NA62/KLEVER prospects for future high-intensity K^+ and K_L running, including beam dump

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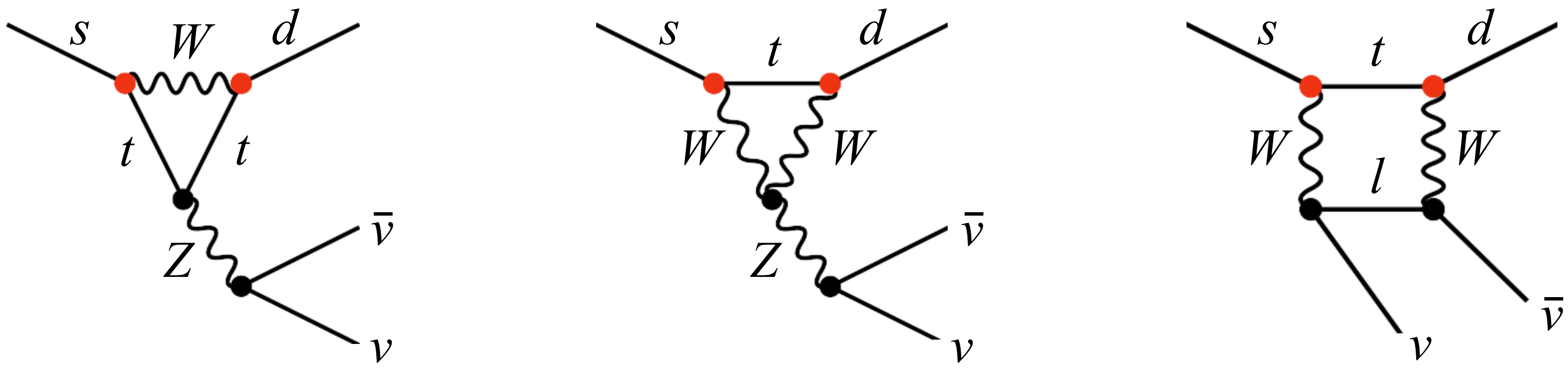
On behalf of the NA62/KLEVER Collaborations

Physics Beyond Colliders Annual Workshop,
BSM session,
2 March 2021

Golden channel: $K \to \pi \nu \bar{\nu}$ in the Standard Model



Extremely rare decays with rates very precisely predicted in SM

	SM predicted rates Buras et al, JHEP 1511*	**Experimental status**
$K^+ \to \pi^+ \nu\nu$	**BR = $(8.4 \pm 1.0) \times 10^{-11}$**	**BR($K^+ \to \pi^+ \nu\nu$) = $(11.0\ ^{+4.0}_{-3.5\,\mathrm{stat}} \pm 0.3_{\mathrm{syst}}) \times 10^{-11}$** NA62, 20 events observed (ICHEP2020)
$K_L \to \pi^0 \nu\nu$	**BR = $(3.4 \pm 0.6) \times 10^{-11}$**	**BR $< 300 \times 10^{-11}$ 90%CL** KOTO, PRL122 (2019)

* Tree-level determinations of CKM matrix elements

Rare kaon decays

Decay	Γ_{SD}/Γ	Theory err.*	SM BR × 10^{11}	Exp. BR × 10^{11} (Sep 2019)
$K_L \to \mu^+\mu^-$	10%	30%	685-811 ±80-150	684 ± 11
$K_L \to \pi^0 e^+ e^-$	40%	10%	3.2 ± 1.0	$< 28^\dagger$
$K_L \to \pi^0 \mu^+\mu^-$	30%	15%	1.5 ± 0.3	$< 38^\dagger$
$K^+ \to \pi^+ \nu\nu$	90%	4%	8.4 ± 1.0	$< 18.5^\dagger$
$K_L \to \pi^0 \nu\nu$	>99%	2%	3.4 ± 0.6	$< 300^\dagger$

*Approx. error on LD-subtracted rate excluding parametric contributions

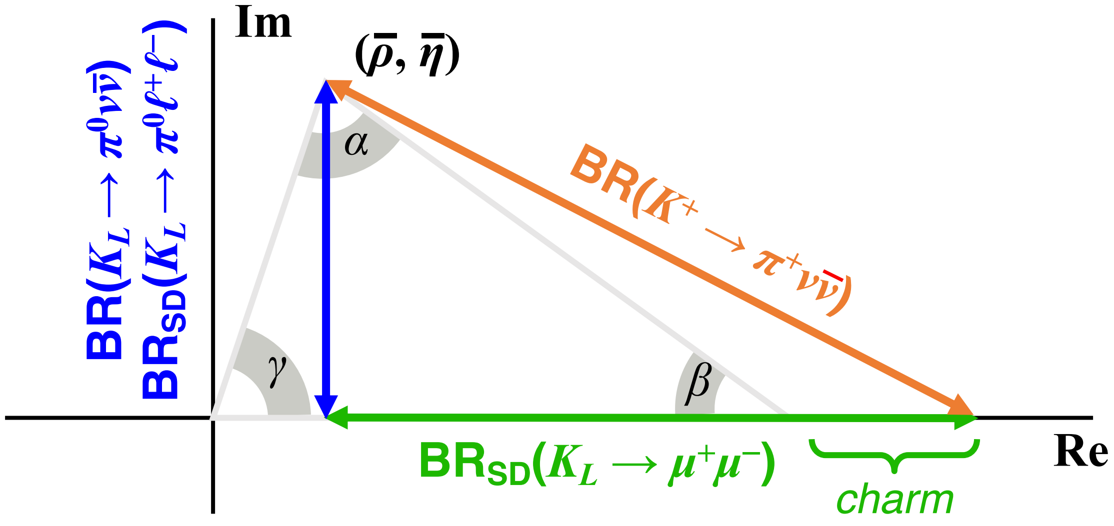
†90% CL

Flavor-changing processes dominated by short-distance amplitudes

Rates related to CKM matrix elements with minimal non-parametric uncertainty

BRs over-constrain CKM matrix and may provide evidence for new physics

Need for an integrated programme to pin down new physics in kaon decays



Measuring all charged and neutral rare K decay modes can give clear insight about the new physics flavour structure

$K \to \pi\nu\bar{\nu}$ and the unitarity triangle

$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.39 \pm 0.30) \times 10^{-11} \cdot \left[\frac{|V_{cb}|}{0.0407}\right]^{2.8} \cdot \left[\frac{\gamma}{73.2^\circ}\right]^{0.74}$$

$$\mathrm{BR}(K_L \to \pi^0 \nu\bar{\nu}) = (3.36 \pm 0.05) \times 10^{-11} \cdot \left[\frac{|V_{ub}|}{3.88 \times 10^{-3}}\right]^{2} \cdot \left[\frac{|V_{cb}|}{0.0407}\right]^{2} \cdot \left[\frac{\sin\gamma}{\sin 73.2^\circ}\right]^{2}$$

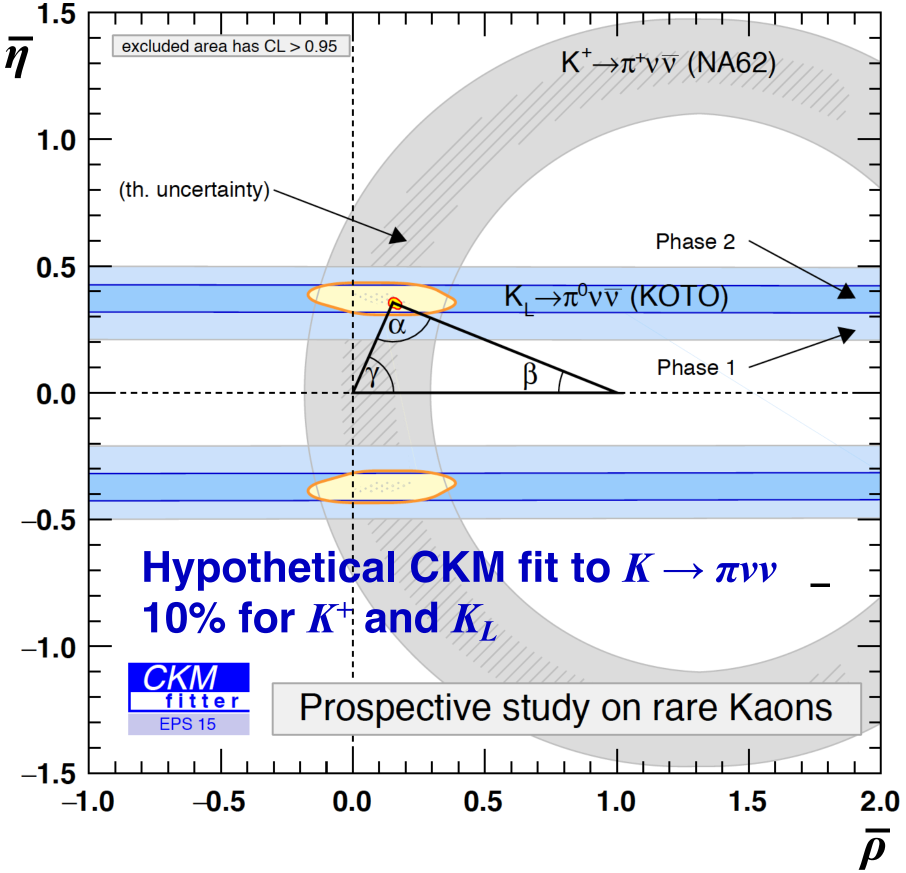
Buras et al.,
JHEP 1511

Dominant uncertainties for SM BRs are from CKM matrix elements

Intrinsic theory uncertainties 1.5-3.5%

Measuring BRs for both $K^+ \to \pi^+\nu\nu$ and $K_L \to \pi^0\nu\nu$ can determine the CKM unitarity triangle independently from B inputs:

- Rare Kaon decays determine CKM matrix → reveal NP effects
- **Sensitivity to O(100) TeV scale**
- Sensitivity complementary to B decays
- To constrain NP, correlations are crucial



$K \to \pi\nu\bar{\nu}$ and BSM models

NP effects on $K \to \pi\nu\nu$ BRs with constraints from Re ε'/ε, ε_K, Δm_K, $K_L \to \mu\mu$

Model	Λ [TeV]	Effect on BR($K^+ \to \pi^+\nu\bar{\nu}$)	Effect on BR($K_L \to \pi^0\nu\bar{\nu}$)
Leptoquarks, U_1	1–20	+10% to +60%	+100% to +800%
Vector-like quarks	1–10	−90% to +60%	−100% to +30%
Vector-like quarks + Z'	10	−80% to +400%	−100% to 0%
Simplified modified Z, no tuning	1	−100% to +80%	−100% to −50%
General modified Z, cancellation to 20%	1	−100% to +400%	−100% to +500%
SUSY, chargino Z penguin	4–6 TeV		−100% to −40%
SUSY, gluino Z penguin	3–5.5 TeV	0% to +60%	−20% to +60%
SUSY, gluino Z penguin	10	Small effect	0% to +300%
SUSY, gluino box, tuning to 10%	1.5–3	±10%	±20%
LHT	1	±20%	−10% to −100%

Specific models for effects of NP on $K \to \pi\nu\nu$ BRs are constrained by other kaon measurements, esp. Re ε'/ε, ΔM_K

RBC/UKQCD, arXiv 2004.09440
(21.7 ± 8.4) 10^{-4}

Measurements: Re $\varepsilon'/\varepsilon \times 10^4$

KTeV	19.2 ± 1.1 ± 1.8
NA48	14.7 ± 1.7 ± 1.5
PDG fit	**16.6 ± 2.3 (S = 1.6)**

Theory uncertainty ~8 10^{-4} for $(\varepsilon'/\varepsilon)_{SM}$ still leaves room for significant NP contributions to this ratio

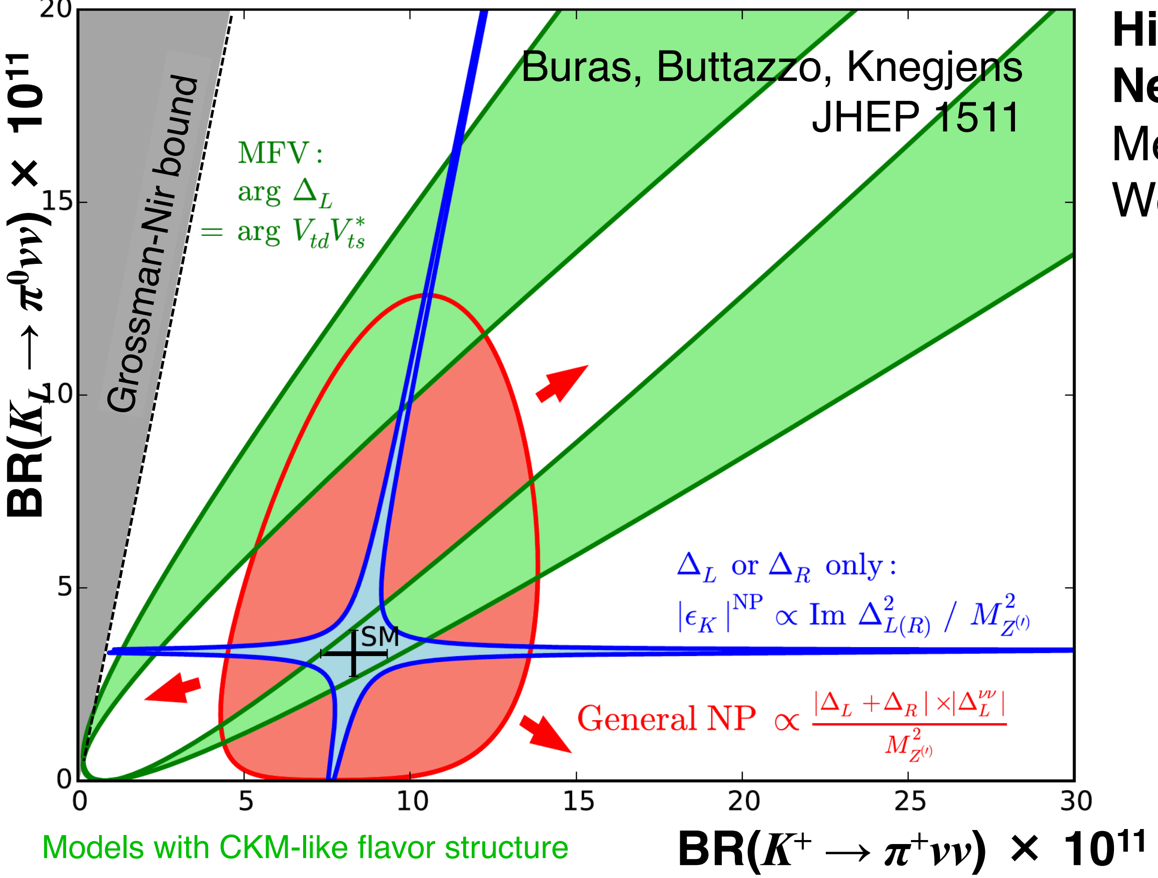
$K \to \pi\nu\bar{\nu}$ and new physics

High sensitivity to NP (non-MFV): significant variations wrt SM

New physics affects K^+ and K_L BRs differently

Measurements of both can discriminate among NP scenarios

Weak constraints from other observables



Models with CKM-like flavor structure

- Models with MFV

Models with new flavor-violating interactions in which either

LH or RH couplings dominate

- *Z*/*Z′* models with pure LH/RH couplings
- Littlest Higgs with *T* parity

Models without above constraints

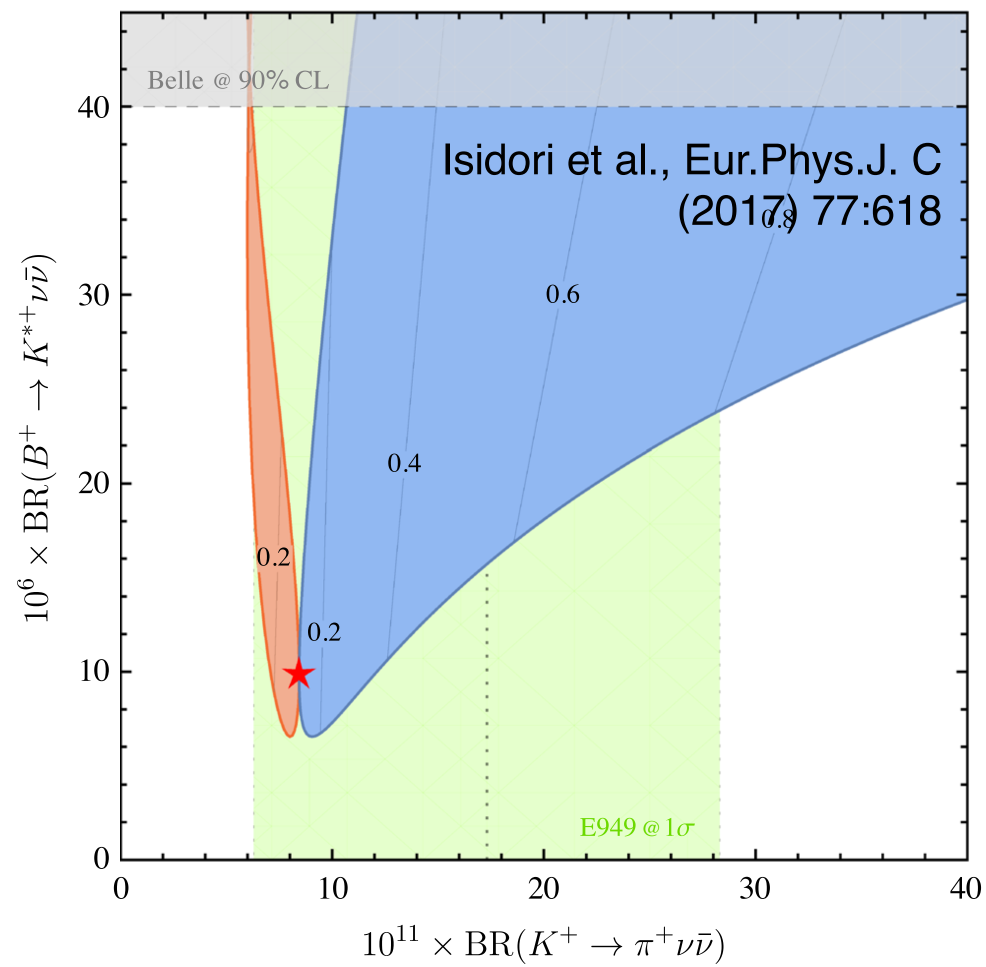
- Randall-Sundrum

Grossman-Nir bound

Model-independent relation

$$\frac{\text{BR}(K_L \to \pi^0\nu\bar{\nu})}{\text{BR}(K^+ \to \pi^+\nu\bar{\nu})} \times \frac{\tau_+}{\tau_L} \leq 1$$

LFU Violation

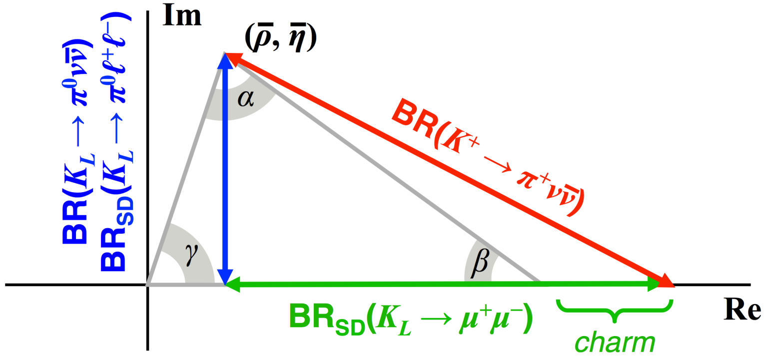


Isidori et al., Eur.Phys.J. C (2017) 77:618

$K_L \to \pi^0\ell^+\ell^-$

$K_L \to \pi^0\ell^+\ell^-$ vs $K \to \pi\nu\nu$:

- Somewhat larger theoretical uncertainties from long-distance physics
  - SD CPV amplitude: γ/Z exchange
  - LD CPC amplitude from 2γ exchange
  - LD indirect CPV amplitude: $K_L \to K_S$
- $K_S \to \pi^0\ell^+\ell^-$ will help reducing theoretical uncertainties
  - measured NA48/1 with limited statistics
  - planned by LHCb Upgrade
- $K_L \to \pi^0\ell^+\ell^-$ can be used to explore helicity suppression in FCNC decays



$K_L \to \pi^0\ell^+\ell^-$ CPV amplitude constrains UT in same way as BR($K_L \to \pi^0\nu\nu$)

Experimental status:

BR($K_L \to \pi^0 e^+e^-$) < 28 × 10^{-11} Phys. Rev. Lett. 93 (2004) 021805

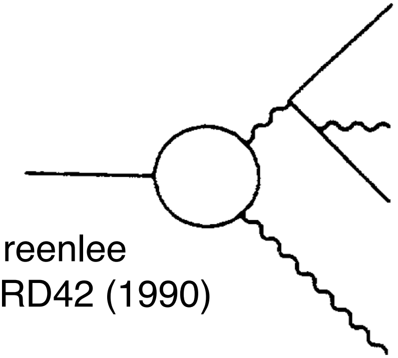
BR($K_L \to \pi^0\mu^+\mu^-$) < 38 × 10^{-11} Phys. Rev. Lett. 84 (2000) 5279–5282

Main background: $K_L \to \ell^+\ell^-\gamma\gamma$

- Like $K_L \to \ell^+\ell^-\gamma$ with hard bremsstrahlung

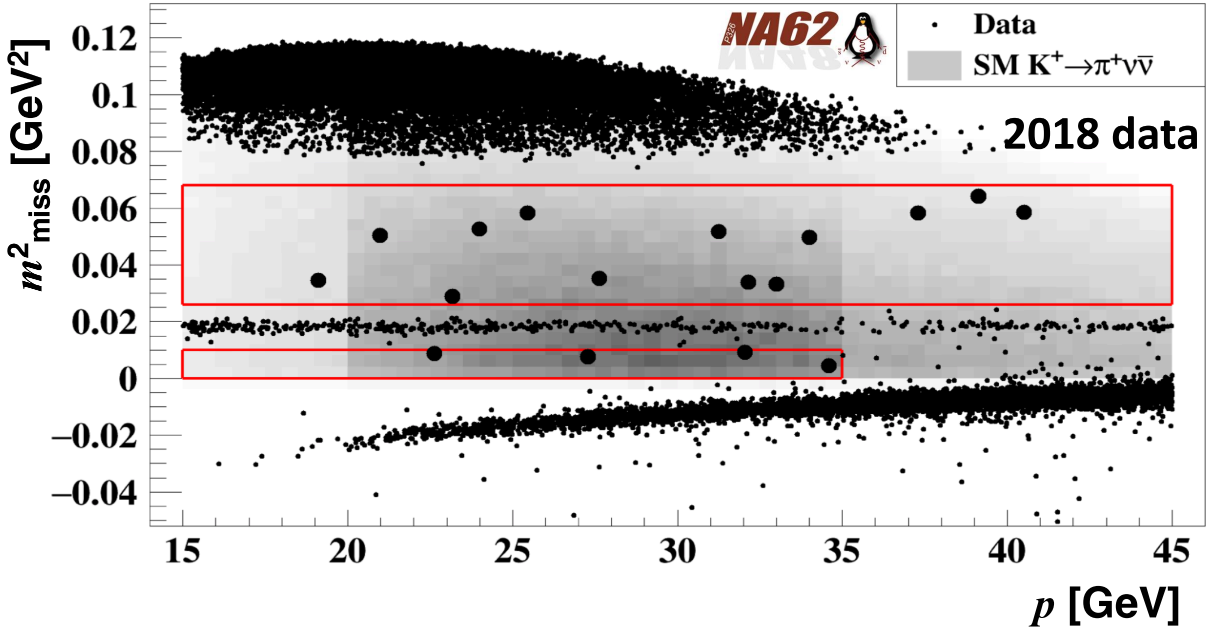
BR($K_L \to e^+e^-\gamma\gamma$) = (6.0 ± 0.3) × 10^{-7} $E_\gamma^* > 5$ MeV

BR($K_L \to \mu^+\mu^-\gamma\gamma$) = 10^{+8}_{-6} × 10^{-9} $m_{\gamma\gamma} > 1$ MeV



Greenlee
PRD42 (1990)

NA62 through LS3

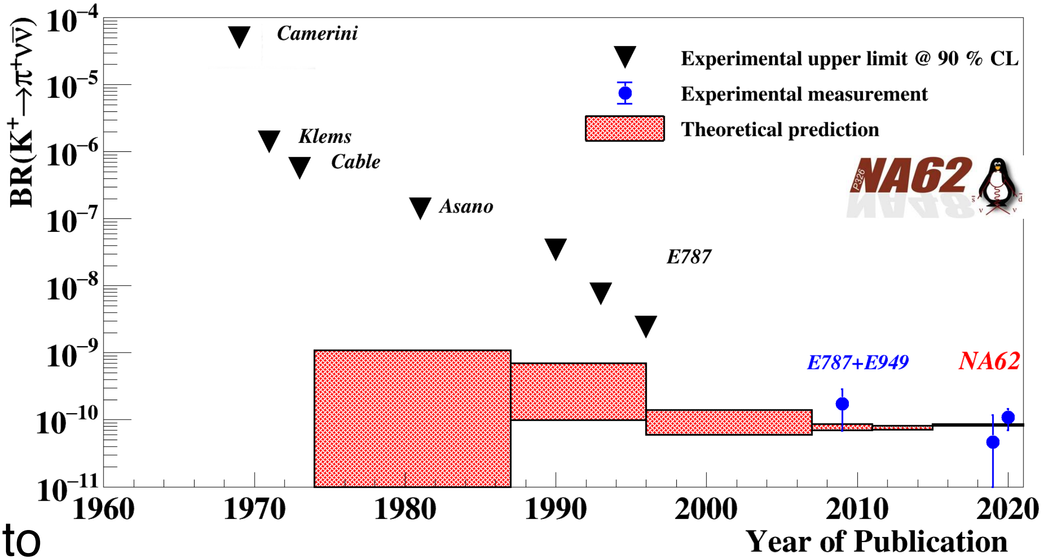


Summary of NA62 Run 1 (2016-2018):

- **Expected signal (SM): 10 events**
- **Expected background: 7 events**
- **Total observed: 20 events**
  - 3.5σ signal significance
  - Most precise measurement to date

$\mathrm{BR}(K^+ \to \pi^+ \nu\nu) = (11.0\,^{+4.0}_{-3.5\,\mathrm{stat}} \pm 0.3_{\mathrm{syst}}) \times 10^{-11}$ (ICHEP2020)

publication imminent



NA62 Run 2 (from 2021 to LS3):

NA62 to resume data taking in mid-July 2021

Key modifications to reduce background:

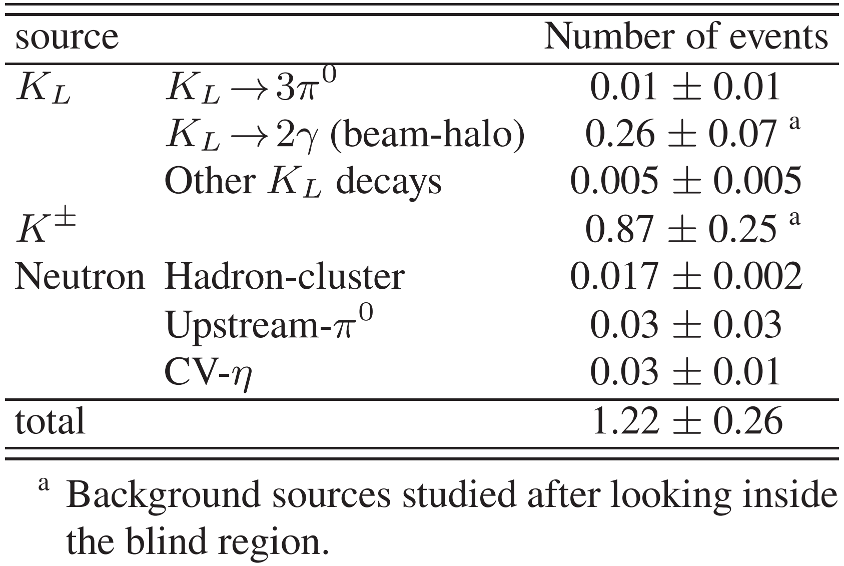
- Rearrangement of beamline elements around GTK achromat
- Add 4th station to GTK beam tracker
- New veto hodoscope upstream of decay volume and veto counters around downstream beam pipe

Run at higher beam intensity (70% → 100%), control random veto

Expect to measure $\mathrm{BR}(K^+ \to \pi^+ \nu\nu)$ to O(10%) by LS3

KOTO: 2016-2018 data

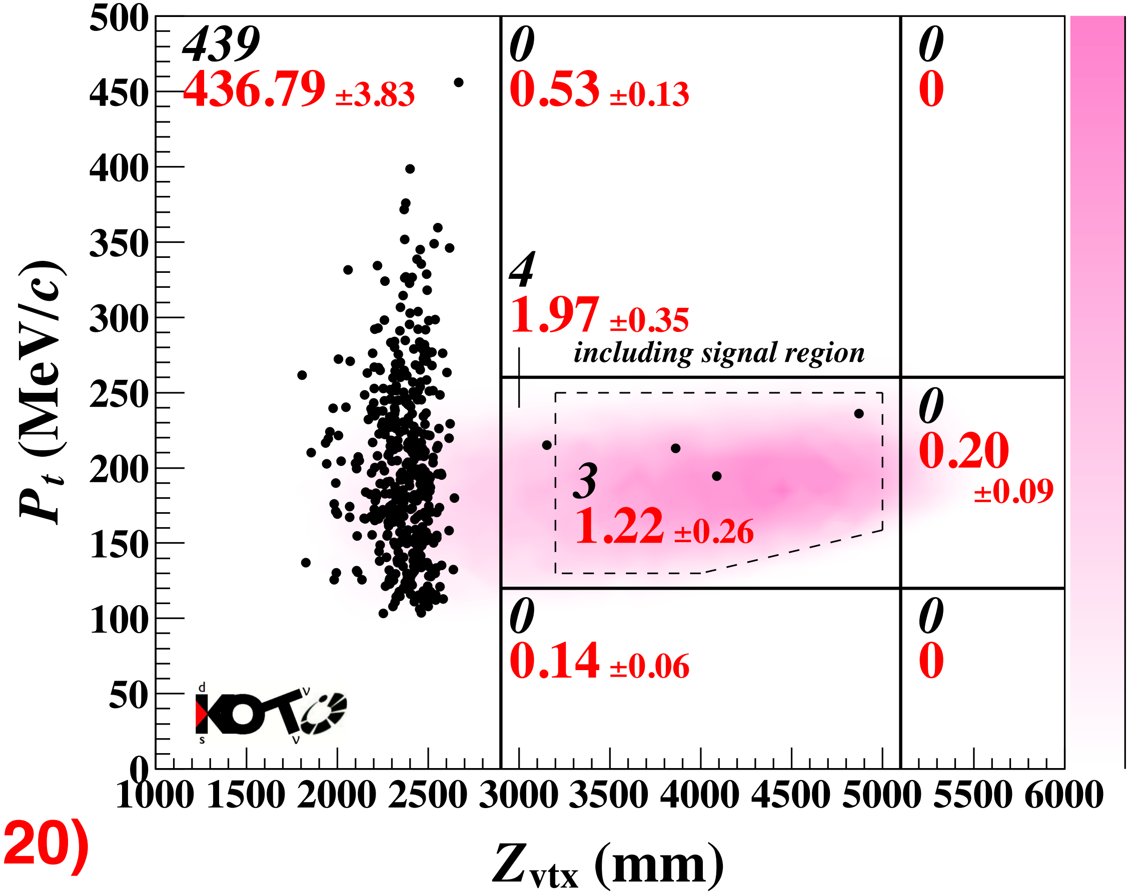
KOTO $K^0 \to \pi^0 \nu\nu$ SES: $(7.20 \pm 0.05_{stat}\ 0.66_{syst}) \times 10^{-10}$ (0.05 SM evts)
3 candidate events
Expected bkg: 1.22 ± 0.26 evts
Probability of observing 3 events: 13%



source		Number of events
K_L	$K_L \to 3\pi^0$	0.01 ± 0.01
	$K_L \to 2\gamma$ (beam-halo)	0.26 ± 0.07 [a]
	Other K_L decays	0.005 ± 0.005
$K^\pm$		0.87 ± 0.25 [a]
Neutron	Hadron-cluster	0.017 ± 0.002
	Upstream-π^0	0.03 ± 0.03
	CV-η	0.03 ± 0.01
total		1.22 ± 0.26

[a] Background sources studied after looking inside the blind region.

arXiv:2012.0757.v1



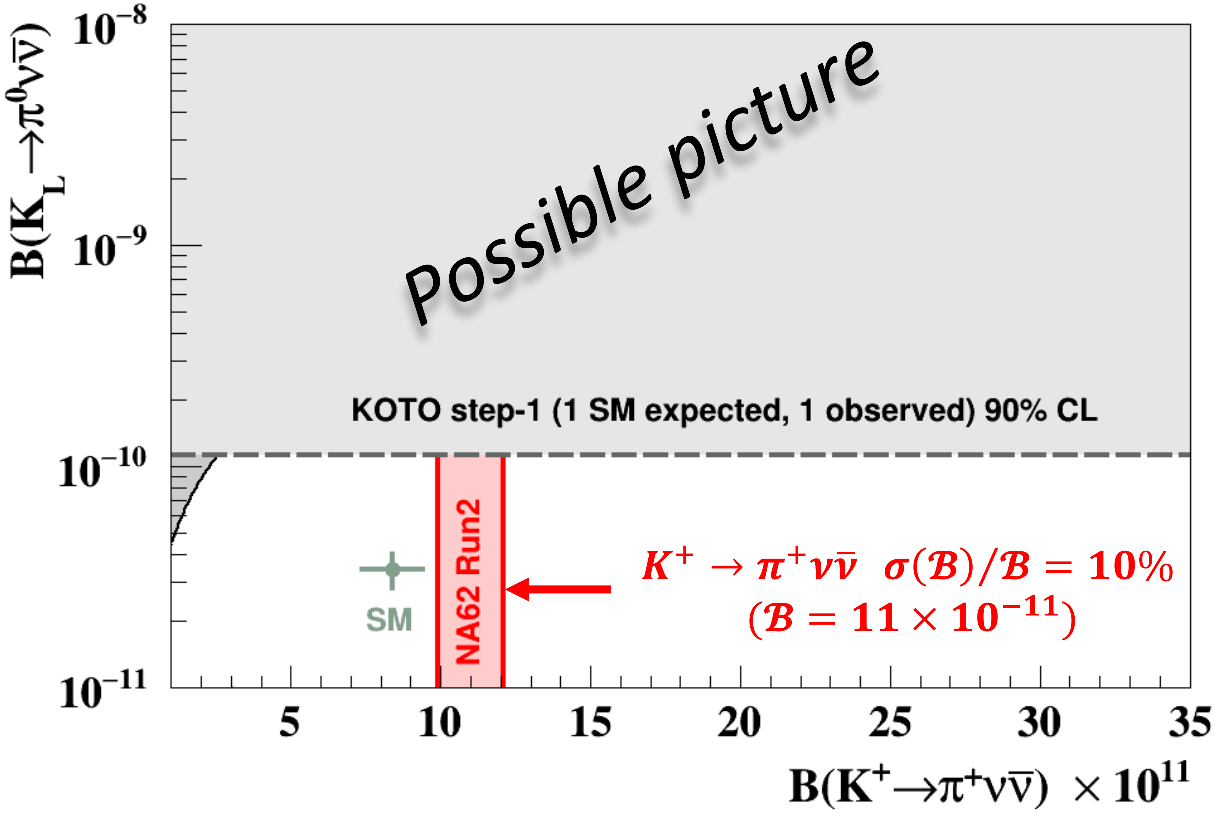
BR($K^0 \to \pi^0 \nu\nu$) < 4.9 x 10^{-9} @90% CL (2020)

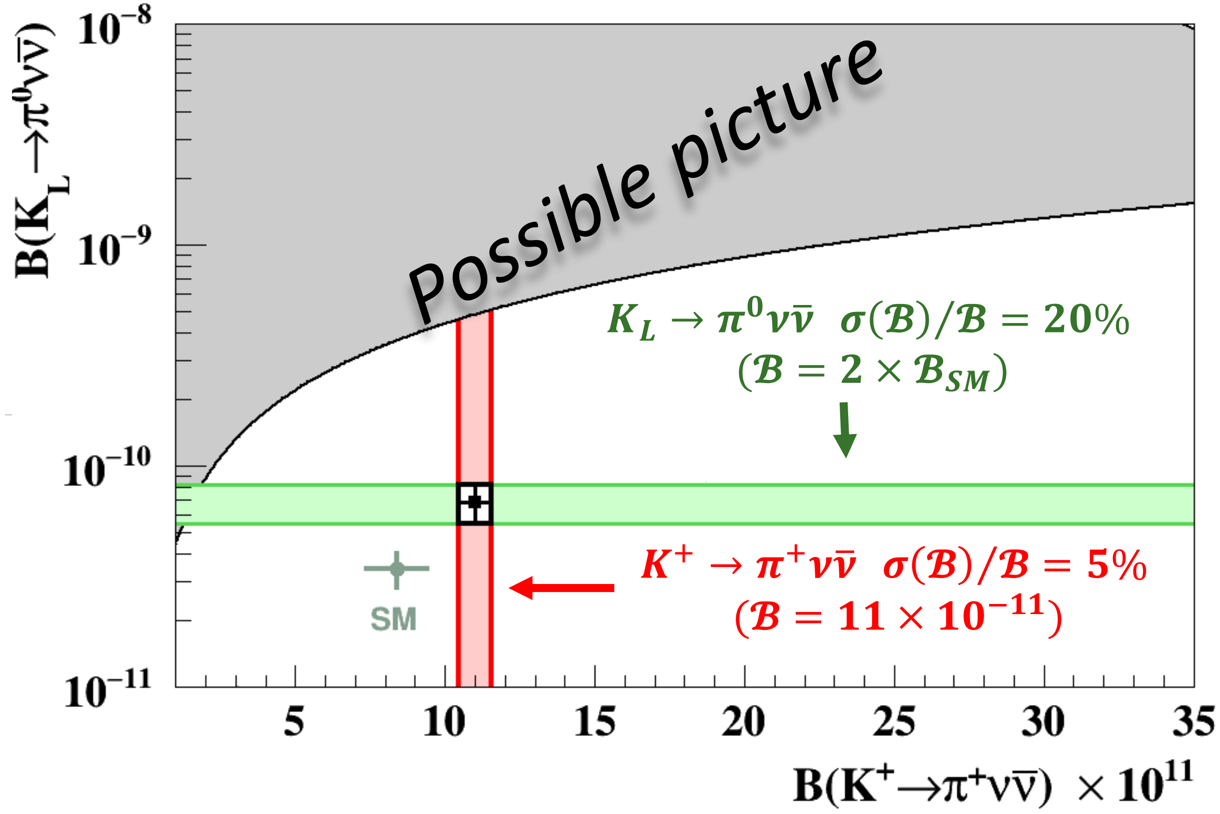
KOTO will reach SM SES by mid-decade
Step-2: ~60 SM evts - requires large engineering project

Clear opportunity in the Kaon sector

Going beyond 10% measurement on $K^+ \to \pi^+ \nu\nu$

Precision measurements of $K \to \pi\nu\nu$ BRs can provide model-independent tests for new physics at mass scales of up to O(100 TeV)





Approach theory error, possibility to find clear evidence of deviation from SM

$K^+ \to \pi^+ \nu\nu$ at high intensity

The NA62 decay-in-flight technique works well and is scalable to higher statistics

- Background estimates validated by in-depth study with data and MC
- Improvements based on 2016-2018 data studies will be put in action in 2021-2024

An experiment at the SPS NA-ECN3 to measure BR($K^+ \to \pi^+ \nu\nu$) to within ~5%

Requires 4x increase in intensity → Beam line consolidation, stable and reliable operation

5 years of data taking to collect ~400 SM events

Basic design of experiment will work at high intensity

Key points:

- Require much improved time resolution to keep random veto rate under control
- Must maintain other key performance specifications at high-rate:
  - Space-time reconstruction, low material budget, single photon efficiencies, control of non-gaussian tails, etc.

Synergies for detectors with collider projects and other rare processes experiments:

- Challenges often broadly aligned with High Luminosity LHC projects and next generation rare processes/ flavor/ dark matter experiments

Integrated programme with K^+ and K_L beams

Availability of high-intensity K^+ and K_L beams at the SPS NA-ECN3:
Unique facility, clear physics case
Important physics measurements also at boundary of NA62x4 and KLEVER

Example: Experiment for rare K_L decays with charged particles

- K_L beamline, as in KLEVER
- Tracking and PID for secondary particles, as in NA62
- **10^{13} K_L decays in fiducial volume /year @ 10^{19} POT/year** (200 days, 50% efficiency)

Physics objectives:

- $\boldsymbol{K_L \to \pi^0 \ell^+ \ell^-}$
  Excellent π^0 mass resolution – look for signal peak over Greenlee background
- Lepton-flavor violation in K_L decays
- Radiative K_L decays and precision measurements
- K_L decays to exotic particles

Will provide valuable information to characterize neutral beam

- Example: Measurement of K_L, n, and Λ fluxes and halo
- Experience from KOTO and studies for KLEVER show this to be critical

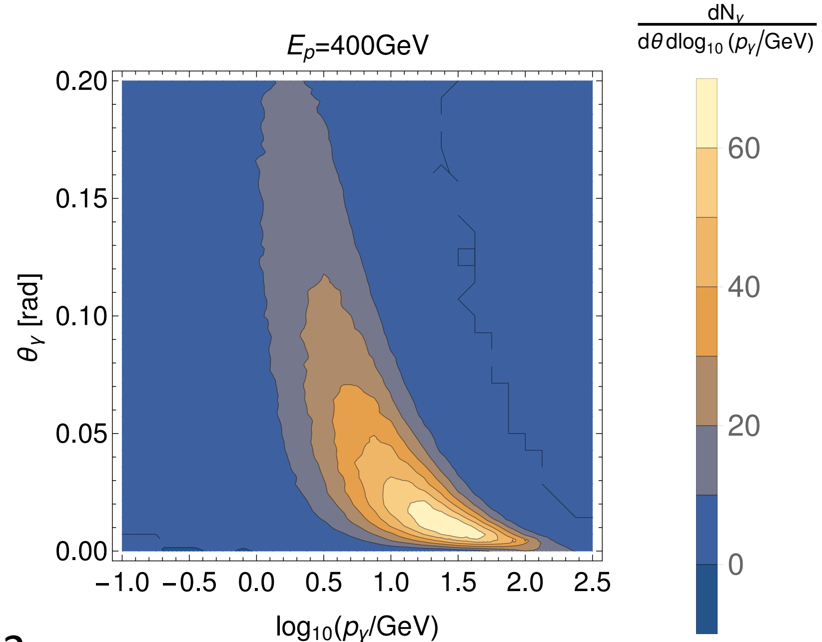
Feebly interacting particles (dump phase)

Physics goals for operation in dump mode after 2025:

- **Search for visible decays of feebly-interacting new-physics particles**
- **x10 statistics improvement expected with respect to 2021-2023 data taking**
- If no signal and negligible background → sensitivity improvement

Dump mode is most sensitive to forward processes, complimentary to off-axis experiments, like SHADOWS

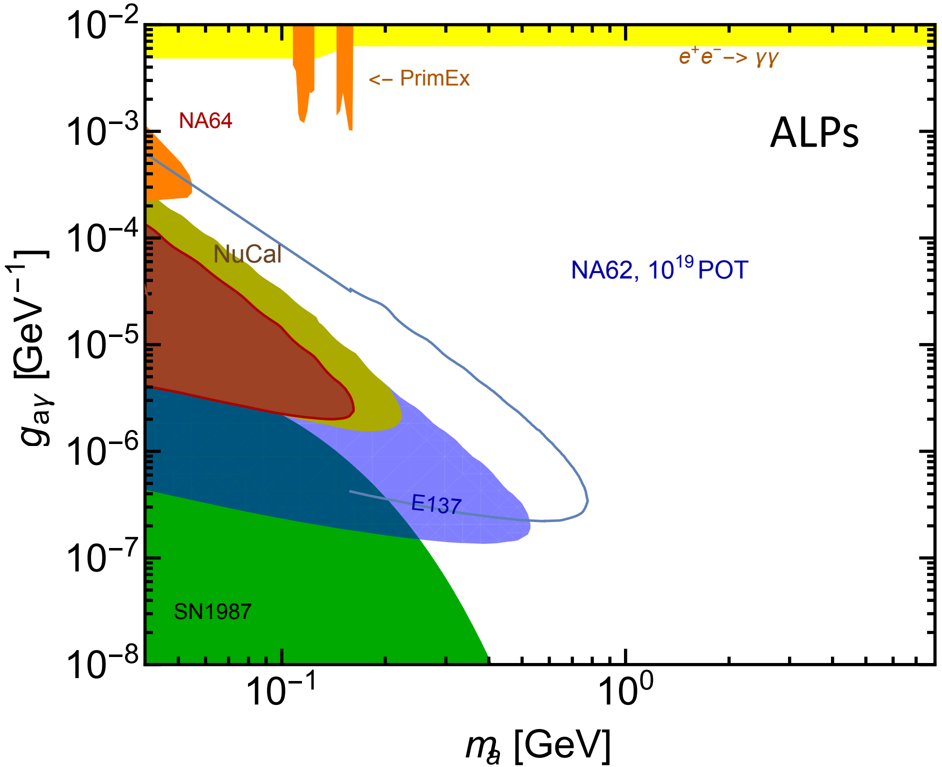
Distribution of photons from neutral pion decays in TAX (Primakov production). ALPs go approximately in the same direction



Can capture distribution up to 5 mrad

Sensitivity to lifetime depends on production-detector distance and length of detector (few ns)

Complimentary to other experiments

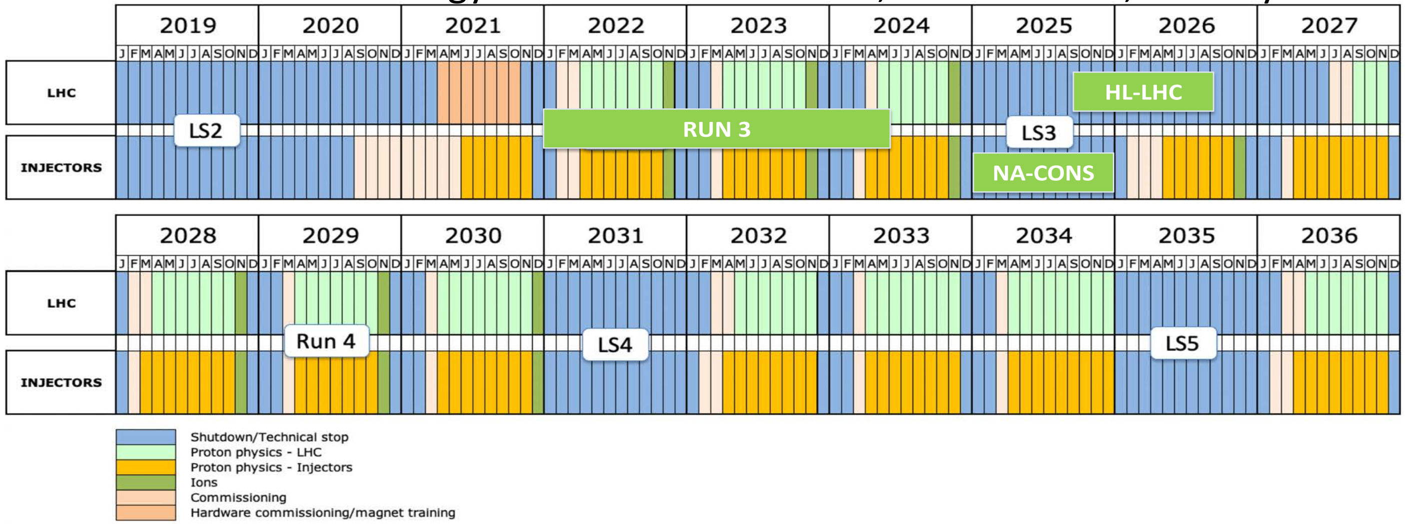


Integrated high-intensity Kaon programme at the SPS

EU Strategy deliberation document: **CERN-ESU-014**
“rare kaon decays at CERN” mentioned in Sec4
“Other essential activities for particle physics”

Long-term Physics Programme in NA-ECN3 to extend to FCC-ee (~2039)

“Accelerator and Technology Introduction” webinar, Mike Lamont, January 2021



Integrated programme with multiple phases, synergies with LHC programme
K^+ and K_L beams for precision measurement of $K \to \pi\nu\nu$
Study of other rare kaon decays, including K_L beam with tracking detector for $K_L \to \pi^0 l^+ l^-$
Data taking in dump mode to reach 10^{19} POT to search for FIPs

Advantage of integrated approach: common upgrades for intensity and detectors between projects, more flexibility on schedule.
Phase order depends on factors like civil engineering and detector readiness.
($K_L \to \pi^0 \nu\nu$ phase KLEVER probably involves civil construction, see later pages)
Dump mode schedule integration to be finalised

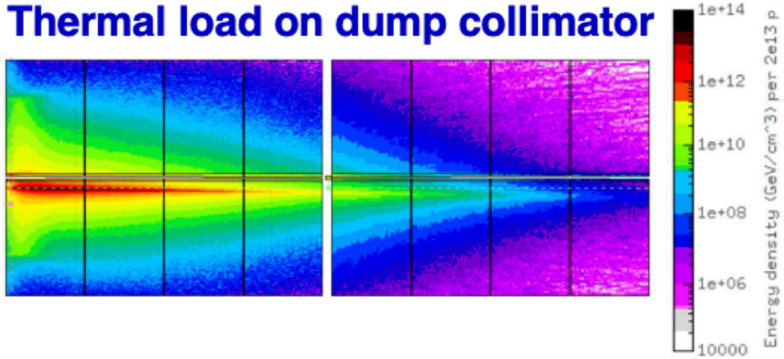
Experiments to measure $K \to \pi\nu\nu$ BRs at the SPS would require:

- **$K^+ \to \pi^+\nu\nu$**
  ~7×10^{18} pot/year
  4x increase
- **$K_L \to \pi^0\nu\nu$**
  1×10^{19} pot/year
  6x increase

Target/TAX upgrade for high intensity

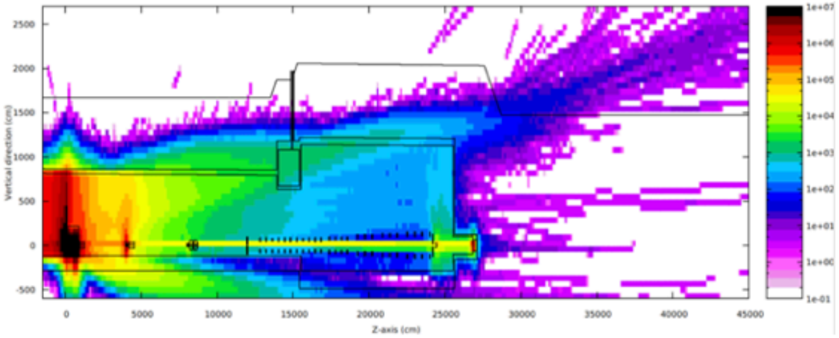
Beam and target simulations

Thermal load on dump collimator



CNGS rod target

Dose rate simulation in ECN3, K_L beam



Target and TAX upgrade:

[CERN-PBC-REPORT-2018-002]

Conceptual development by SY-STI group in framework of Conventional Beam WG studies, 2018-2019 (N.Solieri et al)

Thermal simulations of target and TAX dump collimator

- Identified upgrades needed for high-intensity beam
- Target: CNGS-like design: carbon-carbon supports, pressurized air cooling
- TAX: Cooling elements nearer to center of collimator, like for SPS beam dump

Neutral beam and prompt surface dose

- **Neutrons:** Shielding adequate to reduce surface dose; need access shaft airlock
- **Muons:** Additional shielding at target and/or at downstream end of ECN3

Complete evaluation of random veto and trigger rates with full FLUKA beamline simulation for all particles down to 100 MeV

High-intensity proton beam study

Conclusions from PBC Conventional Beams working group [CERN-PBC-REPORT-2018-002]

Issue	Approach
Extraction losses	Good results on ZS losses and spill quality from SPS Losses & Activation WG (SLAWG) workshop, 9-11 November 2017: https://indico.cern.ch/event/639766/
Beam loss on T4	Vertical by-pass to increase T4 → T10 transmission to ~80%
Equipment protection	Interlock to stop SPS extraction during P0Survey reaction time
Ventilation in ECN3	Preliminary measurements indicate good air containment Comprehensive ventilation system upgrade not needed
ECN3 beam dump	Significantly improved for NA62 Need to better understand current safety margin
T10 target & collimator	Thermal load on T10 too high → Use CNGS-like target? Dump collimator will require modification/additional cooling
Radiation dose at surface above ECN3	8 mrad vertical targeting angle should help to mitigate Preliminary results from FLUKA simulations Proposed target shielding scheme appears to be adequate Mixed mitigation strategy may be needed for forward muons

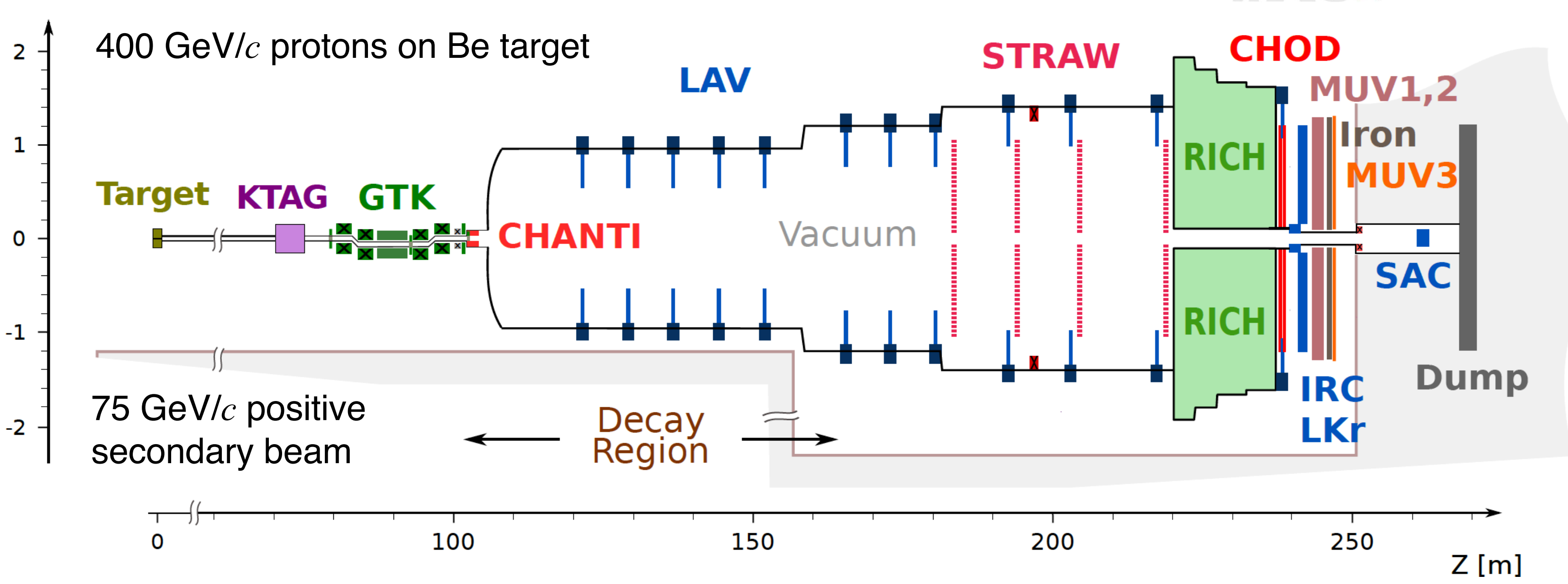
Looked at for K_L beam
Needs checking for K^+

High-rate beam 1.3--2 10^{13} protons on target over ~3 sec effective spill

Unseparated secondary hadron beam

<50ps time resolution (similar to HL-LHC)

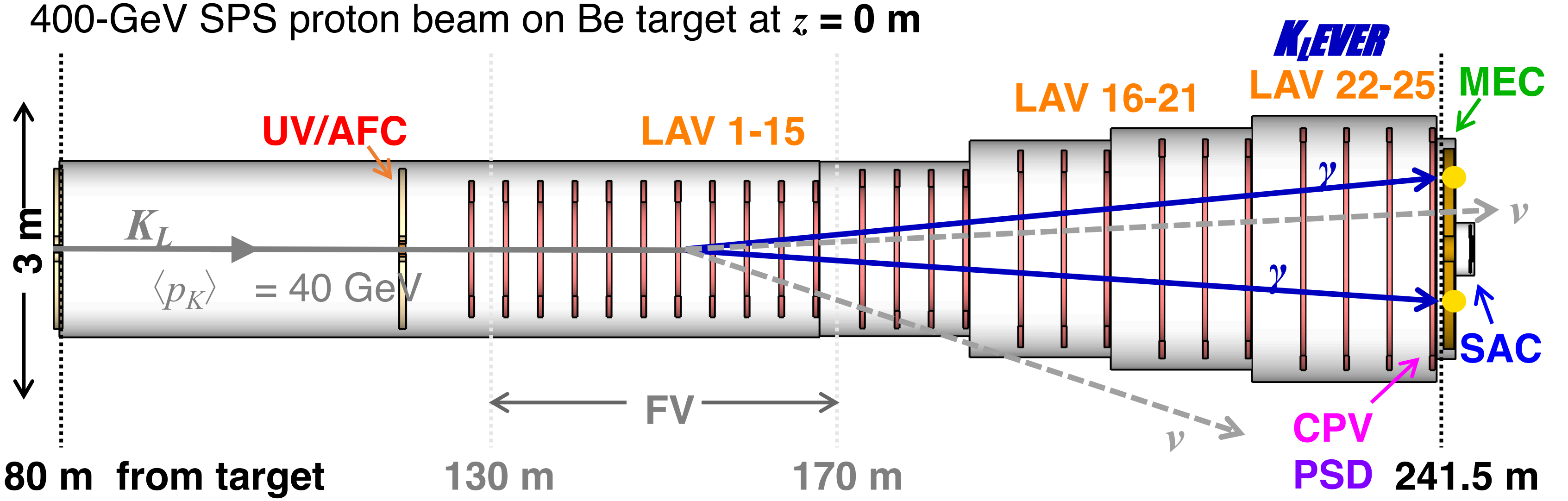
NA62 x 4



K⁺ phase

- Essential K⁺ ID, momentum, space and time – 200 MHz of K⁺
- High-rate, precision tracking of pion
- Minimize material
- Highly efficient PID and muon vetoes
- Highly efficient and hermetic photon vetoes
- High-performance EM calorimeter (energy resolution, linearity, time, granularity)

400-GeV SPS proton beam on Be target at z = 0 m



K$_L$ phase

- 2γ with unbalanced p_T + nothing else
- K$_L$ momentum generally not known
- Background rejection from Λ and neutrons, and dominant K decays
- Background rejection mainly by vetoes

Efficient, large-coverage vetoes

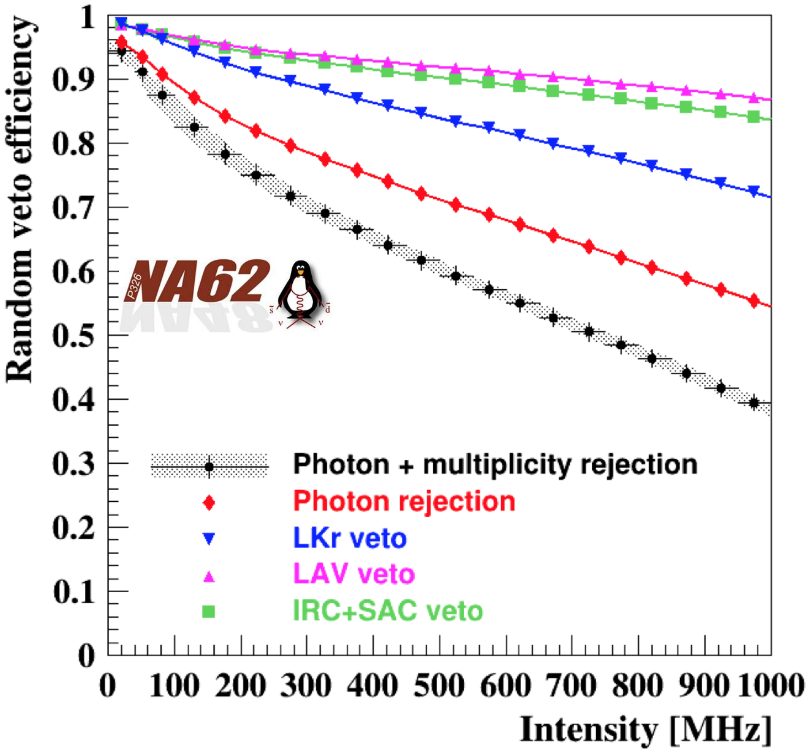
Determination of angle of incident photons

PID for neutron rejection

10^{13} K$_L$ decays in FV /year @ 10^{19} POT/year

Recent: extending ECN3 by 150 m would eliminate Λ background

Random veto considerations



For highest rate, high-frequency digitizing readout to efficiently veto background events without being blinded by pile-up. Detailed signal analysis will also assist with particle identification and discrimination of uncorrelated background, reducing the random veto loss.

High granularity to exploit NN image recognition algorithm to resolve spatial pile-up.

Time resolution for all photon vetoes will be improved for 4x intensity

- Coincidence windows of < 2 ns
- Coincidence time resolution of ~200 ps (±5σ for full efficiency)
- Photon veto time resolution < 200 ps
- Solutions for readout necessary
- These characteristics are necessary for K^+ and K_L beams

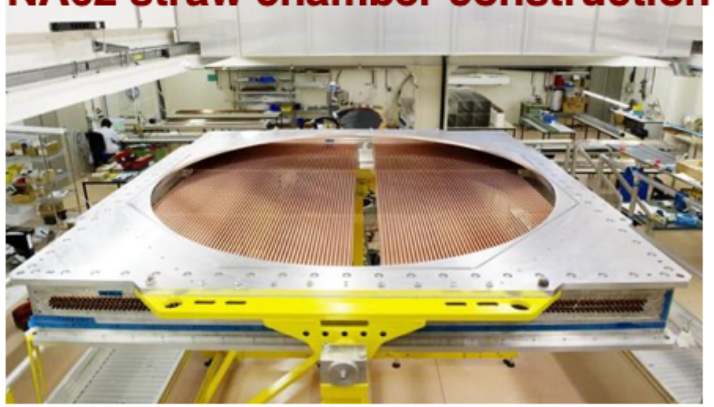
STRAW detector

NA62 has developed techniques for making **state-of-the-art straws by ultrasonic welding**

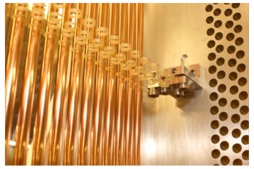
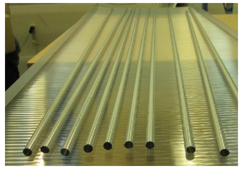
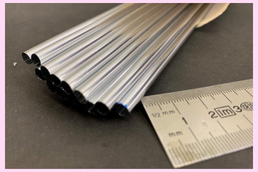
Straw chambers for 4x intensity

- **Main feature: Straw diameter 9.8 mm → ~5 mm**
- **Improved trailing-time resolution: ~6 ns (per straw), 1 ns (for track)**
- **Rate capability increased by factor 6-8, due to geometry and shorter drift**
  - Less space charge due to shorter drift time
    - Ion clusters are faster → can use fast shaping
    - Smaller maximum drift time: 150 ns → ~80 ns
- **Maintain efficiency > 98%**
- **Decreased straw wall thickness**: 36 μm to 12 μm, with copper and gold plating
- Position resolution (from leading edge time resolution) unchanged but can **increase number of straws per track while maintaining low material budget**
- Layout: 4 chambers, ~21000 straws
- **Material budget**: 1.7% → 1.1% X_0

NA62 straw chamber construction



Design study started at CERN and Dubna

	NA62	COMET Phase-I	New Straw
Straw Wall Thickness	36 μm	20 μm	12 μm
Straw Diameter	9.8 mm	9.8 mm	4.8 mm
Metal Deposition	Cu+Au, 70nm	Al, 70 nm	*Al, 70 nm
Photo			
Current Status	In Operation	Under Construction	Just Developed

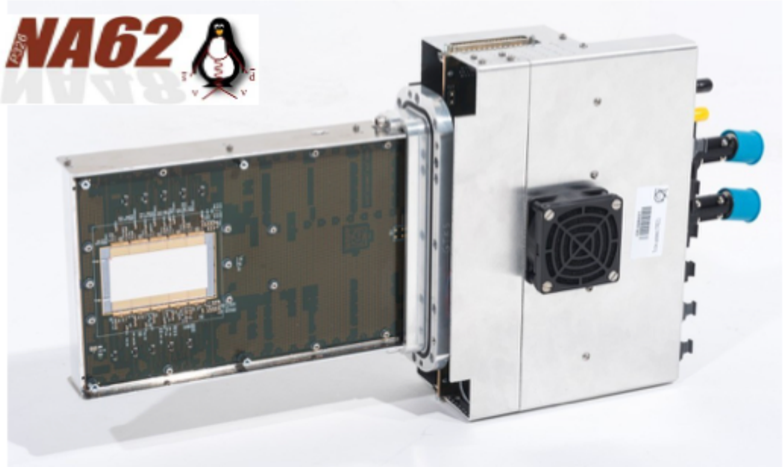
Also COMET Phase-II plans to use 12 μm STRAW

* Al for prototype: final straws will have 50 nm Cu + 20 nm Au like present straws

Beam GigaTracKer

NA62 GTK design from 2007
Time-resolved pixels did not yet exist!
First detector to give 4D reconstruction

- **Strict requirements on material budget:** 0.5% X_0 per tracking plane
- Use minimum number of planes, with time mmts to constrain event reconstruction
- 200 μm planar silicon sensors
- TDCPix readout chips, 6 Gb/sec
- **Cooled with silicon microchannel plates**
- Time resolution with beam = 150 ps /plane at 250V



$$\begin{aligned}\sigma_t &= \sigma_{\text{elec}} \oplus \sigma_{\text{TDC}} \oplus \sigma_{\text{field}} \oplus \sigma_{\text{straggling}} \\ &= 28\text{ ps} \oplus 75\text{ ps} \oplus 85\text{ ps} \oplus 100\text{ ps}\end{aligned}$$

GTK for 4x intensity

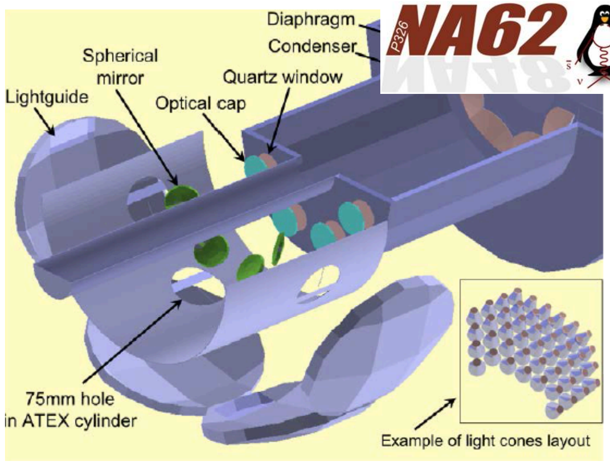
- **Time resolution < 50 ps per plane**
- Pixel size: =< 300×300 μm^2
- **Efficiency**: > 99% (incl. fill factor)
- **Material budget**: 0.3-0.5% X_0
- **Beam intensity**: 3 GHz over ~ 3x6 cm^2
- Maximum local intensity: 8 MHz/mm^2
- Radiation resistance: ~2x10^{15} n eq/cm^2/yr (200 days)

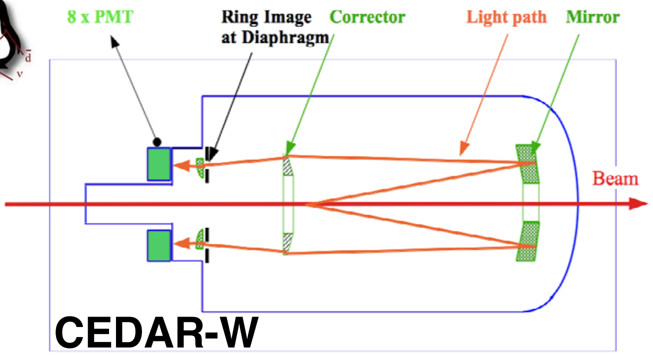
Planar (thinner), 3D or LGAD technologies being considered
Time resolution for sensor is achievable

Probable need for a new ASIC
28 nm technology PicoPix being developed
Precursor Timespot ASIC exists

Kaon ID with Cherenkov

Differential Cherenkov detector, refurbished readout





Currently using N2 as radiator

Working conditions in NA62:

- **Tag K^+ at 50 MHz (nominal intensity)**
- Photon yield: 200 photons/K^+
- High-granularity PMT configuration
- K^+ tagging efficiency with 4 sectors: > 95%
- Max rate of detected photons: ~5 MHz/PMT
- Single-γ time resolution $\sigma_t(1\gamma)$ ~ 300 ps
- K^+ time resolution: ~70 ps
- **Upgrade planned, to use H_2 to minimise material along the beam with new vessel and internal optics (as per design)**

K ID for 4x intensity, Kaon time res ~20 ps

- **Max detected photon rate**: >8 MHz/cm^2
- **Single-photon capability with σ_t = 50-70 ps**
- Good radiation resistance

Microchannel plate (MCP) PMTs

- Excellent time resolution (~20 ps)
- Low dark noise, Single-photon sensitivity
- High gain, good QE
- Good filling factor
- Input rate capability ~MHz/cm^2

Susceptible to aging (QE drops)
Effect of aging must be mitigated

Other possible photodetectors:

- **SiPMs:** With R&D may reach $\sigma_t(1\gamma)$ ~ 20 ps
  - Noisy; sensitive to radiation
- **HPDs:** $\sigma_t(1\gamma)$ ~ 70 ps
  - Sensitive to radiation?

Calorimeter

Main electromagnetic calorimeter requirements:
excellent efficiency and time resolution (~100ps), good two-cluster separation, good energy resolution

Quasi-homogeneous ionization calorimeter, $27X_0$ of LKr @ NA62

$$\frac{\sigma_E}{E} = \frac{3.2\%}{\sqrt{E}} \oplus \frac{9\%}{E} \oplus 0.42\%$$

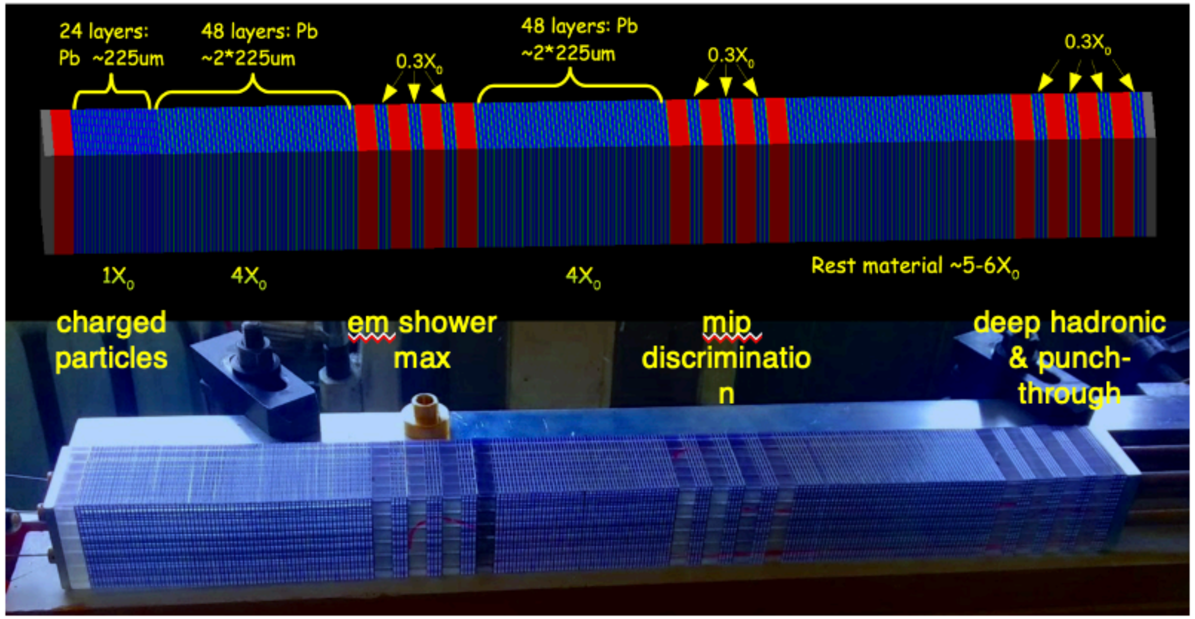
$1 - \varepsilon < 10^{-5}$ for $E_\gamma > 10$ GeV

$\sigma_t \sim 500$ ps for π^0 with $E_{\gamma\gamma} > 20$ GeV

Time performance must be improved
Veto efficiency must be maintained

Shashlyk calorimeter with longitudinal shower information

- PID information: identification of μ, π, n interactions
- Shower depth information: improved time resolution for EM showers



Fine-sampling shashlyk based on PANDA forward EM calorimeter produced at Protvino

PANDA/KOPIO prototypes:

- $\sigma_E/\sqrt{E}$ **~ 3%** $/\sqrt{E}$ (GeV)
- σ_t **~ 72 ps** $/\sqrt{E}$ (GeV)
- σ_x **~ 13 mm** $/\sqrt{E}$ (GeV)

Longitudinal information provides
5-10x improvement in neutron rejection
Overall neutron rejection at level of 10^3

Large-angle photon vetoes

Time resolution for current NA62 LAVs ~ 1 ns

- Cerenkov light is directional
- Complicated paths to PMT with multiple reflections

25 new large-angle photon veto stations (LAV) – veto on a very large area

- 5 sizes, sensitive radius 0.85 to 1.5 m, at intervals of 4 to 5 m
- **Time resolution <250 ps**
- **Hermetic coverage out to 100 mrad**
- **Need good detection efficiency at low energy** ($1 - \varepsilon <$ few 10^{-4} at at least 100 MeV)
- **Full digitization, segmentation in depth**

CKM Vacuum Veto System (VVS)

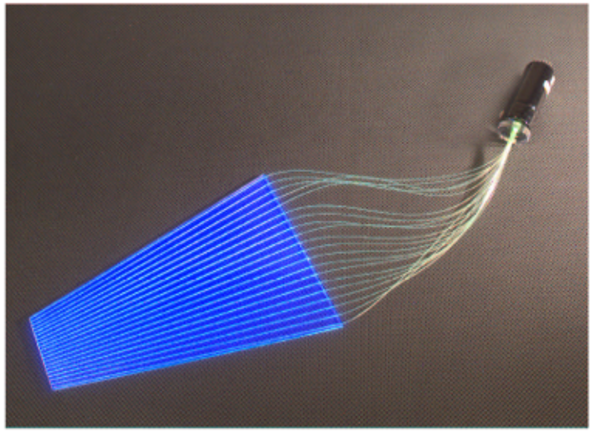
Baseline technology: Lead/scintillator tile with WLS readout

Based on design of CKM VVS

Assumed efficiency based on E949 and CKM VVS experience

Tests at JLAB for CKM:

- $1 - \varepsilon \sim 3 \times 10^{-6}$ at 1200 MeV



- Pb/scintillating tile
- 1 mm Pb + 5 mm scint
  $f_{em} \sim 36\%$
- WLS fiber readout

Light read out with SiPM arrays

Small-angle photon veto

- Rejects high-energy γs from $K_L \rightarrow \pi^0\pi^0$ escaping through beam hole
- **Must be insensitive as possible to extremely high rate 430 MHz of beam neutrons in K_L mode**
- **σ_t < 100 ps**
- **2 pulse separation at ~ 1 ns**
- **Radiation-hardness:** 10^{14} n/cm^2 and 10^5-10^6 Gy
- **Longitudinal and transverse segmentation** for PID

The most stringent requirements for the SAC are in KLEVER

Beam comp.	Rate (MHz)	Req. 1 – ε
γ, $E > 5$ GeV	**50**	**10^{-2}**
γ, $E > 30$ GeV	**2.5**	**10^{-4}**
n	**430**	**–**

For NA62x4, the requirements are slightly less stringent, remnants of the charged beam can be magnetically swept out of acceptance Still expect rates of up to 10 MHz or more in the NA62x4 SAC.

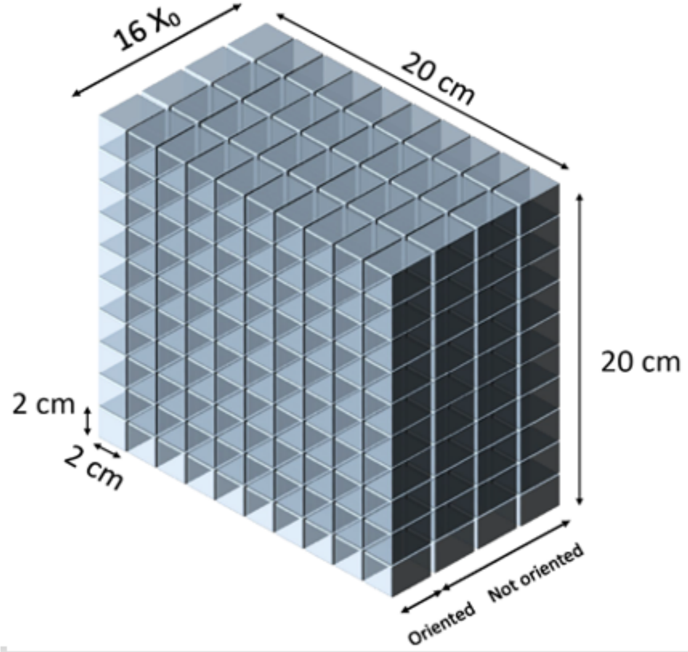
Possible solutions:

- Tungsten/silicon-pad sampling calorimeter with crystal metal absorber to exploit enhancement of photon conversion by coherent interaction with lattice
- Compact Cherenkov calorimeter with oriented crystals

- Optimize choice of photodetectors
    - Excellent time resolution
    - Radiation hardness
- Study response to neutral hadrons
- Possibilities for γ/n discrimination

Collaboration with AIDAinnova

PbF_2 Cherenkov calorimeter

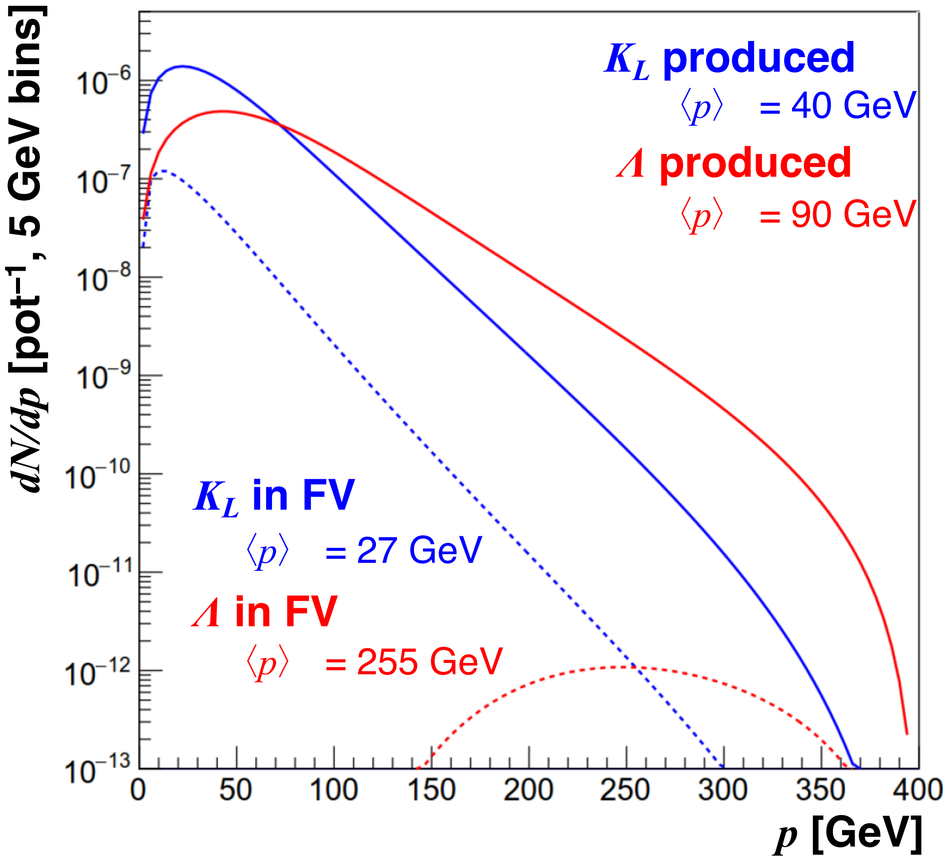


Beam and intensity requirements

Beam Line Design from CB Working Group (M. van Dijk, L. Gatignon, N. Doble), 2017-2019

K_L and Λ fluxes, $\theta = 8.0$ mrad

Parameterized from FLUKA simulation



10^{19} pot/year (= 100 eff. days)
E.g.: 2×10^{13} ppp/16.8 s

- **400 GeV p on 400 mm Be target**
- **Production at $\theta = 8.0$ mrad:**
  - As much K_L production as possible
  - Low ratio of n/K_L in beam ~ 3
  - Reduce Λ production and soften momentum spectrum
- **Solid angle $\Delta\theta$ = 0.4 mrad**
  - Large $\Delta\theta$ = high K_L flux
  - Maintain tight beam collimation to improves $p_\perp$ constraint for background rejection
- **2.1×10^{-5} K_L in beam/pot**
- Probability for decay inside FV ~ 4%

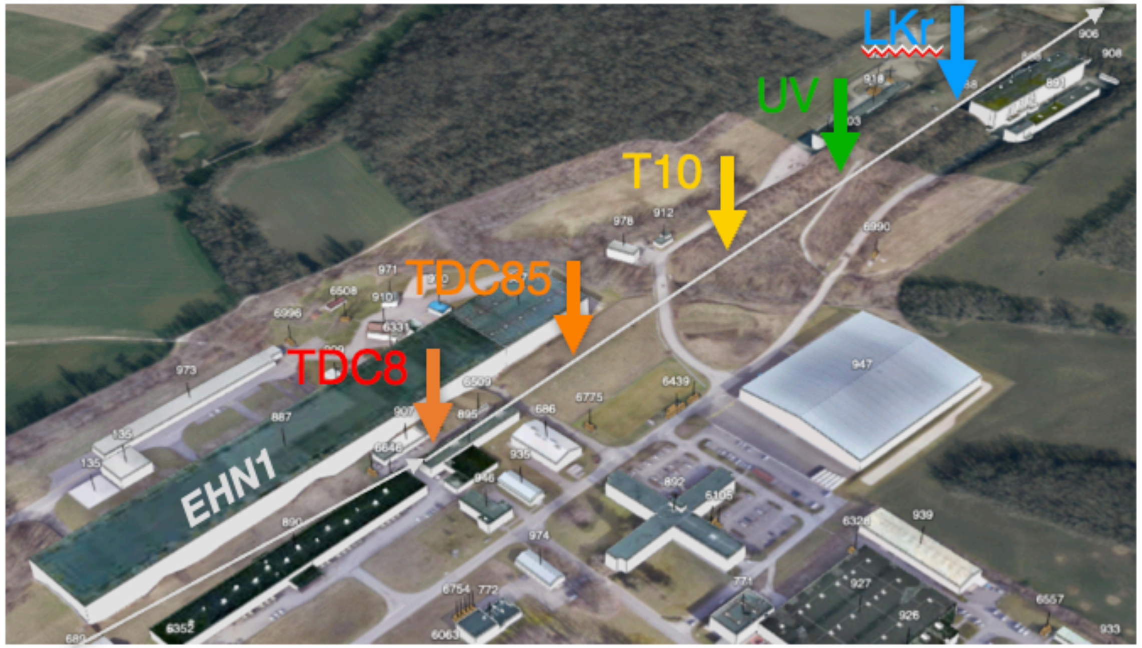
⇨ **10^{13} K_L decays in fiducial volume /year**
@ 10^{19} POT/year (200 days, 50% efficiency)

Long beamline to suppress $\Lambda \to n\pi^0$

Neutral beam line : Design from CB Working Group (M. van Dijk, L. Gatignon, N. Doble), 2017-2019
Conceptual development of beam, target and TAX dump collimator: by CB WG, 2018-2019

Reduction of $\Lambda \to n\pi^0$ decays in FV requires optimization of experiment layout and kinematic conditions

Maintain θ = 8 mrad and increase length of beamline by 150 m



- Maintain K_L momentum
  Fewer design changes for KLEVER
- Preserve K_L flux per solid angle
  Still lose 2x in K_L flux due to tighter beam collimation
- Infrastructure work needed
- RP issues for area downstream of TDC85 under investigation

Extending ECN3 by 150 m would eliminate Λ background and respect RP constraints – technical investigation ongoing

Dump mode: results from past PBC mandate

MC simulation of the beam-dump operation (closed TAX configuration)

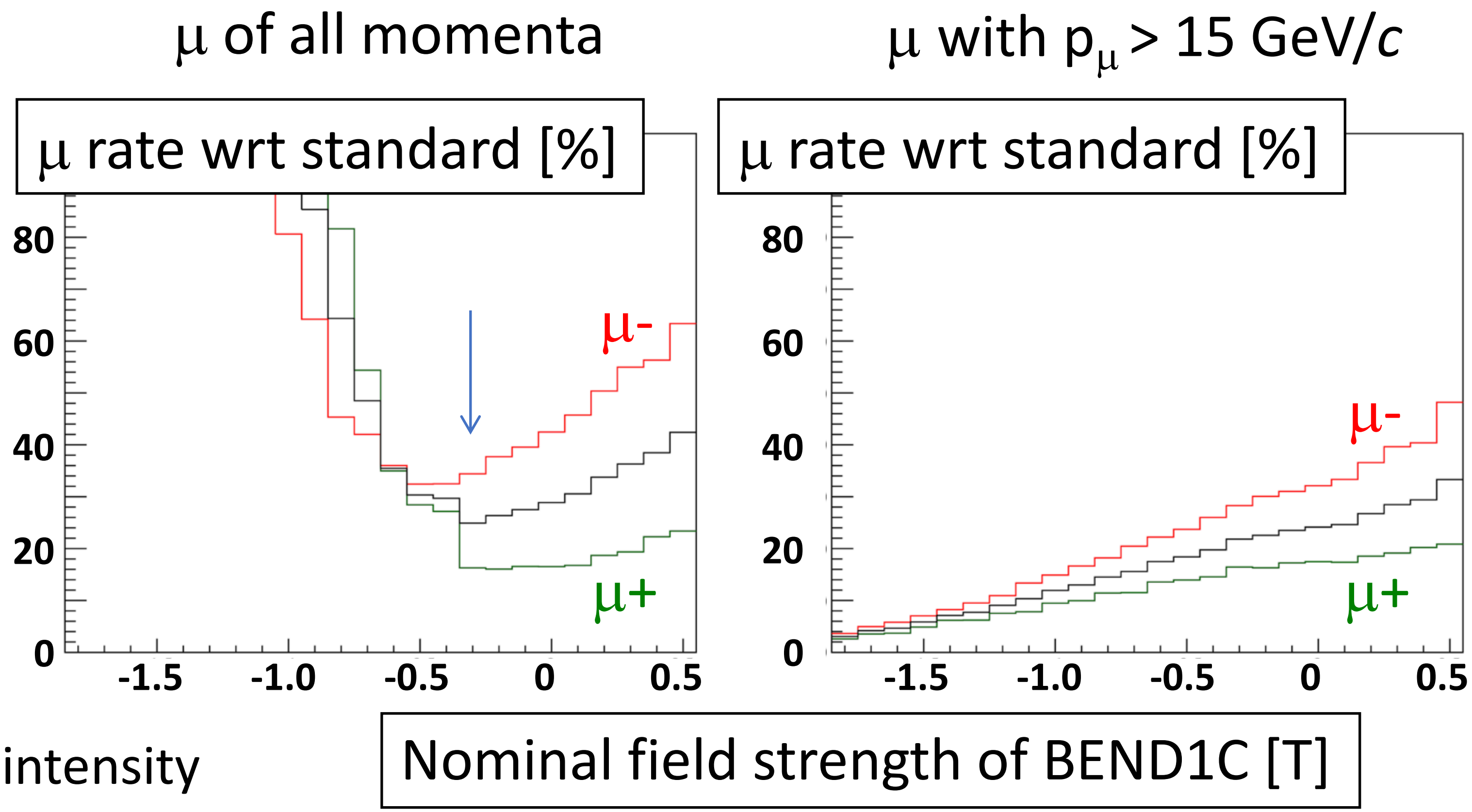
Qualitative agreement of data vs MC distributions for halo muons

Disentangle background rates: target residual material vs tax production

Beam-line tuning for improved dump operation defined:

Improved sweeping: can reduce single μ rate by ~ x4

Focus: set beam focus at TAX, reducing spot size by x10



Physics results expected soon for 10^{16} POT dump data taken in 2016-2018

Plan to collect 10^{18} POT with x2 nominal intensity at NA62 in 2021-2024

Operation in dump mode

Operation in dump mode:

total integrated intensity: 10^{19} protons on dump as goal

beam intensity, x4 with respect to the nominal: equivalent to ~1.2 10^{13} protons/s

total integrated time, x4 intensity: ~200 days (could be distributed over the years, or concentrated)

Further needs defined assuming thermal and radioprotection safety of operation

Operation at x4 intensity induces x16 increase in combinatorial background

Potentially dominating on top of prompt background [μ-induced showers]

New optimization of sweeping might be required:

to reduce single and double track rate

to reduce the hard-momentum muon component [$e^{\pm}/\gamma$ background]

To be investigated in the Conventional beam WG

Summary

$K \rightarrow \pi \nu\nu$ and other rare kaon decays are uniquely-sensitive indirect probes for new physics at high mass scales

Unique opportunity to address clear physics case at CERN NA facility

High intensity frontier synergetic with LHC program - time res <50 ps, combined flavour program

Need precision measurements of both rare K^+ and K_L decays to pin down BSM physics

NA62 will improve on current knowledge of BR($K^+ \rightarrow \pi^+ \nu\nu$) in short term, ultimately reaching O(10%) precision

Next generation rare kaon experiments with high-intensity beams will provide a powerful tool to search for physics beyond the Standard Model

Data taking phase in dump mode to collect 10^{19} POT can reach unique sensitivity to forward processes in the search for FIPs

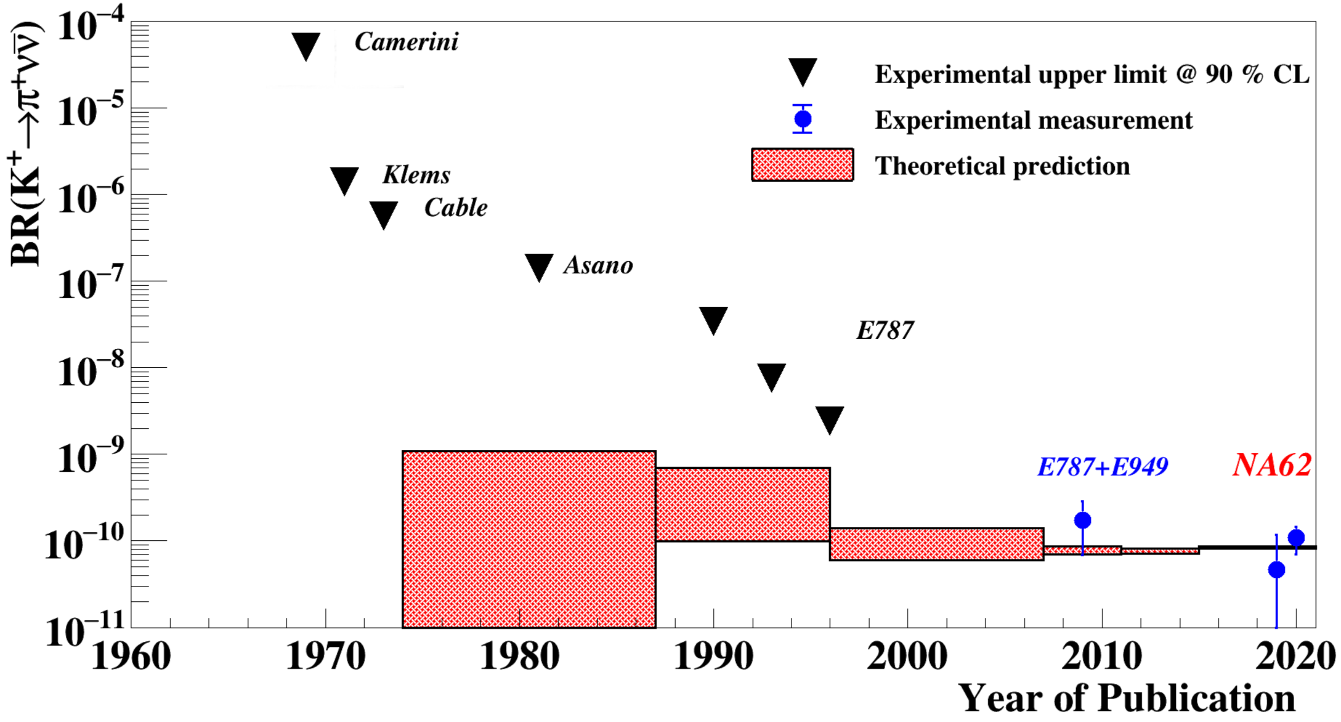
We are planning an integrated program of K^+ and K_L , and dump, experiments in ECN3

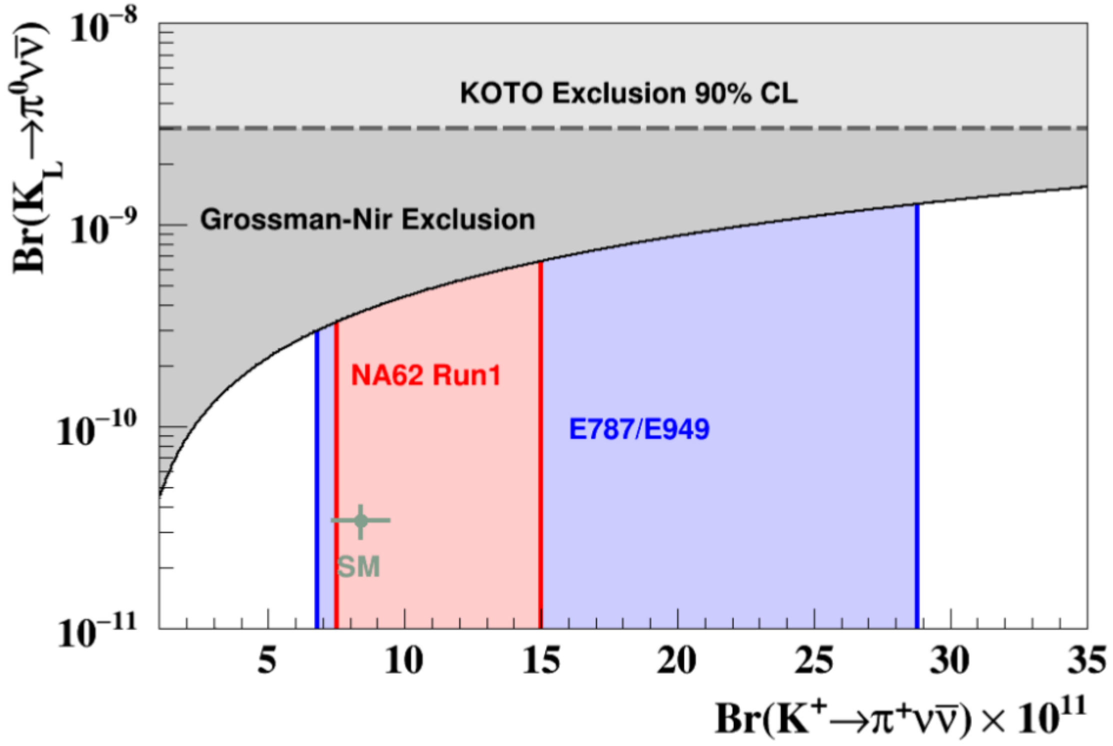
Extra Material

Findings of the European Particle Physics Strategy Group (announced, together with the CERN Council resolution that updates the Strategy)
https://webcast.web.cern.ch/event/i924500

Deliberation document: **CERN-ESU-014**
"rare kaon decays at CERN and KEK" mentioned in Section 4 "Other essential activities for particle physics", pag 9:
"A diverse programme that is complementary to the energy frontier is an essential part of the European particle physics Strategy. Experiments in such diverse areas that offer potential high-impact particle physics programmes at laboratories in Europe should be supported, as well as participation in such experiments in other regions of the world. "

Status of Br($K^+ \to \pi^+ \nu\nu$)



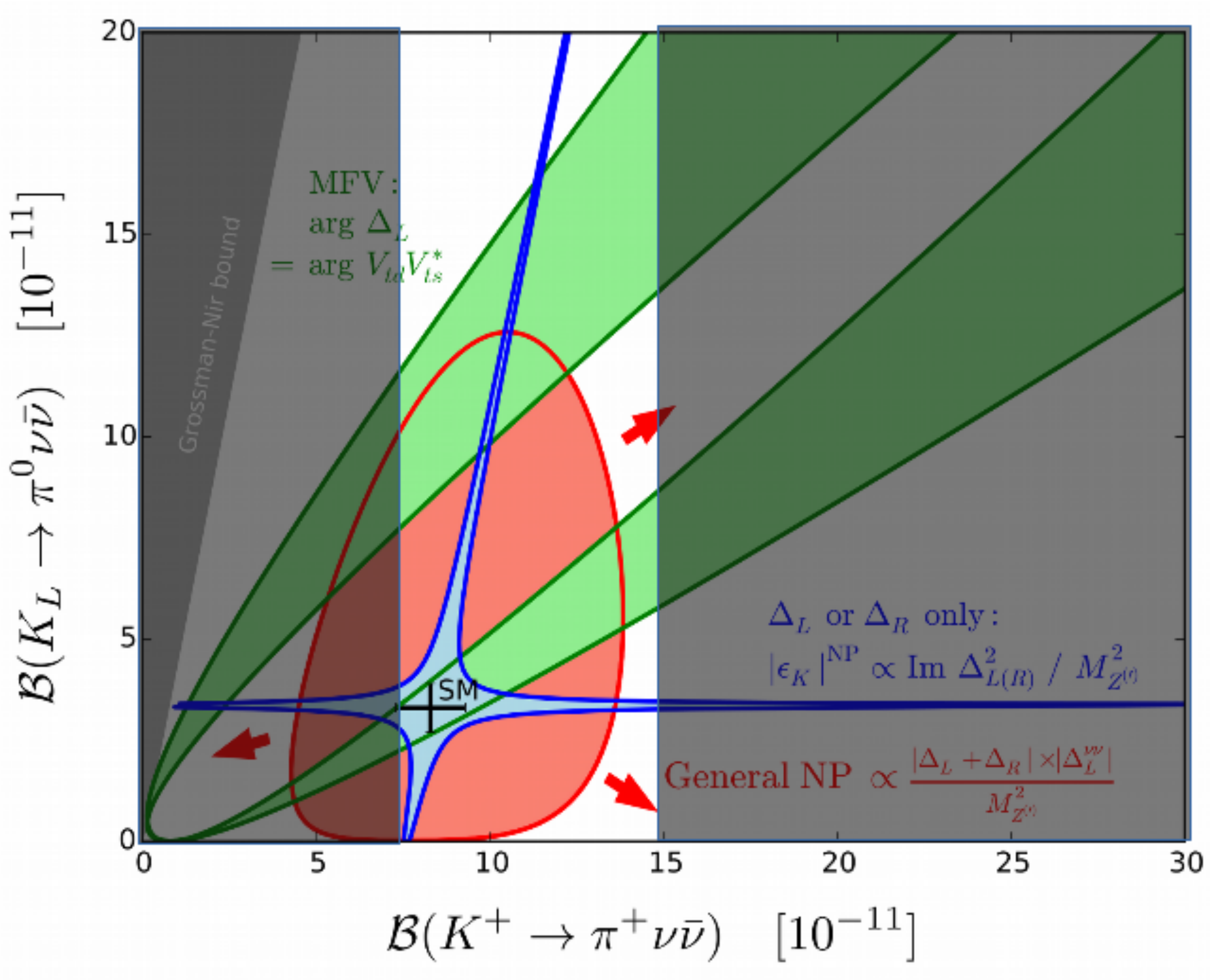


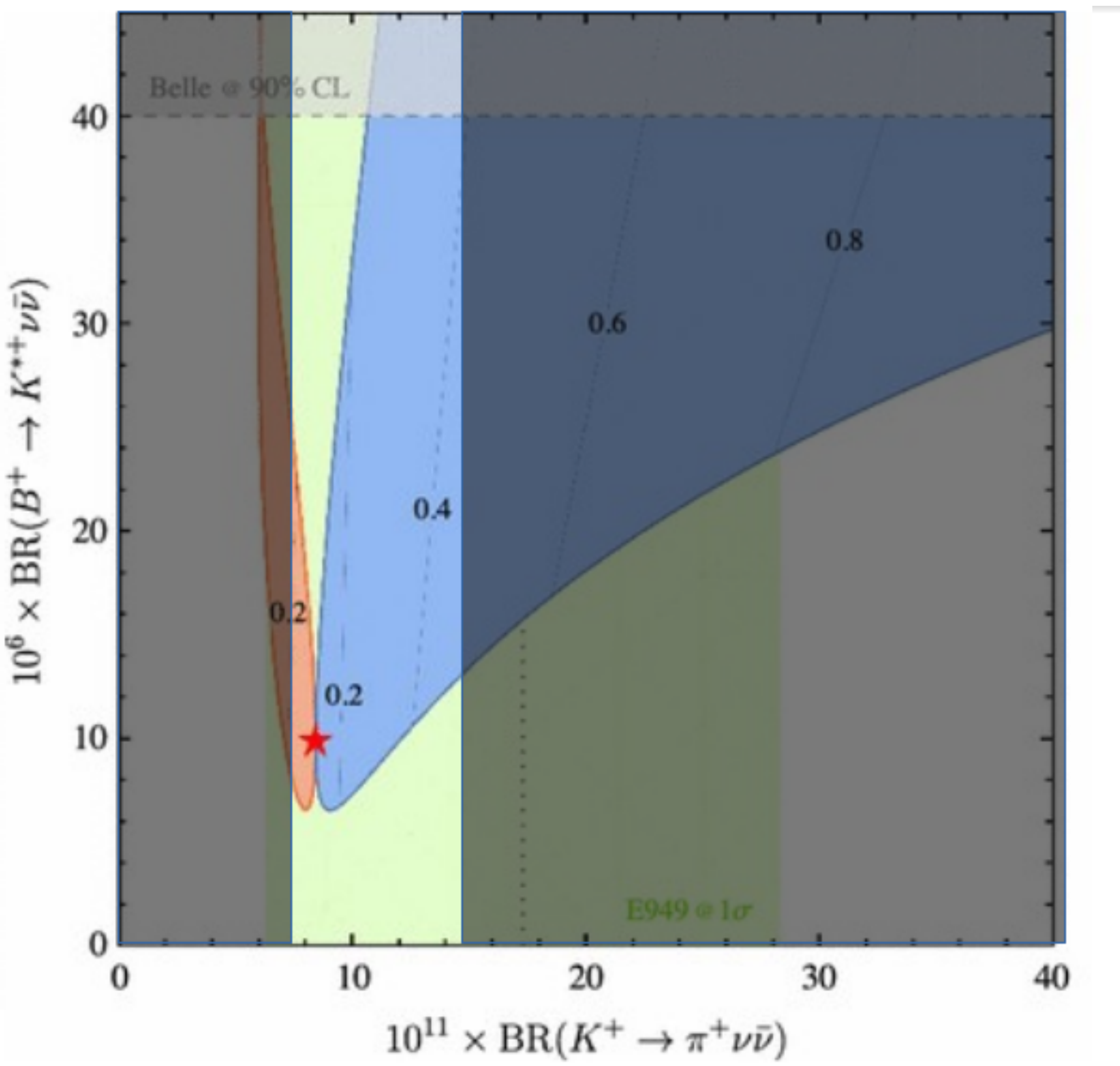
$$Br^{NA62}_{16+17+18}(K^+ \to \pi^+ \nu\bar{\nu}) = (1.10^{+0.40}_{-0.35stat} \pm 0.03_{syst}) \cdot 10^{-10} \text{ (preliminary)}$$

$$Br^{SM}(K^+ \to \pi^+ \nu\bar{\nu}) = (0.84 \pm 0.10) \cdot 10^{-10}$$ *[Buras et al., JHEP11(2015)033]*

Grossman-Nir limit: $Br(K_L \to \pi^0 \nu\bar{\nu}) < 4.3 \cdot Br(K^+ \to \pi^+ \nu\bar{\nu})$ *[Phys. Lett. B 398, 163 (1997)]*

Implications of $K^+ \to \pi^+ \nu\nu$

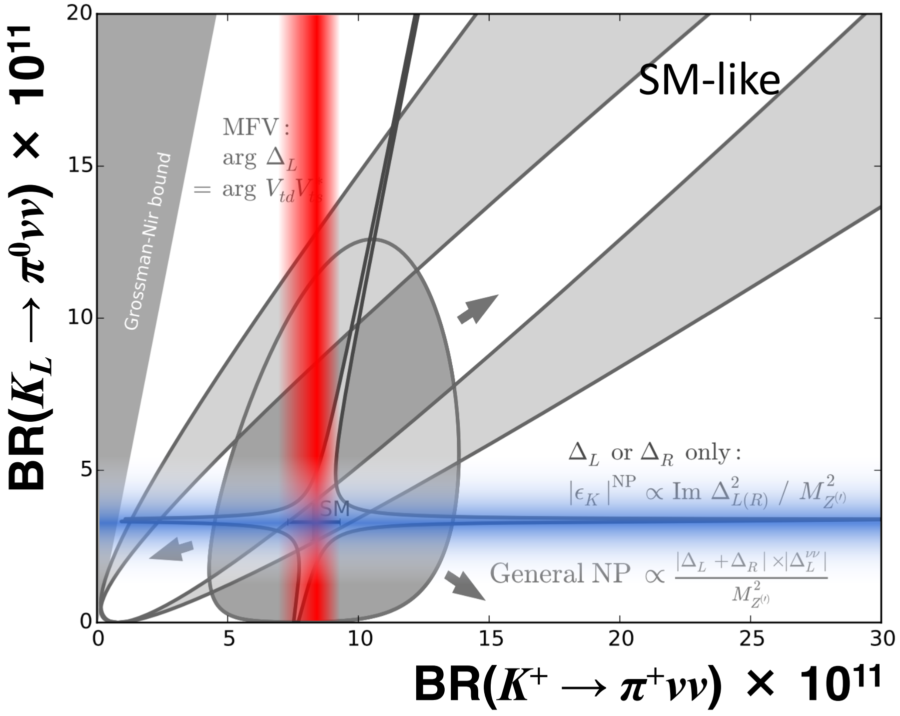




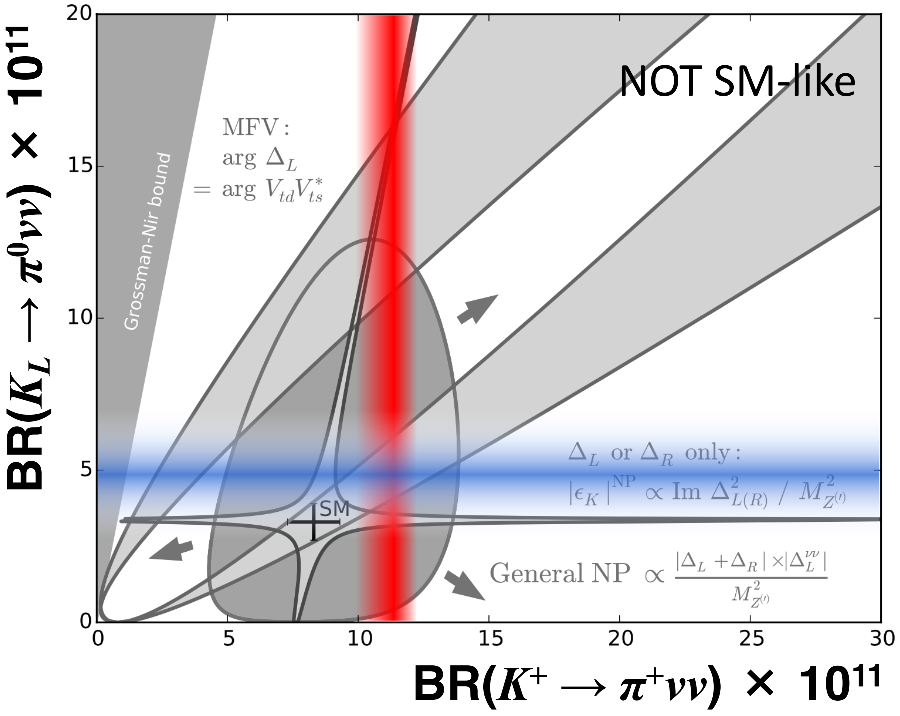
Clear opportunity in the Kaon sector

Going beyond 10% measurement on $K \rightarrow \pi+\nu\nu$

Precision measurements of $K \rightarrow \pi\nu\nu$ BRs can provide model-independent tests for new physics at mass scales of up to O(100 TeV)

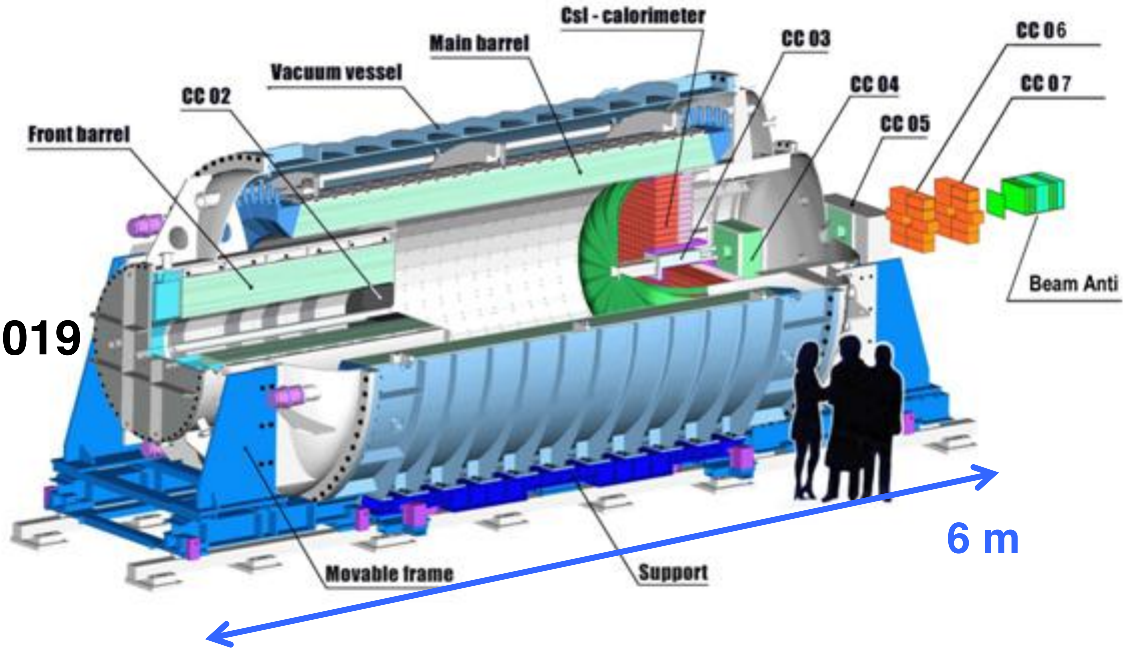


- BR($K^+ \rightarrow \pi^+\nu\nu$) = **$\mathbf{BR_{SM}}$** with δBR = **5%**
- BR($K_L \rightarrow \pi^0\nu\nu$) = **$\mathbf{BR_{SM}}$** with δBR = **20%**



- BR($K^+ \rightarrow \pi^+\nu\nu$) = **1.33 $\mathbf{BR_{SM}}$** with δBR = **5%**
- BR($K_L \rightarrow \pi^0\nu\nu$) = **1.50 $\mathbf{BR_{SM}}$** with δBR = **20%**

$K_L \to \pi^0 \nu \nu$ at J-PARC



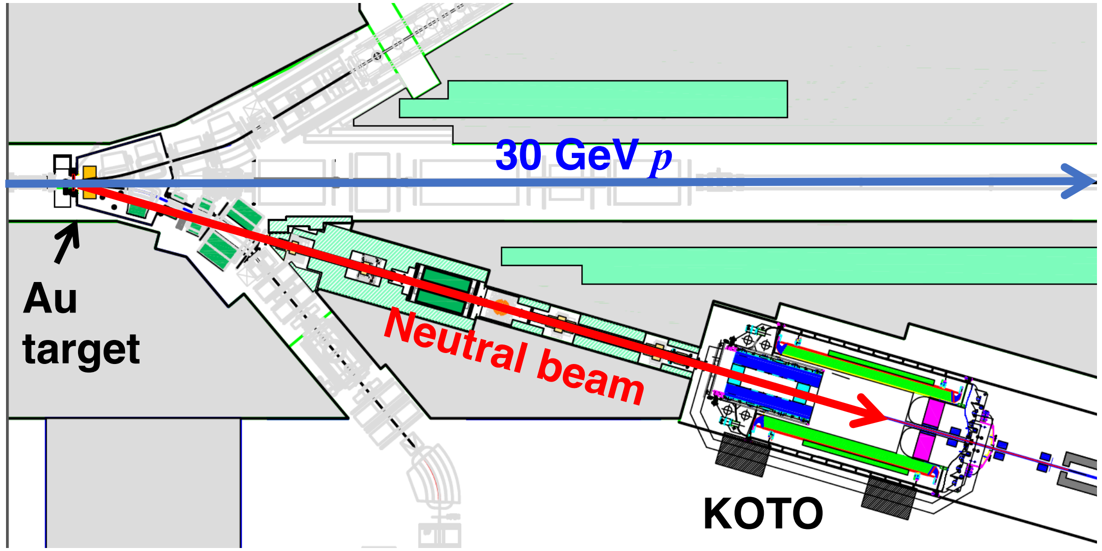
Primary beam: 30 GeV p

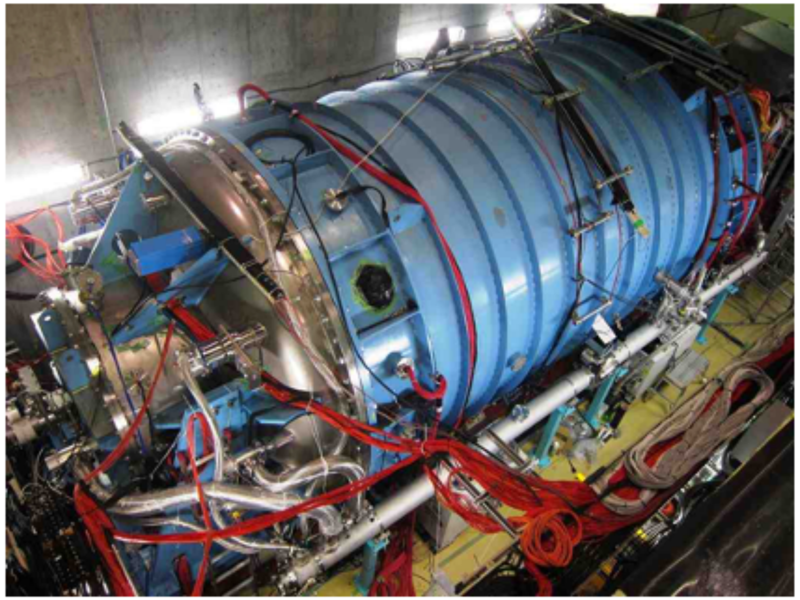
50 kW=5.5×10^{13} p/5.2 s as of 2019

Neutral beam (16°)

$\langle p(K_L) \rangle$ = 2.1 GeV

- 50% of K_L have 0.7-2.4 GeV
- 8 μsr “pencil” beam





Theorists’ interpretation of KOTO events

NB! BR($K \to \pi X$) vs m_X curves estimated by theorists – not by KOTO and NA62

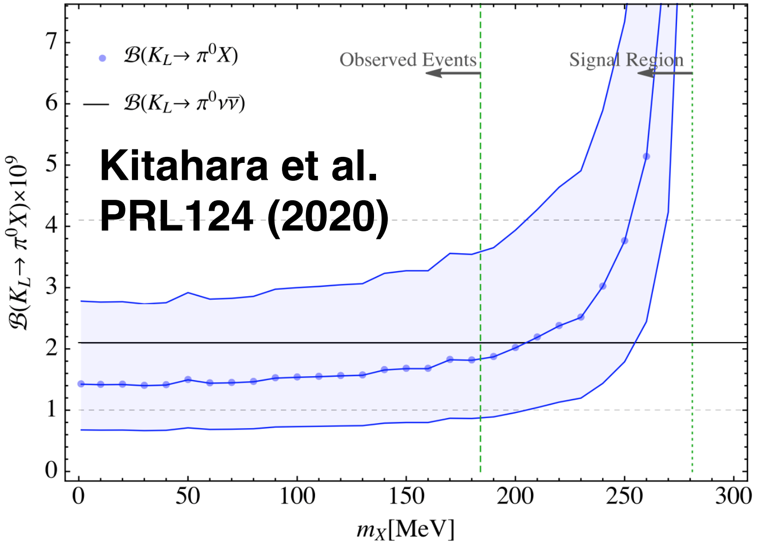
Interpretations requiring mechanism for evasion of GN bound from $K^+ \to \pi^+ \nu\nu$:

1. Heavy NP boosting SM signal
2. $K_L \to \pi^0 X$, with X = new light particle

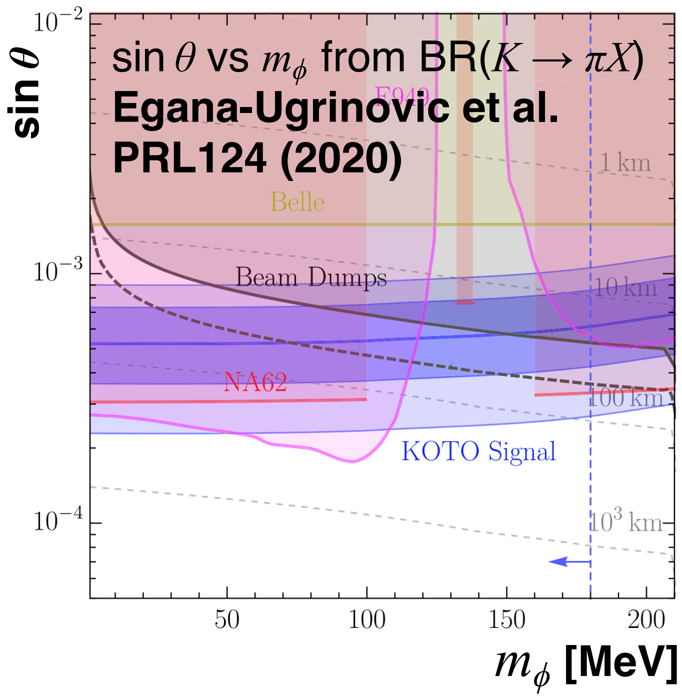
Additionally:

3. $X \to \gamma\gamma$ originating from target
   - E.g. X = ALP with photon couplings

BR($K_L \to \pi^0 X$) vs m_X est. for KOTO

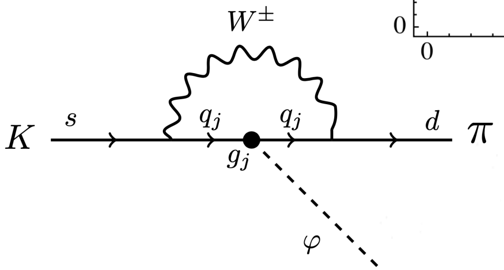


Kitahara et al. PRL124 (2020)



sin θ vs m_ϕ from BR($K \to \pi X$)

Egana-Ugrinovic et al. PRL124 (2020)



Example: $K \to \pi\phi$

ϕ = Higgs-mixed scalar

GN bound evaded if:

- $m_\phi \sim m_{\pi 0}$: Not in NA62 signal boxes
- NA62 has geom. acceptance for longer τ_ϕ: Secondaries cause event to be vetoed in NA62

KOTO Step-1 outlook

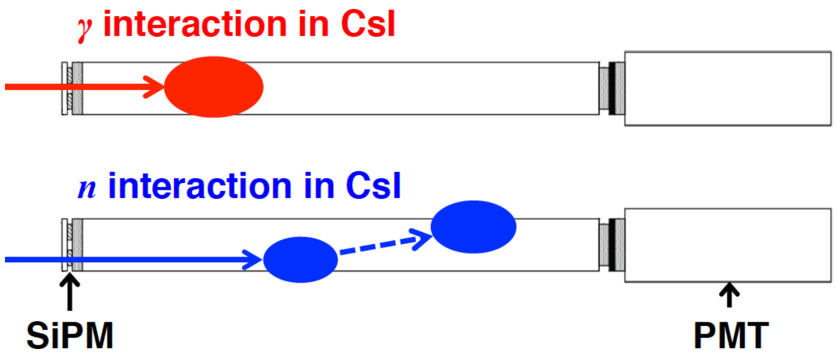
Signal: Need ~20x more (flux × acceptance) to reach SM SES

- Beam power expected to increase 50 → 100 kW gradually by 2024
- 8-16 months of additional running planned in 2020-2024

Background: Need ~7x more background rejection to get $S/B \sim 1$ at SM SES

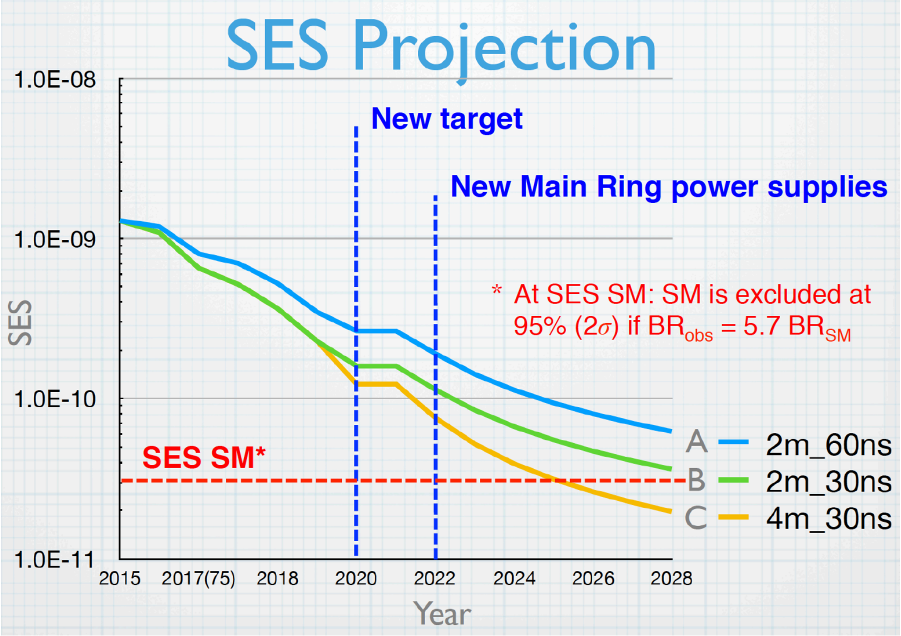
- Continuing program of detector upgrades

Example:
Dual side readout for CsI modules
Installed at end of 2018 run



Resolve γ/n interaction depth by reading light from front CsI face with SiPM

T. Nomura, J-PARC PAC, Jan 2020

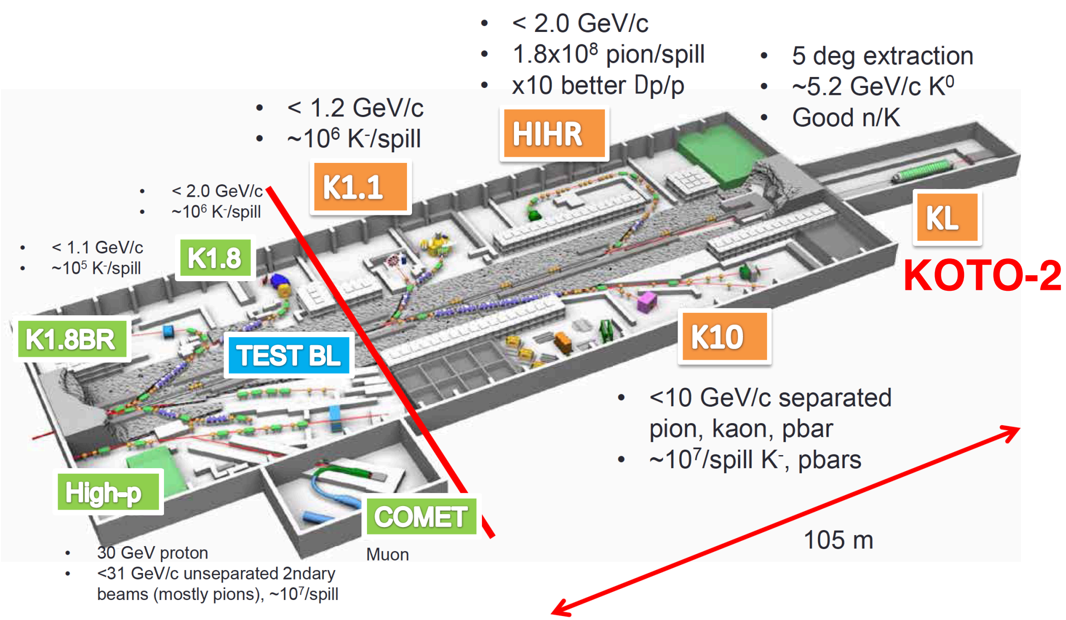


Expect to reach SES of $< 7\times10^{-11}$ ($<$ 2x BR_{SM}) by 2024

KOTO long-term plans: Step-2

- **Plan outlined in 2006 proposal to upgrade to O(100) SM event sensitivity over the long term**
- **Now beginning to seriously consider a new experiment to achieve this sensitivity**

- Increase beam power to > 100 kW
- New neutral beamline at 5°
  $\langle p(K_L) \rangle$ = 5.2 GeV
- Increase FV from 2 m to 11 m
  Complete rebuild of detector
- **Requires hadron-hall extension**

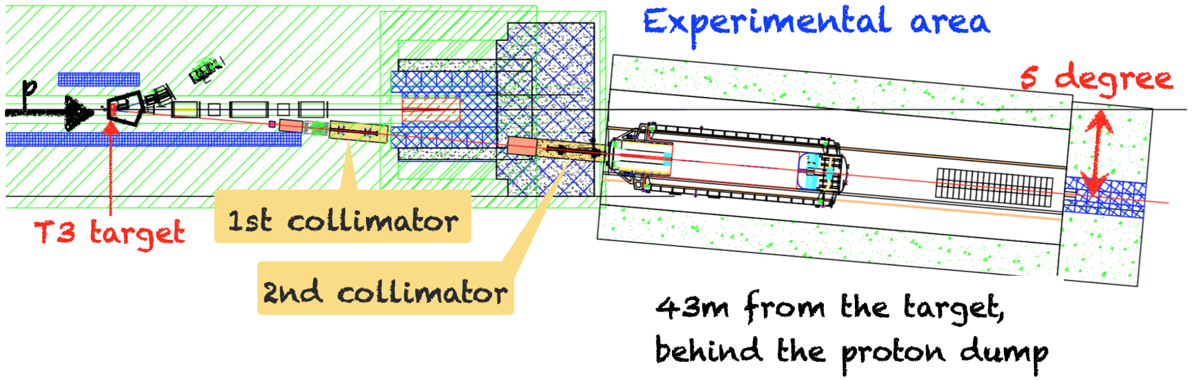


- Hadron-hall extension is a joint project with nuclear physics community
  KOTO Step-2 is a flagship project
- On the list of KEK future large-scale projects, with medium priority
  Staging plan for construction under development

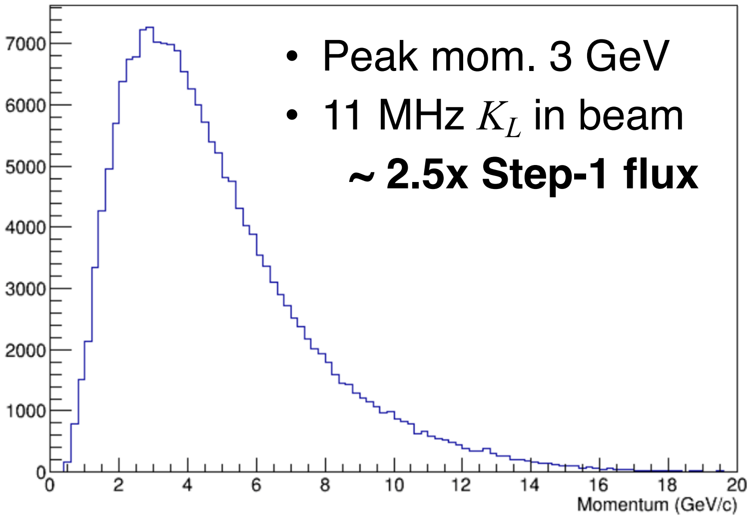
KOTO Step-2 detector

Step-2 beamline setup in hadron-hall extension

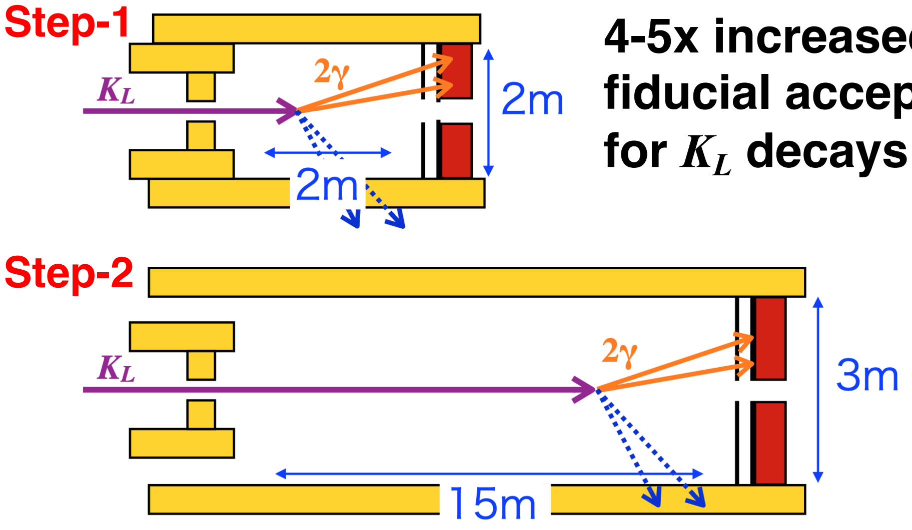
- Smaller angle (16° → 5 °)
- Longer beamline (20 → 43 m)
- 2 collimators



K_L spectrum at beam exit



- Peak mom. 3 GeV
- 11 MHz K_L in beam
  ~ 2.5x Step-1 flux



4-5x increased fiducial acceptance for K_L decays

New sensitivity studies for smaller beam angle & larger detector:
~ 60 SM evts with S/B ~ 1 at 100 kW beam power (3×10^7 s)

$K_L \to \pi^0 \nu\nu$: Discovery potential

K_LEVER target sensitivity:
5 years starting Run 4

60 SM $K_L \to \pi^0 \nu\nu$
$S/B \sim 1$

δBR/BR($\pi^0 \nu\nu$) ~ 20%

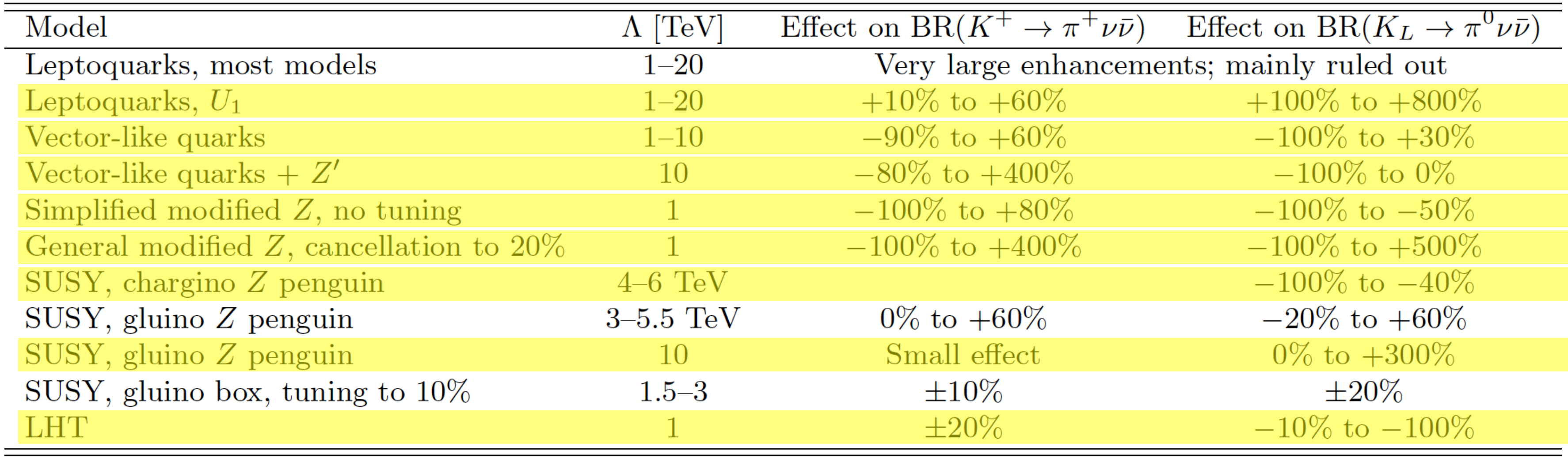
60 $K_L \to \pi^0 \nu\nu$ events at SM BR
60 background events

$$\text{Signif.} \approx \frac{S_{\text{obs}} - S_{\text{SM}}}{\sqrt{S_{\text{obs}} + B_{\text{obs}}}}$$

If BR($K_L \to \pi^0 \nu\nu$) is:

- Suppressed to 0.25 BR_{SM} 🦹 **5σ**
- Enhanced to 2 BR_{SM} 🦹 **5σ**
- Suppressed to 0.5 BR_{SM} 🦹 **3σ**

NP effects on $K \to \pi\nu\nu$ BRs with constraints from Re ε'/ε, ε_K, Δm_K, $K_L \to \mu\mu$



Model	Λ [TeV]	Effect on BR($K^+ \to \pi^+ \nu\bar{\nu}$)	Effect on BR($K_L \to \pi^0 \nu\bar{\nu}$)
Leptoquarks, most models	1–20	Very large enhancements; mainly ruled out	
Leptoquarks, U_1	1–20	+10% to +60%	+100% to +800%
Vector-like quarks	1–10	−90% to +60%	−100% to +30%
Vector-like quarks + Z'	10	−80% to +400%	−100% to 0%
Simplified modified Z, no tuning	1	−100% to +80%	−100% to −50%
General modified Z, cancellation to 20%	1	−100% to +400%	−100% to +500%
SUSY, chargino Z penguin	4–6 TeV		−100% to −40%
SUSY, gluino Z penguin	3–5.5 TeV	0% to +60%	−20% to +60%
SUSY, gluino Z penguin	10	Small effect	0% to +300%
SUSY, gluino box, tuning to 10%	1.5–3	±10%	±20%
LHT	1	±20%	−10% to −100%

High-intensity kaon beams at the SPS

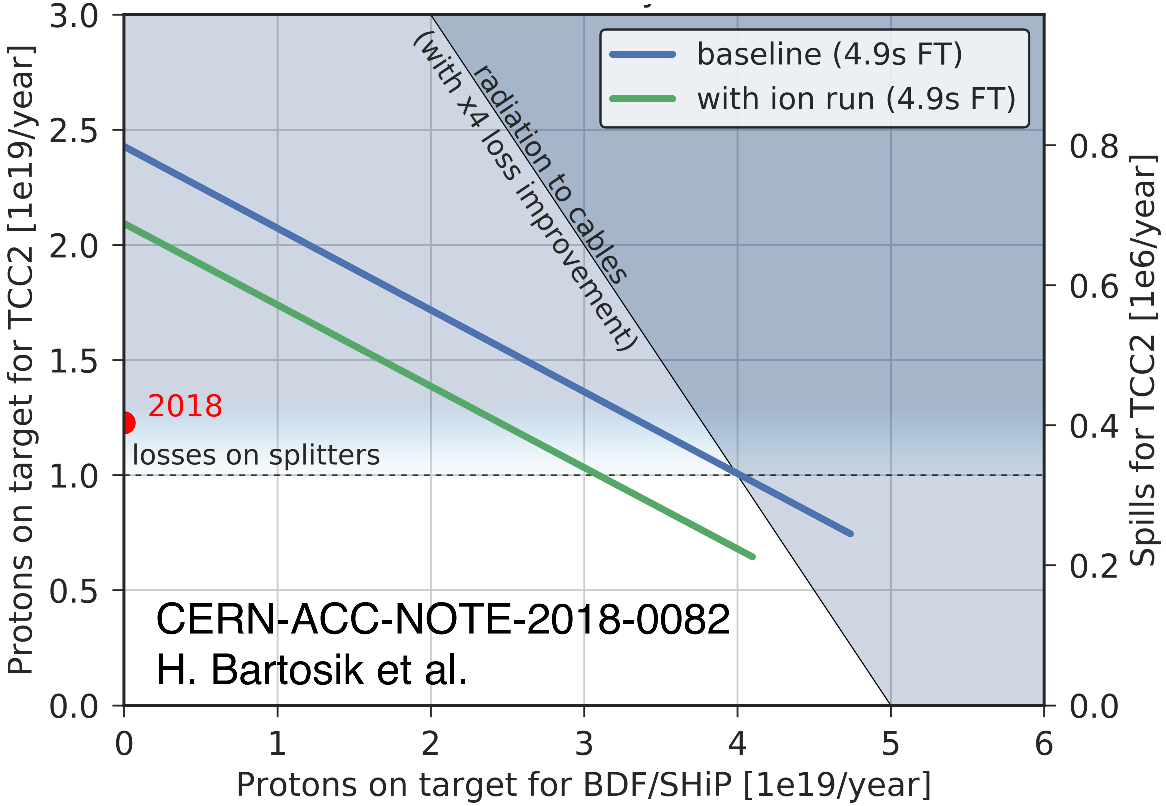
Operational scenarios and limits on the intensity deliverable to the North Area targets were studied in context of the BDF proposal as part of Physics Beyond Colliders

Experiments to measure $K \to \pi\nu\nu$ BRs at the SPS would require:

- **$K^+ \to \pi^+\nu\nu$**
  6×10^{18} pot/year
  4x increase
- **$K_L \to \pi^0\nu\nu$**
  1×10^{19} pot/year
  6x increase

increases with respect to present primary intensity

SPS proton sharing (4.9 sec flat top, 80% uptime)



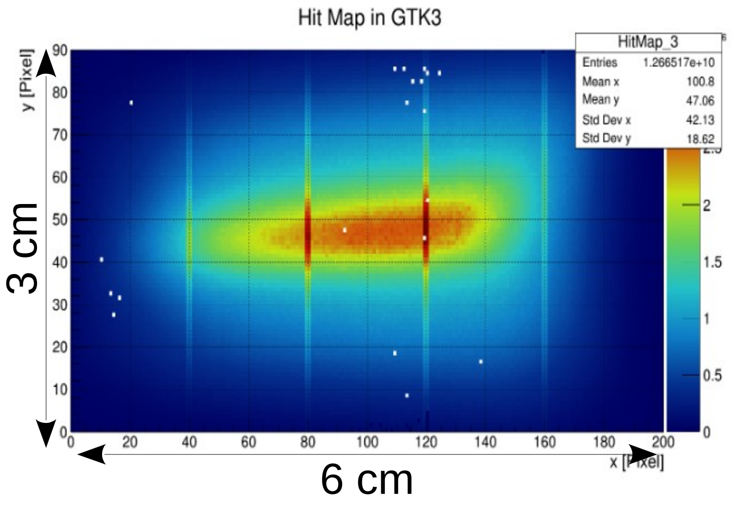
CERN-ACC-NOTE-2018-0082
H. Bartosik et al.

A kaon experiment at 6x present intensity is compatible with a diverse North Area program

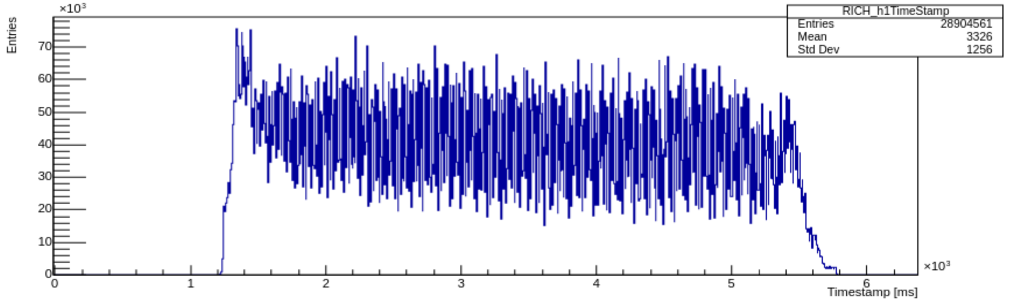
High-intensity K$^+$ beam: characteristics

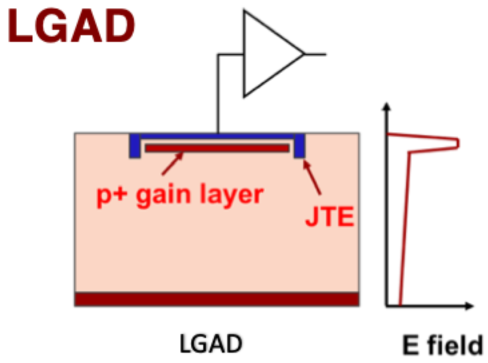
- **Future K$^+$ intensity ≥ ×4 NA62 (~ 180 MHz K$^+$)**
  - What could the maximum available intensity be?
  - Is the beam composition going to be the same (~ 6% K$^+$)?
  - How would the muon halo scale?

- **Beam shape**
  - How would the beam tails scale?
  - More uniformly distributed beam spot @ GTK? (e.g. by defocusing the beam @ GTK?)



- **Spill quality**
  - Low/High frequency modulations? (e.g. 50 Hz / 200 MHz structure?)
  - Instantaneous intensity variation?





Optimized for timing measurements

Add thin doped layer to conventional silicon detector to produce low, controlled multiplication

$$\sigma_t = \sigma_{\text{jitter}} \oplus \cancel{\sigma_{\text{time walk}}} \oplus \cancel{\sigma_{\text{TDC}}} \oplus \sigma_{\text{field}} \oplus \sigma_{\text{straggling}}$$

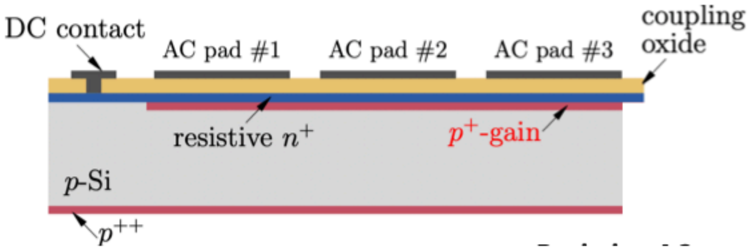
minimized by optimized readout electronics and correction techniques

- **Excellent time resolution**: 30-35 ps
- **Thin sensors** ~ 50 µm → reduced contribution to material budget
- Optimized gain layer design enhances reliability and **radiation hardness**
  No significant performance degradation up to 1.5×10^{15} n eq/cm^2
- New technologies to reduce impact of structures between readout pads
  (no-gain areas for signal)

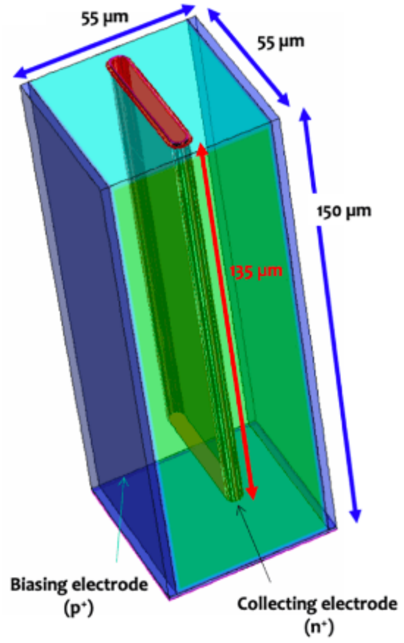
See also:
[N.Cartiglia Detector Seminar 5 Jun 2020]

Trench-isolated LGAD

Resistive AC-coupled LGAD (RSD)



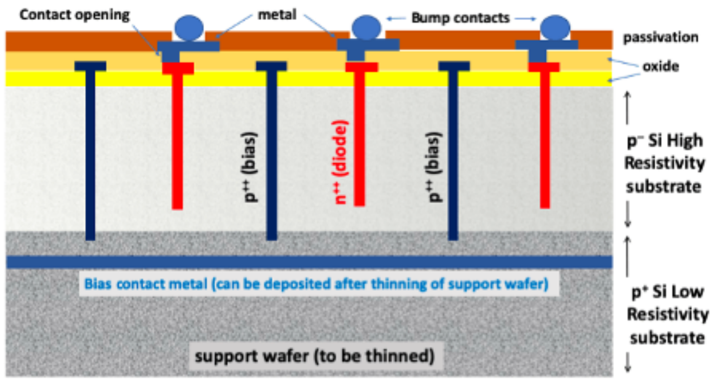
Still, >99% efficiency requirement is challenging



TimeSPOT

Trench geometry improves
charge collection time uniformity

- Spatial resolution: O(10µm)
- Time resolution: ~30-50 ps/pixel seen in preliminary tests
- Radiation hardness $> 10^{16}\ n_{\mathrm{eq}}/\mathrm{cm}^2$
- Data throughput > 1 TB/s



- Use of 3D sensors for vertex detectors demonstrated
  ATLAS IBL Pixel Detector Upgrade
  NIMA694 2012
- Potential for timing not yet explored

Pros:

- **Unmatched radiation hardness**
- **Effect of Landau fluctuations mitigated by geometry**
- **Extremely fast signals**

Possible cons:

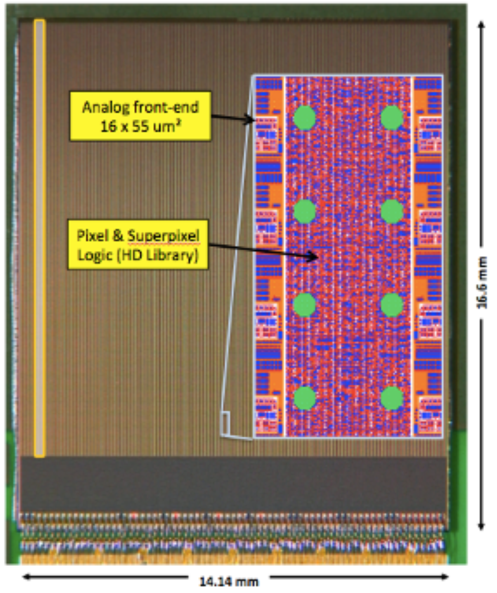
- Complexity of fabrication
- Geometric inefficiency (blind electrodes)
- Shape of time distribution ?

See also:

A.Cardini
CERN Detector
Seminar 19 Jun 2020

New ASIC

Thinking underway on requirements and possibility for frontend ASIC



the VeloPix

	VeloPix (2016)	Timepix4 (imminent)	PicoPix ? (2025)
Technology	130 nm	65 nm	28 nm
Pixel Size	55 x 55 µm	55 x 55 µm	55 x 55 µm
Pixel arrangement	3-side buttable 256 x 256	4-side buttable 512 x 448	4-side buttable 256 x 256
Sensitive area	1.98 cm^2	6.94 cm^2	1.98 cm^2
Event packet	24 bit	64-bit	32-bit
Max rate	~400 $Mhits/cm^2/s$	178.8 $Mhits/cm^2/s$	~12000 $Mhits/cm^2/s$
Best time resolution	25 ns	~200ps	~50 ps
Readout bandwidth	19.2 Gb/s	81.92 Gb/s	~600 Gb/s

'PicoPix' (still at conceptual stage)

Multiple challenges of high rate/data capability, high time resolution, pixel size requirements

Precursor already exists in the form of the 28 nm Timespot ASIC

Photo-detectors

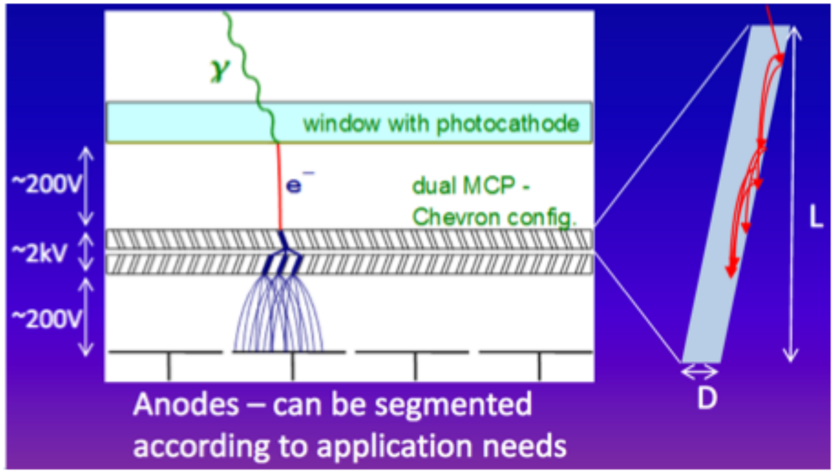
K ID for 4x intensity

- **Need 4x better kaon time resolution: ~20 ps**
- **Max detected photon rate**: >8 MHz/cm^2
- **Single-photon capability** with σ_t = 50-70 ps
- Good radiation resistance

Other possible photodetectors:

- **SiPMs**
  - With R&D may reach $\sigma_t(1\gamma) \sim 20$ ps
  - Noisy; sensitive to radiation
- **HPDs**
  - $\sigma_t(1\gamma) \sim 70$ ps
  - Sensitive to radiation?

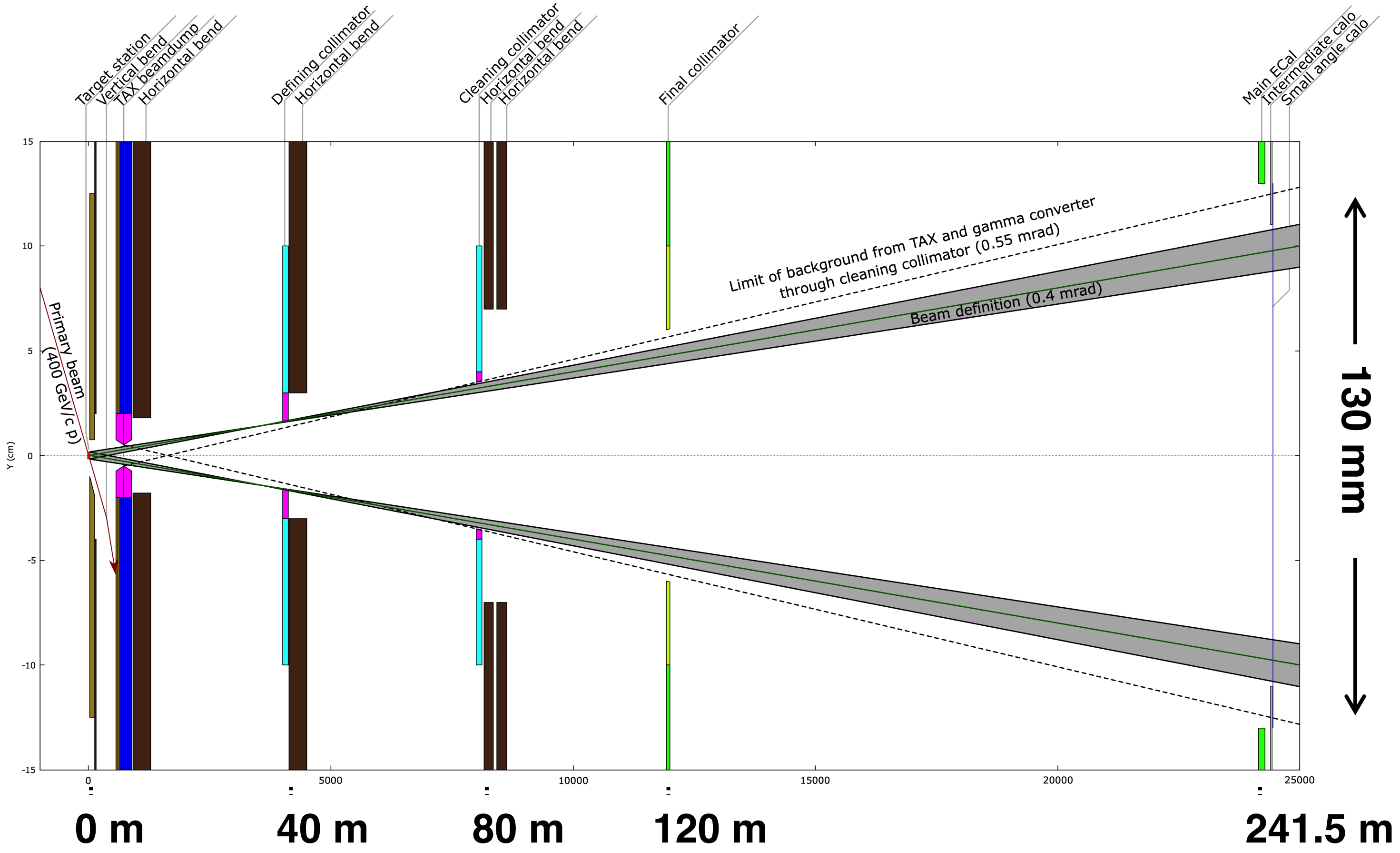
- **Microchannel plate (MCP) PMTs**
  - Excellent time resolution (~20 ps)
  - Low dark noise
  - Single-photon sensitivity
  - High gain, good QE
  - Good filling factor
  - Input rate capability ~MHz/cm^2



- **Susceptible to aging: QE drops due to to ion feedback to photocathode**
  Effect of aging must be investigated and/or mitigated

Neutral beamline layout

Design from CB Working Group (M. van Dijk, L. Gatignon, N. Doble), 2017-2019



- 400 GeV/c protons from SPS incident at **8 mrad** on **beryllium target**
- Vertical bending magnet to dump proton beam on collimator
- **Tungsten γ absorber** in dump collimator
- **4 collimation stages** to minimize neutron halo, including beam scattered from absorber
- Horizontal sweeping magnet after each collimator
- Active final collimator in LYSO

Calorimetry readout system

Provide very fast response (<100 ps, double-pulse separation <1ns).
High-frequency digitizing readout to efficiently veto background events without being blinded by pile-up. Detailed signal analysis will also assist with particle identification and discrimination of uncorrelated background, reducing the random veto loss.

Development of free-running, fully digitizing readout system for acquisition at 100 MHz, with low-level event selection in front end:

- **Versatile analog front-end stage:**
    - Configurable signal shaping/amplification for different detectors
- **Digital front-end stage:**
    - FADC digitization at up to 1 GHz; zero suppression; time framing
    - Parallel signal processing/data filtering implemented on FPGAs or ASICs
    - Autonomous trigger generation
    - High radiation tolerance (single-event-upset resistant)
- **Readout/data transmission stage**
    - Trigger and clock distribution
    - Merging of channels and trigger information; additional signal processing as needed
    - Data transmission via standard network protocol.

KLEVER further work:

It is imperative to further reduce $\Lambda \rightarrow n\pi^0$ decays in FV by at least 4 orders of magnitude

Currently 10^8 $\Lambda \rightarrow n\pi^0$ decays in FV: need to reduce to < 10^4 for safe elimination by kinematic cuts

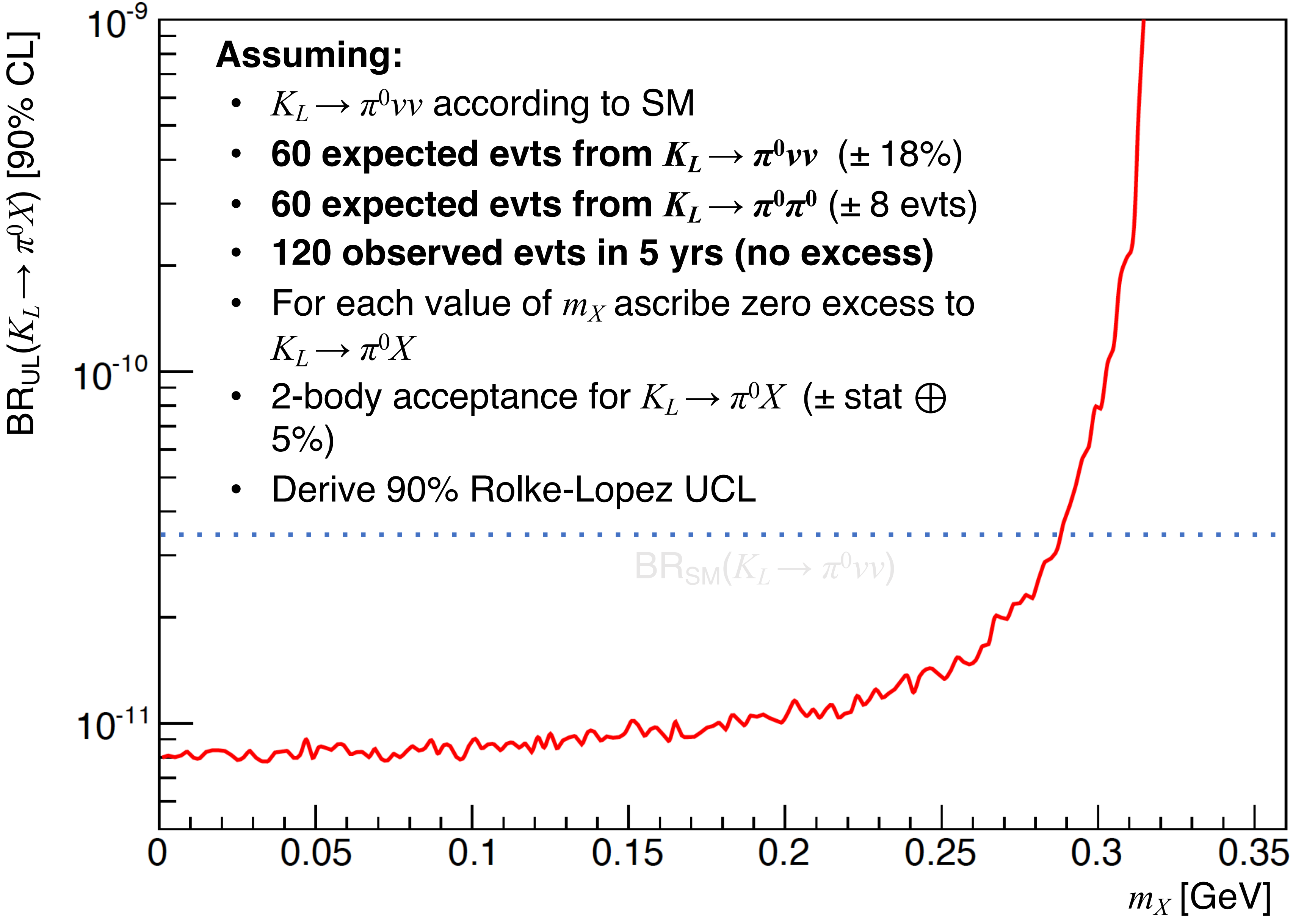
Observations from preliminary simulations:

- **Λ rejection should be sufficient with 270 m total length from target to AFC**
- Reduction of K_L flux by factor (0.25 mrad/0.40 mrad)^2 = 0.4
- Currently around 7 $K_L \rightarrow \pi^0\nu\nu$ events in 5 years, including:
  - K_L losses on photon absorber in TAX ~ 0.6x
  - PSD losses (at least 1 hit on PSD for signal events) ~ 0.6x
  - Reduction of K_L flux with solid angle ~ 0.4x (as above)
- Good prospects to **recover acceptance** to obtain **O(50) events in 5 years**
  - 2-3x with intelligent use of PSD
  - 2-3x by moving FV downstream:
    - Changes to veto layout needed for sufficient $K_L \rightarrow \pi^0\nu\nu$ rejection

These observations are very preliminary!

- **Full results require comprehensive experimental re-optimization**
- **Must recalculate rates with FLUKA/BDSIM once beam layout stable**

Limits on $K_L \to \pi^0 X$ from $K_L \to \pi^0 \nu\nu$



Assuming:

- $K_L \to \pi^0 \nu\nu$ according to SM
- **60 expected evts from $K_L \to \pi^0 \nu\nu$** (± 18%)
- **60 expected evts from $K_L \to \pi^0 \pi^0$** (± 8 evts)
- **120 observed evts in 5 yrs (no excess)**
- For each value of m_X ascribe zero excess to $K_L \to \pi^0 X$
- 2-body acceptance for $K_L \to \pi^0 X$ (± stat $\oplus$ 5%)
- Derive 90% Rolke-Lopez UCL

Limits on $K_L \to \pi^0 A'$ from $K_L \to \pi^0 \nu\nu$

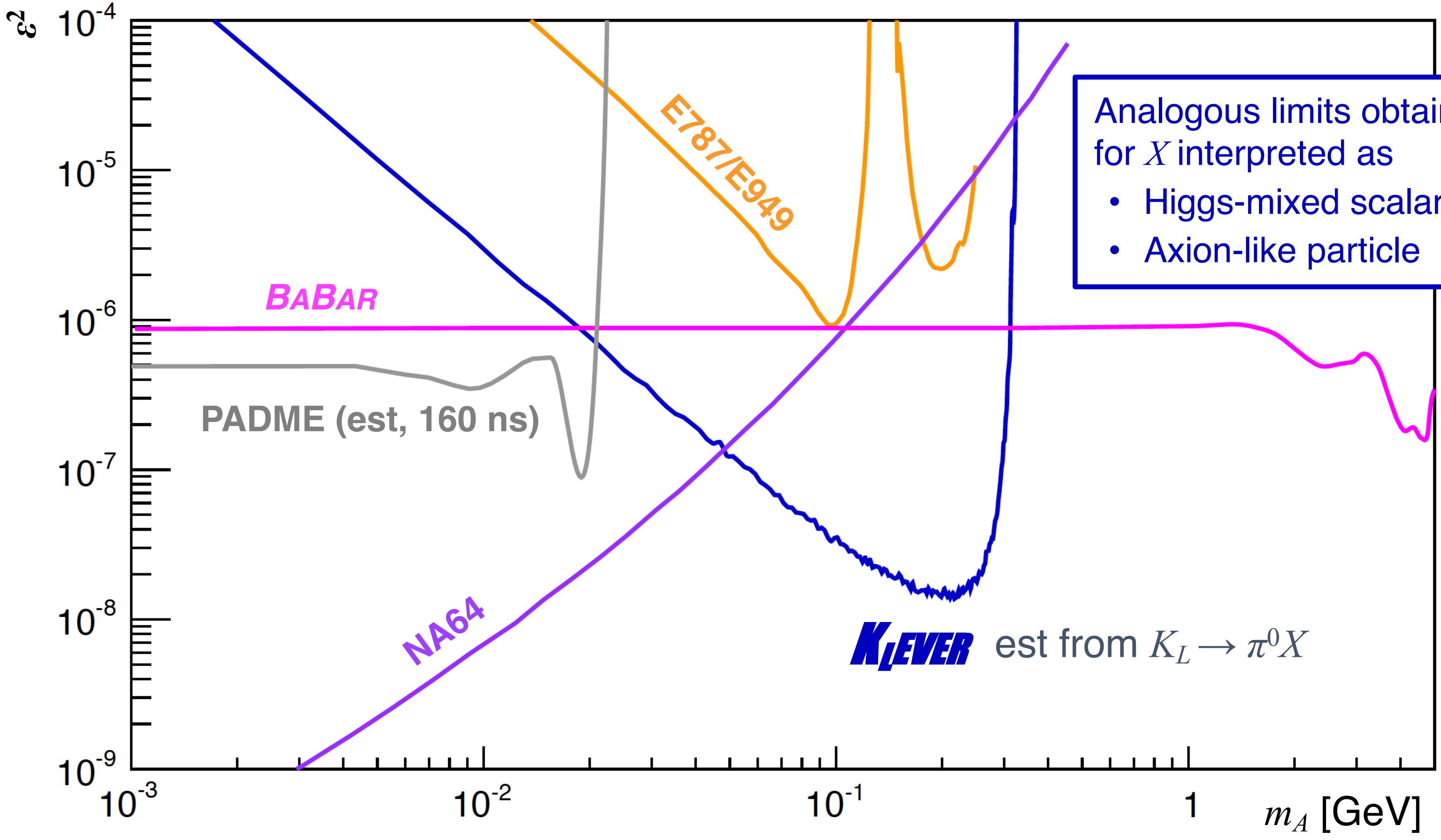
For $K_L \to \pi^0 X$ interpret X as dark photon A' with no decays to SM particles

Obtain limits in ε^2 vs. m_A plane

ε^2 = kinetic mixing angle for A' and γ

As per Davoudiasl, Lee, Marciano 2014

Weaker limits obtain if A' also mixed with Z



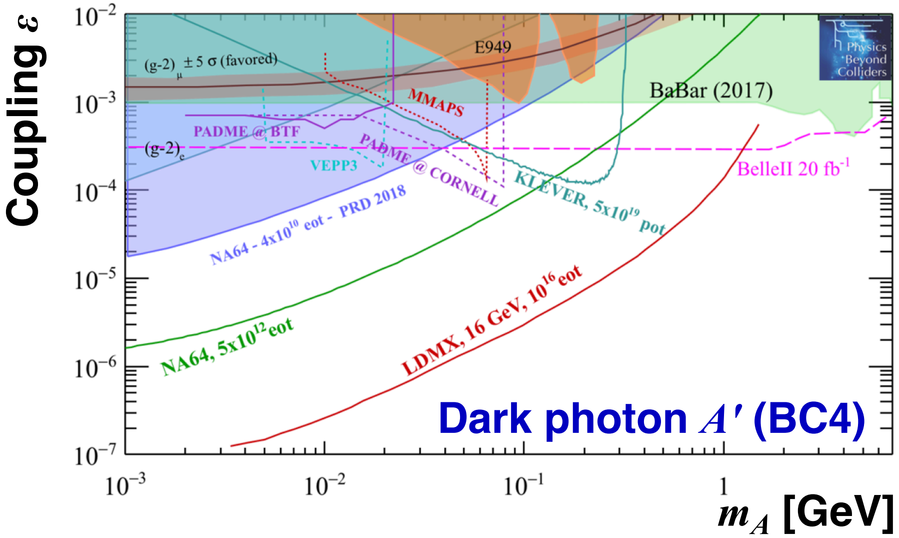
Analogous limits obtained for X interpreted as
- Higgs-mixed scalar
- Axion-like particle

Exclusion potential from $K_L \to \pi^0 X$

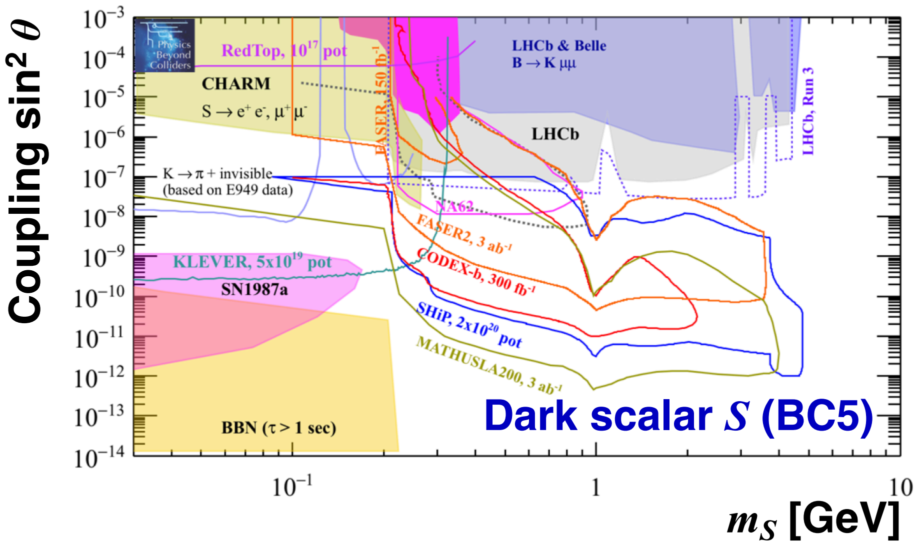
For $K_L \to \pi^0 X$, interpret X as:

- Invisible dark photon A' (BC2)
- Higgs-mixed scalar S (BC4)
- Axion-like particle a with fermion couplings (BC10)

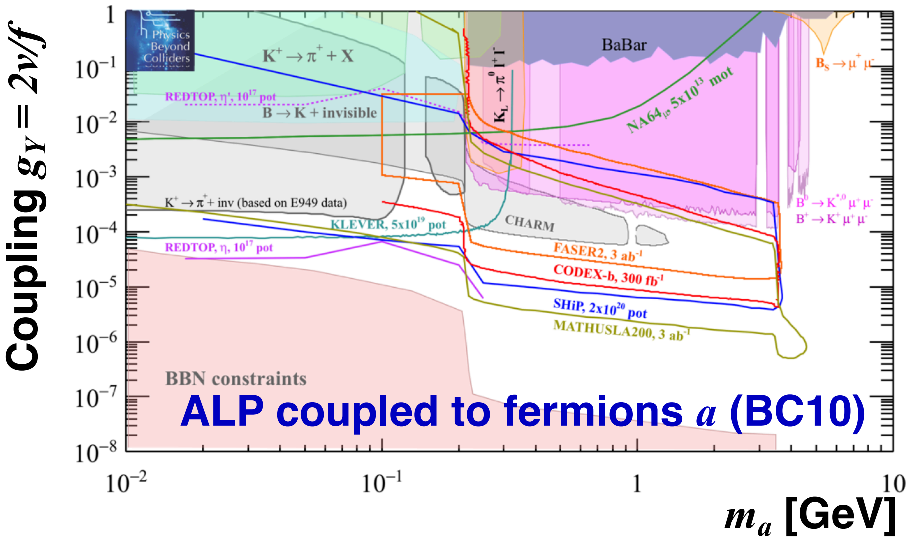
Obtain limits in coupling vs. mass plane for each scenario*



Dark photon A' (BC4)



Dark scalar S (BC5)



ALP coupled to fermions a (BC10)

* Calculation assumes that decaying particles escape the decay volume

Wide physics programme

Enter a new high precision era, down to 10^{-12}

Rare kaon decays:

$K^+ \to \pi^+\mu^+\mu^-$, $\pi^+e^+e^-$
$K^+ \to \pi^+\pi^+\pi^-\gamma$
$K^+ \to \pi^+\gamma\gamma$
$K^+ \to l^+\nu\,(\gamma)$
$K^+ \to \pi^0 e^+\nu\gamma$
$K^+ \to l_1^+\nu l_2^+ l_2^-$ etc.

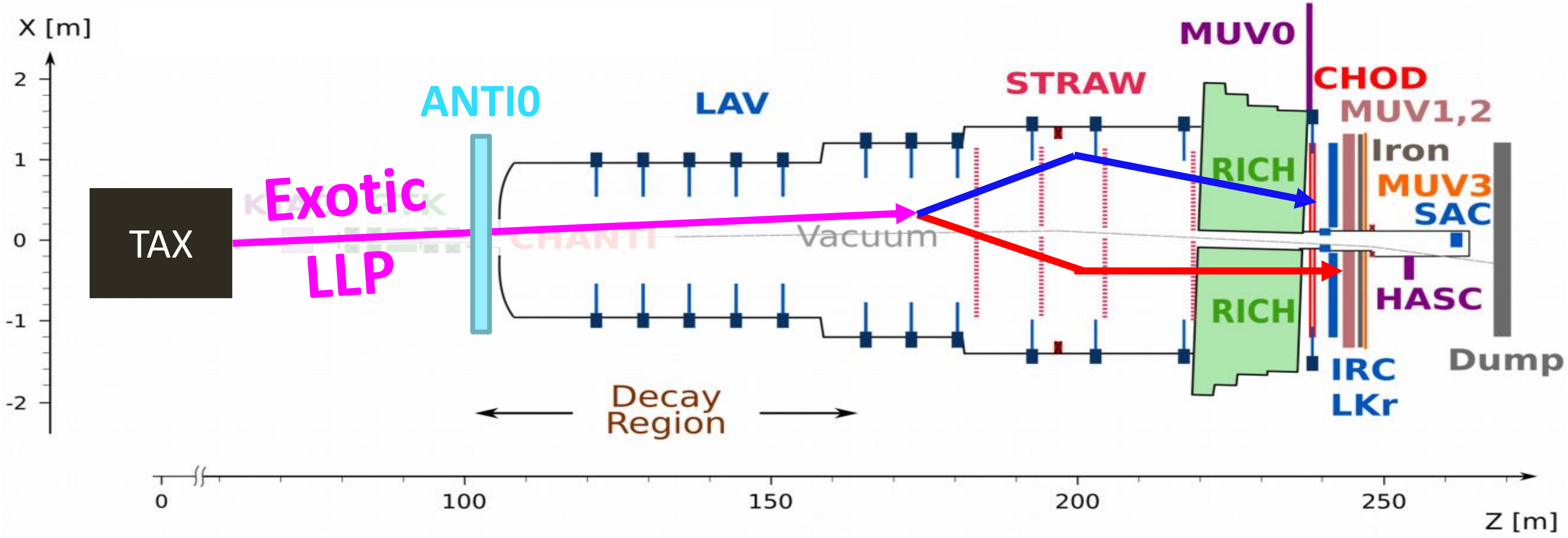
Lepton Flavour / Number Violation and Exotic searches:

$K^+ \to \pi^- l^+ l^+$
$K^+ \to l^+ N$ etc.

Lepton Universality test: $\Gamma(K^+ \to e^+\nu)/\Gamma(K^+ \to \mu^+\nu)$

Control of systematics with data-driven methods: record special sample to address specific effects and background sources

NA62 in dump mode



Long decay volume and detector characteristics/performances:
suitable to search for feebly-interacting long-lived particles
Extend Dark Particle mass range > M(K) (D, B associated production)

Collect 10^{18} Protons On Target before LS3
New Anti0 under construction to veto muons produced in TAX

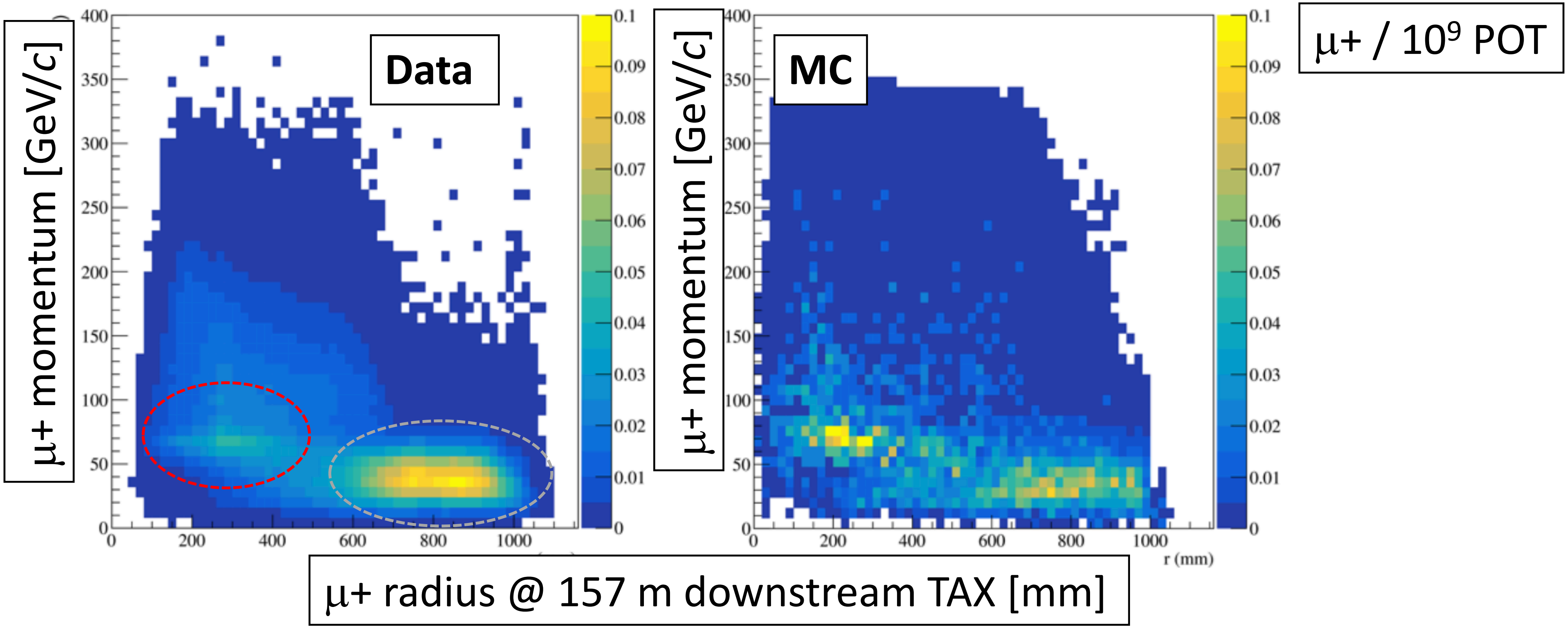
Possibility to increase beam intensity beyond nominal being investigated

Results from past PBC mandate

MC simulation of the beam-dump operation (closed TAX configuration)

Qualitative agreement of **data** vs **MC** distributions for halo muons

Disentangle background rates: **target residual material** vs **tax** production



FIP lifetime sensitivity

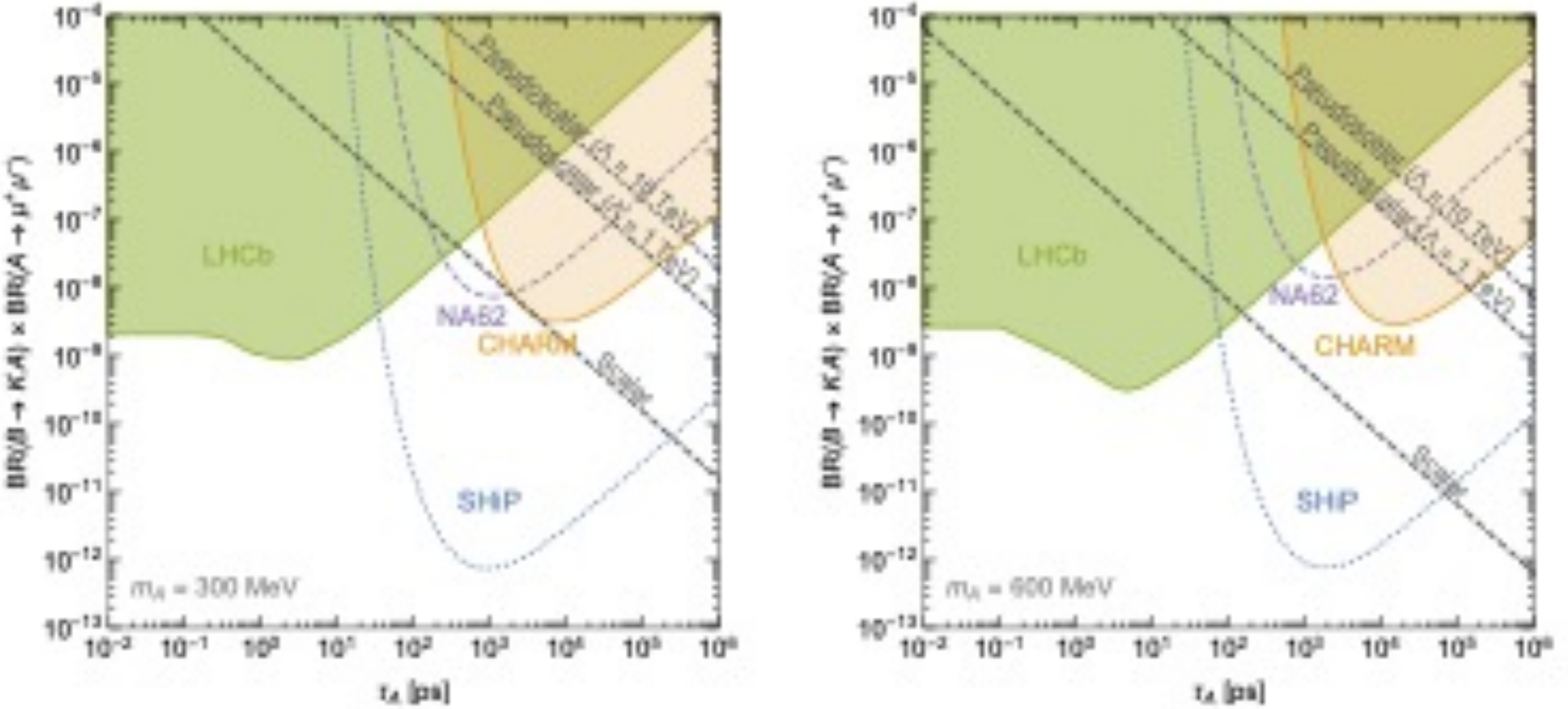


Figure 3: Model-independent constraints at 95% confidence level on the production and decay of light scalars or pseudoscalars, expressed as bounds on $\mathrm{BR}(B \to KA) \times \mathrm{BR}(A \to \mu^+\mu^-)$ as a function of the lifetime τ_A for different values of the boson mass m_A. We also show for illustration the specific predictions obtained from the pseudoscalar model considered in section 2 for different values of Λ, as well as from the scalar model discussed in Ref. [68].