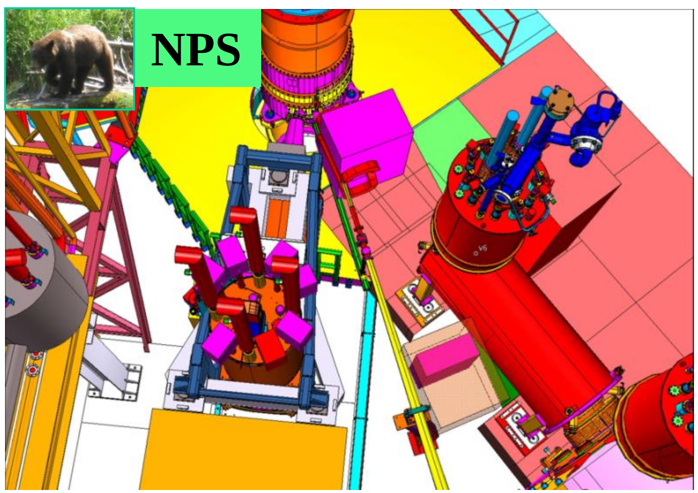
Physics Opportunities with the Neutral Particle Spectrometer in Hall C

The NPS project is supported by NSF MRI PHY-1530874



Tanja Horn

The Catholic University of America

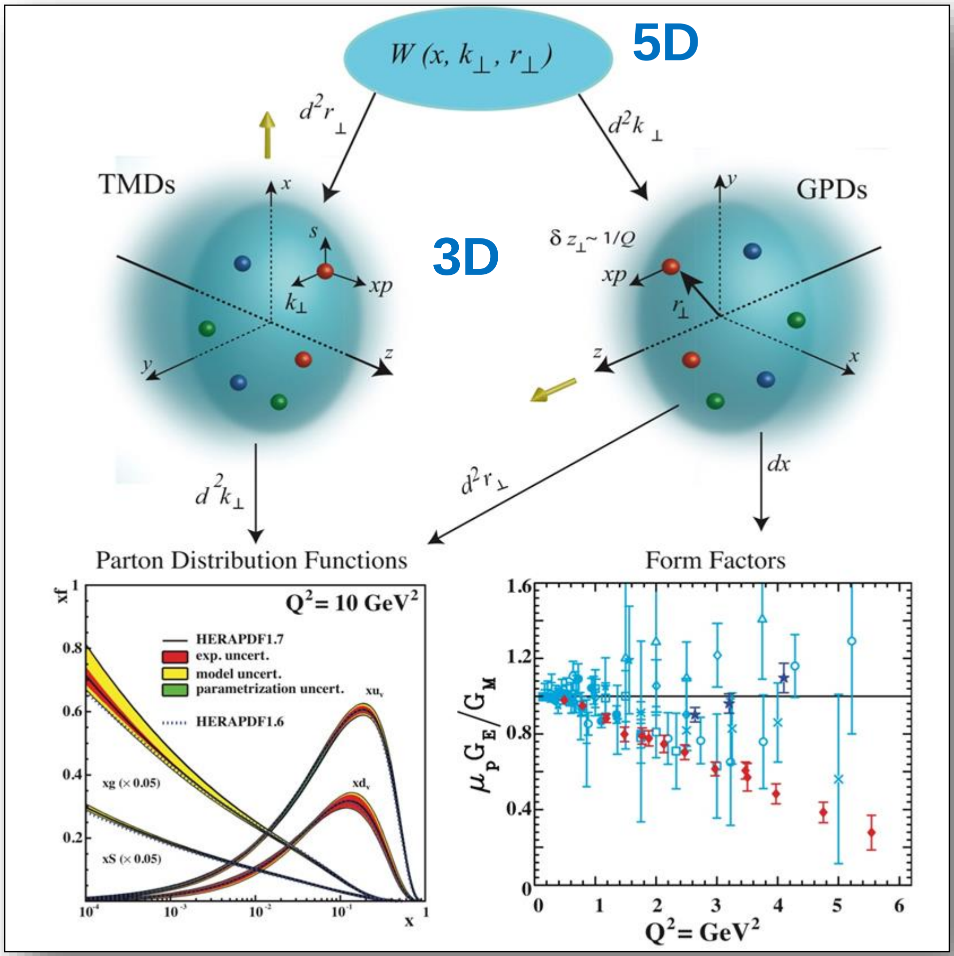
Jefferson Lab
Thomas Jefferson National Accelerator Facility

DNP2015, Fall Meeting of the
APS Division of Nuclear Physics

Santa Fe, NM, 28-31 October 2015

Tomography of the Nucleon

- Beyond one-dimensional spatial densities (form factors) and longitudinal momentum densities (parton distributions)
- Connection to orbital angular momentum – nucleon spin



3D description:

- TMDs
– Confined motion in a nucleon (semi-inclusive DIS)
- GPDs
– Transverse spatial imaging (exclusive DIS)

Major new capability with JLab12

Confirming the potential for GPD/TMD studies at 12 GeV JLab

- To extract the rich information on nucleon structure encoded in GPD and TMDs one needs to show that the scattering process is understood

- Measurements with neutral final states offer unique advantages

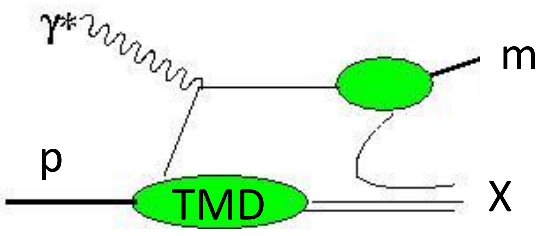
- 5 experiments have been approved by the JLab PAC to date
  - E12-13-007: Measurement of Semi-inclusive π^0 production as Validation of Factorization
  - E12-13-010 – Exclusive Deeply Virtual Compton and π^0 Cross Section Measurements in Hall C
  - E12-14-003 – Wide-angle Compton Scattering at 8 and 10 GeV Photon Energies
  - E12-14-005 – Wide Angle Exclusive Photoproduction of π^0 Mesons
  - E12-14-006 – Initial State Helicity Correlation in Wide-Angle Compton Scattering

- The two-arm combination of a neutral-particle detection and high-resolution magnetic spectrometers, e.g., the HMS (or SHMS) in Hall C, offer the scientific capabilities for these measurements requiring both precision and high luminosity

E12-13-007: Basic $(e,e'\pi^0)$ cross sections

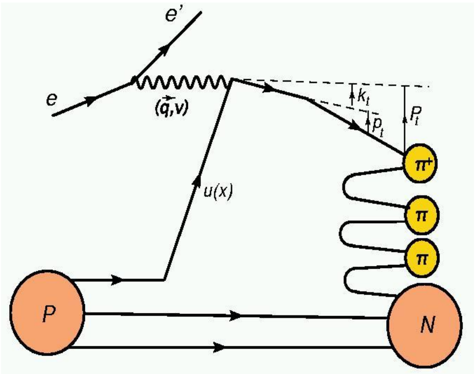
- Linked to framework of *Transverse Momentum Dependent Parton Distributions*
- Basic cross sections are a fundamental test of understanding SIDIS in 12 GeV kinematics and essential for most future experiments and their interpretation
  - Validation of factorization theorem

$$\sigma = \sum_q e_q^2 f(x) \otimes D(z)$$



  - Target-mass corrections and ln(1-z) re-summations require precision large-z data

$TMD^q(x,k_T)$



$P_T = p_t + z\, k_t + O(k_t^2/Q^2)$

  - Transverse momentum widths of quarks with **different flavor (and polarization)** can be different

Advantages of $(e,e'\pi^o)$ beyond $(e,e'\pi^{+/-})$

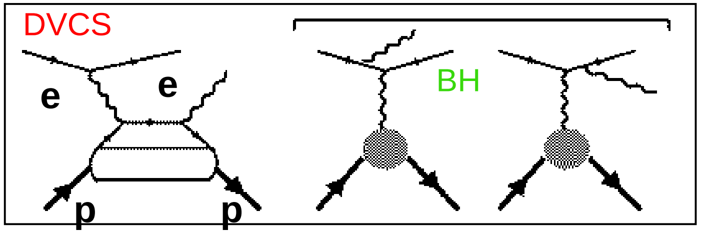
- Experimental and theoretical advantages to validate understanding of SIDIS
- Can verify: $\sigma^{\pi^o}(x,z) = ½\, (\sigma^{\pi^+}(x,z) + \sigma^{\pi^-}(x,z))$
- Confirms understanding of flavor decomposition/k_T dependence

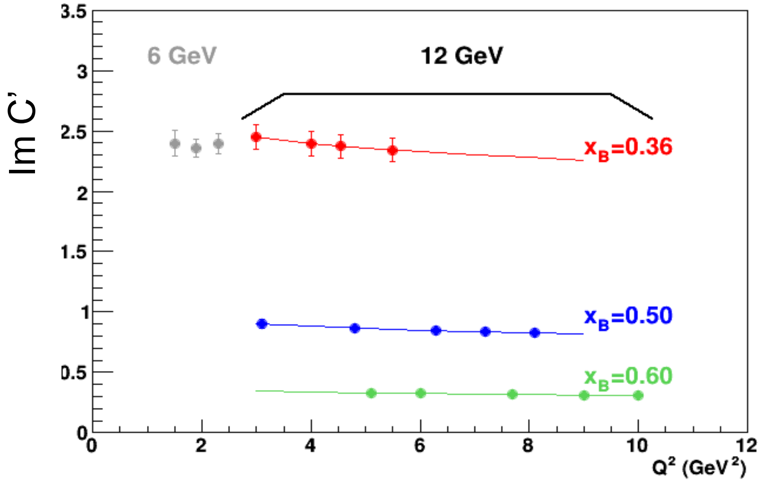
E12-13-007 goal: Measure the basic SIDIS cross sections of π^o production off the proton, including a map of the P_T dependence ($P_T \sim \Lambda < 0.5$ GeV), to validate(*) flavor decomposition and the k_T dependence of (unpolarized) up and down quarks

(*) *Can only be done using spectrometer setup capable of %-type measurements (an essential ingredient of the global SIDIS program!)*

E12-13-010: Experimental Access to GPDs

- Simplest process: **e + p → e' + p + γ (DVCS)**



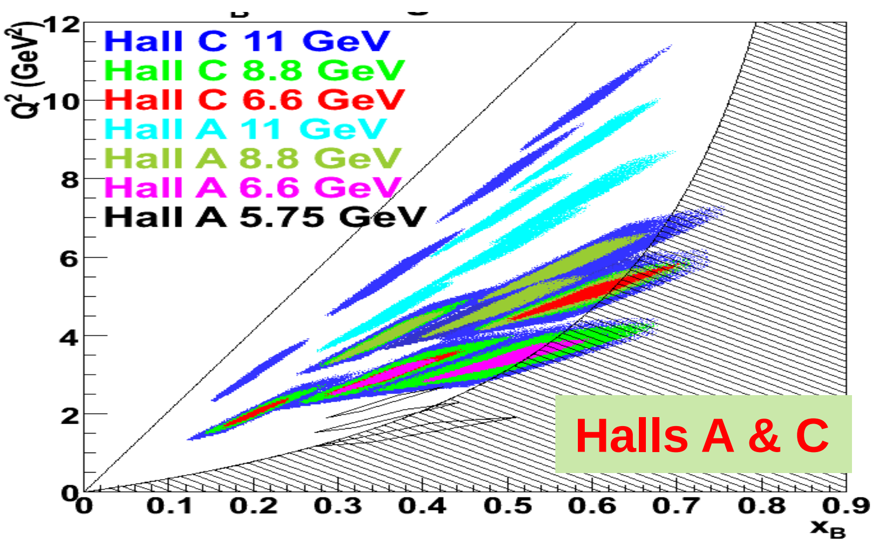


- Hall A Jlab 6 GeV data for CFF (over *limited* Q^2 range) agree with hard scattering
- Measurements in the 12 GeV Halls A and Hall C with NPS combined cover a large kinematic range

E12-13-010 goals:

- Confirm scaling of the Compton Form Factor (CFF)
- Extraction of the real part of CFFs through Rosenbluth-like separation of DVCS through cross section measurements at multiple beam energies

$$\sigma = |BH|^2 + \mathrm{Re}\big[\underbrace{DVCS^{\perp}\, BH}_{\sim E_{beam}^2}\big] + \underbrace{|DVCS|^2}_{\sim E_{beam}^3}$$



E12-13-010: Exclusive π^0 cross sections

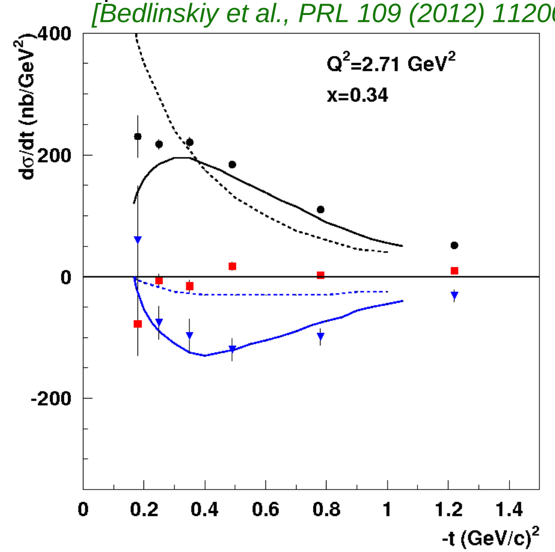
- Chiral-odd GPDs may contribute to the transverse xsec

  [Goloskokov, Kroll, EPJA, 47:112 (2011)] *[Ahmad, Goldstein, Liuti, PRD79 054014 (2009)]*

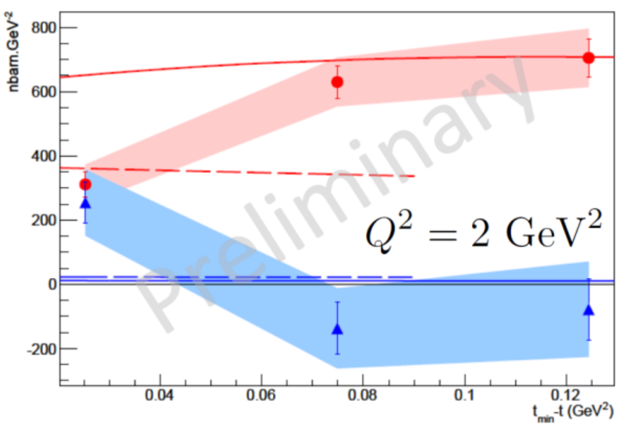
- Recent pion cross section data suggest that transverse photons play an important role in pion electroproduction

- To confirm the estimates of the contribution of transverse photons and potential to access GPDs in meson production requires a full separation of the cross section

Unseparated π^0 data from 6 GeV Jlab Hall B
[Bedlinskiy et al., PRL 109 (2012) 112001]



red circle=σ_T, blue triangle=σ_L



[M. Defurne, talk at DIS2015]

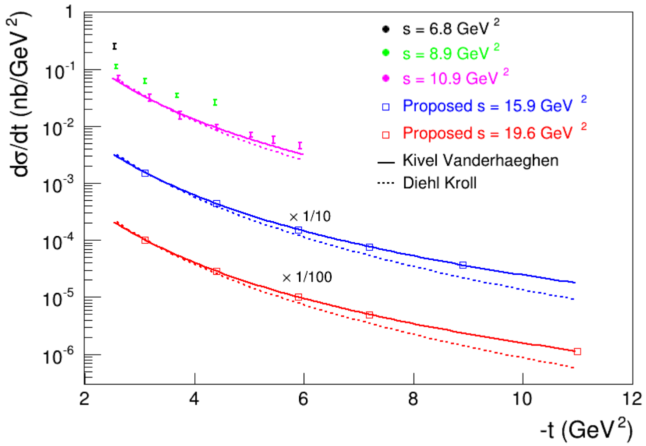
[F. Sabatie, talk at CIPANP2015]

- Preliminary results from Hall A at 6 GeV Jlab suggest that at Q^2~2GeV^2 σ_T dominates for large values of t, but that σ_L is non-zero at Q^2~2GeV^2

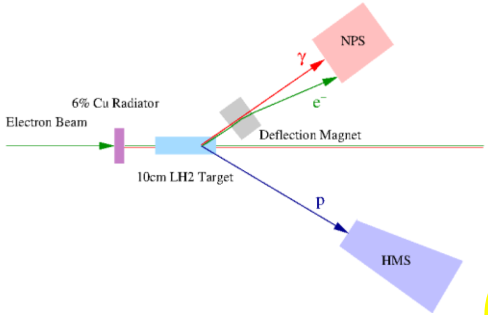
E12-13-010 goals:

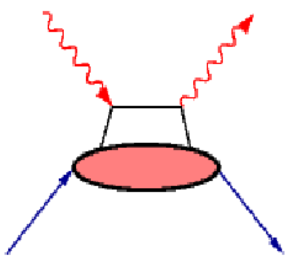
Measure π^0 cross sections over a larger kinematic range to confirm the dominance of σ_T in 12 GeV kinematics

E12-14-003: exploring factorization in Wide-Angle Compton Scattering (WACS)



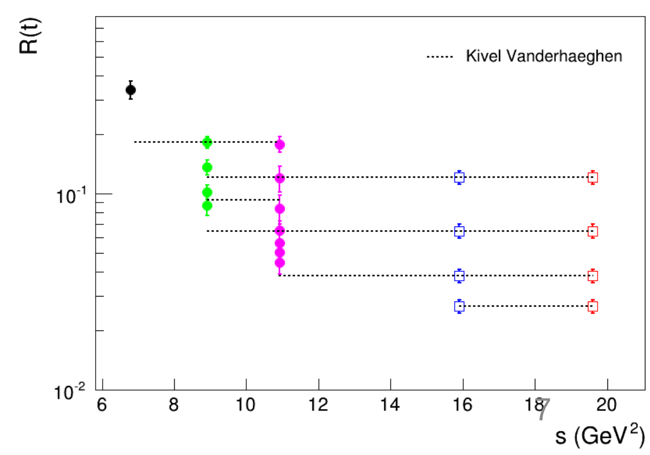
- WACS is a powerful probe of nucleon structure -several theoretical approaches developed in recent years.
  - Developments within the Soft Collinear Effective Theory (SCET) demonstrated importance of future data for interpretation of a wide variety of hard exclusive reactions.
- JLab Hall A data suggest factorization into hard and soft-collinear parts (but limited in -t).
- E12-14-003 will use the Hall C HMS and the new **Neutral Particle Spectrometer** to measure the differential cross section up to s~20 GeV^2!





Two main goals of E12-14-003

- Four fixed -t scans will allow for a rigorous test of factorization.
- The t-dependence of the Compton form factor will allow for gaining valuable insights into proton structure at high momentum transfer.

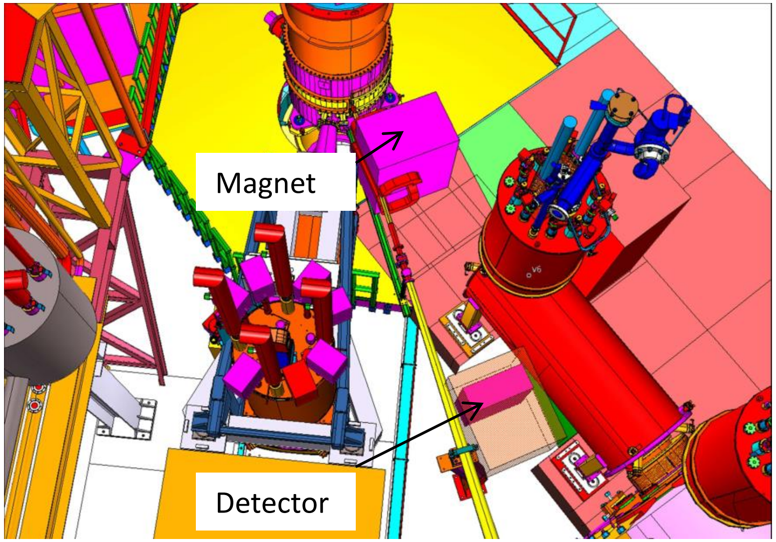


The Neutral-Particle Spectrometer (NPS)

NSF MRI PHY-1530874

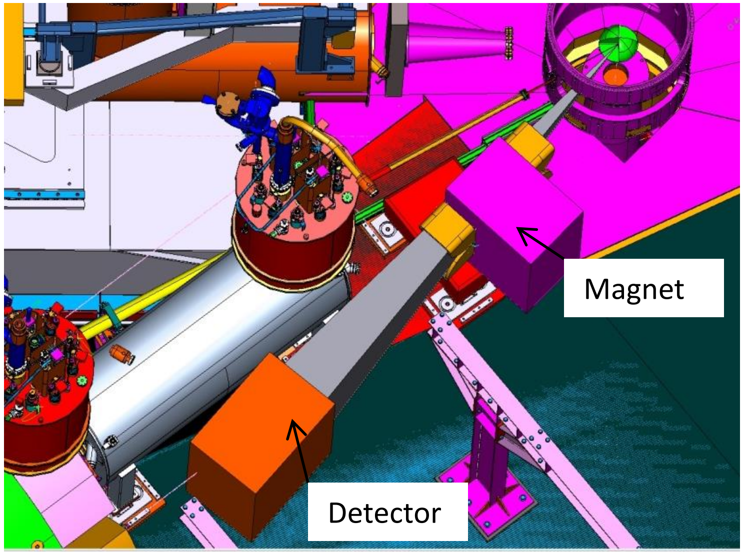
- The NPS is a standalone 25 msr spectrometer allowing for precision (coincidence) cross section measurements of neutral particles
- Consists of a PbWO4-based calorimeter preceded by a sweeping magnet

NPS cantelevered off SHMS platform



NPS angle range: 5.5 – 30 degrees

NPS on SHMS platform



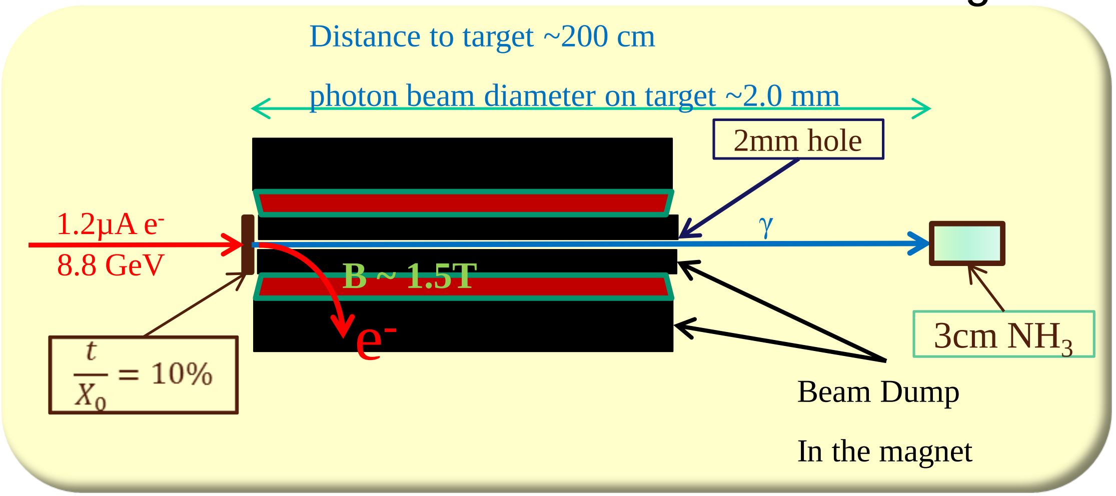
NPS angle range: 25 – 60 degrees

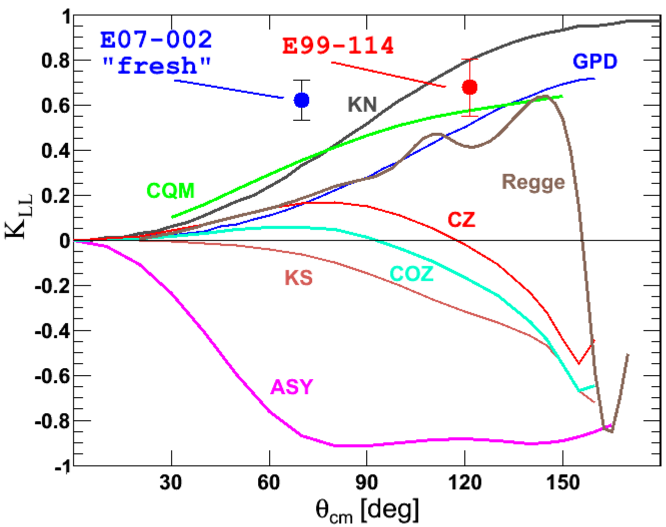
Remotely rotatable with the SHMS carriage

The NPS is is an efficient way to meet the experimental requirements of the approved science program taking maximum advantage of existing infrastructure

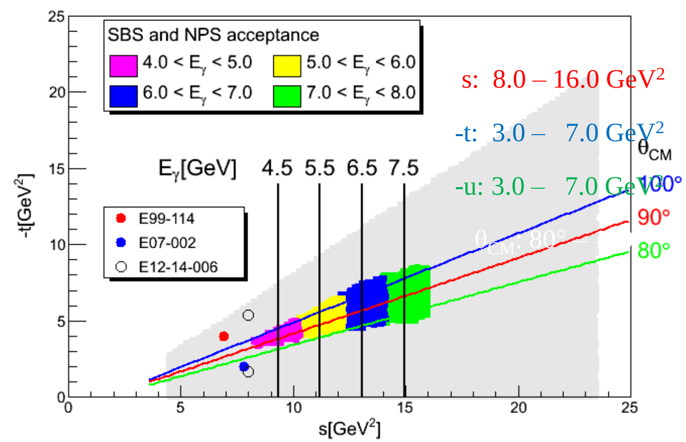
Magnet-Dump as a Compact Photon Source

- Idea was discussed in detail at the November 2014 NPS collaboration meeting
  - Uses a magnet as dump for the electron beam producing a narrow intense untagged photon beam





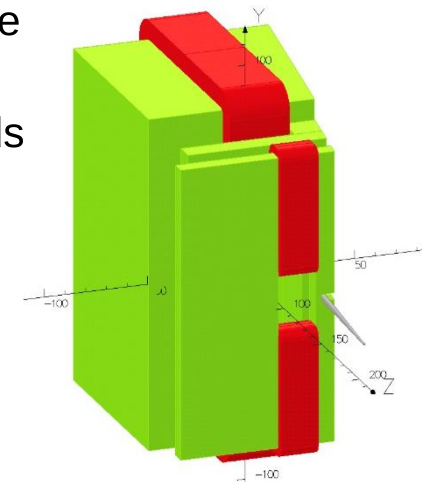
- **PR12-15-003:** worked out the concept in more detail for WACS-ALL measurements with NPS extending the range in s with wide kinematic coverage

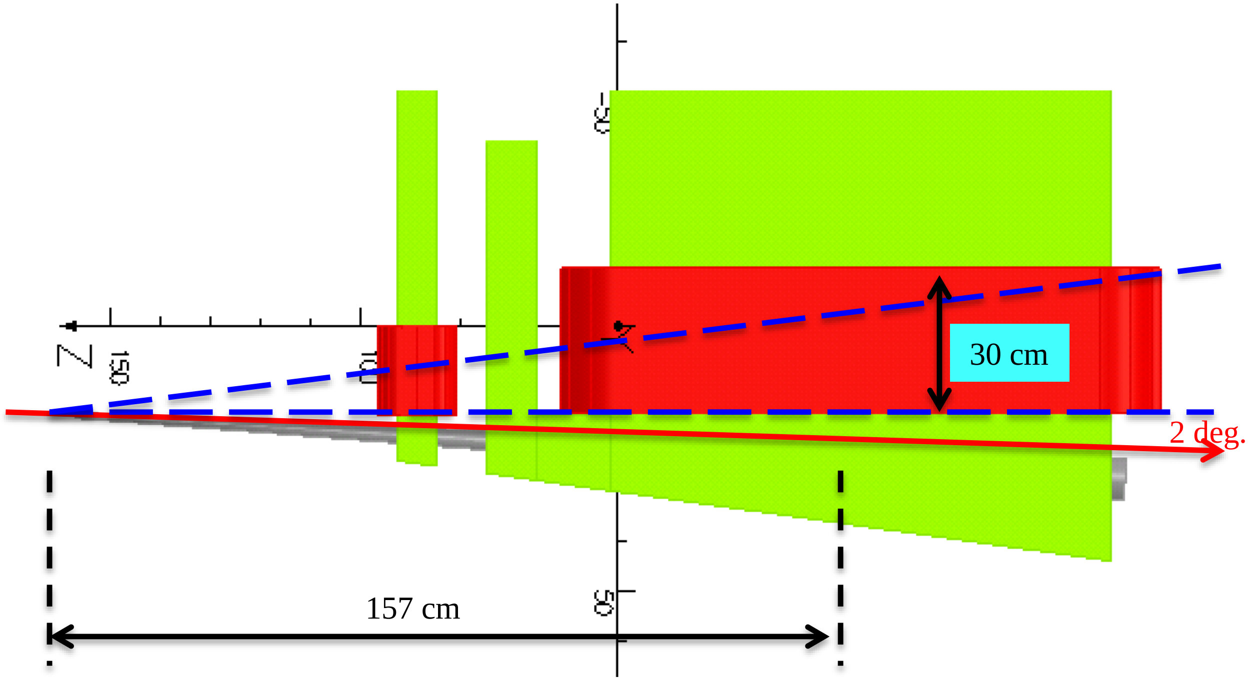


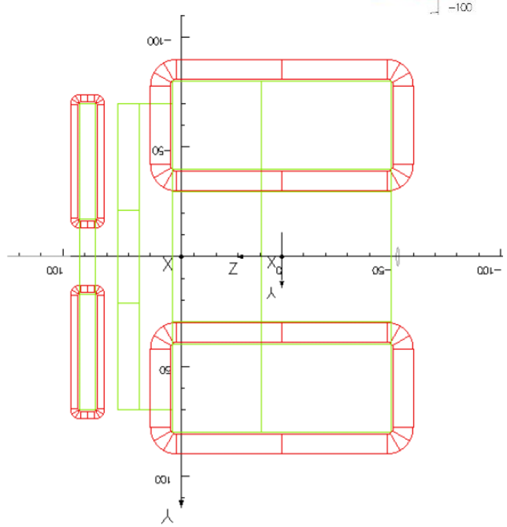
Compact Photon Source would optimize science using photon beam accessible with NPS

NPS Sweeping Magnet Construction

- Horizontal field design satisfies the requirements of all approved NPS experiments
  - Small angle operation at 0.3 Tm (for electroproduction) and large angle operation at 0.6 TM (photo-production)
  - Field clamp and bucking coil in front of the magnet minimize stray fields
  - Compatible with existing power supplies





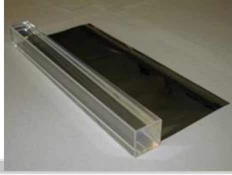


Magnet Features:

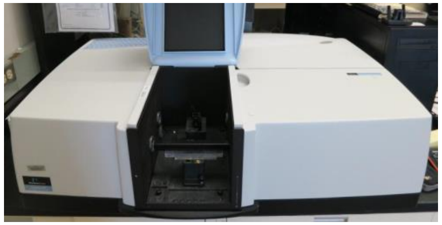
- the beam side is free of coils
- the beam opening is +/- 1 degree
- open aperture to detector above 2 degrees!
- vertical aperture is 60 cm; horizontal is 30 cm

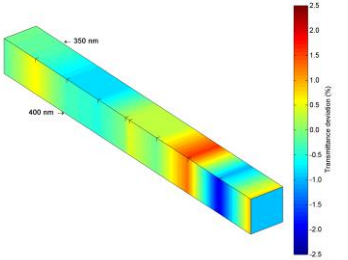
- Design drawings are underway

$PbWO_4$ crystal testing at universities

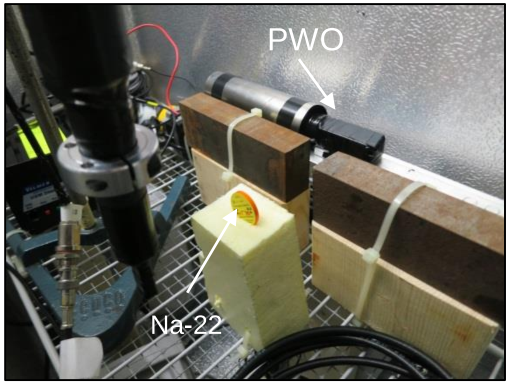


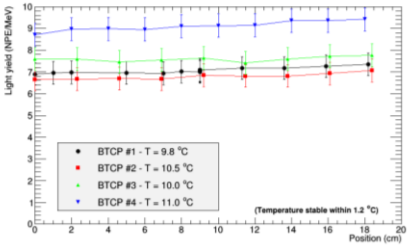
- **Optical Transmittance** Measurements
  - Perkin-Elmer Lambda 750 spectrometer
  - Longitudinal and transverse
  - Setup was commissioned with BTCP crystals on loan from University of Giessen – reproducibility ~0.2%

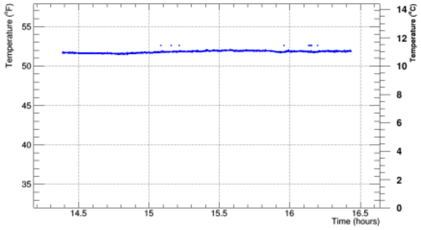




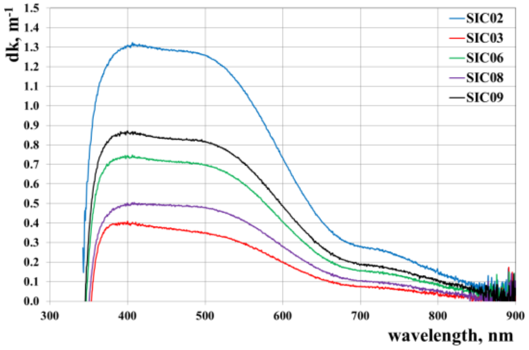
- Crystal **light yield**
  - A setup consists of a Na-22 source and calibrated PMT
  - Light yield can be measured with better than 1 degree *temperature stabilization*





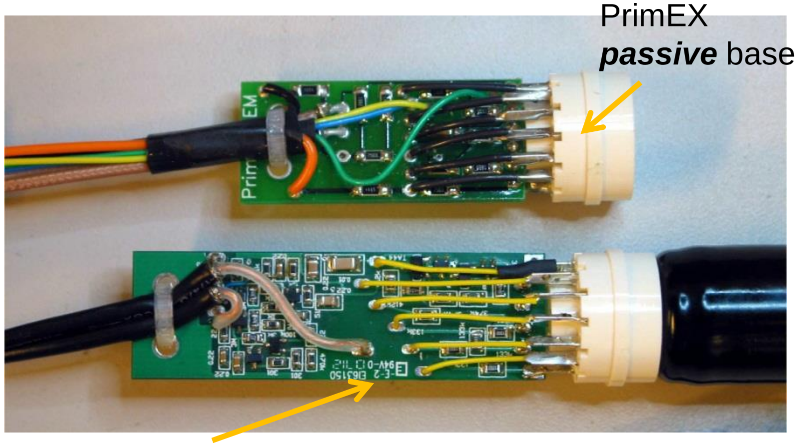


- Crystal **radiation hardness** has been tested at IAC and in collaboration with Giessen University. Options at the university with, e.g., Xrays are being explored



Irradiation tests performed in collaboration with Giessen university show SIC produced crystals are radiation hard

Active PMT HV dividers

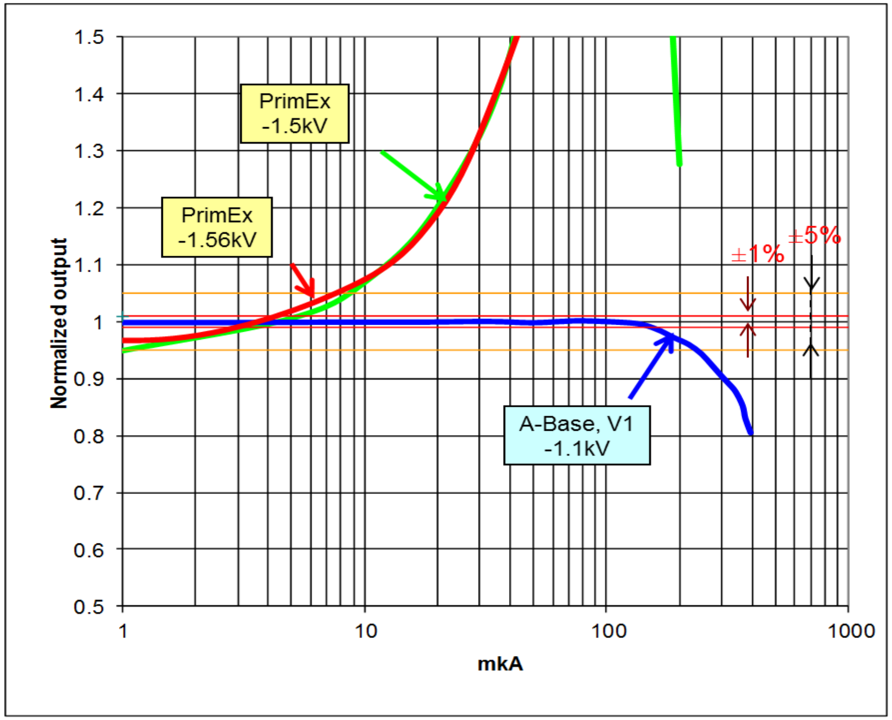


New ***active*** base design *[Popov et al., 2012]*

New active HV distribution bases with built-in amplifiers allow PMT operation in high rate environment

- Maximum linear count rate up to 1.2 MHz of 300 mV output pulses
- Gain stability +/- 1% with efficient output signal range up to ~160uA
- No degradation for radiation dose of 100 kRad – based on tests in 2012

- Detector performance, e.g., PMT gain may change for high flux rates
- For expected rates up to 1 MHz need PMT with fast response, operated at low gain and anode current



Active base equivalent output integral current is about 400 mkA and outperforms PrimEX passive base by factor of ~25

Summary and Outlook

- Precision cross section measurements are essential for the GPD/TMD program at 12 GeV JLab
  - The NPS has a primary role in confirming the understanding of the scattering mechanism for DVCS, WACS, and neutral pion production in SIDIS and exclusive electro- and photoproduction

- The neutral particle physics program in Hall A/C plays an important role in the GPD/TMD program

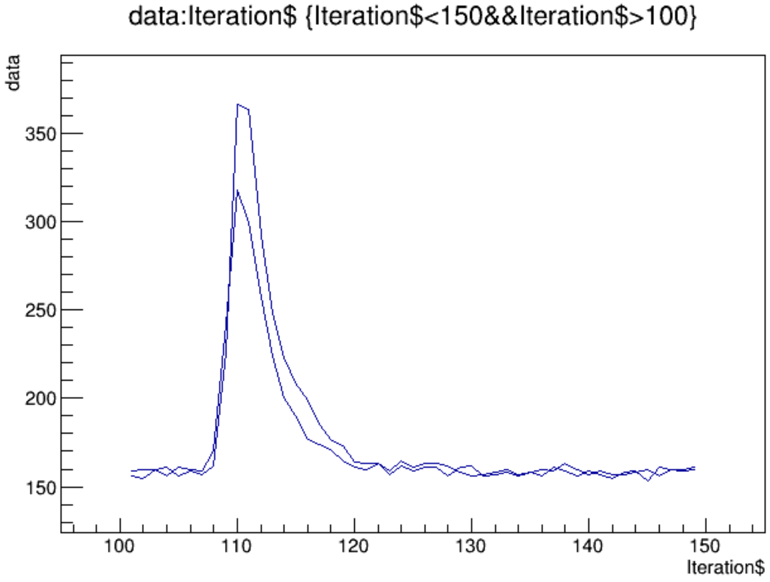
- About 20% of the approved science experiments in Hall C use the Neutral Particle Spectrometer

- The Neutral Particle Spectrometer gives unique opportunity for coincidence precision cross section measurements with neutral particles
  - NPS construction underway supported by NSF MRI PHY-1530874

NPS readout and trigger tests

To take full advantage of high-resolution crystals operating in a high-background environment flash ADCs (fADCs) will be used to digitize the signal

- Support both high-rate operations in singles mode as well as advanced, trigger-level cluster finding in coincidence mode
  - Coincidence trigger takes advantage of fADCs ability to perform pulse integration and pass it along for cluster finding, e.g, to select DVCS events
- A setup to test fADC based readout with PWO crystals was constructed
  - Cosmic trigger
  - 150 Hz pulser max
- Next:
  - Develop trigger clustering
  - High speed readout using VTP and cluster readout
  - High rate source to test for pile up



NPS General Design Concept

- a ~25 msr neutral particle detector consisting of up to 1116 **$PbWO_4$ crystals** in a temperature-controlled frame including gain monitoring and curing systems

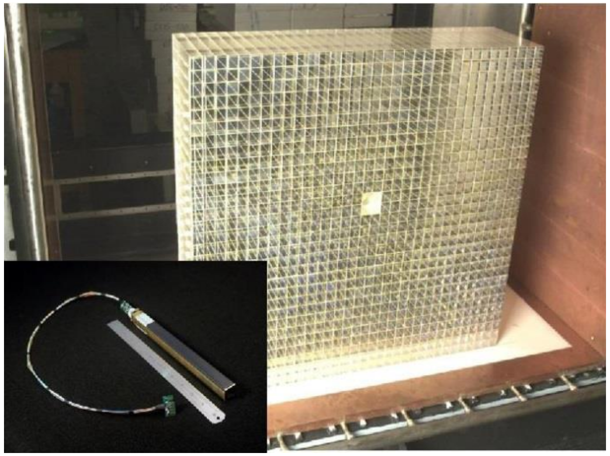
- HV distribution bases with built-in amplifiers for operation in a high-rate environment

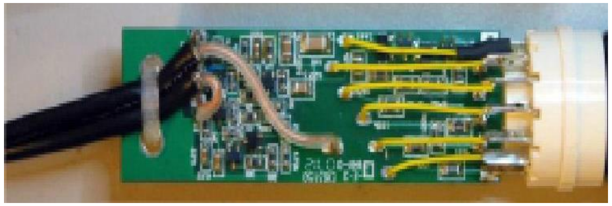
- Essentially deadtime-less digitizing electronics to independently sample the entire pulse form for each crystal – JLab-developed Flash ADCs

- A new sweeping magnet allowing for small-angle operation at 0.3 Tm (for electro-production) and large angle operation at 0.6 TM (for photo-production). The magnet is compatible with existing JLab power supplies.

- Cantelevered platforms off the SHMS carriage to allow for remote rotation (in the small angle range), and platforms to be on the SHMS carriage (in the large angle range) – new

- A beam pipe with as large critical angle as possible to reduce beamline-associated backgrounds – further study showed only a small section needs modification (JLab/Hall C)





Modified beam pipe: critical angle 13.5 mr