# Compact Photon Source

- Developments since PAC44
  - High-Intensity Photon Workshop
  - Working Group Activities
- Compact Photon Source – General Concept and Implementations
- CPS Feasibility Studies
  - Radiation Calculation Benchmarking
  - Prompt Radiation and Dose Rate Calculations
  - Engineering Aspects
- Similarity of CPS Concept for Halls A/C and KL/Hall D
- Engineering Concepts
- Summary

# Timeline

- **PAC43 on PR12-15-003**

  *“The PAC is impressed by the concept for a new photon source. It strongly encourages the proponents to work with the members of the previously approved E12-14-006 in order to see whether it could be possible be incorporated here.“*

- **PAC 44 on PR12-16-009**

  *“We recommend that the laboratory provide resources for a workshop focused on developing  the physics case, as well as an optimized compact photon source and beam dump, organized jointly by the spokespersons of the PR12-16-009, PR12-15-003, and E12-14-006 proposals.“*

- **New Opportunities with High-Intensity Photon Sources workshop**

  *6-7 February 2017 @ Catholic University of America*

  *Organizers: T. Horn, C. Keppel, C. Munoz-Camacho and I. Strakovsky*

  *All spokespersons of E12-14-006, PR12-15-003 and PR12-16-009, and also the spokespersons of PR12-17-001 (Hall D KL beam effort) actively involved.*

  *HIPS conclusion: Lab will set up a meeting with interested groups to fix goals and timeline to benchmark and finalize Compact Photon Source concept*

# New Opportunities with High-Intensity Photon Sources Workshop


*6-7 February 2017*
High-Intensity Photon Sources Workshop (CUA)

The Catholic University of America

https://www.jlab.org/conferences/HIPS2017/

**Workshop on High-Intensity Photon Sources (HIPS2017) Mini-Proceedings**

6th - 7th February, 2017 Catholic University of America, Washington , DC, U.S.A.

S. Ali, L. Allison, M. Amaryan, R. Beminiwattha, A. Camsonne, M. Carmignotto, D. Day, P. Degtiarenko, D. Dutta, R. Ent, J. L. Goity, D. Hamilton, O. Hen, T. Horn, C. Hyde, G. Kalicy, D. Keller, C. Keppel, C. Kim, E. Kinney, P. Kroll, S. Liuti, M. Mai, A. Mkrtchyan, H. Mkrtchyan, C. Munoz-Camacho, J. Napolitano, G. Niculescu, M. Patsyuk, G. Perera, H. Rashad, J. Roche, M. Sargsian, S. Sirca, I. Strakovsky, M. Strikman, V. Tadevosyan, R. Trotta, R. Uniyal, A.H. Vargas, B. Wojtsekhowski, , and J. Zhang

**Editors**: T. Horn, C. Keppel, C. Munoz-Camacho, and I. Strakovsky

# Goal of HIPS 2017

**“This workshop aims at producing an optimized photon source concept with potential increase of scientific output at Jefferson Lab, and at refining the science for hadron physics experiments benefitting from such a high-intensity photon source. The workshop is dedicated to bringing together the communities directly using such sources for photo-production experiments, or for conversion into $K_L$ beams.** The combination of high precision calorimetry and high intensity photon sources can provide greatly enhances scientific benefit to (deep) exclusive processes like wide-angle and time-like Compton scattering. Potential prospects of such a high-intensity source with modern polarized targets will also be discussed. The availability of $K_L$ beams would open new avenues for hadron spectroscopy, for example for the investigation of "missing" hyperon resonances, with potential impact on QCD thermodynamics and on freeze-out both in heavy ion collisions and in the early universe.”

***Optimization of photon source concept – largely driven by Wide Angle Compton Scattering***

# Science Gain with a CPS: FOM

Impact of a high intensity photon source for hadron physics at JLab:

- WACS must reach several $GeV^2$ in s, t, and u, but since the WACS rates drop with $\sim 1/s^{7.5}$ this science needs a luminosity boost.
- The KL project is based on a 5 kW photon intensity (>100 times above the 15 W design level for the Hall D beam line) to do "prime physics with a secondary beam".

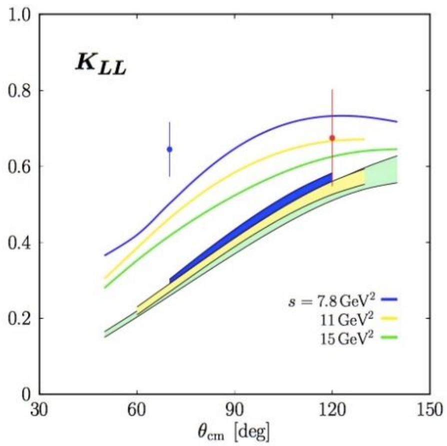
Impact of the photon source for WACS:

- The heat/radiation load is a limiting factor for luminosity with the polarized target. The target can take 20 times more photons than electrons.
- **The experiment productivity is improved even more (30 times)** due to higher target polarization averaged over the experiment, and reduced overhead time for the target annealing procedure.

Impact of the photon source for the KL project:

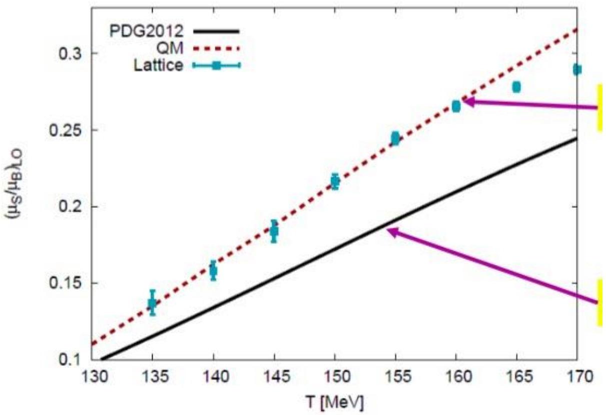
- The hermetic CPS concept allows **2 decades increase** of the beam intensity in the existing photon Tagger Area without major rebuilding of the facility.

# Multiple Science Opportunities With CPS (and NPS)




**Wide Angle Compton Scattering (PAC45)**
($K_{LL}$, $A_{LL}$, $K_{LS}$, $A_{LS,..}$)

**Hadron Spectroscopy with secondary $K_L$ beam (PAC45)**
Cross sections and polarization of $\Lambda$, $\Sigma$, $\Xi$, $\Omega$ hyperons




measured yields of different hadron species in heavy ion collisions

***Additional Science Topics under study***

- ❑ WACS exclusive photoproduction
- ❑ Timelike Compton Scattering
- ❑ Short Range Correlations
- ❑ Photoproduction of Few Body Systems
- ❑ *Also: Missing mesons, Phi production,…*

# Follow-up – Compact Photon Source Working Group

*HIPS conclusion: Lab will set up a meeting with interested groups to fix goals and timeline to benchmark and finalize Compact Photon Source concept*

- **Working group established composed of Hall A/C Leader, NPS spokesperson, Physics AD, RadCon, and 2-3 members each from Hall A and Hall C WACS efforts, and Hall D KL effort.**

  *T. Keppel, T. Horn, R. Ent, P. Degtiarenko, D. Day, D. Keller, J. Zhang, G. Niculescu, B. Wojtsekowski, I. Strakovsky (and D. Hamilton in last meetings)*

- **Working Group Meetings on CPS**
  - **March 28:** **Organizational meeting, define benchmark simulation input**
  - **April 20:** **Benchmark radiation/activation results with toy CPS models**
  - **May 11:** **Followup radiation/activation simulations, power deposition estimates**
  - **May 18:** **Converged common CPS concept presented at NPS meeting, letter sent to Bob McKeown**

*These meetings led to a common CPS concept, with many similarities be it in Halls A/C for WACS or in Hall D for the KL beam*

# Compact Photon Source (CPS) – Concept

- Strong magnet after radiator deflects exiting electrons
- Long-bore collimator lets photon beam through
- No need in tagging photons, so the design could be compact, as opposed to a Tagger Magnet concept
- The magnet itself is the electron beam dump
- Water-cooled Copper core for better heat dissipation
- Hermetic shielding all around and close to the source to limit prompt radiation and activation
- High Z and high density material for bulk shielding
- Borated Poly outer layer for slowing, thermalizing, and absorbing fast neutrons still exiting the bulk shielding

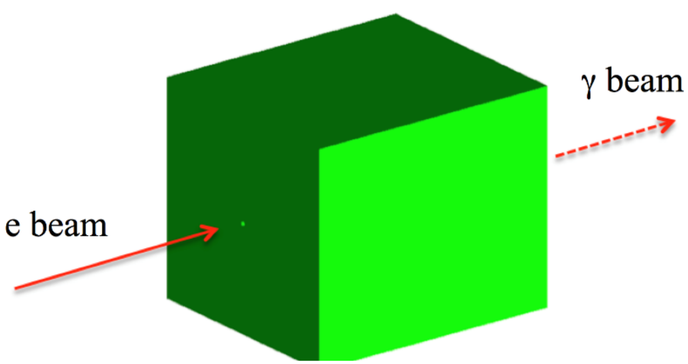
# General design concept CPS

*(Polarized Wide-Angle Compton Scattering as Example)*

- Beam intensity is the key at high *s* & *t*: need $dN/dE_\gamma$ ~ few * $10^{12}$ equivalent quanta/s
- It is critically important to have
  a) a small beam spot at target (~1 mm, for background suppression)
  b) low radiation at detectors (it sets a practical limit in many expts).
  Use of a collimator is not effective because of loss of beam intensity.
  A better solution is to ensure a short distance between the radiator and the target.

A. The short-distance requirement for an 11 GeV beam energy is solved by means of use of a 2 Tesla, one meter long magnet – It tolerates a high radiation level.

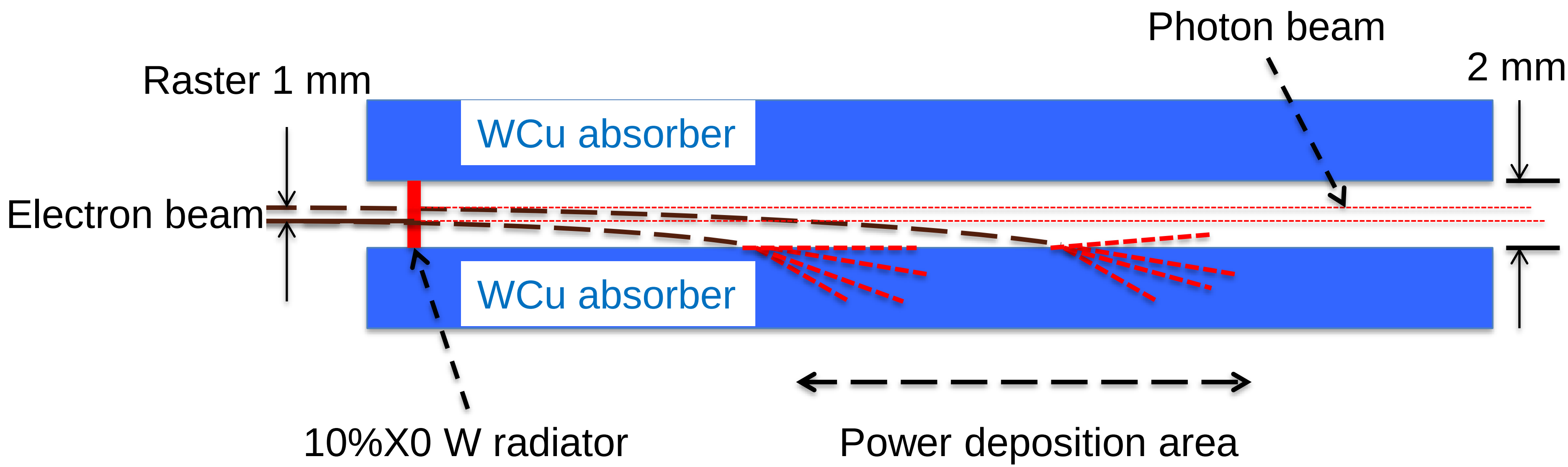
B. Key item of a photon source is a beam dump. The solution is a hermetic box (HCPS) which results in low radiation outside.



2.6 m x 2.5 m x 2.5 m structure

The openings for the incident electron beam and produced photon beam are very narrow compared with the box size.

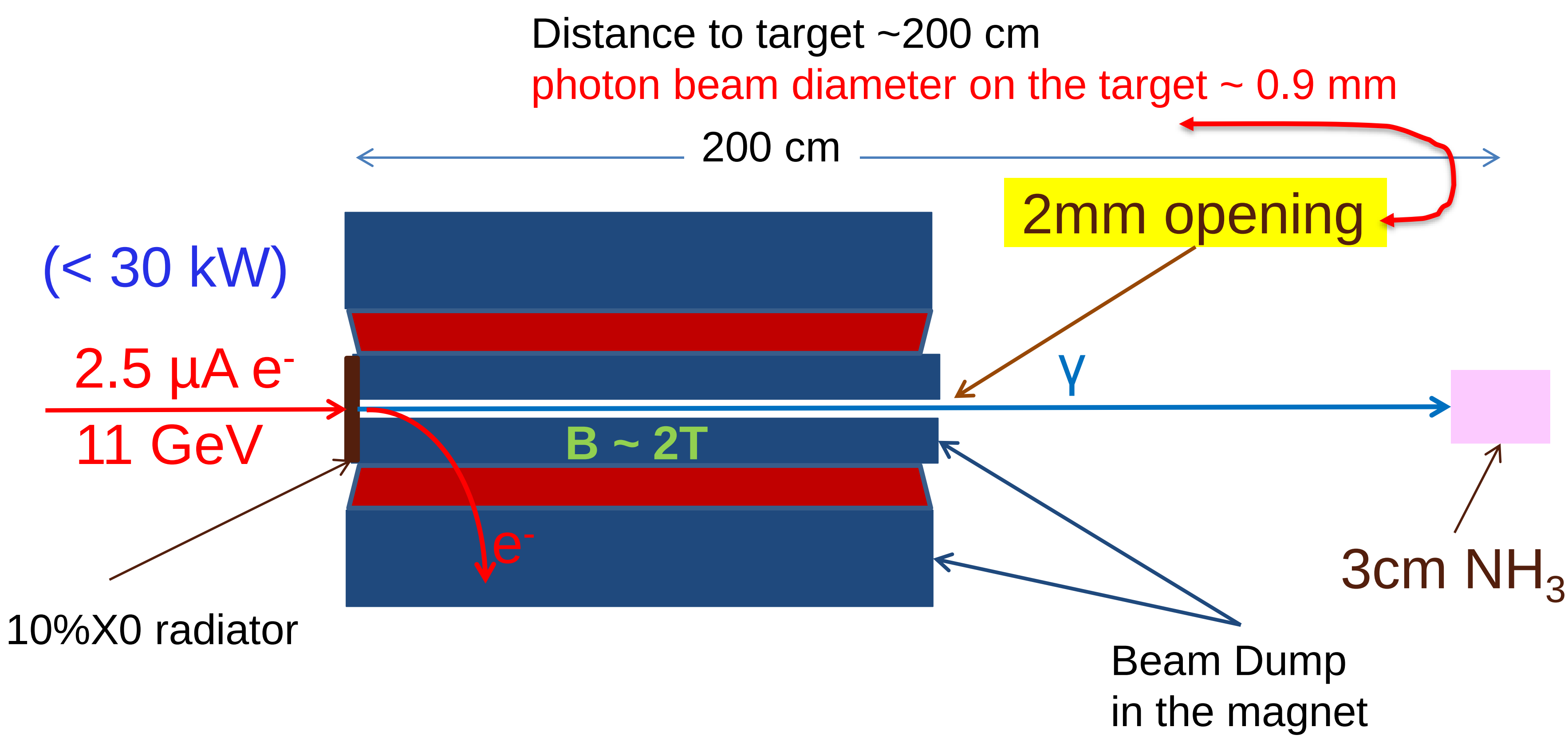
# General design concept Hermetic CPS




- Key problem of a beam dump is high power density in an absorber. The solution is a small impact angle with a small (1 mm) raster in a narrow channel (2 mm).

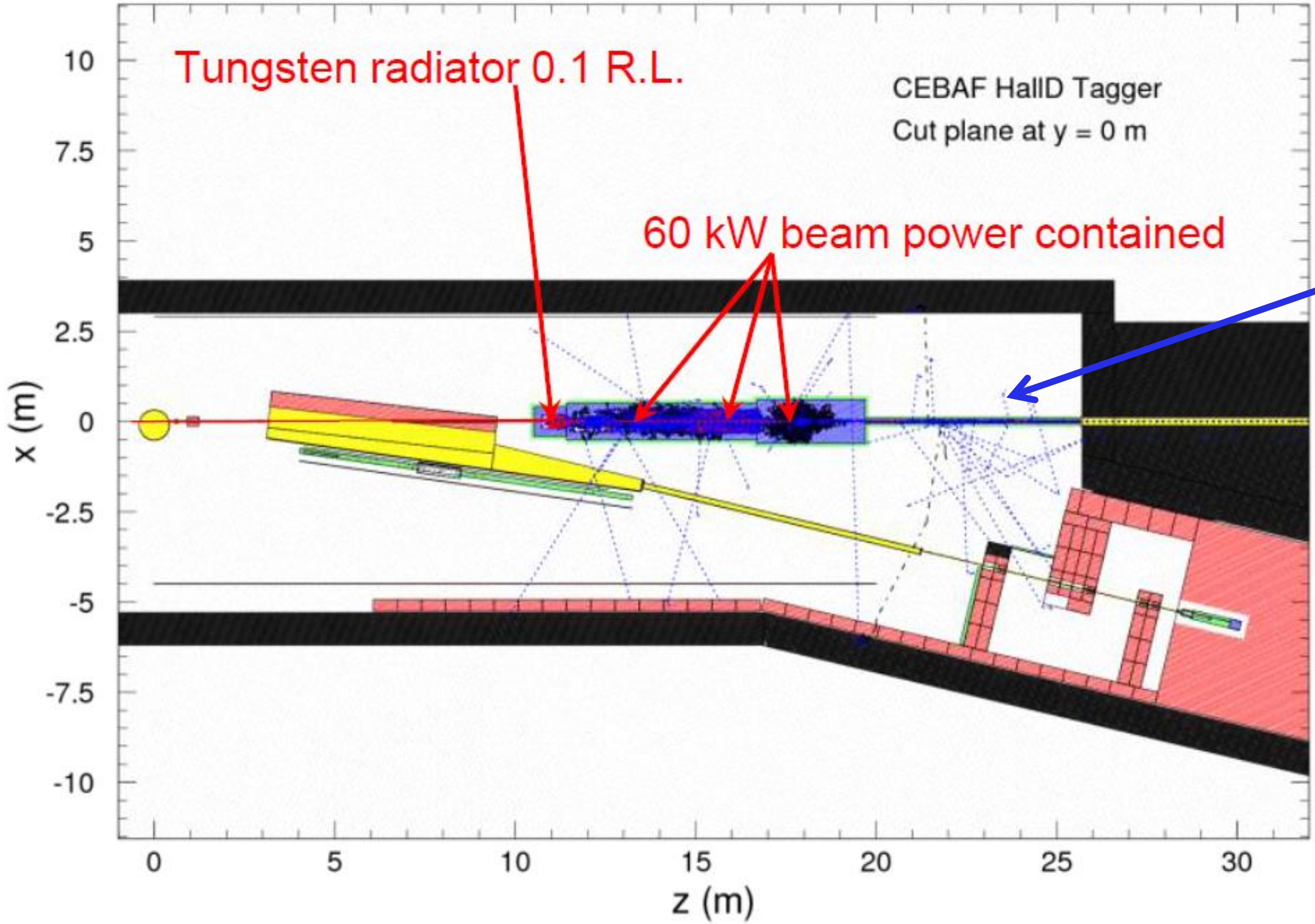
- A 30 kW configuration was proven via G4 and heat dissipation calculations. Larger space available in the Hall D/KL project application (and modest horizontal raster) will allow twice higher beam power (60 kW).

# (Hermetic) CPS – Halls A/C Implementation




**Novel concept allows high photon intensity and low radiation in the hall**

# KL beam Photon Source – Hall D Implementation

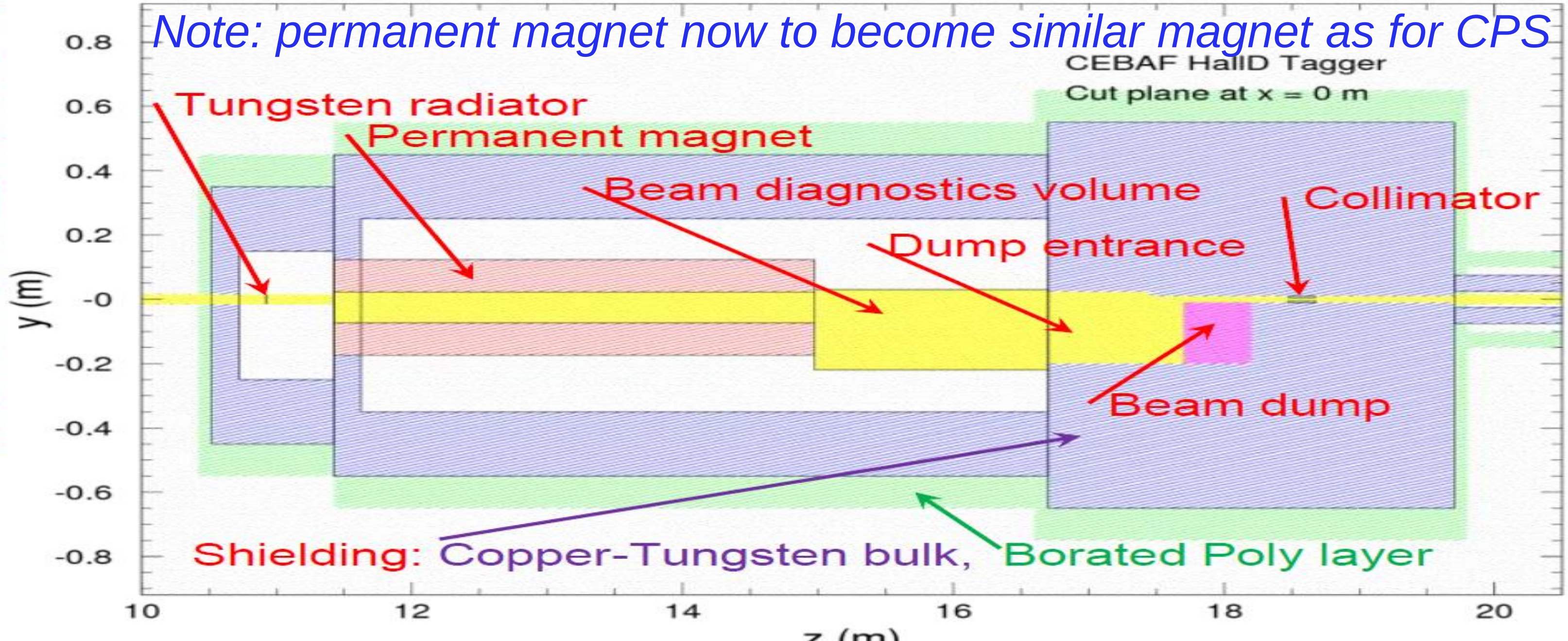



Permanent magnet here for beam protection system

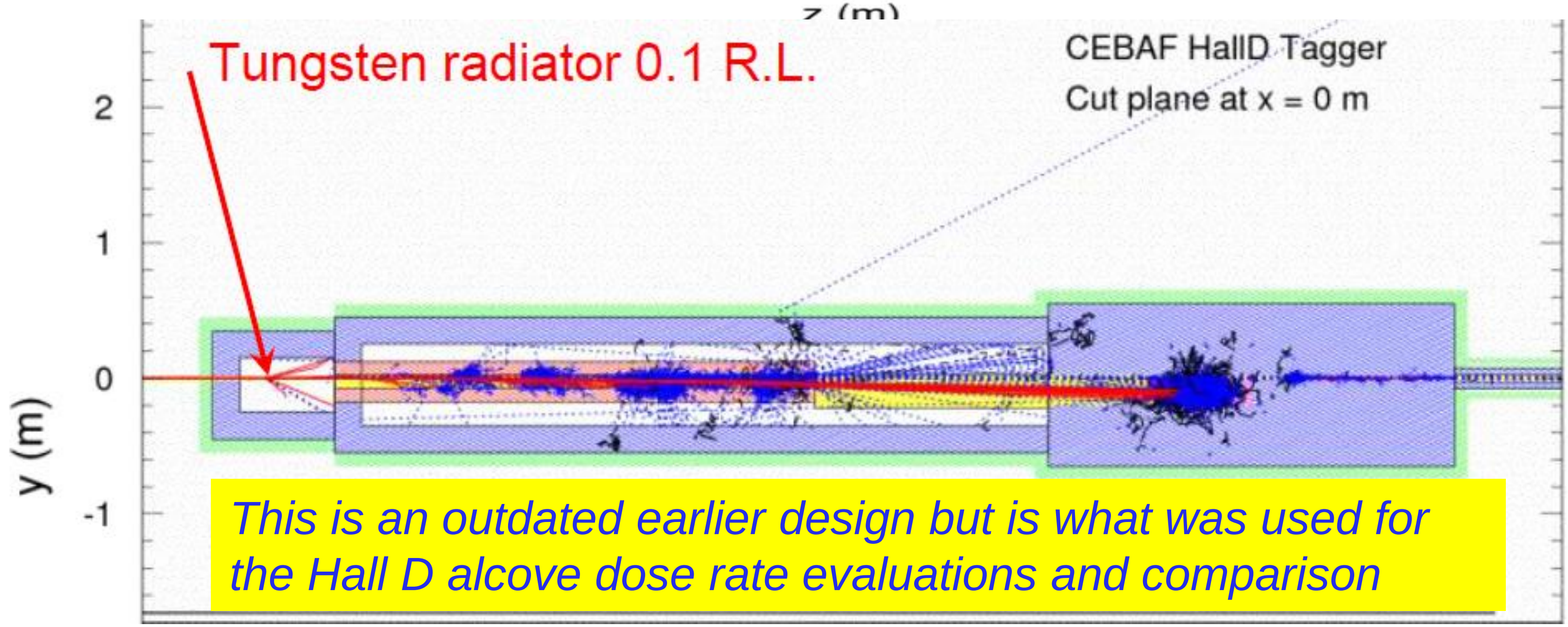
**Compact Photon Source Concept similar – but use more space (longer magnet and more shielding potential) to achieve 60 kW beam power**

# KL beam Photon Source – Earlier Design

*Note: permanent magnet now to become similar magnet as for CPS*



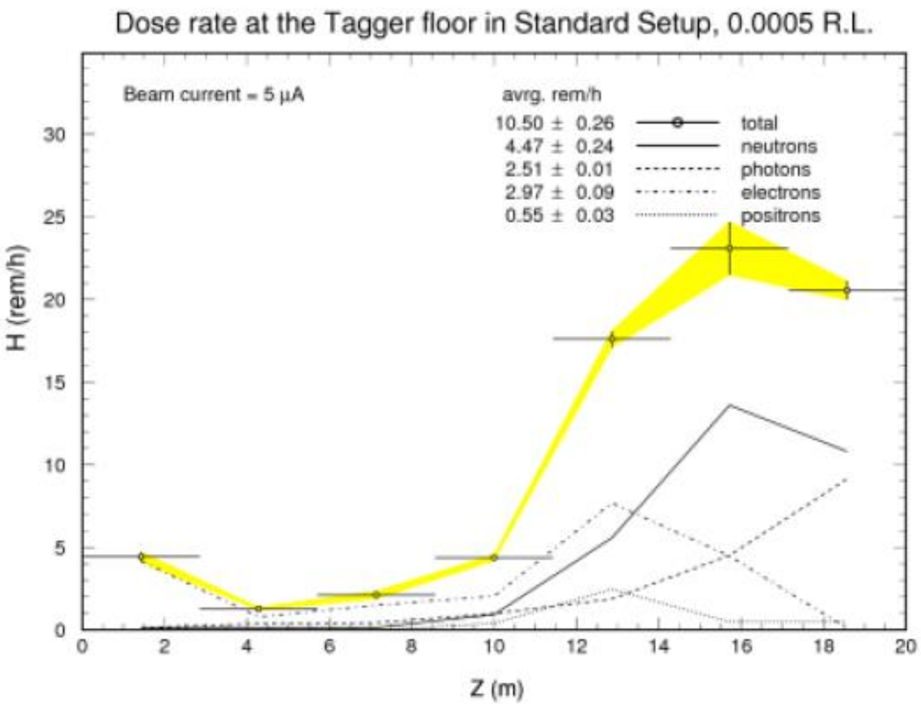

Still need permanent magnet here for beam protection system



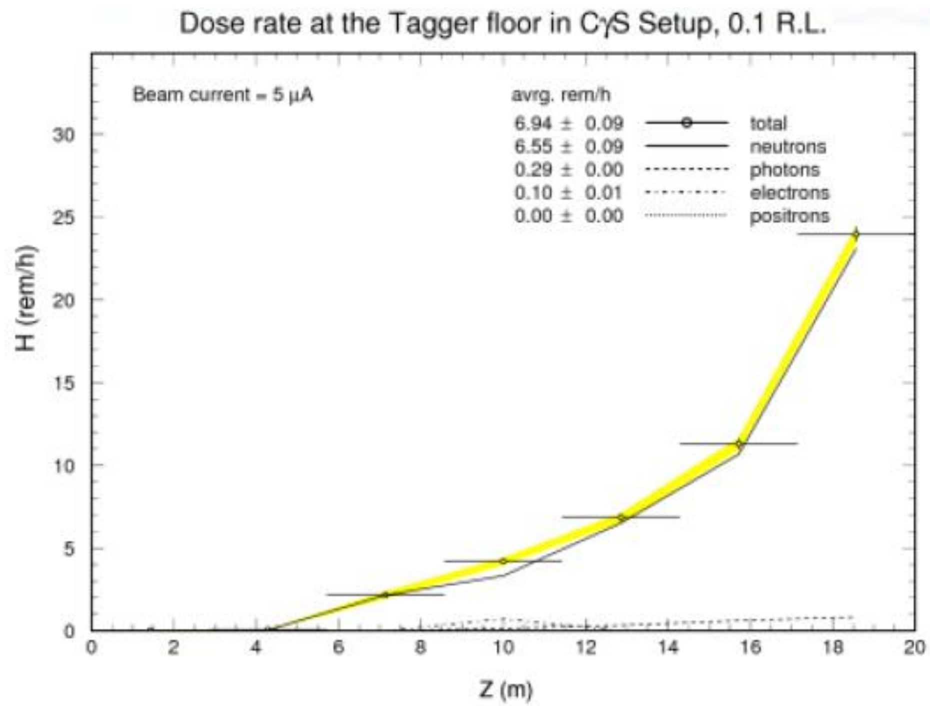

*This is an outdated earlier design but is what was used for the Hall D alcove dose rate evaluations and comparison*

# Dose Rate Evaluation and Comparison

Hall D with Tagger Magnet, <5 μA and 0.0005X0

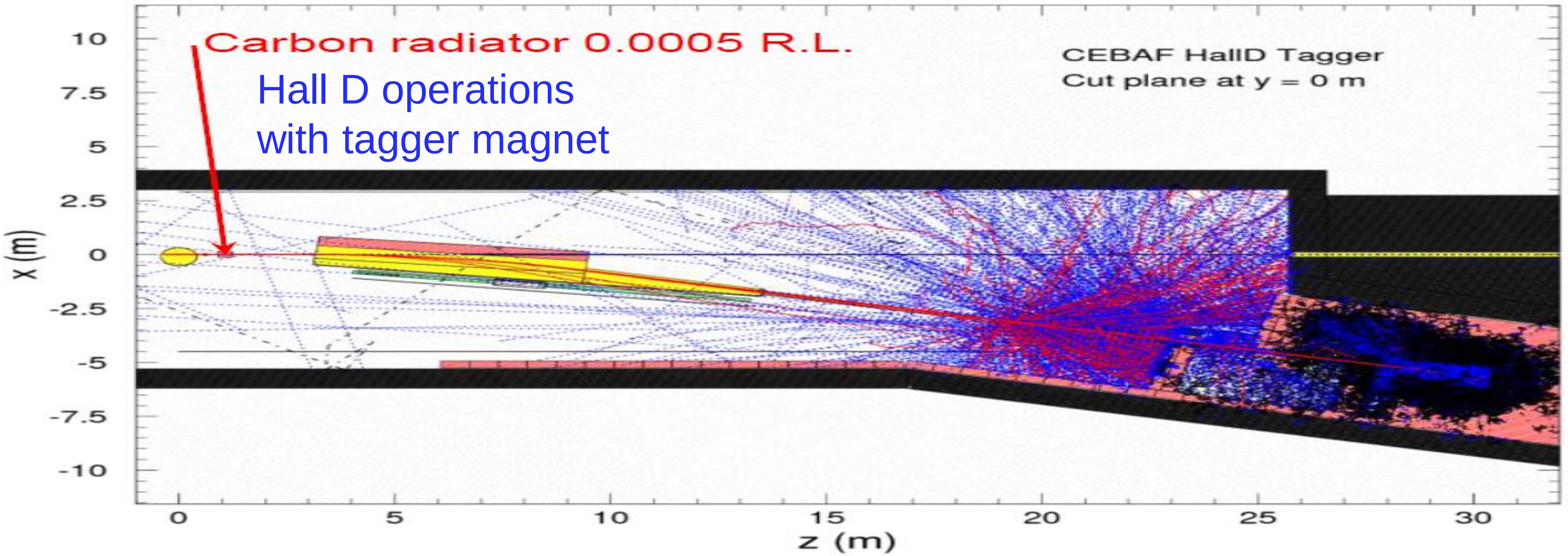


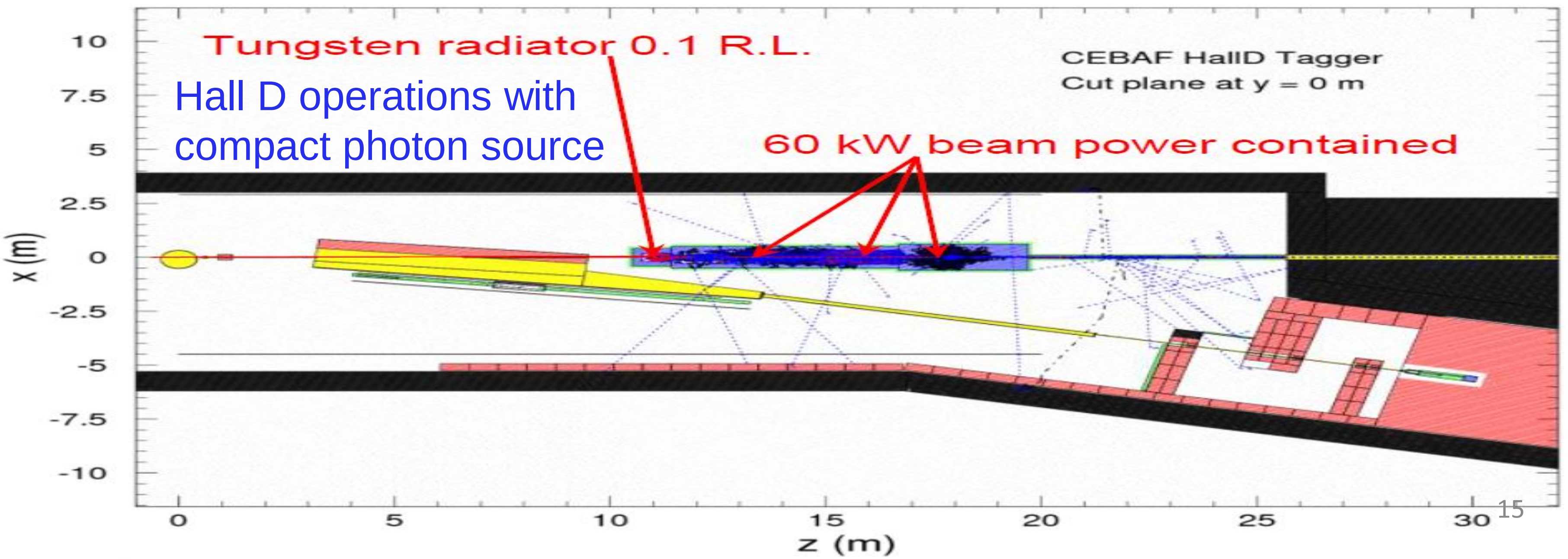

Hall D with CPS, <5 μA and 0.10X0




- Even though for the KL beam/CPS setup a 10% r.l. radiator is used, compared to only a 0.05% r.l. for the default Hall D operations, the **generated dose rates are similar**.
- The reason is because the radiation spectral composition is different. The hermetic and high-Z shielding close to the source of radiation removes the photons, electrons and positrons, and leaves mostly the high-energy neutrons. Thus, the activation levels will be similarly less.

# Comparison – GEANT3 with 2000 Electrons



# Feasibility Studies of the CPS by radiation calculation benchmarking Studies

❑ Goal of the Compact Photon Source (CPS): high energy photon beams

- Beam energies up to 11.5 GeV
- Up to 30kW electron beams (current 2.6uA)
- Runtime: 1000 hours
- Photon source as close to target as possible

❑ Parameters for feasibility studies and minimal set of requirements

- Prompt dose rates in the hall: < several rem/hr at 10m from the device
- Activation dose rates outside the device envelope at 1 ft distance: < several mrem/h after one hour following the end of a 1000 hour run
- Prompt dose rates at the CEBAF site boundary <1μrem/hr (2.4μrem/hr corresponds to a typical experiment not requiring extra shielding) during run

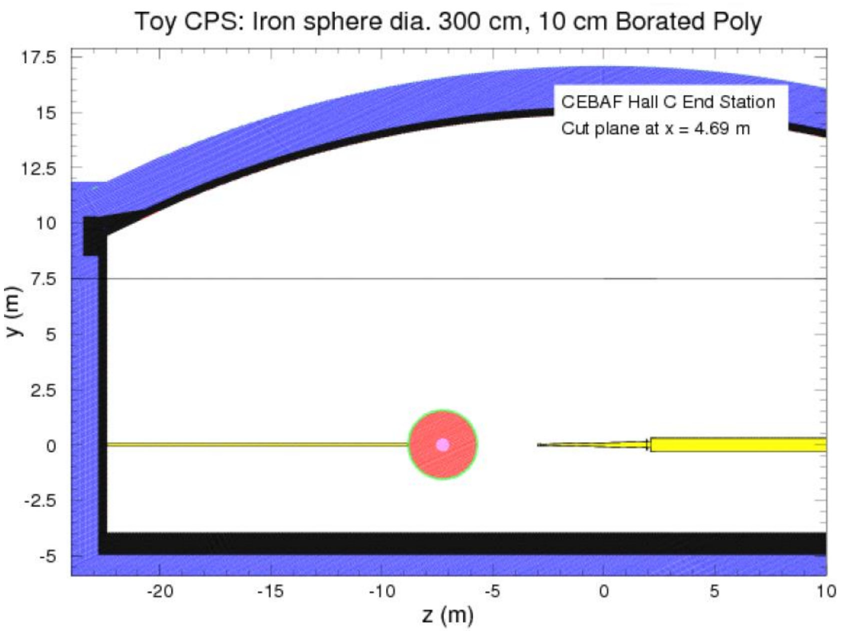
❑ Benchmarking of simulation models

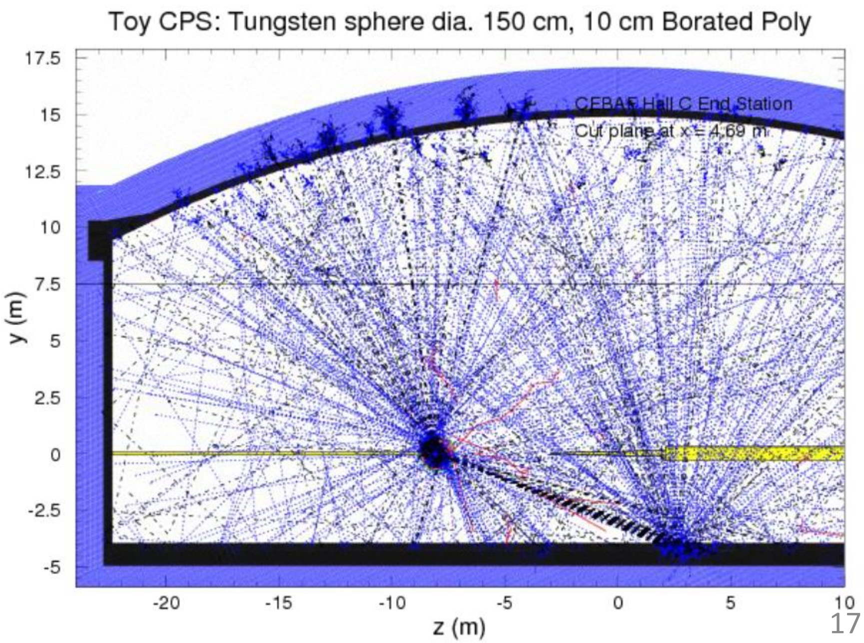
- GEANT3/DINREG – prompt dose rates, site boundary (official)
- FLUKA – dose rates and activation
- MCNP – prompt dose rates
- GEANT4 – prompt dose rates, site boundary

# CPS Toy Model for Benchmarking

- Geometries – for beam energy 11.5 GeV and 30kW electron beam
  - Iron 7.8 g/cm3, 300cm diameter sphere, 30 cm upstream from center
  - Tungsten powder 15.6 g/cm3, 150cm diameter sphere, 15 cm upstream from center

- Shielding: 10 cm layer of standard borated polyethylene (5% Boron by weight) surrounding the spheres to help thermalize and absorb low energy neutrons



# CPS Toy Model: Comparison of Prompt Dose Rates

- Integrated prompt dose rates (rem/h) measured at points 90 degrees around spheres and at 3 m radial distance from the beam line

| Material | Source | No boron | No boron | No boron | No boron | No boron | With 10cm Boron | With 10cm Boron | With 10cm Boron |
|---|---|---|---|---|---|---|---|---|---|
| Model | | DINREG GEANT3 | FLUKA (5 MeV $E_\gamma$ cut) | MCNP6 | FLUKA (7MeV $E_\gamma$ cut) | GEANT4 | DINREG GEANT3 | FLUKA (5 MeV $E_\gamma$ cut) | GEANT4 |
| Iron | neutron | 146 | 10.0 +-0.1% | 11.5+-6% | 9.5+-0.39% | 123.2 | 0.8 | 0.11+-3.4% | 0.28 |
| Iron | $\gamma$ | 0.44 | 0.039 +-0.6% | 0.16+-29% | 0.025+-0.9% | 0.56 | 2.8 | 0.063+-0.7% | 0.56 |
| Tungsten Powder | neutron | 13.0 | 9.37+-0.9% | 4.4+-11% | N/A | 6.34 | 2.7 | 0.52+-15.3% | 1.76 |
| Tungsten Powder | $\gamma$ | 0.06 | 0.001+-10.3% | 0.0002 | N/A | 0.33 | 0.003 | 0.0052+-8.3% | 1.28 |

# CPS Toy Model: Summary and Conclusions

- Results from MCNP6, FLUKA and GEANT differ in order of magnitude for neutrons and a factor of 2-3 for photons
  - This difference is expected due to model ingredients, but all agree that radiation is constrained

- All results show that iron produces more low energy neutrons compared to W

- GEANT3 and 4 agree in order of magnitude for both neutrons and photons

Overall results suggest that a high-intensity photon source design is possible that satisfies both the requirements in the hall (people working on pivot) and outside (site boundary condition). Materials still need to be optimized

# Hermetic CPS – Radiation Calculations

Radiation calculation tasks to evaluate the feasibility of the Compact Photon Source for Halls A & C or for the KL beam facility in Hall D:

- Dose rates at the CEBAF boundary – radiation budget
- Prompt radiation dose rates in the Hall and/or the Hall D Tagger Vault
- Activation dose rates around the setups after the run – we have taken one hour as "typical" for access to equipment reasons

# CPS – Dose Rates at the Boundary

## Hall D/CPS for KL beam:

- Design compatible with the site boundary as the conditions for regular tagger magnet running dumps 60 kW in a local beam dump, and now the 60 kW is dumped in the CPS itself. **The Hall D tagger vault is designed for this (but additional local shielding may be required).**

## CPS in Hall C (or A) operation:

- Dose rate estimates in $\mu$R/hr at the RBM-3 boundary condition for the benchmark calculations (3 m iron sphere vs 1.5 m tungsten sphere)
  - iron: 0.24 $\mu$R/hr total (0.19 due to n, 0.05 due to $\gamma$)
  - W: 2.4 $\mu$R/hr total (1.9 due to n, 0.5 due to $\gamma$)
- With proper material and ordering choice of iron and W, and a (10 cm) outer layer of borated poly, **the boundary dose can likely be tuned below the 2.4 $\mu$R/hr that corresponds to a typical run not requiring additional local shielding, per the radiation budget.**

*Note: a 1000 hour experiment would give 2.4 mr, and the total annual boundary dose is typically capped at 10 mr.*

# CPS – Prompt Radiation Doses

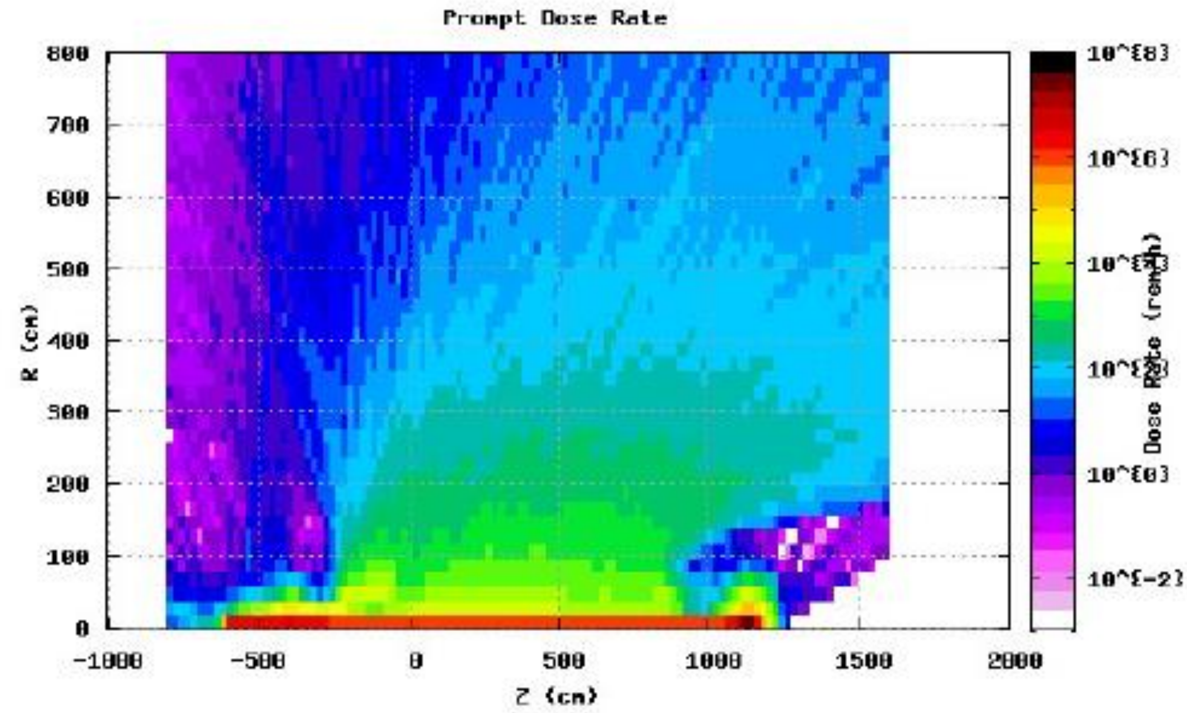
| | at 3 m from center | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pavel | | | Igor | | | Gabriel | | |
| | DINREG/GEANT3 | | | MCNP6 | | | GEANT4 | | |
| Dose Rates [rem/h] | n | g | total | n | g | total | n | g | total |
| 3m Fe | 146 | 0.44 | 146.4 | 12.5 | 0.13 | 12.63 | 123.2 | 0.56 | 123.8 |
| 3m Fe+PolyB | 0.8 | 2.8 | 3.6 | | | | 0.284 | 0.56 | 0.844 |
| 1.5m W | 13 | 0.06 | 13.1 | 4.5 | 0.03 | 4.53 | 6.34 | 0.33 | 6.67 |
| 1.5m W+PolyB | 2.7 | 0.003 | 2.7 | | | | 1.76 | 1.28 | 3.04 |

*This table is for the CPS toy model benchmark calculations*

- Must have an outer shielding layer of (10 cm) borated poly!
- In general, prompt radiation doses in the Hall (calculated here at a distance of 3 meter) become O(rem/hr), for the experiment run conditions in Hall C (or A).
- **In a more realistic configuration with 30 cm tungsten powder and 10 cm polyB the prompt dose (G4) is 5.6 rem/hr**
- Recall that the typical dose in the Hall D tagger vault was calculated to be much higher (~25 rem/hr for 5 μA beam current)

# Prompt radiation along beam line

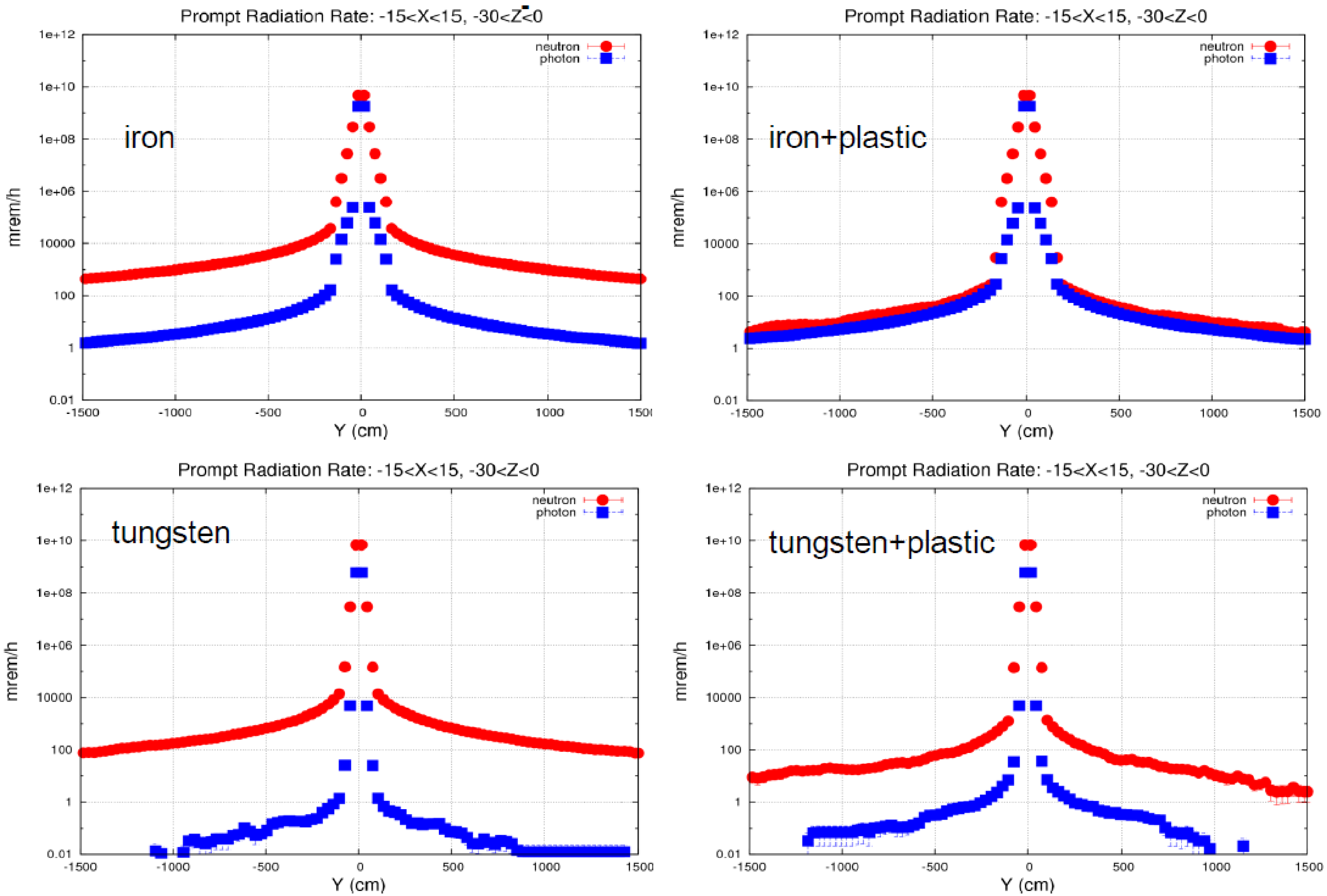
*(Example here from somewhat earlier design)*




Not a major variation as function of z (along beam line)

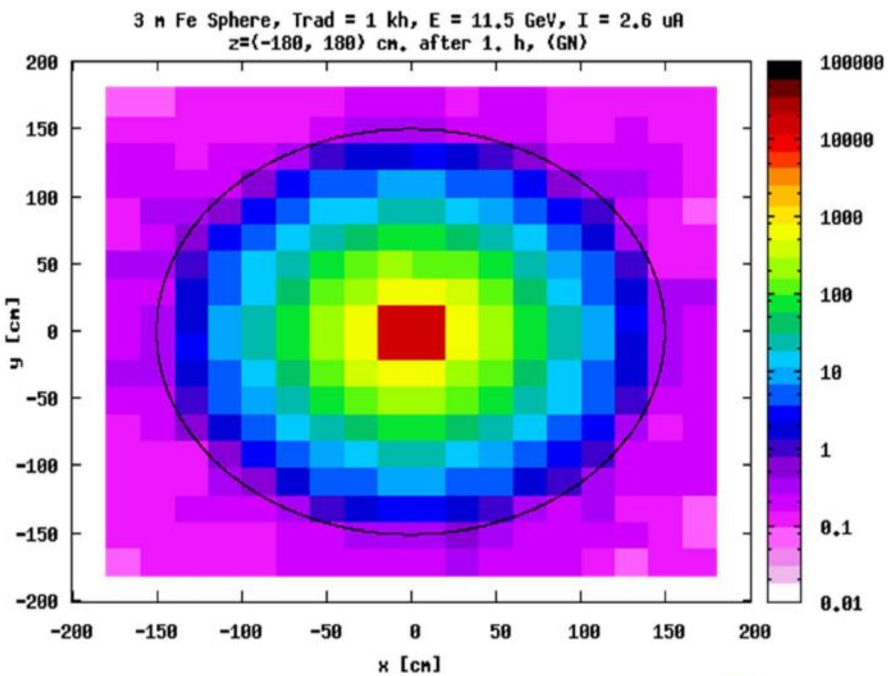
- @ 1 meter from beam line, typical prompt radiation dose of 1000 mr/hr
- @ 4 meter from beam line, typical prompt radiation dose of 100 mr/hr

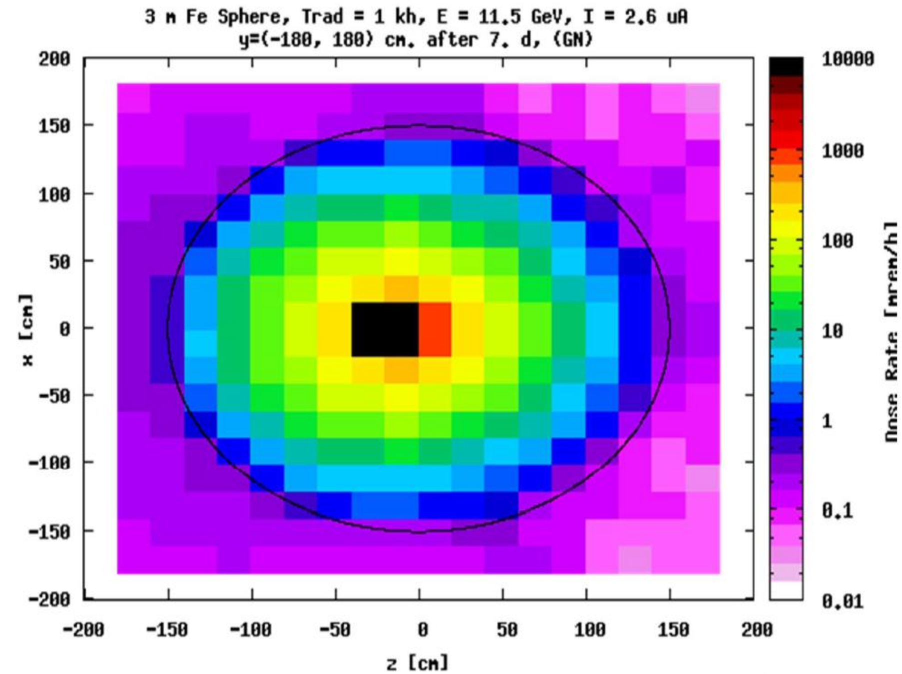
# CPS – Prompt Radiation Doses




- Similar prompt radiation doses along z (the beam axis)
- Borated plastic largely reduces prompt neutron radiation (such that iron + plastic is similar effective as tungsten + plastic), tungsten is more effective for photons

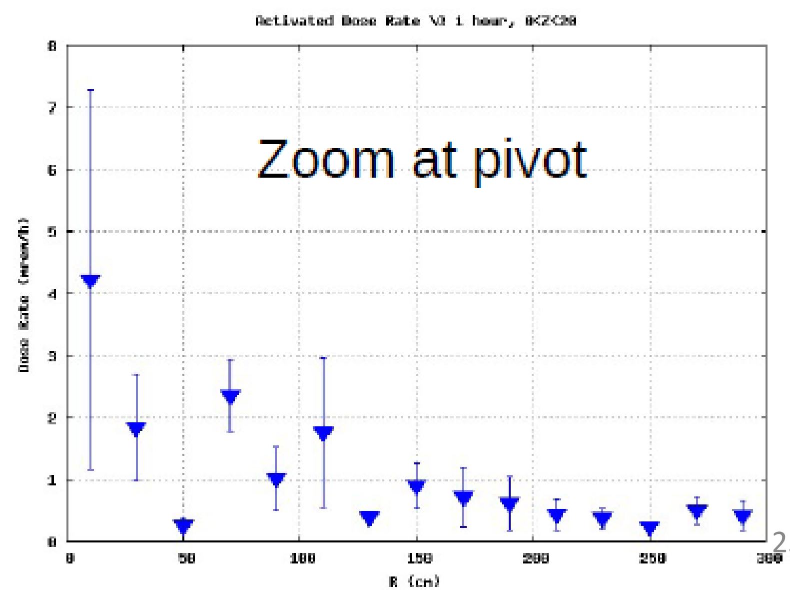
# CPS – Activation Dose @ Pivot



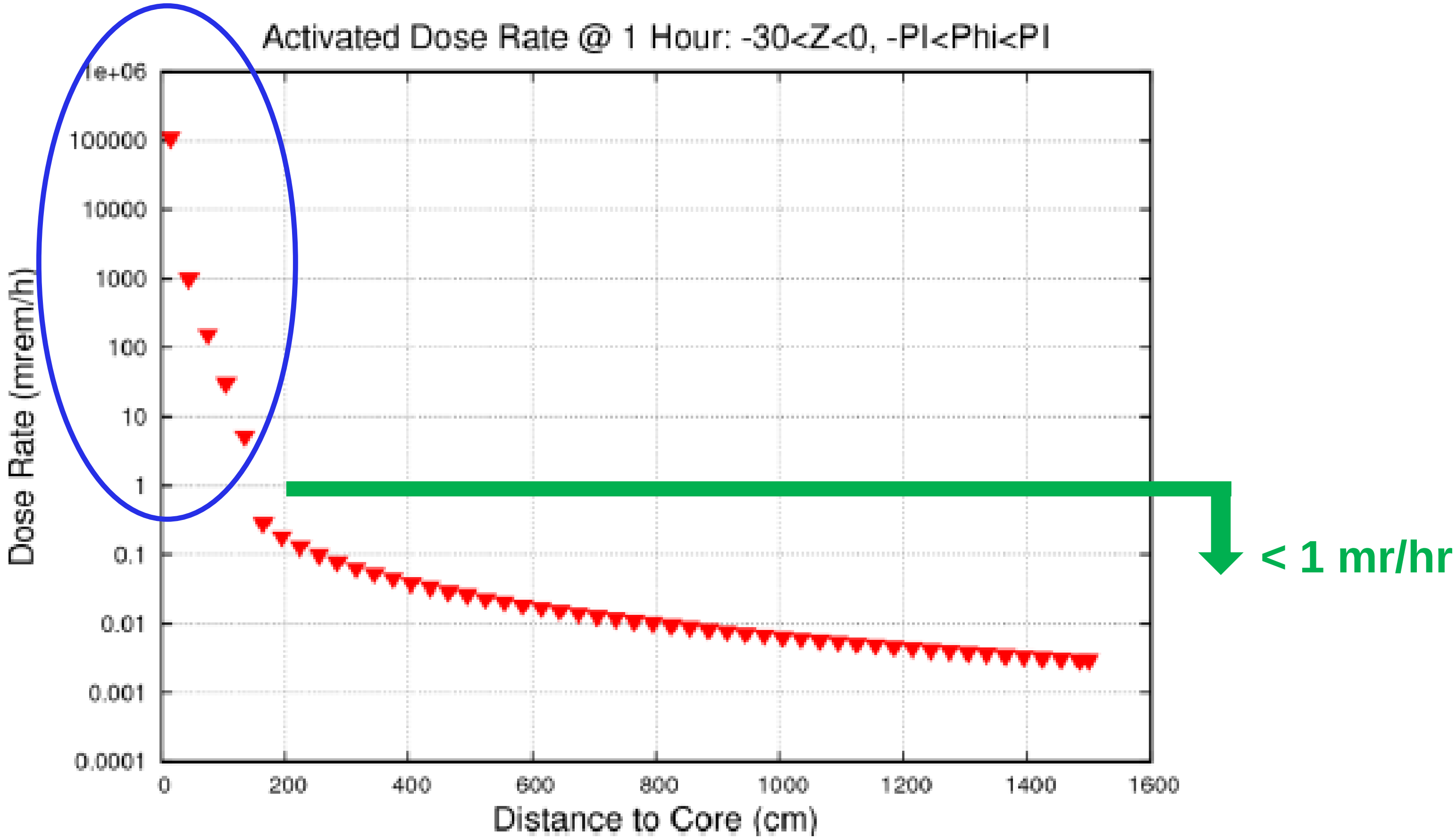

- ❑ Benchmarking: Simulations by different groups are consistent
- ❑ x and y are radial, z is along beam
- ❑ Typical find O(0.1mr) for activation dose radial from CPS, and <2 mr for activation dose at the pivot.

  This assumes access 1 hour after a 1000 hour run (11 GeV, 2.5 $\mu$A)
- ❑ We believe we can reduce this to <1mr with shielding material choice.



# CPS – Activation Doses after 1 Hour

Worst-case calculation, activation dose 1 hour after 1000 hours at 11.5 GeV & 2.6 $\mu$A

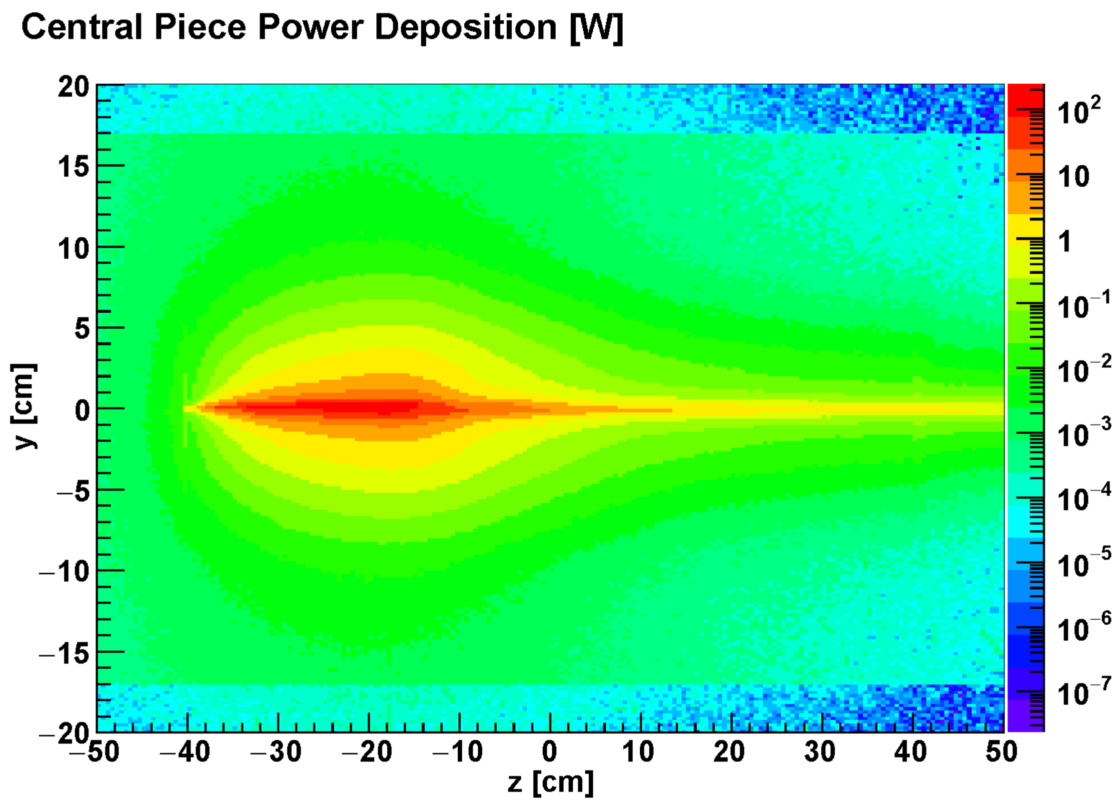



Activation doses inside the CPS remain large, but not outside the CPS
→ Impact for considerations for de-assembly of CPS, not for general Hall maintenance or work/repairs

# Engineering Aspects – Power Deposition

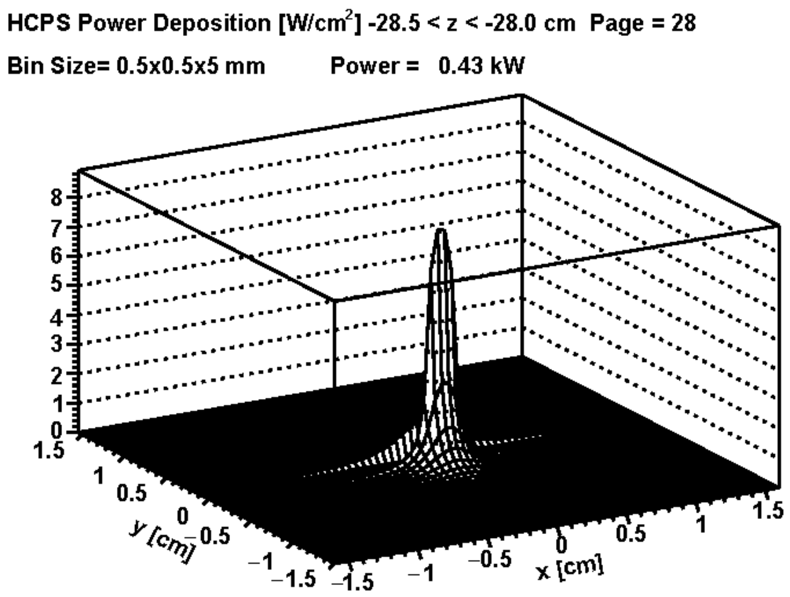
To evaluate power deposition in the central region of the CPS:

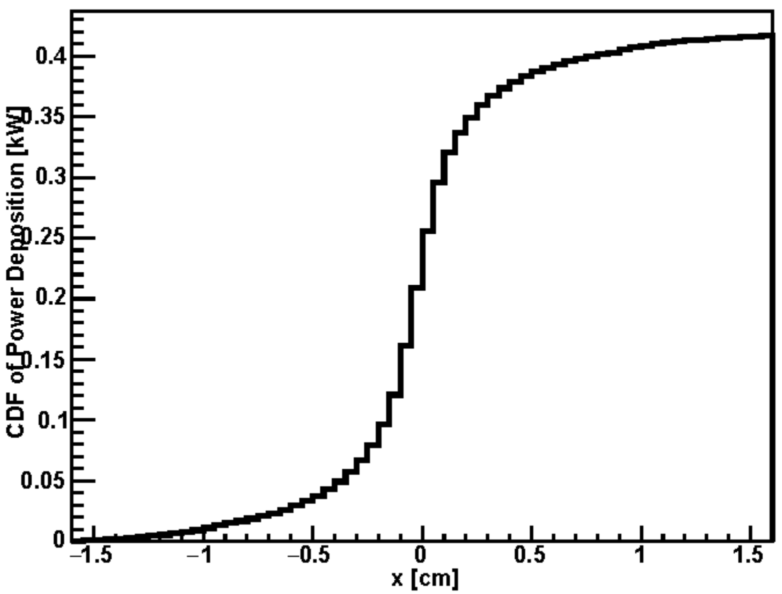
- Modify "standard" G4 code to have smaller step size in central region
- 100 um vs 700 um
- ~eV range IR cutoff
- It takes a while to run!
- Collect energy deposition data in a 0.5 x 0.5 x 5 mm mesh in the central region
- Analyze G4 output to get the power (density) deposited

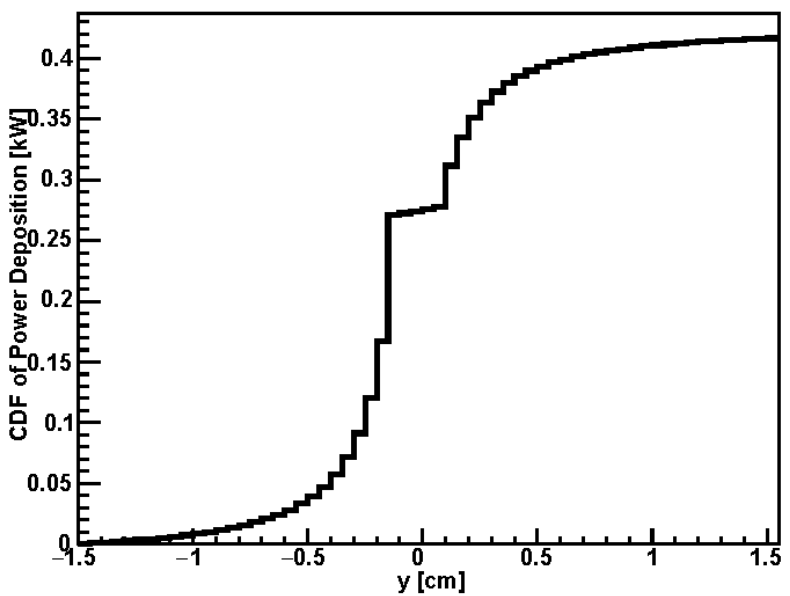



✓ *Check: Integrate all this power deposition…..get 27.001 kW*

# Engineering Aspects – Power Deposition



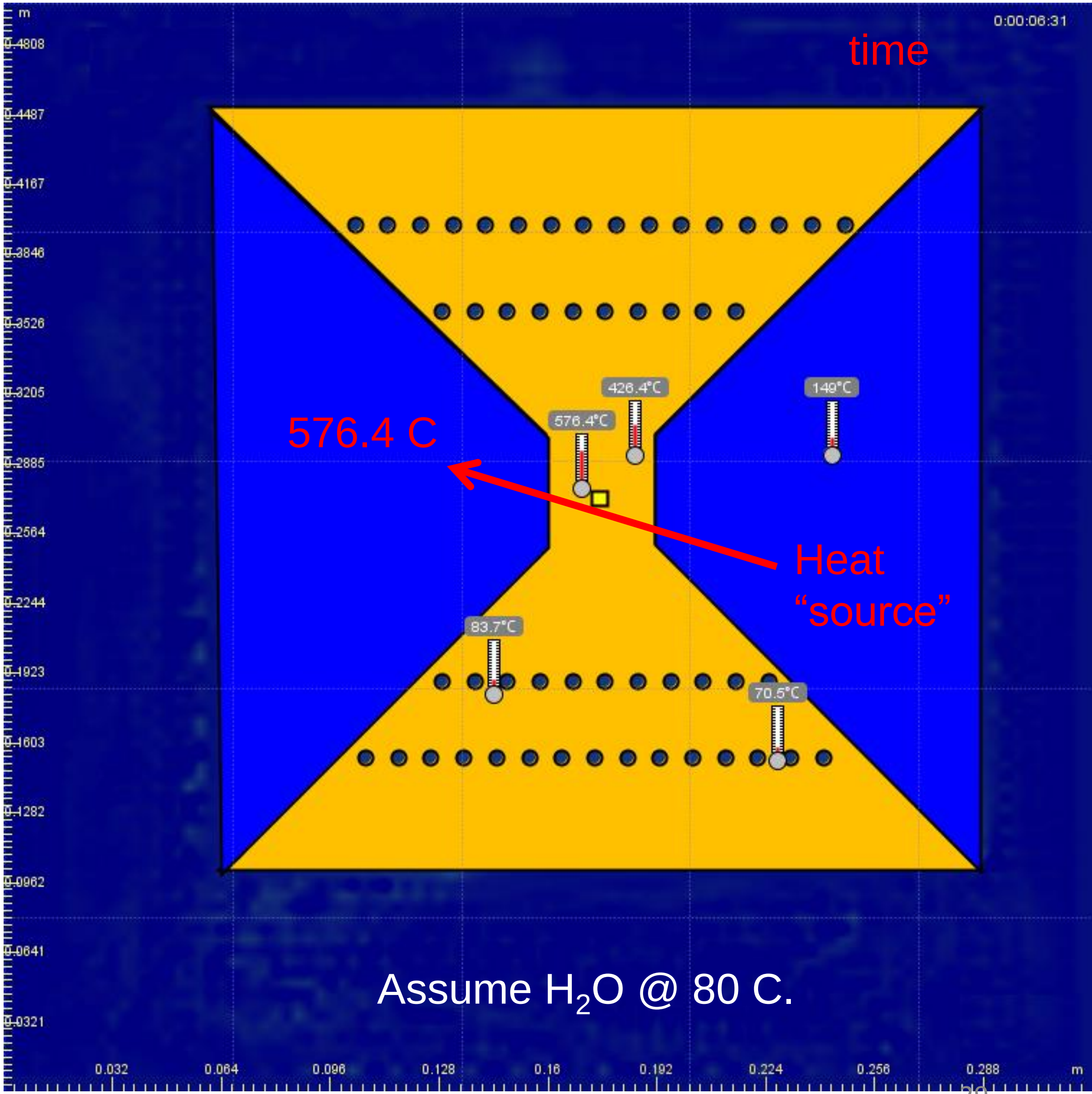




- XY Power Deposition for a 5 mm z slice (0.5 x 0.5 mm$^2$ in x-y)
- Peak: ~0.7kW @ z=-18 cm
- + 166 more slides like this!

# Engineering Aspects – Heat Flow and Cooling

- Input the power deposition data into a heat-flow simulator.
- Assume various pipe configurations
- Record equilibrium temperature

- *Temperature stabilizes at an acceptable value*



# Engineering Aspects – Water Flow and $\Delta T$

- Use the power deposition data to do heat-flow/cooling calculations
- Calculation of coolant flow
- 2D heat transport for z-slices of the central region

typical pressure

**Manageable $H_20$ flow and $\Delta T$.**

| | | Units | | Units | | Units |
|---|---|---|---|---|---|---|
| d | | | 6 | mm | 0.019685 | ft |
| L | 10 | m | 10000 | mm | | |
| epsilon | | | | | 0.000005 | ft |
| nu | 0.00001216 | ft^2/sec | | | | |
| Coil Power | 15 | kW | | | | |

$$v = -2\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}\log_{10}\left(\frac{\varepsilon}{3.7d} + \frac{2.51}{\frac{d}{\nu}\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}}\right)$$

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon}{3.7d} + \frac{2.51}{\frac{d}{\nu}\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}}\right)$$

$$q\left(\frac{gpm}{circuit}\right) = v\frac{\pi d^2}{4} = v\left(\frac{ft}{sec}\right)\frac{\pi d^2}{4}\left(ft^2\right)\times\frac{gal}{0.1337\ ft^3}\times 60\ \frac{sec}{min}$$

$$\left(\frac{\varepsilon}{3.7d} + \frac{2.51}{\frac{d}{\nu}\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}}\right)$$

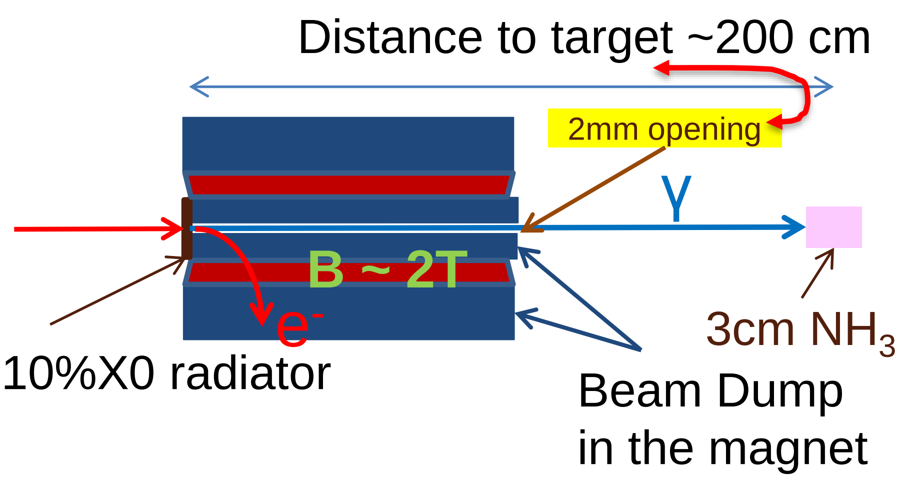
$$\mathrm{Re} = \frac{vd}{\nu}$$

$$\Delta T = \frac{3.8P}{q}$$

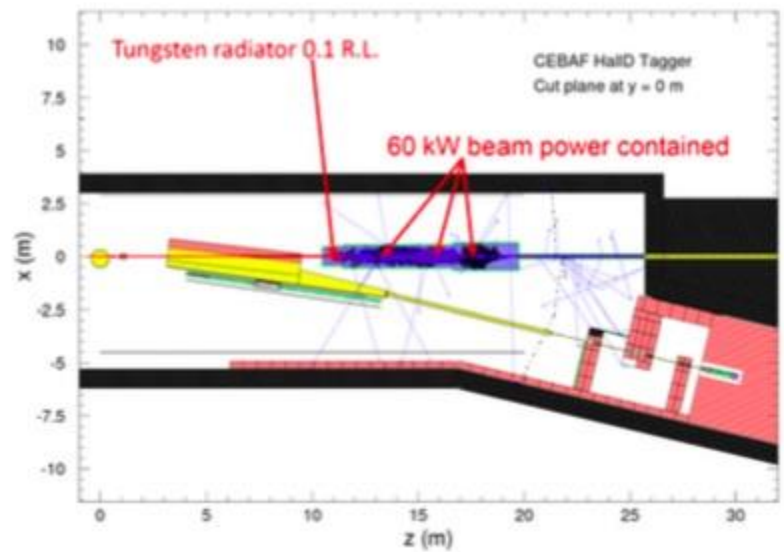
| DeltaP (psi) | $\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}$ (ft/sec) | (no units) | (no units) | f | v (ft/sec) | Re | q (gpm) | DT (deg.C) |
|---|---|---|---|---|---|---|---|---|
| 30 | 1.63619567 | 0.001016 | 5.98598 | 0.027903 | 9.794235 | 15855.25 | 1.3376817[illegible]3 | 42.61103 |
| 35 | 1.76729331 | 0.000946 | 6.048238 | 0.0273[illegible]6 | 10.68901 | 17303.75 | 1.459889[illegible]05 | 39.04406 |
| 40 | 1.88931602 | 0.000889 | 6.101889 | 0.026858 | 11.5284 | 18662.58 | 1.574531[illegible]24 | 36.20126 |
| 45 | 2.00392225 | 0.000842 | 6.148984 | 0.026448 | 12.32209 | 19947.43 | 1.682931[illegible]54 | 33.86946 |
| 50 | 2.11231952 | 0.000803 | 6.190921 | 0.026[illegible]91 | 13.0772 | [illegible]1169.84 | 1.786064648 | 31.91374 |
| 55 | 2.21541941 | 0.000769 | 6.228695 | 0.025[illegible]75 | 13.79917 | [illegible]2338.59 | 1.88467[illegible]139 | 30.24402 |
| 60 | 2.3139301 | 0.000739 | 6.263041 | 0.025[illegible]94 | 14.49224 | [illegible]3460.55 | 1.97932[illegible]035 | 28.79765 |
| 65 | 2.40841481 | 0.000712 | 6.294513 | 0.025239 | 15.1598 | [illegible]4541.22 | 2.07050[illegible]398 | 27.52955 |
| 70 | 2.49933016 | 0.000689 | 6.323544 | 0.025008 | 15.80462 | 25585.09 | 2.15857[illegible]746 | 26.40635 |
| 75 | 2.5870525 | 0.000668 | 6.350475 | 0.024796 | 16.42901 | 26595.87 | 2.24384[illegible]749 | 25.40277 |
| 80 | 2.67189633 | 0.000649 | 6.375581 | 0.024601 | 17.03489 | 27576.69 | 2.32659[illegible]875 | 24.49927 |
| 85 | 2.7541277 | 0.000632 | 6.399087 | 0.024421 | 17.6239 | 28530.2 | 2.40704[illegible]032 | 23.68048 |
| 90 | 2.83397403 | 0.000616 | 6.421178 | 0.024253 | 18.19745 | 29458.68 | 2.48538[illegible]464 | 22.93411 |
| 95 | 2.91163153 | 0.000601 | 6.44201 | 0.024097 | 18.75676 | 30364.11 | 2.5617[illegible]972 | 22.25024 |
| 100 | 2.98727092 | 0.000588 | 6.461713 | 0.02[illegible]395 | 19.30289 | 31248.2 | 2.6363[illegible]925 | 21.62073 |
| 105 | 3.0610418 | 0.000575 | 6.480401 | 0.023812 | 19.83678 | 32112.48 | 2.70927[illegible]988 | 21.03882 |
| 110 | 3.13307617 | 0.000564 | 6.498168 | 0.023[illegible]82 | 20.35925 | 32958.28 | 2.78063[illegible]188 | 20.49891 |
| 115 | 3.20349117 | 0.000553 | 6.515098 | 0.023[illegible]59 | 20.87106 | 33786.81 | 2.85053[illegible]693 | 19.99623 |
| 120 | 3.27239133 | 0.000542 | 6.531264 | 0.023[illegible]43 | 21.37285 | 34599.13 | 2.91907[illegible]772 | 19.52676 |
| 125 | 3.33987042 | 0.000533 | 6.546729 | 0.023[illegible]32 | 21.86523 | 35396.2 | 2.98631[illegible]617 | 19.08704 |
| 130 | 3.40601289 | 0.000524 | 6.561549 | 0.0232[illegible]7 | 22.34872 | 36178.9 | 3.052354[illegible]82 | 18.67411 |
| 135 | 3.47089515 | 0.000515 | 6.575774 | 0.0231[illegible]6 | 22.82382 | 36948.01 | 3.117243[illegible]07 | 18.28539 |
| 140 | 3.53458662 | 0.000507 | 6.589448 | 0.0230[illegible]3 | 23.29097 | 37704.26 | 3.181046[illegible]1 | 17.91863 |
| 145 | 3.59715053 | 0.0005 | 6.60261 | 0.02293[illegible] | 23.75058 | 38448.28 | 3.2438185[illegible]3 | 17.5718[illegible] |
| 150 | 3.65864473 | 0.000492 | 6.615296 | 0.022851 | 24.2030[illegible] | 39180.7 | 3.30561139[illegible] | 17.2[illegible]1 |

# Similarity of CPS concept for Halls A/C & KLong/Hall D

Basic CPS design concept for Halls A/C




CPS in Hall D Tagger Vault




If one uses a 2nd raster system for Hall D to compensate for the initial 1 mm raster, this can be an equivalent essential design

*Some differences…*

- Hall D alcove has more space, so simpler positioning and shielding placement
- Hall D up to 60 kW (<5 μA @12 GeV), Halls A/C up to 30 kW (2.6 μA @ 11 GeV)
- Different length/field magnet for Hall D
- Shielding may differ

# Engineering Concepts - General

A – Magnet with 32 mm gap and 2 Tesla field, with water cooled coils at large distance from the radiation source. Total electrical power 40 kW – 0.75 kA x 40 V

B – Tungsten-Cu alloy insert with a narrow open channel for the beams and water cooling tubes at ~ 20 cm distance from the power deposition.

C – The JPARC proton accelerator high radiation magnet/NIM paper, collaboration.

D – Shielding requires ~ 1 kg/cm$^2$ of material. Minimum weight will be with Tungsten. The plan is to use low cost W powder (16 g/cm$^3$). A 10 cm CH2 layer outside.

E – The plan of development:

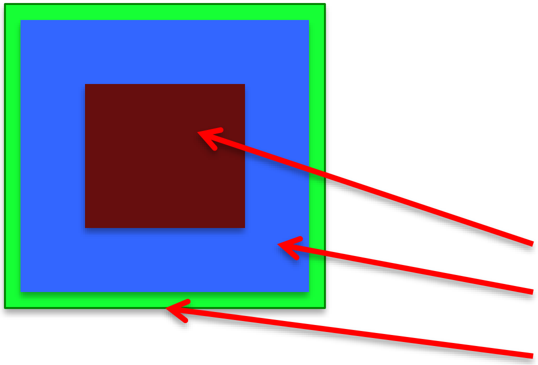
stage #1 engineering (minimize disassembling),
develop a concept of a 100% reliability raster with a power source,
develop a concept of focused raster scheme for the KL case,
procure ~ 2 tons W powder for bench test of Monte Carlo.
study Hall integration

# Engineering Concepts – Material Choice and Weight

Shielding concept:

1 Leaks through the penetrations are tiny
2 Photons/electrons are stopped by 30X0 e.g. 10 cm W
3 Fast neutrons are stopped by the mass of material
4 After that, slow neutrons are stopped in BPoly layer
5 Several-MeV photons from activated inner part are very well shielded by 1 kg of material

The Hermetic CPS weight totals ~ 51 tons:

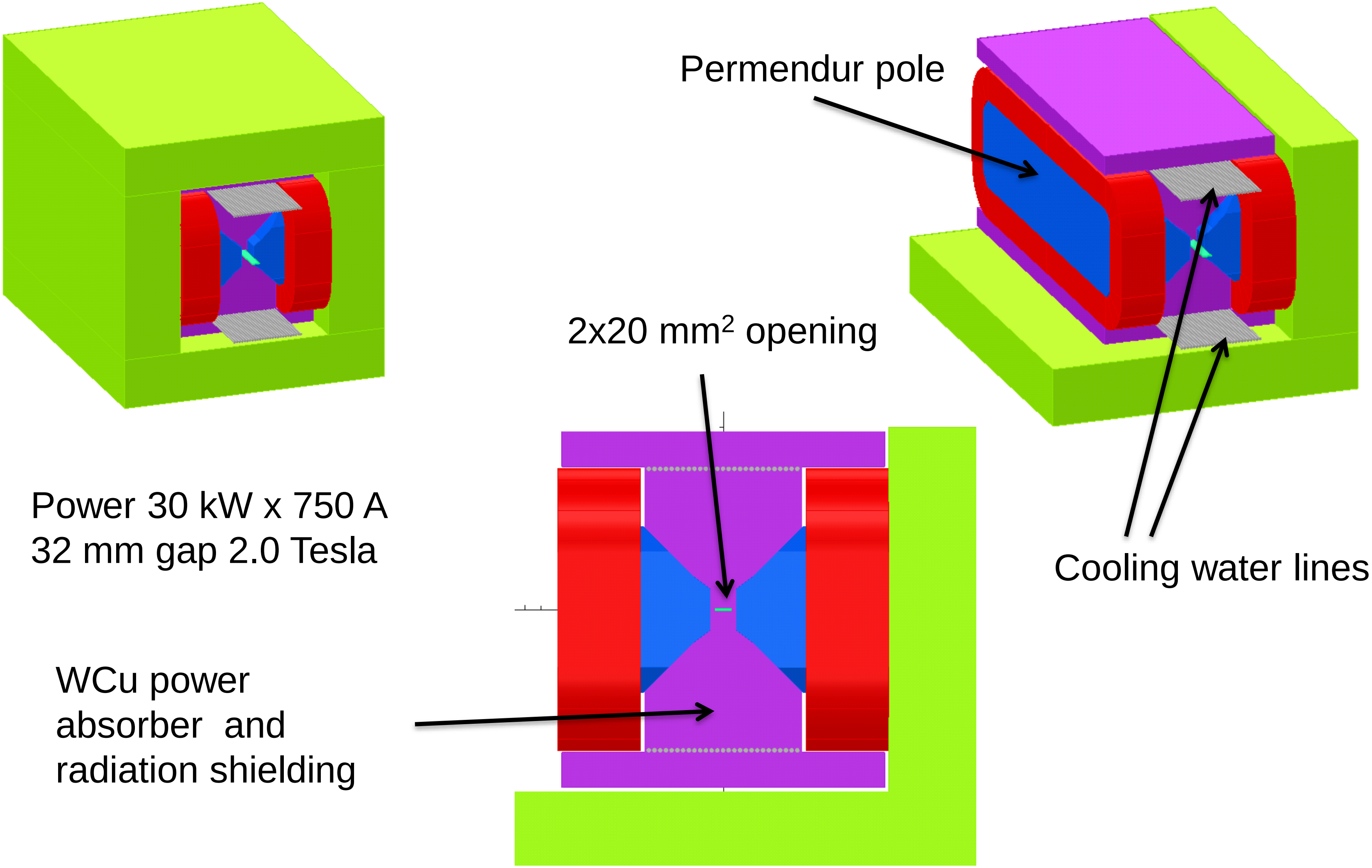


View along the beam

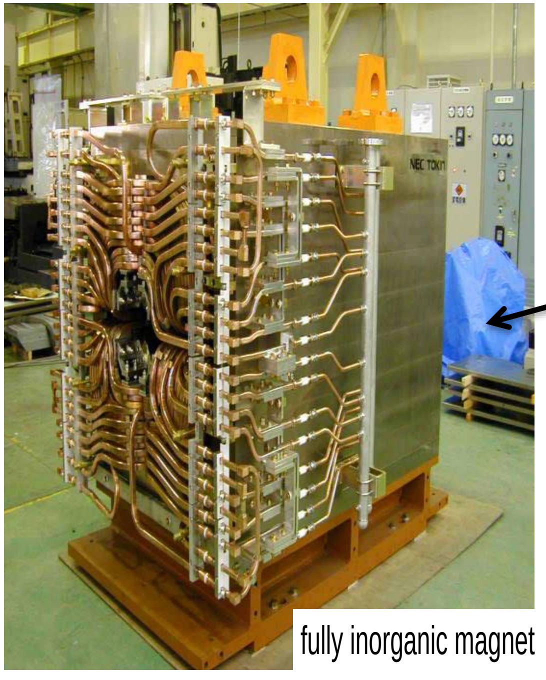
1 Magnet yoke+coils+WCu insert – 5 tons
2 Tungsten powder 30 cm – 30 tons
3 Outer layer BPoly 10 cm – 0.7 ton
4 Holding frame – 5 tons

~50 tons weight should not be an issue for floor loading or the Hall C beam line posts (with a steel plate to spread the load) – for Hall C this is not much different than the very large shielded bunkers and magnets used before.

# Engineering Concepts - Magnet



# Engineering Concepts – Radiation Hard Magnet Example




fully inorganic magnet

J-PARC – warm magnet

e-mail from Dr. K. Tanaka:

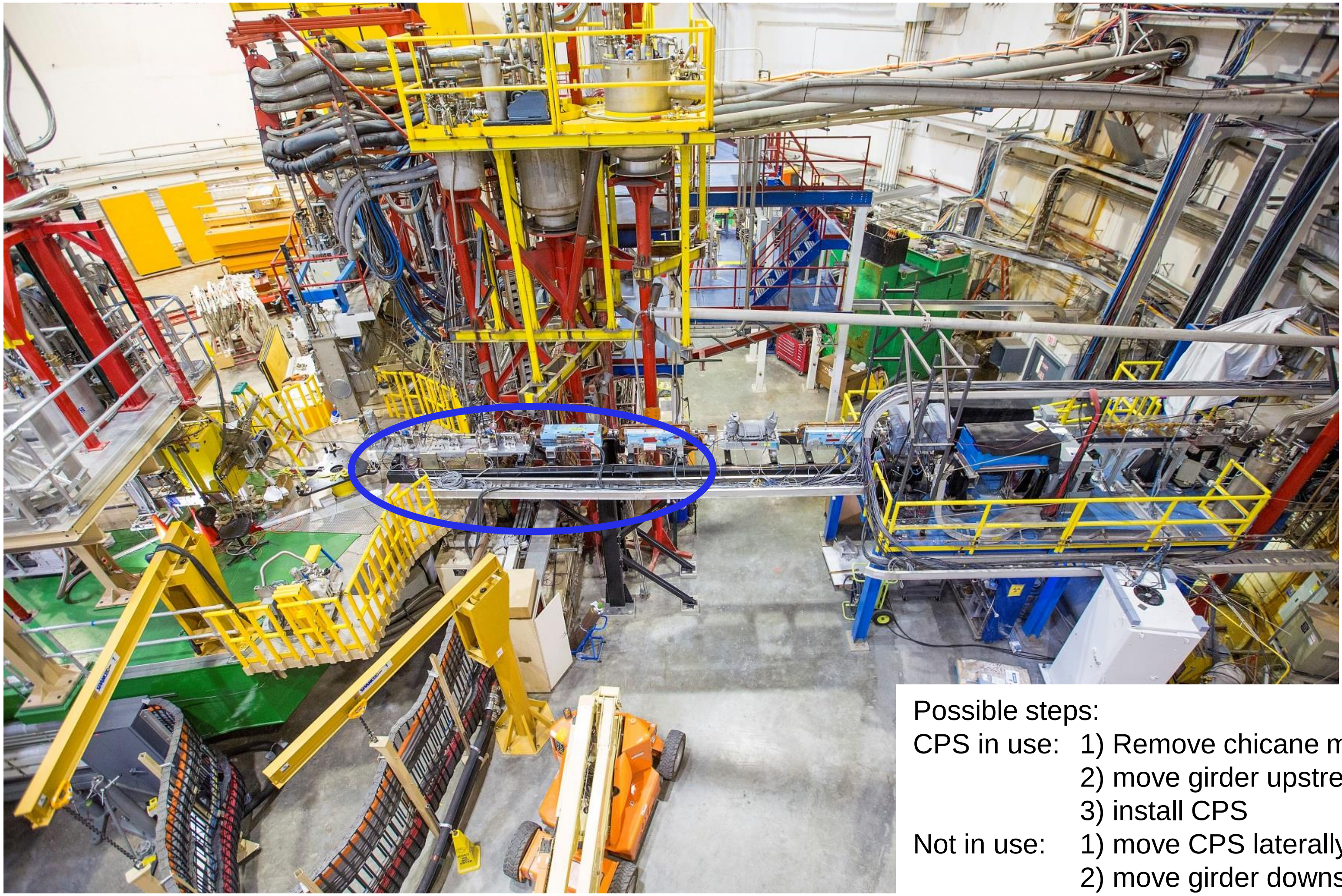
100 kRad/hour = 1K Gy/hour = 5M Gy/year (assuming 5000h operation/year)
-> 5x10e7 Gy/10 years.

This radiation dose is not very serious if you select appropriate insulation resin.
Some epoxy resin can survive well against 5x10e7 Gy. However, if you select BT resin, magnet will be much stronger against the radiation dose.

There are several manufacturer of electromagnets in Japan. I can ibtroduce some of companies for you.

# Engineering Concepts – Minimize Disassembly

- In Hall D Tagging Facility Alcove it is conceivable to leave the CPS in place as passive element when running tagged photon beam
- In Hall C a scheme of moving the CPS laterally when not in use looks promising



Possible steps:

CPS in use: 1) Remove chicane magnets
2) move girder upstream
3) install CPS

Not in use: 1) move CPS laterally
2) move girder downstream
3) re-install chicane magnets

# Summary

- Science at Jefferson Lab benefits from an optimized high intensity photon source

- CPS is a novel concept allowing for ***high photon intensity*** (equivalent photon flux: ~$10^{12}$ photons/s) and ***low radiation*** (low activation: <1mrem/h after one hour) in the hall

- Strong interest by Hall A/C and Hall D/$K_L$ to jointly develop and seek funding for CPS

## PAC43 on PR12-15-003

**Summary:**
The PAC considers the measurement of $A_{LL}$ to be very valuable. However, as discussed above, it feels that the present proposal does not describe the best approach of addressing the main physics issues. Clearly, coverage of a broader angular range appears necessary. That said, there is added value of going to larger energies. The PAC is impressed by the concept for a new photon source. It strongly encourages the proponents to work with the members of the previously approved E12-14-006 in order to see whether it could possibly be incorporated there. We also note that connecting with E12-14-006 would bring additional polarized target expertise.

## PAC44 on PR12-16-009

**Issues:** The PAC commends the PR12-16-009 collaborators on the development of two new photon source designs that move the electron dump away from the polarized target. However, the specifics of the dump design, cost and heat/radiation load to associated equipment in the hall has not been estimated. This needs to be completed in order to fully evaluate the proposal. The PAC recommends working closely with lab management while optimizing the photon source beam and dump design.

**Summary:**
The PAC considers investigations into the mechanisms behind WACS to be very valuable. We encourage the collaborators on the approved E12-14-006 experiment and the proposed PR12-15-003 and PR12-16-009 to unify their efforts and submit a new proposal with a fully developed photon source, beam dump, polarized target and raster design. Ideally this proposal would encompass the primary physics motivations from all three proposals, with an emphasis on the verification that $A_{LL} = K_{LL}$ and the measurement of $A_{LL}$ at large angles (120 degrees) and in the kinematic regime that will allow interpretation within the handbag framework.

We recommend that the laboratory provide resources for a workshop focused on developing the physics case, as well as an optimized compact photon source and beam dump, organized jointly by the spokespersons of the PR12-16-009, PR12-15-003, and E12-14-006 proposals.

## 3.4 The Photon Source

The experimental program laid out in this proposal requires a real photon source. At JLab, Halls B and D have built-in real photon capabilities, but those sources are designed for a tagged photon beam with an intensity of $10^7$ Hz, which is many orders of magnitude below the intensity required for a WACS experiment at 8-10 GeV. One of the primary tasks of the WACS collaboration is to propose an optimum concept, design, simulate and build a high intensity photon source that can provide required intensity with sufficiently low radiation in the hall, especially in the target and detector area during operation and soon after beam shutdown. After a decade of considering the technical challenges, a conceptual solution was found and presented at the NPS collaboration meeting in November 2014 [48, 19].

This solution is based on the observation that with one meter of heavy shielding a hermetic source could be constructed because the opening channel for the incident electron beam and produced photon beam needs to be just 2 mm in diameter for such a compact size of the source (overall 3x3x3 $m^3$). The radiation will be produced inside and contained (except of course the photon beam) because the source is hermetic (HCPS). The concept also provides a small photon beam spot at the target which is very important for data analysis and background suppression. The magnetic deflection of the beam is an obvious way to cleanly separate the photon and electron beams. However, the challenge of beam power absorption required a new solution. The standard dump for 1 MW beam power has a reliable but complicated design. However, even for our case of 30 kW beam power, local peaks in power density could melt the absorber. We noticed that for the proposed 2.5 T field for the cleaning magnet and a 2 mm vertical size of the opening channel in the magnet leads to the desirable small incident angle of electron entry to the absorber. When combined with a 1 mm vertical raster of the beam, the area of power deposition become 30 cm long and local power density is well within operational regime for proposed WCu absorber.

The technical parameters of the source components are modest in complexity:

- a 10 % radiator;
- a compact 1 m long magnet with 2.5 T field in small 3 cm wide gap (designed);
- an inner absorber of WCu alloy;
- low cost W-powder for outer shielding.

More detailed information on the photon source, prompt radiation levels, activation and beam power capabilities can be found in Ref. [22]. For the purposes of the current proposal, it is simply assumed that the beam parameters are defined by a 2 m radiator-to-target distance and 2.5 $\mu A$ primary electron beam current, corresponding to an integrated photon flux on target ($> 0.5E_{\mathrm{Beam}}$) of $1.5 \times 10^{12}$ s$^{-1}$.

# General design concept HCPS

# A backup slide

A 100 kW power concept with an additional 20-mm horizontal raster

Top view (x-y are not in scale)