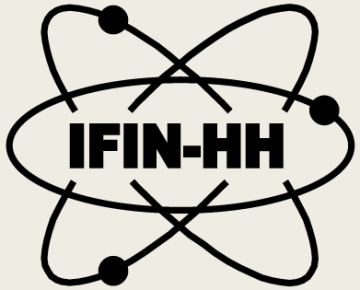

FIRST RESULTS FOR SEARCHES OF EXOTIC DECAYS WITH NA62 IN BEAM-DUMP MODE

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on behalf of the NA62 collaboration

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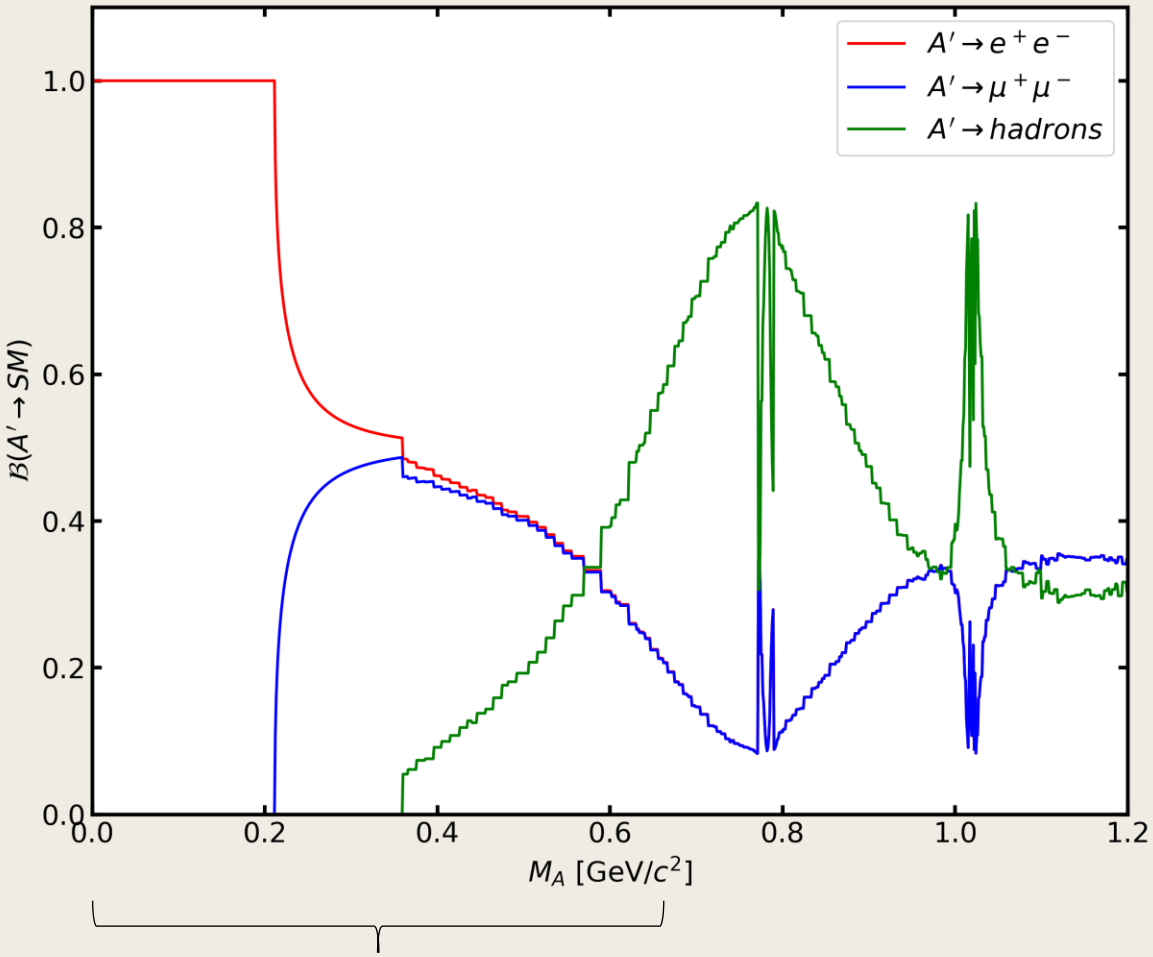
Search Motivation

- Several extensions of the Standard Model (SM):
  - ***Vector portal → Dark Photons (DP)***
  - *Scalar portal → Dark Scalars*
  - *Neutrino portal → Heavy Neutral Leptons*
  - *Axion portal → Axion-like particles*
- The Dark Photon model introduces a new vector field $F'_{\mu\nu}$ symmetric under U(1) transformations which feebly interacts with the SM fields.
- Kinetic missing interaction with the SM hypercharge:

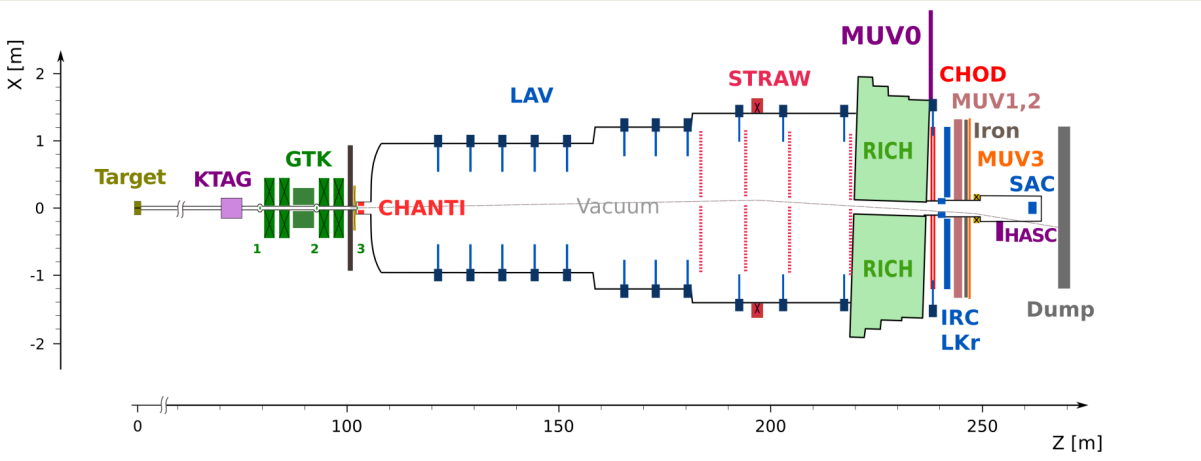
$$\mathcal{L} \subset -\epsilon \frac{1}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$$

- The mass of the DP, $M_{A'}$, and the coupling, ϵ, are free parameters



Decay width dominated by lepton-antilepton final states for $M_{A'} < 700$ MeV/c^2

The NA62 experiment at the CERN SPS



Broad physics program:

- Main goal: measurement of the $K^+ \to \pi^+ \nu\bar{\nu}$ branching ratio
- Rare and forbidden decays
- Precision measurements
- Exotic searches (beam-dump mode): DP, HNLs, ALPs

Primary beam:
400 GeV/c SPS protons,
$\sim 10^{12}$p/sec

Secondary beam:
75 GeV/c $K^+(6\%), \pi^+(70\%), p(24\%)$
~750MHz at GTK

Timeline of the NA62 experiment

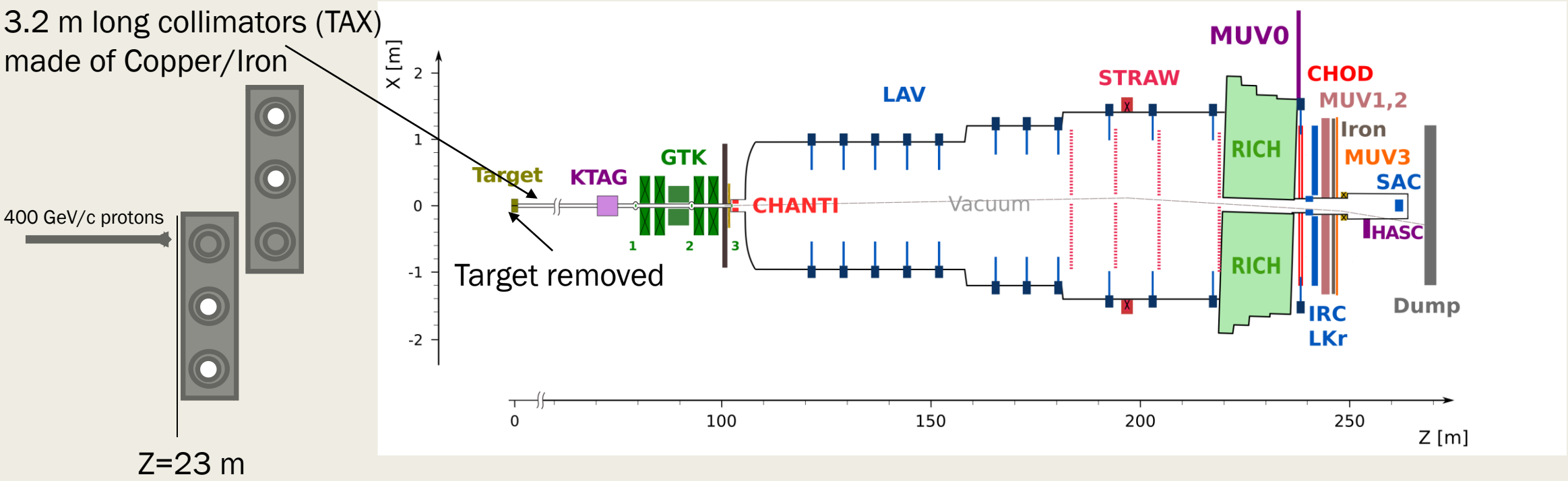
2008 NA62 approval → 2009-2014 detector R&D, installation → 2016-2018 Physis Run → 2019-2021 LS2 upgrades → 2021-2025 Physics Run

Past results:

$BR(K^+ \to \pi^+ \nu\bar{\nu}) = \left(10.6^{+4.0}_{-3.4\text{stat}} \pm 0.9_{\text{syst}}\right) \times 10^{-11}$[NA62, JHEP06 (2021) 093]

$BR(K^+ \to \pi^+ \nu\bar{\nu})_{\text{SM}} = (8.4 \pm 1.0) \times 10^{-11}$[Buras et al., JHEP11 (2015) 033]

NA62 in beam-dump mode



STRAW: tracking of charged particles;
NewCHOD: fast detector used for trigger ($\mathcal{O}(600\text{ps})$)
MUV3: muon veto/ID detector
LKr: electromagnetic calorimeter for PID and photon identification
LAV: (Large angle photon veto detectors)

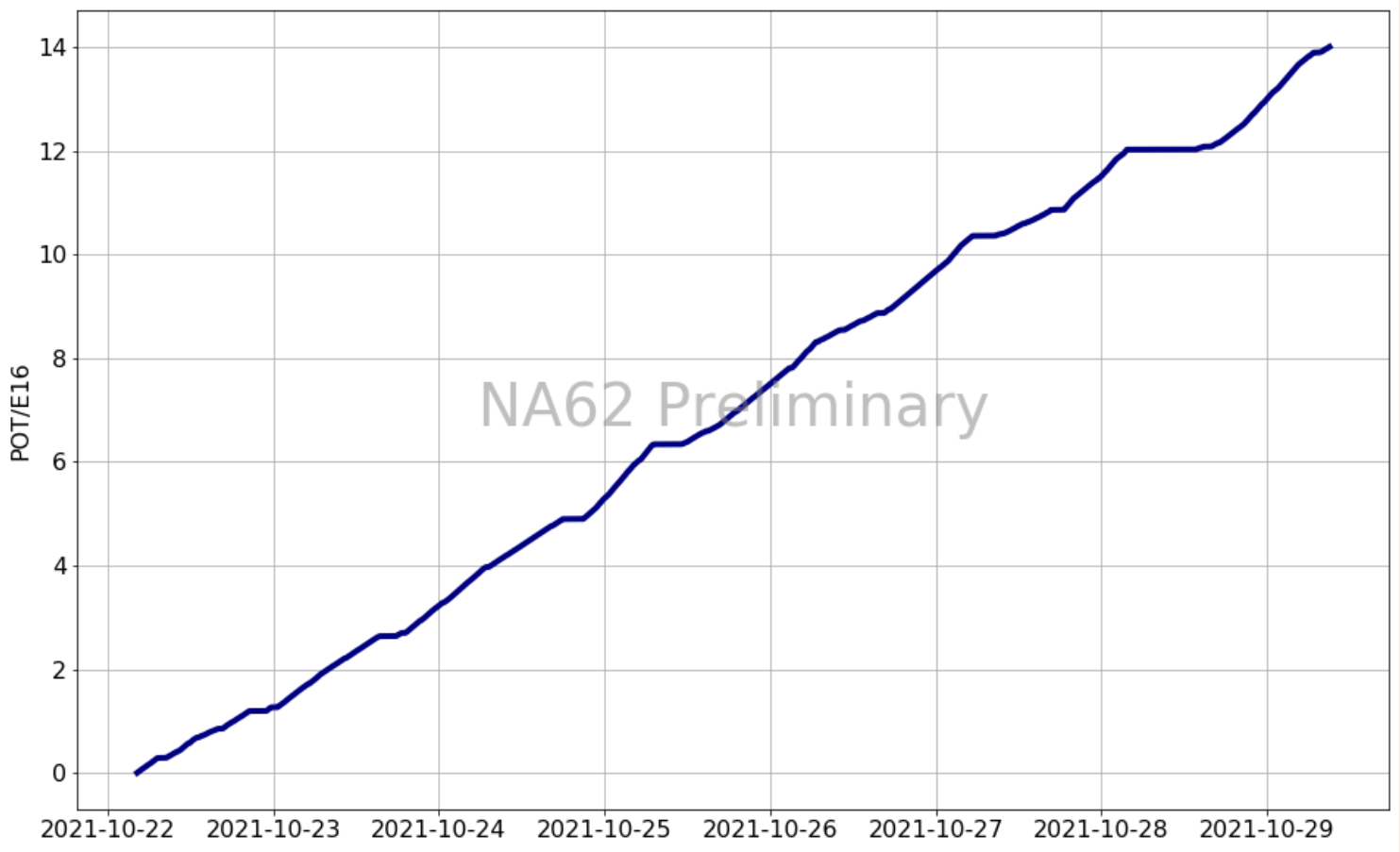
Conditions for beam-dump data taking:

- TAXes closed and target removed
- Improved sweeping from dipoles downstream of TAXes
- Beam intensity 1.5 times higher than the nominal

Data sample

Collected $(1.4 \pm 0.28) \pm 10^{17}$ POT in ~ 10 days of data taking

POT measured by beam secondary emission monitor



Two trigger lines for charged final states:

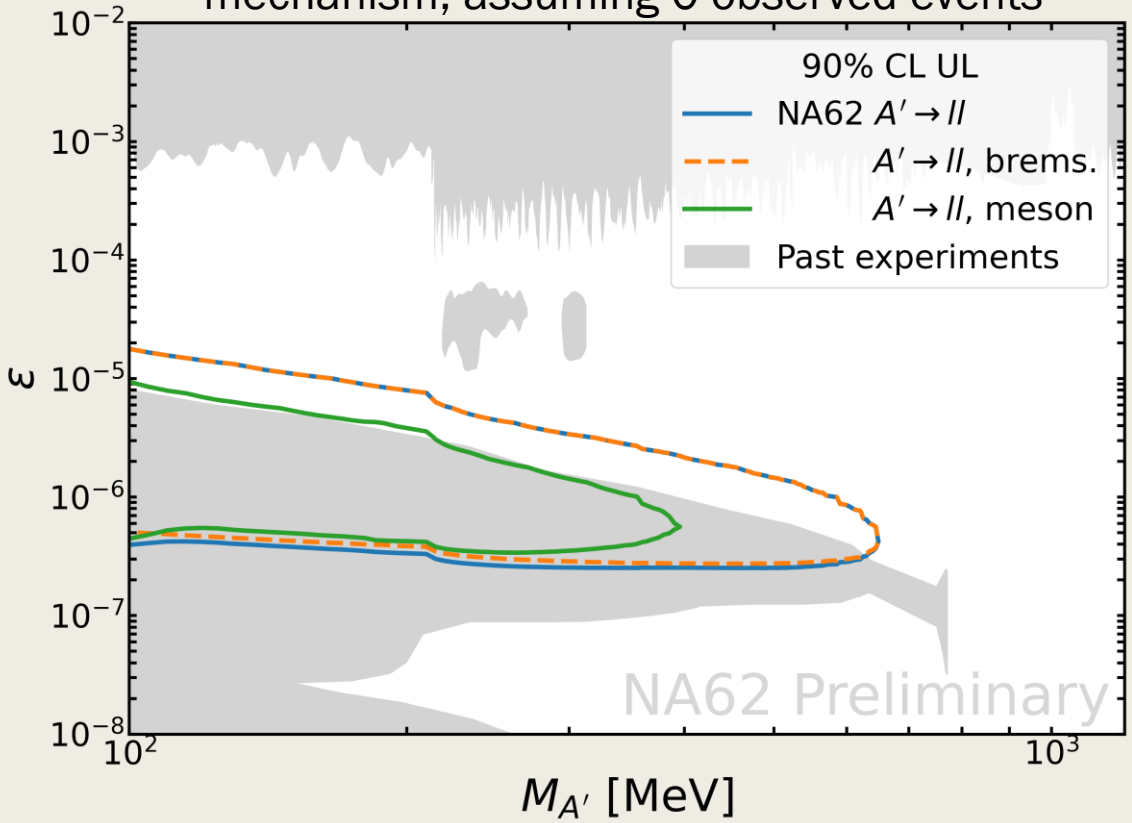
- **Single-track trigger** asking for one hit in the NewCHOD: $\mathbf{Q1}/\mathrm{D_S}(\mathrm{D_S} = 20)$ (14kHz)
- **Two-track trigger**, asking for two hits in the NewCHOD: $\mathbf{H2}$ (18kHz)

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

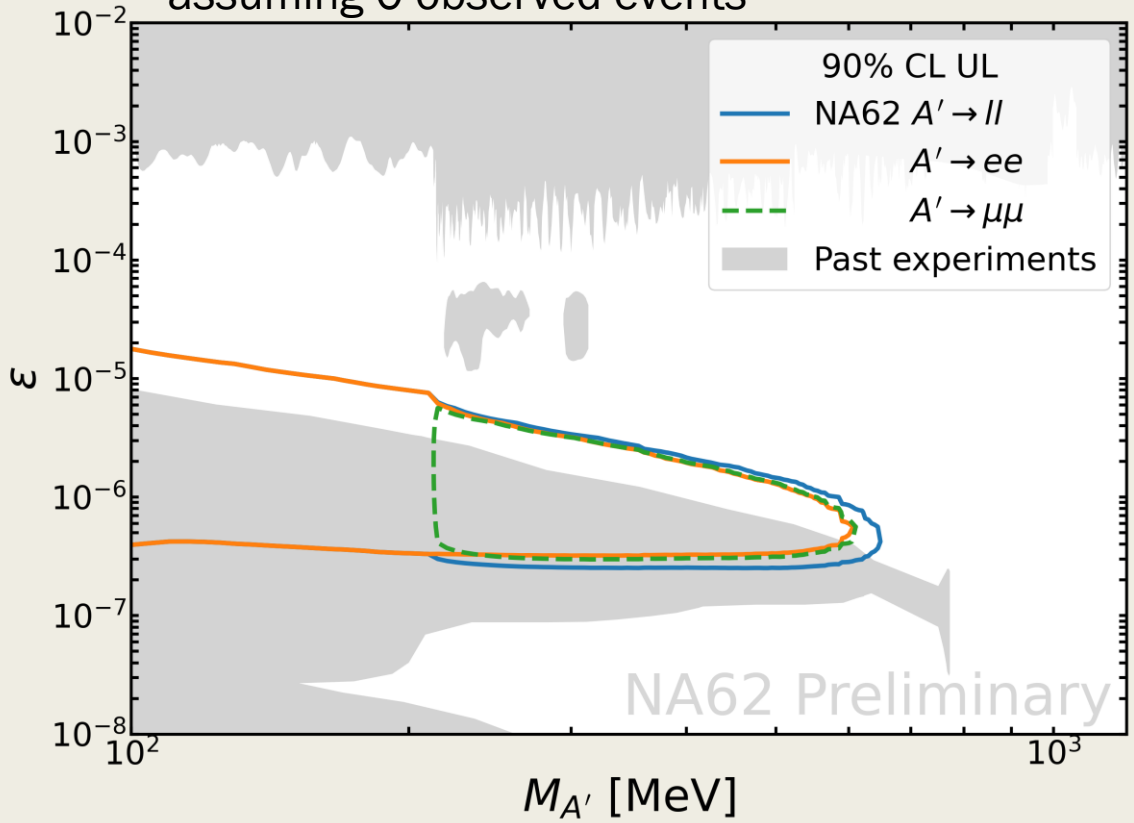
Q1 trigger efficiency = 99.8%
H2 trigger efficiency = 98%

Expected sensitivity: geometrical acceptance

Sensitivity plot, separated per production mechanism, assuming 0 observed events



Sensitivity plot, separated per decay mode, assuming 0 observed events



Two production mechanisms are in action in proton-nucleus interaction scenario:

- Bremsstrahlung production: $pN \to XA'$
- Meson-mediated production: $pN \to XM, M \to A'\gamma(\pi^0)$, where $M = \pi^0, \omega, \rho$ etc.

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

Analysis Strategy

CR = control region
SR = signal region

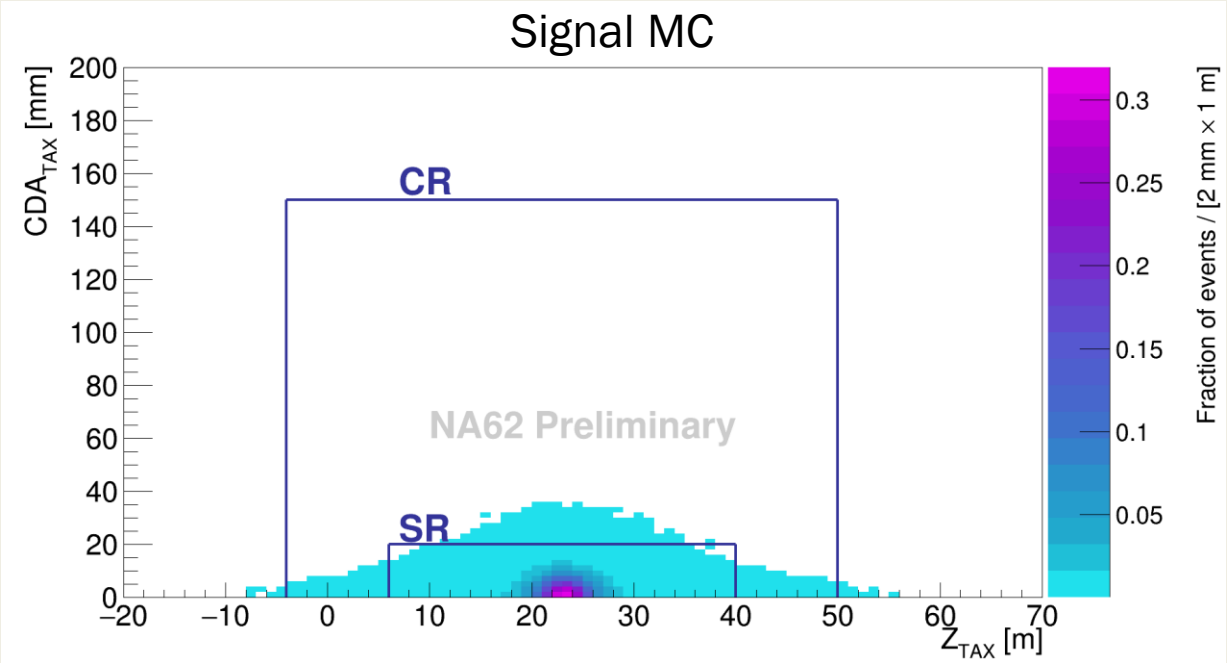
Signal signature:

- Lepton-antilepton vertex reconstructed withing the NA62 fiducial volume and a primary vertex in the direction of the lepton-antilepton pair and the proton beam at the TAXes

Event selection:

- Reconstructed track quality
- Track timing coincidence with the trigger
- Muon identification with calorimeter and muon detector
- No in-time activity at large angle veto (LAV) to reduce possible selection of vertices by interaction of incoming muons with the material in the LAVs
- Signal region selection

CR and SR kept blind up to analysis approval

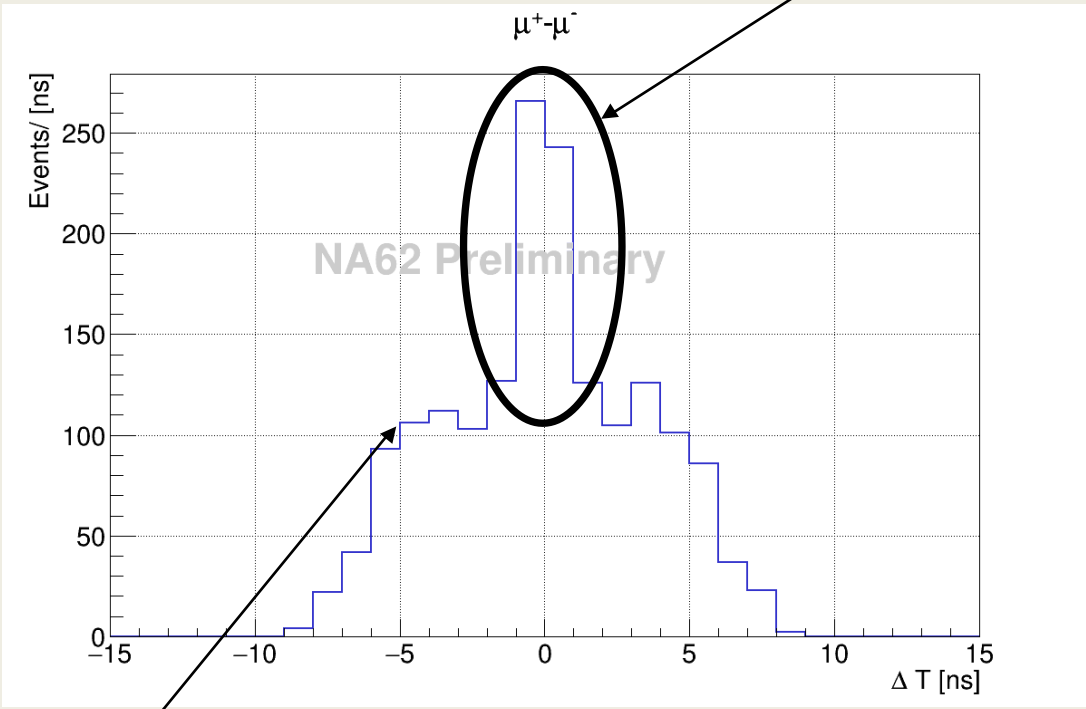


$\mathrm{CDA_{TAX}}$: closest distance of approach between the beam direction at the TAX entrance and the lepton-antilepton pair direction. $\sigma_{\mathrm{CDA}} = 7$ mm.
$\mathrm{Z_{TAX}}$: longitudinal position of the vertex. σ_Z = 5.5 mm

SR:
- $6 < \mathrm{Z_{TAX}} < 40$ m
- $\mathrm{CDA_{TAX}} < 20$ mm

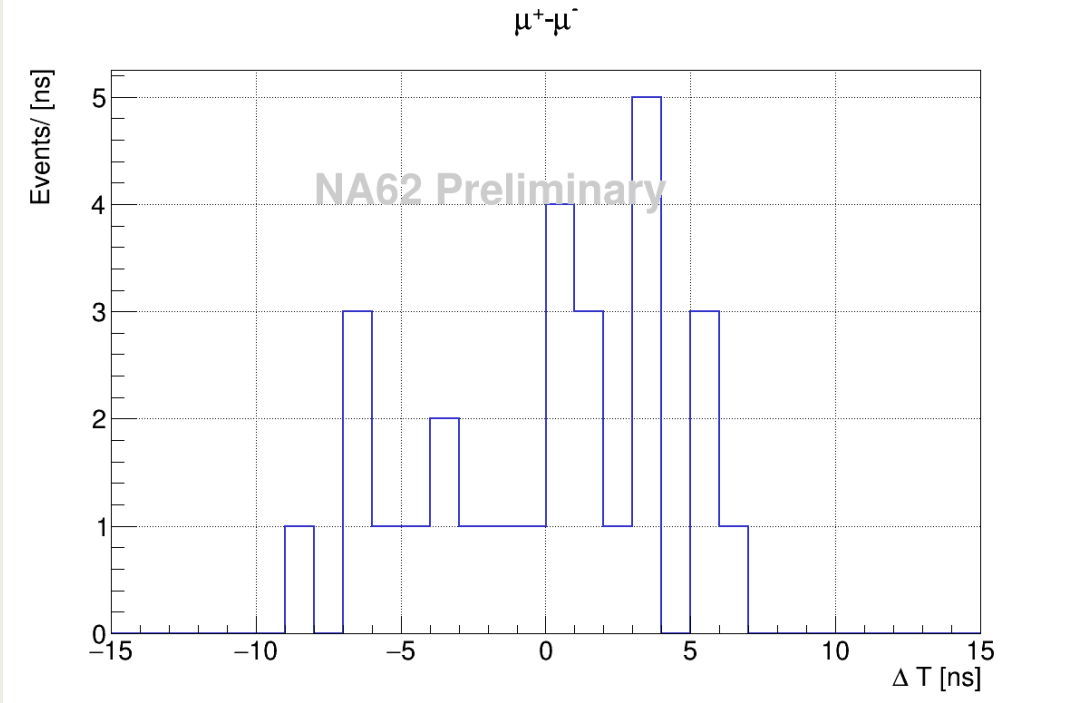
Distribution of track time difference

In-time background



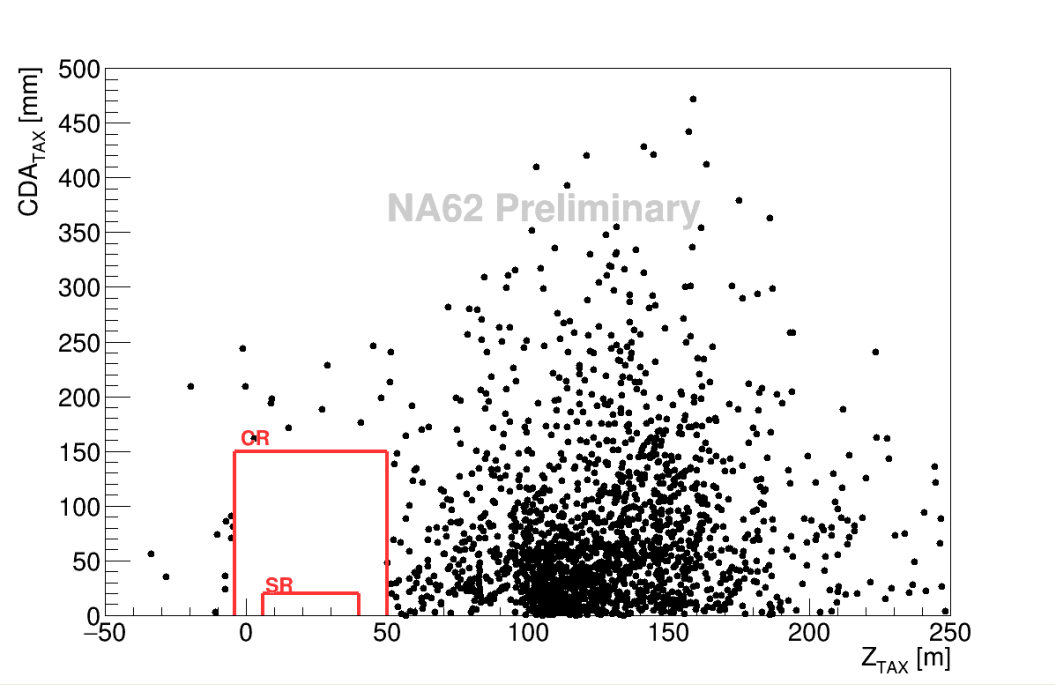
Combinatorial background

Before LAV veto is applied
(CR and SR blinded)

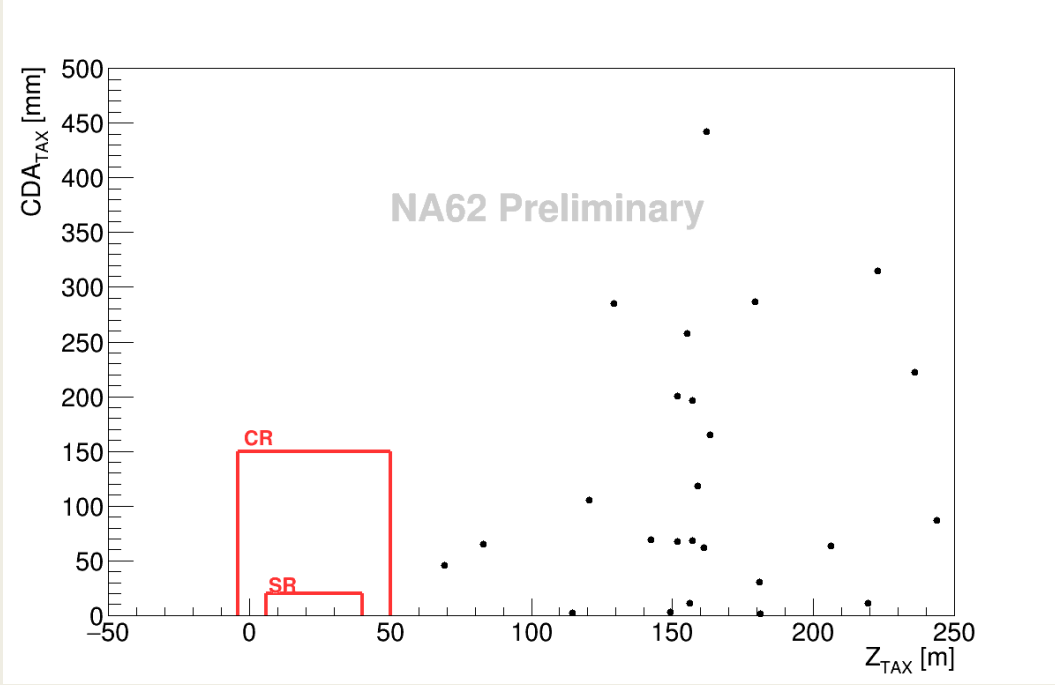


Final events selected
(CR and SR blinded)

Improvement w.r.t. 2018 data taking



2018 data → 2.6×10^{16} POT



2021 data → 1.4×10^{17} POT

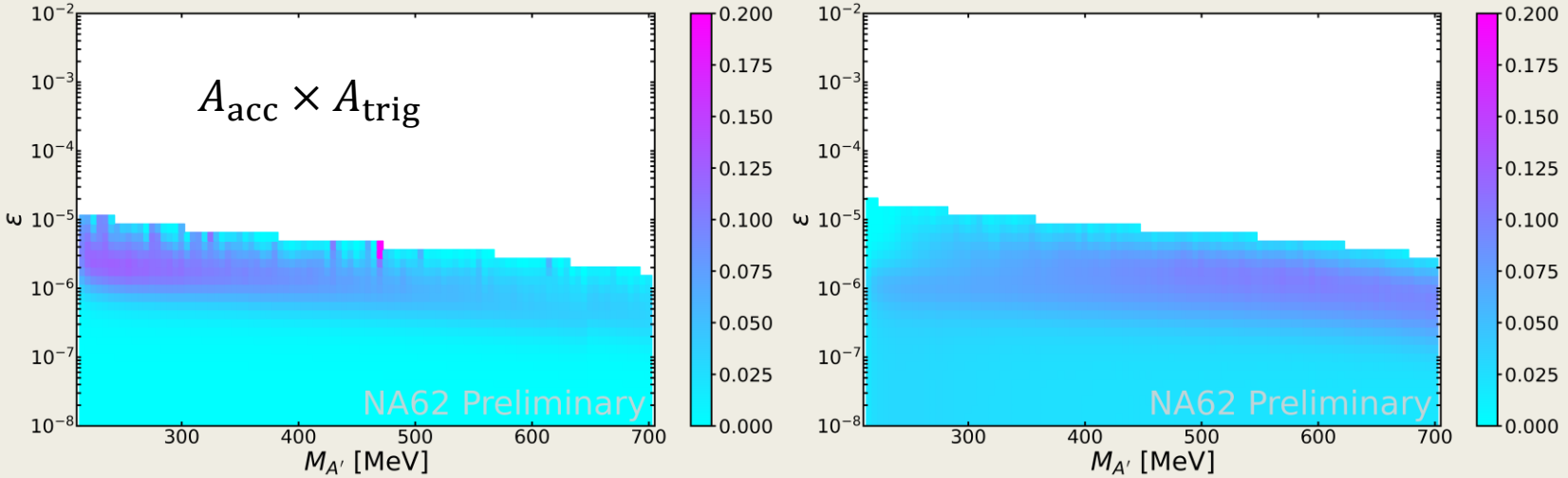
$\mathcal{O}(200)$ background reduction, despite higher intensity thanks to beam optimization

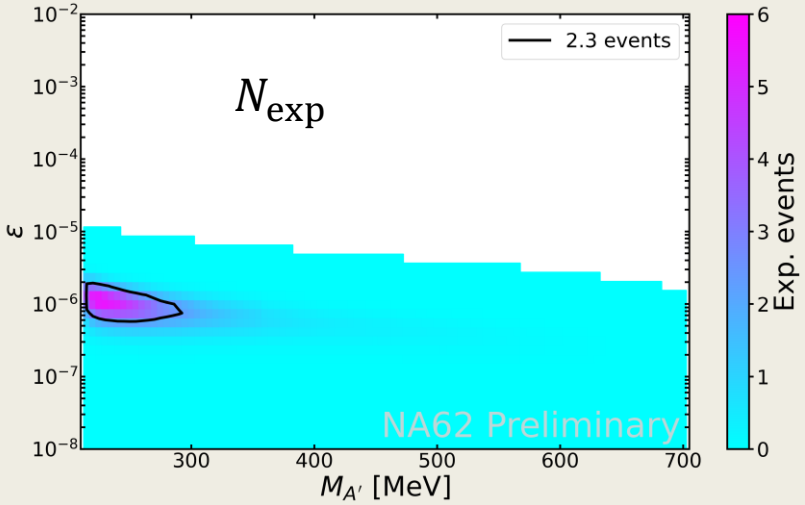
Selection efficiency and signal yield

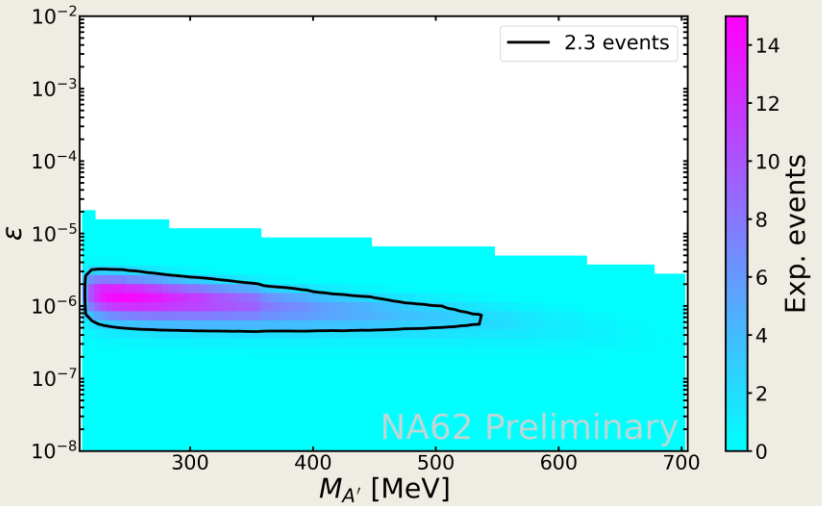
$$N_{\mathrm{exp}} = POT \times \chi(pp \to A') \times \mathcal{B}(A' \to \mu\mu) \times P_{\mathrm{rd}}(\epsilon) \times A_{\mathrm{acc}} \times A_{\mathrm{trig}}$$

Meson-mediated production

Direct production







$\chi(pp \to A')$ = DP production probability;

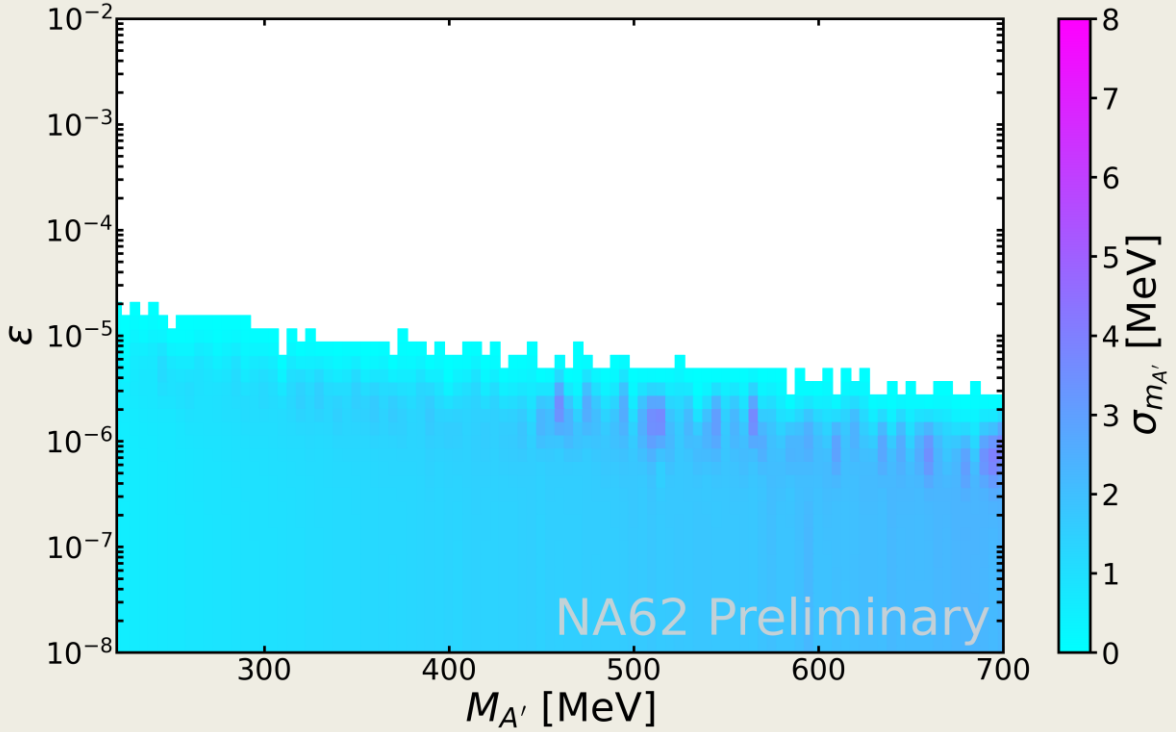
$\mathcal{B}(A' \to ll)$ = branching fraction of DP decay;

$P_{\mathrm{rd}}(\epsilon)$ = probability for DP to reach the NA62 fiducial volume and decay therein;

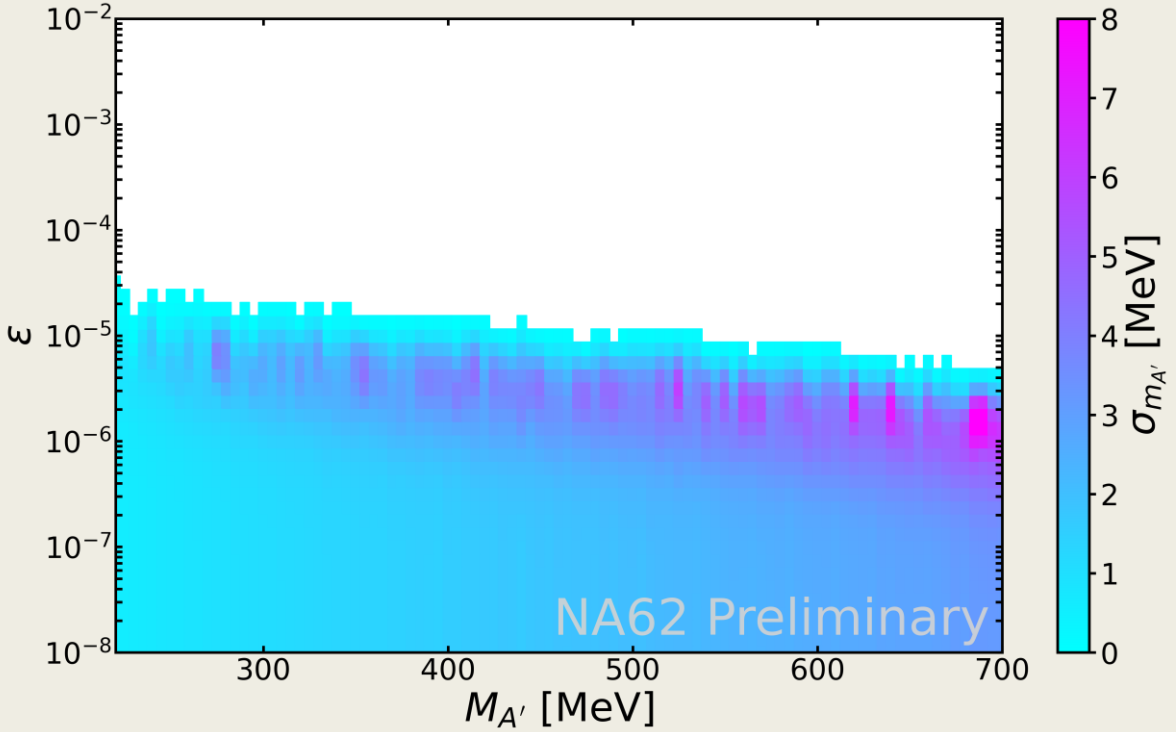
A_{acc} = selection efficiency;

A_{trig} = trigger efficiency.

Invariant mass resolution



Meson-mediated production



Direct production

Background

Combinatorial background

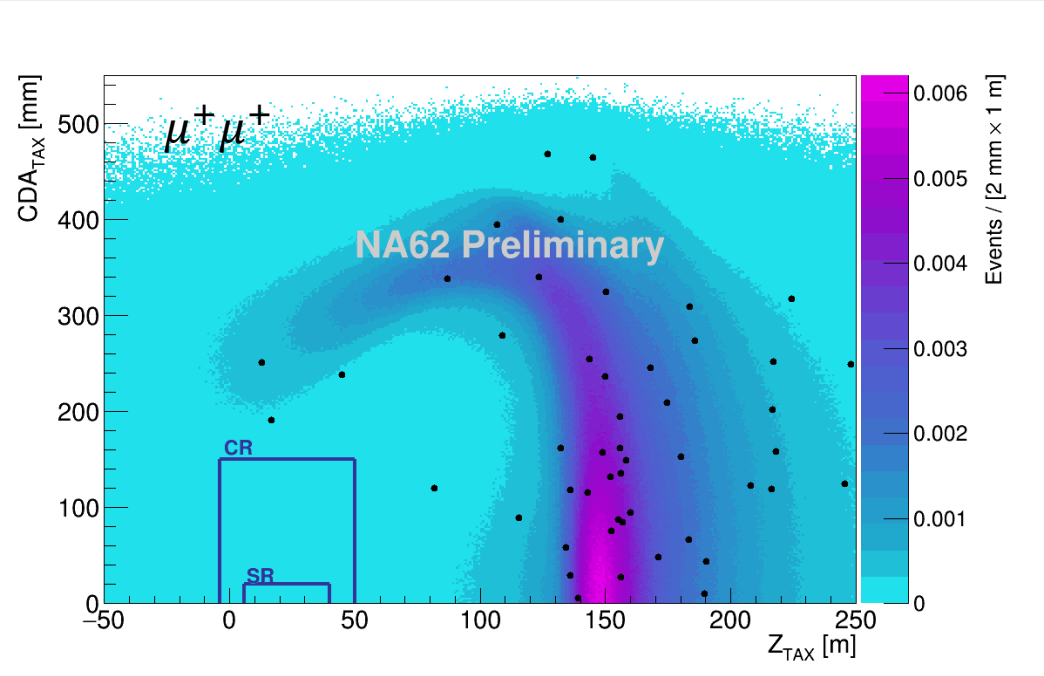
- Background from random superposition of two uncorrelated “halo” muons
- Selected single tracks in a data sample orthogonal to the one used for the analysis
- Track pairs are artificially built to emulate a random superposition
- Each track pair has a weight independent on the rate to account for the 10 ns time window

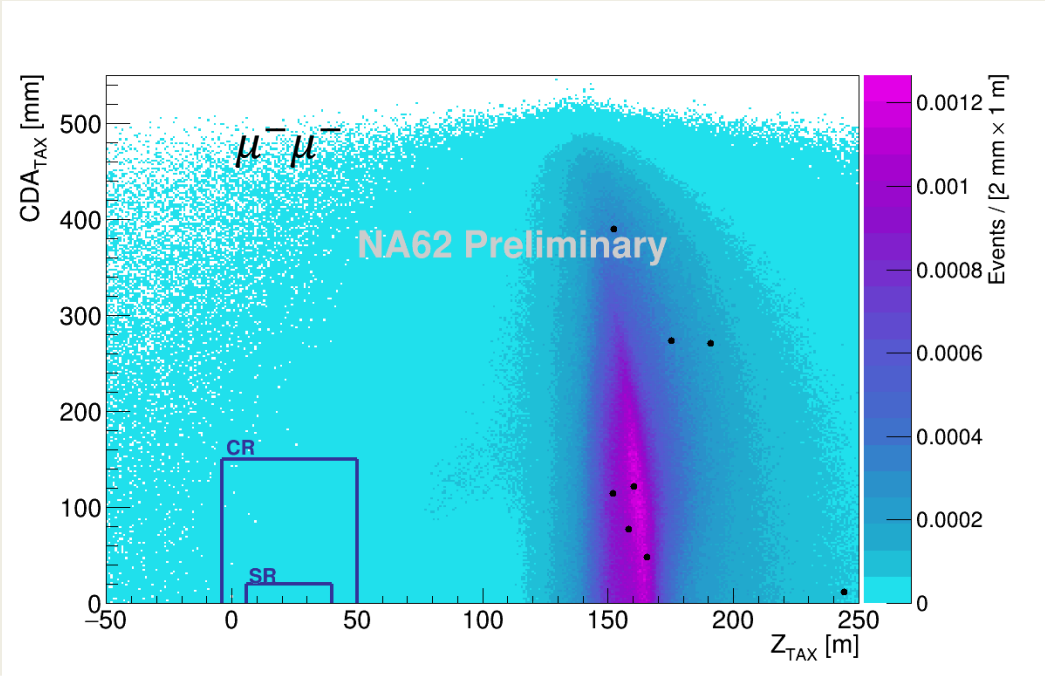
Prompt (in-time) background

- Background from secondaries of a muon interaction with the traversed material
- 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 ~ 100%

Prompt background negligible w.r.t. combinatorial (UL at 90% CL is 30% of combinatorial)

Data-MC comparison: control samples

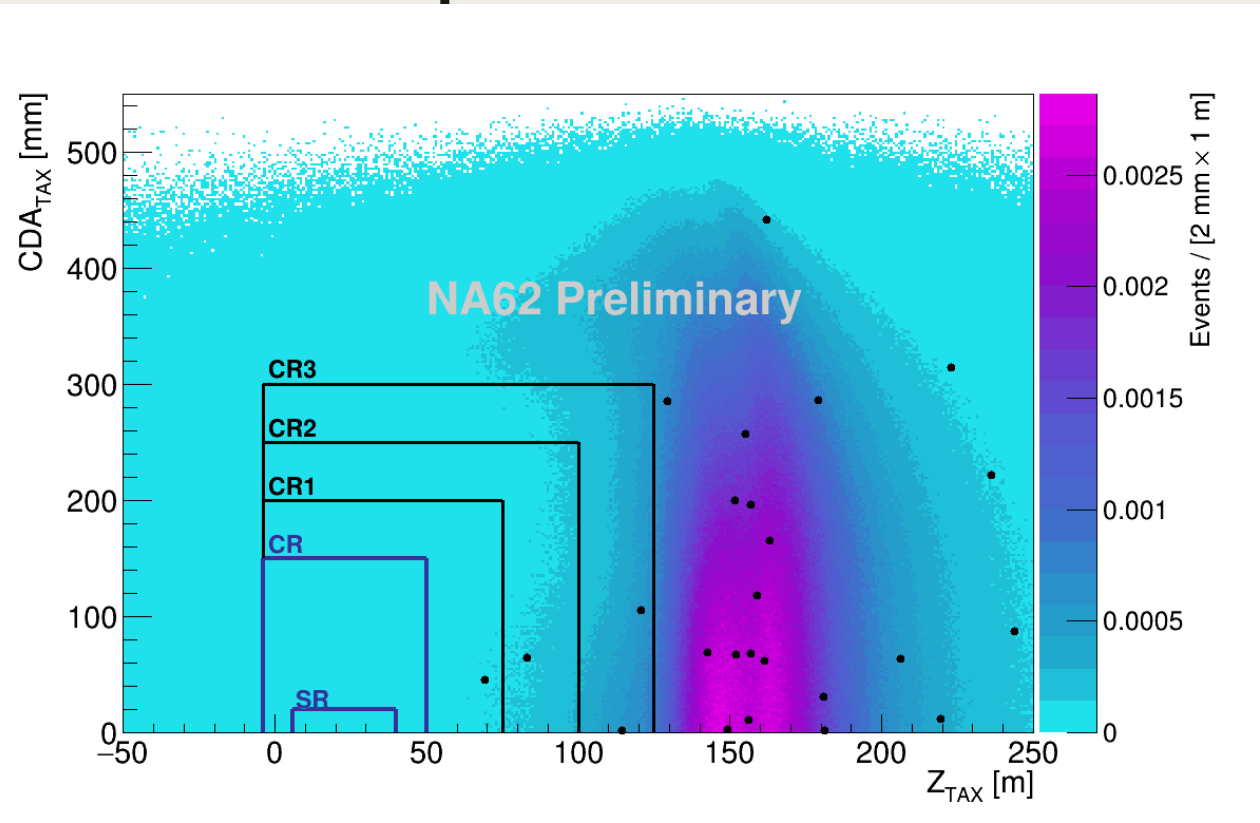




	$N_{exp} \pm \delta N_{exp}$	N_{obs}	$p(N \geq N_{obs})$	$p(L \leq L_{obs})$
Outside CR	62.5 ± 9.4	53	0.79	0.46
CR	0.46 ± 0.07	0	1.0	1.0
SR	0.040 ± 0.006	0	1.0	1.0

	$N_{exp} \pm \delta N_{exp}$	N_{obs}	$p(N \geq N_{obs})$	$p(L \leq L_{obs})$
Outside CR	9.1 ± 1.4	8	0.67	0.88
CR	0.050 ± 0.007	0	1.0	1.0
SR	0.005 ± 0.001	0	1.0	1.0

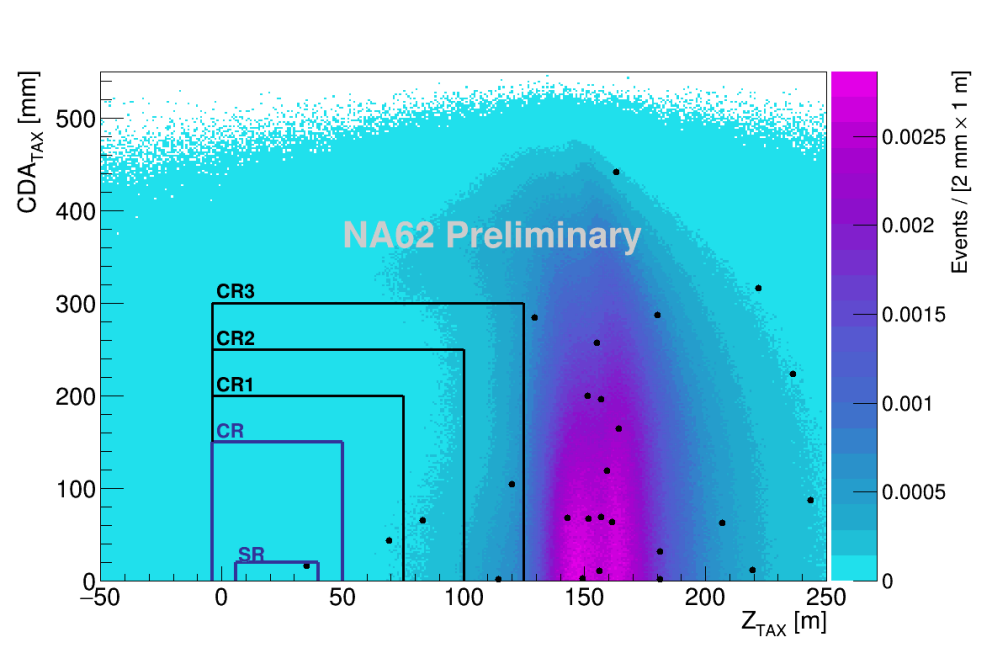
Data-MC comparison: signal sample, CRs opened

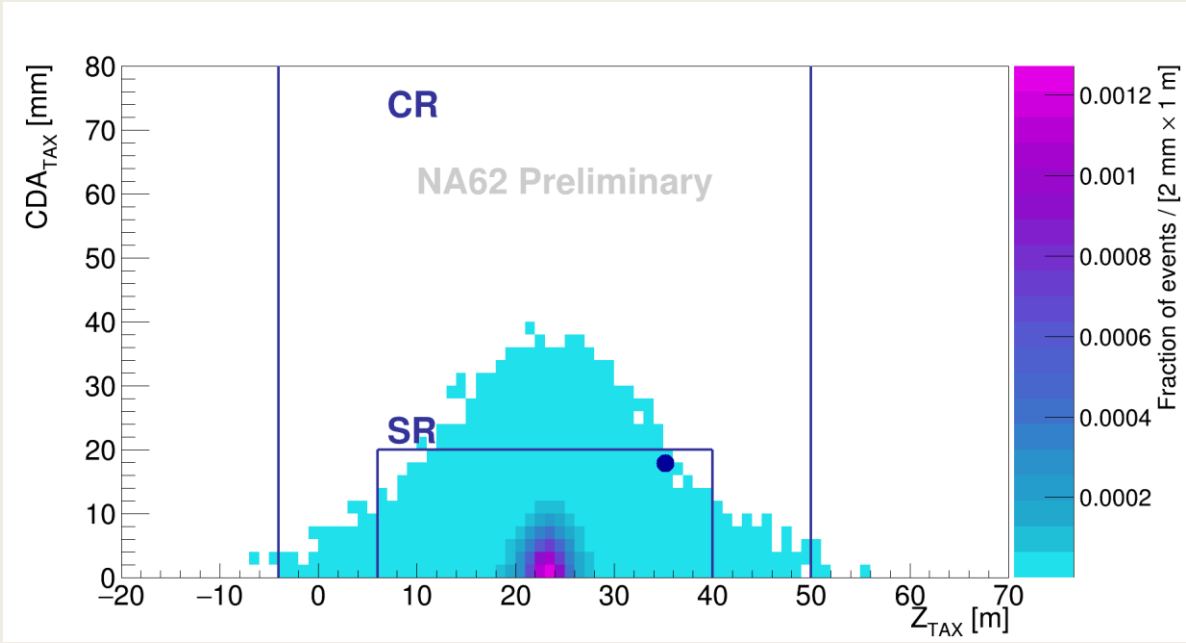


	$N_{exp} \pm \delta N_{exp}$	N_{obs}	$p(N \geq N_{obs})$	$p(L \leq L_{obs})$
Outside CR	26.3 ± 3.4	28	0.47	0.74
CR1	0.29 ± 0.04	1	0.25	0.25
CR2	0.58 ± 0.07	1	0.44	0.44
CR3	1.70 ± 0.22	2	0.50	0.68
CR1+2+3	2.57 ± 0.22	4	0.26	0.24
CR	0.17 ± 0.02	0	1.0	1.0
SR	0.016 ± 0.02	–	–	–

Probability for a non-zero observation in SR is 1.59%

Data-MC comparison: signal sample, SR opened





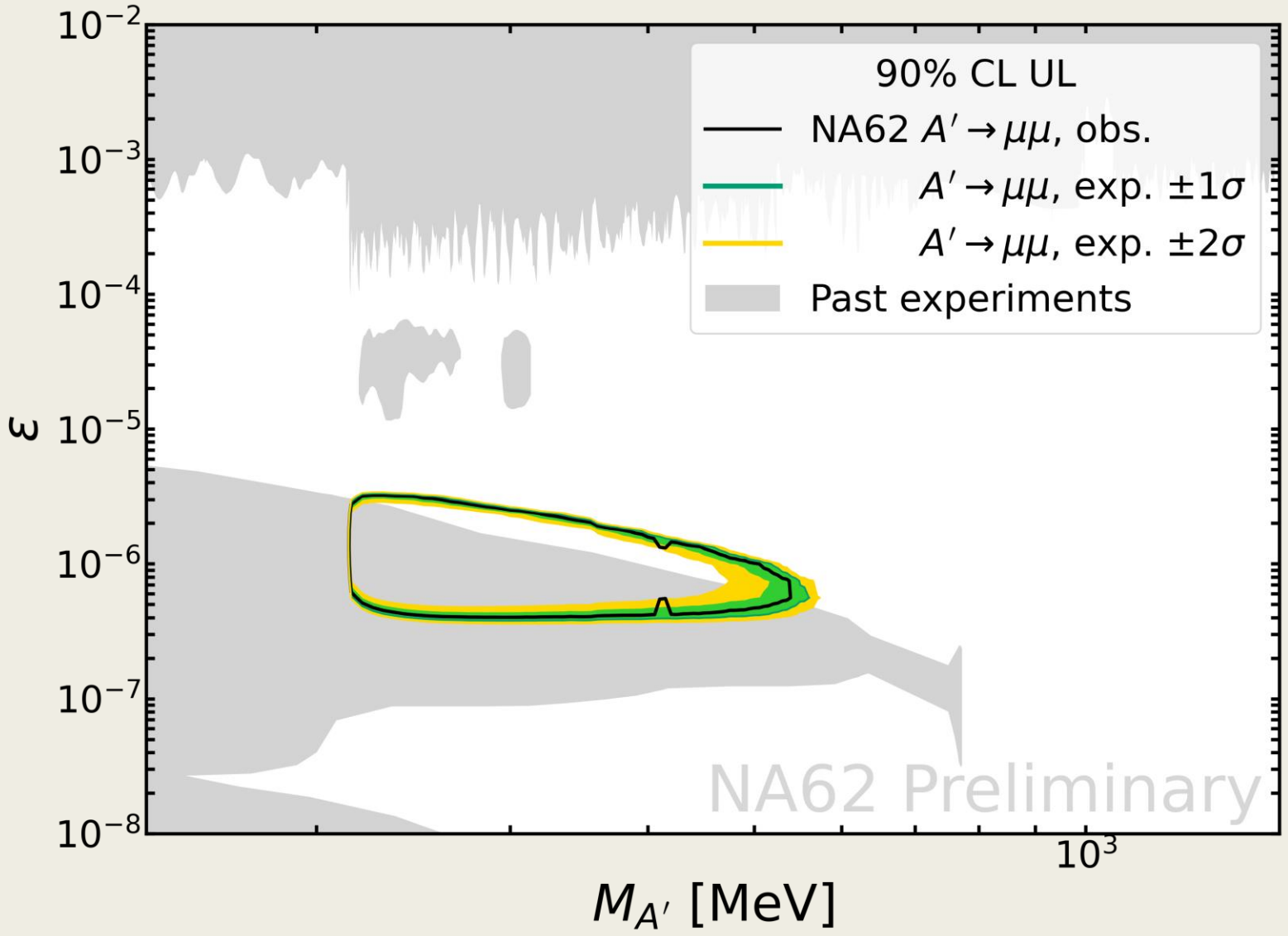
1 event observed

Counting experiment with 2.4σ significance

Signal shape not taken into account for the significance

Final result

The region enclosed by the contour is excluded



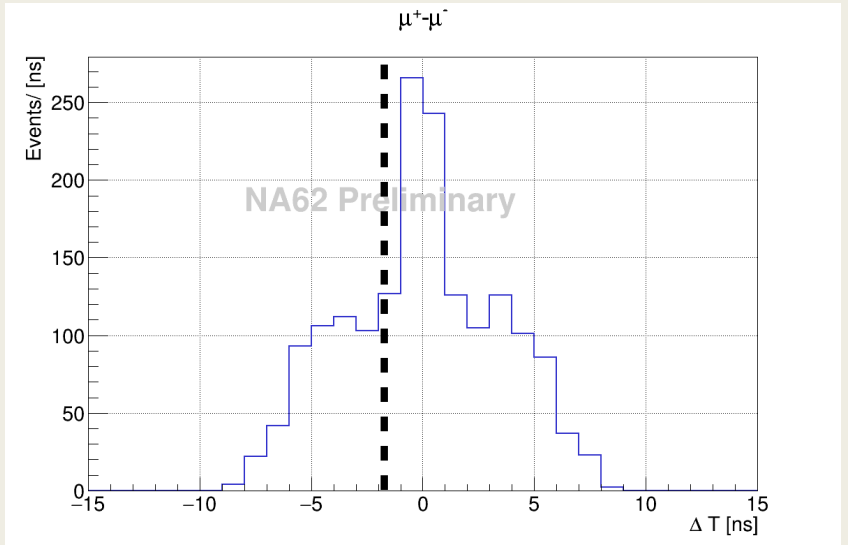
Conclusions and prospects

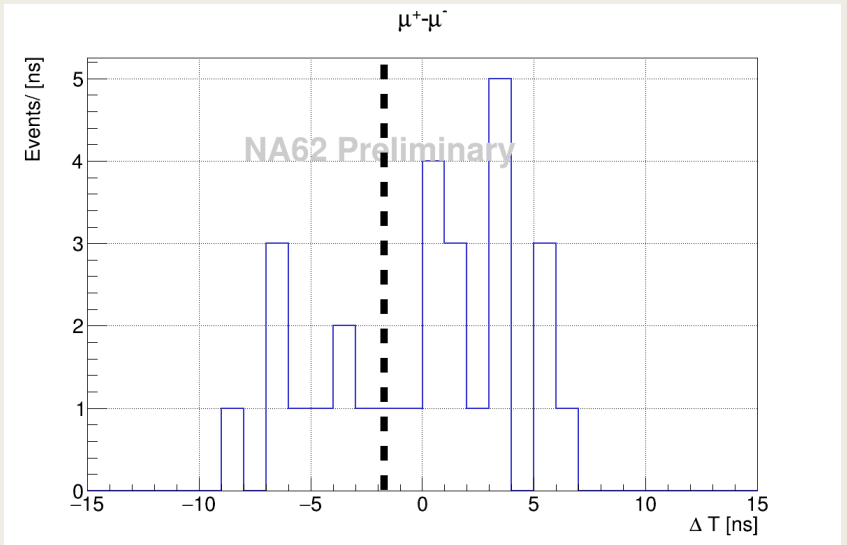
- The first preliminary result on search for production and decay of an exotic particle from data collected by the NA62 experiment in beam-dump mode has been presented;
- A cut-based counting experiment blind analysis to search for $A' \to \mu^+\mu^-$ has been performed on the data collected in 2021;
- With $(1.4 \pm 0.28) \times 10^{17}$POT, a 90% CL upper limit has been set, exploring a new region of the parameter space;
- Search 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 10^{18} POT in beam-dump in 2022-2025 with interesting perspectives on dark photons, ALPs, dark scalars and HNLs

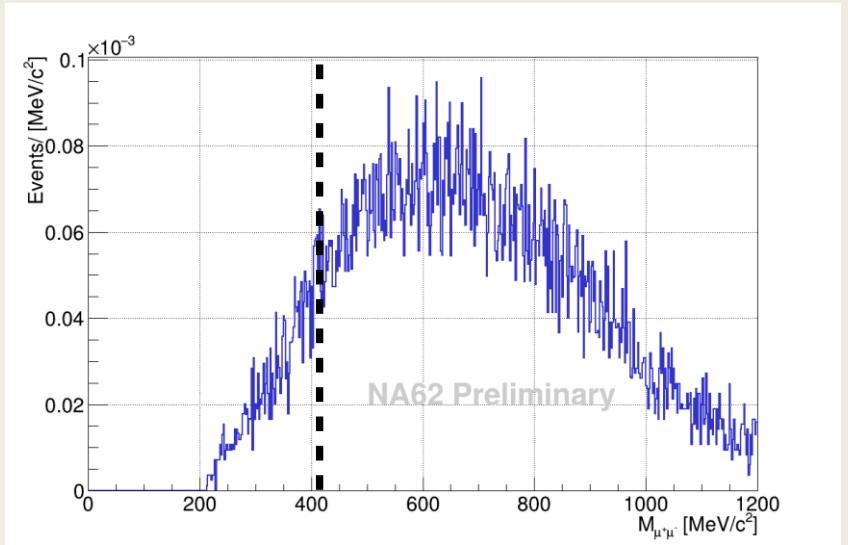
Backup

Information of the observed event in SR

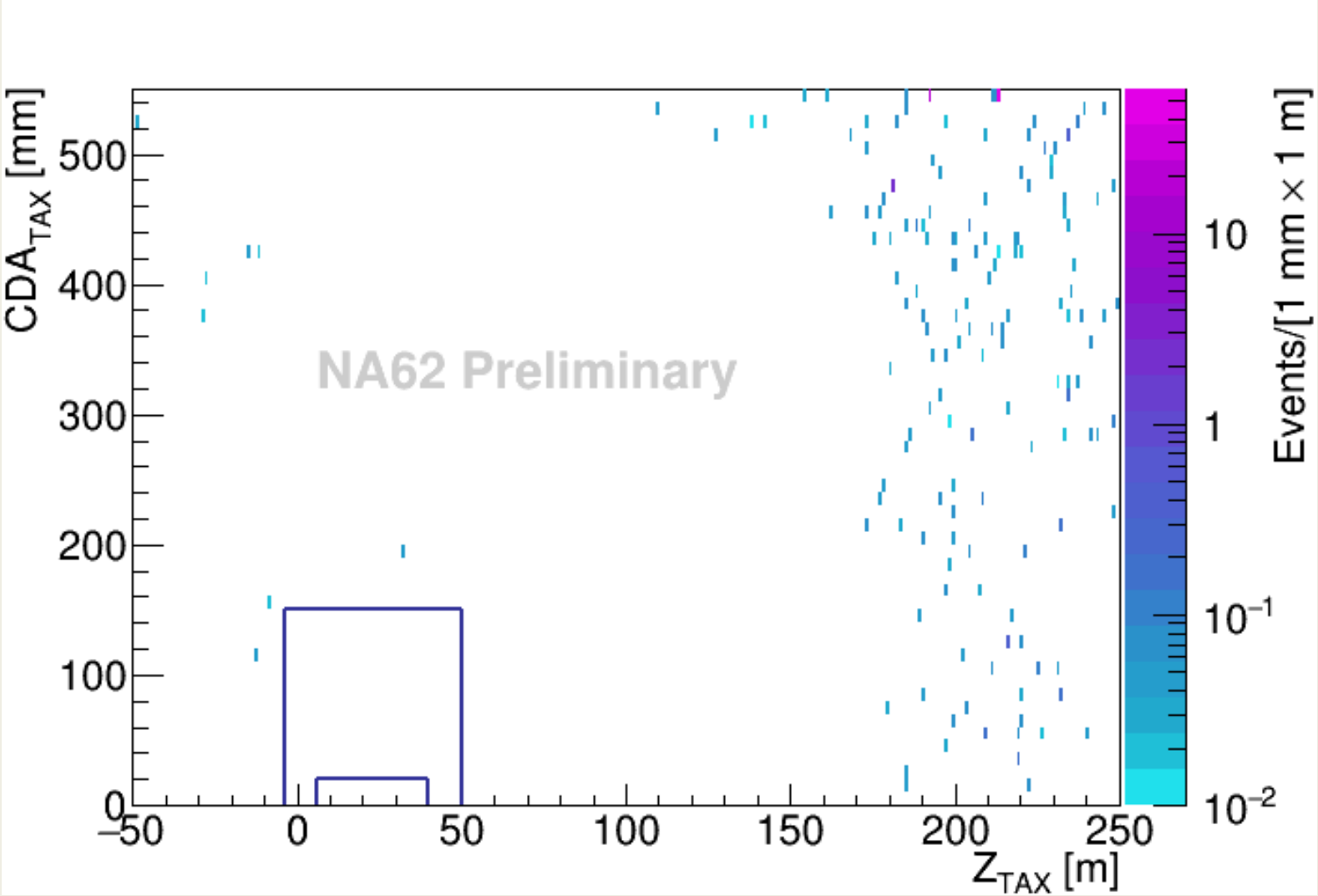
- $M_{\mu\mu} = 411\ \mathrm{MeV}/c^2$
- $\Delta T = -1.69\ \mathrm{ns}$
- $P(\mu^+) = 99.5\ \mathrm{GeV}/c$
- $P(\mu^-) = 39.5\ \mathrm{GeV}/c$
- $Z_{\mathrm{FV}} = 157.8\ \mathrm{m}$
- $CDA_{\mathrm{FV}} = 382\ \mathrm{mm}$
- $Z_{\mathrm{TAX}} = 35.3\ \mathrm{m}$
- $CDA_{\mathrm{TAX}} = 17\ \mathrm{mm}$
- $E/P(\mu^+) = 0.008$
- $E/P(\mu^-) = 0.018$







MC prompt background



Expected background summary for CR and SR

Region	Combinatorial	Prompt	Upstream-prompt
CR	0.17 ± 0.02	< 0.033	< 0.052
SR	0.016 ± 0.002	< 0.003	< 0.005

*Limits defined at 90% CL