Waveform Analysis for a Precision Pion Decay Measurement

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Physics Motivation / Theory

- Precision Measurement of the $\pi^+ \rightarrow e^+\nu$ branching ratio.

$$B = \frac{\Gamma(\pi^+ \to e^+\nu_\mu(\gamma))}{\Gamma(\pi^+ \to \mu^+\nu_\mu(\gamma))} = \left(\frac{g_e}{g_\mu}\right)^2 \left(\frac{m_e}{m_\mu}\right)^2 \frac{\left(1-m_e^2/m_\mu^2\right)^2}{\left(1-m_\mu^2/m_\pi^2\right)^2} (1+\delta R)$$

$B_{calc} = (1.2352 \pm 0.0001) \times 10^{-4}$ Cirigliano&Rosel, HepPH/07073439v1 (2007)

$B_{exp} = (1.230 \pm 0.004) \times 10^{-4}$ Experiment World Average (Current PDG)

Lepton Universality: W. Loinaz, et. al., Phys. Rev. D **65**, 113004 (2004) [hep-ph/0403306]

$$\left(\frac{g_e}{g_\mu}\right)_\pi = 1.0021 \pm 0.0016$$

Our Goal: $\frac{\Delta B_{exp}}{B_{exp}} \leq 5 \times 10^{-4}$

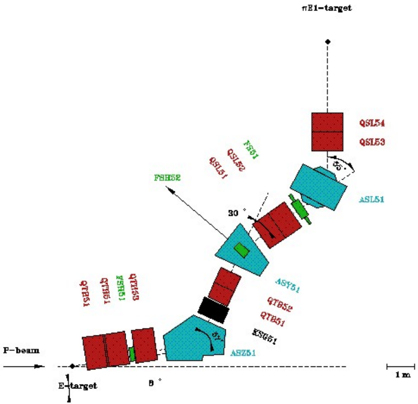
Mass Limits on Leptoquark and Supersymmetric Particles

We will be able to give lower bounds on the masses of some hypothetical particles.

Mass of the Charged Higgs Boson: $m_H > 6.9$ TeV
Mass of the Pseudoscalar Leptoquark: $m_p > 3.8$ TeV
Mass of the Vector Leptoquark: $M_G > 630$ TeV

Current limits: $m_H > 2$ TeV, $m_p > 1.3$ TeV, $M_G > 220$ TeV.

Beamline


πE1–target
QSL54
QSL53
FS51
QSL52
QSL51
FSH52
ASL51
30 °
ASY51
QTB52
QTB51
KSG51
QTB51
QTH51
FSH51
QTH53
ASZ51
P–beam
E–target
8 °
1 m

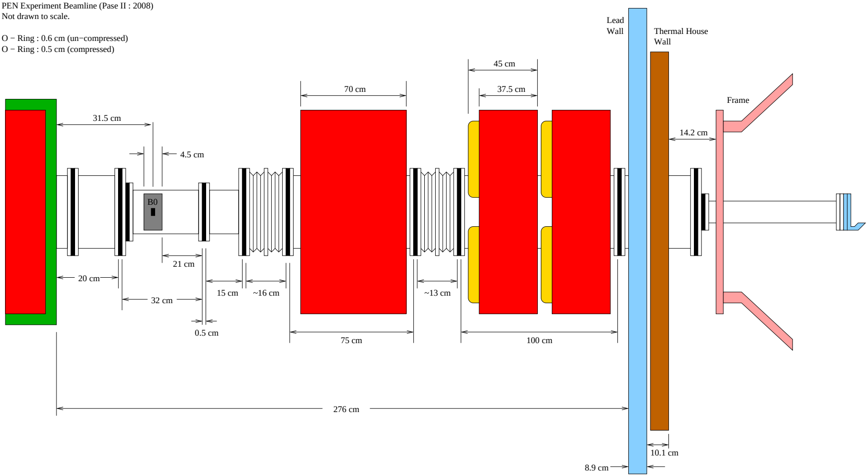
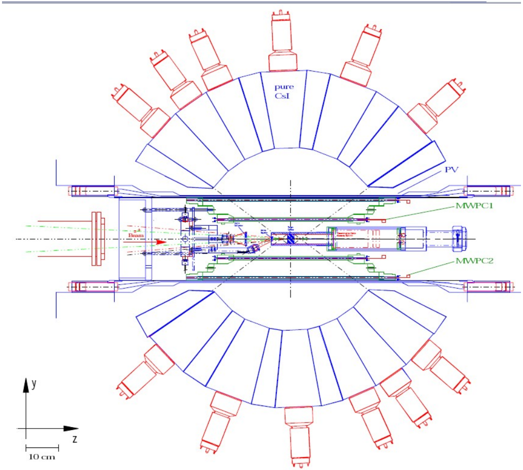
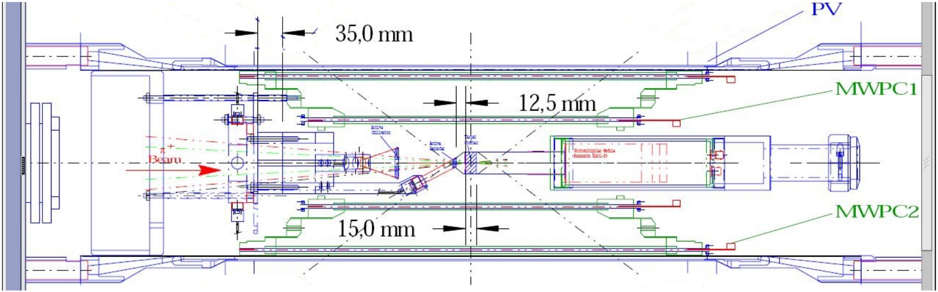


Figure: Beam Counter and Focusing Magnets.

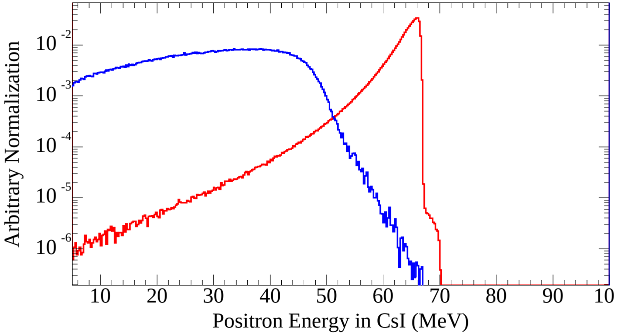
Detector



Detector



Tails via Geant4



Must accurately distinguish the $\pi^+ \to e^+\nu_\mu$ events from the $\pi \to \mu \to e$ events.

Suppress the Michel events and recover the $\pi^+ \to e^+\nu_\mu$ tail.

Acqiris High Speed 10-bit PXI/CompactPCI Digitizer, Model DC282
4 Channels, each with 2 GS/s

Digitized PMT waveforms from three beamline detectors:

- Beam Counter
- Degrader (wedge: left,right,top,bottom)
- Target

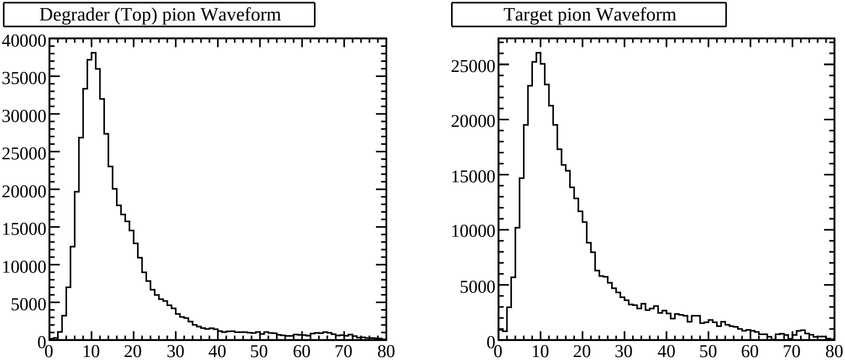


Figure: System Response Functions (Waveforms).

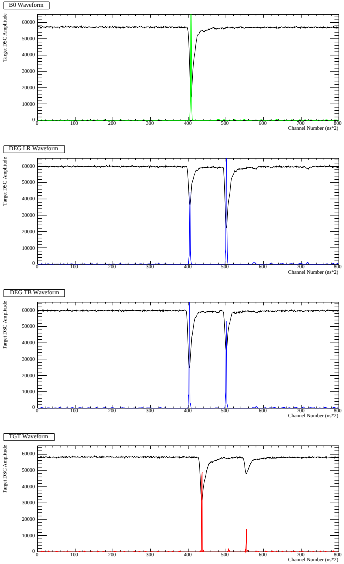


Figure: Digitizer Waveforms and Deconvolution Output.

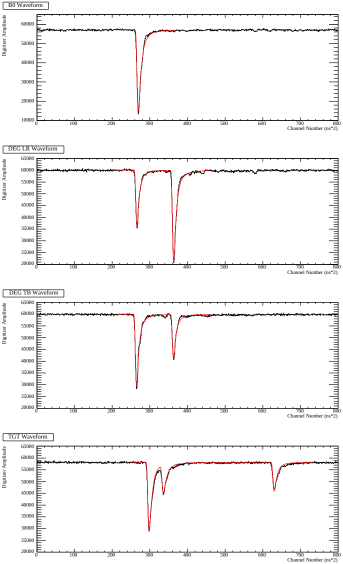


Figure: Fitted Digitizer Waveforms.

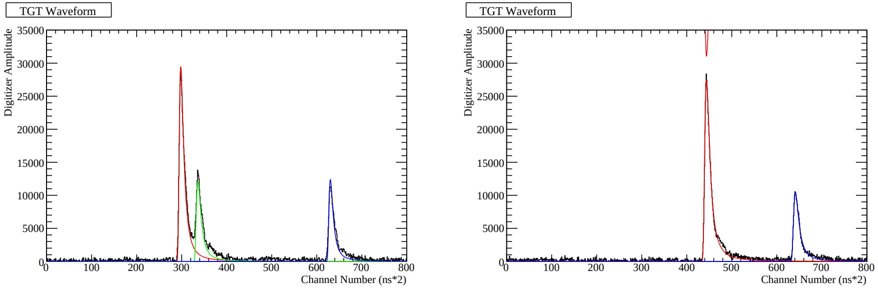


Figure: Michel vs. $\pi^+ \rightarrow e^+\nu_\mu$ Waveforms.

Target Waveform Fit Parameters

Pulse	Position in time (bin)	Amplitude
π^+	Known (from Degrader)	Known (from TOF and $E_{B0} + \sum E_{deg}$)
μ^+	Unknown	Known
e^+	Known (from Plastic Hod.)	Known (from tracking)

π^+ Position

Determined from bin position of π in degrader.

$\sigma \sim$ 110 ps

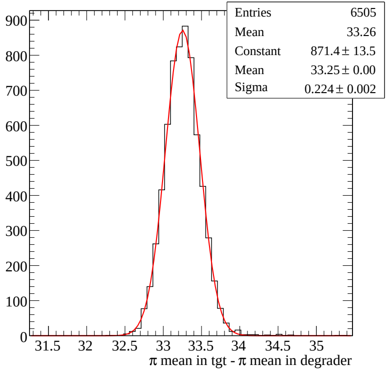


Figure: π^+ Bin Prediction Accuracy

π^+ Amplitude

Determined from TOF and the energy deposited in beam counter and degrader.

$\sigma \sim 250\ \text{keV}_{ee}$

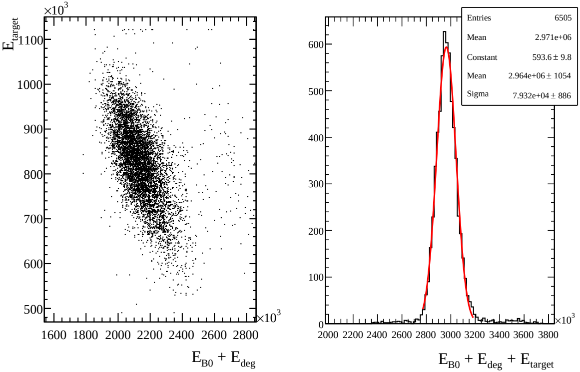


Figure: π^+ Energy Prediction Accuracy, $\sigma/\text{mean} = 2.6\%$

e^+ Position

Determined from the time of the Plastic Hodoscope.

$\sigma \sim 250$ ps

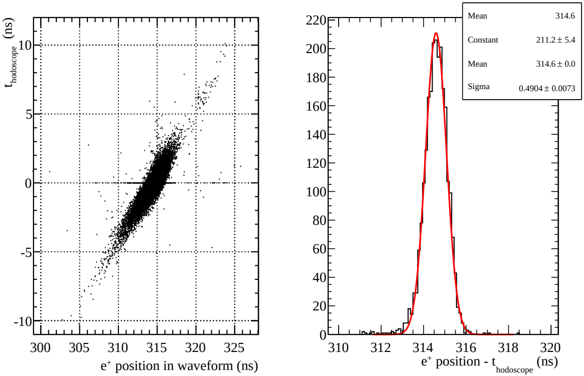


Figure: e^+ Timing Prediction Accuracy

e^+ Amplitude

Determined from the distance e^+ travels in the target.

Requires knowledge of the positron decay vertex.

- π^+ entry position from wedged degraders.
- e^+ track from MWPC, Plastic Hodoscope, and CsI Calorimeter.

μ^+ Amplitude

Known precisely since it is a two body decay.

$\sigma \sim 100$ keV$_{ee}$

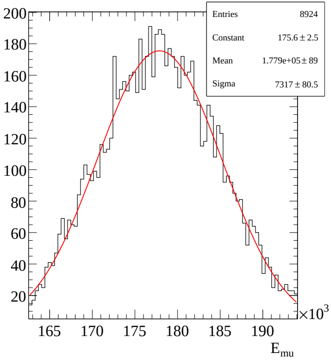
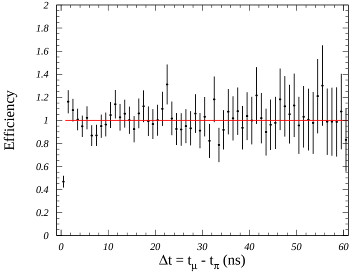
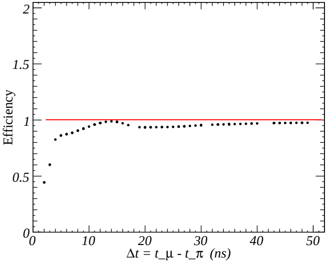


Figure: μ^+ Energy from Waveform, $\sigma/\text{mean} = 4.2\%$

Conclusion - PRELIMINARY





- Currently, only the positions are implemented as initial fit parameters. This results in a reliable $\pi \longrightarrow \mu \longrightarrow e$ event identification with a π^+,μ^+ separation as small as ~ 1 ns.
- Inclusion of π^+ and e^+ amplitude data will increase speed and accuracy.

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