

# A Precise Measurement of the $\pi^+ \rightarrow \pi^0 e^+ \nu_e$ Decay Rate

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# The standard model of electroweak interactions

Three generations of leptons and quarks

$$\begin{pmatrix} u \\ d \end{pmatrix}; \begin{pmatrix} c \\ s \end{pmatrix}; \begin{pmatrix} t \\ b \end{pmatrix}$$

$$\begin{pmatrix} e \\ \nu_e \end{pmatrix}; \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}; \begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}$$

Mass eigenstates are related to the quark eigenstates via the Cabibbo-Kobayashi-Maskawa (CKM) matrix <sup>1)</sup>

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

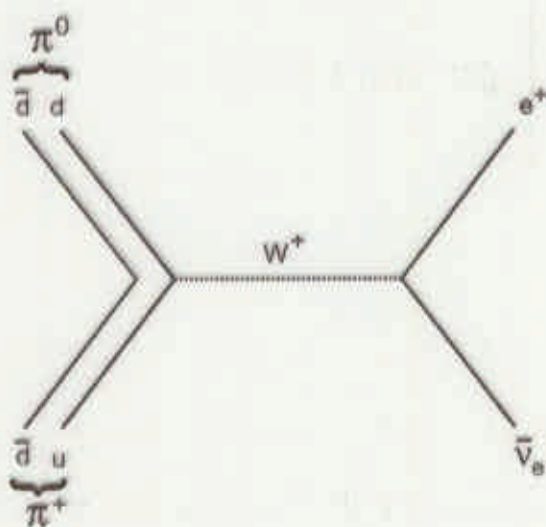
With three generations one can formulate the unitarity test:

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1$$

<sup>1)</sup> M. Kobayashi and T. Maskawa, *Prog. Theor. Phys.* **49**, 652 (1973)

# Measurement of $V_{ud}$

- Super-allowed nuclear Fermi decay
  - Nuclear corrections
  - Final state coulomb interaction
- Neutron Decay
  - mixed vector-axial transition
  - difficult measurement
- Pion-Beta decay
  - Problem: small branching ratio BR



$$BR_{\pi\beta} = \frac{\Gamma(\pi^+ \rightarrow \pi^0 e^+ \nu_e)}{\Gamma(\pi^+ \rightarrow \mu^+ \nu_\mu)} \approx 10^{-8}$$

$$V_{ud}^2 = \frac{K}{G_\mu^2 f (1 + \delta) \frac{t_\pi}{BR}}$$

$$f = \frac{1}{30} \left( \frac{m_{\pi^+} - m_{\pi^0}}{m_e} \right)^5 \times \text{corr.}$$

## Summary of measurements

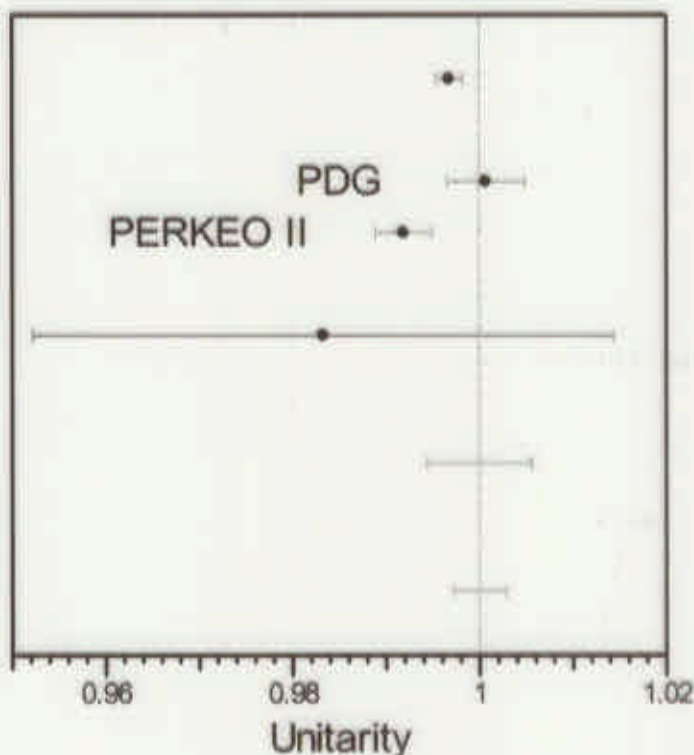
Nuclear Beta Decay ('98)

Neutron Decay ('98)

Pion Beta Decay ('85)

PIBETA 0.5%

PIBETA 0.2%



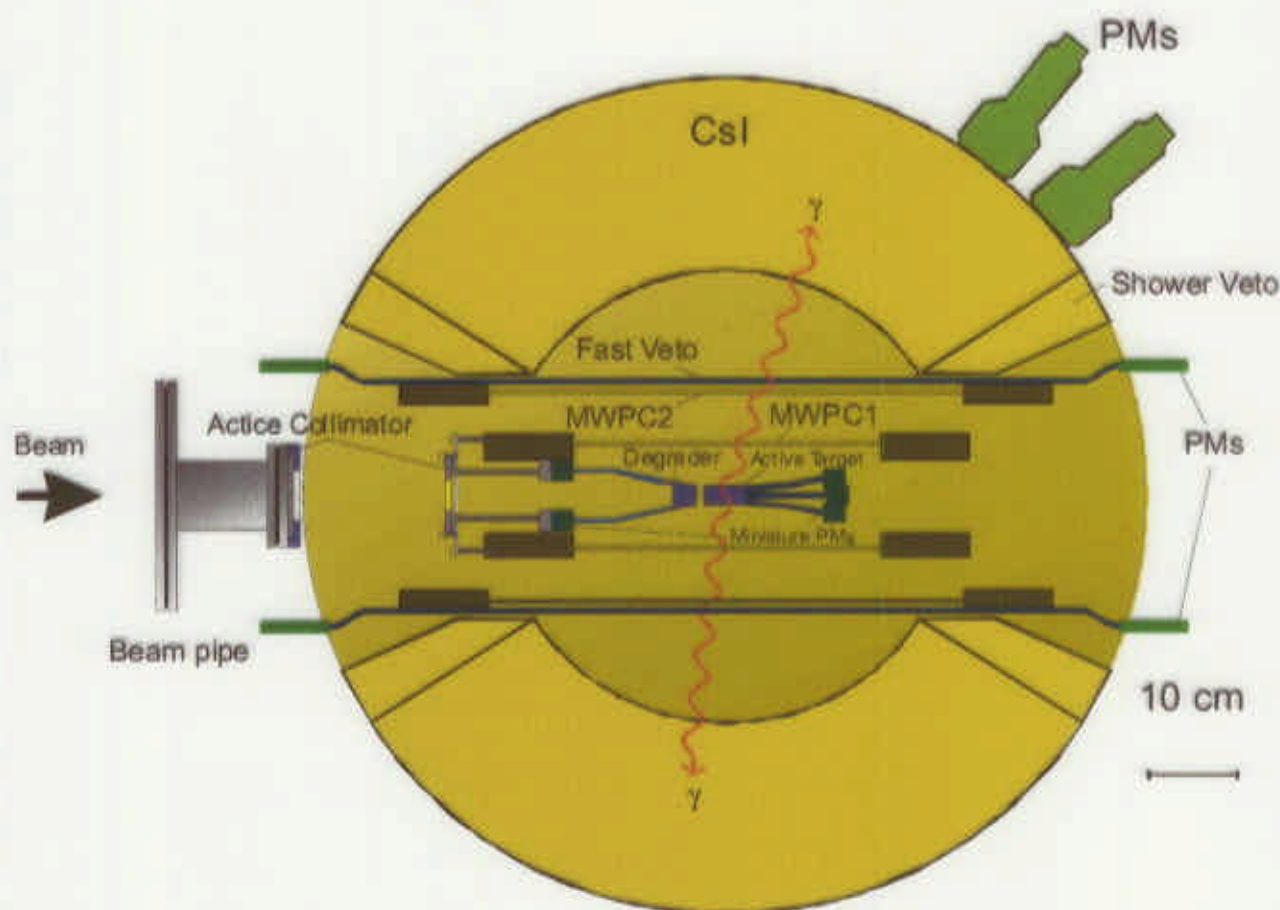
- Test of Standard Model
  - at  $\leq 1\%$ : CVC and radiative corrections
  - at  $\leq 0.5\%$ : nuclear  $\beta$  decay vs. neutron decay
  - at  $\leq 0.3\%$ : CKM unitarity
- Implications of unitarity violation
  - Fourth generation  $0.01 < V_{ub} < 0.08$  at 90%CL<sup>1)</sup>
  - Additional neutral gauge bosons  
 $m_Z > 300 \text{ GeV}^2)$

1) W.J. Marciano and A. Sirlin, *Phys. Rev. Lett.* **56**, 22 (1986)

2) W.J. Marciano and A. Sirlin, *Phys. Rev. D* **35**, 1672 (1987)

# Pion-Beta Detector

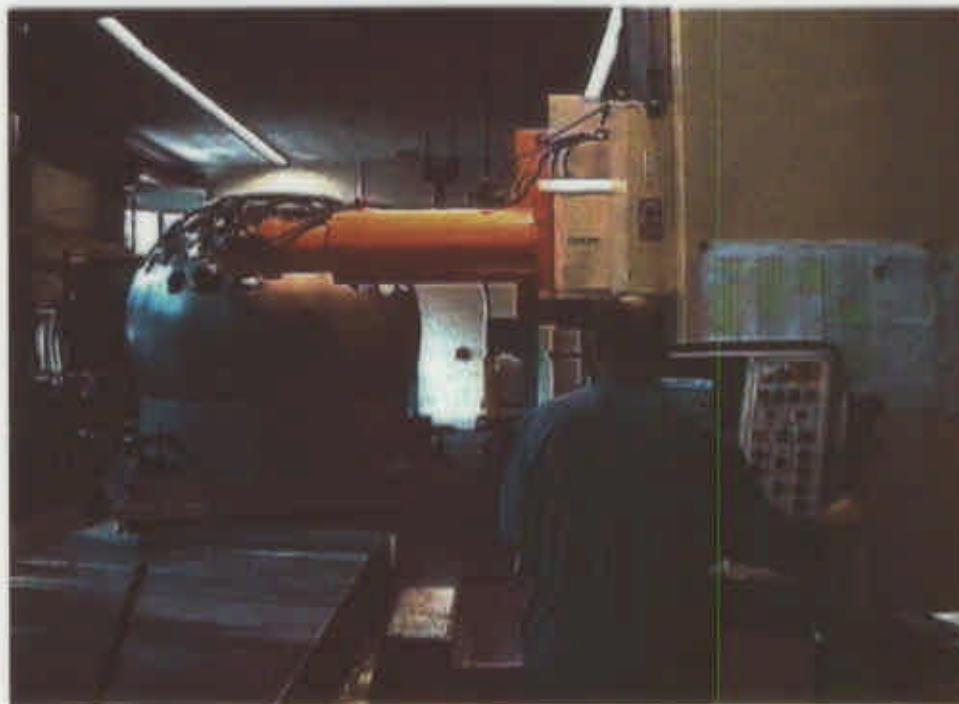
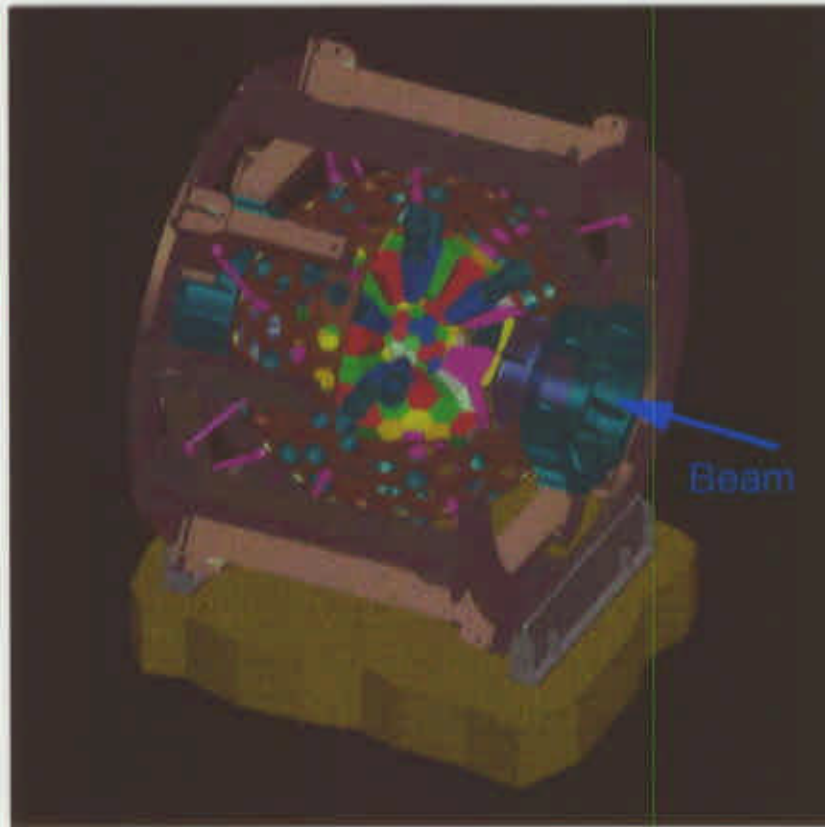
## Cross-section



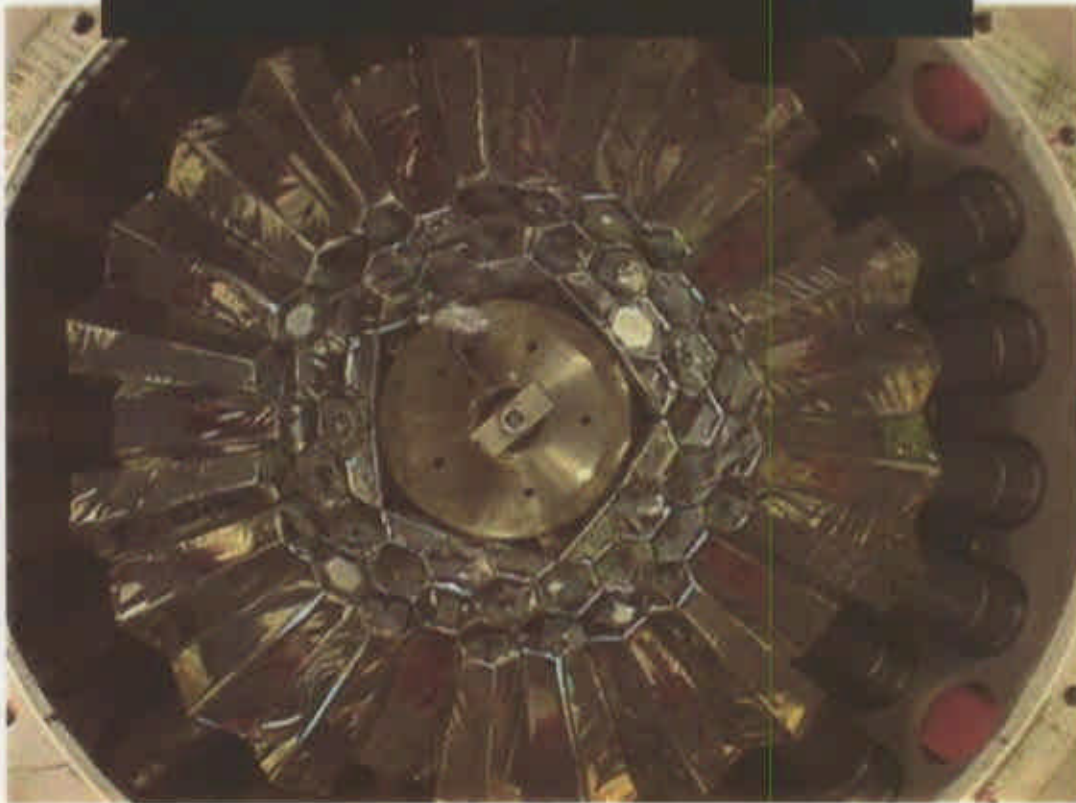
- First phase: 0.5% accuracy
- Stopped pion experiment:  $10^6 \pi/s \rightarrow 1$  y beamtime
- Relative measurement

$$BR_{\pi\beta} = \frac{BR_{\pi e \nu}}{N_{\pi e \nu}} \cdot \frac{N_{\pi\beta}}{BR_{\pi^0 \gamma\gamma}} \times \text{corrections}$$

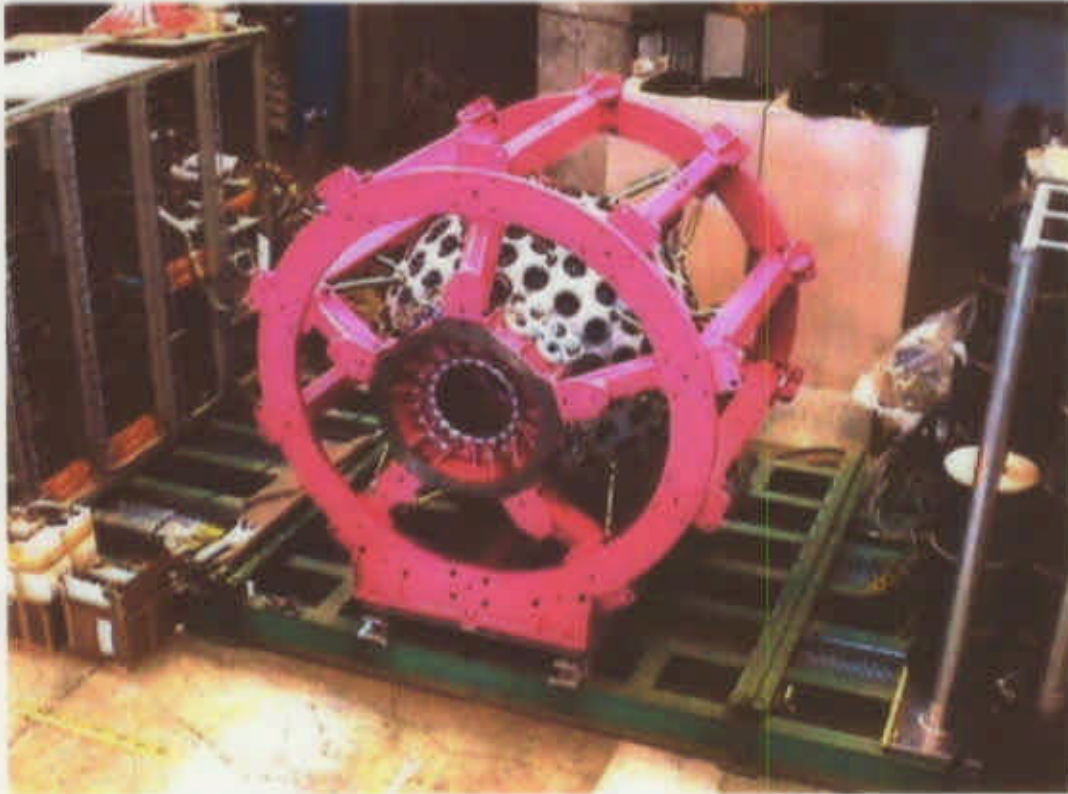
# Pion-Beta Detector



# Pion-Beta Detector

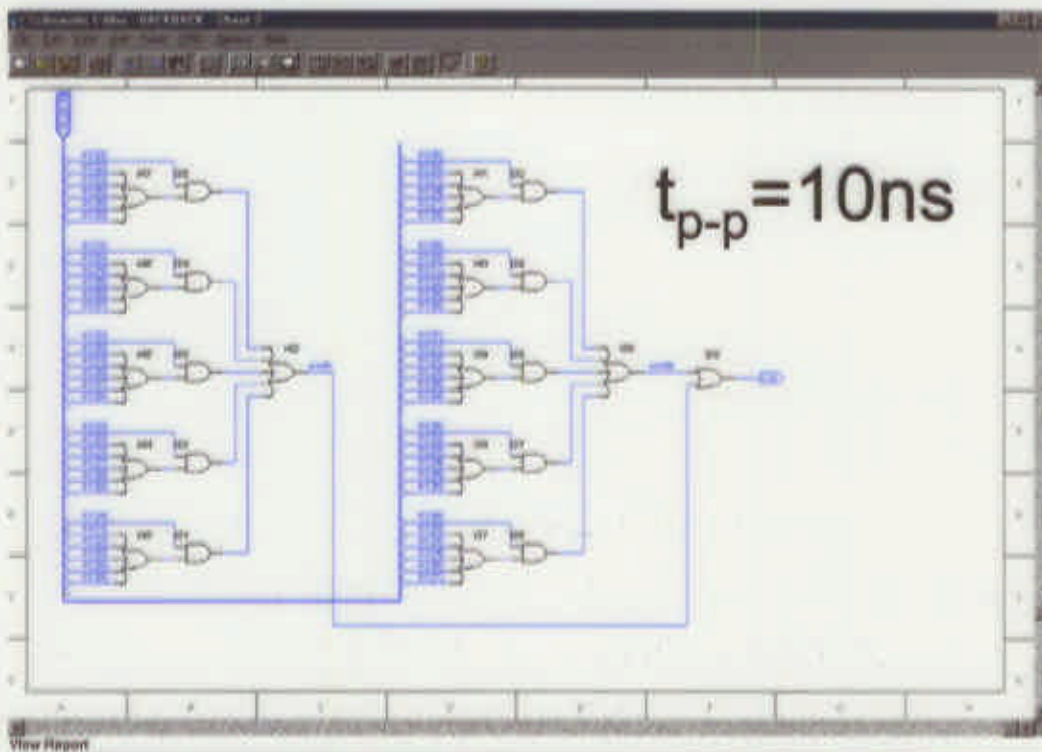
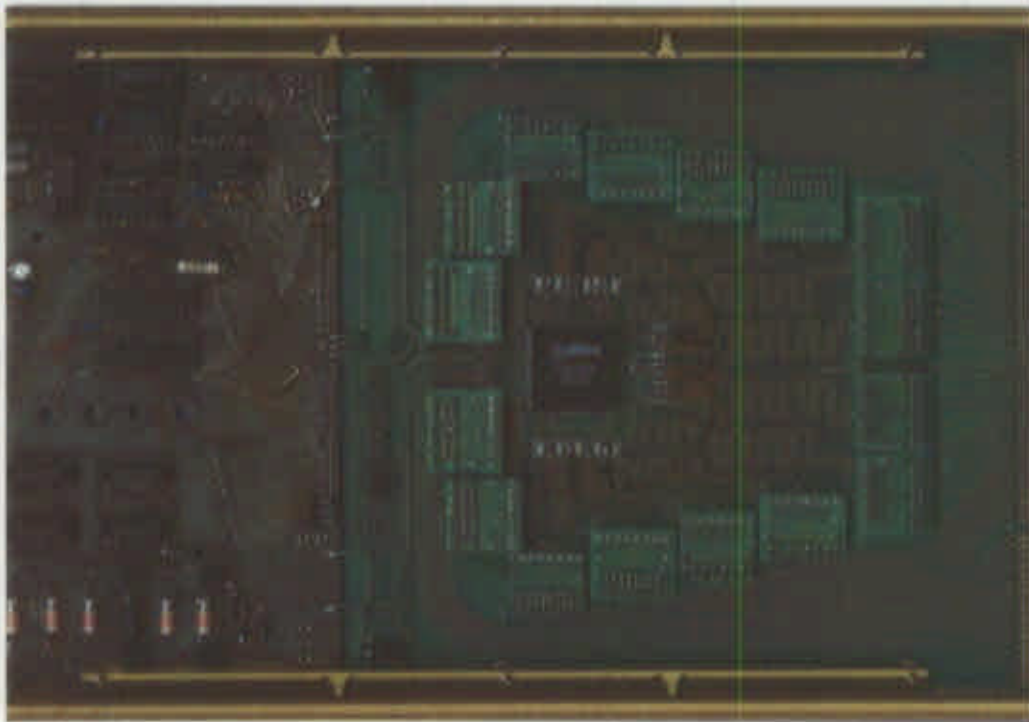


# Pion-Beta Detector

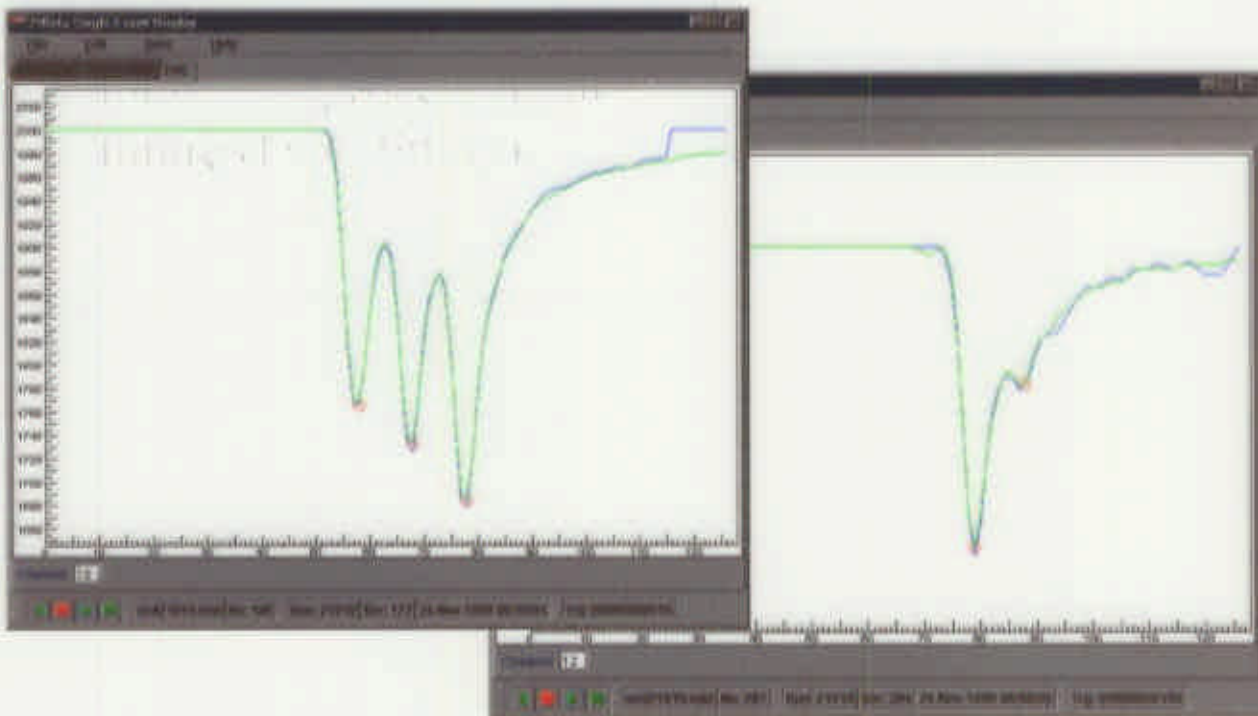
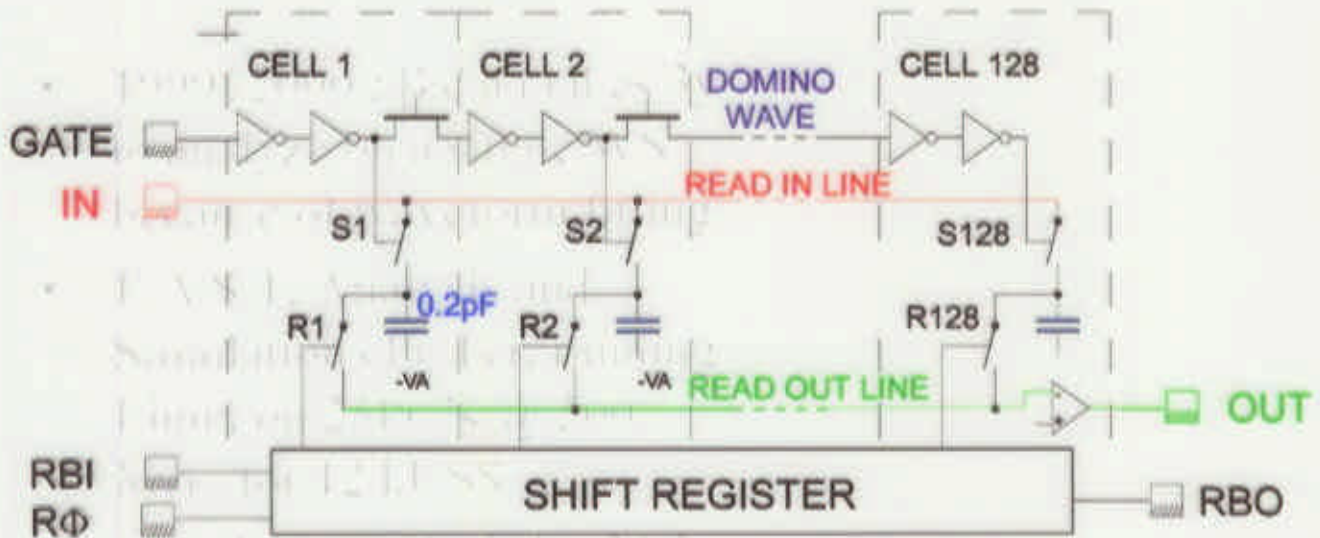




# New logic unit using Lattice FPGA for 1<sup>st</sup> level trigger



# Domino Sampling Chip



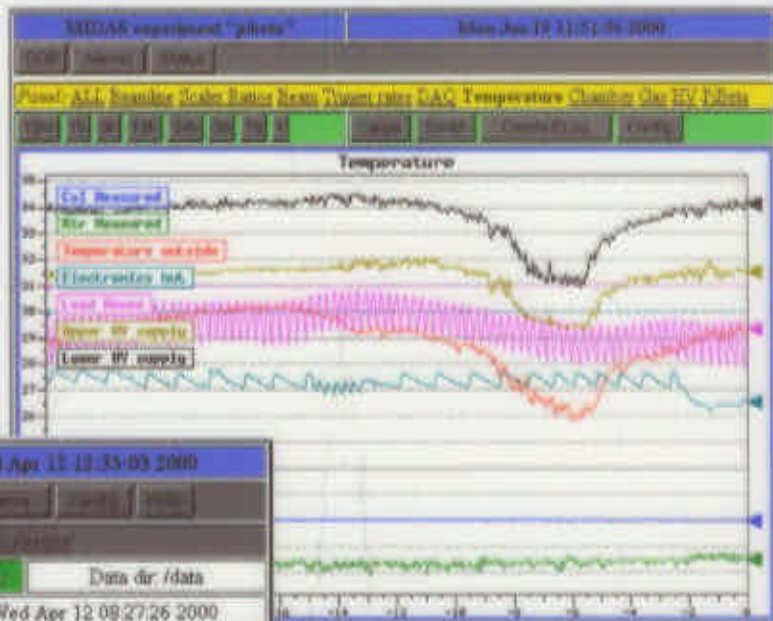
- Sampling speed: 500 – 1200 MHz
- Readout at 5 MHz with conventional ADC
- Readout daisy chaining of 48 DSC's
- Costs: <50 US\$/channel
- Next generation planned: 10GHz, 40MHz

## F.A.S.T. cluster

- 1999+2000  $\pi\beta$  data takes 3y to analyze on a single WS because of waveform fitting
- **F.A.S.T. Analysis and Simulation clusTer**, running Linux on 25PC's @ 500 MHz for 12 kUS\$
- Speeds up analysis by 23.5
- Rack mounting: may be used for online processing in future (DSC fitting)

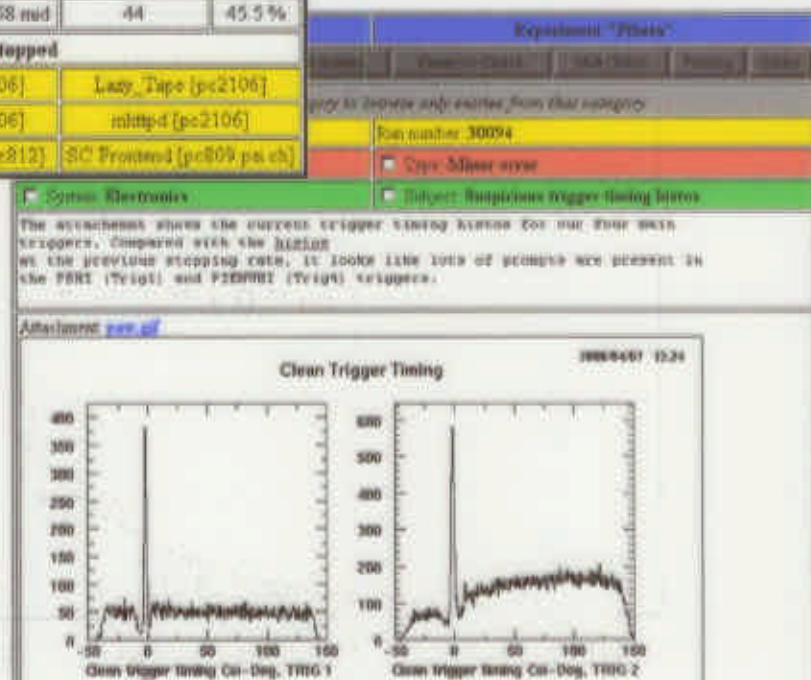


# MIDAS DAQ



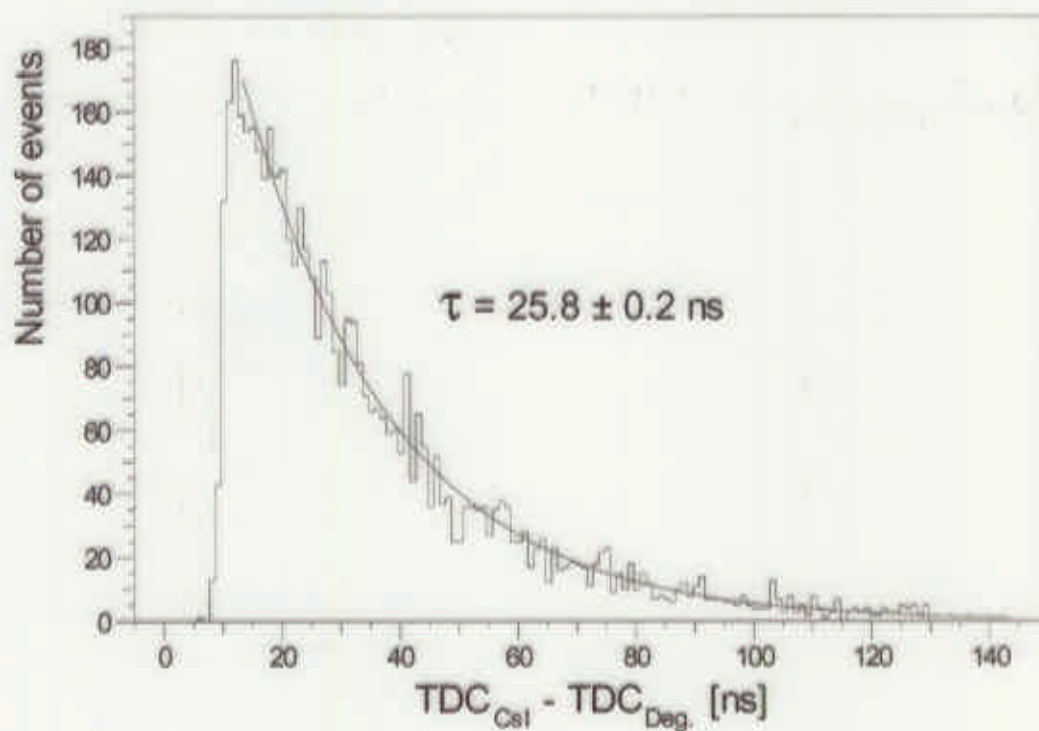
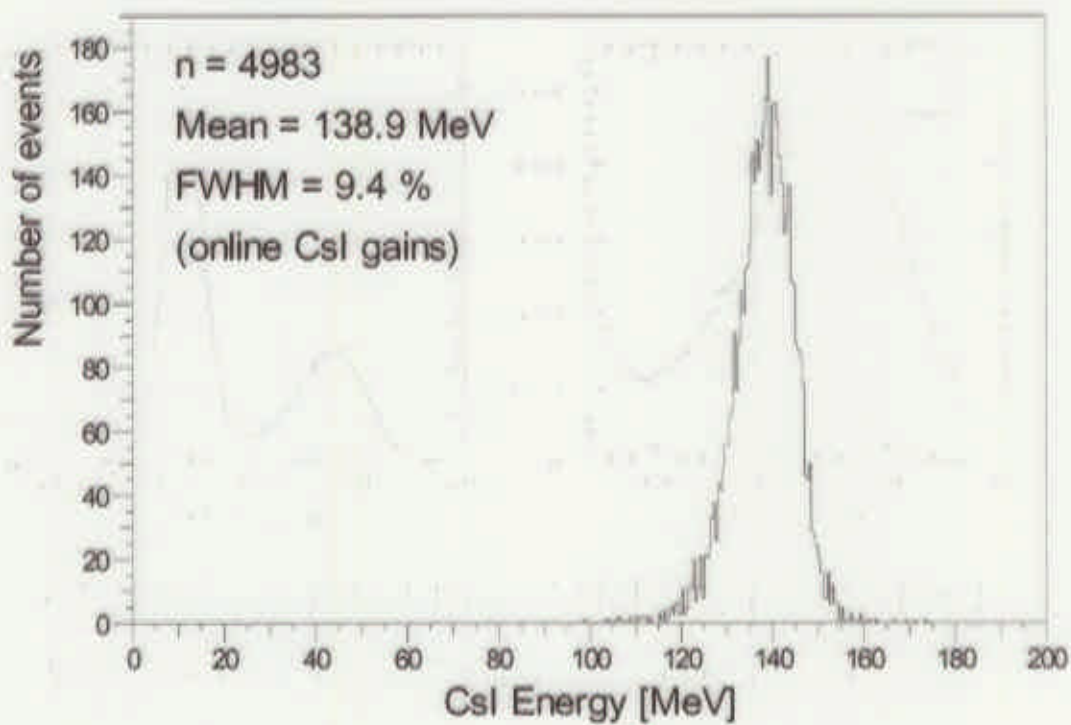
MIDAS experiment "Jbeta"		Wed Apr 12 13:35:03 2000			
Run #30160	Stopped	Alarm Off	Completed	Data dir /data	
Start: Wed Apr 12 07:50:46 2000		Stop: Wed Apr 12 08:27:26 2000			
Equipment	FE Node	Events	Event rate/s	Data rate[kB/s]	Analyzed
Trigger	Trigger Frontend [pc2106]	22029	0.0	0.0	100.0%
Scaler	Trigger Frontend [pc2106]	217	0.0	0.0	100.0%
IV	SC Frontend [pc809 psi.ch]	0	0.0	0.0	0.0%
Electronics	SC Frontend [pc809 psi.ch]	0	0.0	0.0	0.0%
Chamber	Trigger Frontend [pc2106]	38	0.0	0.0	100.0%
Resonator	SC Frontend [pc809 psi.ch]	0	0.0	0.0	0.0%
Channel	Active	Events	MB written	GB total	
run30160.msd	Yes	22362	32.440	31.286	
Lazy Destination	Progress	File Name	Speed [kB/s]	Total	
psarc14ye	100 %	run30158.msd	773.9	2.3 %	
Lazy Label	Progress	File Name	# Files	Total	
1000.2	100 %	run30158.msd	44	45.5 %	
11:01:44 [ODBEdit2] Program ODBEdit2 on host pc2106 stopped					
ODBEdit [pc2106]	Lazy_FTP [pc2106]	Lazy_Tape [pc2106]			
Logger [pc2106]	ODBEdit1 [pc2106]	mhttpd [pc2106]			
Analyzer [pc2106]	Trigger Frontend [pc2106]	SC Frontend [pc809 psi.ch]			

- DAQ for smaller experiments and tests
- Standard system at PSI and TRIUMF (>30 experiments)



<http://midas.psi.ch>

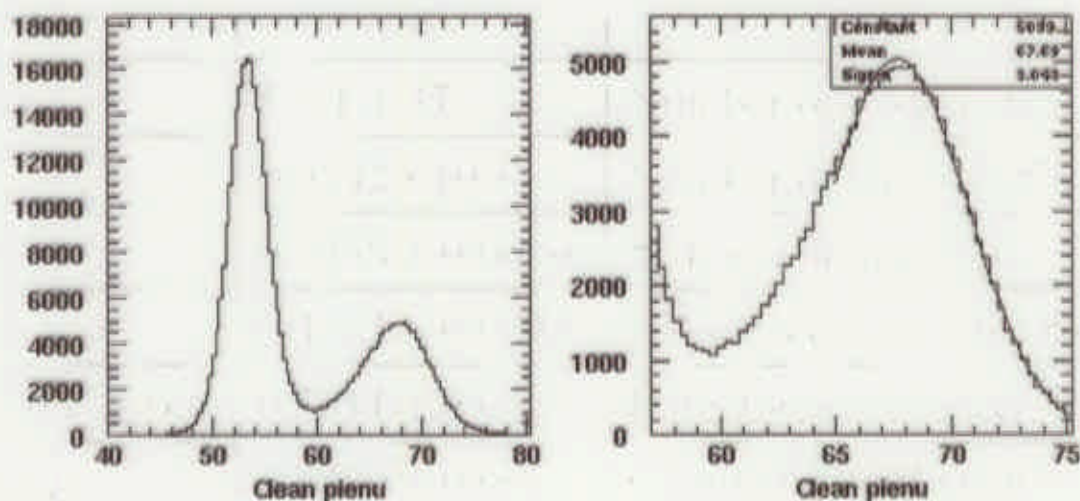
# $\pi\beta$ spectra



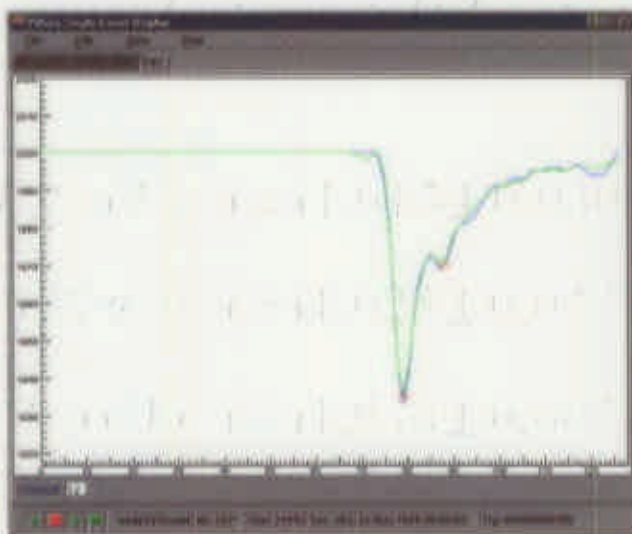
# $\pi$ ev spectra

CsI Clean pi-e-nu ADCs

2000/04/12 10:55



- Clearly separated from Michels, FWHM = 10.2%
- Will be improved by (need DSC data)
  - adding energy loss in active target and plastic veto hodoscope
  - subtracting baseline shift from pile-up in CsI



## $\pi\beta$ Branching Ratio Check

Item	Value	Remark
$N_{\pi\beta}$	$1441 \pm 37$	Number of $\pi\beta$ events
$N_{\pi\text{stop}}$	$0.9242 \cdot 10^{12}$	Number of stopped $\pi$ 's
$f_{\pi^+}$	$0.9238 \pm 0.0070$	$\pi^+$ fraction in $\pi\text{stop}$
$f_{\text{DPG}}$	$0.4254 \pm 0.0035$	$\pi$ decays covered by $\pi$ gate
$A$ (Geant)	$0.5611 \pm 0.0030$	Detector acceptance
$f_{\text{CPP}}$	$0.8460 \pm 0.0002$	Charged particle veto pile-up
$\tau_{\text{cl}}$	$0.8562 \pm 0.0001$	Computer live time
$f_{\pi\gamma\gamma}$ (PDP)	$0.9880 \pm 0.0003$	$\pi^0 \rightarrow \gamma\gamma$ BR
$f_{\text{tail}}$ (Geant)	$0.954 \pm 0.003$	Low energy tail correction

$$BR_{\pi\beta} = \frac{N_{\pi\beta}}{N_{\pi\text{stop}} \cdot f_{\pi^+} \cdot f_{\text{DPG}} \cdot A \cdot f_{\text{CPP}} \cdot \tau_{\text{cl}} \cdot f_{\pi\gamma\gamma} \cdot f_{\text{tail}}}$$

$$BR_{\pi\beta}(\text{Exp}) = (1.015 \pm 0.030) \cdot 10^{-8}$$

$$BR_{\pi\beta}(\text{PDG98}) = (1.025 \pm 0.034) \cdot 10^{-8}$$

$$BR_{\pi\beta}(\text{CVC}) = (1.048 \pm 0.005) \cdot 10^{-8}$$

## Conclusions

- Building the experiment (1993-1999) took longer than expected due to late delivery of Russian CsI crystals
- Detector now fully operational including waveform digitizing
- Took  $\sim 10,000$   $\pi\beta$  events in 1999 yielding in a 1% branching ratio measurement soon to be published
- Collect statistics in 2000 and 2001 for a 0.5% measurement
- Second phase of the experiment to go down to 0.2-0.3% after 2001

<http://pibeta.psi.ch>