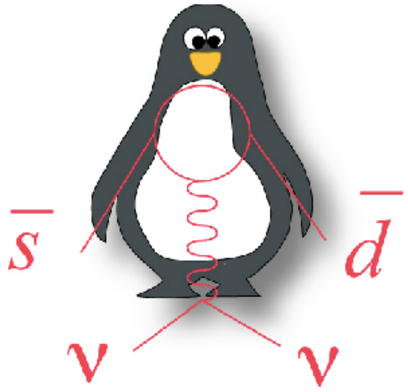


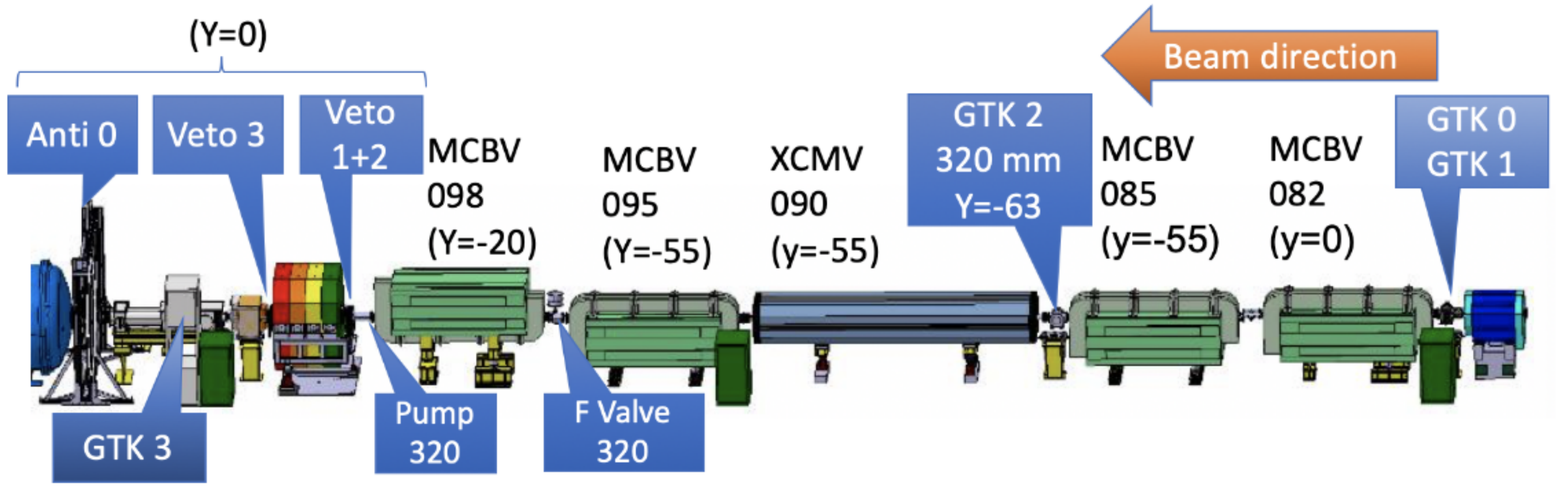
NA62

Riunione CSN1 LNF

Silvia Martellotti, 24 Ottobre 2022

NA62 Run 2 (2021-2025)

New detectors after Long Shutdown 2 (LS2)



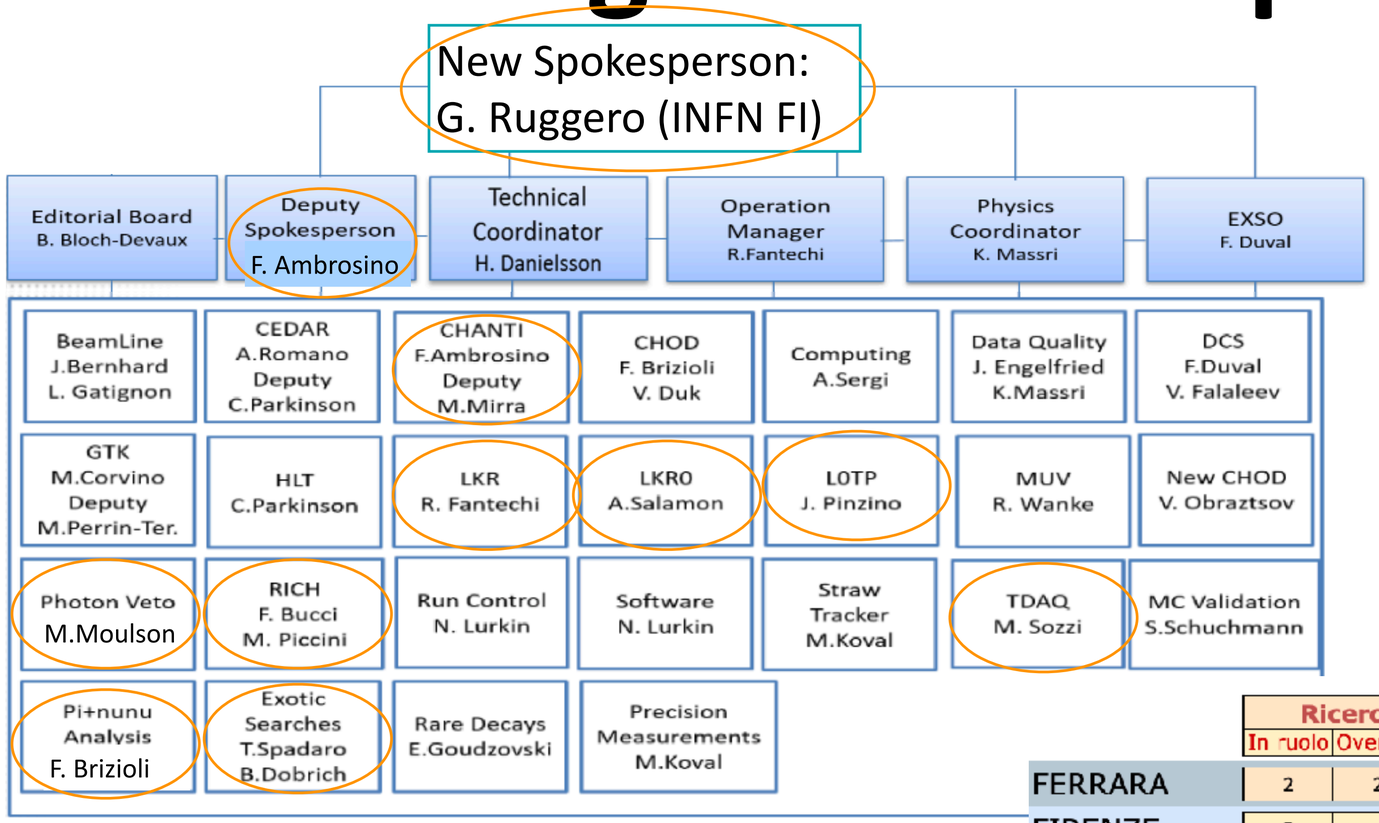
SPSC has approved NA62 run up to the LS3

Goal: measure BR($K^+ \to \pi^+ \nu\nu$) with a precision matching the theoretical one (O(10%)).

Run in dump mode scheduled for hidden sector searches (10^{18} POT)

- A 4th GTK station (**GTK0**) to improve efficiency, time resolution and K-π matching
- New **VetoCounter** detectors upstream (Veto 1+2) and downstream (Veto 3) the final (rainbow) collimator to reduce upstream background
- Veto detector installed at the beginning of the Fiducial Volume (**Anti 0**) for muon halo
- Additional small calorimeter module downstream (**HASC**) to improve photon rejection of photons from conversions in the RICH pipe (not in the picture)

Anagrafica e responsabilità LNF



- A. Antonelli: responsabile nazionale
- M. Moulson: convener future working group
- T. Spadaro: convener exotic searches working group
- S. Martellotti, G. Tinti: run coordinator during data taking 2022

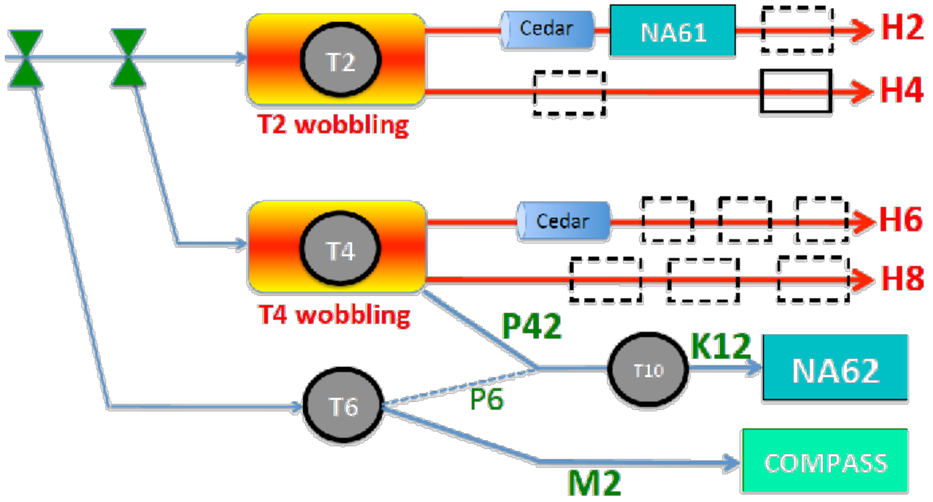
	Ricercatori			Tecnologi			Sinergie		Totale FTE	Totale Firmatari	FTE / Firmatari
	In ruolo	Over 70	FTE	In ruolo	Over 70	FTE	FTE	Progetti			
FERRARA	2	2	0,40	2		1,00	1,00	OREO / AIDAINNOVA	2,40	6	0,40
FIRENZE	5		3,30						3,30	5	0,56
FRASCATI	8		4,70				1,40	AIDAINNOVA / LLMCP	6,10	8	0,76
NAPOLI	10	1	4,90				0,10	AIDAINNOVA	5,00	11	0,45
PERUGIA	6	1	3,20						3,20	7	0,46
PISA	5	3	4,40	2		0,10	0,10	IGNITE	4,60	10	0,46
ROMA I	5		1,10	4		0,60	1,40	APEIRON / ML_INFN	3,10	9	0,34
ROMA II	3		1,60	1		0,40	0,20	APEIRON	2,20	4	0,55
TORINO	2	1	0,60						0,60	3	0,20
TOTALE	**46**	**8**	**24,20**	**9**	**0**	**2,10**	**4,20**		**30,50**	**63**	**0,48**

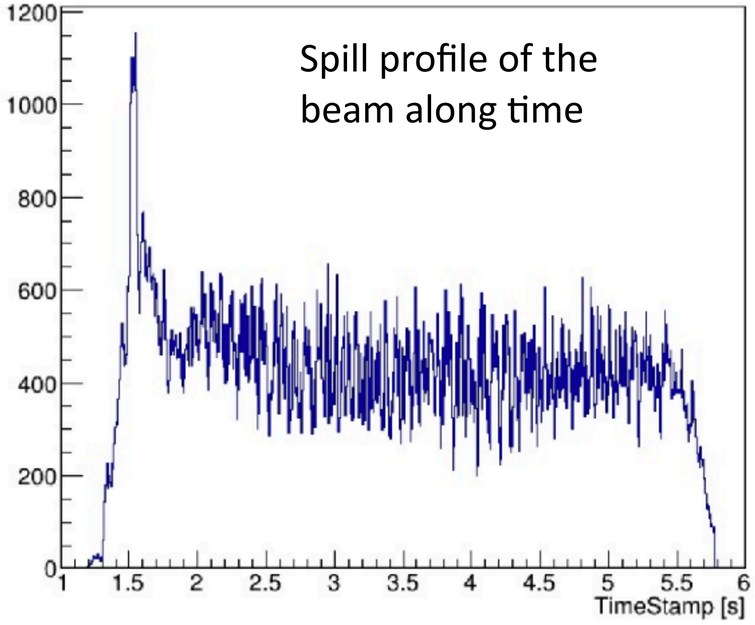
Incremento FTE per apertura / partecipazione a progetti sinergici con HIKE

Run 2021

July 12th - November 14th (18 weeks)

- First Kaon beam: end of August (different hardware problems in the beam lines P42 and K12)
- **100% intensity from September**
- T4 availability = ~ 70% , T10 availability = ~ 87%
  NA62 efficiency = ~ 92%
- **POT ~ 0.6 x 10^{18} (similar to 2017)**

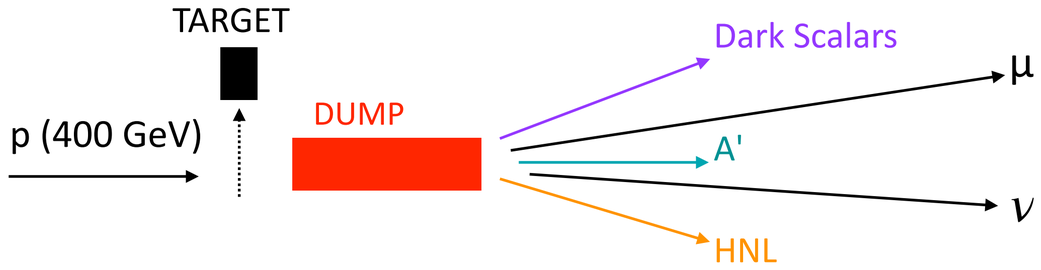




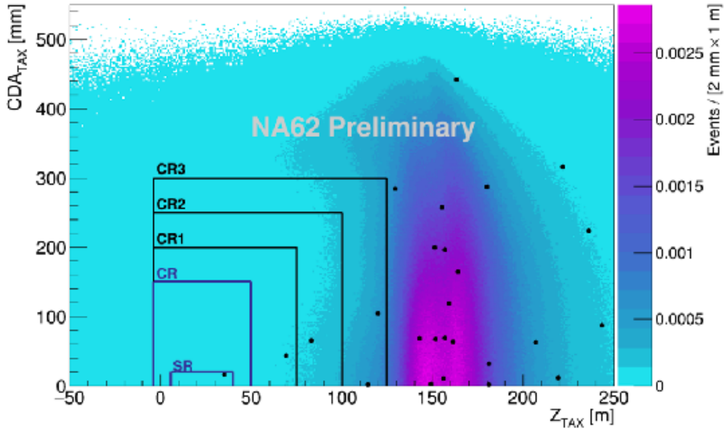
- Quality of the spill structure severely limited protons usable for physics. Too high instantaneous intensity in the first second: unsustainable high rate for readouts, trigger and DAQ
- 2021 data analysis in progress:
  - are the data in the spill bump good?
  - improve K-π matching
  - studies of backgrounds with the new detectors

Between latest physics result (LNF analysis)

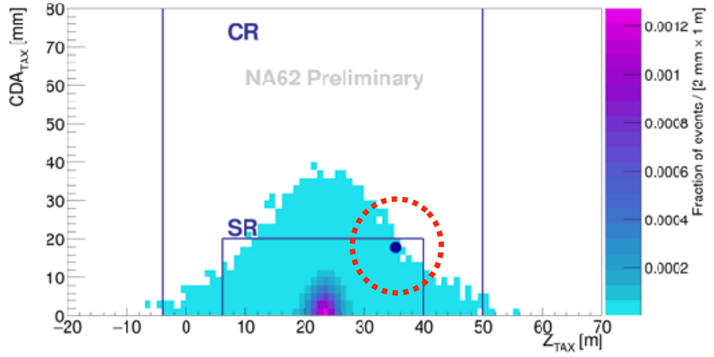
Search for A → μ⁺μ⁻ with 2021 dump mode data



- NP searches for MeV-GeV mass hidden-sector candidates (dark photons, HNL, Axions..)
- 10 days **run in dump mode in 2021: 1.4 x 10^{17} POT**. Intensity: 1.4 x I_{max}

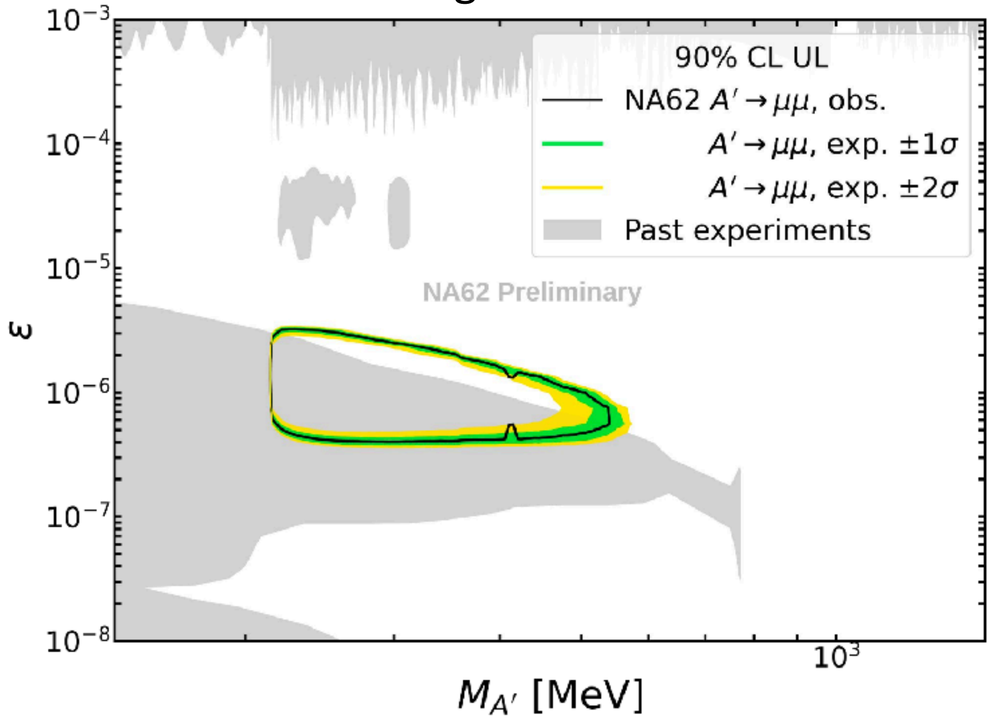


μ+μ- background: probability for a non-zero observation in SR: 1.59%



Signal shape (MC)
1 event observed

New excluded region:



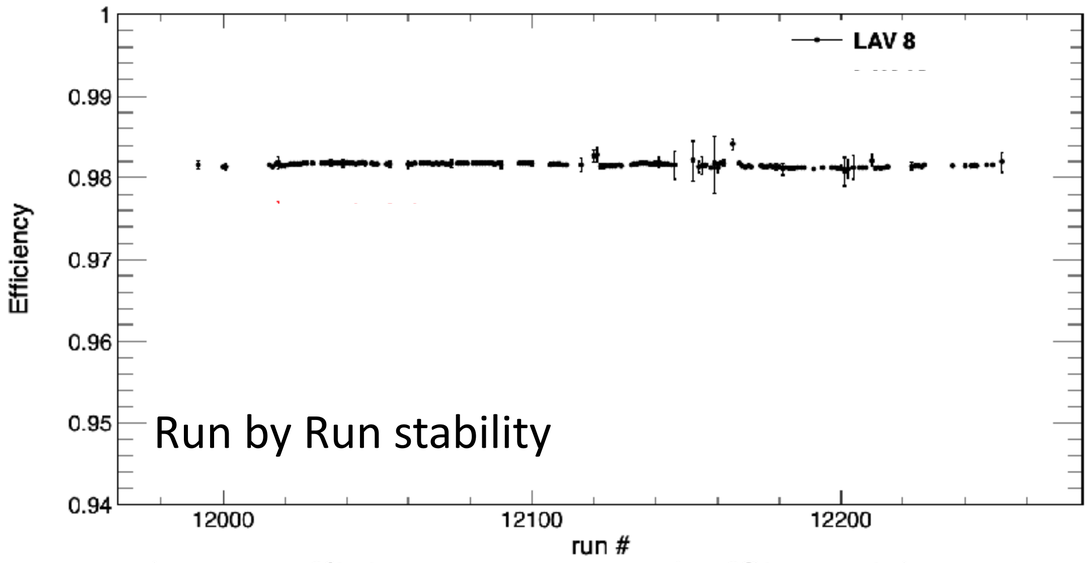
ICHEP 2022
Paper in preparation
T.Spadaro et al.

Run 2022

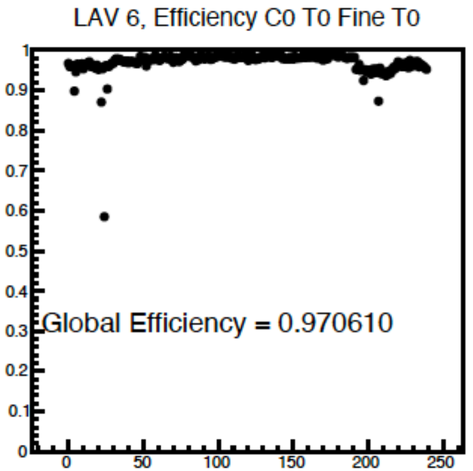
April 15th - November 14th (29 weeks) - on going

- First Kaon beam: beginning of May (again problems in the beam lines)
- NA62 developed many tools to give fast feedback to the beam people
- **Origin of the bump understood**. An SPS RF cavity had a small residual field, feedback system to have $V_{RF} = 0$ installed
- **100% intensity**

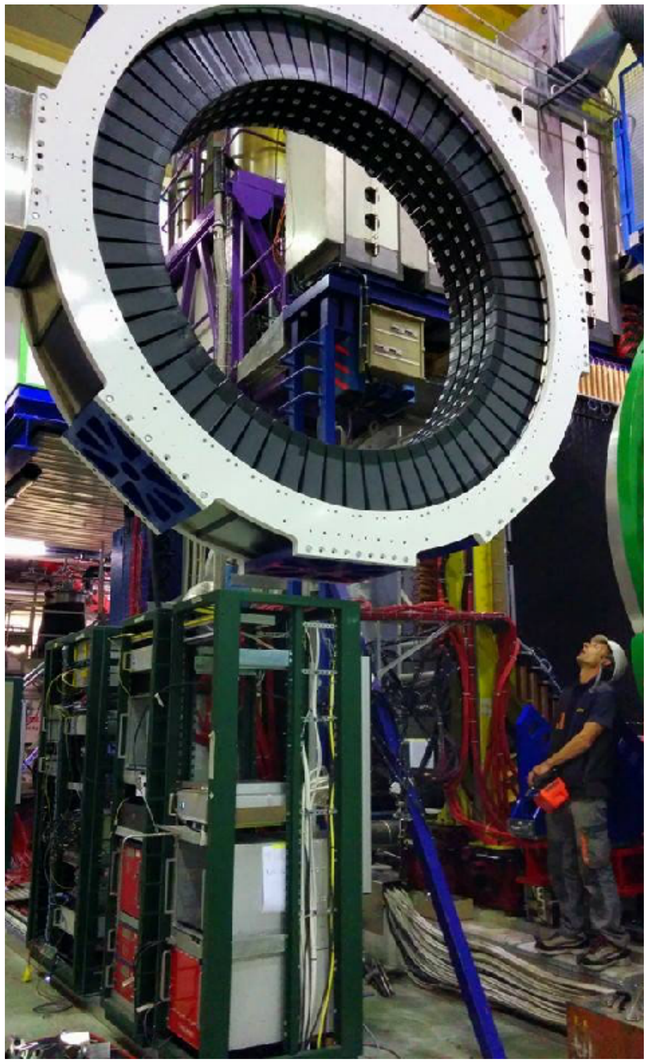
Optimal LAV detectors (LNF) performance



Photon efficiency measured offline with $\pi^+\pi^0$

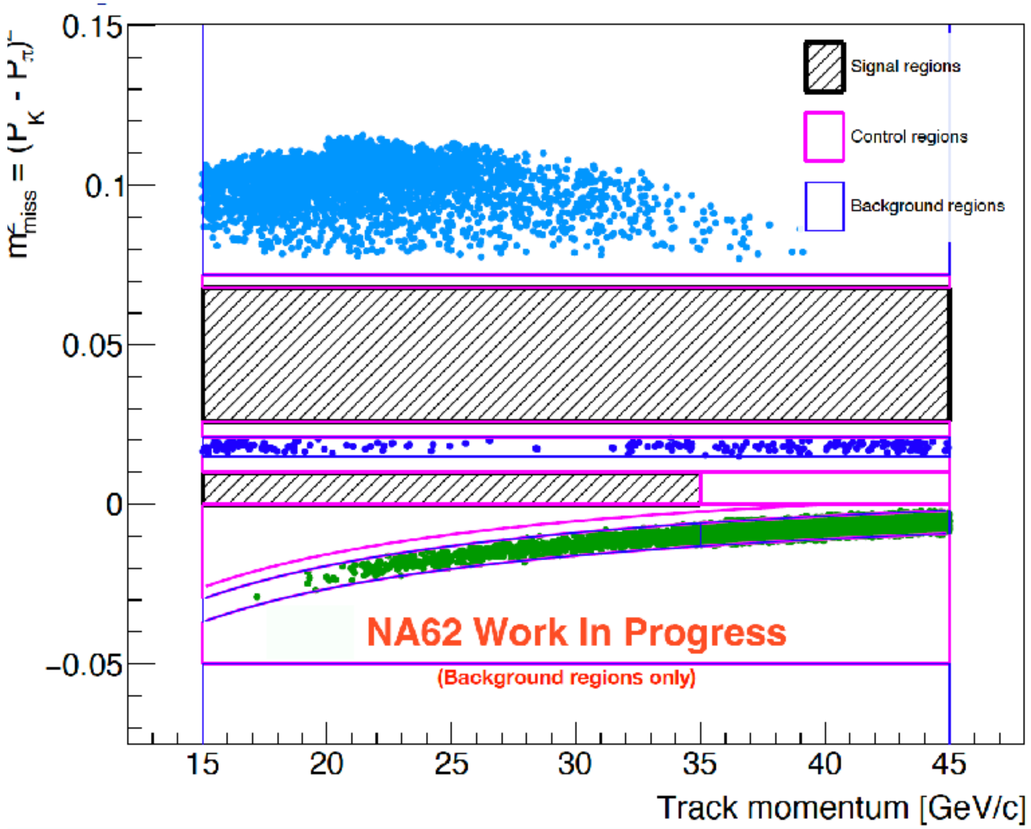


Each channel efficiency monitored online with MIP to check stability and readout problem



Run 2022

Analysis improvements



Random veto

- Random veto similar to 2018 at higher intensity (LKr: new reconstruction, LAV: photon/mip id via BDT)

Photon rejection

- HASC improves small angle photon rejection

Upstream background rejection

- New VetoCounter and GTK0 additional station reduce upstream background

Signal efficiency

- Improve K–π matching (GTK0, new algo)… In progress
- Combined PID RICH + calorimeter… In progress
- Optimization of signal kinematic selection and signal region… In progress

LNF group:

- LAV random veto reduction
- combined RICH + STRAW to optimize the signal efficiency vs background rejection

Future program

High Intensity Kaon Experiment: HIKE

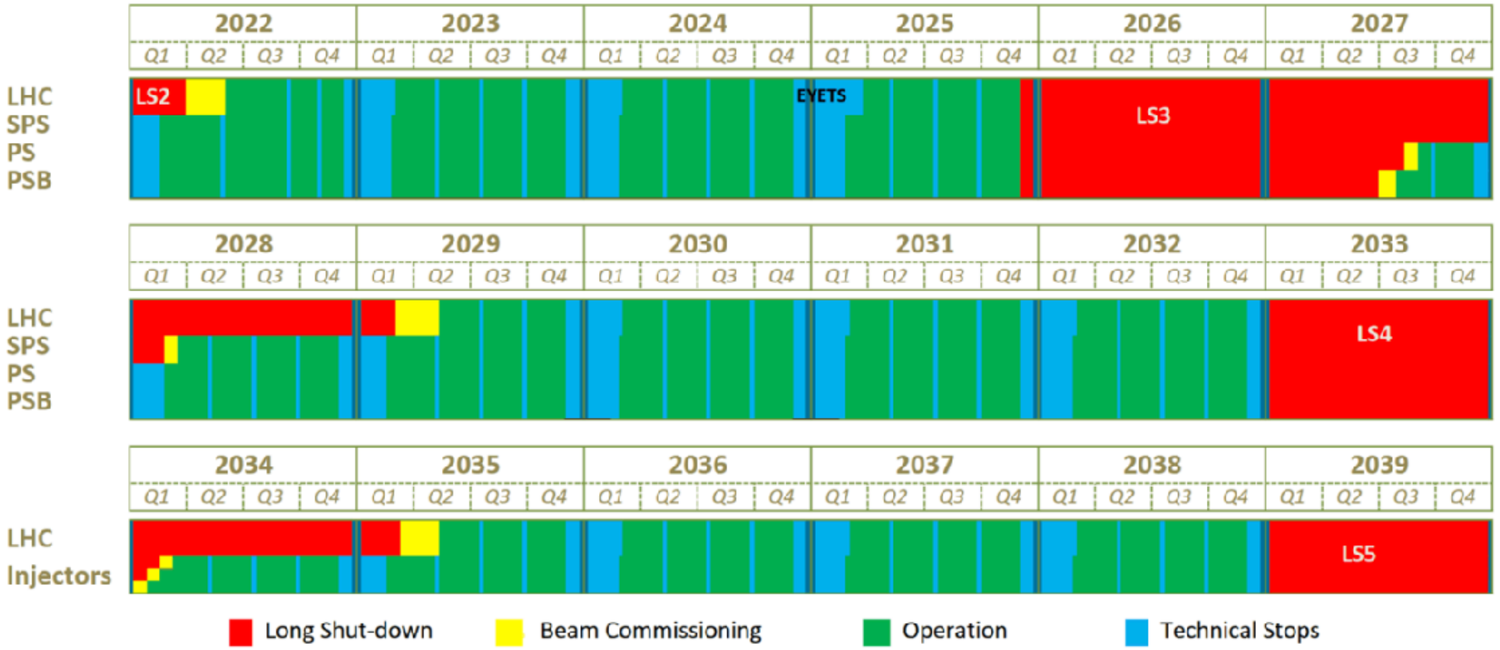
- High intensity Kaon beam at the SPS gives a unique opportunity to pin down new physics in kaon decays. **Exceptional sensitivity to discover new physics.** Complementary to LHC
- A comprehensive, multi-staged project for kaon physics at CERN is widely studied and discussed inside Physics Beyond Colliders (PBC) working group

K^+ phase		
$K^+ \to \pi^+\nu\nu$	BR to ~5%	New physics in FCNC decays
$K^+ \to \pi^+\ell\ell$	Form factors at ~1% level	LFUV
$K^+ \to \pi\mu e, \pi^-\ell^+\ell^+$	O(10^{-12}) sensitivity	LFV, LNV
$R_K = \Gamma(K \to e\nu)/\Gamma(K \to \mu\nu)$	R_K to ~0.1%	LFUV
$K^+ \to \pi^+\gamma\gamma, \pi^+\pi^0\gamma, \pi^+\pi^0 ee$	As best as possible	Chiral parameters (LECs)
Hybrid phase		
$K_L \to \pi^0\ell\ell$	Observation	New physics in FCNC decays
$K_L \to \mu\mu$	BR to < 1%	New physics in FCNC decays
$K_L \to \mu e, \pi^0\mu e$	O(10^{-12}) sensitivity	LFV
$K_L \to \gamma\gamma, \pi^0\gamma\gamma$	As best at possible	Ancillary to $K_L \to \mu\mu$, LECs
K_L phase (KLEVER)		
$K_L \to \pi^0\nu\nu$	BR to ~20%	New physics in FCNC decays

HIKE (NA62x4 + KLEVER) program:

- **K^+ at 4xNA62 intensity**: 500 $K^+ \to \pi^+\nu\nu$ decays (after LS3)
- Transitional program: K_L beam, downstream tracking & PID like NA62.
- **K_L at 6xNA62 intensity**: 60 $K_L \to \pi^0\nu\nu$ decays (after LS4)
- Periodic runs in **beam dump mode** (10^{19} POT)

LoI for HIKE- future steps



- Discussed and studied inside PBC (updated document end 2022)
- Submitted document to the Snowmass process (April 2022, arXiv:2204.13394)
- **LoI to SPSC by first week of Nov 2022**. Writing group defined and working. Discussion inside NA62 ongoing on interests and responsibility*

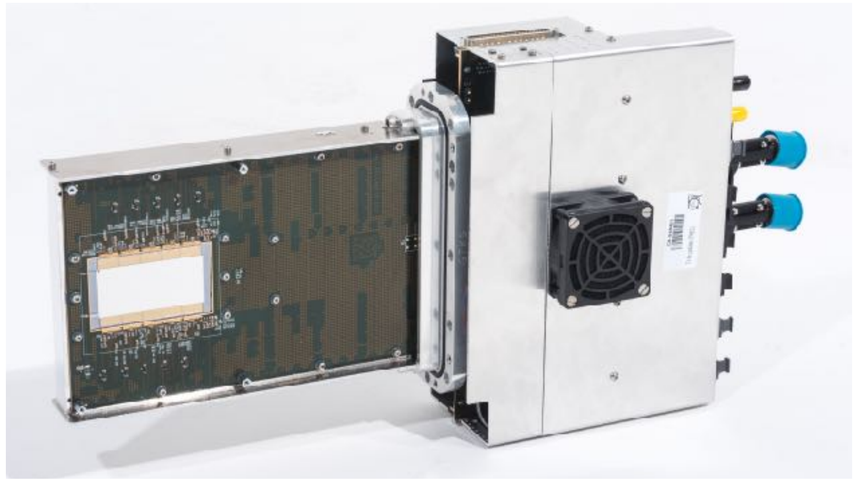
First discussion at SPSC meeting of LoI of the candidate experiments for ECN3: November 2022. SPSC statement on meaningful physics justification: February 2023. Research board decision on go ahead. Final SPSC conclusion: **November 2023**

*Collaboration: Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna (JINR), Fairfax (GMU), Ferrara, Florence, Frascati, Glasgow, Lancaster, Liverpool, Louvain-la-Neuve, Mainz, Moscow (INR), Naples, Perugia, Pisa, Prague, Protvino (IHEP) , Rome I, Rome II, San Luis Potosi, TRIUMF, Turin, Vancouver (UBC), **Max Planck, Marseille, EPFL**

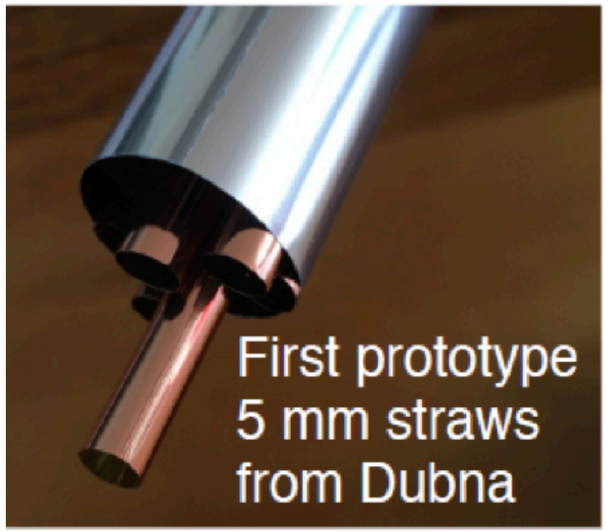
NA62x4 - K^+

The NA62 upgrade for x4 intensity is based on the well consolidated NA62 running experience.
Challenge: **20–40 ps time resolution** for key detectors to keep random veto under control, while maintaining all other NA62 specifications. Appropriate modifications to the current design to cope with higher intensity

Key detectors upgrade and R&D:



- **GTK**: increase time resolution < 50 ps, beam intensity: 3 GHz over ~3x6 cm^2 (maximum 8 MHz/mm^2, radiation resistance: $2x10^{15}$ neq/cm/200days). Promising: TimeSpot ,GTK group already in contact with Cagliari group



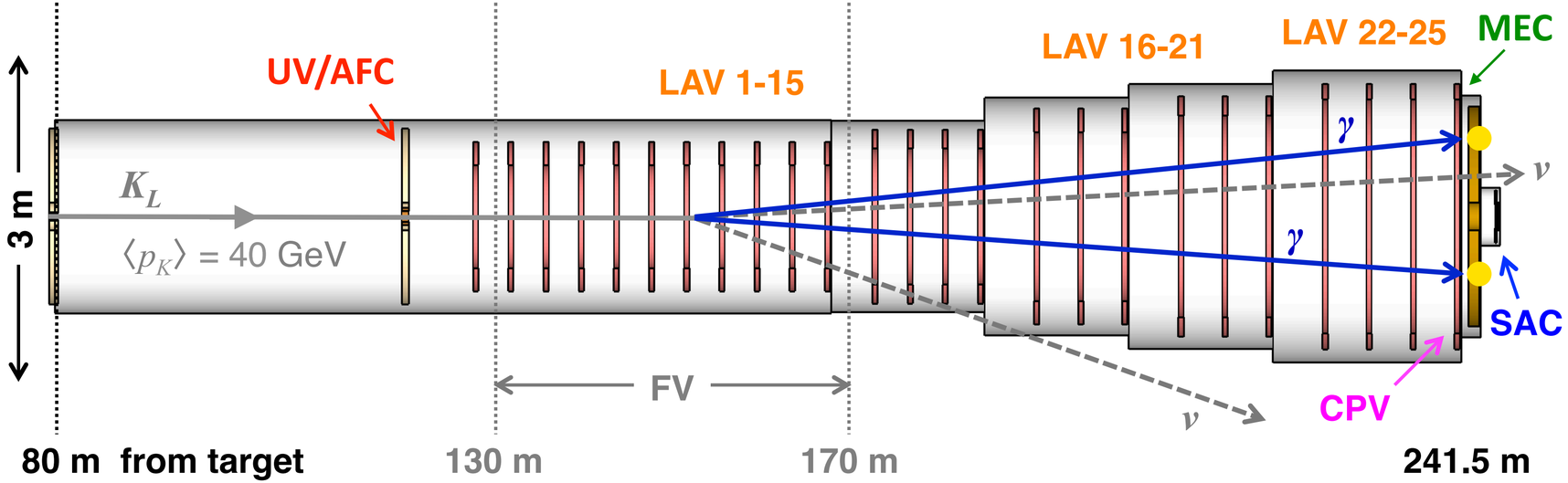
- **STRAW**: Smaller diameter: 5 mm (instead of 9.8 mm). Improved trailing time resolution: 6 ns. Rate capability increased by factor 6-8. Reduced wall thickness (less material budget). Pre-production tests: Au/Cu coated Mylar film 5 m long straws with a 19 µm wall thickness have successfully been produced. Design studies in progress at CERN and Dubna

- **All Calorimeters in common with K_L phase**

KLEVER

Target sensitivity: measure BR($K_L \to \pi^0 \nu\nu$) with (O(20%)) precision.

~ 60 SM events in Run4 (5 years) with S/B ~1



Main detector/veto systems:

UV/AFC Upstream veto/Active final collimator

LAV 1-25 Large angle vetoes (25 stations)

MEC Main electromagnetic calorimeter

SAC Small angle calorimeter

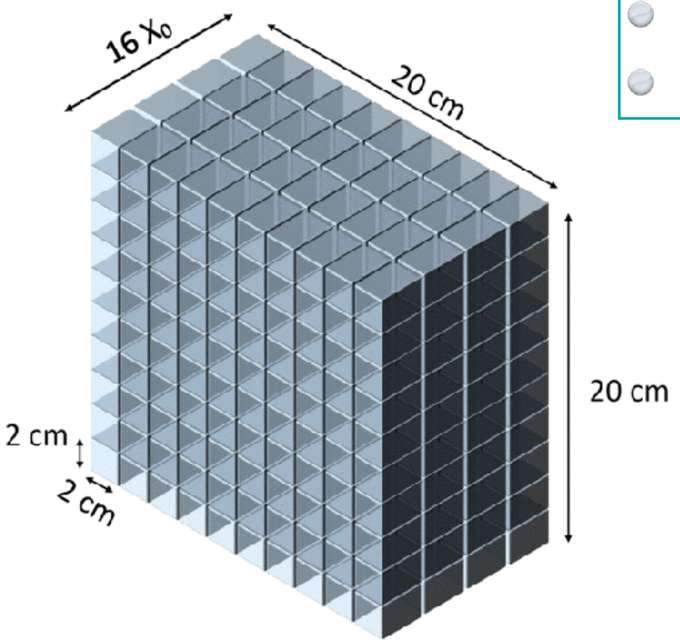
CPV Charged particle veto

Main Italian group interest (led by Frascati, M.Moulson)

Well consolidated design (start on 2012 with PRIN project), detailed simulation of the beam line and detectors.
Input to the 2020 update of the European Strategy for Particle Physics

Beam line for KLEVER needs to be extended by ~150 m to mitigate Λ background.
Optimization on-going to improve signal efficiency

KLEVER: Small Angle Calorimeter (SAC)

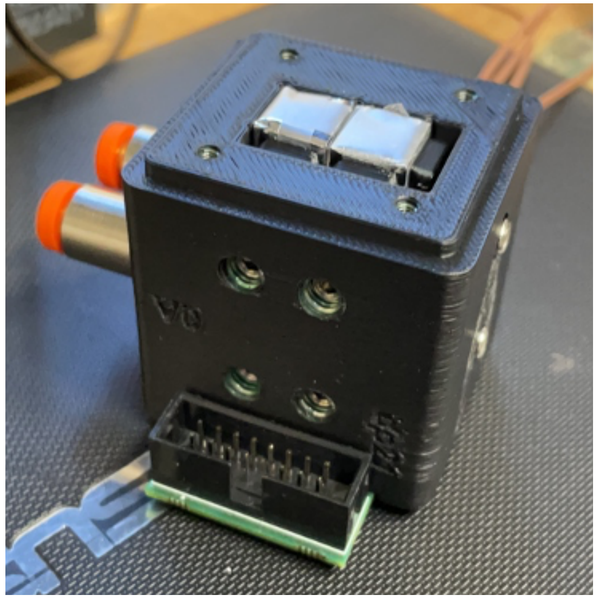


- Rejects photons from $K_L \rightarrow \pi^0 \pi^0$ escaping through beam hole
- Operates inside neutral beam: as insensitive as possible to 430 MHz of neutron

Baseline solution:

- Ultra-fast, heavy **Cherenkov** calorimeter like **PbF_2** or **scintillator** such as **PWO-UF**
- **σ_t < 100 ps, 2-pulse separation** at ~1 ns
- Explore idea of exploiting **coherent interactions in crystals** to reduce thickness

CRILIN prototype



R&D

2021, 2022 test beam at SPS H2 (in collaboration with Muon Collider CRILIN group): e^-, tagged γ, μ

- Validate CRILIN readout electronics and readout scheme
- Study systematics of light collection in small crystals with high density
- Measure time resolution achievable for PbF2 and PWO-UF
- Light yield vs incident angle for PbF_2 and 3rd generation PWO

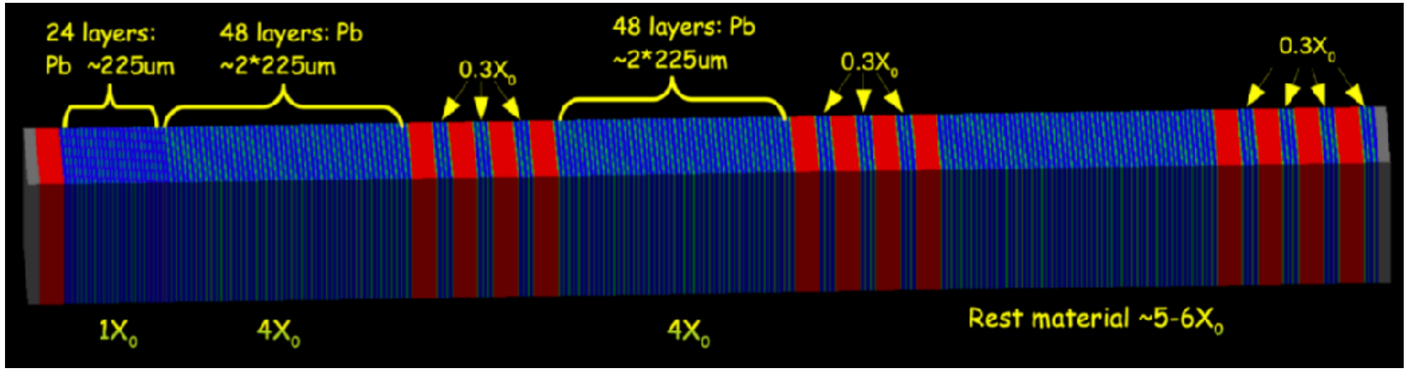
- Very promising results
- Enough data for publication
- 2023 Test beam foreseen with a prototype evolution

KLEVER: Main Electromagnetic Calorimeter(MEC)

Shashlyk Calorimeter with Spy tiles - Nanocomposite scintillator

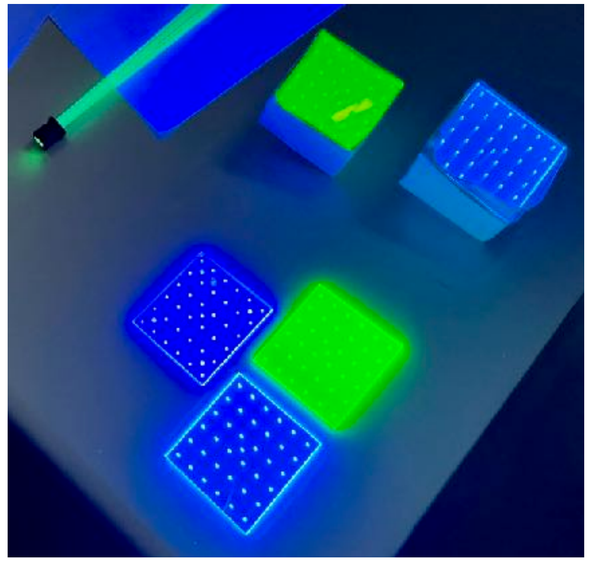
- Excellent efficiency
- Time resolution ~100 ps
- Good 2 clusters separation

- Fine-sampling **Shashlyk** based on PANDA forward EM calorimeter produced at Protvino (0.275 mm Pb + 1.5 mm scintillator)
- PANDA/KOPIO prototypes: **$\sigma_t \sim 72$ ps, $\sigma_E/\sqrt{E} \sim 3\%$, $\sigma_x \sim 13$ mm** (/√E in GeV)
- Longitudinal shower information from spy tile

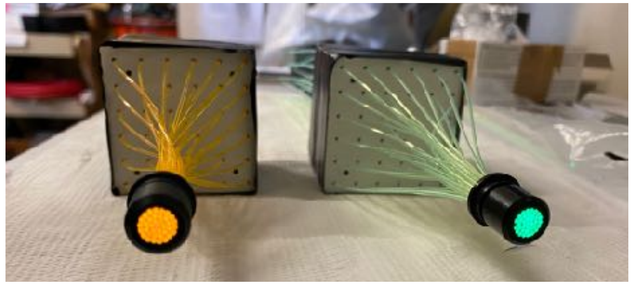


Shower depth information for PID

NanoCal project (AIDAInnova)



NanoCal(left) & Protvino(right):



R&D
2022 beam test a SPS H2

Test Shashlyk calorimeter based on semiconductor nanostucture tiles (decay times down to O(100 ps). Radiation hard to O(1 MGy)) comparing it with traditional scintillator tiles (new test beam with bigger prototype: 2023)

Conclusions

NA62 is taking data at full intensity with an upgraded detector,

aiming to reach a BR($K^+ \to \pi^+ \nu\nu$) measurement at 10% precision, comparable to the theoretical one

- Data analysis just started. Promising indications for random veto reduction and background suppression improvement
- Run in dump mode for exotic search: first results based on 1.4x 10^{17} POT. 10^{18} POT will be collected by the end of RUN2

Plans and proposal for longer term high-intensity kaon beam experiments are in develop

- LNF is the focus of conception and R&D for the future detectors. If HIKE will be approved we will need spaces and resources

NA62 Frascati group has grown in the last year

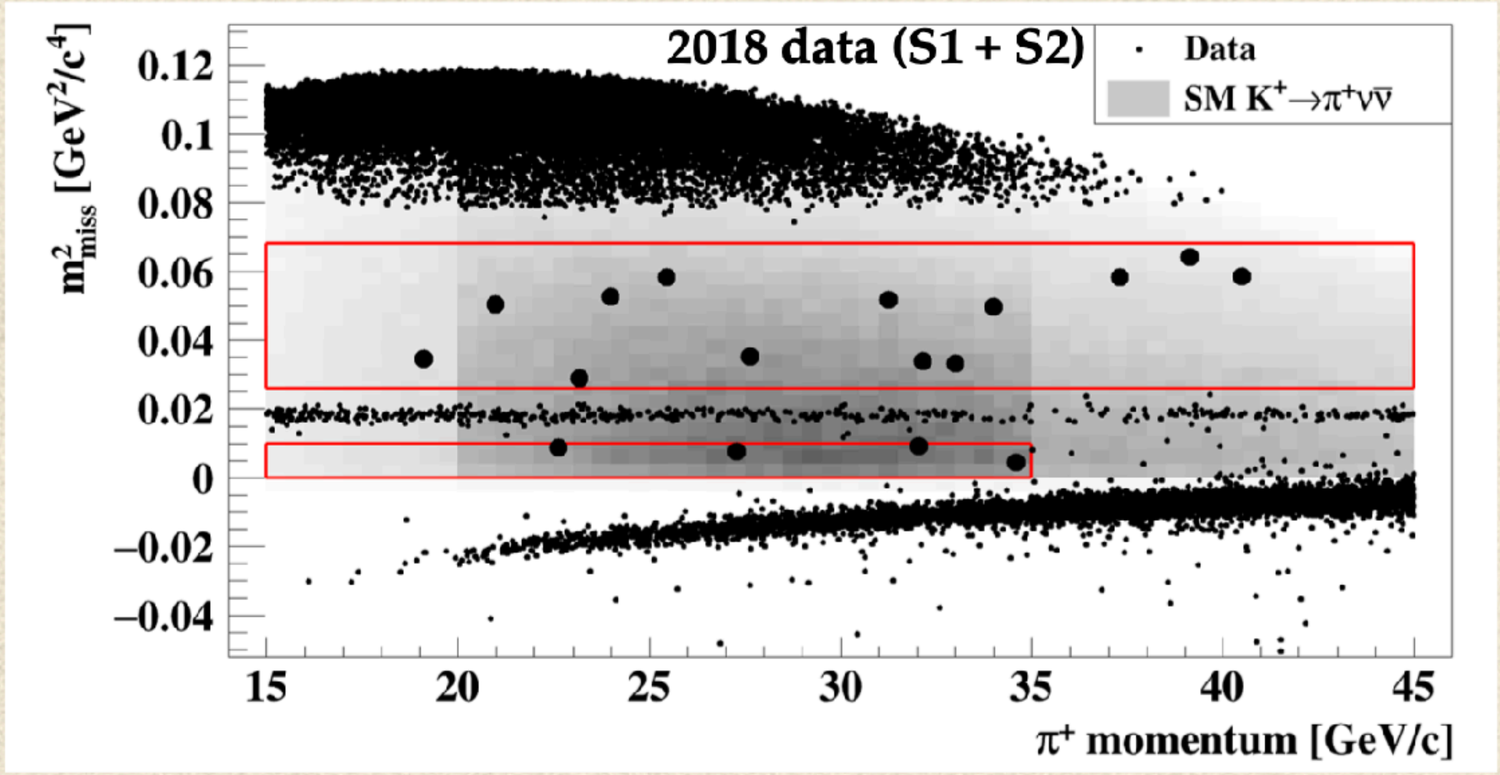
- 1 more permanent researcher

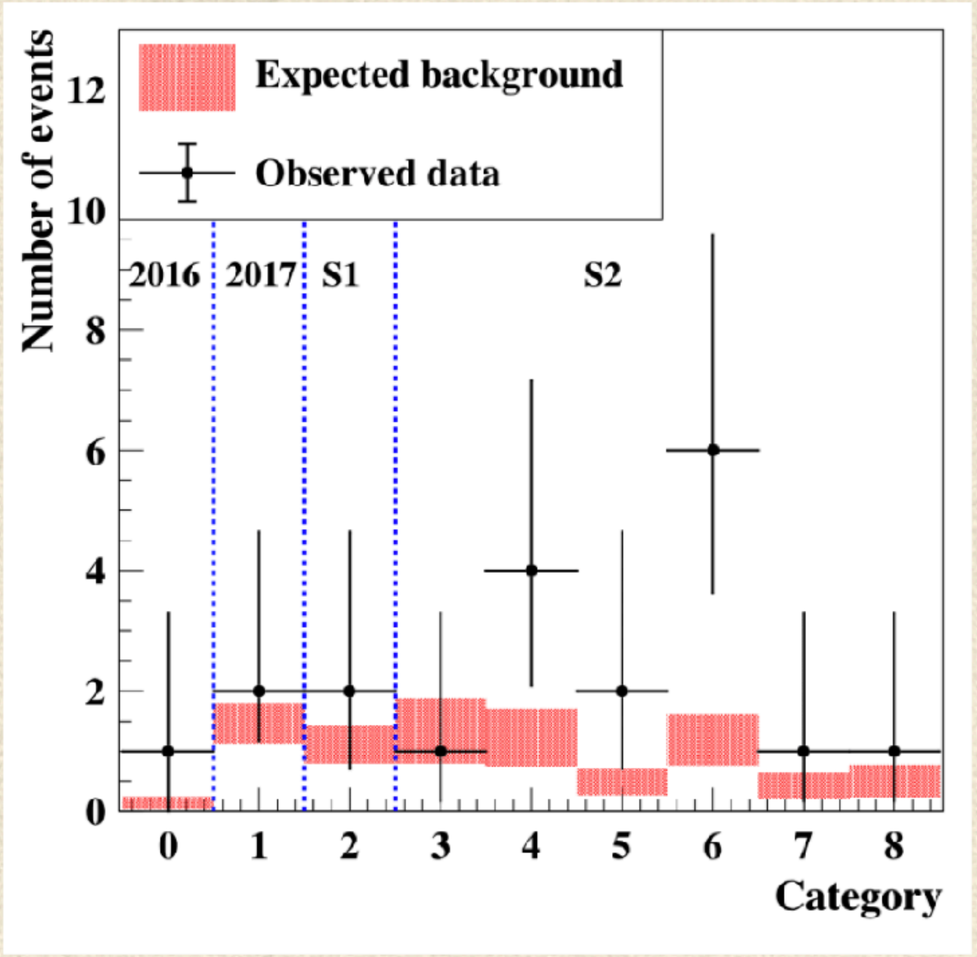
Gruppo 1 allocated 300 K euro/per year for the next 3 years available for Upgrade and R&D in Flavor physics

- 63 K euro approved for NA62 future in 2023

Backup

Results NA62 Run 1 (2016-18)





- 20 events observed in signal region in NA62 Run 1 data
- $BR(K^+ \to \pi^+ \nu\bar{\nu}) = (10.6^{+4.0}_{-3.4}|_{stat} \pm 0.9_{syst}) \times 10^{-11}$ [JHEP 06 (2021) 093]

3.4σ significance