Rare Opportunities:
Seeking New Physics with Rare Decays of Light Particles

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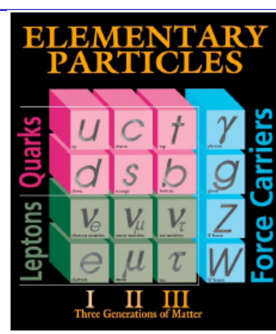
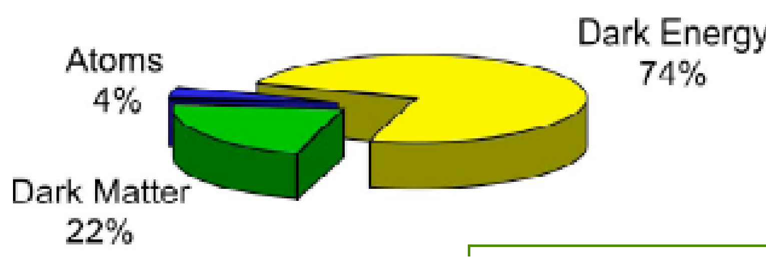
Standard Model : *A great story …*
but not likely the whole story…

- ***Cosmological issues***: inflation, dark matter, dark energy, **matter anti-matter asymmetry…**
- ***Theoretical issues***: gravity, neutrino mass, ***flavor problem***, hierarchy problem, divergences ….





Energy Frontier

Tevatron → LHC; TeV Energy Scale

New Physics

Higher Mass Scales?

Precision Frontier

Flavor Physics

Rare Decays and CP violation

Symmetry Violation

DARK Matter Frontier

COSMOLOGICAL EVOLUTION, BBN

LEPTOGENESIS?

NEUTRINO PHYSICS

NOBEL
Laureates in Physics

Particle Physics

- **2008 Yoichiro Nambu, Makoto Kobayashi, Toshihide Maskawa**

Related to “Flavor physics and CP violation”

2004 David J. Gross, H. David Politzer, Frank Wilczek
2002 Raymond Davis, Jr., Masatoshi Koshiba, Riccardo Giacconi

…

The Flavor Puzzle

Quarks

u	c	t
d	**s**	b

Leptons

e	μ	τ
ν_e	ν_μ	ν_τ

- Fermion weak states $\not\Leftrightarrow$ mass states
- Quark, lepton flavors not conserved
- Three flavors $\Rightarrow$ **CP violation**, …BAU,…

Unexplained observations (no theory of flavor):

- Huge mass differences between and within the generations
- Universality of interactions
- Symmetry, relationship between lepton and quark sectors
- Tiny neutrino mass

Five Special Rare Decay Experiments

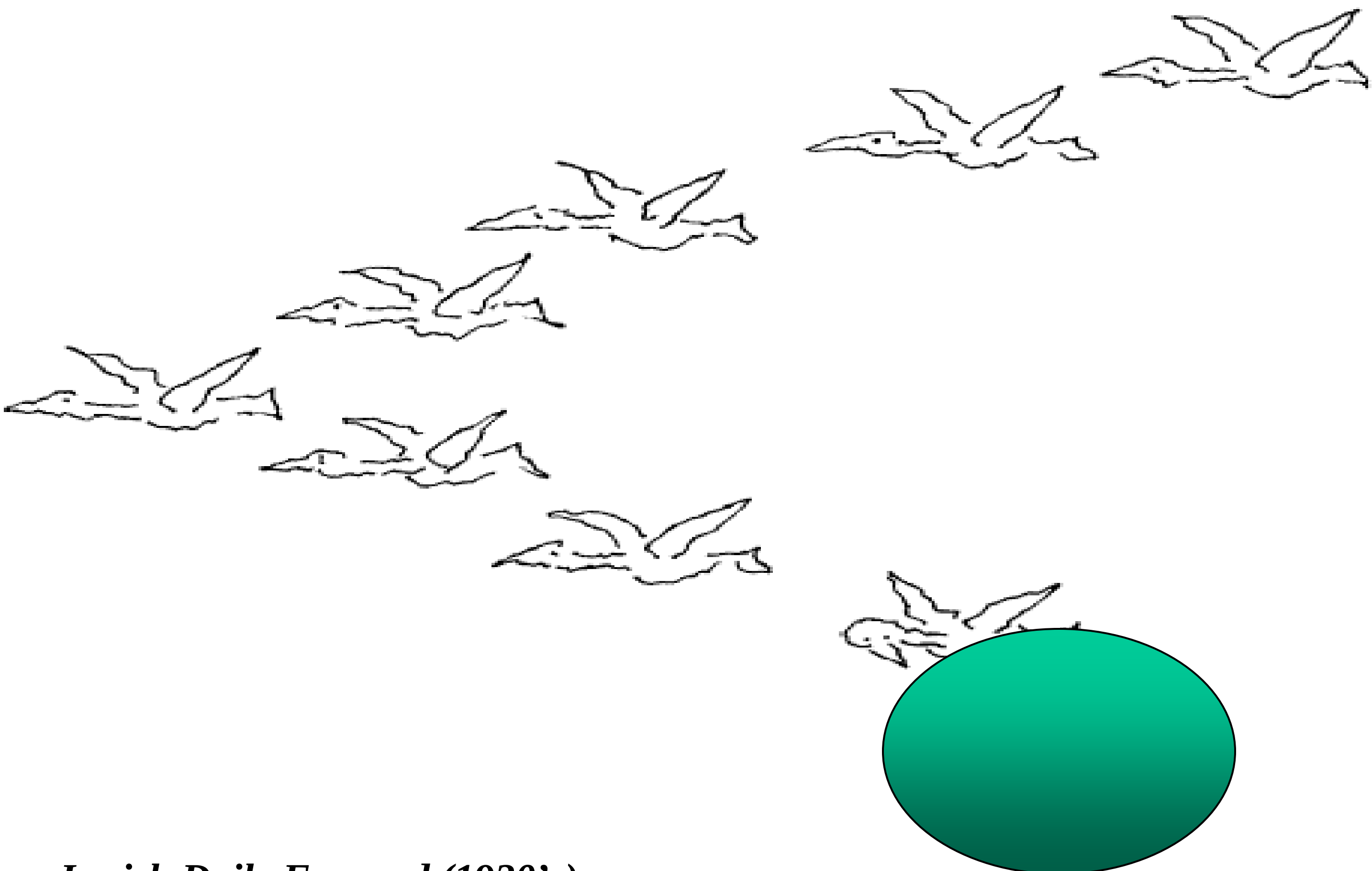
Probe new physics at the 1-1000 TeV Scales!

State of the art:

: 10^{-12}

Exotic Searches- ***New physics if seen since SM effects are negligible.***	Lepton Flavor Violation: $\mu \to e\gamma$ $\mu^- N \to e^- N$	 **<1.2 10^{-11}** **<7.8 10^{-13}**
SM Parameters and BSM Physics ***New physics if deviations from well-calculated SM predictions occur.***	$\dfrac{\pi^+(K^+) \to e^+\nu}{\pi^+(K^+) \to \mu^+\nu}$ Universality $K^+ \to \pi^+ \nu \bar{\nu}$ $\quad |V_{td}|$ $K_L^0 \to \pi^0 \nu \bar{\nu}$ $\quad CP$ violation	*****±0.4%** *****10^{-10}: 7events**

Seeking Answers with Rare Decays

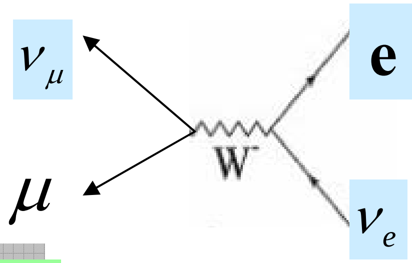


Cartoon from Jewish Daily Forward (1920's)

Lepton Flavor Violation

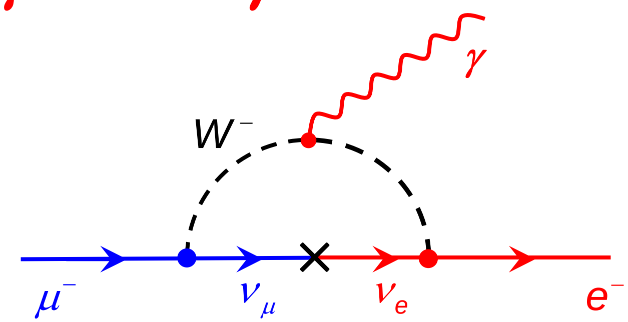
Muon Decay

$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$$



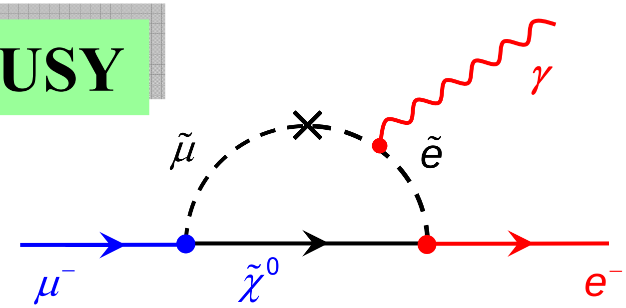
$$\mu \rightarrow e\gamma$$

SM



$$BR(\mu^- \rightarrow e^- \gamma)\big|_{SM} \propto \frac{m_\nu^4}{m_W^4} \approx 10^{-60}$$

SUSY

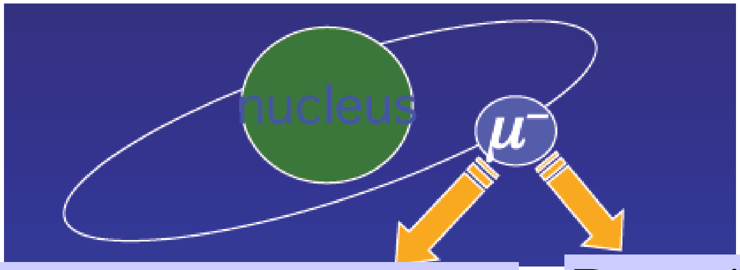


$$BR(\mu^- \rightarrow e^- \gamma)\big|_{SUSY} \approx 10^{-5} \frac{\Delta m^2_{\tilde{e}\tilde{\mu}}}{\bar{m}^2_{\tilde{\ell}}} \left(\frac{100 \text{ GeV}}{m_{SUSY}}\right)^4 \tan^2\beta \approx 10^{-12}$$

- Observation means new physics.
- Some SUSY models predict BR($\mu \rightarrow e\gamma$) near the experimental limit $\sim 10^{-11}$.

$$\text{Sensitivity to new physics} \sim \frac{1}{M_H^4}$$

$\mu \rightarrow e$ Conversion



Nuclear Muon Capture

$\mu^- + (N,Z) \rightarrow \nu_\mu + (N, Z-1)$

Decay in orbit

$\mu \rightarrow e \nu \bar{\nu}$

Or?

Neutrinoless

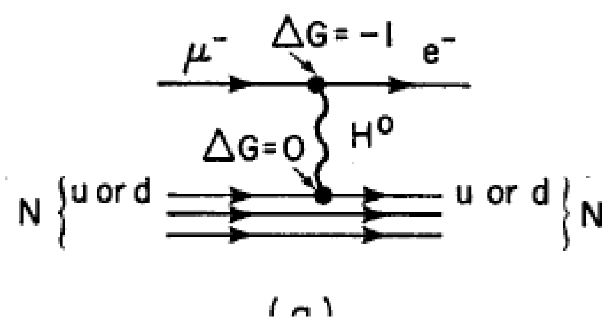
$\mu^- \rightarrow e^-$ Conversion

$\mu^- + (N,Z) \rightarrow e^- + (N,Z)$

$P_e = m_\mu - b.e. \sim 100 MeV/c$

Coherent process

Sensitive to a wide variety of models at high mass scales:
Z μe, H μe couplings, horizontal gauge bosons,
heavy neutrino mixing, …



$$\frac{\Gamma(\mu^-(N,Z) \rightarrow e^-(N,Z))}{\Gamma(\mu^-(N,Z) \rightarrow \nu(N,Z-1))} \sim \frac{1}{(M_H)^4}$$

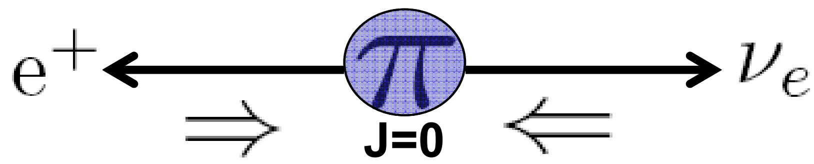
Current limits ($<7\text{x}10^{-13}$) $\rightarrow M_H > 340\,TeV$

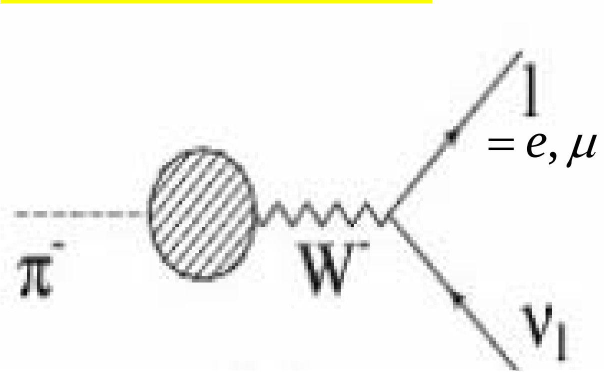
Updated from Cahn and Harari (1980).

Lepton Universality

Standard Model: e, μ, τ have identical electroweak gauge interactions: differ only in mass and coupling to Higgs boson.

$$\pi^+ \to e^+ \nu$$





S=0

$$\frac{\Gamma(\pi \to e\nu)}{\Gamma(\pi \to \mu\nu)} = \frac{g_e^2 m_e^2 \left(1 - \frac{m_e^2}{m_\pi^2}\right)^2}{g_\mu^2 m_\mu^2 \left(1 - \frac{m_\mu^2}{m_\pi^2}\right)^2}$$

SM: $g_e = g_\mu$. But new physics may not respect universality.

Including Radiative Corrections:

$$\frac{\pi^+ \to e^+ \nu(\gamma)}{\pi^+ \to \mu^+ \nu(\gamma)}$$

$$\mathrm{R}^{th}_{e/\mu} = \left(1.2353 \pm 0.0001\right) x10^{-4}$$

W. Marciano → V. Cirigliano (2007)

Possibly the most accurately calculated decay process involving hadrons .

$$K^+ \to e^+ \nu$$

$$\mathrm{R}^{th}_{K \to e/\mu} = \left(2.477 \pm 0.001^*\right) x10^{-5}$$

$Finkemeier (1995)$
$Cirigliano, Rosell (2007)$

Helicity suppression 5x $\pi^+ \to e^+ \nu$

Structure dependent radiation included ?

High Precsion in Branching Ratio:

$$R_{e/\mu} = \frac{\Gamma(\pi \to e\nu + \pi \to e\nu\gamma)}{\Gamma(\pi \to \mu\nu + \pi \to \mu\nu\gamma)}$$

THEORY $\mathrm{R}_{e/\mu}^{SM} = 1.2353(1)x10^{-4} \quad (\pm 0.01\%)$

EXPERIMENT $\mathrm{R}_{e/\mu}^{\exp\pi} = 1.2306(37)\ \mathrm{x}10^{-4} \quad (\pm 0.4\%)$

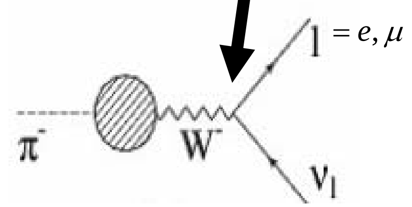
$1.2265(34)(44)x10^{-4}$ TRIUMF (1992)

$1.2346(35)(36)x10^{-4}$ PSI (1993)

$$\mathrm{R}_{e/\mu}^{SM} - \mathrm{R}_{e/\mu}^{\exp} = 43(37)x10^{-8}$$

Best test of Lepton Universality

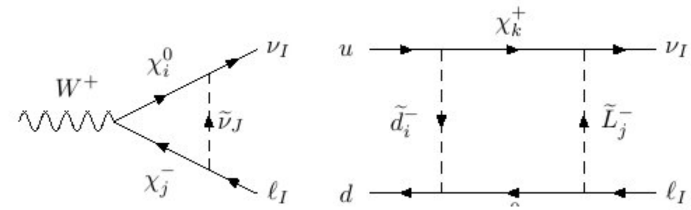
g_e/g_μ
0.9985 ± 0.0016



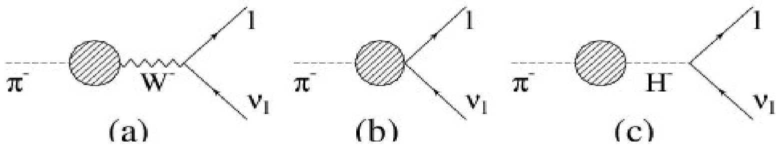
Order of magnitude difference in precision between theory and experiment -> **window for new effects!**

New Physics in $\pi \rightarrow e\nu \sim \frac{1}{M_H^2}$

R-parity violating SUSY



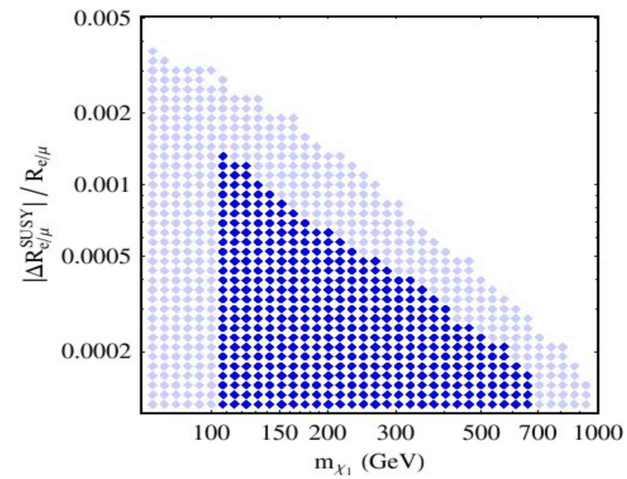
New Pseudoscalar interaction



$$1 - \frac{R^{New}_{e/\mu}}{R^{SM}_{e/\mu}} \sim \mp \frac{\sqrt{2}\pi}{G_\mu} \frac{1}{\Lambda^2_{eP}} \frac{m_\pi^2}{m_e(m_d + m_u)}$$

$$\sim (\frac{1TeV}{\Lambda_{eP}})^2 \times 10^3$$

Marciano…

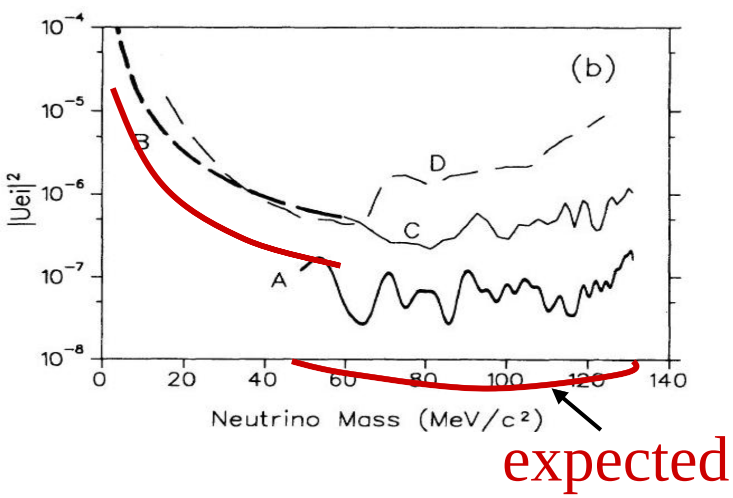


Lowest chargino mass

Ramsey-Musolf…

0.1 % measurement→Λ~1000TeV

ν_H



Others

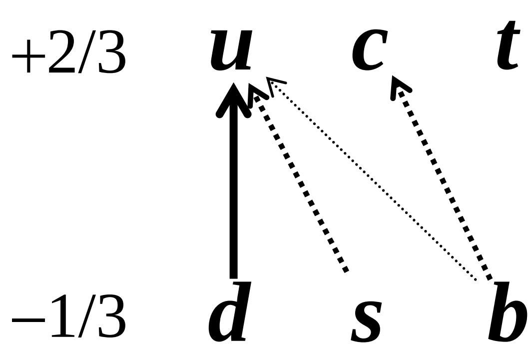
- -Leptoquarks
- -Excited gauge bosons
- -Compositeness
- -SU(2)xSU(2)xSU(2)xU(1)
- -Lepton Flavor Violation
- -Extra dimensions…

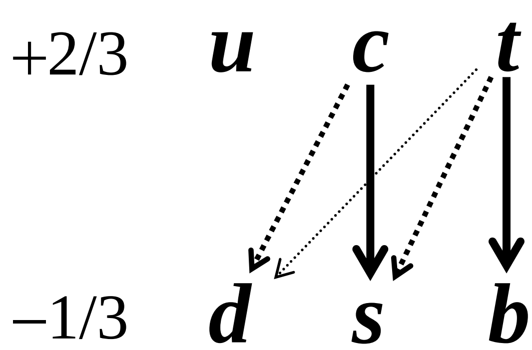
$$K \to \pi \nu \bar{\nu}$$

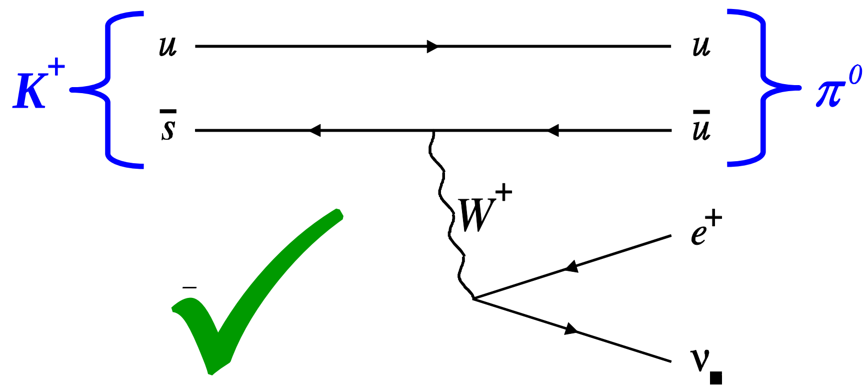
FCNC!

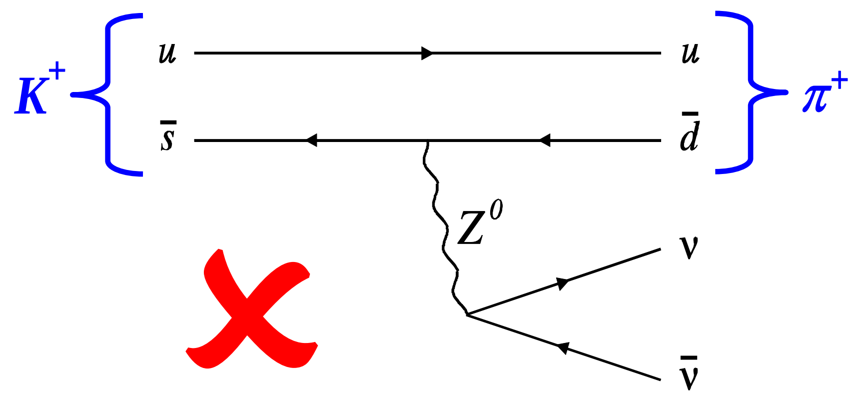
The case of the dog that didn't bark.

Flavor-changing neutral currents (e.g. s → d) are absent in the Standard Model:



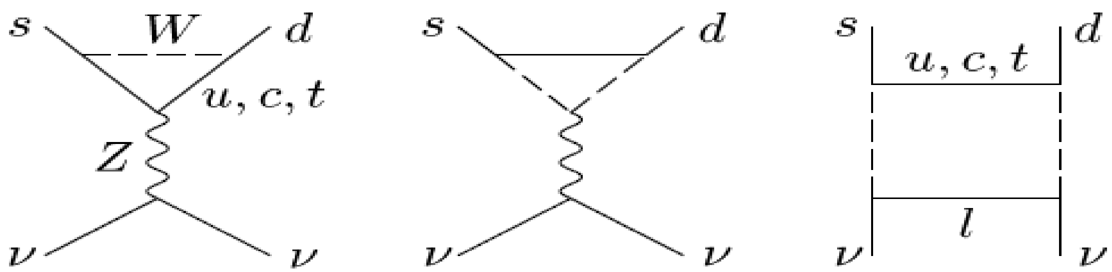






$K \to \pi\nu\bar{\nu}$ in the SM

2nd order weak: proceeds very slowly!



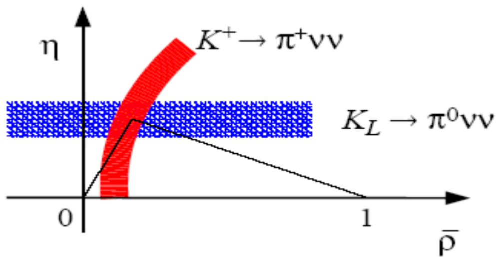
Standard Model (*Buras*):

$$\mathrm{Im}\,\lambda_t = \mathrm{Im}V_{ts}^{*}V_{td} = \eta A^2 \lambda^5$$

$$B(K_L^0 \to \pi^0 \nu\bar{\nu}) = 1.8\, x10^{-10} \left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2 = 2.76 \pm 0.40\, x10^{-11}$$

$$B(K^+ \to \pi^+ \nu\bar{\nu}) \sim 1.0\, x10^{-10} A^4 \left[\eta^2 + (\rho_0 - \rho)^2 \right] = 8.5 \pm 0.7\, x10^{-11}$$

Golden Relation: $\sin(2\beta)_{\psi K_S} = \sin(2\beta)_{K\to\pi\nu\bar{\nu}}$

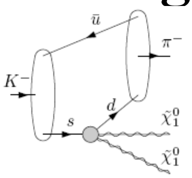


$K \to \pi\nu\bar{\nu}$: Great Discovery Potential

10% measurement $K_L^0 \to \pi^0 \nu\bar{\nu} \;\to$ mass scale ~1280 TeV!

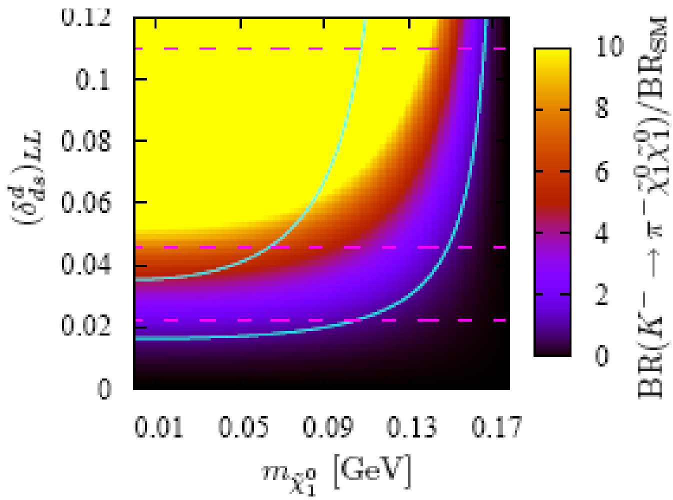
Two Examples:

SUSY: Rare meson decays into light neutralinos



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

$\to$ N x SM

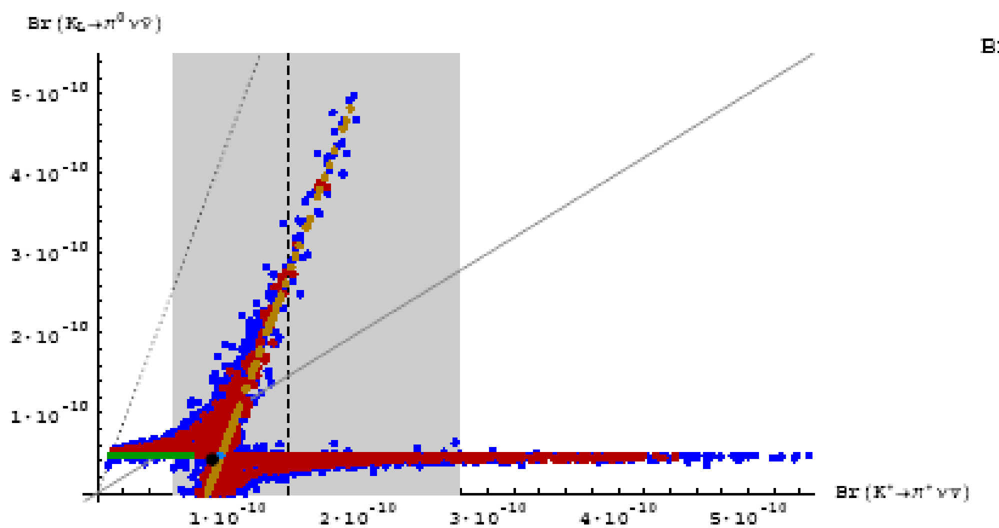


H. K. Dreiner *et al.* Bonn-TH-2009-04

Minimal Flavor Violation e.g.

Littlest Higgs Model with T-parity

$B(K_L^0 \to \pi^0 \nu\bar{\nu})$ *vs.* $B(K^+ \to \pi^+ \nu\bar{\nu})$

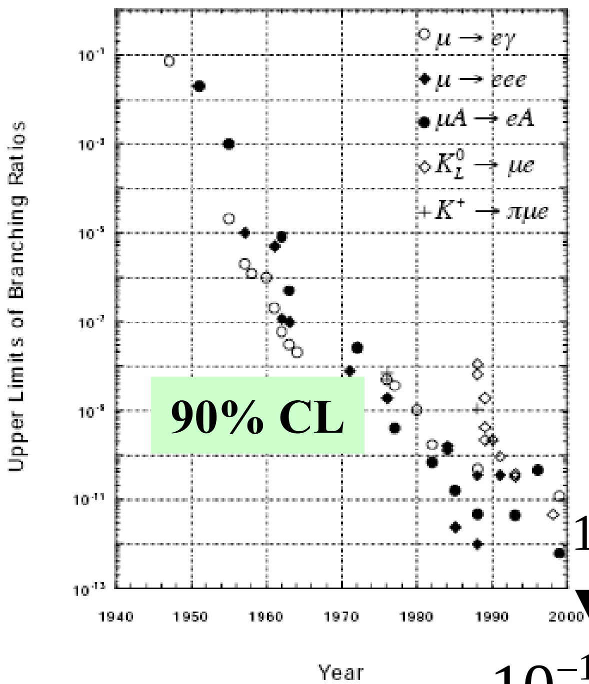


M. Blanke, *et al.*,arXiv:hep-ph/0610298.

Experiments

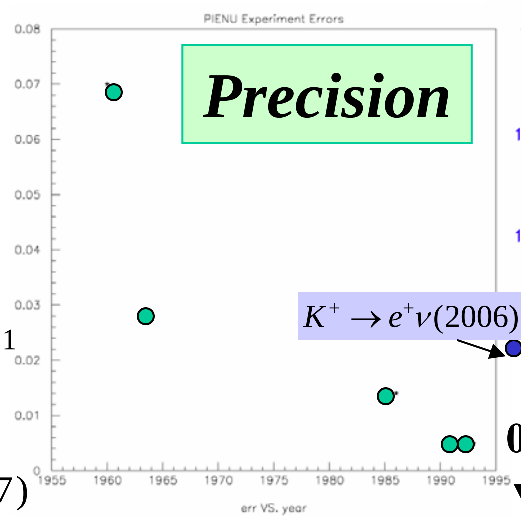
Prospects for 10-1000 x improvements.

Lepton Flavor Violation



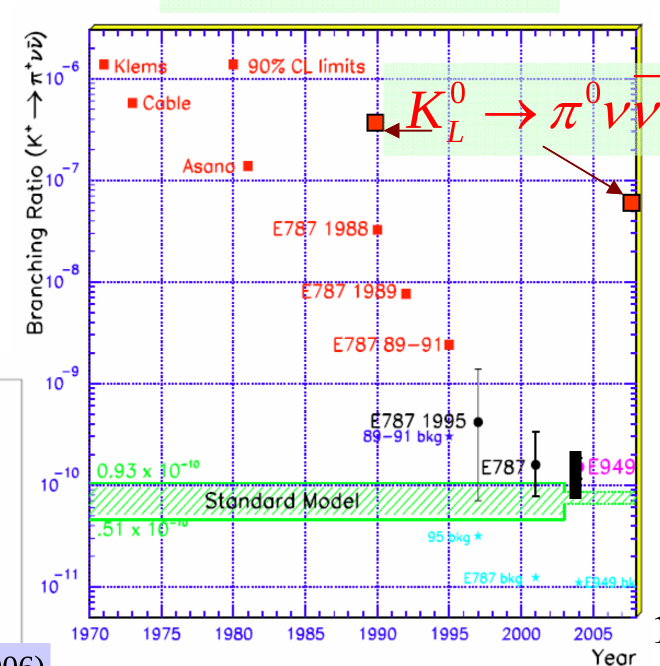
10^{-11} ↓ $10^{-13(17)}$

$\pi^+ \to e\nu$



0.4% ↓ 0.04%

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

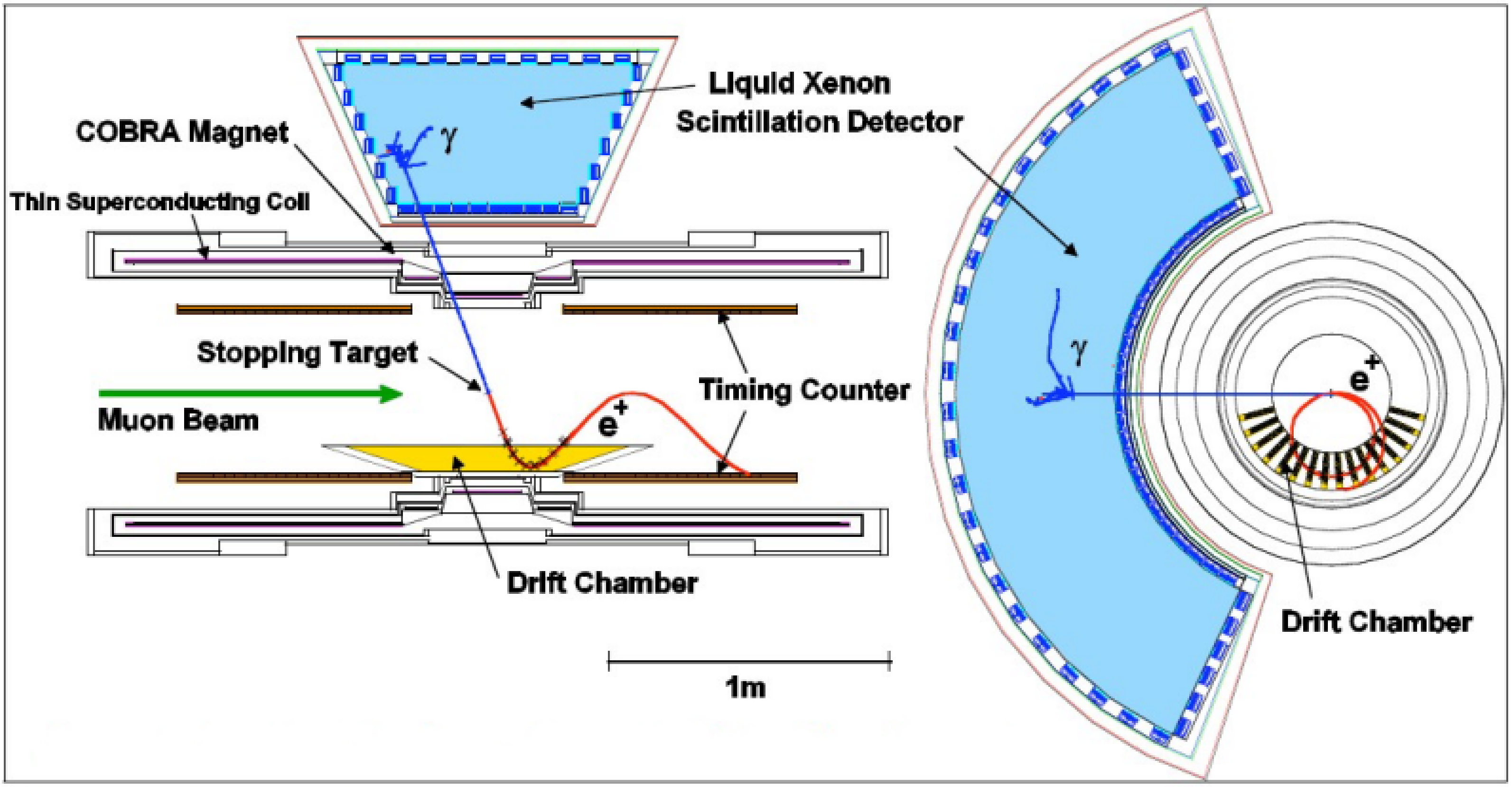


7 ↓ 100 ↓ 1000

$\mu \rightarrow e\ \gamma$

MEG Experiment at PSI

Goal (limit) <1.3 10^{-13} (0.01 x prev. exp)



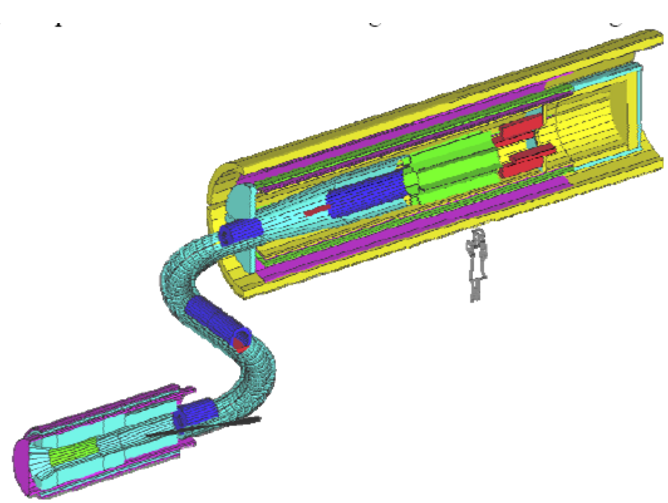
- $10^7 - 10^8$ μ/sec, 100% duty factor
- LXe for efficient γ detection
- Solenoidal magnetic spectrometer

S. Ritt 2006

Proposals:

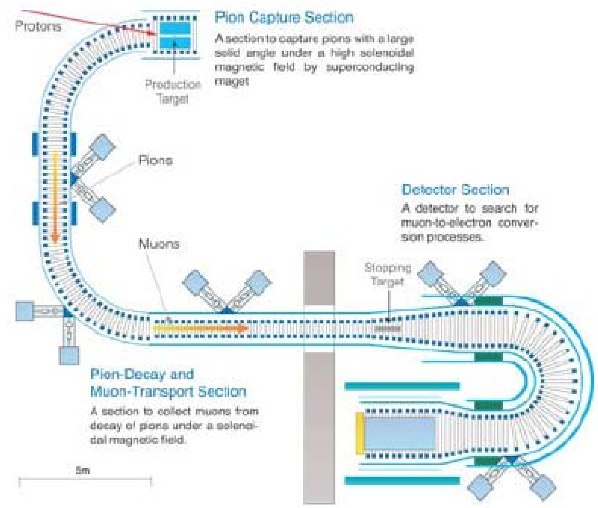
$$\mu^- N \to e^- N \text{ at } 10^{-16}$$

Lobashov (1980): Solenoid Pion Collector; flux x 1000.



BNL MECO $\rightarrow$ *Mu2E*

$\mu \rightarrow$ e Conversion at Fermilab



$\mu \rightarrow$ e Conversion

COMET at JPARC

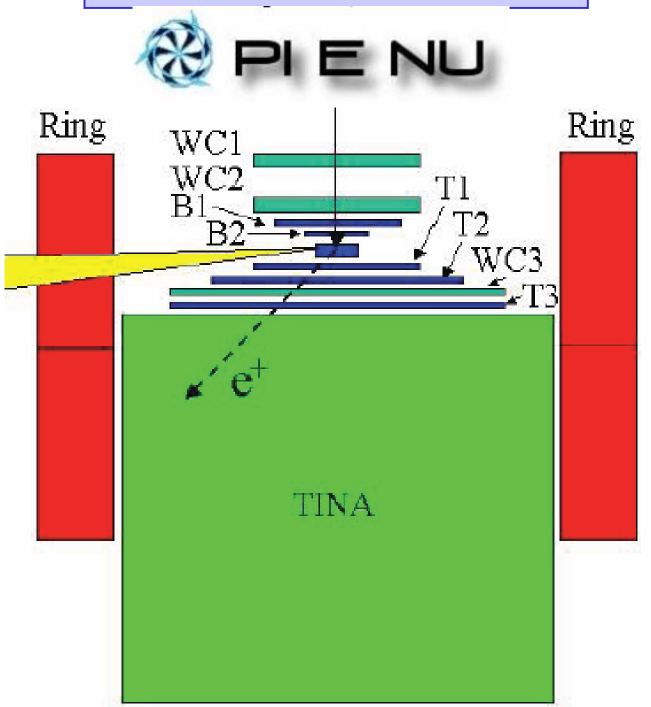
- **Singles experiment mitigates high rates.**
- **Background (decay-in-orbit) known and calculable.**
- **High resolution detector feasible.**
- **Possible improvement x 10^4**

+ new idea: Aoki

New $\pi^+ \rightarrow e^+\nu$ Experiments

Aim for <0.1% Precision

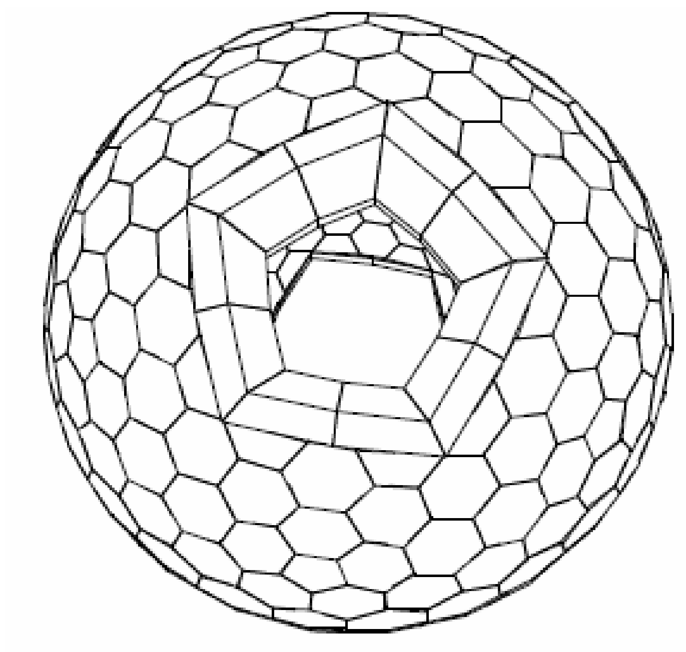
TRIUMF PIENU



Canada-China,Japan-US

ASU, BNL, Osaka University, TRIUMF, Tsinghua, UBC, VPI

PSI PIBETA Spectrometer



PSI, Zurich

Experiment Concepts

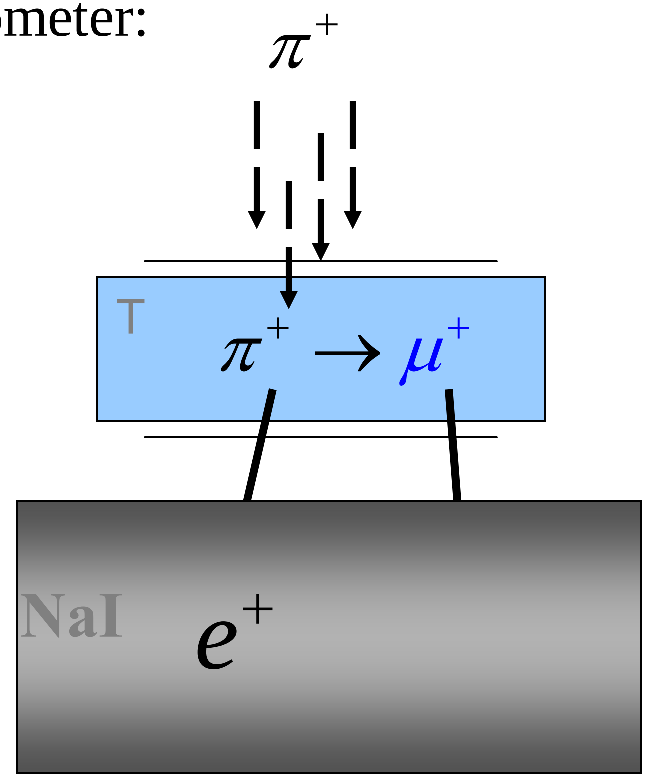
Stop π^+;Measure positrons in a crystal spectrometer:

$$\left[\pi^+ \to e^+ \nu\right] \qquad P_e = 70 MeV/c$$

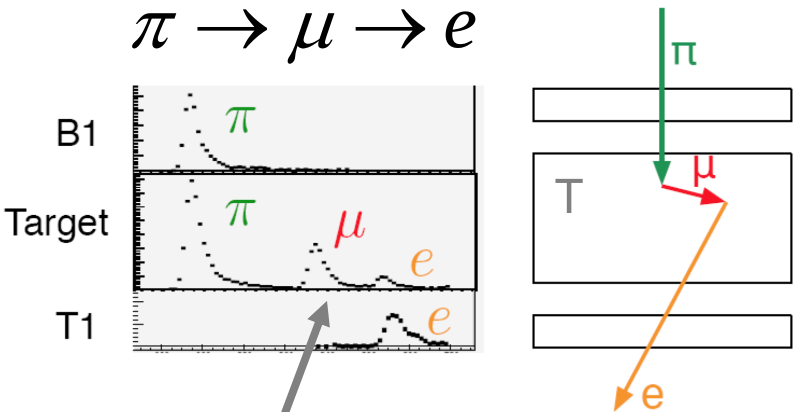
$$\left[\pi^+ \to \mu^+ \nu\right] \qquad P_\mu = 30 MeV/c$$

$$T_\mu = 4.2 MeV, \; R_\mu = 1.4 mm$$

$$\left[\mu \to e^+ \nu \bar{\nu}\right] \quad P_e = 0 - 53 MeV$$



$$\pi \to \mu \to e$$



$\tau_\pi = 26ns, \tau_\mu = 2200ns$

Extra pulse $T_\mu = 4.2MeV$

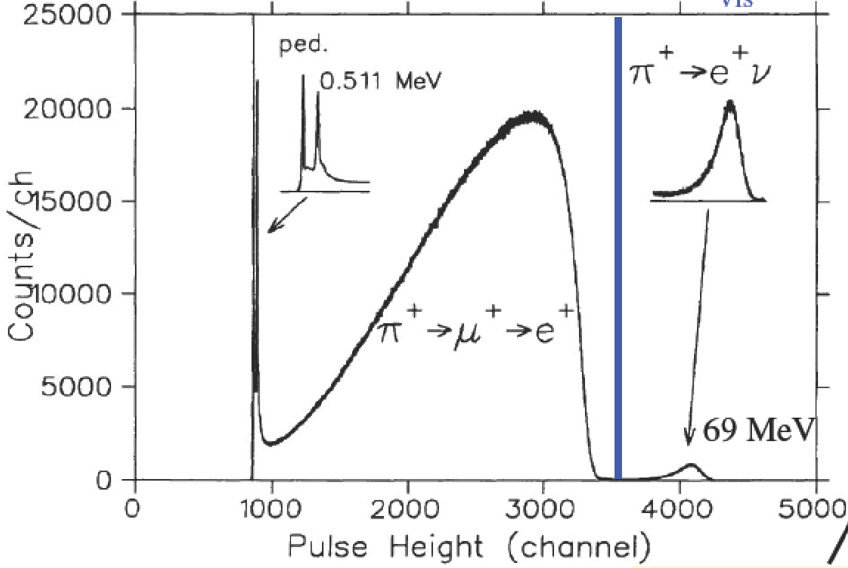
for $\pi \to \mu \to e$ only.

Systematic effects cancel for $\dfrac{\Gamma(\pi \to \mathrm{e})}{\Gamma(\pi \to \mu \to \mathrm{e})}$

Britton et al. (1993)

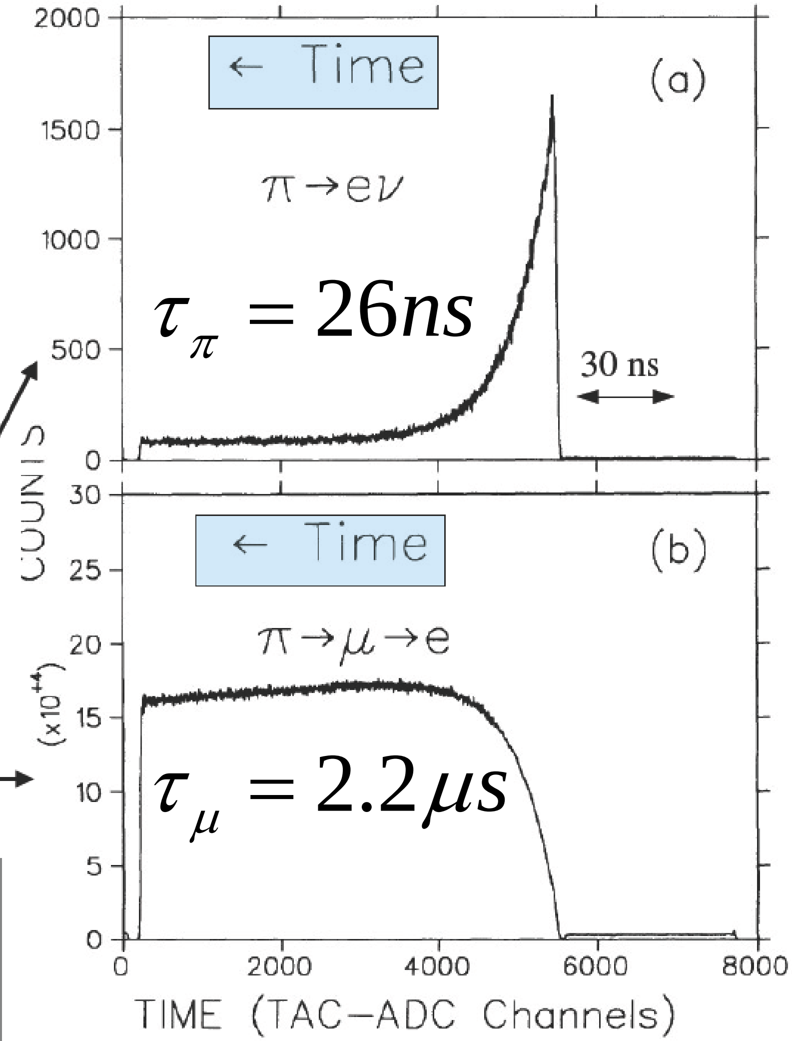
Energy and Time spectra

Separate events by Energy: (E_{vis} ~52 MeV)



π–μ–e region

π→eν



Fit both spectra simultaneously
and obtain the ratio.

Britton et al. (1993)

Tail correction

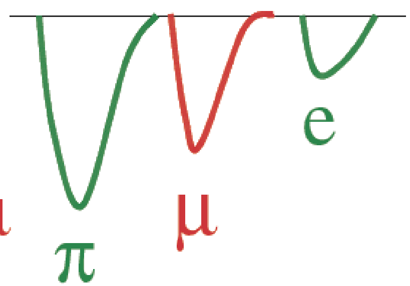
(the main source of systematics)

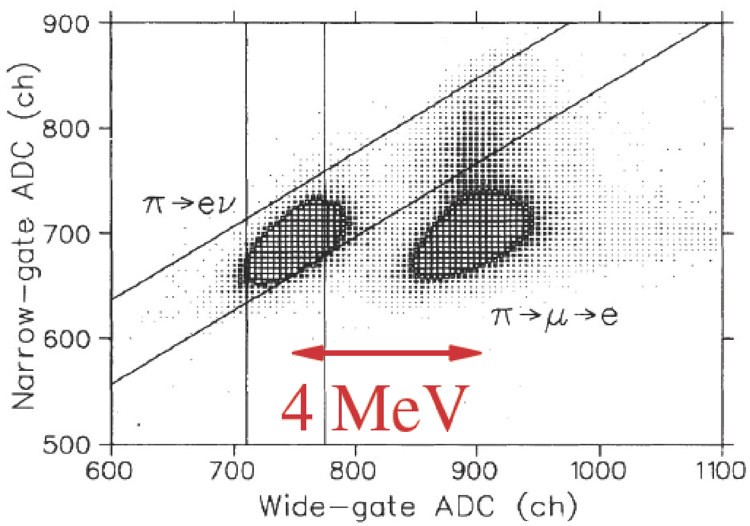
π–eν

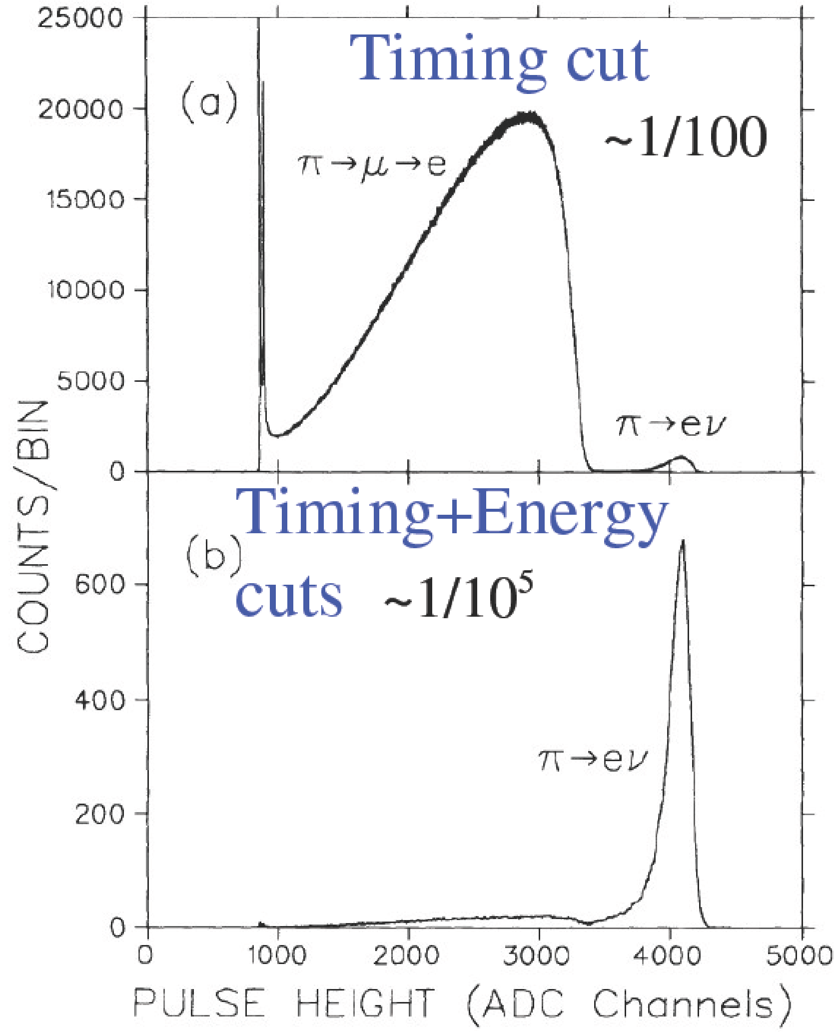
Tπ+ΔEe

π–μ–e

Tπ+ΔEe+Eμ

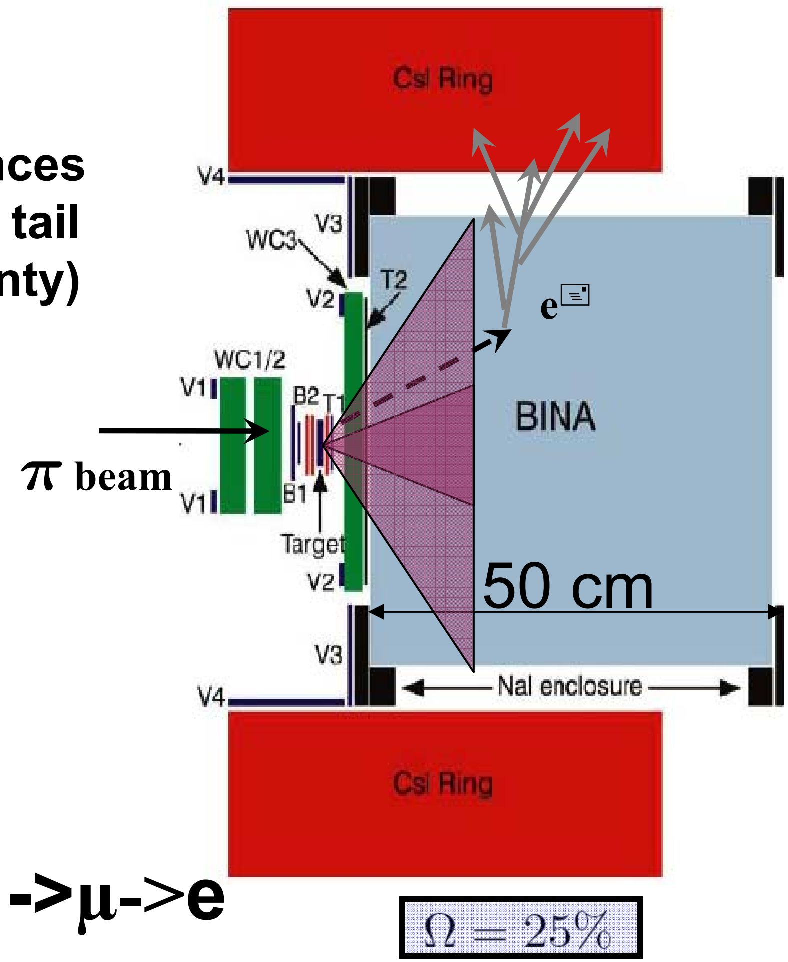






Key Aspects

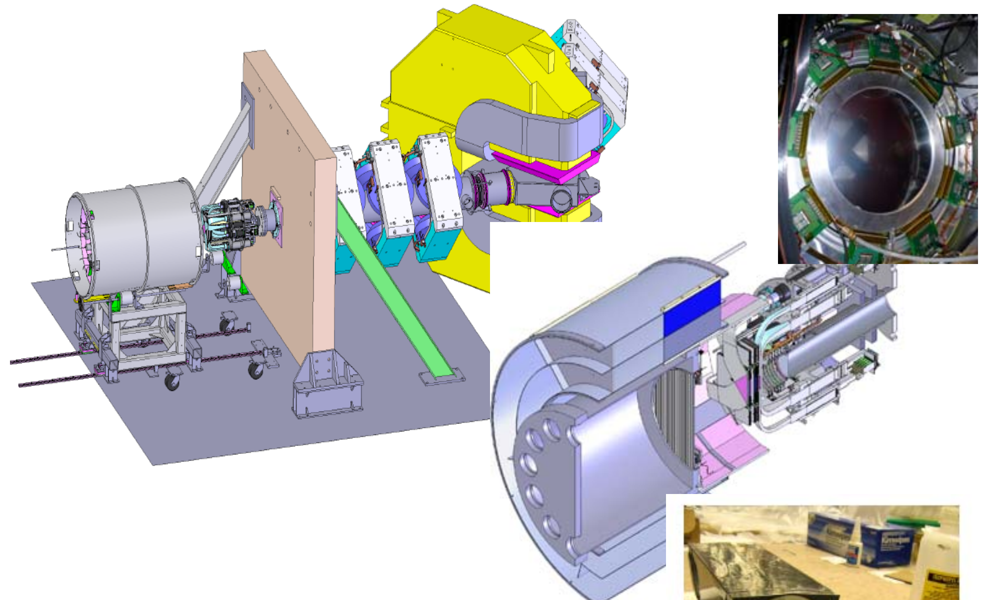
- **Large solid angle (⌖x10)**
  - High statistics
  - Low energy dependent acceptance differences
  - Detect shower leakage (CsI) for low energy tail
  - measurement (biggest systematic uncertainty)
- **Silicon Strips & WC Tracking**
  - Detect Decay-In-Flight ✹ for tail correction
- **High resolution calorimeter**
  - BINA resolution 2 times better than TINA
- **Use of 500 MHz fast digitizers**
  - Good separation between π->eν and π ->μ->e



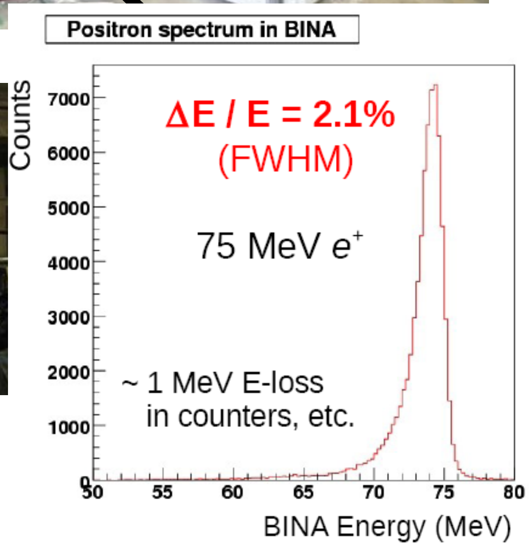
Detectors

View of the PIENU detector in the TRIUMF M13 area

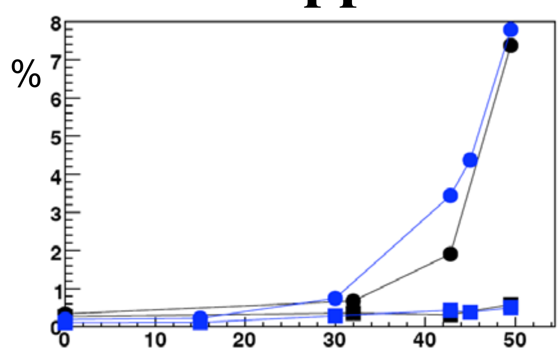
Solidworks design of the experiment



50 cm



Tail Suppression



CsI crystal and PMT

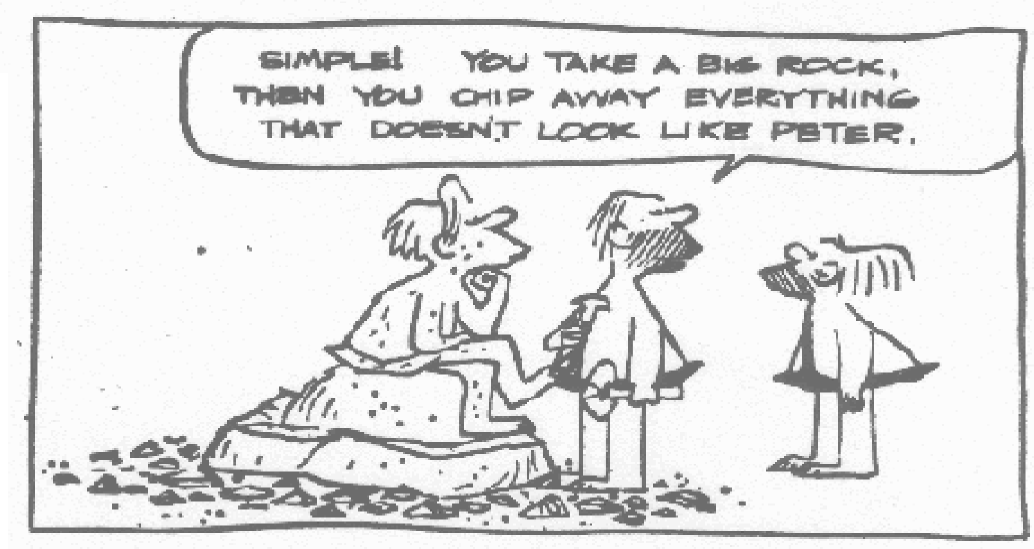
The challenge: control all systematic uncertainties at the 0.0001 level.

source	E248	PiENu
Statistical	0.0028	0.0005
Low E tail ($\pi^+ \rightarrow e^+\nu$)	0.0025	0.0003
Acceptance difference	0.0011	0.0003
π^+ lifetime	0.0009	0.0002
Others	0.0011	0.0003
Total	0.0047	0.0006

PiENu schedule :

2008	09	End of beamline extension work
	10-12	Test run
2009	01-03	Construction and Final Installation
	04-07	Engineering run
	08-12	Physics run

The Secrets of Rare Decay Experiments



Johnny Hart "BC"

$K \to \pi \nu \bar{\nu}$ Experiments

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

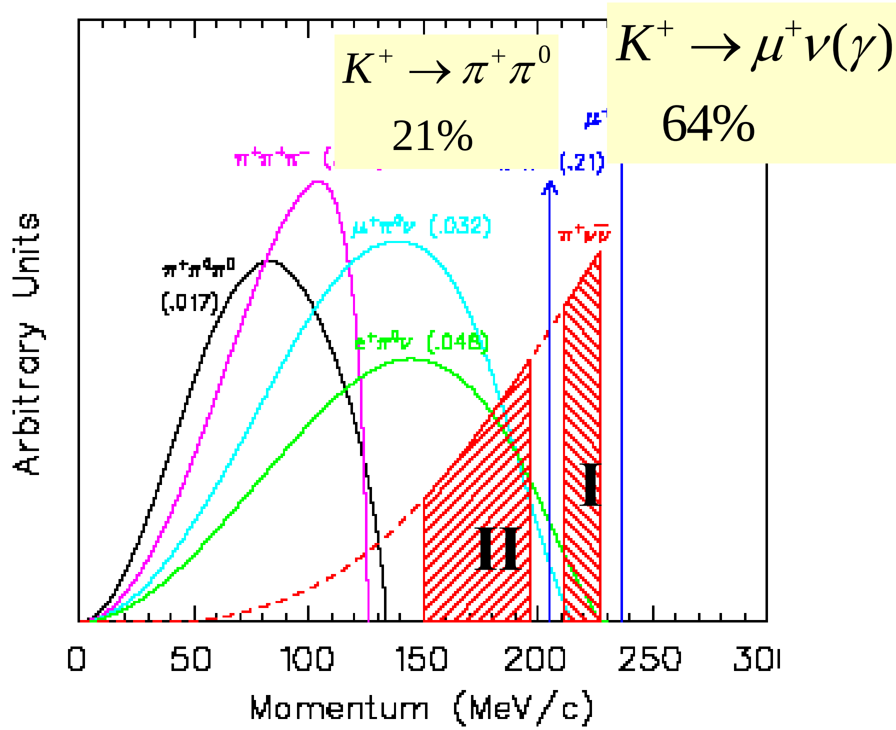
- BNL E949 $B(K^+ \to \pi^+ \nu \bar{\nu}) = 1.73^{+1.15}_{-1.05} x 10^{-10}$
- New Techniques: CERN NA62

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

- E391a $\to$ KOTO -- KEK $\to$ JPARC

Special Features of Measuring $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

Background processes exceed signal by $>10^{10}$

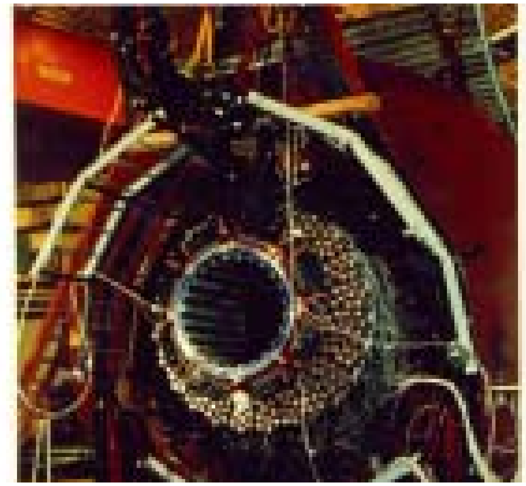


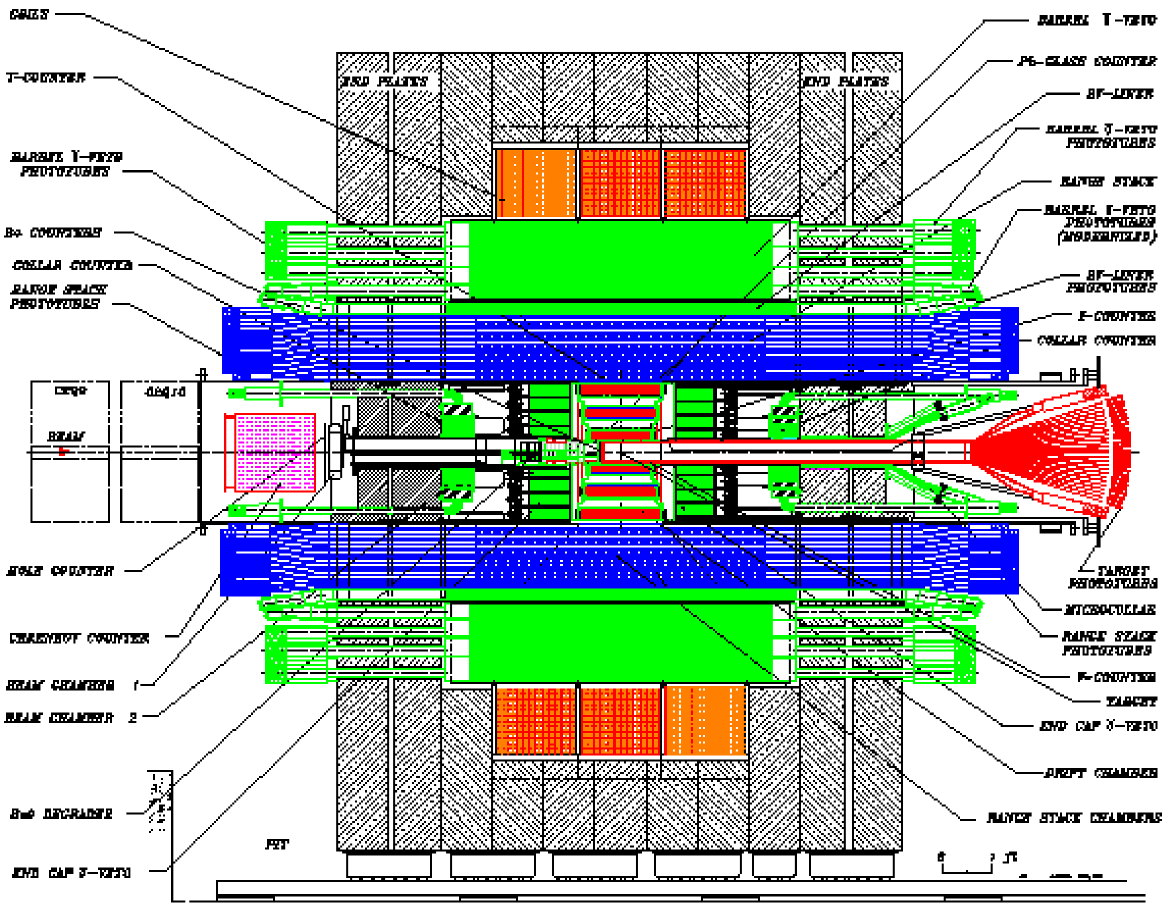
- Determine everything possible about the K^+ and π^+
  - * π^+/μ^+ particle ID better than 10^6 (π^+-μ^+-e^+)
- Eliminate events with extra charged particles or ***photons***
  - * π^0 inefficiency $< 10^{-6}$
- Suppress backgrounds well below the expected signal (S/N~10)
  - * Predict backgrounds *from data*: dual independent cuts
  - * Use “Blind analysis” techniques
  - * Test predictions with “outside-the-box” measurements
- Evaluate candidate events with S/N function

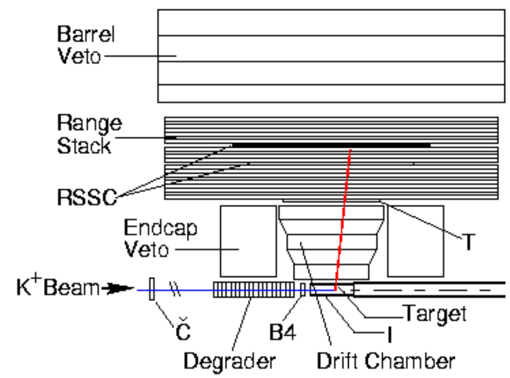
BNL E949

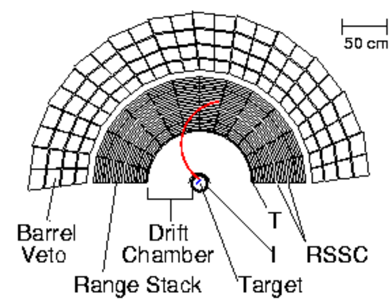
Measurement of

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









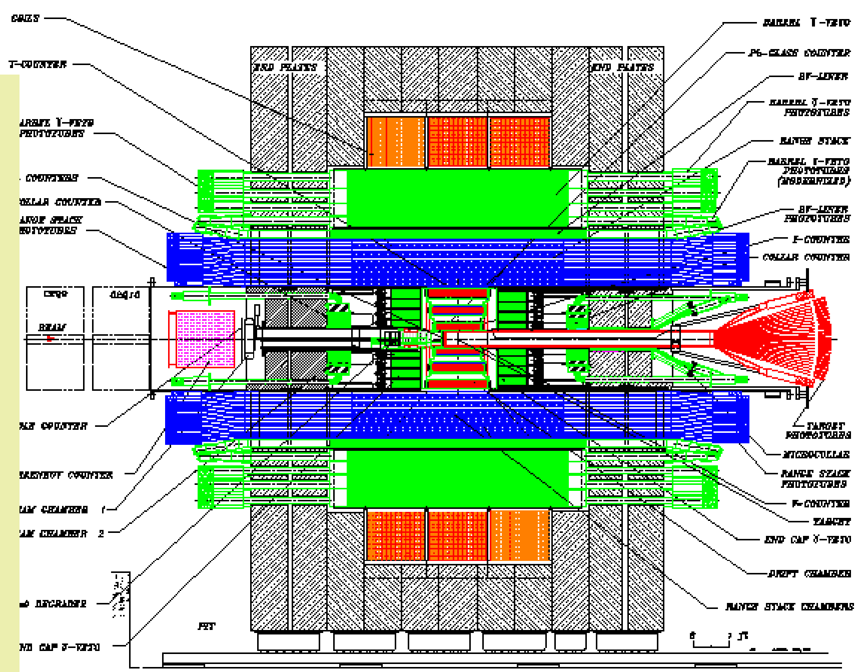
BNL E787/949 Measurement of $K^+ \to \pi^+ \nu \bar{\nu}$

CANADA-CHINA-JAPAN-RUSSIA-USA Collaboration:

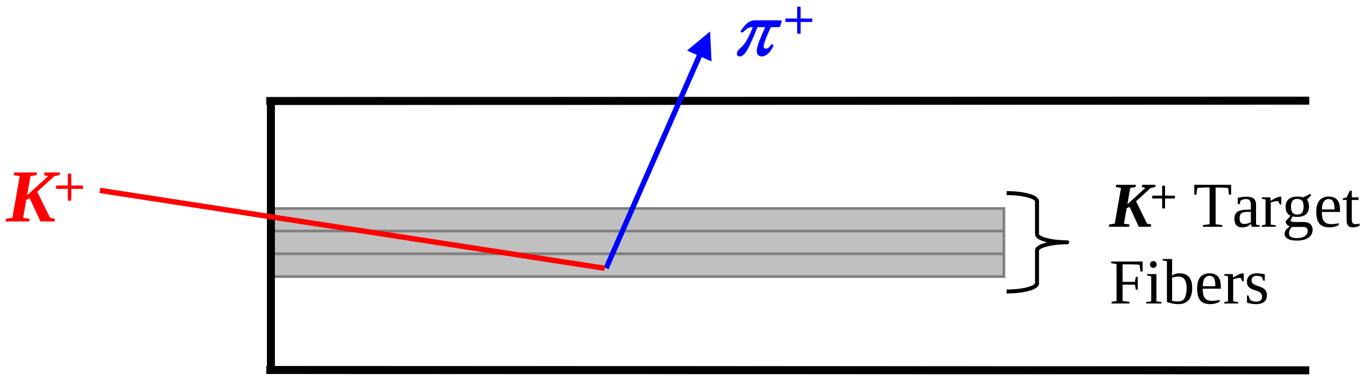
Institute for Nuclear Research **(Moscow),** Institute for High Energy Physics **(Protvino),** University of **New Mexico**, **Princeton** University, **Brookhaven National Laboratory,** **TRIUMF**, University of **British Columbia**, **Tsinghua** University (Beijing), **Stony Brook** University, **Fermilab**, **Kyoto** University, **KEK,** University of **Alberta**, **Fukui** University, **Osaka** University, **National Defense Academy** (Japan)

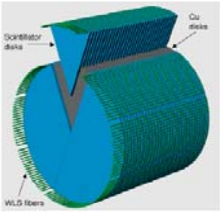
Advanced Technologies:

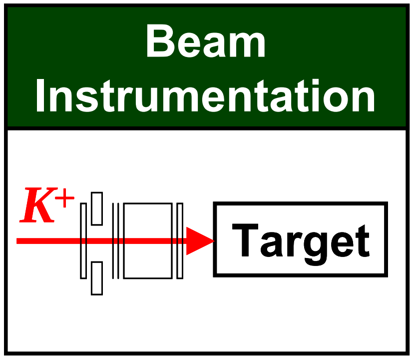
- **Highest Efficiency Detection**
- **Low mass central tracking chamber - inflated cathodes**
- **500 MHz digitizers**
- **Scintillating fiber target**
- **Pure CsI calorimeter**
- **"Blind Analysis"**

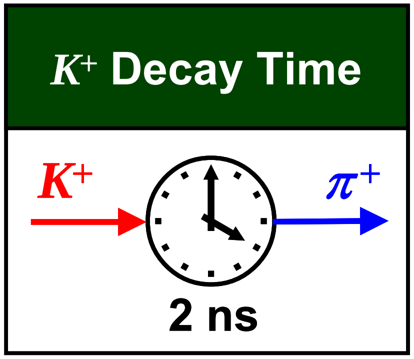


700 MeV/c kaon enters and decays-at-rest in the scintillator-fiber target





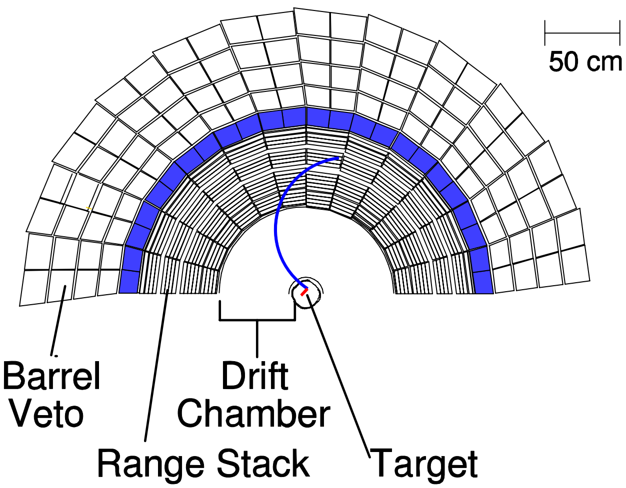


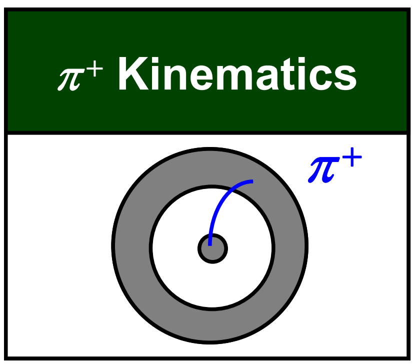


Beam instrumentation is used to identify a single K^+ from the beam

Kaon comes to rest in the target and we wait at least 2 ns for K^+ to decay

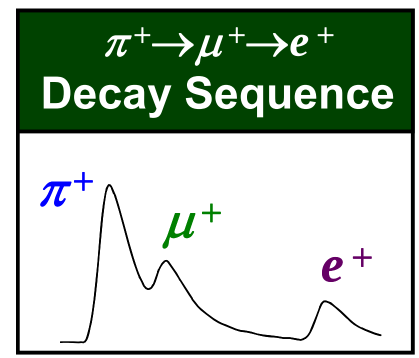
Pion comes to rest in the range-stack and undergoes the $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ decay sequence





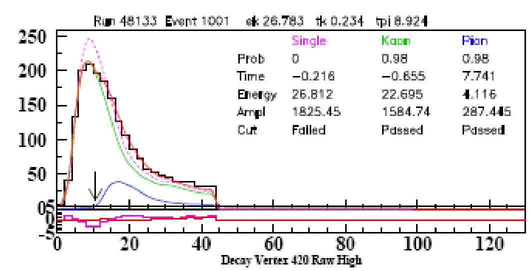
π^+ momentum is measured in the drift chamber

π^+ range and energy are measured target and range-stack

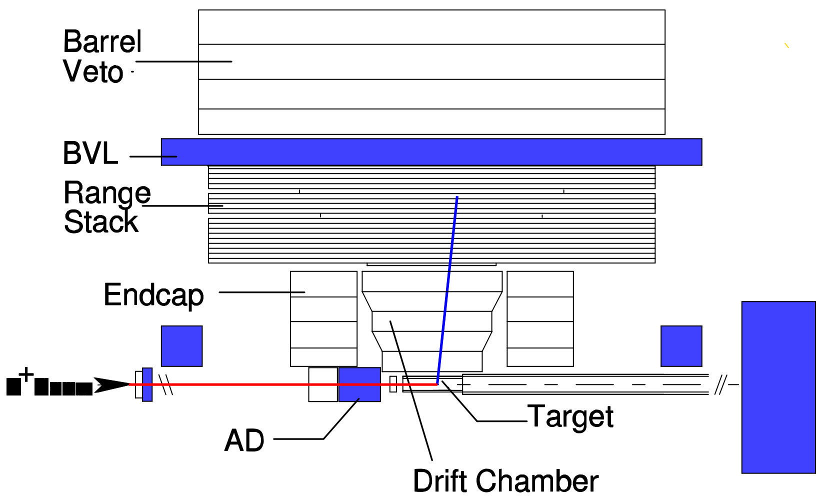


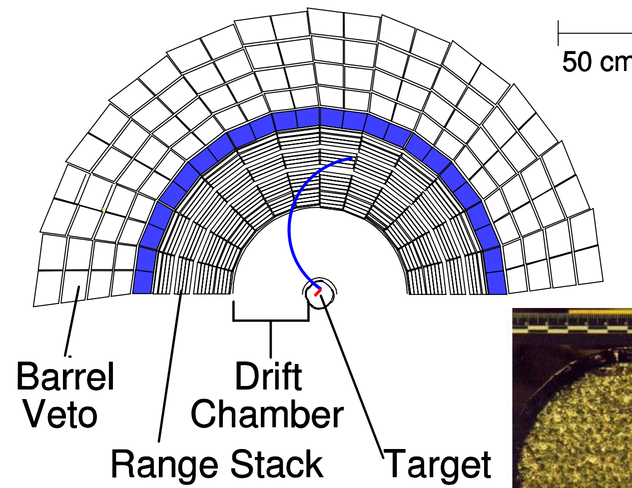
$\pi^+ \rightarrow \mu^+ \rightarrow e^+$ decay sequence is observed in the range-stack scintillator

500 MHz digitizers

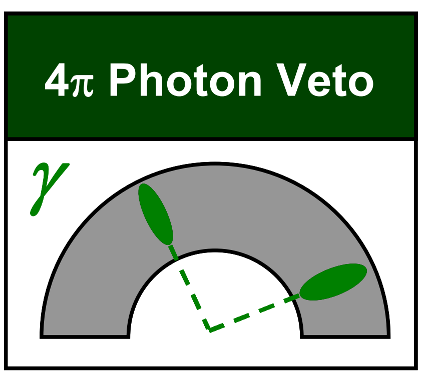


Photons and any additional charged particle activity are vetoed

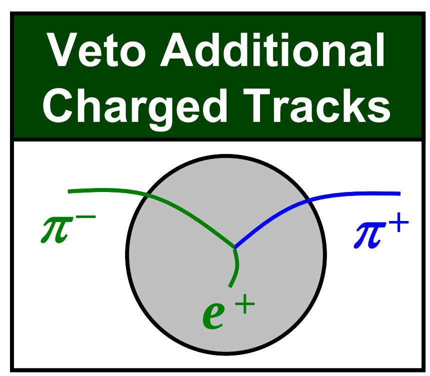


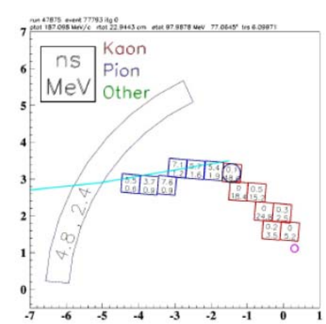


Each fiber is 0.5 × 0.5 × 300.0 cm

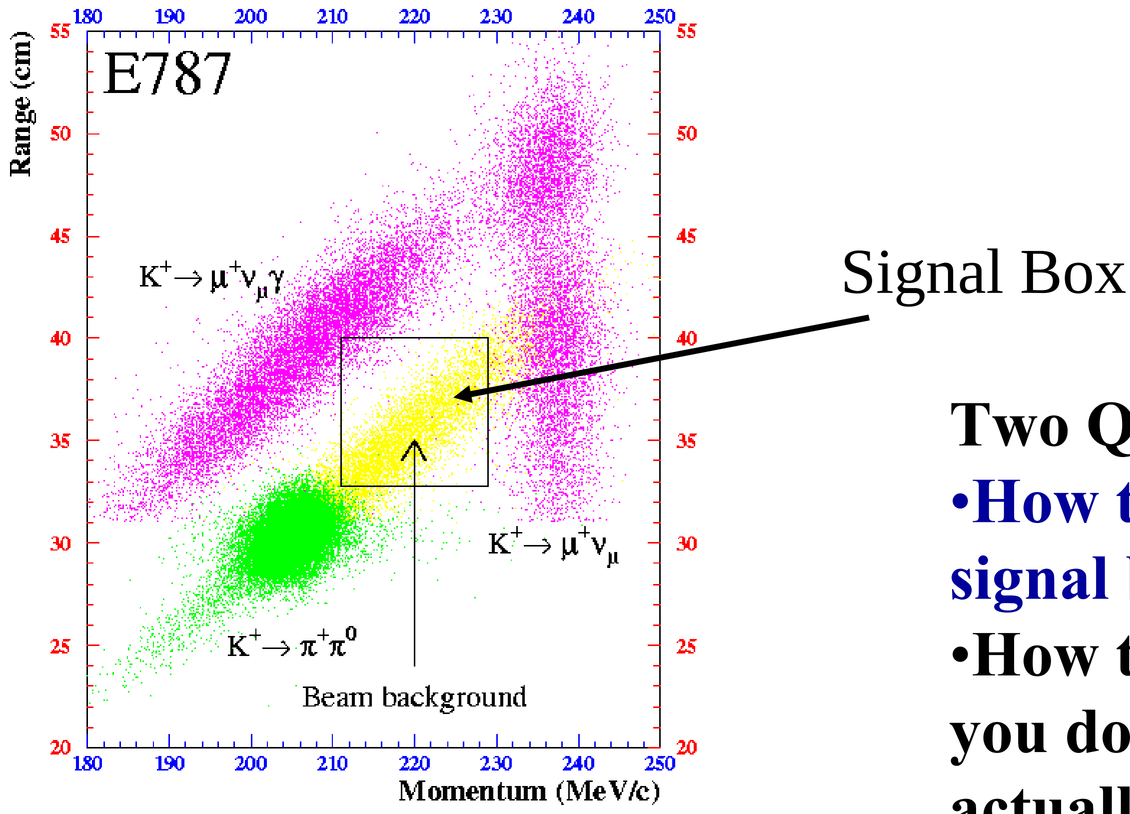


Pattern recognition is used in the target, drift chamber and range-stack





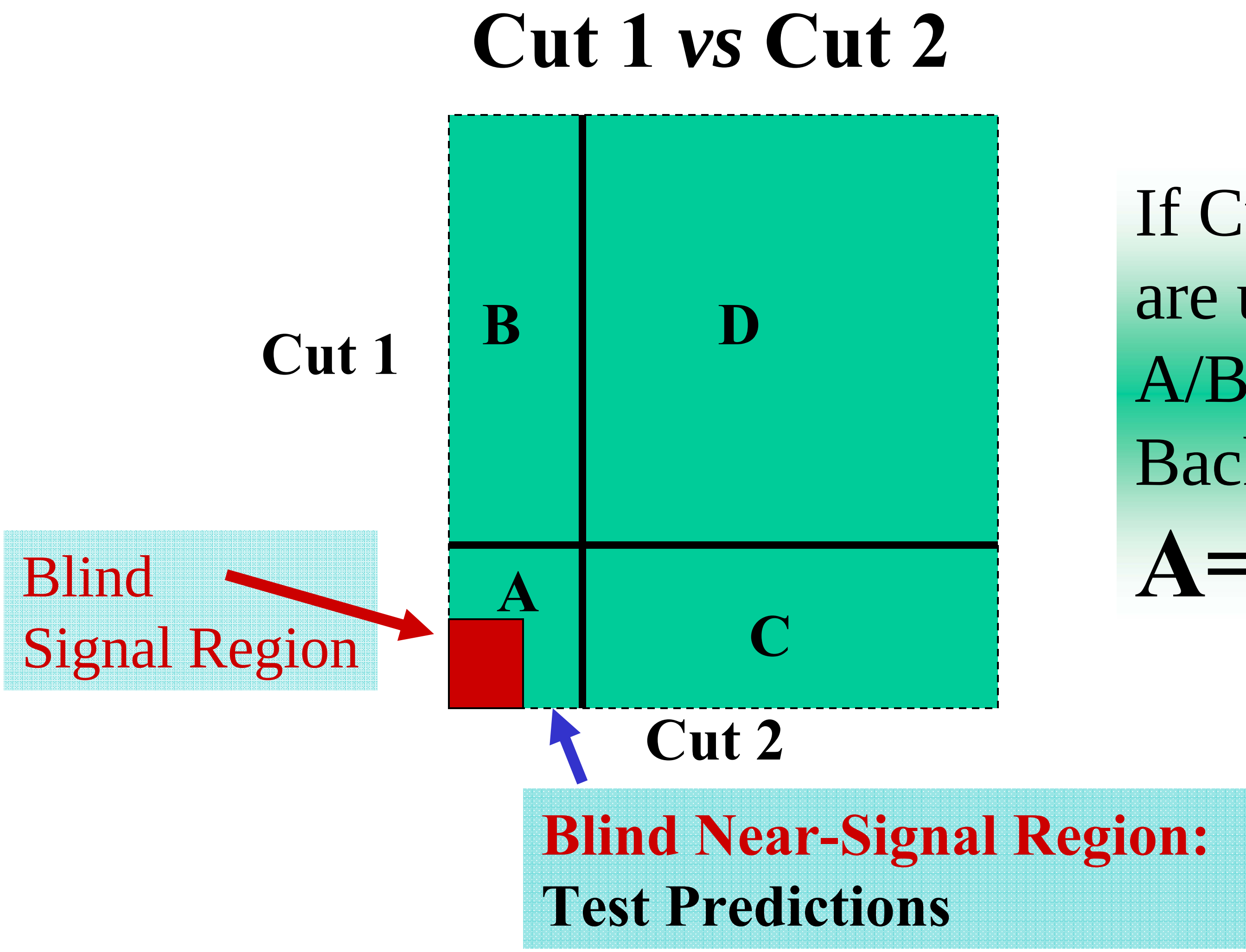
Background Processes: Range vs. Momentum



Two Questions:

- **How to find a tiny signal buried here!**
- **How to make sure you don't miss it if it's actually there?**

Estimating Backgrounds
Dual-Cut BLIND Analysis Method



If Cuts 1 and 2 are uncorrelated:
A/B=C/D
Background in A:

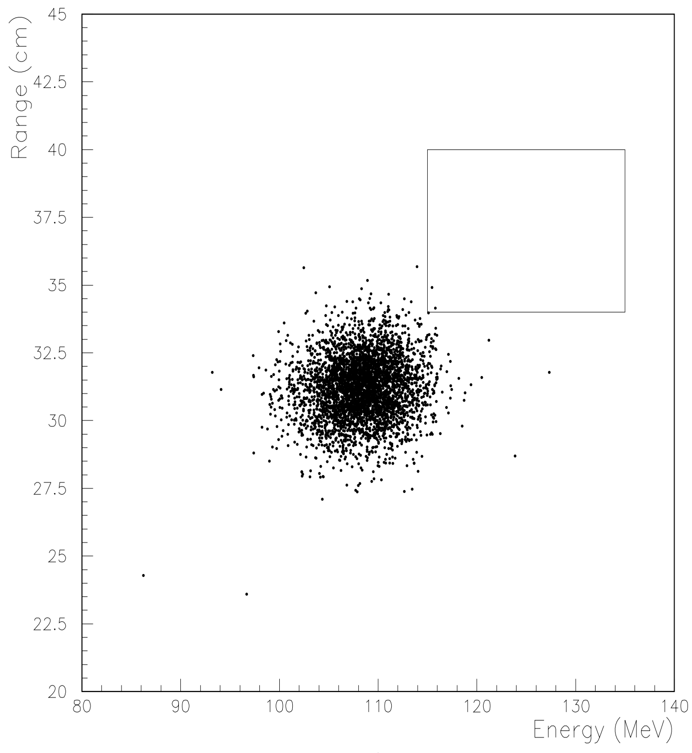
A=B C/D

$K^+ \rightarrow \pi^+\pi^0$ Background Suppression

Dual cuts: γ Veto and Kinematics (P,R,E...)

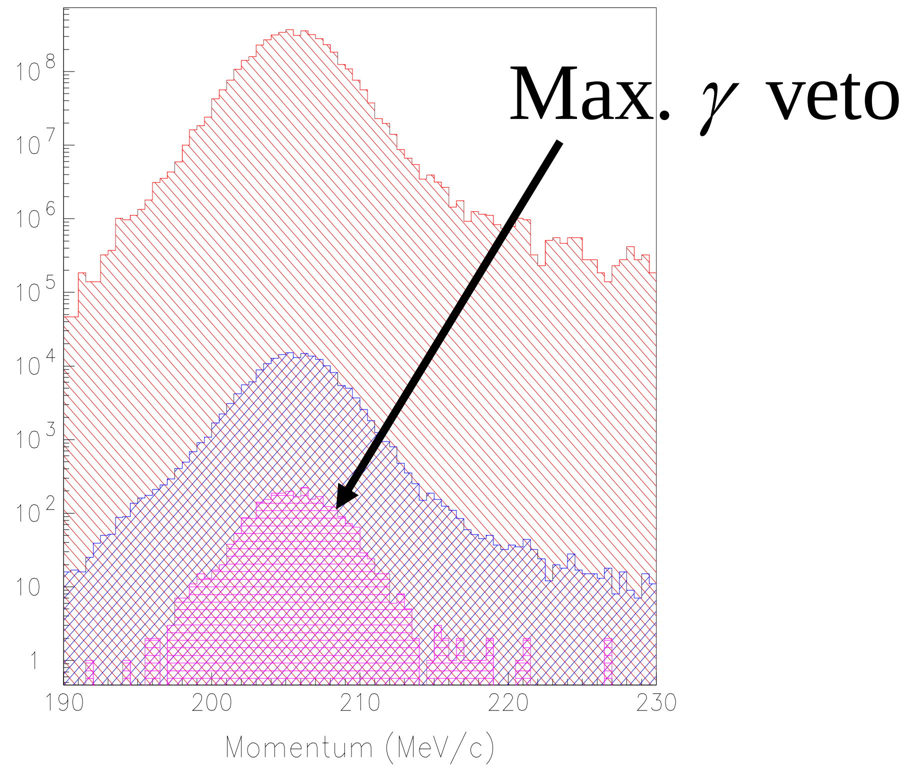
γ Veto Reversed

Range vs. Energy



γ Veto Applied

Momentum



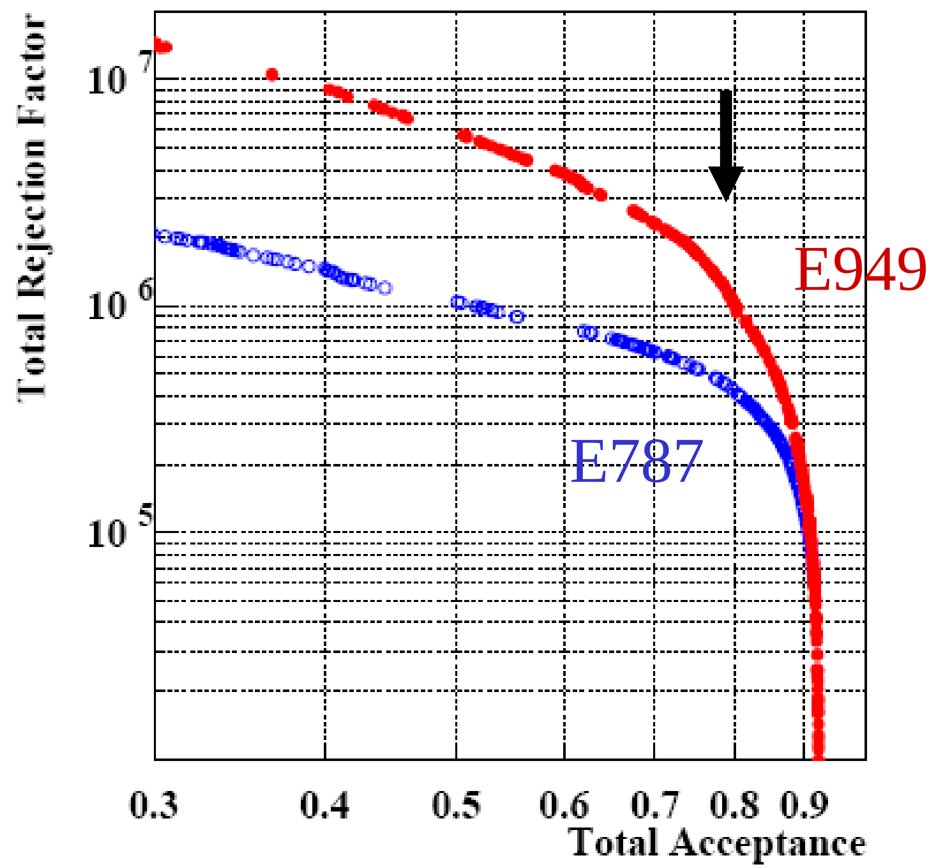
Check for correlations

Background Suppression: E949 Extreme Photon Detection Efficiency

π^0 Rejection: $>10^6 - 10^7$

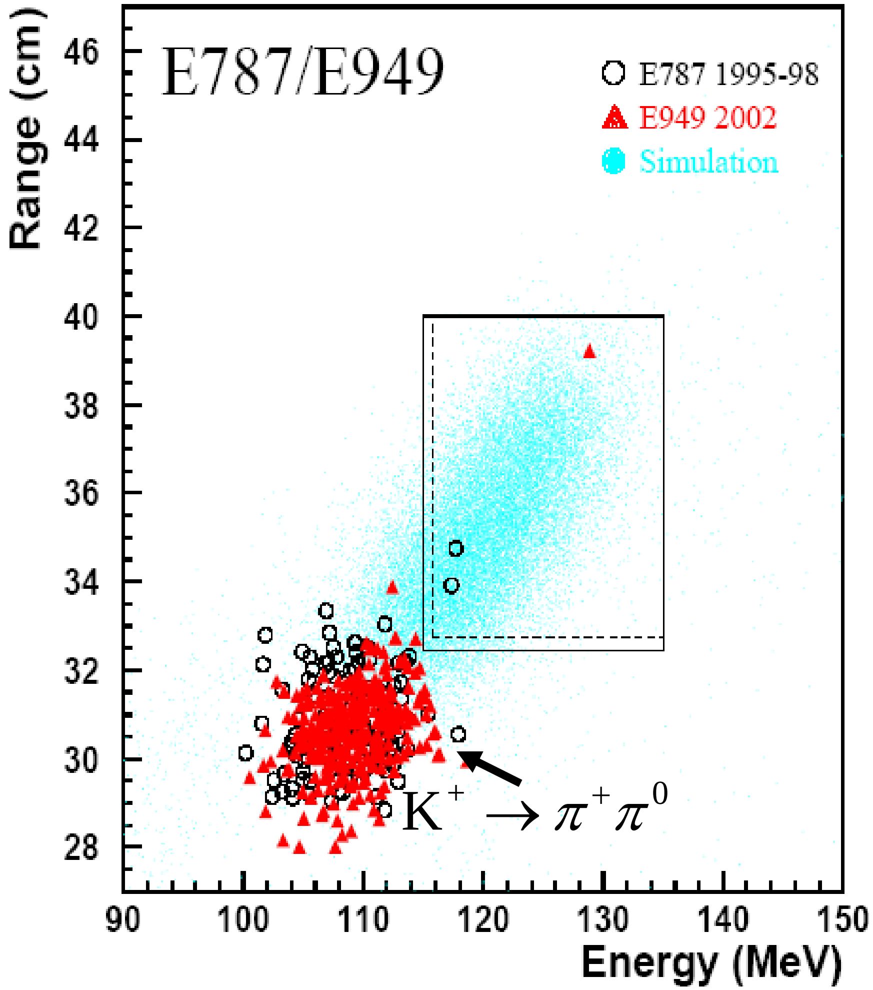
(Twice the rejection of π^0 backgrounds at comparable acceptance compared to previous efforts.)

Rejection vs. Acceptance



Combined E787/E949 Branching Ratio

1st Results: $B(K^+ \to \pi^+ \nu\bar{\nu}) = 1.47^{+1.30}_{-0.89} \; x\, 10^{-10}$

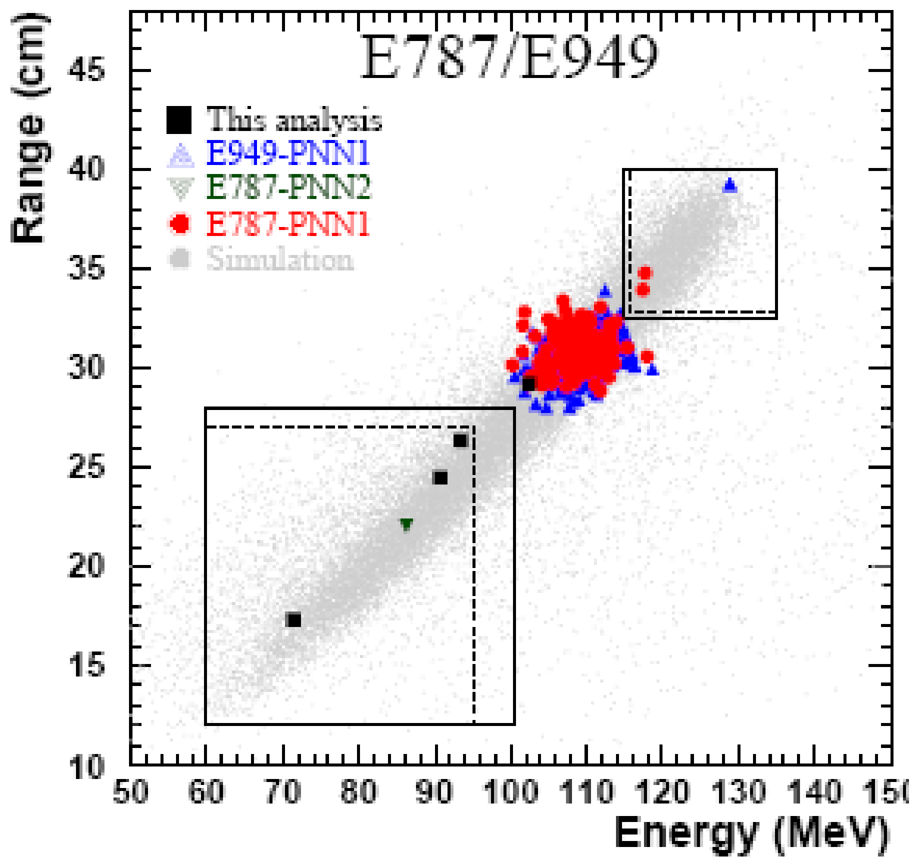


3 events – consistent with SM

	E787		E949
N_K	5.9×10^{12}		1.8×10^{12}
Total Acceptance	0.0020 ± 0.0002		0.0022 ± 0.0002
Total Background	0.14 ± 0.05		0.30 ± 0.03
Candidate	1995A	1998C	2002A
S/b	50	7	0.9
W	0.98	0.88	0.48
Background Prob.	0.006	0.02	0.07

Including the Region below the $K_{\pi 2}$ Peak: 7 events

$$\text{Final Result: } B(K^+ \to \pi^+ \nu \bar{\nu}) = 1.73^{+1.15}_{-1.05} x10^{-10}$$



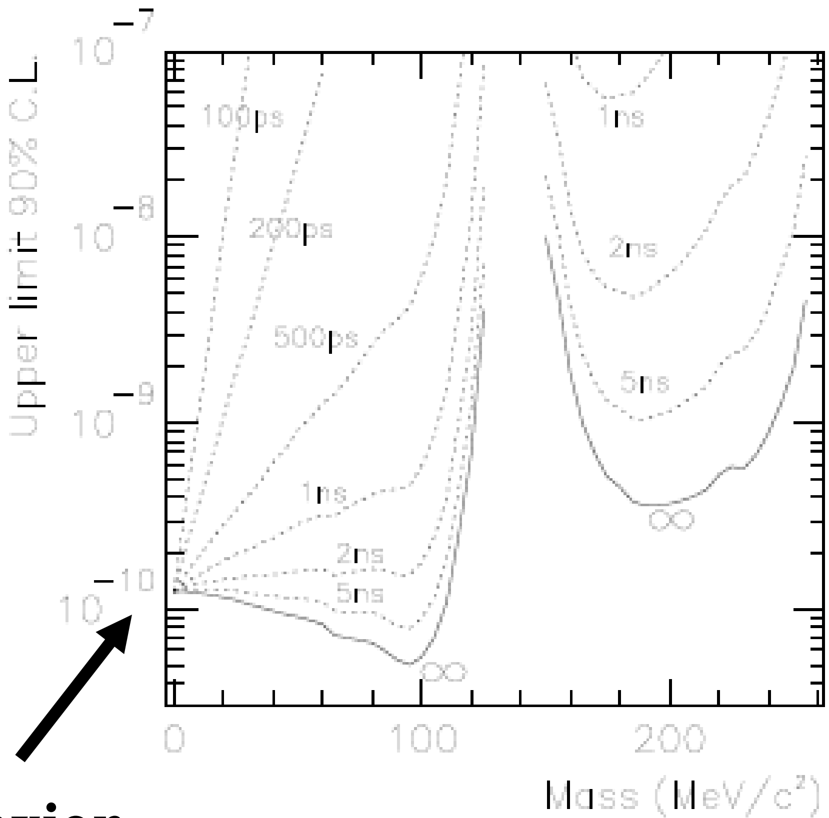
E787(dashed) and E949(solid) signal regions shown. All cuts applied.

Standard Model:

$$B(K^+ \to \pi^+ \nu \bar{\nu}) = (0.85 \pm 0.07) x10^{-10}$$

Probability for all 7 events to be due to background: 0.001

Search for $K^+ \to \pi^+ X$

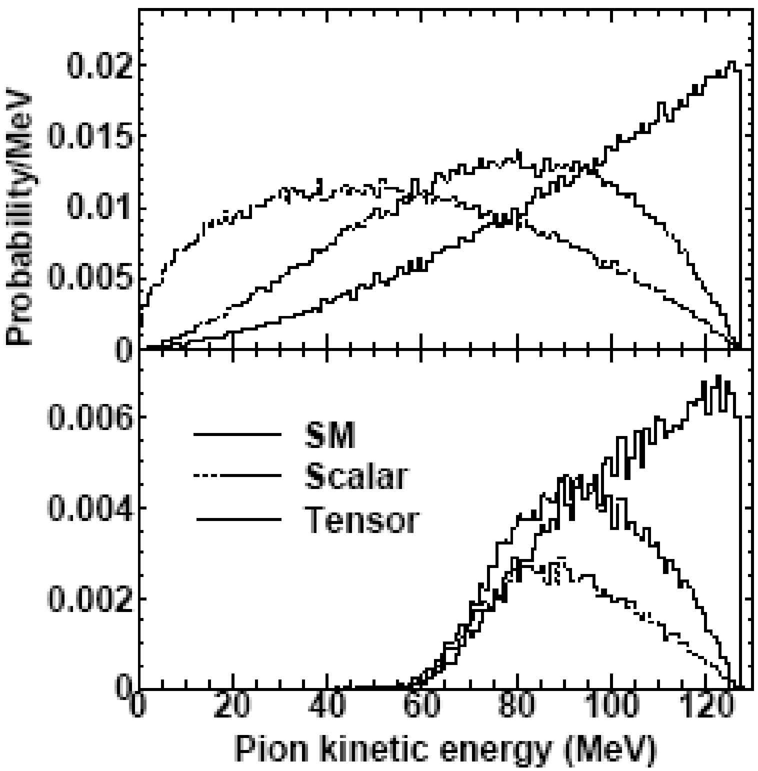


X=axion

90% CL limits on $K^+ \to \pi^+ X$ where X is a massive non-interacting particle for $\tau(X) \geq 100$ ps, assuming 100% detection efficiency if X decays within the outer radius of the barrel photon veto.

Also: $\mathcal{B}(K^+ \to \pi^+ X) < 5.6 \times 10^{-8}$ (90%CL) for $M(X) = M(\pi^0)$ from limit on $\mathcal{B}(\pi^0 \to \nu\bar{\nu}) < 2.7 \times 10^{-7}$ (E949, PRD**72** 091102 (2005)).

Search for $K^+ \to \pi^+ XX$



Interpretation assuming a scalar or tensor interaction:

$\mathcal{B}_{\rm scalar} = (9.9^{+8.5}_{-4.2}) \times 10^{-10}$

$\mathcal{B}_{\rm tensor} = (4.9^{+3.9}_{-2.4}) \times 10^{-10}$

Figure:

Top is simulated π^+ energy spectra

Bottom are events passing the trigger

BNL E787/E949 Results

Discoveries

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

$K^+ \to \pi^+ \gamma\gamma$

$K^+ \to \pi^+ \mu\mu$

$K^+ \to \mu\nu\gamma(SD)$

$K^+ \to \pi^+ \pi^0 \gamma(DE)$

Searches

$K^+ \to \pi^+ a$

$K^+ \to \pi^+ \gamma$

$K^+ \to \pi^+ H$

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

$\pi^0 \to \gamma X$

$K^+ \to e\nu\mu\mu$

$K^+ \to \pi^0 \pi^+ \nu\bar{\nu}$

Still to come: $K^+ \to \pi^0 \mu^+ \nu\gamma, \;\; K^+ \to \pi^+ \pi^0 \gamma, K^+ \to \mu\nu_H$

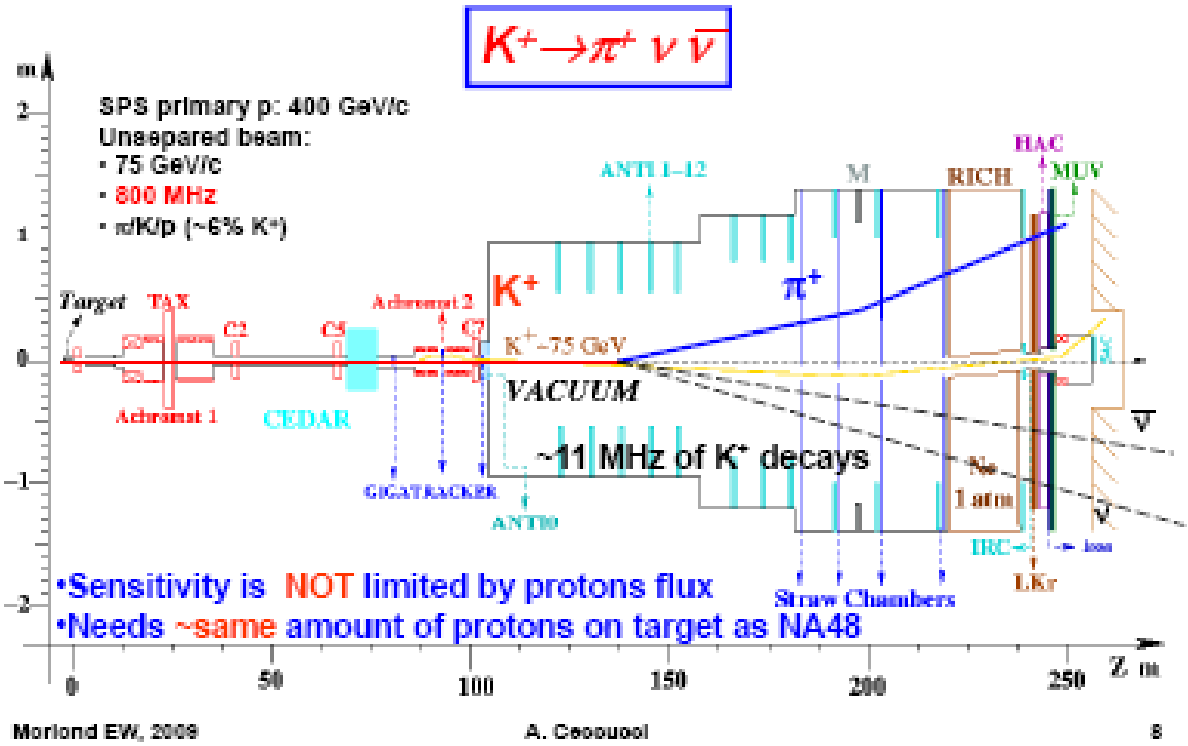
New Approaches to $K^+ \to \pi^+ \nu\bar{\nu}$:

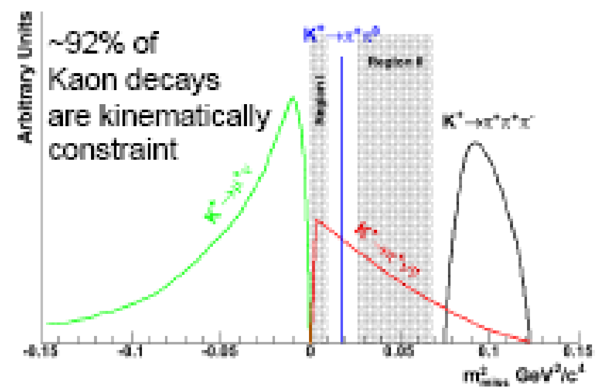
CERN Proposal

NA62

Goal: 10 x E949
New technique.

Proposed Detector Layout





Goal: 55 events/yr.
Bkg.~ 14%

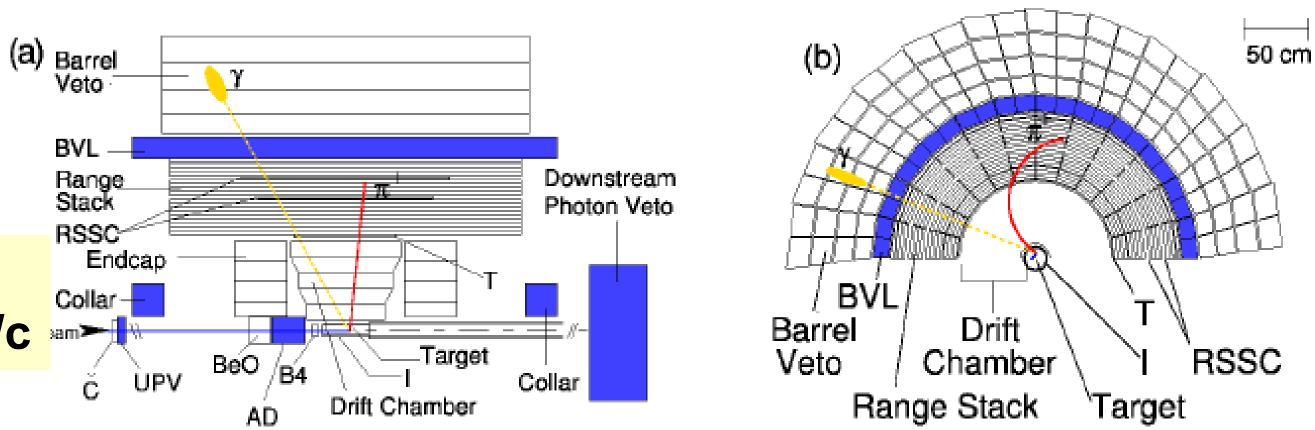
New opportunity:

100 x E949
Same technique.

$K^+ \to \pi^+ \nu \bar{\nu}$ at JPARC or Fermilab:

Stopped K technique: 1000 events!

Lower P_k
400 MeV/c



Improved Acceptance (x5):

- **5 x higher stop efficiency at low momentum**
- **Reduced randoms and accidental spoiling of events (photon veto) due to low momentum.**

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

Theory: $2.76 \pm 0.40\, x10^{-11}$

Limit from $K^+ \to \pi^+ \nu \bar{\nu}$ via isospin : $< 1.4\, x10^{-9}$ • $[Grossman,\ Nir]$

- KTEV (FNAL) result: $B(K_L^0 \to \pi^0 \nu \bar{\nu}) < 5.9\, x10^{-7}$ $(90\% CL)$
- KEK E391a: $B(K_L^0 \to \pi^0 \nu \bar{\nu}) < 6.7\, x10^{-8}$ $(90\% CL)$
- JPARC Proposal E14 KOTO:

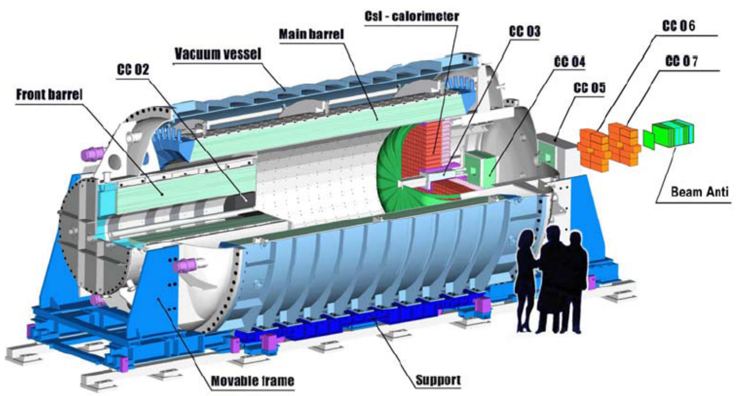
  Sensitivity Goal: $10^{-11} (S/N = 2)$

The Challenge

- $B(K_L \rightarrow \pi^0 \nu \bar{\nu}) \sim 3\times10^{-11}$;

  need huge flux of K's -> high rates
- Weak Kinematic signature (2 particles missing)
- Backgrounds with π^0 up to 10^9 times larger
- Veto inefficiency on extra particles must be $\leq 10^{-4}$
- Neutrons dominate the beam
  - make π^0 off residual gas – require high vacuum
  - halo must be very small
  - hermeticity requires photon veto in the beam
- Need convincing measurement of background

KEK PS E391a >>> JPARC KOTO with KTEV CsI



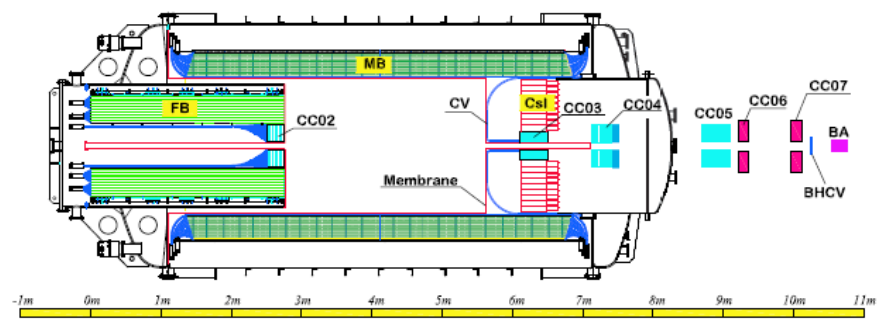


FIG. 1: Cross section of the E391a detector. K_L^0's enter from the left side.

Features:

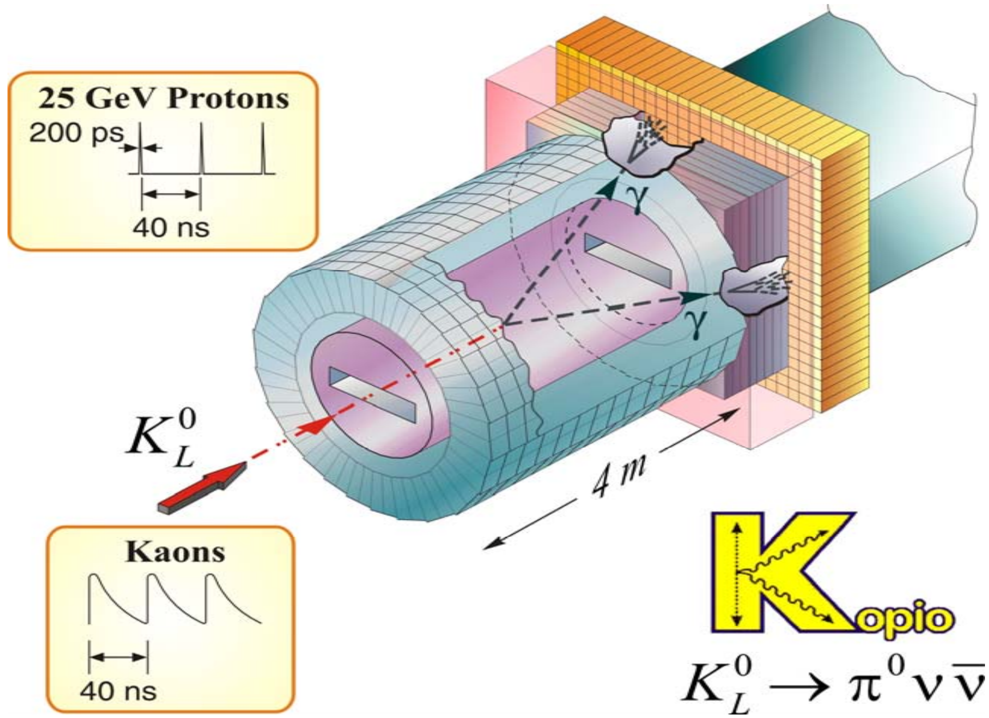
Pencil Beam , High P_T selection

•High acceptance

•Reliance on high photon veto efficiency

E391a Result: $B(K_L^0 \rightarrow \pi^0 \nu \bar{\nu}) < 6.7\, x 10^{-8}$ (90%CL)

KOPIO Concepts: Goal >100 events



Possibilities at JPARC or Fermilab: 300-1000 Events?

- Use time-of-flight 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

Summary

Rare Decays of $\mu, \pi,$ and K offer unique, clean access to the flavor breaking and CP-violating structure of new physics -- access to short distance effects and high mass scales are complementary to LHC.

Star Attractions: New Physics Sensitvity

- $\mu \rightarrow e$ Conversion and $\mu \rightarrow e\gamma$ $\qquad \dfrac{1}{M_H^4}$

  PSI-MEG, *Mu2E, Comet*

- $\pi \rightarrow \mathrm{e}\nu / \pi \rightarrow \mu\nu$ $\qquad \dfrac{1}{M_H^2}$

  PI E NU **/PSI-PEN**

- $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$ and $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ $\qquad \dfrac{1}{M_H^2}$

KOTO, CERN NA62 ***New Fermilab, JPARC?***