Status and plans for NA64 @ M2

Laura Molina Bueno on behalf of NA64 collaboration

PBCacc-Conventional Beams WG-EHN2 technical meeting #10

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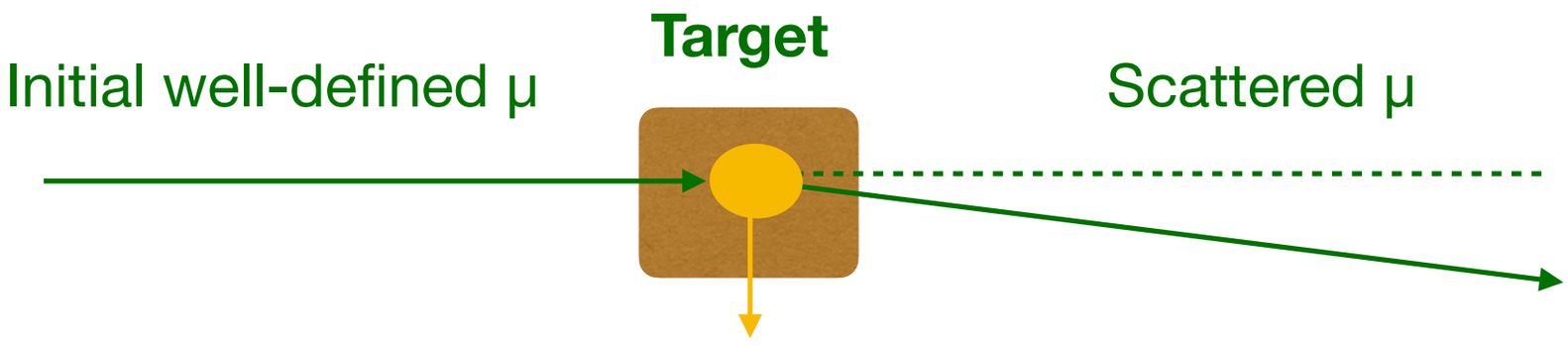
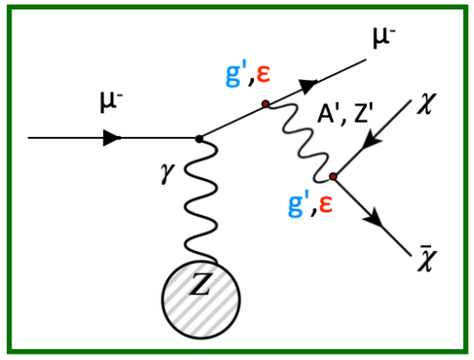
Dark sector exploration using muons ($NA64_{\mu}$)

*Exploring **DS physics weakly coupled to μ** using the unique CERN SPS*
M2 high energy (up to 250 GeV)** and **high intensity muon beam (up to 10^7μ/s)
(LDM, muon g-2 anomaly, ALPs, Lepton Flavour Conversion processes,…)





$\sigma \sim g'^2 Z^2 \alpha^2 / m^2$

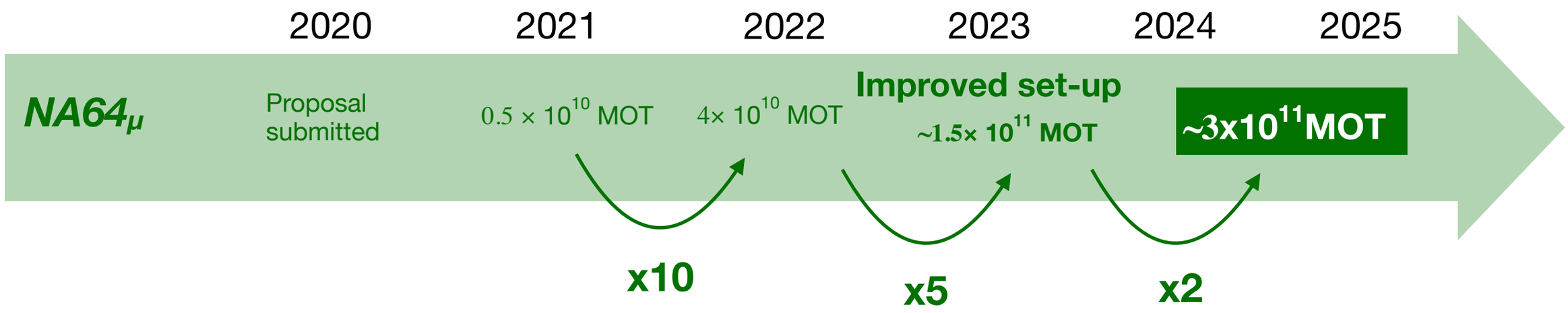
Signature and challenge

Missing energy + *missing momentum*

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

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

Overview of NA64$_\mu$

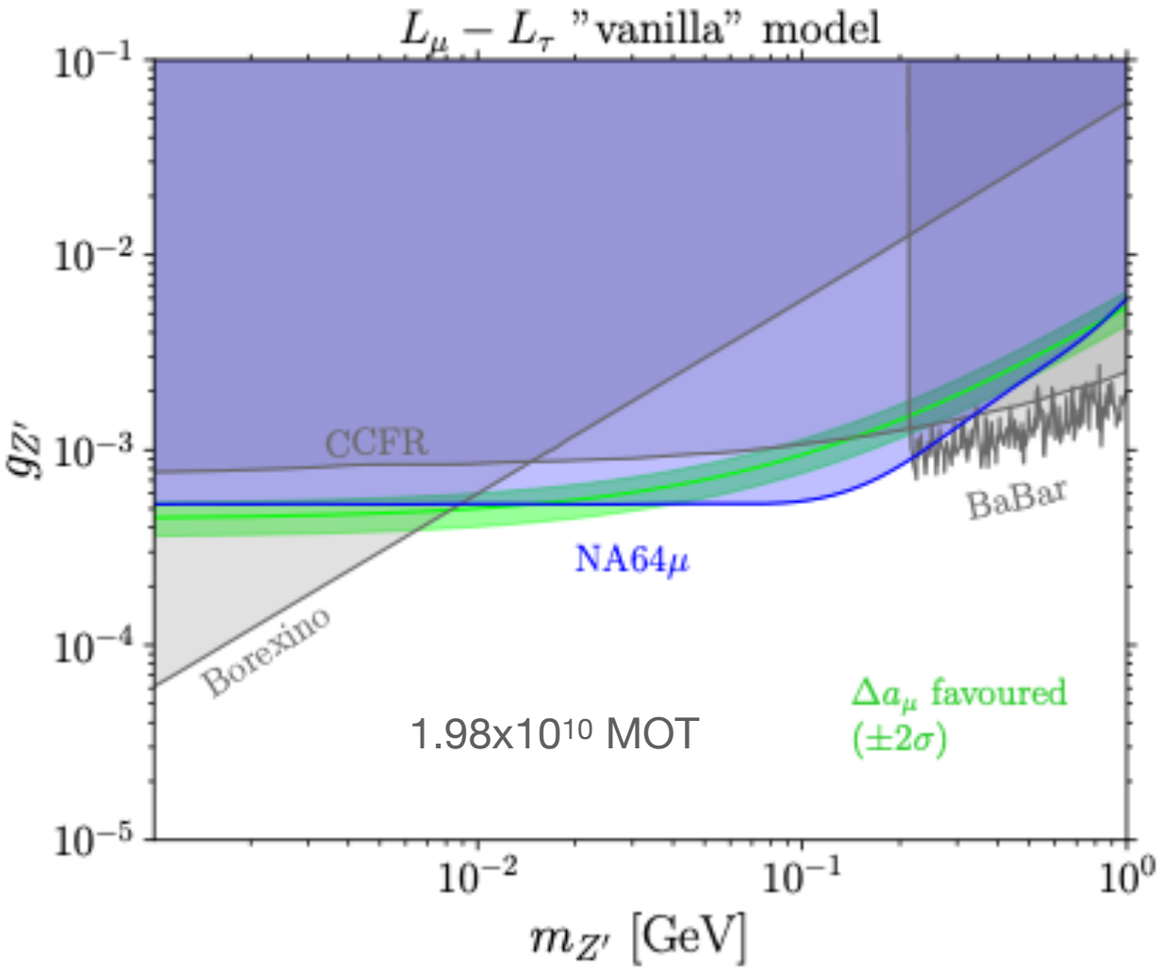


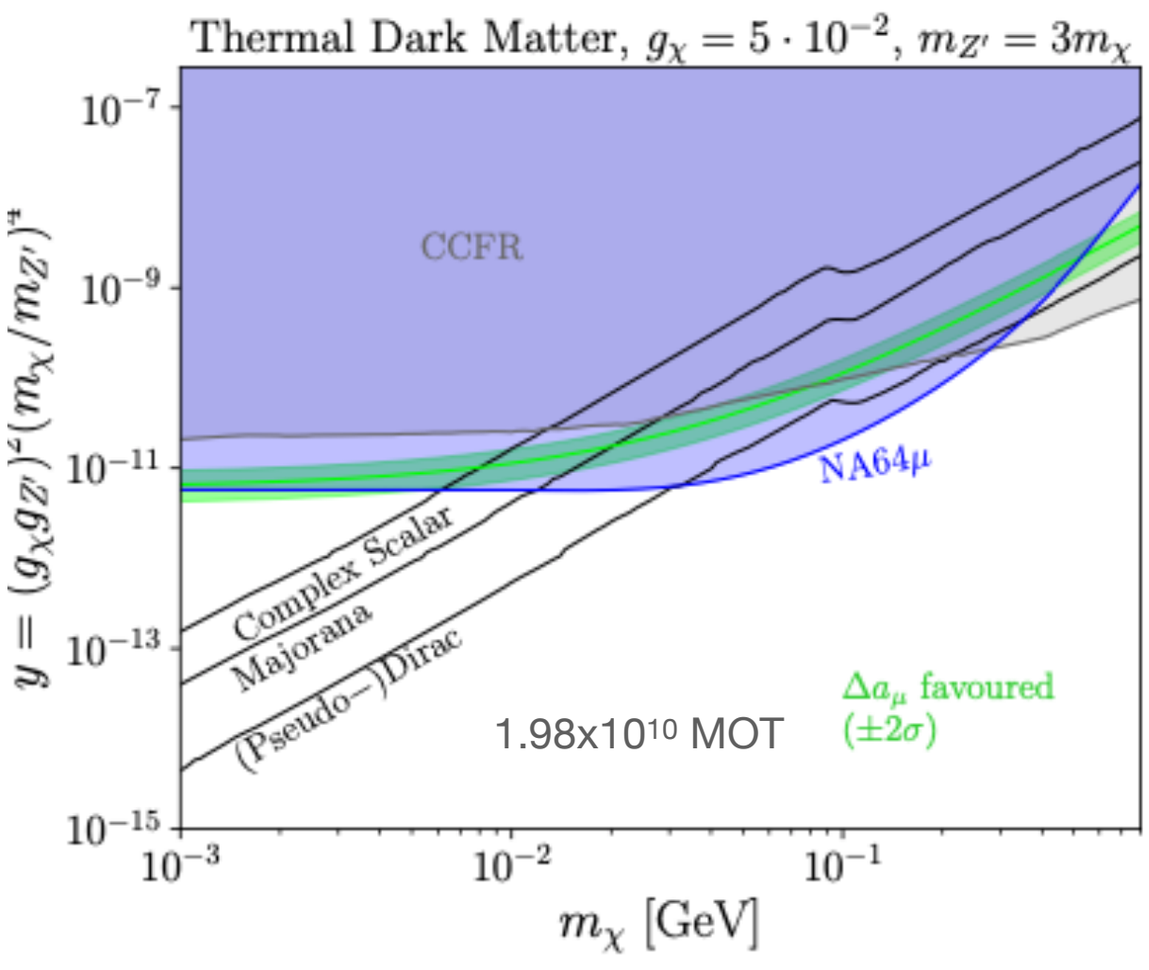
Energy	160 GeV	160 GeV	160 GeV		**160-100 GeV**
Intensities	10^6 μ/spill	2x10^6 μ/spill	**4.7x10^6 μ/spill**		**Test up to 10^7 μ/spill**
Set up			Double number of trackers Improved trigger Two spectrometers for initial momentum Two VHCALs		Similar setup to 2023 (additional trackers and veto counters under study)
Beam time Days	**5 days** including installation, calibration and commissioning (14 days)	**10 days** Set up already installed	**19 days** • 10 days for installation • 1 week for commissioning and calibration	**19 days** • 10 days for installation • 1 week for commissioning and calibration	**19 days** • Setup installed and calibrated in 2024

First NA64μ physics results

1.98x10[10] MOT collected

Background source	Background, n_b
(I) Momentum mis-reconstruction	0.05 ± 0.03
(II) $K \to \mu + \nu$, ... in-flight decays	0.010 ± 0.001
(III) Calorimeter non-hermeticity	< 0.01
Total n_b (conservatively)	0.07 ± 0.03



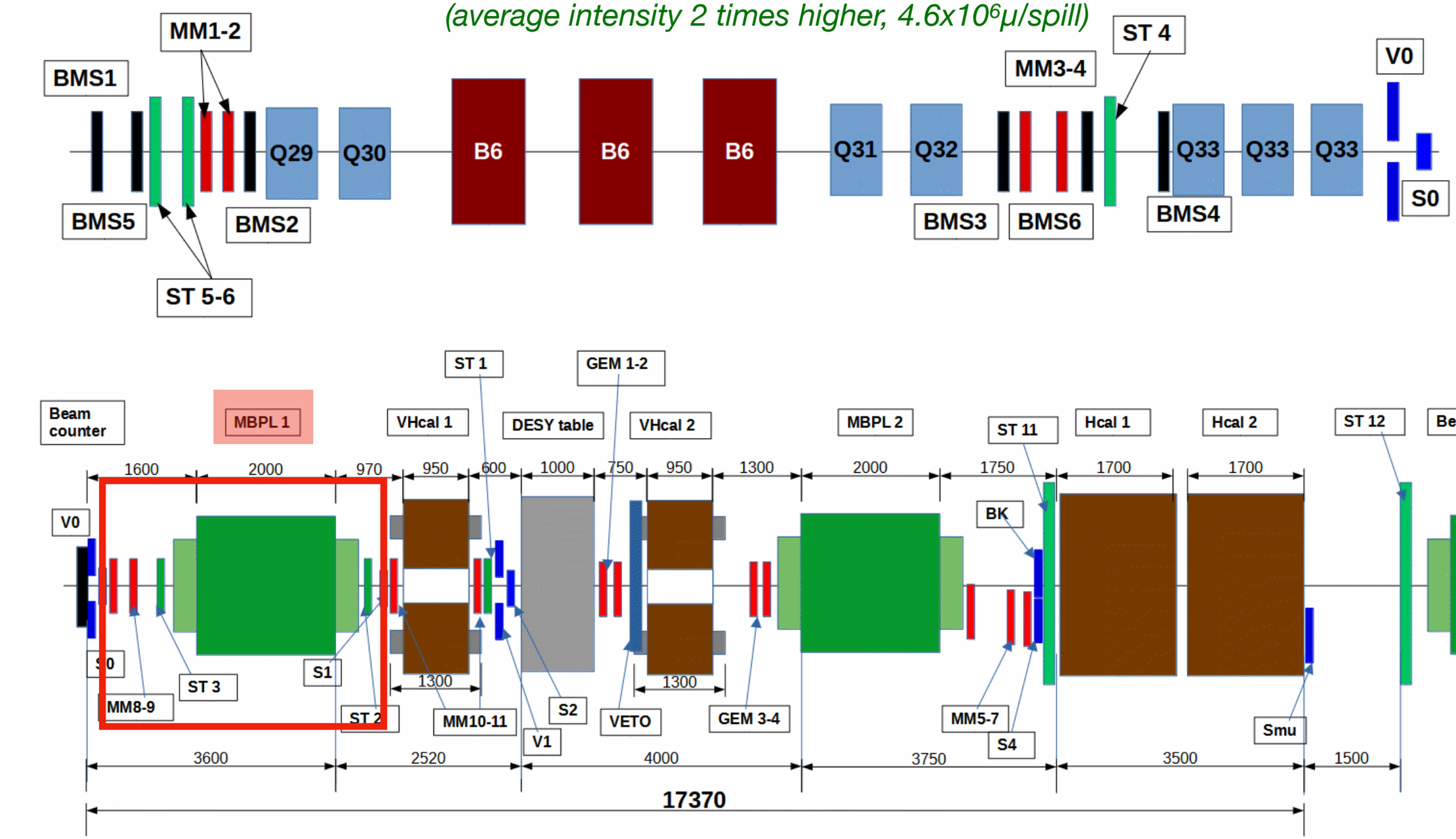


NA64 collaboration [arXiv:2401.01708 [hep-ex]].

2023 run: *goal and setup*

Main goal: ***Improve the momentum mis-reconstruction level introducing a new spectrometer (MBPL1)***

1.5x10^{11} MOT collected with a significantly improved setup (average intensity 2 times higher, 4.6x10^{6}μ/spill)



Additional improvements: more trackers, 2xVHCAL, trigger (BK), …

Open questions to be solved before LS3

New data will be essential to drive the optimisation setup and detector upgrades needed for the post-LS3 phase where we expect to collect two orders of magnitude more data. In particular, we would like to answer the following questions carrying out additional measurements:

- ***Is the initial muon beam energy optimal?:*** The trigger efficiency for signal events in the mass region < 100 MeV is higher at 100 GeV. We would like to collect ~10^{11} MOT understand the trade off between background and signal efficiency. This point is difficult to address with simulations due to the uncertainties on simulating muon-nuclear processes with final state neutral and charged hadrons.

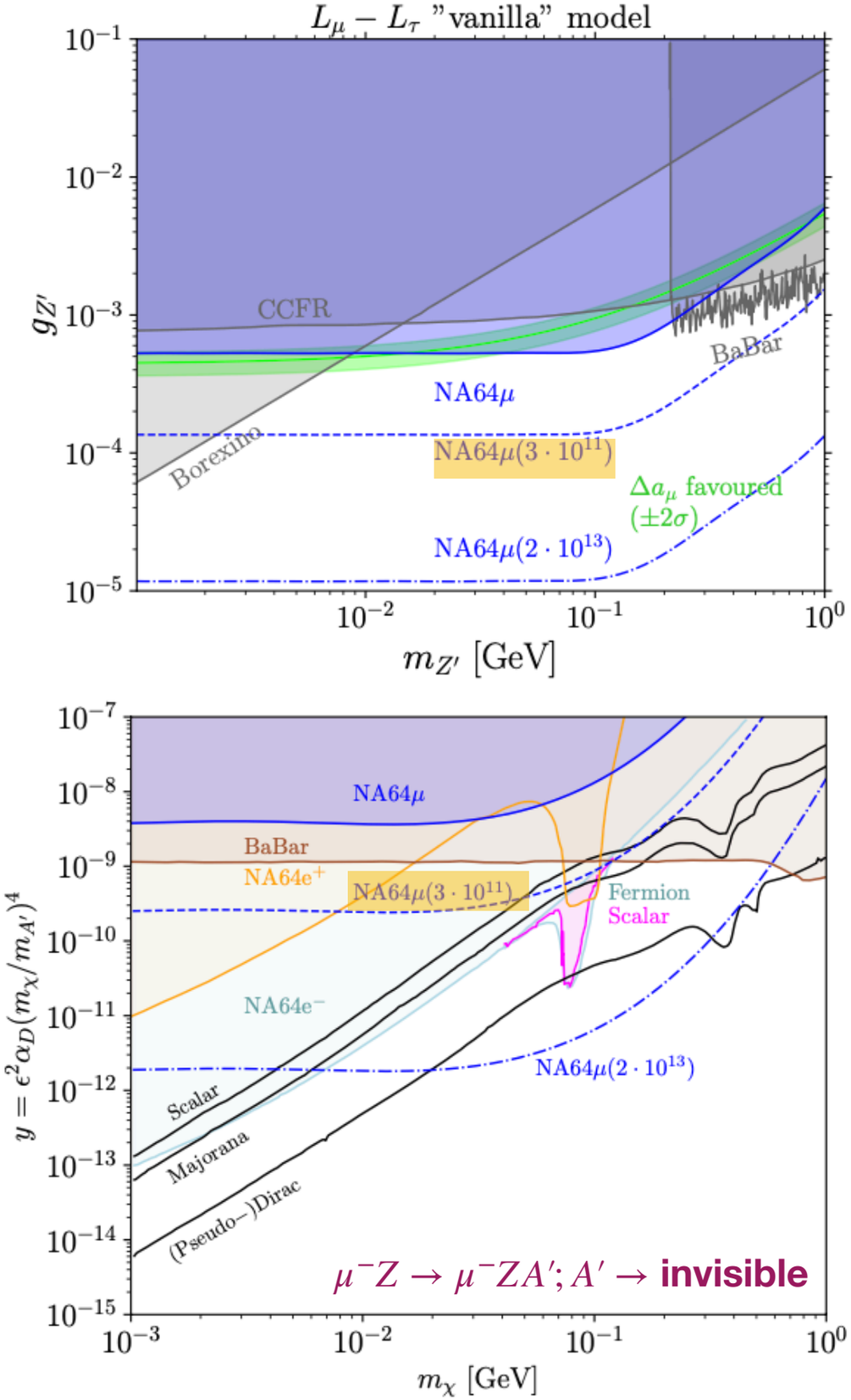
- ***Maximum intensity at which we can run reliably:***
  - Level of accidentals and pile up.
  - A prototype of more segmented trigger counters (S4 and Sμ) will be tested to guide the design of the new system that will be developed during LS3.

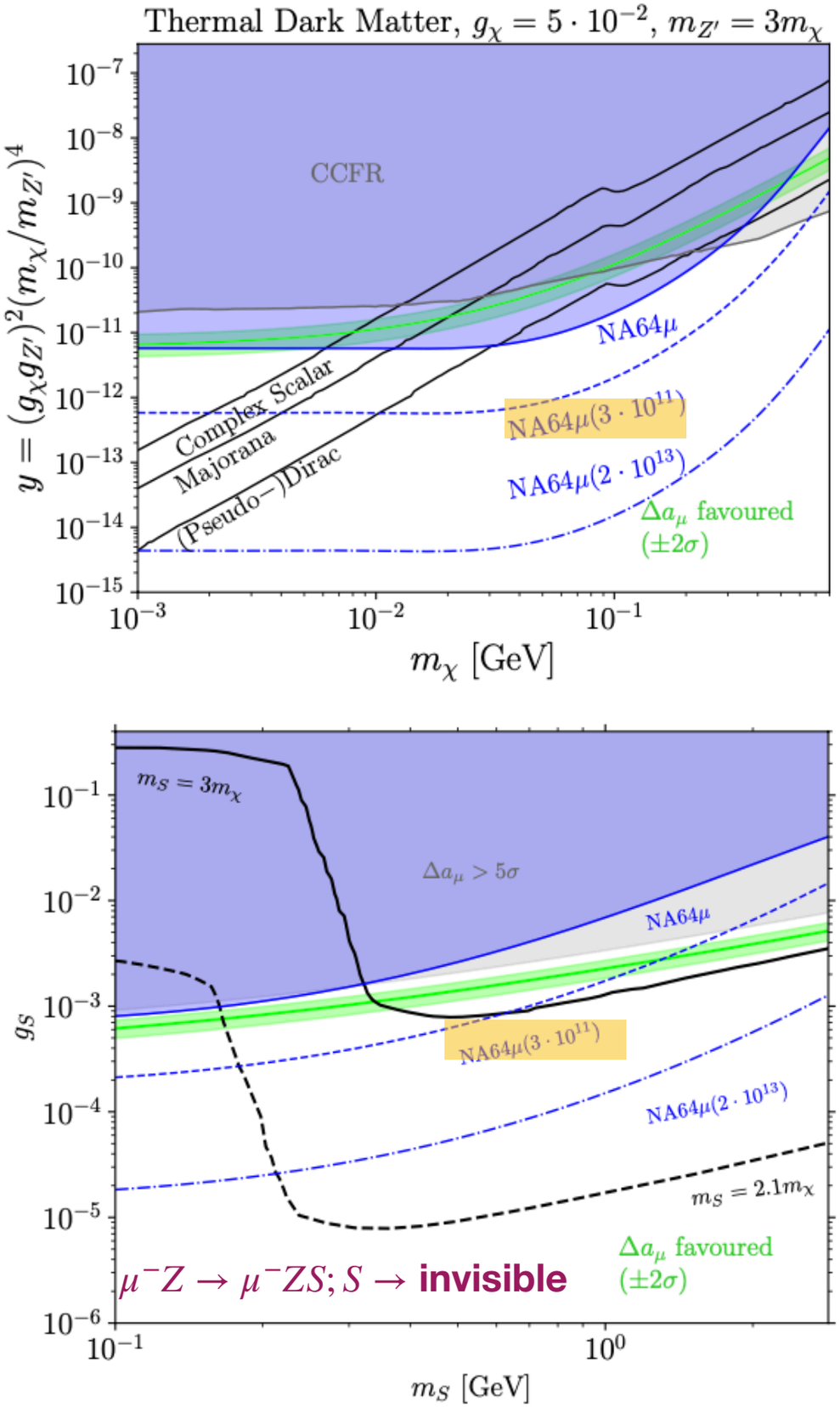
- ***Increase our physics scope:*** Besides a single muon in the final state, ***can we also search for processes involving missing energy in ECAL?.*** We would like to include ECAL in the trigger logic and for example study the feasibility to search for μ→e processes.

- **More reliable extrapolation of the background level:** *momentum mis-reconstruction, hadron contamination in the beam*, *hermeticity****,…***

Physics goals before LS3

$\mu^- Z \to \mu^- Z Z'; Z' \to$ **invisible**





Preliminary plan

Given the **complexity of the setup** and the **absence of its permanent location at M2**:

a step-by-step approach would be the most effective and robust way for achieving our post-LS3 goal of single event sensitivity ~10^{-13}

Therefore, our preliminary plan for data taking before LS3 would be:

➡ **2024: 5 weeks of beam time** (2 weeks for installation and commissioning plus three weeks of data taking) at the end of 2024 SPS year.

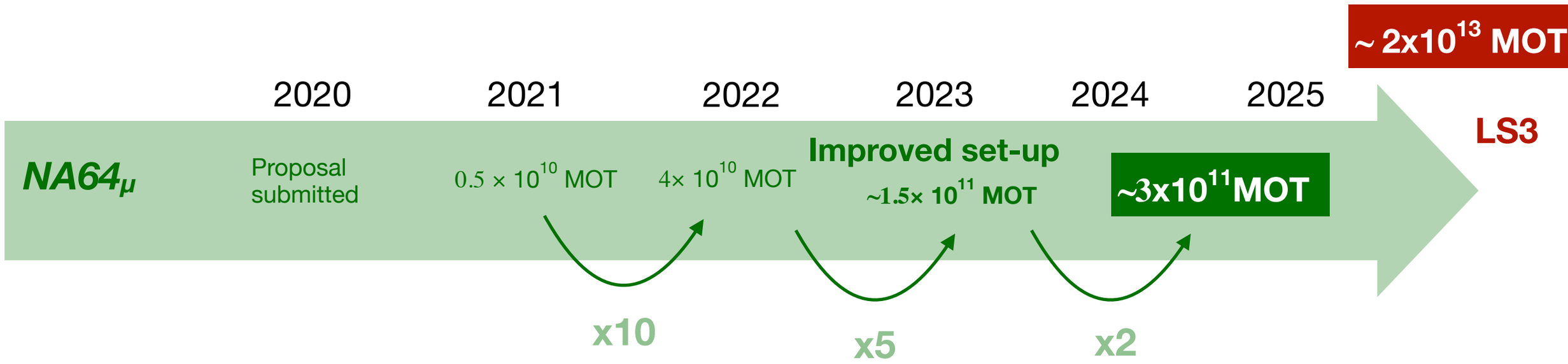
➡ **2025:** leave the setup installed during the shutdown and **request 3 weeks of beam time** at the beginning of the 2025 SPS year. In this way, minimal improvements in the setup can be installed.

Alternative scenario (not ideal but in case is better for the other users)

➡ **2024: 8 weeks of beam time** (2 weeks for installation and commissioning plus 6 weeks of data taking) after NA64 run @H4 from beginning of July until end August.

Plans after LS3

Overview of NA64$_\mu$



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- Optimisation of the setup during LS3
- *Further beam improvements might be required*: beam size and halo, hadron contamination (extra hadron absorber) etc after the study is completed.

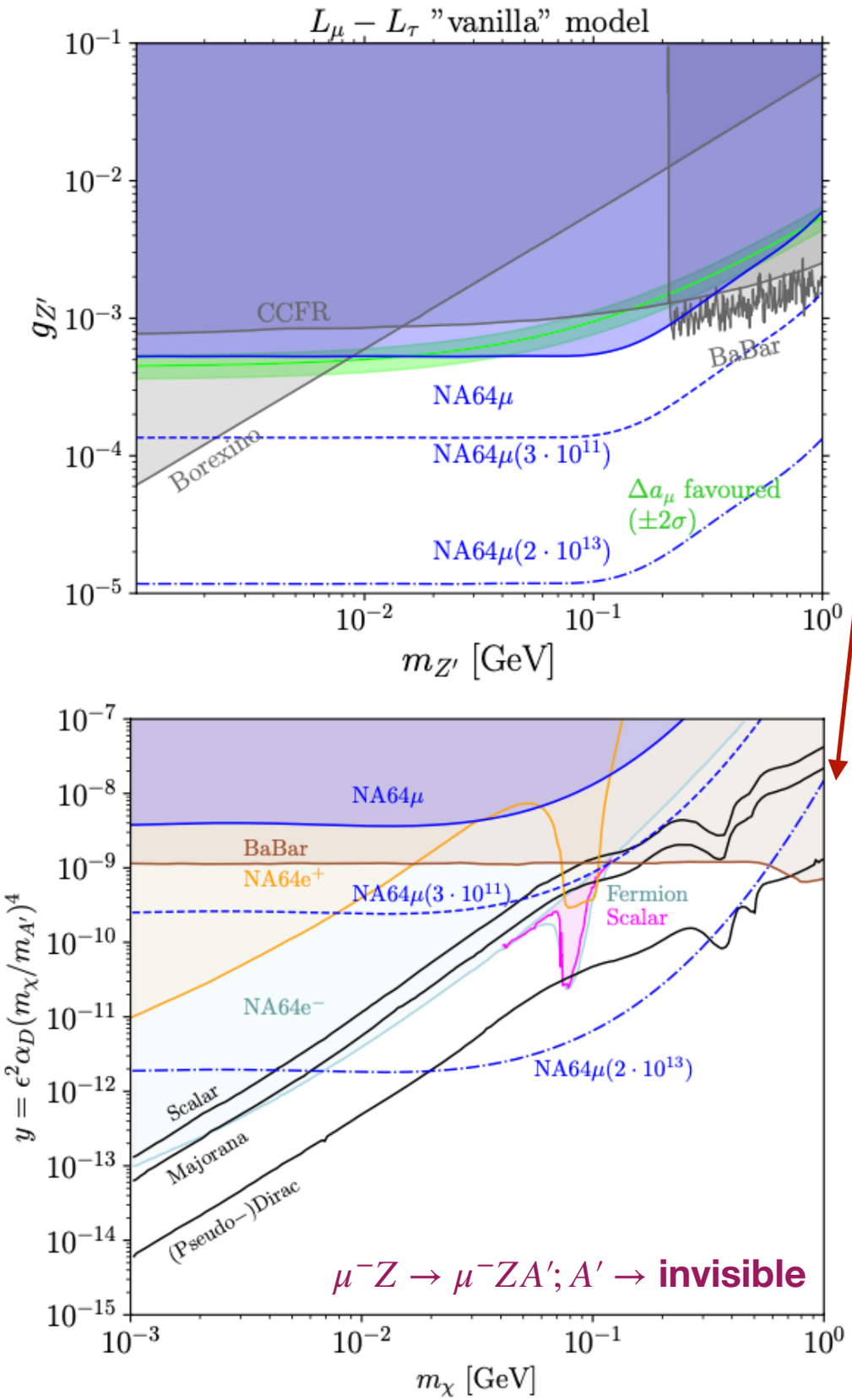
the corresponding study is completed.

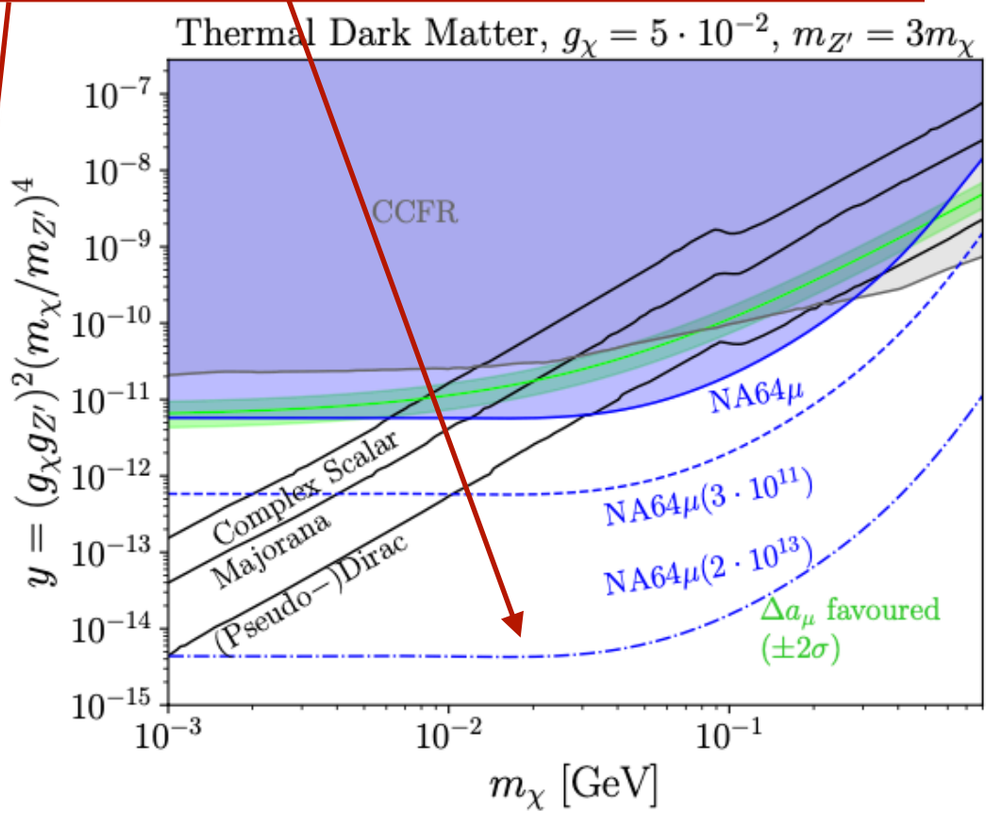
- Ideally we would like to have more space available (~20m) so we can place if needed an additional magnet downstream.

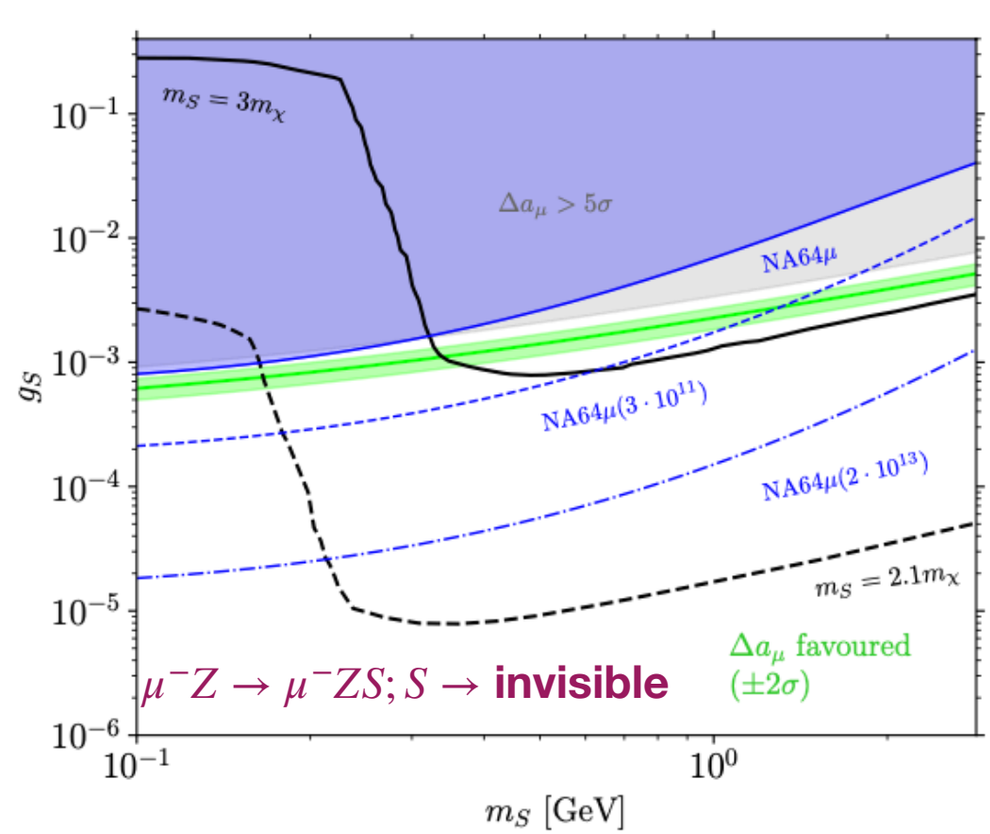
After LS3

collect 2x10[13] MOT

- **run at higher intensities (> 10[7] μ/spill)** profiting the excellent M2 capabilities

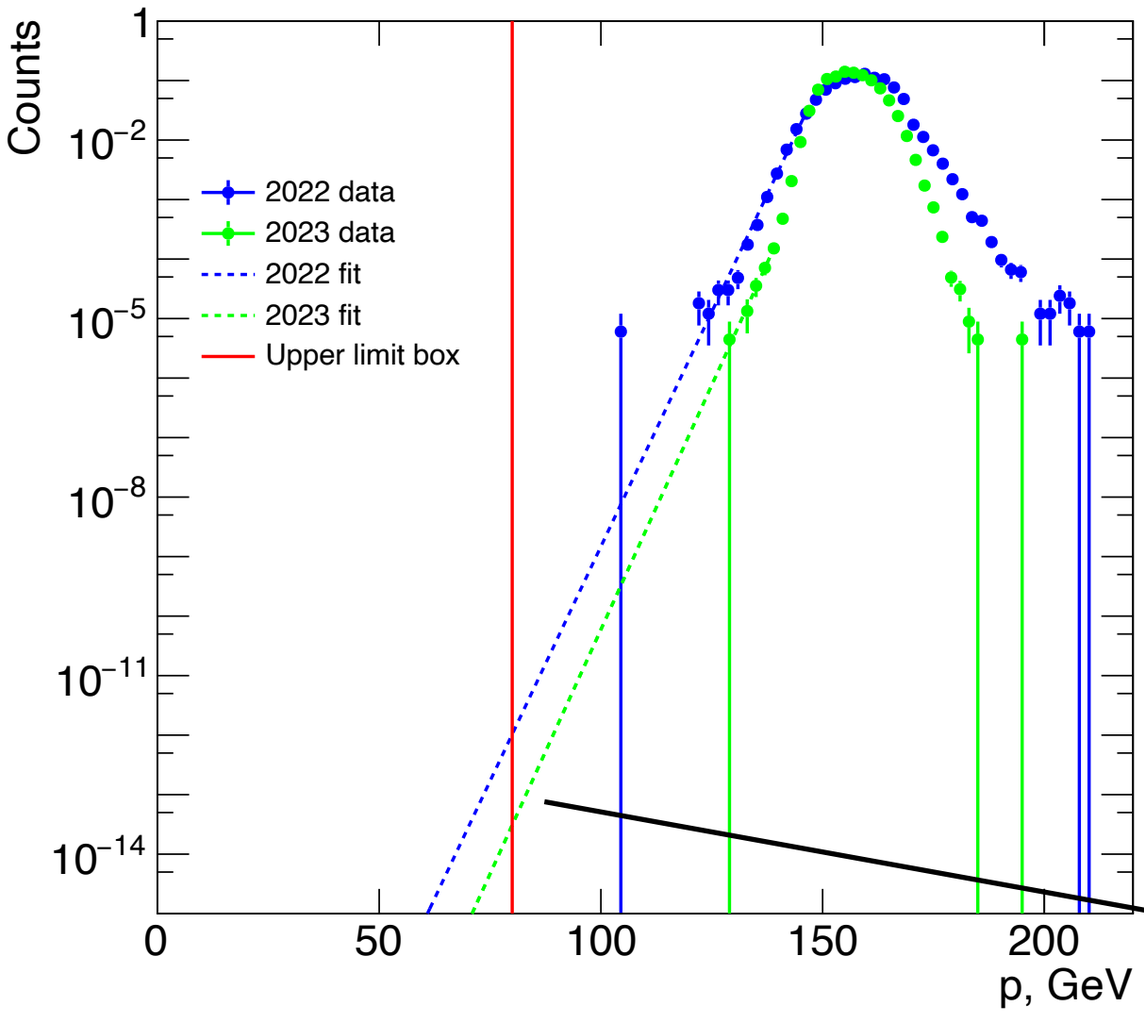






Back-up

2023 run: *preliminary results (analysis ongoing)*



The preliminary results indicate that the level of background from momentum mis-reconstruction is about 30 times less than in 2022.