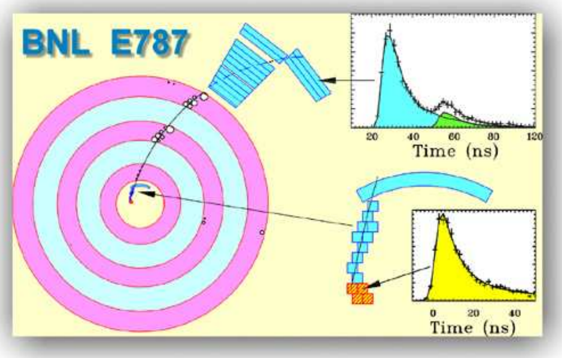


HQ98
FNAL
October 12, 1998

Evidence for $K^+ \to \pi^+ \nu\overline{\nu}$ and Search for T-violation in $K_\mu 3$

Outline

Part I (Time Reversal Violation in $K_\mu 3$ Decays)
1) Why 2) KEK-246/BNL-936 3) BNL-923

Part II (Evidence for $K^+ \to \pi^+ \nu\overline{\nu}$)

1. Motivation
2. Detector/Proceedure
3. Analysis/Background studies
4. Results

Steve Kettell
Brookhaven National Laboratory

e787

S. Adler, M.S. Atiya, I-H. Chiang, M. Diwan, J.S. Frank, J.S. Haggerty, V. Jain, S.H. Kettell, T.F. Kycia, K.K. Li, L.S. Littenberg, C. Ng, A. Sambamurti, A.J. Stevens, R.C. Strand, and C.H. Witzig

Brookhaven National Laboratory

M. Miyajima, J. Nishide, K. Shimada, T. Shimoyama, and Y. Tamagawa

Fukui University

M. Aoki, T. Inagaki, S. Kabe, M. Kobayashi, Y. Kuno, T. Sato, T. Shinkawa, and Y. Yoshimura

High Energy Accelerator Research Organization (KEK)

T. Komatsubara, M. Kuriki, N. Muramatsu, K. Omata, and S. Sugimoto

KEK: Tanashi-branch

M. Nomachi and T. Nakano

Research Center for Nuclear Physics, Osaka University

M. Ardebili, A.O. Bazarko, M.R. Convery, M.M. Ito, D.R. Marlow, R.A. McPherson, P.D. Meyers, F.C. Shoemaker, A.J.S. Smith, and J.R. Stone

Princeton University

P. Bergbusch, E.W. Blackmore, D.A. Bryman, S. Chen, A. Konaka, J.A. Macdonald, J. Mildenberger, T. Numao, P. Padley, J-M. Poutissou, R. Poutissou, G. Redlinger, J. Roy, and A.S. Turcot

TRIUMF

P. Kitching, H.-S. Ng and R. Soluk

Centre for Subatomic Research, University of Alberta

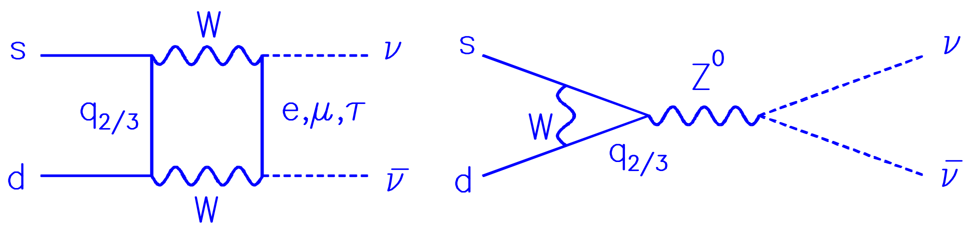
CKM Matrix and $K^+ \to \pi^+ \nu\overline{\nu}$

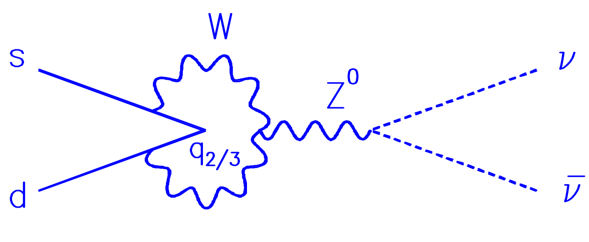
$$V_{\rm CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

the Cabibbo angle $\lambda = \sin\theta_C = 0.2205 \pm 0.0018$.

FCNC: — no tree-level diagrams:

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



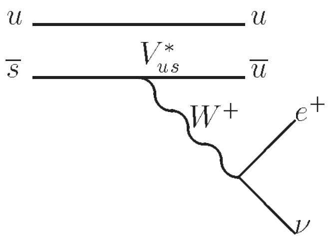


- Short-distance, t dominated
- c contribution is reasonably well known.
- Very clean determination of $|V_{ts}^* V_{td}|$

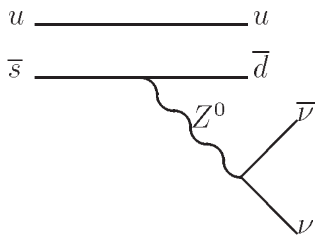
The $K^+ \to \pi^+ \nu \overline{\nu}$ branching ratio

$K^+ \to \pi^+ \nu \overline{\nu}$ is related to K_{e3} by isospin.

$K^+ \to \pi^0 e^+ \nu_e$



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



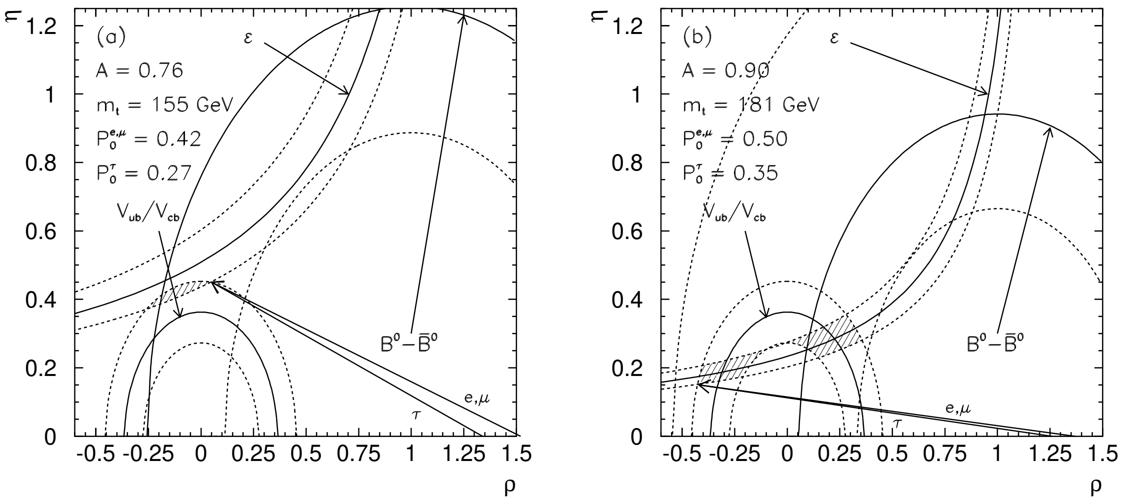
Differences due to isospin violation, electroweak radiative corrections, and phase space provide a 10% correction. (Marciano and Parsa 1995)

$$B(K^+ \to \pi^+ \nu \overline{\nu}) = \frac{\alpha^2 \times B(K^+ \to \pi^0 e^+ \nu_e)}{2\pi^2 \sin^4 \theta_W |V_{us}|^2} \sum_l |X_t^l(x_t) V_{ts}^* V_{td} + X_c^l(x_c) V_{cs}^* V_{cd}|^2$$

The uncertainty on X_c^l from NLLA is 20% (Buchalla and Buras 1994).

$$B(K^+ \to \pi^+ \nu \overline{\nu}) \simeq 1.97 \times 10^{-11} A^4 x_t^{1.18} [(\rho_0 - \rho)^2 + \eta^2].$$

with the c quark contribution in $\rho_0 (\approx 1.3)$



$$0.6 \times 10^{-10} < B(K^+ \to \pi^+ \nu \overline{\nu}) < 1.5 \times 10^{-10}$$

Unitarity Triangle

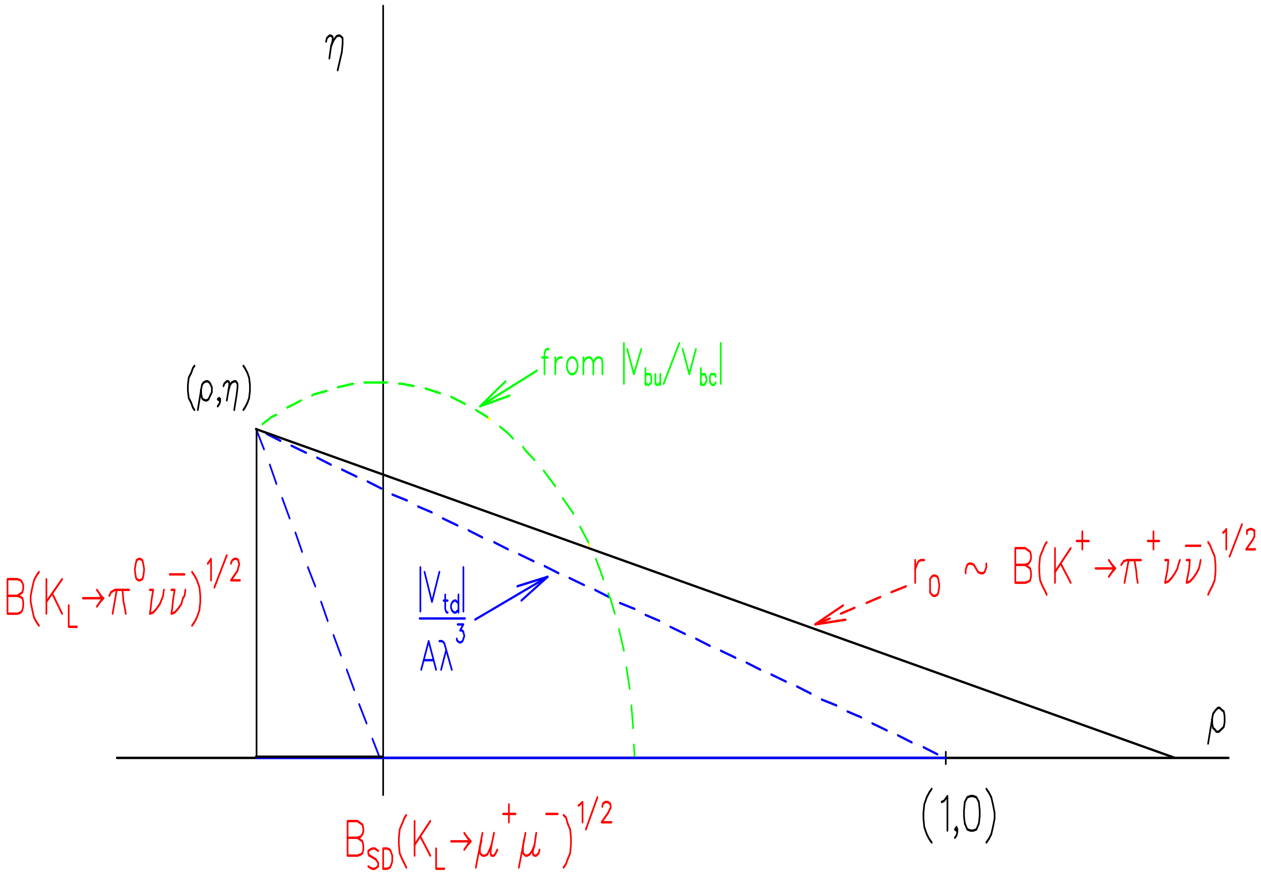
$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

Unitarity implies that

$$V_{ub}{}^* V_{ud} + V_{cb}{}^* V_{cd} + V_{tb}{}^* V_{td} = 0$$
$$V_{ub}{}^* - \lambda V_{cb}{}^* + V_{td} \simeq 0$$
$$V_{ub}{}^*/A\lambda^3 + V_{td}/A\lambda^3 \simeq 1$$

We can draw a triangle with sides of length $(|V_{ub}|/\mathrm{A}\lambda^3)$, $(|V_{td}|/\mathrm{A}\lambda^3)$ and (1).

A measurement of $|V_{td}|$ will determine a circle in the ρ,η plane centered at (1,0).

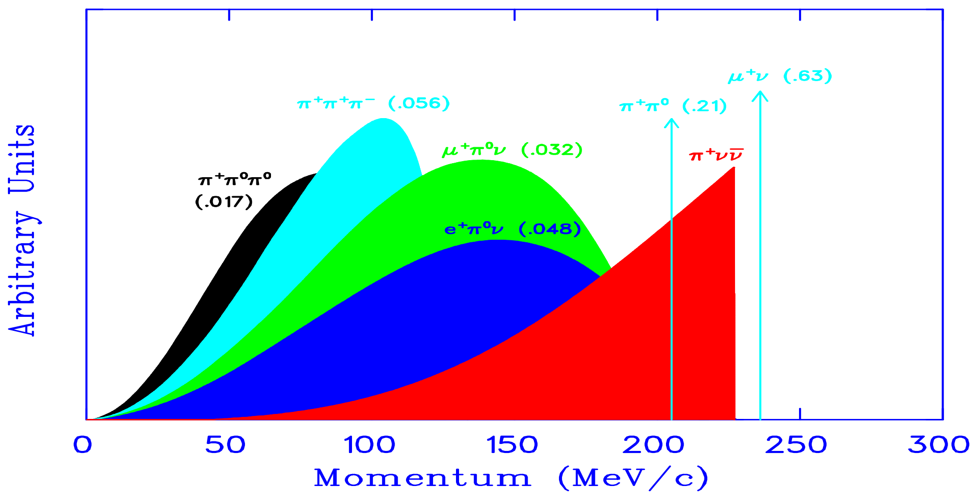


(If we replace ρ by $\overline{\rho} = \rho(1-\frac{\lambda^2}{2})$ and η by $\overline{\eta} = \eta(1-\frac{\lambda^2}{2})$ we can derive the same relations to $\mathrm{O}(\lambda^6)$.)

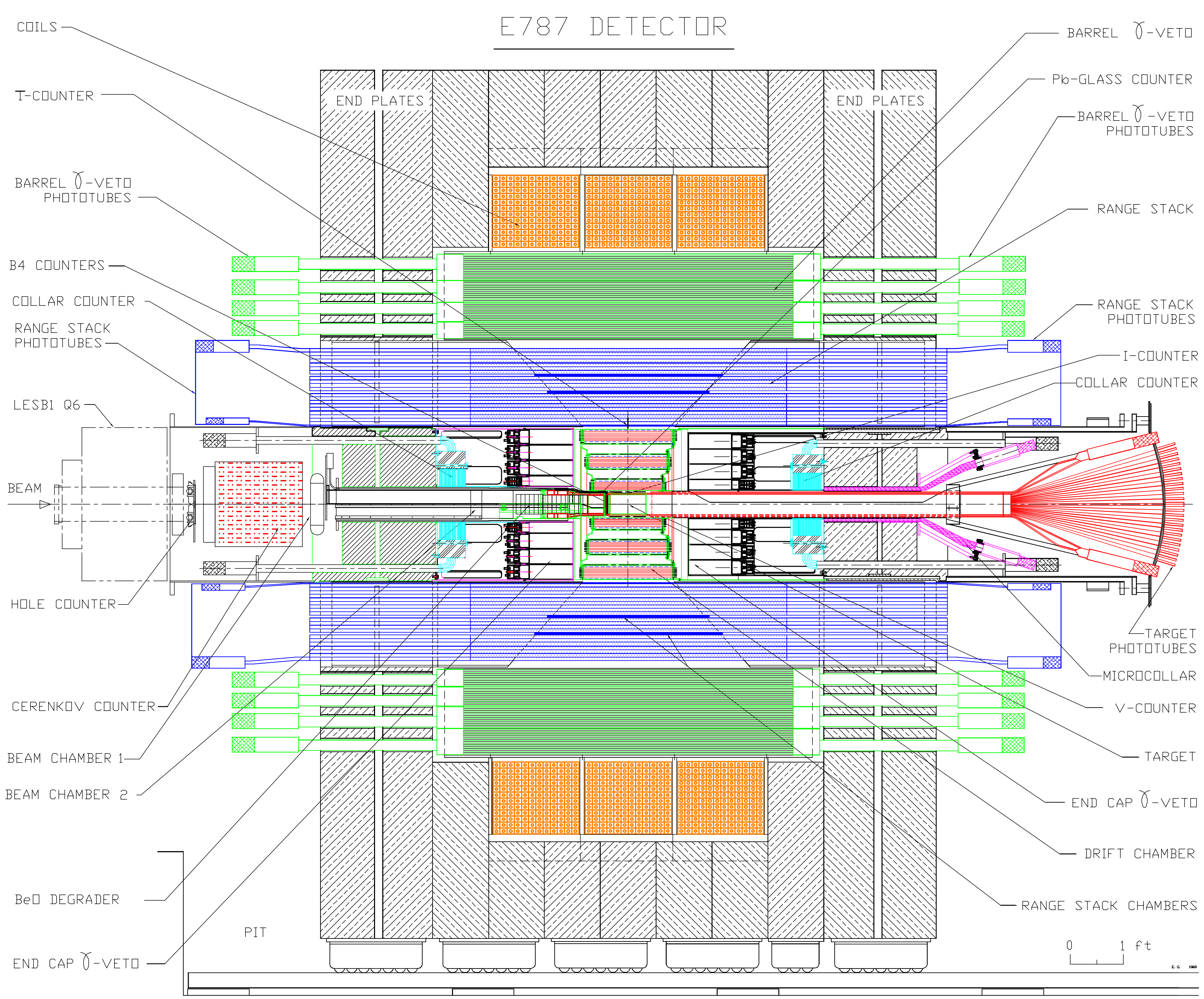
$K^+ \to \pi^+ \nu\overline{\nu}$ Experimental Considerations

- **Strategy:**
  - **The two largest BR's are mono-energetic.**
    Stop the K$^+$ beam and maintain very good kinematic resolution.
  - **No major K$^+$ decays have a π^+ with $|p_\pi| > 205$ MeV/c.**
    Identify outgoing π^+ track(detect $\pi^+ \to \mu^+ \to e^+$, dE/dx, R vs. P)
  - **Most K$^+$ decays with π^+'s have γ's too.**
    Hermetic photon veto (4π).

- **Backgrounds:**

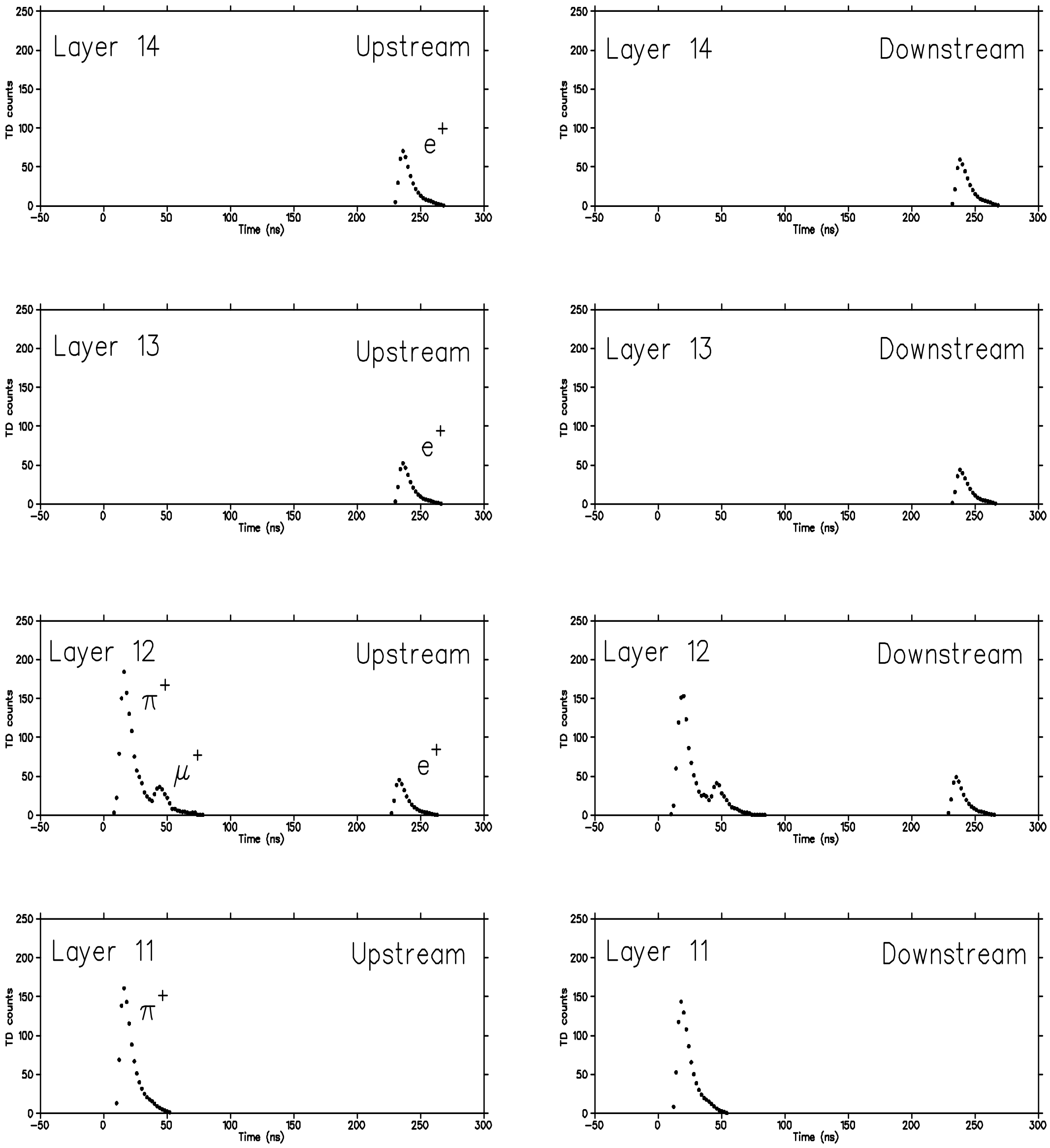


decay mode	BR	particle id	γ veto	extra tracks	kinematic suppression	beam PID	Delay Coinc.
$K^+ \to \mu^+\nu$	0.63	$\surd$	-	-	$\surd$	-	-
$K^+ \to \pi^+\pi^0$	0.21	-	$\surd\ \surd$	-	$\surd$	-	-
$K^+ \to \pi^0\mu^+\nu$	0.032	$\surd$	$\surd\ \surd$	-	-	-	-
$K^+ \to \pi^0 e^+\nu$	0.048	$\surd$	$\surd\ \surd$	-	-	-	-
$K^+ \to \pi^+\pi^-\pi^+$	0.056	-	-	$\surd$	$\surd\ \surd$	-	-
$K^+ \to \mu^+\nu\gamma$	5×10^{-3}	$\surd$	$\surd$	-	-	-	-
$K^+ \to \pi^+\gamma\gamma$	1×10^{-6}	-	$\surd\ \surd$	-	-	-	-
π^+ (beam)	-	-	-	-	-	$\surd$	$\surd$
$K^+ + n \to K_L^\circ + p$							
$\hookrightarrow K_L^\circ \to \pi^+\ell^-\nu$	-	-	-	$\surd$	-	-	$\surd$


E787 DETECTOR
COILS
T-COUNTER
BARREL γ-VETO PHOTOTUBES
B4 COUNTERS
COLLAR COUNTER
RANGE STACK PHOTOTUBES
LESB1 Q6
BEAM
HOLE COUNTER
CERENKOV COUNTER
BEAM CHAMBER 1
BEAM CHAMBER 2
BeO DEGRADER
END CAP γ-VETO
PIT
END PLATES
END PLATES
BARREL γ-VETO
Pb-GLASS COUNTER
BARREL γ-VETO PHOTOTUBES
RANGE STACK
RANGE STACK PHOTOTUBES
I-COUNTER
COLLAR COUNTER
TARGET PHOTOTUBES
MICROCOLLAR
V-COUNTER
TARGET
END CAP γ-VETO
DRIFT CHAMBER
RANGE STACK CHAMBERS
0 1 ft

Transient Digitizers: $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ Tagging

- Sample pulse height every 2 nsec for 4.5 μsec
- π^+ stops in Range Stack Scintillator (each layer is 2cm thick)
- $\pi^+ \longrightarrow \mu^+\nu_\mu$: $E_{\mu^+} = 4.1$ MeV, $R_{\mu^+} \sim 1$ mm, $\tau_{\pi^+} = 26.0$ nsec.
- $\mu^+ \longrightarrow e^+\nu_e\overline{\nu_\mu}$: $E_{e^+} \leq 53$ MeV, $\tau_{\mu^+} = 2.20$ μsec.



Muon background

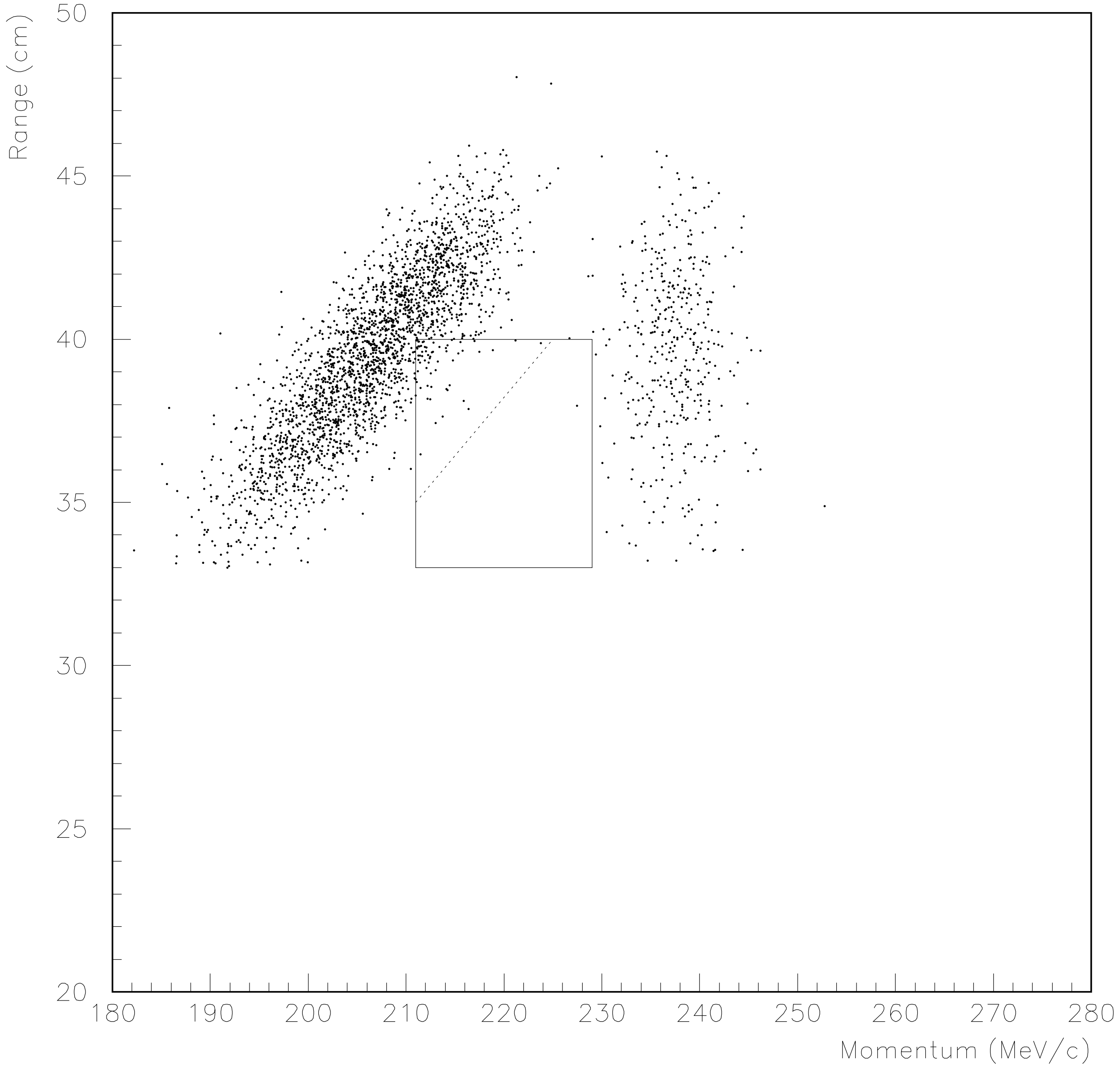
Two categories:

1. $K\mu2$ at fixed momentum (236MeV/c).
2. $K\mu2\gamma$, etc. in muon "band"

1. is subject to momentum cut

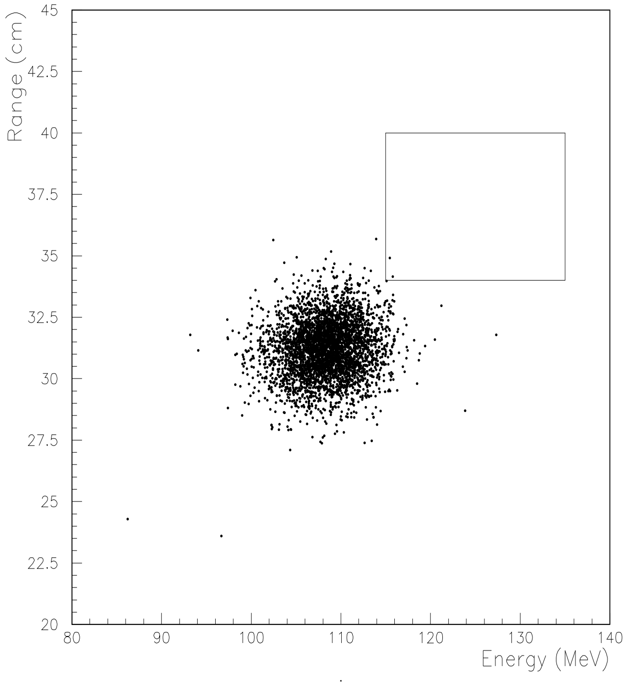
2. is subject to p vs R cuts

Cuts on each could be made tighter w/o much acceptance loss.



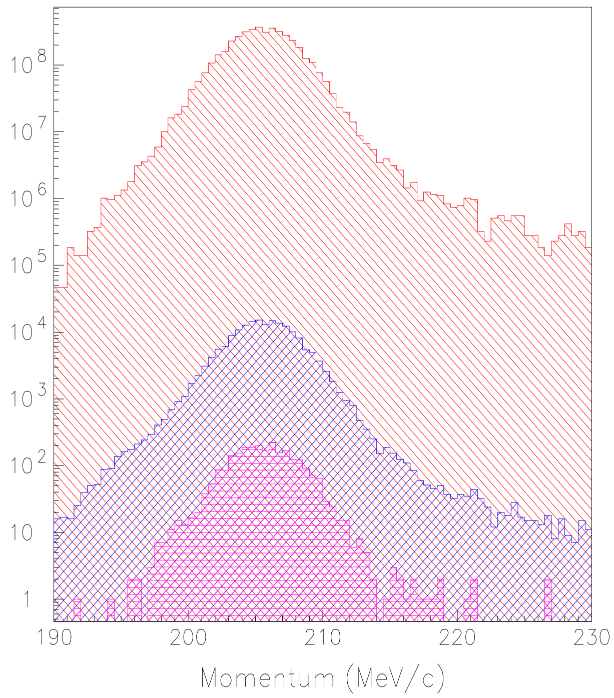
$K_{\pi 2}$ background.

γ veto reversed



$N = 2/1.6$

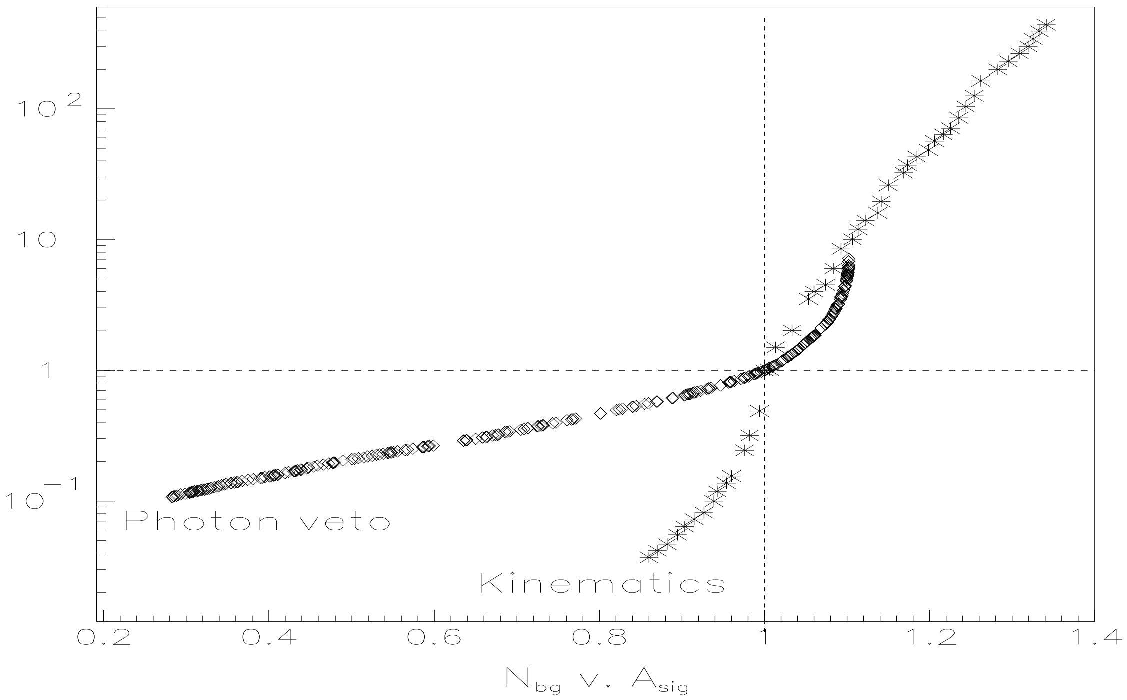
$K_{\pi 2}$ (E,R peak)



$\mathrm{Rej}(\overline{\gamma}) = 46.6$

$$N_{b.g.} = N_{Kin.}/R_{\bar{\gamma}} = 0.03$$

$K^+ \to \pi^+\pi^0$ background (cont).



Number of expected $K^+ \to \pi^+\pi^0$ background (normalized to final cuts) vs acceptance.

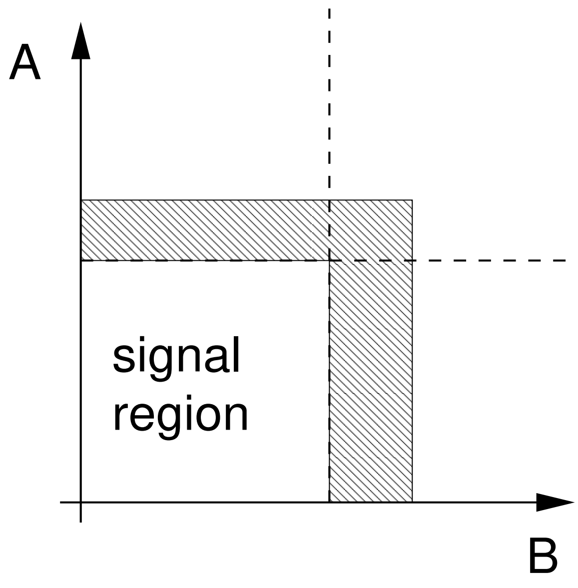
Offline analysis

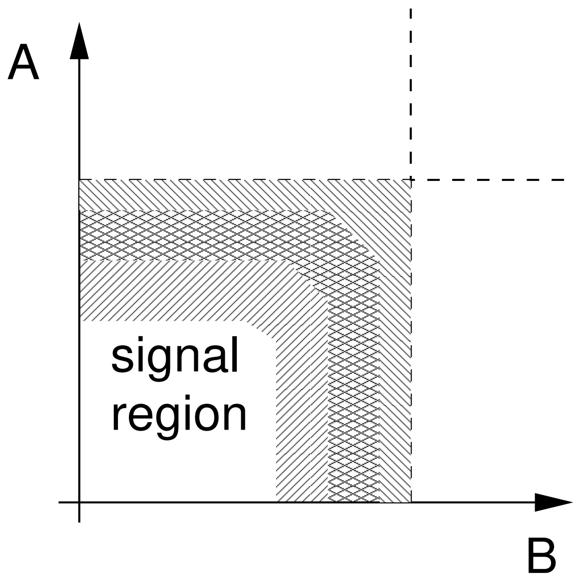
- Blind analysis
  - Signal region is hidden (by inverting cuts) while cuts are developed and background levels estimated
- "Bifurcated" analysis
  - A priori identification of background sources
  - Same dataset for background studies and signal search
  - Two independent cuts with high rejection for each background
  - Measurement of background levels in the signal region at the $10^{-3} - 10^{-2}$ event level
- Correlation studies
- Prediction of background levels around signal region (followed by confirmation)
- Background likelihood analysis (using predetermined likelihood functions) in the signal region for assessing candidate events.

Background Summary

Background	events in signal region
$K_{\pi 2}$	0.03 ± 0.02
$K_{\mu 2}$	0.02 ± 0.02
Single beam	0.012 ± 0.009
Double beam	0.007 ± 0.007
CEX	0.01 ± 0.01
Total background	0.08 ± 0.03

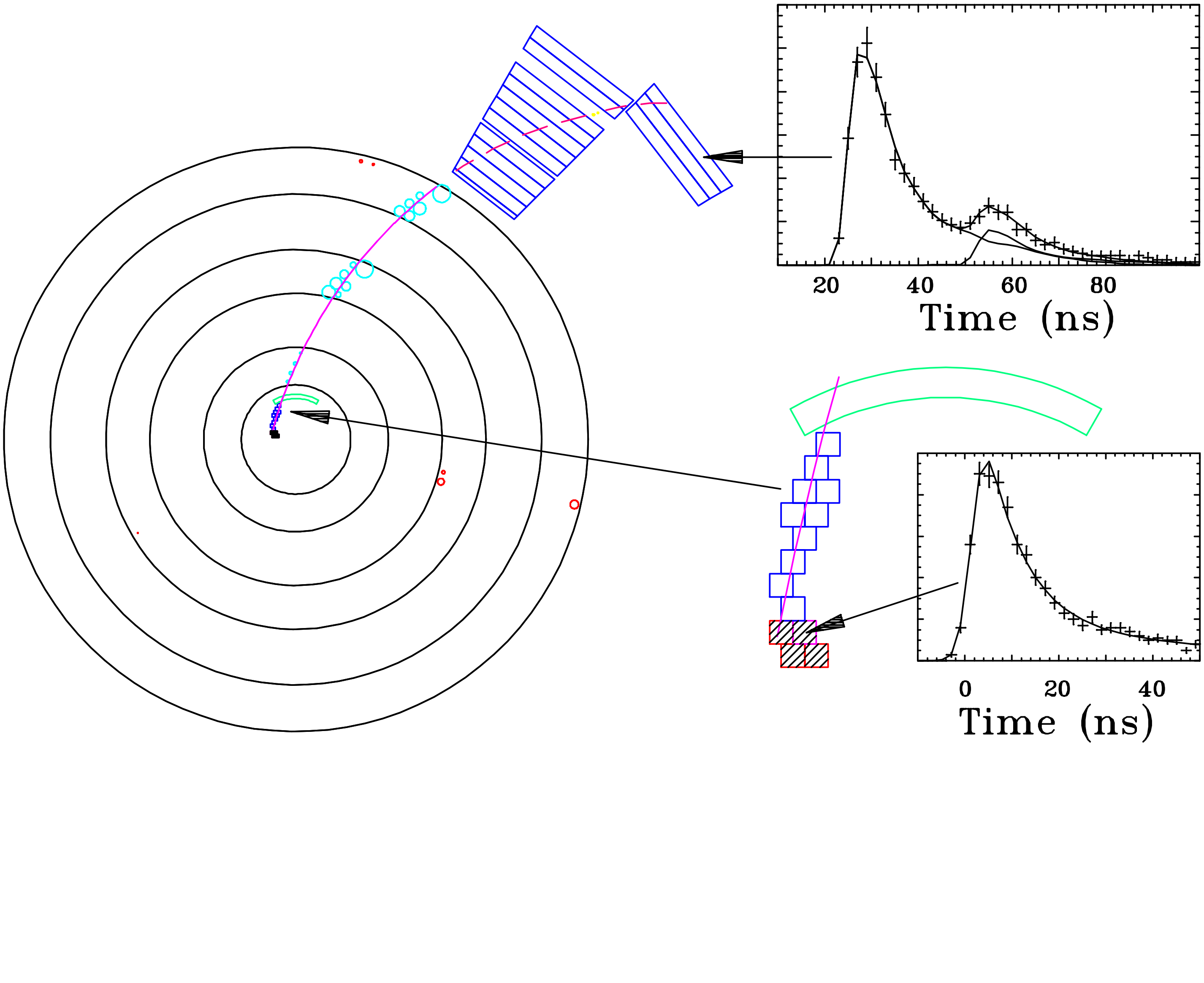
In addition, to further our confidence in this background calculation, we want to predict the amount of background in a region 'just outside' the signal region and then compare this prediction to data (Fig 1) ...and we want to predict the background levels within the signal region with ever tighter cuts to establish the 'quality' of any candidate events (Fig 2). We extend the cuts to get $\times 10$ more rejection with 55% of the 'standard' acceptance.





region	expected	observed
$150 \times b$	12 ± 5	15
$20 \times b$	1.6 ± 0.6	2
$10 \times b$	0.8 ± 0.3	0
$1 \times b$	0.08 ± 0.03	-
$0.1 \times b$	0.008 ± 0.005	-

- Observed numbers are consistent with expectations.
- All 15 events are identified with known background types.



20
40
60
80
Time (ns)
0
20
40
Time (ns)

E787 1995 Result

1.49×10^{12} K^+ stops recorded
Acceptance = 0.0016(1)

Check by measuring BR($K^+ \to \pi^+\pi^0$)

$$\mathrm{BR}(K^+ \to \pi^+\pi^0) = 0.202 \pm 0.009 \text{ (e787)}$$
$$(0.2116 \pm 0.0014 \text{ PDG })$$

$$\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu}) = 4.2^{+9.7}_{-3.5} \times 10^{-10}$$

$$6 \times 10^{-3} < |V_{td}| < 6 \times 10^{-2}$$

Analysis of 1995–7 data is ongoing. Preliminary indications are that the background rejection is 3 times larger, with an increased acceptance. Results are expected this year.

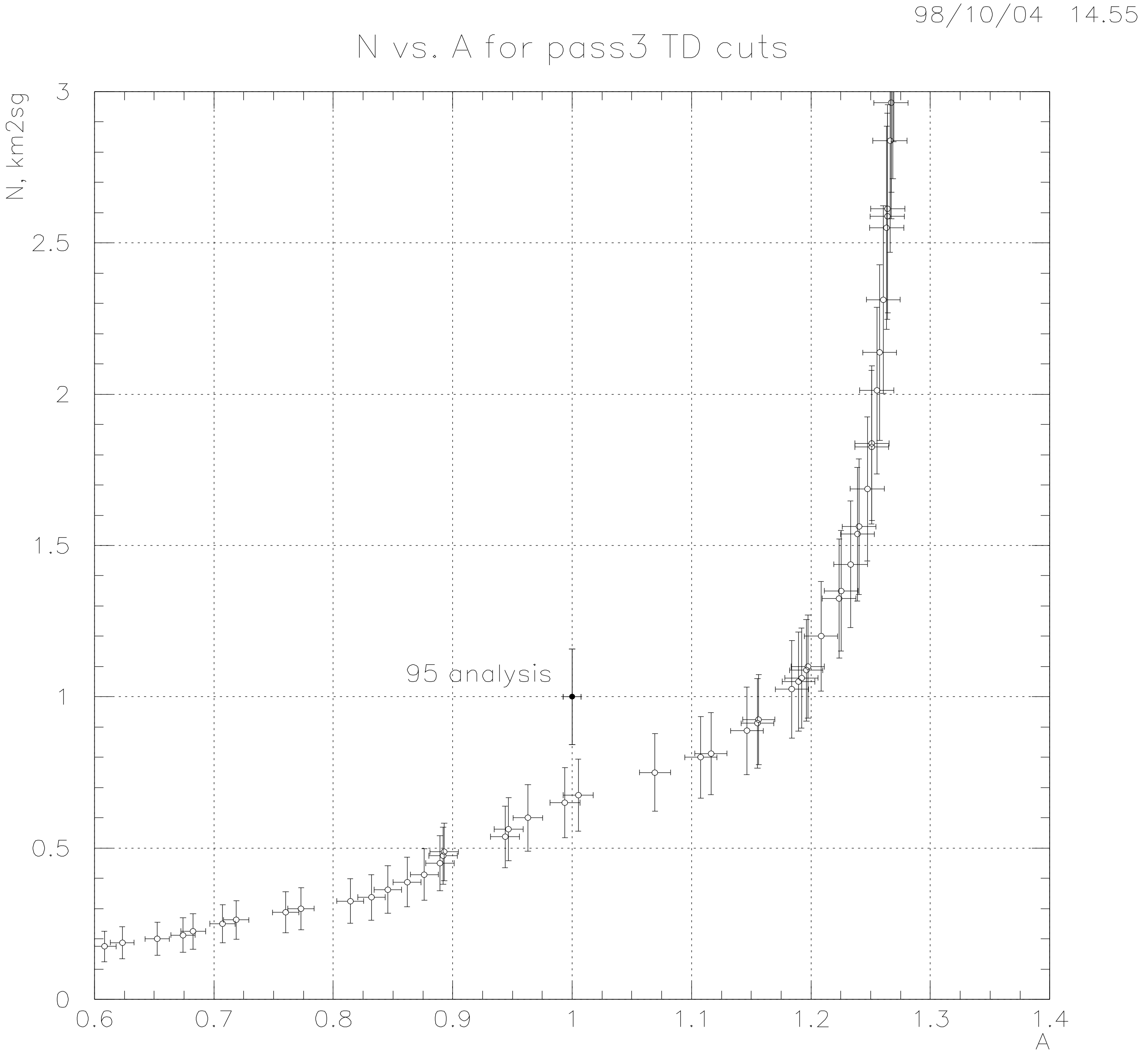
Improvement in TD analysis

Transient digitizer analysis of $\pi \to \mu \to e$ quite mature

Nonetheless significantly improved since publication

Plot shows current relative acceptances of signal & backgnd

Can get $\sim 30\%$ greater rejection or $\sim 20\%$ greater acceptance

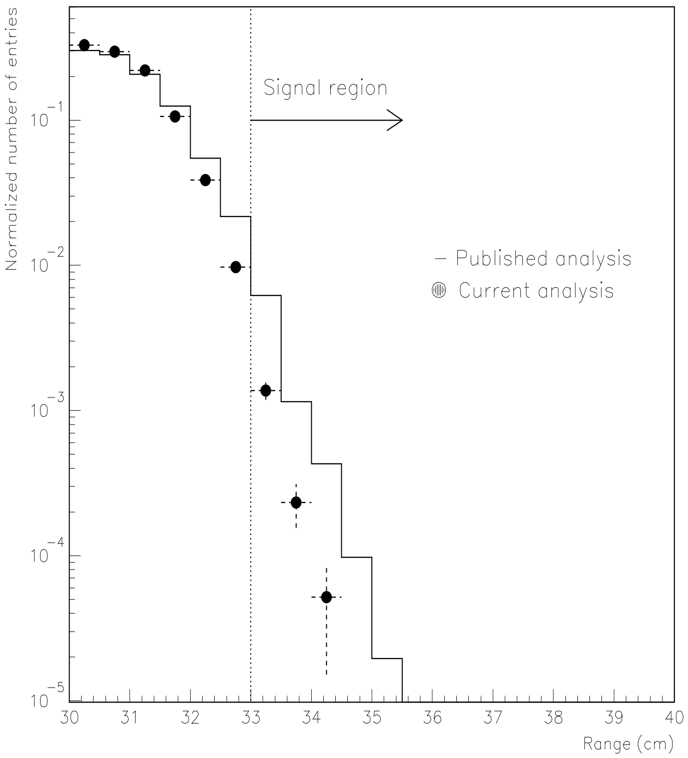


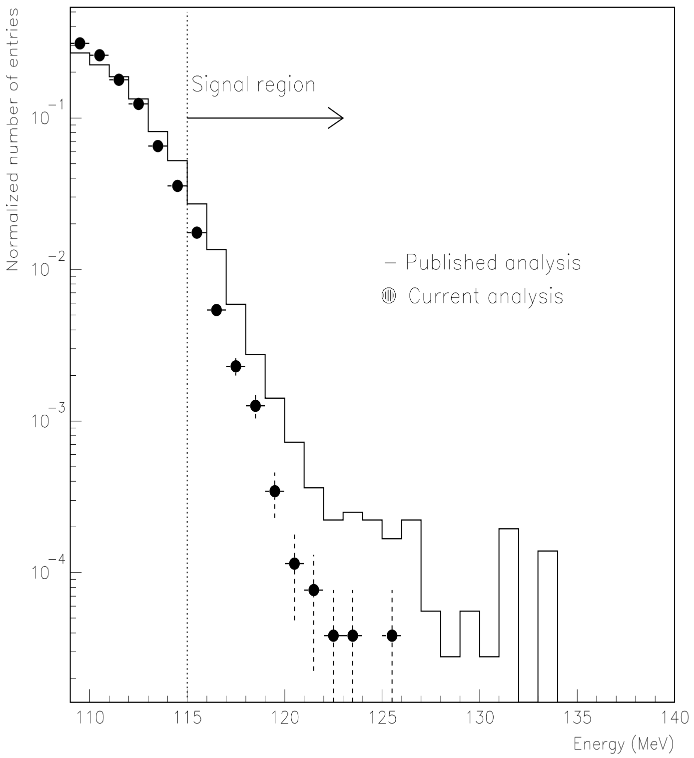
Progress in kinematic analysis of $K\pi2$

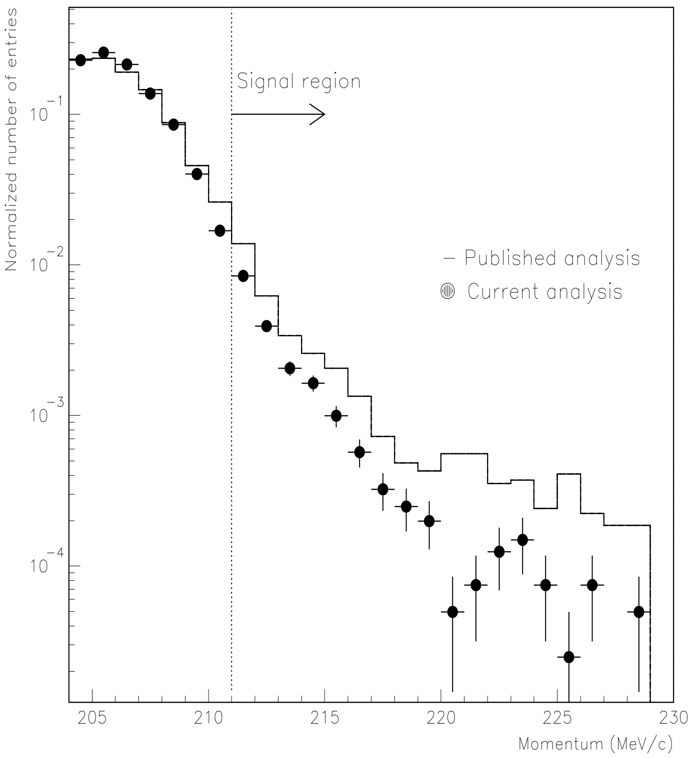
π^+ kinematic quantities range, kinetic energy, & momentum are used to reject $K\pi2$ background events.

Reconstruction improvements have led to a significant increase in rejection.

Further rejection can be achieved without much loss of acceptance, particularly in the case of the range cut







Running Conditions

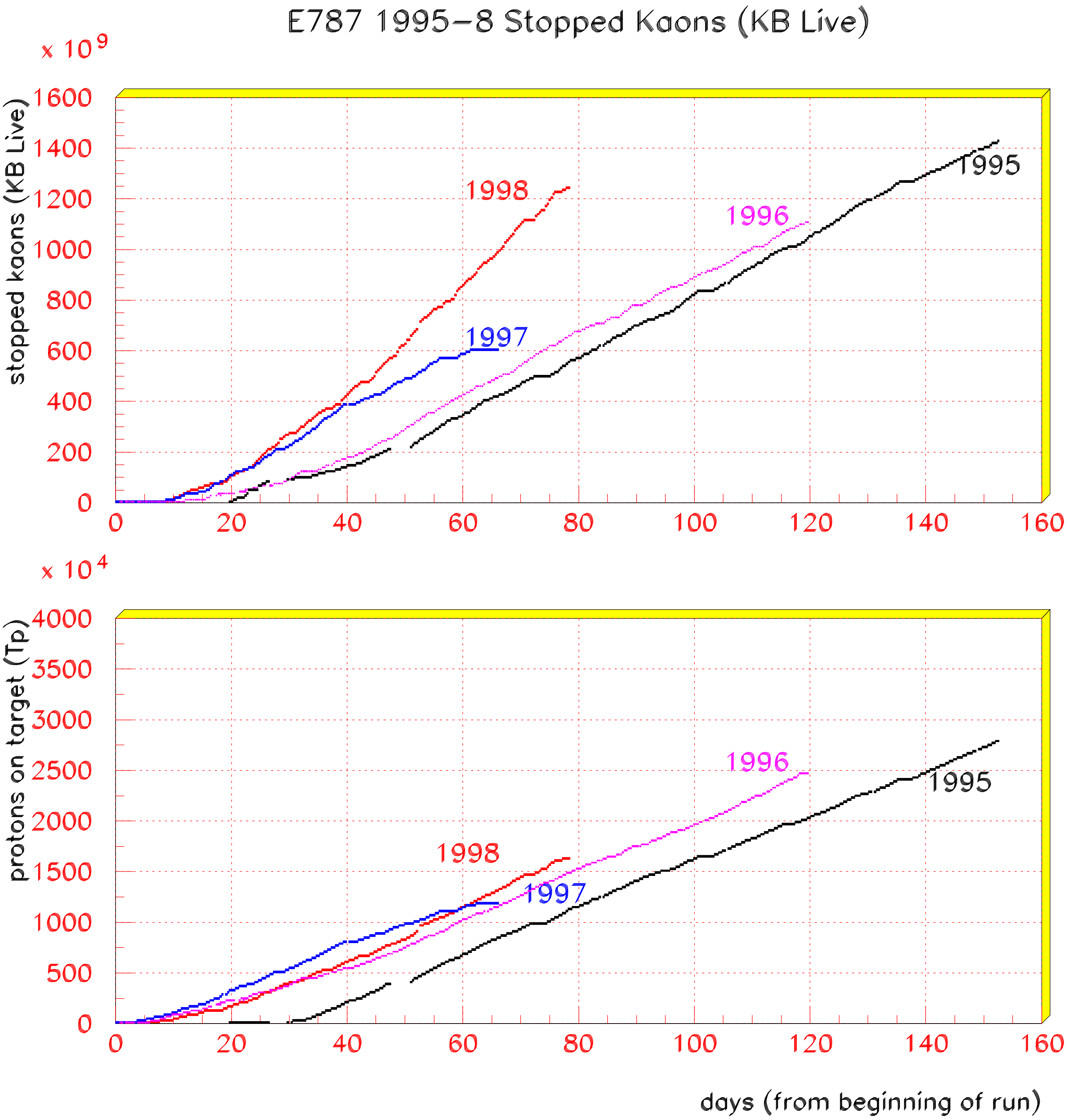
- Running Conditions
  - Duty Factor 38% $\longrightarrow$ 44%.
  - Incident K^+ momentum = 790 MeV/c
  - $K^+/\pi^+ = 3.7$
  - Incident K^+ (Ck) rate = 6.2 M/spill
  - Stopped K^+ (KB) rate = 1.2 M/spill (19% stopped)
- Trigger
  - KB/L0 = 800
    * Solid angle (50%)
    * Delayed K decay
    * Range (layer + z)
    * Photon Veto
  - L1/L0 = 15
    * $\pi^+ \rightarrow \mu^+$ (height to area in TD's)
  - Live Time = 73%
- Data Collected
  - 25 week run (17 week useful data)
  - $\sim$ 4000 8mm tapes analyzed ($\sim$ 15 Tbytes)
  - $\sim$ 150 M events
  - Total stopped kaons KB = 1.49 $\times 10^{12}$

E787 Status

- 1989-91: $\mathrm{BR}(K^+ \to \pi^+ \nu\overline{\nu}) < 2.4 \times 10^{-9}$ (90%CL)
- 1994: Engineering run with upgraded detector; $K^+ \to \mu^+ \nu_\mu \gamma$ data.
- 1995:
  - First long run with upgraded detector (17 weeks data), 1.1 M K^+_{Stop}/spill, Duty Factor 38% $\to$ 44%.
  - Backgrounds under control ($O[10^{-11}]$).
  - $\mathbf{BR}(K^+ \to \pi^+ \nu\overline{\nu}) = 4.2^{+9.7}_{-3.5} \times 10^{-10}$
- 1996:
  - Lower p_K from 800 MeV/c to 730 MeV/c, 1.3 M K^+_{Stop}/spill, Increased L1.1 trigger efficiency($\sim$25%), Trigger Rejection/Bandwidth limited, Short run and slow AGS start. (13 weeks data)
  - Expected sensitivity $\sim 2 \times 10^{-10}$ (95–6)
  - Pass1 finished 1/97.
- 1997:
  - Lower p_K from 730 MeV/c to 670 MeV/c, 1.5 M K^+_{Stop}/spill, Deadtime reduced, Short run (8 weeks/ 6 weeks data)
  - Expected sensitivity $\sim 1.5 \times 10^{-10}$ (95–7)
  - Pass1 finished 8/97. Pass2 (1995–7) finished 3/98
- 1998-9:
  - $p_K = 710$ MeV/c, DF $= \to 55\%$, expect 24 week run.
  - Expected sensitivity (98-9) $\sim 10^{-10}$

P949

- Goals:
  - Determine V_{td} to $\lesssim$ 20–5%.
  - Need to measure B($K^+ \to \pi^+ \nu\overline{\nu}$) to < 25–35%.
  - Need at least 3–4 events/year.
  - Background/Signal $\lesssim$ 10%.
- Status:
  - Near term e787 sensitivity is SES $\sim 2 \times 10^{-10}$ per year.
  - Want an increase of 5–7×
  - Backgrounds: $\lesssim 10^{-11}$.
- How?
  - Reduce incident p_K to 700 MeV/c.
  - Increase duty factor (spill /cycle: 1.6/3.6 $\to$ 5.3/7.8) (×1.5)
  - Detector upgrades: Photon Veto upgrade (underway), reduce Dead-time, additional trigger improvements...
- $\Longrightarrow$
  - $\sim$ **3–4 events/year**


E787 1995−8 Stopped Kaons (KB Live)
x 10^9
stopped kaons (KB Live)
1998
1997
1996
1995
x 10^4
protons on target (Tp)
1998
1997
1996
1995
days (from beginning of run)

P949 Improvement Factors

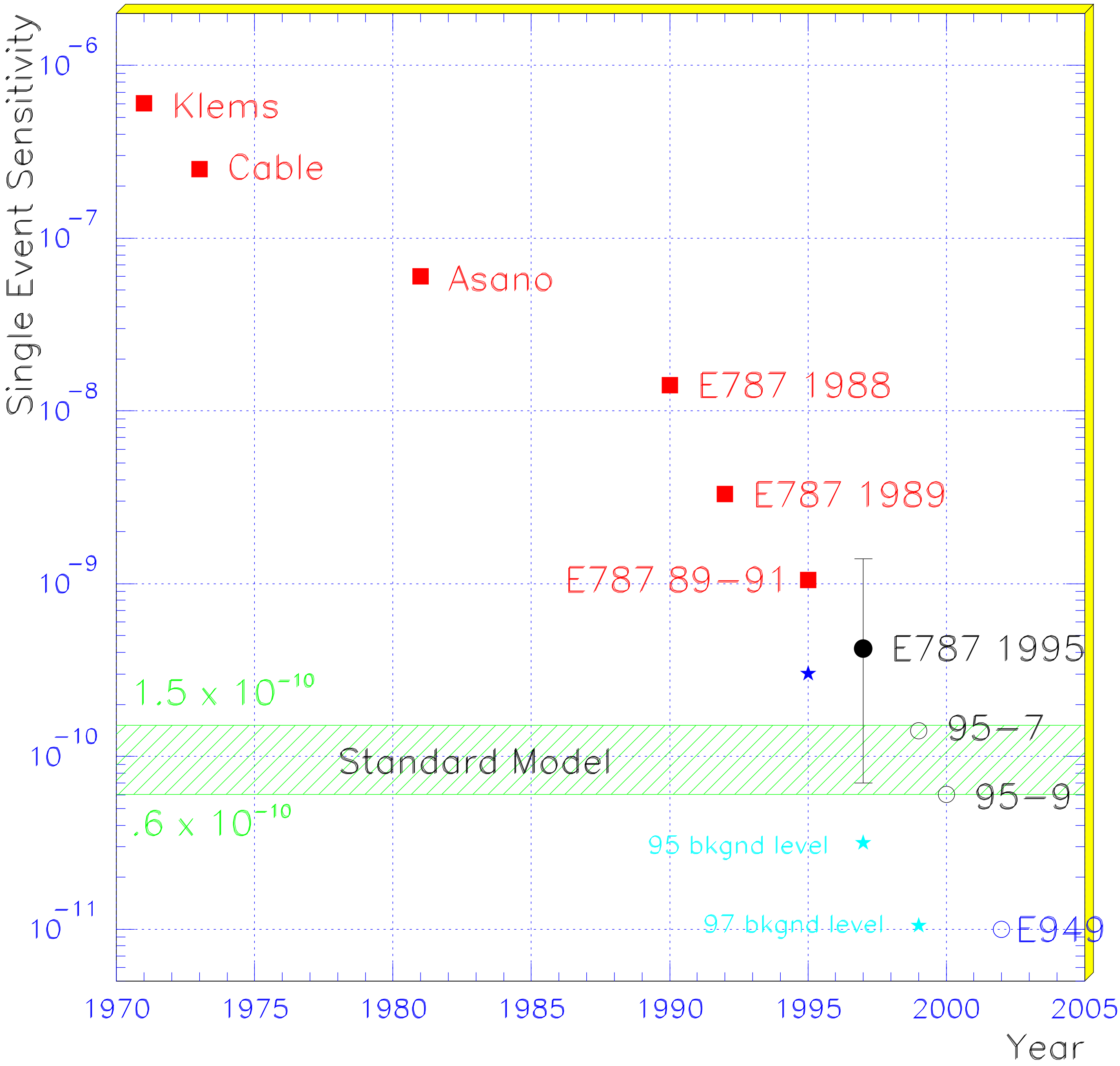
- 1.44: Lowering P_{K+}

- 1.53: Increasing the Duty Factor

- 1.27: L1.1 efficiency (rejection recovered with L1.2)
- 1.05: extend e^+ time from 4.4 μsec to 6.5 μsec
- 1.15: Reduce Deadtime from 28%→17%/KB(MHz)

- 1.06: Additional Deadtime reduction 17%→12%/KB(MHz)
- 1.06: T-counter PMT replacement (higher QE)
- 1.04: reduced online PV loss (HEX,BV meantiming)
- 1.10: offline production software (Pass1) (calibrated TD energy, 3-pulse fit)
- 1.15: trigger improvements (reduce deadtime in KB, IC, T*2)
- 1.30: offline acceptance (BVL, increased statistics on background samples, extend e^+ time from 6.5 μsec to 20 μsec)

- 2.0: higher rates (use increased rejection to run at higher rate)
- 2.0: include the larger phase space from below the $K_{\pi 2}$
- 13: total increase



Single Event Sensitivity
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
Klems
Cable
Asano
E787 1988
E787 1989
E787 89−91
E787 1995
95−7
95−9
1.5×10^{-10}
Standard Model
$.6 \times 10^{-10}$
95 bkgnd level
97 bkgnd level
E949
1970
1975
1980
1985
1990
1995
2000
2005
Year

Search for T-violating muon polarization in kaon decays

- The out of plane polarization in the $K^+ \to \pi^0 \mu^+ \nu$ decay is ≈ 0 in SM.
- A precise measurement would be uniquely sensitive to non-standard CP violation, possibly the source of the baryon asymmetry of the universe.
- 18 year old BNL experiment gives a limit on the out of plane polarization of $|P_\mu^T| < 0.009$ at 95% confidence level.
- Experiment KEK-246 will improve on this limit and planned new experiments at BNL could improve this limit by up to a factor of 30–40.

Measurement	Value 95%	$\bar{P}_\mu^T <$ $m_h \sim 2m_W$
d_n	$< 1.2 \times 10^{-25} e - cm$	0.064
d_e	$< 1.7 \times 10^{-26} e - cm$	–
$\frac{\epsilon'}{\epsilon}$	$(1.5 \pm 0.8) \times 10^{-3}$	–
$m_{K_L} - m_{K_S}$	$(3.510 \pm 0.018) \times 10^{-6} eV$	–
$B(b \to s\, \gamma)$	$(2.32 \pm 0.67) \times 10^{-4}$	0.02
$B(b \to X \tau \nu)$	$(2.72 \pm 0.34) \times 10^{-2}$	0.008
B–factory $P_\tau(b \to X \tau \nu)$	Proposed 0.005?	0.00018

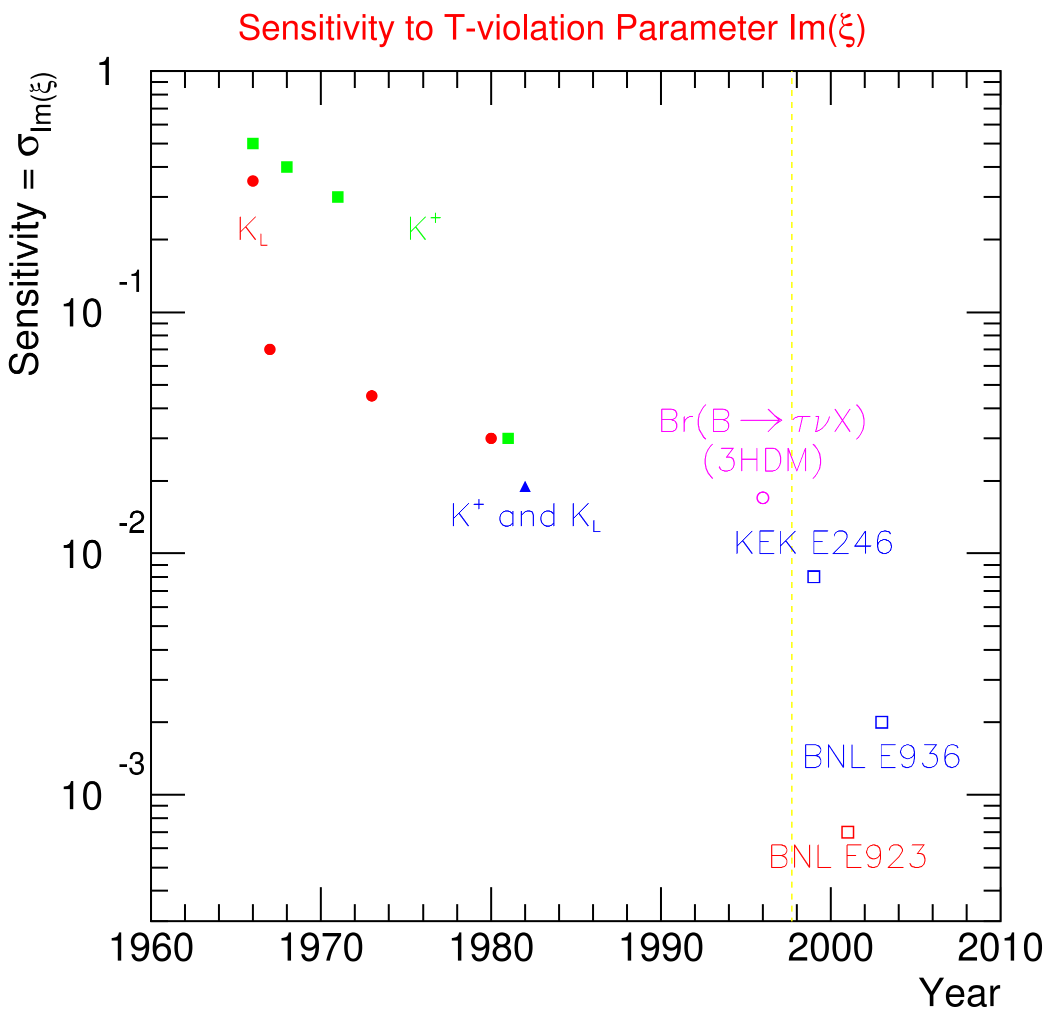
There are no severe constraints from other observables on this measurement in the context of a multi-Higgs (MHM) model.
In B semileptonic decays under the MHM model the P_τ^T has to be measured to $\pm 0.4\%$ to match the sensitivity that can be achieved at the AGS with $K^+ \to \pi^0 \mu^+ \nu$ decays.

KEK E246 and AGS E936

- KEK E246
  - Stopped K$^+$ beam, 2.7$\times10^5 K^+$/pulse, $\pi/K = 6$;
  - Muon momentum analyzed in S.C. toroid (1.8T);
  - $\pi^0 \to \gamma\gamma$ decays measured in CsI(Tl) calorimeter, forward and backward.
  - Muon polarization analyzed in 12 identical polarimeter elements.
  - Measure a double ratio, $(\mathrm{CW/CCW})_{\mathrm{forward}}/(\mathrm{CW/CCW})_{\mathrm{backward}}$
  - expect 5M events in 1996, ΔP_T=0.0022
    After 1997 and 1998 runs, ΔP_T=0.0013

- AGS E936
  - proposal submitted in Jan 1996
    scientific approval after PAC in Feb 1997
  - Move KEK E246 to AGS C4 line (LESB3),
    4.8$\times10^6 K^+$/pulse, $\pi/K = 0.3$;
  - Detector upgrade (new readout system);
  - Will collect 205M $K_{\mu 3}$ events in 3000 hours,
    $\Delta P_T = 0.00035$

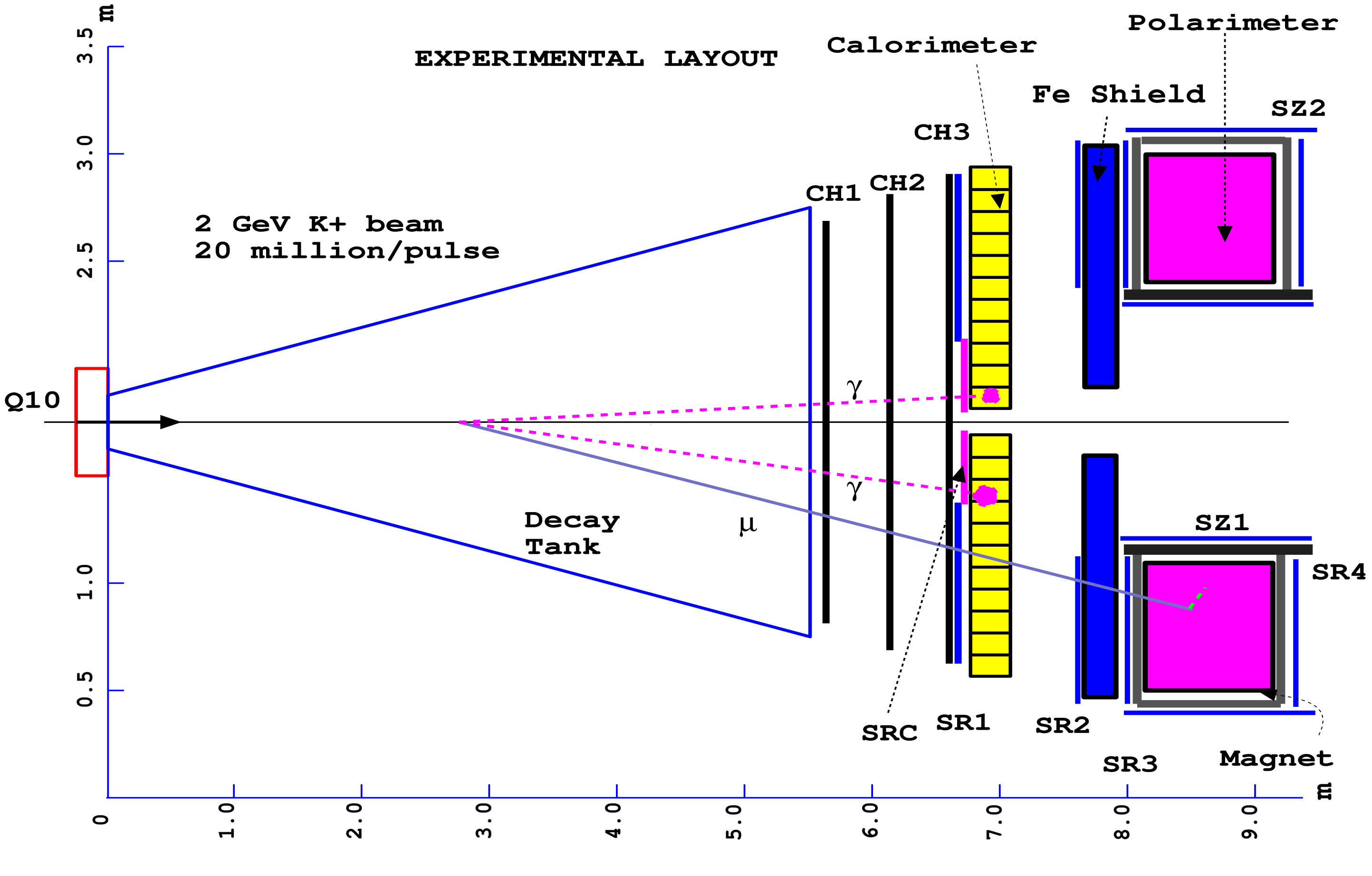
- J. J. Sakurai in 1958 proposed the tests of Time reversal in $K_{\mu 3}$ decay.
- Experimental measurements:



- Recent theoretical interests:
  M. Leurer, PRL 62(1989) 1967
  G. Belanger and C. Geng, PRD 44(1991)2789
  R. Garisto and G. Kane, PRD 44(1991)2038
  Y. Grossman and Z. Ligeti, Phys. Lett. B347(1995)399
  G. Wu and J. Ng, Phys. Lett. B392(1997)93

Detector Design

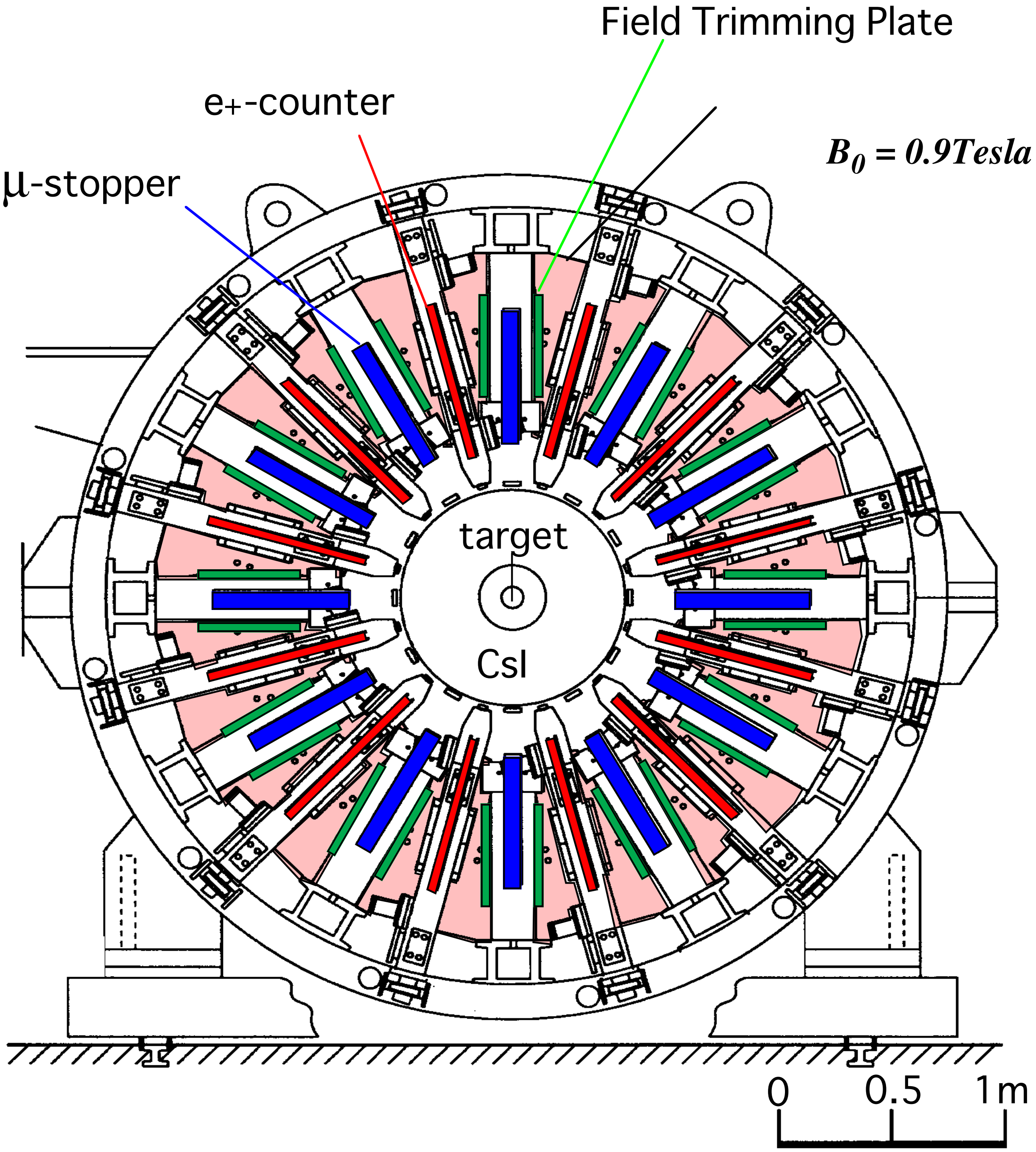
- Muon polarimeter
  96 Wedges, graphite absorber + PWC(or Scint)
- Pb-Scint Shashlik Calorimeter
  450 10×10 cm^2 blocks, 15 radiation length
- Muon tracking chambers (CH1, CH2, CH3)
  Three stations with stereoviews.
- Scintillator trigger counters(SR1,SR2,SR3,SR4,SRC,SZ1,SZ2)
- Precession magnet



KEK-PS E246 Detector
(end view)

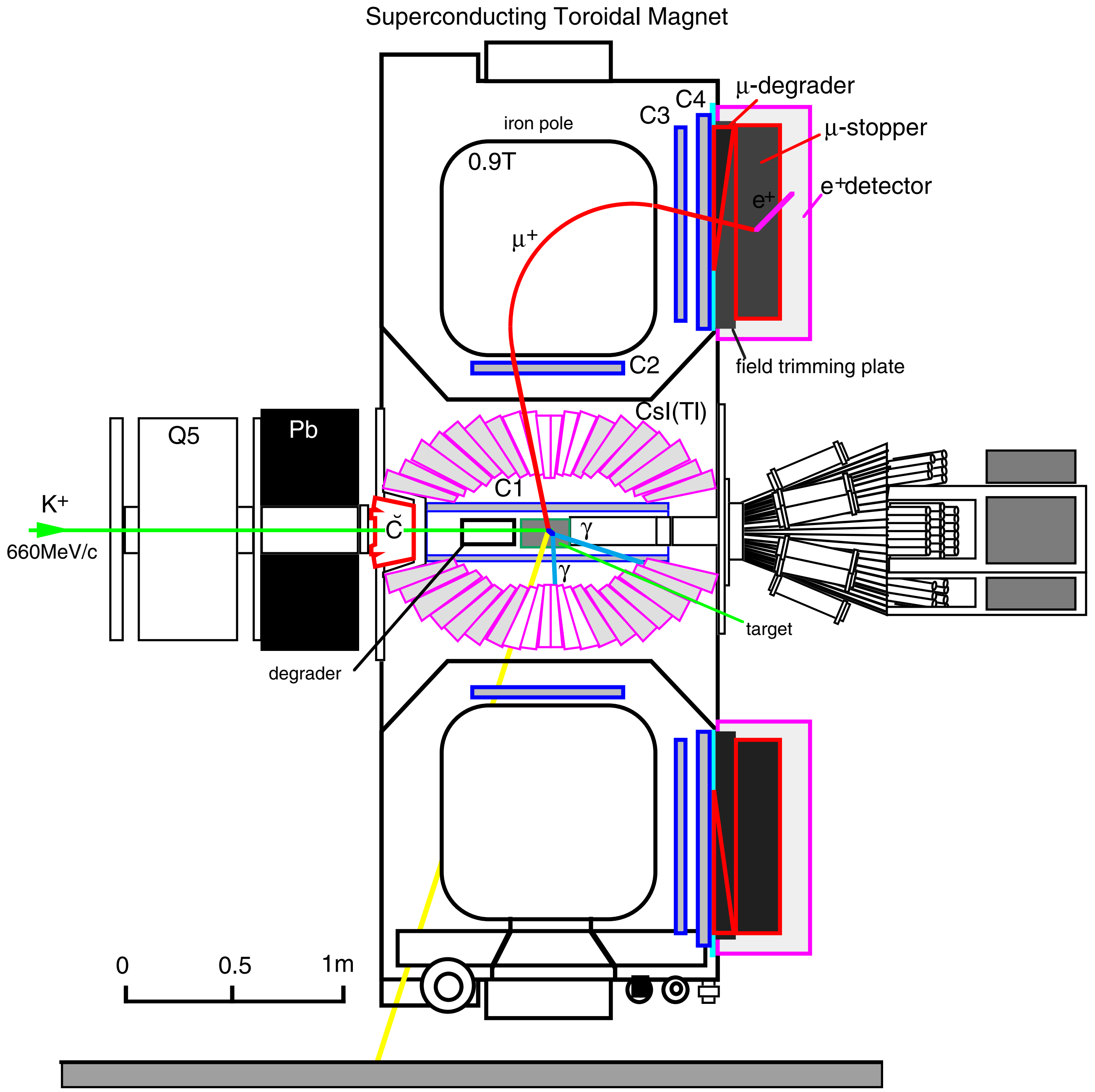
K decays at rest are used.

12 rotational symmetry



KEK PS-E246 Detector (side view)

K decays at rest are used.



Preliminary Result

- Two independent analyses are done (KEK/Princeton and INR) for the data taken from May, 1996 up to November, 1997. Both results are consistent.

- Preliminary result of P_T in $K^+ \rightarrow \pi^0 \mu^+ \nu$ decay

$$P_T = (-2.5 \pm 5.7(\mathrm{stat}) \pm 1.0(\mathrm{sys}))\ \mathrm{x}10^{-3}$$
$$\mathrm{Im}(\xi) = (-0.77 \pm 1.9(\mathrm{stat}) \pm 0.3(\mathrm{sys}))\ \mathrm{x}10^{-2}$$

- The whole data samples is more than two times, and will be analyzed soon. The expected final sensitivity is $\Delta\mathrm{Im}(\xi)$ (stat) $\leq 1.1 \times 10^{-2}$.

- P_T in $K^+ \rightarrow \mu^+ \nu \gamma$ decay is also being analyzed.

Sensitivity

- Assume 2×10^6 spills using 30×10^{12} protons on target.
- 352 analyzed $K_{\mu 3}$ event (Bkgd: 11 KPI2, 48 KPI3) per spill
- 10^9 events in 2000 hr
- Dilution factors: $P = A * D$

$$D = D_A * D_B * D_{Pr} / < \cos\theta >$$

  - Polarimeter analyzing power: $D_A = 1/(AP) = 1/0.39$
  - Background: $D_B = \sqrt{(S+B)/S} = 1.08$
  - Precession: $D_{Pr} = \sqrt{2}$
  - Mean decay plane angle: $< \cos\theta > \sim 0.80$

- Statistical error on $P_\perp$

$$\delta P_\perp = \frac{(2 \times 10^6 \cdot 352)^{-\frac{1}{2}} \cdot 1.17^{\frac{1}{2}} 2^{\frac{1}{2}}}{0.39 \cdot 0.8} = 1.8 \times 10^{-4}$$

- T-violating parameter: $Im\xi = P_\perp / < F >$
  - $F = \hat{P}_\perp / Im\xi$, variation on the Dalitz plot
  - In our previous definition we had included the $< \cos\theta >$ factor in F

$$\delta Im\xi = \delta P_\perp / 0.27 = 6.8 \times 10^{-4}$$

BNL-YALE 1980 K_L and K^+ combined $Im\xi = -0.01 \pm 0.019$

First Order Systematics

Systematic effects examined throughly by the technical review in Jan, 97.
Requirements for keeping systematics at $\sim 10^{-4}$ identified.
Class A: Vary as $\cos(\omega t)$

- Angular misalignment of wedge with respect to radius.

  Keep outside aligned to $\pm 0.5mm$ random.

- Clock delay (t_0) changes with field direction.

  Keep SR3 t_0 constant to within $\pm 300ps$ random.

- Magnetic field changes magnitude upon reversal.

  Causes T-violating asymmetry to increase as $\delta\omega t/2$

  Keep $\Delta B < 6\ mG$.

- Extra longitudinal field rotates muon in flight.

  Keep $B_{long-stray} < 1\ G$

  Magnetic fields measured in the area and detailed calculations performed. Need more work on magnetized materials.