$K^+ \rightarrow \pi^+ \nu\nu$ at Fermilab

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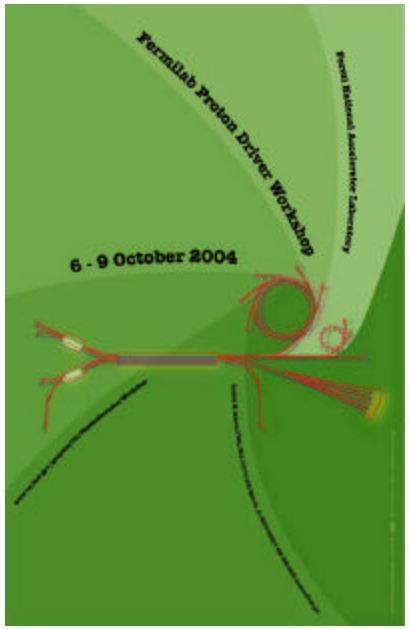
FNAL

P940

I. Current status of $K^+ \rightarrow \pi^+ \nu\nu$.

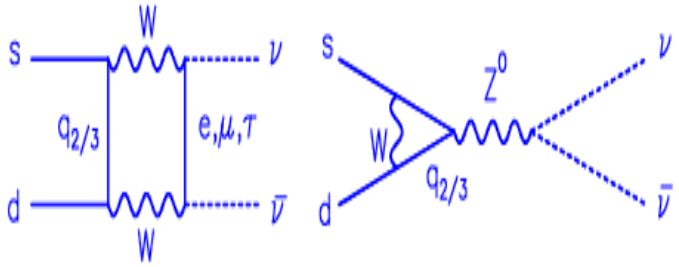
II. $K^+ \rightarrow \pi^+ \nu\nu$ at Fermilab.

III. Longer term outlook.

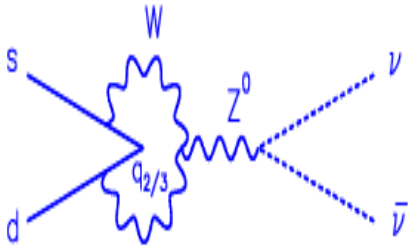


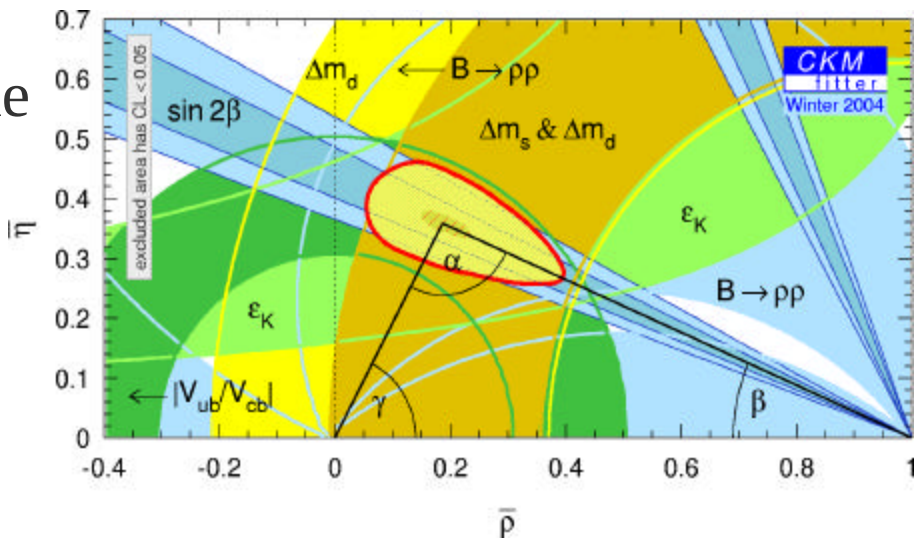
$K^+ \rightarrow \pi^+ \nu\nu$ Motivation

This decay is determined by loop processes and has reach for *new physics at the EW scale and beyond*.

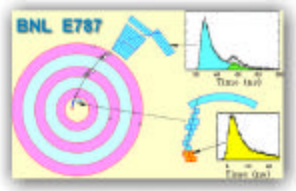


One of the Golden Modes for study of the CKM matrix and CP violation. The rate can be calculated precisely (~8% now→~5% future) from the fundamental SM parameters, and hence any deviation in the measured rate will be a clear signal for new physics.





$K^+ \to \pi^+ \nu\nu$ Status

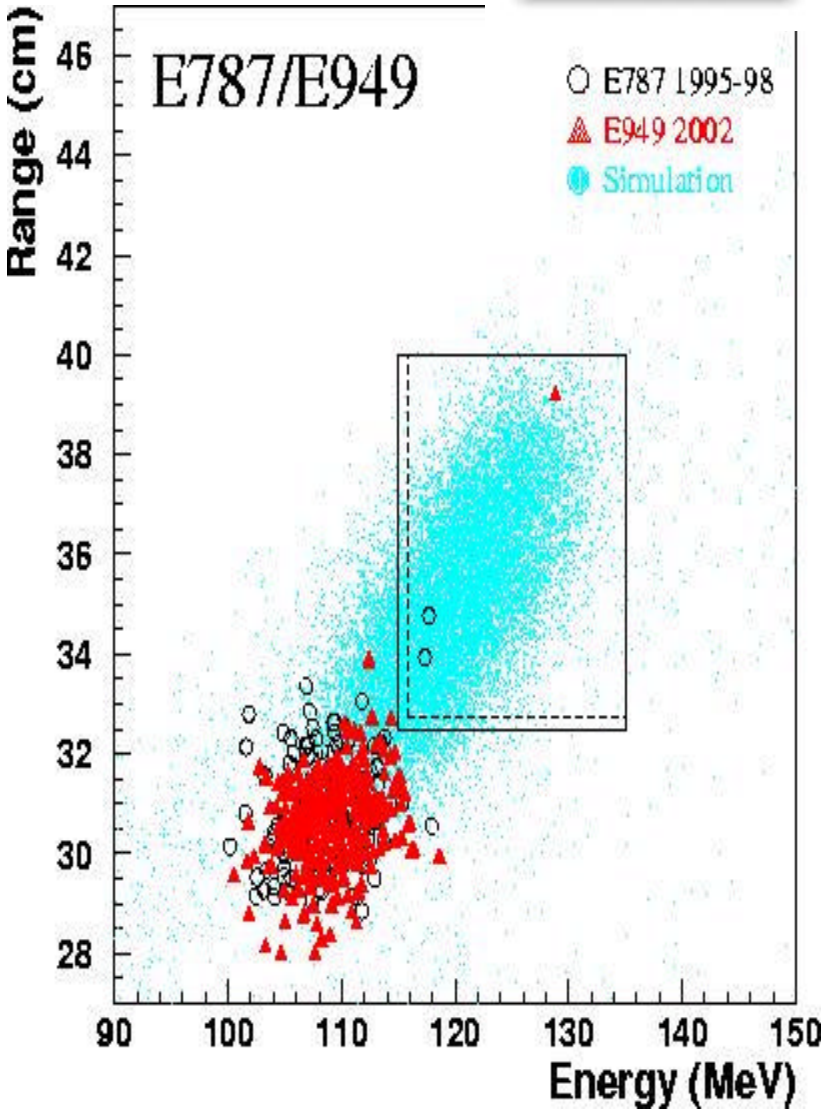


- E949 has observed a 3rd $K^+ \to \pi^+ \nu\nu$ event.

$B(K^+ \to p^+ nn) = 1.47^{+1.30}_{-0.89} \times 10^{-10}$

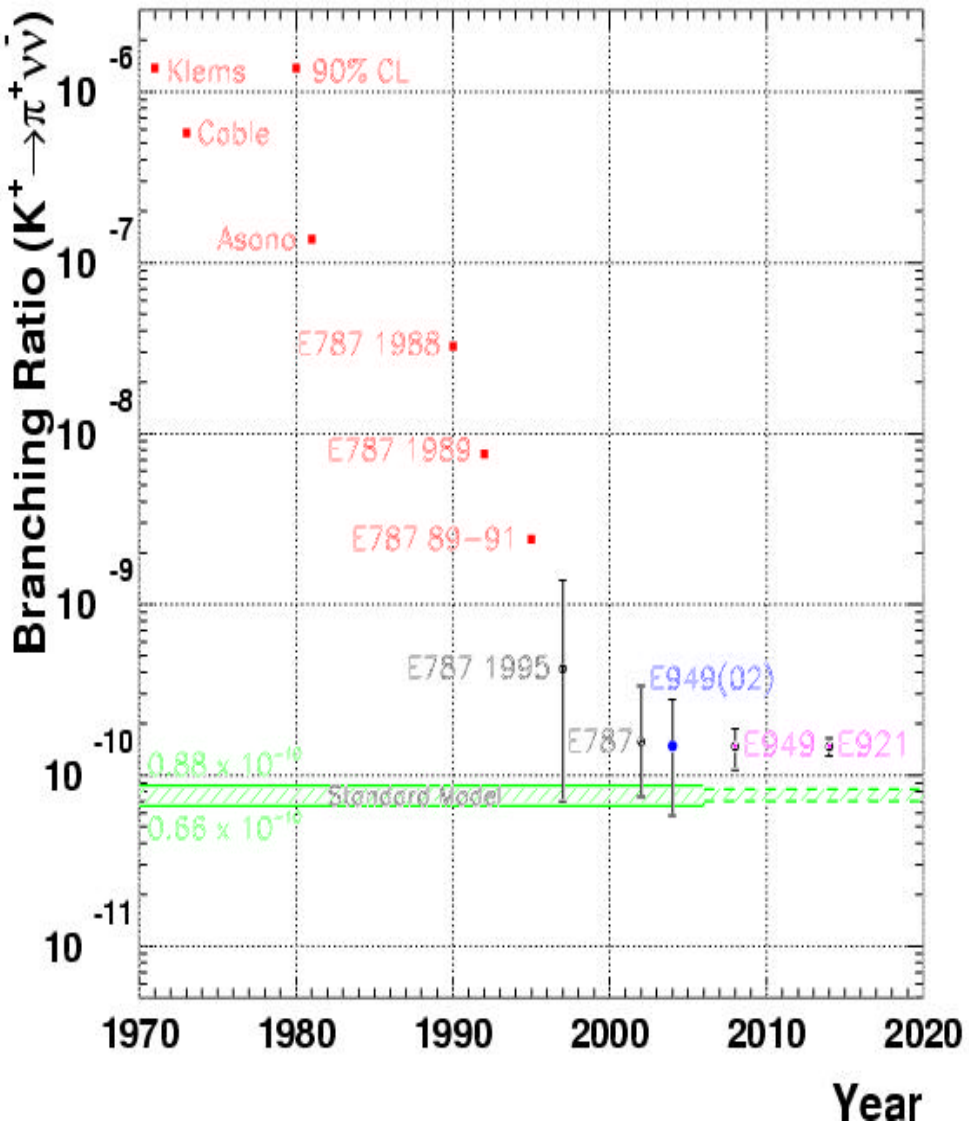
(SM: 0.8×10^{-10})

- PRL **93** (2004) 031801
- Detector and collaboration ready to complete experiment but DOE has not supplied funding for the running time that they approved.
- Proposal to complete E949 submitted to NSF.

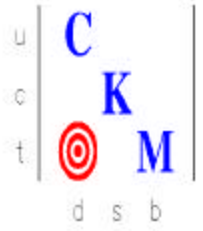


$K^+ \rightarrow \pi^+ \nu\nu$ History

- E787 discovered $K^+ \rightarrow \pi^+ \nu\nu$ and measured a BR twice the SM expectation
- BNL and FNAL developed a plan to fully exploit this kaon component of flavor physics with E949 and CKM.
- E949 was approved by DOE-HEP to exploit the investment in E787 and the expertise and proven detector to run at minimal marginal cost with RHIC. From the Director of DOE-HEP `It is highly desirable to smoothly transfer hard-won expertise from the AGS rare kaon decay program to the Fermilab Main Injector…'
- CKM was approved by FNAL (with BNL support and participation) to take the next step and push the measurement of $K^+ \rightarrow \pi^+ \nu\nu$ to the limits of theory.



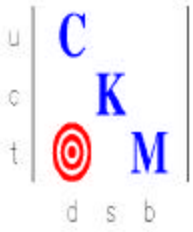
CKM Status and plans



- CKM(E921) at Fermilab is an approved experiment to measure Br[$K^+ \to p^+ n \bar{n}$] with 100 signal and <10 background in a high flux separated kaon beam at 22 GeV/c
- **P5** stops **CKM** - Oct 2003

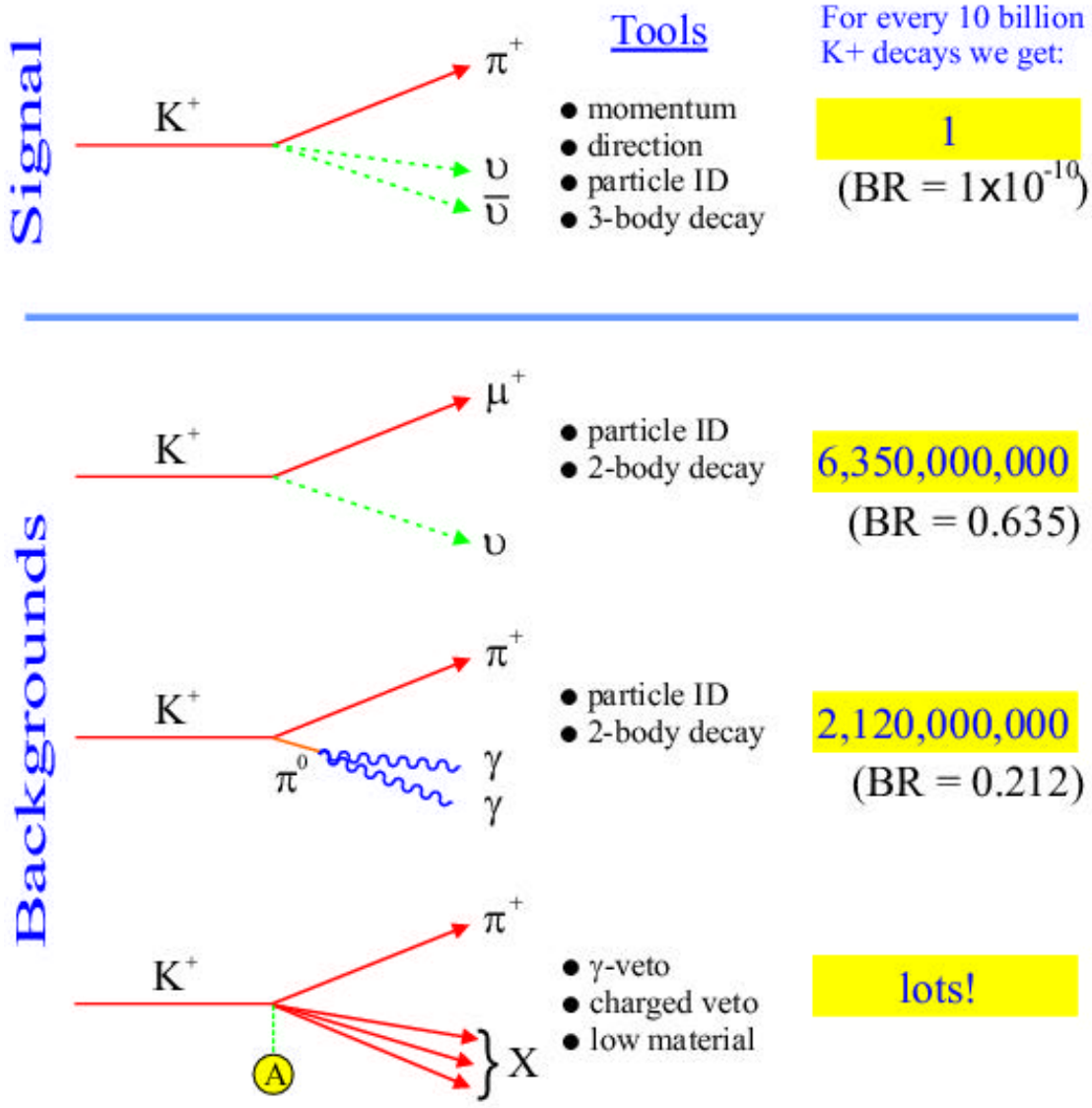
  P5 judged *"CKM to be an elegant world class experiment* which *based on present budgetary models should not proceed."*
- Adapt to an unseparated ~45 GeV/c beam in KTeV hall - **P940**
  - Demonstration of μMegas in NA48 ® tracking in 230MHz tractable
  - Detectors other than beam tracker remain identical.
  - Vetoing photons gets easier ($E_{\pi^0} > 1$ GeV ® >7 GeV)
  - Accidental π/p backgrounds?

Other Physics Measurements

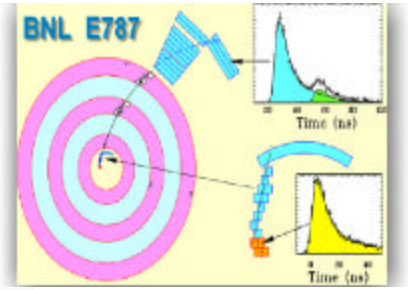


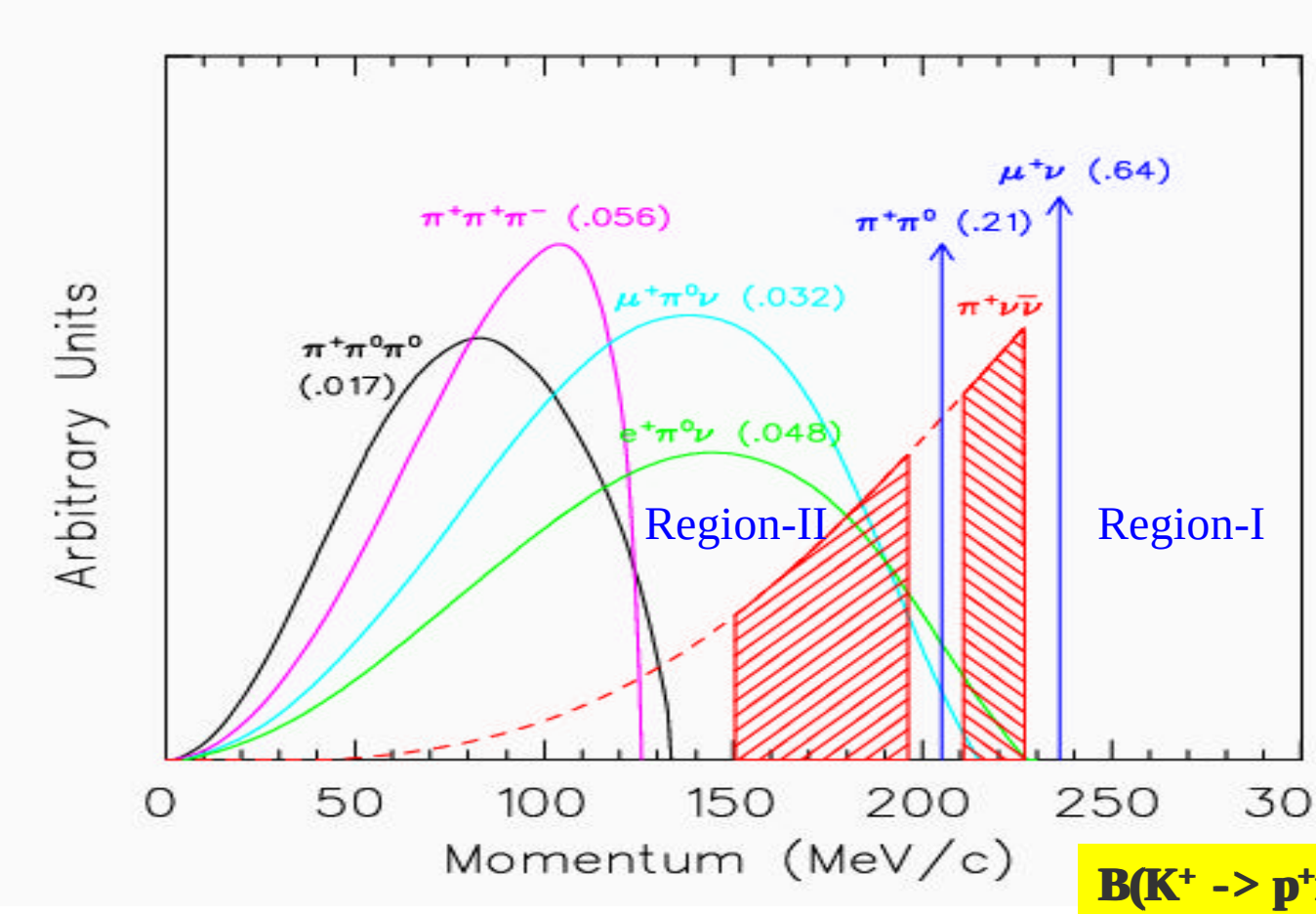
- π^+ decay physics
  - $\Gamma[\pi^+ \to e^+\nu(\gamma)]/\ \Gamma[\pi^+ \to \mu^+\nu(\gamma)]$ is calculated to 0.05% in the SM
  - Helicity suppression of the dominant V-A and IB amplitudes
  - $\pi^+ \to e^+\nu\gamma$ Dalitz plot – access to non V-A terms in hadronic weak current
  - An excellent place to search for models like leptoquarks, multiple Higg, etc.
- Other K^+ decay physics
  - All the other K decays studies from the CKM proposal remain
    - K_{e3}, K_{e4}, $K_{\mu 3}$, $K_{\mu 4}$, $K^+ \to \pi^+ e^+ e^-$, $K^+ \to \pi^+ \mu^+ \mu^-$
    - Lepton flavor violation - $K^+ \to \pi^- \mu^+ \mu^+$, etc.
    - T odd correlations in $K^+ \to \pi^+ l^+ \nu\gamma$
  - $\Gamma[K^+ \to e^+\nu(\gamma)]/\ \Gamma[K^+ \to \mu^+\nu(\gamma)]$, $K^+ \to e^+\nu\gamma$ in parallel with pion decays

Backgrounds a (the) Problem!



Stopped K^+ Kinematics





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

3 events seen.

In-Flight Measurement of $K^+ \to p^+ n \bar{n}$

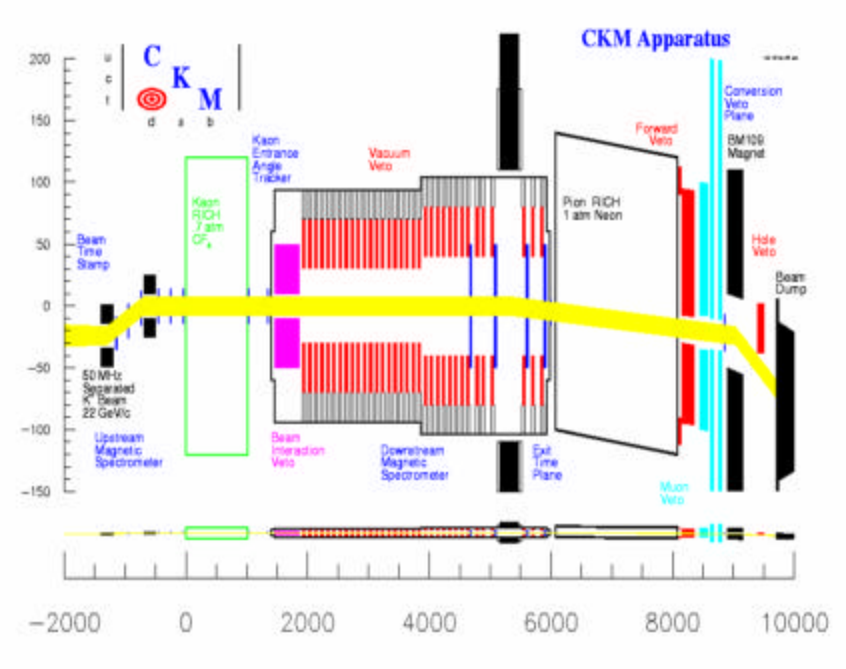
- Must measure K^+ momentum to effectively recover rest-frame kinematics.
- Relatively large decay volume.
- Not possible to follow the π–μ–e decay chain.
- Decay occurs in vacuum, no low-energy K^+A interactions, no complex energy loss mechanisms.
- Kinematics ***and backgrounds*** of Region-I and Region-II 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: BNL E871 & E865 & KTeV & NA48.

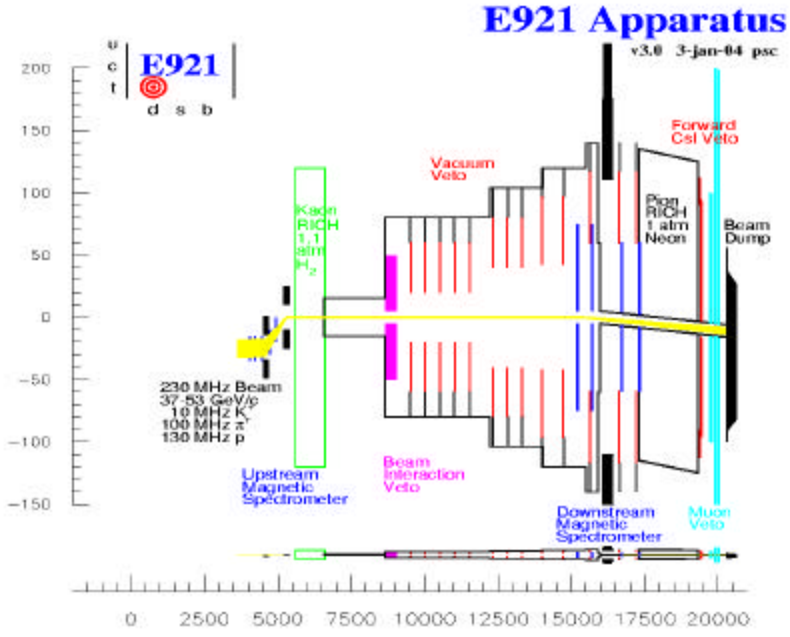
New Technique: P940

- **High Flux Un-separated 37-53 GeV/c Beam - 4% K^+**
  - Proton / π^+ : 120 / 100, **230 MHz total, ~30 MHz/cm^2 in beam tracker. 1x1 cm^2** beam in decay volume.
  - 10 MHz K^+, 1.7 MHz decay in the accepted decay volume.
  - 5 x10^{12} 120 GeV proton /sec in slow spill from the Main Injector to produce the required K^+ beam (17% of design intensity)
  - Debunched proton beam required (~10% 53MHz ripple ok).
- **Apparatus**
  - Decay in flight spectrometer with both velocity (RICH) and momentum (magnetic) spectrometer both both K^+ and π^+.
  - Significant requirements on photon vetoes, CsI ineff $< 1x10^{-6}$ @ high energy.
  - **All detector technologies used are well established**
  - **Redundancy** is critical to **measure** all backgrounds
  - Exploit signal regions on **both** sides of the $K^+ \rightarrow \pi^+\pi^0$ background peak.

Apparatus

- Decay in flight
- Redundant high rate detectors and veto systems.
- separated K+ beam at 22 GeV/c. Un-separated + beam at 37-53 GeV

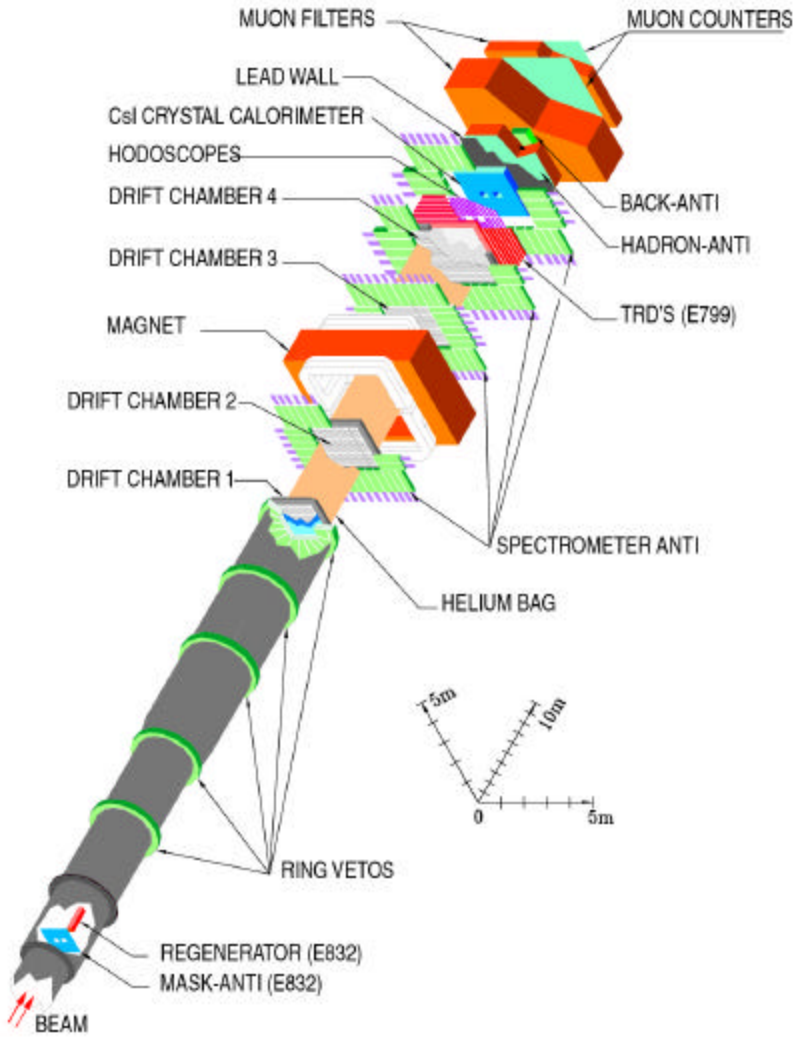




P940: Exploiting the Legacy of the KTeV Detector.

KTEV Kaons at the Tevatron

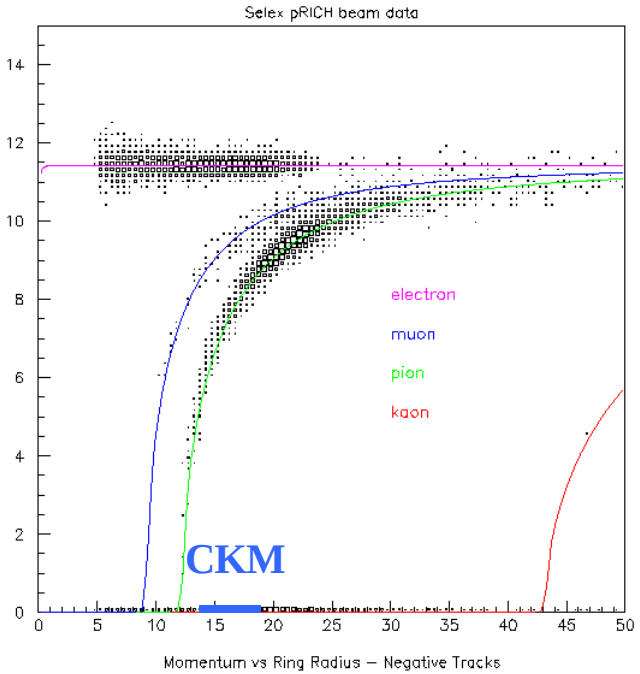
- **Pure CsI Calorimeter:**
  (Energy resolution < 1% at $<E_g>$ = 10GeV; p/e rejection of > 700)
- **Four drift chambers:**
  resolutions: ~100mm
- **Transition radiation detectors:**
  (p/e rejection of > 200) [E799]
- **Spectrometer magnet**
- **Photon veto rings**
- **Intense beams: 5 x 10^{12} protons on target per spill → 5 x 10^9 kaons/spill**
  (existing target station and beamline)

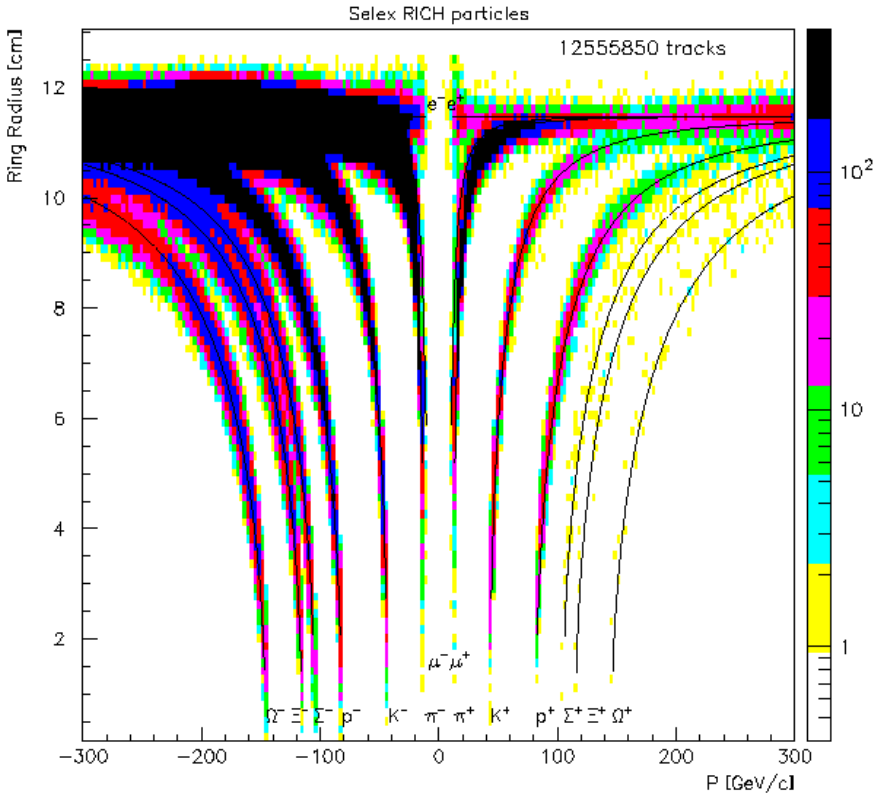


- **KTeV E_K ~ 70 GeV: K_S: gbct ~ 3.5 m**
  K_L: gbct ~ 2.2 km
- **P940 E_K ~ 45 GeV: K^+: gbct ~ 0.3 km**

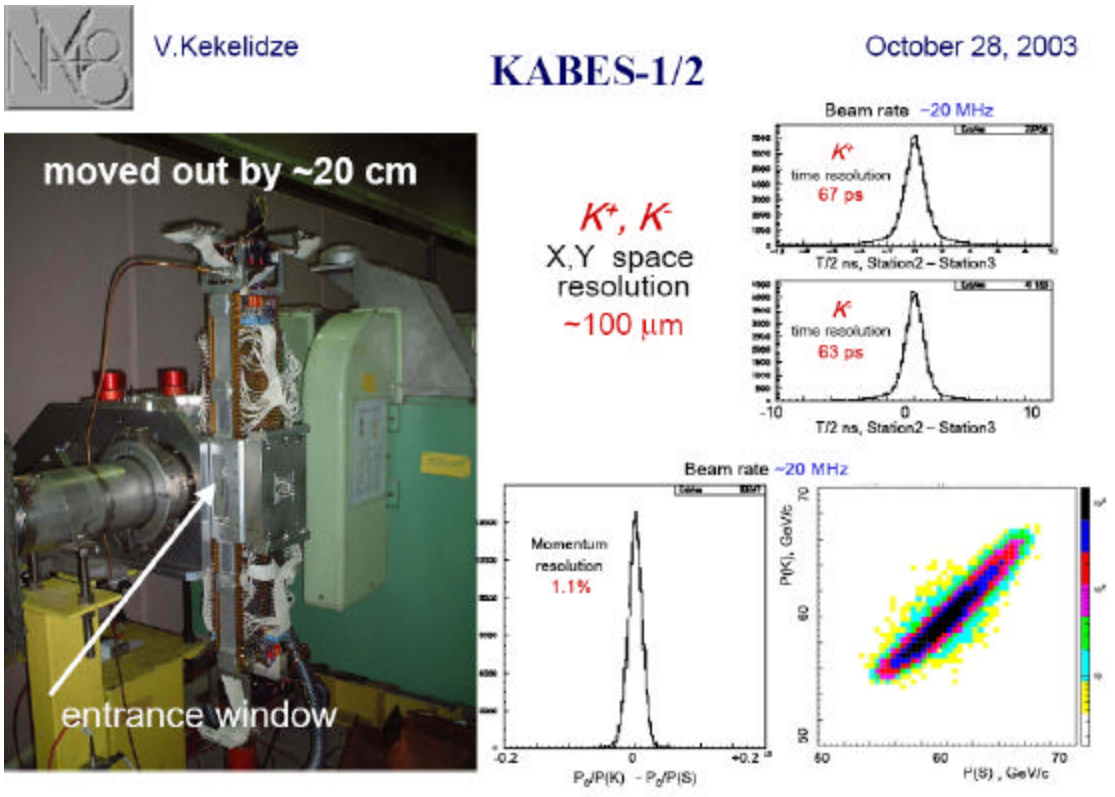
RICH Based Velocity Spectrometer

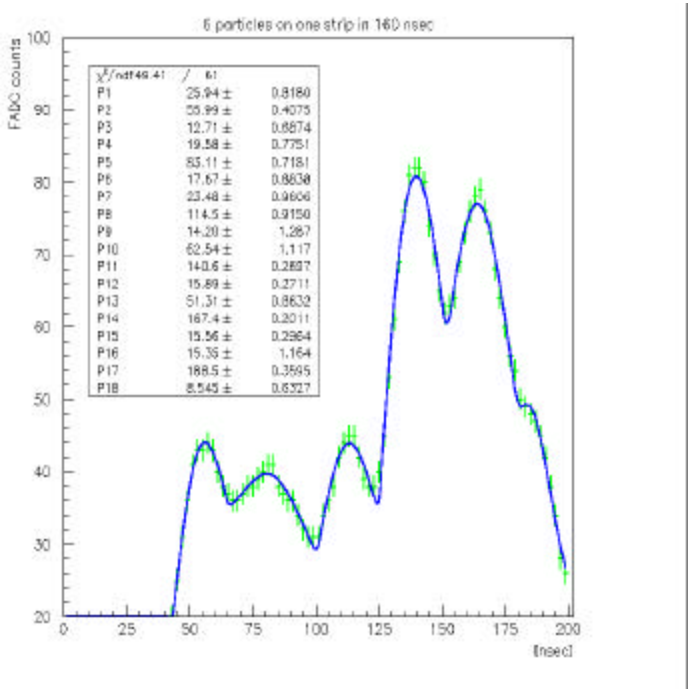
- High rate high resolution
- Matched to momentum resolution
- Based on successful Selex RICH
- Photo-detectors are individual PMTs





The NA48 Beam Tracker: Ultra-high Rate Tracking.



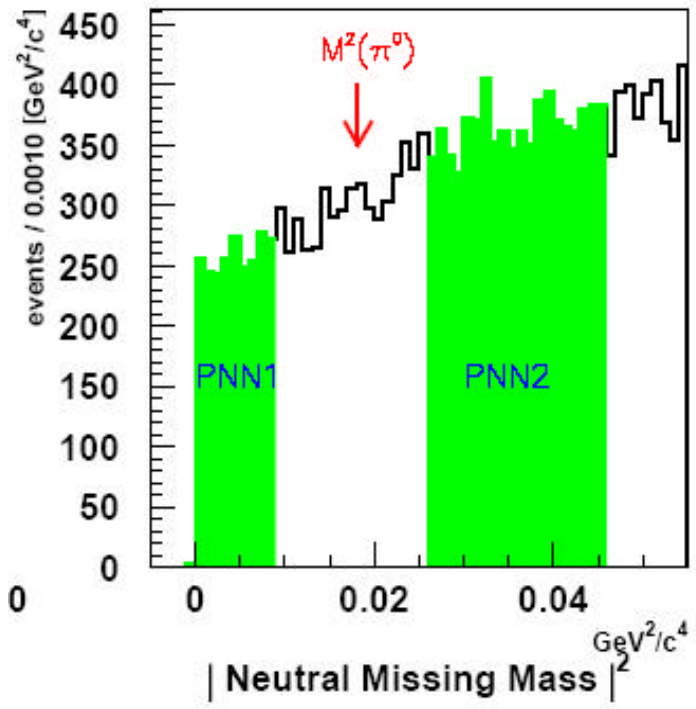


3 MHz/cm^2, 700 psec tag.
No rate effects seen.

FNAL/NA48 collaboration on narrow gap KABES demonstrated x4 higher rate capability than needed by P940

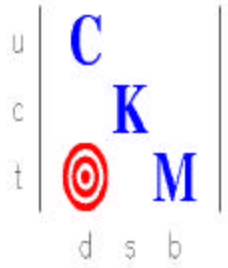
P940 Acceptance

- Acceptance was re-evaluated for P940. Decay fraction increased 13% → 16.5%
- PNN2 acceptance conservatively estimated at 1.4x PNN1 pending more serious background studies
- Nearly identical sensitivity as CKM for same 120 GeV beam incident.



parameter	CKM	E921(**P940**)
$K^+ flux[MHz]$	30	10
beam-sec/year	0.75×10^7	0.75×10^7
years of data	2	2
sensitive K decays	5.8×10^{13}	2.5×10^{13}
nominal Branching ratio	1×10^{-10}	1×10^{-10}
taxes (other losses)	−15%	−15%
PNN1 (s+b)	$95+ \leq 10$	$44+ \leq 4$
PNN2	$(130+ \leq 40)$	$62+ \leq 20$
total	$95+ \leq 10$	$106+ \leq 24$
Br precision	< 11%	< 12%

P940 Backgrounds Studies



Background Source	Effective BR ($\times 10^{-12}$) CKM	P940
• $K^+ \rightarrow \mu^+ \nu_\mu$	< 0.04	-
• $K^+ \rightarrow \pi^+ \pi^0$	3.7	~5
• $K^+ \rightarrow \mu^+ \nu_\mu \gamma$	< 0.09	-
• $K^+ A \rightarrow X K^0_L \rightarrow \pi^+ e^- \nu$	< 0.14	TBD
• $K^+ A \rightarrow \pi^+ X$ (trackers)	< 4.0	TBD
• $K^+ A \rightarrow \pi^+ X$ (gas)	< 2.1	TBD
• Accidentals (K^+ + beam track)	-	TBD
• Accidentals (2 K^+)	0.51	0.17
• TOTAL	<10.6	TBD

Fermilab Near-term Plan

- In the middle of P940 redesign now – goals:
  - Complete the unseparated beamline design for KTeV hall.
  - Assess KABES feasibility in a 230 MHz beam
  - Re-evaluate backgrounds from Kaon interaction in detectors
  - Estimate backgrounds from non-kaon interaction accidentals
  - Evaluate PNN2 cuts, acceptance and backgrounds
  - Re-assess losses from deadtime, reconstruction, …
- The Plan
  - Complete the list above
  - Return to Fermilab and the PAC with a vetted re-design
  - Time scale of a few months yet.

Summary & Outlook

- The US has dropped the ball in the pursuit of flavor physics (entire K sector left out): with the premature termination of E949 and the halting of CKM. Now CERN is looking at the opportunity to clean up in this field where the US left off.
- The recent breakthrough performance of the micro-megas "KABES" technology allows consideration of an unseparated beam experiment to measure $K^+ \to p^+ n\bar{n}$, either at CERN or the Main Injector
- The US has the opportunity to stay in the game with P940
- Future developments in the theory of $K^+ \to \pi^+ \nu\nu$ could motivate an extension of P940 to become a critical component of a proton driver program, if P940 gets started soon.