First results from the NA64 experiment using a high energy muon beam

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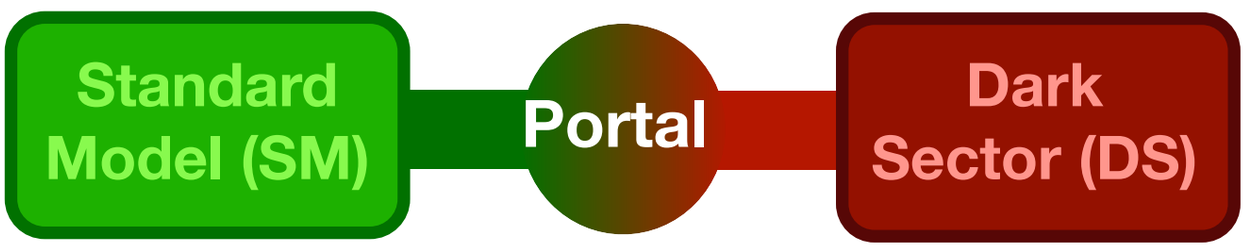
XVI CPAN days 19th-21st November 2024, Madrid

Dark sectors *in a nutshell*

An interesting framework to explain SM open questions with New Physics at low energy scales

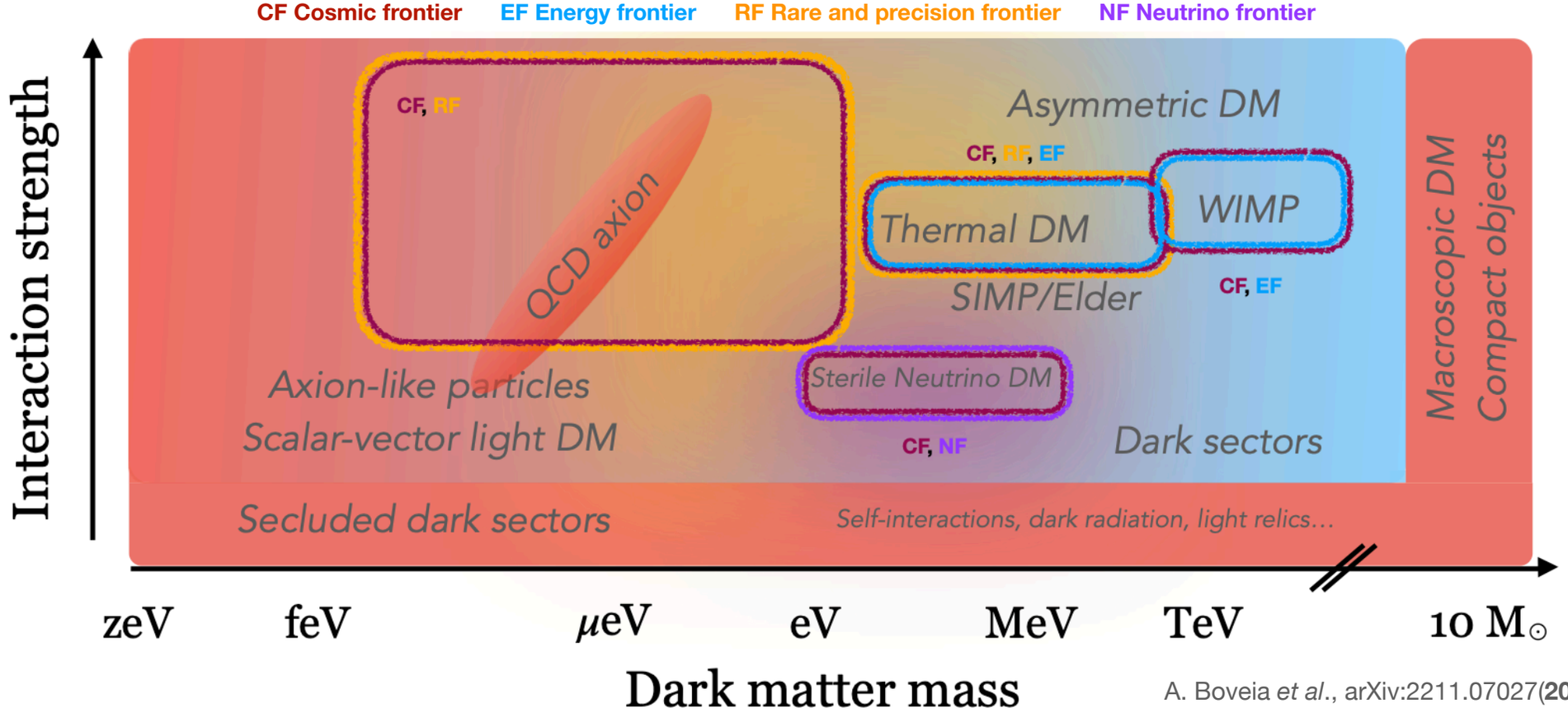


$$L_{Total} = L_{SM} + L_{DS} + L_{Portal}$$

They can solve some of the most pressing questions in particle physics: *the* ***origin of neutrino masses****, the* ***baryon asymmetry of the universe*** and the ***Dark Matter origin***.

J. Jaeckel et al. Nature Phys. 16 (2020) 393-401

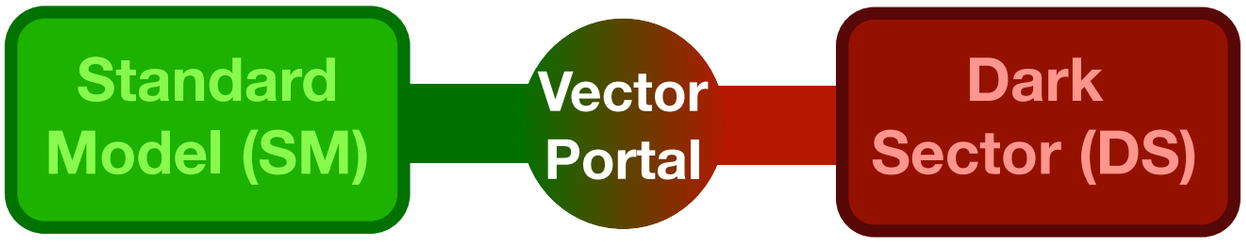
Vector (***Dark Photon)***, Scalar (***Dark Higgs)***, Fermion (***Heavy neutral lepton)***, Pseudo-scalar (***Axion)***



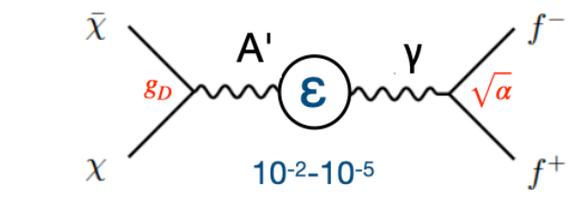
A. Boveia *et al.*, arXiv:2211.07027(**2022**)

NA64 target: *the vector portal and Light Dark Matter*

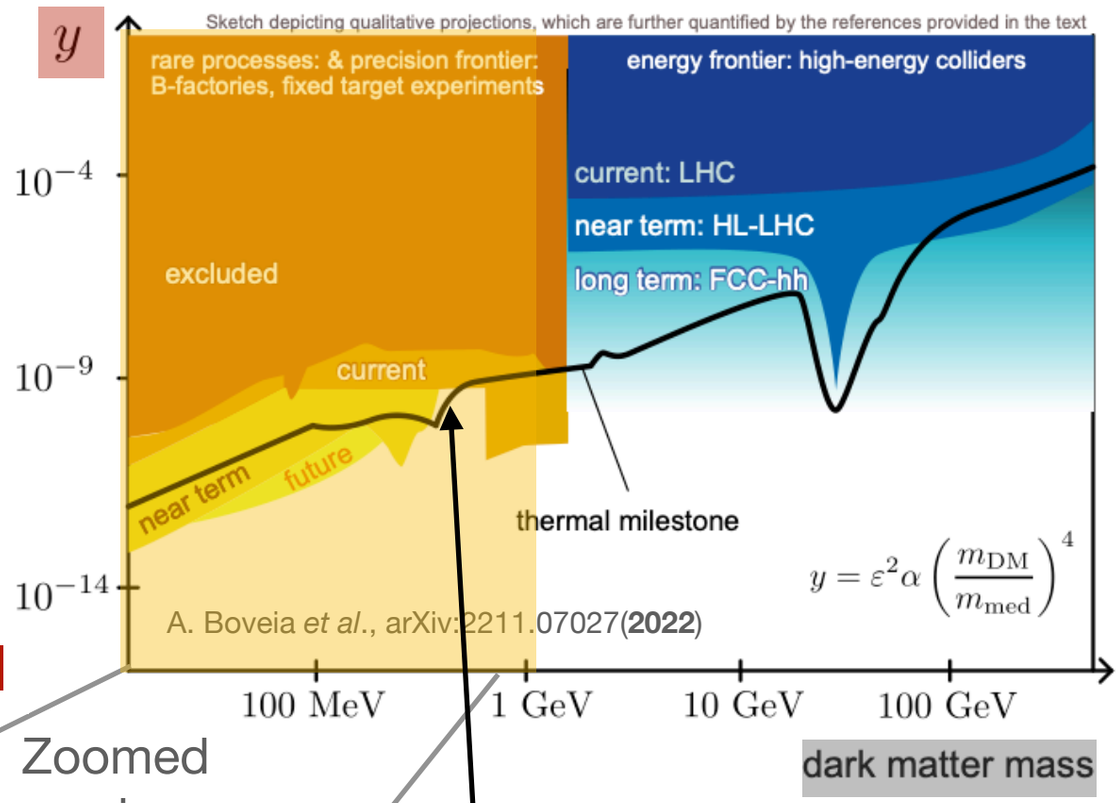
Dark Matter origin as thermal relic



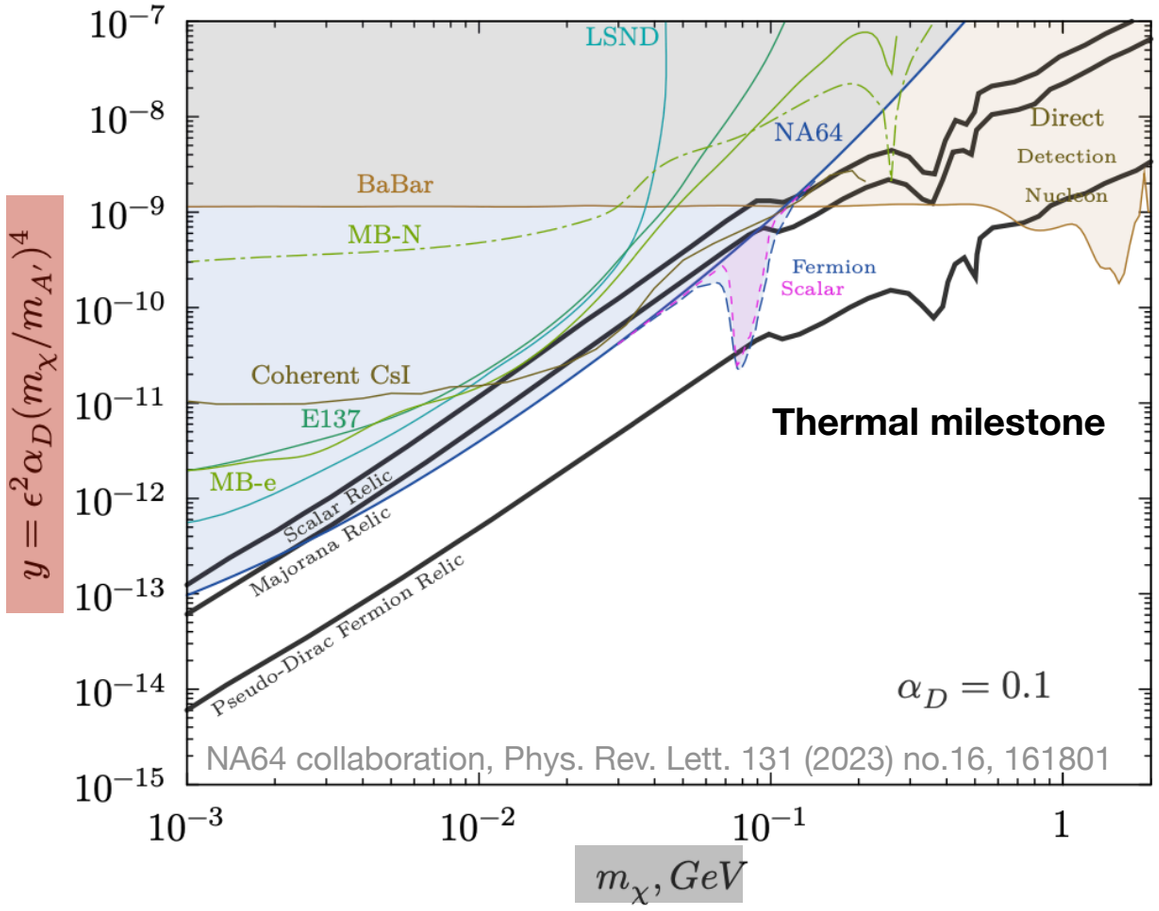
Dark Photon, A'



DM candidate



NA64 goal



NA64 collaboration, Phys. Rev. Lett. 131 (2023) no.16, 161801

Zoomed region

Thermal milestone

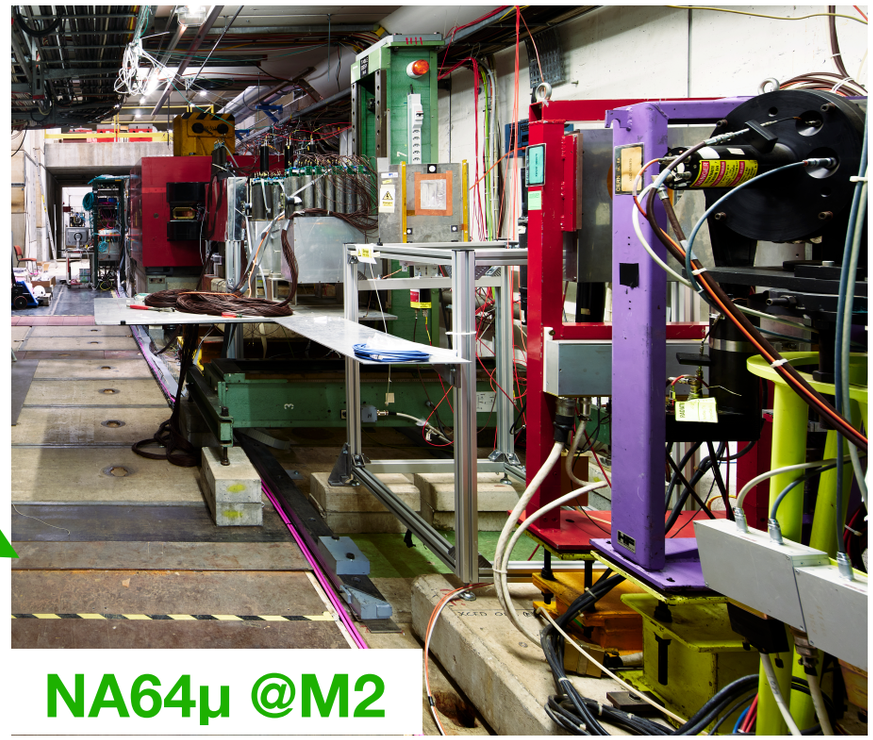
$$\Omega_\chi \propto \frac{1}{<\sigma v>} \sim \frac{m_\chi^2}{g_\chi^4}$$

$$\sigma v(\chi\chi \to A' \to ff) \propto \epsilon^2 \alpha_D \frac{m_\chi^2}{m_{A'}^4} = \frac{y}{m_\chi^2}$$

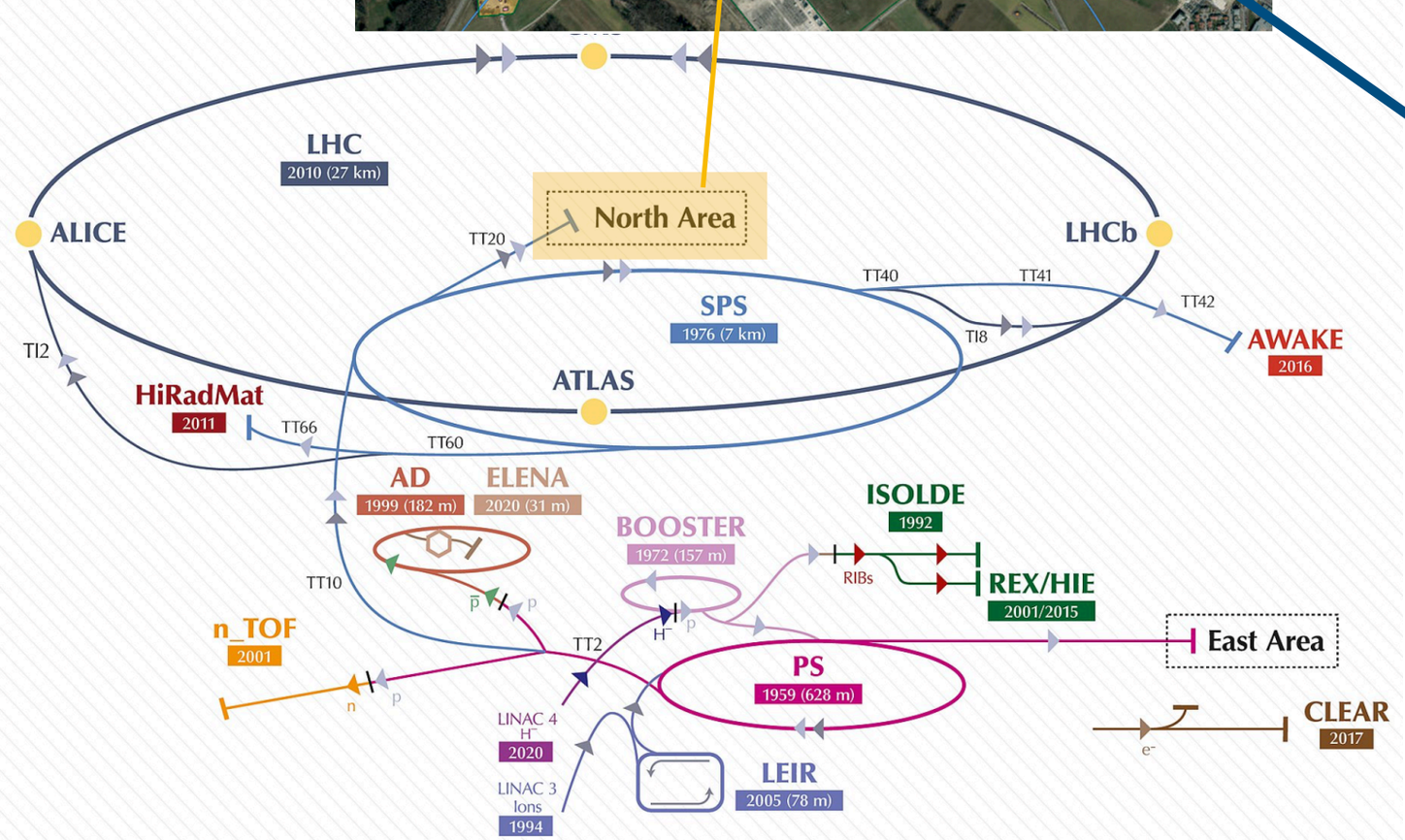
J.Feng, J. Kumar
Phys. Rev. Lett.101231301

The NA64 experiment

Fixed target experiment at the CERN Super Proton Synchrotron accelerator designed to probe Dark Sector physics.



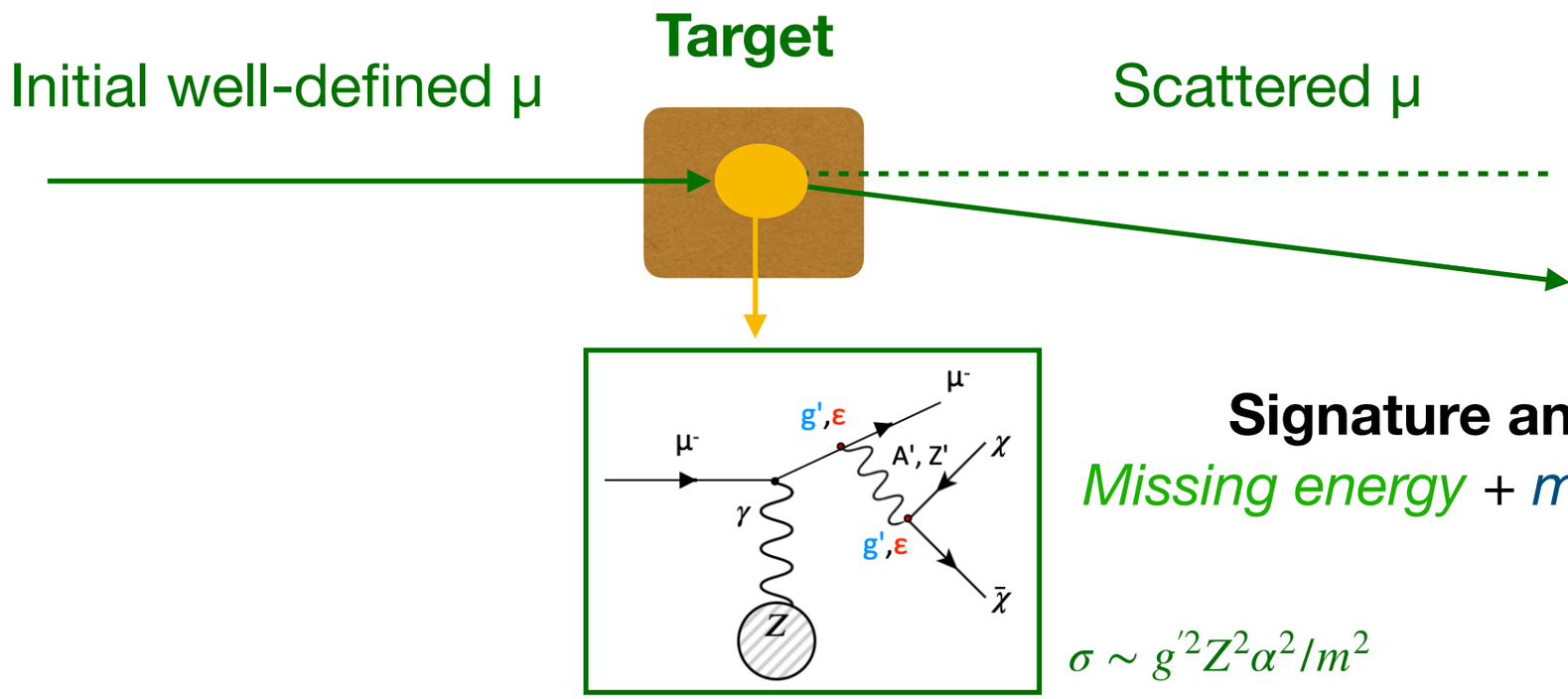
NA64μ @M2



NA64e$^{-/+}$ @H4

Dark sector exploration using muons (NA64$_\mu$)

*Exploring **DS physics weakly coupled to μ** using the unique CERN SPS*
M2 high energy (up to 250 GeV)** and **high intensity muon beam (up to 10^7μ/s)



Signature and challenge

Missing energy + *missing momentum*

$\sigma \sim g'^2 Z^2 \alpha^2 / m^2$

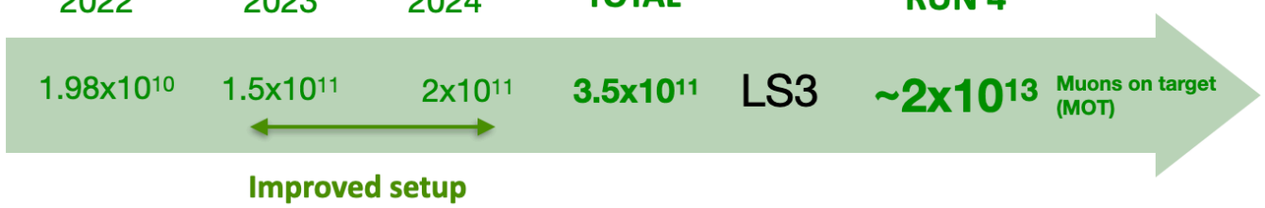
Physics Goals

- **Sub-GeV Z'** as remaining explanation of the **muon g-2 anomaly.**
- **Light dark matter** in the A' mass region ≥ 0.1 GeV (complementary search to NA64e$^{-/+}$).
- **Scalar, ALPs** coupled to the muon**, Milli-Charged** particles, **Lepton Flavour Violation** in **μZ -> eZ** and **μZ -> τZ conversion in flight.**

S.Gninenko et al. PLB796, 117 (2019)

D. Banerjee et al. [NA64 Collaboration]. CERN-SPSC-2019-002 / SPSC-P-359, January 14, 2019.

Dark sector exploration using muons (NA64$_\mu$)



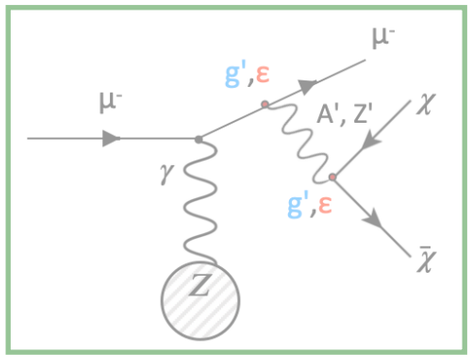
Challenges

- Fully hermetic detector.
- Initial and final μ momenta mis-measurements down to $\lesssim 10^{-13}$.
- High intensity/low hadron contamination upgrade to fully exploit the beam capabilities.

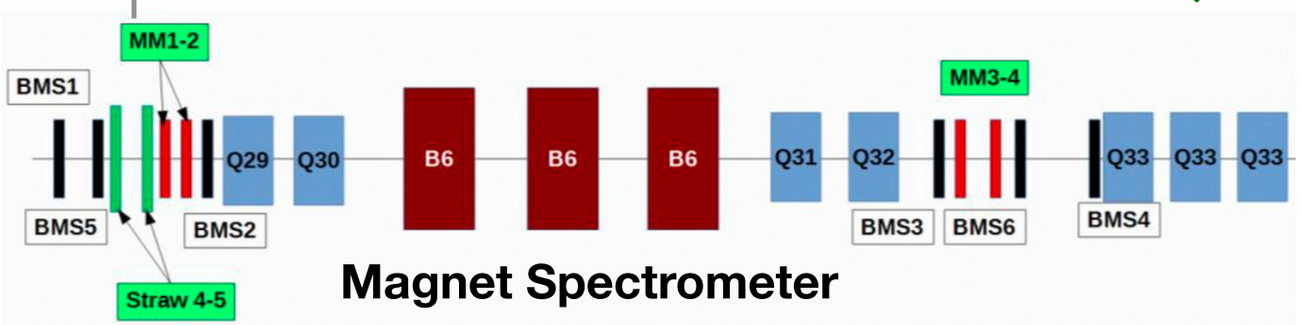
First NA64$_\mu$ physics results

Initial well-defined μ

Target



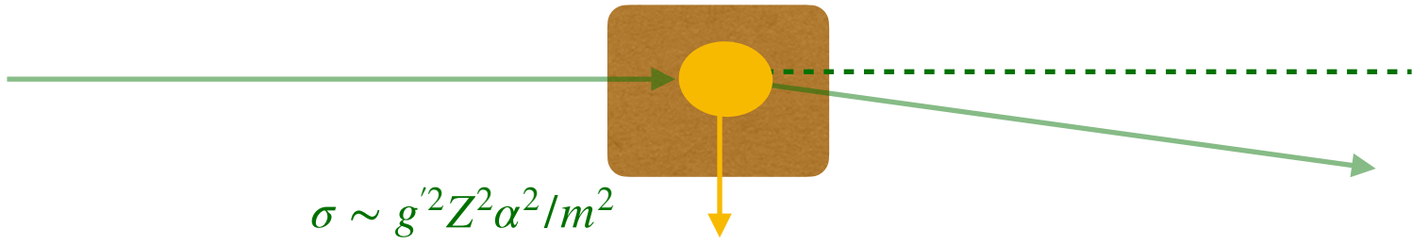
1) Incoming muon momenta 160 GeV



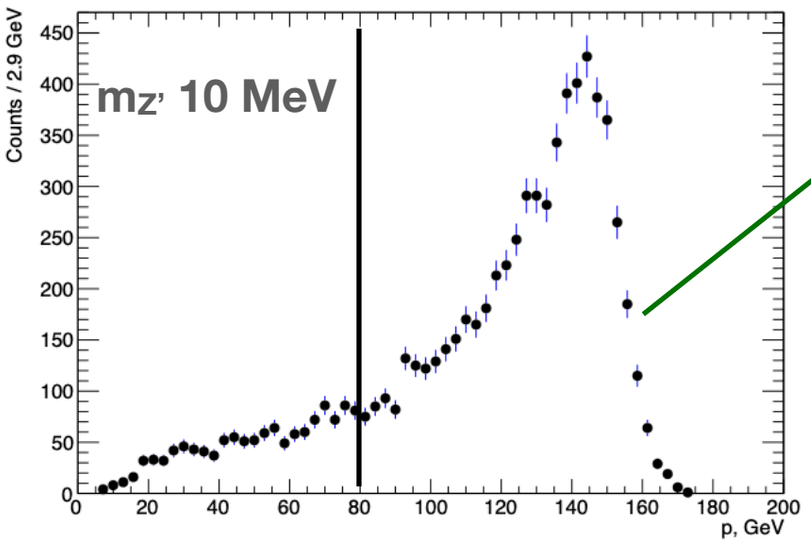
H. Sieber, *et al.* Phys. Rev. D 108 (2023) no.5, 056018
H. Sieber, Phys. Rev. D 105 (2022) no.5, 052006

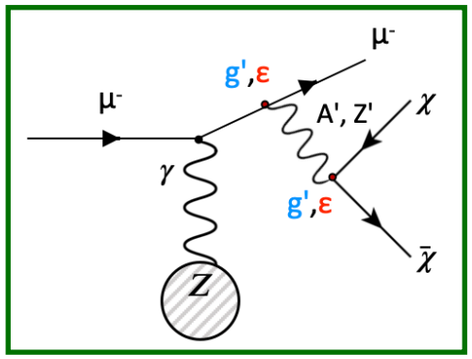
First NA64μ physics results

Target (ECAL)

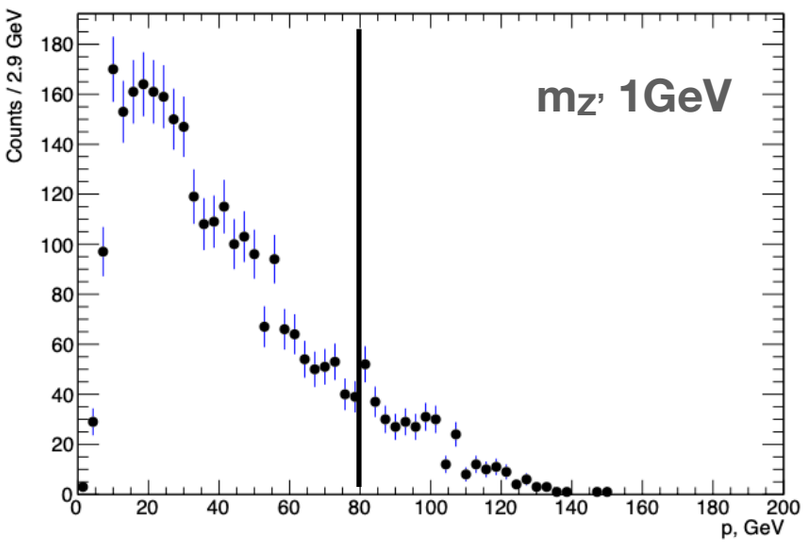


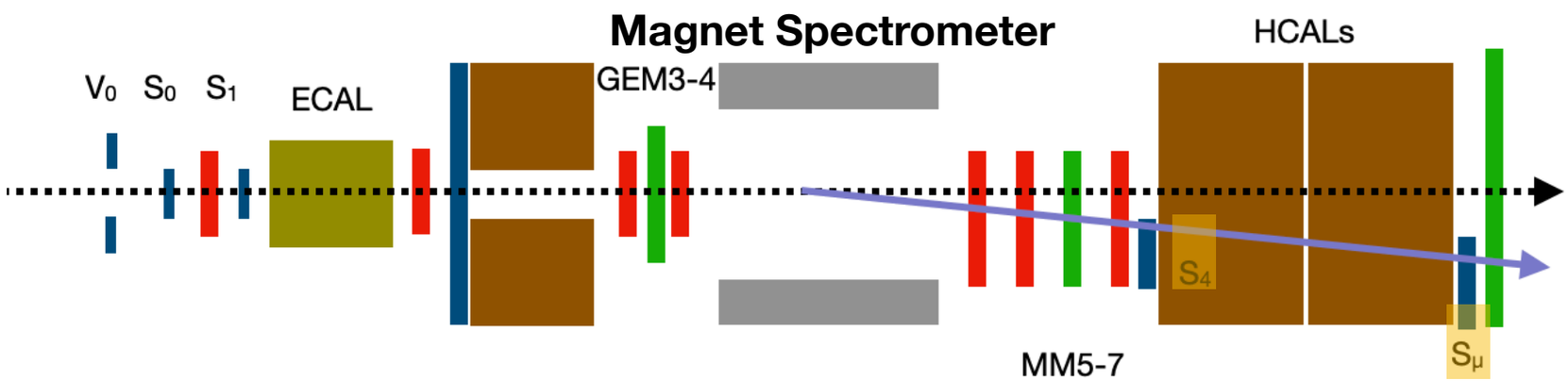
$$\sigma \sim g'^2 Z^2 \alpha^2 / m^2$$





2) -Scattered muon with momentum <80 GeV
-MIP energy in ECAL and HCAL
-No activity in VETO and VHCAL





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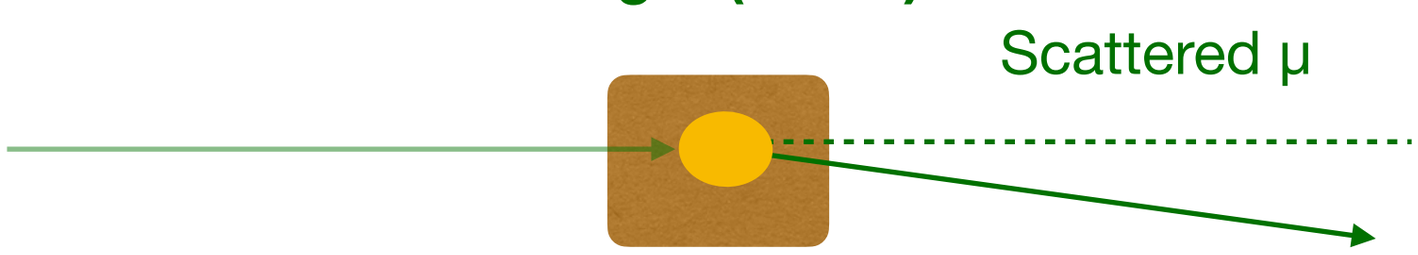
First NA64$_\mu$ physics results



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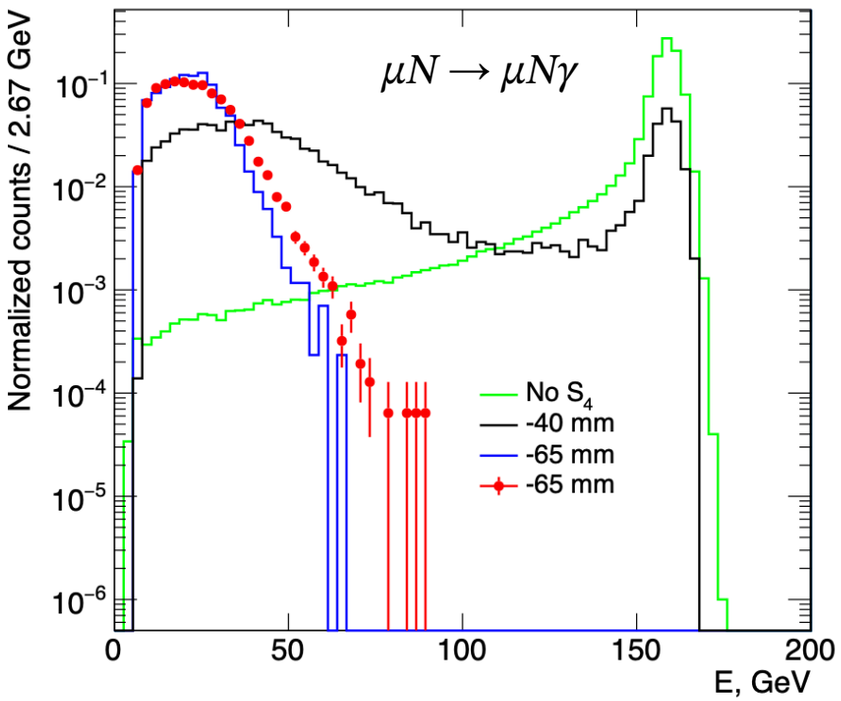
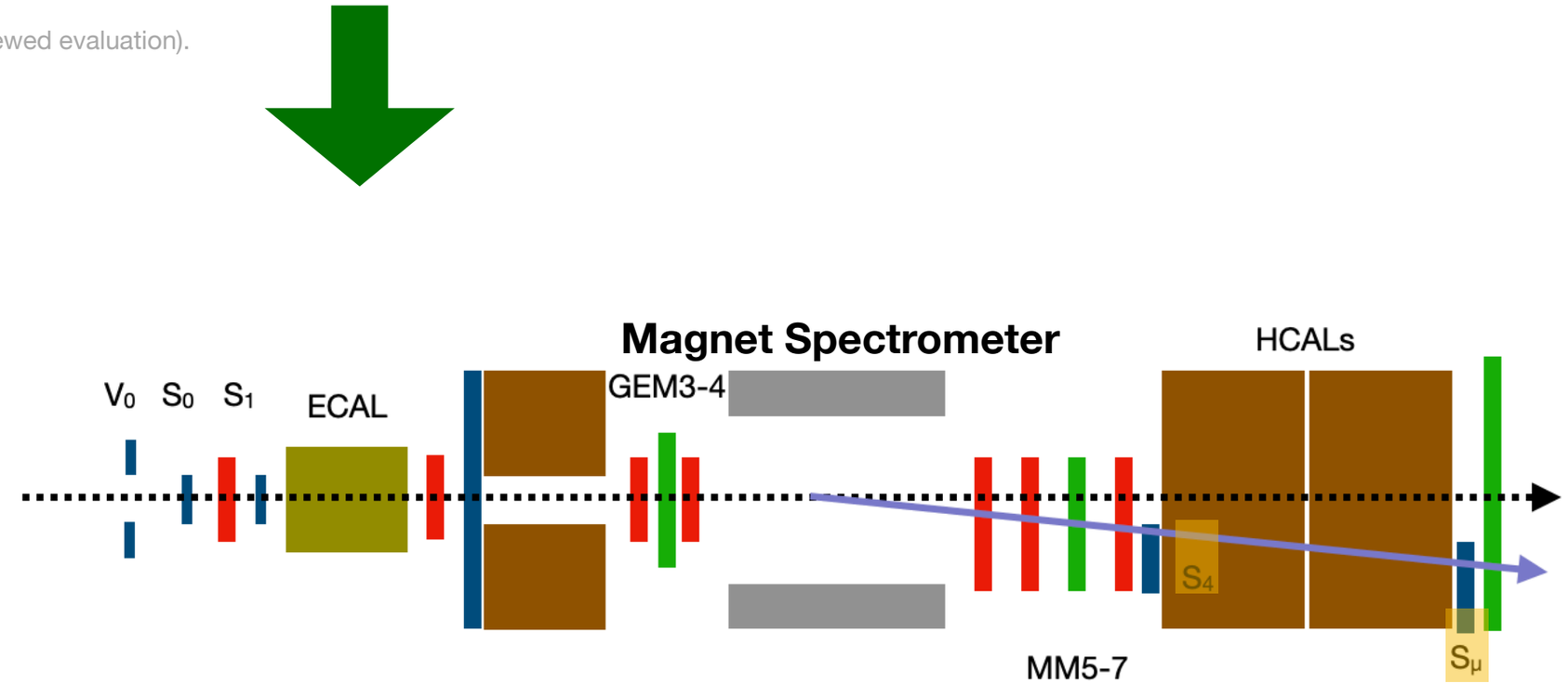
NA64 collaboration [arXiv:2409.10128 [hep-ex]] (under peer-reviewed evaluation).





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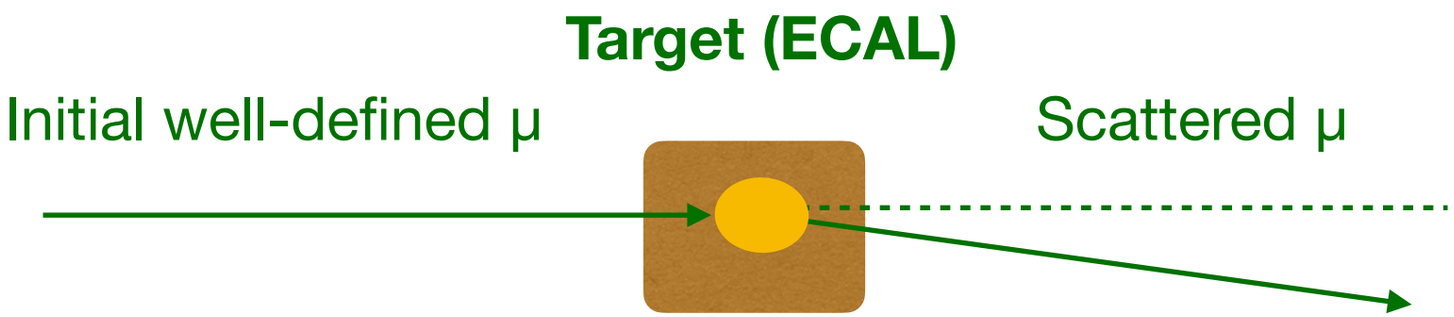
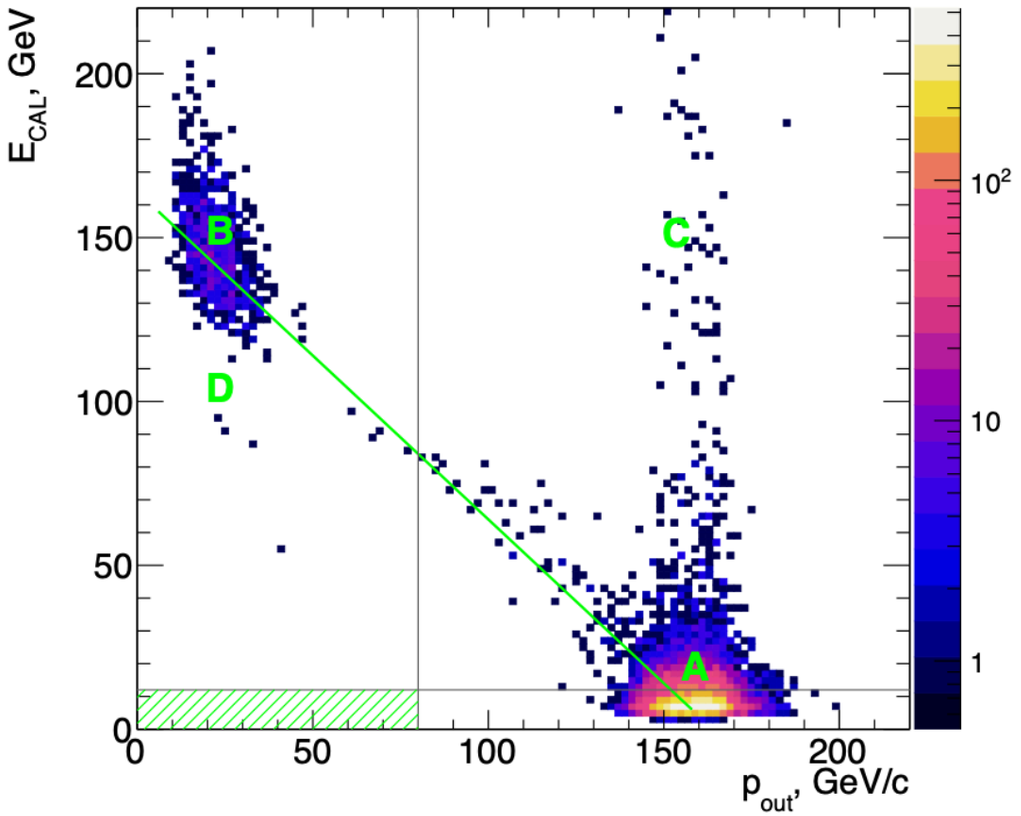
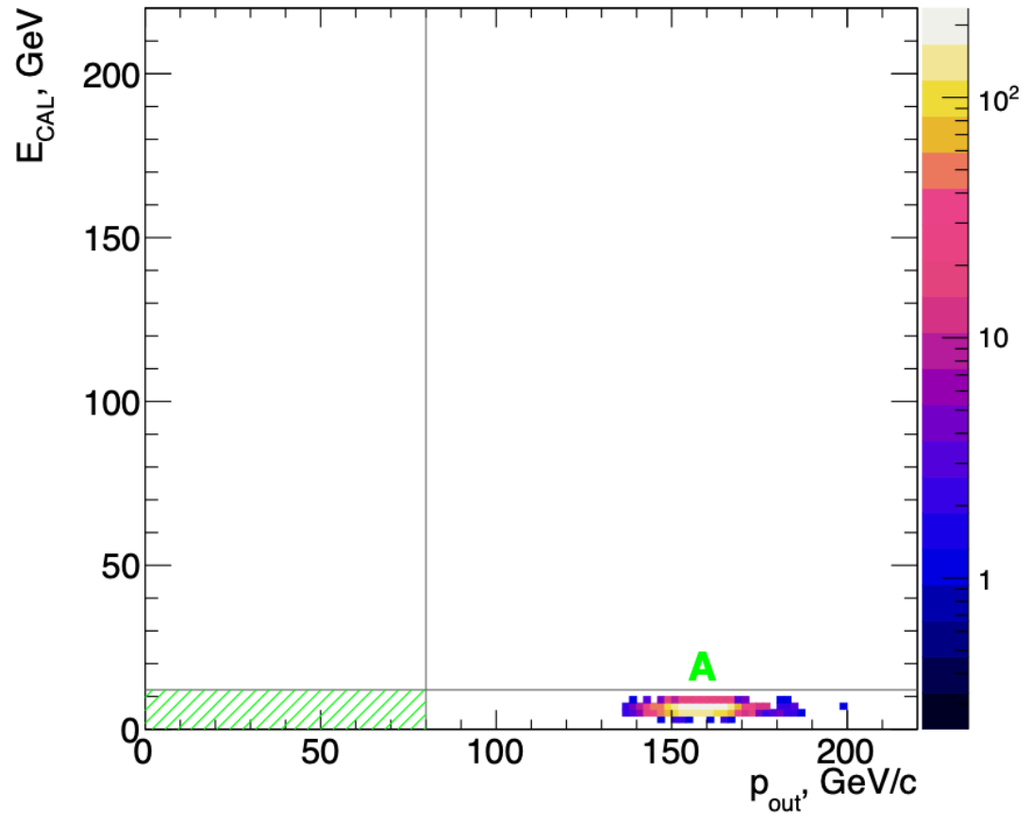
First NA64$_\mu$ physics results







Background source	Background, n_b
(I) Momentum misreconstruction	0.05 ± 0.03
(II) $K \to \mu + \nu, \ldots$ in-flight decays	0.010 ± 0.001
(III) Calorimeter non-Hermiticity	< 0.01
Total nb (conservatively)	0.07 ± 0.03

No signal observed in 1.98x10^{10} MOT

NA64 collaboration, Phys. Rev. Lett. 132 (2024) no.21, 211803 doi:10.1103/PhysRevLett.132.211803

NA64 collaboration [arXiv:2409.10128 [hep-ex]] (under peer-reviewed evaluation).

First NA64$_\mu$ physics results

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First Results in the Search for Dark Sectors at NA64 with the CERN SPS High Energy Muon Beam

Yu. M. Andreev *et al.*
Phys. Rev. Lett. **132**, 211803 – Published 21 May 2024

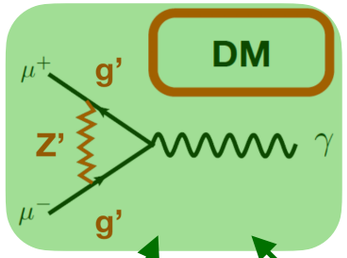
Physics See synopsis: Careful Accounting Could Reveal the Dark Sector

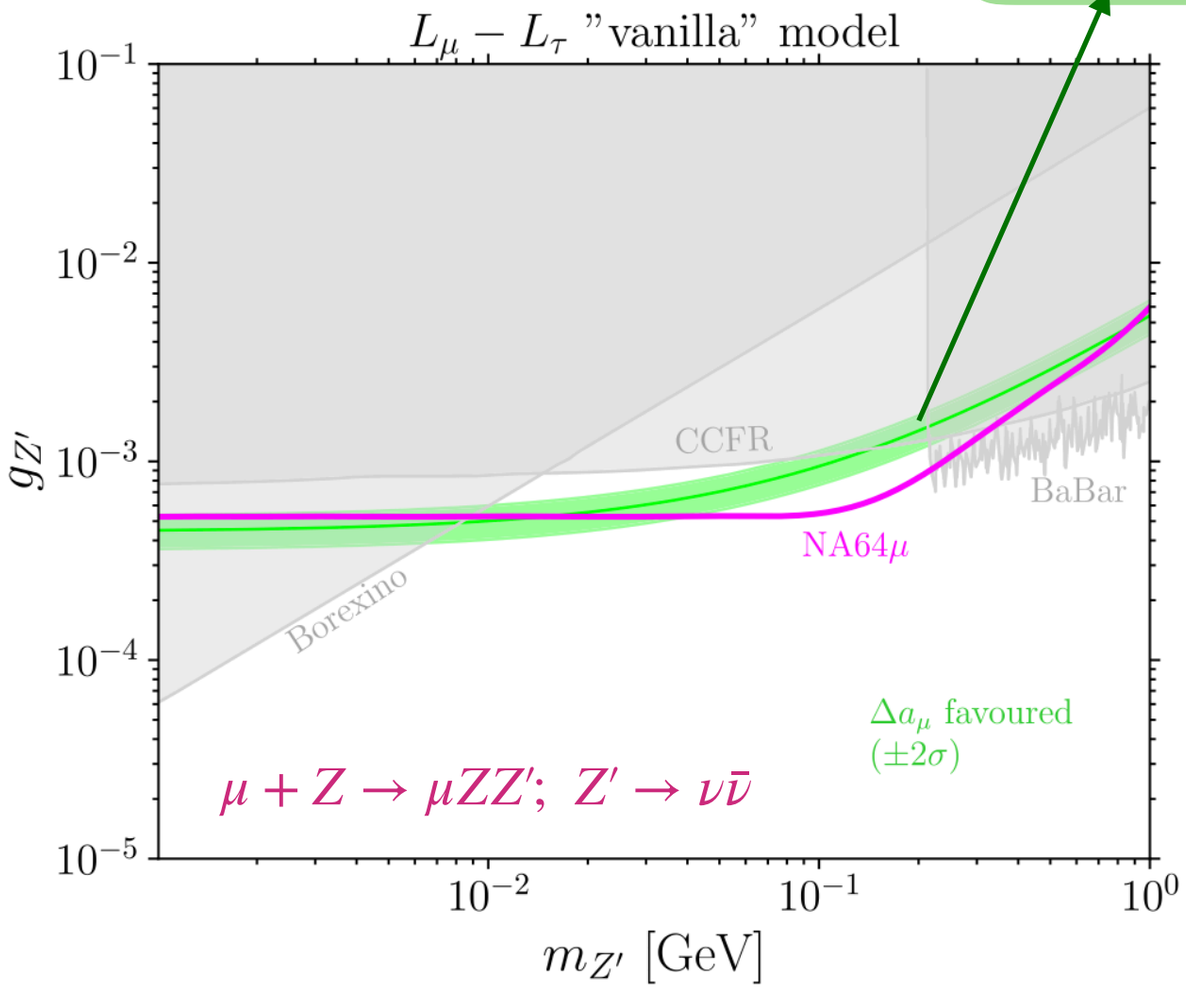
Careful Accounting Could Reveal the Dark Sector

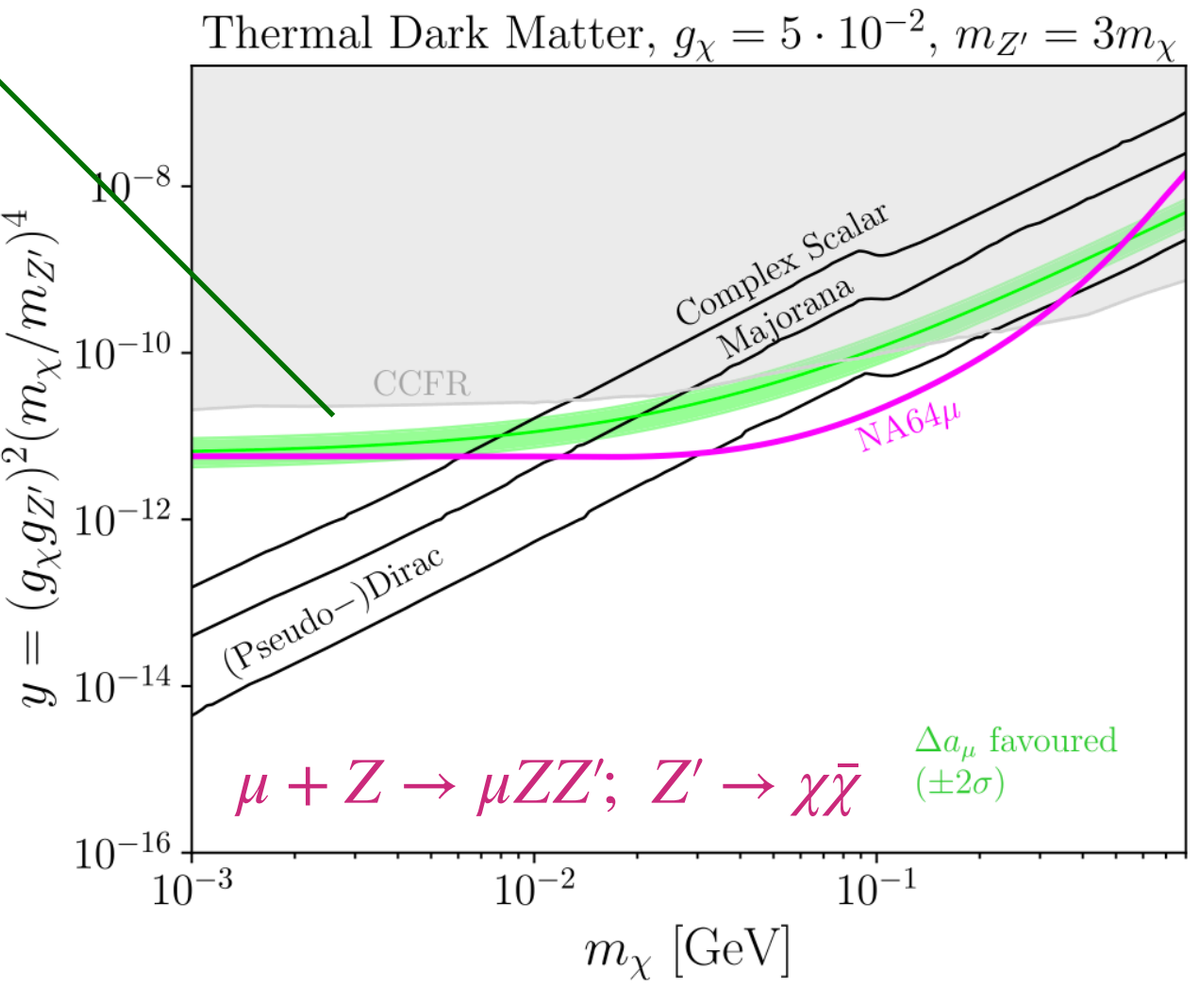
HIGHLIGHTED IN PHYSICS

May 21, 2024 • *Physics* 17, s54

An experiment at CERN seeks signs of dark matter by looking for missing energy and momentum in the debris of particle collisions.







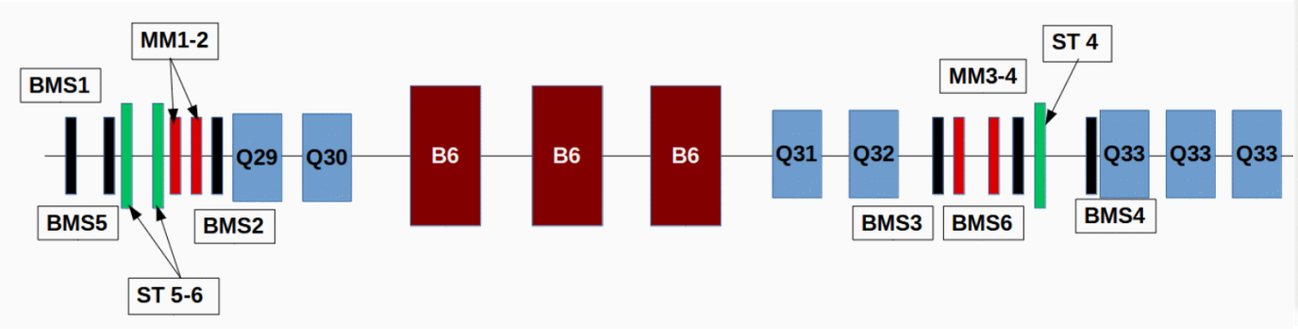
Improvement of the setup in 2023/2024

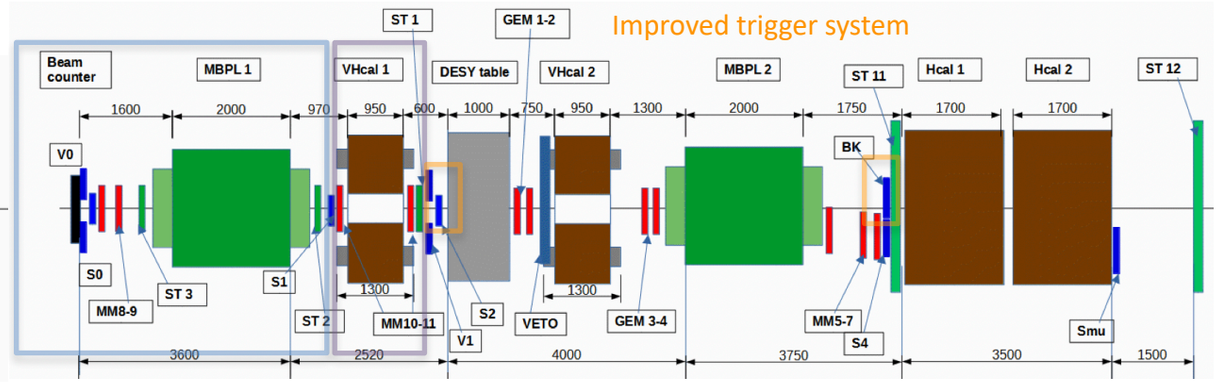
NEW MAGNET SPECTROMETER

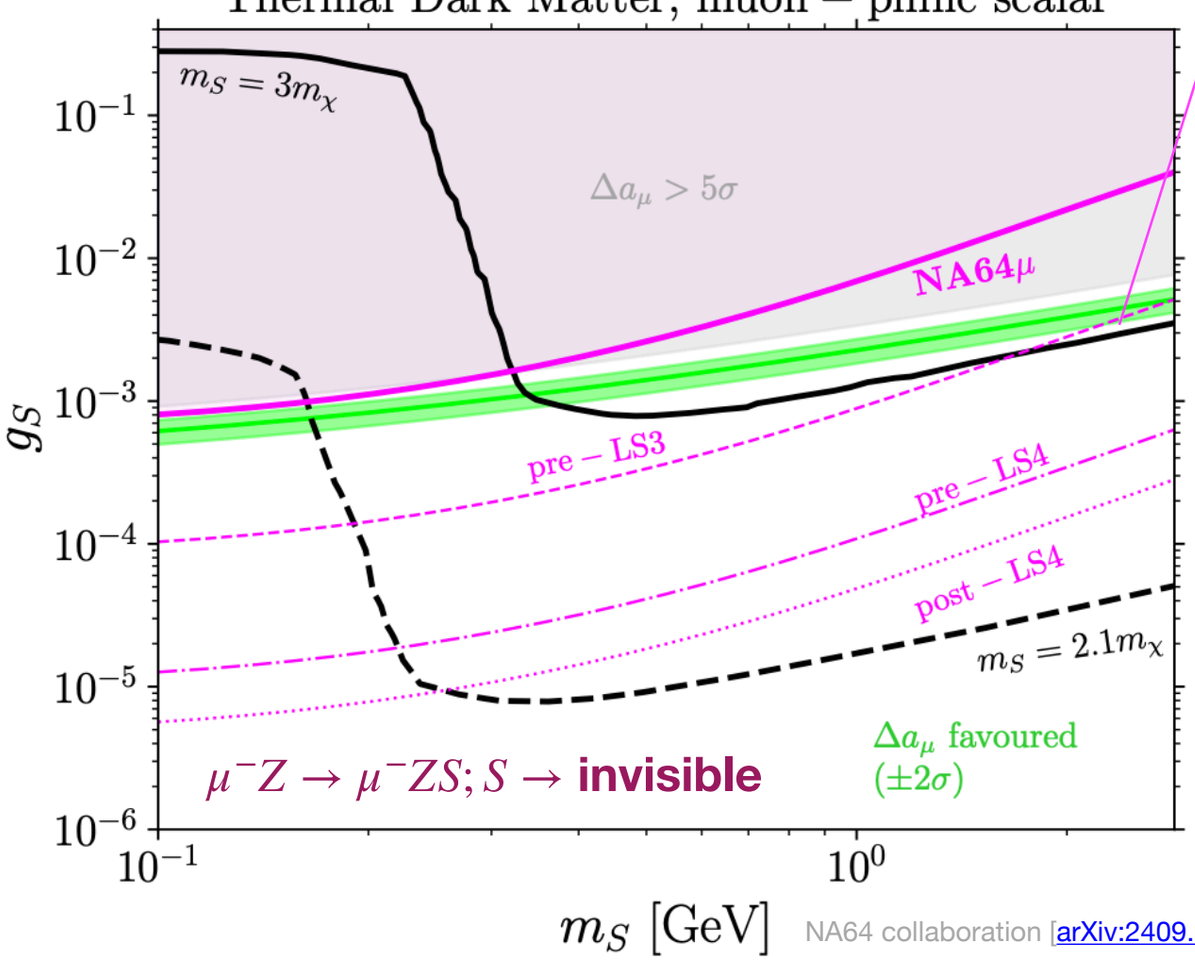
Additional VHCAL prototype

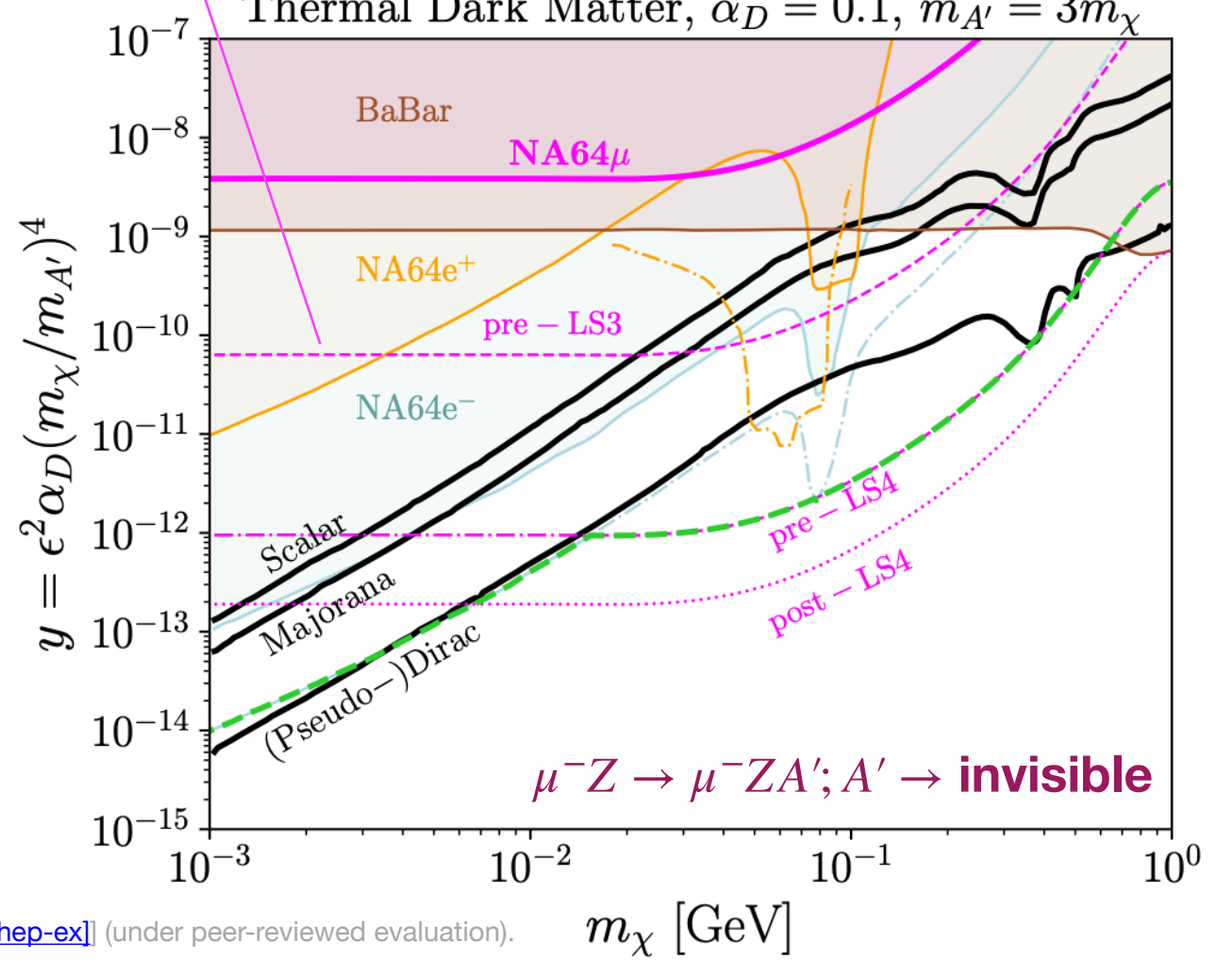
Additional trackers

Improved trigger system









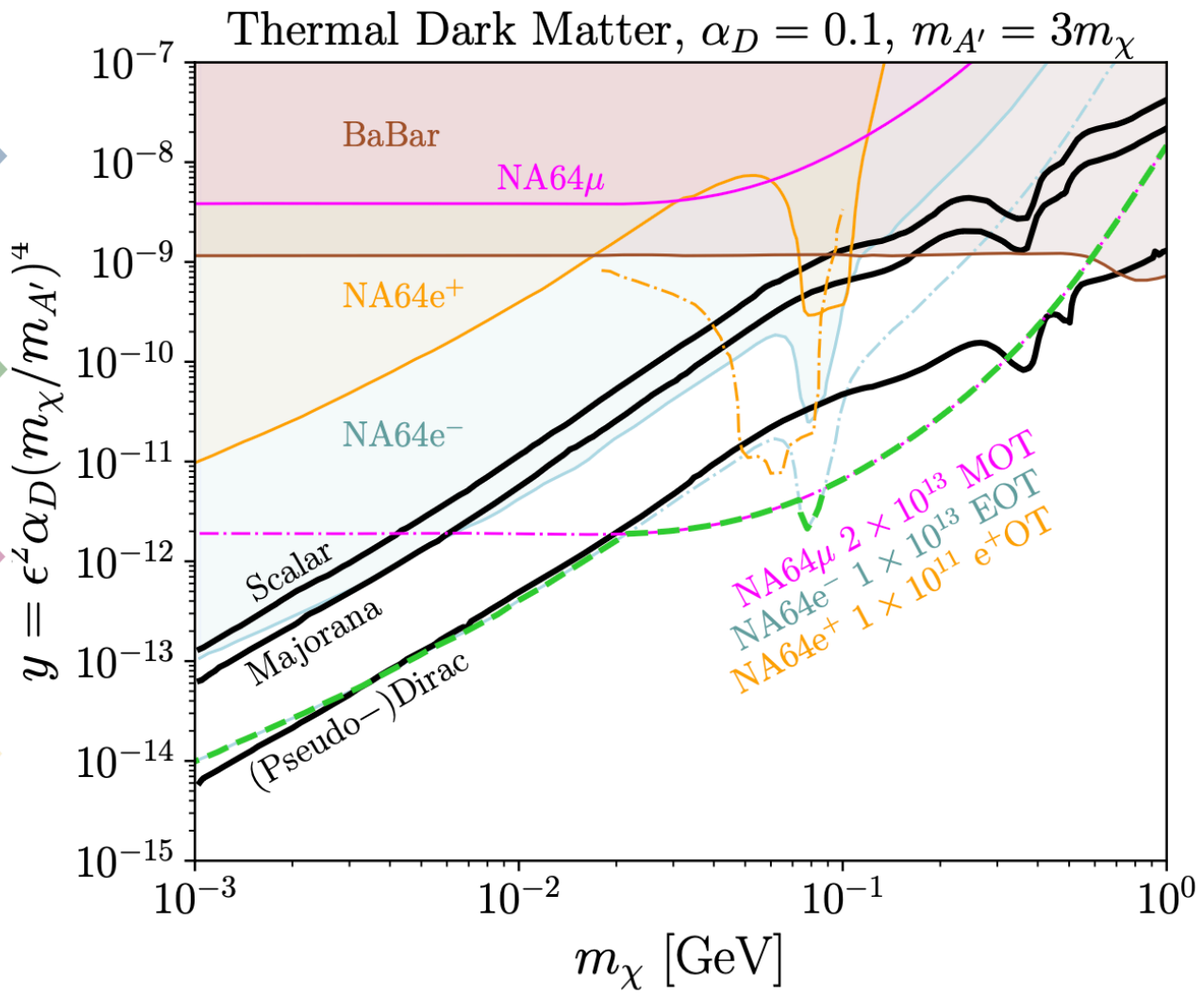
NA64 collaboration [arXiv:2409.10128 [hep-ex]] (under peer-reviewed evaluation).

Future prospects

Explore Dark sector and many well motivated New Physics scenarios in a complementary way to other approaches: using electron, muons, positrons and hadron beams and ***the missing energy/momentum technique***

	Goals	Particle/energy	TOTAL	2025	2026	Run 4	(statistics aimed)
NA64e	Dark sector Light Dark Matter (LDM) ALPs, Z',...	100 GeV e^-	**~1.9x10¹² EOT**	~2x10¹² EOT		**LS3**	**~10¹³ EOT**
NA64μ	Dark sector LDM (higher masses) Muon g-2 ALPs, μ→τ, ...	160 (~100) GeV μ^-	**~3.5x10¹¹ EOT**		Possible upgrade test	**LS3**	**~2x10¹³ MOT**
NA64e⁺	LDM (higher masses) ...	150, 60 and 40 GeV e^+	**~4.3x10¹⁰e+OT**	~10¹¹e+OT		**LS3**	**~1.3x10¹²e+OT**
NA64h	Invisible decays from η, η', π_0, $K^0_{S,L}$ ➡ **Proof of principle** using charge-exchange reactions of beam hadrons with just 1 day of data taking: ***Phys. Rev. Lett. 133, 121803 (2024)***		**2 weeks test at T9 in PS**			**LS3**	**Proposal to be submitted in 2025**

Complementarity of NA64μ and NA64e:
Improved sensitivity in the high A' mass range by a factor of 10^2



NA64 is an ideal experiment to decisively discover or disprove very attractive predictive LDM models, and greatly explore DS below electroweak scale in the coming years.

High complementarity with present and planned experiments such as FASER, SHIP, HL-LHC, present and future dark matter direct detection and neutrino experiments

THANKS!

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