

Hidden Sectors: from Cosmos to Accelerators

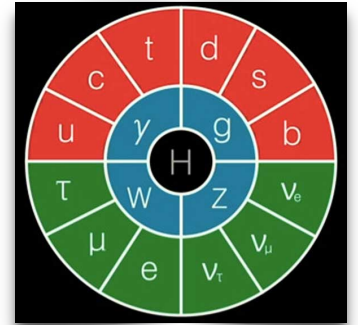
Stefania Gori
University of Cincinnati

9th International Particle Accelerator Conference (IPAC'18)
May 4, 2018

Particle physics: past, present & future

With the Large Hadron Collider (LHC) **discovery of the Higgs boson** in 2012, a new era of particle physics has started.

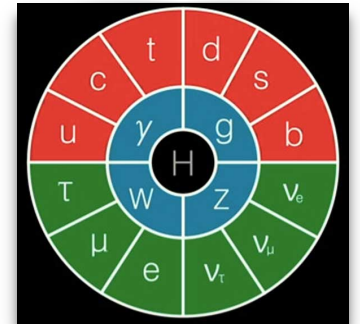
The Standard Model (SM) is now **complete**



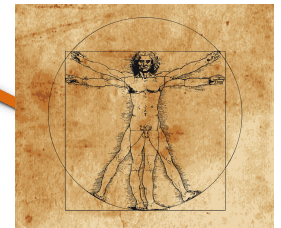
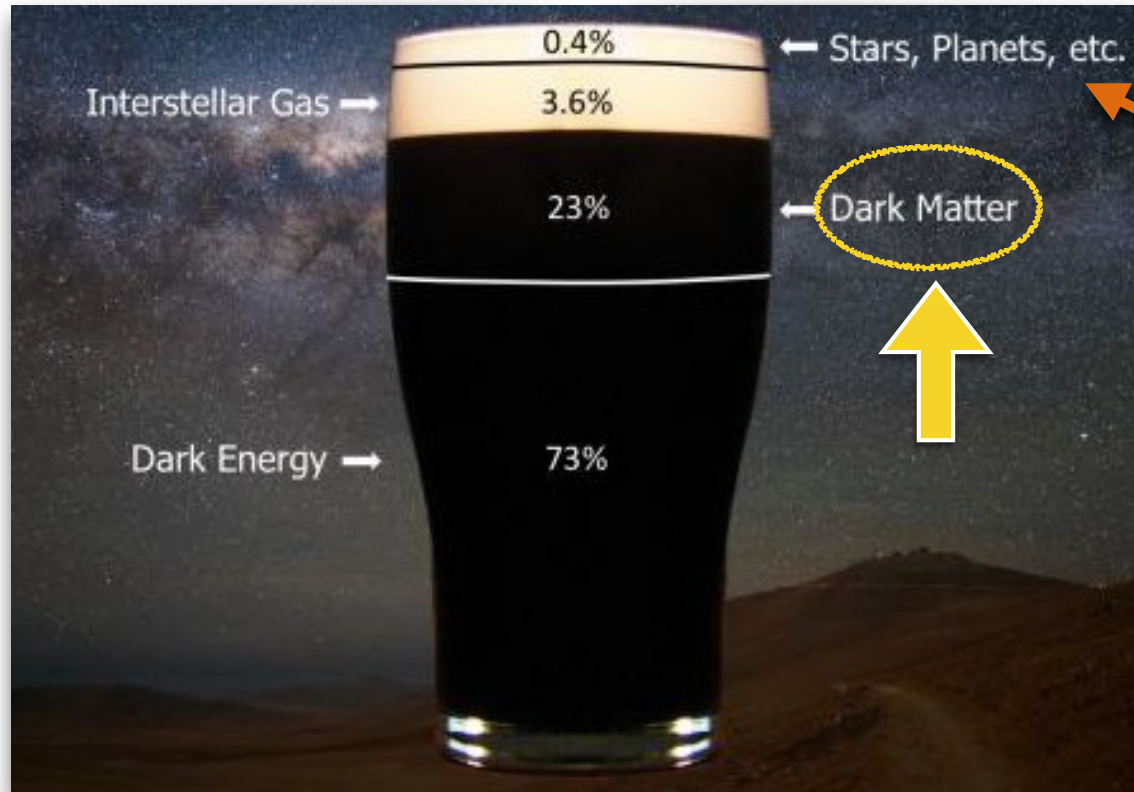
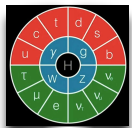
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BUT:



us

S.Gori

What do we know about Dark Matter (DM)?

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1. It gravitates

1933 Fritz Zwicky



Coma cluster (of galaxies)

1970, Vera Rubin



Andromeda Galaxy

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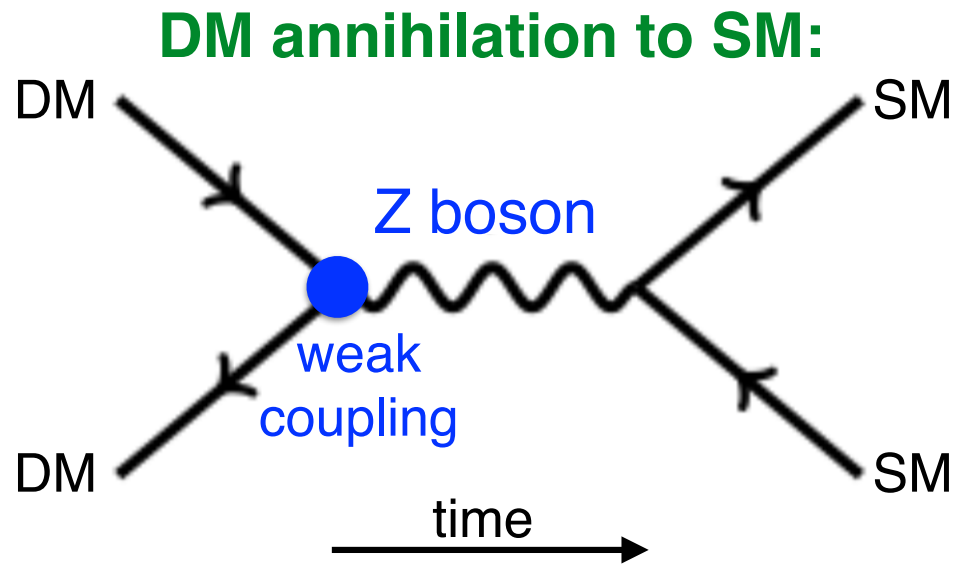
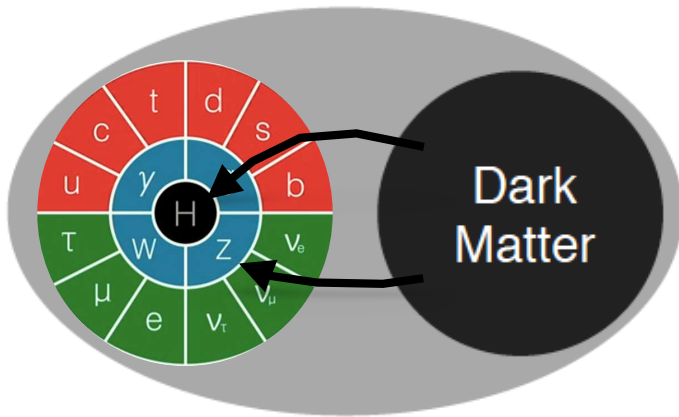
2. It is dark (i.e. it does not interact with photons)

3. It is stable on cosmological scales

There is lots of DM in the Universe, but for DM particles weighing several hundred times the mass of the proton, there should be about one DM particle per coffee-cup-sized volume of space.

The “WIMP” paradigm

Weakly Interactive Massive Particles (WIMP) models:
One of the dominant models for more than 3 decades



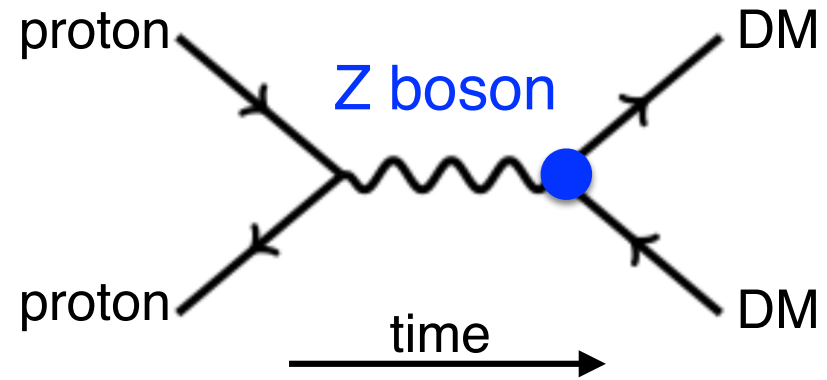
Thanks to these interactions, DM with a mass $O(100 \text{ GeV})$ can “freeze out” and obtain the measured relic abundance

WIMP “miracle”? ... or “coincidence”

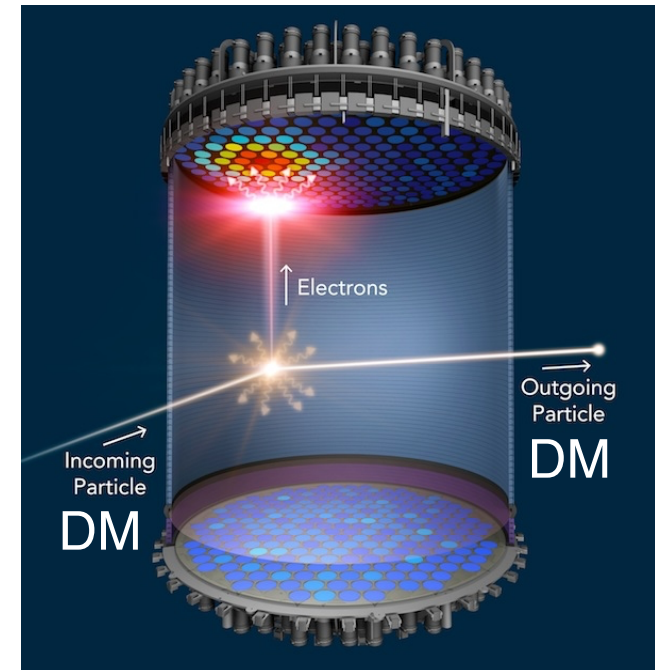
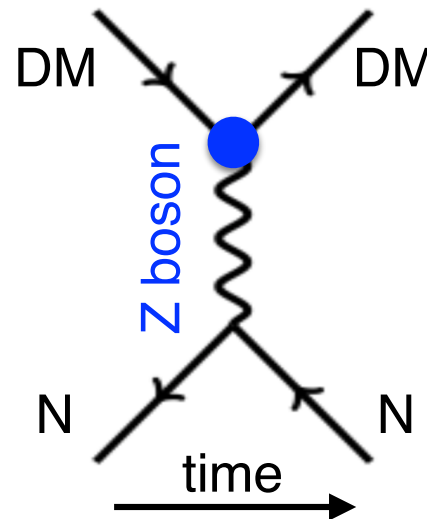
\sim mass of the Higgs boson

We have learned a lot about WIMPs!

The **LHC** is a “WIMP factory”:



Additionally,
direct detection experiments can measure
WIMP-nucleus (N) scattering

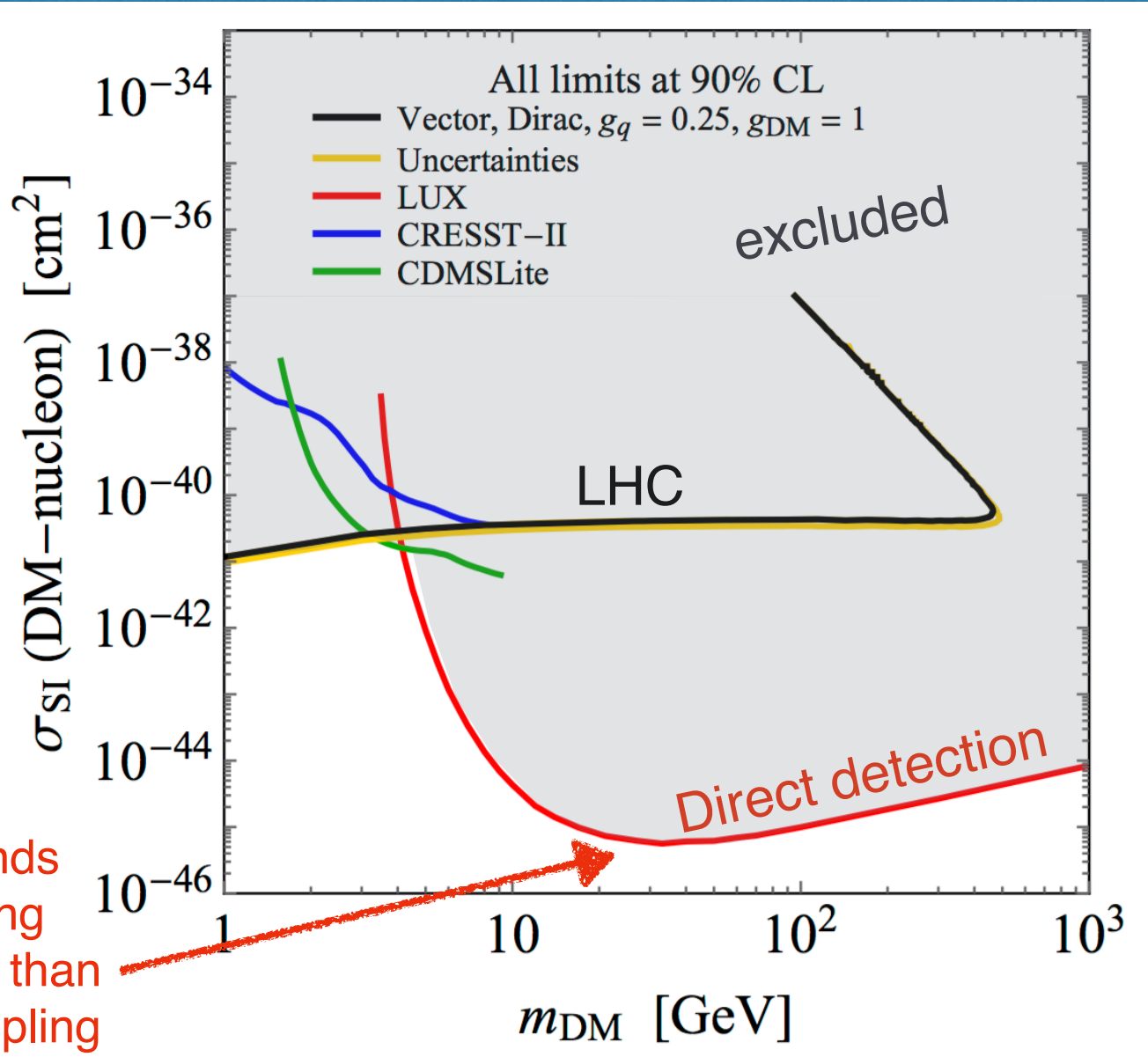


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The
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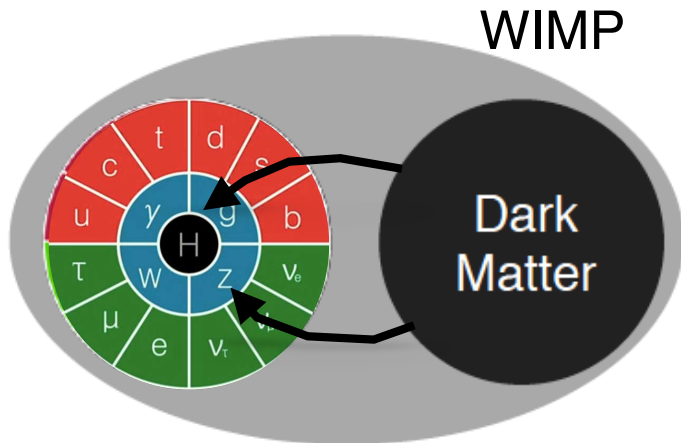
Larger
coupling
↑

it corresponds
to a coupling
 $\sim 10^{-3}$ weaker than
the weak coupling



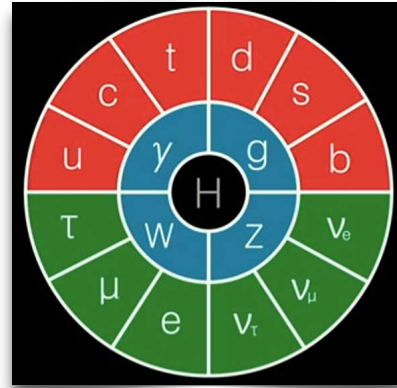
→
Outgoing
Particle
DM

Life beyond WIMPs: dark sectors

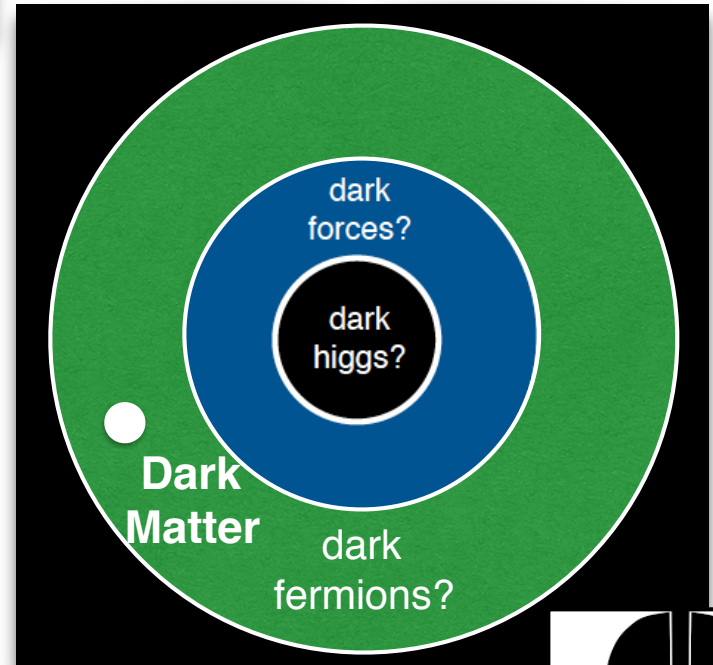


Minimality

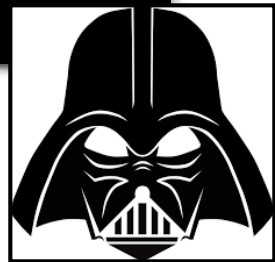
versus



The "dark sector"



Plentitude



Easier to have lighter (< 100 GeV) DM

Dark sectors in a nutshell



Further motivations?

Several anomalies in data can be addressed by dark sectors (eg. $(g-2)_\mu$, B-physics anomalies, Dark Matter anomalies, ...)

What theories?

DM theories, Supersymmetric theories (NMSSM), neutral naturalness theories, theories for baryogenesis, ...



Dark sectors in a nutshell

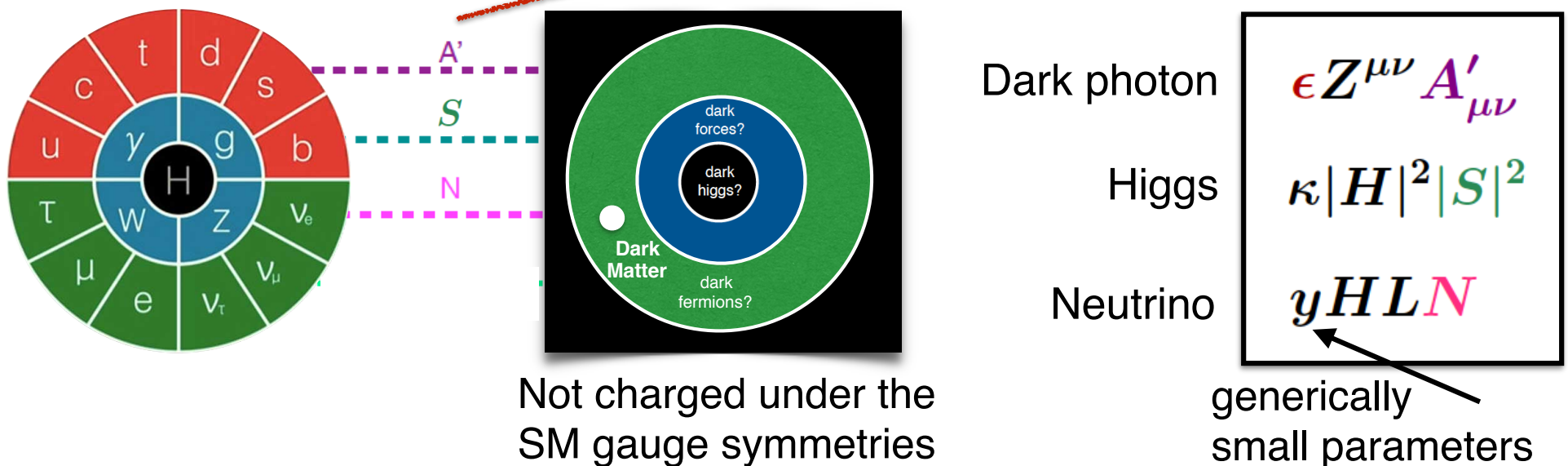
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How to test this emerging paradigm?





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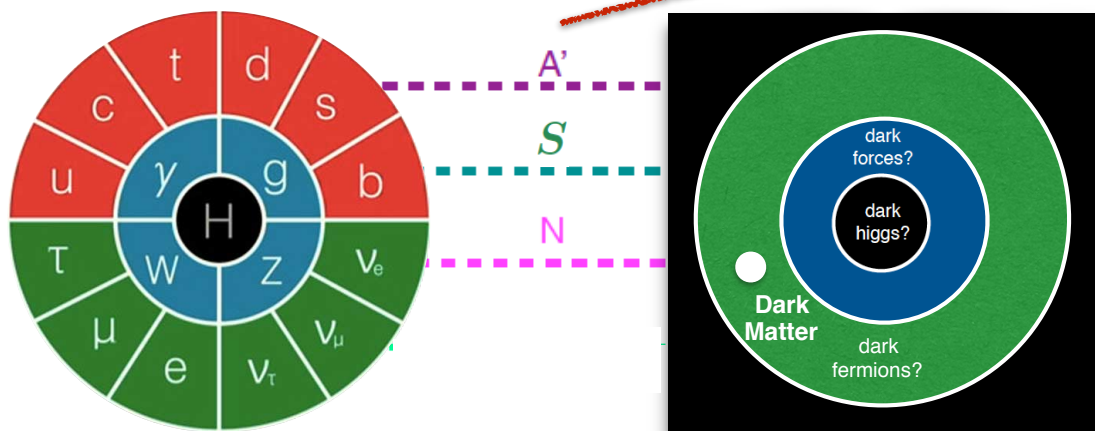
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Not charged under the SM gauge symmetries

“Portals”:

Dark photon

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



Community effort: the Dark Sector Program

Worldwide search for Dark Sectors involves hundreds of scientists, dozens of analyses & experiments in last few years



Dark Interactions Workshop, BNL, June 11-13 , 2014



Dark sectors workshop,
SLAC, April 28-30, 2016

High Energy Physics at
the Sensitivity Frontier
KITP, Mar 26 - May 25, 2018



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IBS CONFERENCES

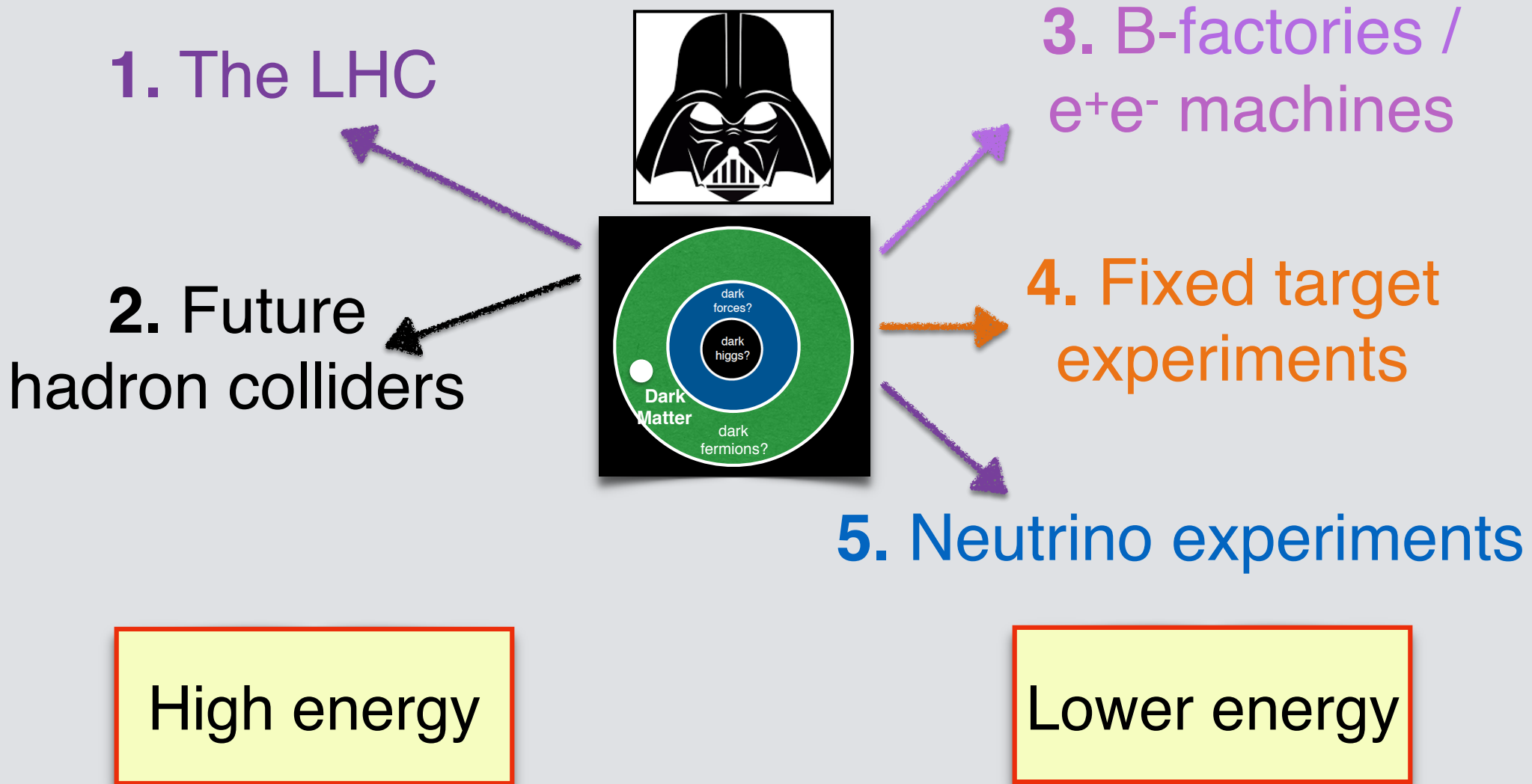
IBS Conference on Dark World

30th October - 3rd November 2017

Lecture Building, KAIST Munji Campus, Daejeon, Korea

Light Dark Matter @ Accelerators,
Isola d'Elba, Italy, May 24-28, 2017

Dark sectors at accelerator experiments



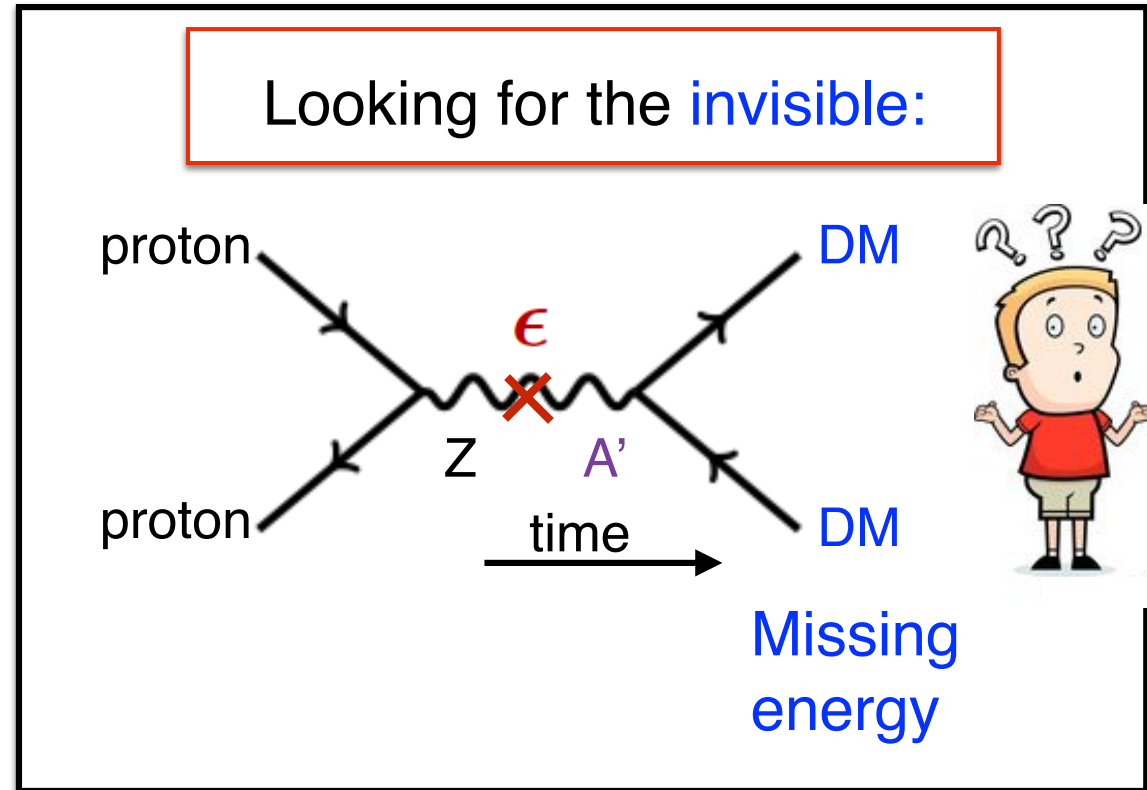
Complementarity with muon colliders, heavy ion experiments, ...

The LHC: dark matter searches

1.

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

The dark photon, A' , will have a small quantum component of the SM Z boson and vice versa

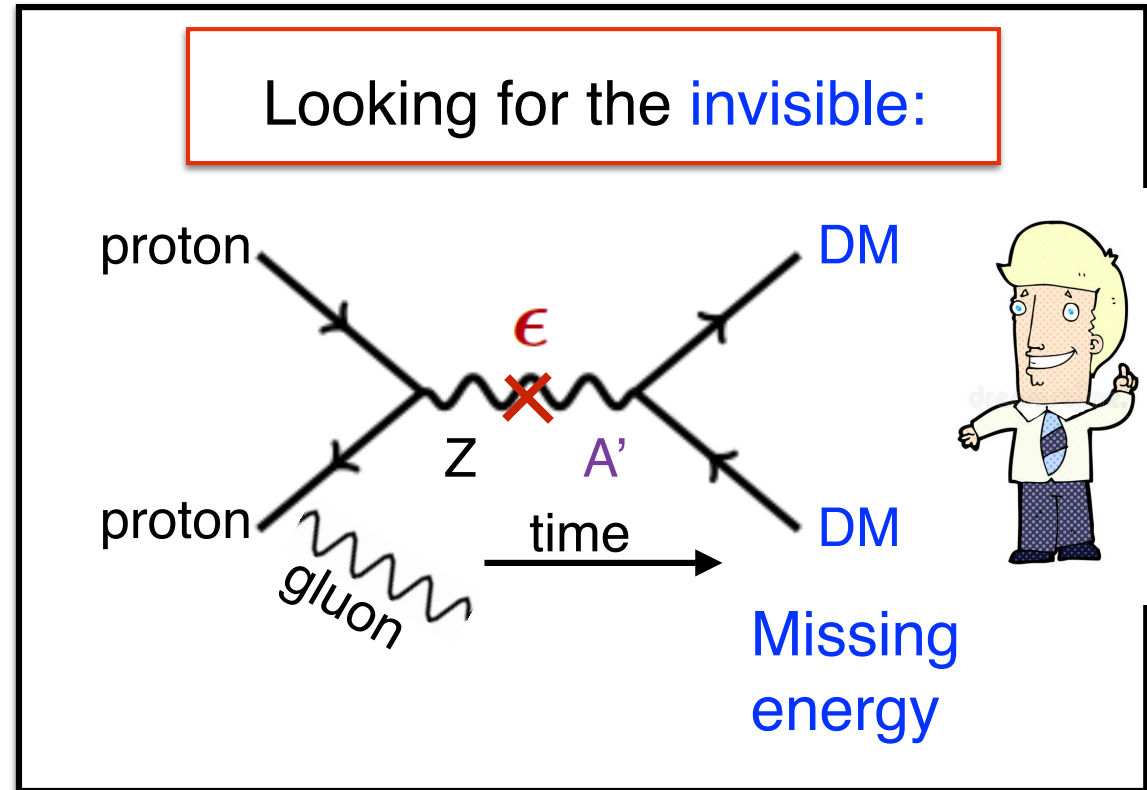


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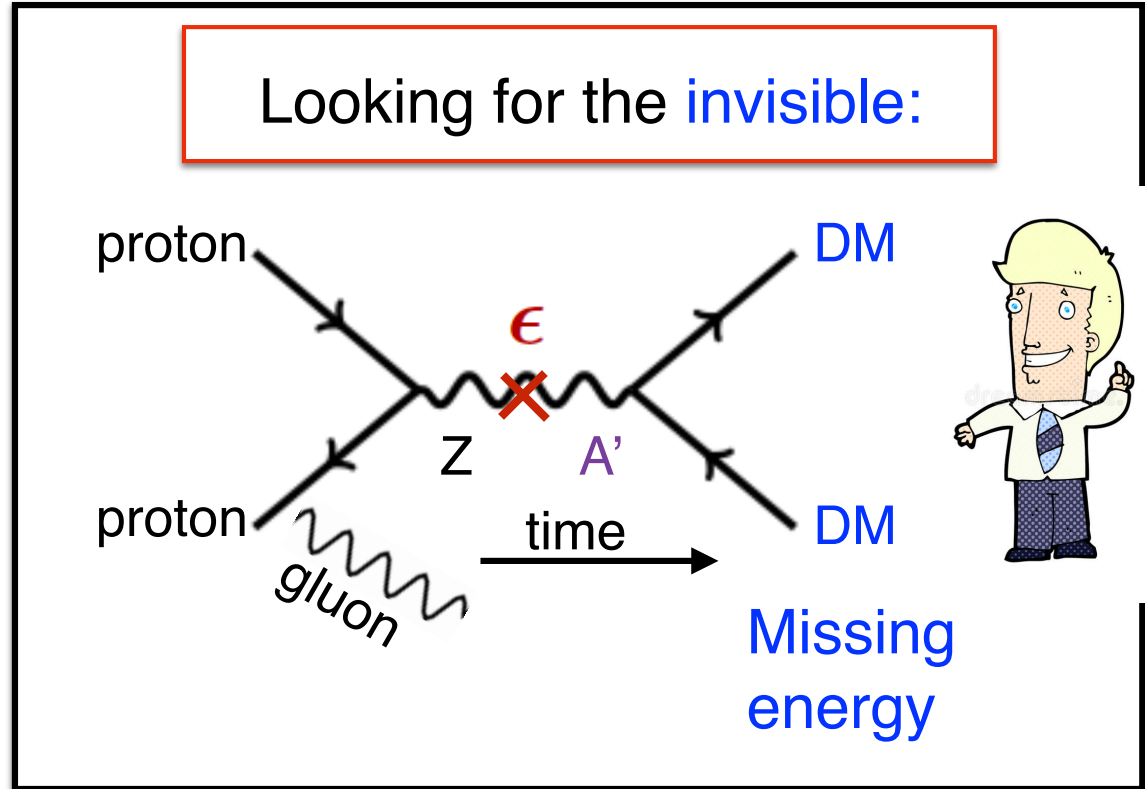
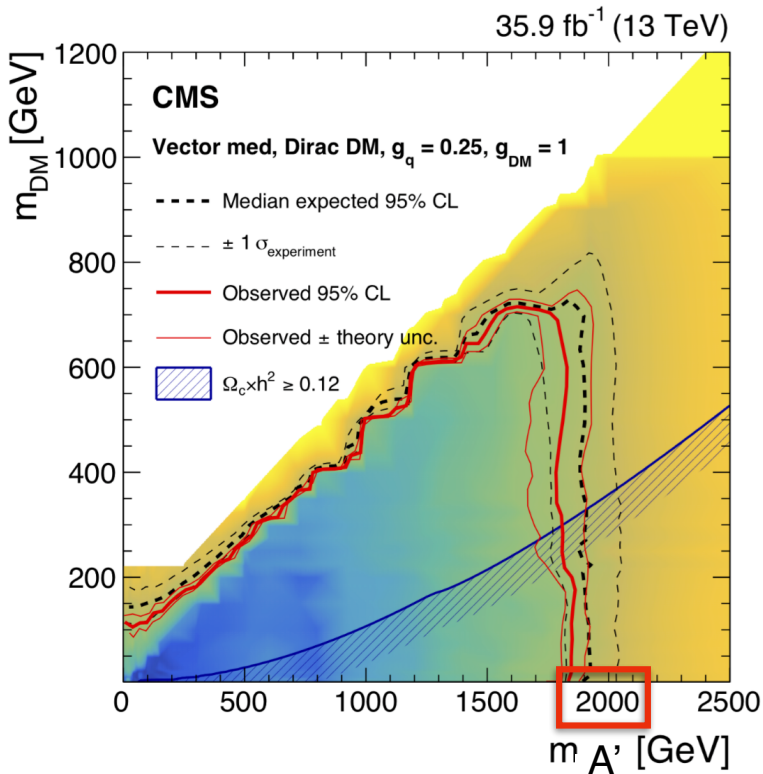
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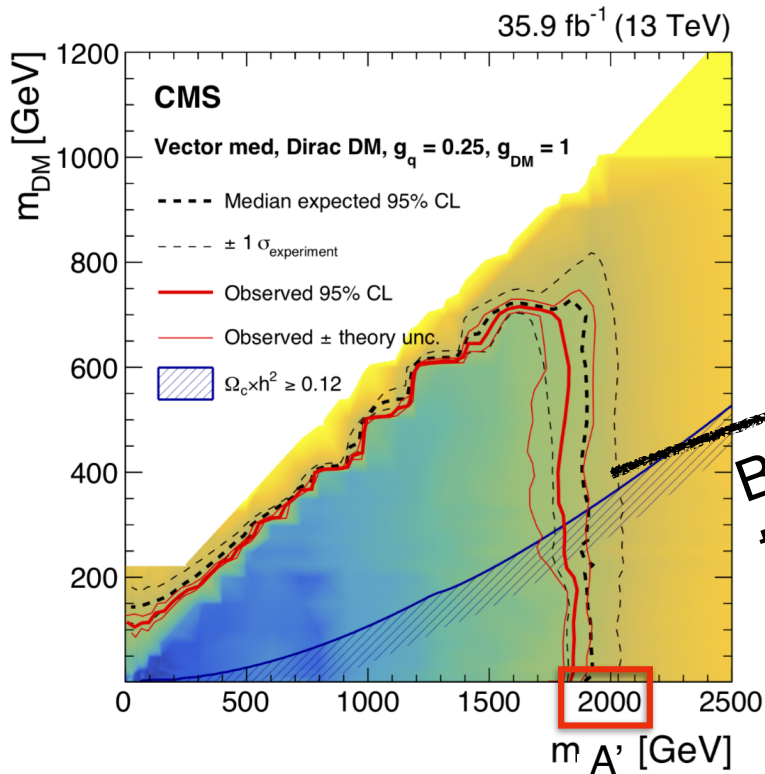
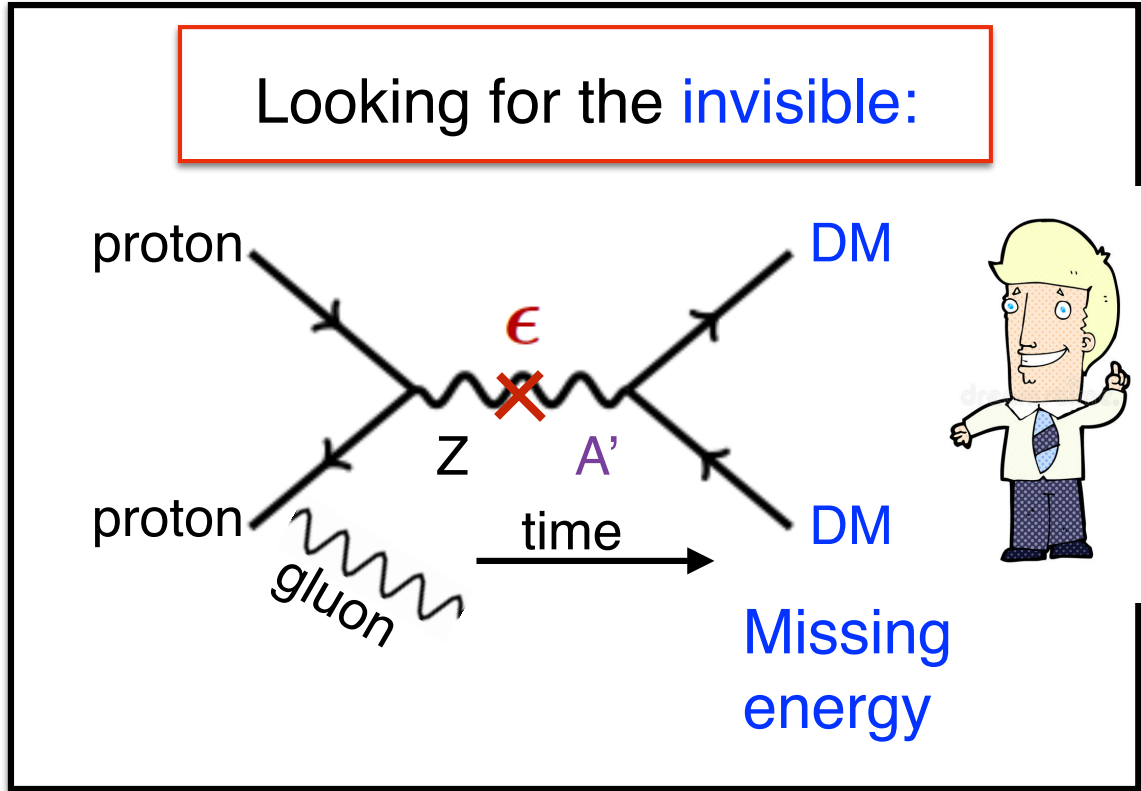
2000 GeV dark photons are probed currently!

Present bound,
arXiv: 1712.02345

The LHC: dark matter searches

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Bounds can extend in this direction in the future ... or maybe a discovery?

Present bound, arXiv: 1712.02345

2000 GeV dark photons are probed currently!

The LHC: the Higgs probe

The Higgs is still the least-known particle of the Standard Model

The Higgs is special!

It naturally interacts with dark matter / dark sectors
If DM/dark sectors are light, then:



Higgs



A'?



A'?

www.particlezoo.net

Dark particles

“Higgs exotic decays”

The LHC: the Higgs probe

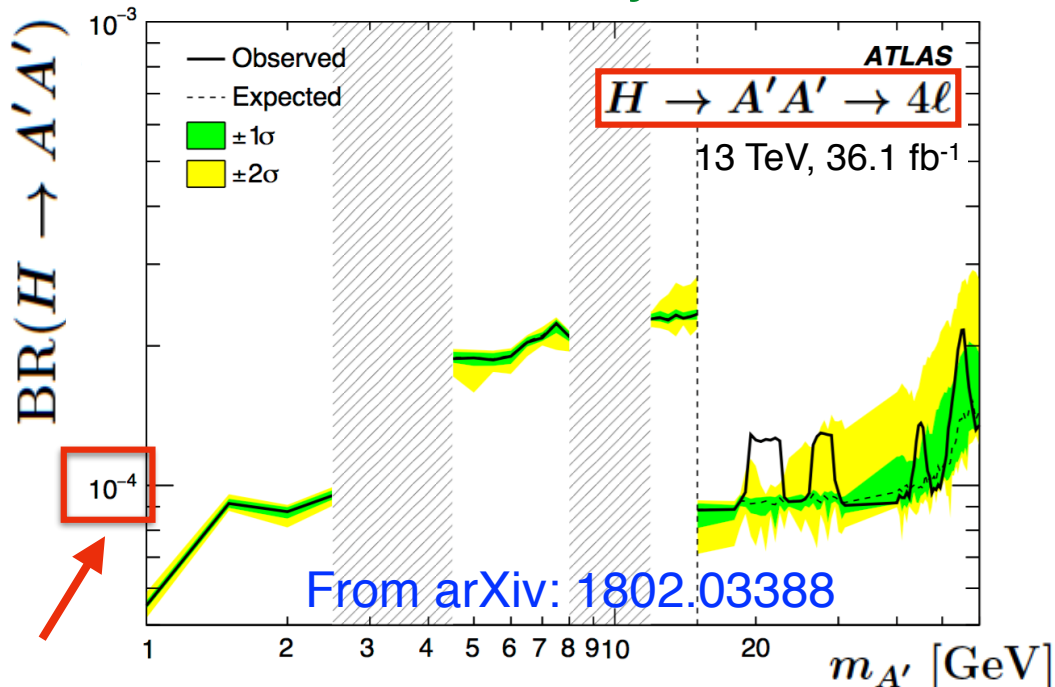
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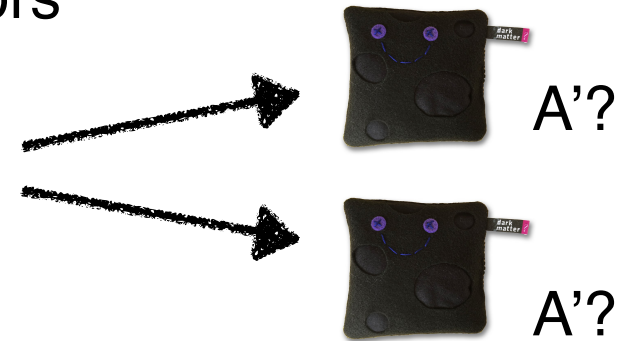
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If DM/dark sectors are light, then:

Ongoing theoretical & experimental program looking for these new decay modes



Higgs



Dark particles

www.particlezoo.net

“Higgs exotic decays”

Many new channels to investigate!

Curtin, Essig, SG, et al. arXiv: 1312.4992

Future high energy hadron colliders

2.

Huge impact on testing dark sectors

High energy

Heavier dark particles
can be probed



2 TeV A'

2.5 TeV A'

8 TeV A'

20 TeV A'



© Can Stock Photo

- * Now
- * HL-LHC
- * HE-LHC (15ab⁻¹)
- * 100 TeV collider (15ab⁻¹)

Future high energy hadron colliders

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- * Now
- * HL-LHC
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“Higgs factories”

Number of Higgs bosons produced grows quickly!

3 million Higgs

170 million Higgs

2500 million Higgs

15000 million Higgs

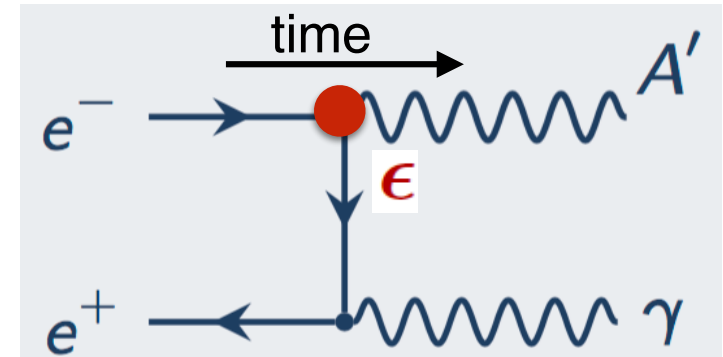


Extraordinary reach on Higgs exotic decays

B-factories & $e^+ e^-$ colliders

Many (lighter) dark photons are produced at e^+e^- facilities

Advantage: very clean environment



B-factories & $e^+ e^-$ colliders

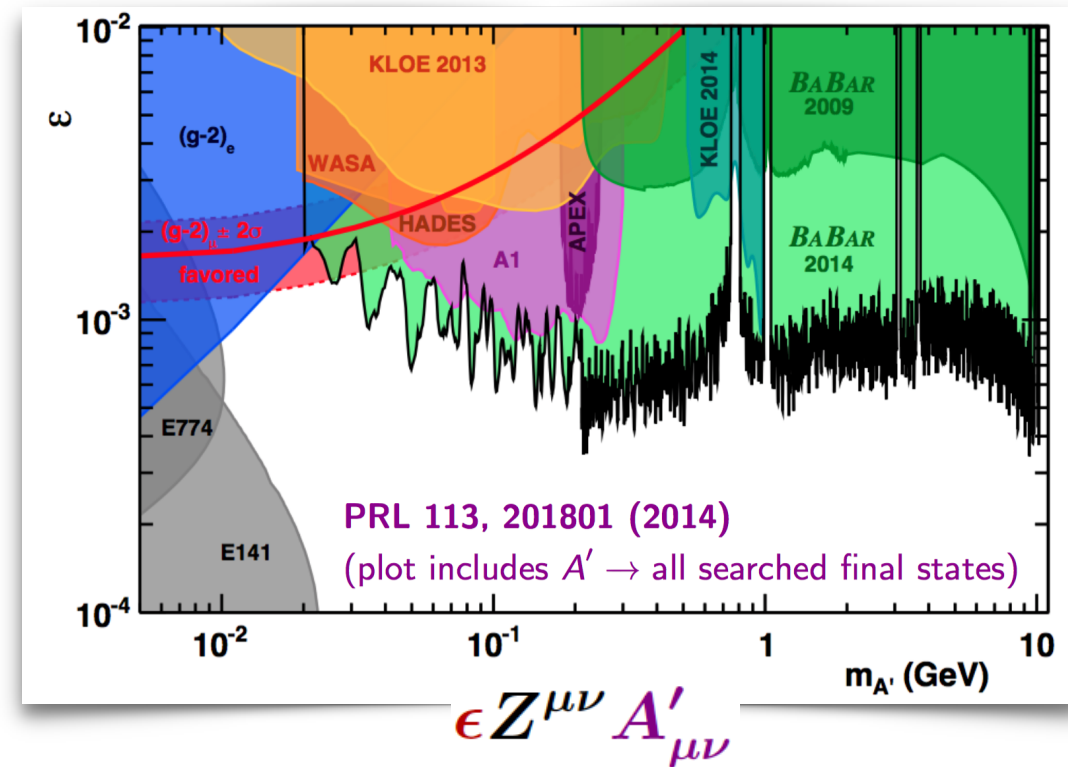
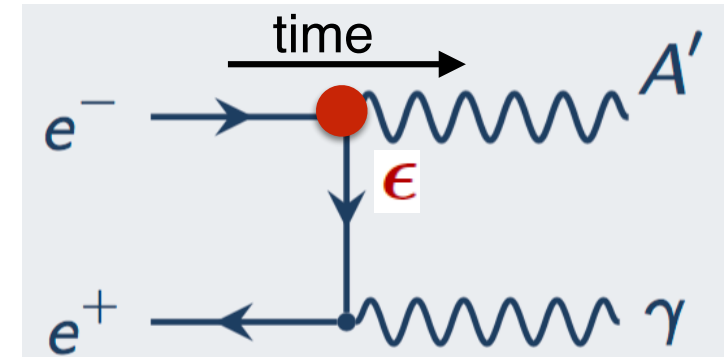
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Advantage: very clean environment

As an example,

Babar has lead a broad program for dark sector searches

(e.g. invisible and visible dark photons, light scalars, axions, ...)



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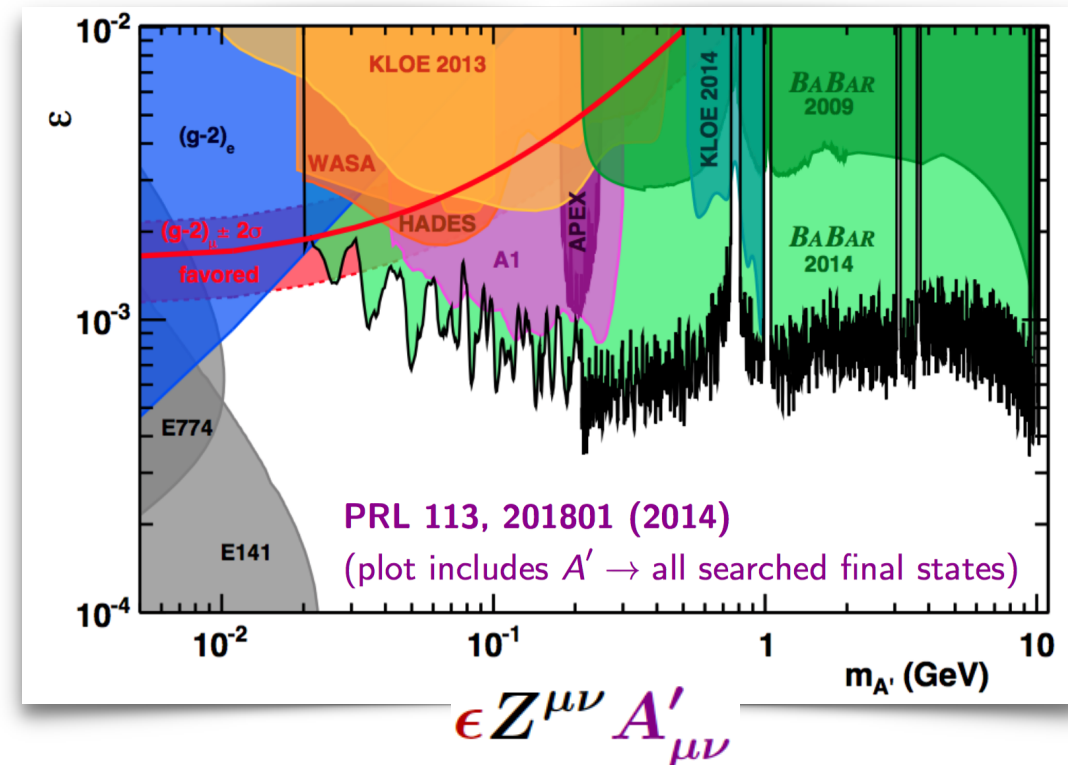
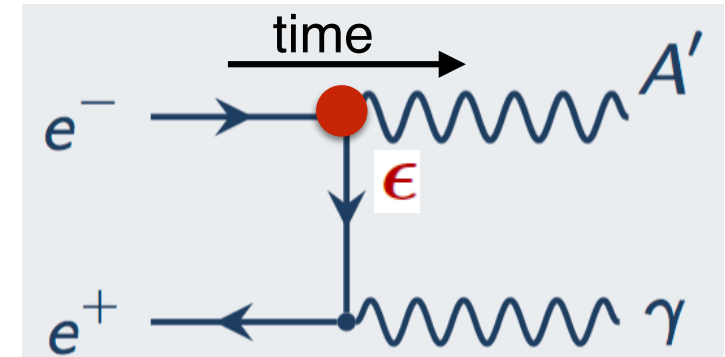
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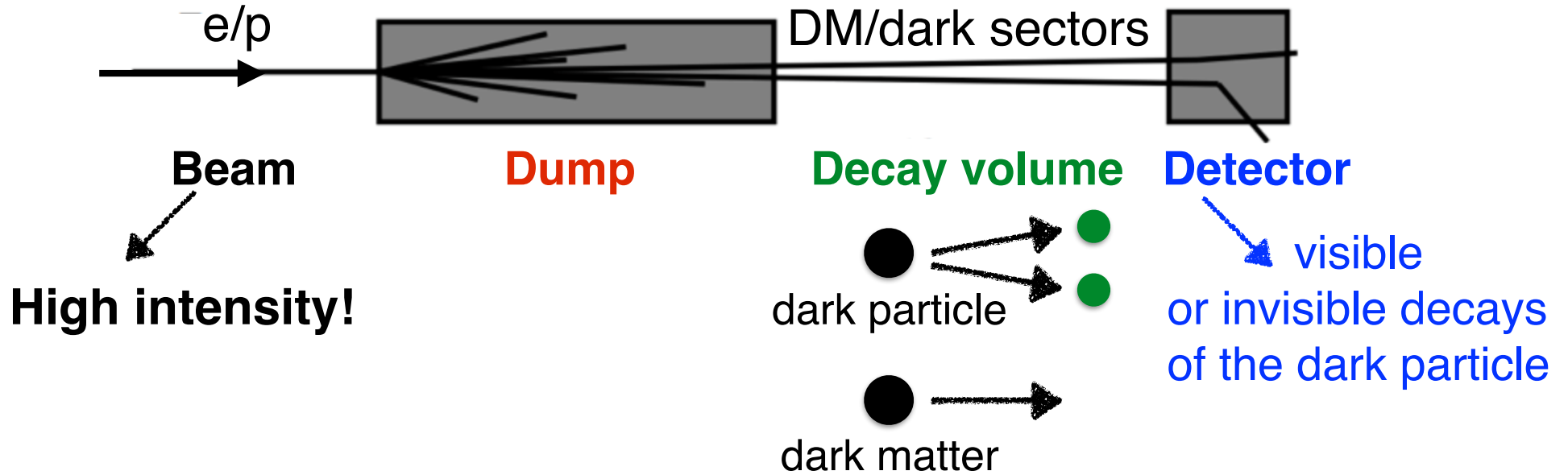
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In the future...

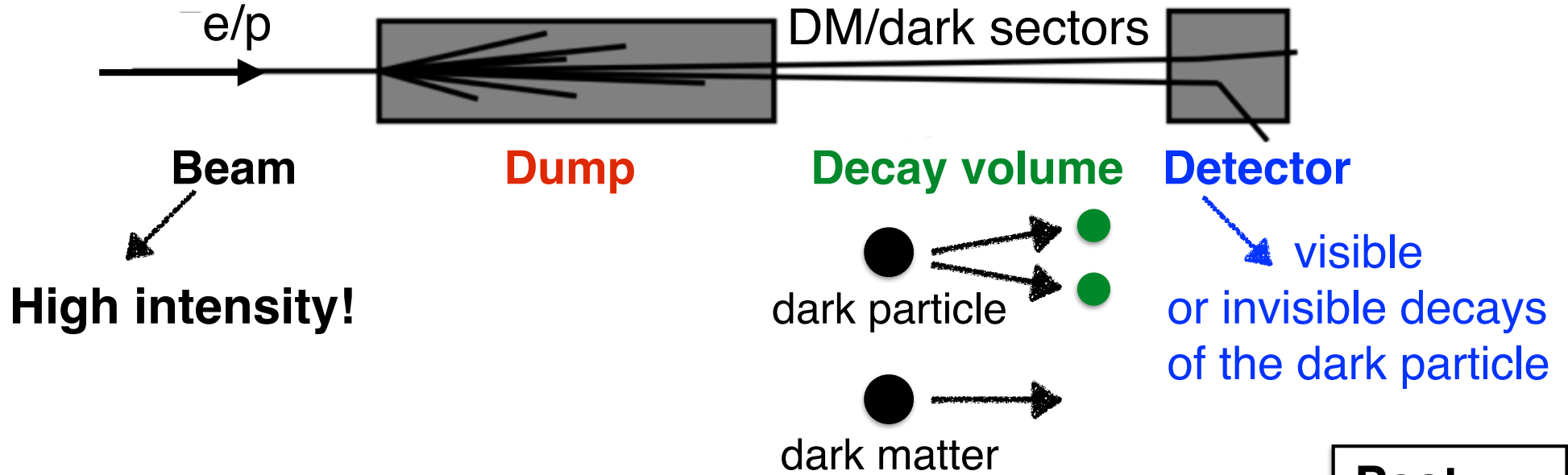
- * Belle-II will have a unique opportunity to spearhead a even broader program
- * Fantastic opportunities for higher energy e^+e^- colliders (ILC, FCC-ee, CLIC,...) ahead



Fixed target experiments



Fixed target experiments



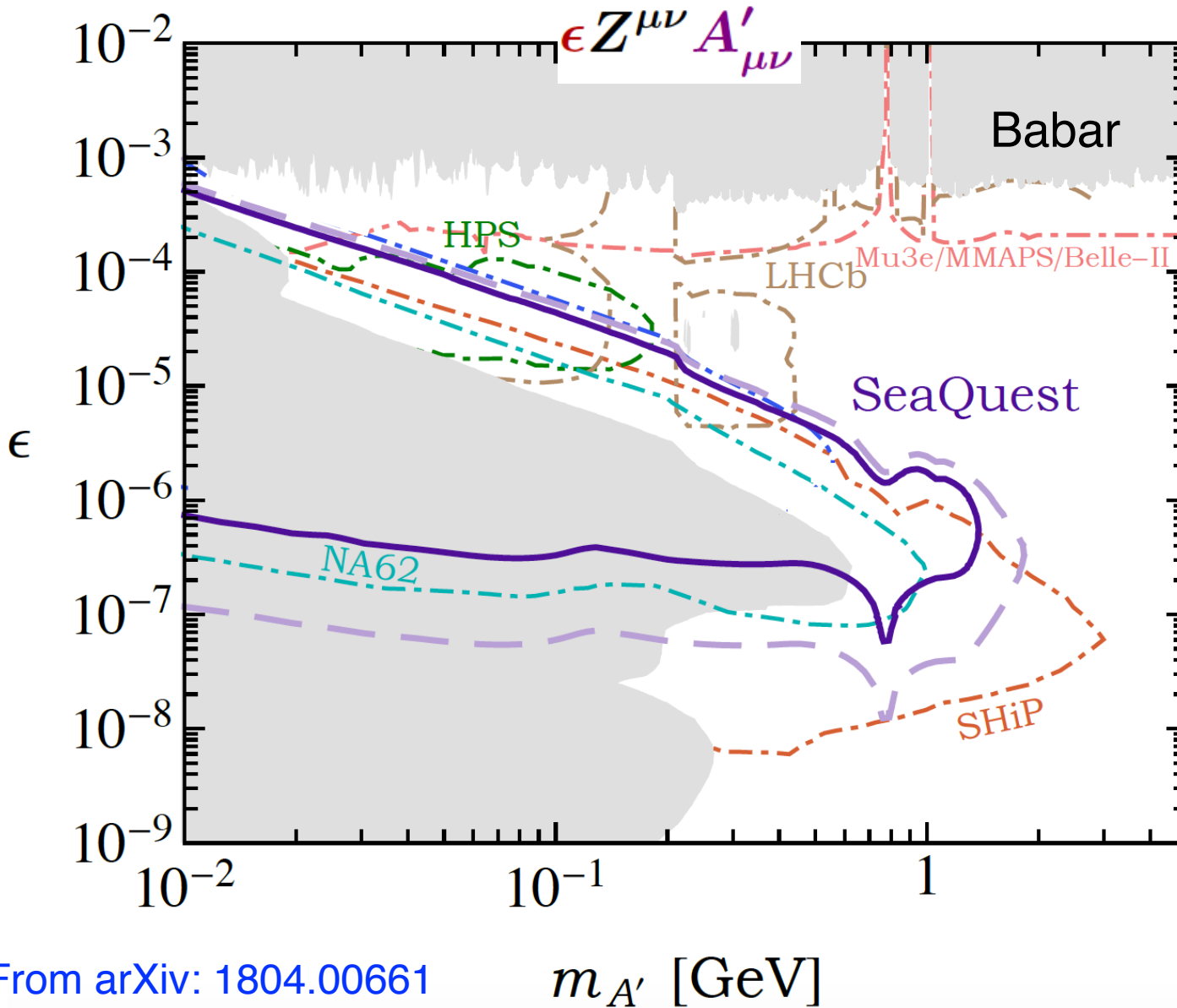
Past
Present
 Future

Experiment	Proton energy	N. protons
CHARM	400 GeV	2.4×10^{18}
LSND	800 MeV	10^{22}
NA62 (dump mode)	400 GeV	5×10^{18}
SeaQuest	120 GeV	1.44×10^{18}
ShiP	400 GeV	2×10^{20}

Experiment	Electron energy	N. electrons
E137	20 GeV	10^{20}
HPS	2 GeV	5.6×10^{17}
LDMX	4 GeV	4×10^{14}

and many more...

Dark photons at fixed target experiments

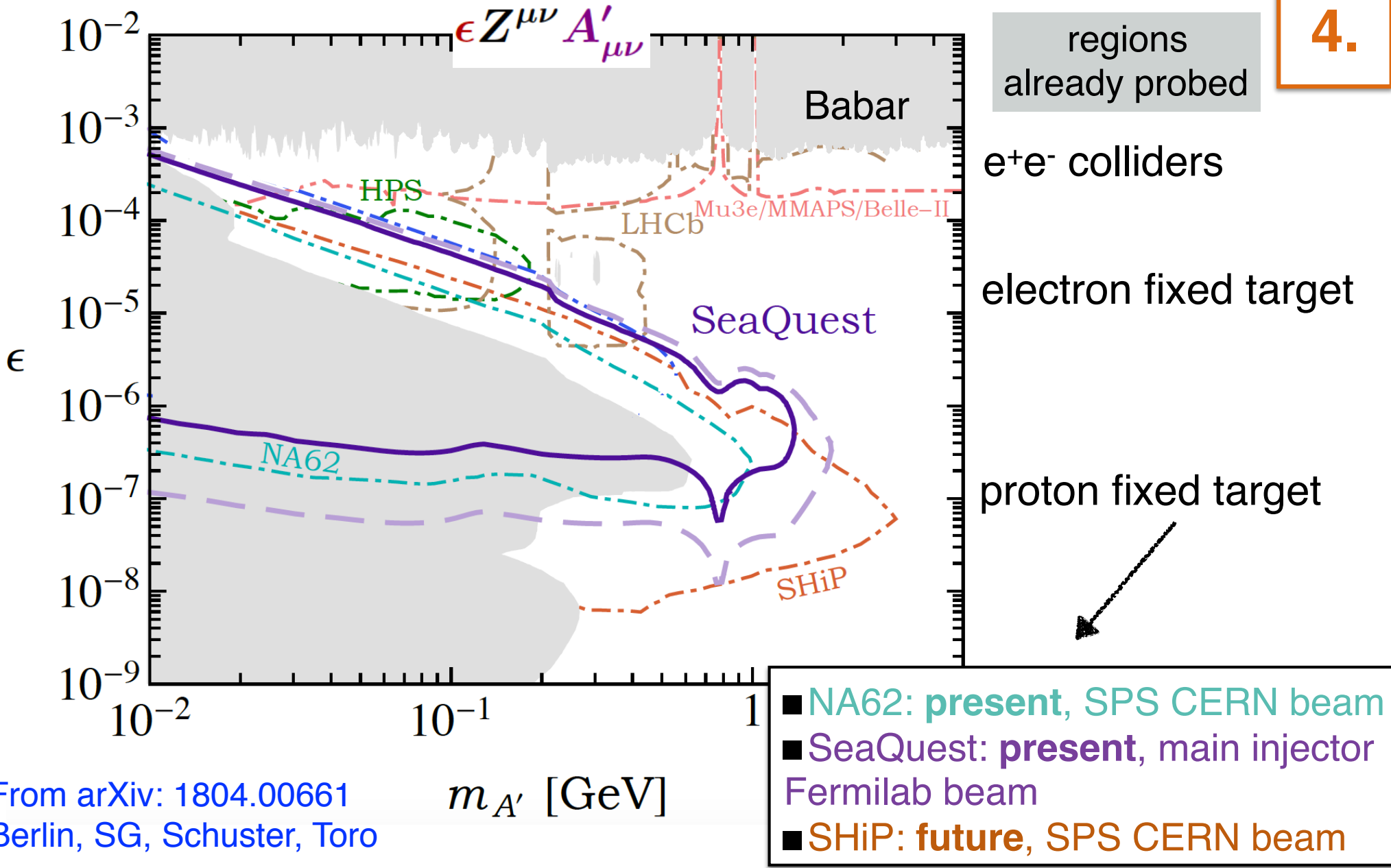


regions
already probed

4.

Dark photons at fixed target experiments

4.



From arXiv: 1804.00661
 Berlin, SG, Schuster, Toro

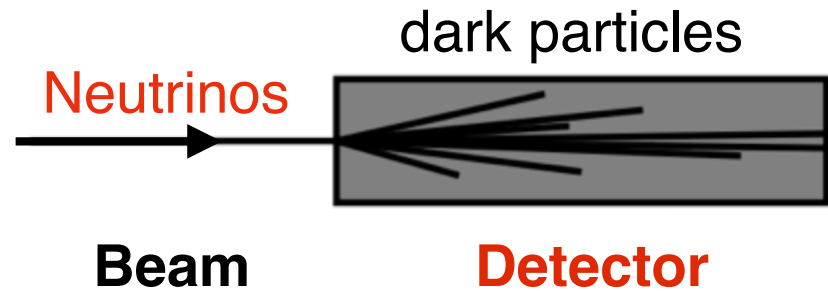
Neutrino experiments & dark sectors

5.

1. “Neutrino fixed target” experiments can be used to produce dark particles



High intensity!



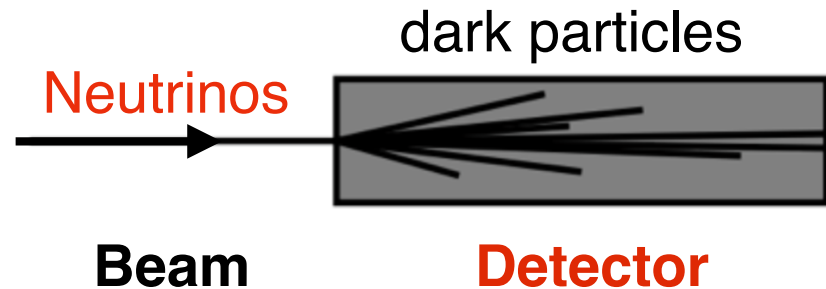
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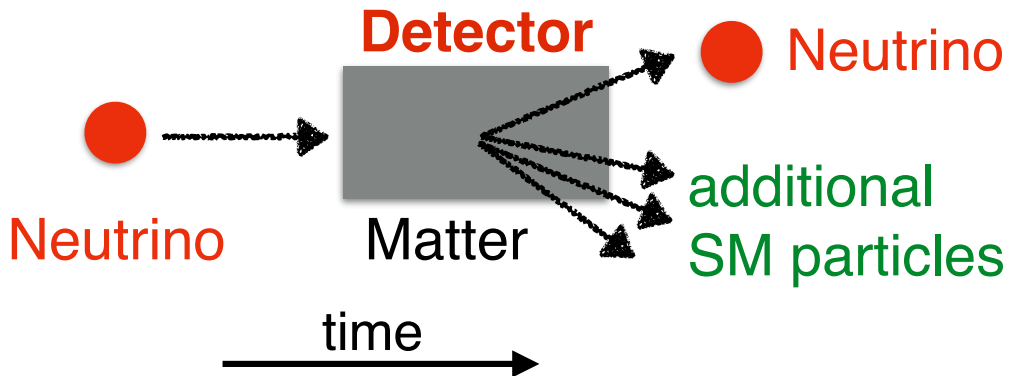
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High intensity!



2. Neutrino experiments can be used to test “virtual” dark particles

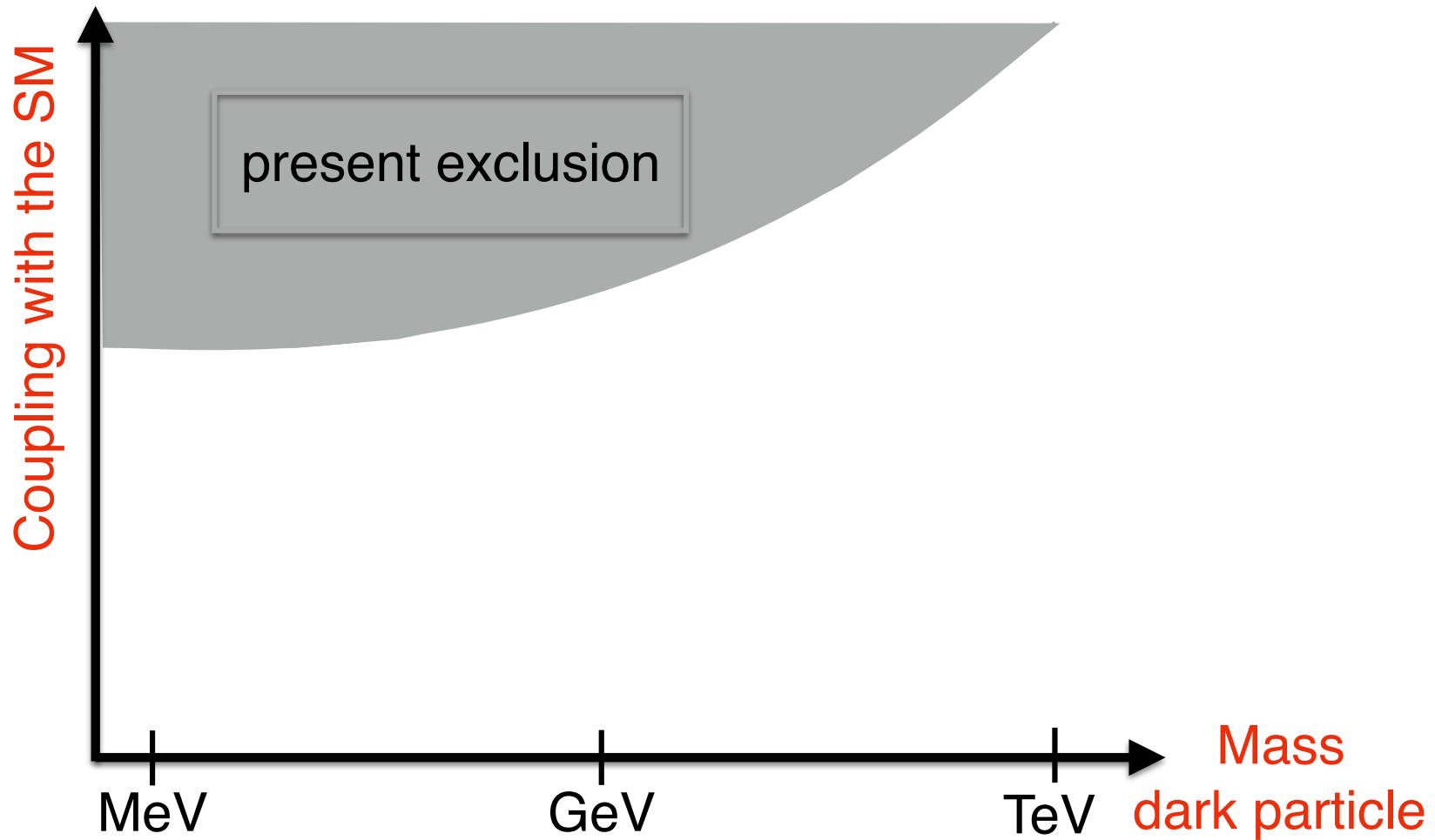


The probability for this process to happen is affected by the presence of dark particles
eg. new force interacting with neutrinos

Many processes can be measured at the present and future neutrino experiment near detectors

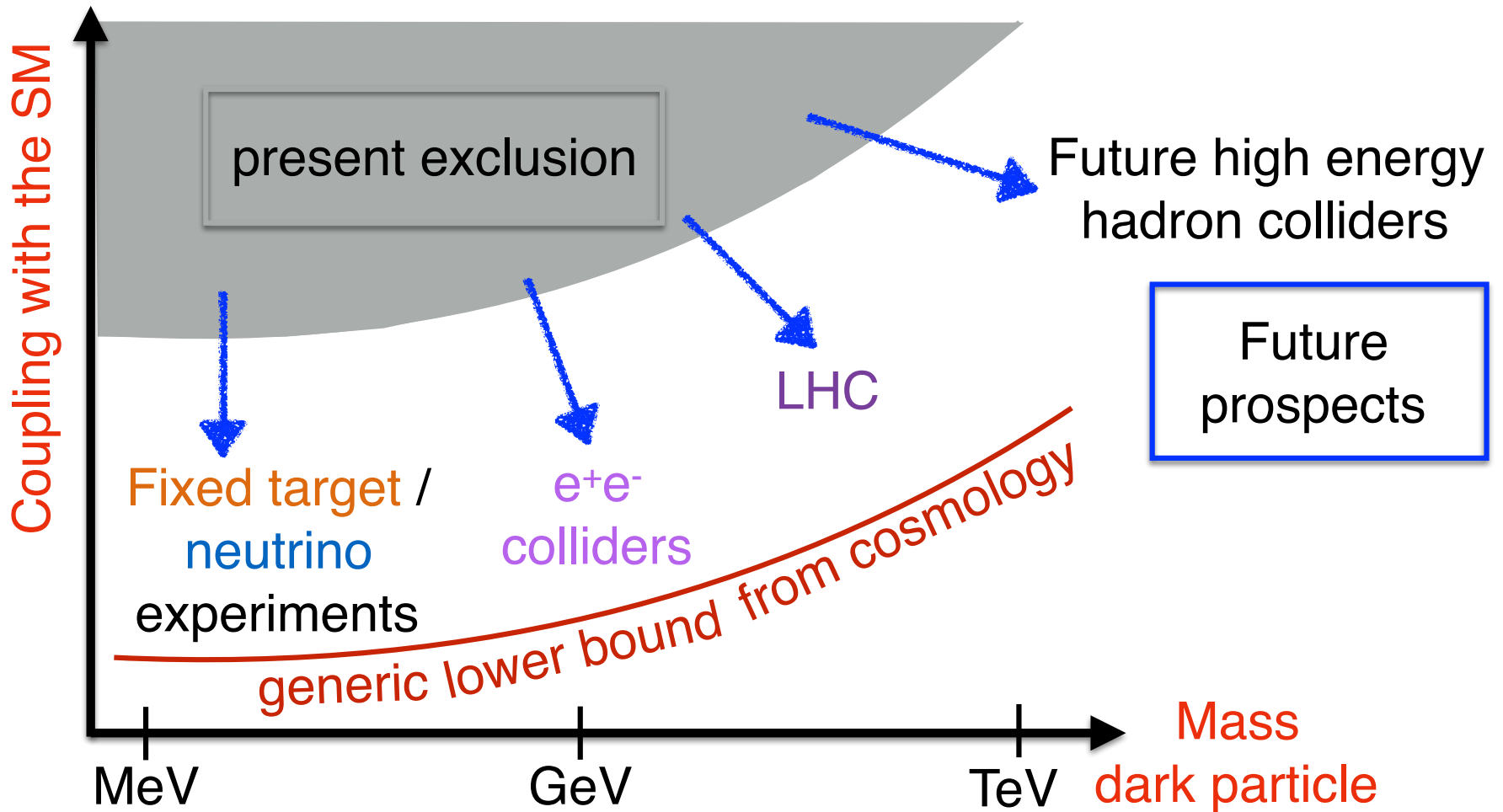
Summary of the complementarity

For a generic dark sector particle:



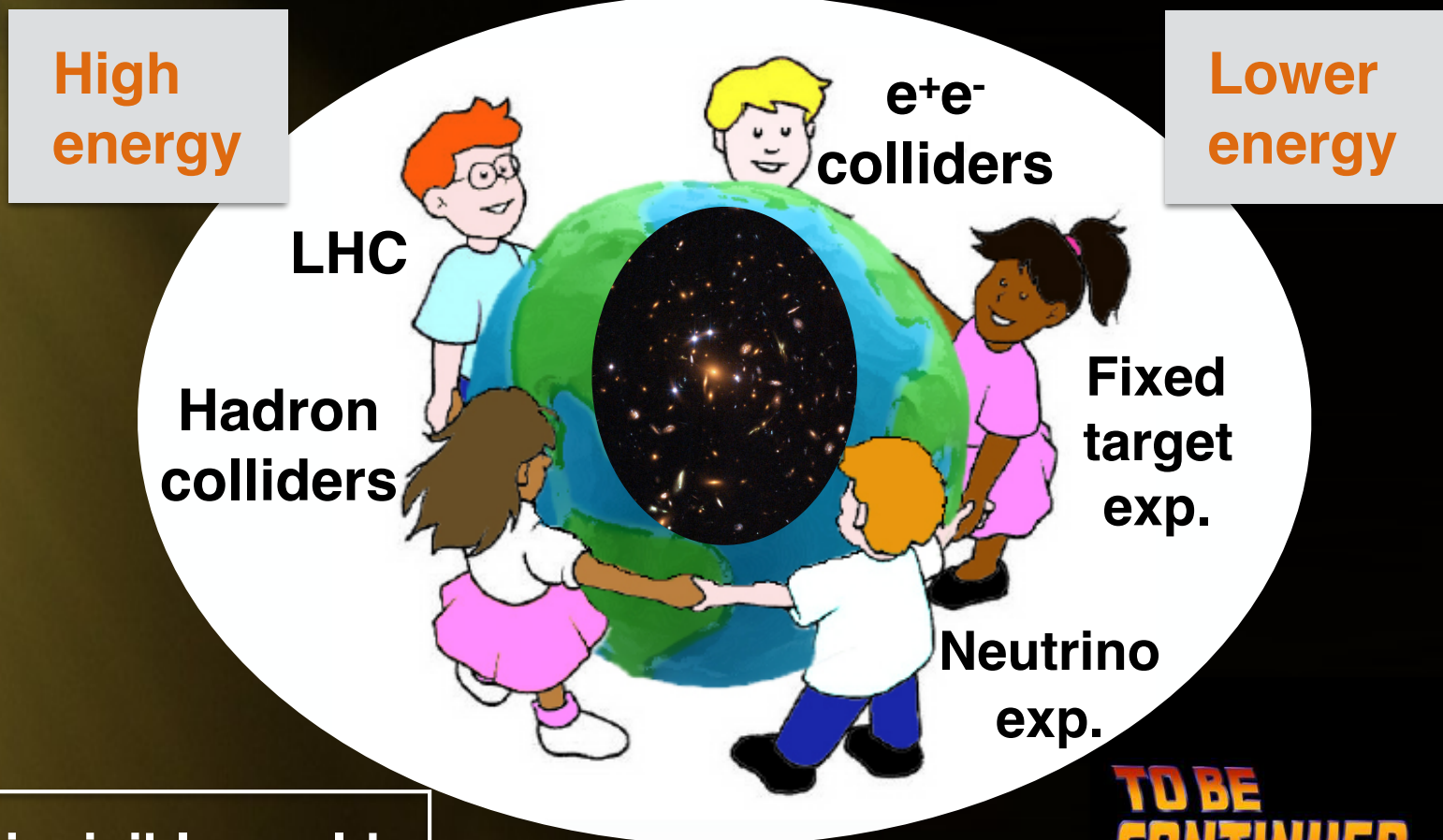
Summary of the complementarity

For a generic dark sector particle:



Conclusions & Outlook

Present and future accelerator experiments offer a unique opportunity to test the (newly formed) dark sector paradigm



Shedding light on invisible worlds

**TO BE
CONTINUED...**

What do we know about Dark Matter (DM)?

4. It interacts very weakly

Optical, X-ray gas (ordinary matter), dark matter

