

Search for dark photon decaying into μ⁺μ⁻ pair with NA62 in beam-dump mode

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on behalf of the NA62 Collaboration

Outline:

- Introduction
- The NA62 experiment in beam-dump mode
- Search for $A' \to \mu^+ \mu^-$
- Summary & Prospects

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-+ hadrons

1.0

Several New Physics models have been proposed as extension of the Standard Model:

- Vector portal Dark Photons \rightarrow
- Scalar portal \rightarrow Dark Scalars
- Neutrino portal \rightarrow Heavy Neutral Leptons
- Axion portal Axion-like particles \rightarrow

A simple model introduces a new vector field $F'_{\mu\nu}$ symmetric under U(1) transformation which feebly interacts with the SM fields.

Kinetic-mixing interaction with the SM hypercharge $B^{\mu\nu}$:

$$\mathcal{L} \subset -arepsilon rac{1}{2cos heta_W} F'_{\mu
u} B^{\mu
u}$$

The mass of the Dark Photon (DP), M_{a} , , and the coupling ϵ are free parameters.

For masses $M_{A'}$ < 700 MeV/c² the DP decay width is dominated by decay to lepton-antilepton final states

0.2 0.80 0.2 0.6 0.8 M_A [GeV/c²]

0.8

B(A' → SM)

0.4

Two production mechanisms are in action after a proton-nucleus interaction:

- one inducing a "direct" **A'-bremsstrahlung-like** production $\rightarrow pN \rightarrow XA', A' \rightarrow l^+l^-$
- one corresponding to a **meson-mediated** tertiary production $\rightarrow pN \rightarrow XM, \ M \rightarrow A'\gamma(\pi^0), \ A' \rightarrow l^+l^ M=\pi^0,\eta,\omega.$.

The NA62 experiment at the CERN SPS





Broad physics program

- Main goal measure $K^+ \rightarrow \pi^+ vv$ branching ratio
- Rare and forbidden kaon decays
- Precision measurements
- Exotics searches(beam-dump mode): DP, HNLs, ALPs



Due to the feeble interaction with the SM particles, DPs produced in the TAXes can reach the NA62 fiducial volume more than 100 m downstream, and therein decay into a lepton-antilepton pair.

Downstream Upstream X [m] 2 STRAW LAV C2 GTK MIN 1 Target **KTAG** SAC 0 CHANT] TAXes are movable RICH collimators -1 \bigcirc Dump LKr \bigcirc -2 400 GeV/c protons \bigcirc 0 100 150 200 0 250 Z [m] \bigcirc **STRAW:** track charged particle **NewCHOD:** fast detector used for the trigger (σ ~600 ps) $(\bigcirc$ MUV3: muon veto/ID detector

LKr: electromagnetic calorimeter for PID and photon identification **LAV** (Large Angle Veto): photon veto detectors

Optimised conditions for the beam-dump setup:

- TAXes closed and target away from the beam
- improved sweeping from dipoles downstream of TAXes
- beam intensity 1.5 higher than the nominal 1.1 x10¹² protons per second per spill



Data sample



Collected (1.40 \pm 0.28) x 10¹⁷ POT in ~ 10 days of data taking



POT measured by beam secondary emission monitor

Two trigger lines for charged final states:

- 1) Single-track trigger asking for one hit in the NewCHOD: Q1/D_s (D_s=20) (~14kHz)
- 2) Two-track trigger, asking for two hits in the NewCHOD: H2 (~18kHz)

One control trigger based on the LKr, used to measure the efficiency of the NewCHOD-based trigger (~4kHz)

Q1 trigger efficiency: ϵ_{O1} ~ 99.8%

H2 trigger efficiency: ϵ_{H2} ~ 98%

NA62

NA62 expected sensitivity: geometrical acceptance



Sensitivity plot separated per production mechanism assuming 0 observed events

Sensitivity plot separated per decay final state assuming 0 observed events

The grey underlying exclusion is the one adapted by the PBC and originally based on: Phys. Rev. Lett. 126, no.18, 181801 (2021)

Search for A' $\rightarrow \mu^{+}\mu^{-}$: Analysis strategy

The signal signature is defined by a lepton-antilepton reconstructed vertex within the NA62 fiducial volume and a primary vertex between the direction of the lepton-antilepton pair and the proton beam at the TAXes

Event selection requires:

- reconstructed track quality
- track timing coincidence with the trigger
- muon identification with calorimeter and muon detector
- no in-time activity at large angle veto detectors (LAV) to reduce possible selection of vertices derived by interaction of incoming muons with the material in the LAVs.
- Signal region (plot)





CR= control region SR= signal region



 CDA_{TAX} : closest distance of approach between the beam direction at the TAX entrance and the lepton-antilepton pair direction $\Rightarrow \sigma_{CDA} = 7 \text{ mm}$

 Z_{TAX} : longitudinal position $\rightarrow \sigma_7 = 5.5 \text{ m}$

*SR not optimised with respect to the signal and background distributions







CR and SR blinded



O(200) background reduction, despite higher intensity thanks to the beam line optimization





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Combinatorial background:

background from random superposition of two uncorrelated "halo" muons

- Selected single tracks in a data sample orthogonal to the one used for the analysis
- Track pairs are artificially built to emulate a random superposition
- Apply same event selection criteria as in the analysis
- Each track pair has a weight independent on the rate to account for the 10 ns time window

Prompt background:

background from secondaries of a muon interaction with the traversed material

- Muon kinematic distributions extracted from selected single muons in data (backward MC)
- To correct the spread induced by the backward-forward process (straggling, multiple scattering) an unfolding technique is applied to better reproduce the data distributions.
- Relative uncertainty of MC expectation ~ 100%

Prompt background negligible with respect to combinatorial (UL @ 90%CL is 30% of combinatorial)

Data-MC comparison: control samples





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Data-MC comparison: signal sample, CRs opened





Probability to observe 1 or more events in the SR is 1.59%

	$N_{exp} \pm \delta N_{exp}$	N _{obs}	$\mathbf{p} \ (\mathbf{N} \ge \mathbf{N}_{obs})$	$p(L \le L_{obs})$
Outside CR	26.3 ± 3.4	28	0.41	0.74
CR1	0.29 ± 0.04	1	0.25	0.25
CR2	0.58 ± 0.07	1	0.44	0.44
CR3	1.70 ± 0.22	2	0.50	0.68
CR1+2+3	2.57 ± 0.33	4	0.26	0.24
CR	0.17 ± 0.02	0	1.0	1.0
SR	0.016 ± 0.002	_	_	_





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Final result







The first preliminary result on search for production and decay of an exotic particle from data collected by the NA62 experiment in beam-dump mode has been presented

A cut-based counting experiment blind analysis to search for $A' \rightarrow \mu^+ \mu^-$ has been performed on the data collected in 2021.

With (1.4 \pm 0.28) x 10¹⁷ POT a 90% CL upper limit has been set, exploring a new region of the parameter space.

Searches for decays of exotic particles to e^+e^- , $\gamma\gamma$, $\pi^+\pi^-\gamma$ final states, using the data collected in 2021, are ongoing.

NA62 intends to take 10¹⁸ POT in beam dump in 2022-2025 with interesting perspectives on dark photons, ALPs, dark scalars and HNLs





Backup slides

Information on the observed event in the SR





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Region in CDA _{TAX} - Z _{TAX}	Combinatorial	Prompt	Upstream-prompt
CR	0.17 ± 0.02	< 0.033	< 0.052
SR	0.016 ± 0.002	< 0.003	< 0.005

Summary of expected background events for the search of $A' \rightarrow \mu^+ \mu^-$ with the related uncertainty. The limits reported are defined with a 90% confidence level