Status of the NA62 experiment

Data collection for 2025 progressing very well

- Beam intensity optimized for signal selection efficiency → optimal conditions for KPNN measurement
- 2023-2024 sample statistically equivalent to the 2016-2022 sample
- 2025 data taking at same rate as 2024, with excellent data quality and DAQ performance
- Fundamental contributions from INFN groups (including LNF) to detector operation and maintenance

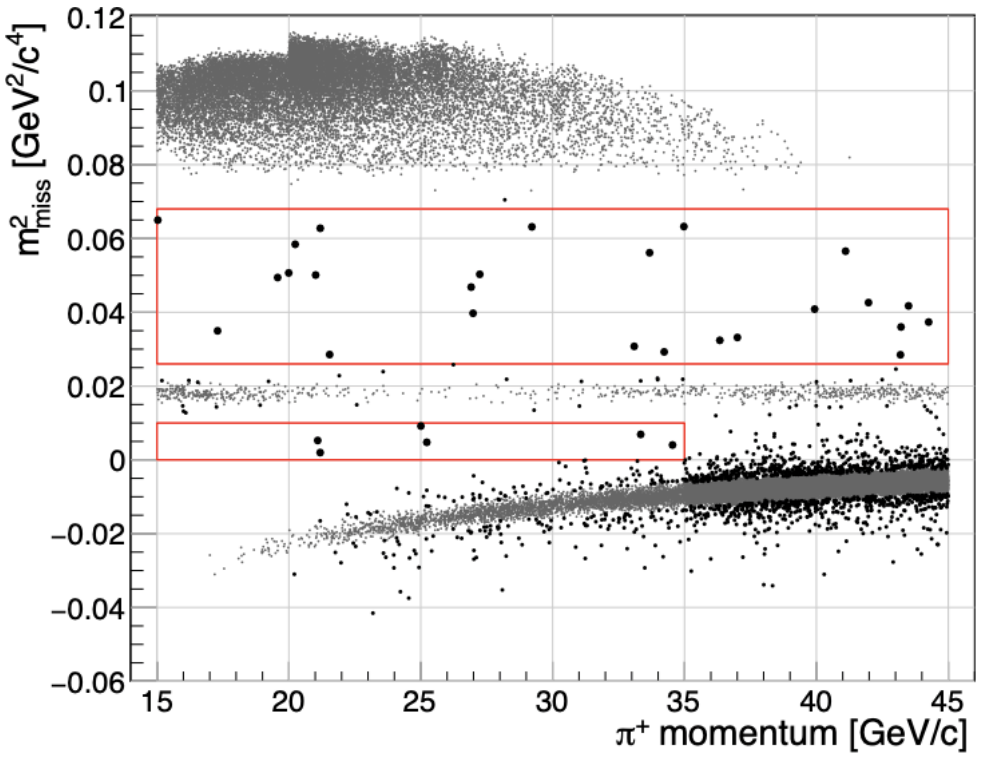
$K^+ \to \pi^+ \nu\nu$

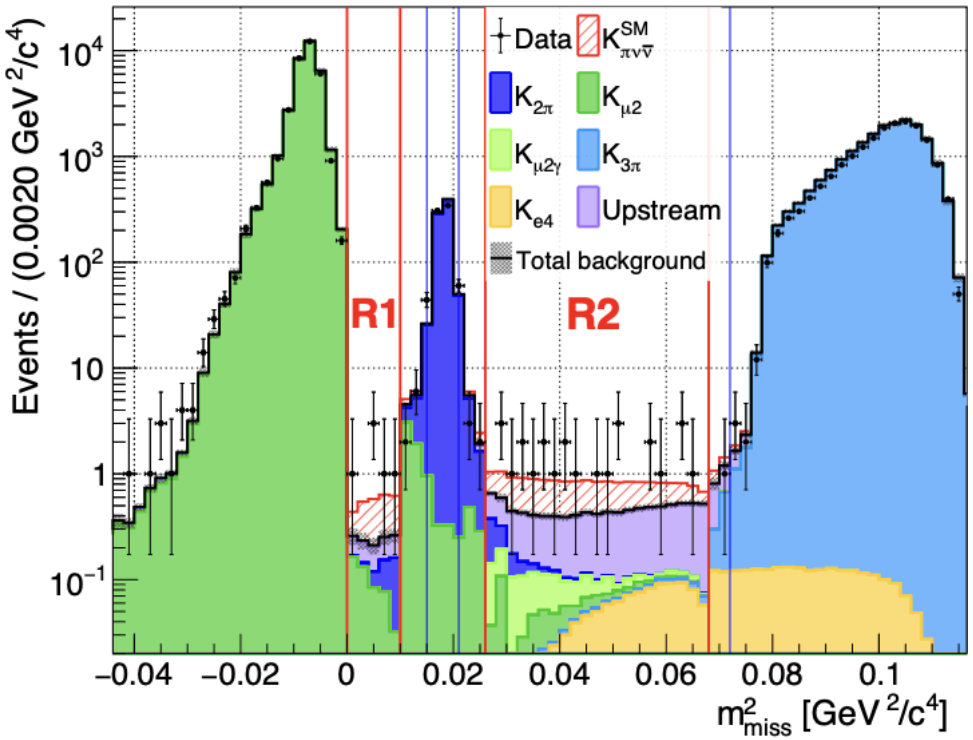
- Major milestone in 2024: 5σ observation of $K^+ \to \pi^+ \nu\nu$ decay and BR measured to 25% with 2016-2022 data
- 2023-2024 data: signal yield per spill slightly improved compared to 2022 → result expected by summer 2026
- Possibility of achieving a final precision of 15% on BR($K^+ \to \pi^+ \nu\nu$) with the addition of all data from 2023-2026 (3x statistics of current measurement)
- Significant INFN (and LNF) contributions to analysis coordination

Other analyses (K, π, ν, FIPs), with significant INFN (and LNF) coordination:

- Search for heavy neutral leptons ($\pi^+ \to e^+ N$ search)
- Search for feebly interacting particles (FIPs) in beam-dump mode
- Precision measurement of V_{us} from semileptonic K^+ decays acquired in low-intensity runs

$K^+ \to \pi^+ \nu\nu$





Background	Events
$K^+ \to \pi^+\pi^0(\gamma)$	0.83 ± 0.05
$K^+ \to \mu^+\nu(\gamma)$	1.70 ± 0.47
$K^+ \to \pi^+\pi^+\pi^-$	0.11 ± 0.03
$K^+ \to \pi^+\pi^- e^+\nu$	$0.89^{+0.33}_{-0.27}$
$K^+ \to \pi^+\gamma\gamma$	0.01 ± 0.01
$K^+ \to \pi^0\ell^+\nu$	< 0.001
Upstream	$7.4^{+2.1}_{-1.8}$
Total	$11.0^{+2.1}_{-1.9}$

JHEP 02 (2025) 191

New $K^+ \to \pi^+\nu\nu$ result from 2021-2022 data!

- **Expected signal (SM): 10 events**
- **Expected background: 11 events**
- **Total observed: 31 events**

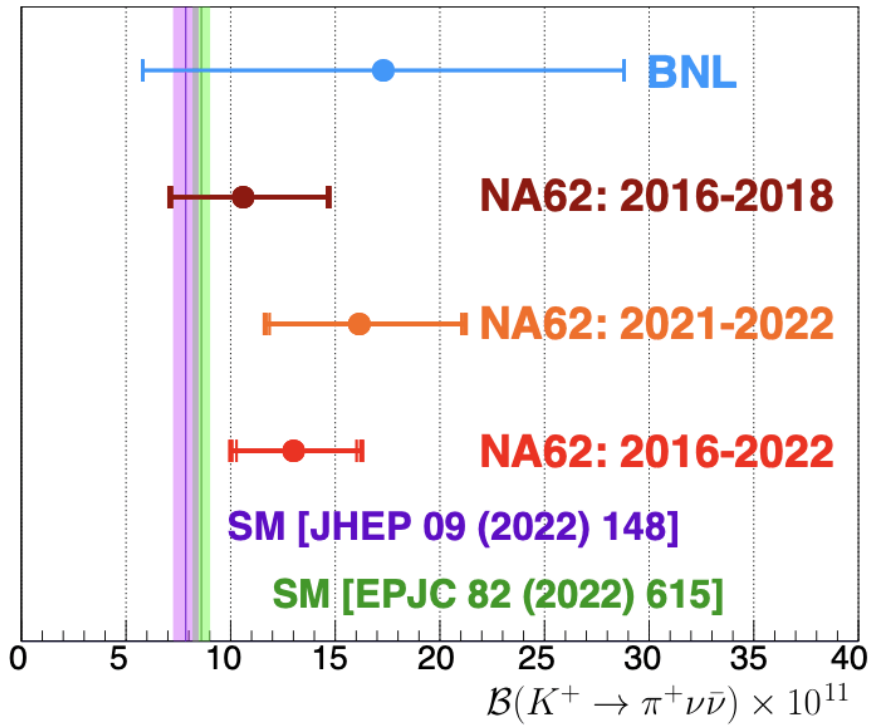
Combined with result from 2016-2018 data:

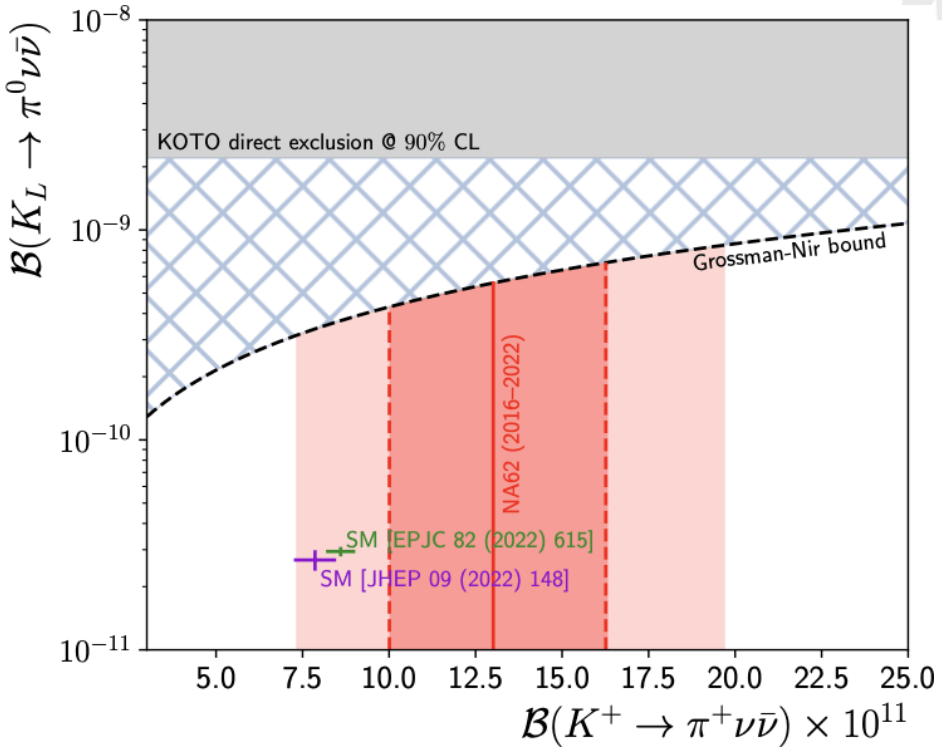
$BR_{16\text{-}22} = (13.0\ ^{+3.0}_{-2.7\ stat} \pm 1.3_{syst}) \times 10^{-11}$

- Total observed: 51 events, 18 expected background
- **First conclusive (> 5σ) observation of $K^+ \to \pi^+\nu\nu$**

LNF WG convener

$K^+ \to \pi^+ \nu\nu$ through LS3





$BR_{16\text{-}22}(K^+ \to \pi^+ \nu\nu) = (13.0\ ^{+3.0}_{-2.7\ \text{stat}} \pm 1.3_{\text{syst}}) \times 10^{-11}$

- Increased acceptance and slightly decreased background after 2022
- Better beam structure and optimization of intensity
- Continuous stream of analysis improvements
- 22 SM signal events expected in 2023-2024 + similar amount in 2025-2026

Dataset	2022	2023	2024
Number of spills $[10^3]$	326	363	519
$<$ Beam intensity $>$ [GHz]	0.57	0.48	0.41
$< N_{\pi\pi}/\text{spill} >$ $[10^2]$	4.9	4.7	4.4
N_K $[10^{12}]$	2.3	2.5	3.3
ε_{RV}	0.63	0.68	0.73
$N_{\pi\nu\nu}$	8	9	13
$N_{\pi\nu\nu}/\text{spill}$ $[10^{-5}]$	2.5	2.5	2.6
$B_{\text{total}}/N_{\pi\nu\nu}$	1.1	1.1	1.0

NA62 expects to measure BR($K^+ \to \pi^+ \nu\nu$) to 15-20% by LS3 (August 2026)

Searches for exotic production and decay

LNF WG convener

Production from protons dumped in the beamline collimators

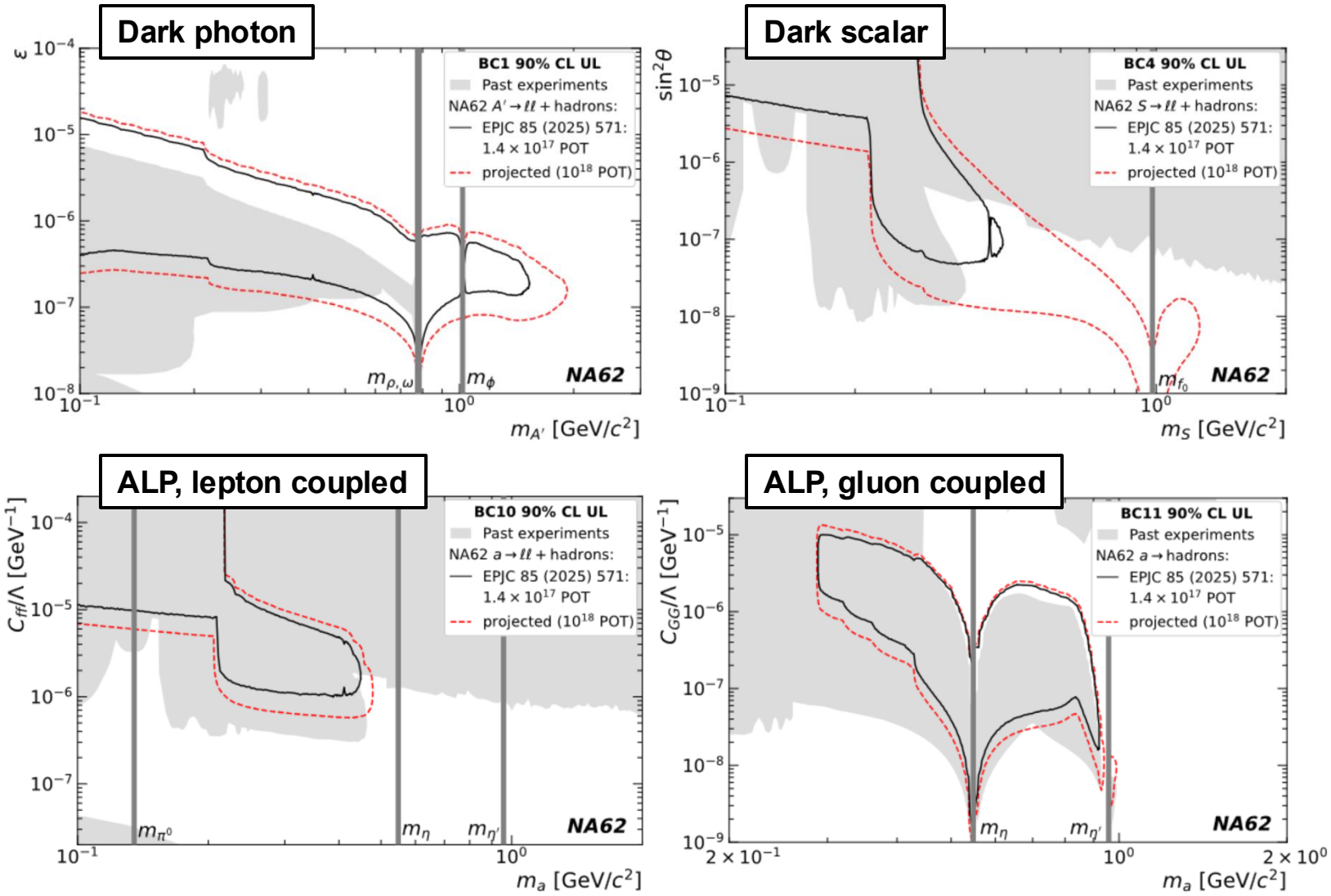
Blind-analysis search for **decays** in NA62 decay volume > 80 m downstream

Results from 1.4 x 10^{17} dumped protons (POT) with final states:

$\mu^+\mu^-$	**JHEP 09 (2023) 035**
e^+e^-	**PRL 133 (2024) 11**
hadrons	**EPJC 85 (2025) 5**

Aim to **update** using 10^{18} POT, CERN-OPEN-2025-005

Will include semileptonic decays for heavy-neutral leptons



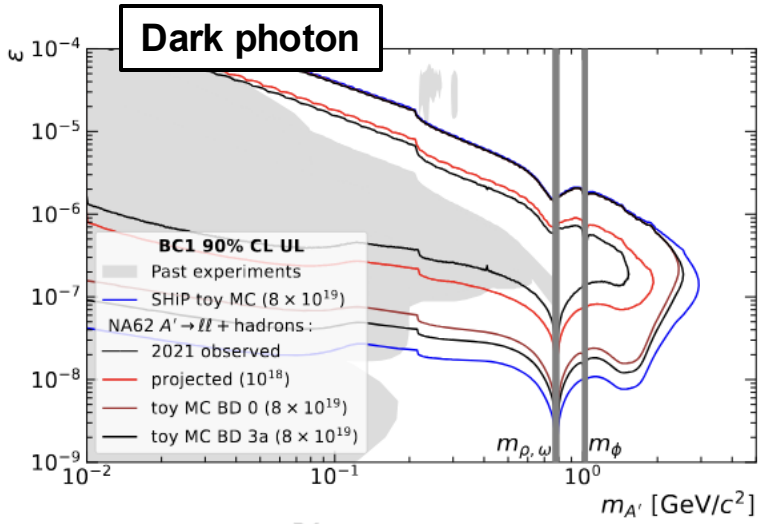
Projections for potential sensitivity in ECN3

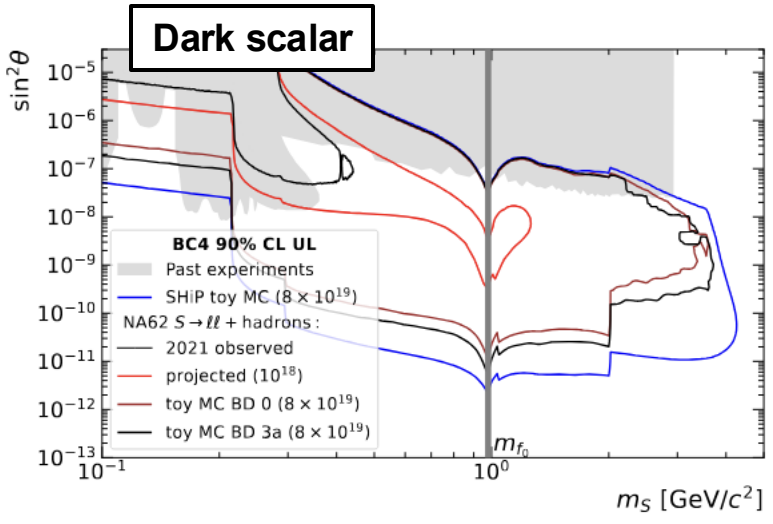
Interest in publishing expected sensitivities with various geometrical configurations in ECN3

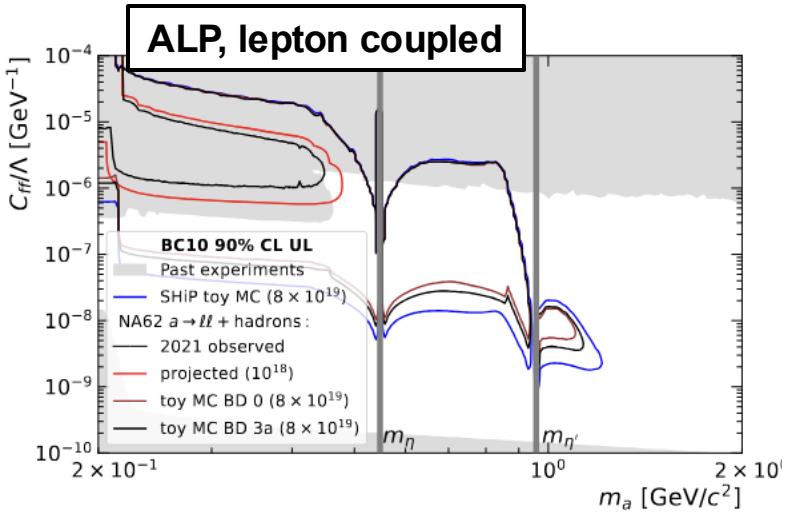
Assume 8 x 10^{19} POT on the future beam dump facility (BDF) before LS4

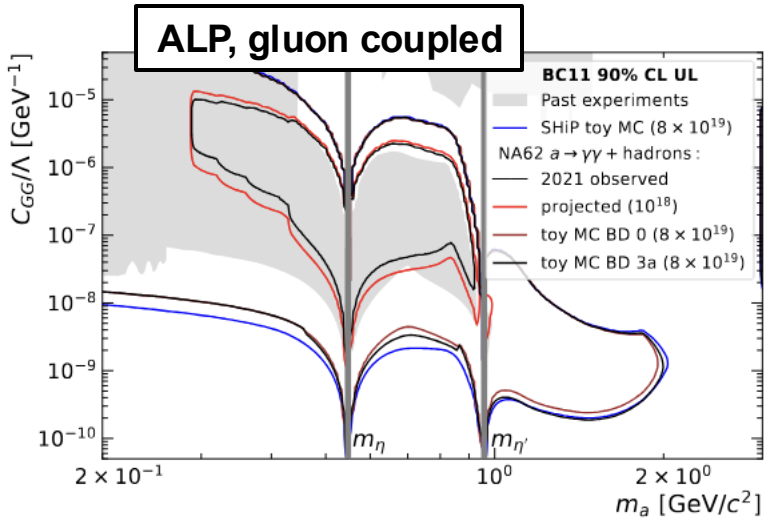
Consider a number of experimental arrangements as a pre-SHiP phase:

- Scenario 0: everything from LAV6 downstream stays as now (166.5 m downstream of present T10)
- Scenario 3a: detector rearrangement, RICH removed, LKr stays









NA62 LNF team

A. Antonelli	90%	National coordinator NA62 (through July)	SASS in 2025
V. Kozhuharov	50%		Associate
S. Martellotti	70%	Photon veto WG co-coordinator	
M. Moulson	70%	Co-coordinator Detector R&D, Future WG	
L. Plini	90+10%		PJAS in 2025
T. Spadaro	40%	Exotics WG co-coordinator	
J. Swallow	90%	PNN WG co-coordinator	Now at CERN
G. Tinti	60+10%	Photon veto WG co-coordinator	

LNF group activities and responsibilities

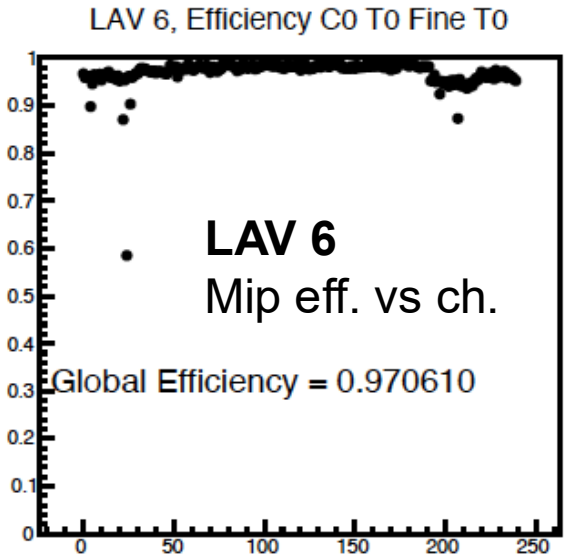
- $K^+ \to \pi^+ \nu\nu$ analysis, including coordination
- Exotics analysis, including coordination
- Photon veto operation and maintenance
- Analysis software development and improvements
- R&D for detectors for future experiments

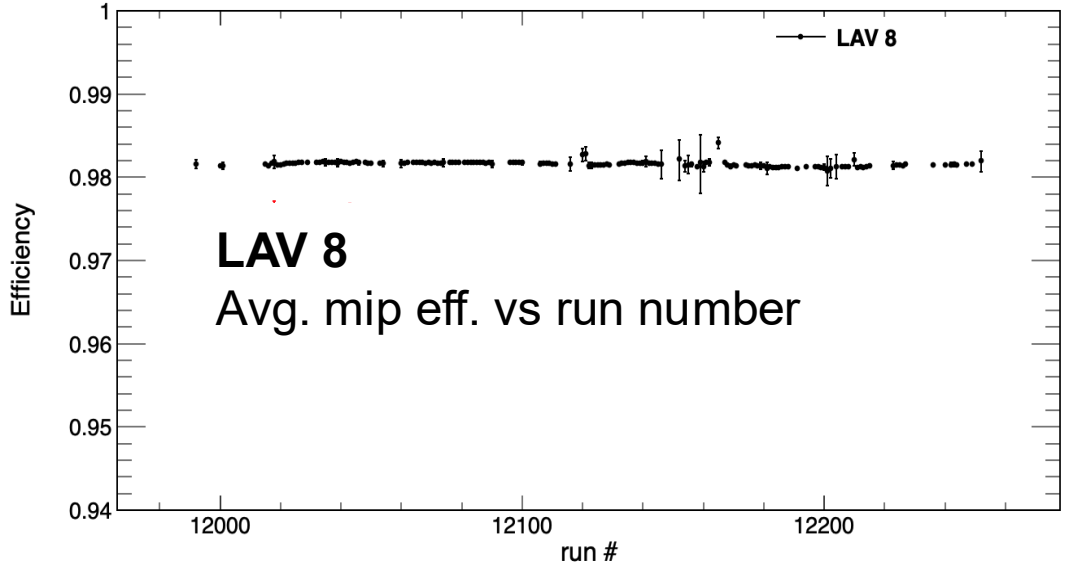
NA62 LNF: Photon veto operations

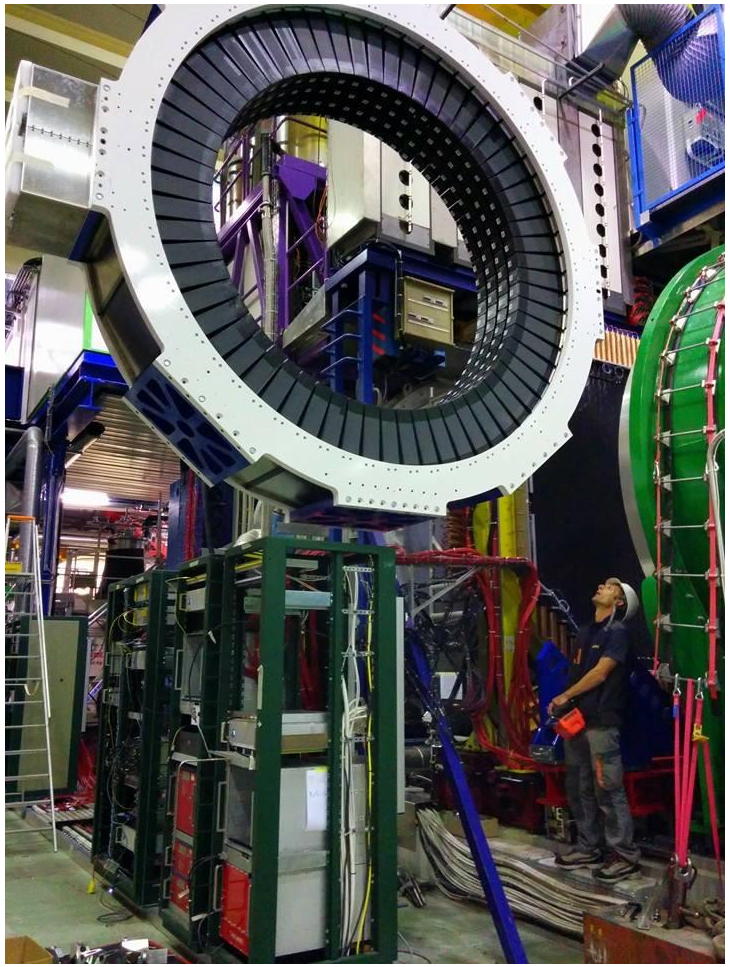
2025 run in progress: 17 April-24 November (30 weeks)

LNF group has developed many tools to monitor LAV data quality

- Stable efficiency for all the LAV stations
- Only few hardware interventions (mainly HV board replacement)
- Outstanding operational stability of the PMTs







2026 will be last year of data taking!

- Group emphasis shifts from ensuring operability to planning for decommissioning of 12 big detectors

NA62 LNF: Photon veto decommissioning

Physical decommissioning most likely to start in 2027

Material to be recovered and brought to LNF:

- 12 CAEN 4527 HV crates + 81 A1536N 32 ch HV boards
- 12 VME crates + 12 TEL62 digital readout boards + 90 dual-threshold discriminator boards
- Vacuum flanges (HV, signal, pulser)
- Cables
- IRC & SAC

Need two technicians from LNF for the following work:

- Dismounting and transport of crates and electronics: 1-1.5 weeks (1.5-2 stations/day)
- Deflanging of LAV stations: 2-2.5 weeks (1-1.5 stations/day)
- Removal of LAV stations from vacuum tank: 4-6 weeks (2-3 stations/week)

The LAV stations themselves will be discarded: we are starting to look at options for disposal

- Possible use of one or more stations for permanent exhibition, including at LNF

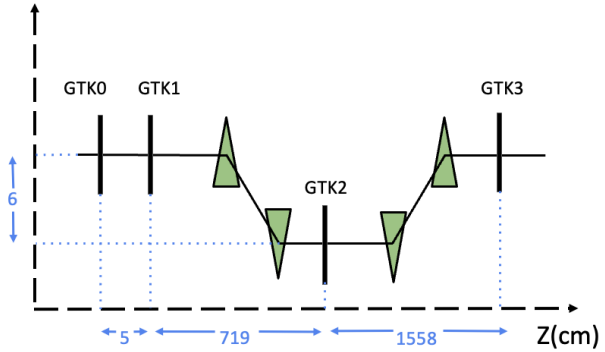
NA62 LNF: GTK reconstruction with ML

Good GTK reconstruction critical for PNN performance:

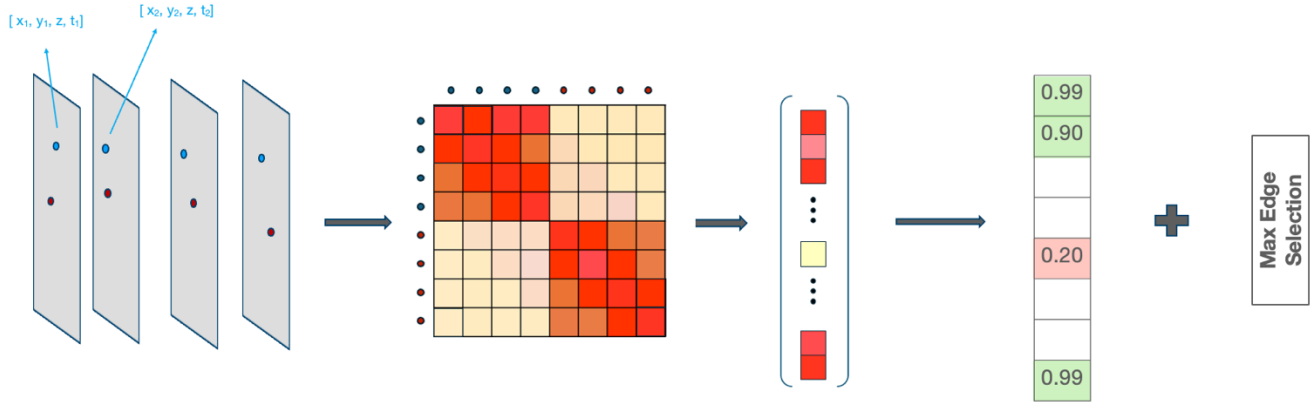
- Mismatched K and π tracks degrade kinematic rejection

Up to now, GTK reconstruction affected by high rate of fake tracks

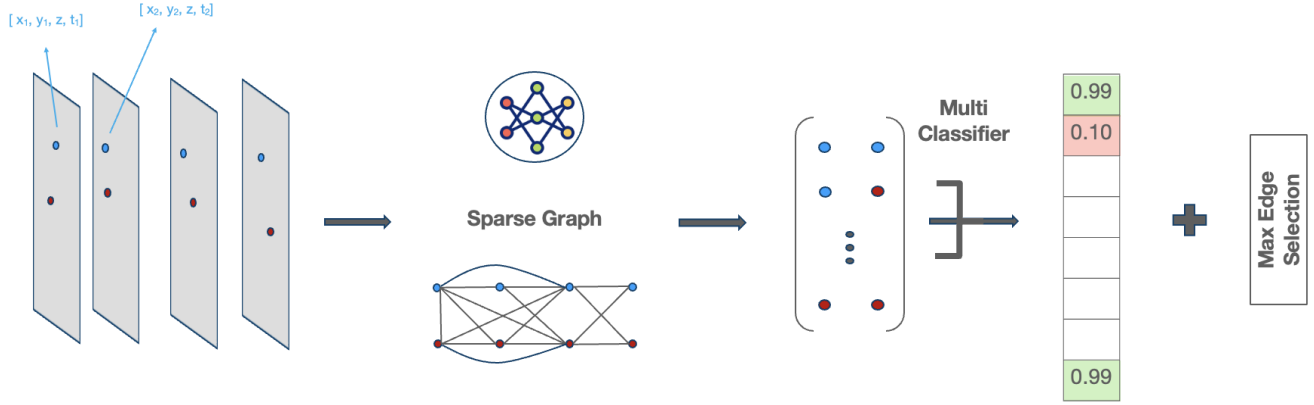
- Exploring use of ML algorithms to improve performance



Transformer

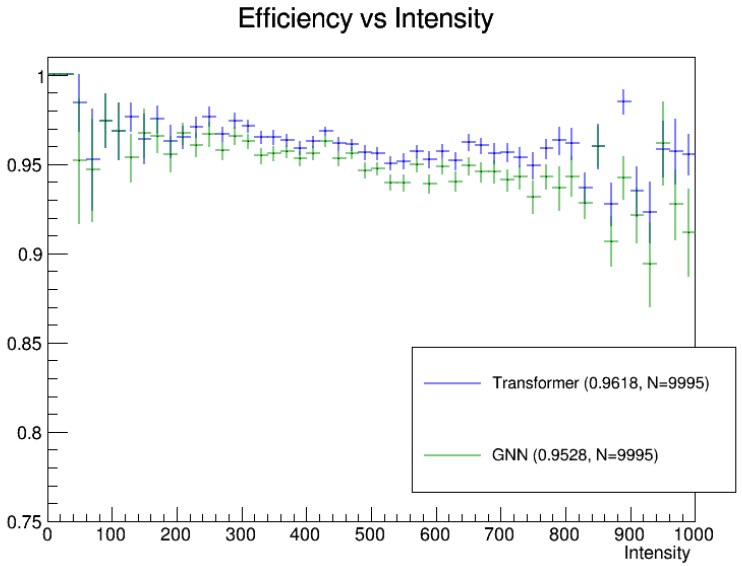


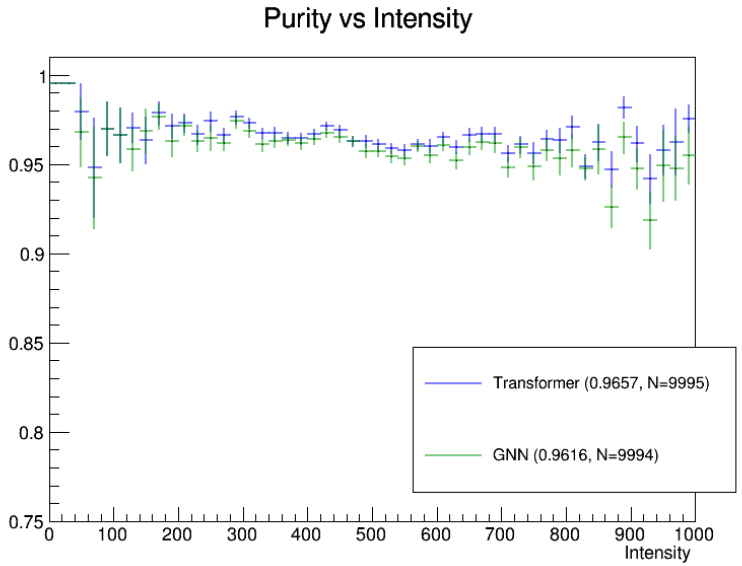
Graph neural network

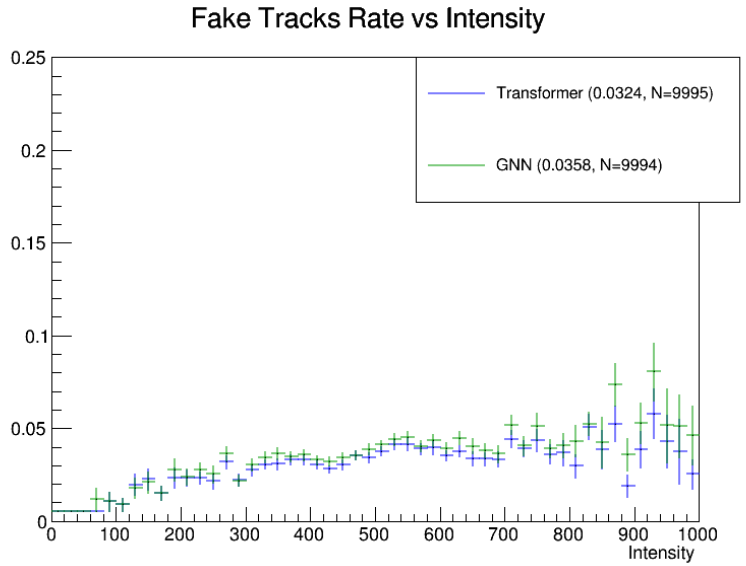


- 4D tracking: reconstruction exploits hit position (x, y, z) and timing t
- The ML architecture allows hits to interact with each other, producing meaningful pairwise representations
- These representations are used to predict whether an edge exists, selecting the best entering and exiting edge for each hit while avoiding multiple tracks sharing the same hit
- We then rely on these predictions to perform the pattern recognition

NA62 LNF: GTK reconstruction with ML







- Inference workflow fully integrated and deployed within the NA62 C++ software framework using the ONNX Runtime library
- Preliminary performance tests show higher efficiency, higher purity and lower rate of fake tracks than previous reconstruction
- In $K^+ \to \pi^+ \pi^+\pi^-$ **sample**, the mis-id of a fake track similar to the real K^+ is reduced by 15%
- Upcoming focus: **feasibility study** for **full-event reconstruction** of the $K^+ \to \pi^+ \nu\nu$ decay chain

NA62 LNF: R&D for future experiments

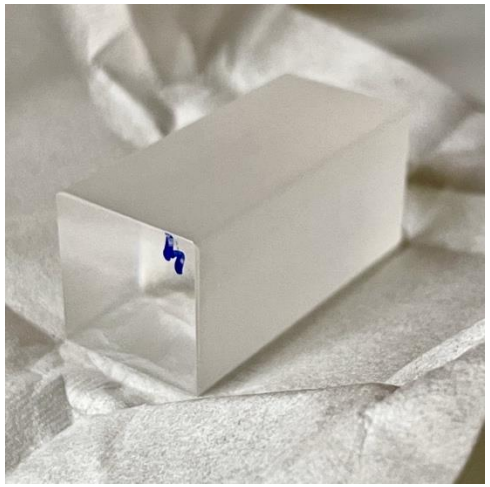
In collaboration with CRILIN, developed a prototype for the small-angle calorimeter (SAC) for HIKE:

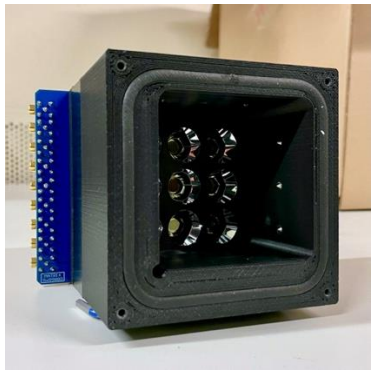
- Veto photons while operating in a 600 MHz neutral hadron beam
- Reltively insensitive to neutrons
- Very fast to avoid random veto losses from residual neutron interactions
- High granulatrity (transverse and longitudinal) for good γ/n separation
- Radiation hard for operation in beam

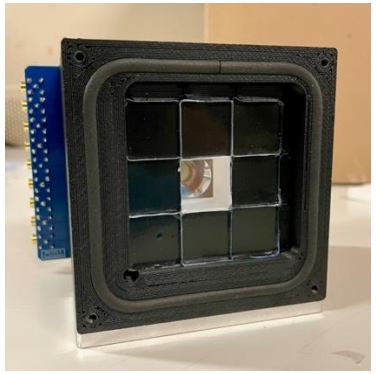
- Beam-hole photon veto for KOTO II (J-PARC) has similar requirements
- Adapt SAC design for KOTO II
- Beam test of prototype at CERN PS 27 Aug–03 Sep

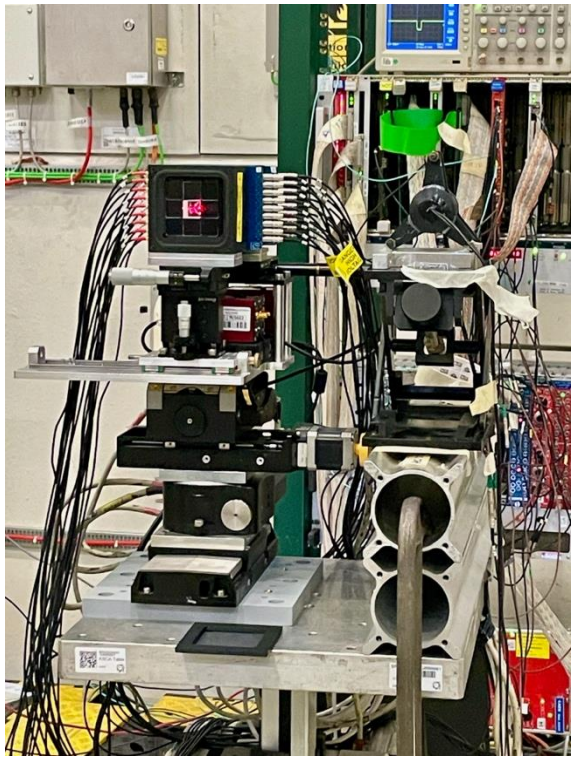
HIKE SAC prototype for KOTO II:

- Two alignable layers, 3x3 crystals, 18x18x40 mm^3
- Sensor planes with HV dividers, Hamamatsu metal-package PMTs







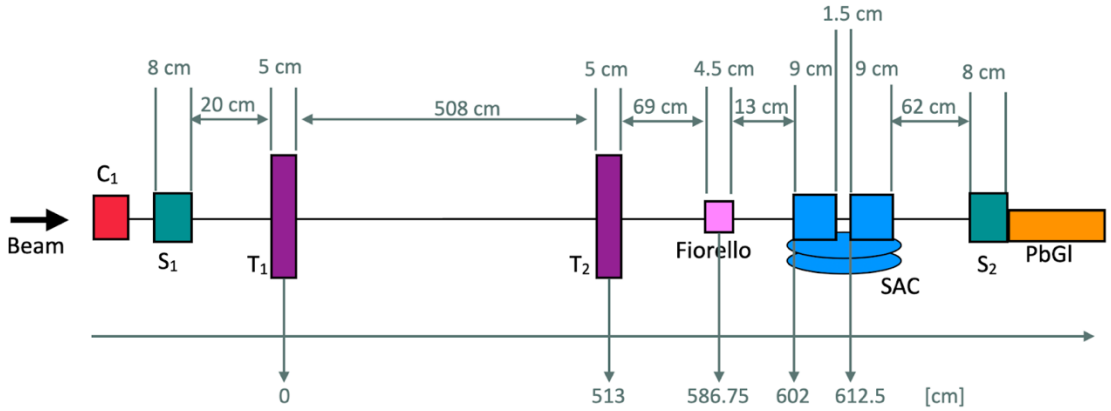


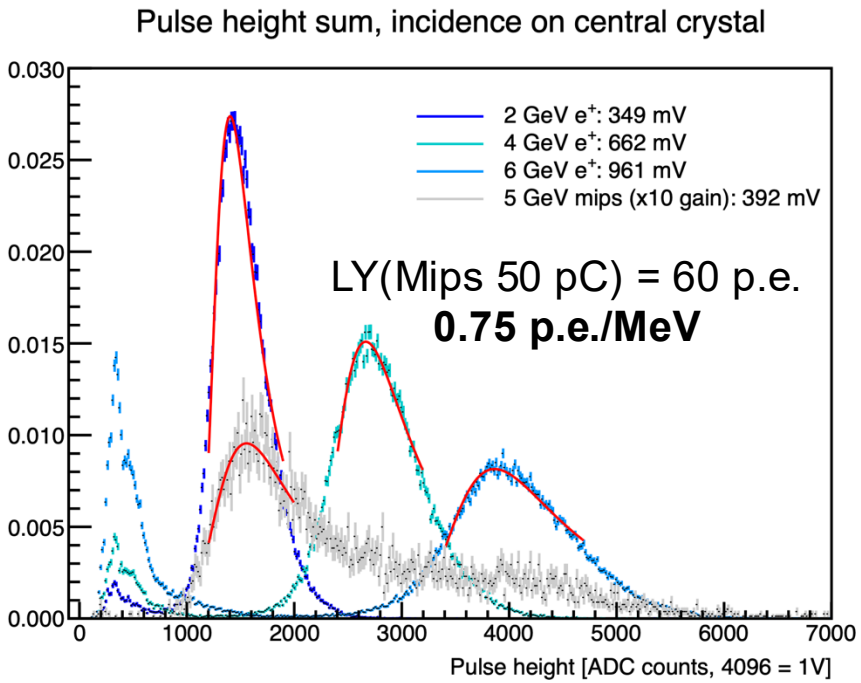
NA62 LNF: R&D for future experiments

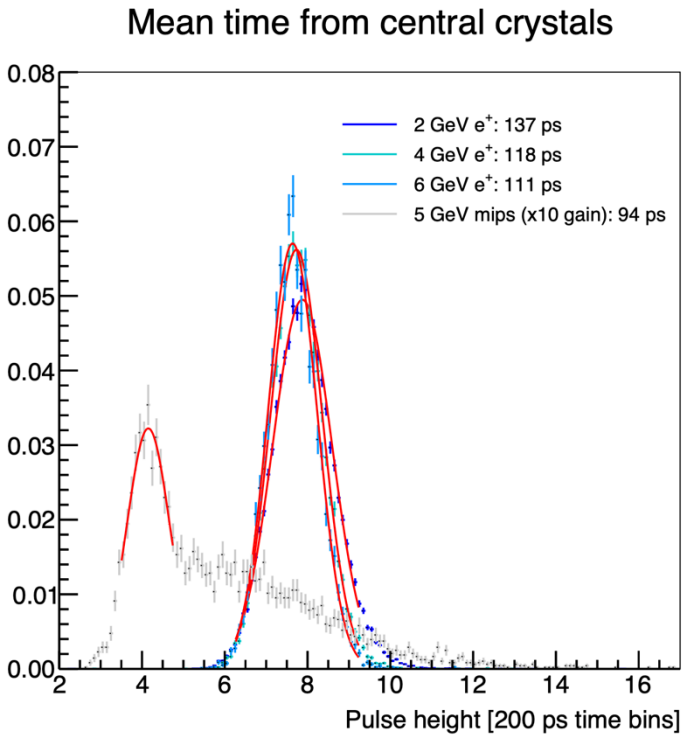
Test beam setup

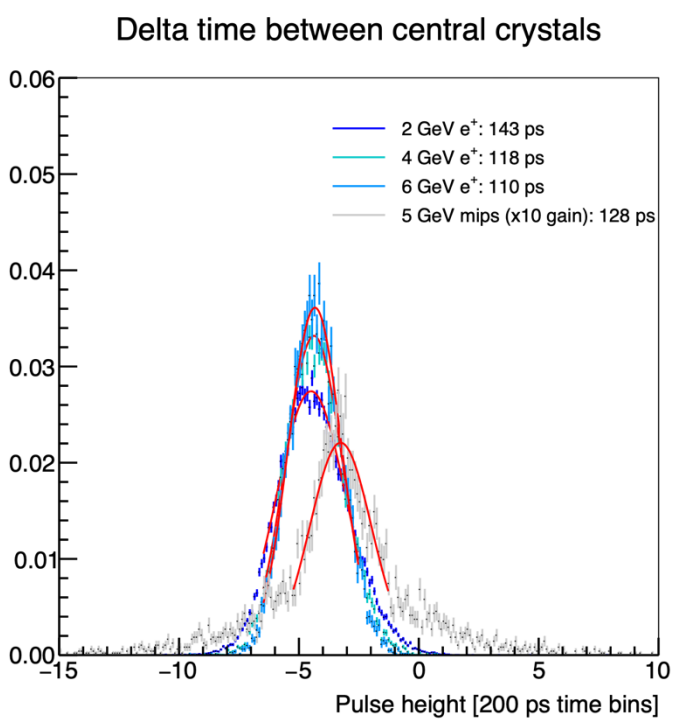
Prototype tested 27 Aug-03 Sep in CERN PS T9 beamline

- 5 GeV parallel mips
- 5 GeV parallel e^+
- 2, 4, 6 GeV focused e^+ to study effects of crystal alignment









Good consistency between methods! $\sigma_t \sim$ **140 ps/$\sqrt{E}$ (GeV) $\oplus$ 95 ps**

Interactions with referees: Milestones

Completamento milestone 2025

31/12	Risultato preliminare HNL e ALP dati 2024	Kaon mode: OK (arXiv:2507.07345) Dump mode: 60%. Probabile raggiungimento 100% in autunno
31/12	Sensibilità $K^+ \to \pi^+ \nu\nu$ con dati 2023-2024 (mostrato a conferenza)	100% (vedi ad esempio FLASY 2025)
31/12	Analisi dati test beam SAC e pubblicazione	Test beam 09/25, arXiv entro 12/25

Milestone proposte per il 2026

31/12	Risultato preliminare $K^+ \to \pi^+ \nu\nu$, dati 2023-2024 (mostrato a conferenza)
31/12	Pubblicazione articolo su HNL, dati 2021-2024
31/12	Pubblicazione della prima osservazione del decadimento $K^+ \to \mu^+ \nu \mu^+ \mu^-$ e misura BR