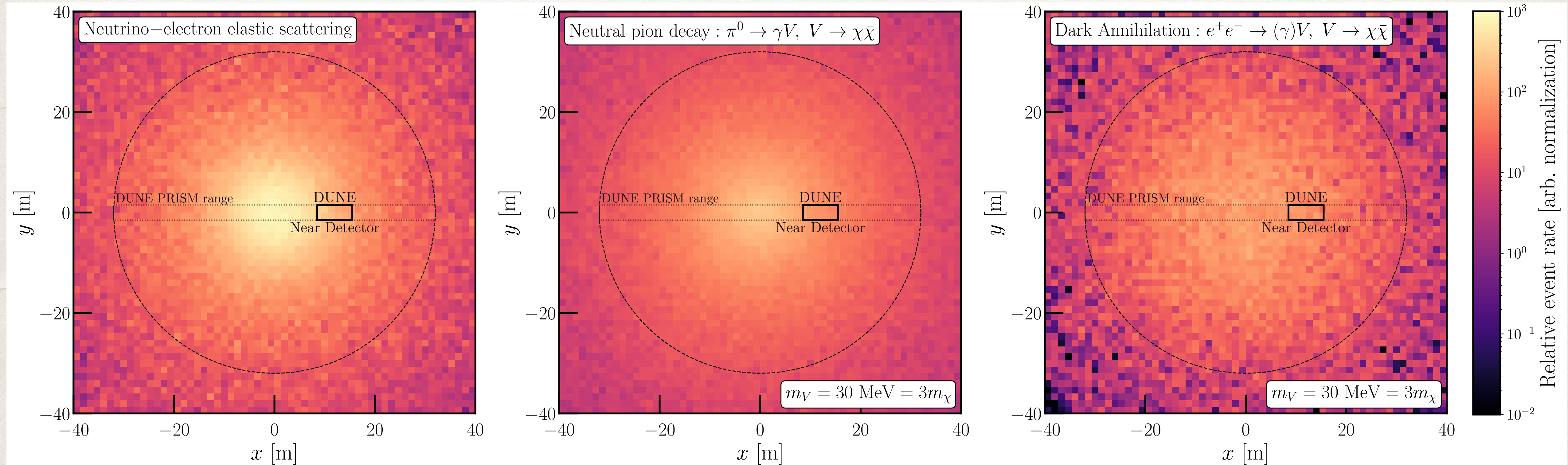


"Elastic" Dark-Photon/Dark-Matter Scenario

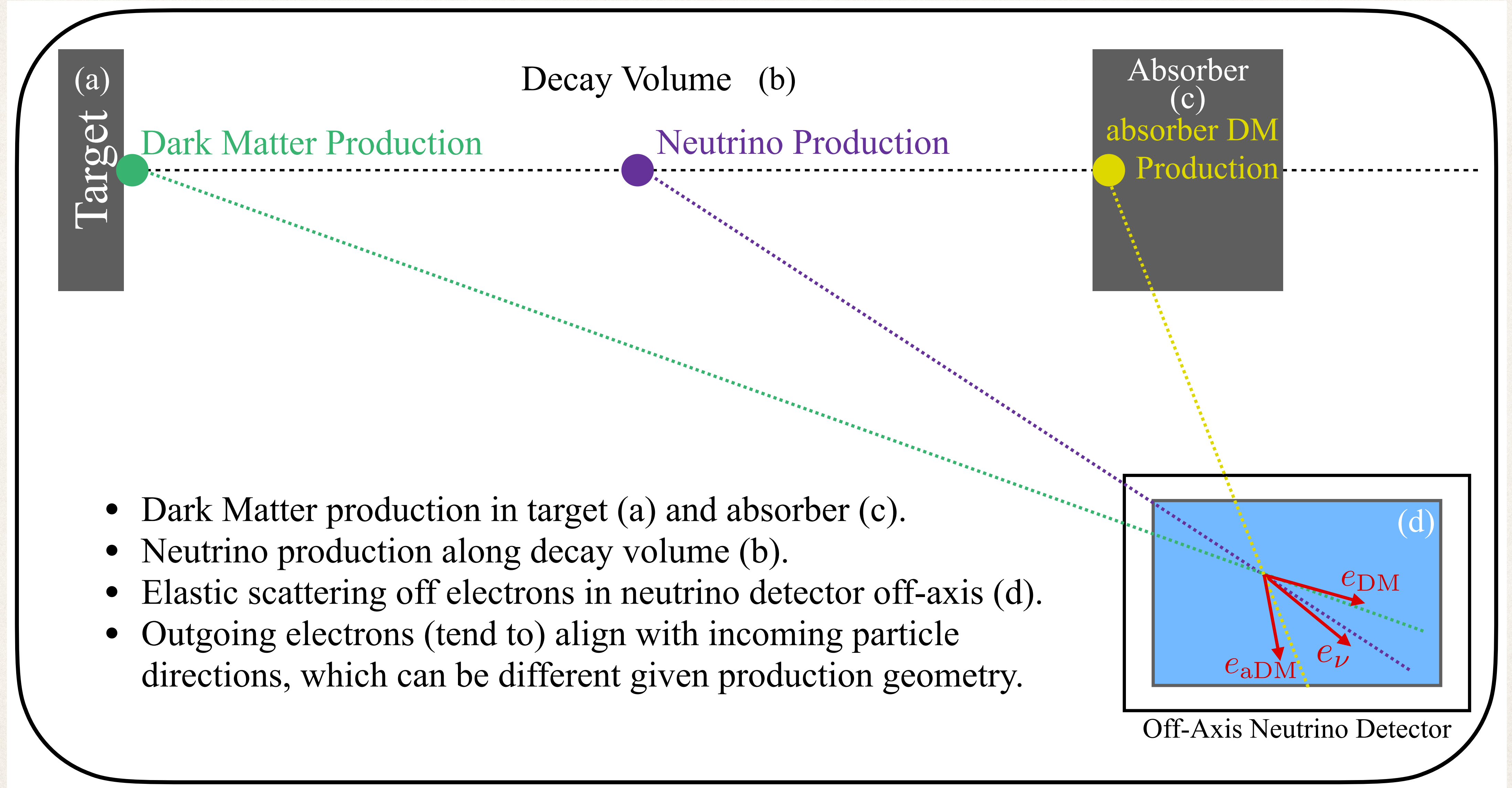
Neutrino Backgrounds — Blessing & Curse

Highly capable neutrino detectors (tracking particles' energy, direction, particle ID precisely) unlock precision neutrino physics understanding as well as BSM signal classification.

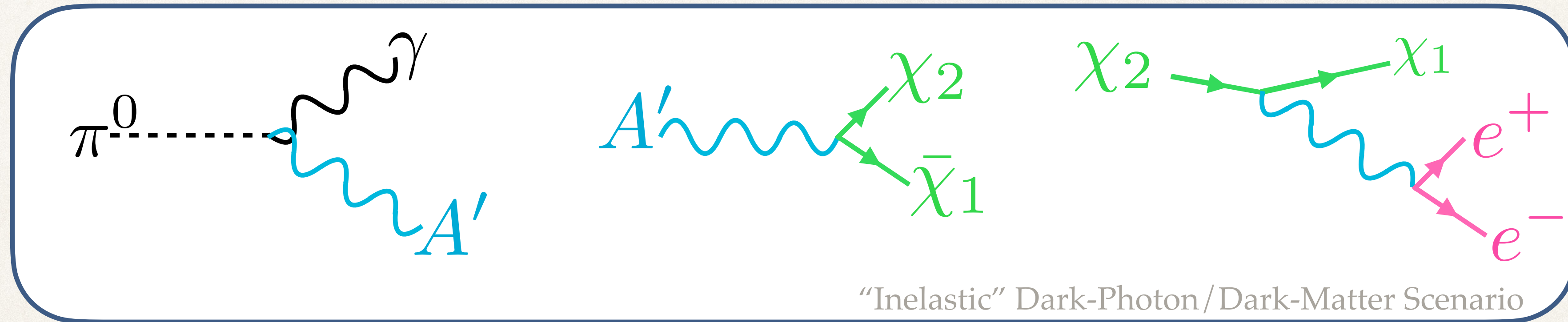
Spatial distribution of dark matter vs. neutrino scattering unlocks production mechanisms.



Taking advantage of Detector/Beam Geometry

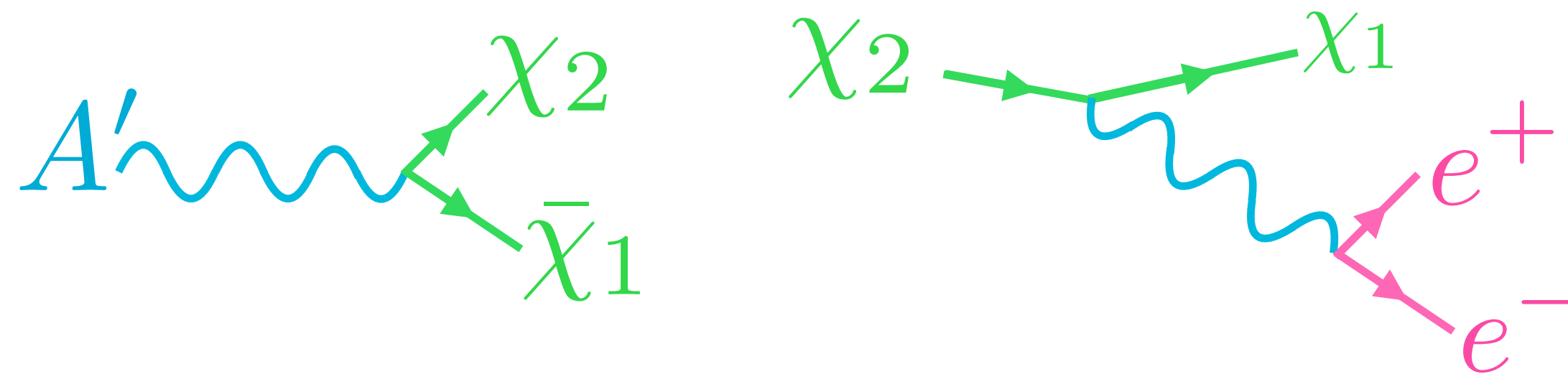


In the event of a discovery, can we determine the origin of the excess?



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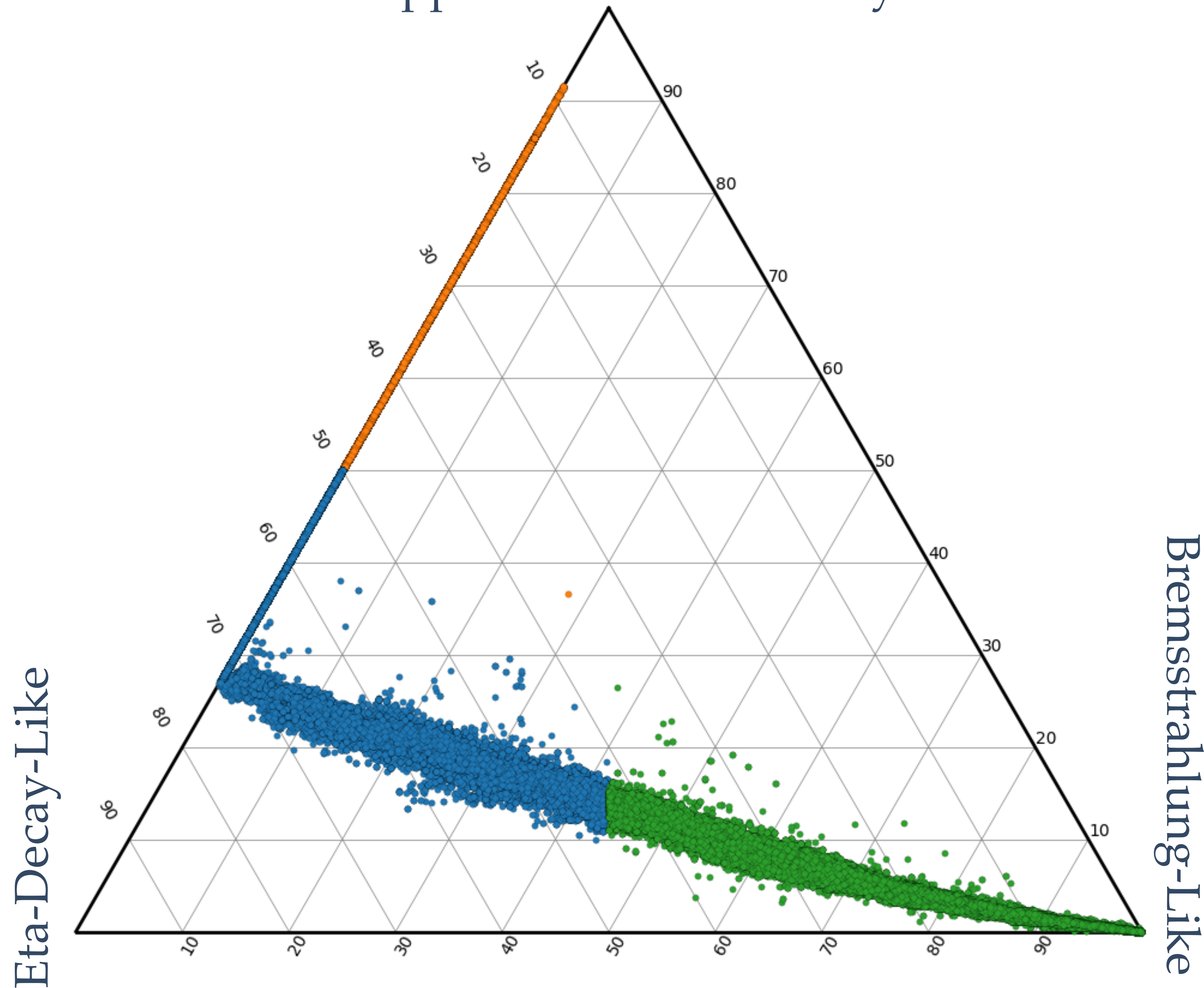
Unknown
Production
Mechanism?



"Inelastic" Dark-Photon/Dark-Matter Scenario

Example: Using SBND + Signal Kinematics

Events Appear more Pion-Decay-Like



- Consider production of inelastic DM via
 - Neutral Pion Decay
 - Eta Meson Decay
 - Proton-Proton Bremsstrahlung
- ML Classifier based on decay-electron kinematics, detection position, etc.
 - Scores event-by-event as what production channel it most appears like.
 - Constructing a metric for characterizing an ensemble of signal events based on production channel(s).

Wrapping up...

Conclusions

- ❖ In the hunt for new physics, we need all the help we can get — neutrino experiments and beam-dump facilities offer a complementary approach to detecting many of the same new-physics scenarios.
- ❖ New tools are being developed *constantly* that improve our ability to predict what may await.
- ❖ In the event of a discovery, what comes next? Can we determine the origin of new physics / the model behind its production?

Conclusions

* In the hunt for new physics, we need all the help we can get — neutrino experiments and beam-dump facilities offer a complementary approach to detecting many of the same new-physics scenarios.

Thank you!

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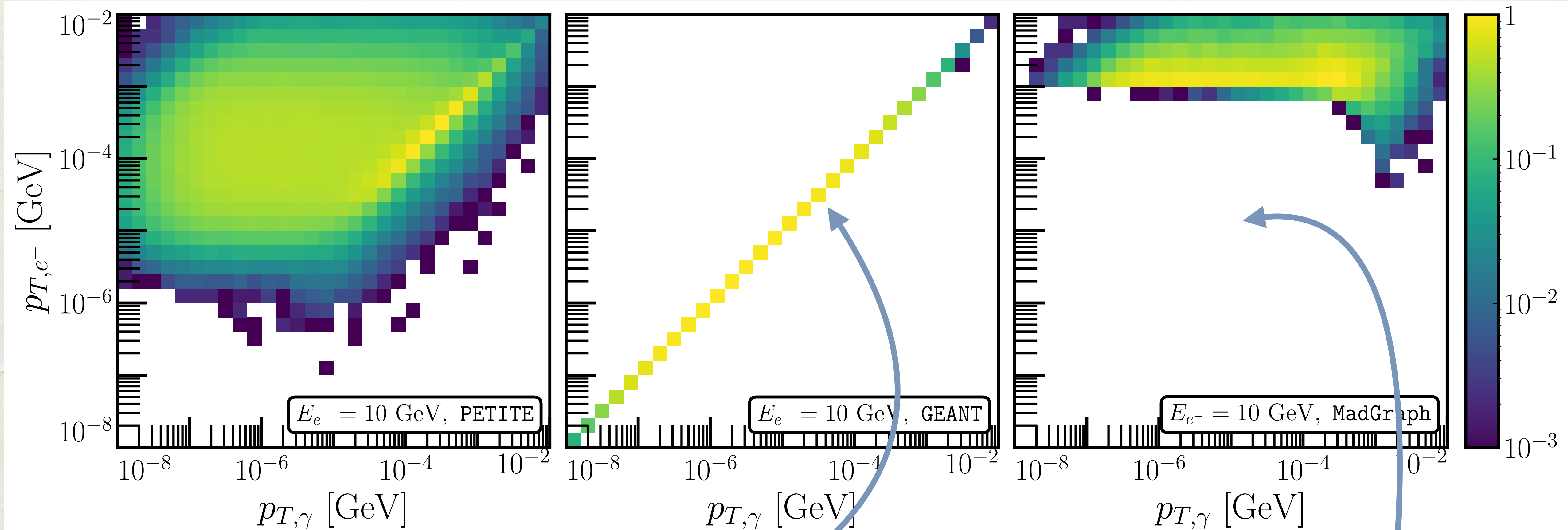
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Backup

Learning about other software...

Idea: let's simulate SM bremsstrahlung, $e^-Z \rightarrow e^-Z\gamma$, for an electron with $E_{e^-} = 10$ GeV striking a graphite target.

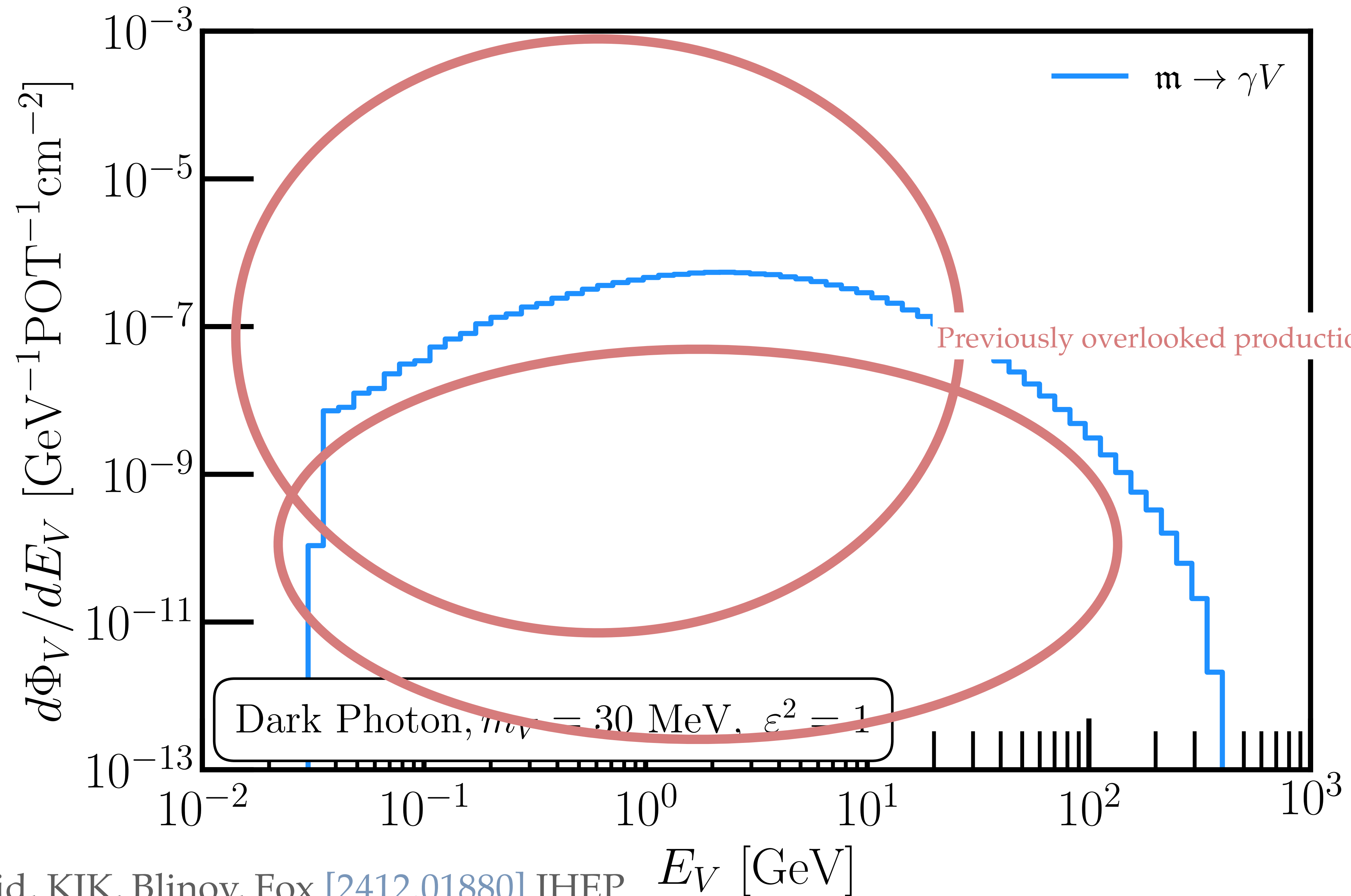
What is the distribution of outgoing electrons and photons, specifically their transverse momenta?



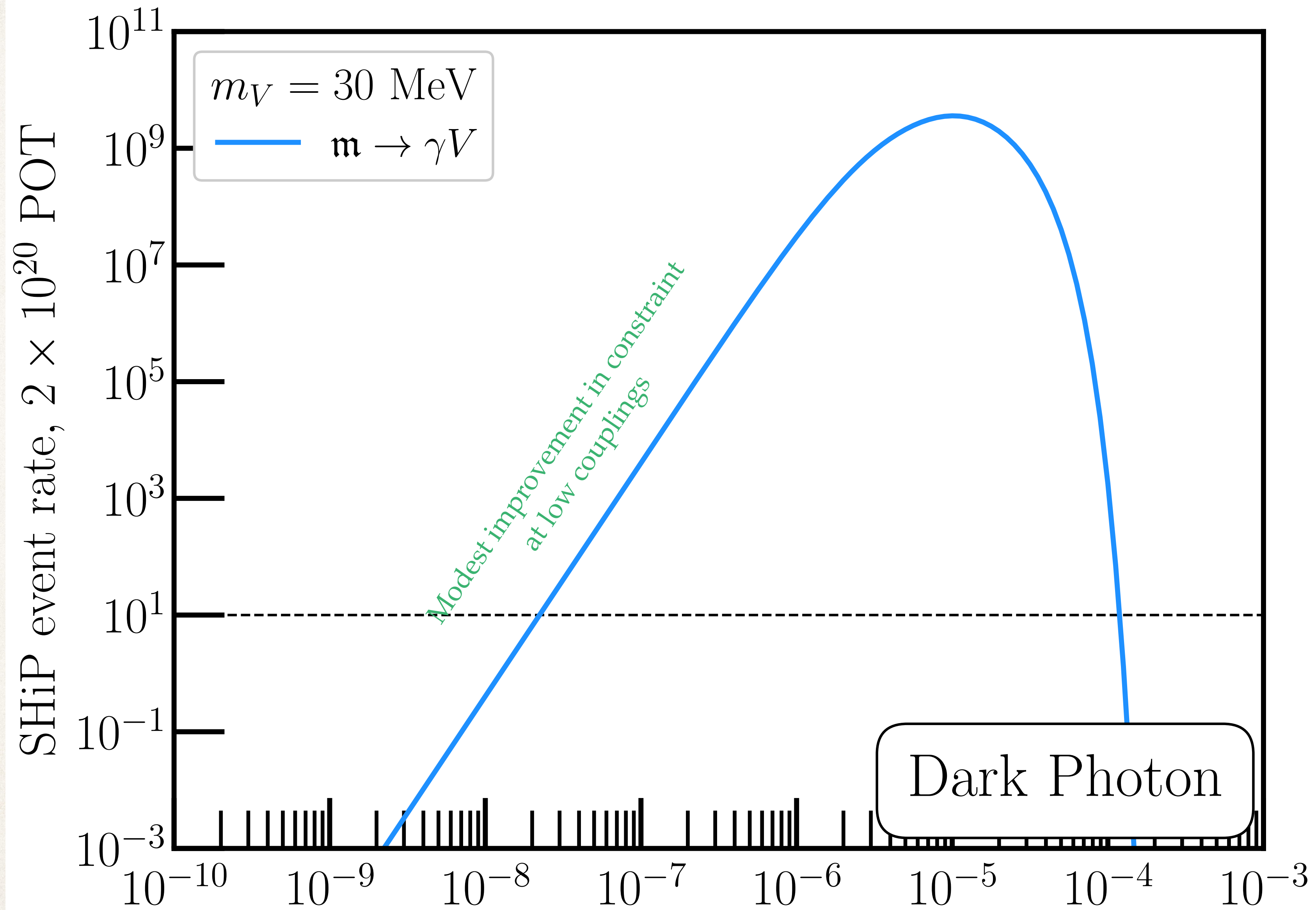
GEANT intrinsically assumes no momentum transfer to the nucleus!

MadGraph misses out on significant phase space!

New Production Mechanisms at SHiP



How does this impact SHiP Sensitivity?



Alternative model scenarios? Leptophilic Gauge Bosons?

