

AI-Optimized Polarization at Jefferson Lab

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1. Introduction
2. Polarized Beam at GlueX
3. Polarized Target
4. Conclusion

Introduction

Polarized sources and targets are complex, dynamical systems.

Experiments at Jefferson Lab rely on human operators to control and optimize the performance of these systems.

Can AI/ML control exceed the performance of human operators?

Potential benefits both in terms of improved statistics and cost savings.

AI-Optimized Polarization (AIOP)

AIOP is a 2-year, DOE-funded project that began in March 2024.

An initiative of the Experimental Physics Software and Computing Infrastructure (ESPCI) group at Jefferson Lab.

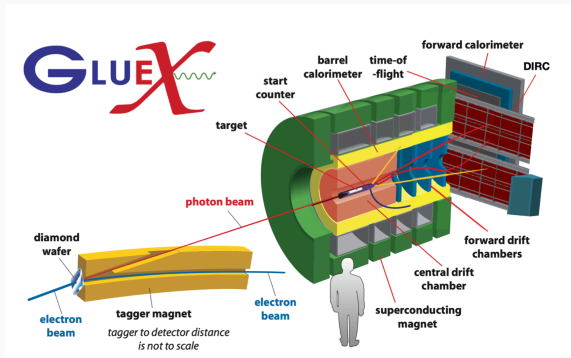
Consists of two sub-projects:

1. Polarized Photon Beam;
2. Polarized Cryogenic Target.

Polarized Beam at GlueX

The GlueX Experiment at Hall D

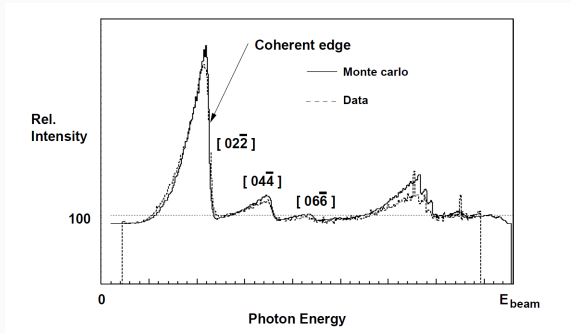
GlueX uses a polarized photon beam to search for and measure exotic hybrid mesons predicted from lattice QCD.



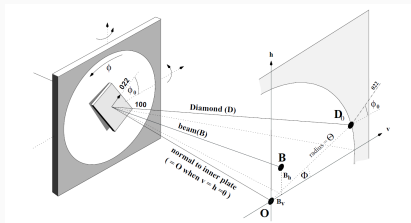
GlueX Photon Beam

The interaction of the CEBAF electron beam with a thin ($\sim 50\mu\text{m}$) diamond radiator produces a polarized photon beam via coherent bremsstrahlung radiation.

The position of the primary peak (E_γ) is determined by the orientation of the diamond, but also by the electron beam position and the degradation of the diamond.



GlueX Goniometer

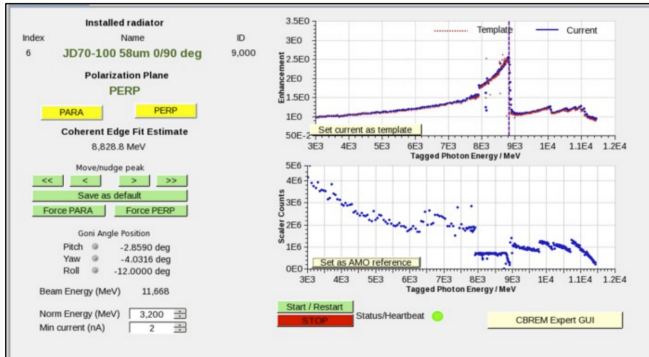


The diamond is mounted on a goniometer which can be rotated with respect to the x, y, and z axes of the lab frame (called pitch, yaw, and roll angles, respectively).

The **roll** angle determines the polarization plane and is held constant.

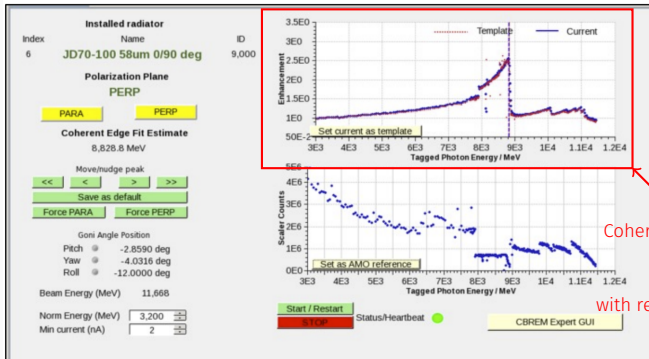
The **pitch** and **yaw** angles determine the location of the coherent bremsstrahlung peak and, if necessary, are adjusted at the start of a run.

Human-operation of the goniometer



The Hall D polarized photon source control GUI.

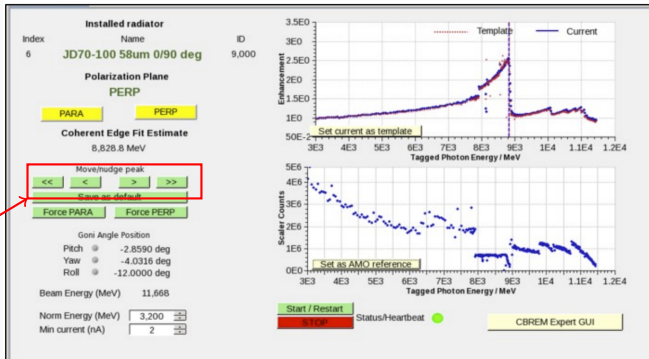
Human-operation of the goniometer



Coherent enhancement spectrum aligned with reference spectrum

The Hall D polarized photon source control GUI.

Human-operation of the goniometer



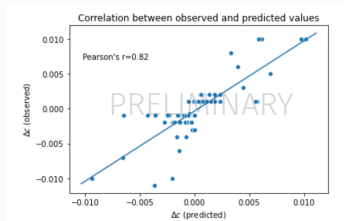
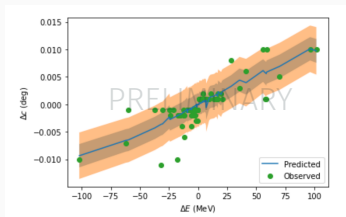
Buttons to
nudge spectrum
left or right

The Hall D polarized photon source control GUI.

Gaussian Process Regression

Can we train a surrogate model on GlueX historical data that can learn that complex dynamics affecting the polarization?

Gaussian Process Regression is a flexible, non-parametric approach to regression, which allows for uncertainty quantification in predictions.



GP inputting coherent edge positions and beam positions and outputting the change in angle (left), and the observed vs. predicted values for the change in angle (right).

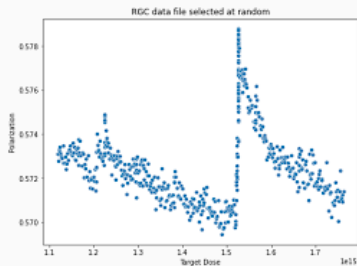
Polarized Target

DNP has been used in Halls A-C at Jefferson Lab.

Most commonly-used materials are irradiated solid ammonia (NH_3) and deuterated ammonia (ND_3).

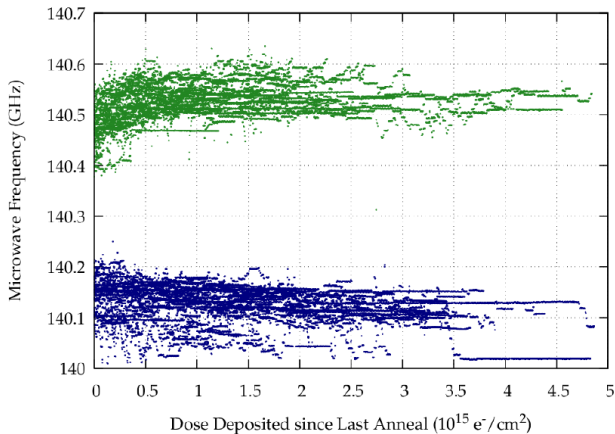
Polarized target operation requires constant monitoring and adjustment throughout data-taking.

Shift workers manually adjust the microwave frequency



Example increase in polarization (left) after operator decreased microwave frequency (right). The data was taken from an experiment during Run Group C in Hall B.

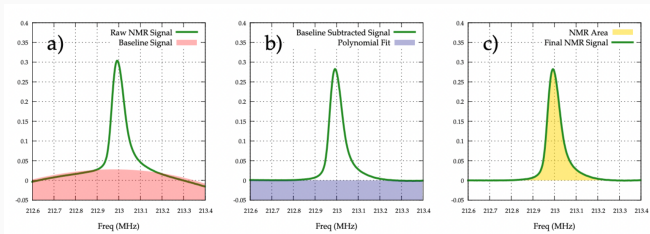
The optimal frequency is not straightforward to predict



Chosen microwave frequency versus beam dose since the last anneal in Hall C.

Measuring the Polarization

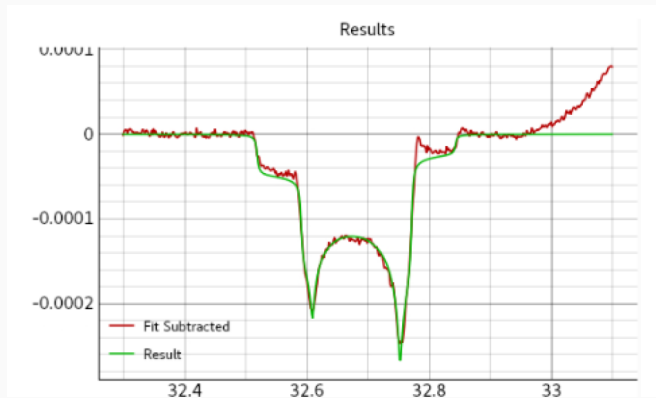
The target polarization is measured using continuous-wave NMR. Requires performing background subtraction.



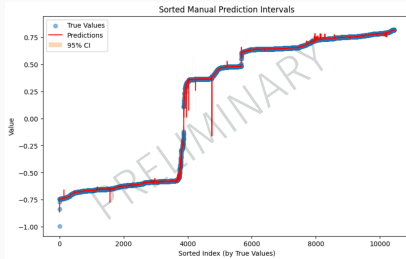
NMR signal extraction process for a polarized proton target. From left to right: background subtraction, residual subtraction, signal integration.

Measuring the Polarization

Extracting the polarization is even more difficult for deuteron which has a characteristic double NMR peak.



Gaussian Process Regression



Input Variables Used

Means and std. dev. of
NMR curves

Target dose

Calibration constants

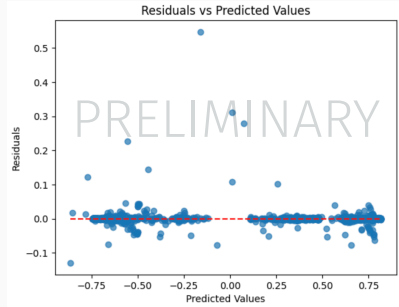
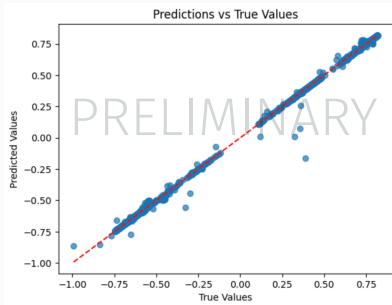
Microwave frequency

Target temperature

Solenoid current

Beam current

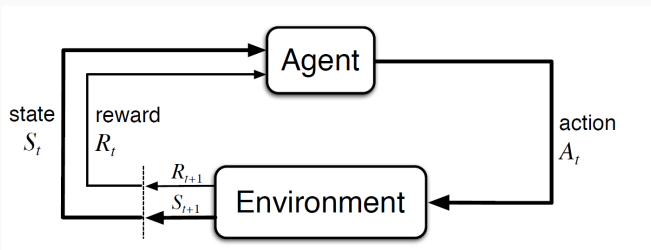
Gaussian Process Regression



Reinforcement Learning

Reinforcement Learning is a machine learning paradigm where an agent learns to make decisions by taking actions in an environment to maximize cumulative rewards.

Can we use our surrogate models to define an environment for an RL agent to learn an optimal policy?



Work currently in progress.

Conclusion

Summary

AIOP seeks to optimize nuclear using AI/ML for experimental control.

Preliminary results shown using ML to learn a surrogate model for a polarized photon beam and polarized target.

Plan to integrate with the JLab experimental hall controls system in 2025-26.

Results could help lay the foundation for future autonomous experiments at other facilities (e.g. EIC).

Questions?



K. Livingston.

The stonehenge technique. a method for aligning coherent bremsstrahlung radiators.

Nucl. Inst. & Meth. in Phys. Res. A, 603(3):205–213, 2009.



A. W. Sáenz and H. Überall.

Coherent Radiation Sources.

Springer-Verlag, Berlin, DE, 1985.



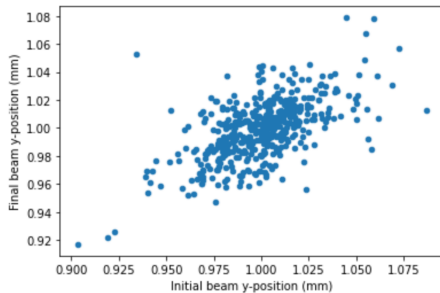
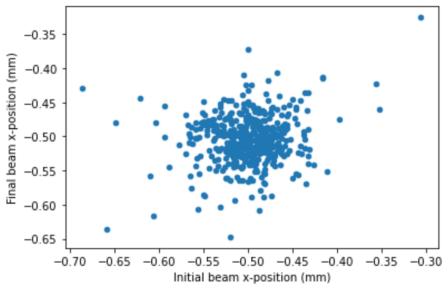
U. Timm.

Coherent bremsstrahlung of electrons in crystals.

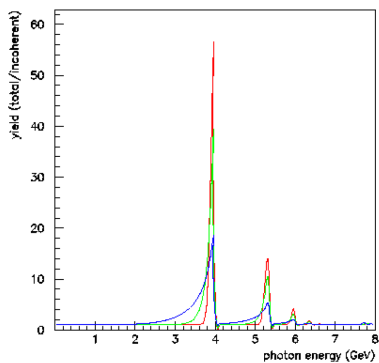
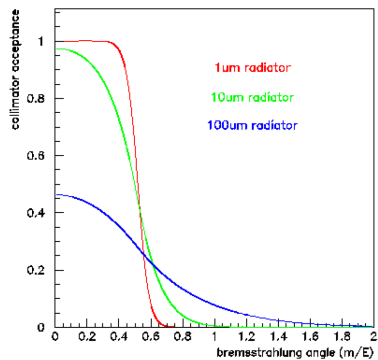
Fortschritte der Physik, 17(65):765–808, 1969.

Backup Slides

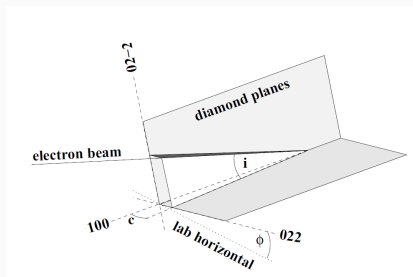
GlueX Beam Position Drift



Effect of Diamond Thickness



Crystal Coordinate System



$$c \approx \frac{k}{gE_0 \left[\frac{1}{E_c} - \frac{1}{E_0} \right]}$$

with k, g constant.

- Adjusting the angle c adjusts the coherent edge position E_c .
- ϕ determines the orientation of the polarization. $\phi = 0^\circ$ or 90° for PARA/PERP orientation of polarization.