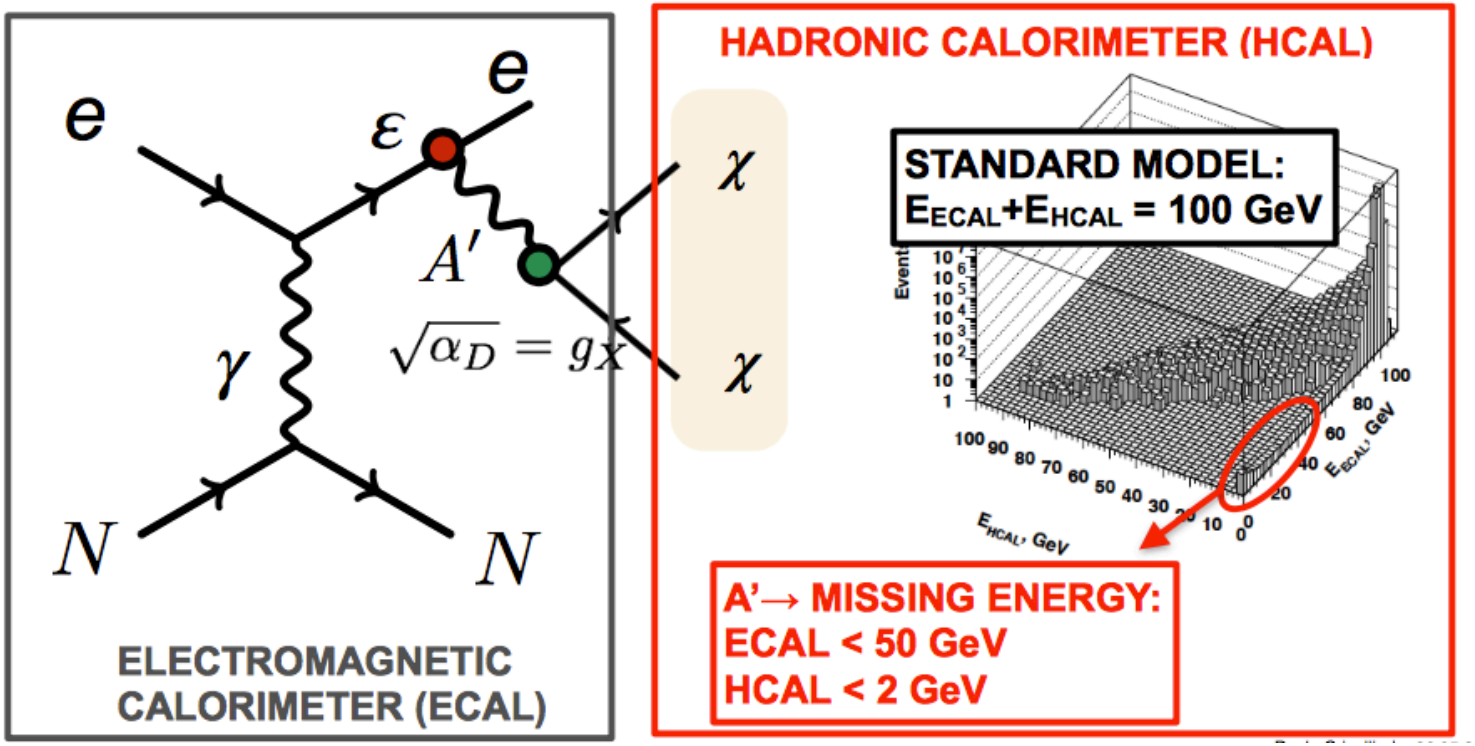
NA64 Annual Review

M. Bona, M. Contalbrigo, L. Gatignon, G. Schnell

Meeting with spokespersons on June 9, 2020

138th SPSC Meeting, April 11 2020

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



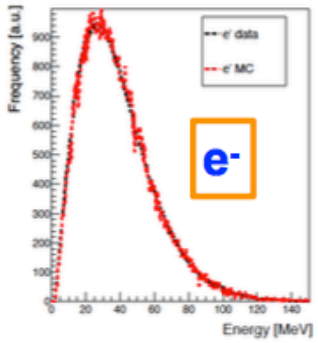
Appearance (dump) experiments
Visible far χ rescattering

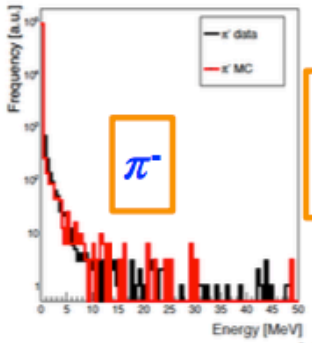
$$\sigma \propto \epsilon^4 \alpha_D$$

Disappearance NA64 approach
Missing energy

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

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





HCAL:High hermeticity due to Lorentz boost

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

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

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

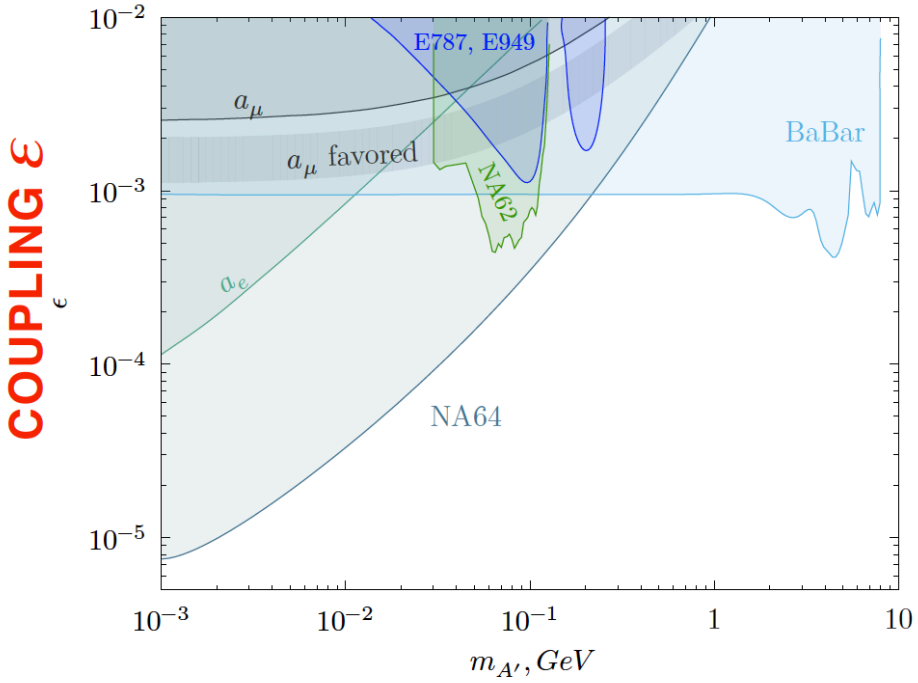
Combined results (2016-2018)

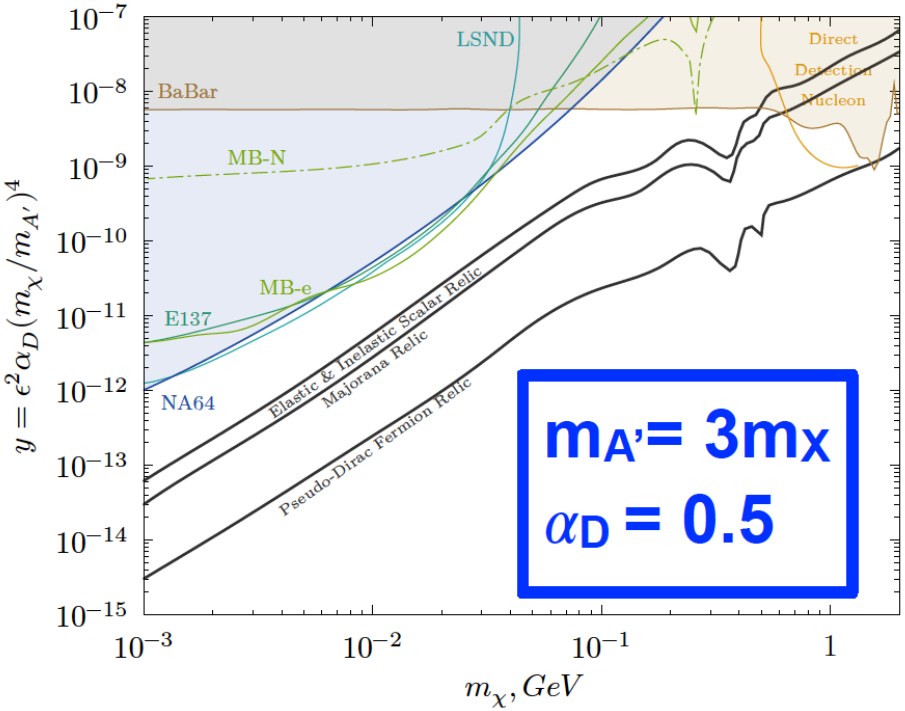
TOT: 2.84 x 10^{11} electrons on target

(~ 1/20 of the expected statistics before LS3)

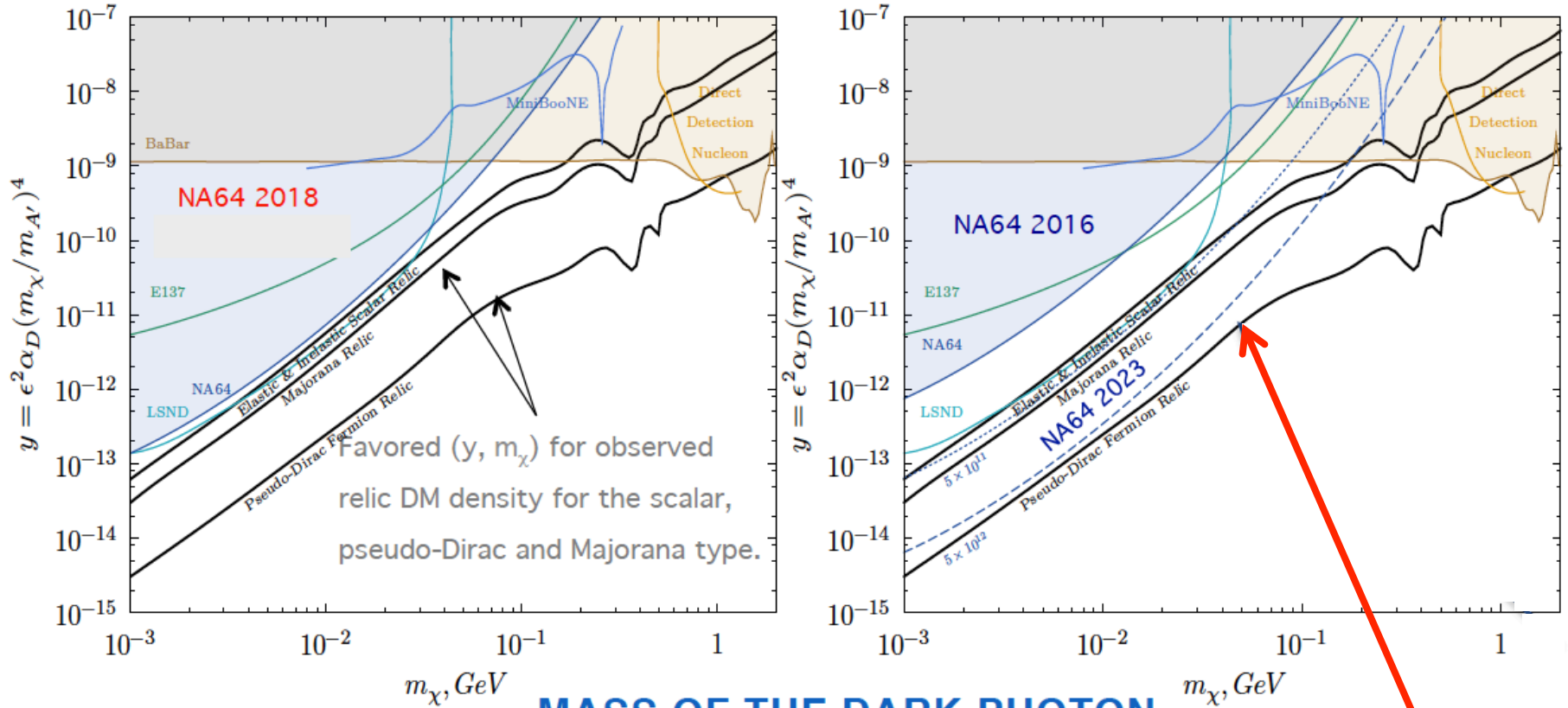
NA64 Coll., PRL 123 (2019) 121801

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





Current bounds on thermal relic DM & projected NA64 sensitivity



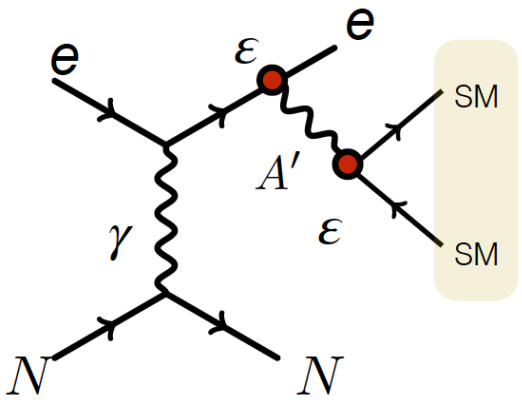
$m_{A'} = 3m_X$

$\alpha_D = 0.1$

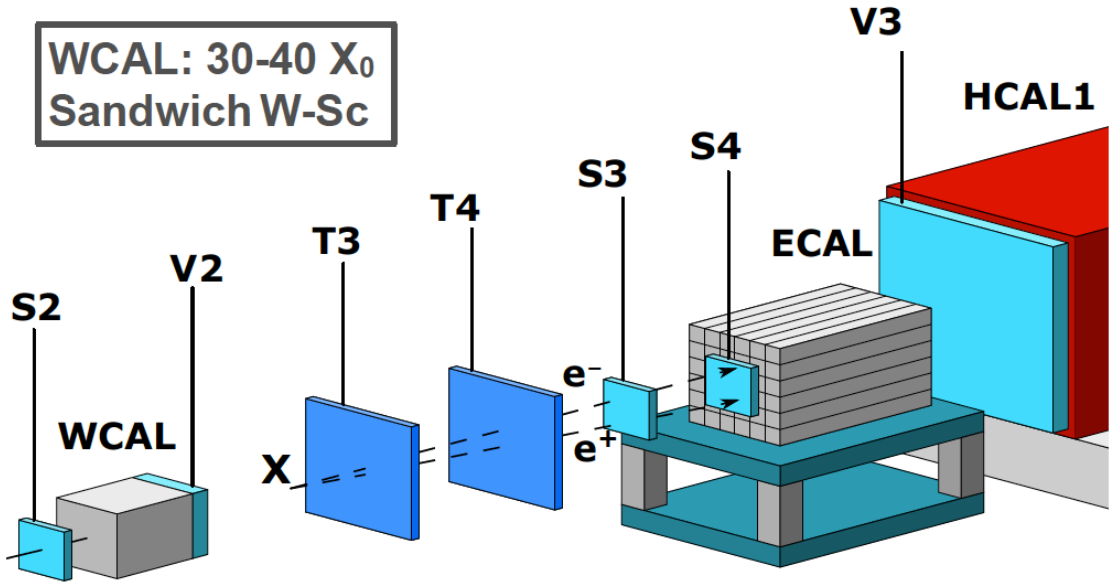
Setup and beam upgrade required

The NA64 search for X/A' → e⁺e⁻

VISIBLE DECAY MODE $m'_A < 2m_X$

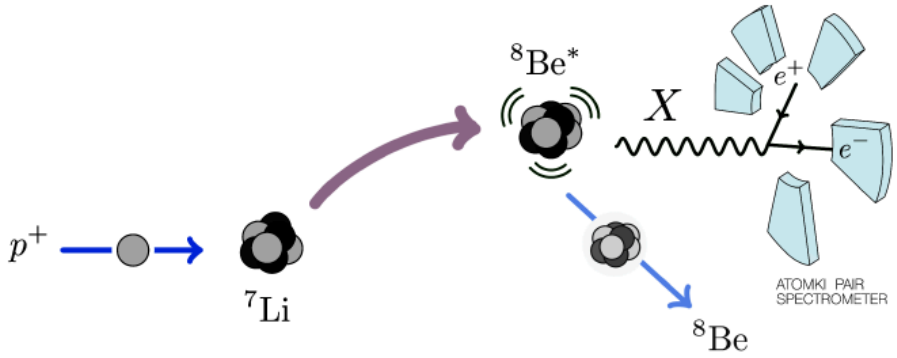


Pair production of SM particles

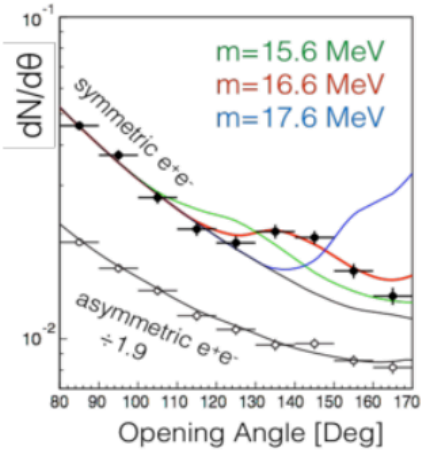


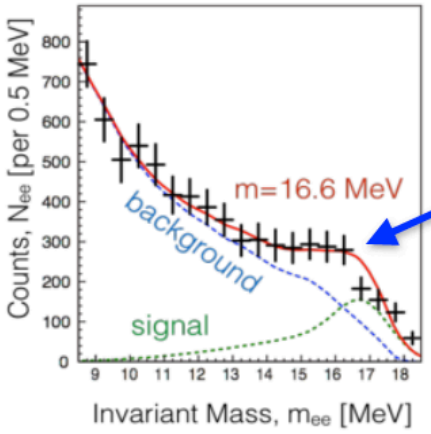
Signature:
1) $E_{WCAL}+E_{ECAL}$ = 100 GeV
2) No activity in $V_{2,3}$ and HCAL
3) Signal in S3, S4
4) e-m shower in ECAL

^{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





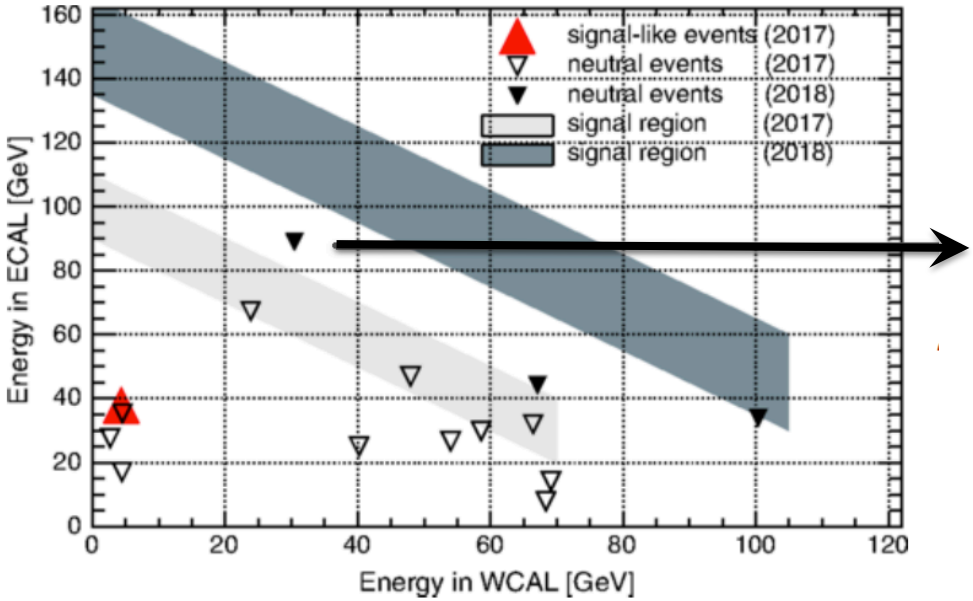
Could be explained by new 'protophobic' gauge boson X with mass around 17 MeV

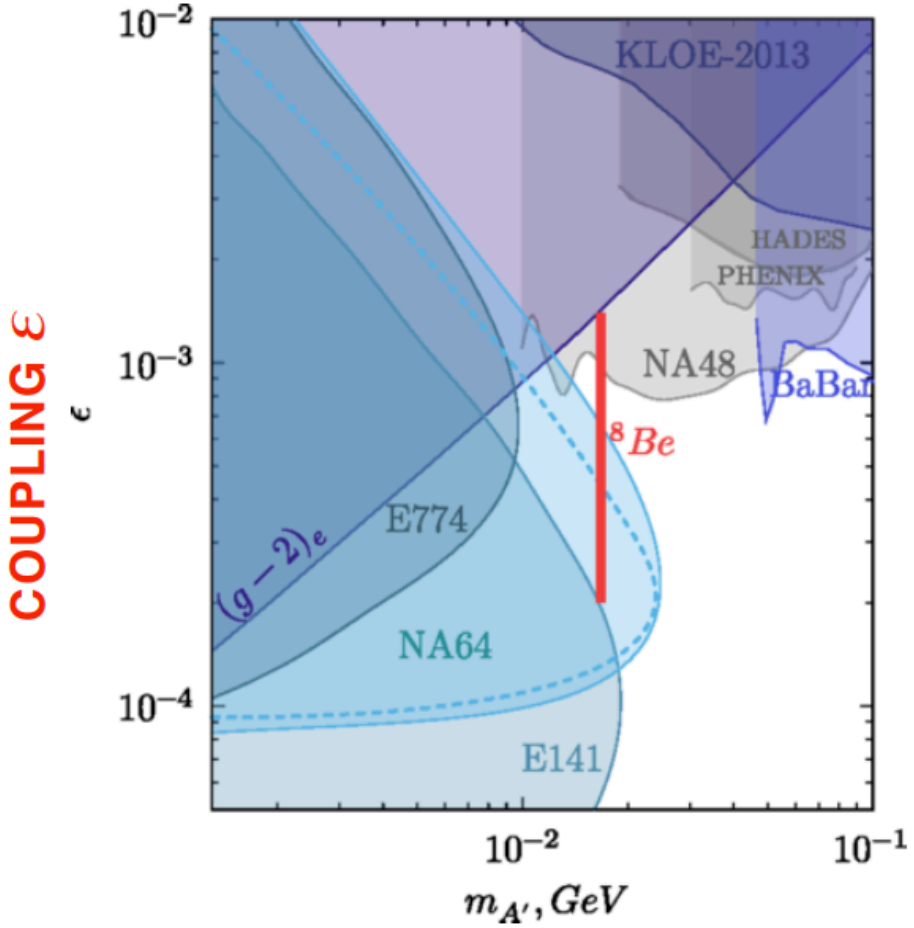
J. L. Feng et al., Phys. Rev. D95, 035017 (2017)
J. L. Feng et al., arXiv 2006.01151

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

~ 8 x 10^{10} electrons on target

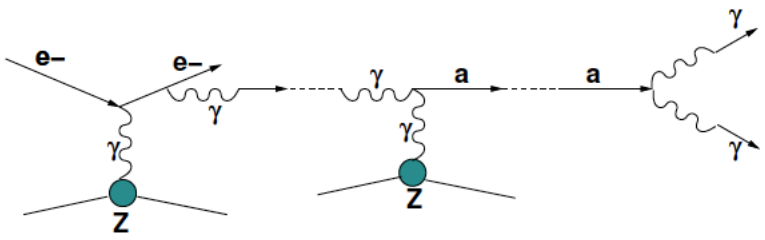
No signal-like event in signal box





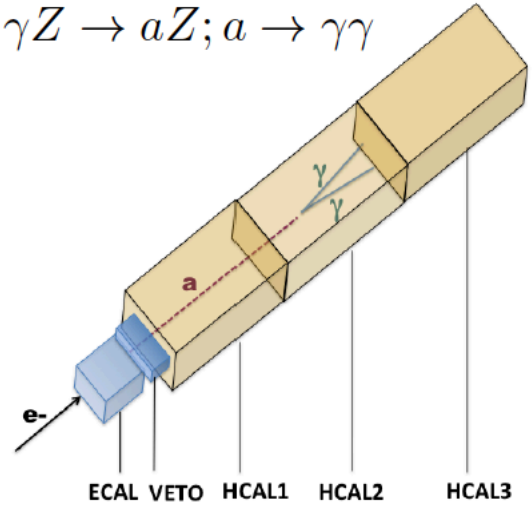
NA64 Coll., PRL 120 (2018) 231802
NA64 Coll., PRL 107 (2020) 071101

The NA64 search for ALP

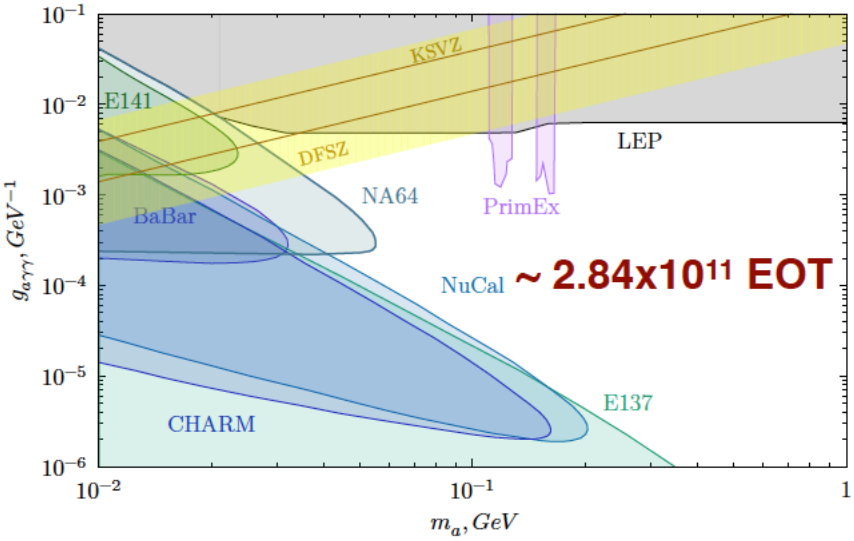


Production via Primakoff effect

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



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

Paolo Crivelli | 26.05.2020 | 20

NA64 Coll., arXiv. 2005.02710 (2020), submitted to PRL

Additional publications - Theory working group

(i) S. Demidov, S. Gninenko and D. Gorbunov, "Light hidden photon pro- duction 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. Kras- nikov, "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 mil- licharged 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].

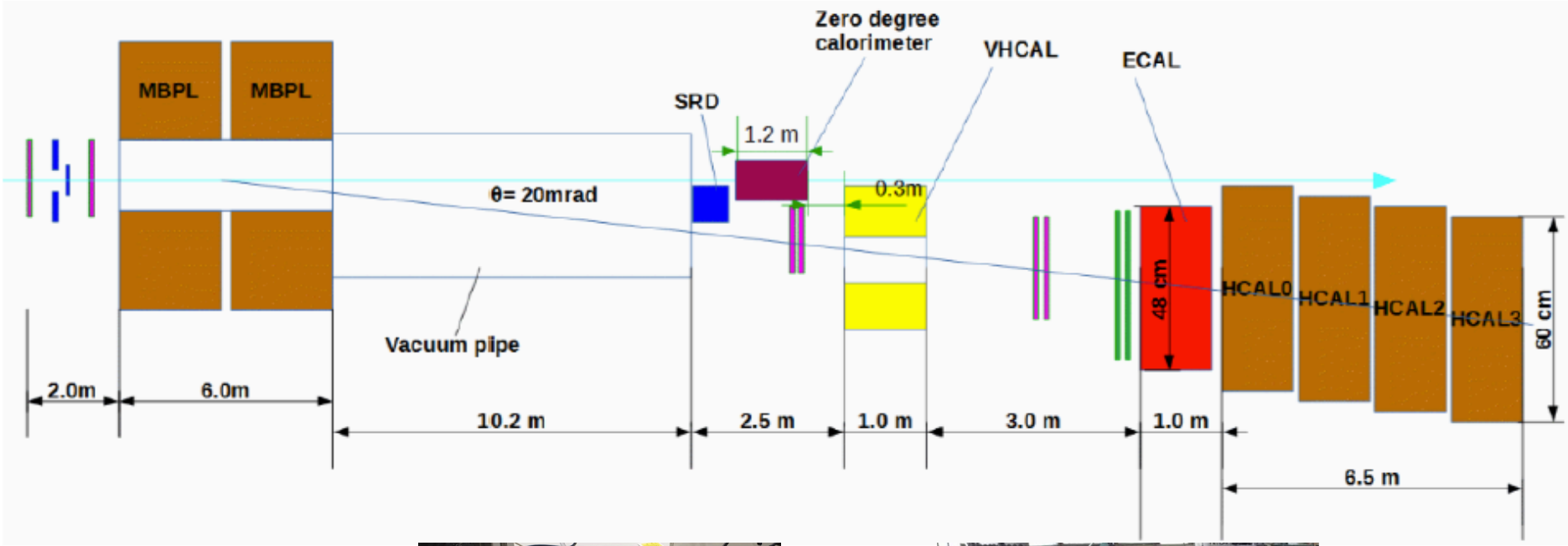
(vii) N. V. Krasnikov, "Implications of last NA64 results and the electron g_e-2 anomaly for the X(16.7) boson survival," arXiv:1912.11689 [hep-ph].

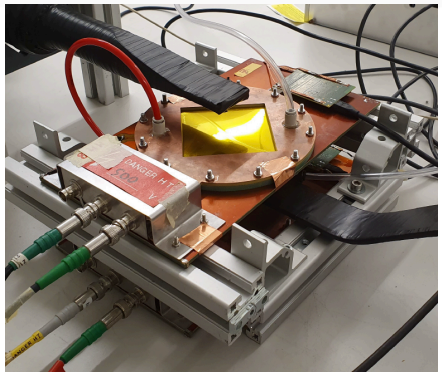
Staus of Preparation of new area in H4

Installation expected to be completed in 2021 when SPS will resume

Wider range of search for new physics than foreseen in the proposal
Collaboration with EN-EA-LE and EN-AE-DC groups for maximize electron flux and minimize halo and hadron contamination

New Area in H4





SRD with higher segmentation

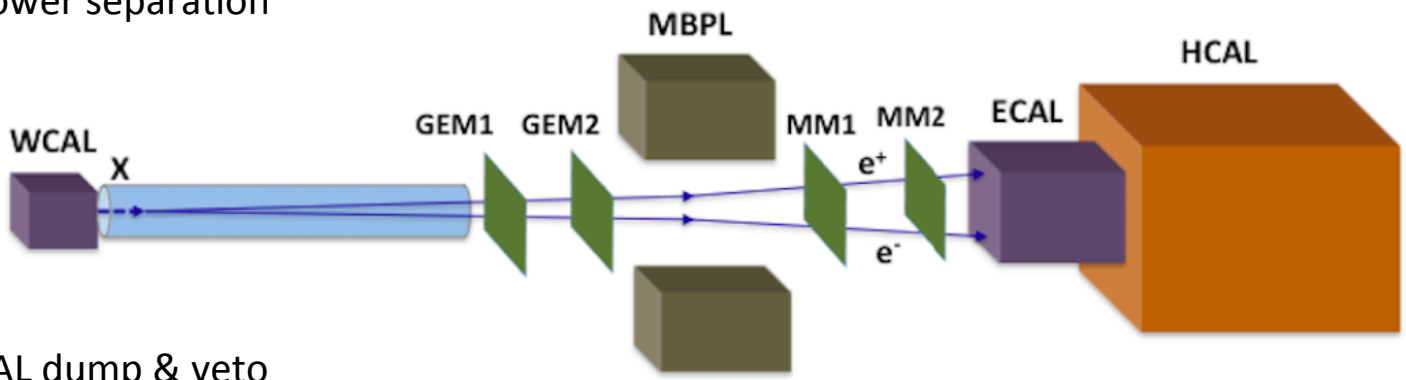
Additional MM, GEM, ST tracking stations

New VHCAL for better rejection of upstream e- hadronic interactions

New Area in H4

MBPL spectrometer
for e-shower separation

New ECAL with larger dimension

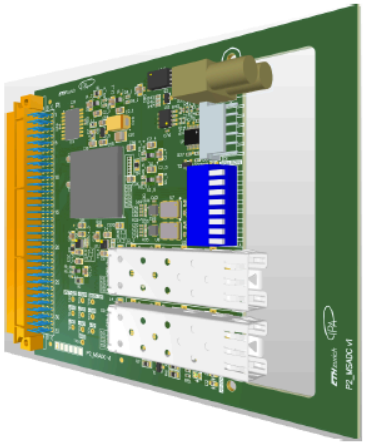


New WCAL dump & veto
Shorter: 30 X_0

New large area trackers

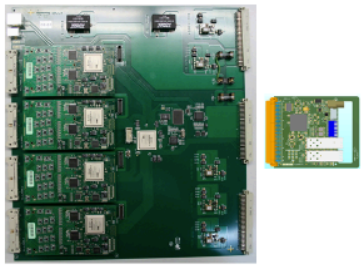
New electronics - ~ 200 MHz MSADS to admit working at high beam intensity by 2022 run.

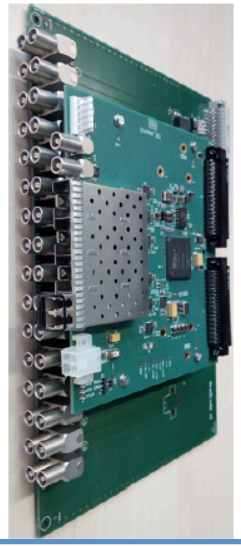
8k events with 20% dead time / spill → 50k events with <1% dead time / spill



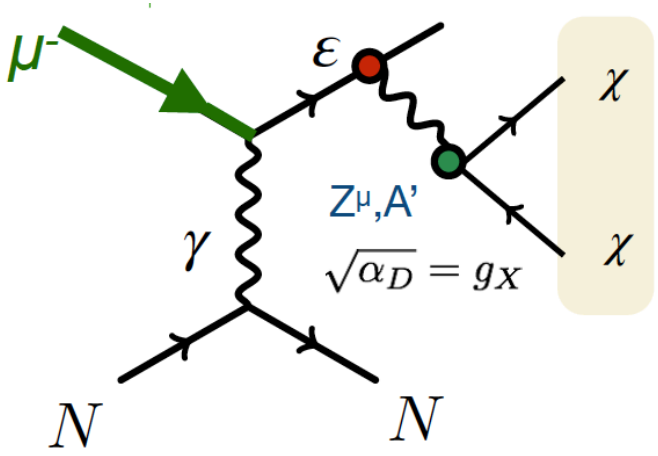
NEW P2MSADC

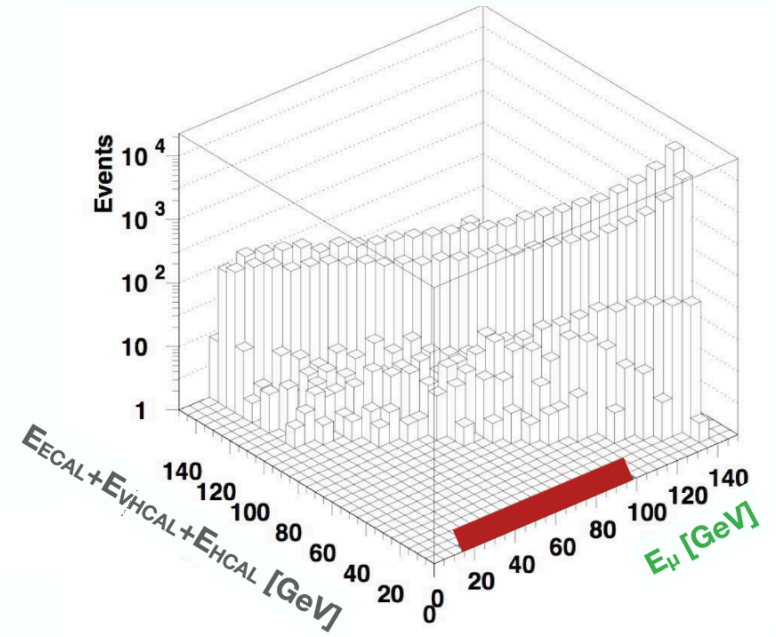
MSADC + P2MSADC





NEW PRESCALERS





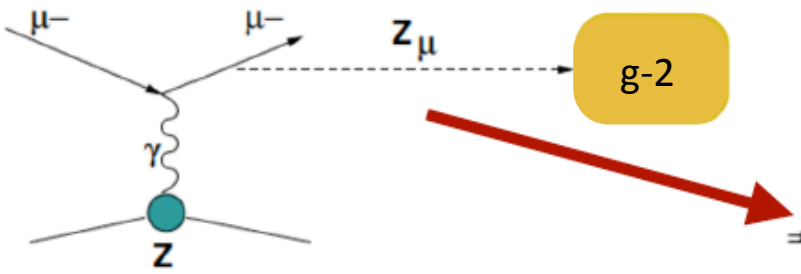
Main physics goals:

1. **Light Z' coupled to the muon**, as a remaining explanation of the $(g-2)_\mu$ (the muon anomaly).
2. **Light Dark Matter** interacting with the Standard Matter via dark photon A' 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.

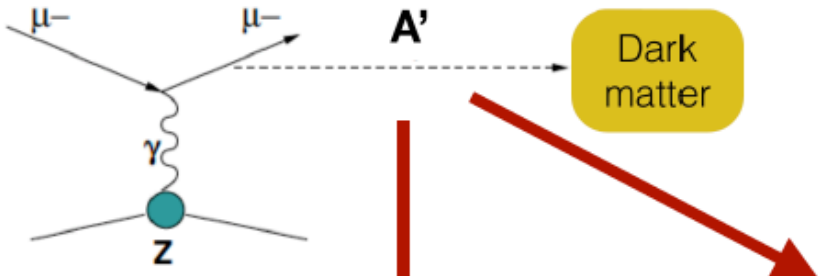
Signature:

- Deflected muon with E<80 GeV
- No energy in the calorimeters other than muon MIP

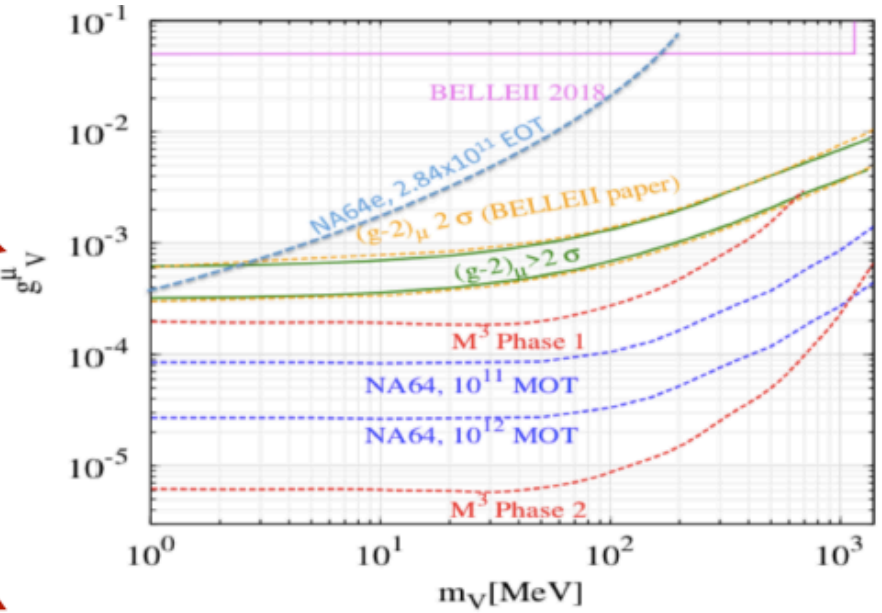
NA64μ Physics Goals

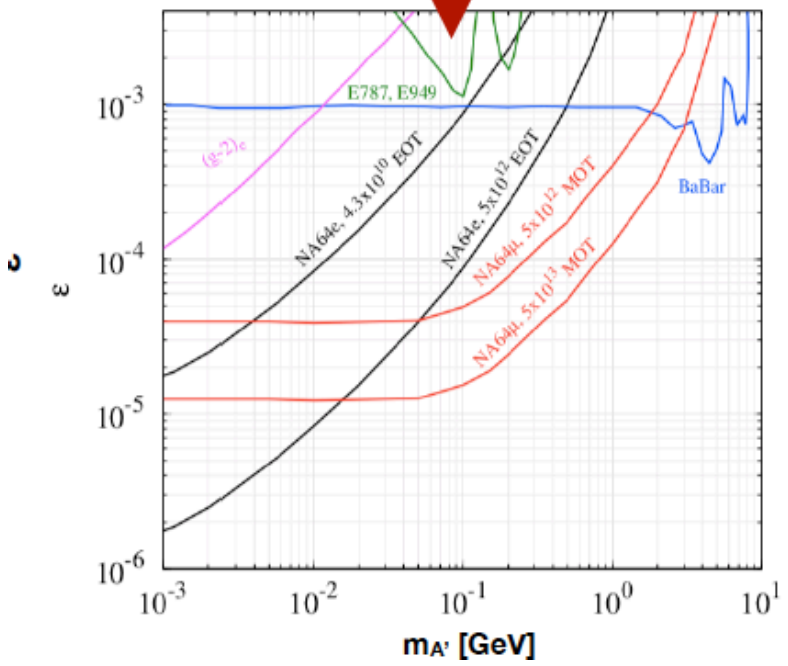


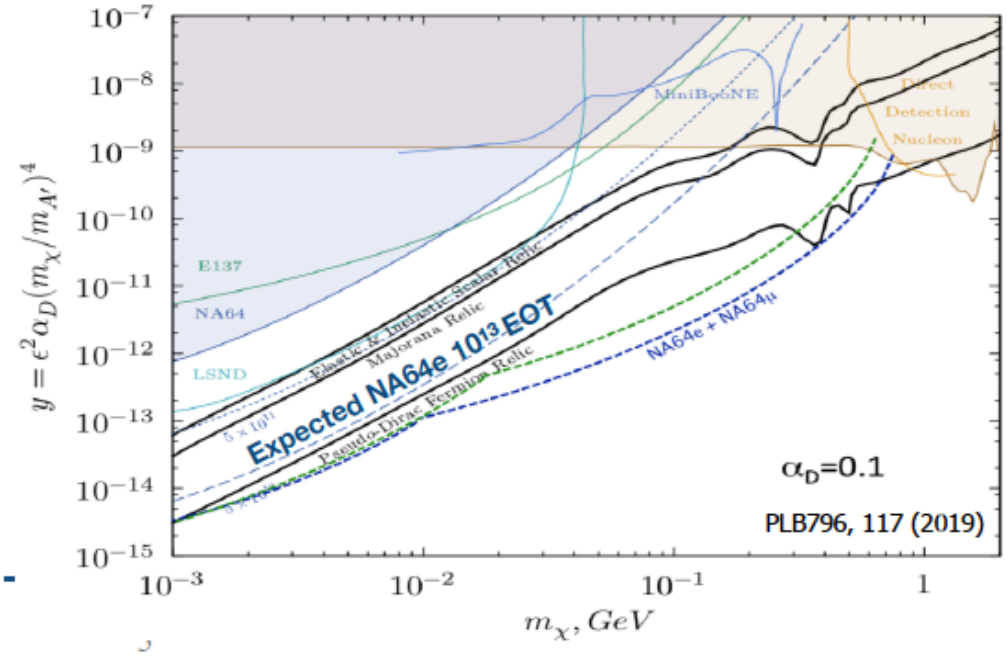
g-2



Dark matter





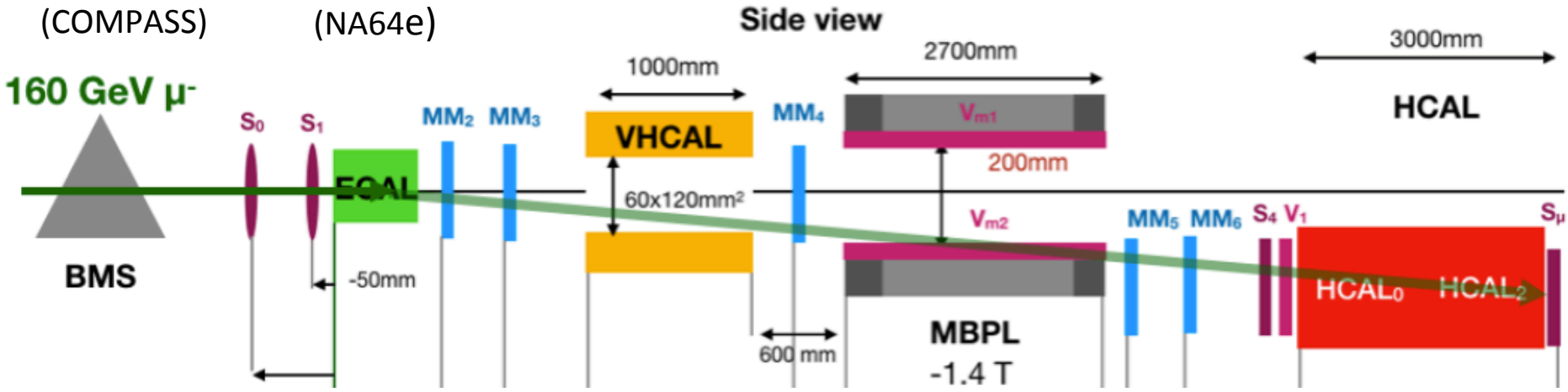


NA64μ Apparatus & Plans

BMS (COMPASS)

ECAL, MM, GEM (NA64e)

4 x HCAL (NA64e)

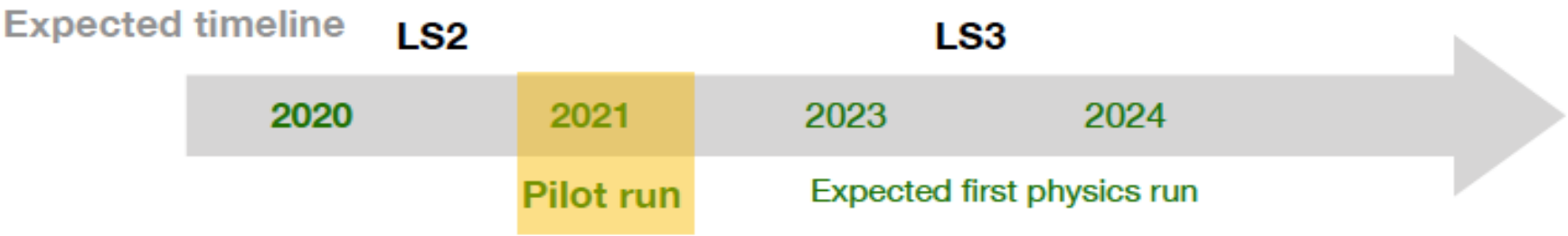


New:

VHCAL
Trigger counters

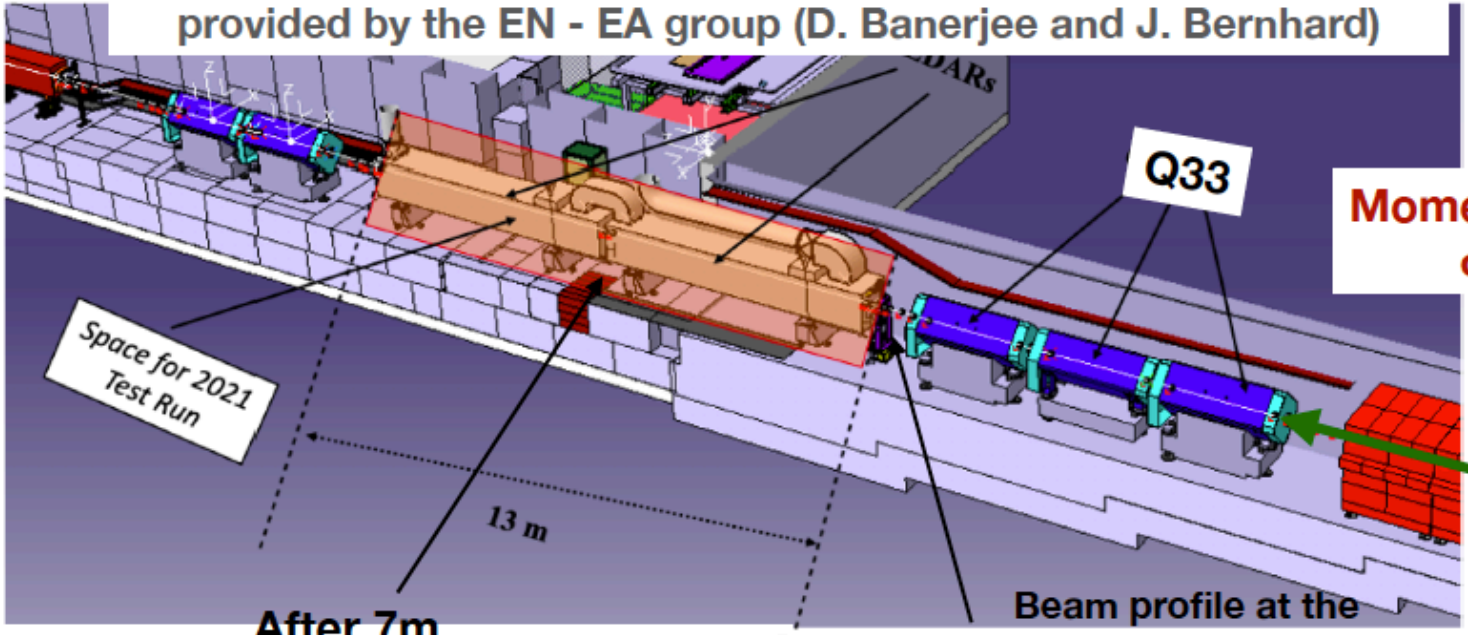
MBPL with 20 cm gap

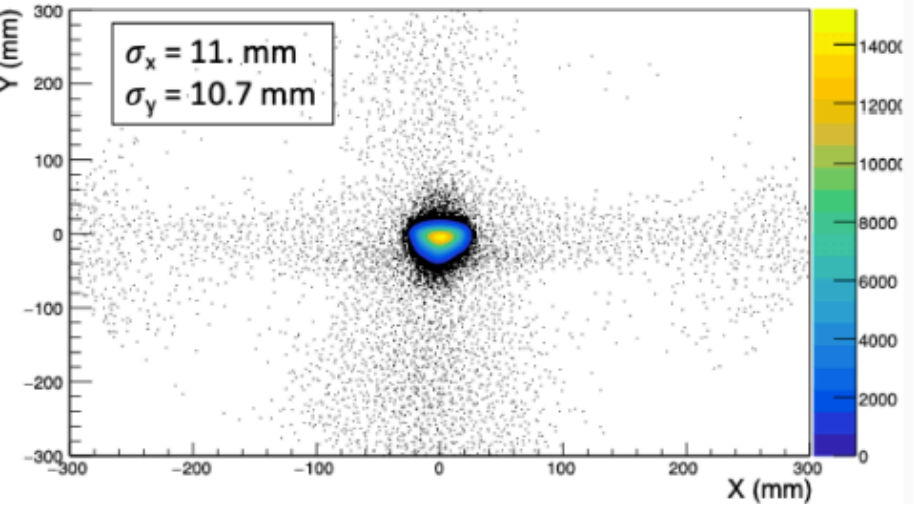
25 x 8 cm^2 MM
120 x 60 cm^2 straw

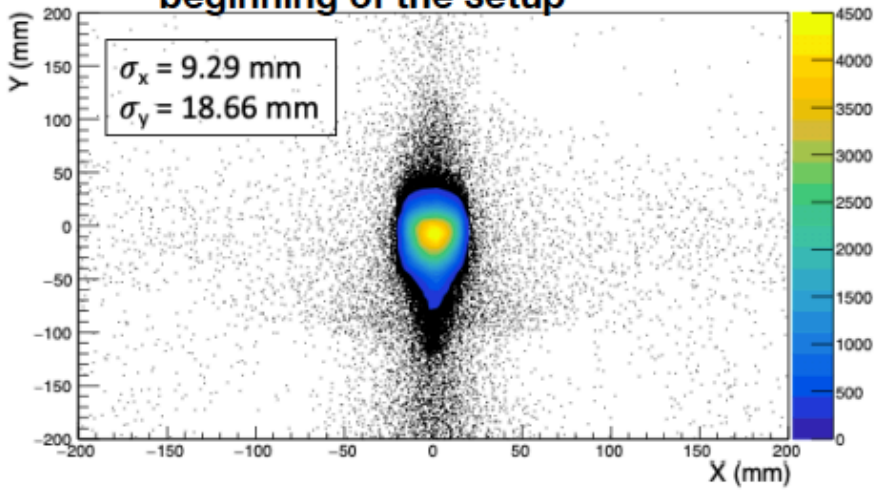


NA64μ Beam

Input μ beam and halo profiles from the M2 beam line simulations
provided by the EN - EA group (D. Banerjee and J. Bernhard)



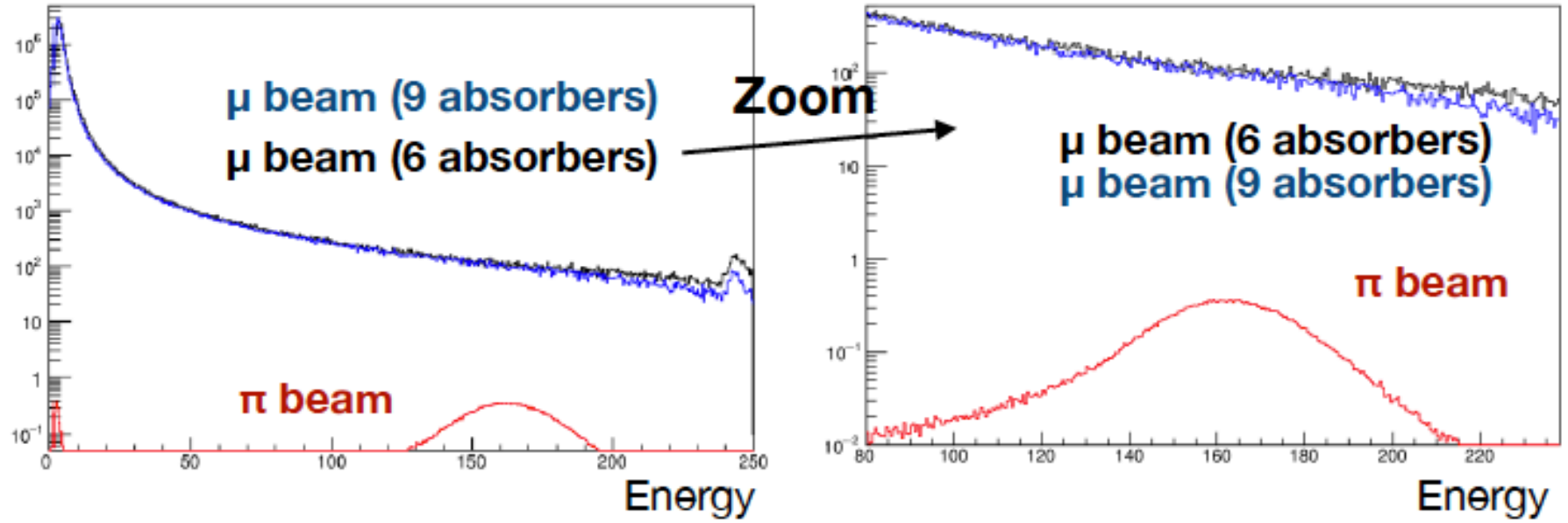




NA64μ Beam

Study by S.Donskov & V.Poliakov and HCAL calibration for 160 GeV π
Comparison between muon beam (6 and 9 absorbers) and hadron (π) beam

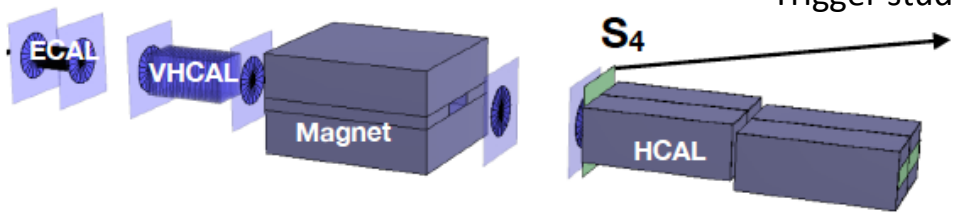
Preliminary result $\pi,K/\mu = (9.7\pm1.4)\times10^{-5}$

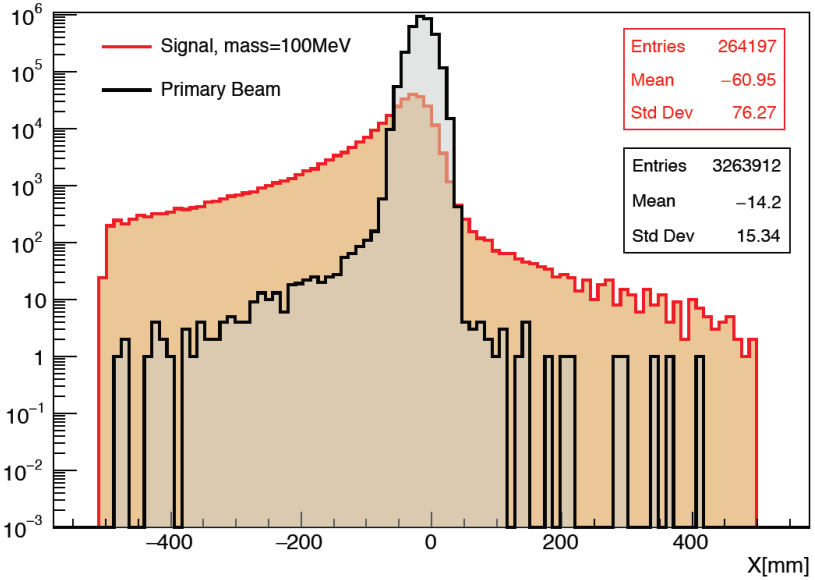


Plan to redo the measurement at NA64μ location
Key quantity for background estimation and mitigation

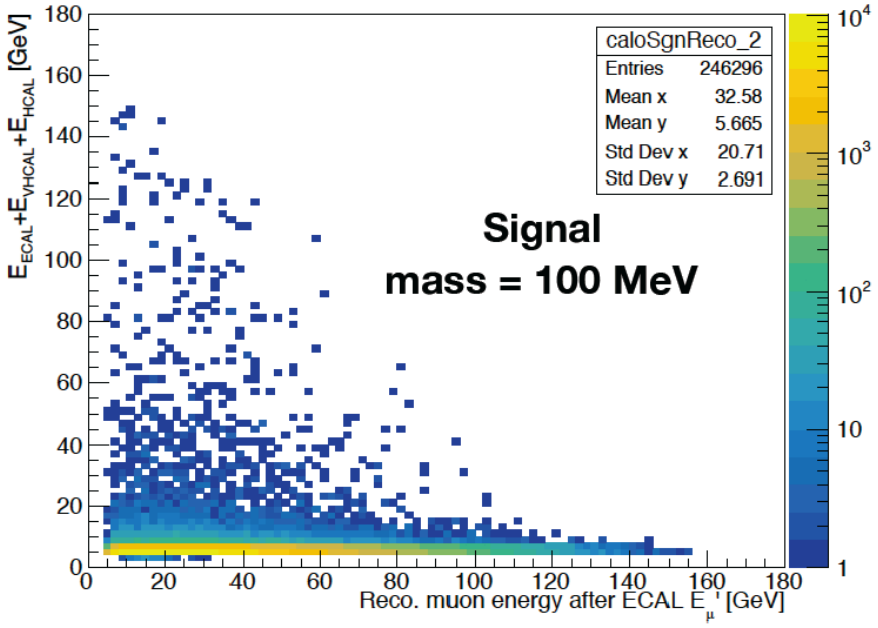
NA64μ Detector

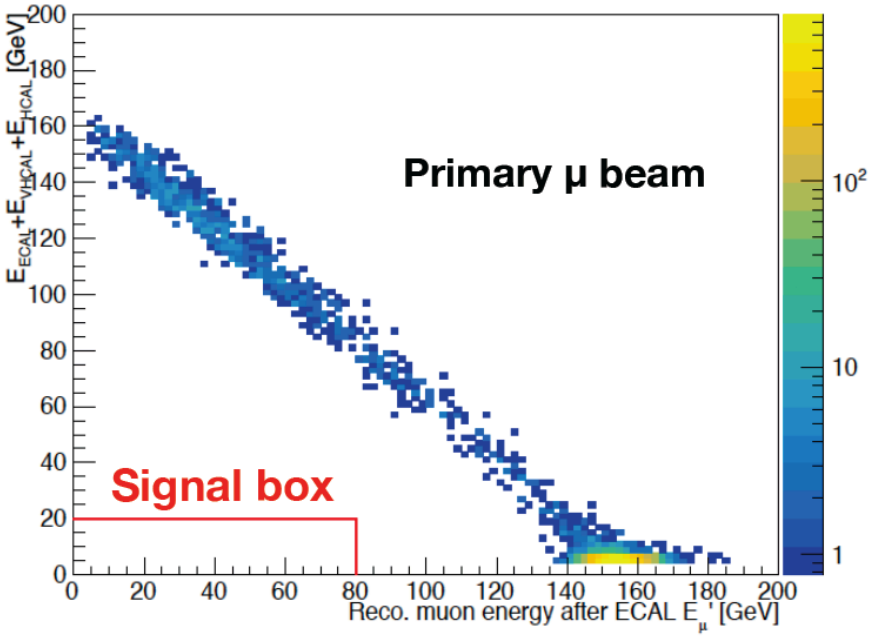
Full simulation and reconstruction package developed in Geant4





Event selection study





NA64 Plans & Priorities

2021: cover yet unexplored areas in light dark matter and gauge boson X parameter space

Early beam: ~2 week for NA64_mu commissioning in M2 pilot run

Summer 2021: 3 weeks for NA64_e commissioning in H4 (invisible mode) and accumulation of data

Autumn 2021: 6-7 weeks for NA64_e commissioning in H4 (visible mode) and accumulation of ~10^{11} EOT

2022++: High luminosity setup completed with new DAQ

2023++: physics runs with muon beams

Before LS3 goal: 5 x 10^{12} EOT to probe full parameter space for scalar and Majorana sub-GeV dark matter models

NA64 Minutes

134th SPSC Meeting

The Committee notes with satisfaction the analysis update of the vector mediator of Dark Matter production in the invisible decay mode based on the full 2016-2018 data sample and the preliminary results in the search for a new X(16,7) boson decaying to e+e- with the 2017 and 2018 statistics. The SPSC is looking forward to the publication of these results.

135th SPSC Meeting

The SPSC congratulates the NA64 collaboration on the publication of its 2016–2018 invisible channel search results.

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 NA64μ 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.

Suggested minutes of the 138th SPSC meeting:

The SPSC **congratulates** the NA64 Collaboration on finalizing the analysis of the 2016-2018 data and on the publication of the bounds on light dark-matter candidates and X boson.

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