

Program of Compton Scattering Studies on Light Nuclei at HIGS

Gerald Feldman

**Department of Physics
George Washington University**



Compton@HIGS Collaboration



James E. Shepard, Founder



Introduction

- polarizability – measure of induced dipole moment in external field

electric

$$D = \alpha E$$

$$\Delta\varepsilon = -d \cdot E - \frac{1}{2} \alpha |E|^2$$

magnetic

$$M = \beta B$$

$$\Delta\varepsilon = -\mu \cdot B - \frac{1}{2} \beta |B|^2$$

$q, \mu \Rightarrow \Rightarrow \Rightarrow \Rightarrow$ **1st order response**

$\alpha, \beta \Rightarrow \Rightarrow \Rightarrow \Rightarrow$ **2nd order response**

(lowest order response of *internal* structure)

- for the free nucleon:
 - fundamental structure constants (and not so well known)
 - test of models of nucleon structure

Measuring Nucleon Polarizability

□ Proton

- Compton scattering

$$\sigma_p(\omega) \approx r_0^2 - 2 r_0 \alpha_p \omega^2$$

Measuring Nucleon Polarizability

□ Proton

- Compton scattering

$$\sigma_p(\omega) \approx r_0^2 - 2 r_0 \alpha_p \omega^2$$

□ Neutron

- difficulties

- ✓ no free neutron targets
- ✓ neutron is uncharged (no Thomson scattering)

$$\sigma_n(\omega) \approx \alpha_n^2 \omega^4$$

Measuring Nucleon Polarizability

□ Proton

- Compton scattering

$$\sigma_p(\omega) \approx r_0^2 - 2 r_0 \alpha_p \omega^2$$

□ Neutron

- difficulties

- ✓ no free neutron targets

$$\sigma_n(\omega) \approx \alpha_n^2 \omega^4$$

- ✓ neutron is uncharged (no Thomson scattering)

- techniques

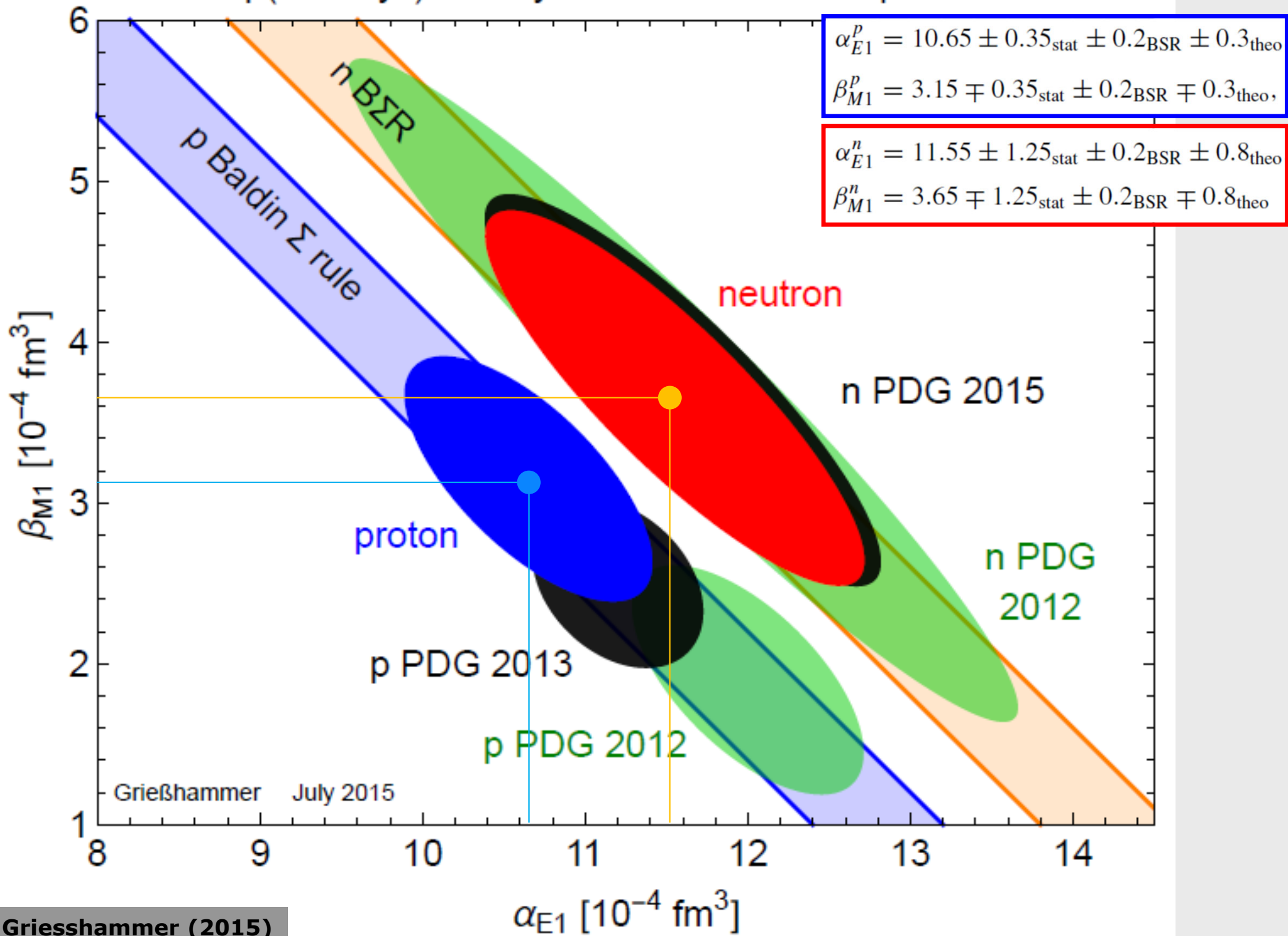
- ✓ neutron scattering by heavy nucleus

- ✓ quasi-free Compton scattering: $D(\gamma, \gamma' n)p$

- ✓ elastic Compton scattering: $D(\gamma, \gamma)D$

$$\sigma_D(\omega) \approx r_0^2 - 2 r_0 (\alpha_p + \alpha_n) \omega^2$$

exp(stat+sys)+theory/model 1 σ -error in quadrature



High Intensity Gamma-Ray Source (HIGS)

Duke University



TUNL

**Triangle Universities
Nuclear Laboratory**

**Duke University
Univ. of North Carolina
NC State University
NC Central University**

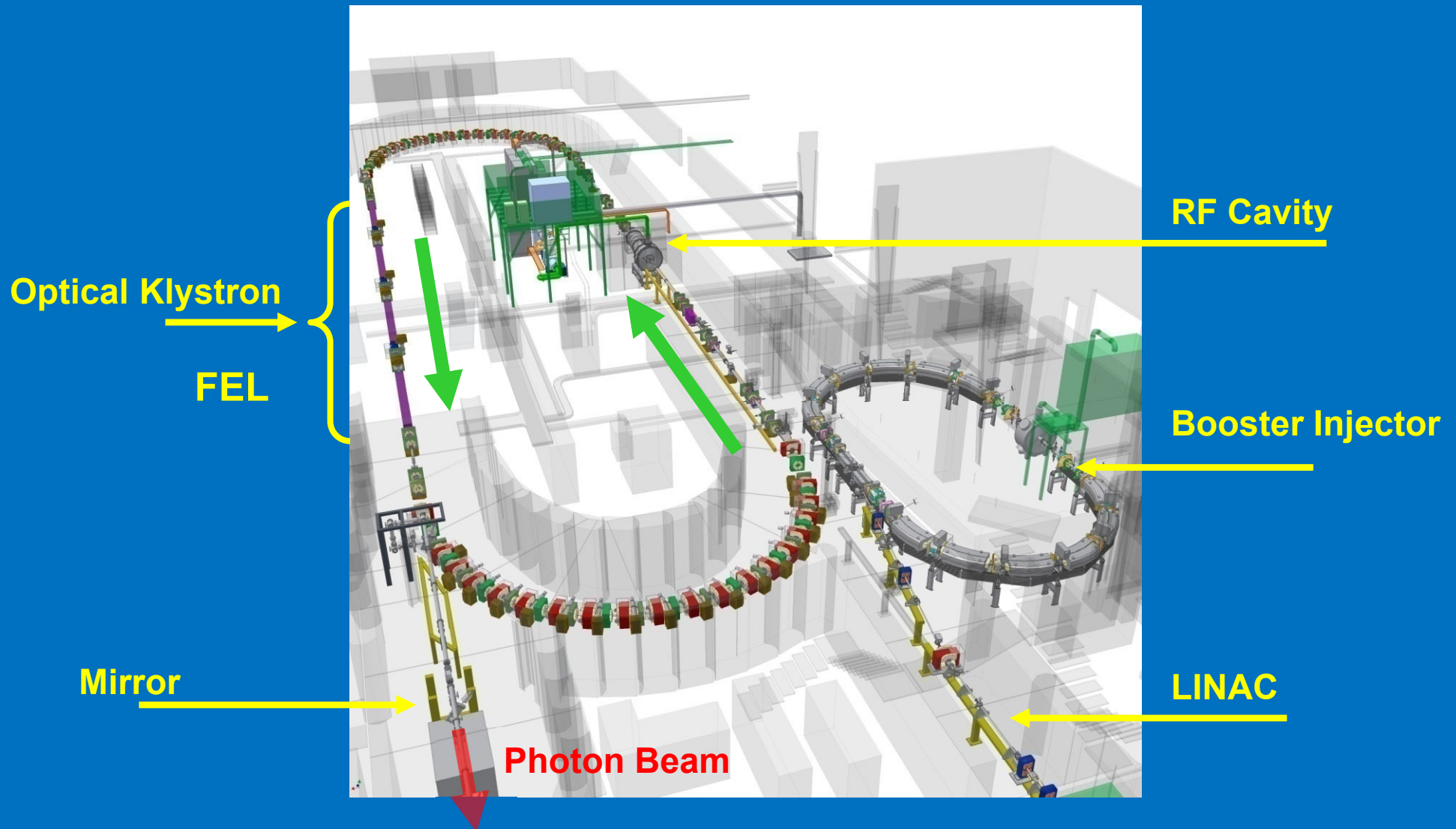


**Duke
Free-Electron
Laser Lab**

**High Intensity
Gamma-Ray Source**

Storage Ring and Booster

Circularly and linearly polarized γ rays, nearly **monoenergetic** ($E_\gamma = 1\text{--}120$ MeV)
Utilizes Compton backscattering to generate γ rays

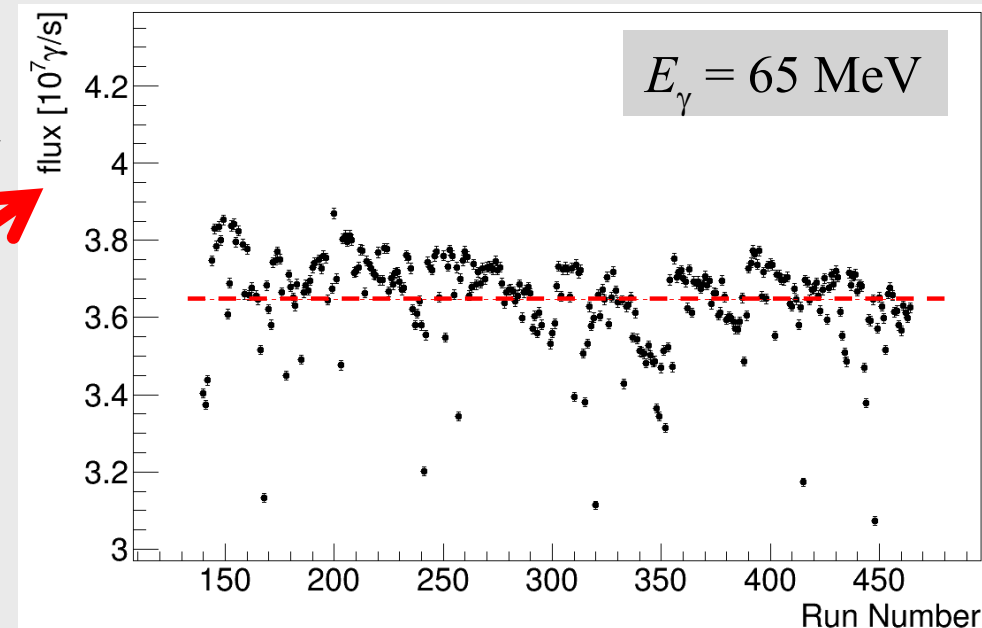


HIGS Photon Beam

- ❑ monoenergetic photons 1 - 100 MeV (soon 120 MeV)
 - beam energy resolution depends on collimation
- ❑ nearly 100% linear or circular polarization

- ❑ high photon beam intensity

- $\sim 5 \times 10^6$ Hz above 80 MeV
- $\sim 10^7$ Hz at 20-80 MeV
- $\sim 10^8$ Hz below 20 MeV



- ❑ low beam-related background

- no bremsstrahlung typical of tagged photons

Compton Scattering on ${}^4\text{He}$

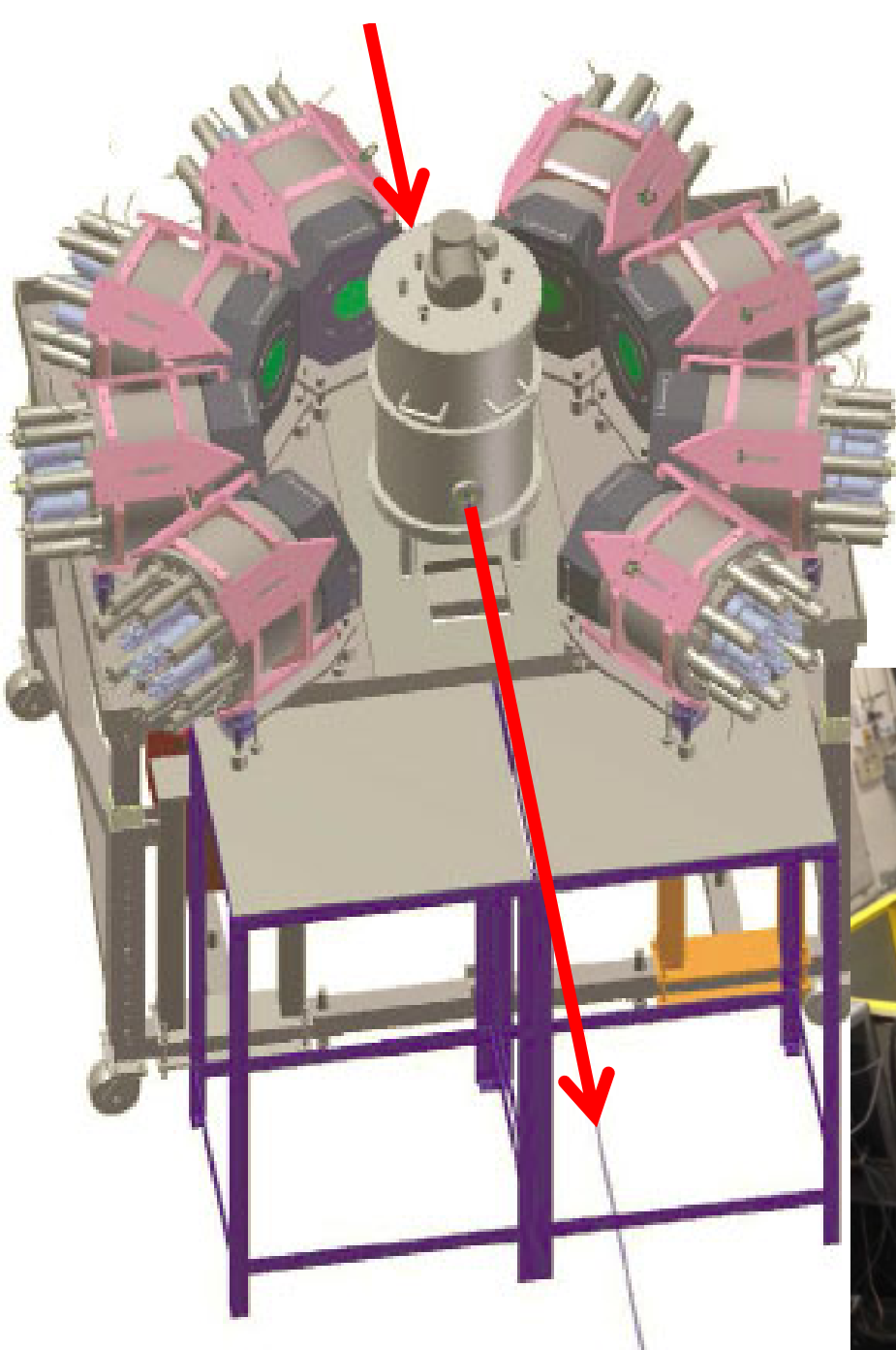
Experimental Setup

HIGS
NaI
Detector
Array

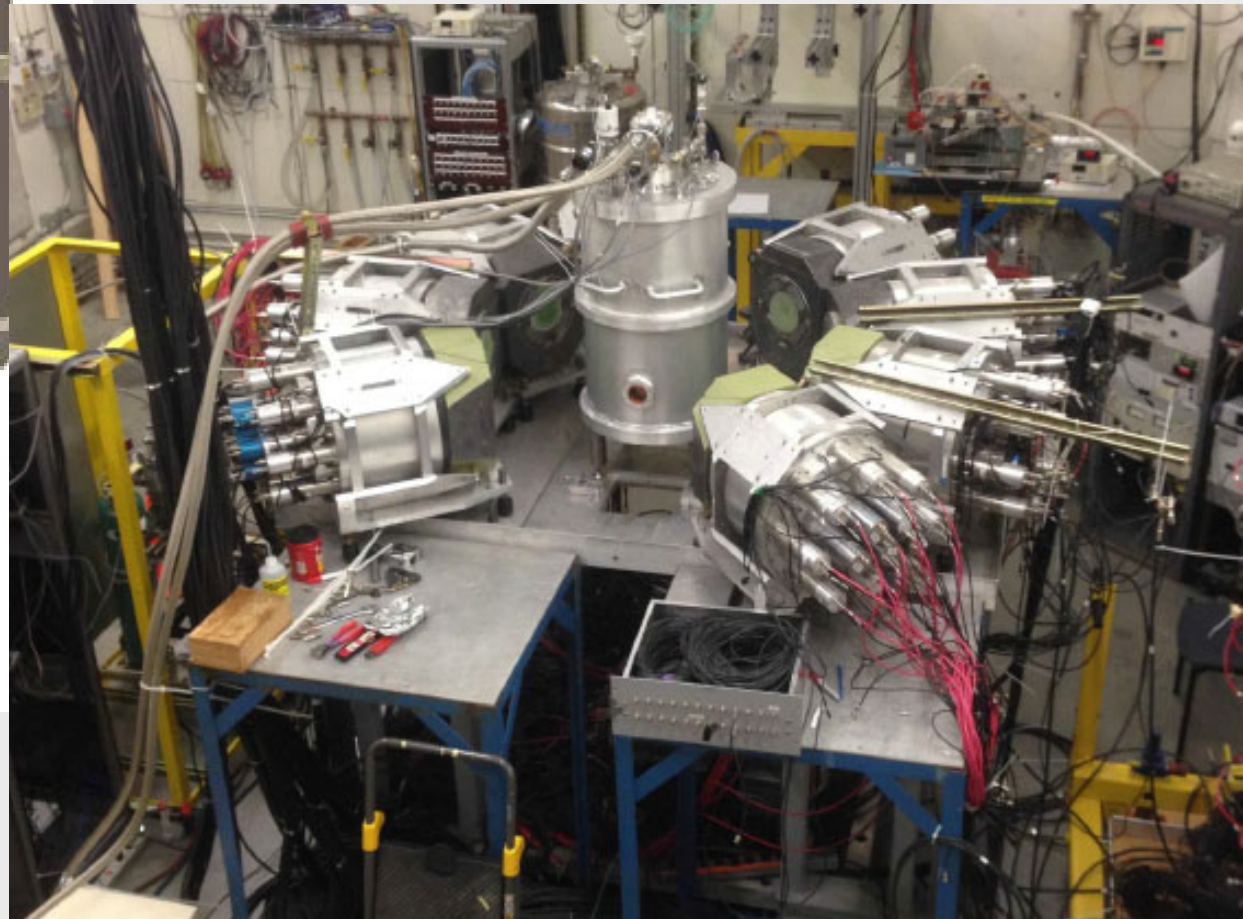
cryotarget

LH₂/LD₂/LHe

(3.5 K – 24 K)



HINDA detectors



NaI Detectors

Paraffin n shield

25 cm × 30 cm
NaI core detector

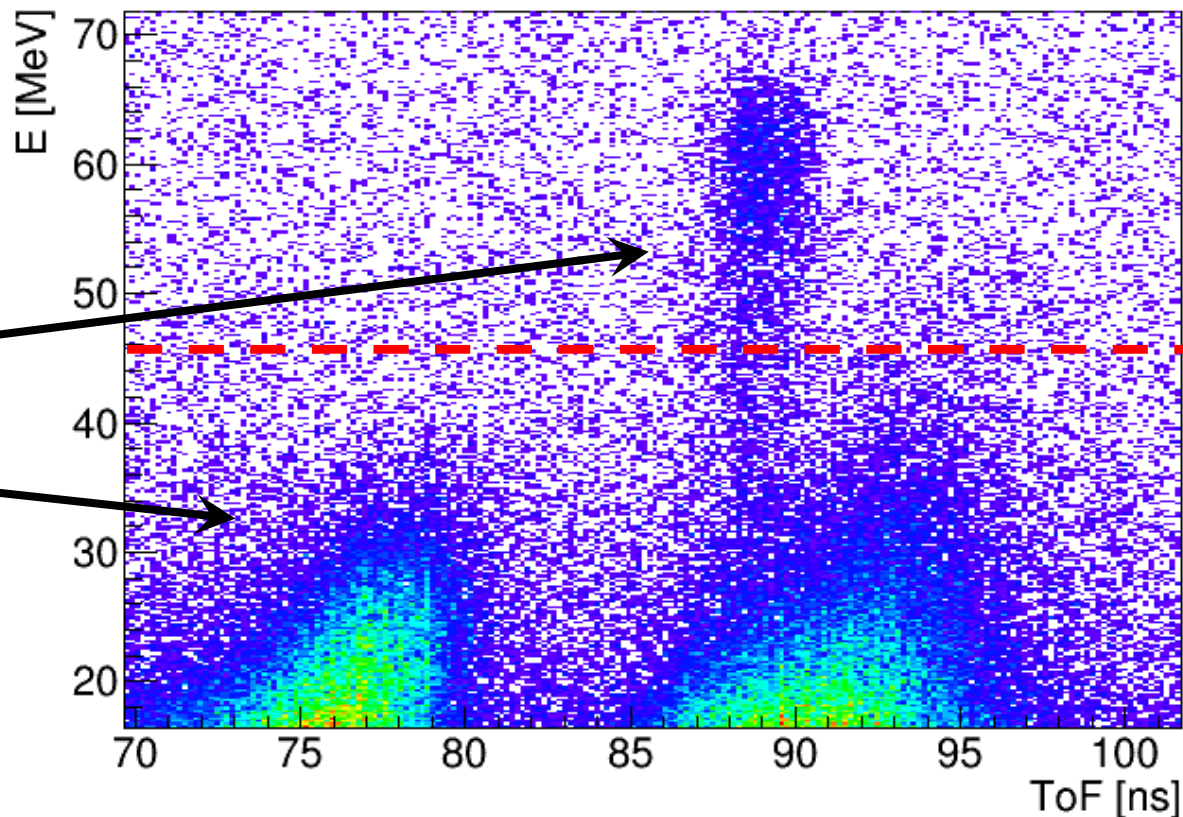
8-cm-thick optically isolated
NaI shield segments (8 in total)

Pb collimator

from the detector we obtain
energy and **timing** information

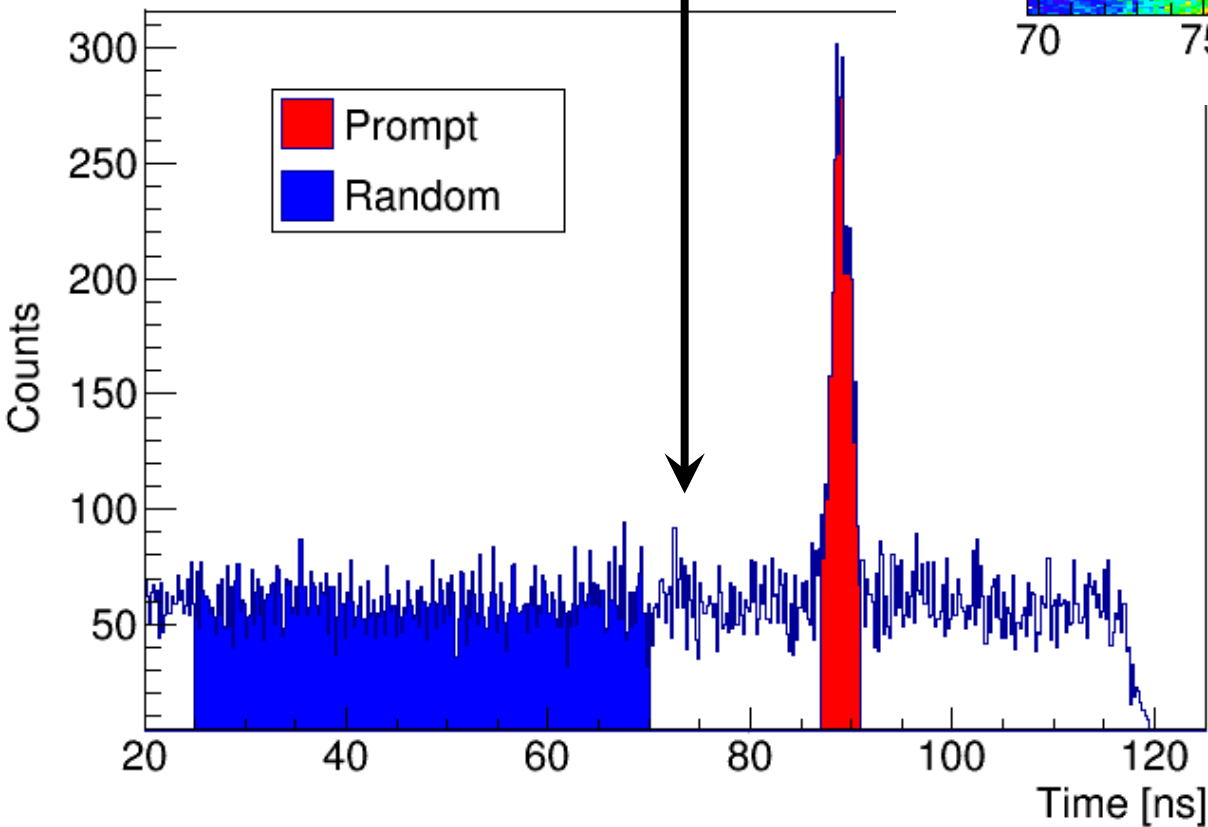


TDC Coincidence Timing



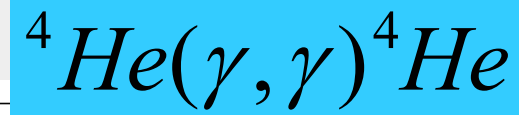
photons

neutrons

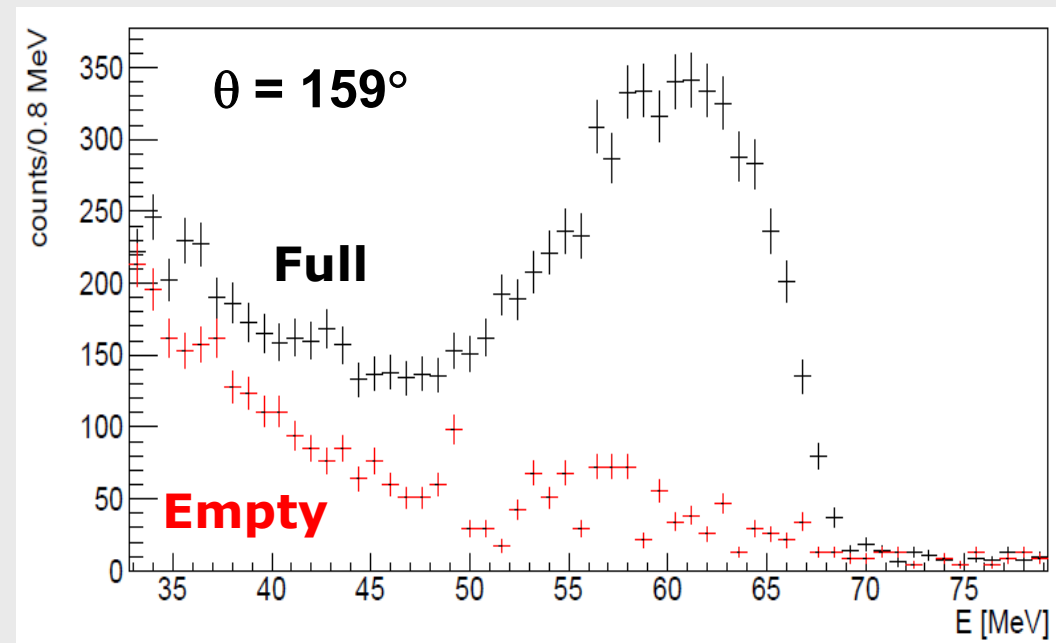
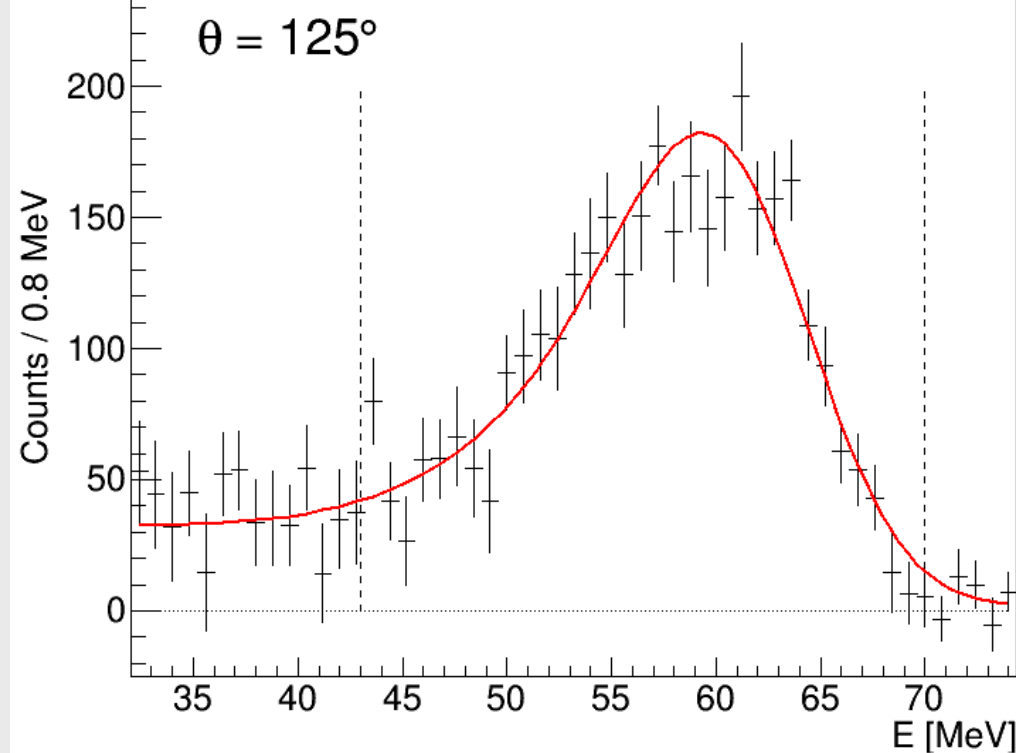
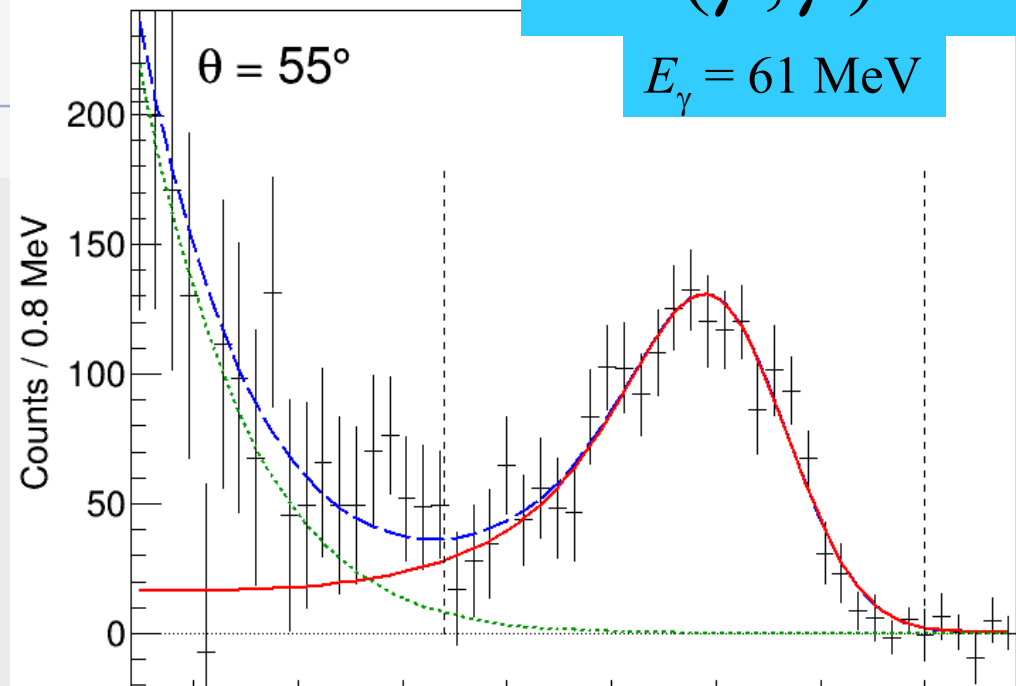


energy vs. TOF plot

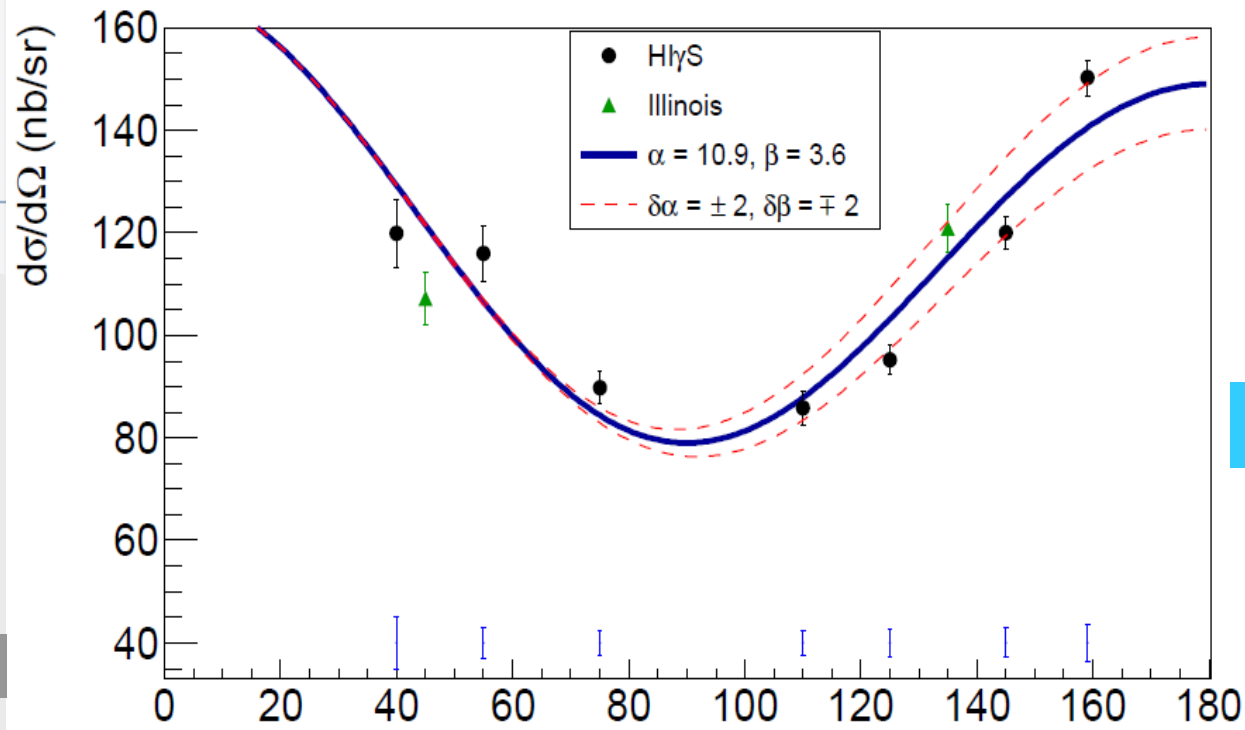
Spectra of Scattered Photons



$E_\gamma = 61 \text{ MeV}$

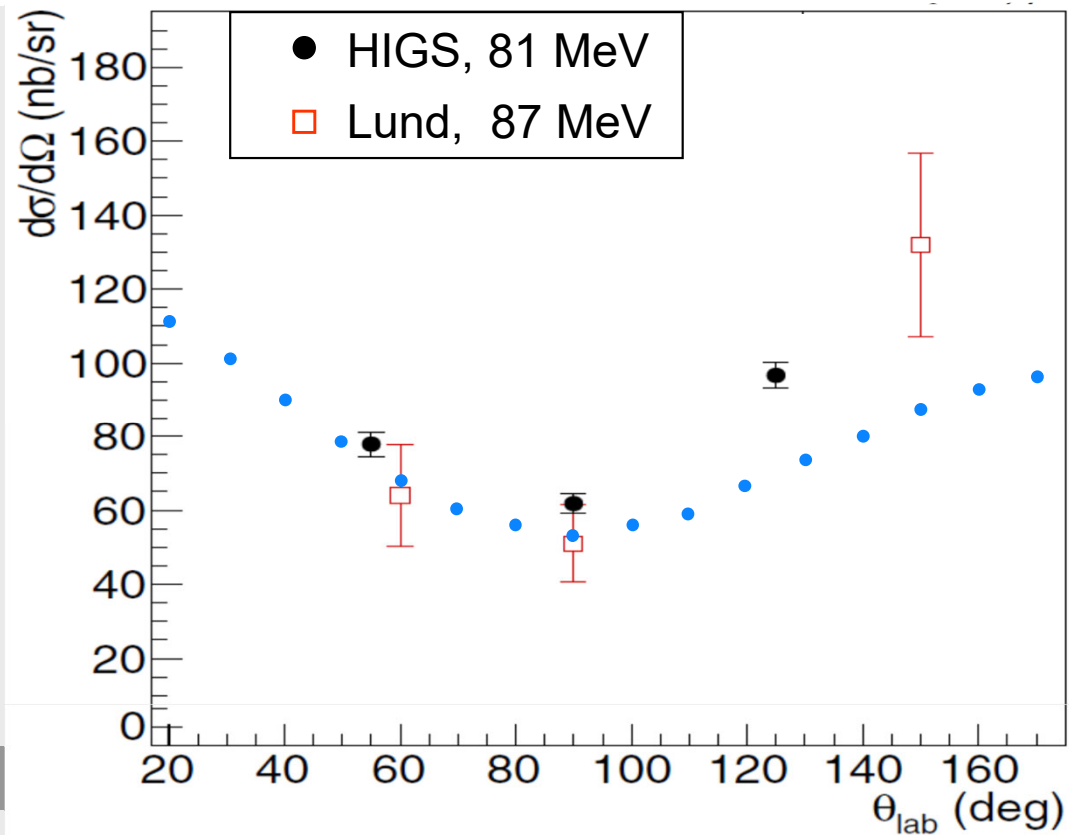


${}^4\text{He}(\gamma, \gamma){}^4\text{He}$



$E_\gamma = 61$ MeV
(54 hrs)

M. Sikora (2017)

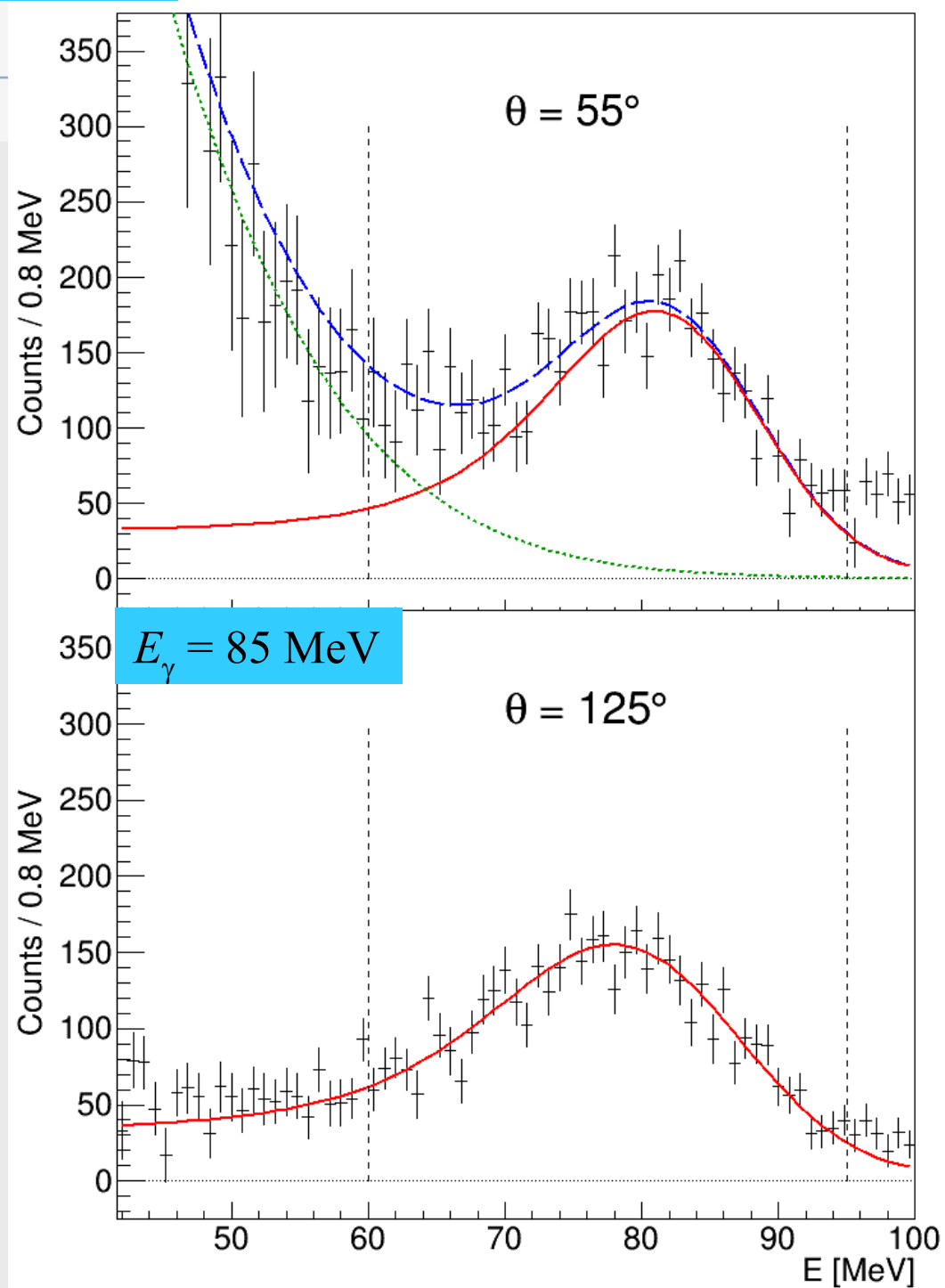
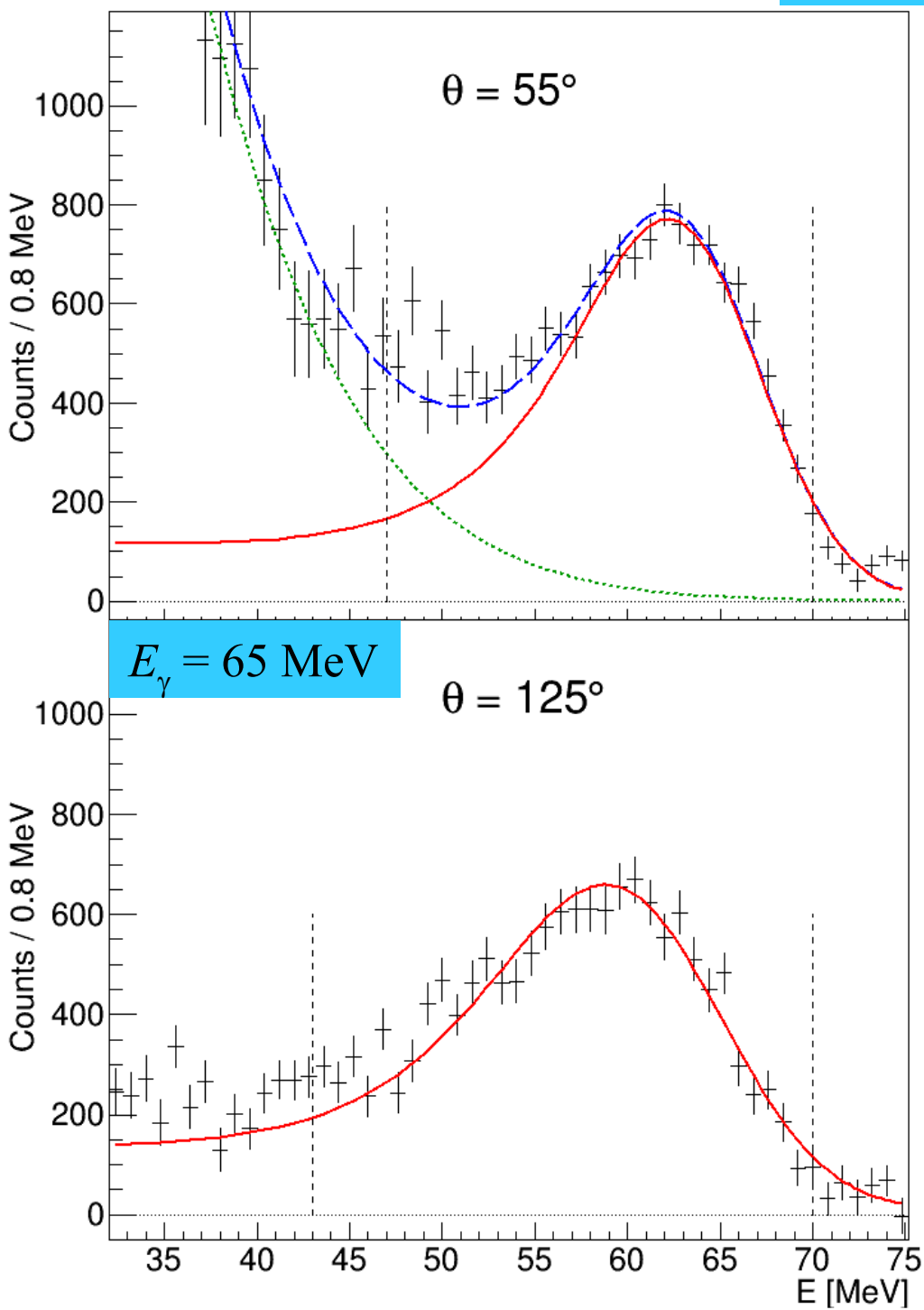


$E_\gamma = 81$ MeV
(100 hrs)

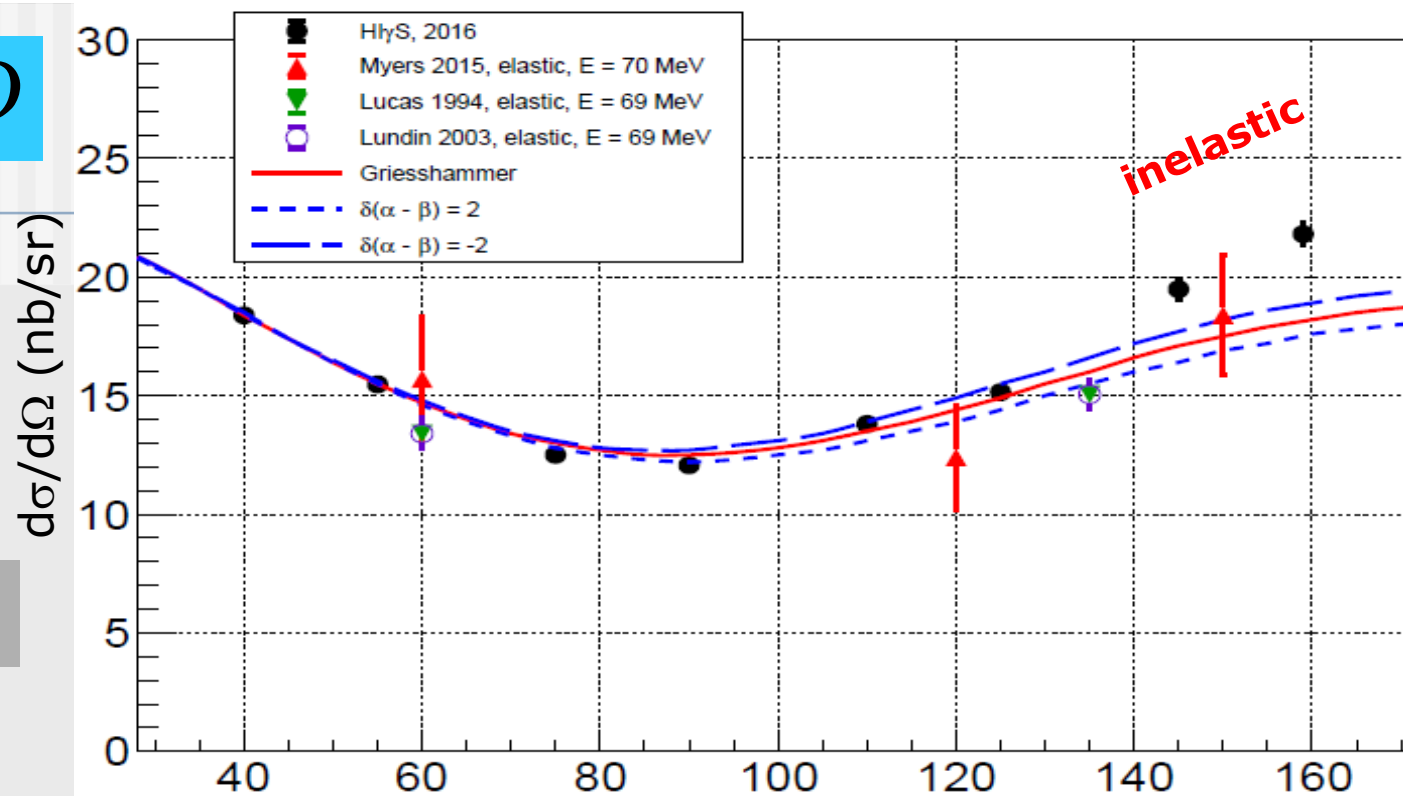
X. Li (2020)

Compton Scattering on Deuterium

$D(\gamma, \gamma)D$

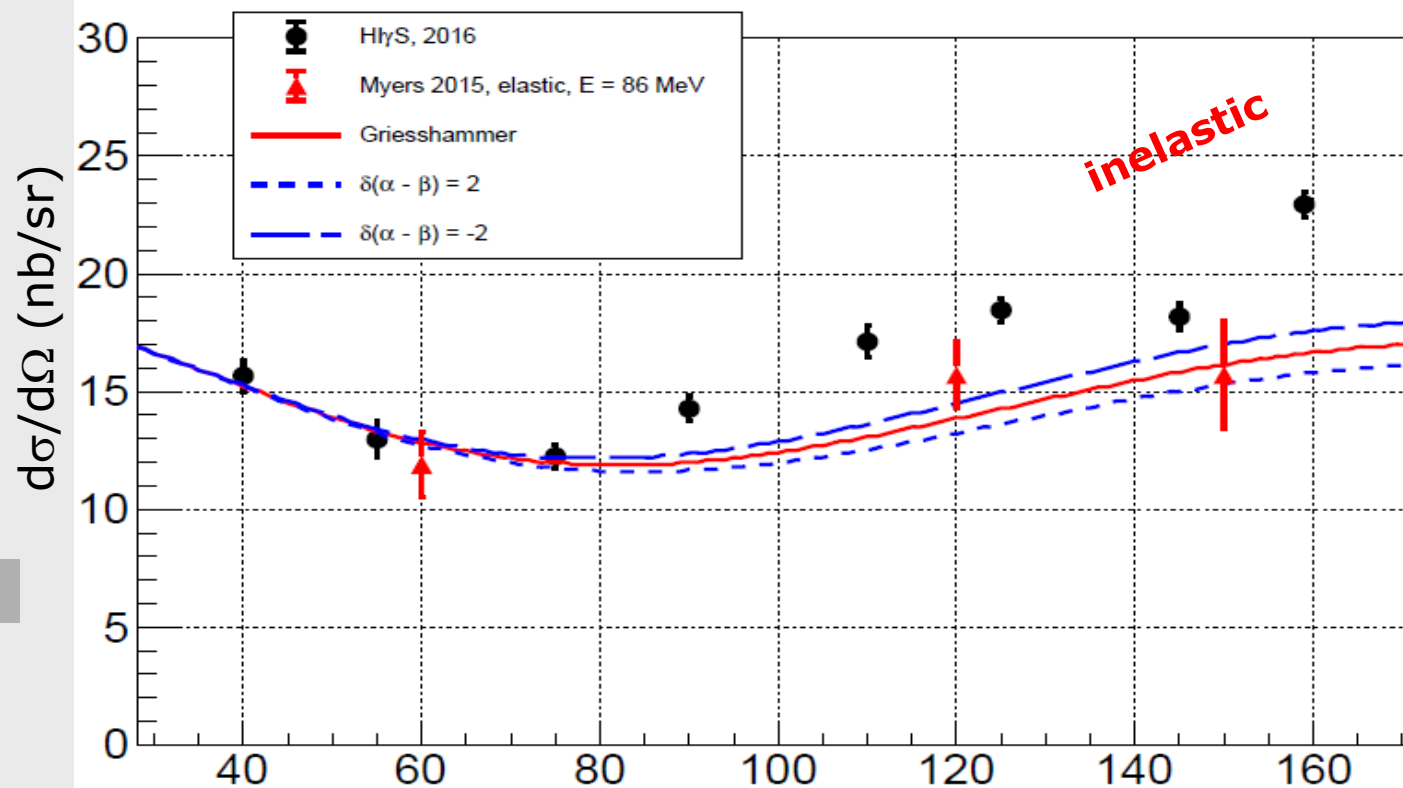


$$D(\gamma, \gamma)D$$



EFT curves
(Griesshammer)

$E_\gamma = 65$ MeV
(300 hrs)



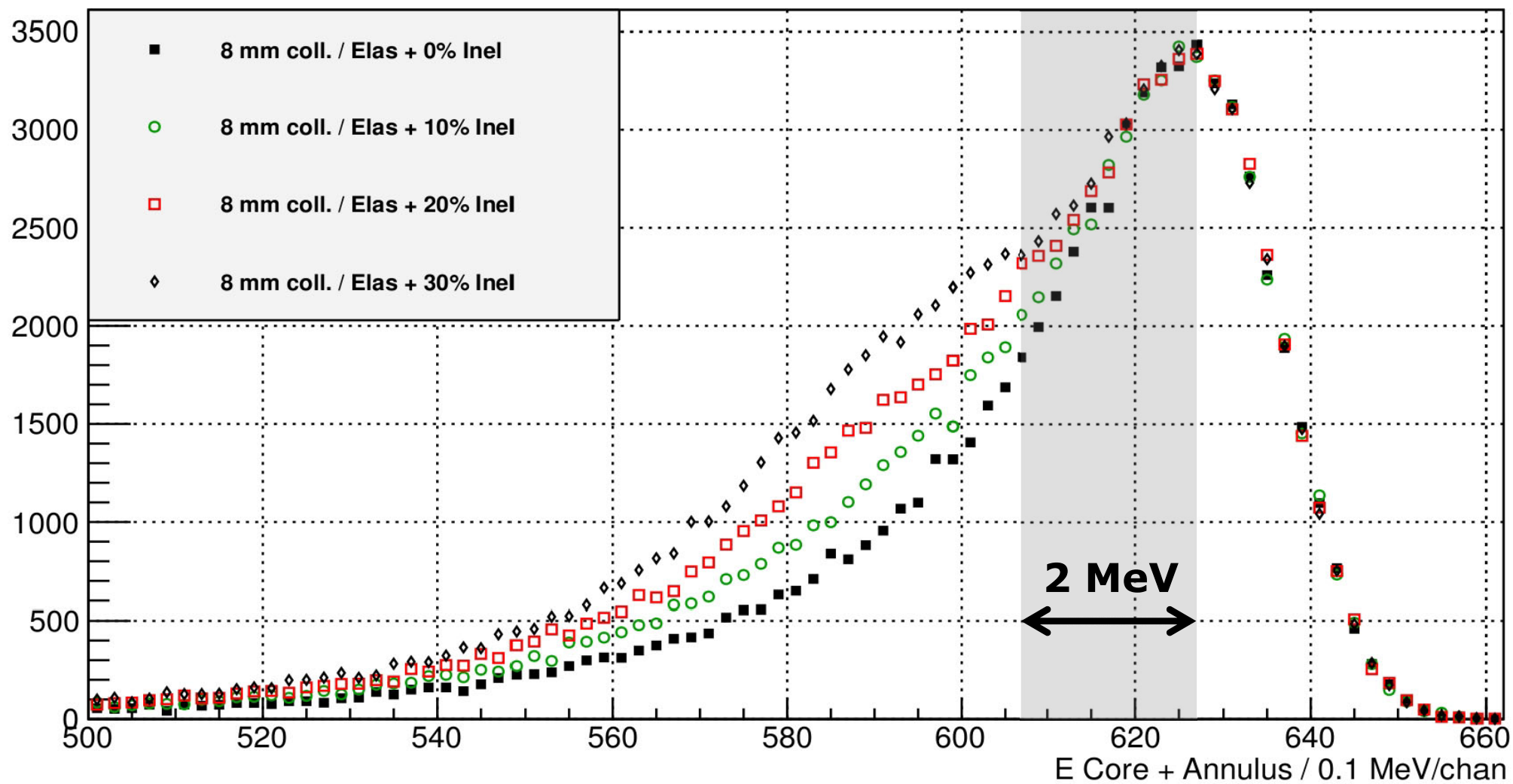
M. Sikora (2020)

$E_\gamma = 85$ MeV
(270 hrs)

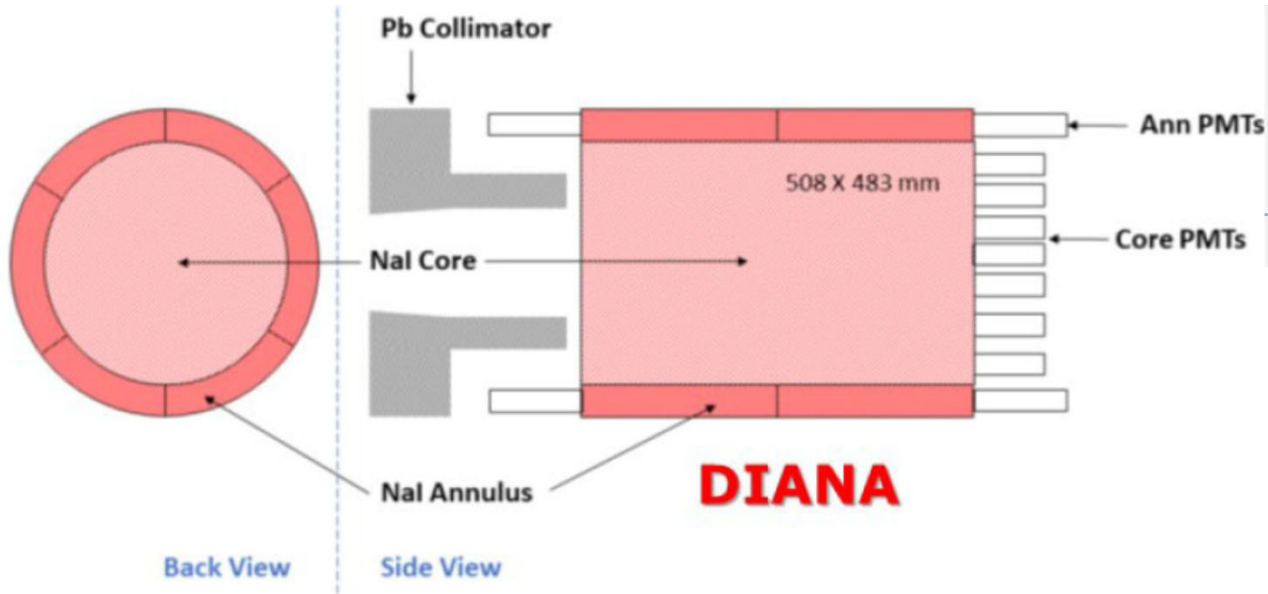
$$D(\gamma, \gamma)D$$

$E_\gamma = 62.7 \text{ MeV}$

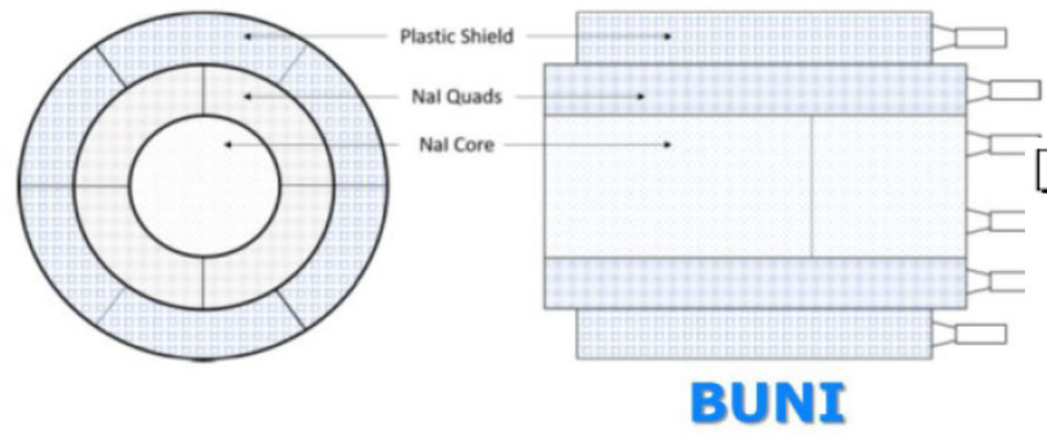
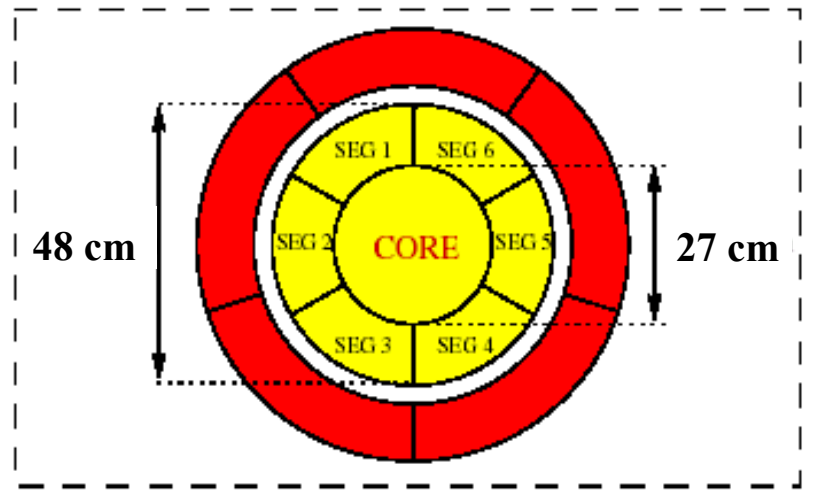
Elastic & Inelastic



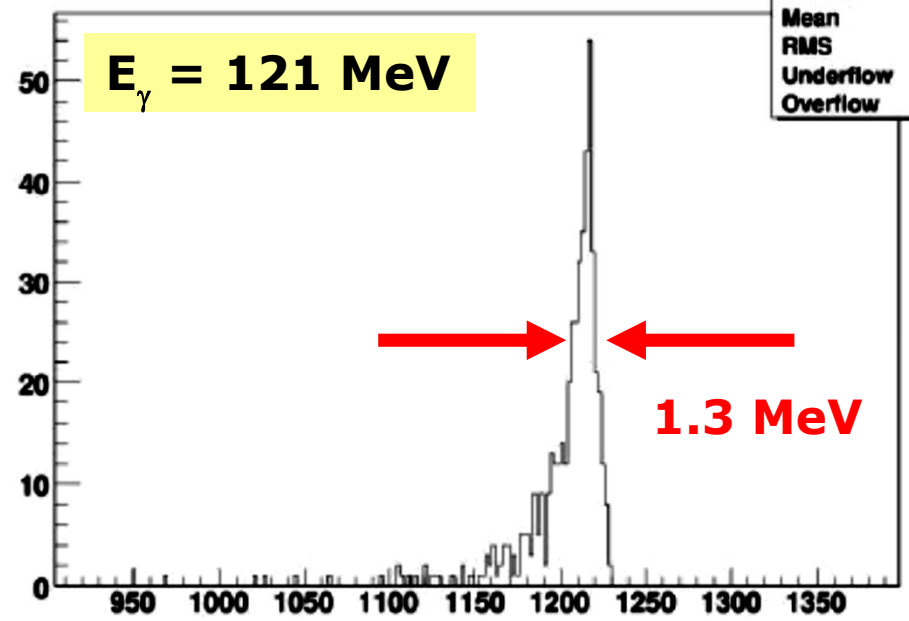
M. Kovash (2018)

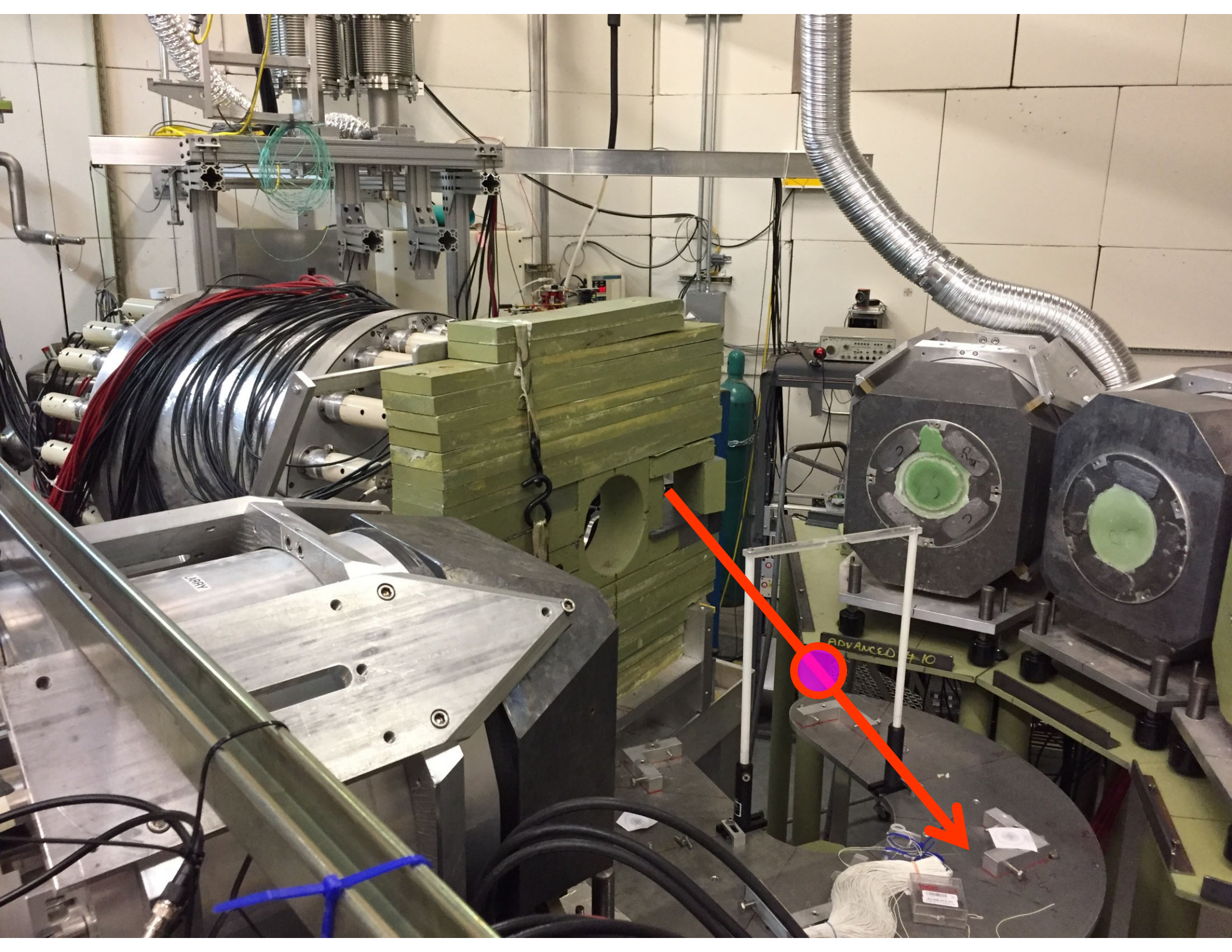


CATS
Front View



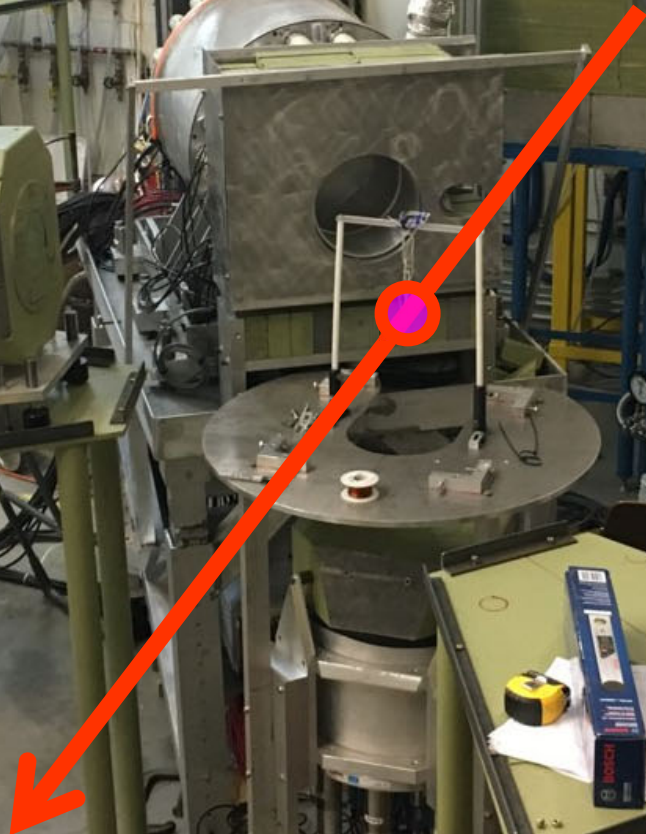
Energy Core



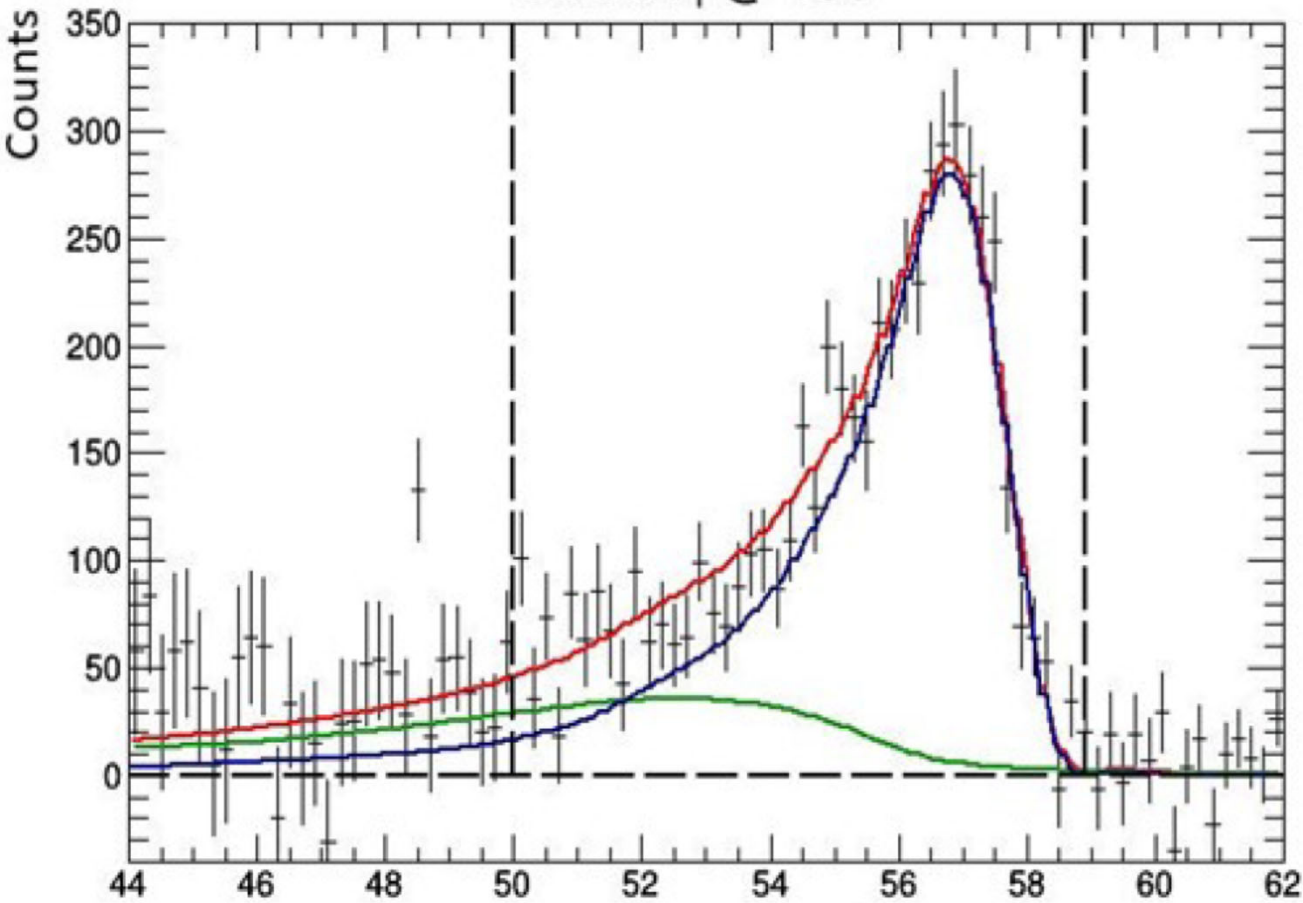


DIANA @ 150°

BUNI @ 115°



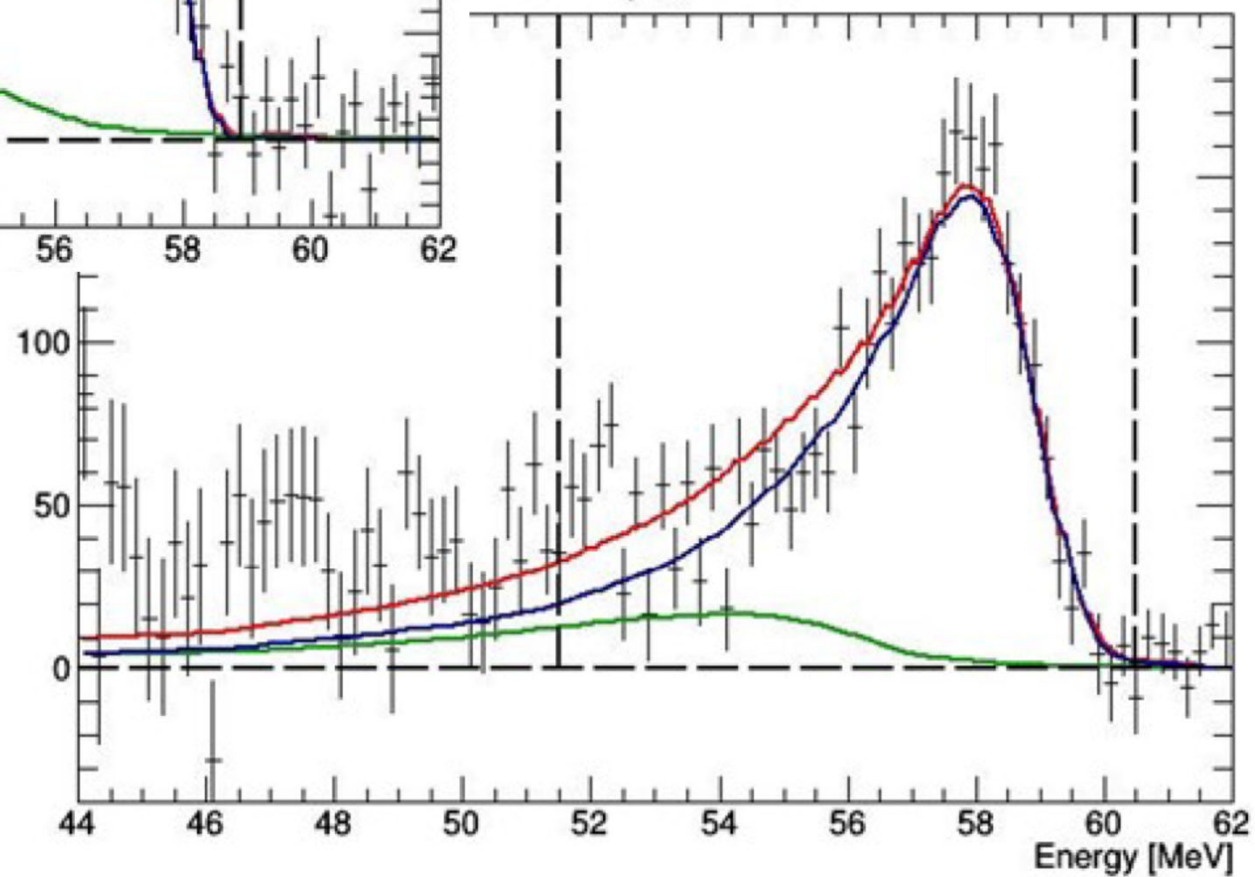
DIANA | @ 150°



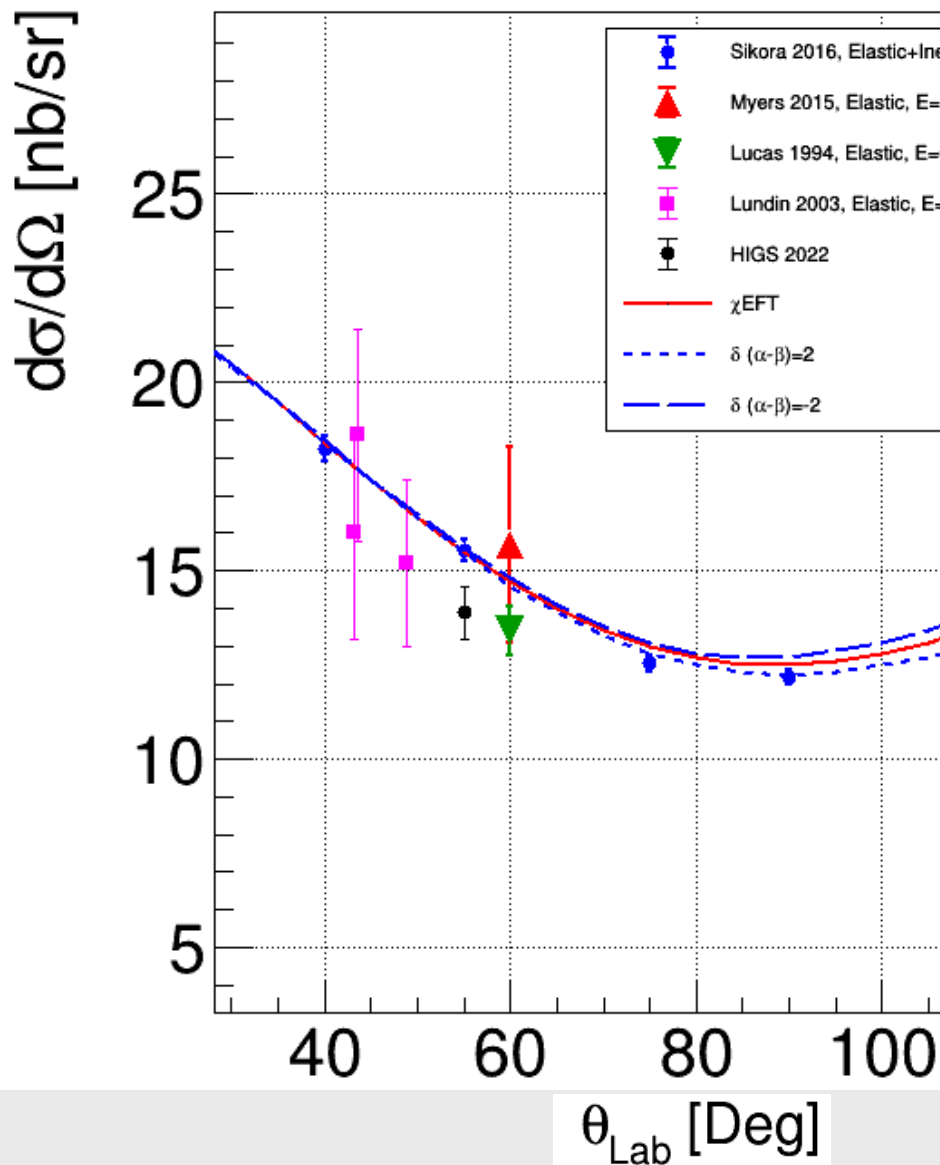
$$D(\gamma, \gamma)D$$

$$E_{\gamma} = 61 \text{ MeV}$$

BUNI | @ 115°



D. Godagama (2022)

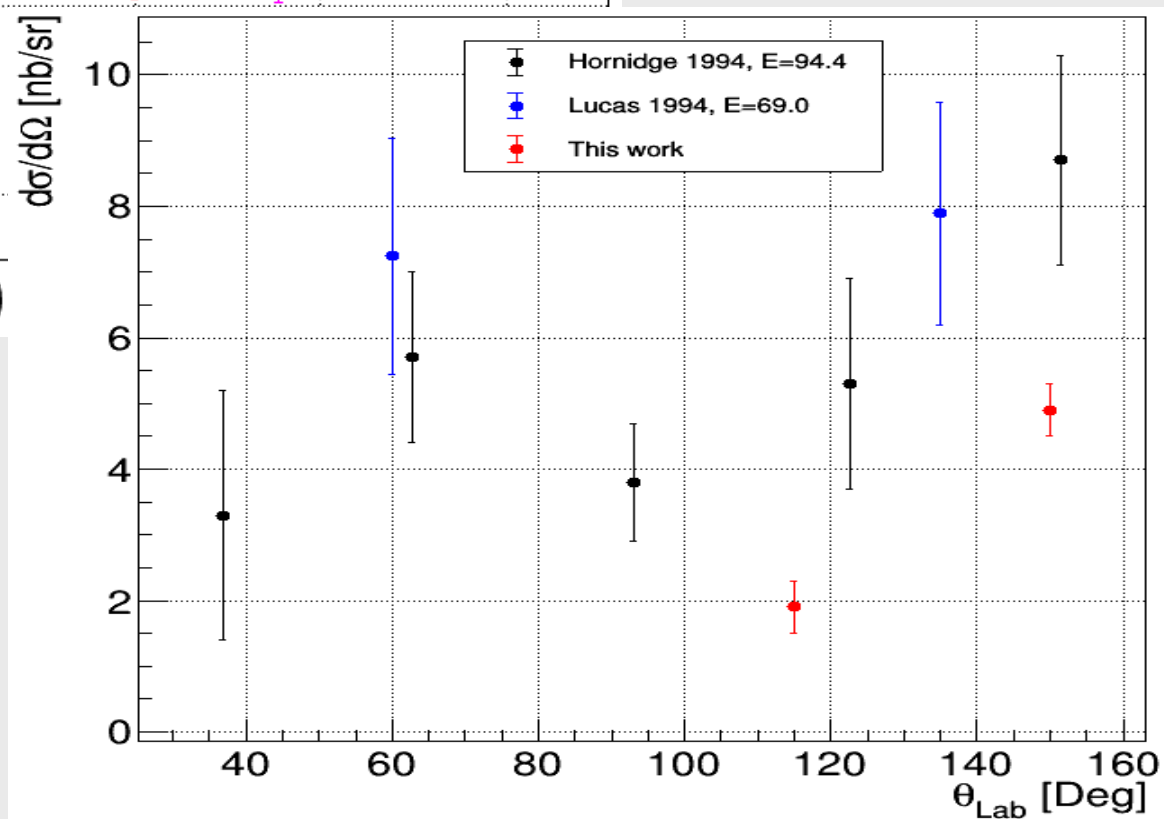


$$D(\gamma, \gamma)D$$

$$E_\gamma = 61-70 \text{ MeV}$$

inelastic

$$E_\gamma = 61-94 \text{ MeV}$$



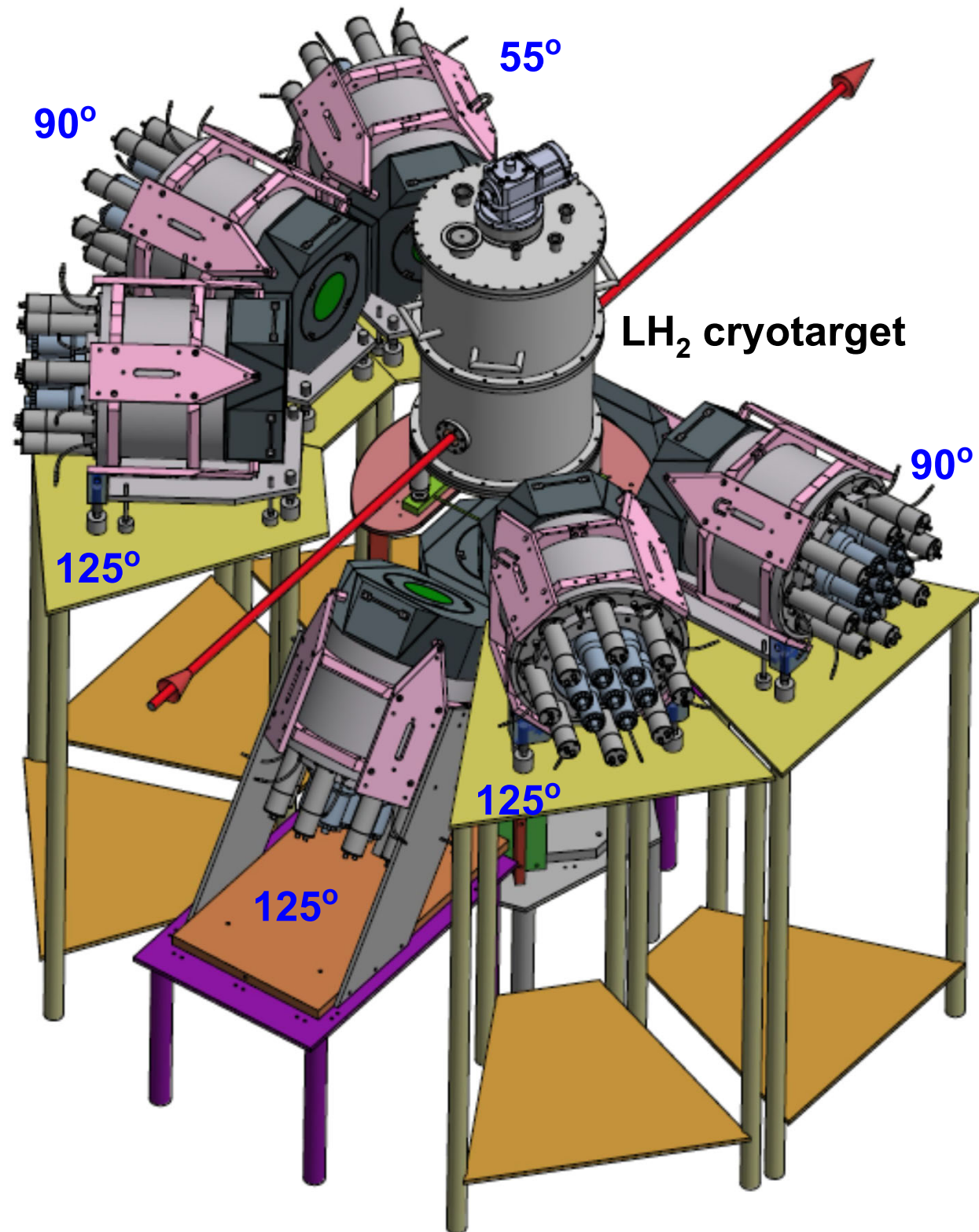
Polarized Compton Scattering on the Proton

Experimental Setup

polarized Compton scattering on proton

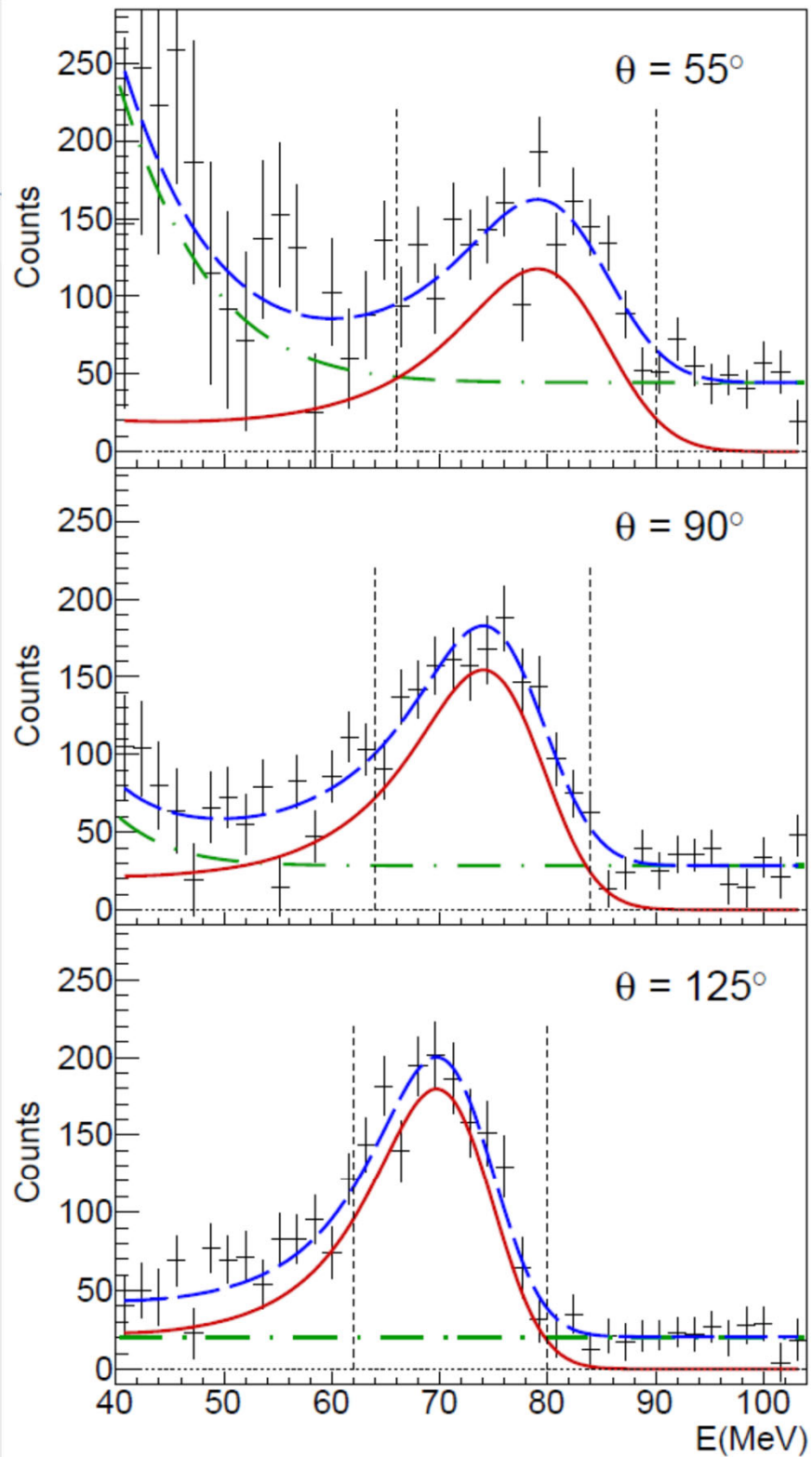
beam polarization in **horizontal** plane

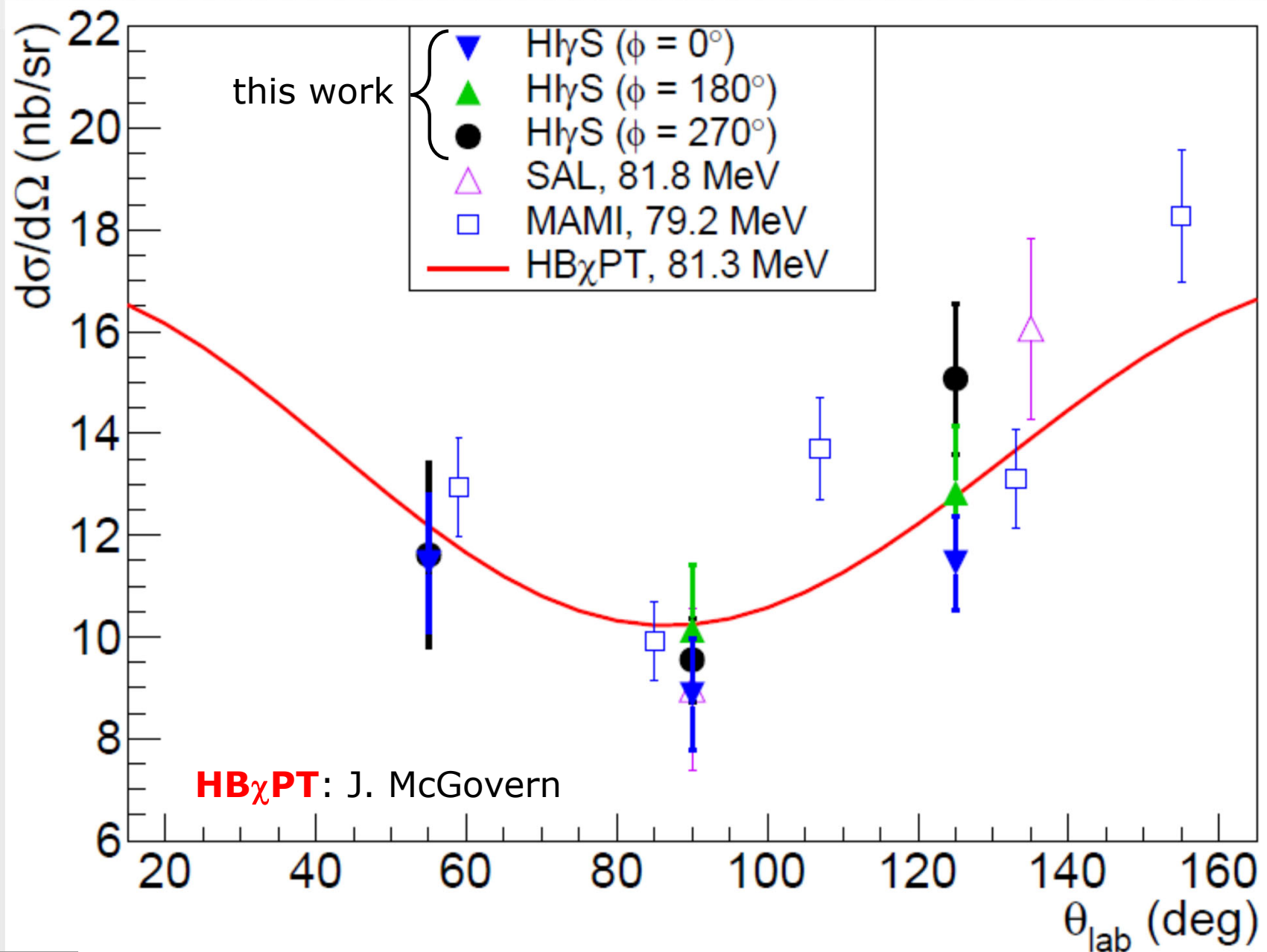
5 parallel NaI's
3 perpendicular



$$p(\vec{\gamma}, \gamma)p$$

$$E_{\gamma} = 83 \text{ MeV}$$

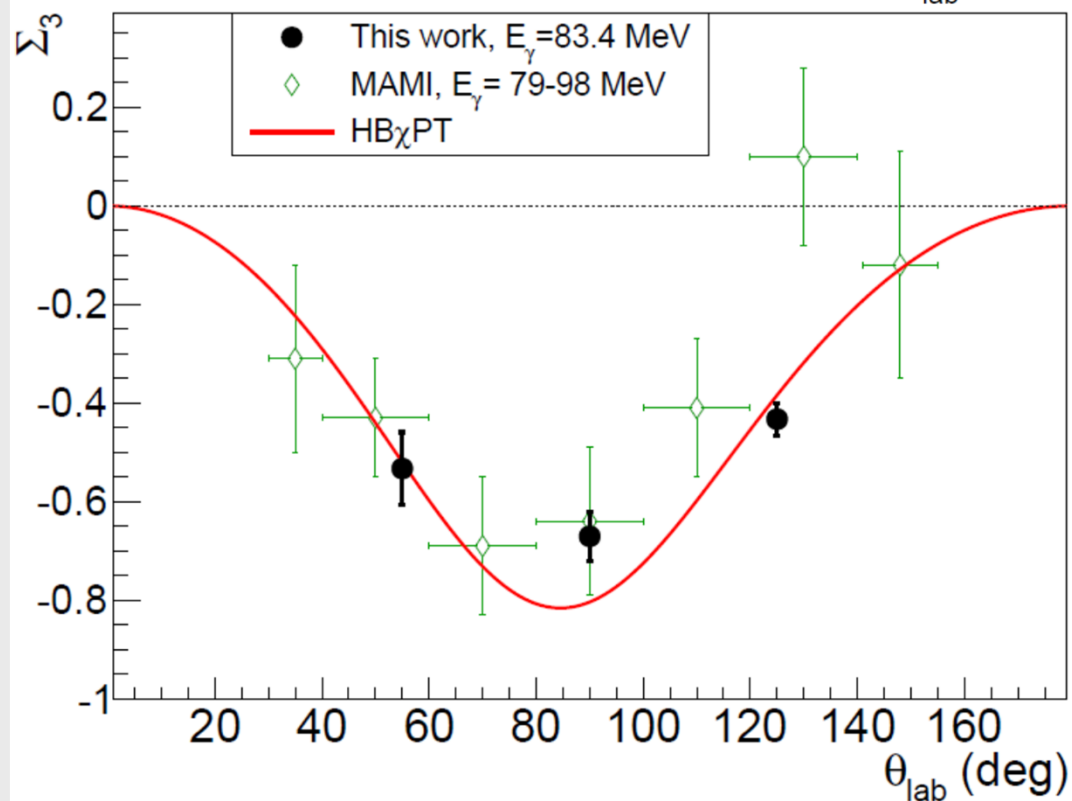
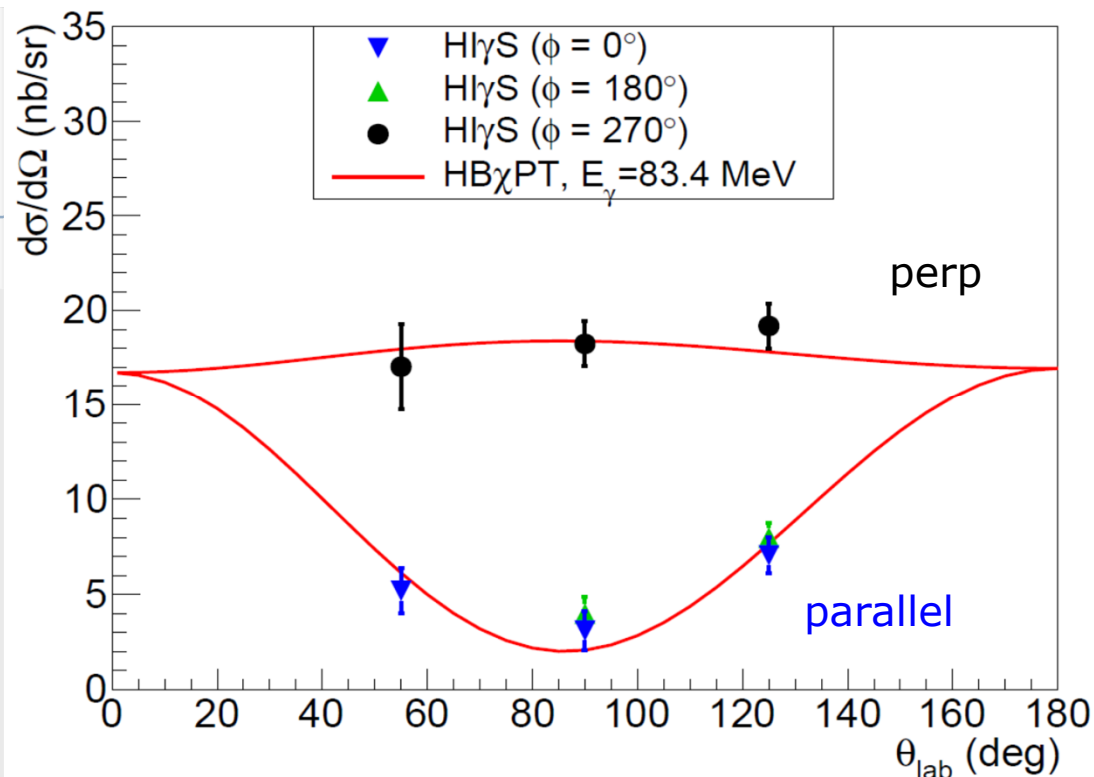




$$p(\vec{\gamma}, \gamma)p$$

$$E_\gamma = 83 \text{ MeV}$$

HB χ PT: J. McGovern



$$\Sigma_3(\theta) = \frac{\sigma_{\parallel}(\theta) - \sigma_{\perp}(\theta)}{\sigma_{\parallel}(\theta) + \sigma_{\perp}(\theta)}$$

Compton Scattering on ${}^3\text{He}$

New Experiment ${}^3\text{He}(\gamma,\gamma){}^3\text{He}$

□ experiment details

- higher cross section for $Z = 2$ target (compared to deuterium)
- exploit different Compton scattering channel to access α and β
- no previous Compton data on ${}^3\text{He}$ exists!
- modify cryotarget: lower base temperature and ${}^3\text{He}$ recovery

New Experiment ${}^3\text{He}(\gamma,\gamma){}^3\text{He}$

□ experiment details

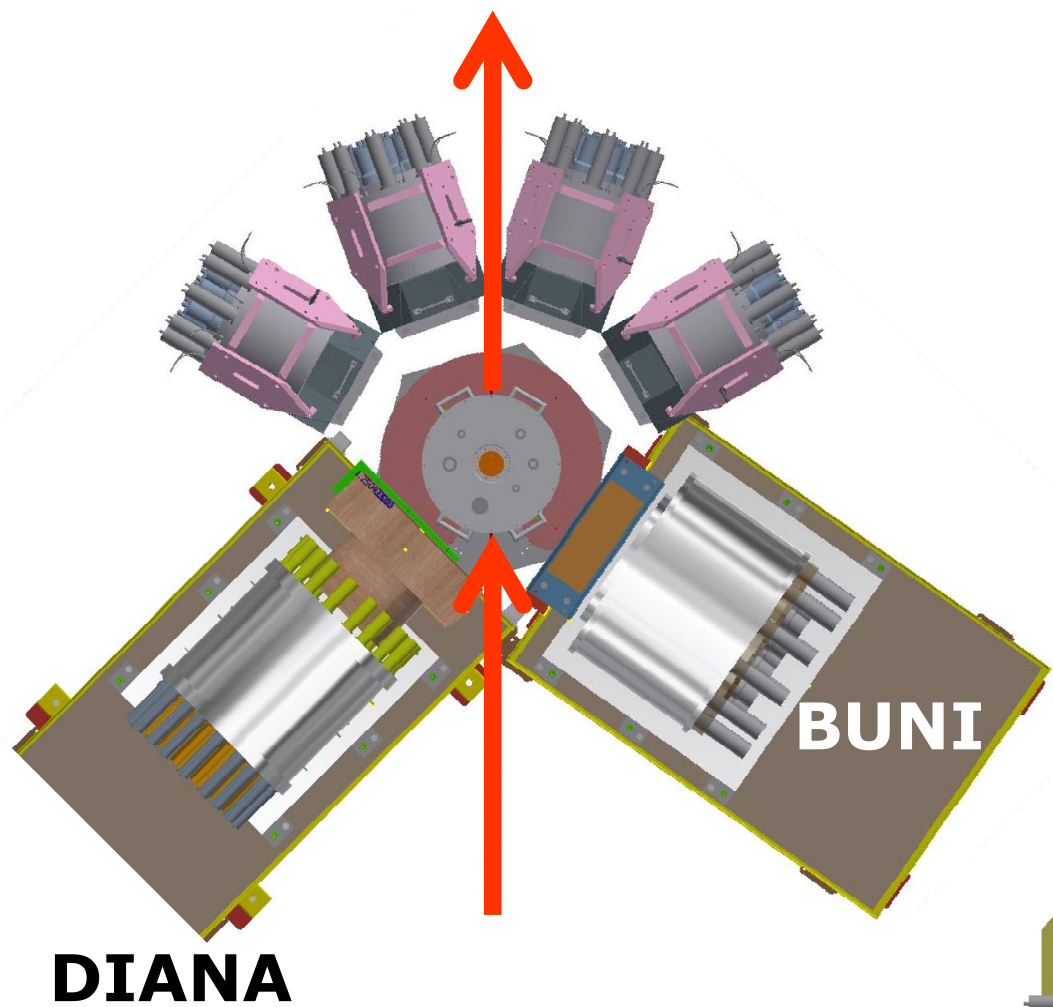
- higher cross section for $Z = 2$ target (compared to deuterium)
- exploit different Compton scattering channel to access α and β
- no previous Compton data on ${}^3\text{He}$ exists!
- modify cryotarget: lower base temperature and ${}^3\text{He}$ recovery

□ energies: $E_\gamma = 60, 80, 100, 120 \text{ MeV}$

□ angles: $\theta_\gamma = 45^\circ - 150^\circ$

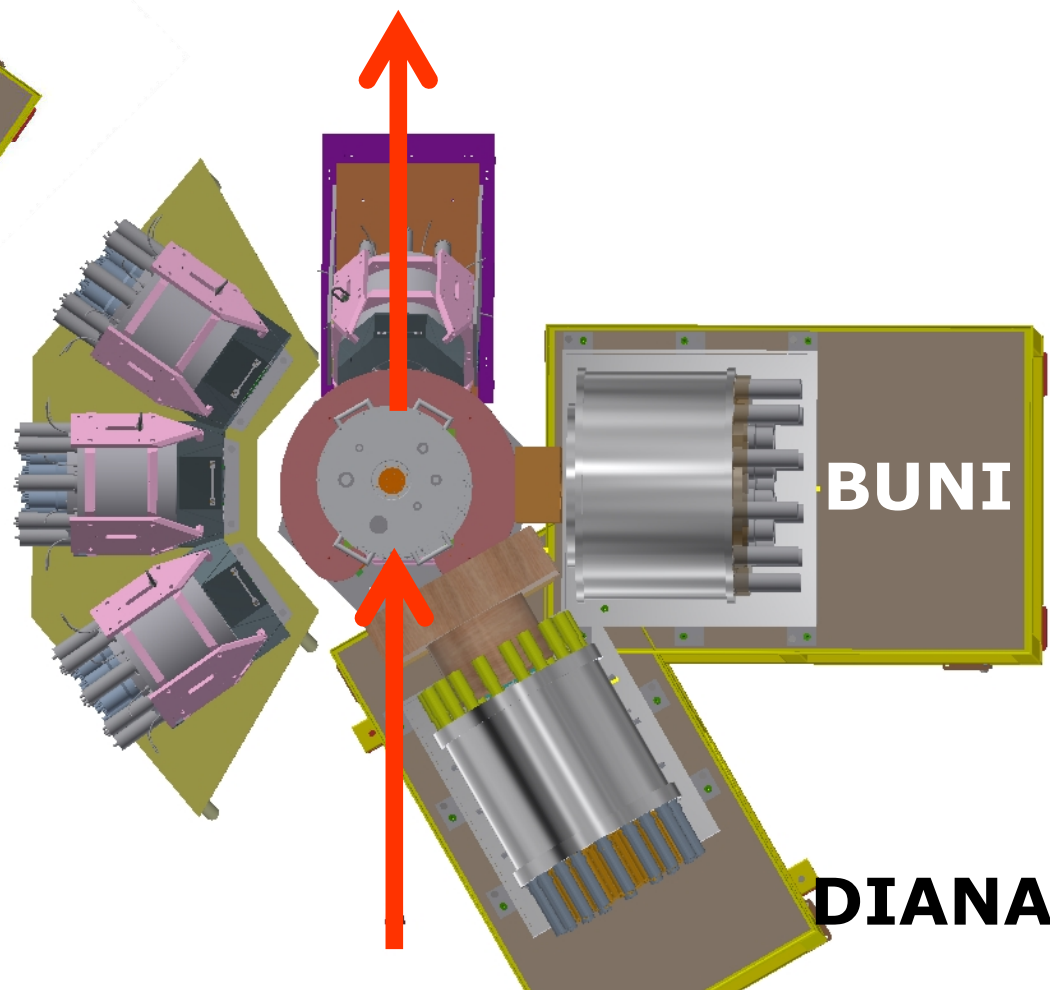
□ target: liquid ${}^3\text{He}$ cryogenic target

□ detectors: **BUNI, DIANA, and 4 HINDA NaI's**



DIANA

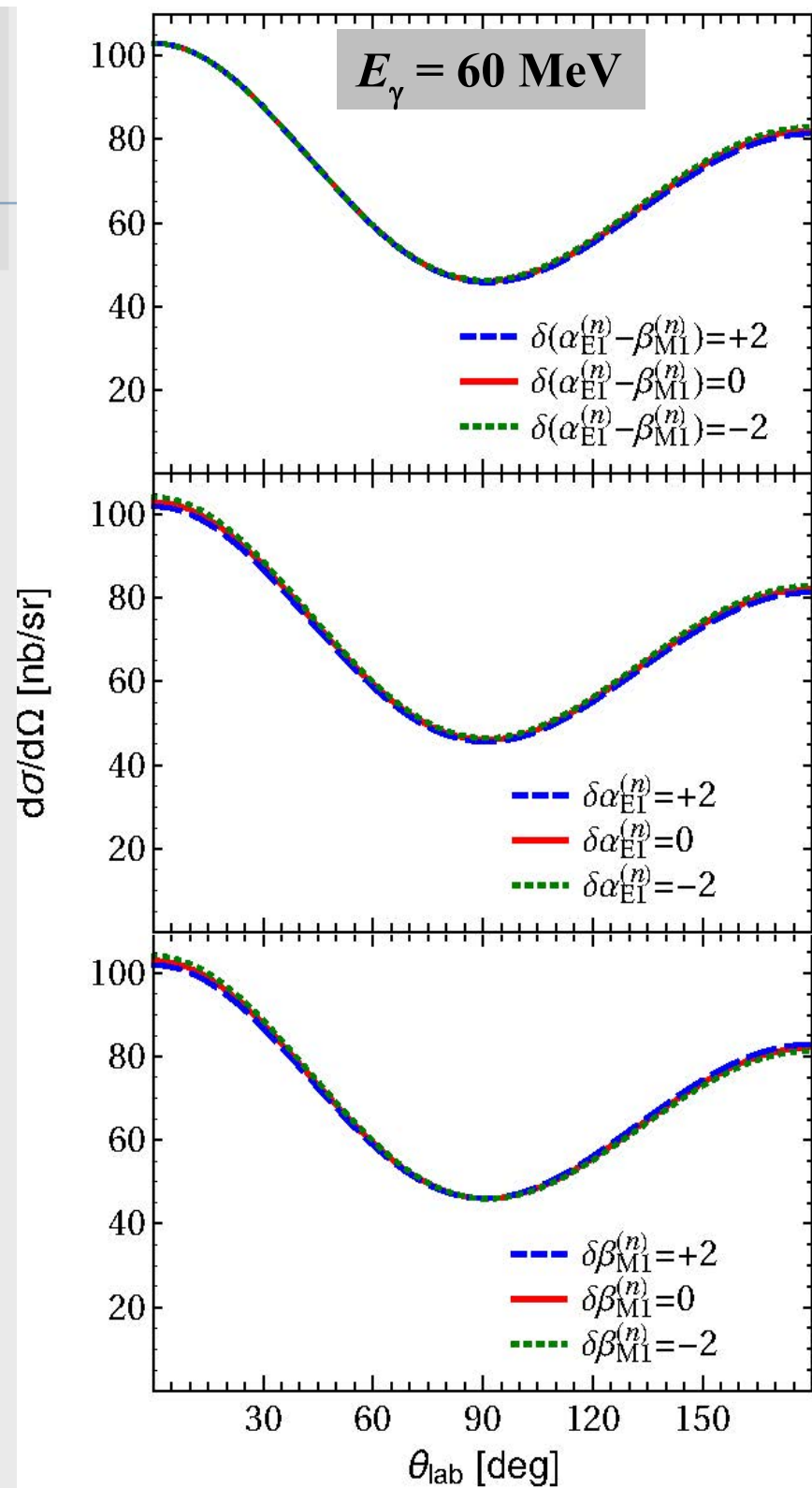
BUNI



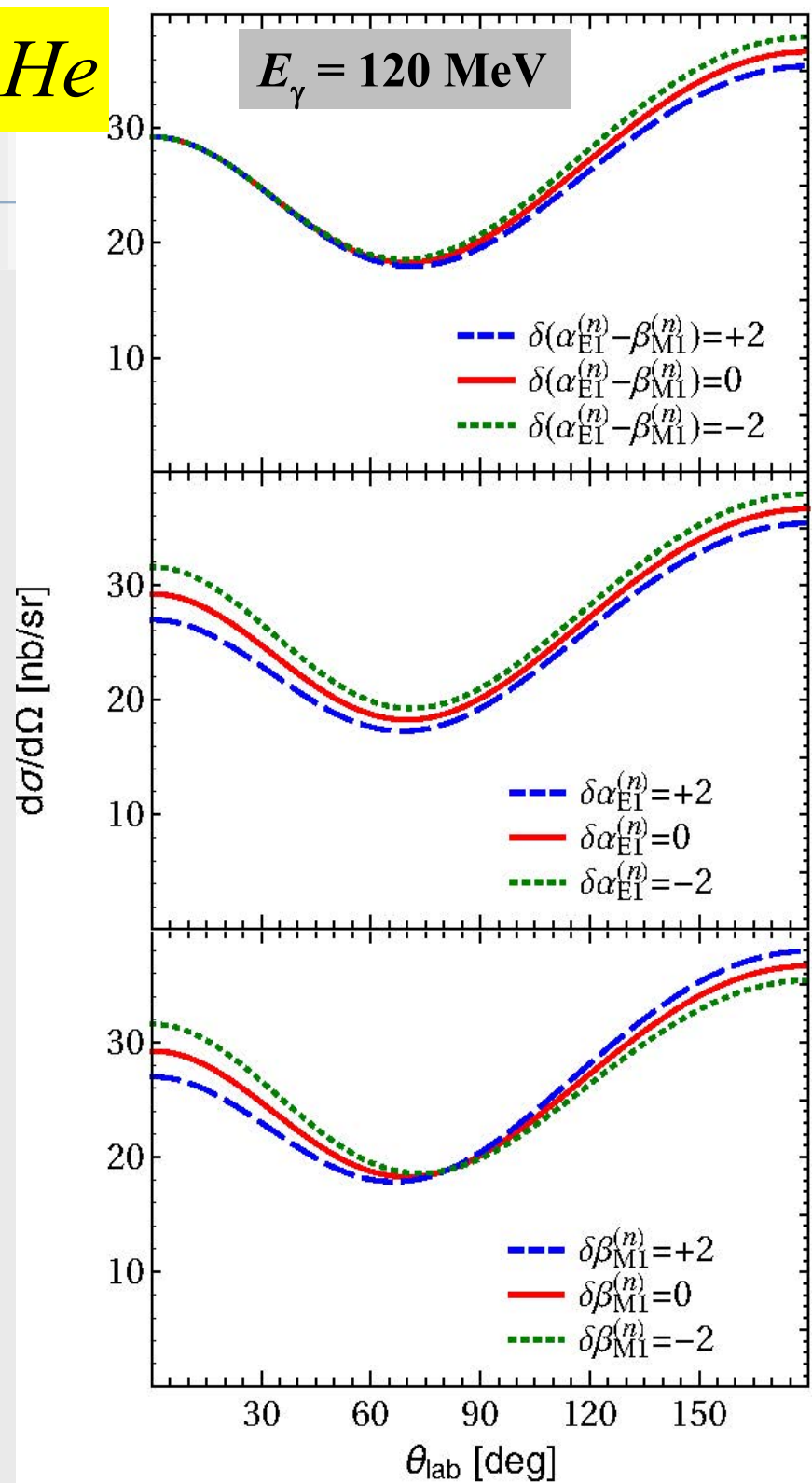
BUNI

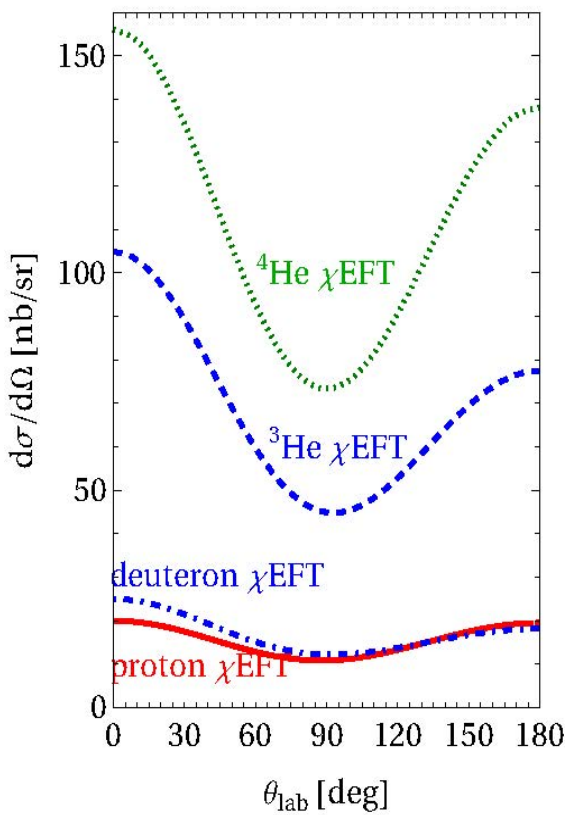
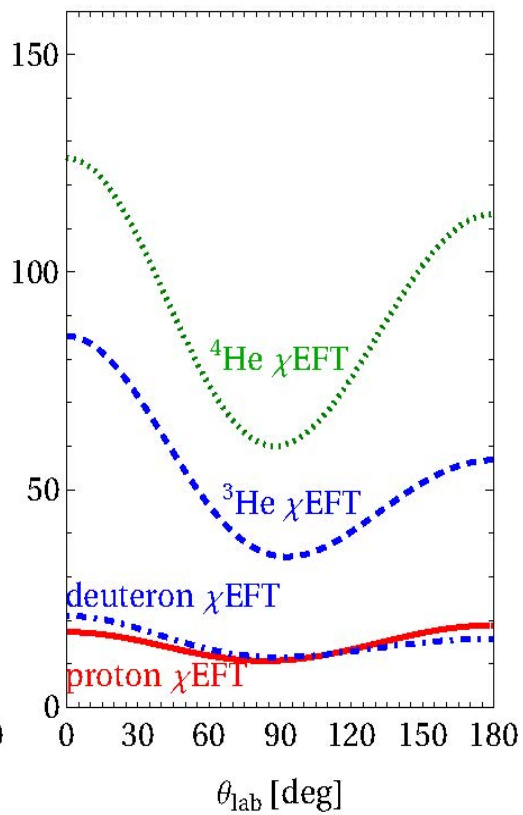
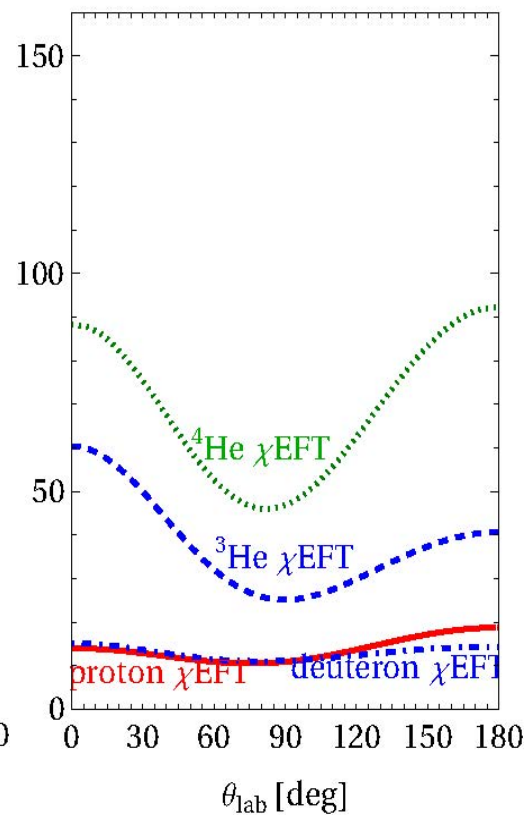
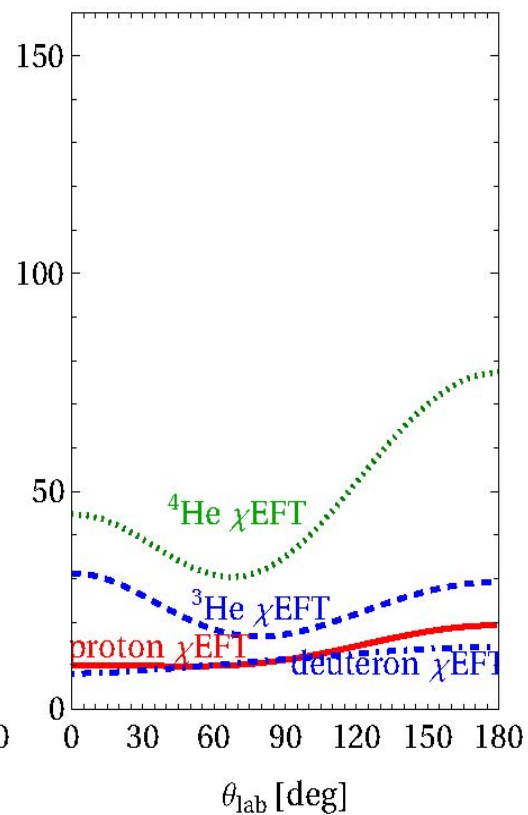
DIANA

${}^3\text{He}(\gamma, \gamma){}^3\text{He}$



Griesshammer



$E_\gamma = 60 \text{ MeV}$  $E_\gamma = 80 \text{ MeV}$  $E_\gamma = 100 \text{ MeV}$  $E_\gamma = 120 \text{ MeV}$ 

Summary

- ❑ ^4He and ^2H **unpolarized** data
 - ❑ proton: photon beam asymmetry with **linearly polarized** beam
 - ❑ ^6Li , ^{12}C and ^{16}O unpolarized data
-

Summary

- ❑ ^4He and ^2H **unpolarized** data
 - ❑ proton: photon beam asymmetry with **linearly polarized** beam
 - ❑ ^6Li , ^{12}C and ^{16}O unpolarized data
-
- ❑ ^2H : high resolution run (separate elastic/inelastic)
 - ❑ **^3He : first Compton on $A = 3$ (coming in Spring 2024)**
 - ❑ ^4He : measure energy dependence (60-120 MeV)
-

Summary

- ❑ ^4He and ^2H **unpolarized** data
 - ❑ proton: photon beam asymmetry with **linearly polarized** beam
 - ❑ ^6Li , ^{12}C and ^{16}O unpolarized data
-

- ❑ ^2H : high resolution run (separate elastic/inelastic)
 - ❑ **^3He : first Compton on $A = 3$ (coming in Spring 2024)**
 - ❑ ^4He : measure energy dependence (60-120 MeV)
-

- ❑ **Strong EFT support (Griesshammer, McGovern, Phillips)**
 - next milestone – theory framework for $A = 4$
- ❑ **HIGS can contribute high-quality data!**
 - stay tuned for further developments in the future...