Fast Neutron Detection with MITPC

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Motivation:

- Fast neutrons are a background
- Lack of measurements
- MITPC is a directional fast neutron detector

This talk:

- Detector design
- DCTPC run at Double Chooz
- MITPC run at Fermilab
- Neon studies
Cathode Mesh
-7.5kV

Ground Mesh

Anode 700V

Neutron

$E = 2kV/mm$

$87.5\% \ ^4\text{He}/\text{Ne} + 12.5\% \ CF_4 \ @ \ 600 \ Torr$

$\ ^4\text{He}/\text{Ne}$

$e^-$

Readout

$e^-$

$e^-$

$e^-$

$e^-$

$e^-$
Field cage outside of chamber
Prototype and full-size detector installed at Double Chooz

Prototype
- 2.8 L
- 0.2 – 10 MeVr

Full-sized detector
- 40/60 L
- 0.3 – 20 MeVr
Event readout of an alpha

Pixel readout

Waveform readouts: anode (top); mesh (bottom)
Neutron-Induced Nuclear Recoil, $^{4}\text{He}/\text{CF}_4$ gas

~1 MeV

1024 pixels = 35.3 cm
Neutron-Induced Nuclear Recoil, $^4\text{He}/\text{CF}_4$ gas

$\sim 2$ MeV

1024 pixels = 35.3 cm
$^{220}\text{Rn} \rightarrow ^{216}\text{Po} \rightarrow ^{212}\text{Pb}$

$\sim 5 \text{ MeV each}$

1024 pixels = 35.3 cm
Energy reconstruction from 3D length, SRIM simulation

Energy loss of alpha particles in $^4$He/CF$_4$

Height = $T_{deposit} \times v_{drift}$
Near detector: 400 m away 120 mwe

Far detector: 1 km away 300 mwe
Neutron Background at Double Chooz

Neutrons come from:
- $(\alpha, n)$ interactions from U/Th in rock
- Stopped muon capture
- Deep inelastic muon events
60 L detector, Double Chooz near hall, 7 months

α’s from decay of:

- $^{210}$Po, 5.3 MeV; $^{218}$Po, 6.0 MeV
- $^{214}$Po, 7.7 MeV
- $^{222}$Rn, 5.5 MeV; $^{214}$Po, 7.7 MeV
- $^{220}$Rn, 6.3 MeV; $^{212}$Po, 9.0 MeV
α's from decay of:

- $^{210}$Po, 5.3 MeV; $^{218}$Po, 6.0 MeV
- $^{222}$Rn, 5.5 MeV; $^{214}$Po, 7.7 MeV
- $^{220}$Rn, 6.3 MeV; $^{212}$Po, 9.0 MeV

40 L detector, Double Chooz far hall, 6 months
Prototype detector, Double Chooz far hall, 4 months
Booster Neutrino Beamline at Fermilab
Booster Neutrino Beamline at Fermilab
# Energy Sensitivity

<table>
<thead>
<tr>
<th></th>
<th>DCTPC at Double Chooz</th>
<th>MITPC at FNAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas (600 torr)</td>
<td>87.5% (^4)He, 12.5% CF(_4)</td>
<td>87.5% Ne, 12.5% CF(_4)</td>
</tr>
<tr>
<td>Nuclear Recoil Sensitivity</td>
<td>0.3-20 MeV</td>
<td>Over 100 MeV</td>
</tr>
</tbody>
</table>
Choosing gas for MITPC at Fermilab

<table>
<thead>
<tr>
<th>Need</th>
<th>Test?</th>
<th>Calculate?</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Sufficient stopping power</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>• Sufficient gain</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>• Low diffusion</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>
Range of particles in (87.5% $^4$He, 12.5% CF$_4$, 600 torr) with SRIM software.
Range of particles in (87.5% Ne, 12.5% CF$_4$, 600 torr) with SRIM software
Electron diffusion in noble gases

Kinetic parameters of electrons in noble gases in an electric field of 75 V/cm.

<table>
<thead>
<tr>
<th></th>
<th>$V, 10^5$ cm s$^{-1}$</th>
<th>$eD_T/\mu$, eV</th>
</tr>
</thead>
<tbody>
<tr>
<td>He</td>
<td>2.8</td>
<td>0.25</td>
</tr>
<tr>
<td>Ne</td>
<td>3.5</td>
<td>1</td>
</tr>
<tr>
<td>Ar</td>
<td>2.3</td>
<td>3.0</td>
</tr>
<tr>
<td>Kr</td>
<td>1.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Xe</td>
<td>1.05</td>
<td>2.7</td>
</tr>
</tbody>
</table>

E. Aprile, et al., “Nobel Gas Detectors”
Alpha tracks in 87.5% $^4$He, 12.5% CF$_4$, 600 torr ($^{241}$Am source)

1024 pixels = 16.7 cm
Alpha tracks in 87.5% Ne, 12.5% CF$_4$, 600 torr ($^{241}$Am source)

1024 pixels = 16.7 cm
Ne/CF$_4$

- 9% more diffuse
  - not 400%!
- 63% shorter

$^4$He/CF$_4$
Decreased Spark Rate in Neon

- Sufficient gain with lower voltage in Ne than in $^4$He
- Breakdown voltage of Ne is lower than that of $^4$He
- Fewer sparks in Ne
- Higher efficiency in Ne

<table>
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<tr>
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<th>$^4$He/CF$_4$</th>
<th>Ne/CF$_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating voltage</td>
<td>710 V</td>
<td>680 V</td>
</tr>
<tr>
<td>Approx. breakdown voltage of noble gas</td>
<td>690 V</td>
<td>710 V</td>
</tr>
</tbody>
</table>
Simulated 5 MeV neutron-induced nuclear recoil (87.5% Ne, 12.5% CF$_4$)

1024 pixels = 35.3 cm
Simulated 30 MeV neutron-induced nuclear recoil (87.5% Ne, 12.5% CF₄)

1024 pixels = 35.3 cm
Simulated 75 MeV neutron-induced nuclear recoil (87.5% Ne, 12.5% CF₄)

1024 pixels = 35.3 cm
MITPC at Fermilab

- Monte Carlo prediction for neutron background on Booster Neutrino Beamline (BNB)
- Neutrino experiments on BNB:
  - MicroBooNE
  - SBND
  - ANNIE
MITPC at Fermilab

- Ready for BNB turn-on
- Sensitive to over 100 MeVr
- 300-500 neutrino-induced neutrons over $6.6 \times 10^{20}$ POT
- Also beam-induced skyshine, cosmogenic and radiogenic neutrons
- Run for 3 years
- Co-exist with ANNIE
Takeaway

• MITPC is a directional fast neutron detector
• Successful run at Double Chooz
  – Paper coming out!
• Demonstrated use of neon in a TPC
  – Paper coming out!
• Measure fast neutrons at Fermilab

Thank you!
MITPC Collaboration

Allie Hexley
Marjon Moulai
Janet Conrad

Josh Spitz

Adrien Hourlier
Jaime Dawson
Back-up
"Luckily", there is a lot of \( \alpha \) activity in the detection volume (from Rn decay chains). We can use these lines as calibration points.
Efficiency/Acceptance of 60 L detector, $^4\text{He}/\text{CF}_4$

- Black line: reconstruction (fully contained in r)
- Red line: fully contained in r
- Blue line: fully contained in r and z

![Graph showing efficiency fraction vs. true energy (MeV).]
Range of particles in (12.5% CF$_4$ 87.5% He/Ne, 600 torr)

Kinetic energy (MeV)

Range (mm)

- He in He-CF$_4$ mix
- Ne in Ne-CF$_4$ mix
- C in He-CF$_4$ mix
- C in Ne-CF$_4$ mix
- F in He-CF$_4$ mix
- F in Ne-CF$_4$ mix
Neutron Energy Spectra (II)

At the location, 1 m area centered on the beam axis. Forward- and backward-going neutron spectra look different. Not surprisingly.

- Neutrons through 1m x 1m area 1m upstream of MicroBooNE over 2.1-3.2 x 10^{19} POT
- MITPC would see 6-9 neutrons (on carbon) over 6.6 x 10^{20} POT (2 years)
Expected neutron rate

- Neutrino flux $\sim 60 \times$ higher in SciBooNE Hall
- MITPC would see 300-500 neutrons over $6.6 \times 10^{20}$ POT (2 years)
Diffusion with Xe & CF4

80 torr Xe with \textit{xyz} torr CF4

Hidefumi Tomita’s Thesis