HPV of Deuteron Photodisintegration at HIγS2

Motivations:

- Sensitive to ΔI = 2 NN parity violation
- Sensitive to a unique combination of HPV coupling parameters

Schindler, Springer, Vanasse, PRC **93**, 025502 (2016).

Imposing LO large N$_c$ symmetry

$$pp \rightarrow \mathcal{C}^{(\Delta I=0)}_{(^1S_0-^3P_0)}\ ,\ \cancel{\mathcal{C}^{(\Delta I=1)}_{(^1S_0-^3P_0)}}\ ,\ \mathcal{C}^{(\Delta I=2)}_{(^1S_0-^3P_0)} \quad \rightarrow \mathcal{C}_{(^3S_1-^1P_1)}, \mathcal{C}^{(\Delta I=2)}_{(^1S_0-^3P_0}$$

$$nn \rightarrow \mathcal{C}^{(\Delta I=0)}_{(^1S_0-^3P_0)}\ ,\ \cancel{\mathcal{C}^{(\Delta I=1)}_{(^1S_0-^3P_0)}}\ ,\ \mathcal{C}^{(\Delta I=2)}_{(^1S_0-^3P_0)} \quad \rightarrow \mathcal{C}_{(^3S_1-^1P_1)}, \mathcal{C}^{(\Delta I=2)}_{(^1S_0-^3P_0}$$

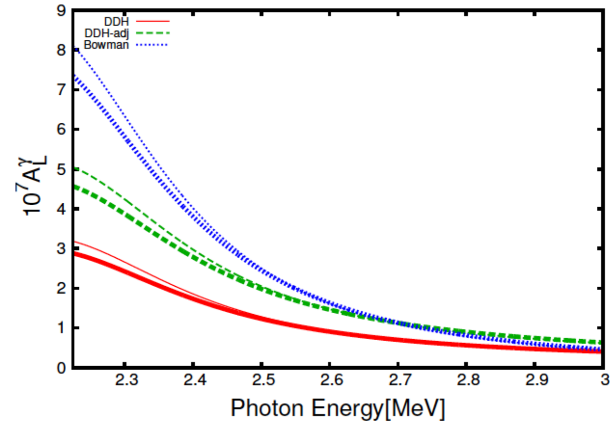
$$np\ (^1S_0) \rightarrow \mathcal{C}^{(\Delta I=0)}_{(^1S_0-^3P_0)}\ ,\ \mathcal{C}^{(\Delta I=2)}_{(^1S_0-^3P_0)} \quad \rightarrow \mathcal{C}_{(^3S_1-^1P_1)}, \mathcal{C}^{(\Delta I=2)}_{(^1S_0-^3P_0}$$

$$np\ (^3S_1) \rightarrow \mathcal{C}_{(^3S_1-^1P_1)}\ ,\ \cancel{\mathcal{C}_{(^3S_1-^3P_1)}} \quad \rightarrow \mathcal{C}_{(^3S_1-^1P_1)}$$

$$(\vec{n}p \rightarrow d\gamma) \rightarrow \cancel{\mathcal{C}_{(^3S_1-^3P_1)}}$$

$$(np \leftrightarrow d\overset{\circlearrowleft}{\gamma}) \rightarrow \mathcal{C}_{(^3S_1-^1P_1)}\ ,\ \mathcal{C}^{(\Delta I=0)}_{(^1S_0-^3P_0)}\ ,\ \mathcal{C}^{(\Delta I=2)}_{(^1S_0-^3P_0)} \quad \rightarrow \mathcal{C}_{(^3S_1-^1P_1)}, \mathcal{C}^{(\Delta I=2)}_{(^1S_0-^3P_0}$$

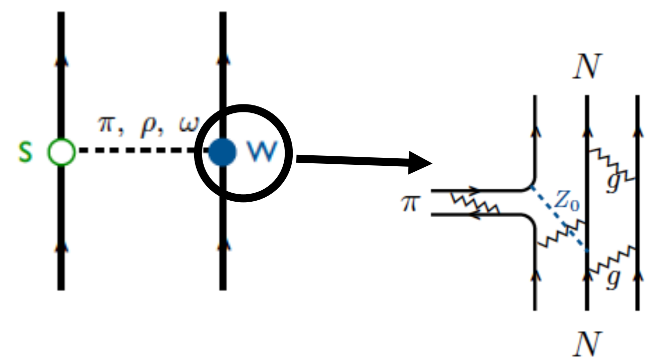
$$n \text{ rotation off } d \rightarrow \cancel{\mathcal{C}_{(^3S_1-^3P_1)}}, \mathcal{C}_{(^3S_1-^1P_1)}, \mathcal{C}^{(\Delta I=0)}_{(^1S_0-^3P_0)}, \cancel{\mathcal{C}^{(\Delta I=1)}_{(^1S_0-^3P_0)}} \rightarrow \mathcal{C}_{(^3S_1-^1P_1)}$$



Vanasse/Schindler, PRC 90, 044001 (2014)

A_γ *(threshold)= -8.44* h_ρ^0 *+3.63* h_ω^0 *-17.6* h_ρ^2

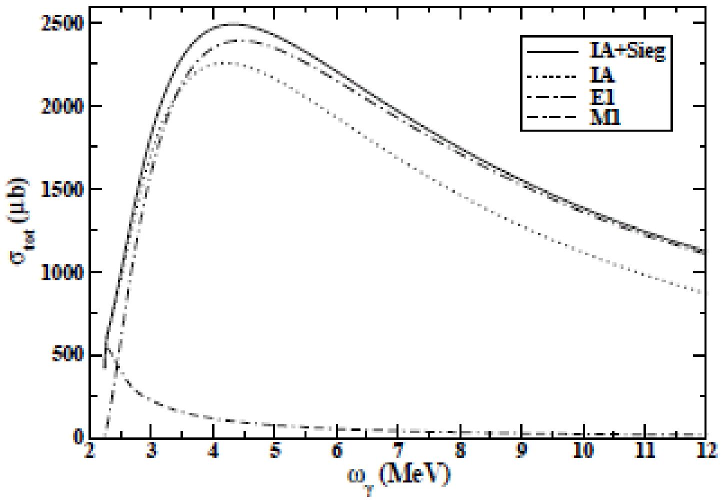
C.-P. Liu, C.H. Hyun and B. Desplanques, arXiv:nucl-th/0403009v1



By: C.R. Howell, Duke University and TUNL

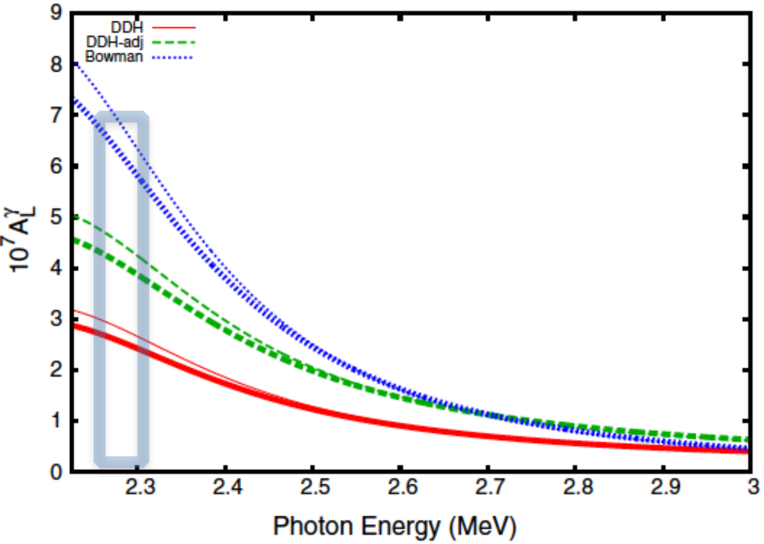
PV Asymmetry in γd → np

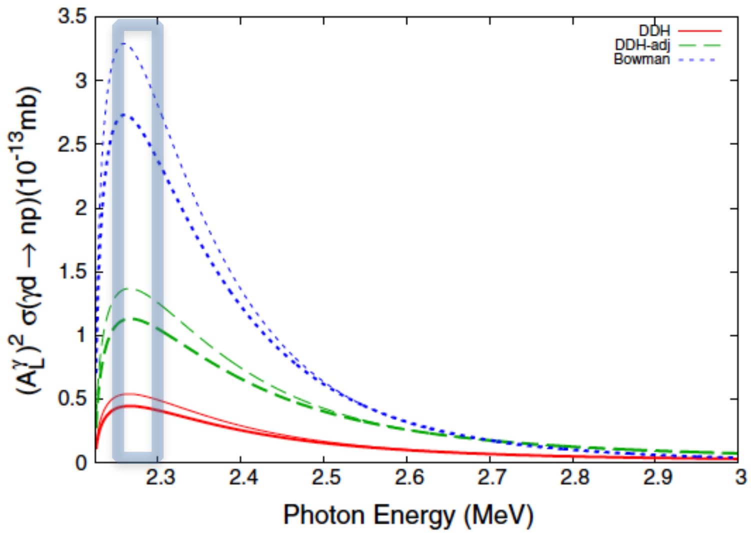
C.-P. Liu, C.H. Hyun and B. Desplanques, arXiv:nucl-th/0403009v1.



E_γ = 2.25 – 2.30 MeV
<σ> ~ 600 μb
A ~ 4 x 10^{-7}

Vanasse and Schindler, PRC 90, 044001 (2014)





Experiment concept and beam requirements

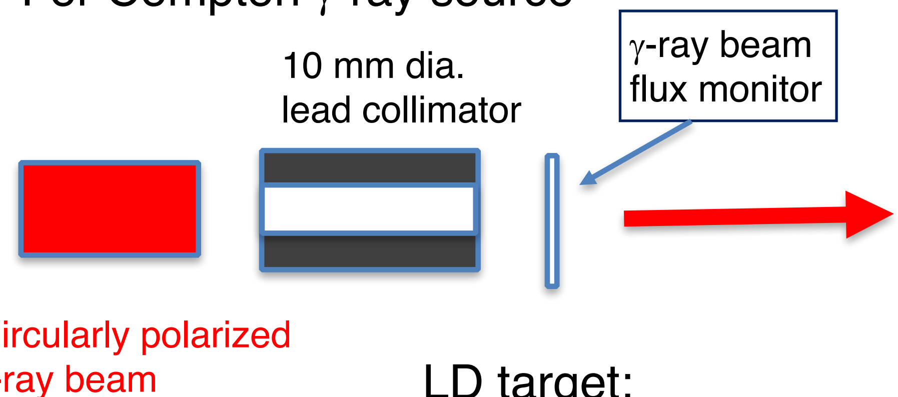
from M. Snow

Suggested beam parameters for PV in deuteron photodisintegration.

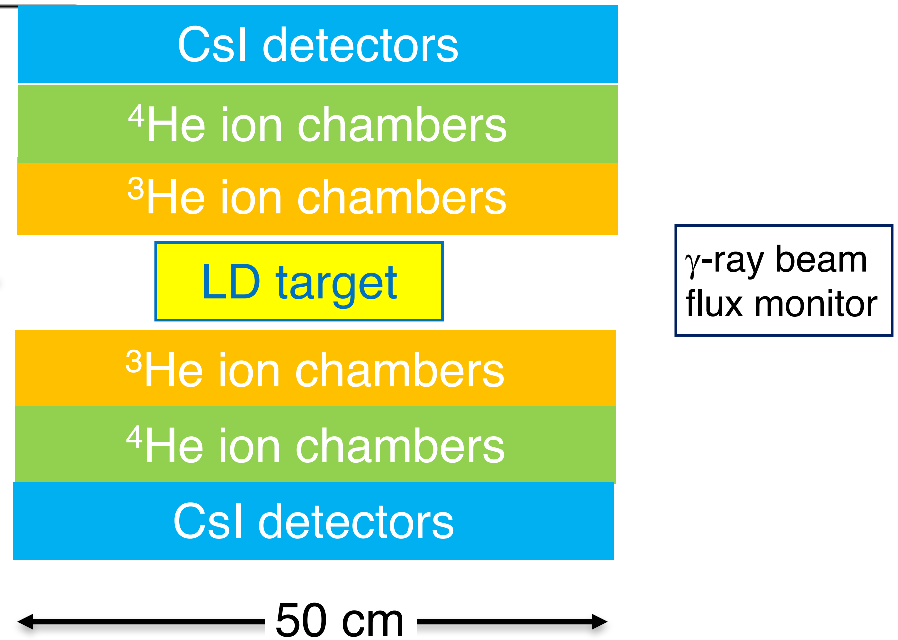
Parameter	Value
Energy	2.25-2.30 MeV
Flux	10^{10}
Polarization	Circular
Diameter	100 mm on target
Time Structure	10 Hz polarization flip

➔ ~2% fwhm

For Compton γ-ray source



Cylindrical geometry



LD target:

length = 21 cm

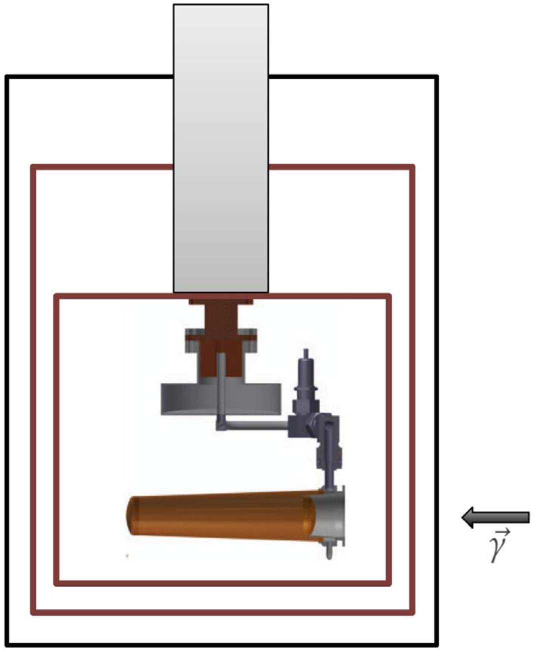
diameter > 5 cm

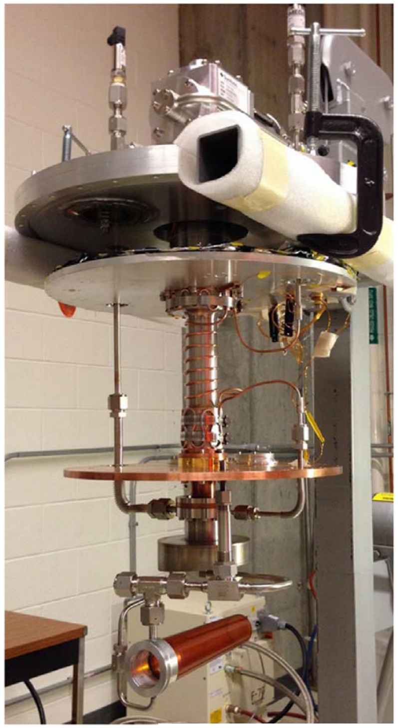
$\rho = 0.164\ \mathrm{g/cm^3}$

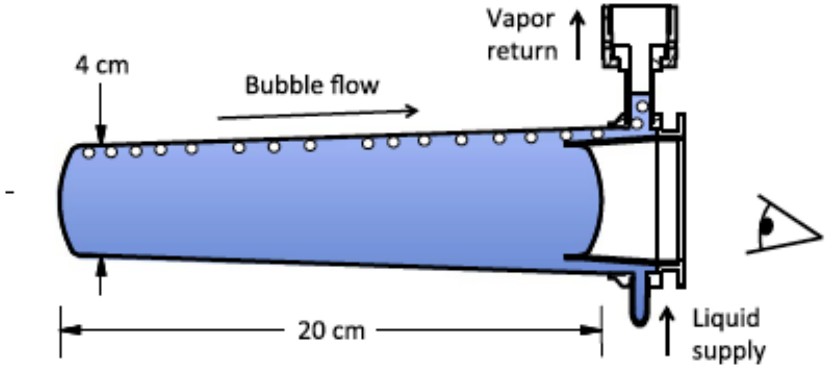
$\lambda = \rho\sigma = 2.5$ mm

Example of LD target at HIγS

D.P. Kendellen *et al.*, NIMA **840**, 174 (2016)







Main instrumental asymmetries from γ-ray beam

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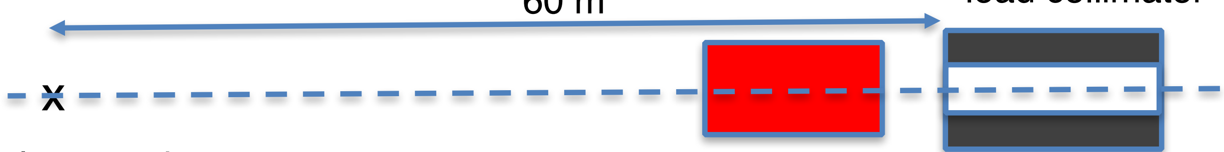
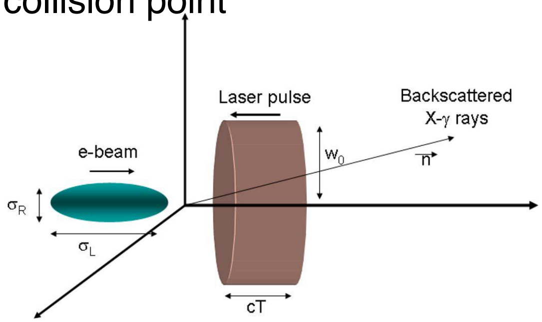
- Possible sources of instrumental asymmetry associated with helicity flip(change in relative detection efficiency due to helicity flip must be less than ~10^{-7}):
  - Beam density profile change
  - Change in position
  - Change in angle of incidence

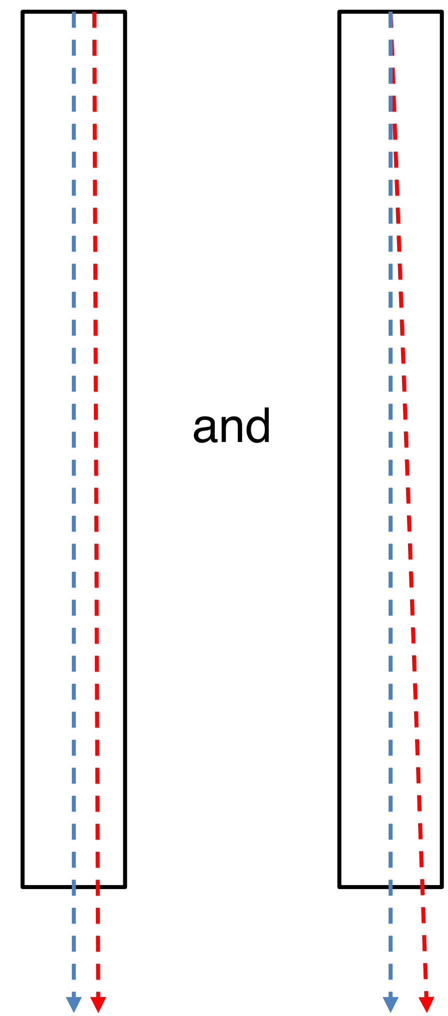


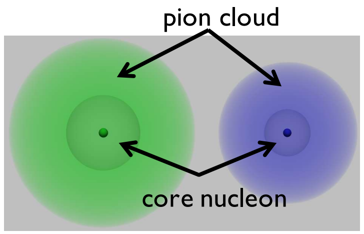
electron-photon collision point

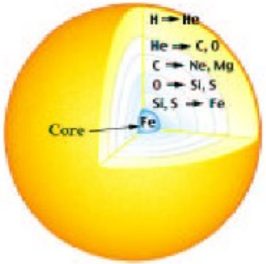
Circularly polarized γ-ray beam

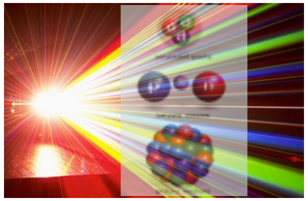


$|\Delta r_c| < 60\ \mu m$

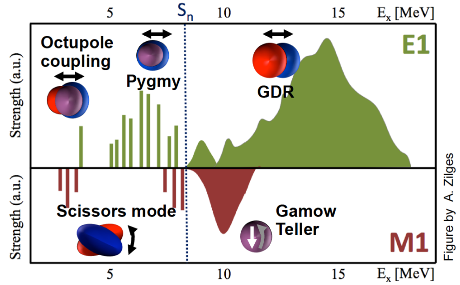


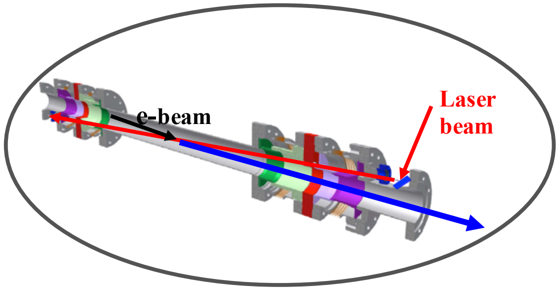






1. Nuclear-Physics Research Opportunities
   - Low-Energy QCD
     - Nucleon polarizabilities
     - Testing confinement scale QCD with photopion production
     - Hadronic Parity Violation
   - Nuclear Structure
   - Nuclear Astrophysics
   - Applications
     - Security
     - Medicine
2. Gamma-ray Source Technology
   - Electron accelerators
   - Lasers
   - Optics





WS: Low-energy QCD - medium energies

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The emergence of hadron structure and the nuclear force from QCD is a key scientific problem. These phenomena are a consequence of quarks and gluons interacting at confinement-scale distances where color forces are strong. The beams at a next generation Compton γ-ray source will enable measurements that uniquely probe hadron structure and hadronic interactions in this non-perturbative regime of QCD, achieving unprecedented precision in the photon energy range from about 60 MeV to the Nucleon-to-Delta(1232) transition. Key elements of the program include high-precision nucleon polarizability (scalar and spin) measurements by Compton scattering and near-threshold photo-pion production measurements; both rely on polarized beams and targets. Such measurements, together with advances in calculations using Lattice QCD and QCD-based effective field theories, will explore the QCD origin of nucleon structure and charge-symmetry breaking in novel contexts and with unprecedented sensitivity.

Physics Contributions:

- Highest precision determinations of nucleon polarizabilities
  - Nucleon EM polarizabilities (E_γ = 65 – 250 MeV): α^p, β^p, α^n, β^n
  - Nucleon spin polarizabilities (E_γ = 120 – 250 MeV): γ_{E1E1}, γ_{M1M1}, γ_{E1M2}, γ_{M1E2}
- High-energy resolution measurement of π^0 production cross section near threshold ($\Delta E_\gamma/E_\gamma < 0.015$)

Gamma-ray Source Capabilities:

- E_γ = 60 – 350 MeV
- Flux > 3 x 10^8 γ/s on target
- $\Delta E_\gamma/E_\gamma < 0.02$
- Circular and Linear Polarization > 90%
- Fast switching of beam polarization direction

Hadronic Parity Violation:

The beams at an advanced γ-ray beam facility will enable measurements of parity violating (PV) photodisintegration of few-nucleon systems. In particular, a measurement of parity violation in deuteron photodisintegration near threshold is sensitive to a nucleon-nucleon (NN) PV amplitude that is not accessible using other systems. Such measurements sample the short-range part of the NN interaction, providing unique quantities for comparison with Lattice QCD calculations.

Physics Contributions:

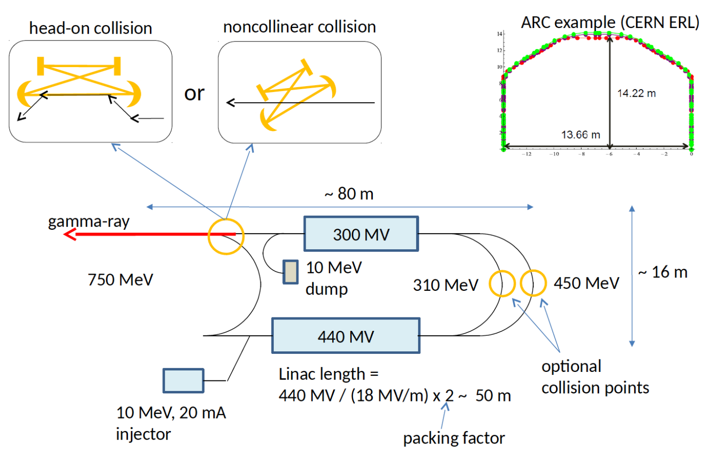
- First measurements of parity violating asymmetry for photodisintegration of deuterium

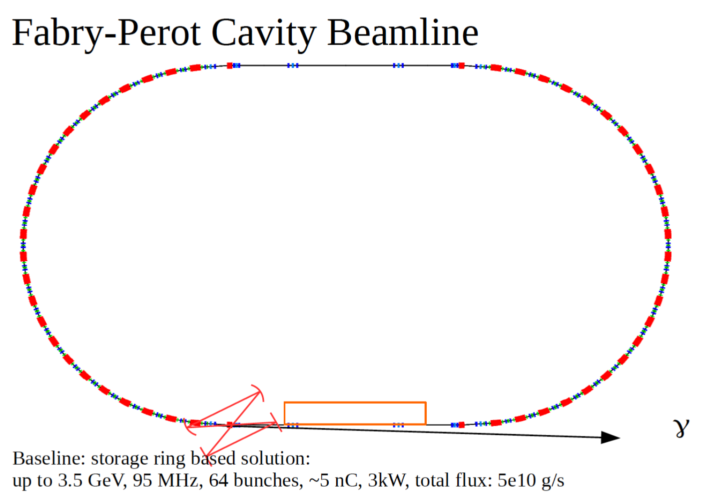
Gamma-ray Source Capabilities:

- $E_\gamma = 1 - 10$ MeV
- Flux > 1 x 10^{11} γ/s on target
- $\Delta E_\gamma / E_\gamma < 0.02$
- Circular Polarization > 90% and unpolarized

WS: Observations and conclusions

- It is unlikely that a single γ-ray beam source can meet the requirements of the low-energy and medium-energy parts of the field.
- γ-rays are produced by Compton scattering of electrons from photons inside an optical cavity that is pumped with an external laser.
- **Low-energy facility (Eγ < 20 MeV):** Options included an energy-recovery linac (with superconducting RF cavities) and a storage ring.
- **Medium-energy facility (Eγ = 60 – 350 MeV):** A storage ring was the primary option for the higher energy γ-ray source. There is confidence that a high electron beam quality (low emittance and low energy spread) can be maintained in modern storage-ring lattices, thereby enabling production of γ-ray beams with low energy spread.
- **New facility cost:** The new facility construction cost of the storage-ring option for either a low-energy or medium-energy next-generation Compton γ-ray source will be over about $150M. This is extremely coarse and is intended only to set the cost scale within about a factor of two. Less expensive options for the low-energy sources, e.g., upgrades to existing facilities, were also presented.





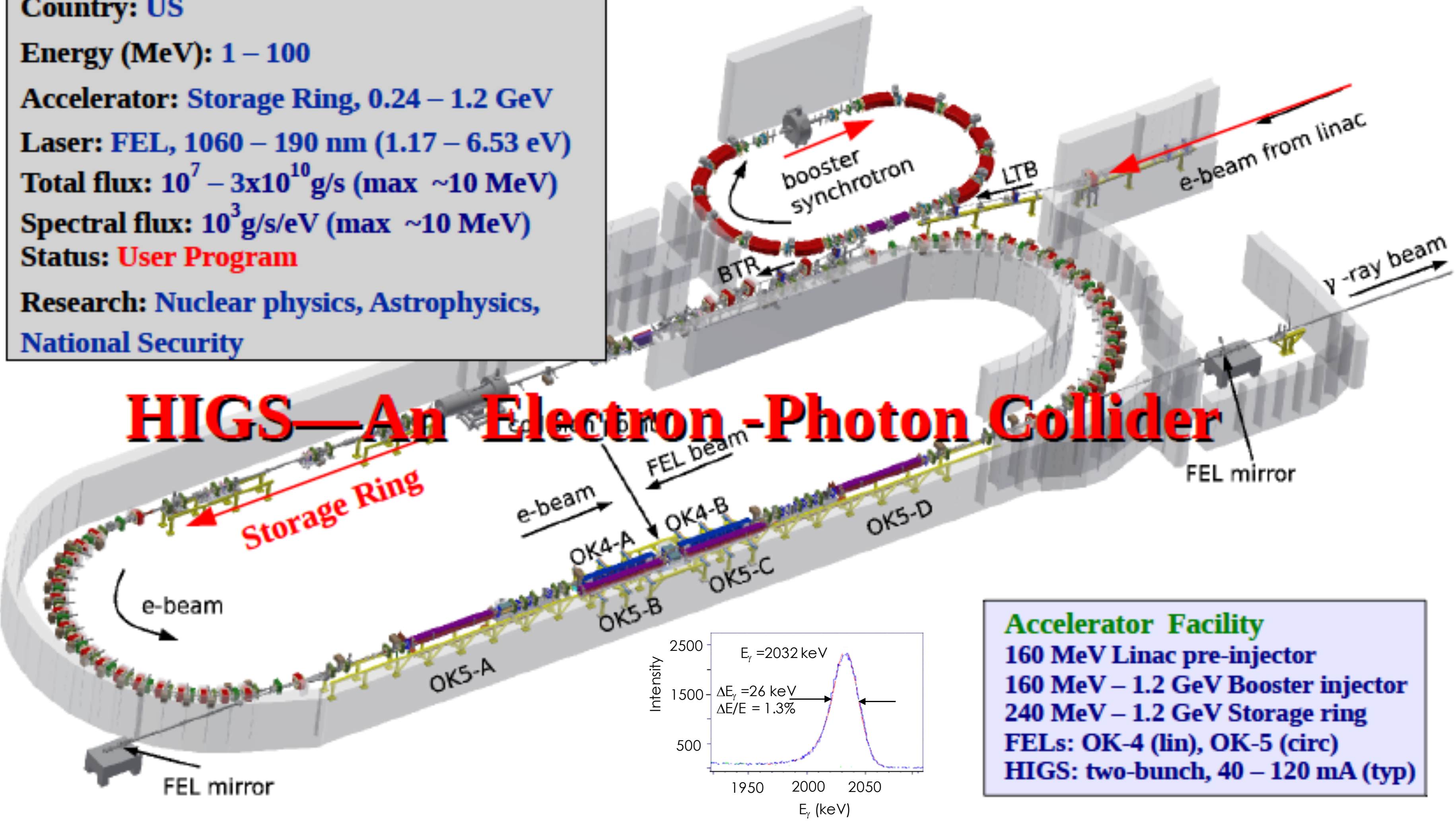
WS: Resolutions

- R&D recommended to reduce risk on γ-ray source design, e.g., optical cavity development
- R&D to develop an alternative option to Compton scattering for producing γ-rays with energies above the pion-production threshold, e.g., a system for virtual photon tagging in small-angle electron scattering
- Investments in polarized targets needed to prepare for experiments at next generation Compton γ-ray beam facilities
- Investments in active targets are needed to carryout the highest impact nuclear astrophysics measurements at a γ-ray beam facility
- Investments in nuclear theory are needed to support LE QCD experiments at the next generation γ-ray beam facilities

HIγS Facility Layout

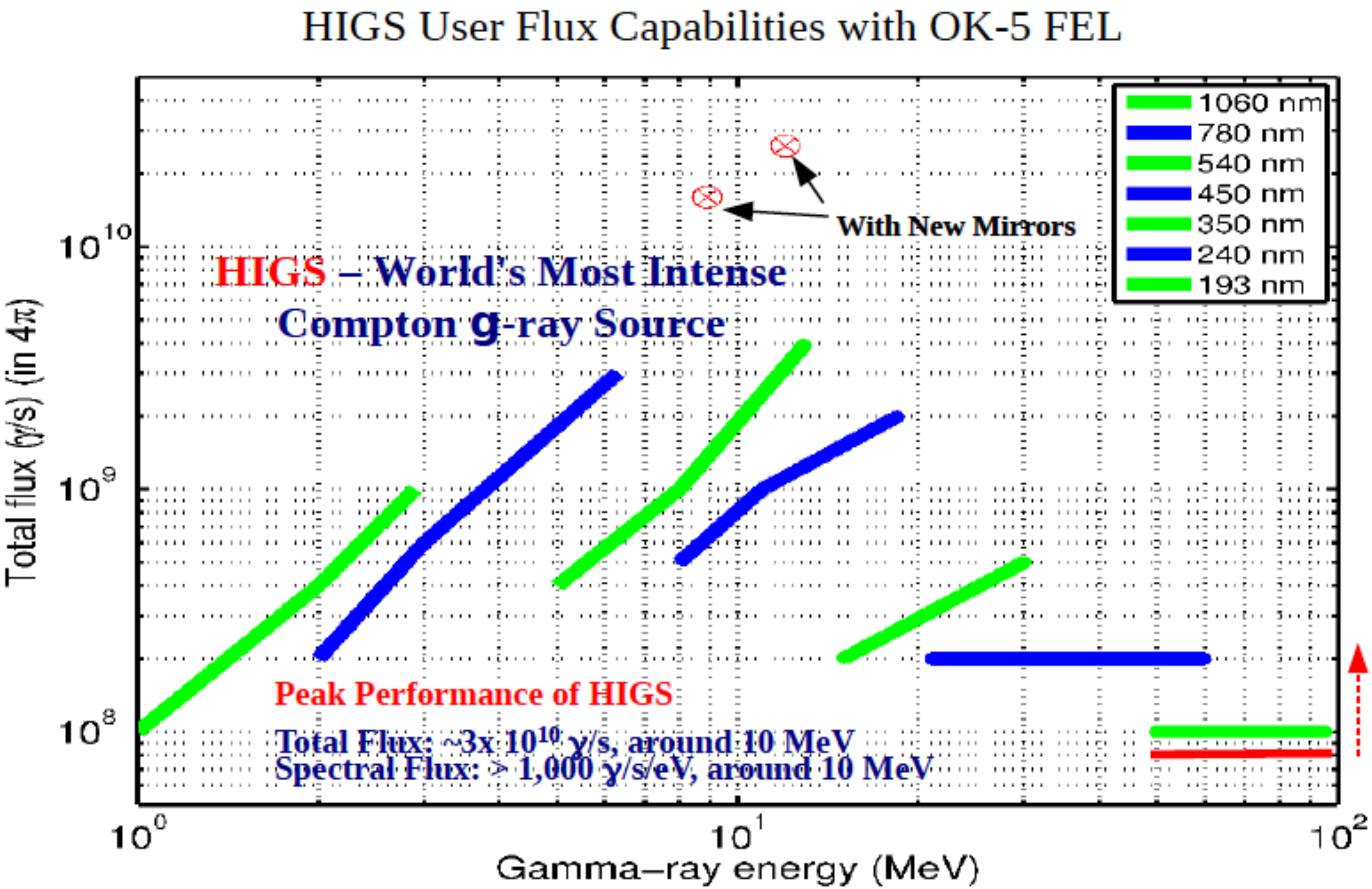
Facility/Project: HIGS
Institution: TUNL and Duke University
Country: US
Energy (MeV): 1 – 100
Accelerator: Storage Ring, 0.24 – 1.2 GeV
Laser: FEL, 1060 – 190 nm (1.17 – 6.53 eV)
Total flux: $10^7 - 3\times10^{10}$ g/s (max ~10 MeV)
Spectral flux: 10^3 g/s/eV (max ~10 MeV)
Status: User Program
Research: Nuclear physics, Astrophysics, National Security

HIGS—An Electron -Photon Collider



Accelerator Facility
160 MeV Linac pre-injector
160 MeV – 1.2 GeV Booster injector
240 MeV – 1.2 GeV Storage ring
FELs: OK-4 (lin), OK-5 (circ)
HIGS: two-bunch, 40 – 120 mA (typ)

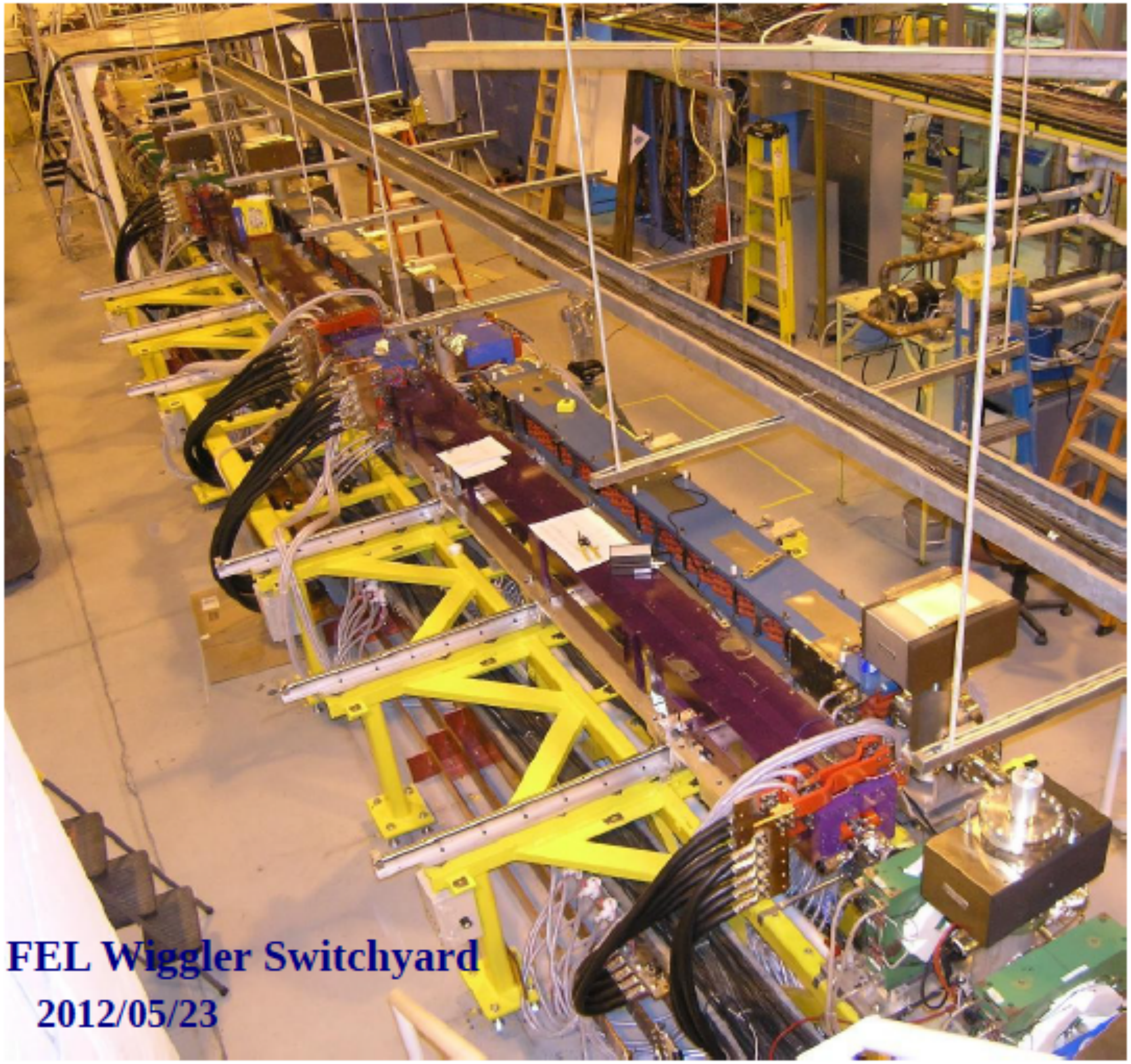
HIgS: Energy Range and Current Beam Flux



HIgS Research Program: PAC 2016 Expt. Status

Program	Hours Approved	Hours Completed	Hours Continue	Run Plans
Nuclear Structure	659	659		
LEQCD - Compton	341	0	341	2018-19
LEQCD - FB	304	0	304	P-12-16, 2020 P-13-16, 2018
Total	1304	659	645	

HIγS: FEL Wiggler Switchyard



HIγS2 Design Concept

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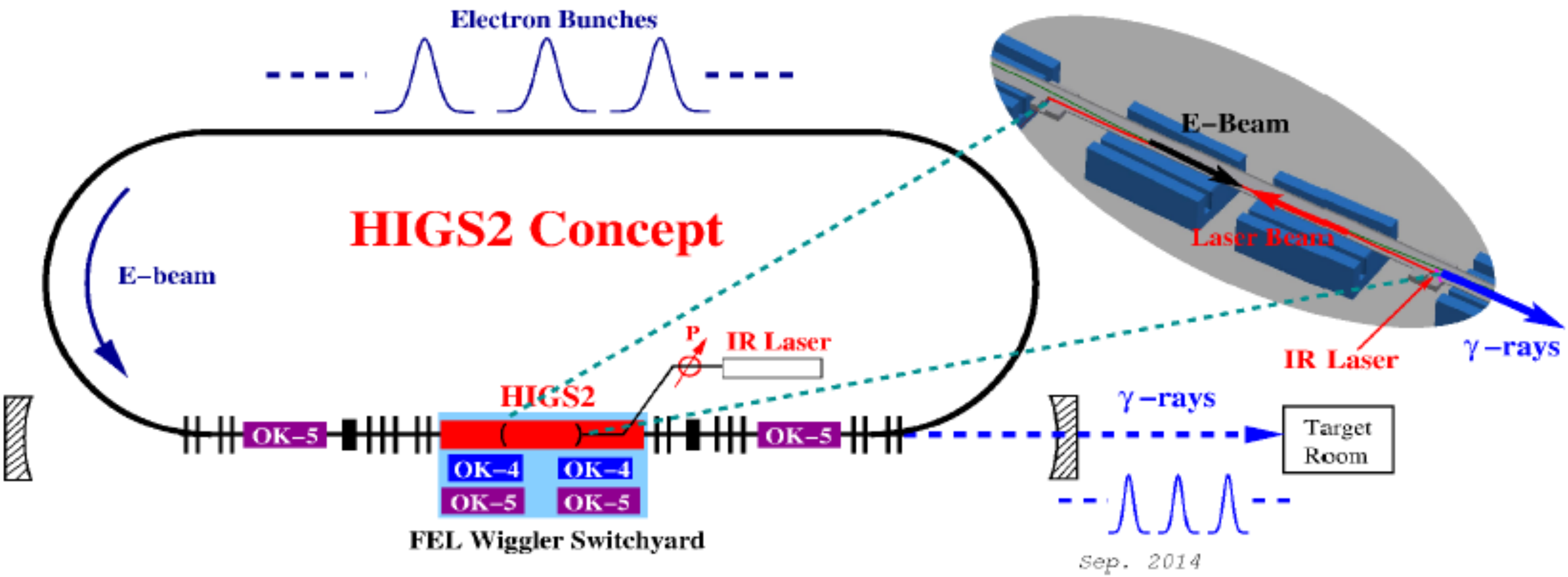


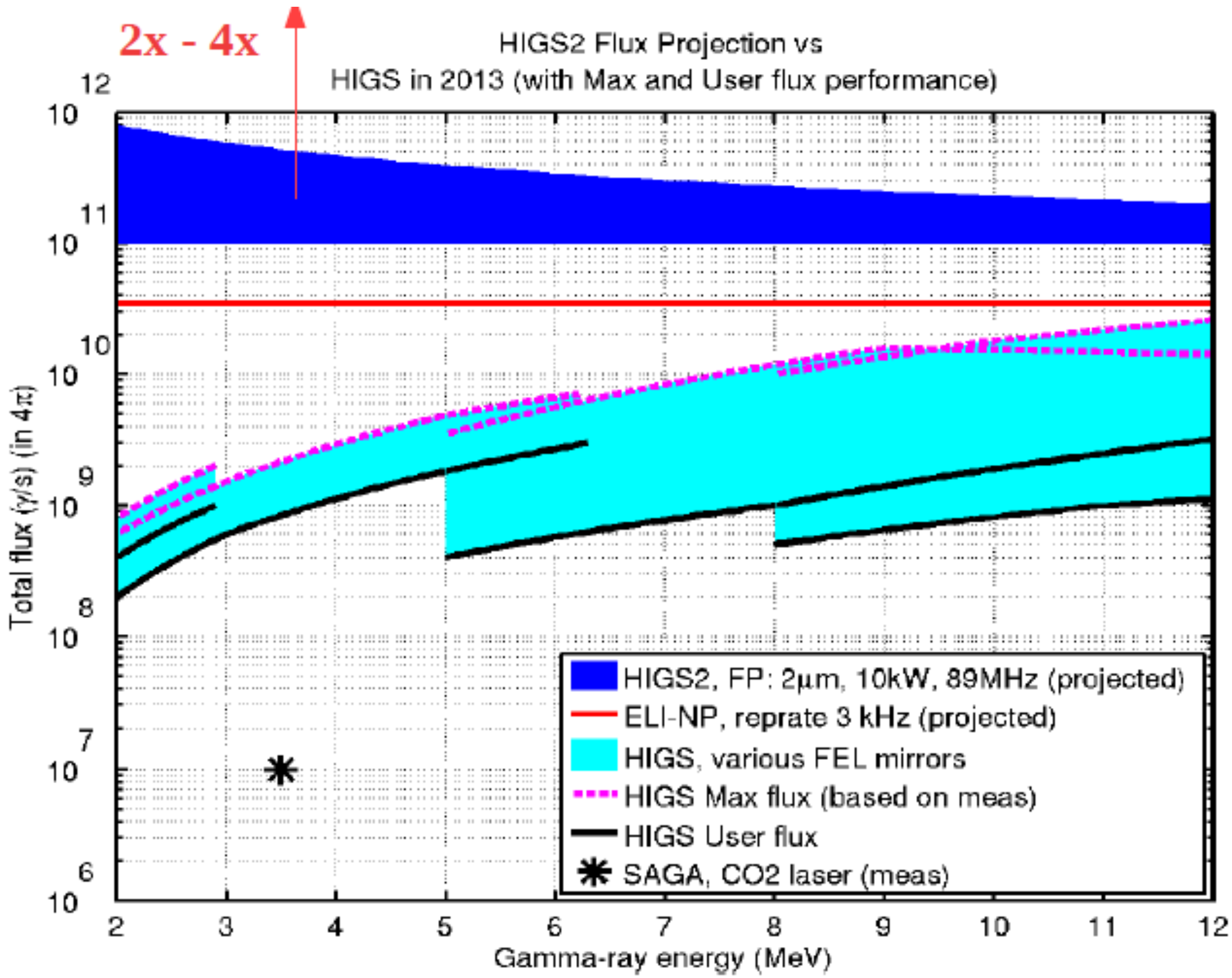
Research Programs

- Hadronic Parity Violation
- Nuclear Astrophysics
- Nuclear Structure

Projected Performance

- 1.064 micron FP cavity: 2 – 18 MeV
- 2.5 MeV performance:
  - Total Flux: 2 – 4 x 10^{12} gamma/s
  - Pol: Linear, or Circular (rapid switch)
  - Flux on-target: 2 – 5 x 10^{10} gamma/s, 1% FWHM

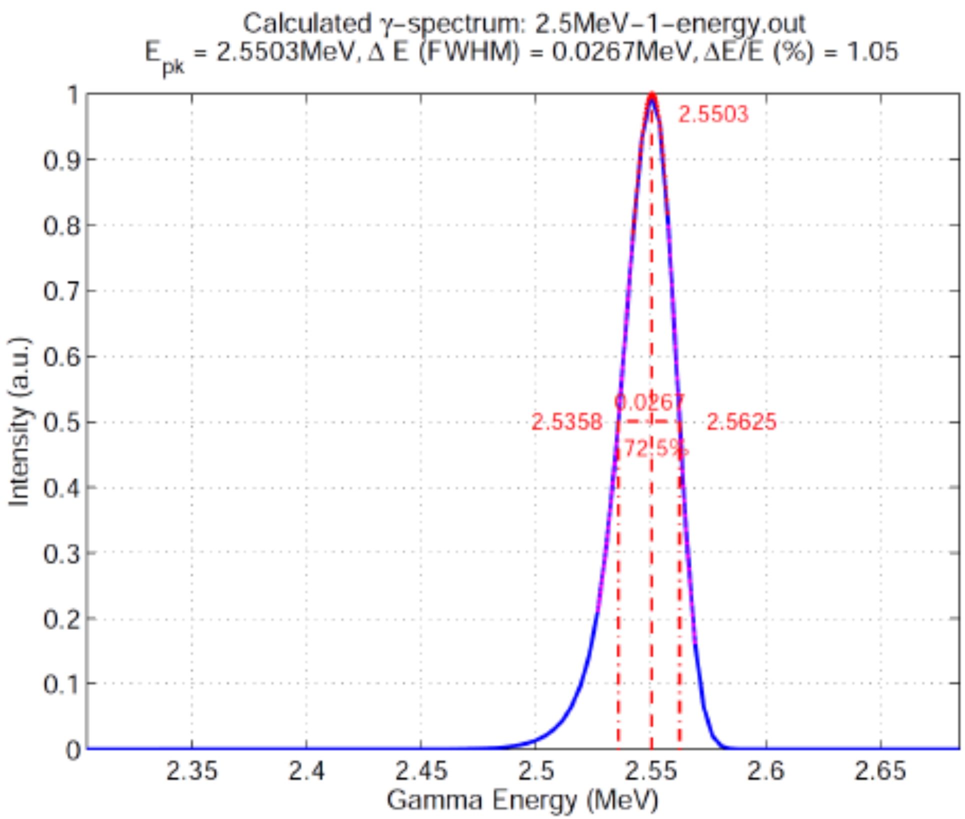
HIγS2: γ-ray Beam Flux Projection

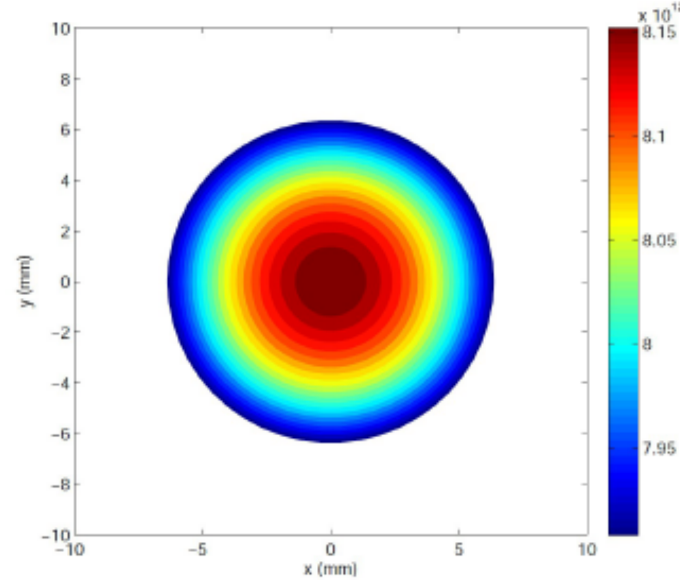


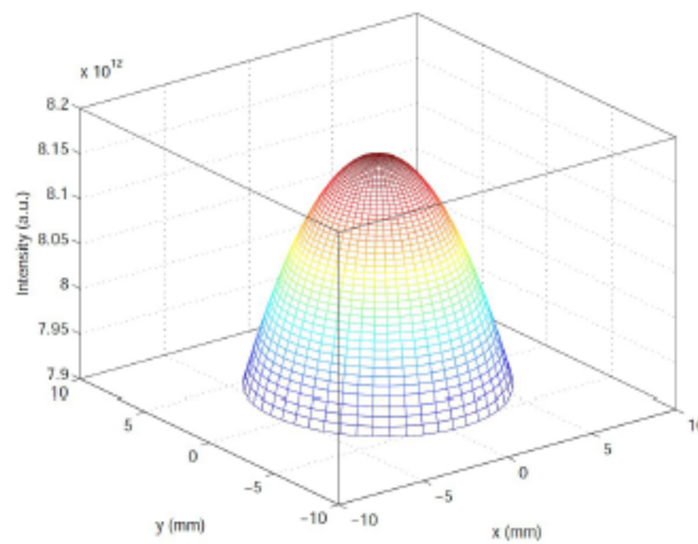
ELI-NP: A. Bacci et al. J. Appl. Phys. 113, 194508 (2013)

2.5 MeV Beam Distribution

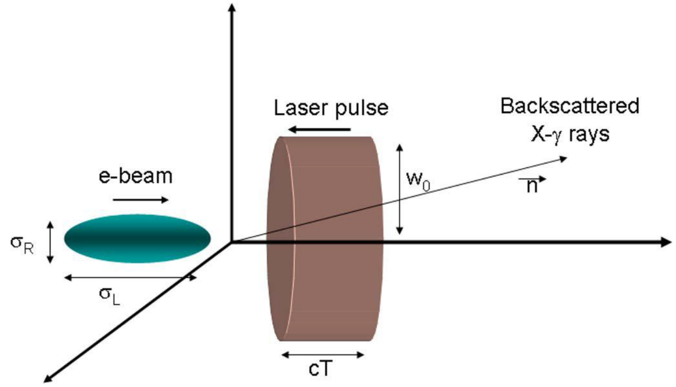
- **Collimator: D = 13 mm at 52.8 m**

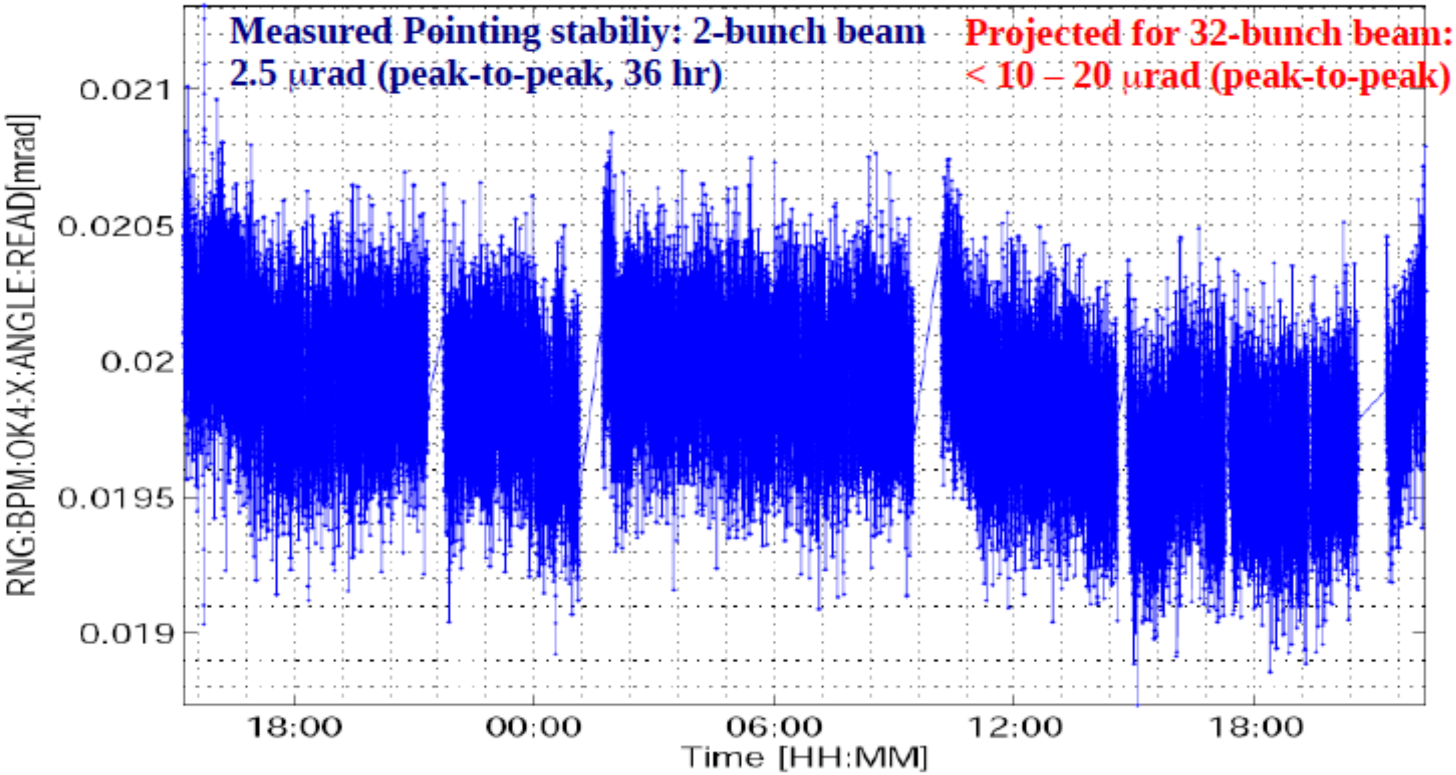






Aiming Stability of Electron Beam in HIγS Storage Ring





HIγS2: Summary of Projected Beam Performance

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Projected Parameters for 2.5 MeV production

- Laser: 1.064 micron fiber laser, 89 MHz intracavity power 50 kW
- Electron beam: 380 MeV, 300 mA in 32 bunches (89 MHz)
- Gamma-ray beam: 2.56 MeV, total flux: 2 – 4 x 10^{12} gamma/s
  - Pol: Linear, or Circular (rapid switch)
  - Energy resolution: 1% (FWHM)
  - Flux on-target: 2 – 5 x 10^{10} gamma/s (1% FWHM)

Requirement: $|\Delta r_c| < 60\ \mu m$

Requires simulation to assess whether the Δr_c requirement is achieved

Summary

- The U.S. Low-energy QCD Community supports R&D on optical cavity for use in a next generation laser Compton γ-ray Source;
- The features of the HIγS electron storage ring are highly compatible with optical cavity R&D;
- The electron beam current and beam aiming stability performance of the HIγS storage ring meets the requirements of HPV using photonuclear reactions on few-nucleon systems;
- We plan to develop a HIγS2 proposal for submission in 2019 (estimated budget = $5M)
  - ❑ Mirror Cavity R&D for Next Generation Laser Compton γ-ray Source (includes: mirror cavity, laser and optics for loading the cavity, laser polarization, polarization orientation change, modifications to straight section of storage for collision for electron-photon collision in optical cavity);
  - ❑ Creates new reach capabilities at HIγS: (1) HPV measurements on few-nucleon systems, (2) Nuclear Astrophysics, e.g., $^{16}O(\gamma, \alpha)^{12}C$, and (3) Nulcear Structure (NRF on weak dipole states)