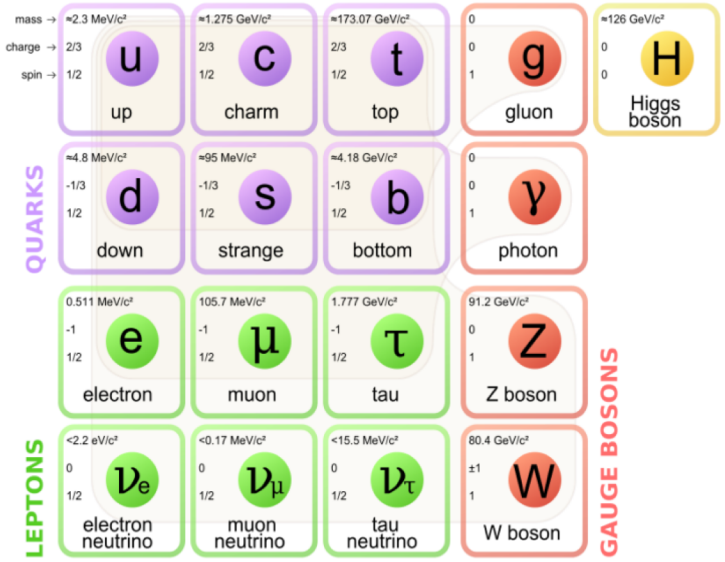
The NA64μ experiment at the CERN SPS

S. Gertsenberger
on behalf of the NA64 Collaboration

ICPPA, 30.11.2022

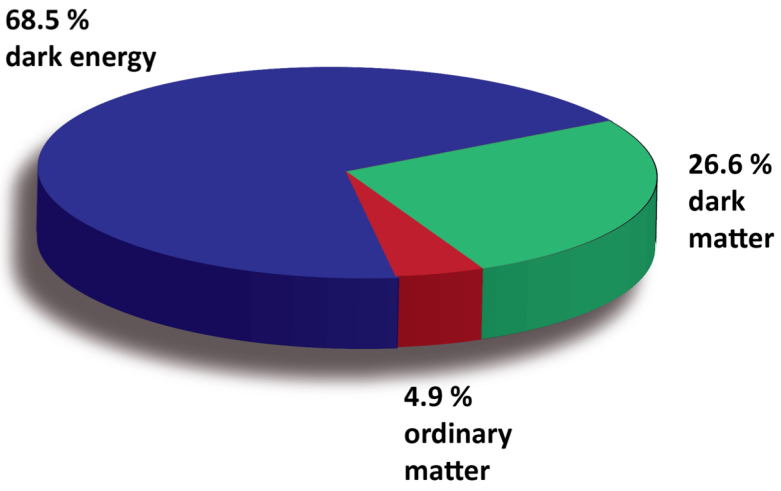
introduction



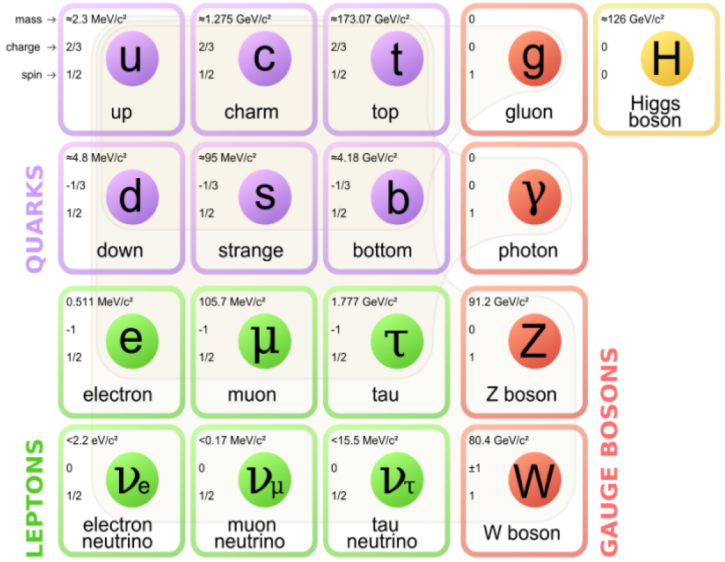
Standard Model (SM) describes the fundamental particles of matter and all their interactions.

Despite its impressive success in describing experiments, the SM cannot be considered the ultimate theory of elementary particles.

introduction



Astrophysical and cosmological observations, obviously demonstrate the existence of the dark matter (DM) and dark energy (DE) which are not described in the SM.



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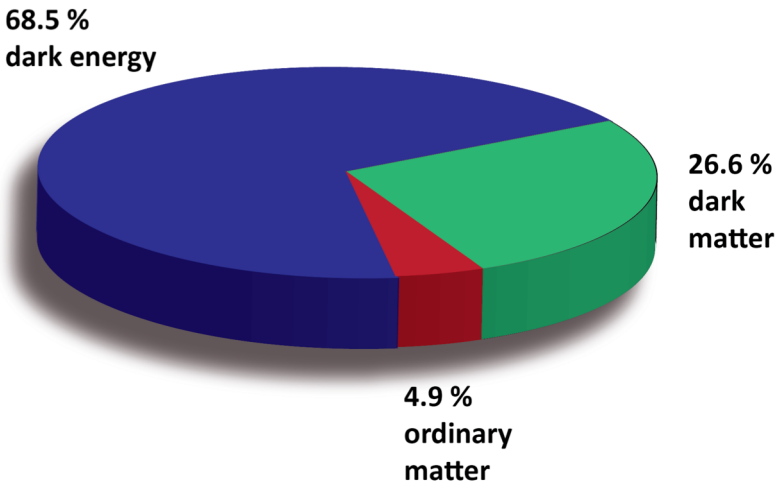


How can we find dark matter if it

- doesn't participate in electromagnetic interaction,
- invisible to direct observation,
- interacts only gravitationally and on a galactic scale?

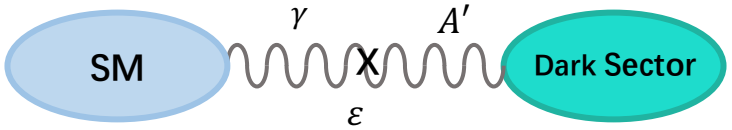
An extension of the SM is needed to explain the existence of DE and DM

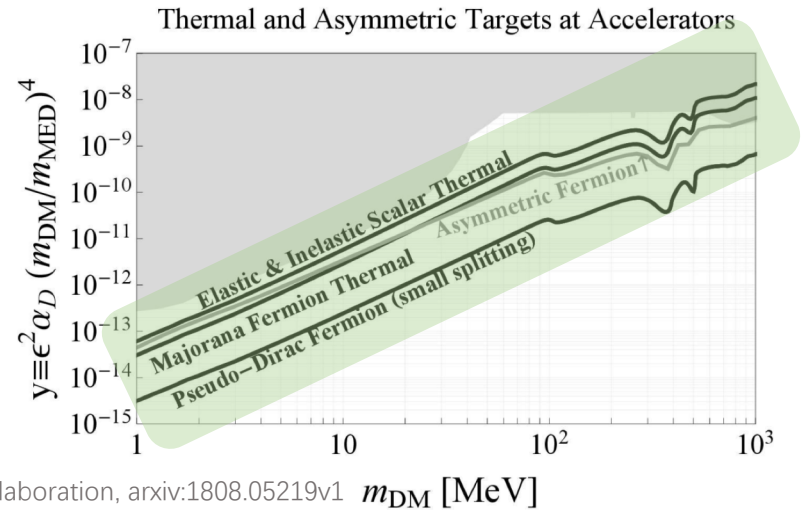
SDSS J1038+4849 from HST

introduction

What if..?

What if **the DM is part of the Dark Sector** which couple weakly with standard model particles? It is assumed that the hierarchy of particles in the dark sector can be similar to the SM. One of the most popular models suggests that DM interacts with the SM via a vector mediator, e. g dark photon A', which is kinetically mixed with our photon

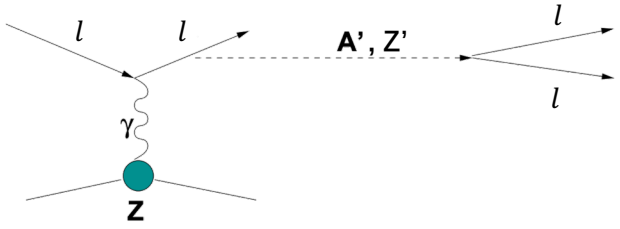




LDMX Collaboration, arxiv:1808.05219v1

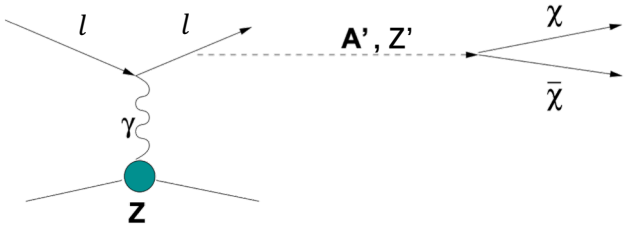
Visible mode

Signature: SM particles pair production



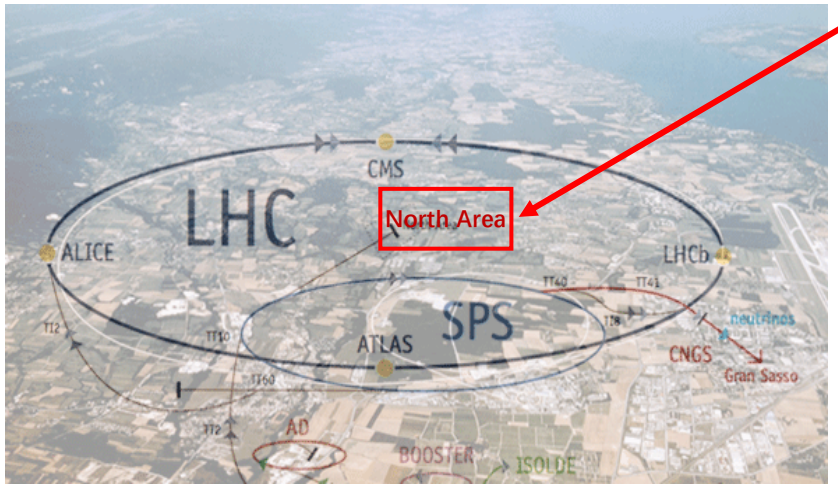
Invisible mode

Signature: missing energy



To search for such DM particles in underground experiments is difficult because of the very small cross-sections of their scattering off electrons or nuclei and small recoil energy.
NA64 approach allows searching for Light Dark Matter (LDM) in the range mass MeV – GeV in the experiment at the SPS accelerator at CERN

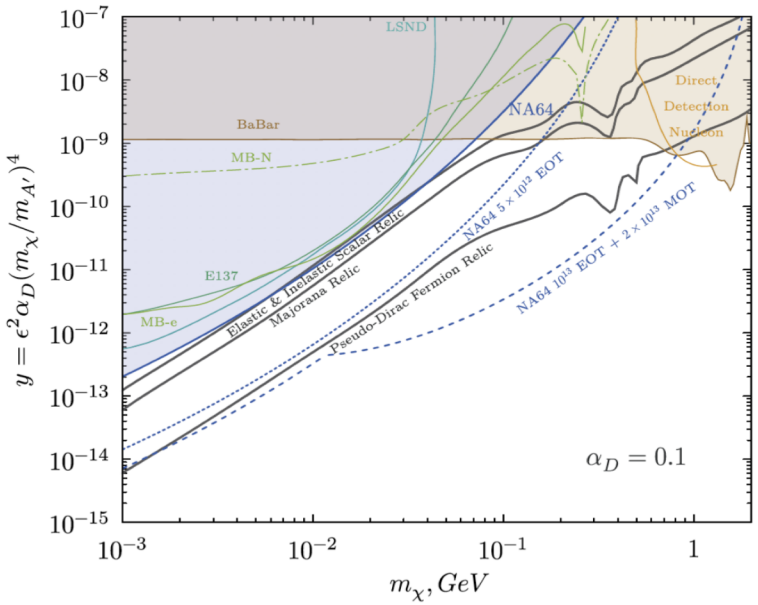
NA64 experiment



NA64

Motivation: search of new physics beyond the SM particularly LDM
Realization: combine the active beam dump and missing energy techniques to search for rare events

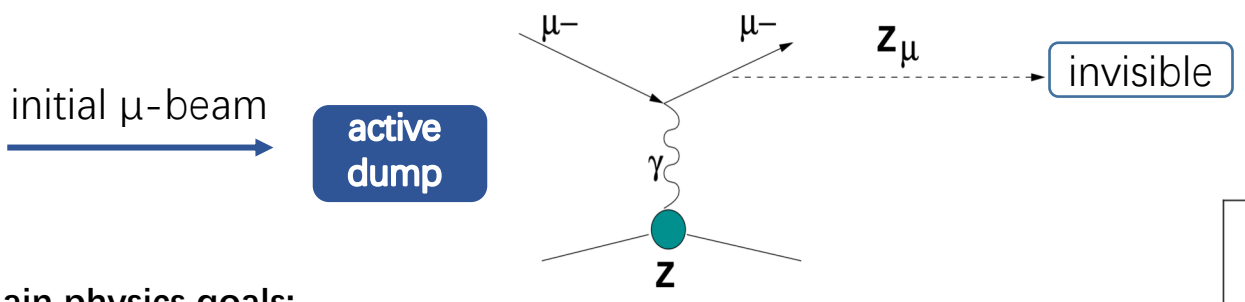
- **NA64e**
  100 GeV e-beam
  see D. Kirpichnikov's talk
- **NA64μ**
  160 GeV μ-beam
  Pilot runs 2021-2022
- **NA64h** in future
  ~100 GeV h-beam



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

NA64μ experiment

2018	LS2	2021		2022	2023	2024	2025	LS3
Experimental proposal		5x10^9 MOT	Pilot runs	4x10^{10} MOT		Phase 1		

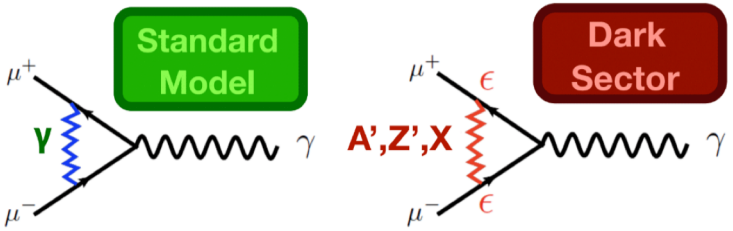


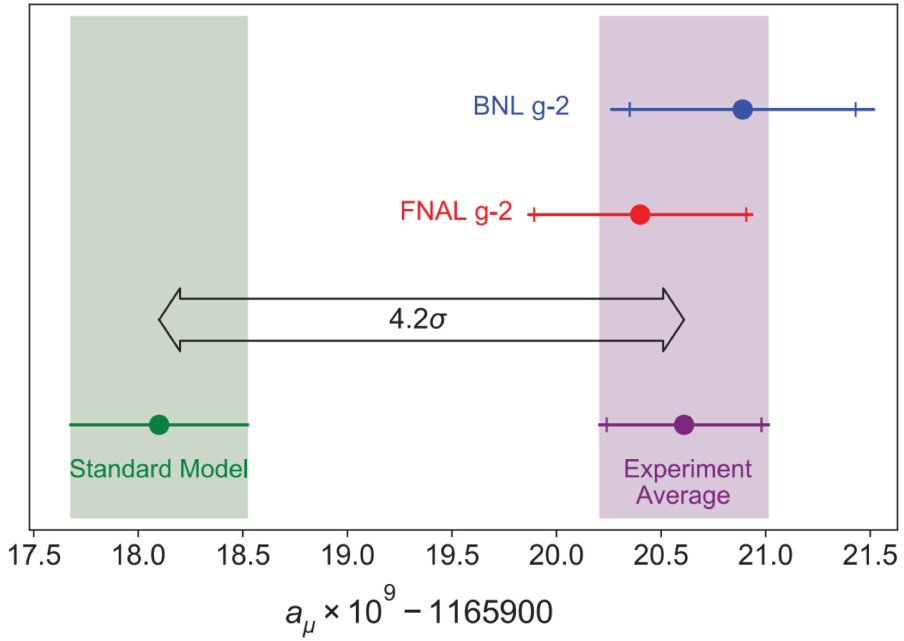
Signature: missing energy and momentum

Main physics goals:

- Z_μ – light boson coupled to the muon, as a remaining low mass explanation of the $(g-2)_\mu$ (the muon anomaly)
- LDM interacting with the Standard Matter via a new gauge vector-boson mediator Z_μ
- Scalar, Axion Like Particles coupled to the muon
- Lepton Flavour Violation in $\mu \to \tau$ and $\mu \to e$ conversion

S. Gninenko et al. PLB796, 117 (2019)
D. Banerjee et al. [NA64 Collaboration]. CERN-SPSC-2019-002 / SPSC-P-359, January 14, 2019.



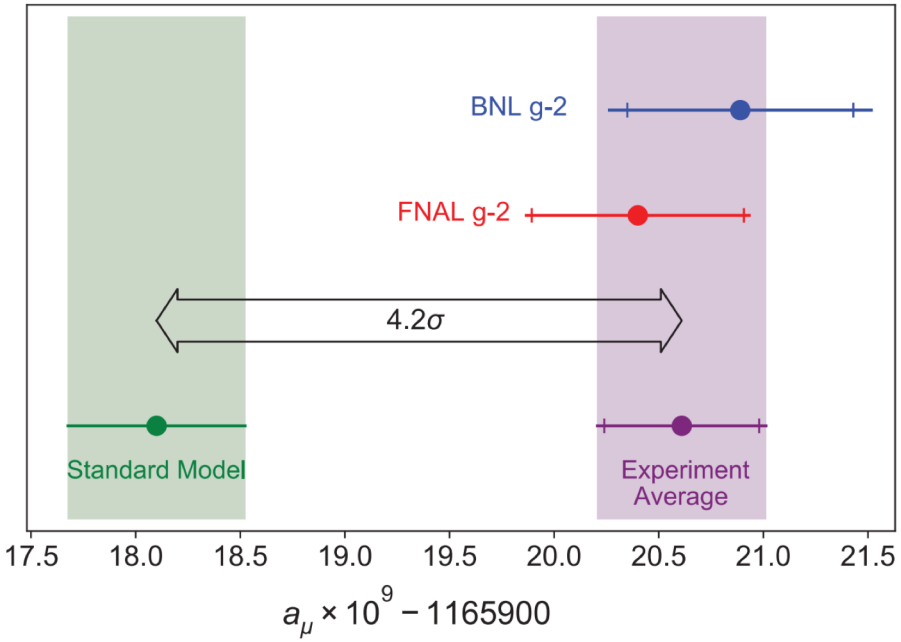


B. Abi et al. Muon g-2 collaboration Phys. Rev. Lett. 126, 141801
T. Aoyama et al. Phys. Rept. 887 (2020) 1-166

NA64μ main motivation is (g-2)$_\mu$ anomaly

The combined experimental average is

$$a_\mu^{EXP} = 116592061(41)\times10^{-11}$$



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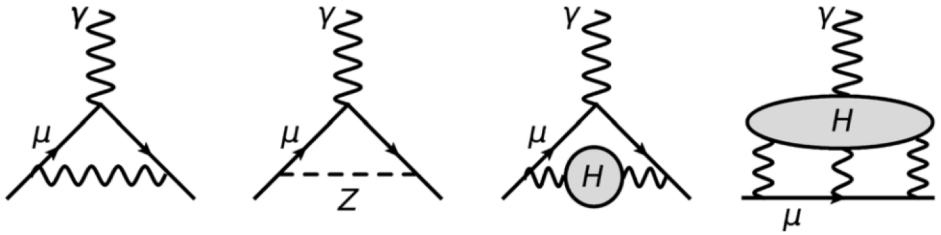
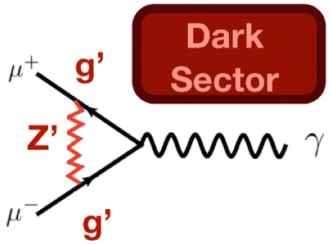


$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{HVP} + a_\mu^{HLbL}$$

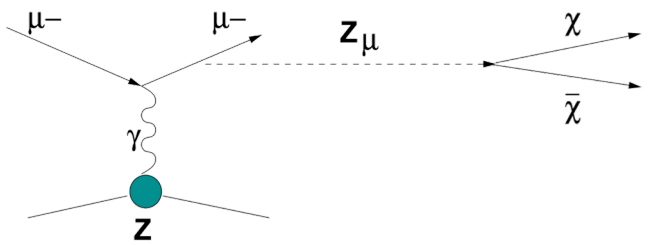
$$a_\mu^{SM} = 116592089(63)\times10^{-11}$$

$$\boldsymbol{a_\mu^{EXP} - a_\mu^{SM} = (251 \pm 59)\times10^{-11}}$$

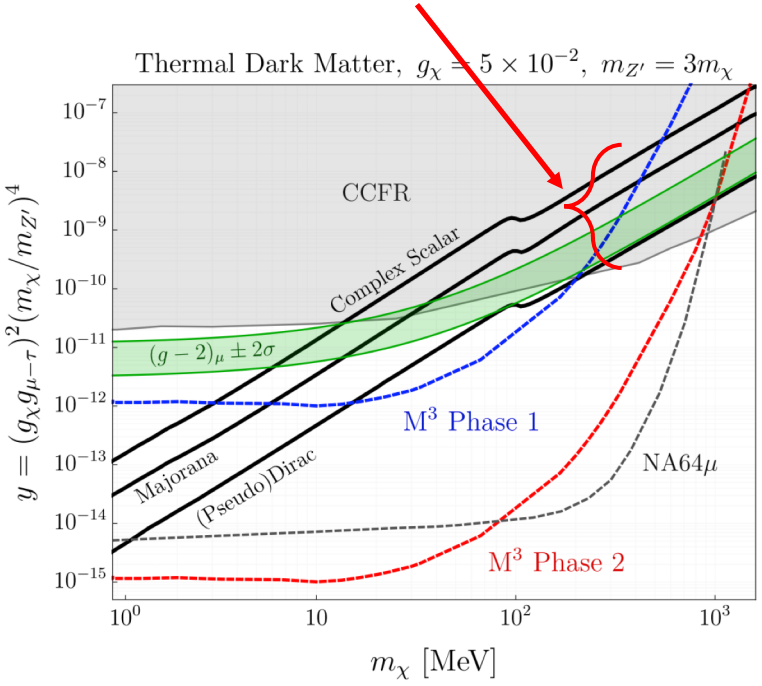


New Physics contribution?
Boson vertex corrections could explain the discrepancy (g-2)$_\mu$

NA64μ projection sensitivity for LDM and muon (g-2)$_\mu$



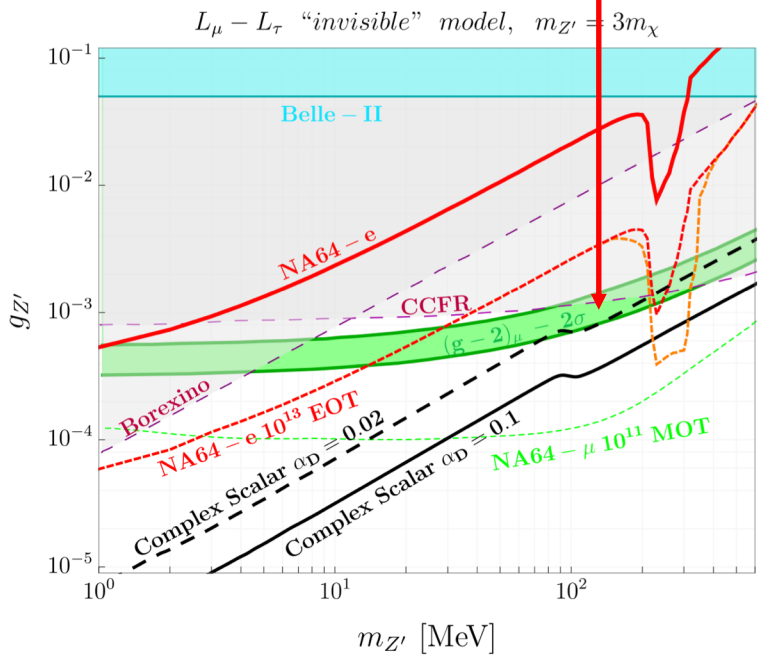
LDM models parameter space



Y. Kahn, G. Krnjaic, N. Tran, and A. Whitbeck, JHEP 09 153 (2018)

$L_\mu - L_\tau$ models Z_μ could explain *(g-2)$_\mu$*

(g-2)$_\mu$ parameter space



NA64 Collaboration, Phys. Rev. D **106** (2022) no 3, 032015
doi:10.1103/PhysRevD.106.032015

NA64μ setup

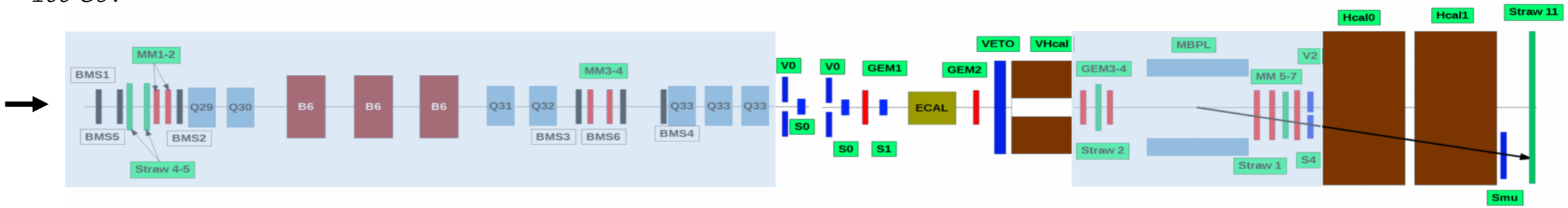
April 2022

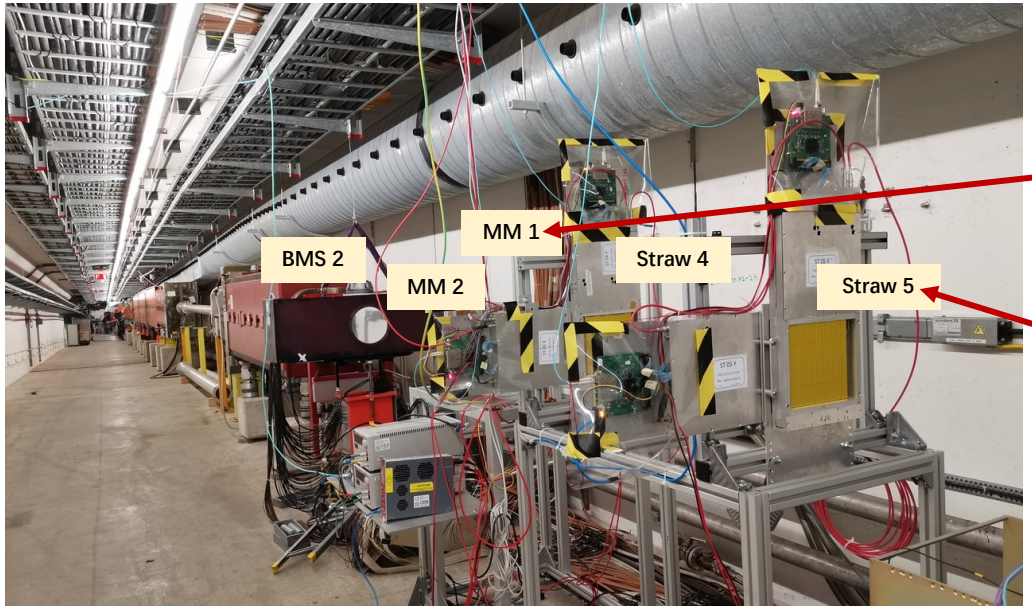
muon beam
160 GeV

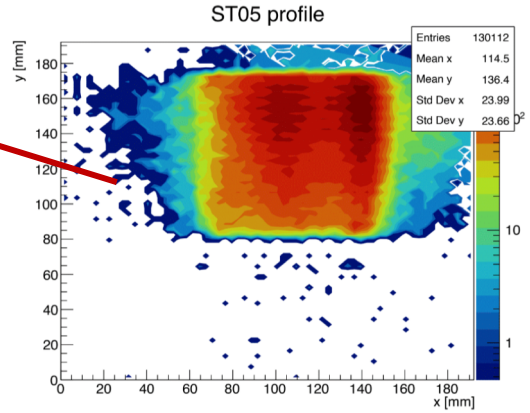
MS1

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

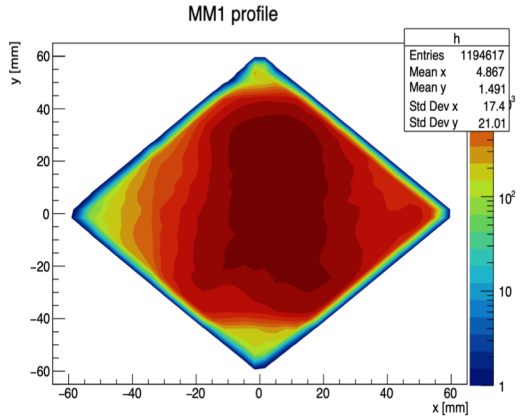
MS2







developed in JINR



April 2022 data

NA64μ setup

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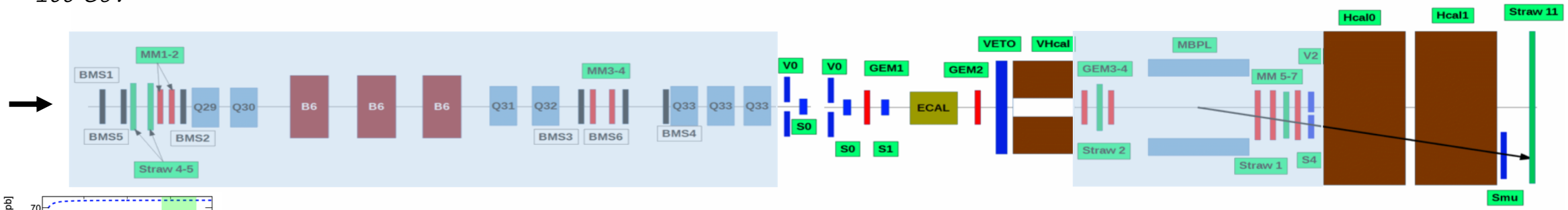
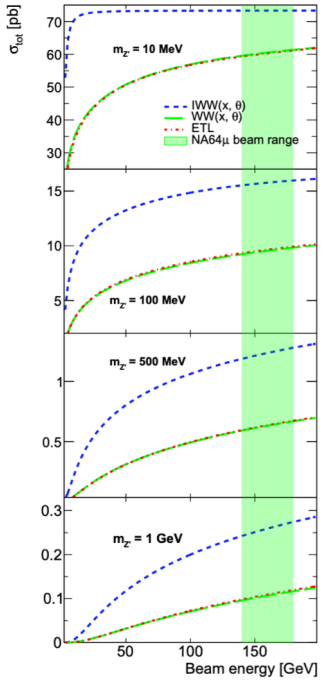




Signature: missing energy and momentum

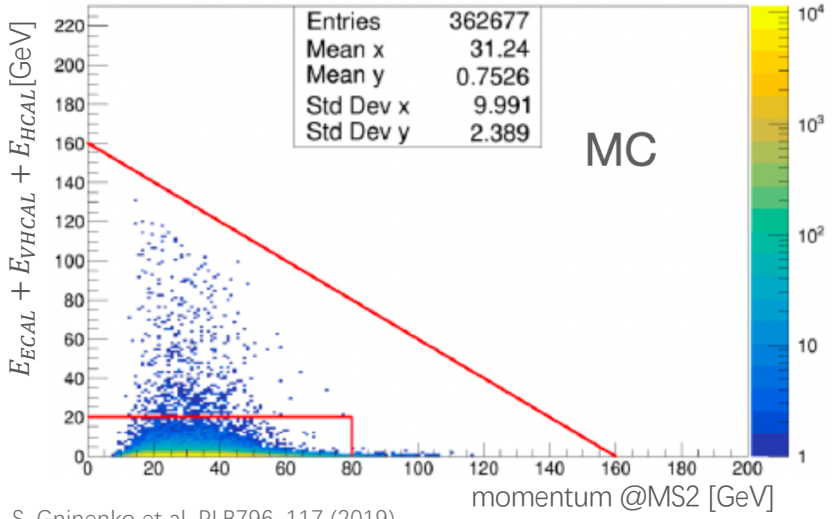
- Initial μ-momentum 160 GeV (MS1)
- Scattered μ-momentum < 80 GeV (MS2)
- No energy in all calorimeters, ECAL, HCAL and VHCAL (energy deposit compatible with a MIP)

Signal simulations performed in a Geant4-based Dark Matter simulation framework **DMG4**

M. Bondi et al., Comput. Phys. Commun. 26, 108129 (2021)

D. V. Kirpichnikov *et al.*, Phys. Rev. D 104, 076012 (2021)

Z_μ signal-like events for $m_{Z_\mu} = 100$ MeV



S. Gninenko et al. PLB796, 117 (2019)
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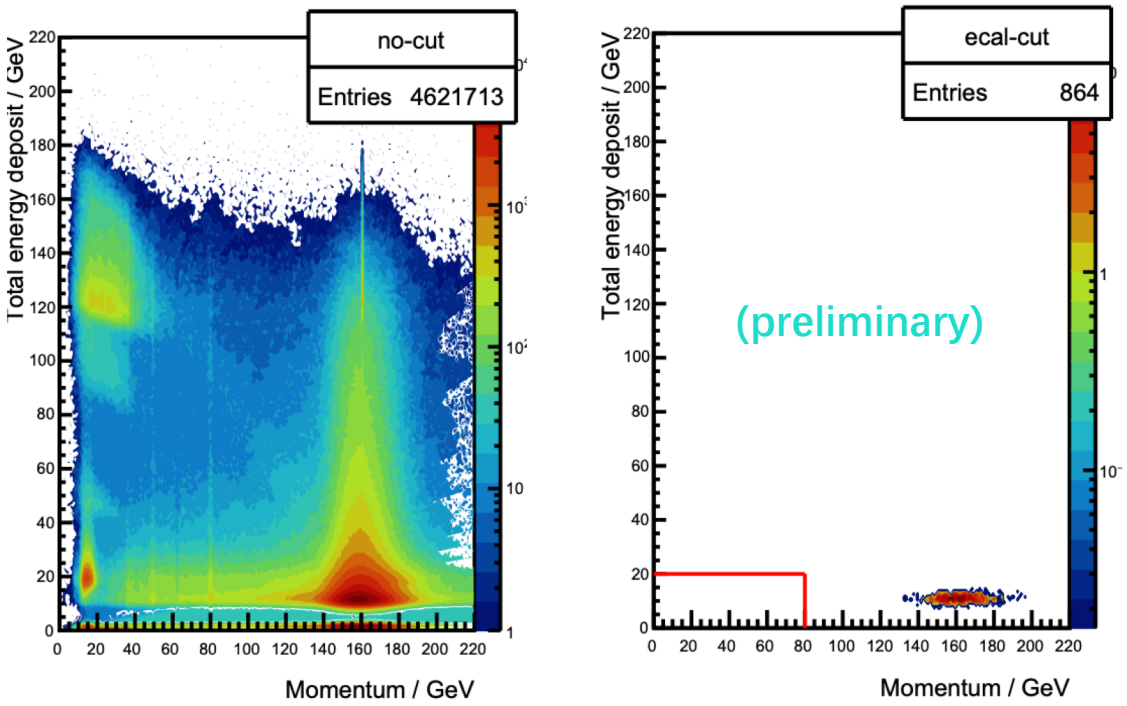
NA64μ: preliminary results

Cut-flow analysis for the 2021 pilot run for ~ 5×10^9 MOT



data 2021

Event Selection Criteria:

1. In-time events
2. Single-hit per tracker
3. Reconstructed momenta in MS1
4. Quality cut on downstream momenta in MS2 based on χ2.
5. Energy compatible with MIP energy in calorimeters and veto

No signal observed

Data analysis 2022 is in progress

summary and plans

- Pilot run for 2021 and first data taking 2022 collected $5x10^9$ MOT and $4x10^{10}$ MOT respectively
- Start probing $(g-2)_\mu$ and Z_μ
- No events in the signal region for the data collected in 2021. Data analysis for data collected in 2022 is in progress

- Continue data taking
- Trigger and DAQ system optimization
- Assemble new electronics capable of withstanding high beam intensity (for MM)
- Increase the number of STRAW stations

Thanks!

Acknowledgements

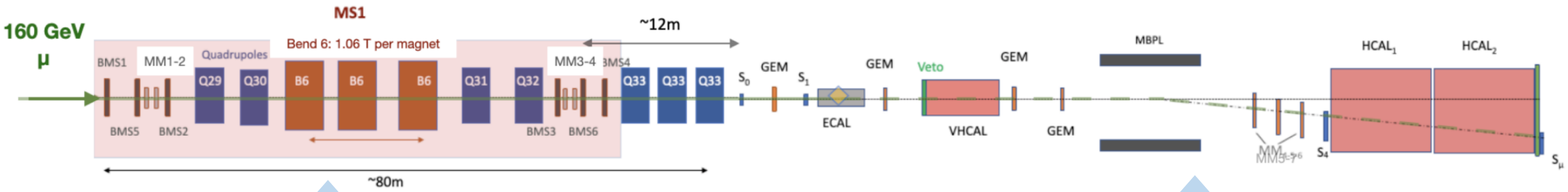
NA64 Collaboration in particular **S. Gninenko** and **P. Crivelli**
ETH group in particular **L. Molina Bueno** and **H. Sieber**
JINR group in particular **A. Ivanov**

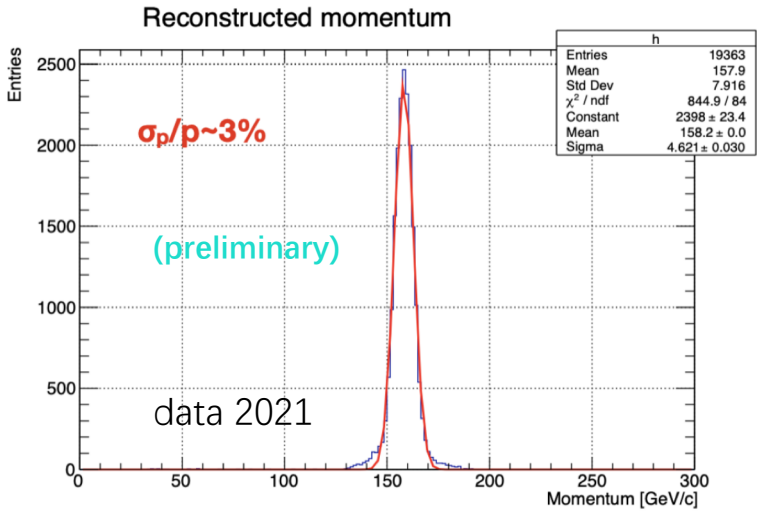
NA64μ setup 2021

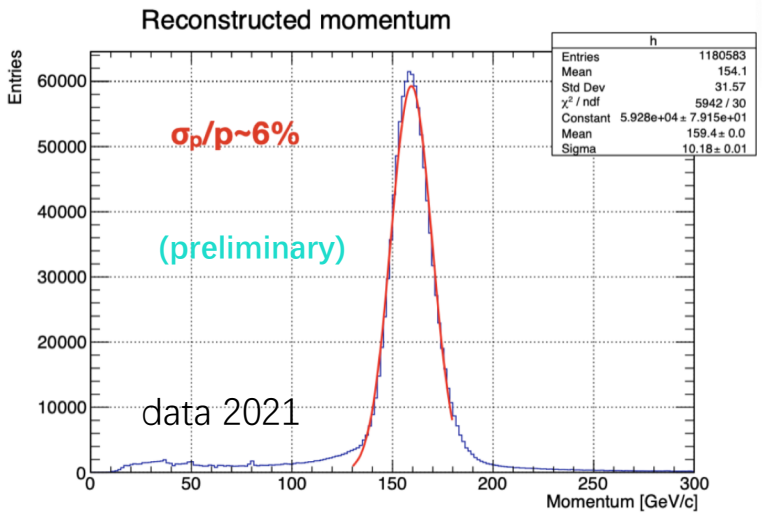
MS1

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

MS2







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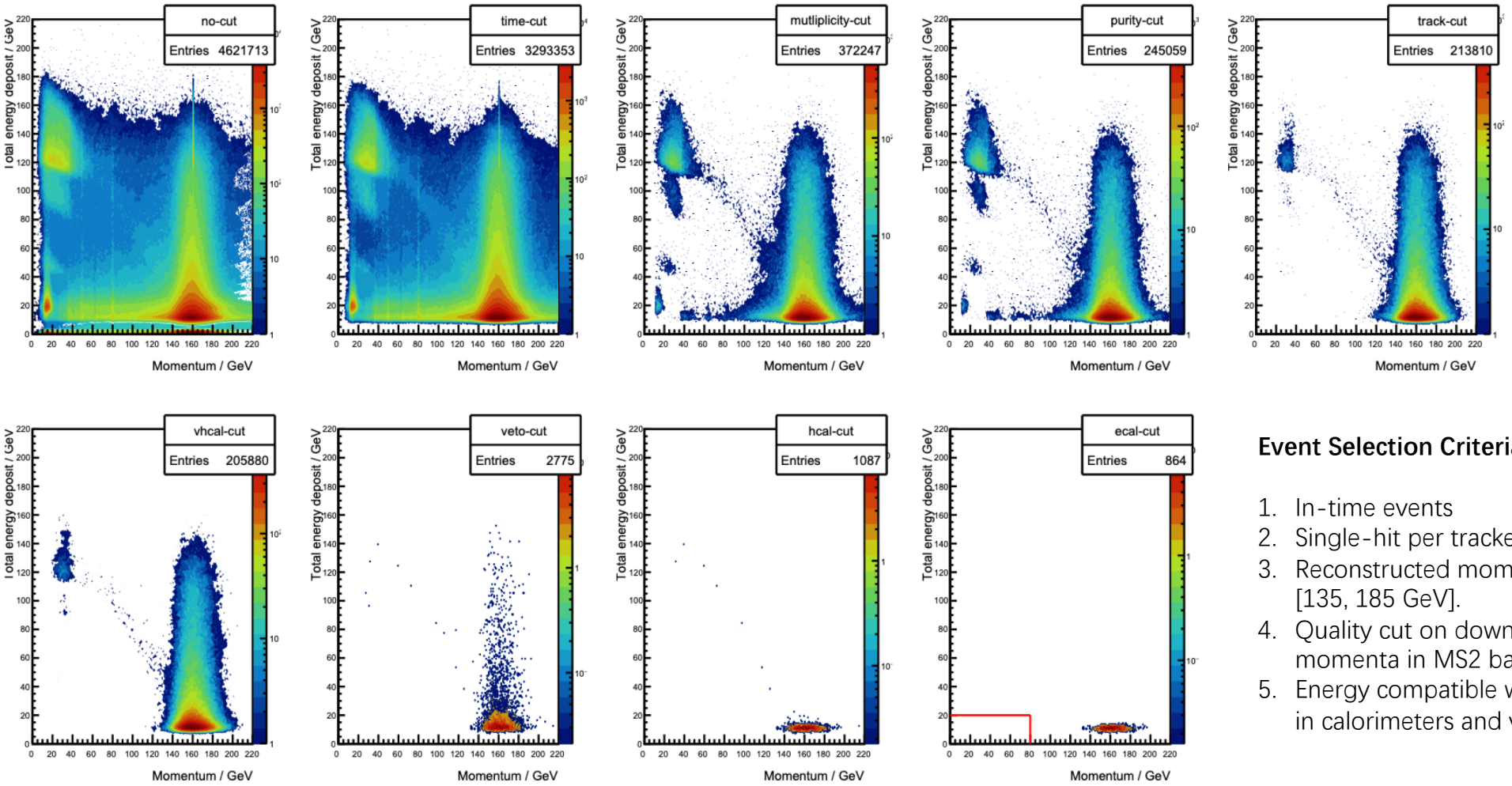
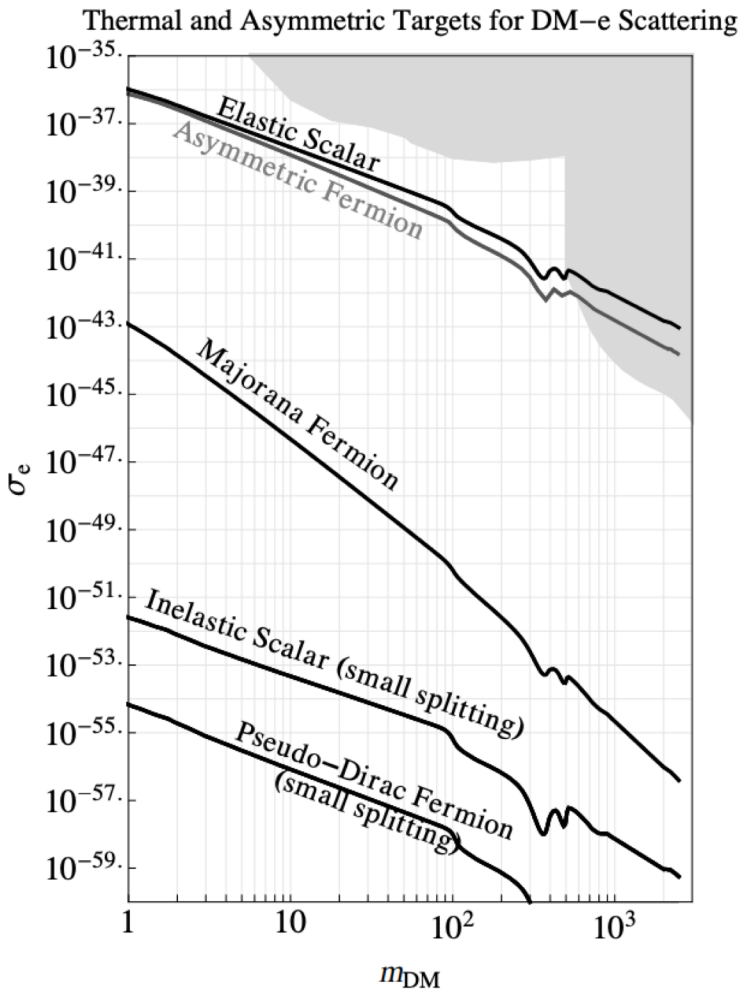


(preliminary)

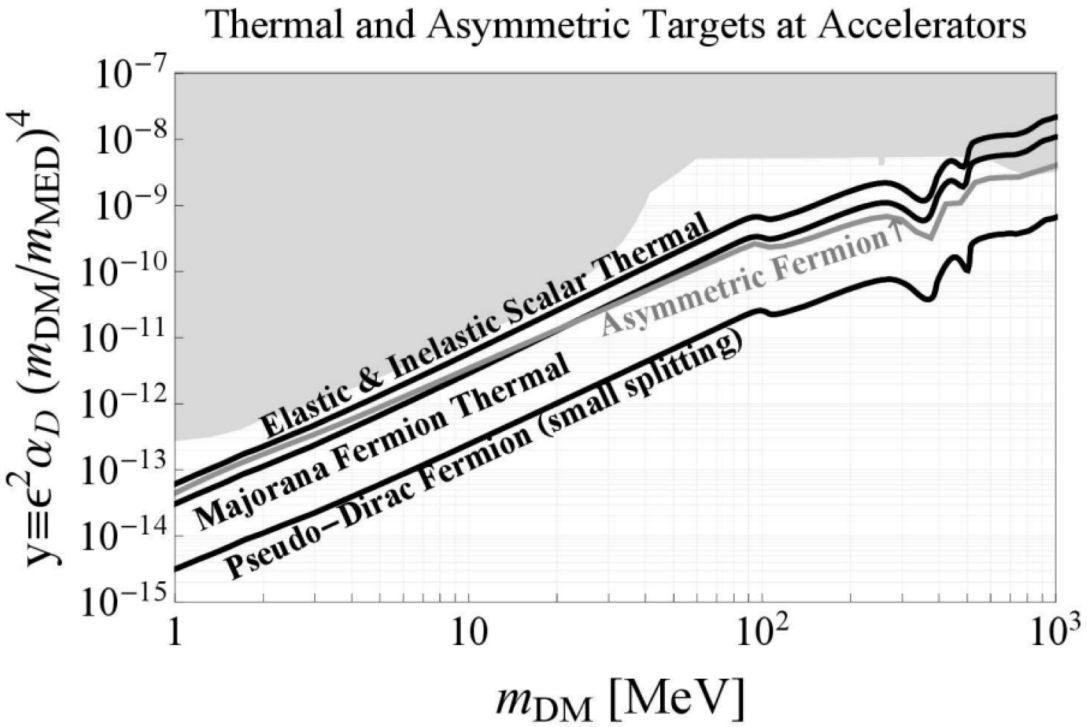
Event Selection Criteria:

1. In-time events
2. Single-hit per tracker
3. Reconstructed momenta in MS1 [135, 185 GeV].
4. Quality cut on downstream momenta in MS2 based on $\chi2$.
5. Energy compatible with MIP energy in calorimeters and veto

Thermal target



Since nonrelativistic direct detection cross sections can often be loop or velocity suppressed in many models, these targets vary by dozens of orders of magnitude in some cases. However, these vast differences in the direct detection plane mask the underlying similarity of these models in relativistic contexts where both the scattering and annihilation cross sections differ only by order-one amounts.



LDMX Collaboration, arxiv:1808.05219v1