Proton & Neutron Polarizabilities with Compton Scattering from Low-Mass Nuclear Targets at the High Intensity Gamma-ray Source (HIGS)

Kent Leung (Nuclear Photonics 2025, Darmstadt, Germany)

Assist. Prof., Physics & Astronomy Dept., Montclair, New Jersey

NSF

MONTCLAIR STATE UNIVERSITY

Proton & Neutron Polarizabilities with Compton Scattering from Low-Mass Nuclear Targets at the High Intensity Gamma-ray Source (HIGS)

Kent Leung (Nuclear Photonics 2025, Darmstadt, Germany)

Assist. Prof., Physics & Astronomy Dept., Montclair, New Jersey

View 20 km in this direction

NSF

MONTCLAIR STATE UNIVERSITY

Compton @ HIGS

Nuclear Compton Scattering @ the High-Intensity Gamma-ray Source

Duke University: J. Zhou, E. Mancil, F. Friesen, H. Gao, D. Godagama, C. R. Howell, S. Jia, S. Mikhailov, Y. K. Wu, B. Yu, C. Martin

North Carolina Central University: M. Ahmed, B. Crowe, D. Markoff

George Washington University: E. Downie, G. Feldman, M. Lewis,

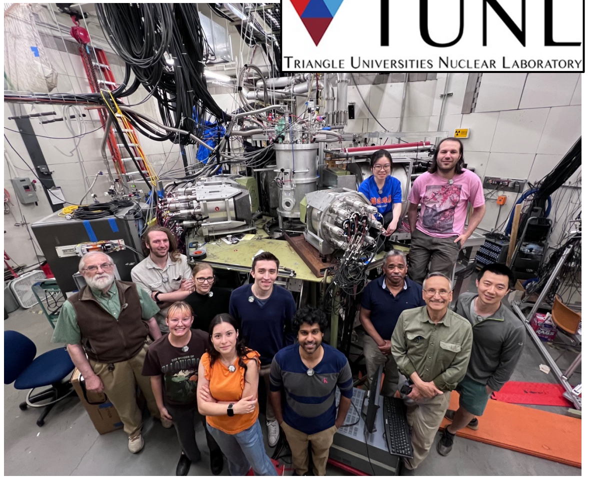
Mount Allison University: D. Hornidge

University North Carolina at Chapel Hill: H. Karwowski

University of Kentucky: M. Kovash

Montclair State University: K. Leung, S. Estupinan Jimenez

University of Saskatchewan: R. Pywell

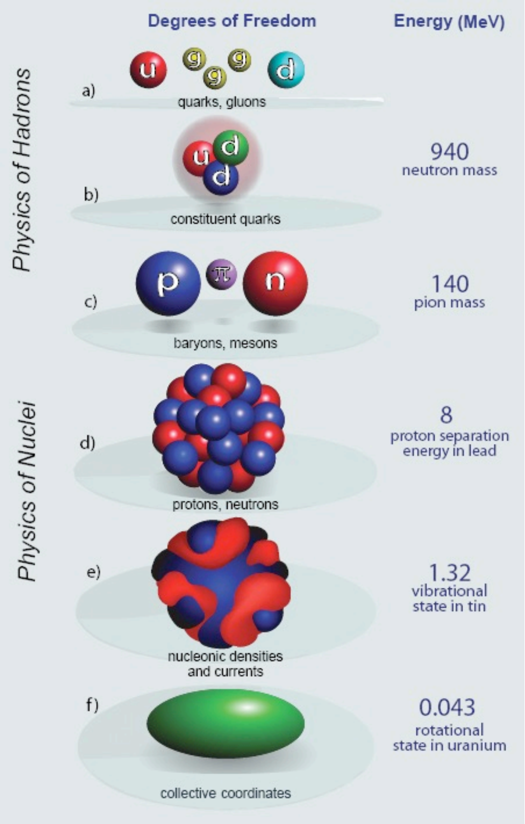


TUNL
TRIANGLE UNIVERSITIES NUCLEAR LABORATORY

This research is supported by the U.S. DOE under Contracts DE-FG02- 03ER41231, DE-SC0016581, DE-SC0005367, DE-FG02-97ER41033, DE-SC0016656, and National Science Foundation 2232117.

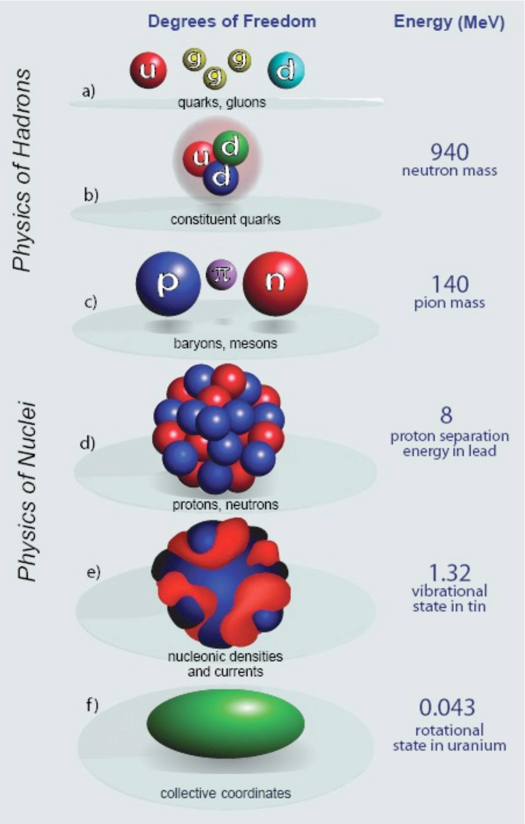
Low-energy QCD with nucleon polarizabilities

- QCD Asymptotic Freedom. Gross, Wilczek & Politzer. Physics Nobel 2004. Non-perturbative.

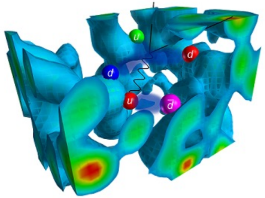


Low-energy QCD with nucleon polarizabilities

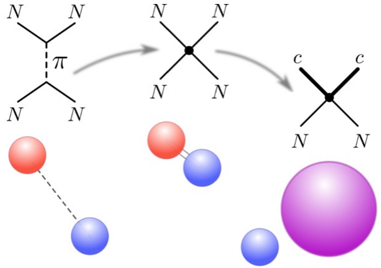
- QCD Asymptotic Freedom. Gross, Wilczek & Politzer. Physics Nobel 2004. Non-perturbative.



Lattice QCD

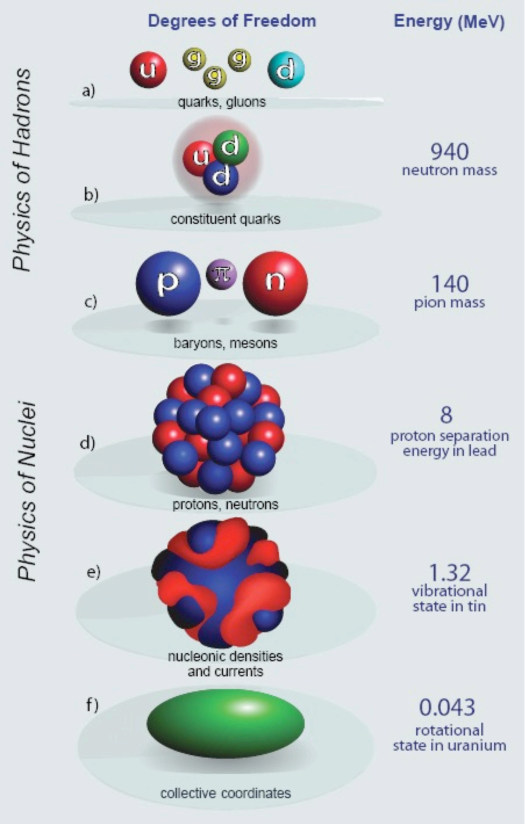


Chiral Effective Field Theory

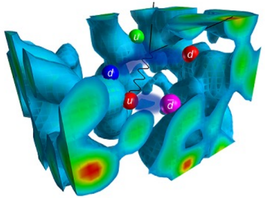


Low-energy QCD with nucleon polarizabilities

- QCD Asymptotic Freedom. Gross, Wilczek & Politzer. Physics Nobel 2004. Non-perturbative.

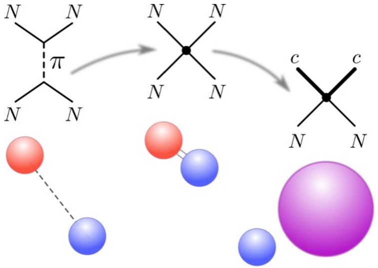


Lattice QCD



Nucleon polarizabilities

Chiral Effective Field Theory



Nucleon polarizabilities

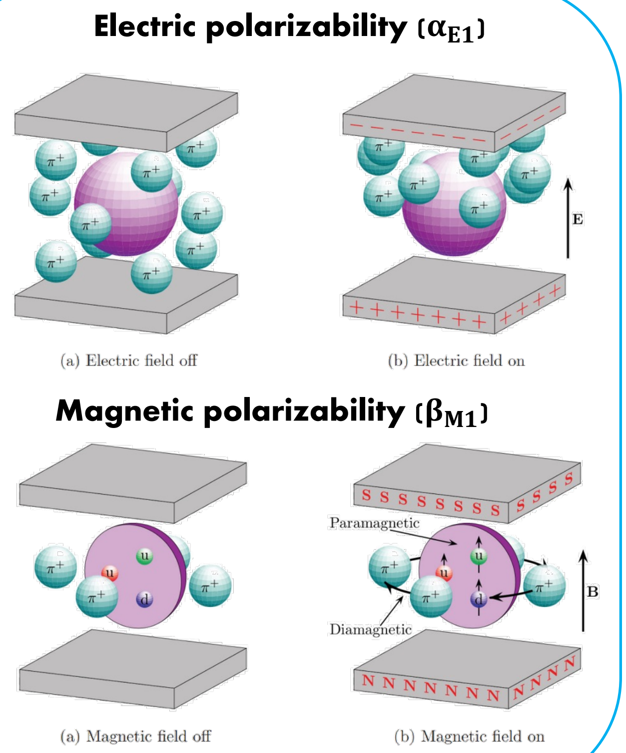
- Fundamental properties probing nucleon structure
- Induced dipole moments from static fields:

$$\vec{\mathbf{d}}_{\mathbf{ind}} = \boldsymbol{\alpha}_{\mathbf{E1}}\,\vec{\mathbf{E}}\,,\ \vec{\mathbf{m}}_{\mathbf{ind}} = \boldsymbol{\beta}_{\mathbf{M1}}\,\vec{\mathbf{H}}$$

scalar electromagnetic polarizabilities

Why scalar polarizabilities?

- Low-energy QCD: Bridge between emerging lattice QCD calculations & χEFT
- Input to Lamb shift in muonic hydrogen for proton radius puzzle
- Electromagnetic contribution to charge symmetry breaking: uncertainty dominated by $\boldsymbol{\alpha}_{\mathbf{E1}}^{p-n}$, $\boldsymbol{\beta}_{\mathbf{M1}}^{p-n}$



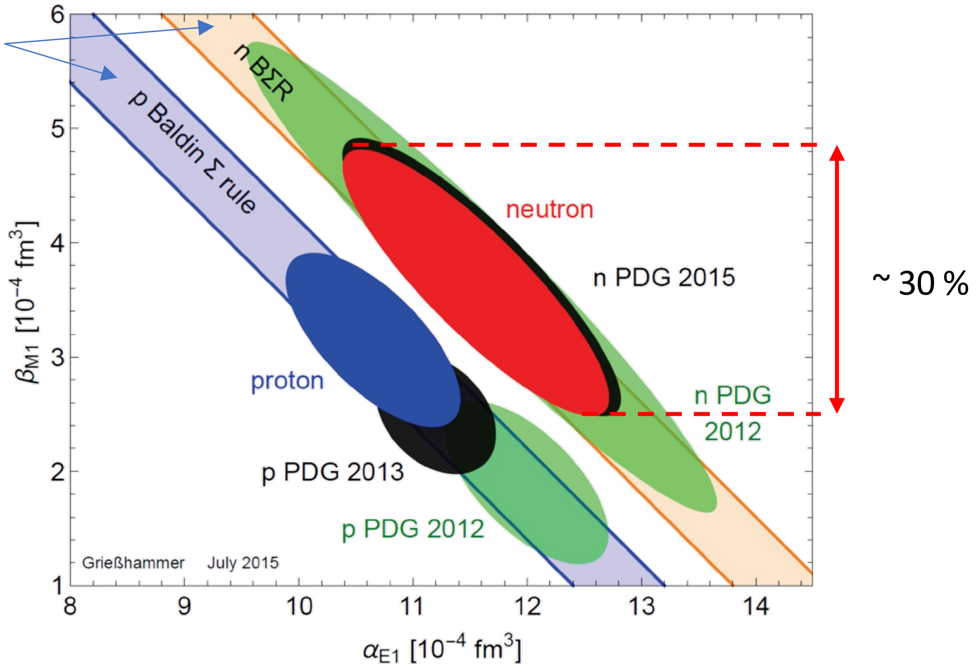
(Graphs credited to P. Martel)

➢ e.g., the β_M (magnetic polarizability) of a nucleon is an interplay between diamagnetic charged pion currents and paramagnetic Δ resonance

Thanks to Jingyi Zhou

Current knowledge of scalar polarizabilities

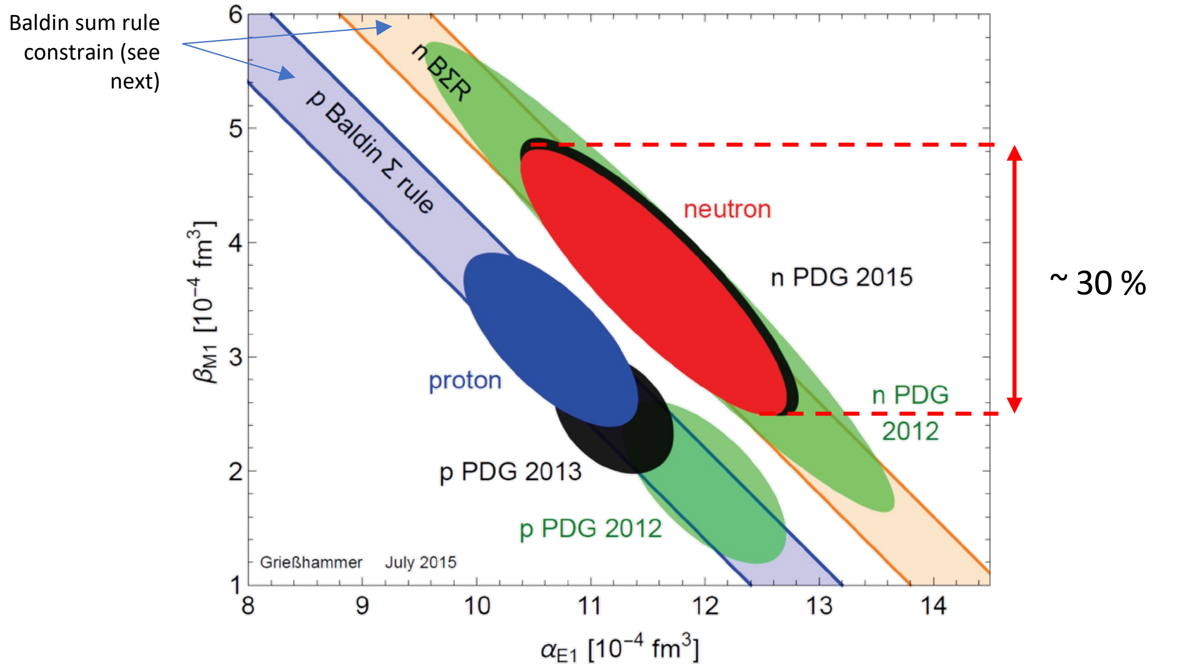
Baldin sum rule constrain (see next)



Scalar Dipole Polarisabilities: "canonical units" $[10^{-4}\ \mathrm{fm}^3]$

	$\alpha_{E1}\ [10^{-4}\ \mathrm{fm}^3]$	$\beta_{M1}\ [10^{-4}\ \mathrm{fm}^3]$
proton (Baldin, N^{2}LO) McGovern/Phillips/hg EPJA 2013	$10.65 \pm 0.35_{\text{stat}} \pm 0.2_{\Sigma} \pm 0.3_{\text{theory}}$	$3.15 \mp 0.35_{\text{stat}} \pm 0.2_{\Sigma} \mp 0.3_{\text{theory}}$
neutron (Baldin, NLO) COMPTON@MAX-lab PRL 2014	$11.55 \pm 1.25_{\text{stat}} \pm 0.2_{\Sigma} \pm 0.8_{\text{theory}}$	$3.65 \mp 1.25_{\text{stat}} \pm 0.2_{\Sigma} \mp 0.8_{\text{theory}}$

Current knowledge of scalar polarizabilities



Wang et al. PRL (2024).
Lattice QCD with physical π-mass:

$\alpha_p = 10.0 \pm 1.3$ & 9.3 ± 2.2

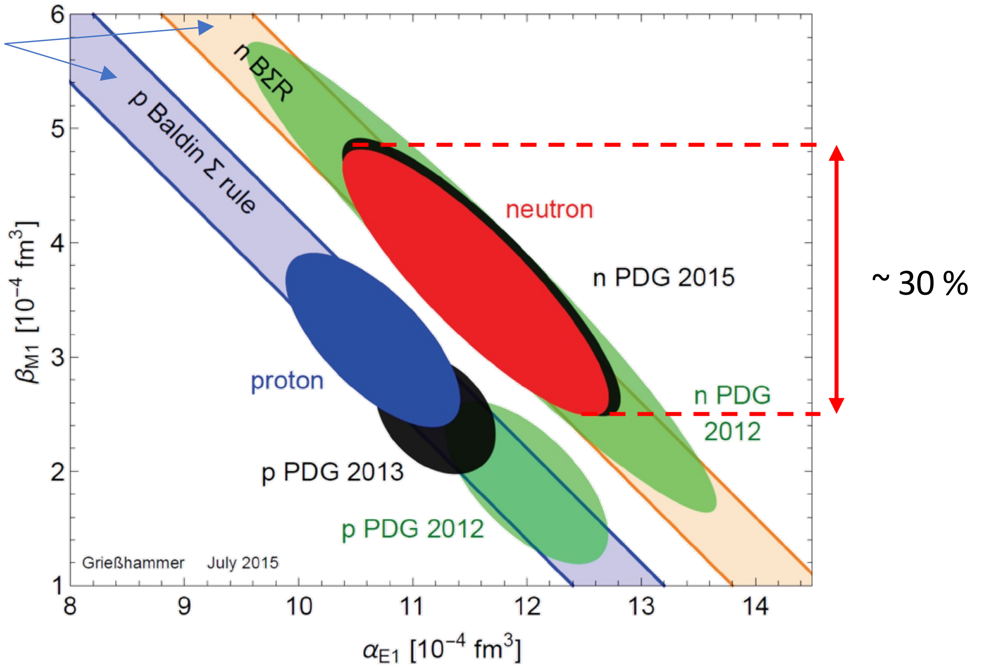
$\alpha_n = 9.7 \pm 1.4$ & 10.1 ± 2.4

Scalar Dipole Polarisabilities: "canonical units" $[10^{-4}\ \mathrm{fm}^3]$

	α_{E1} $[10^{-4}\ \mathrm{fm}^3]$	β_{M1} $[10^{-4}\ \mathrm{fm}^3]$
proton (Baldin, N^{2}LO) McGovern/Phillips/hg EPJA 2013	$10.65 \pm 0.35_{\mathrm{stat}} \pm 0.2_{\Sigma} \pm 0.3_{\mathrm{theory}}$	$3.15 \mp 0.35_{\mathrm{stat}} \pm 0.2_{\Sigma} \mp 0.3_{\mathrm{theory}}$
neutron (Baldin, NLO) COMPTON@MAX-lab PRL 2014	$11.55 \pm 1.25_{\mathrm{stat}} \pm 0.2_{\Sigma} \pm 0.8_{\mathrm{theory}}$	$3.65 \mp 1.25_{\mathrm{stat}} \pm 0.2_{\Sigma} \mp 0.8_{\mathrm{theory}}$

Current knowledge of scalar polarizabilities

Baldin sum rule constrain (see next)



Wang et al. PRL (2024).
Lattice QCD with physical π-mass:

$\alpha_p = 10.0 \pm 1.3$ & 9.3 ± 2.2

$\alpha_n = 9.7 \pm 1.4$ & 10.1 ± 2.4

Scalar Dipole Polarisabilities: "canonical units" $[10^{-4}\ \mathrm{fm}^3]$

	$\alpha_{E1}\ [10^{-4}\ \mathrm{fm}^3]$	$\beta_{M1}\ [10^{-4}\ \mathrm{fm}^3]$
proton (Baldin, N^{2}LO) McGovern/Phillips/hg EPJA 2013	$10.65 \pm 0.35_{stat} \pm 0.2_{\Sigma} \pm 0.3_{theory}$	$3.15 \mp 0.35_{stat} \pm 0.2_{\Sigma} \mp 0.3_{theory}$
neutron (Baldin, NLO) COMPTON@MAX-lab PRL 2014	$11.55 \pm 1.25_{stat} \pm 0.2_{\Sigma} \pm 0.8_{theory}$	$3.65 \mp 1.25_{stat} \pm 0.2_{\Sigma} \mp 0.8_{theory}$

Better experimental data needed already to improve comparison!

Technique: measure absolute differential cross-sections

Nuclear Compton scattering:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Powell} - \frac{e^2}{4\pi M_N}\left(\frac{\omega'}{\omega}\right)^2 \omega\omega' \left\{\frac{\alpha+\beta}{2}(1+cos\ \theta)^2 + \frac{\alpha-\beta}{2}(1-cos\ \theta)^2\right\} + O(\omega^4)$$

Scattering angle

χEFT theory

Cross-section of point-like particle with anomalous magnetic moment

Outgoing & incoming energy

Forward angles sensitive to $\alpha + \beta$ (cross-check with Baldin sum rule)

Backward angles sensitive to α - β (what we extract)

Baldin Sum Rule:

$$\boldsymbol{\alpha_{E1} + \beta_{M1} = \frac{1}{2\pi^2}\int_{\omega_{thr}}^{\infty} \frac{\sigma_{Tot}(\omega')}{\omega'^2} d\omega'}$$

Total photo-nuclear cross-section (from other experimental data)

Technique: measure absolute differential cross-sections

Nuclear Compton scattering:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Powell} - \frac{e^2}{4\pi M_N}\left(\frac{\omega'}{\omega}\right)^2 \omega\omega' \left\{\frac{\alpha+\beta}{2}(1+cos\ \theta)^2 + \frac{\alpha-\beta}{2}(1-cos\ \theta)^2\right\} + O(\omega^4)$$

Scattering angle

χEFT theory

Cross-section of point-like particle with anomalous magnetic moment

Outgoing & incoming energy

Forward angles sensitive to $\alpha + \beta$ (cross-check with Baldin sum rule)

Backward angles sensitive to α - β (what we extract)

Baldin Sum Rule:

$$\boldsymbol{\alpha_{E1} + \beta_{M1} = \frac{1}{2\pi^2}\int_{\omega_{thr}}^{\infty} \frac{\sigma_{Tot}(\omega')}{\omega'^2} d\omega'}$$

Total photo-nuclear cross-section (from other experimental data)

Proton polarizabilities directly from ^{1}H target.

Technique: measure absolute differential cross-sections

Nuclear Compton scattering:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Powell} - \frac{e^2}{4\pi M_N}\left(\frac{\omega'}{\omega}\right)^2 \omega\omega' \left\{\frac{\alpha+\beta}{2}(1+cos\ \theta)^2 + \frac{\alpha-\beta}{2}(1-cos\ \theta)^2\right\} + O(\omega^4)$$

Scattering angle

χEFT theory

Cross-section of point-like particle with anomalous magnetic moment

Outgoing & incoming energy

Forward angles sensitive to $\alpha + \beta$ (cross-check with Baldin sum rule)

Backward angles sensitive to α - β (what we extract)

Baldin Sum Rule:

$$\boldsymbol{\alpha_{E1} + \beta_{M1} = \frac{1}{2\pi^2}\int_{\omega_{thr}}^{\infty} \frac{\sigma_{Tot}(\omega')}{\omega'^2} d\omega'}$$

Total photo-nuclear cross-section (from other experimental data)

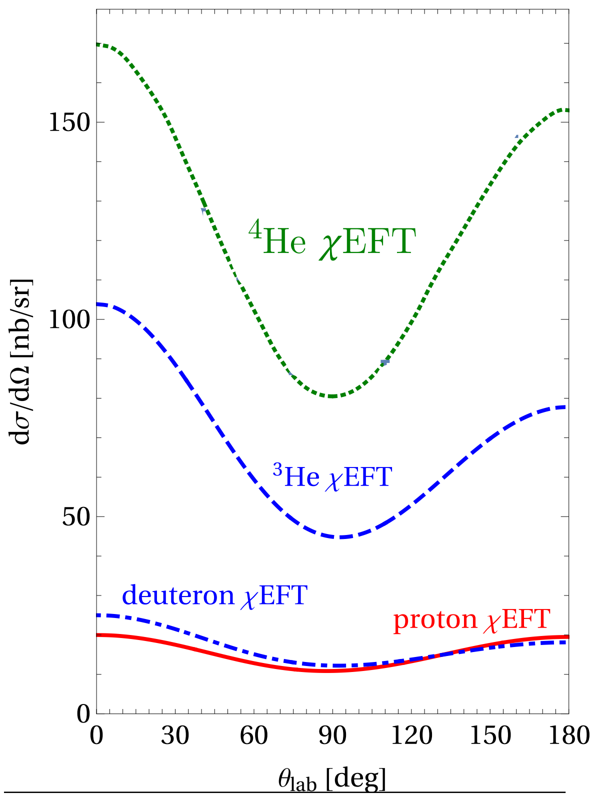
Proton polarizabilities directly from ^{1}H target.

Neutron polarizabilities harder to determine:

- Uncharged, α^n_{E1}, β^n_{M1} appear at the order of ω^4, smaller cross section
- No stable free neutron target.
- Can use light nuclear targets: **D, ^{4}He, ^{3}He** for different summed isoscalar combinations

χEFT calculations of differential cross-sections

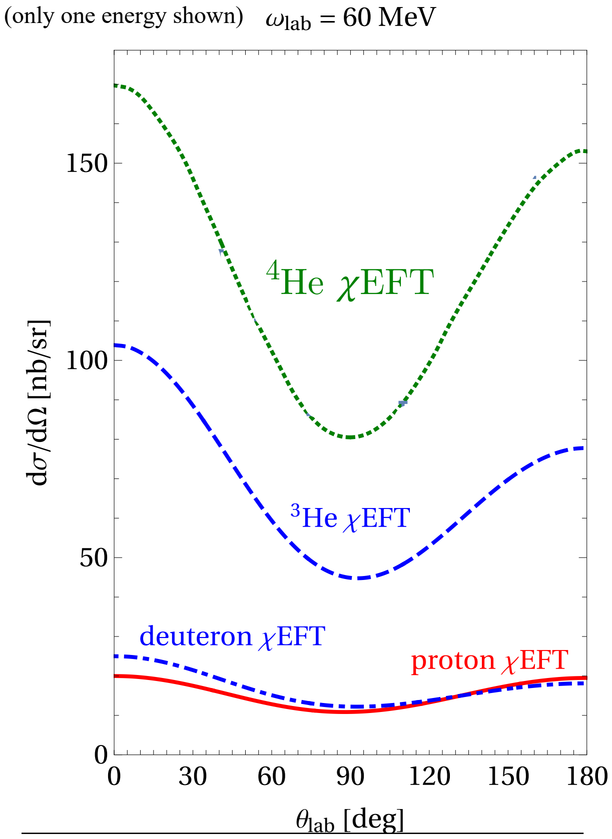
(only one energy shown) ω_{lab} = 60 MeV



(Thanks to H. Griesshammer)

- χEFT gives unique **angular dependence at different energies** for different α and β input values. (later, plots for different α and β for sensitivity)

χEFT calculations of differential cross-sections

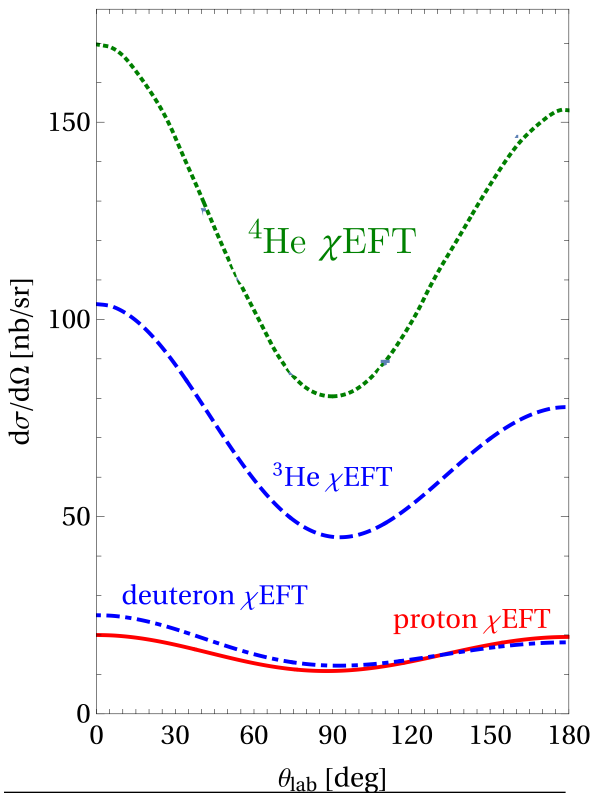


(Thanks to H. Griesshammer)

- χEFT gives unique **angular dependence at different energies** for different α and β input values. (later, plots for different α and β for sensitivity)
- Cross-sections are ~ 10-100 nb. Need **liquid target** to have high density
- Goal ~ ± 3 % total uncertainty with E_γ = 60 - 100 MeV (sub pion-threshold)

χEFT calculations of differential cross-sections

(only one energy shown) ω_{lab} = 60 MeV



(Thanks to H. Griesshammer)

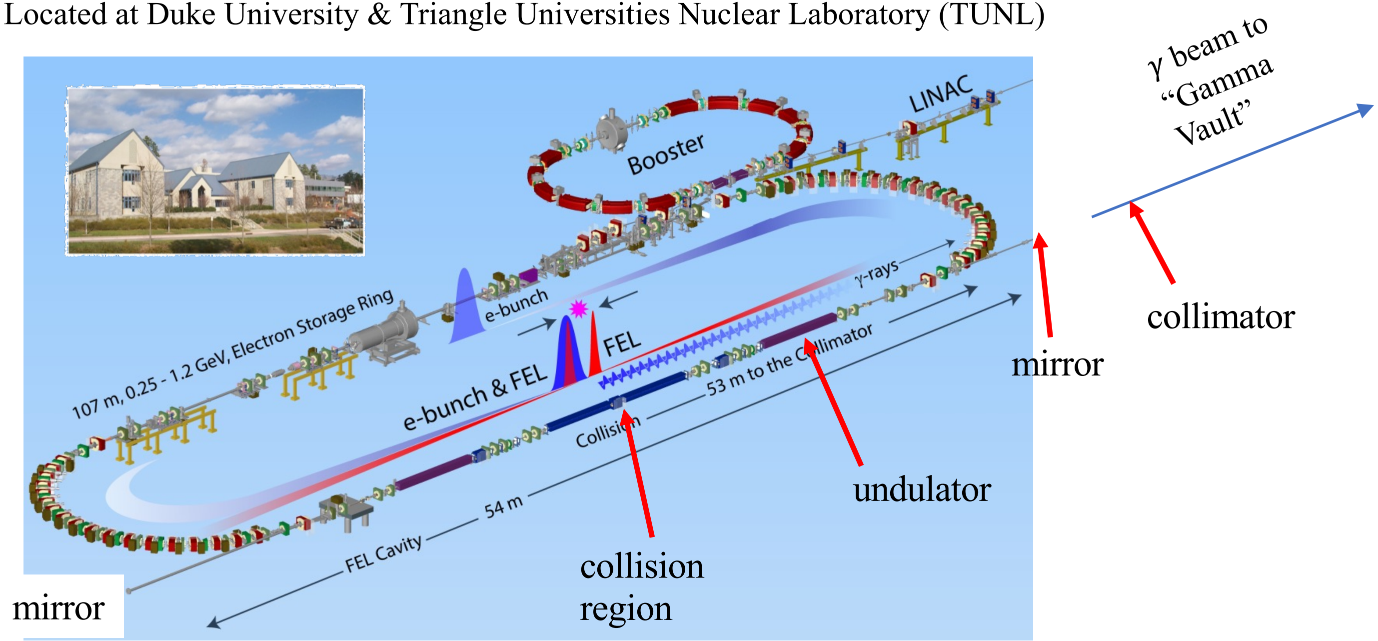
- χEFT gives unique **angular dependence at different energies** for different α and β input values. (later, plots for different α and β for sensitivity)
- Cross-sections are ~ 10-100 nb. Need **liquid target** to have high density
- Goal ~ ± 3 % total uncertainty with E_γ = 60 - 100 MeV (sub pion-threshold)
- While higher mass means larger cross-sections, but the theory gets more difficult and newer effects (good cross-check).
- Also need to consider systematics from **inelastic channels** (not of interest):

$$\gamma + \mathrm{D} = \mathrm{n} + \mathrm{p} + \gamma' \ (> 2.2\,\mathrm{MeV\ loss})$$
$$\gamma + {}^3\mathrm{He} = \mathrm{p} + {}^3\mathrm{He} + \gamma' \ (> 5.5\,\mathrm{MeV\ loss})$$
$$\gamma + {}^4\mathrm{He} = \mathrm{n} + {}^3\mathrm{He} + \gamma' \ (> 20\,\mathrm{MeV\ loss})$$

- Need detector resolution to separate these from (elastic) Compton scattering. Difficult for D.

High Intensity γ-Ray Source (HIγS)

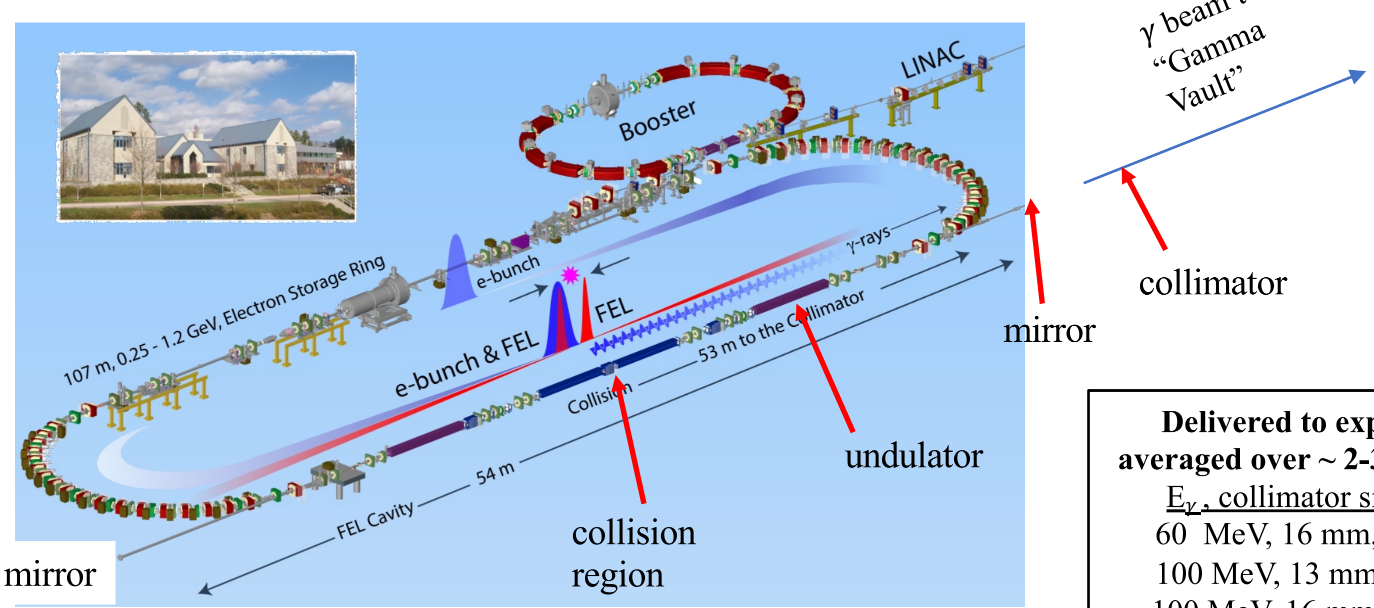
Located at Duke University & Triangle Universities Nuclear Laboratory (TUNL)



- Quasi-monoenergetic, pulsed γ-ray beams
- Synchrotron storage ring for bunches of ~ 1 GeV electrons.
- Free-electron-laser light pulse from one electron bucket reflects off mirror, and Compton scatters off next bucket of electrons to get boosted to gamma energies.
- γ beam rate and bandwidth depends on energy, collimator, mirror conditions.

High Intensity γ-Ray Source (HIγS)

Located at Duke University & Triangle Universities Nuclear Laboratory (TUNL)



Delivered to experiments averaged over ~ 2-3 weeks each

E_γ, collimator size, γ rate

60 MeV, 16 mm, 1.4E7 γ/s

100 MeV, 13 mm, 4E6 γ/s*

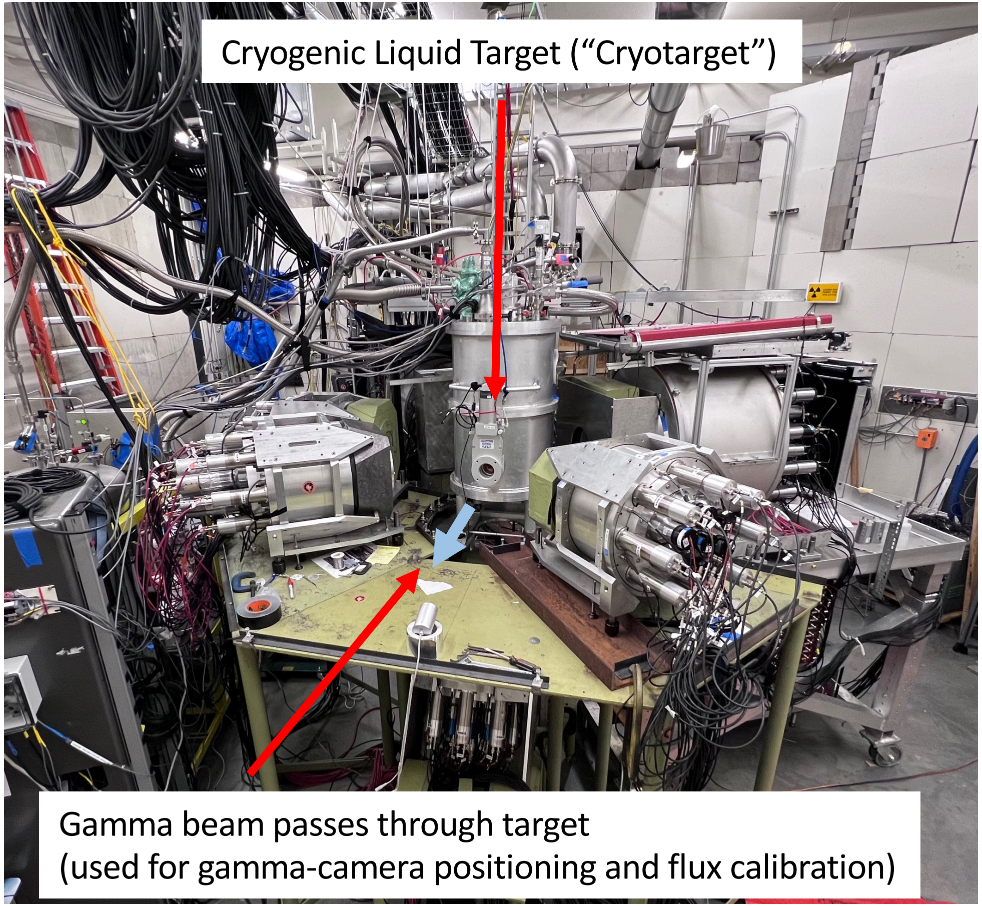
100 MeV, 16 mm, 1.2E7 γ/s

87 MeV, 16 mm, 1.1E7 γ/s

(*1st time running @ 100 MeV)

- Quasi-monoenergetic, pulsed γ-ray beams
- Synchrotron storage ring for bunches of ~ 1 GeV electrons.
- Free-electron-laser light pulse from one electron bucket reflects off mirror, and Compton scatters off next bucket of electrons to get boosted to gamma energies.
- γ beam rate and bandwidth depends on energy, collimator, mirror conditions.

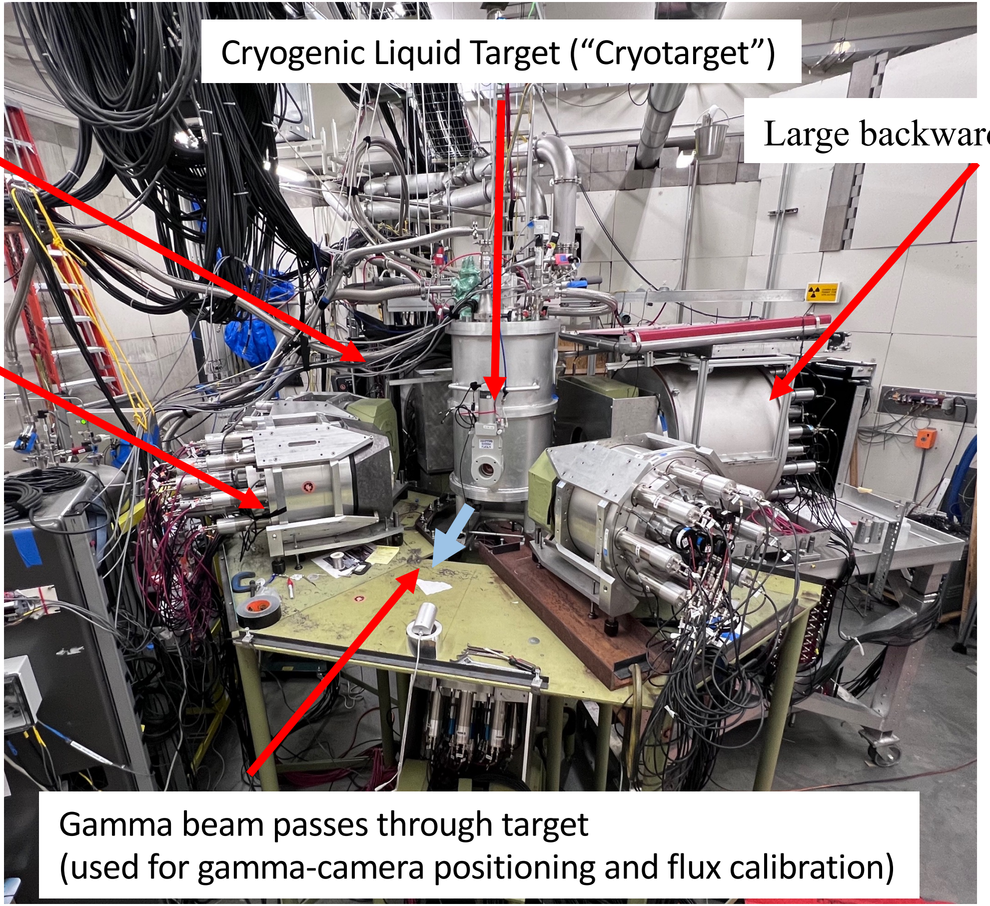
Experimental setup in Gamma Vault



Experimental setup in Gamma Vault

Large backward-angle detector #1

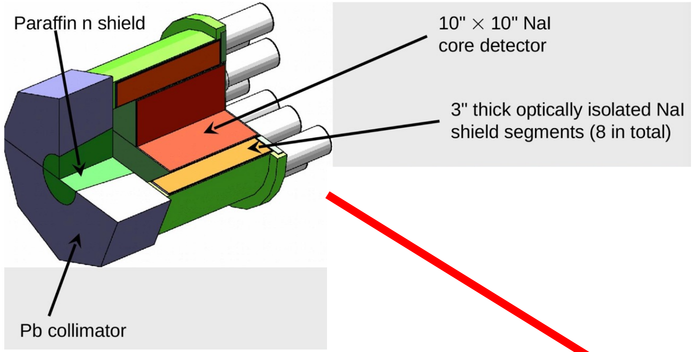
5x Smaller "HINDA" NaI detectors

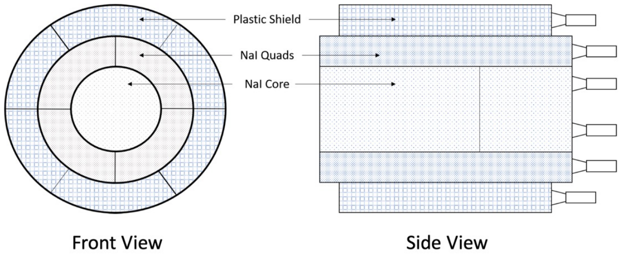


Sodium-Iodide Detectors

HINDA array (our ”small” detectors)

25cm x 25 cm core



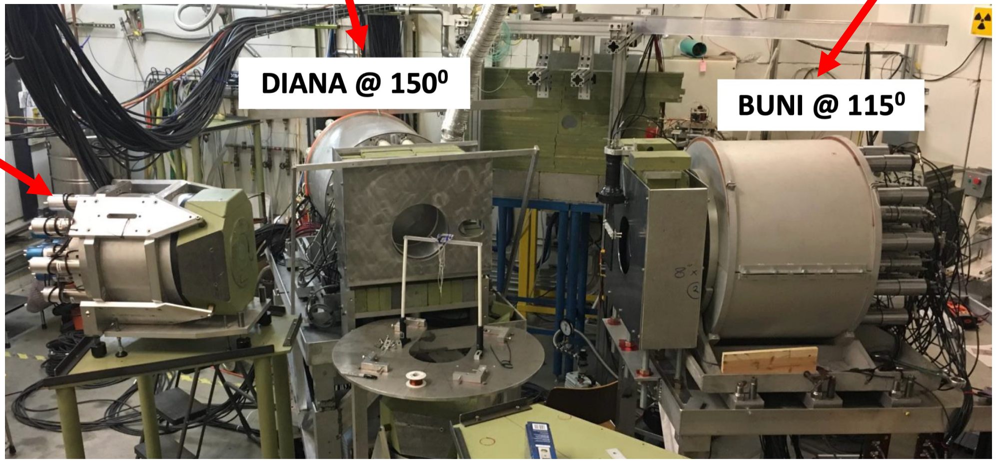


DIANA (large backward det. #1)

Core: 48-cm-⌀, 51-cm-long

BUNI (large backward det. #1)

Core: 2x 56-cm-long, ⌀27cm core glued together



- Size needed for ~ 100 MeV γ’s
- Single crystals help with timing
- ~ 100% detection efficiency of showers
- Outer segments infer “energy leakage”

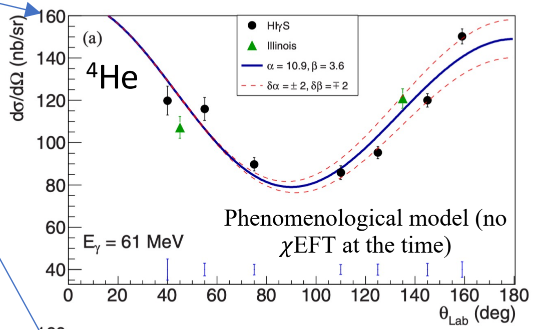
Published results

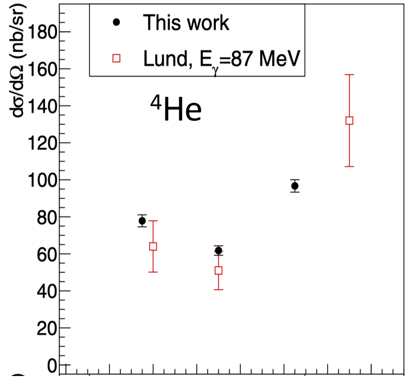
3-K cryogenic target constructed (cooling directly with 2nd stage of GM cryocooler). More on target later.

Demonstrates target, beam, and HINDA detectors.
Energy resolution to separate quasi-elastic not needed.

^{4}He (60 MeV, 7 angles): Sikora et al. PRC (2017).

^{4}He (80 MeV, 3 angles): Li et al. PRC (2020).





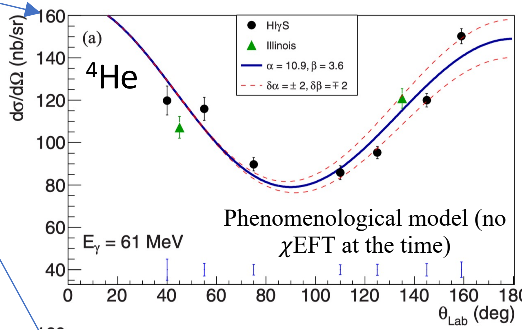
Published results

3-K cryogenic target constructed (cooling directly with 2nd stage of GM cryocooler). More on target later.

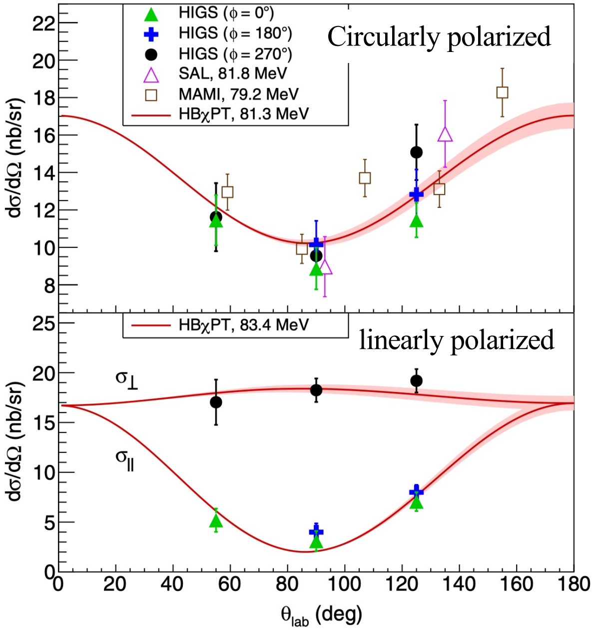
Demonstrates target, beam, and HINDA detectors.
Energy resolution to separate quasi-elastic not needed.

^{4}He (60 MeV, 7 angles): Sikora et al. PRC (2017).

^{4}He (80 MeV, 3 angles): Li et al. PRC (2020).



^{1}H (80 MeV, 3 angles): Li et al. PRL (2022).



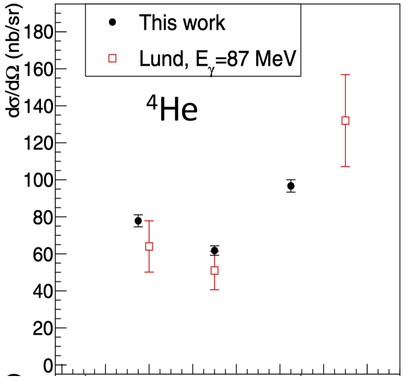
Our result:

$$\alpha^p_{E1} = 15.4 \pm 1.8_{\text{stat}},$$
$$\beta^p_{M1} = 2.1 \pm 2.0_{\text{stat}},$$

Mornacchi et al. (MAMI), PRL (2022).
(All uncertainties added in quadrature):

$$\alpha^p_{E1} = 10.99 \pm 0.63$$
$$\beta^p_{M1} = 3.14 \pm 0.51$$

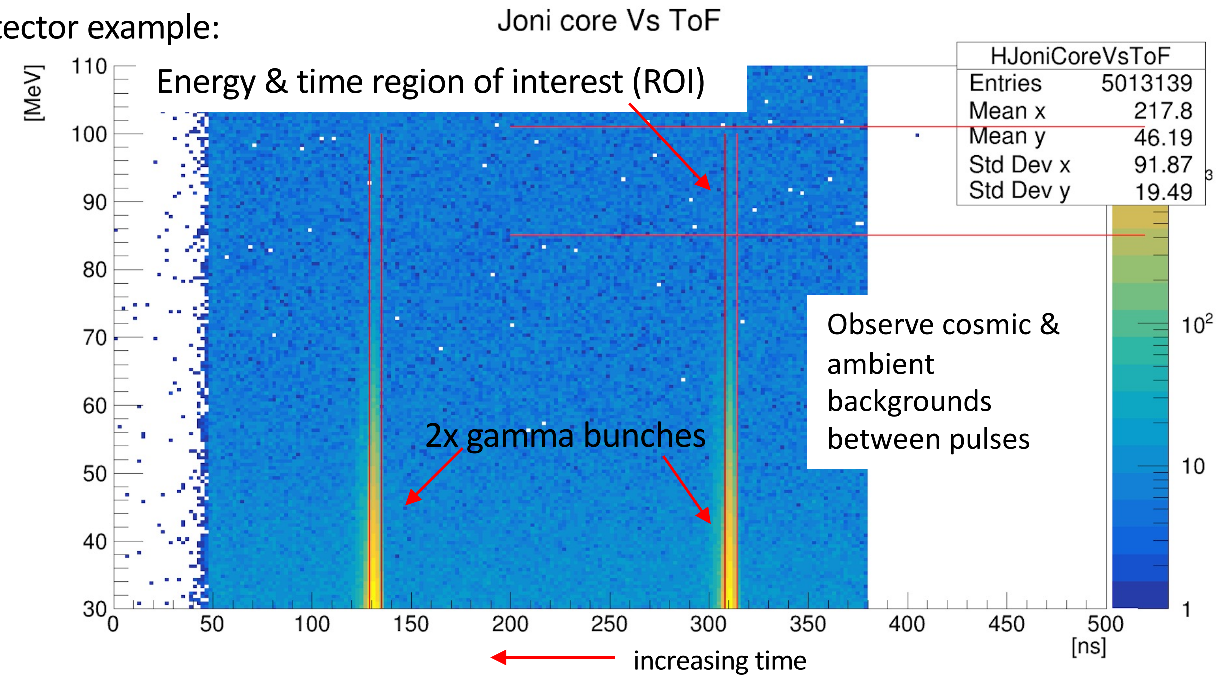
<u>2.3 σ tension in α^p</u>



Time and energy histograms in a detector

- Cosmic muon peak @ ~ 250 MeV, rate of tail in ROI still high → **cosmic veto paddles**
- γ bunches (~ **10 ns wide every ~150 ns**) allow **time cuts** and observation of beam-uncorrelated BG
- Inelastic processes lower in energy than elastic Compton → **lower energy cut**
- Count rate in **ROI ~ 10-20 /hour** in large detectors
- **Empty cell subtraction** to remove beam-correlated BG due vacuum windows & cell walls + others

Smaller HINDA detector example:



Example data from D_2

Detector put "in beam"

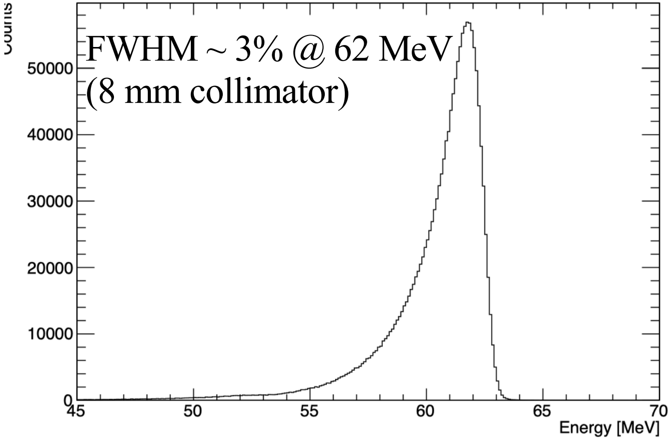


FIG. 4. Measured in-beam spectrum by DIANA. ToF and shield cuts were applied to this energy spectrum.

- Above measures beam bandwidth convoluted with detector response: ~ $[(\text{beam } 2\%)^2 + (\text{detector response } 2\%)^2]^{1/2}$

Example data from D_2

Detector put "in beam"

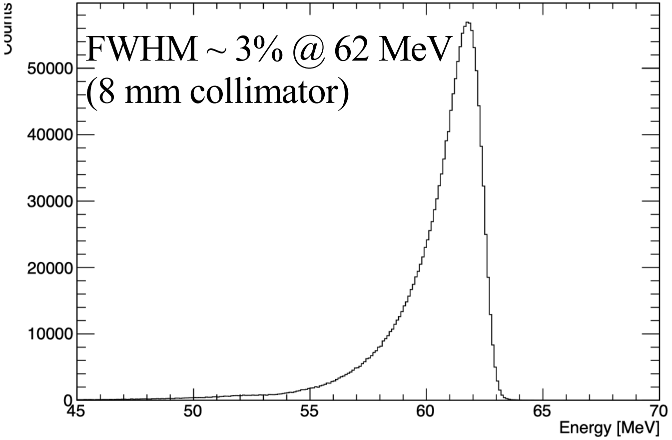
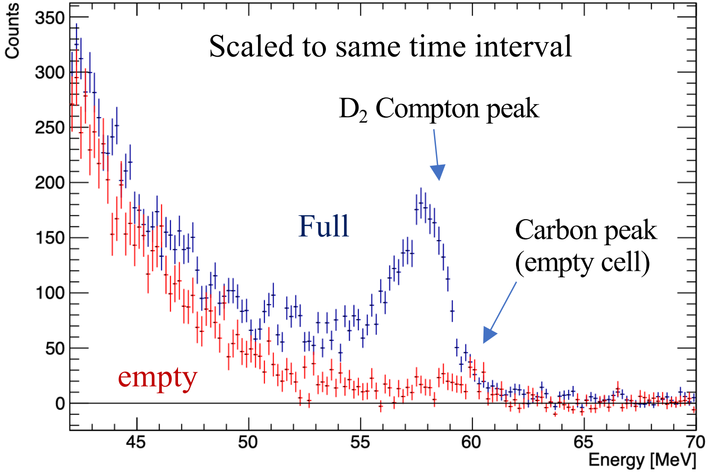


FIG. 4. Measured in-beam spectrum by DIANA. ToF and shield cuts were applied to this energy spectrum.

- Above measures beam bandwidth convoluted with detector response: ~ [(beam 2%)^2 + (detector response 2%)^2]$^{1/2}$

Cell full and cell empty subtraction

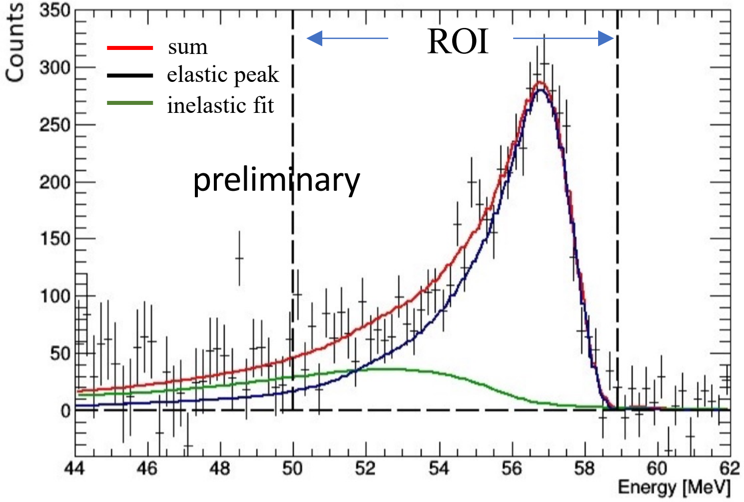


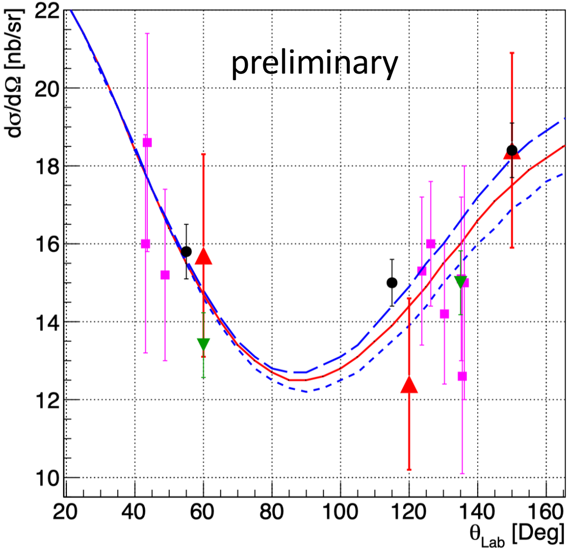
- Compton peak energy shift depends on angle of detector & mass of target.
- Corrects for BGs not from the target liquid
- Dominated by scattering by Kapton in vacuum & cell windows (carbon with high Z)

Deuteron Compton Scattering

- 60 MeV on deuteron data taken in 2022 (**Danula Godagama, PhD thesis**). Paper in draft.
- Needed the large DIANA & BUNI detectors (at backwards angles) to separate inelastic contribution
- **Adding only our 3x dσ/dΩ** to the world data set of ~50 values to a χEFT fit, **we improve α_n & β_n by ~10-15%**

Example: 150° HINDA detector.

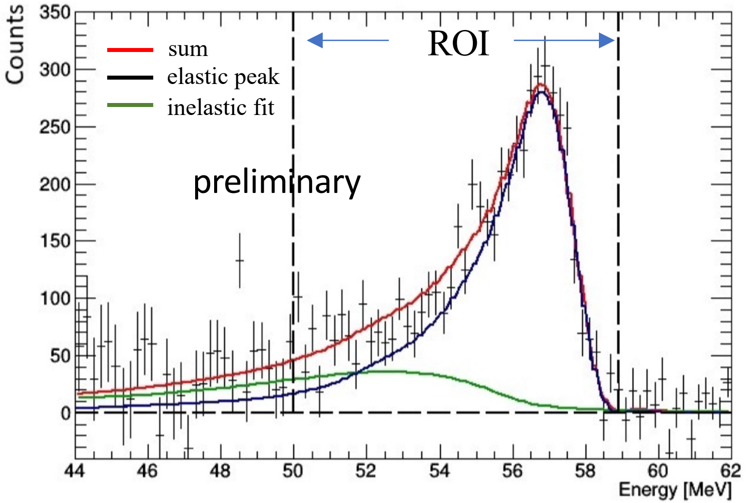


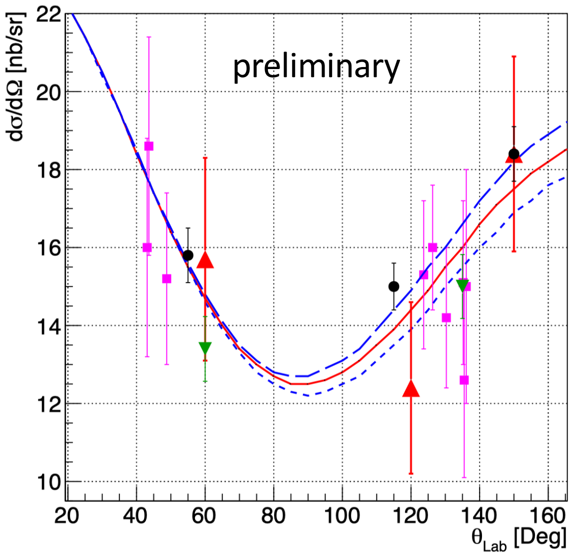


Deuteron Compton Scattering

- 60 MeV on deuteron data taken in 2022 (**Danula Godagama, PhD thesis**). Paper in draft.
- Needed the large DIANA & BUNI detectors (at backwards angles) to separate inelastic contribution
- **Adding only our 3x dσ/dΩ** to the world data set of ~50 values to a χEFT fit, **we improve α_n & β_n by ~10-15%**
- Besides statistics, still contending with sizable correction for inelastic falling into ROI.
- **^{3}He** (never done before!) balances good statistics, good theory (mass 3), and **inelastic 5 MeV away.**

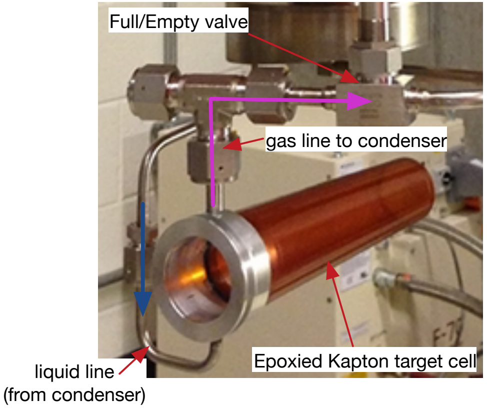
Example: 150° HINDA detector.

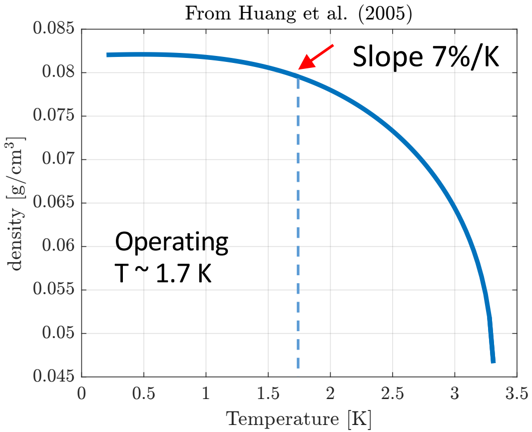


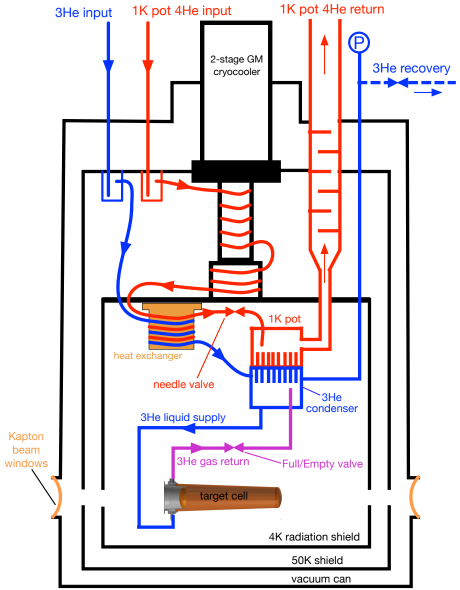


L^3He Cryotarget

- Kapton cell & vacuum window to reduce backgrounds (and for optical access). Made from 0.1-mm-thick epoxied-together sheets. (Flimsy!)
- 1.7 K operation temperature for density & density stability
- In-house recirculating ^4He 1K pot precooled with 1.5 W @ 4K GM cryocooler.
- Target liquid cooled with a thermosiphon loop
- 0.3 L of liquid in cell -> 300 bar-L of ^3He. (~50 bar-L in vapor above liquid.)

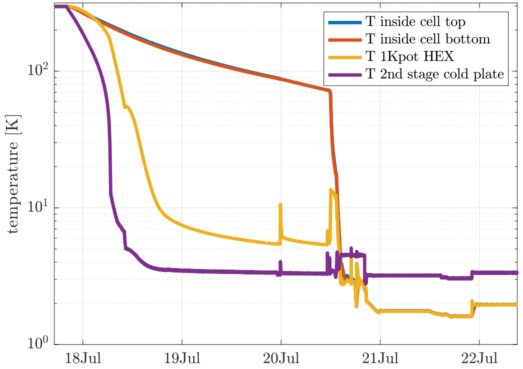


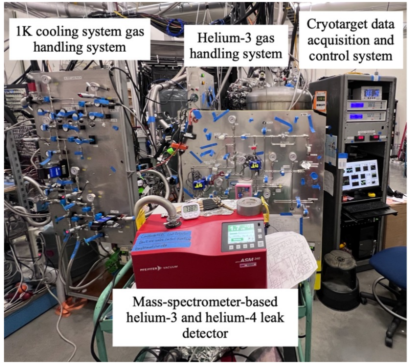




Cryogenic performance

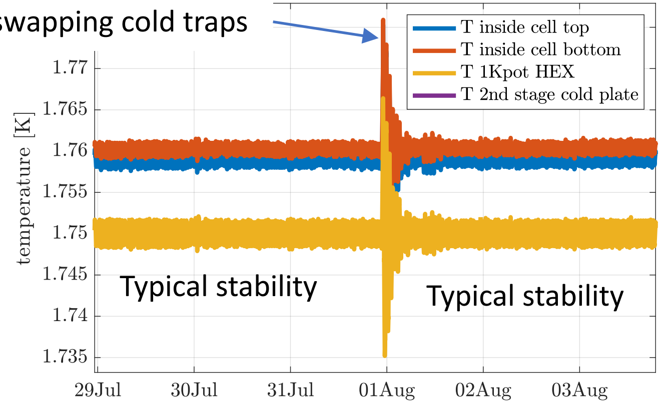
Initial cooldown



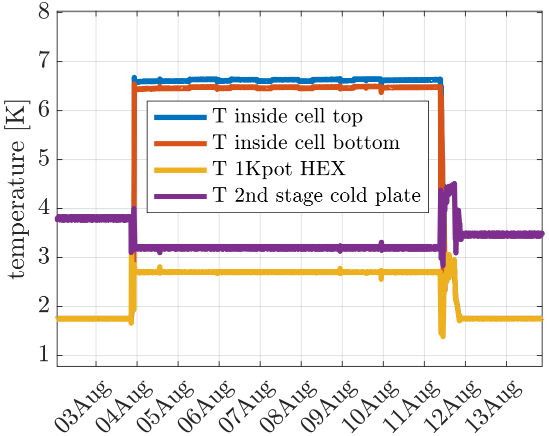


- Ran 1st time Summer '24.
- 2x 4 weeks continuously cold runs
- Temperature stability at operating better than ± 3 mK
- Did not observe any loss of ^{3}He
- < 1 bar*L used for RGA studies
- ^{4}He contamination in ^{3}He ~ 2% level

Planned procedure swapping cold traps



Empty cell running (cold gas density negligible)

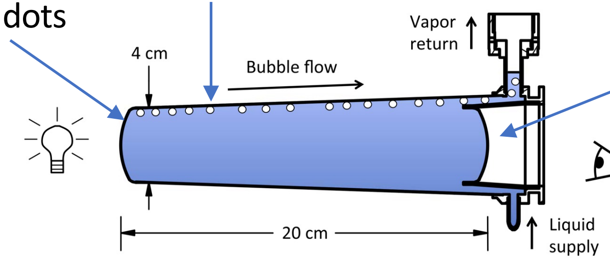


Visual access to target cell

Kapton sheet glue seam

Drawn on ring of 5 dots

Single drawn on dot



Allows visual estimate of bubbling in target liquid and to set bounds on density reduction

During condensing and filling cell with ^{3}He

During operation when full (Light illuminating fluid, which heats it, turned off during production data)

Systematics from ^{3}He cryotarget

- Summer 2024: 1st experiment @ 60 MeV to test system (**Ethan Mancil PhD thesis**)
- Main physics run: 100 MeV, 360 hrs production data (~12hr /day), ± 3-4% statistics reached (**Jingyi Zhou PhD thesis**)

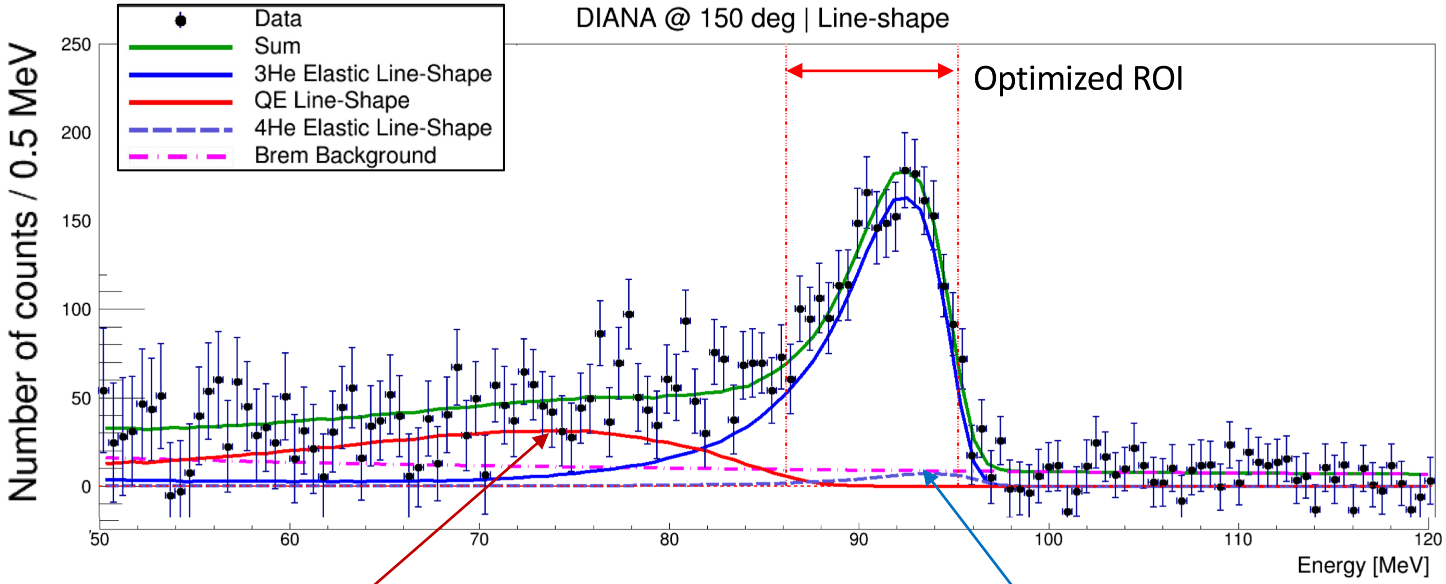
From ^{3}He cryotarget design document:

Source of uncertainty	Uncertainty
Target length measurement at room temperature	0.2 %
Thermal contraction	0.1 %
Pressurized cell flexing against vacuum	0.8 %
Thermometer uncertainty	< 0.1 %
Temperature stability	< 0.1 %
Bubbling	< 0.1 %
Temperature gradients	0.7%
Total (added in quadrature)	**1.1 %**

Measured ^{3}He cryotarget performance from Summer 2024:

- **Temperature stability:** better than ± 5 mK leads to < 0.1% systematic
- **Temperature gradient:** measured < 10 mK difference top and bottom. Systematic < 0.1%
- **Thermometer calibration uncertainty:** < ± 10 mK. Systematic < 0.1% (radiation levels are low)
- **Bubbling:** analyze videos and develop theory (depends on latent heat, bubble velocity, etc.)
- **Length of target** (pressure flexing and beam position on curved end windows): under study
- **^{4}He contamination:** Measured ~ 2% ^{4}He in ^{3}He gas inventory. ^{4}He is soluble in L^{3}He. RGA studies.
- **Note:** literature values for mass density of liquid ^{3}He is ± 1-2 %

^3He @ 100 MeV results: DIANA 150° detector



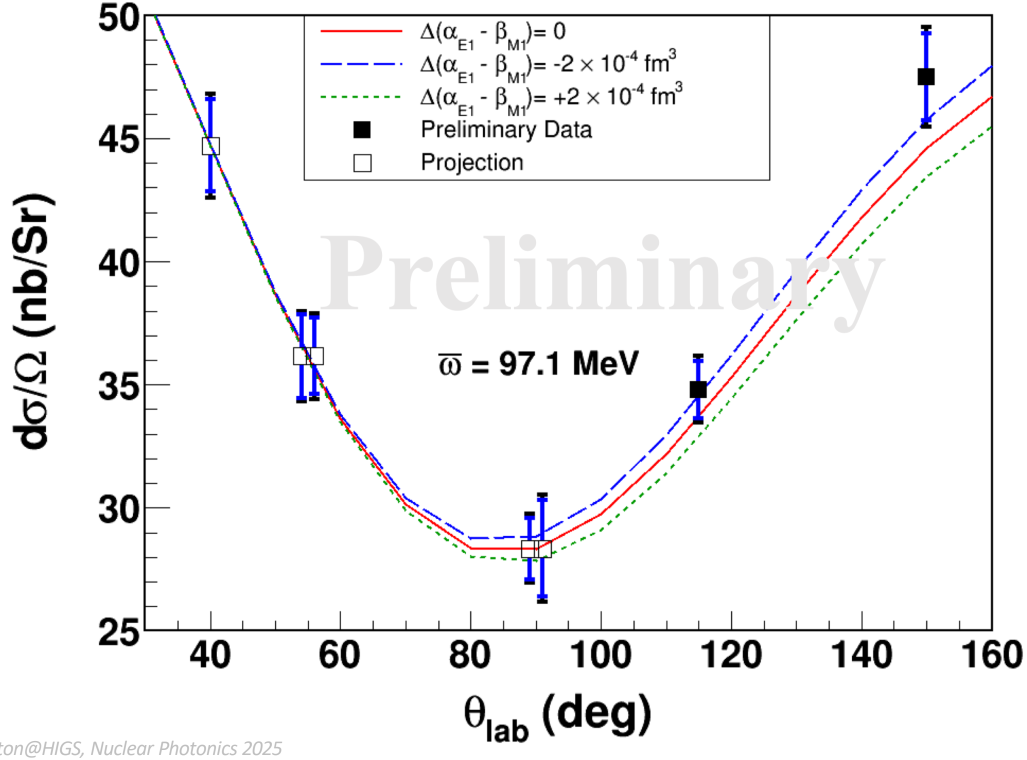
Better separation of inelastic scattering c.f. D_2

^4He Compton contamination. ~2% of ^4He determined by RGA & cross-section from measurements & theory (precision not needed).

(**Thanks, Jingyi Zhou** for this and next figure.)

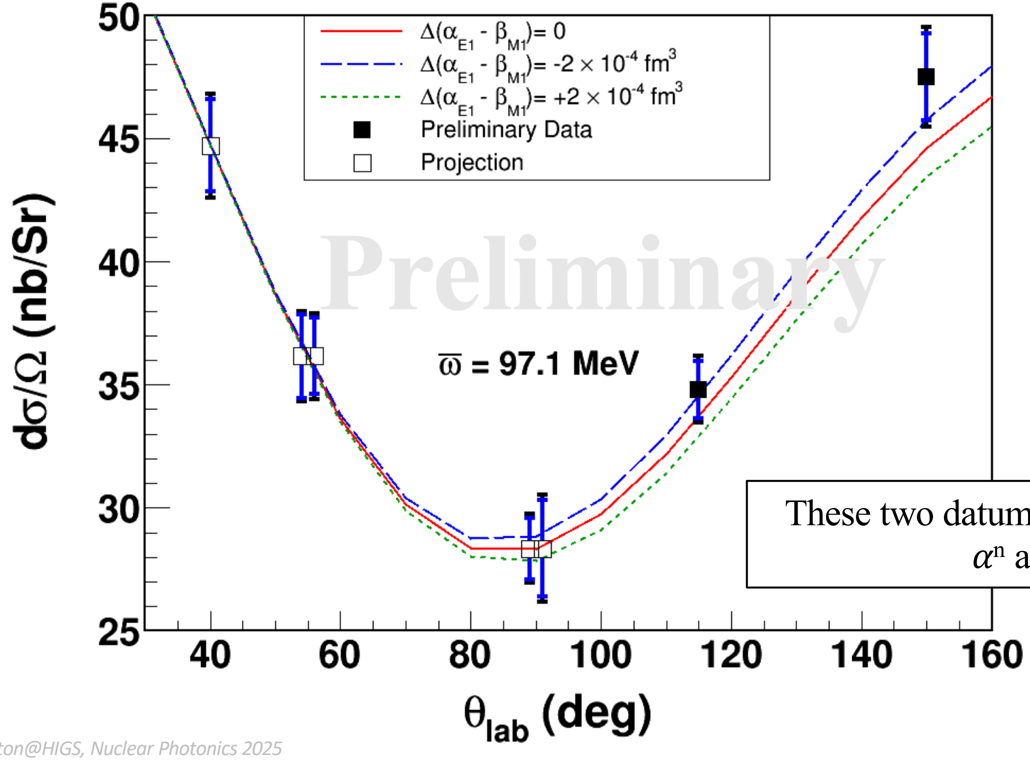
^{3}He results: differential cross-sections

- Recall: No other data to compare because first time this process has been measured!
- Large backward angles constrain physics.
- Forward angles verifies the Baldin sum rule.
- ("Projection" = still working on analysis of data from these detectors.)



^{3}He results: differential cross-sections

- Recall: No other data to compare because first time this process has been measured!
- Large backward angles constrain physics.
- Forward angles verifies the Baldin sum rule.
- ("Projection" = still working on analysis of data from these detectors.)



These two datum gives ~ 30-50% improvement in α^n and β^n uncertainties !

Compton@HIGS summary & future

- **^{1}H @ 80 MeV:** 2.3 σ tension in proton polarizabilities. Proposing to revisit at 100 MeV

- Upgraded **Cryotarget to 1.7 K** and safely handling **350 bar-L of ^{3}He** and incorporated **large NaI detectors (DIANA & BUNI)** for energy resolution

Compton@HIGS summary & future

- **^{1}H @ 80 MeV:** 2.3 σ tension in proton polarizabilities. Proposing to revisit at 100 MeV
- Upgraded **Cryotarget to 1.7 K** and safely handling **350 bar-L of ^{3}He** and incorporated **large NaI detectors (DIANA & BUNI)** for energy resolution
- Beam flux monitoring system & technique improved + vacuum tube for reducing air scattering BGs
- D @ 60 MeV (3 datum) improved **neutron polarizabilities by 10-15%.** Proposing to revisit at 80 MeV.
- ^{3}He @ 100 MeV (2 datum) should improve **neutron polarizabilities by 30-50%.** Have data @ 60 MeV. Proposing to do this at 80 MeV.

Compton@HIGS summary & future

- **^{1}H @ 80 MeV:** 2.3 σ tension in proton polarizabilities. Proposing to revisit at 100 MeV
- Upgraded **Cryotarget to 1.7 K** and safely handling **350 bar-L of ^{3}He** and incorporated **large NaI detectors (DIANA & BUNI)** for energy resolution
- Beam flux monitoring system & technique improved + vacuum tube for reducing air scattering BGs
- D @ 60 MeV (3 datum) improved **neutron polarizabilities by 10-15%.** Proposing to revisit at 80 MeV.
- ^{3}He @ 100 MeV (2 datum) should improve **neutron polarizabilities by 30-50%.** Have data @ 60 MeV. Proposing to do this at 80 MeV.
- This summer (2025) ran with **^{4}He @ 90 & 100 MeV** (Mitchell Lewis PhD thesis). There is now χEFT theory for ^{4}He. Early estimates ~ 30 % improvement in neutron polarizabilities.
- R&D for next generation of experimemnts: **spin polarizabilities** @ HIGS below pion threshold.

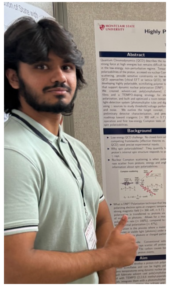
Spin polarizabilities @ HIGS

- Compton amplitude $\mathcal{O}(\omega^3)$ gives 4x **spin polarizabilities**: characterizes stiffness of nucleons' spin degrees of freedom to photons
- Requires **polarized beams** + **polarized target** → **Dynamic Nuclear Polarized** (DNP) *protons* in polymers
- To suppress backgrounds from carbon scattering → scintillating target

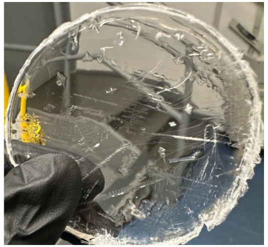
Spin polarizabilities @ HIGS

- Compton amplitude $\mathcal{O}(\omega^3)$ gives 4x **spin polarizabilities**: characterizes stiffness of nucleons' spin degrees of freedom to photons
- Requires **polarized beams** + **polarized target** → **Dynamic Nuclear Polarized** (DNP) *protons* in polymers
- To suppress backgrounds from carbon scattering → scintillating target
- DNP: **polarize electrons in ~ 5 T**. Apply ~10 mW microwaves @ ~0.7 K to **transfer e-polarization to nuclear pol.**
- **"Frozen spin"**: remove 5 T magnet (blocks outgoing photons), **cool down to 10 mK**, and leave in small ~ mT coils
- Ben van den Brandt (PSI) was developing **TEMPO (free-radical) doped scintillating films**
- **R&D launched** at Montclair

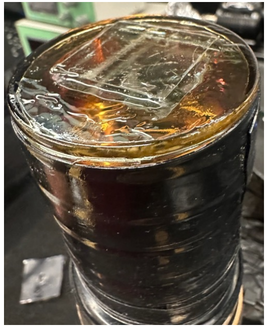
Undergrad Taha Qadir



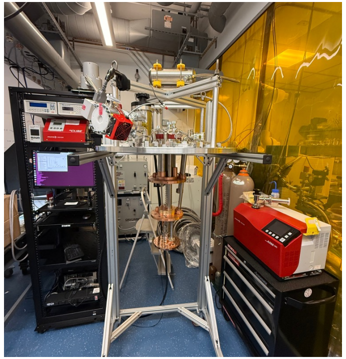
solvent-cast polyvinyl toluene scintillating films



scintillation tests with PMT



0.4 K dry-^{3}He fridge @ Montclair



Thank you!

PhD thesis projects