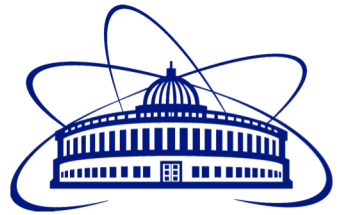


Search for new physics in ρ_0 decays in the NA64 experiment

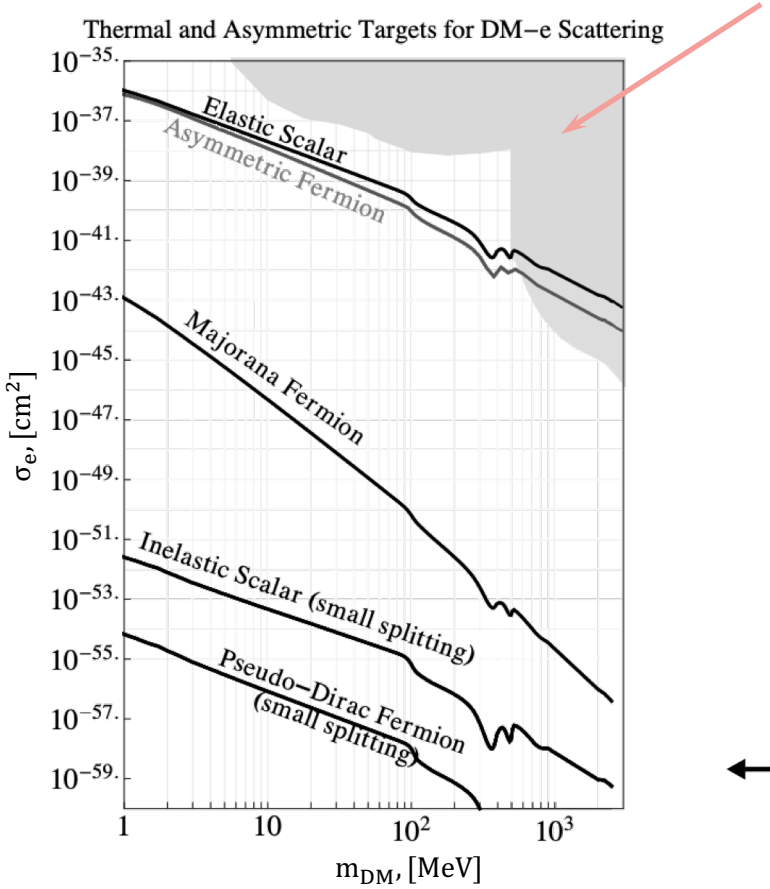
Svetlana Gertsenberger[1], A. Ivanov[1], A. Zhevlakov[2]

[1] JINR, Veksler and Baldin Laboratory of High Energy Physics

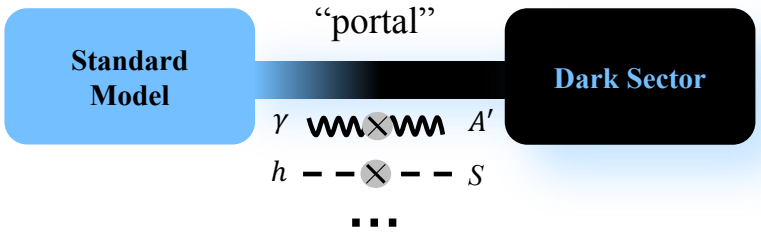
[2] JINR, Bogolyubov Laboratory of Theoretical Physics

AYSS 2025, 27.10.2025

introduction



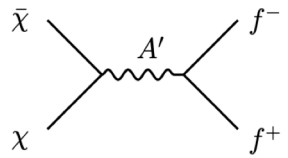
LDMX Collaboration, arxiv:1808.05219v1



Thermal targets for representative Dark Matter candidates in terms of the electron-recoil direct detection cross section σ_e vs. mass m_{DM}

Each scenario differs by many orders in the σ_e plane due to DM velocity suppression factors, loop-level factors, or spin suppression, any of which are significant for non-relativistic scattering.

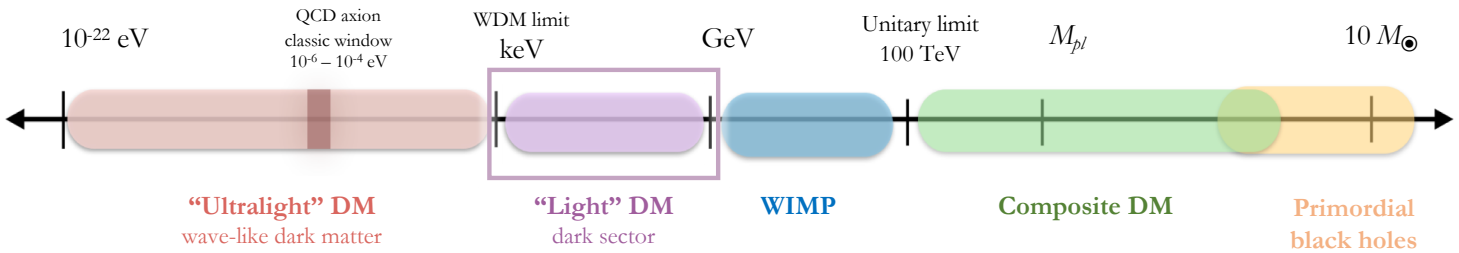
$$\sigma v \propto \epsilon^2 \alpha_D$$



DM particles scattering off electrons or nuclei has very small cross section and small recoil energy.

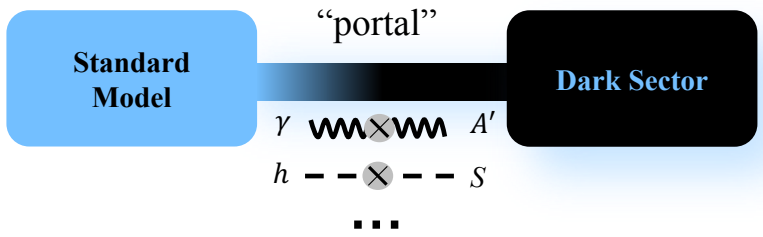
DM-SM thermal equilibrium in early Universe. Currently observed DM relic density is connected to $\chi + \chi \rightarrow SM + SM$ annihilation cross section ("freeze-out" mechanism).

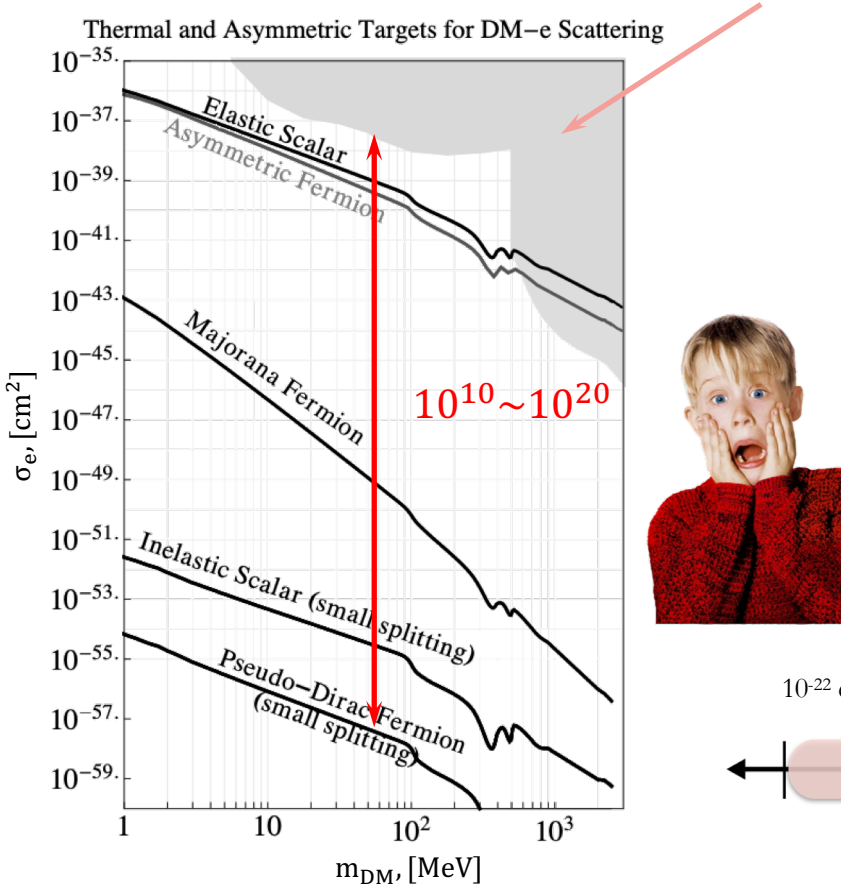
$\alpha_D = e_D^2/4\pi$ – *dark coupling*



arXiv:1904.07915

introduction





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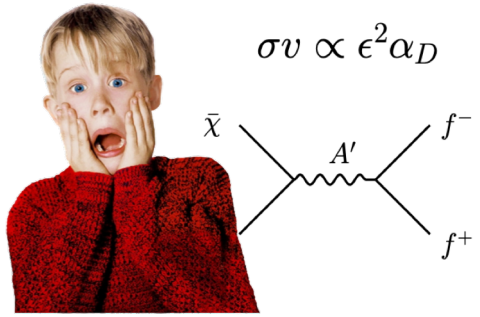

DM particles scattering off electrons or nuclei has very small cross section and small recoil energy.

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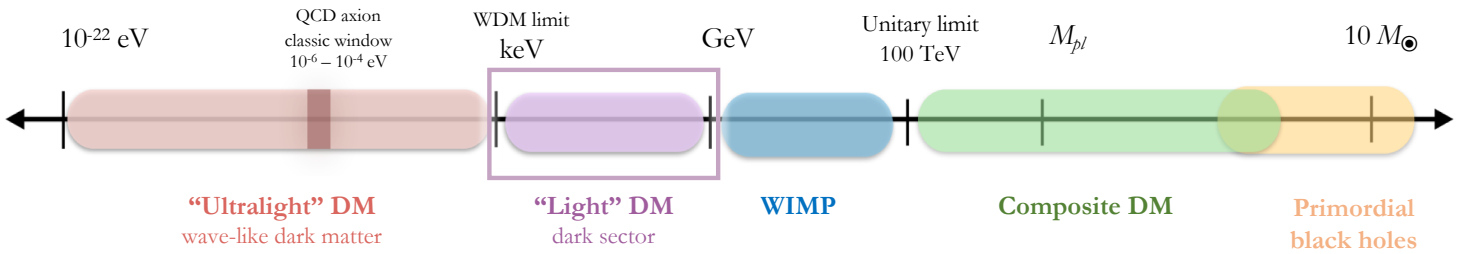
$\alpha_D = e_D^2/4\pi$ – *dark coupling*

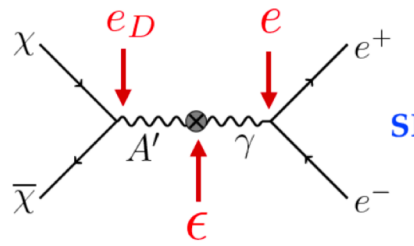


arXiv:1904.07915

introduction

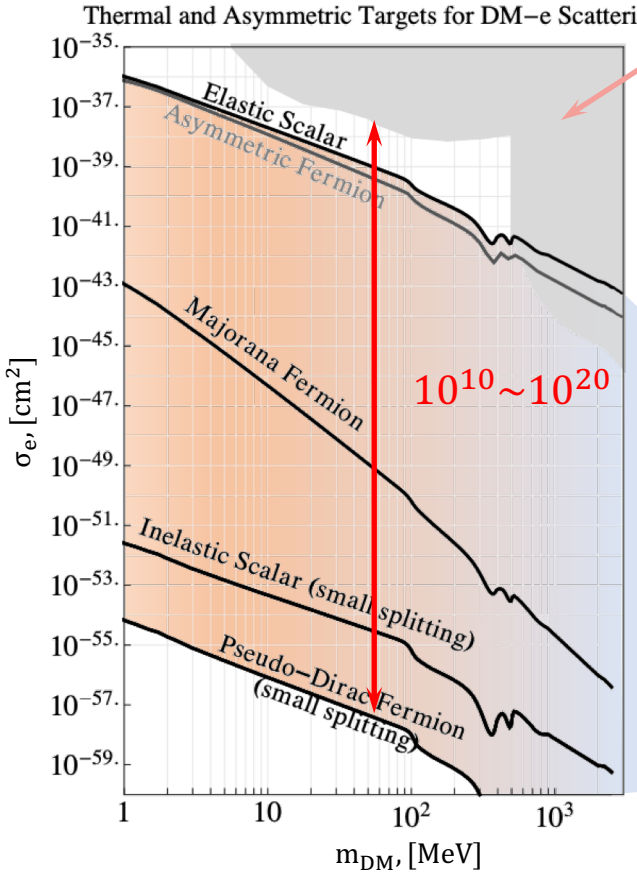
Current constraints

$\alpha_D \equiv \frac{e_D^2}{4\pi}$ **DM** **SM** $\alpha \equiv \frac{e^2}{4\pi}$



$$\sigma v(\chi\chi \to A'^* \to ff) \propto \epsilon^2 \alpha_D \frac{m_\chi^2}{m_{A'}^4} = \frac{y}{m_\chi^2} \quad , \quad y \equiv \epsilon^2 \alpha_D \left(\frac{m_\chi}{m_{A'}}\right)^4$$

useful coupling for comparison different experiments



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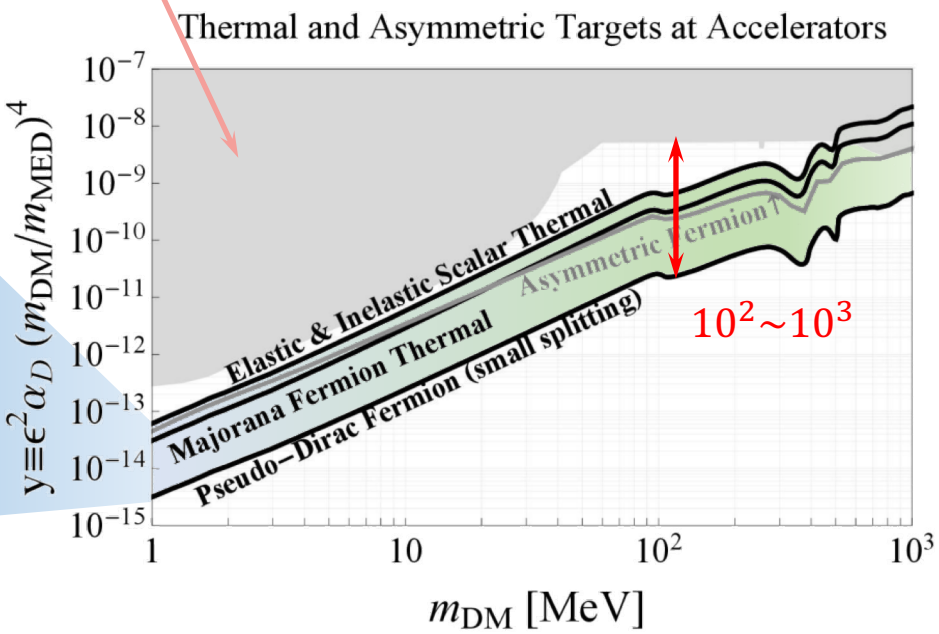
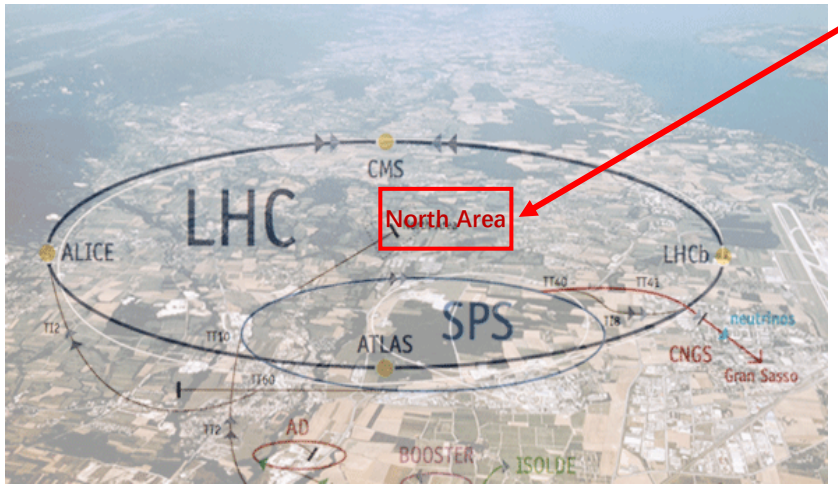


NA64 approach allows searching for Light Dark Matter (LDM) in the range mass MeV – GeV in the experiment at the SPS accelerator at CERN

NA64 experiment



Motivation: search for new physics beyond the SM

Realization: combine the active beam dump and missing energy techniques to search for rare events

NA64e (since 2015)
100 GeV *e*-beam

Search for vector-mediated LDM

The NA64 Collab., arXiV:1312.3309

NA64μ (since 2021)
160 GeV μ-beam
Z' as a solution to the $(g-2)_\mu$ and complementary LDM searches

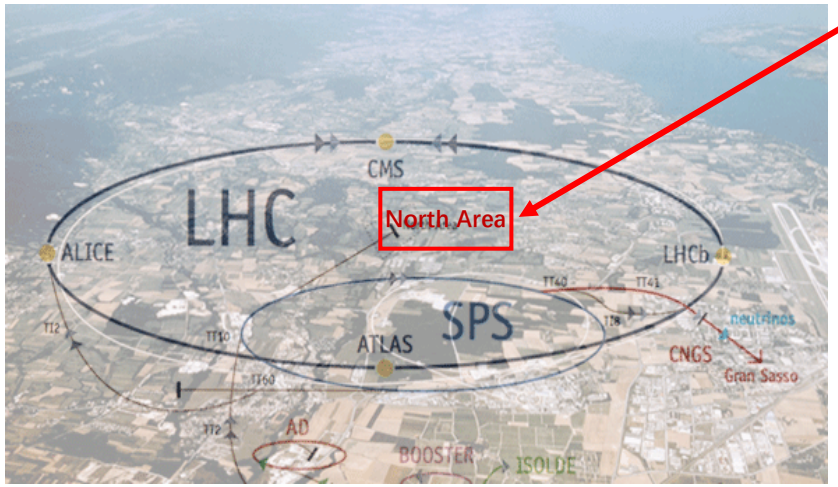
D. Banerjee et al. (The NA64 Collab.), CERN-SPSC2019-002/SPSC-P-359

NA64h (test run 2025)
50 GeV π-beam

Search for hadrophilic DS

Y. M. Andreev et al. [NA64] arXiv:2406.01990

NA64 experiment



NA64

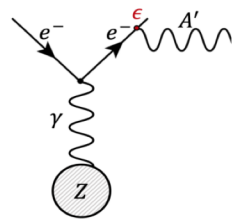
NA64e (since 2015)
100 GeV *e*-beam

Search for vector-mediated LDM

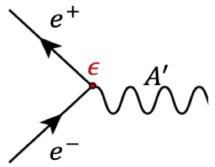
The NA64 Collab., arXiV:1312.3309

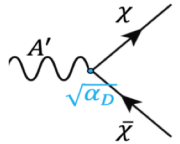
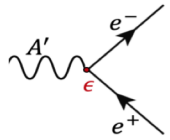
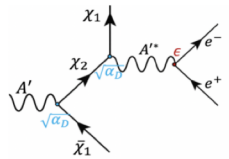
Active Dump + **Fully hermetic detector**

A'-Bremsstrahlung



Resonant A' production



Decay	Signature
• *Invisible* $m_{A'} > 2m_\chi$ 	Missing energy
• *Visible* $m_{A'} < 2m_\chi$ 	SM pair particles
• *Semi-Visible* $m_{A'} > m_{\chi_1} >> m_e$ 	Missing energy + SM pair particles

B. Banto Oberhauser DOI 10.22323/1.481.0015

Motivation: search for new physics beyond the SM

Realization: combine the active beam dump and missing energy techniques to search for rare events

NA64 experiment

NA64e (since 2015)
100 GeV e-beam

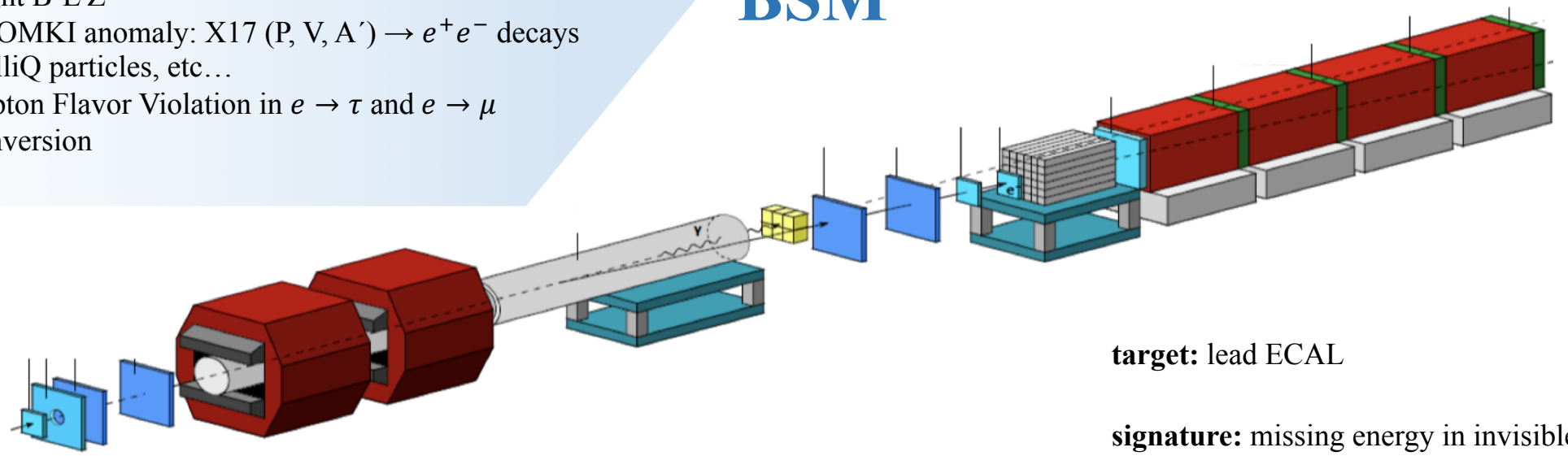
Search for vector-mediated LDM

The NA64 Collab., arXiV:1312.3309

- **Thermal sub-GeV Dark Matter (LDM)**
- axions, ALP, S $\rightarrow \gamma\gamma$ decays
- S, P, V, and A dark portal particles, their invisible, visible, semi-visible decays
- Light B-L Z′
- ATOMKI anomaly: X17 (P, V, A′) $\rightarrow e^+e^-$ decays
- MilliQ particles, etc…
- Lepton Flavor Violation in $e \rightarrow \tau$ and $e \rightarrow \mu$ conversion

BSM

$N_{eot} = 2.6 \times 10^{12}$

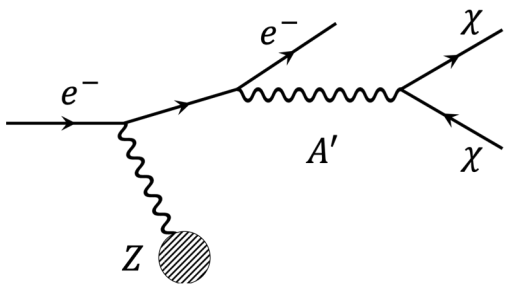


target: lead ECAL

signature: missing energy in invisible mode or SM particles pair production in visible mode

A. Andreas et al. [NA64 Collaboration]. CERN-SPSC-2013-034; SPSC-P-348 (2013)
Yu. Andreev et al. [NA64 Collaboration] Phys.Rev.Lett. 129 (2022) 16, 161801
Phys. Rev. Lett. 125, 081801 (2020)

vector meson search motivation



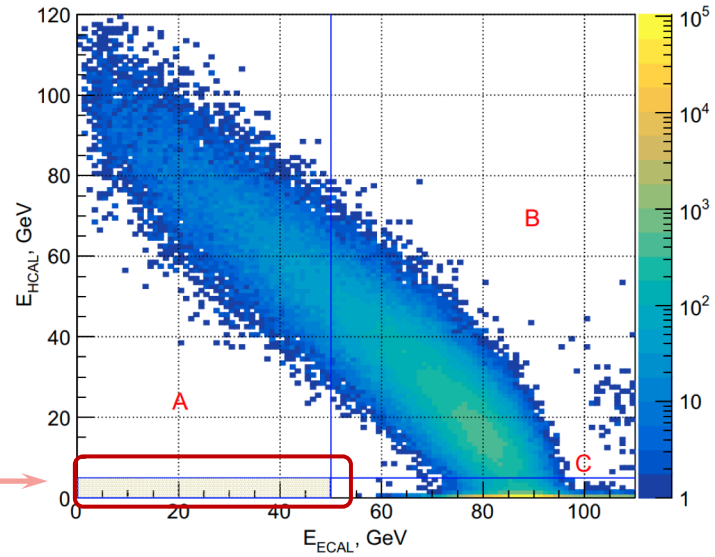
Schematic view of the Dark Matter (DM) signal from A' Bremsstrahlung.
DM is produced in the target (ECAL)

$E_{ECAL} < 50\ GeV + E_{HCAL} < 1\ GeV$

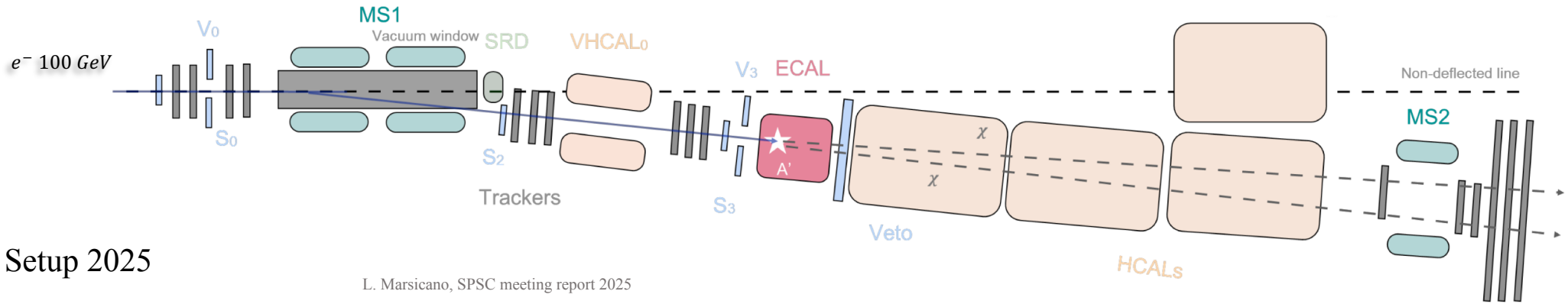
$E_{ECAL} + E_{HCAL} \simeq 100\ GeV$

Well-reconstructed 100 GeV electron track

NA64 collaboration, Phys. Rev. Lett. 131, 161801



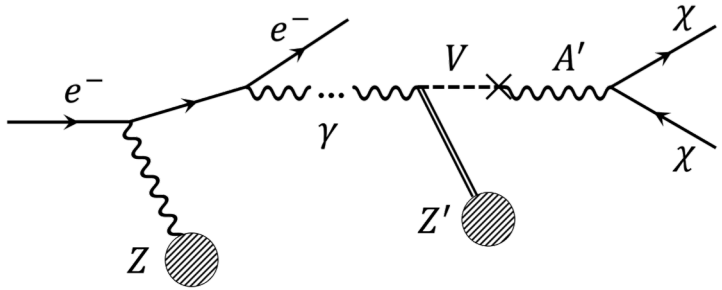
Signal box



Setup 2025

L. Marsicano, SPSC meeting report 2025

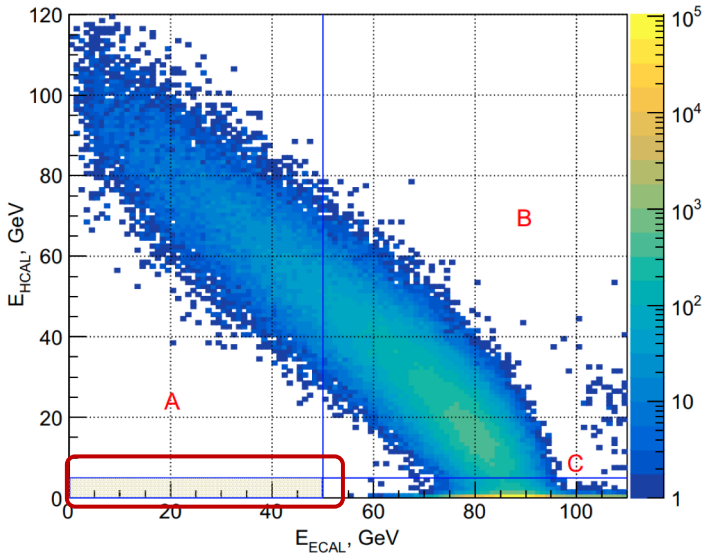
vector meson search motivation

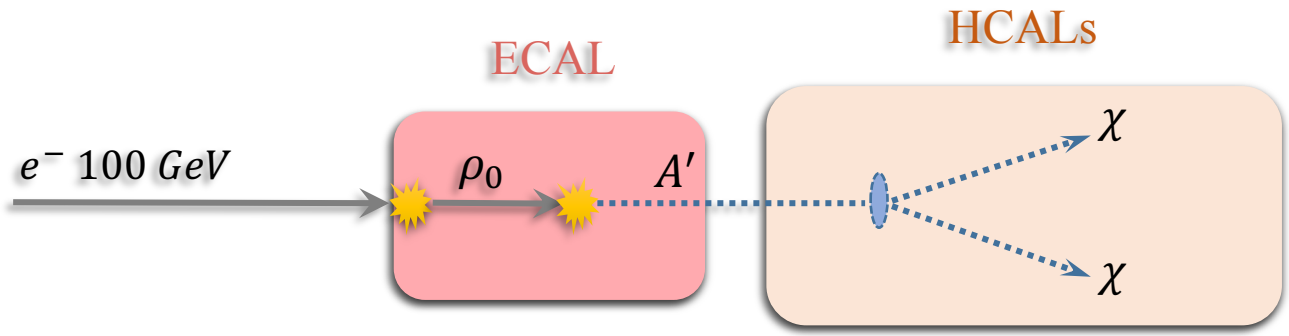


$V = \rho_0, \omega, \varphi$

A hard photon is produced in the ECAL, and converts to a vector meson V in an exclusive photoproduction process in the calorimeter. The vector meson then decays invisibly to DM via mixing with the A'.

NA64 collaboration, Phys. Rev. Lett. 131, 161801





New additional channel for A' searches

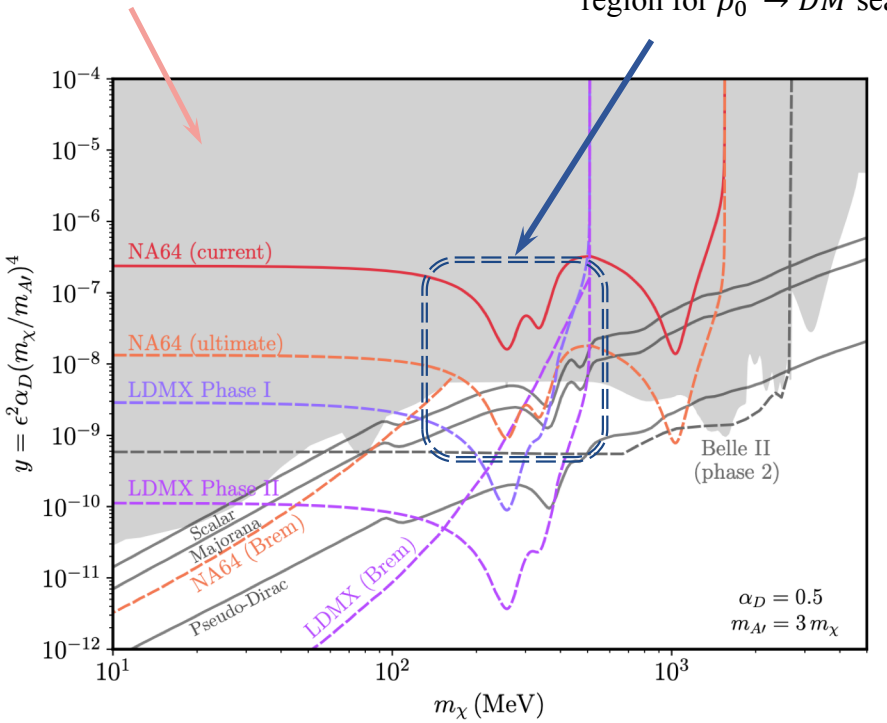
theoretical bounds

P. Schuster, Phys. Rev. D 105, 035036 (2022)

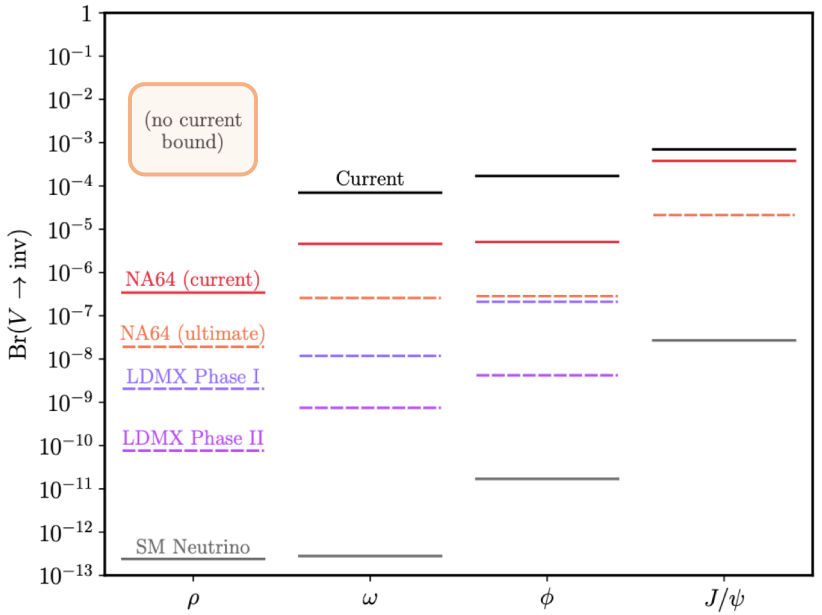
The constraints on dark sectors

Current constraints on the A' model

region for $\rho_0 \rightarrow DM$ searching

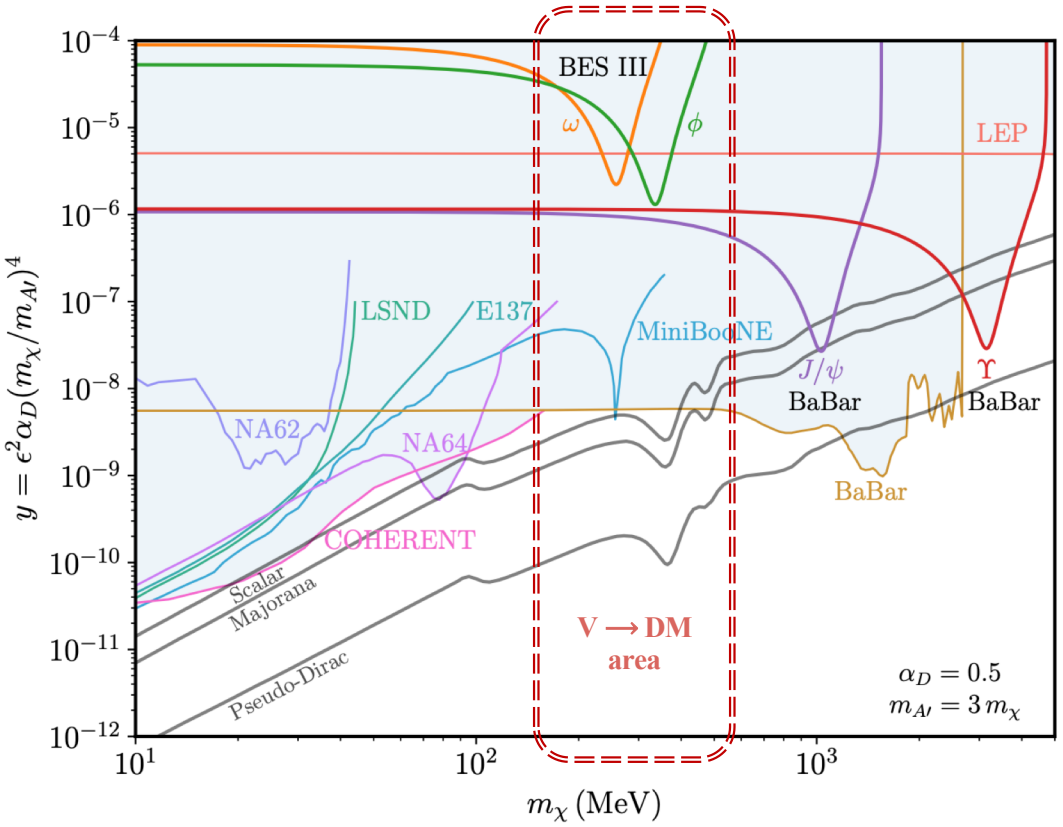


Projected exclusions for the NA64 and LDMX experiments



Bounds on invisible meson decay

experimental searches



Constraints on the dark photon model and existing constraints from current bounds on invisible vector meson decays

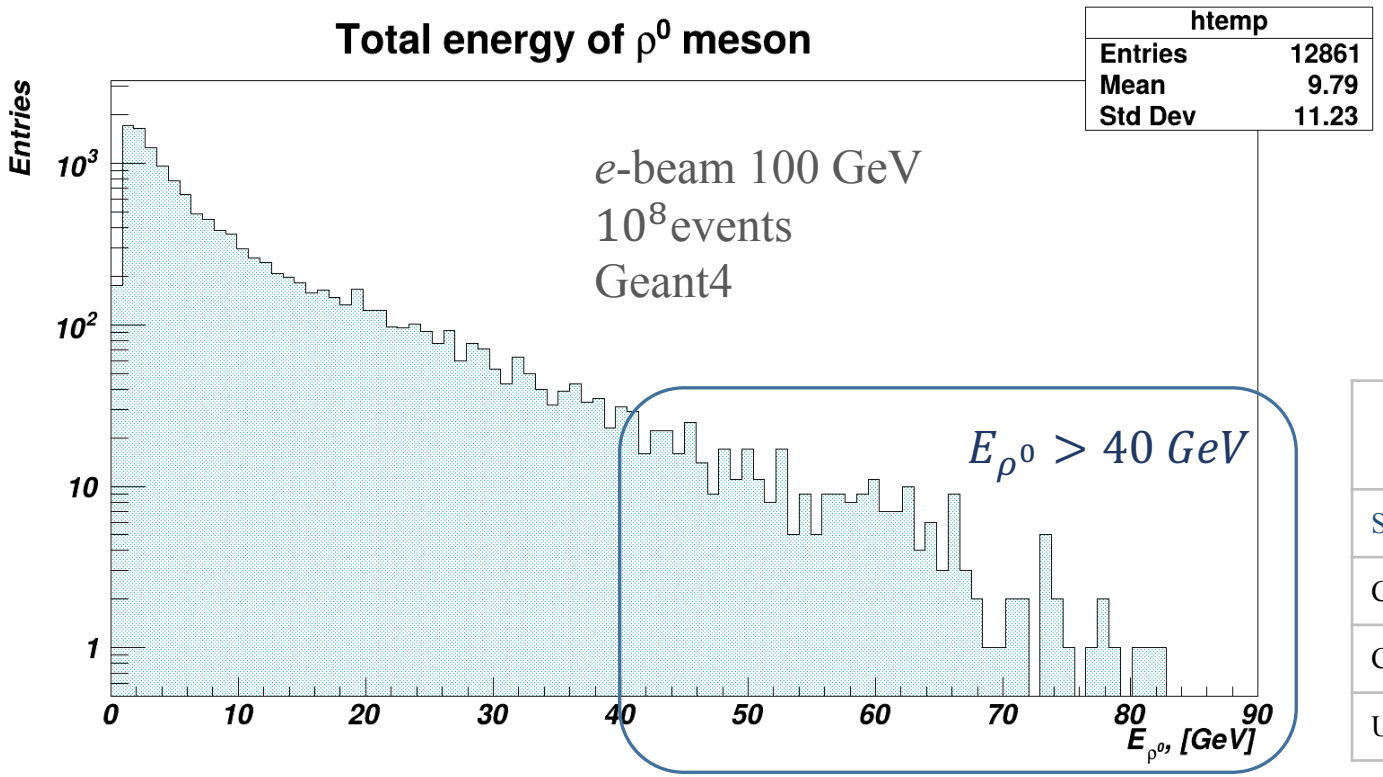
P. Schuster, Phys. Rev. D 105, 035036 (2022)

There is no existing experimental bound for $\rho_0 \rightarrow DM$ process.

	Br(V ⟶ invisible)	Experiment
ρ_0	?	**NA64?**
ω	$< 7.3\times10^{-5}$	BES III (2018) arXiv:1805.05613
φ	$< 1.7\times10^{-4}$	BES III (2018) arXiv:1805.05613
J/ψ	$< 7\times10^{-4}$	BaBar (2013) arXiv:1303.7465
Υ	$< 3\times10^{-4}$	BaBar (2009) arXiv:0908.2840

y – dimensionless coupling that defines the annihilation cross section
m_χ – DM mass
$\alpha_D = e_D^2/4\pi$ – dark coupling
$V = \rho_0, \omega, \varphi$

ρ_0 - *mesons simulation*



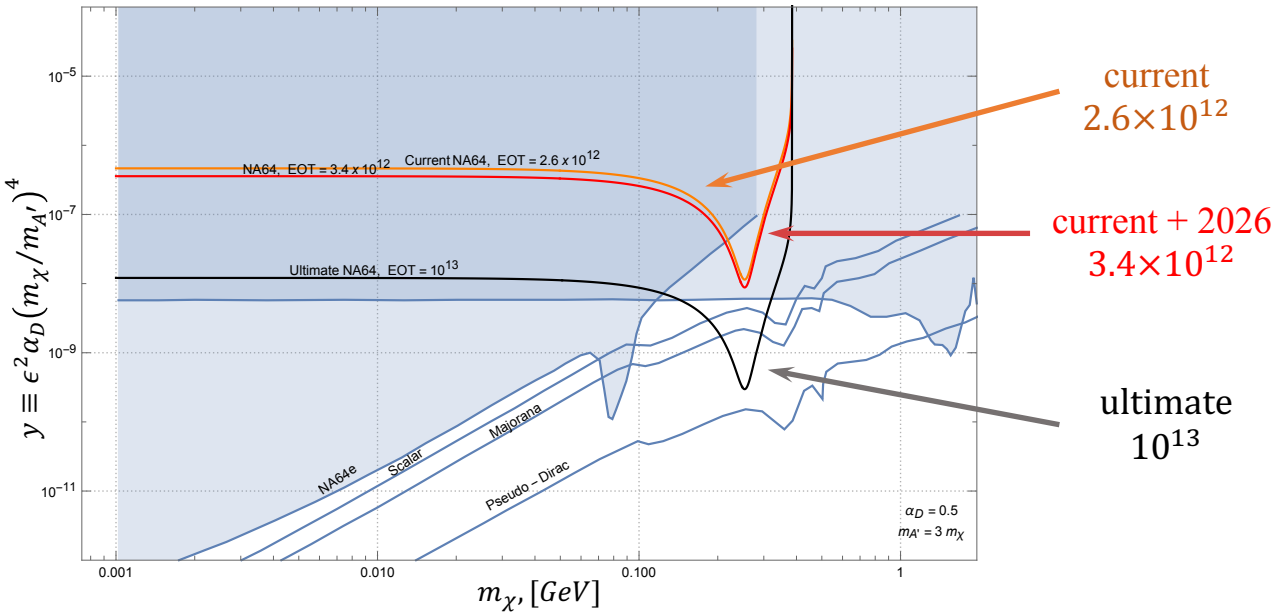
The total energy distribution of ρ_0 - mesons produced in 100 million events of a 100 GeV electron beam

- the majority of ρ_0 - meson are low energy and decay early in the target
- For the further analysis it is necessary $\boldsymbol{E_{\rho^0} > 40\ GeV}$ or $E_{\rho^0} > 30\ GeV$ in the optimistic case

Statistics	N_{EOT}	N_{ρ_0} for different energies		
		40 GeV	30 GeV	20 GeV
Simulation	10^8	3.6×10^3	8.7×10^3	1.9×10^4
Current	2.6×10^{12}	9.47×10^6	2.7×10^7	4.95×10^7
Current + 2026	3.4×10^{12}	1.23×10^7	2.96×10^7	6.45×10^7
Ultimate (+ run 4)	10^{13}	3.64×10^8	8.74×10^8	1.9×10^9

ρ_0 - *mesons simulation*

The constraints on the dark photon model based on the simulation



current
2.6×10^{12}

current + 2026
3.4×10^{12}

ultimate
10^{13}

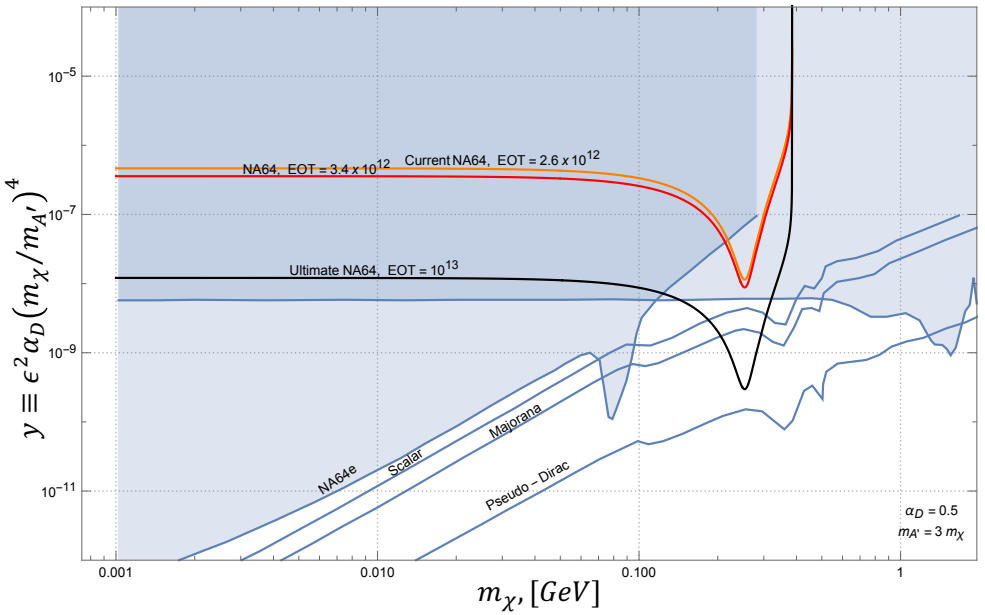
$E_{\rho^0} > 40\ GeV$

- Still not enough amount of ρ^0 to improve dark photon constraints
- Anyway it can be the first experimental results for this type of ρ^0 decay

ρ_0 - *mesons simulation*

The constraints on the dark photon model based on the simulation

Due to ECAL threshold it is impossible to investigate region $80\ GeV < E_{ECAL} < 100\ GeV$ and very hard $70\ GeV < E_{ECAL} < 100\ GeV$

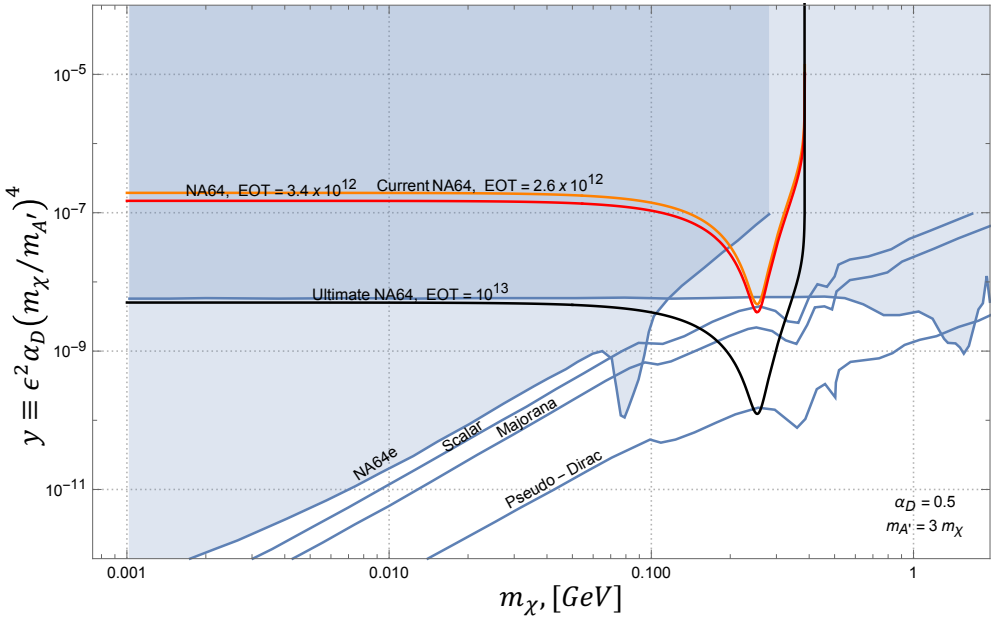


$E_{\rho^0} > 40\ GeV$

current
2.6×10^{12}

current + 2026
3.4×10^{12}

ultimate
10^{13}



$E_{\rho^0} > 30\ GeV$

summary

- With statistics of total electrons on target $N_e = 2.6 \times 10^{12}$ collected since 2015,

9.47×10^6 high energy ρ_0 with energy $E_{\rho^0} > 40\ GeV$ are expected.

- After analysing the data, this will be the first experimental constraint on invisible ρ_0 meson decays.

Despite this, the dark photon model limit cannot be improved with the current statistics.

- It is difficult to use existing strategy. A different analysis strategy is needed.

For example change the setup or investigate of ρ_0 decay using others beams

Thanks!