PIBETA: a new experimental strategy toward V_{ud}

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for the PIBETA Collaboration

- motivation
- design and experimental method
- preliminary results
- further plans

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The PIBETA Experiment: MOTIVATION

Provide precision tests of Standard Model and QCD predictions:

- $\pi^+ \to \pi^0 e^+ \nu_e$ – main goal
  - SM tests from CKM unitarity

- $\pi^+ \to e^+ \nu_e \gamma(ee)$
  - F_A/F_V, π polarizability (χPT prediction)
  - tensor coupling besides $V-A$

- $\mu^+ \to e^+ \nu_e \bar{\nu}_\mu \gamma(ee)$
  - departures from $V-A$ in $\mathcal{L}_{\text{weak}}$

- $\pi^+ \to e^+ \nu_e$ – 2nd phase
  - e-μ universality
  - pseudoscalar coupling besides $V-A$
  - massive neutrino, Majoran, ...

STATUS OF CKM UNITARITY

$|V_{us}| \simeq 0.2196 \pm 0.0025$ from K_{e3} decays.

$|V_{ub}| \simeq 0.0033 \pm 0.0008$ from B decays.

(a) Superallowed Fermi nuclear β decays

1990 Hardy reconciled discrepancies between Ormand & Brown and Towner et al. ft values:

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9962 \pm 0.0016,$$

or $1 - 2.4\sigma$.

(b) Neutron β decay

$$\sum_{i=1}^{3} |V_{ui}|^2 = 1.0096 \pm 0.0044, \text{ or } 1 + 2.3\sigma,$$

[after Erozolimskiĭ et al. (1990)]

$$\sum_{i=1}^{3} |V_{ui}|^2 = 0.9917 \pm 0.0028, \text{ or } 1 - 3.0\sigma.$$

[after PERKEO II, Nov. 2001]

(a) optimistic?

Are the quoted uncertainties optimistic?

cf. Marciano and Sirlin, Phys. Rev. Lett. **56** (1986) 22.

M& S on the radiative corrections in Fermi beta decay, and associated uncertainties:

> "...Structure dependent term arising from the axial-vector current ... [estimated using two independent methods]:
>
> $$\frac{\alpha}{2\pi}\left(\ln\frac{m_p}{m_A}+2C\right)=0.0012\pm0.0018\ .''$$

To date this is the most reliable lower limit to the theoretical uncertainty.

New calculation of pion beta decay radiative corrections in the light-front quark model

W. Jaus, Phys. Rev. D **63** (2001) 053009.

Applied light-front quark model to the pion to determine structure-dependent axial-current radiative corrections.

Total RC for pion beta decay:

$$\delta = (3.230 \pm 0.002) \times 10^{-2} \ .$$

Using nuclear β decay data as input Jaus finds:

$$V^2 = 0.9956 \pm 0.0011 \ ,$$

i.e., about 4σ violation of unitarity.

PION BETA DECAY:

$\pi^{\pm} \to \pi^0 e^{\pm} \nu$ BR $\simeq 1 \times 10^{-8}$

Pure vector transition: $0^- \to 0^-$

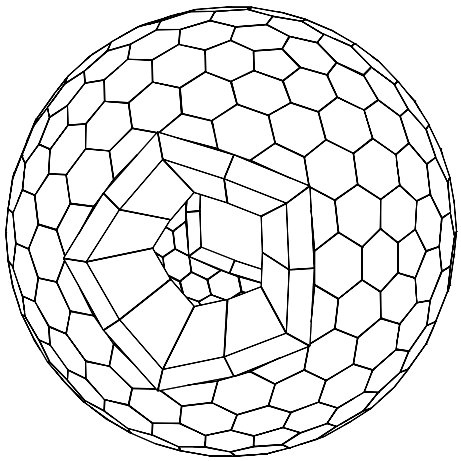
Theoretical rate: $\dfrac{1}{\tau_{\pi\beta}} = 0.3996 \pm 0.0006\,\mathrm{s}^{-1}$

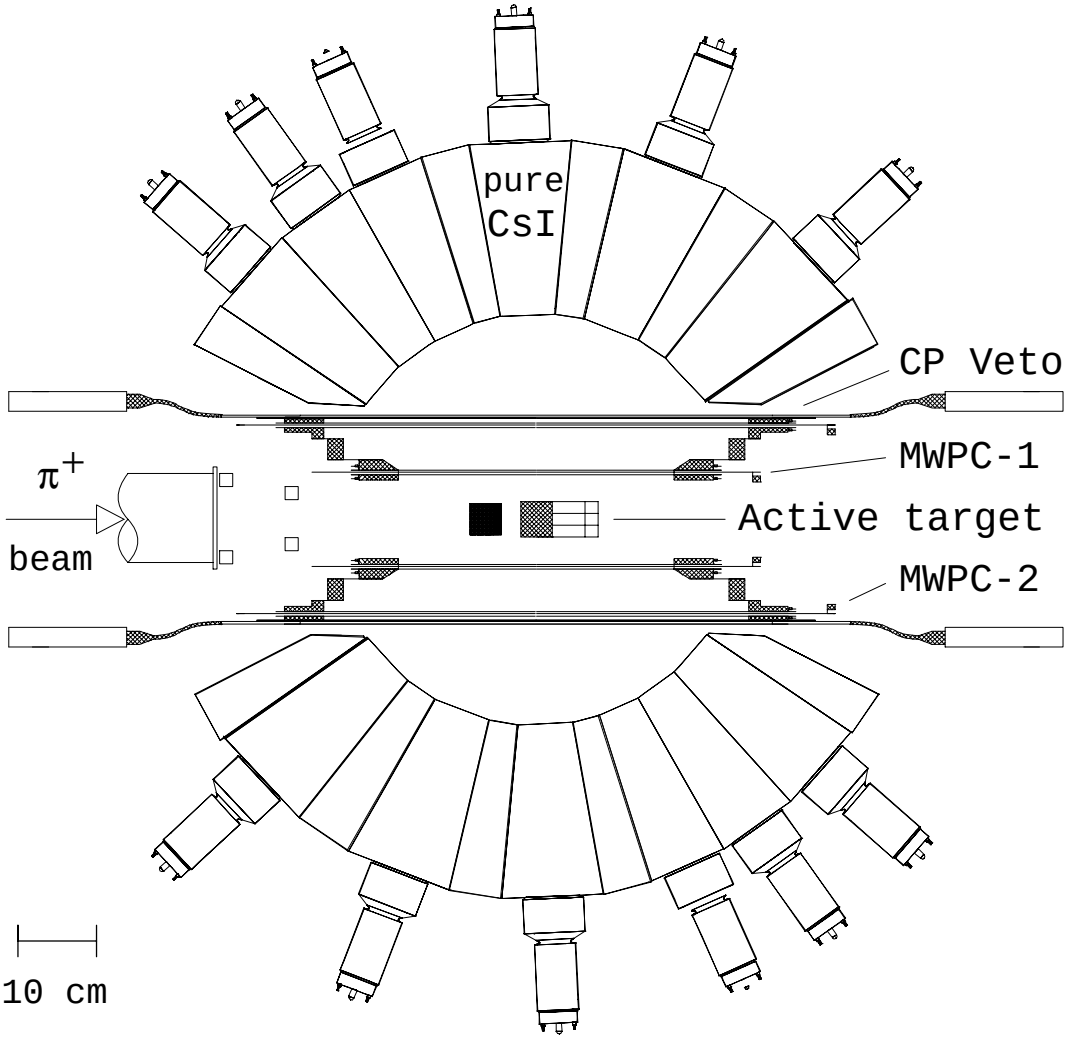
Accuracy	Constraints on
4 %	Present result
≤ 1 %	CVC and radiative corrections
~ 0.5 %	SAF vs. n β decay V_{ud}
< 0.3 %	New check of CKM unitarity: • 4^{th} generation coupling • $m_{Z'}$ • Λ of compositeness • SUSY viol. of q-l universality

DESIGN OF THE EXPERIMENT

PIBETA experiment:

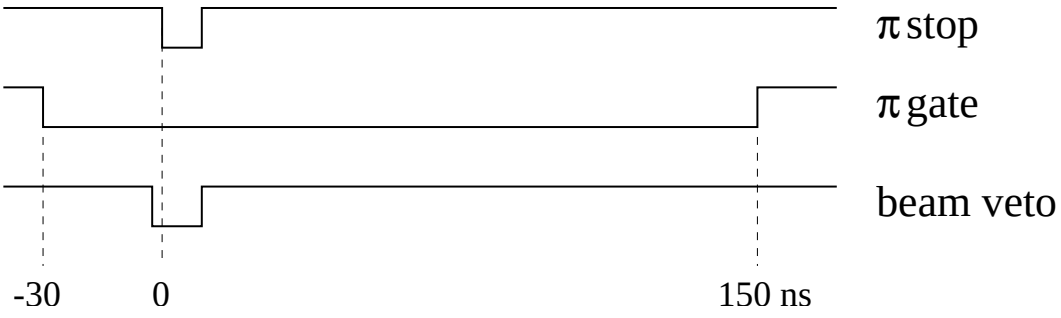
- stopped π^+ beam
- segmented active tgt.
- 240-elem. CsI(p) calo.
- central tracking
- digitized PMT readout
- cosmic μ antihouse
- stable temp./humidity





EXPERIMENTAL METHOD: SUMMARY

- Detect π^+ decays <u>at rest</u> (during a delayed 180 ns gate).



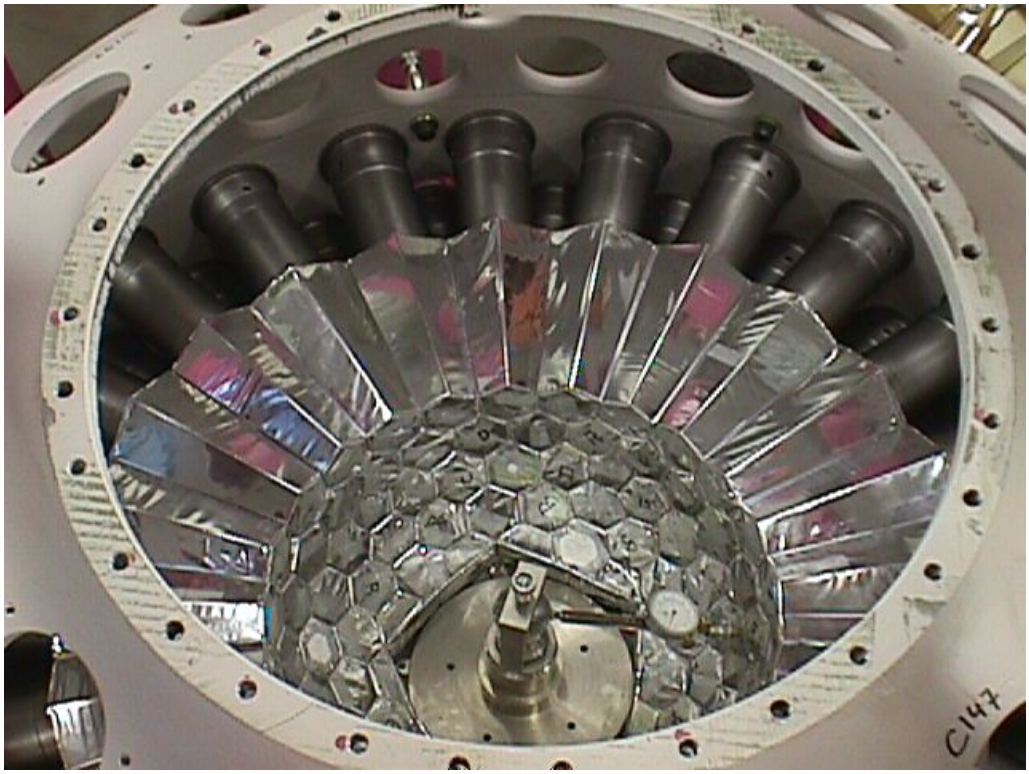
- Use $\pi^+ \to e^+\nu$ prescaled for normalization.

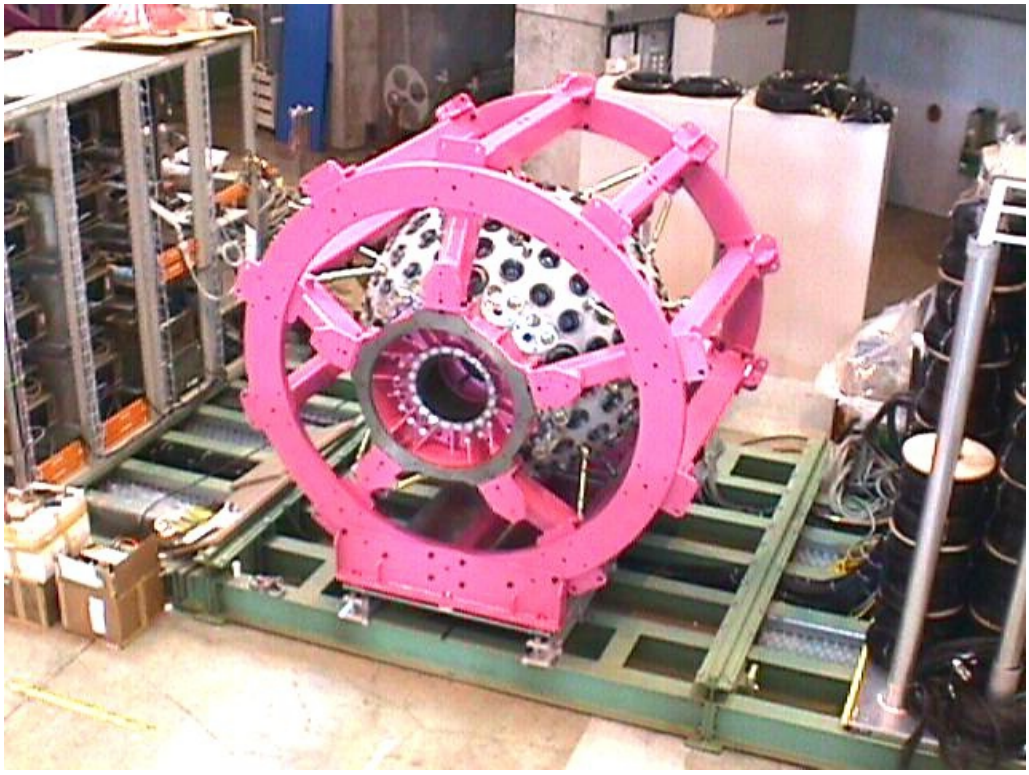
- Accept every $\pi\beta$ trigger – unbiased ($\gamma\gamma$ coincidences above Michel endpoint)

$$\frac{1}{\tau_{\pi\beta}} = \frac{1}{\tau_{\pi^+}} \cdot \frac{BR_{e\nu} f_{\text{presc}}}{BR_{\pi^0 \to \gamma\gamma}} \cdot \frac{A_{e\nu}}{A_{\pi\beta}} \cdot \frac{N_{\pi\beta}}{N_{e\nu}}$$

$A_{\pi\beta}$, $A_{e\nu}$ are acceptances for the decay modes, respectively.

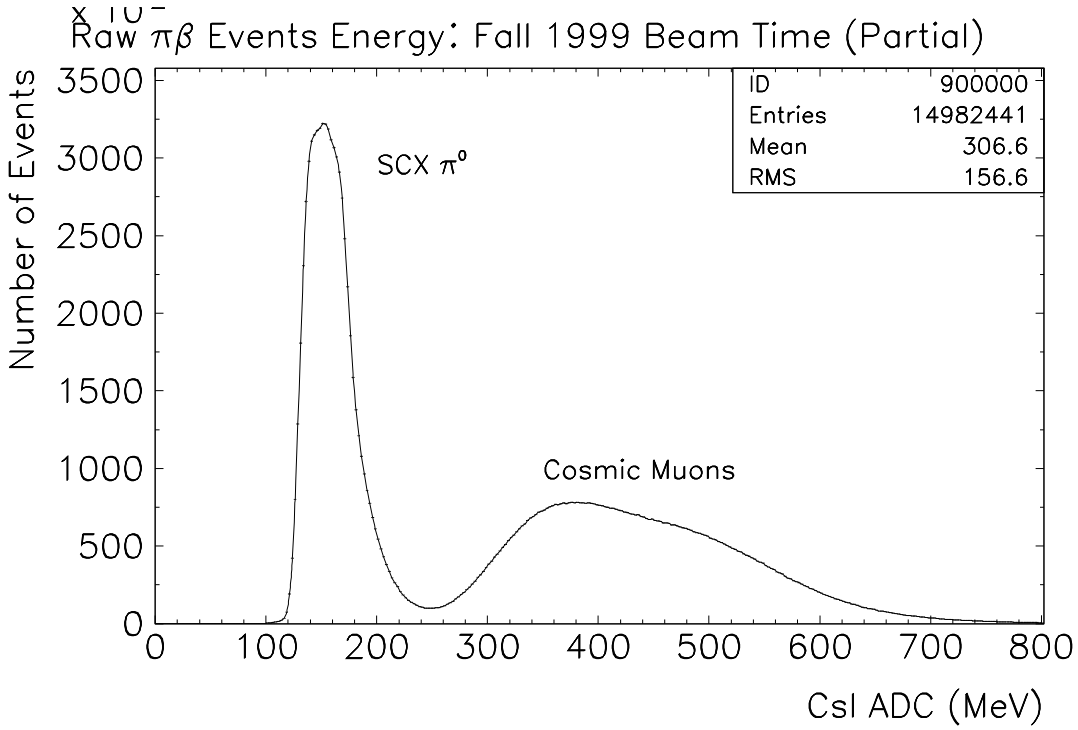
PIBETA Detector Assembly (1998)





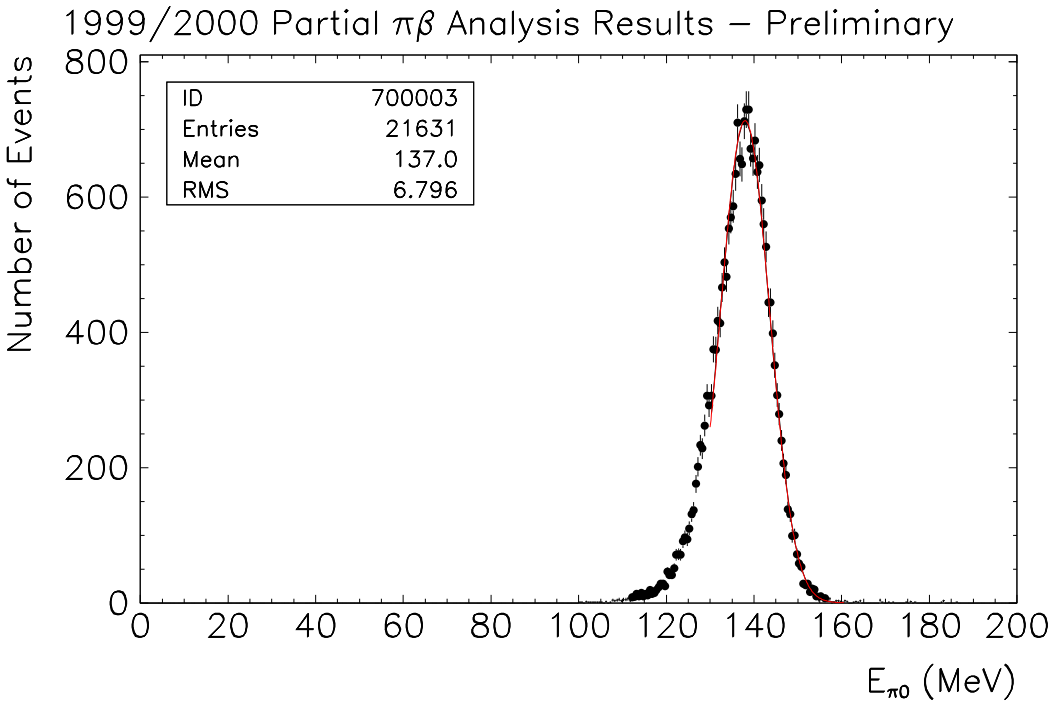
DETECTOR PERFORMANCE

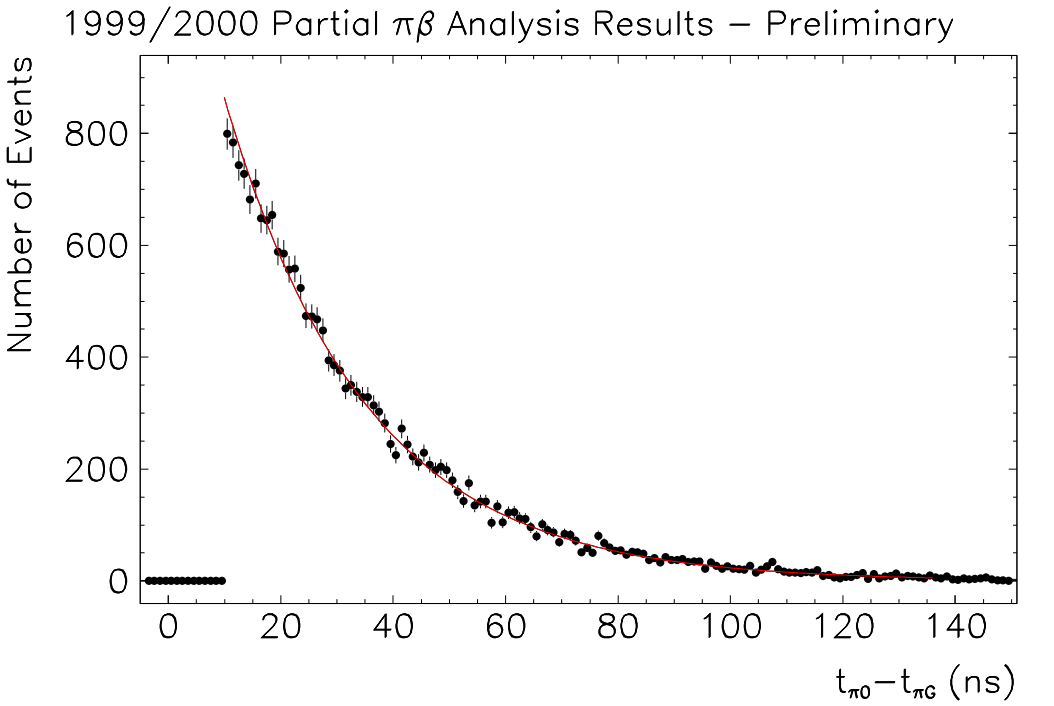
Online "$\pi\beta$" Energy Spectrum:



True $\pi\beta$ events buried deep under overwhelming background!

1999/2000 RESULTS: $\pi^+ \to \pi^0 e^+ \nu$





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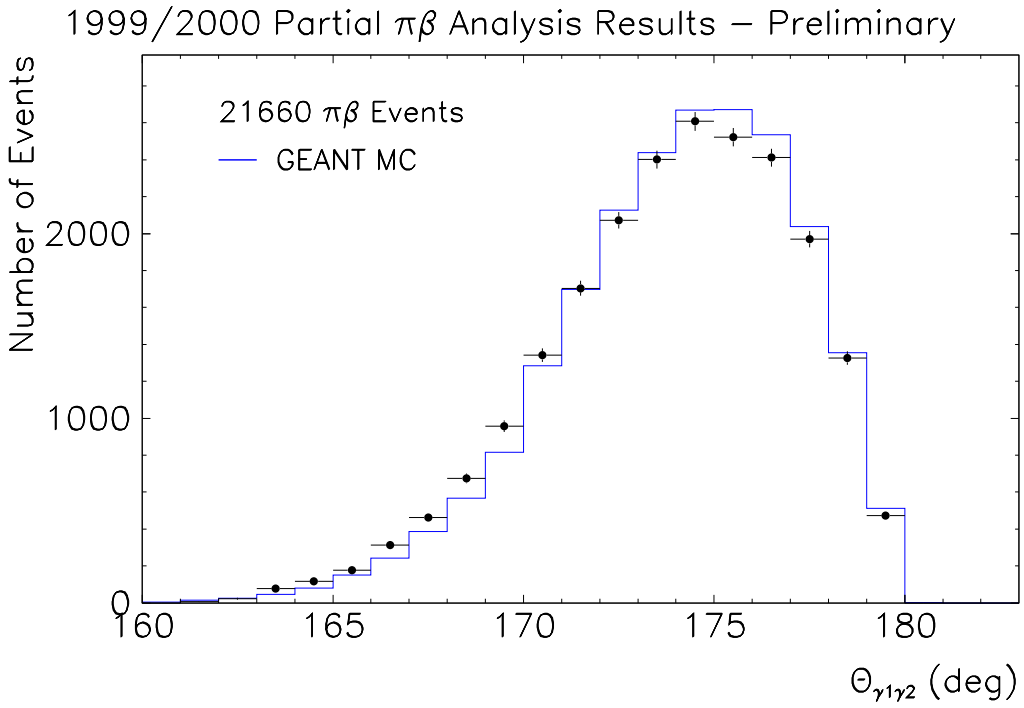

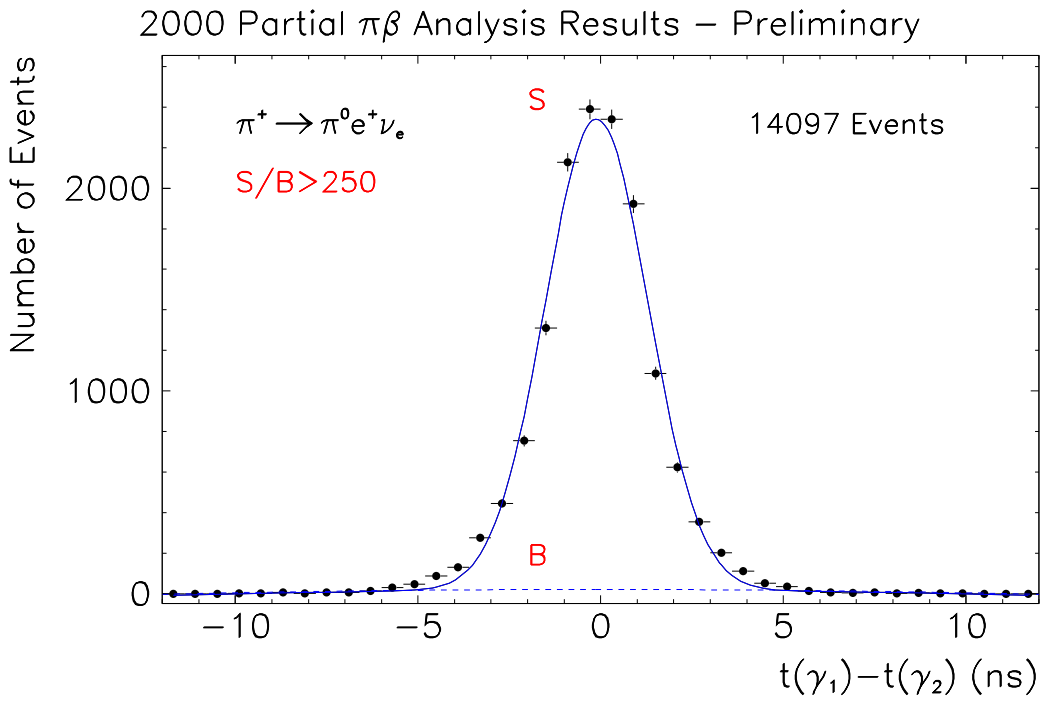

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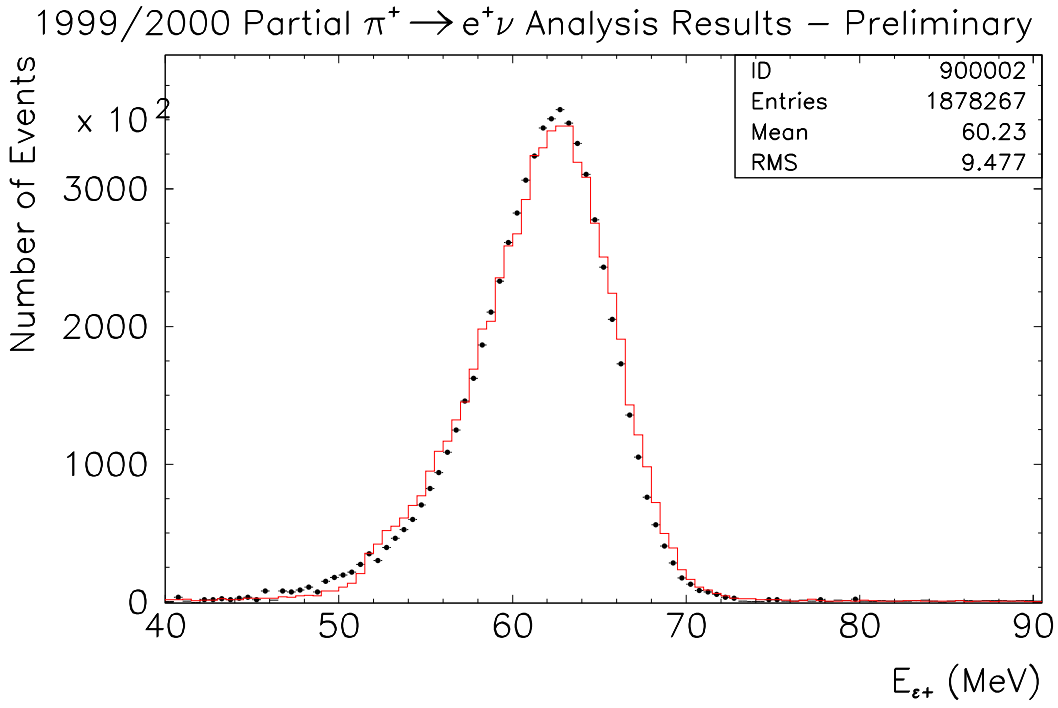

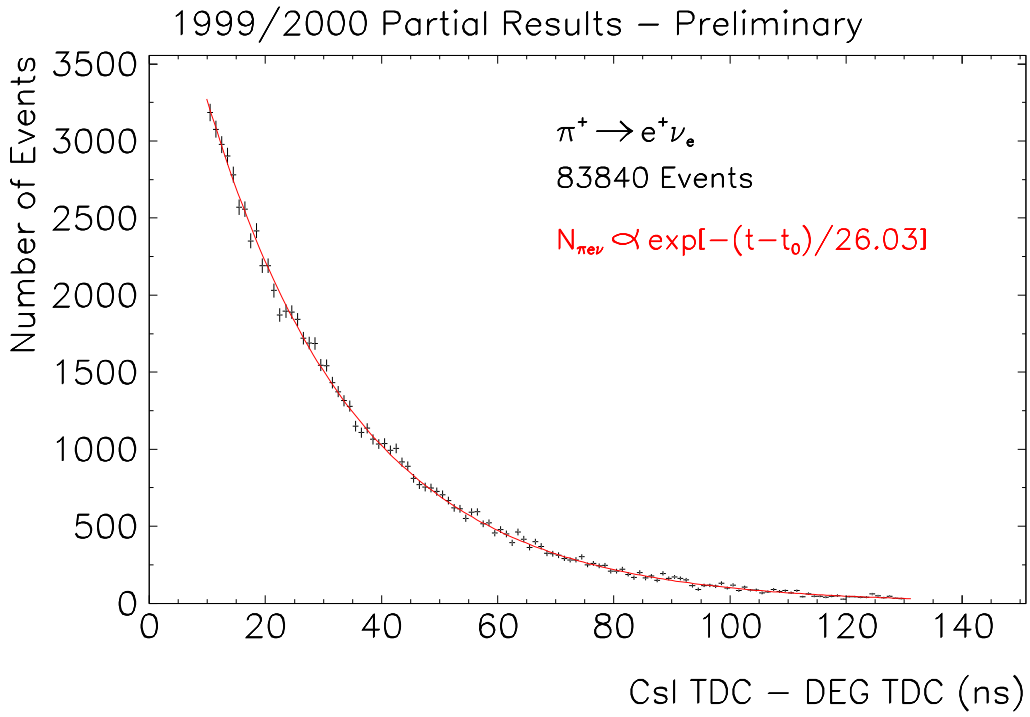

EXPERIMENT SYSTEMATICS

Main sources of uncertainty:

- Acceptance: beam geometry
- Timing: pion decay fraction
- External: BR($\pi \rightarrow e\nu$)

Branching Ratio for $\pi\beta$ Decay

Our Preliminary Interim Result:

$$BR \simeq 1.044 \pm 0.007 \text{ (stat.)} \pm 0.015 \text{ (syst.)} \times 10^{-8}$$

McFarlane et al. (Phys. Rev. D 1984):

$$BR \simeq 1.026 \pm 0.039 \times 10^{-8}$$

SM Prediction (PDG, 2000):

$$BR = 1.038 - 1.041 \times 10^{-8} \quad \text{(90\% C.L.)}$$

$$(1.005 - 1.008 \times 10^{-8} \quad \text{excl. rad. corr.})$$

CVC + Fermi Nucl. Decays (PDG 2000):

$$BR = 1.037 \pm 0.002 \times 10^{-8}$$

SUMMARY OF UNCERTAINTIES

at end of analysis phase:		current (%)	final (%)
external			
	pion lifetime	0.019	0.019
	$BR(\pi \to e\nu)$	0.33	~ 0.1?
	$BR(\pi^0 \to \gamma\gamma)$	0.032	0.032
internal			
	$A(\pi\beta)/A(e\nu)$	0.35	< 0.2
	$\Delta t(\gamma - e)$	0.03	0.03
	E thresh.	< 0.1	< 0.1
statistical:		0.5	0.33
total:		0.70	~ 0.41

PLANS FOR 2002 AND LATER

- Bring analysis up to the proposed level of uncertainty.

- Prepare new proposal and collaboration for a precise $\pi \to e\nu$ measurement.

http://pibeta.phys.virginia.edu/∼pibeta
http://pibeta.psi.ch/∼pibeta