



Massachusetts Institute of Technology



Two- and Three- body Photo-disintegration of ^3He with Double Polarizations

Georgios Laskaris

On behalf of the polarized ^3He collaboration at TUNL

Duke University, NC USA

Massachusetts Institute of Technology (MIT), MA USA

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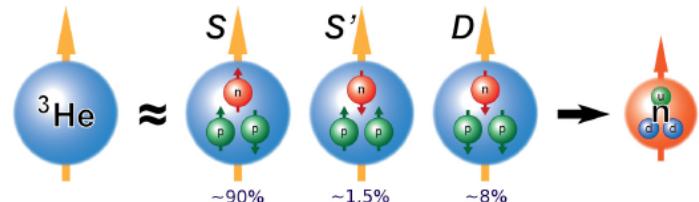
Urbana-Champaign, Illinois, USA

Outline

- Physics Motivation
- Experimental Apparatus for $\overrightarrow{^3He}(\vec{\gamma}, n)pp$
- Results from $\overrightarrow{^3He}(\vec{\gamma}, n)pp$
- First Measurement of $\overrightarrow{^3He}(\vec{\gamma}, p)D$
 - Experimental Apparatus
 - Current Status of Data Analysis
- Summary

Goal I: Test of State-of-the-Art Calculations on ^3He

- Three-nucleon system provides an excellent testing ground of few-body theories
 - e.g. Nuclear corrections on effective neutron target



- Three-body calculations
 - **Deltuva et al.** : using AGS equations with CD Bonn + Δ -isobar + **Coulomb potential** +...
 - **Skibinski et al.** : using Faddeev equations with AV18+UIX+...
 - **xEFT** including one- and two- pion exchange at NLO and $N^2\text{LO}$
 - The advancement of theories needs more precise experimental data, new observables

Frameworks: L.D. Faddeev in Sov. Phys.; E.O. Alt *et al.* in Nucl. Phys. B

CD-Bonn: A. Deltuva A.C Fonseca, P.U. Sauer *et al.* in PRC, Ann. Rev., Nucl. Part. Sci.

AV18: R. Skibinski, J. Golak, H. Witala *et al.* in PRC

xEFT: D. Rozpedzik *et al.*, in PRC; S. Konig *et al.* in PRC, J. Vanasse *et al.* , in PRC

Goal II: Investigation of the GDH Sum Rule

$$I^{GDH} = \int_{\nu_{thr}}^{\infty} \frac{d\nu}{\nu} [\sigma_N^P(\nu) - \sigma_N^A(\nu)] = \frac{4\pi^2 \alpha}{M_N^2} \kappa_N^2 I$$

σ_N^P σ_N^A spin dependent total photon-absorption cross section
 κ_N anomalous magnetic moment

ν_{thr} pion production/photodisintegration threshold

Based on general principles of physics: Lorentz and gauge invariance, crossing symmetry, causality and unitarity

Measurements on proton up to 0.8 GeV (Mainz, MAMI) and up to 2.9 GeV (Bonn, ELSA) and on neutron between 0.8 GeV and 1.8 GeV (Bonn, ELSA) agree with GDH within assumptions for contributions from un-measured region

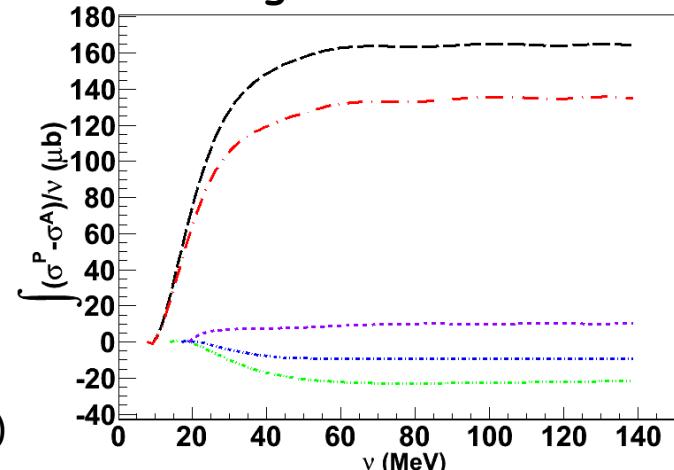
Plateau value of the GDH integral of ${}^3\text{He}$ below pion threshold based on state-of-the-art calculations is $\sim 140 \mu\text{b}$.

Total $I^{GDH, {}^3\text{He}} = 496 \mu\text{b}$

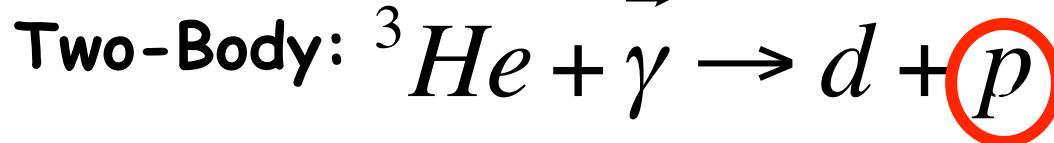
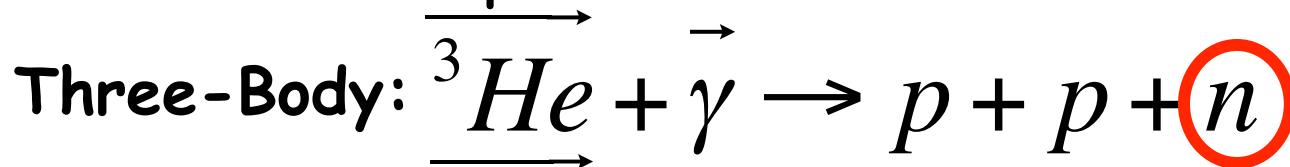
S.B.Gerasimov, Sov. J. Nucl. Phys. 2 430 (1966)

S.D. Drell *et al.*, Phys. Rev. Lett. 16 908 (1966)

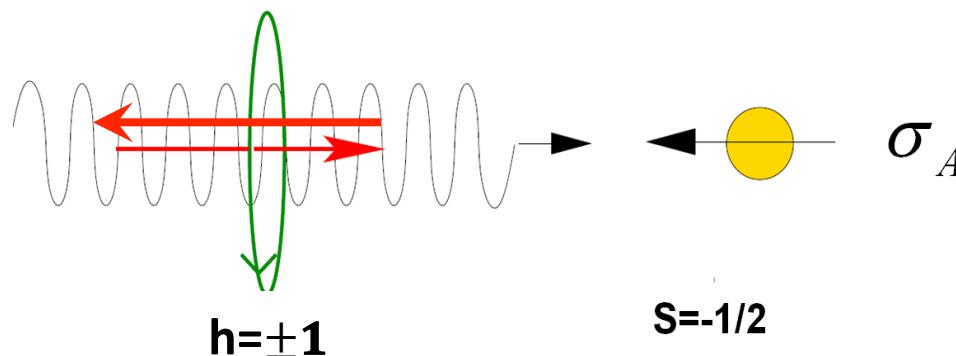
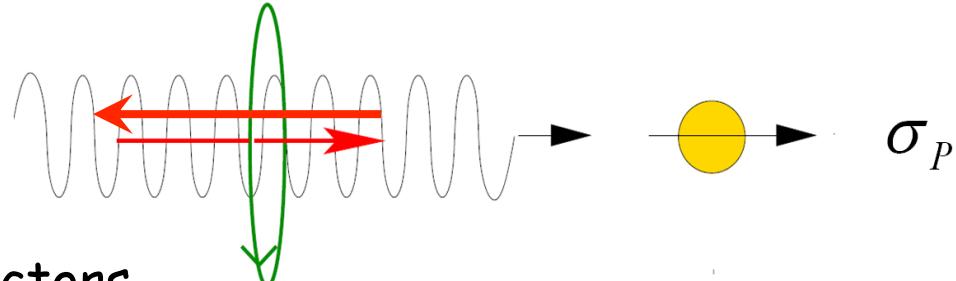
K. Helbing, Progress in Particle and Nuclear Physics 57, 405 (2006)



Two- and Three- body Photodisintegration of ^3He : Experimental Overview

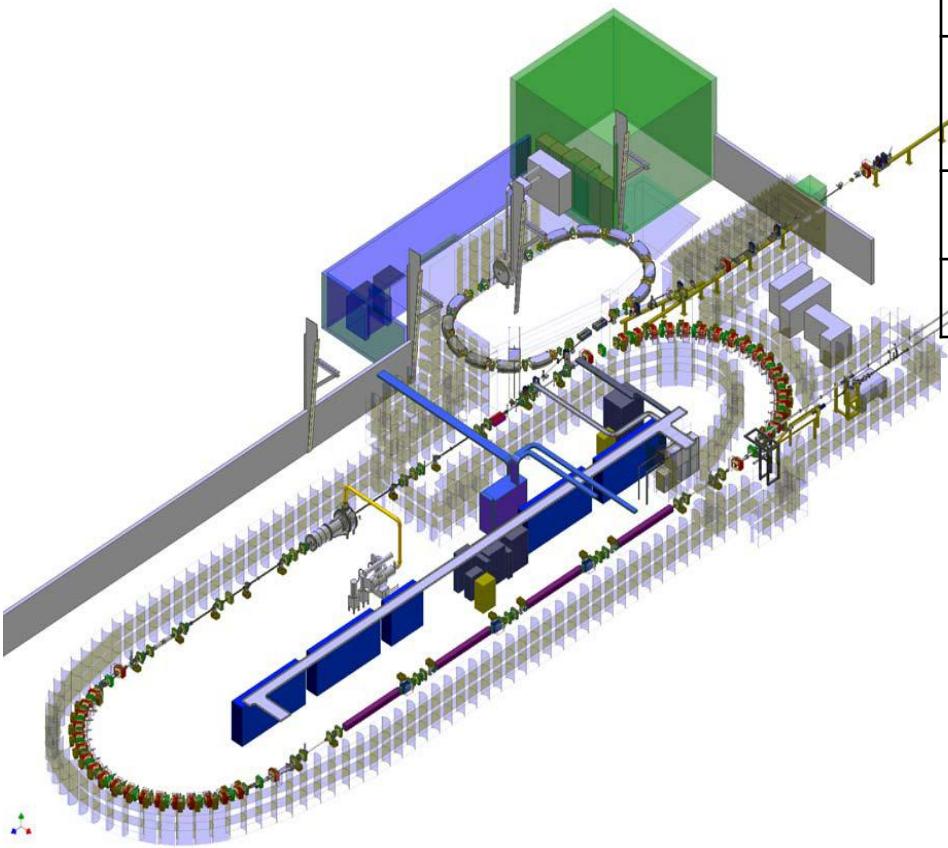


- ~100% circularly polarized γ -ray
- Polarized ${}^3\text{He}$ target
- **Neutrons:** liquid scintillator detectors
- **Protons:** Silicon Surface Barrier Detectors (SSBD)



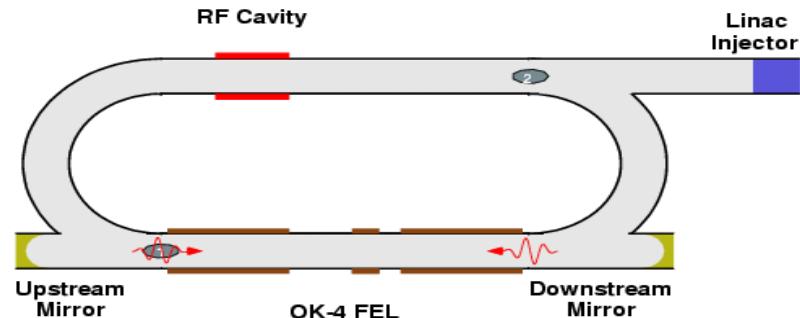
HI γ S Facility at TUNL

Schematics of FEL



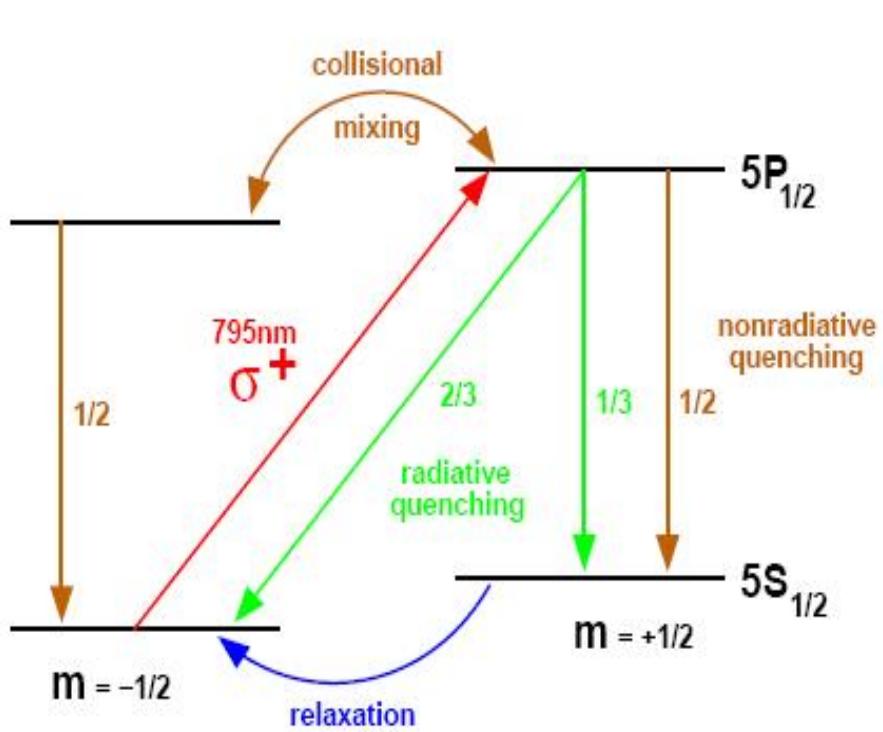
Beam Parameters	Values
Energies (MeV)	12.8, 14.7 16.5, 29.0
Polarization	\sim 100% (circular)
Flux on target (γ/sec)	$1 - 2 \times 10^8$
$\Delta E/E$	\sim 3-5%

Two Bunch Mode



H.R. Weller, H. Gao *et al.*, Progress in Particle and Nuclear Physics 62, 257 (2009)

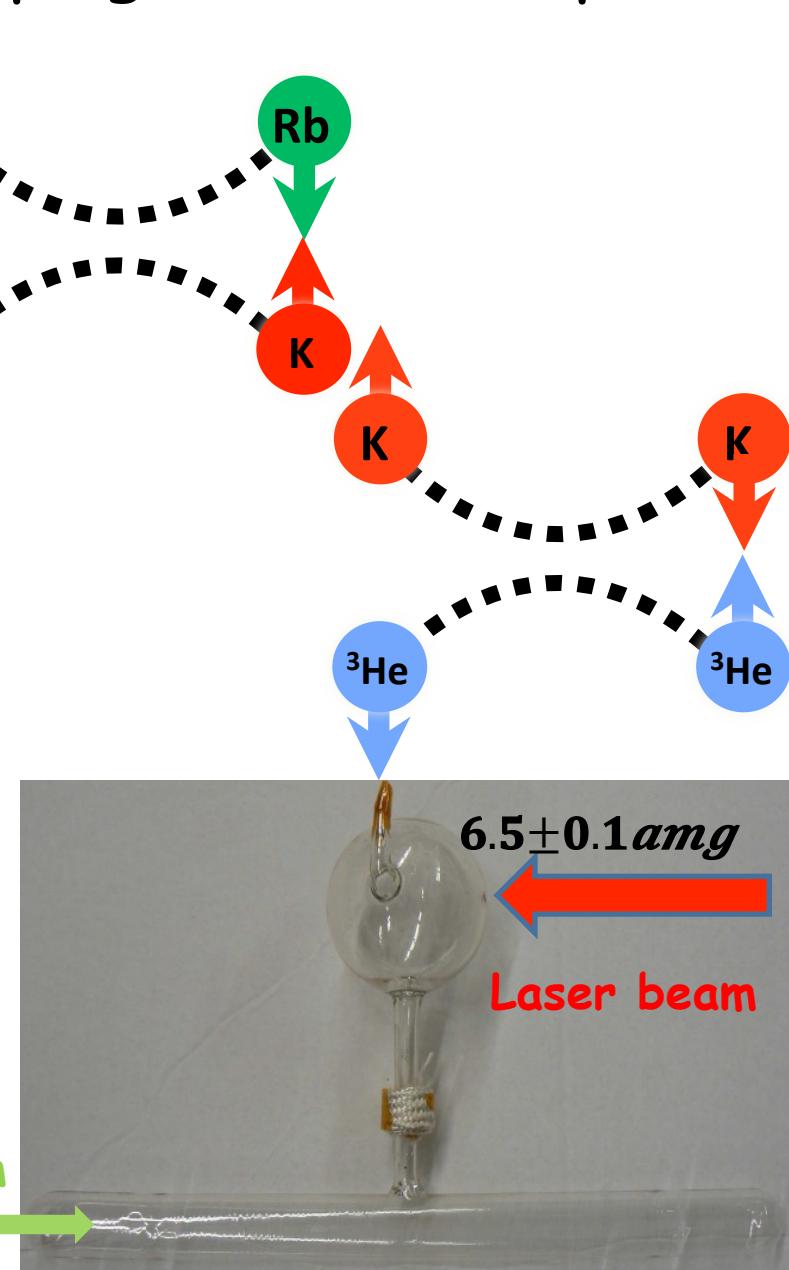
Spin Exchange Optical Pumping of Alkali Vapor



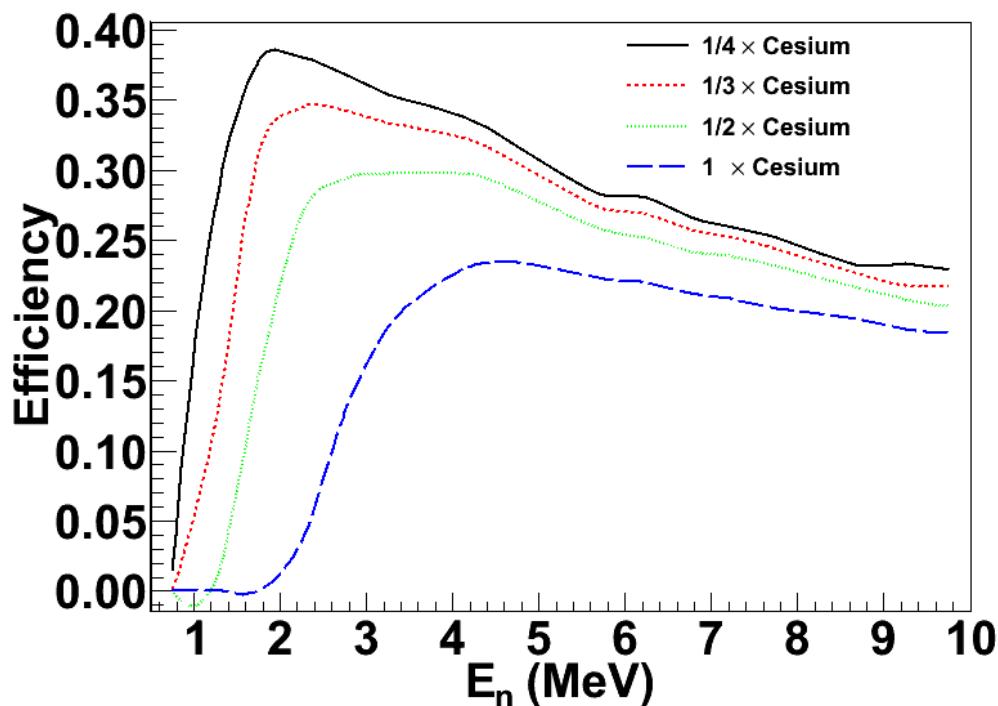
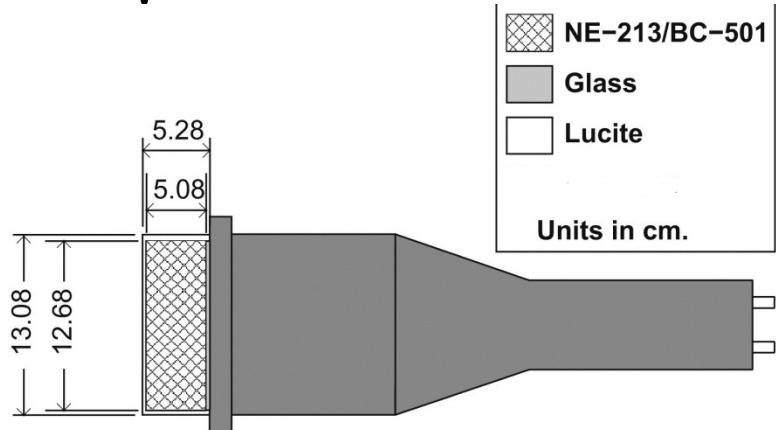
W. Happer, Rev. Mod. Phys. 44, 169 (1972)

- Polarization measured using NMR and EPR
- Polarization: 38-43%
- Polarization systematic uncertainty 5.5%

Q. Ye, G. Laskaris *et al.*, Eur. Phys. J. A 44, 55 (2010)



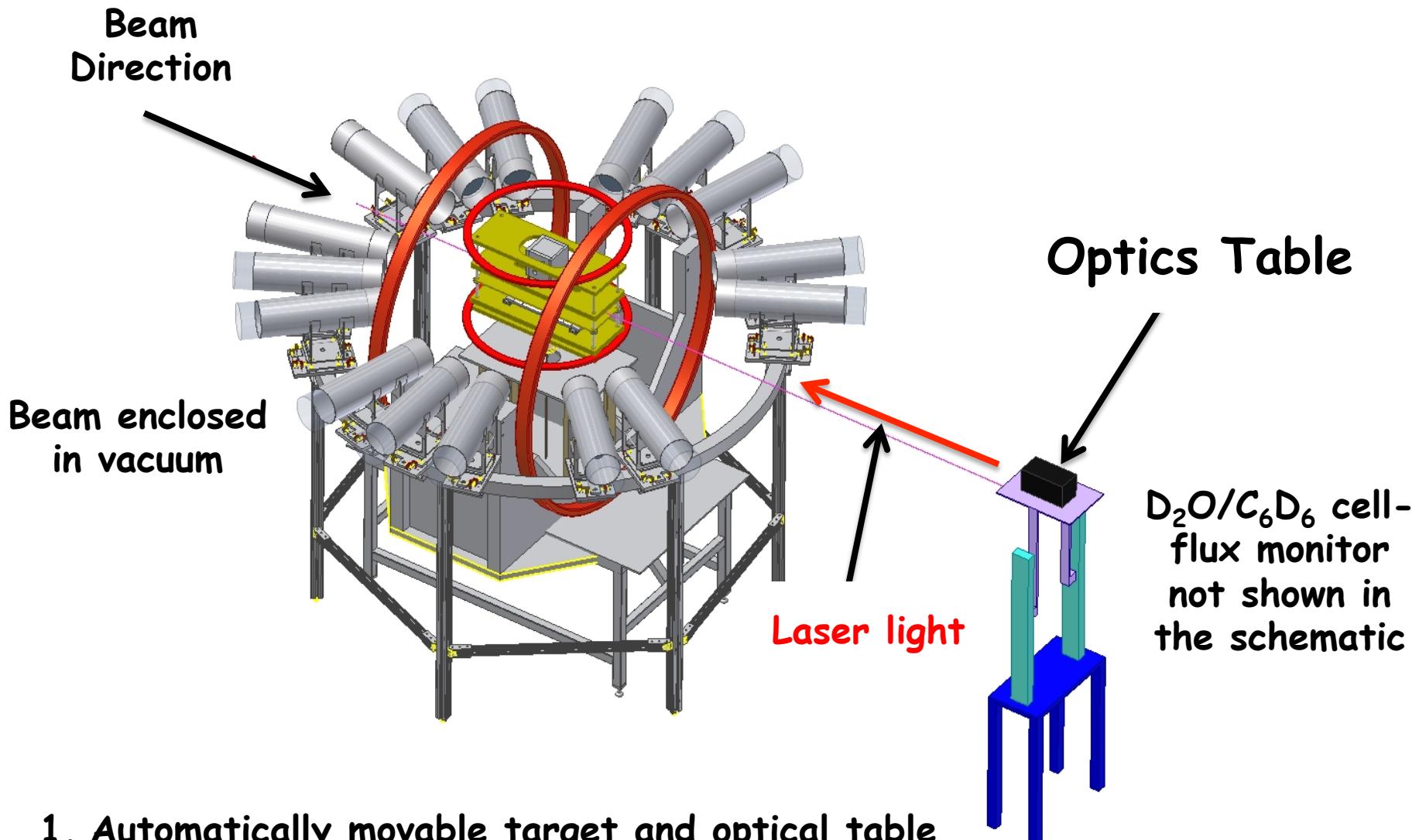
Liquid Scintillator Fast Neutron Detector



Pulse Shape Discrimination (PSD)
Pulse Height (PH)
Time Of Flight (TOF)

Property of BC-501A	Value
Density	0.874 gr/cm ³
Ref. Index	1.530
Wavelength	425 nm
Light output % Anthracene	78
Decay constant	3.2 nsec, 32.3 nsec, 270 nsec
H/C Ratio	1.212
Scintillating Materials	Xylene (C_8H_{10}) Naphthalene ($C_{10}H_8$)

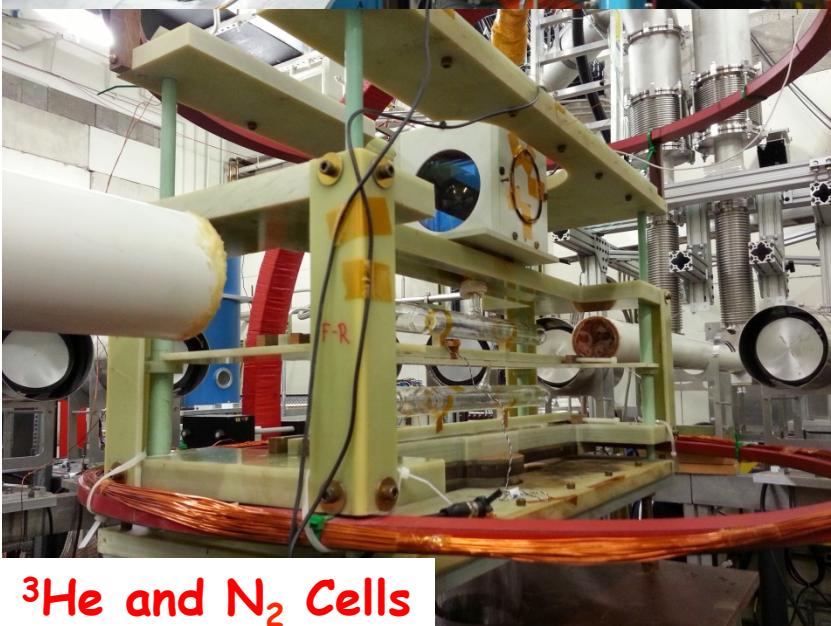
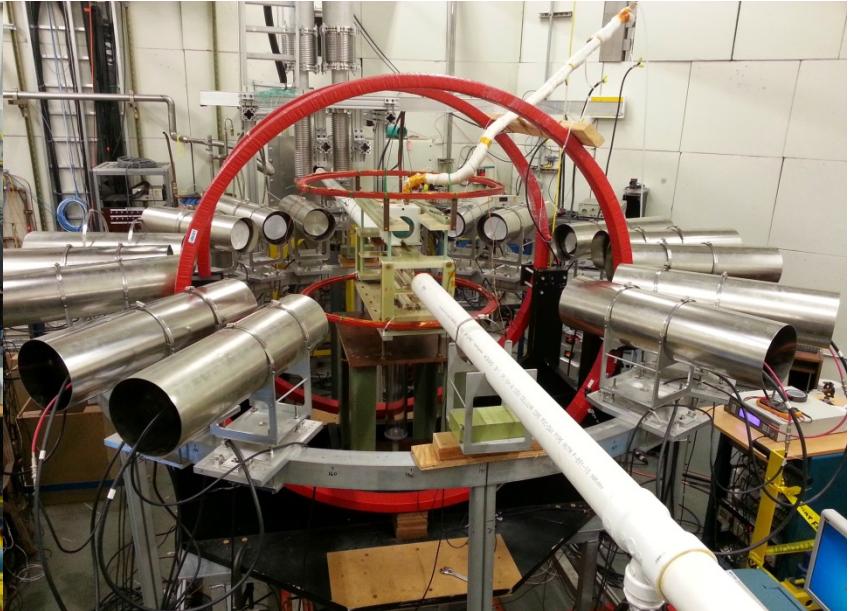
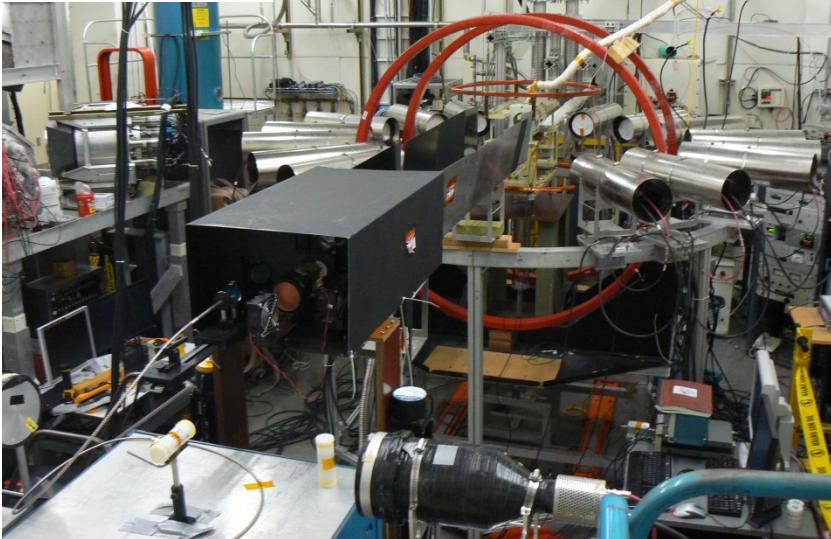
Apparatus of the Three-body Photodisintegration Experiment



1. Automatically movable target and optical table
2. Detectors in mu-metal shielding tubes

First Measurement of $\overline{^3He}(\vec{\gamma},n)pp$

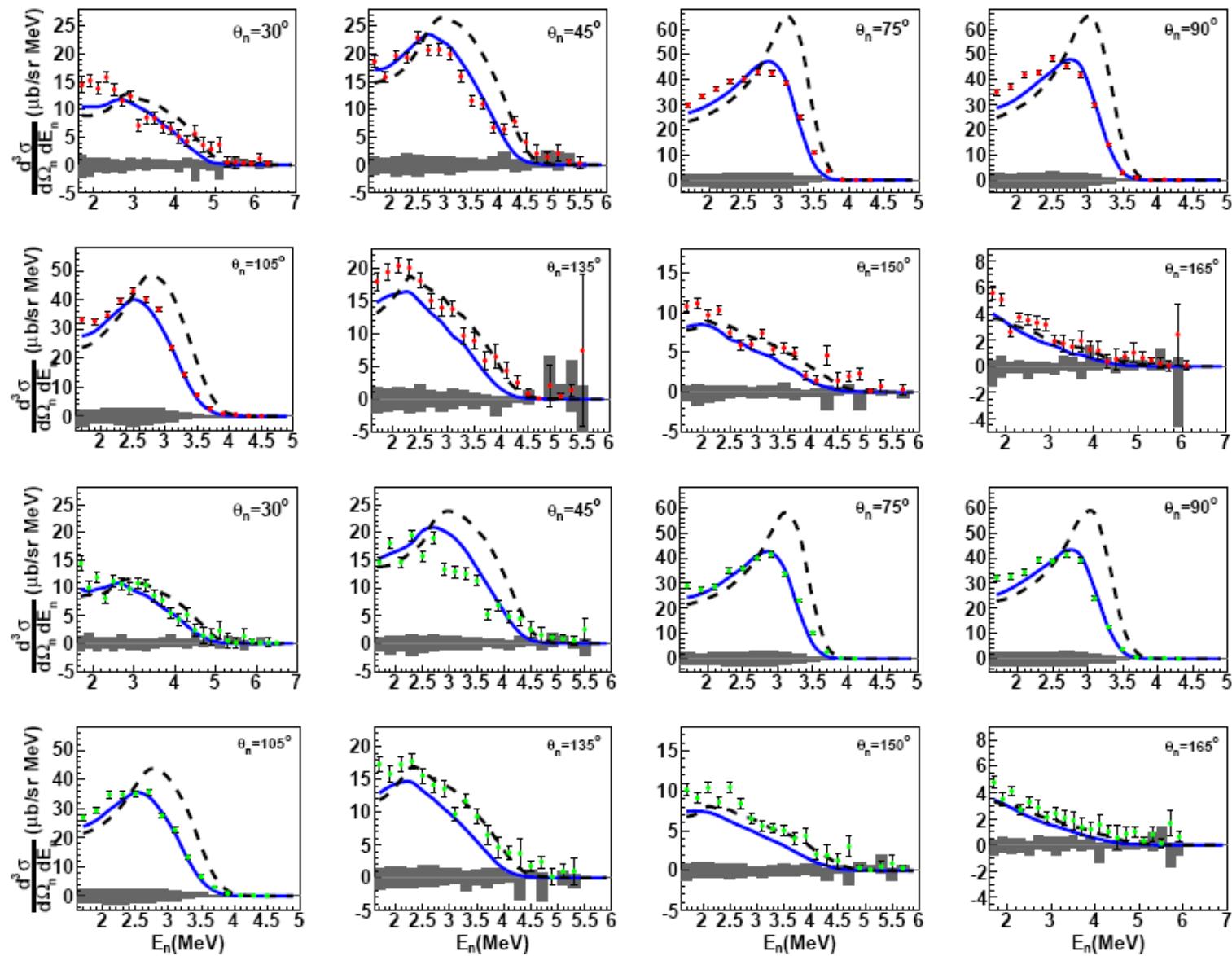
Overview



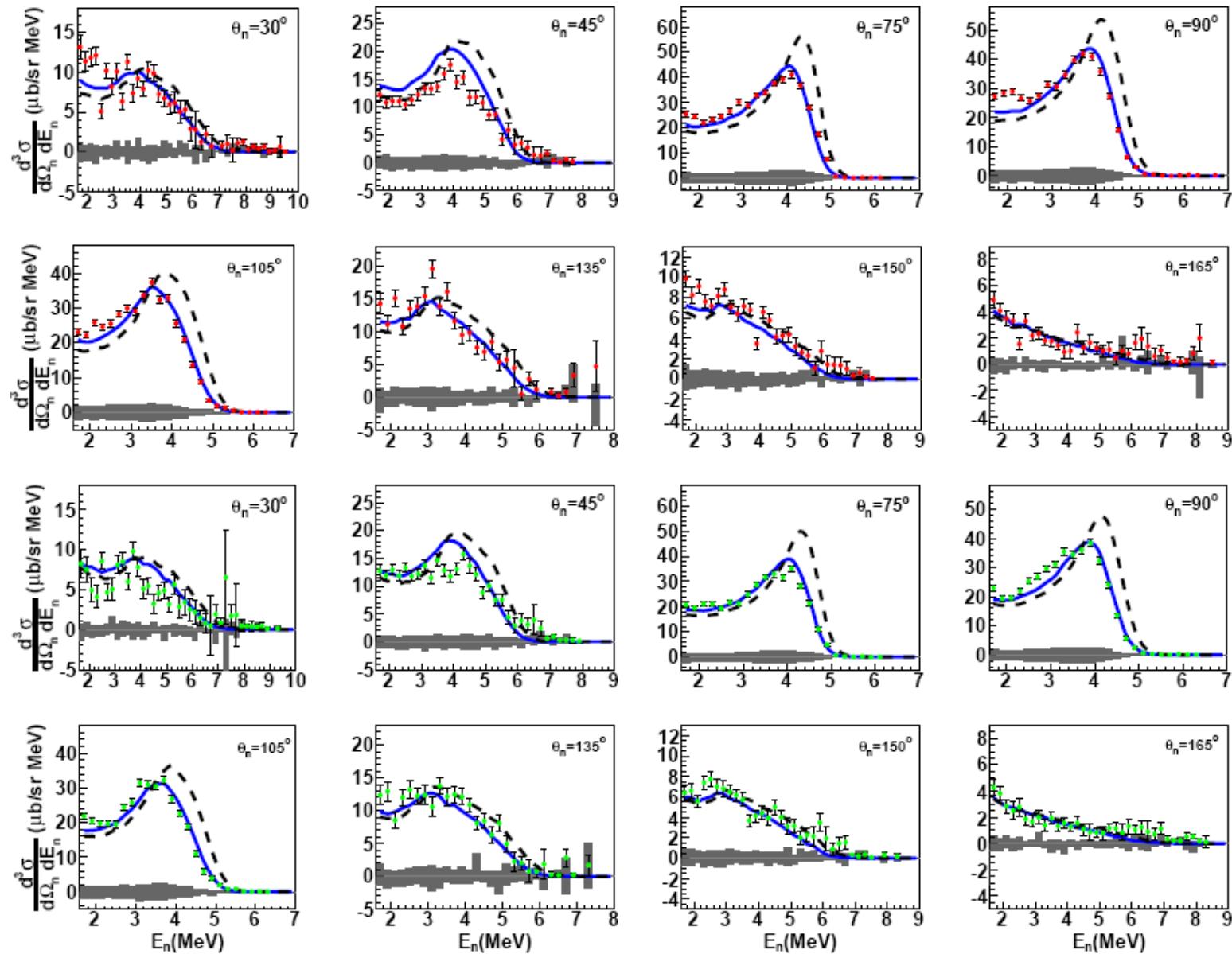
^3He and N_2 Cells

Front and Back Vacuum Pipes

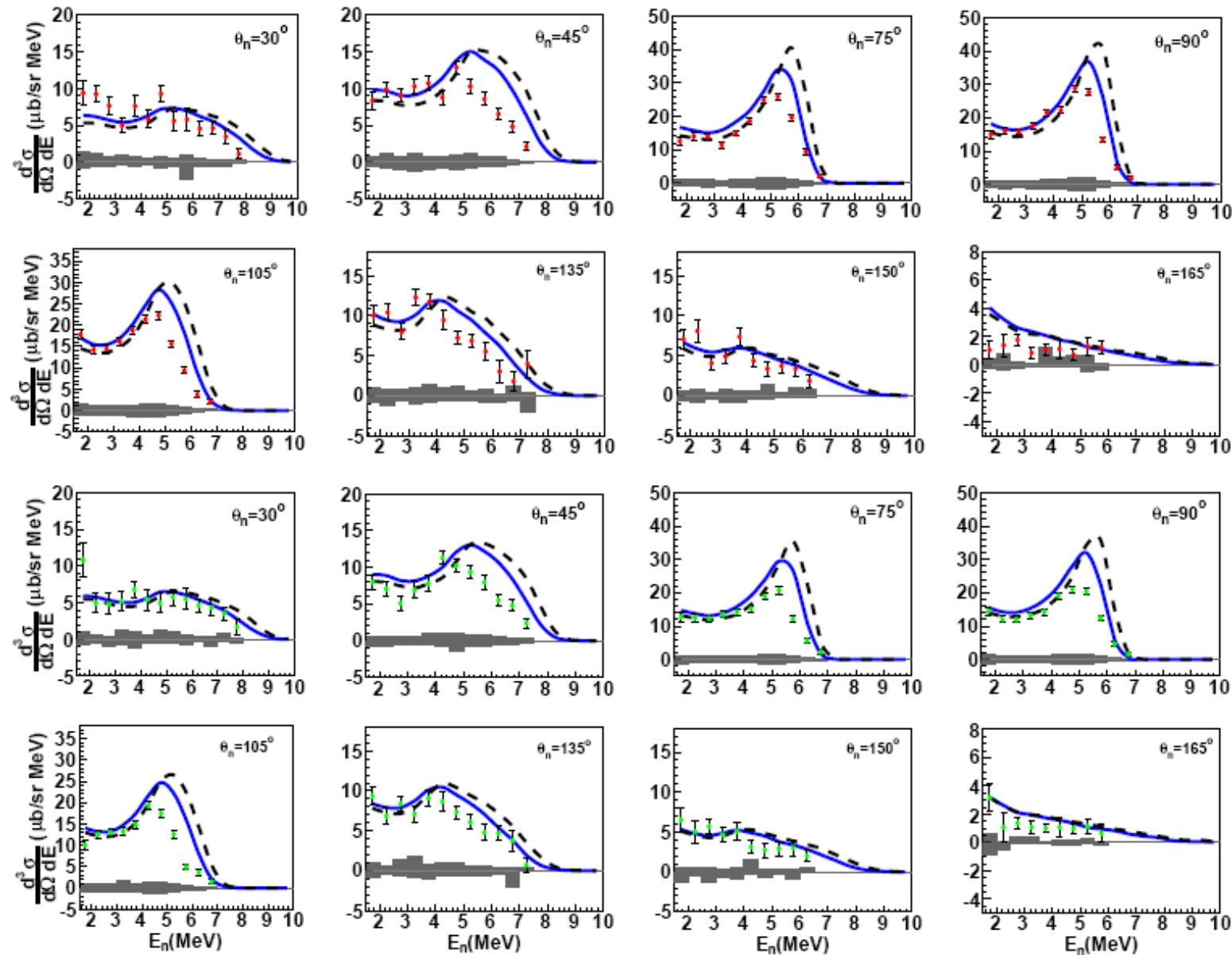
Spin-Dependent Double Differential Cross Sections at 12.8 MeV compared with theoretical calculations



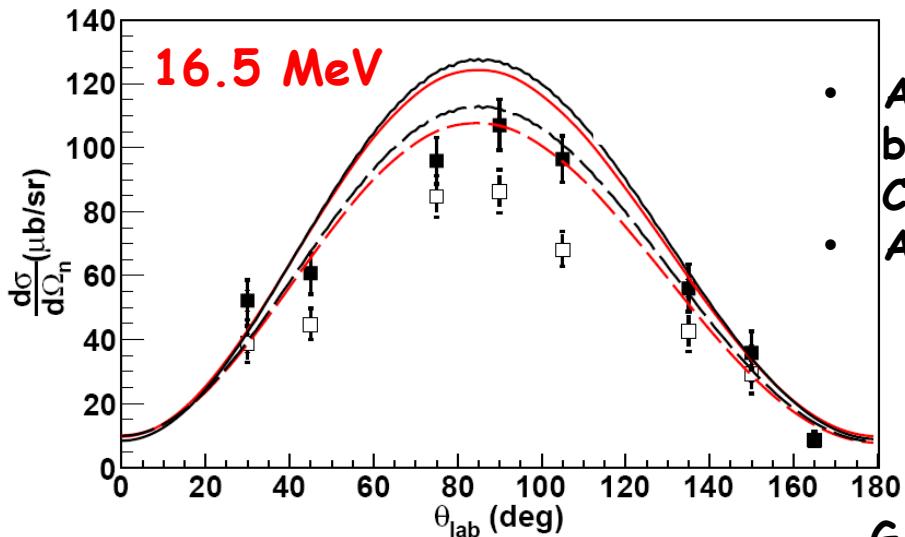
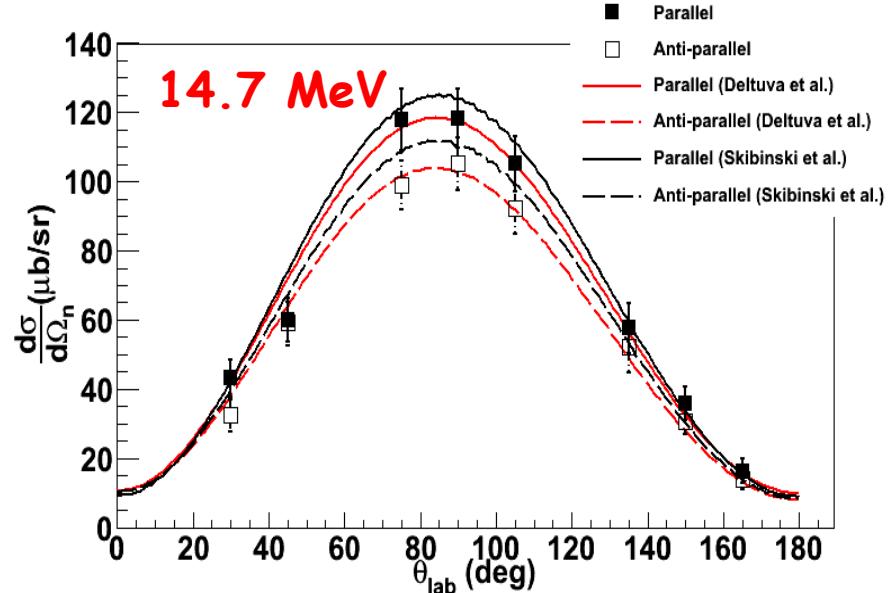
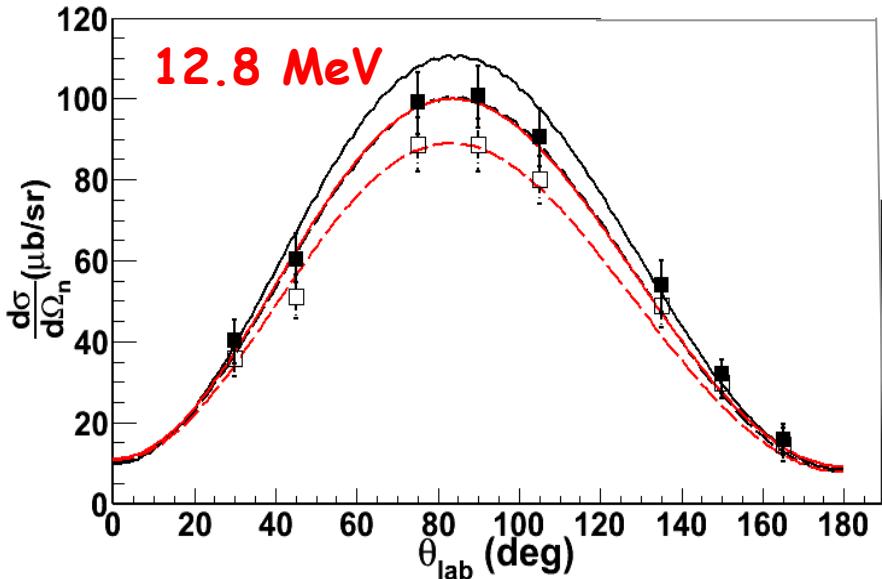
Spin-Dependent Double Differential Cross Sections at 14.7 MeV



Spin-Dependent Double Differential Cross Sections at 16.5 MeV



Spin-Dependent Single Differential Cross Sections

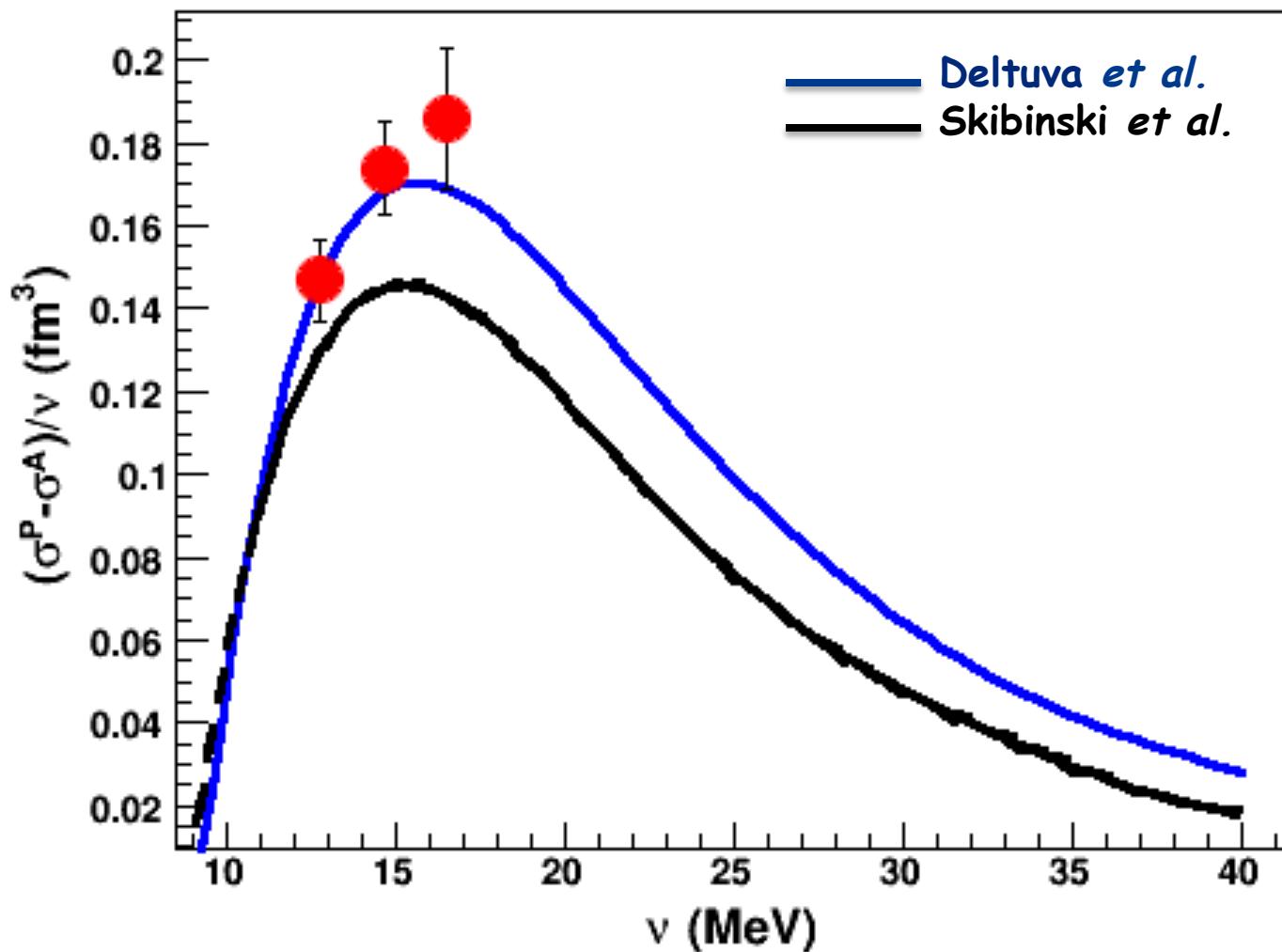


- Agreement observed at 12.8 and 14.7 MeV between the data and the theory including Coulomb
- A general disagreement observed at 16.5 MeV

G. Laskaris et al., Phys. Rev. C 89, 024002 (2014)

G. Laskaris et al., Phys. Lett. B 750, 547 (2015)

Contribution of $\overrightarrow{^3He}(\vec{\gamma},n)pp$ to the GDH integrand



G. Laskaris *et al.*, Phys. Rev. Lett. **110**, 202501 (2013)

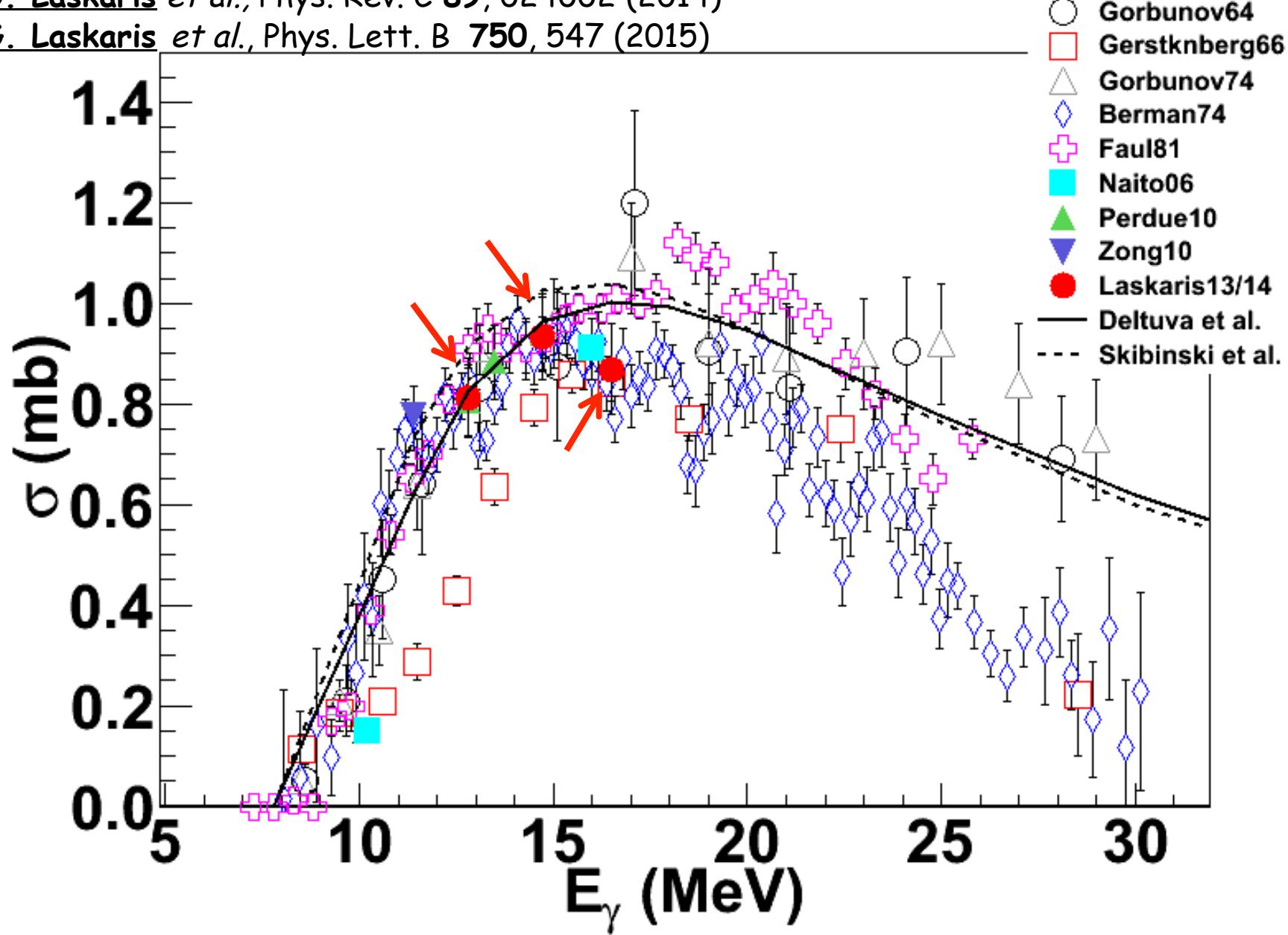
G. Laskaris *et al.*, Phys. Rev. C **89**, 024002 (2014)

G. Laskaris *et al.*, Phys. Lett. B **750**, 547 (2015)

Total Cross Sections for ${}^3\text{He}(\gamma, n)\text{pp}$

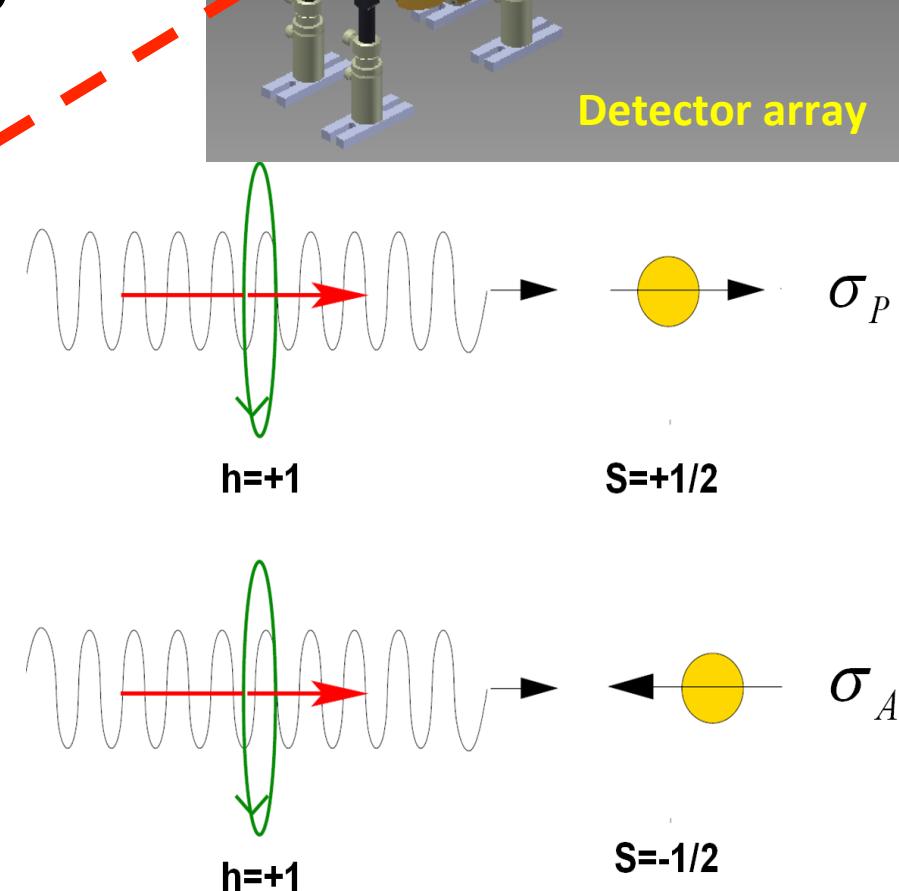
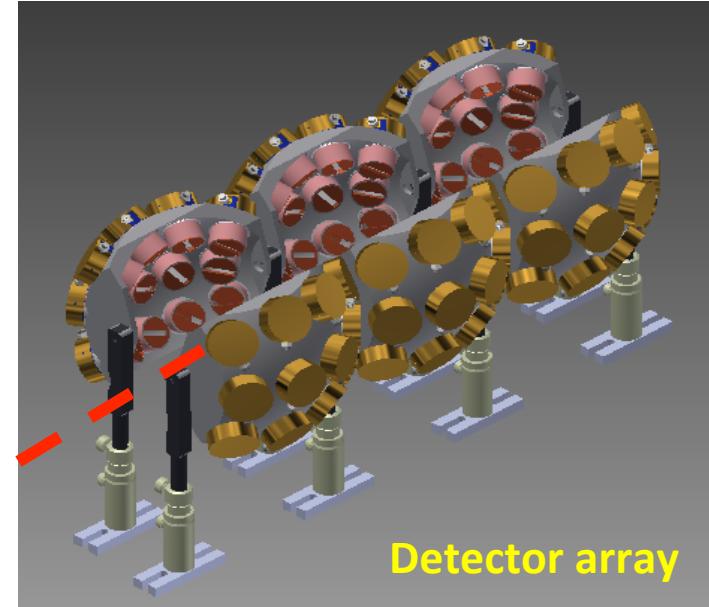
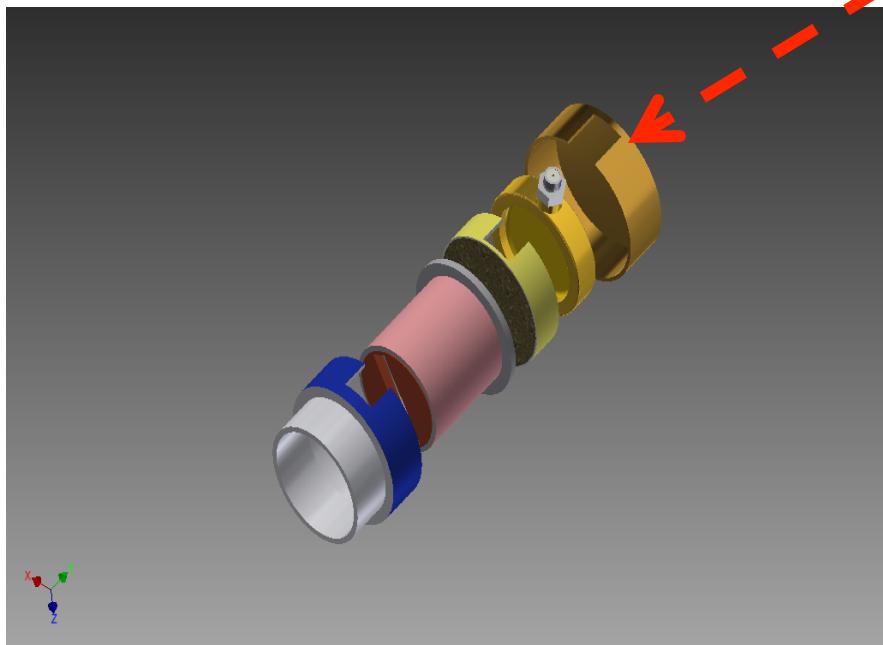
G. Laskaris et al., Phys. Rev. C 89, 024002 (2014)

G. Laskaris et al., Phys. Lett. B 750, 547 (2015)

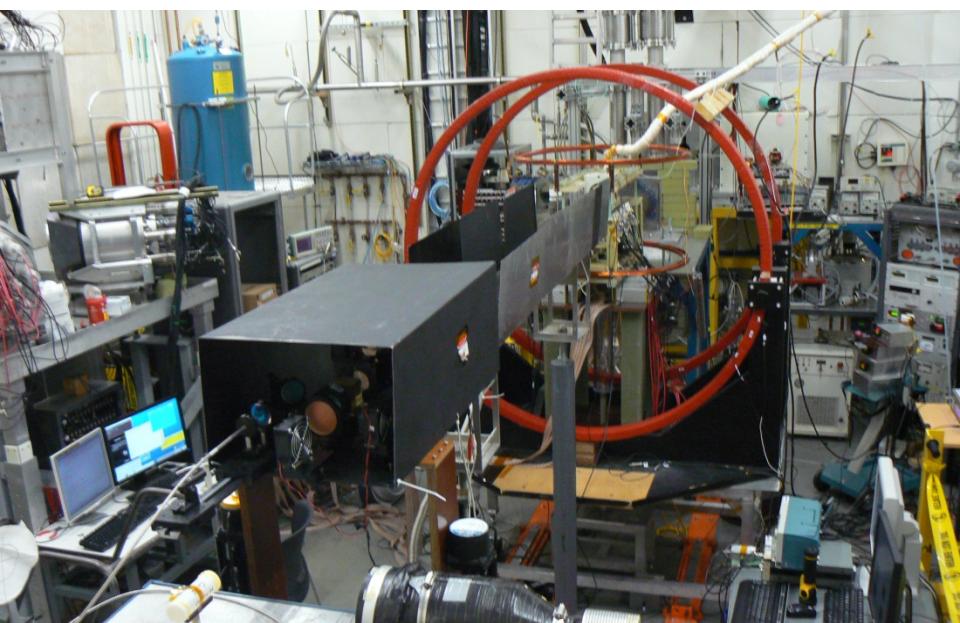


Experimental Overview

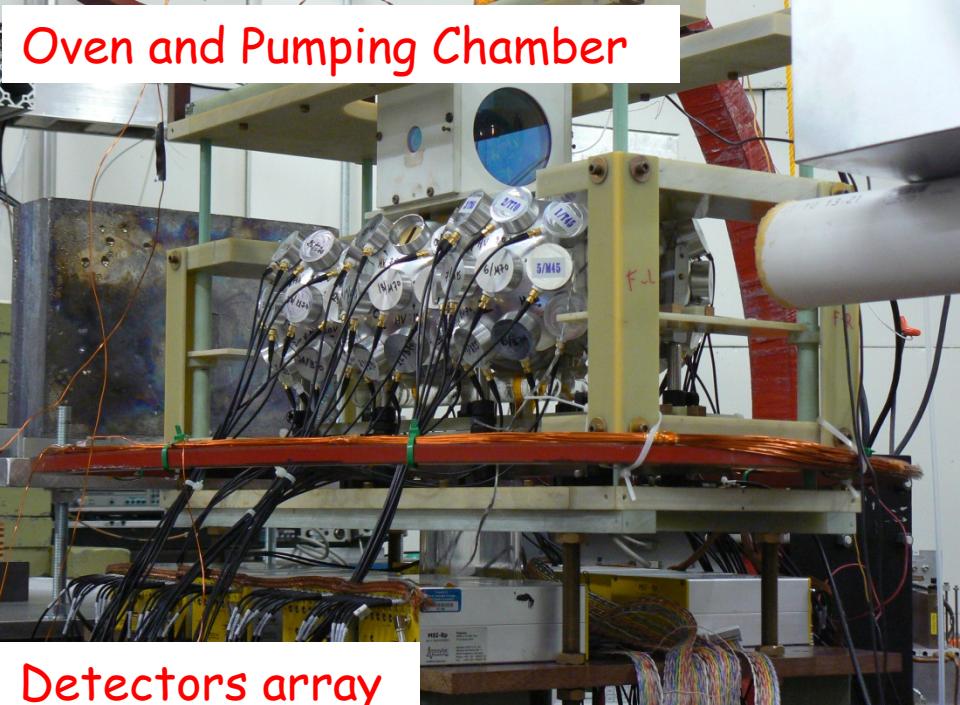
- ~100% circularly polarized γ -ray
- Polarized ${}^3\text{He}$ target, spin flip every 15 min
- Detect Protons using 72 SSB Detectors
300-500 μm thick, 450 mm 2 at 45°, 70°,
95° and 120° (18 detectors per angle)
- 142 hrs on ${}^3\text{He}$ cell and 58 hrs on N_2
reference cell



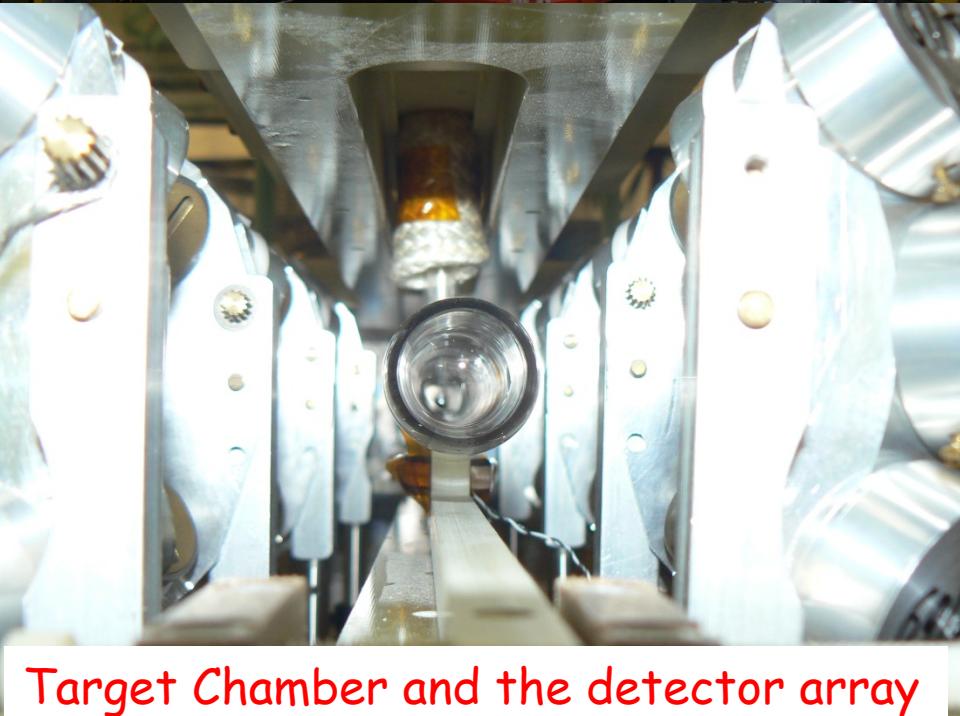
Experimental Apparatus



Oven and Pumping Chamber

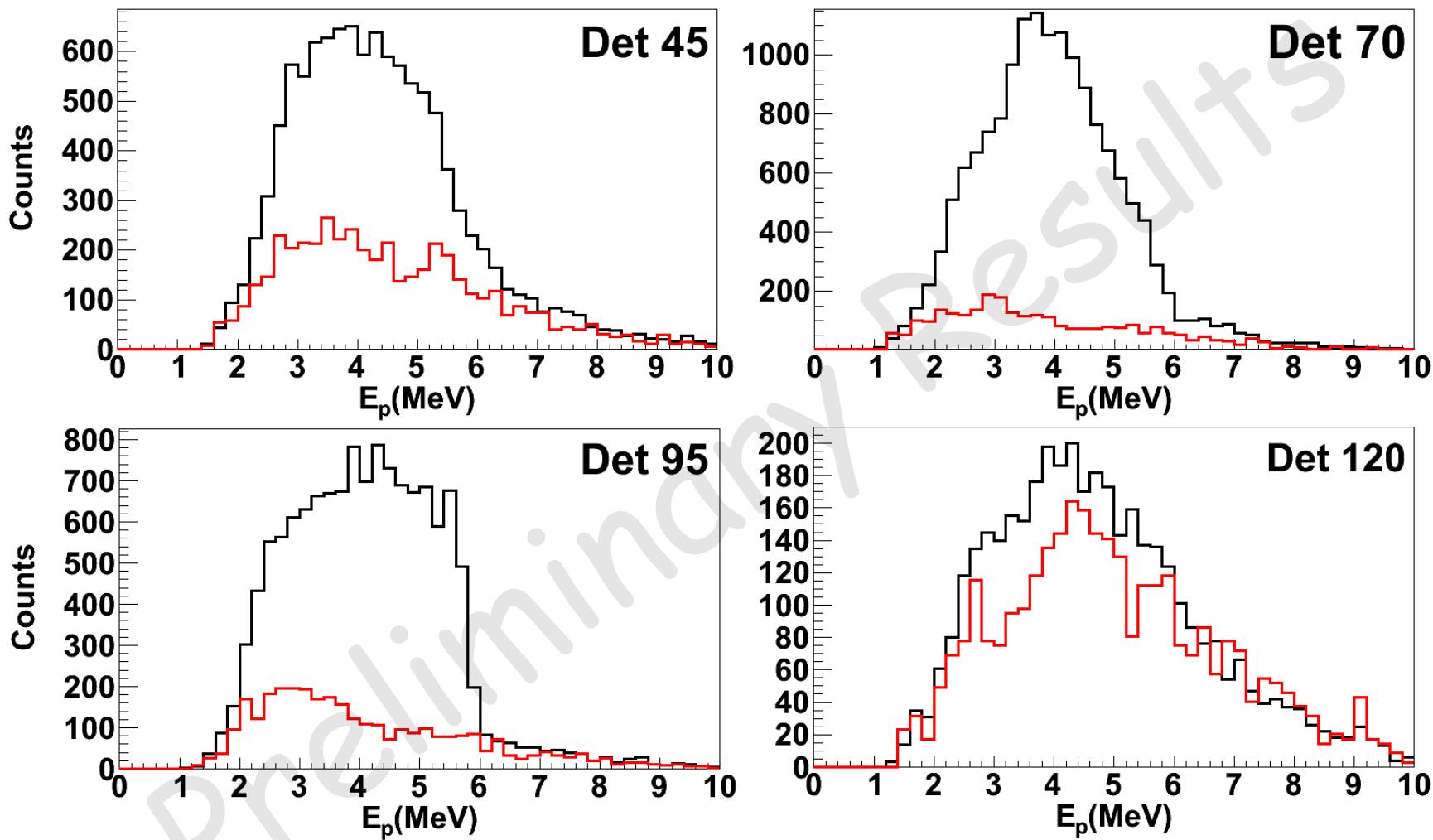


Detectors array

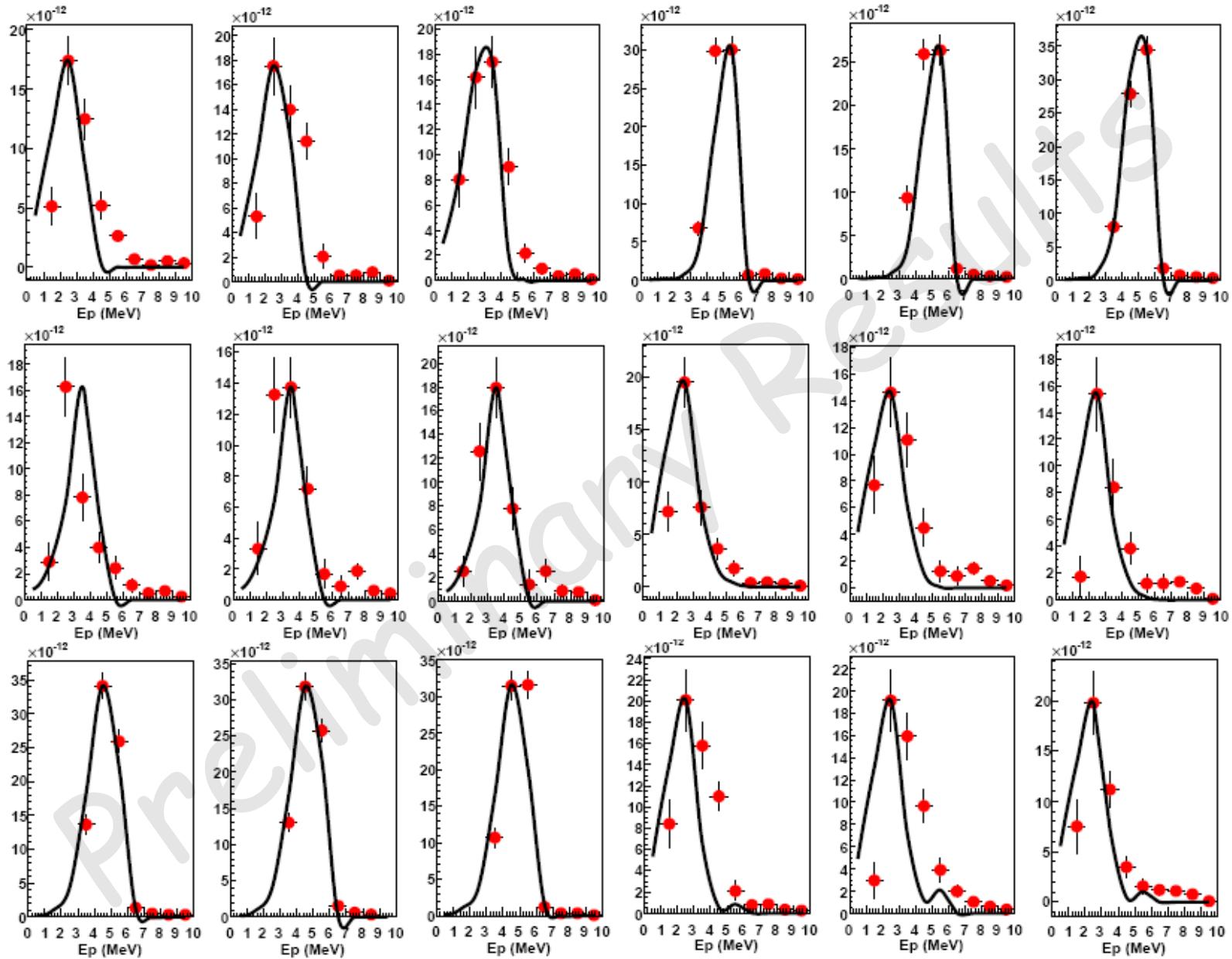


Target Chamber and the detector array

^3He vs N_2 cell Energy Spectra



Comparison of Yields: ^3He vs Theory, 95°



Summary

- The first experiments on the $\overrightarrow{^3He}(\vec{\gamma}, n)pp$ and $\overrightarrow{^3He}(\vec{\gamma}, p)D$ took place at HIyS/TUNL
- Spin-dependent double/single differential, total cross sections and GDH integrand values were extracted
- An agreement between data and theory observed for the cross sections at 12.8 and 14.7 MeV while a disagreement observed at 16.5 MeV
- A general agreement found between the measured and the predicted GDH integrand values
- Results from $\overrightarrow{^3He}(\vec{\gamma}, p)D$ will show how important the two-body break-up contribution might be to the overall GDH integrand

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Collaborations

Three-body

M.W. Ahmed, T. Averett, P.-H. Chu, A. Deltuva, C. Flower, A.C. Fonseca,
H. Gao (co-spokesperson), J.N Heideman, J. Golak, H.J. Karwowski , M.
Meziane, G. Laskaris, J.M. Mueller, P.U. Sauer, R. Skibinski, H.R.
Weller (co-spokesperson), H. Witala, Y.K. Wu, W. Xiong, X. Yan, W.R.
Zimmerman

Two-body

M.W. Ahmed (co-spokesperson), T. Averett, P.-H. Chu, A. Deltuva, C. Flower,
A.C. Fonseca, H. Gao (co-spokesperson), J.N Heideman, J. Golak, A.
Kafkarkou, H.J. Karwowski, G. Laskaris, J. Manfredi, M. Meziane, J.M.
Mueller, C. Peng, P.U. Sauer, R. Skibiski, B. Tsang, H.R. Weller, H. Witala, Y.K.
Wu, W. Xiong, X. Yan, Y. Zhang, W.R. Zimmerman