# Measurement of the Rare Decay $K^+ \to \pi^+ \nu \bar{\nu}$ at the CERN SPS

## *NA62 Project (Collaboration NA62)*

***Theme 02-1-1096-2010***

## *Extension for 2025-2027*


**Belgium:** Université Catholique de Louvain (**Louvain-La-Neuve);**
**Bulgaria:** University of Sofia St. Kliment Ohridski, Faculty of Physics **(Sofia);**
**Canada:** TRIUMF, University of British Columbia **(Vancouver);**
**Czech Republic:** Charles University (**Prague);**
**France:** Centre de Physique de Particules de Marseille **(Marseille);**
**Germany:** Johannes-Gutenberg-Universitat Mainz (**Mainz),** Max-Planck-Institut fur Physik **(Munich);**
**Italy:** Università di Ferrara (**Ferrara),** Universita e INFN (**Florence),** Istituto Nazionale di Fisica Nucleare (INFN), Laboratori Nazionali di Frascati **(Frascati),** Universita e INFN (**Naples),** Universita e INFN (**Perugia),** Sezione di Pisa, INFN **(Pisa),** Universita degli Studi di Roma Tor Vergata, Sezione di Roma Tor Vergata, INFN (**Rome),** Universita e INFN, Roma I, Sezione di Roma I, INFN**(Rome),** Universita e INFN (**Turin);**
**Kazakhstan:** Institute of Nuclear Physics **(Almaty);**
**Mexico:** Universidad Autónoma de San Luís Potosi, Instituto de Fisica (**San Luis Potosi);**
**Romania:** Horia Hulubei National Institute of Physics and Nuclear Engineering (**Bucharest-Magurele);**
**Russia:** **Joint Institute for Nuclear Research – JINR (Dubna),** Institute for Nuclear Research RAS (**Moscow),** Institute for High Energy Physics, National Research Centre “Kurchatov Institute” (**Protvino);**
**Slovakia:** Comenius University (**Bratislava);**
**Switzerland:** Conseil Européen pour la Recherche Nucléaire – CERN (**Geneva)**, Ecole Polytechnique Federale Lausanne **(Lausanne);**
**United Kingdom:** University of Birmingham (**Birmingham),** University of Bristol, H. H. Wills Physics Laboratory (**Bristol),** University of Glasgow (**Glasgow),** University of Liverpool, Lancaster University (**Lancaster);**
**United States of America:** George Mason University (**Fairfax),** SLAC National Accelerator Laboratory (**Menlo Park).**

## Лаборатория физики высоких энергий им. В.И. Векслера и А.М. Балдина

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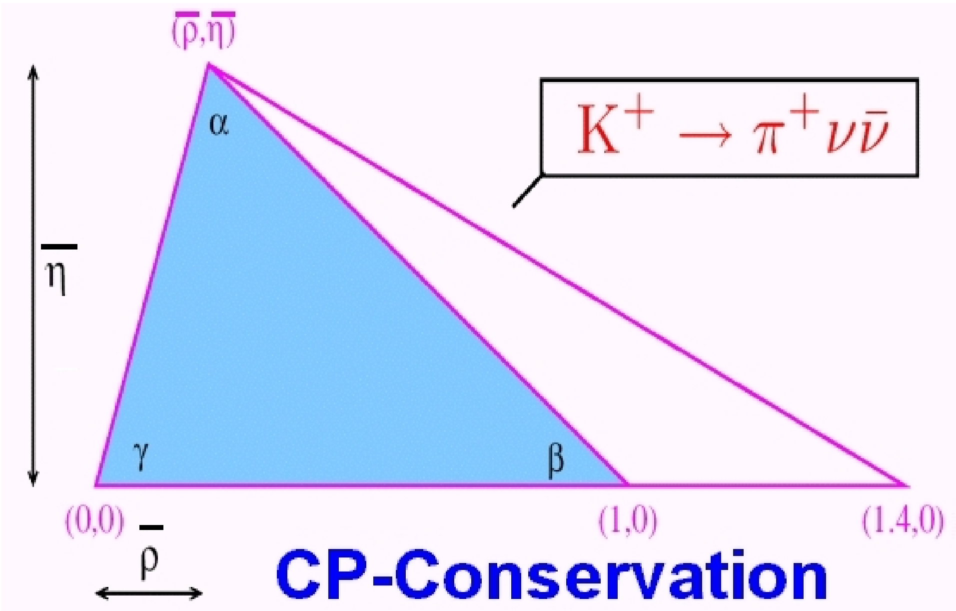
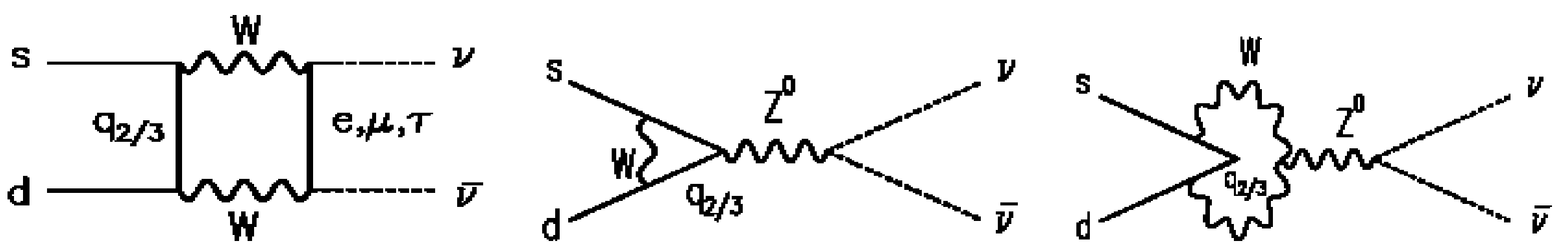
# NA62 motivation




The "golden decays" $K^0 \to \pi^0 \nu\bar\nu$ and $K^+ \to \pi^+ \nu\bar\nu$ give an opportunity to make a very sensitive tests of SM, as their probabilities are directly related to $\eta^2$ (height of triangle) and $(\rho - 1.4)^2 + \eta^2$ in Wolfenstein notation of CKM.




- $K^+ \to \pi^+ \nu\bar\nu$ is theoretically clean, hadronic matrix element measured with $K_{l3}$ decays

- SM predictions [Phys. Rev. D 83 034030 (2011), JHEP11 (2015) 033]:

$$BR(K^+ \to \pi^+ \nu\bar\nu) = (8.4 \pm 1.0) \times 10^{-11}$$

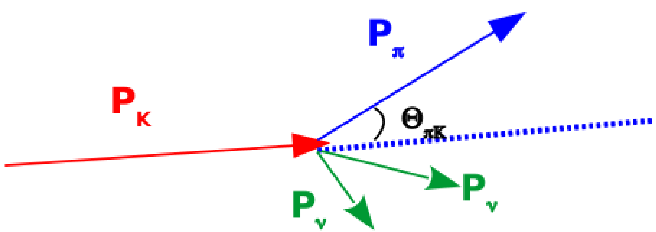
- The earlier available experimental result is based on **7 events** [BNL, K decays at rest. Phys. Rev. D 79, 092004 (2009)] :

$$BR(K^+ \to \pi^+ \nu\bar\nu) = (17.3^{+11.5}_{-10.5}) \times 10^{-11}$$

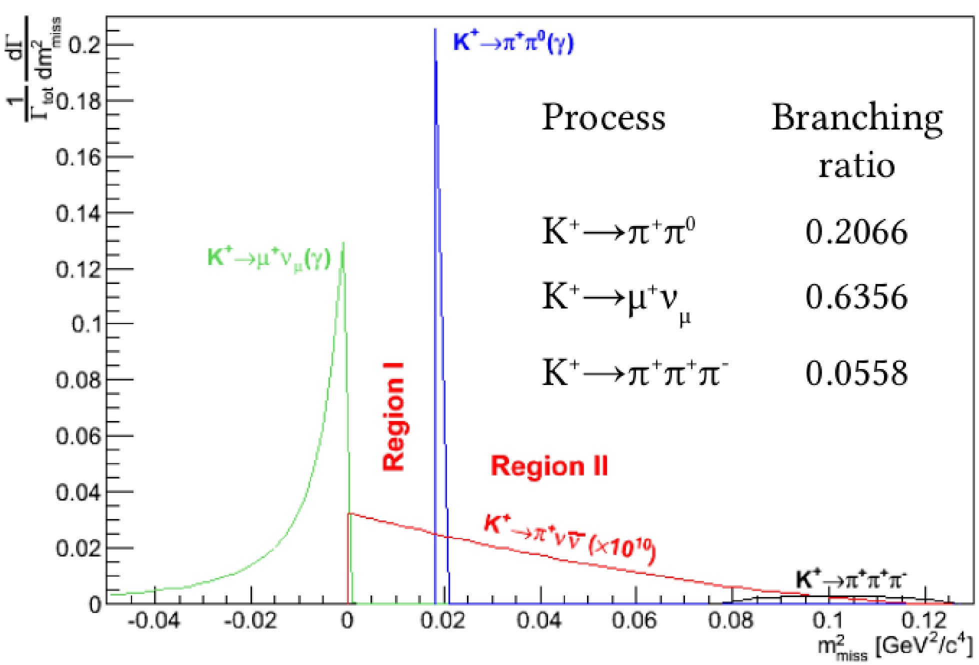
# NA62 $\pi\nu\bar{\nu}$ strategy

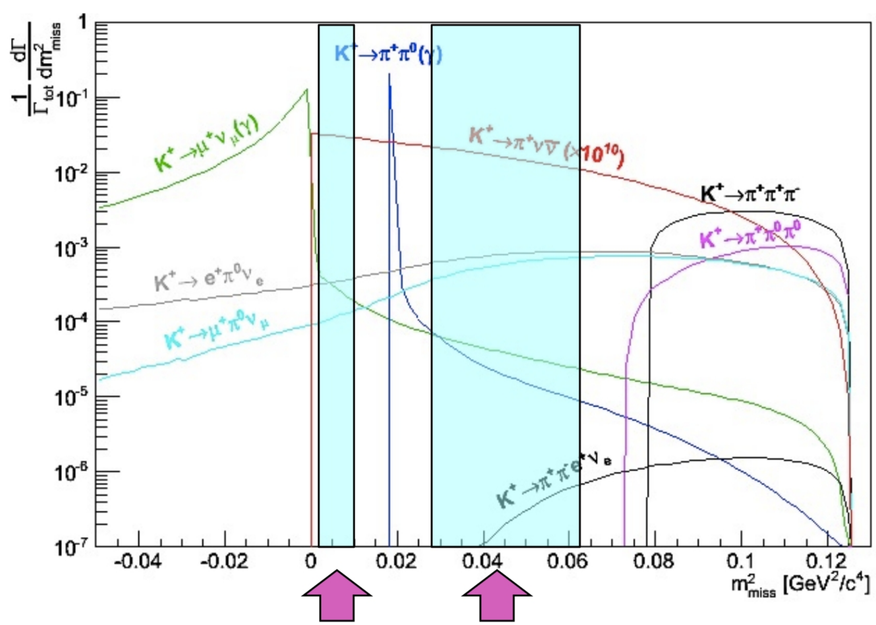
**NA62 ultimate goal is ~ 10% precision for Br($K^+ \rightarrow \pi^+\nu\bar{\nu}$)**
**that assumes ~ 100 reconstructed events and a small background.**

Decay in flight technique $m^2_{miss} = (P_K - P_{\pi^+})^2$



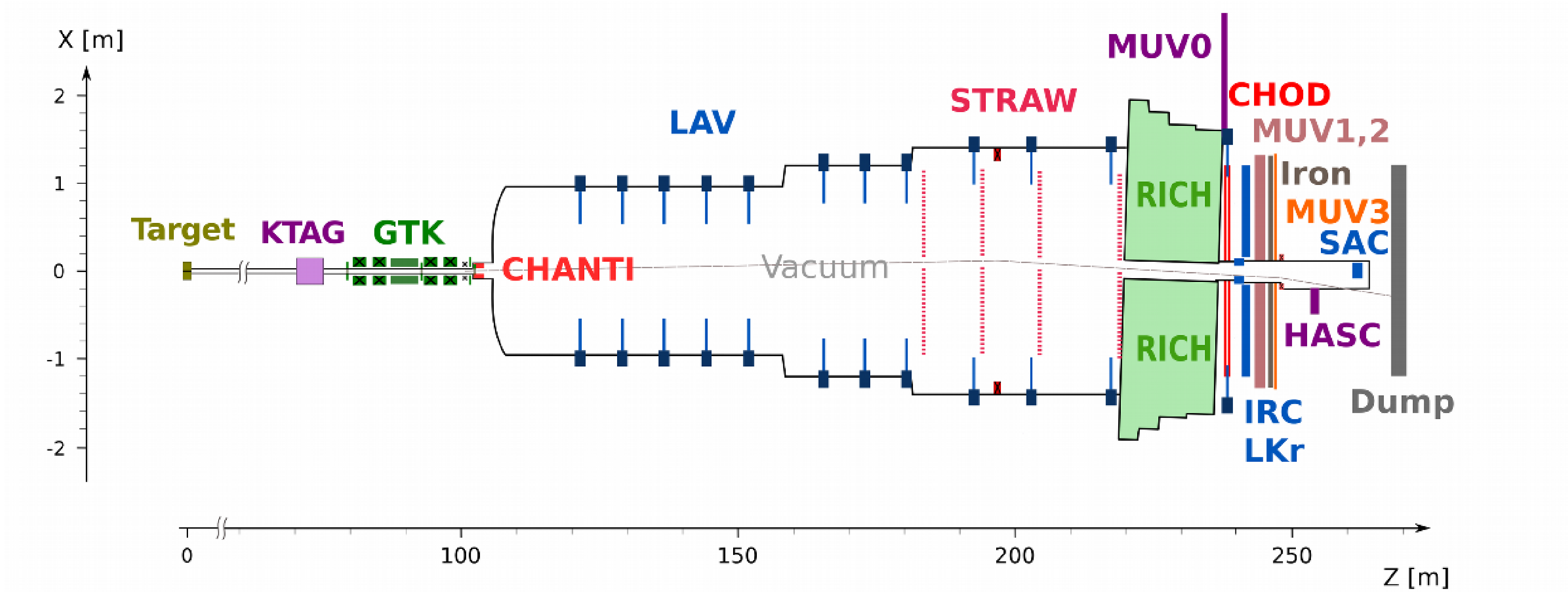

- Keystones of the analysis:
  - Timing between sub-detectors ~ O(100 ps)
  - Kinematic suppression ~ O($10^4$)
  - Muon suppression > $10^7$
  - $\pi^0$ suppression (from $K^+ \longrightarrow \pi^+\pi^0$ ) > $10^7$



- History of JINR in CERN kaon decays program: NA48,NA48/1,NA48/2, NA62($R_K$).
- Analysis of NA48/2 data just finished in 2024.
- NA62 inherits some elements of NA48/2, but it is a really novel setup that solves a new challenging task.

# NA62 beam and detector




**SPS Beam:**

- 400 GeV/c protons
- $10^{12}$ protons/spill
- 3.5s spill

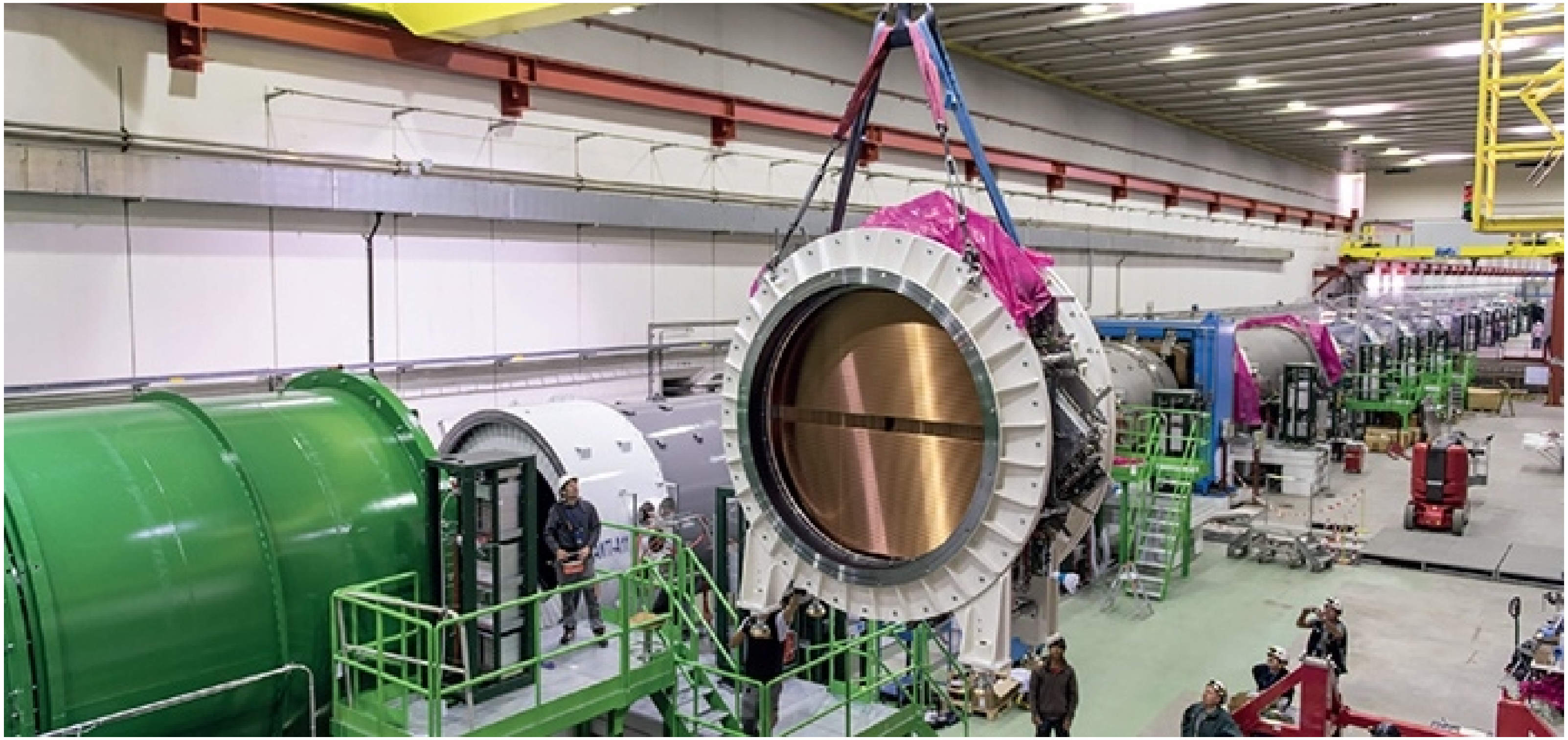
**Secondary positive Beam:**

- 75 GeV/c momentum, 1 % bite
- 100 μrad divergence (RMS)
- 60x30 mm$^2$ transverse size
- $K^+(6\%)/\pi^+(70\%)/p(24\%)$
- 33x$10^{11}$ ppp on T10 (750 MHz at GTK3)

**Decay Region:**

- 60 m fiducial region
- ~ 5 MHz $K^+$ decay rate
- Vacuum ~ O($10^{-6}$) mbar

# JINR+CERN responsibility :
# Spectrometer made of straw tubes working in vacuum

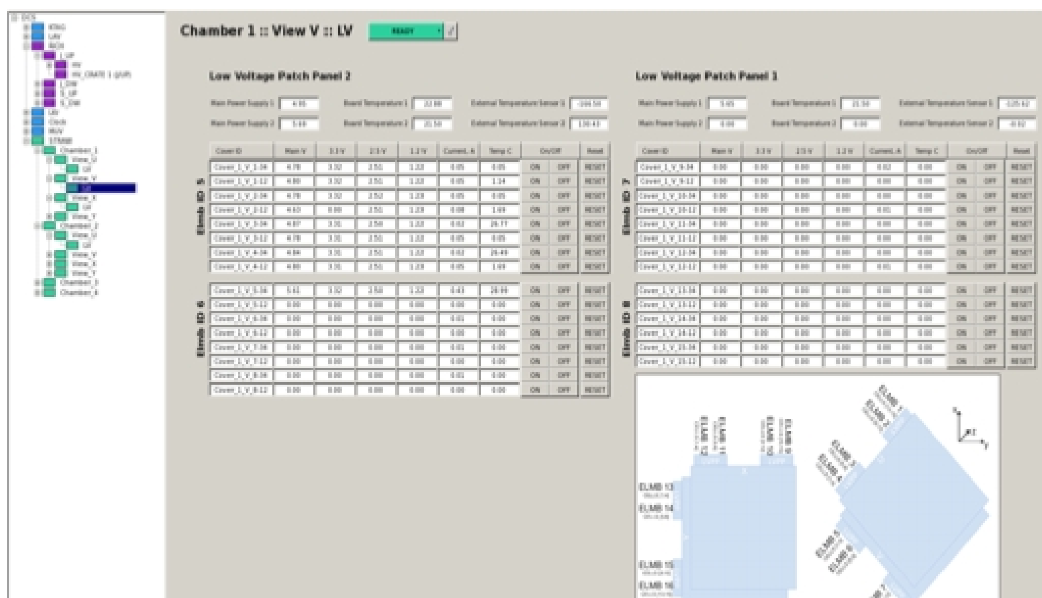


JINR contribution is very important and is defining in many aspects:

- R&D (2 prototypes),
- MC simulation,
- Straws geometry,
- Frames etc. design,
- straws production (~7000 in JINR),
- Modules assembling.

Installed in 2014.

HV and LV power suppliers

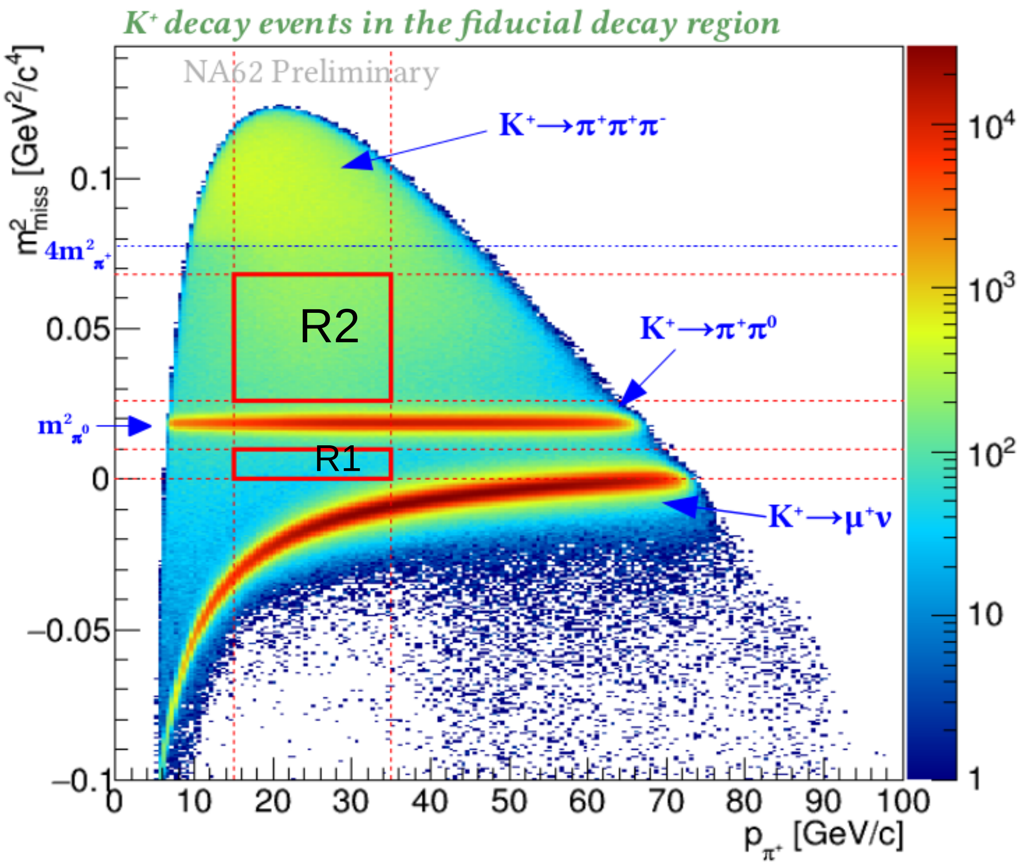



Detector Control System (DCS) for the NA62 Spectrometer

# NA62 πνν

**Blind analysis strategy** to avoid the influence of selection criteria variation:

- Signal region is predefined and closed.
- Selection is developed looking on the background regions and MC.
- Signal region is opened, events are counted, selection is frozen.

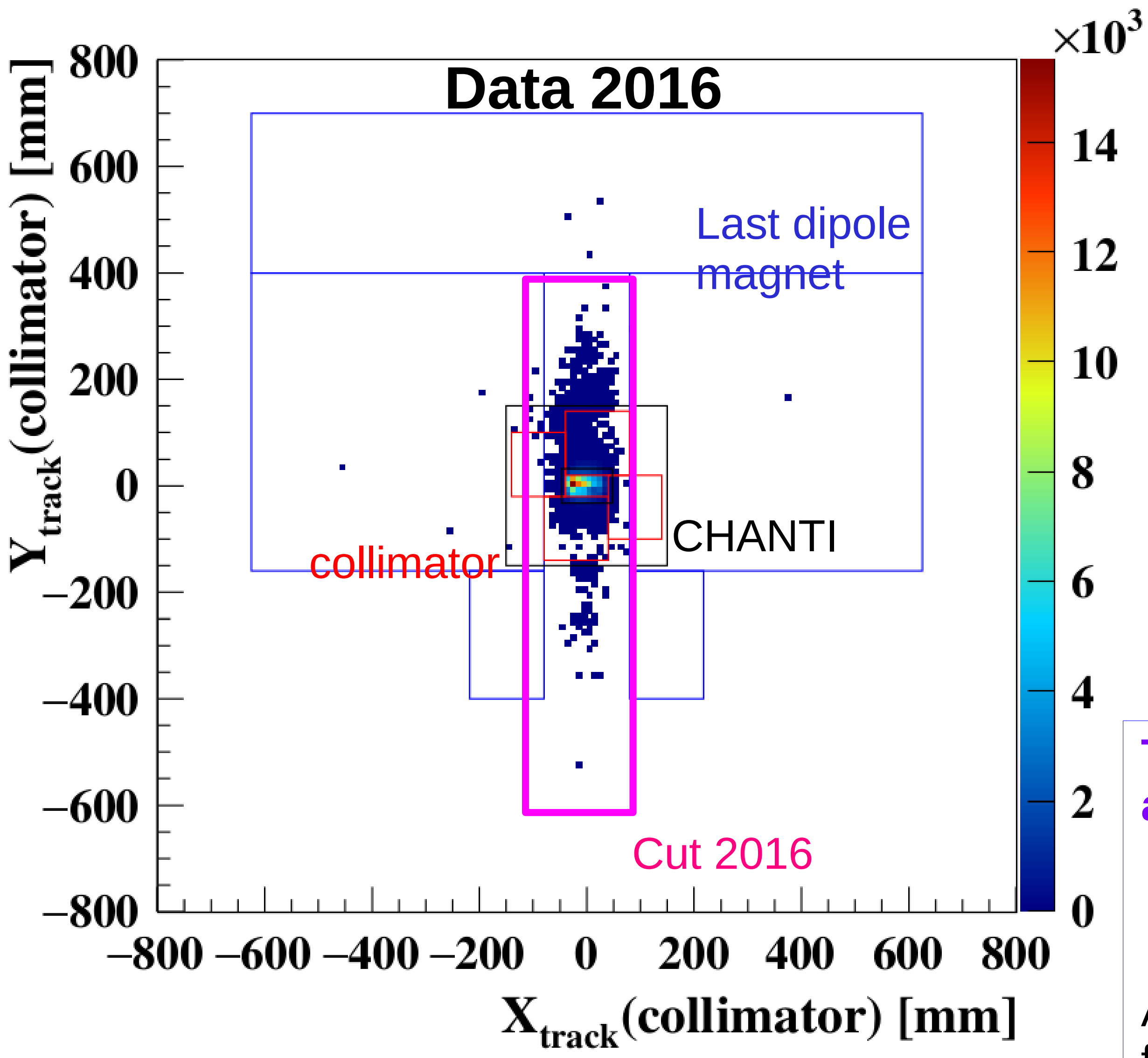



R1,R2: signal regions

- Selection criteria
  - single track decay topology
  - $\pi^+$ identification
  - photon rejection
  - multi-track rejection

- Performance
  - $\epsilon_{\mu^+} = 1\cdot 10^{-8}$ (64% $\pi^+$ efficiency)
  - $\epsilon_{\pi^0} = 3\cdot 10^{-8}$
  - $\sigma(m^2_{miss}) = 1\cdot 10^{-3}$ GeV$^2/c^4$
  - $\sigma_T \sim O(100$ ps$)$

# Unexpected "upstream background" problem




Pion track projections to the last collimator before decay volume: Artificially background-enriched by inverting tracks multiplicity cut.

- The last dipole of the beam line changes direction of π from upstream decays (interactions) happened in the beam line.
- The pion pass the existing shielding.
- Accidentally this pion crosses some kaon path and forms a vertex in decay volume.

- Additional shielding from the second part of 2017 run.
- Enlarged cut on the pion position on the last collimator.

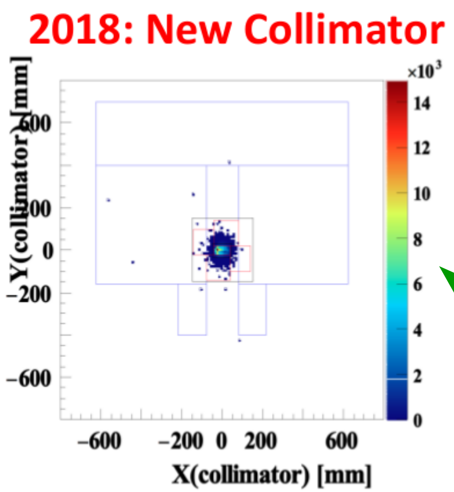
**The cost of the cut for πνν acceptance:**

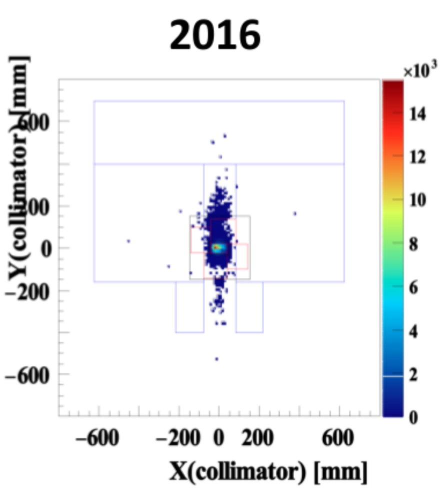
**3-4% instead of 10%**

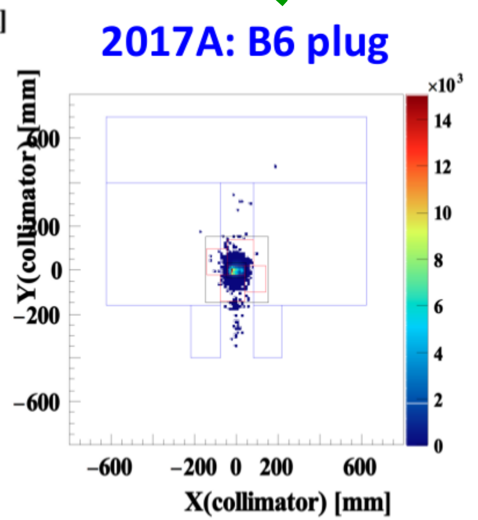
A better shielding design and search for the upstream background off-line rejection where needed.

A new **Fixed collimator** (tons of iron with a hole) has improved NA62 upstream background situation dramatically.

Upstream backgrounds are significantly reduced by the introduction of The B6 plug (2017) and the fixed Collimator (2018)



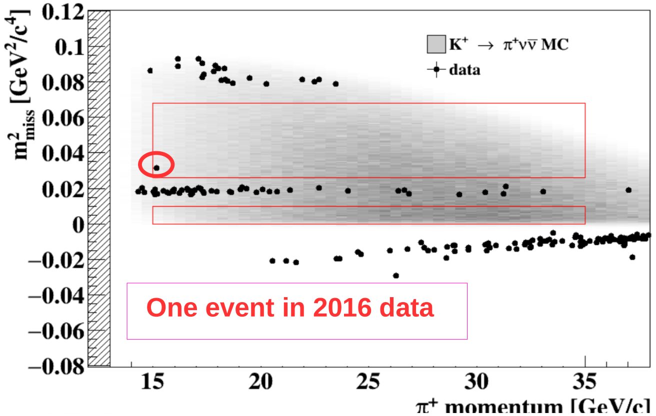



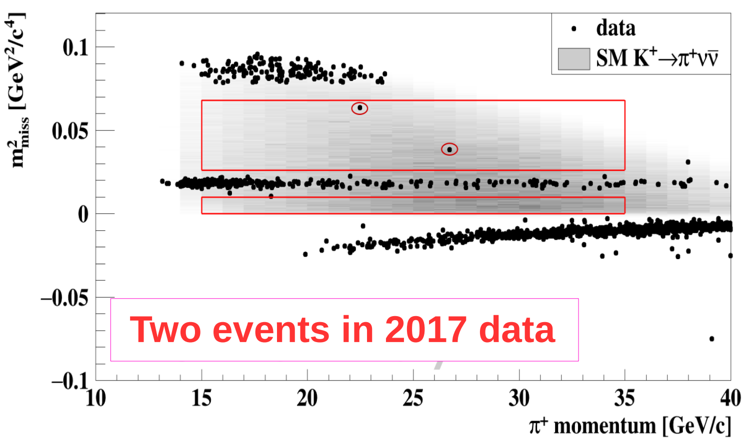



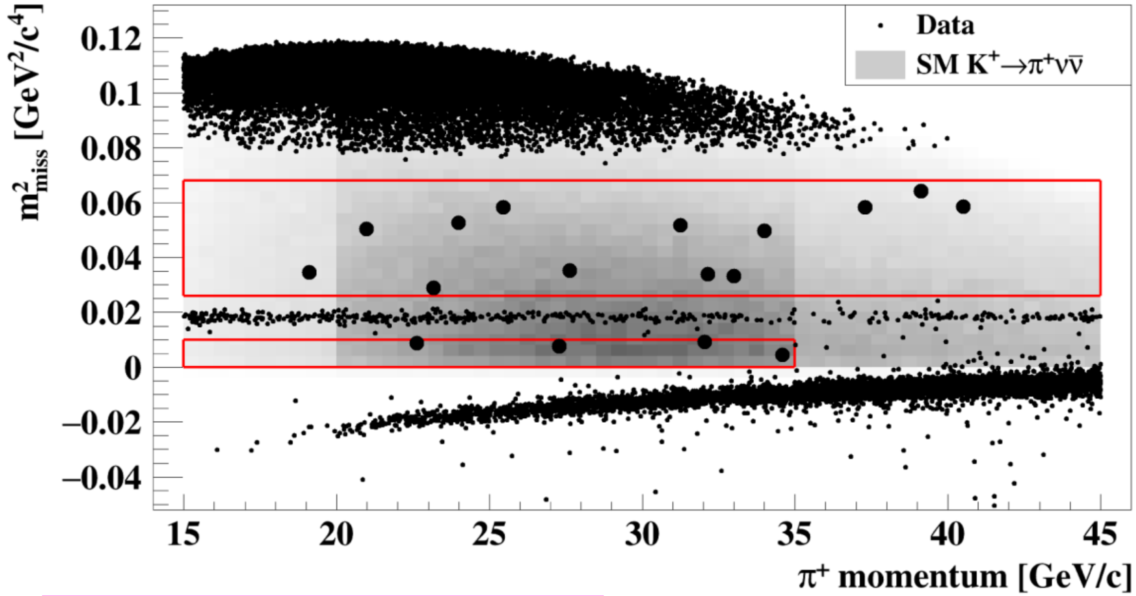

During the LS2 the upgrade of the limiting electronics was done.

# Intermediate result on $K^+ \to \pi^+ \nu\bar{\nu}$ decay

| 2014 | 2015 | 2016 | 2017 | 2018 | 2019 -2020 | 2021 - ... |
|---|---|---|---|---|---|---|
| Pilot Run | Commissioning | Commissioning + Physics Run | Physics Run | Physics Run | Long shutdown 2 | NA62 Run2 |



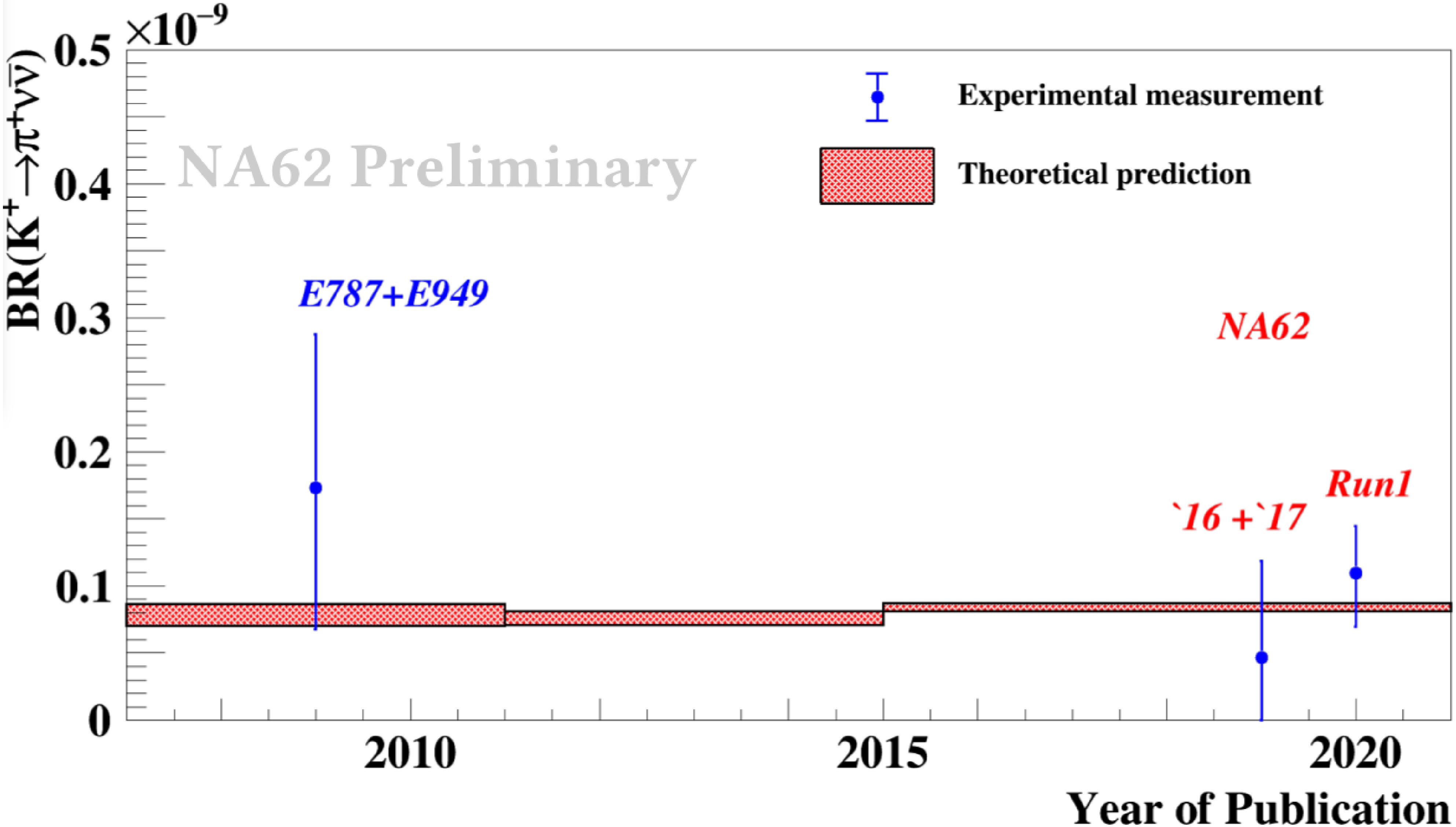

17 events in 2018 data

Expected total background : 7 events

2016+2017+2018 [*JHEP* 06 (2021) 093]:

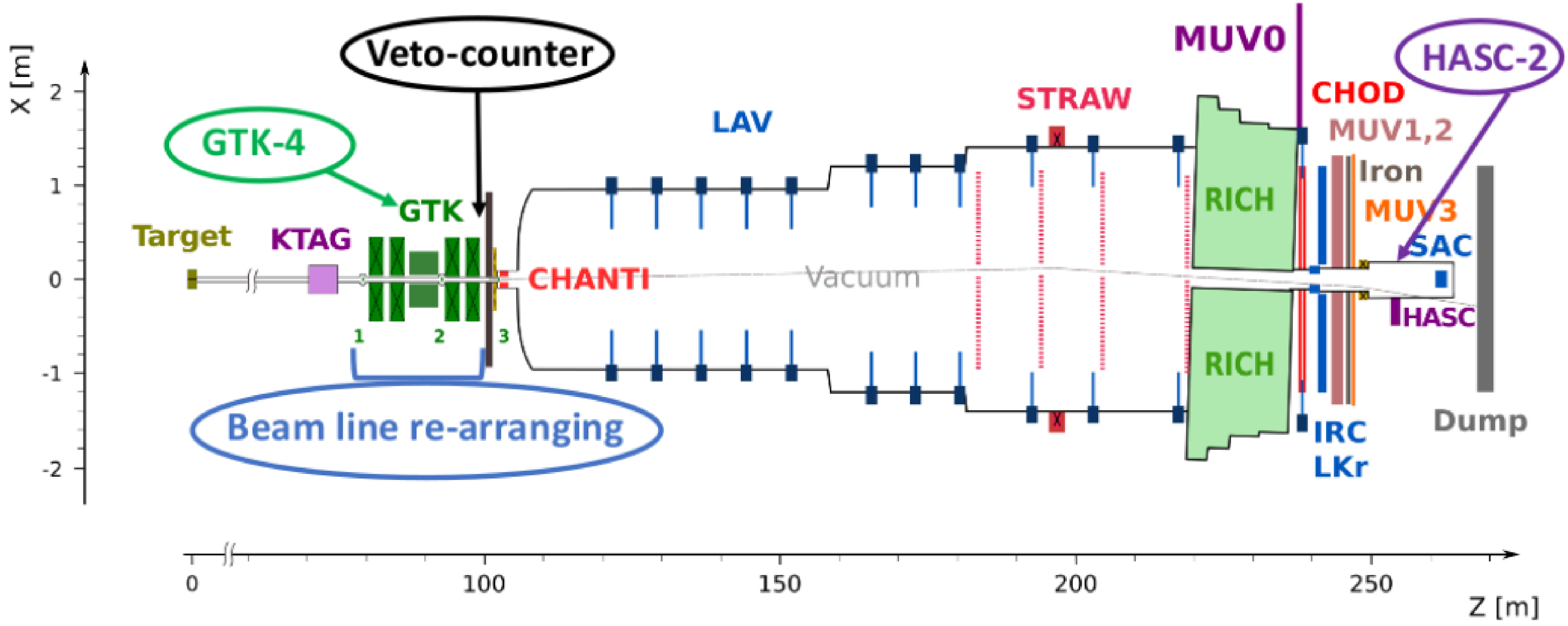
$$BR(K^+ \to \pi^+\nu\nu) = (10.6^{+4.0}_{-3.4} \pm 0.9_{syst}) \times 10^{-11}$$

- Standard Model expectation: $(8.4 \pm 1.0) \times 10^{-11}$
- Best earlier result: 2009, E787/E949@BNL, 7 events : $(17.3^{+11.5}_{-10.5}) \times 10^{-11}$



$\times 10^{-9}$
0.5
0.4
0.3
0.2
0.1
0
$BR(K^+ \to \pi^+ \nu \bar{\nu})$
Experimental measurement
Theoretical prediction
NA62 Preliminary
E787+E949
NA62
Run1
`16 +`17
2010
2015
2020
Year of Publication

# Prospects for $Br(K^+ \to \pi^+ \nu \bar{\nu})$ measurement

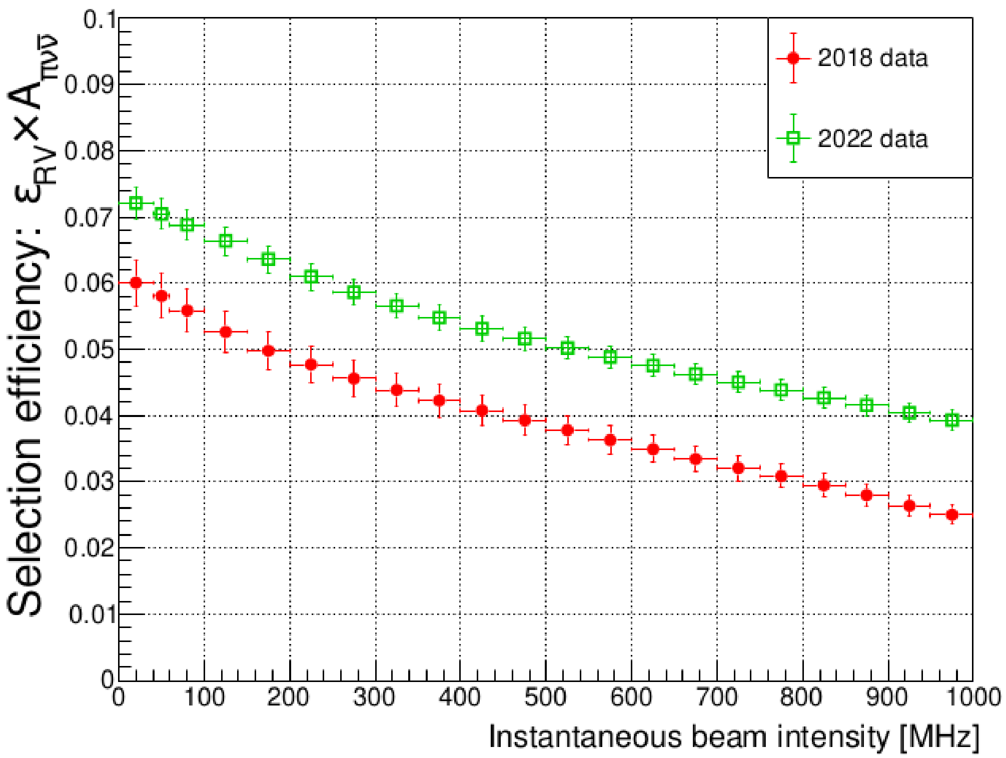


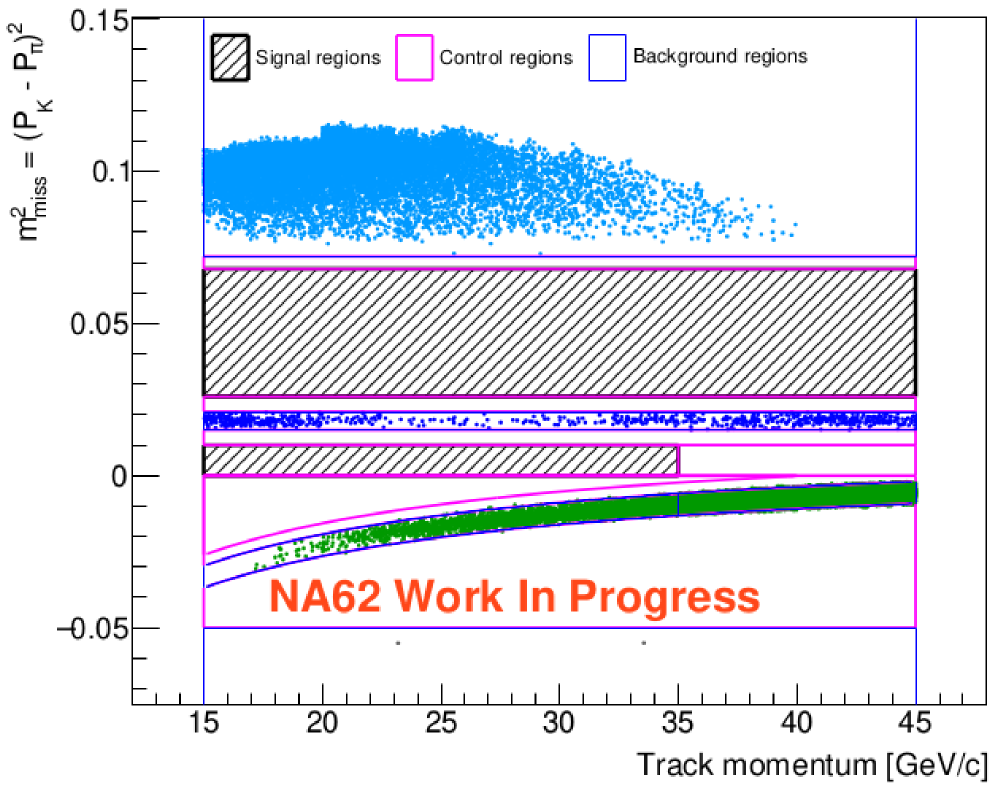

## Data taking between CERN LS2 and LS3

- Upstream background suppression: beam line re-arranging to swip away *upstream* $\pi^+$, adding a fourth Gigatracker station (GTK-4), new veto-counter system to detect upstream decays products
- additional off-axis calorimeter (HASC-2) to further suppress $K^+ \to \pi^+ \pi^0$ background
- **goal**: $Br(K^+ \to \pi^+ \nu \bar{\nu})$ measurement with $O(10\%)$ statistical precision

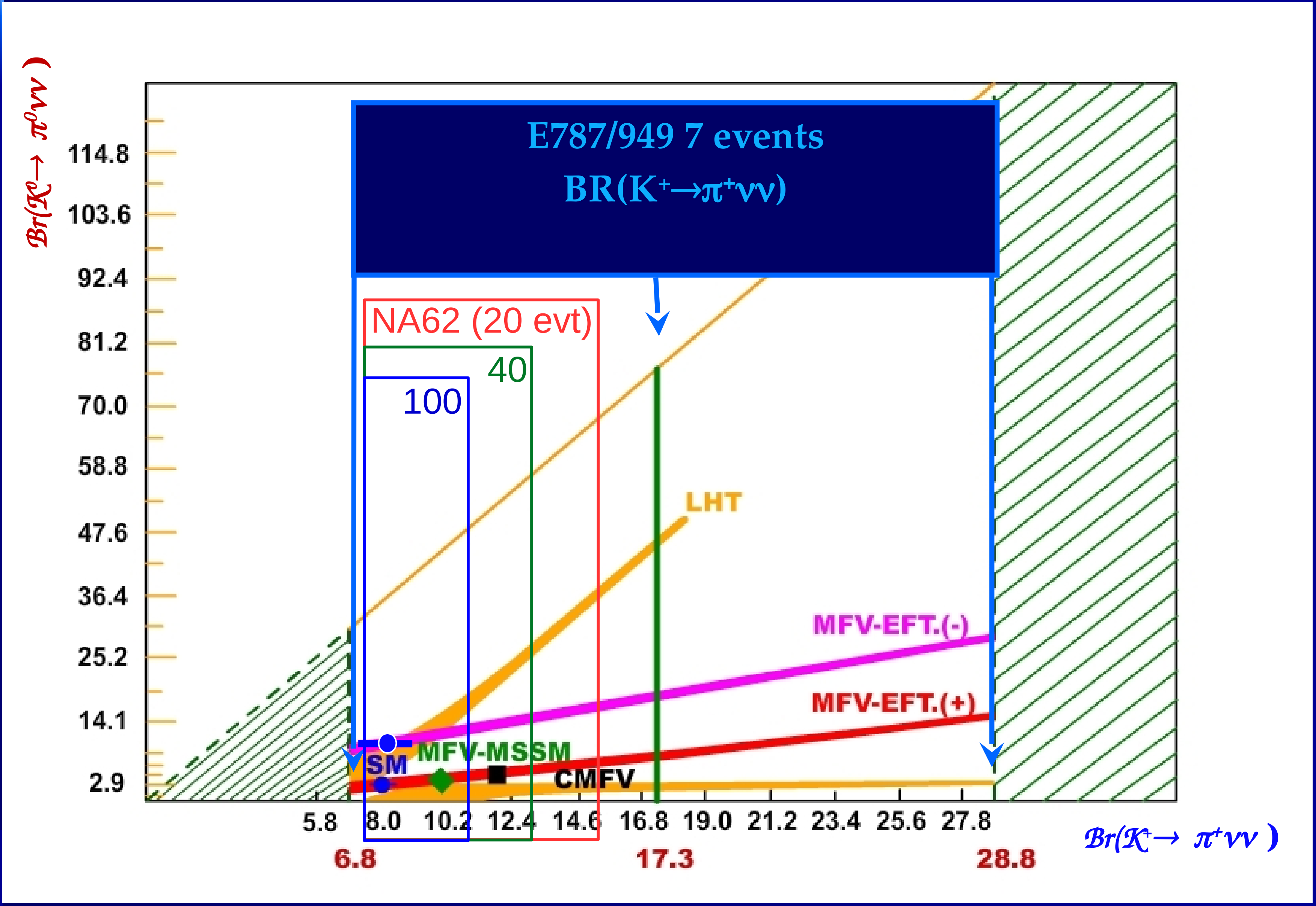
# Improvements in the data and analysis 2021-2024

- Additional GTK station – increase of kaon track reconstruction efficiency by 3%;
- Additional veto counters – decrease of background from beamline;
- New LKr reconstruction – decrease of accidental photon veto;
- Selection is re-optimized;
- Signal acceptance $A_{\pi\nu\nu}$ increased by 20% with the same level of random veto ($\varepsilon_{RV}$ ~ 65%) despite higher intensity (2018: 400 MHz, 2022: 580 MHz);



## Conservative scenario: 40 SM events, initial goal: 100 SM events.

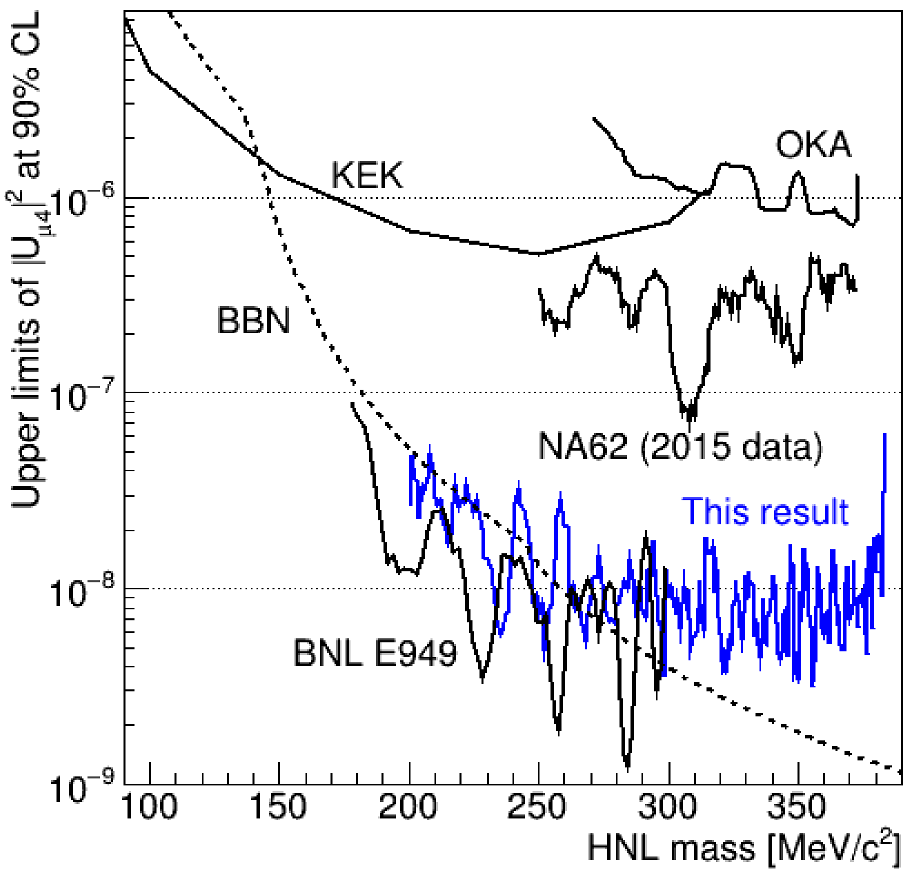


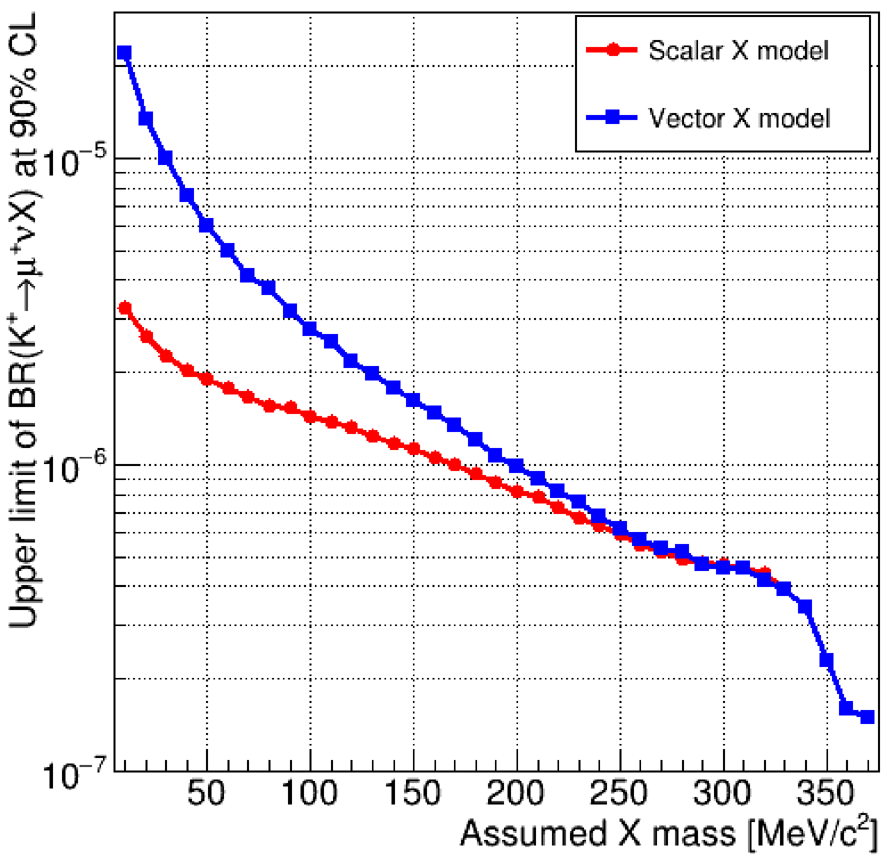

Currently no real competition:
Old JPARC and FNAL projects were abandoned (costs)

# Some of the additional rare decay results

Searches for $K^+ \to \mu^+ N$ and $K^+ \to \mu^+ \nu X$ decays, where N and X are massive invisible particles.

*Phys.Lett.B* 816 (2021) 136259



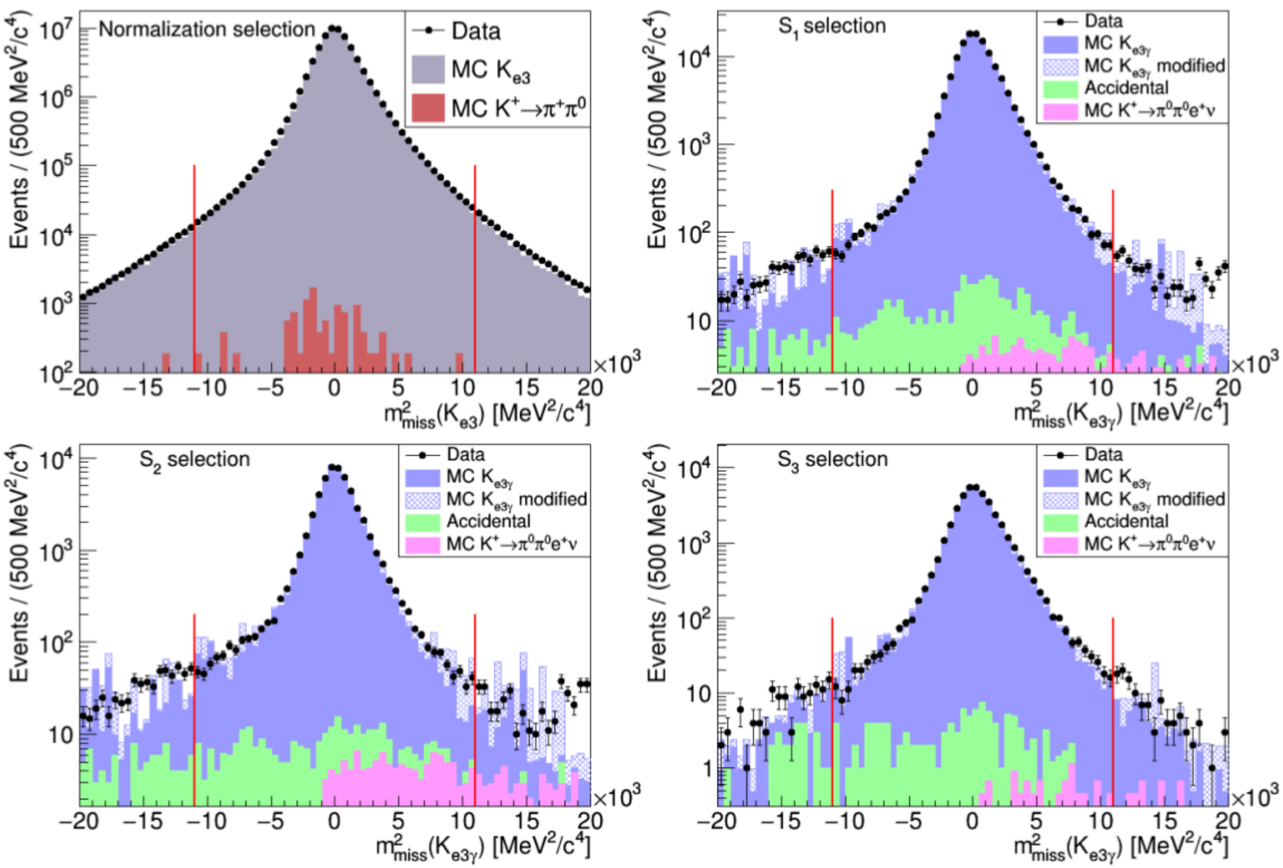



The final results of the analysis of the decay $K^+ \to \pi^0 e^+ \nu \gamma$ [*JHEP* 09 (2023) 040].

| | $E_\gamma^j,\ \theta_{e\gamma}^j$ | ChPT | ISTRA+ | OKA |
|---|---|---|---|---|
| $R_1 \times 10^2$ | $E_\gamma > 10\,\mathrm{MeV},\ \theta_{e\gamma} > 10^\circ$ | $1.804 \pm 0.021$ | $1.81 \pm 0.03 \pm 0.07$ | $1.990 \pm 0.017 \pm 0.021$ |
| $R_2 \times 10^2$ | $E_\gamma > 30\,\mathrm{MeV},\ \theta_{e\gamma} > 20^\circ$ | $0.640 \pm 0.008$ | $0.63 \pm 0.02 \pm 0.03$ | $0.587 \pm 0.010 \pm 0.015$ |
| $R_3 \times 10^2$ | $E_\gamma > 10\,\mathrm{MeV},\ 0.6 < \cos\theta_{e\gamma} < 0.9$ | $0.559 \pm 0.006$ | $0.47 \pm 0.02 \pm 0.03$ | $0.532 \pm 0.010 \pm 0.012$ |

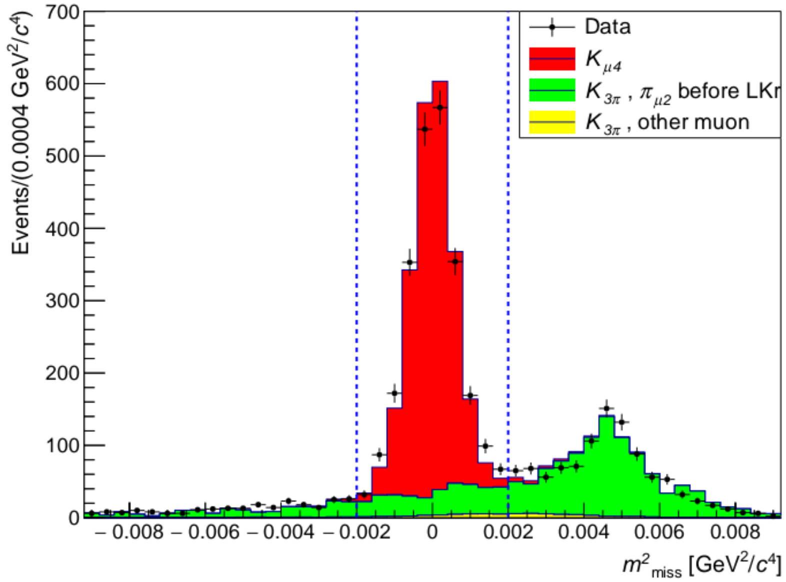
**NA62:**

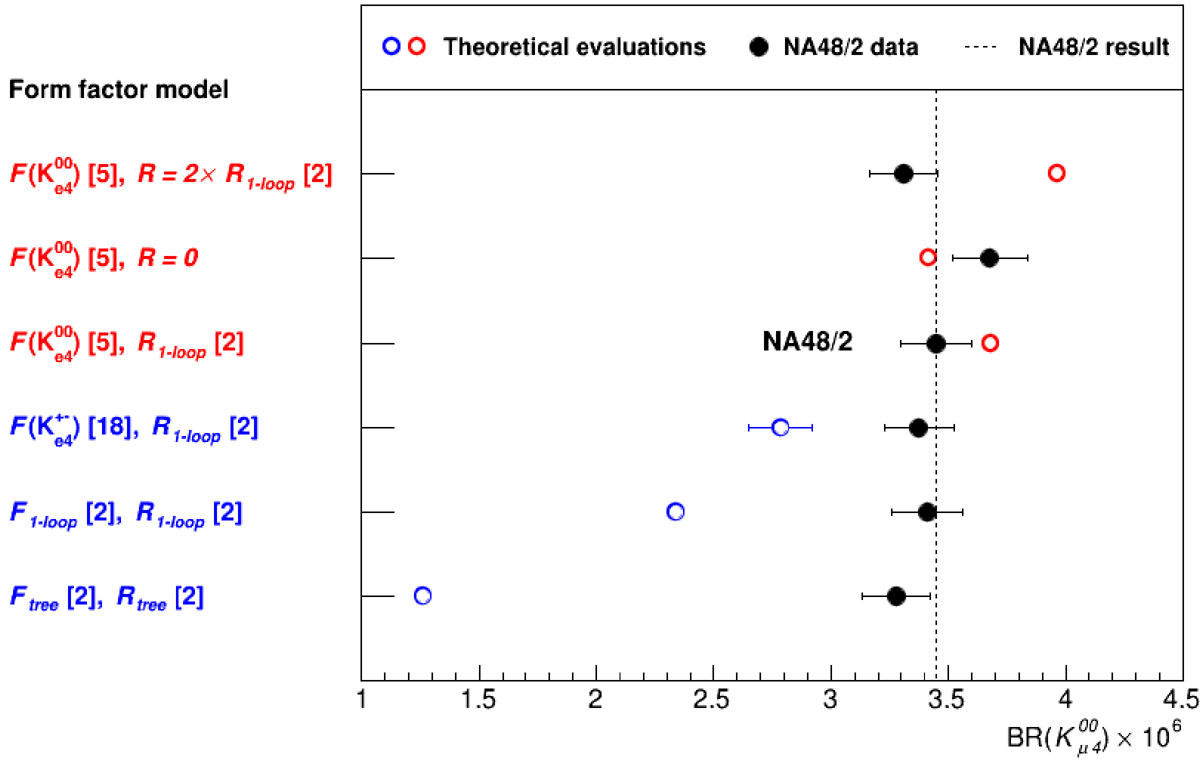
$$R_1 \times 10^2 = 1.715 \pm 0.005_{\mathrm{stat}} \pm 0.010_{\mathrm{syst}} = 1.715 \pm 0.011,$$
$$R_2 \times 10^2 = 0.609 \pm 0.003_{\mathrm{stat}} \pm 0.006_{\mathrm{syst}} = 0.609 \pm 0.006,$$
$$R_3 \times 10^2 = 0.533 \pm 0.003_{\mathrm{stat}} \pm 0.004_{\mathrm{syst}} = 0.533 \pm 0.004.$$



# First observation and study of the rare $K^{\pm} \rightarrow \pi^0\pi^0\mu^{\pm}\nu$ ($K_{\mu4}^{00}$) decay

- Accepted for journal publication [JHEP,2024].
- The last paper from NA48/2 (2003-2004 data).
- 2437 detected candidate signals
- Signal-to-background ratio of about 6
- **BR($K_{\mu4}^{00}$) = (3.4 ± 0.2) × $10^{-6}$**



- 16 journal NA62 papers have been published with the Dubna group participation in 2021-2024. In 11 of them the Dubna group members where the principal co-authors.
- Obtained results in 2021-2024 were presented at the international conferences, including 16 presentations given by the representatives of JINR group.

# Journal papers (2021-2024)

- E. Cortina Gil et al. Measurement of the very rare $K^+ \to \pi^+ \nu\nu$ decay. *JHEP* 06 (2021) 093. Jun 15, 2021.
- E. Cortina Gil et al. Search for Lepton Number and Flavor Violation in $K^+$ and $\pi^0$ Decays. *Phys.Rev.Lett.* 127 (2021) 13, 131802. Sep 24, 2021.
- **E. Cortina Gil et al. Search for $K^+$ decays to a muon and invisible particles. Phys.Lett.B 816 (2021) 136259. May 10, 2021.**
- E. Cortina Gil et al. A measurement of the $K^+ \to \pi^+ \mu^+ \mu^-$ decay. *JHEP 11 (2022) 011*.
- **E. Cortina Gil et al. Searches for lepton number violating $K^+ \to \pi^-(\pi^0)e^+e^+$ decays. Phys.Lett.B 830 (2022) 137172.**
- **E. Cortina Gil et al. Search for $K^+$ decays into the $\pi^+e^+e^-e^+e^-$ final state. *Phys.Lett.B* 846 (2023) 138193.**
- **E. Cortina Gil et al. A study of the $K^+ \to \pi^0 e^+ \nu\gamma$ decay. *JHEP* 09 (2023) 040.**
- E. Cortina Gil et al. Search for dark photon decays to $\mu^+\mu^-$ at NA62. *JHEP* 09 (2023) 035.
- **E. Cortina Gil et al. A search for the $K^+ \to \mu^- \nu e^+ e^+$ decay. Phys.Lett.B 838 (2023) 137679.**
- E. Cortina Gil et al. Measurement of the $K^+ \to \pi^+ \gamma\gamma$ decay. *Phys.Lett.B* 850 (2024) 138513.
- **R.J. Batley et al. First observation and study of the $K^{\pm} \to \pi^0 \pi^0 \mu^{\pm} \nu$ decay. E-Print: 2310.20295 [hep-ex]. Accepted for publication in the Journal of High Energy Physics.**
- **V. Bautin, K. Salamatin, T. Enik, O. Minko, Y. Kambar. Online Gas Gain Monitoring System. Phys.Part.Nucl.Lett. 20 (2023) 5, 1240-1242.**
- **A. Zelenov, V. Bautin, S. Bulanova, T. Enik, E. Kuznetsova, V. Maleev, S. Nasybulin, K. Salamatin, D. Sosnov. Testbeam measurements and realistic simulation for straw drift tubes. Phys.Atom.Nucl. 86 (2023) 5, 832-837.**
- **V. Bautin, M. Demichev, T. Enik, E. Kuznetsova, V. Maleev, R. Petti, S. Nasybulin, K. Salamatin, D. Sosnov, A. Zelenov. VMM3 ASIC as a potential front end electronics solution for future Straw Trackers. Nucl.Instrum.Meth. A 1047 (2023) 167864.**
- **S. Gevorkyan, I. Larin, R. Miskimen, E. Smith. Photoproduction of pion pairs at high energy and small angles. Phys.Rev.C 105 (2022) 6, 065202.**
- **S.R. Gevorkyan, A.V. Guskov. Impact of vector mesons polarization on its interaction with matter. Eur. Phys. J. C. 84 (2024) 1, 7.**

## Conference talks (2021-2024)

1) E. Goudzovski. The NA62 experiment at CERN: recent results and prospects. New Physics at the Intensity Frontier workshop (virtual, organized by ITEP Moscow), 7–8 June 2021.
2) E. Goudzovski. Hidden sectors in $K^+$ decays: NA48/2, NA62, future. Workshop on Searches for Hidden Sectors at Kaon and Hyperon Factories (virtual, organized by CERN), 12 July 2021.
3) E. Goudzovski. Searching for X17 in $\pi^0$ decays by NA48/2 at CERN. "Shedding light on X17" workshop, Rome, Centro Ricerche Enrico Fermi, 6–8 September 2021.
4) D. Kereibay. Search for heavy neutral lepton production in NA62. The 20th Lomonosov Conference on Elementary Particle Physics, Moscow, Russia, August 19-25, 2021. *Moscow Univ.Phys.Bull. 77 (2022) 220-222. Issue 2.*
5) D.Madigozhin. New measurement of radiative decays at the NA62 experiment at CERN. The XXVIII International Conference on Supersymmetry and Unification of Fundamental Interactions (SUSY 2021), Shanghai, China (virtual), August 23 – 28, 2021.
6) D. Madigozhin, on behalf of the NA62 Collaboration. New measurement of radiative decays at the NA62 experiment at CERN. *30th International Symposium on Lepton Photon Interactions at High Energies, The University of Manchester, Manchester (online only), United Kingdom, 2022.*
7) D. Madigozhin, on behalf of the NA48/2 collaboration. Precise measurement of the Decay $K^{\pm}\to\pi^0\pi^0\mu^{\pm}\nu$. *XLI International Conference on High Energy Physics (ICHEP 2022), Italy, Bologna. PoS ICHEP2022 723.* Contribution to ICHEP 2022.
8) A.Korotkova, on behalf of the NA48/2 collaboration. First measurement of the $K^{\pm}\to\pi^0\pi^0\mu^{\pm}\nu$ ($K^{00}_{\mu4}$) decay. *56-th Recontres de Moriond. EW session. 2022. La Thuile AO, Italy.*
9) A.Korotkova, on behalf of the NA48/2 collaboration. First measurement of the $K^{\pm}\to\pi^0\pi^0\mu^{\pm}\nu$ decay. International Conference on Kaon Physics 2022 (KAON2022), *Osaka, Japan. J.Phys.Conf.Ser.* 2446 (2023) 1, 012012. Contribution to KAON2022.
10) E. Goudzovski. Present and future kaon experiments. *American Physical Society April Meeting 2022, American Physical Society, New York, USA, 2022.*
11) E. Goudzovski. Search for new physics in kaon decay. *Vulcano Workshop 2022: Frontier Objects in Astrophysics and Particle Physics, INFN, Elba, Italy, 2022.*
12) E. Goudzovski. Recent results from the NA62 experiment at CERN. *NuFact 2022 conference, University of Utah, Snowbird, Utah, USA, 2022.*
13) D. Baigarashev. Latest results and precision measurements from the NA62 experiment. Twenty-first Lomonosov conference on elementary particle physics. MSU, Moscow, Russia, 24-30 August 2023.
14) E. Goudzovski. HIKE, High Intensity Kaon Experiments at CERN. XIXth Rencontres du Vietnam – Windows on the Universe, Quy Nhon, Vietnam, 6–12 August 2023.
15) E. Goudzovski. Search for new physics in kaon decays at NA62. PASCOS 2023, Irvine, US, 26–30 June 2023.
16) E. Goudzovski. Exotica from kaon decays: experiment. Kaons@CERN workshop, CERN, 11–14 September 2023.

# JINR NA62 project prolongation request

- 2025 : The last year of NA62 data taking;
- 2026-2027: Data analysis and MC tuning, rare decay studies, papers writing and publishing.

## JINR contributions

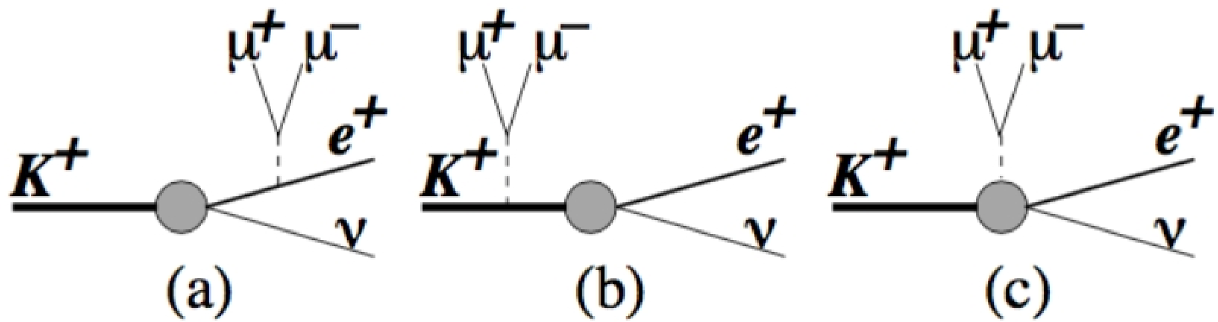
- Participation in the LKr fine calibration based on $\pi^0$ decays;
- Participation in the analysis of rare background sources for $K^+ \to \pi^+ \nu\nu$;
- Data processing and analysis of the collected experimental data to measure the four-lepton decay modes of charged kaon;
- Form factors measurement for $K_{l3}$ decays from NA62;
- Search for the light sgoldstio signatures;
- Diagnostics and necessary repair of the Spectrometer straw chambers and their low and high voltage power supply;
- Participation in R & D for a new straw module creation;
- Participation in the NA62 data taking run in 2025;
- Support the NA62 Spectrometer during the data taking run in 2025.

# Additional goals for the JINR group analysis

- Rare four-lepton decays with the branching ratios of the order of $10^{-8}$ (ChPT checks):
  - $K^+ \to e^+ \nu \mu^+ \mu^-$ **signal selection improvement in progress**;
  - $K^+ \to e^+ \nu e^+ e^-$ **started**;
  - $K^+ \to \mu^+ \nu e^+ e^-$ **signal selection improvement in progress**;
  - $K^+ \to \mu^+ \nu \mu^+ \mu^-$ (was not observed) - **branching fraction extraction**;

- $K_{\mu 4}^{+-}$ analysis (ChPT) : **signal selection improvement in progress**;
- Search for the Goldstone fermion superpartners - “sgoldstino” P in decays $K^+ \to \pi^+ \pi^0 P$ ($P \to \gamma\gamma$) : **signal selection improvement in progress**.

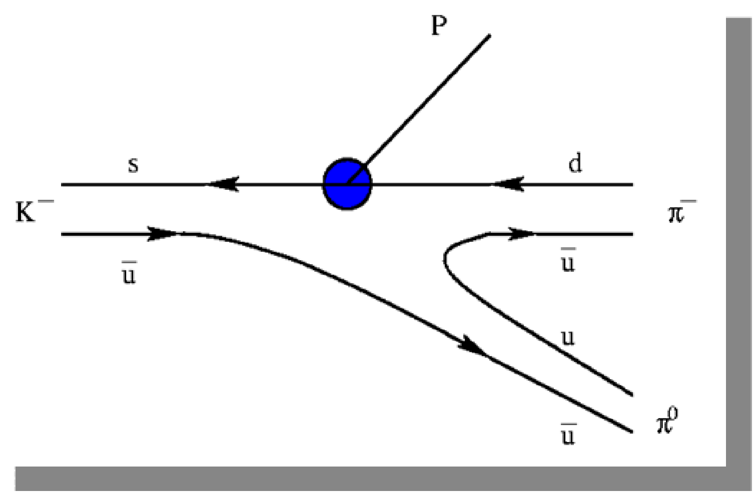
## $K_{l4}$ decays

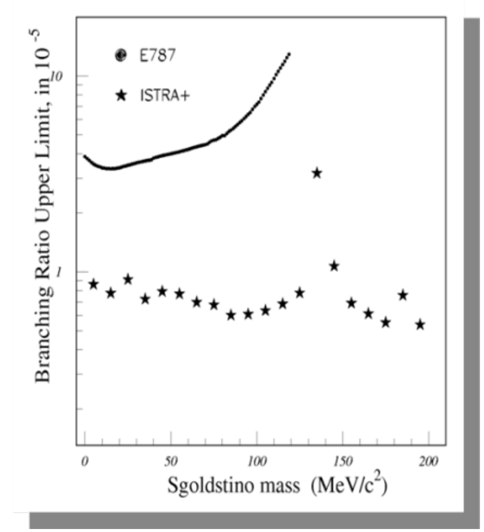



- The internally converted $K_{l2}\gamma^*$ decays, $K_{l4}$, are the source of information for the kaon physics.
- Within the Chiral Perturbation Theory (ChPT) these decays provide a test of the theory and the source of its parameters.
- Inner Bremsstrahlung is helicity-suppressed for $K_{e2}\gamma^*$ (better for the form factor measurements).

Light (within kaon mass) pseudoscalar sgoldstino: Goldstone fermion superpartners [D.S.Gorbunov, V.A. Rubakov. Phys.Rev.D73:035002, 2006.].

A search for New physics, and at least new limit for production will be established.



# Full-time equivalent values for JINR (VBLHEP) participants

| Name | FTE | PhD student | Work (apart from common duties like shifts) |
|---|---|---|---|
| D. Baygarashev | 1.0 | + | Data quality control, calibration, physical analysis |
| A. Baeva | 1.0 | + | Physical analysis |
| S. Gevorgyan | 1.0 | | Theory of rare decays, MC models development |
| V. Gorbunova | 0.5 | | Documentation |
| E. Goudzovski | 0.1 | | MC development, analysis |
| D. Emelyanov | 1.0 | + | Software tools development, analysis |
| T. Enik | 0.3 | | Hardware development and support |
| V. Kekelidze | 0.1 | | Project leader |
| D. Kereibay | 1.0 | + | Physical analysis |
| A.Korotkova | 0.7 | + | Physical analysis |
| D.Madigozhin | 1.0 | | MC development, data quality control, analysis |
| N. Molokanova | 0.9 | | Physical analysis |
| I. Polenkevich | 1.0 | | Physical analysis |
| K. Salamatin | 0.3 | | Straw detector development |
| S. Shkarovskiy | 1.0 | + | DCS development, hardware support, analysis |
| V. Falaleev | 0.2 | | Slow control, DCS development, hardware support |
| V. Bautin | 0.3 | | Straw detector development |
| Y. Kambar | 0.3 | | Straw detector development |
| **TOTAL** | **11.6** | | |

# Strengths, Weaknesses, Opportunities, Threats

Strengths:

- fundamental importance of the scientific program;
- fully operating NA62 detector setup built with the JINR essential participation;
- a large amount of experimental data collected in 2016-2023;
- data taking prolongation till 2025 from CERN side;
- experience in analysis of senior participants of the JINR team;
- young participants who will in future bring the best CERN practice into JINR projects;

The main weakness is the global policy dependence of JINR participation in CERN.

The non-trivial opportunities of the project are the improved measurements of rare decay modes based on the large statistics of kaon decays. Also there is a chance to find new physics in the case if new results will be incompatible with SM. Additionally, the participation in software development and detector calibration for NA62 will increase the qualification of young participants that will be needed in other JINR experiments.

No ongoing competition is known currently in the measurement of the charged kaon golden mode. So there are no threats to the project extension scientific importance.

## Resource request for 2025-2027

| ***Expenditures*** | **Cost (thousands Of USD)** | 2025 **(run)** | 2026 | 2027 |
|---|---|---|---|---|
| International cooperation | 340 | 115+35 | 60+35 | 60+35 |
| Materials | 135 | 45 | 45 | 45 |
| R&D contracts with other research organizations | 30 | 10 | 10 | 10 |
| ***Total*** | 505 | 205 | 150 | 150 |

- Participation in the run 2025 and NA62 maintenance.
- Development of straw detectors.
- Contributions to the NA62 common fund (35 USD/year).
- Conferences.
- Computers and technical support for MC simulation, processing and analysis of experimental data.

# Spare slides

**JINR II prize (2019)**

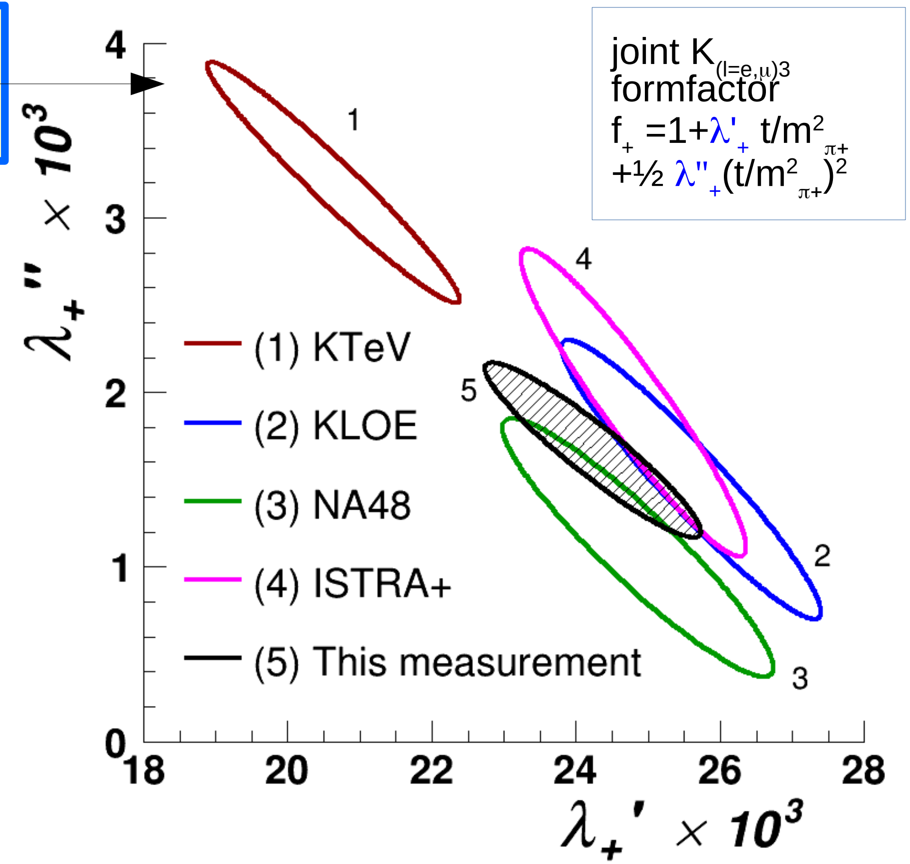
## $K^\pm \to \pi^0 l^\pm \nu$ ($K_{l3}$) form factors

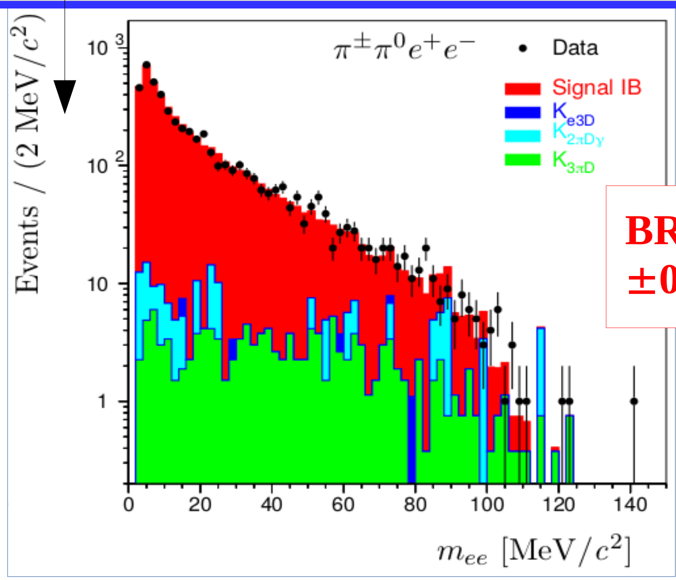
JHEP 1810 (2018) 150.

## First observation $K^\pm \to \pi^\pm \pi^0 e^+ e^-$ decay

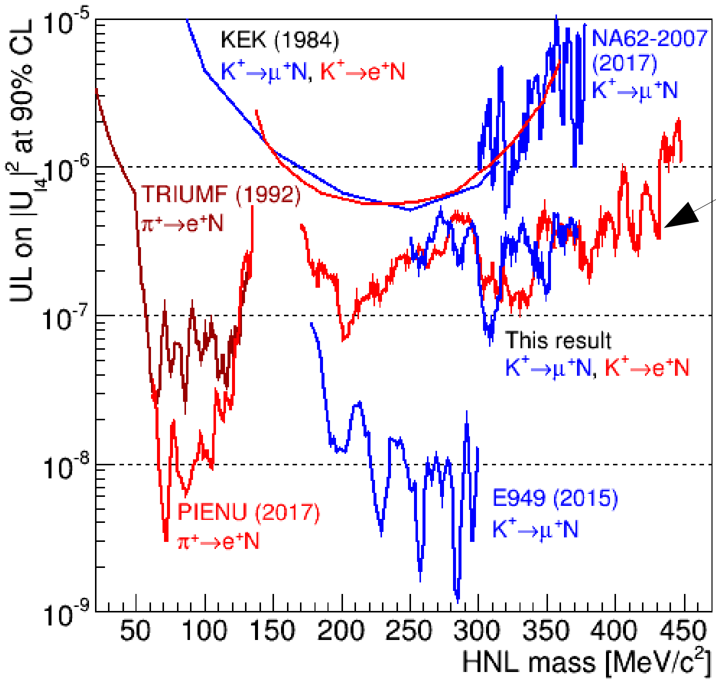
Phys.Lett. B788 (2019) 552

## NA48/2




$BR = (4.237 \pm 0.063_{stat} \pm 0.033_{syst} \pm 0.126_{ext}) \, 10^{-6}$




## Searches for heavy neutral lepton production in $K^+$ decays

Phys.Lett. B778 (2018) 137

## NA62

## Searches for lepton flavour and lepton number violation

Phys.Lett. B797 (2019) 134794

$BR(K^+ \to \pi^- e^+ e^+) < 2.2 \times 10^{-10}$

$BR(K^+ \to \pi^- \mu^+ \mu^+) < 4.2 \times 10^{-11}$