(Tony Mann)

Exclusive Channel Strange-Particle Production in Neutrino Scattering ($E_\nu \approx 6$ GeV)

I. Charged Current, $\Delta S = 0$ Reactions

		ANL	BNL
*	$\nu_\mu n \to \mu^- K^+ \Lambda^0$	8 evts	8 evts
	$\nu_\mu n \to \mu^- \pi^0 K^+ \Lambda^0$	1 "	2 "
	$\nu_\mu n \to \mu^- \pi^+ K^0 \Lambda^0$	1 "	1 "
	$\nu_\mu n \to \mu^- K^- K^+ p$	1 "	
	$\nu_\mu p \to \mu^- K^+ \bar{K}^0 \pi^0 p$	1 "	

II. Charged Current, $\Delta S = 1$ Reactions

*	$\nu_\mu p \to \mu^- K^+ p$	12 evts
	$\nu_\mu n \to \mu^- K^0 p$	1 "
	$\nu_\mu n \to \mu^- \pi^+ K^0 n$	1 "

III. Neutral Current $\Delta S = 0$ Reactions

*	$\nu_\mu p \to \nu K^+ \Lambda^0$	1 evt	2 evts
	$\nu n \to \nu K^0 \Lambda^0$	2 "	0 "
	$\nu n \to \nu \pi^- K^+ \Lambda^0$	1 "	

Cross Section Measurements - obtained by bubble chamber - accelerator ν beam exp'ts of the 1970's and '80's:

Gargamelle at CERN ($\nu_\mu + \bar{\nu}_\mu$ into heavy liquid)

H. Deden et al., Phys. Lett 58B, 361 (1975).

O. Erriquez et al., Phys. Lett 70B, 385 (1977); Nucl. Phys. B140, 123 (1978).

12-ft diam. bubble chamber at Argonne ($\nu_\mu D_2$)

S. J. Barish et al., Phys. Rev. Lett 33, 1446 (1974); Phys Rev. D19, 2521 (1979).

W. A. Mann et al., Phys. Rev D 34, 2545 (1986).

7-ft diam. bubble chamber at Brookhaven ($\nu_\mu D_2$)

N. J. Baker et al., Phys. Rev. D 24, 2779 (1981).

Theory / Phenomenology:

R. Shrock, Phys. Rev D 12, 2049 (1975).

A. A. Ames, Phys. Rev D 18, 2290 (1978).

H. K. Dewan, Phys. Rev. D 24, 2369 (1981).

Cross Section Ratios:

Strange/non-strange:

$$\frac{\sigma(\nu N \to \mu^- \Lambda K^+ + \mu^- p K)}{\sigma(\nu N \to \mu^- N + \text{pion(s)})} \simeq 0.07 \qquad \text{(ANL)}$$

NC/CC:

$$\frac{\sigma(\nu V^0 + \cdots)}{\sigma(\mu^- V^0 + \cdots)} = 0.22 \pm 0.14 \qquad \text{(BNL)}$$

$$\frac{\sigma(\nu K^+ \Lambda^0)}{\sigma(\mu^- K^+ \Lambda) + \sigma(\mu^- K^+ \Lambda X^0)} = 0.18 \pm 0.13 \qquad \text{(BNL)}$$

Charmed baryon production yields reactions resembling CC-$\Delta S=1$, e.g.

$$\nu p \to \mu^- \Sigma_c^{++}$$
$$\hookrightarrow \Lambda_c^+ \pi^+ \to \Lambda^0 \pi^+ \pi^+ \pi^-$$

(BNL)

Comments:

The large-volume bubble chambers were remarkable imaging devices, providing millimeter spatial resolution with magnetic tracking. It will not be easy – even for a modern detector (e.g. Sci-Fi tracker) to improve upon the existing ensemble of exclusive channel strangeness cross sections.

The strangeness $\Delta S = 0, 1$ ν_μ reactions do not pose backgrounds for a

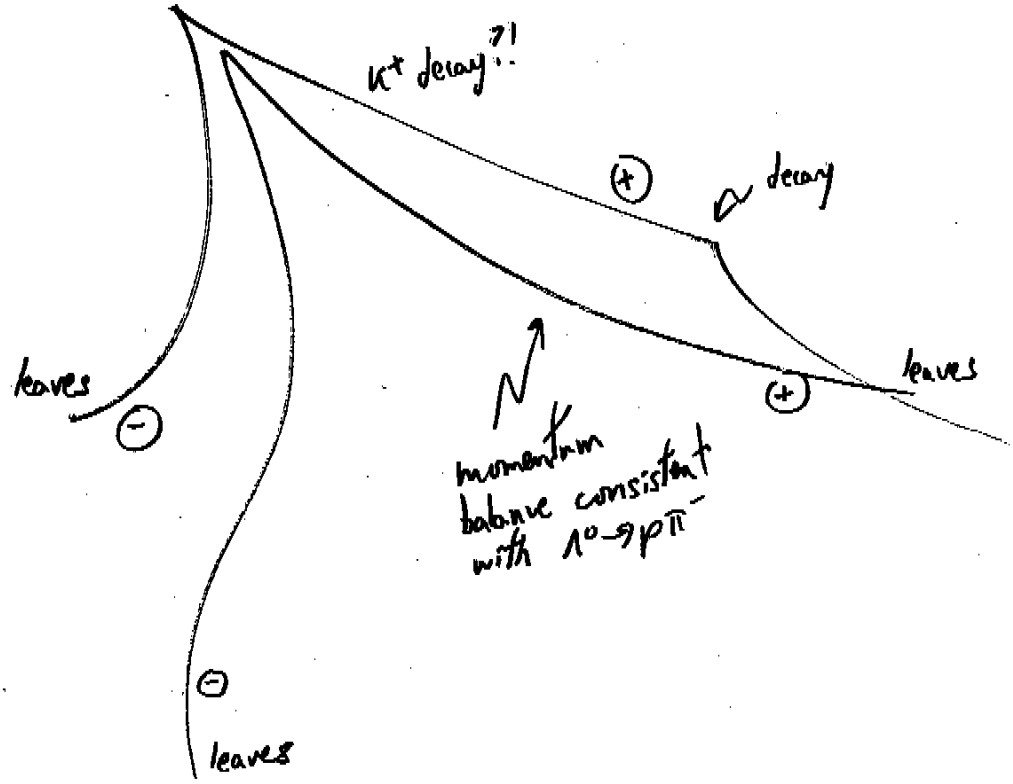
$\nu_\mu \leftrightarrow \nu_e$ oscillation search.

Is there a compelling HEP physics motivation for precision determination of the various exclusive-channel strangeness cross sections ??
(Not obvious to this Speaker – but I'm here to learn ...)

(8

$\nu_\mu n \to \mu^- K^+ \Lambda^0$

749
503



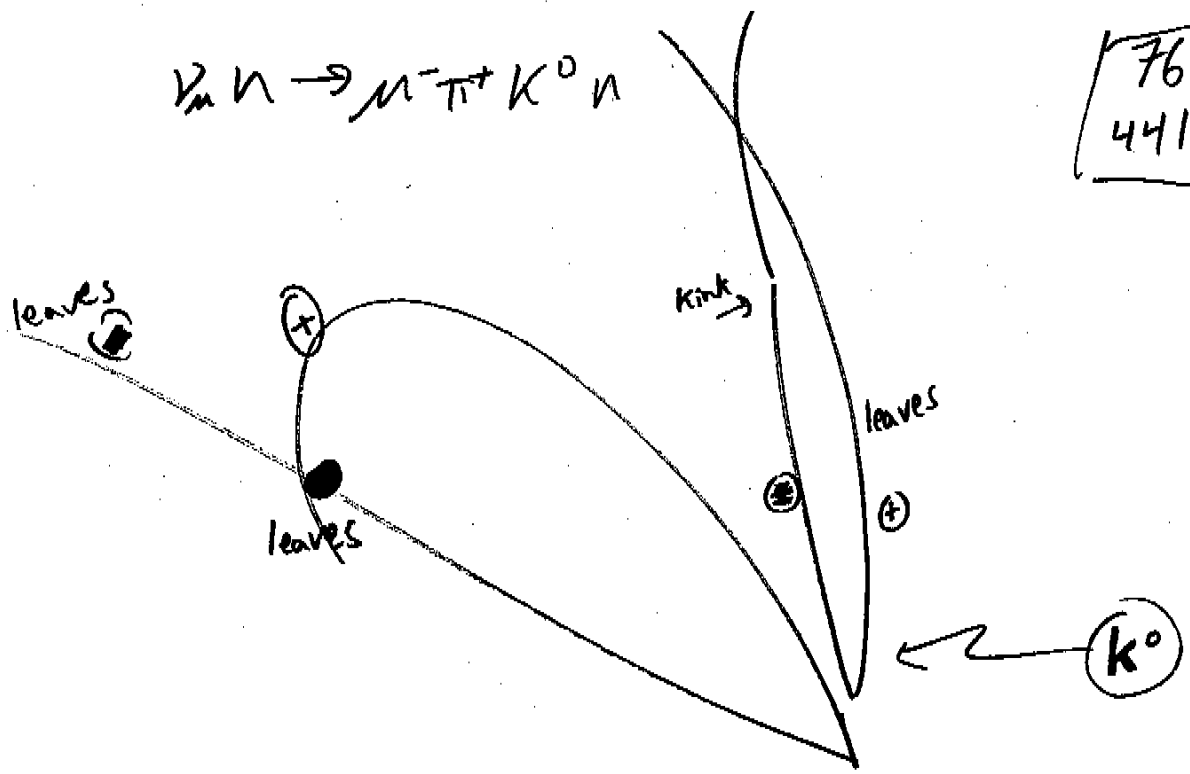
Kinematics ok,
ionization consistent.

Accept

(9)

765
4416

$\nu_\mu n \rightarrow \mu^- \pi^+ K^0 n$



Consistent

Accept

Kinematics ok,
ionization consistent, accept.

Beyond the Standard Model with Grand Unified Theories

Charge quantization explained, fundamental fermions and their masses and mixings nicely accomodated.

$\Rightarrow$ SO(10)

Convergence of EW + S couplings at a high mass scale: $\Rightarrow$ SUSY GUT

'Natural' Seesaw mechanism to explain light neutrino masses; augmented with a family symmetry, can accomodate neutrino bimaximal mixing

$\Rightarrow$ SUSY SO(10)

But the nucleon should be unstable!

"Fast" Modes ($\tau_p \sim 10^{34}$ yrs)	Slow Modes ($\sim 10^{36-38}$ yrs)
* $p \to \nu K^+$	$p \to e^+ \pi^0$
* $n \to \nu K^0$	$\to \mu^+ \pi^0$
(and maybe $p \to e^+ K^0$, $\mu^+ K^0$)	$\to \ell^+ \eta^0$
	$n \to \bar{\nu} \pi^0$

Nucleon Decay Lifetime Lower Limits by SuperK (see S. Mine, NUINT02 @ UCI)

$\tau(p \to e^+ \pi^0) \leq 5.4 \times 10^{33}$ yrs

Great limit, but much longer lifetime expected in SUSY SO(10).

Ditto: $p \to \mu^+ \pi^0$, $e^+ \eta^0$, $\mu^+ \eta^0$, $n \to \bar{\nu} \pi^0$

$n \to \nu K^0$

$\hookrightarrow K^0_S \to \pi^+ \pi^-$, $\pi^0 \pi^0$

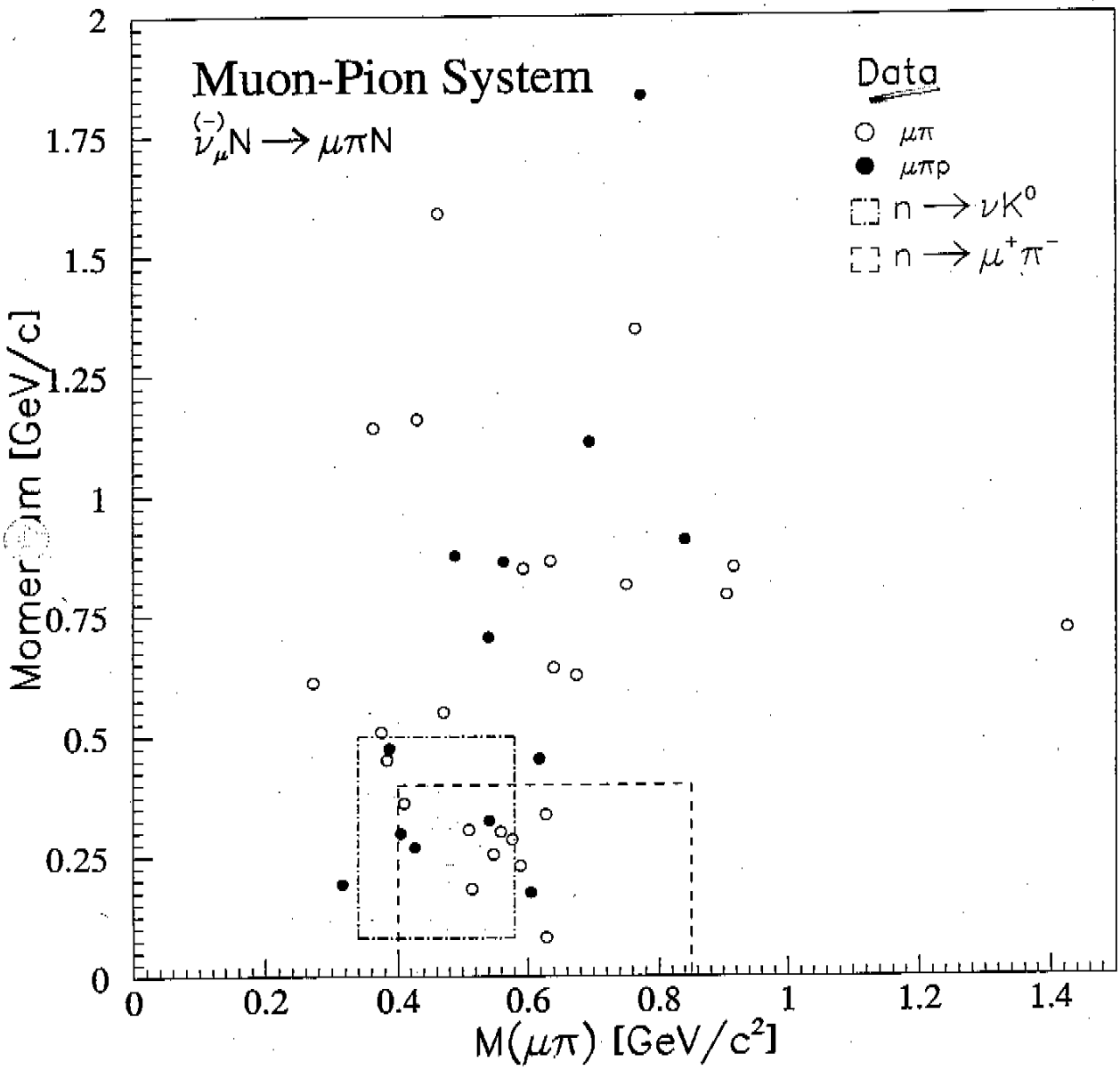
This mode is already background-limited for searches probing $\gtrsim 10^{32}$ yrs.

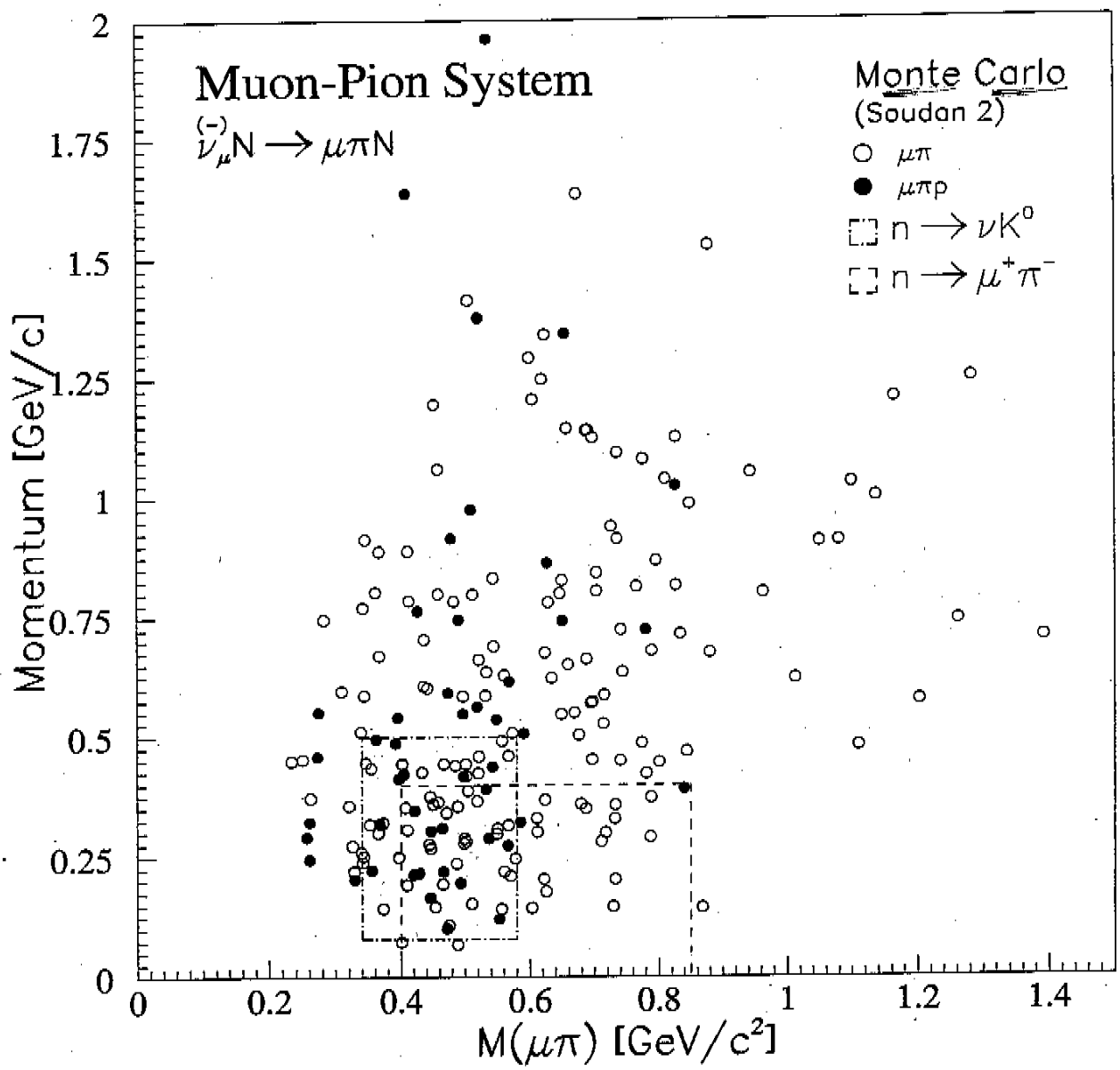
$\tau(p \to \nu K^+) \leq 2.2 \times 10^{33}$ yrs

Great limit!

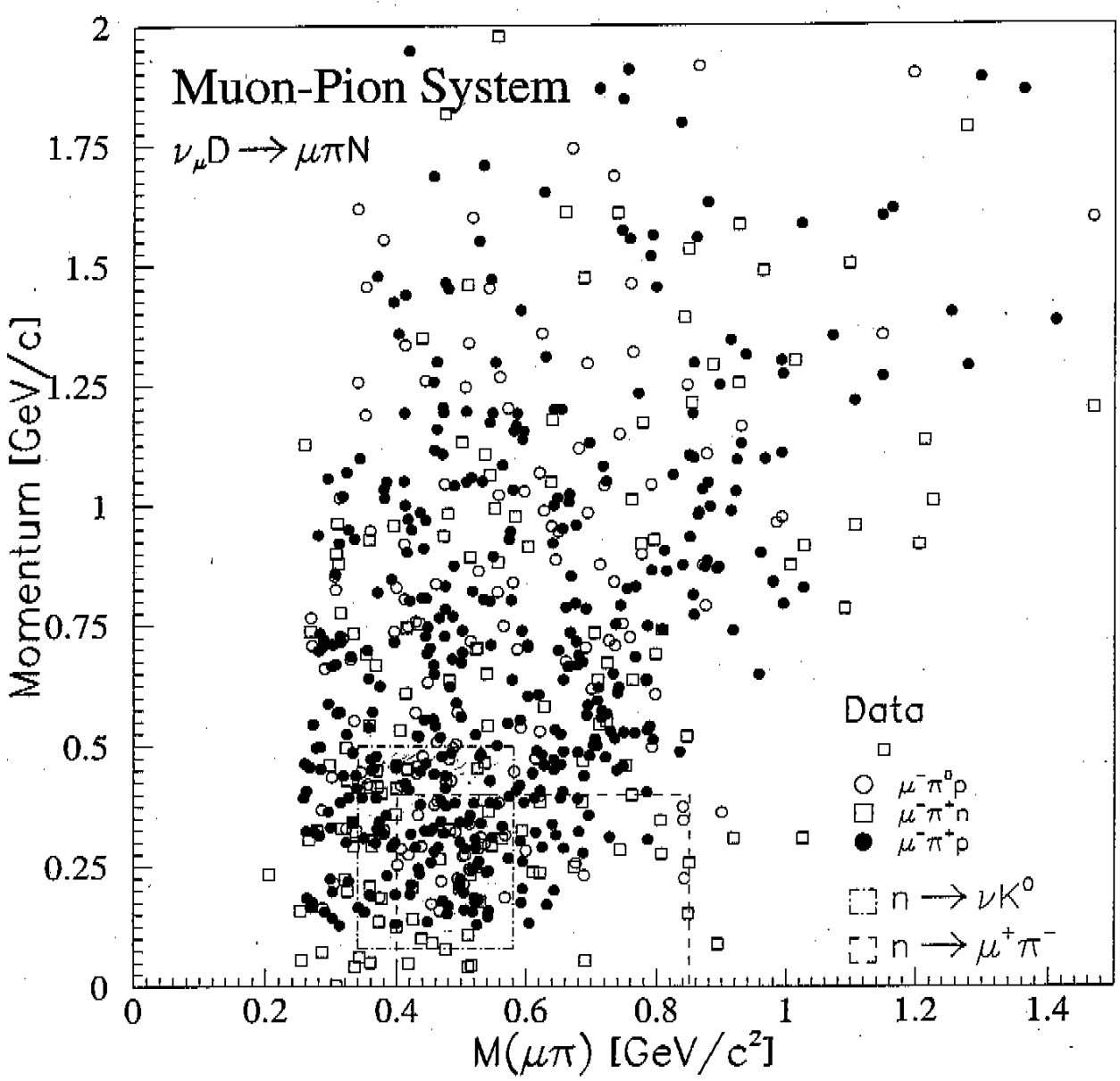
From perspective of SUSY SO(10), herein lies the best hope for discovery of baryon instability.

Sondan 2


Muon-Pion System
$\overset{(-)}{\nu}_\mu N \rightarrow \mu\pi N$
Data
$\mu\pi$
$\mu\pi p$
$n \rightarrow \nu K^0$
$n \rightarrow \mu^+\pi^-$
Momentum [GeV/c]
$M(\mu\pi)$ [GeV/c^2]
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
0.2
0.4
0.6
0.8
1.2
1.4


Muon-Pion System
$\overset{(-)}{\nu}_\mu N \rightarrow \mu\pi N$
Monte Carlo
(Soudan 2)
$\mu\pi$
$\mu\pi p$
$n \rightarrow \nu K^0$
$n \rightarrow \mu^+\pi^-$
Momentum [GeV/c]
$M(\mu\pi)$ [GeV/c^2]
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
0.2
0.4
0.6
0.8
1.2
1.4

Argonne 12-ft $\nu_\mu D_2$ interactions:



$p \rightarrow \bar{\nu} K^+$ search selection criteria

$K^+ \rightarrow \mu^+ \nu$ spectrum search

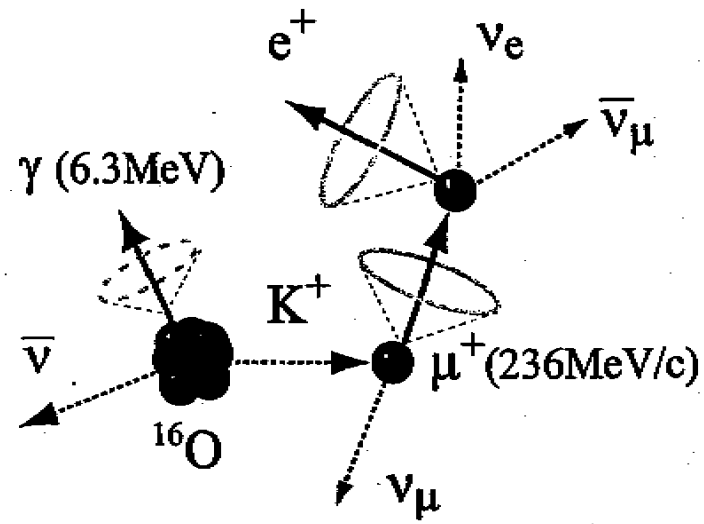
- 1 μ-like ring
- 1 Michel electron
- $215 < p_\mu < 260$MeV/c
- $N_{\gamma hit} < 7$, $N_{\gamma hit} > 60$

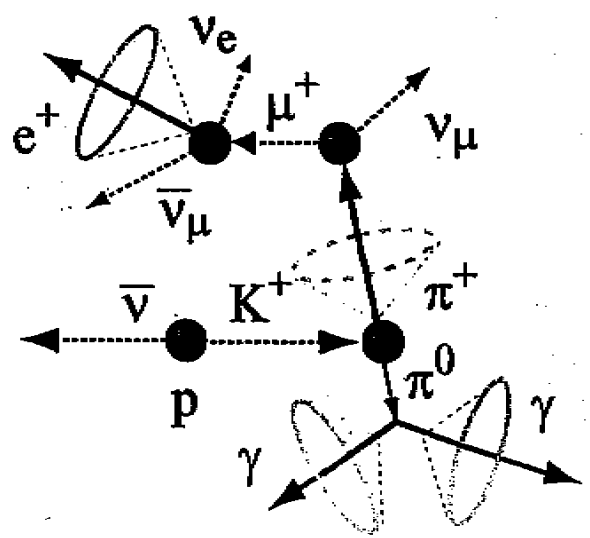
$K^+ \rightarrow \mu^+ \nu$ gamma search

- 1 μ-like ring
- 1 Michel electron
- $215 < p_{\mu^+} < 260$MeV/c
- $0.6 < g, d_{\mu e} < 2$m (proton rejection)
- $7 < N_{\gamma hit} < 60$ (prompt γ)

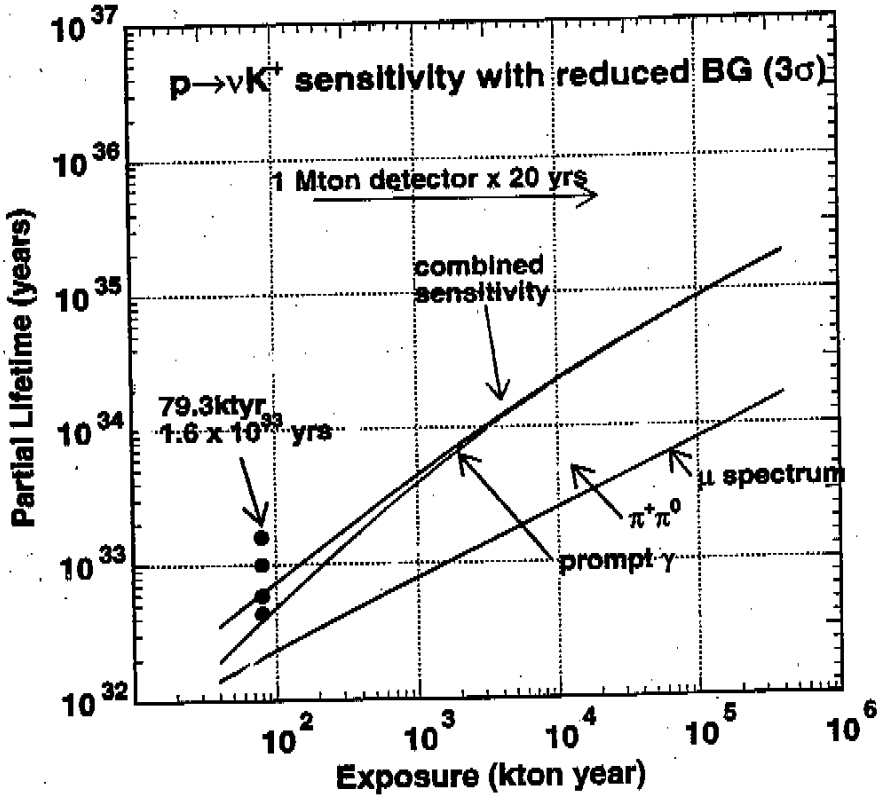
$K^+ \rightarrow \pi^+ \pi^0$ search

- 2 e-like ring
- 1 Michel electron
- $85 < m_{p\theta} < 185$ MeV/c^2
- $175 < p_{p\theta} < 250$MeV/c
- $40 < Q_{p^+} < 100$PE, $Q_{res} < 70$PE





Lifetime sensitivity with reduced BG



Prompt γ tagging is essential

With 3σ (99.73%) level
- 1Mton $\times$ 20 years $\rightarrow$ $\sim 3 \times 10^{34}$ years lifetime

In a deep underground water Cherenkov detector (SuperK ⋯→ HyperK/UNO), there is but one neutrino reaction which can fake $p \to \nu K^+$:

Proton Decay:

$$^{16}O \to \nu K^+ + {}^{15}N\,\gamma$$
$$\hookrightarrow \mu^+ \nu$$

Atmospheric Neutrino Background:

$$\nu + {}^{16}O \to \nu \Lambda^0 K^+ + {}^{15}N\,\gamma$$
$$\downarrow \quad \hookrightarrow \mu^+ \nu$$
$$(p\,\pi^- \text{ below } \check{C} \text{ threshold})$$

$\underline{\nu + p \to \nu \Lambda^0 K^+}$ completely mimics the proton decay signal if K^+ and $\Lambda^0 \to p\pi^-$ do not emit Cherenkov light.

Propose:

A precision measurement at Fermilab of the exclusive $\Delta S = 0$ NC channel

$$\frac{d\sigma}{dE_\nu}(\nu_\mu p \to \nu_\mu K^+ \Lambda^0)$$

together with its $\Delta S = 0$ CC companion

$$\frac{d\sigma}{dE_\nu}(\nu_\mu n \to \mu^- K^+ \Lambda^0)$$

How?

The events have relatively low primary multiplicities (3 & 4 prongs, assuming $\Lambda \to p\pi^-$)

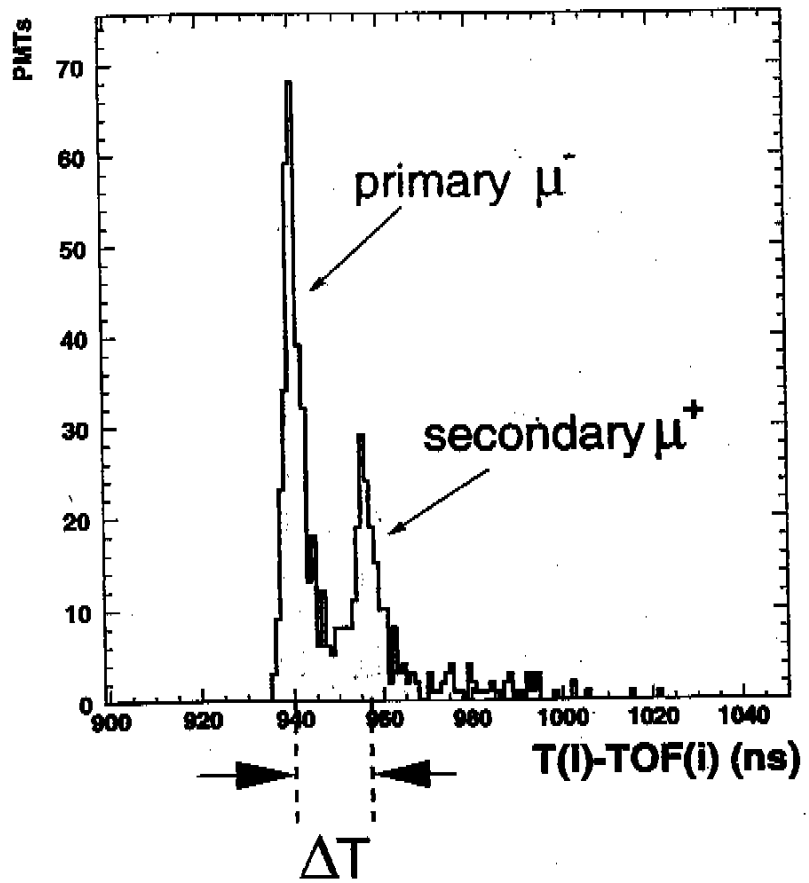
* K^+ decay at rest within the detector may provide a distinctive time signature.

$K^+ \to \mu^+\nu$ provides large-angle μ^+.

(S. Mine)

Relevant measurements are underway now at the K2K near detector site:

Typical time distribution for $\nu n \longrightarrow \mu^- \Lambda^0 K^+ (K^+ \longrightarrow \mu^+ \nu)$ event @1KT



Clear two peaks w/ ΔT~a few 10ns can be observed

Two peaks separation: ΔT>5ns
→ K decay prob.~64%

However the E_ν reach of the K2K beam is limited ($E_\nu \lesssim 3$ GeV); the higher energy NuMI beam may provide a more complete picture ($\sigma(E_\nu)$) for these reactions.