Design of a Compact Photon Source for Compton Scattering from Solid Polarized Targets

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Introduction

Time permitting, I shall talk about...

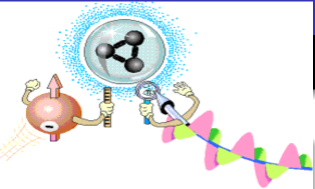
- electromagnetic probes in nuclear/particle physics
- Brief history of photon sources
- CPS concept.
- CPS design & engineering.
- Outlook

Disclaimer:

This is just GN's $0.02 worth...

- Many people contributed (directly or indirectly) to this talk (collab. from CUA, Glasgow, GWU, St. Mary's, UVa, JMU, JLab).
- ...and they all have done their level best! thanks!
- Therefore, all **inaccuracies, miss-statements, controversial, or just plain wrong statements** are mine alone!
- That said, onward to the:
  Why should one want/need photon beams? question...

Electromagnetic probes...



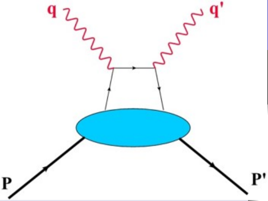
excellent for probing nuclear substructure:

- High energy, intensity, “clean”
- QED is well understood

However...

- target is not static!
- probe affects the dynamics (recoil, pair prod., relativistic eff.)
- e^- **beam**: low cross–section, radiative corrections, ...
- **photon beam**: possible alternative/complementary to e^- beams. (Avoids the problem or at least it presents a diff. perspective!)

GPD formalism holds to promise of...



"nuclear femtography":

- 3D picture of the nucleon substructure.
- use **exclusive** reactions at high mom. transfer $-t$, high s too.
- e^- and γ can/should be used over a wide range of s and $-t$ to disentangle H, $\tilde{H}$, E, $\tilde{E}$ (Compton FFs?).
- simultaneous access to all of these functions requires target polarization (ideally both long. and trans. pol. targets!)
- for the particular case of RCS: $\vec{\gamma} + \vec{p} \rightarrow \gamma + p$

$$\frac{d\sigma}{dt} = \frac{d\sigma}{dt}_{KN} \left(\frac{1}{2} \left[R_V^2 + \frac{-t}{4m^2} R_T^2 + R_A^2 \right] - \frac{us}{s^2 + u^2} \left[R_V^2 + \frac{-t}{4m^2} R_T^2 - R_A^2 \right] \right)$$

...

$$R_V(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} H^a(x,0,t)$$

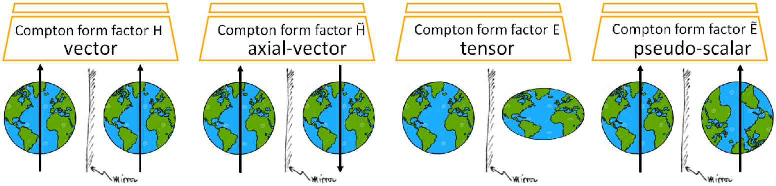
$$R_A(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} sign(x) \hat{H}^a(x,0,t)$$

$$R_T(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} E^a(x,0,t)$$

M.Diehl & P.Kroll

Looking at polarization obs.

one gets access to ratios of *Rs* and thus to (integrals of) GPDs.



Photon Sources: a lightning–quick history (I)

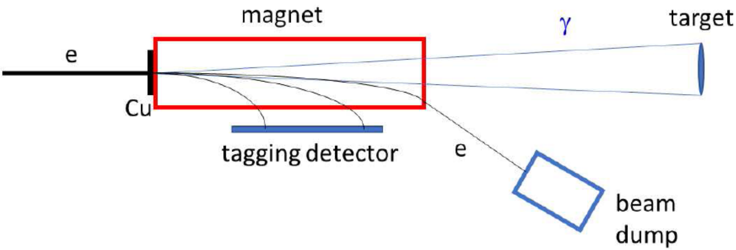
alas...

- "designer" exclusive reactions come at a price:
- competing processes/backgrounds, (very)low cross–sections.
- thus the need of developing high energy, high intensity photon beams.
- brief review of possible options follows

photon source options

- $\sim$ few MeV - radioactive isotopes
- $>$ few TeV – cosmic rays
- In-between – use bremsstrahlung radiation to "build" your own.
- For RCS work: high s and $-t$, so $\sim$10 GeV (or more) would be ideal.

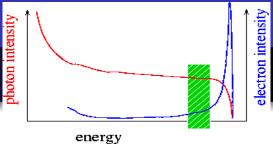
Photon sources (II)

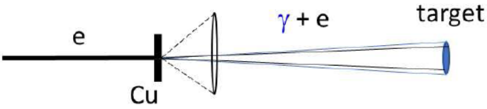


Radiator, Sweeper, (Tagger), Dump.

- early examples: DESY (1971), SLAC (1971), CEA ('72-'73)
- $s > 2GeV^2$, low t. Flux $\sim 2 \times 10^8 \gamma/s$
- Cornell (1975), flux $\sim 1.5 \times 10^{10} \gamma/s$.
- Bauer-Spital-Yennie review, RMP 50 (1978)
- If tagging, usable flux much lower ($\sim 10^{7-8} \gamma/s$).

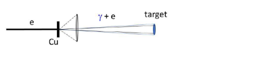
Photon sources (III)



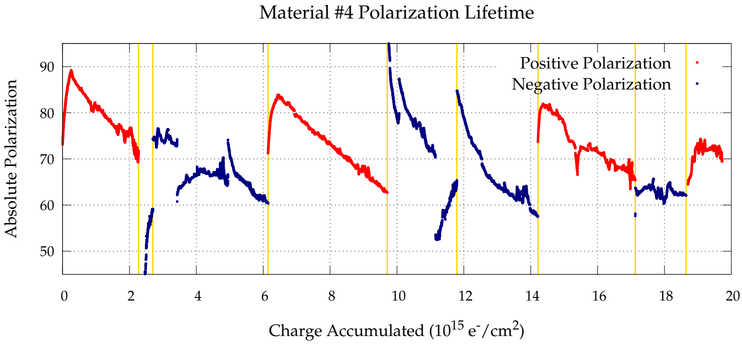


Mixed e^-/γ beams.

- JLab (2002, 2008). Flux $\sim 2 \times 10^{13} \gamma/s$!
- competing reactions: π^0 photoproduction, $e - p$ elastic.
- difficult analysis (low cross-section, solid angle).
- low efficiency & analyzing power of the proton polarimetry
- if polarized target - luminosity much lower.
- ...and for awhile this was the "state-of-the-art" in the field!



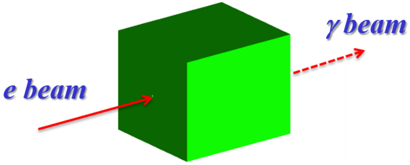
Photon sources (IV)



SANE exp. (J. Maxwell Ph.D. Thesis)

- mixed e/γ beam + pol. target = lots of problems
- frequent annealing needed. change of material as well.

Compact Photon Source Concept

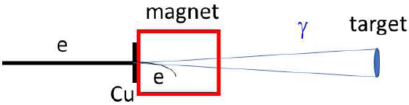


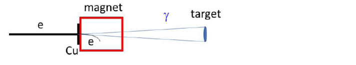
CPS.

- Incident beam: small trans. size
- Outgoing γ beam: m/E angular size
- Source could be hermetic!!!

...

- What to do w/ the electron beam?
- Traditional approaches - **NO!**
- no hermeticity, large, $$$.
- Idea: Use the magnet as a dump, *ergo*, problem is solved!
- Can this be done?

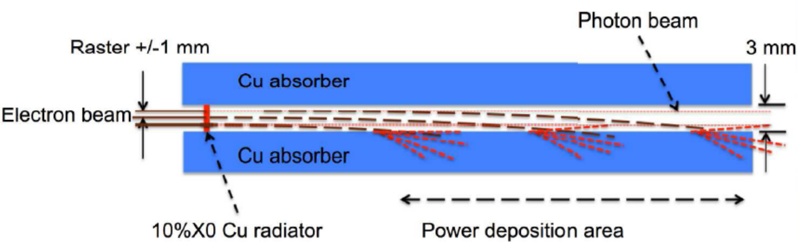




CPS Central piece

...

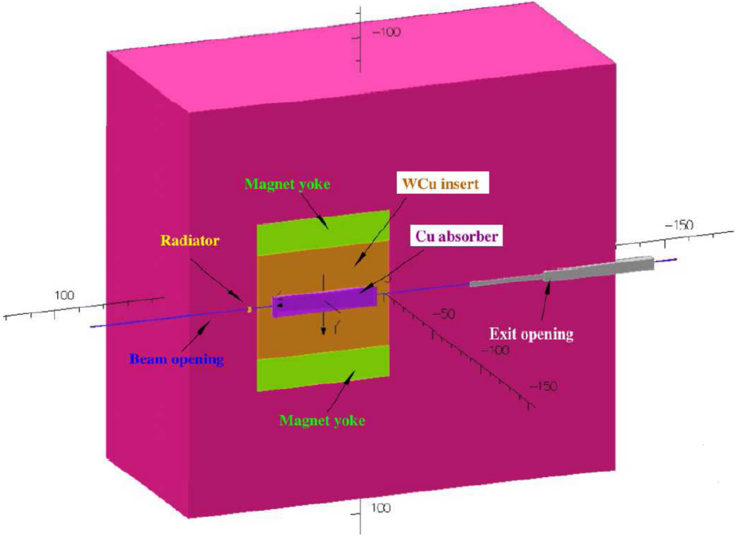
Deflect, degrade, (begin to) dispose of residual e^- beam



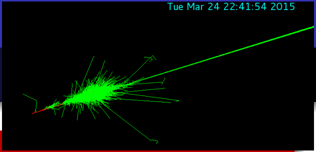
For the current (09/2019 design) ...

- Radius R for 11 GeV e^- $\sim$10 m
- For 0.3 cm channel power deposition area 17 $\pm$ 12 cm
- Total field integral: $\sim$1000 kG-cm. 50 cm iron dominated magnet.

Compact Photon Source



CPS Q&A:



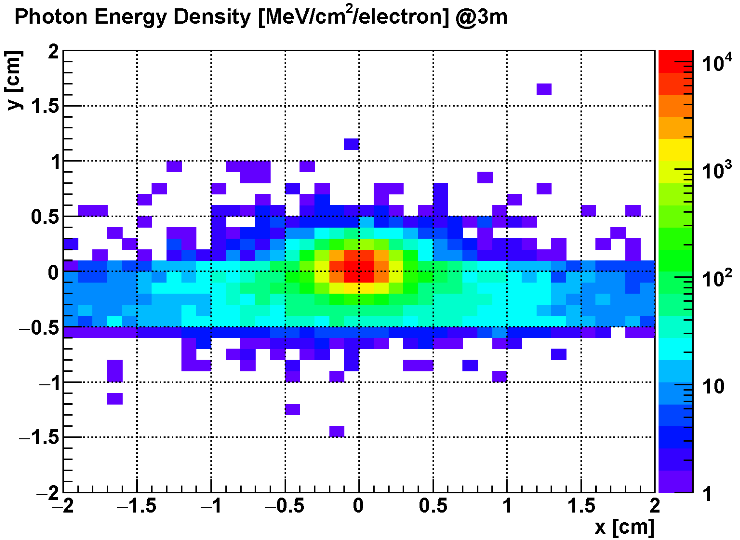
CPS Questions

- How will the γ beam look like?
- Will the central piece melt? How hot will it get?
- Is the shielding adequate? How about activation?
- How heavy, co$tly will this thing be?
- Is fabricating such device possible?

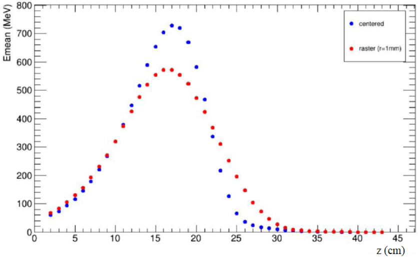
CPS development tools

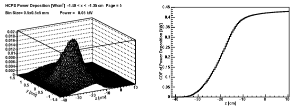
- OPERA (magnet)
- Geant 4 (γ beam profile, prompt radiation, power deposition)
- Fluka (prompt and activation calculations)
- ROOT/C++, Python.

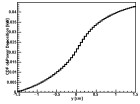
Beam Profile



Central Piece Power Dissipation





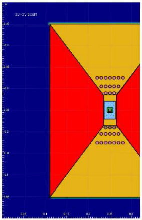


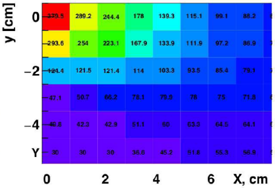
CP Power

- Study CP power deposition.
- Position, extent, amount.

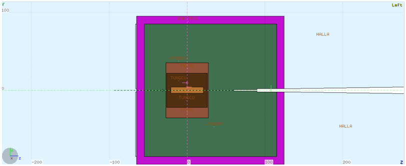
...

- Focus on the z region w/ the most energy deposited.
- Heat transport simulation.
- ... w/ various cooling options.
- **Hot but VERY FAR from melting!**

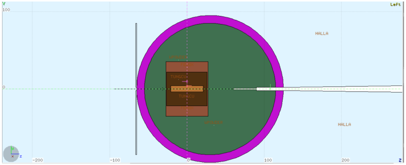




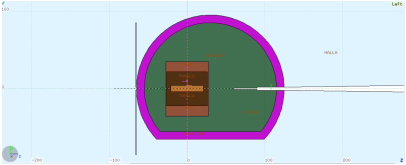
CPS Shielding Configurations:



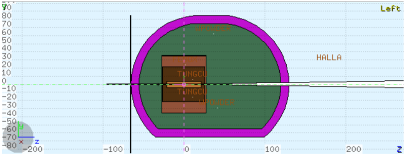
01 - Square shielding. Offset.



02 - Spherical shielding.



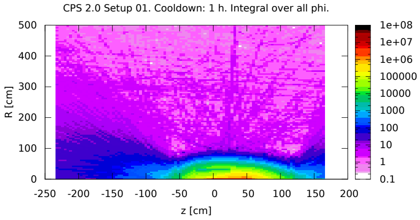
03 - Cut Spherical shielding.

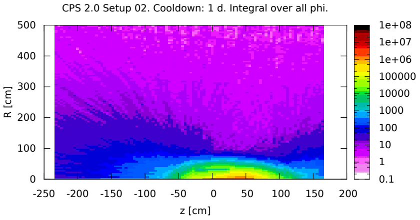


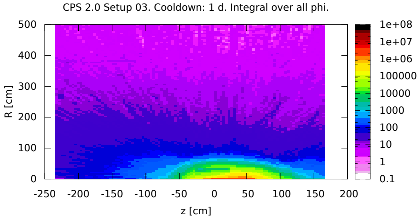
04 - Cut "egg-shape".

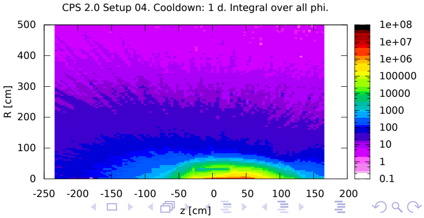
NOTE: Figures not to scale! Powder *W* volume is reduced: $4.8\ m^3$, $2.2\ m^3$, ... $1.8\ m^3$.

Rad. level [mrem/h] after 1 day cooling. (1 h, 7d & 30 d. avail.)

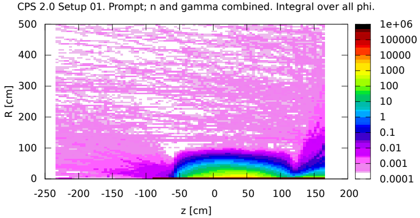


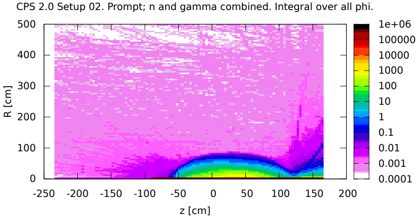


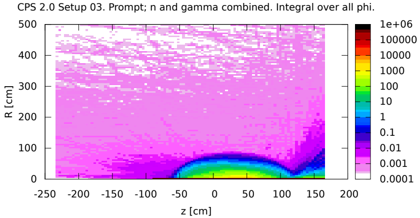


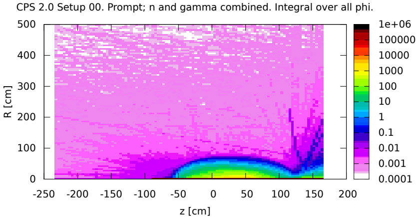


Prompt radiation level. n & γ combined





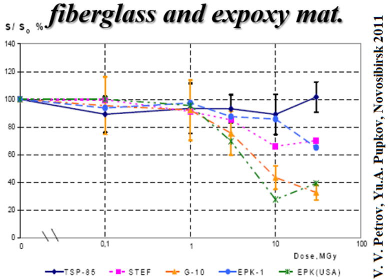


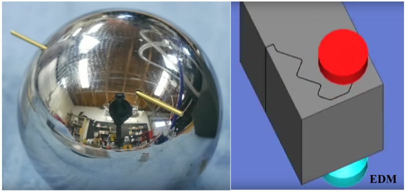


Identify materials, techniques, expertise

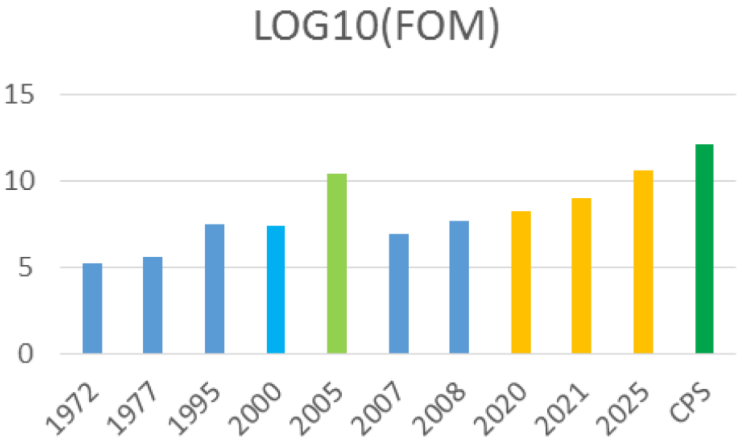
Can it be built?

- Expertise in building/operating magnetic systems in high rad. env. exists (ORNL, J-PARC)
- Identify rad. hard materials for magnet building
- Potential vendors* for W- powder, $W - Cu$ alloy, etc.
- Study/identify technique for CP machining.

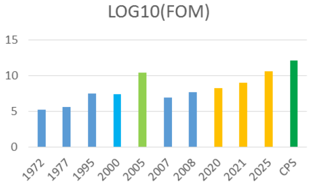




High energy photon sources, past/present/future



Outlook



Hopefully I convinced you that CPS is...

- a novel technique for producing untagged γ beams (JLab).
- well matched w/ the UVa polarized target & Hall C/A setups.
- $\times$ **30 FOM** improvement over current and projected setups!
- relatively low cost; concept adaptable to other areas.

Thank you!