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

UVa Option

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and friends

High Intensity Photon Sources Workshop
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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

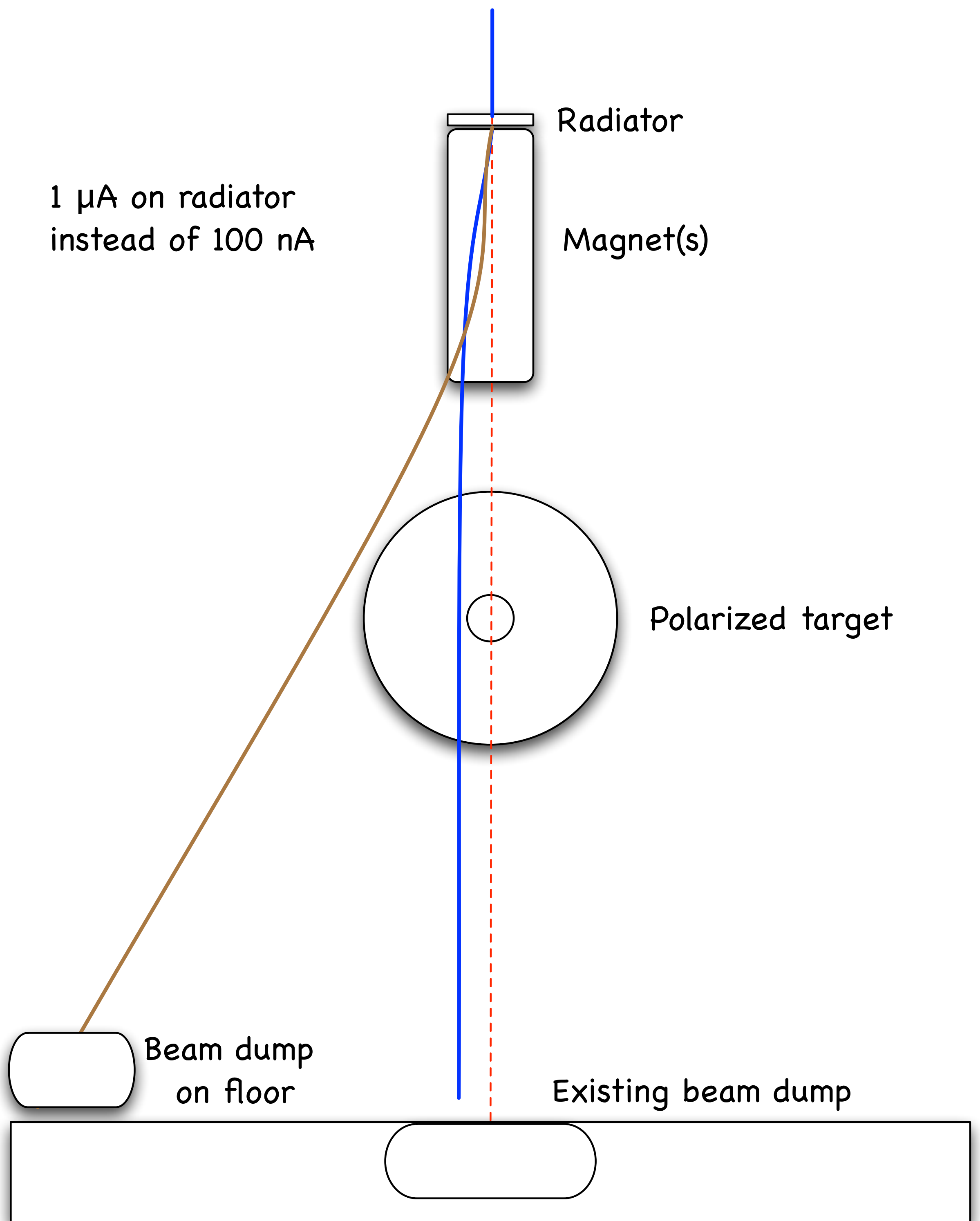
Wide Angle Compton Scattering

- 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 at NPS meeting on 10/9/14.
7. Polarization Observables in Wide-Angle Compton Scattering at Photon Energies up to 8 GeV, PR12-15-003, deferred by PAC 43, 10 kW Compact Photon Source introduced.
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

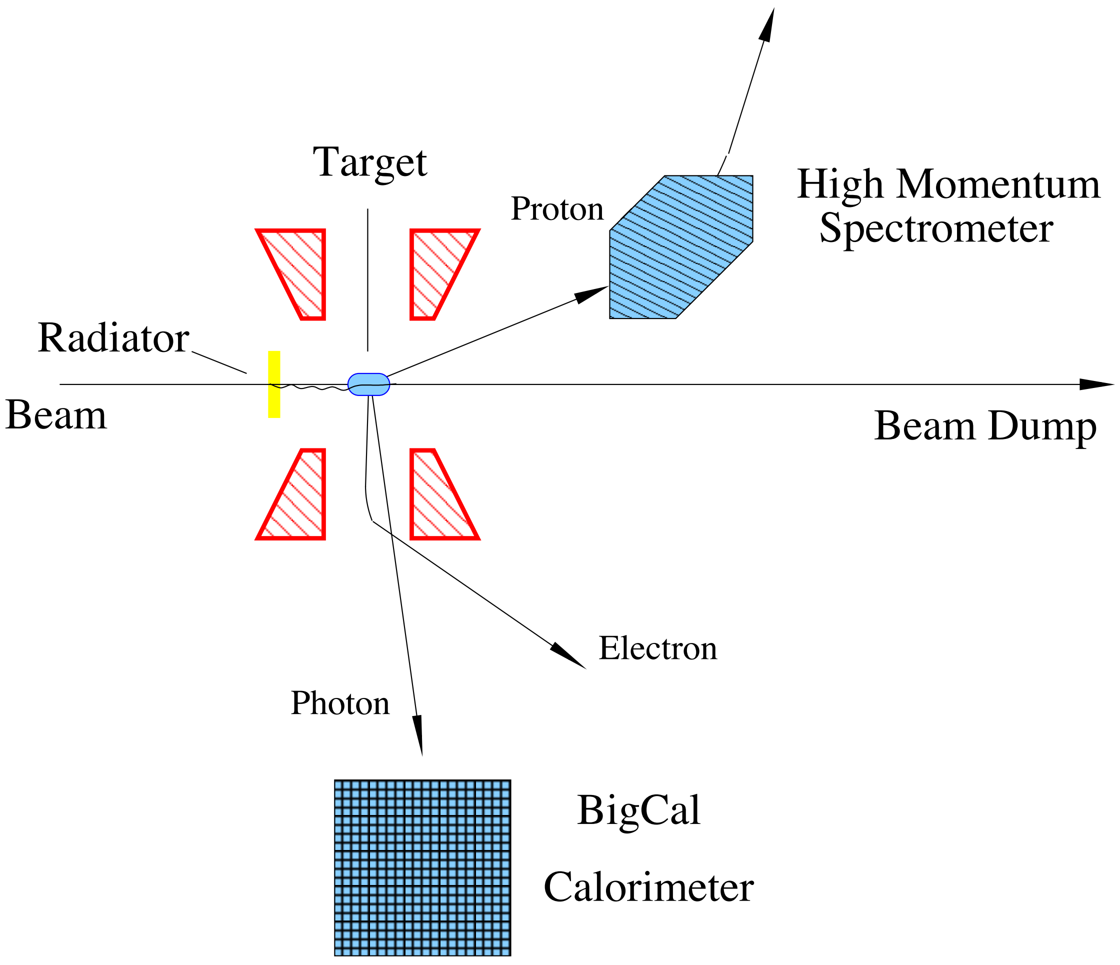


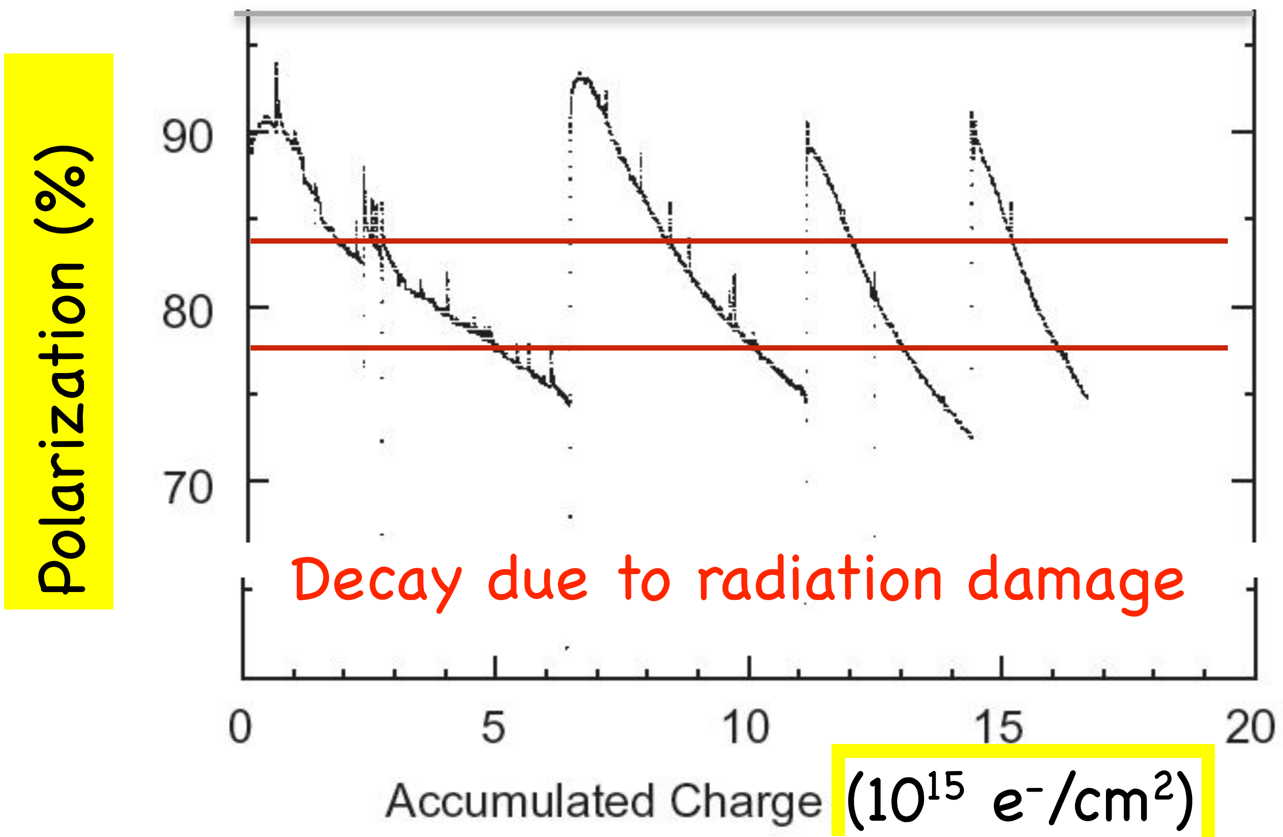
Also at joint 2010 Hall A/Hall C workshop on High Intensity Polarized Targets at 12 GeV

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





5×10^{15} e^-/cm^2 = 9 hours at 100 na

Significant Overhead

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

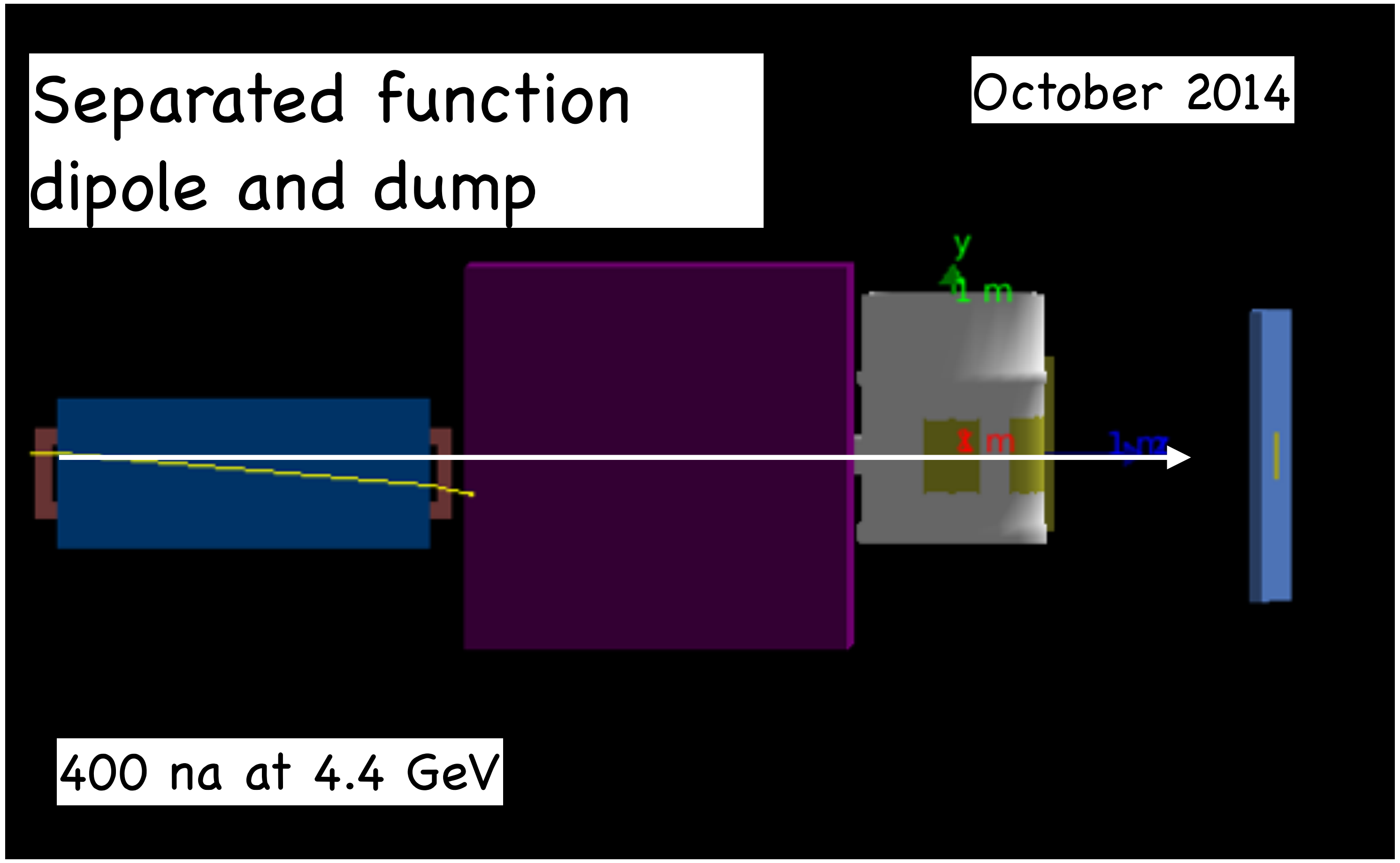
- Change targets (top/bottom) every 8 hours
  - Polarize
  - Anneal, Cooldown, TE, Polarize [2 times/day - 2 hours]
  - Replace target material at least once/week: Warm up, pull stick, replace material, take TE's top and bottom, polarize !< 8 hours

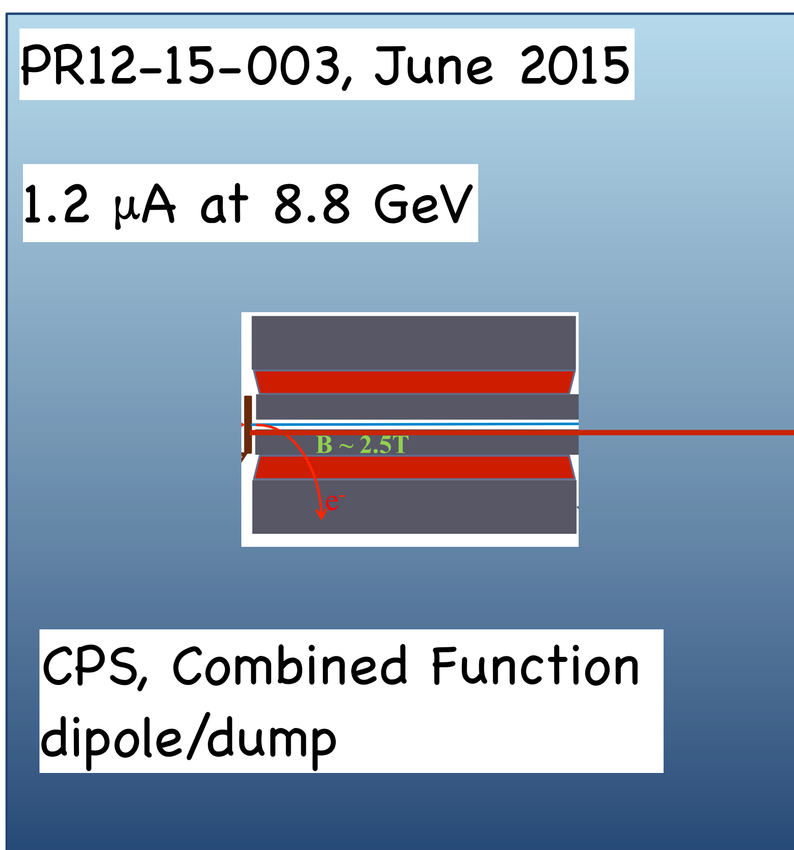
Benefits of a real photon beam

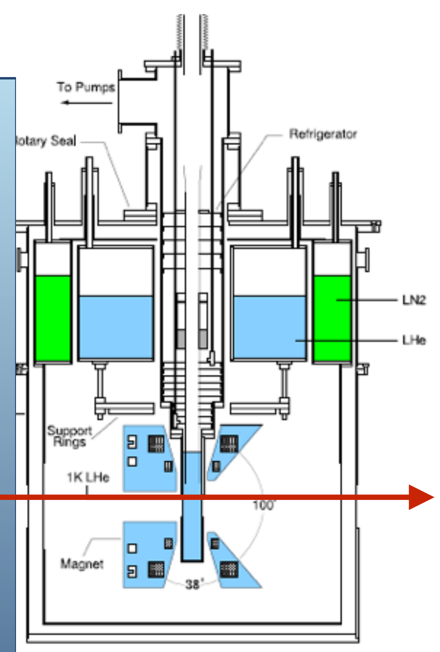
- Heat load on target reduced
  - Higher maximum target polarization with beam: 90% ==> 95%
- Production of depolarizing free radicals much reduced
  - Higher average polarization FOM = $(90/70)^2$ = 1.65
  - Fewer target changes
  - Significant reduction in target overhead
- Higher electron intensity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

- New Physics
  - TCS
  - Photo-disintegration of tensor polarized deuteron

Pure Photon Source







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

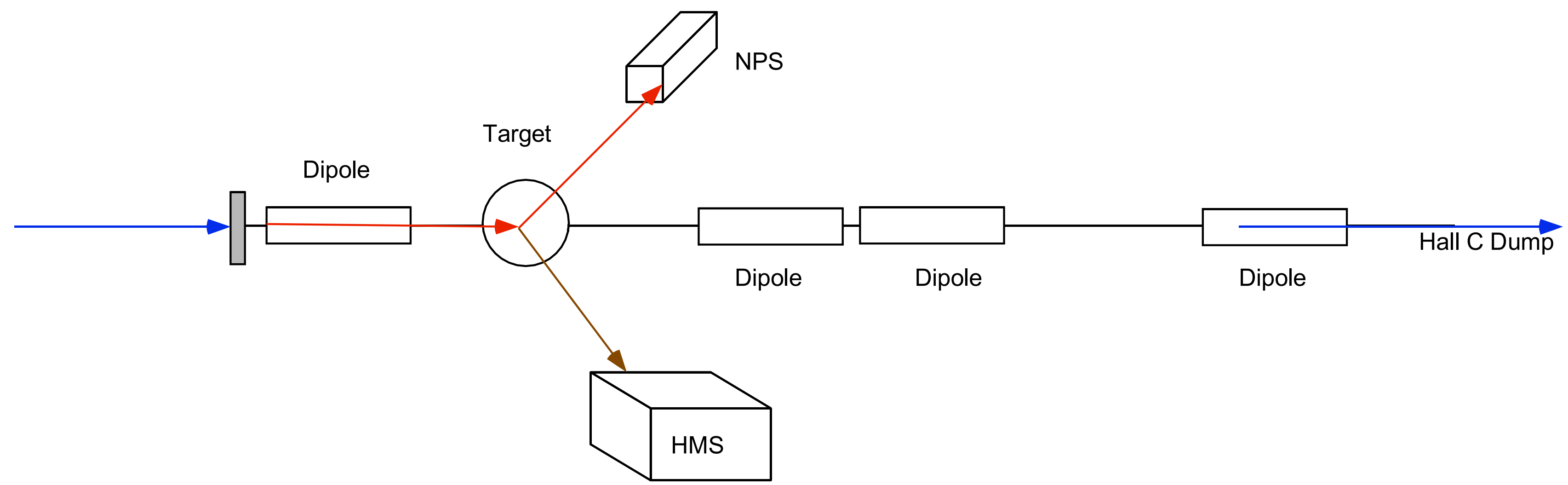
AHA!

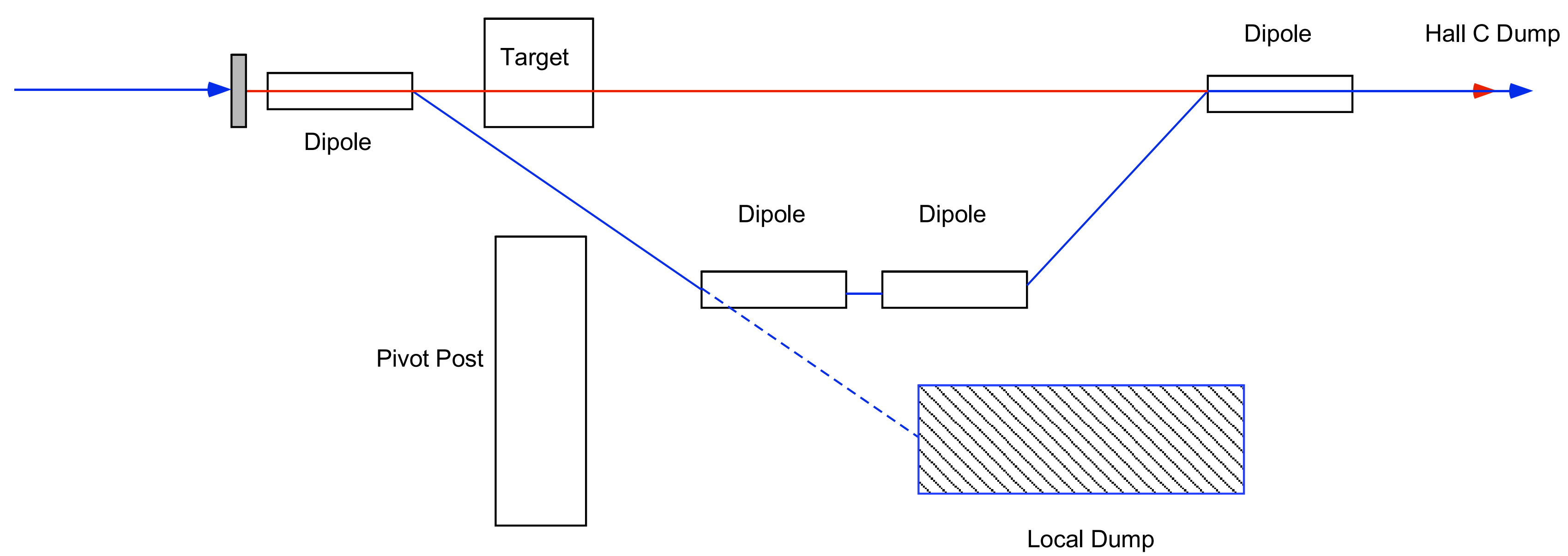
Target hangs on a platform above the pivot post

Experimental Setup: PR12-16-009

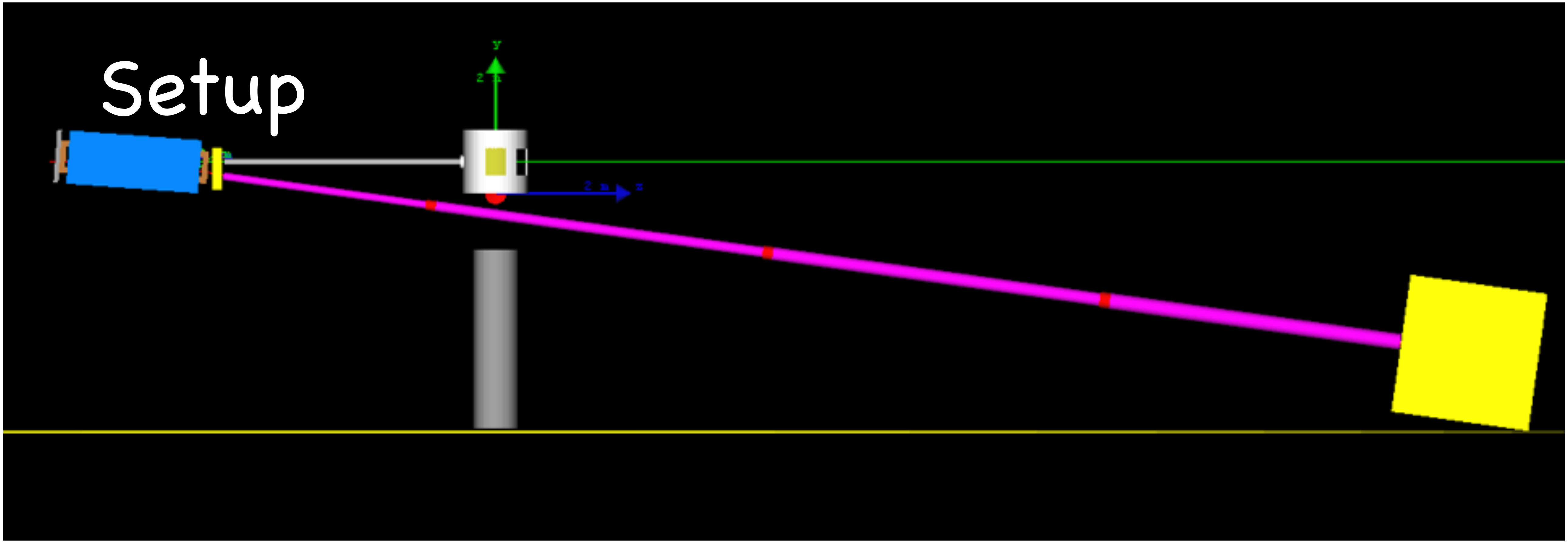
3μA at 8.8 GeV, May 2016

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



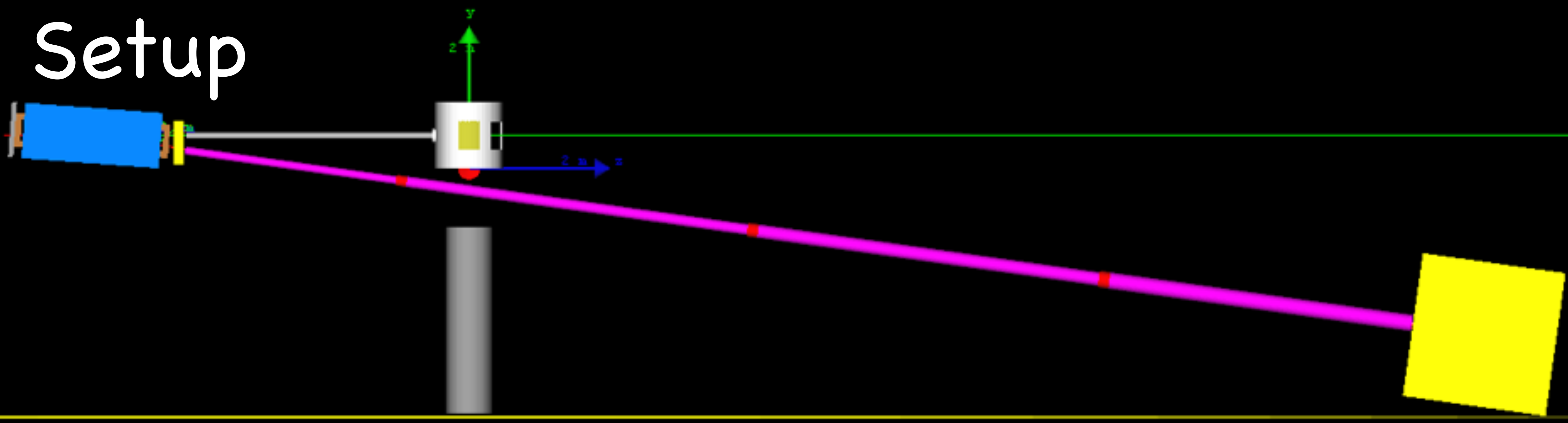


Vertical deflection at target: > 48 cm && < 129 cm



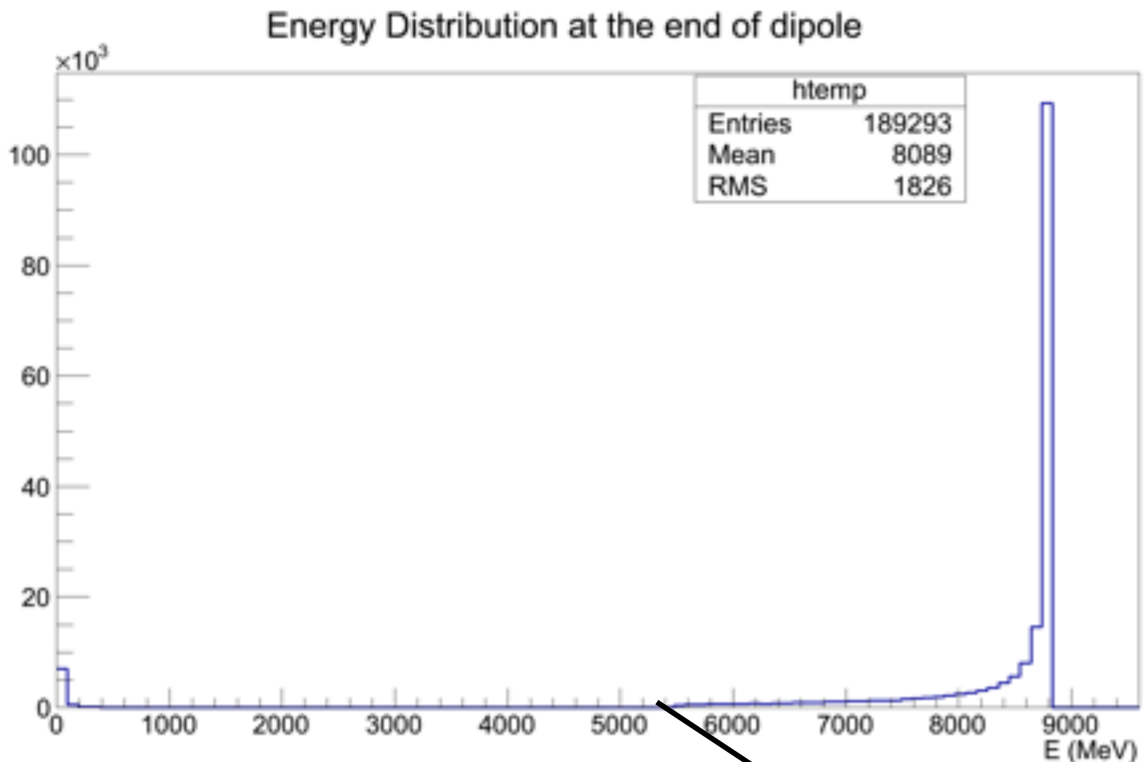
- Floor in vertical: -3943 mm
- Dump: Z = 14305.71 mm
- Radiator: Z= -6495.45 mm
- Dipole Center : Z = -5314 mm
- Post and target Z = 0 mm
- Magnet container length : 2320 mm
- FZ Magnet : 2T @ 2m (Bdl~4)

Setup



- 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.

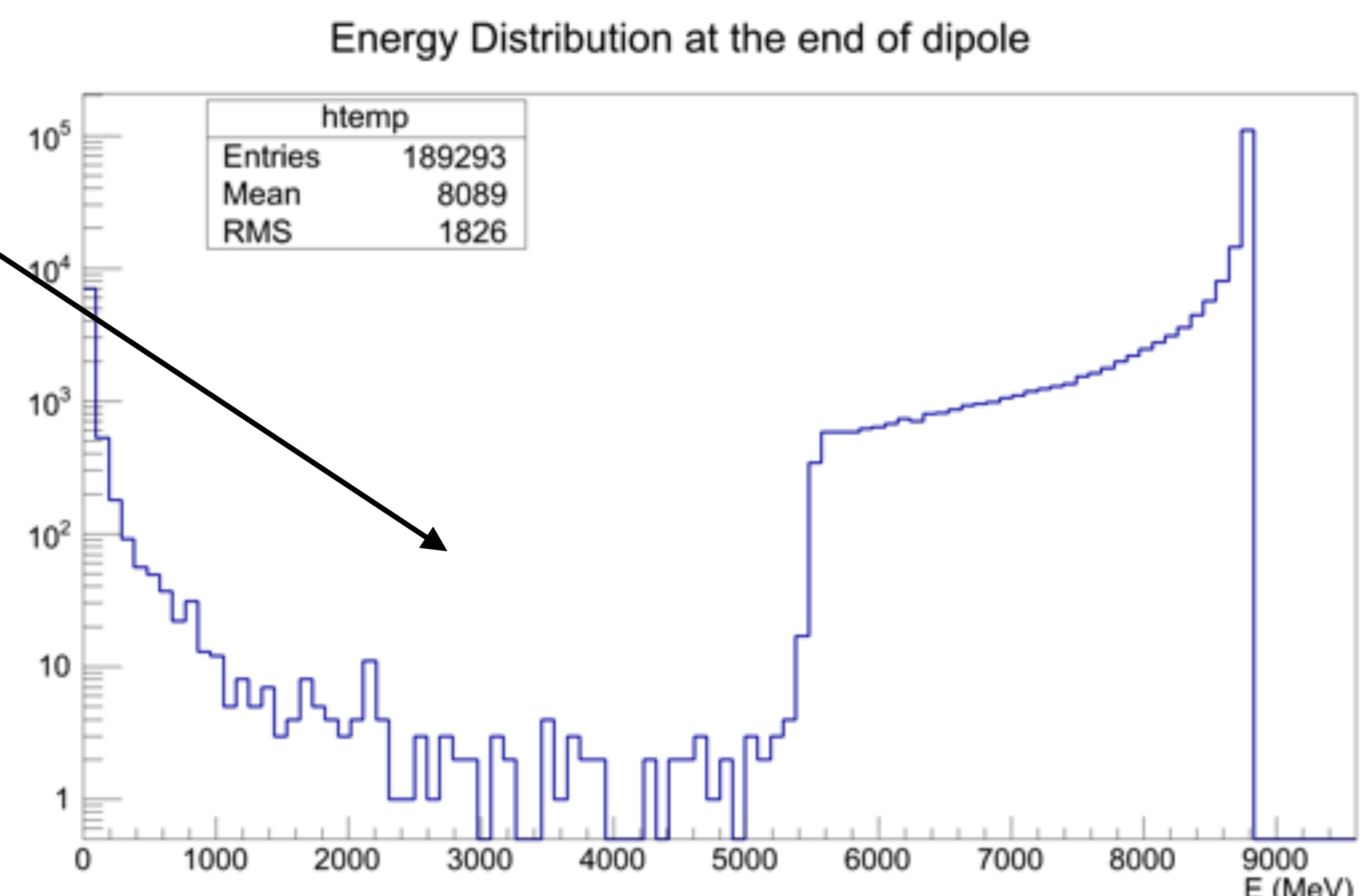
Electron energy spread out of radiator is broad – it is dispersed



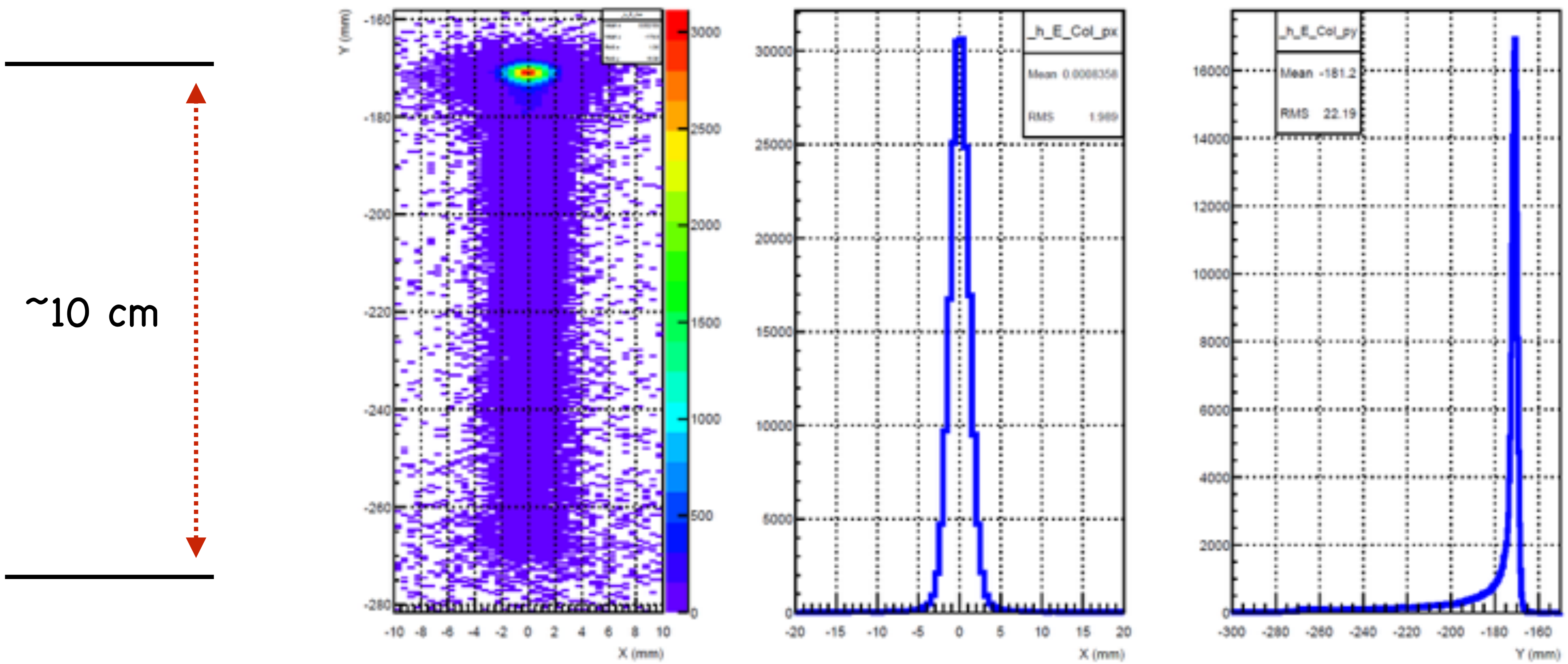
Electrons < ~6000 MeV will intercept a spacer bar in the dipole magnet.

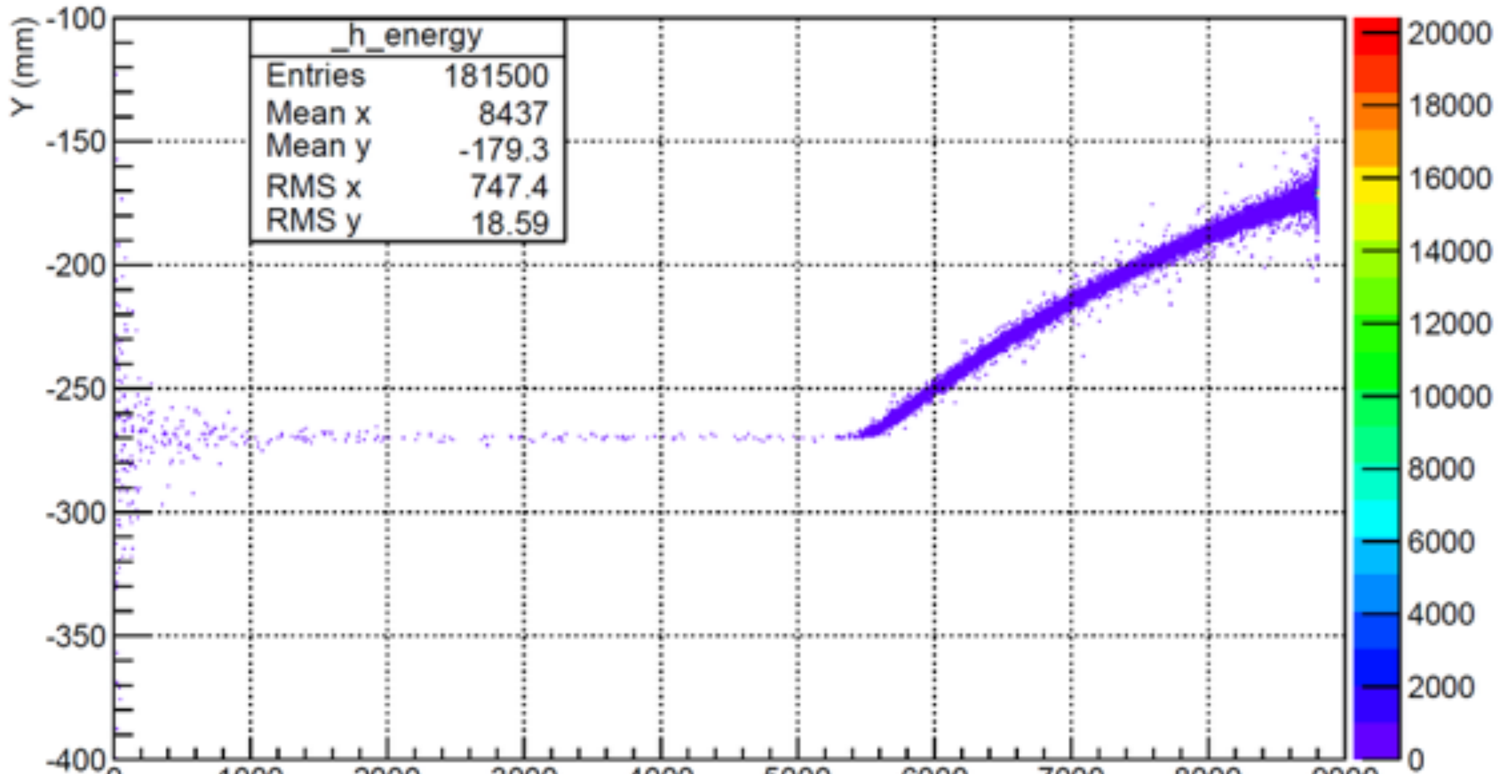
Low energy electrons produced by pair production

0.18 (0.11) kW/uA for 10% (6%)



Electron Beam dispersion after the dipole, NC

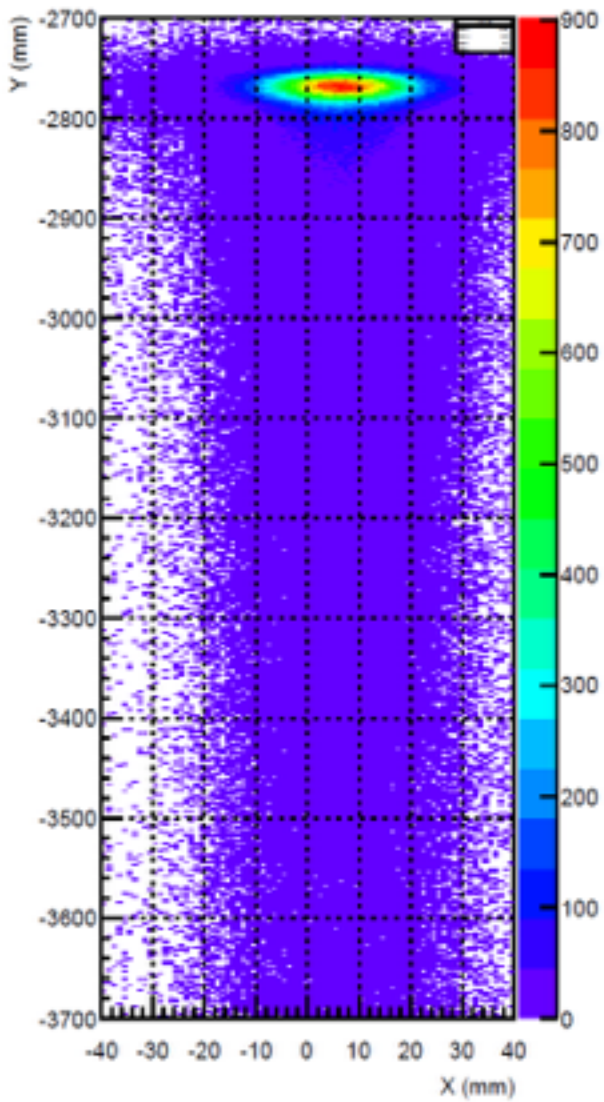


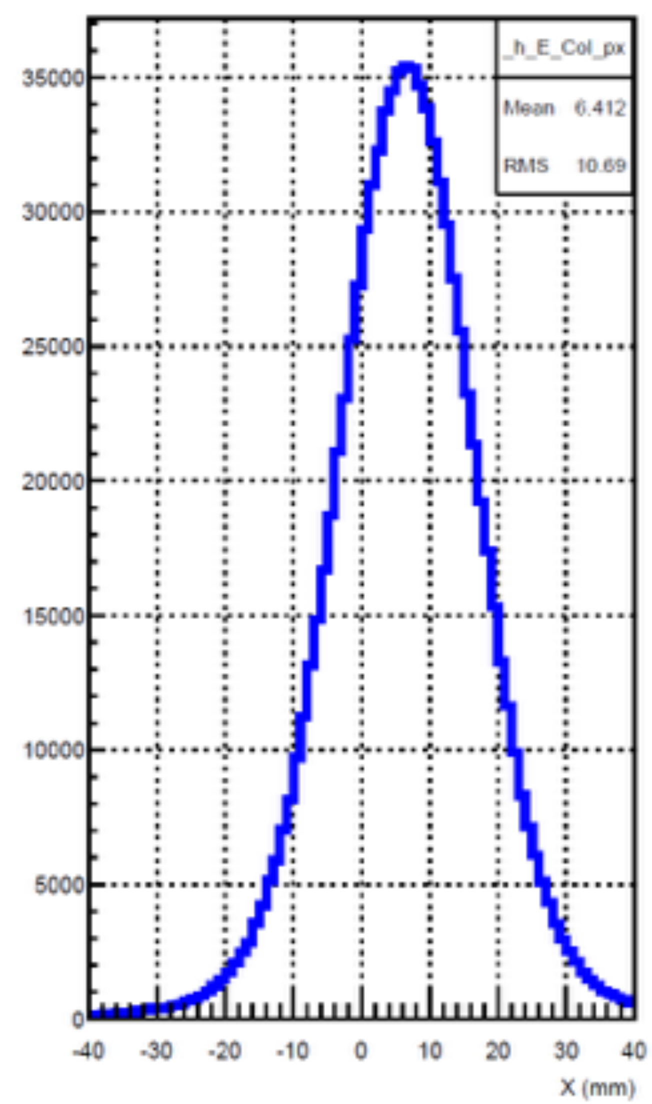


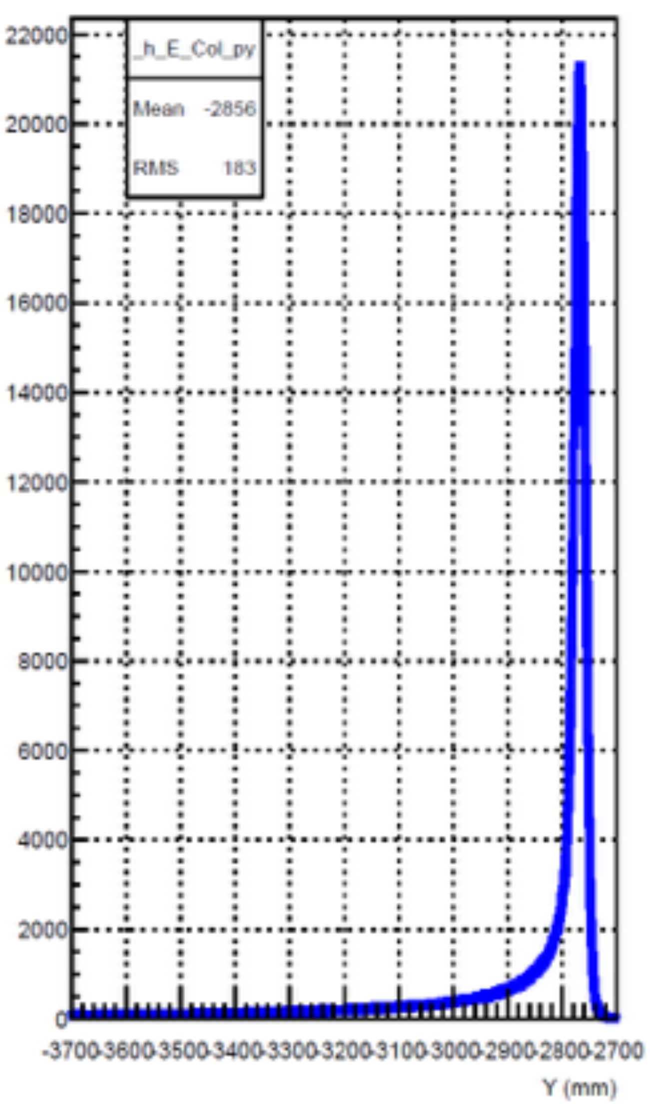
Energy

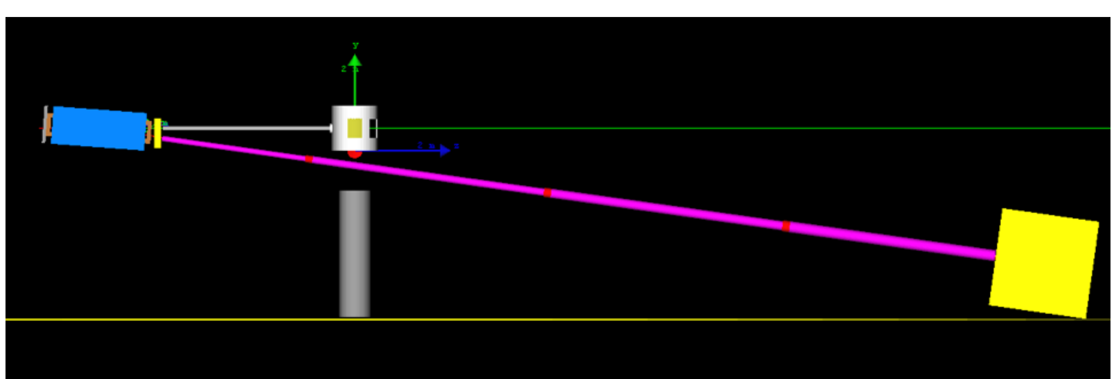
Electron Beam Spread at dump

~100 cm



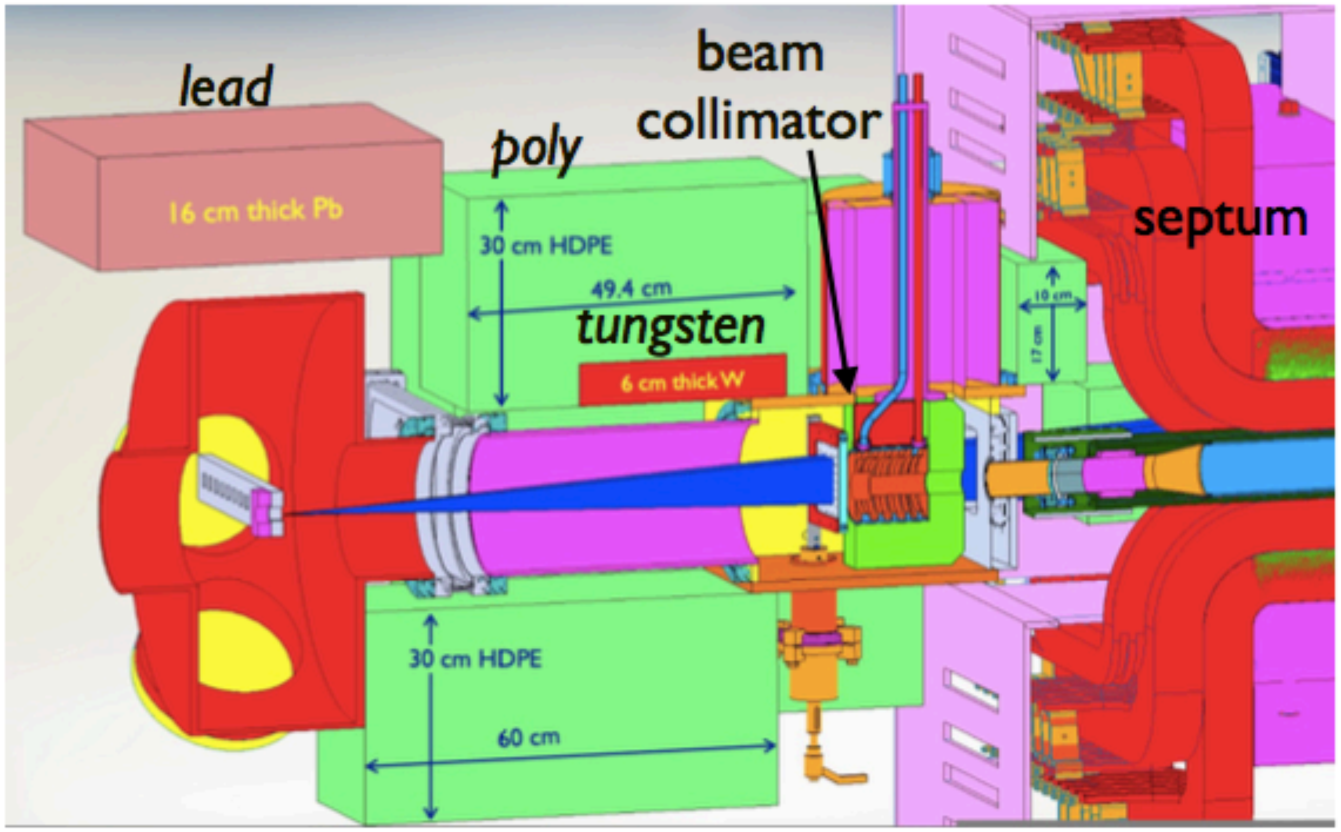






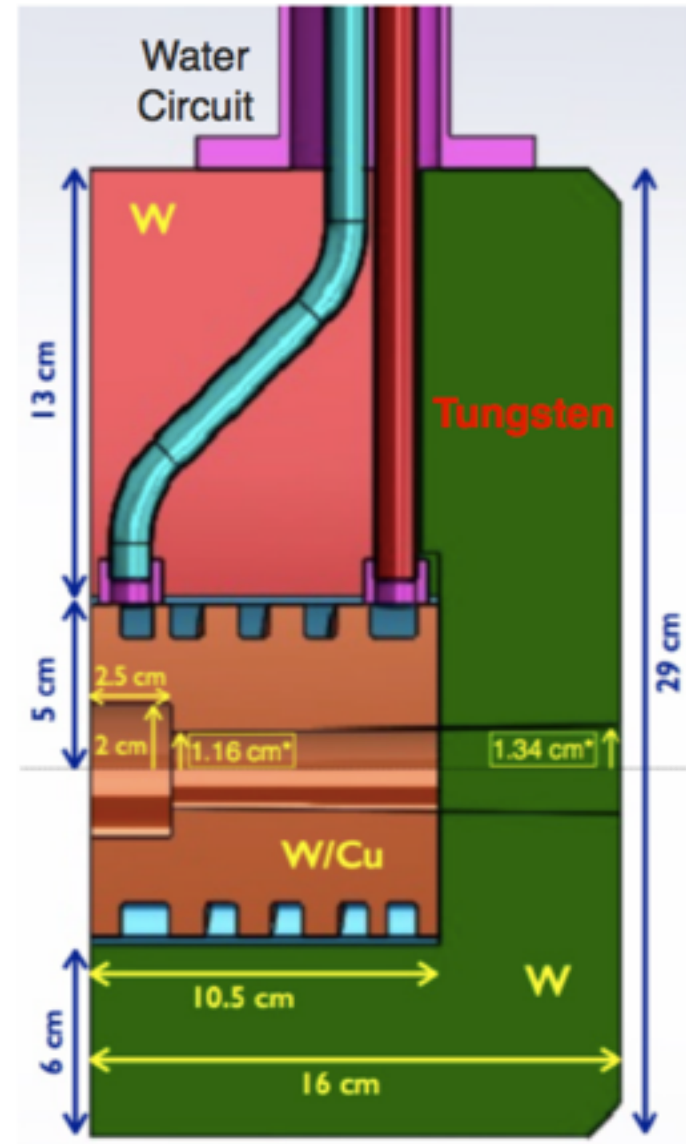
Solution: Collimator/Absorber

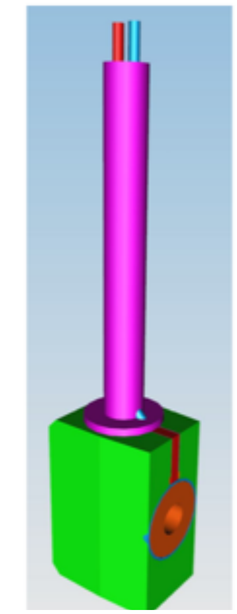
Build collimator based on Prex



Prex-II collimator

- Collimator front face 85cm from target, intercepts electrons >0.78^{o}
- 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

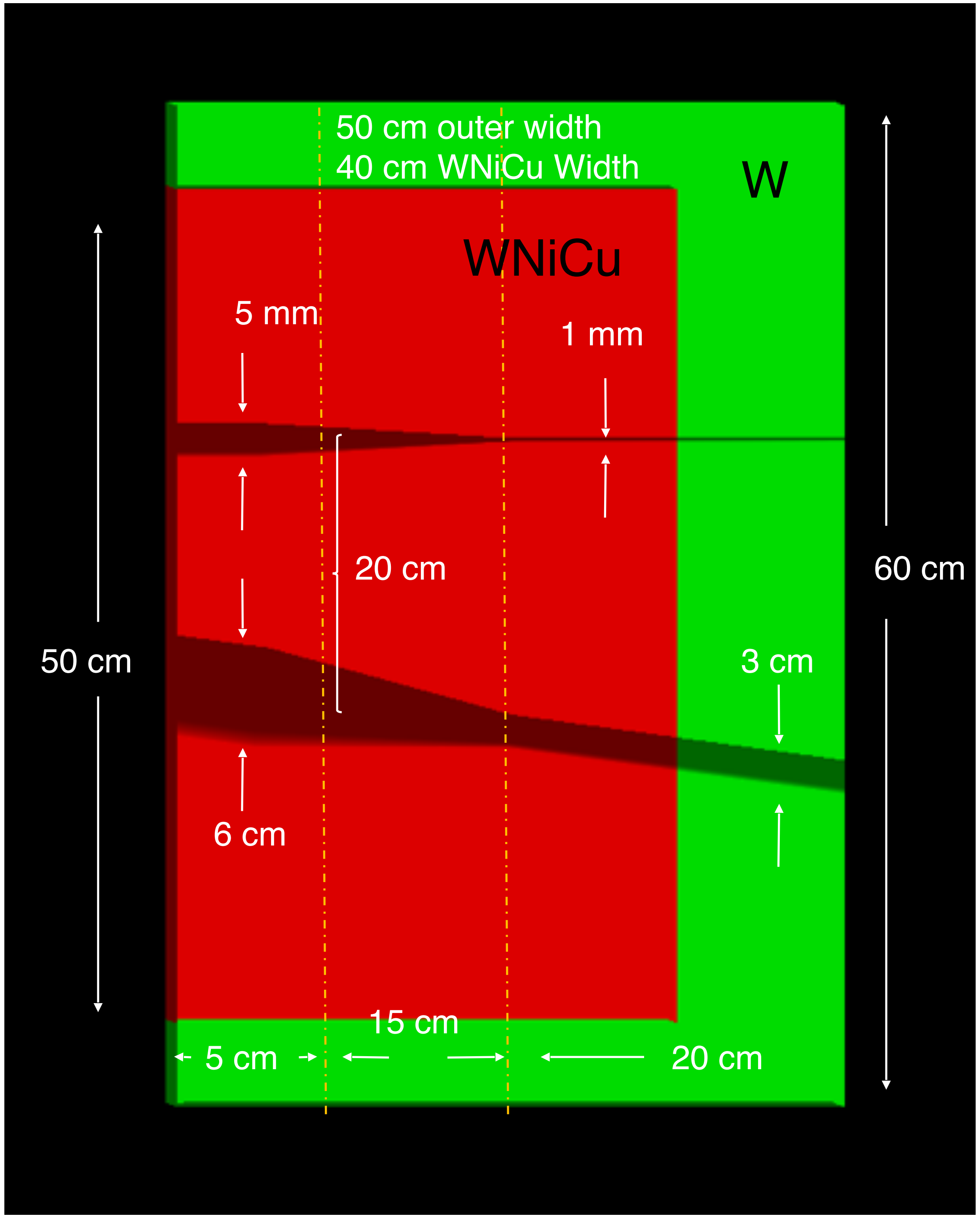




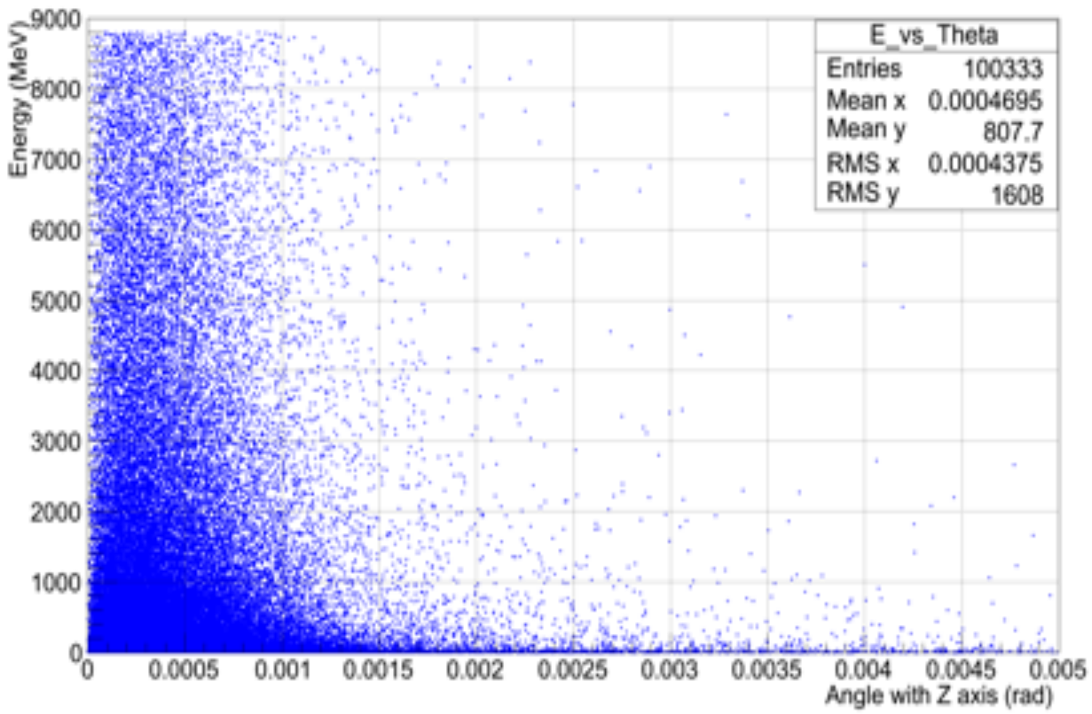
Moller plans a 4 kW collimator

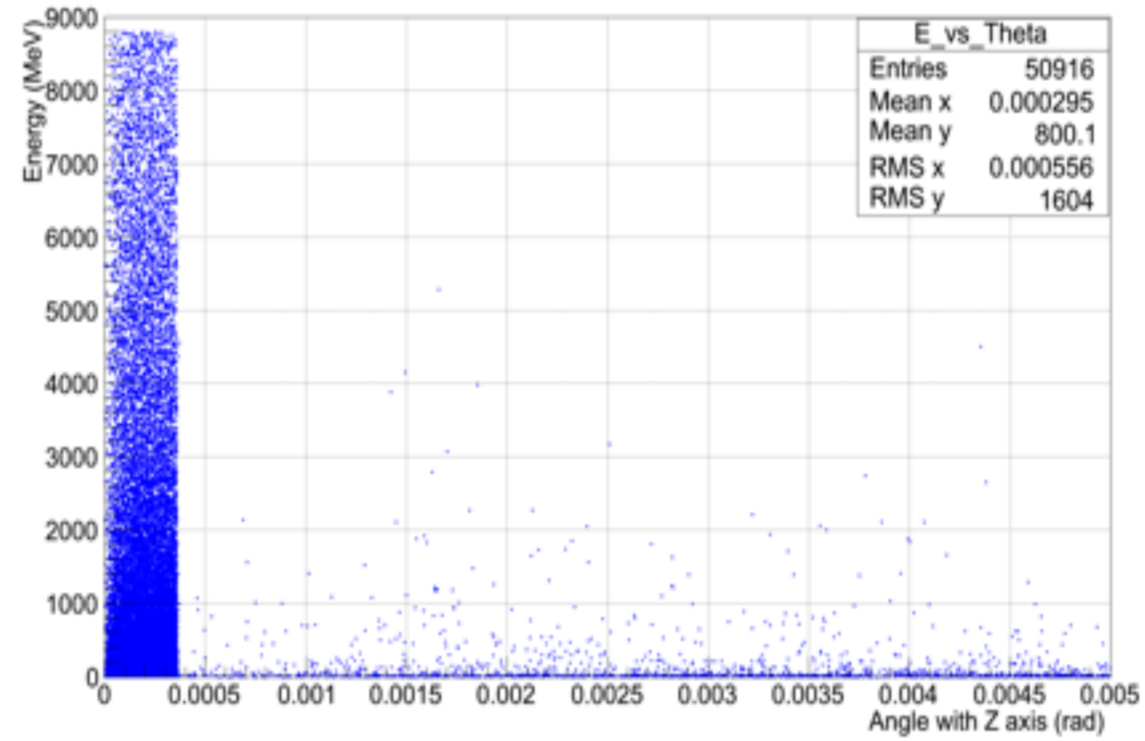
Caryn Palatchi, Hall A Mtg

Photon Collimator/ Electron Absorber



Photon Energy versus angle



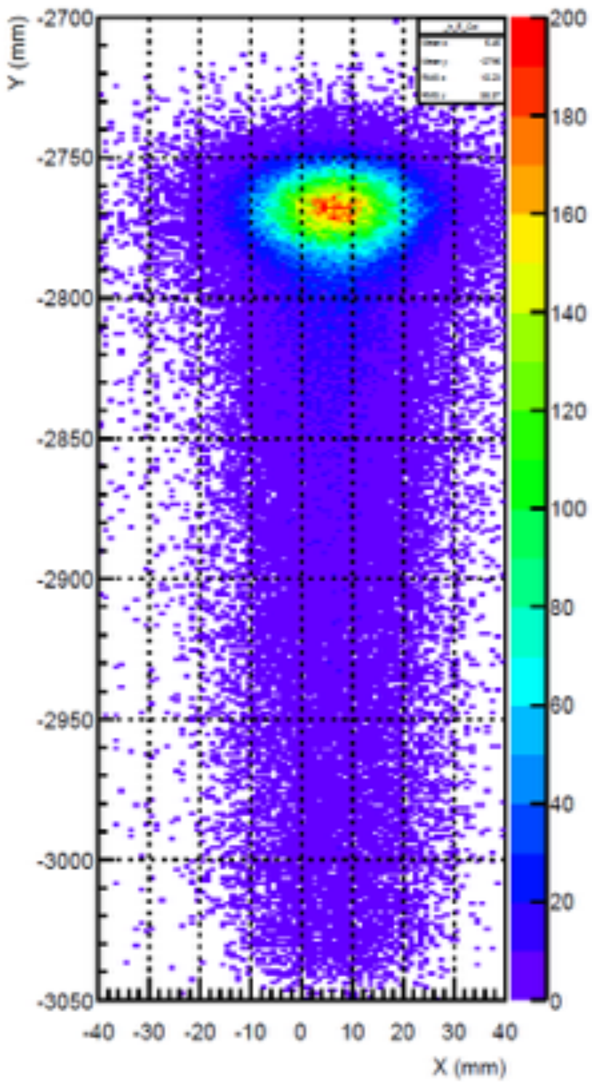


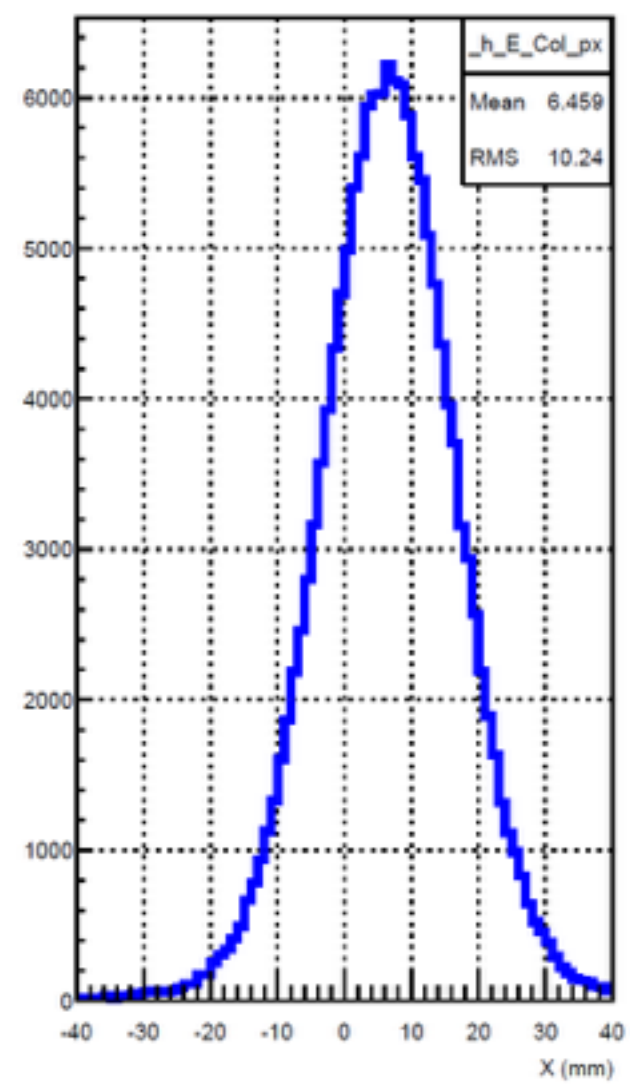
No collimator

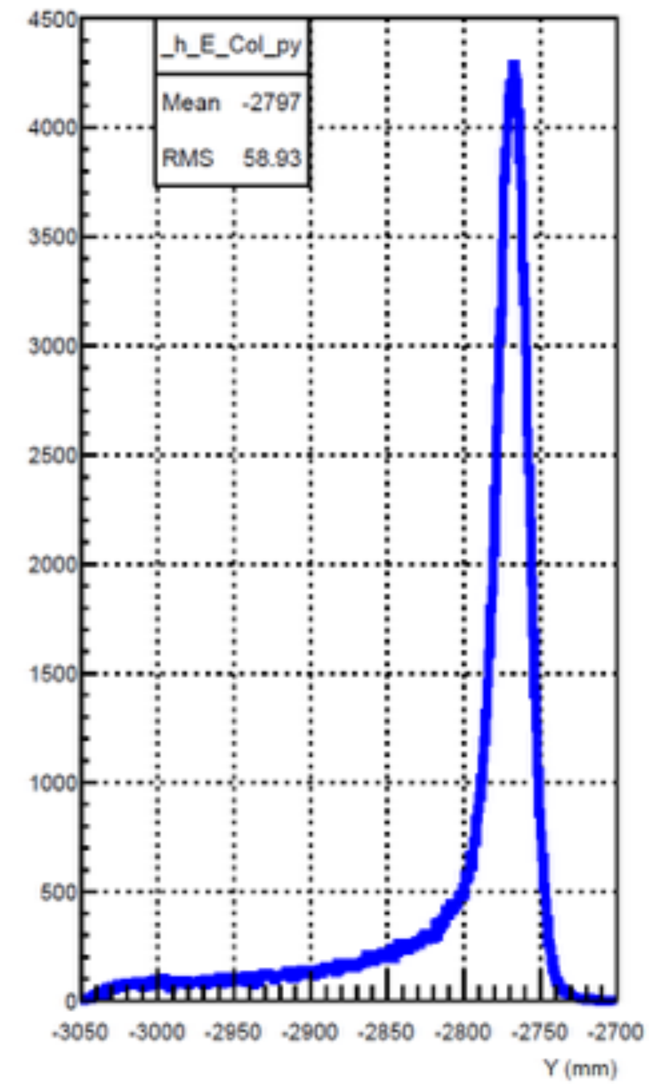
With collimator

Electron Beam Spread at dump with collimator

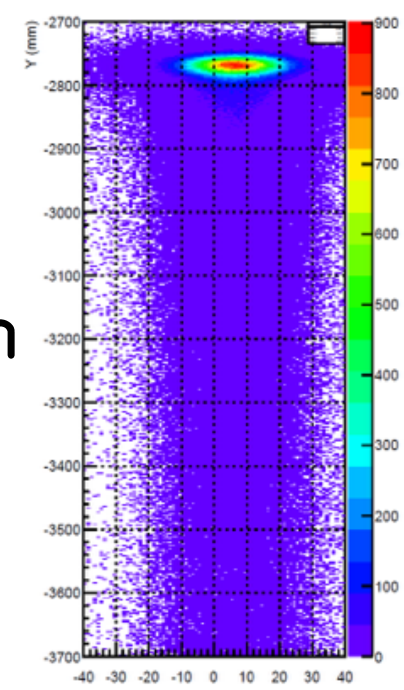
30 cm







Without spread was 100 cm



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

B	L0	L1	L1+L0	BDL	tht	thtd	Vert	DLoc	S
2.00	1.50	2.00	3.50	3.00	0.10	5.86	0.28	23.19	N
2.00	1.50	2.50	4.00	3.00	0.10	5.86	0.33	22.69	N
2.00	1.50	3.00	4.50	3.00	0.10	5.86	0.38	22.19	N
2.00	1.50	3.50	5.00	3.00	0.10	5.86	0.44	21.69	N
2.00	1.50	4.00	5.50	3.00	0.10	5.86	0.49	21.19	Y
2.00	2.00	2.00	4.00	4.00	0.14	7.81	0.41	16.40	N
2.00	2.00	2.50	4.50	4.00	0.14	7.81	0.48	15.90	N
2.00	2.00	3.00	5.00	4.00	0.14	7.81	0.55	15.40	Y
2.00	2.00	3.50	5.50	4.00	0.14	7.81	0.62	14.90	Y
2.00	2.00	4.00	6.00	4.00	0.14	7.81	0.69	14.40	Y

B	L0	L1	L1+L0	BDL	tht	thtd	Vert	DLoc	S
2.50	1.50	2.00	3.50	3.75	0.13	7.32	0.35	17.96	N
2.50	1.50	2.50	4.00	3.75	0.13	7.32	0.42	17.46	N
2.50	1.50	3.00	4.50	3.75	0.13	7.32	0.48	16.96	Y
2.50	1.50	3.50	5.00	3.75	0.13	7.32	0.55	16.46	Y
2.50	1.50	4.00	5.50	3.75	0.13	7.32	0.61	15.96	Y
2.50	2.00	2.00	4.00	5.00	0.17	9.77	0.52	12.47	Y
2.50	2.00	2.50	4.50	5.00	0.17	9.77	0.60	11.97	Y
2.50	2.00	3.00	5.00	5.00	0.17	9.77	0.69	11.47	Y
2.50	2.00	3.50	5.50	5.00	0.17	9.77	0.77	10.97	Y
2.50	2.00	4.00	6.00	5.00	0.17	9.77	0.86	10.47	Y

B	L0	L1	L1+L0	BDL	tht	thtd	Vert	DLoc	S
3.00	1.50	2.00	3.50	4.50	0.15	8.79	0.42	14.47	N
3.00	1.50	2.50	4.00	4.50	0.15	8.79	0.50	13.97	Y
3.00	1.50	3.00	4.50	4.50	0.15	8.79	0.58	13.47	Y
3.00	1.50	3.50	5.00	4.50	0.15	8.79	0.66	12.97	Y
3.00	1.50	4.00	5.50	4.50	0.15	8.79	0.73	12.47	Y
3.00	2.00	2.00	4.00	6.00	0.20	11.72	0.62	9.83	Y
3.00	2.00	2.50	4.50	6.00	0.20	11.72	0.72	9.33	Y
3.00	2.00	3.00	5.00	6.00	0.20	11.72	0.83	8.83	Y
3.00	2.00	3.50	5.50	6.00	0.20	11.72	0.93	8.33	Y
3.00	2.00	4.00	6.00	6.00	0.20	11.72	1.04	7.83	Y

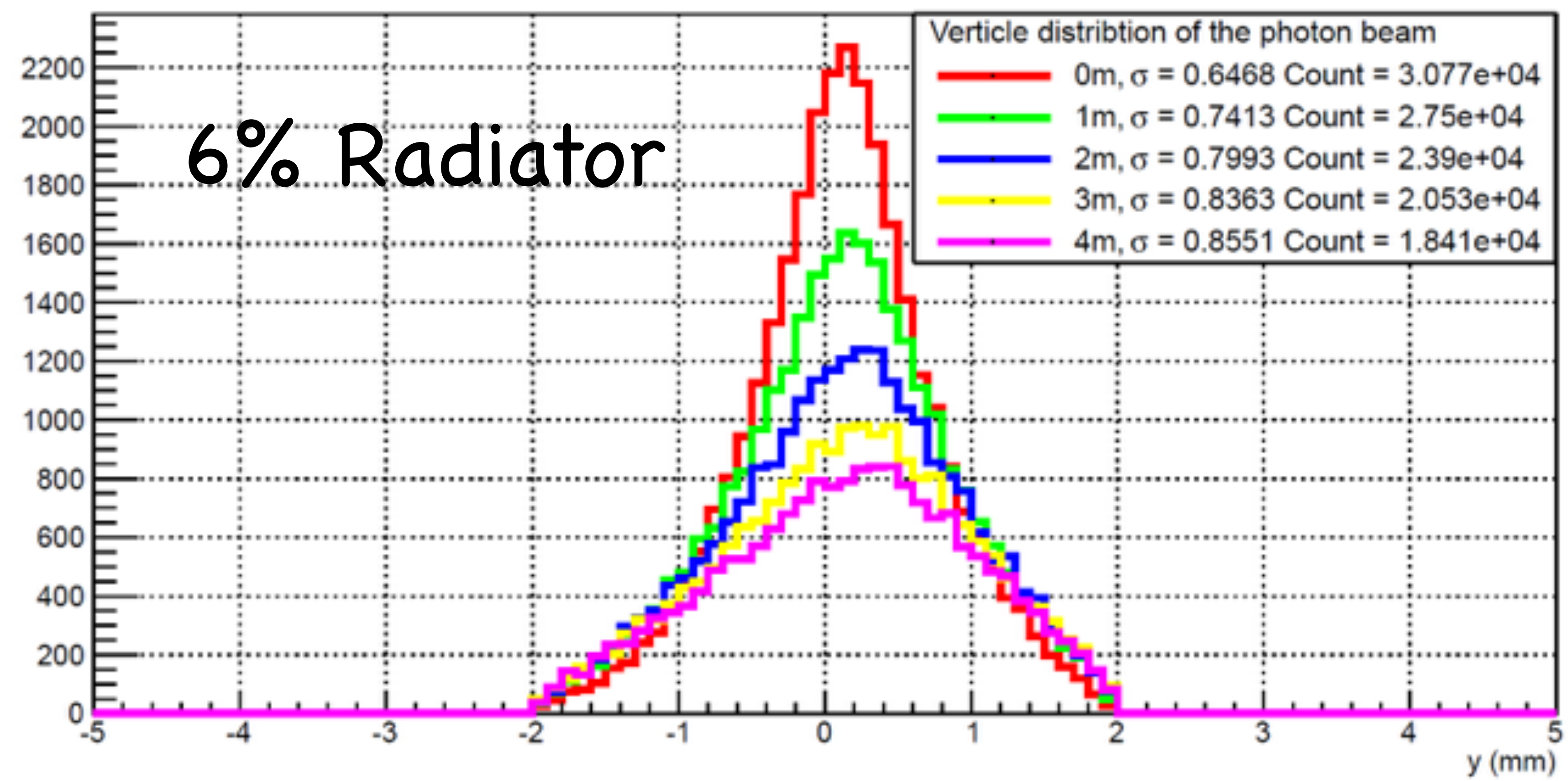
B	L0	L1	L1+L0	BDL	tht	thtd	Vert	DLoc	S
3.50	1.00	2.00	3.00	3.50	0.12	6.84	0.30	19.71	N
3.50	1.00	2.50	3.50	3.50	0.12	6.84	0.36	19.21	N
3.50	1.00	3.00	4.00	3.50	0.12	6.84	0.42	18.71	N
3.50	1.00	3.50	4.50	3.50	0.12	6.84	0.48	18.21	N
3.50	1.00	4.00	5.00	3.50	0.12	6.84	0.54	17.71	Y
3.50	1.50	2.00	3.50	5.25	0.18	10.25	0.50	11.97	Y
3.50	1.50	2.50	4.00	5.25	0.18	10.25	0.59	11.47	Y
3.50	1.50	3.00	4.50	5.25	0.18	10.25	0.68	10.97	Y
3.50	1.50	3.50	5.00	5.25	0.18	10.25	0.77	10.47	Y
3.50	1.50	4.00	5.50	5.25	0.18	10.25	0.86	9.97	Y
3.50	2.00	2.00	4.00	7.00	0.24	13.67	0.73	7.94	Y
3.50	2.00	2.50	4.50	7.00	0.24	13.67	0.85	7.44	Y
3.50	2.00	3.00	5.00	7.00	0.24	13.67	0.97	6.94	Y
3.50	2.00	3.50	5.50	7.00	0.24	13.67	1.09	6.44	Y
3.50	2.00	4.00	6.00	7.00	0.24	13.67	1.21	5.94	Y

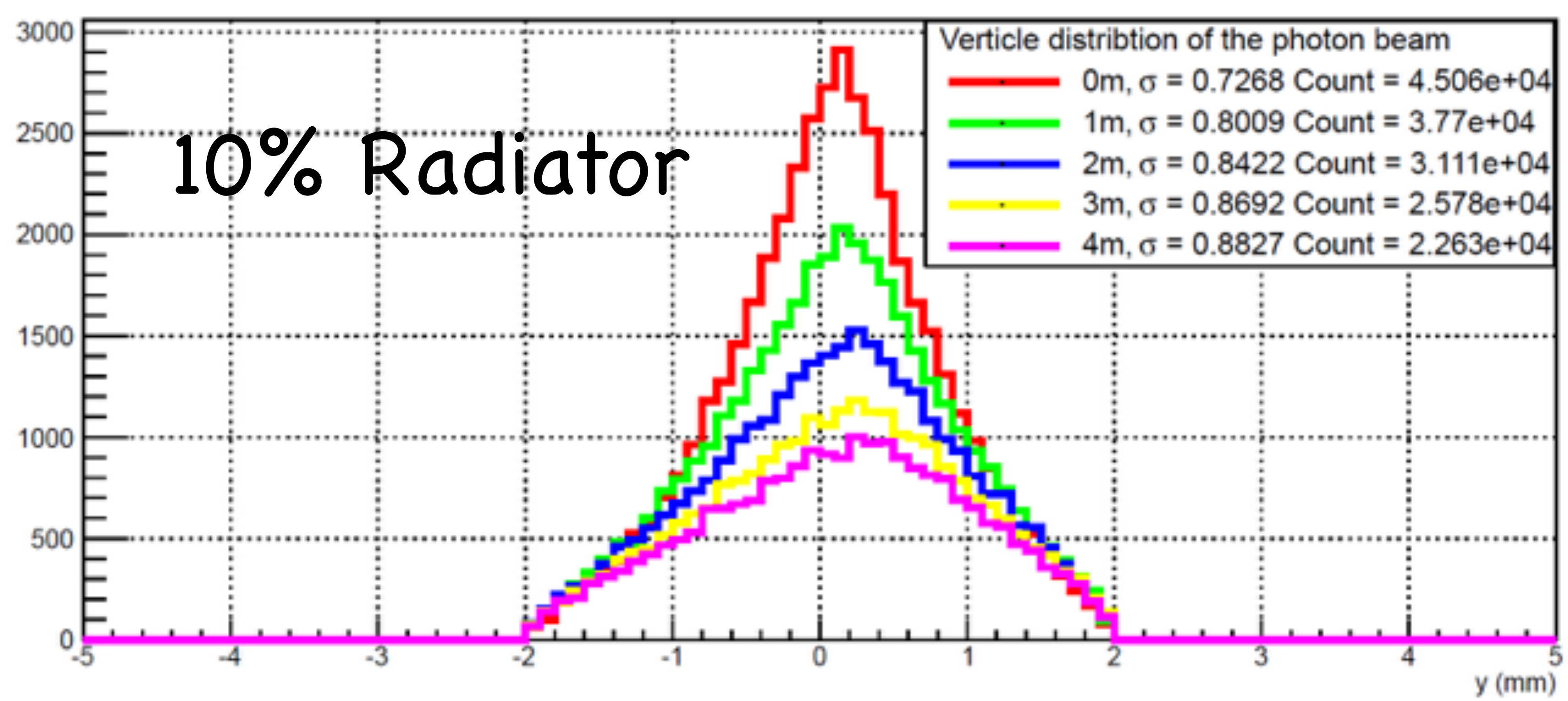
B	L0	L1	L1+L0	BDL	tht	thtd	Vert	DLoc	S
4.00	1.00	2.00	3.00	4.00	0.14	7.81	0.34	16.90	N
4.00	1.00	2.50	3.50	4.00	0.14	7.81	0.41	16.40	N
4.00	1.00	3.00	4.00	4.00	0.14	7.81	0.48	15.90	N
4.00	1.00	3.50	4.50	4.00	0.14	7.81	0.55	15.40	Y
4.00	1.00	4.00	5.00	4.00	0.14	7.81	0.62	14.90	Y
4.00	1.50	2.00	3.50	6.00	0.20	11.72	0.57	10.08	Y
4.00	1.50	2.50	4.00	6.00	0.20	11.72	0.67	9.58	Y
4.00	1.50	3.00	4.50	6.00	0.20	11.72	0.78	9.08	Y
4.00	1.50	3.50	5.00	6.00	0.20	11.72	0.88	8.58	Y
4.00	1.50	4.00	5.50	6.00	0.20	11.72	0.98	8.08	Y
4.00	2.00	2.00	4.00	8.00	0.27	15.63	0.83	6.52	Y
4.00	2.00	2.50	4.50	8.00	0.27	15.63	0.97	6.02	Y
4.00	2.00	3.00	5.00	8.00	0.27	15.63	1.11	5.52	Y
4.00	2.00	3.50	5.50	8.00	0.27	15.63	1.25	5.02	Y
4.00	2.00	4.00	6.00	8.00	0.27	15.63	1.39	4.52	N

B	L0	L1	L1+L0	BDL	tht	thtd	Vert	DLoc	S
4.50	1.00	2.00	3.00	4.50	0.15	8.79	0.39	14.72	N
4.50	1.00	2.50	3.50	4.50	0.15	8.79	0.46	14.22	N
4.50	1.00	3.00	4.00	4.50	0.15	8.79	0.54	13.72	Y
4.50	1.00	3.50	4.50	4.50	0.15	8.79	0.62	13.22	Y
4.50	1.00	4.00	5.00	4.50	0.15	8.79	0.70	12.72	Y
4.50	1.50	2.00	3.50	6.75	0.23	13.18	0.64	8.61	Y
4.50	1.50	2.50	4.00	6.75	0.23	13.18	0.76	8.11	Y
4.50	1.50	3.00	4.50	6.75	0.23	13.18	0.88	7.61	Y
4.50	1.50	3.50	5.00	6.75	0.23	13.18	0.99	7.11	Y
4.50	1.50	4.00	5.50	6.75	0.23	13.18	1.11	6.61	Y
4.50	2.00	2.00	4.00	9.00	0.31	17.58	0.94	5.40	Y
4.50	2.00	2.50	4.50	9.00	0.31	17.58	1.10	4.90	Y
4.50	2.00	3.00	5.00	9.00	0.31	17.58	1.26	4.40	Y
4.50	2.00	3.50	5.50	9.00	0.31	17.58	1.42	3.90	N
4.50	2.00	4.00	6.00	9.00	0.31	17.58	1.58	3.40	N

B	L0	L1	L1+L0	BDL	tht	thtd	Vert	DLoc	S
5.00	1.00	2.00	3.00	5.00	0.17	9.77	0.43	12.97	N
5.00	1.00	2.50	3.50	5.00	0.17	9.77	0.52	12.47	Y
5.00	1.00	3.00	4.00	5.00	0.17	9.77	0.60	11.97	Y
5.00	1.00	3.50	4.50	5.00	0.17	9.77	0.69	11.47	Y
5.00	1.00	4.00	5.00	5.00	0.17	9.77	0.77	10.97	Y
5.00	1.50	2.00	3.50	7.50	0.26	14.65	0.72	7.44	Y
5.00	1.50	2.50	4.00	7.50	0.26	14.65	0.85	6.94	Y
5.00	1.50	3.00	4.50	7.50	0.26	14.65	0.98	6.44	Y
5.00	1.50	3.50	5.00	7.50	0.26	14.65	1.11	5.94	Y
5.00	1.50	4.00	5.50	7.50	0.26	14.65	1.24	5.44	Y
5.00	2.00	2.00	4.00	10.00	0.34	19.53	1.05	4.50	Y
5.00	2.00	2.50	4.50	10.00	0.34	19.53	1.23	4.00	Y
5.00	2.00	3.00	5.00	10.00	0.34	19.53	1.41	3.50	N
5.00	2.00	3.50	5.50	10.00	0.34	19.53	1.59	3.00	N
5.00	2.00	4.00	6.00	10.00	0.34	19.53	1.76	2.50	N

Flux at target in different locations from collimator





Collimator chosen to fix spot size

Table of Flux Vs. Target Location

Distance From Collimator (m)	Flux for 10% radiator per 1μA	Flux for 6% radiator per 1μA
0	2.8E+11	1.9E+11
1	2.4E+11	1.7E+11
2	1.9E+11	1.5E+11
3	1.6E+11	1.3E+11
4	1.4E+11	1.1E+11

Energy Deposited

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

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

Beam Energy (GeV)	Beam Current (uA)	Radiator	Distance	Flux Lost (%)	gamma/s
4.4	0.1	6%	100	1.9	2.1E+10
4.4	3	6%	633	63.4	2.4E+11
4.4	0.1	10%	100	3.3	3.5E+10
4.4	3	10%	633	71.6	3.0E+11
8.8	0.1	6%	100	0.8	2.2E+10
8.8	3	6%	633	28.7	4.8E+11
8.8	0.1	10%	100	0.9	3.6E+10
8.8	3	10%	633	40.6	6.6E+11

$0.5 < E\gamma/\text{Beam} < 0.95$, requiring the spot size on target within a 1mm (rms) radius circle.

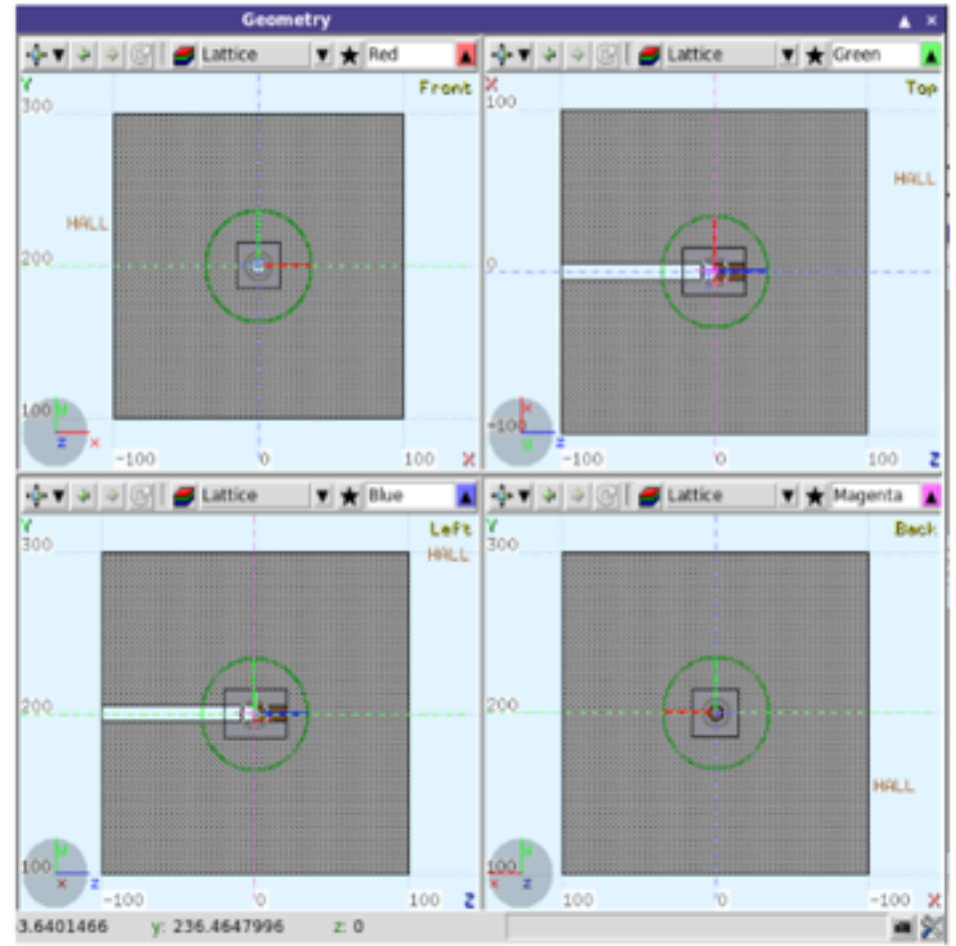
4.2*10^11

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!

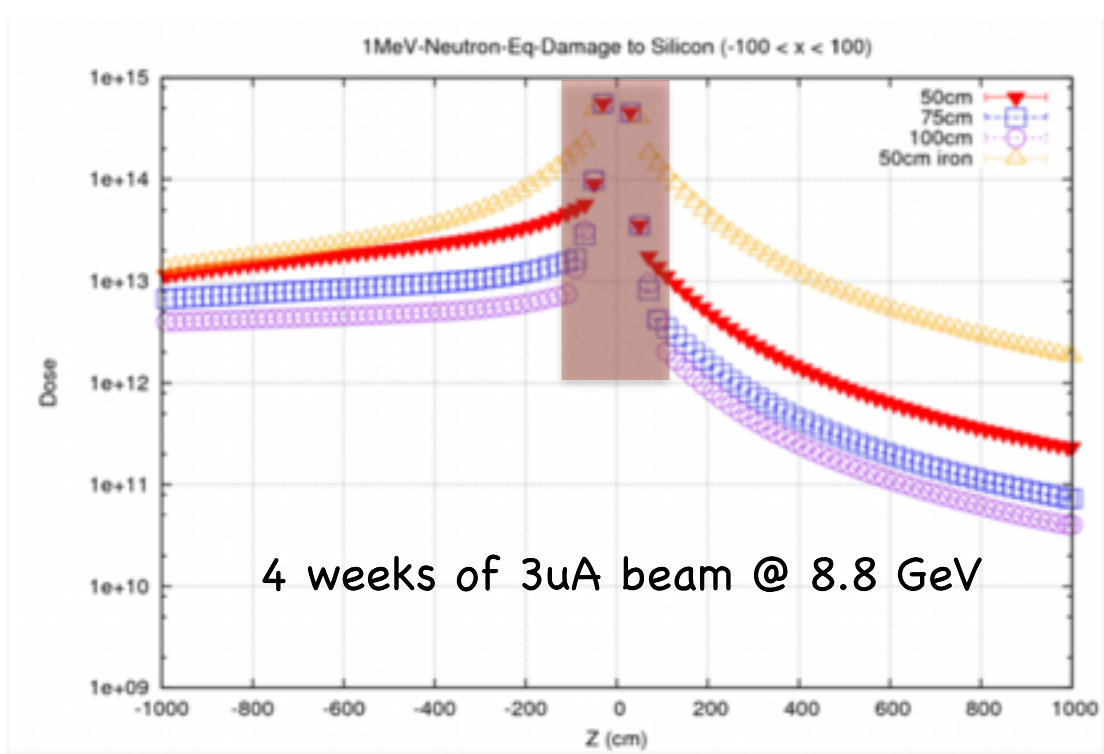
If cooling power was only issue we could put 8-10 μA on radiator to illuminate the PT: target would operate "normally".

Fluka Work

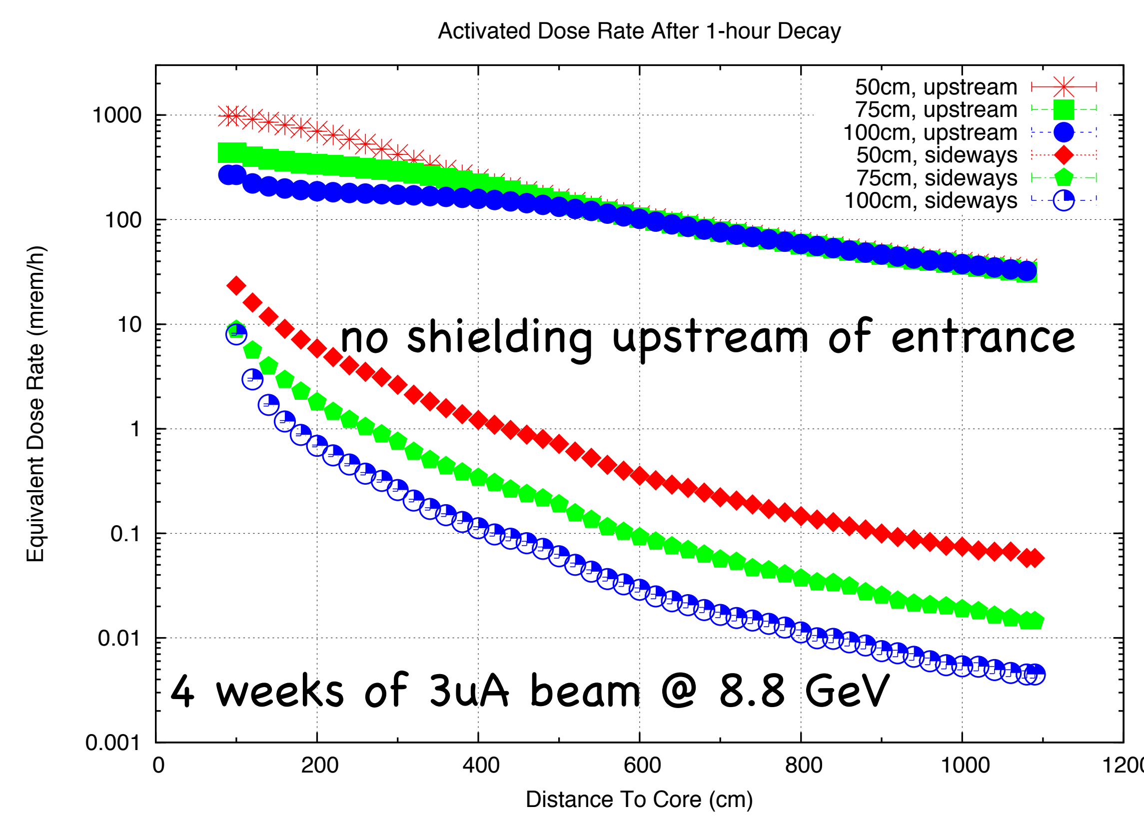
- Cylinder core: R=5cm, L=20cm (HD17)
- Dump box: 30cm x 30cm x 40cm (Lead)
- The core is aligned to the back face of the dump, therefore there is 20 cm entrance space inside lead box
- Concrete shielding box: 2m x 2m x 2m, with entrance tunnel - 80 cm



Pivot -1400 cm



Pivot 1400 cm



Fluka Work, previously

- Cylinder core: R=5cm, L=20cm (HD17)
- Dump box: 30cm x 30cm x 40cm (Lead)
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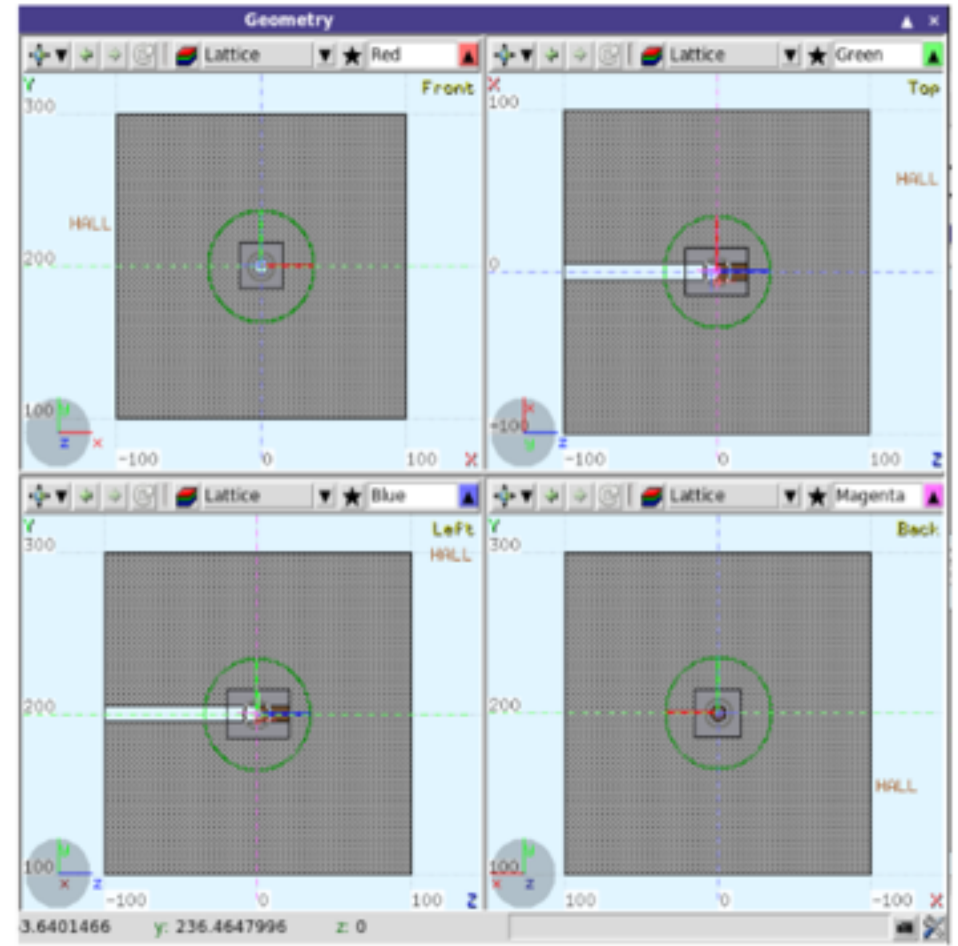
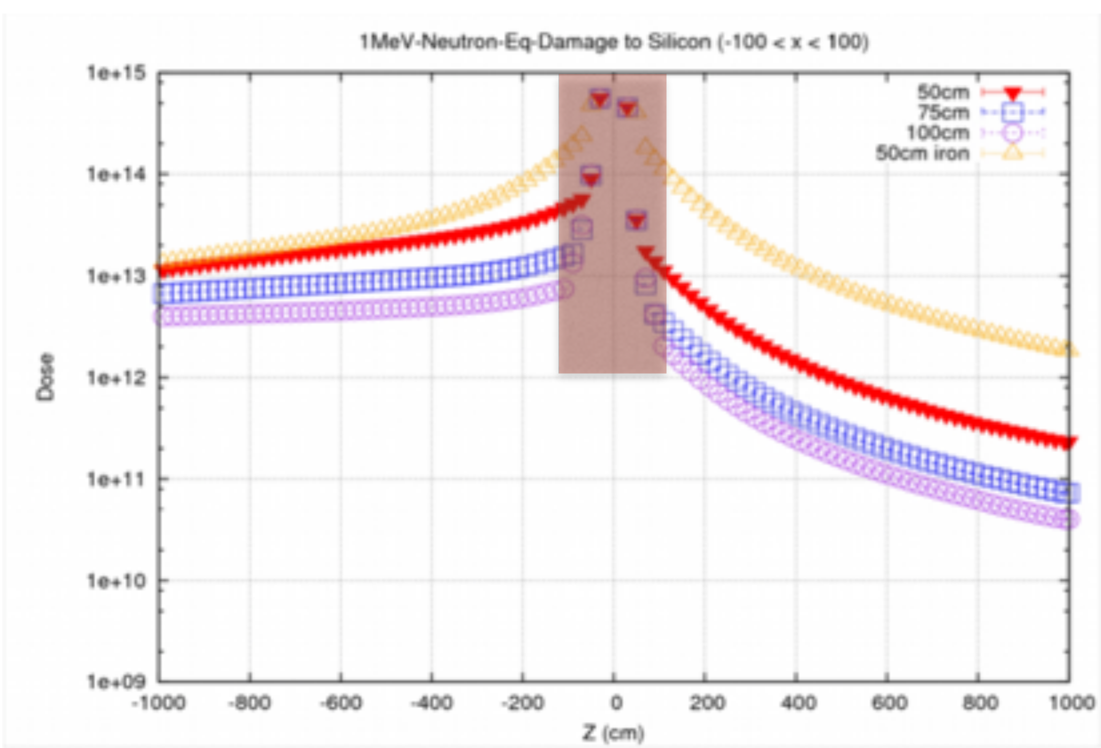
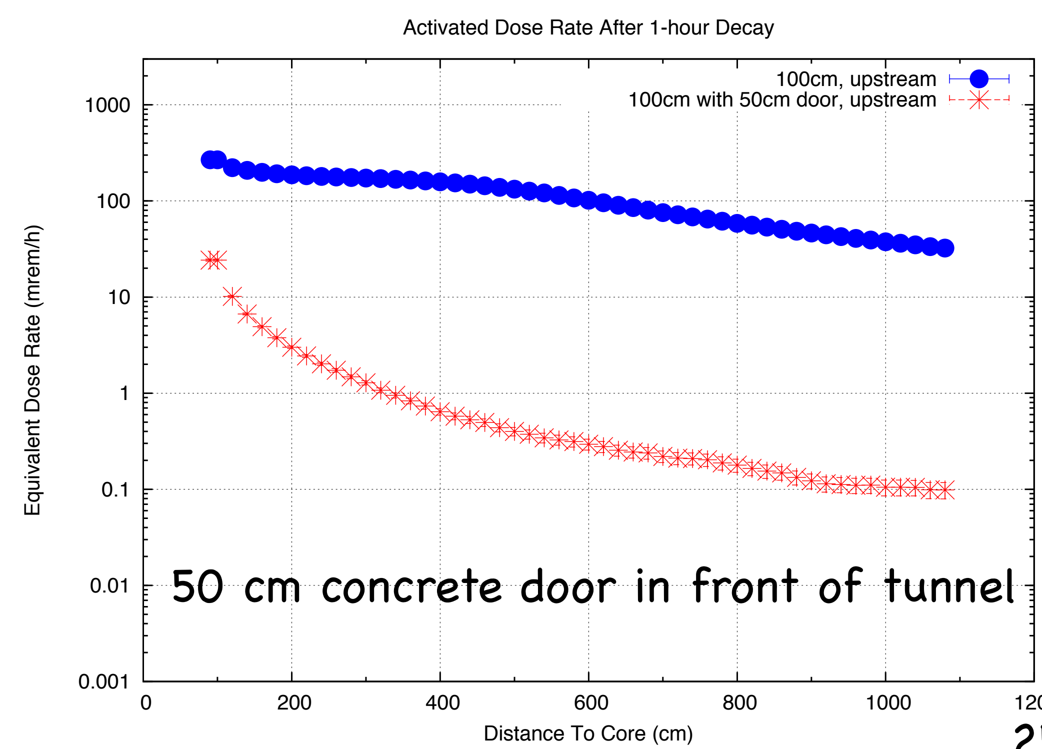


Pivot -1400 cm

4 weeks of 3uA beam @ 8.8 GeV

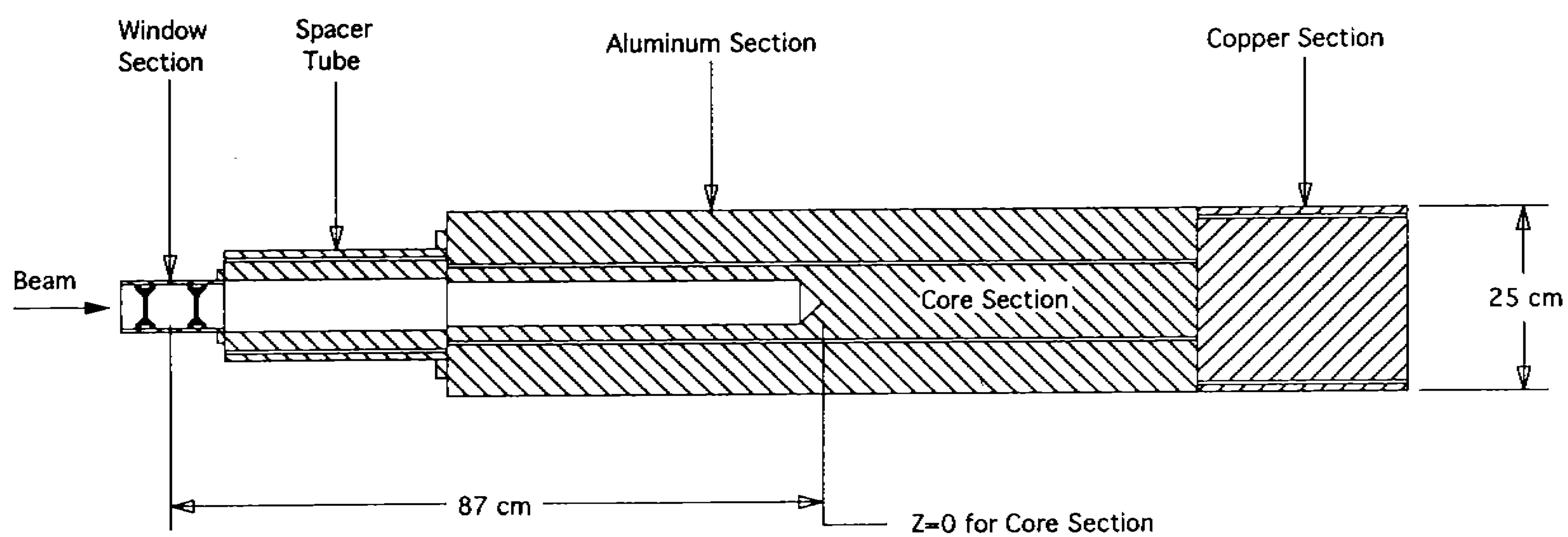
Pivot 1400 cm





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 …



Upgraded Tune up Dump, Side View

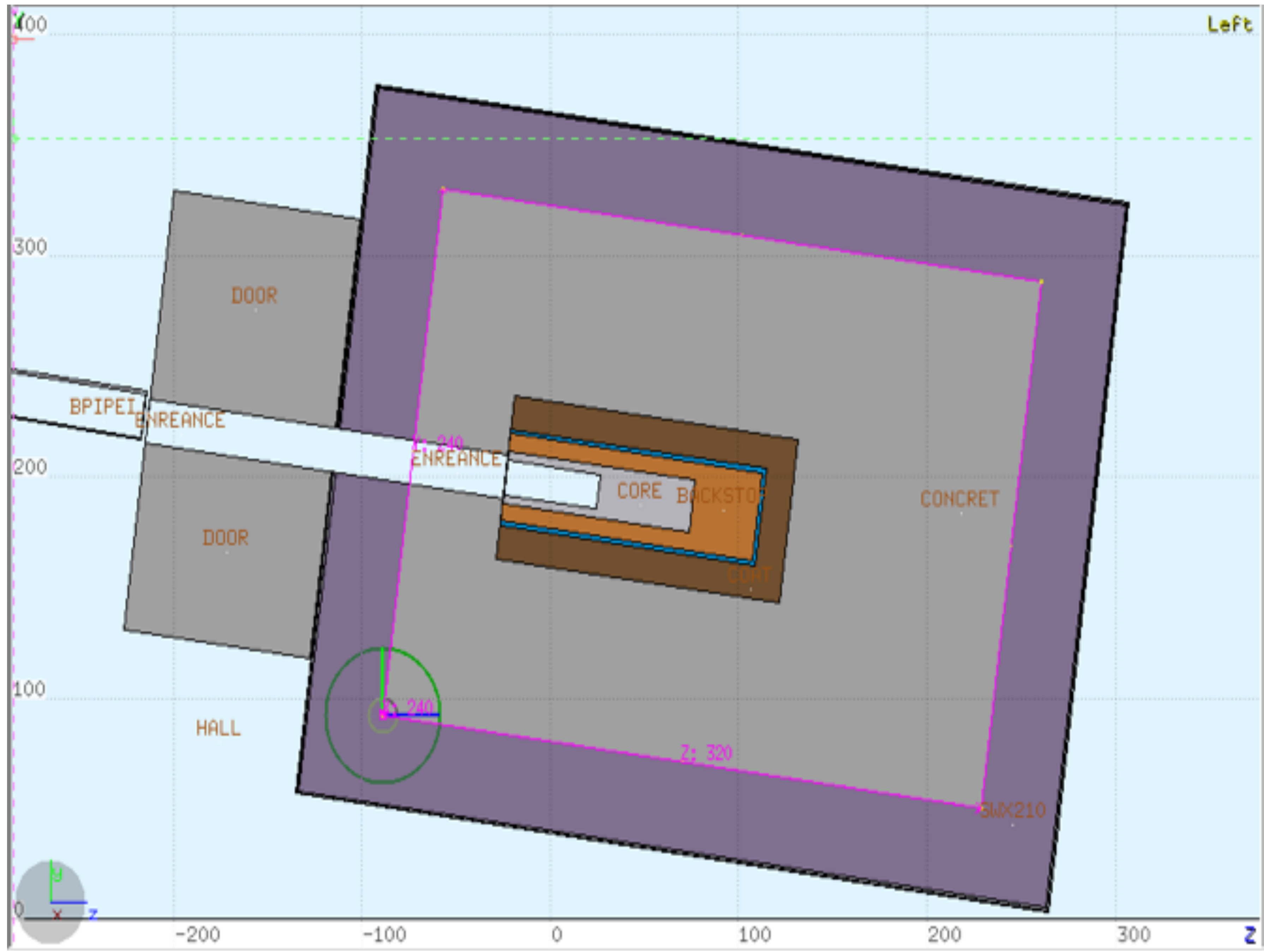
Aluminum cylinder core: R=12cm, L=100cm, drilled by 50cm deep as entrance, entrance radius=8cm

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

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

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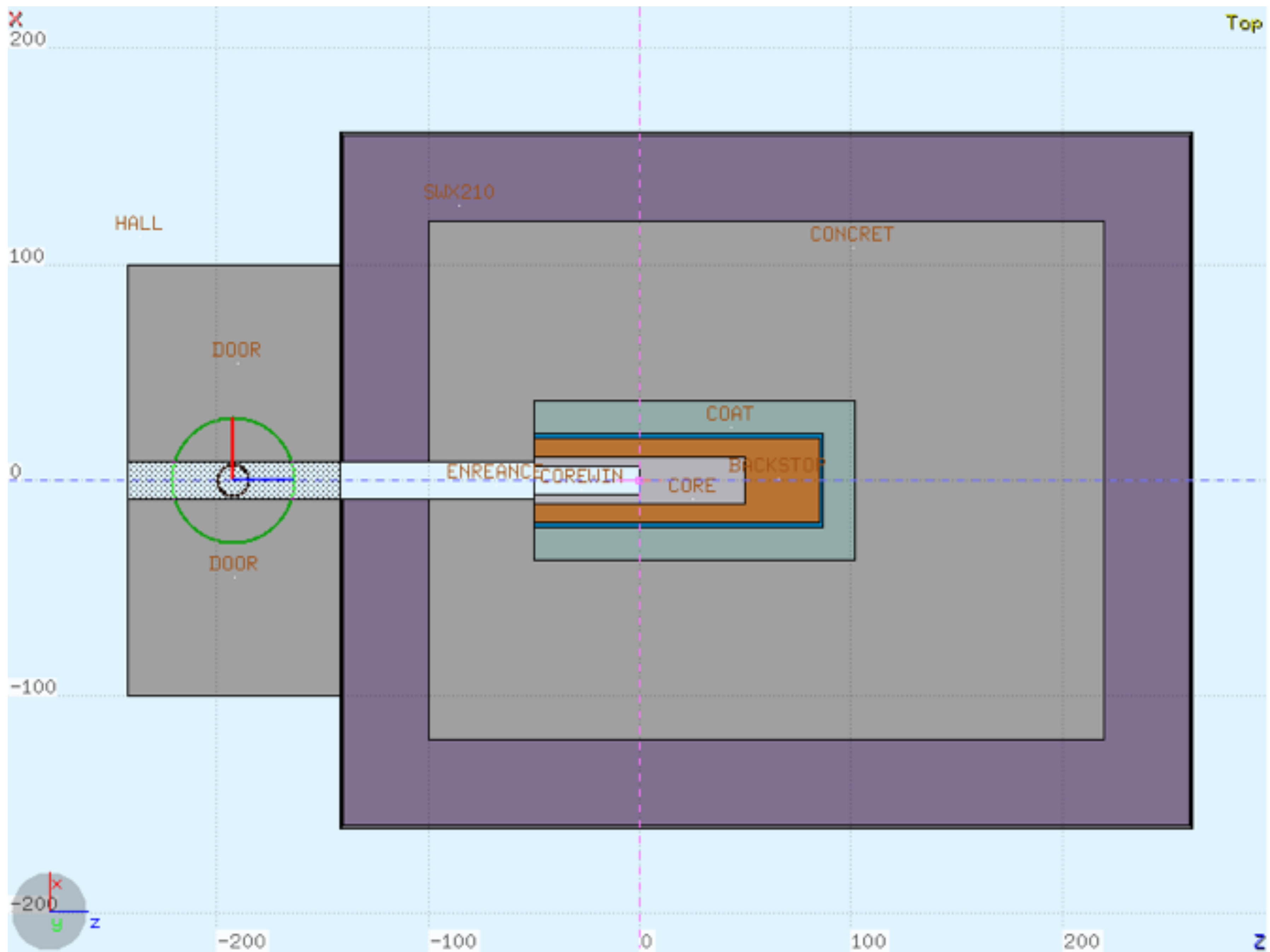

Shift the door horizontally (right) by 20cm when the beam is off to block the dump entrance

Upgraded Tune up Dump, Top View

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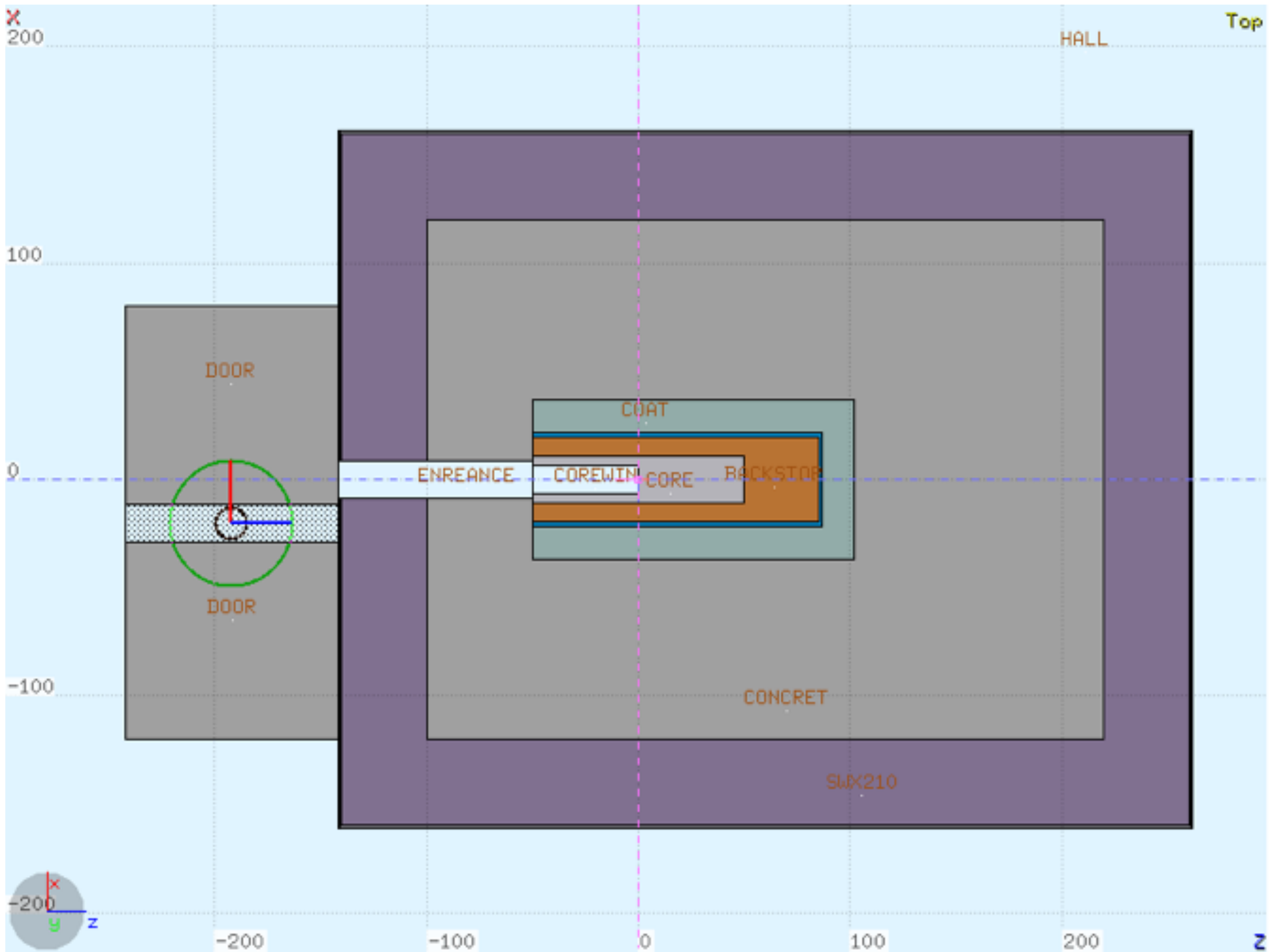
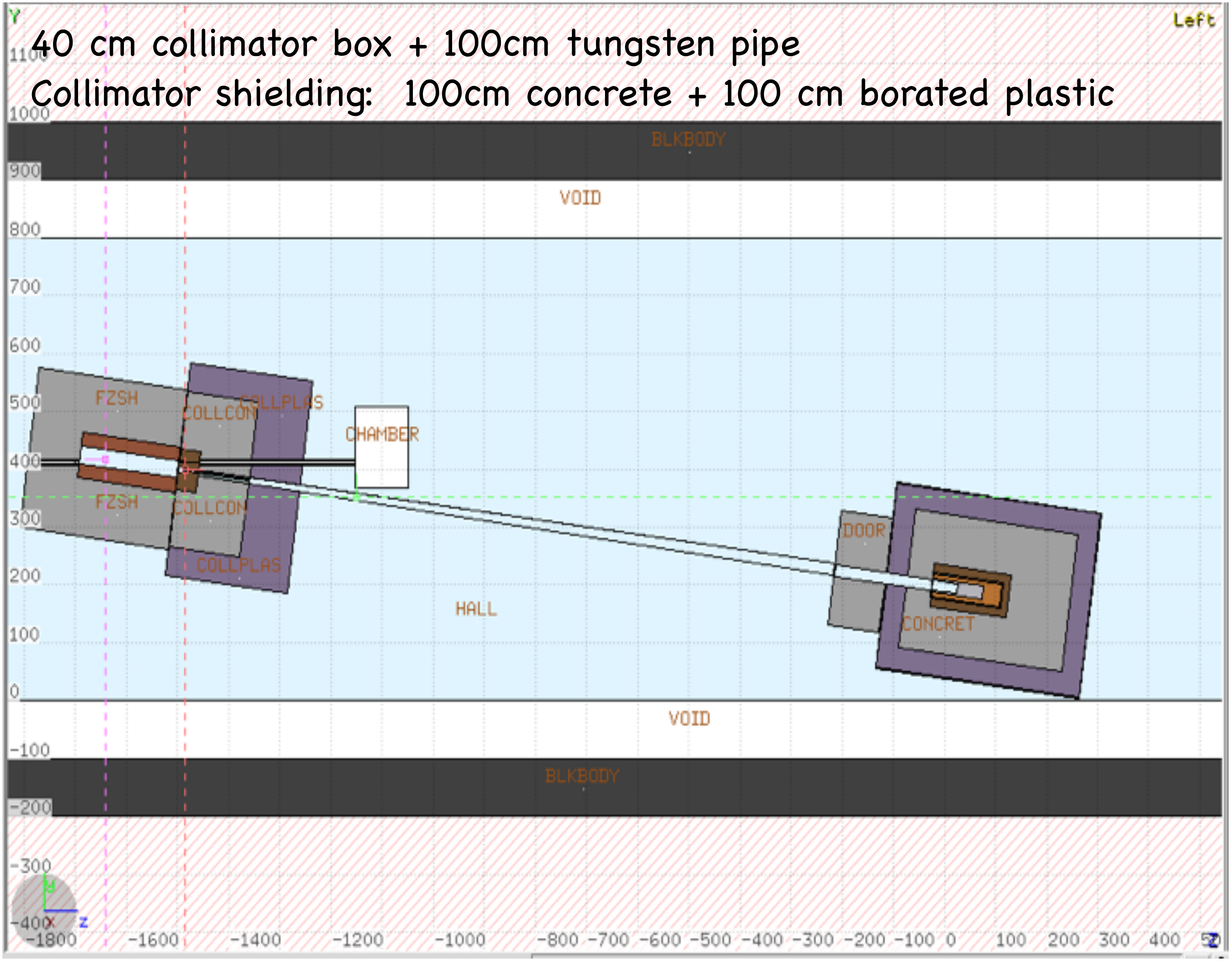


Shift the door horizontally (right) by 20cm when the beam is off to block the dump entrance

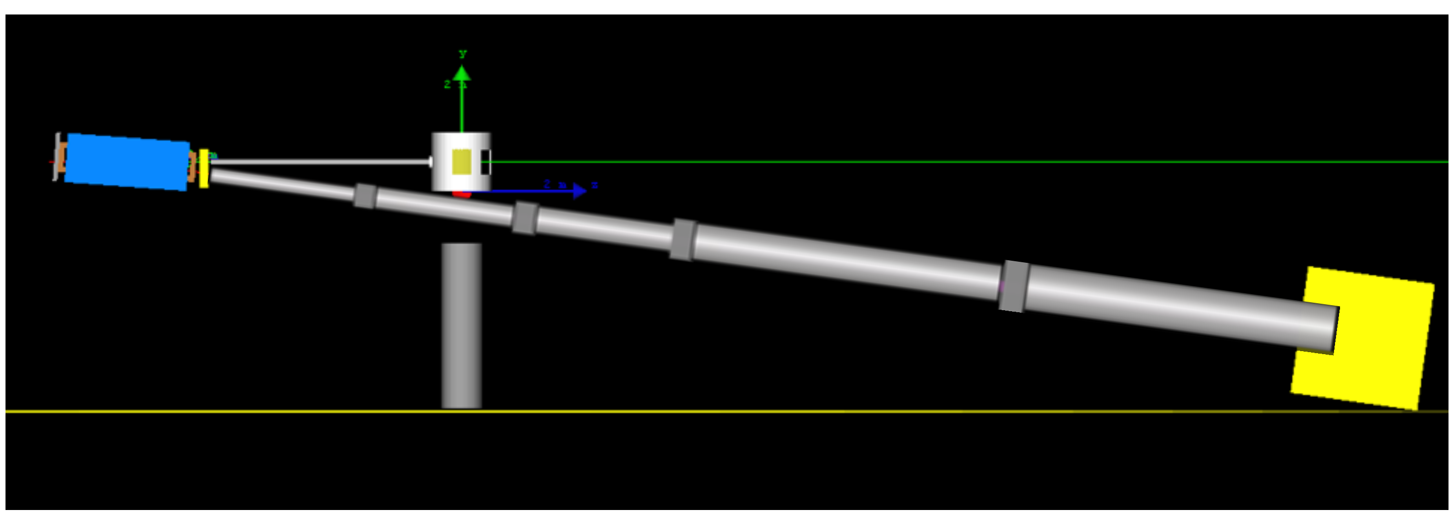
Dipole + Collimator + Dump



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

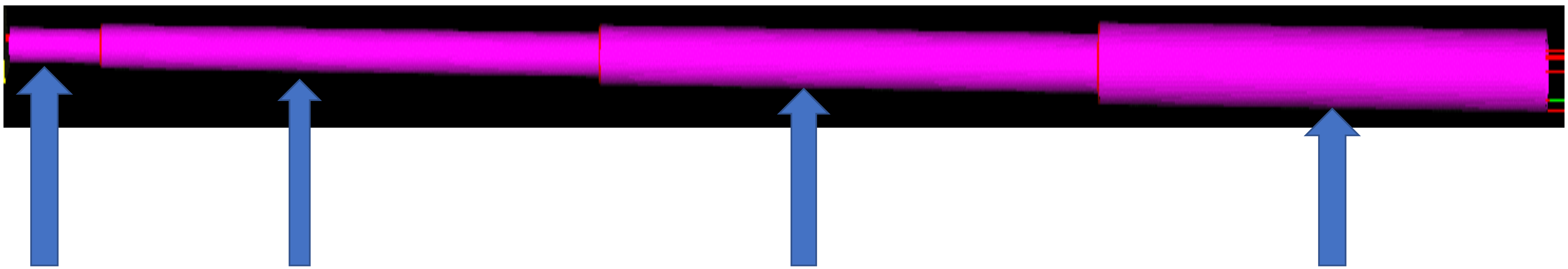
- Neither collimator nor local dump present extraordinary challenges

- We invite open collaboration wth no preconditions

What do we want?

Extra

Beam Pipe



L = 1 m
R = 7 cm

L = 5.5 m
R = 9 cm

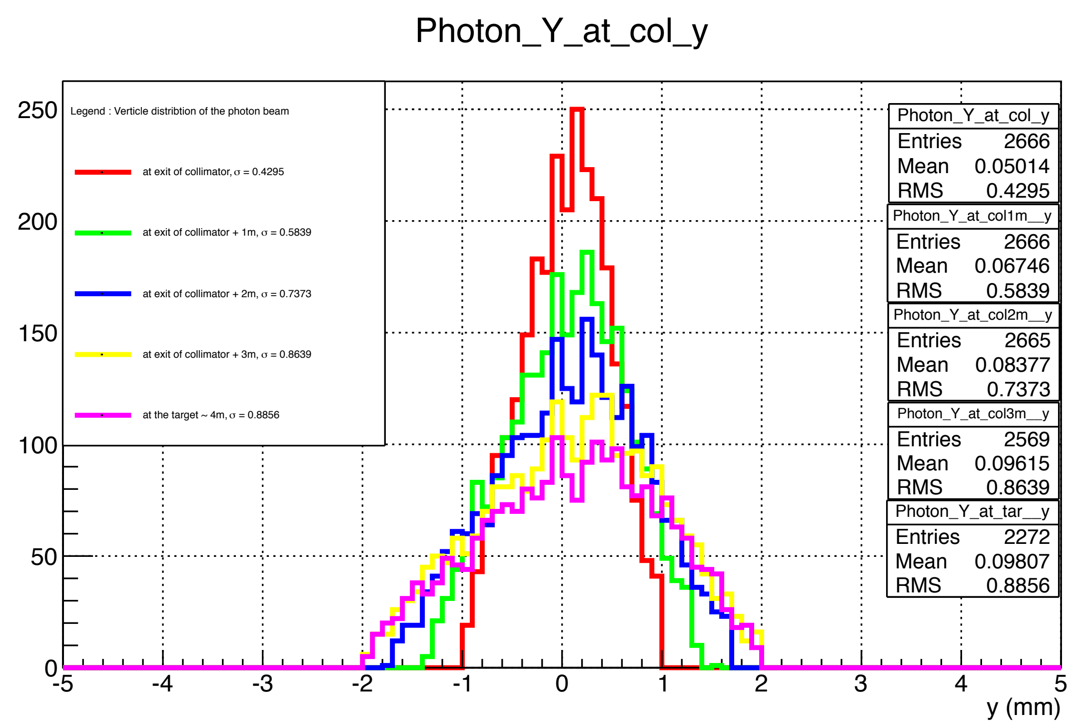
L = 5.5 m
R = 12.5 cm

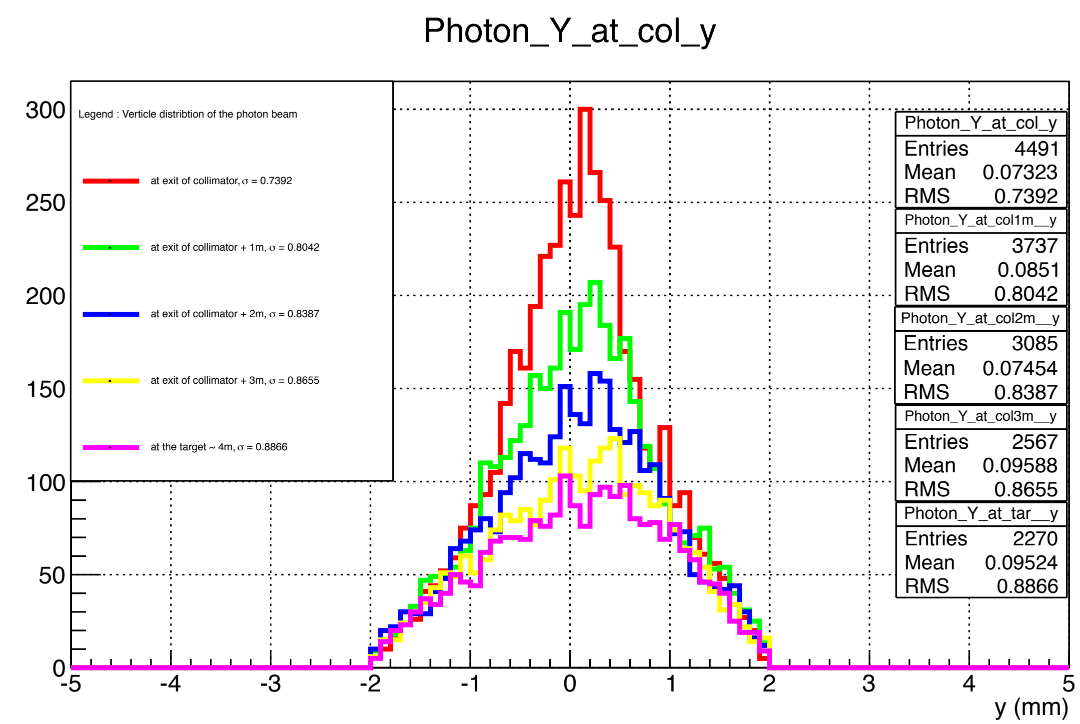
L = 4.94 m
R = 17.5 cm

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

Photon spot at target

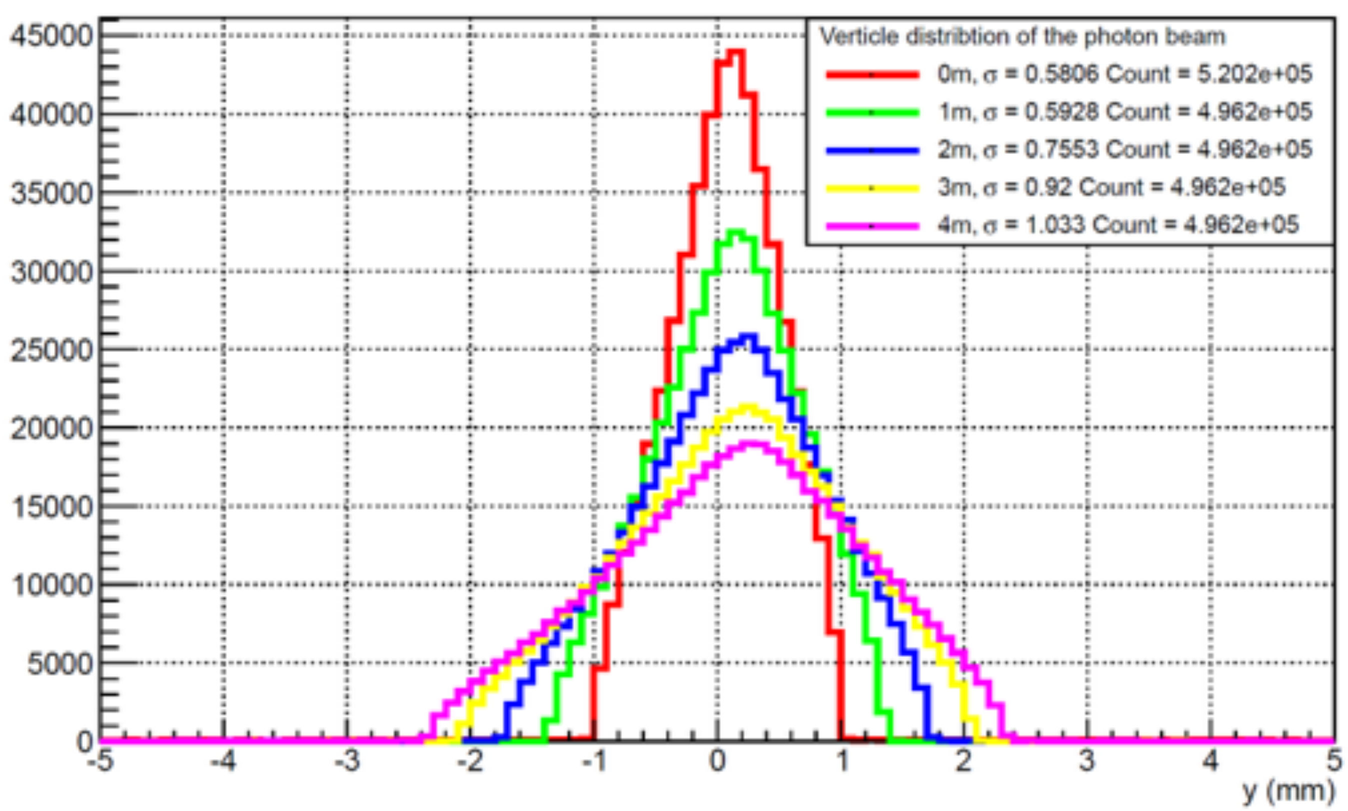
Important to have small spot to preserve inherent resolution of NPS
Poor knowledge of xbeam, ybeam leads to smearing in photon arm
HMS has very good momentum resolution
1mm offset in vertical leads to a shift of 0.1% in Δp
1mm offset in horizontal leads to 1mr shift in the proton in-plane angle
Through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



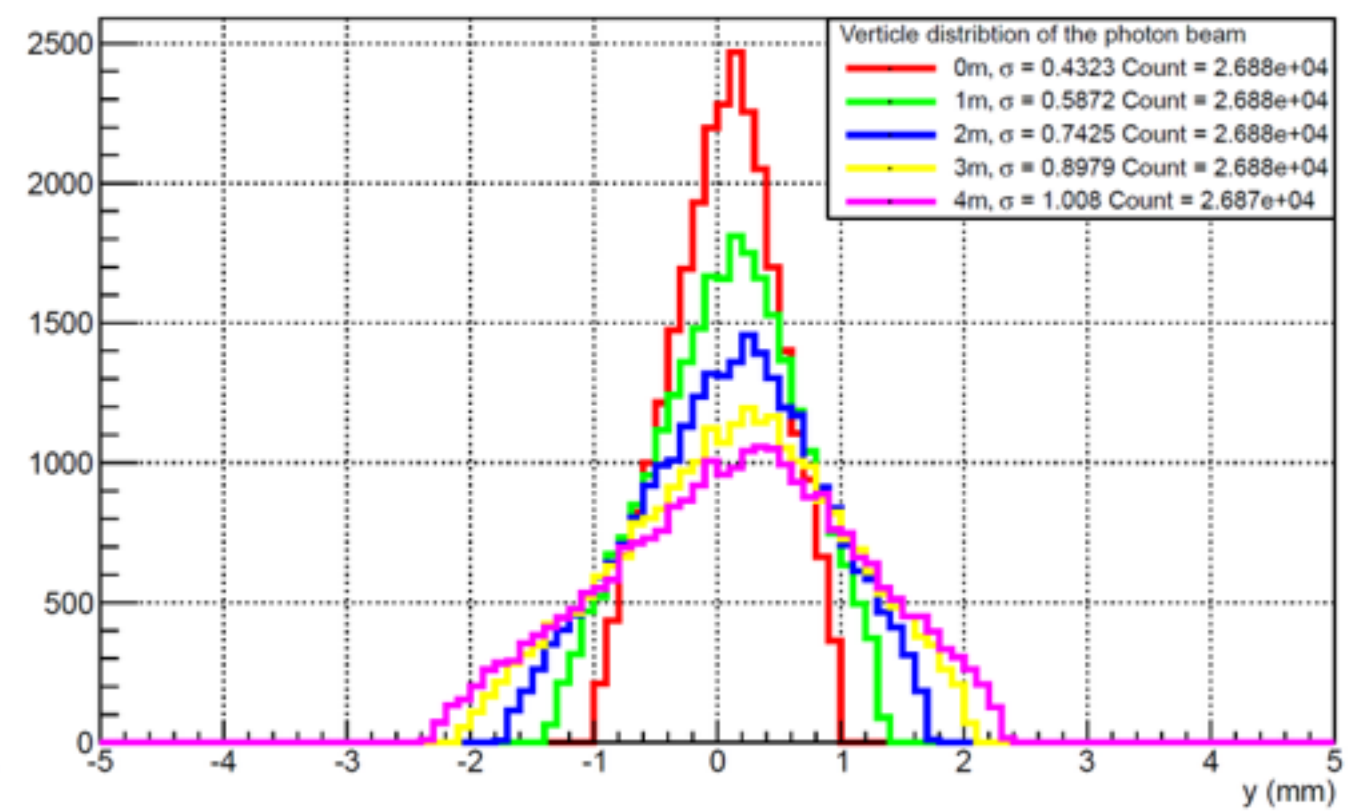


With energy cut and cut on 2mm spot

Photon Spread : With Collimator hole 1.0mm (Fixed collimator size)



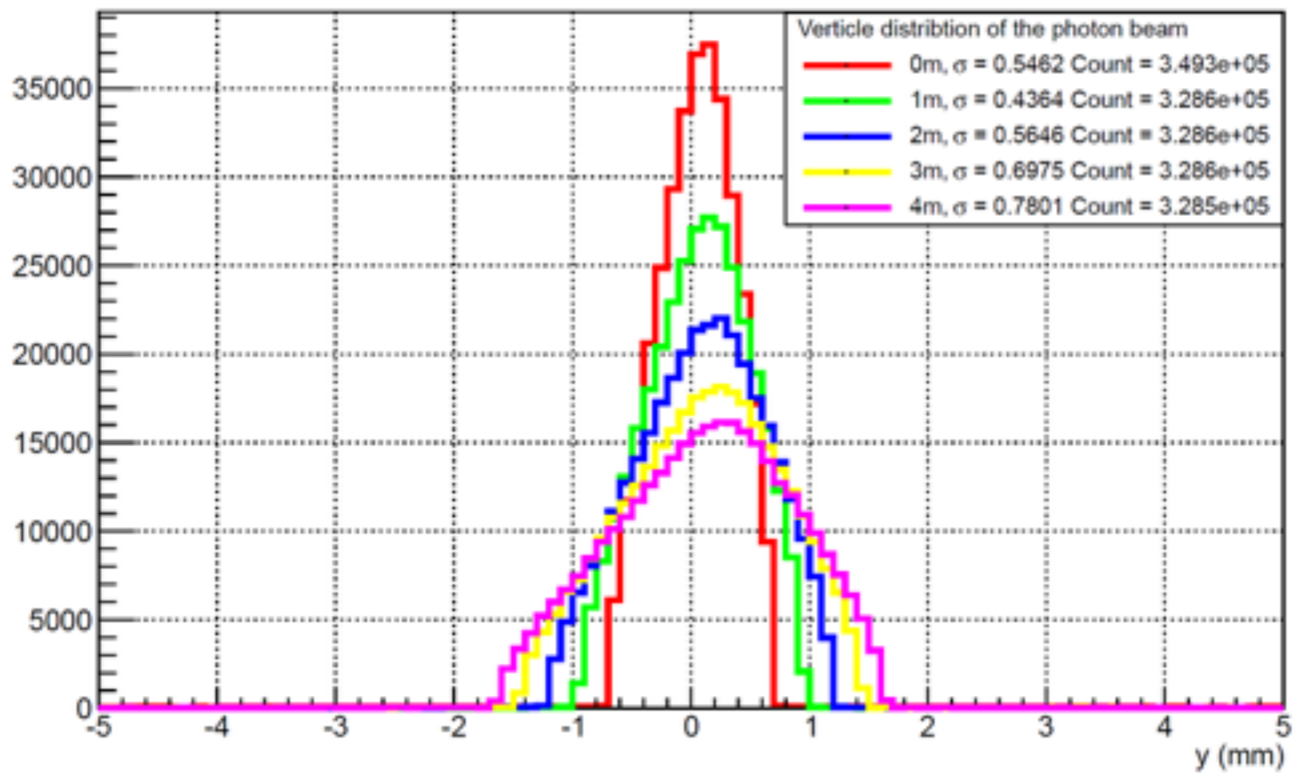
With No Cut

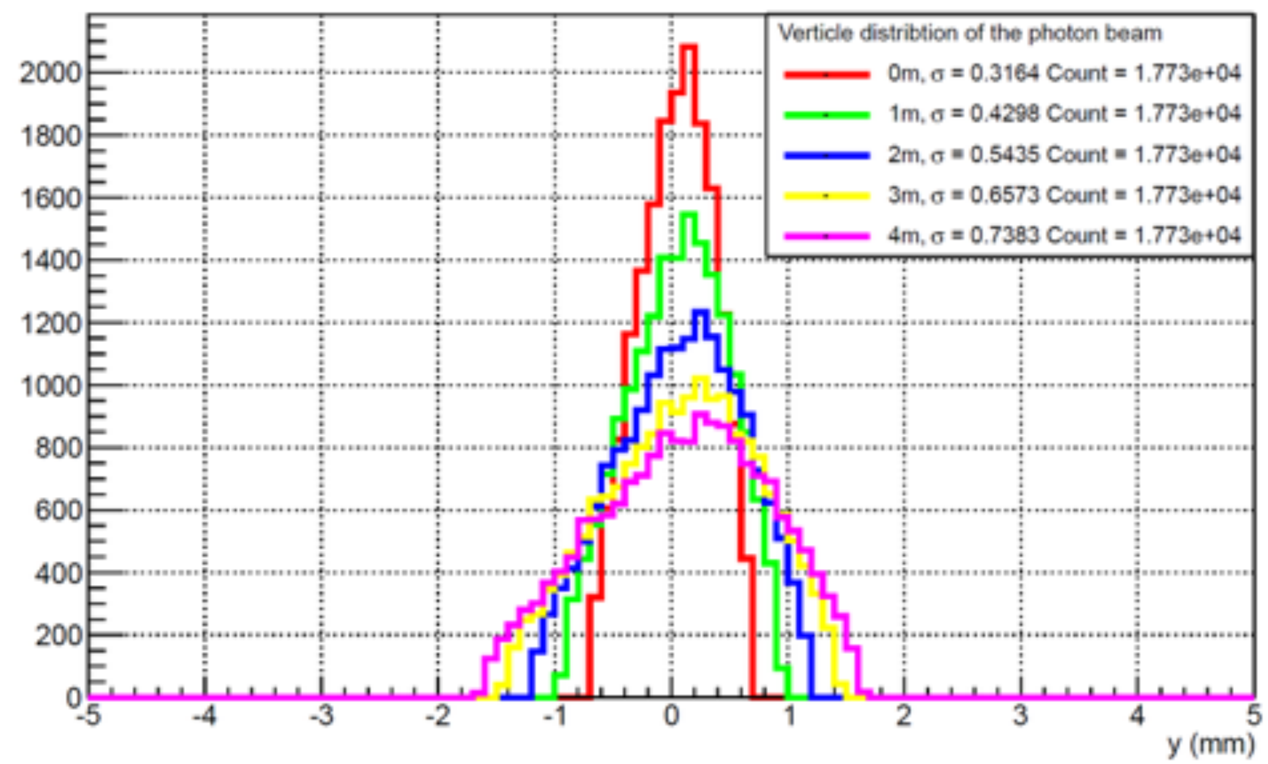


With Energy Cut

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