Latest results and future prospects of the NA64/POKER experiment at CERN SPS

Luca Marsicano for the NA64 collaboration

INFN-Genova



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 947715 (ERC Starting Grant POKER, 2020).

Outline				
Introduction	The NA64 experiment	The POKER project	Conclusions	



- 2 The NA64 experiment
- 3 The POKER project



Introduction ●00	The NA64 experiment	The POKER project	Conclusions 0
The dark sector			

Dark matter: it is there, but very little is known about it! What is it? Where did it come from?

- "WIMP miracle:" electroweak scale masses (≃100 GeV) and DM annihilation cross sections (10⁻³⁶ cm²) give correct dark matter density / relic abundances. No need for a new interaction!
- Intense experimental program searching for a signal in this mass region. So far, no positive evidences have been found
- What about light dark matter, in the mass range 1 MeV ÷ 1 GeV?



Introduction ○●○	The NA64 experiment	The POKER project	Conclusions O
1 • 1 • 1 • • •			

Light dark matter

The light dark matter hypothesis can explain the observed relic abundance, provided a new interaction mechanism between SM and dark sector exists¹

• Simplest possibility: "vector-portal". DM-SM interaction through a new U(1) gauge-boson ("dark-photon") coupling to electric charge

Model parameters:

- Dark-photon mass, $m_{A'}$ and coupling to electric charge ε
- Dark matter mass, m_{χ} and coupling to dark photon, g_D ($\alpha_D \equiv g_D^2/4\pi$)

Experimental searches:

- A comprehensive LDM experimental program must investigate **both** the existence of χ particles and of dark photons
- Experiments at accelerators at the *intensity frontier* are particularly suited to explore this paradigm



¹For a comprehensive review: 1707.04591, 2005.01515, 2011.02157

Dark photon r	reduction mechanisms with	lantan haama	
000	000000	000	0
Introduction	The NA64 experiment	The POKER project	Conclusions

Dark photon production mechanisms with lepton beams

Three main production mechanisms with $e^+ - e^-$ beams:

-) A'-strahlung
 - Radiative A' emission in nucleus EM field
 - forward boosted, $Z^2 \alpha_{EM}^3$ scaling
- Non-resonant e^+e^- annihilation
 - Forward backward emission in the CM frame
 - $Z\alpha_{EM}^2$ scaling

Resonant e^+e^- annihilation

- Resonant, Breit-Wigner like cross section with $M_{A'} = \sqrt{2m_e E}$
- Zα_{EM} scaling
- Most efficient LDM production process for given kinematics²



²L. Marsicano et al., Phys. Rev. Lett. 121 (2018) 041802.

Introduction		The NA64 experiment			The POKER project	Conclusions
000		000000		C	000	0

Fixed *active* thick-target LDM searches: missing energy experiments

Missing energy approach - the active thick target is the detector

- \blacksquare High intensity e^+/e^- beam impinging on thick active target \rightarrow EM shower is initiated
- 3 A' are produced from e^+/e^- in the shower and promptly decay to LDM particles χ
- \bigcirc χ particles escape the detector without interacting

Missing Energy Signature

- Specific beam structure: impinging particles impinging "one a ta time" on the active target
- Deposited energy $E_{dep}\ {\rm measured}\ {\rm event-by-event}$
- Signal: events with large $E_{miss} = E_B E_{dep}$
- Backgrounds: events with ν / long-lived (K_L) / highly penetrating (μ) escaping the detector



Target/ECAL/HCAL



- Beam identification system: magnetic spectrometer and SRD tagging (MBPL magnets)
- EM-Calorimeter: 40X₀, Pb/Sc Shashlik
- Plastic scintillator VETC
- Hadron calorimeter: 4 m, 30 λ





³Phys.Rev.Lett. 123 (2019) 121801









³Phys.Rev.Lett. 123 (2019) 121801

NA64 results	Introduction 000	The NA64 experiment 00●000	The POKER project	Conclusions O
	NA64 results			

- NA64 results based on $2.84\cdot 10^{11}$ EOT collected during 2016-2018
- After applying all selection cuts, no events observed in the signal region $E_{ECAL} < 50~{\rm GeV},~E_{HCAL} < 1~{\rm GeV}$
- Expected number of background events \sim 0.5 compatible with null observation
- Most competitive exclusion limits in large portion of the LDM parameters space
- Secondary positron annihilation contribution included in recent analysis







Vacuum vess

Z

NA64 collaboration, Phys. Rev. D 101 (2020) no.11, 071101(R)

• Interest has recently grown towards A' visible decay $A' \rightarrow e^+e^-$ in the ~ 17 MeV mass region (X17 anomaly)

Magnet

- NA64 visible mode: A' produced in WCAL detector (plastic and tungsten calorimeter). Search for decay products in ECAL
- 8.4×10^{10} EOT collected in visible mode: ruled out part of the available X17 parameter space



Introduction	The NA64 experiment	The POKER project	Conclusions
000	0000●0		O
NA64 visible - future	e upgrade		

The sensitivity to the X17 in the NA64 visible mode is limited by the WCAL length ($\gamma c \tau_{X17} \sim 30$ mm) and the capability to separate the very close tracks of the $X17 \rightarrow e^+e^-$ decay

 \rightarrow new setup for 2023 run under consideration

- New WCAL geometry for improved signal efficiency
- Dipole magnet $+ \sim 18$ m vacuum pipe for tracks separation
- GEM trackers + ECAL for invariant mass measurement (10% invariant mass resolution)
- Possible to probe the remaining X17 parameter space in a ~ 20 days run





Introduction 000	The NA64 experiment 00000●	The POKER project	O
NA64 status a	nd future prospects		
Electron Be			

straw detectors and veto hadron calorimeter for background reduction up to more than 10^{12} EOT) • High statistic run in 2022 expected to collect ~ 10^{12} EOT; up to ~ 5×10^{12} EOT collected by

 High statistic run in 2022 expected to collect ~ 10¹² EOT; up to ~ 5 × 10¹² EOT collected by LS3: probe significant part of the A' invisible parameter space and many BSM extensions such as ALPs, Z' in Lmu-Ltau, B-L models

 2.84×10^{11} EOT collected during 2016 and 2018 runs Additional ~ 6×10^{10} EOT collected in 2021 (data analysis ongoing), after detector upgrade (electronics,

Muon Beam:

- NA64-µ: missing momentum and energy experiment with a muon beam
- Ongoing parallel effort of the NA64 collaboration
- See L. Molina's talk tomorrow!



Positron Beam:

- Primary e^+ beam allows to exploit the enhanced resonant annihilation cross section \rightarrow high sensitivity to large A' masses
- Dedicated e^+ run foreseen in Fall 2022: 10 days to accumulate $2\times 10^{10}~e^+{\rm OT}$



Introduction The NA64 experiment The POKER project Conclusions of POKER: POsitron resonant annihilation into darK mattER

An optimized light dark matter search with positrons in the NA64 framework⁴

Signal production reaction: $e^+e^- \to A' \to \chi \overline{\chi}$

- Large event yield: $N_s^{annihil} \propto Z \alpha_{EM}$ vs $N_s^{brem} \propto Z^2 \alpha_{EM}^3$
- Missing energy distribution shows a peak around $E_R=\frac{M_{A'}^2}{2m_e}\to {\rm clear~signal~signature}$

Project goal

- Perform a preliminary missing energy measurement with a positron beam, using a new high resolution detector (*PbWO*₄ calorimeter) replacing the existing NA64 ECAL
- Demonstrate the technique and set the basis of the first optimized light dark matter search at a positron-beam facility





Introduction	The NA64 experiment	The POKER project	Conclusions
000		0●0	O
POKER sensitivity to	o LDM		

Pilot measurement at the H4 beamline with 100 GeV $e^+ \rm \ beam^5$

- Baseline scenario: $5 \cdot 10^{10}$ e^+ OT, 50 GeV missing energy threshold
- Aggressive scenario: $3 \cdot 10^{11}$ e^+ OT, 25 GeV missing energy threshold
- Future experimental program with multiple $10^{13} e^+ \text{OT}$ runs at different energies

Pilot run sensitivity - 0 bck



 $^{^5 \}mathrm{Currently}$ discussing within NA64 and SPSC to possibly run the pilot measurement in 2024

Introduction	The NA64 experiment	The POKER project	Conclusions
000		00●	0
Hadron contamination	on in H4 line e^+ mode		

Hadron contamination in H4 in e^+ mode is a crucial aspect for POKER. The hadron fraction is expected to increase significantly due to protons from the Λ decay: $\Lambda \to p\pi^-$

- First set of measurements at a low beam intensity, $0.2\times 10^6~e^+\rm OT/spill,$ performed in 2021
- Hadron fraction estimated to be $\sim 5-6\%$
- Further studies foreseen during fall 2022 e^+ run



Introduction 000	The NA64 experiment	The POKER project	Conclusions •
Conclusions			

- Light dark matter scenario (MeV-to-GeV range) is largely unexplored and theoretically well motivated
 - A collection of complementary searches exploring this paradigm is required. Among these, searches at accelerator play a key role.
- NA64 is an electron-beam missing-energy experiment at CERN
 - NA64 produced several important results in the search for dark photon, both in the visible and invisible decay scenario
 - The high statistics 2022 run will allow to probe a significant part of the preferred LDM parameter space
 - The experiment sensitivity could be further improved by using a positron beam
- POKER is an ERC funded project, aiming to perform the first optimized missing energy measurement with a positron beam
 - The project foresees the realization of a high-resolution active target to be implemented in the NA64 setup
 - Studies on hadron contamination and detector R&D currently ongoing possibility to run the pilot measurement in 2024 currently discussed