
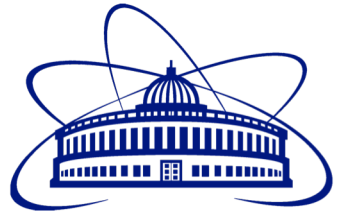

# First steps of searching for invisible decays of $\rho_0$ in the NA64 experiment

**Svetlana Gertsenberger**[1], A. Ivanov[1], A. Zhevlakov[2]

[1] JINR, Veksler and Baldin Laboratory of High Energy Physics

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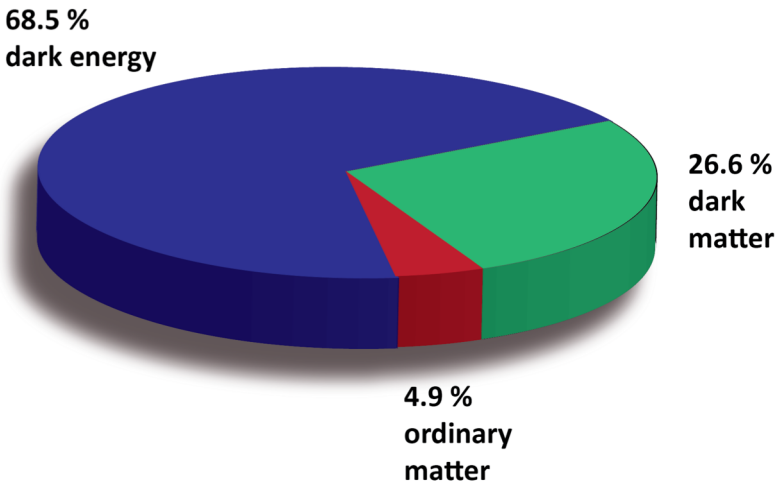
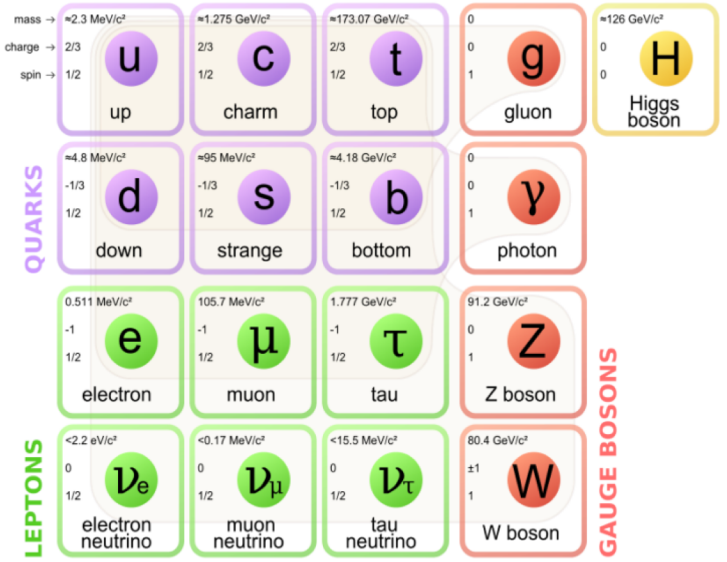
AYSS 2024, 01.11.2024

# *introduction*



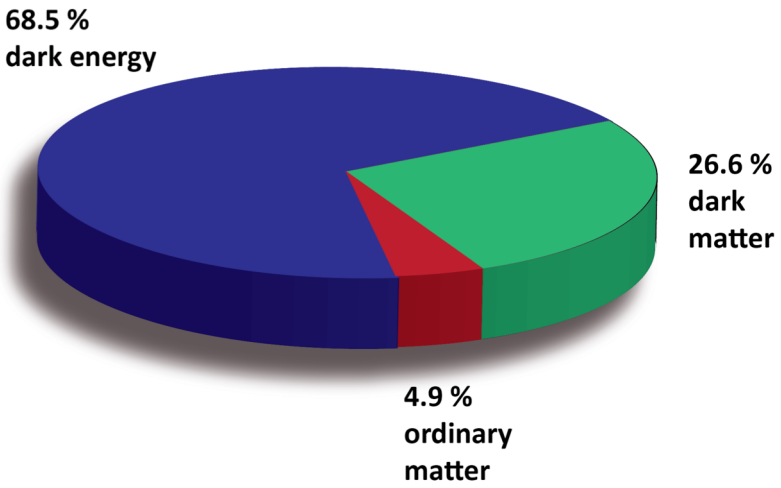

Astrophysical and cosmological observations, obviously demonstrate the existence of the dark matter (DM) and dark energy (DE) which are not described in the SM.




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*




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?

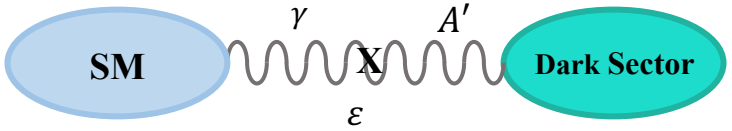
An extension of the SM is needed to explain the existence of DE and DM

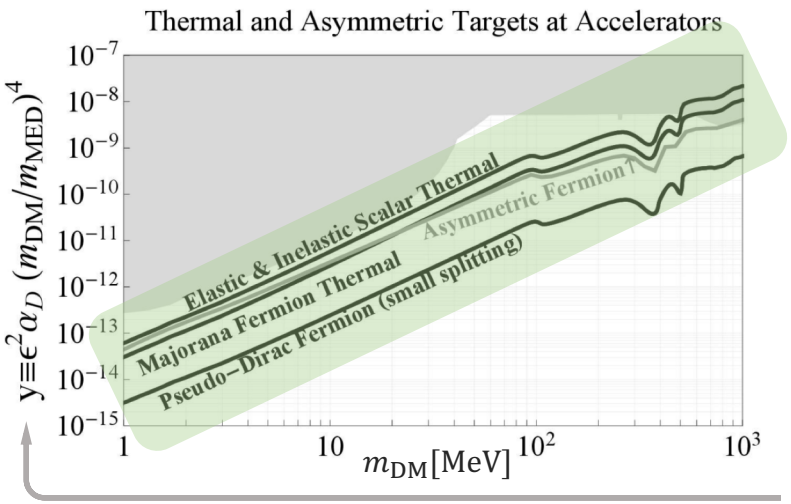
SDSS J1038+4849 from HST


# *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**. DM interacts with the SM via a vector mediator, e. g. dark photon $A'$, which is kinetically mixed with our photon



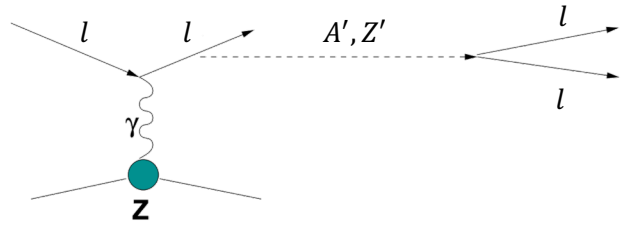




LDMX Collaboration, arxiv:1808.05219v1

useful coupling for comparison different experiments

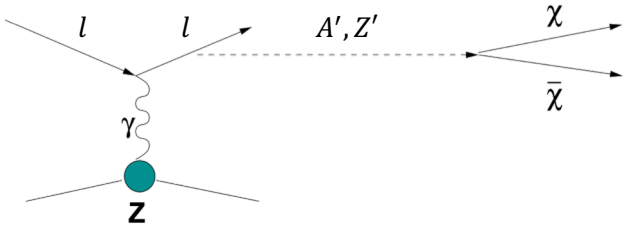
**Visible mode**

**Signature**: SM particles pair production




**Invisible mode**

**Signature**: missing energy/momentum




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

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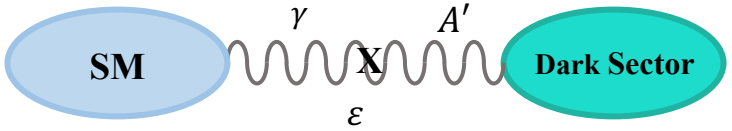


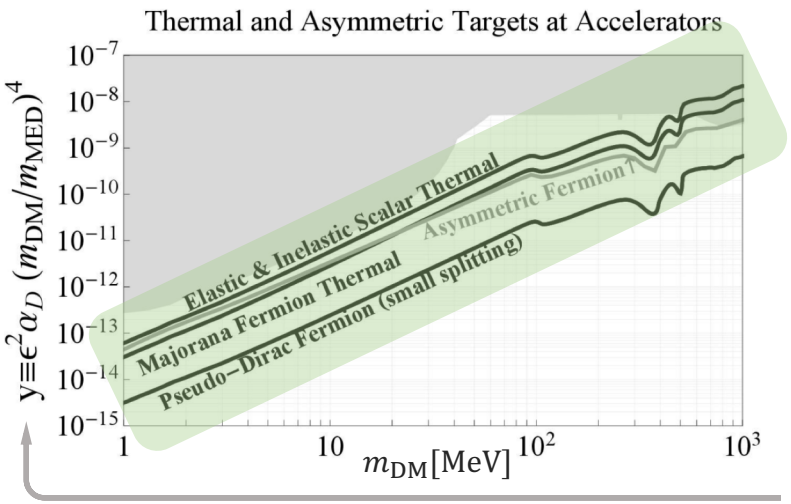


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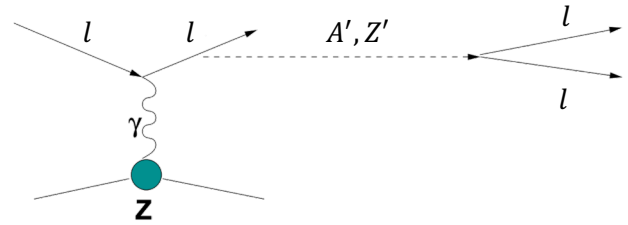


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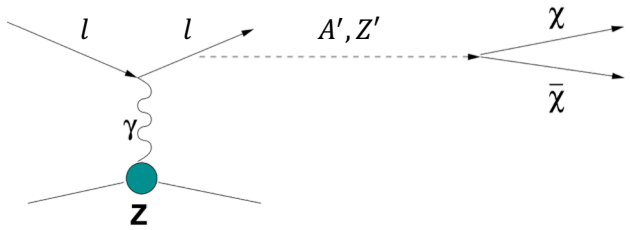


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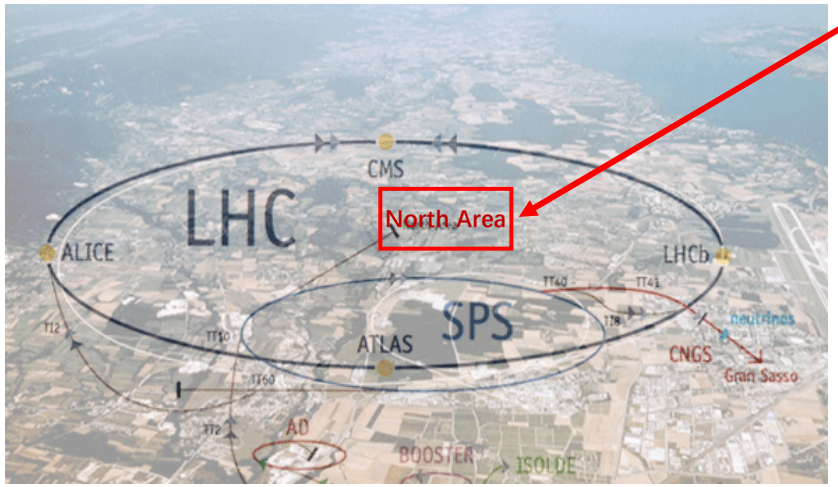
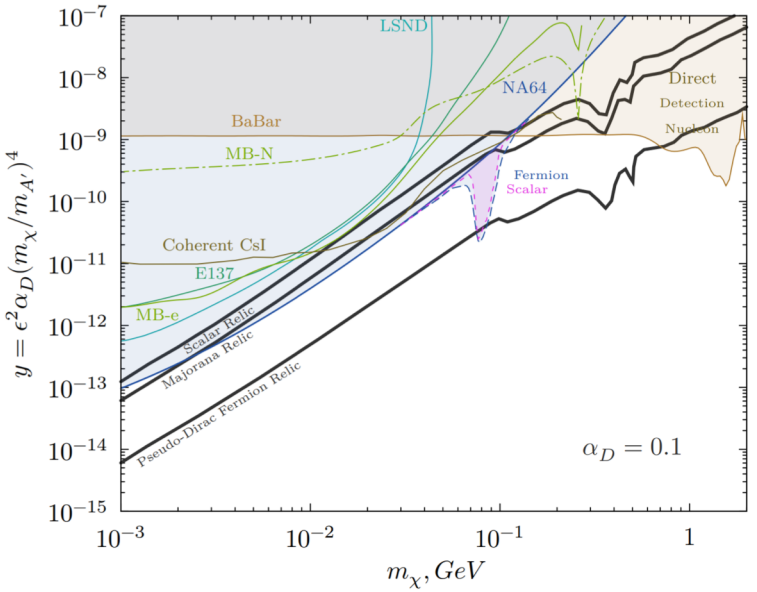
# *NA64 experiment*




**Motivation**: search for new physics beyond the SM

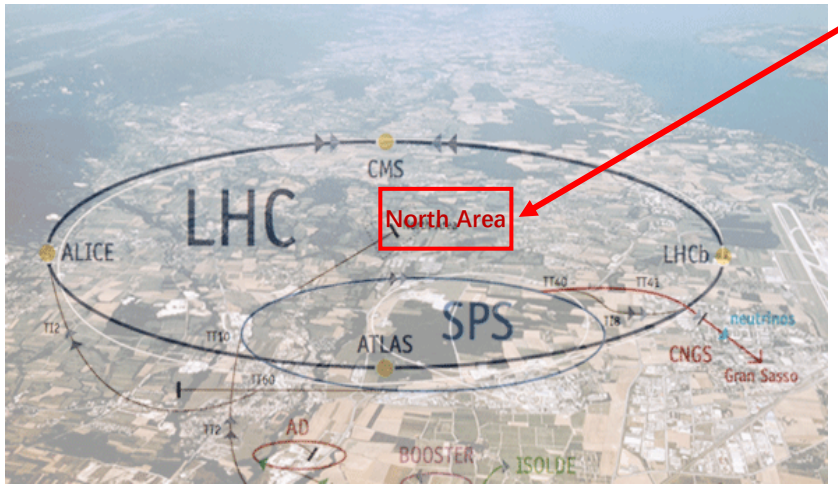
**Realization**: combine the active beam dump and missing energy techniques to search for rare events

- **NA64e** (since 2015)
  100 GeV *e*-beam
- **NA64$\mu$** (since 2021)
  160 GeV $\mu$-beam
- **NA64h**
  *~100 GeV h-beam*




Yu. Andreev et al. [NA64 Collaboration] arXiv:2307.02404 (2023)

# *NA64 experiment*

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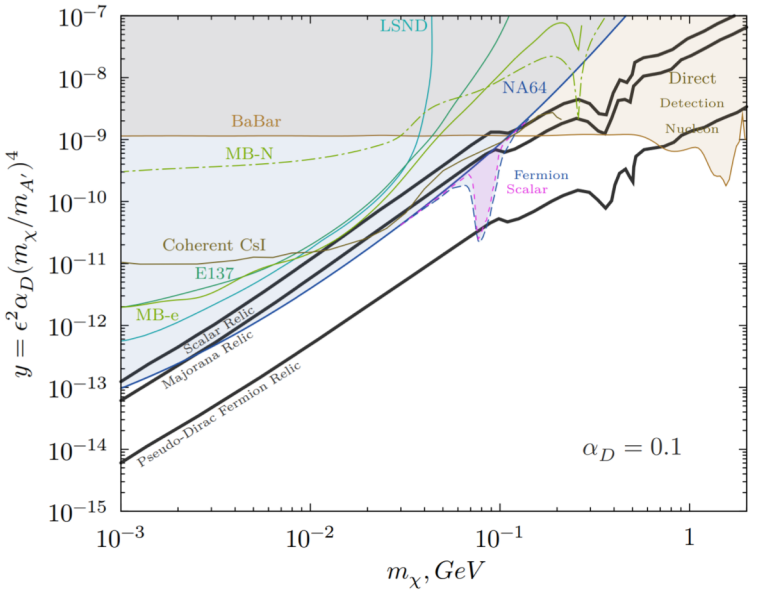



Yu. Andreev et al. [NA64 Collaboration] arXiv:2307.02404 (2023)

# *NA64 experiment*

**NA64e** (since 2015)
100 GeV $e$-beam

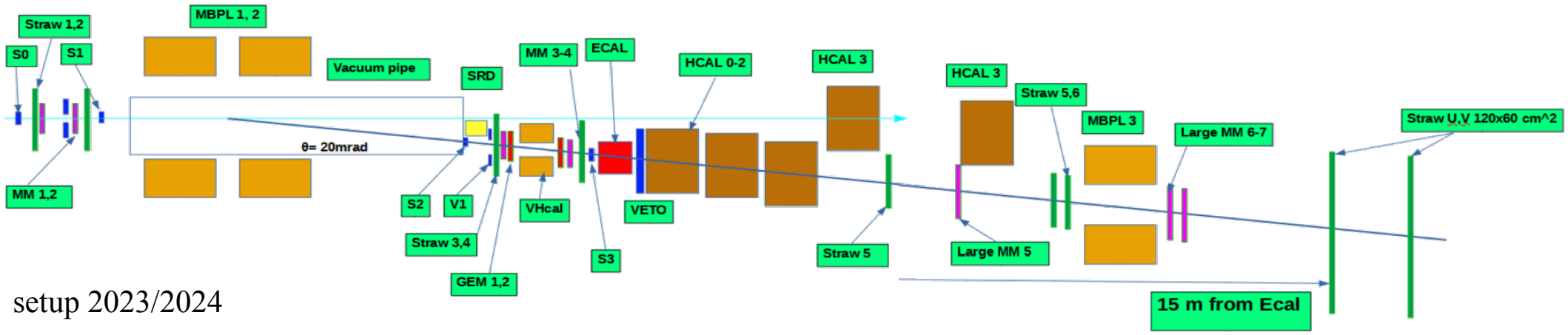
$N_{eot} = 5.2 \times 10^{11}$

- Thermal sub-GeV Dark Matter (LDM)
- axions, ALP, S → γ γ decays
- S, P, V, and A dark portal particles, their invisible, visible, semi-visible decays
- Light B-L Z′
- ATOMKI anomaly: X17 (P, V, A′) → e+e- decays
- MilliQ particles, etc…
- Lepton Flavor Violation in $e \to \tau$ and $e \to \mu$ conversion

**target:** lead ECAL

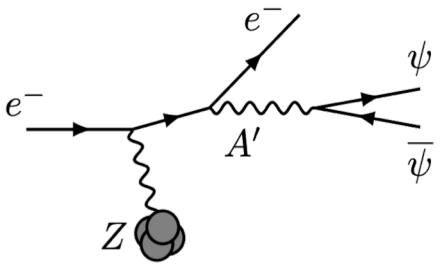
**signature:** missing energy in invisible mode or SM particles pair production in visible mode


A. Andreas et al. [NA64 Collaboration]. CERN-SPSC-2013-034; SPSC-P-348 (2013)
Yu. Andreev et al. [NA64 Collaboration] Phys.Rev.Lett. 129 (2022) 16, 161801
Phys. Rev. Lett. 125, 081801 (2020)

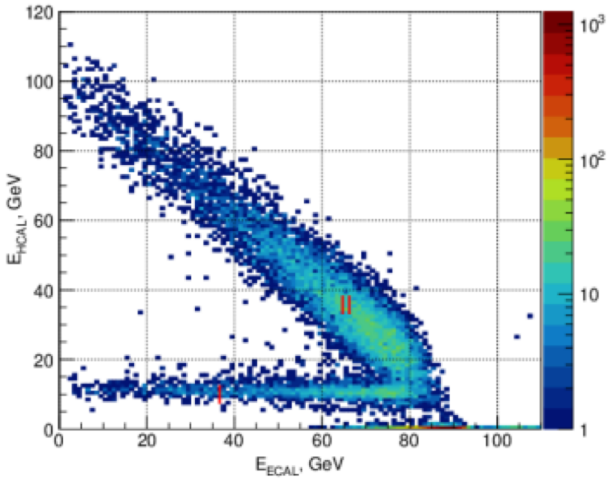

setup 2023/2024

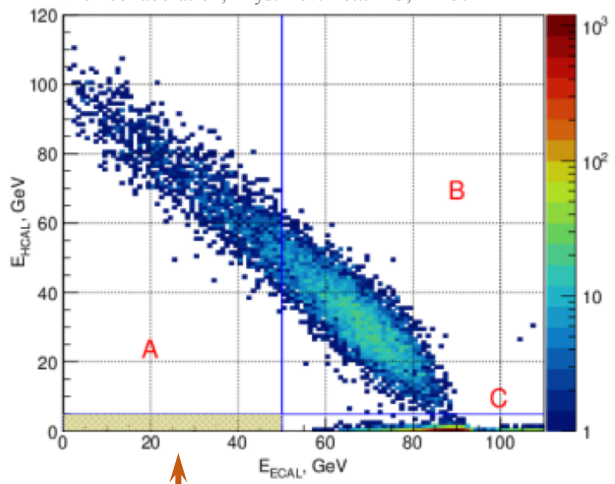
# *vector meson search motivation*




Schematic view of the Dark Matter (DM) signal from $A'$ Bremsstrahlung. DM is produced in the target (ECAL)

NA64 collaboration, Phys. Rev. Lett. 123, 121801



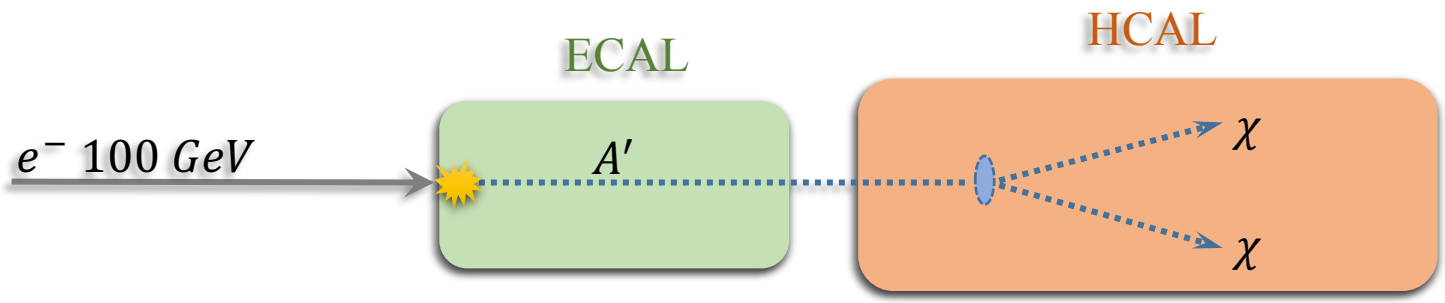




Signal box:

$E_{ECAL} < 50\ GeV + E_{HCAL} < 1\ GeV$

I: Dimuons background
$e^- Z \to e^- Z\gamma;\ \gamma \to \mu^+\mu^-$

II: $E_{ECAL} + E_{HCAL} \simeq 100\ GeV$



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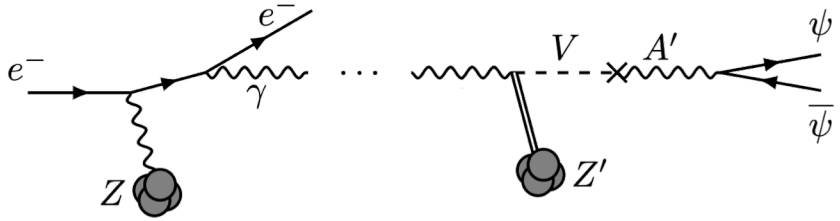
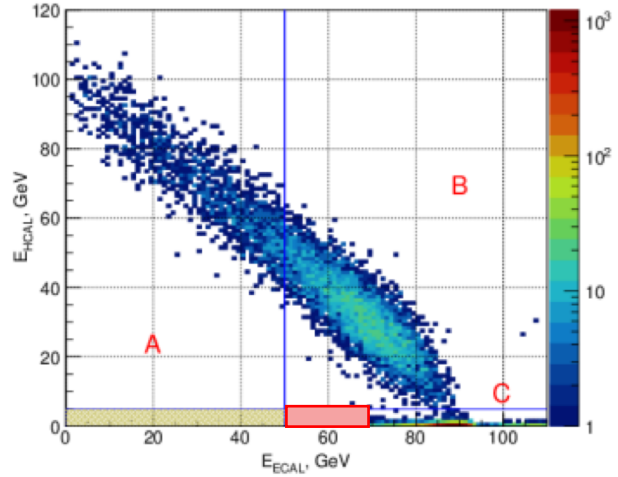



$$V = \rho_0, \omega, \varphi$$

A hard photon is produced in the ECAL, and converts to a vector meson V in an exclusive photoproduction process in the calorimeter. The vector meson then decays invisibly to DM via mixing with the $A'$.

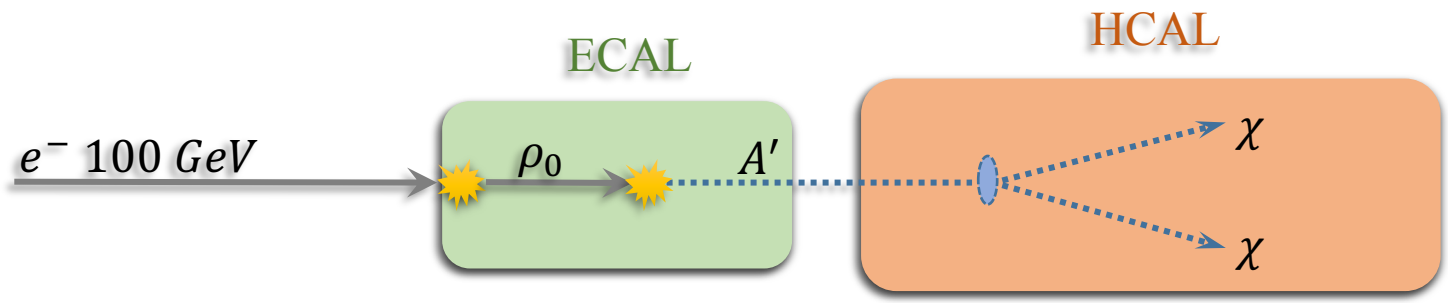
NA64 collaboration, Phys. Rev. Lett. 123, 121801



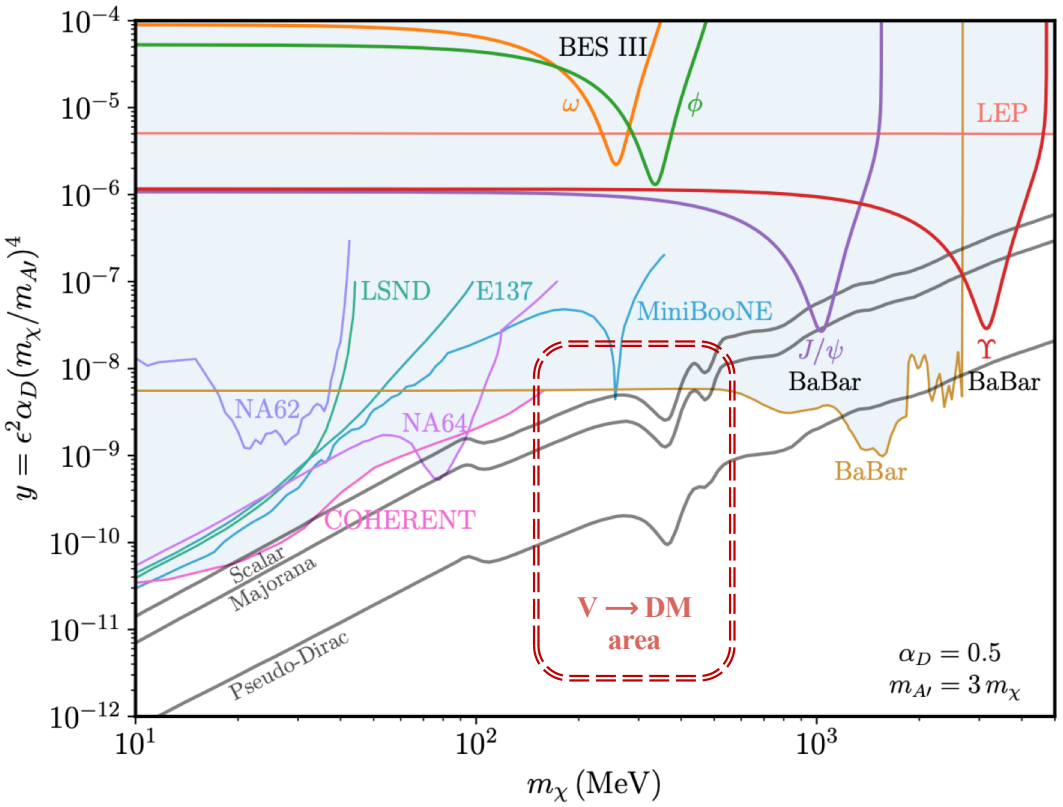

Signal box:

$E_{ECAL} < 70\ GeV + E_{HCAL} < 1\ GeV$

Due to ECAL threshold it is impossible to investigate region $80\ GeV < E_{ECAL} < 100\ GeV$



# *experimental searches*

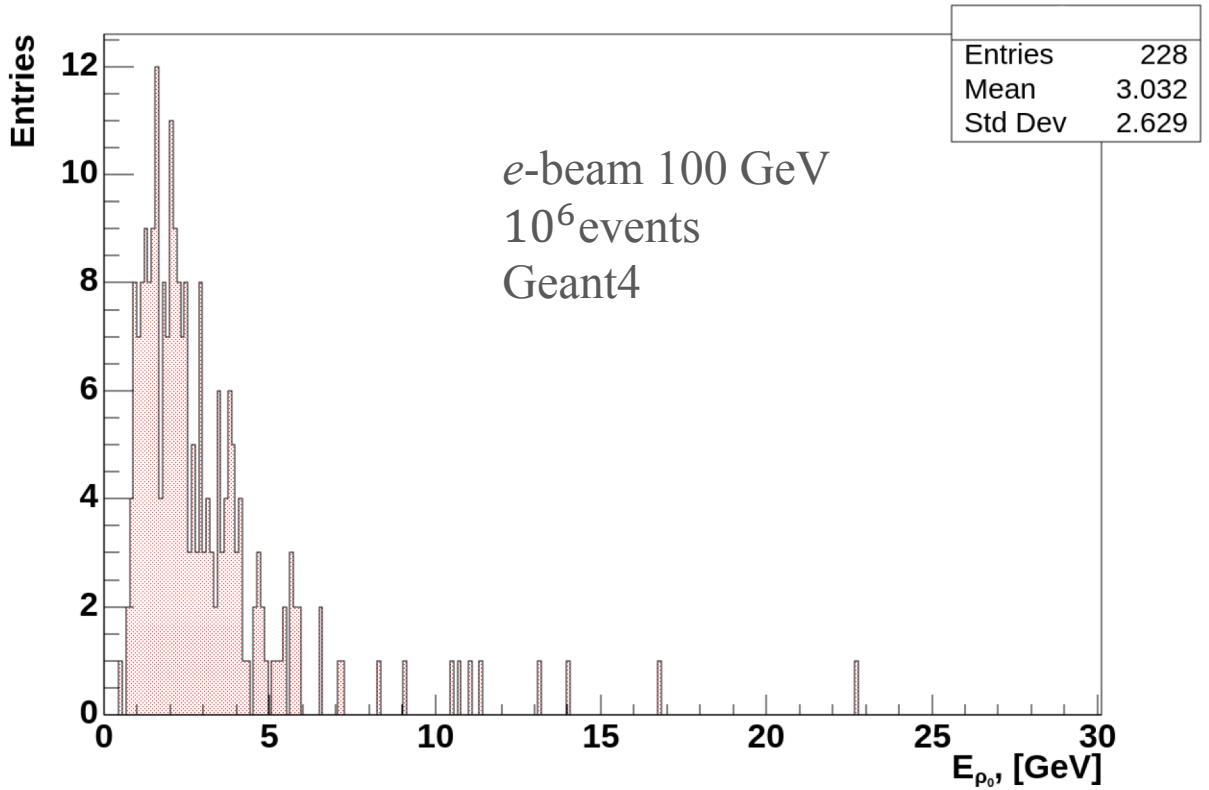



P. Schuster, Phys. Rev. D 105, 035036 (2022)

| | Br( V ⟶ invisible ) | Experiment |
|---|---|---|
| $\rho_0$ | ? | NA64? |
| $\omega$ | $< 7.3\times10^{-5}$ | BES III (2018) arXiv:1805.05613 |
| $\varphi$ | $< 1.7\times10^{-4}$ | BES III (2018) arXiv:1805.05613 |
| $J/\psi$ | $< 7\times10^{-4}$ | BaBar (2013) arXiv:1303.7465 |
| $\Upsilon$ | $< 3\times10^{-4}$ | BaBar (2009) arXiv:0908.2840 |

*$y$ – dimensionless coupling that defines the annihilation cross section*
*$m_\chi$ – DM mass*
*$\alpha_D = e_D^2/4\pi$ – dark coupling*
*$V = \rho_0, \omega, \varphi$*

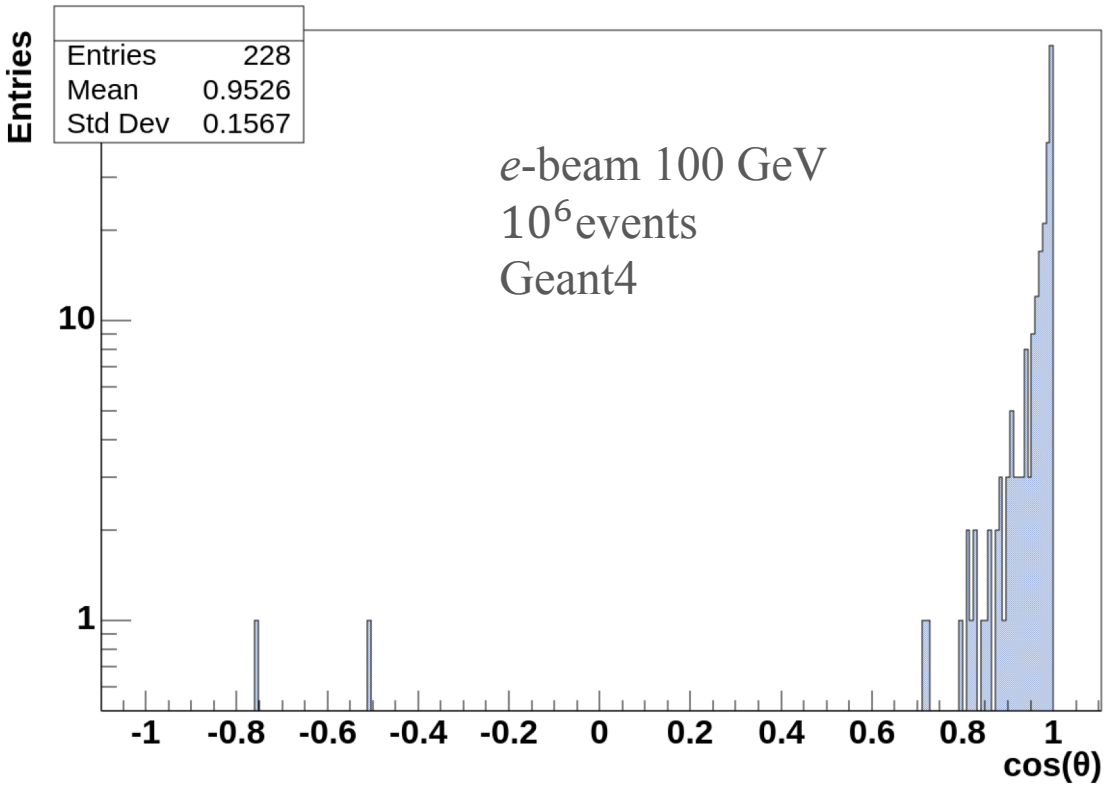
# $\rho_0$ - *mesons simulation*




- the majority of $\rho_0$ - meson are low energy and decay early in the target
- contribution from $\rho_0$ - decay will be small for existing strategy
- need more energetic $\rho_0$ - meson
  (need to simulate higher statistic to estimate more precisely the amount of energetic $\rho_0$ )
- $1.3 \times 10^7$ all $\rho_0$ - mesons or $\sim 10^5$ high energy $\rho_0$ are expected (with current statistics)

The total energy distribution of $\rho_0$ - mesons produced in 1 million events of a 100 GeV electron beam

# $\rho_0$ - *mesons simulation*



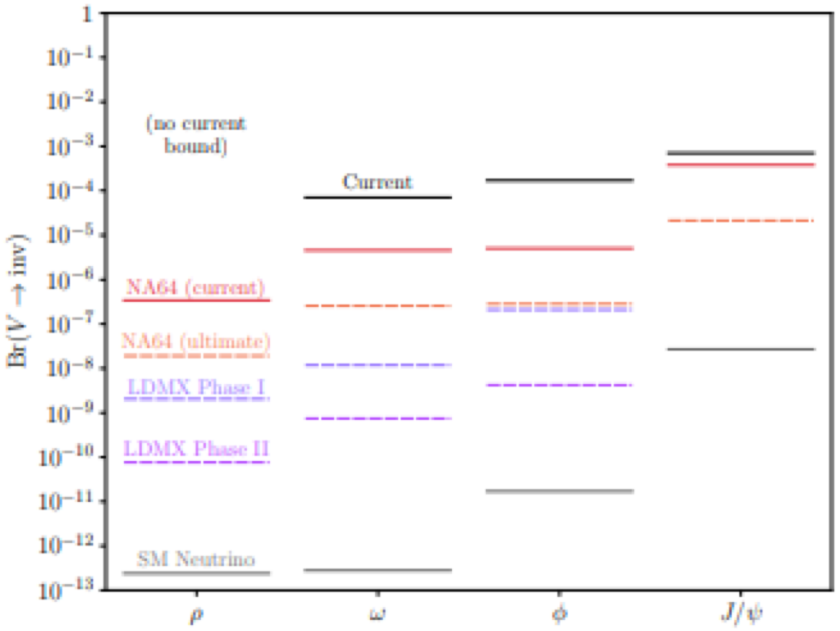

- almost all $\rho_0$ - mesons are directed towards the HCAL
- in case of energetic $\rho_0$ it possible to register the deposition energy from the decay products or the absence of energy with current setup
- to register the decay products from low energy $\rho_0$ we have to change trigger, reconstruct the setup, install additional detectors

The angular distribution of $\rho_0$ mesons produced in 1 million events of a 100 GeV electron beam.

# *theoretical bounds*

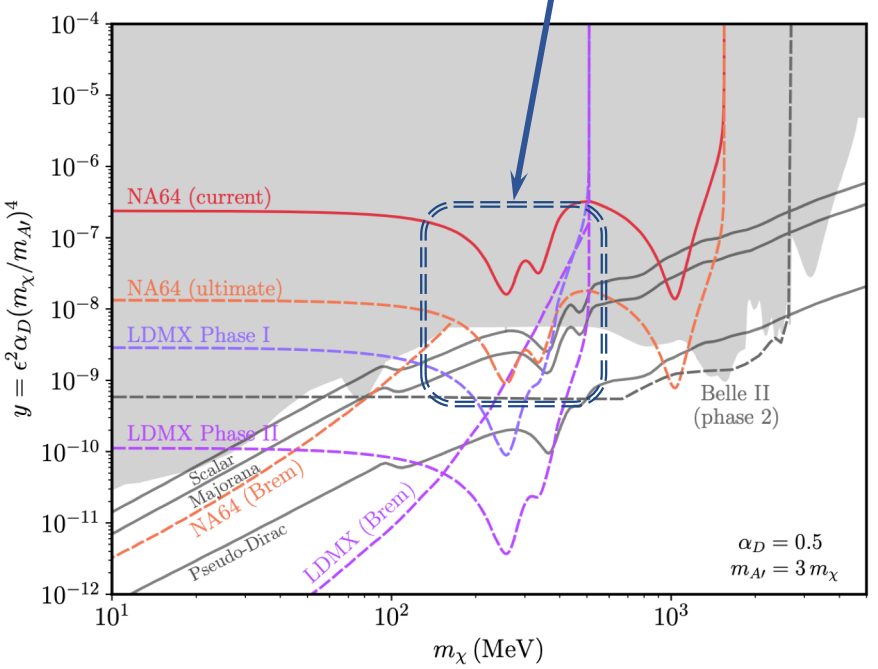
The constraints on dark sectors

P. Schuster, Phys. Rev. D 105, 035036 (2022)




There is no existing experimental bound for $\rho_0 \to DM$ process.

region for $\rho_0 \to DM$ searching




The NA64 ultimate line should have lower sensitivity than the first estimation because of the low energy of $\rho_0$.

In any case, there is an opportunity for this work =)

# *summary*

With statistics of total electrons on target $N_e = 5.2 \times 10^{11}$ collected since 2015,
$1.3 \times 10^7$ $\rho_0$ - mesons or $\sim 10^5$ high energy $\rho_0$ are expected

It is possible to increase signal box for the $A'$ searching. But due to ECAL threshold it is impossible to investigate region $80\ GeV < E_{ECAL} < 100\ GeV$

It is difficult to use existing strategy. It is necessary to change the analysis strategy. For example change the setup or investigate other channel of $\rho_0$ decay
$\rho_0 \to \mu^+\mu^- (\sim 10^{-5}\ \%)$

# Thanks!