The NEWS-G3 experiment

On behalf of the NEWS-G collaboration
Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)

\[
\frac{d\sigma}{dT_A} = \frac{G_F^2 m_A}{2\pi} \frac{Q^2}{E_W^2} \left( 2 m_A T_A \right)
\]


Detection of reactor neutrinos with the NEWS-G3

Detection of reactor neutrinos through CEvNS

What physics can we do with CEvNS?
- Non-standard neutrino interactions, new mediators
- Weak mixing angle
- Nuclear form factors
- Neutrino magnetic moment

What practical applications can we have?
- Direct monitoring of the nuclear fuel

How to detect CEvNS with the NEWS-G3 detector?
- Low energy threshold
- High gain for low energy recoils
- Large mass - high pressure
- Exact knowledge of our background
The NEWS-G3 detector
The NEWS-G3 detector

**Compact Shield**
- Lead
- Active muon veto
- Polyethylene
- Copper

- $\Phi = 60 \text{ cm}$
- Aiming for 20 bar pressure
- Candidate materials: copper (C10100), stainless steel
- Candidate gas targets: Ar, Ne, Xe

Photo of the shielding at Queen’s lab
Active muon-veto

Muon-veto specs

- 12 Plastic scintillators
- 1 PMT on each panel

Off-shield panel characterization

- Comparison of expected muon events to detected ones
Muon-veto validation

In-shield characterization/simulation

- GEANT4 simulation
- Panel validation
Background simulations

Sources of background

• Muon-induced background (neutrons, gammas)
• Cosmogenic activation
• Atmospheric neutrons
• Fast/Thermal neutrons from the reactor
Backing detector for quenching factor measurements

**QF measurements with neutron scattering**

- Low energy neutron beam at university of Montreal
- Building a backing detector at Queen’s for QF measurements
- Better angular coverage
- Detection efficiency 27% at 2 keV
- Mean neutron capture time 17 μs
Pressure characterization
Pressure characterization

**SPC for pressure characterization**

- 30 cm diameter
- Stainless-steel
- 10 bar pressure certified
- 5 kV feedthrough
Pressure characterization

**Argon:CH4(98:2)**
- SPC: 30 cm diameter
- 1 mm anodes
- Fe55 calibration
- 1 to 5 bar

- **First time to operate an SPC up to 5 bar Argon**
- **Almost 5000 V at 5 bar**
- **Limit of feedthrough (5 kV)**
- **Observed instabilities and increased rate of electronic spikes**
- **Cause of instabilities: high voltages**

Solution: Use smaller anode (next slide)
Pressure characterization

**Anode**

- \( \Phi = 500 \, \mu m \) (diameter)
- No hole
- Contact with conductive glue

- Spikes \( \sim \) improve grounding/shielding/cleaning

- First successful stable operation at 5 bar

- Voltage = 3250V (4900V with 1mm)
Pressure characterization

**Conditions**

- 0.5 mm anode
- Pressure = 10 bar
- Gas = Ar+2%CH4
- HV = 4920 V
- HV_umbrella = 0 V

**First successful stable operation at 10 bar**

- No sparks, no instabilities
- Gas leak observed (~264 mbar/day)
- Ordered clamps for high pressure
Expected CEvNS events
Expected number of CevNS events

\[ N_{\text{events}} = P_{th} L \Phi N_{\text{nuc}} \int_{E_{nr_i}}^{E_{nr_i} + \Delta E_{nr}} dE_{nr} \int_{E_{\nu}^{\text{min}}}^{E_{\nu}^{\text{max}}} dE_{\nu} \frac{dN_{\nu}}{dE_{\nu}}(E_{\nu}) \cdot \frac{d\sigma}{dE_{\nu}}(E_{nr}, E_{\nu}) \]

\[ N_{\text{events}} \equiv \text{Number of events between } [E_{nr_i}, E_{nr_i} + \Delta E_{nr}] \]

\[ P_{th} \equiv \text{Reactor thermal power} \]

\[ L \equiv \text{Reactor load factor} \]

\[ \Phi = \text{Flux} \]

\[ N_{\text{nuc}} = \frac{N_A}{M_{\text{molar}}} \equiv \text{Number of nuclei per gr} \]

\[ E_{\nu}^{\text{min}} = \sqrt{\frac{M_{\text{nucleus}} E_{nr}}{2}} \]
Flux estimation through simulation

- Estimate the $\nu$ flux at the SPC for non-point-source
- $2e9$ neutrinos
- Uniform and isotropic emission
- Darlington reactor
  - core radius = 3 532 mm
  - core length = 5 944 mm
- SPC
  - $R = 30$ cm
  - Distance = 10-30 m
Flux estimation through simulation

- Verifying isotropic emission for cylinder

- Verifying source uniformity
Flux simulation results

Point source vs Cylindrical source

- \( N_{\text{point source}} \): Total number of \( \nu \) at SPC from point-source
- \( N_{\text{cyl}} \): Total number of \( \nu \) at SPC from cylindrical source
- Reactor dimensions become significant below 10 m

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>((1 - \frac{N_{\text{point source}}}{N_{\text{cyl}}})) %</th>
<th>Total ( \nu ) simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>11%</td>
<td>2e9</td>
</tr>
<tr>
<td>10</td>
<td>5%</td>
<td>2e9</td>
</tr>
<tr>
<td>15</td>
<td>2%</td>
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<tr>
<td>20</td>
<td>1%</td>
<td>2e9</td>
</tr>
<tr>
<td>30</td>
<td>&gt;1%</td>
<td>2e9</td>
</tr>
</tbody>
</table>

Flux at SPC at 10 m

\( Cyl > PS \)

5% difference
Expected number of CevNS events

\[
N_{\text{events}}^i = P_{\text{th}} L \Phi N_{\text{nuc}} \int_{E_{nri}}^{E_{nri} + \Delta E_{nr}} \int_{E_{\nu}^{\text{min}}}^{E_{\nu}^{\text{max}}} \frac{dN_{\nu}^i}{dE_{\nu}}(E_{\nu}) \cdot \frac{d\sigma}{dE_{\nu}}(E_{nr}, E_{\nu}) \, dE_{nr} \, dE_{\nu}
\]
Expected number of CevNS events

Complementary cumulative distribution of events in Argon

Complementary cumulative distribution of events in Neon

Complementary cumulative distribution of events in Xenon
Conclusion

- **First successful SPC operation at 10 bar Ar+2%CH4**
- **On-going background simulations**
- **Obtained expected number of events for Ne,Ar,Xe at various reactor-detector distances**
- **Constructing backing detector at Queen’s for QF measurements at university of Montreal**
Thank you
Back-up
5 bar Ar with 500 μm anodes

- Pressure = 5 bar
- Gas = Ar+2%CH4
- V = 3250 V
- Mean = 8900 V
- Resolution = 13%
Pressure characterization

Exploring gases/pressures

- $\Phi = 30 \text{ cm}$
- *Gases: Ar+2%CH4, Ne+2%CH4*
Pressure characterization

Neon-Argon comparison

- Rise-time vs multiplication
- Raw Width vs multiplication
Expected number of CevNS events

Events in Argon

Events in Neon

Events in Xenon
Expected number of CevNS events

Cumulative distribution of events in Argon

Cumulative distribution of events in Neon

Cumulative distribution of events in Xenon
Differential CevNS cross-section

\[ \frac{dR}{dE_{nr}} = N \int_{E_{\nu}^{\text{min}}} dE_{\nu} \times \frac{d\sigma(E_{\nu}, E_{nr})}{dE_{nr}} dE_{\nu} \]

\( N \equiv \text{Number of nuclei per kg} \)

\[ \frac{d\phi}{dE_{\nu}} \equiv \text{Differential flux (}\nu\text{ spectrum, flux at SPC)} \]

\[ \frac{d\sigma(E_{\nu}, E_{nr})}{dE_{nr}} \equiv \text{Differential cross section} \]
Active muon-veto

Muon Detection Efficiency

Counts

Noise  Gamma  Muons

The NEWS-G3 Experiment