NA64

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On behalf of the NA64 collaboration

(The NA64 Collaboration)
NA64: Search for dark sector physics in missing energy events

• Approved in March 2016 for the $A' \rightarrow$ invisible decay search with electron beam.

• Two runs in 2016 $\rightarrow$ focus on the $A'$ parameter space suggested for the $(g-2)_\mu$ anomaly.

• First results from the two weeks beam time in July’2016 published, most of the $(g-2)_\mu$ favoured parameter space excluded.

• 10 times more statistic acquired in October’2016. Analysis in progress.
NA64: Setup

Key Features of the setup:
NA64: Search for dark sector physics in missing energy events

**NA64** $\rightarrow$ fixed target experiment combining the active beam dump technique with missing energy measurement searching for invisible decays of massive $A'$ produced in the reaction $eZ \rightarrow eZ A'$ of electrons scattering off a nuclei $(A,Z)$, with a mixing strength $10^{-6} < \varepsilon < 10^{-3}$ and masses $M_{A'} \sim$ sub-GeV range.

**100 GeV electrons** dumped against an ECAL, a sandwich of lead and scintillators ($34 \ X_0$), to produce massive $A'$ through scattering with the heavy nuclei.

The typical signature for a signal will be **missing energy in the ECAL** and no activity in the the VETO and HCAL.

Background from hadrons, muons and low energy electrons must be rejected upstream.
NA64: Search for dark sector physics in missing energy events

**Standard model**

**With Dark photon**

A’ spectra, 100 GeV e⁻

GEANT4 + A’ emission

**signal**
Key Features of the setup:

- High energy beam to trigger the reaction: 100 GeV e- beam from the CERN SPS.
- Max intensity $\sim 5 \times 10^6$ e$^-$/spill.
- Typically 2 spills/minute.
- Main impurities of H4 beam: $\pi^-$, low energy e$^-$ ($\sim 1\%$), $\mu^-$ and K$^-$ ($\approx 0.1\%$).
Key Features of the setup:
• High energy beam to trigger the reaction: 100 GeV e- beam from the CERN SPS.
• Max intensity $\sim 5 \times 10^6$ e$^{-}$/ spill.
• Typically 2 spills/min
• Main impurities of H4 beam: $\pi^-$, low energy e$^-$ (\~1%) $\mu^-$ and K$^-$ (\~0.1%)
Key Features of the setup:
- High hermeticity: ECAL - PbSc sandwich, $38 \times 38 \times 445 \text{ mm}^3$ ($\sim 40 \times X_0$) with WLS fiber inserted in spiral $\sim 9\%/\sqrt{E[\text{GeV}]}$ energy resolution
Key Features of the setup:
• High hermeticity: 4 HCAL FeSc sandwich modules, 60×60×150 cm³ (~7 λ for each module) with WLS fiber and 60%/√(E[GeV]) energy resolution.
Key Features of the setup:
• Measure momentum: Tracking system made of 4 MicroMegas modules and 2 GEM detectors together with 2 MPBL magnet \(\sim 7 \text{T} \cdot \text{m} \) to measure momentum of incoming particles.
Key Features of the setup:
- Measure momentum:
- Reconstructed momentum

% of ndf
\chi^2 / ndf 825.9 / 23
Constant \text{Constant} 6.808e+01 ± 3.892e+04
Mean 0.00 ± 99.97
Sigma 0.002 ± 1.184

\begin{center}
\begin{tabular}{lcc}
\hline
Energy (GeV) & \multicolumn{2}{c}{Entries} \\
\hline
70 & 0 & 0 \\
80 & 0 & 0 \\
90 & 0 & 0 \\
100 & 0 & 0 \\
110 & 0 & 0 \\
120 & 0 & 0 \\
130 & 0 & 0 \\
140 & 0 & 0 \\
\hline
\end{tabular}
\end{center}
NA64: Setup

Key Features of the setup:
• Measure momentum: Momentum tracked as a function of incoming angle

Low energy tail to be suppressed
Key Features of the setup:
• Suppress hadronic background: Synchrotron radiation tagging system (BGO/PbSc sandwich calorimeter) to reject $\mu^-$, $\pi^-$ and $K^-$ decay in flight after interaction with ECAL.
Key Features of the setup:
• Suppress hadronic background: Synchrotron radiation tagging to reject hadrons at a level of $10^{-5}$.

arXiv: 1703.05993
July’ 2016 Run
July 2016 results

No selection cut applied

2.75 x 10^9 electrons on target with beam intensity of 1.4 x 10^6 e^-/4.8 s spill for a ~ 2 cm diameter beam:

- Region I —> rare QED dimuon production e^- Z → e^- Zγ; γ → µ^+µ^-, characterised by the energy of ≃ 10 GeV deposited by the dimuon pair in the HCAL.
- Region II —> SM events from the hadron electroproduction in the target: E_{ECAL} + E_{HCAL} ≃ 100 GeV.
- Region III —> few ~ 10^{-2} mostly pile-up of e− and beam hadrons.
July 2016 results

Event Selection Criteria:
- Pile up suppression using timing information.
- Selecting clean incoming track (angle + single hit in all 4 MMs) with correct momentum.
- Hadron suppression with synchrotron radiation.
- Events with shower profile as expected.
- No activity in Veto 2.

Selection cuts applied
July 2016 results

- No event observed in the signal box from the July’2016 data.
- New limits set on the $\gamma$-$A'$ mixing strength.

arXiv:1610.02988
Explanation of $(g-2)_\mu$ with invisible $A'$ is excluded.
October 2016 run and prospects

- October 2016 run:
  - Good performance at $5 \times 10^6$ e-/spill
  - 4$x10^{10}$ eot collected.
  - Data analysis in progress.

- 2017 run:
  - Improved e- tagging: tracker+SRD
  - Tests at intensity $(7-8) \times 10^6$ e-/spill
  - Goal $(2-3) \times 10^{11}$ eot.

Projected Sensitivity
Summary

The conceptual idea of NA64 is to search for dark sector physics in missing-energy events with an active beam dump experiment.

The run 2016:
• All detectors performed quite efficiently at high intensity and showed positive results for being able to run at even higher flux.
• The July 2016 run set new limits on the $\gamma$-$A'$ mixing and explanation of the $(g-2)_{\mu}$ anomaly with invisible $A'$ is excluded.
• October 2016 data analysis in progress.

The run 2017:
• Plan to collect up to few $10^{11}$ electrons on target for the invisible channel and cover significant area of the $A'$ parameter space.
• Upgrades to the tracking system as well as to the synchrotron radiation detectors are foreseen.
• We also intend to switch to visible mode to collect few $10^{10}$ eot (> 1 week ) to address the Be8 decay anomaly which could be explained by a 17 MeV boson.
# Physics Prospects

<table>
<thead>
<tr>
<th>Process</th>
<th>New Physics</th>
<th>Sensitivity</th>
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<tbody>
<tr>
<td>1. $e^+Z \rightarrow e^+Z + E_{\text{miss}}$</td>
<td>- $A' \rightarrow e^+e^-$ - $A' \rightarrow$ invisible - alps - milli-Q</td>
<td>Dark Sector: - Dark Photons and DM - New light states (V,S) weakly coupled to $e^-$ - $^{8}\text{Be}$ excess</td>
</tr>
<tr>
<td>2. $\mu^+Z \rightarrow \mu^+Z + E_{\text{miss}}$</td>
<td>- $Z_{\mu} \rightarrow \nu \nu, \mu^+\mu^-$ - $a_\mu$ - $\mu \rightarrow \tau$ conversion</td>
<td>- $(g-2)<em>\mu$ anomaly, - New $Z</em>{\mu}$ from $L_{\mu}$-$L_{\tau}$ gauged symm., scalars coupled to $\mu$ LFV</td>
</tr>
<tr>
<td>3. $\pi(K)p \rightarrow M^0n + E_{\text{miss}}$</td>
<td>- $K_L \rightarrow$ invisible - $K_S \rightarrow$ invisible - $\pi^0, \eta, \eta' \rightarrow$ invisible</td>
<td>- CP, CPT symmetry - Bell-Steinberger Unitarity, - new WC particles: NHL, $\phi\phi$, $VV$</td>
</tr>
<tr>
<td>4. $pA \rightarrow Z^\prime + E_{\text{miss}}$</td>
<td>- leptophobic $Z^\prime$</td>
<td>$\sim \text{GeV DM}$</td>
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Thank You !!