Status and plans of the NA64 experiment

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142nd Meeting of the SPSC
10th June 2021
Outline

Motivation

1) Light dark matter:
   - Invisible decays
     - Plans for August 2021 run
     - Future prospects:
       - $e^+$ beam (NEW)
       - $\mu^+\rightarrow p$ pilot run in 2021

2) Constraints on new physics:
   - (g-2)$_\mu$
   - Semi-visible decays (NEW)
   - $\mu^+\rightarrow p$ pilot run in 2021
   - ALPs
   - (g-2)$_e$
     - 2016-2018 analysis

$^8$Be anomaly:
   - Visible decays
     - Highlights from 2016-2018 analysis
     - Plans for 2022

NA64 experiment

Fixed target experiment
NA64 target: dark sectors → the vector portal

An interesting framework to explain the origin of dark matter

Existence of dark sectors which couple weakly with standard model particles and can decay into dark matter candidates.

\[ L_{\text{Total}} = L_{\text{SM}} + L_{\text{DS}} + L_{\text{Portal}} \]

- Vector: Dark Photon

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

Complementary searches involving different techniques

G. Lanfranchi, M. Pospelov and P. Schuster
arxiv:2011.02157
NA64 target: Light thermal dark matter (LTDM)

Complementary searches involving different techniques

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

Predictions from DM relic abundances

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

Light Dark Matter experiment arXiv:1808.05219v1
NA64 target: \((g-2)_\mu\) an additional motivation

\[ a_\mu = \frac{g_\mu - 2}{2} \]

Anomalous muon magnetic moment

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

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

Specific target for NA64

- B. Abi et al. Muon g-2 collaboration Phys. Rev. Lett. 126, 141801

Including the latest lattice QCD calculations the discrepancy with the experimental value gets reduced below 2\(\sigma\): Sz. Borsanyi et al Nature volume 593, pages 51–55 (2021)
NA64 technique \textit{for $A'$ decays and its signatures}\newline
\textit{Fixed target experiment at the CERN SPS designed to probe Dark sector physics}

\begin{itemize}
\item \textbf{Setup:} \newline \begin{itemize}
\item \textbf{Visible mode} \newline $m_{A'} < 2m_\chi$ \newline \begin{itemize}
\item $e$ \quad \begin{array}{c}
\Downarrow \\
\epsilon
\end{array} \quad \begin{array}{c}
\Downarrow \\
\gamma
\end{array} \quad \begin{array}{c}
\Downarrow \\
A' \epsilon
\end{array} \quad \begin{array}{c}
\Downarrow \\
N \quad N
\end{array}
\end{itemize}
\item \textbf{Invisible mode} \newline $m_{A'} > 2m_\chi$ \newline \begin{itemize}
\item $e$ \quad \begin{array}{c}
\Downarrow \\
\epsilon
\end{array} \quad \begin{array}{c}
\Downarrow \\
\gamma
\end{array} \quad \begin{array}{c}
\Downarrow \\
\sqrt{\alpha_D} = g_\chi
\end{array} \quad \begin{array}{c}
\Downarrow \\
\chi \quad \chi
\end{array}
\end{itemize}
\end{itemize}
\item \textbf{Signature:} \newline \begin{itemize}
\item \textbf{SM particles pair production} \newline \textbf{Missing energy}
\end{itemize}
\end{itemize}

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

Tracking system:
8 XY multiplexed resistive micromegas and 4 GEM detectors
E. Depero et al., NIMA 866 (2017) 196-201
D. Banerjee et al., NIMA 881 (2018) 72-81

Beam tagged through S1-3 ➡ Lead Scintillator sandwich ➡ High hermeticity (∼40 $X_0$) ➡ Energy resolution ~ 9%/√(E[GeV])

Beam tagged through S1-3 ➡ Iron Scintillator sandwich ➡ High hermeticity (∼28λ) ➡ Energy resolution ~ 60%/√(E[GeV])

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

Standard model $E_{ECAL} + E_{HCAL} = 100$ GeV

$\alpha_D = g \chi$

$\sqrt{\alpha_D} = 9 \chi$

$N \gamma$, $N \chi$

Signal box

$E_{HCAL}$ [GeV] vs $E_{ECAL}$ [GeV]
NA64 invisible mode: main physics goal LDM

2014 | 2015 | 2016 | 2017 | 2018

Invisible

Beam time

\[
\sigma_A'_{\text{NA64}} \propto \epsilon^2 \quad \text{Vs} \quad \sigma_A'_{\text{Beam Dump}} \propto \epsilon^4 \alpha_D
\]

Reminder:

Proportional to DM→SM annihilation cross-section

\[
m_{A'} = 3 \cdot m_\chi
\]

Combined invisible analysis data 2016-2018 with \(2.84 \times 10^{11}\) EOT

A’ → χχ’: Results exceeded sensitivity of previous experiments to thermal sub-GeV dark matter.
**Motivation:**

**NA64 invisible mode:** Constraints on new physics in \((g-2)_{\mu}\)

**Signature:** semi-visible decay

**Dark photon explanation for \((g-2)_{\mu}\)** excluded by NA64 and BaBar


Motivation:

\[(g-2)_{\mu} \text{ anomaly+LTDM}\]


G. Mohlabeng, PRD 99, 115001 (2019)

Y. Tsai, et al., PRL126, 181801 (2021)

\[
\Gamma(\chi_2 \to \chi_1 e^+ e^-) \simeq K \frac{4 e^2 \alpha_{EM} \alpha_D \Delta^5}{15 \pi m_{A'}^4}
\]

\[
\Delta = m_{\chi_2} - m_{\chi_1} \quad K \simeq 0.640 \pm 0.001
\]

**Signature:** Missing energy + SM particles pair production


Paper under collaboration review

\[\Delta = 0.4 m_{\chi_1}, \ m_A = 3 m_{\chi_1}, \ \alpha_D = 0.1\]

Update

Analysis using combined 2016-2018 invisible data

P. Crivelli, EP CERN seminars 25th May 2021
**NA64 invisible mode: ALPs**

ALPs predominantly coupled to photons produced via Primakoff effect

\[ L_{\text{int}} = -\frac{1}{4} g_{\gamma\gamma} F_{\mu\nu} \tilde{F}^{\mu\nu} a \]

NA64 invisible setup

**Signature:**
No signal on veto and HCAL1

A. **Visible Decay into \( \gamma\gamma \)** on HCAL2 \(\parallel\) HCAL3
B. **Decays after HCAL3:** no activity on HCAL2 \& HCAL3

Main goal: to probe the gap in the parameter space between the beam-dump and LEP searches

Update

NA64 collaboration, Phys. Rev. Lett. 125, 081801

100 GeV \(e^-\)

EOT

Update

2.84 \(\times\) \(10^{11}\) EOT

L.Molina Bueno
NA64 invisible mode: Constraints on new physics in (g-2)_e

\[
\Delta a_e = a^{exp}_e - a^{LKB}_e = (4.8 \pm 3.0) \times 10^{-13} (1.6\sigma) \\
\Delta a_e = a^{exp}_e - a^B_e = (-8.8 \pm 3.6) \times 10^{-13} (-2.4\sigma)
\]

Results from high precision measurements of \(\alpha\):

Could a new generic boson contribute to (g-2)_e?

\[ e^- Z \rightarrow e^- ZX; X \rightarrow \text{invisible}\]

\(e^- - X\) with coupling strength: \(g_x = \varepsilon_x e\)

NA64 approach on probing new physics in (g-2)_e one order of magnitude more sensitive than high precision experiments


NA64 collaboration, Phys. Rev. Lett. 126, 211802

L. Molina Bueno
NA64 DMG4 simulation framework developments

Dedicated Dark Matter simulation package in fixed target experiments DMG4 (M.Bondi et al arXiv:2101.12192) developed using GEANT4 (G4) toolkit and fully compatible with any G4-based simulation framework:

- **Several processes implemented**: electron and muon Bremstrahlung, resonant in flight positron annihilation on atomic electrons and gamma to ALP (axion-like particles) conversion on nuclei.

- **Different particle mediators**: Scalar, pseudoscalar, axial and vector

Several improvements have been included since last report:

- **More flexible configuration of the Dark matter type**
- **Different particle mediators also implemented in the positron annihilation process**
- **Extension of the kinematics limits on the X variable ($E_{DM}/E_0$) in electron and muon Bremsstrahlung process**
- **In the case of muon Bremsstrahlung**:
  - Implementation of all $Z'$ decay modes
  - Cross-sections calculated using ETL, WW and IWW approximations
  - Cross-sections also derived as a function of the scattered muon angle
  - Faster sampling for $A'$ Bremsstrahlung
**NA64 invisible mode: LDM future prospects**

- New fixed location at H4 beam line.
- Beam, setup and electronics upgrades:
  - **Improve performance**
  - **Reduce background from electro nuclear interactions.**
- **Goal:** Accumulate few $10^{11}$ EOT in 2021 and $5 \times 10^{12}$ EOT before LS3.

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**Main source:** electro-nuclear interactions along the beam line

<table>
<thead>
<tr>
<th>Background source</th>
<th>Background number, $n_b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>punchthrough $\gamma$'s, cracks, holes</td>
<td>$&lt; 0.01$</td>
</tr>
<tr>
<td>loss of dimuons</td>
<td>$0.024 \pm 0.007$</td>
</tr>
<tr>
<td>$\mu \rightarrow e\nu\pi$, $K \rightarrow e\nu$, $K_{e3}$ decays</td>
<td>$0.02 \pm 0.01$</td>
</tr>
<tr>
<td>$e^-$ interactions in the beam line</td>
<td>$0.43 \pm 0.16$</td>
</tr>
<tr>
<td>$\mu, \pi, K$ interactions in the target</td>
<td>$0.044 \pm 0.014$</td>
</tr>
<tr>
<td>accidental SR tag and $\mu, \pi, K$ decays</td>
<td>$&lt; 0.01$</td>
</tr>
<tr>
<td>Total $n_b$</td>
<td>$0.53 \pm 0.17$</td>
</tr>
</tbody>
</table>

S. Gninenko, PBC workshop 2021

NA64 invisible mode: 2021 run preparation

2021 Resume data taking 11th August (5 weeks)

Status of new H4 experimental area

- **Improved beam properties** and design of the new area in close collaboration with BE-EA liaison physicists and technical experts, [https://edms.cern.ch/document/1865057/3.1.](https://edms.cern.ch/document/1865057/3.1).

- Beam optimisation based in MC and optics studies.
  - **Goals:** maximise the electron flux, reduce the beam halo and minimise the electron beam hadronic contribution to a level less than **2%**.
  - Full realistic H4 beam line simulation including all secondaries, beam-loss points for radiation shielding design and showing the effect of collimation, size and divergence of the beam along its propagation.
**NA64** invisible mode: 2021 run preparation

### Setup and detector upgrades

**New** higher transverse segmentation **Synchroton radiation (SRD)** detector with improved readout

**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.

**New Micromegas trackers**
- Reduced material budget
- Larger traverse size to enlarge acceptance

- New detectors already produced in Protvino.
- Delivery at CERN in June second half.

- Produced and already delivered at CERN.
- Characterisation with cosmics ongoing
**NA64 invisible mode: 2021 run preparation**

**DAQ system and electronics upgrade**

<table>
<thead>
<tr>
<th></th>
<th>Previous</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trigger rate capabilities</td>
<td>6 kHz</td>
<td>30 kHz</td>
</tr>
<tr>
<td>Dead time</td>
<td>20%</td>
<td>4%</td>
</tr>
</tbody>
</table>

The FARO modules are plugged to P2 connector of the MSADCs and transmit data directly to the DAQ.

Each module can transmit up to 160MB/s.

New electronics under development by INFN Genova with faster MSADC boards (80 MHz → 250 MHz) for future high intensity runs.
NA64 invisible mode: LTDM future prospects

How can we enlarge the sensitivity at higher masses?

New ideas:

- **Positron beam and A' resonant production**
  
  Explore the **resonance annihilation channel using the secondary positrons** present in the electromagnetic (EM) shower in the target **induced by the initial e⁺ beam**

  NA64 internal note 19-04
  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)

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

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


Status in few slides
NEW! Future prospects: $A'$ resonance

1) Resonance annihilation channel using the secondary positrons present in the EM shower in the target induced by the initial electron beam.

Sensitivity calculated for a generic $X$ boson (S,P,A,V)

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

Combined 2016-2018 invisible mode data

2) NA64-like experiment using 100 GeV positron beam

A factor 10 improvement in $\varepsilon$ translates to a factor 100 in $y$ ($\sim \varepsilon^2$)
Future prospects: \( \text{NA64}_\mu \) experiment

**Exploring Dark sector physics weakly coupled to muons**

Location M2 beam line upstream COMPASS

160 GeV \( \mu^- \)

**Signature**
- Missing momentum (Deflected \( \mu^- \) energy <80 GeV).
- Energy on ECAL, VHCAL and HCAL compatible with a muon energy deposit.

\[ \sqrt{\alpha_D} = gX \]

\( \gamma \)

\( Z^\mu, A' \) decaying to DM particles

\( Z^\mu, A' \) decaying to DM particles
Future prospects: **NA64$\mu$** physics goals

1. *Light Z' coupled to the muon*, as a remaining low mass explanation of the $(g-2)_\mu$ (the muon anomaly).

2. *Light thermal dark matter* in the $A'$ mass region $\geq 0.1$ GeV (complementary search to NA64e).

3. *Scalar, ALPs coupled to the muon, millicharged particles, ....*

4. *Lepton Flavour Violation in $\mu Z \rightarrow \tau Z$ conversion* in flight.

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**LS2** | **LS3**
---|---
2020 | 2021 | 2022 | 2023 | 2024

- **Pilot run**
- **Phase 1**
- **Phase 2**

**19 days end of October**

*Expected first physics runs to probe $Z'$ as $(g-2)_\mu$ explanation*

$N'_A \sim L_\sigma A'_A \sim \frac{e^2}{m_A^2}$

$e^- L^e = X_0$

$\mu^- L^\mu = 40X_0$

---

$\alpha_D = 0.1$

*S.Gninenko et al. PLB796, 117 (2019)*
Future prospects: **NA64*μ 2021 pilot run**

*In collaboration with BE-EA group (D.Banerjee and J. Bernhard)*

**19 days in October 2021**

**Goal:** Feasibility of the technique to search for a Z’ boson in the MeV-GeV range

Space for commonly used infrastructures such as gas, electrical outlets, grounding, DAQ fibres, space for racks and control room already in preparation.

**Beam Momentum Stations (BMS)**

**Status of new detectors**

- 25x8 cm² Micromegas for tracking after the magnet.
- MBPL magnet with 20 cm gap
- Simplified trigger system for pilot run based on scintillators counters in production.
- VHCAL and ECAL (delivery second half of June)
- Two large HCAL modules 120x60cm² (production and delivery ongoing)
Future prospects: NA64$_\mu$ feasibility studies

1) Accurate Z' (A') Bremsstrahlung simulation using a $\mu$ beam:
   - Trigger based on the scattered muon → Important to simulate the muon angle emission accurately
   - Impact of the different phase space approximations used in cross-section calculations to reduce a 2→3 to a 2→2 body decay on the signal yield.
   - Differences between exact calculations, the so called Weizacker Williams (WW) approximation and the simplified version to faster simulations (IWW).
   - Paper in preparation

2) Full simulation and reconstruction package developed in GEANT4 for NA64$_\mu$:
   - Realistic M2 beam line and halo profiles simulations provided by the BE - EA group (D. Banerjee and J. Bernhard) + Experimental Setup

<table>
<thead>
<tr>
<th>Source of background</th>
<th>Level per MOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scattered muon momentum reconstruction mismatch</td>
<td>$\lesssim 10^{-13}$</td>
</tr>
<tr>
<td>Detector non-hermeticity</td>
<td>$\lesssim 10^{-12}$</td>
</tr>
<tr>
<td>Single-hadron punch-through</td>
<td>$\lesssim 10^{-12}$</td>
</tr>
<tr>
<td>Hadron in-flight decay</td>
<td>$\lesssim 10^{-13}$</td>
</tr>
<tr>
<td>Dimuon production</td>
<td>$\lesssim 10^{-12}$</td>
</tr>
<tr>
<td>Total (conservatively)</td>
<td>$\lesssim 10^{-12}$</td>
</tr>
</tbody>
</table>

Future prospects: NA64μ 2021 pilot run

Plans for the 19 days in October 2021

1. **Assembly** and **commissioning** of the detector

2. Commissioning of the M2 beamline and study and optimisation of the M2 beam and halo in collaboration with BE-EA group.

3. **Study of the trigger rate** and the **accidental rate**. For the first phase we expect to run at 2x10^6 μ/spill.

4. **M2 hadron contamination**: crucial step to understand the level of background in our measurement.

5. **Measurement of the magnetic spectrometers (MS1 and MS2) performance**: accuracy in momentum reconstruction.

6. Collect a large sample of events to study the detector hermeticity and validate the beam simulations with data.

The analysis of the beam and the obtained results would play an essential role to understand the detector and the next steps.
NA64 visible mode: $A' \rightarrow e^+e^-$

$N \rightarrow \gamma A' \rightarrow e^\epsilon$ SM

$e^-Z \rightarrow e^-ZX_{17}; X_{17} \rightarrow e^+e^-$

Motivates the need of an independent measurement

New recent results on other nuclei, $^4\text{He}$, show a similar excess

Motivates the need of an independent measurement


A magnetic spectrometer consisting of two MPBL magnets is designed for a direct search of the short-lived particles at the CERN SPS in the sub-GeV range. These values of responding to a short-lived dark photon excluding, in particular, the parameters that could be associated with the anomalous 0.005 anomaly. However, the mechanism responsible for this anomaly remains unexplored.

Matter puzzle. An intriguing possibility is that in addition to the ordinary photon, there exists a new light vector boson, massless and visible matter, transmitted by a new vector boson, weakly coupled to quarks and lepton, see e.g. [6–11]. Various phenomenological aspects of light vector bosons with the ordinary photon are considered in [12–16], for a review see, e.g. [15].

FIG. 1: Schematic illustration of the setup to search for defects of particles charged under both the dark and ordinary gauge interactions. In this Letter we report results of an optimized electron beam dump experiment employing the 100 GeV electron beam from the H4 beam line in the North Area of the CERN SPS.

**Challenge:** very short-lived X17

**Improvements in the 2018 setup**

- Beam energy from 100 to 150 GeV to boost X17 outside WCAL.
- Shorter WCAL to probe large epsilon.
- Thinner veto (W2) after WCAL to minimise the probability that X17 decays in it.
- For Background suppression: vacuum pipe installed+increased WCAL–ECAL distance.
- Additional trackers.
NA64  \textbf{visible mode:} 2017-2018 combined analysis

\[ e^{-}Z \rightarrow e^{-}ZX_{17}(A'); \ X_{17}(A') \rightarrow e^{+}e^{-} \]

\[ e^{-}Z \rightarrow e^{-}Za; \ a \rightarrow e^{+}e^{-} \]

**Vector-like boson** (benchmark model)

**Pseudo scalar boson**

--

NA64 collaboration, PRL 120, 231802 (2018), PRD 107, 071101 (R) 2020

NA64 collaboration, CERN-EPT.-2021-069, arXiv:2104.13342
Submitted to PRD (letter)
NA64 collaboration, PRL 120, 231802 (2018), PRD 107, 071101 (R) 2020

$e^-Z \rightarrow e^-ZX_{17}(A') \Rightarrow X_{17}(A') \rightarrow e^+e^-$

**Vector-like boson**
(benchmark model)

$10^{-2}$
$10^{-3}$
$10^{-4}$

$10^{-1}$

$m_{A'}, GeV$

KLOE-2013

HADES

BEPC

E774

NA48

BABar

E141

$g-2_e$

NA64

~20 days with optimised setup

**New detectors on preparation for 2022 run**

- New Tungsten calorimeter (WCAL)
- New ECAL with larger transverse dimensions
- New SRD optimised for 150 GeV beam energy
- New larger transverse size micromegas (same design as NA64μ)

**Full parameter space**
Invariant mass reconstruction

Update

Invariant mass reconstruction precision at the level of 2%

**New setup**

- Reduce WCAL length keeping the same number of X0
  (no impact from energy resolution loss in the measurement)
- Separate the $e^+e^-$ tracks
- Reconstruct the two electromagnetic showers

NA64 collaboration, EPJ C 80 (2020) 12, 1159
The NA64 experiment and its physics program

<table>
<thead>
<tr>
<th>Year</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>LS3</th>
</tr>
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<tbody>
<tr>
<td><strong>NA64e</strong></td>
<td>Invisible mode</td>
<td>Invisible mode</td>
<td>Invisible mode</td>
<td>Invisible mode</td>
<td>LS3</td>
</tr>
<tr>
<td></td>
<td>5 weeks</td>
<td>6 weeks</td>
<td>6 weeks</td>
<td>6 weeks</td>
<td></td>
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<tr>
<td></td>
<td>11th August</td>
<td>Visible mode</td>
<td>Visible mode</td>
<td>Visible mode</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 weeks</td>
<td>3 weeks</td>
<td>3 weeks</td>
<td>3 weeks</td>
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<tr>
<td><strong>NA64μ</strong></td>
<td>Pilot run</td>
<td>4 weeks</td>
<td>4 weeks</td>
<td>4 weeks</td>
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<tr>
<td></td>
<td>19 days</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>October 21st</td>
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</tbody>
</table>

**Broad physics program**

International collaboration: 50 researchers from 16 institutions

<table>
<thead>
<tr>
<th>Process</th>
<th>New Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^{-}$ beam</td>
<td>Dark photon</td>
</tr>
<tr>
<td>$A' \to e^+e^-$, and</td>
<td>sub-GeV Dark Matter ($\chi$)</td>
</tr>
<tr>
<td>$A' \to invisible$</td>
<td>new gauge X- boson</td>
</tr>
<tr>
<td>$A' \to \chi \chi$</td>
<td>Dark Sector, charge quantisation</td>
</tr>
<tr>
<td>$X \to e^+e^-$</td>
<td>Axion-like particles</td>
</tr>
<tr>
<td>milliQ particles</td>
<td></td>
</tr>
<tr>
<td>$a\to \gamma\gamma$, invisible</td>
<td></td>
</tr>
</tbody>
</table>

| $\mu^-$ beam | |
| $Z_\mu \to \nu\nu$ | gauge $Z_\mu$-boson of $L_\mu - L_\tau < 2m_\mu$ |
| $Z_\mu \to \chi \chi$ | | |
| milliQ | | |
| $a_\mu \to invisible$ | | |
| $\mu - \tau$ conversion | | |

| $\pi^-, K^-$ beams | Current limits, PDG’2018 |
| $\pi^0 \to invisible$ | $Br(\pi^0 \to invisible) < 2.7 \times 10^{-7}$ |
| $\eta \to invisible$ | $Br(\eta \to invisible) < 1.0 \times 10^{-4}$ |
| $\eta' \to invisible$ | $Br(\eta' \to invisible) < 5 \times 10^{-4}$ |
| $K^0_S \to invisible$ | no limits |
| $K^0_L \to invisible$ | no limits |

| e$^+$ beam | |
| Resonant $A'$ production | |
| True Muonium | |

CERN Council Open Symposium on the Update of European Strategy for Particle Physics
13-16 May 2019 - Granada, Spain

CERN-PBC-REPORT-2018-007

L.Molina Bueno
**Summary and outlook**

*Dark sector physics* interesting framework to explain dark matter

NA64 is an ideal experiment for testing benchmark scalar, Majorana and pseudo-Dirac thermal sub-GeV dark matter models

**Prospects before LS3**

- New area at H4 and setup upgrade to run at high intensity
- **Main goal** to explore LDM parameter space with > goal $5 \times 10^{12}$ EOT
  - Start **searches of dark sectors weakly coupled to muons** with NA64μ:
    - $(g-2)_\mu$ and $L_\mu-L_\tau Z'$: pilot run in 2021 at M2
    - Probing light dark matter parameter space for mA'> 100 MeV
  - **Increase sensitivity to A' → e+e- decays** and explore X17→ e+e- remaining parameter space in 2022: *in case of signal-like events reconstruct the invariant mass with precision at few percent level.*

**Exploration of LDM with NA64 has just began.**

**Full physics potential to be exploited in the coming years!**
THANKS!

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ETH Zürich group in particular P. Crivelli, B. Bento, E. Depero, H. Sieber

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