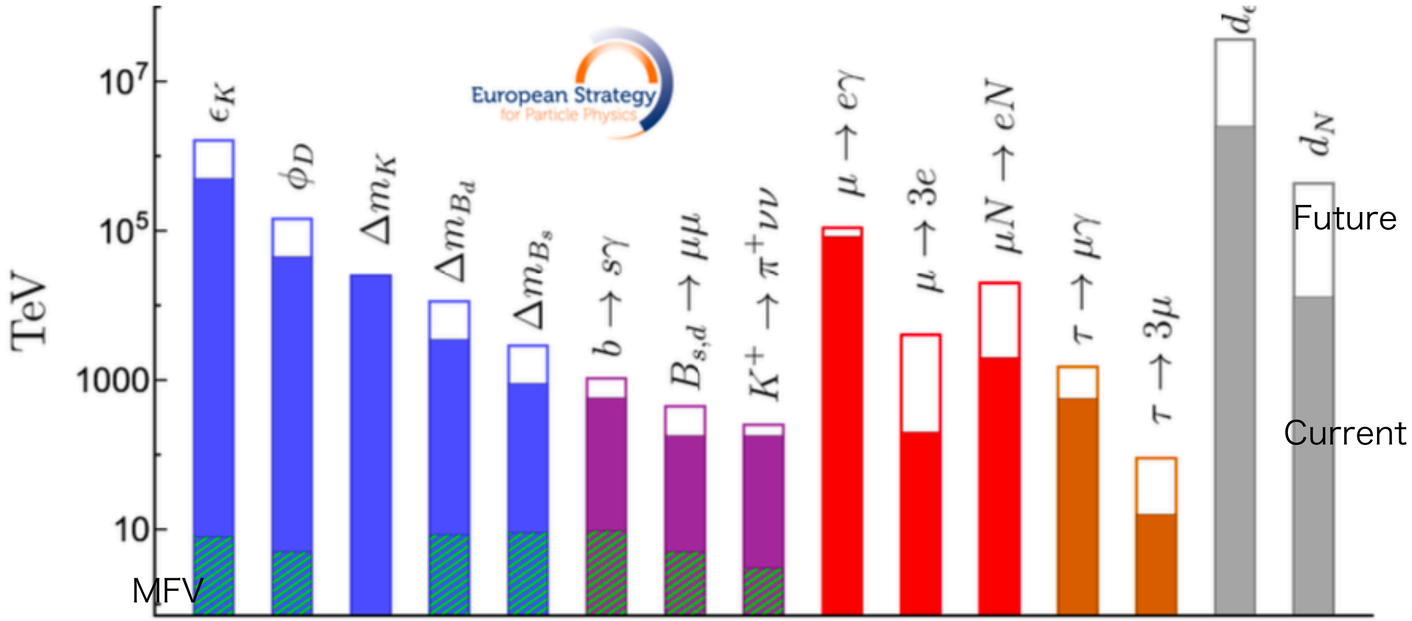
Quark flavor non-collider experiments

Hajime Nanjo
(The University of Osaka)

Nov 3, 2026 ICFA seminar 2026

Flavor transition in quark sector

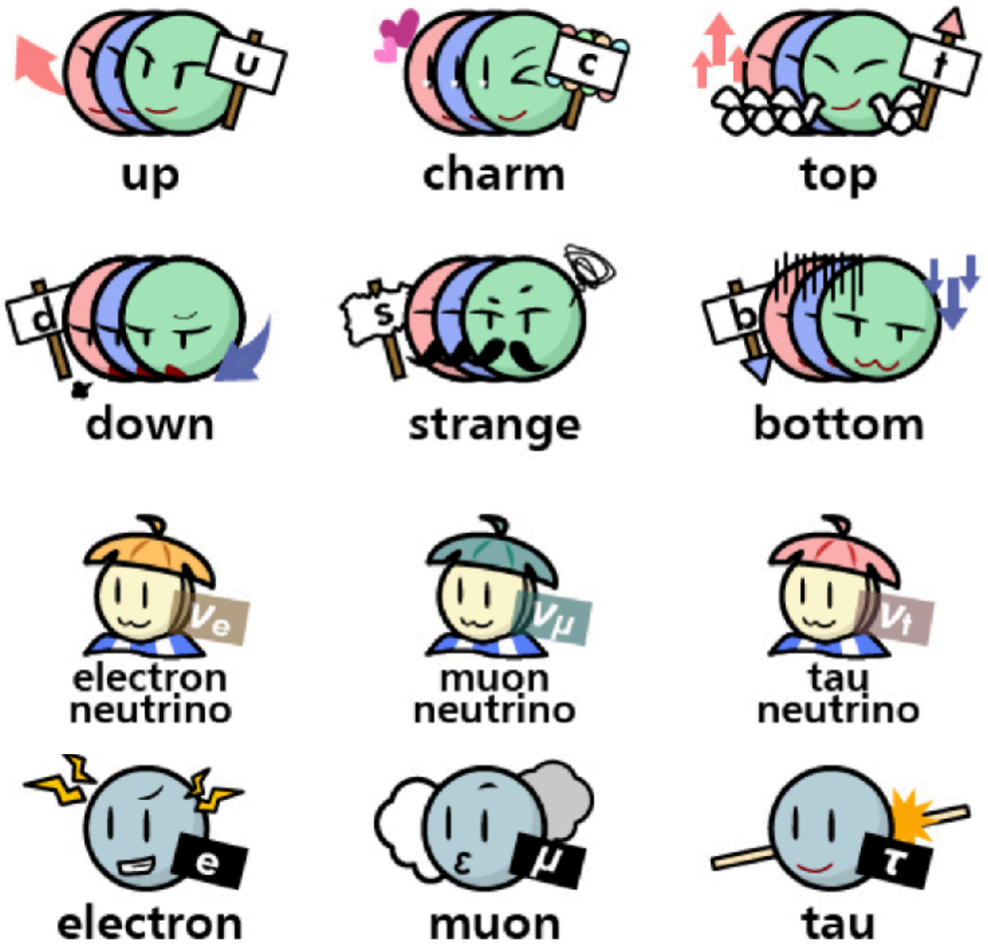
- CKM matrix (or Higgs) governs flavor transition in Standard Model
- New physics
  - Generic: May have common flavor structure
  - Flavor specific: May detect new physics in a specific flavor
- Characteristics
  - Sensitive to high energy scale
  - There may be a hint in
    - Lepton Flavor Universality
    - Unitarity in CKM matrix
    - CP or T violation



Flavor Physics

Flavor transition i.e. $s \to d$, $q \to X \to q$: Decay, Electric Dipole Moment, ⋯

→ Physics in high energy scale may contribute in the intermediate state



Targets for New Physics search

Rare phenomena / Tiny effects

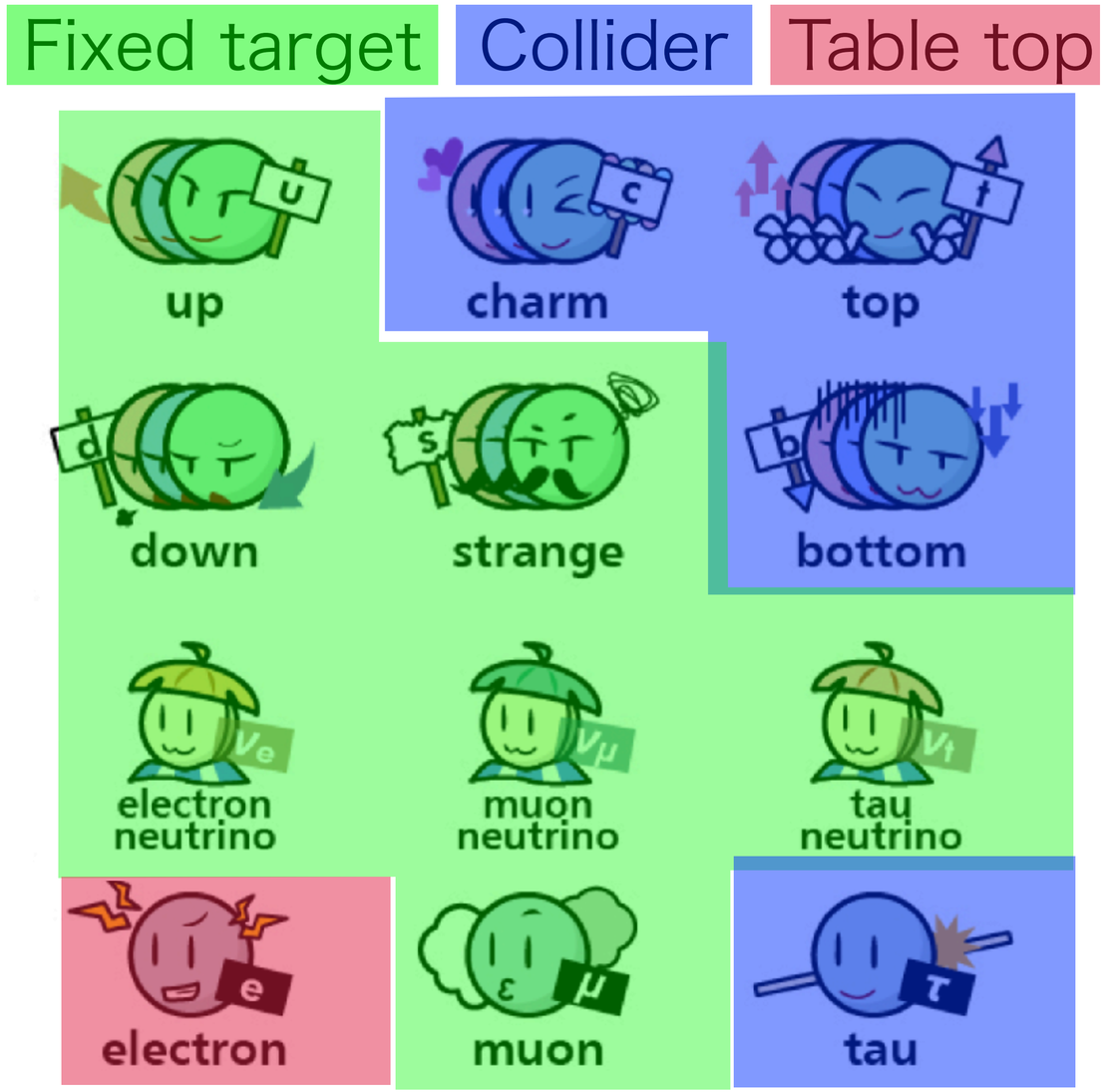
- Signal: New Physics in high energy scale $\Delta E \times \Delta t \sim \hbar$
- Background: Suppressed SM contribution

Precise or Negligible contribution of SM effects

- to detect new physics effects

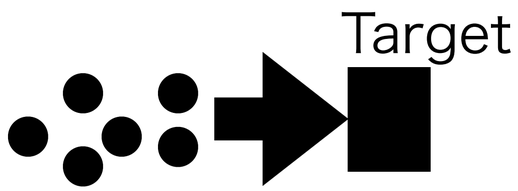
Need to prepare huge number of events
→ High Intensity (Flux/Luminosity)
→ Accelerator in intensity frontier

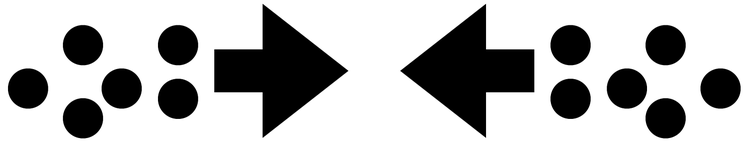
Flavor Physics —Collider or Fixed target?—



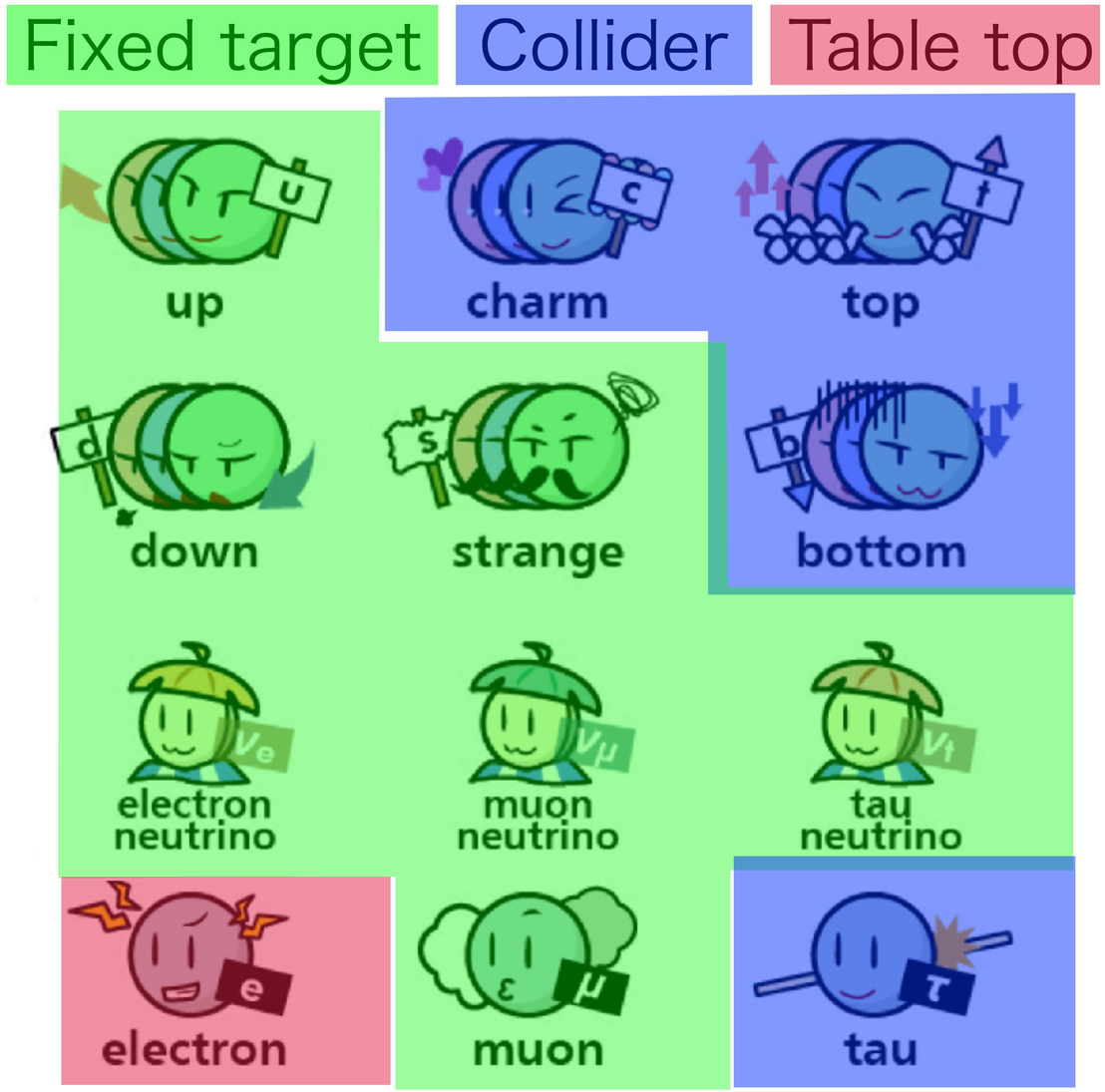
Huge number of interactions
to produce hug number of events
→ Fixed target is better

High energy
→ Collider is better





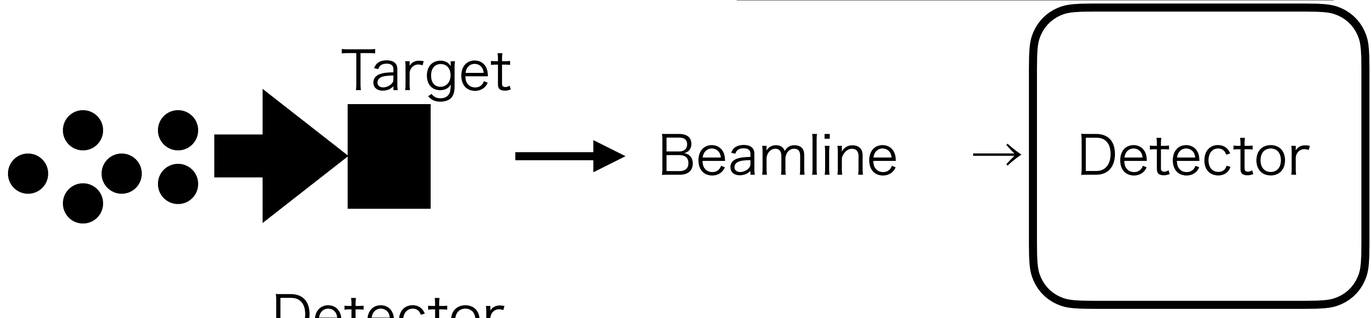
Flavor Physics —Collider or Fixed target?—

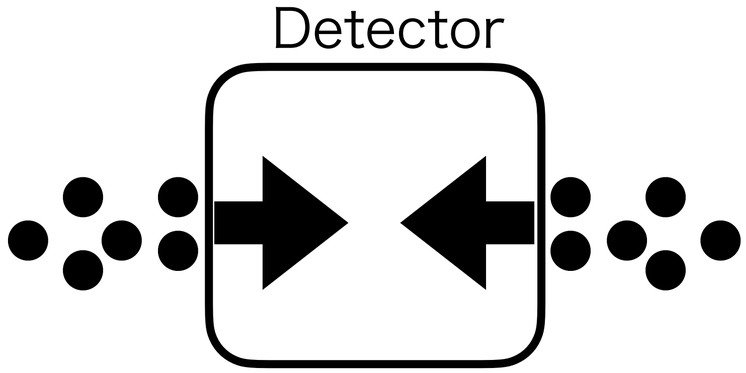


Huge number of interactions
to produce hug number of events
→ Fixed target is better

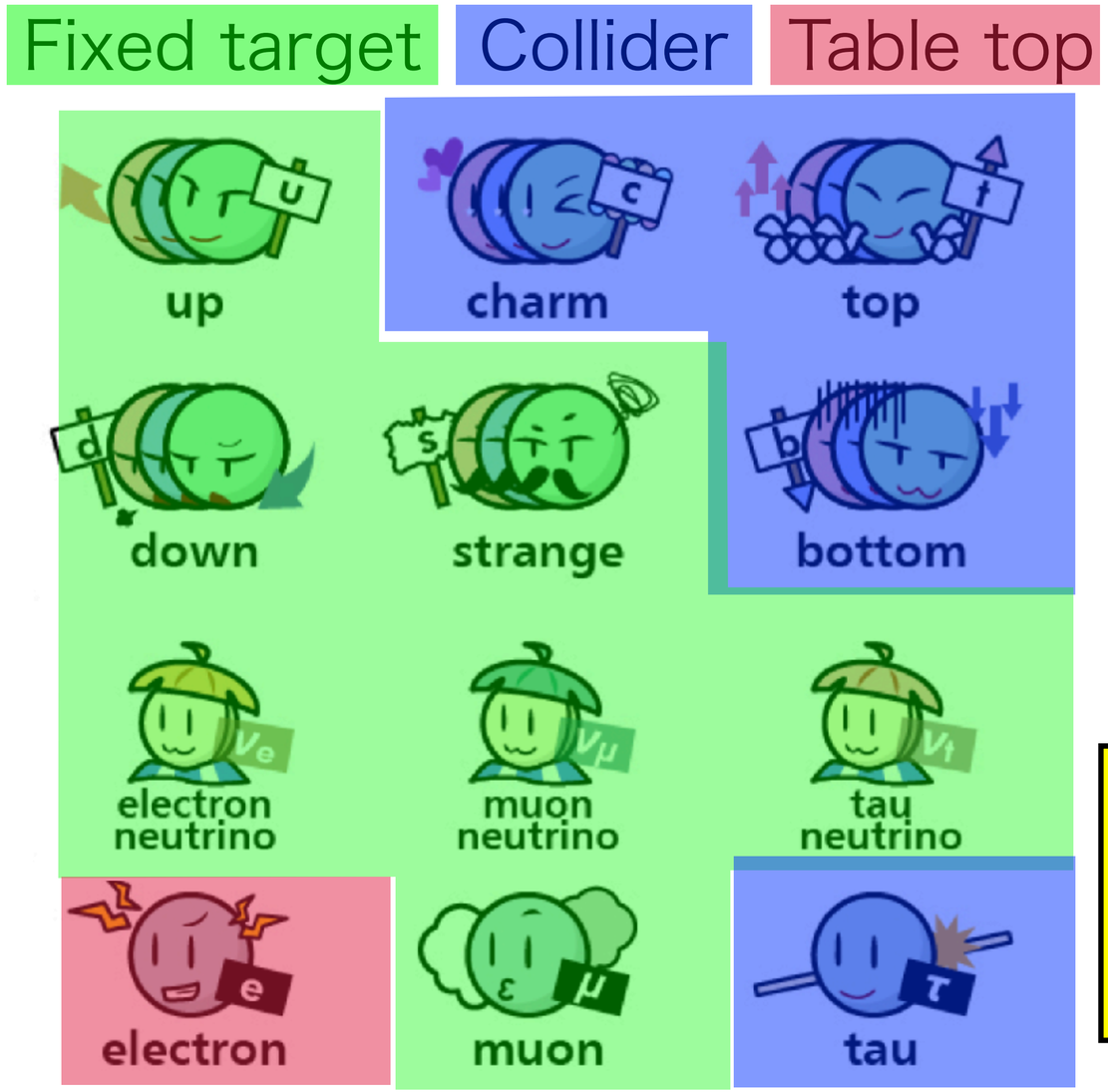
High energy
→ Collider is better

Usually, away from the production target



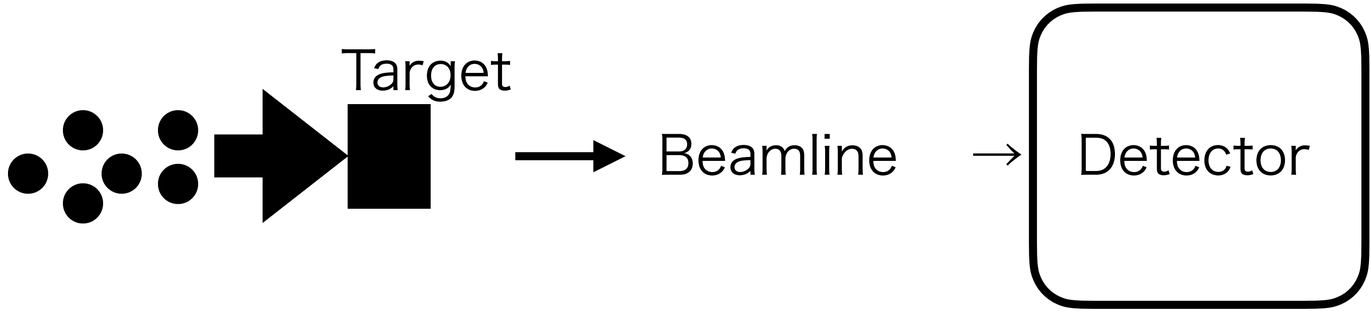


Flavor Physics —Collider or Fixed target?—



Huge number of interactions
to produce hug number of events
→ Fixed target is better

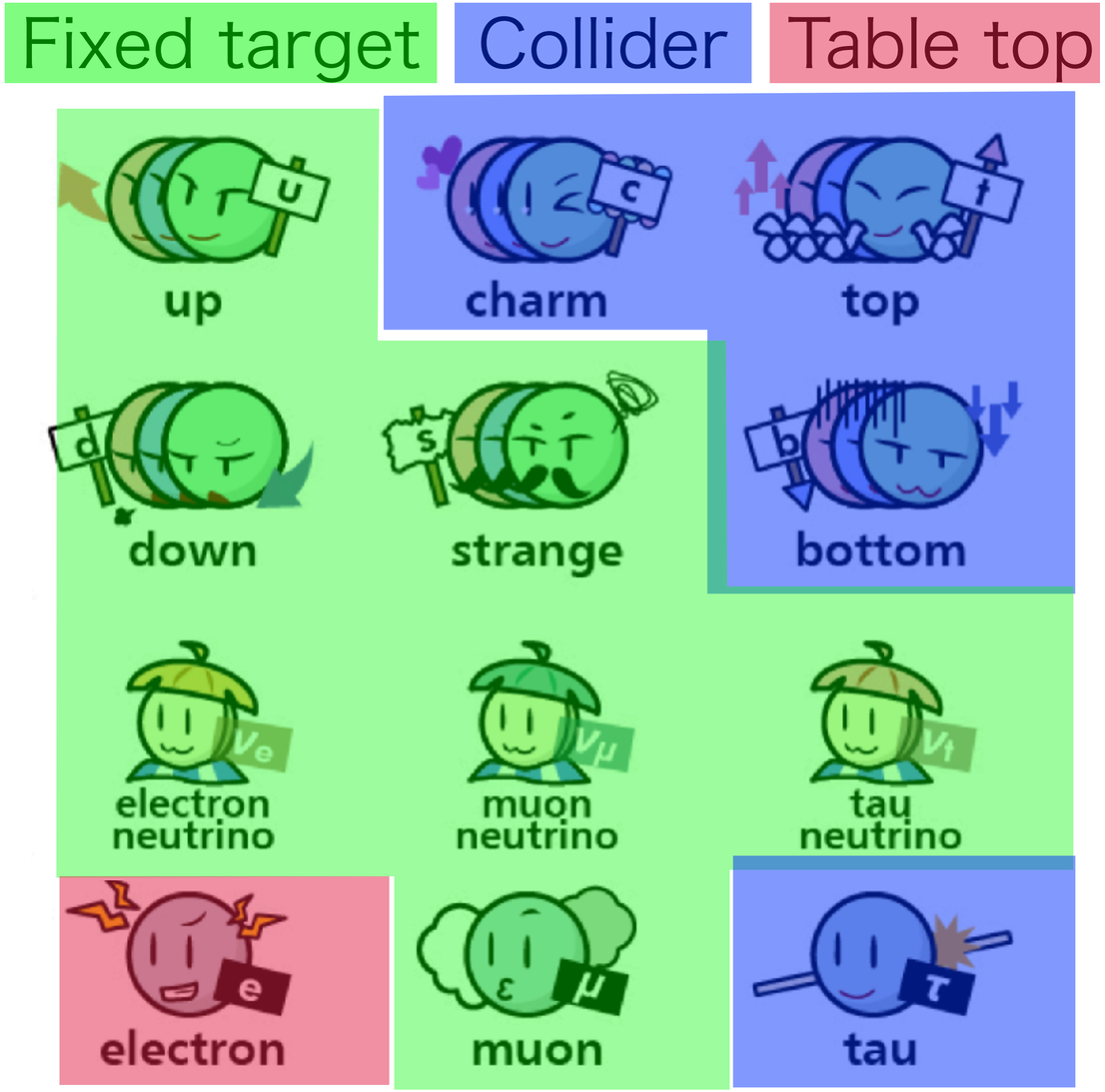
High energy
→ Collider is better



Fixed target / non-collider → Light particles
Huge interaction→High radiation/rate
→ prepare beamline to guide particles of interest
↔ Characteristics of each experiment

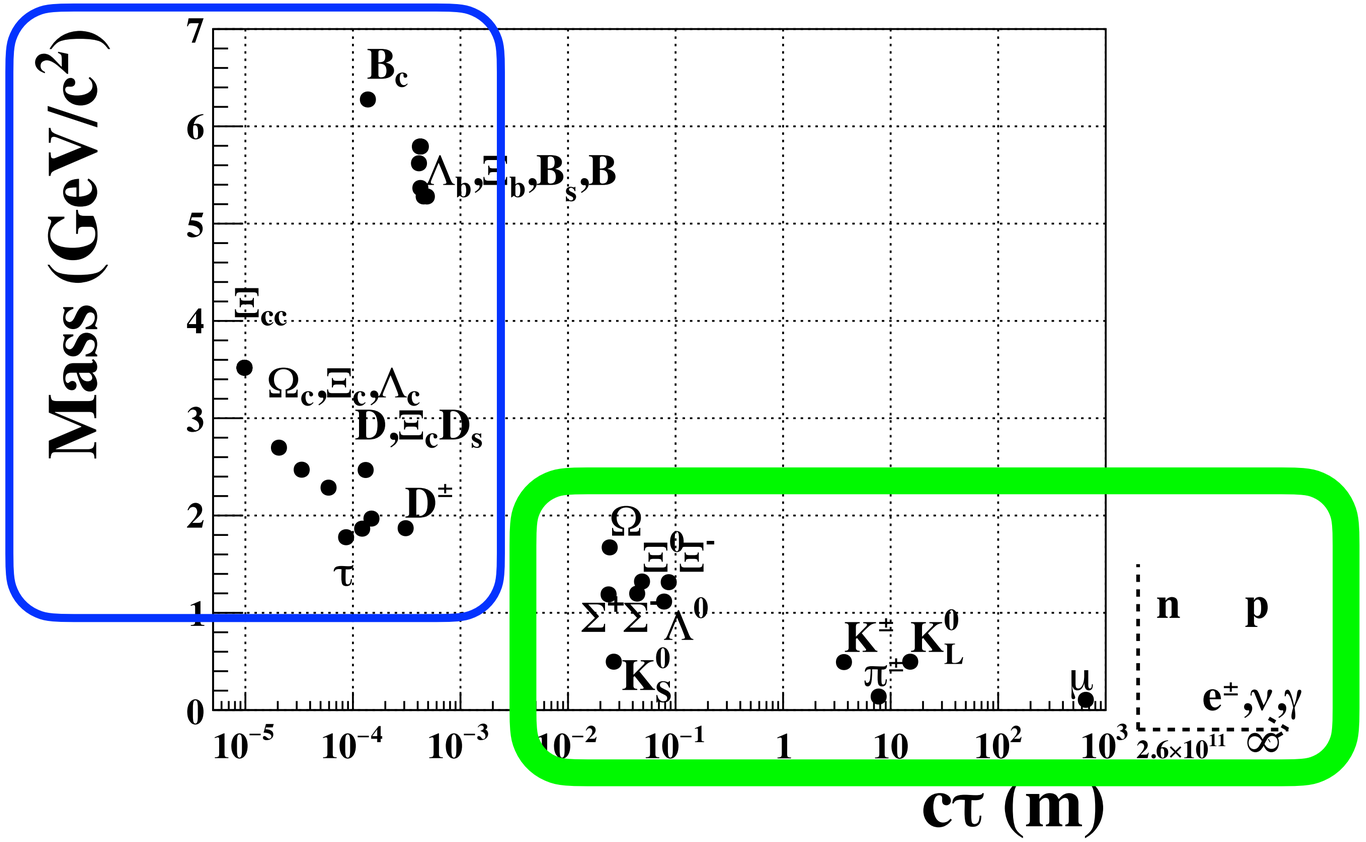
Flavor Physics —Topics on Fixed target—

Fixed target | Collider | Table top



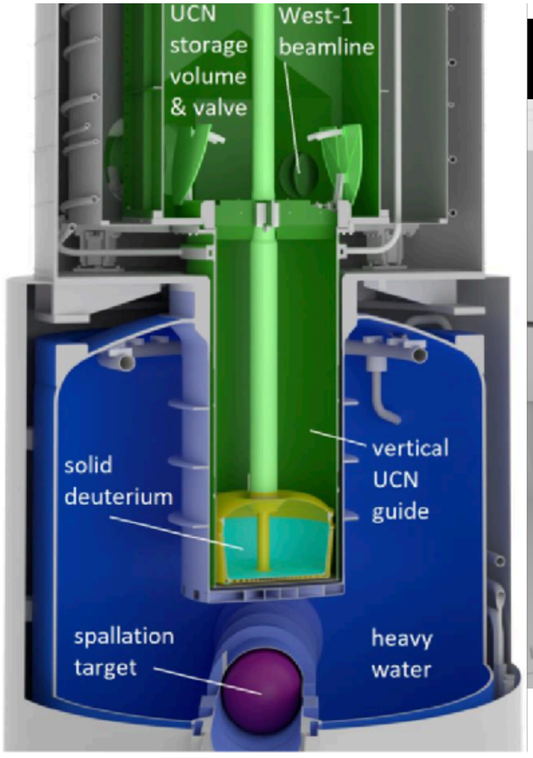
Guiding particles: Long-lived particles are suitable.
Lighter and long-lived particles

$K^{\pm}, K_L\, \pi^{\pm}, \mu^{\pm}$, neutron, ν, $(p, e^{\pm})$

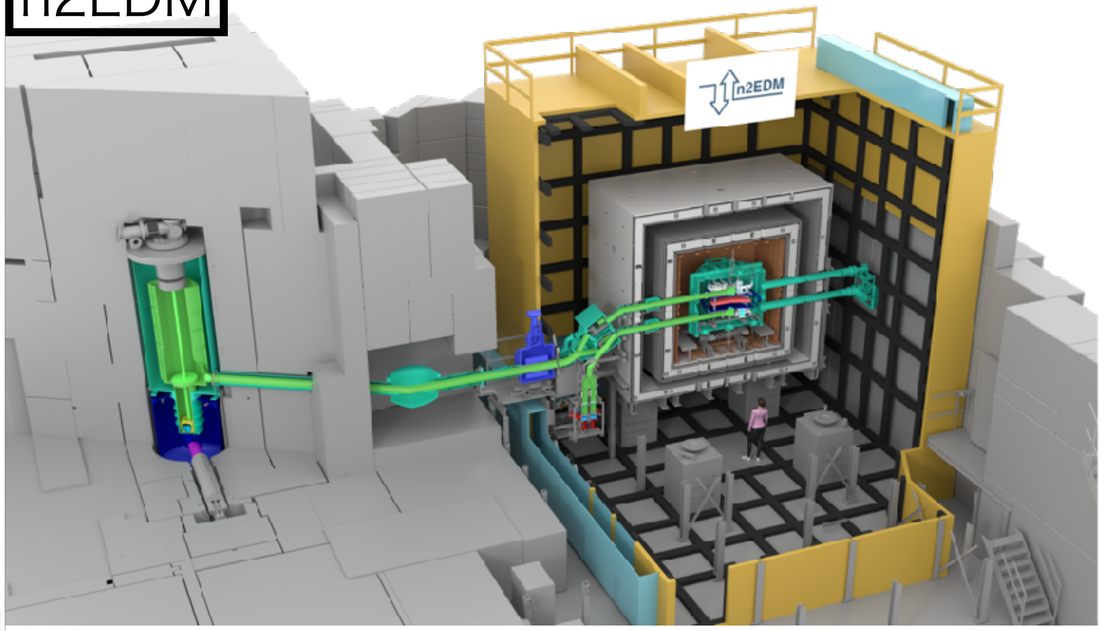


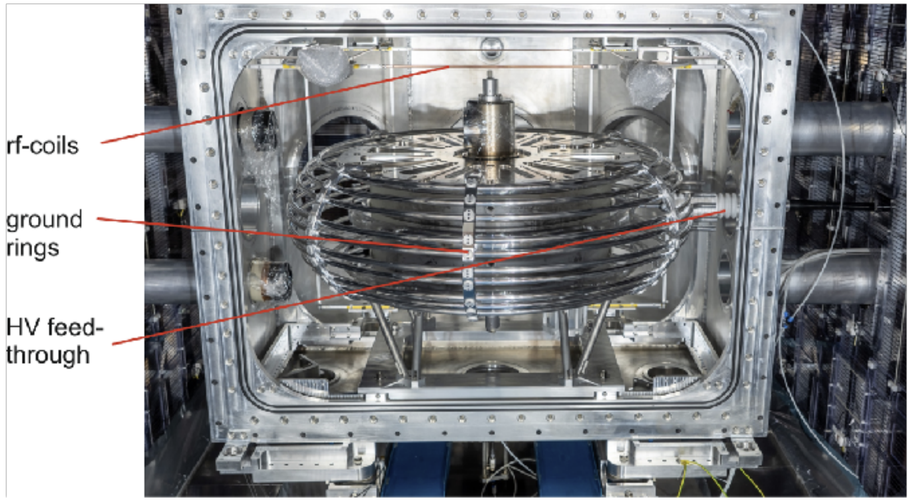
Neutron EDM

- $H = -d\vec{\sigma} \cdot \vec{E}$: T odd → T violating → CP violating effect
- SM contribution: $d_n^{\mathrm{SM}} \sim \mathcal{O}(10^{-32})$ → larger value observed→ new physics
- Experimental bound: $|d_n| < 1.8 \times 10^{-26} (90\,\%\,\mathrm{CL})$ by nEDM@PSI in 2020
- Next generation experiments with sensitivity $\mathcal{O}(10^{-27})$



n2EDM



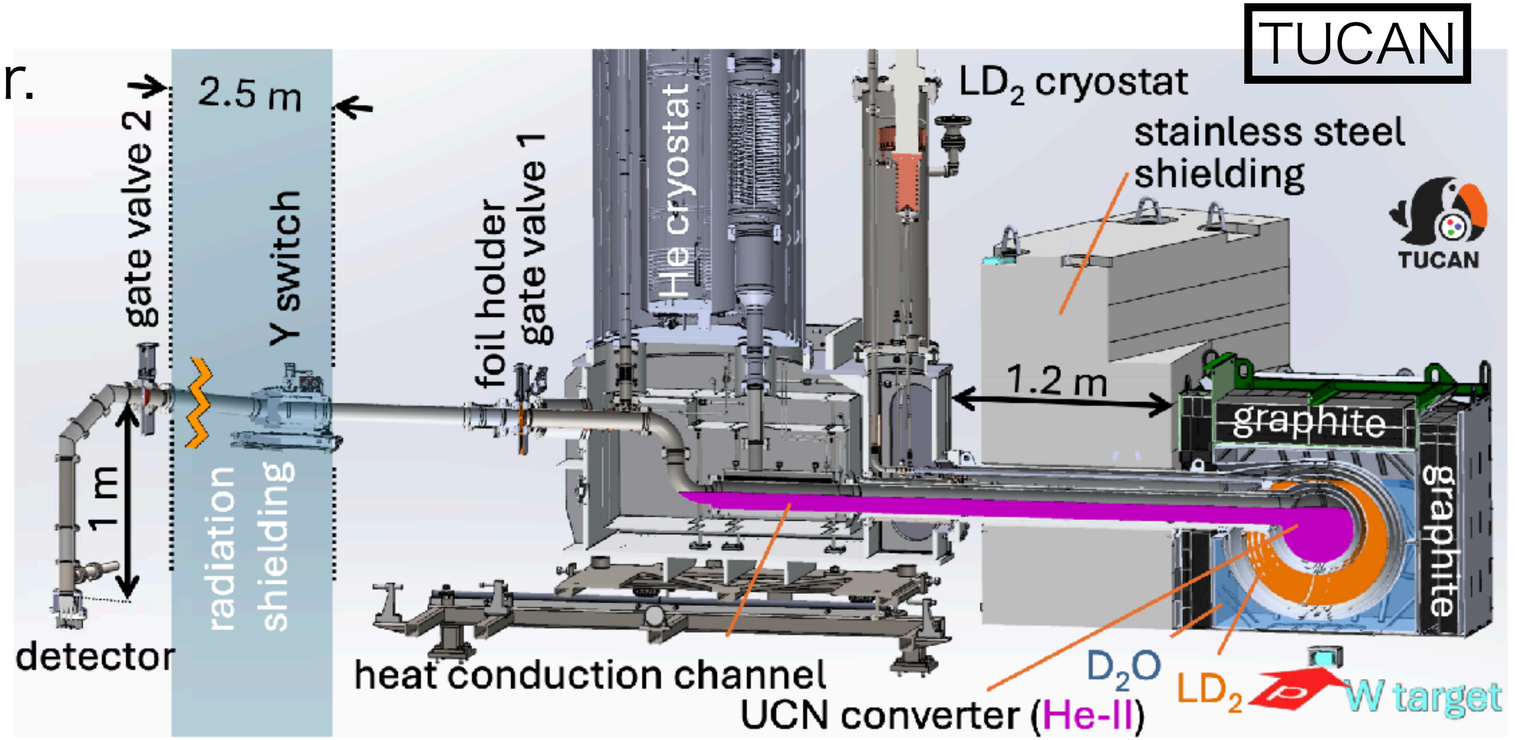


Neutron EDM

- n2EDM@PSI … Blinded data taking was started from June 2026
- TUCAN@TRIUMF … New UNC source was completed.
  World highest class UCN density was achieved in JFY2025
- nEDM@LANL … Preparation is on-going.
- panEDM@ILL … with reactor.

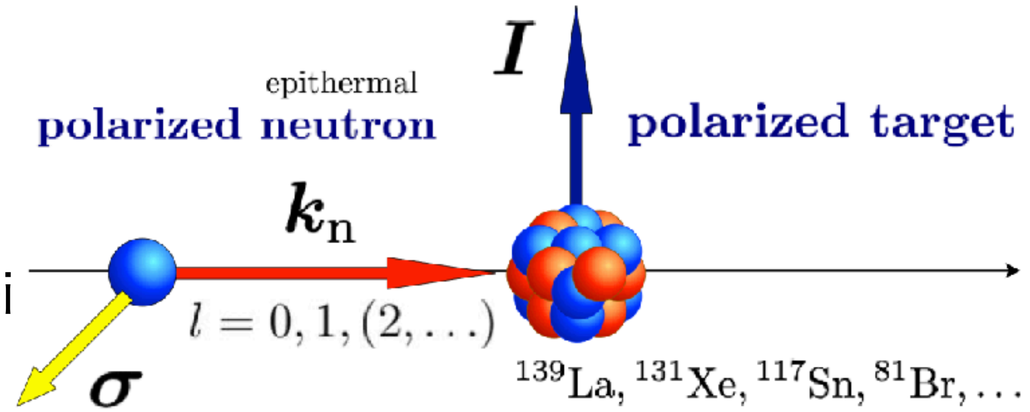
C. CRAWFORD,
DPF MEETING,
2026-07-22

arXiv:2607.03033



T-violation with neutron scattering

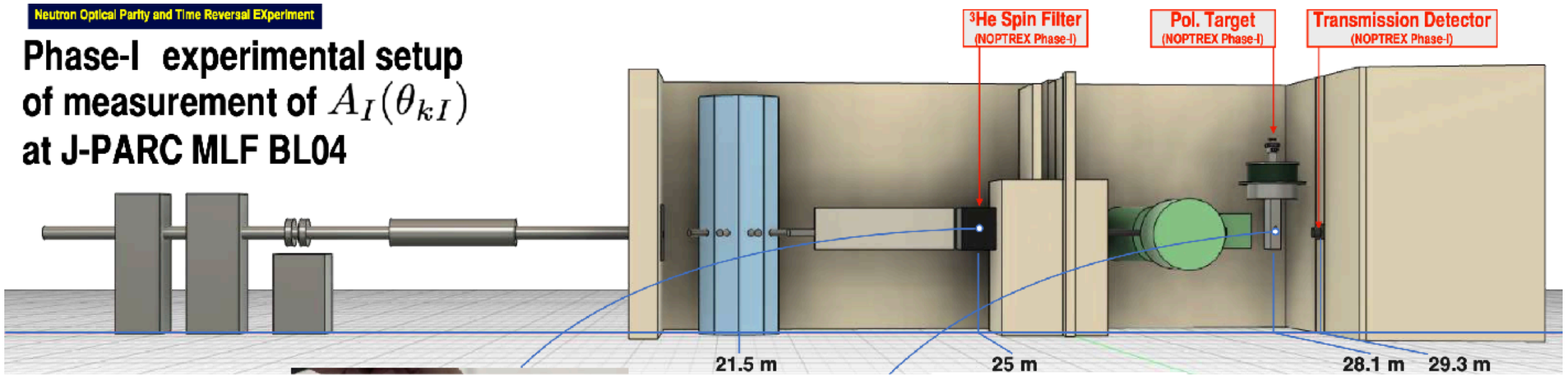
- NOPTREX@J-PARC MLF
- Measure the forward scattering amplitude.
- Amplification mechanism in compound nuclei
- It may depends on T-odd parameter.
  → T-violation effect.
- Physics run in Phase I is in progress.



P-odd T-odd $\boldsymbol{\sigma} \cdot (\boldsymbol{k}' \times \boldsymbol{I})$

$$P : \boldsymbol{\sigma} \cdot (\hat{\boldsymbol{k}} \times \hat{\boldsymbol{I}}) \rightarrow \boldsymbol{\sigma} \cdot ((-\hat{\boldsymbol{k}}) \times \hat{\boldsymbol{I}})$$

$$T : \boldsymbol{\sigma} \cdot (\hat{\boldsymbol{k}} \times \hat{\boldsymbol{I}}) \rightarrow (-\boldsymbol{\sigma}) \cdot ((-\hat{\boldsymbol{k}}) \times (-\hat{\boldsymbol{I}}))$$



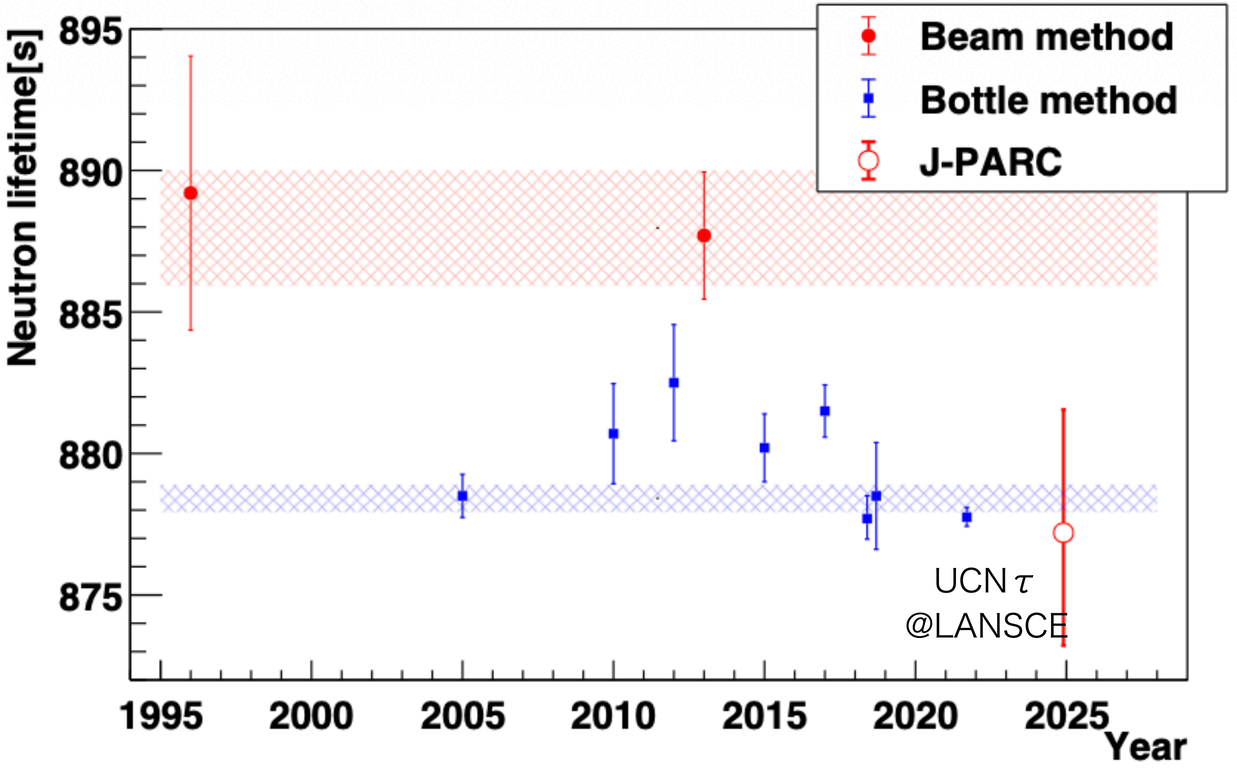
H.M.Shimizu
42nd J-PARC PAC

Neutron lifetime

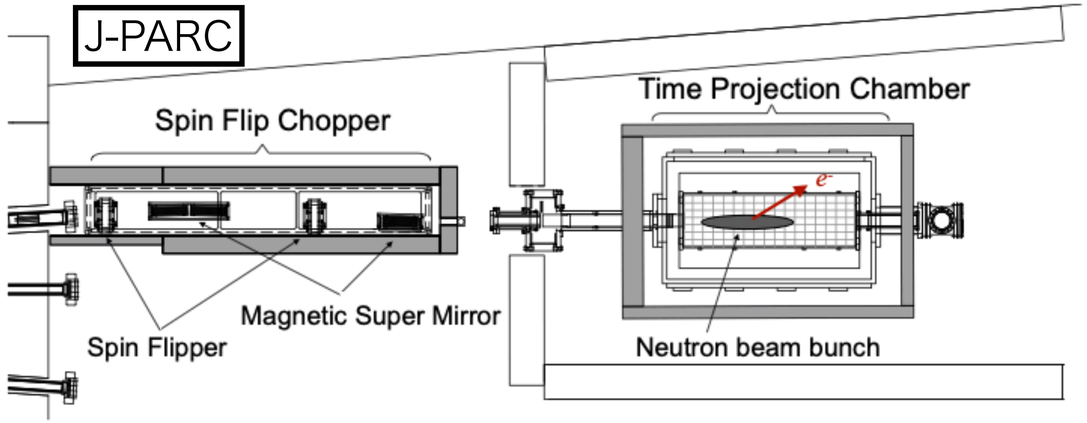
Bottle: neutron in a trap → count N^0_{neutron}, N^1_{neutron}, and $t_1 - t_0$

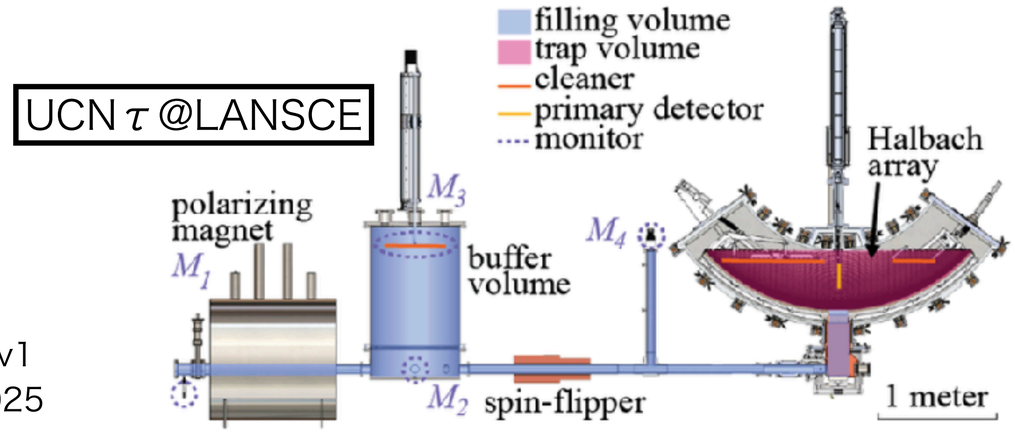
Beam: neutron beam → count N_{neutron} and $N_{\text{decay proton}}$ with different detectors

J-PARC@MLF→ count N_{neutron} and $N_{\text{decay electron}}$ with the same detector (TPC)

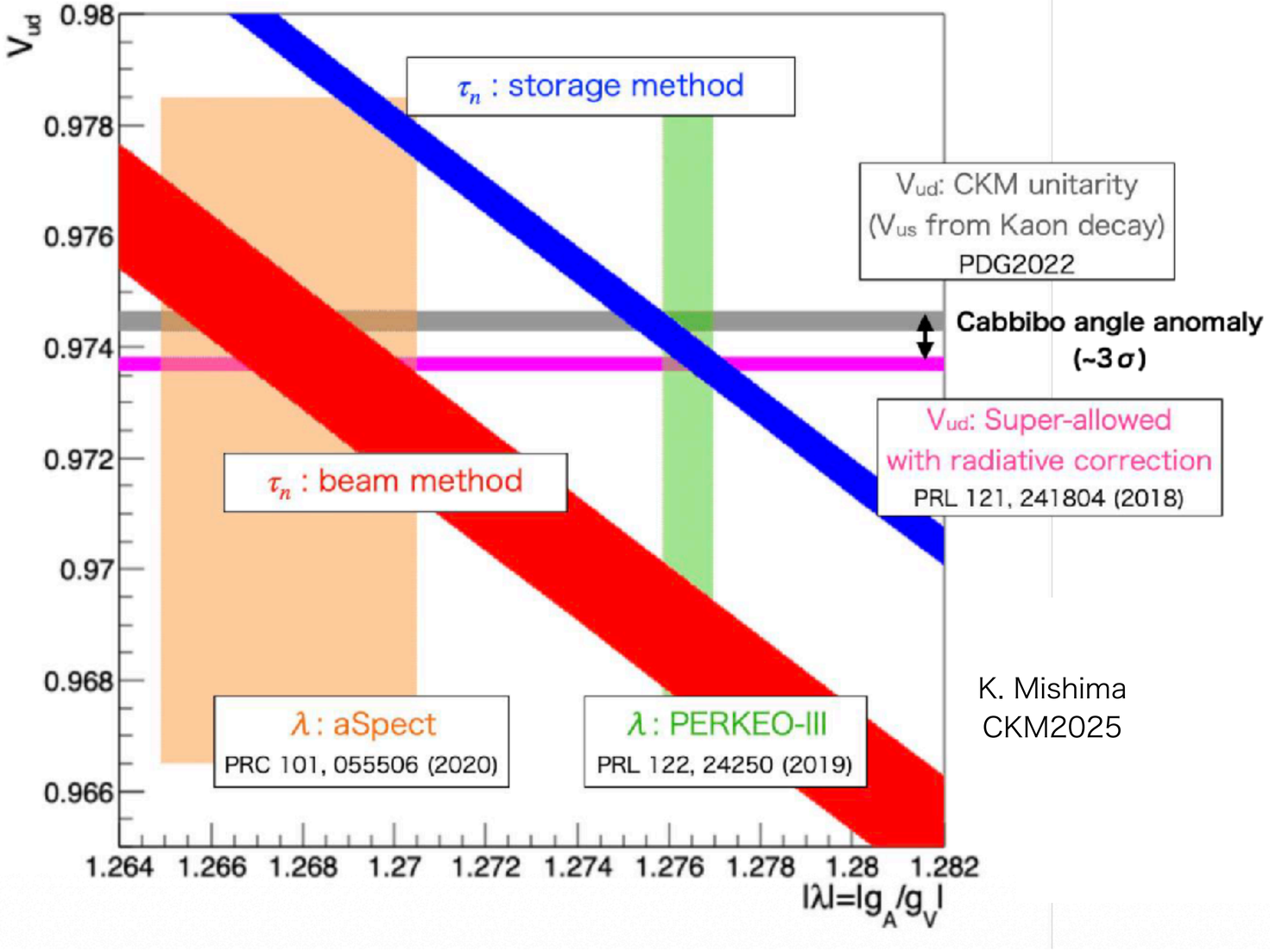


arXiv:2412.19519v1
K. Mishima CKM2025





Neutron lifetime



K. Mishima
CKM2025

Discrepancy

τ_{neutron} 4.6σ

- bottle
- beam

$g_A/g_V \sim 3\sigma$

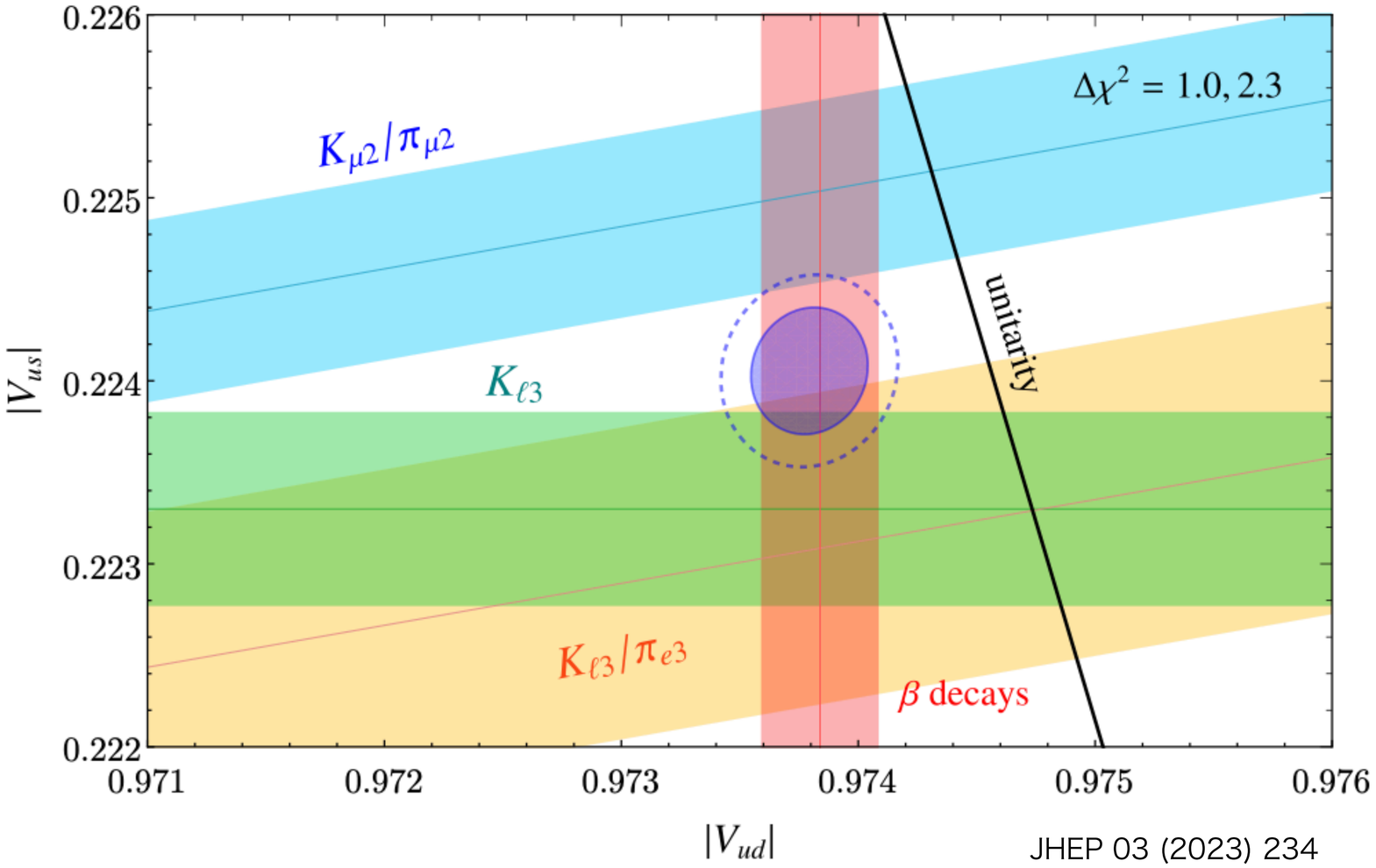
V_{ud} $\sim 3\sigma$

- from V_{us} with

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1 \rightarrow V_{ud}^2 + V_{us}^2 \sim 1$$

- from supper-allowed beta decay

Another look for Cabbibo Angle Anomaly



Discrepancy

CKM unitarity 2.8σ

- global fit
- unitarity

New Physics may contribute

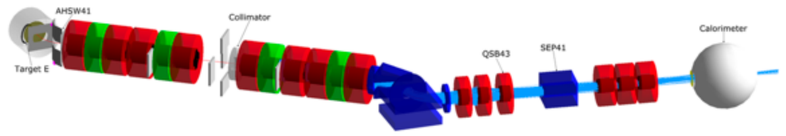
Modified W/Z quark coupling, for example

JHEP 03 (2023) 234

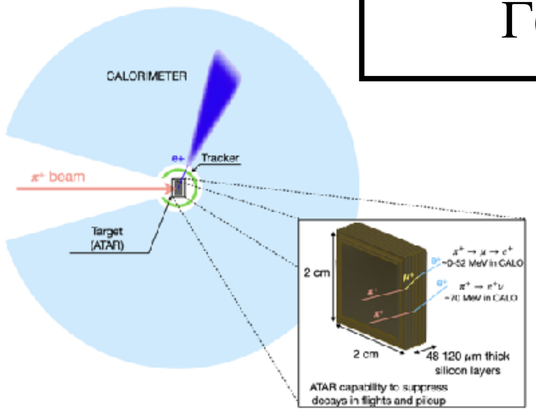
$\pi^{\pm}$ decay: PIONEER@PSI

- V_{ud} can be obtained from BR of pion beta decay (BR $\sim 10^{-8}$) and τ_{π}
- PIBETA experiment: $V_{ud} = 0.97386(283)$
  Super-allowed beta decay: 0.97367(32)
- Need more precision in pion beta decay
  → Phase II PIONEER experiment@PSI

PRL 93, 181803 (2004)
arXiv 2208.11707

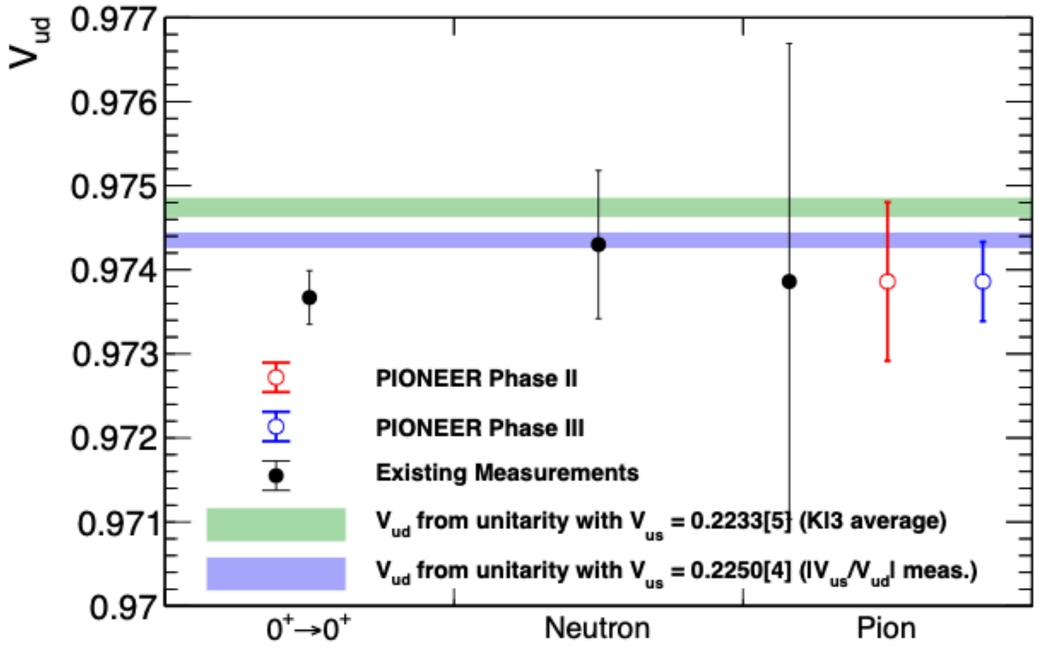


πE5 beamline
transport $\pi^{\pm}$



Phase I: LFU test

with $\dfrac{\Gamma(\pi^+ \to e^+\nu_e(\gamma)}{\Gamma(\pi^+ \to \mu^+\nu_\mu(\gamma)}$



ESPP input 2026

may contribute to solve Cabbibo Angle Anomaly

$K^{\pm}$ and K_L decay

NA62 at CERN

$K^+ \to \pi^+ \nu\bar{\nu}$ (BR $= 8 \times 10^{-11}$ in SM)

NA62 (2016-2024)

$\mathcal{B}_{K^+ \to \pi^+ \nu\bar{\nu}} = (9.6^{+1.9}_{-1.8}) \times 10^{-11}$

5σ observation was already made

Data taking was finished in Summer 2026

arXiv:2607.16413



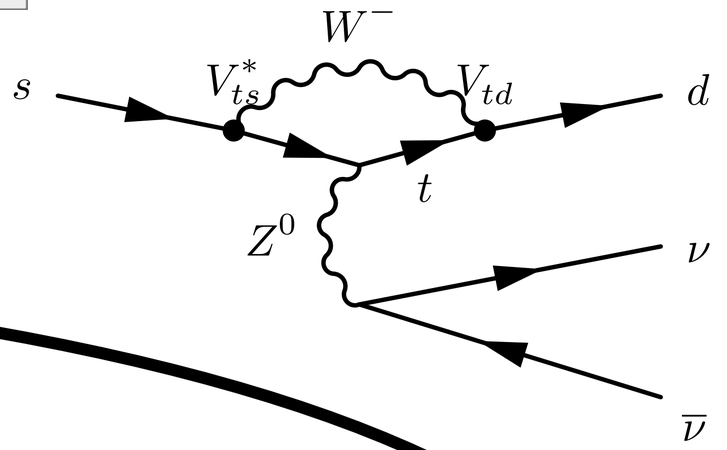
KOTO at J-PARC

$K_L \to \pi^0 \nu\bar{\nu}$ (BR $= 3 \times 10^{-11}$ in SM)

$\mathcal{B} < 2.2 \times 10^{-9} (90\,\%\,\mathrm{CL})$ (2021 data)

not observed yet

PRL 134 (2025) 8, 081802



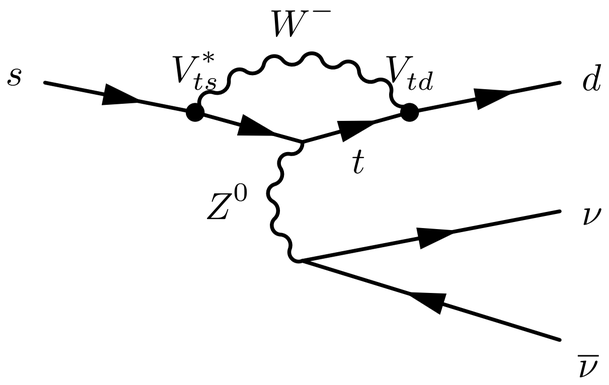
KOTO II (J-PARC E107): Next generation experiment

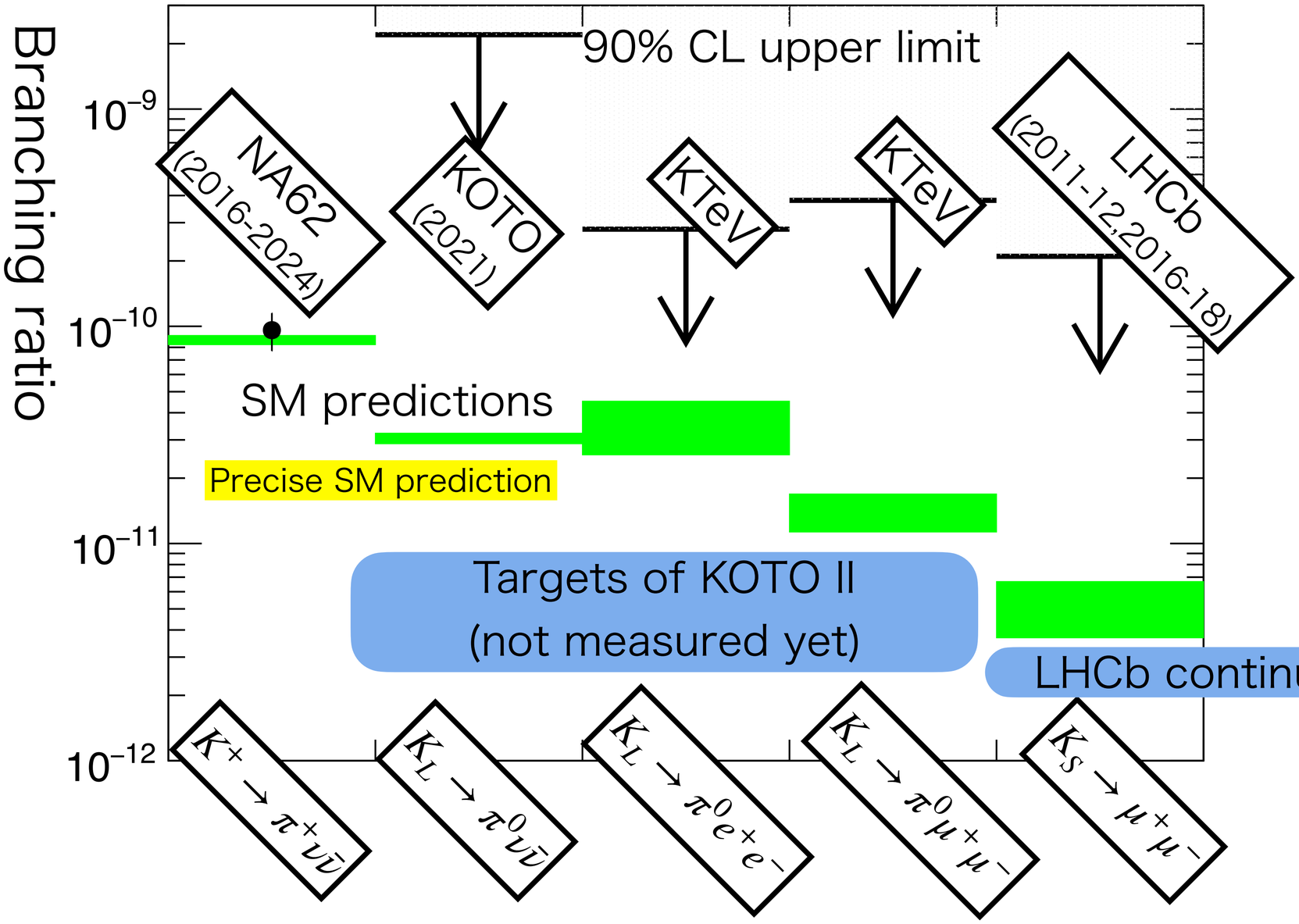
$K_L \to \pi^0 \nu\bar{\nu}$, $K_L \to \pi^0 \ell^+ \ell^-$

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030s
CERN	NA62						single world kaon-dedicated program			
J-PARC	KOTO									KOTO II

Frontiers in Kaon Decays

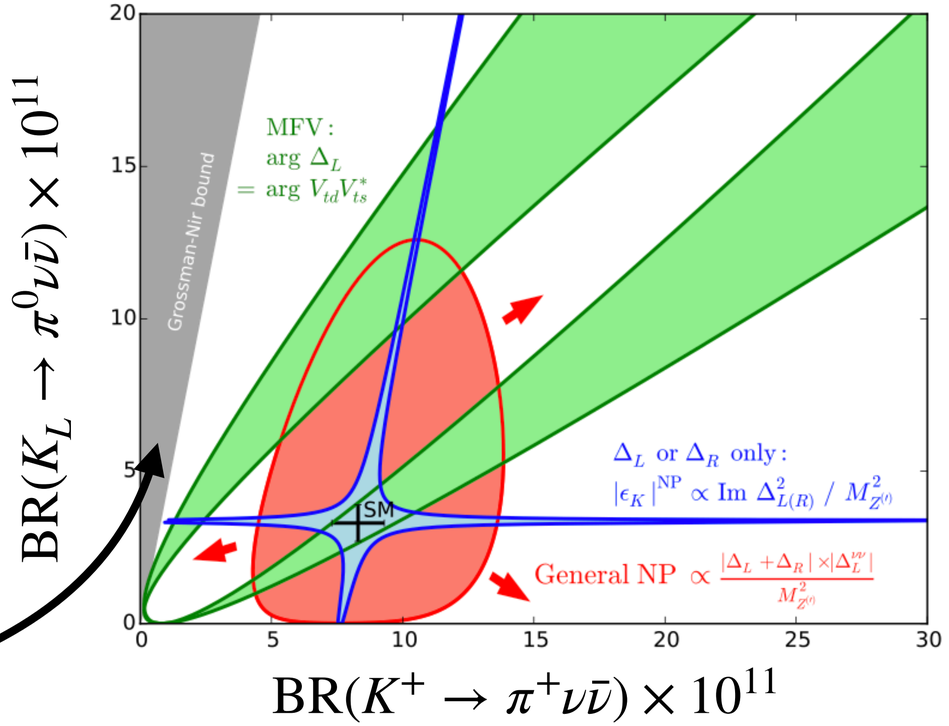
- $K^+ \to \pi^+ \nu\bar{\nu}$
- $K_L \to \pi^0 \nu\bar{\nu}$
- $K_L \to \pi^0 e^+ e^-$
- $K_L \to \pi^0 \mu^+ \mu^-$
- $K_S \to \mu^+ \mu^-$



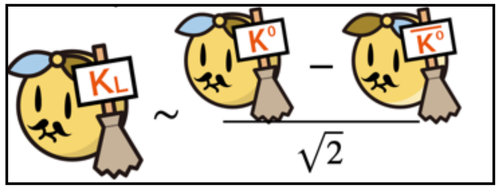


Correlation in $K \to \pi\nu\bar{\nu}$

- Generic model
  - Chiral L/R only (constrained from $K^0 - \bar{K}^0$ mixing)
  - Both chiral L and R contributions
- Minimum flavor violation
- Correlation to K^+ decay



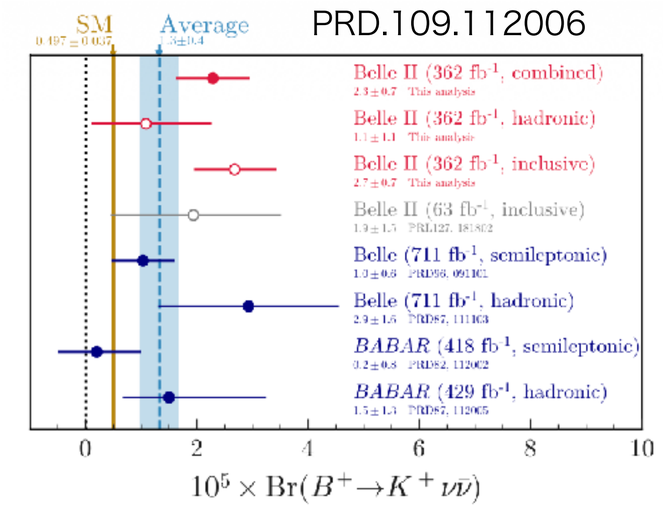
- $\mathscr{A}(K^+ \to \pi^+\nu\bar{\nu}) \propto \mathscr{A}_{s\to d}$ $\quad \to \Gamma(K^+ \to \pi^+\nu\bar{\nu}) \propto |A_{s\to d}|^2 = (\mathrm{Re}A_{s\to d})^2 + (\mathrm{Im}A_{s\to d})^2$
- $\mathscr{A}(K_L \to \pi^0\nu\bar{\nu}) \propto \mathscr{A}_{s\to d} - \mathscr{A}^*_{s\to d} \propto \mathrm{Im}(\mathscr{A}_{s\to d}) \to \Gamma(K_L \to \pi^0\nu\bar{\nu}) \propto \left(\mathrm{Im}A_{s\to d}\right)^2$
- $\mathrm{Br}(K_L \to \pi^0\nu\bar{\nu}) < 4.3 \times \mathrm{Br}(K^+ \to \pi^+\nu\bar{\nu})$: **Grossman-Nir bound**

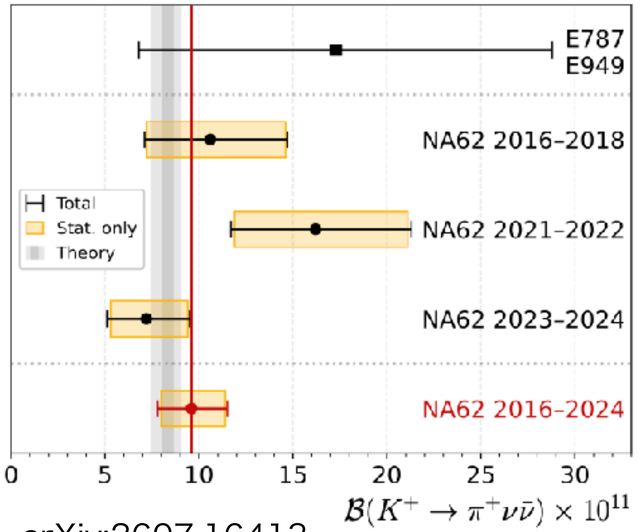


Correlation to B decay

- New Flavor symmetry → correlation to other flavors

PRD.109.112006





arXiv:2607.16413

$\mathrm{BR}(B^+ \to K^+ \nu\bar{\nu})$

2.7σ above SM

$$Y_u = y_t \begin{pmatrix} \cdot & \cdot & \square \\ \cdot & \cdot & \square \\ 0 & 0 & 1 \end{pmatrix}$$

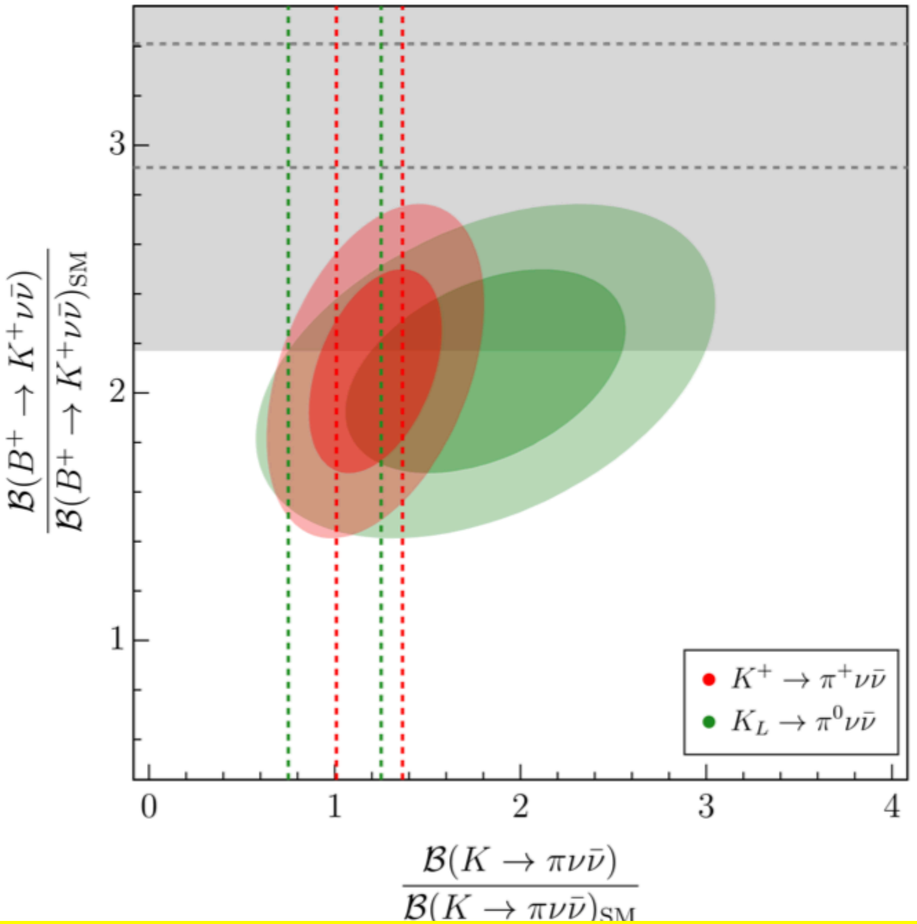
Broken $U(2)$ symmetry

+

New Physics in 3rd gen.

EPJC 86 (2026) 9, 1063

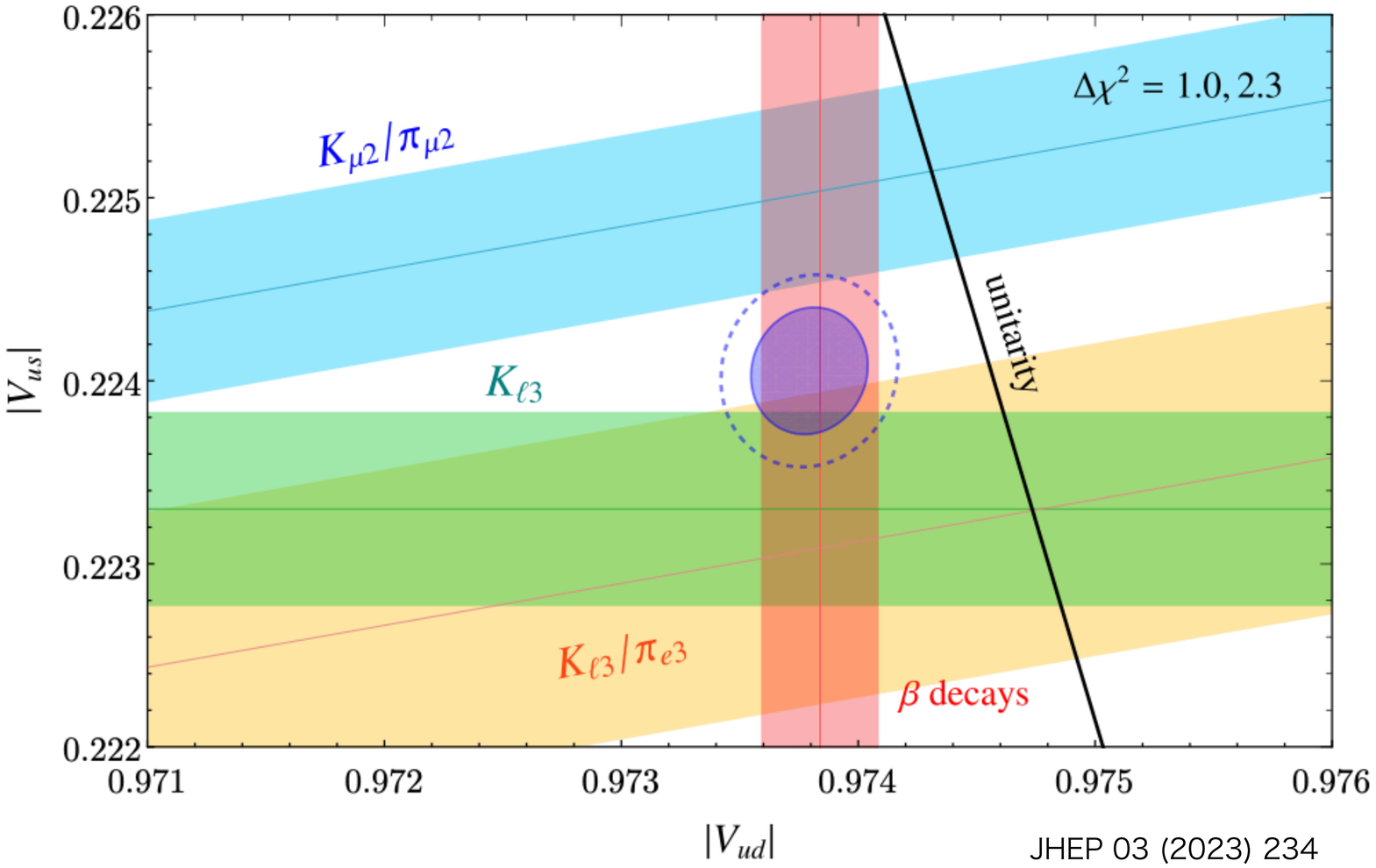
68% and 95% CL regions suggested from global fit



Correlation to B decay

→$\mathrm{BR}(K_L \to \pi^0 \nu\bar{\nu})$: x3 enhancement may occur.

Another look for Cabbibo Angle Anomaly



Discrepancy

CKM unitarity 2.8σ

- global fit
- unitarity

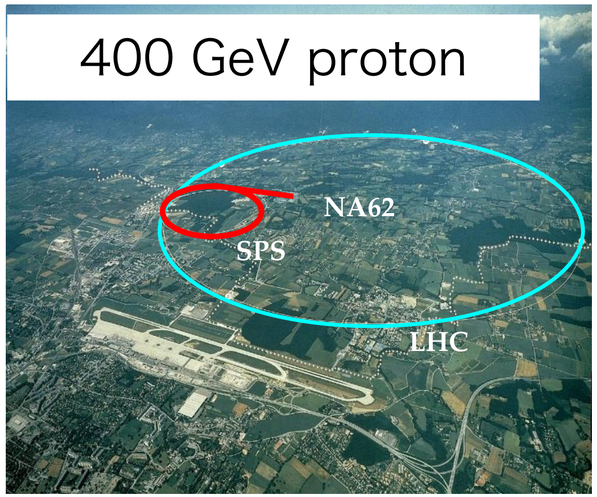
New Physics may contribute

Modified W/Z quark coupling, for example

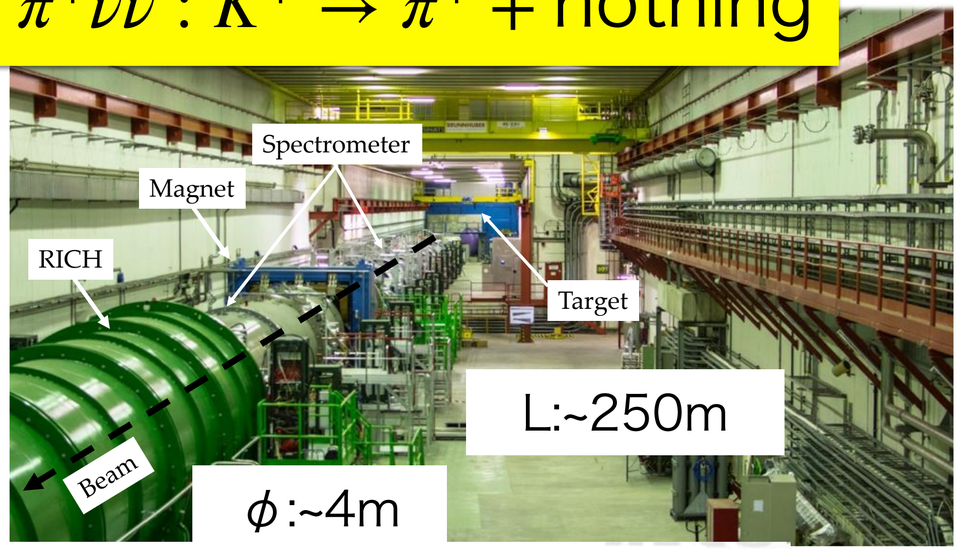
NA62 may give more precision on V_{us} from kaon decays

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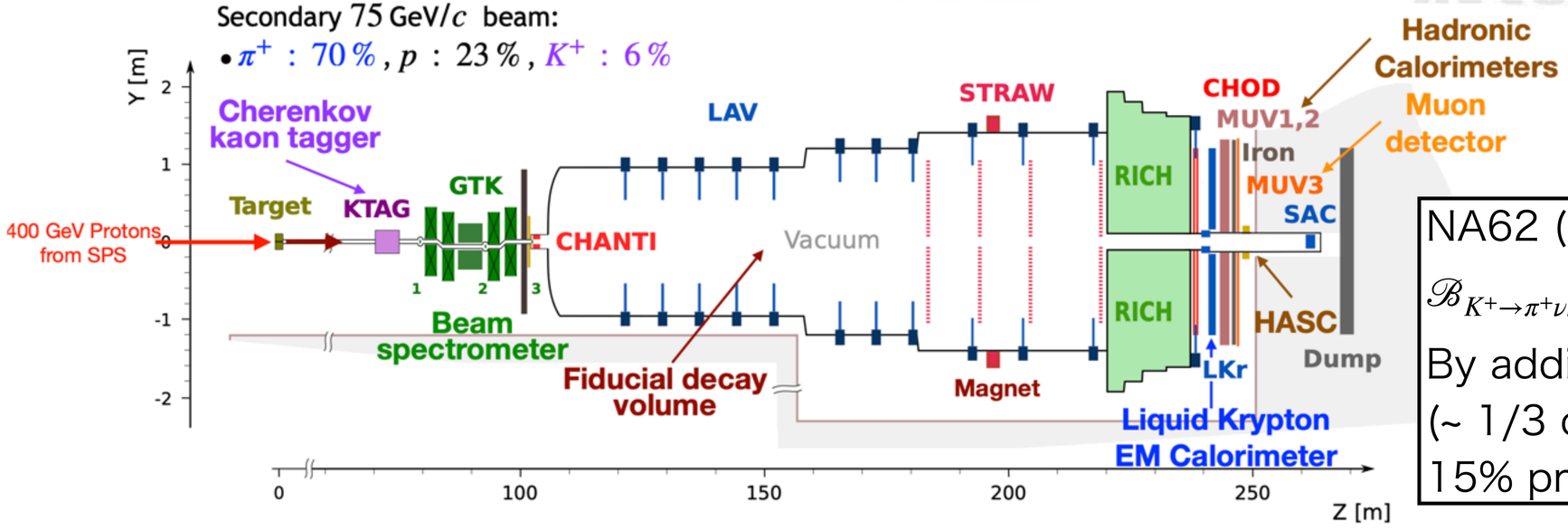
K^+ decay: NA62@CERN SPS



$K^+ \to \pi^+ \nu\bar{\nu} : K^+ \to \pi^+ + \text{nothing}$







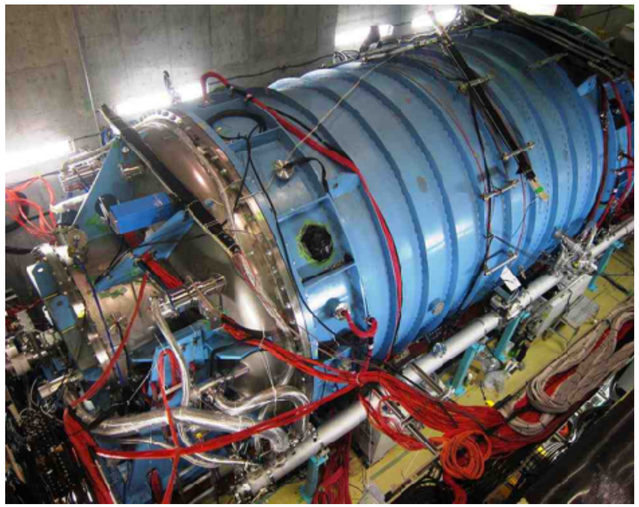
NA62 (2016-2024)

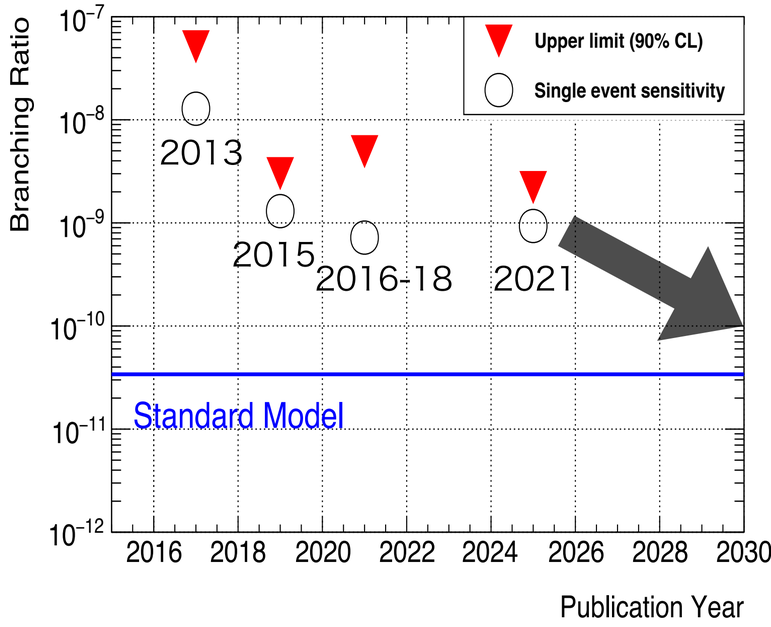
$\mathcal{B}_{K^+\to\pi^+\nu\bar{\nu}} = (9.6^{+1.9}_{-1.8}) \times 10^{-11}$ →20% precision

By adding 2025-26 data
(~ 1/3 of 2016-26),
15% precision is expected.

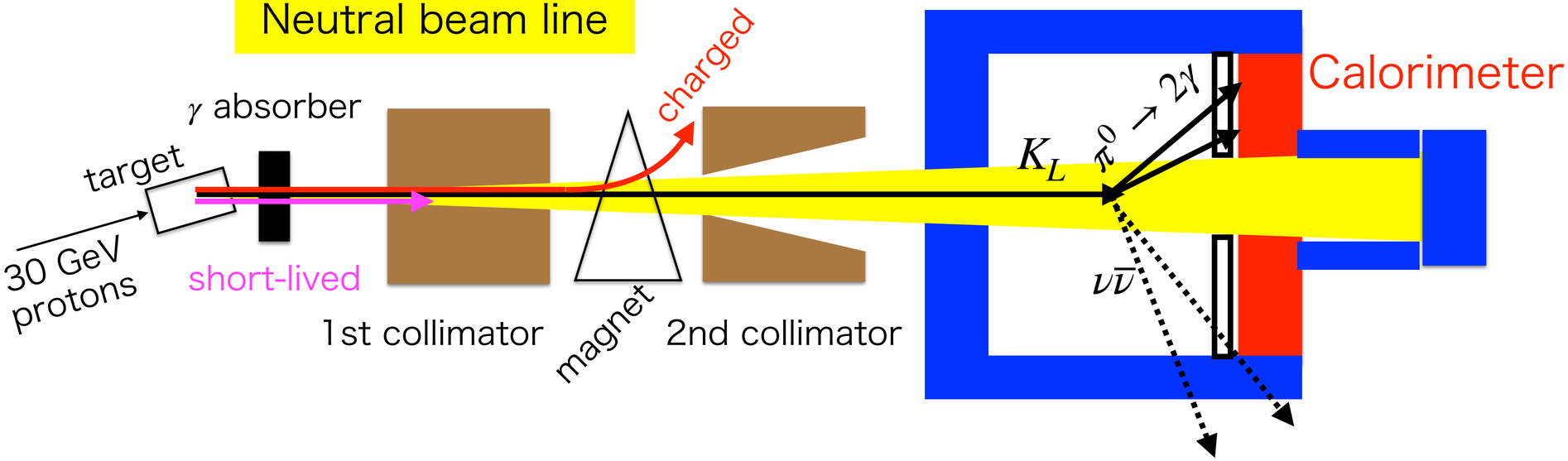
K_L decay: KOTO@J-PARC MR





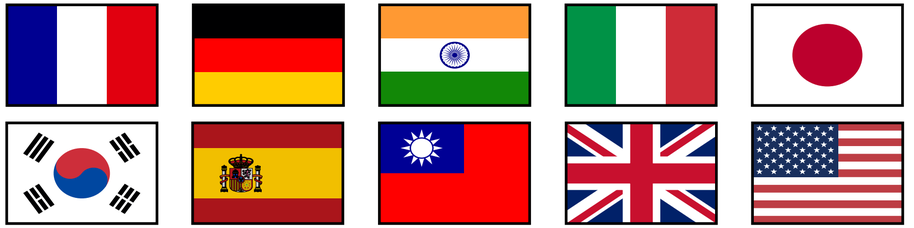


$K_L \to \pi^0 \nu\bar{\nu}$ $\pi^0 +$ nothing



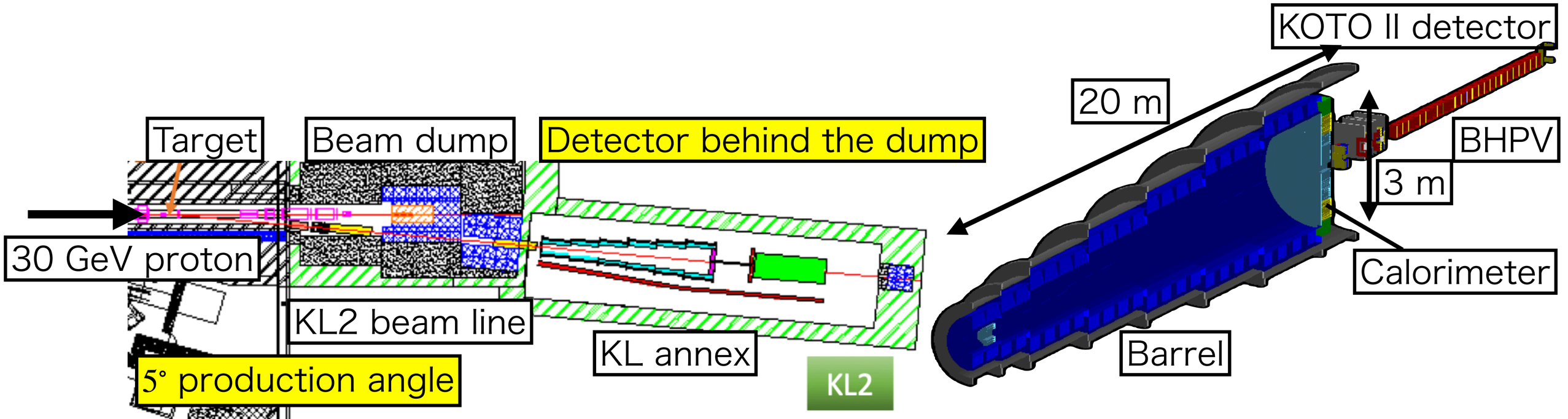
Exceeding Grossman-Nir bound aiming at the sensitivity $< 10^{-10}$ in 2020s.

K_L decay: KOTO II@J-PARC MR

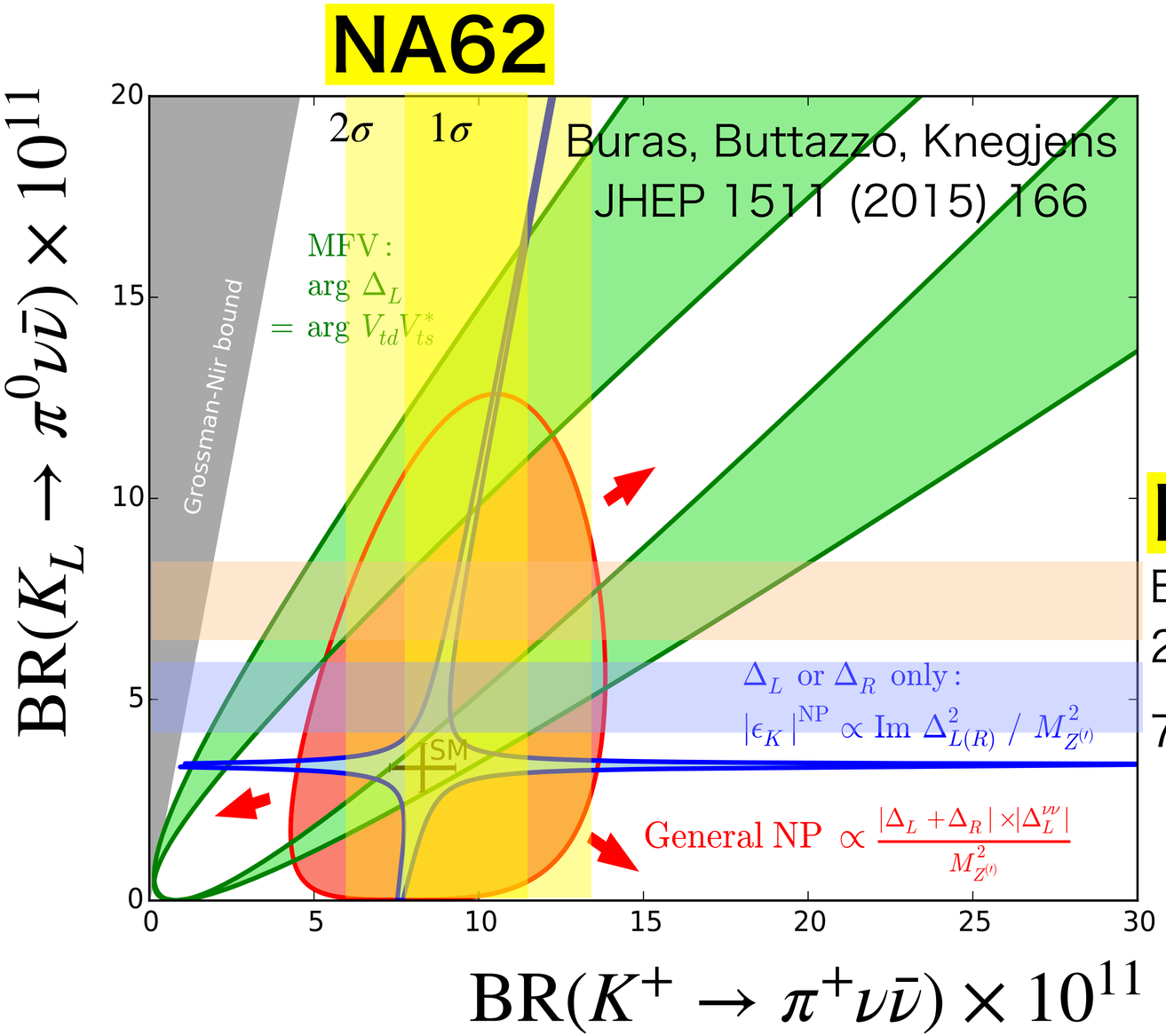


- Next generation rare kaon decay experiment
- Study of rare K_L decay especially on $K_L \to \pi^0\nu\bar{\nu}$ and $K_L \to \pi^0\ell^+\ell^-$
  - Indispensable information in the quest of flavor physics.
- Next generation rare kaon decay dedicated experiment
- $K_L \to \pi^0\nu\bar{\nu}$ search with the same method as in KOTO: "2γ from π^0+ nothing else"

Proposal submitted
in Dec 2024.
arXiv:2501.14827 [hep-ex]
Scientifically approved
with Stage-1 status
in April 2025.



Impact of KOTO II



100-kW beam, 3×10^7 s $= 6.3 \times 10^{20}$ POT

SES: 8.5×10^{-13}, S/B=0.9

- 35 SM signal / 40 background events
  $\to 5.6\sigma$ observation
- $\Delta\mathscr{B}/\mathscr{B} = 25\,\%$ for SM value of $\mathscr{B}$
- 40% deviation from SM
  $\to$90%-CL indication of NP

KOTO II

Example

250% deviation from SM

70% deviation from SM

May find NP effect

Conclusions

- Flavor physics in quark sector will have progress
  with Non-collider (fixed target) experiments. We may find new physics!

2030 2040

nEDM $\mathcal{O}(10^{-27})$

more sensitivity

T-violation with compound nuclei

neutron lifetime

LFU test with π^+ decay

π^+ beta decay

$\mathrm{Br}(K^+ \to \pi^+ \nu\bar{\nu})$ 15% precision

$\mathrm{Br}(K_L \to \pi^0 \nu\bar{\nu})$ exceeding Grossman-Nir bound

$\mathrm{Br}(K_L \to \pi^0 \nu\bar{\nu})$ measurement

New physics, new source of CP violation?