Electron scattering for neutrino physics at MAMI

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Introduction

- Long base-line Neutrino Experiments
- Relevance of Electron-Scattering for Neutrino Physics
- Experiments at MAMI
- Future Directions
Concretely, neutrino experiments employ two methods for reconstructing more. Currently this involved modeling is performed with simulation packages containing theoretical sections in order to test and tune the models presently employed by neutrino experiments and help them to reach their ultimate goals.

**Far Detector**

\[ N_{FD}(\nu_\alpha \rightarrow \nu_\beta, E_R) = \int dE_\nu \Phi_{\nu_\alpha}(E_\nu) \times \sigma(E_\nu) \times R_{\nu_\alpha}(E_\nu, E_R) \times P(\nu_\alpha \rightarrow \nu_\beta, E_V) \]

**Near Detector**

\[ N_{ND}(\nu_\alpha, E_R) = \int dE_\nu \Phi_{\nu_\alpha}(E_\nu) \times \sigma(E_\nu) \times R_{\nu_\alpha}(E_\nu, E_R) \]

Luca Doria Part B2 NU4NU
Why nuclei are relevant for neutrino physics?

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Analysis

Experiment

Detection

Cross section model

\[ \sigma(E_\nu) \]

Oscillation

Production

\[ \nu_l \]

Reconstruct

\[ E_\nu \]

Oscillation Parameters

\( \theta_e, \theta_\mu, \theta_\tau, \delta_{CP} \)

\( \Delta m^2_e, \Delta m^2_\mu, \Delta m^2_\tau \)

The goal of the proposed NU4NU project is to access this information using electrons cross section of neutrinos with nuclei in the detectors. and this will be possible only reducing the present limiting systematic uncertainties on the interaction. The measurement of the neutrino oscillation parameters and at measuring the CP-violating phase activity which is taking a major step forward with the gearing up of two major international initiatives: Measuring the neutrino oscillation parameters is the subject of a world-wide intense experimental ac-

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Electron Scattering vs Neutrino Scattering

Neutrino-Nucleus scattering

\[ \frac{d^2 \sigma}{d\Omega_k' d\omega} = \sigma_0 [L_{CC}R_{CC} + L_{CL}R_{CL} + L_{LL}R_{LL} + L_T R_T \pm L_{T'} R_{T'}] \]

(Unpolarized) Electron-Nucleus scattering

\[ \frac{d^2 \sigma}{d\Omega d\omega} = \left( \frac{d\sigma}{d\Omega} \right)_{Mott} \left[ \frac{Q^4}{q^4} R_L(q) + \left( \frac{1}{2} \frac{Q^2}{q^2} + \tan^2 \frac{\theta}{2} \right) R_T(q) \right] = \left( \frac{d\sigma}{d\Omega} \right)_{Mott} \left[ \sigma_L + \sigma_T \right] \]

Use electrons for testing neutrino-nucleus interactions generators.
The Racetrack Microton
(Institute for Nuclear Physics, U. Mainz)

CW electron beam
Up to 100 uA current
80% polarization
dE <13 keV

up to 855 MeV

MAMI-A
MAMI-B: 855 MeV (seit 1990 in Betrieb)

MAMI
LINAC
Elektronenquelle

umlenkmagnete

up to 1.6 GeV

No. 3
LINAC I (4.90GHz)
Extraction 1507MeV
Matching-Section
4.90GHz

No. 2
B=1.539T
43 turns

No. 4
LINAC II (2.45GHz)
Injection 855MeV

No. 1

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NuSTEC Workshop, Mar 2021
The MAMI Accelerator Facility

MESA
Mainz
Energy-recovery
Superconducting
Accelerator

A1 Collaboration
3-Spectrometers Setup
A1 Collaboration

**Spectrometers**

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration</td>
<td>QSDD</td>
<td>D</td>
<td>QSDD</td>
</tr>
<tr>
<td>Max. Momentum (MeV)</td>
<td>735</td>
<td>870</td>
<td>551</td>
</tr>
<tr>
<td>Solid Angle (msr)</td>
<td>28</td>
<td>5.6</td>
<td>28</td>
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<tr>
<td>Mom. Resolution</td>
<td>$10^{-4}$</td>
<td>$10^{-4}$</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>Pos. Res at Target (mm)</td>
<td>3-5</td>
<td>1</td>
<td>3-5</td>
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</table>
Electron Scattering: Existing Dataset

![Graph showing existing datasets for different elements and their energy-angle relationship.]

- **New $^{12}$C MAMI data**
- **New $^{40}$Ar JLab data**

The graph illustrates the existing data on $^{12}$C (blue points) and $^{16}$O (red points) as a function of beam energy and scattering angle. The new $^{40}$Ar data from JLab [31] is indicated with the green cross. For reference, the neutrino flux of T2K (shaded blue) and the simulated DUNE spectrum (shaded orange) at the far detector in the $\nu$ µ disappearance channel are shown.

In the energy range relevant for next-generation neutrino experiments, electron scattering data is scarce but well within reach of existing electron accelerator facilities.

**Figure 2:**
- Left: Data from JLab [31] demonstrating the approximate validity of super-scaling [32]. The argon data from LNF [33] show a significant deviation from expectation.
- Right: New $^{40}$Ar JLab data showing the effective momentum transfer $q$, while $v_L$ and $v_T$ are kinematic factors. The structure function $R_L$ is theoretically better known and subject of scaling properties [32] which allow in principle its estimation from a limited dataset (Fig. 2).

$R_T$ is less known and more challenging to calculate for theoretical models, since it depends critically from $e^\mu$ effects like meson exchange currents which are instead negligible in $R_L$. Current contributions tend to increase significantly the transverse response $R_T$[34, 35]. The two structure functions can be separated via the Rosenbluth separation technique which requires measurements over a broad range of kinematic settings. Such new measurements can be performed thanks to the availability of a high-quality continuous electron beam up to 1.6 GeV energy at MAMI [36] coupled to three high-resolution magnetic spectrometers of the A1 Collaboration [37] (Fig. 3).

The effectiveness of the spectrometers in achieving excellent results on electron-nucleus scattering was already demonstrated in the past, also with a measurement on oxygen [38]. Electron scattering on oxygen can be efficiently realized employing an existing “waterfall” liquid water target [39], while measurements on argon can be done with an existing cryogenic target. The use of the waterfall target requires the subtraction of the hydrogen contribution, which is very well known at the required precision.

$R_T$ can be efficiently disentangled from $R_L$ with measurements at large backward scattering angles ($>$20°), where the cross section drops significantly. Liquid phase targets are therefore needed for compensating the smaller cross sections with a large luminosity. The waterfall target can sustain beam currents up to 50 $\mu$A with a target thickness of 30 mg/cm$^2$, which is adequate for measuring cross sections of the order of nb/sr. The liquid argon target will also be able to achieve comparable goals.

With the A1 setup and liquid targets, inclusive scattering experiments can be performed matching the precision of the existing datasets within hours of measurement per kinematic setting, thus having the unique opportunity to obtain high-quality data for both the structure functions. Fig. 4 shows a proposal for kinematic settings for inclusive measurements on oxygen and argon. For separating $R_L$ from $R_T$ with the Rosenbluth separation method, a large range of the kinematic factors $v_L$ and $v_T$ must be covered. The proposed settings are all within reach of the A1 facility and can be measured in a reasonable amount of time. One single setting can be measured in about 1 hour. With an average recorded rate between 10 and $10^3$ Hz, all the kinematic points in Fig. 4 can be measured within 6 hours.
MAMI $^{12}$C data

M. Mihovilovic (J.Stefan Inst.)

$^{12}$C(e, e$'$) at 855 MeV

$\theta_e = 36^\circ$

PRELIMINARY

GENIE (2.x tune) calculation kindly from A.Ankowski

$^{12}$C(e, e$'$) at 855 MeV

$\theta_e = 36^\circ$

PRELIMINARY
In the near future: Oxygen and Argon

Waterfall target

- Waterfall target is established equipment of A1.
- Measurement without background from target walls.
- Hydrogen background subtracted using sophisticated simulations.
- Luminosity of $4 \cdot 10^{35}/\text{cm}^2/\text{s}$ at 20μA.

Cluster-jet Target

- Window-less targets: backgrounds reduction
- Exclusive measurements possible

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Summary

Contribute to next generation LB neutrino physics program

- Neutrinos are a concrete case of new physics, top priority in particle/fundamental physics
- MAMI + A1 well suited for precision measurements of eN cross sections
- More $^{12}$C data to analyze: L/T separation, Coulomb sum rule, ...

In the future

- Measurements on Argon and Oxygen with a Jet Target
- Exclusive measurements, pion production, ...
- MESA: precision low energy eN scattering (an opportunity for SN neutrinos?)
- Complementary to the JLab program