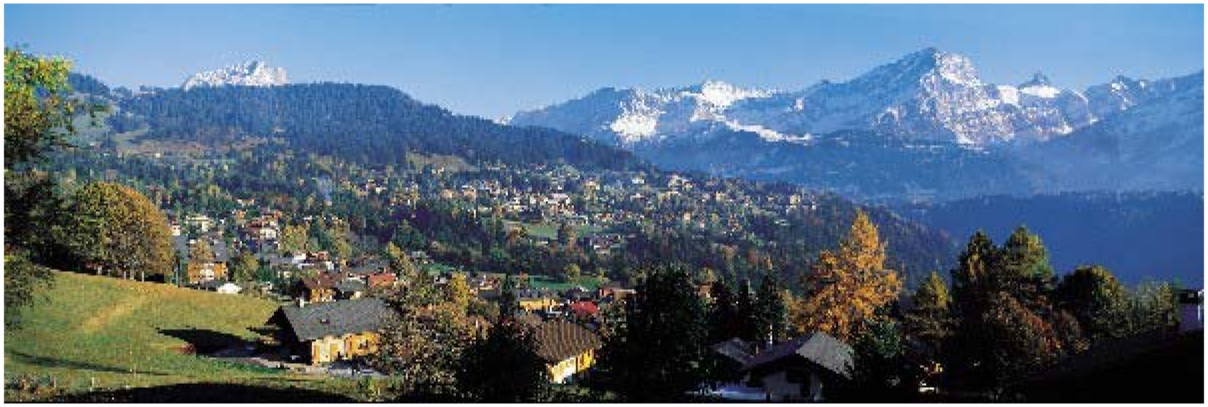
K physics at a high-intensity future machine



Marco S.Sozzi
Scuola Normale Superiore
and INFN – Pisa
for INFN fixed-target working group

SPSC Meeting
Villars
September 26th 2004

Outline

- Where are we now?
  - Very well defined (data in previous talks)
- Where will we be in, say, 10 years from now?
  - Pretty hard question (hopes in previous talks)
- What will we want to do then?
  - Rather hopeless question (this talk)
- Still… a few things are quite clear

Try to give a sampler of opportunities

Caveats

- Small working group set up by the particle physics branch of INFN to assess the interest for fixed-target experiments at possible high-intensity proton machines in the mid-long term future.
- Very difficult to extrapolate to the long term future: quite some wishful thinking and wild guesses.
Steps and milestones are fundamental.
- The big issue: relevance of what we can learn from kaons in 10 years from now
- What this talk IS NOT:
    A specification for a project
    A design of an experiment

Only high-energy physics with K covered (no hyper-nuclei, π,…)

Kaon decays map

1. CP, CPT measurements (well known decays)
   $K^\pm \to \pi^\pm\pi^\pm\pi^\pm$, $K^\pm \to \pi^\pm\pi^0\pi^0$, $K^\pm \to \pi^\pm\pi^0\gamma$, $K_S \to 3\pi^0$, $K_S \to \pi\ell\nu$, ϕ_{+-}, ϕ_{00}
2. Long-distance modes (tests of low-energy effective th.)
   $K^\pm \to \pi^\pm\ell^+\ell^-$, $K_L \to \ell^+\ell^-$
3. "New physics" decays (SM = 0):
   LFV ($K_L \to \mu e$, K_L,$K^\pm \to \pi\mu e$)
4. Precision measurements (SM = small, NP window):
   Transverse μ polarization ($K^+ \to \pi\mu\nu$, $K^+ \to \mu\nu\gamma$)
5. Short-distance modes (SM = precise)
   $K_L \to \pi^0\ell^+\ell^-$, $K_L \to \pi^0\nu\nu$, $K^\pm \to \pi^\pm\nu\nu$

1. CP, CPT violation

•New (direct) CP asymmetries: [NA48/2, OKA starting 2005]
$K \to 3\pi$ slopes and $K \to \pi\pi\gamma$ spectra @ SM level (10^{-5})

•New CP violation: $K_S \to 3\pi^0$ at hadron machines with K_S-K_L interference close to target (see NA48/1).
$K_S \to \pi^+\pi^-\pi^0$ (Dalitz plot analysis).

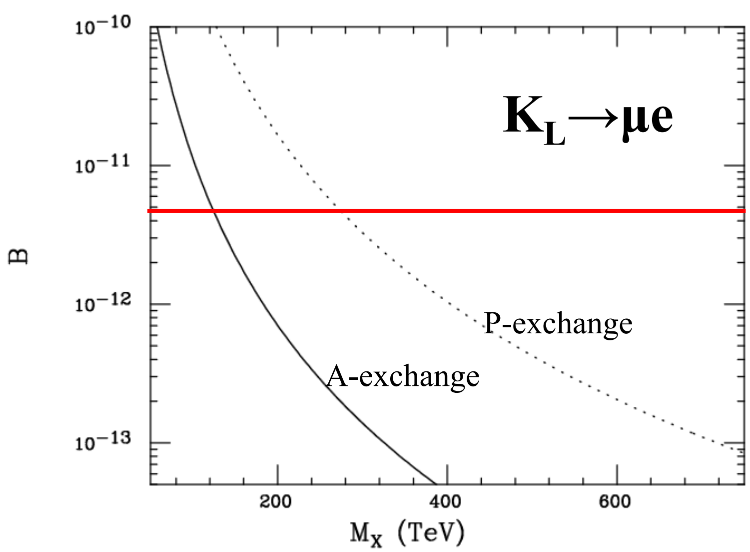
•CPT test at Planck scale (~10^{19} GeV).
Compare ϕ_{+-} to $\phi_{SW} \approx \phi(\varepsilon)$ at very high precision [CPT proposal, 25 GeV].
Need ϕ_{+-} at 0.05° and $\phi(\varepsilon)$ from precise ancillary measurements (semileptonics, 3π, Δm, τ_S, interf. close to target) .
KTeV-1997:
$\phi_{+-} - \phi_{SW} = (0.61 \pm 0.62 \pm 1.01)^\circ$ $\phi_{00} - \phi_{+-} = (0.39 \pm 0.22 \pm 0.45)^\circ$
Syst. limited: acceptance, regeneration physics, $\pi^0\pi^0$ reconstr.
Pure beam, flux, calorimetry, vacuum interference (5-20 τ_S) i.e. pure K^0/K^0, shielding. Also: Bell-Steinberger CPT test, CPV in $K_L \to \pi^+\pi^-\gamma$.
Ambitious, wide-ranging project.

3. Lepton-flavour violation

Stringent limits reached.

Further progress hindered by fluxes but also **backgrounds**.

No longer very competitive with μ system (but complementary).



No new experiments planned.

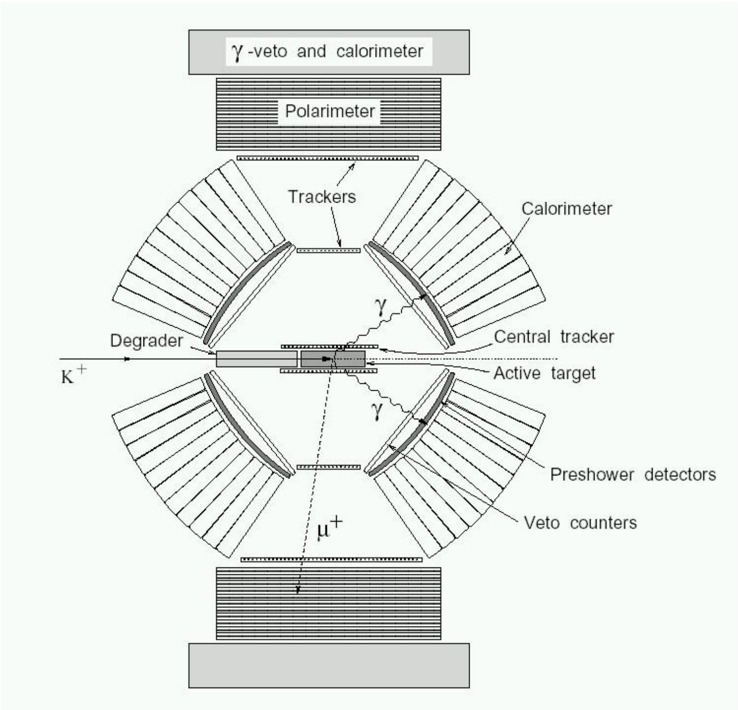
Decay mode	BR limit (90% CL)
$K^+ \to \pi^+\mu^+e^-$	2.8×10^{-11}
$K^+ \to \pi^+\mu^-e^+$	5.2×10^{-10}
$K^+ \to \pi^-e^+e^+$	6.4×10^{-10}
$K^+ \to \pi^-\mu^+\mu^+$	3.0×10^{-9}
$K^+ \to \pi^-\mu^+e^+$	5.0×10^{-10}
$K_L \to \mu e$	4.7×10^{-12}
$K_L \to \mu\mu ee$	4.12×10^{-11}
$K_L \to \pi^0\mu e$	6.2×10^{-9}

Byproducts: limits on direct decays to exotic (s-)particles, Higgs.

New results still expected from high-flux experiments.

4. P_T measurements

$P_T(\mu)$ in 3-body decays (T-odd correlation).
Tiny (10^{-6}) FSI (EM) in SM: sensitive to New Physics.
Stopped K experiments: systematics from detector mis-alignment, magnetic fields asymmetries and (large) in-plane polarization.



KEK-E246 (1996-98, $8\cdot10^{6}$ decays):

$$P_T(\mu) = (-1.7 \pm 2.3 \pm 1.1) \times 10^{-3}$$

Also 10^5 $\mu^+\nu\gamma$ decays (complementary sensitivity to New Physics, higher FSI)

- J-PARC LoI: Stopped K^+. 10^7 K^+/s (1 year), 600-700 MeV/c ± 2%, 2-stage DC-separated. Goal: < 10^{-4} on P_T
- There was a BNL proposal for 10^{-4} on P_T with decay in-flight from 2 GeV separated beam

Window of opportunity open.
Difficult systematics, hard to extrapolate more than x10.

5. $K \to \pi \ell \bar{\ell}$

Phenomenological advantages well known

Experimental problems:
BR ≈ 10^{-11}, few (or no) kinematic constraints, backgrounds with BR x 10^{7}

$K_L \to \pi^0 e^+ e^-$	$(3.7 \pm 1.0) \cdot 10^{-11}$ (CPV_{dir} 1-2 $\cdot 10^{-11}$)	$< 2.8 \cdot 10^{-10}$ (FNAL KTeV)	*CPC+CPV*, $ee\gamma\gamma$ bkg. 3 ev. (2.05 bkg)
$K_L \to \pi^0 \mu^+ \mu^-$	$(1.5 \pm 0.3) \cdot 10^{-11}$ (CPV_{dir} 1-5$\cdot 10^{-12}$)	$< 3.8 \cdot 10^{-10}$ (FNAL KTeV)	*CPC+CPV* 2 ev. (0.87 bkg)
$K^+ \to \pi^+ \nu\bar{\nu}$	$(8.0 \pm 1.0) \cdot 10^{-11}$ (at 7%). No CP	$1.47^{+1.30}_{-0.89} \cdot 10^{-10}$ (BNL E787+E949)	Dedicated expt. 3 evt. (bkg. 0.45)
$K_L \to \pi^0 \nu\bar{\nu}$	$(3.0 \pm 0.6) \cdot 10^{-11}$ (at 2%)	$< 5.9 \cdot 10^{-7}$ (KTeV, Dalitz decay)	Pure CPV dir "*Nothing to nothing*"

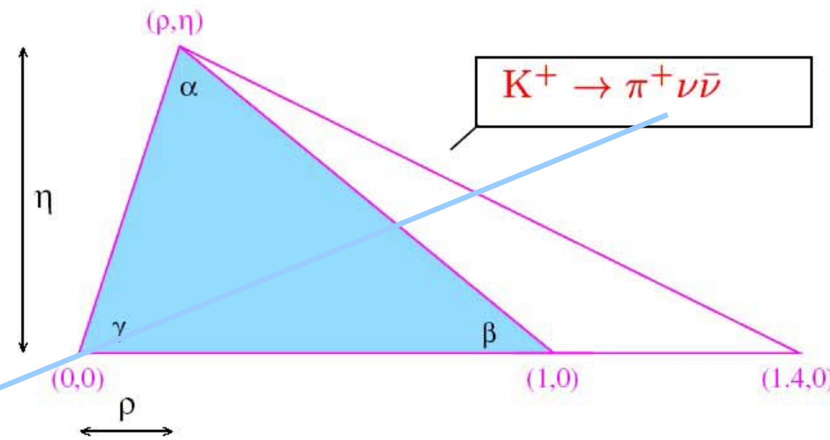
***Dedicated* experiments required**

Unitarity triangle from K

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

$K_L \to \pi^0 e^+ e^-$ $\begin{cases} K_S \to \pi^0 e^+ e^- \\ K_L \to \pi^0 \gamma\gamma \end{cases}$

$\varepsilon, \varepsilon'$



$K^+ \to \pi^+ \nu\bar{\nu}$

BR ≈ O(10^{-4} - 10^{-9})

BR ≈ O(10^{-11})

$K_L \to e^+ e^-$ $\begin{cases} K_L \to \gamma\gamma,\ K_L \to e^+ e^- \gamma \\ K_L \to e^+ e^- e^+ e^-,\ e^+ e^- \mu^+ \mu^- \end{cases}$

In some cases ($\pi^0 \ell^+ \ell^-$) precision ancillary measurements required to fully extract the short-distance (CKM) information

Aside: a super-DaΦne?

KLOE at Frascati reached $L = 10^{32}$ cm^{-2} s^{-1}.
Need 10-20 fb^{-1} (exp. 2 fb^{-1} in 2004) for significant improvement on $K_S \to \pi^0 \ell^+ \ell^-$ (non-optimal acceptance).

Can a high-luminosity ϕ-factory contribute? (tagged K, known momentum)
[*Workshop on e^+e^- in the 1-2 GeV range* (Sett. 2003)]
[F. Bossi et al., EPJ C6 (1999) 109]

Required luminosity for $\pi\nu\nu$ experiments: 10^{35} cm^{-2} s^{-1}.
(Assuming "realistic" detector and vetos).

Discussions for a future (5 years) ϕ-factory for KS physics.
Extrapolating known approaches $L = 10^{33}$ to 10^{34}.
20-100 $K_S \to \pi^0 \ell^+ \ell^-$ events can be collected.
"Conventional" @ 0.5 GeV (4π detector) or "Large crossing-angle" @ 1 GeV (forward detector) options.

Not on the horizon.

$$BR(K_L \to \pi^0 e^+ e^-) = 10^{-12}\left[< 3 + 15.7|a_S|^2 + 2.4 \oplus 6.2|a_S| \right]$$

- CPC (th. + $K_L \to \pi^0\gamma\gamma$)
- CPV ind ($K_S \to \pi^0 e^+ e^-$) 50%
- CPV dir 8%
- CPV int 25%

$$BR(K_L \to \pi^0 \mu^+ \mu^-) = 10^{-12}\left[5.2 + 3.7|a_S|^2 + 1 \oplus 1.6|a_S| \right]$$

$$|a_S| = 1.08^{+0.26}_{-0.21} \quad \textbf{(NA48)}$$

- CPC (th. 30% + $K_L \to \pi^0\gamma\gamma$)
- CPV ind ($K_S \to \pi^0 \mu^+ \mu^-$) 50%
- CPV dir 10%
- CPV int 25%

•Error dominated by CPV_{ind}: need several 100s $K_S \to \pi^0 \ell^+ \ell^-$ (and improvement in theory).

•Sign of interference term crucial; only from theory (positive favoured).

•Background subtraction will be an issue: irreducible $\gamma\gamma\ell^+\ell^-$ at $1.5 \cdot 10^4$ and $8 \cdot 10^2$ hard to reduce below signal. Tight cuts → acceptance → **flux**.

•ee mode requires very good π/e separation: more material (TRD). μμ mode might turn out to be easier (also more handles, small CPC in low mass region).

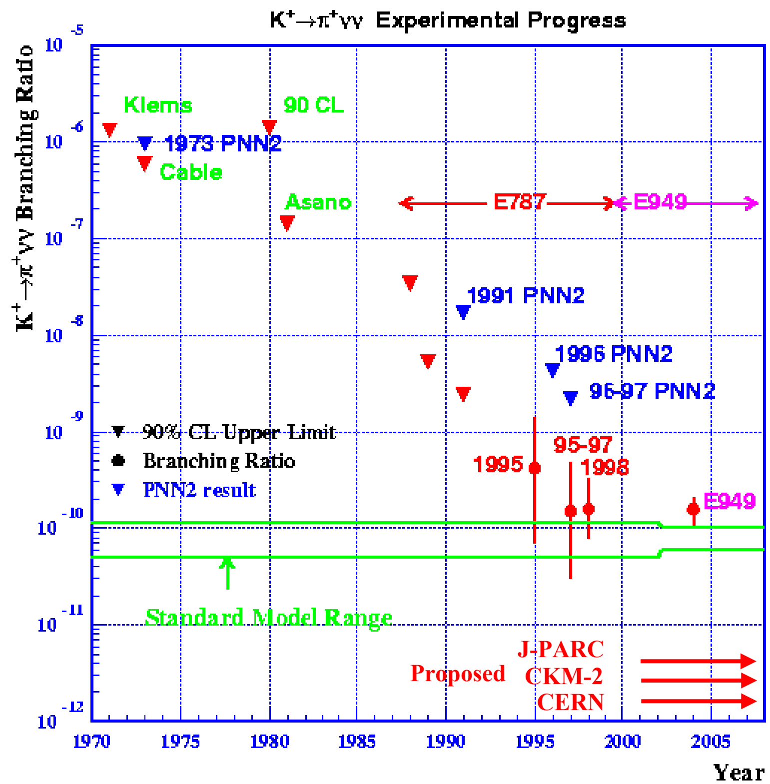
•With very high fluxes more approaches are available: Dalitz plot analysis, time evolution (interference) or polarization analysis (μ mode): $O(10^{14}$ K).

$K^+ \to \pi^+ \nu\bar{\nu}$

BR(SM) ~ 10^{-10} (3 events).
Theoretical uncertainty ~ **7%**
(going down to **2%** ?)

Background from K and beam:
no kinematic constraints.
Suppression 10^{11}: limited by physical processes. Redundancy, particle ID, kinematics, vacuum, live-time, VETO !!!

- Stopped K^+ approach has limits (stop fraction, slow PID, solid angle, π scatter, vetoing).
- In-flight approach (new): needs p_K measurement, no scattering, faster, better vetoing).



Will have some 10s of events

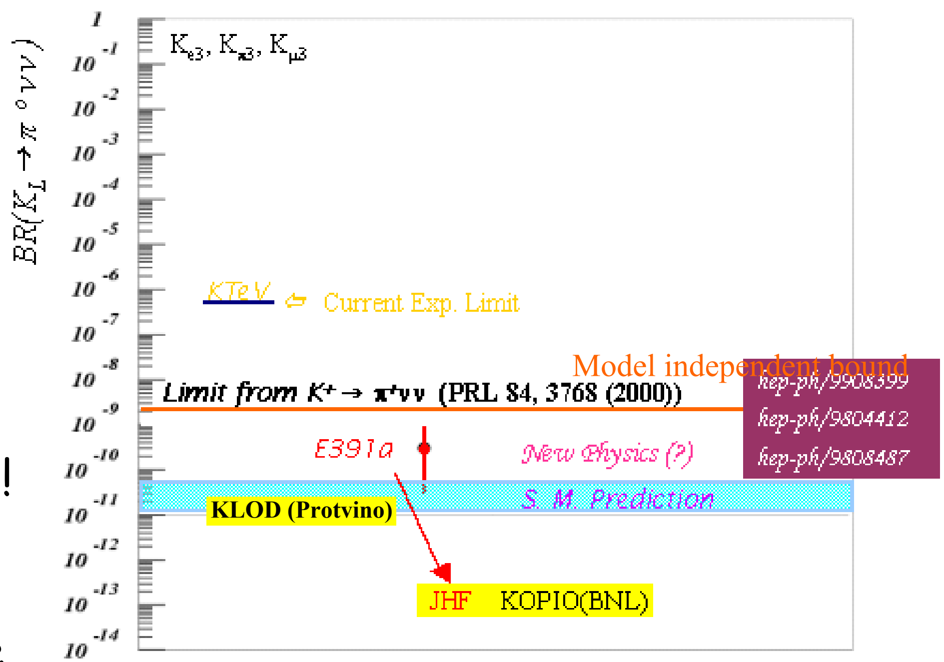
$K_L \rightarrow \pi^0\nu\bar{\nu}$

"Direct" CP-violating
BR ~ $3\cdot10^{-11}$ (or NP?)
(limit $5.9\cdot10^{-7}$, bound $1.7\cdot10^{-9}$)
Theoretical uncertainty ~ **1-2%.**

Background from $\pi^0\pi^0$.
$\gamma\gamma$ mode, n flux, hyperons, vacuum, material, live-time.
Very few handles: missing p_T, VETO!!!

- KOPIO approach (40 events)
- KAMI-(KEK)-JPARC approach: large acceptance, pencil beam (flux), rate! (100-1000 events)

Several options (DC, energy, barrel detection,...



Will have few 10s of events

New projects starting/proposed

		Tp/s	MK/s
K_L KOPIO (BNL):	2010+ on track	14	33
K_L (J-PARC):	2008++ (beam line? accidentals?)	60	320
K_L KLOD (Protvino):	2007+	1.1	9
K^+ (CERN):	After R&D, 2009+ (tracking?)	0.2	9
K^+ CKM-2 (FNAL):	Re-design, 2009+ (tracking?, veto?)	2	3(?)
K^+ (J-PARC):	2008+ (improvements?)	23	2.3
K^+ OKA (Protvino)	2005+ ($K \to 3\pi$)	1.1	0.6

Future scenarios

Experiment: the coming generation of experiments will reach the 10-100 SM events level for $\pi\nu\nu$ decays.

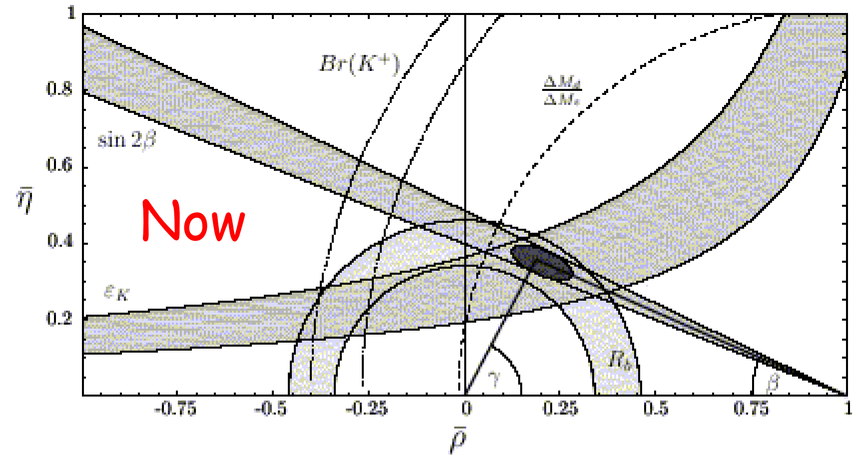
Theory: existing precision data on K system will become quantitative checks of SM (or constraints to NP). Precision on $\pi\ell\ell$ decays will improve to 1-2-5%.

(a) $K \to \pi\nu\nu$ in agreement with SM: for both modes 1 order of magnitude to go to close the window for NP

(b) $K \to \pi\nu\nu$ in disagreement with SM: precision measurement O(1000), access to form factor, other kinematical regions, Dalitz plot, time-interference, $K\to\pi\ell^+\ell^-$

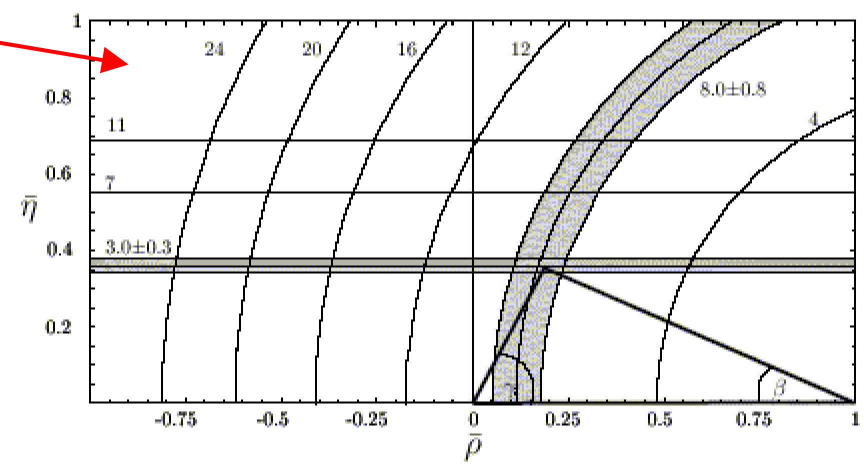
Future scenarios

Impact on unitarity triangle
Buras et al.
hep-ph/0405132



10% 201x   5% 201xx

	Scenario I	Scenario II
$Br(K^+ \to \pi^+ \nu\bar{\nu})/10^{-11}$	8.0 ± 0.8	8.0 ± 0.4
$Br(K_L \to \pi^0 \nu\bar{\nu})/10^{-11}$	3.0 ± 0.3	3.0 ± 0.15
m_t[GeV]	168 ± 3	168 ± 1
$P_c(X)$	0.39 ± 0.03	0.39 ± 0.02
$\lvert V_{cb}\rvert/10^{-3}$	41.5 ± 0.6	41.5 ± 0.4

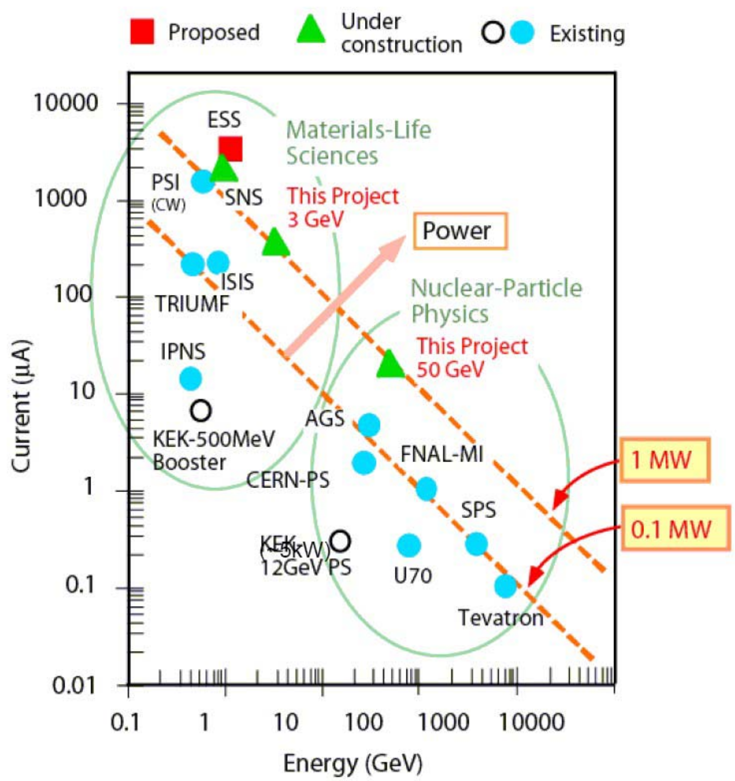


Future machines?

A high intensity p driver (>10^{14} ppp) would be very valuable for "ultimate" K measurements.
Sinergies with neutrino physics? With LHC injectors upgrade?

Energy in the tens of GeV range, slow extraction (high DC)

Intense K^+ beam: $K^\pm$ CP asymmetries
Intense K+ RF-separated beam: $K^+ \to \pi^+\nu\nu$
Tertiary K^0 beam: CPT tests at Planck scale ($K \to \pi\pi$ phases)
Intense K_L beam: $K_L \to \pi^0\nu\nu$, $K_L \to \pi^0 e^+e^-$, $K_L \to \pi^0\mu^+\mu^-$ (with several handles), diverse program



Remember KAON at TRIUMF

The ultimate kaon (+ much more) machine
1985-1993 R.I.P.

30 GeV - 3MW - 100 μA
625 Tp/s

2 RCS + 3 SR
450 MeV → 3 GeV → 30 GeV + stretcher ring

6 K^+ beams: 0.5-21 GeV/c
1-6% $\Delta p/p$
$(0.6\text{-}3.7) \cdot 10^8$ K^+/s

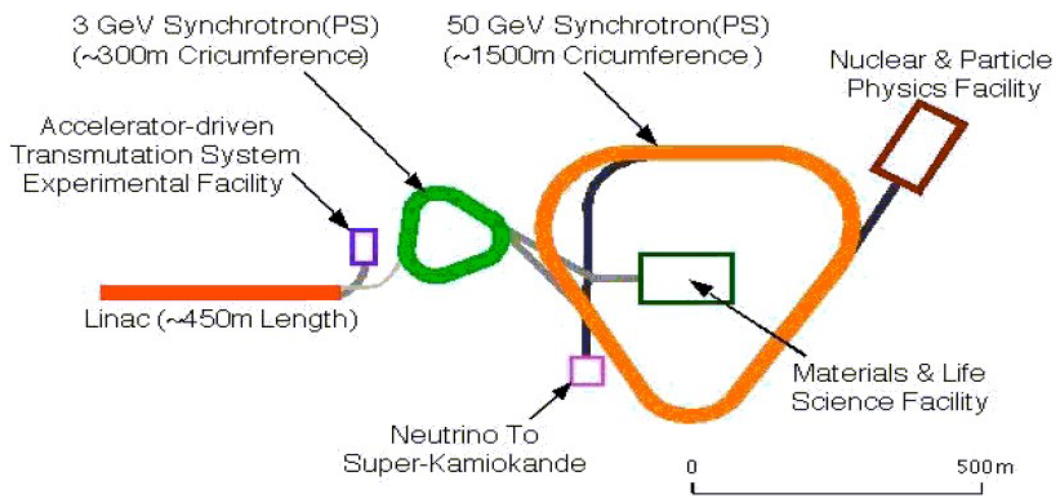
J-PARC at Tokai: phase 2

Phase I: 30 GeV, 0.75 MW
9 μA, 2×10^{14} p/spill
60 Tp/s
0.7s/3.42 s (DC 20% !)

Start physics: 2008

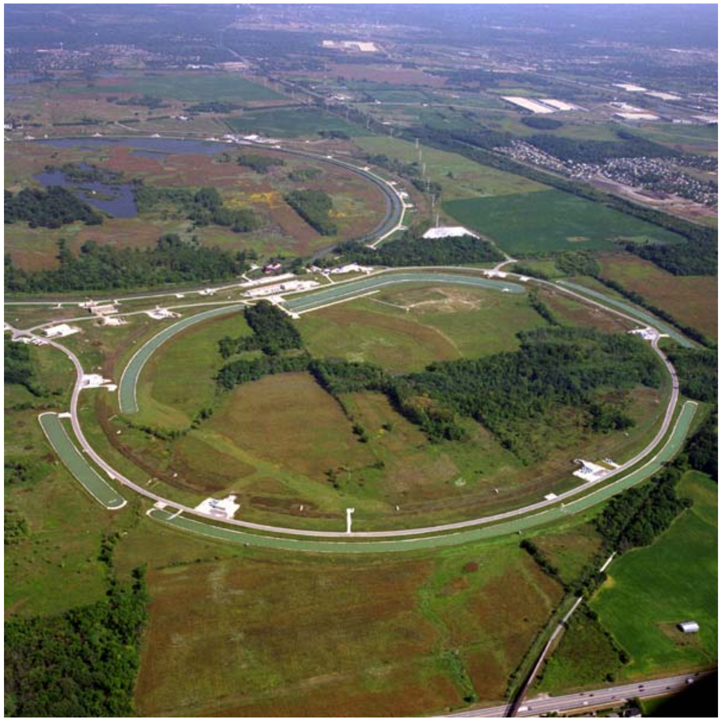
Phase II: 50 GeV, 4 MW
15 μA, 3.3×10^{14} p/spill
94 Tp/s

Better DC required (otherwise
<I> = 6xAGS but I = 15xAGS)



5 HEP kaon physics LoI:
$K_L \to \pi^0\nu\nu$, $K^+ \to \pi^+\nu\nu$, T-violation, BR(K^+), K_{e3}
2 kaon lines initially foreseen:
0.8 - 1.1 GeV K^+ and 2 GeV/c K_L (?)

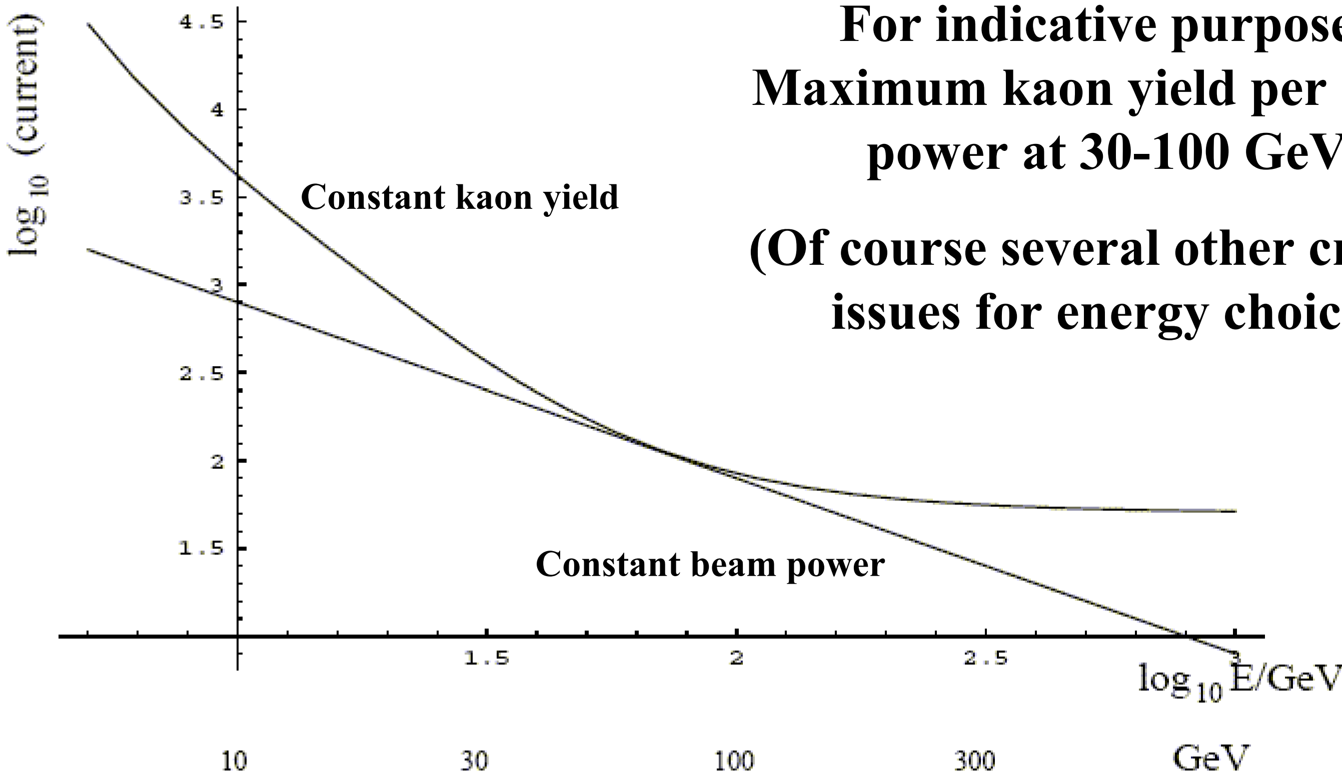
High-intensity upgrades?



BNL: 0.2 MW
More booster cycles: AGS x 1.7
+ accumulator ring: AGS x 3.4
34-60 Tp/s

FNAL: 1 MW
8 GeV p LINAC
5 x MI flux @ 120 GeV
55 Tp/s

Kaon production



For indicative purposes Maximum kaon yield per given power at 30-100 GeV

(Of course several other crucial issues for energy choice)

G. Kalmus, CERN-TH/2001-75

A new proton driver?

Ballpark numbers

Assume: **4 MW** accelerator + stretcher ring

Unseparated ($\pi/K \sim 10$):
30 GeV (7.5 GeV K) 133μA (830 Tp/s: 20xAGS)
120 GeV (30 GeV K) 33μA (210 Tp/s: 7xMI)
400 GeV (100 GeV K) 10μA (63 Tp/s: 9xSPS)

O(few 10^{10}) K^+/s
THz beams

RF-separated (p_K < 50 GeV, O(70%) purity):
50 GeV machine: maximum K^+ yield at 12 GeV (0.48 K^+/p/GeV/sr)

Target efficiency	40%
Beam momentum	12 GeV/c ± 1%
Beam acceptance	75 μsr
Separator acceptance	50%
Duty cycle	30%
K^+/year (10^7 s)	$2.6 \cdot 10^{15}$
K^+ decays/year (in 30m)	$6 \cdot 10^{14}$

$3 \cdot 10^8$ K^+/s
With 2% acceptance*eff:

1000 $K^+ \to \pi\nu\nu$ events/year
(BR at 3%, ultimate)

with beam rate: 1.2 GHz

New K beams

Maximum K^+ yield at fixed beam momentum p: $p_K/p = 0.23$

Naively: fixing this, beam power and geometry:

$N_K = \Phi(p)\,\sigma(p)\,\Omega(p) \propto (1/p)\,p^2\,(1/p)$ for unsep. beam

$\propto (1/p)\,p^2\,(1/p^4)$ for sep. beam

(moreover: decays in fixed volume $\propto 1/p$)

1. Intense K+ beam
2. RF-separation needed at high intensities for measurements requiring kaon tracking: low energy (p_K=30 GeV survival < 0.4), compromise with exp. technique
3. Production of pure K^0 (interference experiments) by charge-exchange at 0° (same p and $\Delta p/p$, 80μb CEX cross-section, factor ~ 10-3): narrow band or separated (?) K^+ beam
4. Neutral broad band beam: need space for sweeping, dump, shielding (higher E): O(few 10^9) K/s: O(1000) $K_L \to \pi^0 \nu\nu$ events

(Some more) experimental issues

High-intensity beams: target, halo, collimation, sweeping, neutron absorber, collimator scattering, secondary production,…

Energy choice: K yield, n,γ,π,hyperon yield, K survival (separated beams), resolutions and veto capability, interactions, acceptance,…

Rates in detectors (E781: 20 MHz/m^2, HyperCP: 30 MHz/m^2, CKM-1: 50 MHz)

DAQ live-time, monitoring, statistics:

E949: 2E12 K dec. @ 700 MeV/c DC-sep. (π/K=3)
E787: 5E12 K dec. @ 700 MeV/c DC-sep. (π/K=4)
NA48/2: 2E11 K dec. @ 60 GeV/c unsep. (π/K=10)
KTeV: >2E11 KL dec. @ 100 GeV/c
KOPIO: 1E14 KL dec. @ 700 MeV/c
E391a: 2E11 KL dec. @ 2 GeV/c
J-PARC KL: 4E14 KL dec. @2 GeV/c

Thirsty for flux?

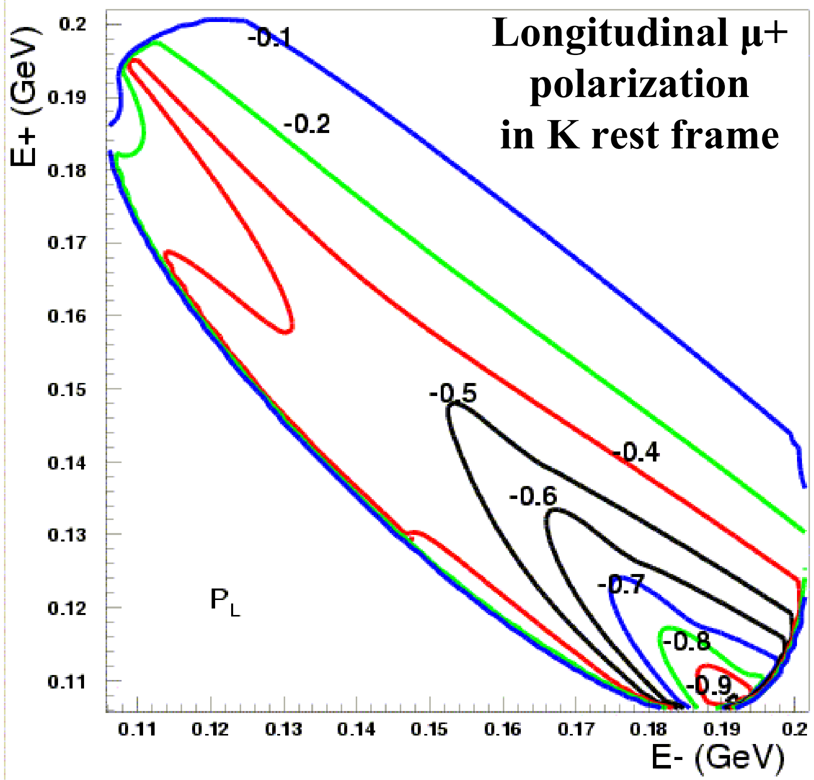
- Sensitivity
- Tighter cuts to control background (pencil beam)
- Absorber for n, targeting angle choice (at 1.6/p angle n/K x1/6 for K yield x0.6)
- Other approaches: Dalitz plot, time-interference analysis, polarizations

Example:
polarization measurements

In the case of $K_L \to \pi^0 \mu^+ \mu^-$ longitudinal μ polarization (P-odd) is non-zero only in presence of direct CPV.

Single-muon polarization measurement is sufficient; large effects.

This helps reducing background and disentangling amplitude components, at some price on statistics



Diwan et al.
PRD 65 (2002) 054020

Outlook:
more fundamental physics with K?

- Importance of K in shaping the SM well known.
- The increase in flux availability led to beyond-state-of-the-art experiments.
- Flavour physics: least understood part of SM, rather unique access to SM or NP couplings before the LC era (the high-precision frontier).
- Flux (not only) required for sensitivity, ancillary measurements, background suppressions (also: improvement in techniques, rate handling,…)
- Existence of clean decay modes stimulated world-wide efforts in an active and strong community with several generations of experience.

Conclusions

A few things are clear:

The information to be gained from rare K decays is not going to be exhausted with the arrival of LHC.

It's not going to be complete by then, either.

The focus is on SD precision rare decays (experiments starting now). These experiments are hard enough that they will require double-checks and complementary approaches.

The quality of the data is as important as the statistics: higher fluxes are crucial for control of backgrounds and systematics.

A high-intensity (MWs, tens of GeV, slow extracted) p machine would give an excellent (unique) opportunity to extract all the rich information available from K decays.

Sinergies with neutrino physics program?

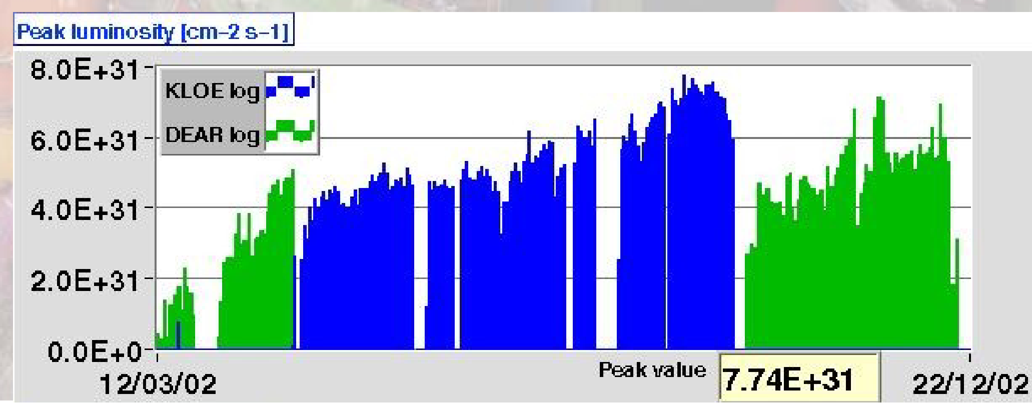
Spare slides

KLOE at Frascati

DAΦNE φ-factory e+e-
Low luminosity at start, constantly improving
Peak luminosity: 8×10^{31} cm^{-2} s^{-1} in 2002
Goal: 5×10^{32} cm^{-2} s^{-1}
500 pb^{-1} (1.5×10^{9} ϕ) collected until 2002.

Currently running.

Good prospects for K_S, interferometry

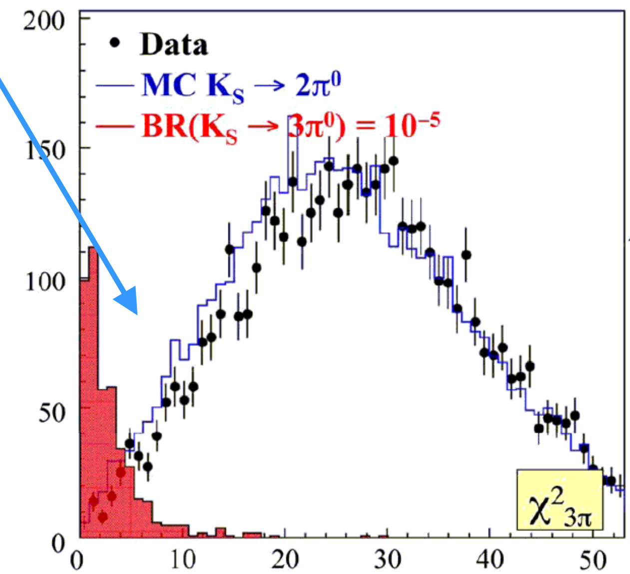


K_S decays: CPV

Search for $K_S \to 3\pi^0$: interf. K_L-K_S at hadron machines, or Φ factories

$BR(K_S \to 3\pi^0) < 3\times10^{-7}$ (90% CL) (NA48/1 prel.)

$BR(K_S \to 3\pi^0) < 2.1\times10^{-7}$ (90% CL) (KLOE prel. 450 pb-1, 4 ev. 3.2 bkg.)



Not yet reached indirect CP violation:

SM expectation: 3×10^{-9}

Dominates indirect CPT violation limits:

$$m(K^0) - m(\overline{K}^0) = (-1.7 \pm 4.2) \times 10^{-19}\ \mathrm{GeV}/c^2$$

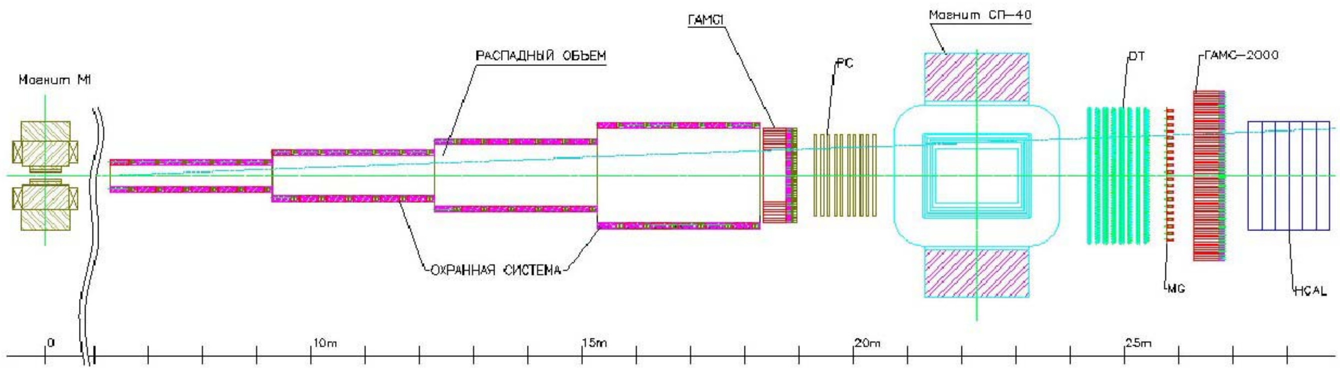
Semileptonic K_S decays (KLOE prel. 170 pb^{-1}):

$$BR(K_S \to \pi e \nu) = (7.09 \pm 0.07 \pm 0.08) \times 10^{-4}$$

K_S charge asymmetry (KLOE prel.):

$\delta_S = (-2 \pm 9 \pm 6) \times 10^{-3}$ ($\to \pm\, 4\cdot10^{-3}$, still far from CPT test)

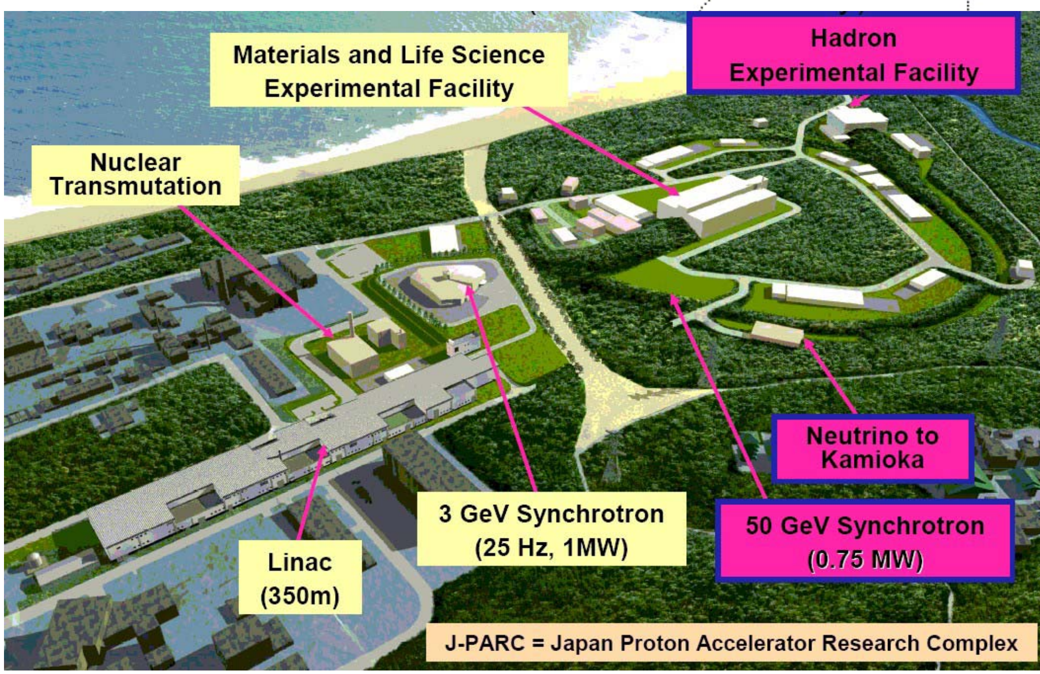
$K^{\pm}$ **decays:** OKA @ Protvino



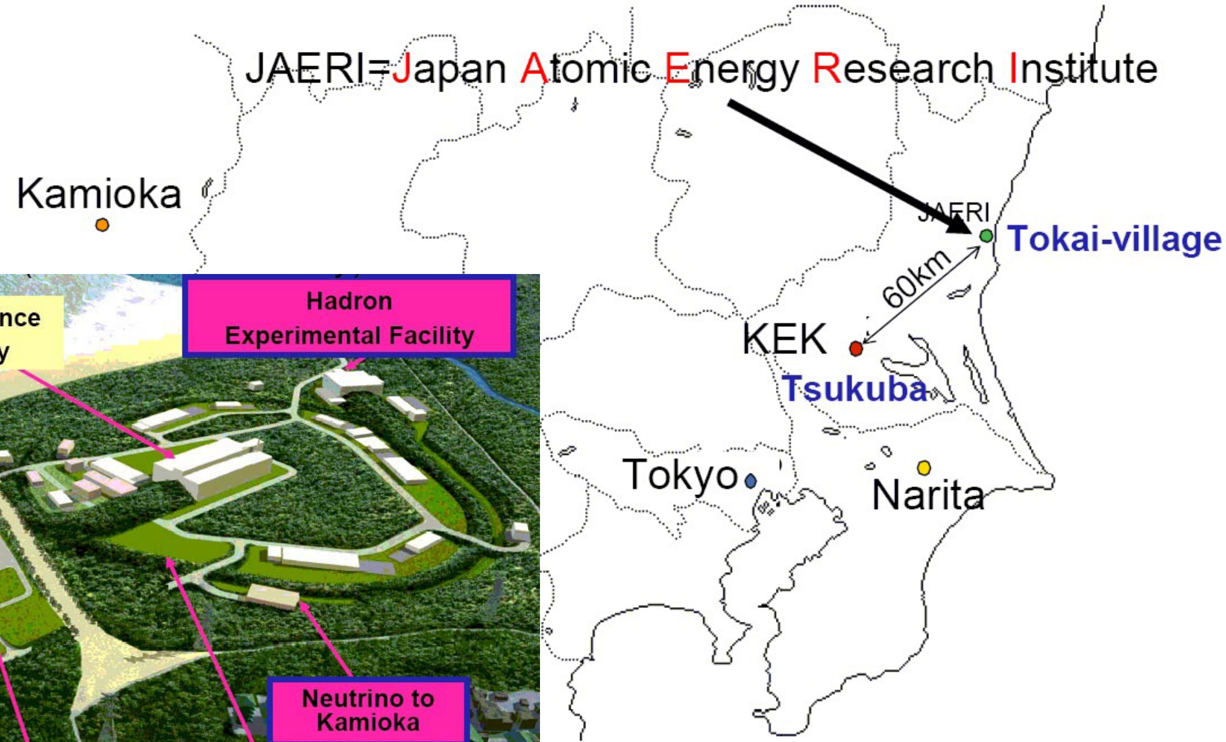
RF-separated beam in preparation at U-70 PS.
15 GeV/c K^+ or K^- (alternated), detector from ISTRA+, GAMS.
Asymmetries of Dalitz plot slopes in 3π decays at $O(1 \times 10^{-4})$
T-odd correlations, search for New Physics in K_{l2} decays

2003: 1/2 beam line, cryogenics, slow extraction of $1.3 \cdot 10^{13}$ ppp
First physics run in 2005

J-PARC @ Tokai



Materials and Life Science Experimental Facility
Hadron Experimental Facility
Nuclear Transmutation
Neutrino to Kamioka
3 GeV Synchrotron (25 Hz, 1MW)
50 GeV Synchrotron (0.75 MW)
Linac (350m)
J-PARC = Japan Proton Accelerator Research Complex



JAERI=Japan Atomic Energy Research Institute
Kamioka
JAERI
Tokai-village
60km
KEK
Tsukuba
Tokyo
Narita

J-PARC
Requested beam lines

Summary of Requested Beam Lines

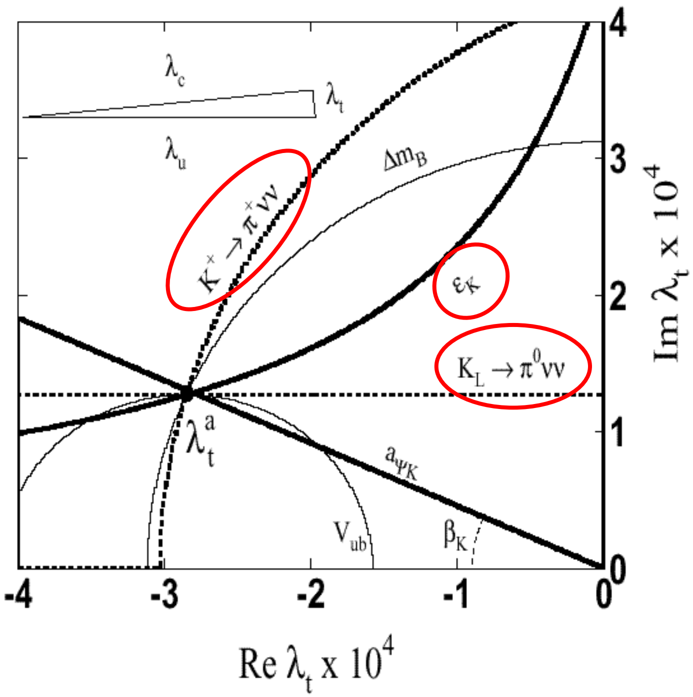
	Contact Person(s)	Requested Beam	Momentum Range (GeV/c)	Phase-1						Phase-2
				K1.8	K1.1	K0.8	KL	Test Beam	High Mom.	Neutrino
LOI-06	K. Imai	K-	0.8, 1.1, 1.8	○	○					
LOI-07	M. Ieiri	K-, π+	1.0-1.6	○	○					
LOI-08	H. Noumi	π+/-	1.0-1.2							
LOI-09	T. Fukuda	K-/π-	0.9/1.0		△					
LOI-10	T. Nagae et al.	K-	0.9, 2-3		○					
LOI-21	S. Ajimura	K-/π+	0.8/1.0		○					
LOI-01	V.V.Sumachev et a	π+/-	0.6-2.1	△						
LOI-03	A.D. Krisch	p	51						○	
LOI-11	S. Yokkaichi	p	31, 51						○	
LOI-13	H. Spinka, S. Sawa	π,K,p	< 6							
		pol.-p/HI								
LOI-15	J.-C. Peng, S. Saw	p, pol.p, HI							○	
LOI-18	T. Murakami	p	30						○	
		p,π-	4.0-14.0						○	
LOI-23	L. Nemenov	p	30(50)						○	
LOI-04	T.K. Komatsubara	K+	0.6-0.8			○				
LOI-05	T. Inagaki	KL	~2				○			
LOI-16	C. Rangacharyulu	K+				○				
LOI-19	Yu. Kudenko, J. Im	K+	0.6-0.7			○				
LOI-20	S. Shimizu	K+	0.6-0.7			○				
LOI-12	K. Nishikawa	neutrino	~0.8							○
LOI-17	B.L. Roberts	μ+								
LOI-22	Y.K. Semertzidis et	μ+								
LOI-25	PRIME Group	μ-								
LOI-02	S. Komamiya	e,μ,π,K,p	0.5-2, <10					○		
LOI-14	S. Sawada	π,K,p, primar	> 5						○	
LOI-24	PRISM Group	μ								
LOI-26	Y. Kuno, R.S. Haya	anti-p, μ, ..								
LOI-27	Y. Kuno, Y. Mori	neutrino								
LOI-28	V. Obraztsov, T. Ts	K-	~12							
LOI-29	T. Kishimoto									
LOI-30	K. McDonald et al.	p	50							

$K \to \pi\nu\bar{\nu}$ at J-PARC

K_L: follow-up of KEK-E391a
100 MHz *pencil beam* (accidentals, rate x500!), acceptance ~ 16%,
high energy (flux, resolution, acceptance, veto efficiency)
New calorimeters (CeF3 ?) and DAQ
Goal: >100 SM events (SES $3 \cdot 10^{-14}$ max, limit) in 3 years ($2 \cdot 10^{15}$ K_L)

K^+: BNL stopped-K technique
Low energy (600-800 MeV/c) DC-separated (K/π >3) beam
Decays at rest (>25% stop)
Incremental upgrade (x4) of detector, new spectrometer?
Goal: >50 SM events in 3 years (SES 2×10^{-12}: E949/5)

Comparing K and B



Constraints from B and K physics (10% BR measurements):

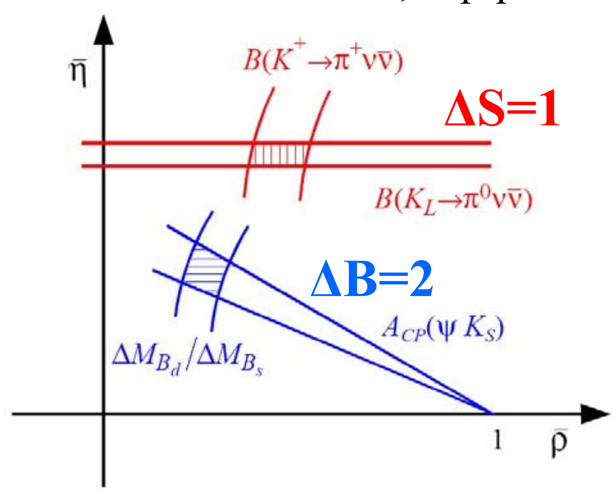
- Errors on ρ, V_{td}: better from B
- Errors on η, $\sin 2\beta$: similar to B- factories
- Error on λ_t: better from K

A. Buras, hep-ph/9905437

Comparing V_{td} from $K^+ \to \pi^+ \nu\nu$ and

$\Delta M(B_d) / \Delta M(B_s)$

Comparing β from $BR(KL \to \pi^0 \nu\bar{\nu}) /$ $BR(K^+ \to \pi^+ \nu\bar{\nu})$ and $A(B_d \to J/\psi K^0)$



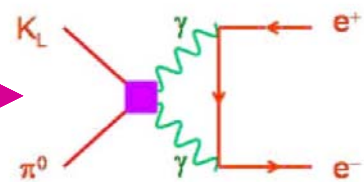
$K_L \to \pi^0 \ell^+ \ell^-$

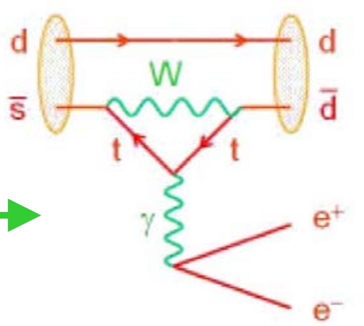
KTeV limits (90% CL):

$BR(K_L \to \pi^0 e^+ e^-) < 2.8\times10^{-10}$
$BR(K_L \to \pi^0 \mu^+ \mu^-) < 3.8\times10^{-10}$

3 contributions to these decays:

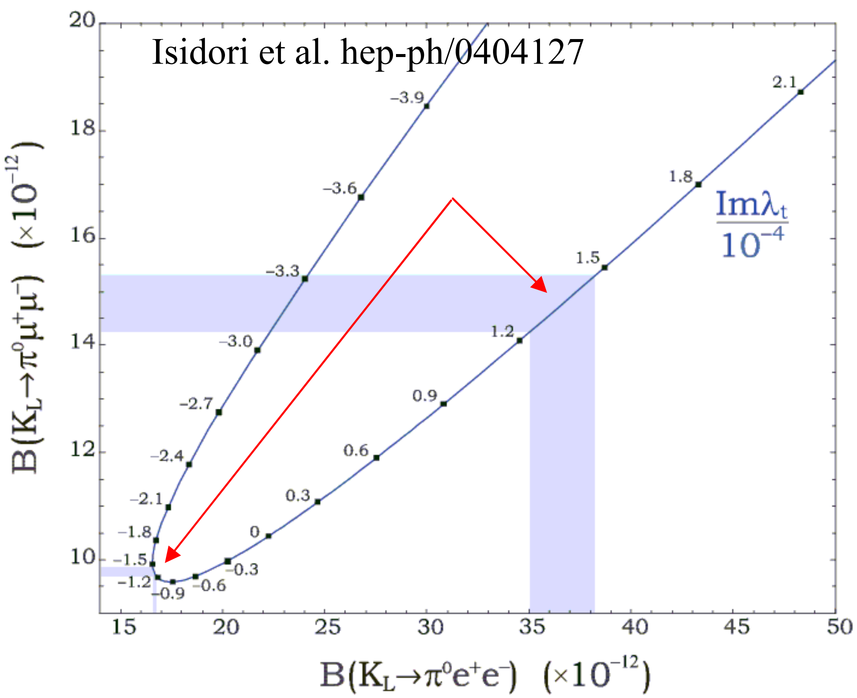
- **CP-allowed**: not predicted, derived from $K_L \to \pi^0\gamma\gamma$ (NA48, KTeV)
- **Indirect CP violation**: not predicted, measured by $K_S \to \pi^0\ell^+\ell^-$ (NA48/1)
- **Direct CP violation**: predicted in terms of CKM phase





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

- K_L measurements: CP-allowed contribution is *small*.
- K_S measurements: indirect CP-violating term *dominates*.
- Sensitivity of BR to CKM phase depends on the (unmeasurable) *relative sign* of the two CP-violating terms. Theoretical predictions: *constructive* interference.



$$BR(K_L \to \pi^0 e^+ e^-)_{CPV} \times 10^{12} \approx 17 \text{ (ind)} \pm 9 \text{ (interf)} + 4 \text{ (dir)}$$

$$BR(K_L \to \pi^0 \mu^+ \mu^-)_{CPV} \times 10^{12} \approx 8 \text{ (ind)} \pm 3 \text{ (interf)} + 2 \text{ (dir)}$$

Future projects and goals

Main focus on the measurement of ultra-rare decays: theoretically clean, highly sensitive, complementary to B

Also:
T-violation searches
CP asymmetries in charged K