Waveform Analysis for a Precision Pion Decay Measurement

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Introduction
Overview of the PEN Experiment
Constraints on pseudoscalar and scalar couplings

PEN Experiment
Detector
Extracting the $\pi^+ \to e^+ \nu_\mu$ Tail

Waveform Digitizer
Digitizer
Waveform Analysis

Conclusion
Physics Motivation / Theory

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

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

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

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


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

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: $m_H > 6.9 \text{ TeV}$
Mass of the Pseudoscalar Leptoquark: $m_p > 3.8 \text{ TeV}$
Mass of the Vector Leptoquark: $M_G > 630 \text{ TeV}$

Current limits: $m_H > 2 \text{ TeV}, m_p > 1.3 \text{ TeV}, M_G > 220 \text{ TeV}$. 
Beamline
PEN Experiment Beamline (Pase II : 2008)
Not drawn to scale.

O – Ring : 0.6 cm (un–compressed)
O – Ring : 0.5 cm (compressed)

Figure: Beam Counter and Focusing Magnets.
PEN Experiment

Detector

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Detector

35,0 mm

12,5 mm

15,0 mm

PV

MWPC1

MWPC2
Must accurately distinguish the $\pi^+ \rightarrow e^+ \nu\mu$ events from the $\pi \rightarrow \mu \rightarrow e$ events.

Suppress the Michel events and recover the $\pi^+ \rightarrow e^+ \nu\mu$ 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

<table>
<thead>
<tr>
<th>Pulse</th>
<th>Position in time (bin)</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+$</td>
<td>Known (from Degrader)</td>
<td>Known (from TOF and $E_{B0} + \sum E_{deg}$)</td>
</tr>
<tr>
<td>$\mu^+$</td>
<td>Unknown</td>
<td>Known</td>
</tr>
<tr>
<td>$e^+$</td>
<td>Known (from Plastic Hod.)</td>
<td>Known (from tracking)</td>
</tr>
</tbody>
</table>
$\pi^+$ Position

Determined from bin position of $\pi$ in degrader.

$\sigma \sim 110$ ps

Figure: $\pi^+$ Bin Prediction Accuracy
\[ \pi^+ \text{ Amplitude} \]

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

\[ \sigma \sim 250 \text{ keV}_{ee} \]

Figure: \[ \pi^+ \text{ Energy Prediction Accuracy, } \sigma/\text{mean} = 2.6\% \]
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.
- \(\pi^+\) entry position from wedged degraders.
- e\(^+\) track from MWPC, Plastic Hodoscope, and CsI Calorimeter.
$\mu^+$ Amplitude

Known precisely since it is a two body decay.

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

Figure: $\mu^+$ Energy from Waveform, $\sigma/\text{mean} = 4.2\%$
• Currently, only the positions are implemented as initial fit parameters. This results in a reliable $\pi \rightarrow \mu \rightarrow e$ event identification with a $\pi^+, \mu^+$ separation as small as $\sim 1$ ns.

• Inclusion of $\pi^+$ and $e^+$ amplitude data will increase speed and accuracy.
Conclusion

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