KAON EXPERIMENTS

Rainer Wanke
Universität Mainz

KET Strategy Workshop
Bad Honnef

Nov 22nd, 2025

Komitee für
Elementarteilchenphysik

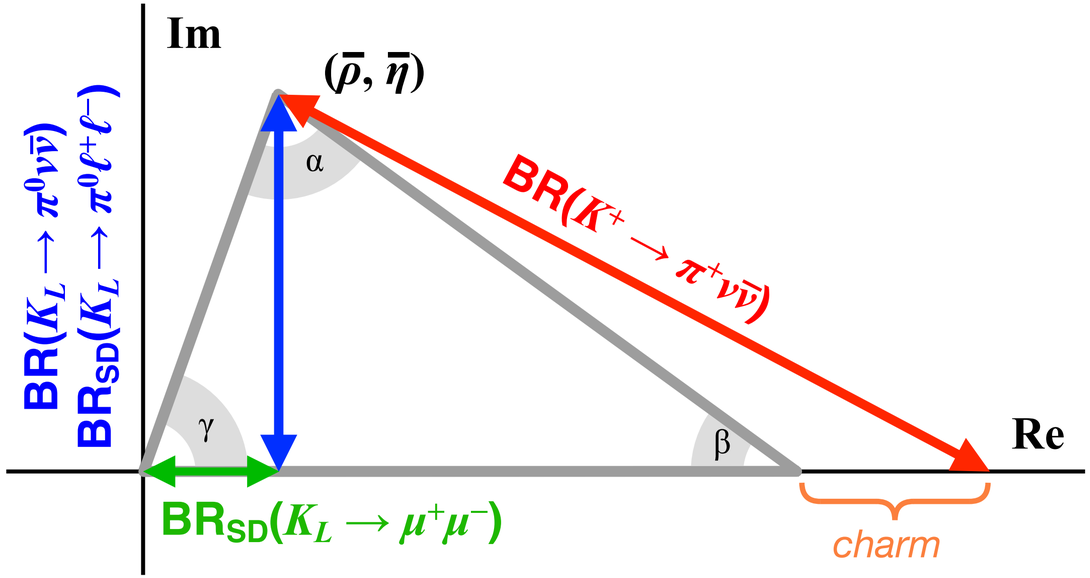
Golden Kaon Decays

Ultra-rare Kaon decays:

- **Flavor-changing processes** with unique **sensitivity to New Physics** because of **box & penguin diagrams**.
- **Highly suppressed** in the SM.

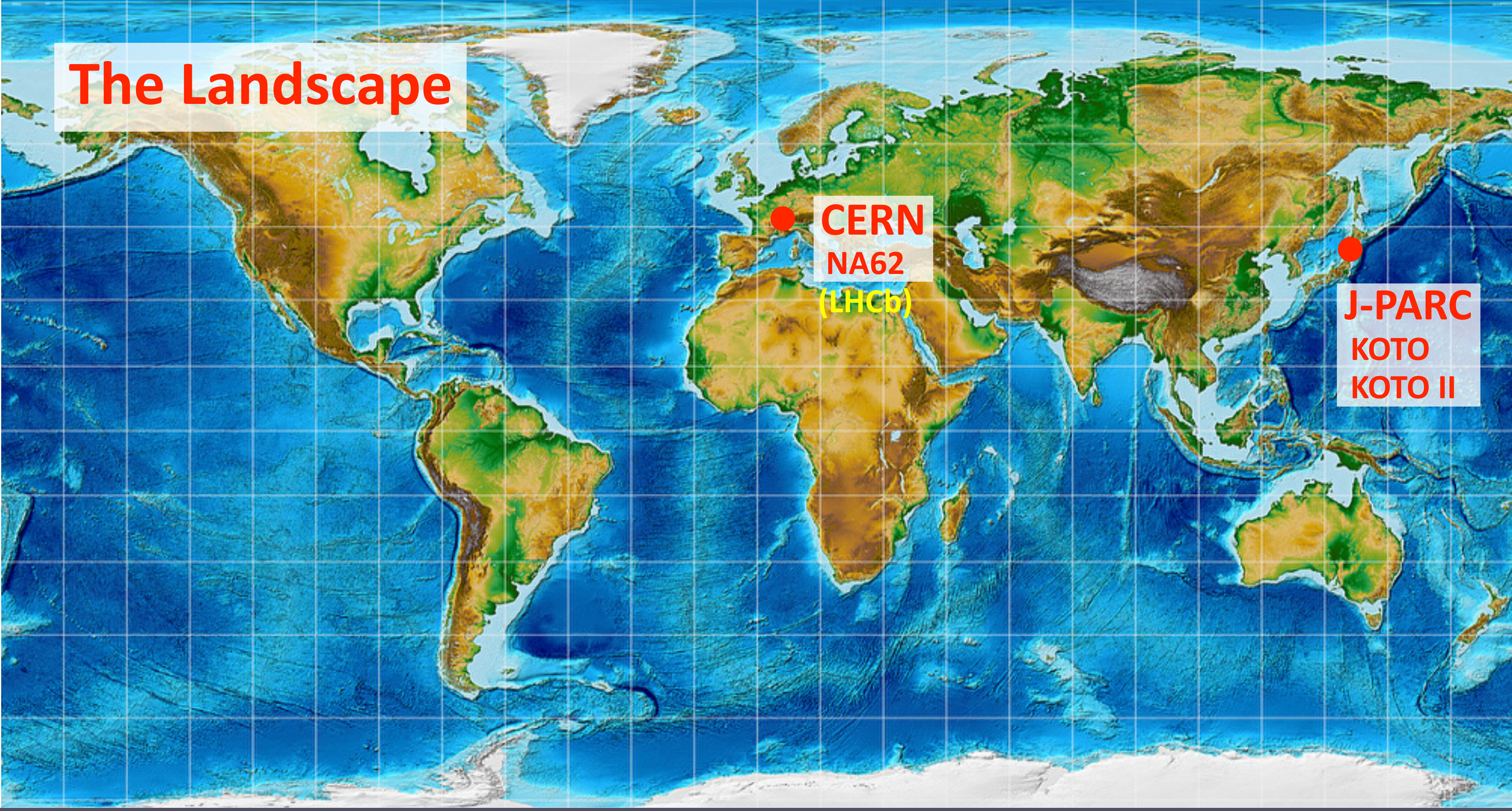
  ➜ **Sensitivity to New Physics at energy scales far beyond collider energies.**

These are the decays to go for!

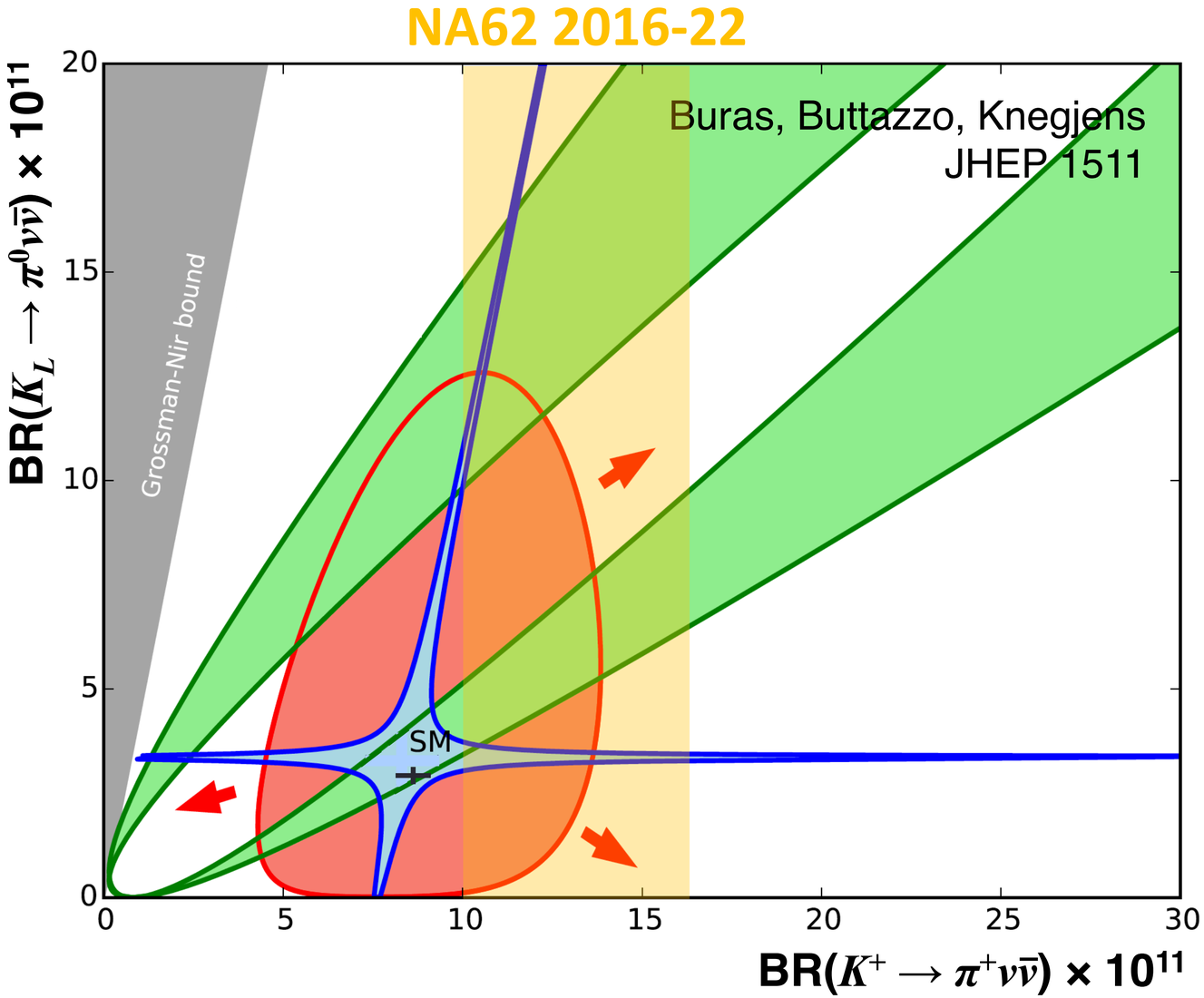


Decay	SM Branching Ratio
$K_L \to \pi^0 \nu\bar{\nu}$	$(2.94 \pm 0.15) \times 10^{-11}$ [1]
$K^+ \to \pi^+ \nu\bar{\nu}$	$(8.60 \pm 0.42) \times 10^{-11}$ [1]
$K_L \to \pi^0 \ell^+\ell^-$ (SD)	$(3.5 \pm {}^{1.0}_{0.9}) \times 10^{-11}$ *ee*, [2] $(1.4 \pm 0.3) \times 10^{-11}$ *μμ*, [2]
$K_L \to \mu^+\mu^-$ (SD)	$(6.8 \pm {}^{0.8}_{0.2}) \times 10^{-9}$ [3]

The Landscape



NA62



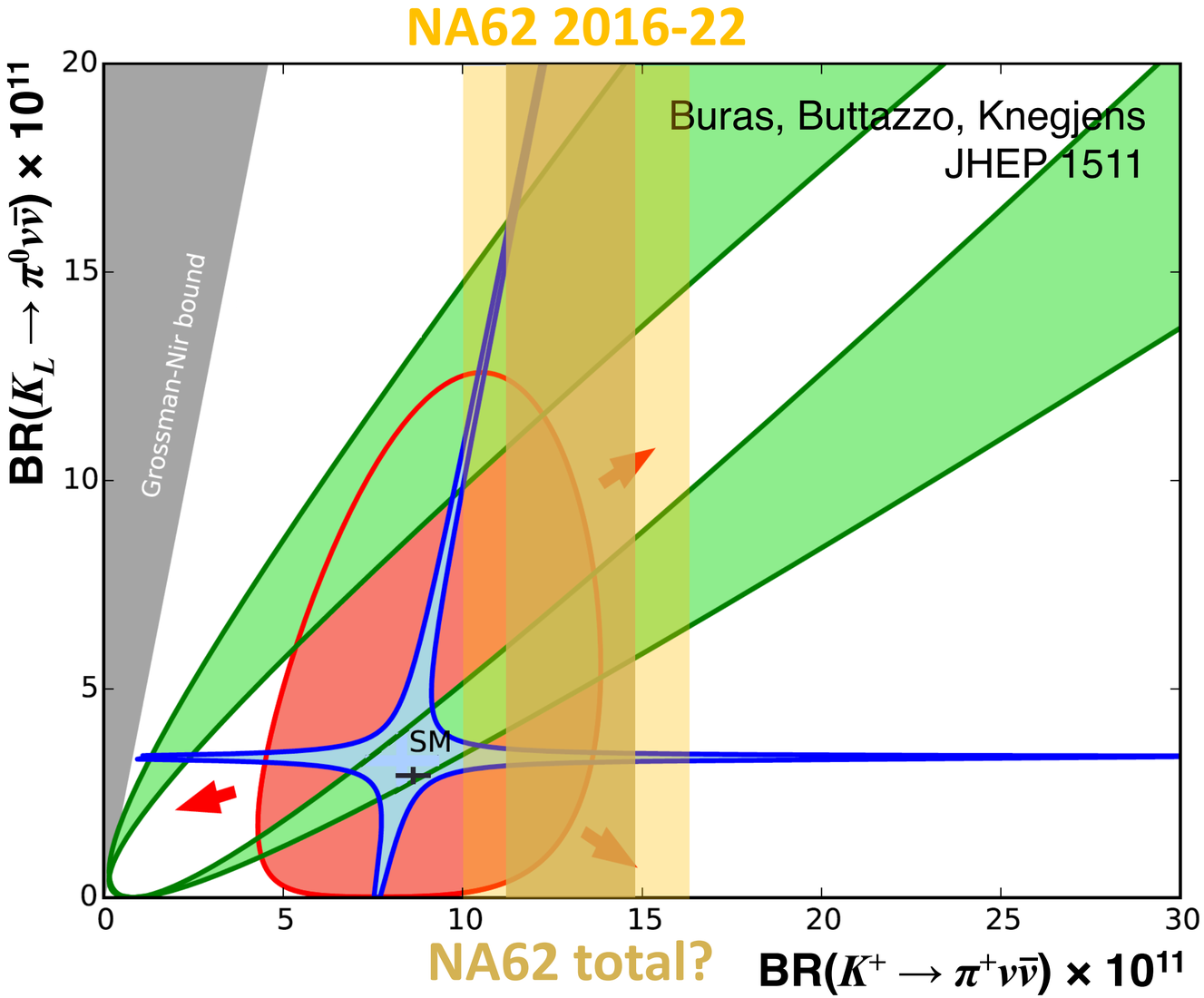
- **2016-18 + 21/22 data:**

  51 events (18 estimated bkg.)

  $Br(K^+ \to \pi^+\nu\bar{\nu}) = (13.0^{+3.3}_{-3.0}) \times 10^{-11}$

  Smallest ever discovered Br!

NA62



- **2016-18 + 21/22 data:**

  51 events (18 estimated bkg.)

  $Br(K^+ \to \pi^+\nu\bar{\nu}) = (13.0^{+3.3}_{-3.0}) \times 10^{-11}$

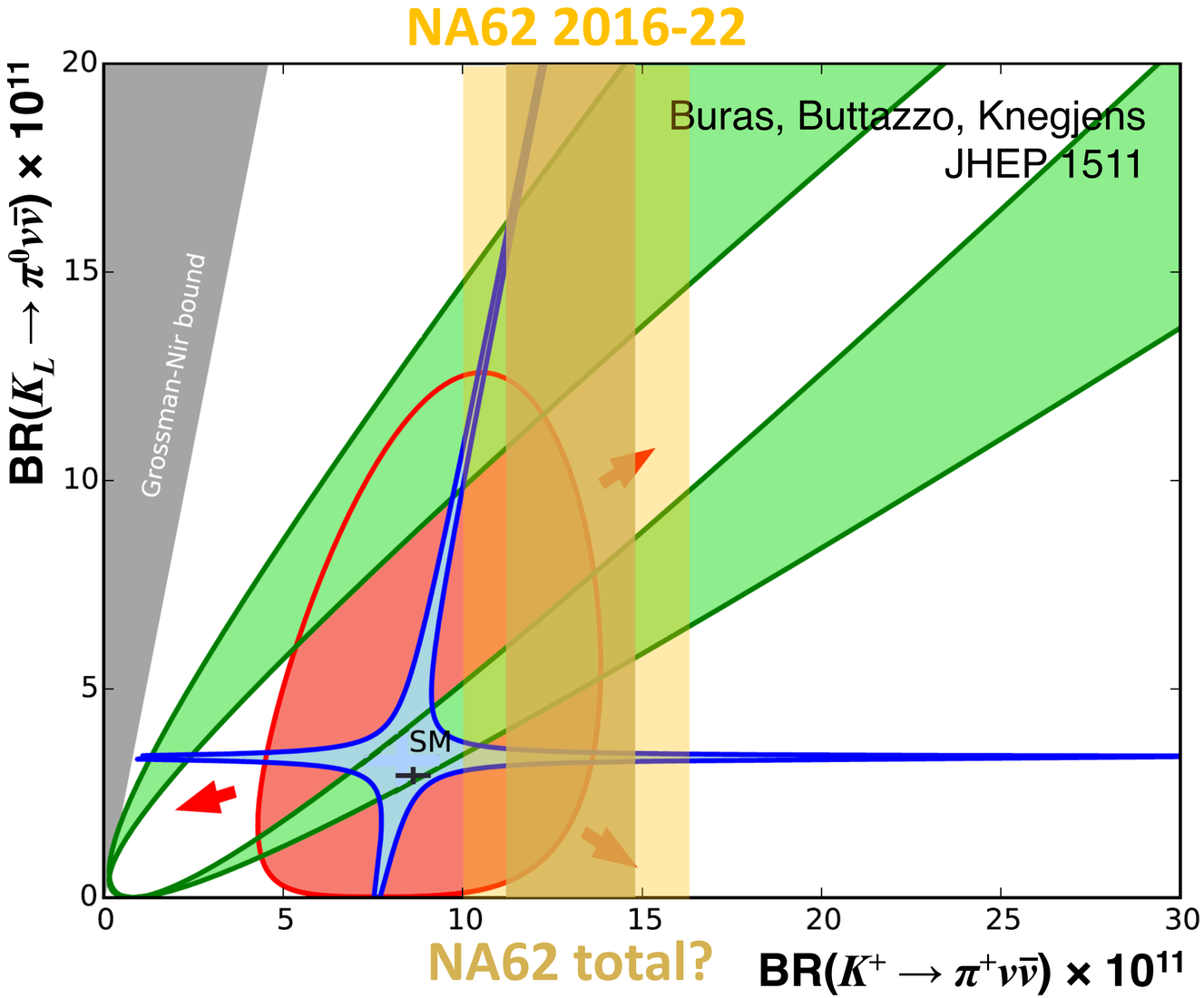
  Smallest ever discovered Br!

- **All NA62: 2016-26** (up to LS 3)

  About 2.5 × N_K with similar S/N.

  ➜ **Total error of ≈ ± 1.8 × 10^{-11}**

KOTO



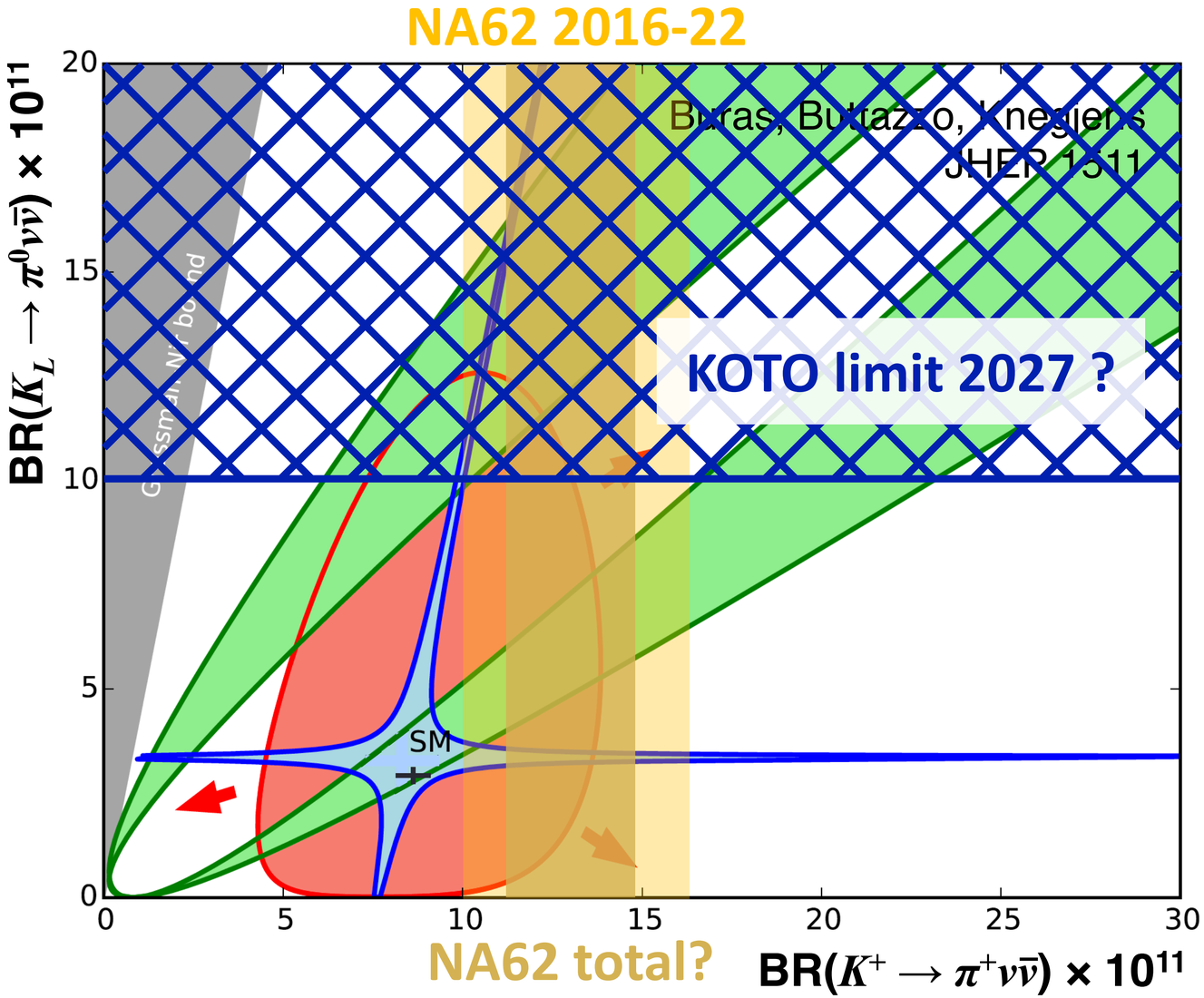
- **2021 Data:**

  Single Event Sens. = 9.3×10^{-10}, no signal candidates.

  ➜ **Upper limit** (PRL 134 (2025) 081802):

  $Br(K_L \to \pi^0\nu\bar{\nu}) < 2.2 \times 10^{-9}$

KOTO



- **2021 Data:**

  Single Event Sens. = 9.3×10^{-10}, no signal candidates.

  ➜ **Upper limit** (PRL 134 (2025) 081802):

  $Br(K_L \to \pi^0 \nu\bar{\nu}) < 2.2 \times 10^{-9}$

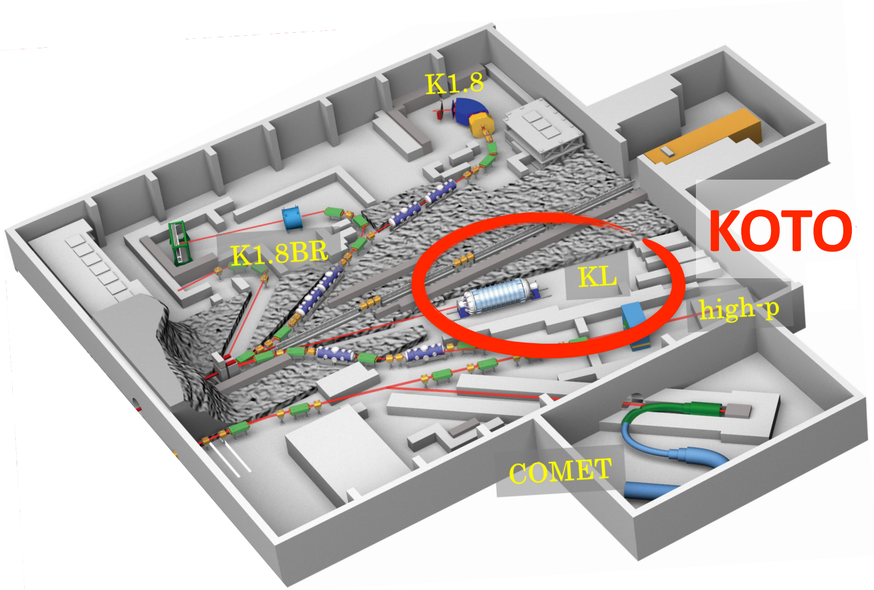
- **Full KOTO: up to ~2030**

  Better **Detector** (less background), better **DAQ** (for 100 kW beam).

  ➜ **Br Sensitivity ~ 1×10^{-10}**

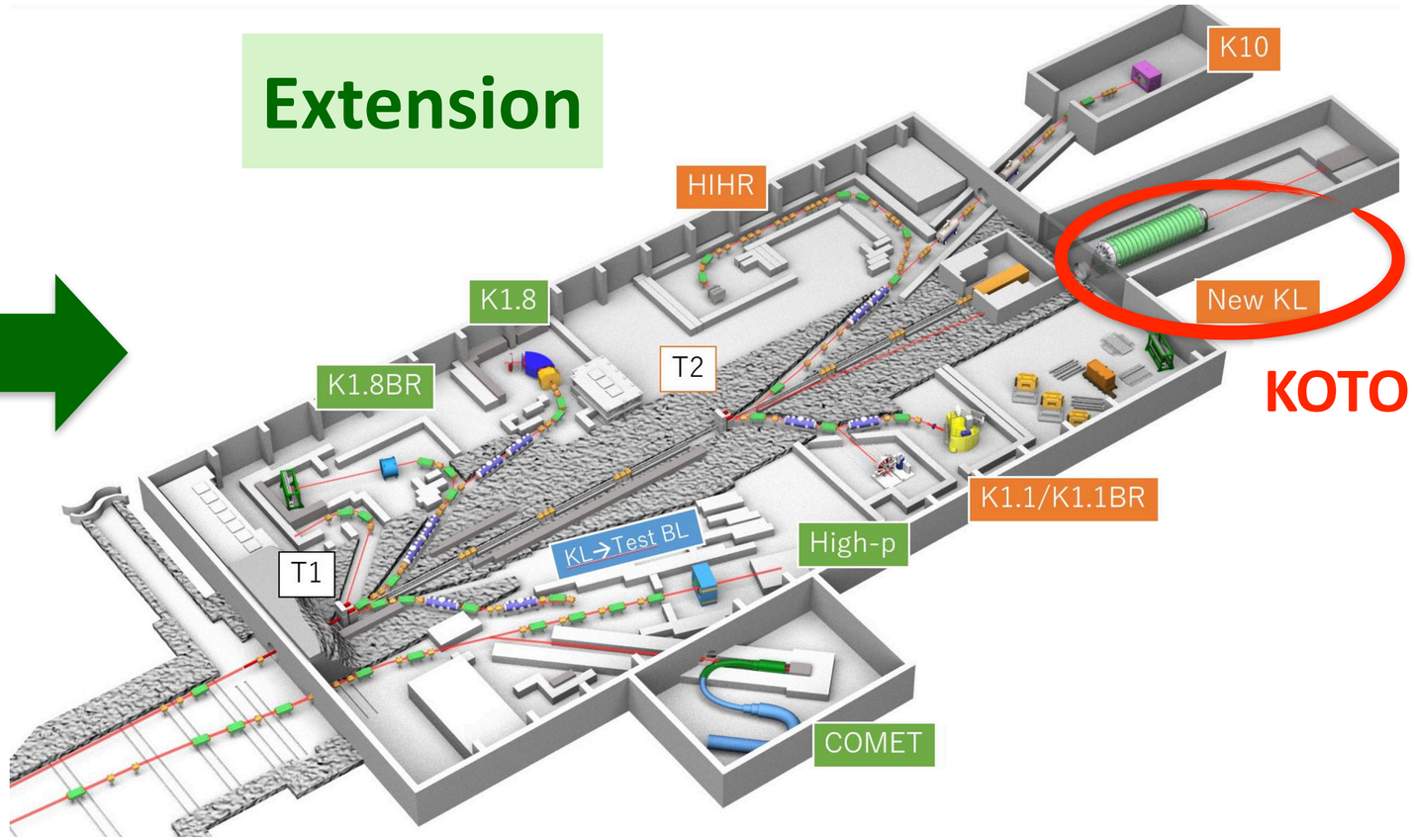
KOTO → KOTO II: J-PARC Hadron Facility Extension

Today



KOTO

Extension

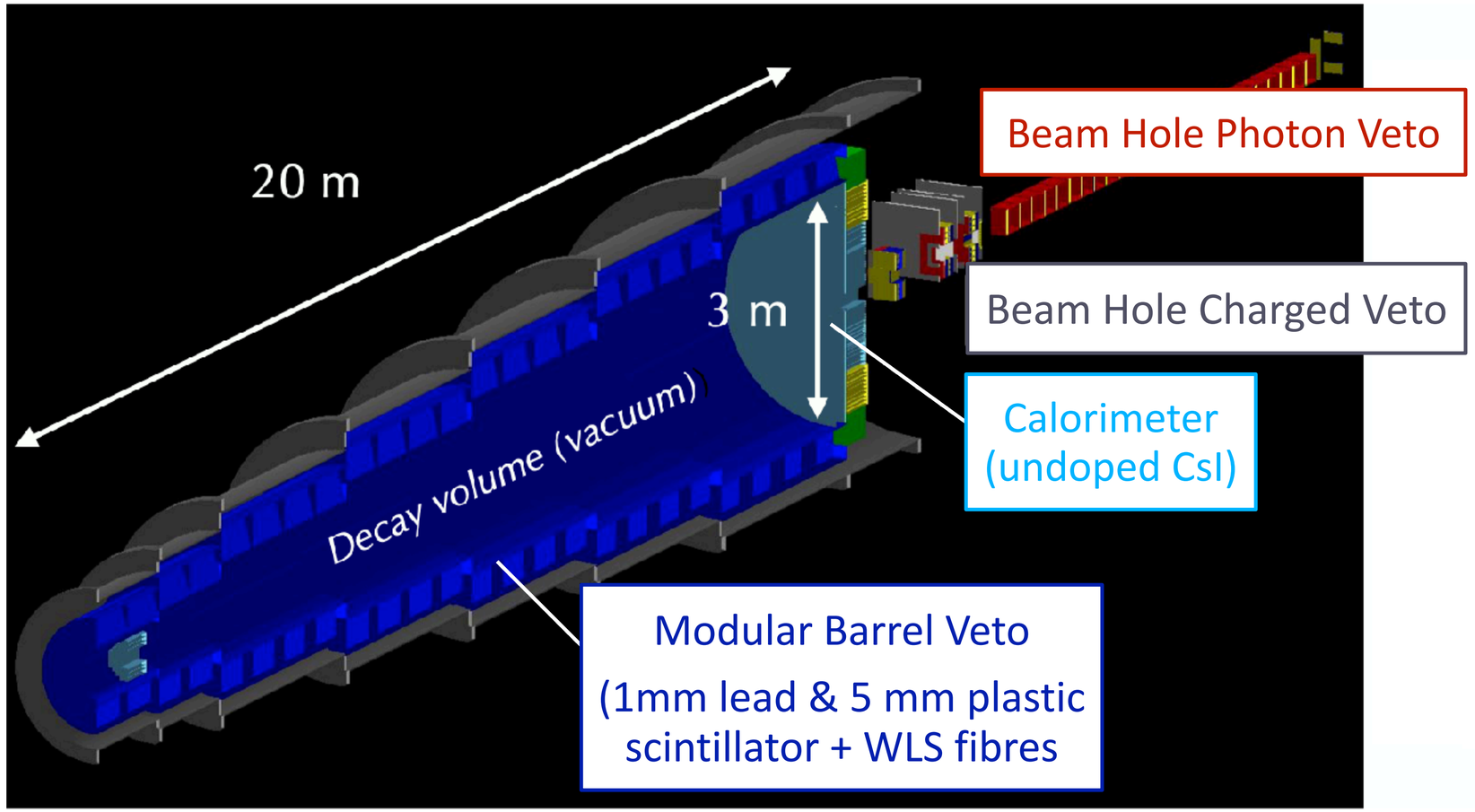


KOTO II

Extension is supported by KEK Project Implementation Plan 2022

➜ Top priority to request new budget, decision in 2027.

KOTO II Detector: Base Design



- **„Hollow calorimeter“**
  - ➜ Both γ detection and low-energy veto.
    - » Time resol. ≤ 1 ns
    - » γ directionality, if possible.
- **For $K_L \to \pi^0 \ell^+ \ell^-$:**
  - ➜ Additional tracker *(not shown, Straws?)*
  - ➜ Tracking barrel veto

KOTO II Expected Signal Yield

Comparison KOTO – KOTO II

	KOTO	KOTO II	K II/K I
K_L **yield** (arb. units)	1	2.6	**2.6**
Decay probability	3.3 %	10 %	**3**
Geom. acceptance	26 %	24 %	**0.9**
Selection efficiency	3 %	26 %	**8.7**
1 – Accidental loss	64 %	39 %	**1.7**
1 – Backsplash loss	50 %	91 %	**1.8**
Total improvement			**190**

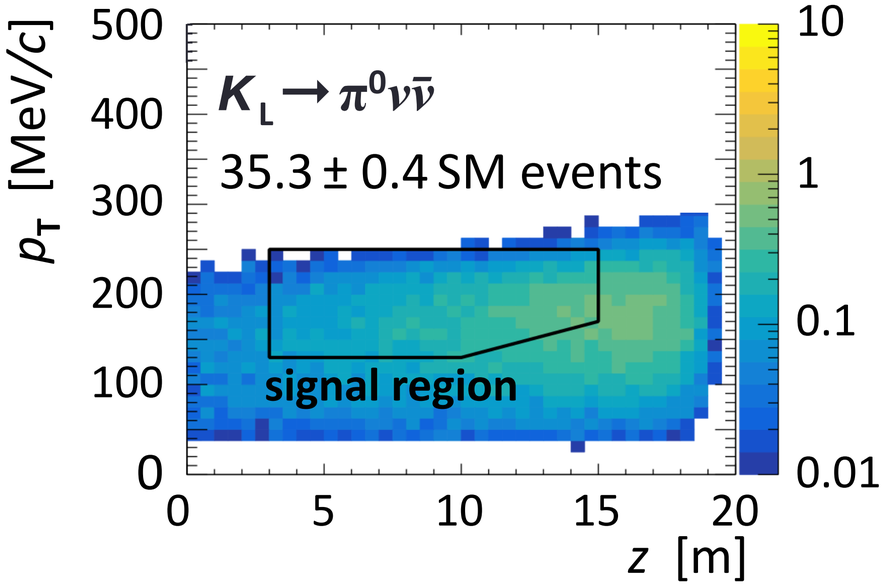
KOTO II 190 × more sensitive than KOTO

Assuming:

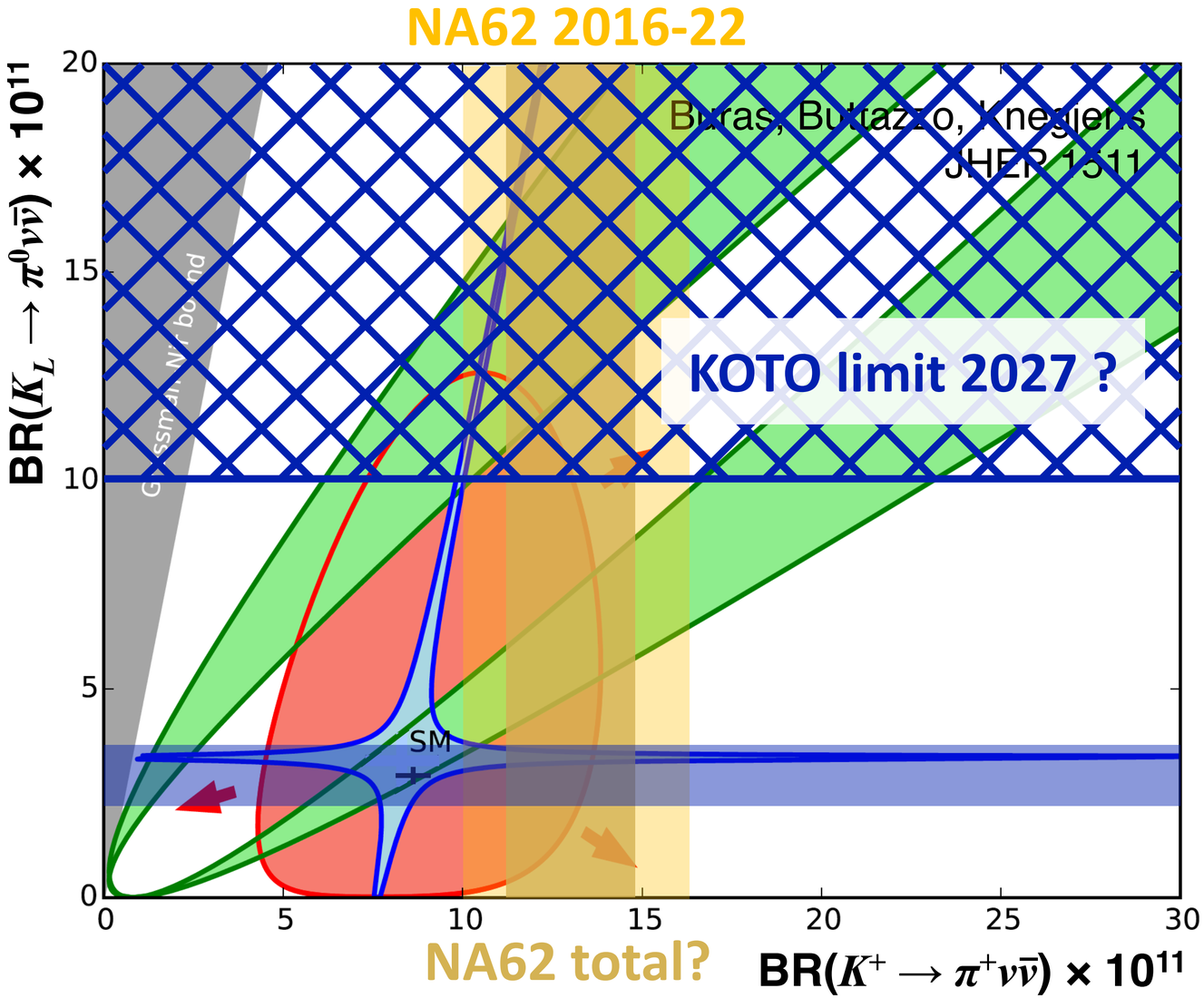
- **Beam power: 100 kW** (as in KOTO)
- **Running time: 3×10^7 s**

➜ **6.3×10^{20} pot**

➜ **35 expected SM $K_L \to \pi^0 \nu\bar{\nu}$ events**



KOTO II Sensitivity



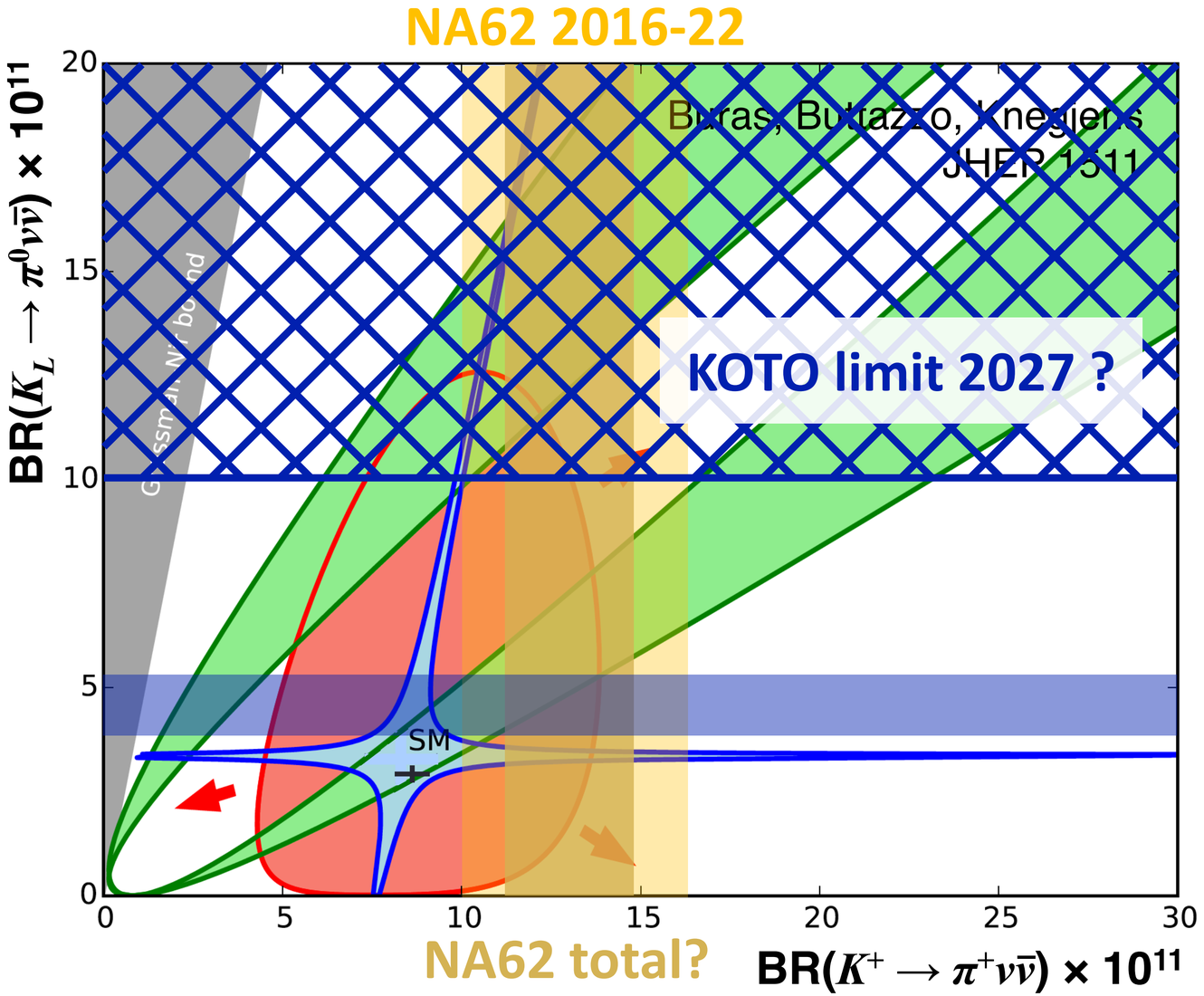
Assumptions:

- 100 kW beam
- 3×10^7 s
- SES = 8.5×10^{-13}, S/B = 0.9

➜ **35 SM signal events**
40 background events

➜ **ΔBr/Br ≈ 25 %**
for SM value of Br.

KOTO II Sensitivity



Assumptions:

- 100 kW beam
- 3×10^7 s
- SES = 8.5×10^{-13}, S/B = 0.9

➜ **35 SM signal events**
40 background events

➜ **ΔBr/Br ≈ 25 %**
for SM value of Br.

➜ **New Physics at 90% CL with 40% deviation from SM.**

KOTO II Roadmap

Year	Hadron Experimental Facility Extension	Beam @Current hall	Beam @Extended hall	Target
2026				
2027	Budget request			Large scale budget request to Government
2028	Construction	On	Off	Budget request outcome and TDR prepration
2029	Construction	On	Off	PAC Stage-2 approval
2030	Construction	On	Off	Finish KOTO data taking + Special runs
2031	Construction	Off	Off	Annex ready (Space can be used)
2032	Construction	Off	Off	Start detector installation
2033	Construction	Off	Off	Installation of beam survey detector
2034	Beam	On	On	Beam line ready Beam survey
2035	Beam	On	On	First physics

Note: J-PARC belongs to KEK. KOTO II is therefore a KEK experiment a Belle 2.

KOTO II Collaboration

- Experiment scientifically approved: **J-PARC KOTO II (E107)**
  Note: J-PARC belongs to KEK. KOTO II therefore is a KEK experiment like Belle 2.
- **KOTO II Collaboration just being formed.**
- **Spokespersons:** Cristina Lazzeroni (Birmingham), Hajime Nanjo (Osaka)
- 77 members, 34 institutions, 11 countries

arXiv > hep-ex > arXiv:2501.14827

Proposal: arXiv:2501:14827

High Energy Physics – Experiment

[Submitted on 22 Jan 2025]

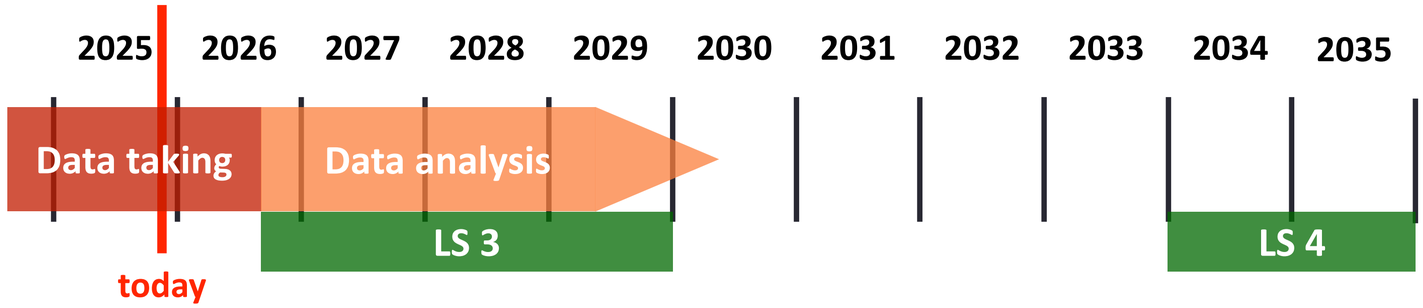
Proposal of the KOTO II experiment

Jung Keun Ahn, Antonella Antonelli, Giuseppina Anzivino, Emile Augustine, Laura Bandiera, Jianming Bian, Francesco Brizioli, Stefano De Capua, Gabriella Carini, Veronika Chobanova, Giancarlo D'Ambrosio, John Bourke Dainton, Babette Dőbrich, John Fry, Alberto Gianoli, Alexander Glazov, Mario Gonzalez, Martin Gorbahn, Evgueni Goudzovski, Mei Homma, Yee B. Hsiung, Tomáš Husek, David Hutchcroft, Abhishek Iyer, Roger William Lewis Jones, Mai Katayama, Yuto Kawata, Eun-Joo Kim, Chong Kim, Takeshi Komatsubara, Katsushige Kotera, Michal Kreps, Gianluca Lamanna, Cristina Lazzeroni, Samet Lezki, GeiYoub Lim, Sanghoon Lim, Chieh Lin, Farvah Mahmoudi, Victoria Martin, Karim Massri, Toru Matsumura, Luigi Montalto, Matthew Moulson, Hajime Nanjo, Matthew Needham, Siavash Neshatpour, Tadashi Nomura, Daiki Ogawa, Keita Ono, Monica Pepe, Letizia Peruzzo, Jacopo Pinzino, Dan Protopopescu, Claire Prouve, Thomas Reddel, Joseph Redeker, Daniele Rinaldi, Marco Romagnoni, Angela Romano, Armine Rostomyan, Jack Sanders, Diego Martínez Santos, Ivano Sarra, Artur Shaikhiev, Koji Shiomi, Ryota Shiraishi, Mattia Soldani, Marco Sozzi, Benjamin Stillwell, Yi-Ting Su, Joel Swallow, Yasuhisa Tajima, Adam Tomczak, Yu-Chen Tung, Yau Wah, Rainer Wanke, Hiroaki Watanabe, John Wendel, Tong Wu, Maresa Wynd, Guang Yang

The KOTO II experiment is proposed to measure the branching ratio of the decay $K_L \to \pi^0\nu\bar{\nu}$ at J-PARC. With a beamline to extract long-lived neutral kaons at 5 degrees from a production target, the single event sensitivity of the decay is 8.5×10^{-13}, which is much smaller than the Standard Model prediction 3×10^{-11}. This allows searches for new physics beyond the Standard Model and the first discovery of the decay with a significance exceeding 5σ. As the only experiment proposed in the world dedicated to rare kaon decays, KOTO II will be indispensable in the quest for a complete understanding of flavor dynamics in the quark sector. Moreover, by combining efforts from the kaon community worldwide, we plan to develop the KOTO II detector further and expand the physics reach of the experiment to include measurements of the branching ratio of the $K_L \to \pi^0\ell^+\ell^-$ decays, studies of other K_L decays, and searches for dark photons, axions, and axion-like particles. KOTO II will therefore obtain a comprehensive understanding of K_L decays, providing further constraints on new physics scenarios with existing K^+ results.

KOTO II Timelines and German Participation

NA62: **JGU Mainz, MPI Munich**



KOTO: No German participation

KOTO II: **JGU Mainz** *(→ Barrel Veto)*, **… ?!**