ORKA: The Golden Kaon Experiment

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

Photo: Life of Sea blogspot

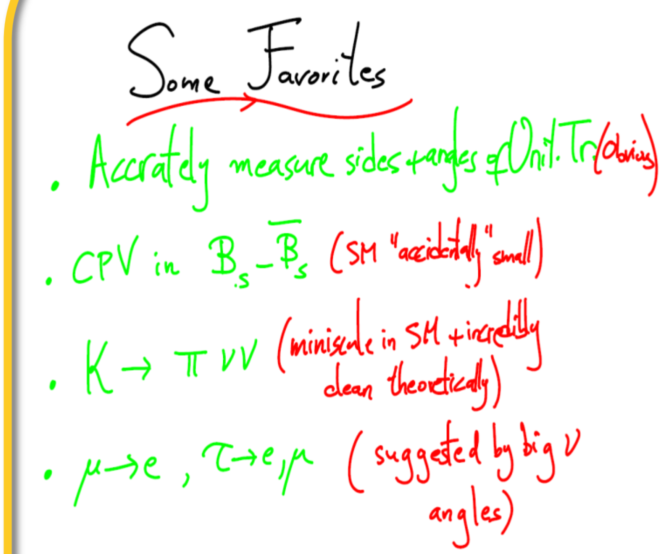
Elizabeth Worcester (BNL)
for the ORKA collaboration
June 13, 2012

ORKA: The Golden Kaon Experiment

- Precision measurement of $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ BR with ~1000 expected events at FNAL MI
- Expected BR uncertainty matches Standard Model uncertainty
- Sensitivity to new physics at and beyond LHC mass scale
- Builds on successful previous experiments (BNL E787/E949 – 7 events already seen)
- High impact measurement
- Total estimated cost: $53M (FY2010)

Motivation

- Flavor problem:
  - We expect new physics at the TeV scale . . .
  - Why don't we see this new physics affecting the flavor physics we study today?
- If new physics found at LHC:
  - Precision flavor-physics experiments needed to explore flavor- and CP-violating couplings
- If no new physics found at LHC:
  - Precision flavor-physics experiments needed to search for new physics beyond the reach of the LHC through virtual effects



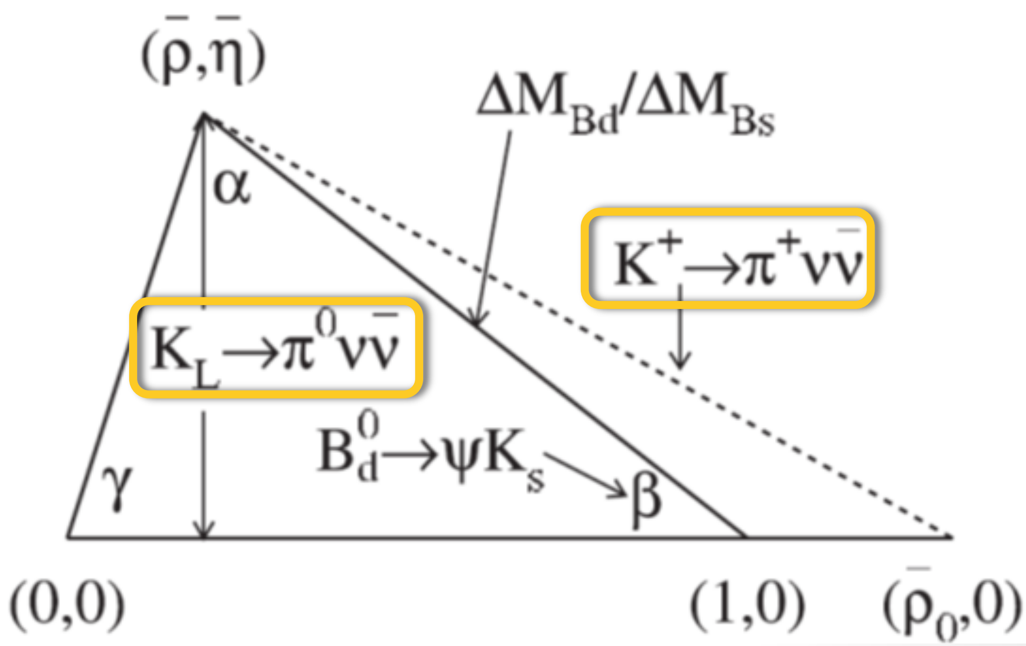
Flavor Physics: Pushing Beyond the LHC.
Intensity Frontier Workshop
Nima Arkani-Hamed
(Princeton, IAS)

CKM Matrix and Unitarity Triangle

Wolfenstein Parameterization

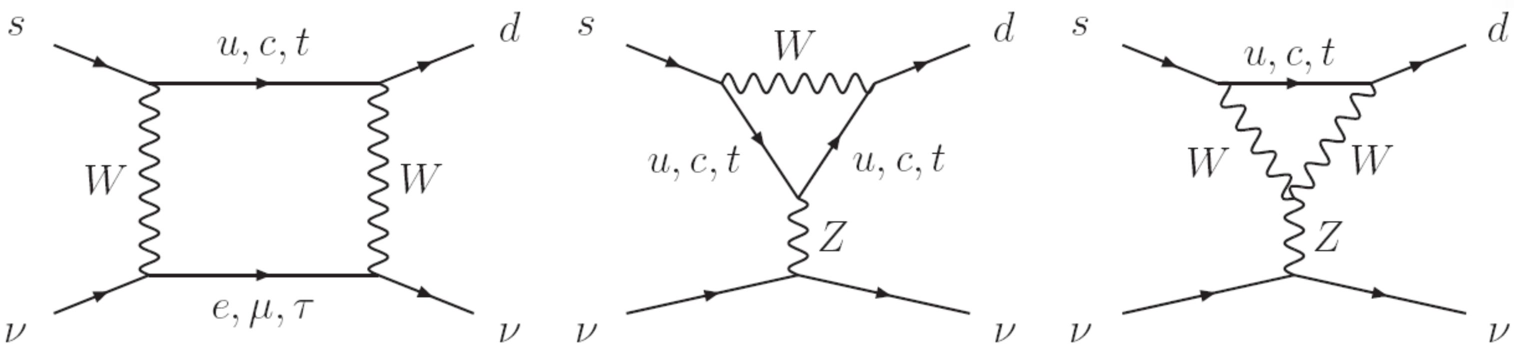
$$\begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

CP Violation



$K^+ \to \pi^+ \nu\bar{\nu}$ in the Standard Model

- $K^+ \to \pi^+ \nu\bar{\nu}$ is the most precisely predicted FCNC decay involving quarks
- $B_{SM}\left(K^+ \to \pi^+ \nu\bar{\nu}\right) = \left(7.8 \pm 0.8\right) \times 10^{-11}$



- A single effective operator: $\left(\bar{s}_L \gamma^\mu d_L\right)\left(\bar{\nu}_L \gamma_\mu \nu_L\right)$
- Dominated by top quark
- Hadronic matrix element shared with Ke3
- Dominant uncertainty from CKM elements (expect prediction to improve to ~5%)

Sensitivity to New Physics

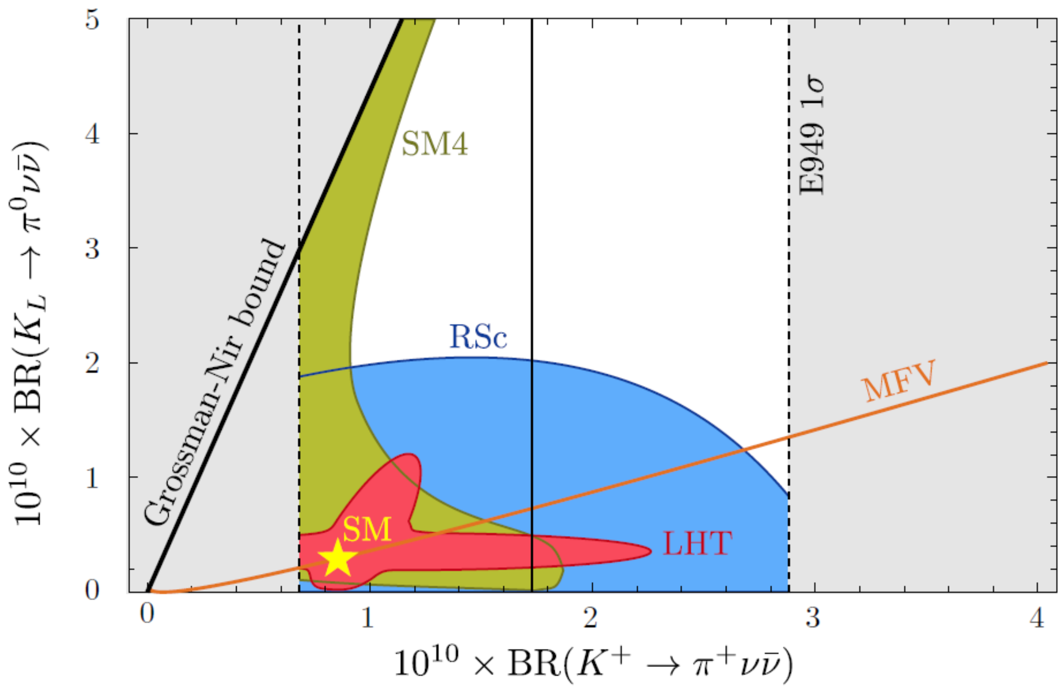
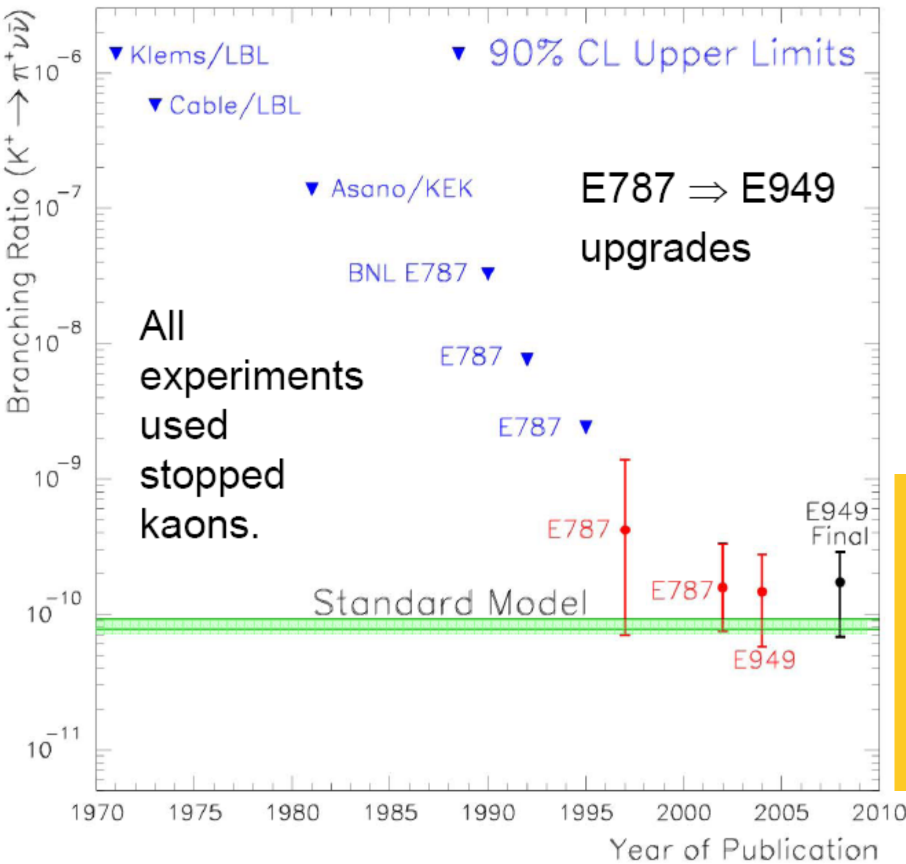


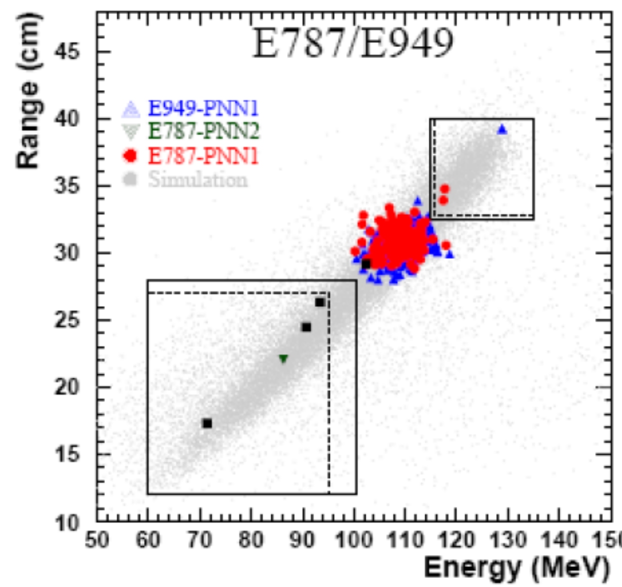
Figure 1: Correlation between the branching ratios of $K_L \to \pi^0 \nu\bar{\nu}$ and $K^+ \to \pi^+ \nu\bar{\nu}$ in MFV and three concrete NP models. The gray area is ruled out experimentally or model-independently by the GN bound. The SM point is marked by a star.

D.M. Straub, CKM 2010 Workshop, arXiv:1012.3893[hep-ph]

Experimental History

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





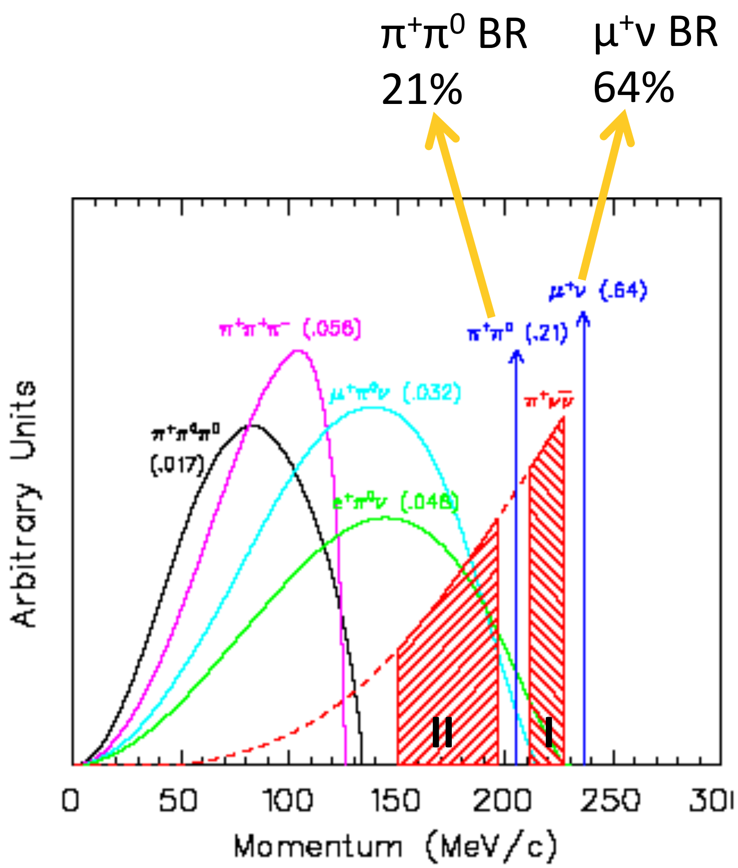
E787/E949 Final: 7 events observed

$$B\left(K^+ \to \pi^+ \nu\bar{\nu}\right) = 17.3^{+11.5}_{-10.5} \times 10^{-11}$$

Standard Model:

$$B\left(K^+ \to \pi^+ \nu\bar{\nu}\right) = 7.8 \pm 0.8 \times 10^{-11}$$

Difficult Measurement

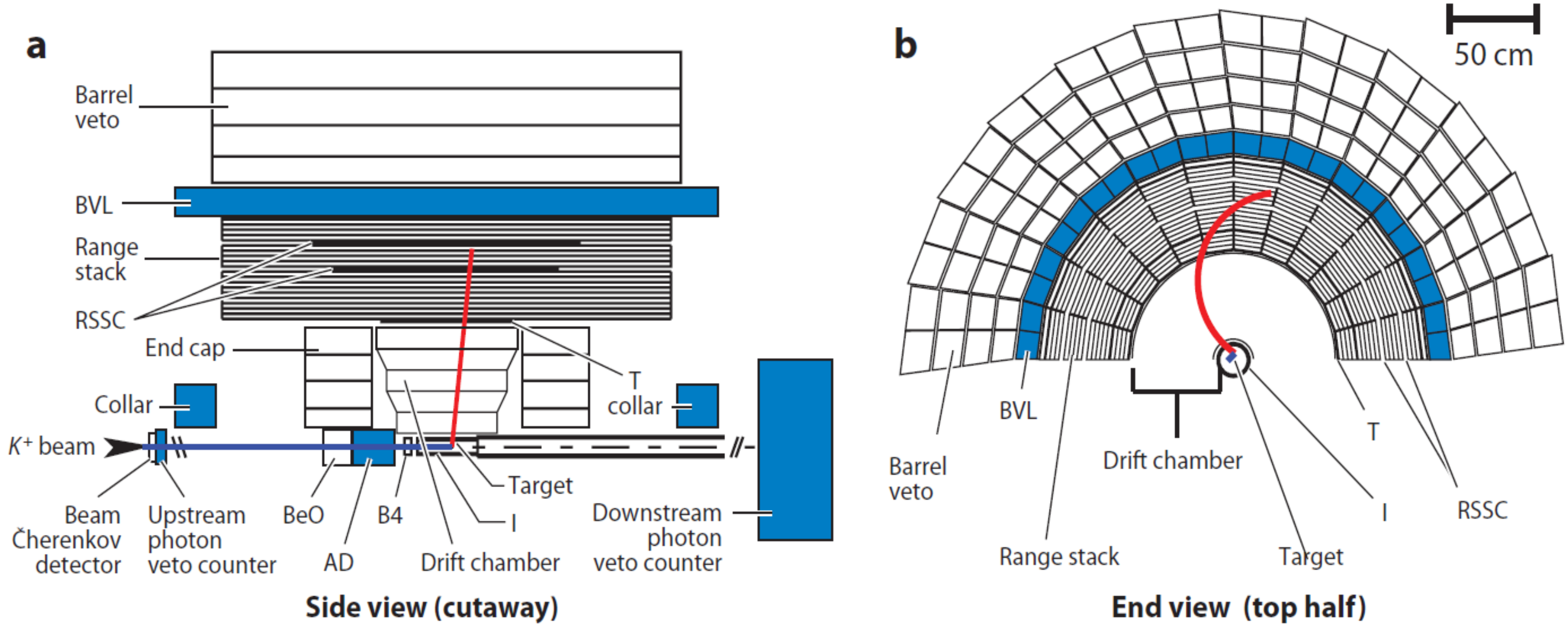


Momentum spectra of charged particles from K^+ decays in the rest frame

- Observed signal is $K^+ \rightarrow \pi^+ \rightarrow \mu^+ \rightarrow e^+$
- Background exceeds signal by $> 10^{10}$
- Requires suppression of background well below expected signal (S/N ~10)
- Requires $\pi/\mu/e$ particle ID $> 10^6$
- Requires π^0 inefficiency $< 10^{-6}$

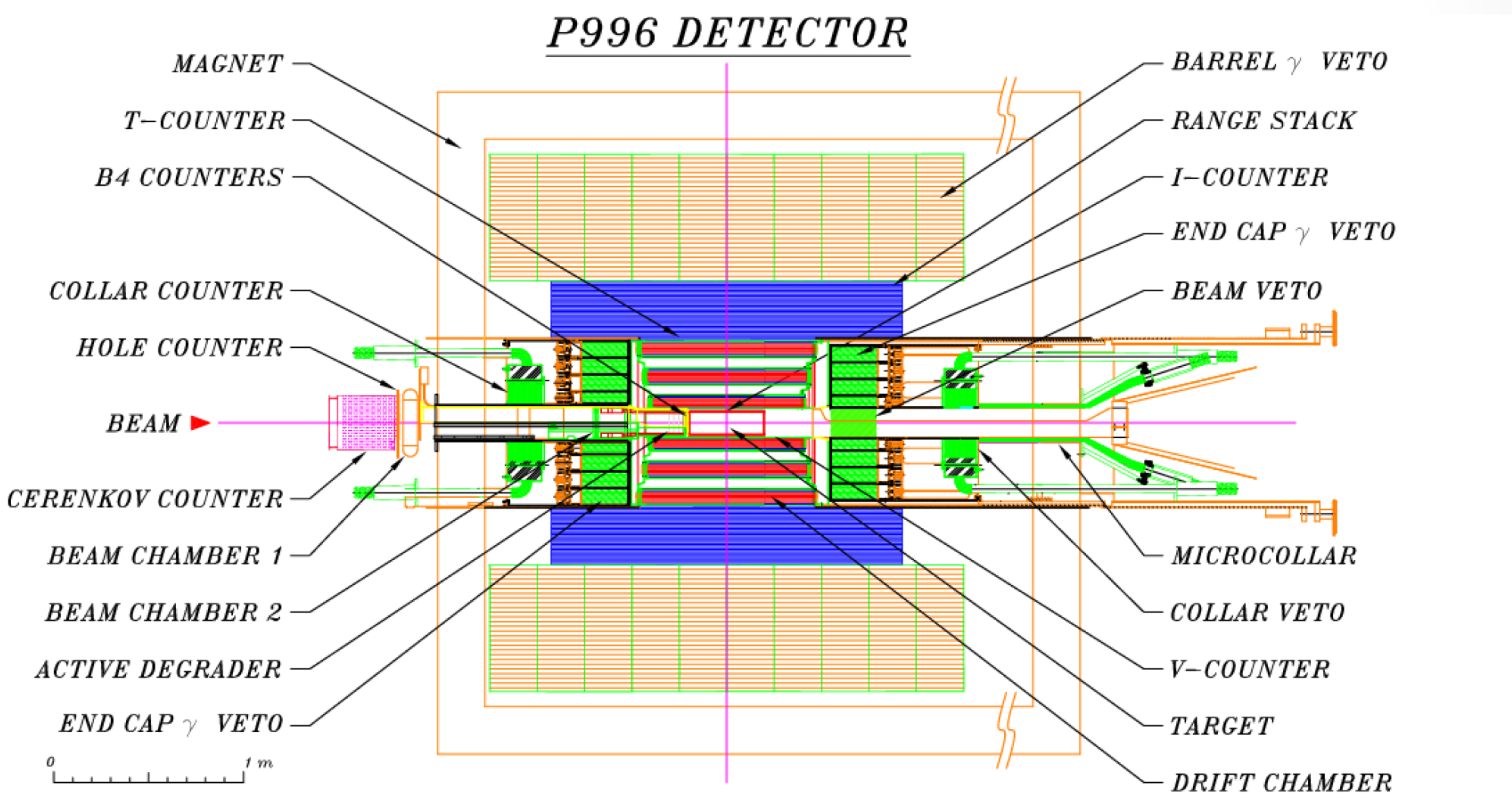
BNL E787/E949 Stopped Kaon Technique

Measure everything!



- K^+ detected and decays at rest in the stopping target
- Decay π^+ track momentum analyzed in drift chamber
- Decay π^+ stops in range stack, range and energy are measured
- Range stack STRAW chamber provides additional π^+ position measurement in range stack
- Barrel veto + End caps + Collar provide 4π photon veto coverage

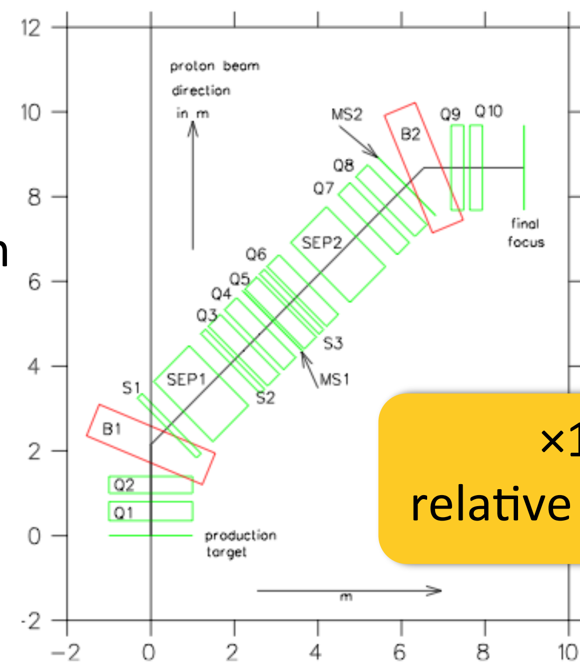
ORKA:
a 4th generation detector



Expect ×100 sensitivity relative to BNL experiment:
×10 from beam and ×10 from detector

Sensitivity Improvements: Beam

- Main Injector
  - 95 GeV/c protons
  - 50-75 kW of slow-extracted beam
  - 48×10^{12} protons per spill
  - Duty factor of ~45%
  - # of protons/spill (**×0.74**)
- Secondary Beam Line
  - 600 MeV/c K^+ particles
  - Increased number of kaons/proton from longer target, increased angular acceptance, increased momentum acceptance (**×4.3**)
  - Larger kaon survival fraction (**×1.4**)
  - Increased fraction of stopped kaons (**×2.6**)
- Increased veto losses due to higher instantaneous rate (**×0.87**)



×10
relative to E949

Sensitivity Improvements: Acceptance

Component	Acceptance factor
$\pi \to \mu \to e$	2.24 ± 0.07
Deadtimeless DAQ	1.35
Larger solid angle	1.38
1.25-T B field	1.12 ± 0.05
Range stack segmentation	1.12 ± 0.06
Photon veto	$1.65^{+0.39}_{-0.18}$
Improved target	1.06 ± 0.06
Macro-efficiency	1.11 ± 0.07
Delayed coincidence	1.11 ± 0.05
Product (R_{acc})	$11.28^{+3.25}_{-2.22}$

×11 relative to E949

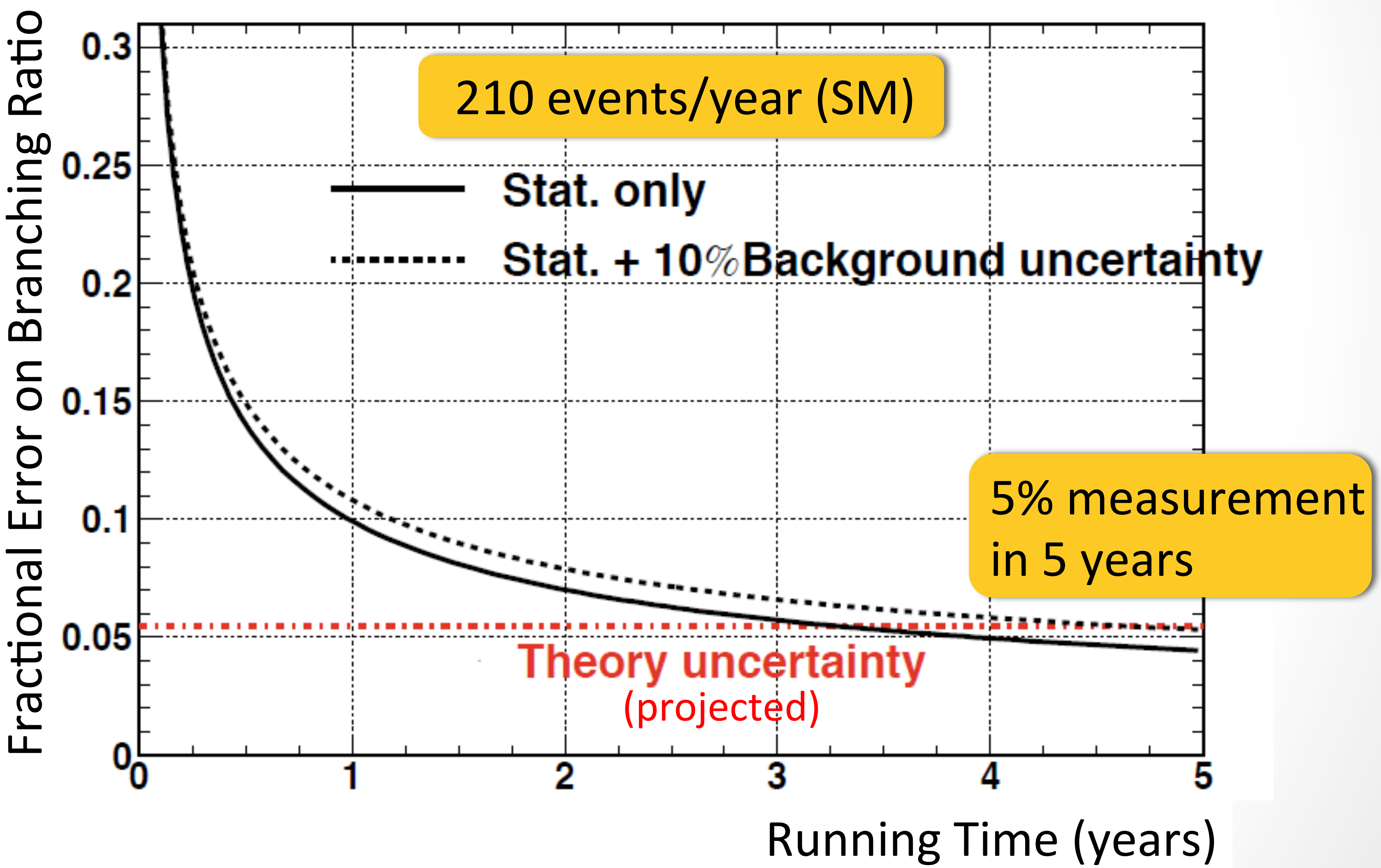
$\pi^+ \to \mu^+ \to e^+$ Acceptance

- E949 PNN1 $\pi^+ \to \mu^+ \to e^+$ acceptance: 35%
- Improvements to increase acceptance relative to E949:
  - Increase segmentation in range stack to reduce loss from accidental activity and improve π/μ particle ID
  - Increase scintillator light yield by using higher QE photo-detectors and/or better optical coupling to improve μ identification
  - Deadtime-less DAQ and trigger so online π/μ particle ID unnecessary
- Irreducible losses:

	Range	Acceptance
Measured π^+ lifetime	3-105 ns	~87%
Measured μ^+ lifetime	0.1-10 ns	~95%
μ^+ escape	n/a	~98%
Undetectable e^+	n/a	~97%
Total		**~78%**

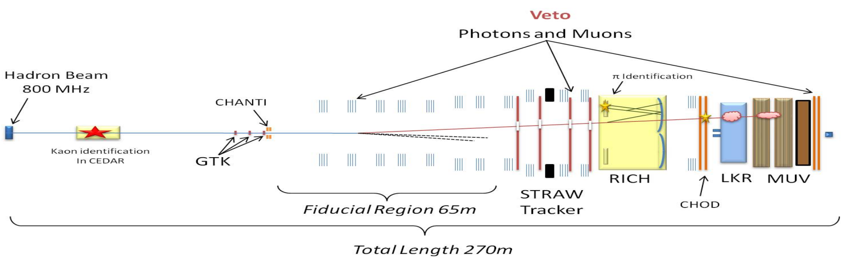
ORKA

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



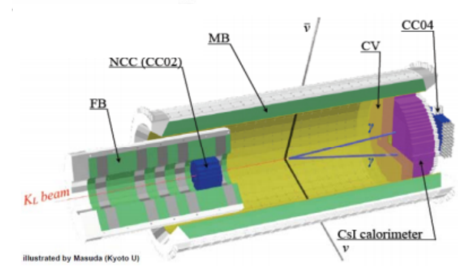
Worldwide Effort

- CERN NA-62 ($K^+ \to \pi^+ \nu\nu$)



- Decay-in-flight experiment
- Builds on NA-31/NA-48
- Expect ~40 $K^+ \to \pi^+ \nu\nu$ events per year (SM)
- Under construction
- Complementary measurement to ORKA

- KOTO ($K^0 \to \pi^0 \nu\nu$)



- Pencil beam decay-in-flight experiment
- Improved J-Parc beam line
- 2nd generation
- Expect ~3 $K^0 \to \pi^0 \nu\nu$ events (SM)
- Under construction

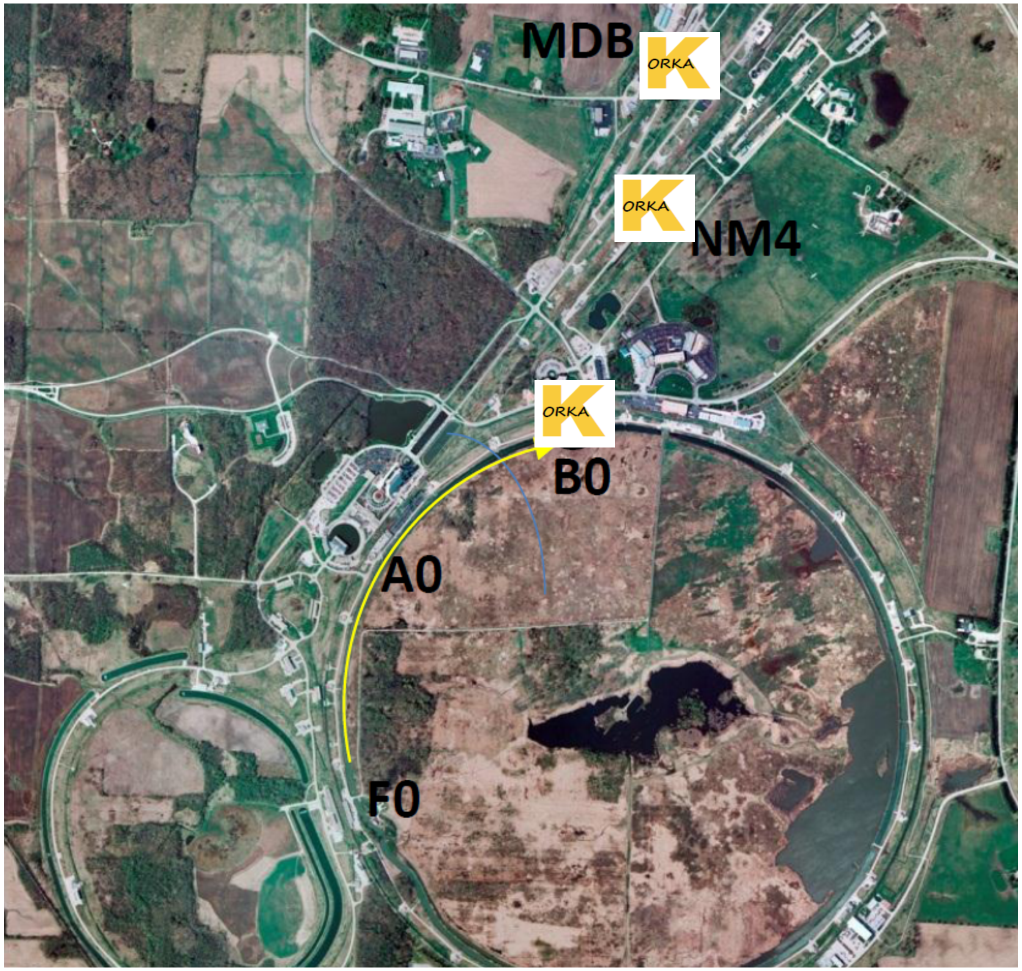
Other Physics Topics

- $K^+ \to \pi^+\nu\bar{\nu}(1)$ ^{T,P}
- $K^+ \to \pi^+\nu\bar{\nu}(2)$ ^{T,P}
- $K^+ \to \pi^+\nu\bar{\nu}\gamma$
- $K^+ \to \pi^+\pi^0\nu\bar{\nu}$ ^{T,P}
- $K^+ \to \mu^+\nu\gamma(\mathsf{SD})$ ^{T,P}
- $K^+ \to \pi^+\pi^-\gamma(\mathsf{DE})$ ^{T,P}
- $K^+ \to \pi^+X$ ^{P}
- $K^+ \to \pi^+\tilde{\chi}_0\tilde{\chi}_0(\mathsf{FF})$ ^{P}
- $K^+ \to \pi^+\gamma$ ^{TP}
- $K^+ \to \pi^+\gamma\gamma\gamma$
- $K^+ \to \mu^+\nu_h$ (heavy neutrino) ^{T}
- $K^+ \to \mu^+\nu M$ (M =majoran)
- $K^+ \to \pi^-\mu^+\mu^+$ (LFV)
- $K^+\pi^+\mathrm{DP}$; $\mathrm{DP} \to e^+e-$ (DP = Dark Photon)
- $K^+ \to \mu^+\nu\bar{\nu}\nu$
- $K^+ \to e^+\nu\bar{\nu}\nu$
- $K^+ \to e^+\nu\mu^+\mu-$
- $\pi^0 \to \mathrm{nothing}$ ^{T,P}
- $\pi^0 \to \gamma\mathrm{DP}$; $\mathrm{DP} \to e^+e^-$
- $\pi^0 \to \gamma X$

^{T}E787/E949 Thesis ; ^{P}E787/E949 Publication

More info in my talk at Project X Physics Study: date?

Potential Sites



- B0 (CDF)
  - Preferred
  - Re-use CDF solenoid, cryogenics, infrastructure
  - Requires new beam line from A0-B0
- Also considering Meson Detector Building and NM4 (SeaQuest)

Schedule

Milestone	Time
Stage One Approval	Winter 2012 ✓
DOE Approval of Mission Need (CD-0)	Fall 2012
Beam/Detector Design	2012-2013
DOE Approval of Cost Range (CD-1)	Early 2013
DOE Baseline Review (CD-2)	End of 2013
Start Construction (CD-3)	Spring 2014
Begin Installation	Mid 2015
First Beam/Beam Tests	End of 2015
Complete Installation	Mid 2016
First Data (Start Operations/CD-4)	End of 2016

Collaboration

- 2 US National Labs, 5 US Universities
- 16 Institutions spanning 6 countries: Canada, China, Italy, Mexico, Russia, USA
- Leadership from successful rare kaon decay experiments
- Many sub-systems: excellent opportunity for universities
- New collaborators welcome!

ASU UNBC INFN Istituto Nazionale di Fisica Nucleare INFN Istituto Nazionale di Fisica Nucleare Ole Miss

ILLINOIS UBC THE UNIVERSITY OF TEXAS AT AUSTIN TSING HUA UNIVERSITY UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

BROOKHAVEN NATIONAL LABORATORY JOINT INSTITUTE FOR NUCLEAR RESEARCH TRIUMF

ORKA Summary

- High precision measurement of $K^+ \to \pi^+ \nu \bar{\nu}$ at FNAL MI
- Expect ~1000 events and 5% BR precision with 5 years of data
- Discovery potential for new physics at and above LHC mass scale
- High impact measurement with 4th generation detector
- Requires modest accelerator improvements and no civil construction
- Total cost $53M (FY2010)
- Construction by 2014, data by 2017 is plausible
- ORKA proposal:
  - http://projects-docdb.fnal.gov/cgi-bin/ShowDocument?docid=1365

Extra Slides

Cost

	Cost (million)	w/ 60% contingency
Accelerator and Beams	**7.5**	**12**
A0 to B0 transport	2.2	3.5
Target and Dump	0.9	1.5
Kaon Beam	4.4	7.0
Detector	**22.4**	**35.8**
Magnet	0.5	0.8
Beam and Target	0.6	1.0
Drift Chamber	1.9	3.0
Range Stack	2.5	4.0
Photon Veto	3.0	4.8
Electronics	4.0	6.4
Trigger and DAQ	2.0	3.2
Software and Computing	2.0	3.2
Installation and Integration	5.9	9.4
Project Management	**2.7**	**4.4**
Total	**33**	**53**

Stage One Approval (Excerpt)

As you see, the PAC recommended Stage I approval, and I accept that recommendation. Nevertheless, as also noted by the PAC, we need to understand better the possible site of the experiment, technical issues associated with use of the Main Injector as proposed, and how we might fit the cost of ORKA into anticipated budgets of the Laboratory. All of these issues will be necessary before Stage II approval might be given.

We look forward to working with you to resolve these issues, recognizing that even working on them now will be difficult, given our severely constrained resources. At the same time, the Stage I approval I am granting now should help in finding additional collaborators, outside resources, and help within the Laboratory.

Sincerely,

Piermaria Oddone