Status and plans of the NA64 experiment

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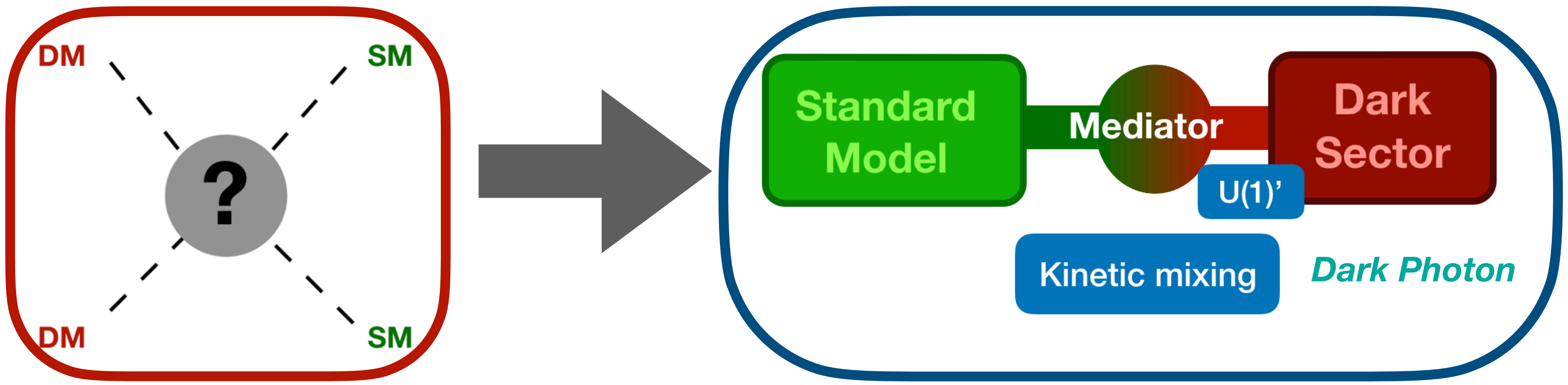
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich
IPA
IFIC INSTITUT DE FÍSICA CORPUSCULAR
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
VNIVERSITAT DE VALÈNCIA

Outline

Motivation



The NA64 physics program

1) Light dark matter:

➡ ***Invisible*** decays

- 2016-2018 combined analysis
- **2021** and **2022**
- Future prospects:

➡ **e+ beam 2022**

➡ **NA64μ➡pilot run in 2021 and 2022**

↘ 2) Constraints on **new physics:**

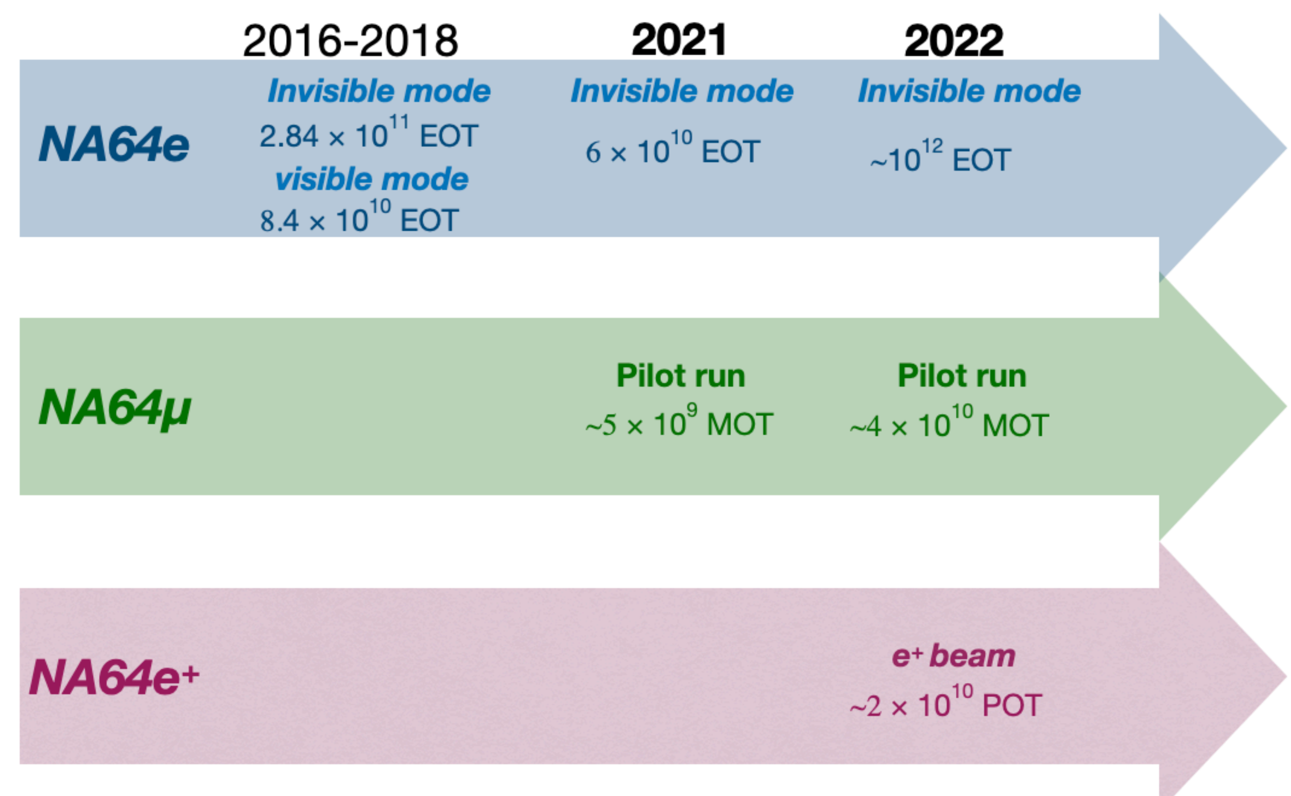
★*(g-2)$_\mu$*

✦*ALPs*

✦*(g-2)$_e$*

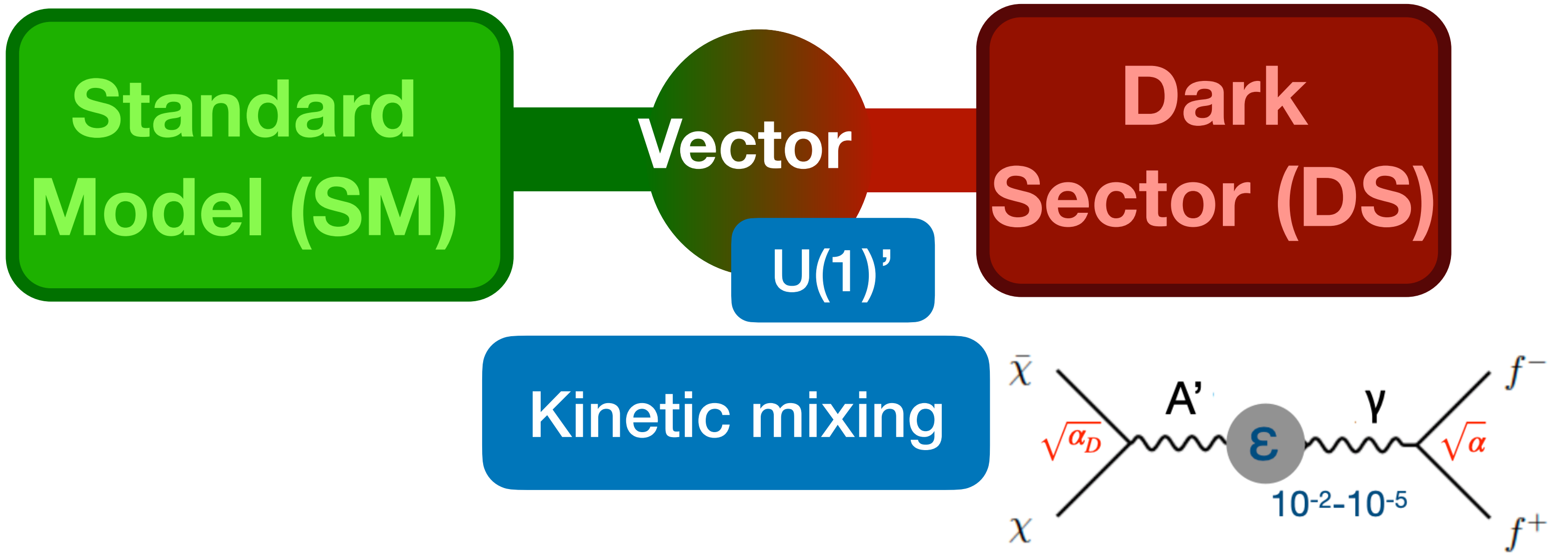
◉ *^{8}Be anomaly:*

➡ ***Visible*** *decays*



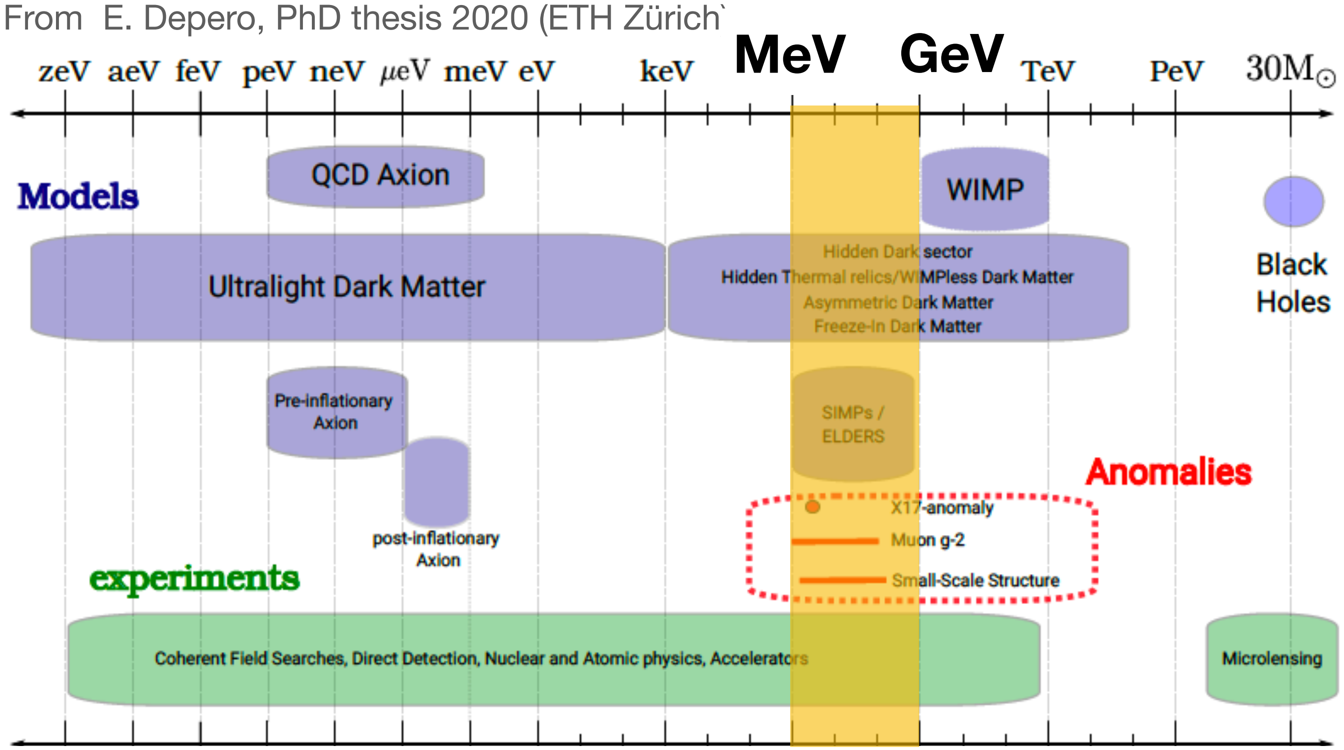
NA64 target: *Dark sectors*

An interesting framework to explain the origin of Dark Matter (DM)

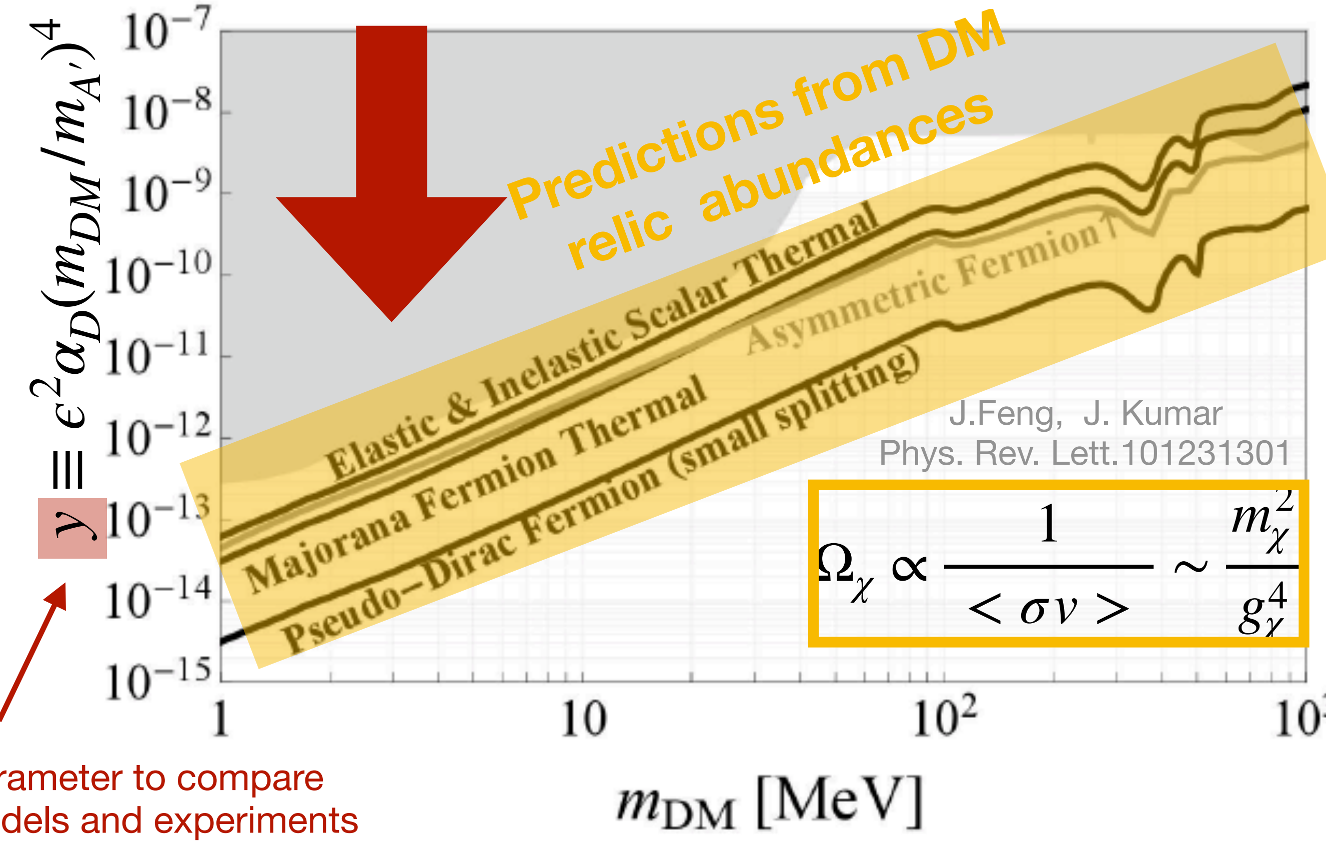


Parameter space defined by *($m_{A'}$,m_χ,ε,α_D)*

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



Goal for NA64 2022-2025 runs!



Useful parameter to compare different models and experiments proportional to the DM-SM annihilation cross-section

From Light Dark Matter experiment arXiv:1808.05219v1

Review about DS:

The Search for Feebly Interacting Particles, Gaia Lanfranchi, Maxim Pospelov, Philip Schuster Annual Review of Nuclear and Particle Science 2021 71:1, 279-313

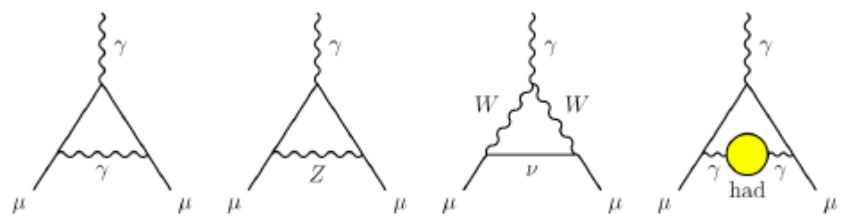
NA64 target: *(g-2)$_\mu$ an additional motivation*

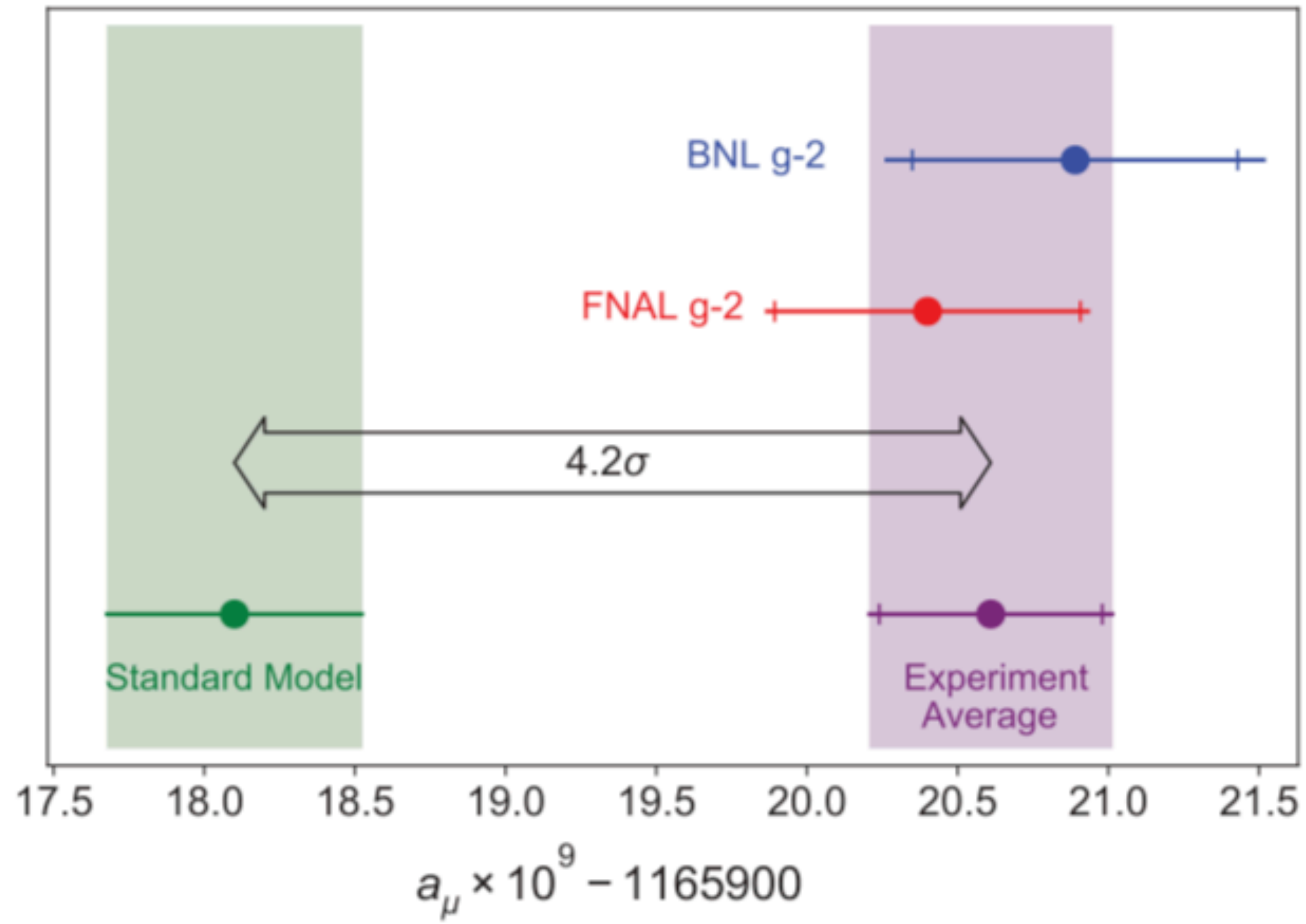
$$a_\mu = \frac{g_\mu - 2}{2}$$

Anomalous muon magnetic moment

$$\Delta a_\mu = a_\mu^{EXP} - a_\mu^{TH} = (251 \pm 59) \cdot 10^{-11}$$

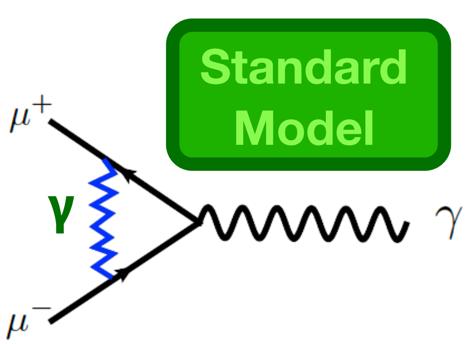
$$a_\mu^{TH} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{HAD}$$

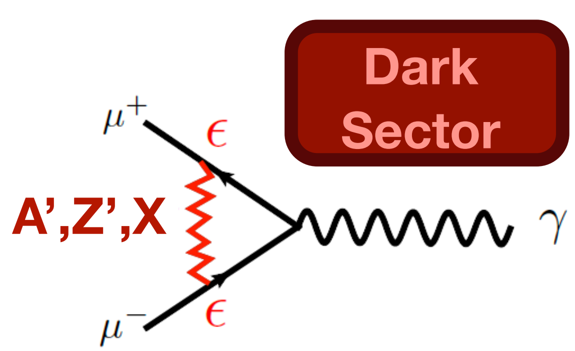




B. Abi *et al. Muon g-2 collaboration* Phys. Rev. Lett. 126, 141801
T. Aoyama *et al.* Phys. Rept. 887 (2020) 1-166

- Including the latest lattice QCD calculations the discrepancy with the experimental value gets reduced below 2σ: Sz. Borsanyi *et al* Nature volume 593, pages 51–55 (2021)
- Main uncertainty in the theoretical calculation coming from the hadronic contributions. Important role of MUONE experiment at CERN to directly measure them: https://indico.cern.ch/event/765096/contributions/3295779/attachments/1785296/2906331/ES_MUonE_document.pdf





Specific target for NA64

NA64 approach: **new physics?**
1-loop contributions from dark sector bosons such as A', Z' or a generic X

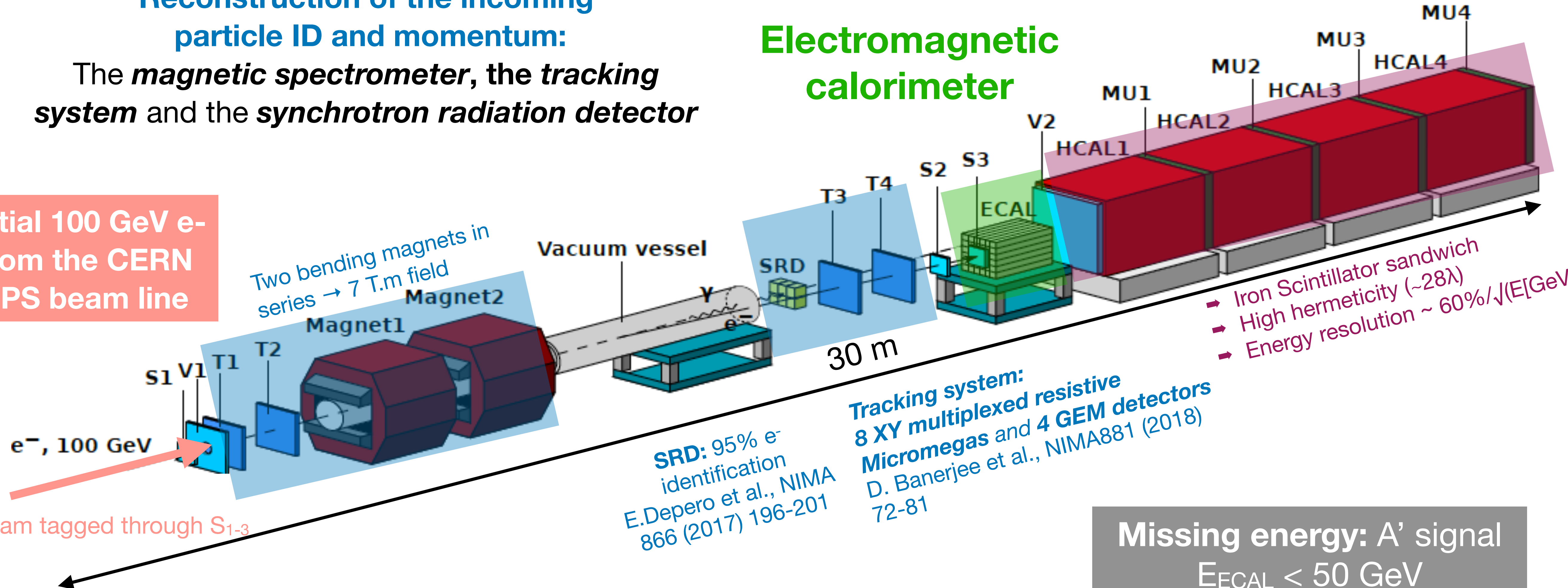
NA64 *invisible* mode: *the setup*

Reconstruction of the incoming particle ID and momentum:
The ***magnetic spectrometer***, the ***tracking system*** and the ***synchrotron radiation detector***

Electromagnetic calorimeter

Hadronic calorimeter

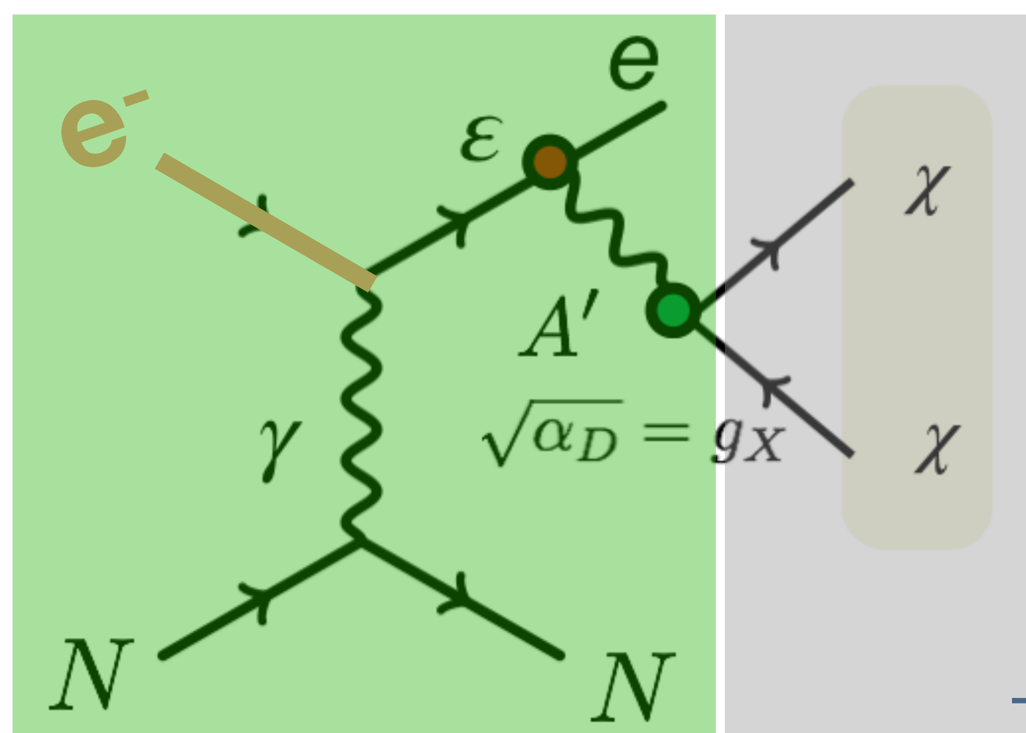
Initial 100 GeV e- from the CERN SPS beam line



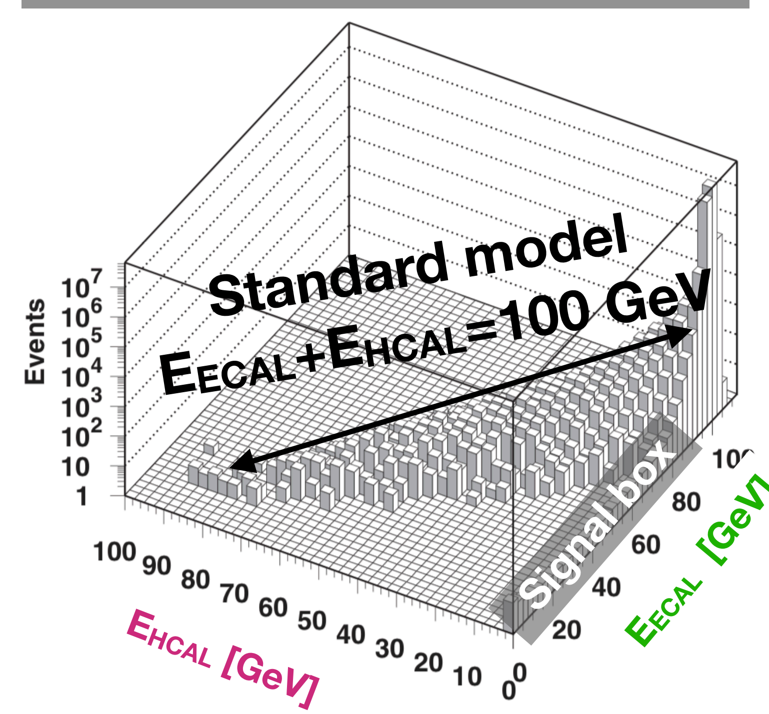
Active target

$$\sigma_{A'} \propto \epsilon^2$$

- Lead Scintillator sandwich
- High hermeticity (~40 X_0)
- Energy resolution ~ 9%/√(E[GeV])



Missing energy: A' signal
E_{ECAL} < 50 GeV
E_{HCAL} energy < 2GeV

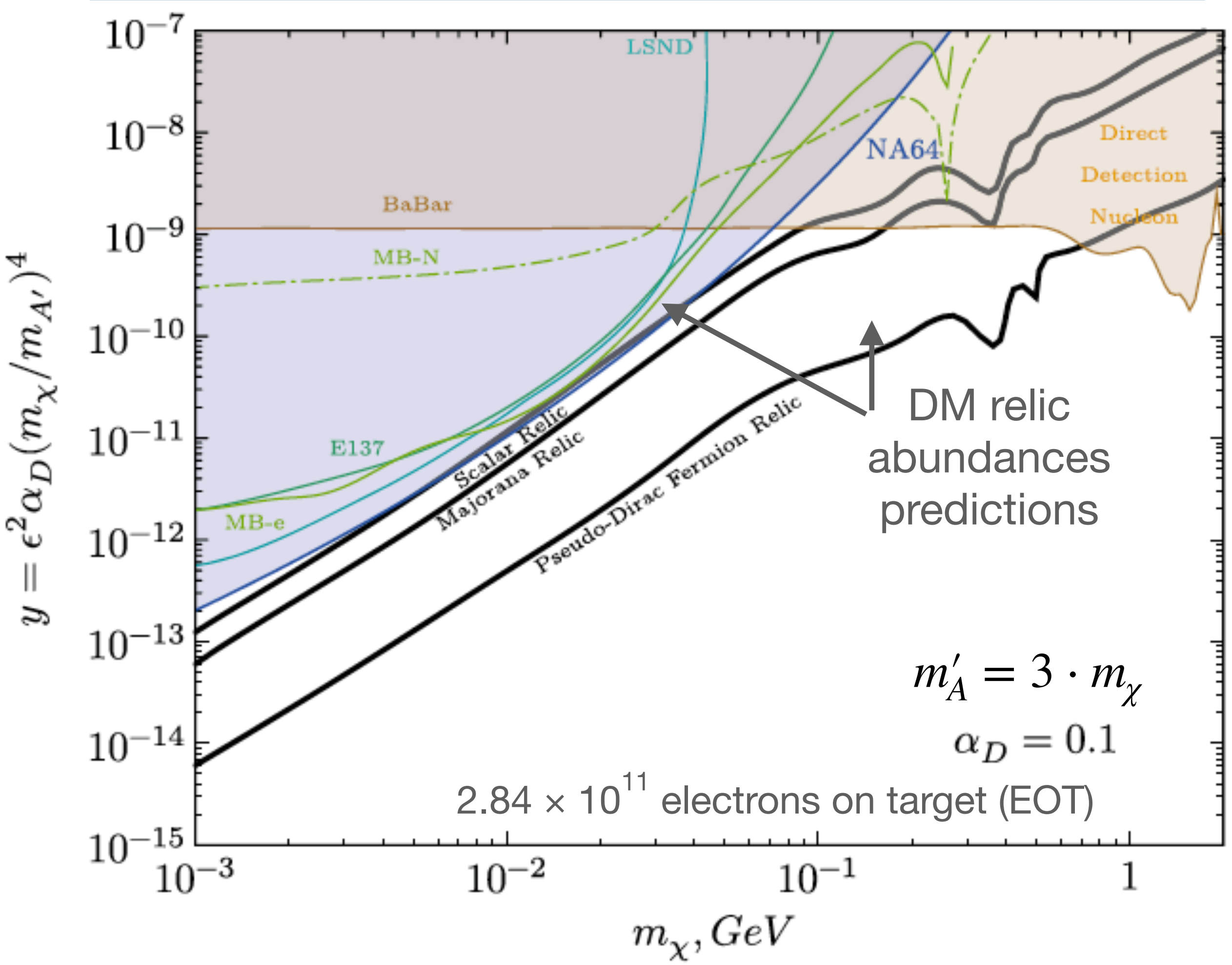


NA64 *invisible* mode: *main physics goal* ***LDM***

2014 2015 **2016** **2017** **2018**

Combined ***invisible analysis*** *data 2016-2018* ***with 2.84 x 10¹¹ EOT***

A' → $\chi\bar{\chi}$: Results exceeded sensitivity of previous experiments to sub-GeV DM.



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
$\mu \to e\nu\nu$, π, $K \to e\nu$, 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

Reminder:

$N_{A'}^{NA64} \propto \epsilon^2$ Vs $N_{A'}^{Beam\ Dump} \propto \epsilon^4 \alpha_D$

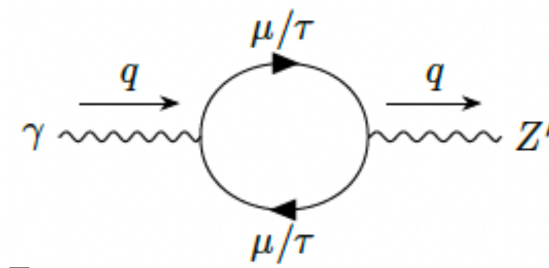
NA64 *invisible searches*: L_μ-L_τ Z'

NEW!

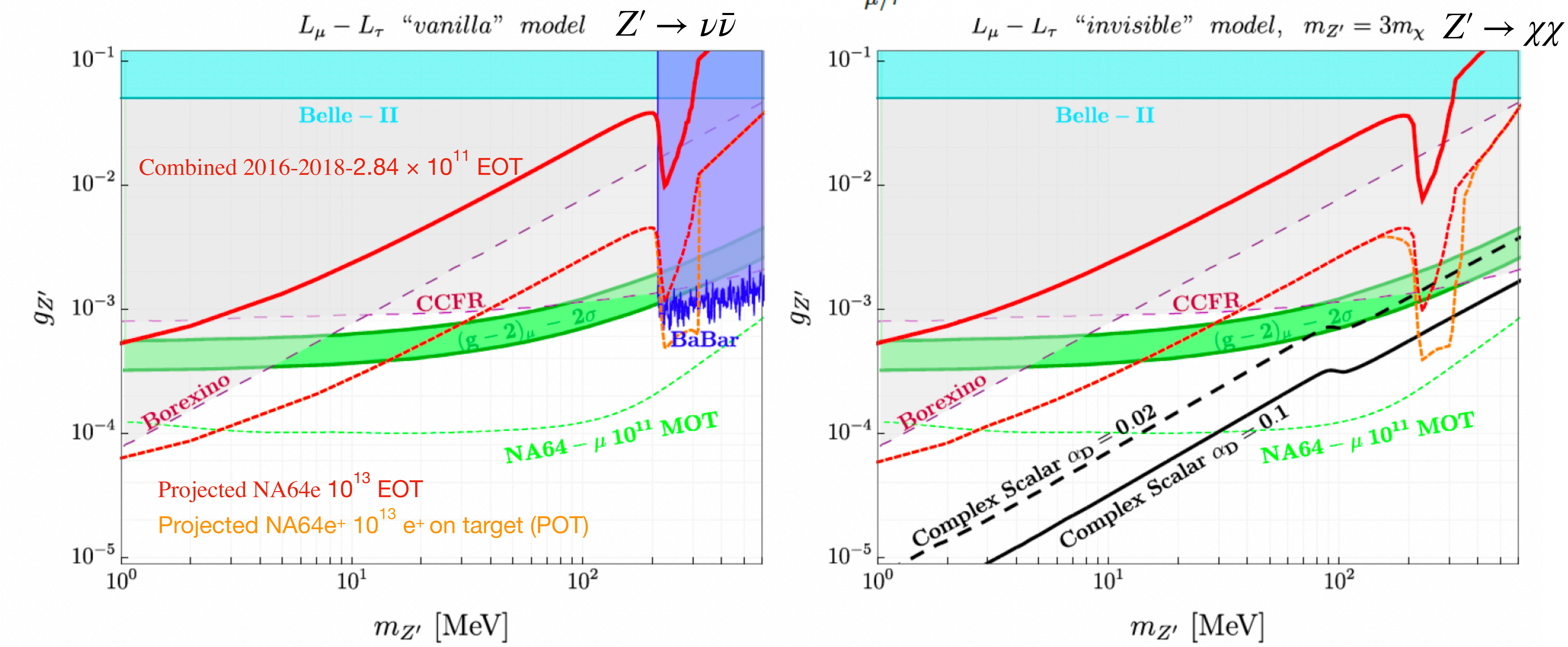
A well-motivated SM extension:

- A **light Z'** arising by gauging the difference of the lepton number between the muon and tau flavour, $\mathbf{L_\mu - L_\tau}$.
- It can accommodate the **muon g-2 anomaly** and the **DM freeze-out relic origin**.

First result using the *NA64e* collected data in 2016-2018



$e^-Z \to e^-ZZ'; Z' \to$ **invisible**;
$e^-e^+ \to Z'; Z' \to$ **invisible**



NA64 collaboration, https://arxiv.org/abs/2206.03101 (June, 8th **2022**)

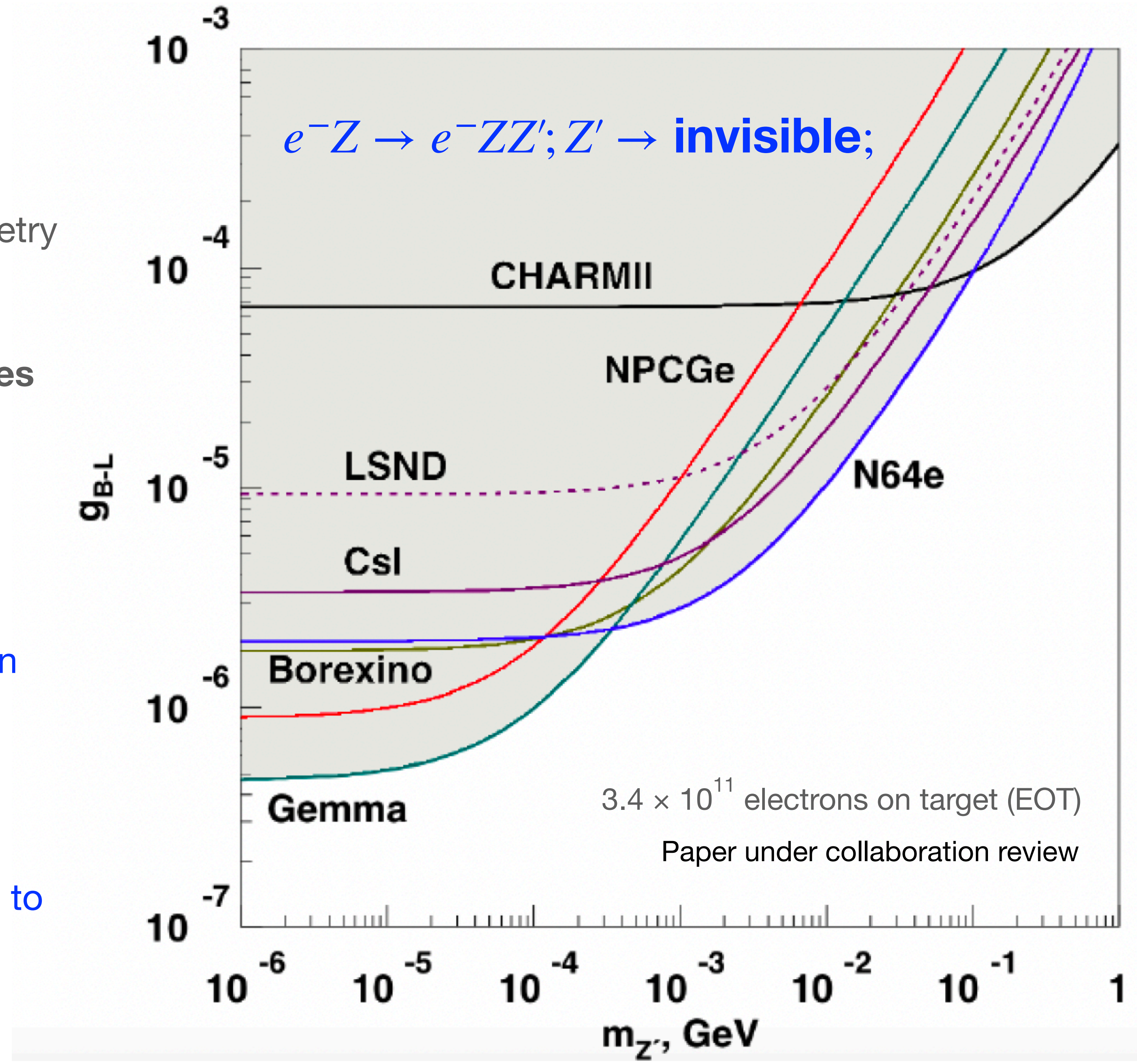
Complementarities between electron, muon and positron programs to unequivocally probe these models.

NA64 *invisible searches*: *B-L Z'*

NEW!

Very appealing SM extension are also:

- A **light Z'** resulting from U(1)' gauge symmetry generated by the difference between the Baryon and Lepton numbers, B-L.
- It can explain the **origin of neutrino masses** and the **DM composition**.



➡ First result using the *NA64e* collected data in 2016-2018 and 2021 corresponding to 3.4 x10^{11} EOT.

➡ The 90%C.L exclusion limits obtained are competitive with the neutrino-electron scattering experiments traditionally devoted to these searches.

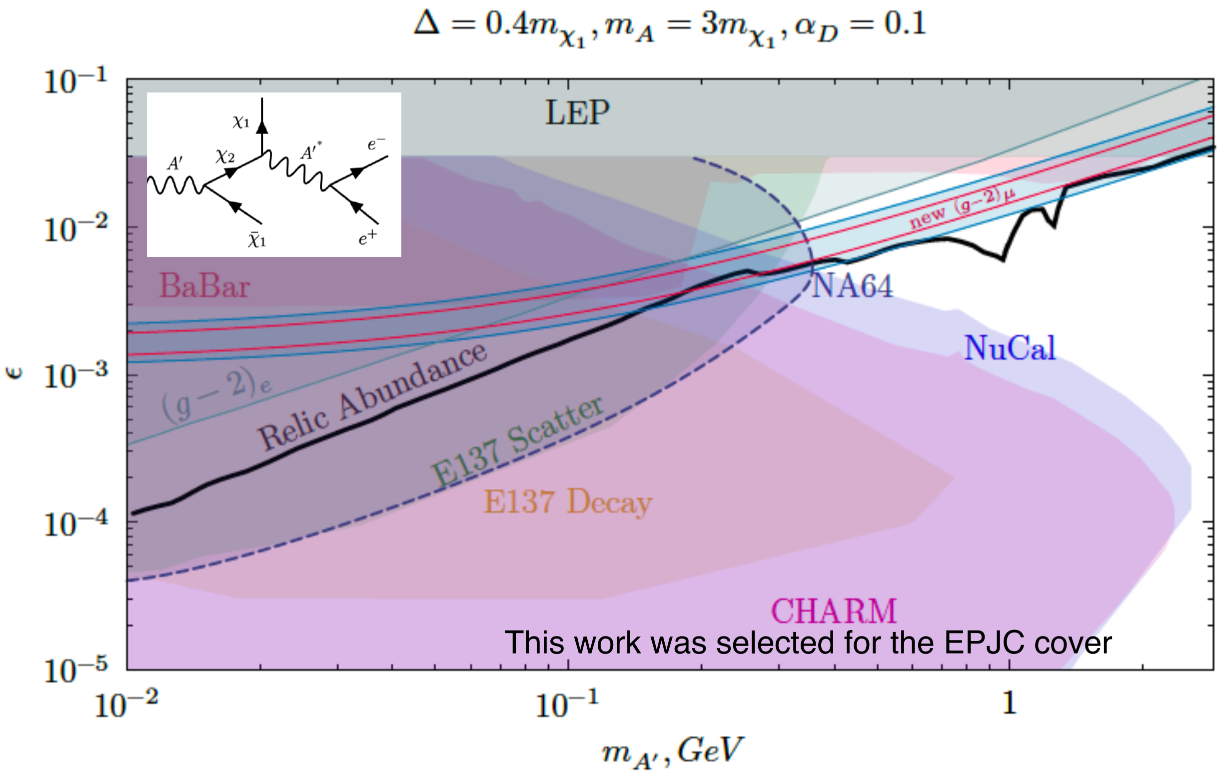
➡ It is the first time that NA64 enters into the neutrino sector.

- B – L models included in the Dark matter standalone simulation framework (**DMG4**, *Bondi et al. Comput. Phys. Commun. 269 108129 (**2021**)*).
- Exact-tree-level cross-section considered to derive the limits.

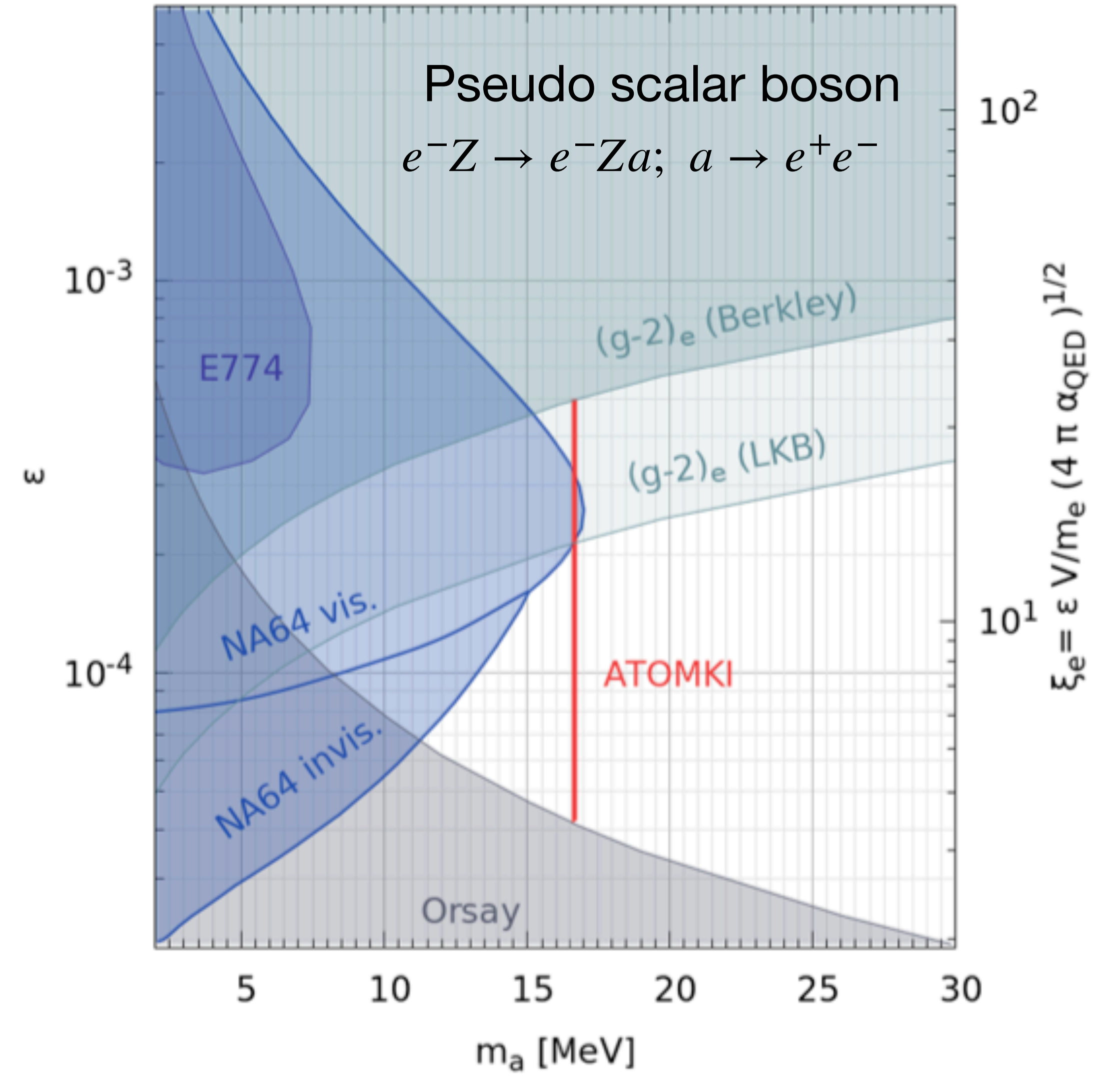
Update on publications

NEW!

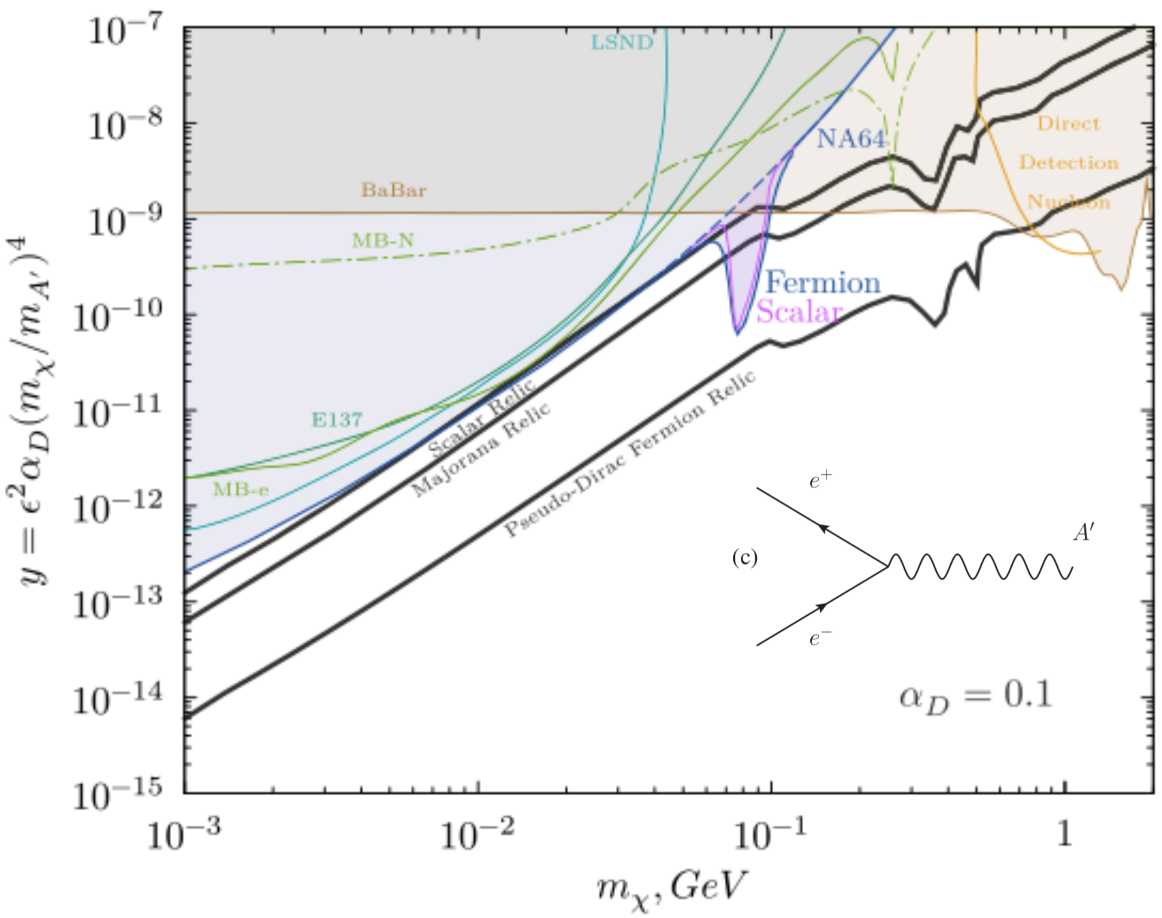
NA64 collaboration, Eur. Phys. J. C 81 (**2021**) no.10, 959



NA64 collaboration, Phys. Rev. D 104 (**2021**) no.11, L111102



NA64 collaboration, Phys. Rev. D 104, L091701 (**2021**)



1. S. N. Gninenko, N. V. Krasnikov and V. A. Matveev, Usp. Fiz. Nauk 191 (**2021**) no.12, 1361-1386.
2. A. Kachanovich, S. Kovalenko, S. Kuleshov, V. E. Lyubovitskij, and A. S. Zhevlakov, Phys. Rev. D 105, no.7, 075004 (**2022**).
3. H. Sieber, D. Banerjee, P. Crivelli, E. Depero, S. N. Gninenko, D. V. Kirpichnikov, M. M. Kirsanov, V. Poliakov and L. Molina Bueno, Phys. Rev. D 105 (**2022**) no.5, 052006.
4. D. V. Kirpichnikov, H. Sieber, L. Molina Bueno, P. Crivelli and M. M. Kirsanov, Phys. Rev. D 104 (**2021**) no.7, 076012.

NA64 *invisible* mode: *2021 upgrade*

2014 2015 2016 2017 2018 LS2 **2021**

- New fixed location at H4 beam-line.
- Beam, setup and electronics upgrades (finished by 2022):
  - ***Improve performance*** (increase intensity up to 10^7 e^-/spill).
  - **Reduce background** from electro-nuclear interactions accompanied by large p_t secondary neutrals (n, K^0_L, …).

Assembly of all detectors along Autumn 2021

Goal: Accumulate 5×10^{12} EOT before LS3.

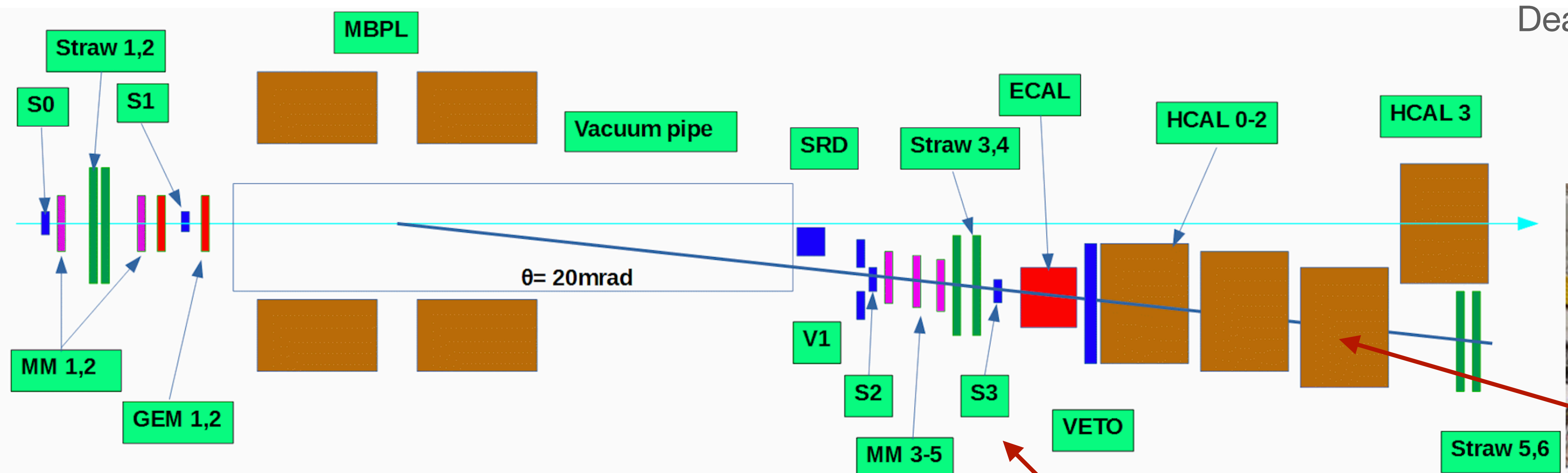
NA64 *invisible* mode: *2021 run @H4 new area*

New H4 area:

- New H4 beam-line commissioned and for the first time **beam intensities up to 2x10^7 e$^-$/spill** delivered.
- **Good beam quality:** 5 mm^2 spot size, halo at the level of 0.5% and hadron contamination in the e$^-$ beam below 2% (at the highest intensity).

Upgrade to improve performance:

DAQ system	Previous		New
Trigger rate capabilities	2 kHz	→	20 kHz
Dead time	20%	→	10%

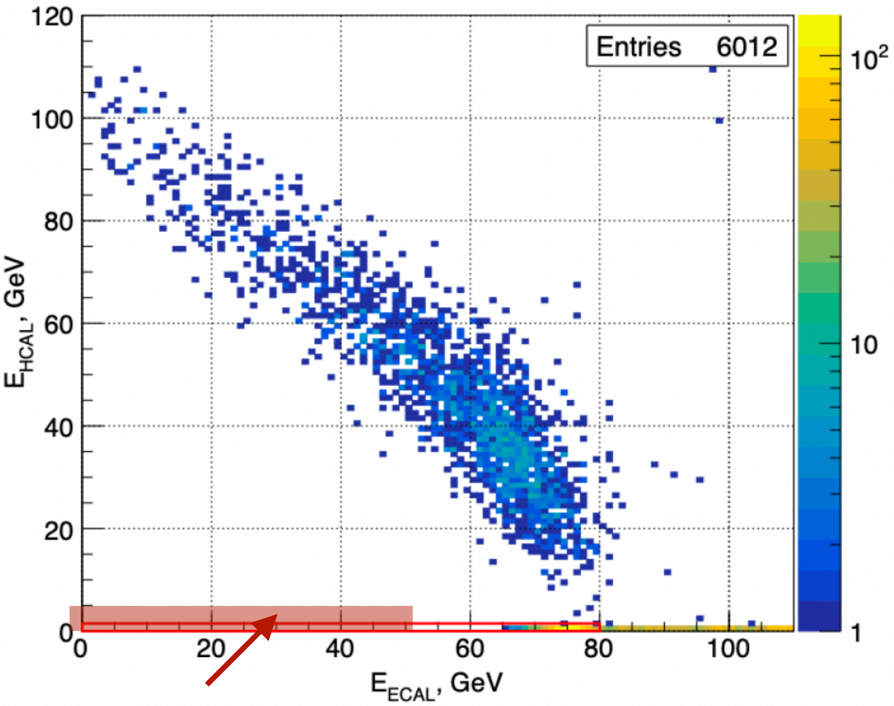


Set up upgrade for 2021 run:

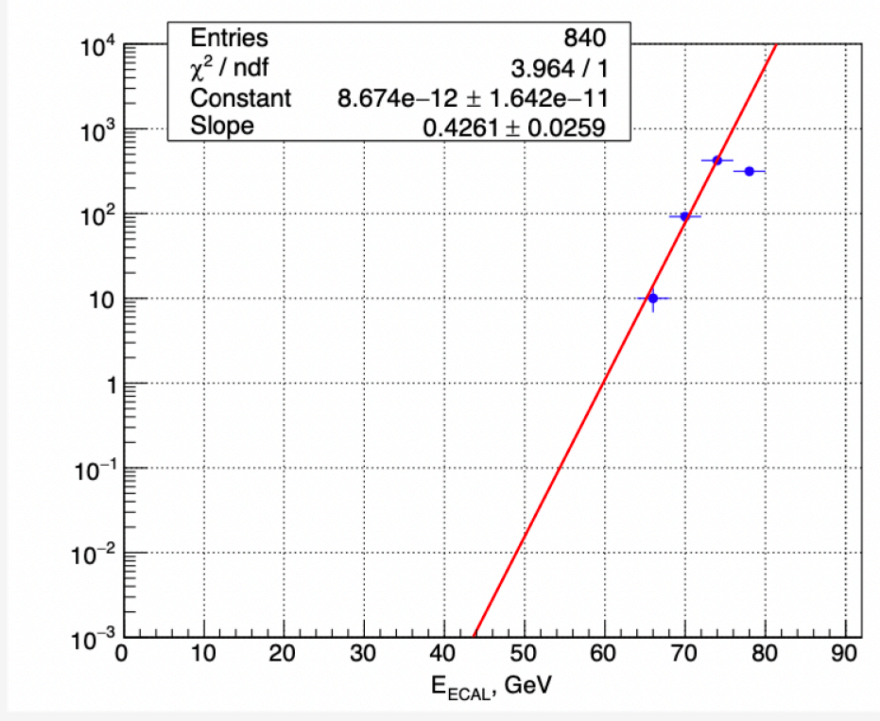
- Installation of large size (20x20 cm^2) straw detectors (straw 3-4) in front of the target *to suppress large angle charged hadronic secondaries*.
- A more compact setup configuration with the HCAL moved upstream *to increase its acceptance and reduce neutral hadronic background*.

NA64 *invisible* mode: *first results from 2021 run*

One week of data taking at an average intensity of 5×10^6 e^-/spill collecting **~6×10^{10} EOT** (one week lost due to SPS instabilities, two weeks for installation, commissioning and calibration).



No events in the signal box:
$E_{ECAL} < 50$ GeV + $E_{HCAL} < 1$ GeV



Event Selection Criteria:

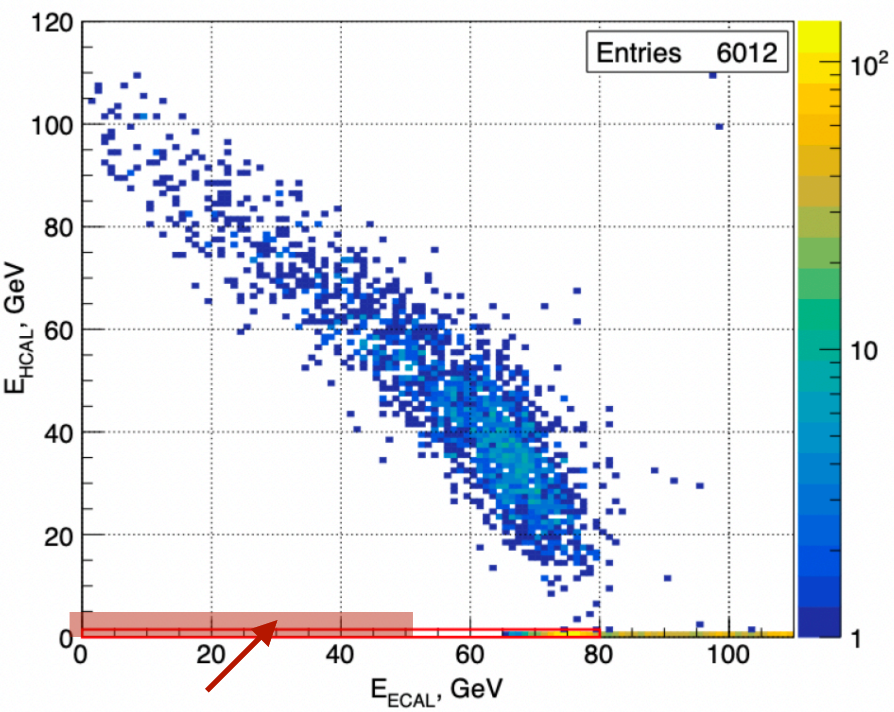
- *Timing information* → Pile up and noise suppression.
- *Clean incoming track:* angle + single hit in all trackers, momentum~100 GeV
- *Electron identification:* Synchrotron radiation + Shower profile compatible with e^- in ECAL → Hadron suppression
- *No punchthrough:* No activity in Veto and in HCAL

BKG events from neutral secondaries estimated from data: 0.031±0.015

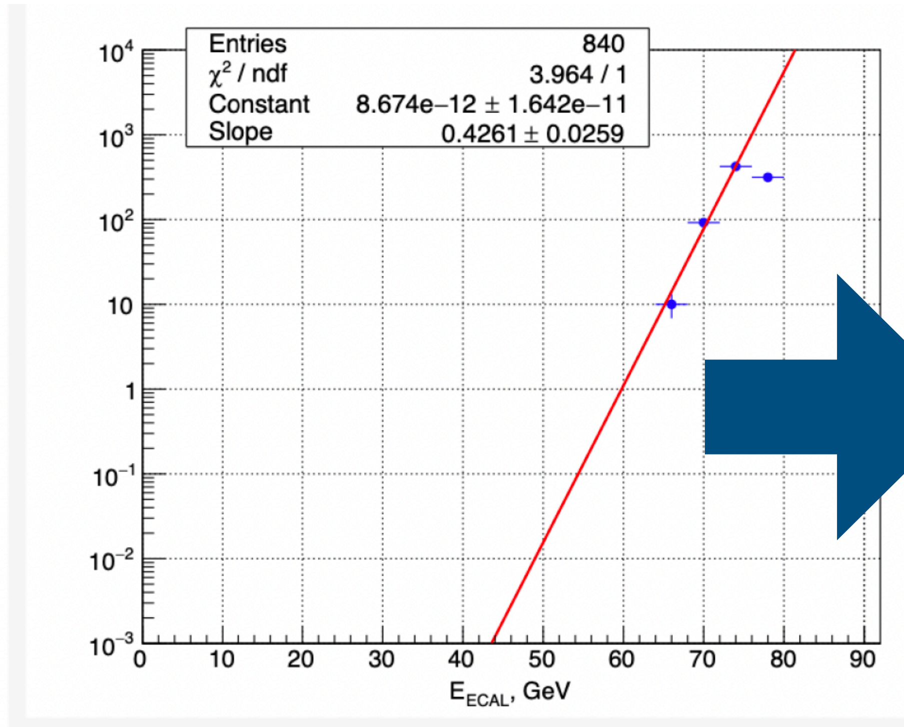
➡ It confirms that we understand our main source of BKG.

NA64 *invisible* mode: *2022 projection*

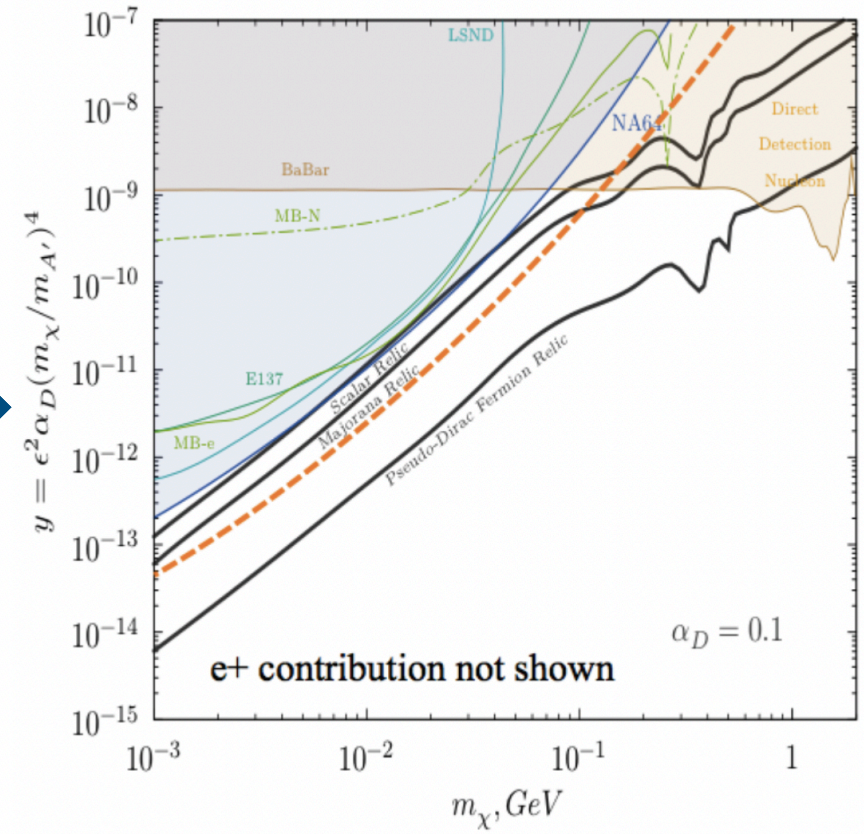
One week of data taking at an average intensity of 5x10[6] e-/spill collecting **~6x10[10] EOT** (one week lost due to SPS instabilities, two weeks for installation, commissioning and calibration).



No events in the signal box:
E_{ECAL} < 50 GeV + E_{HCAL} < 1 GeV



2022: accumulate ~10[12] EOT



Event Selection Criteria:

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- *Clean incoming track:* angle + single hit in all trackers, momentum~100 GeV
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- *No punchthrough:* No activity in Veto and in HCAL

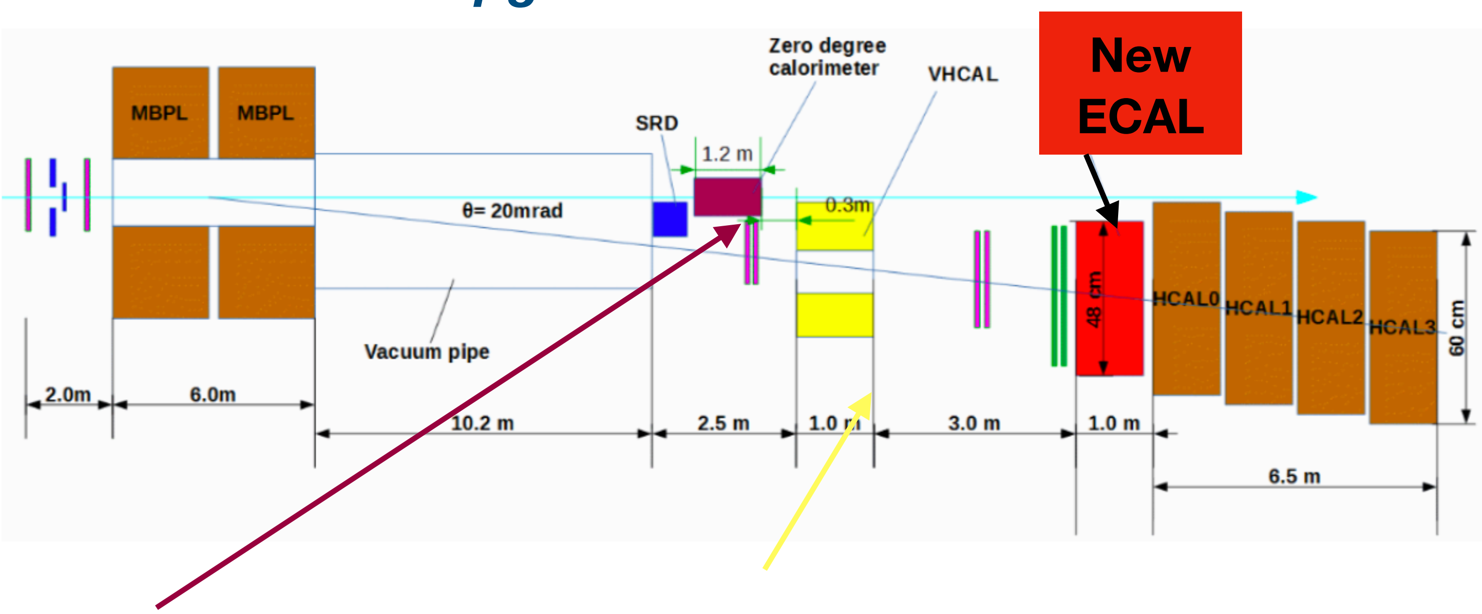
BKG events from neutral secondaries estimated from data: 0.031±0.015

➡ It confirms that we understand our main source of BKG.

➡ **Less than 1 BKG for 10[12] EOT (without 2022 upgrades, see next slide).**

NA64 *invisible* mode: 2022 run preparation

Detector upgrades to further reduce BKG

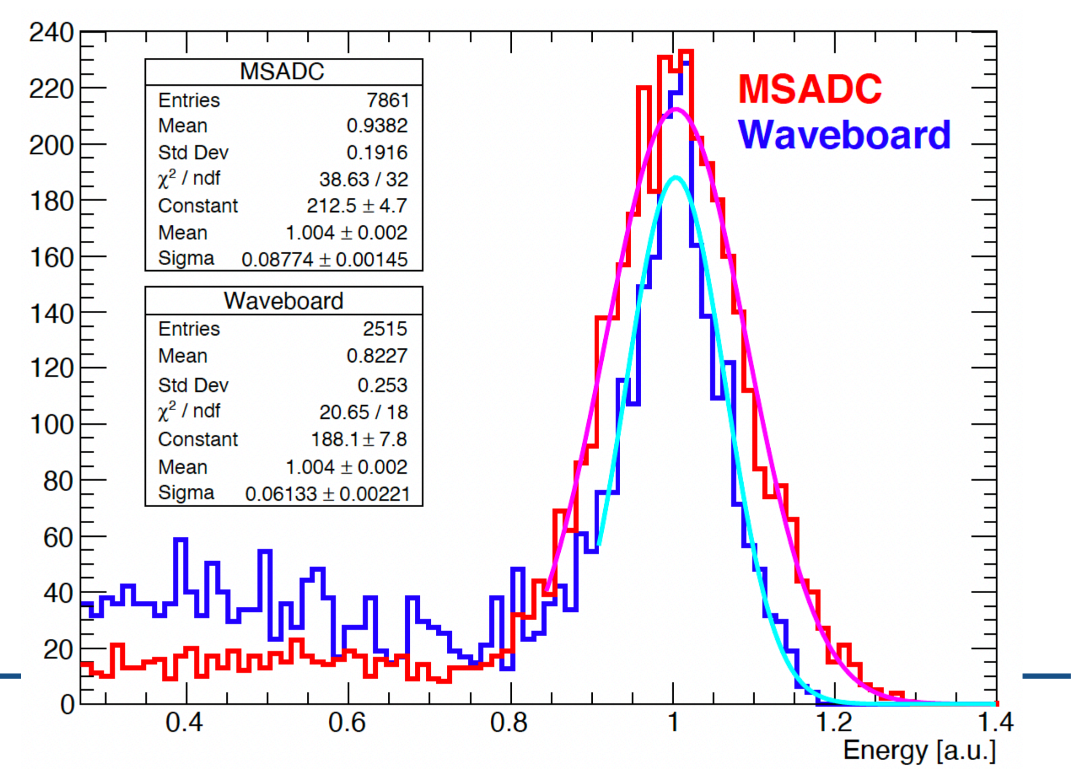


New zero degree calorimeter
To reject events accompanied by a hard neutral from the upstream e^- interactions

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

Improve performance (*intensity up to 10^7 e^-/spill*)

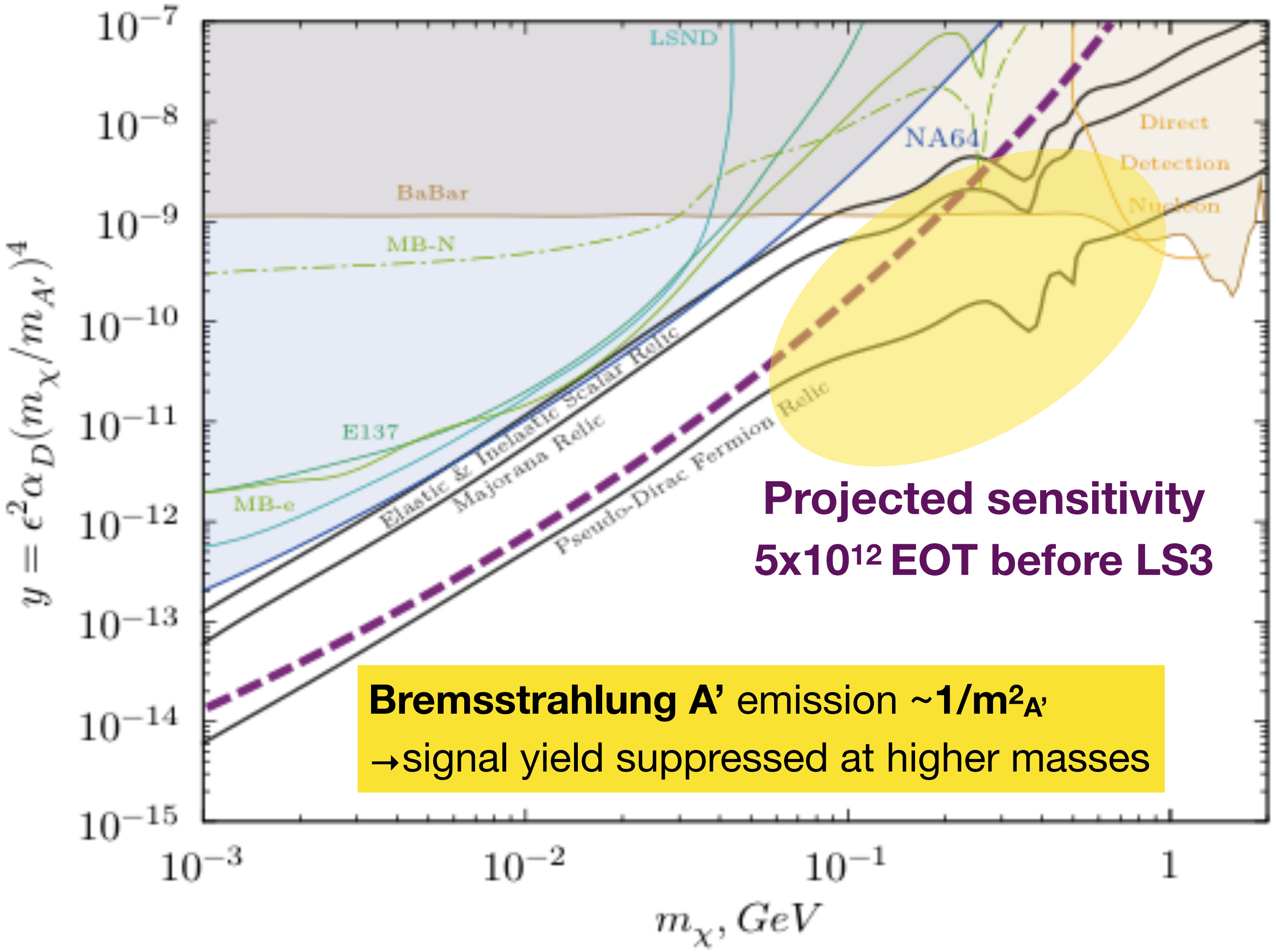
- **The current 80 MHz MSADC boards would be replaced with faster digitisers:** adapt a **250MHz waveboard digitiser developed by INFN**, F. Ameli *et al.* NIM A 936, 286 (2019) (to be tested during 2022 and completed by 2023).
- **The waveboard digitiser does not distort the intrinsic ECAL signal shape** (confirmed by simulations and beam campaigns in 2021 and 2022). A new firmware to accept an external trigger tested in the 2022 measurements.
- Preliminary results indicate that **the higher sampling frequency and dynamic range of the device allows to better sample the ECAL signals.** However, the waveboard need to be fully integrated inside NA64 DAQ to have a one-to-one comparison (to be completed by this Summer 2022).



NA64 *invisible* mode: *LDM future prospects*

2014 2015 2016 2017 2018 LS2 2021 2022 **Before LS3**

How can we enlarge the sensitivity at higher masses?



Projected sensitivity
$5x10^{12}$ EOT before LS3

Bremsstrahlung A' emission **~$1/m^2_{A'}$**
→signal yield suppressed at higher masses

NA64 *invisible* mode: *LDM future prospects*

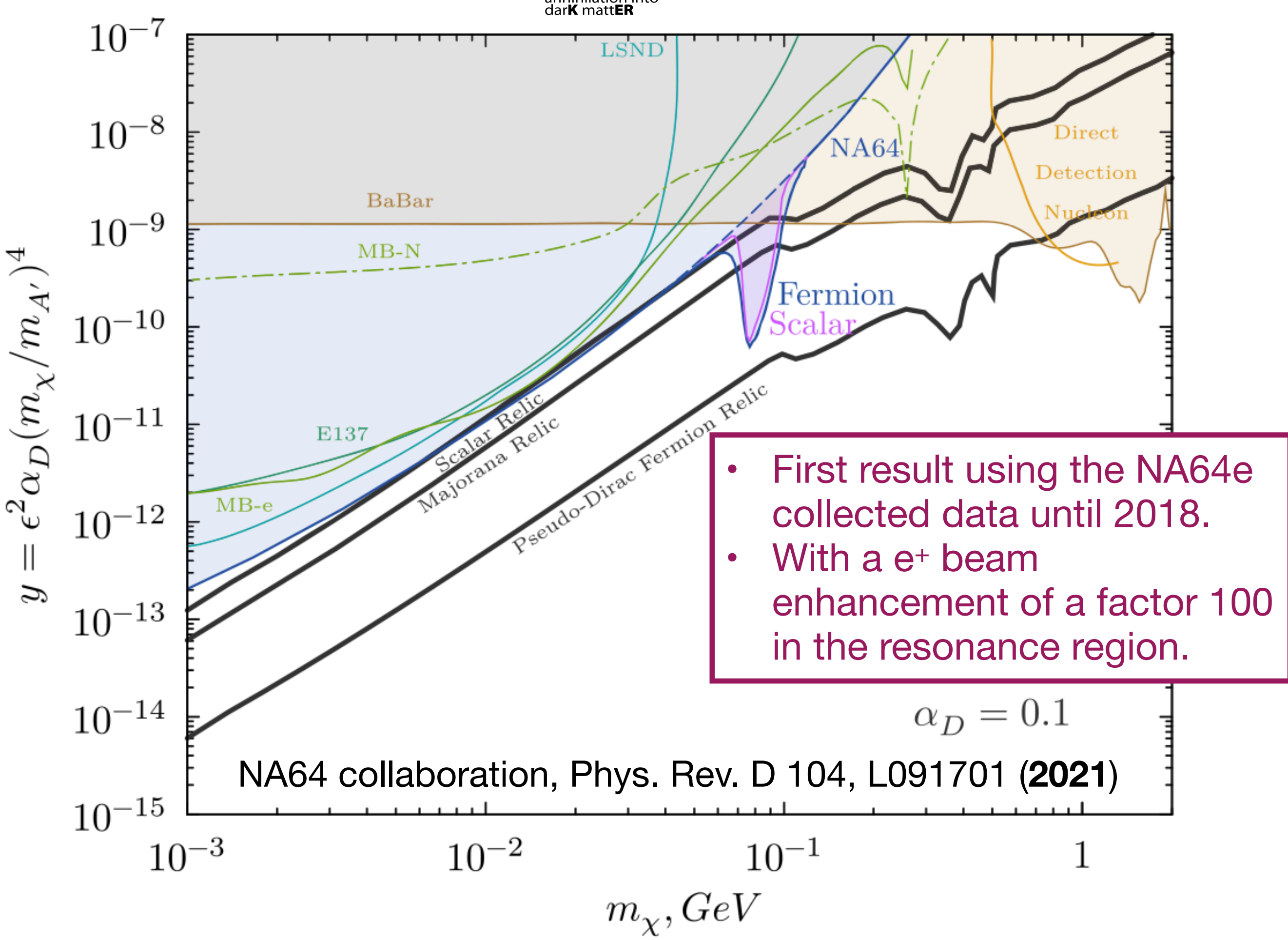
2014 | 2015 | 2016 | 2017 | 2018 | LS2 → **New complementary ideas**

- **Positron beam and A' resonant production**

L. Marsicano *et al.* Phys. Rev. Lett. 121, 041802

Supported by the ERC Starting Grant 2020 project: POKER "POsitron annihilation into darK mattER" A. Celentano (INFN-Genova)

POKER — POsitron resonant annihilation into darK mattER



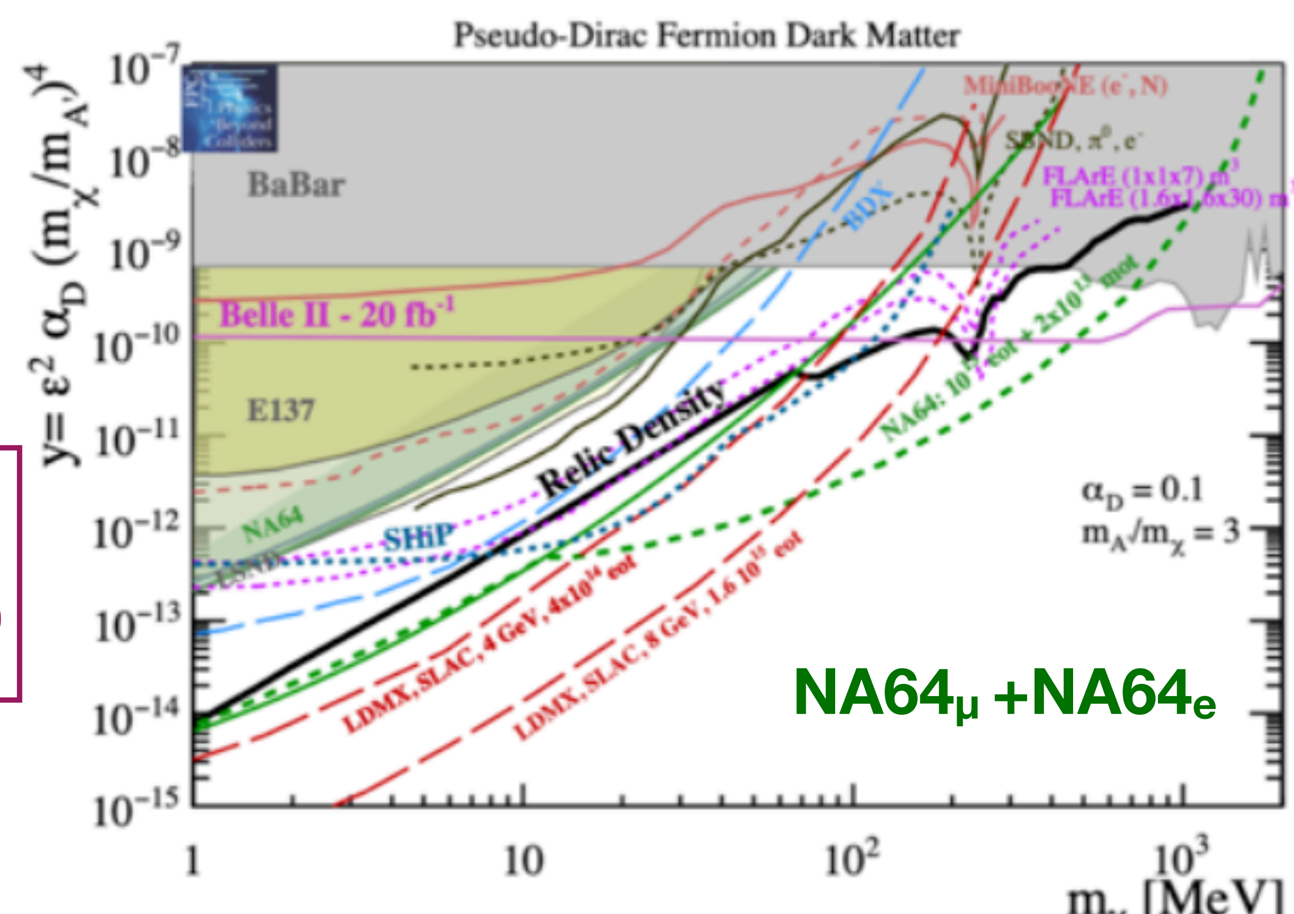
- First result using the NA64e collected data until 2018.
- With a e^+ beam enhancement of a factor 100 in the resonance region.

NA64 collaboration, Phys. Rev. D 104, L091701 (**2021**)

- Use a muon beam: ***NA64μ experiment***

S.Gninenko et al. PLB796, 117 (2019)

D. Banerjee et al. [NA64 Collaboration]. CERN-SPSC-2019-002 / SPSC-P-359, January 14, 2019.

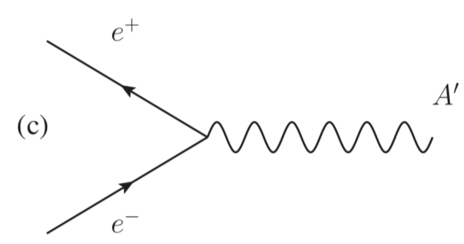


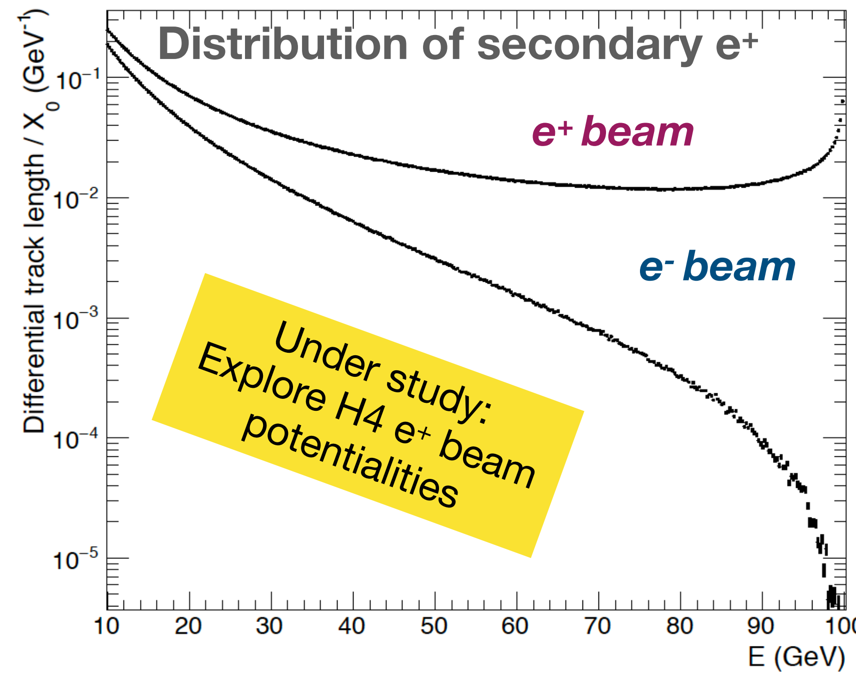
P. Schuster, *"New benchmarks: Light (MeV-GeV) Dark Matter"*, CERN Physics Beyond Collider Workshop, December 3, 2021

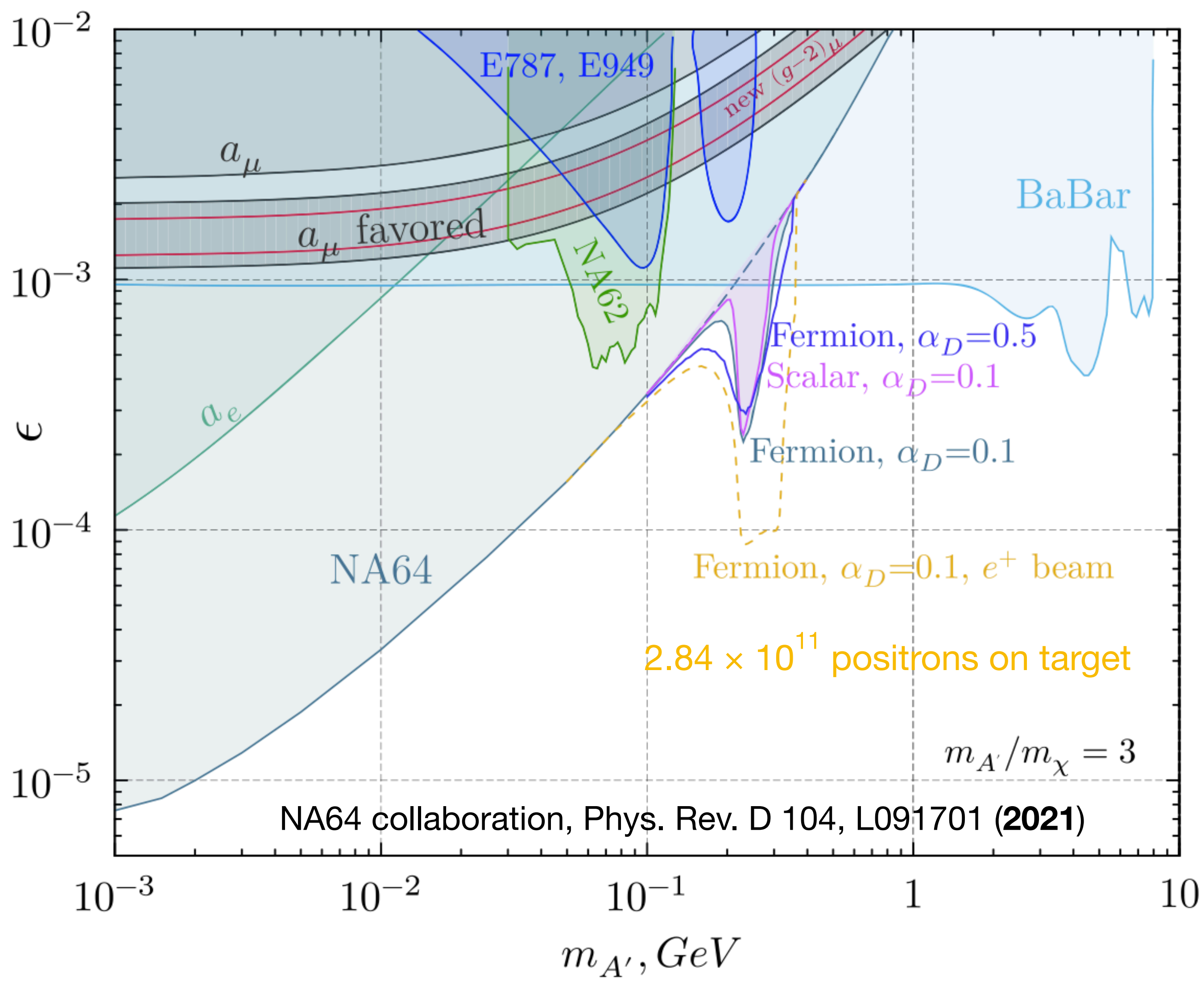
Future prospects: A’ resonance with e^+

Resonance annihilation *channel* ***using a 100 GeV positron beam.***

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





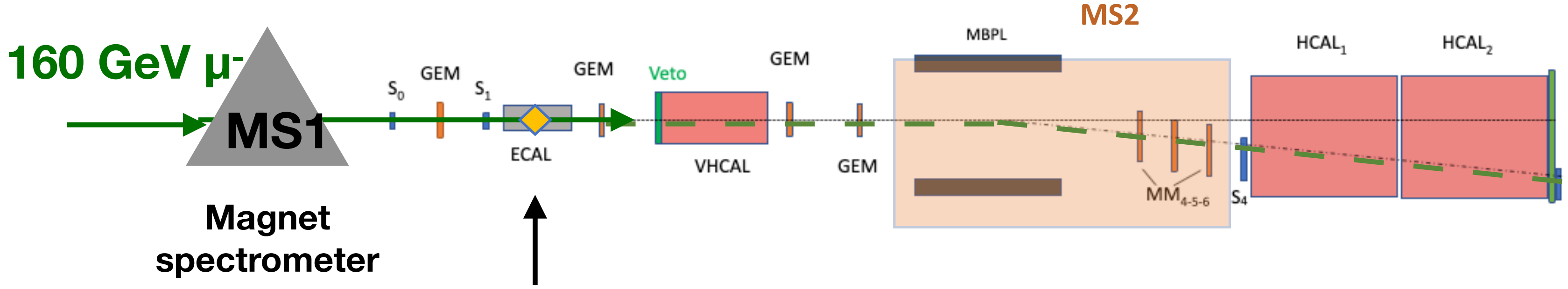


- ***Hadron contamination in H4 in e^+ mode is a crucial aspect***: the hadron fraction is expected to increase significantly mainly due to protons from the decay of $\Lambda \to p\pi^-$.
- A first set of measurements at a low beam intensity, **0.2×10^6 e^+/spill,** was performed in 2021 obtaining an **hadron fraction ~5.6 %.**
- In ***Summer 2022 is foreseen the first e^+ mode run:***
    - Dedicated study about the **hadron contamination for different beam intensities.**
    - ~10 days to accumulate **~2×10^{10} e^+ on target.**

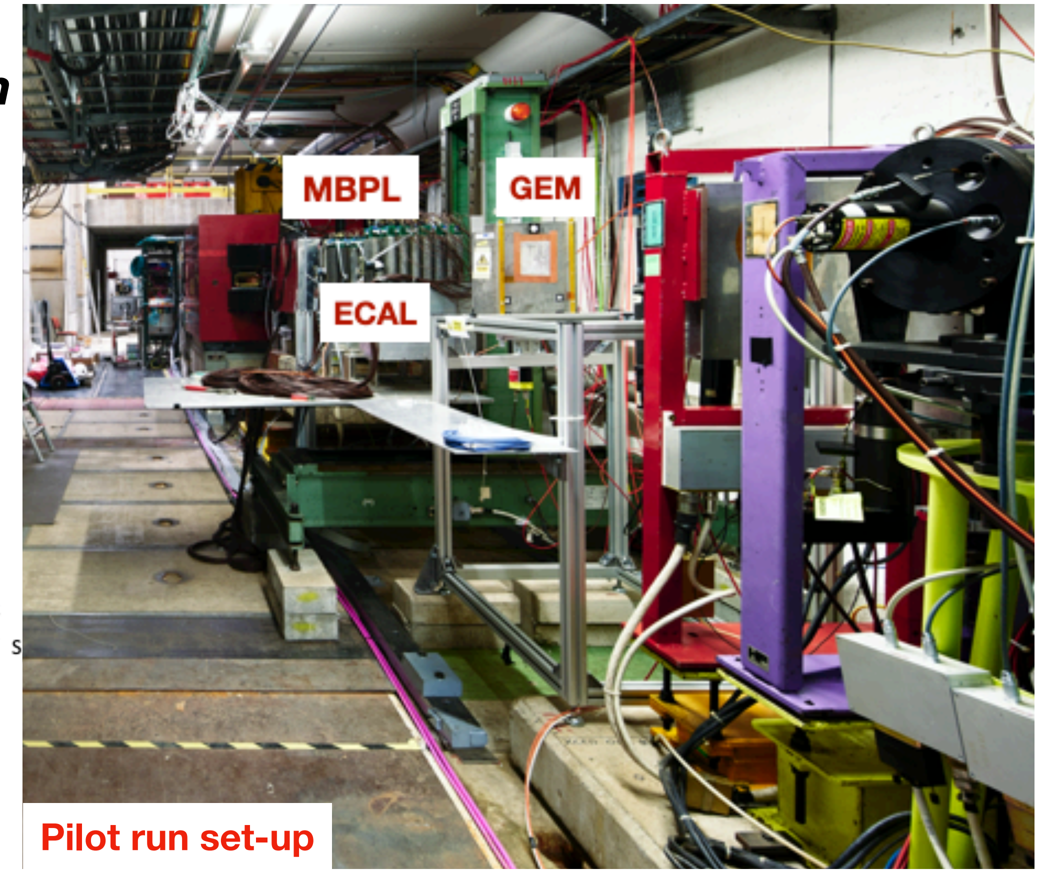
Future prospects: NA64$_\mu$ experiment

Exploring Dark sector physics weakly coupled to muons ***using the unique CERN SPS M2 high energy*** *and* ***high intensity muon beam***

2018	2021	2022	2023	2024	2025	LS3	Phase 2
Proposal to run NA64 in muon mode	1st pilot run 19 days in October	Pilot run 3 weeks end of April		*Phase 1* Muon g-2 anomaly			LDM,…



$$\mu + Z \rightarrow \mu + Z + Z_\mu, \; Z_\mu \rightarrow \nu\bar{\nu}$$



Pilot run setup in 2021 and 2022

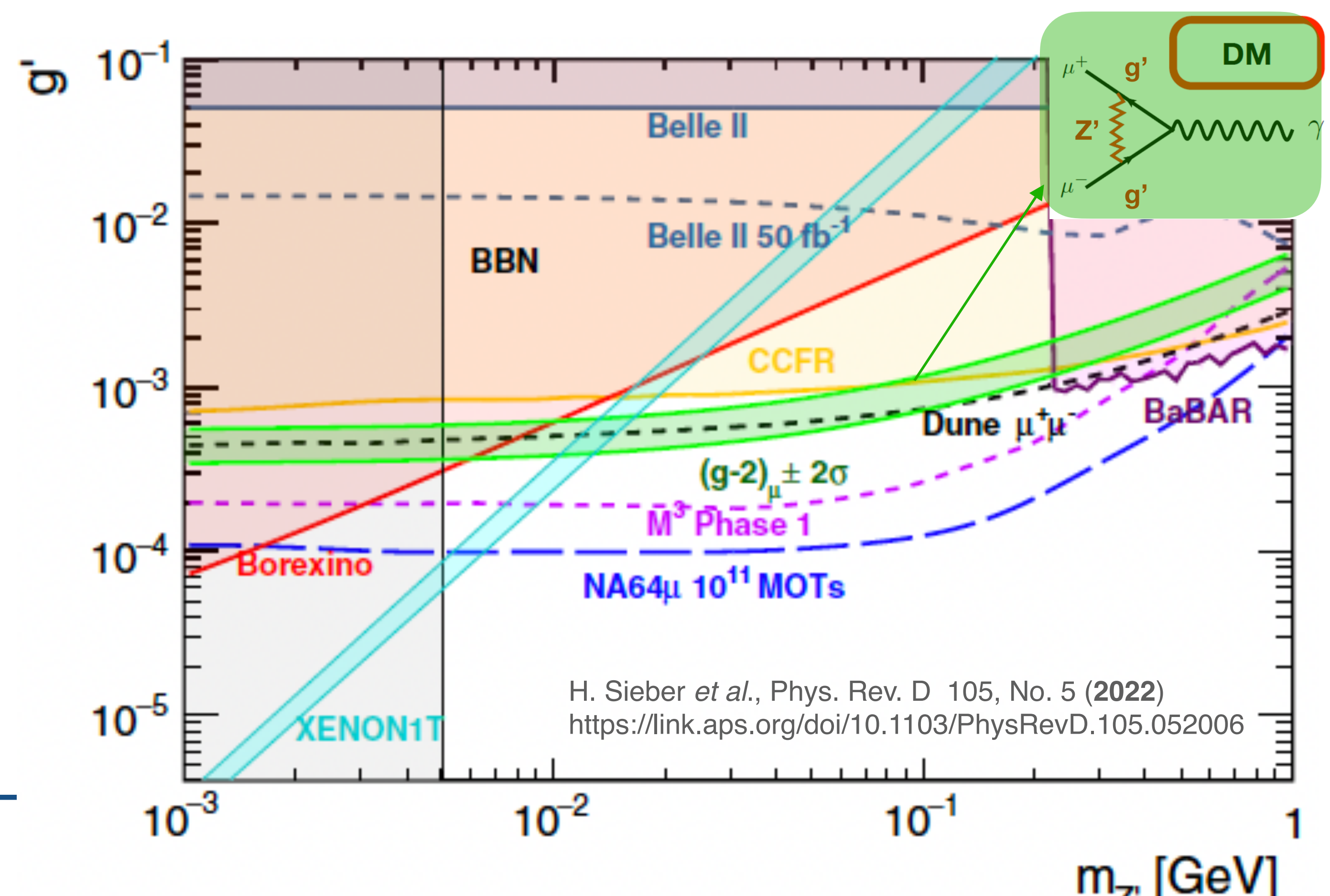
GOAL → study the feasibility of the technique to search for Z' generated in L_μ-L_τ models as remaining explanation of $(g-2)_\mu$ during Phase 1

Signature

1)Initial muon momenta at 160 GeV (MS1)

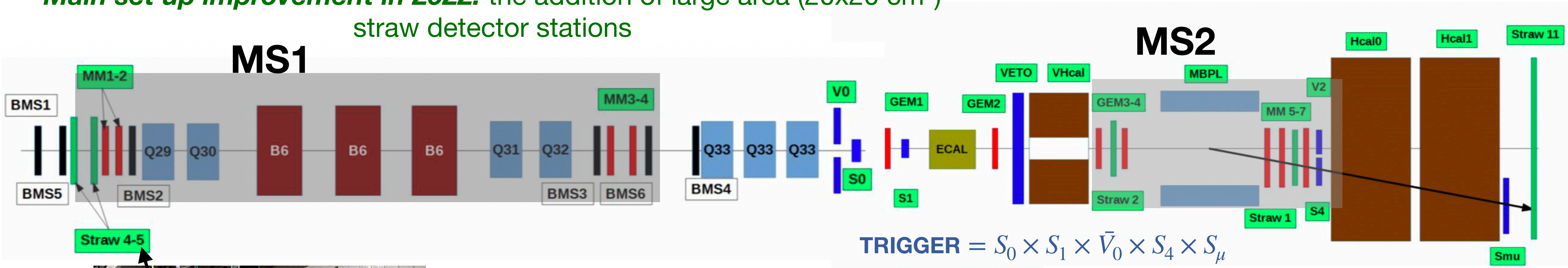
2)Scattered muon momenta at 80 GeV (MS2)

3)No energy in all calorimeters, ECAL, HCAL and VHCAL (energy deposit compatible with a MIP)



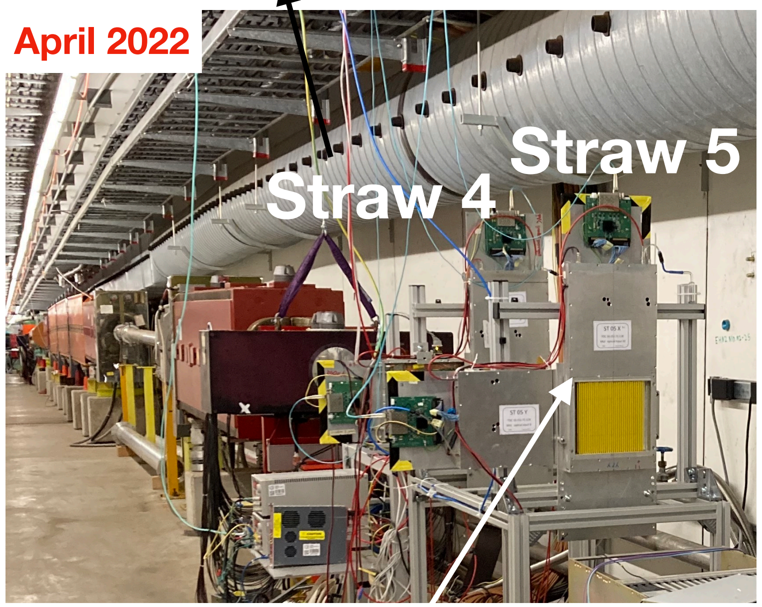
NA64$_\mu$ pilot run set up

Main set up improvement in 2022: the addition of large area (20x20 cm^2) straw detector stations

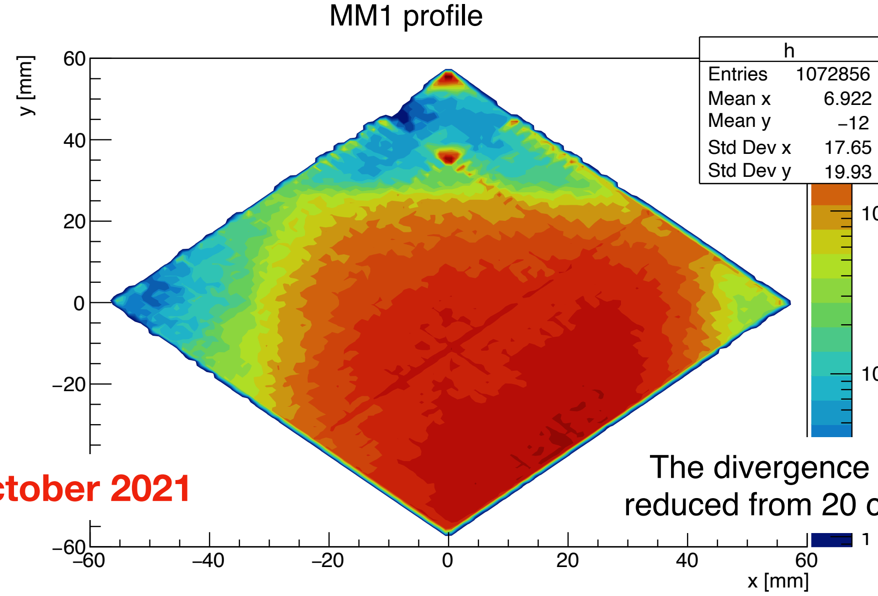


TRIGGER $= S_0 \times S_1 \times \bar{V}_0 \times S_4 \times S_\mu$

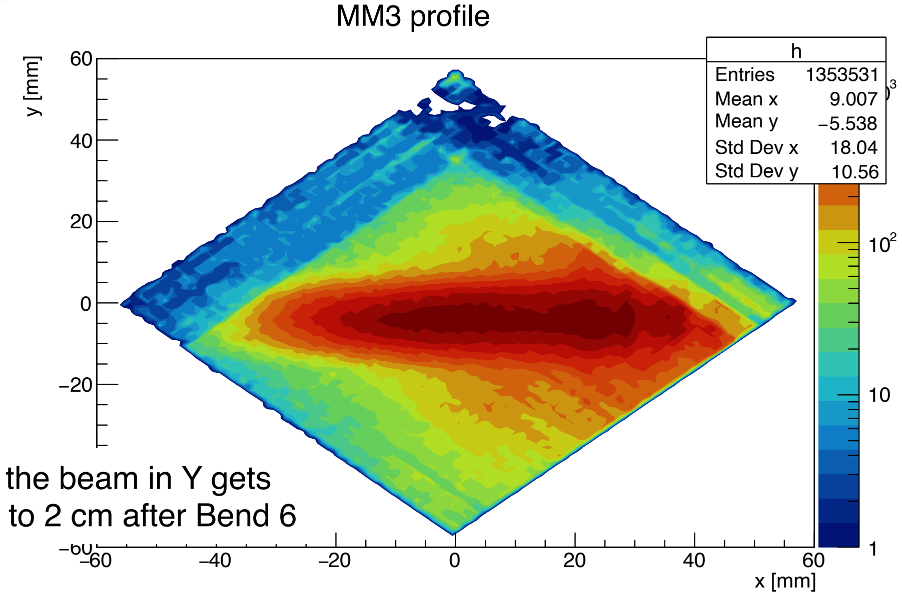
April 2022



MM1 profile



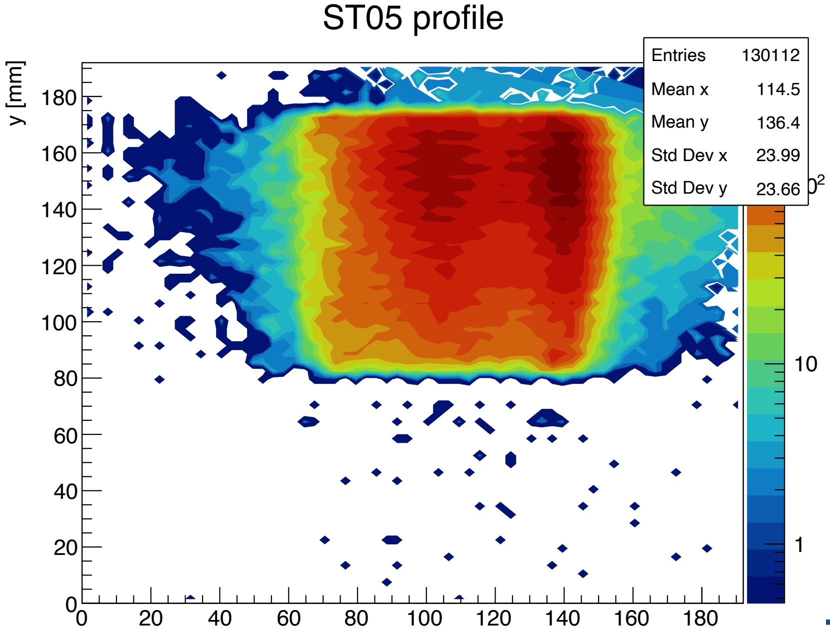
MM3 profile

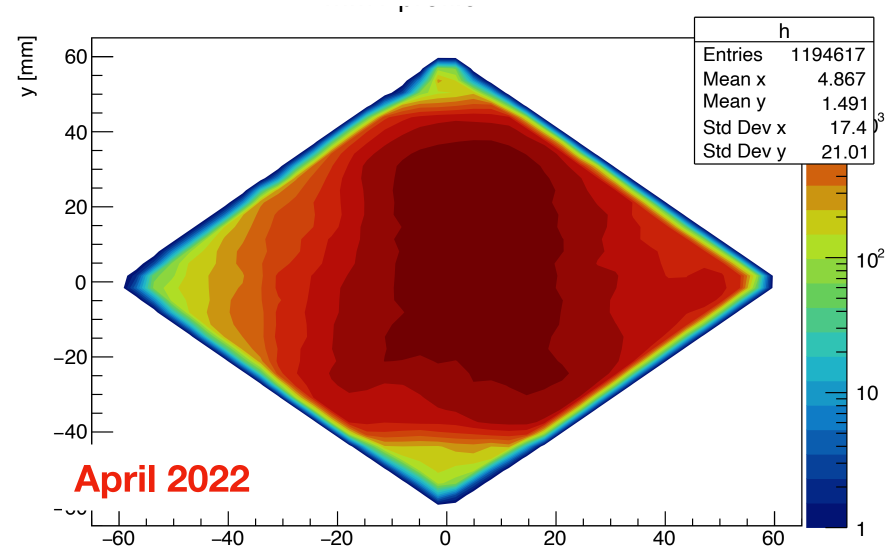


October 2021

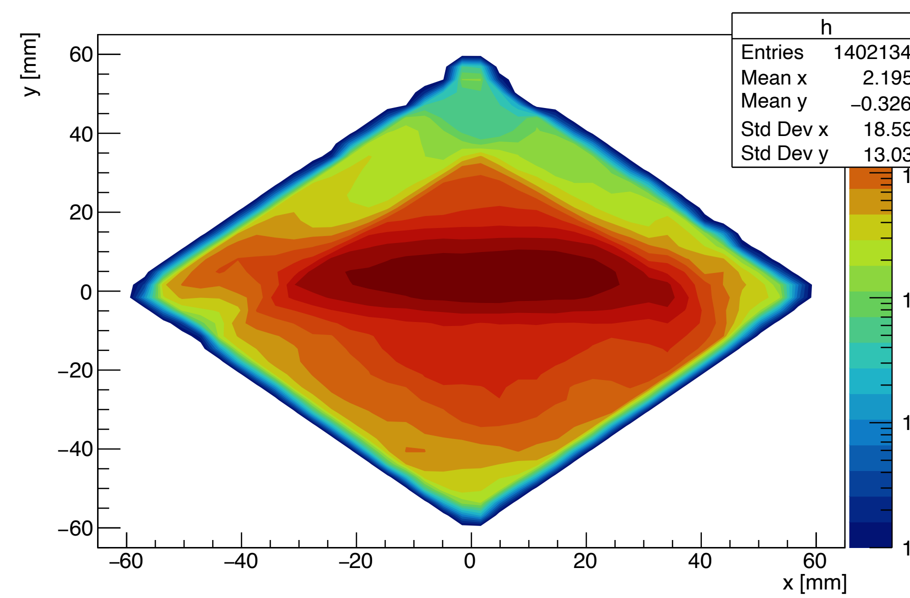
The divergence of the beam in Y gets reduced from 20 cm to 2 cm after Bend 6

ST05 profile





April 2022



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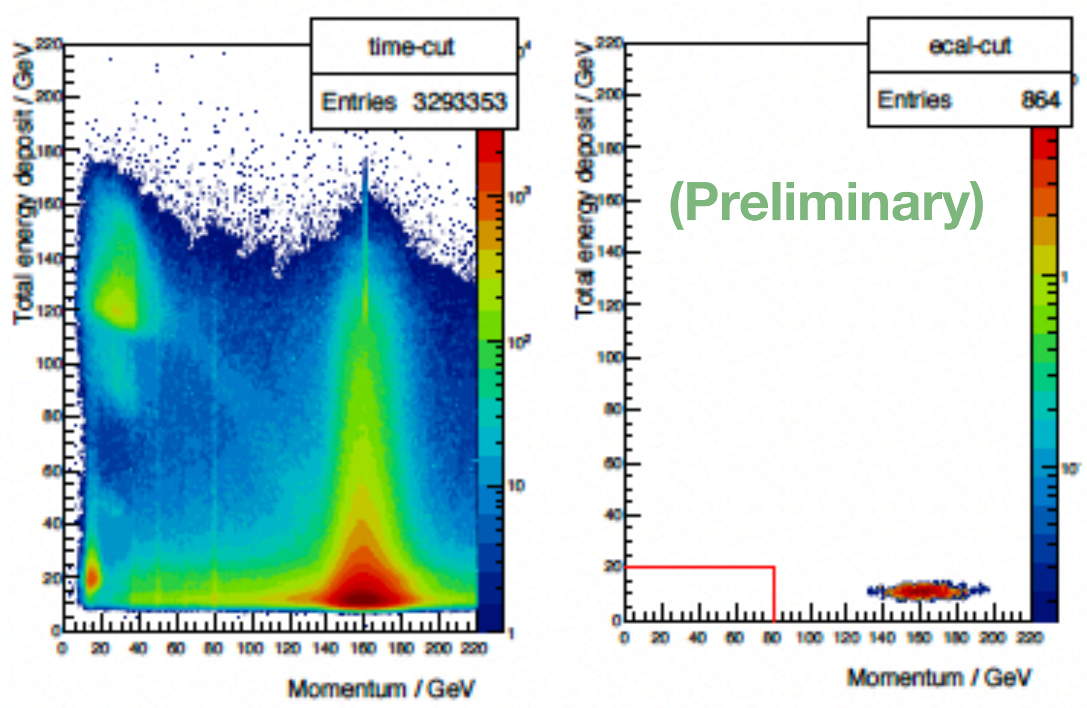
NA64$_\mu$ pilot run: first results

*Cut-flow analysis for the **~5 x 10⁹ MOT** collected in 2021*



Event Selection Criteria:

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II) Single-hit per tracker

III) Reconstructed momenta in MS1 [135, 185 GeV].

IV) Quality cut on downstream momenta in MS2 based on χ^2.

V) Energy compatible with MIP energy in calorimeters and veto

Data analysis: work in progress

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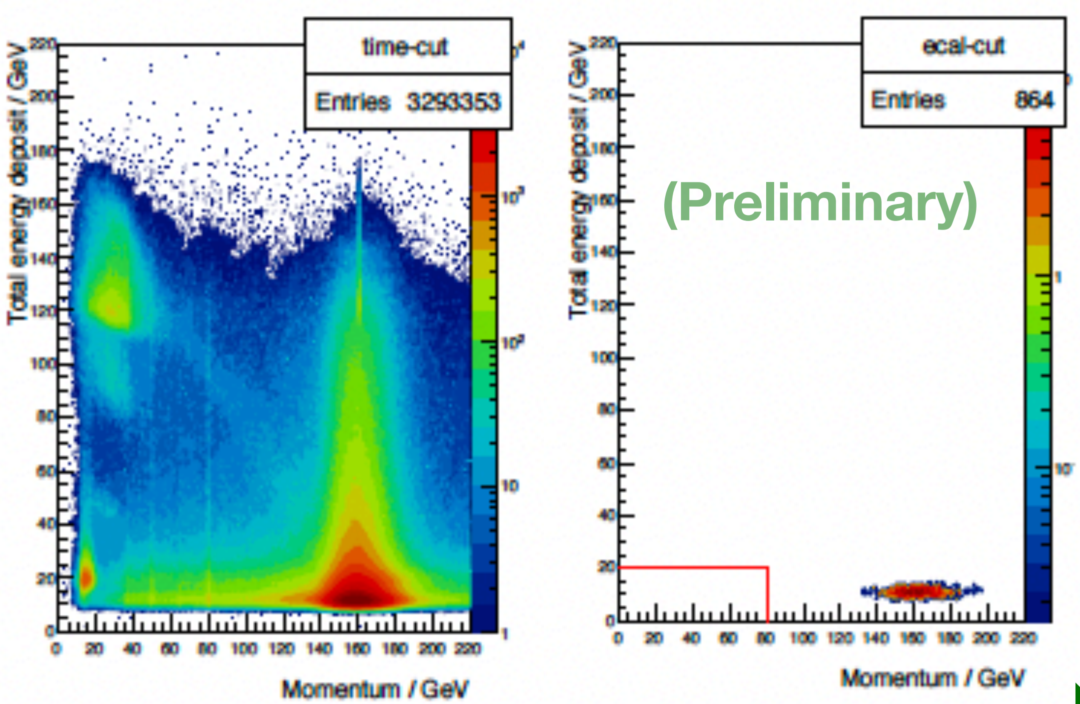

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GOAL in 2022

to collect 5x10^{10} MOT and validate the technique.

➡ Due to the ***improvement in alignment***:

- ✦ A **factor two higher intensities** than in 2021 pilot run obtained, reaching intensities of 2.8x10^6 μ/spill. This has allowed to record about **80% of our planned statistics in just 8 days, 4x10^{10}MOT** (mainly in two trigger configurations).
- ✦ **All trackers had an average efficiency** (at least 1 cluster) **90%**. In 2021, the trackers located upstream MM1-2 had an average efficiency of 35%.

➡ **Improvement in the set up survey measurements:** including the beam-line slope and measuring also all magnets and quadrupoles present in the line. These measurements will impact significantly our alignment helping to improve the tracking algorithm.

➡ **Trigger rates:** Trigger = $S_0 \times S_1 \times \bar{V}_0 \times S_4 \times S_\mu$ with respect to $S_0 \times S_1 \times \bar{V}_0$ coincidences were: 0.07% (S_4 at -65 mm and S_μ at -152 mm), and **0.2% (S_4 at -40 mm and S_μ at-82 mm).** The simulated trigger rates are in reasonable agreement with these measurements.

Data analysis: work in progress

Summary and outlook

Prospects for 2022

NA64e⁻

- New area at H4 and setup upgrade will be completed.
- **Collect ~10^{12} EOT** being background-free probing:
  - The **LDM models** suggested parameter space **for the first time**.
  - The uncovered area for classical axion models and ALPs.
  - New hidden interactions in the neutrino sector, e.g B-L Z'.
  - **Muon g-2 anomaly** with A' semi-visible and L_μ-L_τ Z'.

NA64μ

- **Searches for dark sectors weakly coupled to muons** at M2 beam-line **started**:
  - *$(g-2)_\mu$ and L_μ-L_τ Z'*: **pilot run in 2021** and **2022,** 4x10^{10} MOT collected.
  - Preliminary encouraging results about beam quality, trigger rate and hermeticity.

NA64e⁺

- **Start the positron program this Summer:**
  - Hadron contamination level in e^+ beam @H4
  - Collect ~2x10^{10} positrons on target

NA64 is an ideal experiment to decisively discover or disprove very interesting predictive thermal LDM models and greatly explore DS in the coming years.

The exploitation of the NA64 physics potential has just begun!

THANKS!

Acknowledgements

NA64 collaboration in particular **P.Crivelli** and **S.Gninenko**
ETH Zürich group in particular P. Crivelli, B.Banto, E. Depero, M. Mongillo, H.Sieber and M. Tuzi (PhD student at IFIC)
CERN BE-EA group *in particular* D. Banerjee

Swiss National Science Foundation

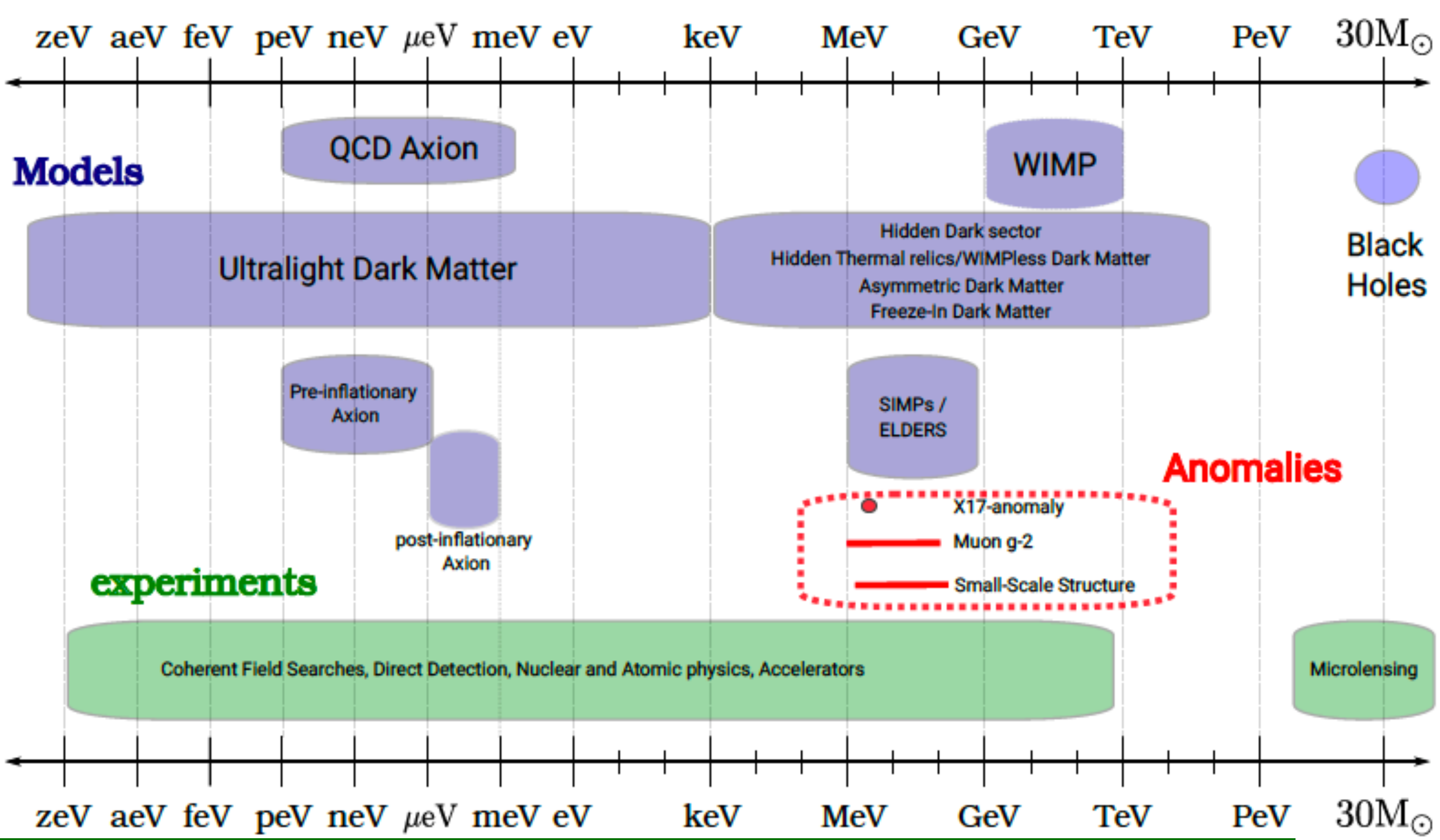
SNSF Ambizione grant: PZ00P2_186158

Dark sectors *in a nutshell*

An interesting framework to explain the origin of Dark Matter (DM)

- In addition to gravity, **a new force** between the DS and the visible matter might exist.
- This new **very weak interaction** might be transmitted by mediators whose masses are below the GeV, and interact with the SM through the so called ***portals***.
- The mediators can then decay into Dark Matter particles.

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



$$L_{Total} = L_{SM} + L_{DS} + L_{Portal}$$

- Vector: ***Dark Photon***
- Scalar: ***Dark Higgs***
- Fermion: ***Heavy neutral lepton***
- Pseudo-scalar: ***Axion***

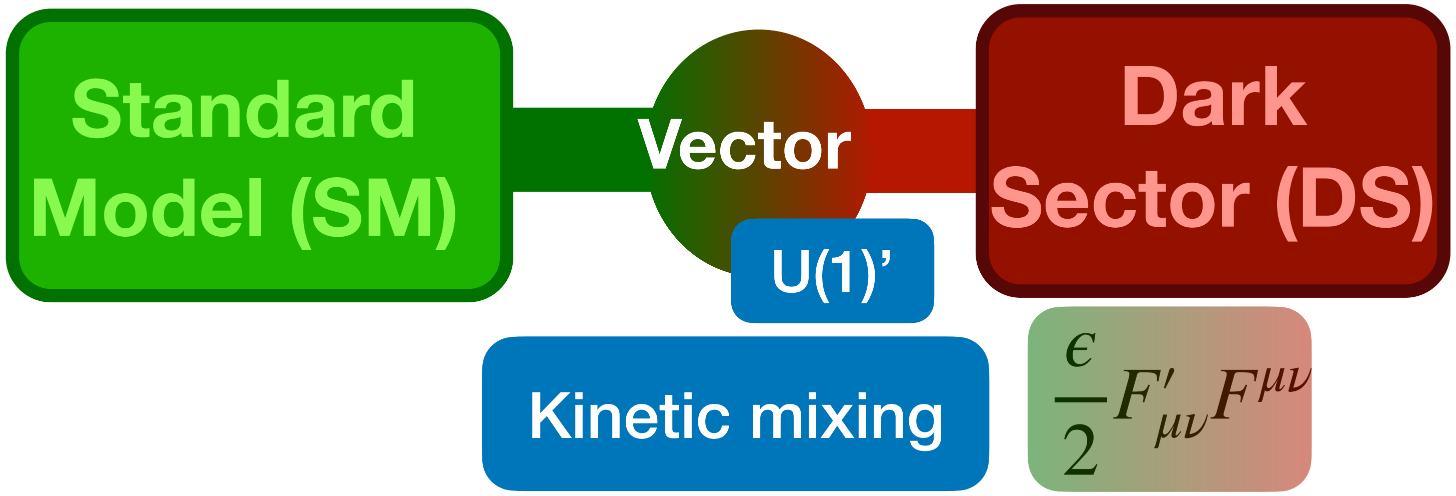
The Search for Feebly Interacting Particles, Gaia Lanfranchi, Maxim Pospelov, Philip Schuster Annual Review of Nuclear and Particle Science 2021 71:1, 279-313

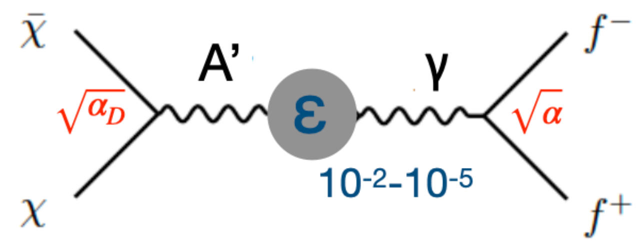
J. Jaeckel et al. Nature Phys. 16 (2020) 393-401

Complementary searches involving different techniques

NA64 target: *Dark sectors*

The existence of DS→ An interesting framework to explain the origin of Dark Matter (DM)

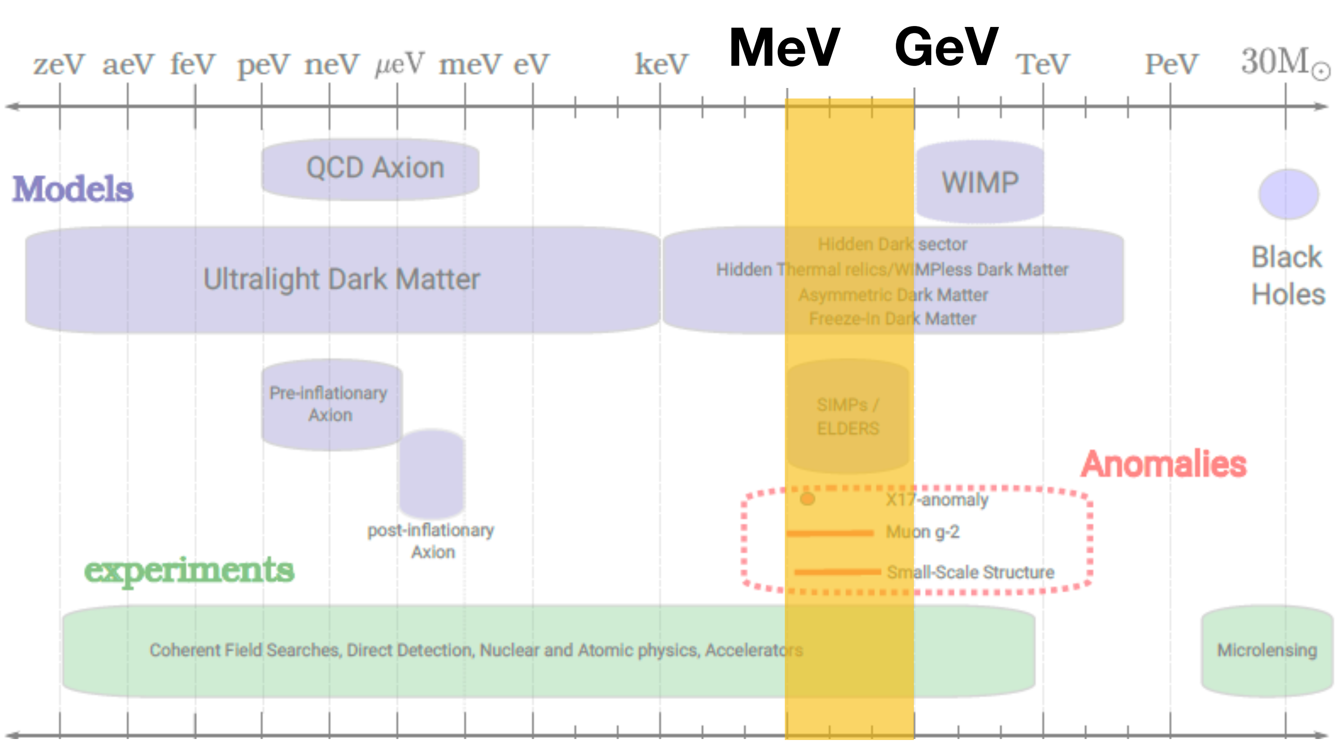




Parameter space defined by ***($m_{A'}$,m_χ,ε,α_D)***

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

Goal for NA64 2022-2025 runs!



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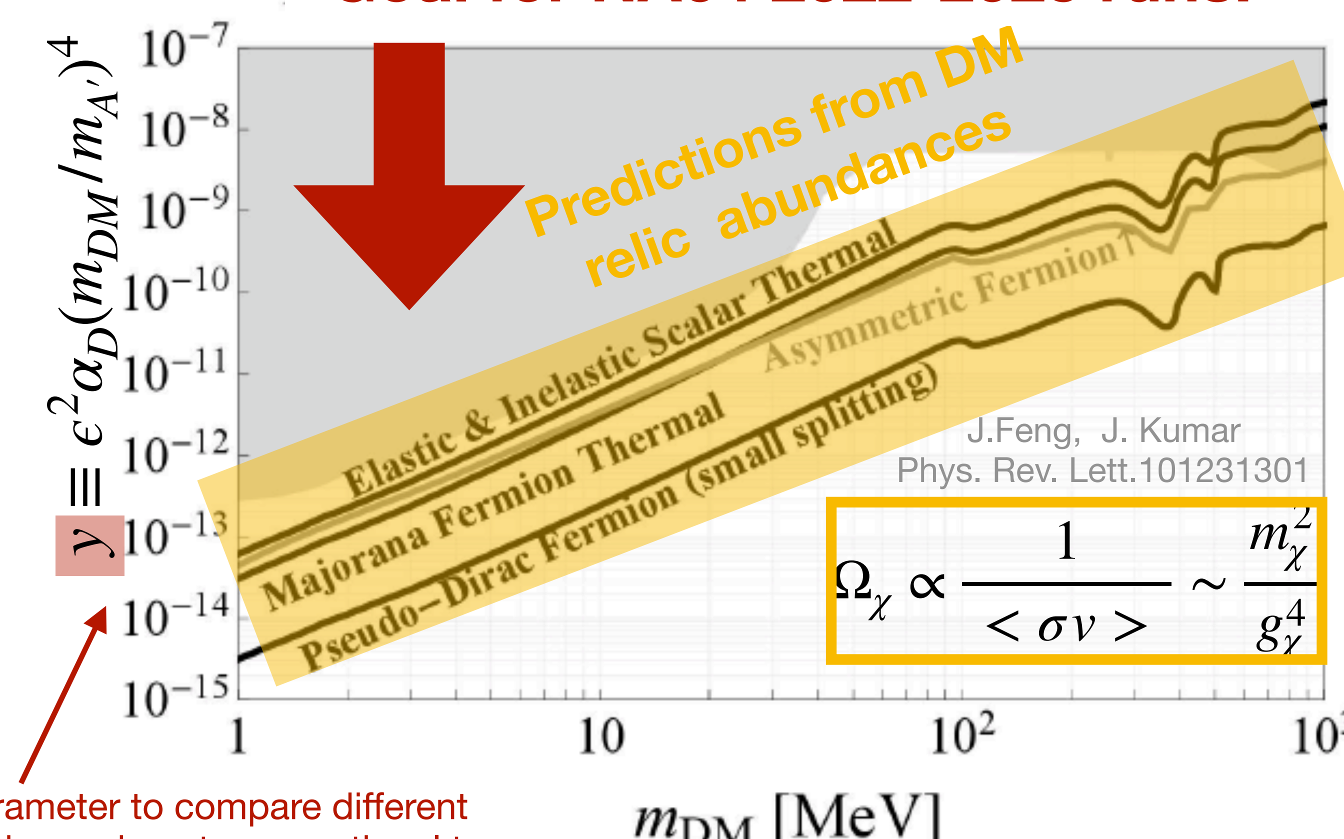


Useful parameter to compare different models and experiments proportional to the DM-SM annihilation cross-section

Light Dark Matter experiment arXiv:1808.05219v1

NA64 technique *for A' decays and its signatures*

Fixed target experiment at the CERN SPS designed to probe Dark sector physics

Initial beam → **Active Dump A'**

Bremsstrahlung of A'

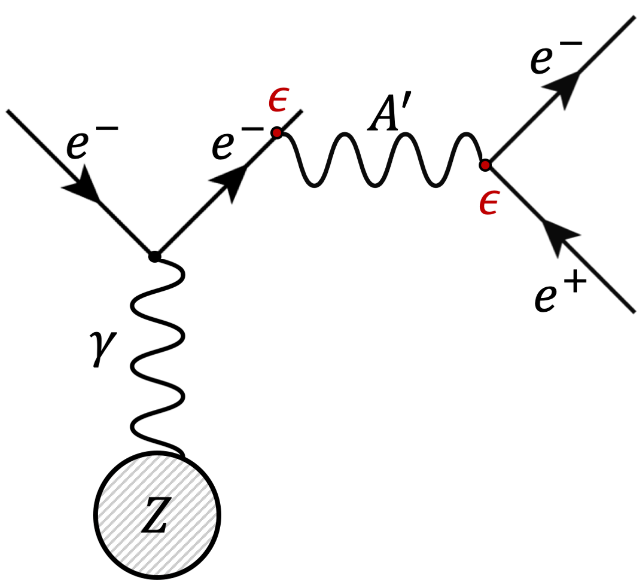
S. Andreas et al., arXiv:1312.3309 (2013)
S. N. Gninenko, Phys. Rev. D 89, 075008 (2014)

Resonant A' production

L. Marsicano et al. Phys. Rev. Lett. 121, 041802

Visible decay

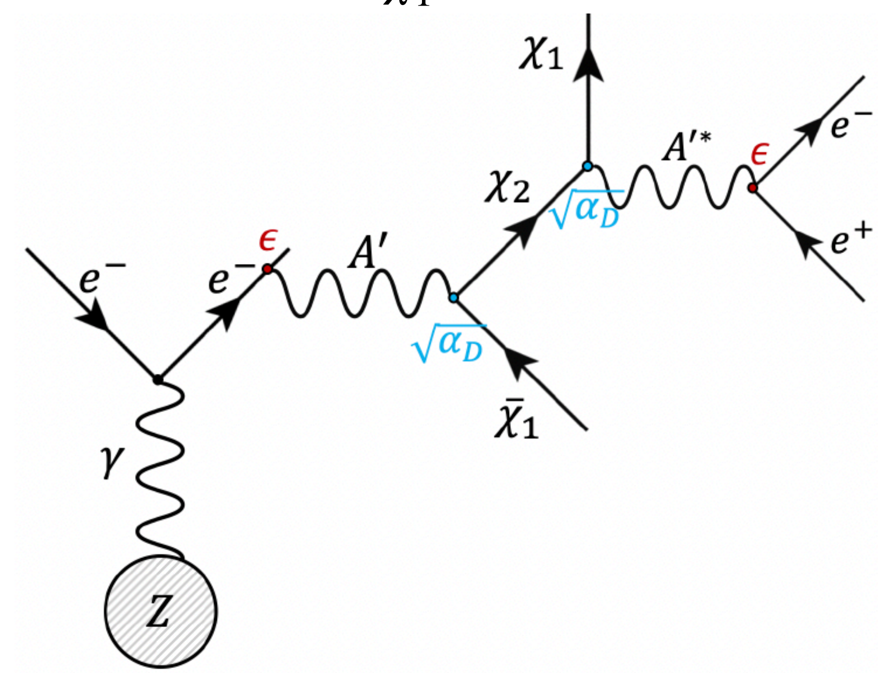
$$m_{A'} < 2m_\chi$$



SM particles
pair production

Semi-visible decay

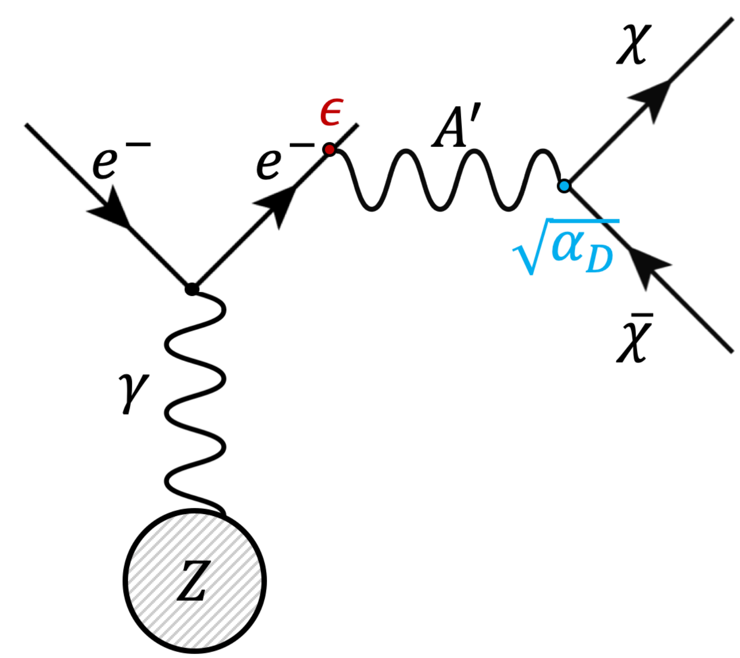
$$m_{A'} >> m_{\chi_1} >> m_e$$



SM particles
pair production + Missing energy

Invisible decay

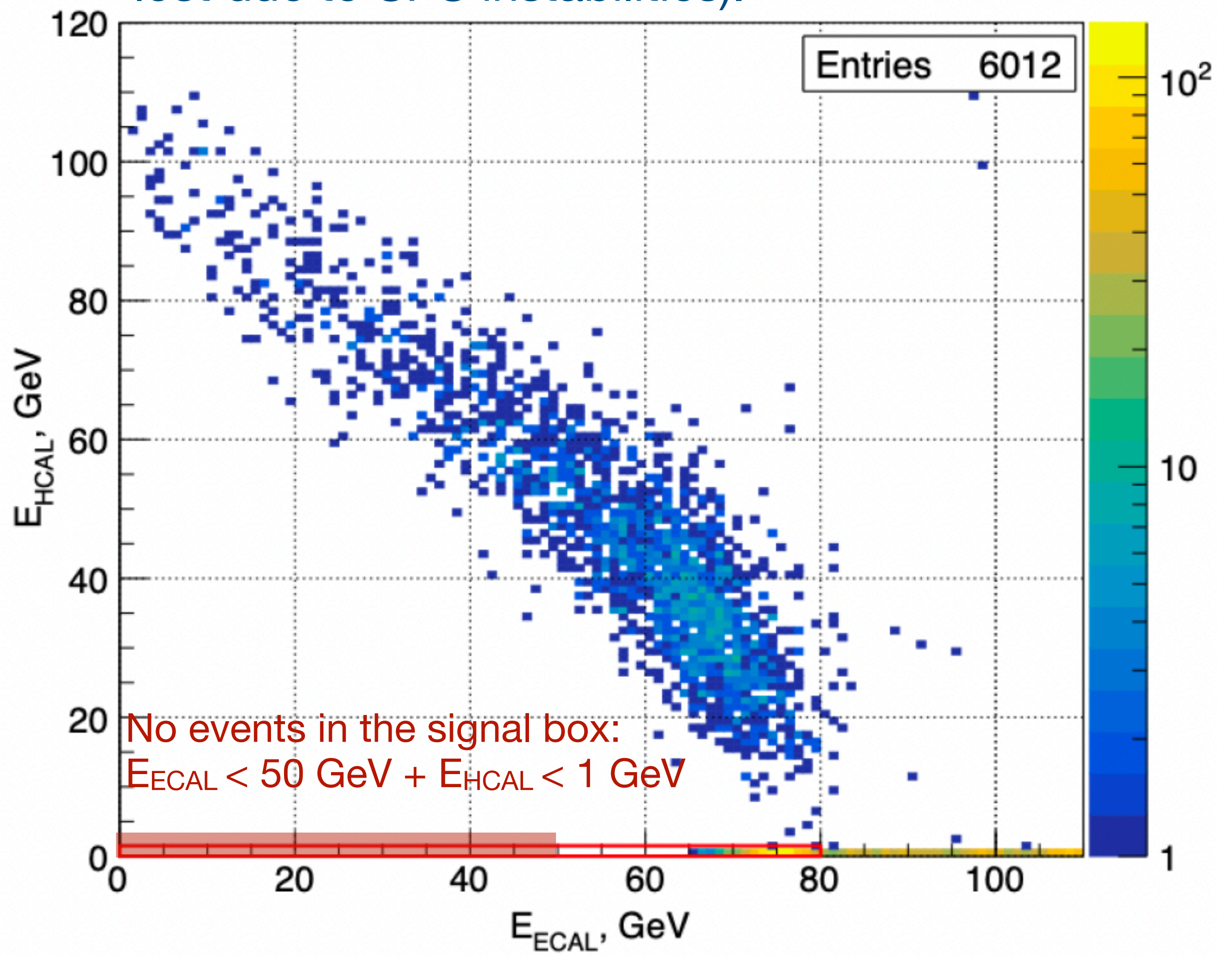
$$m_{A'} > 2m_\chi$$

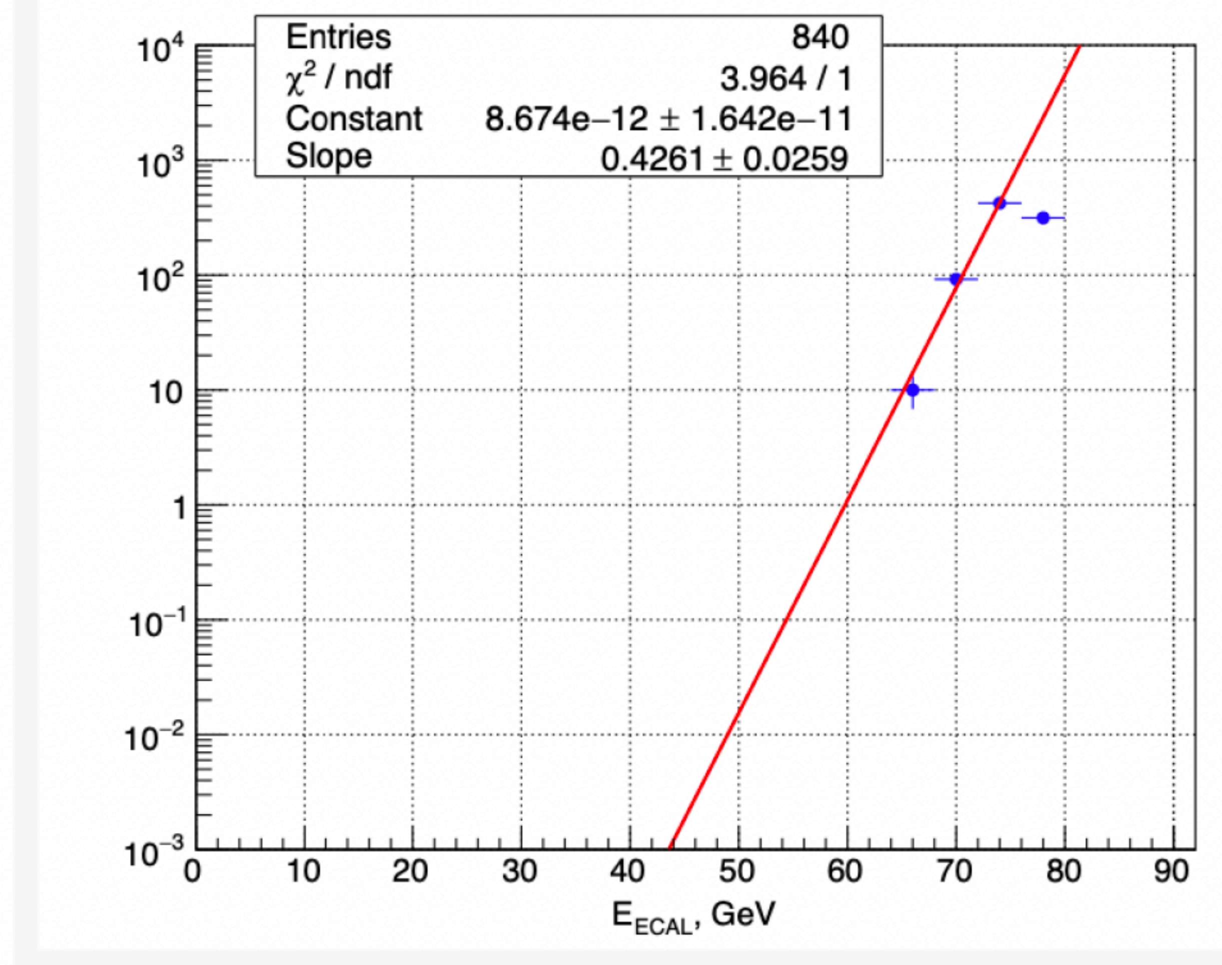


Missing energy
(Focus of this talk)

NA64 *invisible* mode: *first results from 2021 run*

- 4 weeks of beam time from 11th August to 8th September: 2 weeks were dedicated to installation, commissioning and calibration of the detectors after the 2 years stop.
- One week of data taking at an average intensity of 5×10^6 e^-/spill collecting ~6×10^{10} EOT (one week lost due to SPS instabilities).





Event Selection Criteria:

- ✦ *Timing information* → Pile up and noise suppression.
- ✦ *Clean incoming track:* angle + single hit in all trackers, momentum~100 GeV
- ✦ *Electron identification:* Synchrotron radiation + Shower profile compatible with e^- in ECAL → Hadron suppression
- ✦ *No punchthrough:* No activity in Veto and in HCAL

BKG events from neutral secondaries estimated from data: 0.031±0.015

➡ It confirms that we understand our main source of BKG.

➡ Less than 1 BKG event for 10^{12} EOT (without 2022 upgrades, see later in the presentation).

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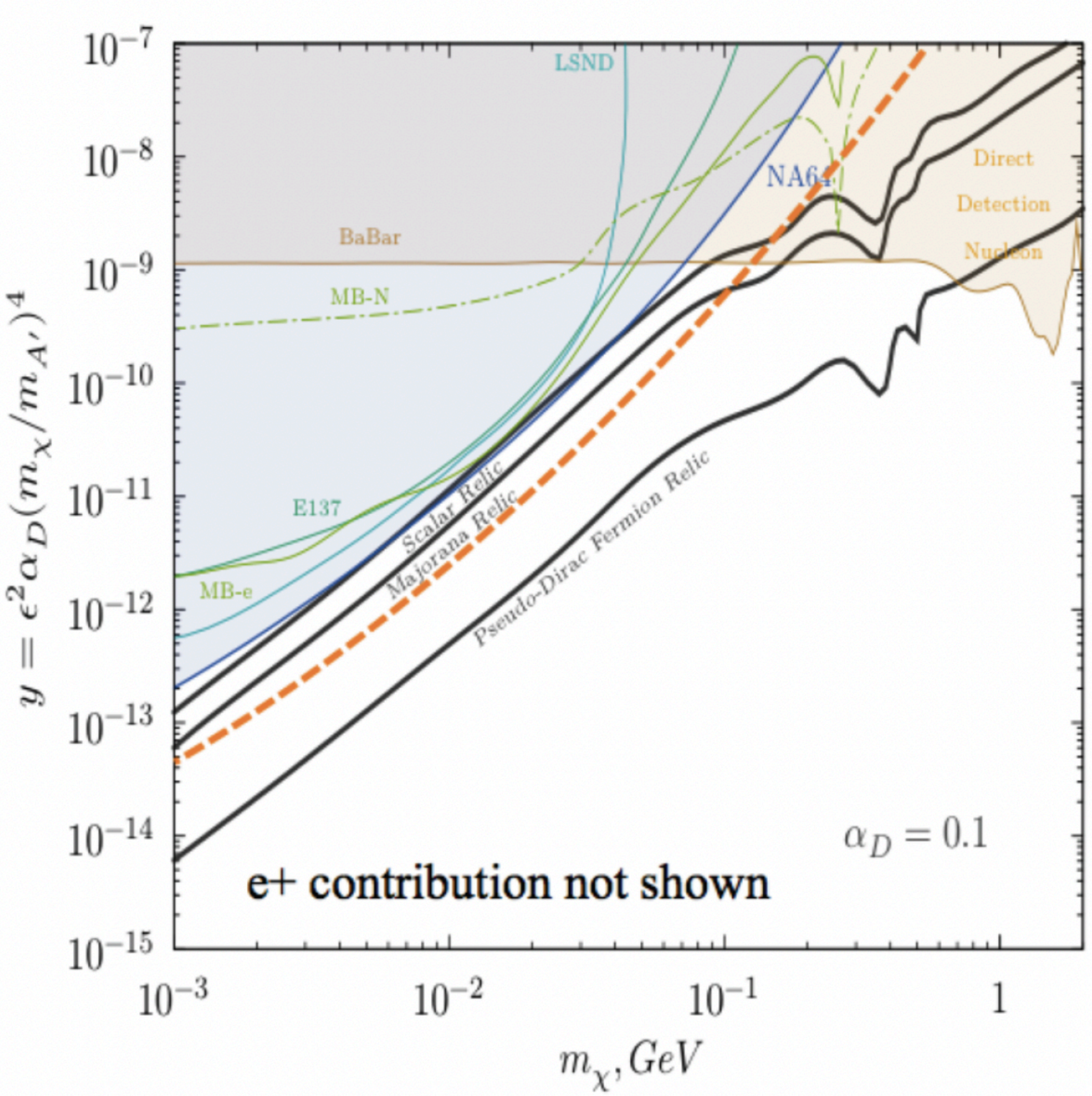
NA64 *invisible* mode: *LDM future prospects*

2014 2015 2016 2017 2018 LS2 2021 **2022**

2022: accumulate ~10^{12} EOT and **probe for the first time the region of benchmark LDM models**

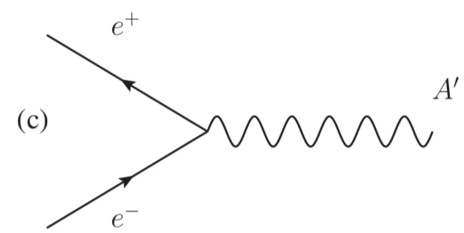


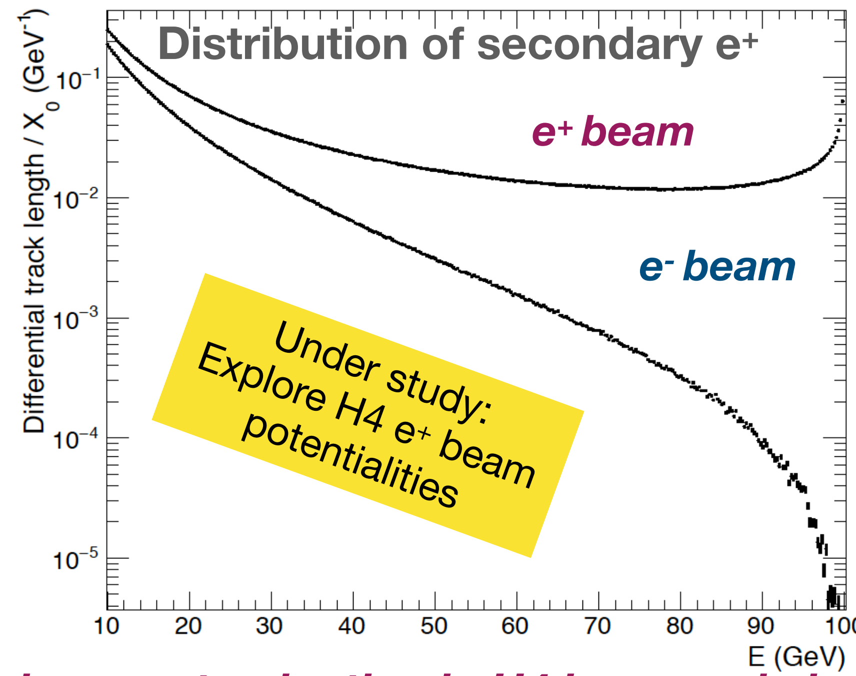
- Complete the setup and electronics upgrades:
  - ***Improve performance*** (increase intensity up to 10^7 e^-/spill): The current 80 MHz MSADC boards would be replaced with faster digitisers. Under study is the possibility to adapt a 250MHz waveboard digitiser developed by INFN, F. Ameli *et al.* NIM A 936, 286 (2019) (to be tested during 2022 run and completed by 2023).
  - Further **Reduce background** from electro-nuclear interactions accompanied by large p_t secondary neutrals (n, K^0_L, ...).
- **7 weeks in Summer 2022** running **at an average intensity of 5x10^6 e^-/spill** to collect **~10^{12} EOT**.

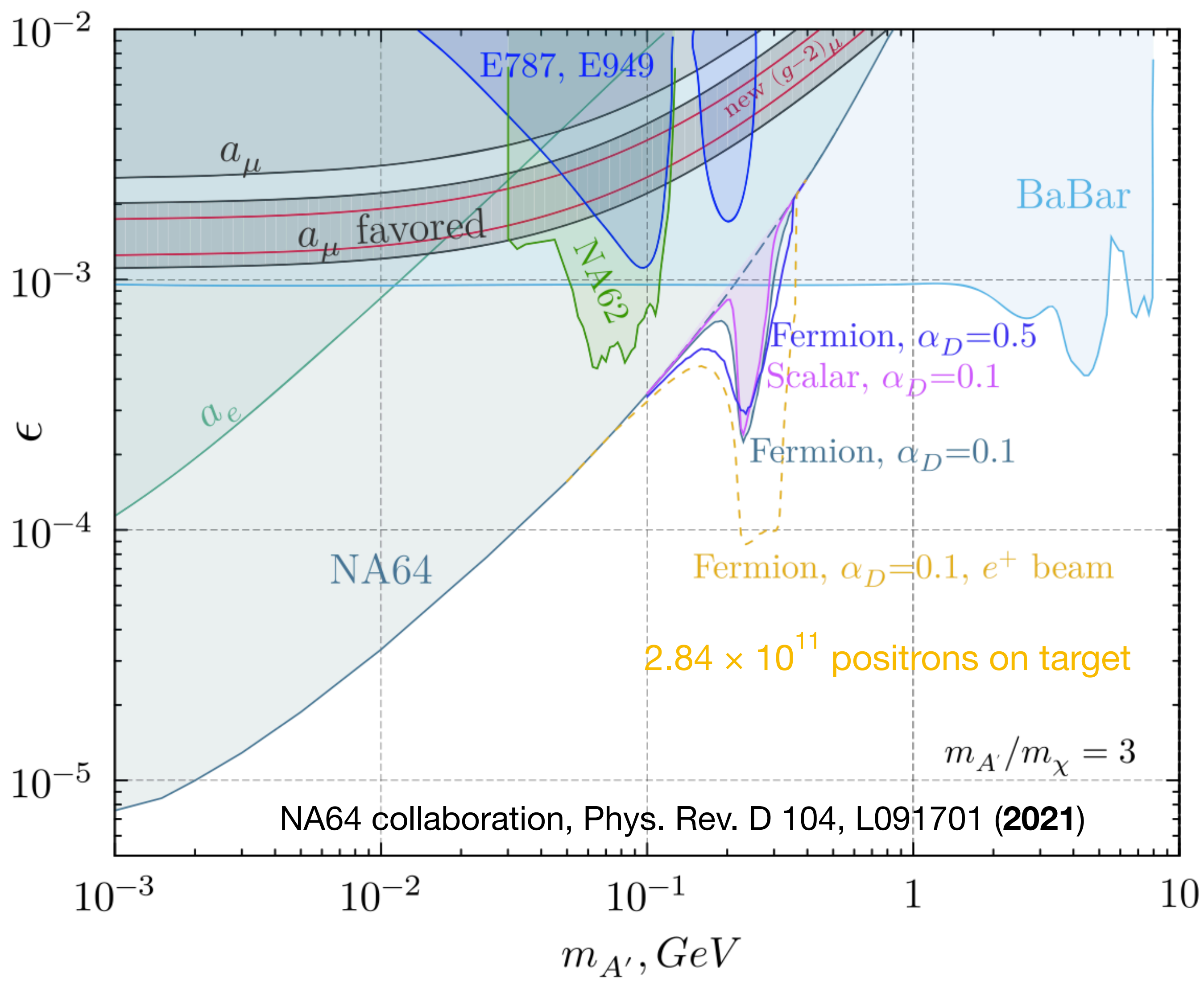
Future prospects: A’ resonance with e+

Resonance annihilation** channel **using a 100 GeV positron beam.

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



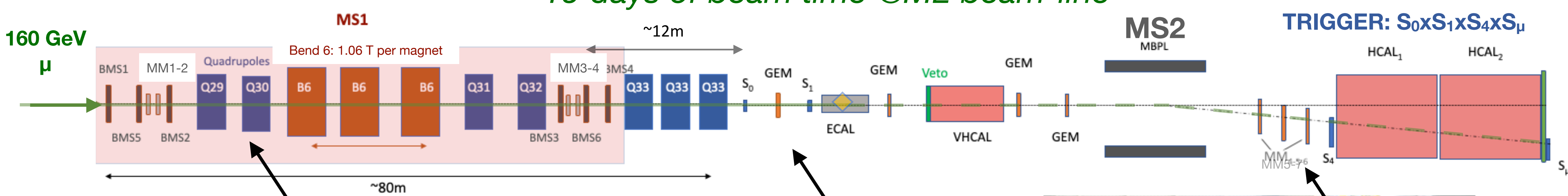


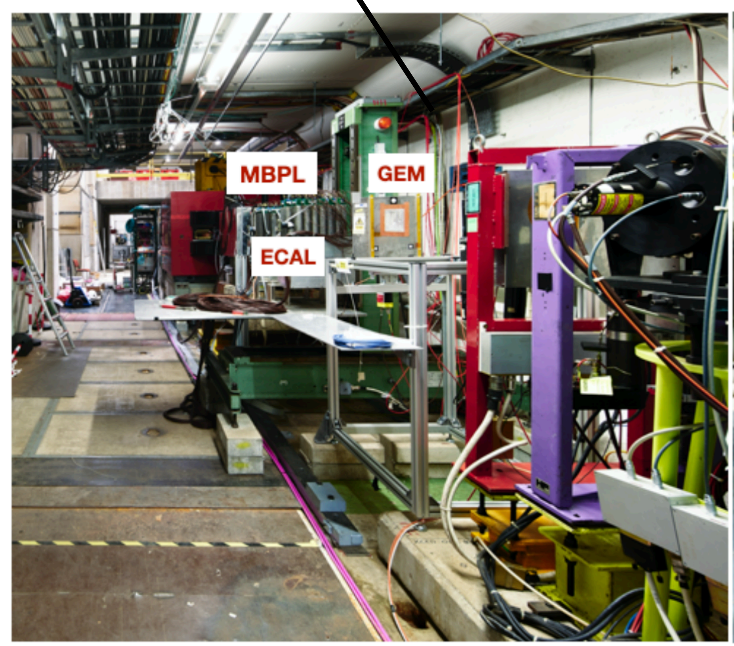


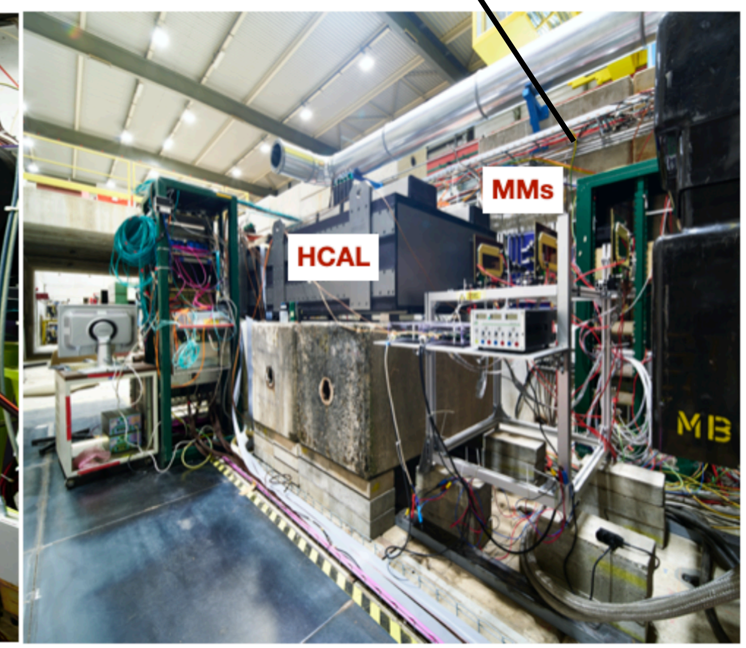
- ***Hadron contamination in H4 in e+ mode is a crucial aspect***: the hadron fraction is expected to increase significantly mainly due to protons from the decay of Λ→pπ-.
- A first set of measurements at a low beam intensity, **0.2x10⁶ e+/spill,** was performed in 2021 obtaining an **hadron fraction ~5.6 %.**
- In ***Summer 2022 is foreseen the first e+ mode run***.
- The first two days will be devoted to perform a dedicated study about the **hadron contamination for different beam intensities** varying from 0.2x10⁶ e+/spill up to 5x10⁶ e+/spill. These measurements would be recorded in e- and e+ modes.
- Then, 10 days would be allocated for the first physics run. Considering ~3000 spills/day at intensities of ~10⁶ e+/spill and a beam efficiency ~70%, we expect to accumulate **~2x10¹⁰ e+ on target.**

NA64$_\mu$ 2021 pilot run

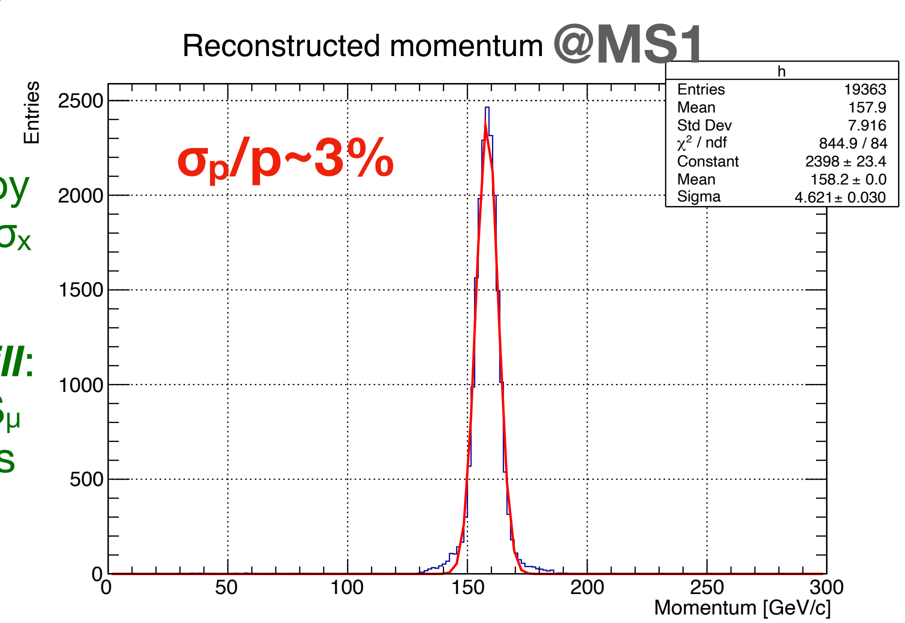
19 days of beam time @M2 beam-line

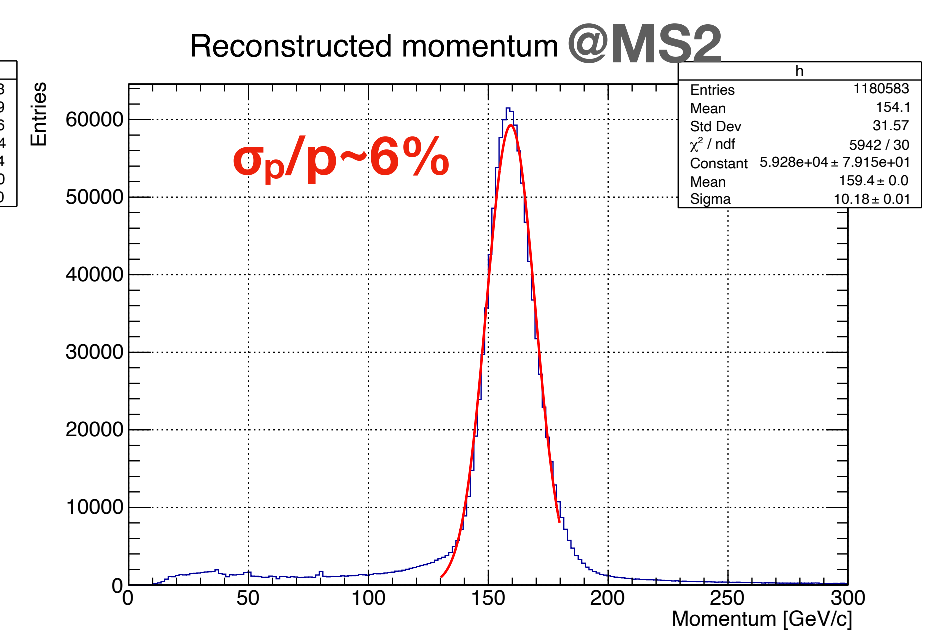






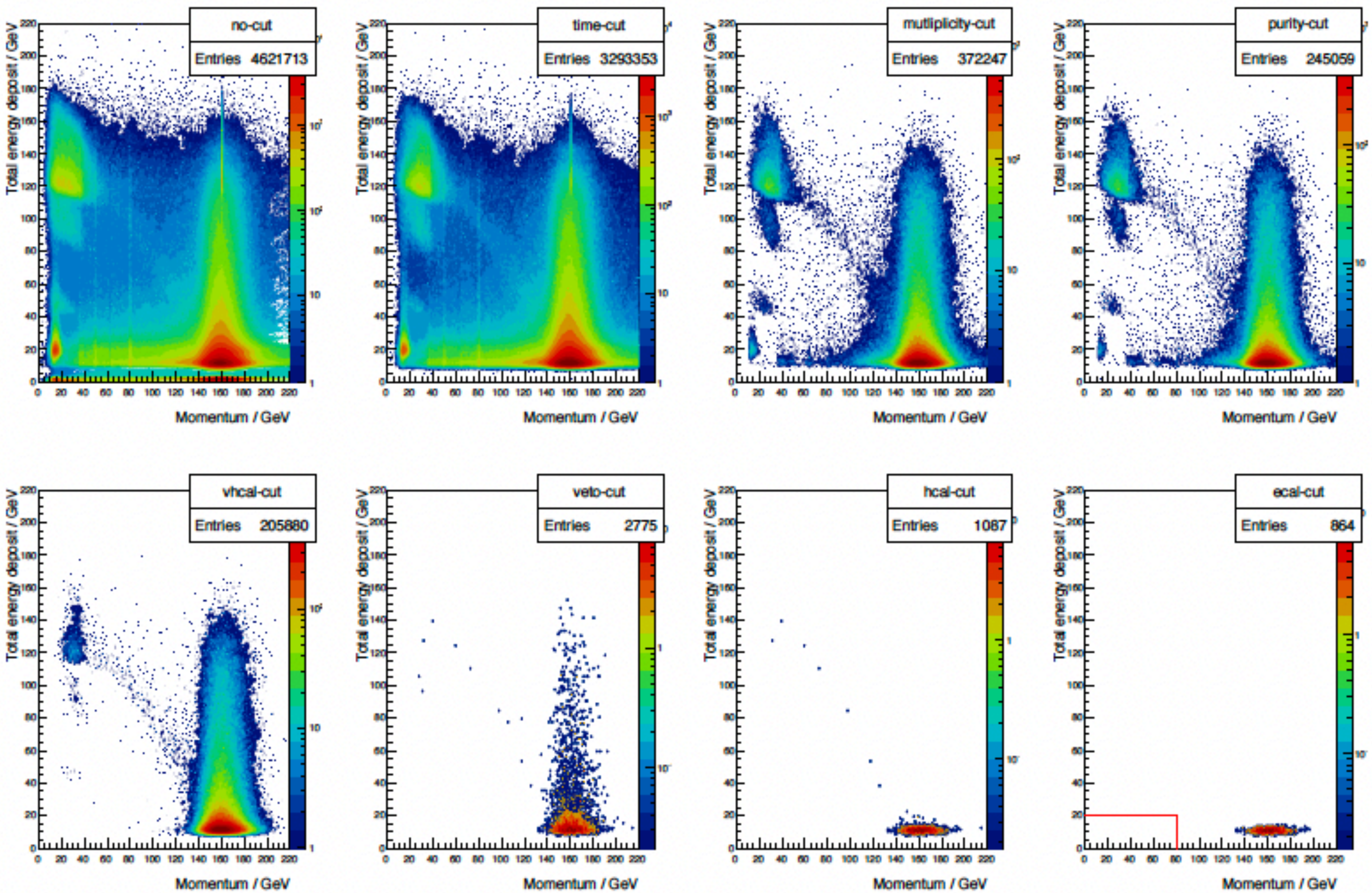
- **The beam profile was measured for the first time**. A narrower beam can be obtained with S_0+S_1 trigger with a divergency compatible with the beam-optics simulation estimations performed by D. Banerjee from the BE-EA department ($\sigma_x \sim$ 0.9 cm and $\sigma_y \sim$ 1.9 cm).
- ***Trigger rate reduced by 500 at 10^6 μ/spill***: coincidence in the 4 counters $S_0 x S_1 x S_4 x S_\mu$ after shifting S_4 and S_μ from the beam axis required.
- ***Accidental rate of ~1%*** measured after delaying S_4 signal by 200 ns.





NA64$_{\mu}$ 2021 pilot run

Cut-flow analysis for the ~5 x 10^9 MOT collected **(Preliminary)**



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Data analysis: work in progress

L. Molina Bueno

NA64$_\mu$ 2022 pilot run: first results

22.04-24.04	**25-27.04.22**	10 days without SPS beam	**8/05-16/05**	17-18/05 MD days

Low beam intensity
(few units on T6 target)
Commissioning of detectors

Recovered 11/05
(we would like to thank to the help from SPS coordinator and the BE-EA department in these circumstances)

From the 23 allocated days, we **only had ~8 full days ➡ *Physics program cancelled*** *to collect as much statistics as possible.*

The data analysis is in progress but the *preliminary outcome from the run* is:

➡ Due to the ***improvement in alignment***:

✦ A **factor two higher intensities** than in 2021 pilot run obtained, reaching intensities of 2.8×10^6 μ/spill triggering on $S_0 \times S_1 \times \bar{V}_0$. This has allowed to record about **80% of our planned statistics, 4×10^{10}MOT** (mainly in two trigger configurations).

✦ **All trackers had an average efficiency** (at least 1 cluster) **90%**. In 2021, the trackers located upstream MM1-2 had an average efficiency of 35%.

➡ **Improvement in the set up survey measurements:** A new survey has been performed this year taking into account the slope and measuring also all magnets and quadrupoles present in the line. These measurements will impact significantly our alignment helping to improve the tracking algorithm.

➡ The **measured trigger rates:** Trigger = $S_0 \times S_1 \times \bar{V}_0 \times S_4 \times S_\mu$with respect to $S_0 \times S_1 \times \bar{V}_0$ coincidences were: 0.07% (S_4 at -65 mm and S_μ at -152 mm), and **0.2% (S_4 at -40 mm and S_μ at-82 mm).** The simulated trigger rates are in reasonable agreement with these measurements.

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