The KARMEN Time Anomaly: Search for a Neutral Particle of Mass 33.9 MeV in Pion Decay

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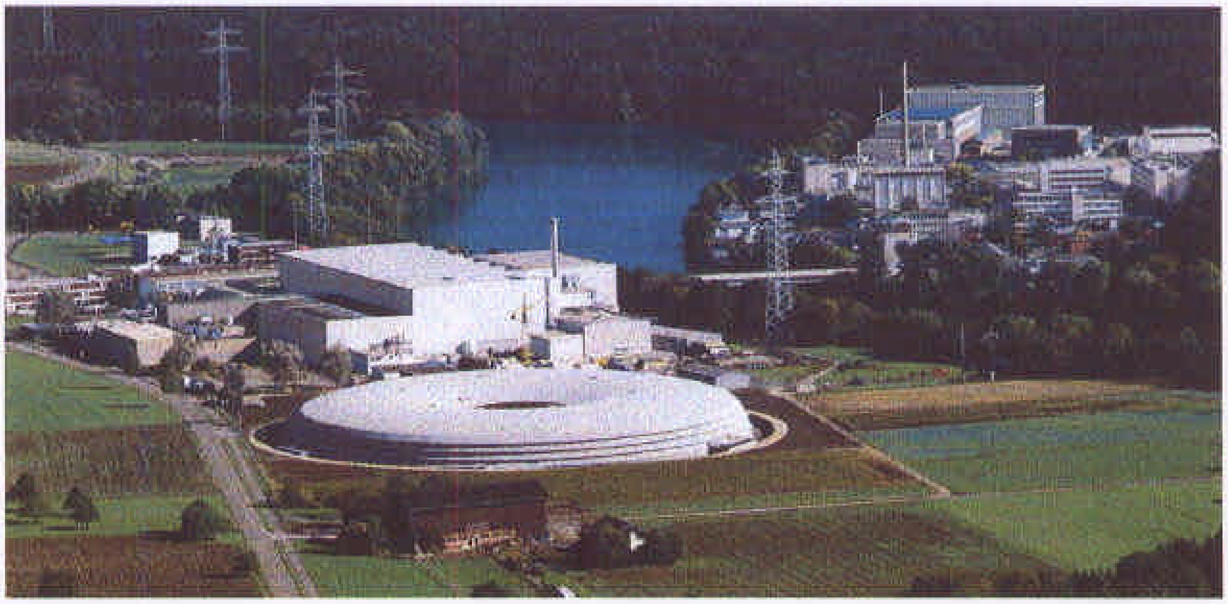
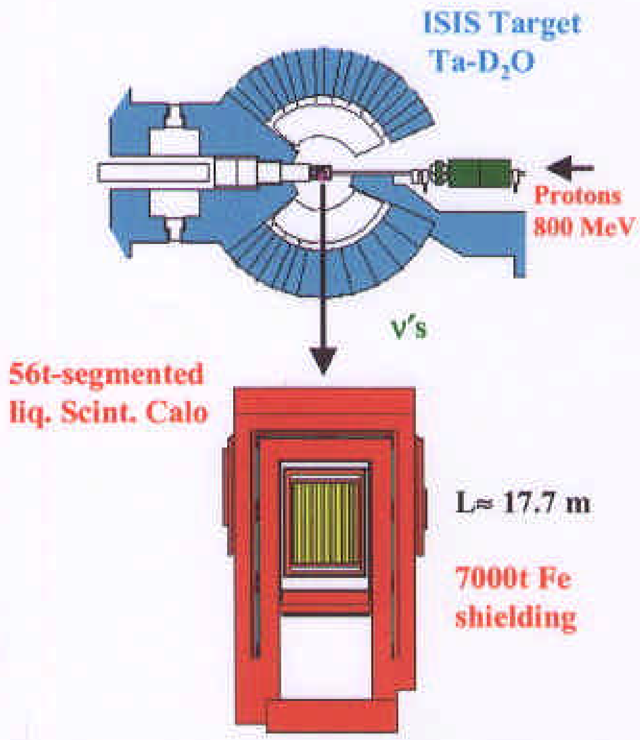


- **Motivation:**
  (i) **Anomaly observed (excess of events) in time distribution of neutrino induced reactions in KARMEN I Data at ISIS**
  - (B. Armbruster et al. Phys. Lett. B 348 (1995) 19-28)

  (ii) **signal for physics beyond SM?**

- **Karmen Experiment:**

(Main Goal- Search for ν-oscillations)



ν-Production:

π- & μ-decay at REST in ISIS target

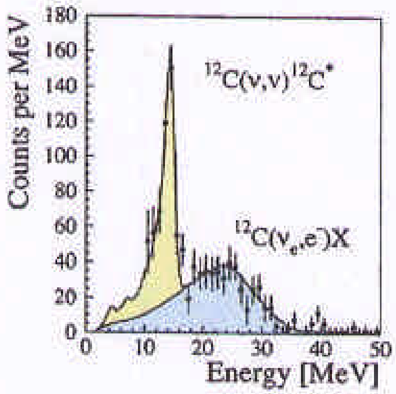
$$\pi^+ \rightarrow \mu^+ + \nu_\mu \qquad \tau_\pi = 26\text{ns}$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu \qquad \tau_\mu = 2.2\mu\text{s}$$

ν-detection:

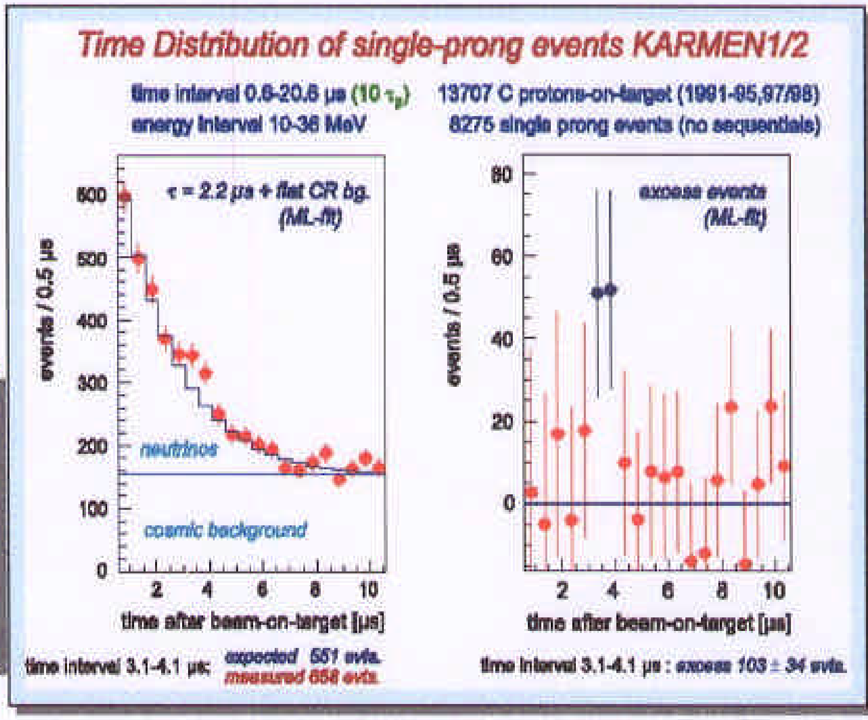
via CC- & NC-reactions

(single-prong event visible energy deposition NC→15.1 MeV Photon, CC→ $E_{e^-} \leq 35$ MeV)



- **Single-prong events**
  (no sequential signature)
- **Time window (0.6 - 20.6) μs**
- **Energy cut**
  ($11 \leq E_{vis} \leq 35$) MeV

➔ Anomaly 3σ Effect!



Characteristics & Implications of Time Anomaly:

- **Events closely clustered in time:**
  t_{mean} ~ 3.6 μs after beam-on-Target
  t_{width} ~ 1 μs
- **If physical must traverse 7m steel**
- **Visible energy $E_{vis} \leq 35$ MeV deposited in detector**

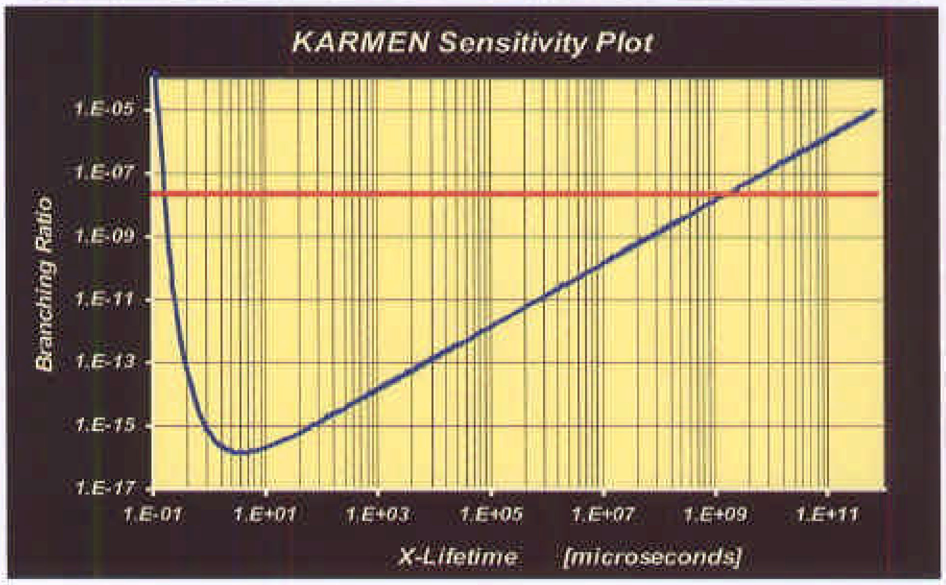
Hypotheses Tested

- **Not Beam-associated background**
- **Not Electronic or DAQ related**
- **Not accelerator after-pulse**
- **≤ 1% prob. of Statistical fluctuation**

X-Particle Hypothesis

- Produced in π-Decay at rest in ISIS target $\pi^+ \rightarrow \mu^+ X$
- Neutral, weakly interacting
- $\upsilon_X \sim 4.9$ m/μs $\beta_X \approx 0.02$ ➔ $M_X = 33.905$ MeV/c^2
- **Decays** in detector $T_X = 5$keV, but $E_{vis} \leq 35$ MeV
- $\tau_X > 0.3$ μs, $X \rightarrow e^+e^-\nu$, $X \rightarrow \nu\gamma$ disfavoured
- From N_X, N_π ➔ **B.R. = $\Gamma(\pi^+ \rightarrow \mu^+ X) / \Gamma(\pi^+ \rightarrow \mu^+ \nu_\mu)$**

10^{-16} ↵ ➔ Branching ratio vs. lifetime



1995 PSI limit

Theoretical interpretations at the Time

- **Isosinglet (sterile) Neutrino, $X \rightarrow e^+e^-\nu$**
  V.Barger, R.J.N. Phillips, S. Sarkar: Phys. Lett. B 352 (1995) 365-371, B 365 (1995) 617
  J. Govaerts, J. Deutsch, P.M. Van Hove: Phys. Lett. B 389 (1996) 700
- **SUSY soln. Lightest neutralino, $X \rightarrow \nu\gamma$**
  D. Choudary, S. Sarkar: Phys. Lett. B 374 (1996) 87-92
- **X-boson in $\mu \rightarrow e^+ X$, $M_X \sim 103.9$ MeV/c^2**
  S.N. Gninenko, N.V. Krasnikov: Phys. Lett. B 434 (1998) 163-168

π-Decay Kinematics: $\pi^+ \rightarrow \mu^+ X$

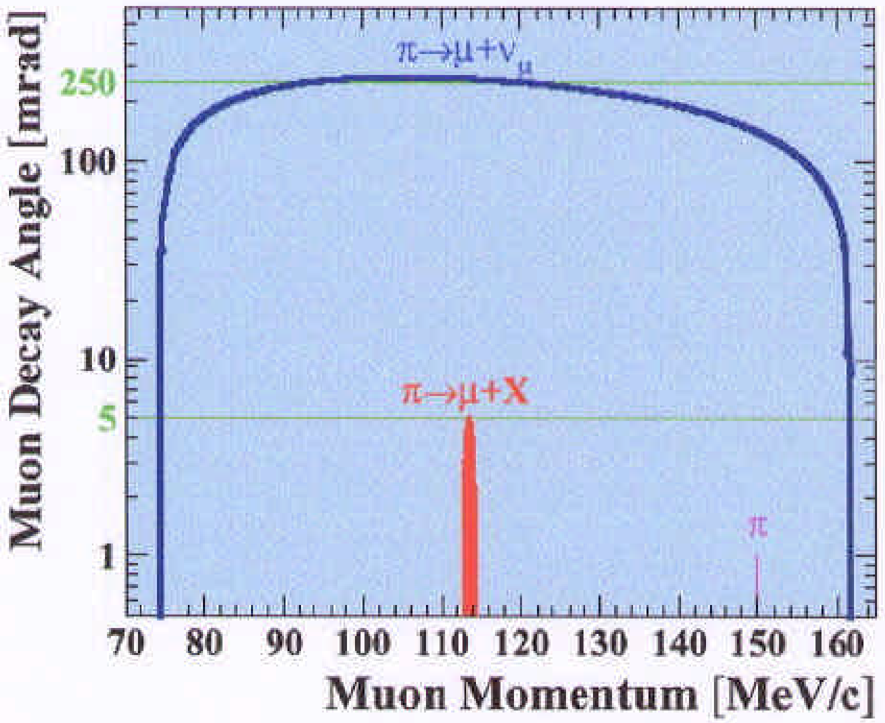
- $M_X = (33.9056 \pm = 0.0004)$ MeV/c² ≈ $(M_{\pi+} - M_{\mu+}) = (33.91157 \pm =.00067)$ MeV/c²
- Q-value of reaction very small
- in C.M. $T_X \approx 5$ keV $T_\mu \approx 1.6$ keV hence prohibitive to search for X-particle via decay at rest, also previous Heavy ν-searches utilizing μ-spectroscopy (also only → 30 MeV/c²)

Conclusion

Search for $\pi^+ \rightarrow \mu^+ X$ in decay-in-flight

Advantages:

- $\beta_\mu \approx \beta_\pi$
- Well defined Momentum $P_\mu \approx P_\pi \cdot m_\mu / m_\pi$
- $(dE/dx)_\mu \approx (dE/dx)_\pi$
- Flight direction of $\mu^+ \approx$ that of π^+
- Use beam-line as spectrometer to separate $\pi^+ \rightarrow \mu^+ X$ from $\pi^+ \rightarrow \mu^+ \nu_\mu$
- pions used to setup timing & Thresholds since ≡ μ's



$P_\pi = 150$ MeV/c

$P_\mu = 0.757 \cdot P_\pi$

1995: 2 Experimental Searches at PSI + Data Search TRIUMF

R. Bilger et al. Phys. Lett. B 363 (1995) 41-45 **B.R. ($\pi \to \mu X$) < $7 \cdot 10^{-8}$ 95% C.L.**
M. Daum et al. Phys. Lett. B 361 (1995) 179 **B.R. ($\pi \to \mu X$) < $2.6 \cdot 10^{-8}$ 95% C.L. ****
D. A. Bryman & T. Numao Phys. Rev. D 53 (1996) 558 **B.R. ($\pi \to \mu X$) < $4\text{-}6 \cdot 10^{-5}$ 90% C.L.**

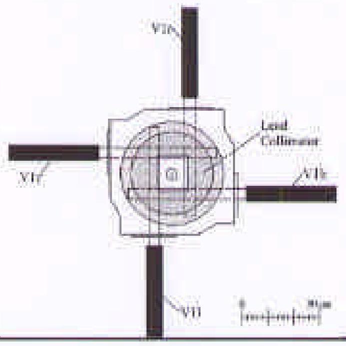
NewHeavns -Experiment:

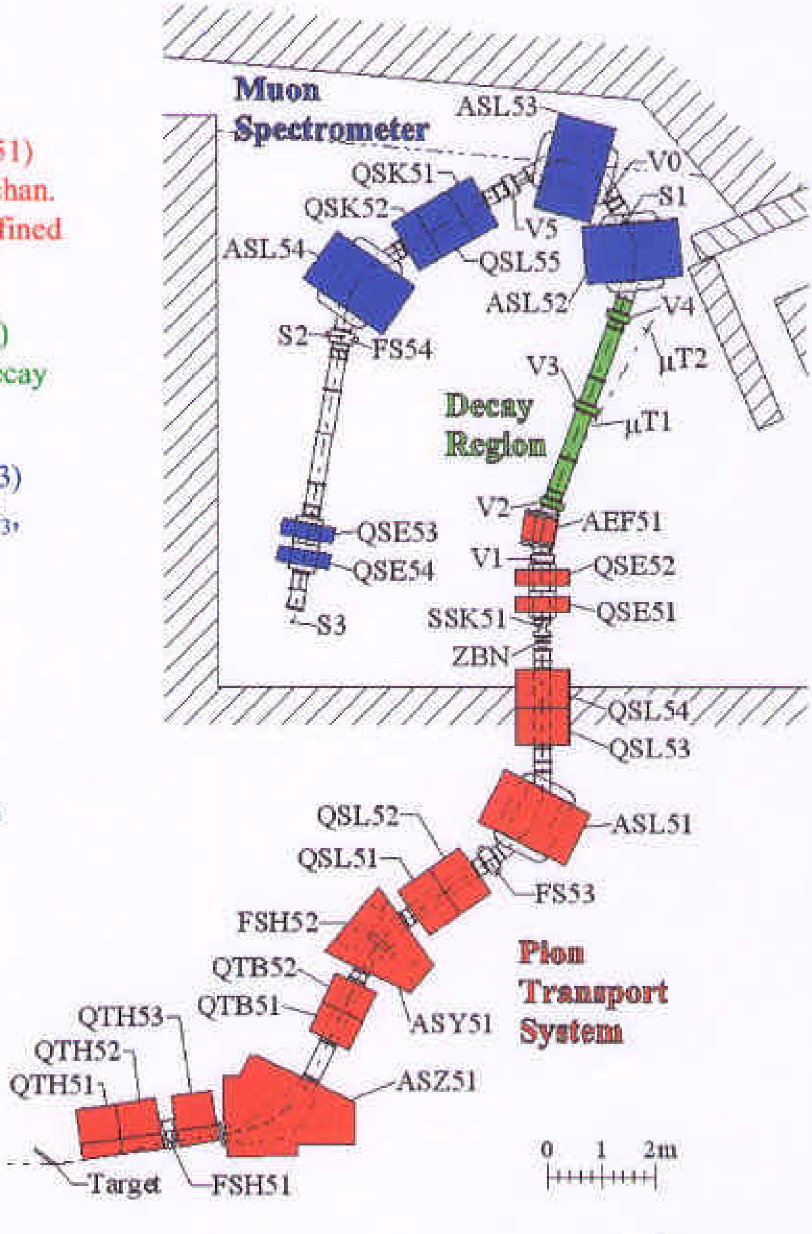
Chronology:
- **1997 - Test run to study Background**
- **1998 - Optimization of setup**
- **1999 - FULL Experiment**

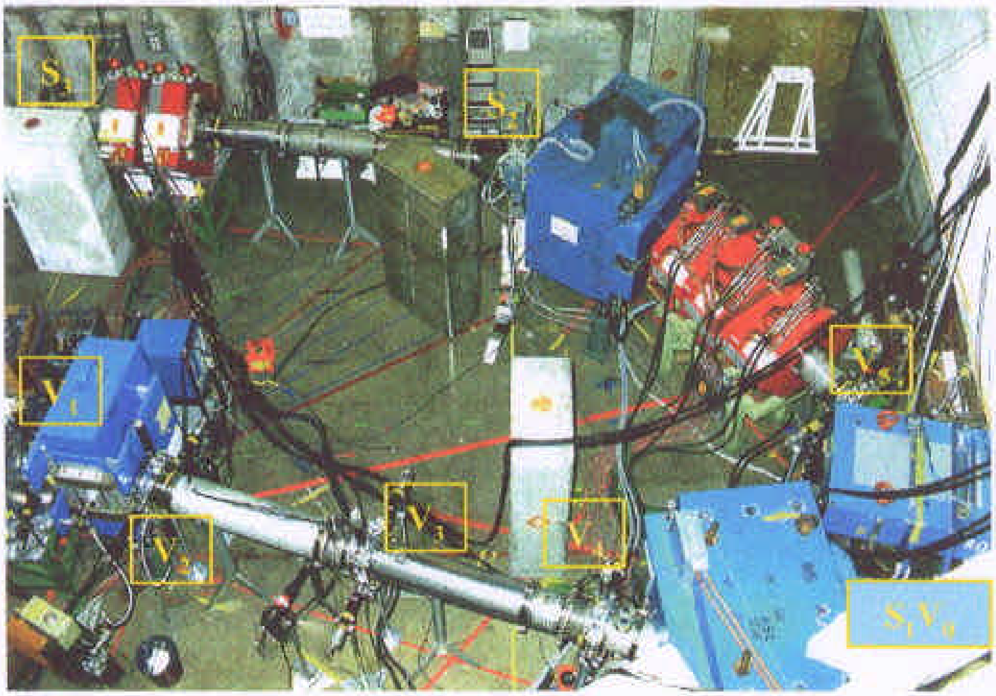
- **Study Decay-in-flight $\pi \to \mu X$** at 150 MeV/c (good particle ID)
- **Backgrounds:** $\pi \to e\nu$, $\pi \to \mu\nu$, $\pi \to \mu\nu\gamma$, scattered particles

Experimental Setup (3-parts:)

- **π-Transport System** (TgE- AEF51)
  50MHz beam, extraction 8°, Quad-chan.
  P_π= 150 MeV/c, $\Delta P_\pi / P_\pi$= 1.2% defined FSH52, beam (14x14)mm^2 at ZBN
- **π-Decay Region** (AEF51 - ASL52)
  4.5m long, B-field free, 42% π's-decay at 1.5mA~ 10^7 decays s^{-1}
- **Muon Spectrometer** (ASL52 - S3)
  phase-space defined by counters S_1-S_3, V_0, V_5, $\Delta P_\pi / P_\pi$= 2.3%
- **Active Veto-counter**
  for scattered & decay particles
  22- Scint. counters + $9X_0$ Pb
- **Monitors** (normalization)
  μ-Telescope 2 plastic counters at 10°
  monitor μ's from π-decay
  Proton- monitor in p-beam







Experimental Method:

- **Whole beam-line tuned to 150 MeV/c π's**
  - setup electronic timing & counter threshold
- **Trigger $S_1 \cdot S_2 \cdot S_3$ & S_1-Only**
- **Decay μ-Scans:**

  Search for $\pi \rightarrow \mu X$
  Pion-part set to 150 MeV/c
  Muon-part scan (103-124) MeV/c steps 0.5 MeV/c
  expect SIGNAL $\pi \rightarrow \mu X$ at ($P_\mu = 0.757 \cdot P_\pi$) (i.e. 113.5 MeV/c
  $\pi \rightarrow \mu X$ $\theta_{\pi\mu} \approx$ 5mrad, $\pi \rightarrow \mu\nu$ $\theta_{\pi\mu} \approx$ 255mrad

- **Pion & Muon Scans: (measured at Reduced Intensity 150μA)**

  Determine peak-shape & -position of μ's from $\pi \rightarrow \mu X$ &
  π- Normalization and spectrometer acceptances
  Pion Scan: Pion-part 150 MeV/c, Muon-part (146-154) MeV/c
  Muon Scan: Pion-part 113.5 MeV/c, Muon-part (110-117) MeV/c

- **Forward Decay (c.m.) $\pi \rightarrow e\nu$ & $\pi \rightarrow \mu\nu$ Scans:**

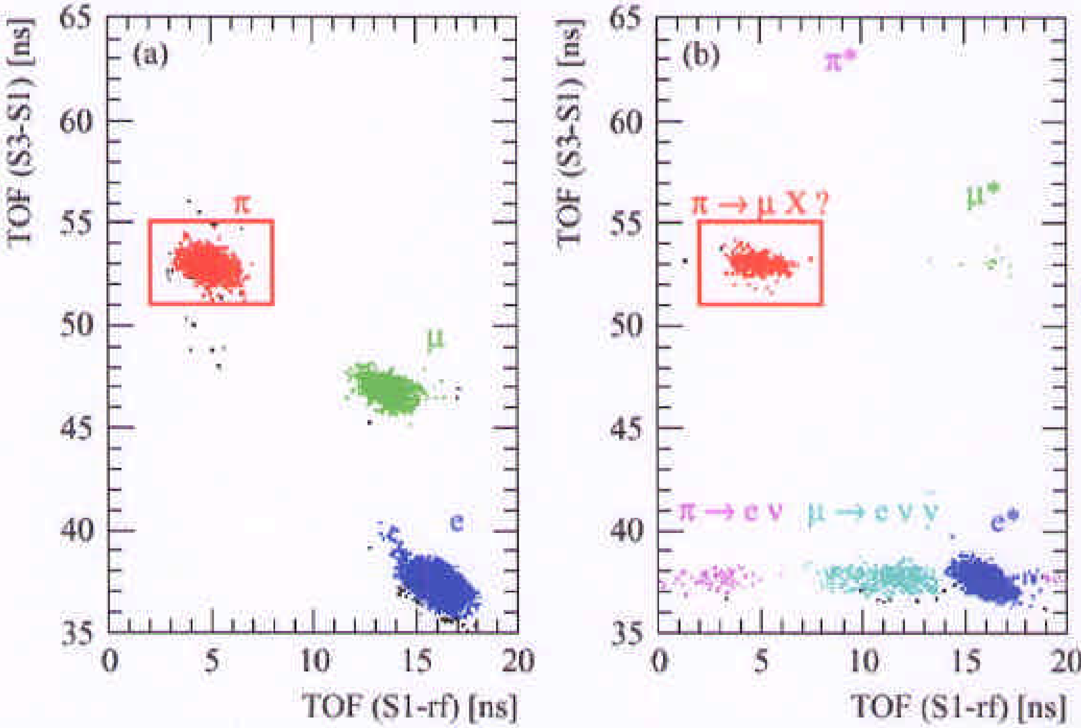
  used for spectrometer acceptance calibration purposes of Monte Carlo

Data-Taking Decay Muon Scans:

- Automated computer-controlled procedure
  changes Magnets & slits in reproducible way for 43 momentum values of a scan
- Event-by-Event data-taking
  Pulse-height, Timing and Scaler data recorded for 3 trigger-, 22 veto- & 5 monitor-counters

Event Selection:

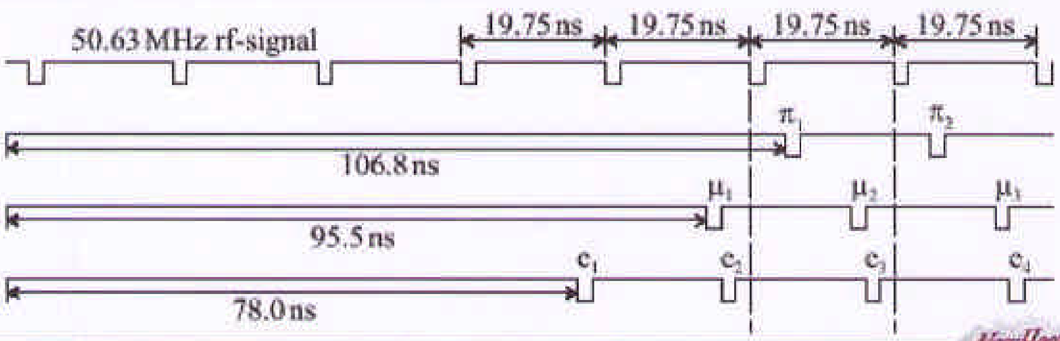
- **Predominantly TOF & veto-cuts:**



Raw timing plots

(a) Pion Run
P_π = 150 MeV/c P_{spect} = 150 MeV/c
1 μC protons I_p = 150 μA
2408 events ($3.6 \cdot 10^4$ events/sec)

(b) Decay Muon Runs
P_π = 150 MeV/c P_{spect} = 113.5 MeV/c
20 C protons I_p = 1500 μA
787 events (0.06 events/sec)



Data Selection & Analysis:

- **Data grouped in 4 data sets -** according to changes made to spectrometer acceptance
- **Each Scan** (43runs) **analyzed separately**
- **Appropriate decay-μ timing cuts applied to each run (p_{spec})** - [2D] timing boxes for various counter combinations
- **[2D] Veto-cuts applied**
- **Events normalized to $N\pi_{decays}$ in Decay Region via measured $N\mu_{telescope}$**

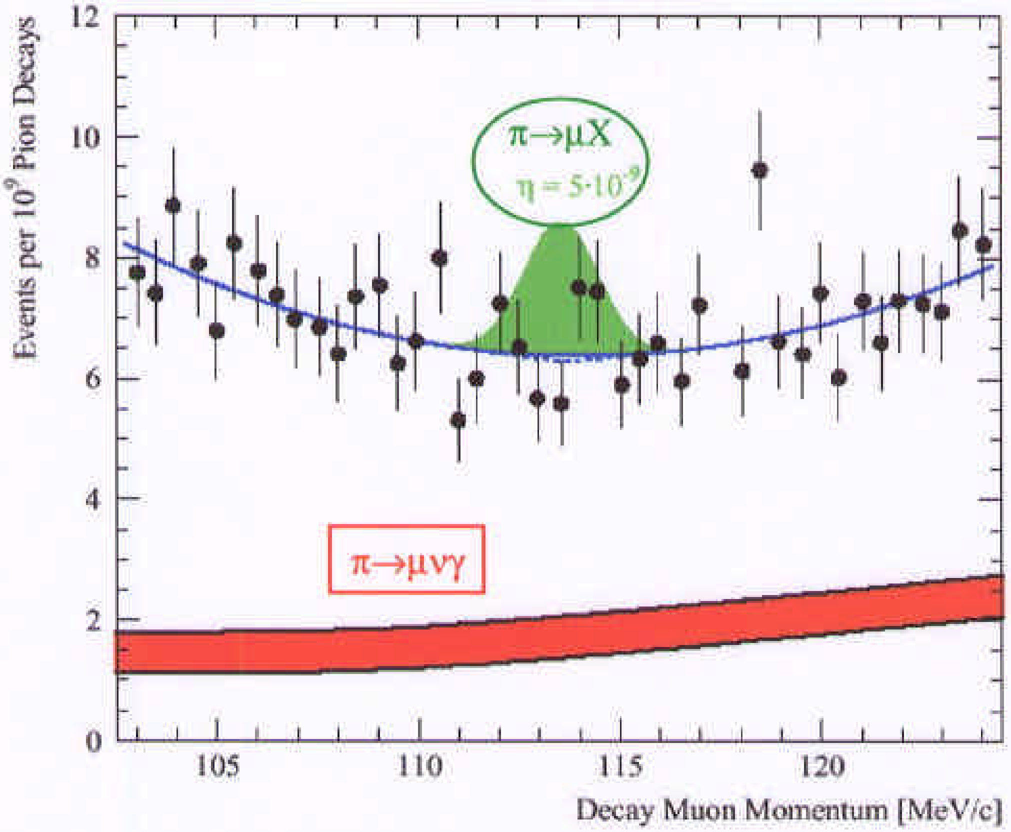
Fitting procedure

From Monte Carlo, π-scan & μ-scan data:

- Signal form $\pi\to\mu X$ well described by ➔ GAUSSIAN
- Background (determined outside signal region) best described by ➔ HYPERBOLA (5dof)

(background minimum≈ peak of signal, since $\Delta\theta_{\pi\mu}$ for signal & background MAXIMAL!)

Typical Scan: Scan 103- Gaussian signal + hyperbolic background

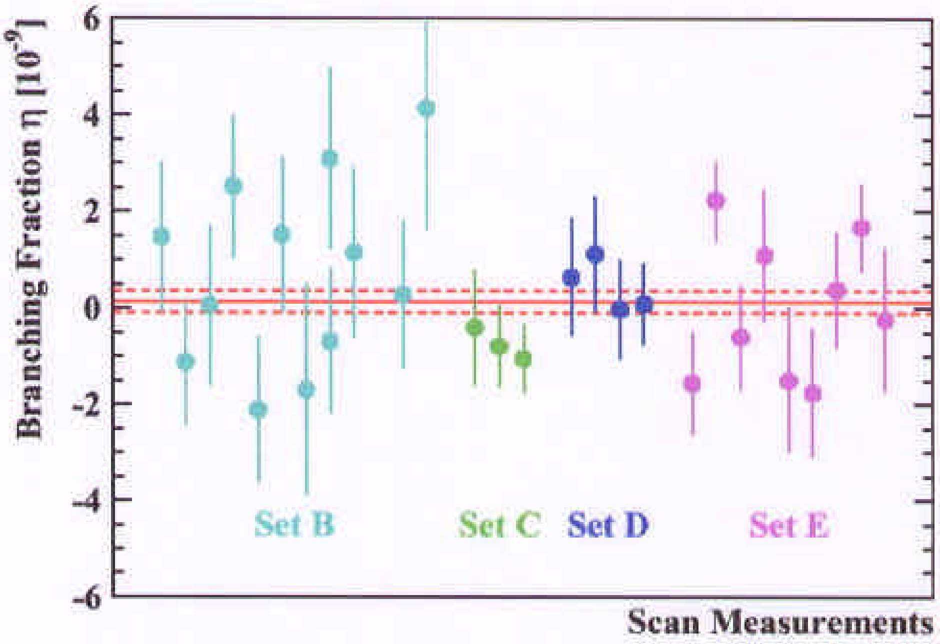


χ^2= 33.6
37 Dof

Final Results:

Fit to 28 Scans ➔

$$\eta = \frac{\Gamma\left(\pi^+ \to \mu^+ X\right)}{\Gamma\left(\pi^+ \to \mu^+ \nu_\mu\right)}$$



Weighted mean of 28 scans

➔ $\eta = (1.27 \pm 2.27)\cdot 10^{-10}$

Systematic Uncertainty- in overall **Normalization & Spectrometer Acceptances** estimated at ➔ 5%

Conservative Approach ➔ $1.05\cdot(\eta \pm \Delta\eta)$

No Evidence for $\pi^+ \to \mu^+ X$
B.R. $\eta = (1.3 \pm 2.4)\cdot 10^{-10}$

Derive upper Limit using 'Frequentist's approach'
[G.J. Feldman and R.D. Cousins Phys. Rev. D57, 3873 (1998)]

B.R. $\eta \le 6.0 \cdot 10^{-10}$
(95% C.L.)

'Bayesian approach' ➔ $\eta \le 5.6\cdot 10^{-10}$ **(95% C.L.)**

Conclusions:

• Have > Our **Experimental Sensitivity** ➔ **Factor 100**

• & < **B.R.** by ➔ **Factor 45**

compared to our previous measurement

M. Daum et al. Phys. Lett. B 361 (1995) 179 **B.R. ($\pi \rightarrow \mu X$) < $2.6 \cdot 10^{-8}$ 95% C.L.**

• **See NO SIGN of $\pi \rightarrow \mu X$**

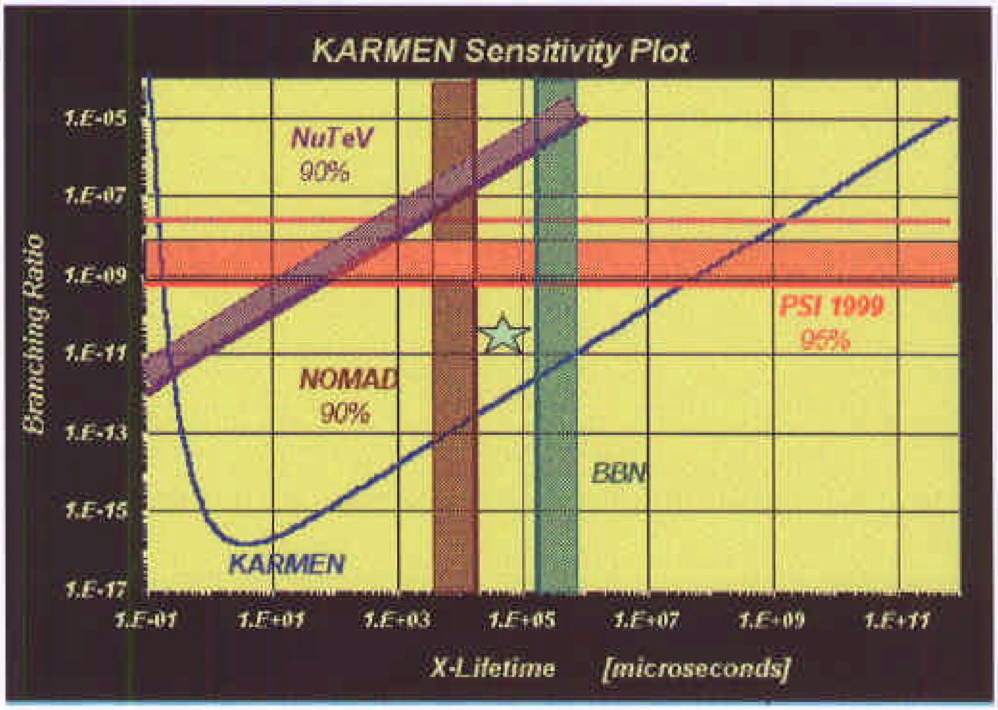
• **Result Rules-out SUSY (R-parity viol.) 2-body Decay Mode X(photino)$\rightarrow \nu_\mu \gamma$**

D. Choudary, S. Sarkar: Phys. Lett. B 374 (1996) 87-92

But NOT 3-body $e^+e^-\nu_{\mu,\tau}$

D. Choudary et al. hep/9911365 (Feb. 2000)

Results ➔ in print PRL



➔ KARMEN report ν2000: full KARMEN2 data Feb97- march2000

No Effect anymore !!!