

Probing dark sectors at fixed target experiments using ILC beam

Stefania Gori
UC Santa Cruz



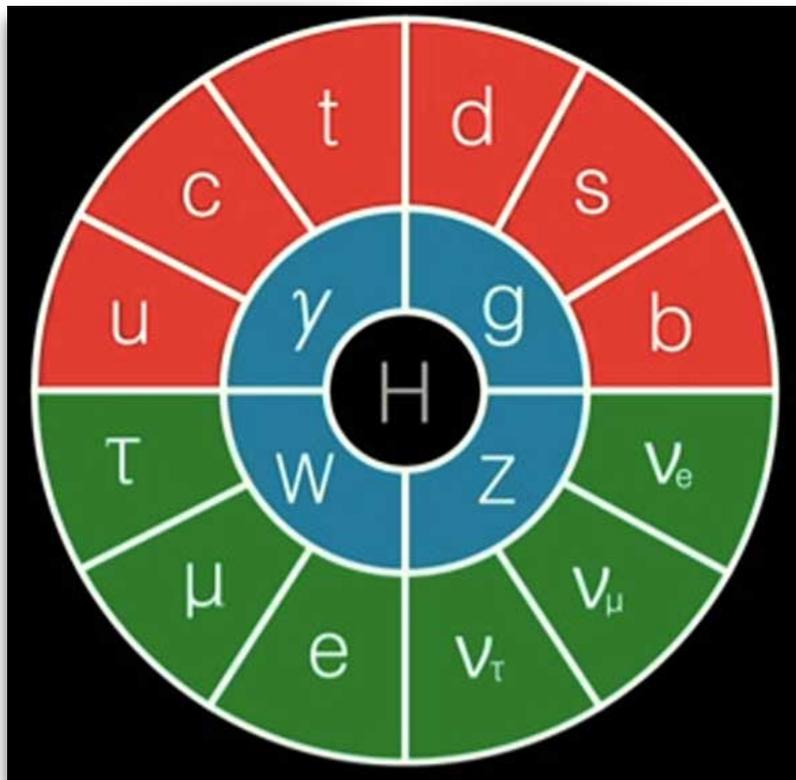
Americas Workshop on Linear Colliders 2020

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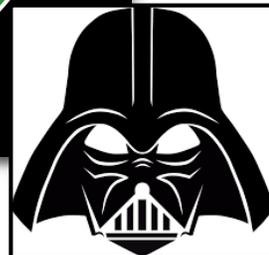
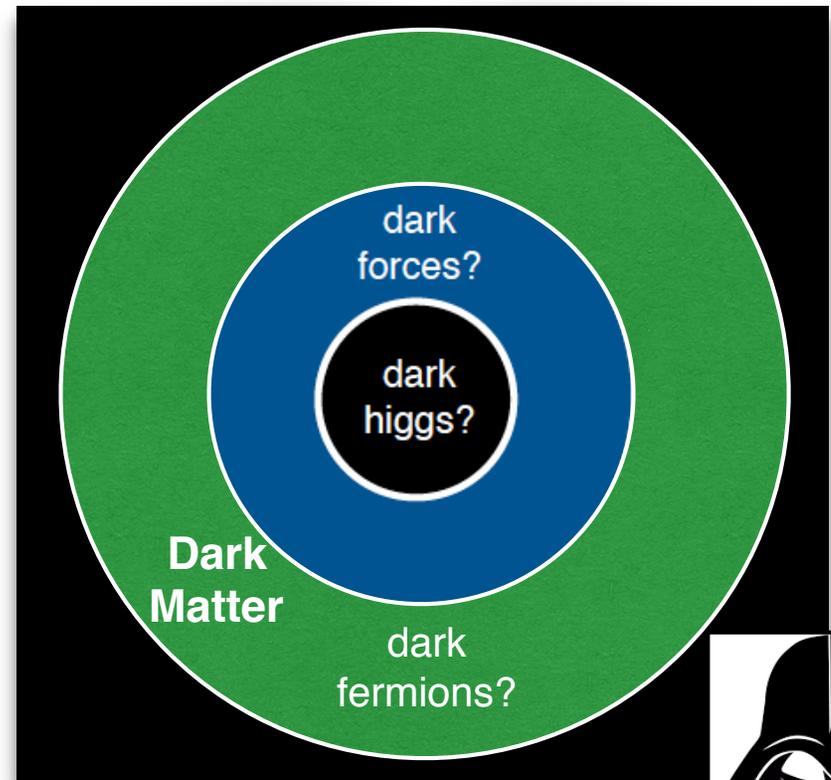
What is a dark sector?

Any particle that does not interact through the Standard Model (SM) forces.

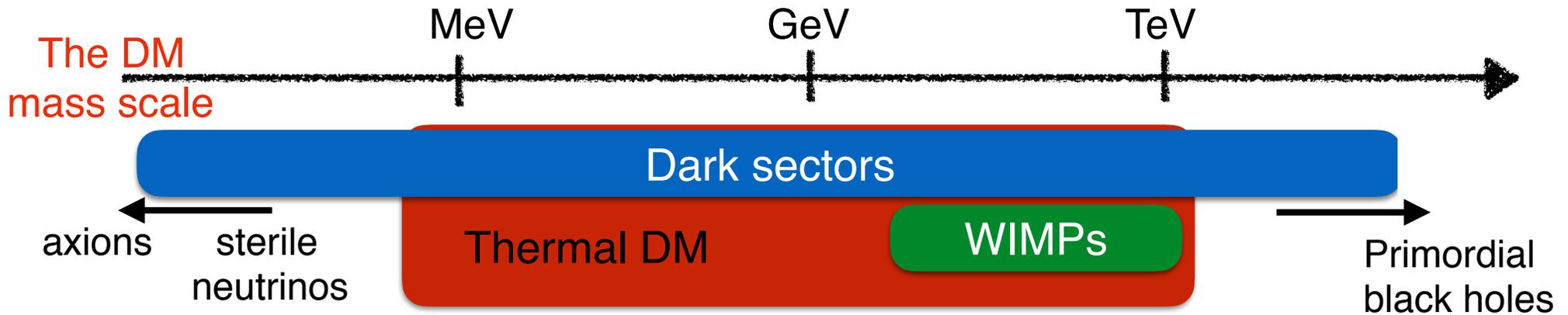
Our visible universe



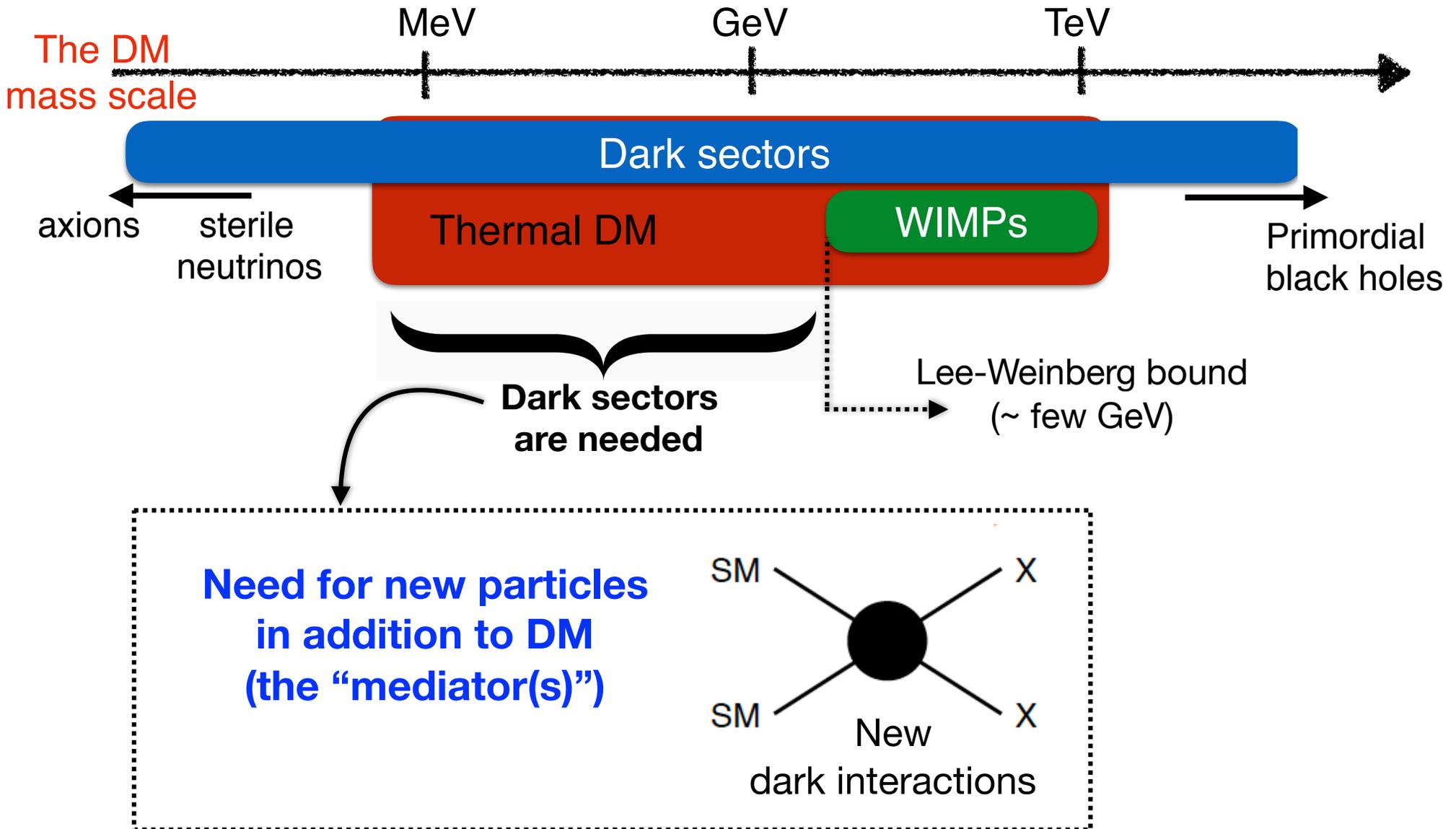
The dark universe



Why a dark sector? (DM)



Why a dark sector? (DM)



Why a dark sector? (beyond DM)

Beyond the DM motivation, many other open problems in particle physics let us think about dark particles.

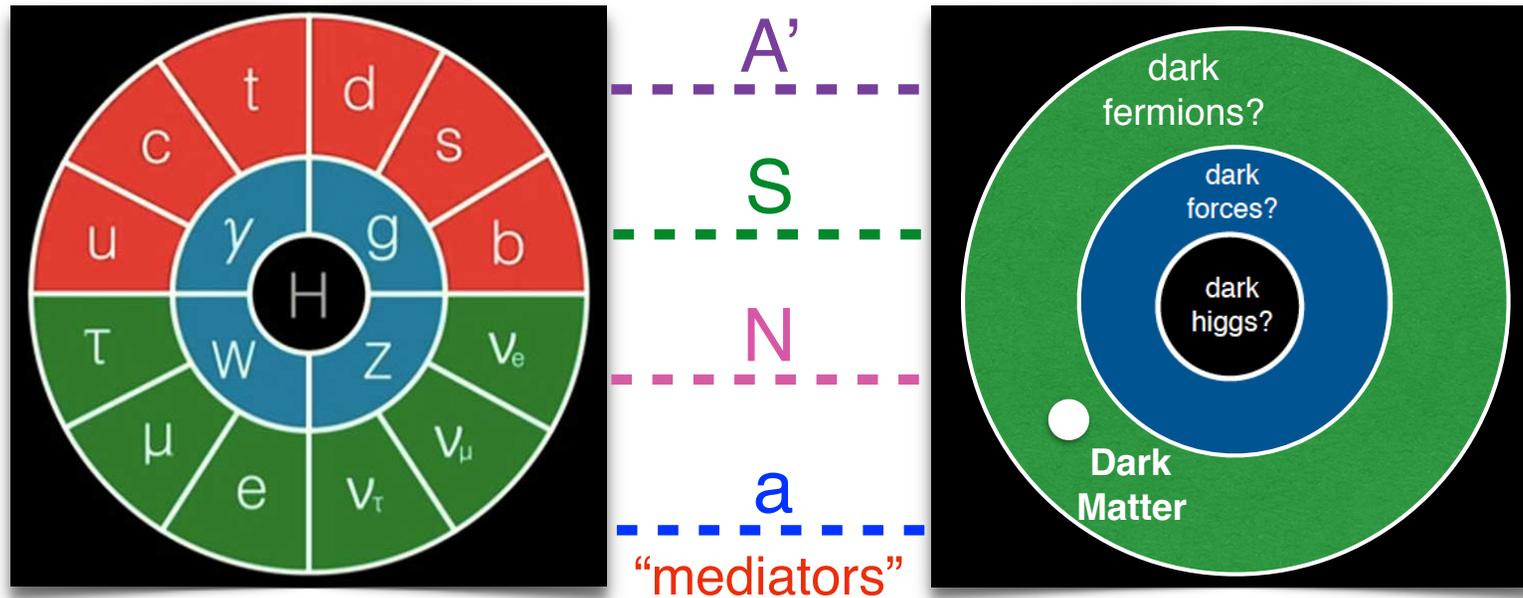
Why a dark sector? (beyond DM)

Beyond the DM motivation, many other open problems in particle physics let us think about dark particles.

- Models to address the **strong CP problem**. Axions and axion-like particles;
- Models to address the **gauge hierarchy problem** (relaxion);
- **SUSY** extended models (Next-to-Minimal-Supersymmetric-Standard-Model);
- Models for **baryogenesis**;
- Models for **neutrino** mass generation;
- Models addressing **anomalies in data**;
($(g-2)_\mu$, galactic center excess for Dark Matter, Xenon1T anomaly, B-physics anomalies, KOTO anomaly, ...).

Some of these particles are naturally light thanks to approximate global symmetries.

How to gain access to the dark sector?



Only a few interactions exist that are allowed by Standard Model symmetries:

“mediators”

“portal interactions”

Dark photon

$$\epsilon B^{\mu\nu} A'_{\mu\nu}$$

Higgs

$$\kappa |H|^2 |S|^2$$

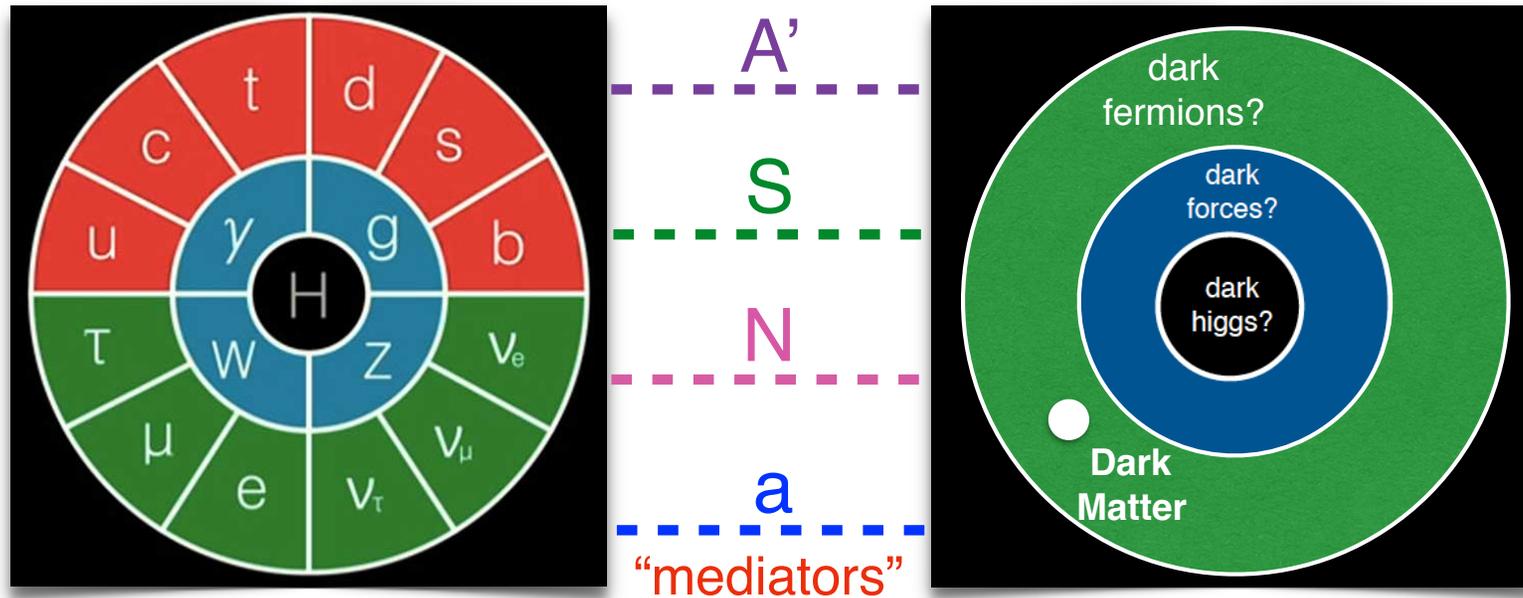
Neutrino

$$y H L N$$

Axion

$$g_{a\gamma} a \tilde{F}_{\mu\nu} F^{\mu\nu}$$

How to gain access to the dark sector?



Only a few interactions exist that are allowed by Standard Model symmetries:

+ possible new dark gauge bosons obtained gauging e.g. B-L, $L_\mu - L_\tau$, ...

“mediators”

“portal interactions”

Dark photon

$$\epsilon B^{\mu\nu} A'_{\mu\nu}$$

Higgs

$$\kappa |H|^2 |S|^2$$

Neutrino

$$y H L N$$

Axion

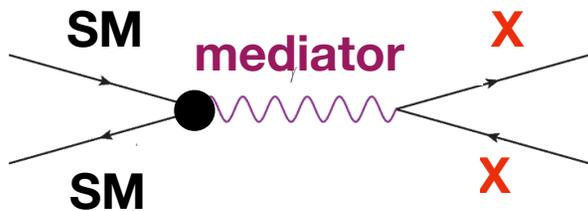
$$g_{a\gamma} a \tilde{F}_{\mu\nu} F^{\mu\nu}$$

Final states to look for

1. Invisible, non-SM

Dark Matter production

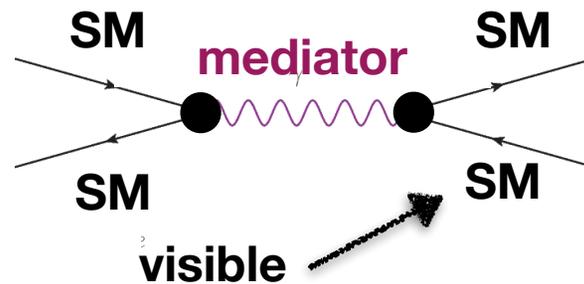
Producing stable particles that could be (all or part of) Dark Matter



2. Visible, SM

Production of portal-mediators that decay to SM particles

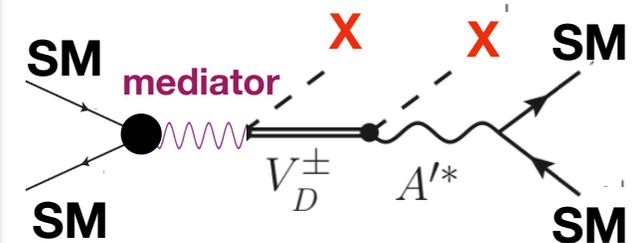
Systematically exploring the portal coupling to SM particles



3. Mixed visible-invisible

Production of “rich” dark sectors

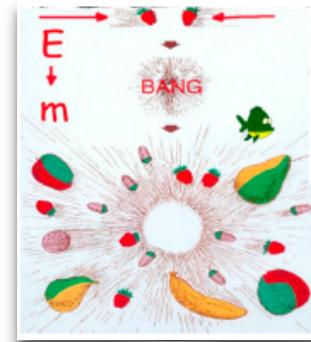
Testing the structure of the dark sector



Experimental opportunities

(Semi) Visible signatures can be looked for at

1. Colliders: LHC, Belle II, ILC, FCC, ...

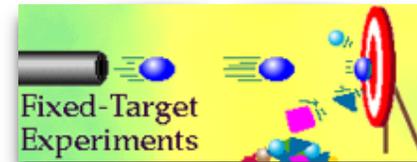


2. Fixed target & beam dump experiments:

past: LSND, E137, CHARM, ...

present: HPS, SeaQuest, ...

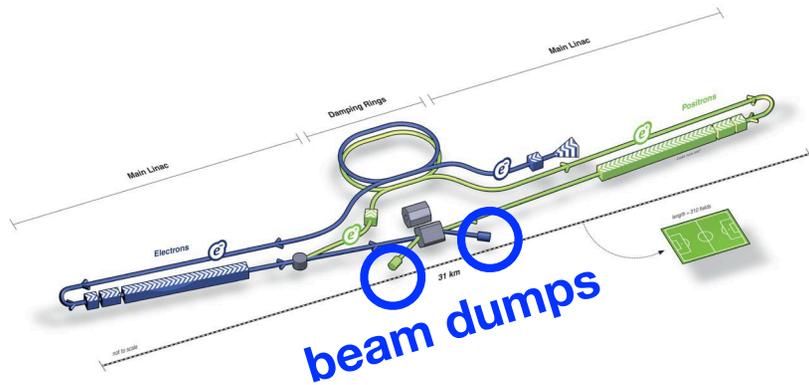
future: SHiP, NA62, **ILC-beam dump**, ...



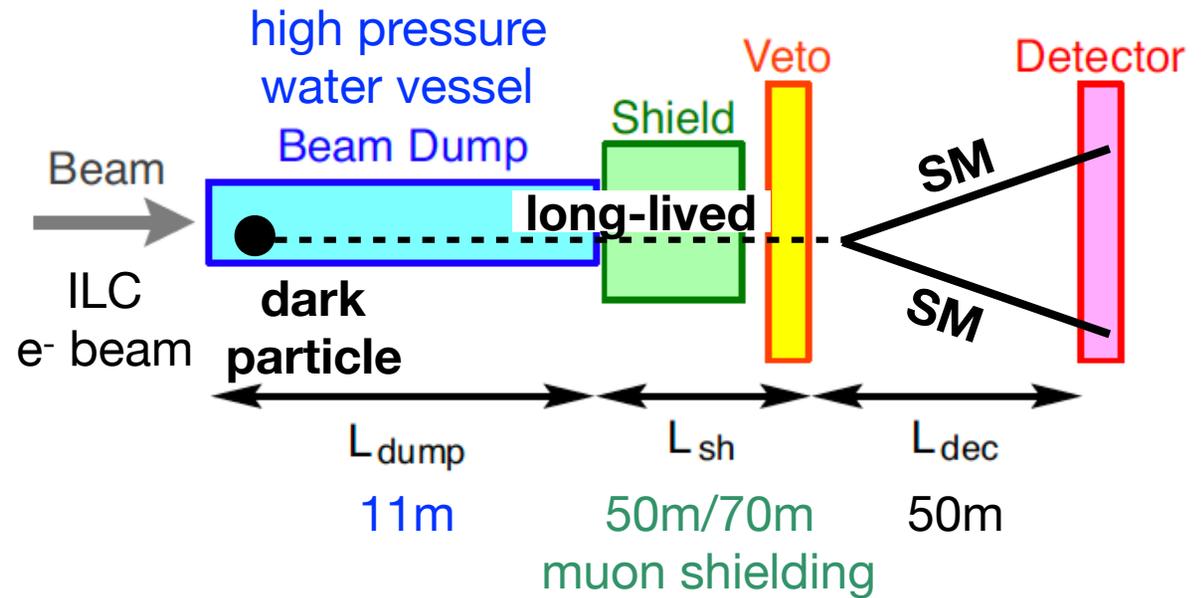
Complementarity

Several proposals for new experiments: Codex-b, FASER, MATHUSLA, ...

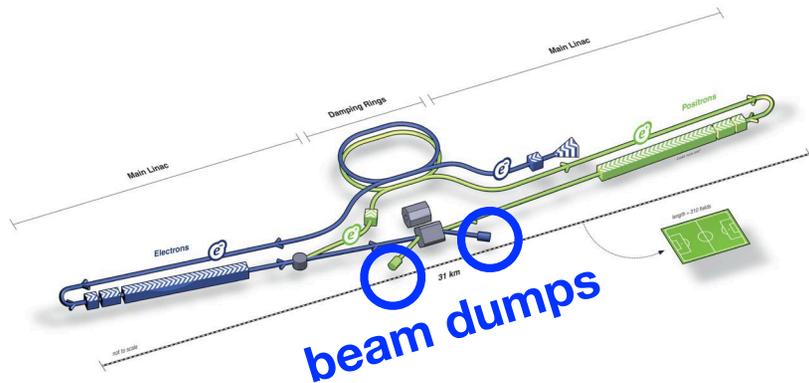
ILC beam-dump setup



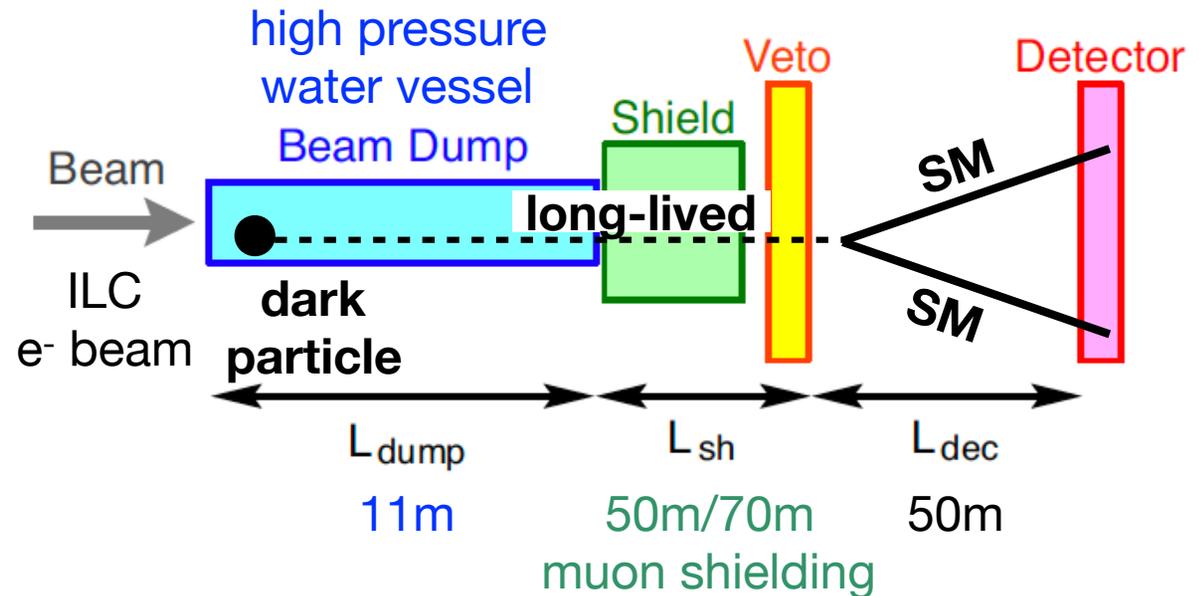
Kanemura, Moroi,
Tanabe, 1507.02809



ILC beam-dump setup



Kanemura, Moroi,
Tanabe, 1507.02809



* Much **larger energy**: 125 GeV, 250 GeV, 500 GeV, 1.5 TeV electron beams compared to past/present e- beam dump experiments:

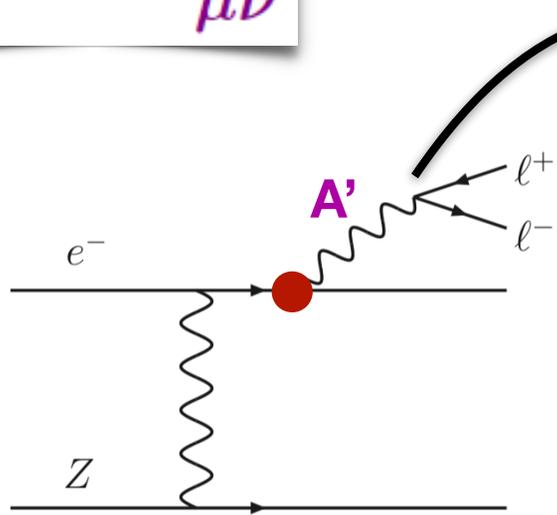
- E137 @ SLAC: ~20 GeV electron beam (past)
- HPS @ JLAB: ~ (1-6) GeV electron beam (present)

* **Very high luminosities**: $\sim 4 \cdot 10^{21}$ electrons on target (EOT)/year compared to

- E137 @ SLAC: $\sim 2 \cdot 10^{20}$ EOT
- HPS @ JLAB: $\sim 10^{18}$ EOT

The minimal dark photon model

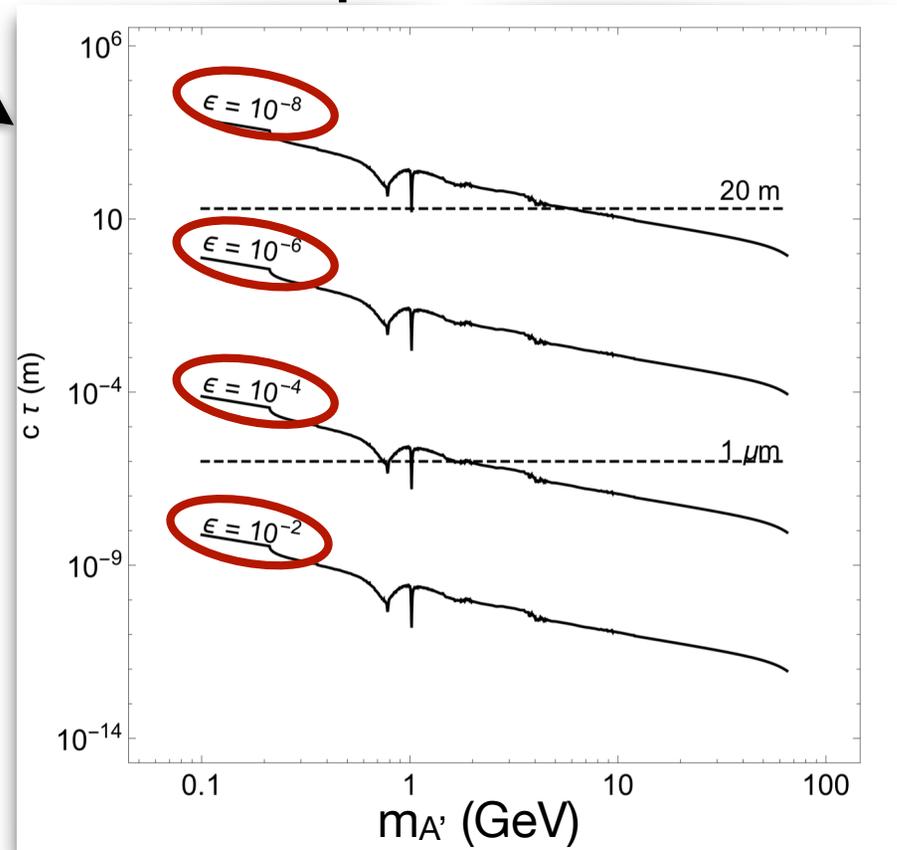
$$\epsilon B^{\mu\nu} A'_{\mu\nu}$$



bremsstrahlung production
in the beam dump

Dark photon produced very forward

Dark photon life time



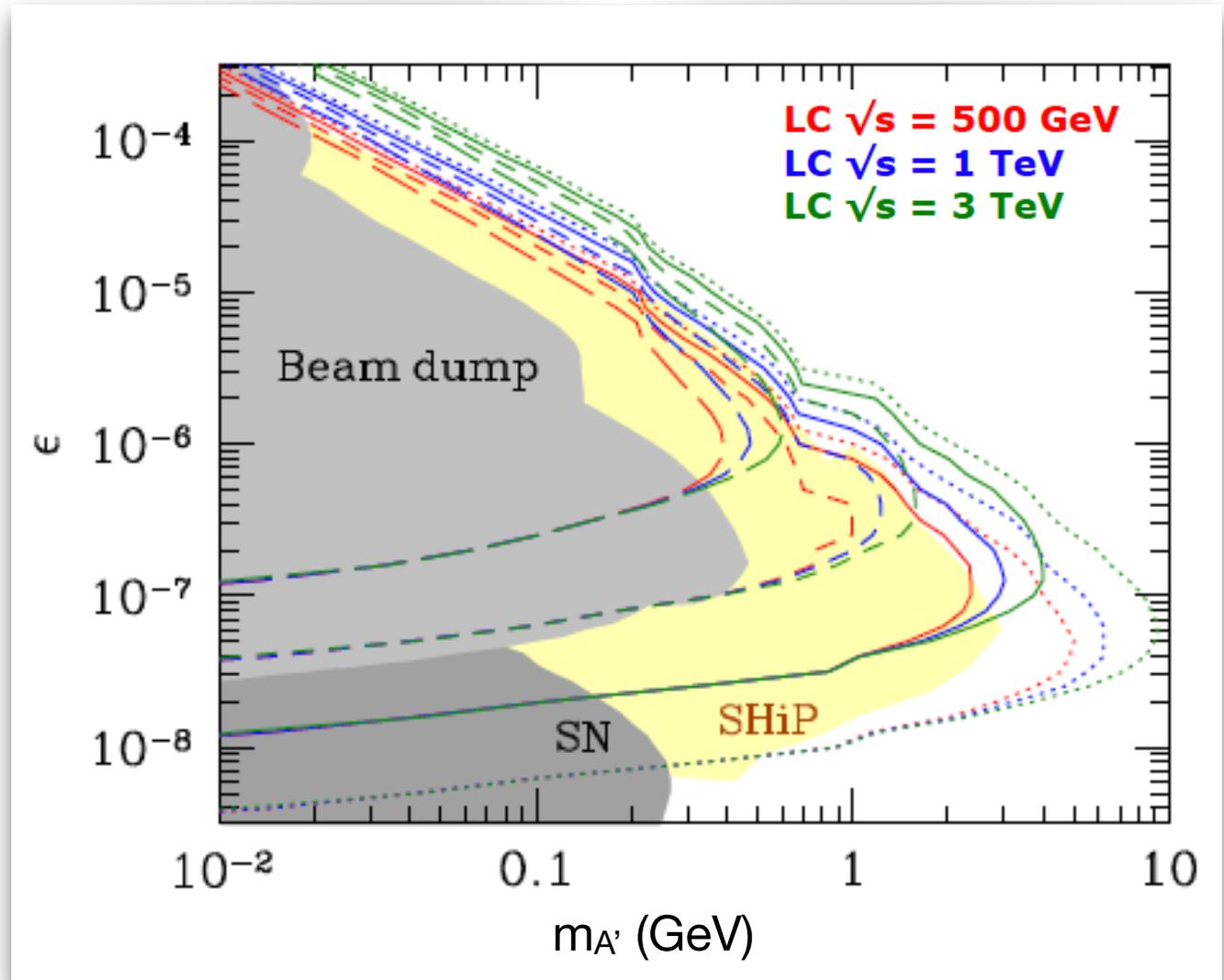
Curtin, Essig, SG, Shelton, 1412.0018

10^6 background muon pairs are produced.

Proposed active muon shielding to reduce the background to a negligible rate.

The reach on the minimal dark photon model

Kanemura, Moroi, Tanabe, 1507.02809

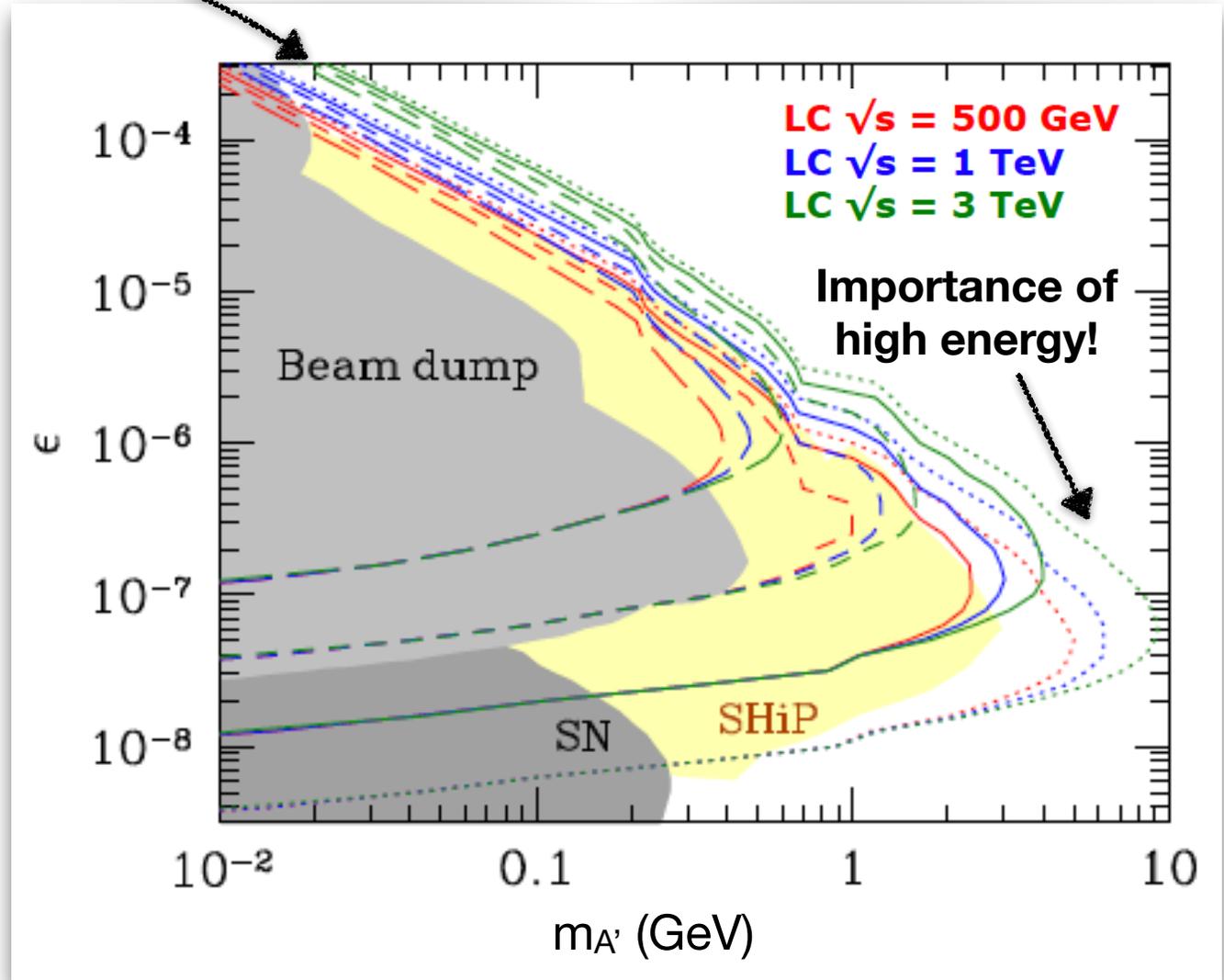


The reach on the minimal dark photon model

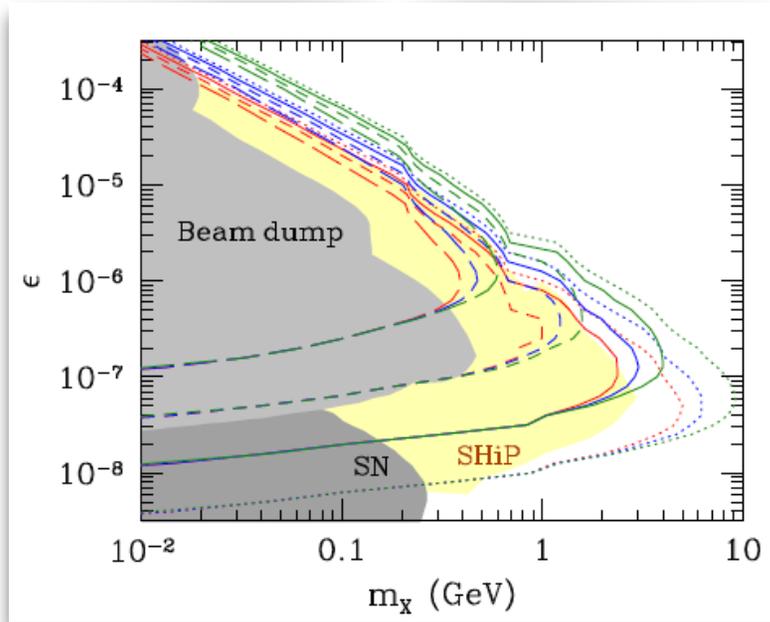
Kanemura, Moroi, Tanabe, 1507.02809

Exponential dependence
on the position of the
detector &
amount of shielding

$N_{\text{sig}} = 10^4$
 $N_{\text{sig}} = 10^2$
 $N_{\text{sig}} = 1$
 $N_{\text{sig}} = 10^{-2}$



Complementarity with other experiments



Kanemura et al., 1507.02809

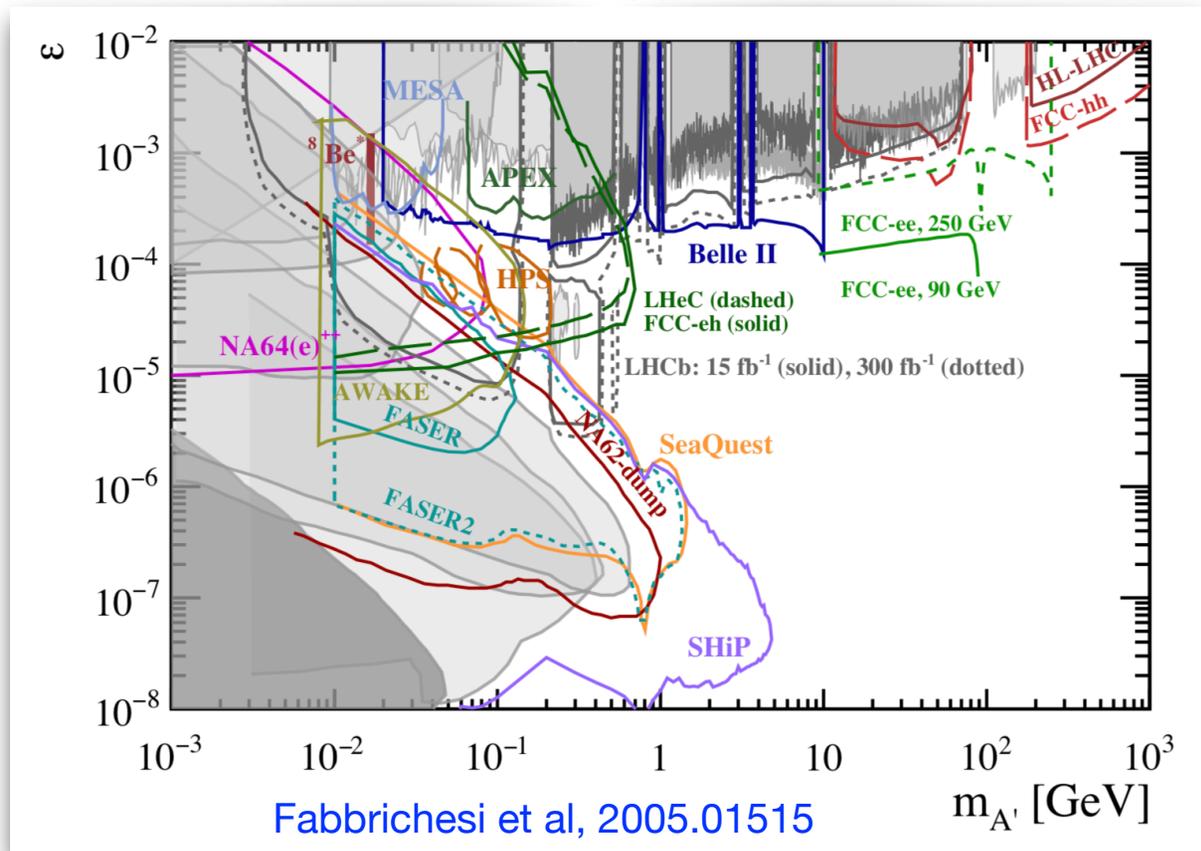
Few references:

- SeaQuest:
- Berlin, SG, Schuster, Toro, 1804.00661
- FCC: Karliner et al., 1503.07209
- SHiP: Alekhin et al., 1504.04855
- FASER: Feng et al., 1708.09389

+ Proposal for the Belle II experiment:
Gazelle (Evans et al.)

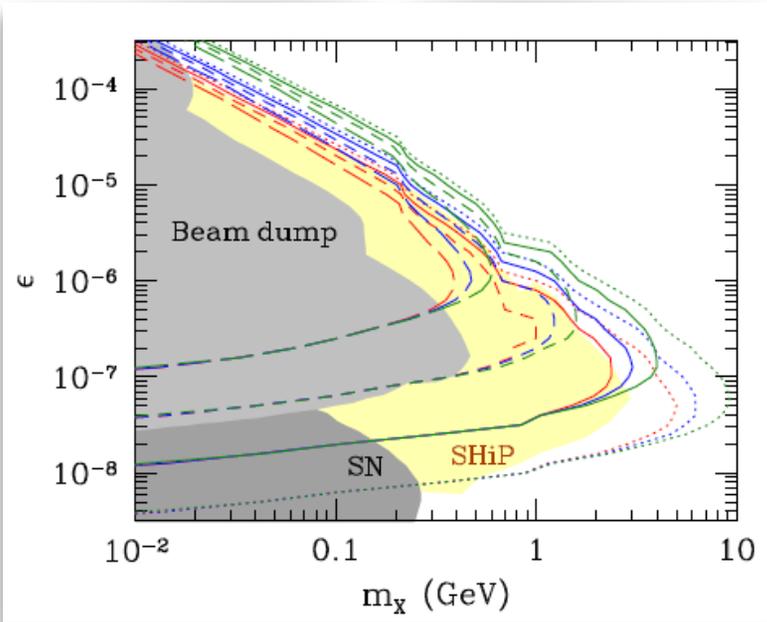
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Future (proposed and approved) experiments



Fabbrichesi et al, 2005.01515

Complementarity with other experiments



Kanemura et al., 1507.02809

Few references:

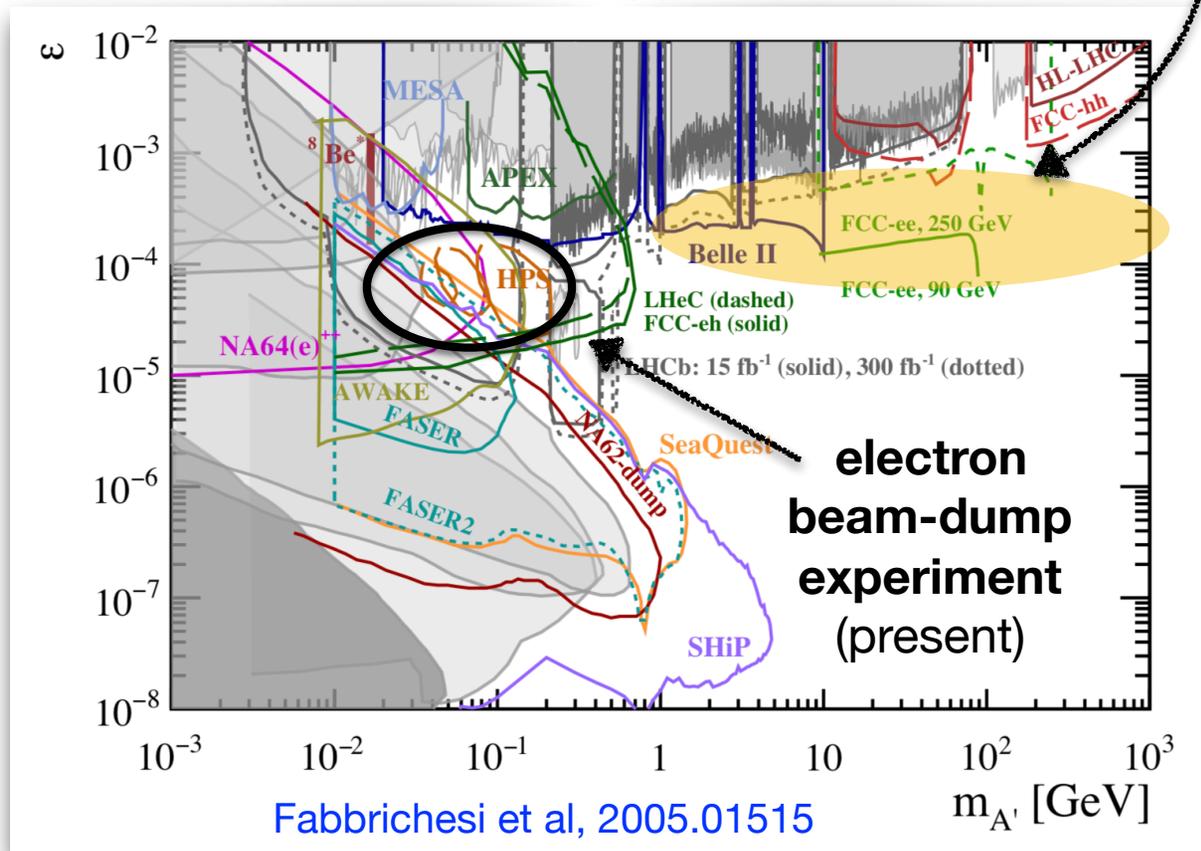
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+ Proposal for the Belle II experiment:
Gazelle (Evans et al.)

S.Gori

Additional opportunities for the ILC here!
 $e^+e^- \rightarrow A' \gamma \rightarrow \gamma l^+ l^-$ (prompt dark photon)

Future (proposed and approved) experiments

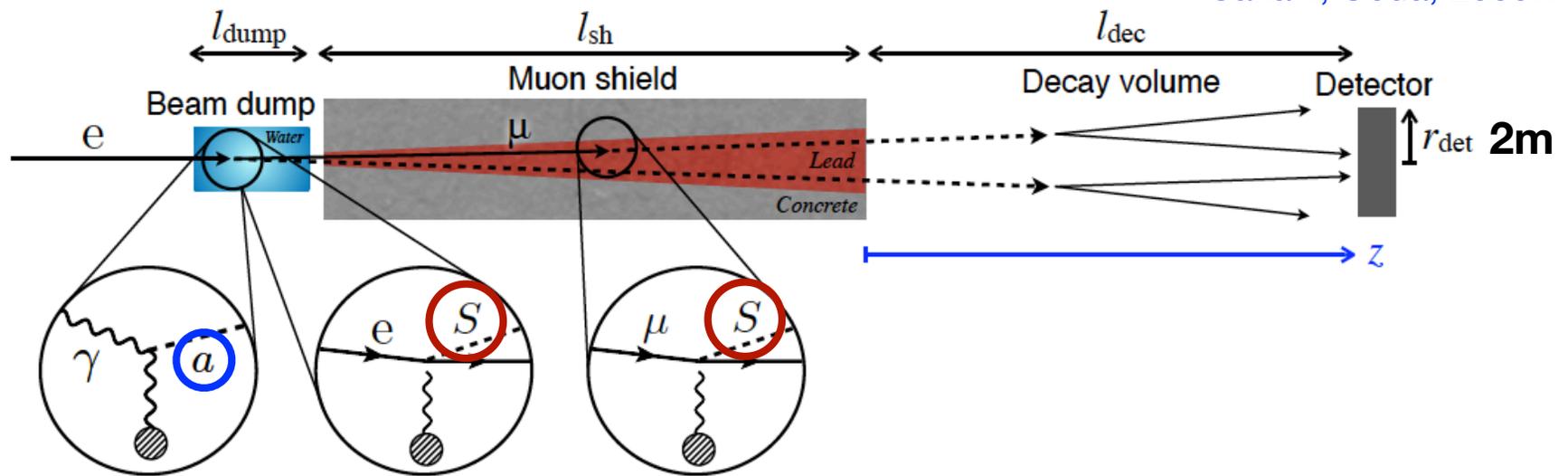


Fabbrichesi et al, 2005.01515

Beyond the dark photon model

A variety of dark particles can be produced:

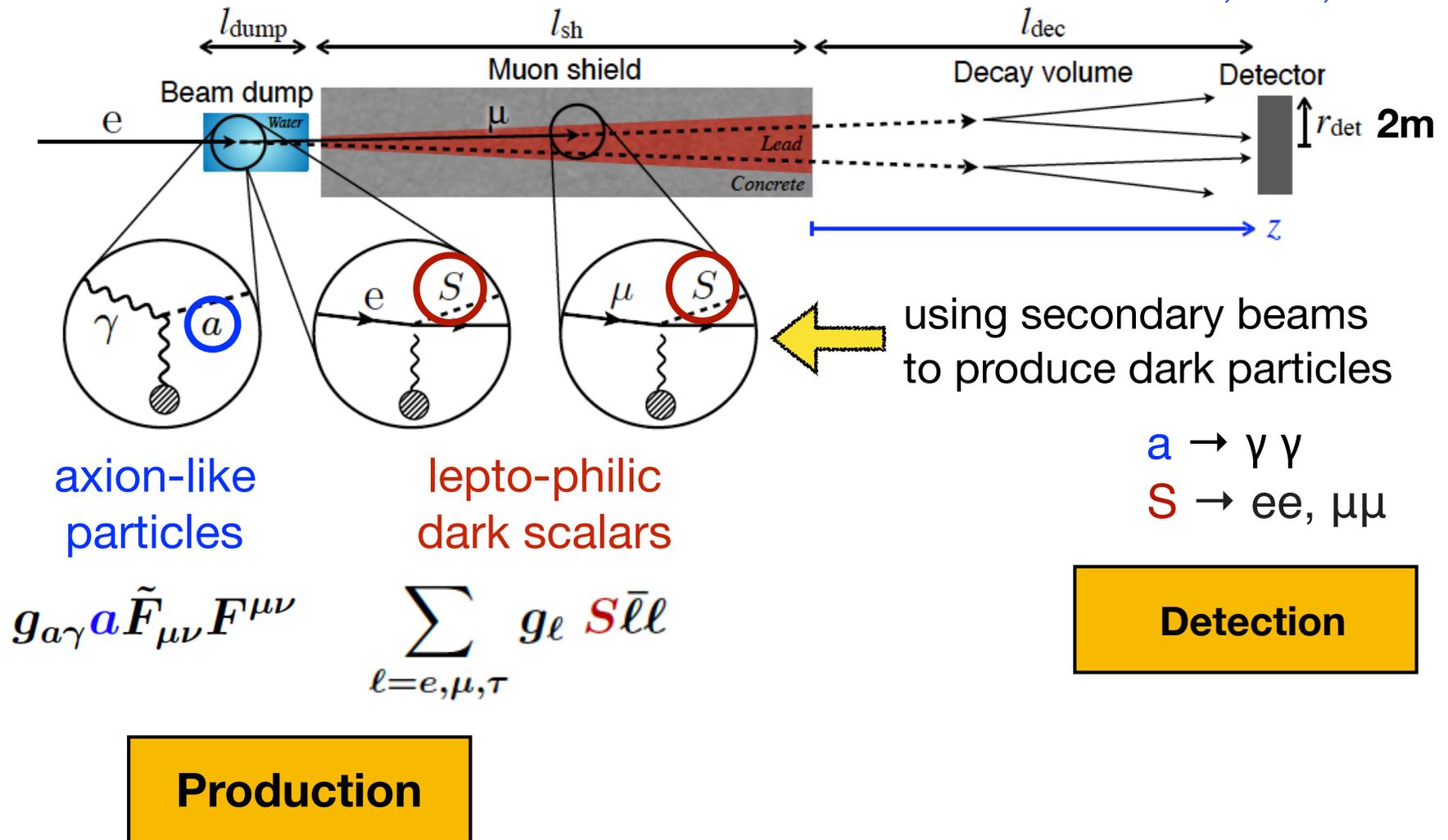
adapted from
Sakaki, Ueda, 2009.13790



Beyond the dark photon model

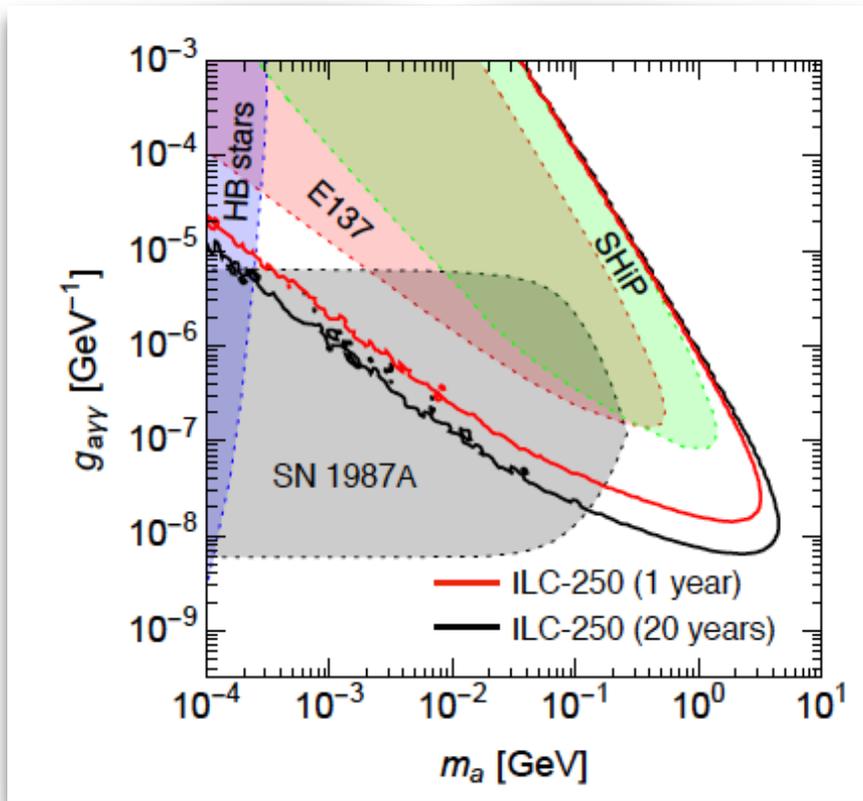
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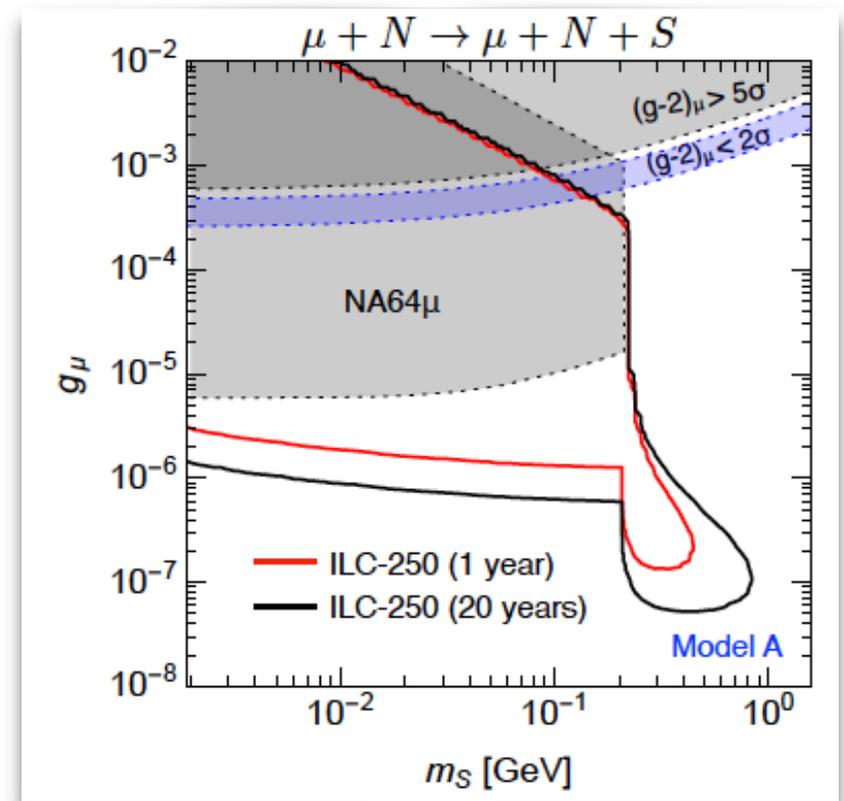


The reach on ALPs and dark scalars

axion-like particles



lepto-philic dark scalars



Sakaki, Ueda, 2009.13790

New models to study?

Several additional dark sector models lead to visible signatures that can be looked for at the ILC beam dump experiment.

New models to study?

Several additional dark sector models lead to visible signatures that can be looked for at the ILC beam dump experiment.

* **Minimal dark scalar** model: $\kappa |H|^2 |S|^2$

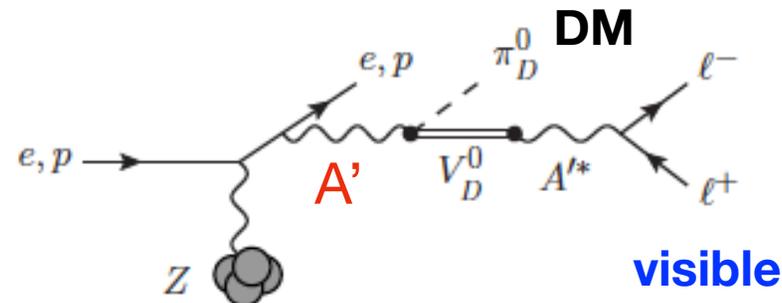
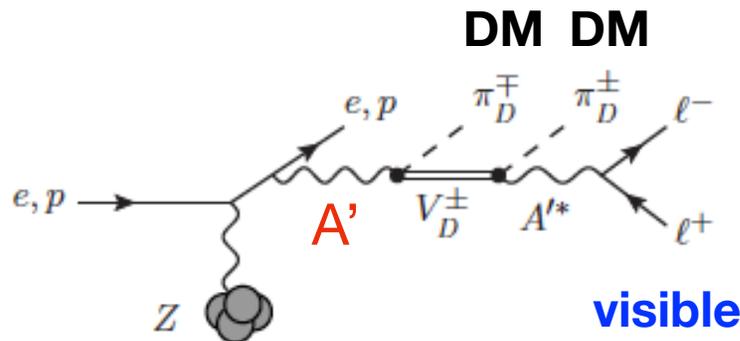
with the scalar acquiring a coupling to all SM quark and leptons

* What about **sterile neutrinos**? $yHLN$

* Beyond minimal models: “**rich dark sectors**”

One example are strongly interacting massive particle models (SIMP) for DM (DM belongs to a dark QCD sector, π_D)

On going study for the HPS beam dump experiment



Additional opportunities?

Invisible dark sectors

* Can we utilize the **dump** for **DM** detection?

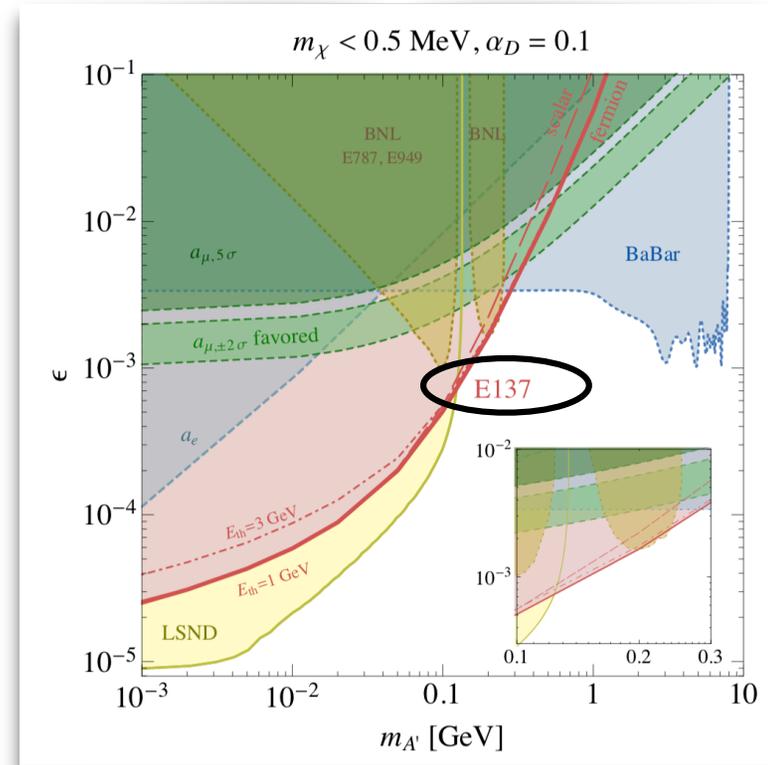
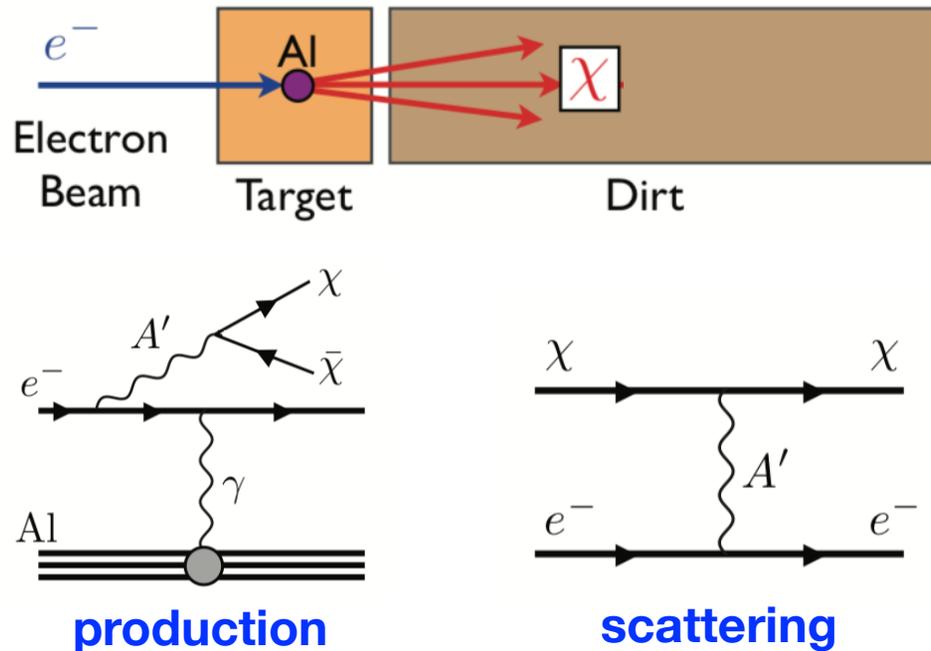
* What about adding a **thin target** before the dump?

Additional opportunities?

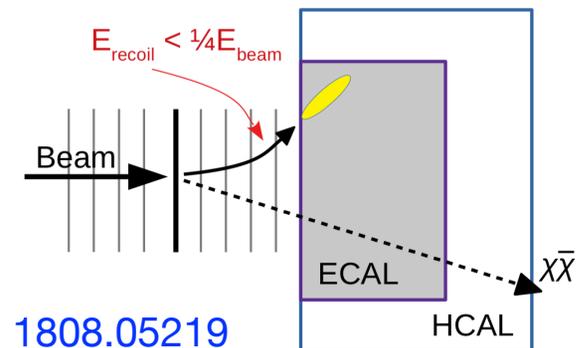
Invisible dark sectors

Batell et al, 1406.2698

* Can we utilize the **dump** for **DM detection**?



* What about adding a **thin target** before the dump, for **missing momentum** measurements? (similarly to the NA64 and LDMX experiment)



Conclusions & Outlook

The high intensity - high energy ILC electron beam can be utilized to search for dark sector particles in fixed target experiments

Only a few studies have been performed: dark photons, axion-like particles, and leptophilic scalars produced in the beam dump

Many additional opportunities:

- new models leading to visible signatures
- invisible signatures (searches for Dark Matter)

Complementarity with other collider searches