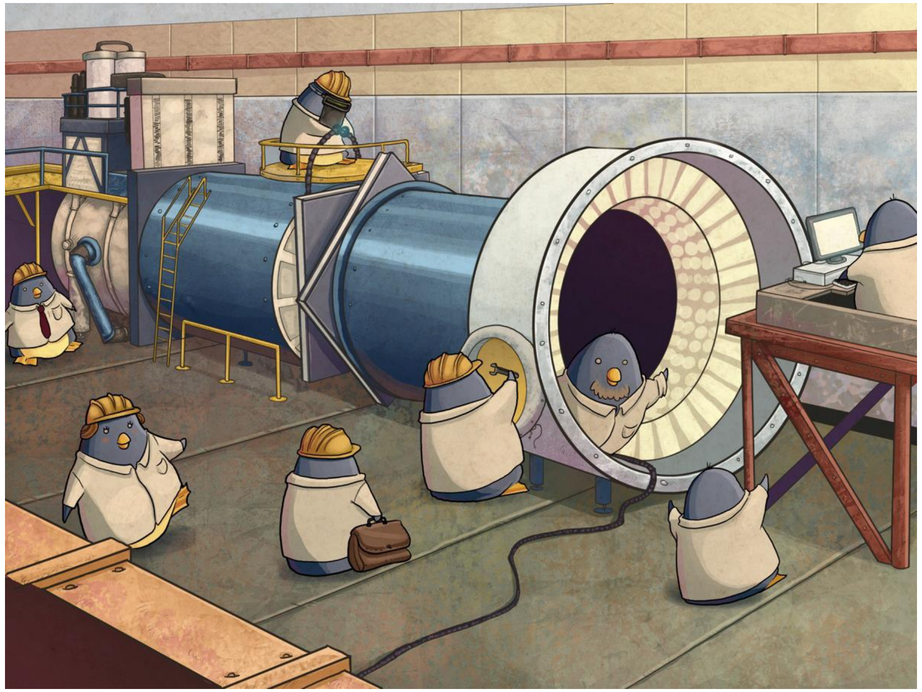
Latest results and precision measurements from the NA62 experiment

Jacopo Pinzino



INFN Pisa

HADRON23
06/06/23

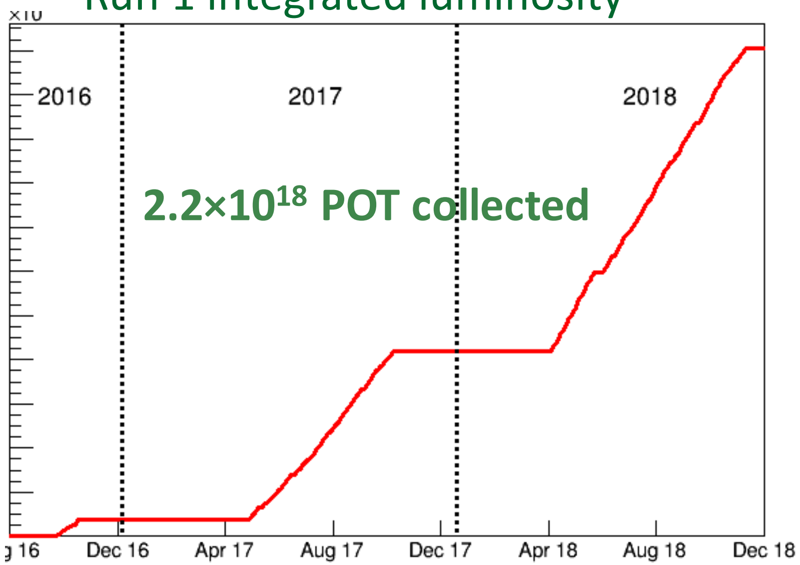
Outline

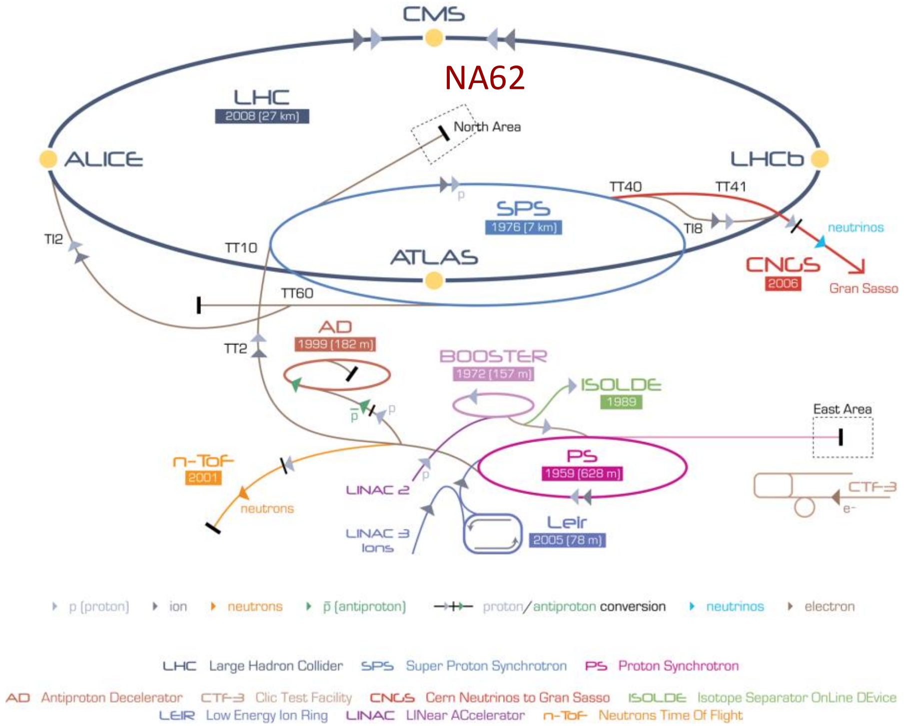
- The NA62 Experiment
- Measurement of the ultra rare $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ process [JHEP06(2021)093]
- Precision measurements of rare decays:
  - $K^+ \rightarrow \pi^+ \mu^+ \mu^-$ [JHEP 11 (2022) 011]
  - $K^+ \rightarrow \pi^+ \gamma\gamma$ [preliminary result]
- Searches for LFV/LNV processes: [PLB 797 2019 134794], [PRL 127 2021 13 131802], [PLB 830 2022 137172]
- Exotic searches (2021 data): $A' \rightarrow \mu^+\mu^-$, $A' \rightarrow e^+e^-$, $K^+ \rightarrow \pi^+ e^+ e^- e^+ e^-$ [preliminary results]

The NA62 Experiment

- NA62: High precision fixed-target Kaon experiment at CERN SPS
- Main goal: measurement of BR($K^+ \rightarrow \pi^+ \nu\bar{\nu}$)
- Broader physics program: LFV / LNV in K^+ decays, precision measurements and hidden sector particles searches.

Run 1 integrated luminosity



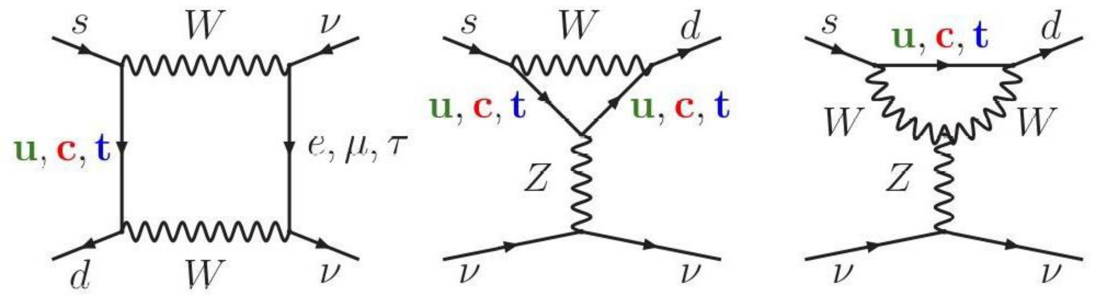


NA62 Timeline

- 2008: NA62 Approval
- 2014: NA62 Pilot Run (partial layout)
- 2015: Commissioning run
- 2016 -2018: NA62 RUN 1
- 2021+: NA62 RUN 2

~ 200 participants from: Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna, GMU-Fairfax, Ferrara, Firenze, Frascati, Glasgow, Lancaster, Liverpool, Louvain, Mainz, Moscow, Napoli, Perugia, Pisa, Prague, Protvino, Roma I, Roma II, San Luis Potosi, Torino, TRIUMF, Vancouver UBC

The $K^+ \to \pi^+ \upsilon\bar{\upsilon}$ decay



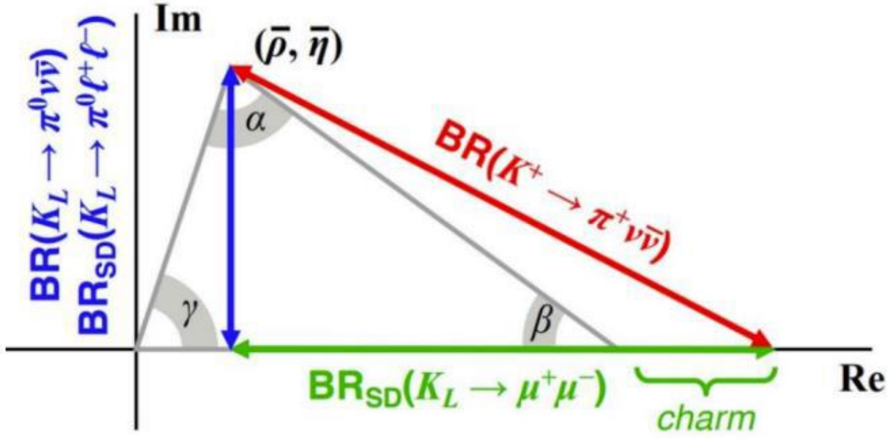
- High sensitivity to New Physics
- FCNC process forbidden at tree level
- Highly CKM suppressed (BR ~ $|V_{ts} x V_{td}|^2$)

- Very clean theoretically: Short distance contribution
- hadronic matrix element extracted from precisely measured BR($K^+ \to \pi^0 e^+ \upsilon$)
- Precise SM predictions:

$$BR(K^+ \to \pi^+ \upsilon\bar{\upsilon}) = (8.60 \pm 0.42) \times 10^{-11}$$

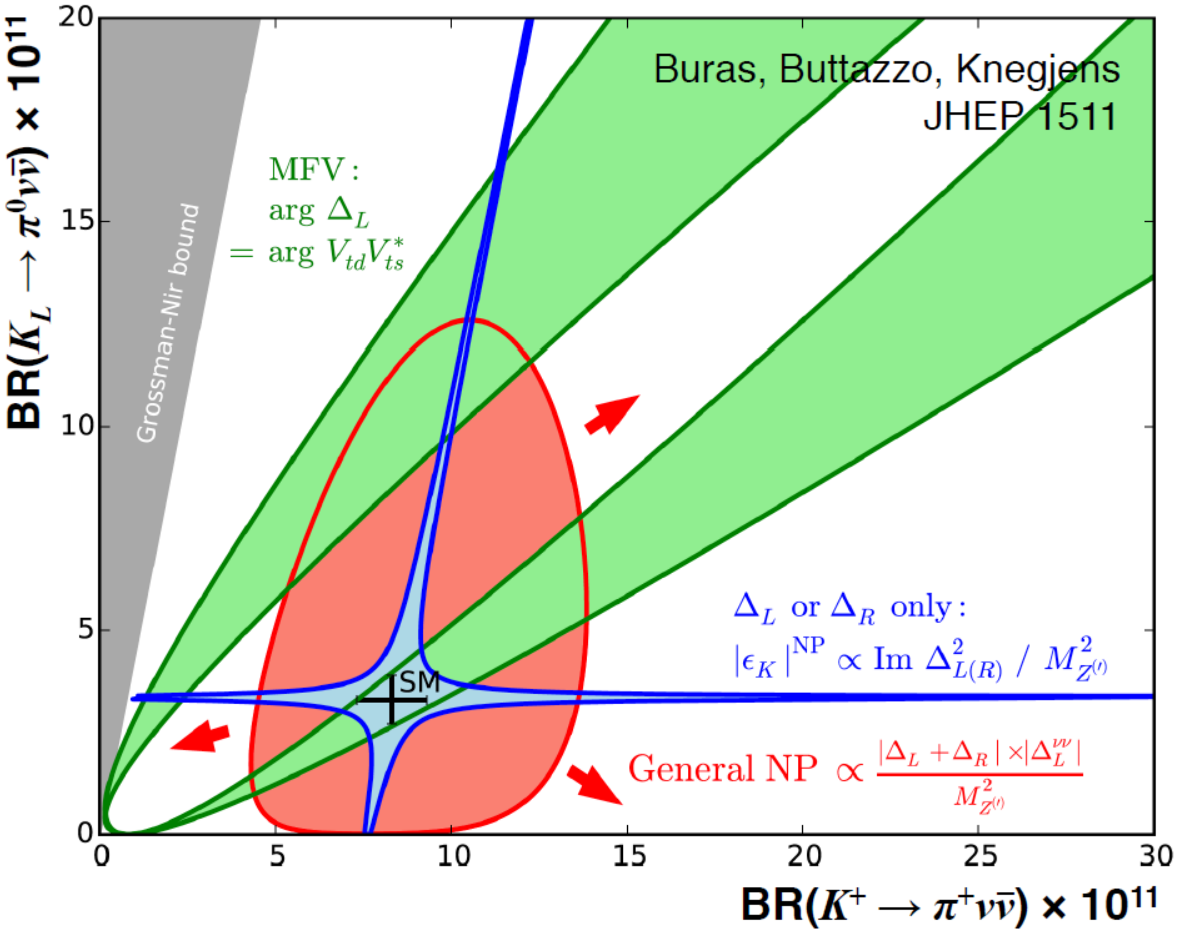
$$BR(K_L \to \pi^0 \upsilon\bar{\upsilon}) = (2.94 \pm 0.15) \times 10^{-11}$$

[Buras et al. arXiv:2205.01118v1]



$K^+ \to \pi^+ \upsilon\bar{\upsilon}$ and New Physics

Measurement of charged ($K^+ \to \pi^+ \upsilon\bar{\upsilon}$) and neutral ($K_L \to \pi^0 \upsilon\bar{\upsilon}$) modes can **discriminate among different NP scenarios**

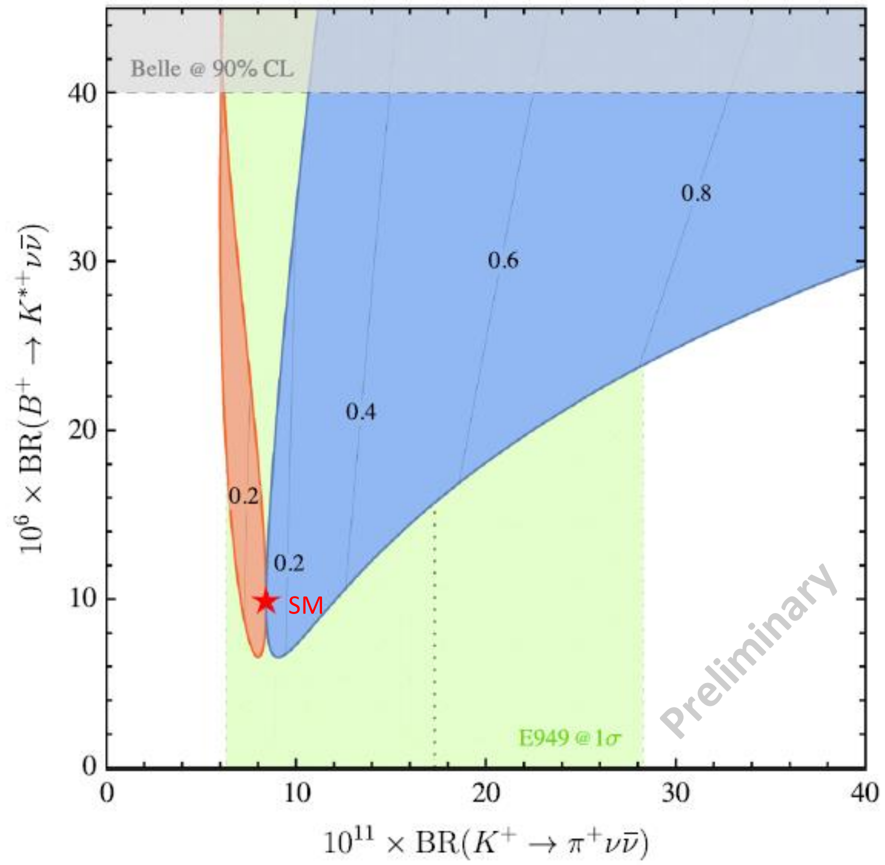


- Models with CKM-like flavor structure (Models with MFV)
  [Buras, Buttazzo,Knegjens, JHEP11(2015)166]
- Custodial Randall-Sundrum
  [Blanke, Buras, Duling, Gemmler, Gori, JHEP 0903 (2009) 108]
- Simplified Z, Z' models
  [Buras, Buttazzo,Knegjens, JHEP11(2015)166]
- Littlest Higgs with T-parity
  [Blanke, Buras, Recksiegel, Eur.Phys.J. C76 (2016) 182]
- LFU violation models
  [Isidori et al., Eur. Phys. J. C (2017) 77: 618]
- Leptoquarks
  [S. Fajfer, N. Košnik, L. Vale Silva, arXiv:1802.00786v1 (2018)]
- MSSM analyses
  [Blazek, Matak, Int.J.Mod.Phys. A29 (2014) no.27],[Isidori et al. JHEP 0608 (2006) 064]

$K^+ \rightarrow \pi^+ \upsilon\bar{\upsilon}$ and the LFU violation

The Measurement of $K^+ \rightarrow \pi^+ \upsilon\bar{\upsilon}$ together with $B^+ \rightarrow K^{*+} \upsilon\bar{\upsilon}$ can **can probe the Lepton-Flavour Universality**

- An interactions responsible for LFU violations can couple mainly to the third generation of left-handed fermions;
- $K \rightarrow \pi\upsilon\bar{\upsilon}$ is the only kaon decays with third-generation leptons (the τ neutrinos) in the final state;

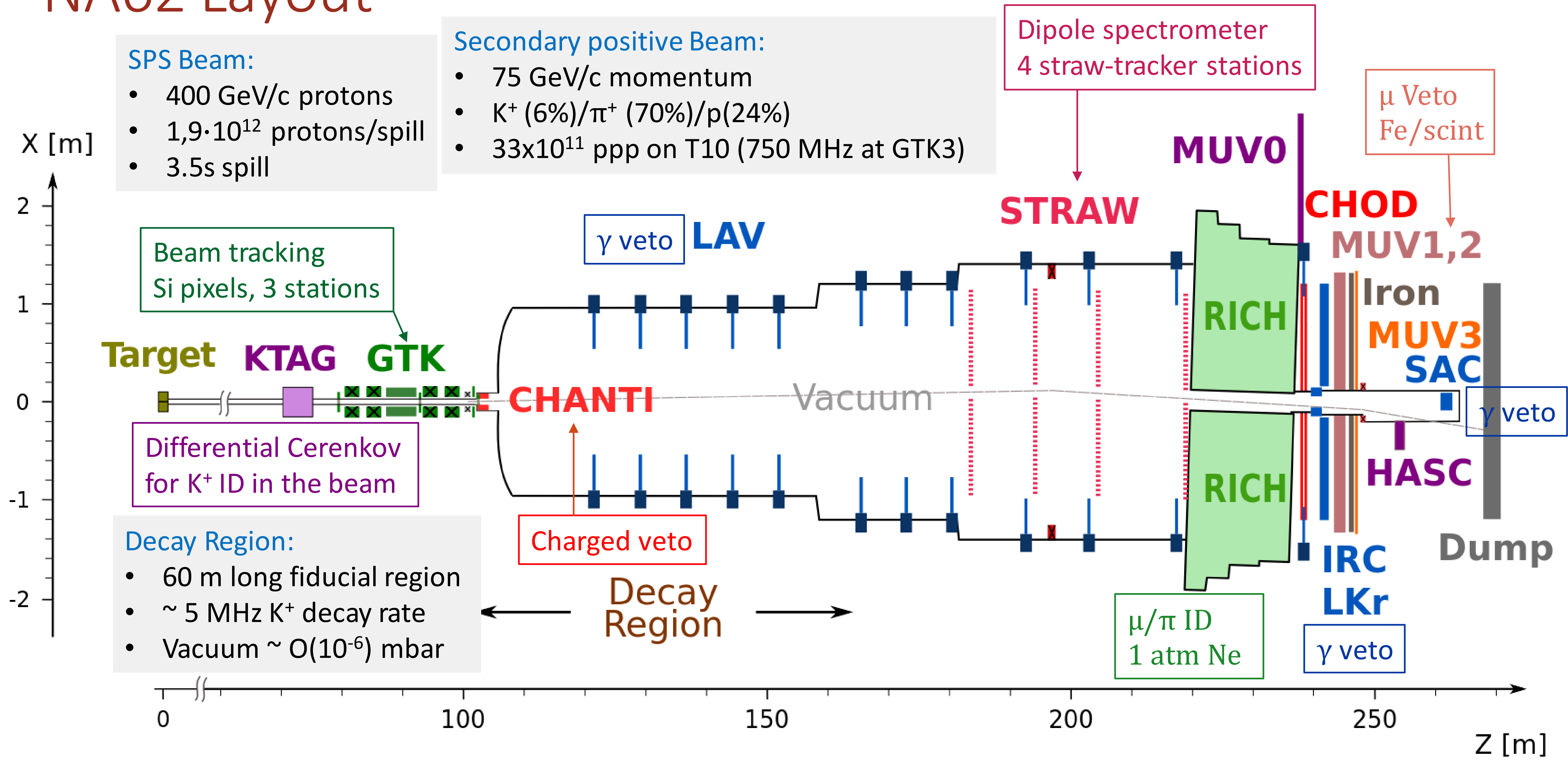


EPJ C (2017) 77: 618

NA62 Layout

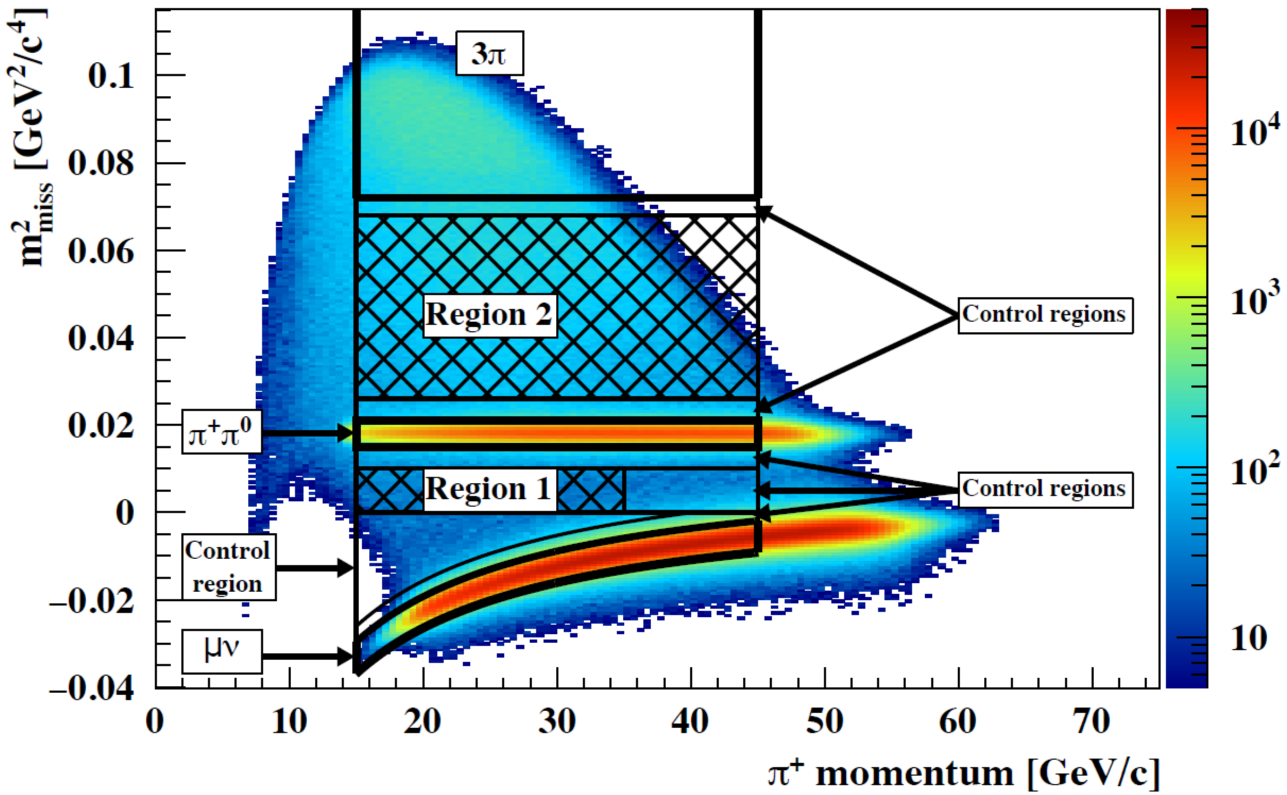
SPS Beam:
- 400 GeV/c protons
- $1{,}9 \cdot 10^{12}$ protons/spill
- 3.5s spill

Secondary positive Beam:
- 75 GeV/c momentum
- K^+ (6%)/π^+ (70%)/p(24%)
- 33×10^{11} ppp on T10 (750 MHz at GTK3)



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

Analysis strategy



Key analysis requirements:

- highly boosted decay (γ ~ 150)
- Large undetectable missing energy (neutrinos)
- All energy from visible particles must be detected
- Hermetic detector coverage
- 2 signal regions in m^2_{miss}
- $15 < P_{\pi^+} < 45$ GeV/c
- 60 m long decay region

Performance:

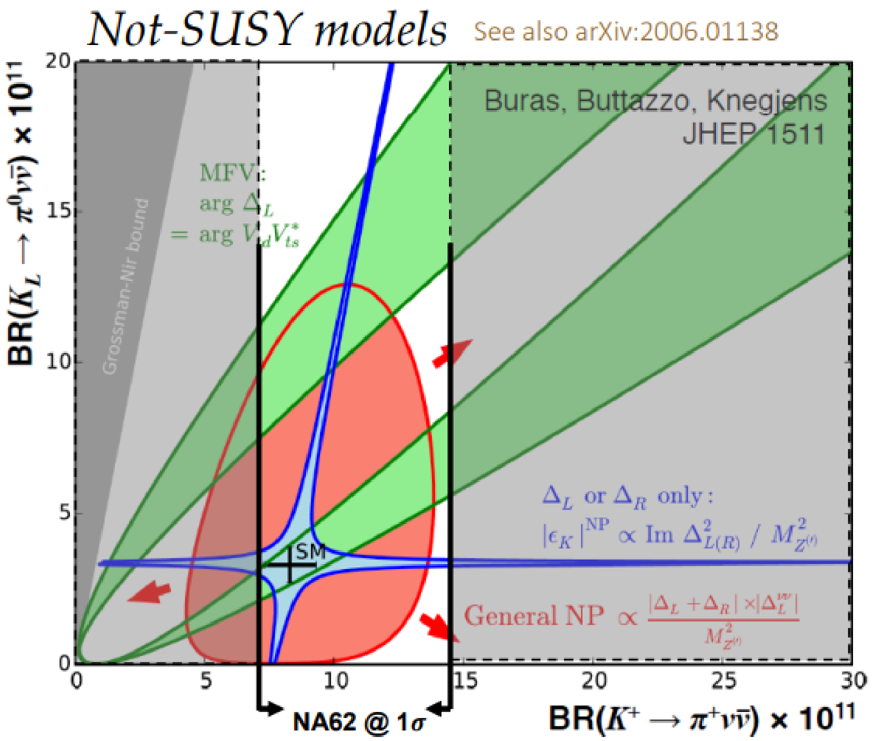
- 10^{-3} GeV^2/c^4 m^2_{miss} resolution
- $> 10^3$ kinematic background suppression
- $> 10^8$ Muon suppression
- $> 10^8$ π^0 (from $K^+ \to \pi^+\pi^0$) suppression
- O(100 ps) timing between sub-detectors

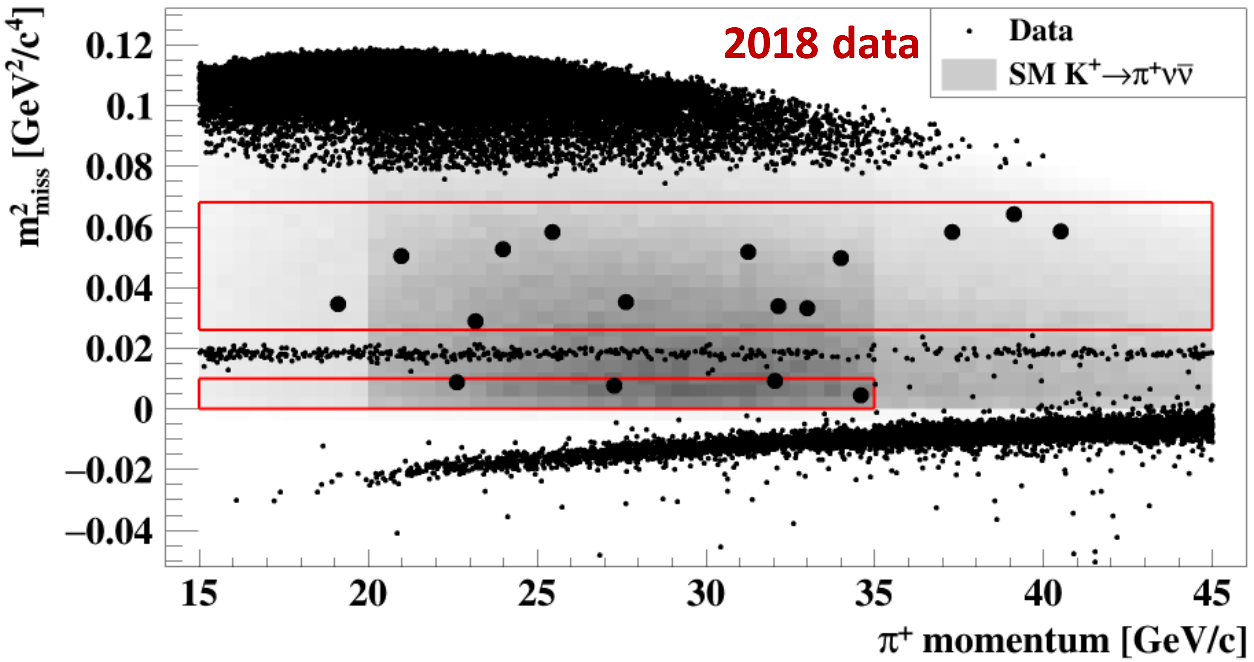
$K^+ \to \pi^+\nu\bar{\nu}$: RUN1 result (2016 -2018)

[JHEP 06(2021) 093]

NA62 Run1 result:

- $N_{\pi\nu\bar{\nu}}^{exp} = 10.01 \pm 0.42_{syst} \pm 1.19_{ext}$
- $N_{bg}^{exp} = 7.03^{+1.05}_{-0.92}$
- $SES = (0.839 \pm 0.053_{syst}) \times 10^{-11}$
- 20 events observed in the signal region
- $Br(K^+ \to \pi^+\nu\bar{\nu}) = (10.6^{+4.0}_{-3.5}{}_{stat} \pm 0.9_{syst}) \cdot 10^{-11}$ at 68% CL (3.4σ significance)





Precision Measurement: $K^+ \to \pi^+\mu^+\mu^-$

FCNC decay described in the scope of ChPT, mediated by one photon exchange $K^+ \to \pi^+ \Upsilon^*$

[Nucl. Phys. B291 (1987) 692–719], [Phys. Part. Nucl. Lett. 5 (2008) 76–84]

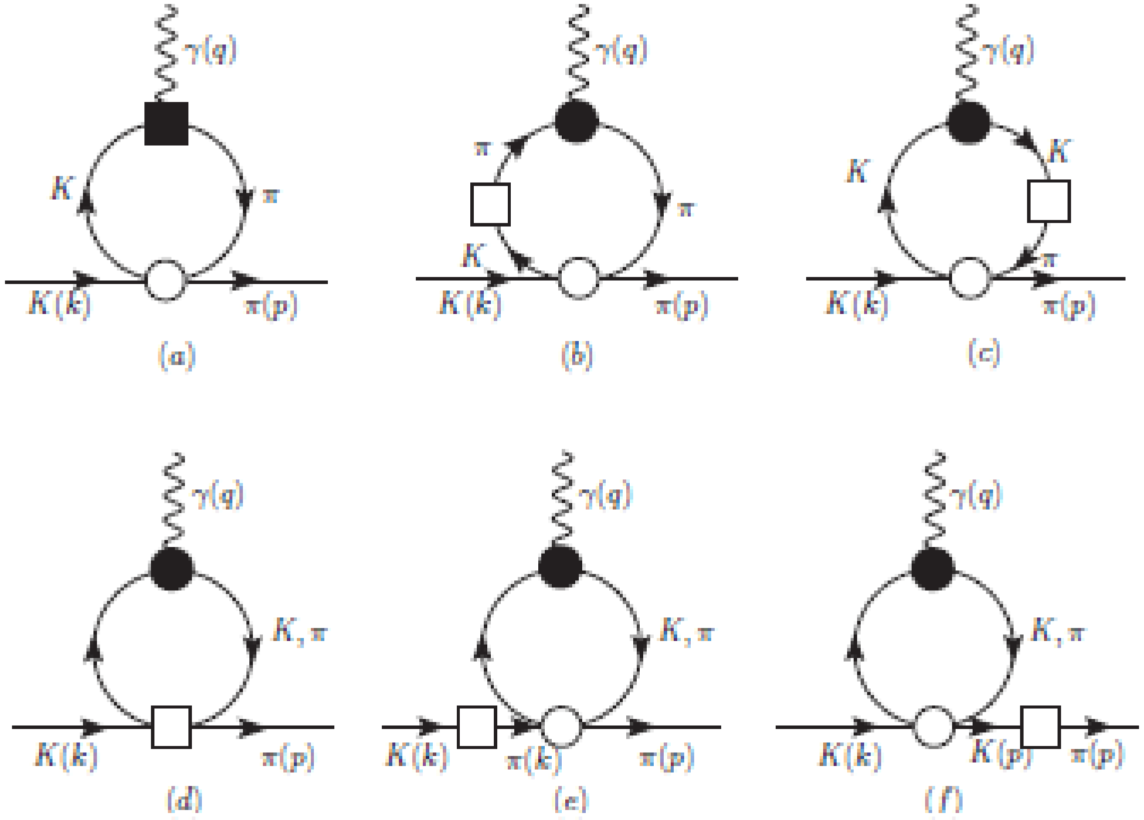
Together with $K^+ \to \pi^+ e^+ e^-$ allow to Test the Lepton Flavour Universality.

[JHEP 02, 049 (2019)]

Form factor parametrization at $O(p^6)$:

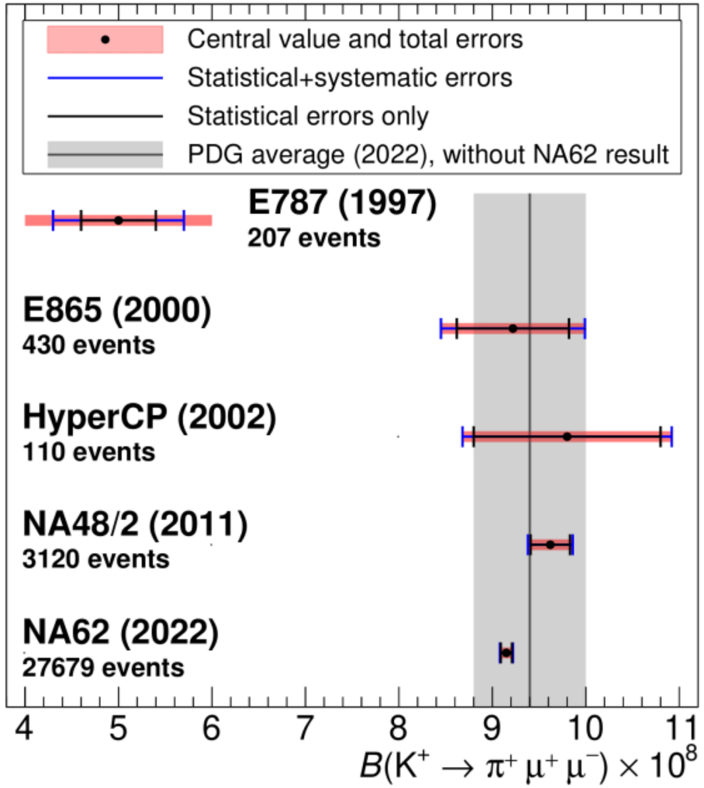
$$W(z) = G_F m_K^2 (a_+ + b_+ z) + W^{\pi\pi}(z)$$

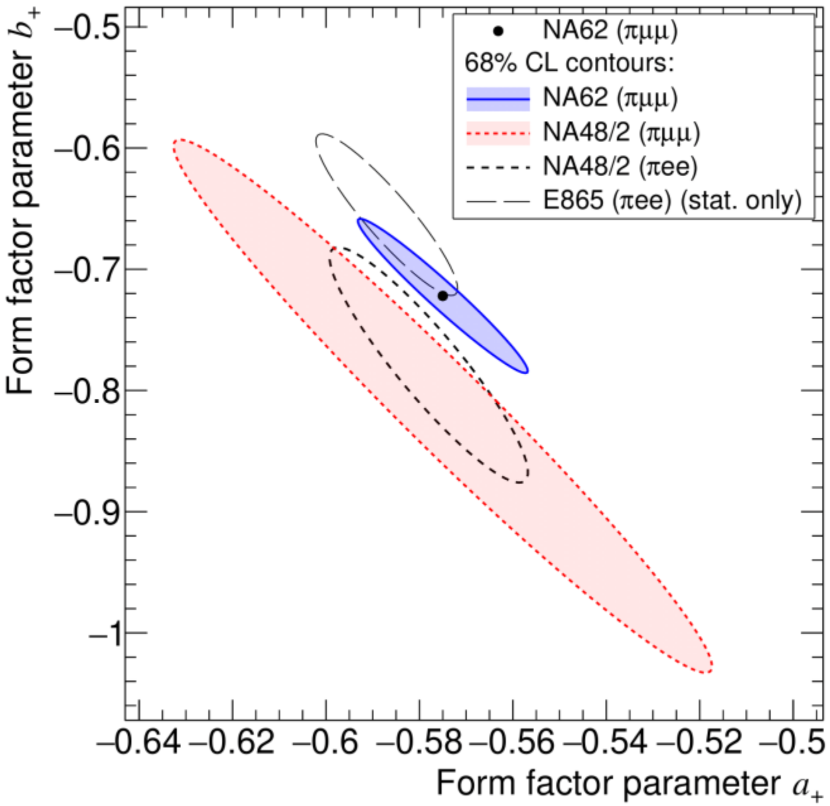
$$z = \frac{m^2(l^+ l^-)}{m_K^2}$$

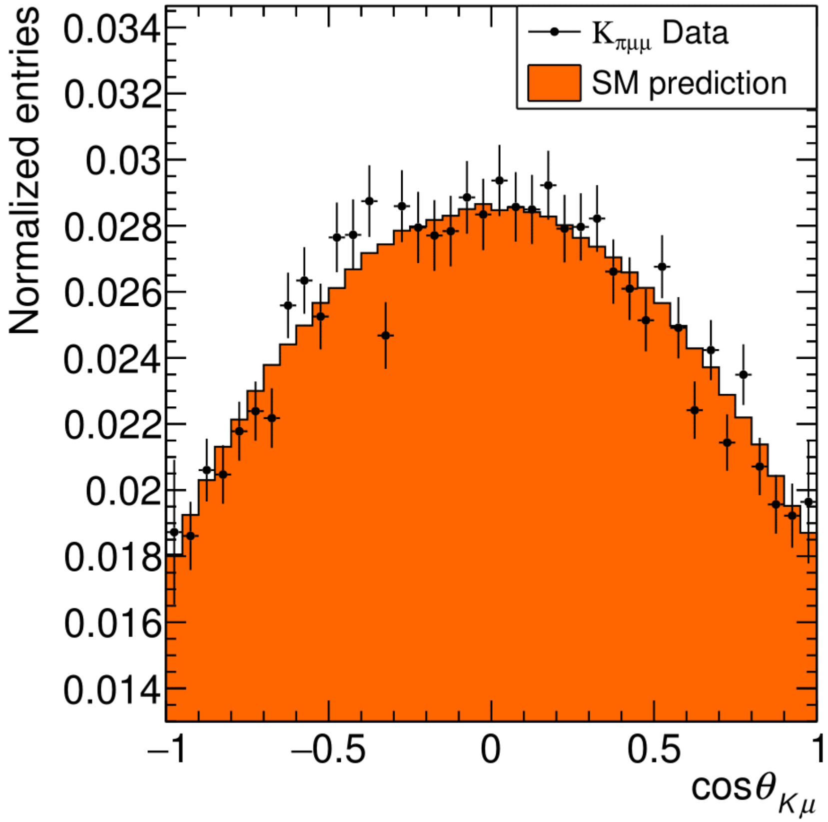


$K^+ \to \pi^+\mu^+\mu^-$: result

$$A_{\mathrm{FB}} = \frac{\mathcal{N}(\cos\theta_{K\mu} > 0) - \mathcal{N}(\cos\theta_{K\mu} < 0)}{\mathcal{N}(\cos\theta_{K\mu} > 0) + \mathcal{N}(\cos\theta_{K\mu} < 0)}$$







$Br_{\pi\mu\mu} = (9.27 \pm 0.11) \cdot 10^{-8}$

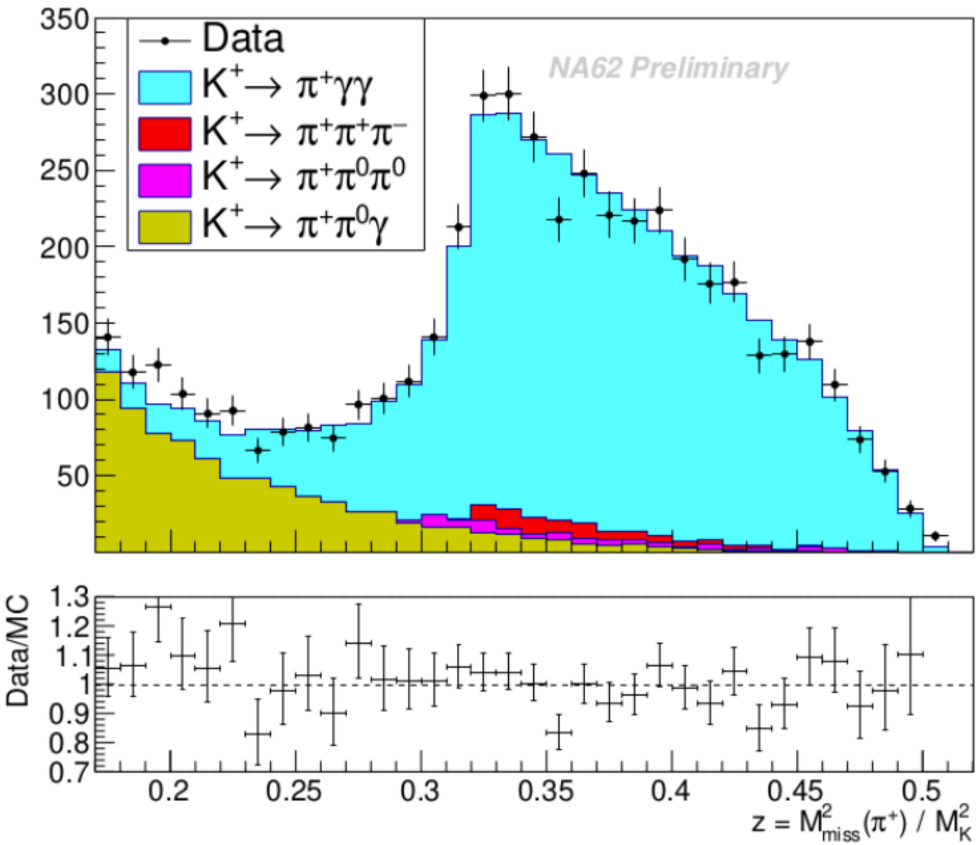
$a_+ = -0.575 \pm 0.012_{stat}$
$b_+ = -0.722 \pm 0.040_{stat}$

$A_{\mathrm{FB}} = 0.0 \pm 0.7_{stat} \times 10^{-2}$

[JHEP 11 (2022) 011]

Precision Measurement: $K^+ \to \pi^+\gamma\gamma$

- Rare decay that allow ChPT tests at $O(p^6)$
- Main kinematic variable: $z = \frac{m^2(\gamma\gamma)}{m_K^2}, y = \frac{P_K(Q_{\gamma_1} - Q_{\gamma_2})}{m_K^2}$
- BR($K^+ \to \pi^+\gamma\gamma$) at $O(p^6)$ parametrized by a real parameter $\hat{c}$



Goal: Measurement of BR($K^+ \to \pi^+\gamma\gamma$) and $\hat{c}$

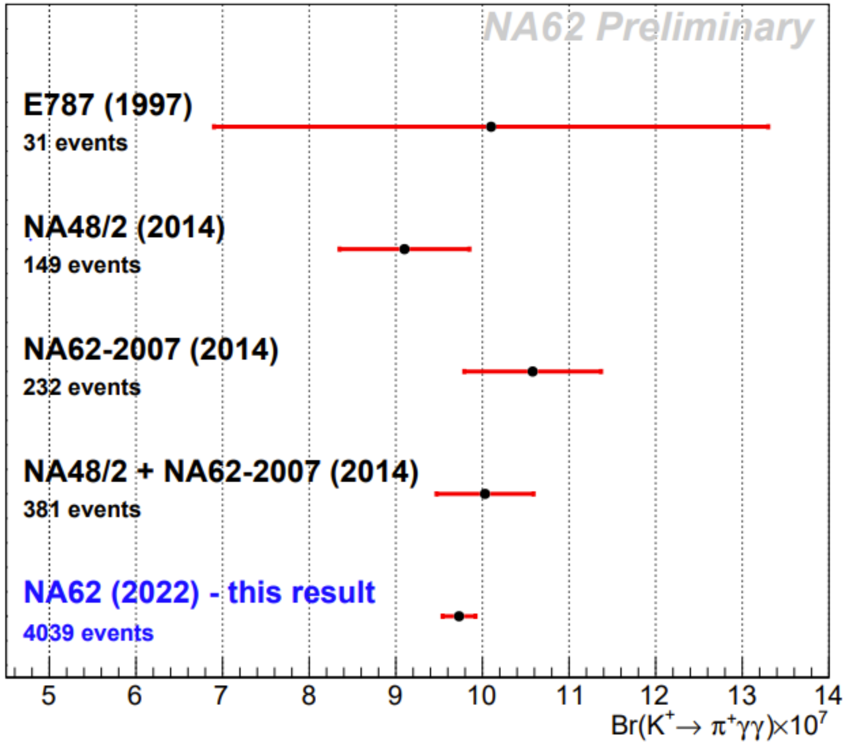
Signal selection: π^+ track matching K^+ track; EM calorimeter γ pair;

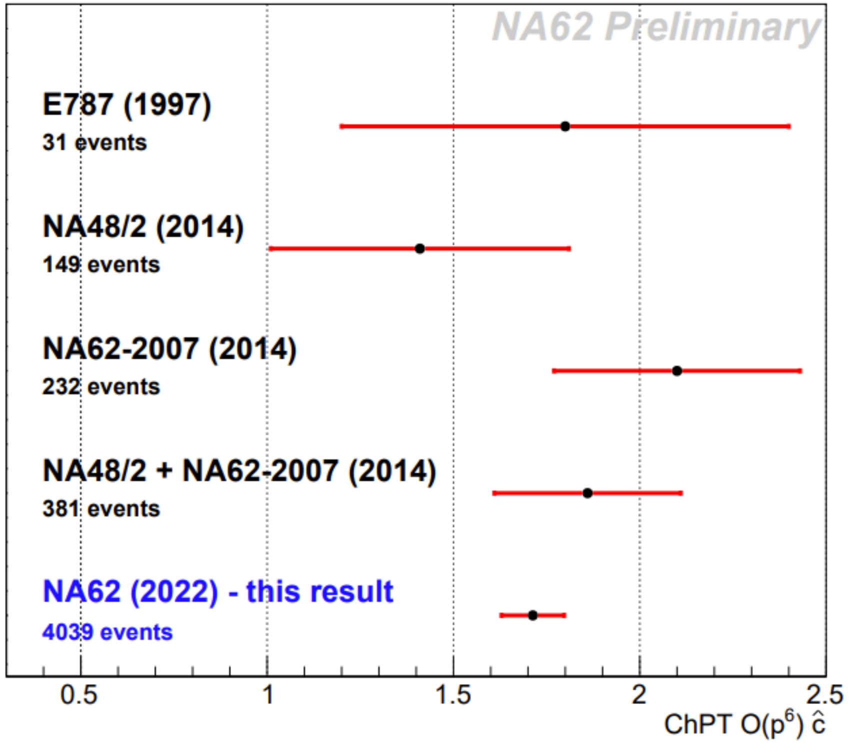
$K^+ \rightarrow \pi^+\gamma\gamma$ Preliminary result

$$N_{obs} = 4039 \qquad N_{bkg} = 393 \pm 20$$

$$\hat{c} = 1.713 \pm 0.075_{stat} \pm 0.037_{syst} \quad O(p^6)$$

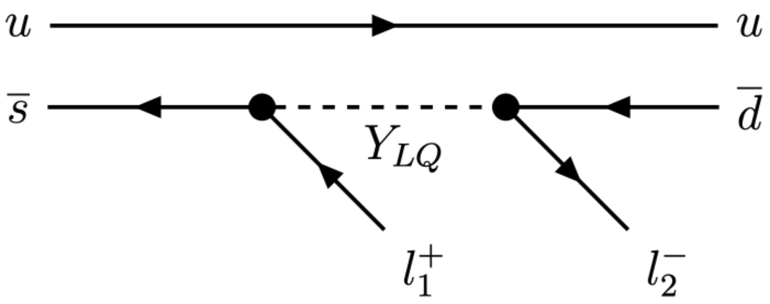
$$BR(K^+ \rightarrow \pi^+\gamma\gamma) = \left(9.73 \pm 0.17_{stat} \pm 0.08_{syst}\right) \times 10^{-7}$$

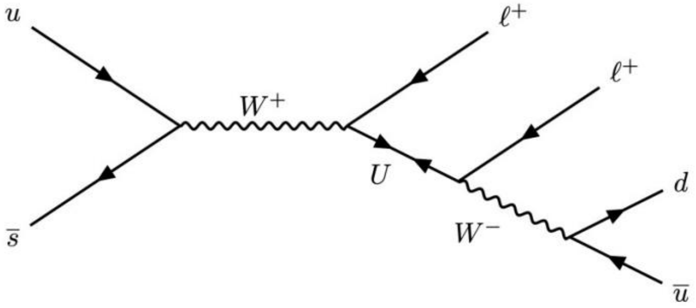


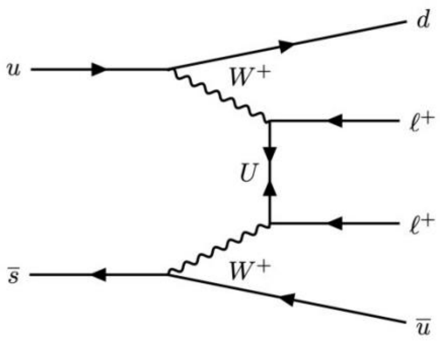


LFV & LNV in Kaon Decays

Violation of LN and LF conservation laws predicted in BSM models (for example via Majorana neutrinos or leptoquark)







Previous experimental results:

- BR($K^+ \rightarrow \pi^- e^+ e^+$) < 6.4×10^{-10} @ 90% CL
  [BNL E865 : PRL 85 2877 (2000)]
- BR($K^+ \rightarrow \pi^- \mu^+ \mu^+$) < 8.6×10^{-11} @ 90% CL
  [CERN NA48/2 : PL B769 67 (2017)]

LNV/LFV searches in NA62:

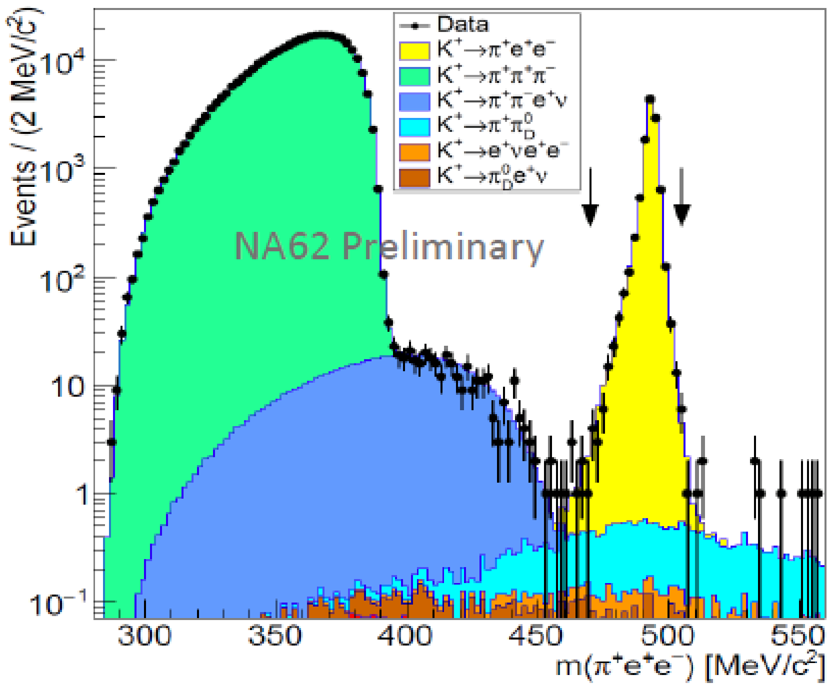
- 2017 + 2018 data
- Blind analysis
- Normalization to SM decays ($K^+ \rightarrow \pi^+ l^+ l^-$ and $K^+ \rightarrow \pi^+ \pi^+ \pi^-$)
- Acceptance:
  - ~5% for $K^+ \rightarrow \pi^- e^+ e^+$ and $K^+ \rightarrow \pi e \mu$
  - 10% for $K^+ \rightarrow \pi^- \mu^+ \mu^+$
- Main background is due to pion mis-identification and pion decays in flight

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

[PLB830 (2022)137172]

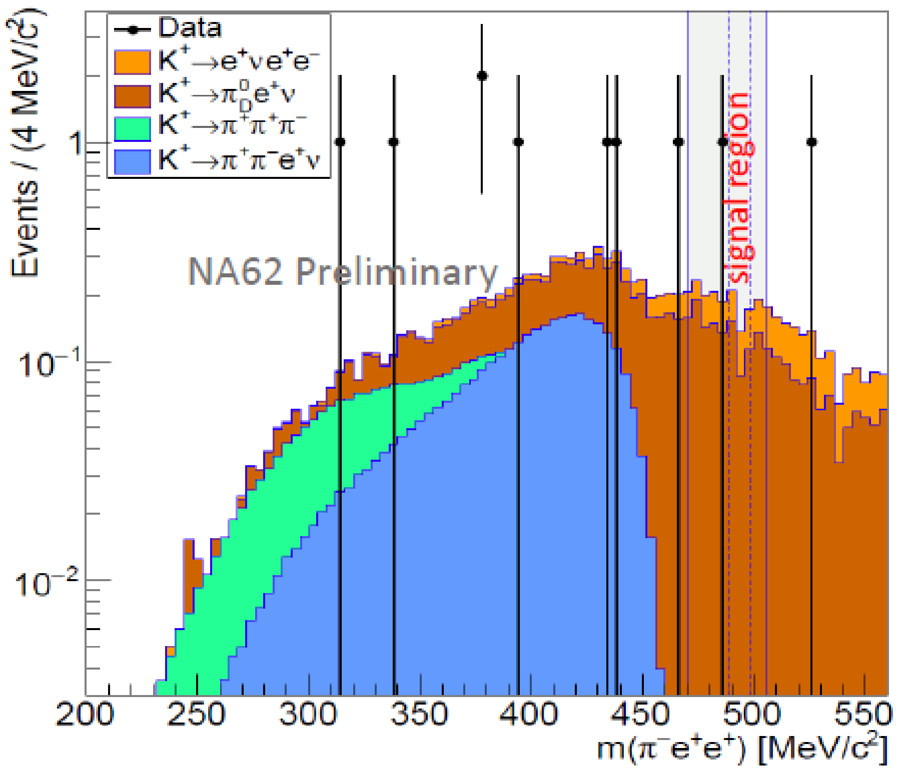
- Full RUN1 data set
- Expected background in the blinded region: 0.43 ± 0.09
- No candidate observed in the signal region
- $\mathrm{BR}(K^+ \to \pi^- e^+ e^+) < 5.3 \cdot 10^{-11}$ @ *90% CL*

SM selection: $m(\pi^+ e^+ e^-)$



K^+ decays in FV: $(1.015 \pm 0.032) \times 10^{12}$

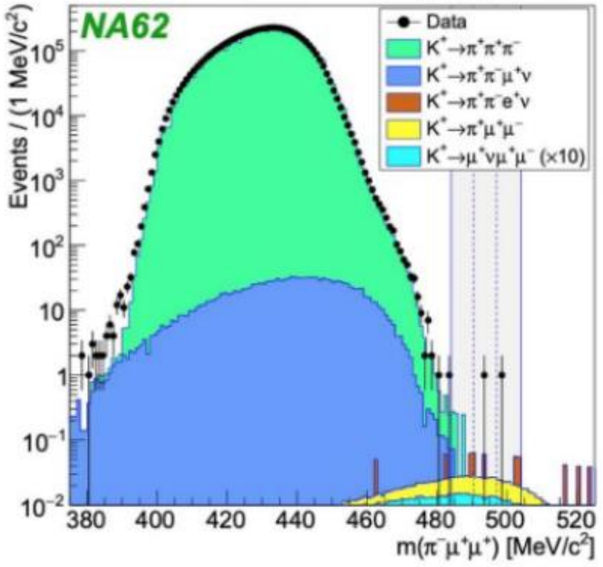
LNV selection: $m(\pi^- e^+ e^+)$



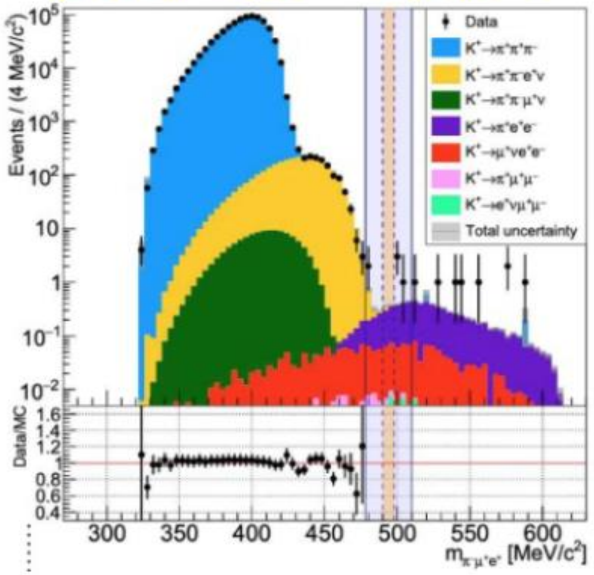
LFV & LNV results

	BR UL PDG 2019	BR UL NA62	Expected background	Observed		
$K^+ \to \pi^- \mu^+ e^+$	50×10^{-11}	4.2×10^{-11}	1.07 ± 0.20	0	PRL 127 (2021) 131802	*Factor 12 improvement*
$K^+ \to \pi^+ \mu^- e^+$	52×10^{-11}	6.6×10^{-11}	0.92 ± 0.34	2	PRL 127 (2021) 131802	*Factor 8 improvement*
$\pi^0 \to \mu^- e^+$	34×10^{-10}	3.2×10^{-10}	0.23 ± 0.15	0	PRL 127 (2021) 131802	*Factor 11 improvement*
$K^+ \to \pi^- \mu^+ \mu^+$	8.6×10^{-11}	4.2×10^{-11}	0.91 ± 0.41	1	PLB 797 (2019) 134794	*Factor 2 improvement*
$K^+ \to \pi^- e^+ e^+$	64×10^{-11}	5.3×10^{-11}	0.43 ± 0.09	0	PLB 830 (2022) 137172	*Factor 12 improvement*
$K^+ \to \pi^- \pi^0 e^+ e^+$	N/A	8.5×10^{-10}	0.044 ± 0.020	0	PLB 830 (2022) 137172	
$K^+ \to \mu^- \nu e^+ e^+$	N/A	8.1×10^{-11}	0.26 ± 0.04	0	PLB 838 (2022) 137679	

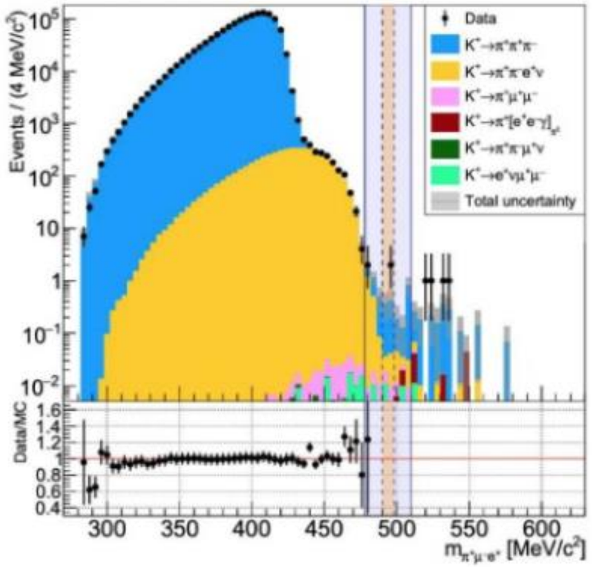
LNV : $K^+ \to \pi^- \mu^+ \mu^+$



LNV/LFV : $K^+ \to \pi^- \mu^+ e^+$



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

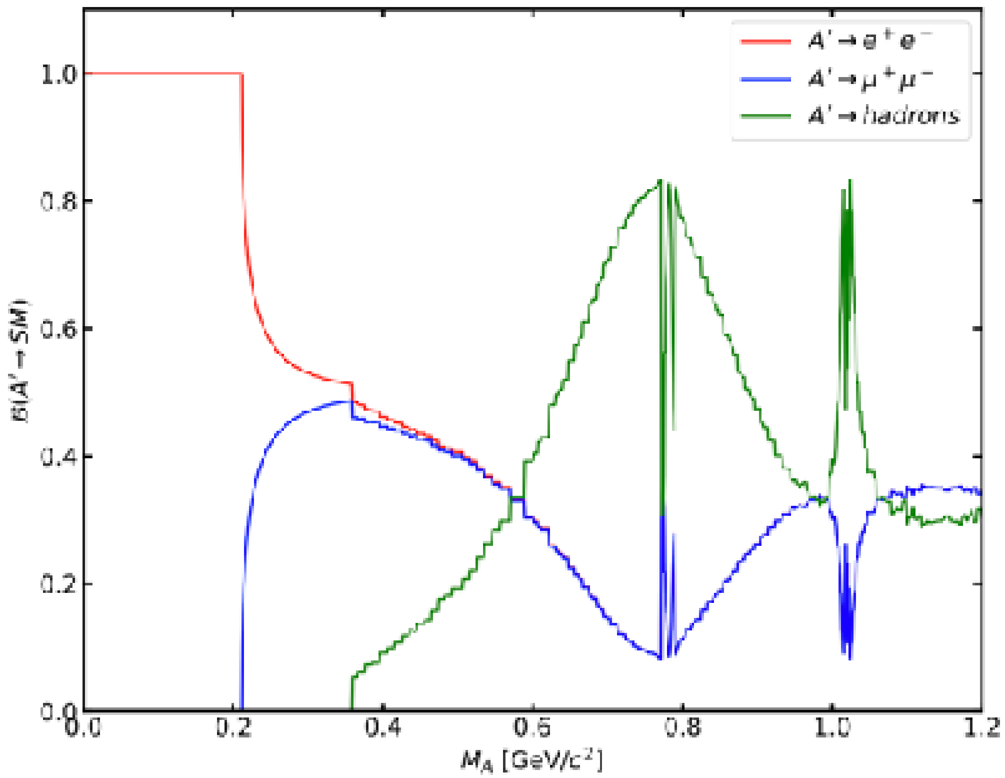


Search for Dark Photon in NA62

- Dark Photon: One of the several extensions of the SM (vector portal)
- Lepton – antilepton final states dominates for $M_A < 600$ MeV/c^2

NA62 beam-dump mode

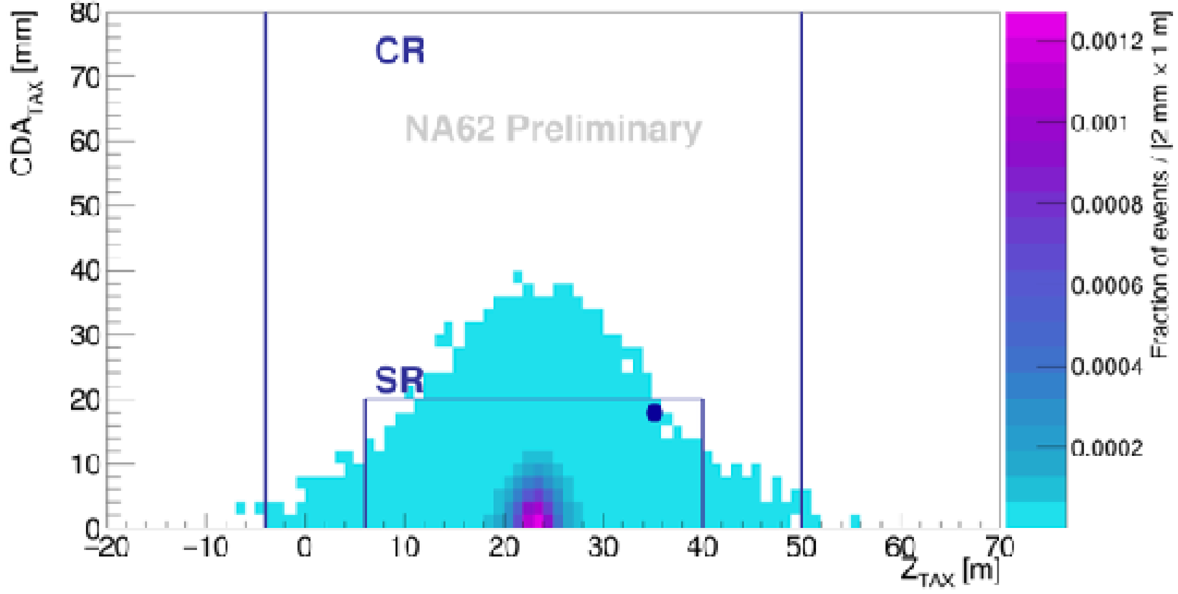
- Target removed
- 3.2 m Cu-Fe collimators put in the p^+ beam path
- ~ 1.5× nominal beam intensity
- In 2021, NA62 collected $(1.4 \pm 0.28) \times 10^{17}$ PoT

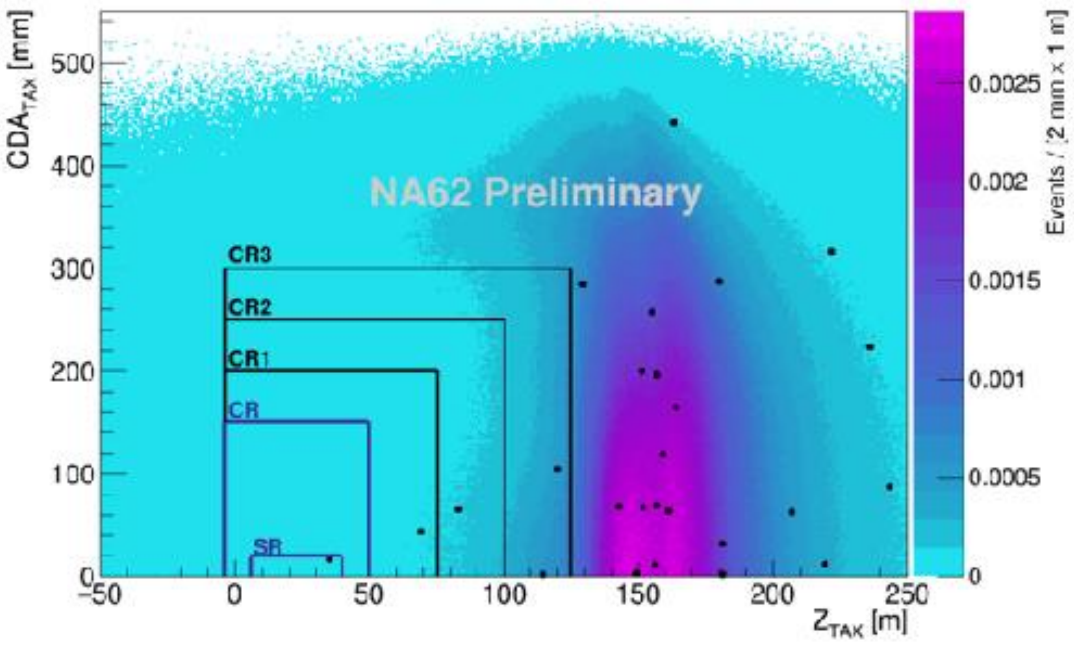


$A' \to \mu^+\mu^-$: result (preliminary)

Signal selection

- Primary vertex close to p beam impact point
- $\mu^+\mu^-$ vertex within fiducial volume
- $\mu^\pm$ PID using LKr and MUV3
- Photon veto (no activity in LAV)
- CRs and SR blinded until analysis approval

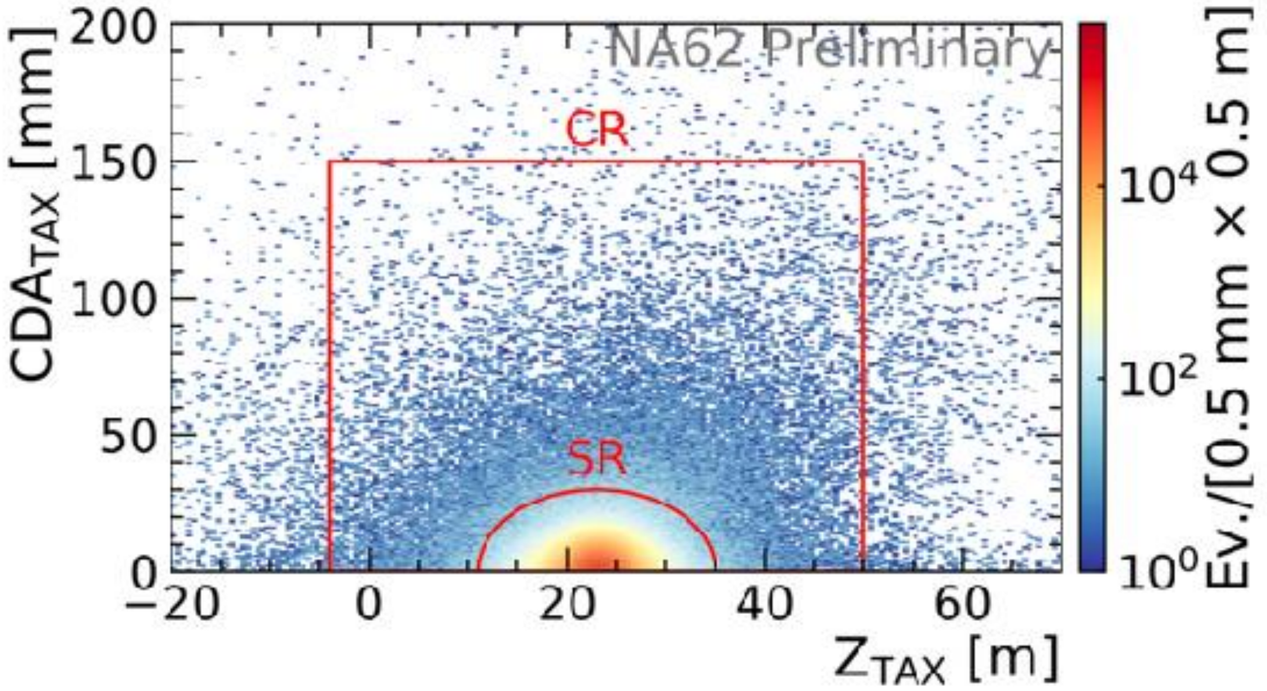




Z_{TAX} → longitudinal position of the primary vertex, $\sigma_Z \sim 5.5$ m
CDA_{TAX} → closest distance of approach between the beam direction and the $\mu^+\mu^-$ pair direction, $\sigma_{CDA} \sim 7$ mm

- 0.016 ±0.002 bkg events expected
- 1 event observed
- 2.4σ significance (counting experiment)

$A' \rightarrow e^+e^-$: result (preliminary)



Signal selection

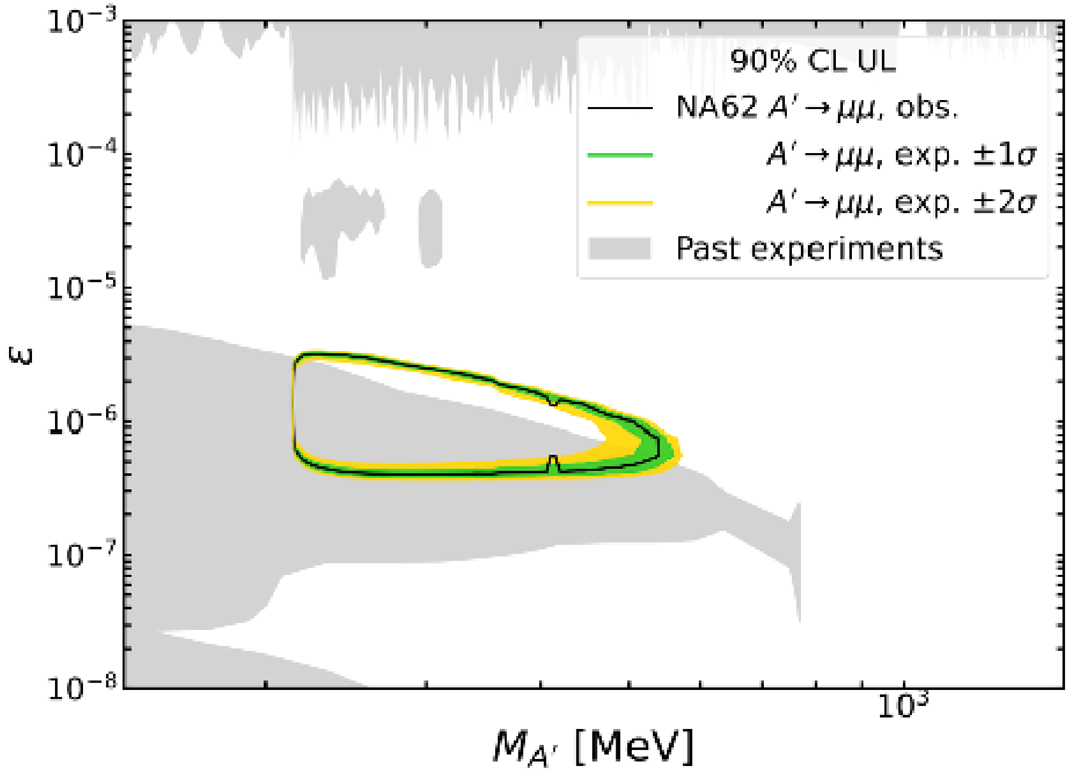
- Primary vertex close to p beam impact point
- e^+e^- vertex within fiducial volume
- $e^\pm$ PID using LKr and MUV3
- No in-time activity in muon detector
- no in-time activity in LAV (to remove interaction of muons with LAV material)
- CRs and SR blinded until analysis approval

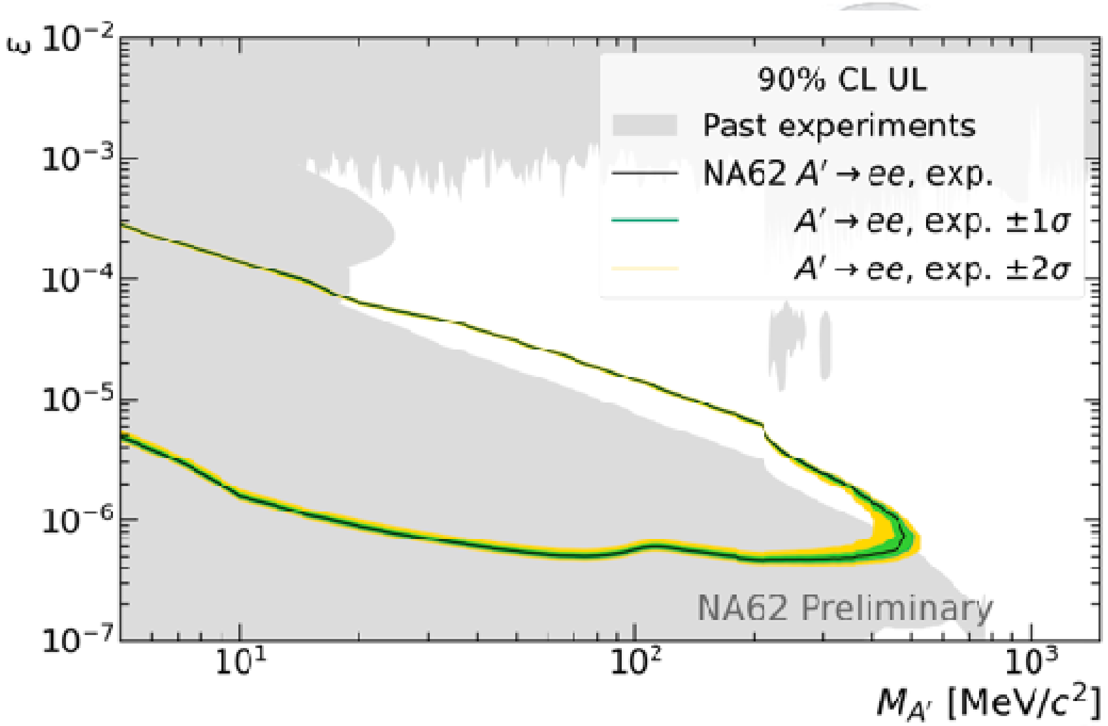
Z_{TAX} → longitudinal position of the primary vertex, $\sigma_Z \sim 5.5$ m
CDA_{TAX} → closest distance of approach between the beam direction and the e^+e^- pair direction, $\sigma_{CDA} \sim 7$ mm

- $0.0094^{+0.049}_{-0.009}$ bkg events expected
- 0 event observed

$A' \to \mu^+\mu^-$ and $A' \to e^+e^-$

With $(1.4 \pm 0.28) \times 10^{17}$ PoT, from a cut-based counting experiment blind analysis, a 90% CL upper limit has been set for $A' \to \mu^+\mu^-$ and $A' \to e^+e^-$ exploring a new region of the parameter space

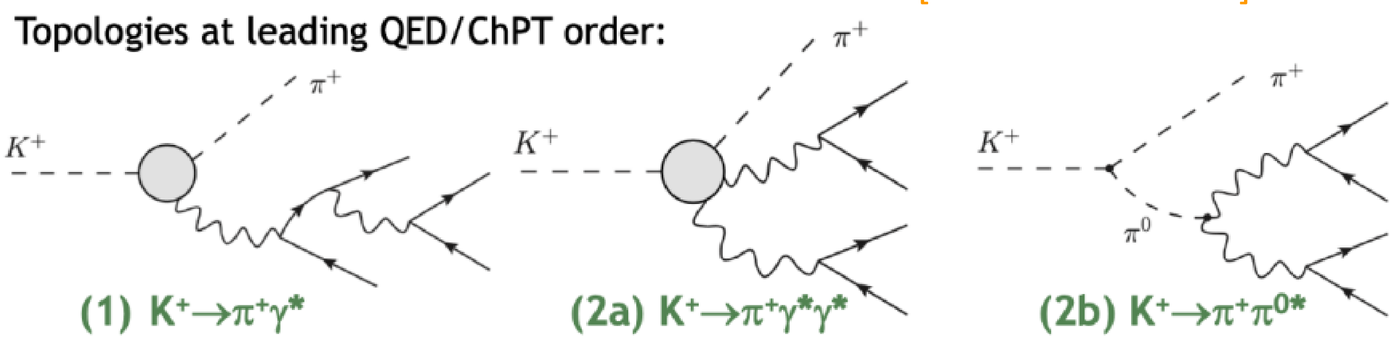




NA62 intends to collect 10^{18} PoT in beam-dump in 2023-2025 with interesting perspectives on dark photons, ALPs, dark scalars and HNLs

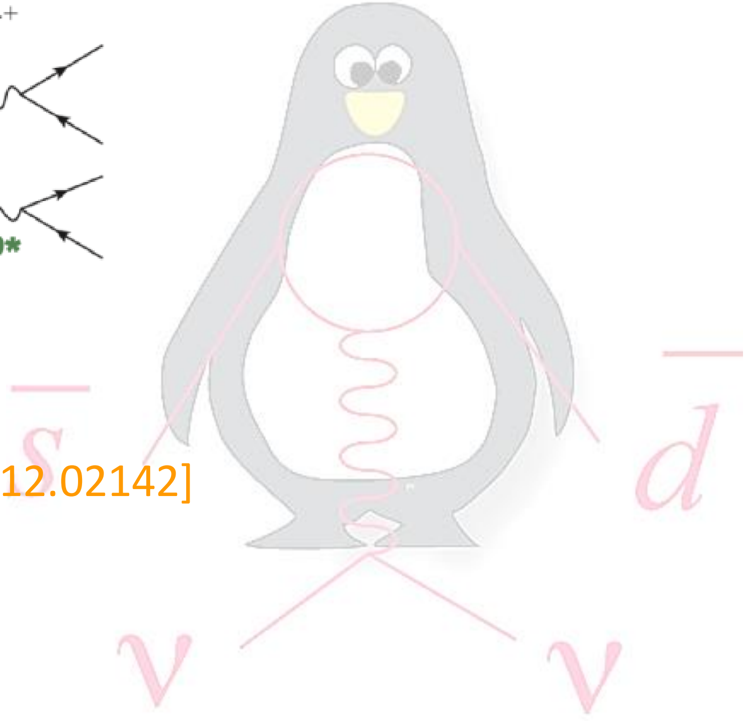
$K^+ \to \pi^+ e^+ e^- e^+ e^-$

Theory: SM allowed $BR = (7.2 \pm 0.7) \times 10^{-11}$ (outside π^0 pole) [arXiv:2207.02234]



Dark sector probe:

- $K^+ \to \pi^+ aa$ with $a \to e^+e^+$ QCD axion, e.g. m_a = 17 MeV $BR = 1.7 \times 10^{-11}$ [arXiv:2012.02142]
- $K^+ \to \pi^+ S$ with $S \to A'A'$ dark scalar and $A' \to e^+e^+$ dark photon ($m_S > 2m_{A'}$)

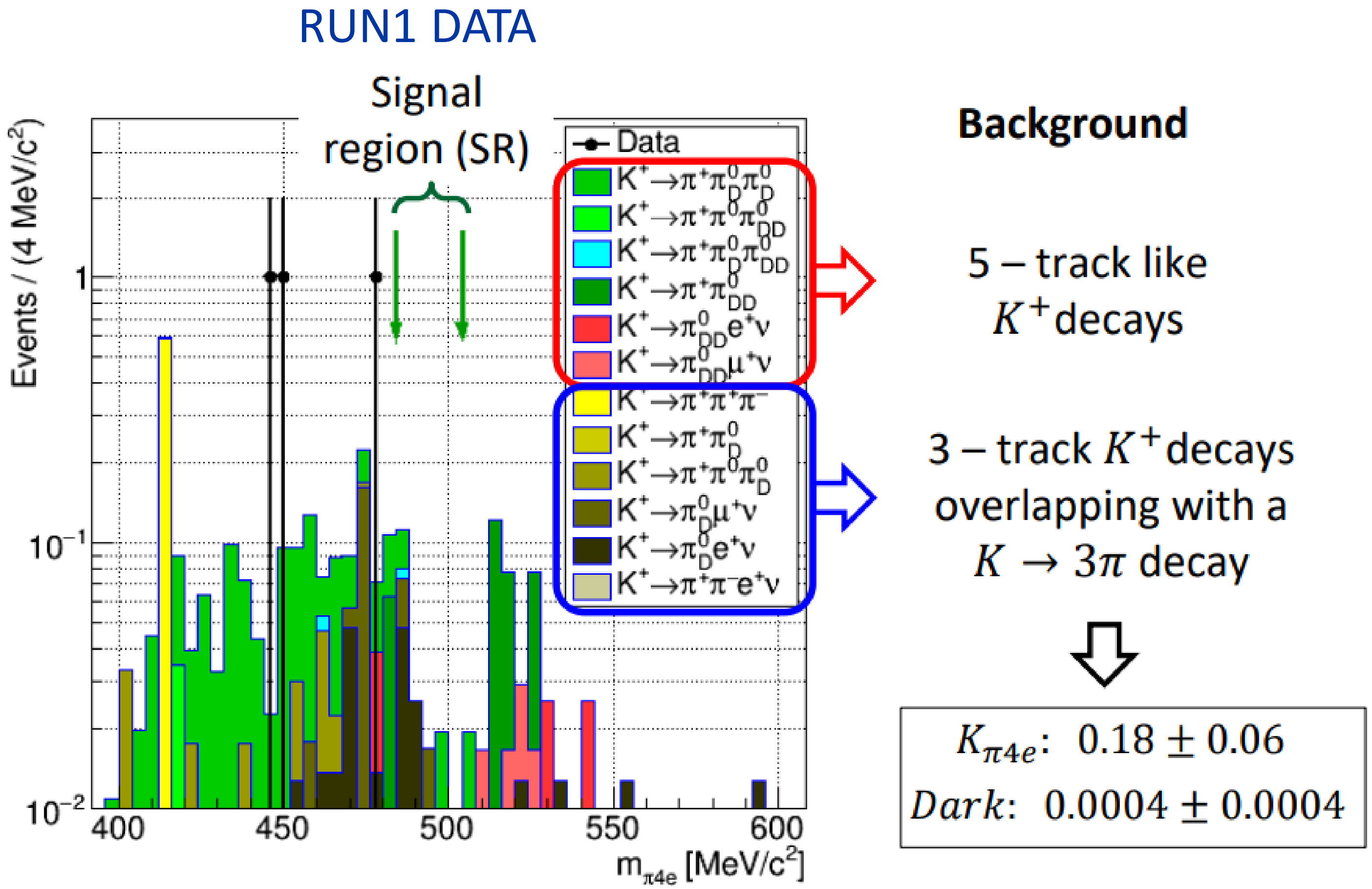


Goal: Search for:

1) SM process ($K_{\pi 4e}$)
2) QCD di-axion
3) Dark cascade

$K^+ \to \pi^+ e^+ e^- e^+ e^-$ result (preliminary)

- Signal ($K\pi4e$)
  - 5 - track vertex topology
  - Kinematic PID of positive tracks
  - Conditions on $m_{\pi 4e}$ and m^2_{miss}
  - m_{4e} outside the π^0 mass region
- Signal ($K^+ \to \pi^+ aa$ "Dark")
  - Same selection as $K_{\pi 4e}$
  - Choice of the optimal e^+e^- mass pair
  - Condition on m_{ee}
- Normalization: $K^+ \to \pi^+\pi^0_{DD}$
  - 5 - track topology and PID as for $K_{\pi 4e}$
  - Kinematic condition on m_{4e}

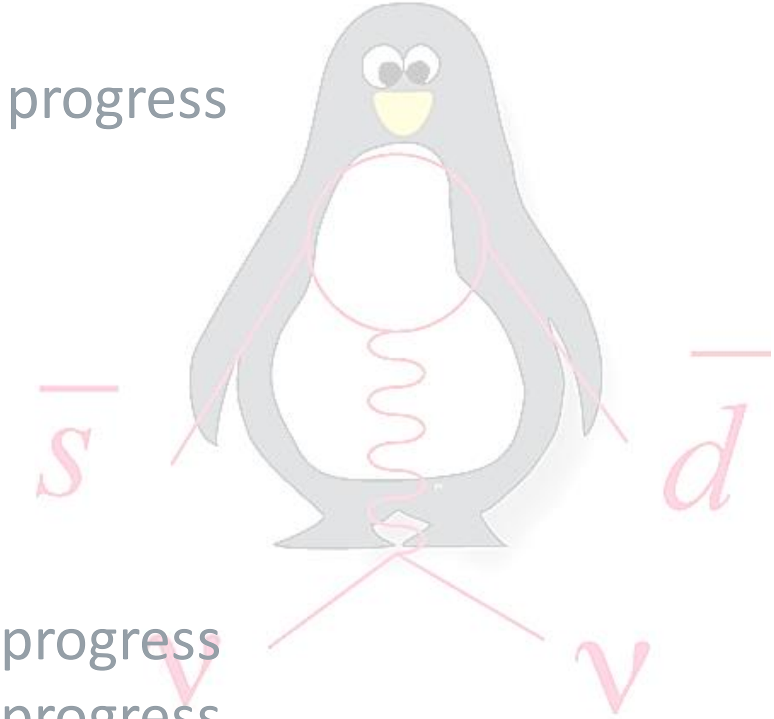


$K_{\pi 4e}$: 0.18 ± 0.06
$Dark$: 0.0004 ± 0.0004

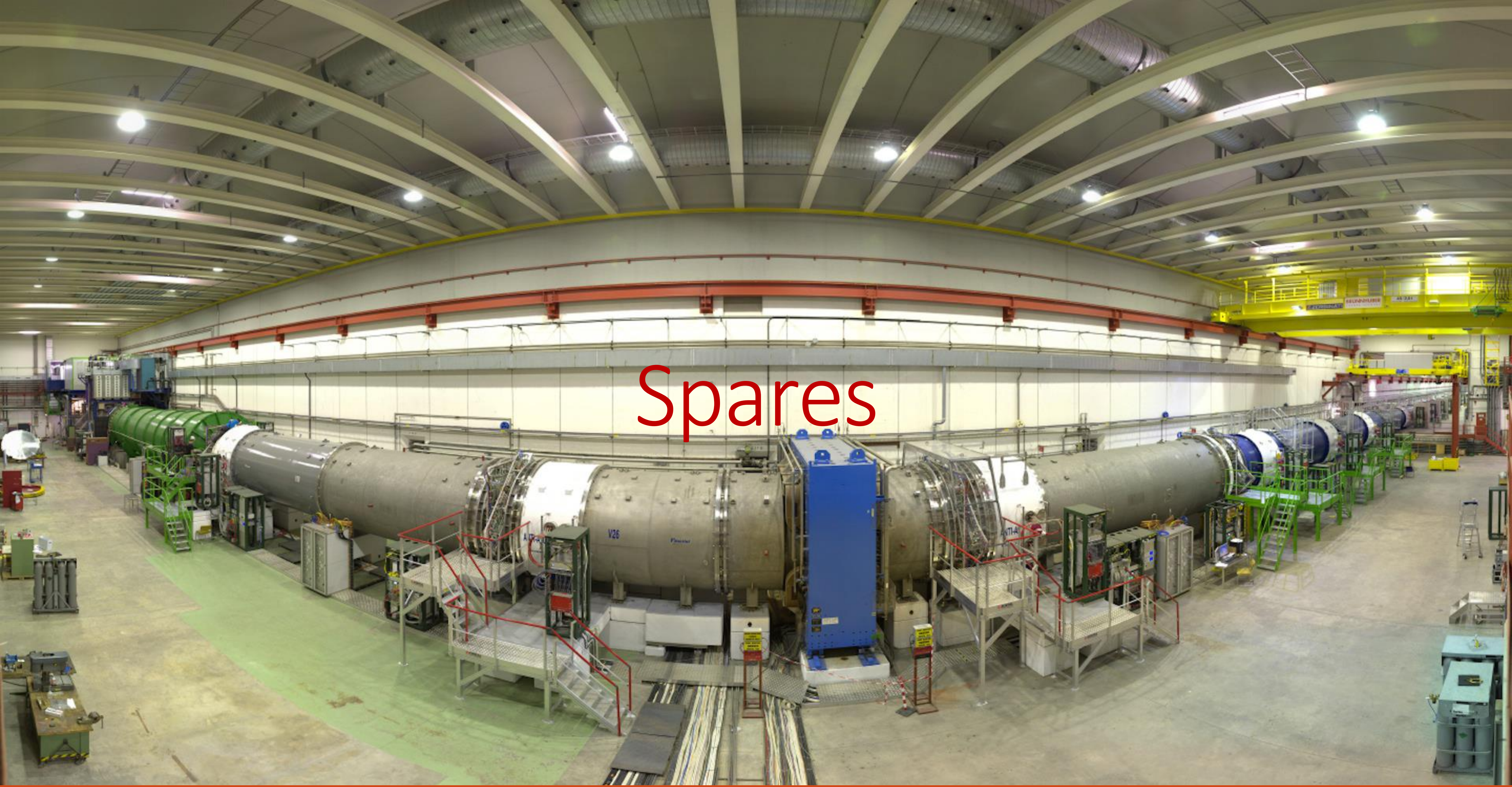
RESULT: $BR(K^+ \to \pi^+ e^+ e^- e^+ e^-) < 1.4 \times 10^{-8}$ @90% CL

Summary

- $K^+ \to \pi^+\nu\bar{\nu}$ NA62 Run1 data JHEP 06 (2021) 093
- $K^+ \to \pi^+\mu^+\mu^-$ NA62 Run1 data JHEP 11 (2022) 011
- $K^+ \to \pi^+\gamma\gamma$ NA62 Run1 data preliminary, final results in progress
- $K^+ \to \pi^{\pm}\mu^{\mp}e^+$ NA62 Run1 data PRL 127 (2021) 131802
- $\pi^0 \to \mu^-e^+$ NA62 Run1 data PRL 127 (2021) 131802
- $K^+ \to \pi^-\mu^+\mu^+$ NA62 Run1 data PLB 797 (2019) 134794
- $K^+ \to \pi^-e^+e^+$ NA62 Run1 data PLB 830 (2022) 137172
- $K^+ \to \pi^-\pi^0e^+e^+$ NA62 Run1 data PLB 830 (2022) 137172
- $K^+ \to \mu^-\nu e^+e^+$ NA62 Run1 data PLB 838 (2022) 137679
- $A' \to \mu^+\mu^-$ NA62 2021 data preliminary, final results in progress
- $A' \to e^+e^-$ NA62 2021 data preliminary, final results in progress
- $K^+ \to \pi^-e^+e^-e^+e^-$ NA62 Run1 data preliminary, final results in progress

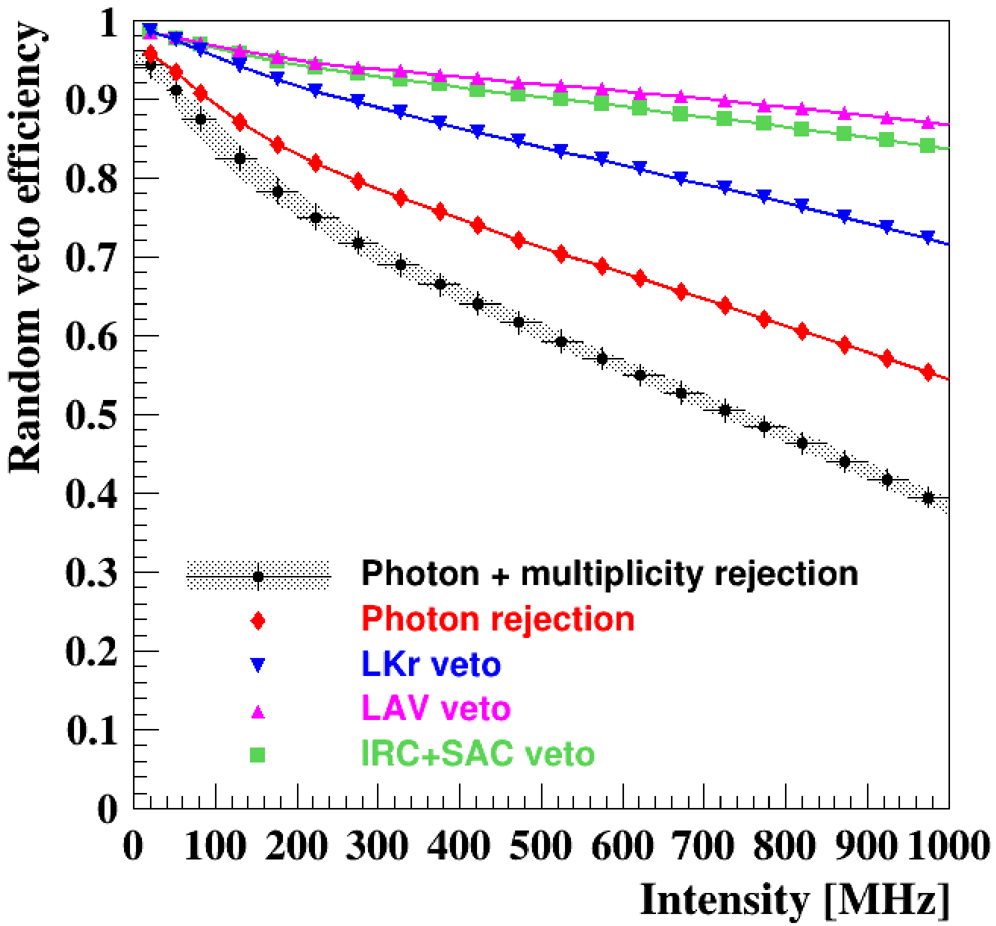


Spares



Single Event Sensitivity (SES)

$$N^{exp}_{\pi\nu\nu} \approx N_{\pi\pi}\epsilon_{trigger}\epsilon_{RV}\frac{A_{\pi\nu\nu}}{A_{\pi\pi}}\frac{Br(\pi\nu\nu)}{Br(\pi\pi)} \Longrightarrow \text{S.E.S.} = \frac{Br(\pi\nu\nu)}{N^{exp}_{\pi\nu\nu}}$$



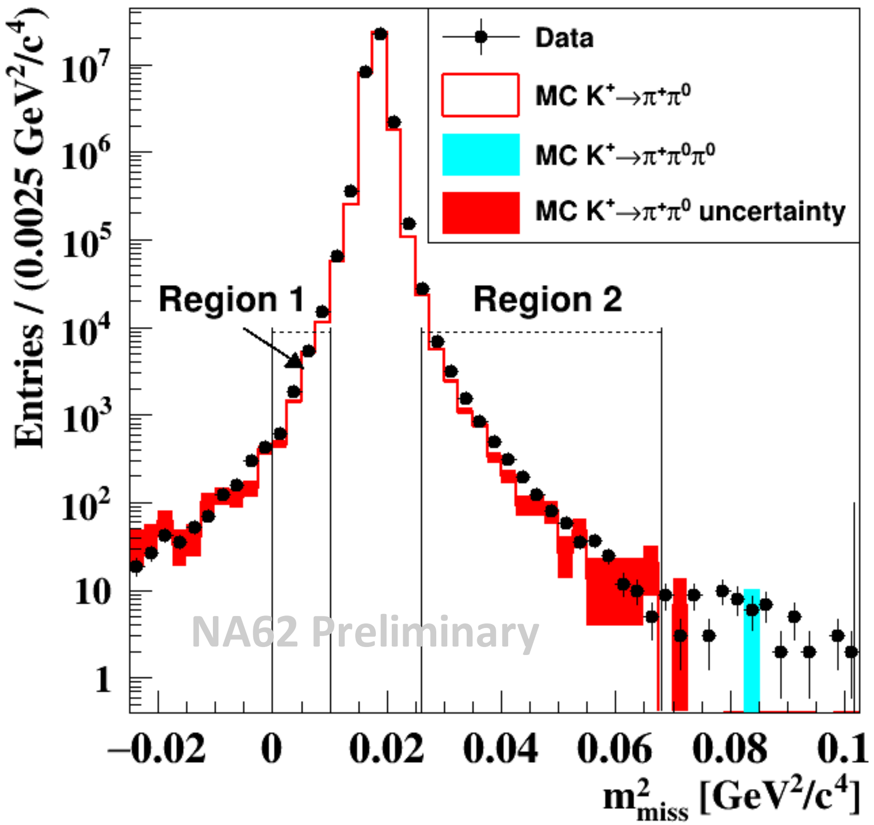
	Subset S1	Subset S2
$N_{\pi\pi} \times 10^{-7}$	3.14	11.6
$A_{\pi\pi} \times 10^{2}$	7.62 ± 0.77	11.77 ± 1.18
$A_{\pi\nu\bar{\nu}} \times 10^{2}$	3.95 ± 0.40	6.37 ± 0.64
$\epsilon^{\mathrm{PNN}}_{\mathrm{trig}}$	0.89 ± 0.05	0.89 ± 0.05
ϵ_{RV}	0.66 ± 0.01	0.66 ± 0.01
$SES \times 10^{10}$	0.54 ± 0.04	0.14 ± 0.01
$N^{\mathrm{exp}}_{\pi\nu\bar{\nu}}$	$1.56 \pm 0.10 \pm 0.19_{\mathrm{ext}}$	$6.02 \pm 0.39 \pm 0.72_{\mathrm{ext}}$

- $K^+ \rightarrow \pi^+\pi^0$ decay used for normalization
- Cancellation of systematic effects (PID, Detector efficiencies, kaon ID and beam related acceptance loss)

$$SES_{Run1} = (0.839 \pm 0.054) \cdot 10^{-11}$$

Background from Kaon Decay Estimation

Control $K^+ \to \pi^+\pi^0$ data used to study the tails of the m^2_{miss} distribution



Data in $\pi^+\pi^0$ region after $\pi\nu\nu$ selection (including π^0 rejection)

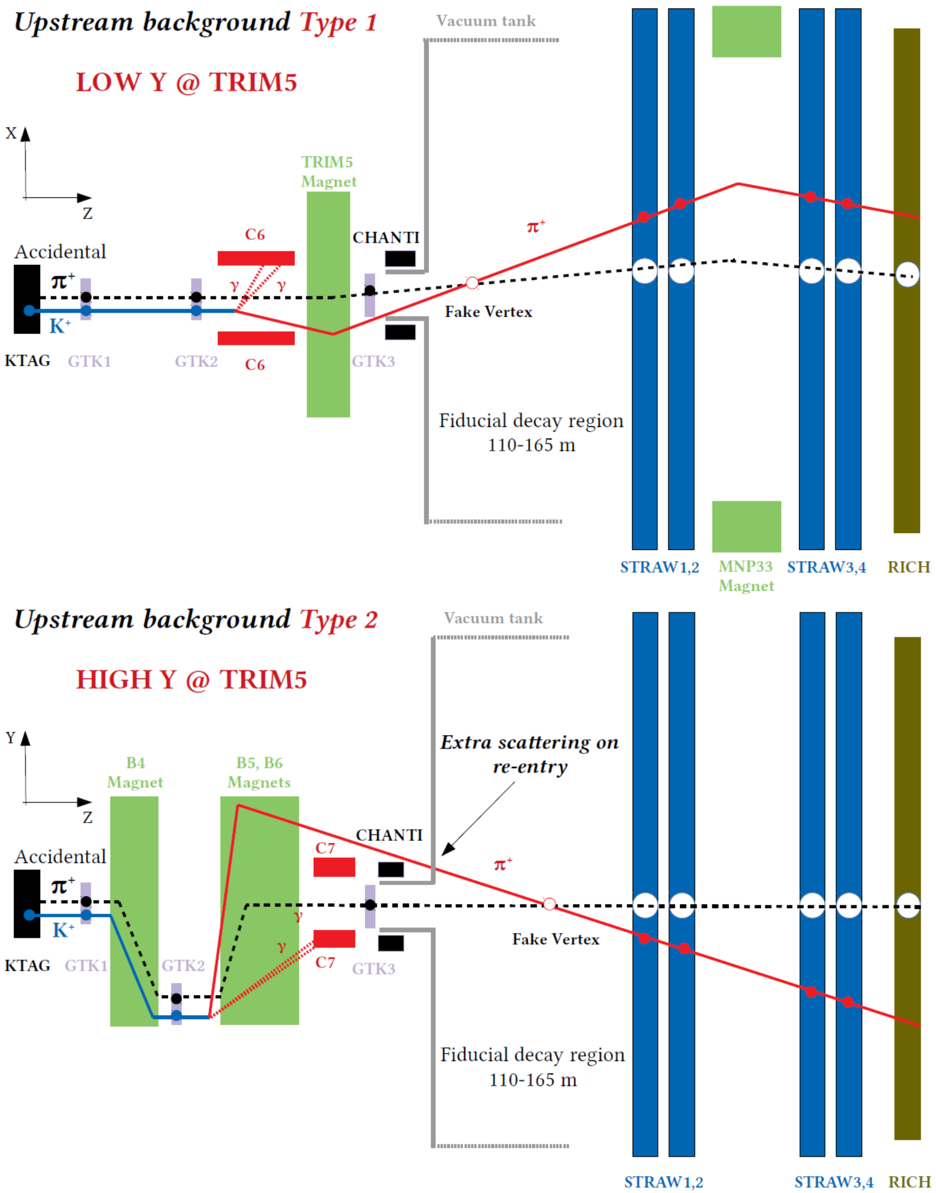
$$\boxed{N^{exp}_{\pi\pi}(region)} = \boxed{N(\pi^+\pi^0)} \cdot \boxed{f_{kin}(region)}$$

Expected $K^+ \to \pi^+\pi^0$ in signal regions after the $\pi\nu\nu$ selection

Fraction of $\pi^+\pi^0$ in signal region measured on control data

- The same procedure is used for $K^+ \to \mu^+\nu$ and $K^+ \to \pi^+\pi^+\pi^-$
- $K^+ \to \pi^+\pi^- e^+\nu_e$ estimation entirely using MC simulations normalized to the S.E.S.

Upstream background

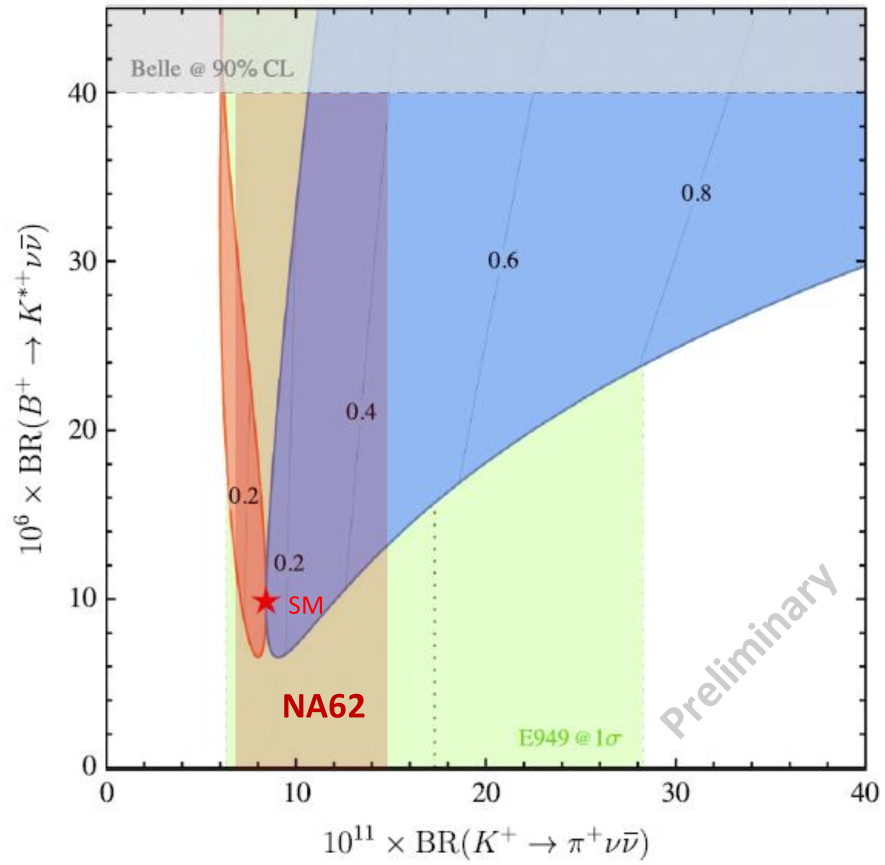


- Pions produced upstream the fiducial volume
  - Early K^+ decay
  - Interaction of beam particles with the beam spectrometer material
- Pions can be associated to an accidental particle of the beam line
- Dangerous if coupled with pion scattering in the first spectrometer chamber
- Kaon-pion association and geometrical cuts effective
- The geometrical origin of those events allow to define samples for backgrounds validation
- Data driven background estimation

$K^+ \to \pi^+ \nu\bar{\nu}$ and the LFU violation

The Measurement of $K^+ \to \pi^+ \nu\bar{\nu}$ together with $B^+ \to K^{*+} \nu\bar{\nu}$ can **can probe the Lepton-Flavour Universality**

- An interactions responsible for LFU violations can couple mainly to the third generation of left-handed fermions;
- $K \to \pi\nu\bar{\nu}$ is the only kaon decays with third-generation leptons (the τ neutrinos) in the final state;



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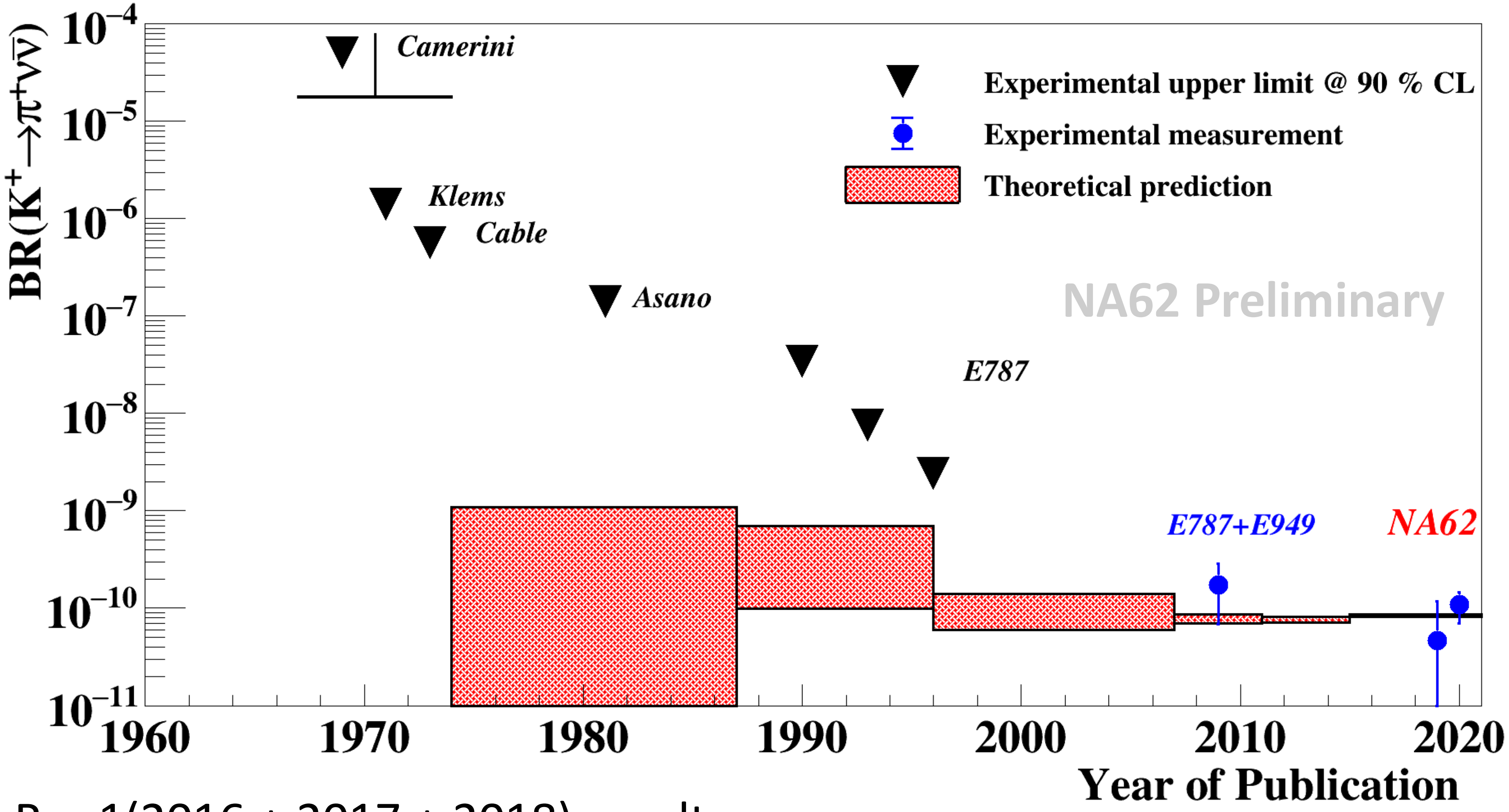
$K \to \pi\nu\bar{\nu}$ Result and historical context

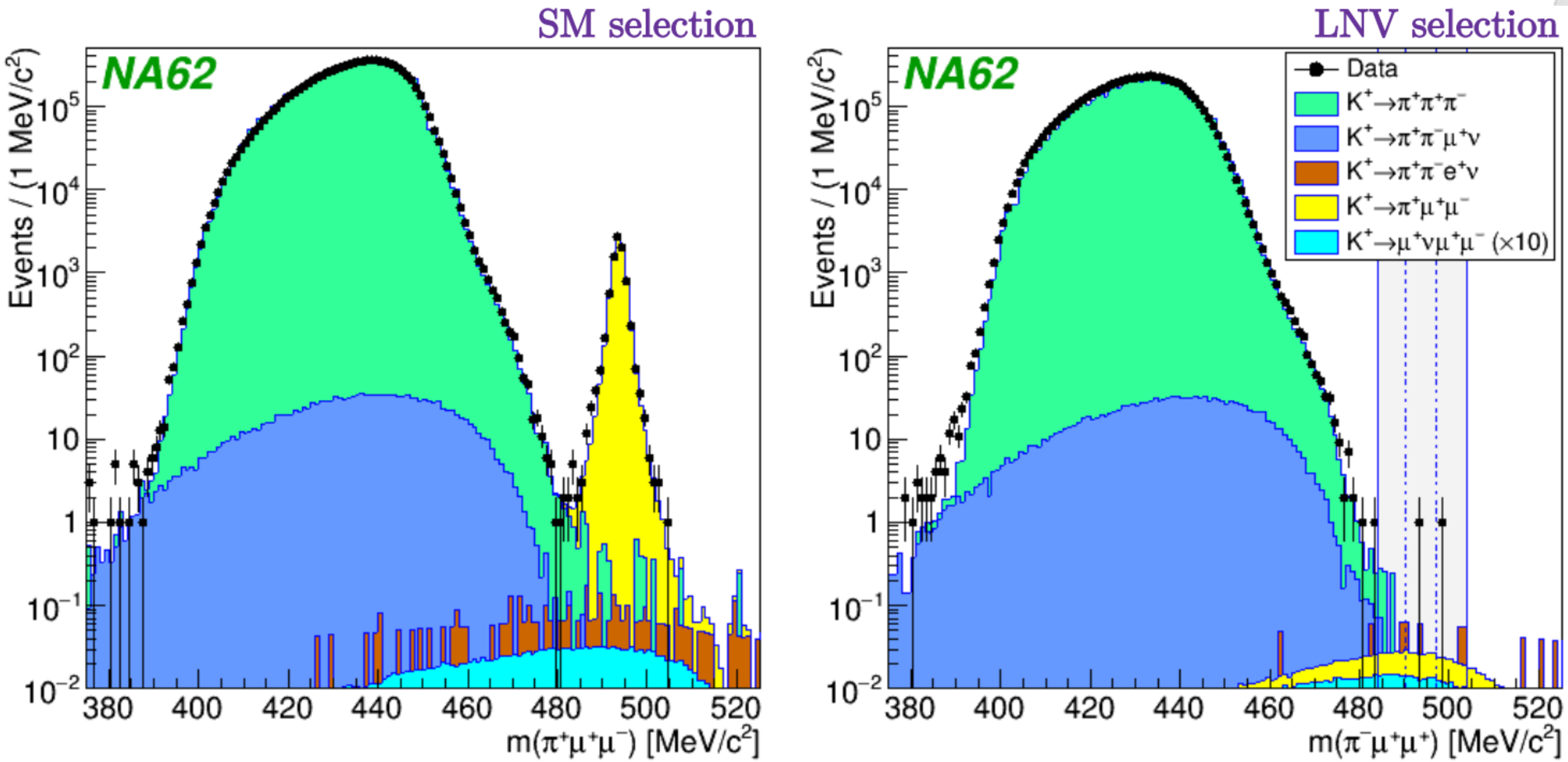


NA62 Run1(2016 + 2017 + 2018) result:

$$Br(K^+ \to \pi^+ \upsilon\bar{\upsilon}) = (10.6^{+4.0}_{-3.5\,stat} \pm 0.9_{syst}) \cdot 10^{-11}\ (3.4\sigma\ \text{significance})$$

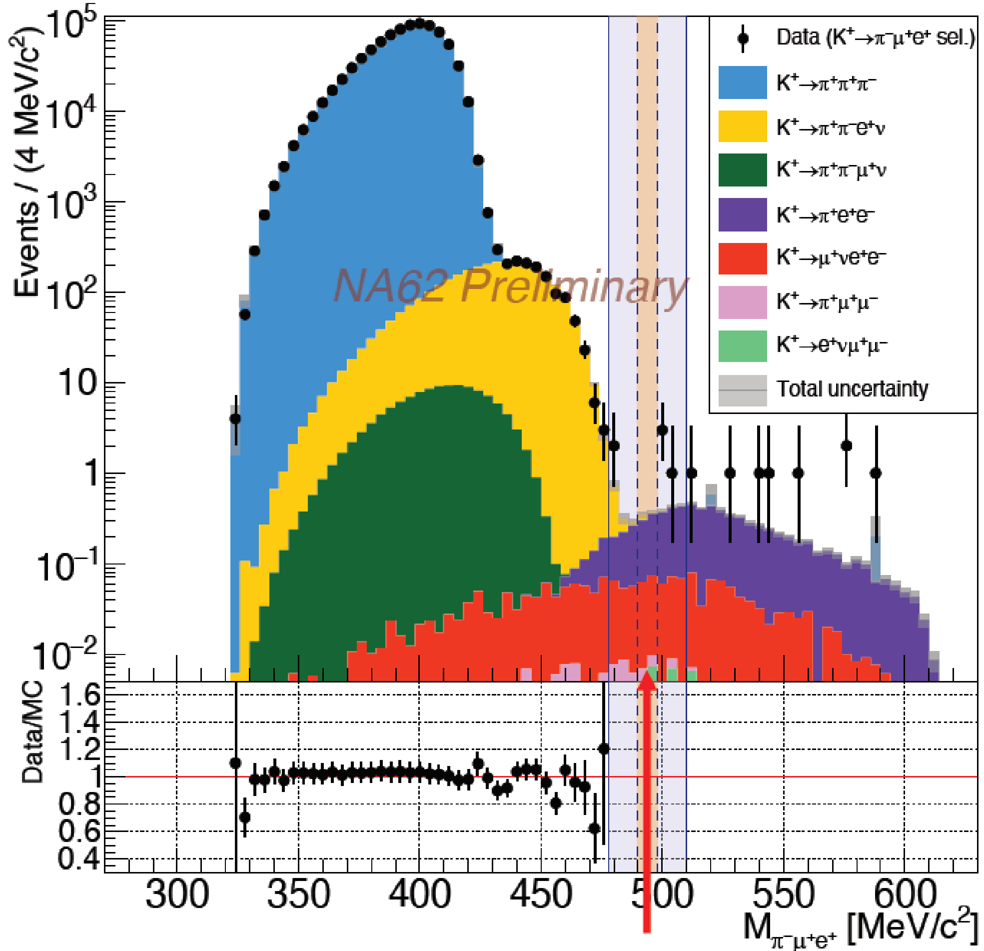
$K^+ \to \pi^- \mu^+ \mu^+$

- Expected background in the blinded region: 0.91 ± 0.41
- One candidate observed in the signal region
- $BR(K^+ \to \pi^- \mu^+ \mu^+) < 4.2 \cdot 10^{-11}$ @ *90% CL*



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

$BR(K^+ \to \pi^-\mu^+e^+) < 4.2\times10^{-11}$ @ 90% CL

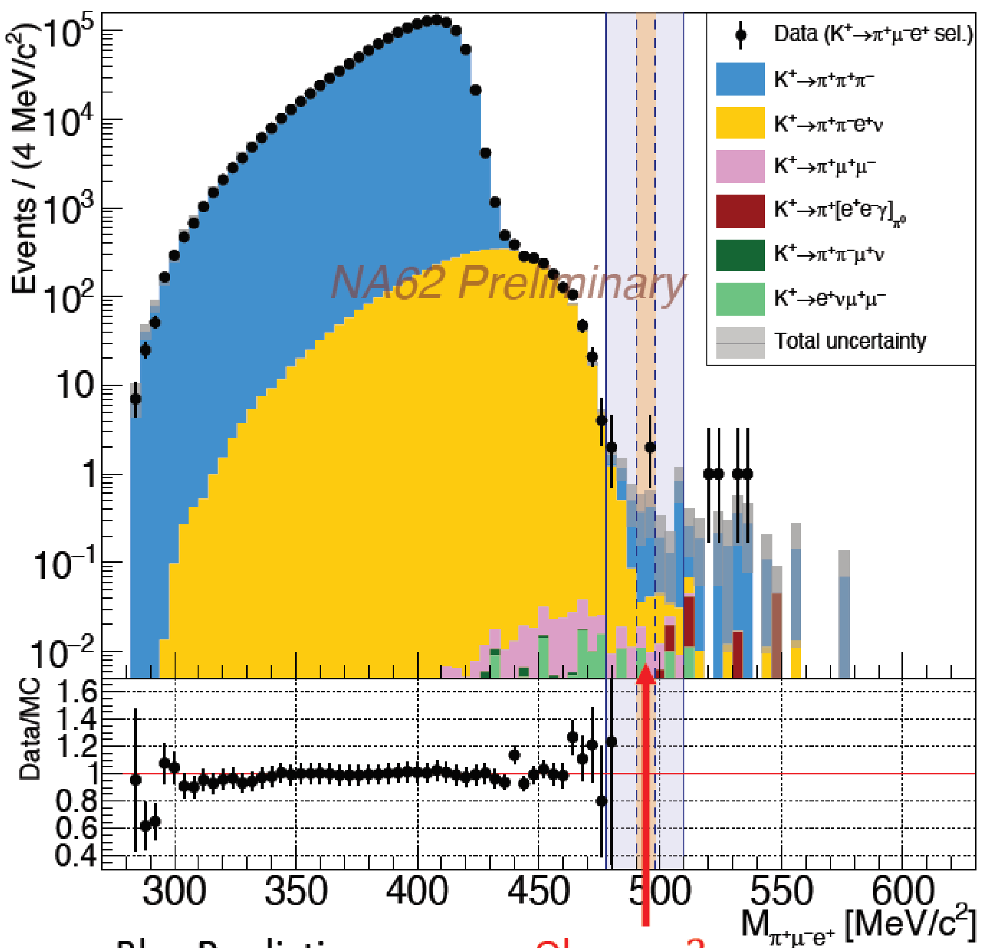


Bkg. Prediction:

$N_{SR}^{tot} = 1.06 \pm 0.20$

Observe 0 events in SR

$BR(K^+ \to \pi^+\mu^-e^+) < 6.6\times10^{-11}$ @ 90% CL



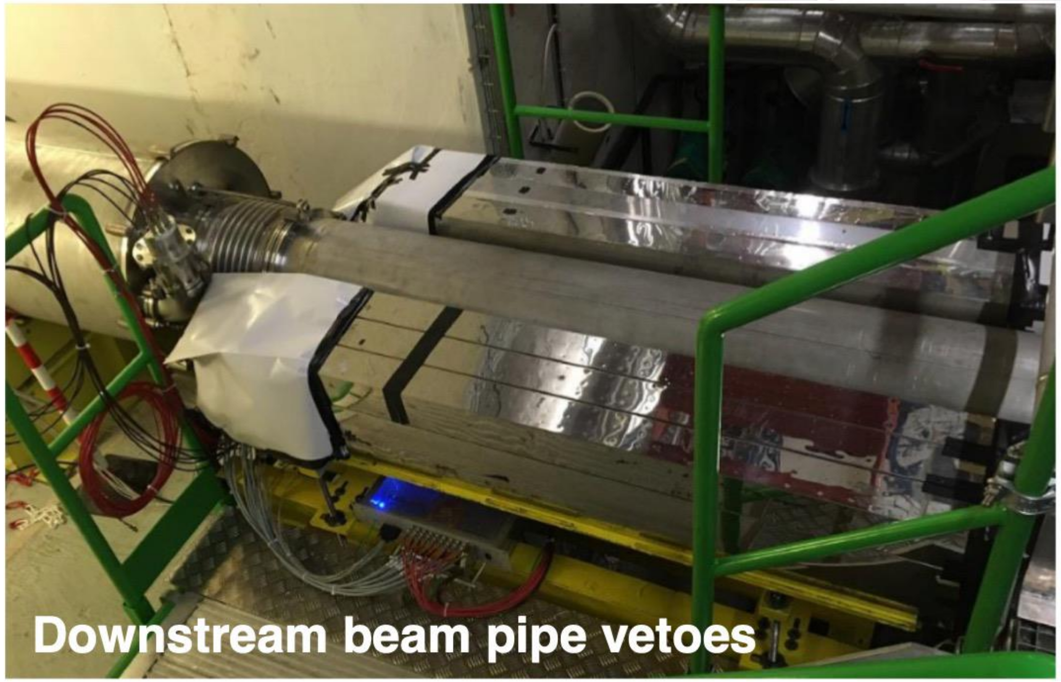
Bkg. Prediction:

$N_{SR}^{tot} = 0.92 \pm 0.34$

Observe 2 events in SR

NA62 Run 2: 2021–LS3

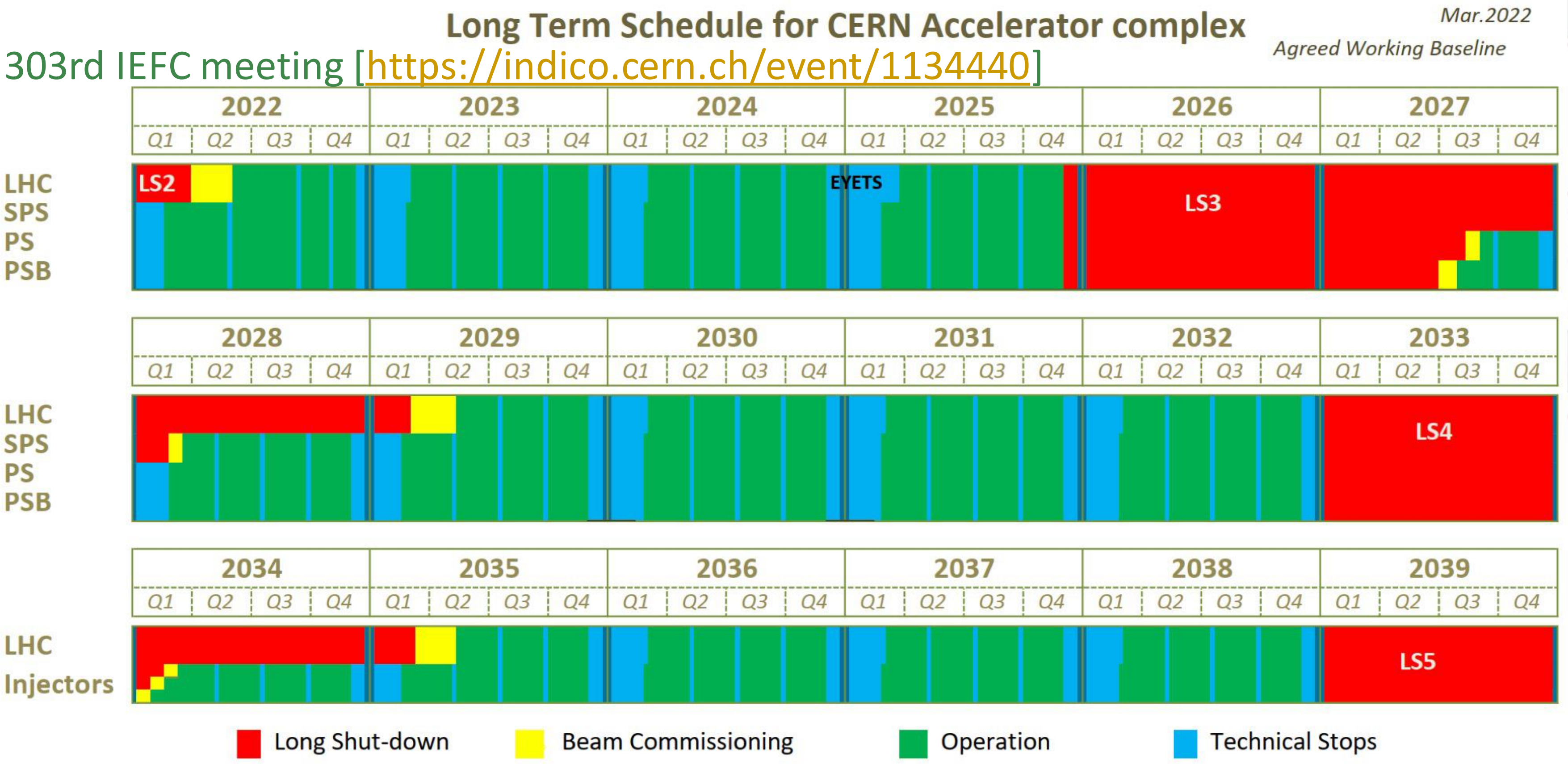
- The technique was firmly established during RUN1.
- Run 2: $K^+ \rightarrow \pi^+\upsilon\bar{\upsilon}$ measurement in a low-background and high-acceptance regime (O(10%) precision).
- Modifications of the setup for background reduction:
  - **fourth kaon beam tracker (GTK)** station added and rearrangement of beamline elements around the GTK;
  - **new veto hodoscopes** upstream of the decay volume;
  - an **additional veto counter** around downstream beam pipe.
- Improved TDAQ: **beam intensity increased by $\sim 30\%$** wrt Run 1.
- It is foreseen a **beam dump mode** to collect **10^{18} pot** in up to 90 days.



Fixed target program at CERN SPS

- SPS fixed target operation foreseen until at least 2038.
- **HIKE** ("High-Intensity Kaon experiment"): a long-term programme at the SPS proposed to search for new physics in kaon decays.
- Measurements of rare K^+ and K_L kaon decay modes: a clear insight into the flavour structure of new physics.
- Details in a Snowmass white paper: arXiv:2204.13394

303rd IEFC meeting [https://indico.cern.ch/event/1134440]



Long-term plan for the $K^+ \rightarrow \pi^+ \upsilon\bar{\upsilon}$

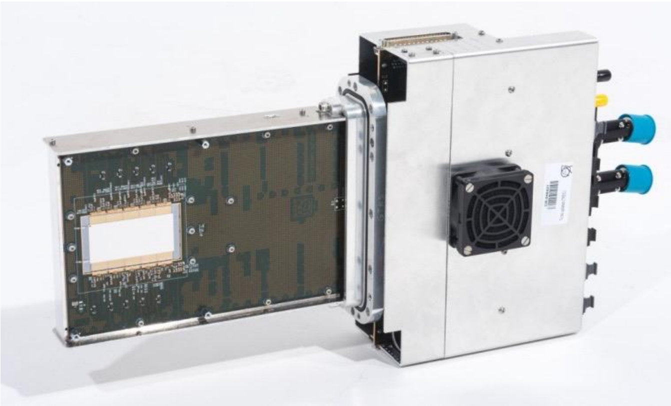
- An in-flight $K^+ \rightarrow \pi^+ \upsilon\bar{\upsilon}$ experiment, up to **×4** the NA62 beam intensity, aiming at ~**5%** precision.
- Challenge: **20 ps** time resolution for key detectors to keep random veto under control, while maintaining all other NA62 specifications.
- Challenges aligned with HL-LHC projects and future flavour/dark matter exp.

New pixel beam tracker (GTK):

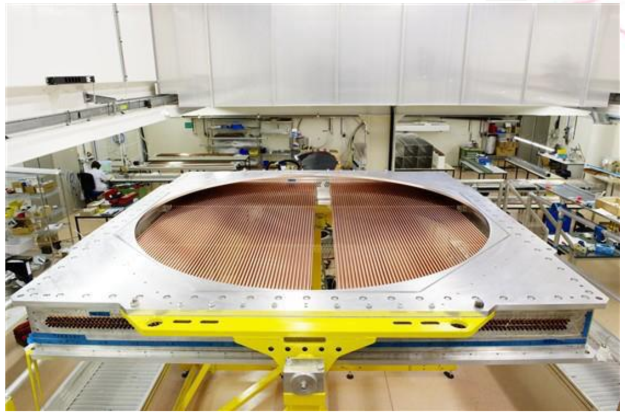
- time resolution: **<50 ps** per plane;
- pixel size: **<300×300 μm^2**;
- efficiency: **>99%** per plane (incl.fill factor);
- material budget : **0.3–0.5% X0**;
- beam intensity: **>3 GHz** on **30×60 mm^2**;
- peak intensity: **>8.0 MHz/mm^2.**

New STRAW spectrometer:

- operation in vacuum;
- straw diameter/length: **5 mm/2.2 m**;
- trailing time resolution: ~**6 ns** per straw;
- maximum drift time: ~**80 ns**;
- layout: ~**21000** straws (4 chambers);
- total material budget: **1.4% X_0**.



← current NA62 design →



Long-term plan for the $K_L \rightarrow \pi^0\nu\bar{\nu}$

- **KLEVER**: a high-energy experiment (**10^{19}** pot/year) complementary to KOTO.
- Photons from K_L decays boosted forward: veto coverage only up to **100 mrad**.
- Vacuum tank layout and fiducial volume similar to NA62.
- A longer beamline is needed for $\Lambda \rightarrow n\pi^0$ background suppression
- **60** SM $K_L \rightarrow \pi^0\nu\bar{\nu}$ events with **S/B** $\sim$ **1** and $\sim$**20%** precision in **5** years of operation;