

# Proposal to participate to Na64 experiment



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Seminario A. Celentano INFN-PD  
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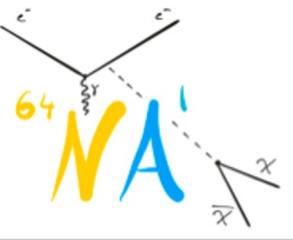




# Dark matter in a nutshell

- Main hypothesis: dark matter (DM) is made of particles,  $\chi$ .
- Thermal Light Dark Matter:
  - predicts a new force between DM and standard model (SM), DM and SM are in equilibrium when the temperature of the Universe  $T \gg m_\chi$
  - DM particles can't find each other to annihilate when  $T < m_\chi$ , thermal equilibrium breaks  $\rightarrow$  freeze-out of DM density
  - solid prediction of DM-SM annihilation cross-section vs. the DM relic abundance
  - $m_\chi$  in sub-GeV mass range, much below the electroweak scale

# Dark matter in a nutshell - 2

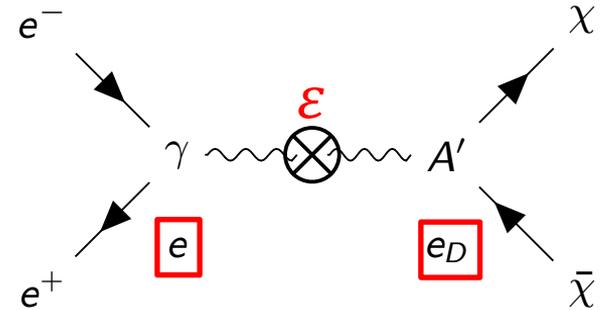


A well motivated model introduces a new U(1) gauge-boson, "dark photon"  $A'$  with 4 parameters:

- Dark photon  $m_{A'}$  and DM  $m_\chi$  masses
- Coupling  $A' - \chi$ ,  $e_D$  with coupling constant,  $\alpha_D$
- $A' - \gamma$  coupling via kinetic mixing  $\epsilon$

Annihilation cross section  $\chi\bar{\chi} \rightarrow SM$ :

$$\langle\sigma v\rangle \propto \frac{\epsilon^2 \alpha_D m_\chi^2}{m_{A'}^4} = \frac{\epsilon^2 \alpha_D m_\chi^4}{m_{A'}^4} \frac{1}{m_\chi^2} \equiv \frac{y}{m_\chi^2}$$



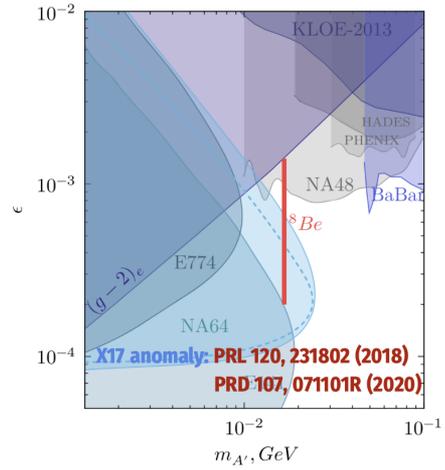
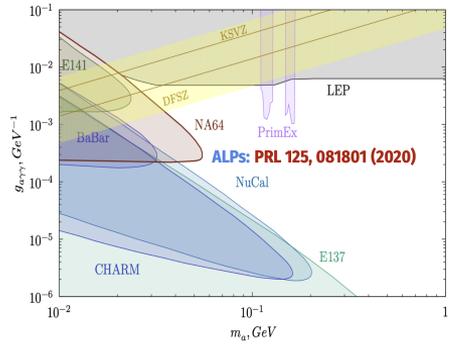
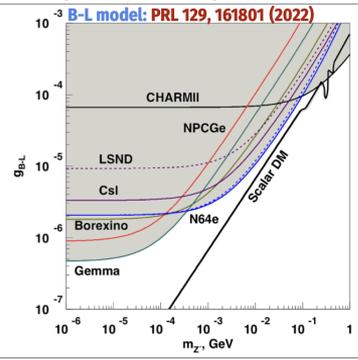
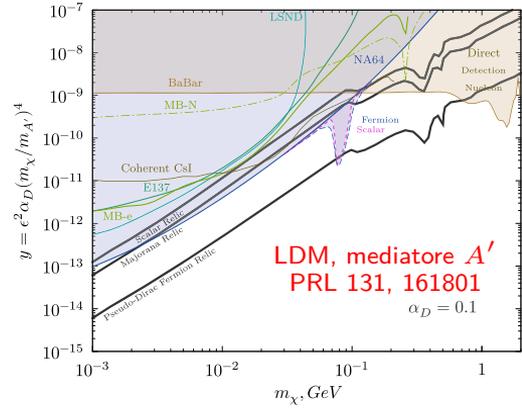
# Dark matter search at NA64

A. Celentano CSN1

Nuova fisica nel Settore Oscuro:

- Modello LDM con mediatore  $A'$
- ALPs, scalari leggeri
- Modelli  $L_\mu - L_\tau$  con mediatore  $Z'$  leggero
- Modelli  $B - L$  con mediatore  $Z'$  leggero (connessione alla fenomenologia dei neutrini)
- Modelli con  $A'$  visibile ( $A' \rightarrow e^+e^-$ ), anomalia  $X_{17}$
- Modelli con  $A'$  semi-visibile

NA64 ha già riportato limiti di esclusione competitivi per tutti questi scenari

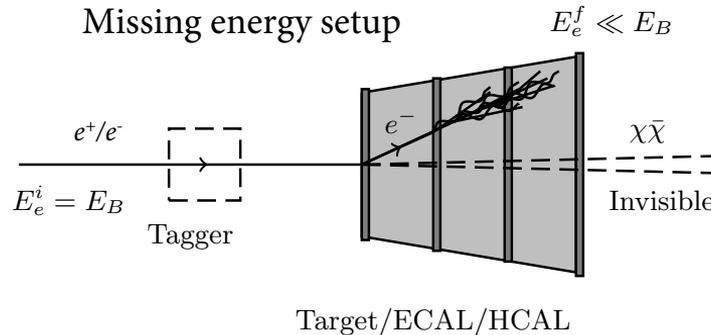


**NA64-e approach:** missing energy measurement, high energy  $e^-/e^+$  beam impinging on an active thick target.

Number of signal events scales as:  $N_S \propto \varepsilon^2$

## Missing Energy Experiment

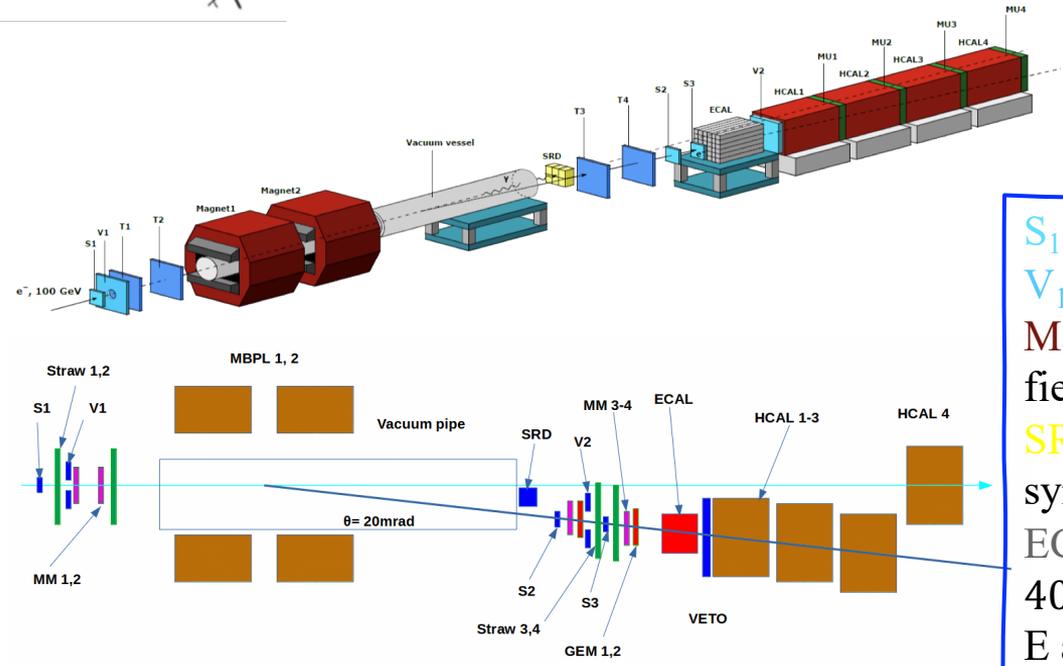
- Specific beam structure: impinging particles impinging “one at time” on the active target
- Deposited energy  $E_{dep}$  measured event-by-event
- Signal: events with large  $E_{miss} = E_B - E_{dep}$
- Backgrounds: events with  $\nu$  / long-lived ( $K_L$ ) / highly penetrating ( $\mu$ ) escaping the detector / eventual beam contaminants



# The NA64- $e$ experiment



CERN North Area, 100 GeV  $e^-$  beam  
 H4 line:  $\approx 10^7 e^-$  /spill ( $\gamma$  conversion).  
 $\sigma_E < 1\%$ , hadron contamination  $\sim 0.5\%$



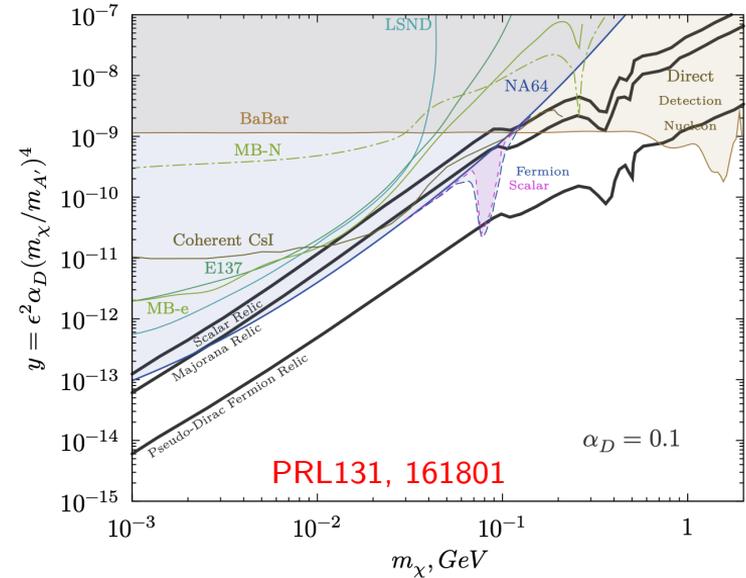
$S_{1-3}$ : scintillator counters to define beam  
 $V_{1-2}$ : veto counters  
**Magnet<sub>1,2</sub>**: dipole magnets, total magnetic field  $\approx 7 \text{ T}\cdot\text{m}$   
**SRD**: array of a PbSc sandwich calorimeter for synchrotron radiation detection  
**ECAL**: active dump target, EM calorimeter,  $40X_0$ , Pb/Sc Shashlik. Measure recoil electron E and EM shower shape  
**HCAL**: hermetic hadronic calorimeter  $\lambda_{Int} \sim 30$

# The NA64- $e$ results

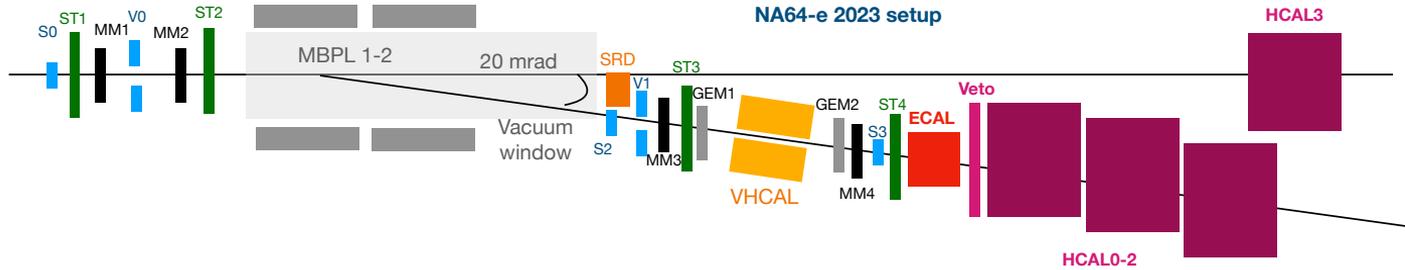


- Statistics (2016-2022)  $\approx 10^{12}$  EOT
- After applying all selection cuts, no events are observed in the signal region,  $E_{\text{ECAL}} < 50$  GeV,  $E_{\text{HCAL}} < 1$  GeV
- Expected number of background events  $\sim 0.5$  compatible with null observation

Background source	Background, $n_b$
(i) dimuons losses or decays in the target	$0.04 \pm 0.01$
(ii) $\mu, \pi, K \rightarrow e + \dots$ decays in the beam line	$0.3 \pm 0.05$
(iii) lost $\gamma, n, K^0$ from upstream interactions	$0.16 \pm 0.12$
(iv) Punch-through leading $n, K_L^0$	$< 0.01$
Total $n_b$ (conservatively)	$0.51 \pm 0.13$



# The NA64-e 2023-2024

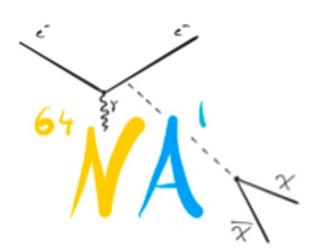


- Introduced **VHCAL**, veto hadronic calorimeter (Cu-Sc layers) to increase acceptance for electro-nuclear events due to upstream interactions.
- New front-end electronics for all calorimeters
- Extended signal window  $E_{\text{ECAL}} < 60 \text{ GeV}$
- Statistics (2023-2024)  $\approx 10^{12}$  EOT
- Data analysis ongoing
- 2025 data taking in progress



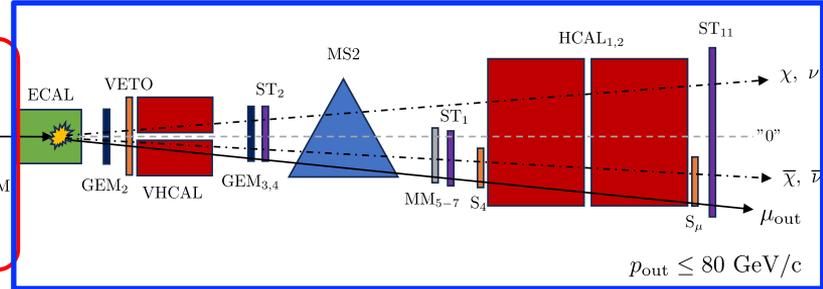
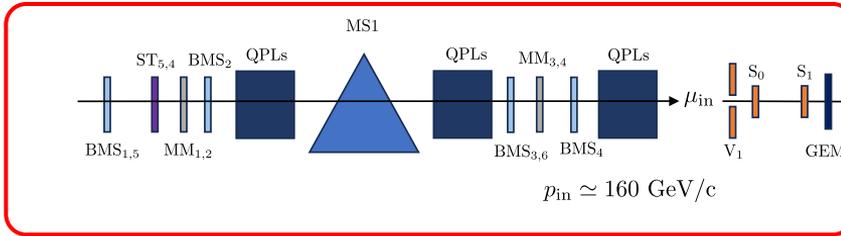
## The NA64- $e^+$

- Primary  $e^+$  beam allows to exploit the enhanced resonant annihilation cross section  $\rightarrow$  high sensitivity to large  $A'$  masses
- Signal production:  $e^+e^- \rightarrow A' \rightarrow \chi\bar{\chi}$ , with missing energy distribution with a peak around  $E_R = \frac{M_{A'}^2}{2m_e}$
- Dedicated pilot  $e^+$  run in 2022 and 2023:  $\approx 10^{10}$   $e^+$  OT accumulated at 100 GeV/70 GeV
- Same detector configuration of NA64- $e^-$  with the new PbWO4 calorimeter PKR-CAL used as fixed target in the 2025 data taking.
- PKR-CAL baseline design:
  - PbWO4 calorimeter with SiPM readout
  - Required  $\sigma_E/E \sim 2.5\%/\sqrt{E} \oplus 1\%$



# The NA64- $\mu$ experiment

Beam: M2 beamline at CERN SPS, 160 GeV muon  $10^5 - 10^6$  muons/s



Incoming muon momentum determined with a spectrometer:

- Magnet 5Tm, MS1
- Tracking detector: MM1-4 (micromega) ST, straw tube chambers
- Scintillator hodoscopes, S<sub>x</sub>

Resolution  $\sigma_{p_{in}}/p_{in} \cong 3.8\%$

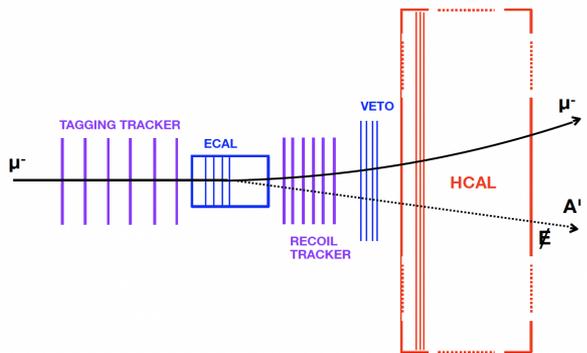
After the target (ECAL):

- Veto counter
- VHCAL, hadronic calorimeter
- Magnet MS2
- Two HCAL module,  $\lambda_{Int} \sim 15$
- Straw tube chambers
- The last two to identify and remove any residuals from interactions upstream

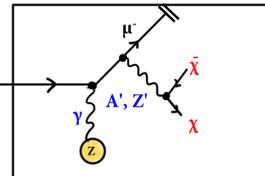
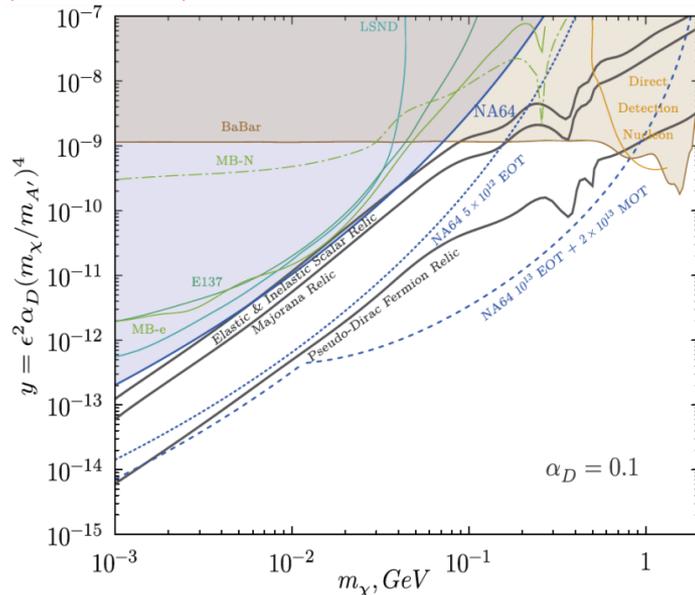
Resolution  $\sigma_{p_{out}}/p_{out} \cong 4.4\%$

LDM search with a **muon beam** impinging on a fixed target, complementary to  $e^\pm$  searches in the high-mass region.

- **Signal production:**  $A'$  radiative emission by beam muons impinging on an active target (ECAL).
- **Signal signature: *missing momentum*.** Well-identified impinging beam track and significant momentum loss in final-state track. No additional activity in downstream detectors (VETO / hadronic calorimeters).



Combined sensitivity of NA64- $e$  ( $10^{13}$  EOT) and NA64- $\mu$  ( $2 \times 10^{13}$  MOT).

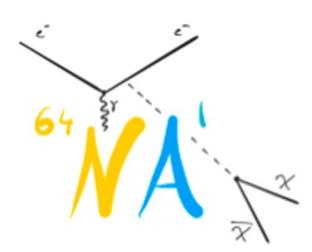




# The Collaboration

Institute Name	Institute Parent Name	Town	Country	Team Leader & Deputy Team Leader(s)
Departamento de Fisica	Federico Santa Maria Technical University	Valparaiso	Chile	
Helmholtz-Institut fuer Strahlen- und Kernphysik	University of Bonn	Bonn	Germany	(TL) KETZER, BERNHARD FRANZ
Institute for Particle Physics and Astrophysics (IPA)	ETH Zurich	Zurich	Switzerland	(TL) CRIVELLI, PAOLO
Instituto de Fisica Corpuscular (IFIC)	Univ. of Valencia and CSIC	Paterna (Valencia)	Spain	(TL) MOLINA BUENO, LAURA
Joint Institute for Nuclear Research		Dubna	JINR	(TL) MATVEEV, VIKTOR (DTL) PESHEKHONOV, DMITRY (DTL) KARJAVINE, VLADIMIR
Millennium Institute for Subatomic Physics at High Energy Frontier		Santiago	Chile	(TL) KULESHOV, SERGEY (DTL) ZAMORA-SAA, JILBERTO
Sezione di Genova	INFN e Universita Genova	Genoa	Italy	(TL) CELENTANO, ANDREA
Universidad Andres Bello		Santiago	Chile	(TL) KULESHOV, SERGEY
York University		Toronto	Canada	(TL) RADICS, BALINT

Around 70 people



# Impegno Italiano

Impegno Italiano inizia con POKER, ERC starting grant che finisce a gennaio 2026

FTE - Febbraio 2025: 3.85

<i>Who?</i>	<i>Posizione</i>	<i>%</i>
A. Antonov	PostDoc	100%
P. Bisio	PostDoc	100%
A. Celentano	Staff	75%
A. Marini	PostDoc	10%
L. Marsicano	PostDoc	100%

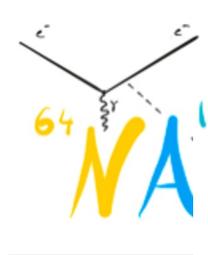
+ collaborazioni informali  
INFN-CT and INFN-Roma1

**Nuova sigla INFN: NA64**      Responsabile: Andrea Celentano (Genova)

INFN-GE nel 2026: 8 persone 4.15 FTE

Nel 2026 si aggiungerà gruppo di Bologna

Altre sezioni INFN che hanno espresso interesse: CT, Fe, TS, Fi



# Impegno Italiano

A. Celentano CSN1

## Obiettivi di POKER pienamente raggiunti:

- Dimostrazione della potenzialità di una misura di *missing-energy* con fascio di  $e^+$  per ricerca di LDM.
- Costruzione di un rivelatore dedicato per questa misura (PKR-CAL), run previsto nel 2025.

## POKER è pienamente integrato in NA64

- Siamo membri di NA64, con ruoli di responsabilità per il detector (schede WB) e l'analisi dati.
- Programma sperimentale dedicato con fascio di  $e^+$  e misure a diversa energia proposto da NA64 a SPSC, ottenendo ottimo feedback.

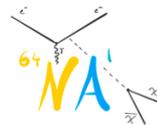
## Chiediamo alla CSN1 di sostenere la nostra partecipazione a NA64 post-ERC

- Beneficio degli investimenti realizzati in POKER
- Richieste di finanziamento limitate: CF e fondi missione per i turni.

## Stima delle richieste 2026-2028

	2026	2027	2028
Missioni (k€)	20	5	10
CF (k€)	15	15	15

## NA64 support letter



**Object:** support letter for the continuation of INFN-Genova group participation within the NA64 experiment at CERN

Dear Dr. Tenchini,

We are writing you this letter in your capacity as chair of the INFN High Energy Physics committee (CSN1) to convey to you our strong request to support the participation of the INFN-Genova group in our experiment for the NA64 program after LS3.



# Impegno Padovano

- Sviluppo e supporto del codice e del framework di simulazione e ricostruzione
- Analisi dei dati
- Partecipazione ai meetings e alla presa dati 2026
- Possibile partecipazione:
  - miglioramenti lettura calorimetri (PM  $\rightarrow$  SiPM) e/o dei tracciatori.
  - ammodernamento schede di lettura DAQ per calorimetri
  - rifacimento sistema di calibrazione calorimetri da LED a laser

	Percentuali
Alessio Gianelle	0.1
Donatella Lucchesi	0.2
Davide Zuliani	0.1
Totale FTE	0.4

Missioni (kE) Turni presa dati+meetings	MOF (kE) (5 CHF/persona)
7	16

Al momento non abbiamo richieste ai servizi, da ridiscutere dopo l'apertura della sigla INFN