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

NA62 Project (Collaboration NA62)

Theme 02-1-1096-2010/2019

Extension for 2019-2021

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);**
Germany: Johannes-Gutenberg-Universitat Mainz (**Mainz);**
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 (**Padua),** 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);**
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)**
United Kingdom: University of Birmingham (**Birmingham),** University of Bristol, H. H. Wills Physics Laboratory (**Bristol),** University of Glasgow (**Glasgow),** University of Liverpool, Oliver Lodge Laboratory (**Liverpool);**
United States of America: Boston University (**Boston),** George Mason University (**Fairfax),** SLAC National Accelerator Laboratory (**Menlo Park),** University of California Merced (**Merced),** Brookhaven National Laboratory (BNL) (**Upton).**

Лаборатория физики высоких энергий

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Руководители проекта: Кекелидзе В.Д. (ЛФВЭ)
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Laboratory of High Energy Physics

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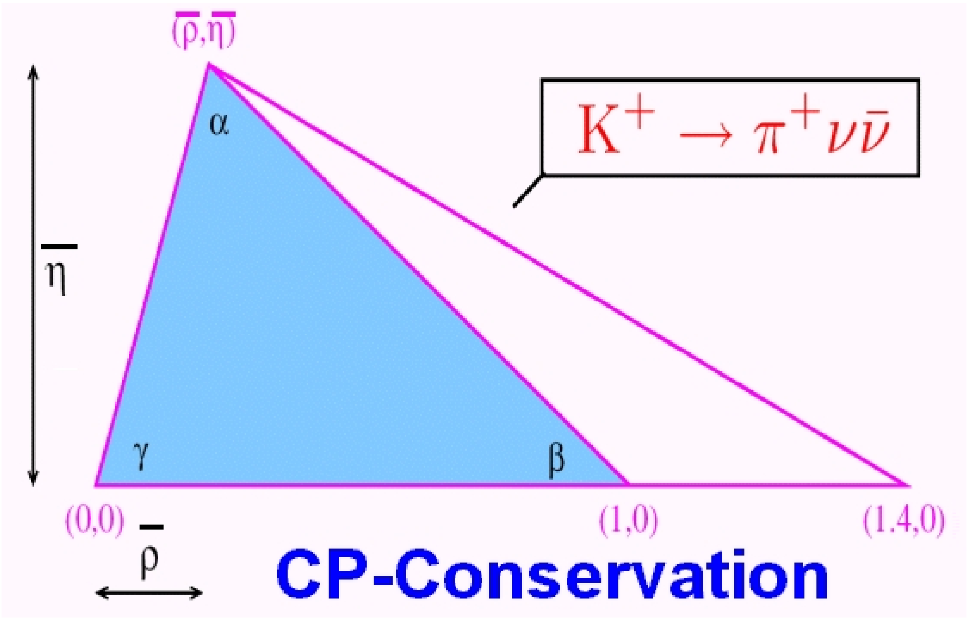
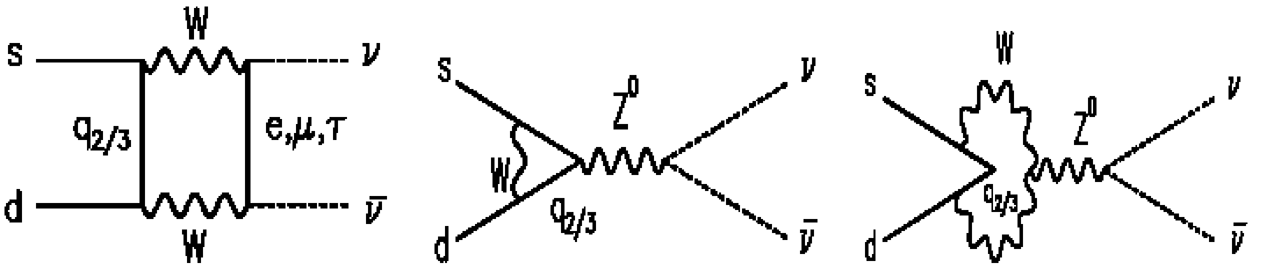
Project leaders: Kekelidze V.D. (LHEP)
Potrebenikov Yu.K. (LHEP)

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

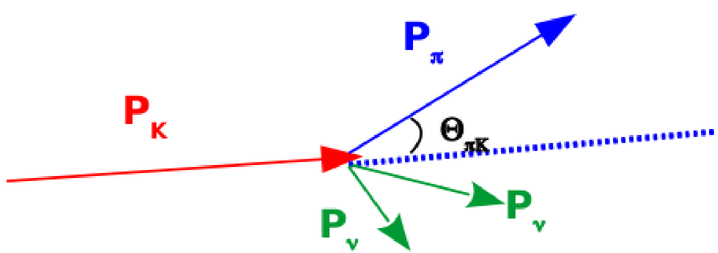
$$BR(K^+ \to \pi^+ \nu\bar\nu) = (17.3^{+11.5}_{-10.5}) \times 10^{-11}$$

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

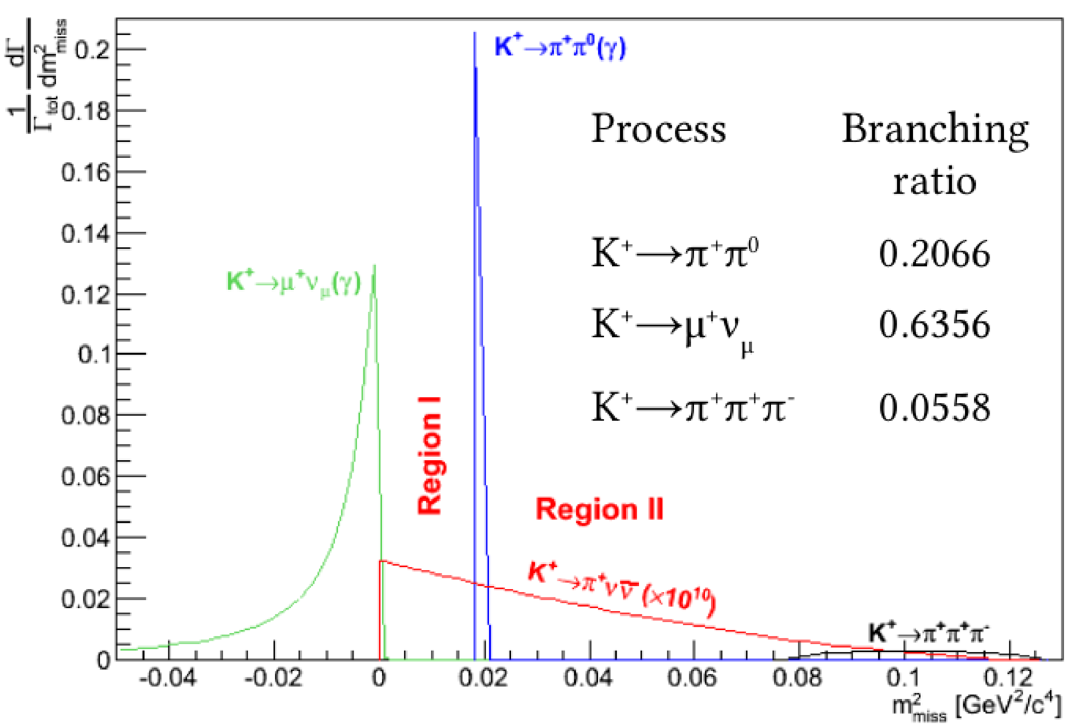
NA62 ultimate goal is ~ 10% precision for Br($K^+ \rightarrow \pi^+\nu\bar{\nu}$)
that assumes ~ 100 reconstructed events and a small background.

Decay in flight technique

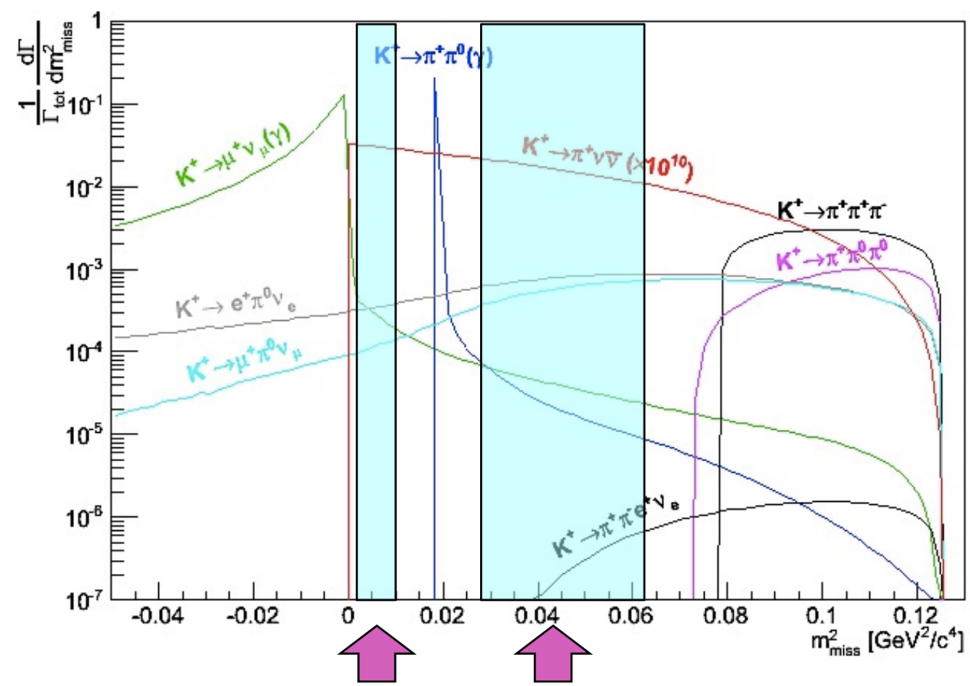
$$m^2_{miss} = (P_K - P_{\pi^+})^2$$



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

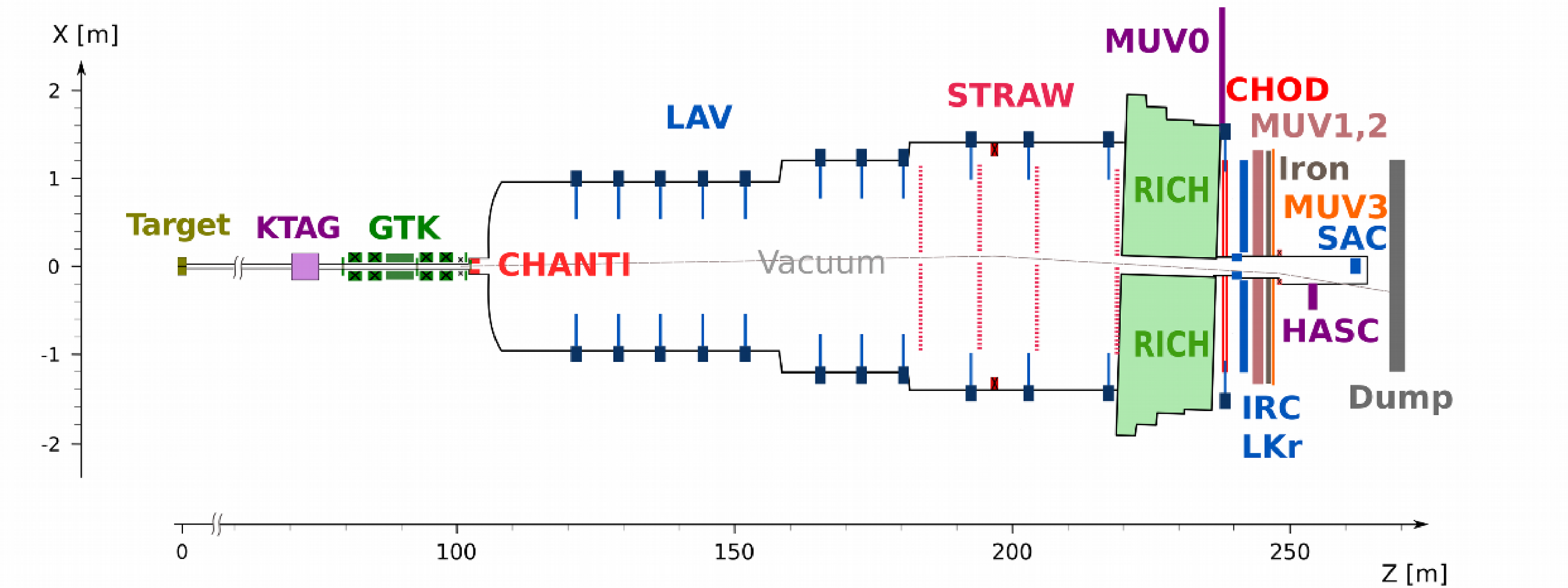


Process	Branching ratio
$K^+ \rightarrow \pi^+\pi^0$	0.2066
$K^+ \rightarrow \mu^+\nu_\mu$	0.6356
$K^+ \rightarrow \pi^+\pi^+\pi^-$	0.0558



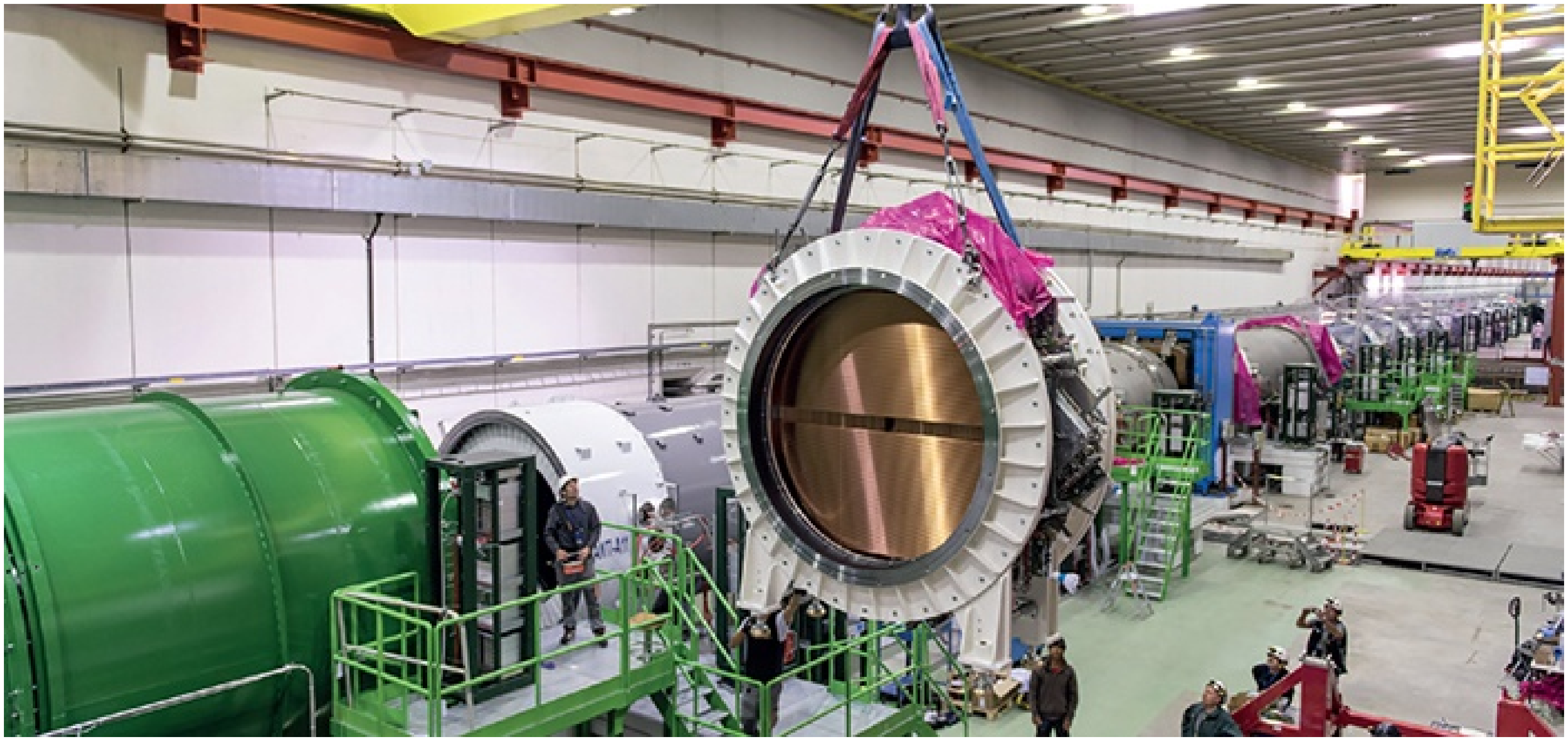
- History of JINR in CERN kaon decays program: NA48,NA48/1,NA48/2, NA62(R_K).
- Analysis of NA48/2 data is still ongoing (at final stage, and we are involved).
- NA62 inherits some elements of NA48/2, but it is a really novel setup that solves a new challenging task.

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%)/π^+(70%)/p(24%)
  - 33x10^{11} ppp on T10 (750 MHz at GTK3)
- **Decay Region:**
  - 60 m fiducial region
  - ~ 5 MHz K^+ decay rate
  - Vacuum ~ O(10^{-6}) mbar

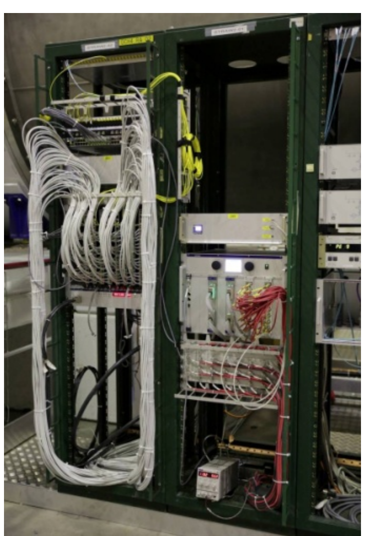
JINR+CERN responsibility :
Spectrometer made of straw tubes working in vacuum



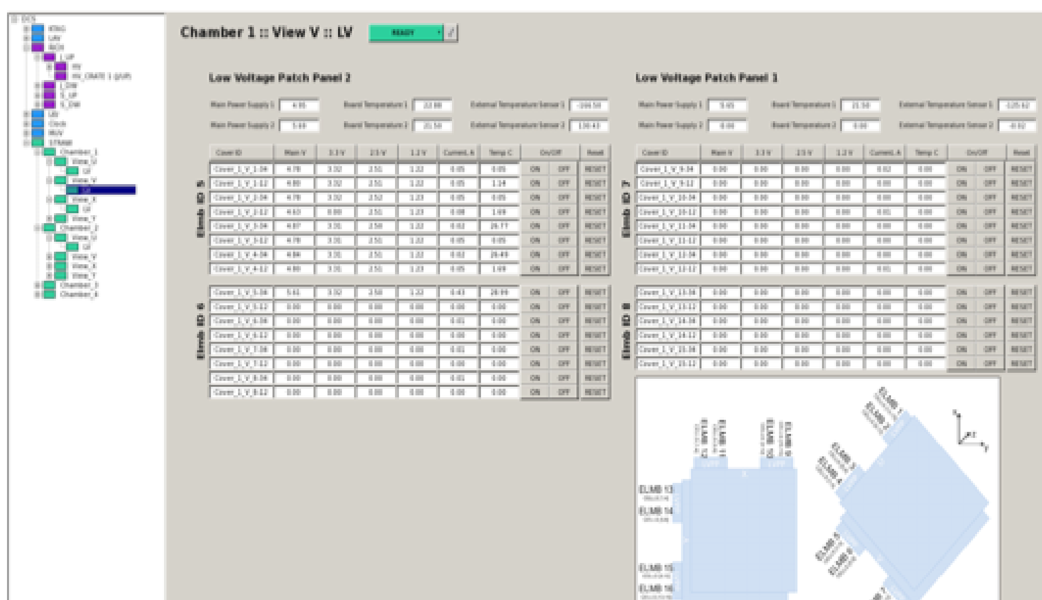
JINR contribution is very important and is defining in many aspects:

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

Installed in 2014.

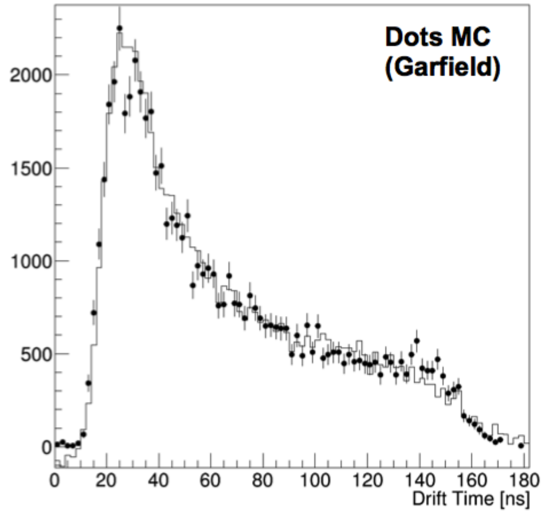


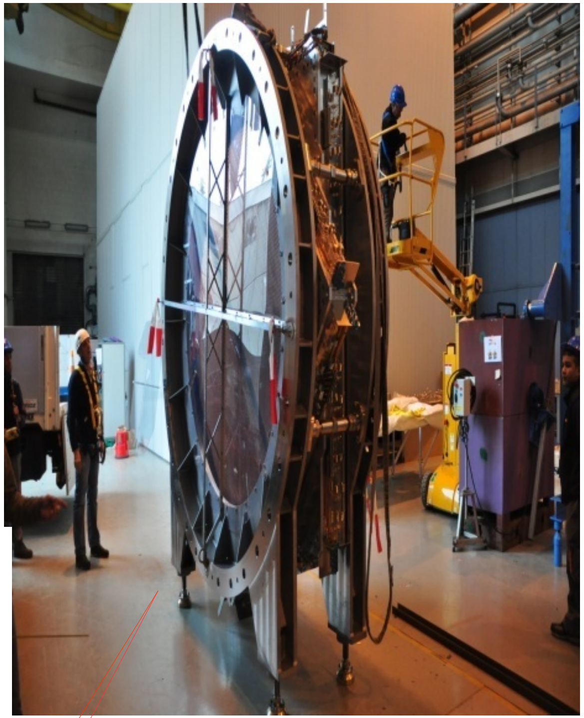
HV and LV power suppliers

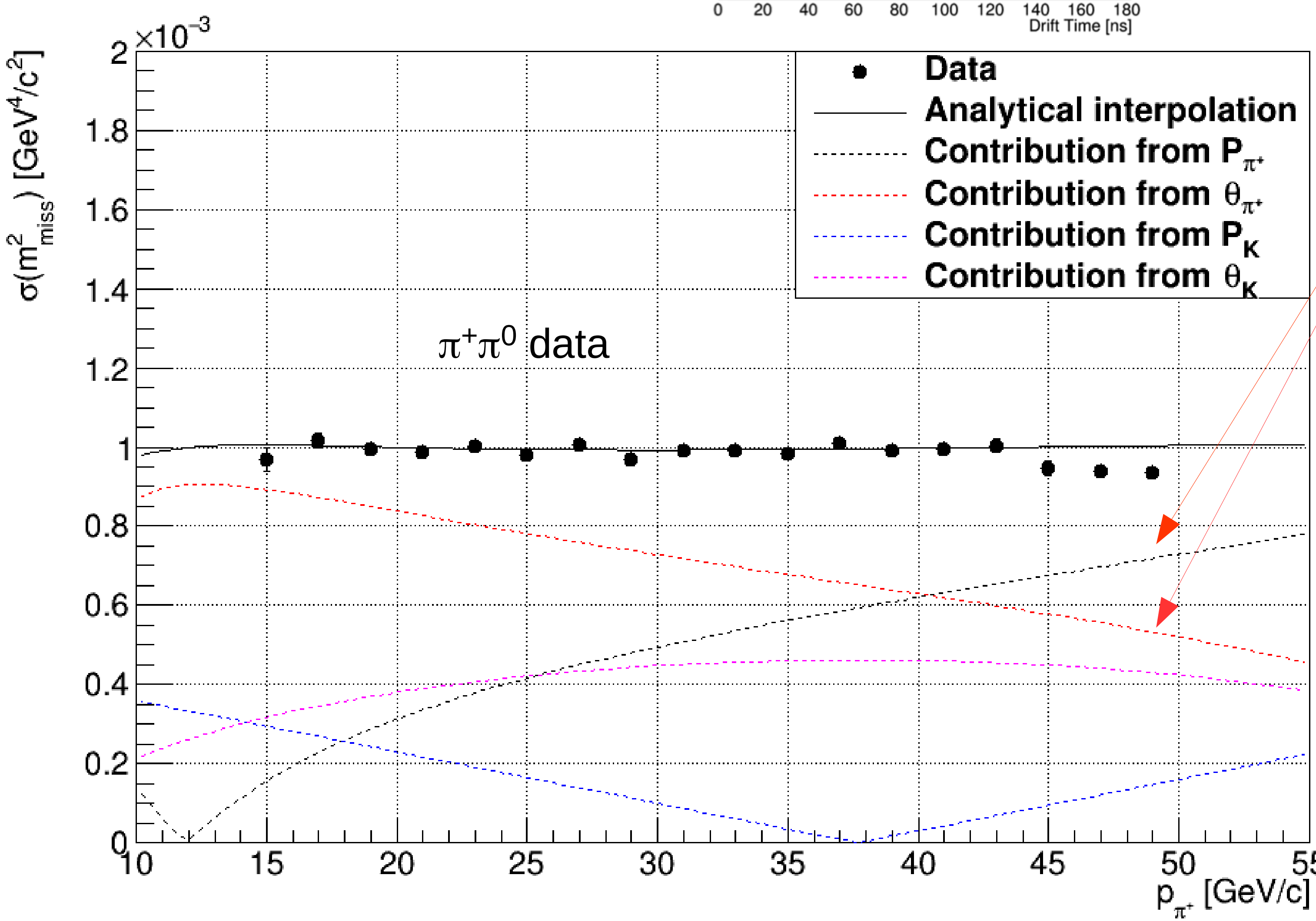


Detector Control System (DCS) for the NA62 Spectrometer

Spectrometer performance





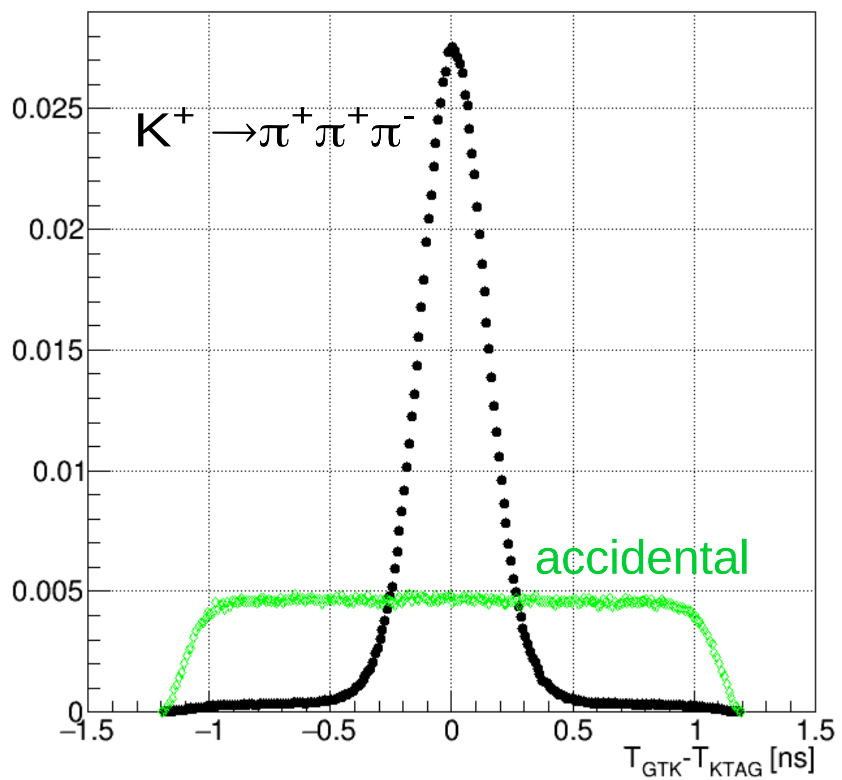


The largest expected contributions are from the spectrometer.

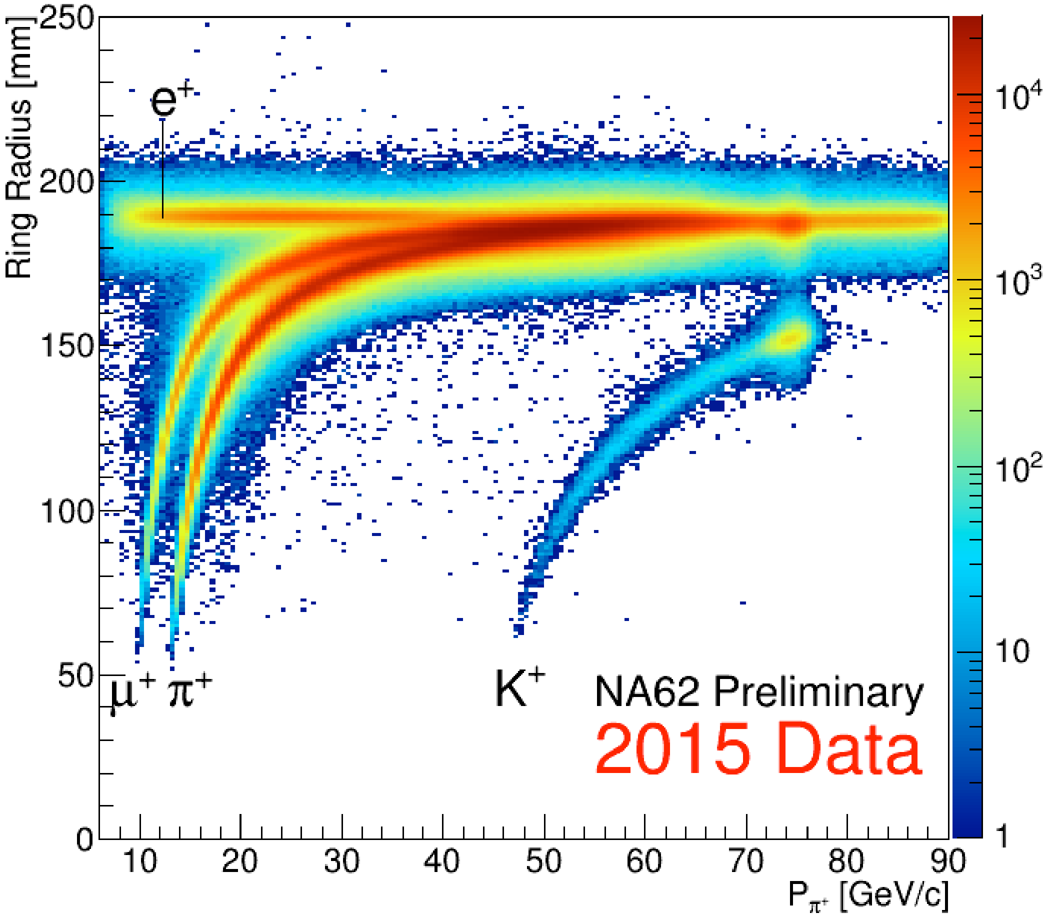
As expected even without very special alignment (just a wire centers positioning).

NA62 first $\pi\nu\nu$ result

- 2014 Pilot run
- 2015 Comissioning run
- Full detector installation completed in September 2016.
- First $\pi\nu\bar{\nu}$ dataset in the end of 2016
- Continuous data taking until the end of 2018 (prolongation after 2020 is expected)



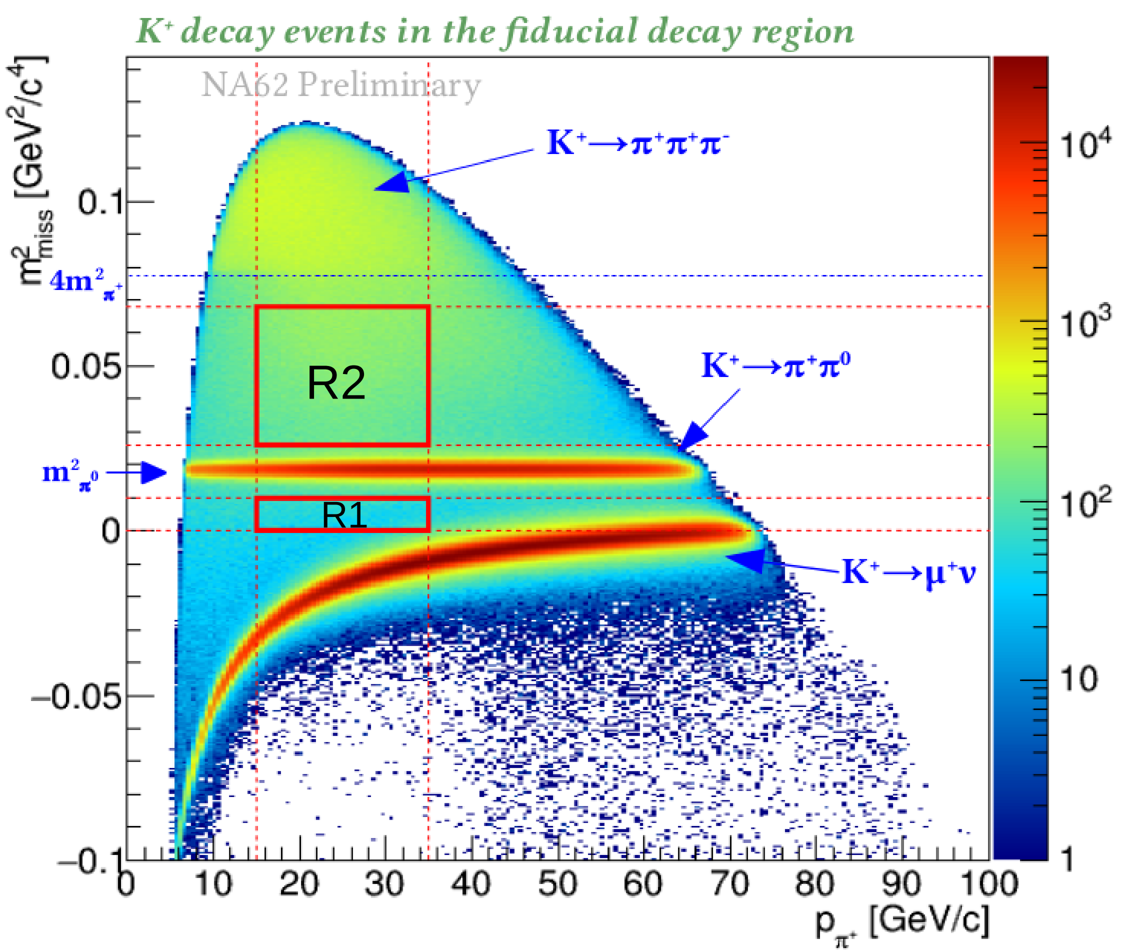
GTK and KTAG (CEDAR) time difference distributions



RICH ring radius vs the track momentum

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.
- If the signal is opened for a partial sample, it can not be added to more complete sample later, but the partial result may be published separately.
- So first we analyze only a small fraction of the available data (collected in 2016).

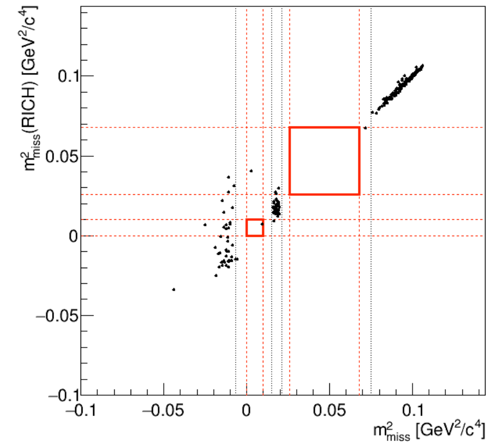


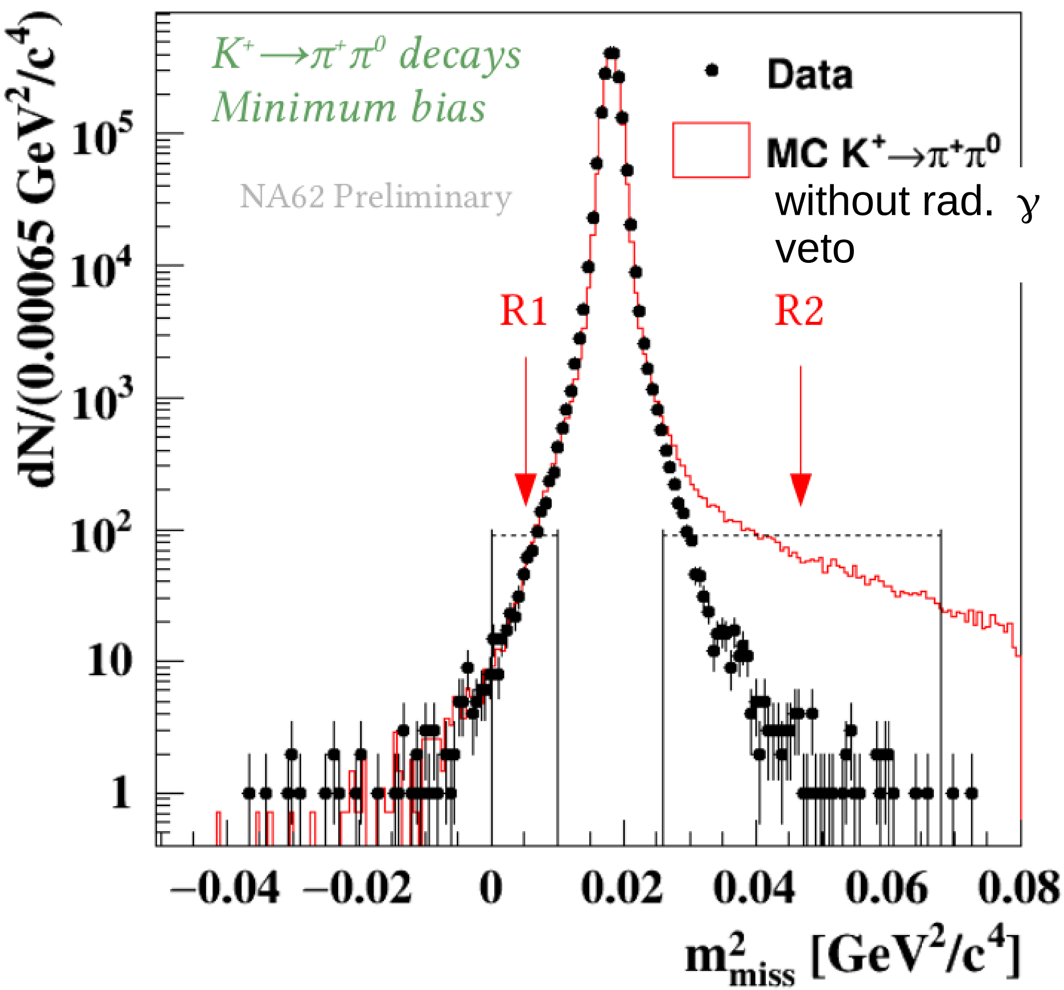
Signal regions R_1 and R_2

- Selection criteria
  - single track decay topology
  - π^+ identification
  - photon rejection
  - multi-track rejection

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

No signal events were observed in the first 5% of 2016 data (small fraction of the small fraction). This very small sample is not used for the present result in order to conform the blind analysis strategy.

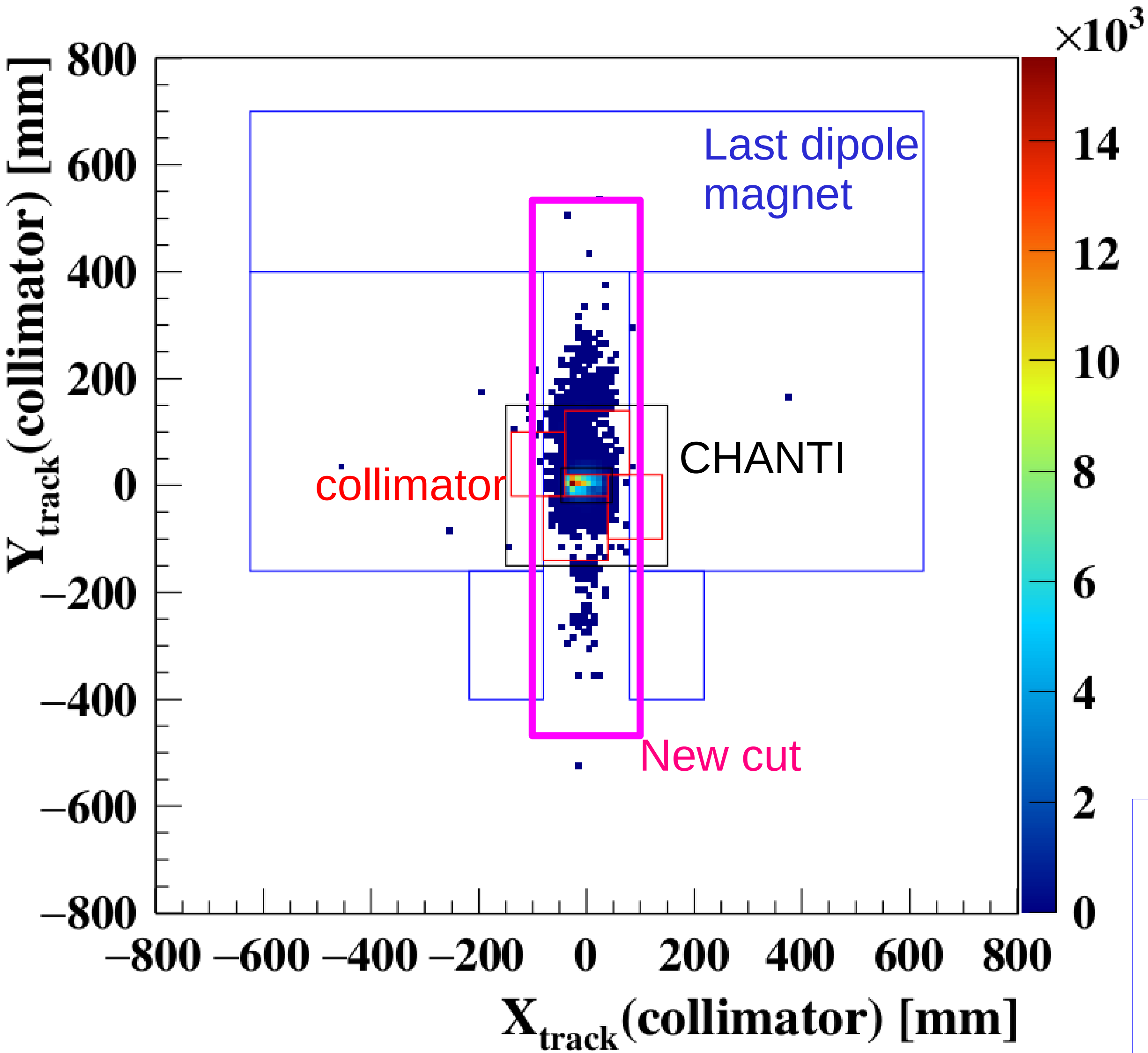




- Three ways to compute the m^2_{miss}
  - m^2_{miss}(STRAW, GTK)
  - m^2_{miss} (RICH, GTK)
  - m^2_{miss} (STRAW, Beam)
- Protects against mis-reconstruction
- Kinematic suppression
  - Measured using data
  - Samples of $K_{\pi\pi}$ and $K_{\mu\nu}$
  - Selected using calorimeters
- Fraction of events in signal regions
  - $K^+ \to \pi^+\pi^0 \sim 1 \cdot 10^{-3}$
  - $K^+ \to \mu^+\nu_\mu \sim 3 \cdot 10^{-4}$

(without vetoes)

Unexpected "upstream background" problem



Pion track projections to the last collimator before decay volume (background-enriched sample).

- 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 $\pi\nu\nu$ acceptance:

4% instead of 10%

A better shielding design and search for the upstream background off-line rejection are in progress.

First NA62 result based on the 2016 data (reported in Moriond in March 2018)

Amount of kaon decays in the fiducial volume: $\mathbf{N_K = 1.21(2)\times 10^{11}}$

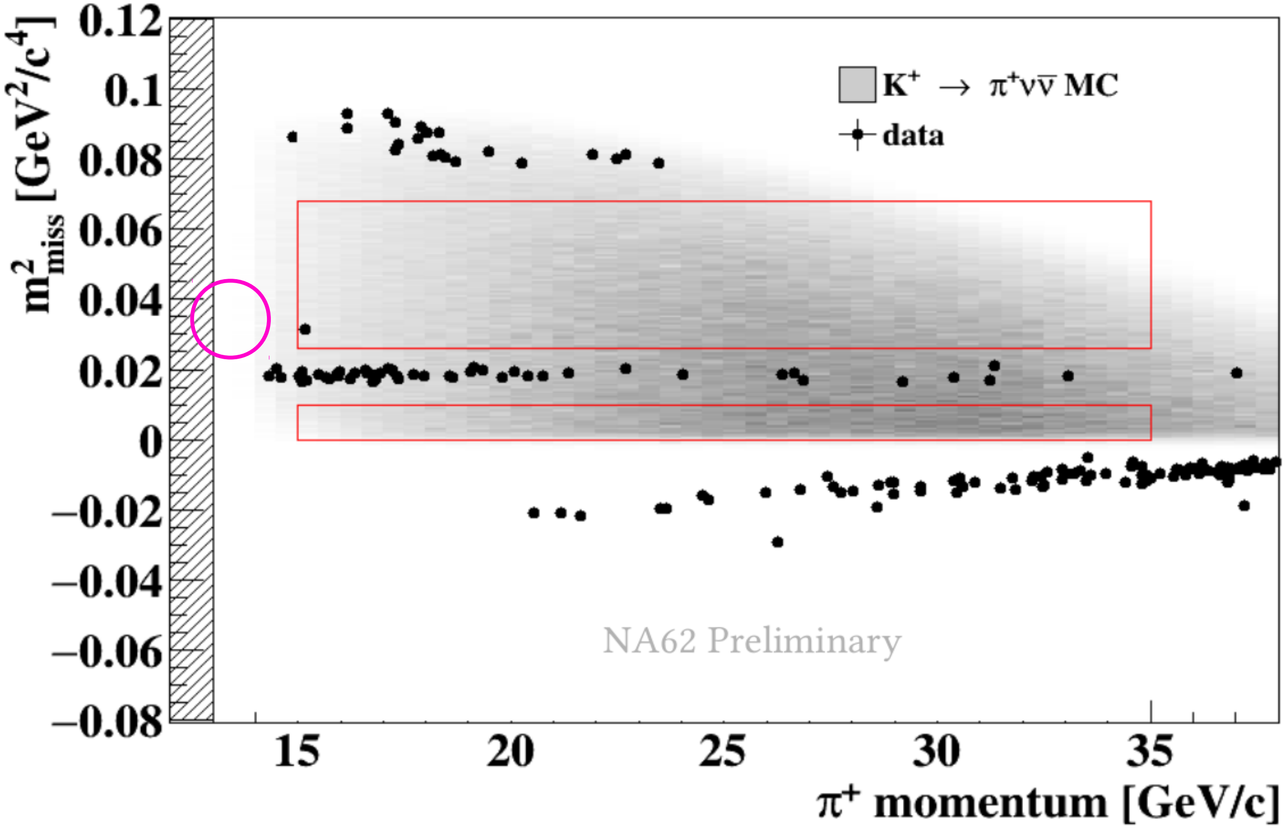
Full set of 2016 data

Process	Expected events in R1 + R2
$K^+ \to \pi^+\nu\bar{\nu}$ (SM)	$0.267 \pm 0.001_{stat} \pm 0.029_{syst} \pm 0.032_{ext}$
$K^+ \to \pi^+\pi^0(\gamma)$ IB	$0.064 \pm 0.007_{stat} \pm 0.006_{syst}$
$K^+ \to \mu^+\nu_\mu(\gamma)$ IB	$0.020 \pm 0.003_{stat} \pm 0.003_{syst}$
$K^+ \to \pi^+\pi^-e^+\nu_e$	$0.018^{+0.024}_{-0.017}\vert_{stat} \pm 0.009_{syst}$
$K^+ \to \pi^+\pi^-\pi^+$	$0.002 \pm 0.001_{stat} \pm 0.002_{syst}$
Upstream background	$0.050^{+0.090}_{-0.030}$
Total background	$0.15 \pm 0.09_{stat} \pm 0.01_{syst}$

- Signal acceptance 4%

- Control triggered $K \to \pi^+\pi^0$ used for normalization
- Normalization acceptance 10%

Results



One event observed

BR($K^+ \rightarrow \pi^+\nu\bar{\nu}$) < 14 ×10^{-10} @ 95% CL

For comparison: $BR(K^+ \rightarrow \pi^+\nu\bar{\nu}) = 28^{+44}_{-23} \times 10^{-11}$ @ 68% CL

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

$$BR(K^+ \rightarrow \pi^+\nu\bar{\nu})_{exp} = (17.3^{+11.5}_{-10.5}) \times 10^{-11}$$ (BNL, "kaon decays at rest")

- 2017 data processing is in progress (reduction of background expected)
- 2018 data taking: 218 days
- **~ 20 SM events expected before LS2 (LHC Long Shutdown 2019-2020)**
- Running after 2018 to be approved

feedback from SPSC

malvezzi [Sandra.Malvezzi@mib.infn.it]

To: Augusto Ceccucci; Hans Danielsson

Cc: gschnell@mail.desy.de; Daniel Boer; giuliana.fiorillo@na.infn.it; Giuseppe Ruggiero; Sandra Malvezzi

23 April 2018 09:17

You forwarded this message on 23/04/2018 09:36.

Dear Augusto and Hans,
congratulations on your 2016 data results.

The official minutes read :
"The SPSC congratulates the NA62 collaboration on the results of $\pi\nu\nu$ analysis of the 2016 data set and on the observation of the first $\pi\nu\nu$ candidate event.The Committee notes with pleasure the publications of physics results from NA62 on searches for heavy neutral leptons and heavy neutrinos, and also acknowledges the continuous analysis of the NA48/2 data and the publication of the results"

On the basis of your projections of 20 $\pi\nu\nu$ events before LS2, the committee looks forward to seeing the experimental strategy and time line for achieving the 10% precision in the BR measurement after LS2.
Waiting for your feedback, we wish you a successful 2018 run

Best regards,

Daniel, Giuliana, Gunar and Sandra

Sandra Malvezzi
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"Bottom line is that we can count on 2021 and 2022 to complete the PNN measurement" (NA62 Augusto Ceccucci)

The ultimate goal of the project (100 SM events and 10% branching precision) looks currently somewhat problematic, as we can't predict the runs prolongation after 2022.

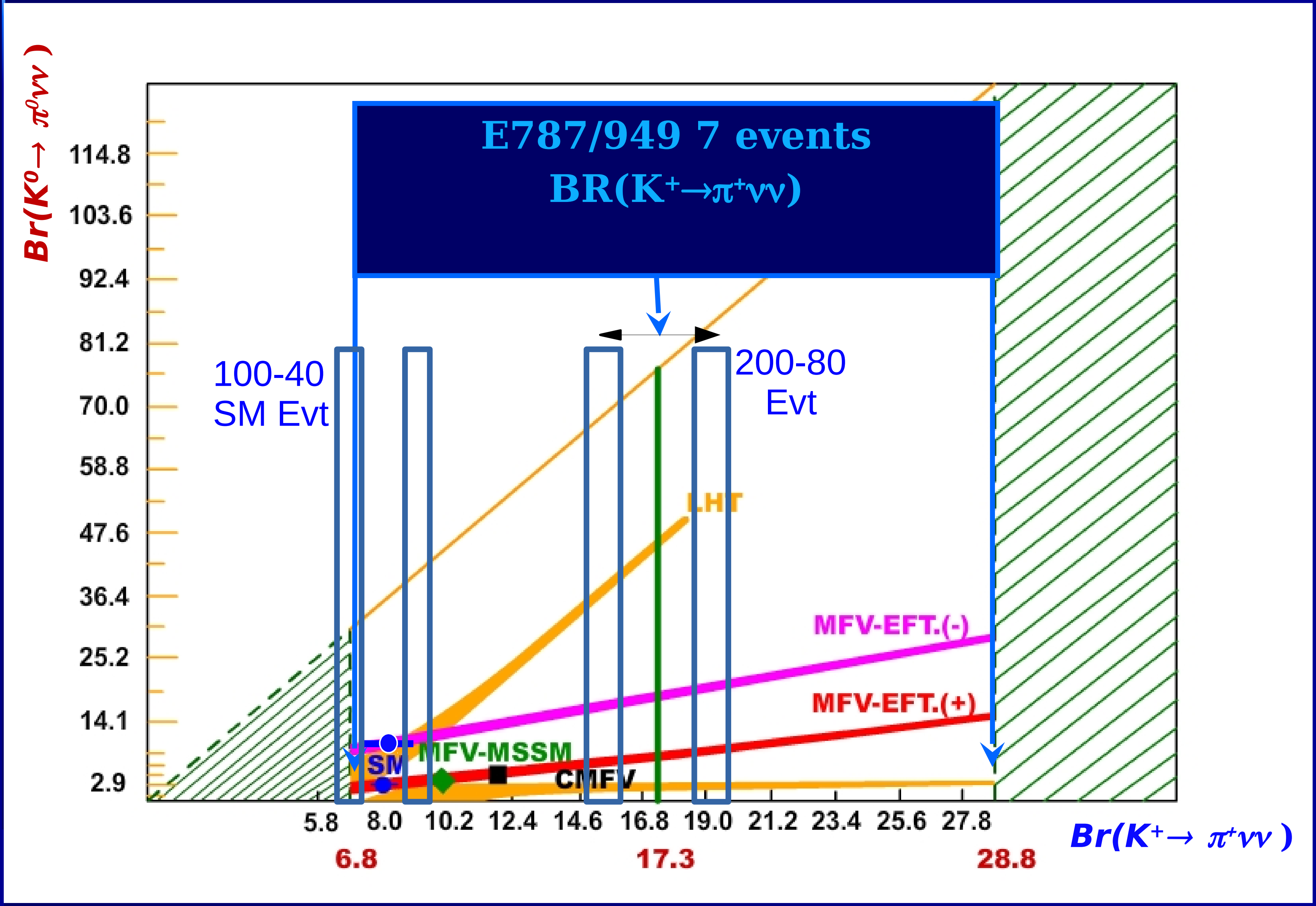
This is an experiment on the intensity frontier, and it was difficult to prevent all the problems.
Main reasons:

- Beam timing profile is worse than expected. It limits the intensity (60% of the nominal), that is partially compensated by the longer runs (> 200 days/year);
- Unexpected background sources from upstream of the decay volume lead to additional cuts and to smaller acceptance (40% of initially expected one). Extra shielding is applied from the end of 2017 and is developed further.

With the current conditions: Total (2016,2017,2018 + 2021,2022) ~ 40 SM events

Assuming small background, it means 16% error instead of 10% (NA62 ultimate goal).

Even 40 SM events will separate the SM and some its extensions, so the discovery potential is not lost.



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

Other results of the last NA62@JINR project period: (2016-2018)

NA48/2 data (2003–2004) analysis results:

- A limit on the lepton number violating decay: $B(K \to \pi \mu^{\pm}\mu^{\pm}) < 8.6\times10^{-11}$ at 90% CL.
- The paper on the **form factors of K_{e3} and $K_{\mu3}$** decays based on NA48/2 data (Dubna group responsibility) is in final edition stage.
- The analysis of the new rare decay $K^{\pm}\to\pi^{\pm}\pi^{0}e^{+}e^{-}$ based on NA48/2 data (first observation) is in its final stage. Preliminary $Br(\pi^{\pm}\pi^{0}e^{+}e^{-}) = (4.22 \pm 0.06_{stat} \pm 0.04_{syst} \pm 0.13_{ext})\times10^{-6}$
- The study of $K_{\mu4}^{00}$ rare decay (first observation) on the basis of NA48/2 data is in progress.

NA62 (R_K) data (2007) analysis results:

- π^{0} electromagnetic transition **form factor slope** $a=(3.68\pm0.57)\times10^{-2}$.
- Limits on the squared matrix element $|U_{\mu4}|^2$ describing the mixing between the muon and heavy neutrino states, for the **heavy neutrino** masses in the range 300-375 MeV/c^2.

Methodical and theoretical results in 2016-2018

- **Software tools** for NA62 collaboration: interactive straw map, straw timing stability monitor, straw wires and tubes positioning control.
- **A review** of the kaon decay studies in NA48, NA48/1, NA48/2 is published.
- NA62 drift **chamber design and acquisition system are described** in journal papers.
- **Straw stability under internal pressure** is studied and a technique of its prediction is developed
- **Wire position measurement** technique with an optical microscope is developed.
- A **device for the straw tubes production is described** in a journal paper.
- Interactions of **polarized mesons with nucleons** are studied theoretically.

- Obtained results in 2016-2018 were presented at the international conferences, including 12 presentations given by the representatives of JINR group.
- During the NA62 experimental runs in 2016-2018 the JINR group members will perform in total about 250 shifts.
- The series of scientific works of Dubna group “Development and construction of gas-filled detectors based on a new type of straw tubes for operation in vacuum in the track spectrometer of the NA62 experimental set-up” was awarded a first JINR prize (2017) in the nomination of scientifically-methodical works.
- Two patents for inventions are obtained by the JINR group members.

Journal papers (2016-2018)

1) Eduardo Cortina Gil *et al.* The beam and detector of the NA62 experiment at CERN. JINST 12 (2017) no.05, P05025.
2) J.R.Batley *et al.* Searches for lepton number violation and resonances in $K^{\pm}\to\pi\mu\mu$ decays. Phys.Lett. B769 (2017) 67-76.
3) C.Lazzeroni *et al.* Measurement of the π^0 electromagnetic transition form factor slope. Phys.Lett. B768 (2017) .
4) C.Lazzeroni *et al.* Search for heavy neutrinos in $K^{+}\to\mu^{+}\nu$ decays. Phys.Lett. B772 (2017) 712-718.
5) A.Cecucci, E.Goudzovski, V.Kekelidze, D.Madigozhin, I.Potrebenikov. Kaon decay studies at CERN SPS in the last decades. Phys.Part.Nucl. 47 (2016) no.4, 567-590.
6) N.Azorskiy *et al.* A drift chamber with a new type of straws for operation in vacuum. Nucl.Instrum.Meth. A824 (2016) 569-570.
7) N.Azorskiy *et al.* The NA62 spectrometer acquisition system. JINST 11 (2016) no.02, C02064.
8) L.Glonti *et al.* Determination of the anode wire position by visible light in a new type straw for NA62 experiment tracker. Nucl.Instrum.Meth. A824 (2016) 532-534.
9) N.I.Azorskii *et al.* New type of drift tubes for gas-discharge detectors operating in vacuum: production technology and quality control. Phys.Part.Nucl.Lett. 14 (2017) no.1, 144-149.
10) E.Chudakov, S.Gevorkyan, A.Somov. Photoproduction of ω mesons off nuclei and impact of polarization on the meson-nucleon interaction. Phys.Rev. C93 (2016) no.1, 015203.
11) L.Afanasyev, S.Gevorkyan, O.Voskresenskaya. Production of dimeson atoms in high-energy collisions. Eur.Phys.J. A53 (2017) no.4, 78.

Preprints (2016-2018)

- E.Cortina Gil *et al.* Search for heavy neutral lepton production in K^{+} decays. CERN-EP-2017-311. 2017. 15 pp.
- L.Glonti *et al.* Longitudinal tension and mechanical stability of a pressurized straw tube. JINR preprint E1-2017-20. 20 pp.

Conference talks (2016-2018)

1) D.Madigozhin. New and recent results from NA48/2. Proceedings of the 52nd Recontres de Moriond. QCD and High Energy Interactions. ARISF. 2017.
2) S.Gevorkyan. The impact of vector mesons polarization on meson-nucleon interaction. 16th Workshop on High Energy Spin Physics (DSPIN-15). J.Phys.Conf.Ser. 678 (2016) no.1, 012033.
3) S.Gevorkyan. Vector mesons polarization versus color transparency. 23rd International Baldin Seminar on High Energy Physics Problems : Relativistic Nuclear Physics & Quantum Chromodynamics. (Baldin ISHEPP 23). EPJ Web Conf. 138 (2017) 08004.
4) Yu.Potrebenikov. A new system of STRAW chambers operating in vacuum for the NA62 experiment. J.Phys.Conf.Ser. 800 (2017) no.1, 012047.
5) S.Shkarovskiy. NA62 spectrometer to search for $K^+ \to \pi^+ \nu \bar{\nu}$. 14th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD16). Siena. Italy. 2016. JINST 12 (2017) no.02, C02027.
6) S.Shkarovskiy. Recent measurement of Kl3 form factors at NA48. 23th International Workshop on High Energy Physics and Quantum Field Theory (QFTHEP 2017). EPJ Web Conf. 158 (2017) 03007.
7) S.Shkarovskiy. Recent QCD-related Results from Kaon Physics at CERN (NA48/2 and NA62). 9th Workshop "Excited QCD" 2017. Acta Phys.Polon.Supp. 10 (2017) 1153-1158.
8) S.Shkarovskiy. Recent results from the NA48 experiment at CERN. 3rd International Conference on Particle Physics and Astrophysics (ICPPA 2017). J.Phys.Conf.Ser. 934 (2017) no.1, 012031.
9) E.Goudzovski. Kaon experiments at CERN: recent results and prospects. 14th International Workshop on Meson Production, Properties and Interaction (MESON 2016). EPJ Web Conf. 130 (2016) 01019.
10) E.Goudzovski. Neutral pion form factor measurement at NA62. 38th International Conference on High Energy Physics (ICHEP 2016). PoS ICHEP2016 (2017) 642.
11) D.Madigozhin *et al*. Searches for lepton number violation and resonances in the $K^{\pm} \to \pi\mu\mu$ decays at the NA48/2 experiment. New Trends in High-Energy Physics. Budva, Becici, Montenegro. 2016.
12) A.Zinchenko *et al*. Searches for lepton number violation and resonances in the $K^{\pm} \to \pi\mu\mu$ decays by NA48/2 at CERN. 14-th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon. July 25-30, 2016, Kyoto, Japan.

Patents

- S.A.Movchan *et al*. A device for the production of cylinder tubes for the gas-filled drift detectors of ionizing radiation. Patent #2555693. 8.06.2016.
- L.Glonti *et al*. A device for the measurement of wire positions in gas wire chambers. Patent #2602492. 15.09.2016.

NA62 JINR group plans for 2019-2021

- Fine calibration and alignment of straw detector on the basis of collected data
- Improvement of the straw detector Monte Carlo simulation used for the main NA62 analysis
- Participation in the analysis of specific background sources for $K^+ \to \pi^+ \nu \bar{\nu}$
- Diagnostics and necessary repair of the Spectrometer straw chambers and their low and high voltage power supply during the shutdown in 2019-2020
- Participation in the next NA62 data taking run in 2021 (including Spectrometer maintenance)

Additional goals for the JINR group analysis

- Search for the Heavy Neutral Lepton in $K^+ \to e^+$ and $K^+ \to \mu^+$ topologies with the measured kaon and lepton momenta.
- Rare four-lepton decays $K^+ \to e^+ \nu \mu^+ \mu^-$, $K^+ \to e^+ \nu e^+ e^-$, $K^+ \to \mu^+ \nu e^+ e^-$ and $K^+ \to \mu^+ \nu \mu^+ \mu^-$ (not yet observed) with the branching ratios of the order of 10^{-8} (ChPT checks).
- Search for the forbidden modes $K^+ \to e^- \nu \mu^+ \mu^+$, $K^+ \to \mu^- \nu e^+ e^+$ (SM check).
- Search for the Goldstone fermion superpartners - “sgoldstino” P in decays $K^+ \to \pi^+ \pi^0 P$ ($P \to \gamma\gamma$). [Gorbunov, Rubakov. Phys.Rev.D73:035002,2006]

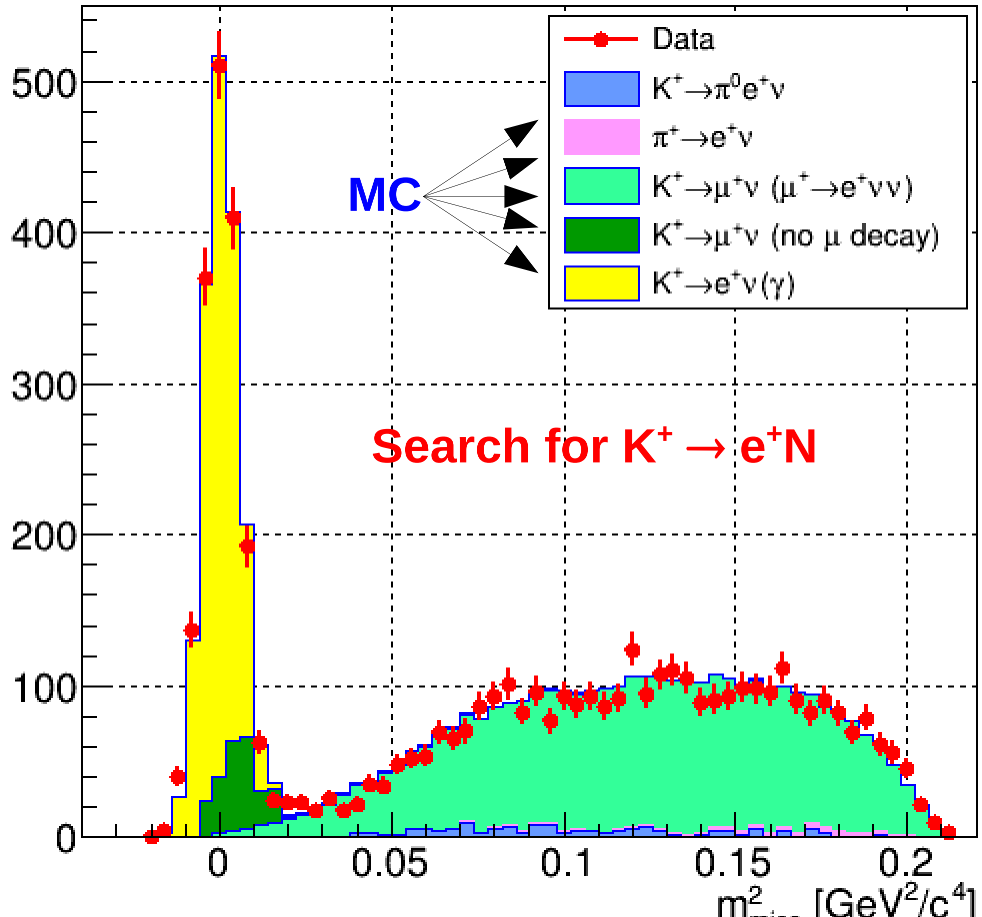
Additional tasks:

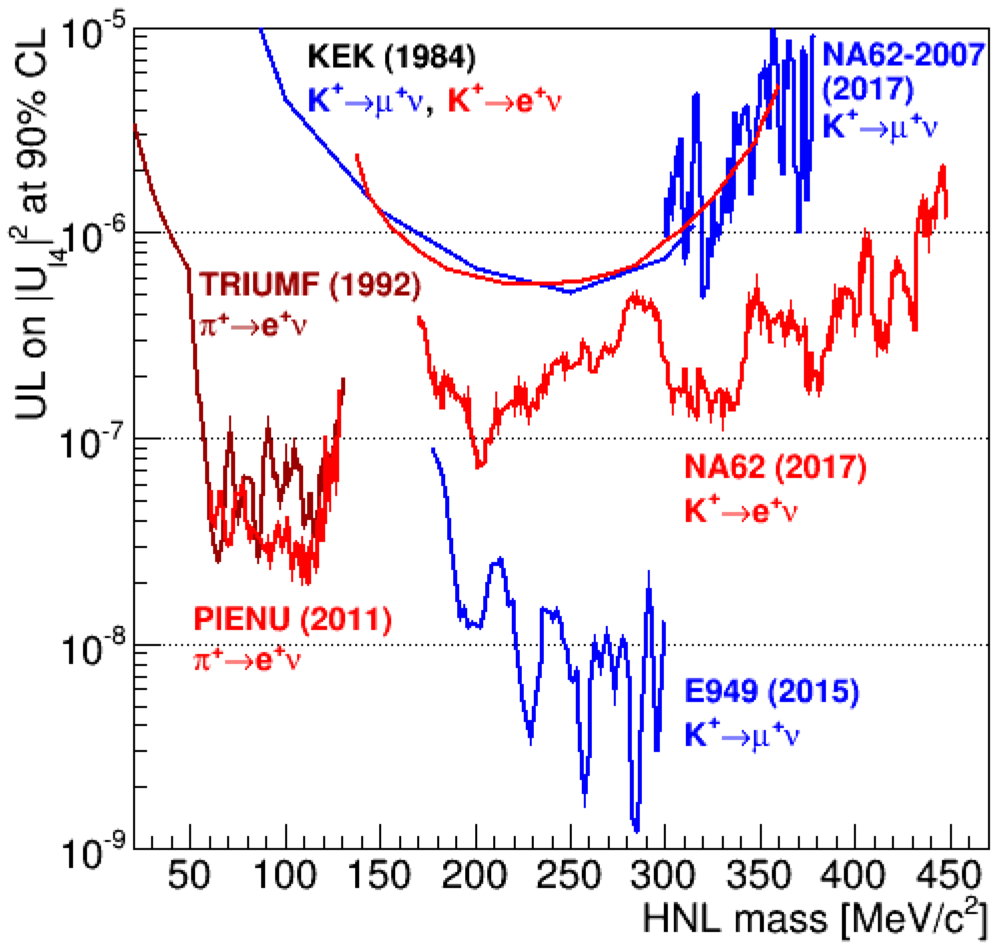
Search for heavy neutral leptons (HNL) in NA62

Some extensions of SM predict the new heavy neutral leptons.

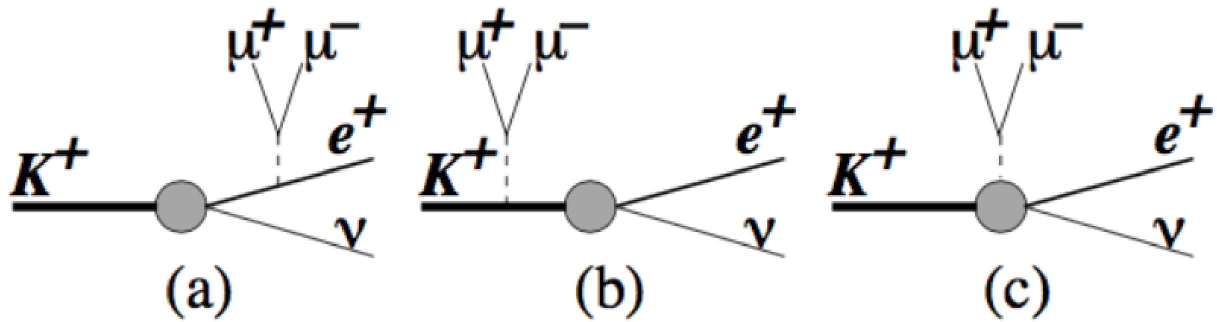
The test data taking in 2015 (1% of the nominal intensity) provided the data for concurrent limit for the mixing parameter $|U_{l4}|^2$, defining the probability of $K^+ \to e^+N$ and $K^+ \to \mu^+N$, where **N** is the heavy neutral lepton. First results are published in Phys.Lett (2017). Analysis of data 2016 and 2017 in progress.

Strategy: search for peaks in the missing mass spectrum (assuming that **N** is long-living and undetectable).





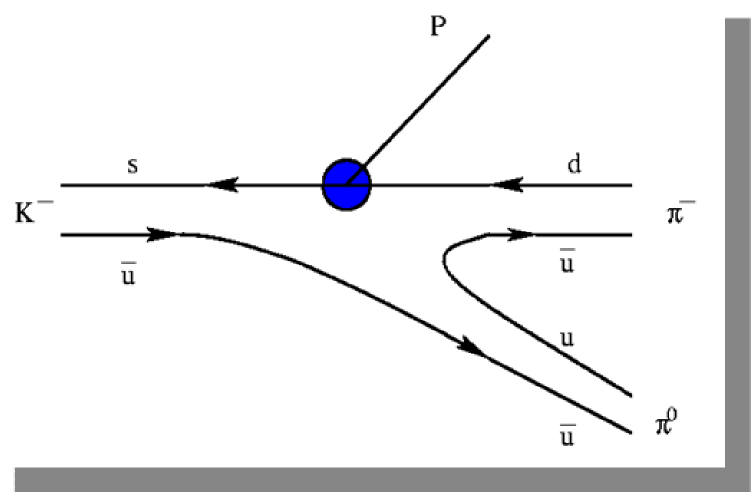
K_{l4} decays

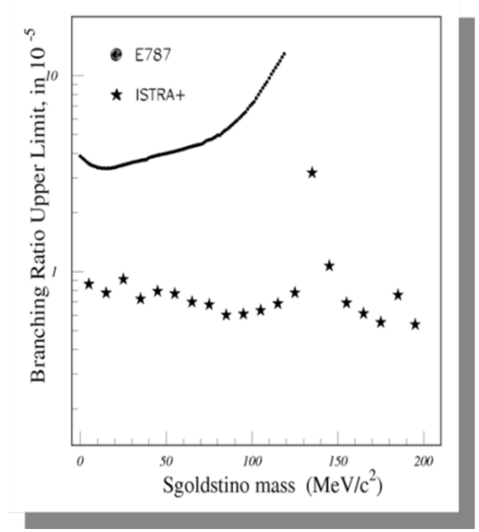


- The internally converted $Kl2\gamma^*$ decays, Kl4, are the source of information for the kaon physics.
- Within the Chiral Perturbation Theory (ChPT) these decays provide a test of the theory and the source of its parameters.
- Inner Bremsstrahlung is helicity-suppressed for $Ke2\gamma^*$ (better 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.





Analysis strategy **assuming the present NA62 running conditions (conservative)**

Year	2016	2017	**2018** (now)	2019	2020	2021	2022	Status after 2022
	Data taking			Long Shutdown 2		Data taking		
$\pi\nu\nu$ SM events added	0.27 (1 is found)	10	10 Paper (data 2016)	-	- Paper (2017-18)	10	10	**40** **(< 100)** **Papers, a new draft**
Heavy neutrino (limits)	Competitive Statistics, paper		Essential improvement		paper		improvement	Series of papers and a new draft
$K^+ \to e^+\nu\mu^+\mu^-$ (Br)	Competitive statistics	Essential improvement			paper		improvement	Paper
$K^+ \to \mu^+\nu e^+e^-$ (Br)		Competitive statistics	Essential improvement			paper	improvement	Paper
$K^+ \to \mu^+\nu\mu^+\mu^-$ (Br)			First observation			paper	Essential improvement	Paper and a new draft
$K^+ \to e^+\nu e^+e^-$ (Br)			Competitive statistics			paper	Essential improvement	Paper and a new draft
Light sgoldstino (limits)			Competitive statistics		The requested extension (3 years)	paper	improvement	Paper

Analyzers involved into NA48/2 are moving now to NA62 analysis (4 experienced physicists). Additionally, 3 young scientists are just now involved into the NA62 analysis.

Full-time equivalent values for JINR participants

Name	FTE	PhD student	Work (apart from common duties like shifts)
D. Baygarashev	1.0	+	Data quality control, calibration, physical analysis
A. Baeva	0.5		Physical analysis
S. Gevorkian	1.0		Theory of rare decays, MC models development
L. Glonti	0.5		Spectrometer calibration and performance checks.
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
A.Korotkova	0.7	+	Physical analysis
D.Madigozhin	1.0		MC development, data quality control, analysis
M. Misheva	0.3	+	Physical analysis
N. Molokanova	0.9		Physical analysis
S. Movchan	0.2		Hardware development and support
I. Polenkevich	0.0		Currently in a long vacation (child)
Yu. Potrebenikov	0.5		Project leader
S. Shkarovskiy	1.0	+	DCS development, hardware support, analysis
TOTAL	**9.1**		

Form № 29

Cost calculation from JINR budget.

№	Expenses item	Unit	2019	2020	2021	2019 – 2021
	Direct costs for the project					
0.	Operational costs	K USD	35	35	35	105
1.	Accelerators					
2.	Design office					
3.	Workshops					
4.	Materials and consumables	K USD	5	5	10	20
5.	Equipment	K USD	10	10	15	35
6.	Payments for R&D works performed according contracts	K USD				
7.	Travel expenses, including:	K USD	53	53	114	220
	a) to countries a) outside the ruble zone	K USD	*50*	*50*	*110*	*210*
	b) to the ruble zone countries	K USD	*3*	*3*	*4*	*10*
	c) according to protocols					
	Total direct expenses	**K USD**	**103**	**103**	**174**	**380**

Project leaders: Kekelidze V.D.

Potrebenikov Yu.K.

For comparison: In 2016-2018 the JINR expenses for NA62 were **504.7 K USD**

Additionally, ~ 50 K USD paid by the Collaboration for JINR group members travels and work on the Spectrometer.

Main expenses in 2019-2021:

- participation in the run 2021 and NA62 maintenance.
- development of straw detectors and on-line software systems.
- contributions to the NA62 common fund.
- computer and technical support of simulation, processing and analysis of experimental data.

SPARES

NA48/2 and NA62 data (collected in 2003–2010) analysis done in parallel with the NA62 data taking (during 2016-2018):

- NA48/2 (2003-2004): an upper limit on the lepton number violating decay: B(**$K \to \pi\ \mu^{\pm}\mu^{\pm}$**) < 8.6×10^{-11} at 90% CL. The upper limits for the products of branching ratios B(**$K^{\pm} \to \mu^{\pm} N_4$**)B($N_4 \to \pi\mu$) and B(**$K^{\pm} \to \pi^{\pm} X$**)B($X \to \mu^+\mu^-$): 10^{-9} and 10^{-11} for the resonance lifetime below 100 ps.
- NA62 (2007): a measurement of **π^0** electromagnetic transition **form factor slope** $a=(3.68 \pm 0.57) \times 10^{-2}$.
- NA62 (2007): A **peak** search in the reconstructed missing mass spectrum of **$K^+ \to \mu^+\nu$** . Limits in the range 2×10^{-6} to 10^{-5} on the squared matrix element $|U_{\mu 4}|^2$ describing the mixing between the muon and heavy neutrino states, for the heavy neutrino masses in the range 300-375 MeV/c^2.
- The paper on the **form factors of K_{e3} and $K_{\mu 3}$** decays based on NA48/2 data (Dubna group responsibility) is in preparation after the internal reviewing.
- The analysis of the new rare decay **$K^{\pm} \to \pi^{\pm}\pi^{0}e^{+}e^{-}$** based on NA48/2 data (first observation) is in its final stage. Preliminary Br($\pi^{\pm}\pi^{0}e^{+}e^{-}$)= $(4.22 \pm 0.06_{stat} \pm 0.04_{syst} \pm 0.13_{ext}) \times 10^{-6}$.
- The study of **$K_{\mu 4}^{00}$** rare decay on the basis of NA48/2 data is in progress (first observation), a preliminary branching ratio is almost ready.
- The analysis of the **four-lepton kaon decays** is started on the basis of the NA62 data collected in 2016 and 2017 years.

Costs in the past

Total NA62 setup creation - **40 million CHF**; JINR contribution - **1.5 million CHF**.

On previous stages of the NA62 project at JINR 12 experts of different fields have been involved. We propose to involve 2 more PhD students for the third part of the Project.

The total JINR expenses during 2016-2018 years to the third stage of the project (the theme of 1096) are **$504.7k**.

About **$10k** have been paid by CERN and collaboration NA62 for the support of the straw detector;

about **$10k** were allocated by CERN for travel support of the JINR experts to CERN.

30K CHF in 2016 for JINR engeneers to support of common works during the preparation of the experiment.

Travel expenses (no data taking)

Item	Numb. of meeting	Numb. of people	Cost for 1 travel						Costs
			Days	Ticket	Subsistense	Insurance	Other	In total	
Collaboration meetings at CERN	3	2	6	400	140	10		1250	7500
Collaboration meetings out of CERN	1	2	6	400	175	10	400	1860	3720
Analysis meetings at CERN	4	2	6	400	140	10		1250	10000
International conferences out of Russia	5	1	6	500	160	10	400	1870	9350
International conferences in Russia	2	1	6	200	100			800	1600
Joint theoretical investigatons	1	1	30	550	90	40		3290	3290
Detector remount and slow control upgrade	1	1	35	500	140	40		5440	5440
Gas system upgrade	1	2	14	500	140	20		2480	4960
Guests receptoon	1	1	30	500	70	40		2640	2640
	1	2	7	500	70	10		1000	2000
Car at CERN									2200
Per diem in Russia for travels outside Russia			300						300
									53000

Kaon decays at CERN

- Prehistory: NA31 (1984-1990) – First evidence of direct CPV with K_L/K_S beams.

JINR participation

Experiment	Data taking	Main goal	Beams
NA48	1997-2001	direct CPV (ε'/ε)	K_L/K_S
NA48/1	2002	Rare K_S and hyperon decays	K_S
NA48/2	2003-2004	Direct CPV in charge asymmetry	K^+/K^-
NA62 (R_K)	2007	Test of μ/e universality $R_K = K_{e2}/K_{\mu2}$	K^+/K^-
NA62	2014-2018 prolongation after 2020?	$K^+ \to \pi^+ \nu\bar{\nu}$ other rare kaon decays.	K^+

Michal Hnatic (MH) :
Weaknesses and potential risks? Strategies for risk scenarios?
Why the aim is not achieved yet?

Answer: The largest risks should be foreseen at the beginning of the project: there are few completely new detector elements, and if the key ones would not be built (for example, Straw spectrometer or Gigatracker), the experiment would be completely lost. Nevertheless, this is our job – new science may be done only with the challenging and risky projects.

In fact, all the problems that were expected from the very beginning and were considered in the Technical Design Progect, have been solved by means of **delays in data taking** (one reason), and JINR group never was responsible for delays. 2014,2015 and the most of 2016 were the setup building stage with a completely operational Spectrometer.

From the other hand, two more problems have appeared without any scenarios (second reason why the aim is not achieved yet):

1) Unexpectedly high variations of the beam intensity (it is also provided for LHC, and we are just a second priority user). Leads to higher maximum intensity on detectors = problems with back-end electronics = we must limit the intensity per burst (40% in 2016 → 60% in 2017).

2)The new sofisticated source of background has been discovered (related to upstream interactions and decays) that enforce us to decrease the fiducial volume => acceptance is smaller than in the design.

The performed analysis of 2016 data show that no other risks of this kind may appear, and only improvements are expected.

As a result, the goal of ~ 100 events may be achieved only with the run prolongation in 2021, at least for 2 years (the improvements in electronics firmware and upstream particles shielding are in progress).

Realistic risks for now (apart from the WW3 etc...):

- There will be no run prolongation after LS2 (not so high probability);

  spare strategy:

  - analysis of the collected data that will give 20 SM events of $\pi\nu\nu$

  - other additional analyses with the available statistics.

- There will be not enough manpower for the fast finishing of all the additional analyses.

  spare strategy:

  - we try to attract even more brilliant young people

  - we will finish all analyses later in parallel with another projects (currently we still work on the NA48/2 data collected in 2003/2004).

MH: what is a fraction of the accumulated data analyzed up to now?
Why 5% of 2016?

Before the 8 of March it was officially only 5% of 2016. It was used for the procedure testing and is excluded from the blind analysis (that is why it was so small).

Now it is the complete 2016 data set (very beginning of full operation), that is ~ 1% of expected (2016-2018) or ~2-3% of the collected data (2017 mainly).

MH: Why is there a schedule break in data collection for 2 years?

LS2 in CERN

MH: What is the target precision, what are the conditions should be met?
Time of running at what luminosity?

Target precision is still 10% for BR($K \rightarrow \pi\nu\nu$).

Accelerator beam intensity itself is not a limiting resource (it is larger that needed) – the burst quality is an issue (variations) that enforces us to diminish the collimator slits, otherwise electronics can't process the data flux.

The realistic request taking into account the expected improvements is 2 years more starting from 2021, and the prolongation process in CERN is in progress.

MH: When enough data will be collected for sgoldstio?

Roughly proportional to $\pi\nu\nu$ (100 SM $\pi\nu\nu$ – 50 sgoldstino for the upper limit of 10^{-8} if no unexpected problems will appear).

MH: How the group will participate in the experiment?

Straw spectrometer is built in the past. Now for the prolongation period (some tasks are overlaid in one person):
- Technical hardware support of the Spectrometer (3 persons).
- Spectrometer on-call expert during the data taking, Detector Control System development and maintenance. (1)
- Software for the data quality control and monitoring development and maintenance. (2)
- Participation in the MC development in the Spectrometer part (1)
- Physical analysis: specific background sources for $\pi\nu\bar{\nu}$, additional physical goals for our group listed above (10 persons with a different intensity).

MH: Are there JINR participants who could be the responsible for the paper writing?

Goudzovskiy and Madigozhin yet were the responsible writers in the past for NA48/NA62 and both are responsible now for the currently prepared papers. Shkarovskiy is currently responsible for a NA48/2 paper. But we expect also that at least each of our PhD students will become a responsible author for his analysis.

MH: New PhD students?
Yes, we need more analysers now and promise a good prospects for PhD thesis, so we currently increase our group by at least two new PhD students.