Compact photon source

Bogdan Wojtsekhowski, for the Collaboration

Photon beams of GeV energy

Process used

- electron bremsstrahlung
- positron annihilation
- laser back scattering
- forward electro-production

Features

- untagged
- tagged
- polarized
- quasi-real
- end-point method

Photon beams of GeV energy

- bremsstrahlung - intensity, $dn/(dE\gamma/E\gamma)$ up to 10^{14}, eq. ph/s
  equivalent photons per second
- positron annihilation – quasi monochromatic near E_{max}
- laser back scattering – all possible polarizations, E_γ vs θ_γ
- untagged – high intensity
- tagged – energy resolution, 10^{-3}, intensity max 10^8, eq. ph/s
- quasi real – compact and intense beam
- end-point method – limited dE/E, hard with 2.2 GeV steps
- polarized – circularly polarized electron beam, crystal radiator, laser back scattering, small angle electron tagging

Examples of photon beams

Cornell, 1975

Energy 2-6 GeV

Photon flux
$1.2\text{x}10^{10}$ eq. ph/s

The experiment was performed at the Wilson 12-GeV Electron Synchrotron at Cornell University. The incident photons were generated by an extracted electron beam focused to a spot approximately 3 mm in diameter on a 0.10-radiation-length aluminum target. The electrons in the resulting beam were magnetically diverted into a water-cooled dump. The bremsstrahlung photon beam passed through a collimator, sweeping magnet, scraper, and another sweeping magnet before entering the hydrogen target which was 11.5 m downstream of the radiator. At this point the beam was about 1.3 cm in diameter at the lowest energy. The hydrogen target cup was a cylinder

Examples of photon beams

ELSA, 1991
Tagged beam

Energy 3 GeV

Photon flux
$1x10^7$ eq. ph/s

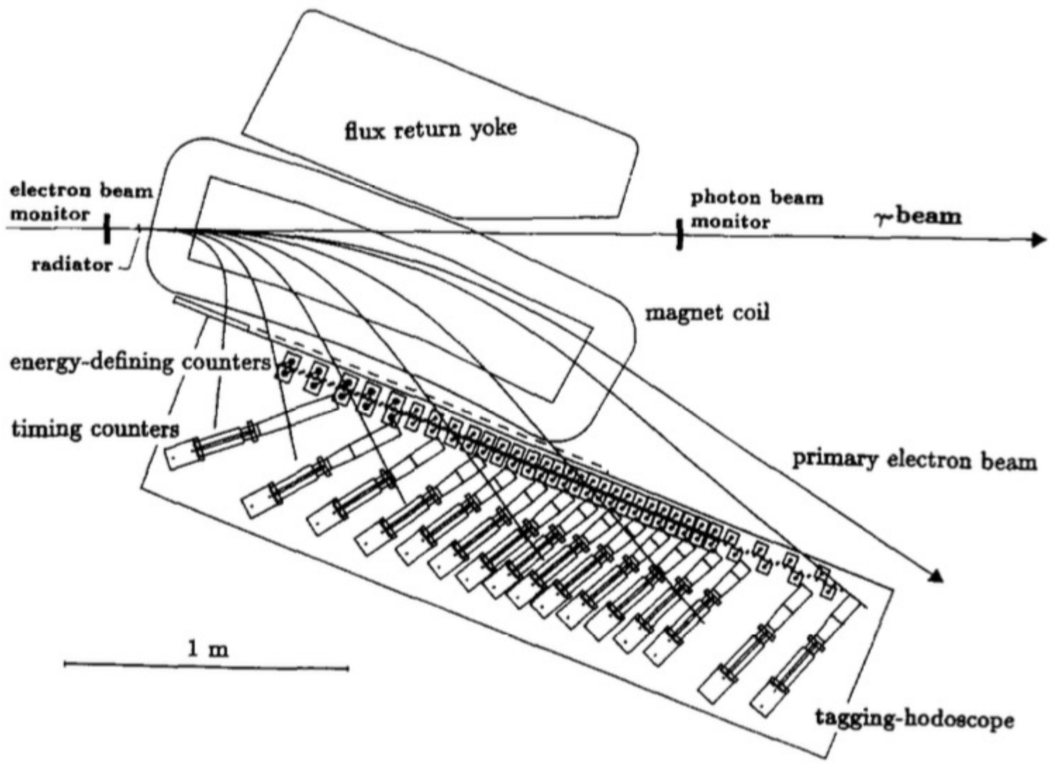
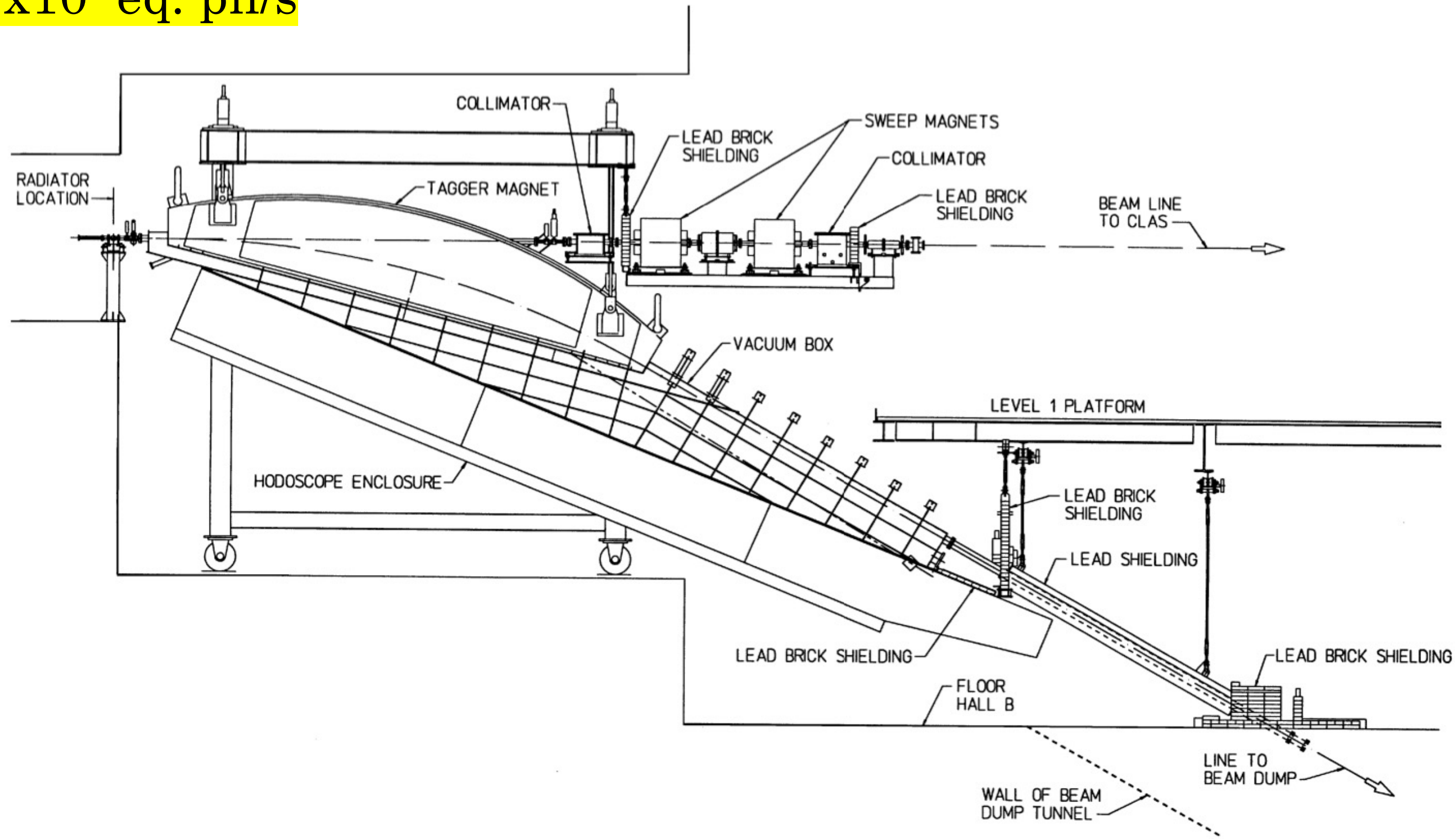


Fig. 1. Schematic setup of the PHOENICS tagging system.

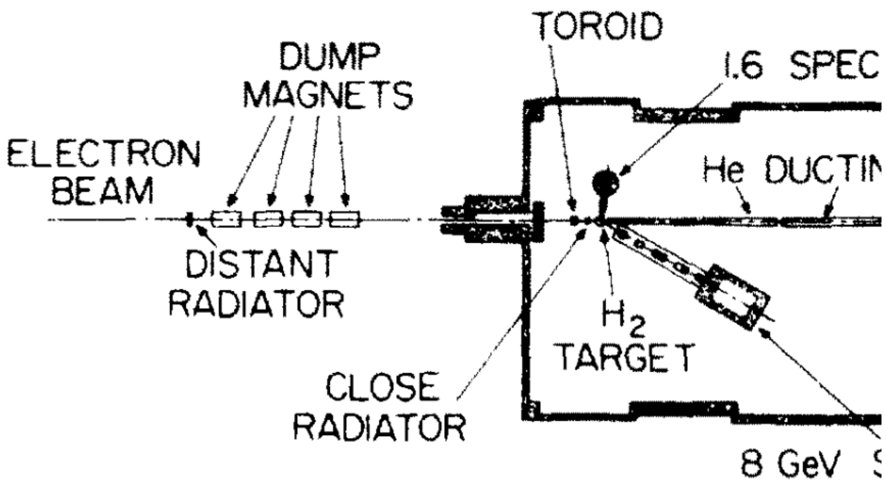
Examples of photon beams

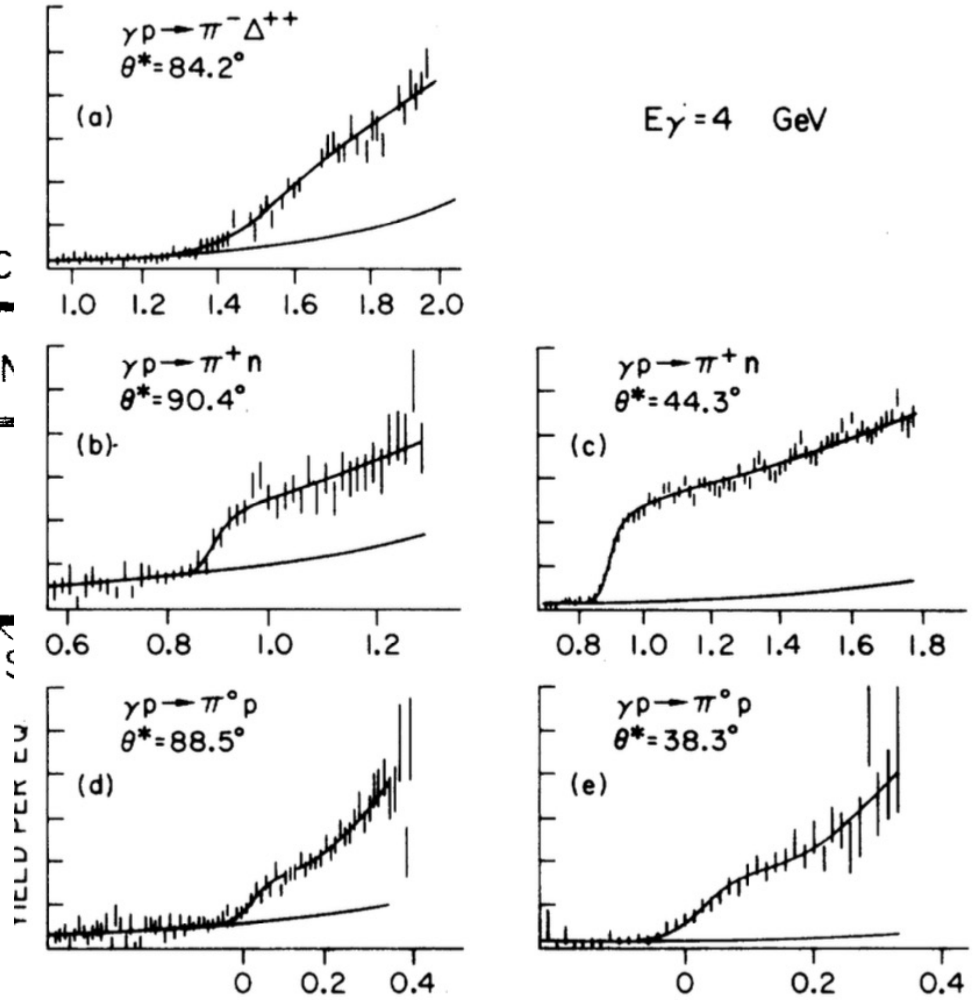
JLab, Hall B,
Tagged beam
$1\text{x}10^8$ eq. ph/s



Examples of photon beams

SLAC,
End-point method
H(e/γ, π)





Examples of photon beams

JLab, Hall A/C,
End-point method
1×10^{11} photons/s

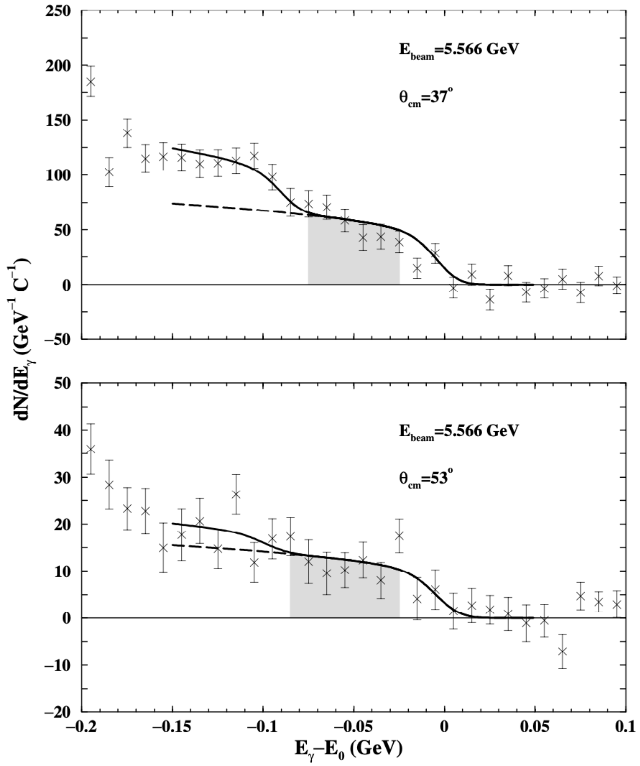


FIG. 1. Photon energy spectra, normalized to collected electron beam charge, for θ_{cm} = 37° (top panel) and 53° (bottom panel) at 5.5 GeV. The grey shaded area denotes the region in E_γ where the photoproton yield is calculated. The curves are described in the text.

PHYSICAL REVIEW C, VOLUME 60, 052201

Coherent π^0 photoproduction on the deuteron up to 4 GeV

D. G. Meekins,[1,2] D. J. Abbott,[2] A. Ahmidouch,[3] C. S. Armstrong,[1] J. Arrington,[4] K. A. Assamagan,[5] O. K. Baker,[2,5]
S. P. Barrow,[6] D. P. Beatty,[6] D. H. Beck,[7] S. Y. Beedoe,[8] E. J. Beise,[9] J. E. Belz,[10] C. Bochna,[7] P. E. Bosted,[11]

VOLUME 87, NUMBER 10 PHYSICAL REVIEW LETTERS 3 SEPTEMBER 2001

Measurement of the High Energy Two-Body Deuteron Photodisintegration Differential Cross Section

E. C. Schulte,[1] A. Ahmidouch,[2] C. S. Armstrong,[3] J. Arrington,[4] R. Asaturyan,[5] S. Avery,[6] O. K. Baker,[3,6]
D. H. Beck,[1] H. P. Blok,[7] C. W. Bochna,[1] W. Boeglin,[8] P. Y. Bosted,[9] M. Bouwhuis,[1] H. Breuer,[10] D. S. Brown,[10]

VOLUME 86, NUMBER 14 PHYSICAL REVIEW LETTERS 2 APRIL 2001

Polarization Measurements in High-Energy Deuteron Photodisintegration

K. Wijesooriya,[10,*] A. Afanasev,[20,26] M. Amarian,[11] K. Aniol,[3] S. Becher,[9] K. Benslama,[23] L. Bimbot,[22] P. Bosted,[16]

PHYSICAL REVIEW C **66**, 034614 (2002)

Polarization measurements in neutral pion photoproduction

K. Wijesooriya,[1,*] A. Afanasev,[21,27] M. Amarian,[12] K. Aniol,[4] S. Becher,[10] K. Benslama,[24] L. Bimbot,[23] P. Bosted,[17]
E. J. Brash,[24] J. Calarco,[19] Z. Chai,[18] C. C. Chang,[16] T. Chang,[11] J. P. Chen,[27] S. Choi,[26] E. Chudakov,[27] S. Churchwell,[7]

PHYSICAL REVIEW C **71**, 044603 (2005)

Cross section measurements of charged pion photoproduction in hydrogen and deuterium from 1.1 to 5.5 GeV

L. Y. Zhu,[1] J. Arrington,[2] T. Averett,[3,4] E. Beise,[5] J. Calarco,[6] T. Chang,[7] J. P. Chen,[4] E. Chudakov,[4] M. Coman,[8] B. Clasie,[1]

Examples of photon beams

JLab, Hall A/C,
Mixed e/γ beam
Exclusive process

$$H(e/\gamma, \gamma + p)$$

Energy 2-6 GeV

Photon flux
$2\text{x}10^{13}$ eq. ph/s

$1\text{x}10^{12}$ photons/s
in HRS acceptance

JLab, Hall A, Wide Angle Compton Scattering

PRL **94,** 242001 (2005) PHYSICAL REVIEW LETTERS week ending 24 JUNE 2005

Polarization Transfer in Proton Compton Scattering at High Momentum Transfer

D. J. Hamilton,[1] V. H. Mamyan,[2,3] K. A. Aniol,[4] J. R. M. Annand,[1] P. Y. Bertin,[5] L. Bimbot,[6] P. Bosted,[7] J. R. Calarco,[8]
A. Camsonne,[5] G. C. Chang,[9] T.-H. Chang,[10] J.-P. Chen,[3] Seonho Choi,[11] E. Chudakov,[3] A. Danagoulian,[10]

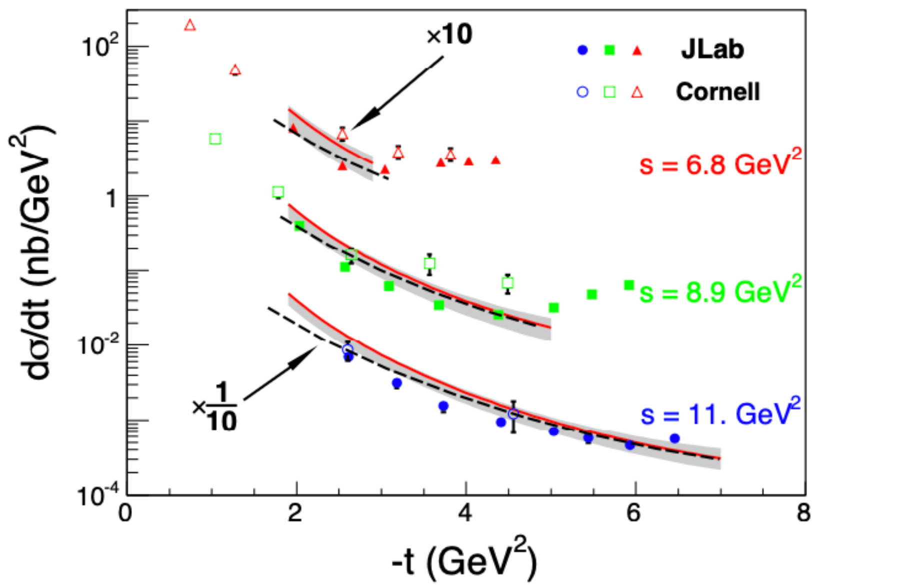


FIG. 4: Cross section of RCS process vs. transfer momentum t at three values of s. Full points and open points are data from the present and Cornell experiments [1], respectively.

Photon source considerations in WACS on the polarized target

- Beam spot size at the target is important for discrimination between Compton process and 100-times more intense pi-0 production. Useful to have a short distance from the radiator to the target.

- High intensity is crucial for reaching sufficient s,-t,-u, all > few GeV^2

- Intensity of the real photons acceptable by NH3 target is 10-30x higher than quasi-real (electron beam) at 100 nA

- Time of installation/removal must be acceptable < three months

- Cost of device is also an important consideration

Compton/Pion in Wide Angle Compton Scattering

Cornell, 1978

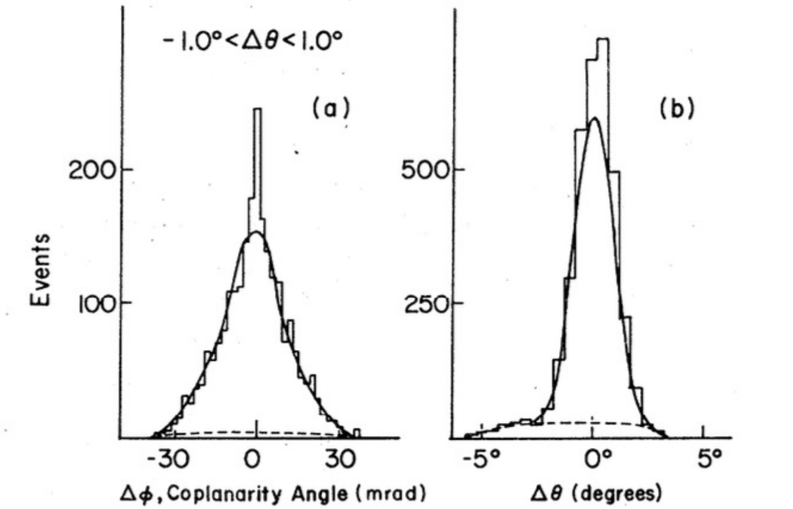


FIG. 3. Angular-difference distribution at 6 GeV and $t = -2.45$ GeV^2. (a) Coplanarity-angle distribution. The solid line is a fit assuming neutral-pion photoproduction, the dashed line is the estimated background from other processes, and the peak at $\Delta\phi = 0$ is due to proton Compton scattering. (b) Angular-difference distribution in the reaction plane. The curves have the same interpretation as in (a). The excess at $\Delta\theta = 0°$ is due to Compton scattering.

1.3 cm beam diameter
clean photon beam

JLab, 2002

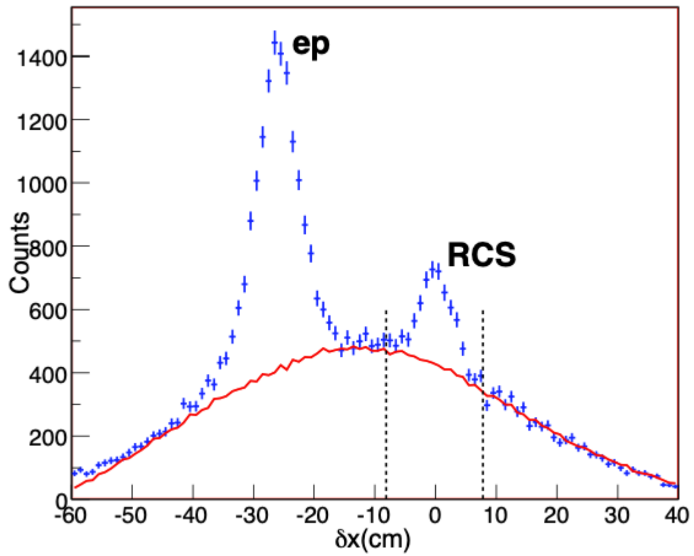


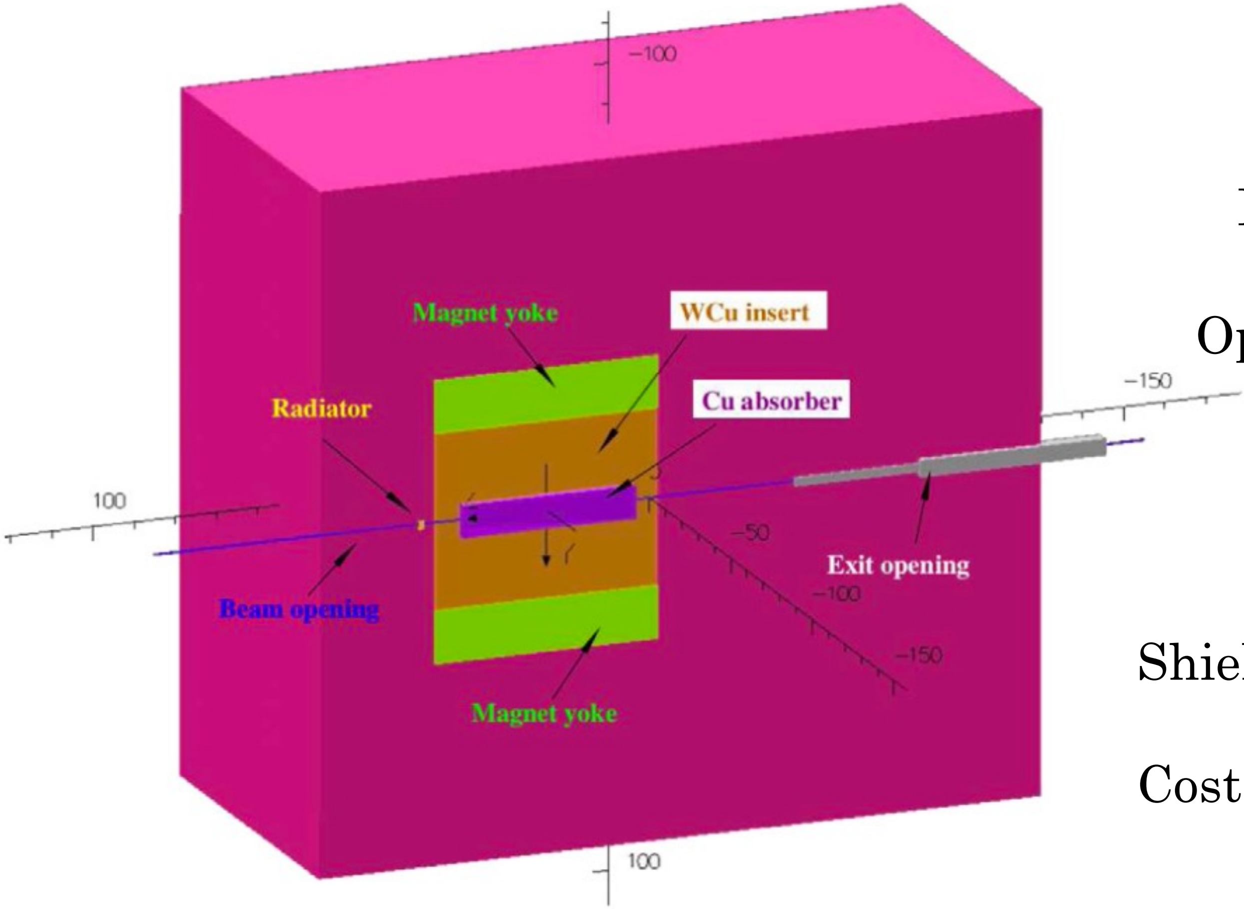
FIG. 3: The δx-distribution for a coplanarity cut $|\delta y| \leqslant$ 15 cm, with the RCS and ep peaks indicated. The curve is a distribution of the continuum π° events. The vertical dashed lines show the cuts used to calculate the number of RCS events.

0.2 cm beam diameter
mixed e/γ beam

Polarized target and CPS

A conceptual design study of a Compact Photon Source (CPS) for Jefferson Lab NIM-A 957 (2020) 163429

D. Day [a], P. Degtiarenko [b], S. Dobbs [c], R. Ent [b], D.J. Hamilton [d], T. Horn [e,b,*], D. Keller [a], C. Keppel [b], G. Niculescu [f], P. Reid [g], I. Strakovsky [h], B. Wojtsekhowski [b], J. Zhang [a]



Concept of shielding:

Radiation is wide, angle ~ 1

Open angle of γ is ~ $m_e/E_e << 1$, so the leak is suppressed

Compact device cost:

Shield thickness $R = C \times \ln(P_i/P_o)$

Cost is proportional to ($LxR^2 + R^3$)

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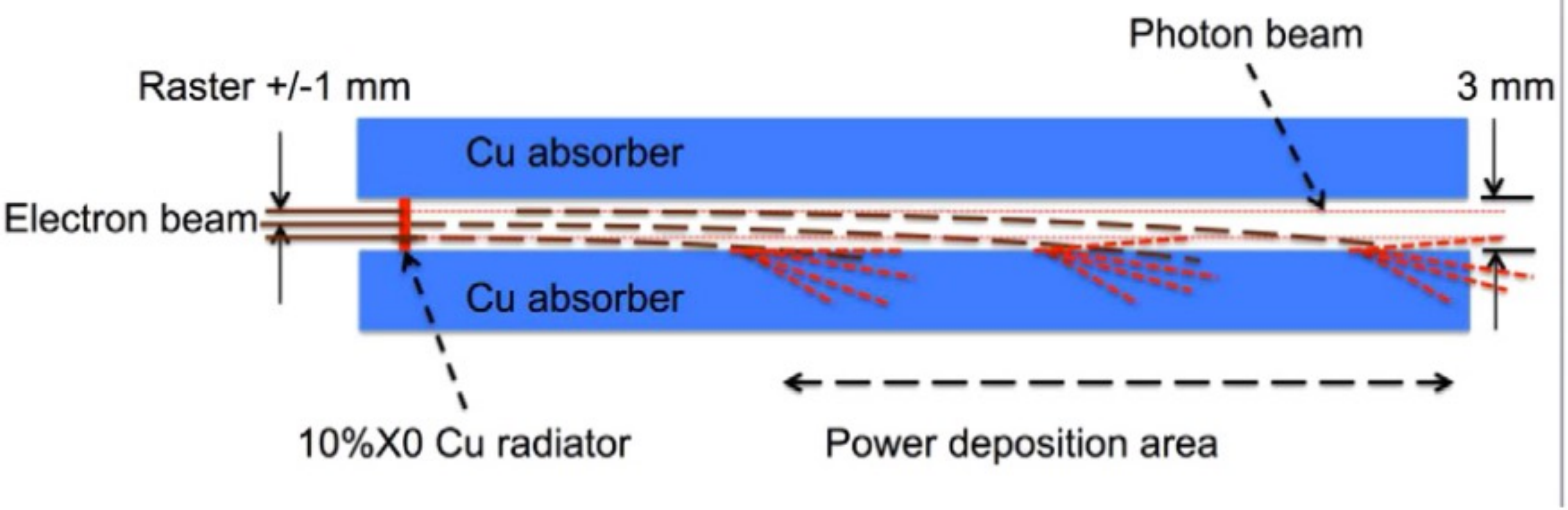
Concept of beam power distribution



First time presented at NPS Collaboration Meeting, 11/19/2014

CPS project in Hall C

A Conceptual Design Study of a Compact Photon Source (CPS) for Jefferson Lab

This study is in response to the PAC45 technical comments for full approval of C12-17-008 that requires a Compact Photon Source (CPS). However, other proposals and LoIs at Jefferson Lab may take advantage of the CPS (PR12-15-003, PR12-16-009, PR12-14-006).

The document describes the technical design concept of a compact, high intensity photon source capable of producing 1.5×10^{12} equivalent photons per second to be used with dynamically nuclear polarized targets.
The equivalent heat load for a pure photon beam impinging such targets corresponds to a photon flux originating from a 2.7 μA electron beam current striking a10% Cu radiator. Hence, the CPS design for Halls A/C should be able to absorb 30 kW in total (corresponding to 11 GeV beam energy and 2.7 μA beam current).

For polarized experiments the proposed solution has a twofold advantages compared to a traditional bremsstrahlung photon source:

a) Large gain in figure-of-merit (by a factor of ~30)
b) Much lower radiation levels: a factor of 1000 reduction in prompt radiation dose compared to a 2.7 μA (30 kW) electron beam current striking a 10% Cu radiator.

The most important aspects in the design and subsequent building of a CPS are:

a) Compatibility with Polarized Targets, including the magnetic field interference with the magnet holding the target polarization.
b) Radiation.
c) Cost.

Compatibility with Polarized Target

The CPS proposal describes a highly intense photon beam impinging upon a solid NH3 target sample dynamically polarized in the transverse direction at 1 K and 5 T. The photon beam has a very small exit aperture of 3 mm by 3 mm limiting possible beam motion. This implies that the standard procedure to raster the beam over the face of the target cup cannot be used. Thus an alternative approach is taken. To ensure that the sample is uniformly irradiated from the beam, it will be rotated about an axis parallel to the beam and simultaneously moved up and down. In this manner the beam spot will trace out a spiral pattern very similar to the combination of the fast and slow rasters used in polarized solid target experiments with electron beams. There are, however, two potential drawbacks to this innovative concept. First, the rotation rate of the target (a few Hertz) is considerably slower than the 100 Hz electron beam raster. This will cause portions of the sample to briefly warm up to about 2 K. However, an in-depth analysis shows that the resulting loss of proton polarization should be negligible, since the time spent at the elevated temperature will be far shorter than the proton's spin-lattice relaxation time. Second, the radiation damage caused by e^+-e^- pair production will be non-uniform, with the downstream portion of the sample receiving more damage than the upstream. This could lead to a significant polarization gradient within the sample, a result that must be considered when designing the NMR coils.
The TAC evaluation of the proposal raised the issue that the proposed solution may compromise the desired 3% relative uncertainty of the target polarization. *In the document there is no discussion about this point, which remains an open issue.*

The CPS magnet will be located relatively close to the 5 Tesla solenoid of the polarized target whose mutual forces need to be taken into account in the design of the support structure.
Another magnetic consideration is the effect on field quality at the polarized target. The fields and gradients imposed on the polarized target will not be large but they must be compensated at the 10^{-4} level.
Those aspects are only mentioned in the document, thus *further studies to model the target environment and to design a compensation system are required.*

Radiation Studies

The proposed source has a dump inside the magnet. The CPS final design features a magnet, a central copper absorber, and hermetic shielding consisting of tungsten powder and borated plastic.
Radiation studies have been carried out assuming 1000 hours of operation with the following radiation requirements:

- Prompt dose rate in hall ≤ several rem/hr at 30 feet from device.
- Prompt dose rate at the site boundary ≤ 1 μrem/hr.
- Activation dose outside the device envelope at one foot distance ≤ several mrem/hr one hour after the end of a1000 hour run.
- Activation dose at the pivot in the experimental target area at one foot distance from the scattering chamber ≤ several mrem/hr one hour after the end of a 1000 hour run.

Status of the CPS project

All aspects of the status will be presented by Steve Lassiter
at the NPS meeting tomorrow

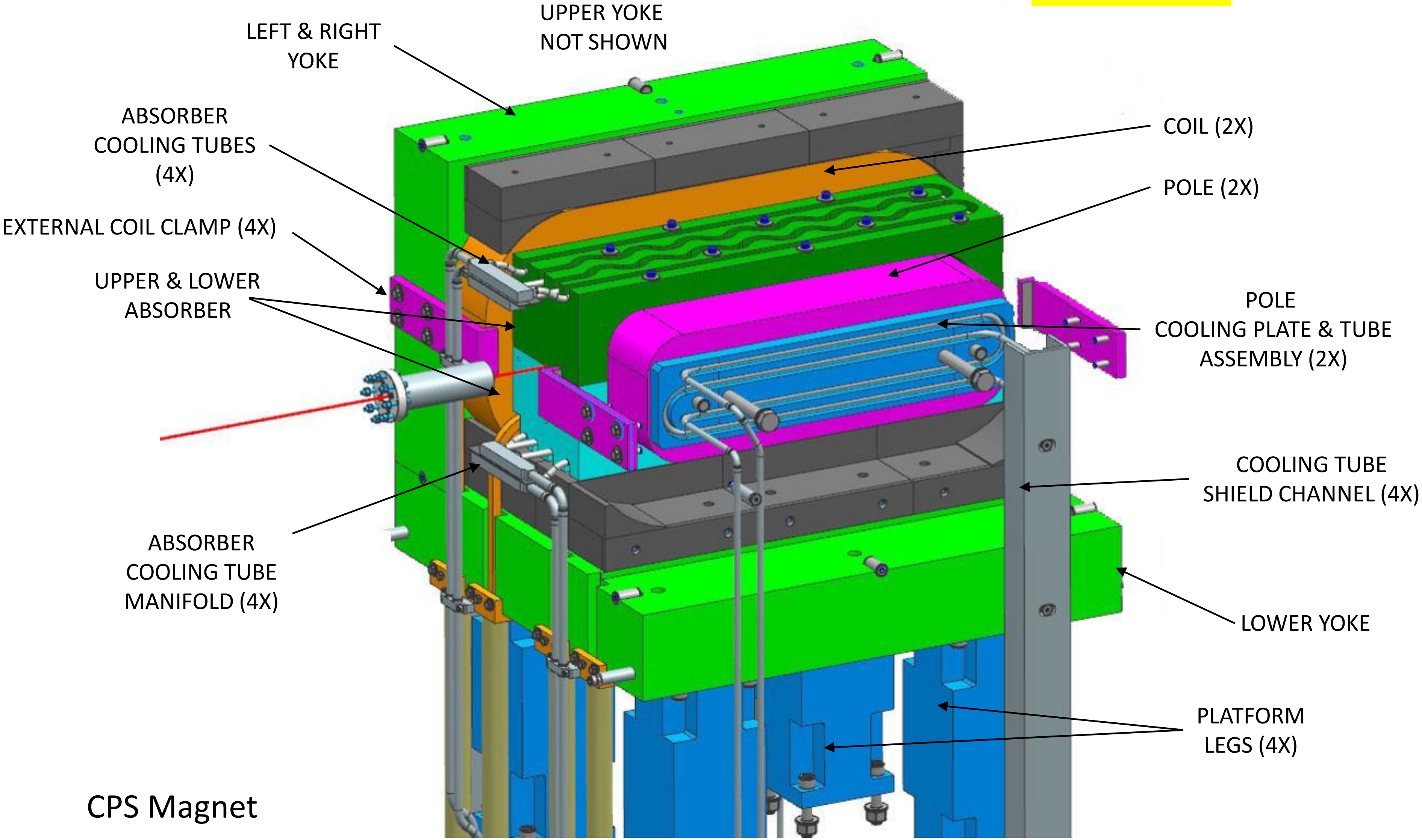
Here is just a bullet list:

- Layout of the mechanical components is well advanced
- Magnet – procured, including the special radiation hard coils, the yoke, the poles
- Shielding – W blocks are procured, received; 28 tons of Pb bricks received
- The power absorber is designed, the prototype test setup is ready
- Shielding of the radiation was calculated in FLUKA, radiation is acceptable

Compact Photon Source

CPS in Hall C

S. Lassiter

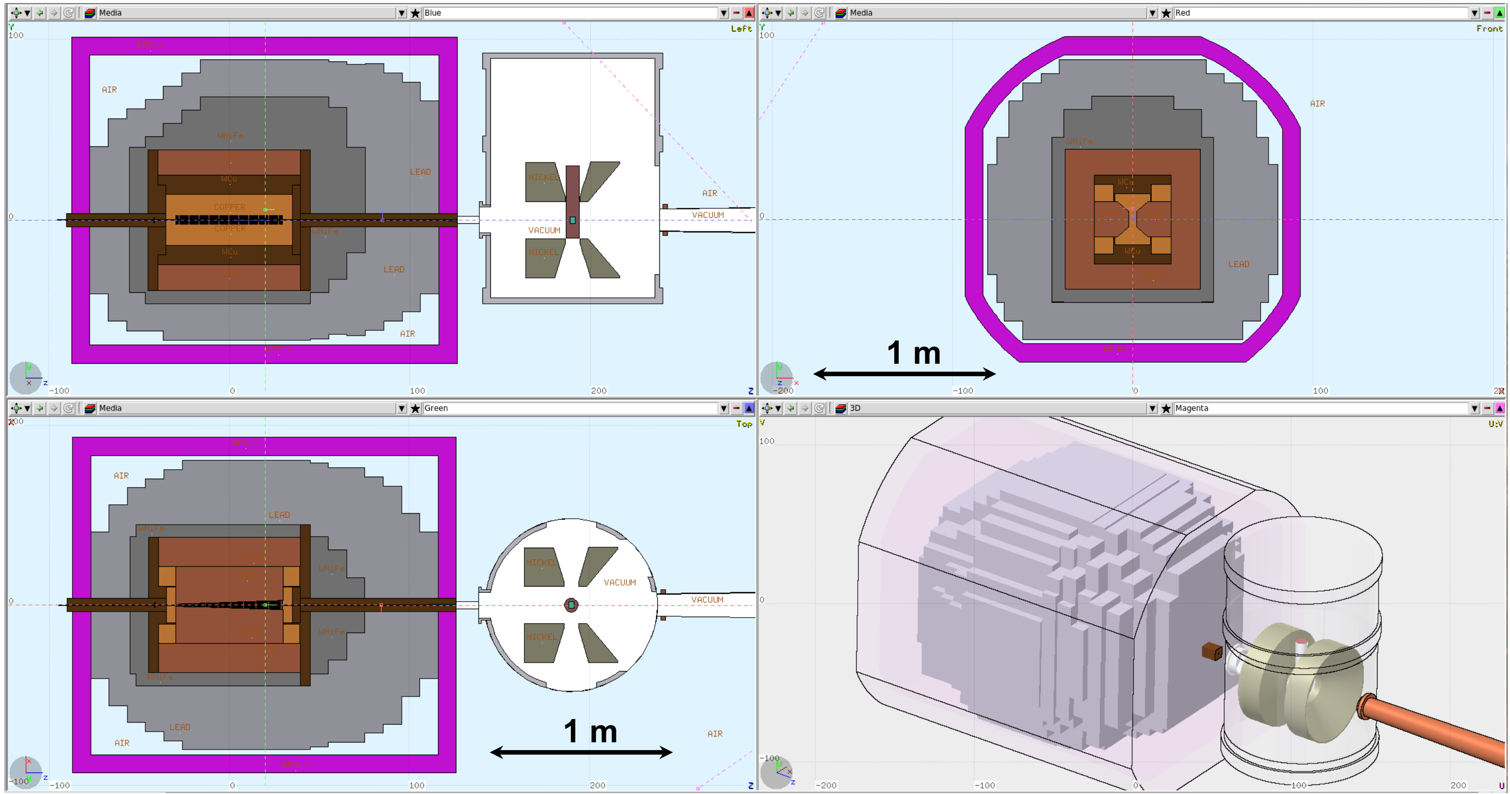


CPS Magnet

Polarized target and CPS

P.Degtiarenko

CPS and Target Geometry Overview

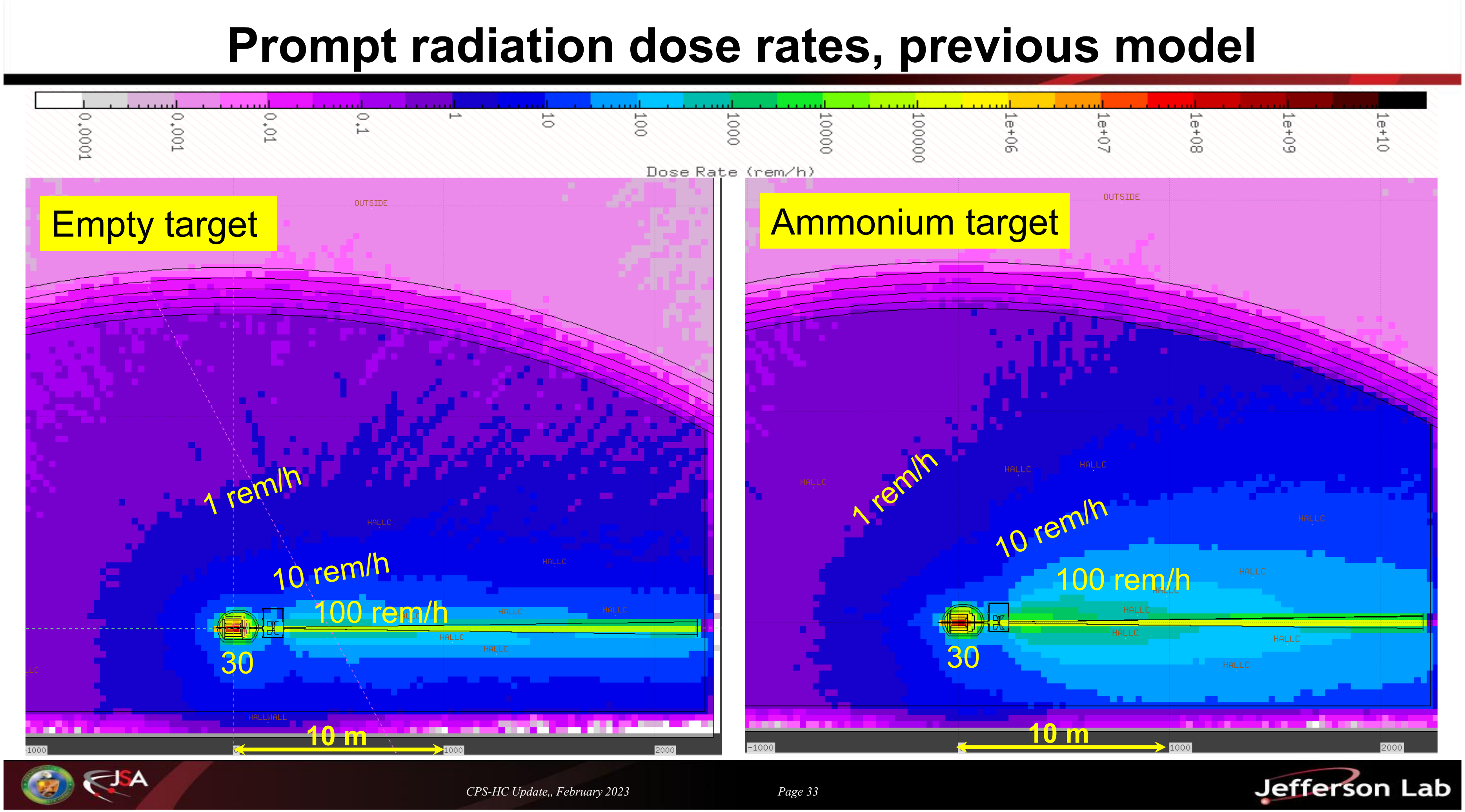


CPS-HC Update,, February 2023 Page 12 Jefferson Lab

2.5 m

Polarized target and CPS

P.Degtiarenko



Polarized WACS, E12-17-008, 46 PAC days

D. Day, D. Hamilton, D. Keller, G. Niculescu, B. Wojtsekhowski and J. Zhang

Recommendation: Approve
The PAC considers WACS to be the process of choice to explore factorization in a whole class of wide-angle processes. The PAC recommends approval with the full allocation of the requested 18 days.

1. A 2.5 μA polarized electron beam incident on a 10 % radiator inside a new Compact Photon Source (CPS) produces a high-intensity untagged photon beam.
2. The proton target is the UVA/JLab solid polarized ammonia target.
3. The recoil proton is detected with the BigBite spectrometer equipped with GEM trackers and trigger detectors.
4. The highly-segmented $PbWO_4$ NPS calorimeter is used to detect the scattered photon.

Photon flux $1.6\text{x}10^{12}$ eq. ph/s

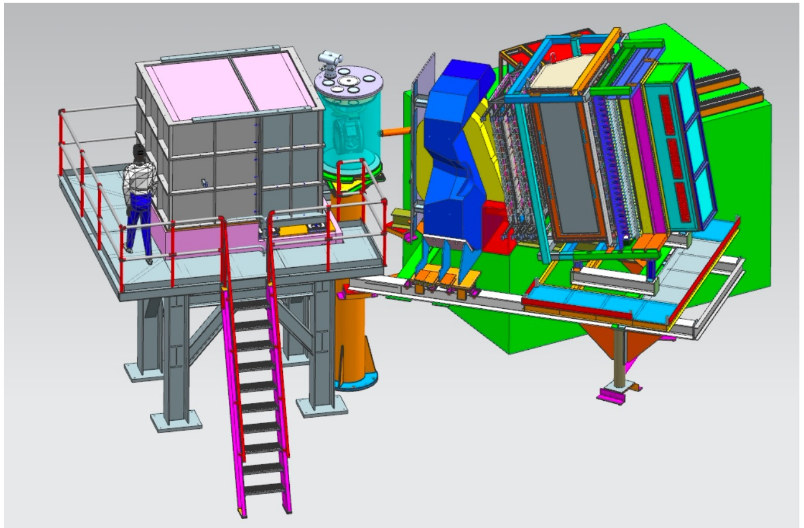


Figure from Steve Lassiter

The use of the CPS and BigBite results in a factor of 30 improvement in figure-of-merit over previous experiments and opens up a new range of polarized physics opportunities at JLab.

Physics with photon beams

$$D(\vec{e},\, \vec{p})n$$

Figure-of-Merit is $P_e^2 \times \Omega_p \times \epsilon A_{pol}^2 \times \frac{\Delta E_\gamma}{E_\gamma} \times Flux_\gamma$

FOM gain is $10/1 \times 0.5^2/(0.115 * 0.27^2) \times 0.1/0.02 \times 1/20 = 75$

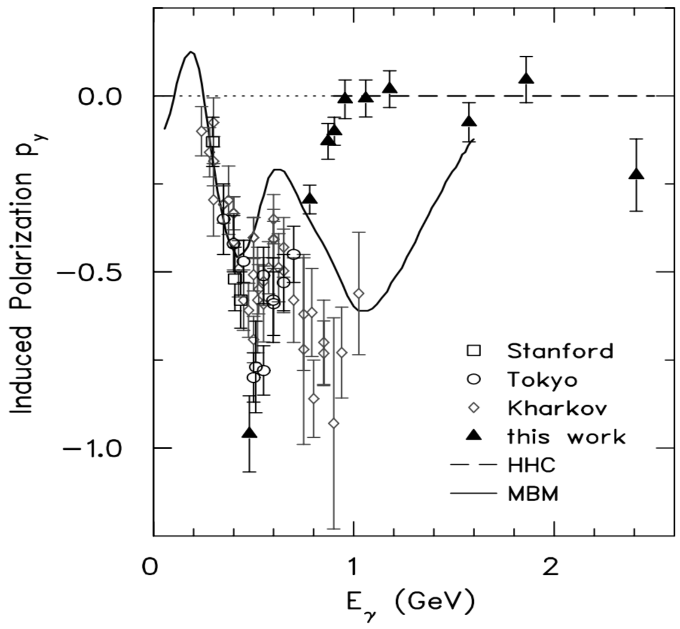


FIG. 1. Induced polarization p_y in deuteron photodisintegration at $\theta_{c.m.} = 90°$. Only statistical uncertainties are shown. The curves are described in the text.

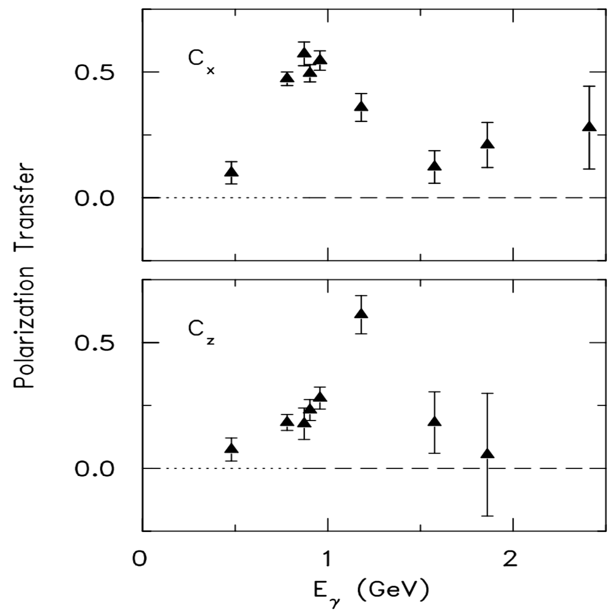


FIG. 2. Polarization transfers C_x and C_z in deuteron photodisintegration at $\theta_{c.m.} = 90°$. Only statistical uncertainties are shown.

Experiments on the polarized solid target

- Polarized Wide Angle Compton Scattering, E12-17-008
- Pion photoproduction from neutron – ALL vs. KLL
- Proton polarization in D(γ, p + n) – higher photon energy
- Pion photoproduction from proton - GPDs

Summary

- Compact Photon source with a 1 kW of 11 GeV photon beam will soon be ready for an experiment – NPS RG3

- Experimental program with CPS is large. Important physics proposals are under development. Please make suggestions and take the lead.