



NA64 Annual Review

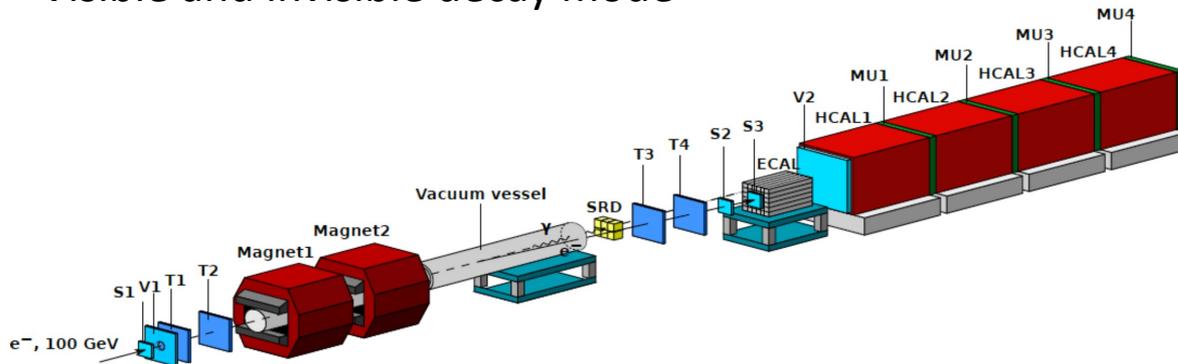
M. Bona, M. Contalbrigo, J. Bernhard

Meeting with spokespersons on June 8, 2021

142nd SPSC Meeting, June 11 2021

NA64 Dark Matter Search

Fixed target hermetic experiment
Visible and invisible decay mode

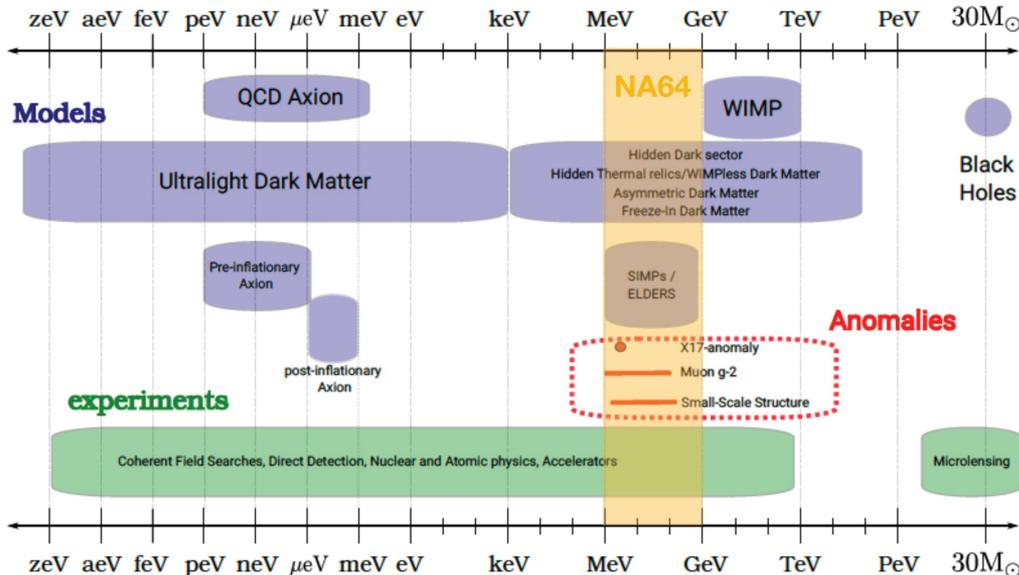


1) Light dark matter:

→ *Invisible* decays

- Plans for **August 2021** run
- Future prospects:
 - ➔ **e⁺ beam (NEW)**
 - ➔ **NA64μ → pilot run in 2021**

From E. Depero, PhD thesis 2020 (ETH Zürich)



2) Constraints on new physics:

★ $(g-2)_\mu$ → *Semi-visible decays (NEW)*
 ↘ **NA64μ → pilot run in 2021**

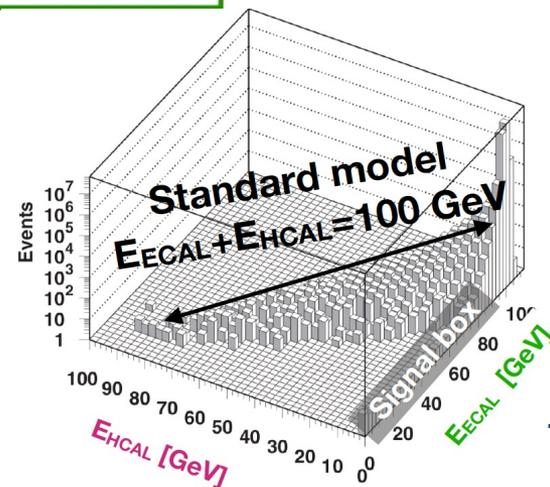
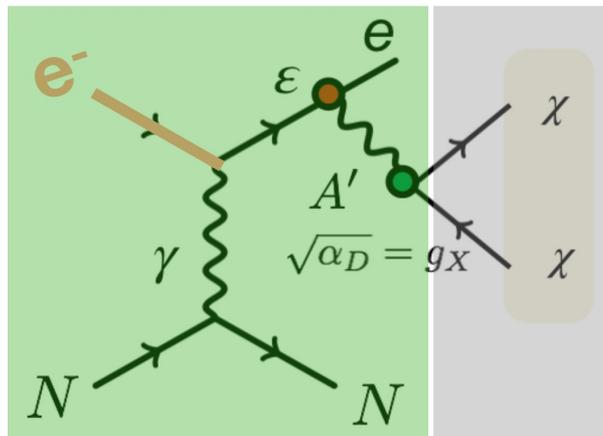
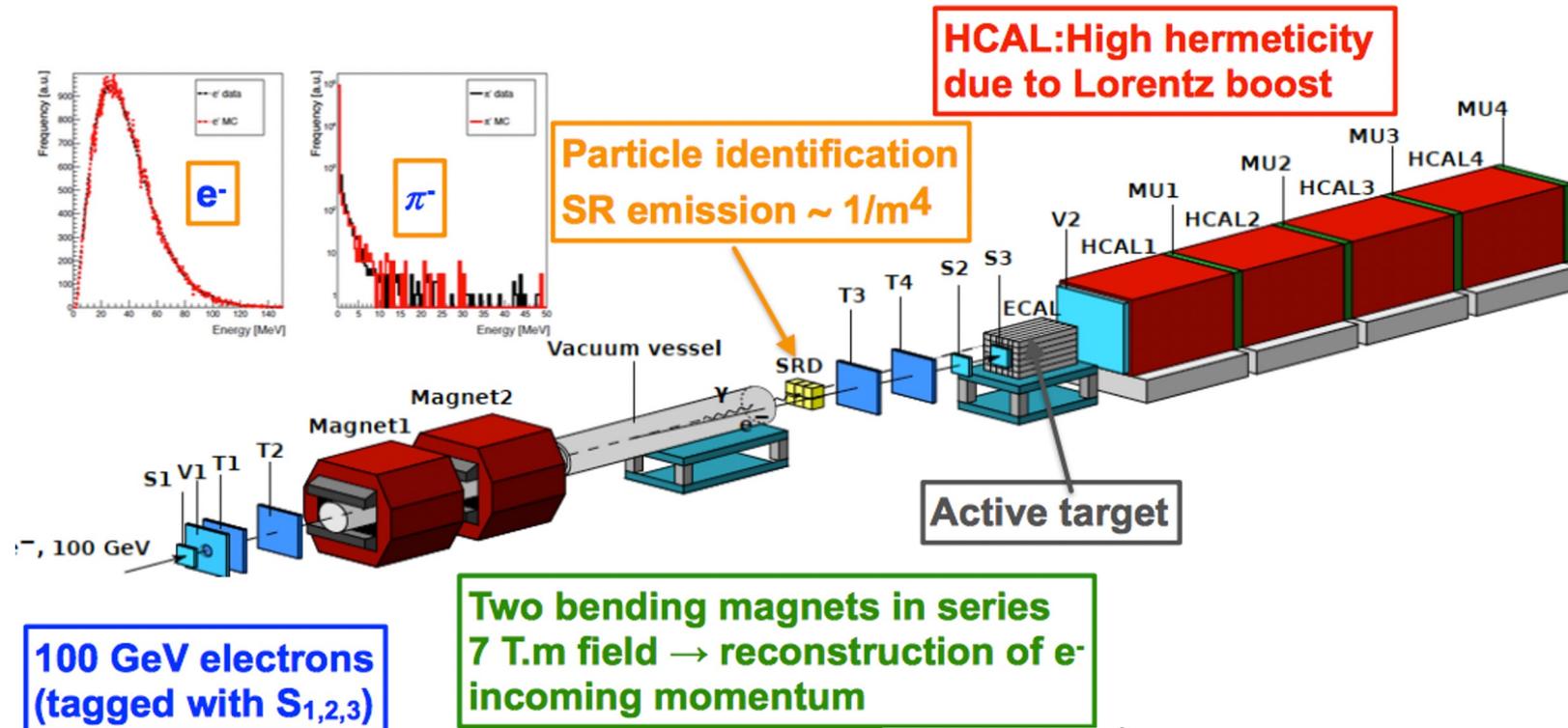
- ◆ ALPs
- ◆ $(g-2)_e$ Highlights from 2016-2018 analysis

◎ ^8Be anomaly:

→ *Visible* decays

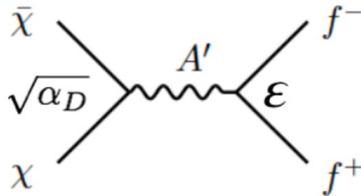
- Highlights from 2016-2018 analysis
- Plans for **2022**

NA64e Invisible Decay Mode Setup



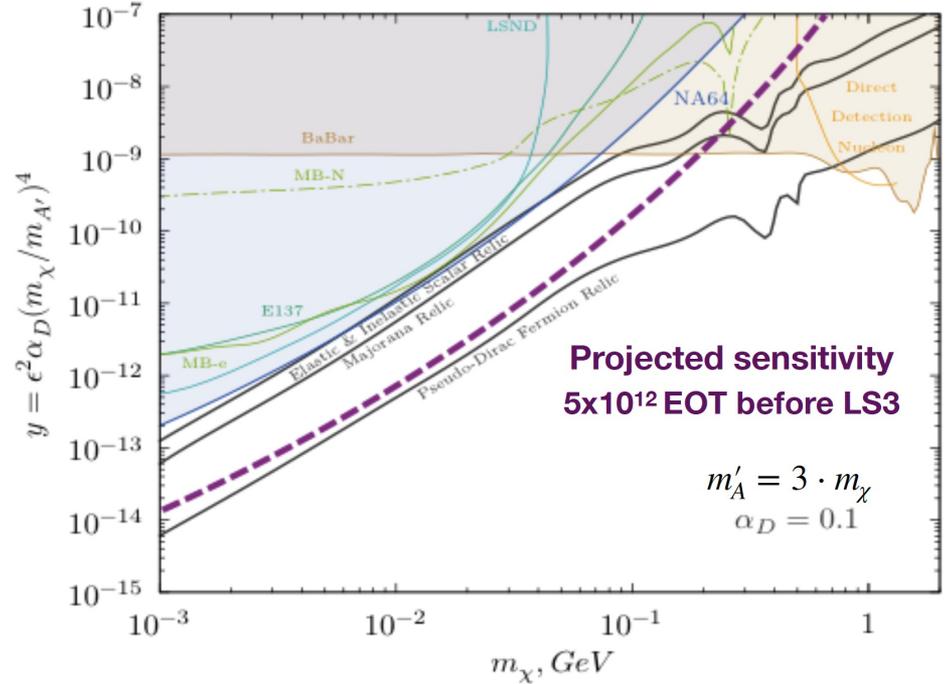
S. Gninenko, *PBC workshop 2021*

DM-SM annihilation cross-section



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

NA64 collaboration,
Phys. Rev. Lett. 123, 121801 (2019)



Main source: **electro-nuclear interactions along the beam line**

Background source	Background number, n_b
punchthrough γ 's, cracks, holes	< 0.01
loss of dimuons	0.024 ± 0.007
$\mu \rightarrow e\nu\nu$, π , $K \rightarrow e\nu$, K_{e3} decays	0.02 ± 0.01
e^- interactions in the beam line	0.43 ± 0.16
μ, π, K interactions in the target	0.044 ± 0.014
accidental SR tag and μ, π, K decays	< 0.01
Total n_b	0.53 ± 0.17

New H4 experimental area

- **Improved beam properties and design of the new area** in close collaboration with **BE-EA liaison physicists and technical experts**, <https://edms.cern.ch/document/1865057/3.1>.
- Beam optimisation based in MC and optics studies.
 - ➔ Goals: **maximise the electron flux, reduce the beam halo and minimise the electron beam hadronic contribution** to a level less than 2%.
 - ➔ Full realistic H4 beam line simulation including all secondaries, beam-loss points for radiation shielding design and showing the effect of collimation, size and divergence of the beam along its propagation.

NA64e Invisible Decay

$$\Delta a_e = a_e^{exp} - a_e^{LKB} = (4.8 \pm 3.0) \times 10^{-13} (1.6\sigma)$$

$$\Delta a_e = a_e^{exp} - a_e^B = (-8.8 \pm 3.6) \times 10^{-13} (-2.4\sigma)$$

Results from high precision measurements of α :

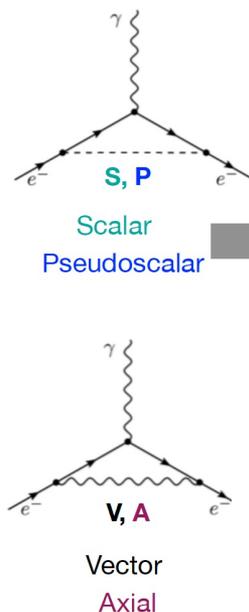
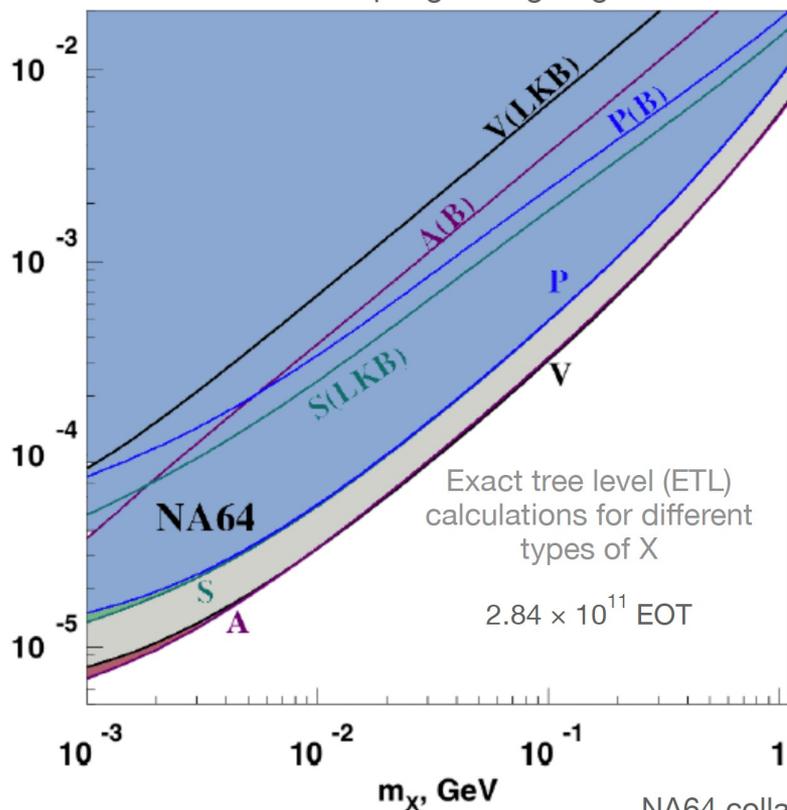
LKB, L. Morel, Zh. Yao, P. Clade, and S. Guellati-Khelifa, *Nature (London)* 588, 61 (2020).

Berkley, R. H. Parker, C. Yu, W. Zhong, B. Estey, and H. Müller, *Science* 360, 191 (2018)

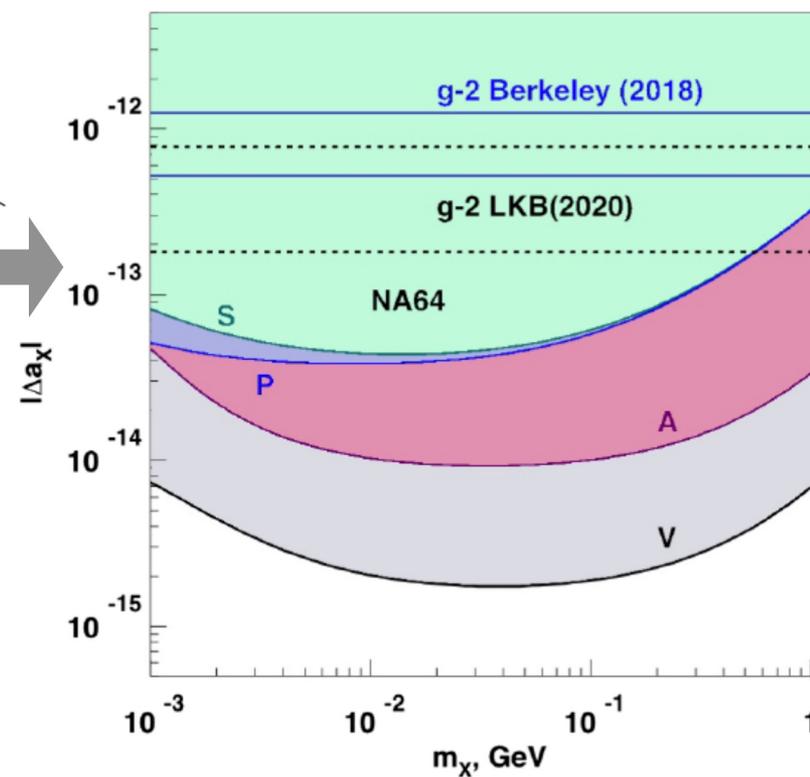
Could a new generic boson contribute to $(g-2)_e$?

$e^-Z \rightarrow e^-ZX; X \rightarrow \text{invisible}$

e^-X with coupling strength: $g_X = \epsilon_X e$



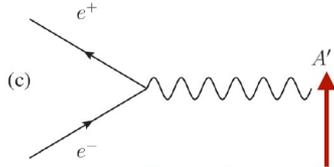
NA64 approach on probing new physics in $(g-2)_e$ one order of magnitude more sensitive than high precision experiments



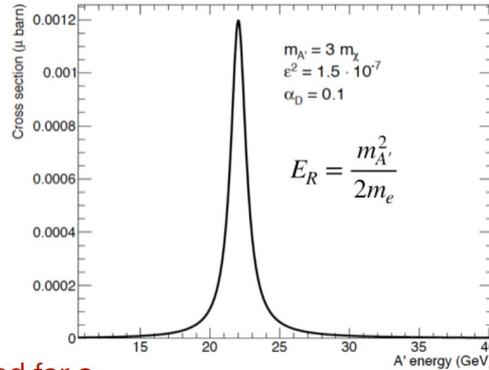
NA64 collaboration, *Phys. Rev. Lett.* 126, 211802

NA64e+ Invisible Decay

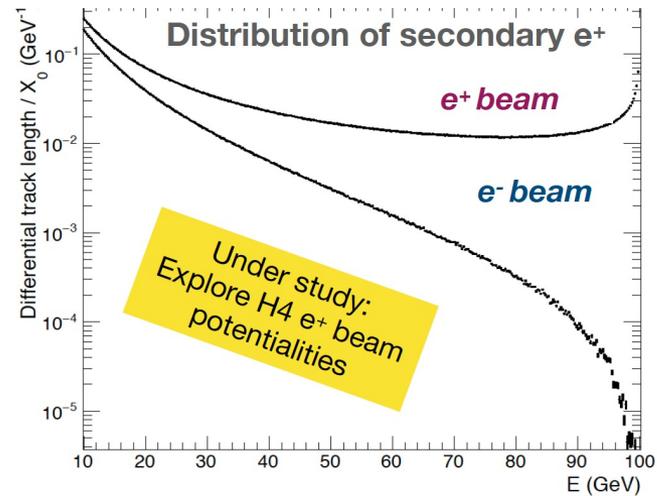
Resonance annihilation channel using the secondary positrons present in the EM shower in the target induced by the initial electron beam.



Sensitivity calculated for a generic **X boson** (S,P,A,V)



L. Marsicano et al. Phys. Rev. Lett. 121, 041802
NA64 internal note 19-04

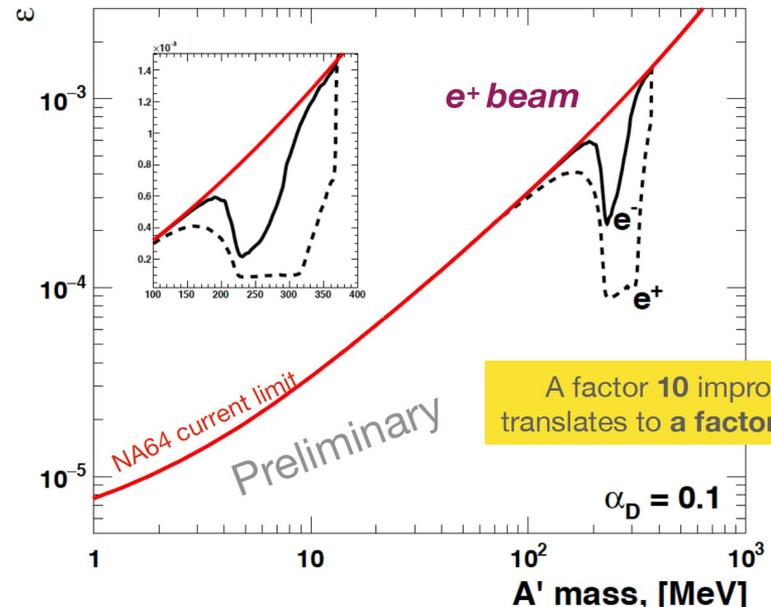


Supported by the ERC Starting Grant
2020 project POKER:
“Positron annihilation into dark matter”
A.Celentano (INFN-Genova)

DMG4 (M. Bondi et al. arXiv:2101.12192)

New DAQ:
MSADC boards: 80 MHz \rightarrow 250 MHz
(INFN-Genova)

NA64-like experiment using 100 GeV positron beam

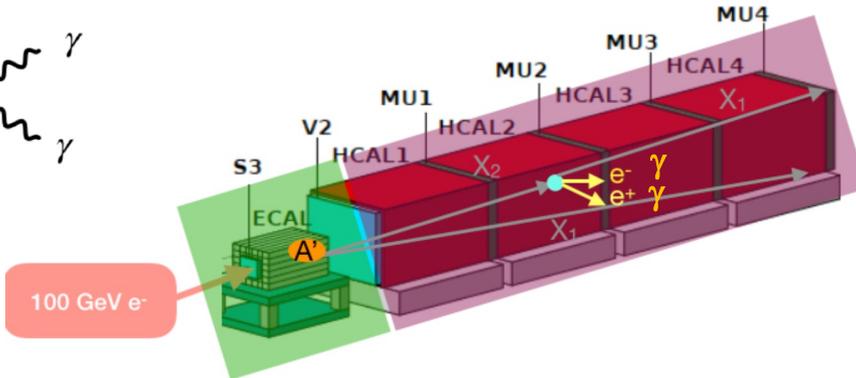
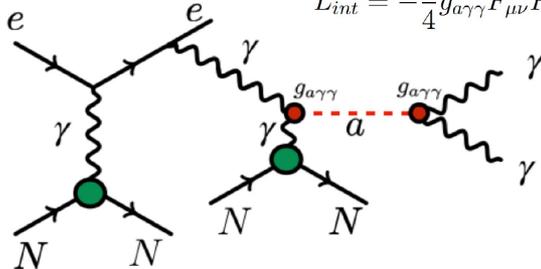


NA64e Semi-Visible Decay

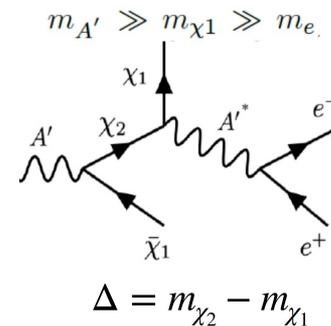
ALPs

via Primakoff effect

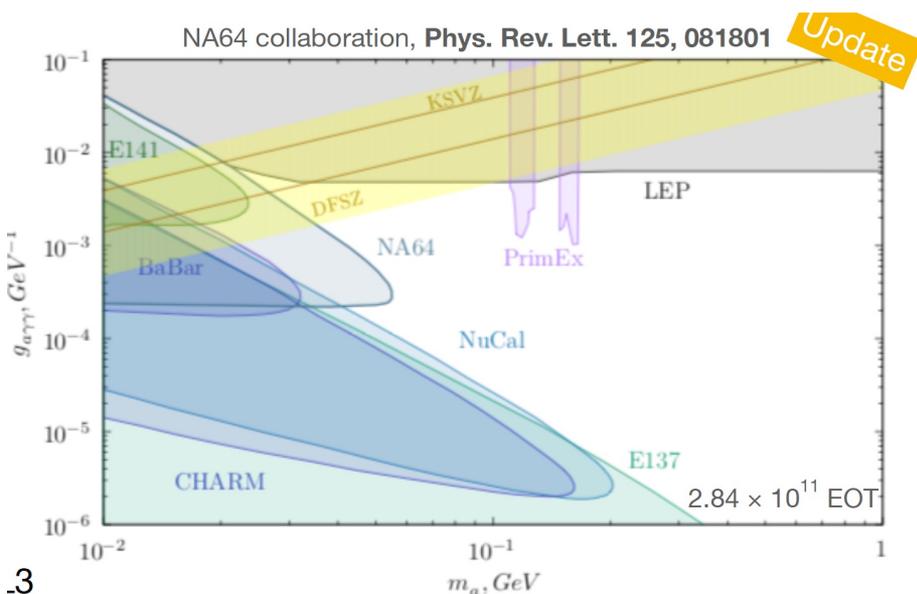
$$L_{int} = -\frac{1}{4}g_{a\gamma\gamma}F_{\mu\nu}\tilde{F}^{\mu\nu}a$$



$(g-2)\mu$

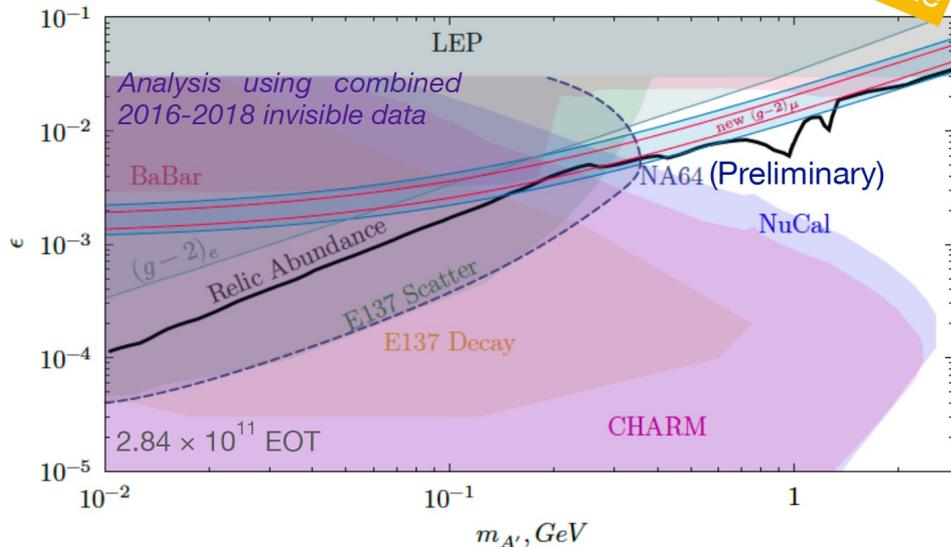


Signature: Missing energy + SM particles pair production



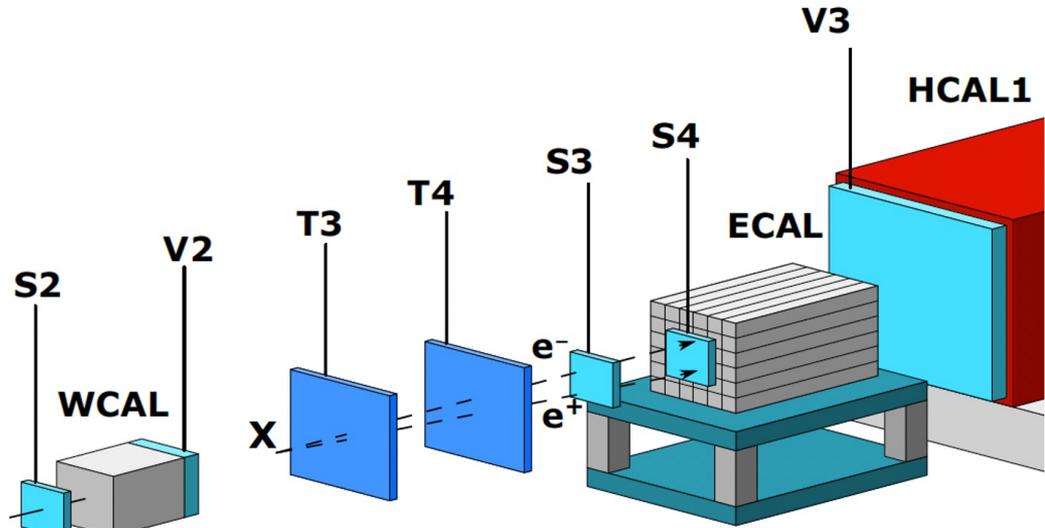
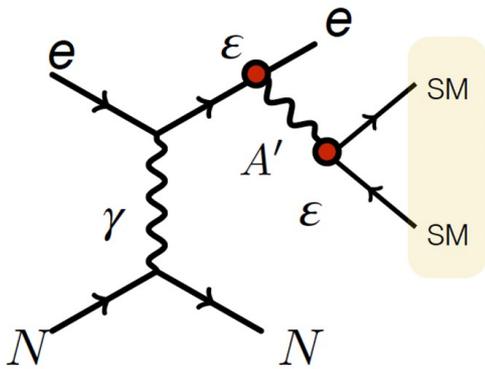
Paper under collaboration review

$$\Delta = 0.4m_{\chi_1}, m_A = 3m_{\chi_1}, \alpha_D = 0.1$$

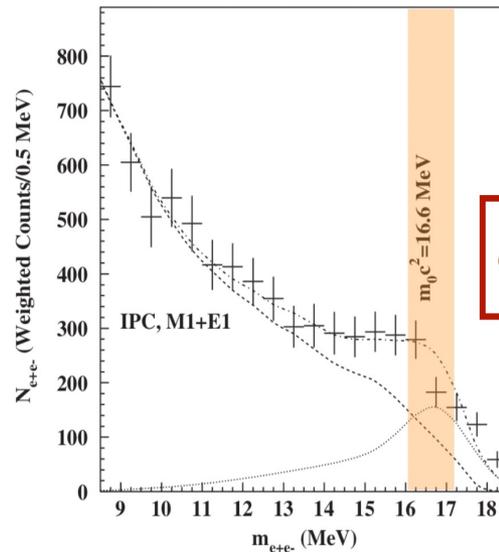
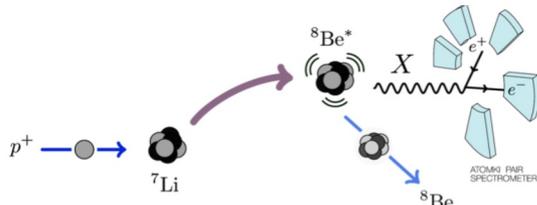


NA64e Visible Decay

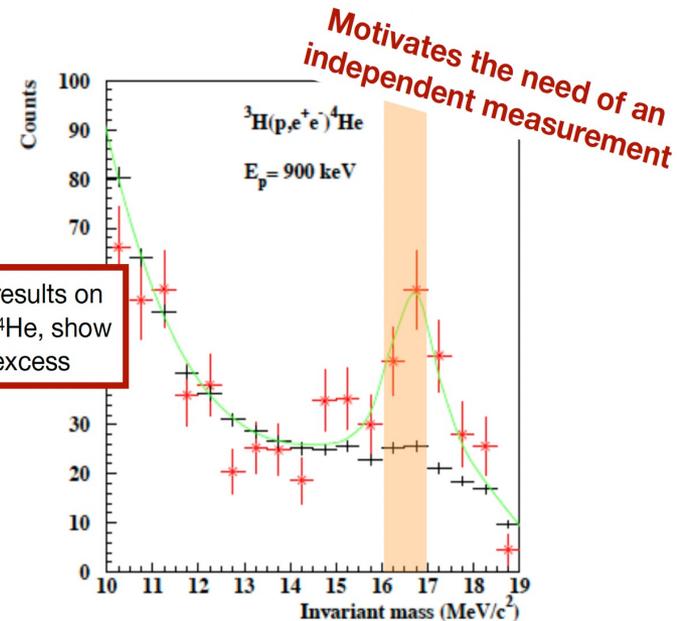
VISIBLE DECAY MODE $m'_A < 2m_X$



Pair production of SM particles



New recent results on other nuclei, ^4He , show a similar excess

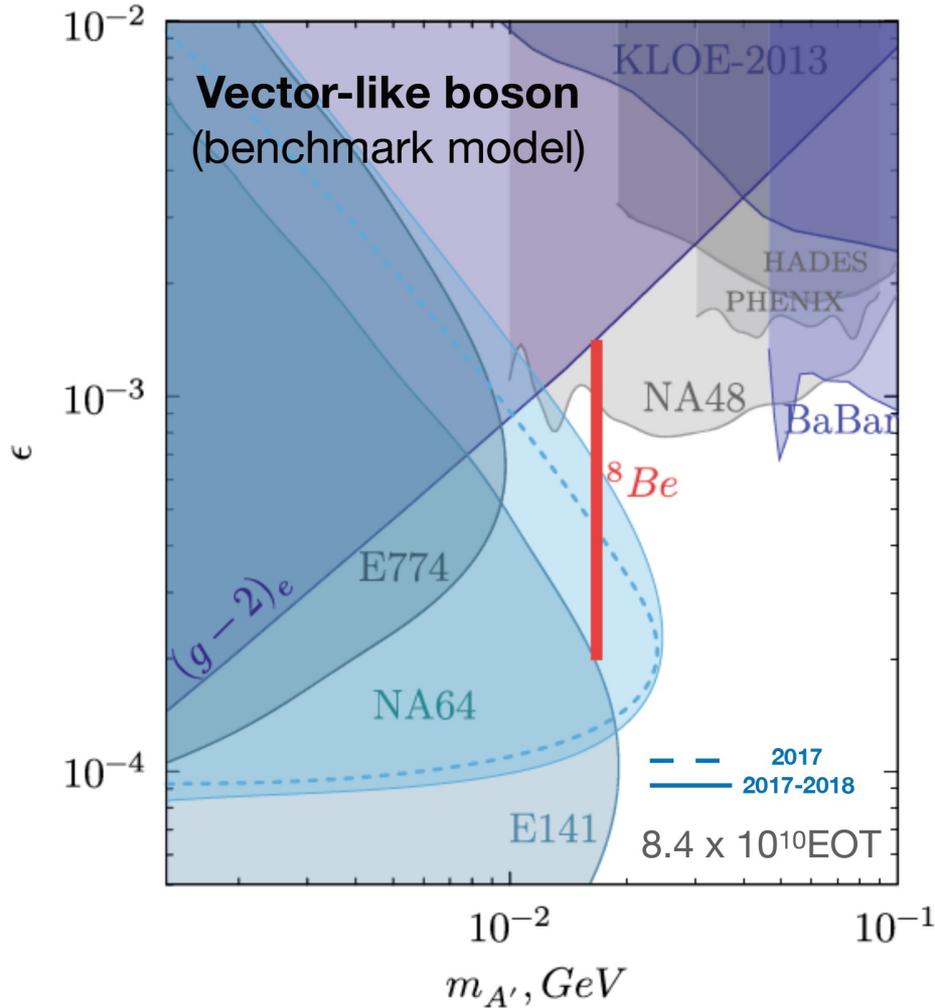


A.J. Krasznahorkay et al. Phys. Rev. Lett.116, 042501 (2015)

A. J. Krasznahaorkay et. Al Arxiv:1910.10459 (2019)

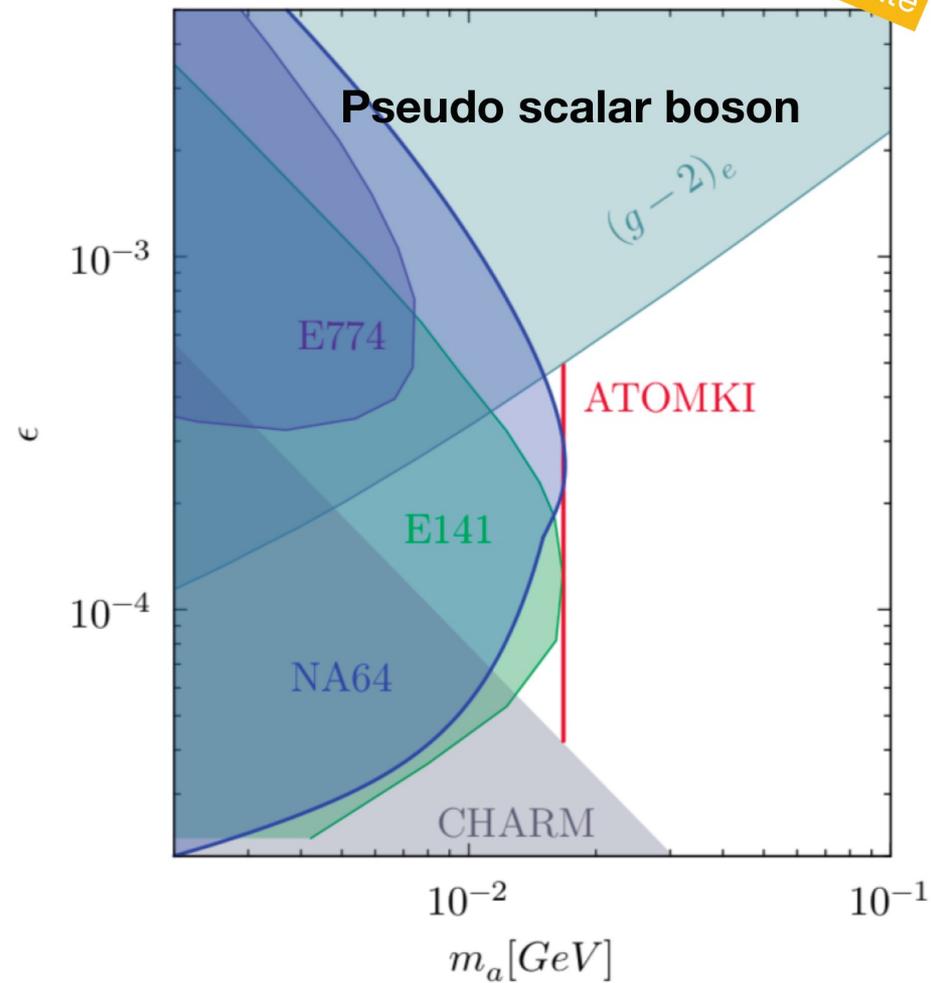
NA64e Visible Decay

$$e^-Z \rightarrow e^-ZX_{17}(A'); X_{17}(A') \rightarrow e^+e^-$$



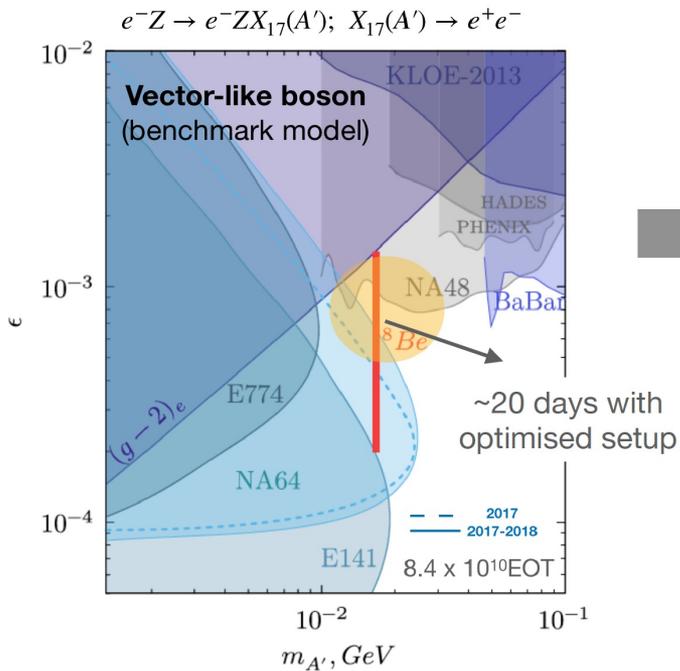
NA64 collaboration,
 PRL 120, 231802 (2018), PRD 107, 071101 (R) 2020

$$e^-Z \rightarrow e^-Za; a \rightarrow e^+e^-$$

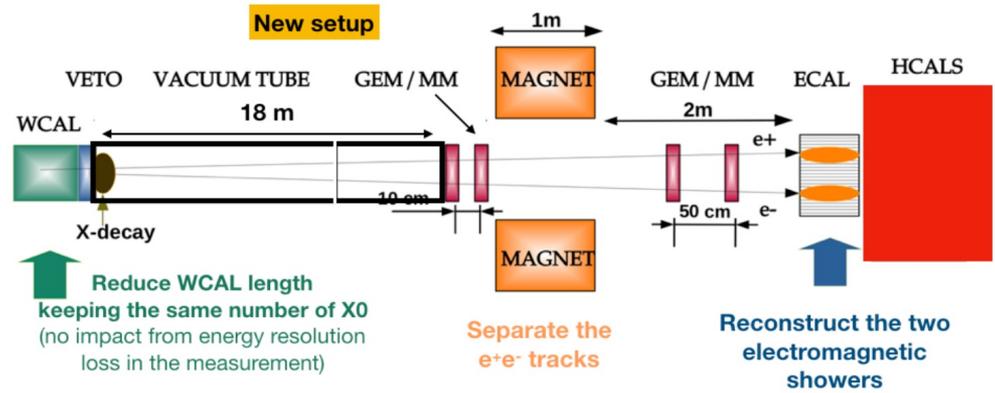


NA64 collaboration,
 CERN-EPT.-2021-069, arXiv:2104.13342
 Submitted to PRD (letter)

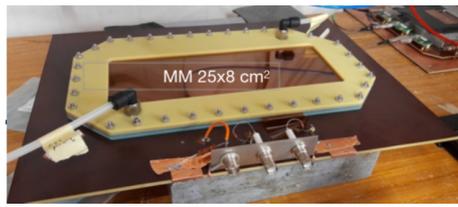
NA64e Visible Decay



Full parameter space Invariant mass reconstruction

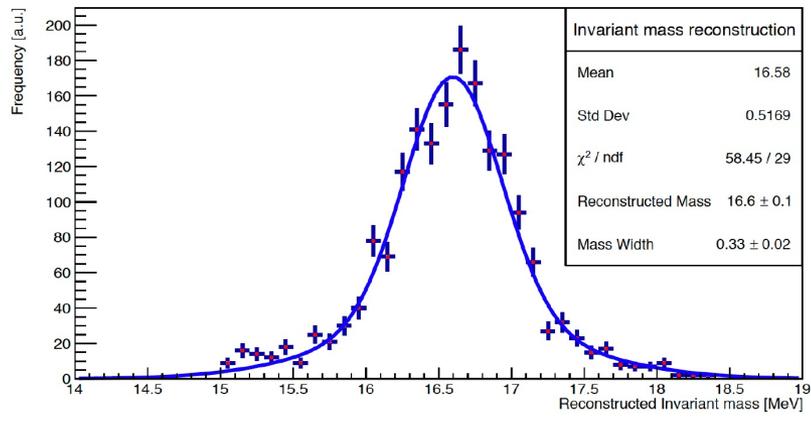


New WCAL



New MMs

Invariant mass reconstruction precision at the level of 2%

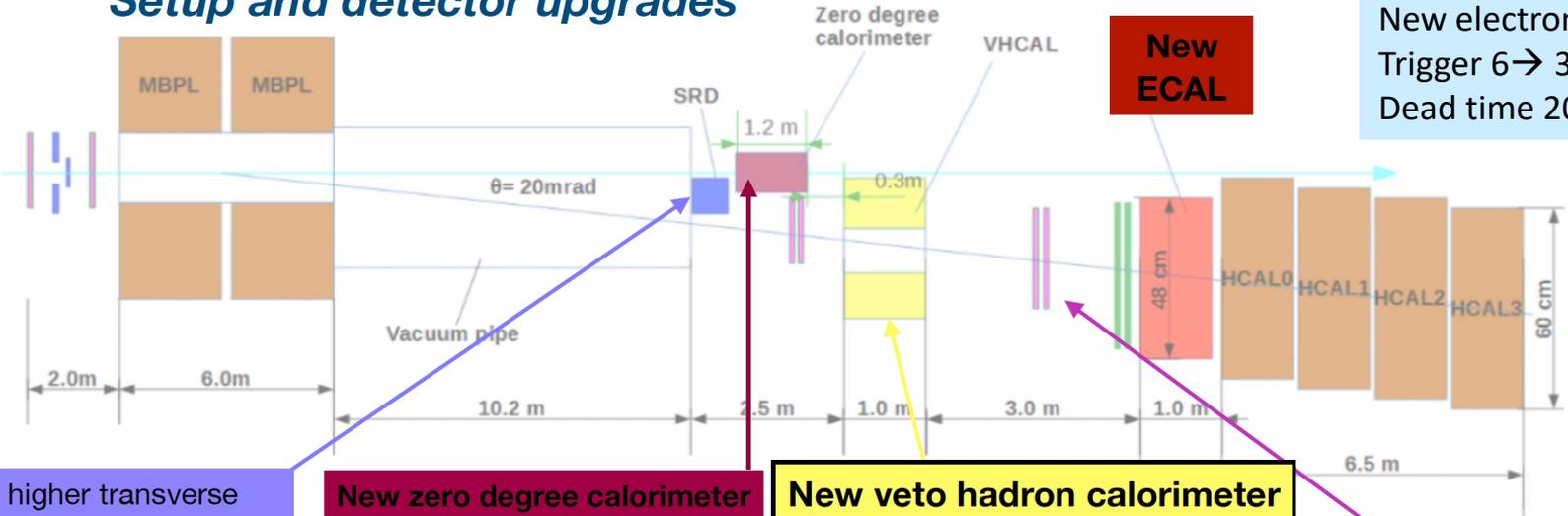


NA64 collaboration, EPJ C 80 (2020) 12, 1159

Update

H4 Experimental Setup

Setup and detector upgrades



New electronics
 Trigger 6 → 30 kHz
 Dead time 20 → 4 %

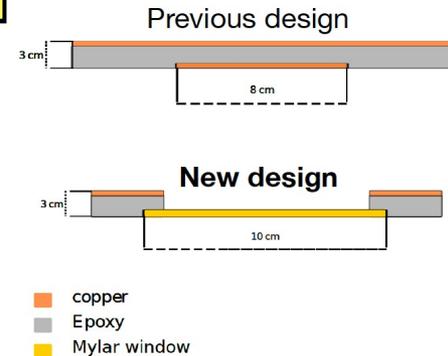
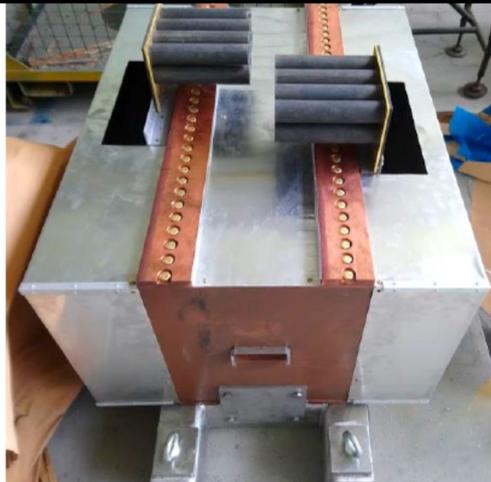
New higher transverse segmentation **Synchrotron radiation (SRD) detector** with improved readout

New zero degree calorimeter
 To reject events accompanied by a hard neutral from the upstream e^- interactions

New veto hadron calorimeter (VHCAL)
 To veto upstream electroproduction of large-angle hadrons.

New Micromegas trackers

- reduced material budget
- Larger transverse size to enlarge acceptance



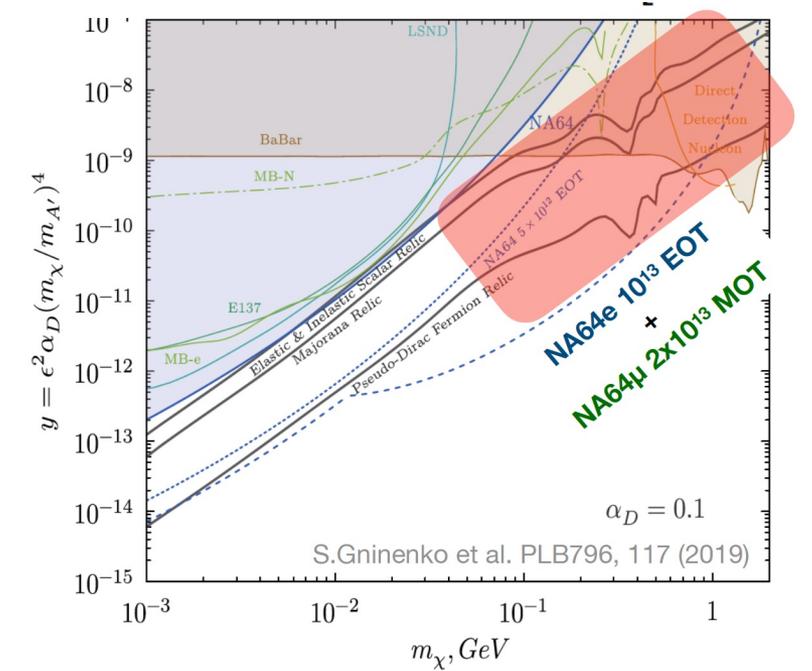
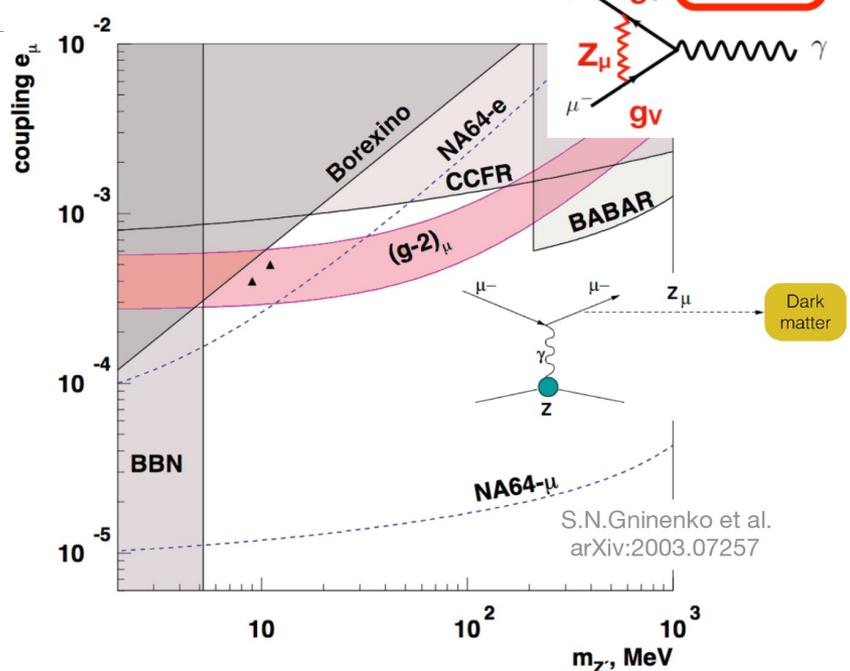
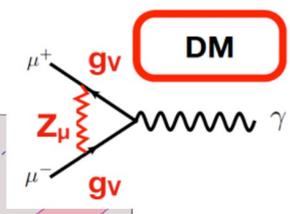
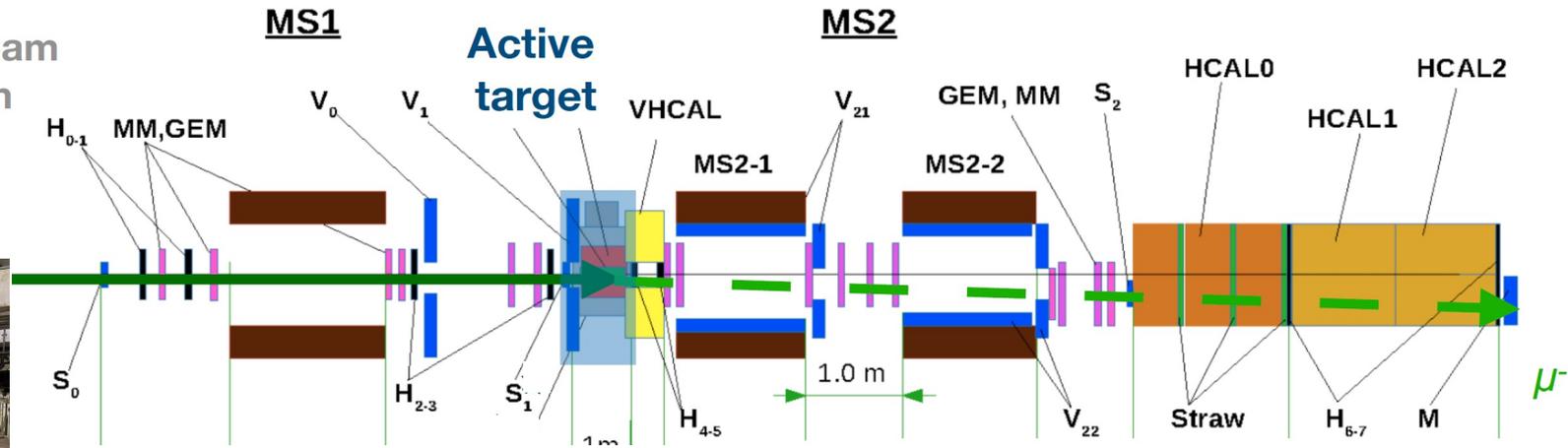
- New detectors already produced in Protvino.
- Delivery at CERN in June second half.

- Produced and already delivered at CERN.
- Characterisation with cosmics ongoing

NA64 μ Invisible Decay

Location M2 beam line upstream COMPASS

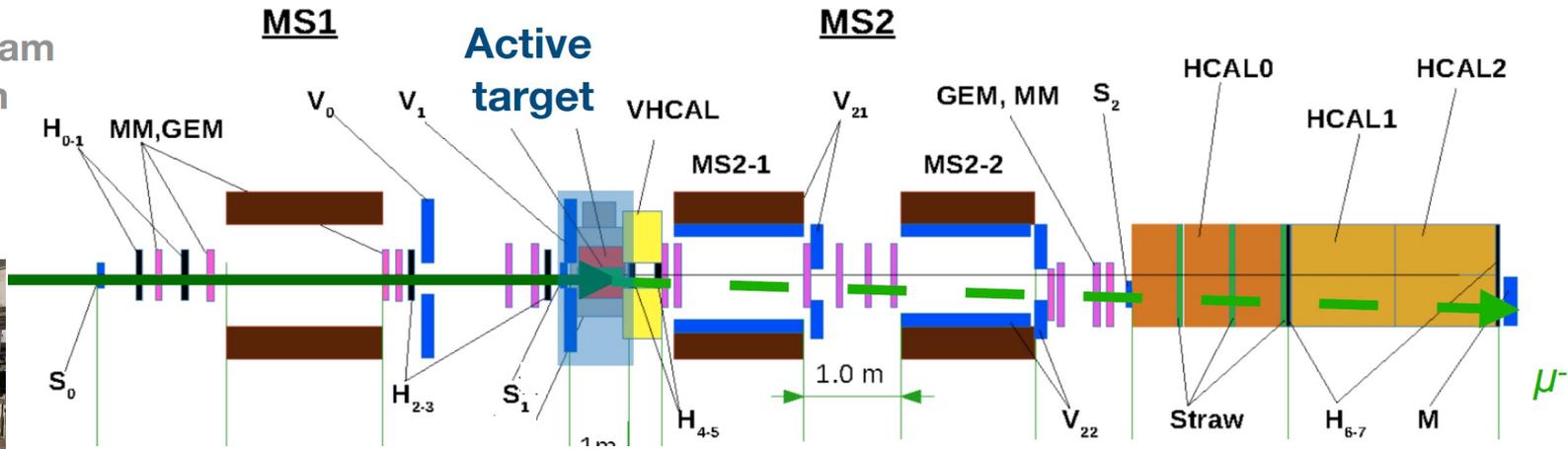
160 GeV μ^-



NA64 μ Invisible Decay

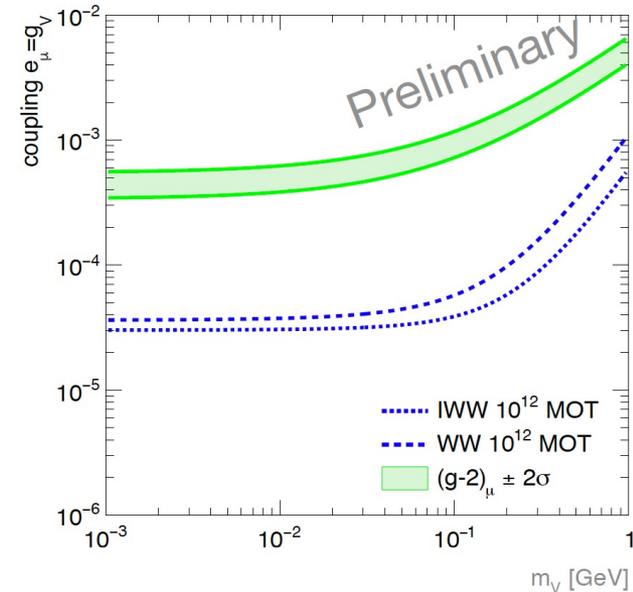
Location M2 beam line upstream COMPASS

160 GeV μ^-

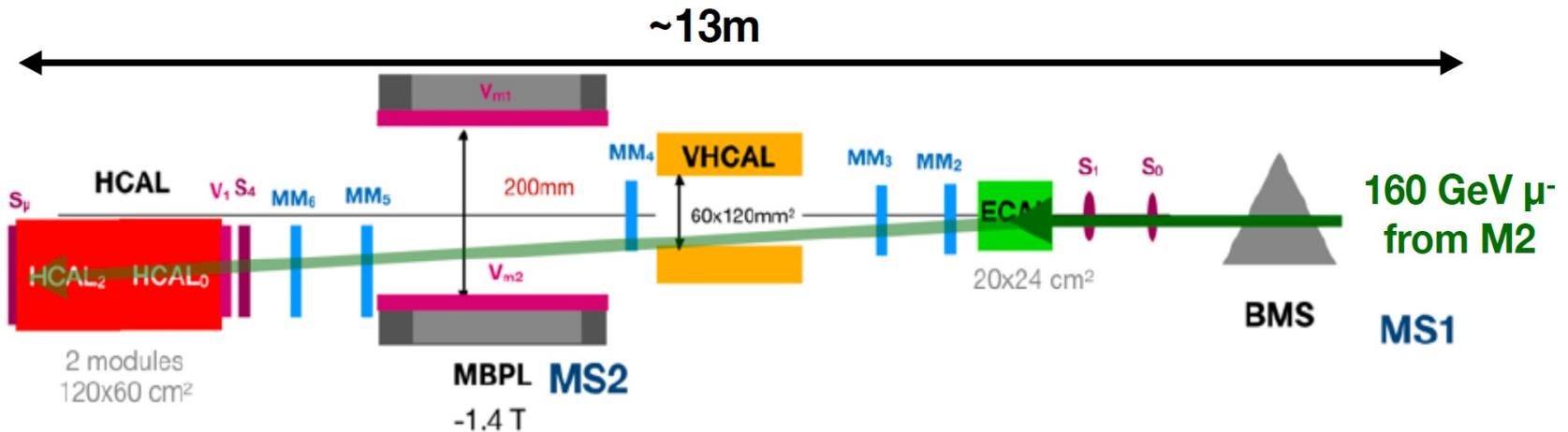


Source of background	Level per MOT
Scattered muon momentum reconstruction mismatch	$\lesssim 10^{-13}$
Detector non-hermeticity	$\lesssim 10^{-12}$
Single-hadron punch-through	$\lesssim 10^{-12}$
Hadron in-flight decay	$\lesssim 10^{-13}$
Dimuon production	$< 10^{-12}$
Total (conservatively)	$\lesssim 10^{-12}$

Paper in preparation.

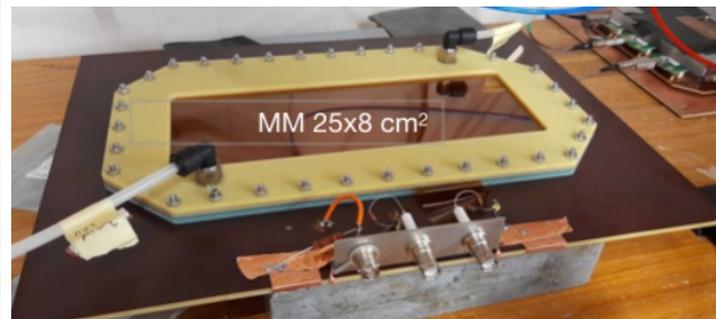


NA64 μ Pilot Run

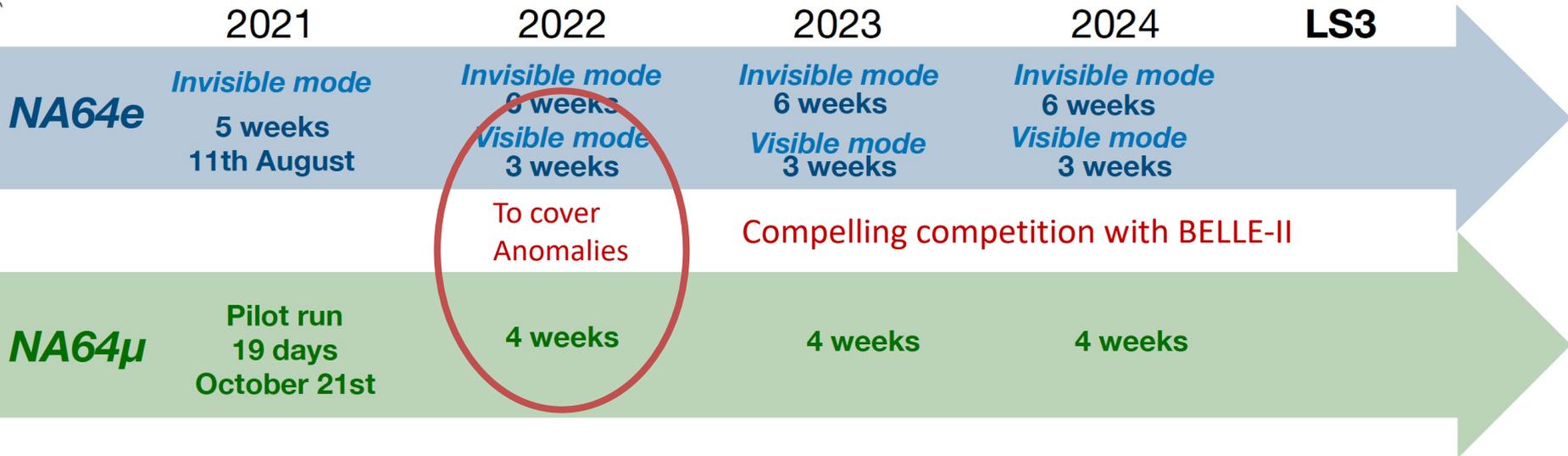


Goal: feasibility of the technique to search for a Z' boson in the MeV-GeV range

- Simplified trigger system for pilot run based on scintillators counters in production.
- VHCAL and ECAL (delivery second half of June)
- 25x8 cm² Micromegas for tracking after the magnet.
- MBPL magnet with 20 cm gap
- Two large HCAL modules 120x60cm² (production and delivery ongoing)



NA64 μ Landscape



Process	New Physics
e^- beam	
$A' \rightarrow e^+e^-$, and $A' \rightarrow invisible$ $A' \rightarrow \chi\bar{\chi}$	Dark photon sub-GeV Dark Matter (χ)
$X \rightarrow e^+e^-$ milliQ particles $a \rightarrow \gamma\gamma, invisible$	new gauge X - boson Dark Sector, charge quantisation Axion-like particles
μ^- beam	
$Z_\mu \rightarrow \nu\nu$ $Z_\mu \rightarrow \chi\bar{\chi}$ milliQ $a_\mu \rightarrow invisible$ $\mu - \tau$ conversion	gauge Z_μ -boson of $L_\mu - L_\tau$, $< 2m_\mu$ $L_\mu - L_\tau$ charged Dark Matter (χ) Dark Sector, charge quantisation non-universal ALP coupling Lepton Flavour Violation

π^-, K^- beams	Current limits, PDG'2018
$\pi^0 \rightarrow invisible$	$Br(\pi^0 \rightarrow invisible) < 2.7 \times 10^{-7}$
$\eta \rightarrow invisible$	$Br(\eta \rightarrow invisible) < 1.0 \times 10^{-4}$
$\eta' \rightarrow invisible$	$Br(\eta' \rightarrow invisible) < 5 \times 10^{-4}$
$K_S^0 \rightarrow invisible$	no limits
$K_L^0 \rightarrow invisible$	no limits
e^+ beam	

Resonant A' production
True Muonium

136th SPSC Meeting:

The Committee **continues reviewing** the proposal SPSC-P-359 for an experiment to search for dark sector particles weakly coupled to the muon at the SPS by the NA64 Collaboration.

The SPSC **recommends** the requested test beam run in 2021 in the M2 beam-line with the goal to commission the NA64 μ detector and to probe for the first time the coupling strengths and masses $M_{Z\mu} < 200$ MeV that could explain the muon $(g-2)_\mu$ anomaly.

138th SPSC Meeting:

The Committee **congratulates** the NA64 Collaboration on the publication of their updated bounds on the hypothetical $X(16.7)$ dark boson coupling and on the dark-photon parameter space in the visible-decay mode.

The SPSC **notes** with pleasure the ongoing efforts to optimise the experimental areas and equipment upgrades for the runs with electrons at H4 and the pilot run with muons at M2 beam lines.

Suggested minutes of the 142th SPSC meeting:

The SPSC **congratulates** the NA64 Collaboration for the publication of new constraints on light axion-like and scalar particles that couple to two photons, and on a generic boson contribution to the electron $g-2$, obtained in the invisible-mode configuration.

The SPSC **notes** with interest the extension of the program to the positron annihilation channel.

The SPSC **is looking forward** to the completion of the planned equipment upgrades and to the assessment of the electron and muon beam quality parameters at the new experimental locations.