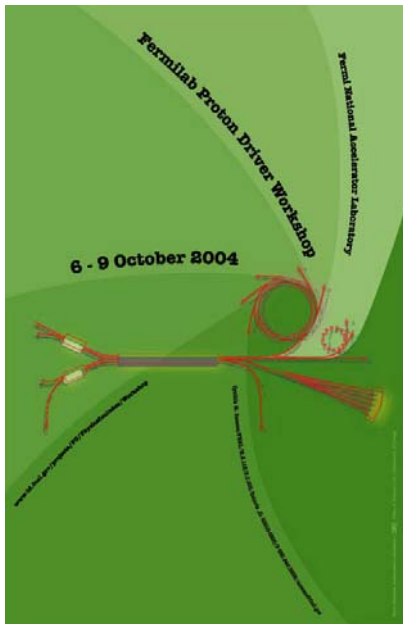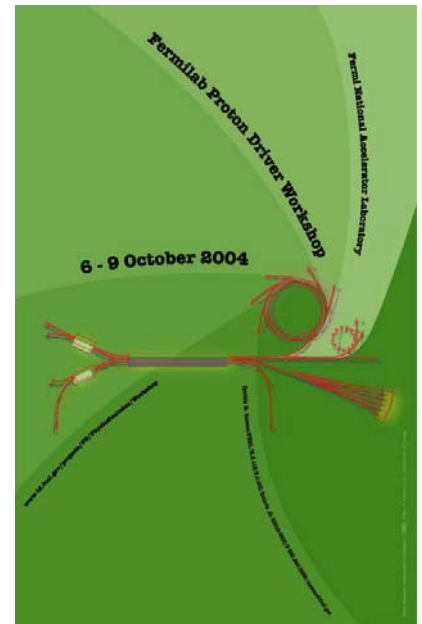# Experimental Challenges of Proton Driver Era Experiments (Starting 2015-2020)

R. Tschirart

Fermilab

Oct 8th 2004

Predicting the Future is Hard…

MicroSoft Team….Early Days.

And even worse…how many us thought these machines would one day rule our lives?
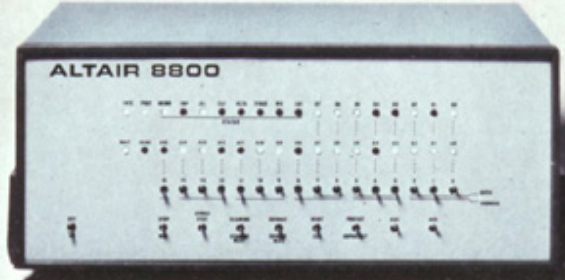
Ultra-Rare Decay Challenges Today

- Infidelity of Approval and Support bodies.
- Programmatic Research usurped by Projects.
- Accelerator macro-Duty Factors.
- High Rates, Veto Blindness.
- Target & Beamline Irradiation.
- Uncertainties of high performance vetoing.
- Ultra-low mass & high speed tracking.

Kaon Physics Treasure Hunt; (Largely identified in 1989 Main Injector workshop)

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},   High Statistics Time evolution of Ke3 decays.

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)
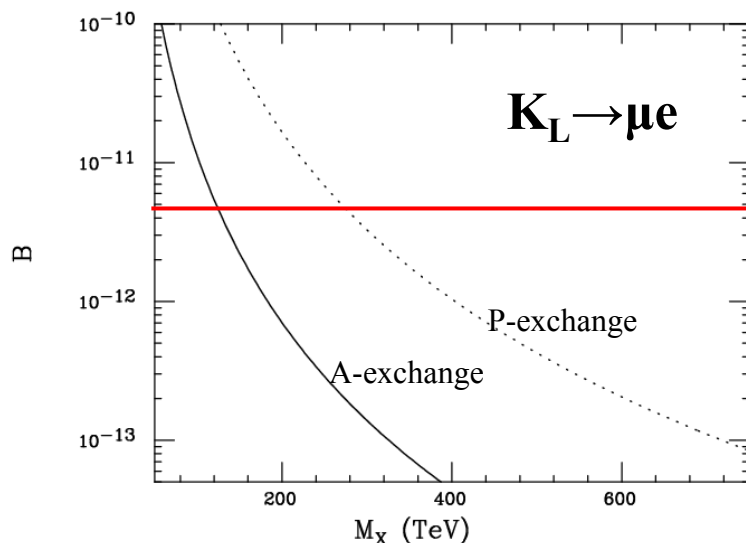 $K_L \to \pi^0\ell^+\ell^-$, $K_L \to \pi^0\nu\nu$, $K^\pm \to \pi^\pm\nu\nu$

e.g., Lepton-flavour violation

Stringent limits reached.

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

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

$K_L \rightarrow \mu e$

P-exchange

A-exchange

No new experiments planned.

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

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

New results still expected from high-flux experiments.

Pion Decay Treasure Hunt

o π^+ decay physics

- $\Gamma[\pi^+ \rightarrow e^+ \nu(\gamma)] / \Gamma[\pi^+ \rightarrow \mu^+ \nu(\gamma)]$ is calculated to 0.05% in the SM, measured to 0.4% by PSI & Triumf.

- Helicity suppresses the dominant V-A and IB amplitudes

- $\pi^+ \rightarrow e^+ \nu \gamma$ Dalitz plot – access to non V-A terms in hadronic weak current

- An excellent place to search for models like leptoquarks, multiple Higg, etc.

Now and Then…How will the Meta-Challenges in 2015 Differ from Now?

- Programmatic concerns: How will the absence of a Rare Decay Physics Program at Fermilab in 2005-2015 affect mounting a program at Fermilab in 2015?….Badly. Fatal?

- Rare decay measurements require high accelerator duty factors. At Fermilab this is the Main Injector or the Main/Injector with a Stretcher Ring. Is this feasible? Supportable? Advisable? More on this later….

Rare Decays have Advanced Programmatically.

For a program to viable in 2015, then the next step of JPARC/KOPIO, FNAL-P940 and/or CERN-NA48/3 must proceed and precede.

$K^+ \rightarrow \pi^+ \gamma\gamma$ Experimental Progress
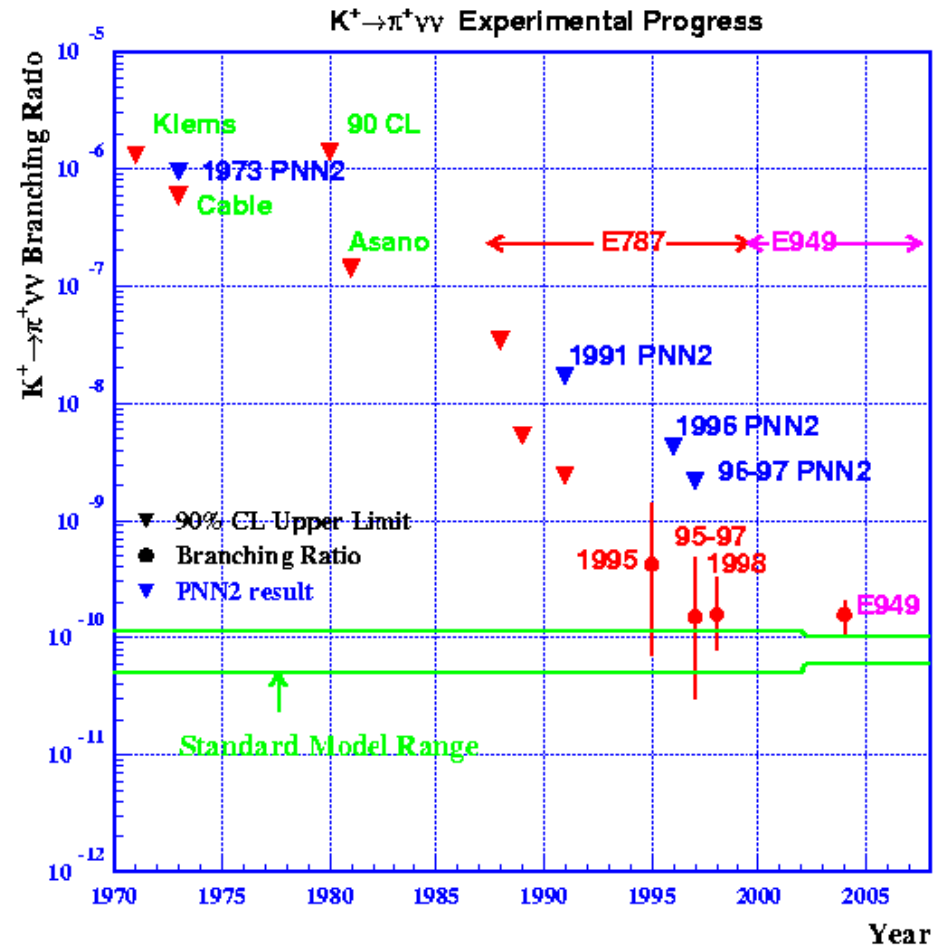
World enough & time for K→πν$\bar{\nu}$
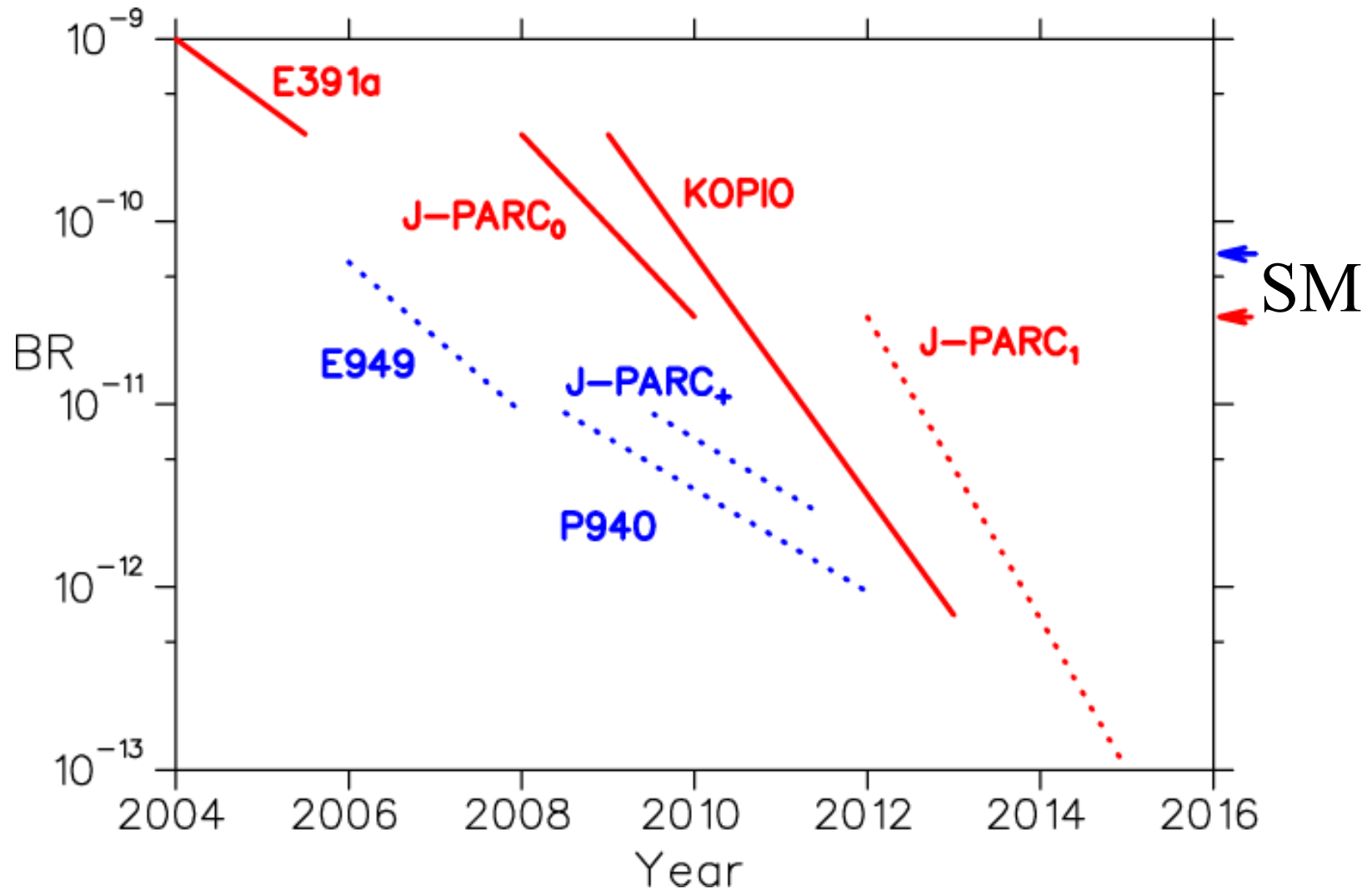
Do we need multiple experiments?

- If we can't get a 4×10^{-1} BR right to 5%

$B(K_L \rightarrow \pi e \nu)$
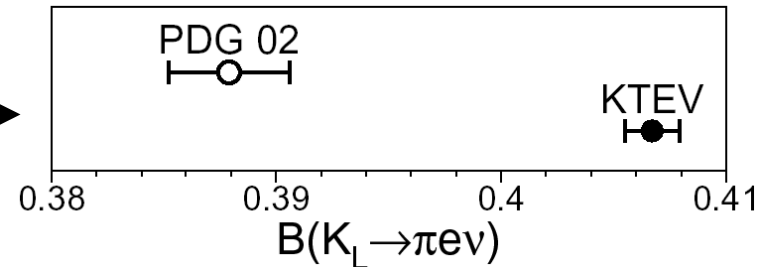
- & we can't get a 2×10^{-1} BR right to 8%

$B(K_L \rightarrow 3\pi^0)$
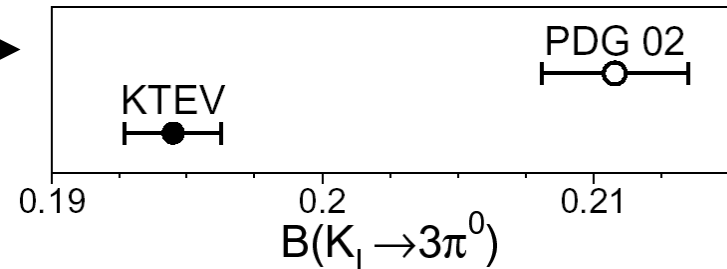
- Are we really going to get a **few $\times 10^{-11}$** BR right to 10% the first time?

A Flavorful, But Not Crazy Scenario in 2015…

- $K \to \pi\nu\nu$ measured with statistics of ~100 events. $K^+ \to \pi\nu\nu$ is x2 SM, $K_L \to \pi\nu\nu$ is x4 SM. Theory improved to 1% in both modes.

- LHC has hints of SUSY.

- BTeV/LHCb mature, complex set of subtle non-conformities of B decays with the Standard Model.

- Daphne has made precision measurements of rare K_S decays, substantially refining SM expectation of $K_L \to \pi^0 e^+ e^-$ CP components in rare K_L decays.

Elements of the 2015+ Challenge

- High duty factor required for rare decays, in contrast to neutrino physics program. This will be a source of tension, but solvable.

- Beam and Target Issues SNS target station experience…. >$100M to get on the air? Where is this budgeted?? Worse for neutrinos.

- Detector Issues. Zero-mass & Ultra-speed; Is this the end of the open geometry era? Or more extreme, the end of the counter-based experimental era?

- Political Issues.

…Some Things Will be Easier

- Possibility of compelling new physics from the LHC or B, K and π decay physics that will motivate further incisive flavor physics studies.

- Triggering, DAQ and Computing.   Zero-mass high rate pixels?

- We will have perspective of what worked and what didn't from the 100-event $K \rightarrow \pi \nu \nu$ experiments.

Measurement Strategies in 2015?

- **Sensitivity Frontier:** Next-to-Next generation sensitivity experiments (1000 $K \rightarrow \pi \nu \nu$ events) will require even lower veto blinding (speed) and next to zero mass. Technologies? Duty Factor!

- **Precision Frontier:** Acceptance control tricks ala Re(ε'/ε) Double Ratio. Can we do this for $\pi e2/\pi \mu 2$ Ratio to the 1×10^{-4} level? CPT tests of δ_e and $\delta_e(\tau)$?

Future machines?

A high intensity p driver (>10^{14} ppp) would be very valuable for "ultimate" K measurements.
Synergies 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+ → π+νν

Tertiary K^0 beam: CPT tests at Planck scale (K → ππ phases)

Intense K$_L$ beam: K$_L$ → π^{0}νν, K$_L$ → π^{0}e$^+$e$^-$, K$_L$ → π^{0}μ$^+$μ$^-$ (with several handles), diverse program

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
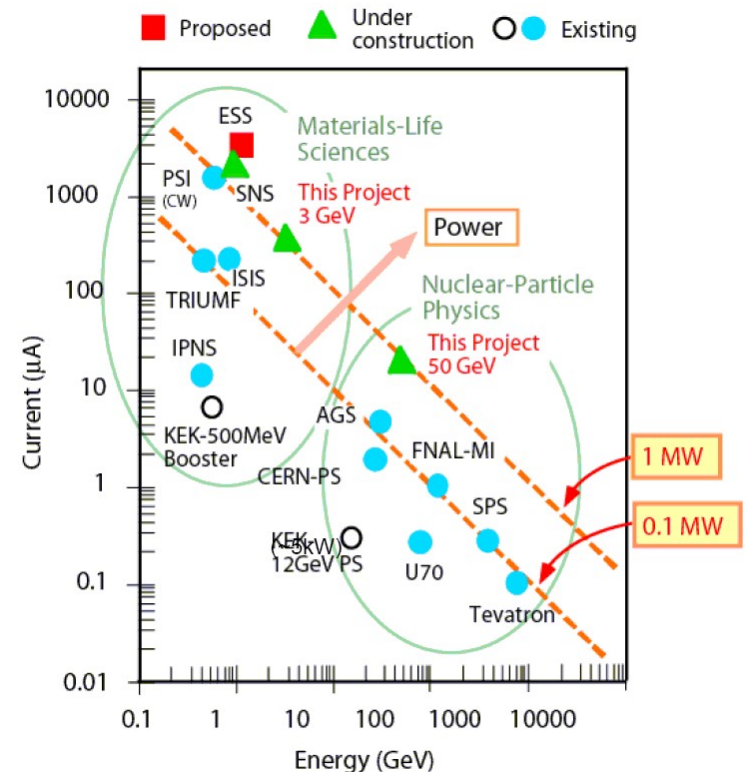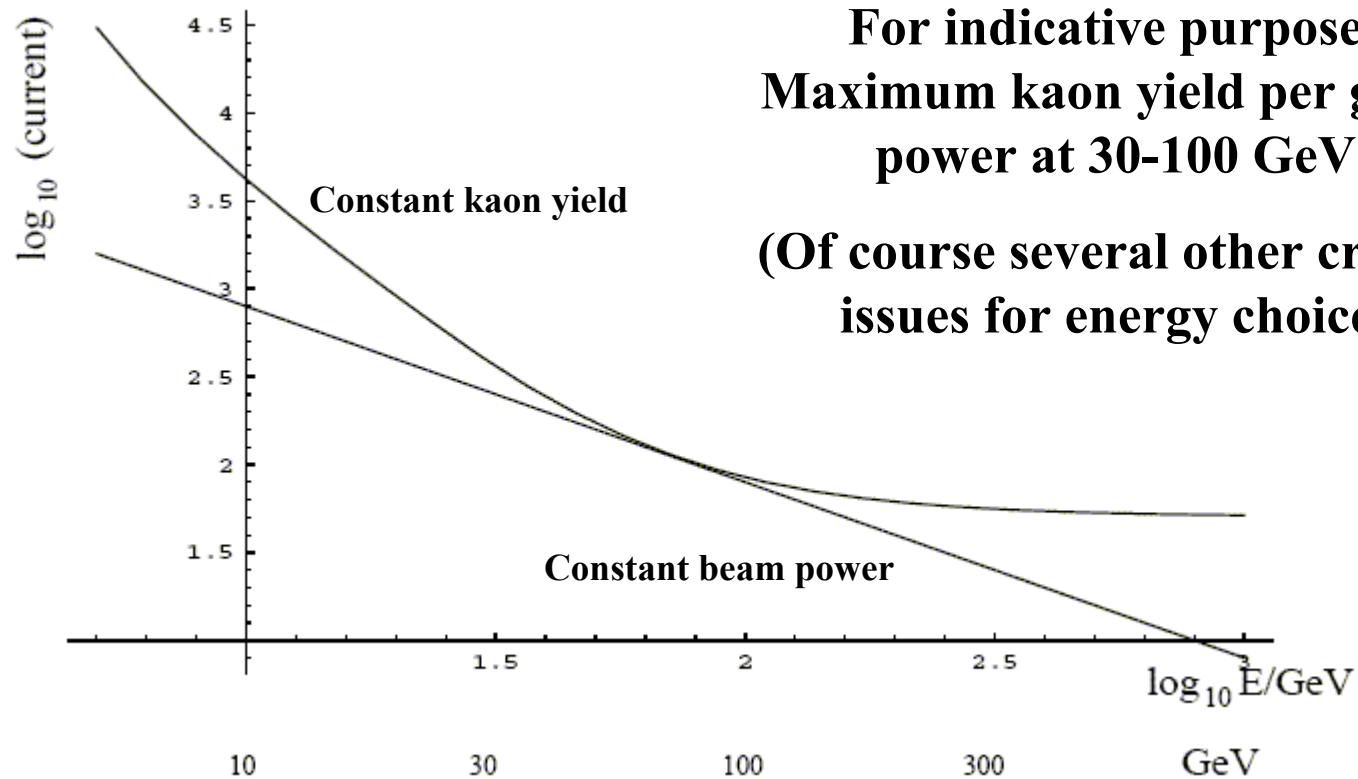
Is There a Future for e^+e^- Kaon Drivers?

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.

What Fermilab Machines are/would-be Optimal Vehicles for Rare Decay Studies.

It's the Duty Factor Stupid! The 8 GeV Linac has only a 1-3% duty factor.

The Main Injector could support a 50% duty factor assuming lower energy running, 30% is straight forward duty factor.

Program Planning Issues

A Stretcher Ring has been discussed for both the 8 GeV Linac and the 120 GeV MI. This will not be free. (>$30M)

The Main Injector is capable of simultaneously providing 2/3 of the possible maximum to both the neutrino and slow-spill programs. Other labs that actually have a rich program deal with this Program Planning problem.

Detector Issues

- Is there a future for Open Geometry? Rates? Limits of Acceptance understanding. KTeV V_{us} analysis demostrates 0.5% absolute acceptance understanding in Open geometry.

- Is there a future for high-mass stopping detectors?

- Nearly Zero Mass Detectors. RICHs, Pixels.

- Limits of TOF/Cerenkov tagging?

- Take a page from the Atomic Physics Playbook: Integration/Frequency Measurements?

"Closed" Toy Geometries that require very high fluxes….

- $K_L \rightarrow \pi\nu\nu$, πe2/$\pi\mu$2: Very long, narrow fully active pipe, effectively all species decay in pipe. Zero mass decay volume. Micro-bunched pencil beam entering instrumented pipe enables kaon momentum measurement with TOF.

- $K^+ \rightarrow \pi\nu\nu$: Pencil beam in a solenoidal field decay volume with a narrow pass for max P_t pions. Aggressive muon veto still required.

More Detector Issues.

- Limits on High Energy muon tagging?
- Limits on High Energy photon tagging?
- DAQ/Trigger limits?
- The race to zero-mass detection: H_2/He RICHs, ultrathin pixels?

Beam and Target Issues

- Time Structure: Flat or micro-bunched?.
- Duty Factor (Stretcher?)
- Optimal energy. Yield, Tagging, Vetoing.
- Beam Purity.
- Target radiation loads, servicing!
- Beam Halo, Halo content. How small of a pencil beam can you make?

Beam Time Structure.

- 8 GeV Linac capable of 5 psec FWHM, nominal 50 psec. 10 Hz macro-cycle. Can we take advantage of this? 1 psec Cerenkov devices? 1-3 msec, 10 Hz, 1-3% duty factor.

- MI: 1.5 sec max rep rate.

- Gap between pings is: 53 Mhz (Sync) 325 MHz for LINAC.

Political Issues

- Approval threshold is high, siege armies required to protect resources. Must fan-out/recruit supporters into review bodies.

- Non traditional collaborators: Our theory colleagues, nuclear physics? commercial partners?

- Meta-Collaborations? Federation of rare decay experiments?

- Danger of on-the-cheap/Danger of not on-the-cheap.

- Marquis backing from proton driver community required from outset…Main Injector experience.

Project Management Issues

- In a broad meta collaboration, who controls resources? Labs? Collaborations?

- Project management is a non-trivial burden; BTeV WBS is 17K lines ($206M TPC), project staff of 5+ and 12 Level-2 managers needed to make it run.

Messages to Carry to the Summary Talk (I).

- Yes, there is a exciting continuous program of rare decay physics that requires a high flux of protons. Other labs JPARC, CERN, and even DAPHNE have validated this.

- The history of rare decay progress clearly demonstrates that programmatic evolution is required, not a luxury. Interest in a Proton Driver rare decay program is coupled to realizing the mid term rare decay program at Fermilab.

Messages to Carry to the Summary Talk (II).

- Lots of Proton Drivers are being talked about, one is actually being built (JPARC). That facility grew from a broad base of partner experiments.

- Rare Decays require High Duty factor first, energy options second.

- Scientists will vote with their feet. If Fermilab wants to be a destination, then the lab will have to acknowledge the rare decay program as an equal partner.

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) $K_L \rightarrow \pi^0 \nu\nu$ events