NA64 project: «Search for the dark sectors in missing energy events»

JINR participation in the NA64 project

Collaboration: Univ. of Bonn (Bonn), JINR(Dubna), INFN (Genova), LPI, INR, SINP MSU (Moscow), IHEP (Protvino), TPU(Tomsk), SAPHIR(Chile), IFIC(Valencia), ETH(Zurich)

VBLHEP: G.Kekelidze, V.Kramarenko, V.Lysan, *I.Zhukov,* T.Enik, K.Salamatin, I.Kambar, P.Volkov, D.Peshekhonov, E.Kasianova, S.Gertsenberger, A.Ivanov
BLTP: V.A.Matveev, A.Zhevlakov
DLNP: V.Frolov

FTE:

Detector operation & support - 3,0;
Analysis and MC simulation - 3,0;
Theory - 0,5

Management and support

V.A.Matveev - JINR team leader
D.Peshekhonov - JINR team co-leader
K.Salamatin – experiment DAQ experts

NA64 experiment in brief

- Proposed as P348 in 2014
- Feasibility run in 2015
- Approved in March 2016.
- Proposal to run with M2 muon beam (NA64μ) in 2019.
- Runs taken

2016 – 5 weeks at H4 (NA64e) ~4,5x10^{10}eot,

2017 – 5 weeks at H4 (NA64e) ~5,5x10^{10}eot,

2018 – 6 weeks at H4 (NA64e) ~2,0x10^{11}eot,

2017-18 in visible mode ~ 8,4x10^{10}eot,

2021 – 5 weeks at H4 (NA64e) ~ 5,2x10^{10}eot,

2022 –10weeks at H4 (NA64e) ~ 6,4x10^{11}eot,

e^+ ~ 5,0x10^{10}eot

Total accumulated **~10^{12}eot, analyzed ~3,4x10^{11}eot**

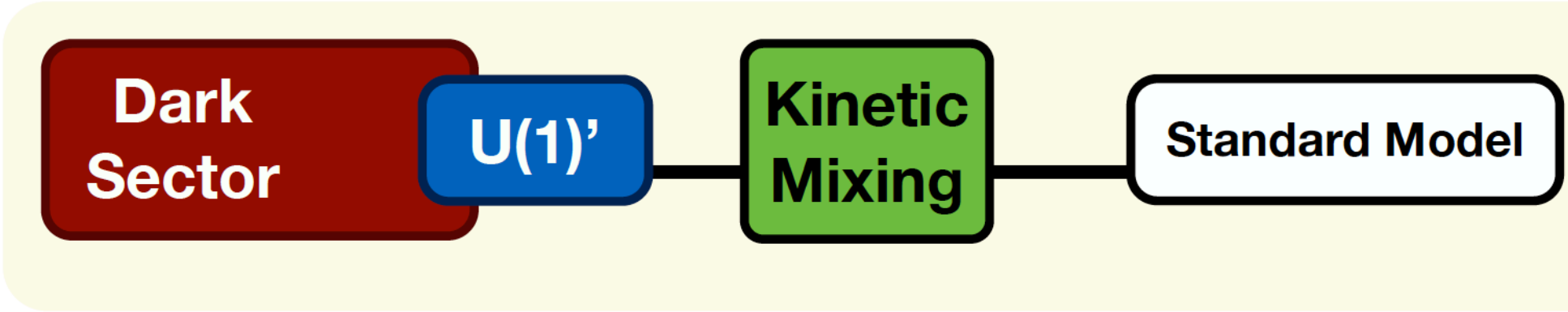
2021 – 3 weeks pilot-run at M2 (NA64μ)

2022 – 3 weeks pilot-run at M2 (NA64μ)

Total accumulated ~4x10^{10}μot

2023 – 8 weeks NA64e & 3weeks NA64μ

Dark Sector the vector portal



DARK SECTOR (DS) charged under a new U(1)' gauge symmetry and interacts with SM through kinetic mixing (ε) of a MASSIVE VECTOR MEDIATOR (A') with our photon. Dark matter with mass (m_X), part of DS.

In this framework DM can be produced thermally in the early Universe

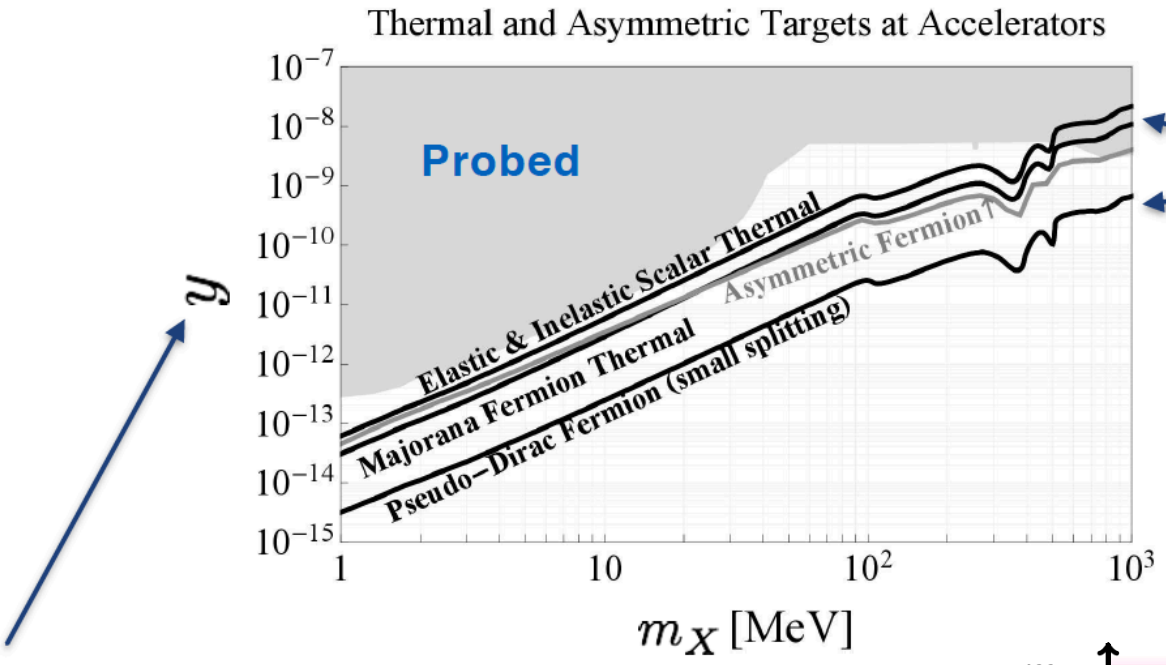
OBSERVED **AMOUNT OF DARK MATTER** TODAY

$$\Omega_X \propto \frac{1}{< v\sigma >} \sim \frac{m_X^2}{y}$$

WHERE $y = \epsilon^2 \alpha_D \left(\frac{m_X}{m_{A'}}\right)^4$

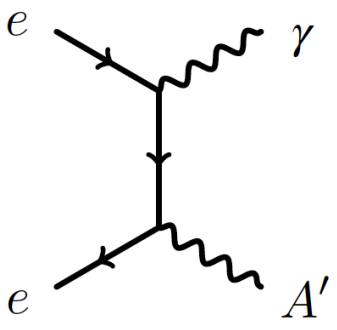
Dark Matter (y,m_x) parameter space

From https://arxiv.org/pdf/1707.04591.pdf

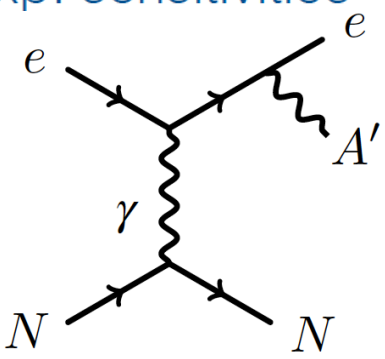


Solid lines predictions from DM relic abundance

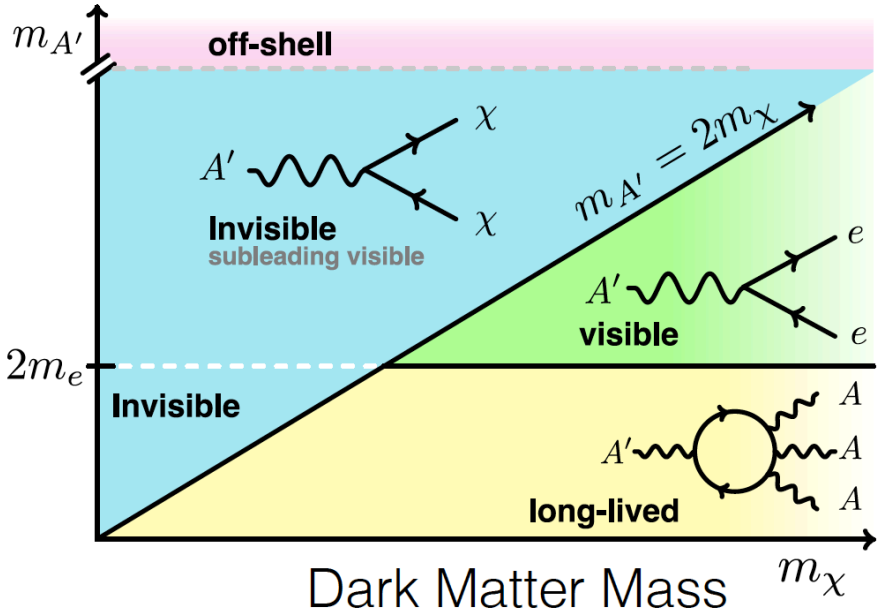
DM -> SM annihilation rate is ~ y, useful variable to compare exp. sensitivities



annihilation

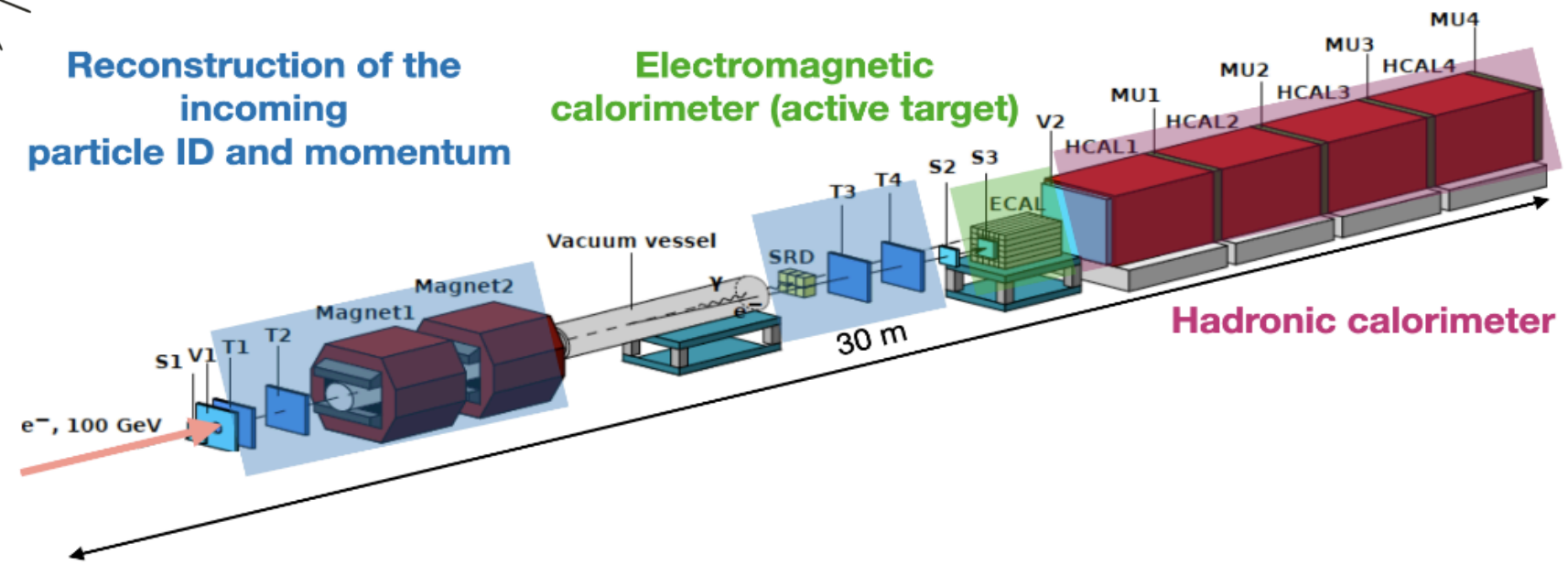


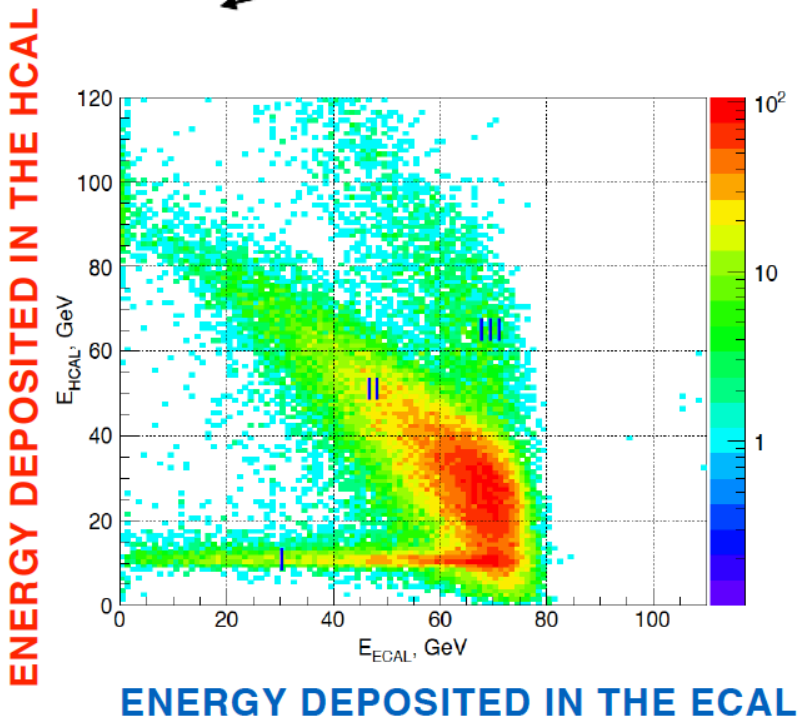
bremsstrahlung



Dark Matter Mass

NA64 approach





★ **Region I:** e- Z → e-Zγ; γ → μ+μ-
→ benchmark for MC

★**Region II:** SM events
$E_{ECAL} + E_{HCAL} \simeq 100$ GeV

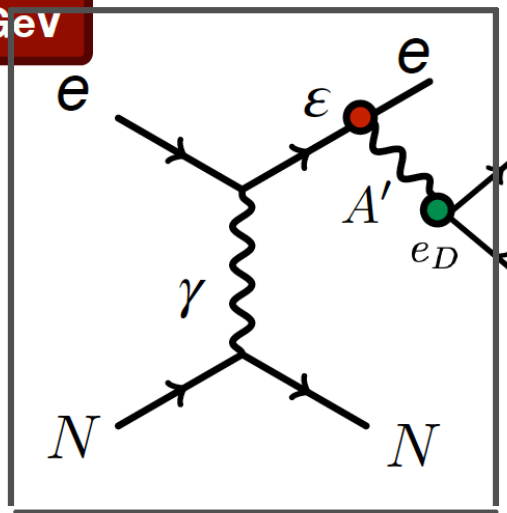
★**Region III** —> pile-up events

NA64 approach

TAGGED 100 Gev

Requested ECAL ENERGY < 50 GeV

Active Dump



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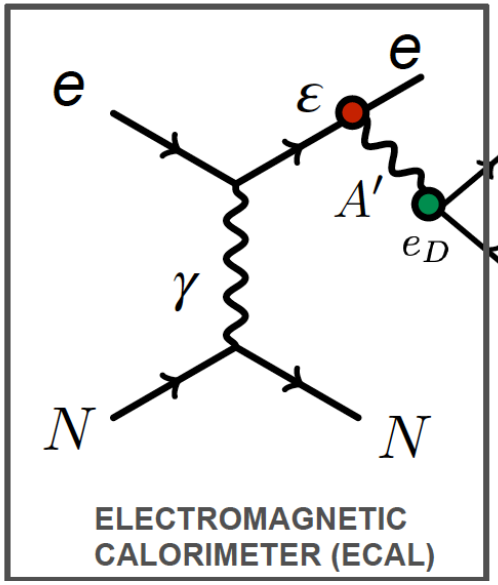
"BREMSSTRAHLUNG" OF A'



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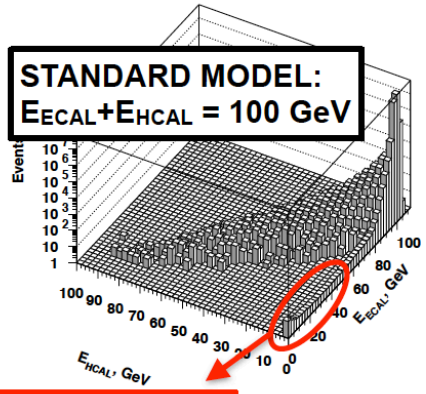
HADRONIC CALORIMETER (HCAL)

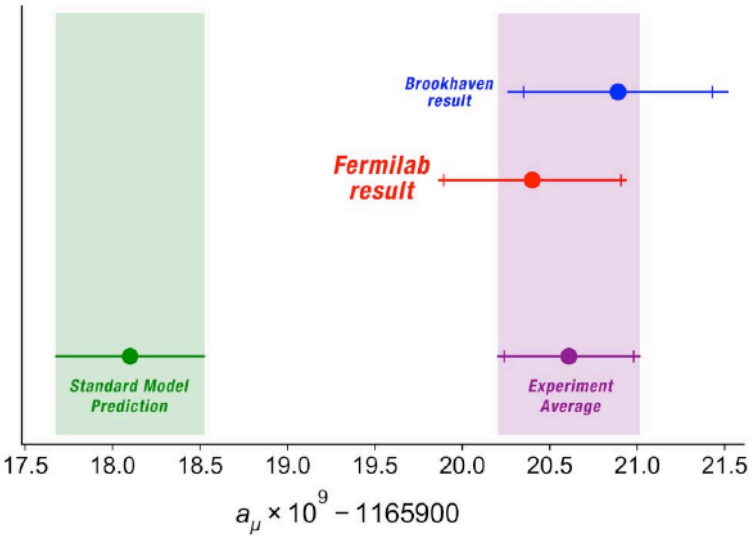
STANDARD MODEL:
$E_{ECAL}+E_{HCAL}$ = 100 GeV

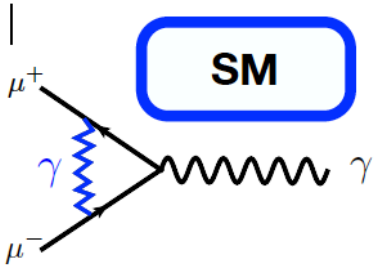


A'→ MISSING ENERGY:
ECAL < 50 GeV
HCAL < 2 GeV

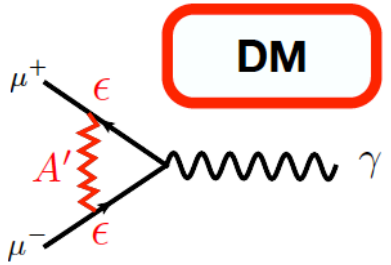
Muon (g-2): additional motivation to search for A'

B. Abi, et al. Phys. Rev. Lett. 126, 141801 (2021)



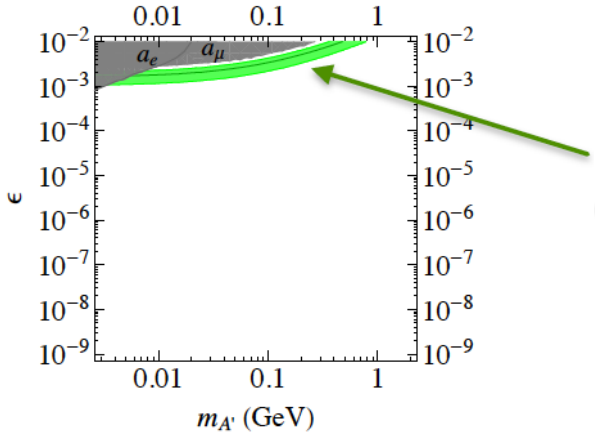


$$(g_s-2)^{\gamma}_{\mu} \simeq \frac{\alpha}{2\pi} \simeq 10^{-3}$$



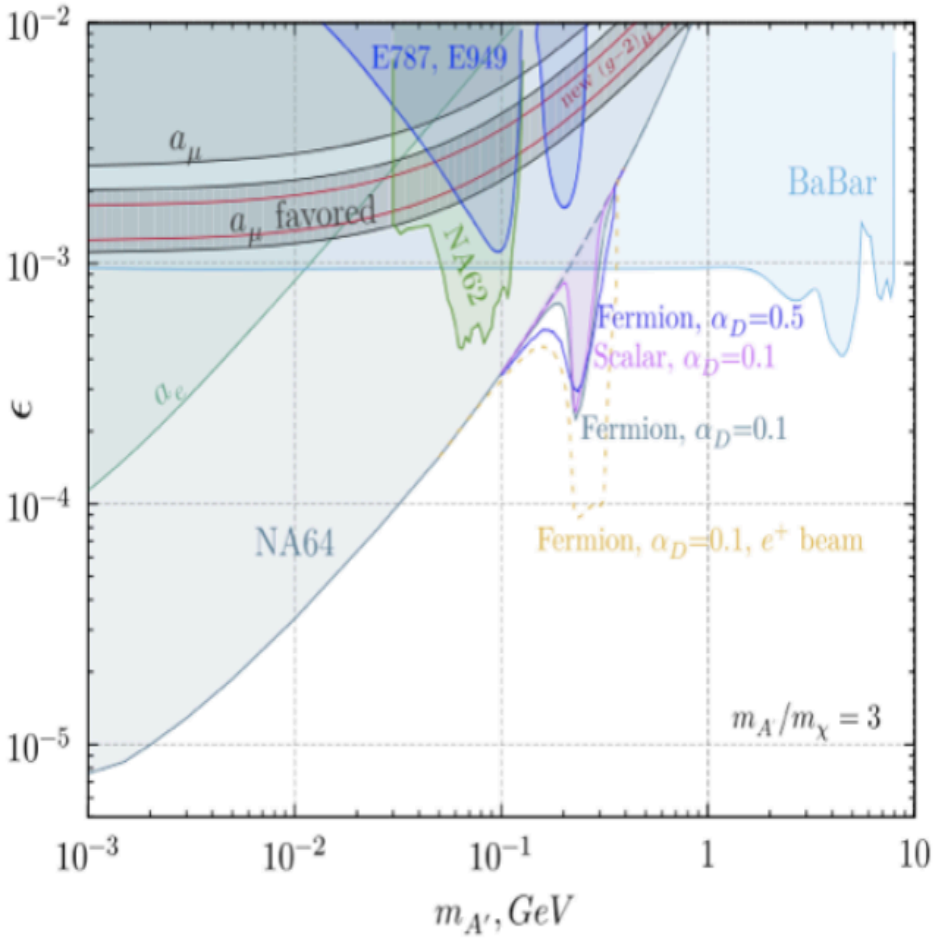
$$(g_s-2)^{A'}_{\mu} \simeq \frac{\alpha}{2\pi} \times \epsilon^2 \simeq 10^{-3} \times \epsilon^2 \qquad (m_{A'} \ll m_\mu)$$

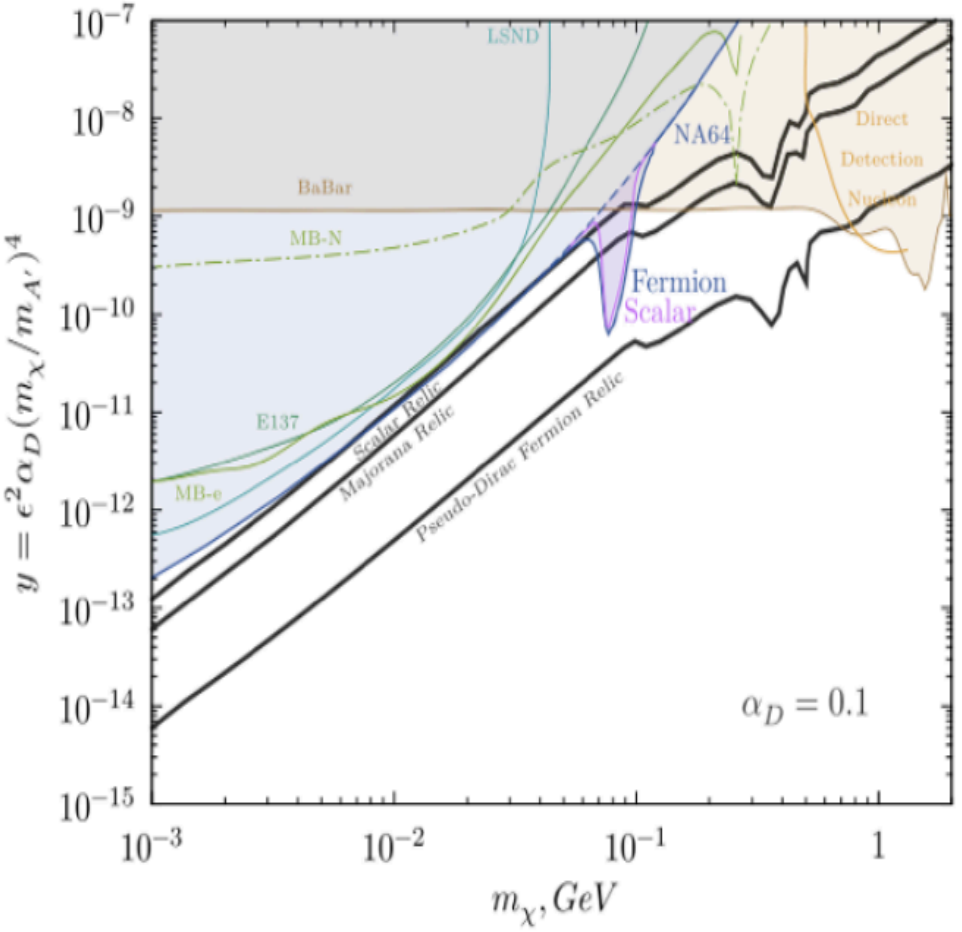
M. Pospelov, A. Ritz and M. B. Voloshin, Phys. Lett. B 662, 53 (2008)



A' may explain observed anomaly

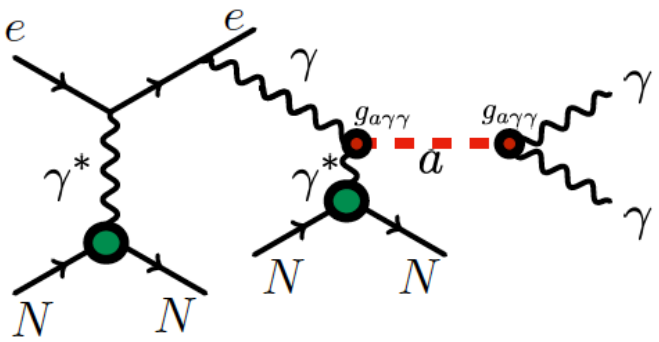
NA64 invisible mode current status





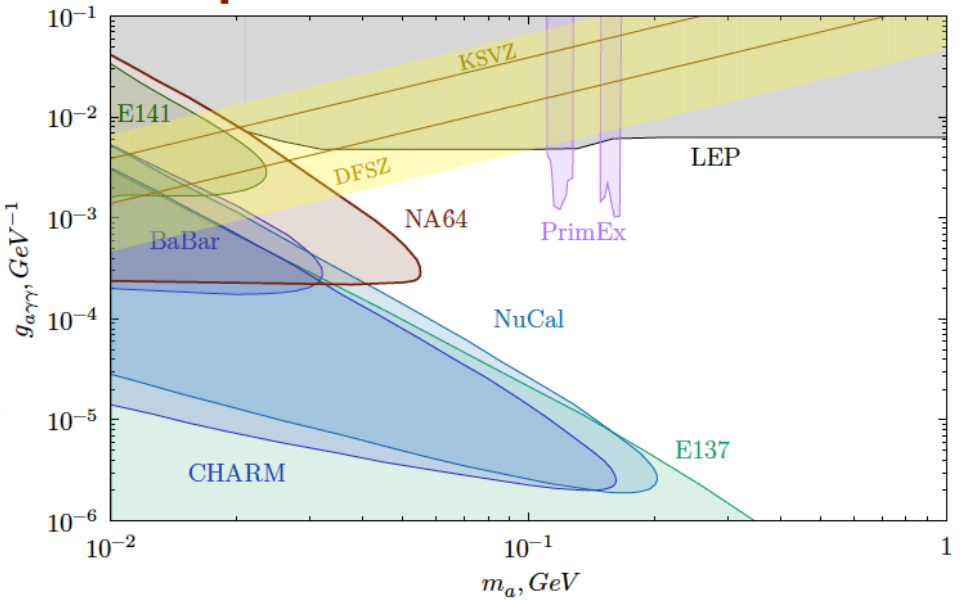
Current status of NA64 experiment 90% C.L. exclusion limits on A' invisible decays including both the Bremsstrahlung and the resonant A' production channeks (left), LDM searches (right)

NA64 ALP search

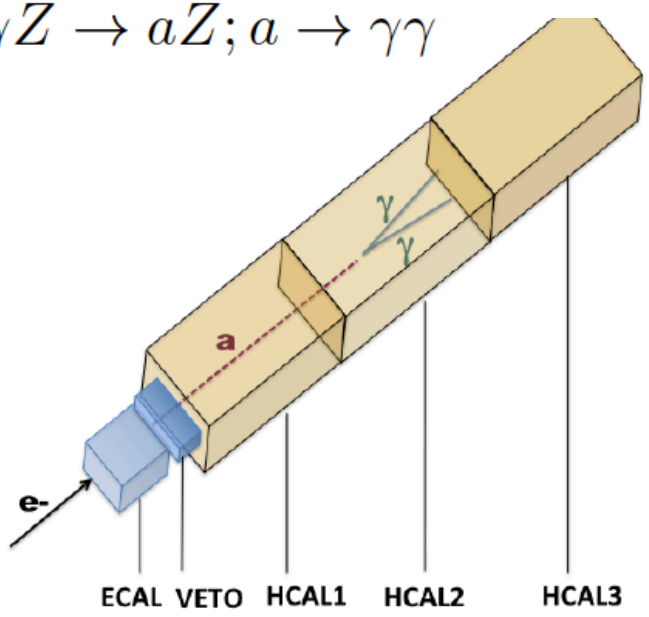


Production via Primakoff effect

Closing the gap between beam dump and colliders

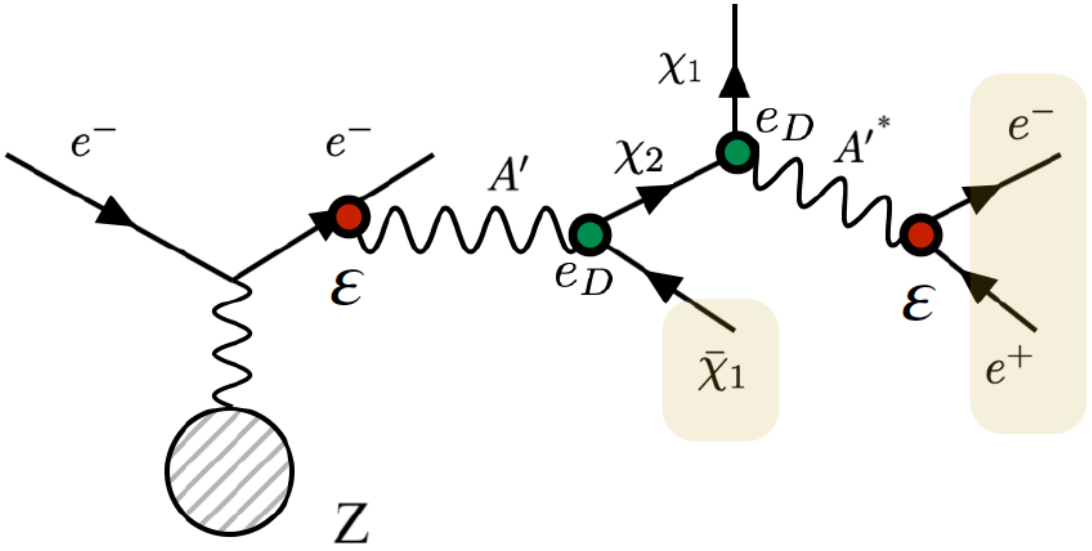


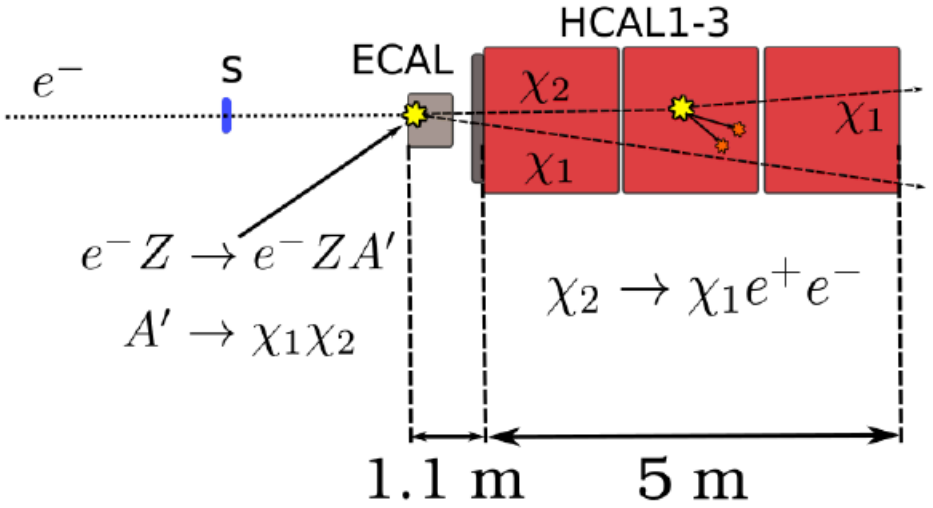
$$e^- Z \to e^- Z\gamma; \gamma Z \to aZ; a \to \gamma\gamma$$



NA64 semivisible mode

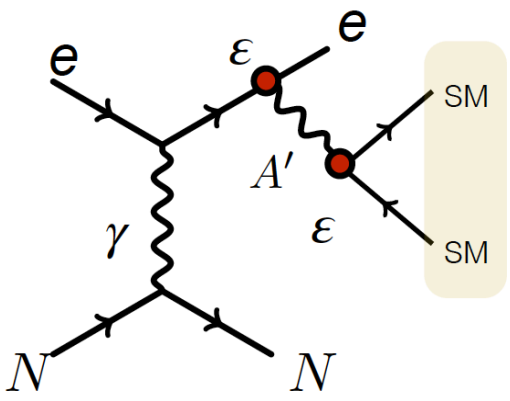
SEMIVISIBLE DECAY MODE

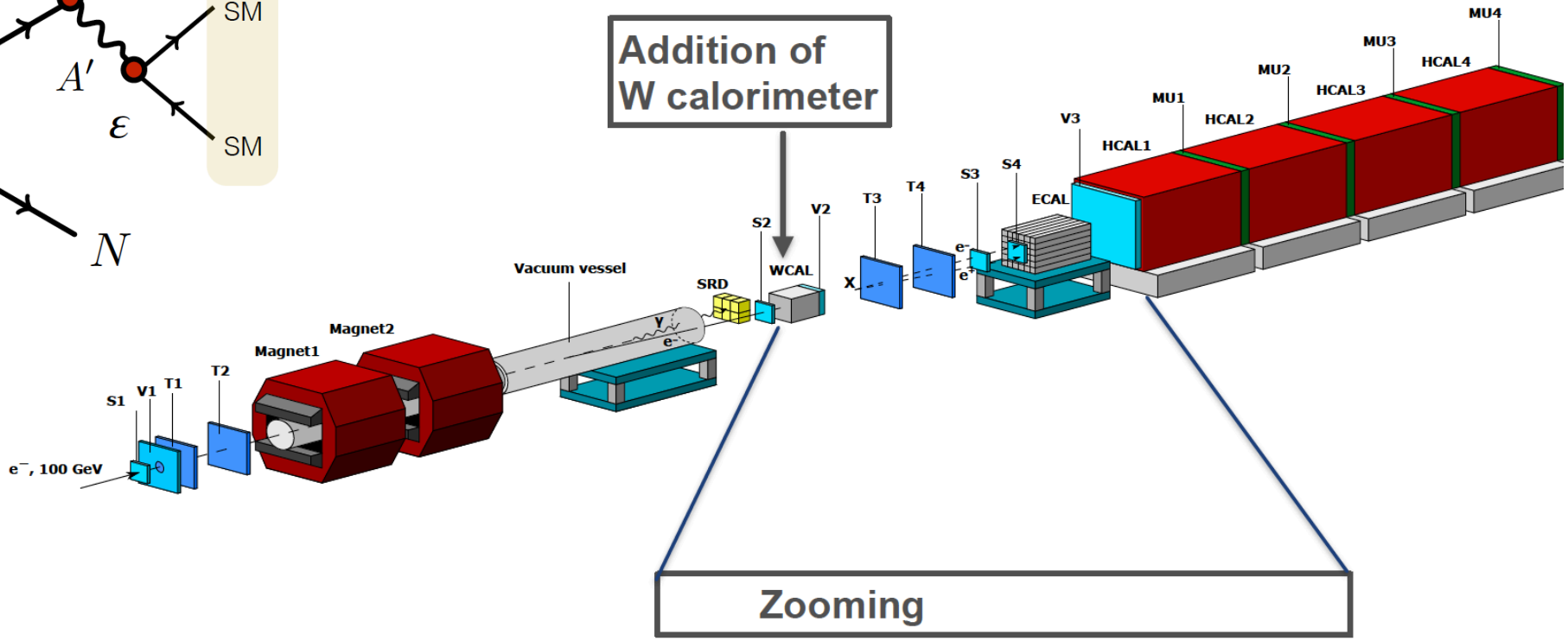


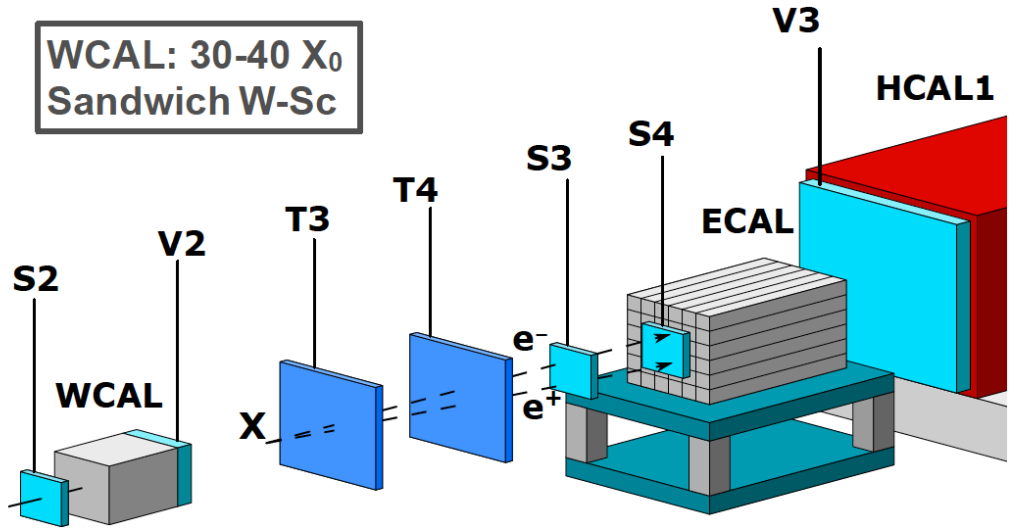


VISIBLE DECAY MODE $m'_A < 2m_X$

NA64 visible mode



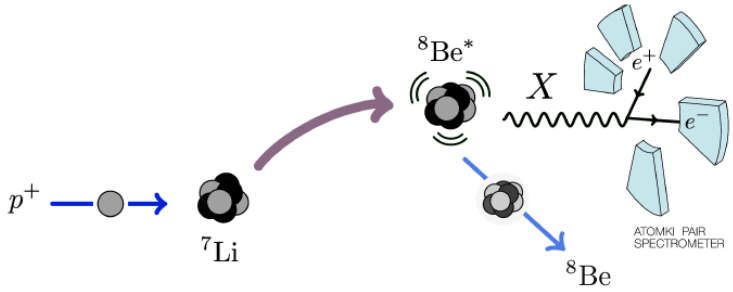




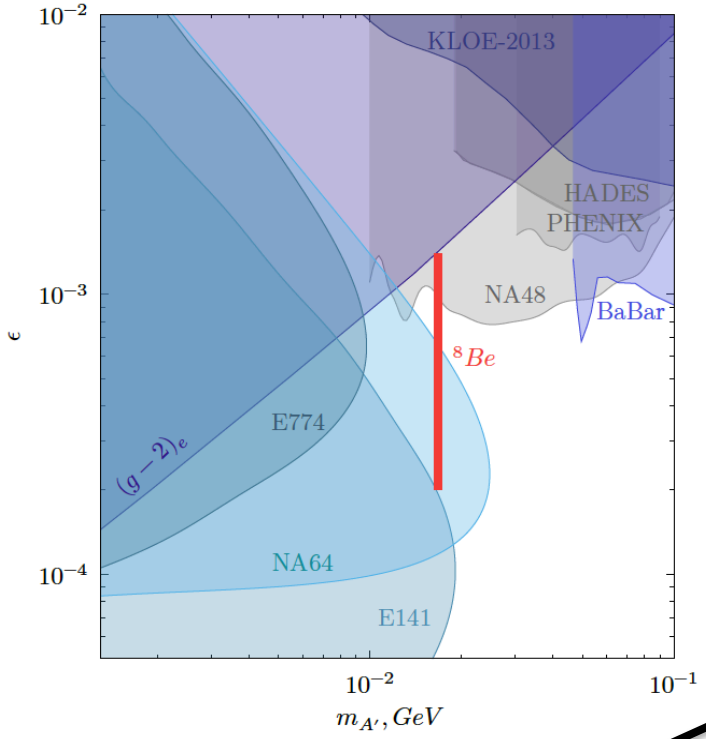
Signature:
1) $E_{WCAL}+E_{ECAL}$ = 100 GeV
2) No activity in $V_{2,3}$ and HCAL
3) Signal in S3, S4
4) e-m shower in ECAL

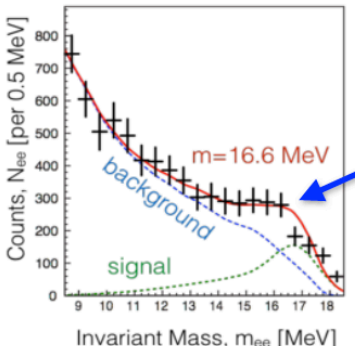
NA64 visible mode

^{8}Be anomaly and X boson



A. J. Krasznahorkay et al. Phys. Rev. Lett.116, 042501 (2015) and recent results for 4He arXiv:1910.10459

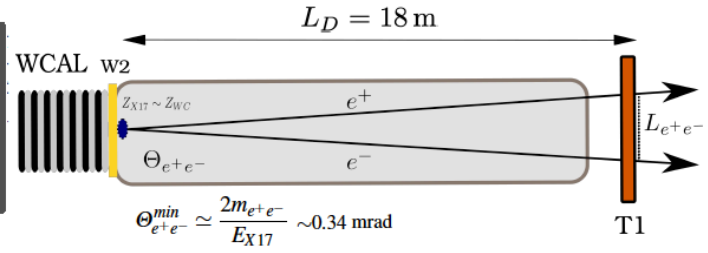




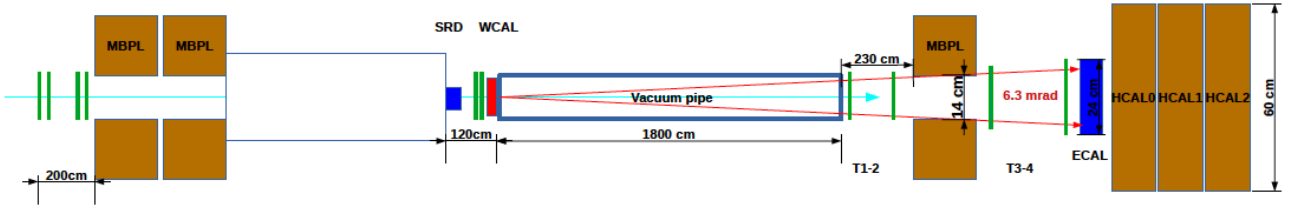
Could be explained by new 'protophobic' gauge boson X with mass around 17 MeV

J. L. Feng et al. Phys. Rev. D95, 035017 (2017)

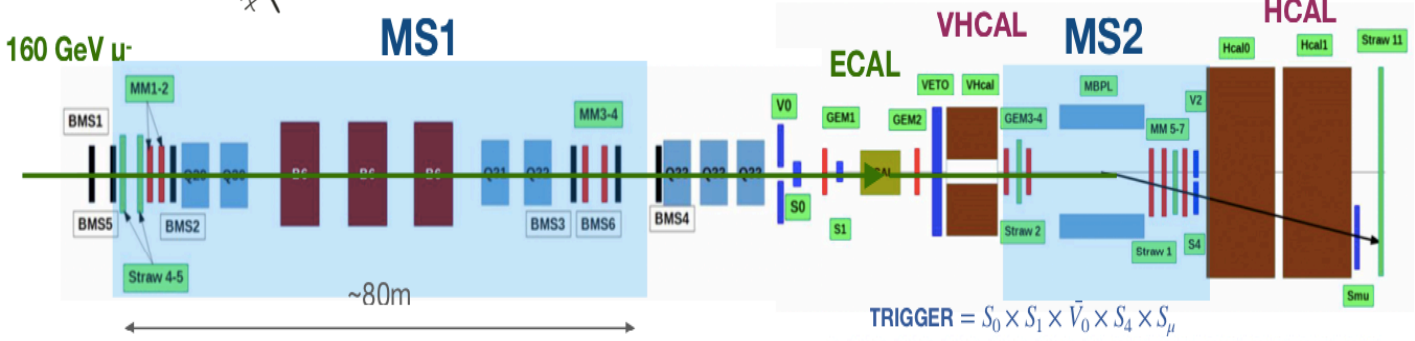
Optimization of WCAL: 20% shorter keeping 30X$_0$



2024: ~ 2 x 10^{11} EOT



NA64 in muon mode (approved & started in 2021)



Signature:
1) Tagged 160 GeV incoming muon
2) Scattered muon with <80 GeV
3) No activity in HCAL

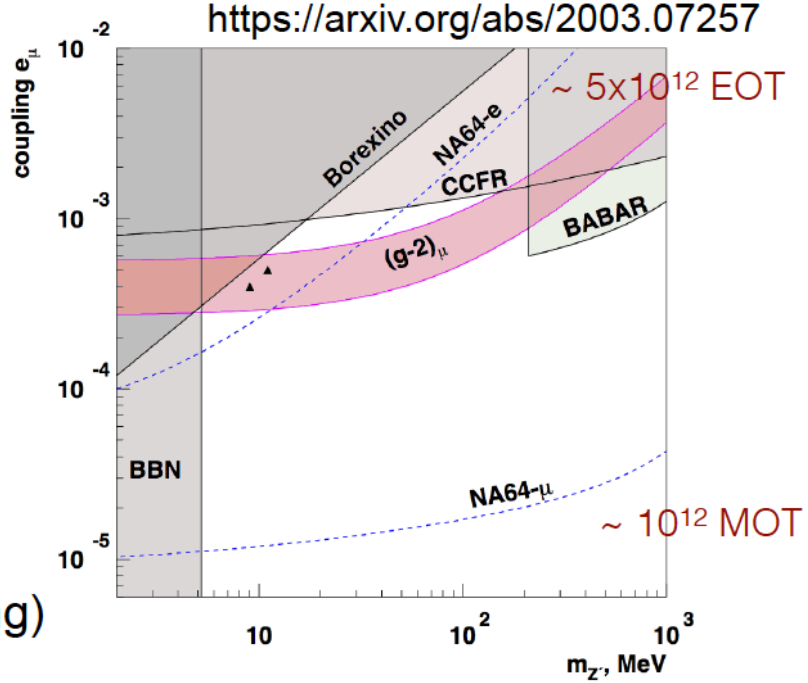
CERN SPS **M2 160 GeV muon beam** offers unique opportunities to further **searches for DS** of particles predominantly weakly-coupled to 2nd second and possibly 3rd generations of the SM.

$$\mu + Z \to \mu + Z + Z_\mu,\ Z_\mu \to \nu\bar{\nu}$$

L_μ-L_τ models Z_μ could explain $(g-2)_\mu$

Sensitivity to be update with exact tree level calculations (ongoing)

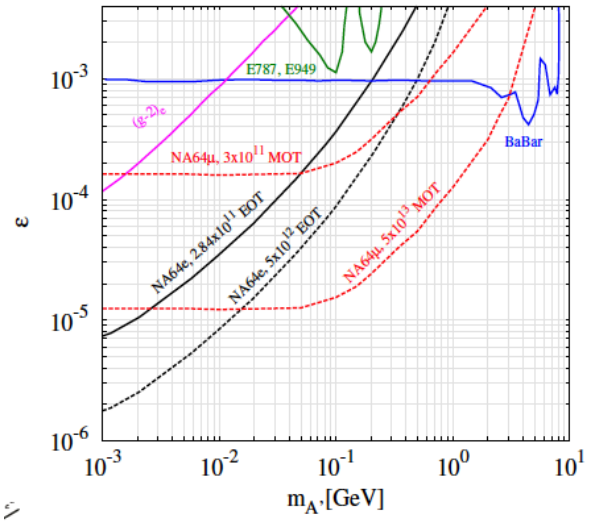
https://arxiv.org/abs/2003.07257



NA64 in muon mode LDM search

Search for **Dark photons** complementary to NA64e in mass region $m_{A'} > 0.1$ GeV

$$\mu + Z \to \mu + Z + A', A' \to \chi\bar{\chi}$$



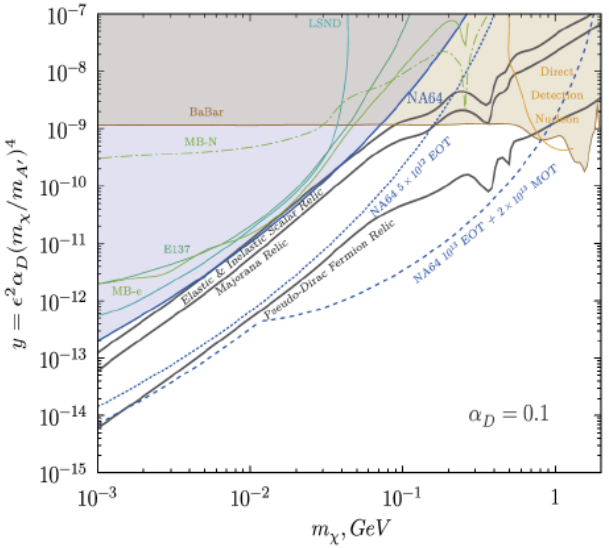
NA64e

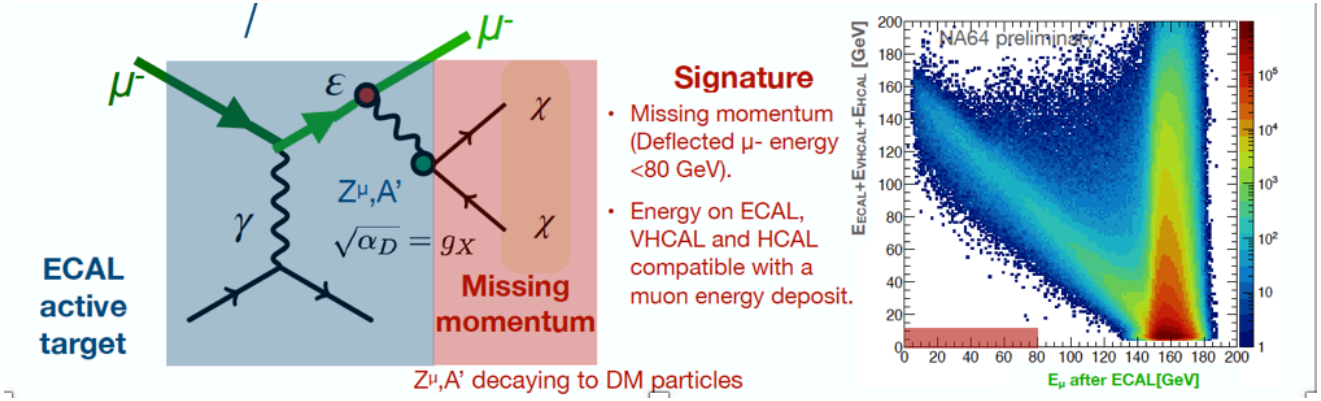
$$N^e_{A'} \sim L^e \sigma^e_{A'}$$
$$L^e \simeq X_0$$
$$\sigma^e_{A'} \sim \epsilon_e^2 / m^2_{A'}$$

NA64μ

$$N^\mu_{A'} \sim L^\mu \sigma^\mu_{A'}$$
$$L^\mu \simeq 40 X_0$$
$$\sigma^\mu_{A'} \sim \epsilon_\mu^2 / m^2_\mu \qquad m_{A'} \lesssim m_\mu$$

Combined LDM sensitivity of NA64e -NA64μ

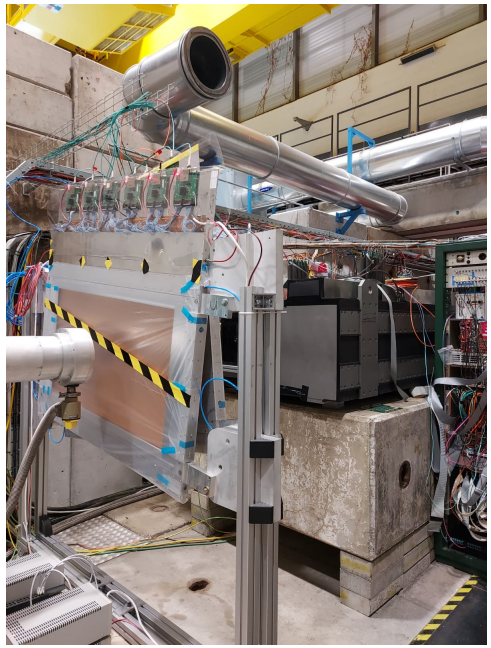


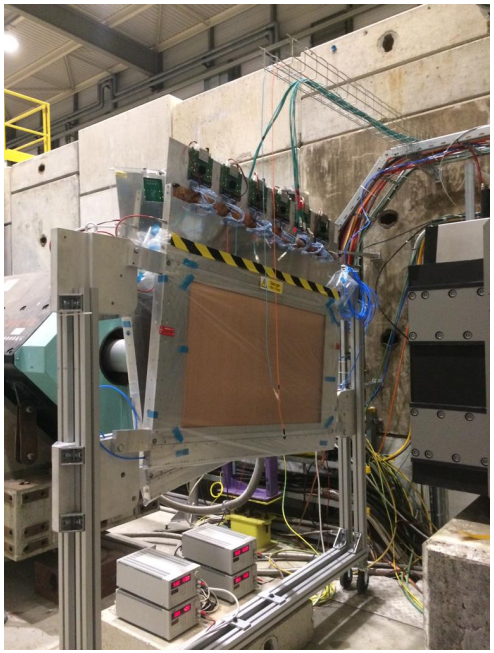


JINR in NA64

electron setup

muon setup





JINR group activities in 2020-2022

- 12 double layer 6mm straw tube chambers with 200x200 mm^2 (used for electron & muon setups); 7 double layer 6mm straw chambers with a size 1200x600 $мм^2$ (used for μ setup);
- full support of the DAQ, straw chamber online-monitor;
- active participation in theoretical investigations, M-C simulation, data taking and analysis
- 2 PhDs in progress
- JINR Encouraging Prizes in 2020, 6 conference reports, papers in PEPAN Letters & JINR news

Financial request

Schedule proposal and resources required for the implementation of the Project / Sub-project of the LRIP

Names of costs, resources, sources of funding		Cost (thousands of dollars) resource requirements	Cost, distribution by year				
			1st year	2nd year	3rd year	4th year	5th year
	International cooperation (IC)		70+35	70+35	40+35		
	Materials		15	15	15		
	Equipment and third-party services (commissioning)		20	20	20		
	Commissioning work						
	Services of research organisations		10	10	10		

Outlook & conclusions

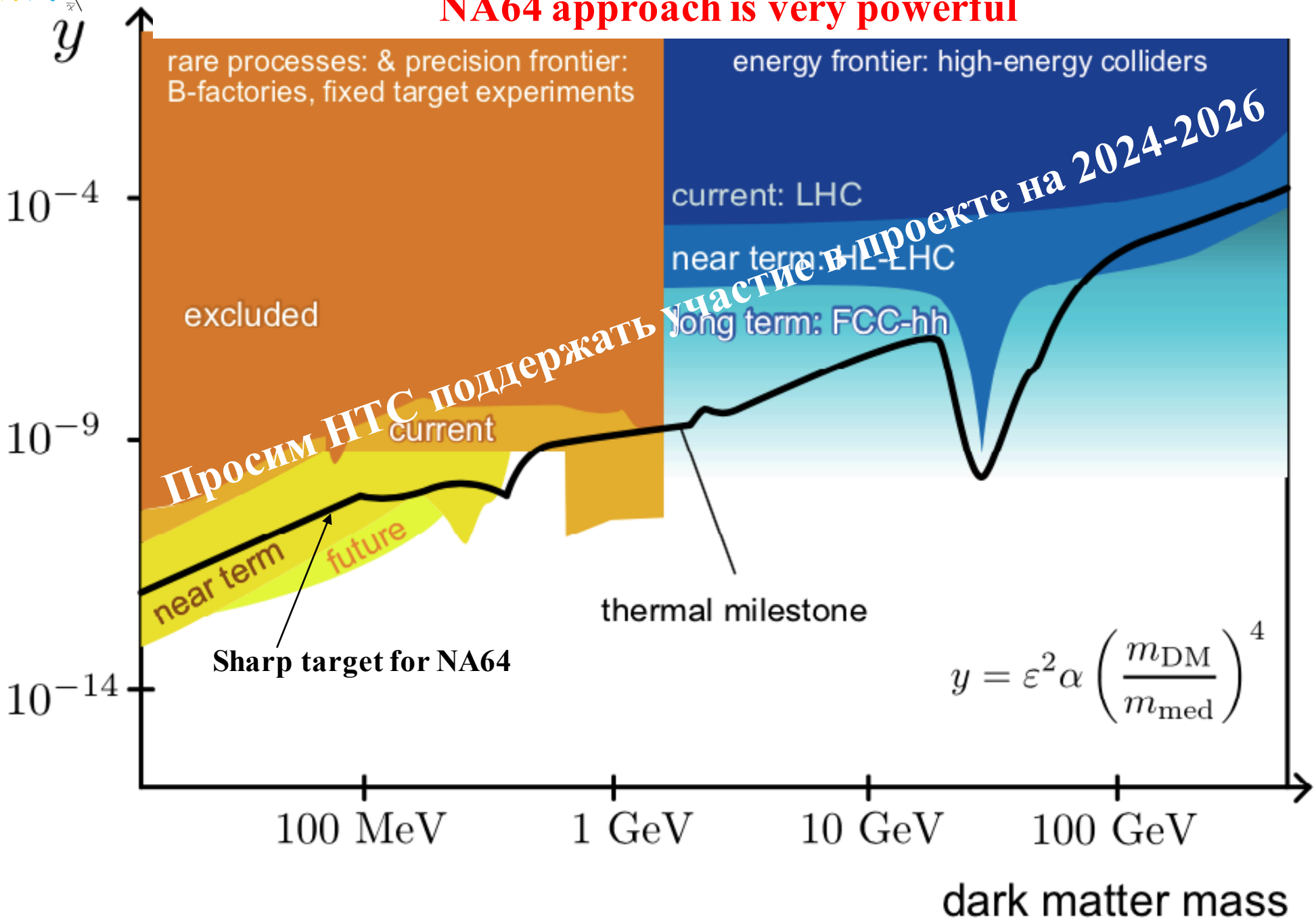
NA64 just reached a major milestone of accumulating ~ 10^{12} EOT which allows one to start probing very interesting LDM benchmark models. The analysis is ongoing and with the increased statistics we expect to improve the sensitivity also of our searches for ALPs, Lμ-Lτ and B-L Z′ bosons, inelastic DM and generic X bosons. The plan until LS3 is to accumulate as many as possible electrons on target (up to 5 10^{12}) and also use the positron mode to enhance the sensitivity in the higher A′ mass region.

NA64 also started its program at the M2 beam-line providing unique high intensity 160 GeV muons to explore dark sectors weakly coupled to muons. The results of the pilot runs show that with an optimized setup, one could collect > 10^{11} MOT before LS3 in order to check if an Lμ-Lτ Z′ boson is the explanation of the g-2 muon anomaly and complement the searches with electrons. After LS3 the experiment would then continue data taking to accumulate ~ 10^{13} MOT to explore the A′ higher mass region and $\mu \rightarrow \tau$ and $\mu \rightarrow e$ LFV processes.

In the 2022 beam-time, we also accumulated ~ 2×10^{9} pions on target in order to understand the potential of NA64 to explore dark sectors coupled predominantly to quarks using the missing energy technique. This will be further investigated and, if the feasibility would be demonstrated, a dedicated search will be performed after LS3.

To conclude the exploration of the NA64 physics potential has just begun. Our proposed searches with leptonic and hadronic beams provide unique sensitivities highly complementary to similar projects.

Dark sector is very interesting candidate for DM.
NA64 approach is very powerful



Просим НТС поддержать участие в проекте на 2024-2026

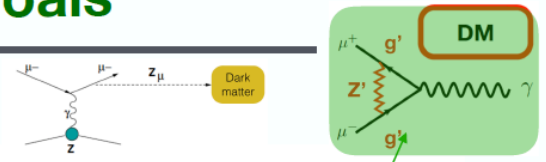
NA64 future prospects

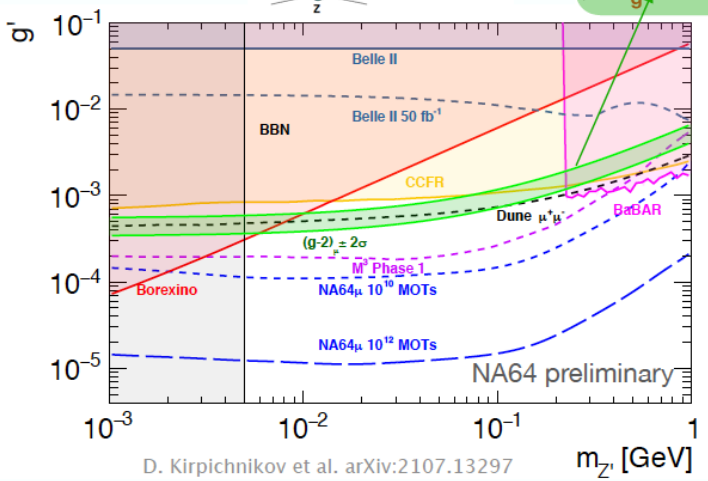
lated electrons on target is required to be around $n_{eot} \sim 5\times10^{12}$ eot before LS3

Future prospects: NA64$_\mu$ physics goals

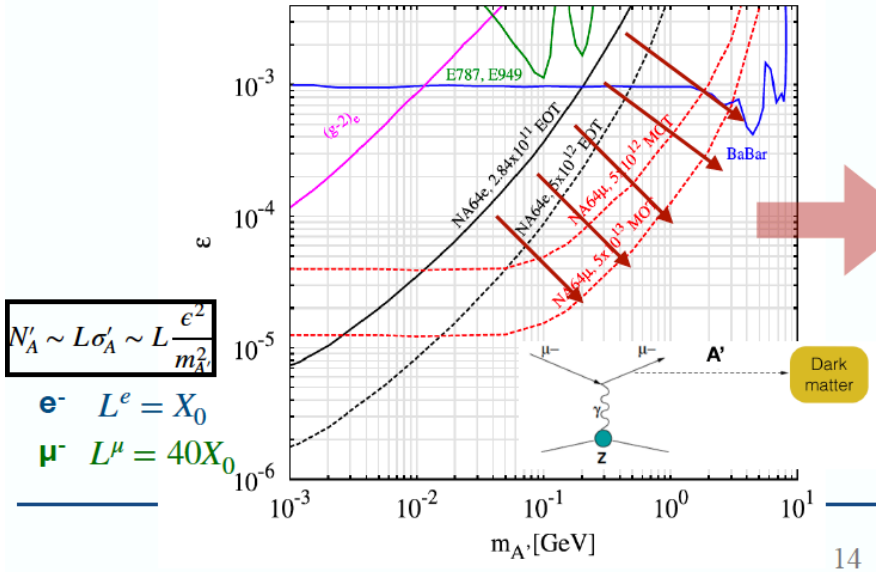
Exploring Dark sector physics weakly coupled to muons

1. **Light Z' coupled to the muon,** as a remaining low mass **explanation of the (g-2)$_\mu$ (the muon anomaly).**
2. **Light thermal dark matter** in the A' mass region ≥ 0.1 GeV (complementary search to NA64e).
3. **Scalar**, **ALPs** coupled to the muon, **millicharged** particles, ...
4. **Lepton Flavour Violation in μZ -> τZ conversion** in flight.





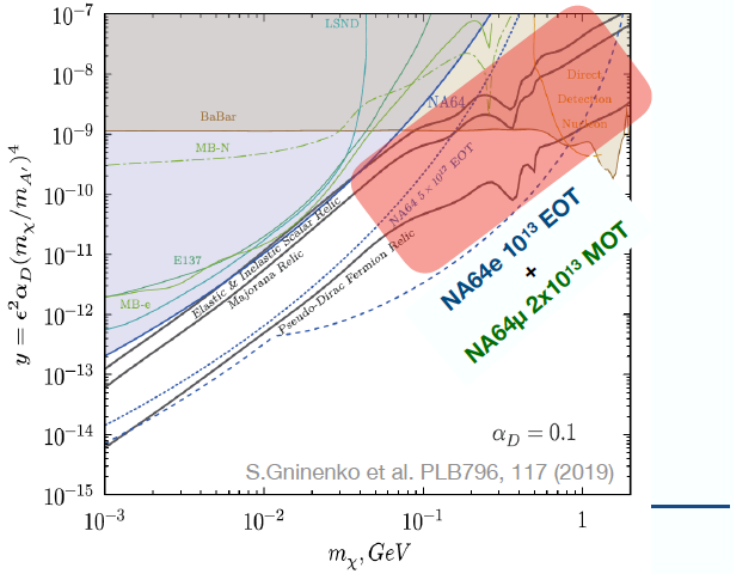
D. Kirpichnikov et al. arXiv:2107.13297



$$N'_A \sim L\sigma'_A \sim L\frac{\epsilon^2}{m^2_{A'}}$$

e⁻ $L^e = X_0$

μ⁻ $L^\mu = 40X_0$



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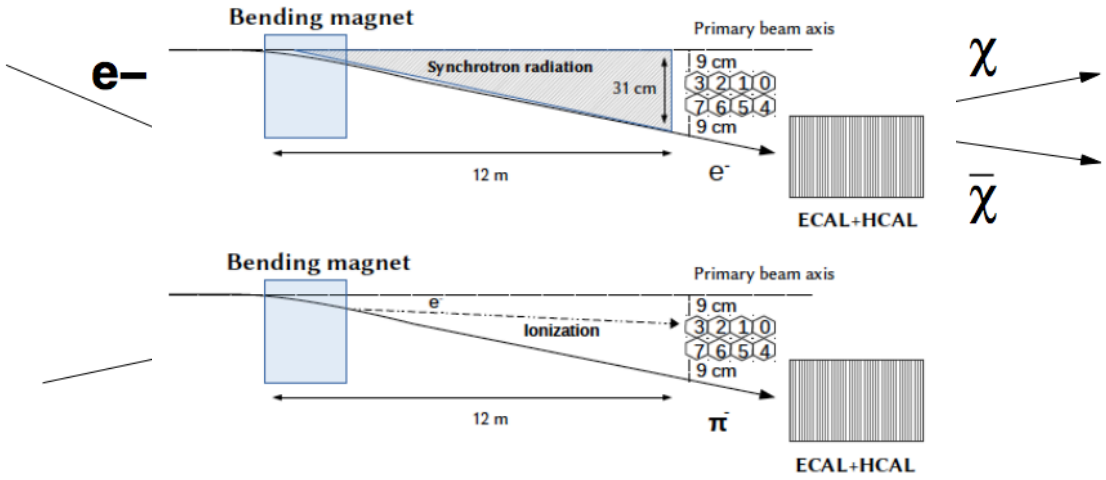
Bending magnet
Primary beam axis
e–
Synchrotron radiation
31 cm
9 cm
3 2 1 0
7 6 5 4
9 cm
12 m
e-
ECAL+HCAL
χ
χ̄
Bending magnet
Primary beam axis
e-
Ionization
9 cm
3 2 1 0
7 6 5 4
9 cm
12 m
π-
ECAL+HCAL