Update on NA64

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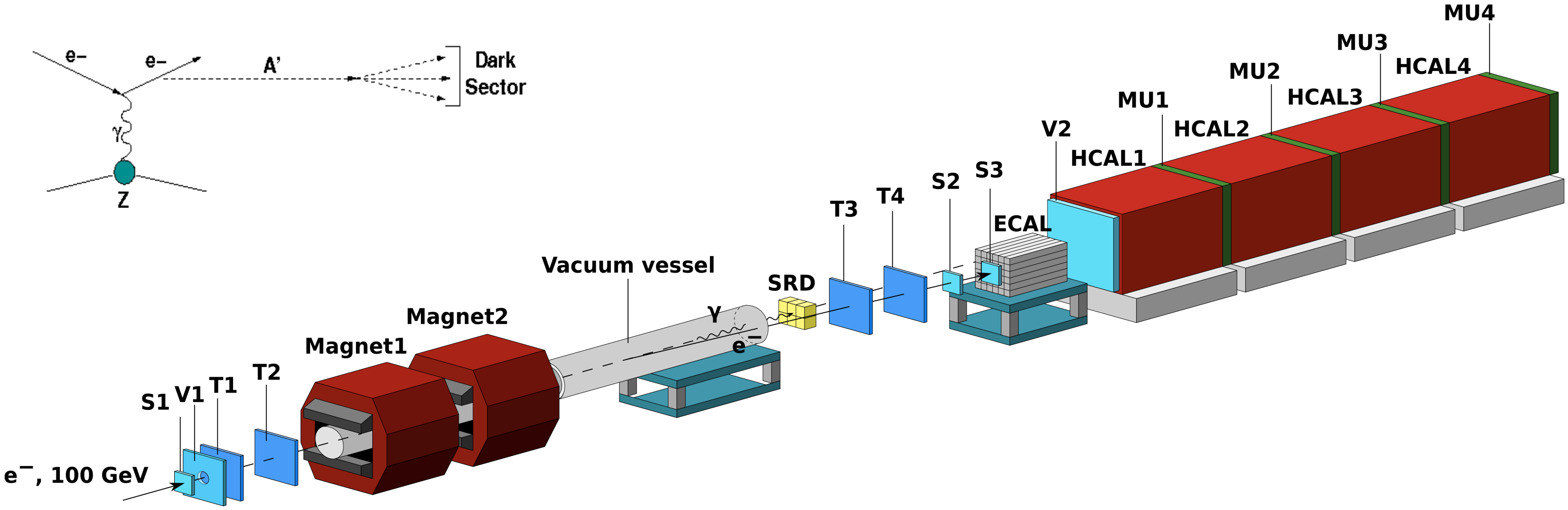
- Light Dark Matter (LDM)
- X(17),A´→ e+e- decays and ^{8}Be anomaly
- ALP decays a → γ γ

Search for LDM in missing energy events

LDM production in invisible decay mode of A´ mediator



Main components :

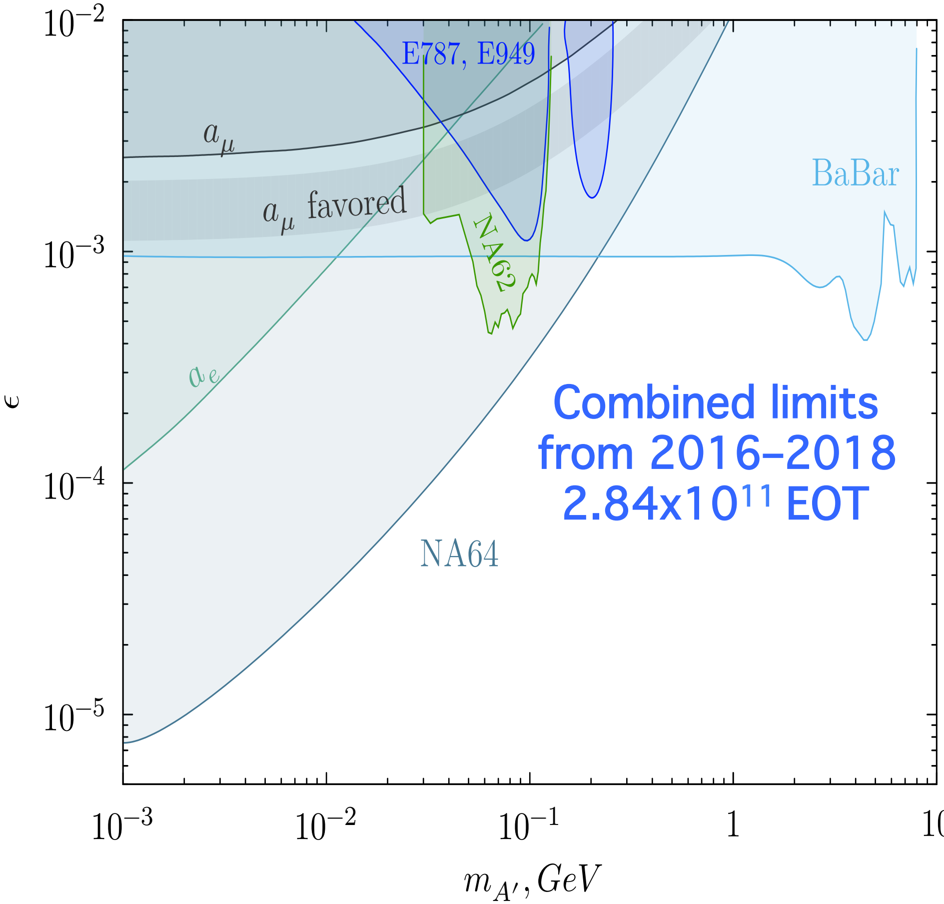
- clean 100 GeV e- beam
- e- tagging: tracker+SRD
- fully hermetic ECAL+HCAL

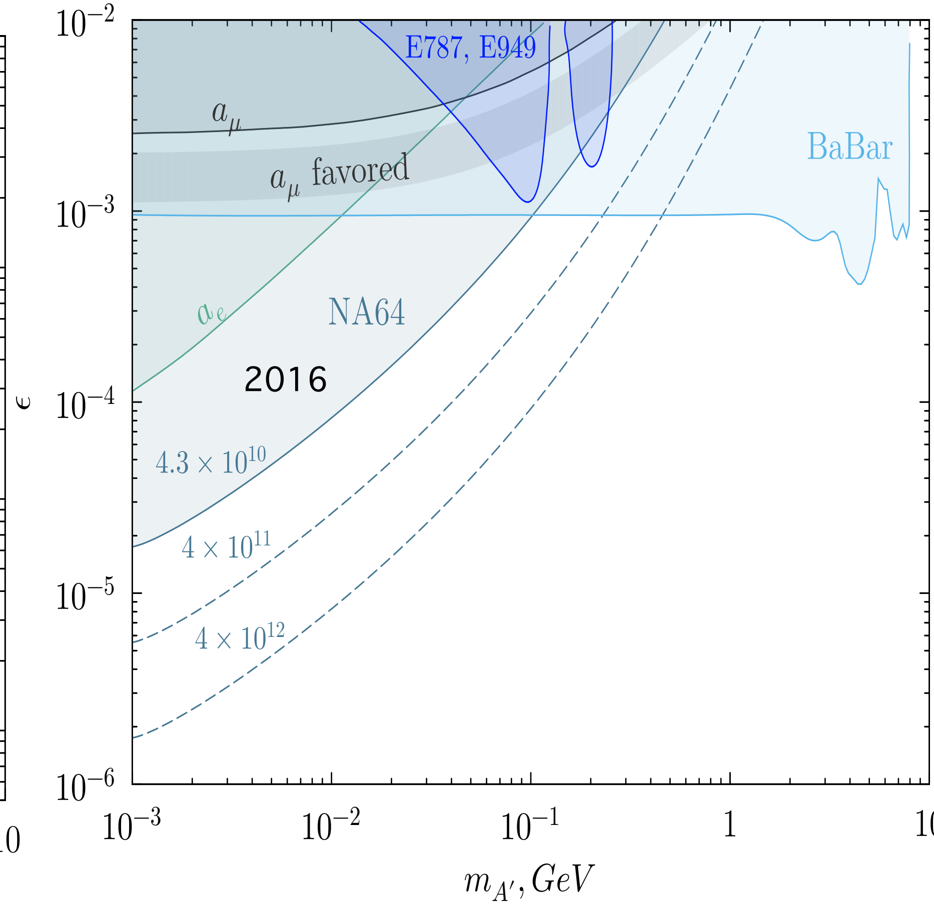
Signature:

- in: 100 GeV e- track
- out: $E_{ECAL} < E_0$ shower in ECAL
- no energy in Veto and HCAL

New results and projections for γ-A´mixing

PRL(2019)

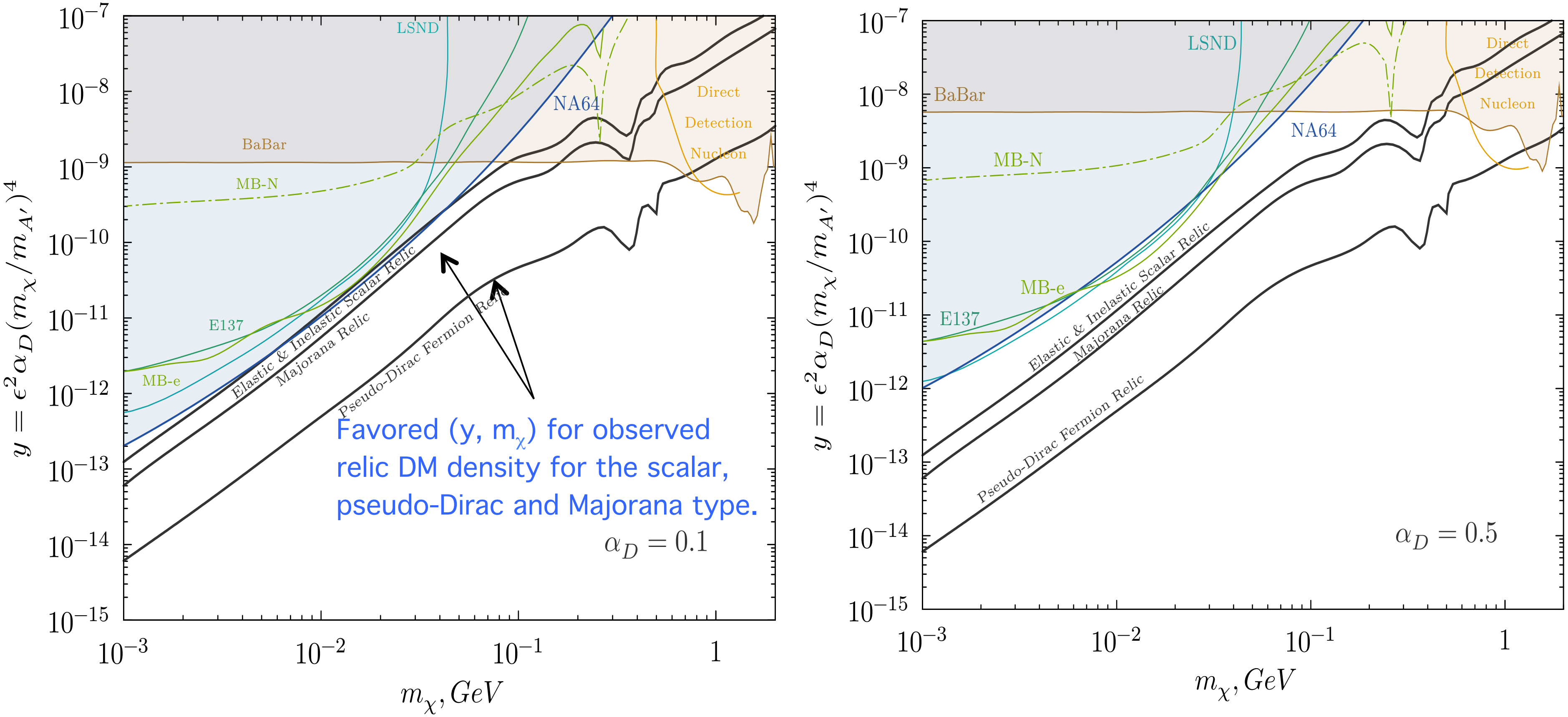




Plans to accumulate ~(4-5)x10^{12} EOT after LS2

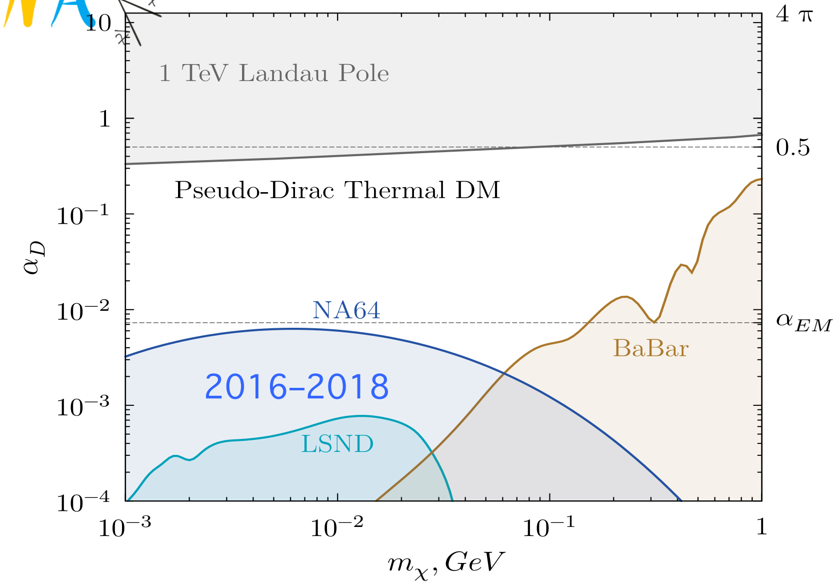
New results and projection for LDM (I)

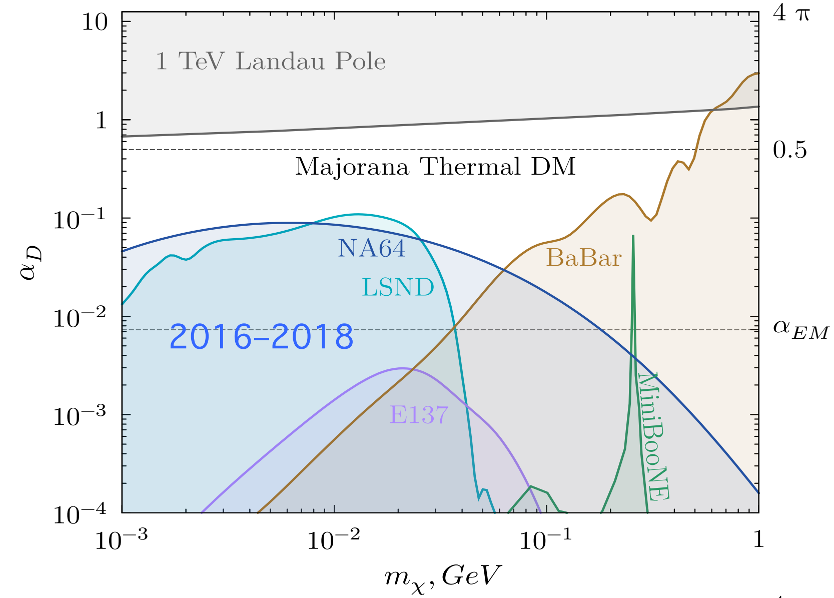
PRL(2019), 2.84×10^{11} EOT, $m_{A'} = 3m_\chi$

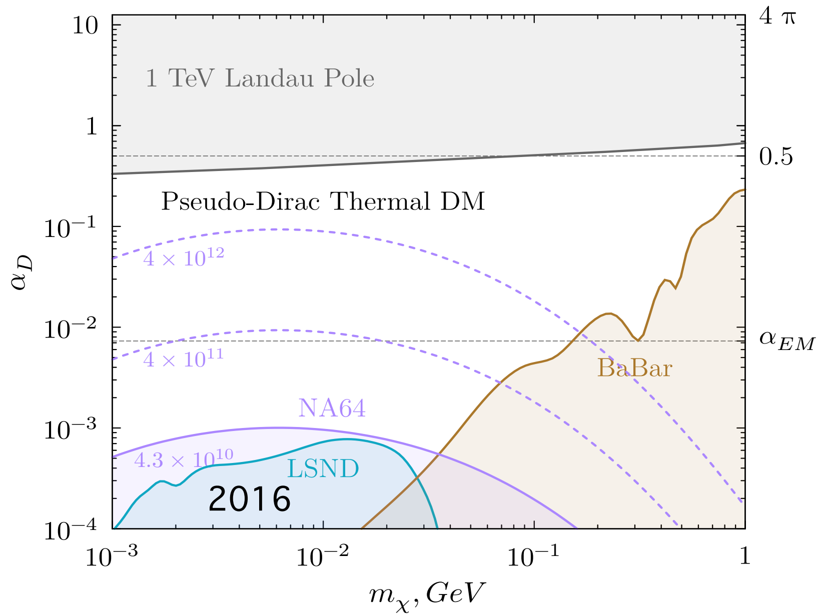


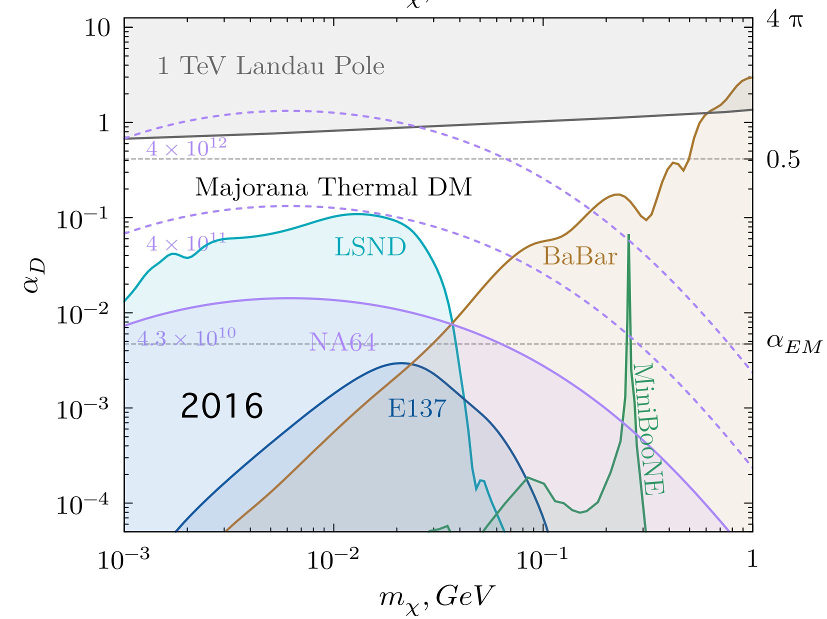
- Sensitivity of a beam-dump $\sim\epsilon^4\alpha_D$, NA64$\sim\epsilon^2$
- Bounds from LSND, SLAC, MiniBooNE for $\sim 10^{22}$, 10^{19}, 10^{20} POT
- NA64 can cover significant area with ~ $(4–5)\times 10^{12}$ EOT

New results and projection for LDM (II)

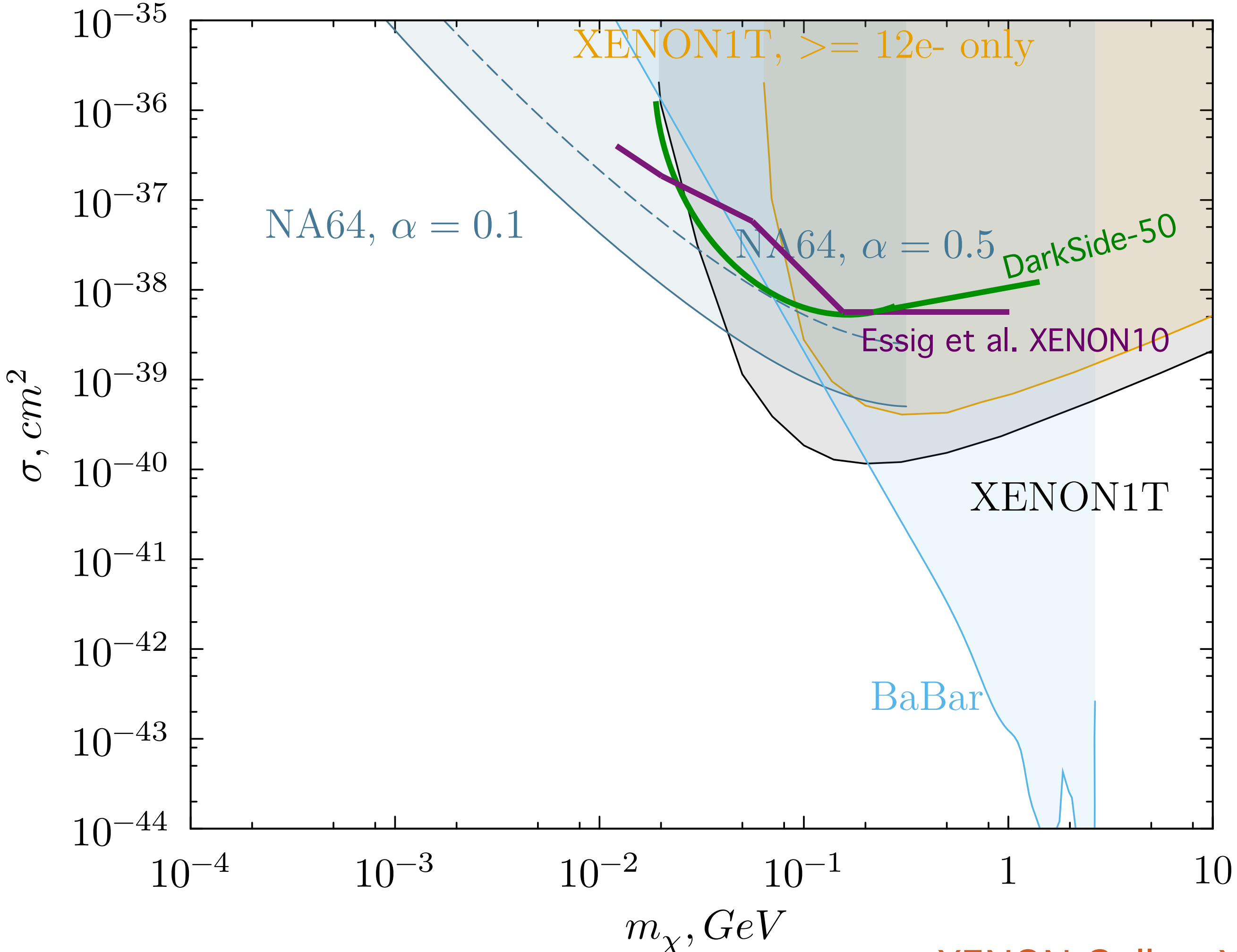








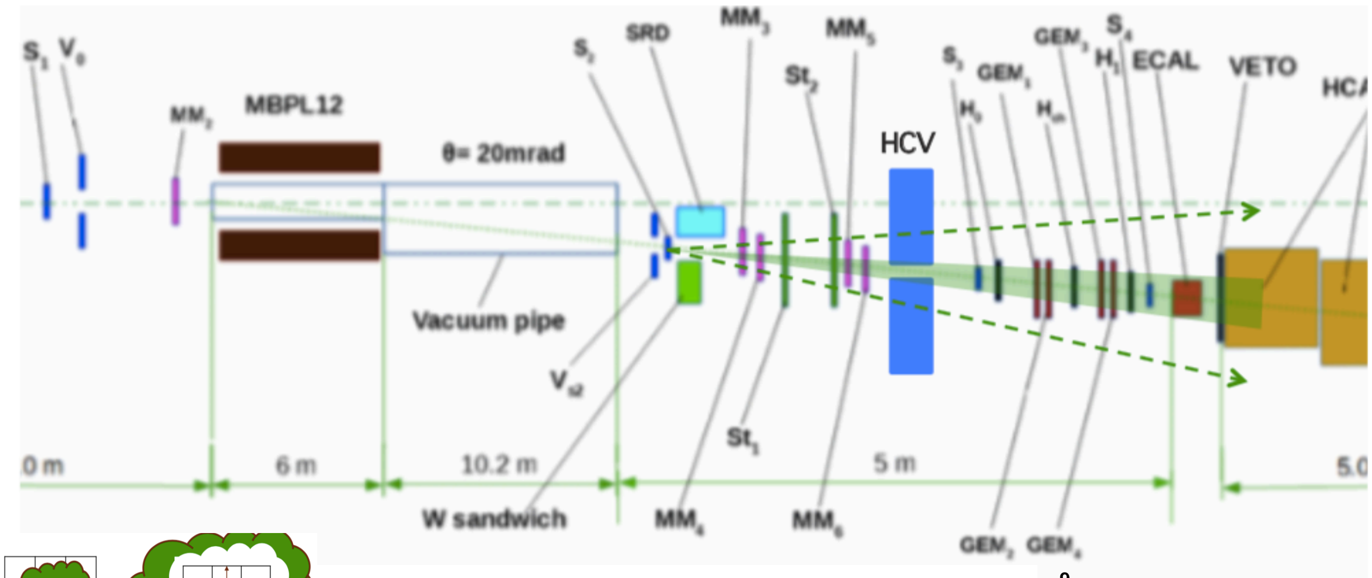
Constraints on DM-electon cross-sections

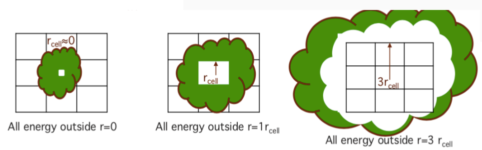


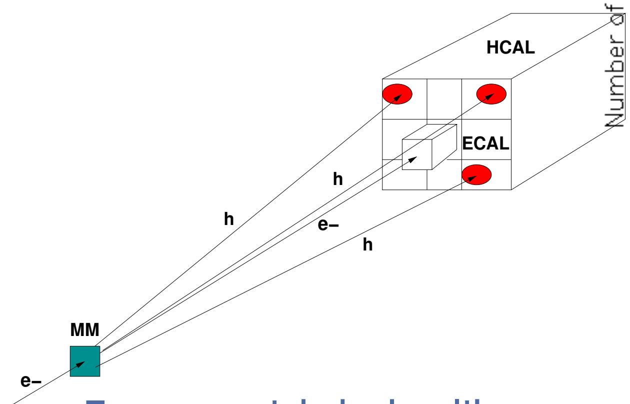
XENON Coll. arXiv:1907.11485

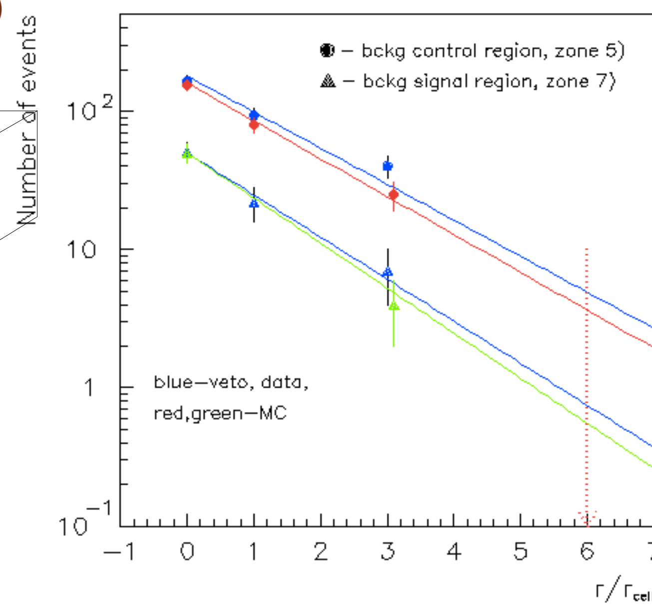
The 90% C.L. upper limits on DM-electron scattering cross-sections
NA64: no assumptions on DM number density and velocity distribution

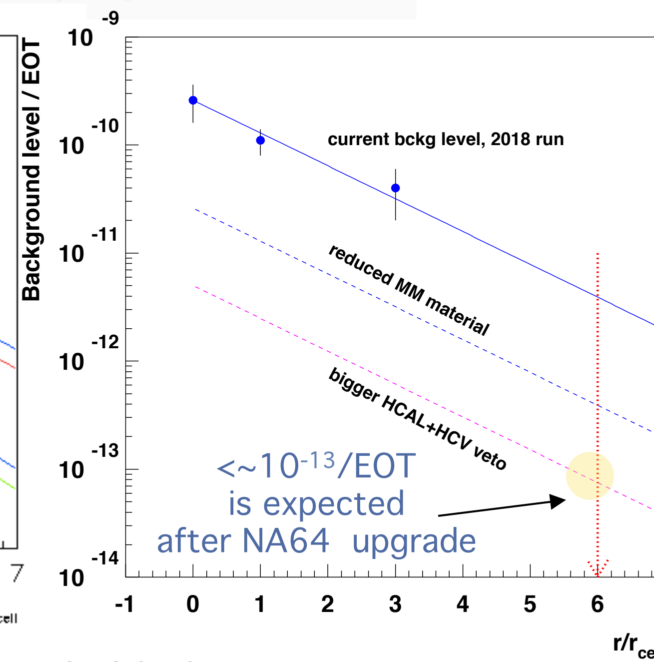
Estimate of background from hadron electroproduction





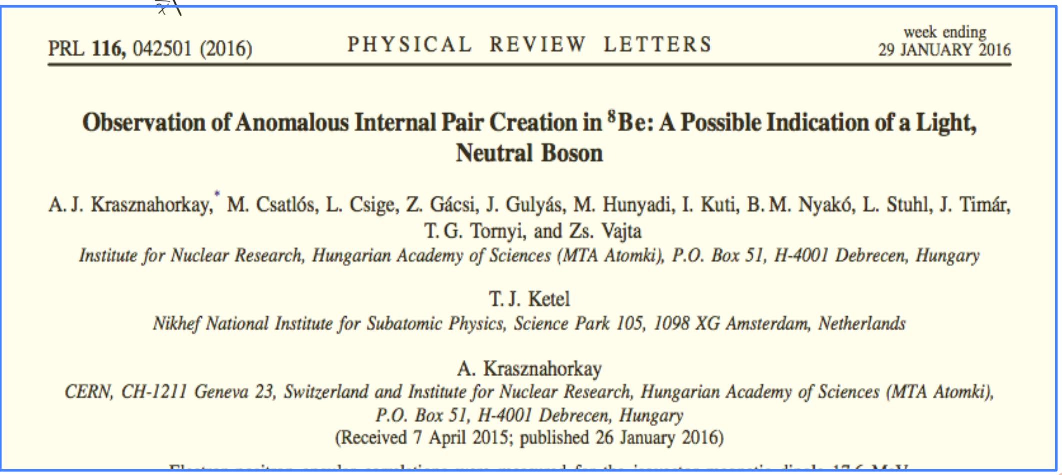






Events with bckg-like topology were studied

^{8}Be anomaly: a new light X boson?


PRL 116, 042501 (2016) PHYSICAL REVIEW LETTERS week ending 29 JANUARY 2016

Observation of Anomalous Internal Pair Creation in ^{8}Be: A Possible Indication of a Light, Neutral Boson

A. J. Krasznahorkay,* M. Csatlós, L. Csige, Z. Gácsi, J. Gulyás, M. Hunyadi, I. Kuti, B. M. Nyakó, L. Stuhl, J. Timár, T. G. Tornyi, and Zs. Vajta
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(Received 7 April 2015; published 26 January 2016)

^{7}Li(p, γ)^{8}Be, M_X =16.7 MeV

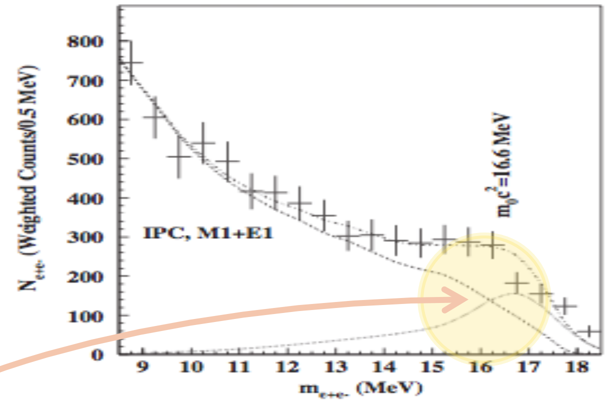
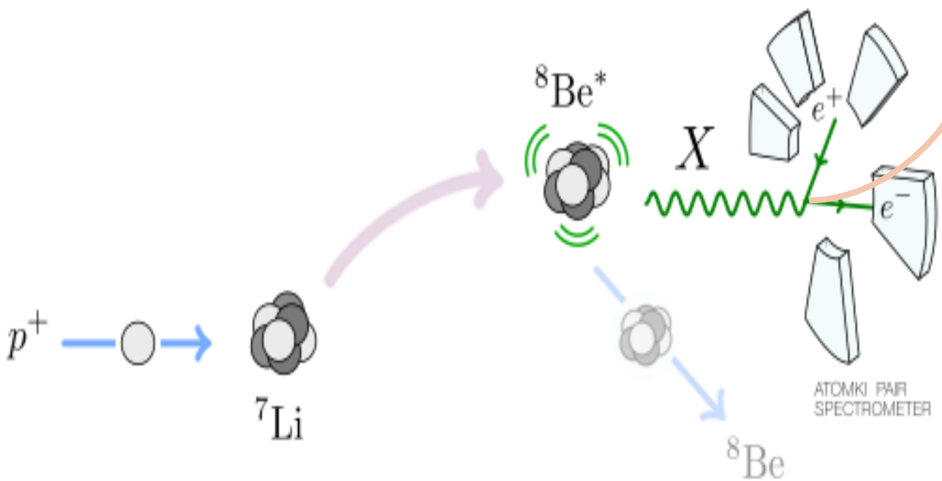


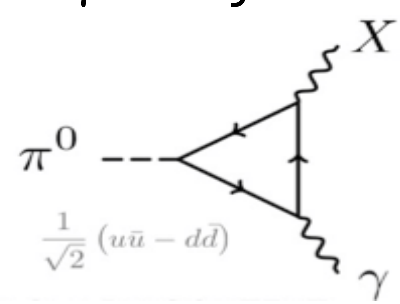
FIG. 5. Invariant mass distribution derived for the 18.15 MeV transition in ^{8}Be.



Feng et al, 2016

$2 \times 10^{-4} < \varepsilon_e < 1.4 \times 10^{-3}$

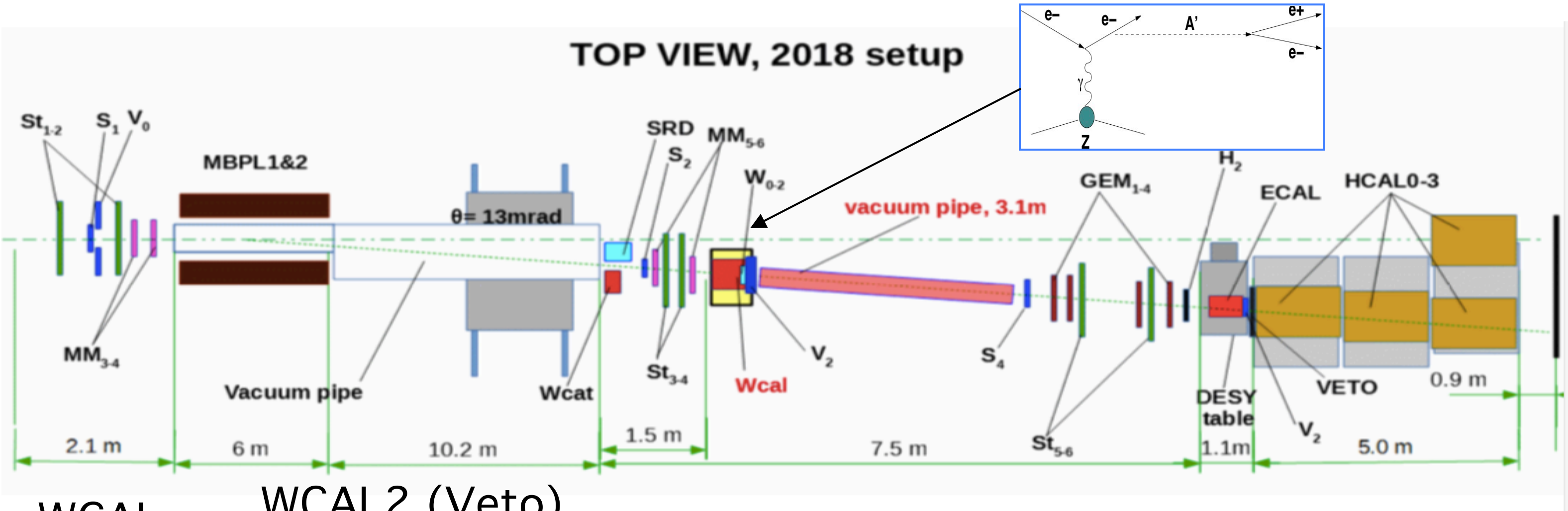
Many X models. E.g. if X is V it cannot be A´due to bounds from $\pi^0 \to X\gamma$ decay:

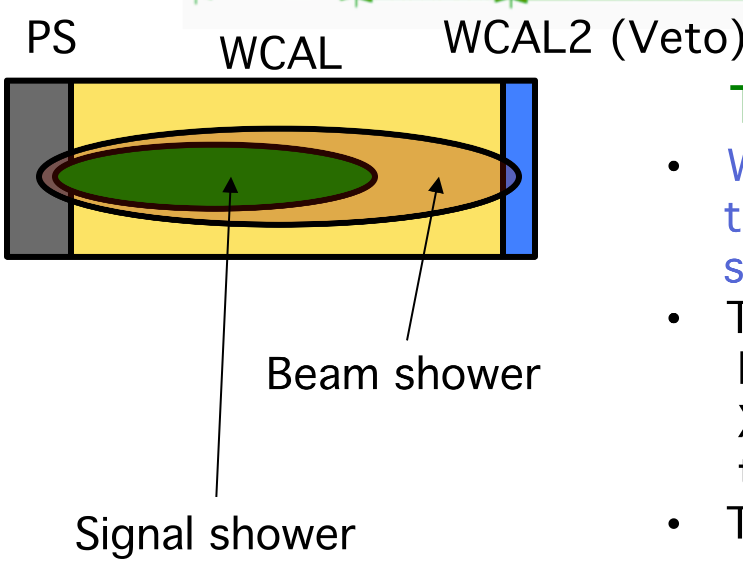


$\Gamma(\pi^0 \to X\gamma) \sim (\varepsilon_u q_u - \varepsilon_d q_d)^2 \sim 0$

if $2\varepsilon_u = -\varepsilon_d$ -> protophobic X

NA64 method to search for the X



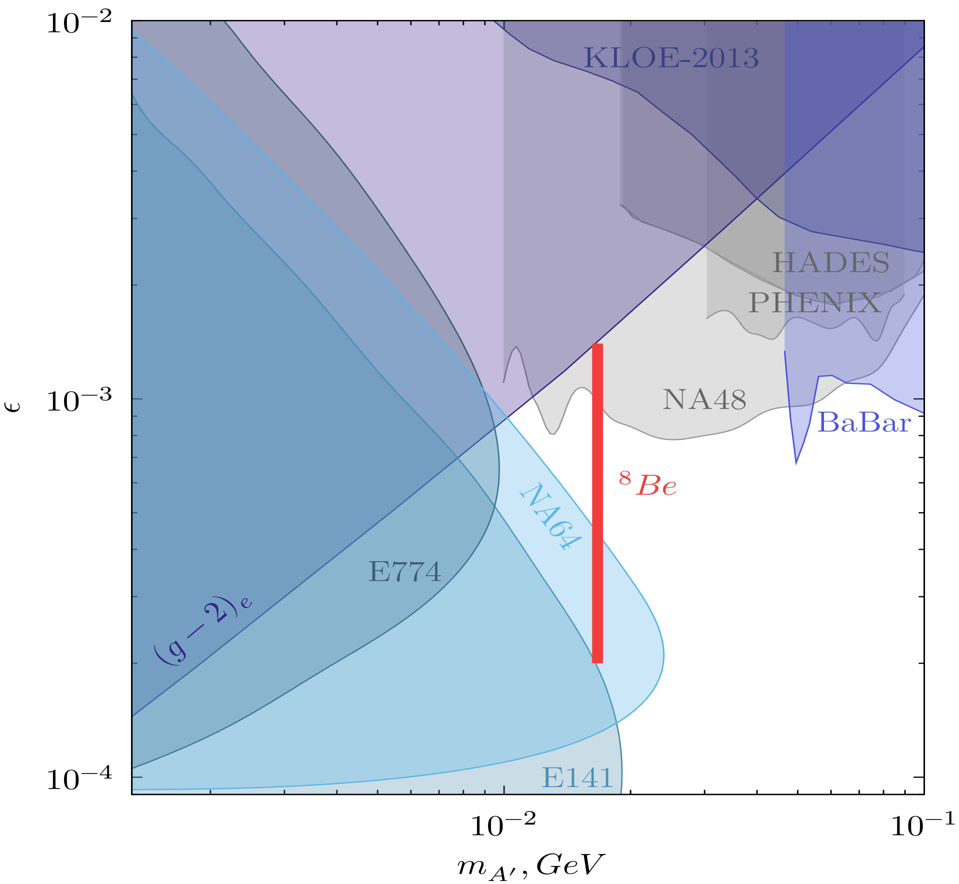


Trick to probe short-lived X

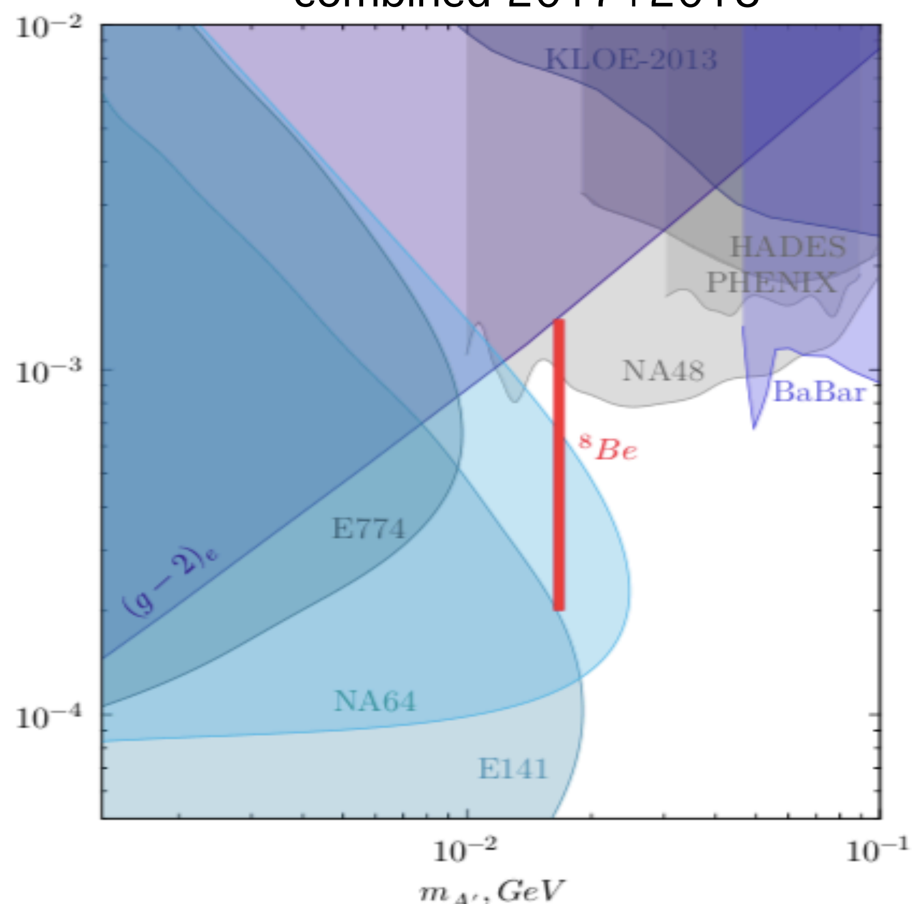
- WCAL dump thickness is optimized not for the beam energy, but for the energy of “signal” shower!
- The signal shower has $E_S < E_o$ => small leakage
  Recall the production kinematics:
  X,A´ carry away most of the beam energy allowing to keep the dump short
- Trigger requires $E_{PS} > E_{th}$ to start shower earlier – also to minimize the leakage
- Great advantage of the NA64 method: use of active beam dump to control the shower leakage!

Recent NA64 results for X, A´ → e^+e^-

NA64 PRL(2018)



NA64 (2019)
combined 2017+2018



$1.3\times10^{-4} < \varepsilon_e < 4.2\times10^{-4}$
2017 run, 5×10^{10} EOT, 100 GeV

$1.2\times10^{-4} < \varepsilon_e < 6.8\times10^{-4}$
+2018run, 3.4×10^{10} EOT at 150 GeV

New evidence for X(17)→ e^+e^- from ^{4}He transitions

New evidence supporting the existence of the hypothetic X17 particle

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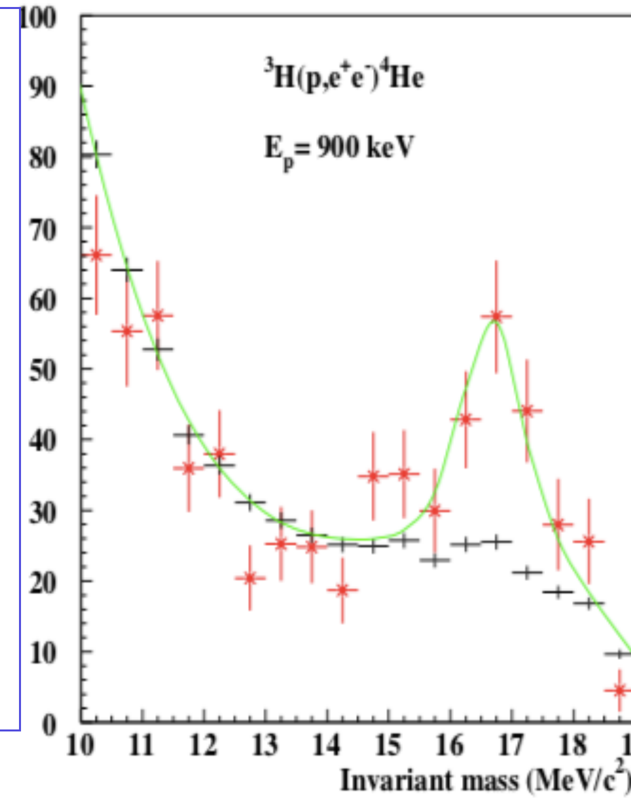
We observed electron-positron pairs from the electro-magnetically forbidden M0 transition depopulating the 21.01 MeV 0^- state in ^{4}He. A peak was observed in their e^+e^- angular correlations at 115° with 7.2σ significance, and could be described by assuming the creation and subsequent decay of a light particle with mass of m_Xc^2=16.84±0.16($stat$) ±0.20($syst$) MeV and Γ_X= 3.9 × 10^{-5} eV. According to the mass, it is likely the same X17 particle, which we recently suggested [Phys. Rev. Lett. 116, 052501 (2016)] for describing the anomaly observed in ^{8}Be.

PACS numbers: 23.20.Ra, 23.20.En, 14.70.Pw

arXiv:1910.10459



- The emission rates look similar:

  $\Gamma_X(^8\text{Be}) = 1.2 \times 10^{-5}$ eV

  $\Gamma_X(^4\text{He}) = 3.9 \times 10^{-5}$ eV

Can both be explained by X? What about J^π properties and couplings?

- A detailed analysis and experimental confirmation are crucial !
- How can we be sure these observations are not a nuclear effect?

The NA64 view

What do we know about the X?

- X could be of any type: *S, PS, V, AV*
- X is obviously coupled to electrons (ε_e). Apparently it is not coupled to photon (only at loop level). It cannot be a dark photon.

  ε_e is constrained only by the need for X to decay rapidly enough
- X has also couplings to quarks($\varepsilon_{u,d}$) which control its emission rate. Can they be predicted/calculated reliably?

The advantage of the NA64 search:

Do not need of any assumptions on the hadronic production of X. The only one we use is: $\varepsilon_e \neq 0$

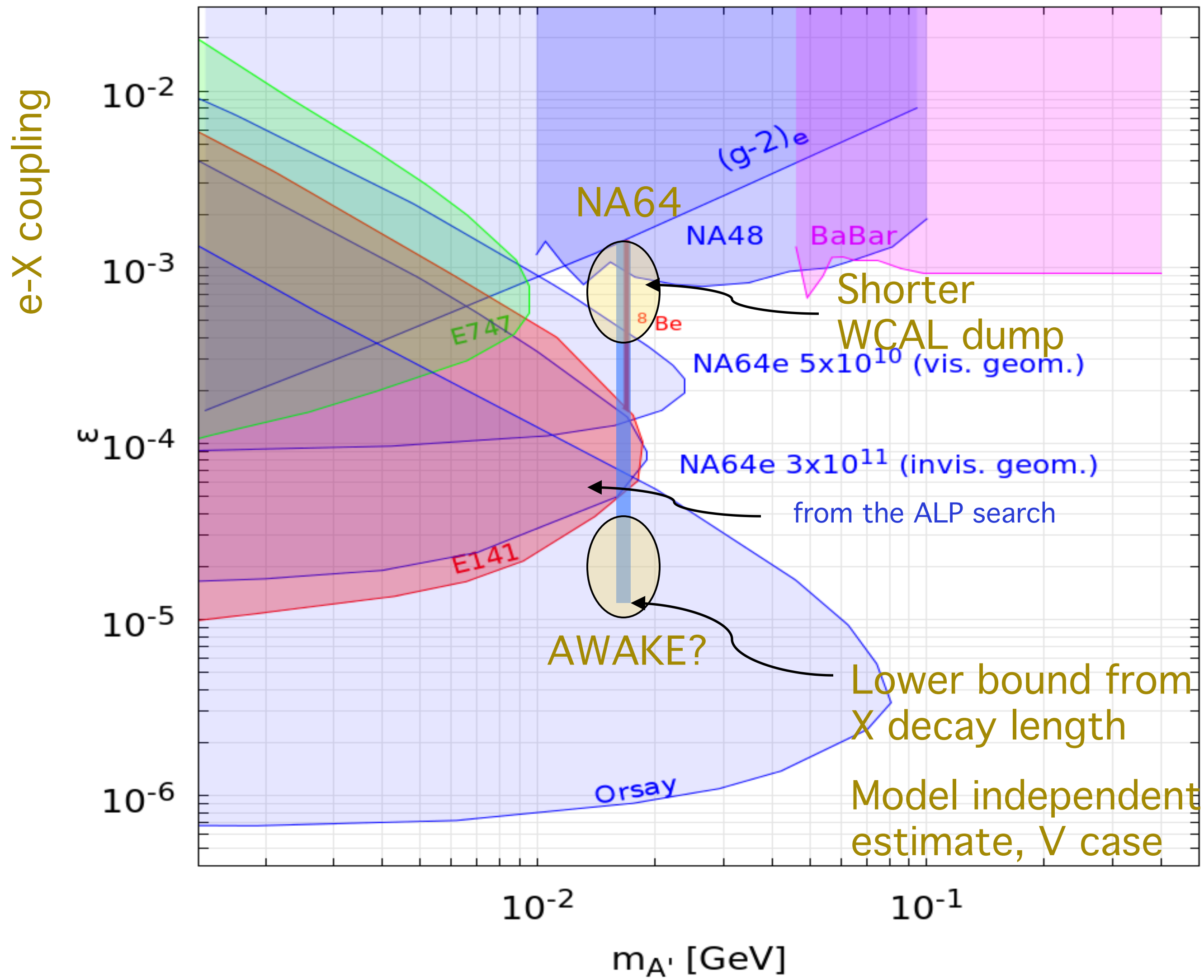
A model-independent estimate (V case): $10^{-5} < \varepsilon_e < 10^{-3}$.

The upper limits came for e- experiments and $(g-2)_e$

The lower estimate came from using only experimental bound on the X decay length <~1 cm.

To test the full region $10^{-5} < \varepsilon_e < 10^{-3}$ would be important

NA64 has the best sensitivity to the 8Be region

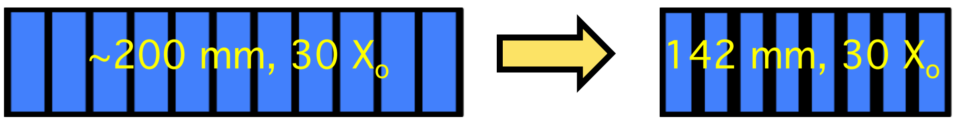


Take a once more careful look at limits around ~10^{-4}.
Na64 plan to explore this region as well.

Optimization of the WCAL dump structure

To improve sensitivity the WCAL should be made shorter
Several different WCAL structures were simulated

WCAL structure [mm](layers)	WCAL length [mm]	epsilon	expected DM for 1E10	Day to Cover the Anomaly
ECAL1:6+2(17)ECAL2:–	142	0.0012	0.063(0.064)	44.7(45.5)
ECAL1:6+2(17)ECAL2:–	142	0.001	0.26(0.078)	10.9(3.32)
ECAL1:3+2(34)ECAL2:–	173	0.001	0.1(0.039)	26.8(10.1)
ECAL1:3+2(25)ECAL2:3+0(9)	153	0.001	0.15(0.029)	18.6(3.6) **Double**
ECAL1:3+2(25)ECAL2:3+0(9)	153	0.001	0.14(0.04)	19.7(5.52)

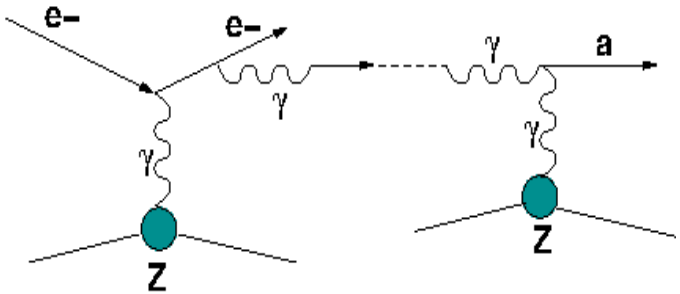


- **Observation:**
  - Impact of energy resolution is very low, most of the X-boson recorded in the experiment are high energetic, so energy deposition in WCAL less relevant than ECAL. X-boson with large energy deposit in WCAL are exponentially suppressed.
  - (6 mm W + 2 mm Sc) is more effective as it is more compact. There is a chance to cover parameter space larger the Beryllium anomaly, but 1.5E-3 is very tough with all design (> 1000 Day of data taking to cover the region)
  - Precise estimate for large ε need large statistic as weight becomes very small. Can one just re-weight the already simulated event? Also larger cut for sensitivity studies needs to be used (currently 30 GeV, but event below 80 GeV are extremely unlikely in this region of parameter space)

Running time to probe given ε_e : $t(\varepsilon_e) \sim 6\exp[10(\varepsilon_e - \varepsilon^0_e)/\varepsilon^0_e]+5$,
With $\varepsilon^0_e = 10^{-3}$. $\varepsilon_e = 10^{-3}$, $1.2\ 10^{-3}$, $1.4\ 10^{-3}$ =>11d, 1.5 m, 10 m.

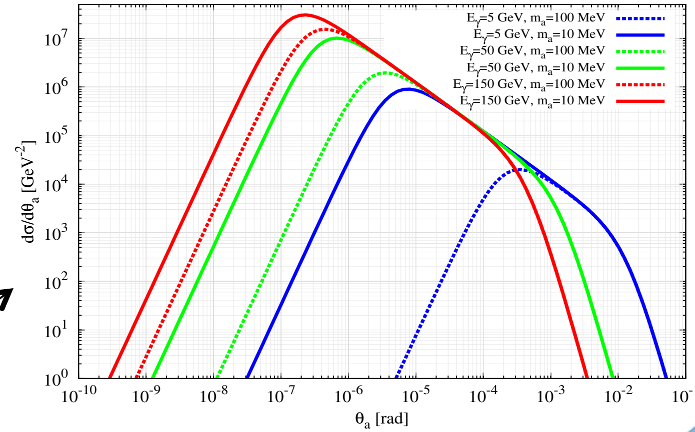
Search for the *a* →*γγ* decays in “invisble” data sample

1) Primakoff production in the ECAL dump :



2) Production cross-section:

ETL full calculations,
e.g. the a emission angle

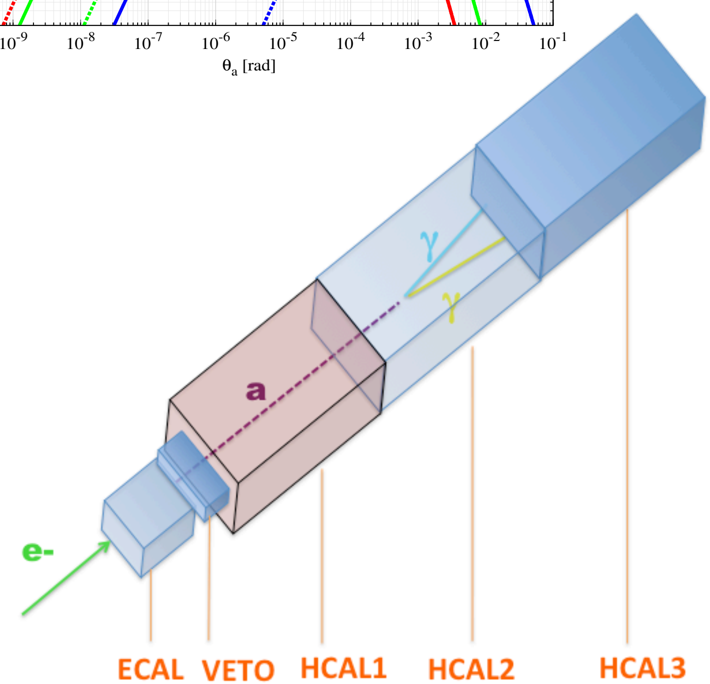


3) Signature:

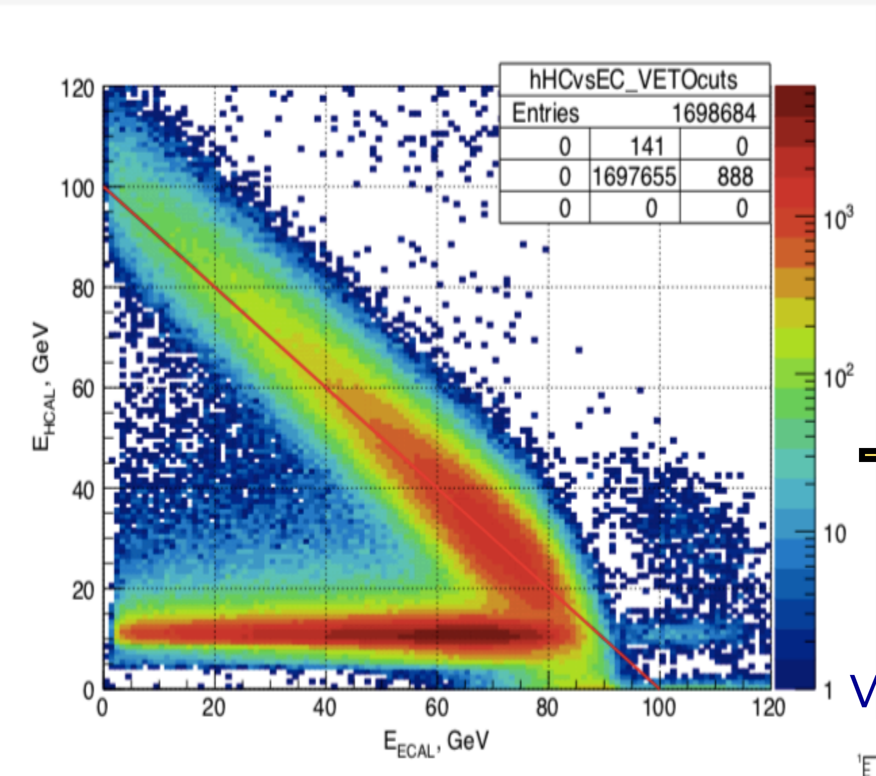
- 100 GeV e- track
- $E_{ECAL} < E_0$ shower in ECAL
- no activity in Veto and HCAL1
- Then, either

i) no activity in HCAL2 and HCAL3:
a decays outside HCAL, or

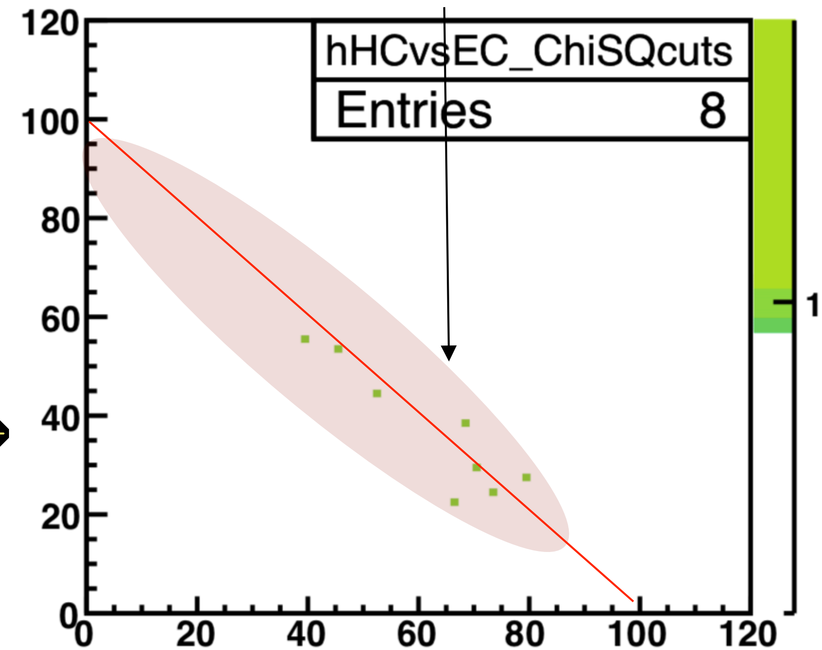
ii) e-m like energy in HCAL2+HCAL3
a decays inside HCAL



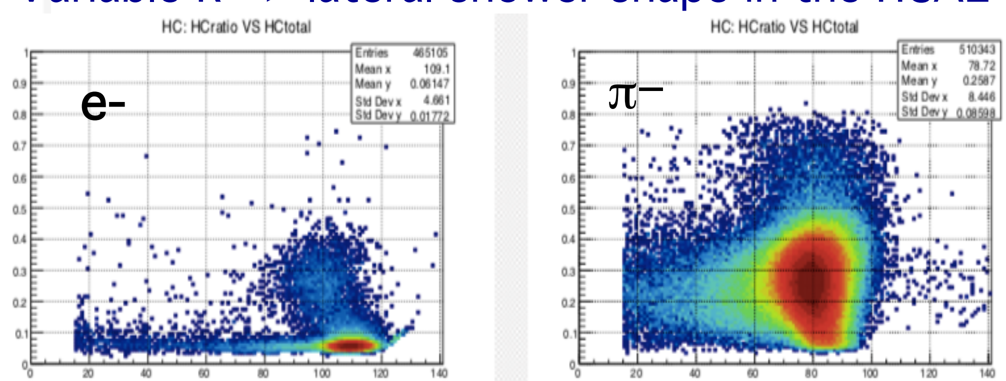
Event selection: similar to those from A´->inv search



Candidate events in HCAL2+HCAL3



Variable R => lateral shower shape in the HCAL



For this search the HCAL was re-calibrated and traced with the monitoring system to ensure that $E_{EC}+E_{HC} = E_0$ (100 GeV)

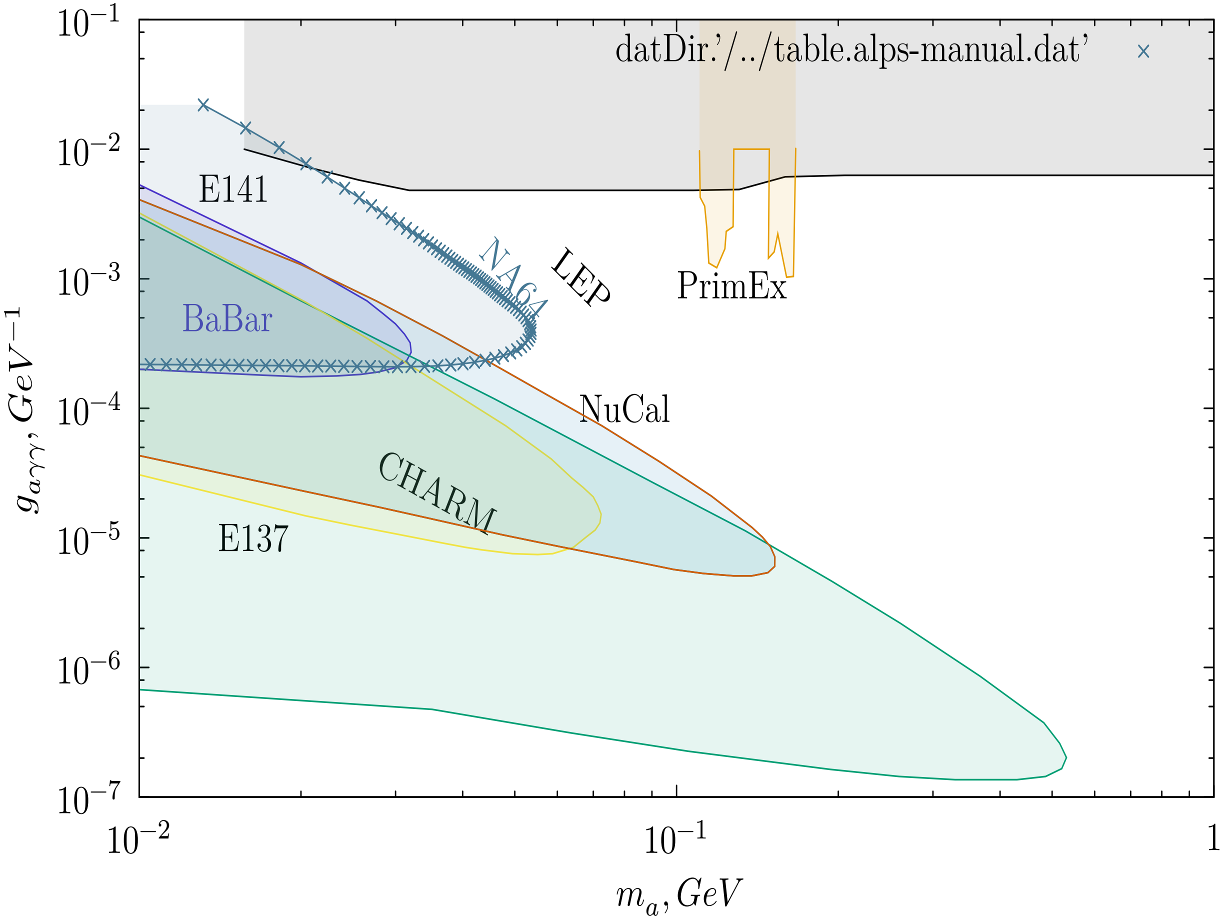
For the A´->inv search the HCAL served mostly as a Veto

Main bckg – punchthrough neutral secondaries (n, K_L)

Well predicted from punchthrough charged hadrons

No events in the signal box after the cut on R

Bounds on the coupling $g_{a\gamma\gamma}$ (preliminary)



The results on the $a \rightarrow \gamma\gamma$ decay are also applicable to the A´->e^+e^- decay search. Plan to improve limits on γ–A´ mixing and ε_e around ~10^{-4} (^{8}Be region).

NA64 plans after LS2

- to start probing for the first time the light dark matter parameter space
- to test the remaining ^{8}Be region of the e-X couplings
- to continue the exploration of the short-lived ALP parameter space

A very exciting time ahead. Stay tuned!