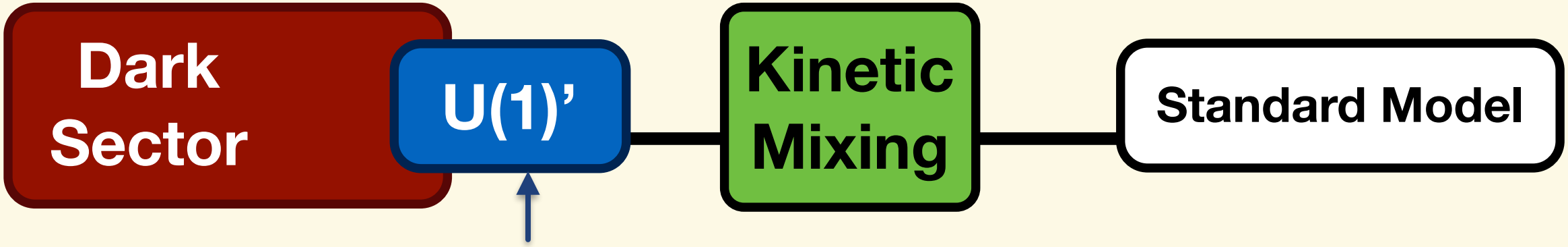
NA64 @ H4 STATUS REPORT 2020

Paolo Crivelli, ETH Zurich, Institute for Particle Physics and Astrophysics on behalf of the NA64 collaboration

DARK SECTORS - THE VECTOR PORTAL

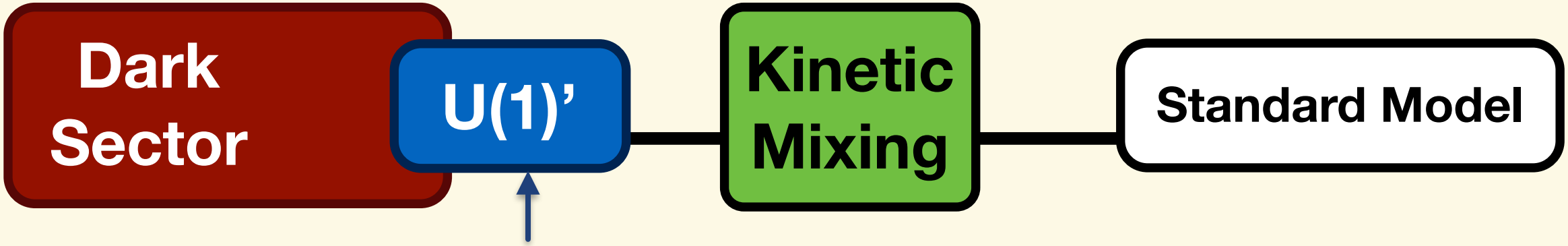


DARK SECTOR (DS) charged under a new U(1)' gauge symmetry and interacts with SM through kinetic mixing (ε) of a MASSIVE VECTOR MEDIATOR (A') with our photon.

Dark matter with mass (m_χ), part of DS. Four parameters: $m_{A'}$, m_χ, α_D ,ε

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} - \frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} + \frac{\epsilon}{2} F'_{\mu\nu} F^{\mu\nu} + \frac{m^2_{A'}}{2} A'_\mu A'^\mu$$
$$+ i\bar{\chi}\gamma^\mu \partial_\mu \chi - m_\chi \bar{\chi}\chi - \alpha_D \bar{\chi}\gamma^\mu A'_\mu \chi,$$

DARK SECTORS - THE VECTOR PORTAL



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

OBSERVED **AMOUNT OF DARK MATTER** TODAY

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$

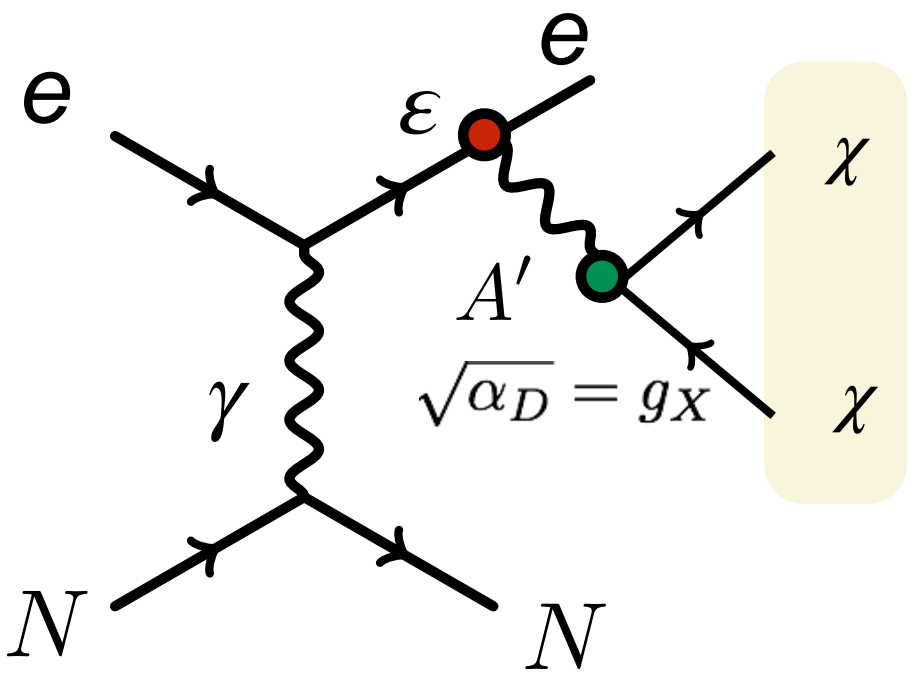
Large range for g_X and m_X

J. Feng and J. Kumar Phys.Rev.Lett.101:231301,2008

SEARCHES FOR DARK SECTORS AT ACCELERATORS

INVISIBLE DECAY MODE $m'_A > 2m_X$

1) BEAM DUMP APPROACH (MiniBooNE, LSND, NA62...)



Flux of X generated by decays of A's produced in the dump.

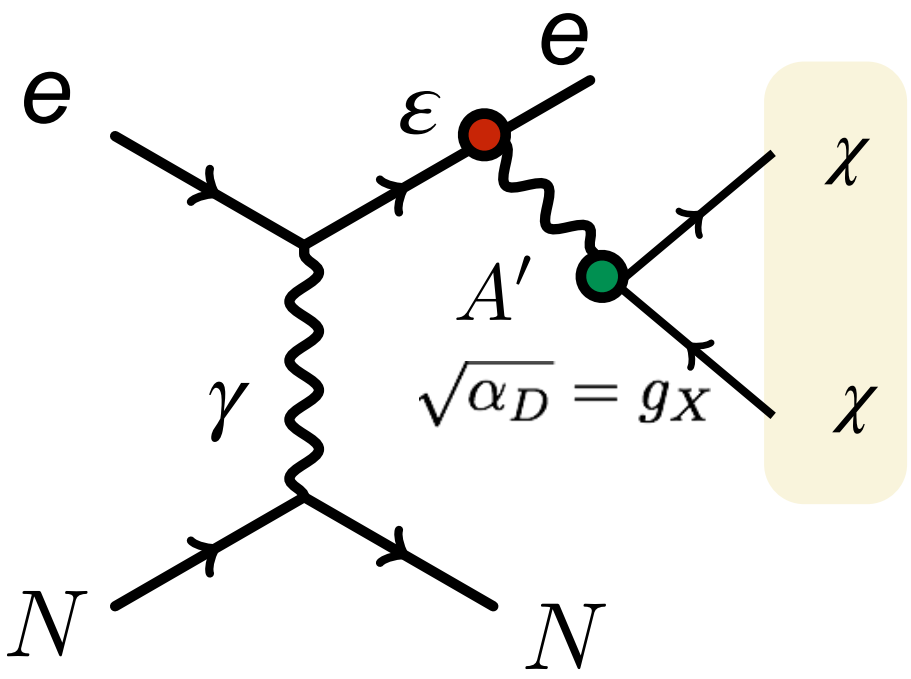
Signal: X scattering in far detector

$$\sigma \propto \epsilon^4 \alpha_D$$

SEARCHES FOR DARK SECTORS AT ACCELERATORS

INVISIBLE DECAY MODE $m'_A > 2m_X$

2) NA64/LDMX APPROACH



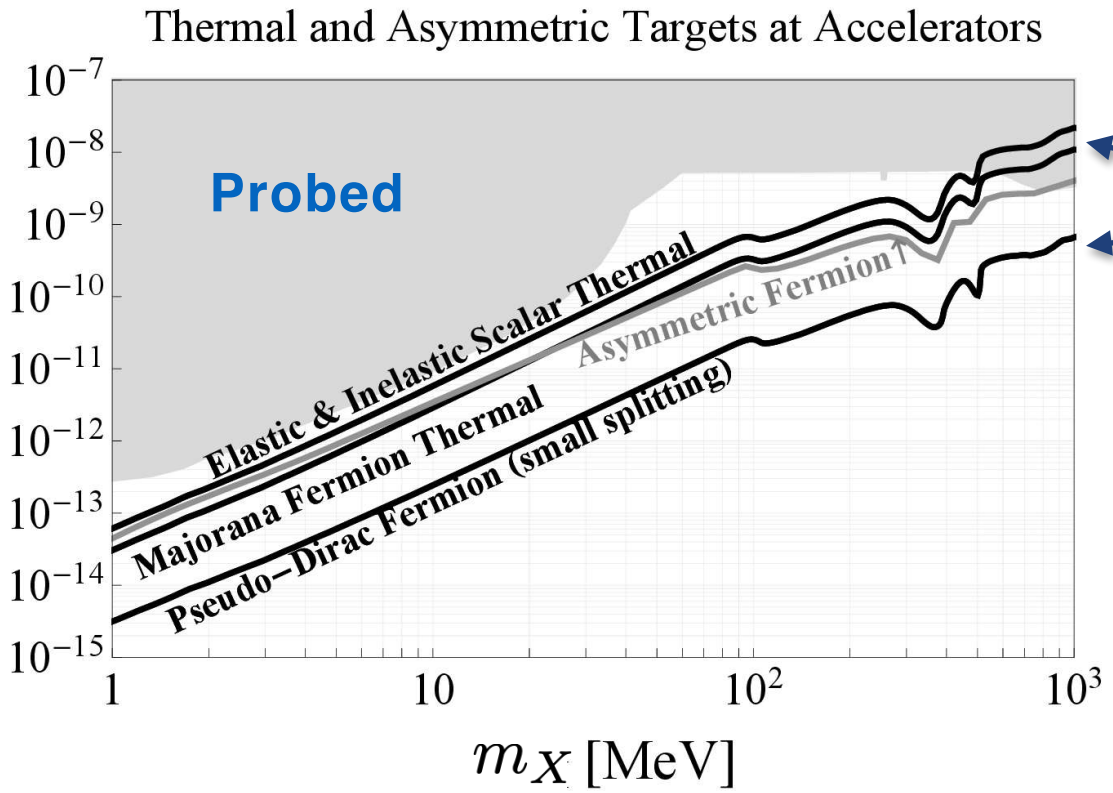
NA64 **missing energy**: produced A's carry away energy from the active dump used to measure recoil e- energy

$$\sigma \propto \epsilon^2$$

EXPLICIT TARGET FOR NA64 (y,m_X) DM PARAMETER SPACE

recent review https://arxiv.org/pdf/1707.04591.pdf

$$y = \epsilon^2 \alpha_D (m_X/m_{A'})^4$$



Solid lines predictions from DM relic abundance

Cross sections DM -> SM annihilation is ~ Y, useful variable to compare exp. sentivities

EXPLICIT TARGET FOR NA64 (y,m_X) DM PARAMETER SPACE

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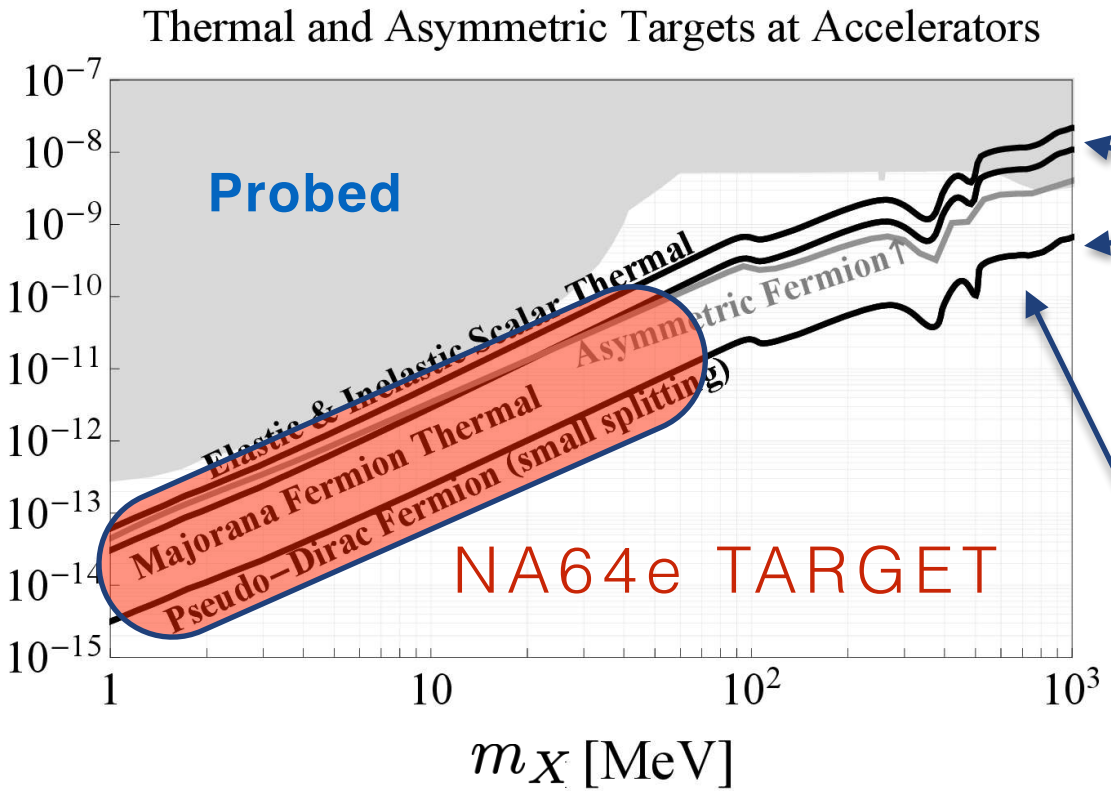


Solid lines predictions from DM relic abundance

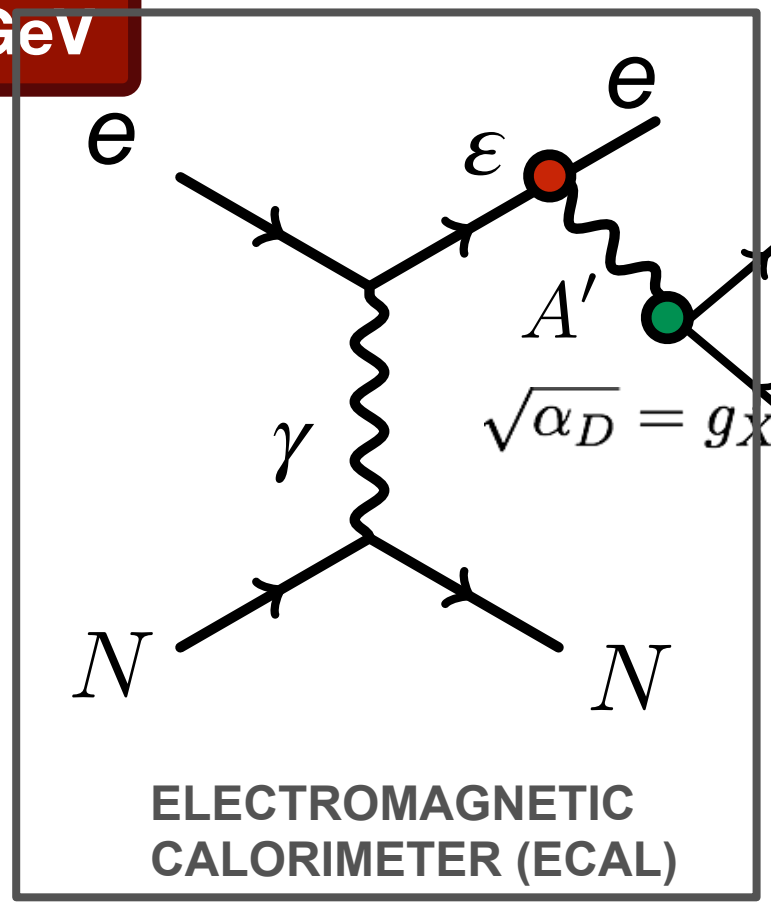
higher mass region could be covered by NA64mu (pilot run in 2021, see report from Laura)

PLB796, 117 (2019)

The NA64 method to search for A' → $\chi\bar{\chi}$

TAGGED 100 GeV

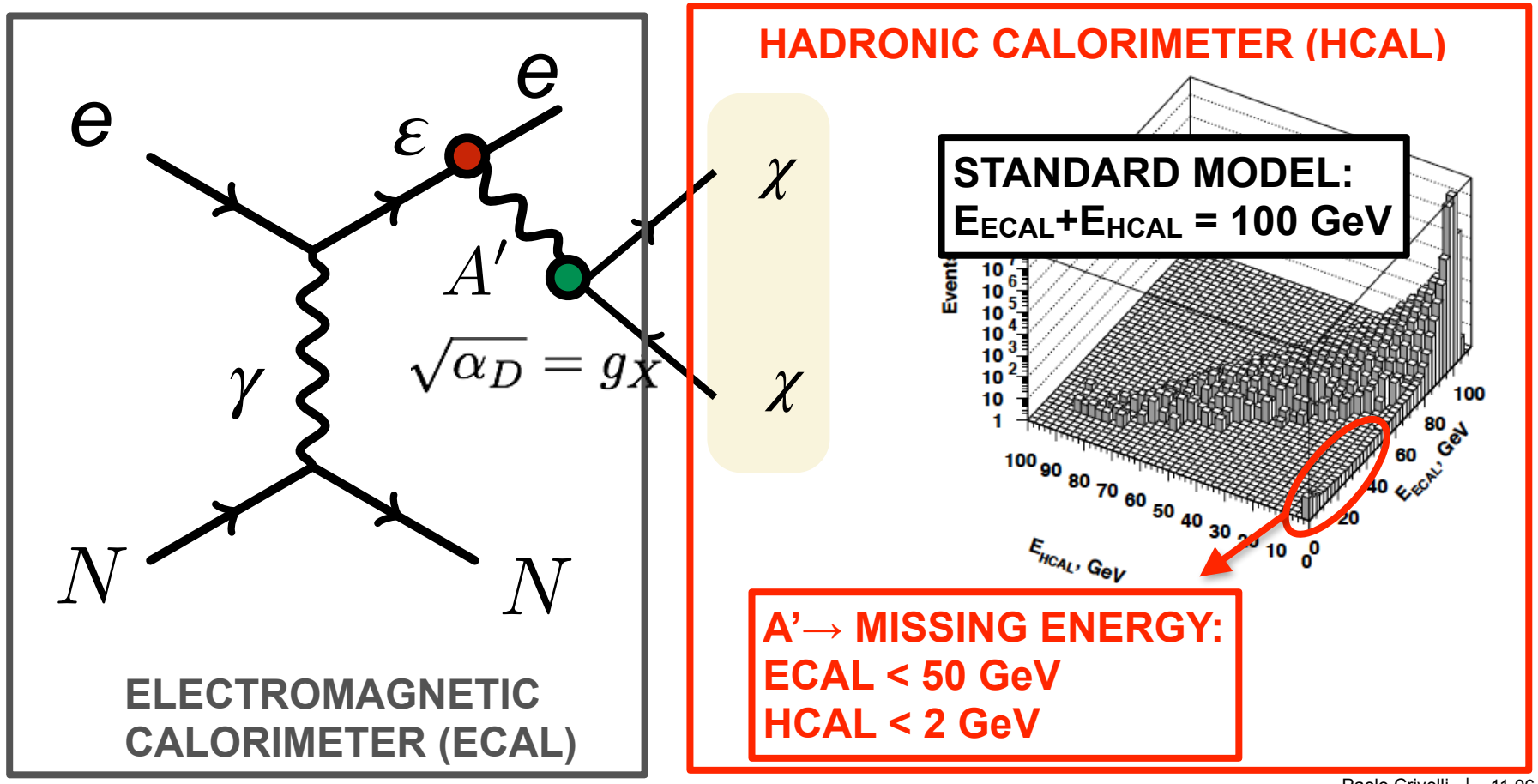
Requested ECAL ENERGY < 50 GeV



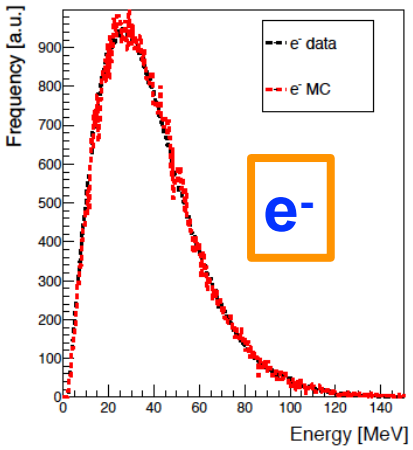
"BREMSSTRAHLUNG" OF A'

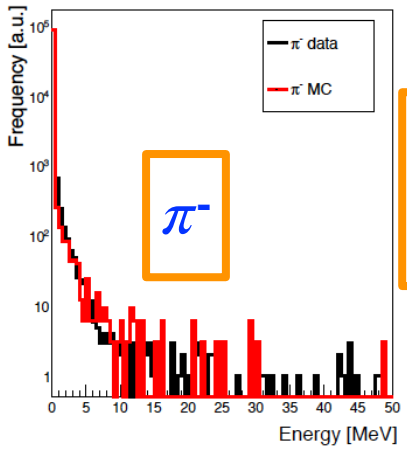
Active Dump

Signature for the invisible decay A' → $\chi\bar{\chi}$ - large missing energy



The NA64 setup to search for A' → $\chi\bar{\chi}$





HCAL:High hermeticity due to Lorentz boost

Particle identification
SR emission ~ $1/m^4$

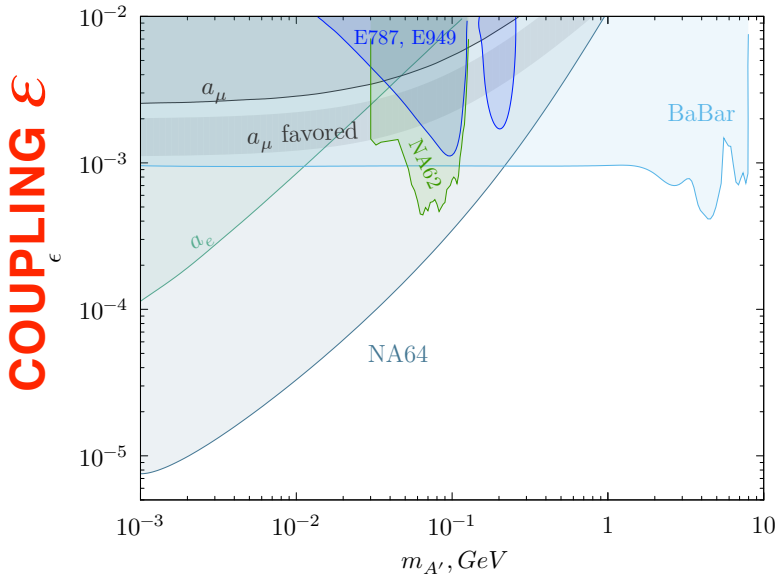
Active target

100 GeV electrons (tagged with $S_{1,2,3}$)

Two bending magnets in series 7 T.m field → reconstruction of e⁻ incoming momentum

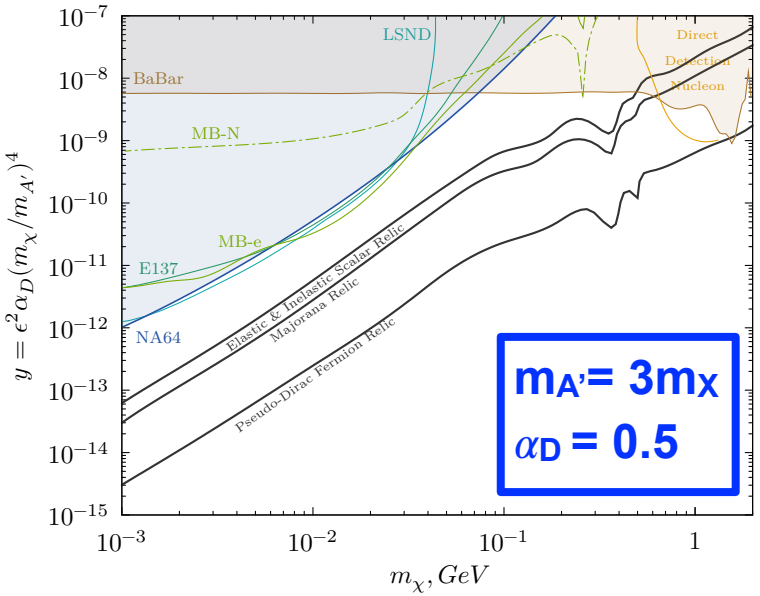
Combined results (2016-2018)

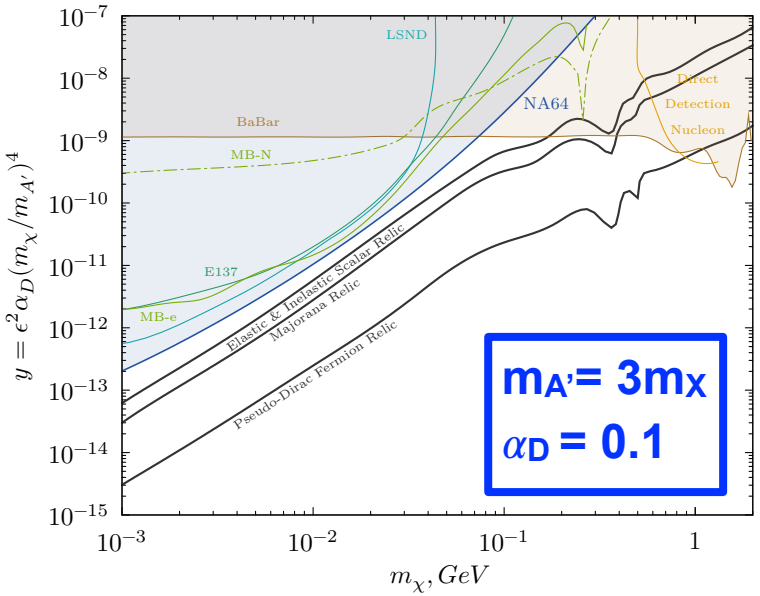
TOT: 2.84 x 10^{11} EOT



MASS OF THE DARK PHOTON

First time NA64 constraints on light thermal DM exceeding sensitivity of beam dump exp. (suppressed by $\epsilon^2\alpha_D$)

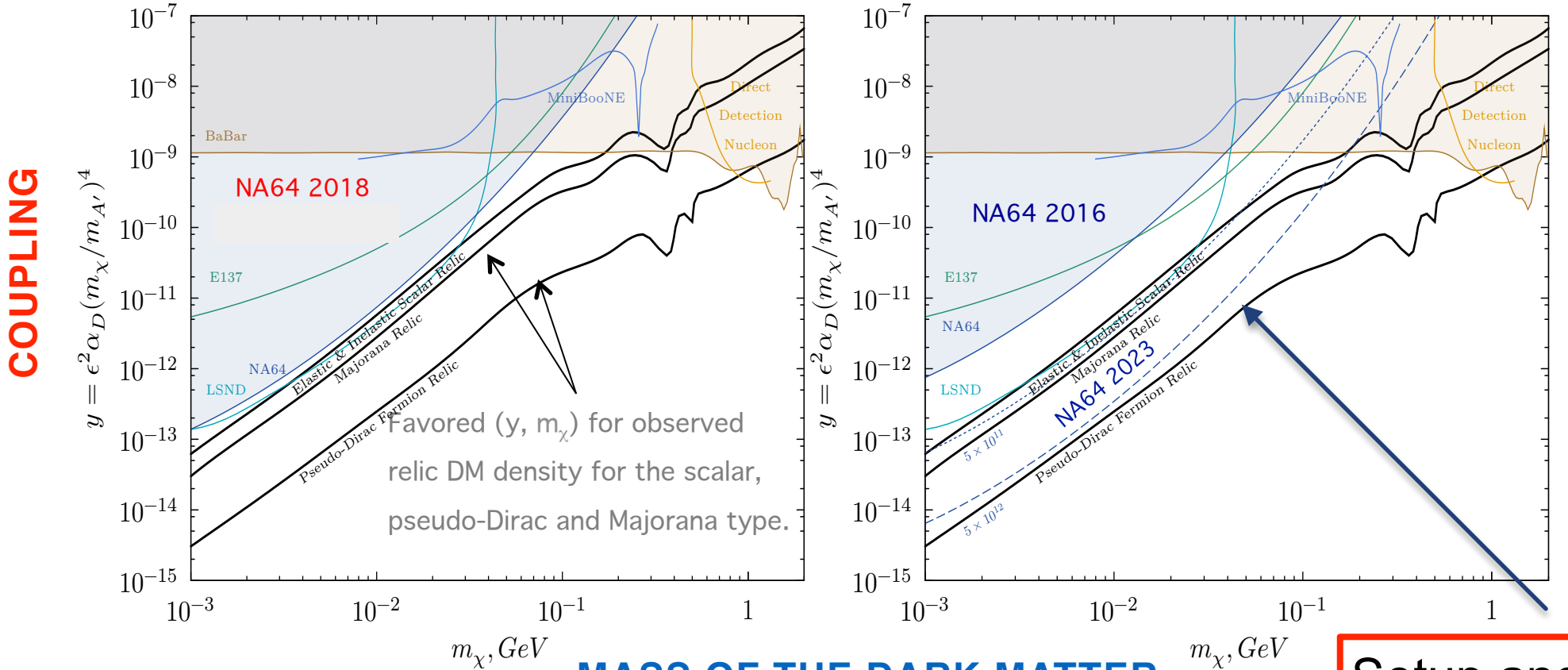




MASS OF THE DARK MATTER

UPDATE NA64 collaboration, Phys. Rev. Lett. 123, 121801 (2019), selected as Editor suggestion

Current bounds on thermal relic DM & projected NA64 sensitivity

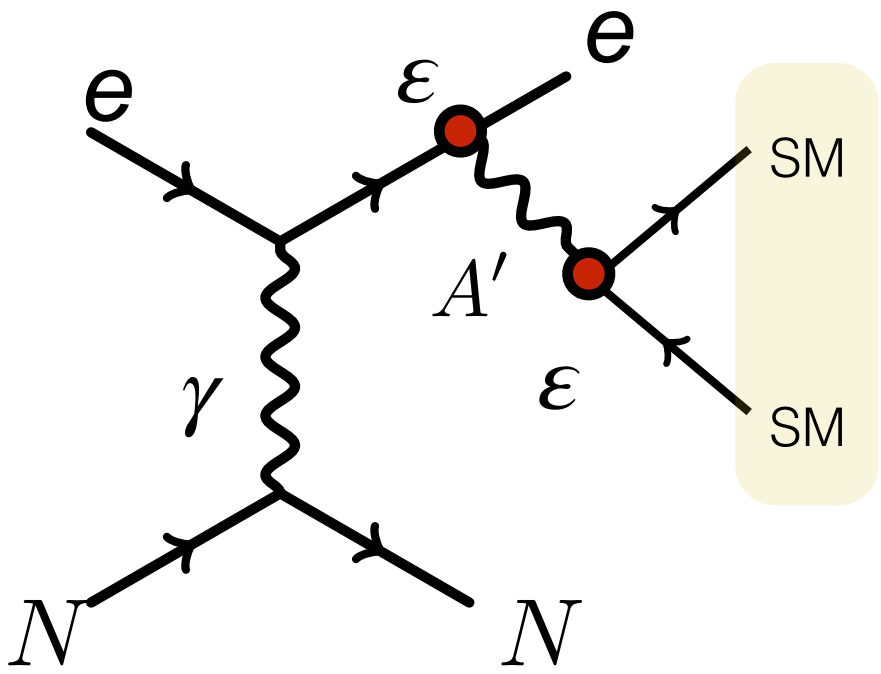


$\alpha_D = 0.1$ and $m_{A'} = 3m_\chi$

Setup and beam upgrade required (status in few slides)

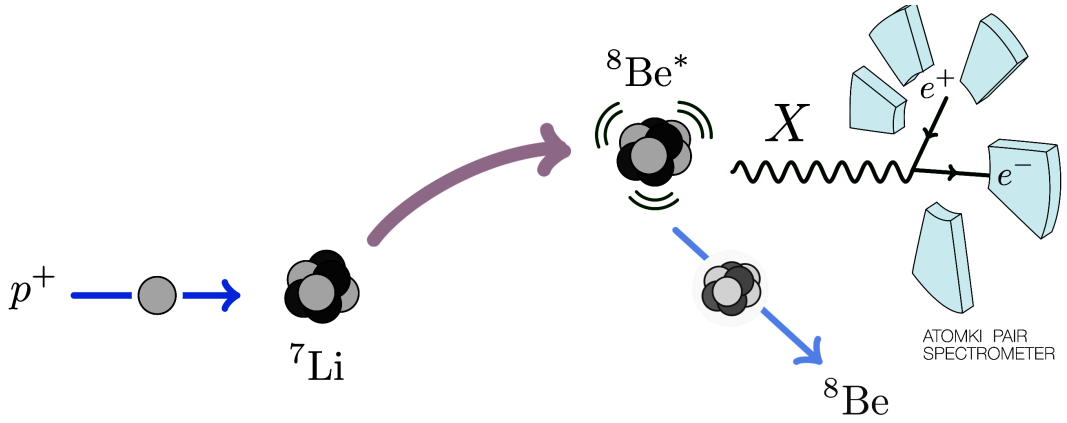
2) The NA64 search for X/A' → e^+e^-

VISIBLE DECAY MODE $m'_A < 2m_X$

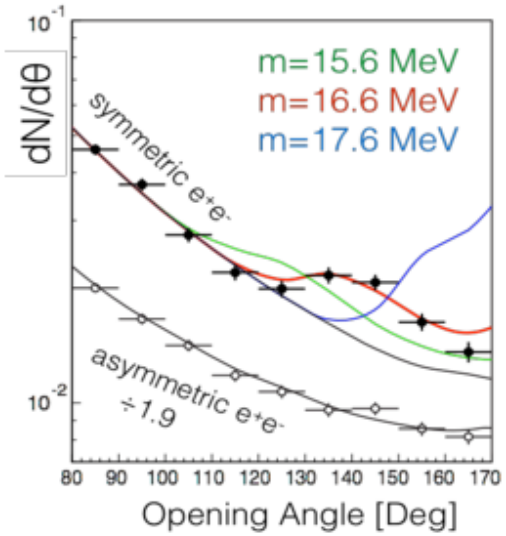


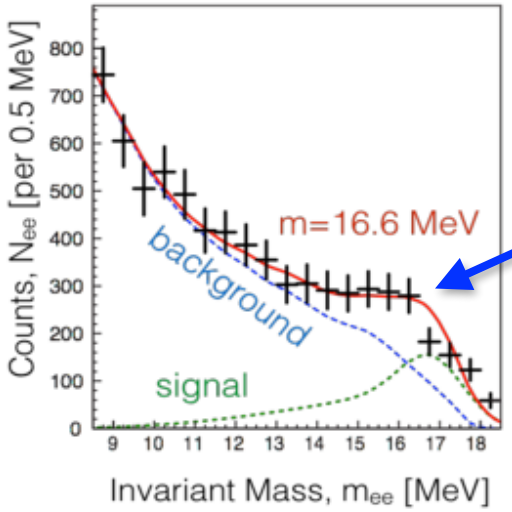
Pair production of SM particles

^{8}Be anomaly and X boson



A. J. Krasznahorkay et al. Phys. Rev. Lett.116, 042501 (2015) and new evidence for X17 from measurements with 4He arXiv:1910.10459

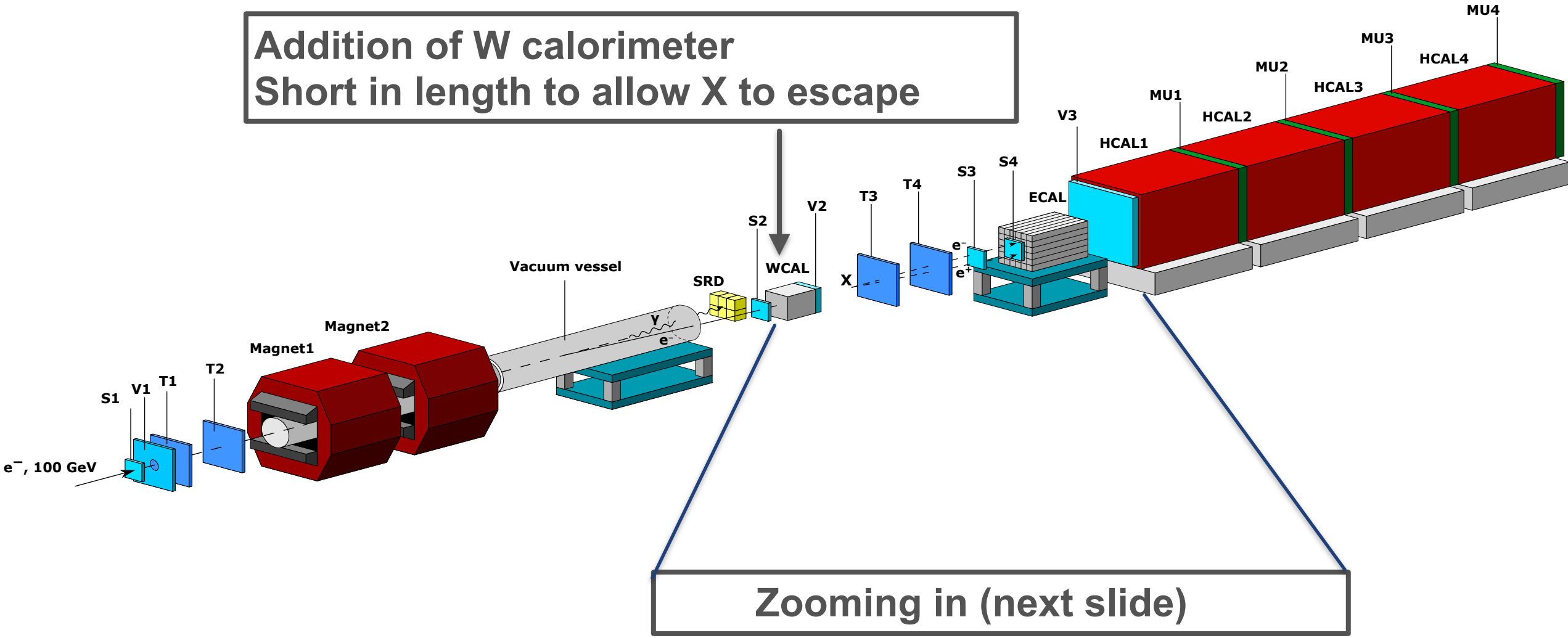




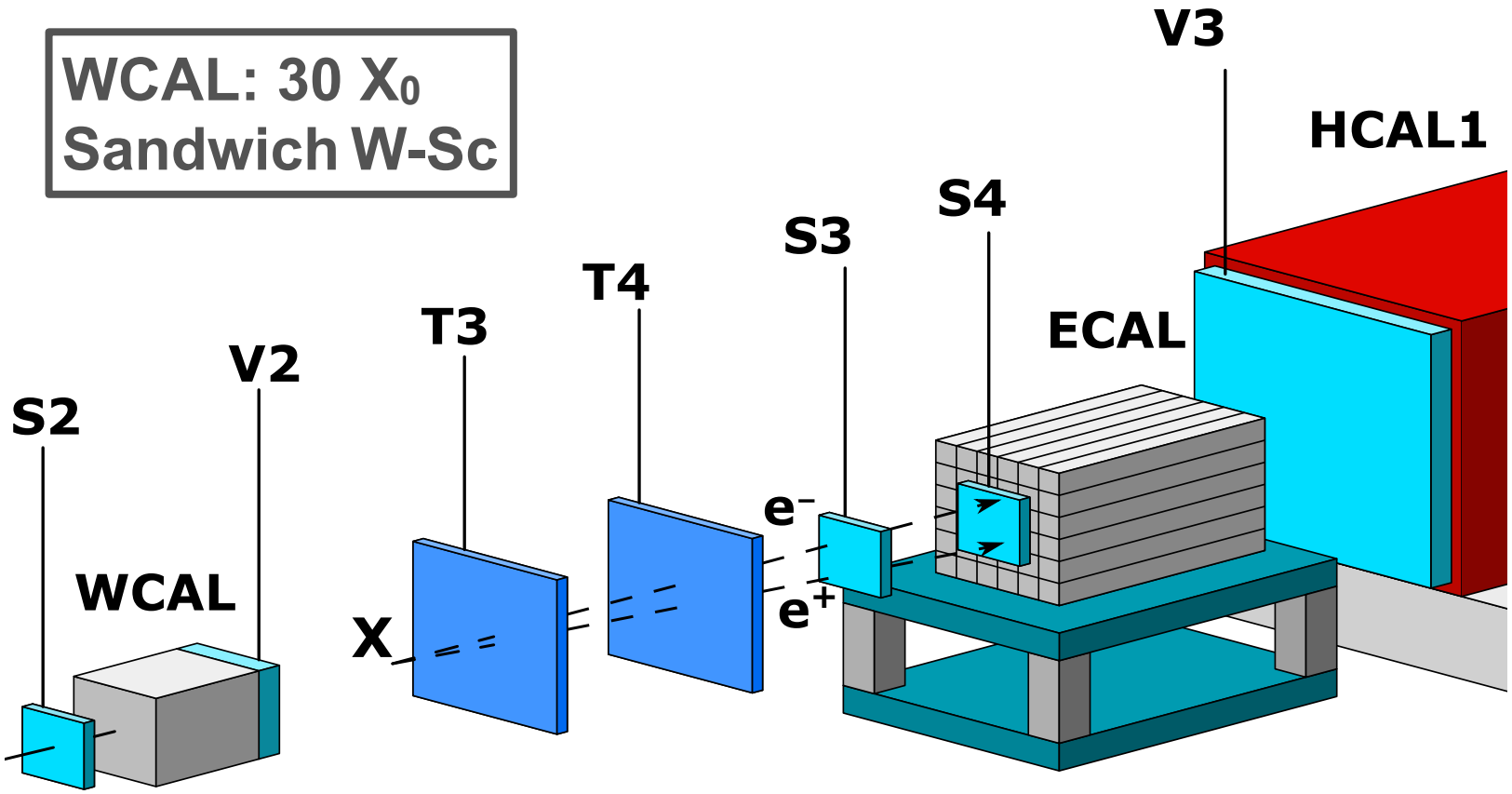
Could be explained by new 'protophobic' gauge boson X with mass around 17 MeV

J. L. Feng et al., Phys. Rev. D95, 035017 (2017)
J. L. Feng et al., arXiv 2006.01151

The NA64 setup to search for $X \rightarrow e^+e^-$ - *calorimetry approach*



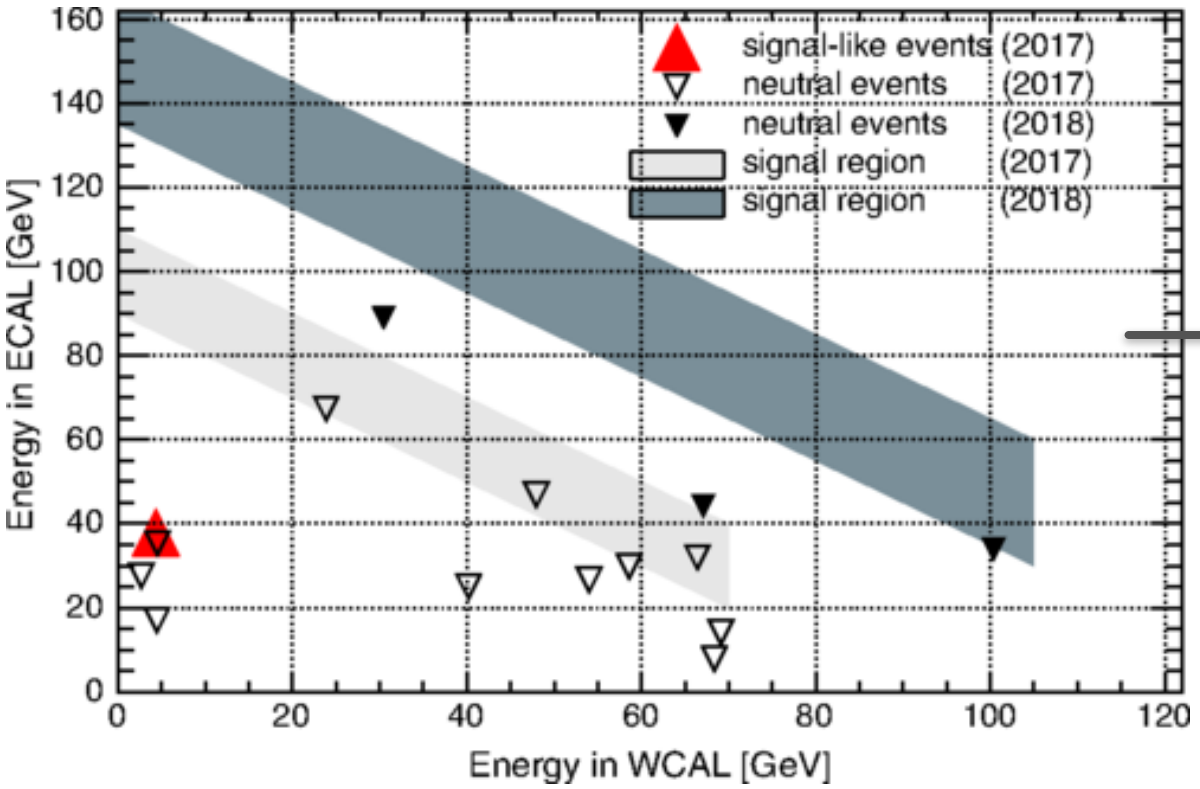
The NA64 search for $X \rightarrow e^+e^-$ - *experimental signature*



Signature:

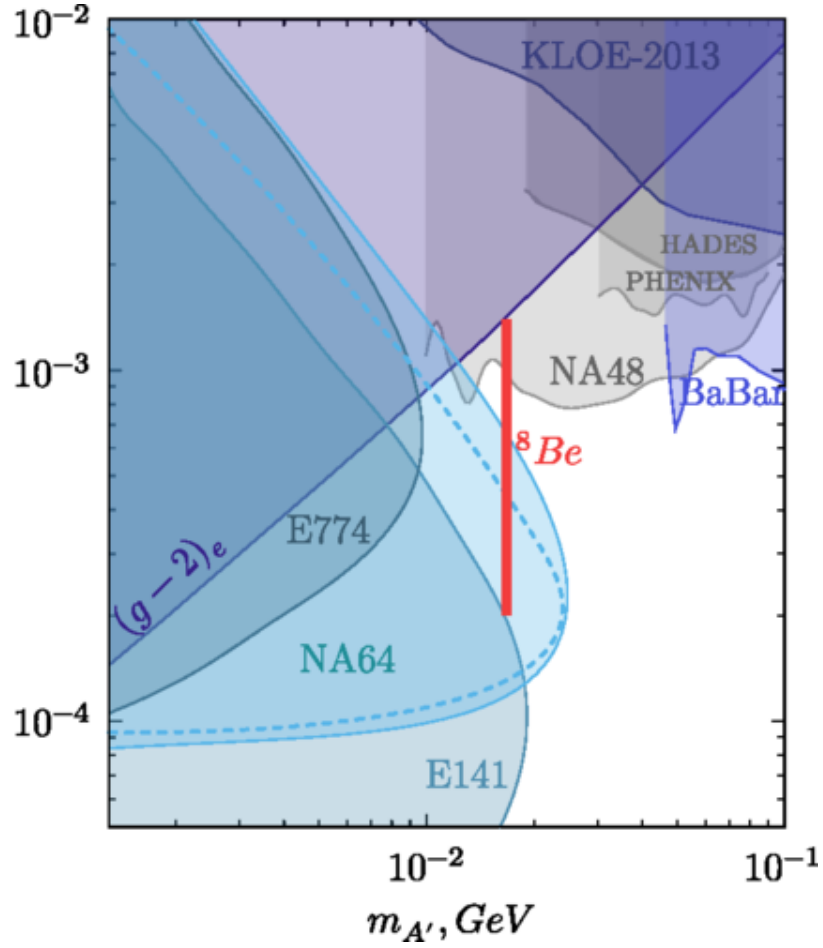
1) $E_{WCAL}+E_{ECAL}$ = 100 GeV
2) No activity in $V_{2,3}$ and HCAL
3) Signal in S3, S4
4) e-m shower in ECAL

The NA64 search for $X \rightarrow e^+e^-$ - *NEW results (2017-2018)*



No signal-like event in signal box

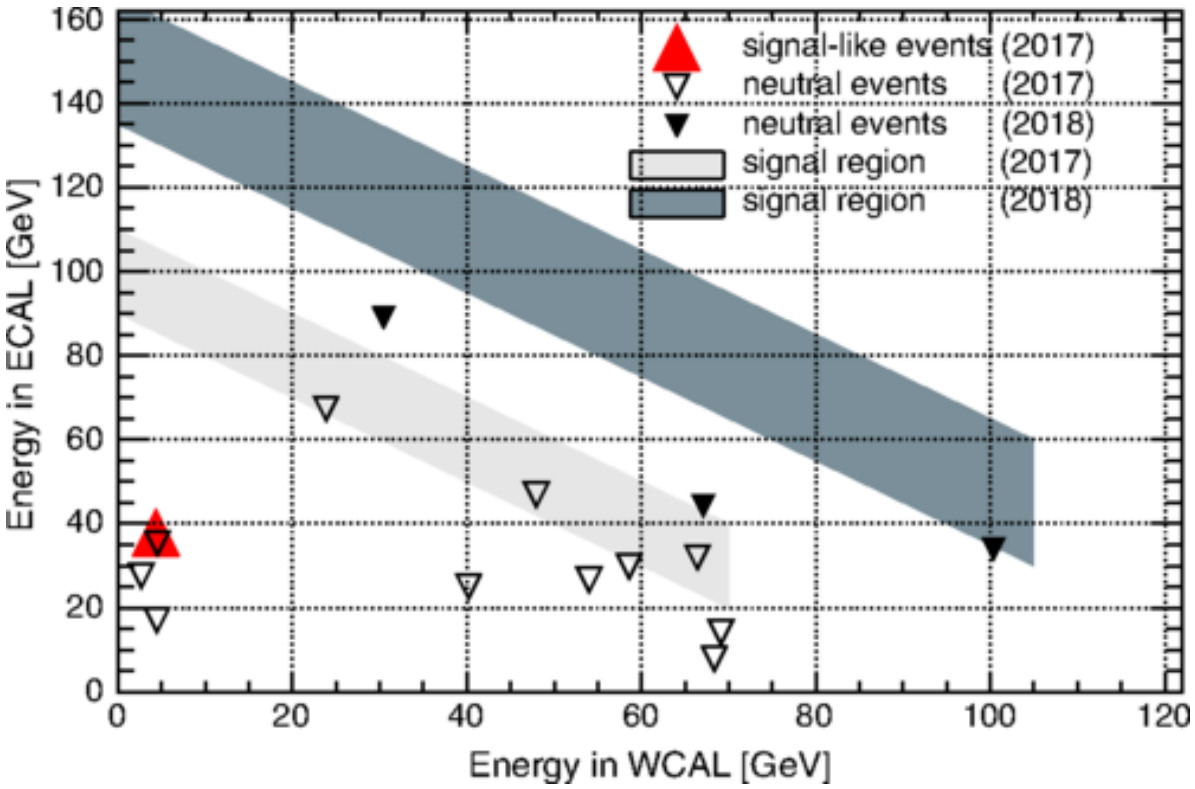
~ 8x10¹⁰ EOT

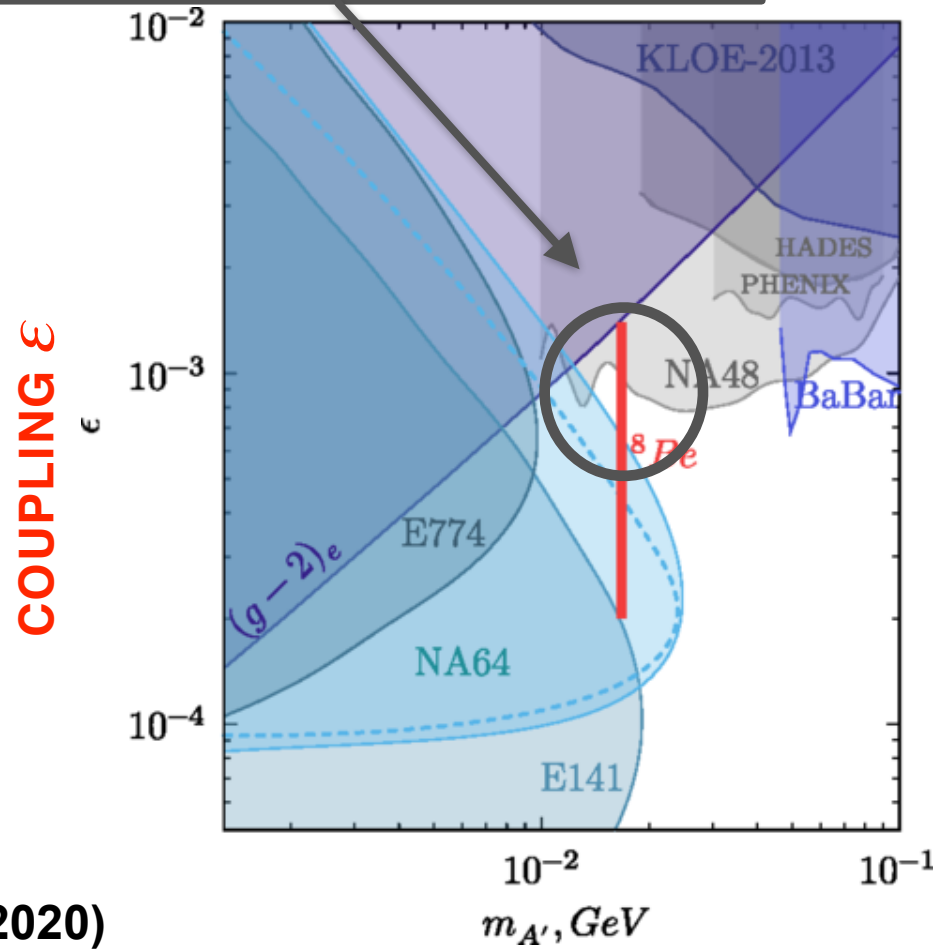


NA64 collaboration, PRL 120, 231802 (2018), **PRD 107, 071101 (R) (2020)**

The NA64 search for $X \rightarrow e^+e^-$ - *prospects (2021)*

Feasibility under study (in few slides)

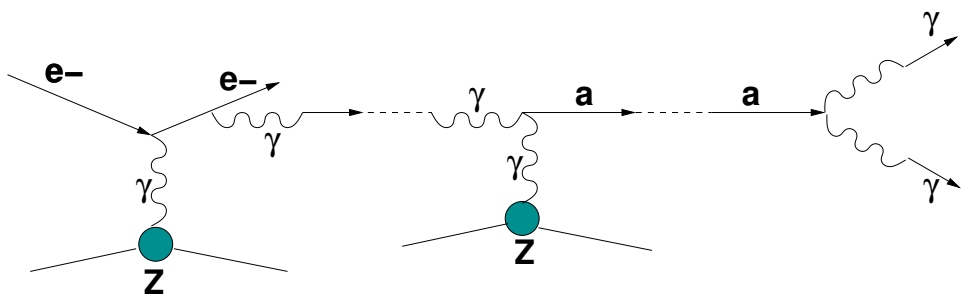




NA64 collaboration, PRL 120, 231802 (2018), **PRD 107, 071101 (R) (2020)**

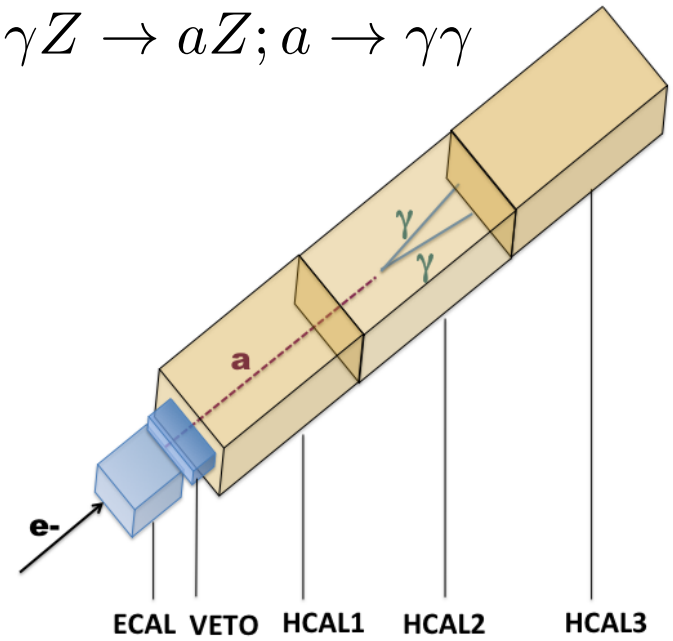
3) The NA64 search for ALP

NA64 collaboration, CERN-EP-2020-068 arXiv:2005.02710
submitted to PRL

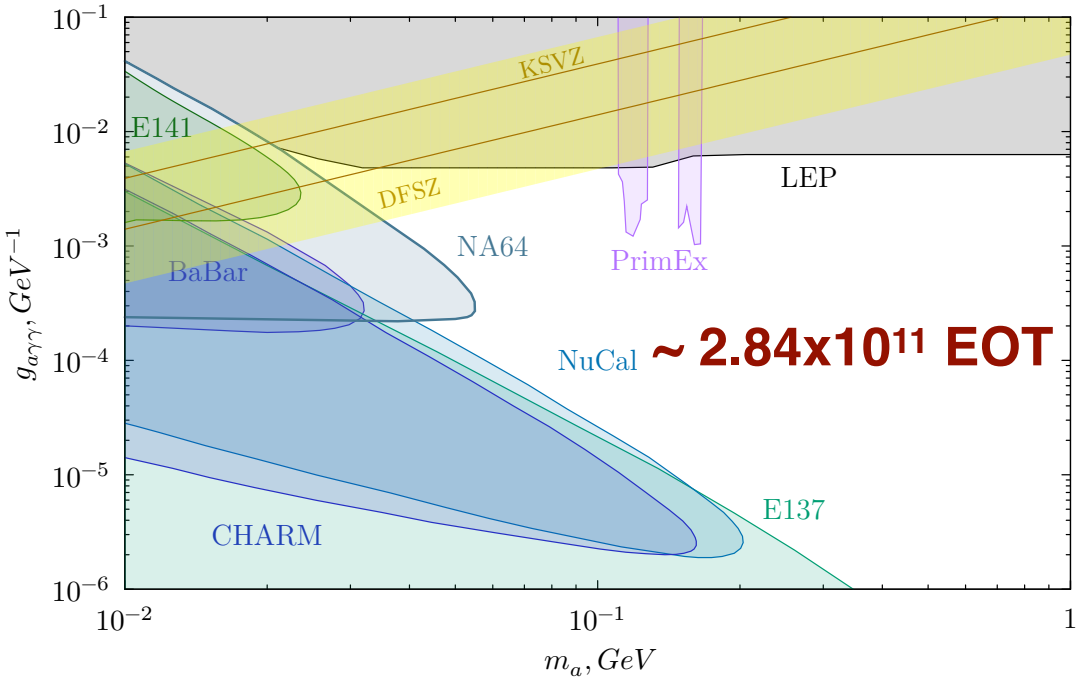


Production via Primakoff effect

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



Closing the gap between beam dump and colliders



Search expected to be BKG free up to ~ 5 x10¹² EOT, allowing to probe ALP masses up to ~ 200 MeV

Additional publications - Theory working group

(i) S. Demidov, S. Gninenko and D. Gorbunov, “Light hidden photon production in high energy collisions,” JHEP 1907 (2019) 162, [arXiv:1812.02719 [hep-ph]].

(ii) S. N. Gninenko, D. V. Kirpichnikov, M. M. Kirsanov and N. V. Krasnikov, “Combined search for light dark matter with electron and muon beams at NA64,” Phys. Lett. B 796 (2019) 117 [arXiv:1903.07899 [hep- ph]].

(iii) S. N. Gninenko, N. V. Krasnikov and V. A. Matveev, “Search for dark sector physics with NA64,” arXiv: 2003.07257 [hep-ph].

(iv) S. N. Gninenko, D. V. Kirpichnikov and N. V. Krasnikov, “Probing millicharged particles with NA64 experiment at CERN,” Phys. Rev. D 100 (2019) no.3, 035003 arXiv:1810.06856 [hep-ph].

(v) R. R. Dusaev, D. V. Kirpichnikov and M. M. Kirsanov, “Photoproduction of axion-like particles at NA64,” arXiv: 2004.04469 [hep-ph].

(vi) D. V. Kirpichnikov, V. E. Lyubovitskij and A. S. Zhevlakov, “Implication of the hidden sub-GeV bosons for the $(g-2)_\mu$, ^{8}Be-^{4}He anomaly, proton charge radius, EDM of fermions and dark axion portal,” arXiv:2002.07496 [hep-ph].

(vii) N. V. Krasnikov, “Implications of last NA64 results and the electron g_e-2 anomaly for the X(16.7) boson survival,” arXiv:1912.11689 [hep-ph].

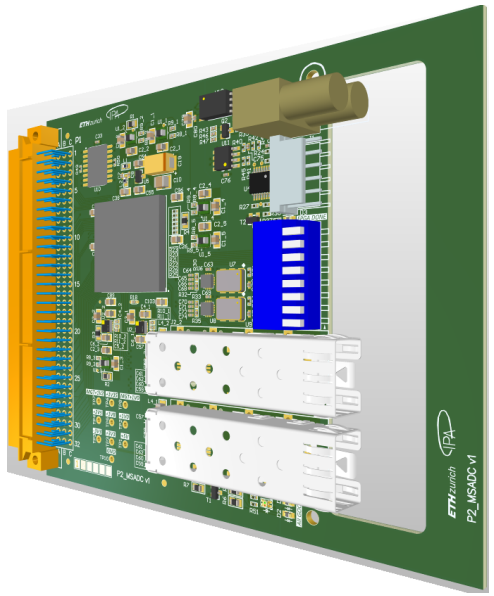
Status of Preparation of new area in H4

- Design of beam line and the experimental area was performed in a **strong collaboration with the EN-EA-LE and EN-EA-DC groups.**
- MC studies: to **maximize electron flux,** reduce beam halo and **minimize background** from hadron contamination in the beam.
- **New H4 zone** will allow for even wider range of searches for new physics with NA64e than was foreseen in the proposal.

INSTALLATION EXPECTED TO BE COMPLETED IN 2021 WHEN SPS WILL RESUME.

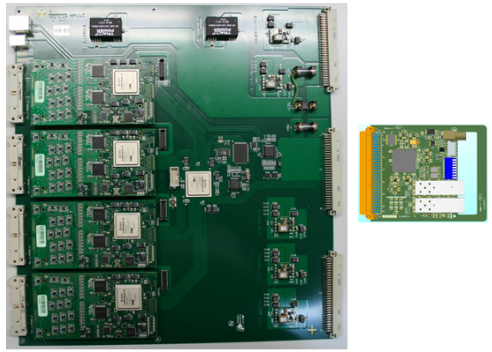
DAQ upgrade

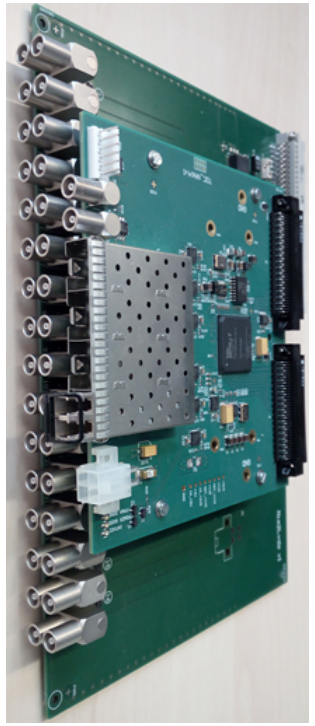
New DAQ : to improve in data-taking efficiency. At the moment the DAQ allows to collect about 8 kHz with a dead time of 20%. After the upgrade we plan to reach more than 50 kHz with less than 1 % dead time.



NEW P2MSADC

MSADC + P2MSADC



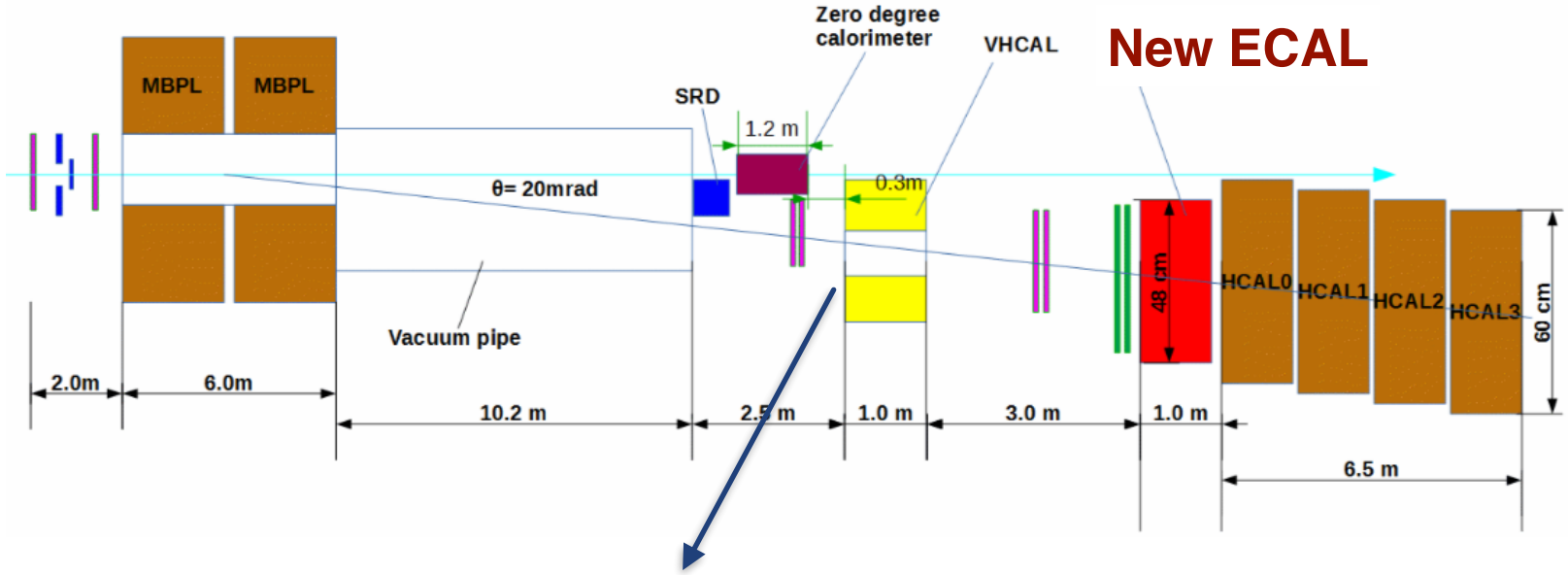


NEW PRESCALERS

New electronics - ~ 80 → 200 MHz MSADC to allow working at high beam intensity by 2022 run.

Setup upgrade A' → $\chi\bar{\chi}$

GOAL: increase the overall performance and improve background rejection



New VHCAL: to improve detector hermiticity and reject high-p_t hadronic secondaries from beam interactions upstream the ECAL dump. Search expected to be BKG free up to ~ 10^{13} EOT

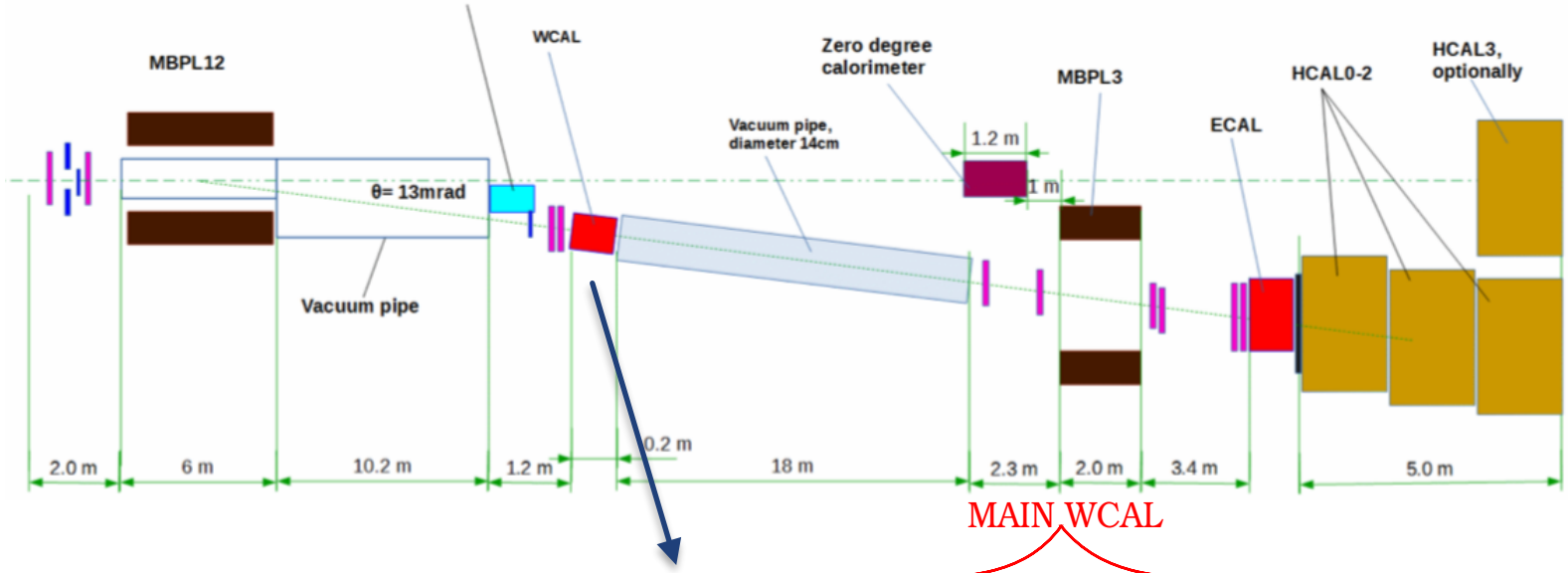
- Dimensions ~ 50 × 50 cm^2 , 16 cells, matrix 4x4 cells
- Central hole size 12 × 6 cm^2
- Cell size 12×12 cm^2
- Length ~100 cm, 5 λ
- 30 layers, 25 mm copper + 2 mm scintillator
- Read out WLS fiber, 12 fibers per scintillator
- Light yield ~15 photoelectrons per MIP

Setup upgrade for X/A' → e^+e^- - Calorimetry + mass reconstruction

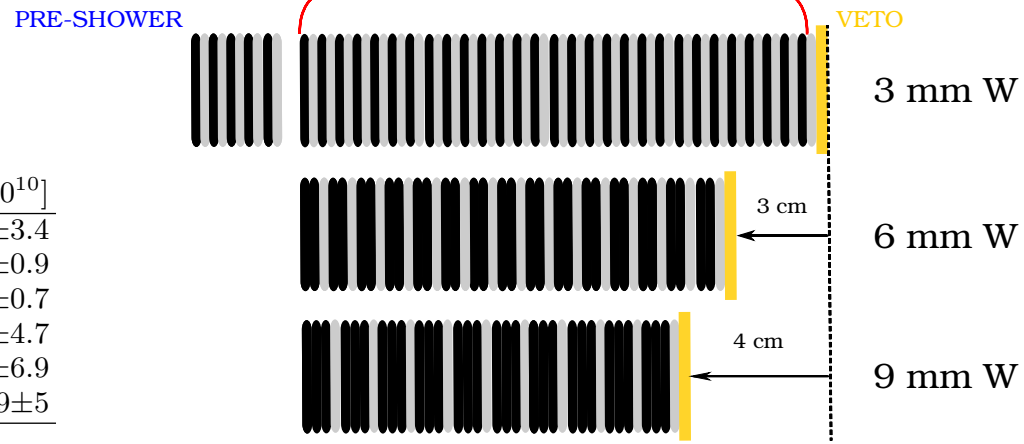
GOALS

i) probe remaining X17 parameter space

ii) claim an unambiguous observation of X17 by reconstructing its invariant mass.



WCAL optimisation: shorter WCAL dump with the total thickness ≃ 30 X_0, and a new WCAL veto counter



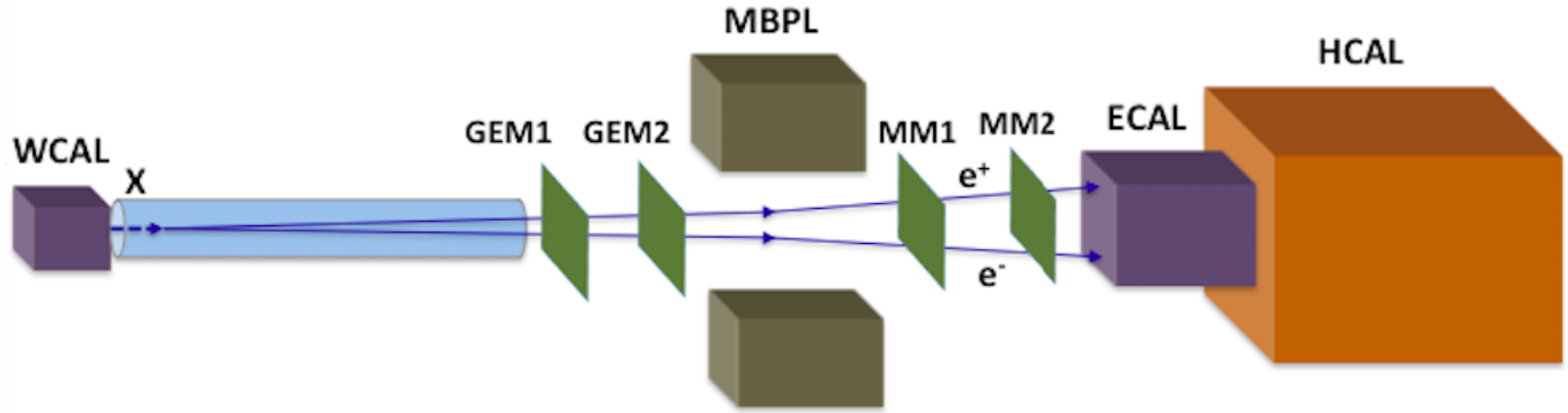
WCAL structure [mm](layers)	WCAL length [mm]	ϵ	EOT to cover $X17$ at 90% confidence [10^{10}]
ECAL1:3+2(34)	178	0.001	17±3.4
ECAL1:6+2(17)	148	0.001	7±0.9
ECAL1:9+2(12)	138	0.001	6±0.7
ECAL1:3+2(34)	178	0.0012	85±4.7
ECAL1:6+2(17)	148	0.0012	24±6.9
ECAL1:9+2(12)	138	0.0012	19±5

Setup upgrade for X/A' → e^+e^- - Calorimetry + mass reconstruction

GOALS

i) probe remaining X17 parameter space

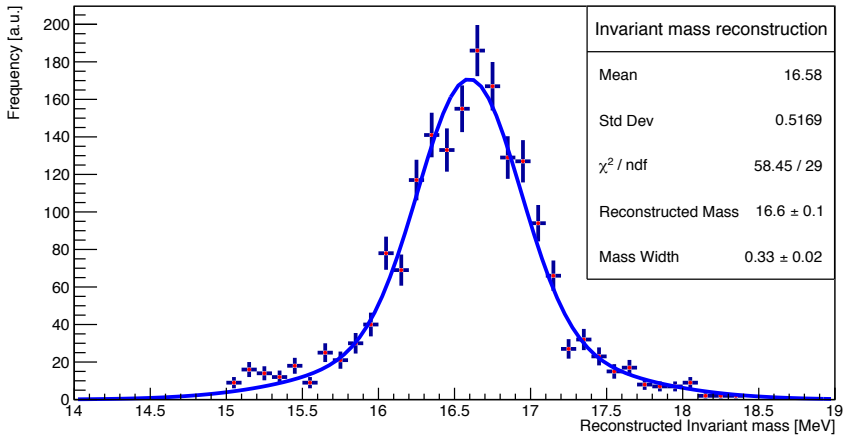
ii) claim an unambiguous observation of X17 by reconstructing its invariant mass.



New large area trackers at 18 m from vertex: measurement of the e^+e^- opening angle.

Additional spectrometer using MBPL magnet: momentum reconstruction + increase track separation at the ECAL.

New ECAL with larger transverse size: measurement of two separate em showers



Paper in preparation, draft submitted to the collaboration

SUMMARY & PLANS FOR 2021

- Preparation of the **new NA64 area at H4** and the detector upgrade is in progress.

- **Summer of 2021:** we plan to request three-weeks run for detector commissioning and accumulation of ≃ **10^{11} EOT in invisible mode** in order to cover yet unexplored areas in the sub-GeV Dark Matter parameter space

- **Autumn of 2021:** about six-seven weeks for detector commissioning and accumulation of ≃ **10^{11} EOT for visible mode at 150 GeV** to perform a more sensitive search for the $A'(X) \rightarrow e^+e^-$ decays.

The exploitation of the NA64 physics potential has just begun!

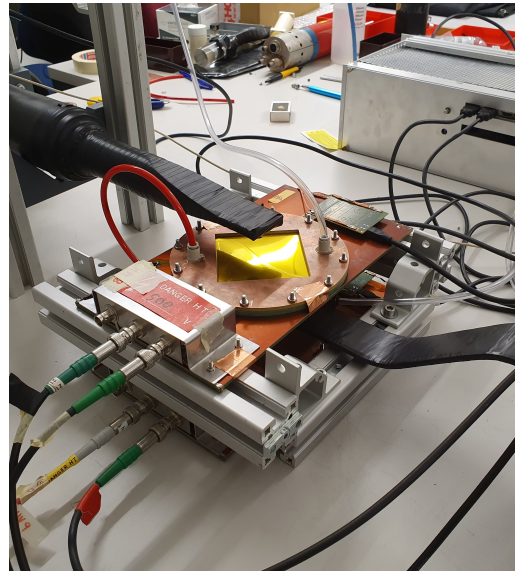
- **Before LS3:** Assuming intensity up to ≃ 10^7 e^-/ spill and on average ≃ 4000 good spills per day means accumulation of up to **5×10^{12} EOT** during 6 months of running is feasible. The results obtained with such number of EOT will allow us to **probe full parameter space for scalar and Majorana sub-GeV dark matter models.**

Backup slides

Summary of setup upgrade

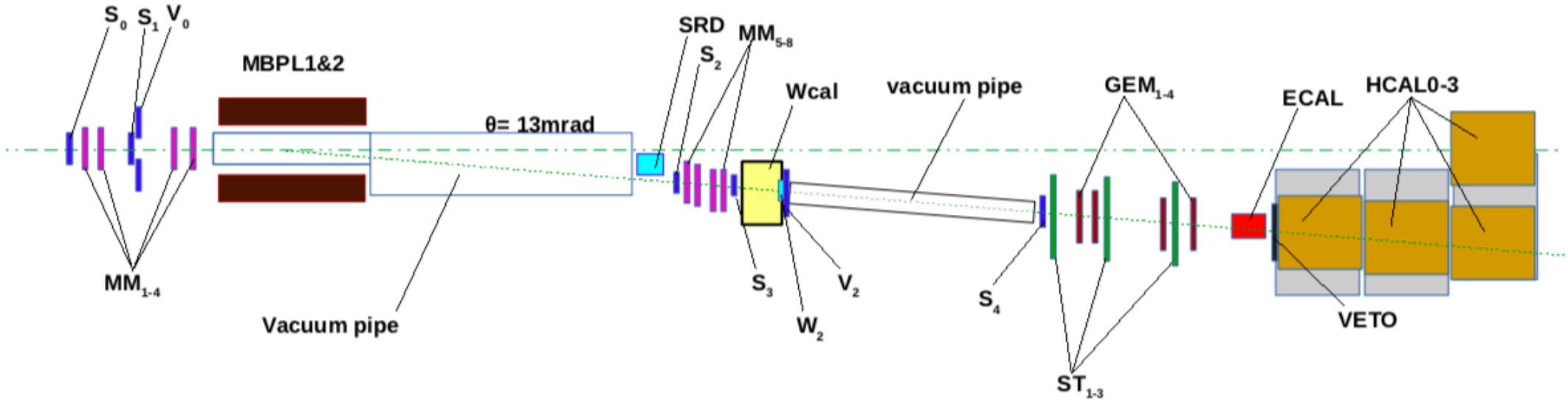
DETECTORS & DAQ UPGRADES: To increase the overall performance and improve background rejection the following upgrade of the setup are ongoing:

(i) additional number of the MM, GEM, ST stations are planned to be installed.
(ii) using of a new ECAL with larger transverse dimensions and new WCAL dump for the visible mode
(iii) using of a higher transversely segmented SRD detector with improved readout
(iv) large Veto HCAL (VHCAL) in front of the ECAL to reject large angle neutral secondaries from the upstream e^- hadronic interactions
(v) further improvement of the DAQ and the analysis program are foreseen to ensure a substantial data collection of $n_{EOT} \simeq 5 \times 10^{12}$ events in 2021-2023.



2018: NA64 search for $X \rightarrow e^+e^-$ - *optimised for very short lived X*

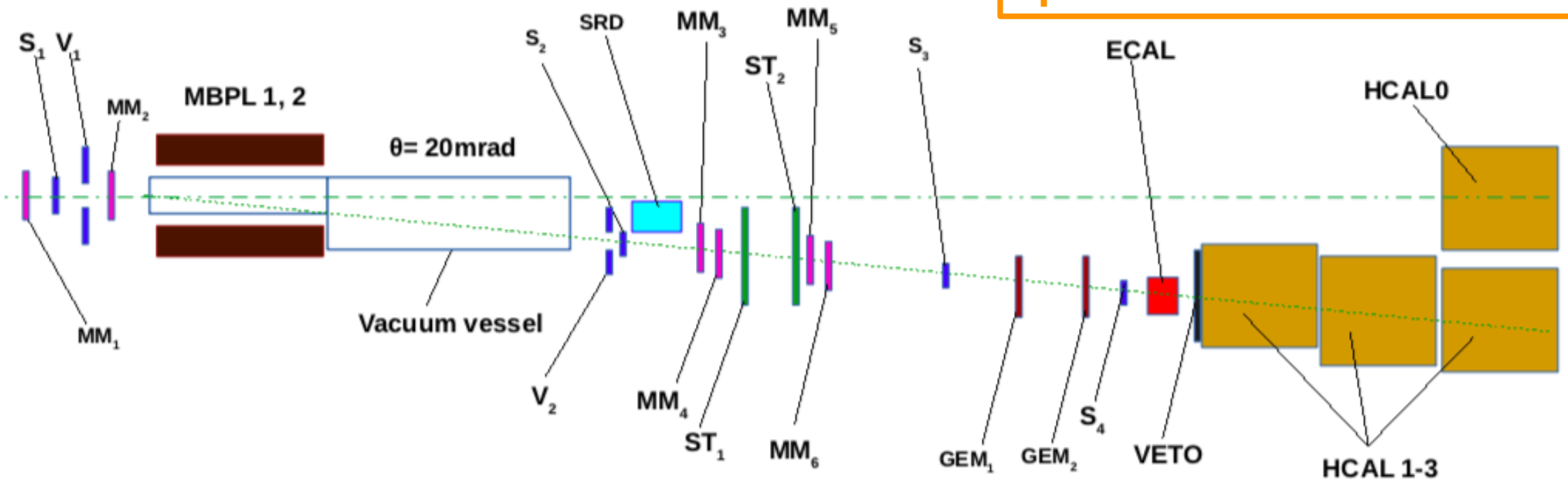
Beam energy: 100 GeV (2017) → 150 GeV



Setup optimization:
shorter WCAL, thinner veto (W2) after WCAL, vacuum pipe installed, additional trackers and increased WCAL- ECAL distance.

2018: Improvement of setup A' → $\chi\bar{\chi}$

HCAL0: Rejection of events with hard neutral from upstream e- interactions



ST1,2: New straw-tube trackers: VETO against hadron electro-production in the beam material upstream the ECAL.