Rare Kaon Decays
Status and perspectives

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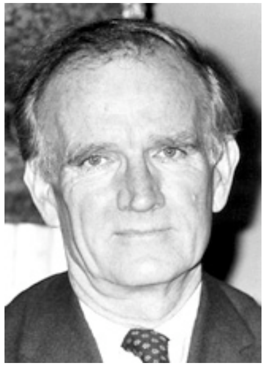
The K legacy

"At present our experimental understanding of CP violation can be summarized by the statement of a single number". (J. Cronin, 10.12.1980)



The search for (direct) CPV in the $K \to 2\pi$ decay amplitude: a long series of precision counting experiments

KTeV, NA48

- in K^0-K^0 mixing ($\Delta S=2$, Indirect CPV: $\mathrm{Re}(\epsilon)$)
- in the decay amplitudes ($\Delta S=1$, Direct CPV: $\mathrm{Re}(\epsilon')$)
- in the interference between decays with and without mixing ($\mathrm{Im}(\epsilon)$ and $\mathrm{Im}(\epsilon')$)

1999: proof of direct CP violation

The *first* test of the CKM paradigm for CP violation - a universal property of weak interactions

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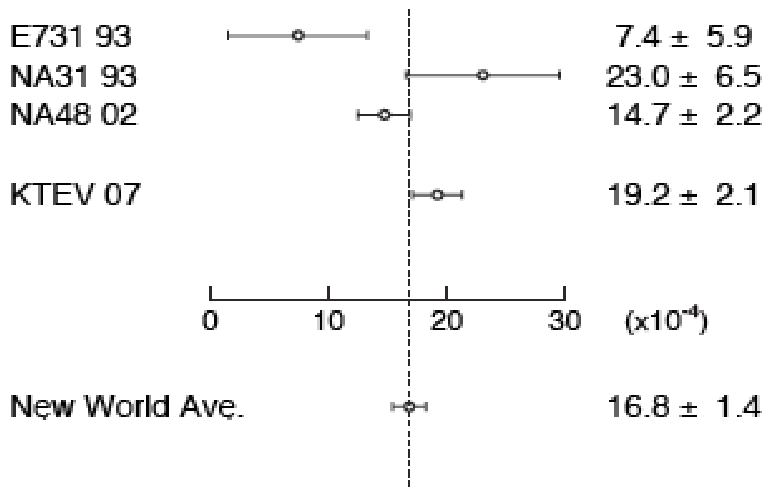
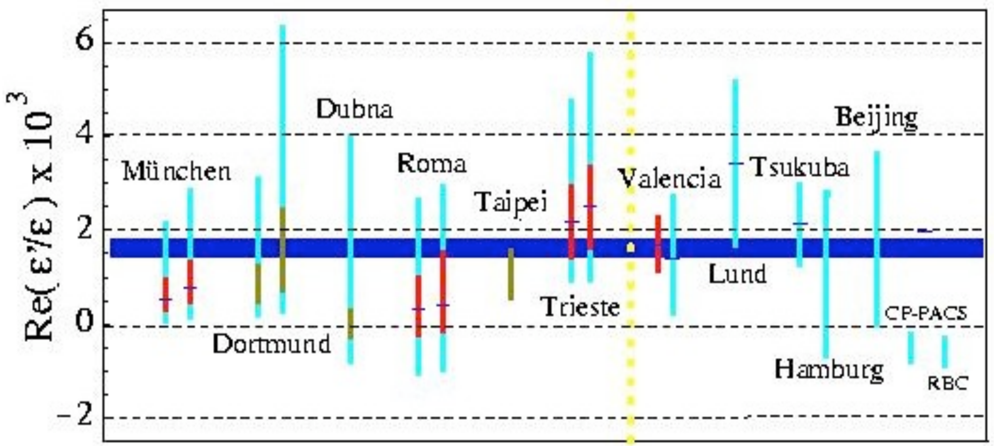
Direct CPV

$$\frac{|\eta_{00}|^2}{|\eta_{+-}|^2} = \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} \frac{\Gamma(K_S \to \pi^+\pi^-)}{\Gamma(K_L \to \pi^+\pi^-)} = 1 - 6\,\mathrm{Re}(\varepsilon'/\varepsilon)$$

Re(ε′/ε)



Theoretical predictions (SM)



Re(ε′/ε) = (16.8 ± 1.4) ·10^{-4}

Direct CPV in K decays at ≈ 9 standard deviations

Measurement compatible with SM

Large hadronic uncertainty in the calculations

Improvement expected with lattice QCD

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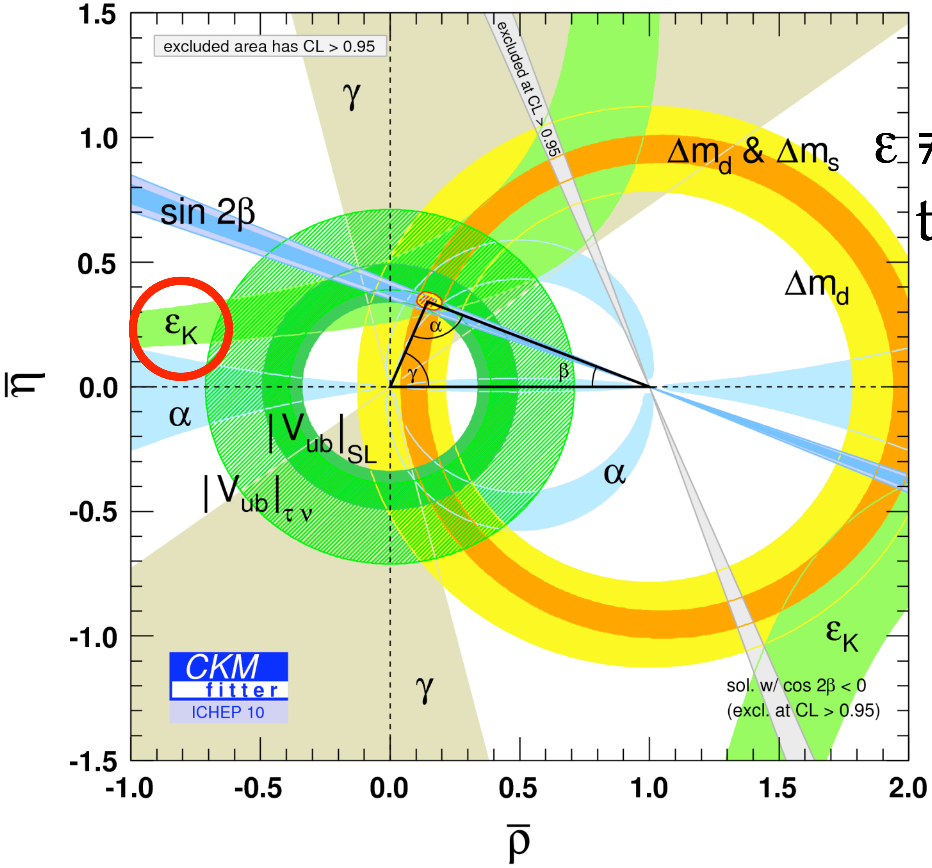
Indirect CP

$$\delta_L(\ell) = \frac{\Gamma(K_L \to \pi^- \ell^+ \nu) - \Gamma(K_L \to \pi^+ \ell^- \nu)}{\Gamma(K_L \to \pi^- \ell^+ \nu) + \Gamma(K_L \to \pi^+ \ell^- \nu)} = \frac{2\,\mathrm{Re}(\varepsilon)}{1+|\varepsilon|^2}$$

(assuming CPT)

$$\eta_{+-} = \frac{A(K_L \to \pi^+\pi^-)}{A(K_S \to \pi^+\pi^-)} \cong \varepsilon + \varepsilon' \approx \varepsilon$$



$\varepsilon \neq 0$ constrains (somewhat poorly) the apex of the Unitary Triangle

ε measured to 0.5%

Needs progress in lattice QCD to become a *quantitative* test of SM

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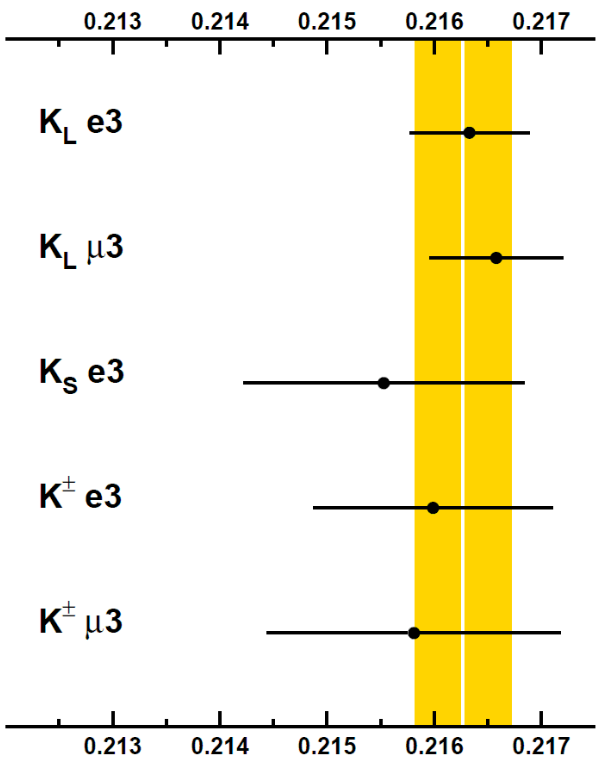
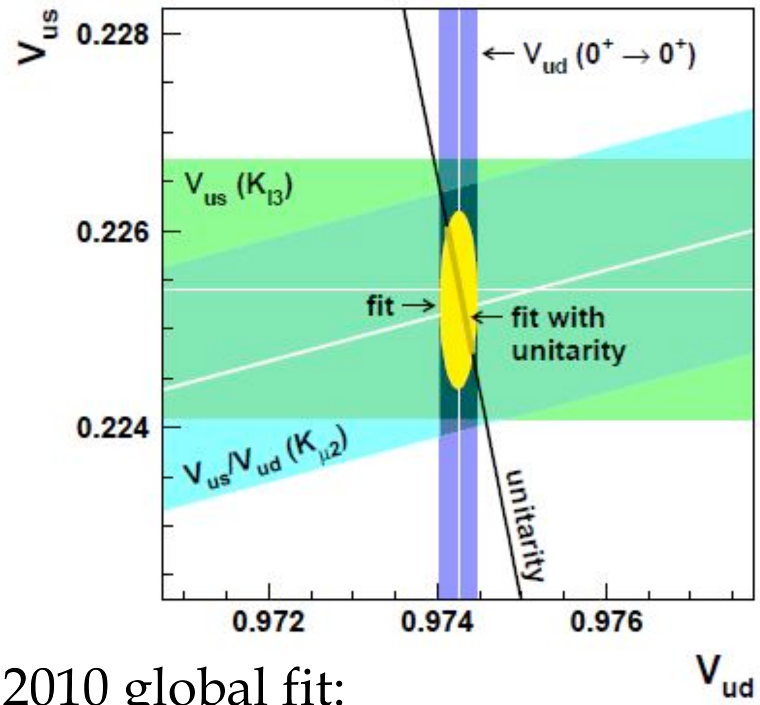
Kaons and $|V_{us}|$





10^5-10^7 events samples
~0.1% background (K^+, K_L)

FlaviaNet 2010 global fit:

$|V_{us}|f_+(0) = 0.2163(5)$

$\chi^2/\text{ndf} = 0.77/4$
(P=94%)

0.23% relative precision
No hint of unitary violations

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This is all *old* stuff…

kaons had their time

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The Framework

Energy Frontier:
Determine the energy scale of New Physics
by direct production of NP particles
Mass reach limited by beam energy

Precision Frontier:
Determine the flavour structure of NP via virtual
effects in precision observables:
deviation from precise SM prediction in rare or
forbidden processes
New degrees of freedom at high mass scale 1-100 TeV

Searches at precision frontier historically tremendously successful:
GIM before discovery of charm, CP violation before discovery of top
and bottom

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Seeking New Physics

Seeking NP with rare decays of light particles:

Searches for explicit violation of SM in exotic or forbidden processes

		90%CL upper limit
$K_L \to \mu e$	Lepton Flavour Violation	$< 4.7\ 10^{-12}$
$K^+ \to \pi^+ X^0$	Axions	$< 7.3\ 10^{-11}$
$\mu \to e\gamma$	Lepton Flavour Violation	$< 1.2\ 10^{-11}$
$\mu N \to eN$	Lepton Flavour Violation	$< 7\ 10^{-13}$

Measurements of SM parameters
$\to$Evidence of NP in deviations from well calculated SM predictions
$\to$High precision electroweak tests as powerful tool to probe SM

$K \to e\nu / K \to \mu\nu$	Lepton Universality	$O(10^{-5})$
$\pi^+ \to \pi^0 e\nu$	$\lvert V_{ud} \rvert$	$O(10^{-8})$
$K^+ \to \pi^+ \nu\nu$	$\lvert V_{td} \rvert$	$O(10^{-10})$
$K^0 \to \pi^0 \nu\nu$	CP violation	$< 6.7\ 10^{-8}$

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Leptonic Kaon decays in SM

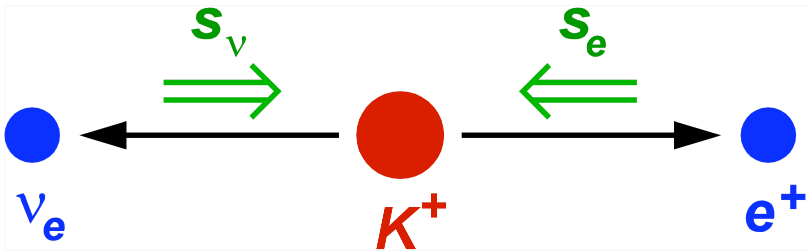
Observable sensitive to lepton flavour violation and its SM expectation:

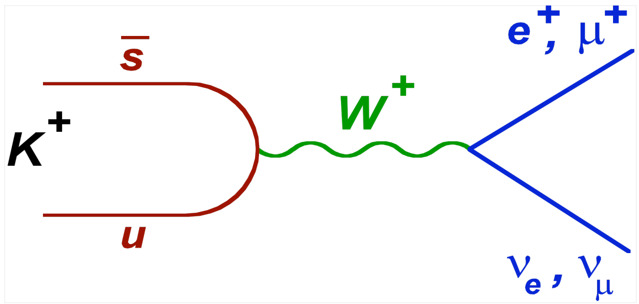
$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \underbrace{\frac{m_e^2}{m_\mu^2}}_{} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot \underbrace{(1 + \delta R_K^{\text{rad.corr.}})}_{}$$

(similarly, R_π in the pion sector)

Helicity suppression: f~10^{-5}

Radiative correction (few %) due to $K^+ \to e^+\nu\gamma$ (IB) process, by definition included into R_K





- SM prediction: excellent sub-permille accuracy due to cancellation of hadronic uncertainties.
- Measurements of R_K and R_π have long been considered as tests of lepton universality.
- Recently understood: helicity suppression of R_K might enhance sensitivity to non-SM effects to an experimentally accessible level.

$R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$

$R_\pi^{SM} = (12.352 \pm 0.001) \times 10^{-5}$

Phys. Lett. 99 (2007) 231801

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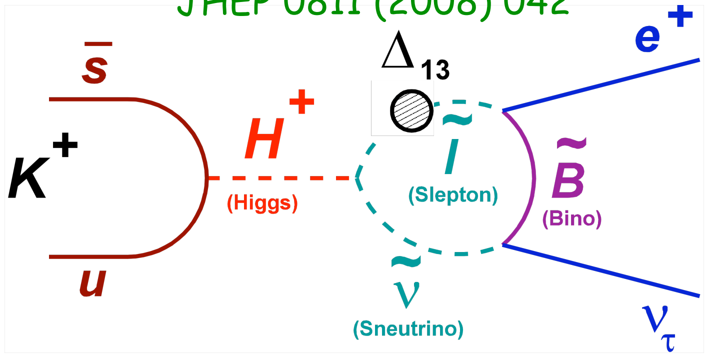
$K_{e2}/K_{\mu 2}$ beyond SM

PRD 74 (2006) 011701,
JHEP 0811 (2008) 042



2HDM – tree level

(including SUSY)

K_{l2} can proceed via exchange of charged Higgs $H^\pm$ instead of $W^\pm$

→ Does not affect the ratio R_K

2HDM – one-loop level

Dominant contribution to ΔR_K: $H^\pm$ mediated LFV (rather than LFC) with emission of ν_τ

→ R_K enhancement can be experimentally accessible

$$R_K^{LFV} \approx R_K^{SM}\left[1+\left(\frac{m_K^4}{M_{H\pm}^4}\right)\left(\frac{m_\tau^2}{M_e^2}\right)|\Delta_{13}|^2\tan^6\beta\right]$$

Up to ~1% effect :

slepton mixing $\Delta_{13}=5\times10^{-4}$,
$\tan\beta=40$, $M_H=500$ GeV/c^2
lead to $R_K^{MSSM} = R_K^{SM}(1+0.013)$

Analogous SUSY effect in pion decay is suppressed by a factor $(M_\pi/M_K)^4 \approx 6\times10^{-3}$

(see also PRD76 (007) 095017)

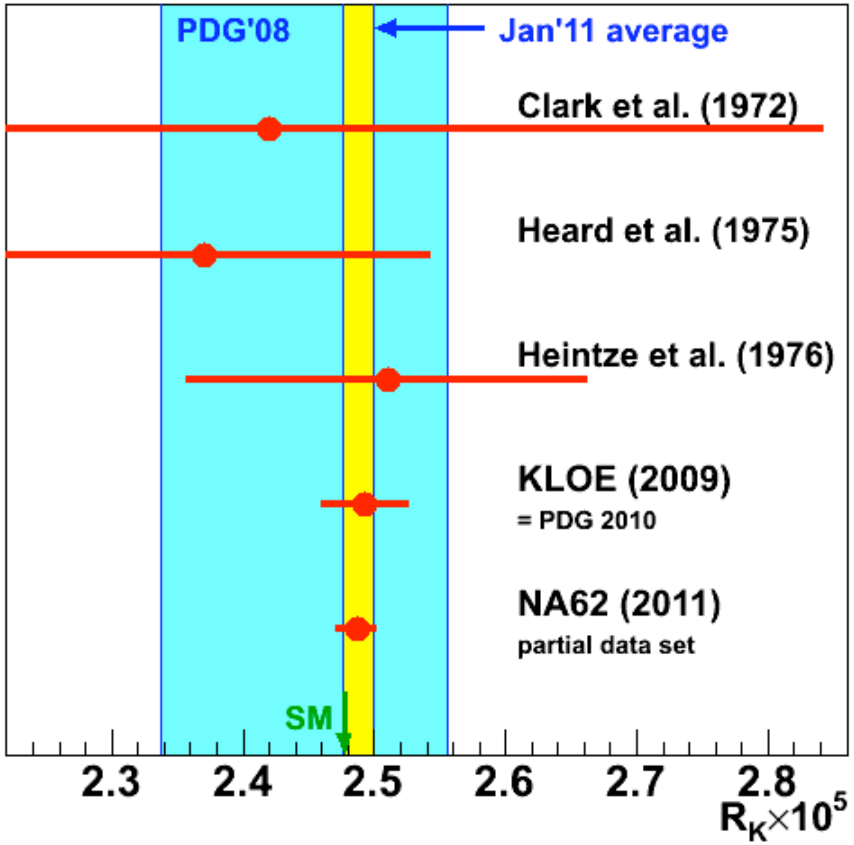
Large effects in B decays due to $(M_B/M_K)^4 \sim 10^4$:

$B_{\mu\nu}/B_{\tau\nu}$ → ~50% enhancement;

$B_{e\nu}/B_{\tau\nu}$ → enhanced by ~one order of magnitude.

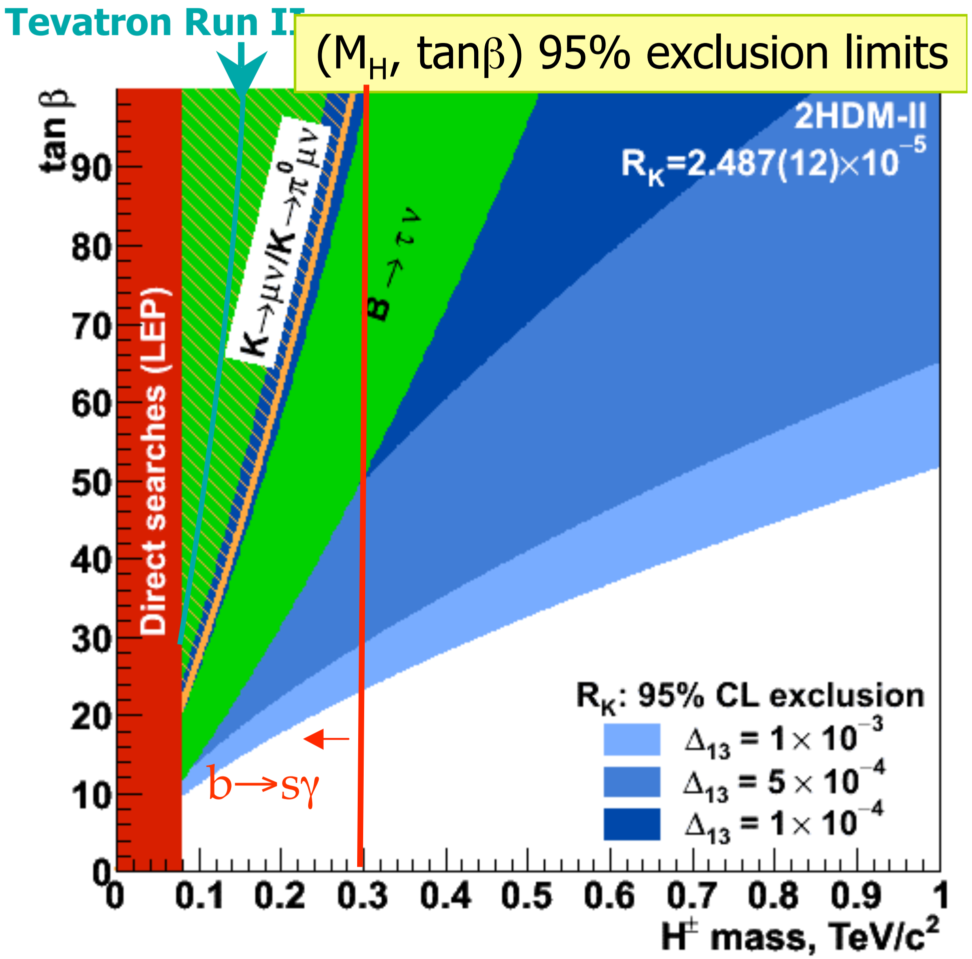
Out of reach: $Br^{SM}(B_{e\nu}) \approx 10^{-11}$

World average



NA62 (40% data set)
60K candidates, 9% background

RK = (2.487±0.012)x10^{-5}



For non-tiny values of slepton mixing Δ_{13},
sensitivity to H$^\pm$ in $R_K=K_{e2}/K_{\mu2}$
is better than in B→τν

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Ultra-rare K decays

The flavour structure of “TeV scale” BSM physics cannot be too weird

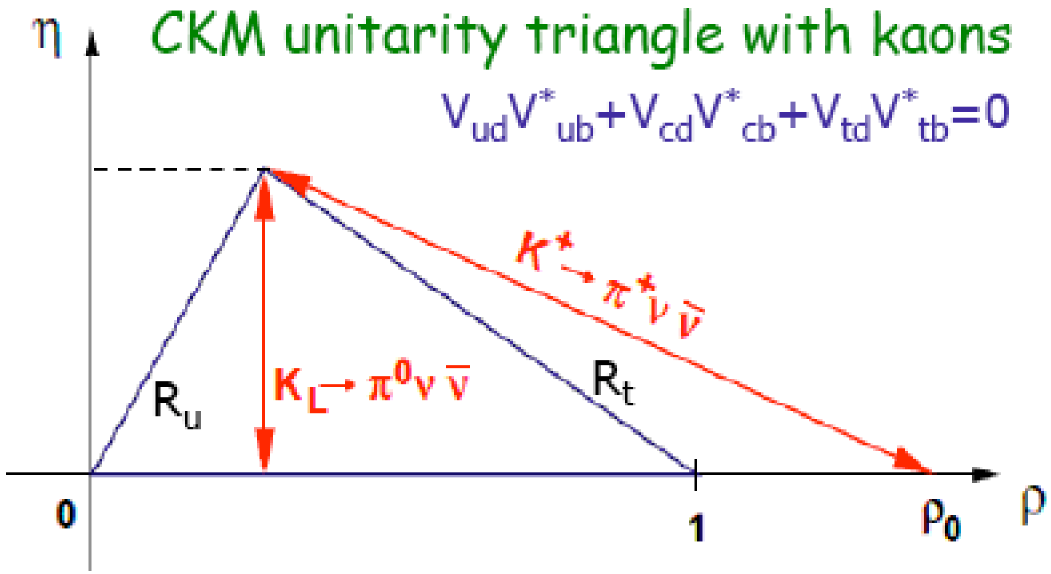
The easy SM stuff has been done already: what next ?

K **theoretical cleanliness** unmatched, simple system, few decay channels

Extreme **hard-GIM SM-suppressed** FCNC decays: room for NP up to 10x SM

Unique sensitivity to **flavour couplings** of BSM physics

10% measurement of $K \rightarrow \pi \upsilon \upsilon$ BR can probe **>100 TeV** NP scale



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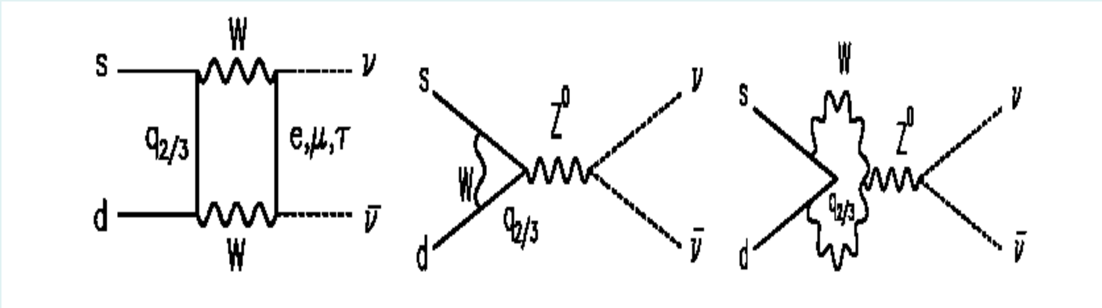
$K \to \pi \nu \nu$: Standard Model

- **FCNC loop processes**
- **Short distance dynamics dominated**
- **One semileptonic operator**
- **Hadronic Matrix Element related to measured quantities in semileptonic K decay**



$$\lambda = V_{us}$$
$$\lambda_c = V_{cs}^* V_{cd}$$
$$\lambda_t = V_{ts}^* V_{td}$$

$$B(K^+ \to \pi^+ \nu\bar{\nu}) = \kappa_+ \cdot \left[\left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2 + \left(\frac{\mathrm{Re}\,\lambda_t}{\lambda^5} X(x_t) + \frac{\mathrm{Re}\,\lambda_c}{\lambda} P_c(X) \right)^2 \right]$$

$$B(K_L^0 \to \pi^0 \nu\bar{\nu}) = \kappa_L \cdot \underbrace{\left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2}_{\text{Top contribution}}$$

Charm contribution

was the largest theoretical error now reduced by NNLO calc

$$\boxed{\kappa_+ = r_{K^+} \cdot \frac{3\alpha^2 Br(K^+ \to \pi^0 e^+ \nu)}{2\pi^2 \sin^4 \theta_W} \cdot \lambda^8}$$

The Hadronic Matrix Element is measured and isospin rotated

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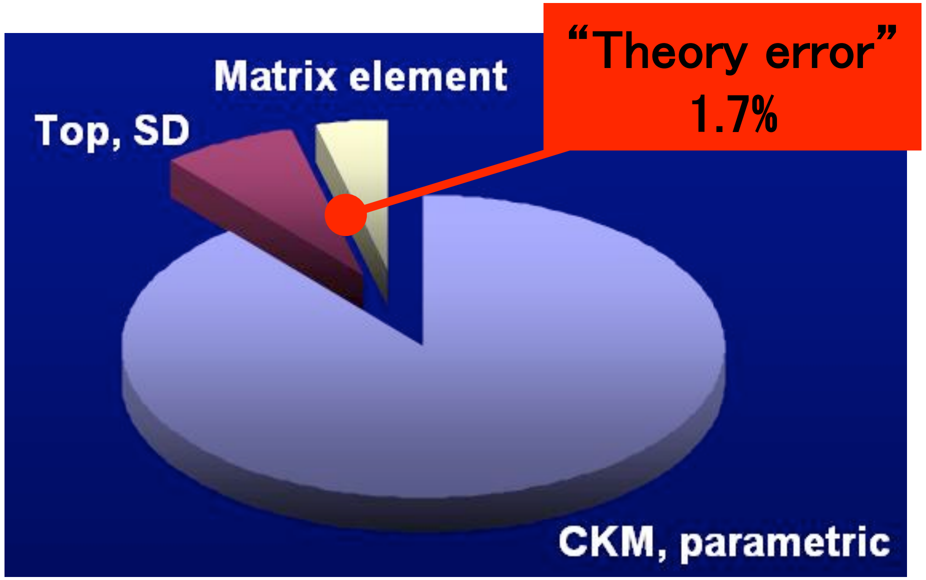
$K \to \pi \nu\nu$ BR predictions

Theoretical improvements make the errors small

$K_L \to \pi^0 \nu\nu$

$$BR_{SM} = (0.276 \pm 0.040) \cdot 10^{-10}$$

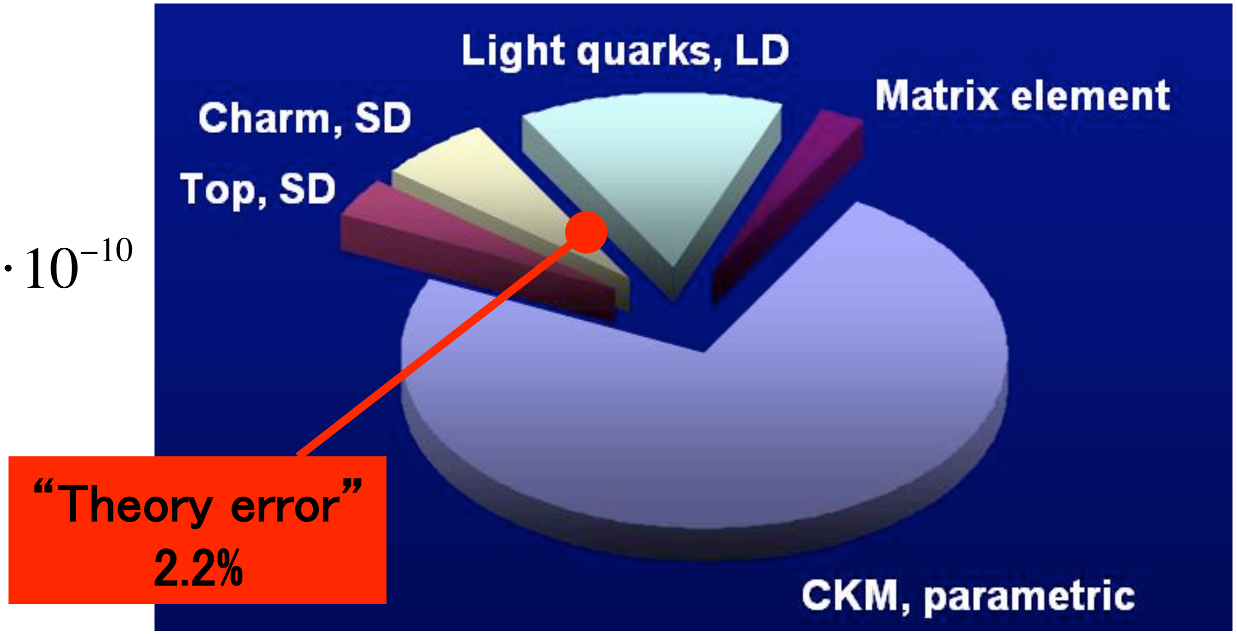
15%



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

$$BR_{SM} = (0.822 \pm 0.084) \cdot 10^{-10}$$

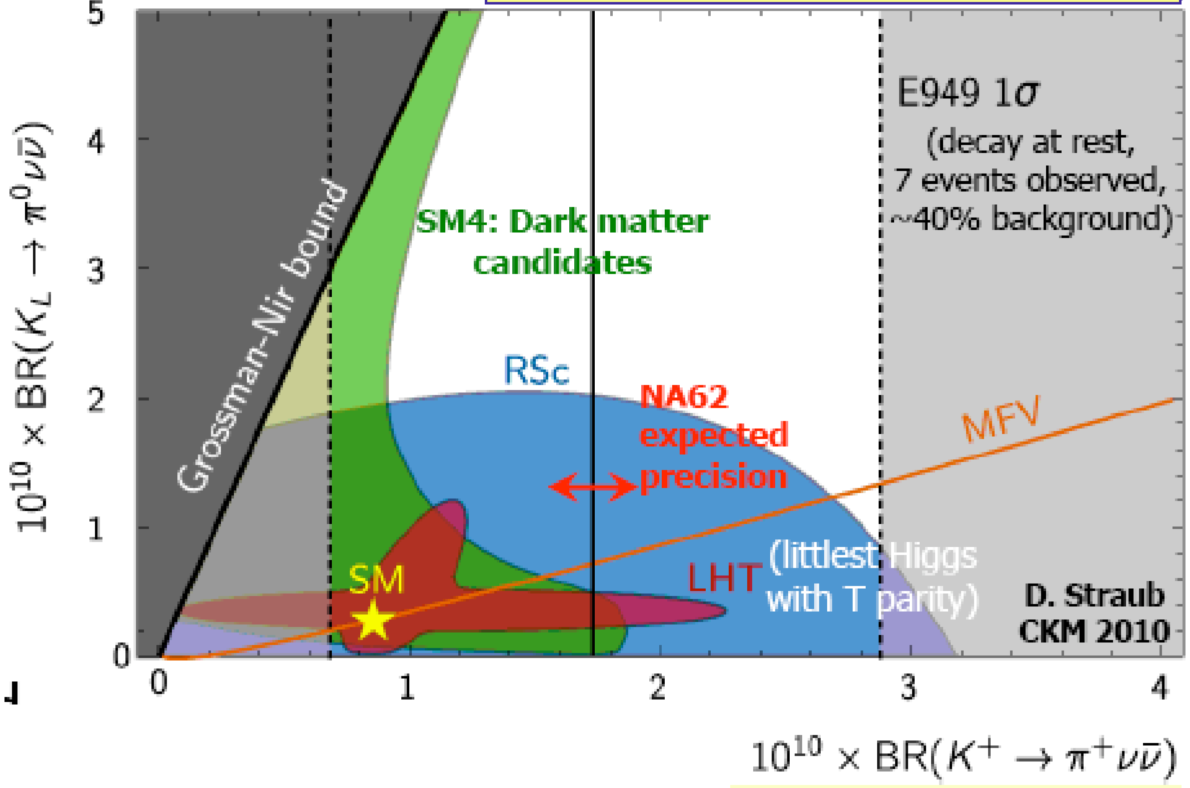
10%



Comparable, unprecedented, *tiny* theoretical errors

$K\rightarrow\pi\nu\nu$ beyond SM

BR($K_L\rightarrow\pi\nu\nu$) vs BR($K^+\rightarrow\pi^+\nu\nu$)



(hep-ph/0906.5454, hep-ph/0812.3803,hep-ph/1002.2126,
hep-ph/0604074)

BR($K^+\rightarrow\pi^+\nu\nu$) $\times10^{10}$: some examples	
SM	0.85±0.07
MFV (hep-ph/0310208)	1.91
EEWP (NPB697 (2004) 133, hep-ph/0402112)	0.75±0.21
EDSQ (PRD70 (2004) 093003, hep-ph/0407021)	up to 1.5
MSSM (NPB713 (2005) 103, hep-ph/0408142)	up to 4.0

$K\rightarrow\pi\upsilon\upsilon$ remains clean also beyond SM:
single effective operator, calculable Wilson coeff., no long-distance effects

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Searching for the holy grail

Sometimes theoretical processes which can be easily handled by theorists are experimental nightmares.....

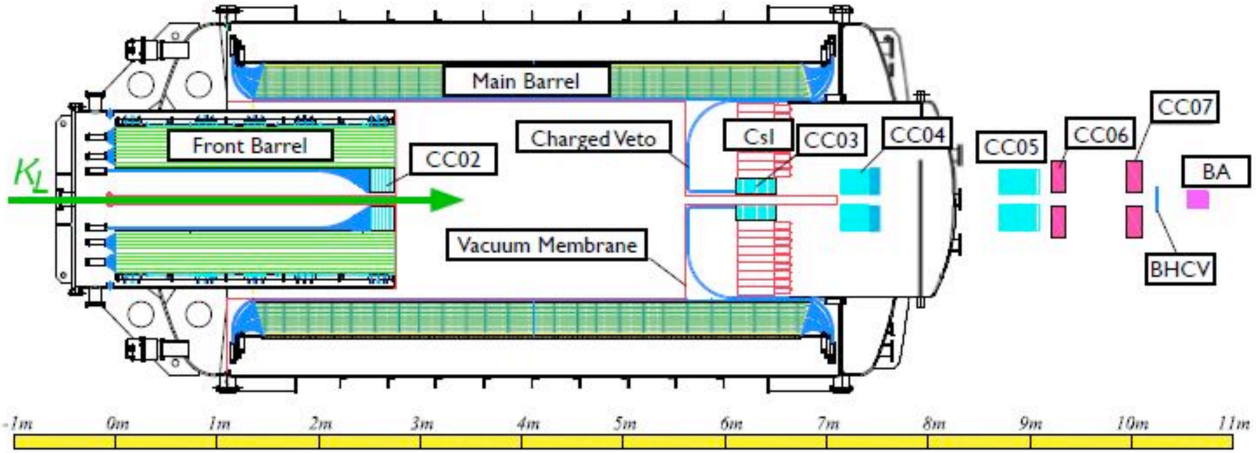
High fluxes, high vacuum, high hermeticity, excellent vetoing, excellent resolutions…
an interesting challenge

"The best it can be said is that so far nobody demonstrated conclusively that the measurement is impossible". (Littenberg)

"Look for a decay of a short-lived particle with 10^9 background, with a poor signature and no kinematic closure."

A typical "needle in 10^5 haystacks" problem

KEK E391a experiment

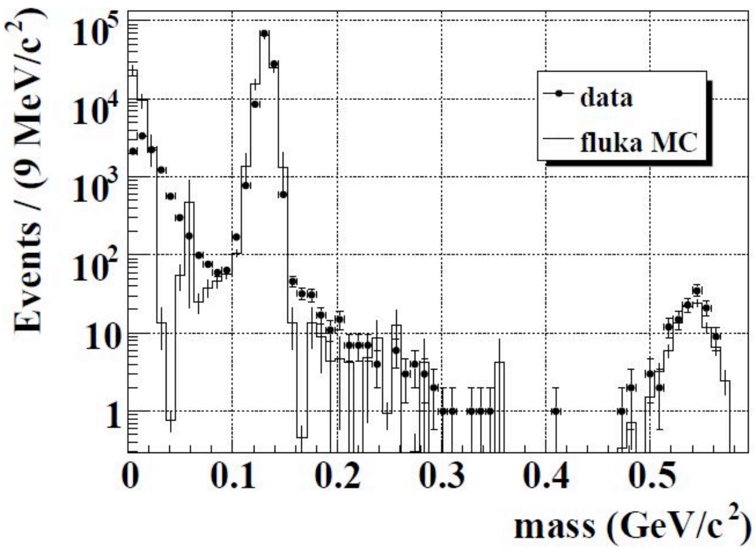


First dedicated pilot experiment to search for $K_L \to \pi^0 \nu\nu$ at the KEK-PS
Improve over **KTeV limit: BR < 5.9 $\cdot 10^{-7}$**

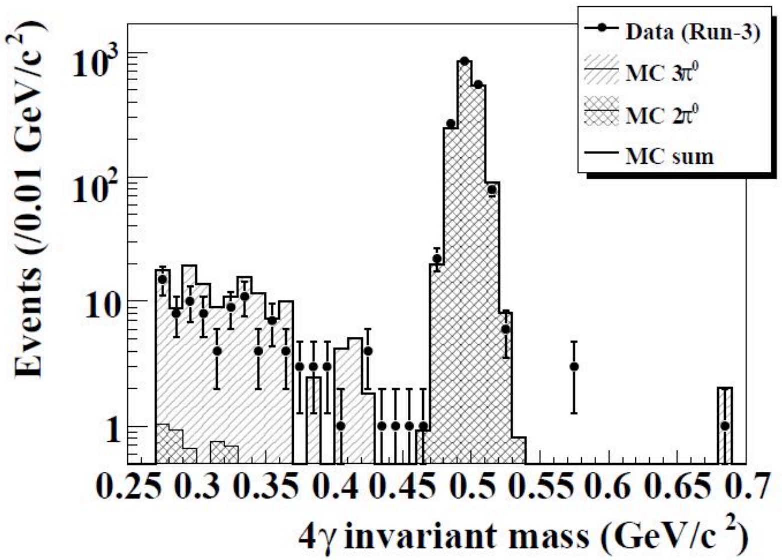
- High intensity: $2 \cdot 10^{12}$ ppp 12 GeV/*c* (50% DC)
- "Pencil" beam as transverse constraint: ~ 2 GeV/*c* K_L at 4° and 11m
- Photon veto hermeticity down to 1-2 MeV: Pb/scint in high vacuum
- Good EM calorimetry: ~500 pure CsI 7x7 cm^2, with central hole

Three runs (2004-2005): 12 month total

KEK E391a results



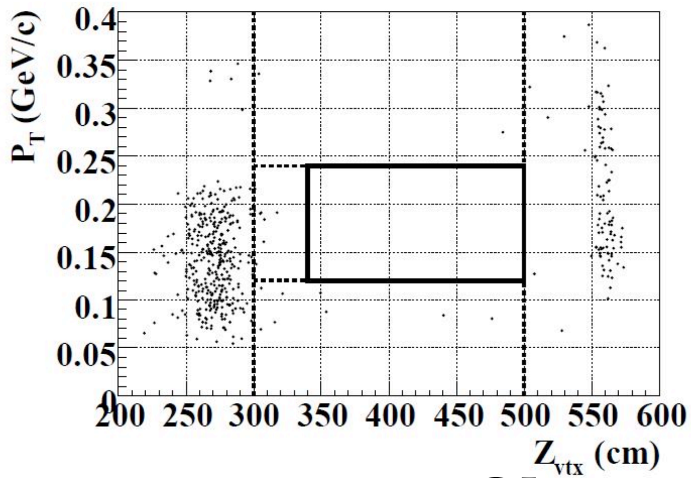
2γ mass with 5mm Al plate run



4γ mass in vacuum run

Detailed understanding of backgrounds
Bkg estimate: 0.87±0.41
3 flux normalizations
~1% total acceptance
SES $(1.11\pm0.02\pm0.10) \cdot 10^{-8}$

$BR(K_L \to \pi^0 \nu\nu) < 2.6 \cdot 10^{-8}$ (90% CL)



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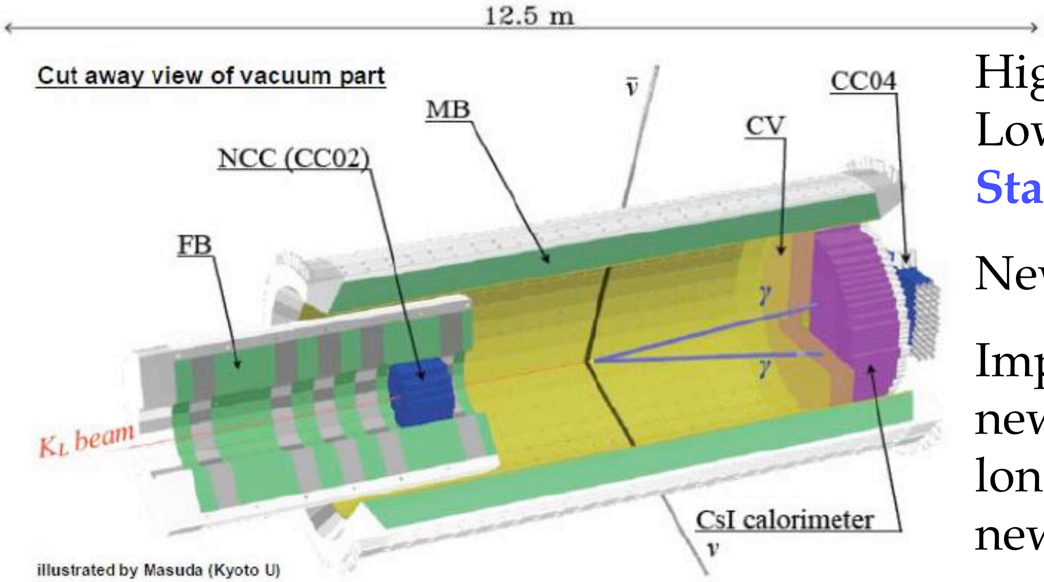
KOTO experiment



Higher beam intensity, acceptance
Lower DC, yield (angle):
Statistics: **3000 x E391a**

New beam line

Improved **background** control:
new EM calorimeter (> granularity, longer), new backside charged veto, new beam-hole γ veto (25x Pb/aerogel)

Step 1: SES = **2.7 SM events** in 3 years (10^7 sec) with **2.2 background**

Step 2 upgrade**: 100 SM events**
(dedicated, improved beam line, larger detector)

66 people, 16 institutions (Japan, Korea, USA, Russia, Taiwan)
Stage 2 approval, beam line commissioned, in preparation

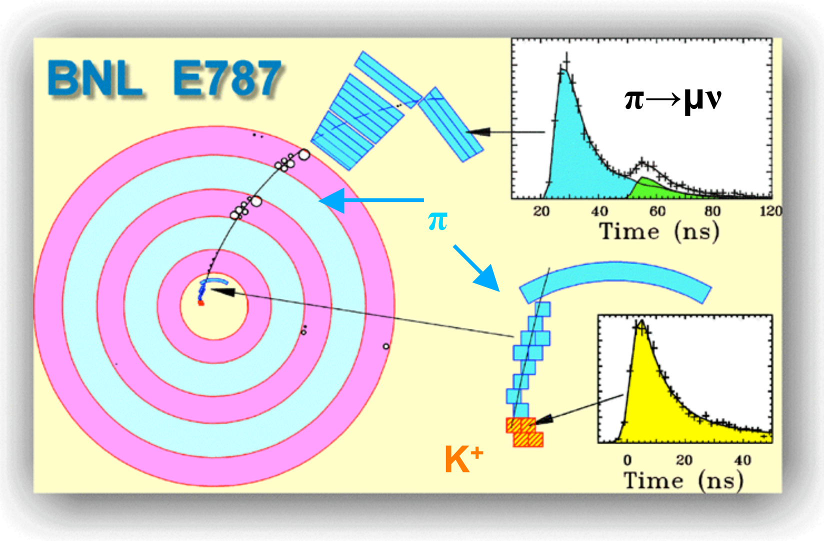
First Run for Step 1 soon

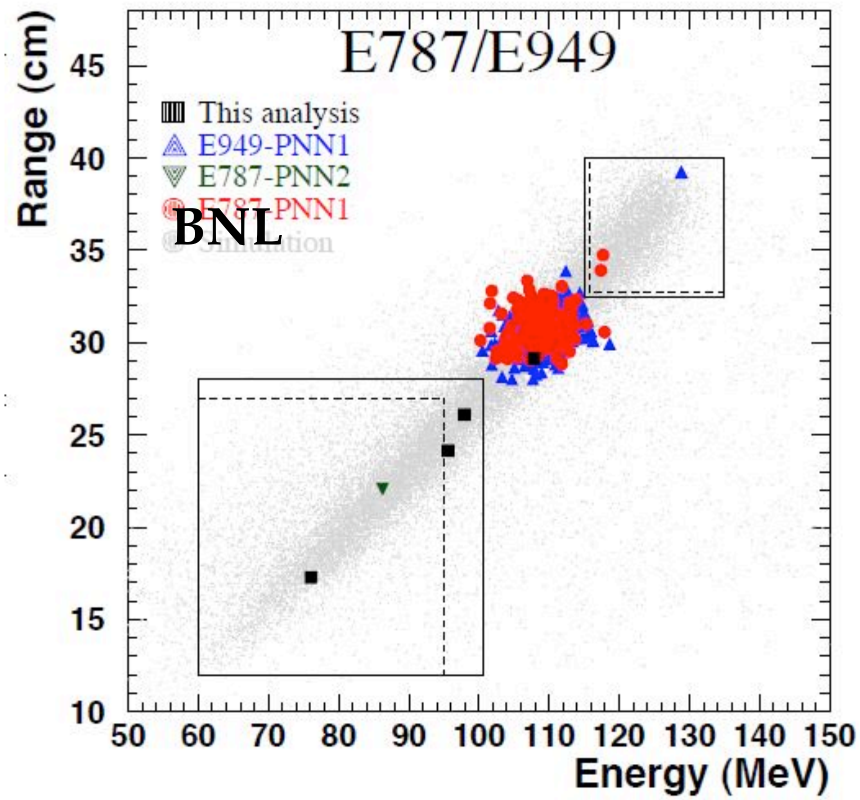
The $K^+ \to \pi^+ \nu\nu$ signal

$1.8 \cdot 10^{12}$ Stopped K^+

$(211 < P_\pi < 229$ MeV/c)

~ 0.1 % signal acceptance





$$BR(K^+ \to \pi^+ \nu\nu) = 1.73^{+1.15}_{-1.05} \times 10^{-10}$$

about 40% background

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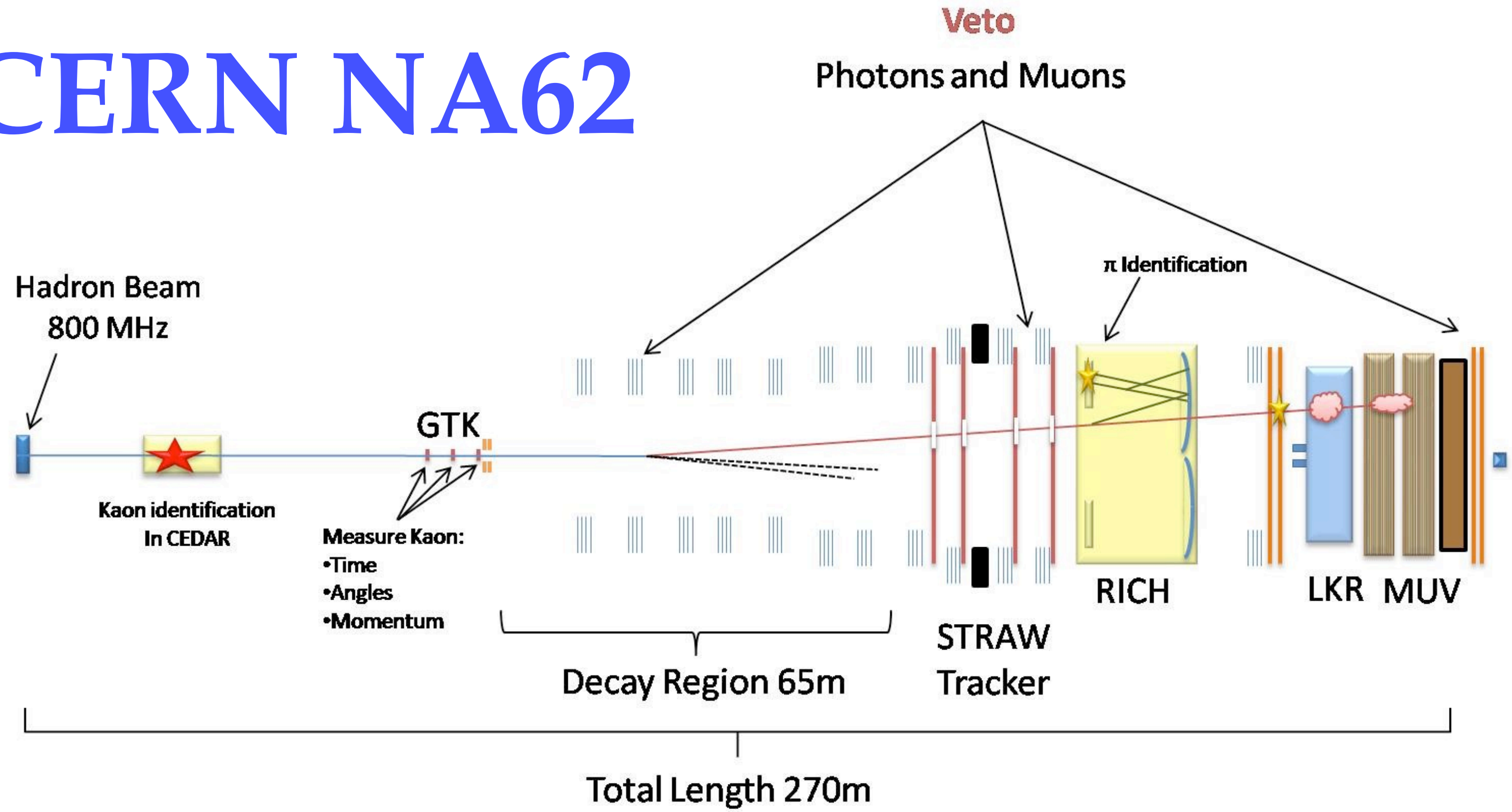
CERN NA62



Measurement of $K^+ \to \pi^+ \upsilon \upsilon$ with new decay in-flight technique
Intense un-separated (6% K^+) 75 GeV/*c* hadron beam: $5 \cdot 10^{12}$ ppp
High-energy: high yield, large decay volume, more powerful vetoing
Track incoming K^+ in 800MHz beam, particle ID, photon vetoing

$5 \cdot 10^{12}$ K^+ decays/year
55 SM events/(< 10^7 sec) year, S/B ≈ 5

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NA62 : principle of experiment

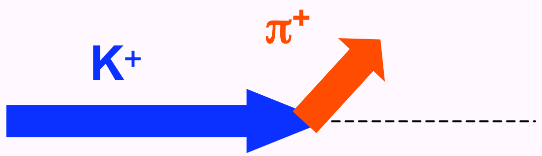
$\mathcal{O}(100)$ events $K^+ \to \pi^+ \nu\bar{\nu}$ in 2 years

~ 10% background

BR(SM) = 8×10^{-11}
$5\ 10^{12}$ K^+ decays
Acceptance= 10%

- K decays in flight
- Intense beam of protons from SPS
- High energy K (P_K = 75 GeV/c)
- Cherenkov K ID: CEDAR

Kinematic rejection



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

Signature:
•Incoming **high** momentum K^+
•Outgoing **low** momentum π^+

- **Kaon: beam tracking**
- **Pion: spectrometer**
- **Excellent timing for K-π association**

Veto and PID

- **γ/μ : calorimeter**
- **Charge Veto : spectrometer**
- **π/μ separation : RICH**

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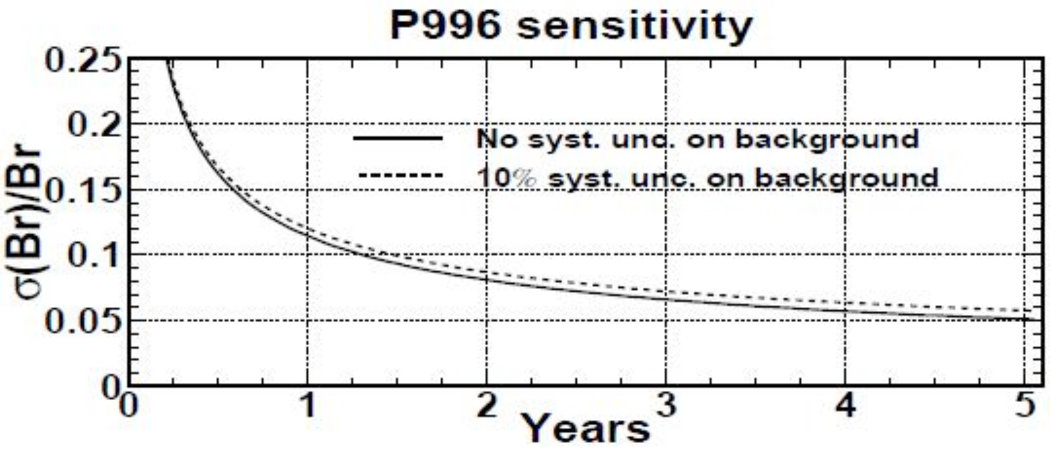
FNAL P996 proposal

5% measurement of BR($K^+ \rightarrow \pi^+ \nu\nu$) with **stopped beam** technique, improving **x100** over BNL E949 by using:

- $9.6 \cdot 10^{13}$ 150 GeV/c protons (kaon yield x7)
- TeVatron as a stretcher ring (95% DC), same detector rates (≈ 8 MHz)
- Separated 550 MeV/c K+ beam (K/π ≈ 2.5, 13.5 m long, K^+ stops x4.5)

Goal: 194^{+89}_{-79} events/year (1 year = 1.8×10^7 sec)
with S/N ≈ 4



Many 10-50% improvements with respect of E949

Competition with NA62 ?

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Kaons at Project-X

High-Intensity frontier
path for Fermilab

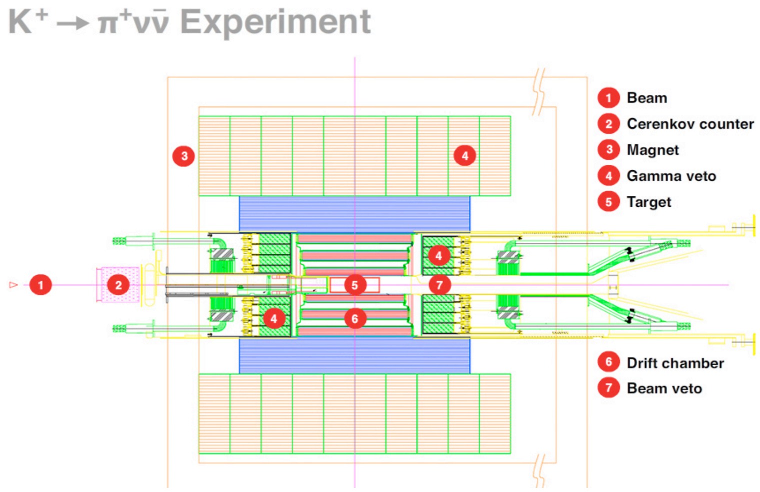
Expect CD-3: 2014
Start construction: 2015
Complete: 2019

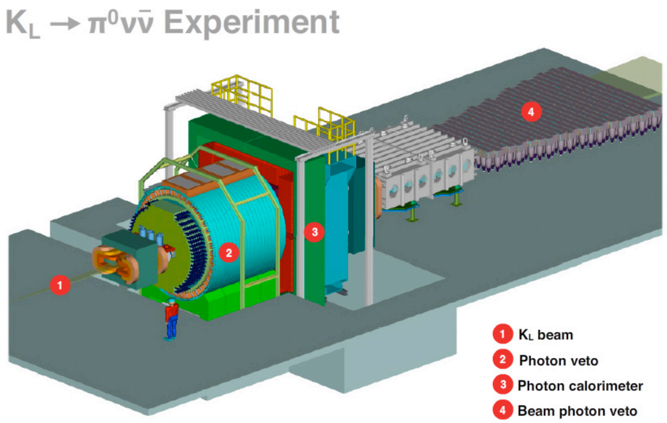
Flux potential for **ultimate** ultra-rare K decay measurements

~500 $K^+ \rightarrow \pi^+ \upsilon\upsilon$ events/year (S/B ~ 4)

$K_L \rightarrow \pi^0 \upsilon\upsilon$ experiment:
- Intrinsic high-precision timing
- Round and small beam
(acceptance and bkg rejection)

~200 $K_L \rightarrow \pi^0 \upsilon\upsilon$ evts/year (S/B ~ 5-10)





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Conclusions

• Kaon experiments **complementary** to proton experiments (LHC)

• From discovery tool to **quantitative probe** of CKM

and even beyond the SM: **ultra-rare K decays**

• Measured BRs and sensitivities in the $\mathbf{10^{-12}}$ range

• More channels available: searches for exotic/forbidden channels, heavy neutrinos, light sgoldstinos etc.

Exciting physics, precise tests of SM and meaningful search for new physics in kaon rare decays

Spares

K_{l3}: lepton universality test

Comparison of $|V_{us}|$ determined from K_{e3} vs $K_{\mu 3}$ decays

SM

$$r_{\mu e} = \frac{[|V_{us}|f_+(0)]^2_{\mu 3,\ \mathrm{exp}}}{[|V_{us}|f_+(0)]^2_{e3,\ \mathrm{exp}}} = \frac{\Gamma_{K\mu 3}}{\Gamma_{Ke3}} \frac{I_{e3}\,(1+2\delta^{Ke}_{\mathrm{EM}})}{I_{\mu 3}\,(1+2\delta^{K\mu}_{\mathrm{EM}})} = (g_\mu/g_e)^2 = 1$$

lepton coupling at the $W \to l\nu$ vertex

Experimental results

$K^\pm$: $r_{\mu e} = 0.998(9)$

K^0: $r_{\mu e} = 1.003(5)$

→ $r_{\mu e} = 1.002(4)$

Non-kaon measurements:

$\pi \to l\nu$: $r_{\mu e} = 1.0042(33)$ (PRD 76 (2007) 095017)

$\tau \to l\nu\nu$: $r_{\mu e} = 1.000(4)$ (Rev.Mod.Phys. 78 (2006) 1043)

The sensitivity in kaon sector approaches those obtained in the other fields.

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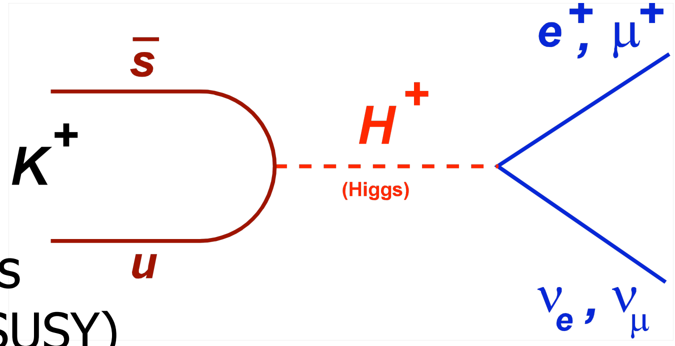
Leptonic meson decays: $P^+ \to l^+\nu$

SM contribution is helicity suppressed:

$$\Gamma(P^+ \to l^+\nu) = \frac{G_F^2 M_P M_l^2}{8\pi}\left(1-\frac{M_l^2}{M_P^2}\right)^2 f_P^2 |V_{qq'}|^2$$



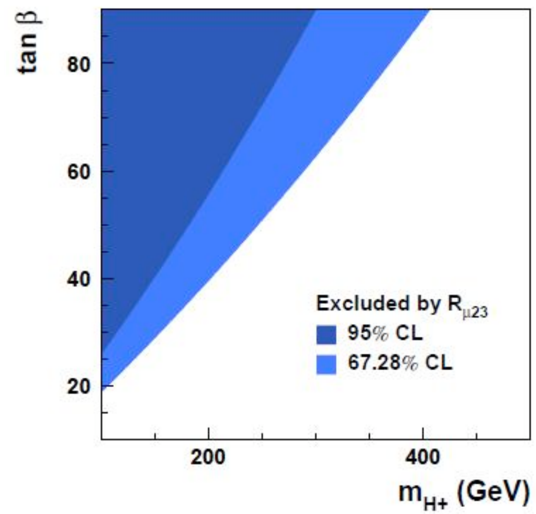
Sizeable tree level charged Higgs ($H^\pm$) contributions in models with two Higgs doublets (2HDM including SUSY)

PRD48 (1993) 2342; Prog.Theor.Phys. 111 (2004) 295

$\pi^+ \to l\nu$:	$\Delta\Gamma/\Gamma_{SM}$	$\approx -2(m_\pi/m_H)^2\, m_d/(m_u+m_d)\, \tan^2\beta$	$\approx 2\times10^{-4}$
$K^+ \to l\nu$:	$\Delta\Gamma/\Gamma_{SM}$	$\approx -2(m_K/m_H)^2 \tan^2\beta$	$\approx 0.3\%$
$D^+_s \to l\nu$:	$\Delta\Gamma/\Gamma_{SM}$	$\approx -2(m_D/m_H)^2\, (m_s/m_c) \tan^2\beta$	$\approx 0.4\%$
$B^+ \to l\nu$:	$\Delta\Gamma/\Gamma_{SM}$	$\approx -2(m_B/m_H)^2 \tan^2\beta$	$\approx 30\%$

(numerical examples for M_H=500GeV/c², $\tan\beta = 40$)

$R = Br(K\to\mu\nu)/Br(K_{e3})$
$(\delta R/R)_{exp}=1.0\%$,
challenging
by not hopeless



BaBar, Belle: $Br_{exp}(B\to\tau\nu)=(1.42\pm0.43)\times10^{-4}$
Standard Model: $Br_{SM}(B\to\tau\nu)=(1.33\pm0.23)\times10^{-4}$

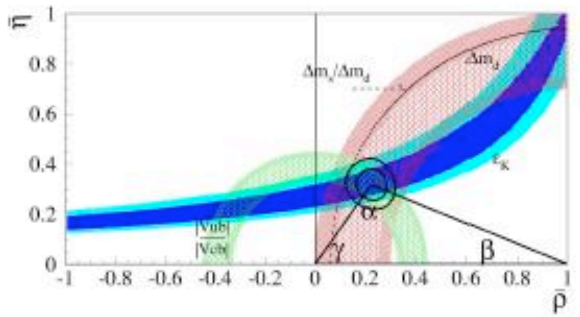
(SM uncertainties: $\delta f_B/f_B$=10%, $\delta|V_{ub}|^2/|V_{ub}|^2$=13%)

Challenged by hadronic uncertainties

Lattice QCD and the Unitarity Triangle

Three of the five determinations of the UT parameters depend in a critical way from Lattice QCD results.

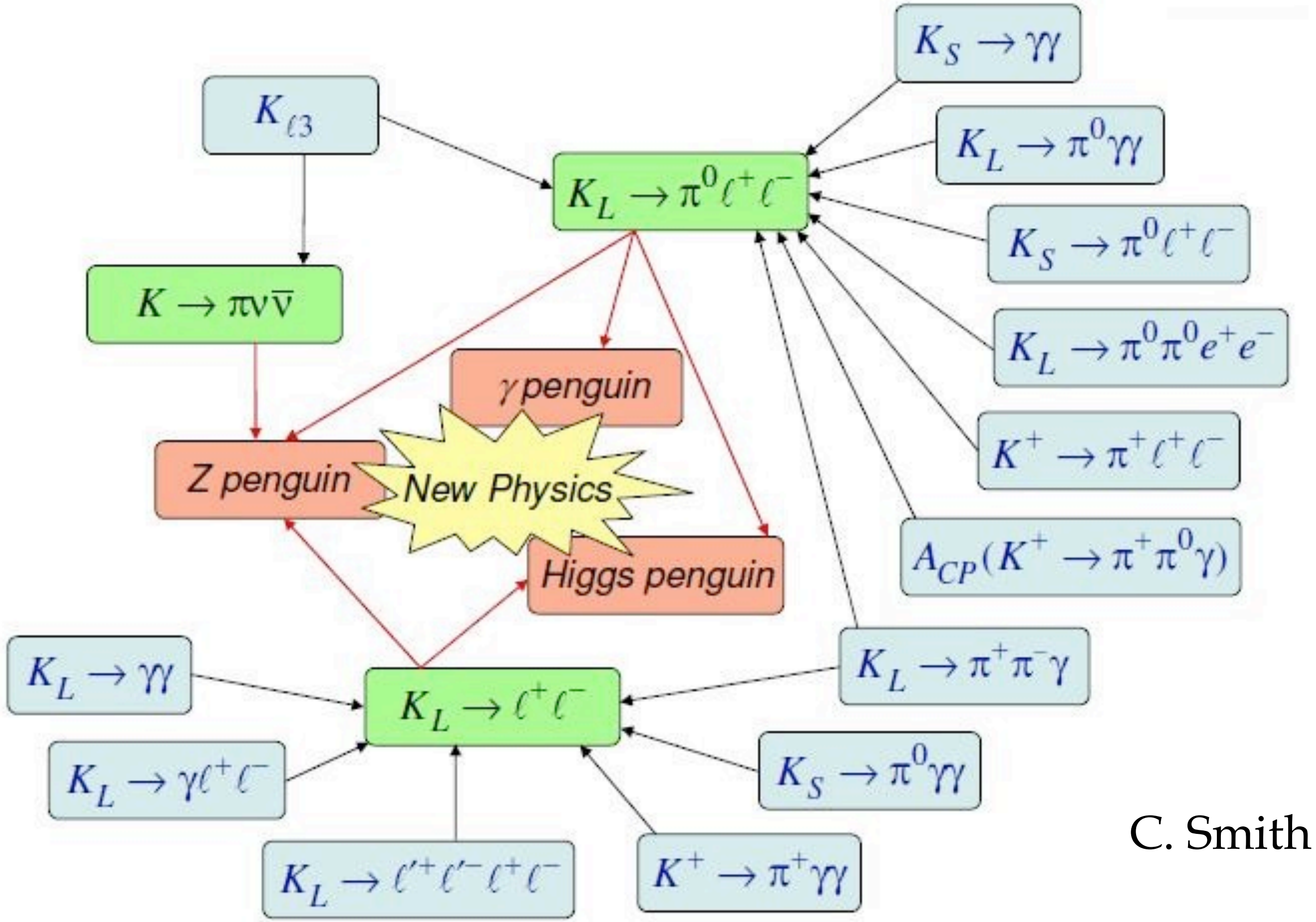
We would like measurements that are as far as possible independent from details of the hadron physics. The answer: $K^+ \to \pi^+ \nu\bar{\nu}$ and $K_L \to \pi^0 \nu\bar{\nu}$.



Measurement	$V_{CKM} \times$ other	Constraint
$b \to u / b \to c$	$\lvert V_{ub}/V_{cb}\rvert^2$	$\bar{\rho}^2 + \bar{\eta}^2$
Δm_d	$\lvert V_{td}\rvert^2 f^2_{B_d} B_{B_d} f(m_t)$	$(1-\bar{\rho})^2 + \bar{\eta}^2$
$\frac{\Delta m_d}{\Delta m_s}$	$\frac{\lvert V_{td}\rvert^2 f^2_{B_d} B_{B_d}}{\lvert V_{ts}\rvert^2 f^2_{B_s} B_{B_s}}$	$(1-\bar{\rho})^2 + \bar{\eta}^2$
ε_K	$f(A, \bar{\eta}, \bar{\rho}, B_K)$	$\propto \bar{\eta}(1-\bar{\rho})$

A. Stocchi, from analysis by M. Ciuchini et al.

Rare K decays: the full picture



C. Smith

Green = must-do measurements
Blue = ingredients

C.Lazzeroni

$K \to \pi \ell \ell$ decays

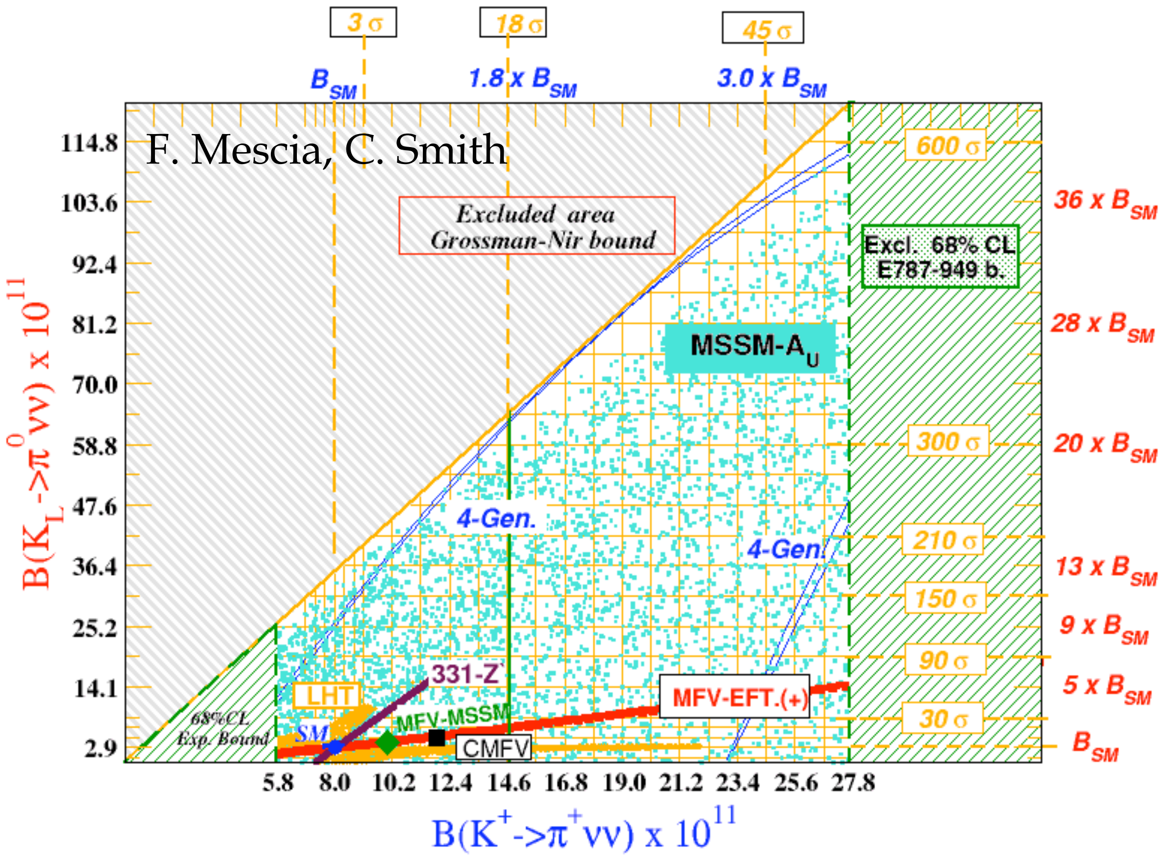
Quantitative tests of the SM :

Tiny BRs can be computed to very high (few percent) precision

$K_L \to \pi^0 e^+ e^-$	10^{-11} (CPV$_{dir}$ $3 \cdot 10^{-12}$)	$< 2.8 \cdot 10^{-10}$ (FNAL KTeV)	3 ev. (2.05 bkg)
$K_L \to \pi^0 \mu^+ \mu^-$	10^{-11} (CPV$_{dir}$ $1 \cdot 10^{-12}$)	$< 3.8 \cdot 10^{-10}$ (FNAL KTeV)	2 ev. (0.87 bkg)
$K^+ \to \pi^+ \nu\nu$	$8.2 \cdot 10^{-11}$	$1.73^{+1.15}_{-1.05} \cdot 10^{-10}$ (BNL E787+E949)	7 evt. (bkg. 1.38)
$K_L \to \pi^0 \nu\nu$	$2.6 \cdot 10^{-11}$	$< 2.6 \cdot 10^{-8}$ (KEK E391a)	*"Nothing to nothing"*

C.Lazzeroni

K→πυυ beyond SM



BR($K^+ \to \pi^+ \nu\nu$) $\times 10^{10}$: some examples	
SM	0.85±0.07
MFV (hep-ph/0310208)	1.91
EEWP (NPB697 (2004) 133, hep-ph/0402112)	0.75±0.21
EDSQ (PRD70 (2004) 093003, hep-ph/0407021)	up to 1.5
MSSM (NPB713 (2005) 103, hep-ph/0408142)	up to 4.0

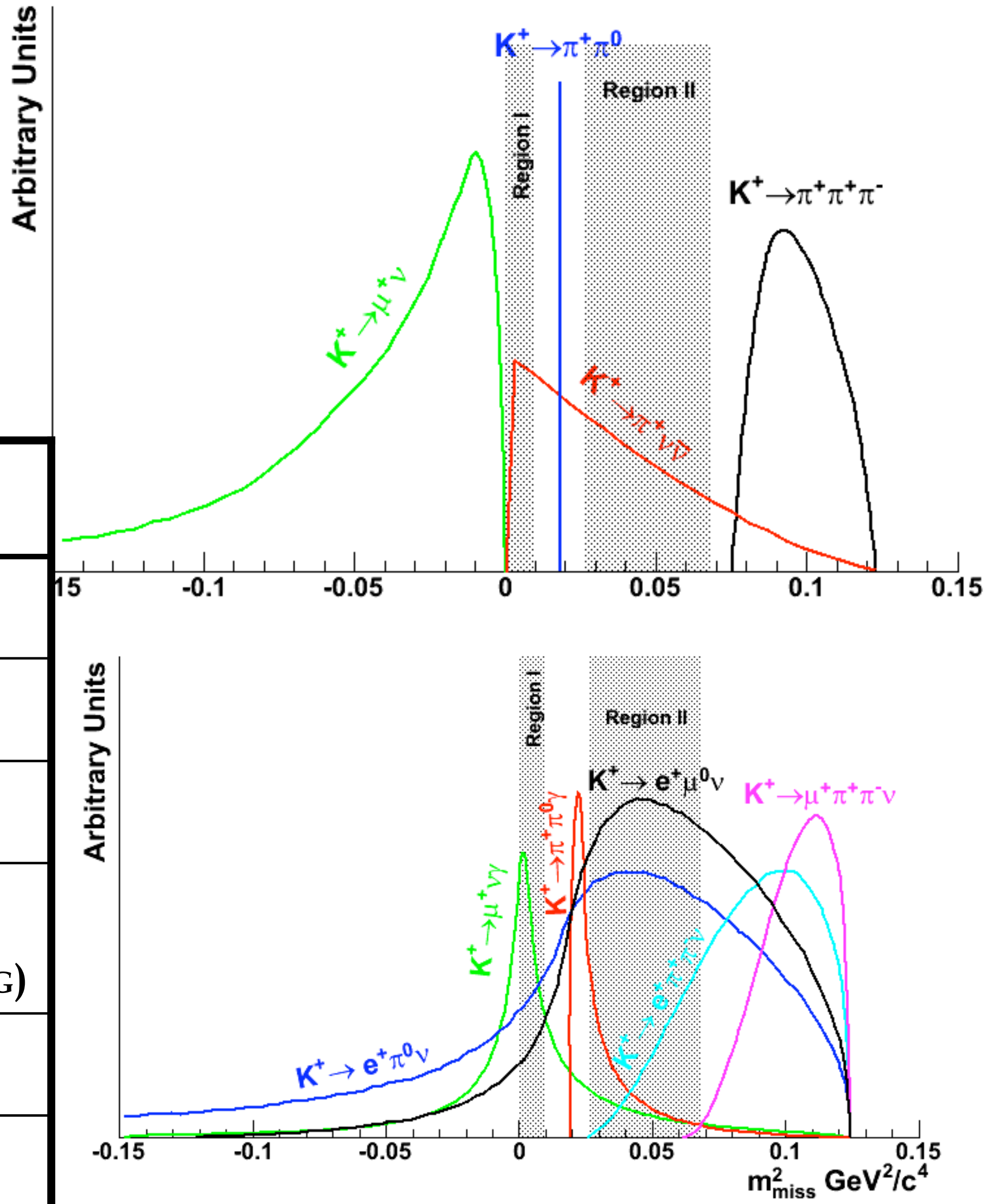
K→πυυ **remains clean** also beyond SM:

single effective υυ operator, calculable Wilson coeff., no long-distance effects

Backgrounds

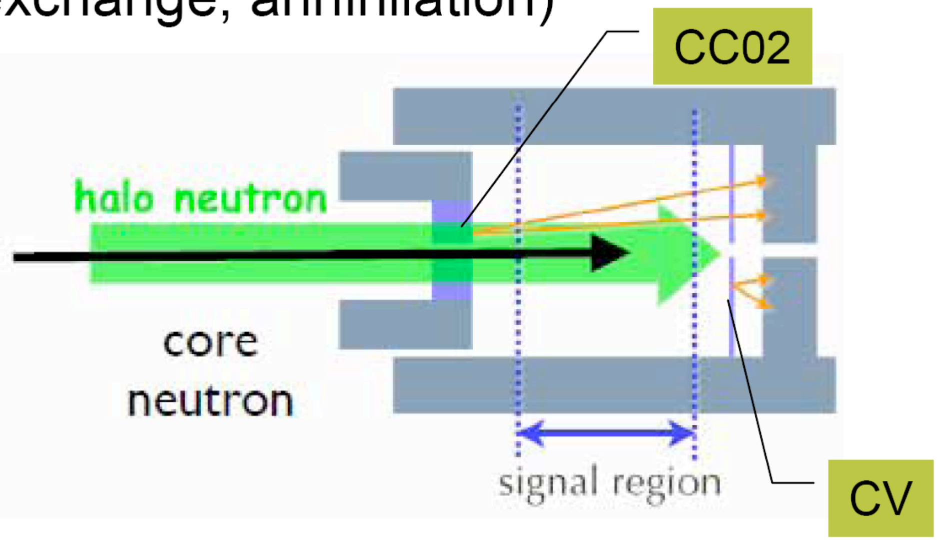
Decay	BR
$K^+ \to \mu^+\nu$ ($K_{\mu 2}$)	0.634
$K^+ \to \pi^+\pi^0$ ($K_{\pi 2}$)	0.209
$K^+ \to \pi^+\pi^+\pi^-$ $K^+ \to \pi^+\pi^0\pi^0$	0.073

Decay	BR
$K^+ \to \pi^0 e^+\nu$ (K_{e3})	0.049
$K^+ \to \pi^0\mu^+\nu$ ($K_{\mu 3}$)	0.033
$K^+ \to \mu^+\nu\gamma$ ($K_{\mu 2\gamma}$)	6.2×10^{-3}
$K^+ \to \pi^+\pi^0\gamma$	1.5×10^{-3} (2.75×10^{-4} PDG)
$K^+ \to \pi^+\pi^- e^+\nu$ (K_{e4})	4.1×10^{-5}
$K^+ \to \pi^+\pi^-\mu^+\nu$ ($K_{\mu 4}$)	1.4×10^{-5}



E391a: technique

- Kaon Decay
  - $K_L \rightarrow \pi^0\pi^0$ (2γ missed; due to inefficiency or fusion)
  - $K_L \rightarrow \pi^+\pi^-\pi^0$ (2 charged pion missed)
  - $K_L \rightarrow \pi^- e^+ \nu$ (charge exchange, annihilation)
- Halo neutron
  - Interact with "CC02","CV"
  - Produce π^0, η

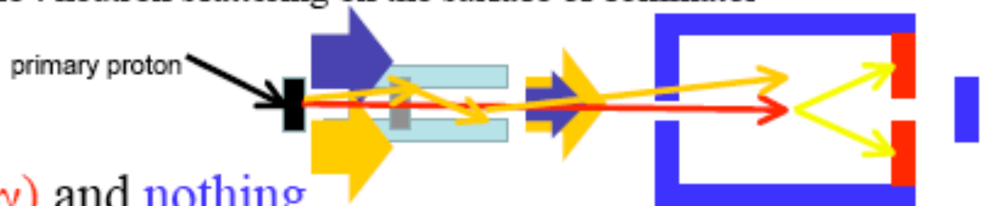


Slide from T. Nomura

JPARC KOTO - designed for $K_L \to \pi^0 \nu\nu$

KOTO Concept of Experiment

- K_L beam (proton → target)
  - neutral beam line
    - » Long beam line → Kill particles with shorter lifetime
    - » Charged particle sweeping magnet.
    - » Pb photon absorber → reduce beam photons
    - » Collimator → shaping KL →Pencil Beam (source of beam halo)
  - Core : K_L, photon, neutron
  - Halo : neutron scattering on the surface of collimator
- Detector
  - π^0 ($\to\gamma\gamma$) and nothing
    - Photon calorimeter and hermetic vetos.
    - Pencil Beam Method. (small beam hole and KL rec.)



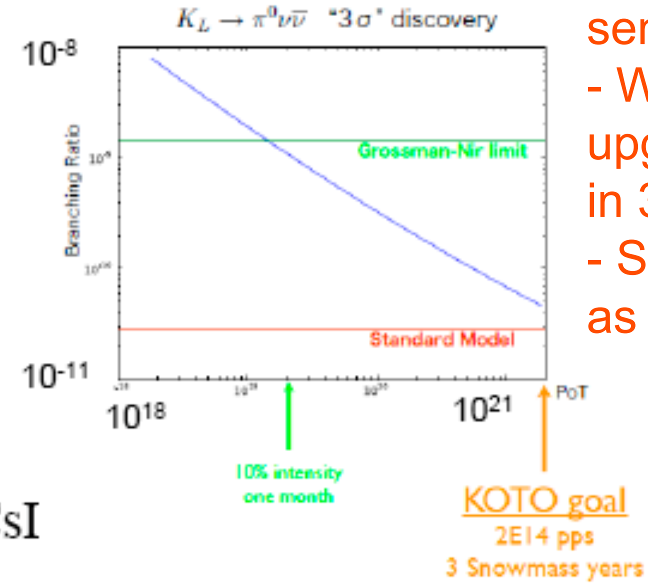
5 Kaon09

Strategy from E391a with 3 improvements:
- High intensity beam
- New beam line (suppress halo neutrons)
- Detector upgrade (suppress background)

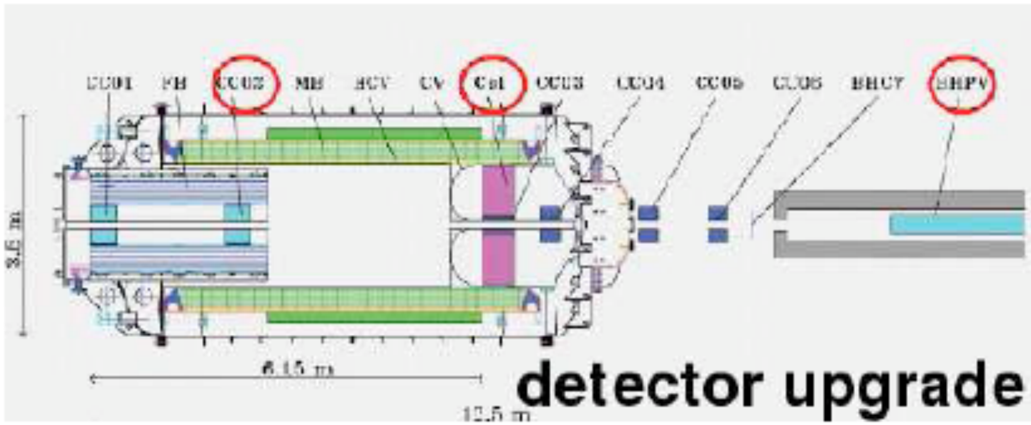
H. Nanjo's talk at KAON09

Schedule

- 2009
  - Beamline construction
  - Beam survey
- 2010
  - CsI calorimeter construction
  - Engineering Run with CsI calorimeter
- 2011
  - Physics Run Start.

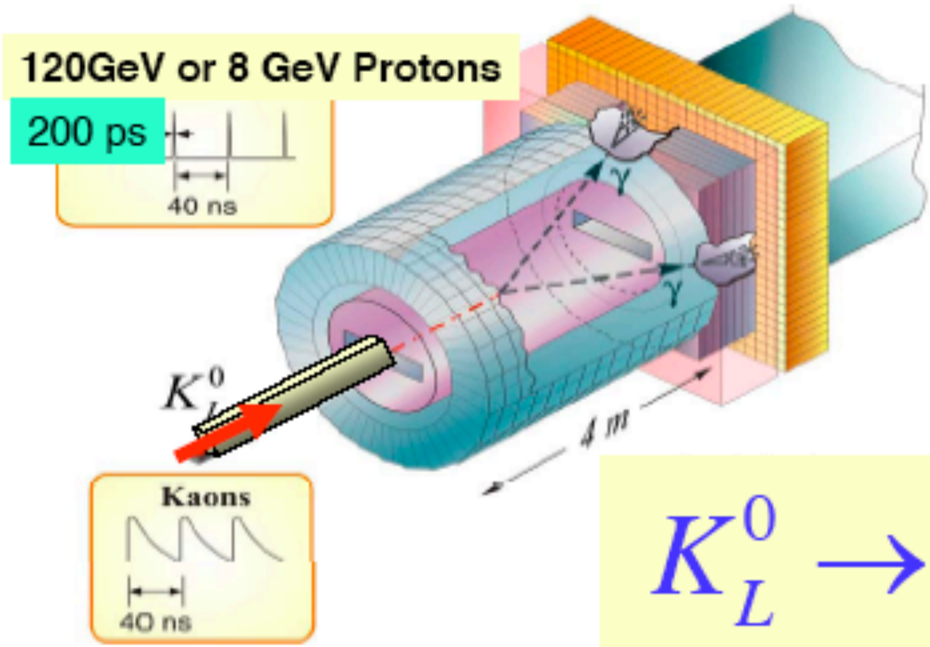


- Reach SM sensitivity in 3 years
- With major JPARC upgrade, reach 100 ev in 3 years
- Same basic 'technique' as NA62 !!



H.Nanjo's talk at KAON09

$K_L^0 \to \pi^0 \nu \bar{\nu}$ Experiment Concept

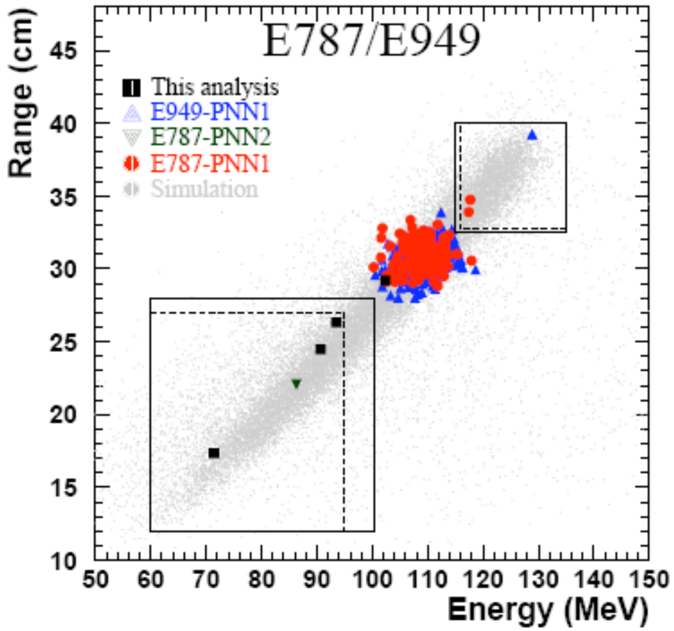


$$K_L^0 \to \pi^0 \nu \bar{\nu}$$

- Use TOF to work in the K_L^0 c.m. system
- Identify main 2-body background $K_L^0 \to \pi^0 \pi^0$
- Reconstruct $\pi^0 \to \gamma\gamma$ decays with pointing calorimeter
- 4π solid angle photon and charged particle vetos

New measurement of the $K^+ \to \pi^+ \nu\nu$ branching ratio (BNL E949)

Three events for the decay $K^+ \to \pi^+ \nu \bar{\nu}$ have been observed in the pion momentum region below the $K^+ \to \pi^+ \pi^0$ peak, $140 < P_\pi < 199$ MeV/c, with an estimated background of $0.93 \pm 0.17(\text{stat.})^{+0.32}_{-0.24}(\text{syst.})$ events. Combining this observation with previously reported results yields a branching ratio of $\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$ consistent with the standard model prediction.



Process	Background events
$K_{\pi 2}$ TG	$0.619 \pm 0.150^{+0.067}_{-0.100}$
$K_{\pi 2}$ RS	$0.030 \pm 0.005 \pm 0.004$
$K_{\pi 2 \gamma}$	$0.076 \pm 0.007 \pm 0.006$
K_{e4}	$0.176 \pm 0.072^{+0.233}_{-0.124}$
CEX	$0.013 \pm 0.013^{+0.010}_{-0.003}$
Muon	0.011 ± 0.011
Beam	0.001 ± 0.001
Total	$0.927 \pm 0.168^{+0.320}_{-0.237}$

TABLE I: Summary of the estimated number of events in the signal region from each background component. Each component is described in the text.

$$BR(K^+ \to \pi^+ \nu\nu) = 1.73^{+1.15}_{-1.05} \times 10^{-10}$$

Comparison of facilities/experiments

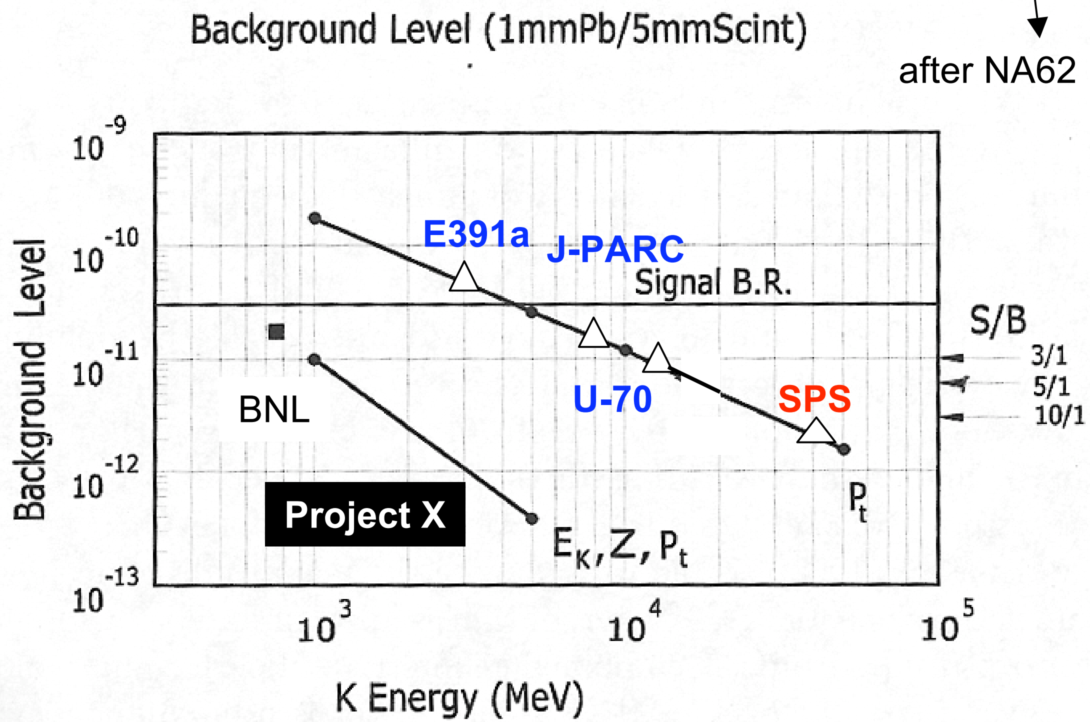
approved

approved

Facility/Exper.	Timescale	Physics reach	Main aims	Improvement
SPS/NA62	2013-2015	wide, 5×10^{12} k decays	50 $\pi^+\nu\nu$/y, LFV, QCD new-physics searches	large
JPARC/KOTO	2011-2014	focused, $\pi^0\nu\nu$	SM sensitivity, few events	large
	$> 2017?$	focused, $\pi^0\nu\nu$	100 ev, S/B = 1.5	large
DAPHNE/KLOE	> 2009	wide, 10^{10} K decays	V_{us}, LFV, BR	small
DAPHNE/KLOE2	$> 2011?$	wide, 4×10^{10} K decays	V_{us}, LFV, BR	medium
Fermilab Stret.	$> 2014?$	focussed, $\pi^+\nu\nu$	200 ev/y	medium
Project X	$> 2018?$	? ,$\pi^+\nu\nu/\pi^0\nu\nu$	200/300 ev/y	large

after NA62

Notes:
1) KOTO $\pi^0\nu\nu$ technique accessible to NA62 - see figure
2) KLOE2 not much improvement wrt KLOE but DAPHNE R&D into accelerator technology
3) Fermilab/JPARC/DAPHNE upgrade timescales uncertain



KLOE-2 at upgraded DAΦNE

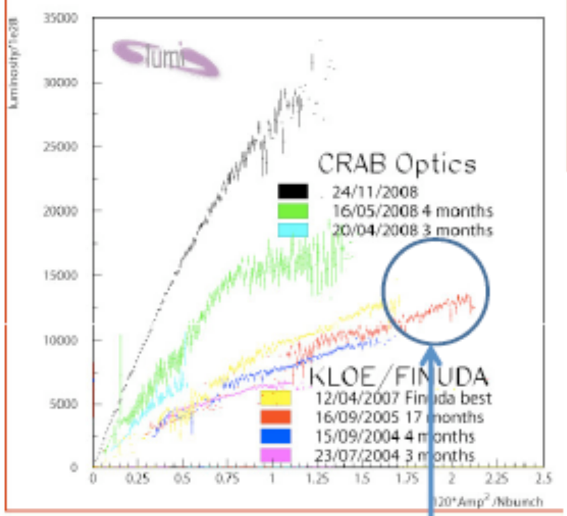
Branchini's talk at KAON09

Upgrade of DAΦNE in luminosity:

Crabbed waist scheme at DAΦNE (proposal by P. Raimondi)
- increase L by a factor $O(5)$
- requires minor modifications
- relatively low cost

- Successful experimental test at DAΦNE

NEW COLLISION SCHEME:
Large Piwinski angle
Crab-Waist compensation SXTs



original collision scheme

KLOE-2 Plan:
- phase 0: KLOE restart taking data end 2009 with a minimal upgrade ($L \sim 5\ fb^{-1}$)
- phase 1: full KLOE upgrade (KLOE-2) > 2011 ($L > 20\ fb^{-1}$)

Physics issues:
- Neutral kaon interferometry, CPT symmetry & QM tests
- Kaon physics, CKM, LFV, rare K_S decays
- Dark matter
- η,η' physics
- Light scalars, $\gamma\gamma$ physics
- Hadron cross section at low energy, muon anomaly

Detector upgrade issues:
- Inner tracker R&D
- $\gamma\gamma$ tagging system
- FEE maintenance and upgrade
- Computing and networking update
- etc.. (Trigger, software, ...)

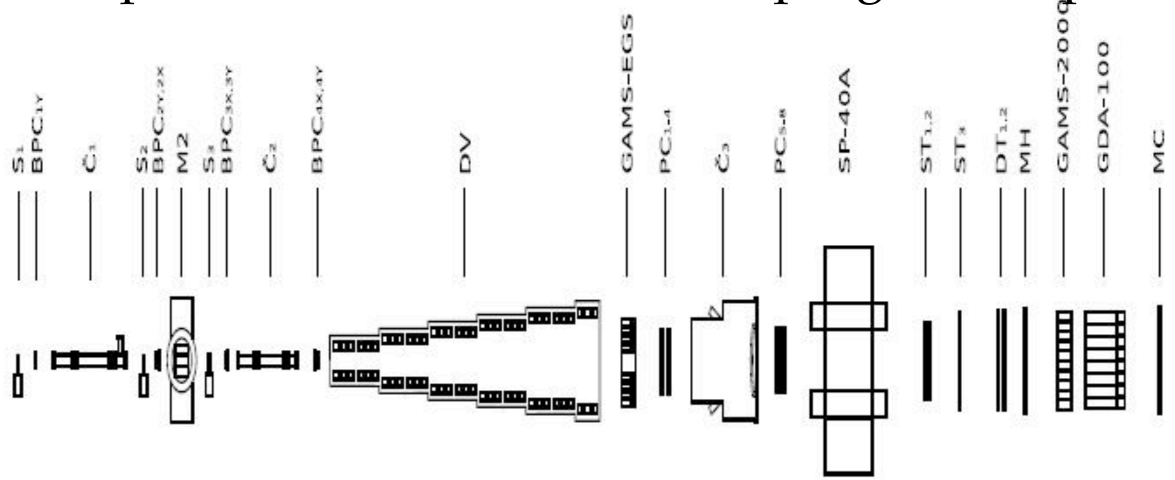
R&D of accelerator technology

V_{us} error : 0.3% (now) $\Rightarrow$ 0.17% ; $1 - |V_{us}|^2 - |V_{ud}|^2$ error : $6\ 10^{-4}$ (now) $\Rightarrow$ $3\text{-}4\ 10^{-4}$
Lepton universality tests with Ke3/Kmu3
Absolute branching ratios

Wide physics programme but not tuned for rare decays:
$20\ fb^{-1} = 2\ 10^{10}$ Kaon decays
Not large improvement with respect to KLOE

Two Protvino projects

SPHINX+GAMS+ISTRA → **OKA** at Protvino:
65-70 GeV 10^{13} ppp at U-70 (38% DC)
12.5 GeV RF-separated K^+ beam **$5 \cdot 10^6$ Kpp** ($K/\pi \approx 4$)
Commissioning beam and detector with runs started 2009
10-100x improvement on ISTRA Kaon program + spectroscopy



Ongoing R&D for a $K_L \to \pi^0 \nu\nu$ experiment **KLOD**
Neutral pencil beam extracted @ 35 mrad, 10 GeV/c K^0
300 MHz n background: dual-readout spaghetti calorimeter
Aim at **1 SM event** ($S/B \approx 3$) with 10 days of beam