Attività e prospettive dell'esperimento NA62

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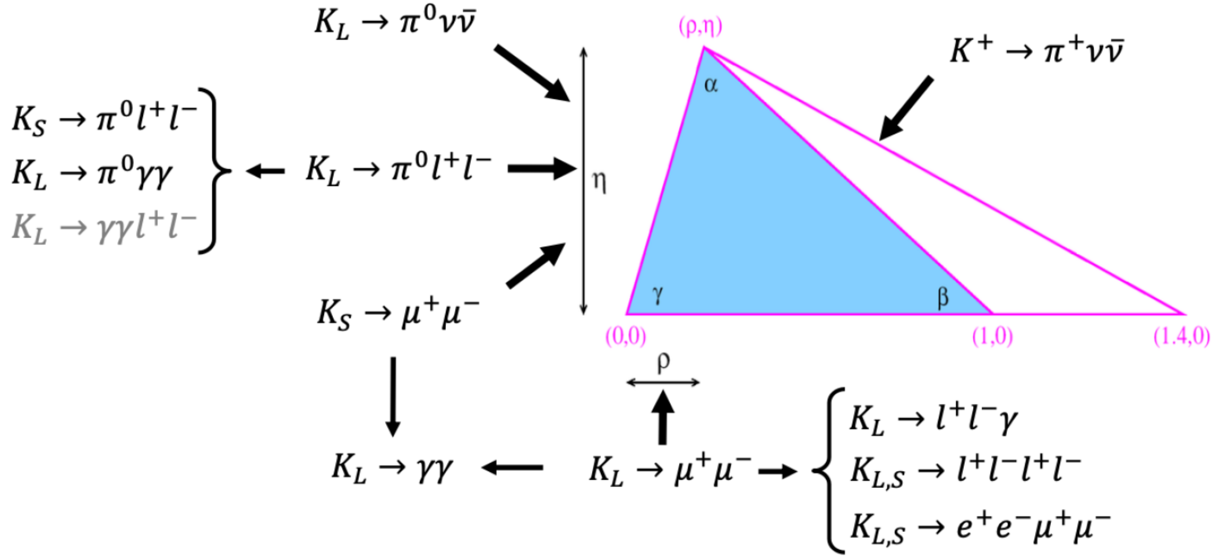
Riunione Gruppo 1, Napoli 12/01/2023

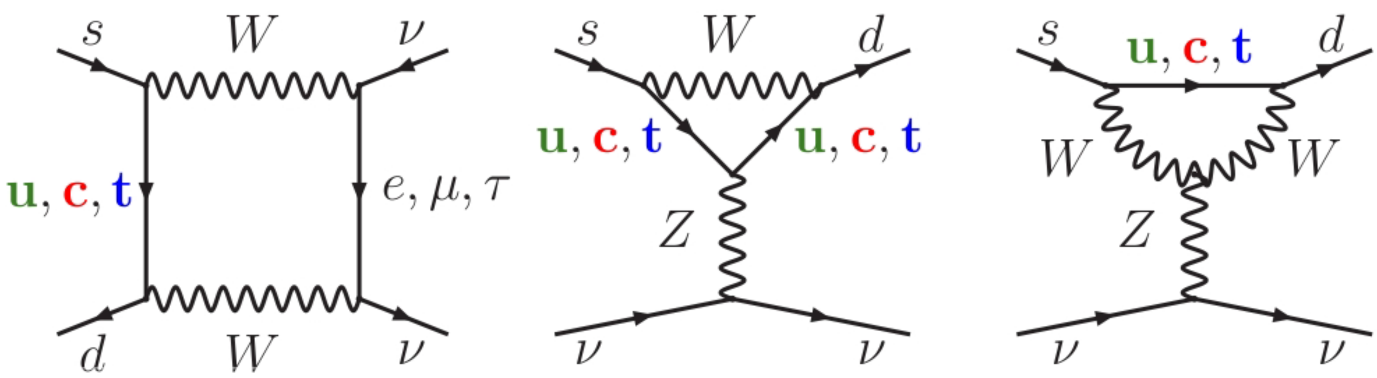
Seeking new physics through kaon decays

New physics at TeV scale not found (so far): explore higher mass scale via virtual production (ultrarare processes)
Over-constraining unitary triangle via kaon decays is a crucial compatibility test of the SM



Long distance contributions are sub-dominant to the amplitudes of $K^+ \to \pi^+ \nu\bar{\nu}$, and negligible for the $K_L \to \pi^0 \nu\bar{\nu}$ decay: these two decay modes belong to the theoretically cleanest probes of the flavour structure of the SM among all the kaon and B meson decays

$K \to \pi\nu\bar{\nu}$ in SM



Extremely rare decays with rates very precisely predicted in SM:

- **FCNC processes, no tree-level SM contribution**
- **$\sin^5\theta_C$ suppression (top loop dominance)**
- **Hadronic part from K_{e3} via isospin rotation**
- **Theoretical uncertainty dominated by CKM elements**

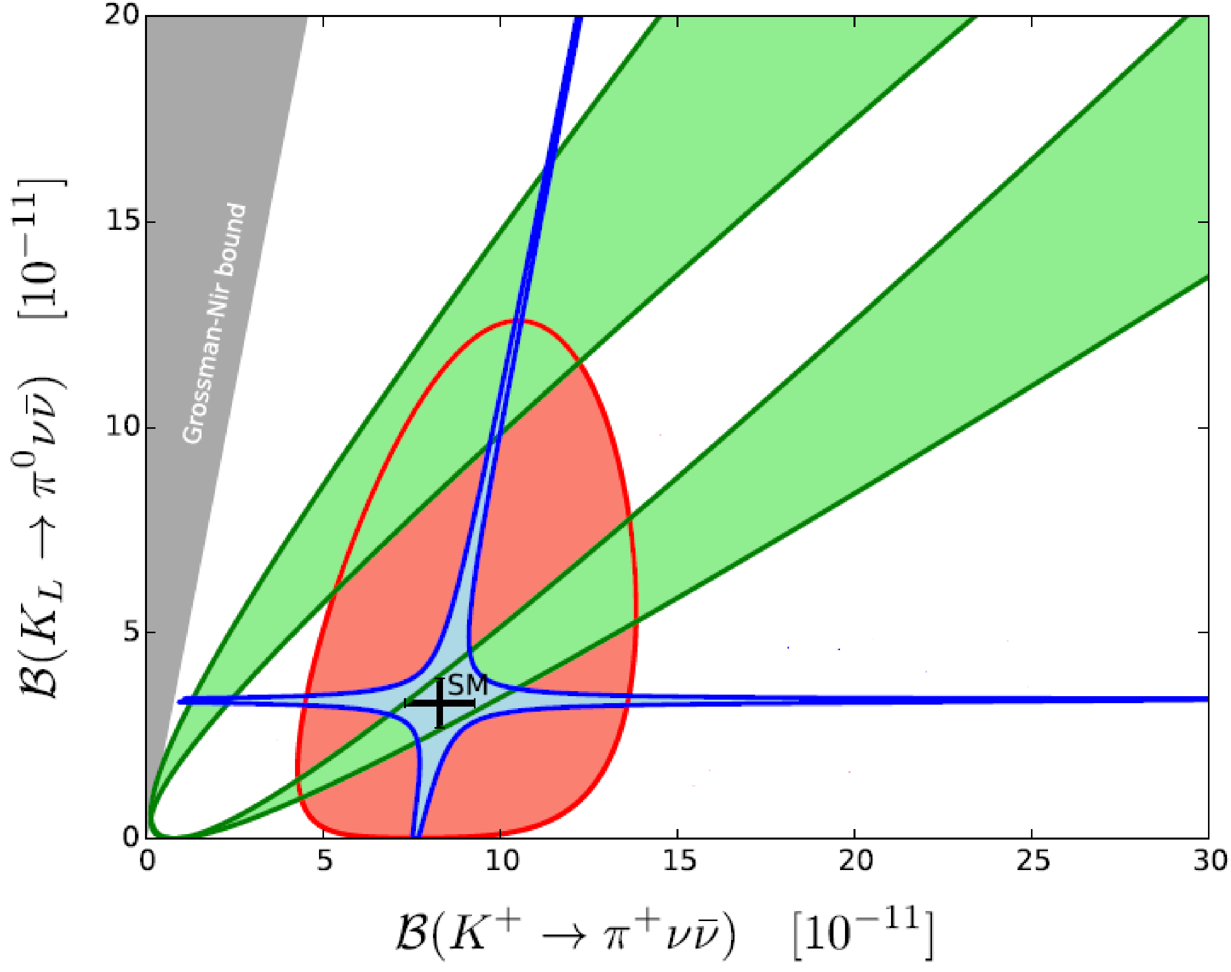
$$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) = (8.39 \pm 0.30) \times 10^{-11} \left(\frac{|V_{cb}|}{0.0407}\right)^{2.8} \left(\frac{\gamma}{73.2^\circ}\right)^{0.74},$$

$$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu}) = (3.36 \pm 0.05) \times 10^{-11} \left(\frac{|V_{ub}|}{3.88 \times 10^{-3}}\right)^{2} \left(\frac{|V_{cb}|}{0.0407}\right)^{2} \left(\frac{\sin\gamma}{\sin 73.2^\circ}\right)^{2}$$

Buras. et. al., JHEP 1511

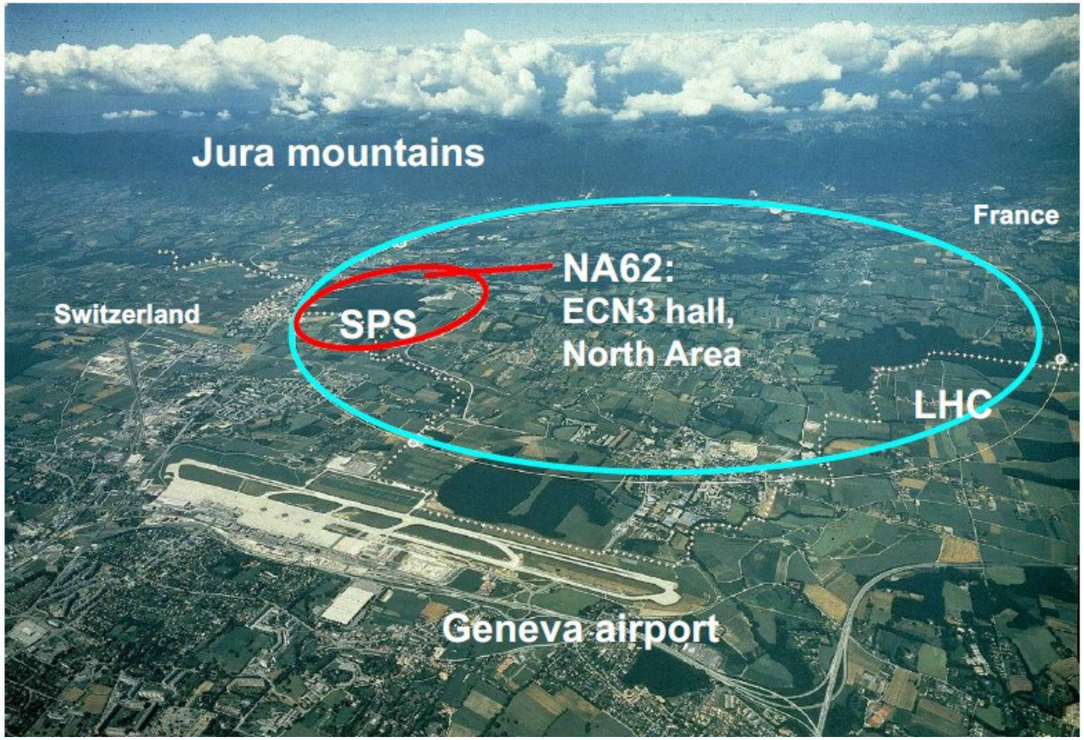
See also most recent results: J. Buras, E. Venturini Eur. Phys. J. C 82 (2022) 7, 615
G. D'Ambrosio, A.M. Iyer, F. Mahmoudi, S. Neshatpour arxiv:2206.14748v1

Possibility to distinguish among different models



- Models with a CKM-like structure of flavour interactions (e.g. MFV)
- Models with new flavour and CP-violating interactions in which either left or right handed currents fully dominate (e.g. Z or Z' FCNC scenarios)
- Models like Randall-Sundrum

Kaon experiments at CERN



- ✓ Fixed target experiment at CERN SPS.
- ✓ Main NA62 goal: BR($K^+ \rightarrow \pi^+ \nu\bar{\nu}$) measurement to 10% precision with a novel decay-in-flight technique.
- ✓ Officially approved to run up to LS3.
- ✓ Currently ~300 participants from 31 institutions.

NA31: K_S /K_L (1984-1990)
CPV

NA48, NA48/1: K_S/K_L(1997-2002)
Discovery of direct CPV, Re(ε'/ε), rare K_S and hyperon decays

NA48/2: K^+/ K^-(2003-2004)
Direct CPV, rare $K^{\pm}$ decays

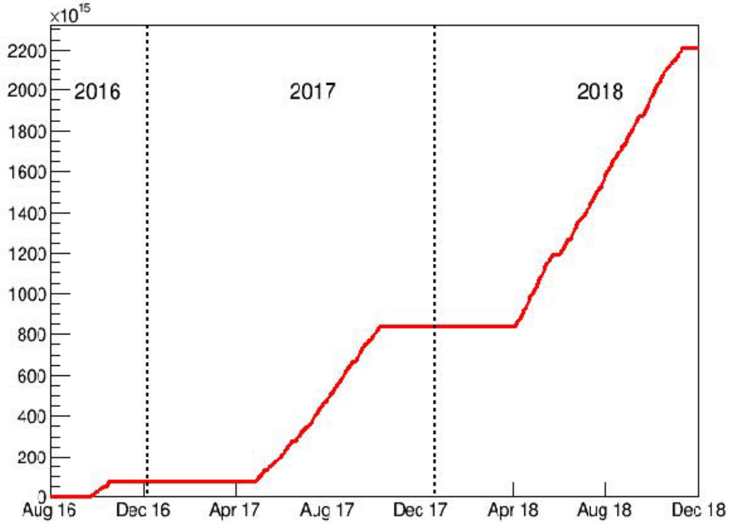
NA62: K^+/ K^-(2007-2008)
$R_K = \Gamma(K_{e2}) / \Gamma(K_{\mu 2})$

NA62: K^+ (2016-2018)
Physics Run1

NA62: K^+ (2021-now)
Physics Run2

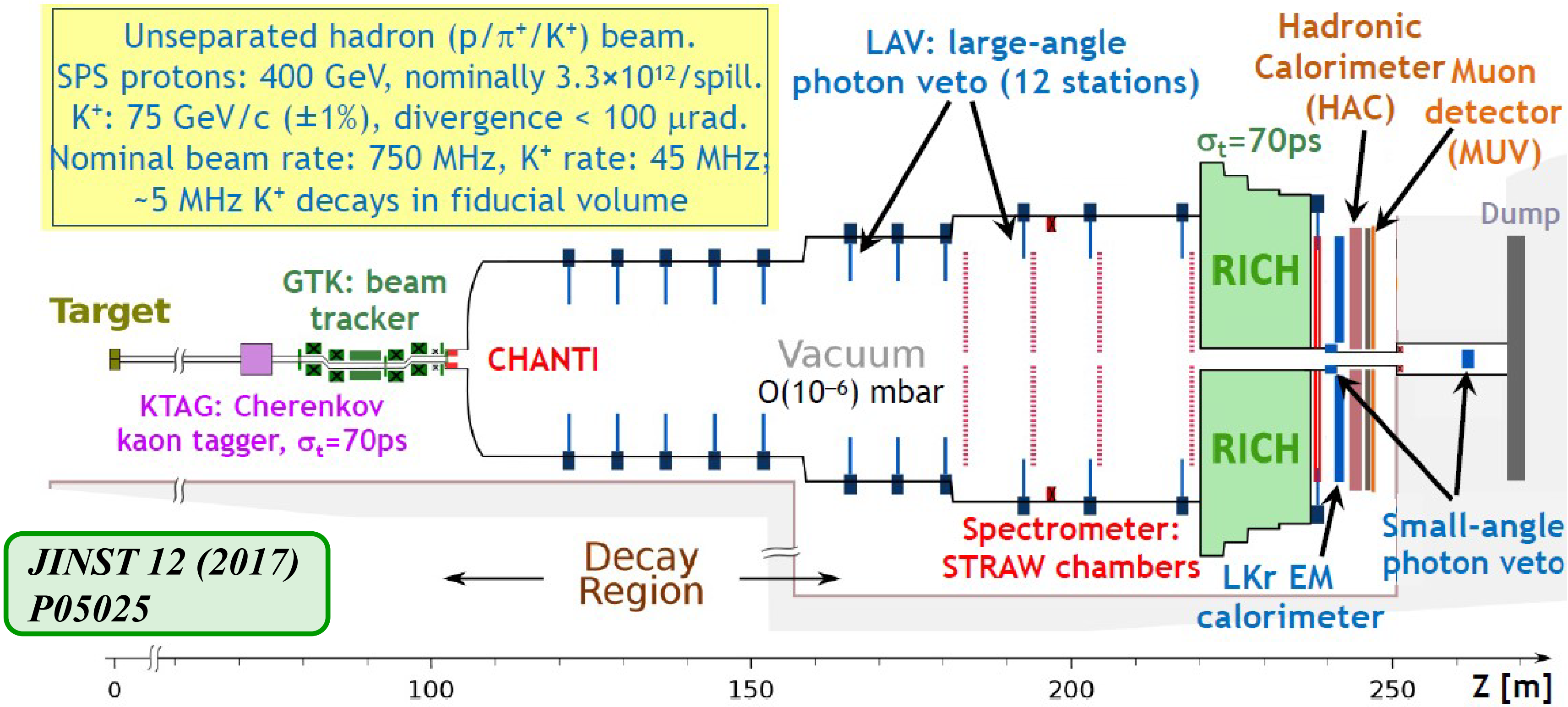
NA62 timeline and dataset

Run 1 (2016-2018) integrated luminosity: 2.2×10^{18} POT collected



- **Commissioning run 2015: minimum bias data ($\sim3\times10^{10}$ protons/pulse).**
- **Physics run 2016 (30 days, $\sim1.3\times10^{12}$ ppp): 2×10^{11} useful K^+ decays.**
- **Physics run 2017 (160 days, $\sim1.9\times10^{12}$ ppp): 2×10^{12} useful K^+ decays.**
- **Physics run 2018 (217 days, $\sim2.3\times10^{12}$ ppp): 4×10^{12} useful K^+ decays.**
- **Run 2 in progress: June 2021 till LS3 ($\sim3\times10^{12}$ ppp + upgraded detector).**

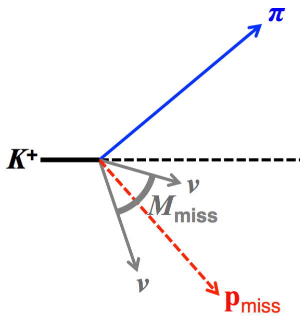
Beamline and detector



- ✓ **Excellent time resolution:** $\mathcal{O}$(100 ps) to match beam and daughter particle information
- ✓ **Kinematics:** rejection of main *K* modes 10^{-4} via kinematics reconstruction
- ✓ **PID capability (RICH+LKr+MUV):** $\mathcal{O}(10^{-7})$ muon suppression for 15GeV < p < 35 GeV
- ✓ **High-efficiency photon veto:** 10^{-7} rejection of π^0 for $E(\pi^0) > 40$ GeV

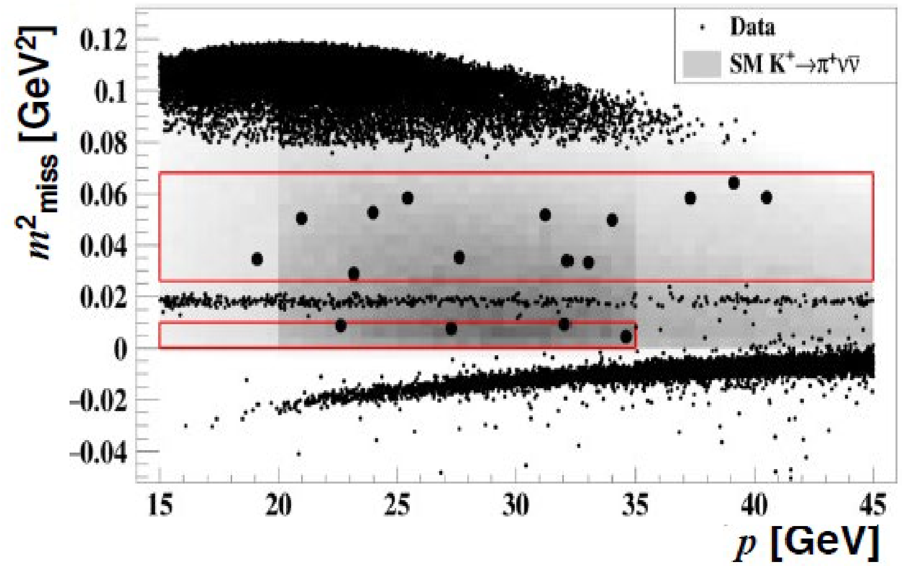
NA62 Run1 $K^+ \to \pi^+ \nu \bar{\nu}$ final result

Signal: BR = (8.4 ± 1.0) × 10^{-11}



K track in
π track out
No other particles in final state
$m^2_{miss} = (P_K - P_\pi)^2$

17 signal candidates in 2018 data



Main backgrounds

$K^+ \to \mu^+ \nu(\gamma)$	BR = 63.5%
$K^+ \to \pi^+ \pi^0(\gamma)$	BR = 20.7%
$K^+ \to \pi^+ \pi^+ \pi^-$	BR = 5.58%

Upstream beam background

JHEP 06 (2021) 093

NA62 2016-2018 data :
Expected SM sig: $10.01 \pm 0.42_{sys} \pm 1.19_{ext}$
Expected bkg: $7.03^{+1.05}_{-0.82}$ evts
20 events observed

See R. Fiorenza's talk

$\mathrm{BR}(K^+ \to \pi^+ \nu \bar{\nu}) = \left(10.6^{+4.0}_{-3.4}\,|_{stat} \pm 0.9_{sys}\right) \times 10^{-11}$ (3.4σ significance)

A general purpose experiment in kaon sector

Flavour Physics with kaons

Hidden sector Physics

Search for New Physics at the EW scale with sizeable coupling to SM particles via indirect effects in loops:

Main goal:
BR($K^+ \to \pi^+ \nu\nu$)

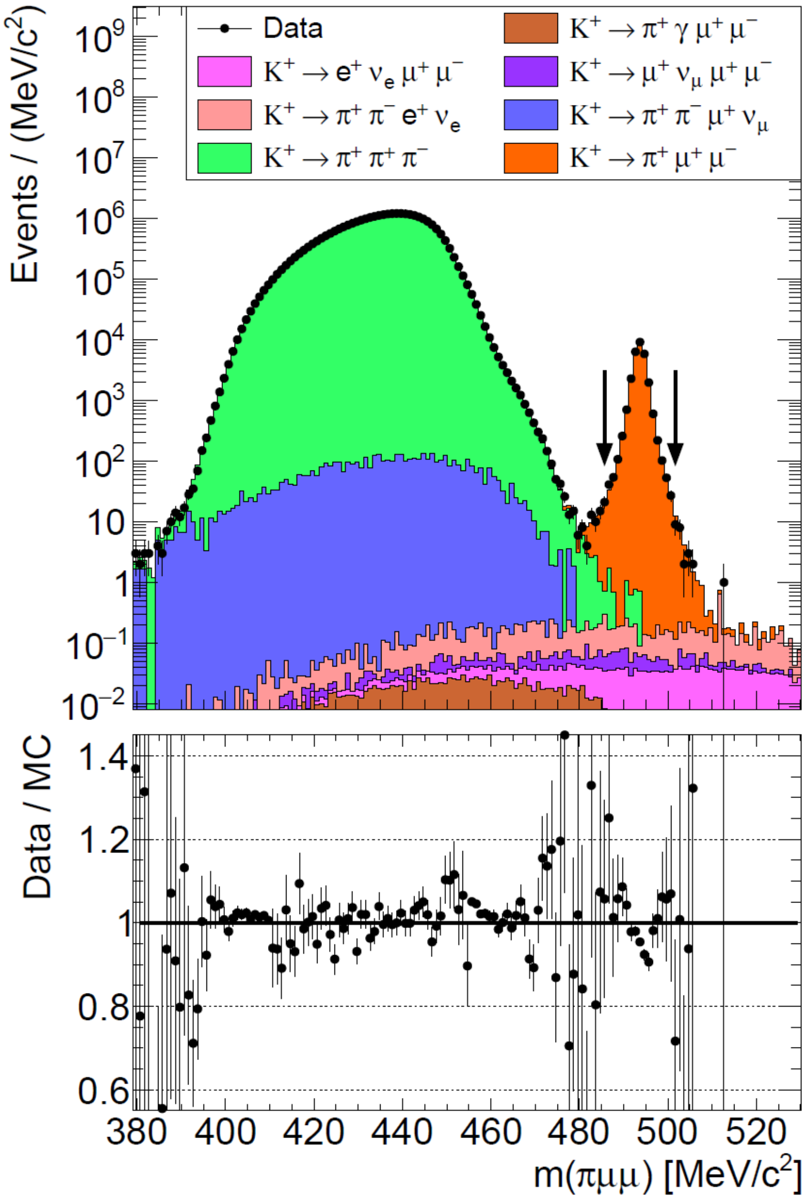
Search for lepton flavour and number violation, rare and forbidden decays:

$K^+ \to \pi^- e^+ e^+ (\gamma)$
$K^+ \to \pi^- \mu^+ \mu^+ (\gamma)$
$K^+ \to \gamma l^+ \nu$
$K^+ \to \pi^+ \mu^\pm e^\mp (\gamma)$
$K^+ \to \pi^- \mu^+ e^+ (\gamma)$
$\pi^0 \to e^+ e^-$,
$\pi^0 \to e^+ e^- e^+ e^-$
$\pi^0 \to \gamma\gamma\gamma$, $\pi^0 \to \gamma\gamma\gamma\gamma$

Search for New Physics below the EW scale (MeV-GeV) feebly-coupled to SM particles via direct detection of long-lived particles:

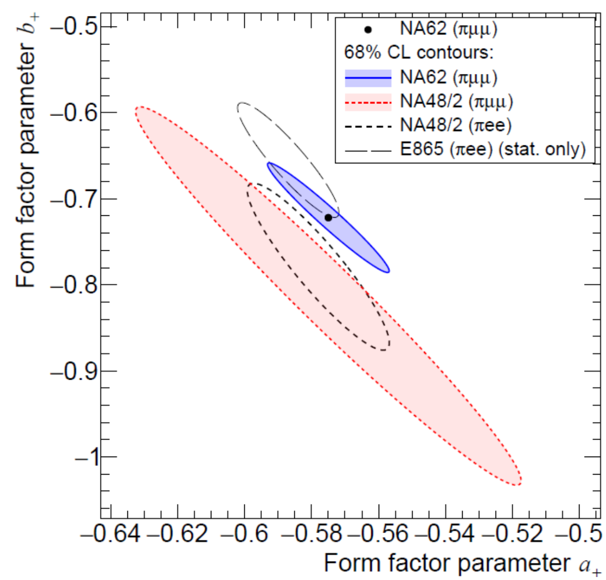
Heavy neutral Lepton(H)
Dark Photon(A'), Axion Like Particle (ALPs), Dark Scalar (S) in K decays:
$K^+ \to \mu^+$ H, $K^+ \to e^+$ H
$K^+ \to \pi^+ \pi^0$ with $\pi^0 \to A' \gamma$

A general purpose experiment in kaon sector



Precision measurement of $K^+ \to \pi^+\mu^+\mu^-$:

- **normalization $K^+ \to 3\pi$: effective number of kaon decays≃3.5×10^{12}**
- **Almost bkg free selection of a process with BR≃10^{-7}**
- **Fit to $d\Gamma(K^+ \to \pi^+\mu^+\mu^-(\gamma))/dz$, z=$m^2_{\mu\mu}/m^2_K$ to extract form factor parameters a_+ and b_+**



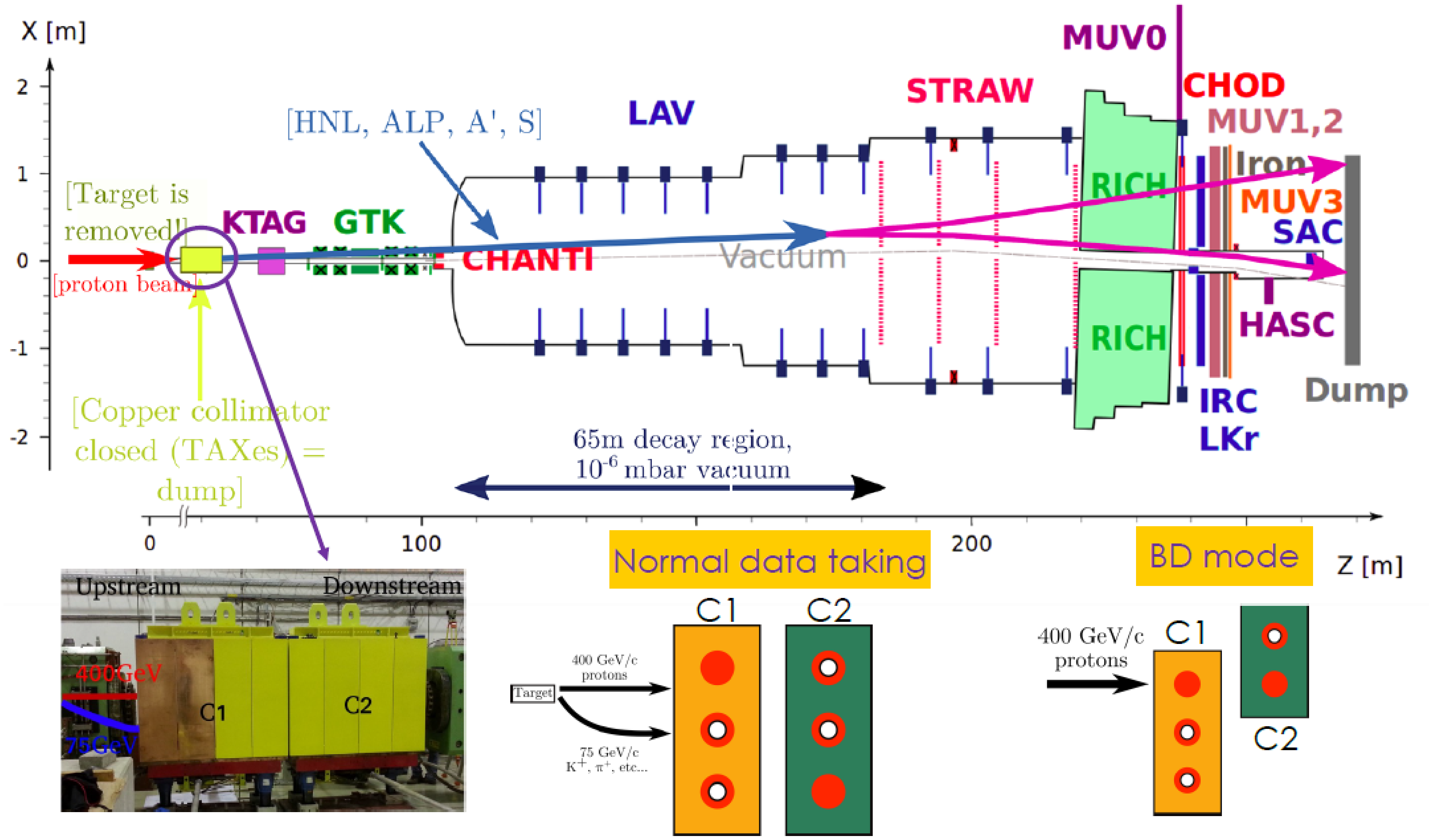
Form factor parameters compatible with $K^+ \to \pi^+e^+e^-$ (LFU test)

JHEP 11 (2022) 011

NA62 in dump mode

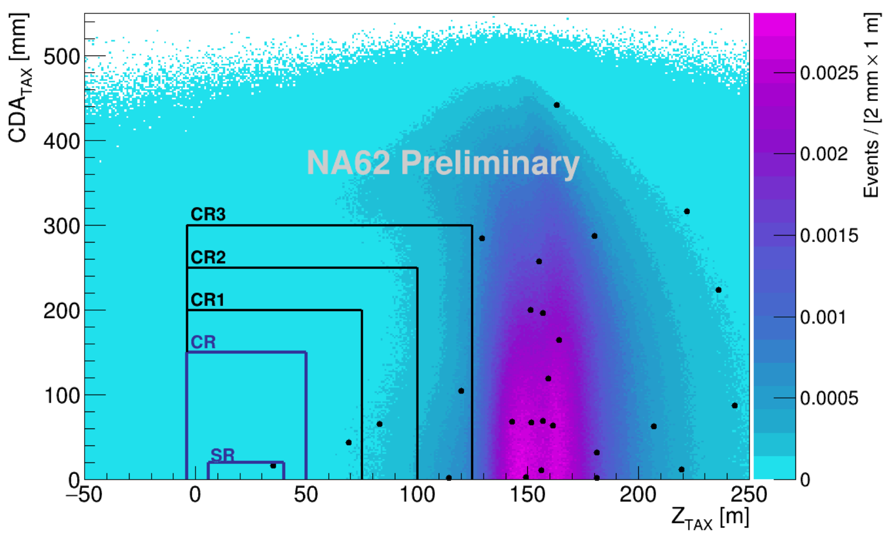
Beam dump mode: 3.2 m Cu-Fe collimators (TAX) used as target removing the Be target; Search for dark sector particles production in interaction with TAXs decaying into visible final states in the NA62 experimental apparatus

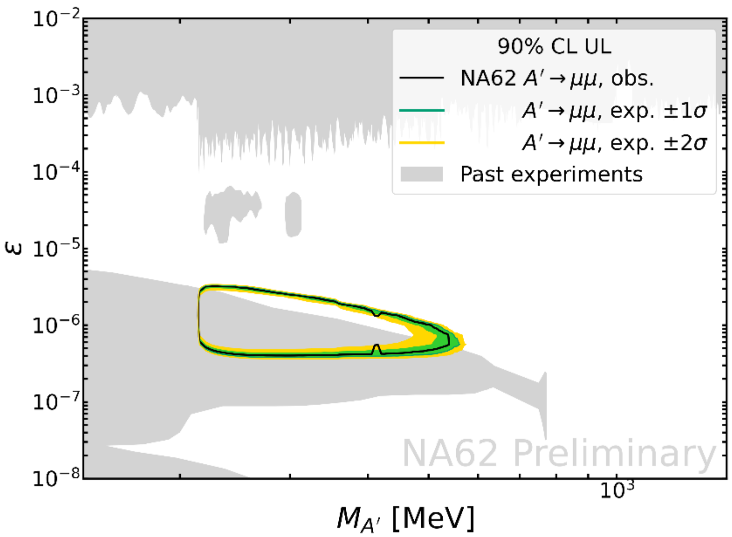
1.5 x nominal intensity, (1.40 ±0.28) $\times 10^{17}$ POT collected in ~10 days during 2021 run



NA62 in dump mode: dark photon search $A' \to \mu^+\mu^-$

- Dark photon A':
  - extra U(1) massive gauge singlet
  - mixing with SM hypercharge
  - ε and $M_{A'}$ are free parameters
- Control samples: same sign leptons (combinatorial background)
- 1 event observed in SR
  - Probability of non-zero counts in SR given the bkg only hyp. is 1.59%
  - Global 2.4 σ significance





NA62 recent results summary

Recent results from NA62:

- $\boldsymbol{K^+ \to \pi^+ \nu\bar{\nu}}$ ***JHEP 06 (2021) 093***

- $K^+ \to \pi^+\mu^+\mu^-$ *JHEP 11 (2022) 011*
- $K^+ \to \pi^0 e^+ \nu_e \gamma$ *preliminary, see PoS (EPS-HEP2021) 553*
- $K^+ \to \pi^+\gamma\gamma$ *preliminary, see KAON2022*
- $\pi^0 \to inv$ *JHEP 02(2021)201*

LNV/LFV, BR limits improved:

- $K^+ \to \mu^- \nu_\mu e^+ e^+$ *accepted by PLB, arXiv:2211.04818, limit improved by factor 250*
- $K^+ \to \pi^-\pi^0 e^+ e^+$ *PLB 830 (2022) 137172, first limit*
- $K^+ \to \pi^- e^+ e^+$ *PLB 830 (2022) 137172, limit improved by a factor 12*
- $K^+ \to \pi^\mp \mu^\pm e^+$ *PRL 127 (2021) 131802, limit improved by a factor ~10*
- $\pi^0 \to \mu^- e^+$ *PRL 127 (2021) 131802, limit improved by a factor 13*
- $K^+ \to \pi^-\mu^+\mu^+$ *PLB 797 (2019) 134794, limit improved by a factor 2*

Dark sector:

- $A' \to \mu^+\mu^-$ *preliminary, see KAON2022* } Dark photon
- $K^+ \to \pi^+\pi^0, \pi^0 \to A'\gamma$ *JHEP 05 (2019)* } Dark photon
- $K^+ \to \pi^+ X$ *JHEP03(2021)058* } Dark scalar or ALP
- $K^+ \to \mu^+ N$ *PLB 816 (2021) 136259* } Heavy Neutral leptons
- $K^+ \to e^+ N$ *PLB 807 (2020) 135599* } Heavy Neutral leptons

Naples working group

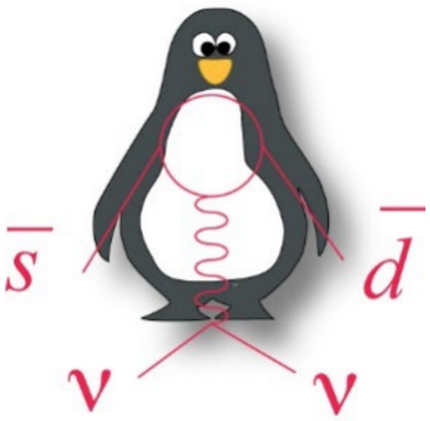
F. Ambrosino(PO) – Deputy Spokesperson	90%
G. De Nardo(PO)	10%
C. Di Donato(PA)	20%
R. Fiorenza(PhD–end 2024)	100%
R. Giordano(PA)	10%
P. Massarotti(PA)	20%

M. Merola(PA)	10%
M. Mirra(Ric. INFN) – Responsabile Locale	60%
M. Napolitano(senior)	
I. Rosa(PhD–end 2026)	100%
G. Saracino(PA)	80%

5 FTE (synergic activities included)

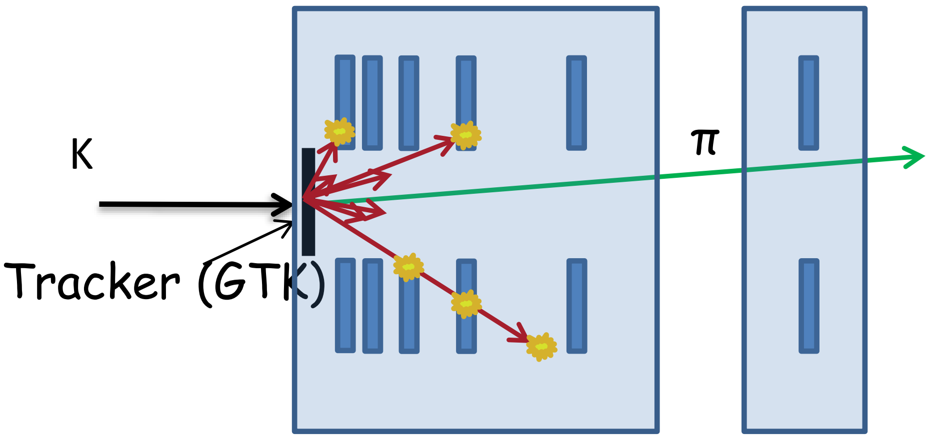
Activities in NA62

- Full responsabily of the CHANTI detector: hw/sw maintanece, data quality analysis
- Involved in the main channel analysis ($K^+ \to \pi^+ \nu\bar{\nu}$), in lepton flavor universality measurements and dark sector
- Ongoing studies for GTK read-out firmware improvements

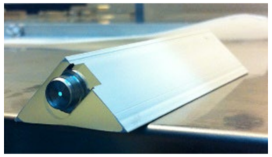


CHANTI postcard

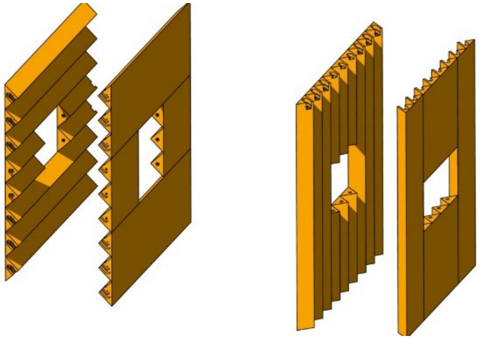
Detector proposed and built entirely in Naples, thanks to the INFN mechanical design and workhop service.
Six guard rings to veto kaon inelastic interaction on GTK3 and beam background.
Staggered scintillator bars with triangular section read via WLS fibers and SiPM forming 6 xy sensitive planes



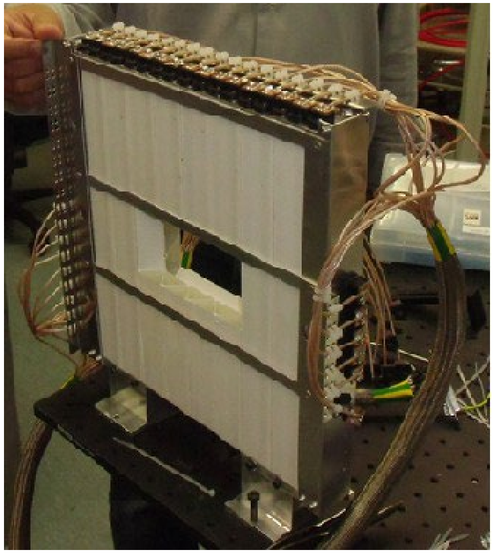
Scintillator bar



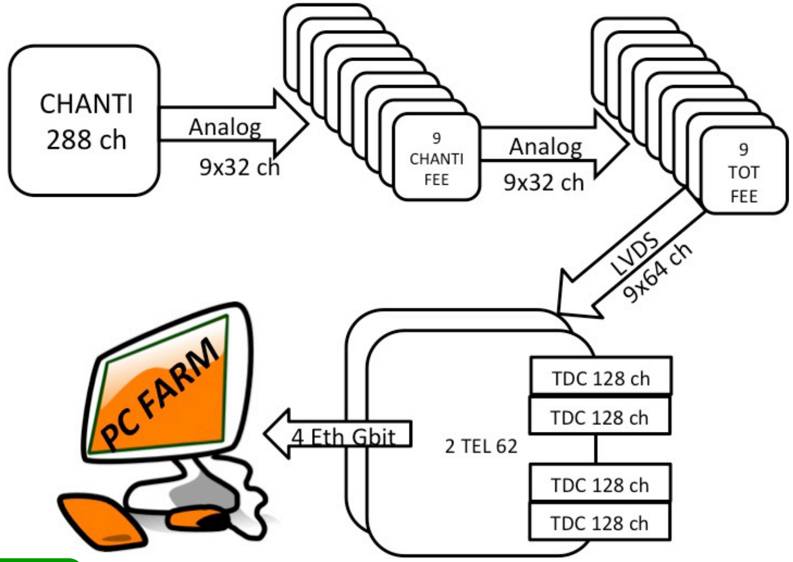
Layout of the X/Y layers



Fully cabled station



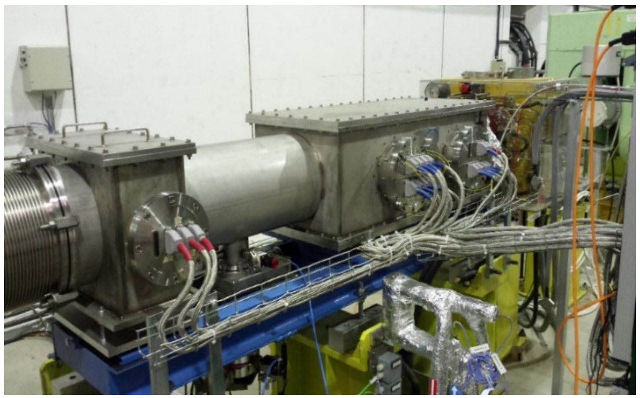
Front end electronics

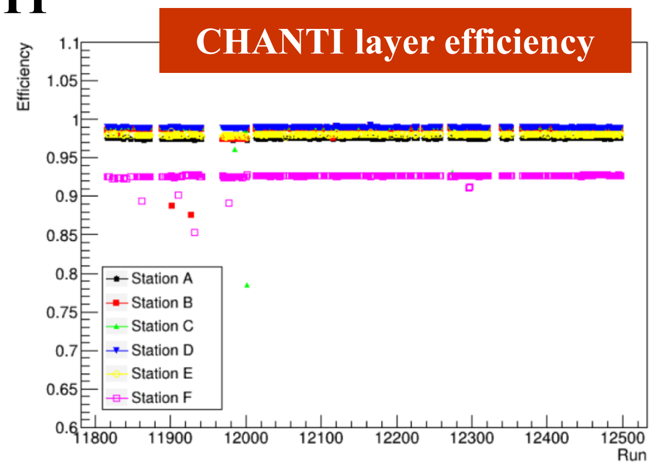


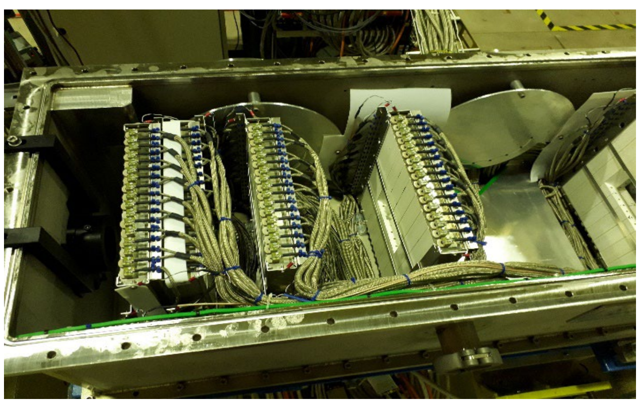
JINST 11 (2016) P03029

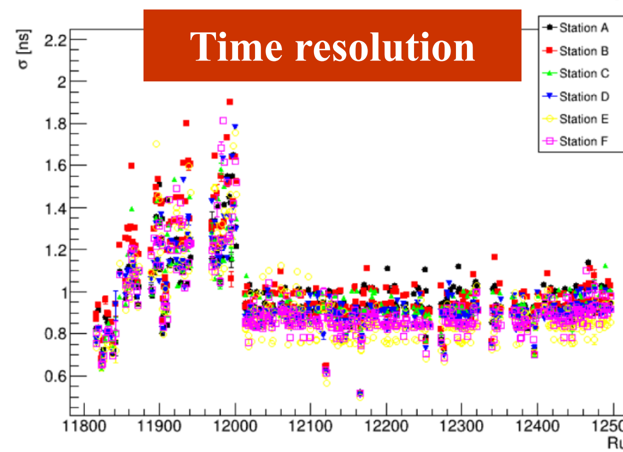
CHANTI in 2022 run

- New FE boards installed to cope with the higher intensity reached in 2021 run
- During LS2 all CHANTI SiPMs, originally installed in 2014, were replaced by new ones to prevent aging effect due to radiation damages. This intervention required a big effort from L. Roscilli and F. Cassese.
- Succesful and smooth 2022 data taking for CHANTI





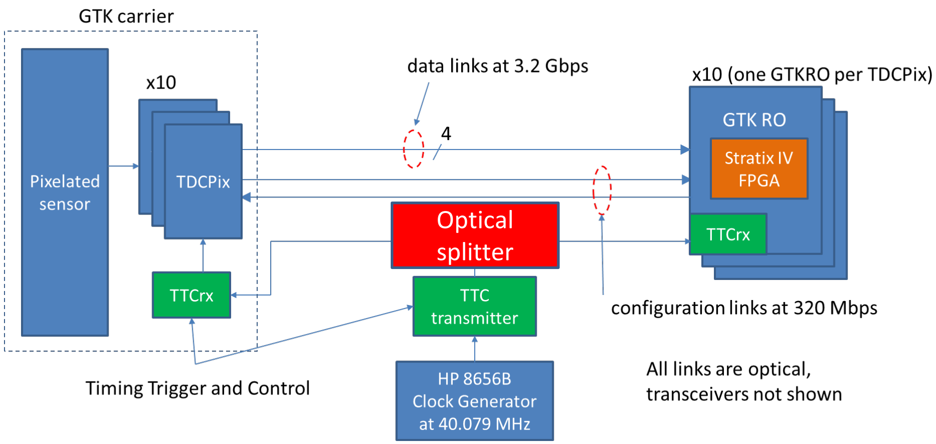


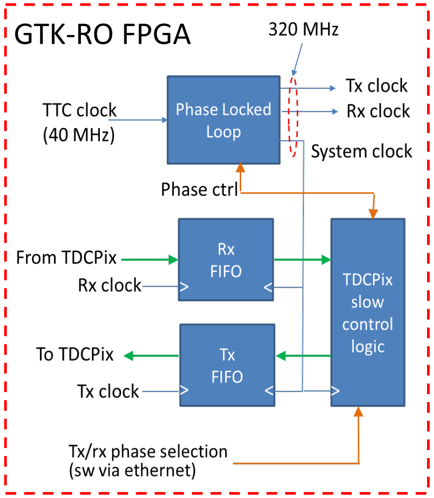


- A new SiPM replacement is foreseen before the 2023 data taking

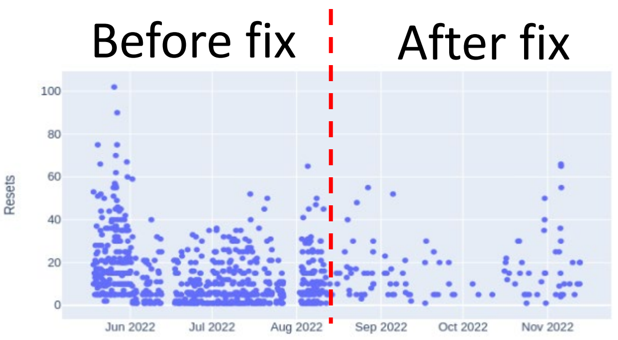
GTK read-out

- Collaboration with INFN FE and CERN for GTK efficiency improvement
- Loss of lock on configuration links to TDCPix chips => GTK resets (inefficiency)
  - new firmware implemented as fix
  - 16 Tx + 16 Rx independent clock phases selectable via sw
- Spotted and fixed issue in optical signal distribution to carriers
  - Installed a test system to verify signal integrity and possible phase drifts
  - Clear improvement in GTK reset rate after mid August 2022
  - Efficiency up from 70% to 85% Optical splitter replaced (Nov. 2022)





Number of GTK resets in 1 hour for GTK0-1 (other stations are alike)

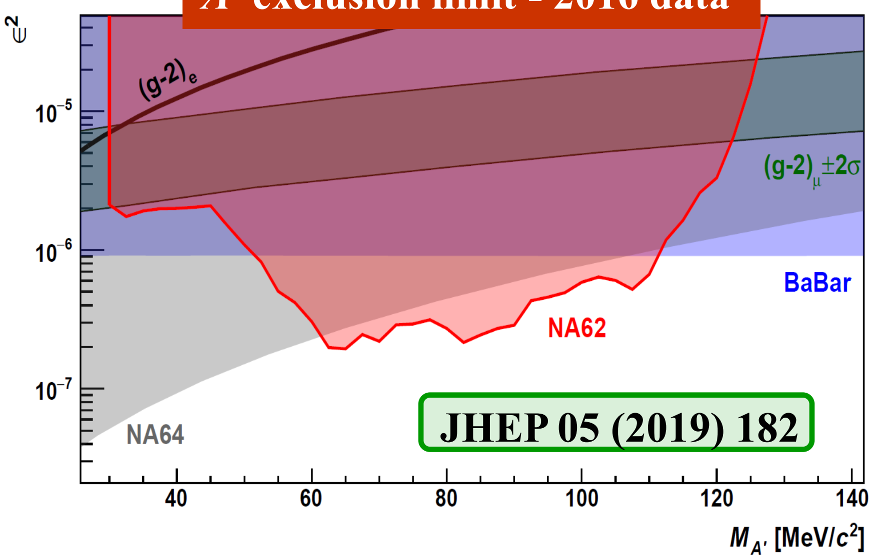


R. Giordano

Analysis activities

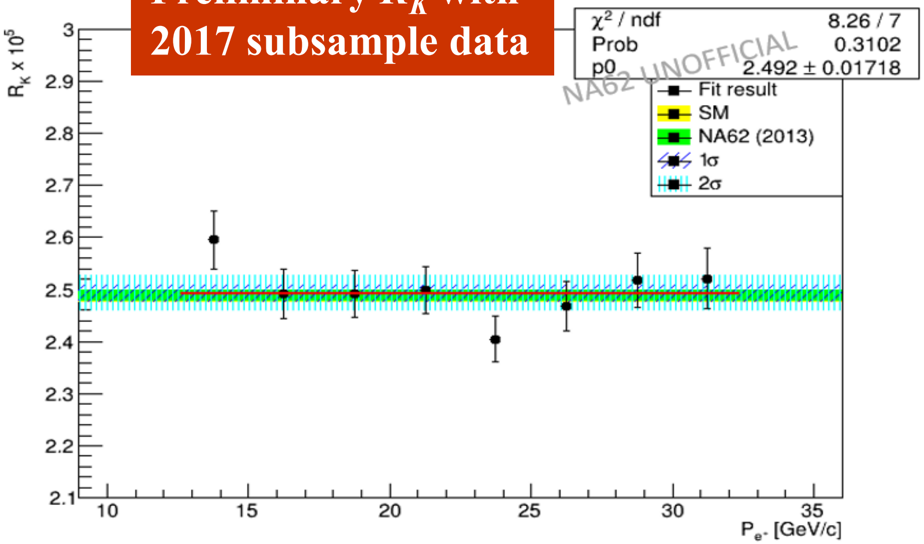
- Improvements in $K^+ - \pi^+$ matching and random veto studies for the main analysis $K^+ \to \pi^+ \nu\bar{\nu}$ (see R. Fiorenza's talk)
- Study of the $K^+ \to l^+ \nu_l e^+ e^-$ (see I. Rosa's talk)
- Measurement of the lepton flavor universality with $R_K = \Gamma(K^+ \to e^+\nu_e)/\Gamma(K^+ \to \mu^+\nu_\mu)$
- Search for an invisible dark photon in π^0 decays: $K^+ \to \pi^+\pi^0, \pi^0 \to A'\gamma,\ A' \to inv$

A' exclusion limit - 2016 data

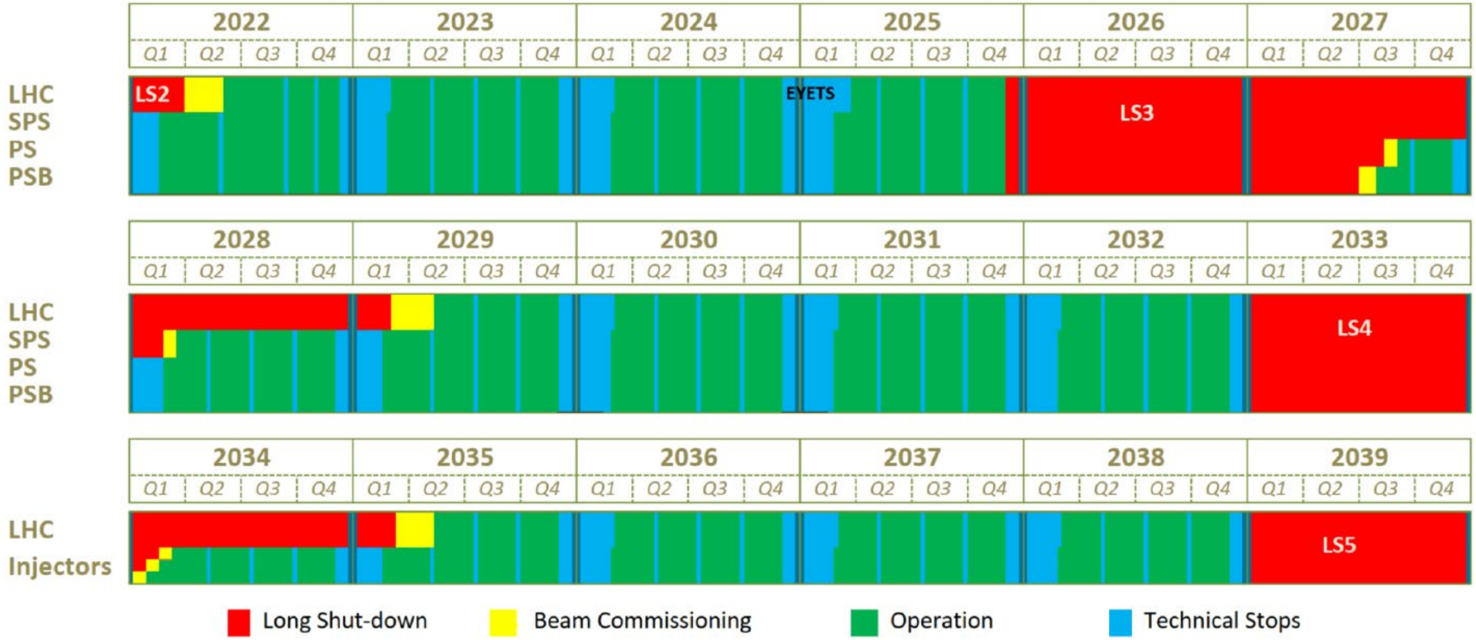


JHEP 05 (2019) 182

Preliminary R_K with 2017 subsample data



Fixed target runs at the SPS



IEFC working baseline, March 2022 – https://indico.cern.ch/event/1134440/

Fixed target runs foreseen through 2040. There is an opportunity at the SPS for an integrated program to pin down new physics in kaon decays. Measurement of all rare kaon decay modes - charged and neutral - to give clear insight into the flavor structure of new physics

A comprehensive, multi-staged project for kaon physics at CERN after LS3: the High Intensity Kaon Experiment (HIKE) project.

Letter of Intent SPSC-I-257, 7 November 2022

HIKE program

Phase 1: High-intensity K^+ experiment to measure BR($K^+ \to \pi^+ \nu\bar{\nu}$) to ~5%

- Also study lepton universality/number/flavor violation:
  $R_K = \Gamma(K \to e\nu)/\Gamma(K \to \mu\nu)$, $K^+ \to \pi^+\ell\ell$, $K^+ \to \pi^-\ell^+\ell^+$, $K^+ \to \pi^+\mu e$
- Radiative and Dalitz decays, chiral parameters, precision measurements

Phase 2: Experiment for rare K_L decays with charged particles

- K_L beamline with tracking and PID for secondary particles, as in NA62
- $K_L \to \pi^0\ell^+\ell^-$, excellent π^0 mass resolution
- Lepton universality/number/flavor violation in K_L decays
- Radiative K_L decays and precision measurements
- Measurement of K_L, n, and Λ fluxes and halo to prepare for K_L phase

During 1&2: Periodic runs with dumped beam, collect up to 5×10^{19} pot

Phase 3: Measurement of BR($K_L \to \pi^0\nu\nu$) to ~20%: KLEVER

NA48 LKr calorimeter in HIKE

Quasi-homogeneous ionization calorimeter: 27 X_0 f LKr

Photon efficiency likely adequate even for K_L program
- NA48-era studies for NA62: $1 - \varepsilon < 10^{-5}$ for $E\gamma > 10$ GeV
- High-energy efficiency confirmed with NA62 data

Time resolution
- $\sigma_t \sim 500$ ps for π^0 with $E\gamma\gamma > 20$ GeV
- Would require 4x improvement in K^+ phase to hold accidental veto rate to current levels
- Critical for KLEVER: Accidental rate ~140 MHz!

Consolidation work necessary

Investigating upgrade possibilities
- Increase operating voltage to increase drift velocity
- Faster digitizers and signal shaping

For K_L phase, LKr inner bore limits beam solid angle

LKr resolution:

$$\frac{\sigma_E}{E} = \frac{3.2\%}{\sqrt{E}} \oplus \frac{9\%}{E} \oplus 0.42\%$$

$$\sigma_t = \frac{2.5\text{ ns}}{\sqrt{E}}$$

Shashlyk calorimeter with spy tiles

Main electromagnetic calorimeter (MEC):

Fine-sampling shashlyk based on PANDA forward EM calorimeter produced at Protvino

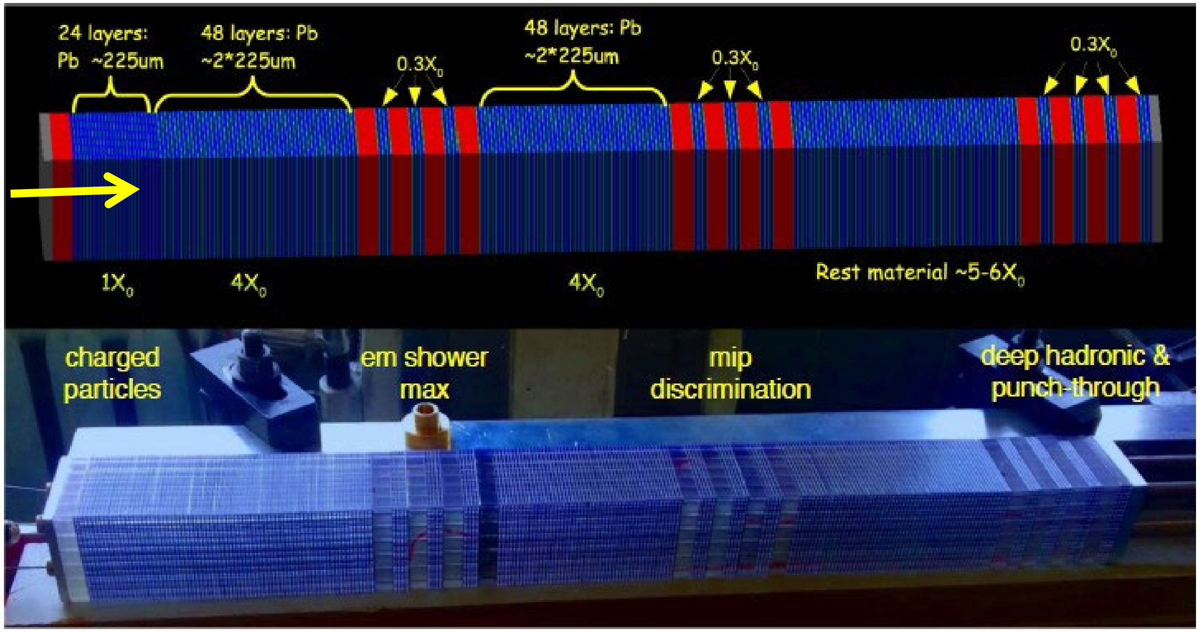
0.275 mm Pb + 1.5 mm scintillator

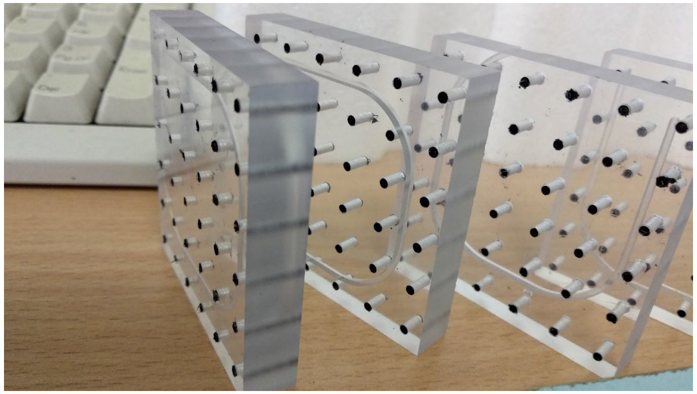
PANDA/KOPIO prototypes:

- $\sigma_E/\sqrt{E} \sim 3\% /\sqrt{E}$ (GeV)
- $\sigma_t \sim 72$ ps $/\sqrt{E}$ (GeV)
- $\sigma_x \sim 13$ mm $/\sqrt{E}$ (GeV)

New for HIKE: longitudinal shower information from spy tiles

- **PID information: identification of μ, γ, n interactions**
- **Shower depth information: improved time resolution for EM showers**

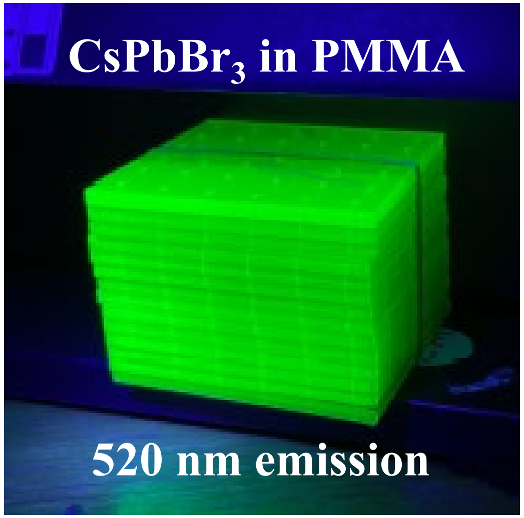


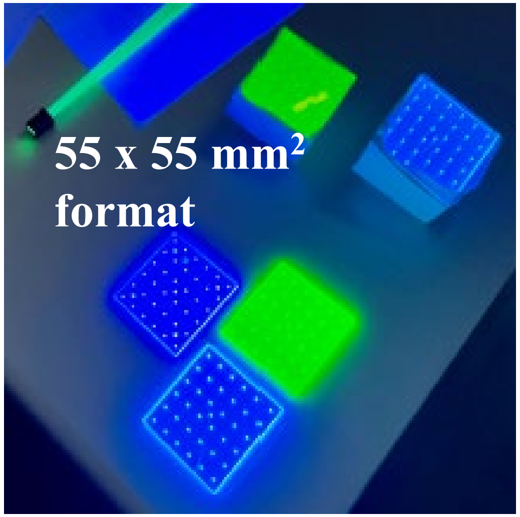


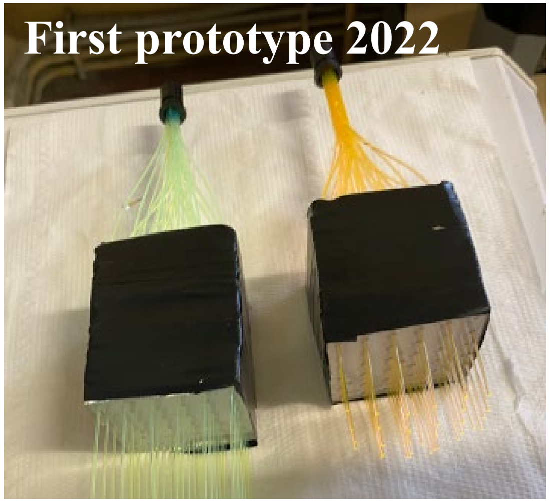
1st prototype assembled in Protvino and tested at OKA in April 2018 and DESY in Nov 2019

Innovative scintillators for shashlyk

R&D in synergy with NanoCal project: perovskite nanostructures in a polymer matrix can be used as sensitizers/emitters for ultrafast, robust scintillators







Quick-start using CsPbBr3, 0.2% w/w in UV-cured PMMA
- Light yield O(few k) photons/MeV deposit
- 50% of light emitted in components with $\tau < 0.5$ ns
- Radiation hard to O(1 MGy)

Progress:
- **Oct 2022: First component test at CERN: fibers/tiles/SiPMs**
- **2023**: Further iterations to improve performance of NC scintillator prototype
- **2024:** Construction of full-scale prototype modules; performance comparison

Conclusions

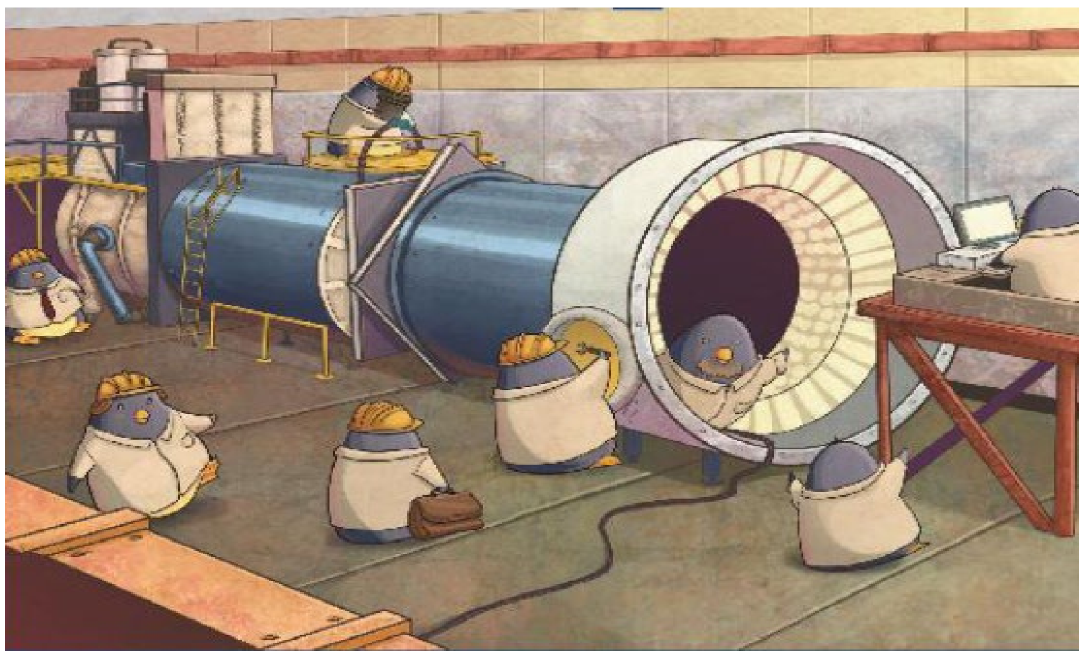
- ✓ **The CERN Kaon factory has a vast and unique physics program for the search of NP, complementary to what can be done at LHC and B-factories**
- ✓ **The current run(2021-2025) will allow to fully exploit the physics reach with the current NA62 setup. It will collect data both in «kaon mode» and in «dump mode» (10^{18} pot by 2025). O(10%) precision on BR($K^+ \to \pi^+ \nu\bar{\nu}$) will be reached by LS3 with optimization of the analysis. High quality physics results are being published by the collaboration.**
- ✓ **Naples working group involved both in detector side (full responsibility of CHANTI, GTK readout firmware) and in physics analysis for the main channel $K^+ \to \pi^+ \nu\bar{\nu}$, lepton universality and dark sector**
- ✓ **Next generation of rare kaon experiments with high-intensity beams and cutting-edge detectors will provide a powerful tool to search for physics beyond the Standard Model.**
- ✓ **HIKE - an integrated program of K^+ and K_L experiments - is taking shape at the CERN SPS. Naples working group interested in the new main calorimeter development.**

Backup

NA62 P326

HIKE

High Intensity Kaon Experiments

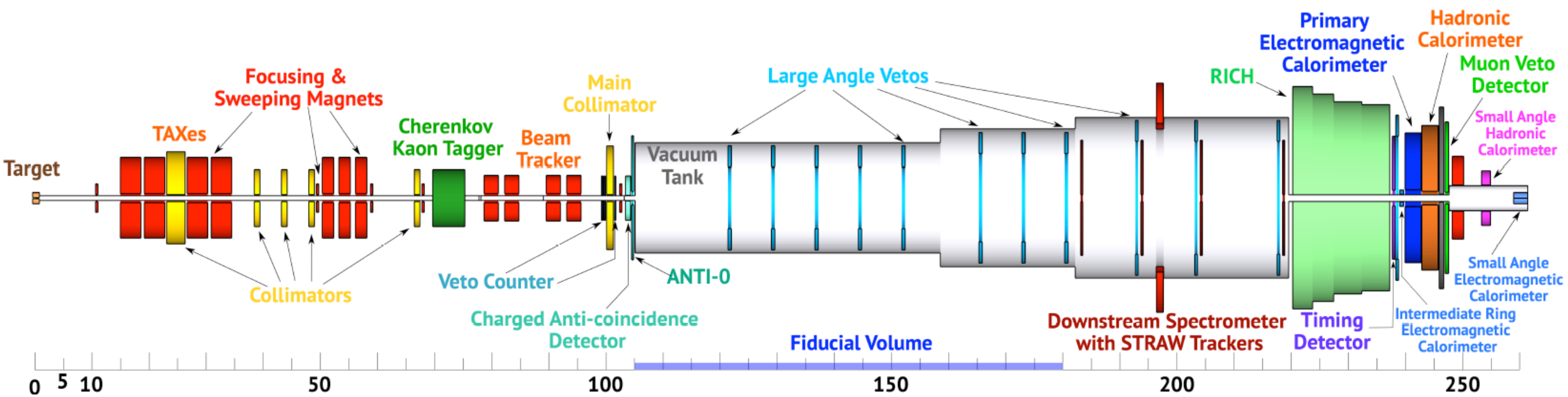


HIKE phase 1: $K^+ \to \pi^+\nu\bar{\nu}$ at high-statistics

Goal: Measure BR($K^+ \to \pi^+\nu\bar{\nu}$) to within ~5%

Requires **4x** increase in intensity

Basic design of NA62 will work at high intensity



1.2×10^{13} ppp = 4x NA62

Key challenges:

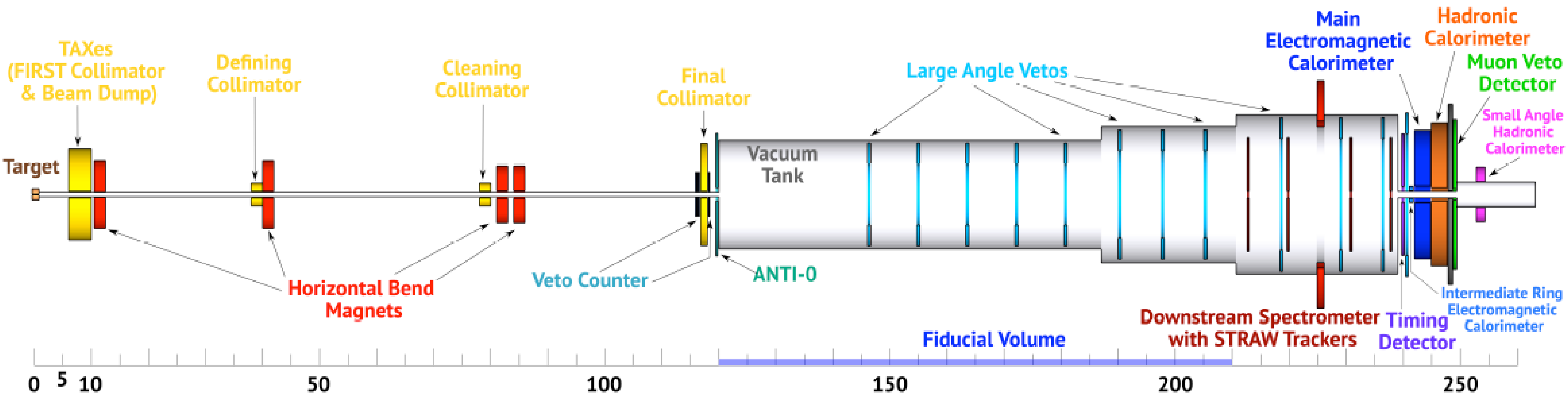
- Require **4x** better time resolution to keep random veto rate under control
- Must maintain other key performance specifications at high-rate:
- Space-time reconstruction, material budget, single photon efficiencies, etc.

These characteristics are necessary for rare K_L decays as well

- Calorimeter, photon vetoes, and readout reused for K_L experiments

HIKE phase 2: rare K_L decays

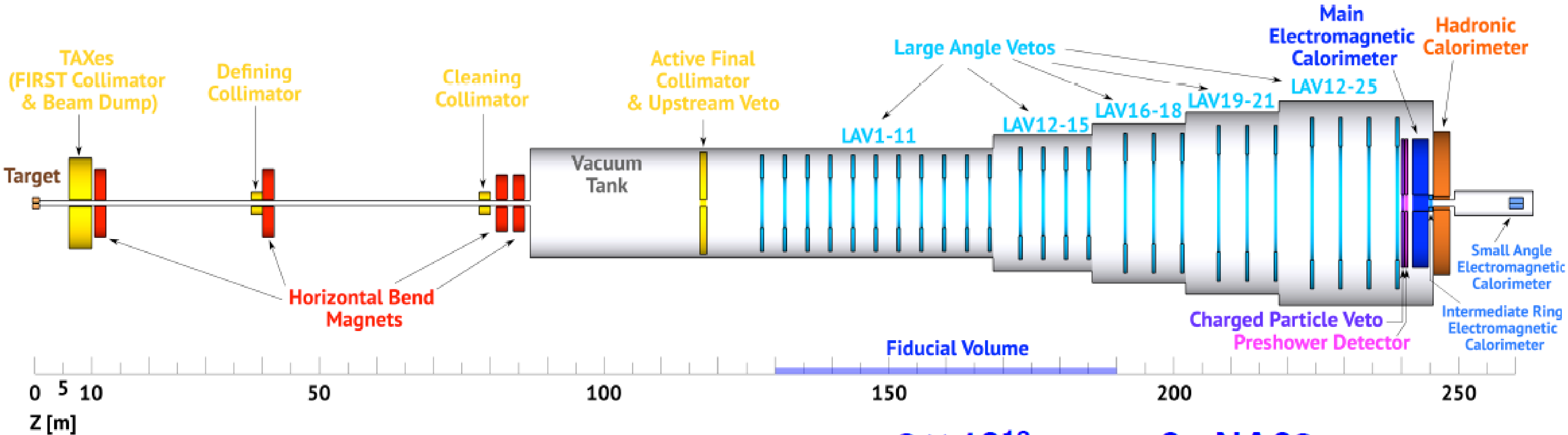
K_L beamline, tracking and PID for secondary particles



2×10^{13} ppp = 6x NA62

- Statistical power: 3.8 10^{13} Kaon decays in decay volume per year (1.2 10^{19} POT/year)
- 120 m long neutral beamline, secondary beam opening angle = 0.4 mrad
- Using detectors of previous phase, with some detectors removed
- Minor modifications to make left/right symmetric and optimize geometrical acceptance.
- Will provide valuable information to characterize neutral beam: measurement of K_L, n, and Λ fluxes and halo

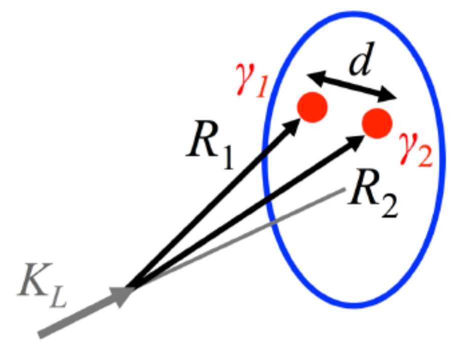
HIKE phase 3: $K_L \to \pi^0 \nu\bar{\nu}$



2×10^{13} ppp = 6x NA62

Studied in context of Physics Beyond Colliders

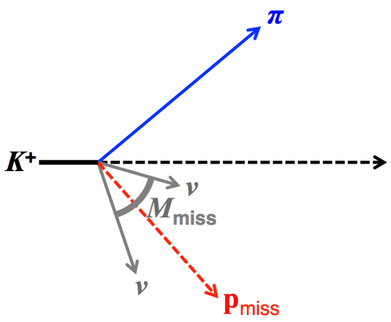
- **Essential signature: 2γ with unbalanced $p_\perp$ + nothing else**
  All other K_L decays have ≥ 2 extra γs or ≥ 2 tracks to veto
  Exception: $K_L \to \gamma\gamma$, but not a big problem since $p_\perp = 0$
- **$M(\gamma\gamma) = m(\pi^0)$ is the only sharp kinematic constraint**
- **Target sensitivity: 6×10^{19} pot in 5 years**
- **~60 SM $K_L \to \pi^0 \nu\nu$, $S/B \sim 1$, δBR/BR($\pi^0\nu\nu$) ~ 20%**
- **High-energy experiment complementary to KOTO**



$$m_{\pi^0}^2 = 2E_1E_2\,(1-\cos\theta)$$

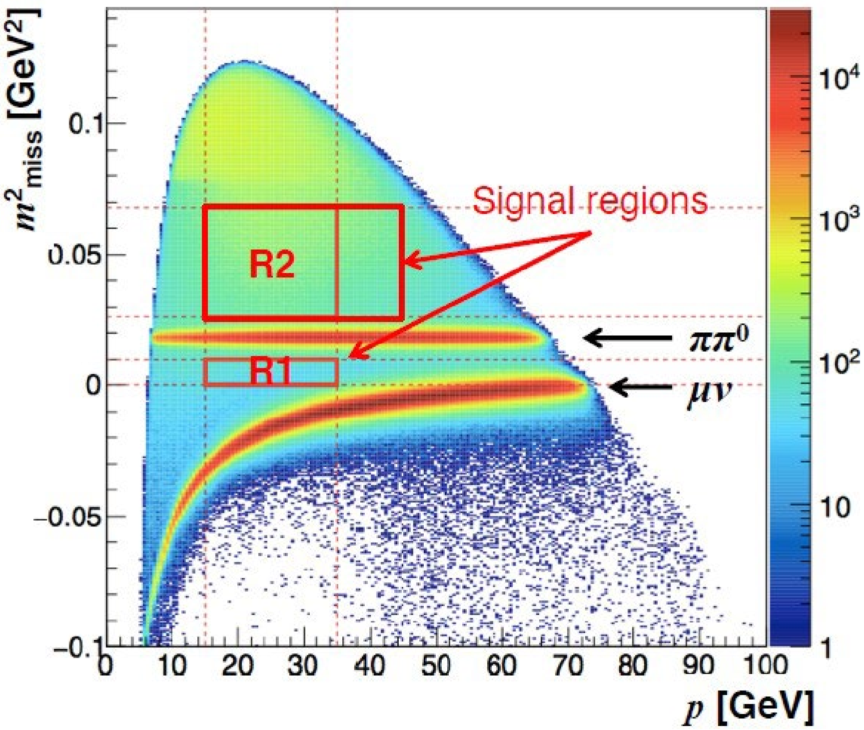
$$R_1 \approx R_2 \equiv R = \frac{d\sqrt{E_1E_2}}{m_{\pi^0}}$$

Signal: BR = $(8.4 \pm 1.0) \times 10^{-11}$



K track in
π track out
No other particles in final state

$$m^2_{miss} = (P_K - P_\pi)^2$$



Main backgrounds

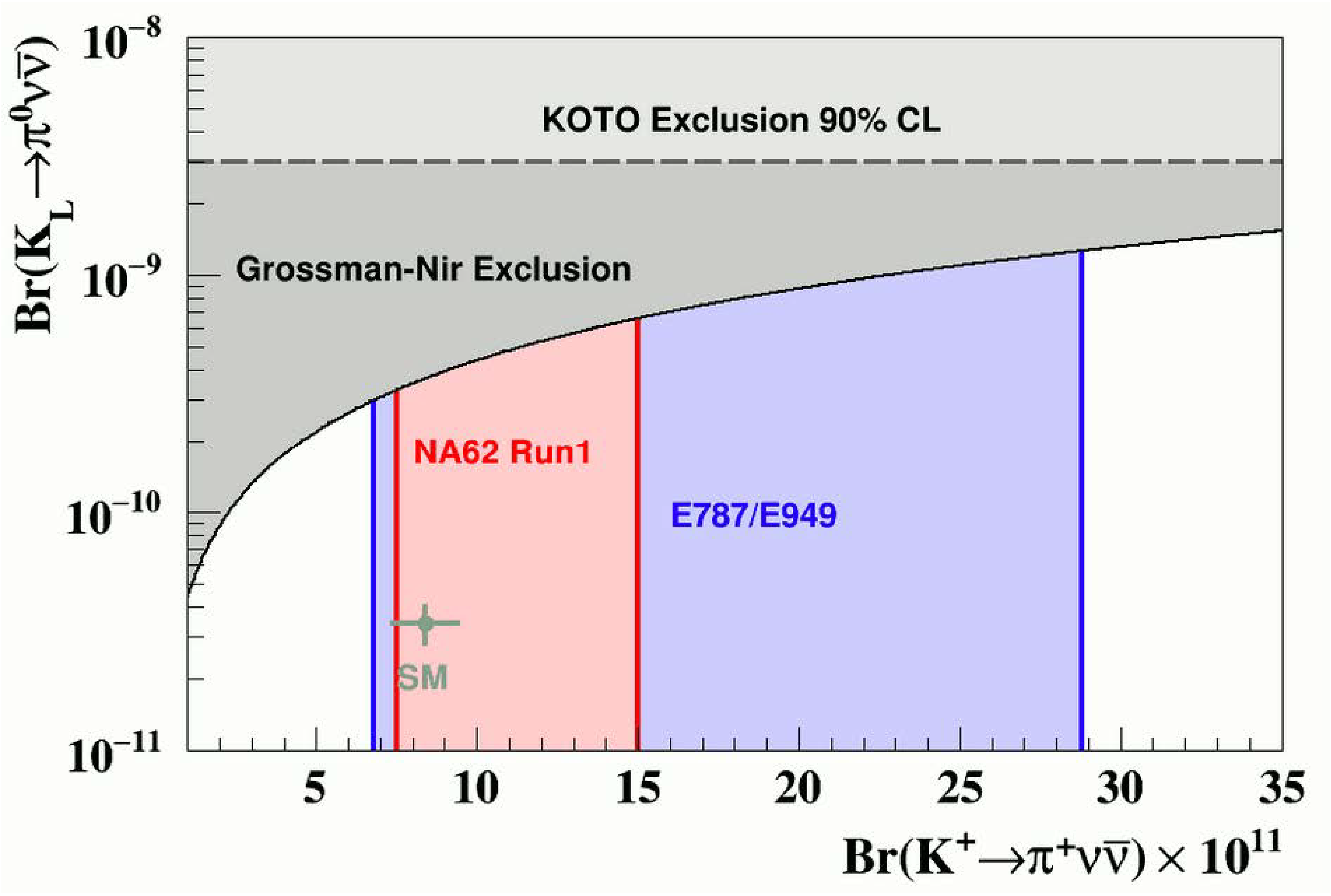
$K^+ \to \mu^+\nu(\gamma)$	BR = 63.5%
$K^+ \to \pi^+\pi^0(\gamma)$	BR = 20.7%
$K^+ \to \pi^+\pi^+\pi^-$	BR = 5.58%
Upstream beam background	

Selection criteria

K^+ beam identification
Single track in final state
π^+ identification (μ^+/e^+ event rejection)
γ rejection

NA62 Run 1 final result

Most precise determination of the decay rate to date. Part of parameter space already ruled out

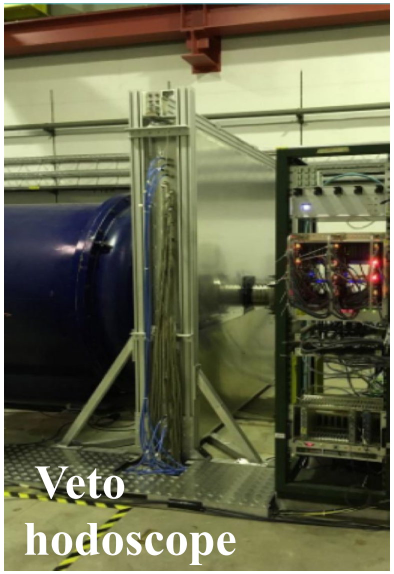


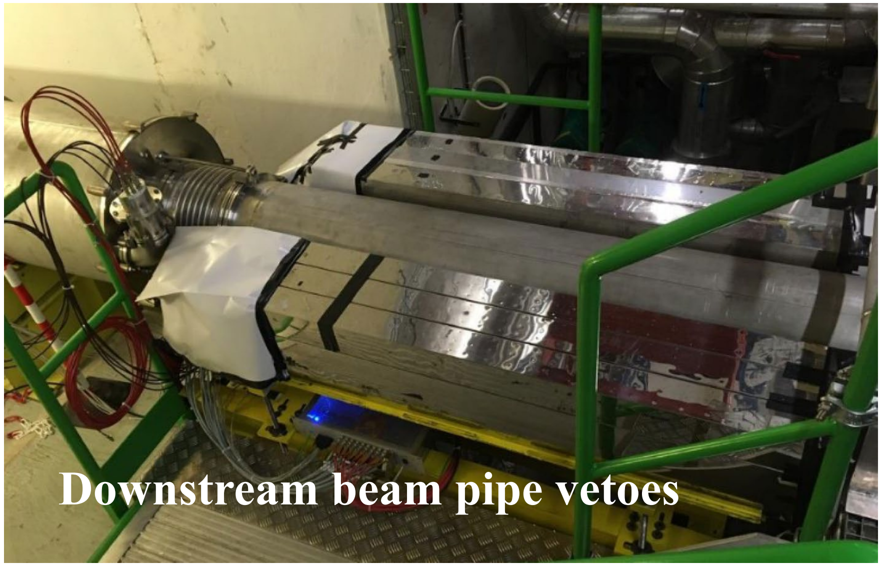
NA62 Run 2

NA62 has resumed data taking in July 2021

Key modifications to reduce background from upstream decays and interactions:

- Rearrangement of beamline elements
- Add 4th station to GTK beam tracker
- New veto hodoscope upstream of decay volume and additional veto counters around downstream beam pipe
- New downstream veto for photon conversion in the beampipe
- Run at higher beam intensity (70% → 100%)





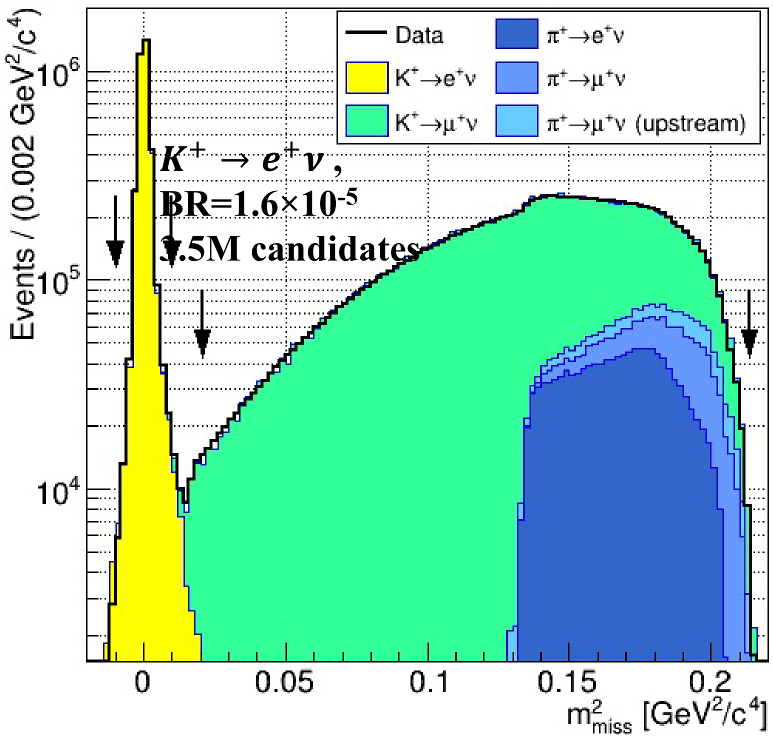
Expect to measure BR$(K^+ \rightarrow \pi^+ \nu\bar{\nu})$ to 10%

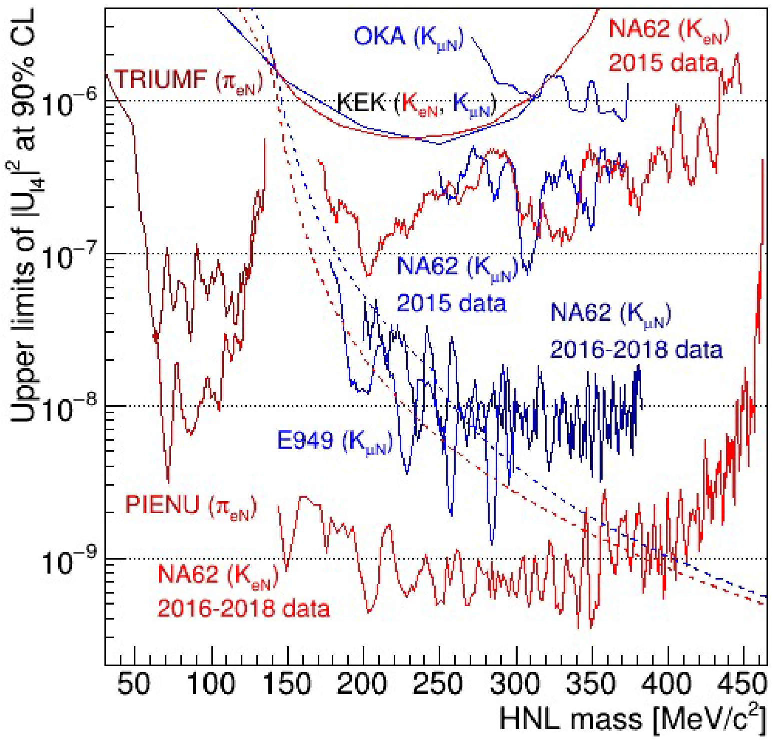
A general purpose experiment in kaon sector

Recent results on hidden-sector mediator production and other BSM physics in kaon decays:

- **searches for heavy neutral leptons from $K^+ \to l^+\nu$ decays**

Events with a K^+ in the initial state and a lepton (e^+ or μ^+) in the final state; squared missing mass $m^2_{miss} = (P_k - P_l)^2$ using STRAW and GTK trackers; HNL production signal: a spike above continuous missing mass spectrum.



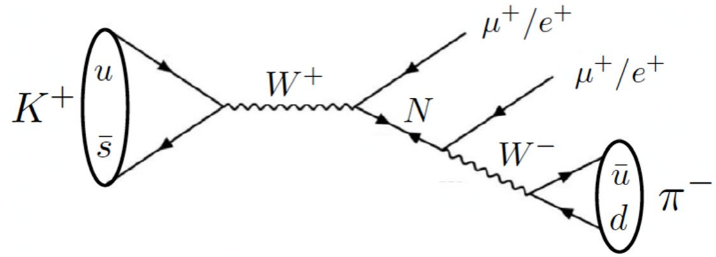


PLB 807 (2020) 135599, PLB 816 (2021) 136259

A general purpose experiment in kaon sector

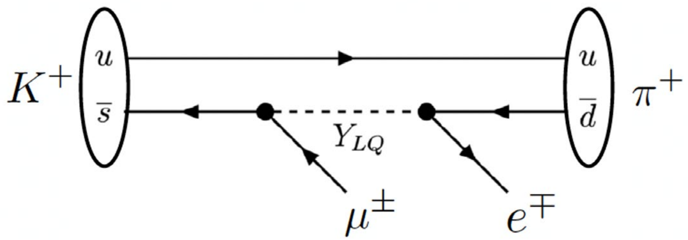
Recent results on hidden-sector mediator production and other BSM physics in kaon decays:

- **Lepton number violation:**



Same sign leptons mediated by Majorana neutrinos

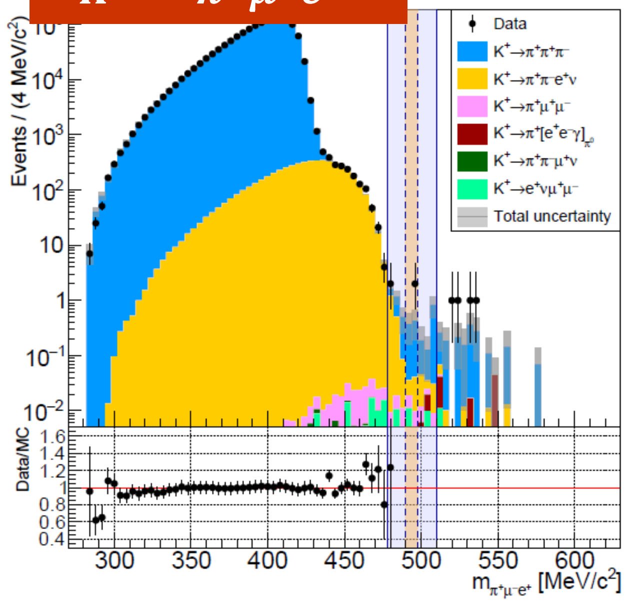
- **Lepton flavour violation:**



Opposite sign – different family leptons mediated by Leptoquarks

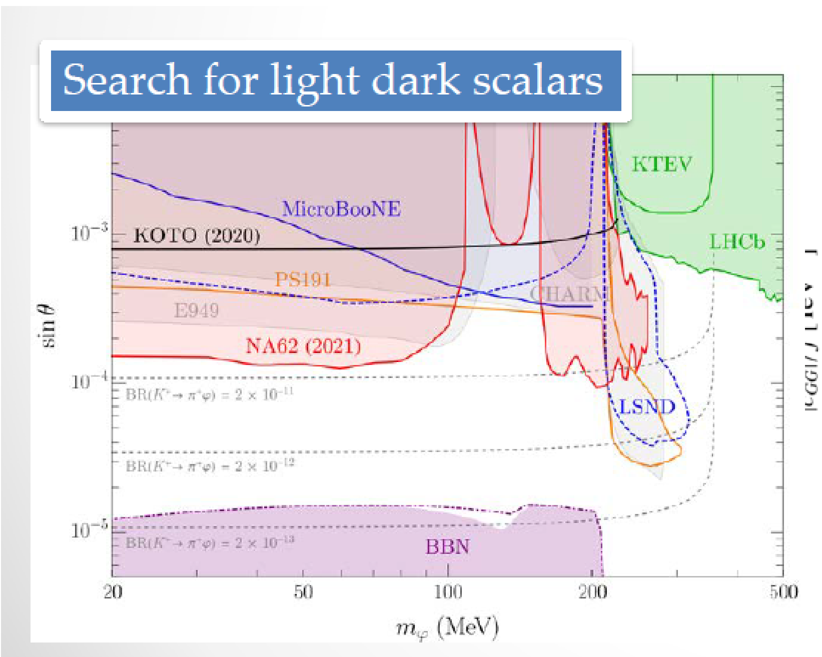
- **Experimental signature: 3 charged tracks with $\pi^\pm\mu^\mp e^+$**
- **Consistent with closed kinematics K^+ decay**
- **The invariant mass $M_{\pi\nu e}$ used to distinguish between signal and background**
- **Main bkg π mis-ID and decay in flight measured with data**
- **Normalized with $K^+ \to \pi^+\pi^+\pi^-$**

$K^+ \to \pi^+\mu^-e^+$

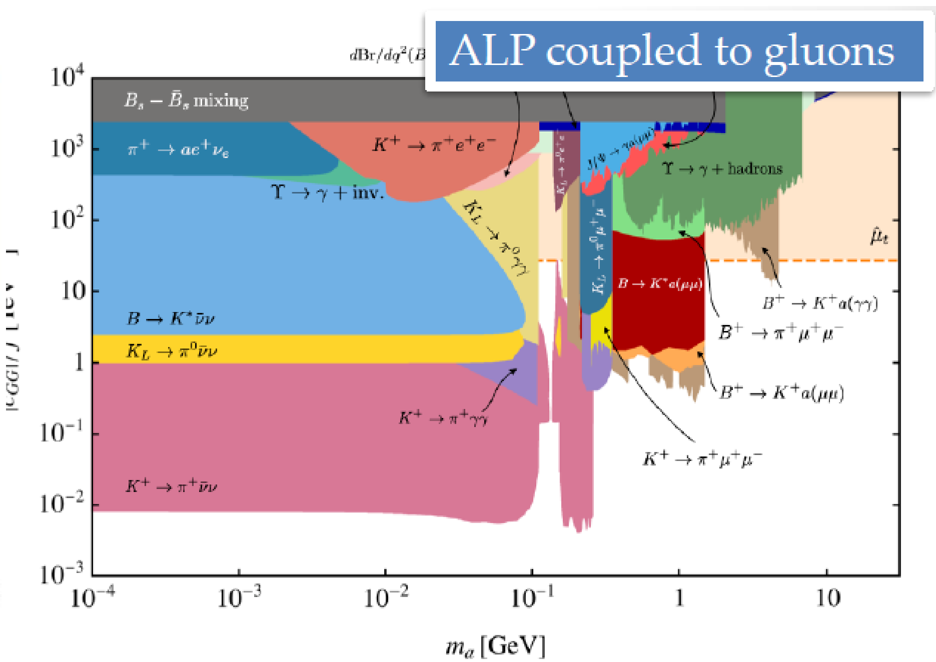


PRL 127 (2021) 131802

Limits on $K^+ \to \pi^+ X$ translate in strong limits on ALPs or scalars in the usual mass / coupling plane



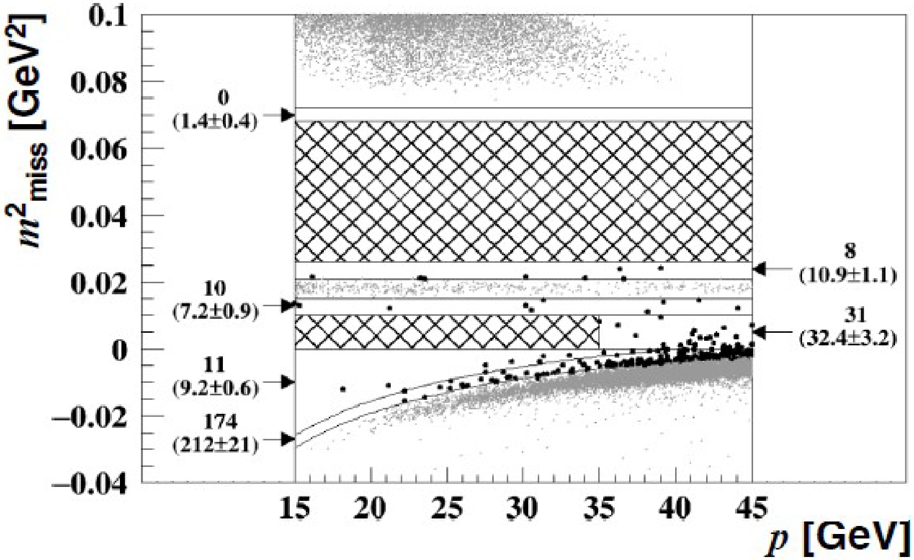
PBC workshop report, *Eur.Phys.J.C* 81 (2021) 11, 1015



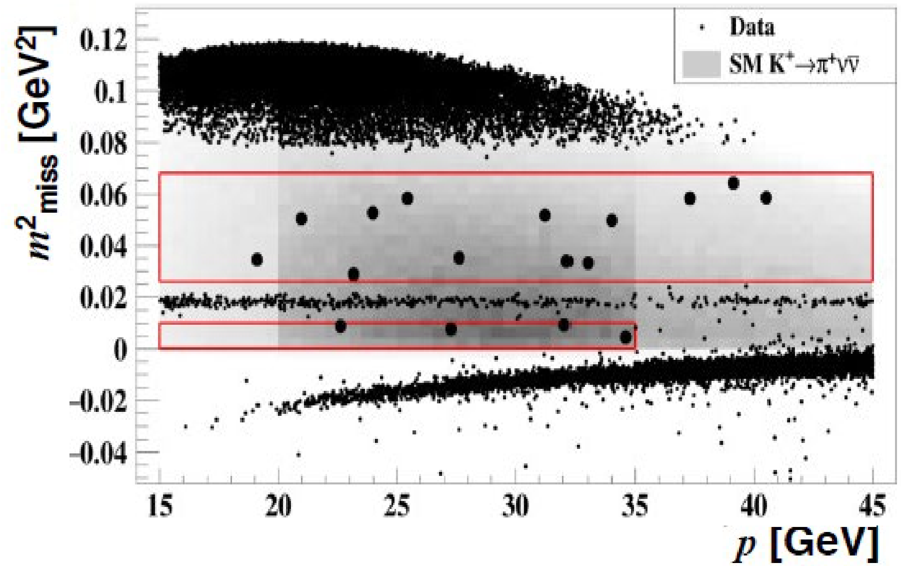
M. Bauer, M. Neubert, S. Renner, M.Schnubel and A. Thamm JHEP 09 (2022) 056

NA62 Run 1 final result

Background estimates for 2018



17 signal candidates in 2018 data



NA62 2016-2018 data : *JHEP 06 (2021) 093*

Expected SM sig: $10.01 \pm 0.42_{sys} \pm 1.19_{ext}$

Expected bkg: $7.03^{+1.05}_{-0.82}$ evts

20 events observed

See R. Fiorenza's talk

$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = \left(10.6^{+4.0}_{-3.4}\,|_{stat} \pm 0.9_{sys}\right) \times 10^{-11}$ **(3.4σ significance)**

HIKE program

Observable	Target	Motivation
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

Plus periodic runs with dumped beam to accumulate at least 10^{19} pot to search for exotic, long-lived particles

Exotic, long-lived particles in HIKE

Searches for visible decays in beam-dump mode

- Low rate in detector allows for potentially much higher beam intensity
- 10x statistics of 2021-2025 data (at least 10^{19} pot)
- Sensitive to forward processes, complimentary to off-axis experiments
  E.g., SHADOWS, an off-axis experiment proposed to run concurrently in ECN3

Searches for invisible decays during kaon running: $K \to \pi X$

- Projected sensitivities to scalars and ALPs for HIKE K^+ and K_L programs