A Pure Photon Source for use with Solid Polarized Targets Progress Report

UVa Option

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Darshana Perera, Jixie Zhang
and friends

High Intensity Photon Sources Workshop
Feb. 06 & 07, 2017
Catholic University
Outline

• Background
  • Real Photons on a Polarized Target – WACS for example
  • Dynamically Polarized Targets and their behavior with electrons
  • Bit of History
  • Benefits and FOM multiples with a pure photon source

• Concept is simple
  • Not painless to achieve in practice
    • High field dipole
    • Photon collimation
    • Sheet of flame
    • Shielding selection and placement

• Results from Geant4 and Fluka

• Work still in progress and planned
Wide Angle Compton Scattering

- One of the most fundamental processes yet it is still not well understood at medium energy

- For wide angle kinematics \((s,-t,-u >> M^2)\) there is consequential untapped information on nucleon structure

- WACS provides complimentary information to elastic FF at high \(Q^2\) and DVCS, TCS, DDVCS, DVMP

- Common thread: large energy scale leading to factorization of scattering amplitude into a hard perturbative kernel and a factor expressing soft non-perturbative WF

- Polarized observables can provide access to information not otherwise available
Bit of history

1. Initial State Helicity Correlation in Wide Angle Compton Scattering, PR-05-003, deferred with regret by PAC 27 - mixed electron/photon beam.

2. E05-101 approved for 14 days by PAC 28 (A-) - mixed electron/photon beam.

3. Pure photon source (radiator, dipole, dump) proposed at Jan. 2006 Hall C meeting.

4. E05-101 was planned to run with SANE (2009) but did not - lack of beam time.

5. E12-14-006 (2014) approved at PAC 42 for 15 days (B) - essentially a resubmission of E05-101, with a mixed electron/photon beam.

6. 2kW pure photon beam (single dipole and dump upstream of target) presented at NPS meeting on 10/9/14.


8. Longitudinal and Transverse Target Correlation Asymmetries in Wide Angle Compton Scattering, PR12-16-009, deferred by PAC 44. Split function pure photon beam with downstream beam dump (25kW) presented.

9. Both PAC 43 and PAC 44 suggested a creation of a single collaboration to present optimized photon source and experiment.
At Hall C Workshop January 7, 2006

1 μA on radiator instead of 100 nA

Polarized target

Existing beam dump

Beam dump on floor

Magnet(s)

Radiator

Also at joint 2010 Hall A/Hall C workshop on High Intensity Polarized Targets at 12 GeV
WACS with Polarized Target

Solid polarized proton target, NH$_3$
- $^4$He evaporation refrigerator
- 5 T polarizing field
- Dynamic Nuclear Polarization
- Mixed photon/electron beam

Decay due to radiation damage

Accumulated Charge \((10^{15} \text{ e}^-/\text{cm}^2)\)

\(5 \times 10^{15} \text{ e}^-/\text{cm}^2 = 9 \text{ hours at 100 na}\)

Significant Overhead

2005 (2014): 88/506 = 17% (16%)

- Change targets (top/bottom) every 8 hours
  - Polarize
  - Anneal, Cooldown, TE, Polarize [2 times/day – 2 hours]
  - Replace target material at least once/week: Warm up, pull stick, replace material, take TE’s top and bottom, polarize !< 8 hours
Benefits of a real photon beam

• Heat load on target reduced
  • Higher maximum target polarization with beam: 90% \(\Rightarrow\) 95%
• Production of depolarizing free radicals much reduced
  • Higher average polarization FOM = \((90/70)^2 = 1.65\)
  • Fewer target changes
  • Significant reduction in target overhead
• Higher electron intensity on radiator - more photons - factor of 18
  • Reduced running time
  • Push to higher energies where \(\sigma\) are \(<<\)
• Overall improvement in FOM by a factor of 30
• Reduced electron background, no ep and no ep\(\gamma\)
• Transverse running creates only incidental problems

• New Physics
  • TCS
  • Photo-disintegration of tensor polarized deuteron
Pure Photon Source

Separated function dipole and dump

October 2014

400 na at 4.4 GeV

A beam dump at the target only if there are absolutely no other possible choices!

Target hangs on a platform above the pivot post

PR12-15-003, June 2015

1.2 μA at 8.8 GeV

CPS, Combined Function dipole/dump
Experimental Setup: PR12-16-009

3µA at 8.8 GeV, May 2016

1) Create Pure Photon Beam
2) 10% radiator
3) 3 µA beam current
4) Resistive Dipole(s)
5) Electron beam deflected under the target chamber then either
   a) drifts to a local dump in the hall or
   b) transported to the standard Hall C dump via an achromat beam line

Vertical deflection at target: > 48 cm && < 129 cm
• Floor in vertical: -3943 mm
• Dump: Z = 14305.71 mm
• Radiator: Z = -6495.45 mm
• Dipole Center: Z = -5314 mm
• Post and target Z = 0 mm
• Magnet container length: 2320 mm
• FZ Magnet: 2T @ 2m (Bdl~4)
• 2T 2m dipole tilted at 5°, ends 4.3m upstream of target.
• Large space available to shield dipole, radiator, collimator, beam pipe – no possibility of charged particles to be transported by HMS
• No disruptive magnetic forces on target.
• Opportunity for radiation exposure minimized.
• Distance and shielding minimizes singles background in NPS.
• Hot spot at collimator/absorber at end of dipole – 2 to 3 kW
  • In development
  • Guidance from PREX/CREX – 2.1 kW
  • Moller plans a 4 kW collimator
• Hermetic local dump can be made with as many meters of material as necessary – no space restrictions. Sliding door seals dump during access to hall.
Electron energy spread out of radiator is broad – it is dispersed

0.18 (0.11) kW/μA for 10% (6%)

Electrons < ~6000 MeV will intercept a spacer bar in the dipole magnet.

Low energy electrons produced by pair production.
Electron Beam dispersion after the dipole, NC

~10 cm
Electron Beam Spread at dump

~100 cm

Solution: Collimator/Absorber
Build collimator based on Prex

Prex-II collimator

- Collimator front face 85cm from target, intercepts electrons >0.78°
- Power deposited: 2.1kW @ 70 μA
- Inner cylinder 30% Cu-70% W
- Water-cooled with Cu brazed sleeve, similar to Qweak collimator
- Outer box: Tungsten
- Outer tungsten cover traps E&M power, self-shields produced neutrons

Moller plans a 4 kW collimator

Caryn Palatchi, Hall A Mtg
Photon Collimator/ Electron Absorber

[Diagram showing dimensions and materials]
Photon Energy versus angle

No collimator

With collimator
Electron Beam Spread at dump with collimator

Without spread was 100 cm

30 cm
### Other combinations of field (B), dipole length (L0), radiator to target distance (L1+L0)

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<th>B</th>
<th>L0</th>
<th>L1</th>
<th>L1+L0</th>
<th>BDL</th>
<th>tht</th>
<th>thtd</th>
<th>Vert</th>
<th>DLoc</th>
<th>S</th>
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</table>
Flux at target in different locations from collimator

6% Radiator

10% Radiator

Collimator chosen to fix spot size
## Table of Flux Vs. Target Location

<table>
<thead>
<tr>
<th>Distance From Collimator (m)</th>
<th>Flux for 10% radiator per 1µA</th>
<th>Flux for 6% radiator per 1µA</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.8E+11</td>
<td>1.9E+11</td>
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<td>1</td>
<td>2.4E+11</td>
<td>1.7E+11</td>
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<td>2</td>
<td>1.9E+11</td>
<td>1.5E+11</td>
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<tr>
<td>3</td>
<td>1.6E+11</td>
<td>1.3E+11</td>
</tr>
<tr>
<td>4</td>
<td>1.4E+11</td>
<td>1.1E+11</td>
</tr>
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</table>
## Energy Deposited

<table>
<thead>
<tr>
<th>Component</th>
<th>Energy Deposited (kW/µA) 10 % radiator</th>
<th>Energy Deposited (kW/µA) 6 % radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiator</td>
<td>0.00191</td>
<td>0.00112</td>
</tr>
<tr>
<td>Dipole magnet</td>
<td>0.18414</td>
<td>0.10565</td>
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<tr>
<td>Collimator</td>
<td>0.78374</td>
<td>0.45622</td>
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<tr>
<td>Photon beam pipe</td>
<td>0.00143</td>
<td>0.00097</td>
</tr>
<tr>
<td>Electron beam pipe</td>
<td>0.01753</td>
<td>0.01182</td>
</tr>
<tr>
<td>Hall Dump</td>
<td>0.41834</td>
<td>0.32889</td>
</tr>
<tr>
<td>Local Dump</td>
<td>6.65685</td>
<td>7.46410</td>
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<tr>
<td>Flux at the Target</td>
<td>1.42*10^11</td>
<td>1.164*10^11</td>
</tr>
</tbody>
</table>

Total Power Deposited: 8.07 kW  
Missing Power: 0.70 kW  

Total Power Deposited: 8.37 kW  
Missing Power: 0.43 kW
Pure Photon Source Performance

<table>
<thead>
<tr>
<th>Beam Energy (GeV)</th>
<th>Beam Current (μA)</th>
<th>Radiator</th>
<th>Distance</th>
<th>Flux Lost (%)</th>
<th>gamma/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4</td>
<td>0.1</td>
<td>6%</td>
<td>100</td>
<td>1.9</td>
<td>2.1E+10</td>
</tr>
<tr>
<td>4.4</td>
<td>3</td>
<td>6%</td>
<td>633</td>
<td>63.4</td>
<td>2.4E+11</td>
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<tr>
<td>4.4</td>
<td>0.1</td>
<td>10%</td>
<td>100</td>
<td>3.3</td>
<td>3.5E+10</td>
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<tr>
<td>4.4</td>
<td>3</td>
<td>10%</td>
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<td>71.6</td>
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<td>8.8</td>
<td>0.1</td>
<td>6%</td>
<td>100</td>
<td>0.8</td>
<td>2.2E+10</td>
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<tr>
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<td>633</td>
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<td>40.6</td>
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0.5 < Eγ/Beam < 0.95, requiring the spot size on target within a 1mm (rms) radius circle.

4.2*10^11

Past use of PT: electrons @ 100nA, 0.36 W are deposited in target: 10 times more than from the photon flux generated by 1 μA on a 10% radiator!

If cooling power was only issue we could put 8–10 μA on radiator to illuminate the PT: target would operate “normally”.

4.2*10^11
Fluka Work

- Cylinder core: R=5cm, L=20cm (HD17)
- Dump box: 30cm x 30cm x 40cm (Lead)
- The core is aligned to the back face of the dump, therefore there is 20 cm entrance space inside lead box
- Concrete shielding box: 2m x 2m x 2m, with entrance tunnel – 80 cm

Pivot -1400 cm

4 weeks of 3uA beam @ 8.8 GeV

Pivot 1400 cm

4 weeks of 3uA beam @ 8.8 GeV

Activated Dose Rate After 1-hour Decay

- no shielding upstream of entrance
Fluka Work, previously

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4 weeks of 3uA beam @ 8.8 GeV
Work in progress since NPS meeting and continuing over next 4 months

- Shielding around absorber/collimator guided by PREX/CREX
- Alternative shielding configurations for the dump
- Modify dump core following JLAB tuneup dump (120kW) design
- Incorporate dipole into Fluka, dump into Geant4
  - Hope to have both Geant4 and Fluka models at some point
  - Cross check
- Other tasks as exposed by discovery ...
Aluminum cylinder core: 
R=12cm, L=100cm, drilled by 50cm deep as entrance, entrance radius=8cm

Copper shell and back stop:  
8cm thick in side and 35cm thick in back

Tungsten coat: 15cm thick in sides and 15 cm in back

Shielding: 2.4mx2.4mx3.2m concrete box then 40 cm thick borated plastic wall

Sliding door: 2mx2mx1m concrete
Upgraded Tune up Dump, Top View

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Shift the door horizontally (right) by 20cm when
the beam is off to block the dump entrance
Upgraded Tune up Dump, Top View

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Shift the door horizontally (right) by 20cm when the beam is off to block the dump entrance
Dipole + Collimator + Dump

40 cm collimator box + 100 cm tungsten pipe
Collimator shielding: 100 cm concrete + 100 cm borated plastic

All details in Jixie Zhang’s talk tomorrow
To examine/study

- Shorter, higher field dipole
  - super ferric?
  - superconducting?
- allows dipole to move closer to pivot
- Fewer photons lost in collimation
- Optimize location of 2T dipole – could be moved closer
- Optimize tradeoff between radiator thickness, photon yield and radiation at collimator/absorber and local dump

Many details in Jixie Zhang’s talk tomorrow
Preliminary Conclusions
Split Function Photon Source

• Provides intense photon beam with sufficient spatial resolution

• Neither collimator nor local dump present extraordinary challenges

• We invite open collaboration with no preconditions

What do we want?
Extra
Beam Pipe

L = 1 m  L = 5.5 m  L = 5.5 m  L = 4.94 m
R = 7 cm  R = 9 cm  R = 12.5 cm  R = 17.5 cm

Thickness = 1 cm
Material = Al
Center Location : X = 0
Y = -1479.4 mm
Z = 4719.7 mm
Photon spot at target

Important to have small spot to preserve inherent resolution of NPS
Poor knowledge of xbeam, ybeam leads to smearing in photon arm
HMS has very good momentum resolution
1mm offset in vertical leads to a shift of 0.1% in $\Delta p$
1mm offset in horizontal leads to 1mr shift in the proton in-plane angle
Through jacobian, shift in photon arm angle $d\theta_y/d\Delta x_{beam} = 1.3$; $d\theta_y/d\Delta p = 1.3$
Smearing at NPS at 2 m = .26 cm

With energy cut and cut on 2mm spot
Photon Spread: With Collimator hole 1.0mm (Fixed collimator size)

With No Cut

With Energy Cut

10%
Photon Spread: With Collimator hole 0.7mm (Fixed collimator size)

With No Cut

With Energy Cut

10%
How the beam spot look like at target for 0.7 mm collimator