Compton scattering on liquid ^{2}H target at HIγS: Measuring nucleon polarizabilities

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On behalf of the COMPTON@HIγS collaboration

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Outline

- Introduction
  - Nucleon polarizabilities, Measuring polarizabilities
- Motivation
- Experiment Setup
  - γ-ray production, Photon detectors and cryogenic target
- Data Analysis
  - Data reduction, Flux calibration, MC simulations and Cross section calculation
- Preliminary Results & Future Work

Introduction

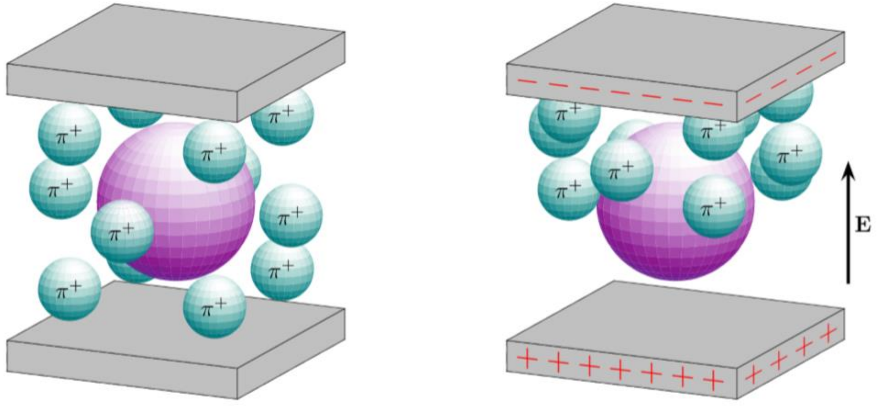
Polarizabilities (α , β)

α, β characterize nucleon response to external electromagnetic fields

They are fundamental structure properties of nucleon: vital to our understanding of the nucleon internal structure

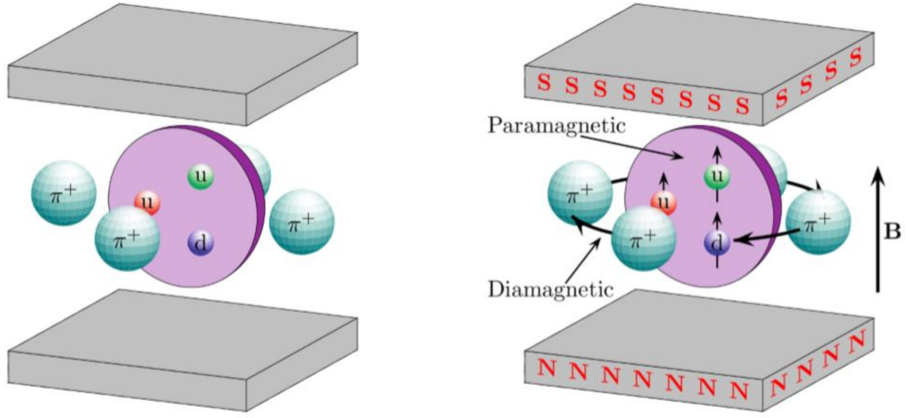
In Compton scattering, the photon provide the external electromagnetic stimulus to the nucleon

Polarizabilities can be accessed via Compton scattering cross sections



(a) Electric field off (b) Electric field on

$$\vec{d} = 4\pi\varepsilon_0\,\alpha\,\vec{E}$$



(a) Magnetic field off (b) Magnetic field on

$$\vec{m} = 4\pi\,\mu_0^{-1}\,\beta\,\vec{B}$$

P. Martel (2013)

Introduction

Measuring nucleon polarizabilities

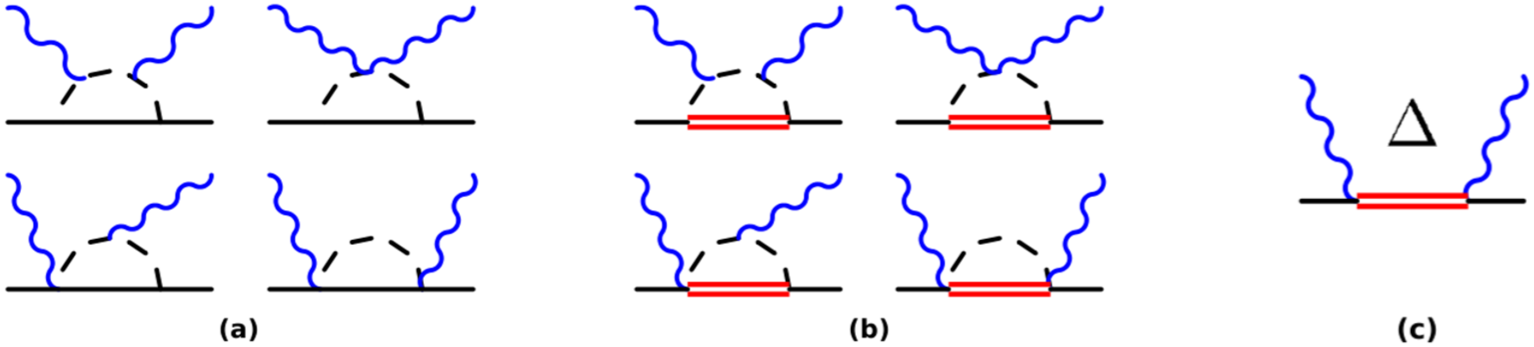
- Proton polarizabilities
  - Compton scattering from liquid hydrogen targets
  - Has a relatively large data set
- Neutron polarizabilities
  - No free and dense neutron targets (lifetime ~15 mins)
  - Charge-neutral (No Thomson scattering)
  - Deuterium elastic scattering d(γ,γ)d
    - Provide a stable and dense neutron target
    - Proton's Thomson term constructively interfere with neutron polarizability term
    - $\sigma_d(\omega) \approx (\alpha_n + \alpha_p)\omega^2$

Chiral effective field theory (χEFT)

Most comprehensive theoretical interpretation of nucleon Compton scattering

χEFT uses nucleons and pions as active degrees of freedom

Include the delta resonance Δ(1232) as an explicit degree of freedom



H. Grießhammer et al. (2013)

Leading order contributions to the nucleon polarizabilities. (a) Photon coupling to pion cloud around the nucleon. (b) photon coupling to pion cloud around the Δ(1232) and (c) Δ(1232) excitation

Motivation

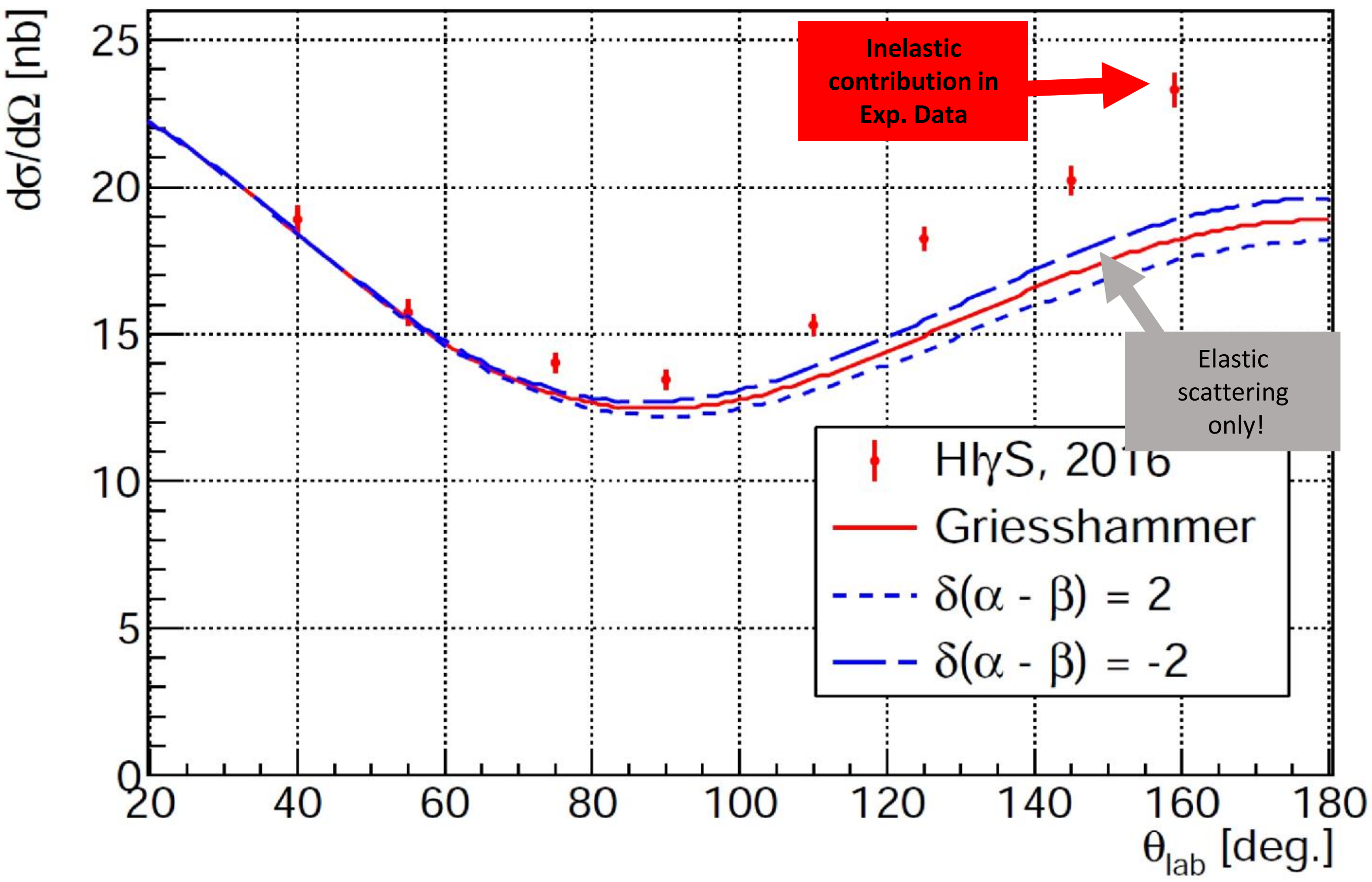
In 2016, HIγS measured the 8-point angular distribution of d(γ,γ)d cross section at 65 and 85 MeV

Measured cross sections rose above the χFET prediction at both energies. Discrepancy is greater at backward-scattering angles

χFET is not yet extended to include inelastic scattering

Discrepancy is qualitatively explained by the inelastic contribution to the cross section

Angular distribution of of d(γ,γ)d cross section at 65 MeV



M. Sikora et al. (2017)

Motivation

- This experiment aimed to separately measure both elastic and inelastic deuteron scattering cross sections at two backward-scattering angles, 115^0 and 150^0

- This requires the separation of an inelastic contribution just 2.2 MeV below the prominent elastic peak

- Used two large-volume high-resolution NaI detectors (DIANA and BUNI), each has better than 2% FWHM at 80 MeV

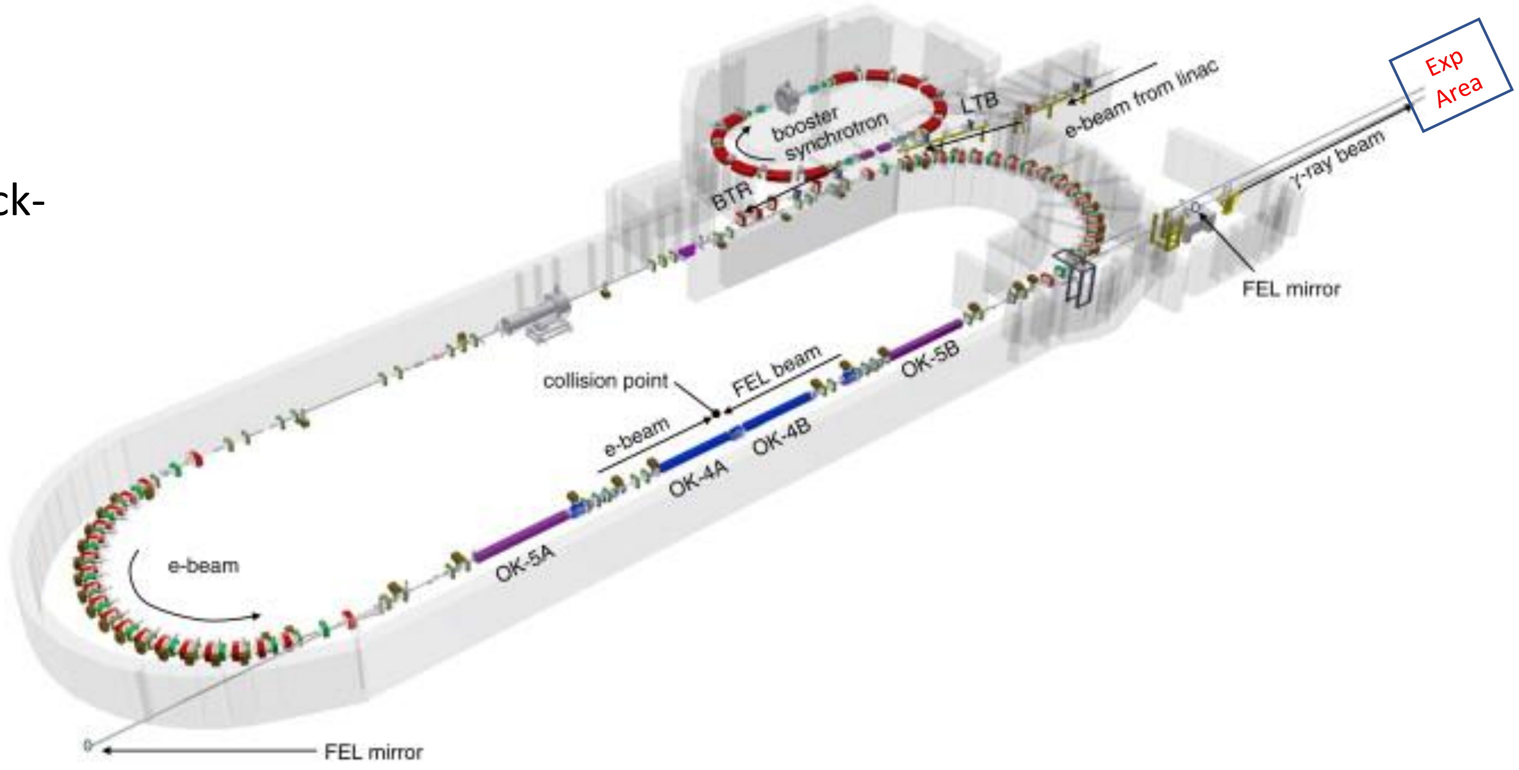
Experiment Setup

HIγS FEL facility

HIγS utilizes an ultra-violet FEL and Compton back-scattering to produce quasi-monoenergetic γ-rays

Produce γ-rays up to 120 MeV with linear or circular polarization

Able to generate ~1 x 10^7 γ/s making it the most intense γ source in operation



Layout of the HIγS facility showing the location of the linear accelerator (LINAC), booster synchrotron (BS), and the electron storage ring (ESR)

Cryogenic target

Small scattering cross sections requires the use of a cryogenic target

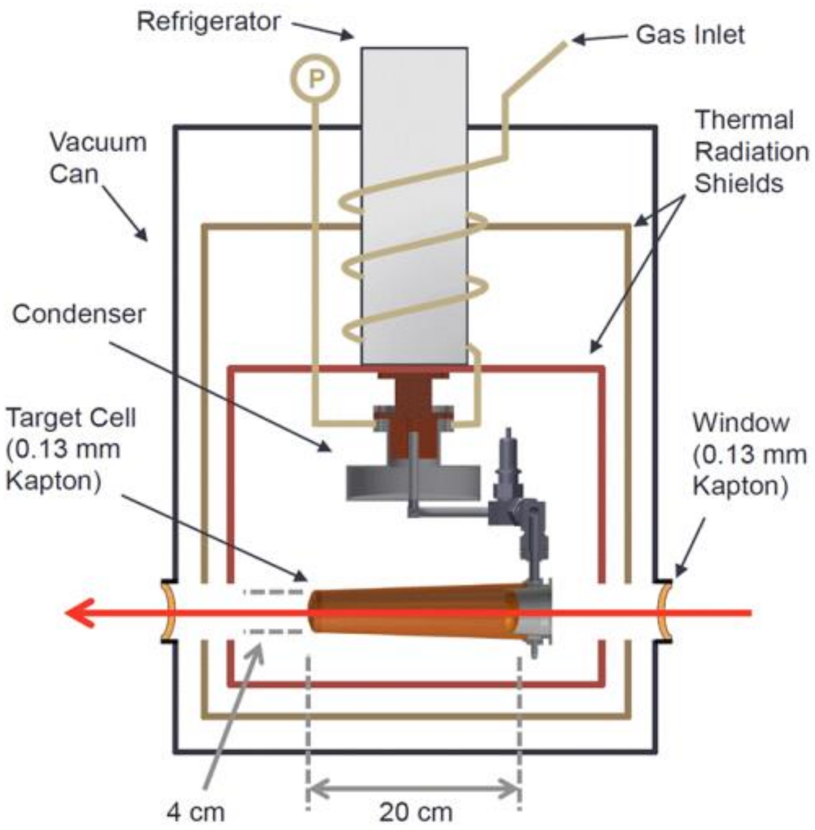
HIγS cryogenic target is capable liquifying ^{1}H, ^{2}H, ^{3}He and ^{4}He

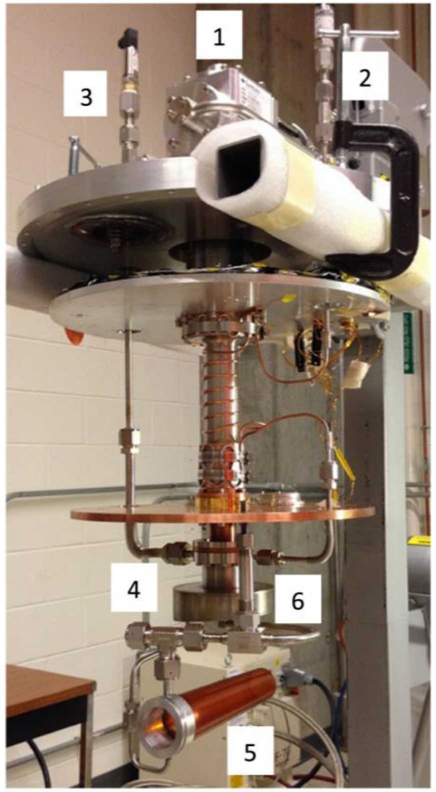
Target cell is a conical frustum made of 0.125 mm thick Kapton

The liquid is kept above the T_{tp} (18.69 K for deuterium) and below the T_c (38.34 K for deuterium)

Target cell operate above 1 atm to prevent air from leaking into the system

Target temperature and condenser pressures are recorded throughout the experiment to ensure the target's density is known to $\sim$ 1.0%



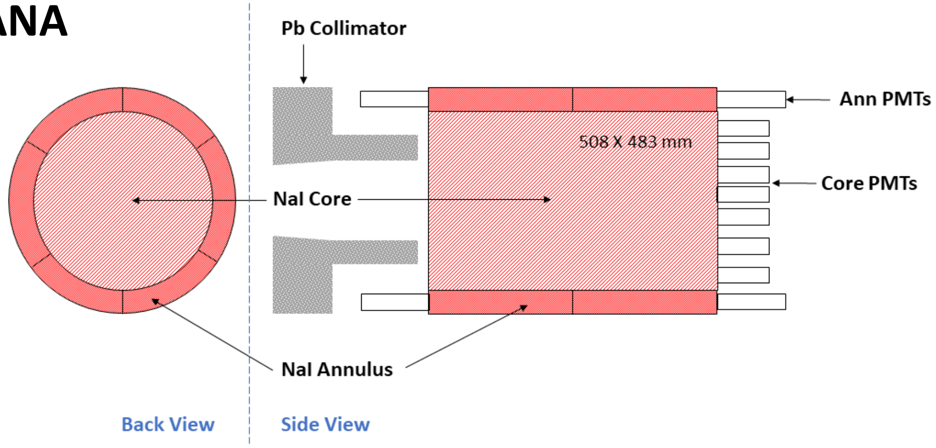


D. Kendellen et al. (2016)

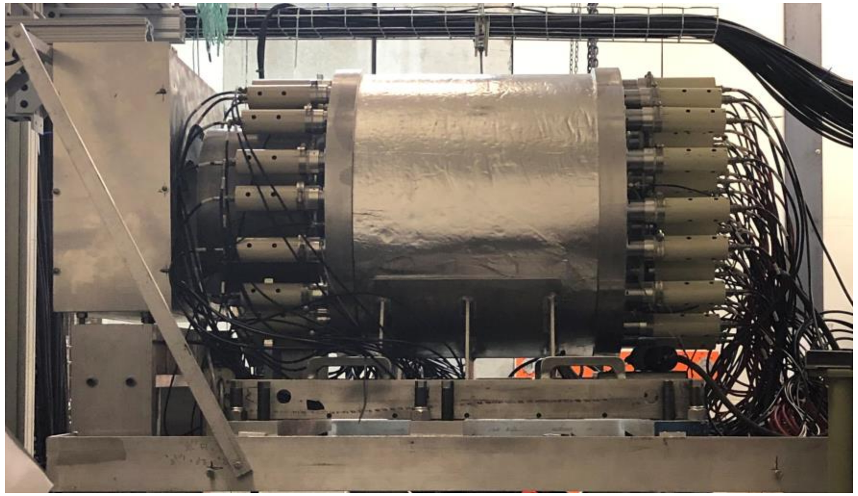
Schematic diagram and photograph of the cryogenic target

Photon detectors

DIANA

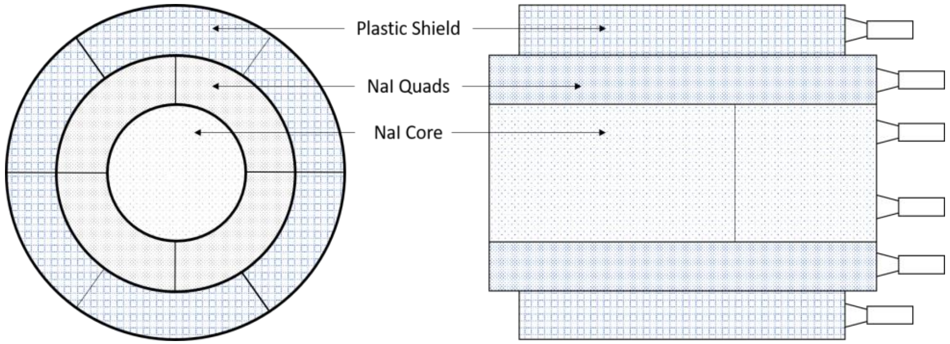


Schematic of the DIANA detector structure



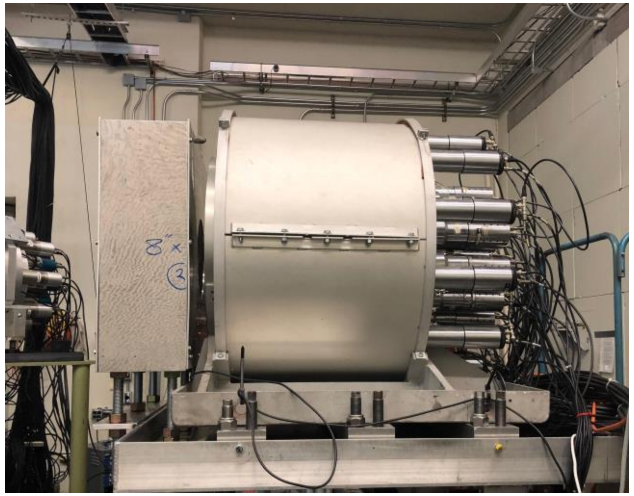
Photograph of the DIANA detector

BUNI



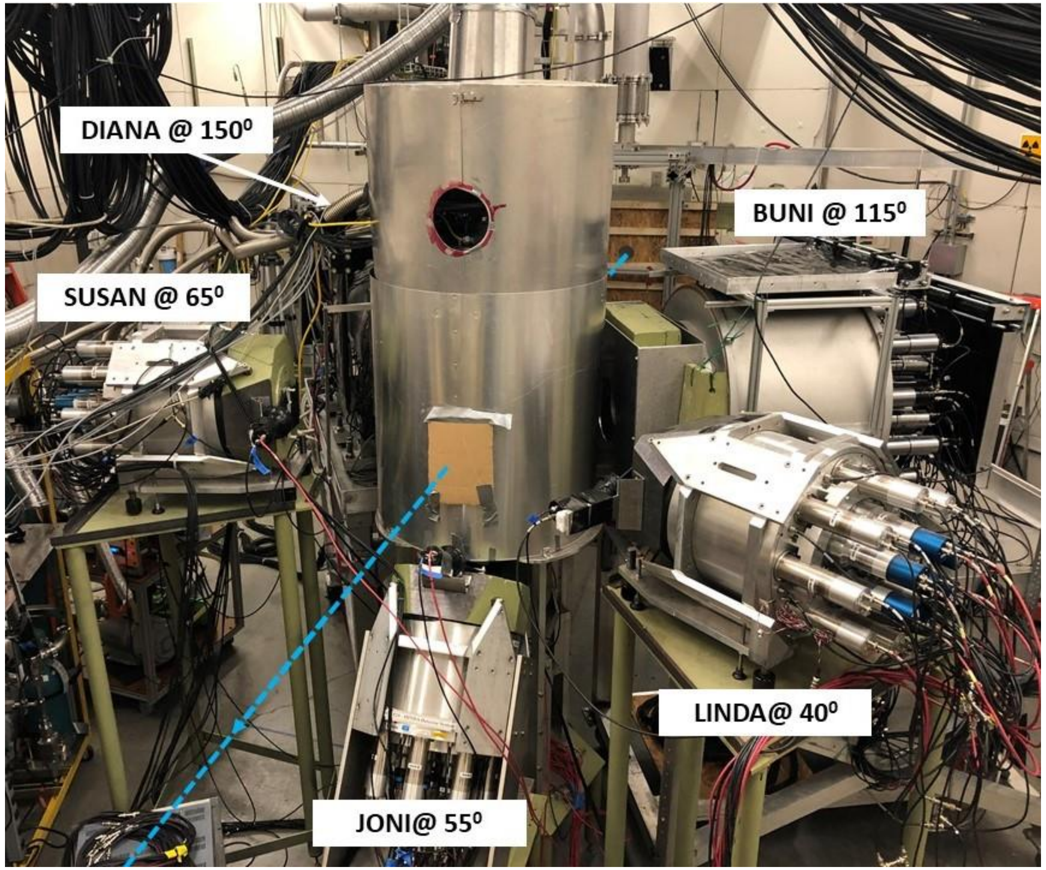
Schematic of the BUNI detector structure

Both have an overall energy resolution of 1.6 % (FWHM) at 80 MeV

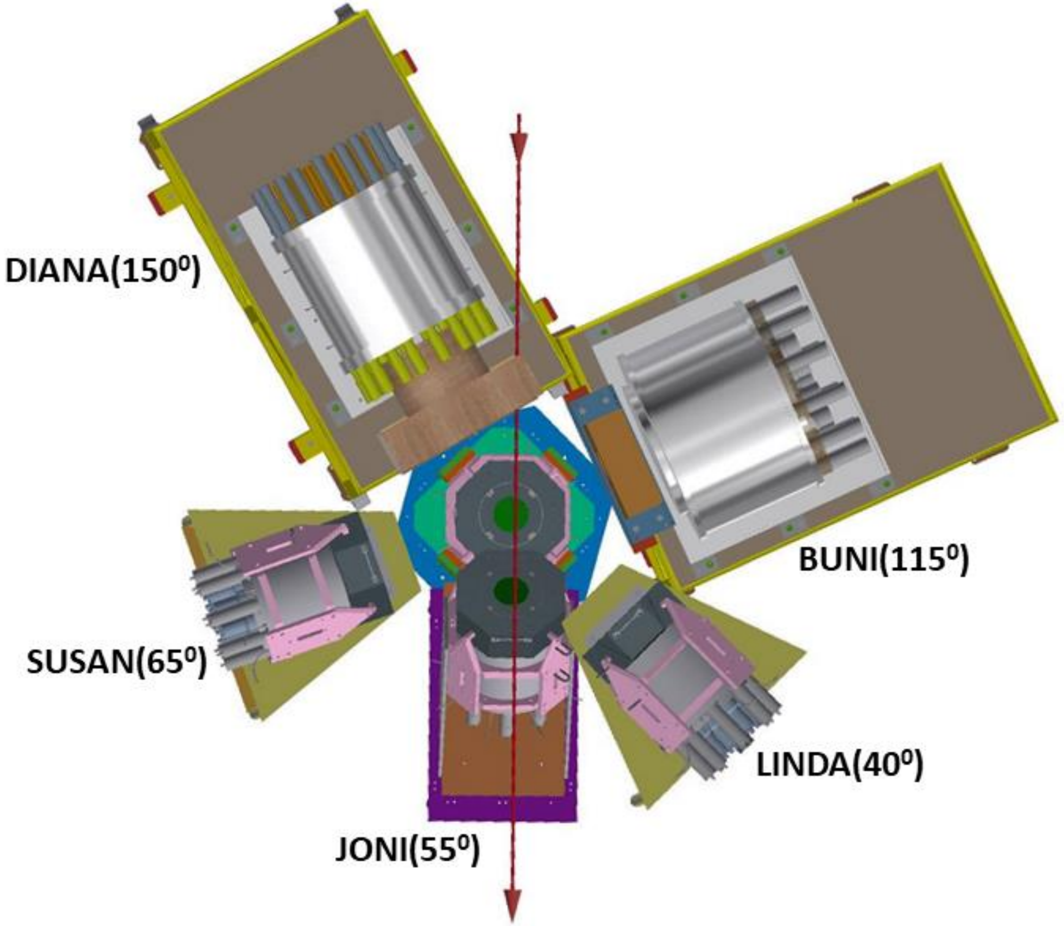


Photograph of the BUNI detector

Gamma vault



Photograph of the detector setup



The plan view of the experiment setup

Data Analysis

The Final goal of the data analysis is to calculate the differential cross section,

$$\frac{d\sigma}{d\Omega} = \frac{\underbrace{Y}_{\text{Photon yield}}}{\underbrace{N_\gamma}_{\text{Number of incident photons}} . \underbrace{f_{in} . f_{out}}_{\text{Target absorption correction factors}} . \underbrace{\kappa}_{\text{Target thickness}} . \underbrace{\eta . \Delta\Omega}_{\text{Peak efficiency and solid angle}}}$$

Photon yield
Data reduction and yield integration

Number of incident photons
Flux monitor readings

Peak efficiency and solid angle
Scattering-mode MC simulations

Target absorption correction factors
MC simulations

Target thickness
Target density analysis

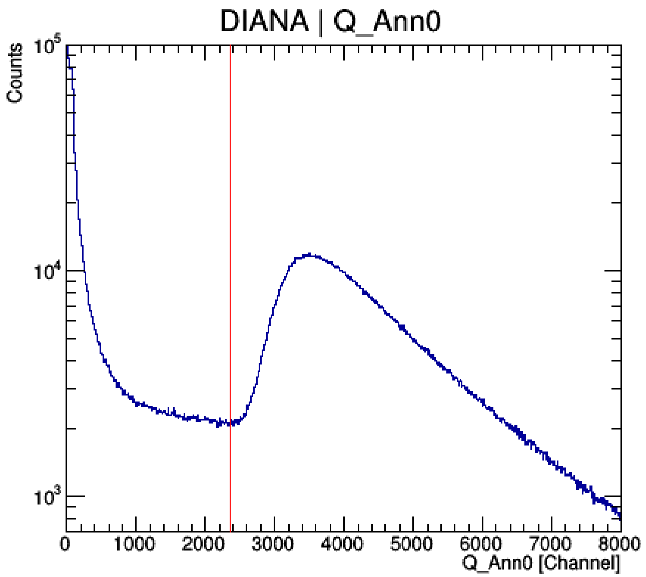
Photon yield

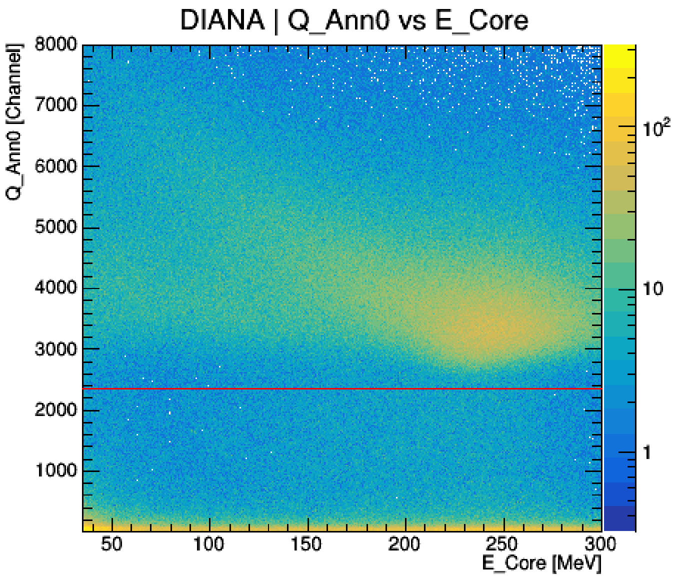
Shield Cut

Cosmic rays was the dominant source of background

Cuts on the energy spectra of annular segments veto the cosmic rays

Shield cut reduce the cosmic background by 85.0 %





(Left) Energy spectrum from one of the DIANA's annulus segments.
(Right) 2-D spectrum of energy deposition in an annulus segment vs energy deposition in the in the core. The shield cut is placed at the red line

Photon yield

ToF Cut

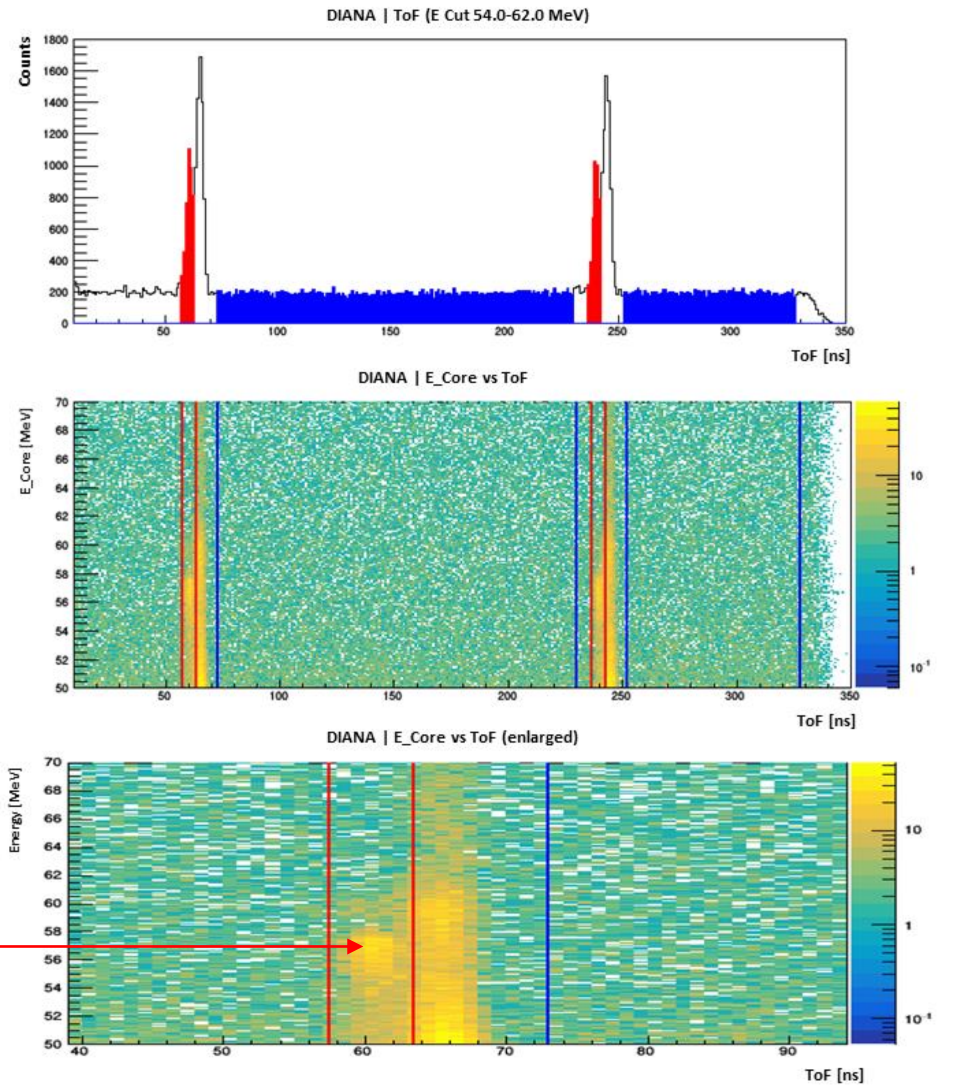
ToF of the gamma rays are measured w.r.t the pulsed beam

Provide a clean timing structure with two prompt peaks on a constant pedestal

Prompt ToF cut rejects 97.0 % of the beam-uncorrelated background

Combined shield + Prompt ToF cut reduce ~99.6% the beam-uncorrelated background

Compton scattering from ^{2}H



1-D and 2-D ToF spectra with shield cut applied

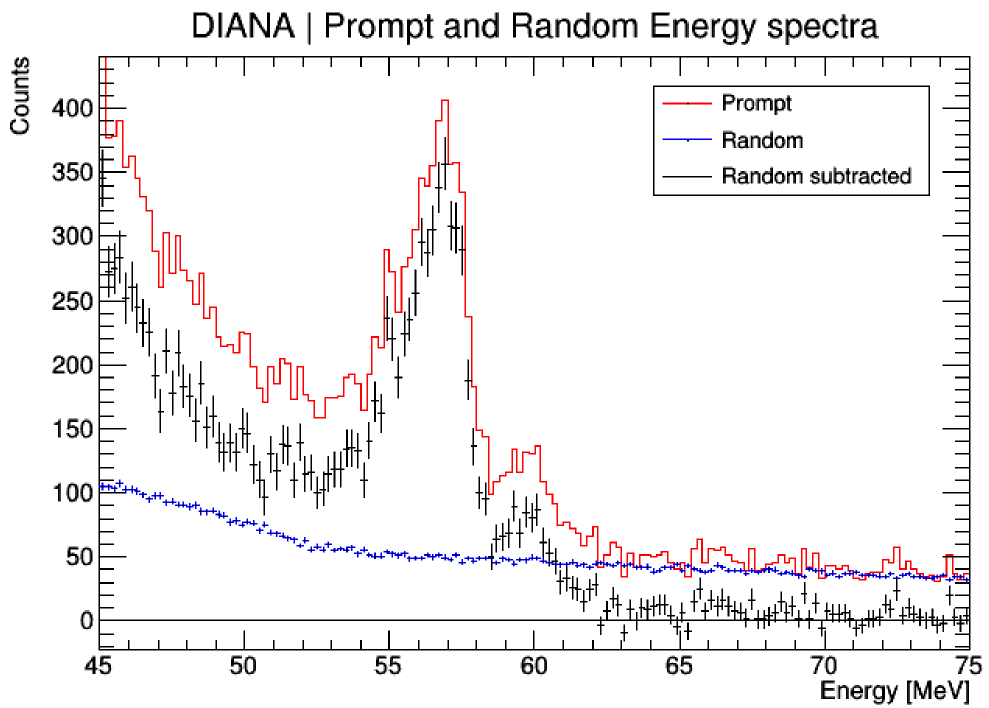
Photon yield

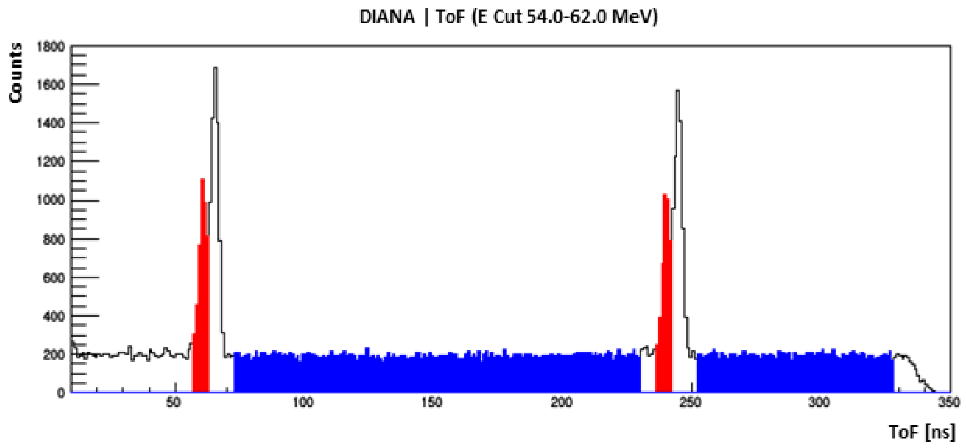
Random event subtraction

Random events subtraction reduce the residual beam-uncorrelated background from energy spectrum

Energy spectrum in the random ToF window is normalized to the relative widths of the windows

Scaled random energy spectrum is subtracted from the prompt energy spectrum bin-by-bin





Photon yield

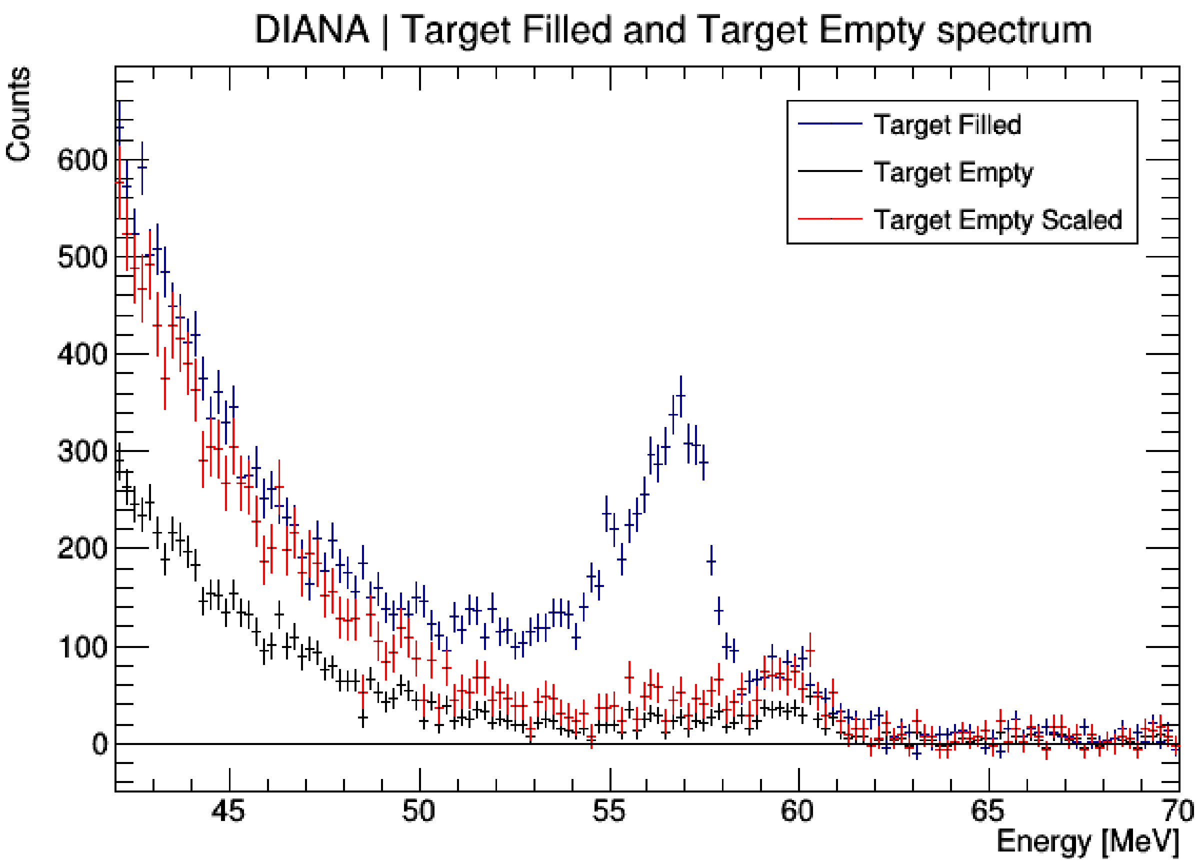
Empty target subtraction

Empty target subtraction reduce any background induced by the cryogenic target apparatus

Shield cut, ToF cut, and the random subtraction are applied target-filled and target-empty data separately

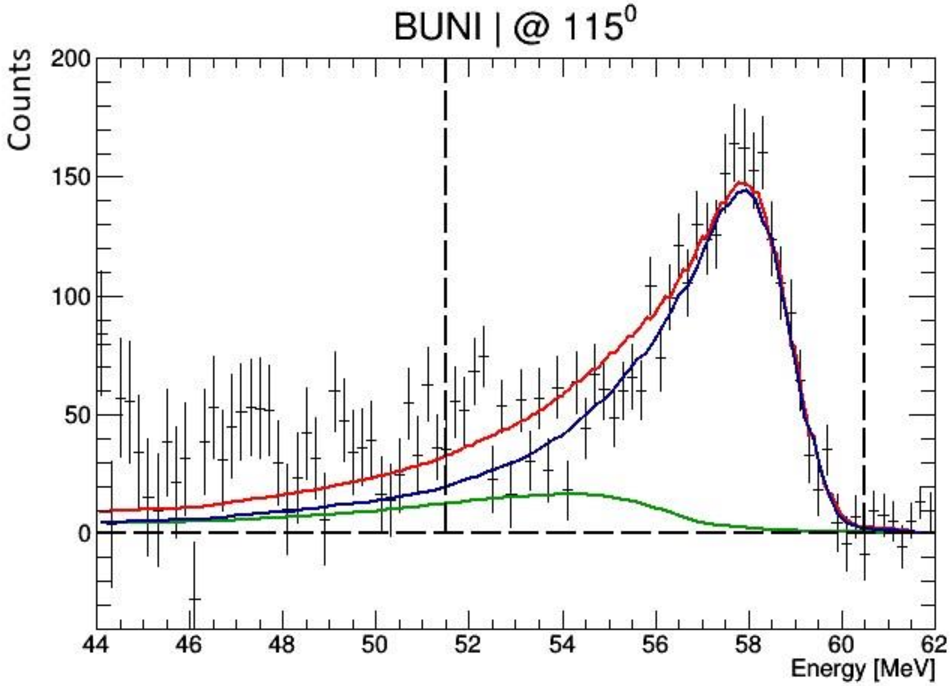
Target-empty spectrum is scaled to the relative flux incident of target-filled and target-empty runs

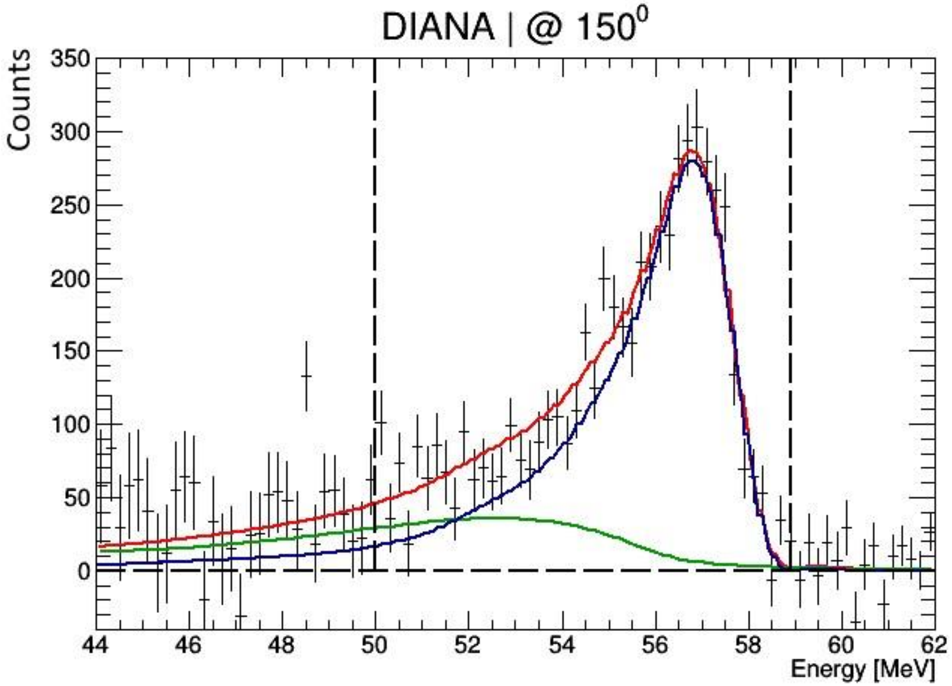
Scaled target-empty spectrum is subtracted from the target-filled spectrum bin-by-bin



Photon yield

Line shape fitting

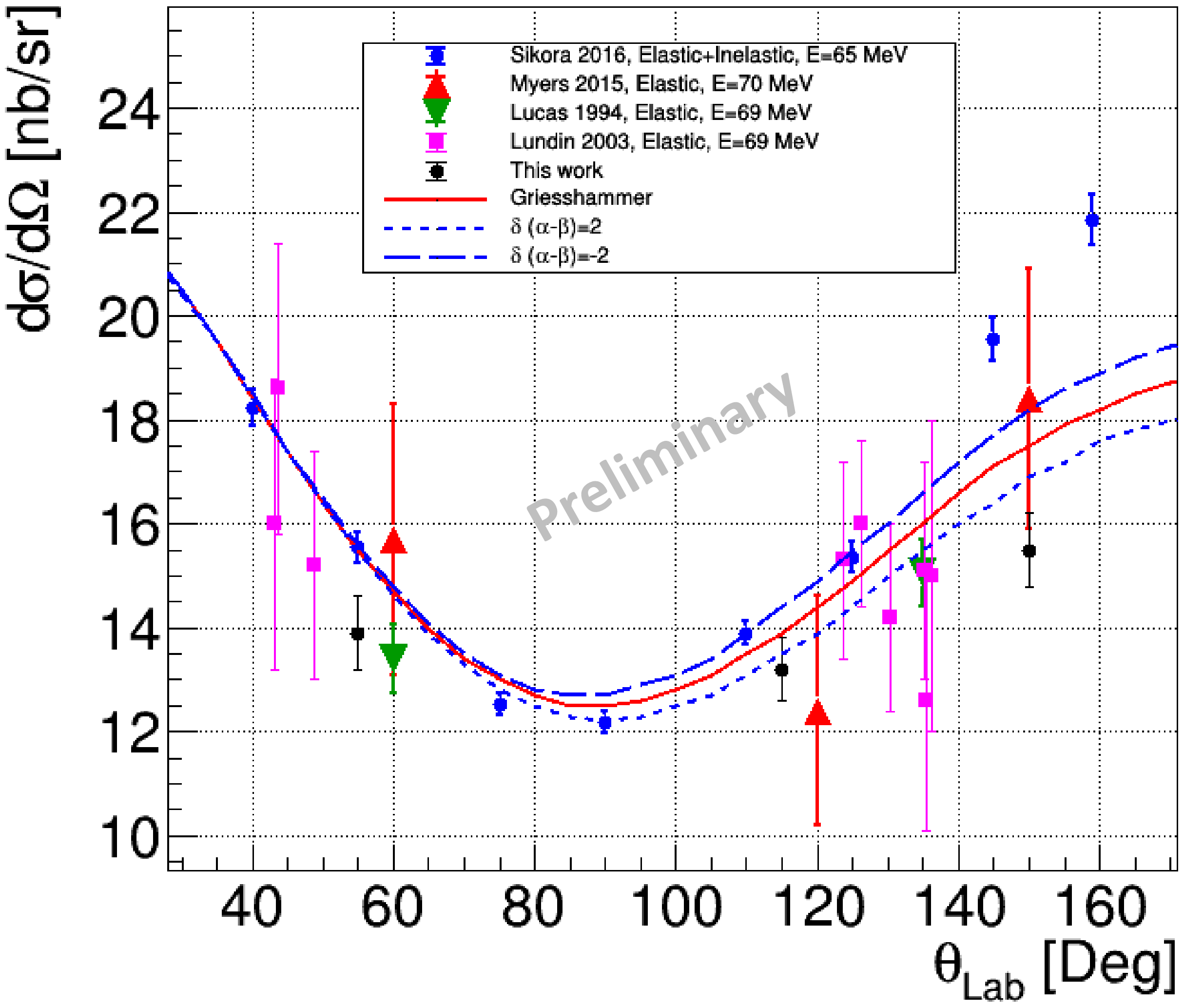




Line shape fit to the DIANA and BUNI spectrum. (Blue) Elastic line shape, (Green) inelastic line shape and (Red) the total fit. Vertical dashed lines indicate the ROI.

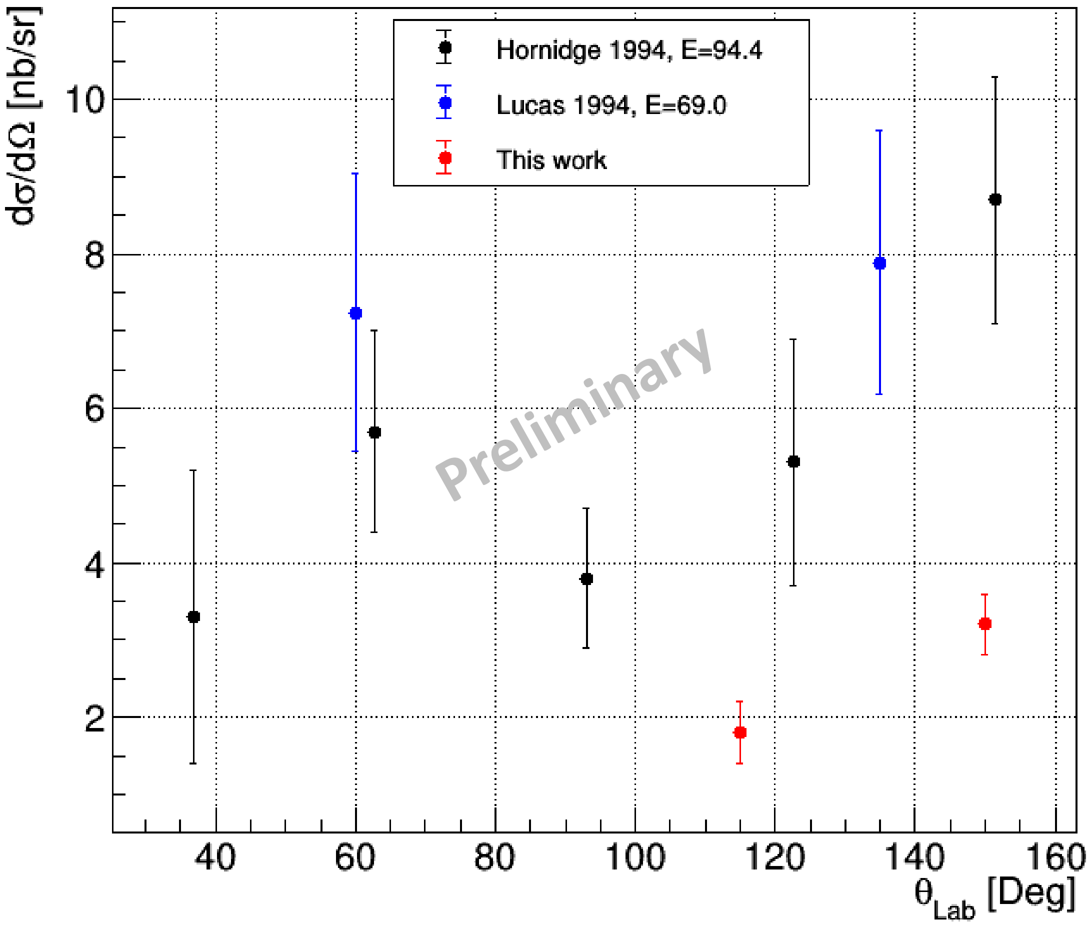
Separation energy of the elastic and inelastic line shapes were fixed to 2.2 MeV

Results



Laboratory elastic Compton scattering cross sections determined in this work compared with the results of previous experiments.

Results



Laboratory inelastic Compton scattering cross sections determined in this work compared with only other inelastic measurement in SAL1994 experiment by Hornidge et al.

Summery

- Both the elastic and inelastic d(γ,γ)d cross sections measured at 61 MeV and 81 MeV at scattering angles 115^0 and 150^0
- Cross section results will be used to extract new neutron polarizability values
- Inelastic cross sections results will provide the ability to correct 2016 HIγS results for the unresolved inelastic contribution

What’s Next …

- d(γ,γ)d at 81 MeV data analysis in progress
- ^{3}He(γ, γ)^{3}He experiment (in 2023)
  - will be carried out at 85 MeV and above
  - Will produce the world’s first-ever ^{3}He Compton scattering data
    - Higher cross sections >> better statistics
    - Easier to resolve the inelastic contribution (~5.6 MeV)
    - Provides a different linear combination (2xp + n) to benchmark χEFT model

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Thank you ! ☺