Istituto Nazionale di Fisica Nucleare

Searches for dark messengers at NA62: a focus on hadronic final states

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Introduction

Search for New Physics (NP) at intensity frontier with fixed-target experiments:

- Complementary to energy frontier (LHC) and indirect searches (precision measurements, LNV, etc.);
- Typically sensitive to MeV-GeV mediators, low couplings (FIPs) accessible (large statistics);
- Dark Sector (SM-DM) portals typically probed:

NP Particle	type	SM portal (dim ≤ 5)	PBC	**decay channels** ($m \lesssim 1\,\text{GeV}$)	
HNL (N_I)	fermion	$F_{\alpha I}(\bar{L}_\alpha H)N_I$	6-8	$\pi\ell$,$K\ell$,$\ell_1\ell_2\nu$	
dark Higgs (S)	scalar	$(\mu S + \lambda S^2)H^\dagger H$	4-5	$\ell\ell$	2π, 4π, $2K$
axion/ALP (a)	pseudoscalar	$(C_{VV}/\Lambda)aV_{\mu\nu}\tilde{V}^{\mu\nu}$ $(C_{ff}/\Lambda)\partial_\mu a\bar{f}\gamma^\mu\gamma^5 f$	9,11 10	$\gamma\gamma$, $\ell\ell$	$2\pi\gamma$, 3π, 4π, $2\pi\eta$, $2K\pi$
dark photon (A'_μ)	vector	$-(\epsilon/2\cos\theta_W)F'_{\mu\nu}B^{\mu\nu}$	1-2	$\ell\ell$	2π, 3π, 4π, $2K$, $2K\pi$

this talk

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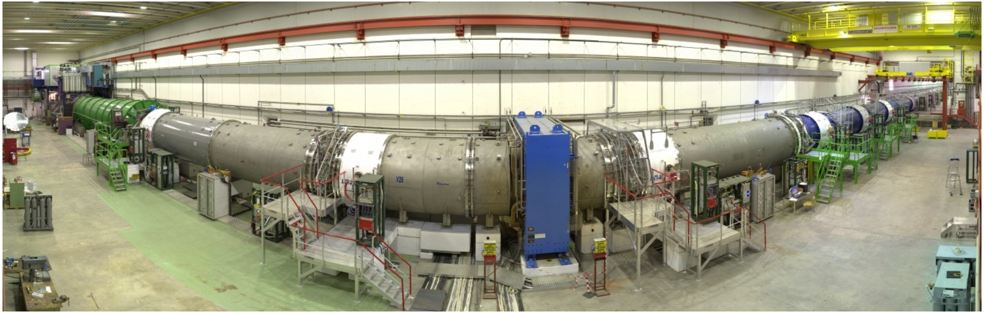
At NA62, two operation modes, K and **beam-dump mode**, and two types of searches for NP particles:[1]

- NP particle production in SM particle decays, e.g.: $K^+ \to \pi^+ a$ (with/without $a \to \ell\ell$)
- NP particle decay to SM particles, e.g.: $A' \to \ell\ell$

[1] See also talks by B. Döbrich and J. Swallow

The NA62 experiment

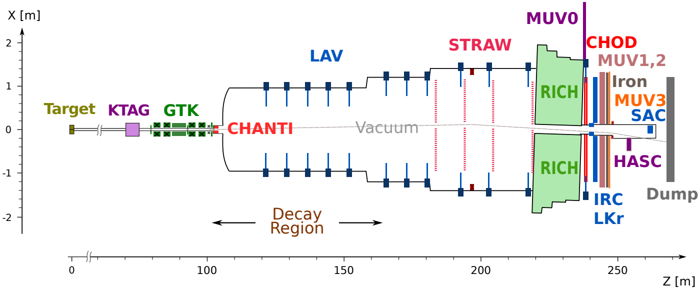
- Fixed-target experiment at CERN SPS (north area).
- Main goal: study of ultra-rare $K^+ \to \pi^+ \nu\bar{\nu}$ decay,
  + Broad physics portfolio, including Kaon physics and dark-sector searches
- Two data-taking periods: 2016-18 (see $K^+ \to \pi^+ \nu\bar{\nu}$ analysis paper[2]), 2021-25 (Run 2, ongoing).



[2] Measurement of the very rare $K^+ \to \pi^+ \nu\bar{\nu}$ decay. *JHEP* 06 (2021) 093, [2103.15389]

NA62 experiment in kaon mode

- 400 GeV/c primary p^+ beam impinges Be target, 10^{12} protons/s on spill
  75 GeV/c secondaries ($\sim 6\%$ K^+) selected using magnetic achromat, **TAX** collimators
- 5 MHz K^+ decay-in-flight in 60 m long fiducial volume (FV)[3];



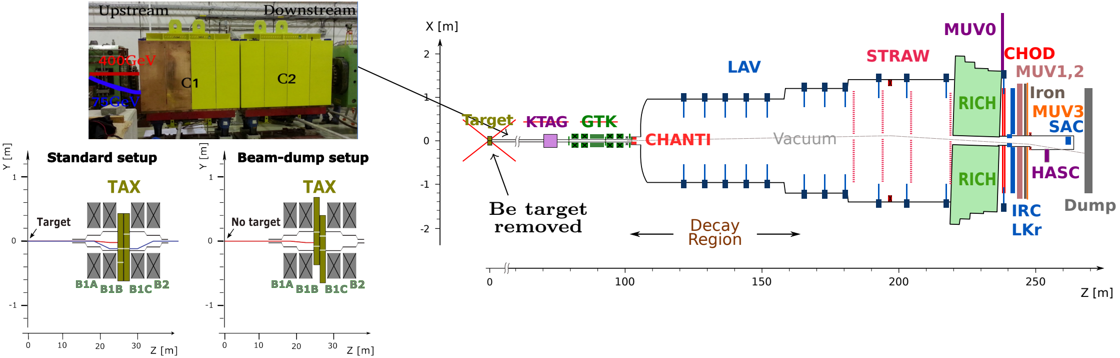
- K^+ tagged by **KTAG** and 3-mom. determined by **GTK**;
- Decay products' 3-mom. measured by **STRAW**, time measured by **CHOD** PID given by **LKr**, **MUV1**, **MUV2** and **RICH**;
  μ ID provided by **MUV3**;
- Photons can be vetoed by **LKr** and at large angles by 12 **LAV** stations or by **SAC**/**IRC** at small angles;

- Overall experimental time resolution reaches $\mathcal{O}(100)$ps

[3] The beam and detector of the NA62 experiment at CERN. *JINST* **12** P05025 (2017), [1703.08501]

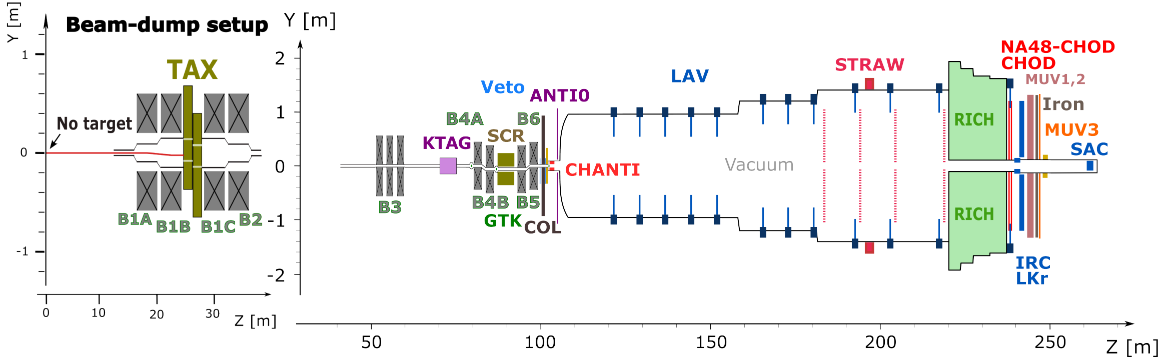
NA62 experiment in beam-dump mode

- target removed and TAX closed, KTAG and GTK not used:

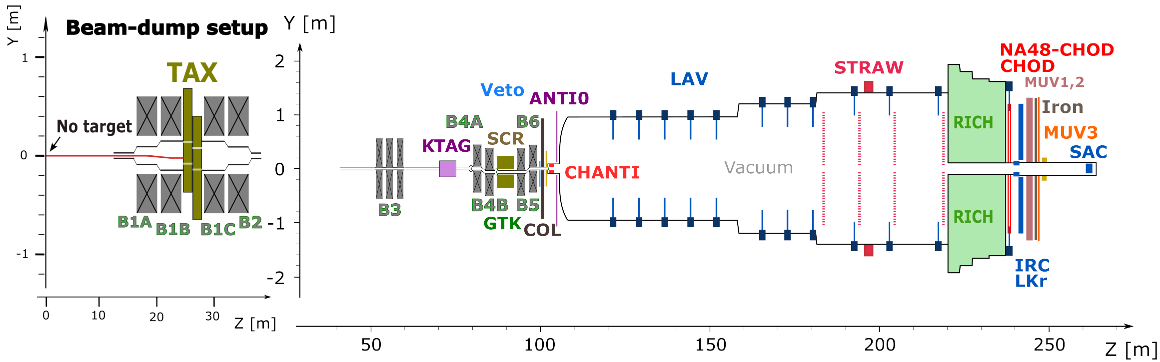


NA62 experiment in beam-dump mode

- improved sweeping from magnets downstream of TAX, reduce background from penetrating particles
- Proton beam intensity $\times 1.5$ of nominal;



NA62 experiment in beam-dump mode



- two trigger lines for charged particles: Q1/20 (≥ 1 hits in CHOD), H2 (> 1 in-time hit in CHOD)
- $N_{\mathrm{POT}} = (1.4 \pm 0.28) \times 10^{17}$ protons on target (POT) collected in 2021; plan: $N_{\mathrm{POT}} = 10^{18}$ in Run 2
- NP searches with ee and $\mu\mu$ in NA62 2021 BD sample published;[4] **today - hadronic decays**

[4] NA62 Collaboration *JHEP* 09 (2023) 035 [2303.08666]; [2312.12055]

Dark messenger signal Monte Carlo

- Numerous possibilities for the messenger X being a dark photon (DP), dark scalar (DS), axion-like particle (ALP), ..

Dark messenger signal Monte Carlo

- Numerous possibilities for the messenger X being a dark photon (DP), dark scalar (DS), axion-like particle (ALP), ..
- $\Rightarrow$ numerous production and decay channels:

DP	DS	ALP
$\pi^+\pi^-$	$\pi^+\pi^-$	$\pi^+\pi^-\gamma$
$\pi^+\pi^-\pi^0$		$\pi^+\pi^-\pi^0$
$\pi^+\pi^-\pi^0\pi^0$	$\pi^+\pi^-\pi^0\pi^0$	$\pi^+\pi^-\pi^0\pi^0$
		$\pi^+\pi^-\eta$
K^+K^-	K^+K^-	
$K^+K^-\pi^0$		$K^+K^-\pi^0$

- ALP: Primakoff (on-, off-shell), mixing with $P = \{\pi^0,\eta,\eta'\}$, $B^{\pm,0} \to K^{\pm,0,(\star)}a$
- DP: Bremsstrahlung, $P \to A'\gamma$, $V \to A'P$ $(V = \{\rho,\omega,\phi\})$
- DS: $B^{\pm,0} \to K^{\pm,0,(\star)}S$

- Altogether 36 combinations of production and decay channels studied

Analysis strategy

Selection of two charged hadrons:

- 2 good quality STRAW tracks in coincidence with each other and the trigger
- Particle ID to select hadrons (LKr and MUV1-3), RICH for tagging K^+
- No in-time activity in LAV, SAV and ANTI0
- Decay vertex selected in a fiducial volume (FV), an upstream region defined as a control sample

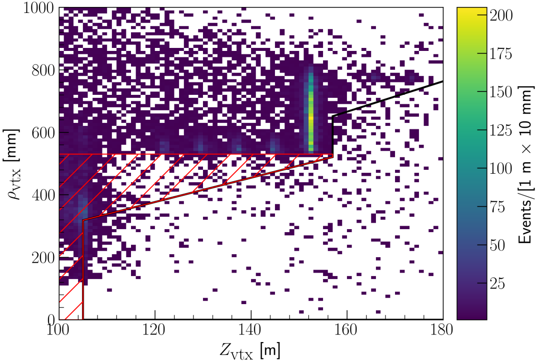


Figure: Two-track vertices (no PID) and definition of fiducial volume and upstream region (red hatched area).

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- No in-time activity in LAV, SAV and ANTI0
- Decay vertex reconstructed in FV

Search strategy:

- select neutral LKr clusters, reconstruction of γ, π^0, η based on time and opening angle;
- dark messenger reconstructed from final states and extrapolation to TAX - definition of signal region (SR) in terms of primary vertex: $\mathrm{CDA_{TAX}}$ vs Z_{TAX}

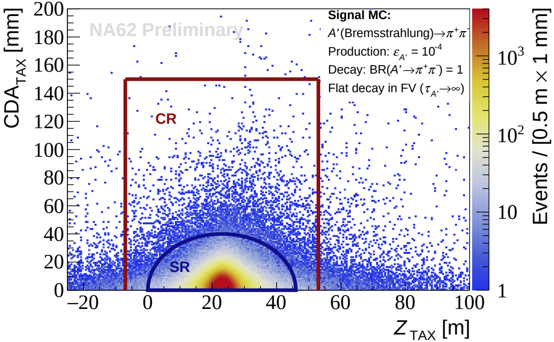

Figure: $A' \to \pi^+\pi^-$ MC: control (CR) and signal (SR) regions.

- SR: ellipse center $\{Z_{\mathrm{TAX}}, \mathrm{CDA_{TAX}}\} = \{23\,\mathrm{m}, 0\,\mathrm{mm}\}$, semi-axes of 23 m and 40 mm
- CR: $\mathrm{CDA_{TAX}} < 150\,\mathrm{mm}$ and $-7\,\mathrm{m} < Z_{\mathrm{TAX}} < 53\,\mathrm{m}$
- **both SR and CR kept masked during the analysis**

Analysis sensitivity

- In a model-independent approach $\mathrm{BR}_{X\to\pi^+\pi^-} = 1$,
  $N_{\mathrm{exp}}(M_X, \Gamma_X) =$
  $N_{\mathrm{POT}}\, \chi_{pp\to X}(C_{\mathrm{ref}})\, P_{\mathrm{rd}}\, A_{\mathrm{acc}}\, A_{\mathrm{trig}}$
- $\chi_{pp\to X}(C_{\mathrm{ref}})$: messenger prod. probability for ref. coupling
- P_{rd}: probability to reach NA62 FV and decay therein
- $A_{\mathrm{acc}}\, A_{\mathrm{trig}}$: signal selection and trigger efficiencies

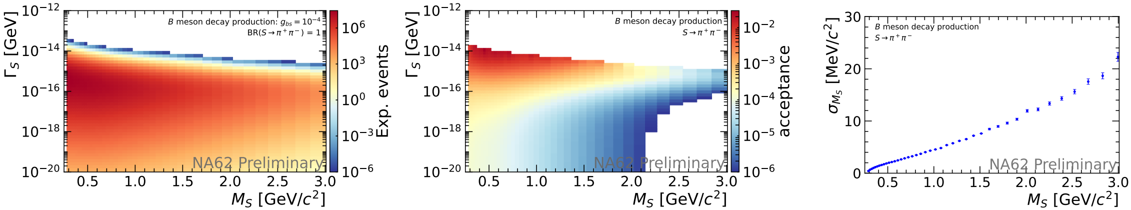

Figure: Left: expected number of $S \to \pi^+\pi^-$ selected events, for $g_{bs} = 10^{-4}$, BR = 1. Center: selection acceptance given a messenger decay in the FV. Right: Mass resolution of the reconstructed messenger.

- Distributions evaluated for all 36 combinations of production and decay channels

Background overview

After masking SR and CR and lifting vetoes, two $\pi\pi$ events observed in data:

- 1 event with vertex upstream of FV, vetoed by ANTI0
- 1 event with vertex inside FV, not vetoed by ANTI0, vetoed by LAV

Background estimations with mix of data-driven and first-principle MC:

- **“Combinatorial:”** data-driven event overlay $\rightarrow$ negligible
- **Neutrino-induced:** GENIE + PYTHIA + GEANT4 $\rightarrow$ negligible
- **“Prompt:”** data-driven + GEANT4, inelastic interaction of halo μ
- **“Upstream:”** data-driven + GEANT4, particles selected by the GTK achromat

Background overview - “prompt” component

- data control sample of halo μ, backward MC (PUMAS tool), unfolding for correct kinematics
- MC statistics equivalent to $N_{\mathrm{POT}} = 1.53 \times 10^{17}$ (exceeding the data stat.)

- $\pi\pi$ **outside CR** (in ANTI0 acceptance + no vetoes applied):
    - $N_{\mathrm{exp}} = 1.8 \pm 1.4$ vs $N_{\mathrm{obs}} = 1$ (Upstream region)
    - $N_{\mathrm{exp}} = 0.20 \pm 0.15$ vs $N_{\mathrm{obs}} = 1$ (FV)

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- after applying full selection the prompt background expectations in CR and SR are below 10^{-4} in all channels

Table: Summary of expected number of prompt background events at 68% CL for all studied decay channels in CR and SR after full selection.

Channel	$N_{\mathrm{exp,CR}} \pm \delta N_{\mathrm{exp,CR}}$	$N_{\mathrm{exp,SR}} \pm \delta N_{\mathrm{exp,SR}}$
$\pi^+\pi^-$	$(5.7^{+18.5}_{-4.7}) \times 10^{-5}$	$(5.5^{+18.0}_{-4.5}) \times 10^{-5}$
$\pi^+\pi^-\gamma$	$(1.7^{+5.3}_{-1.4}) \times 10^{-5}$	$(1.6^{+5.2}_{-1.3}) \times 10^{-5}$
$\pi^+\pi^-\pi^0$	$(1.3^{+4.4}_{-1.0}) \times 10^{-7}$	$(1.2^{+4.3}_{-1.0}) \times 10^{-7}$
$\pi^+\pi^-\pi^0\pi^0$	$(1.6^{+7.6}_{-1.4}) \times 10^{-8}$	$(1.6^{+7.4}_{-1.4}) \times 10^{-8}$
$\pi^+\pi^-\eta$	$(7.3^{+27.0}_{-6.1}) \times 10^{-8}$	$(7.0^{+26.2}_{-5.8}) \times 10^{-8}$
K^+K^-	$(4.7^{+15.7}_{-3.9}) \times 10^{-7}$	$(4.6^{+15.2}_{-3.8}) \times 10^{-7}$
$K^+K^-\pi^0$	$(1.6^{+3.2}_{-1.2}) \times 10^{-9}$	$(1.5^{+3.1}_{-1.2}) \times 10^{-9}$

Background overview - “upstream” component

- 3 sub-components observed in an “ANTI0-blind” control sample in the $Z_{\mathrm{VTX}} - m_{\pi\pi}$ plane:
  - 19 upstream interactions
  - 2 $K_S \to \pi^+\pi^-$ candidates
  - 8 $K^+ \to \pi^+\pi^+\pi^-$, one π^+ lost (6 identified as $\pi^+\pi^-$, 2 $\pi^+\pi^-\gamma$)

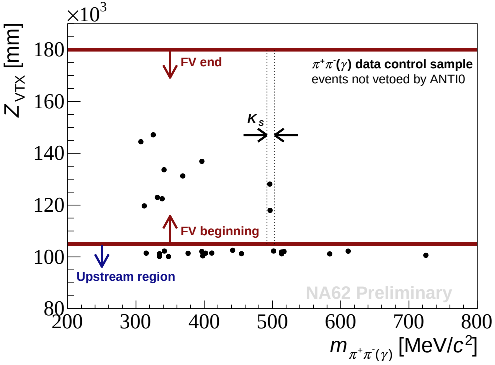

Figure: Events not in ANTI0 acceptance or not vetoed by ANTI0 in Z_{VTX} – invariant mass plane. Solid lines indicate the FV. Dashed lines indicate the K_S 3σ mass window.

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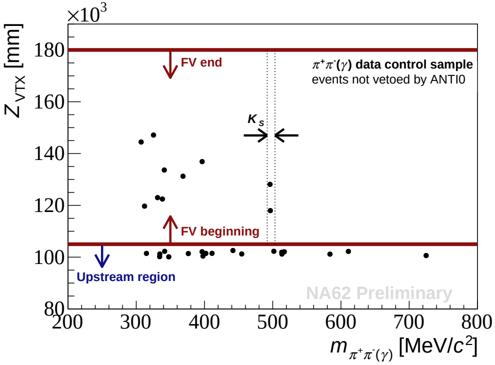
- upstream interactions: vetoed by ANTI0 acceptance and vertex location



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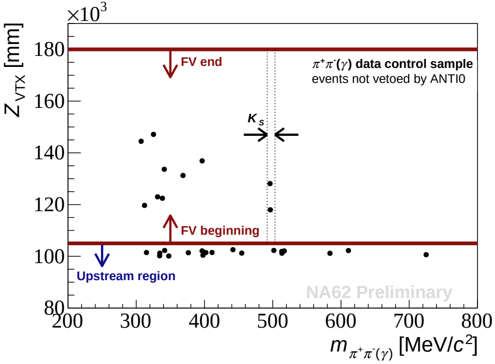

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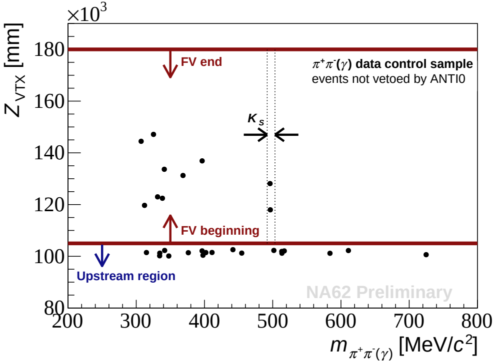
- upstream interactions: vetoed by ANTI0 acceptance and vertex location
- K_S candidates: 3σ window ($\pm 5.7\,\mathrm{MeV}/c^2$) around m_{K_S} kept masked
- K^+-induced background: simulated using selected single K^+ tracks, forced to decay as $K \to \pi^+\pi^+\pi^-$ in the FV



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Background overview - "upstream" component

- Result outside CR/SR before ANTI0 acceptance:

Channel	$N_{\rm exp} \pm \delta N_{\rm exp}$	$N_{\rm obs}$
$\pi^+\pi^-$	5.6 ± 2.8	6
$\pi^+\pi^-\gamma$	2.4 ± 1.2	2

- Result outside CR/SR after ANTI0 acceptance:

Channel	$N_{\rm exp} \pm \delta N_{\rm exp}$	$N_{\rm obs}$
$\pi^+\pi^-$	0.68 ± 0.34	1
$\pi^+\pi^-\gamma$	0.31 ± 0.16	0

- Background expectation in SR and CR:

Channel	$N_{\rm exp,CR} \pm \delta N_{\rm exp,CR}$	$N_{\rm exp,SR} \pm \delta N_{\rm exp,SR}$
$\pi^+\pi^-$	0.013 ± 0.007	0.007 ± 0.005
$\pi^+\pi^-\gamma$	0.031 ± 0.016	0.007 ± 0.004

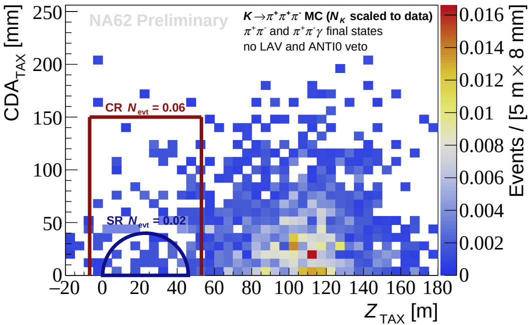

Figure: Expected background from $K_{3\pi}$ in the primary vertex Z vs CDA plane before applying ANTI0 acceptance.

- Simulation performed also for K_{e4} and $K_{\mu 4}$ decays $\Rightarrow$ negligible contributions

Total expected background overview

Table: Expected number of background events (68% CL) in CR and SR. Minimum number of observed events N_{obs} for a background-only p-value above 5σ in SR and SR+CR (global significance, flat background in m_{inv} assumed).

Channel	$N_{\mathrm{exp,CR}} \pm \delta N_{\mathrm{exp,CR}}$	$N_{\mathrm{exp,SR}} \pm \delta N_{\mathrm{exp,SR}}$	$N^{p>5\sigma}_{\mathrm{obs,SR}}$	$N^{p>5\sigma}_{\mathrm{obs,SR+CR}}$
$\pi^+\pi^-$	0.013 ± 0.007	0.007 ± 0.005	3	4
$\pi^+\pi^-\gamma$	0.031 ± 0.016	0.007 ± 0.004	3	5
$\pi^+\pi^-\pi^0$	$(1.3^{+4.4}_{-1.0}) \times 10^{-7}$	$(1.2^{+4.3}_{-1.0}) \times 10^{-7}$	1	1
$\pi^+\pi^-\pi^0\pi^0$	$(1.6^{+7.6}_{-1.4}) \times 10^{-8}$	$(1.6^{+7.4}_{-1.4}) \times 10^{-8}$	1	1
$\pi^+\pi^-\eta$	$(7.3^{+27.0}_{-6.1}) \times 10^{-8}$	$(7.0^{+26.2}_{-5.8}) \times 10^{-8}$	1	1
K^+K^-	$(4.7^{+15.7}_{-3.9}) \times 10^{-7}$	$(4.6^{+15.2}_{-3.8}) \times 10^{-7}$	1	2
$K^+K^-\pi^0$	$(1.6^{+3.2}_{-1.2}) \times 10^{-9}$	$(1.5^{+3.1}_{-1.2}) \times 10^{-9}$	1	1

- Search is background free **not only** at $N_{\mathrm{POT}} = 1.4 \times 10^{17}$ but also in the future full Run 2 dataset of $N_{\mathrm{POT}} = 10^{18}$

Final result and interpretation

0 events observed in all control and signal regions

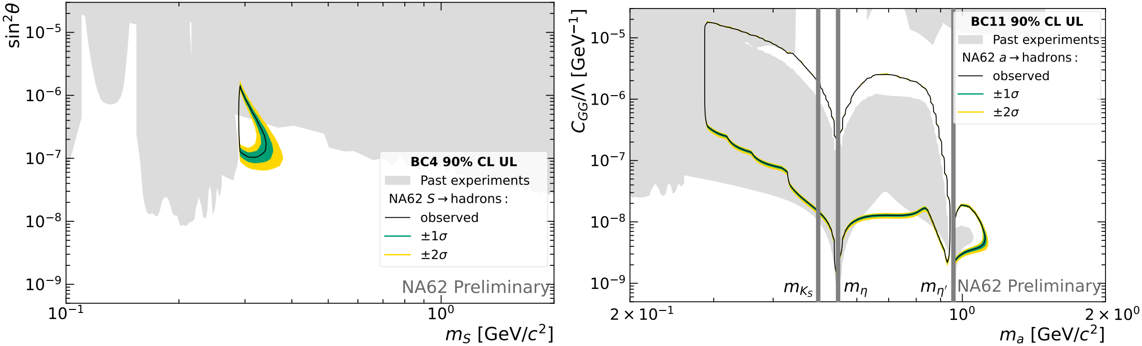

Figure: The observed 90% CL exclusion contours in BC4 (left) and BC11 (right) benchmarks together with the expected $\pm 1\sigma$ and $\pm 2\sigma$ bands (theory uncertainty not included). Public tool ALPINIST[5] used for the combination of the results from the individual production and decay channels. No standalone 90% CL exclusion for BC1 (dark photon).

[5] ALPINIST: Axion-Like Particles In Numerous Interactions Simulated and Tabulated. *JHEP* 07 (2022) 094, [2201.05170]

Conclusion

- Preliminary results on the search for production and decay of a dark-sector messenger from data collected by the NA62 experiment in beam-dump mode have been presented:
  - Analysis basically background free up to 10^{18} POT
  - Blind analysis up to opening of both control and signal region
  - **No** observation of new physics signals;
- Blind analyses to search for new-physics particle decays $X \to \ell^+\ell^-$ and $X \to$ hadrons performed on the data collected in 2021 explore new regions of the parameter space;
- Searches for dark-sector particles decaying into semi-leptonic or di-gamma final states are in progress;
- Data-taking ongoing, new sample collected in 2023, 10^{18} POT in beam-dump mode expected by the LHC LS3 with interesting perspectives on dark photons, ALPs, dark scalars and HNLs.

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Thank you for your attention!

Backup slides

Search for dark photons (DP)

Model of DP A' with kinetic mixing with the SM hypercharge: $\mathcal{L} \supset -\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu} \Rightarrow$

Two DP production mechanisms in the beam-dump setup (in TAX):

- Bremsstrahlung production: $p + N \rightarrow X + A'$
- meson-mediated production: $p + N \rightarrow X + M$, $M \rightarrow A' + \gamma(\pi^0)$, where $M \in \left\{\pi^0, \eta, \rho, \omega, ..\right\}$

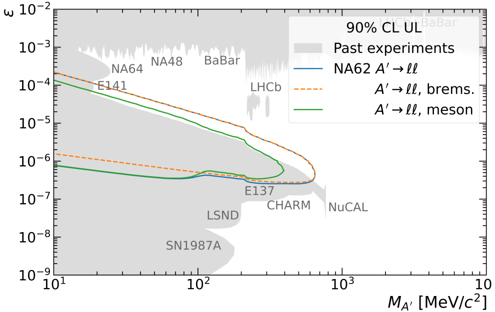


Figure: Sensitivity per production mechanism assuming 0 observed events in 1.4×10^{17} POT.

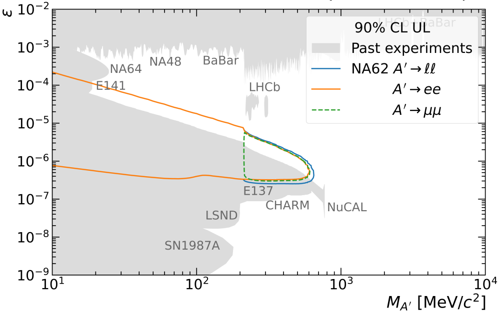


Figure: Sensitivity per decay mode assuming 0 observed events in 1.4×10^{17} POT.

Search for dark photons ($A' \to \mu\mu$)

Search strategy:

- $\mu^+\mu^-$ vertex reconstructed in FV;
- primary production vertex close to TAX.

Event selection:

- good quality tracks with timing in coincidence with each other and the trigger
- particle ID with LKr and MUV3
- no in-time activity in LAV
- extrapolation of di-lepton momentum to TAX - definition of signal region (SR) in terms of primary vertex location: $\mathrm{CDA_{TAX}}$ and z_{TAX}

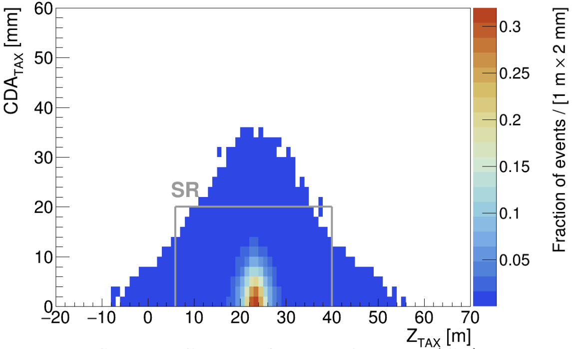


Figure: Signal MC and definition of control (CR) and signal regions (SR) for $A' \to \mu\mu$.

- SR: $6 < z_{\mathrm{TAX}} < 40$ m and $\mathrm{CDA_{TAX}} < 20$ mm;
- both SR and CR kept masked during the analysis

Search for dark photons ($A' \to \mu\mu$)

Search for $A' \to \mu^+\mu^-$ decay - data and MC comparison, CRs opened:

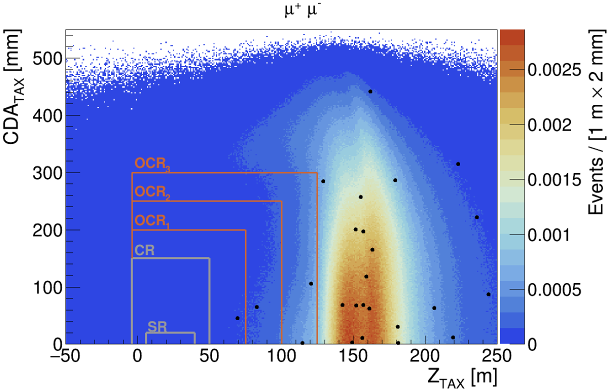


Figure: Data-MC comparison, SR closed.

	$N_{\mathrm{exp}} \pm \delta N_{\mathrm{exp}}$	N_{obs}	$p_{N \geq N_{\mathrm{obs}}}$	$p_{L \leq L_{\mathrm{obs}}}$
outside CR	26.3 ± 3.4	28	0.41	0.74
OCR3	1.70 ± 0.22	2	0.25	0.25
OCR2	0.58 ± 0.07	1	0.44	0.44
OCR1	0.29 ± 0.04	1	0.50	0.68
OCR1+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	-	-	-

- probability to observe 1 or more events in SR is 1.59%

Search for dark photons ($A' \to \mu\mu$)

Search for $A' \to \mu^+\mu^-$ decay - data and MC comparison, CRs and SR opened:

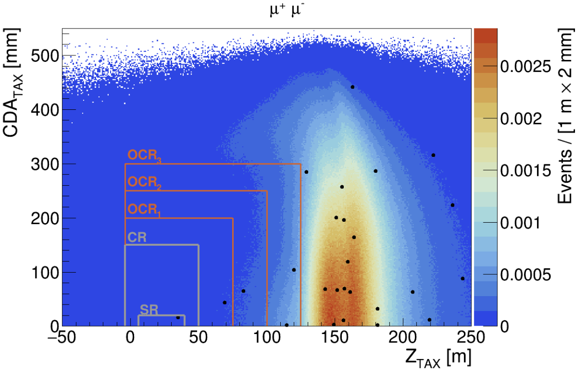


Figure: Data-MC comparison, CRs and SR open.

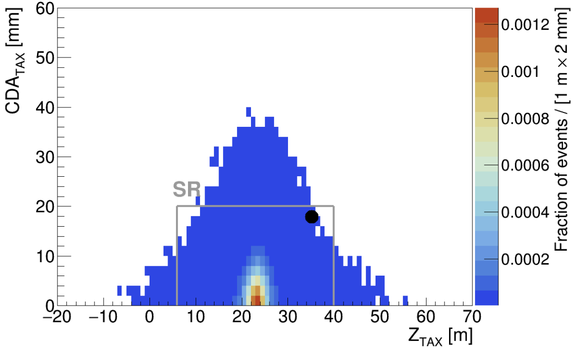


Figure: Signal MC - data: 1 event observed - counting experiment with 2.4σ significance. Signal shape not taken into account for the significance.

Search for dark photons ($A' \to \mu\mu$)

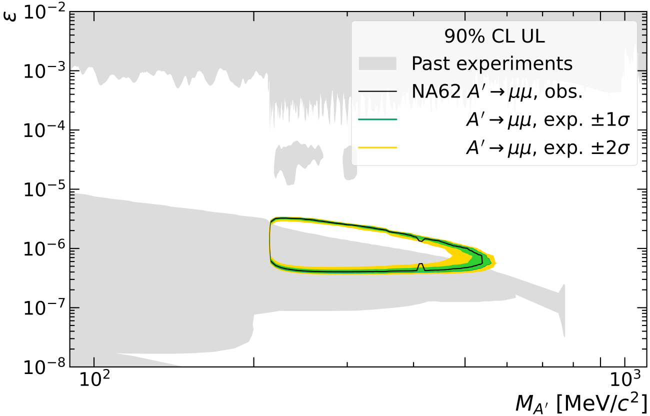


Figure: Final result with upper limit @90% CL[3].

[4] Search for dark photon decays to $\mu^+\mu^-$ at NA62. NA62 Collaboration. [2303.08666]

Search for exotic (pseudo)scalar

Interpretation of $A' \to \mu\mu$ analysis as a search for ALP/scalar a produced in $B \to K^{(\star)}a$ decay:

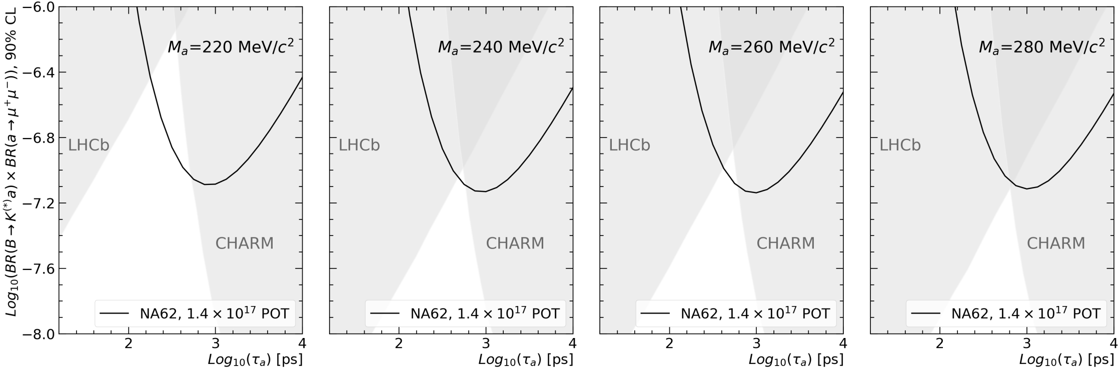


Figure: Resulting exclusion @90% CL for (pseudo)scalar a with mass M_a and lifetime τ_a.

Search for dark photons ($A' \to ee$)

Search strategy:

- e^+e^- vertex reconstructed in optimized FV;
- primary production vertex close to TAX.

Event selection:

- good quality tracks with timing in coincidence with each other and the trigger
- optimized particle ID with LKr and MUV3
- no in-time activity in LAV and ANTI0
- extrapolation of di-lepton momentum to TAX - definition of signal region (SR) in terms of primary vertex location: $\mathrm{CDA_{TAX}}$ and z_{TAX}

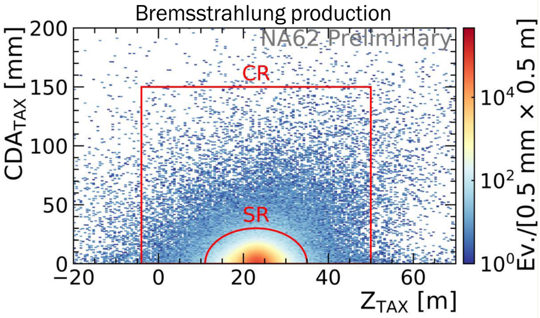


Figure: Signal MC and definition of control (CR) and signal regions (SR) for $A' \to ee$.

- SR: ellipse centered at $z_{\mathrm{TAX}} = 23$ m, $\mathrm{CDA_{TAX}} = 0$;
- both SR and CR kept masked during the analysis

Search for dark photons ($A' \to ee$)

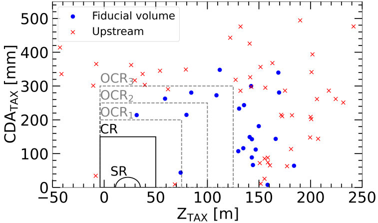


Figure: Data no LAV/ANTI0, CR/SR closed.

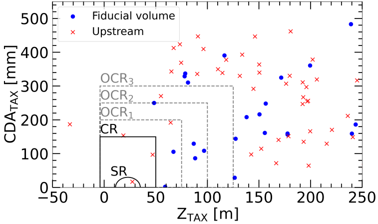


Figure: MC no LAV/ANTI0, CR/SR open.

Condition	$N_{\rm exp} \pm \delta N_{\rm exp}$	$1-\eta$
e^+e^- PID	59.9 ± 6.7	–
e^+e^- PID, LAV & ANTI0	0.72 ± 0.72	$0.012^{+0.020}_{-0.008}$
e^+e^- CR	0.51 ± 0.51	$0.008^{+0.018}_{-0.006}$
e^+e^- SR	0.47 ± 0.47	$0.008^{+0.018}_{-0.006}$

Expected number of events in CR and SR:

- $N^{\rm CR}_{\rm bkg} = 0.0097^{+0.049}_{-0.009}$ 90%CL
- $N^{\rm SR}_{\rm bkg} = 0.0094^{+0.049}_{-0.009}$ 90%CL

Search for dark photons ($A' \to \ell\ell$)

0 events observed in CR and SR:

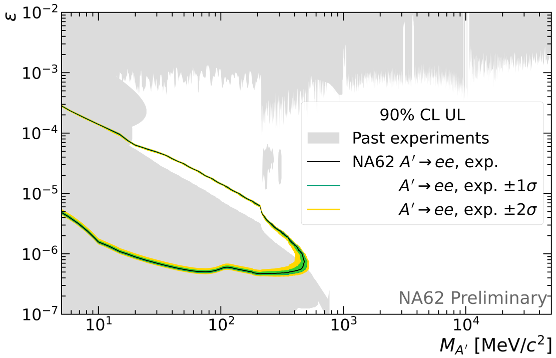


Figure: Final result with upper limit @90% CL.

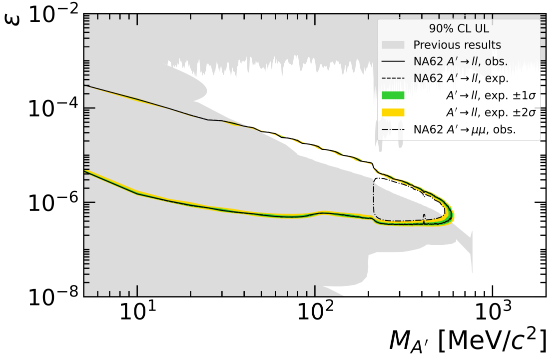


Figure: Resulting exclusion @90% CL from combined results of $\mu\mu$ and ee analyses.

Search for $A' \to \mu\mu$ - backgrounds details

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;
- each track pair weighted to account for the 10 ns time window $\to$ independent on the intensity;
- powerful statistical accuracy from combinatorial enhancement;

Prompt background:

- background from secondaries of muon interactions with the traversed material (hadron photo-production);
- muon kinematic distributions extracted from selected single muons in data (backwards MC);
- to correct the spread induced by the backward-forward process (straggling, MS), an unfolding technique is applied to better reproduce the data distributions;
- relative uncertainty of MC expectation $\sim 100\%$.

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

Search for $A' \to \mu\mu$ - backgrounds details

ΔT of the tracks suggests two types of background mechanisms

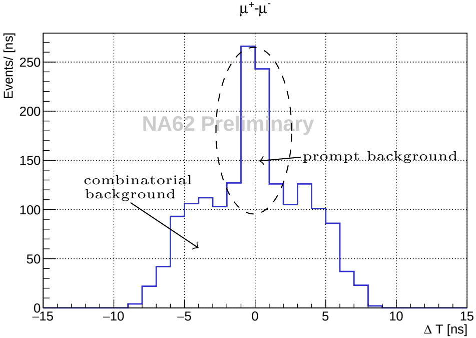


Figure: ΔT before LAV veto is applied (CR, SR masked).

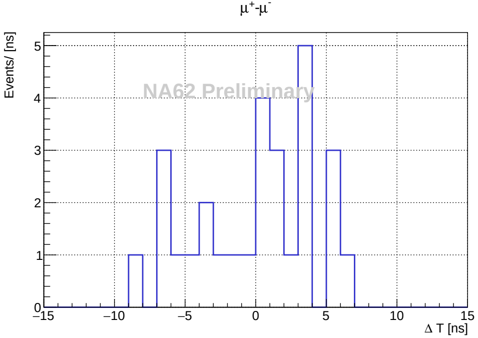
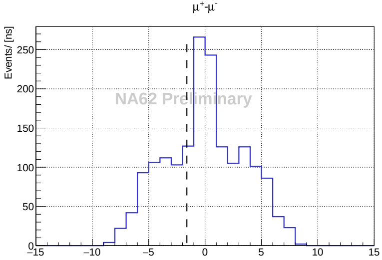
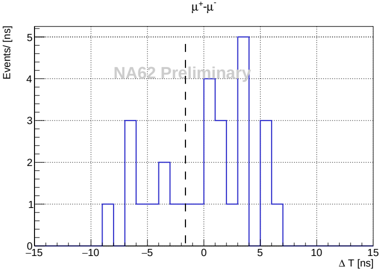


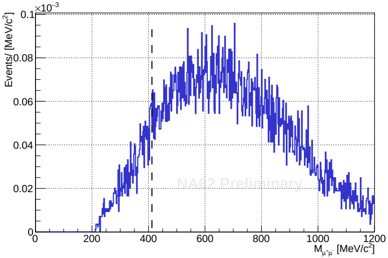
Figure: ΔT after full selection (CR, SR masked).

Search for $A' \to \mu\mu$ - details on observed event

- invariant mass: $m_{\mu\mu} = 411$ MeV
- time difference: $\Delta T = -1.69$ ns
- momenta:
  - $P(\mu^+) = 99.5$ GeV$/c$
  - $P(\mu^-) = 39.6$ GeV$/c$
- $z_{\mathrm{FV}} = 157.8$ m
- $\mathrm{CDA}_{\mathrm{FV}} = 382$ mm
- $z_{\mathrm{TAX}} = 17$ mm
- $E/p(\mu^+) = 0.008$
- $E/p(\mu^-) = 0.018$

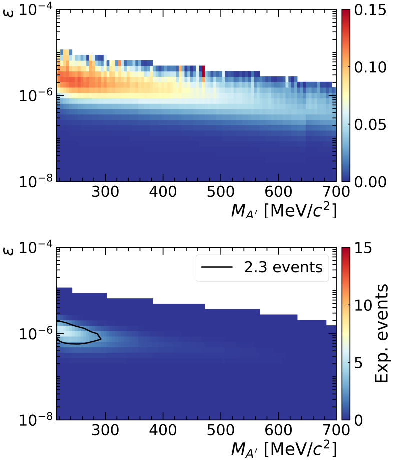




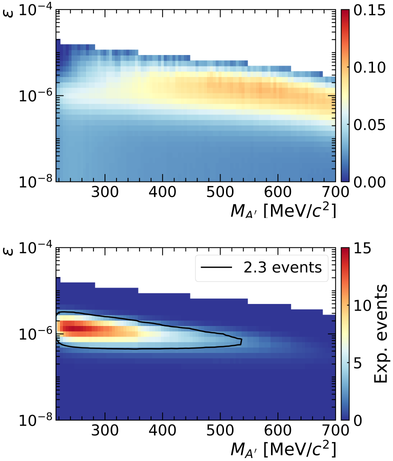


Search for $A' \rightarrow \mu\mu$ - selection efficiency and signal yield

Meson-mediated production:



Bremsstrahlung production:



Search for $A' \to ee$ - background details

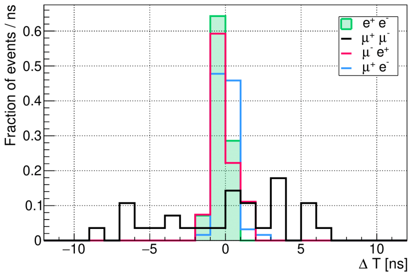
Combinatorial:

- Same technique as for $\mu\mu$ - negligible: $N_{\mathrm{exp}} < 9 \times 10^{-4}$

Prompt:

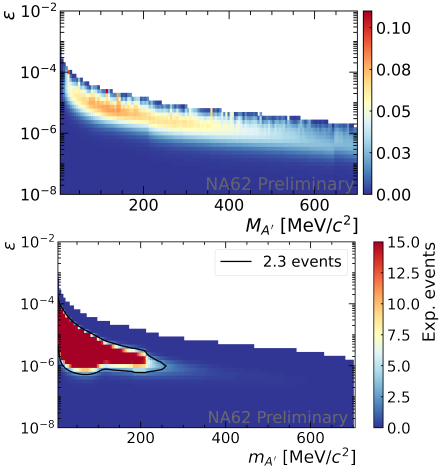
- Dominating for ee. Expected number of events estimated using rejection factors η for LAV, ANTI0, CR, SR obtained from dedicated MC.

Background before LAV veto (SR and CR masked)

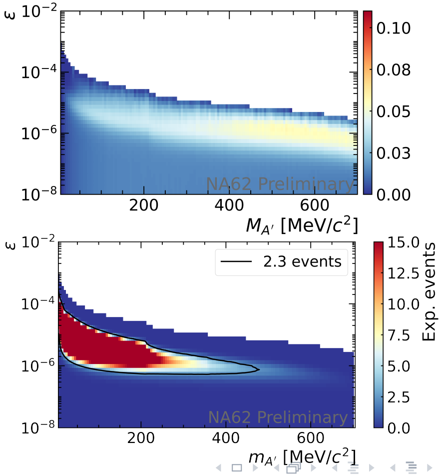


Search for $A' \to ee$ - selection efficiency and signal yield

Meson-mediated production:



Bremsstrahlung production:



MC: DP (Brems) $\to \pi^+\pi^-$

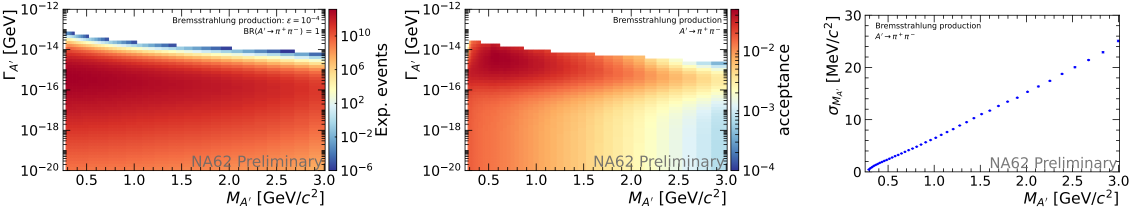


Figure: Left: expected yield after full selection, assuming $\epsilon = 10^{-4}$ and BR = 1. Center: acceptance for events that reached the FV and decayed therein. Right: Mass resolution of the reconstructed new-physics state.