Summary of the Kaon Physics Parallel Session at NP04..

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I. Why are we doing this Physics?

II. LOI's Discussed and the World Scene.

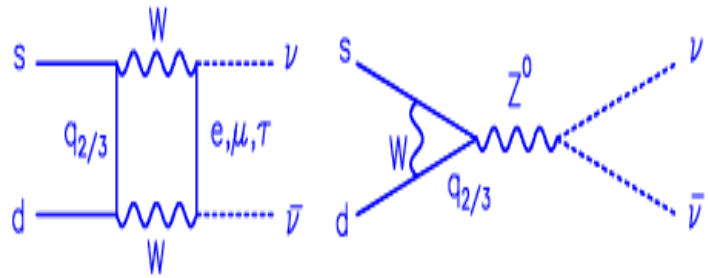
III. Outlook.

Why Does Kaon Physics Remain Topical After 40+ Years? (Komatsubara-san Plenary)

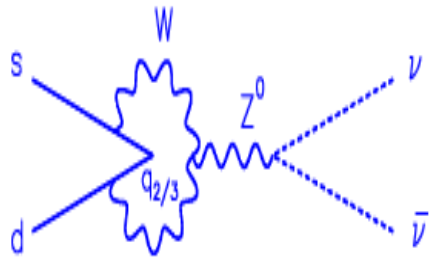
- Flavor changing neutral currents in kaon decays are highly suppressed, and in some cases dominated by second-order weak processes at the Electro-Weak (100 GeV/c^2) mass scale and beyond.
- Are an excellent window to probe CP and T violation in the quark sector. Relevant to Cosmology?
- Precision measurements can refine CKM parameters (e.g Vus), and benchmark ChPT and other low-energy models.

Back Door to the Energy Frontier: Measurement of Br[$K \to \pi \nu \bar{\nu}$]

This decay is determined by loop processes to high order in the SM, and hence has a reach for ***new physics at the EW scale and beyond*.**



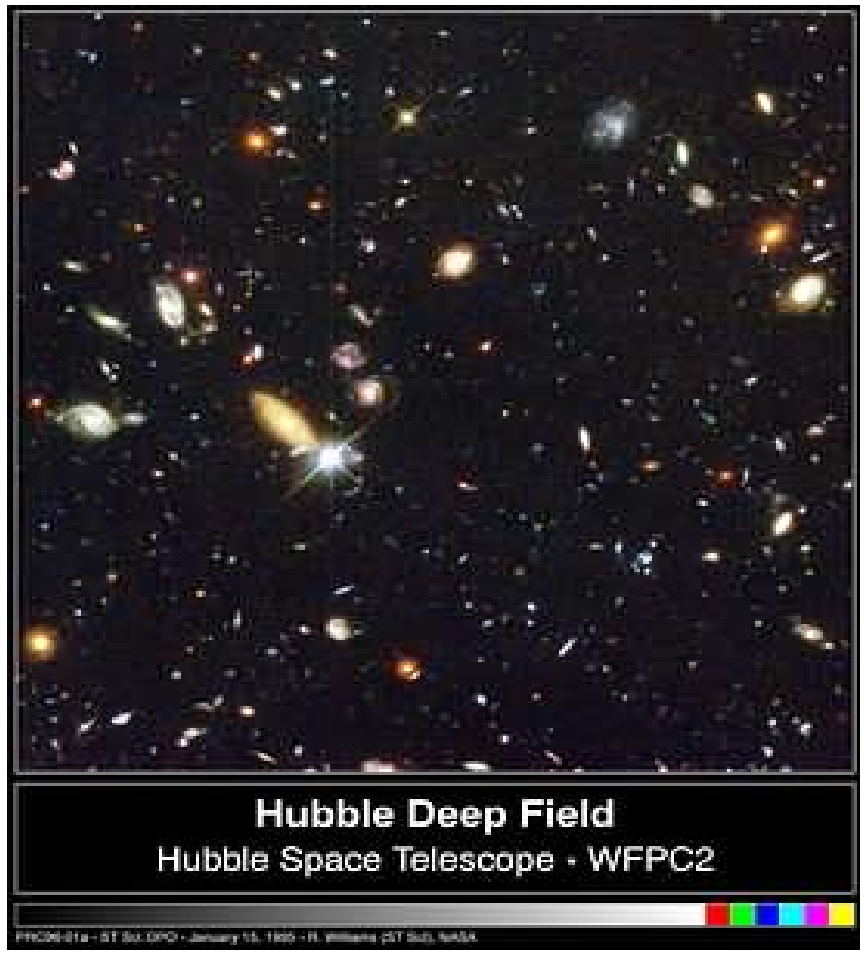
The SM rate can be reliably calculated; hence any deviation in the measured rate is a signal for new physics.



How are We Here? Baryogensis.

- **Sakharov's 3 conditions** for matter dominance
  - baryon number non-conservation
  - C and **CP violation**
  - not in thermal equilibrium

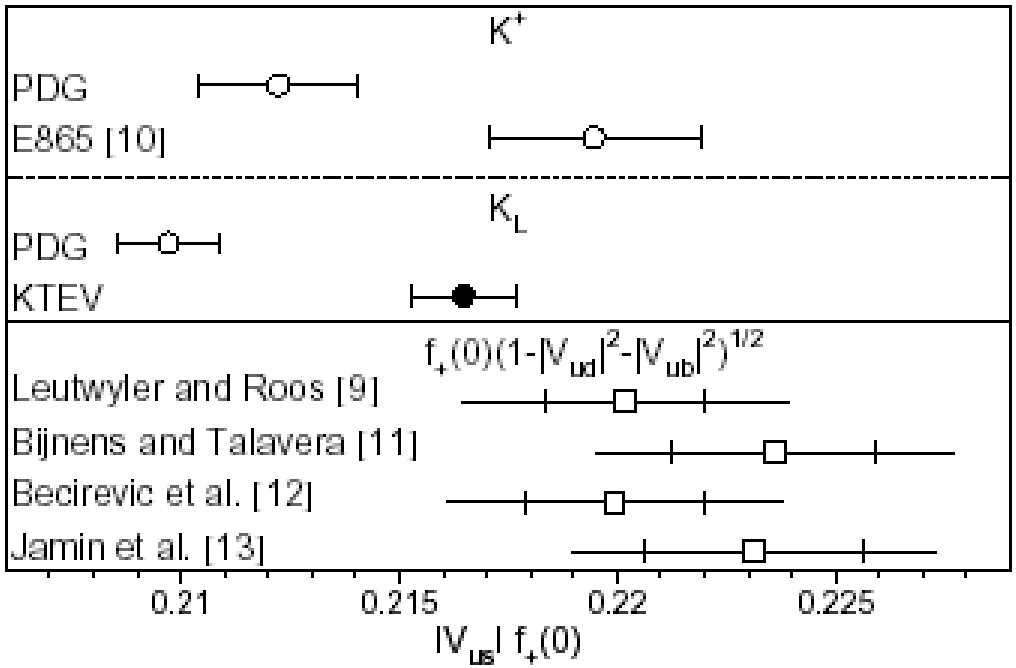
CP Violation in the Quark sector is well modeled by a single phase in the CKM matrix. But this single phase is *inadequate* for Baryogenesis! Exotic CP & T violation?? Leptogenesis??



JPARC LoI's discussed that push the Precision Frontier.

- LoI-16: Migrate the existing KEK-PS T-Violation experiment (E246) to J-PARC with modest upgrades.
- LoI-19: A new K^+ T-violation experiment optimized for JPARC conditions.
- LoI-20: Precision Measurement of the Ke3 Branching fraction to extract |Vus|.

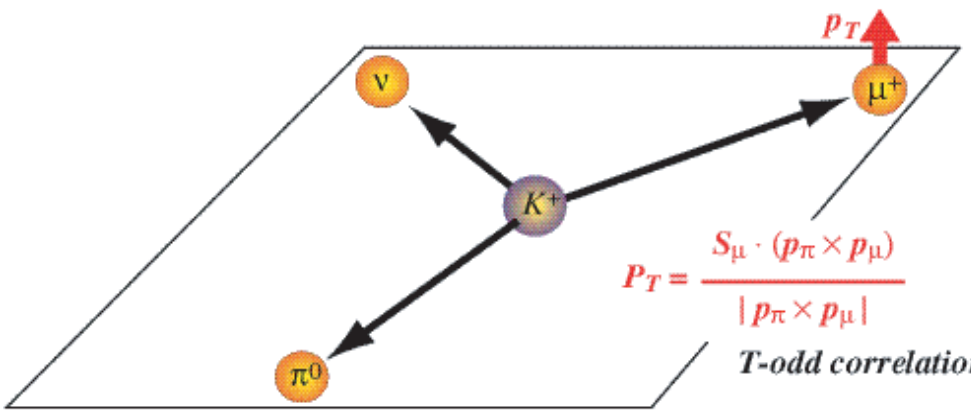
Recent News from the Frontier: Precision measurement of |Vus|.



- 1st Row Unitarity of the CKM matrix has been restored.

Building on the Success of KEK-E246…

Transverse muon polarization in $K^+ \to \pi^0 \mu^+ \nu$



$P_T \neq 0 \rightarrow$ T-violation

$K_{\mu 3}$ decay form factors and T violation

$$M \propto f_+(q^2)\,[2\,\tilde{p}_K^{\lambda}\,\bar{u}_\mu \gamma_\lambda (1-\gamma_5) u_\nu + (\xi(q^2) - 1) m_\mu \bar{u}_\mu (1-\gamma_5) u_\nu]$$

$$\xi(q^2) = f_-(q^2)/f_+(q^2)$$

$$P_T \sim \mathrm{Im}(\xi)\,\frac{m_\mu}{m_K}\,\frac{|p_\mu|}{E_\mu + |p_\mu|\,n_\mu \cdot n_\nu - m_\mu^2/m_K}$$

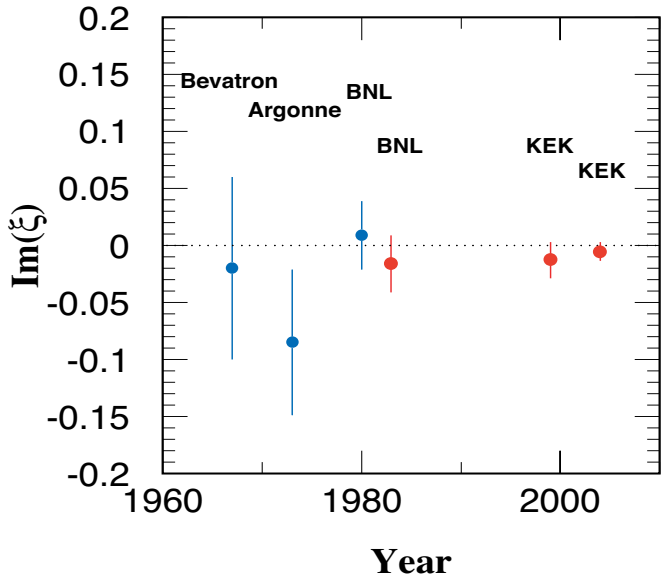
$\mathrm{Im}(\xi) \neq 0 \longleftrightarrow$ T-violation

P_T Systematics now controlled at the 10^{-3} level.

E246 result and model implication

$P_T = -0.0017 \pm 0.0023(stat) \pm 0.0011(syst)$
$(\,|P_T| < 0.0050 : 90\%\ C.L.\,)$

$\mathrm{Im}\xi = -0.0053 \pm 0.0071(stat) \pm 0.0036(syst)$
$(\,|\mathrm{Im}\xi| < 0.016 : 90\%\ C.L.\,)$



Three Higgs doublet model

- $|\mathrm{Im}\xi| < 0.016$ (90% C.L.) $\Rightarrow \mathrm{Im}(\alpha_1\gamma_1^*) < 544$ (at $m_H = m_Z$)
  cf. BR $(B \to X\tau\nu_\tau) \Rightarrow \mathrm{Im}(\alpha_1\gamma_1^*) < 1900$ (at $m_H = m_Z$)

- [R.Garisto and G.Kane, Phys. Rev. D44 (1991)2789]
  $v_2/v_3 = m_t/m_\tau$
  $d_n \approx 4/3\ d_d \propto \mathrm{Im}(\alpha_1\beta_1^*) \times m_d / m_H^2$
  $|\mathrm{Im}\xi| < 0.016$ (90% C.L.) $\Rightarrow d_n < 5 \times 10^{-27}\ e$ cm
  cf. $d_n^{\mathrm{exp}} < 6.3 \times 10^{-26}\ e$ cm

New T-Violation and Spectroscopy Experiments at JPARC.
Presentations by Imazato-san, Shimizu-san & Rangacharyulu-san.

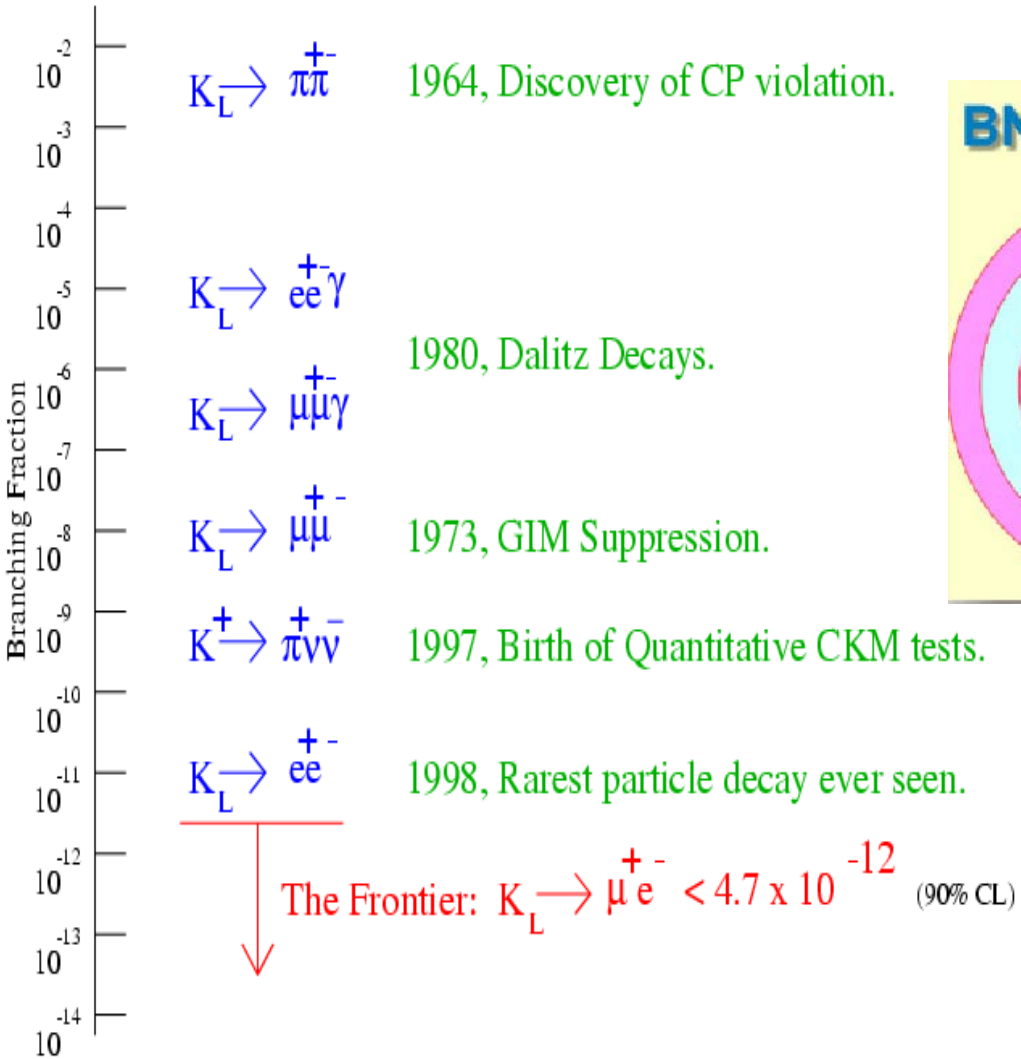
Merit of KEK-E246 Upgrade:

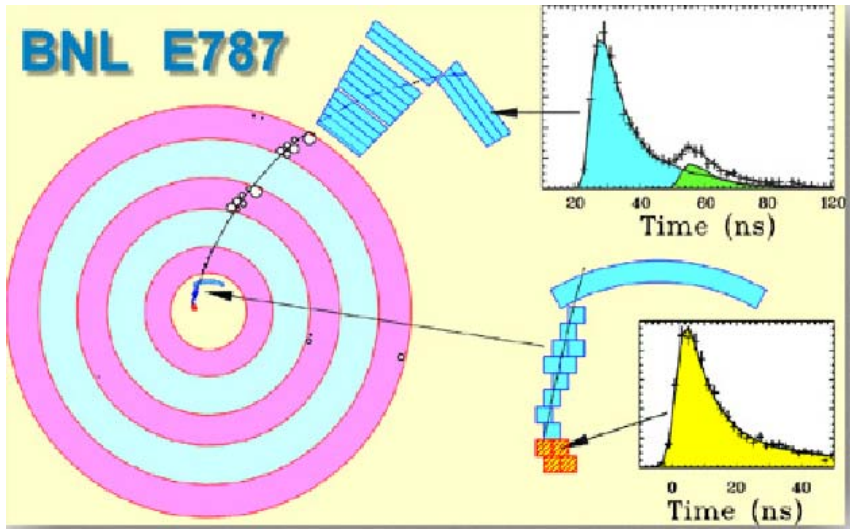
- KEK Result was statistically limited.
- Lower cost than a completely new setup
- Well known detector performance and systematics
- Many possibilities for kaon decay spectroscopy

Merit of a Bottoms'-up New Experiment:

- Plausible to reach P_T sensitivity below the 10^{-4} range.
- Exploits the full potential of JPARC intensities.
- Interesting possibilities of CP tests with K^+ and K^- beams.

Evolution of the Sensitivity Frontier…

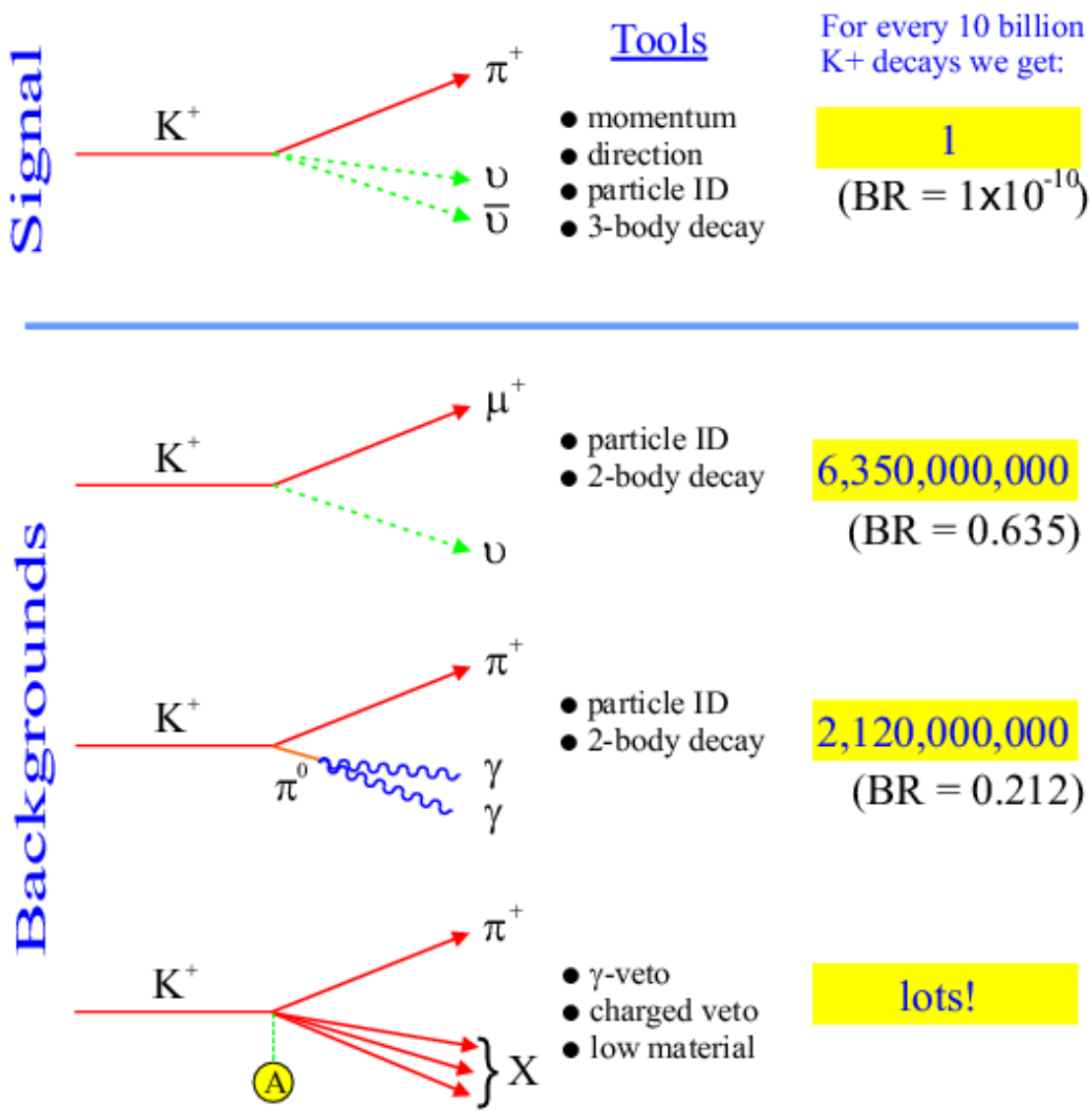




$B(K^+ \to \pi^+\bar{\nu}\nu) = 15^{+13}_{-9} \times 10^{-11}$

3 events seen.

Backgrounds a (the) Problem!



J-PARC LoI's discussed that push the Sensitivity Frontier.

- LoI-04: $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ Some general discussion on how to proceed. High (50% or more) J-PARC Duty Factor is important to success **(Komatsubara-san).**
- LoI-05: $K_L \Rightarrow \pi^0\nu\nu$ Much detailed discussion. Presentations from: **Inagaki-san, Lim-san, Yamaga-san, Watanabe-san, Komatsubara-san, Yamanka-san.**
- These LoI's were discussed in the context of the world scene: Presentations from **Morii-san, Kurilin-san, Tschirhart-san** on the KOPIO(BNL), KLOD(IHEP), and Fermilab/CERN experiments.

The $K^+ \to \pi^+ \nu\bar{\nu}$ World Scene.

- **BNL E787** completed. First run of extension (E949-pnn1) complete. Decay clearly established (3 events), Branching Fraction mean is ***twice*** the Standard Model expectation.

$$B(K^+ \Rightarrow \pi^+ \nu\bar{\nu}) = (15^{+13}_{-9}) \times 10^{-11}$$

- **Fermilab CKM** (**C**harged **K**aons at the **M**ain injector). Decay in-flight technique with a goal of **100 SM events** with small background. The experiment was approved by Fermilab, but stopped by new national PAC (P5) for cost considerations. New proposal in progress to use existing KTeV hall at much reduced cost.
- **CERN NA48** experiment has submitted an EOI where the existing In-flight experiment will be modified to measure **50 events** in 2 years of running.

New Technique:
In-Flight Measurement of $K^+ \to \pi^+ \nu\bar{\nu}$

- Must measure K^+ momentum to recover rest-frame Kinematics.
- Requires a relatively large decay volume.
- Not possible to follow the π–μ–e decay chain as done with stopped K^+ experiments.
- Decay occurs in vacuum, no low-energy K^+A interactions, no complex energy loss mechanisms.
- Kinematics ***and backgrounds*** of different Stopped- K^+ analysis regions are similar, leads to potentially higher total acceptance.
- High energy muons and photons from $K\mu 2$ and $K\pi 2$ are in principle easier to veto.
- Existing high performance Experiments: KTeV & NA48.

The $K_L \Rightarrow \pi^0\nu\nu$ World Scene.

- **KTeV** set limit based on in-flight technique. No events observed. Limit **(90% CL) of $<5.9\times10^{-7}$ established**. Technique required Dalitz decay of π^0 ($\pi^0 \Rightarrow e^+e^-\gamma$) to control backgrounds to 0.1 event level. New techniques required to reach SM level.

- **KEK-E391** commissioning run went very well!. Technique is based on fully hermetic photon veto coverage, "kaon bottle". **Expected sensitivity in the 10^{-10} range.** This is still about x30 above SM level, but this experiment is vital to establish hermetic photon veto techniques. Proposed continuation to JPARC.

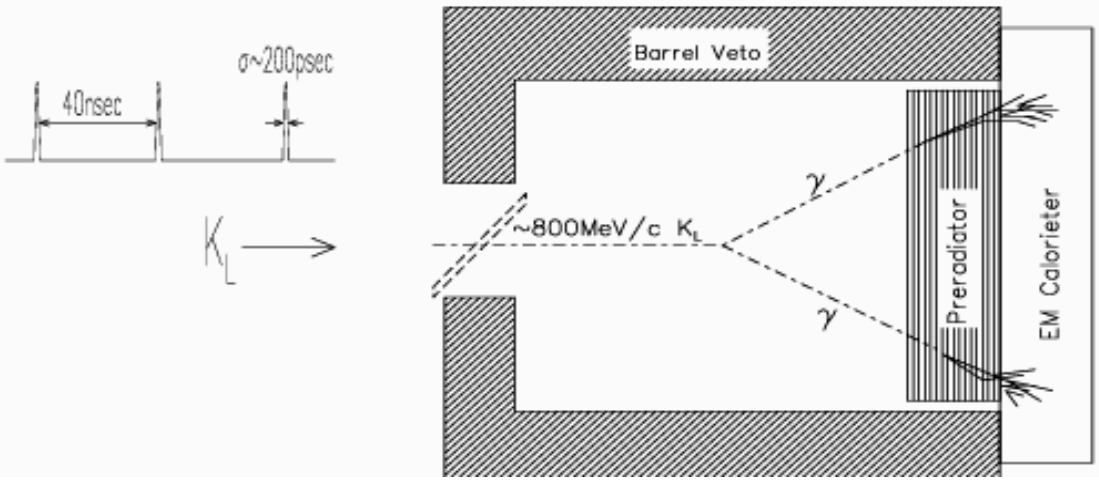
- **BNL KOPIO** experiment approved. Novel techniques to measure K^0 momentum and photon directions. **Expected sensitivity of 50 SM events** over a background of ~20 events. Physics running starts in 2010.

- **KLOD** experiment under development at IHEP/Protvino. Technique is based on the Kaon-bottle technique, possible running at JPARC?

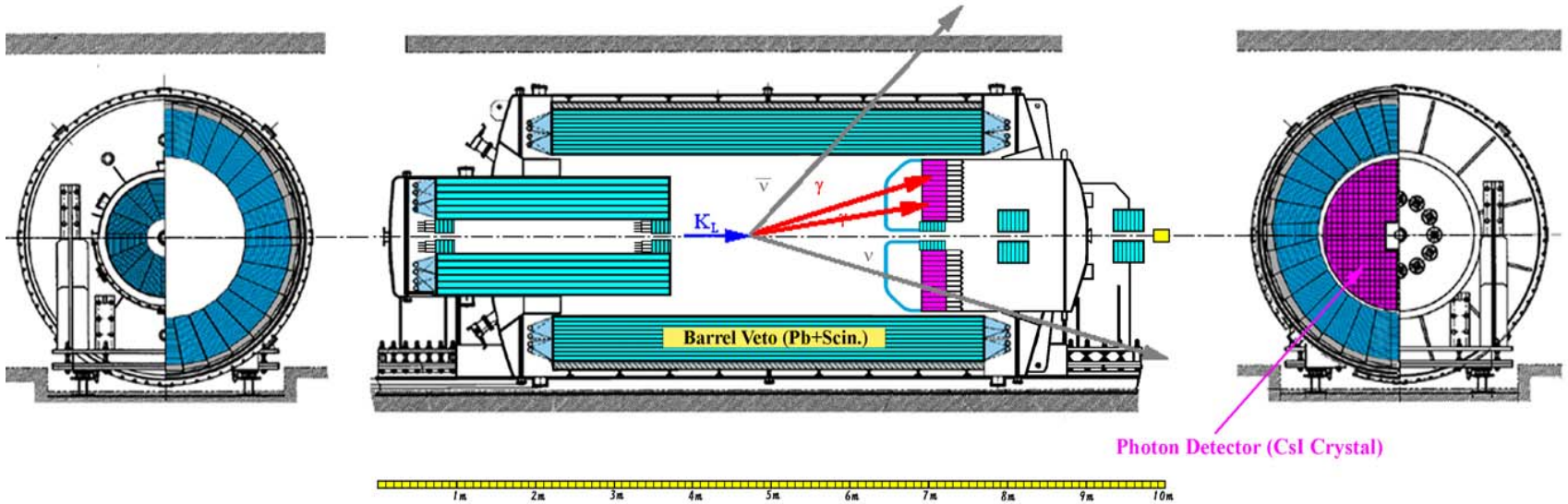
KOPIO: A Proposal to Measure $K_L^0 \to \pi^0 \nu\bar{\nu}$

Lessons from E787:

- Measure as much as possible:
  Energy, position and $ANGLE$ of each photon.
- Work in the C.M. system :
  Use TOF to get the K_L^0 momentum.
- Photon Veto limited by photonuclear interactions at low energies.



E391a: Critical Pilot Run for JPARC.

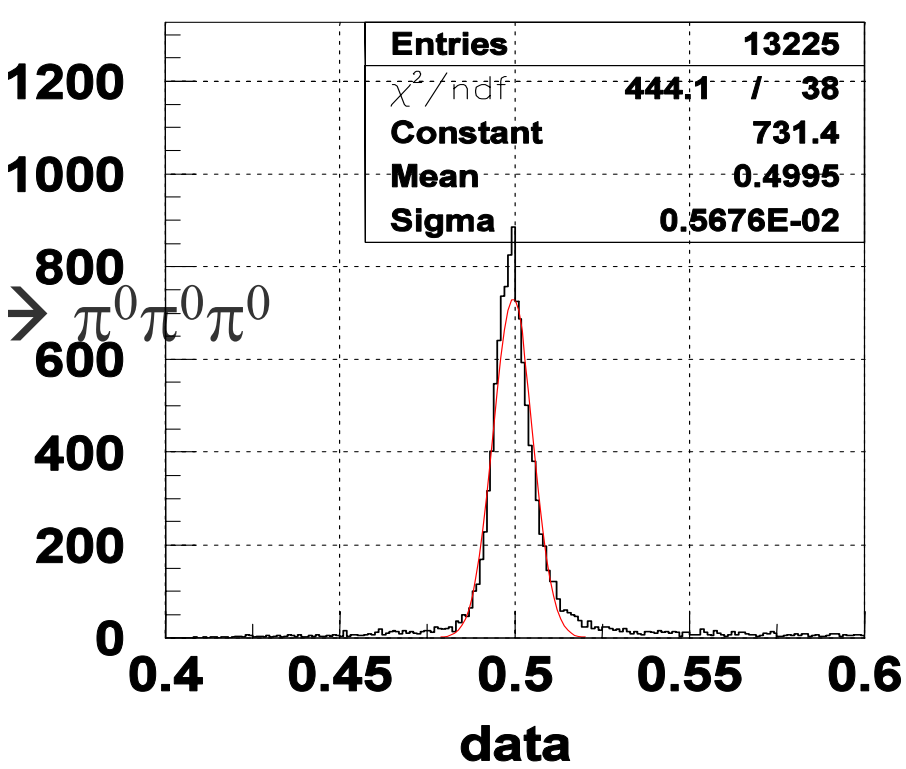


$K_L \rightarrow \pi^o \nu \nu$

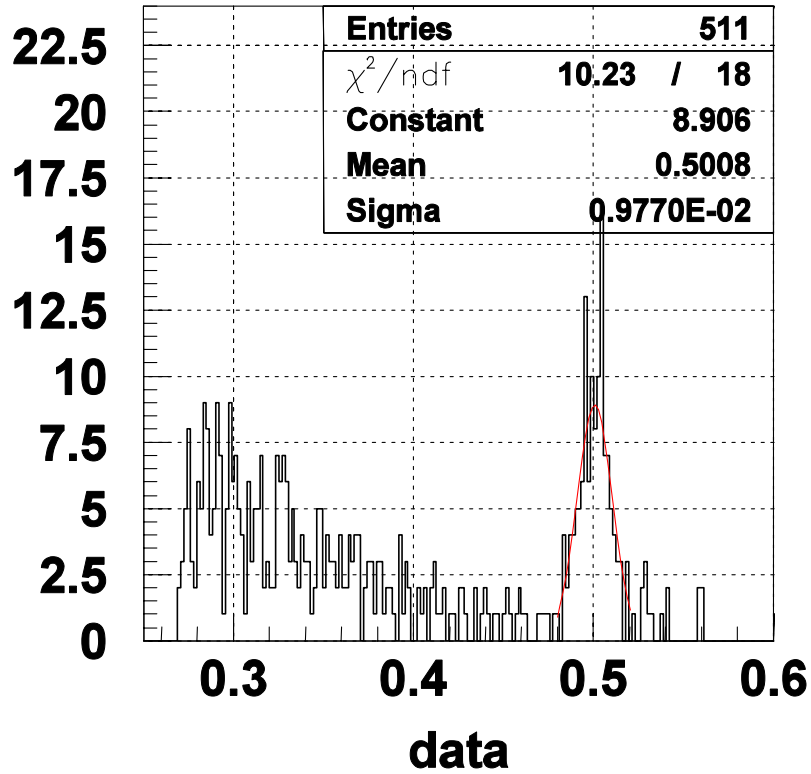
$\pi^o \rightarrow \gamma\gamma$ → pure CsI calorimeter

Nothing → 4π veto system

E391a Run Went Very Well: Cleanly reconstructed K_L decay modes



6-γ invariant mass (GeV/c^2)



4-γ invariant mass (GeV/c^2)

Highlights of the $K_L \Rightarrow \pi^0\nu\nu$ Discussion.

- E391a "Pencil-Beam" concept really works.
- The analysis of the E391a data will clearly address the trade-off of low neutron background in the A-line .vs. the benefit of vetoing higher energy photons from higher energy kaons in the B-Line.

- Using the E391a instrument for early running in the A-line will be useful for both beam and detector designers.

- **Experimenters are thinking boldly**: Considering designs that yield ***hundreds of $\pi^0\nu\nu$ decays***. Novel ideas include using the veto systems as calorimeters.

Summary and Outlook.

- We know there is physics beyond the Standard Model, and kaon physics is an important probe to understand it. Particularly in the LHC-era.
- The new intense J-PARC proton source is a very welcome sight on the quark-flavor physics horizon.
- The J-PARC kaon LoI activity is vigorous now, and will evolve into compelling proposals for J-PARC.