Dark Matter and NA64 experiment

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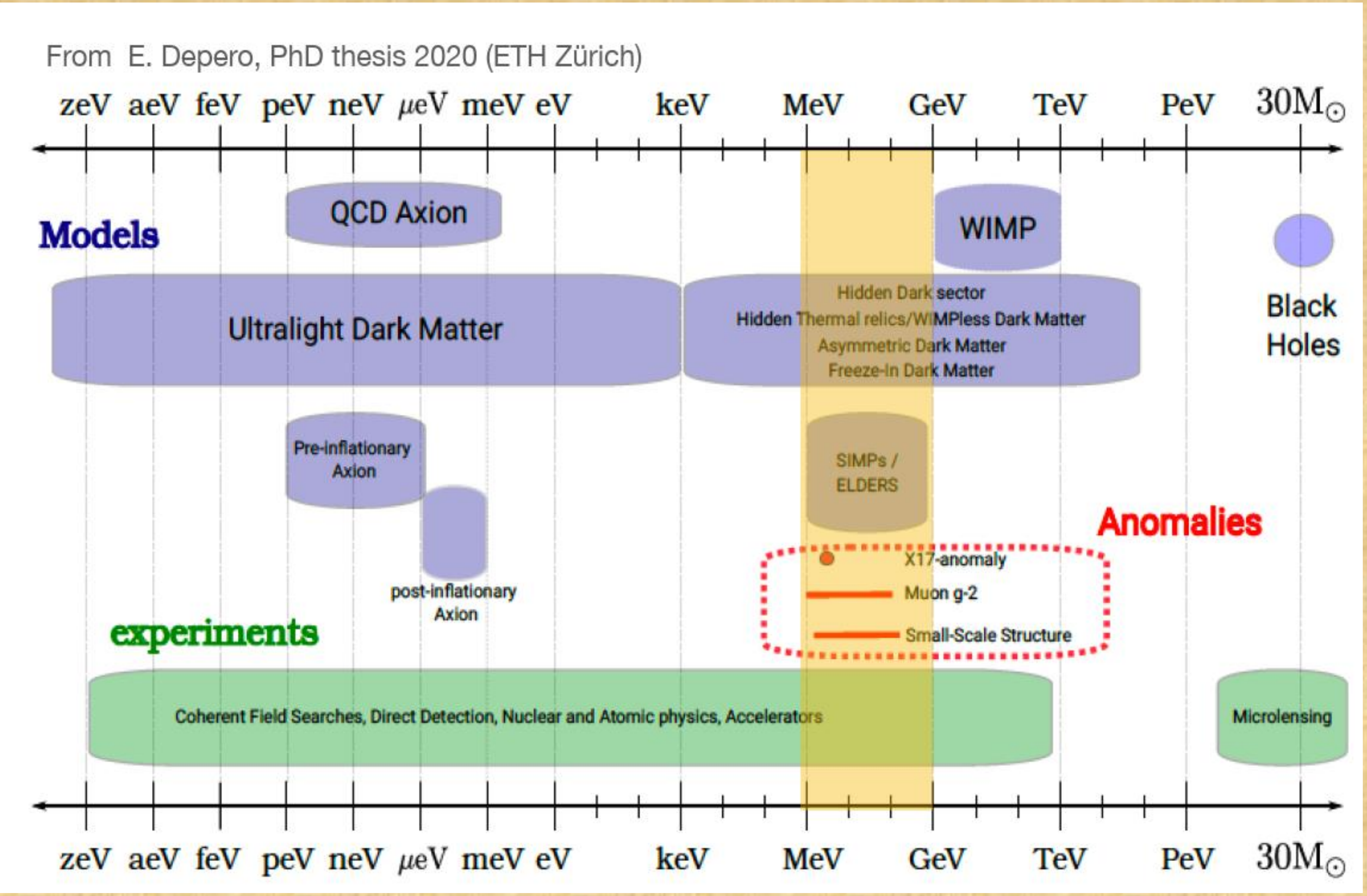
We know that dark matter exists and it is cold (nonrelativistic) or warm

But we don’t know:

1. Spin of dark matter particles
2. Mass of dark matter particles

In SUSY with R-parity LSP is gaugino with s = ½ and m = O(100 GeV) as a rule

Dark matter mass range



WIMP

The most popular mass interval from LHC

point of view between O(1) GeV and

O(1) TeV   -> WIMP = wealy interacting massive particles

Also mass interval between O(1) MeV and

O(1) GeV is popular for fixed target experiments like NA64, BELLE, SHIP, …

So called light dark matter

Typical models

At LHC bounds depend on particular model. There are a lot of models.

Simplified models:

A. Models with vector mediator

B. Models wth scalar mediator

Dark Matter: scalar, fermion, Majorana, vector Spin 1.

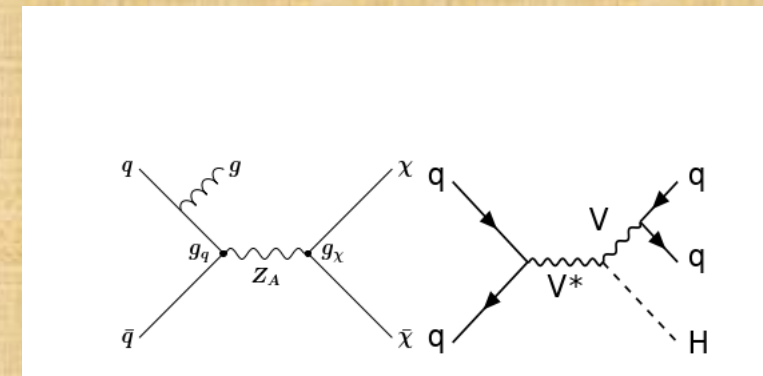
At LHC(CMS and ATLAS)

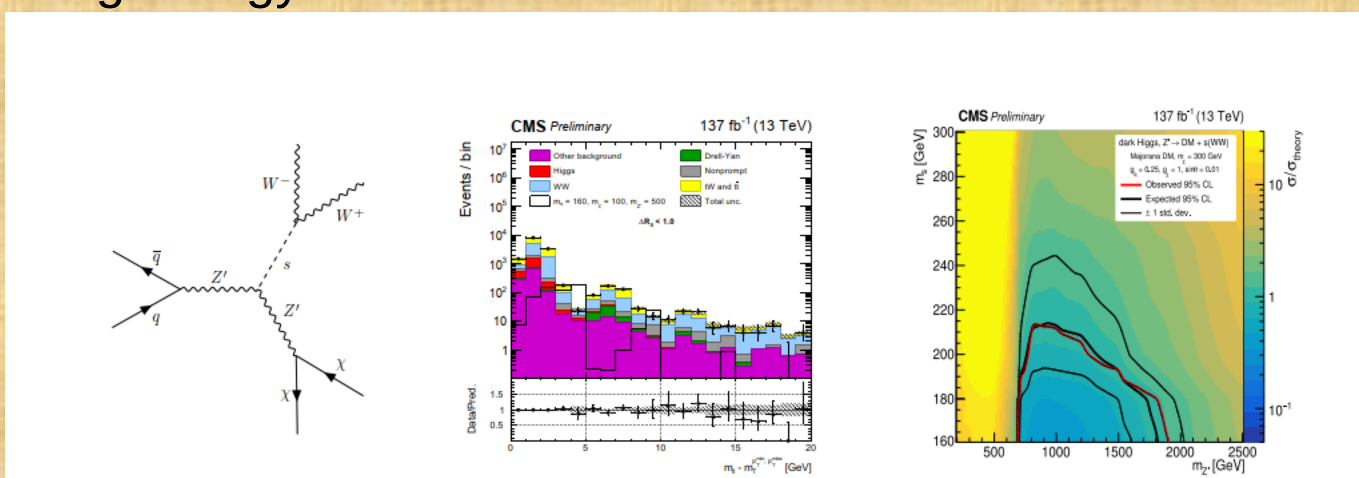
Use the reaction

proton + proton ->jet(s) =

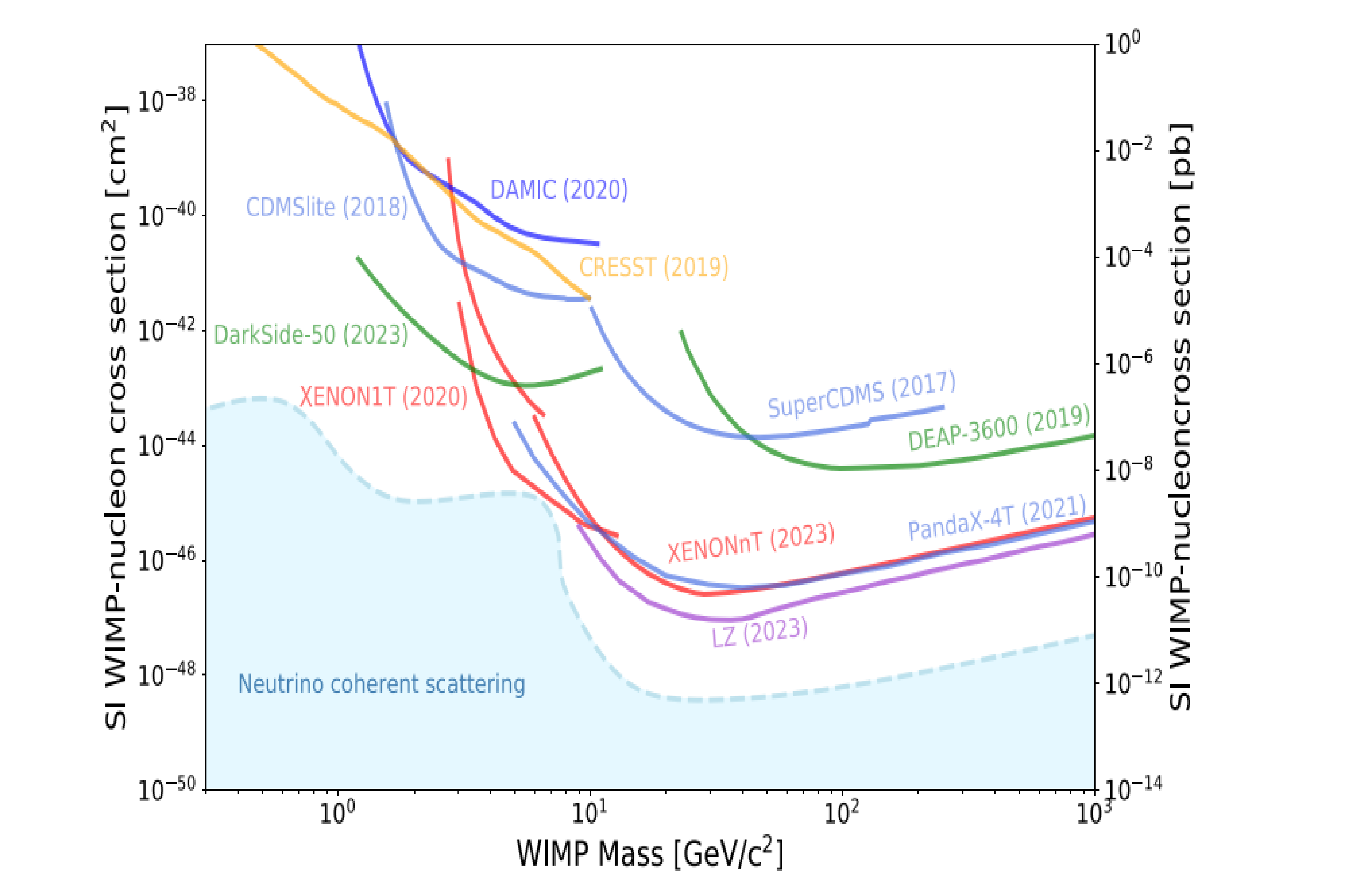
(DM DM ->missing energy)

So the signature – hadron jet(s) + missing energy





Elastic DM nucleon cross sections bounds . Bounds from underground experiments. Particle data



Implications from underground and accelerator experiments for different

DM models are contained in recent review:

M.Lindner et al., arXiv:2403.15860

A lot of models at the level of exclusion

In many cases very strong constraints (for instance B-l model with additional vector bozon

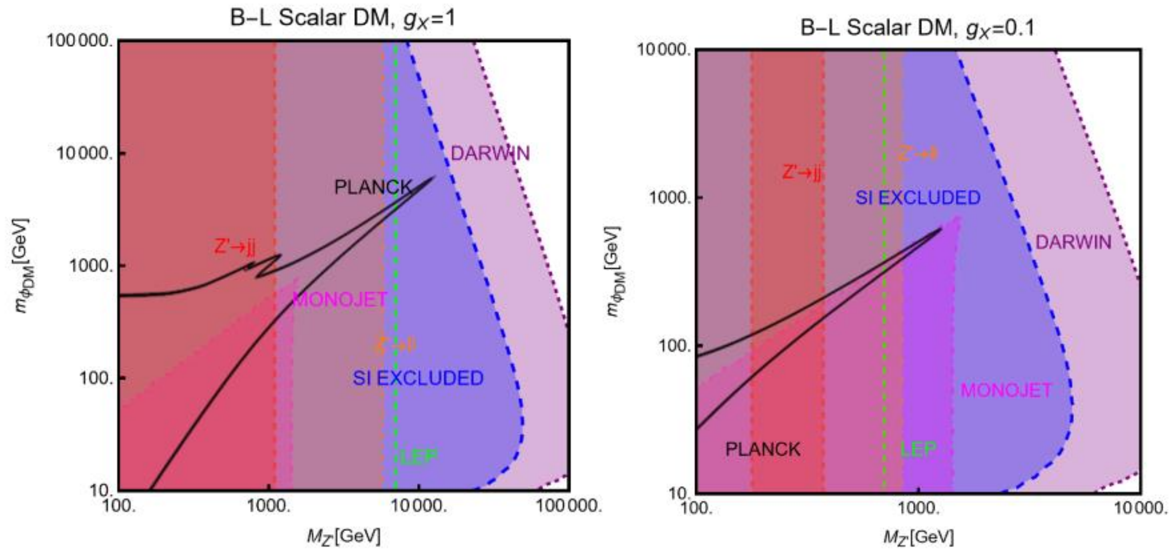
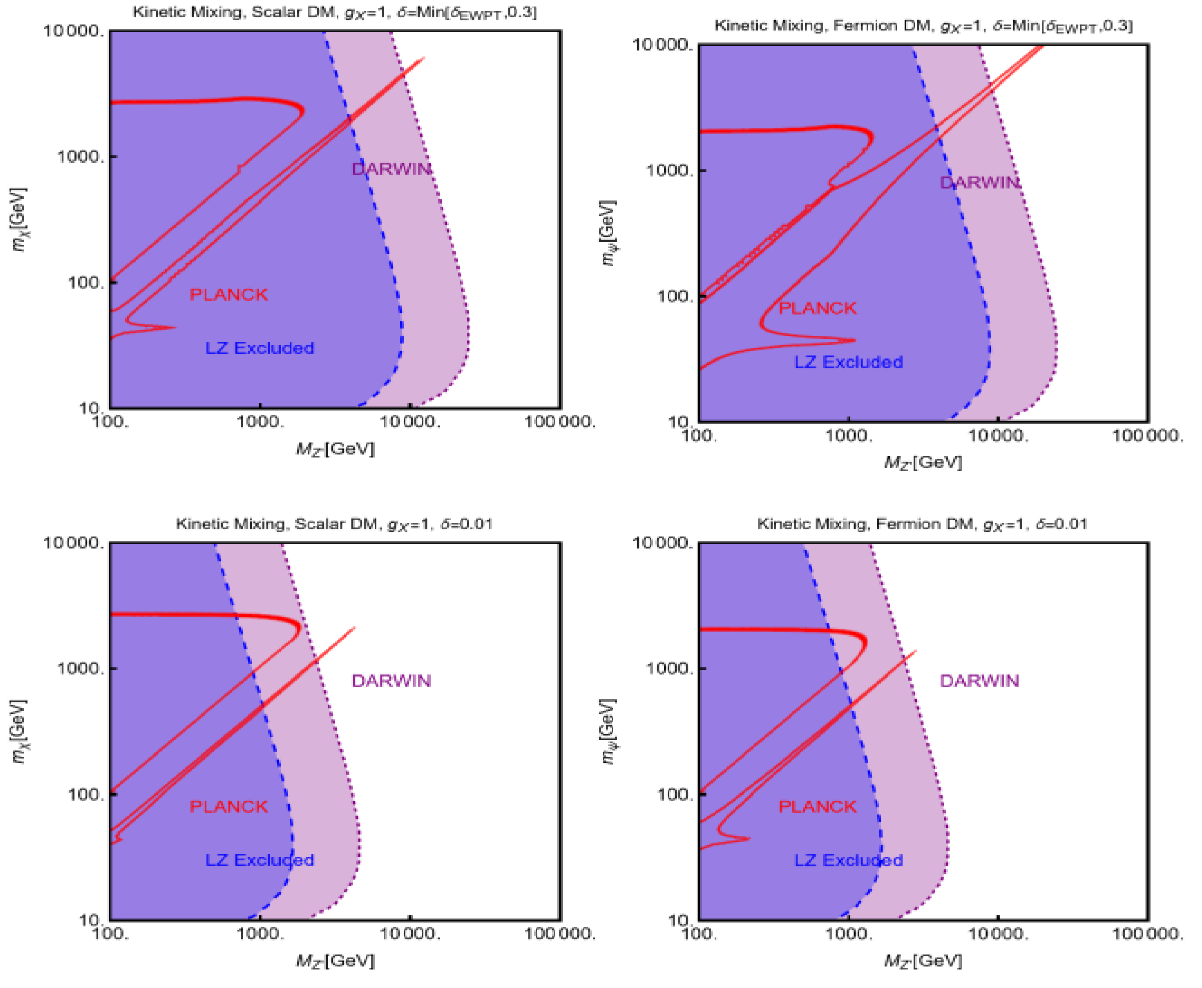


Fig. 36: Combination of constraints for $B-L$ model with a scalar DM ϕ_{DM}. The value of the g_X is 1 (0.1) for the left (right) panel. The red, orange, pink and green coloured regions represent the exclusion limits from the LHC searches of dijets, di-leptons, monojet and the LEP experiment, respectively. The blue (purple) coloured region is based on the sensitivity reach of the current (next generation) DM detection experiments.

Nonzero kinetic mixing



Three most popular light dark models

1. Scalar dark matter
2. Majorana dark matter
3. Pseudo Dirac dark matter

The main assumption – in the early Universe dark matter is in equilibrium with observable matter. At some temperature dark matter decouples.

Observable dark matter density allows to predict the annihilation cross section

The most popular light dark matter model – model with additional U(1) gauge field

A’ – dark photon model (Holdom, Okun)

Dark photon connects our world and dark matter world due to nonzero kinetic mixing between dark photon and ordinary photon

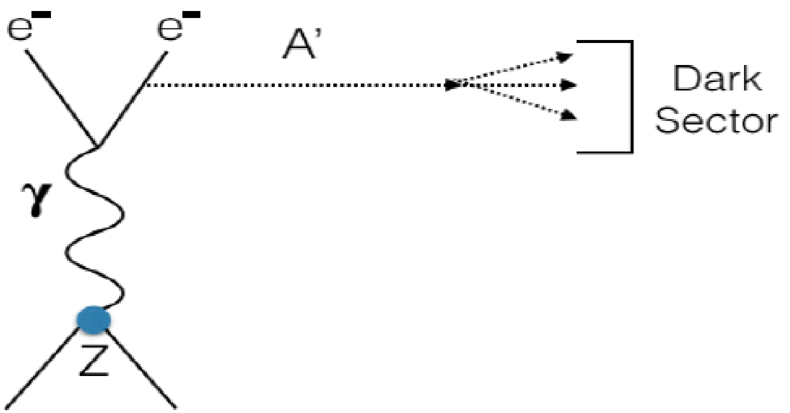
The Lagrangian is the sum of 3 terms

THERMAL ORIGIN

If we assume that in the early Universe dark matter is in equilibrium with the SM matter

Today DM density tells us about annihilation cross-section. Correct DM density corresponds to $<\sigma_{an}v> \sim 0(1)$ pb

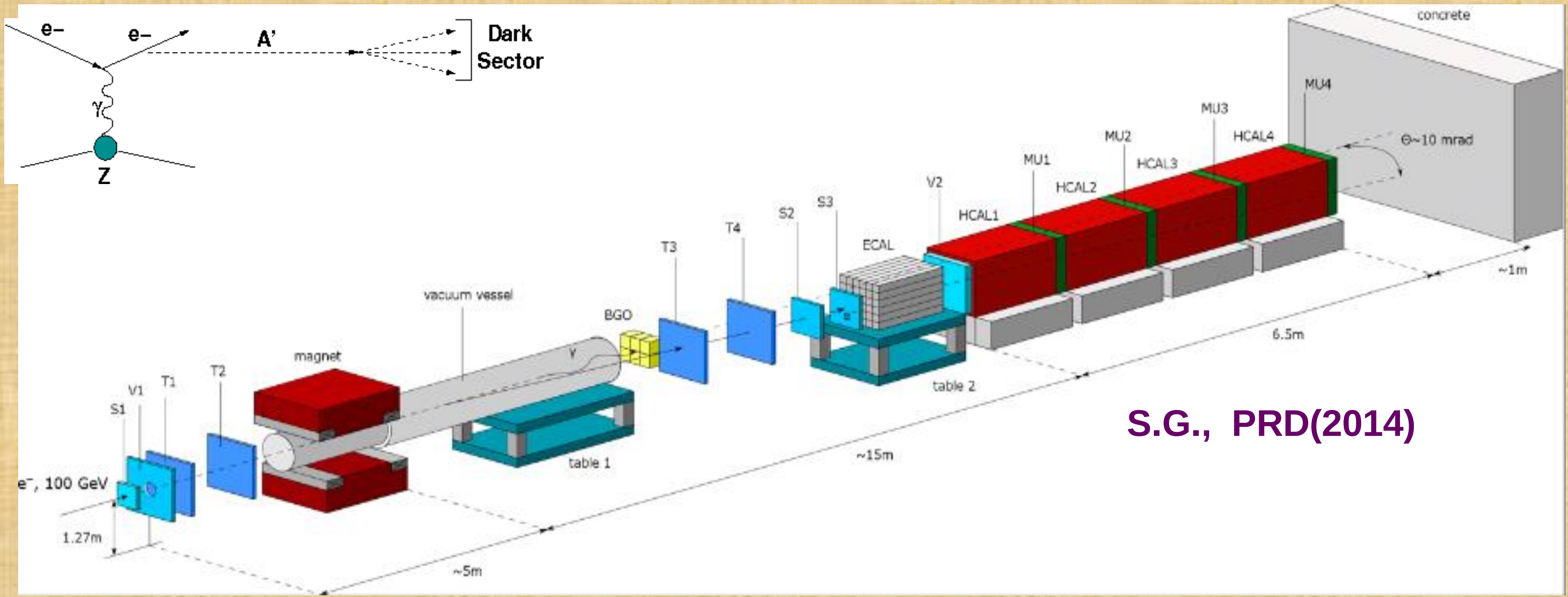
NA64 Experiment



NA64 is a fixed target experiment combining the active beam dump technique with missing energy measurement searching for invisible decays of massive A' produced in the reaction eZ—> eZA' of electrons scattering off a nuclei (A,Z), with a mixing strength $10^{-5} < \varepsilon < 10^{-3}$ and masses $M_{A'} < 100$ MeV.

search for *A´->invisible* at CERN SPS

Invisible decay of Invisible State!



S.G., PRD(2014)

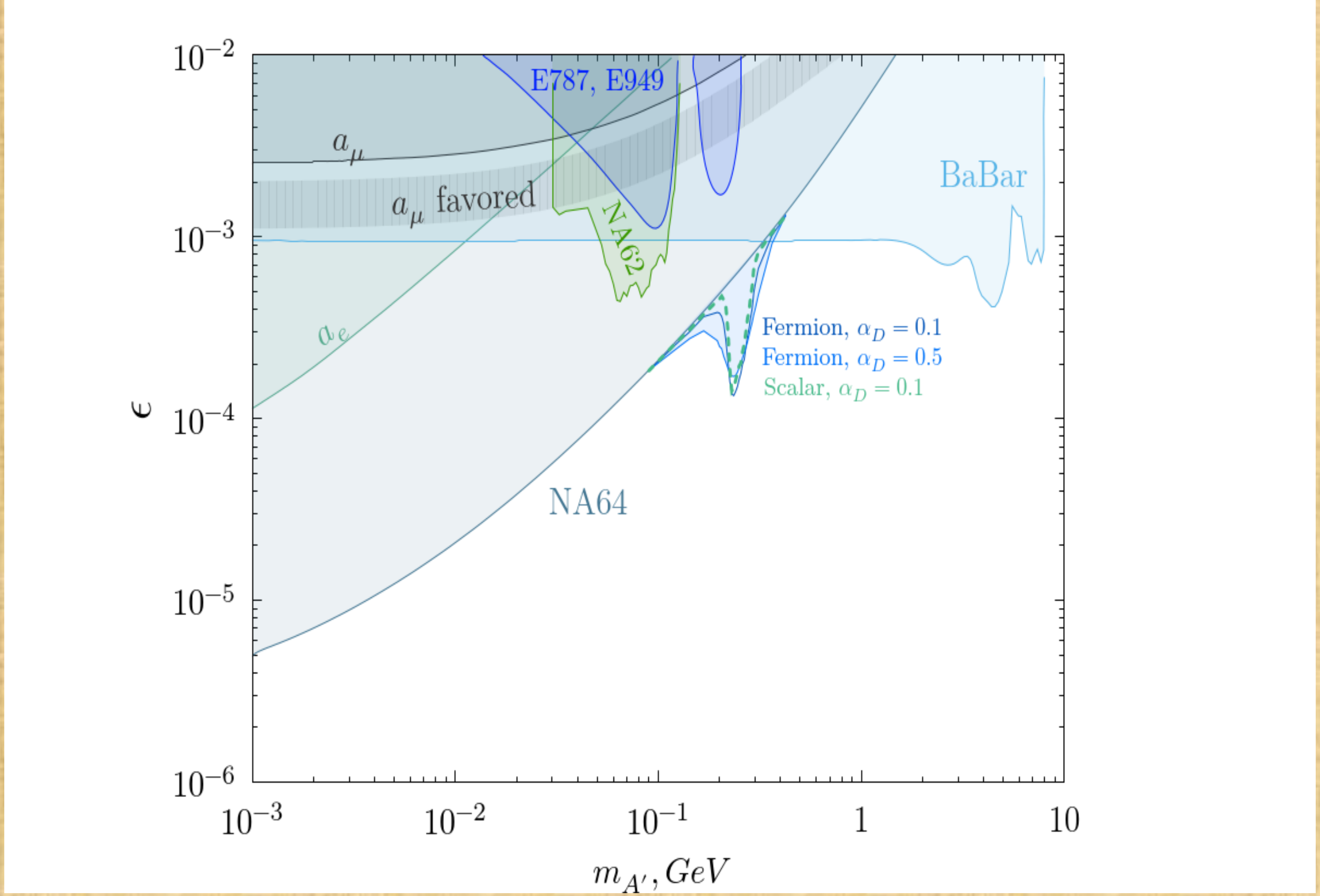
3 main components :

- clean, mono-energ. 100 GeV e- beam
- e- tagging system: MM tracker + SR
- 4π fully hermetic ECAL+ HCAL

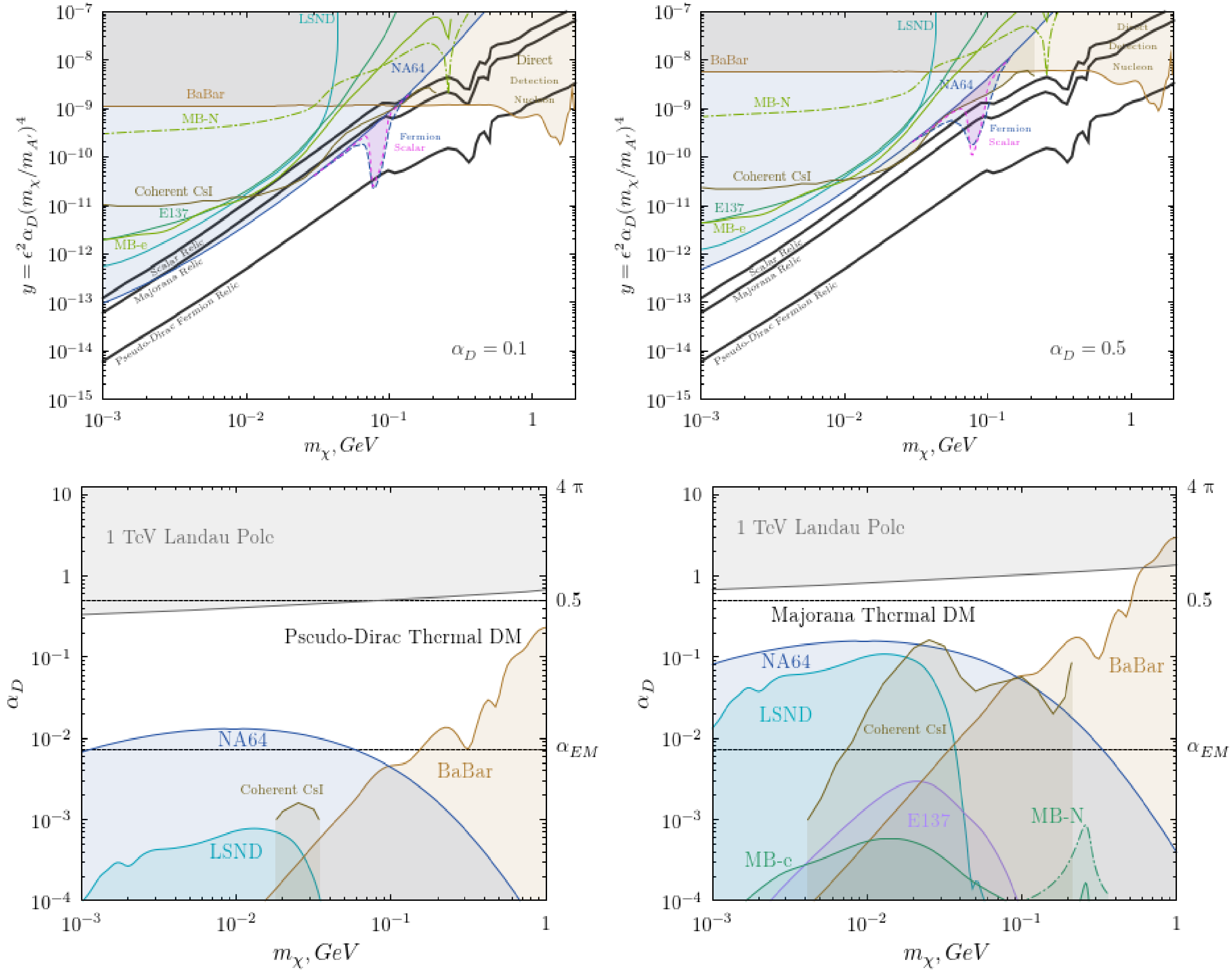
Signature:

- in: 100 GeV e- track
- out: < 50 GeV e-m shower in ECAL
- no energy in the Veto and HCAL
- Sensitivity ~ ε^2

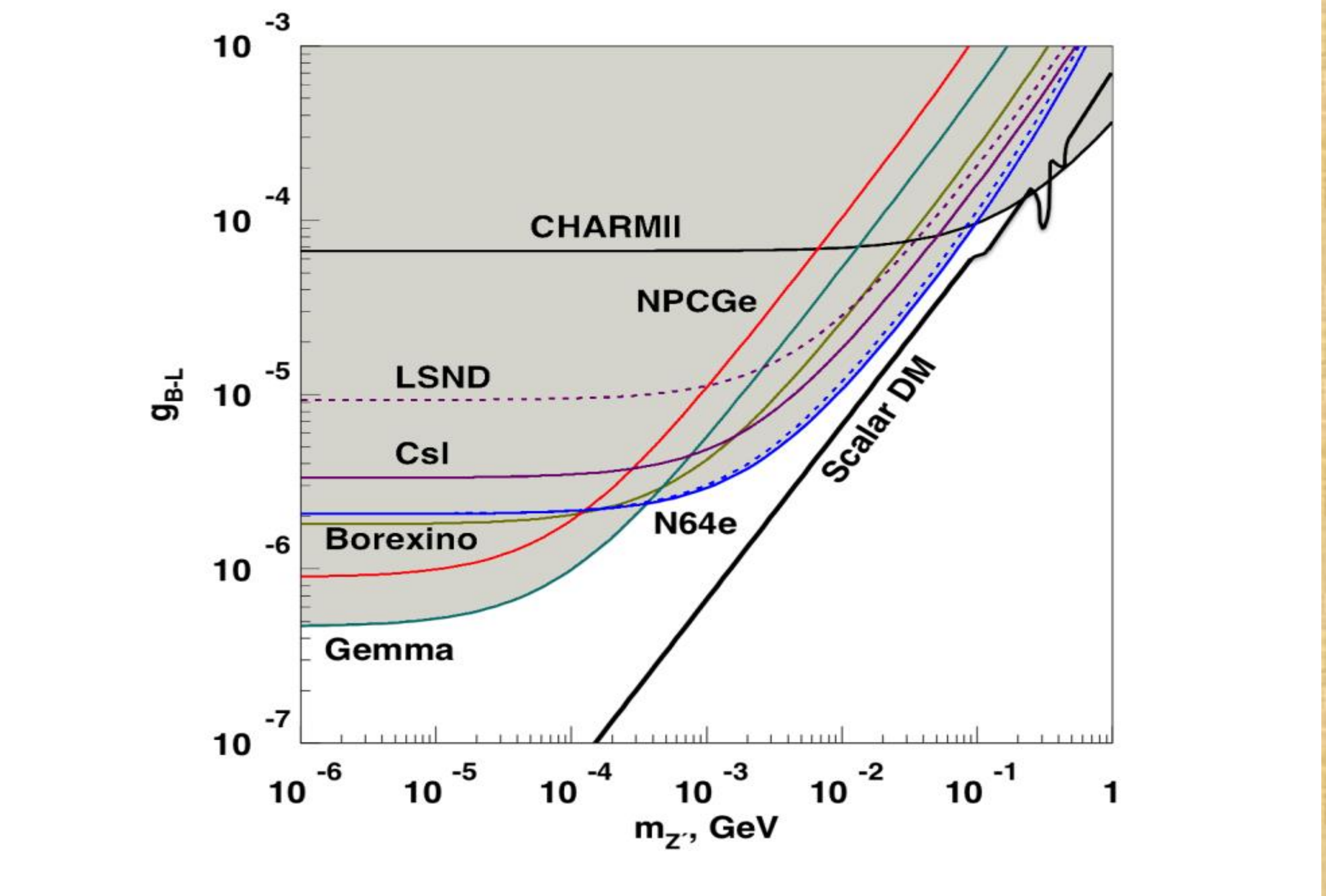
Last NA64 result on ε parameter invisible dark photon decay: $N_{eot} = 0.937*10^{12}$ arXiV:2307.024404, Phys.Rev.Lett.(2023)



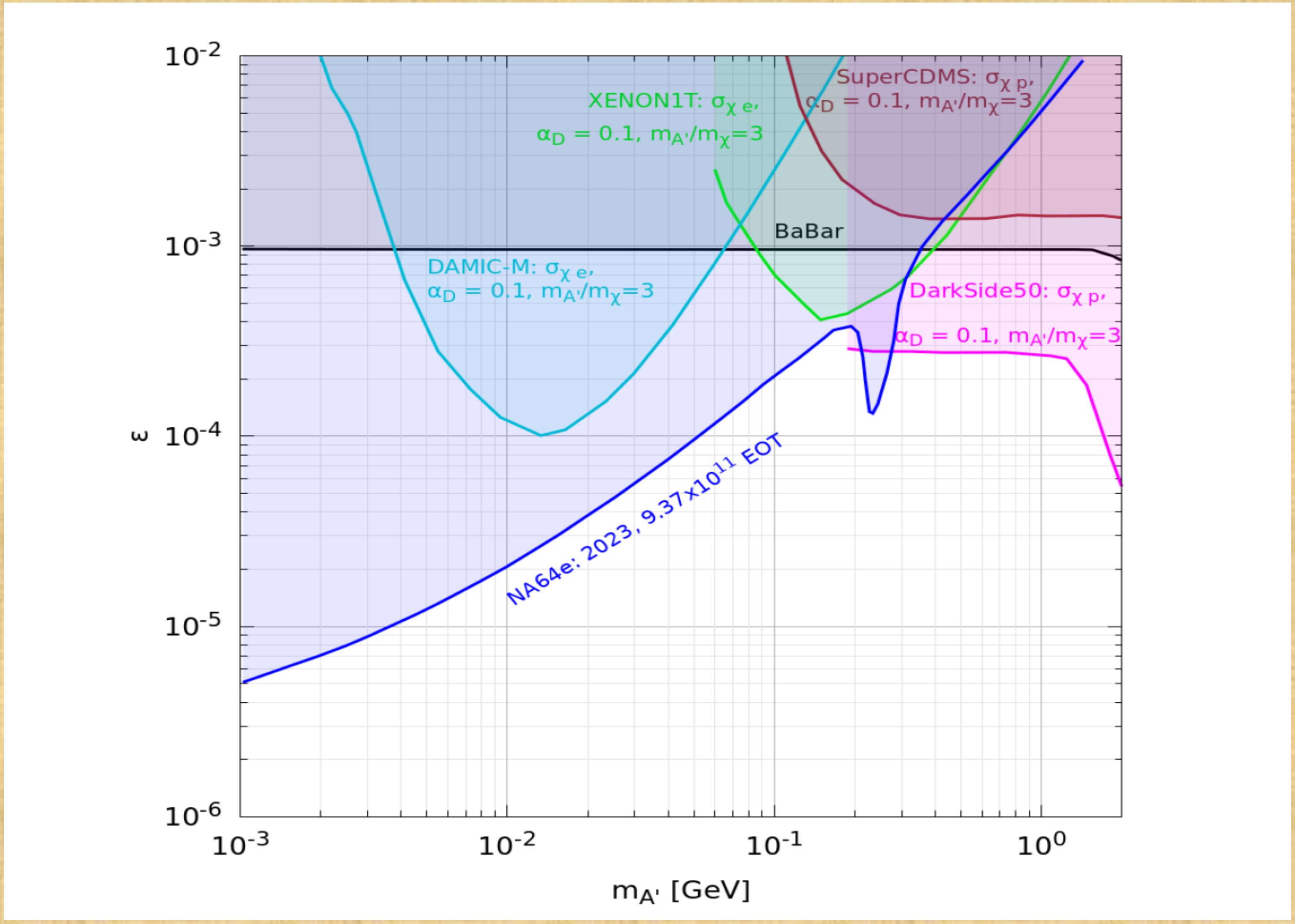
The comparison with different models



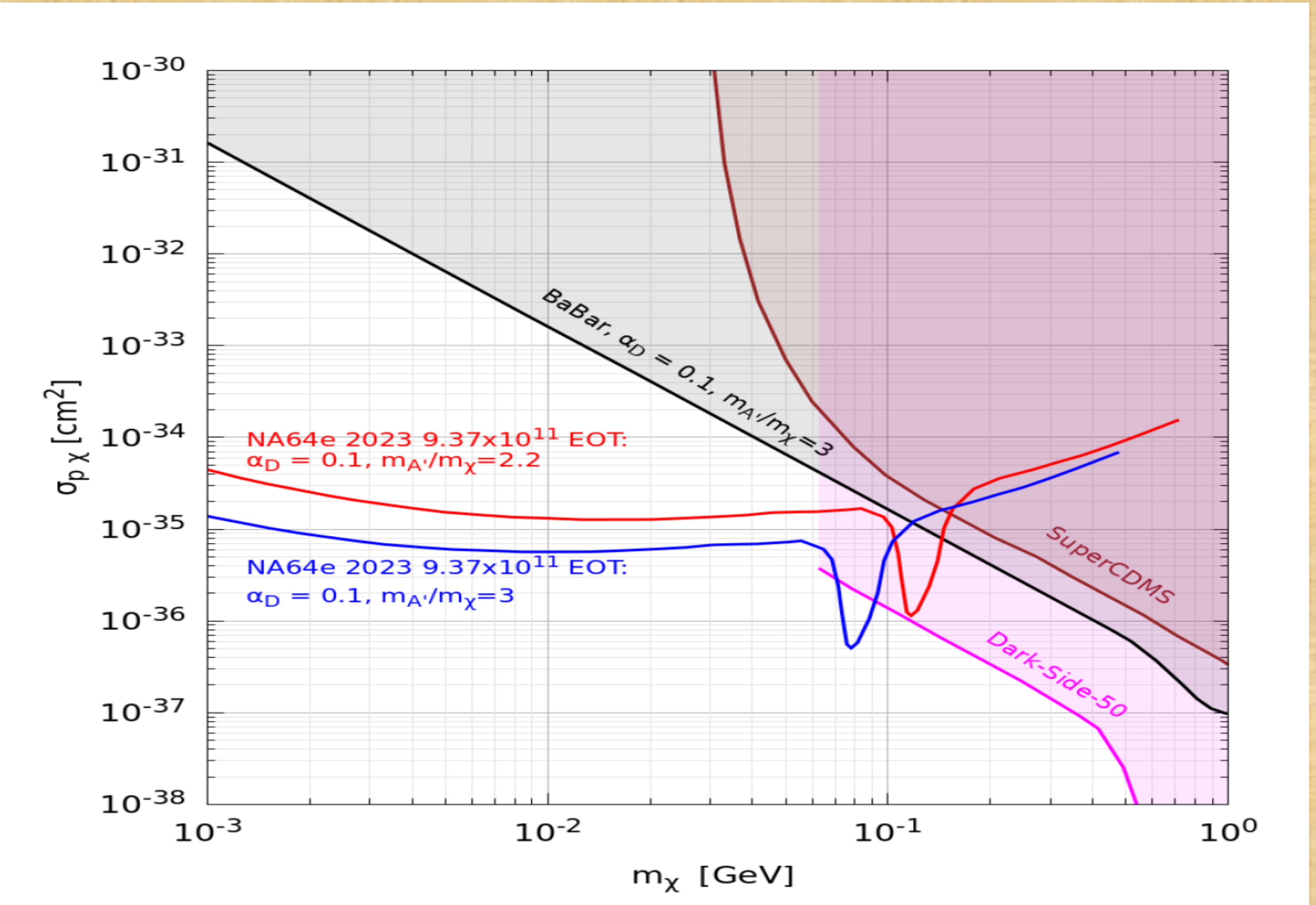
Bound for (B-L) model
Phys.Rev.Lett. 129,1618011(2022)



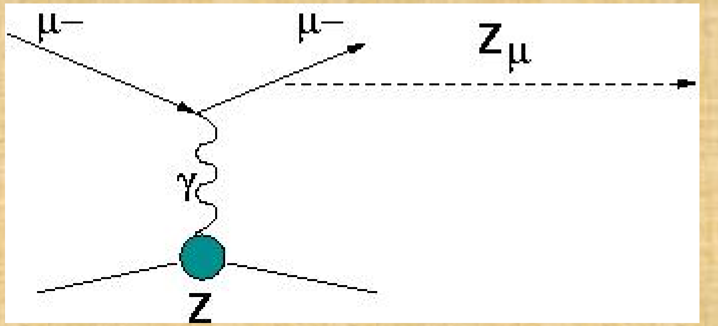
The comparison of NA64 and underground experiments(arXiv:2307.14865) for dark photon model for different ε



The comparison for proton DM cross sections



The NA64 experiment at CERN with muon beam



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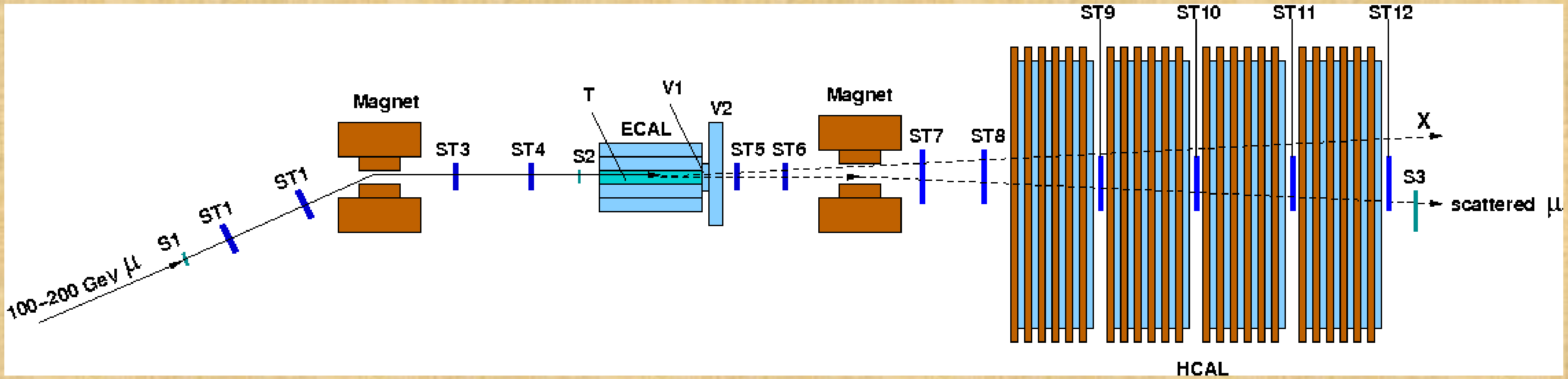
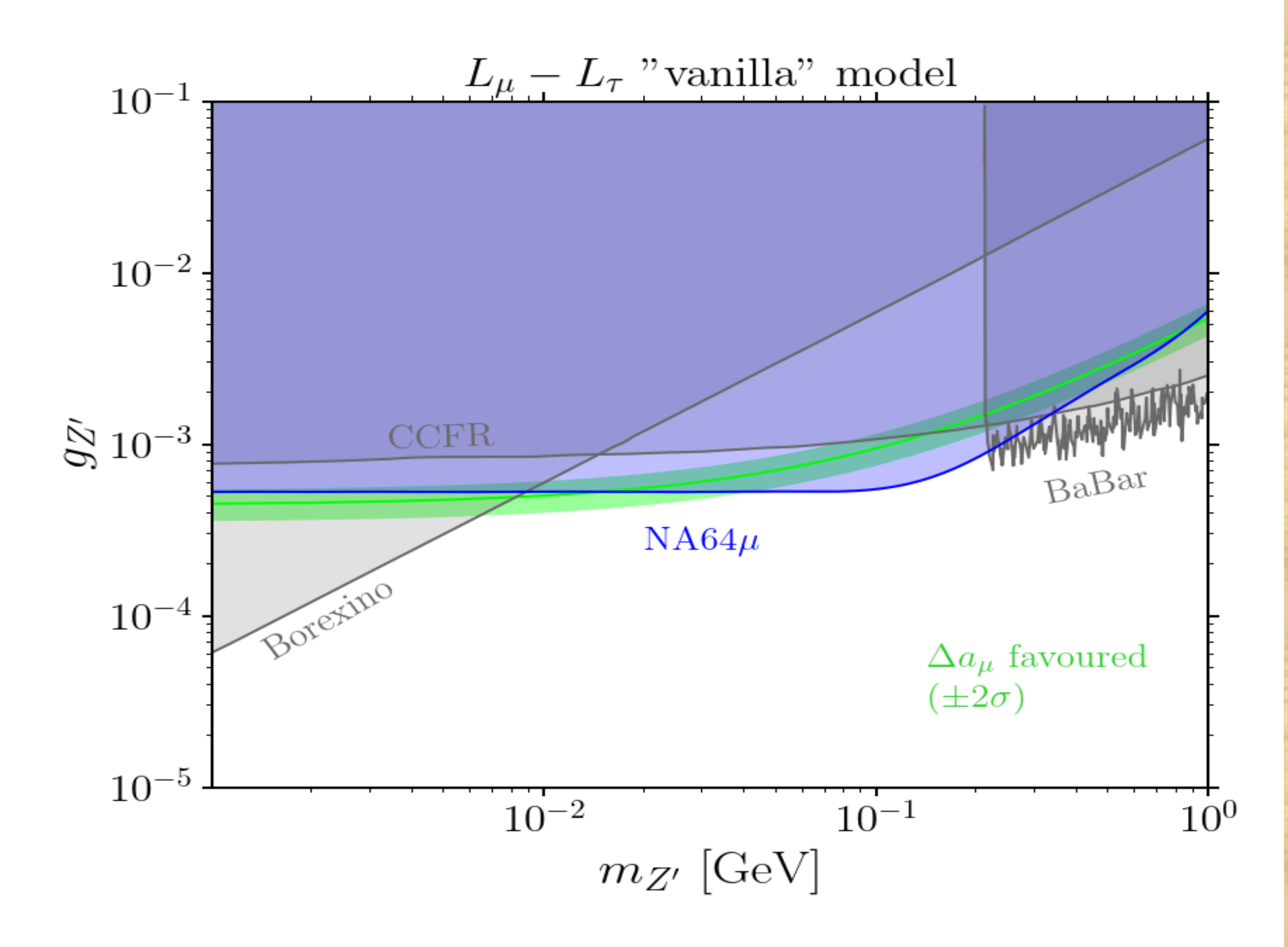
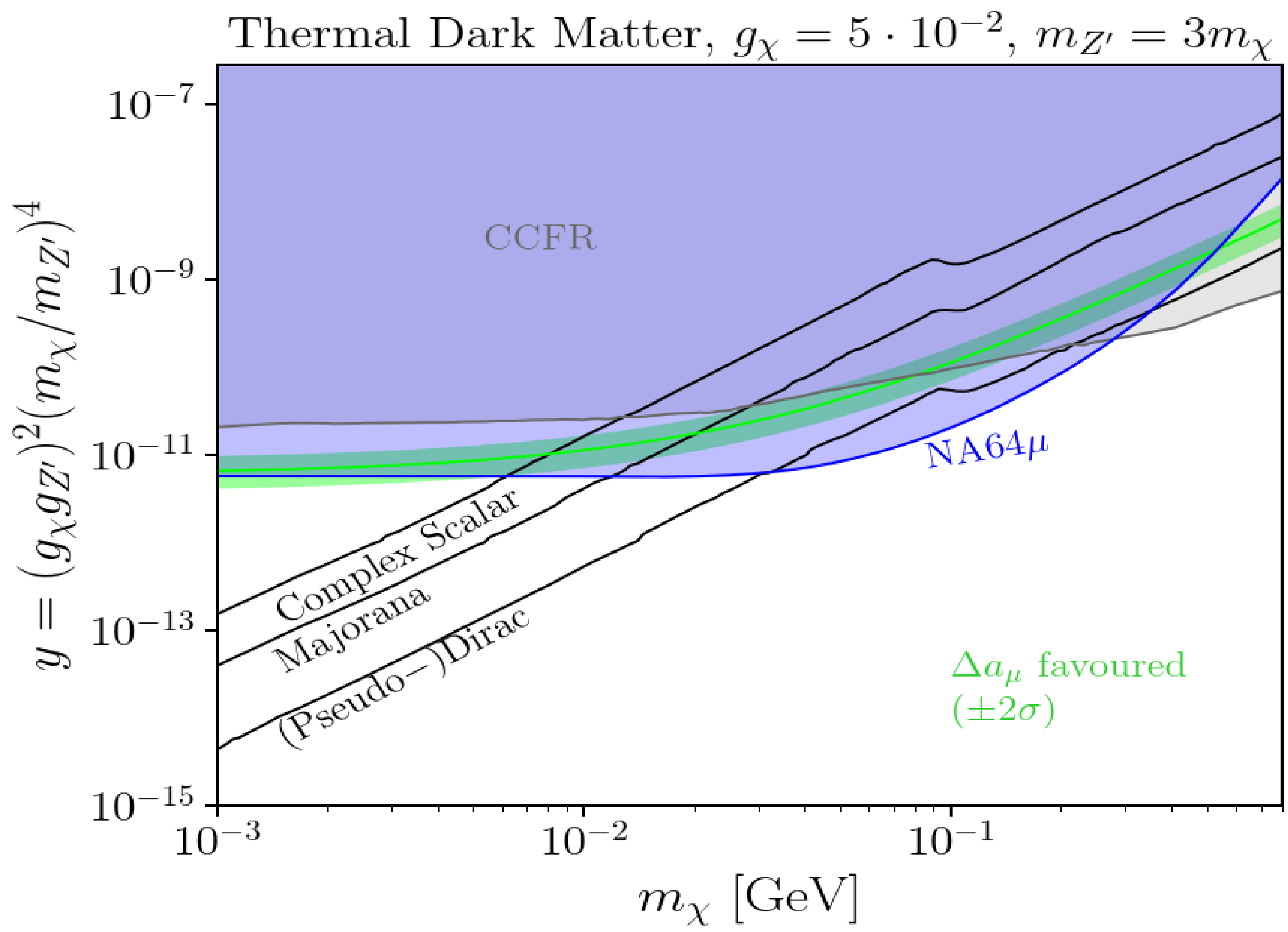
Schematic illustration of the setup to search for dark boson



Last NA64 result Phys.Rev.let.2024



Last NA64 results



4.Conclusions

0. At present there are rather strong underground and accelerator bounds on dark matter models. However

from theoretical point of view it is difficult to choose the most

natural and promising model.

1. Light dark matter – good alternative to SUSY and other models (axions, sterile neutrino, …)

2. Dark photon model is the simplest

realization

3. Dark photon model predicts mixing interesting for experimental search

4. NA64 with future statistics $5 \cdot 10^{12}$ EOT will

be able to test the most interesting models