

Practical Application of Monte Carlo Simulation at Duke Free Electron Laser Laboratory (DFELL)

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Thanks to DFELL personnel!

Patrick Wallace, DFELL Radiation
Safety Manager

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Goal: To determine if Monte Carlo simulation is a helpful tool for making Radiation Safety recommendations when changes are made in experiments at DFELL

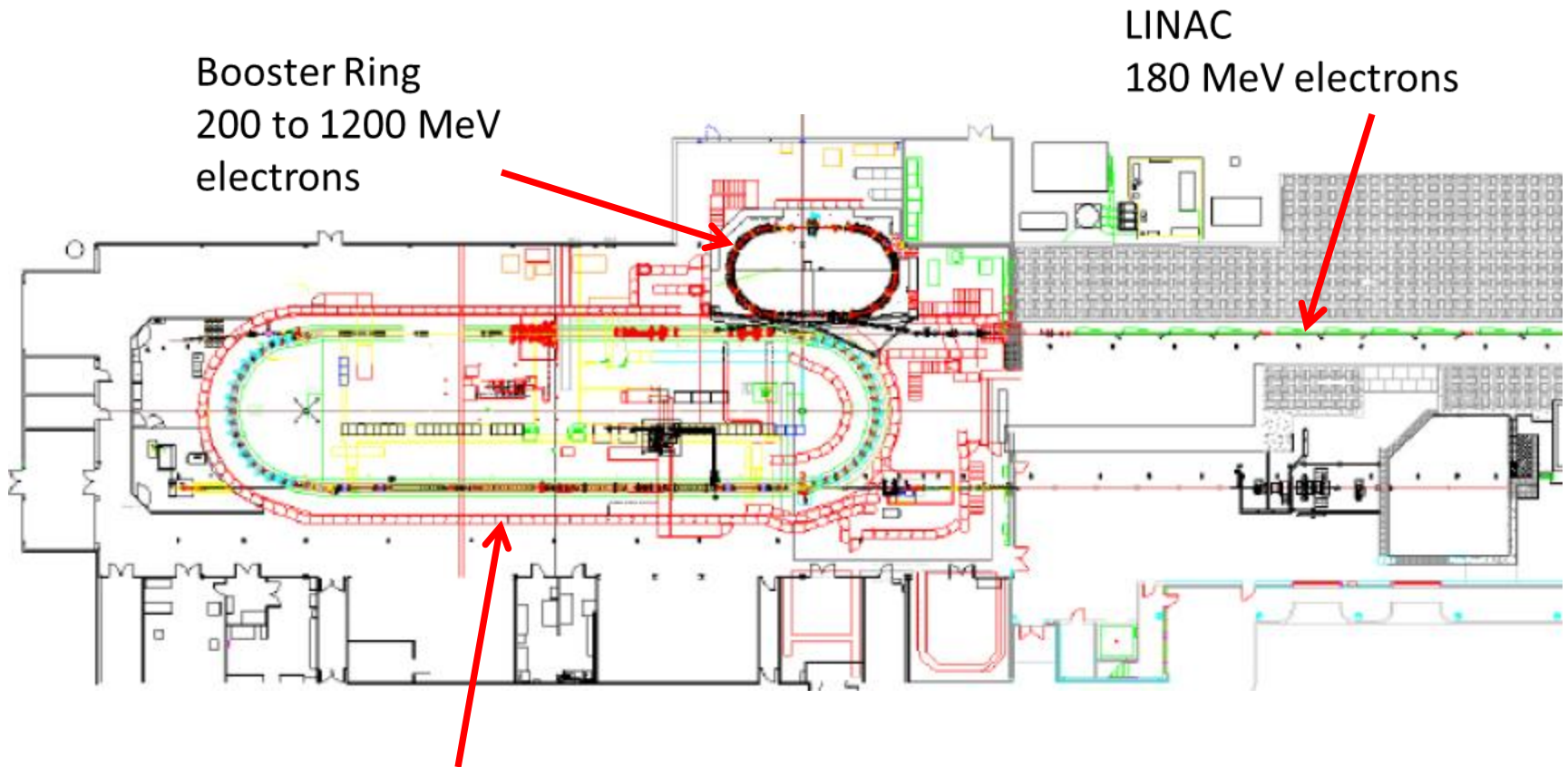
- Description of DFELL facility and new construction
- Monte Carlo Simulation with FLUKA
- Survey Measurements
- Comparison of results
- Conclusion



DFELL

- 52,000 ft² facility plus 13,000 ft² Keck Life Science Research laboratory on Duke University Campus
- Areas of research- physics, nuclear physics, biomedical science, radiation biology

DFELL



Booster Ring
200 to 1200 MeV
electrons

LINAC
180 MeV electrons

Storage Ring
Produces gammas
2 MeV to 50 MeV

LINAC- 180 MeV electrons



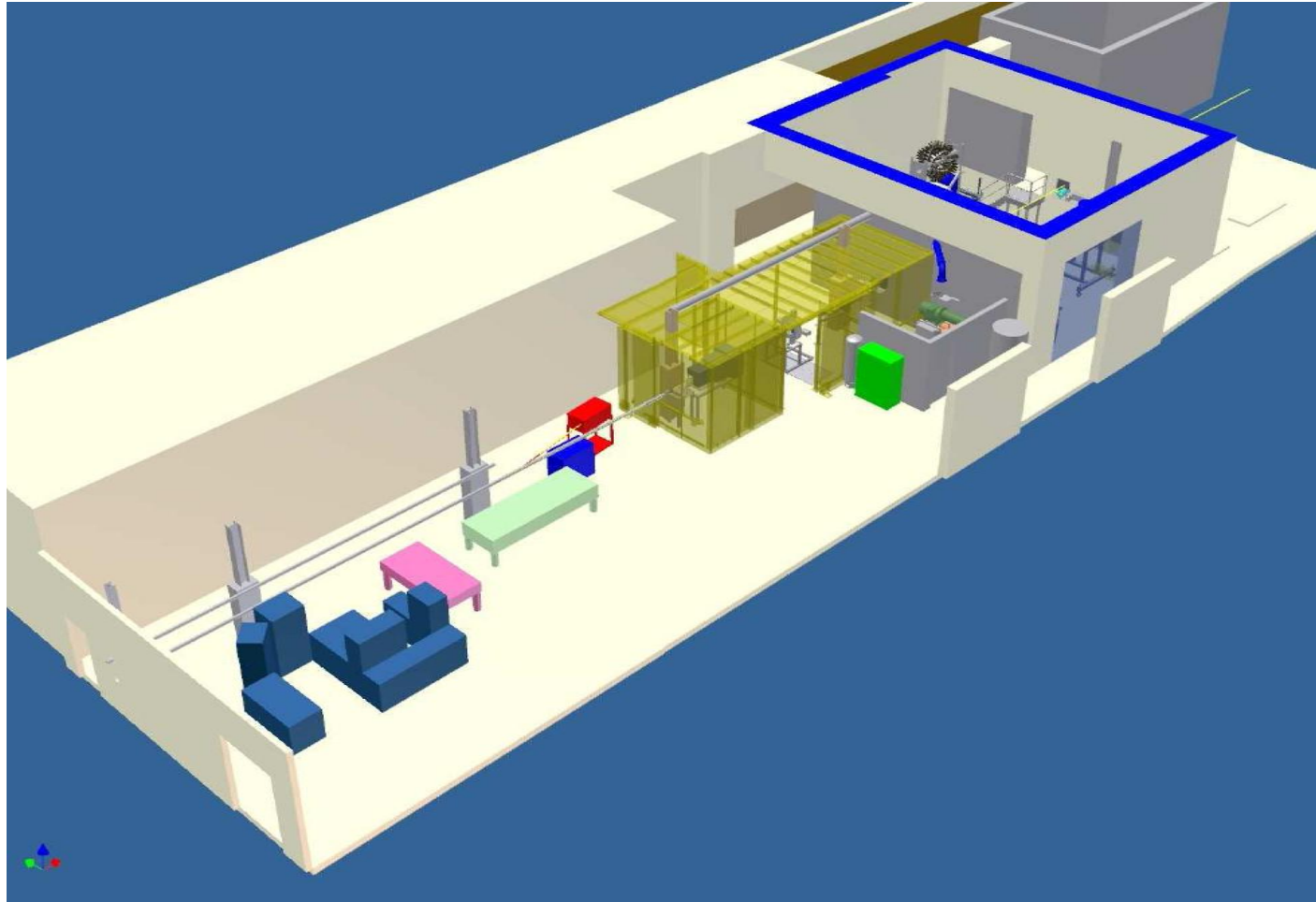
Operation Modes

- Normal mode
 - Produces UV photons
- Gamma mode
 - Photon energy 2 – 50 MeV
 - 10^9 Photons per second
 - high energy gamma rays produced by inverse Compton Scattering

New Construction (why?)

- 2009- only one target room- the Gamma vault
 - ~ 900 ft² with beam passing through the center at 72" from the floor
 - removable wall for installing and removing large experimental equipment
- Upgrade planned to add a Collimator Room and an Upstream Target Room (UTR)
- For new experiments

New Construction-Collimator Room and Upstream Target Room



BEAM ENTRANCE TO COLLIMATOR ROOM



LEAD COLLIMATORS



Health Physics Issues

- Every experiment different
- Different gamma energy
- Changes in size of collimator(s)
- Changes in material of collimator(s)
- Changes in location of collimator(s)
- Other variables
- Want to know before an experiment- what recommendations to make, i.e. shielding

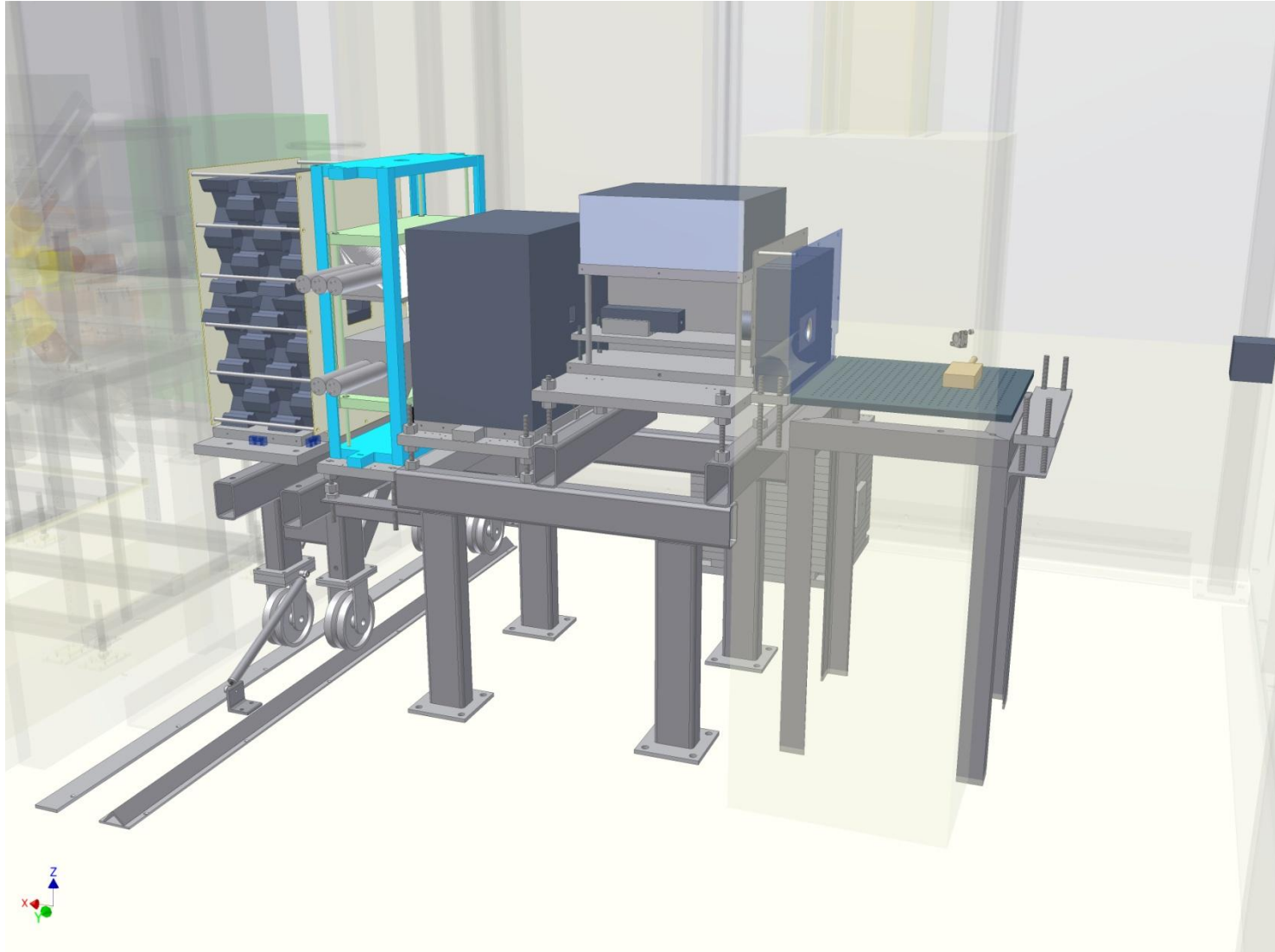
Advantages of Monte Carlo

- Can apply to any radiation- accelerators(n, e, p, photon), irradiator, x-ray machines, radioactive sources
- Do calculations first before new experiment
- Radiation protection, shielding and dosimetry recommendations

FLUKA

- Multi-particle radiation transport code
- Energy range 1 eV to 10,000 TeV
- Can build material from mixture of elements
- Measured cross sections
- Random number generator
- Graphics
- FLAIR- one input method
- <http://www.fluka.org/fluka.php>

Create the Geometry



Geometry File

```

BEAMPOS          0.0      0.0    -200.0
*
GEOBEGIN
  0 0
                                A simple problem
                                COMBNAME
RPP body1 -150.0    +500.0    -500.0    +500.0    -1000.0  +1000.0
RPP body2 -100.0    +400.0    -400.0    +400.0    -900.0  +900.0
RPP body3 -1.91     +1.91     -1.91     +1.91     0.0     +05.0
RPP body4 -1.27     +1.27     -1.27     +1.27     -0.0000001  0.0
RCC body5  0.0      0.0      -200.0     0.0      0.0     200.0000001
          5.08
RCC body6  0.0      0.0      -200.0     0.0      0.0     200.0000001
          2.24
END
* black hole
regBH1 5 +body1 -body2
* vacuum around
regVA2 5 +body2 -body3 -body4 -body5
* Ta target
regBD3 5 +body3
* N target
regBD4 5 +body4
* Al beam pipe
regBD5 5 +body5 -body6
* Inner Al beam pipe
regBD6 5 +body6
END
GEOEND
*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8
MATERIAL 73. 180.9479 16.654 18. 0.0 TANTALUM
MATERIAL 7. 14.0067 0.0117 7. 0.0 NITROGEN
MATERIAL 13. 26.981538 2.699 10. 0.0 ALUMINUM
* AIR defined as air with normal NTP density (0.001205)
MATERIAL 0.0 0.0 0.001205 26. 0.0 AIR
COMPOUND -0.000124 6. -0.755267 7. -0.231781 8. AIR
COMPOUND -0.012827 9. AIR
* Ta and N target
ASSIGNMAT TANTALUM regBD3
ASSIGNMAT NITROGEN regBD4
*External Blackhole
ASSIGNMAT BLCKHOLE regBH1
* Vacuum
ASSIGNMAT AIR regVA2
ASSIGNMAT VACUUM regBD6
ASSIGNMAT ALUMINUM regBD5

```

FLAIR <http://www.fluka.org/flair/index.html>

The screenshot displays the FLAIR software interface. The main window is titled 'flair V0.0a: ntof33.flair'. The menu bar includes 'File', 'Edit', 'Card', 'Input', 'View', 'Options', and 'Help'. The toolbar contains various icons for file operations and simulation control. The left sidebar shows a tree view of the project structure, with 'Input' selected. The main panel displays the configuration for the 'n_TOF lead target' simulation. The configuration is organized into sections: GLOBAL, DEFAULTS, BEAM, BEAMPOS, GEOBEGIN, and several RPP (Region Parameterization) blocks. The status bar at the bottom shows 'Inp: ntof33.inp', 'Exe:', 'Dir: /home/bnv/prg/physics/fluka/flair/examples', and 'Filtered 33 out of 33'.

Section	Parameter	Value
GLOBAL	Max #reg:	
GLOBAL	Analogue:	
GLOBAL	DNear:	
GLOBAL	Input: Names	
GLOBAL	Geometry:	Free
DEFAULTS	EET/TRAN	
BEAM	Beam: Energy	20.0
BEAM	E:	20.0
BEAM	Part:	PROTON
BEAM	Δφ: Gauss	
BEAM	Δp(FWHM):	0.082425
BEAM	Δφ: Gauss	
BEAM	Δφ:	1.7
BEAM	Shape: Rectangular	
BEAM	Δx:	
BEAM	Δy:	
BEAM	Weight:	1.0
BEAMPOS	x:	2.2632
BEAMPOS	y:	-0.5
BEAMPOS	z:	-10.0
BEAMPOS	cosx:	-0.17365
BEAMPOS	cosy:	0.0
BEAMPOS	Dirz:	POSITIVE
GEOBEGIN	Log:	
GEOBEGIN	Acc:	
GEOBEGIN	Opt:	
GEOBEGIN	Inp:	
GEOBEGIN	Out:	
GEOBEGIN	Fmt:	COMBNAME
GEOBEGIN	Title:	n_TOF lead target
Black body	SPH	BLKBODY
Black body	x:	0.0
Black body	y:	0.0
Black body	z:	0.0
Black body	R:	10000000.0
Void sphere	SPH	VOID
Void sphere	x:	0.0
Void sphere	y:	0.0
Void sphere	z:	0.0
Void sphere	R:	10000000.0
Water container	RPP	WATERCNT
Water container	Xmin:	-43.0
Water container	Xmax:	43.0
Water container	Ymin:	-53.6
Water container	Ymax:	53.6
Water container	Zmin:	-32.5
Water container	Zmax:	35.0
Lead Target	RPP	PBTARGET
Lead Target	Xmin:	-40.0
Lead Target	Xmax:	40.0

```
set title of this FLUKA run
*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...
TITLE
n_TOF lead target
```

Inp: ntof33.inp Exe: Dir: /home/bnv/prg/physics/fluka/flair/examples Filtered 33 out of 33

Monte Carlo Simulations(Fluka)

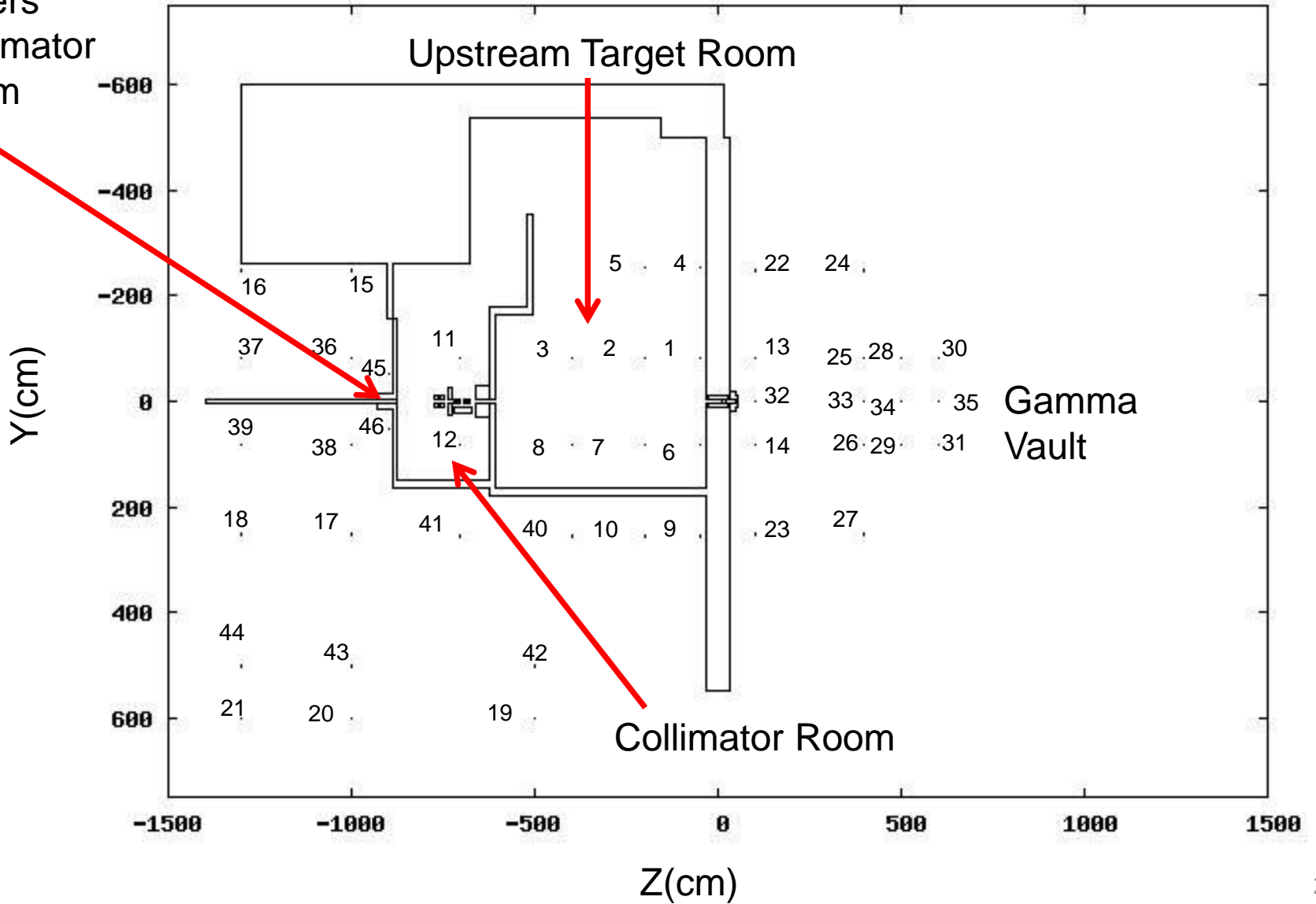
- 10^8 Gamma per second incident on the collimator
- Energy 14 MeV – near to GDR
- Beam stop - Tungsten target 61 cm x 61 cm x 30 cm
- Target wall thickness 61 cm (concrete)
- Exterior wall concrete shielding thickness 15 cm
- Gamma beam transport through 10 cm stainless steel pipe
- Lead collimator 5.08 cm x 5.08 cm x 30.48 cm

Detectors and Locations(MC)

- 46 LiF TLDs
- Dimension of each 2.853 cm x 2.853 cm x 0.0889 cm
- Density 2.64 gcm⁻³
- PVC cover 1.0 mm

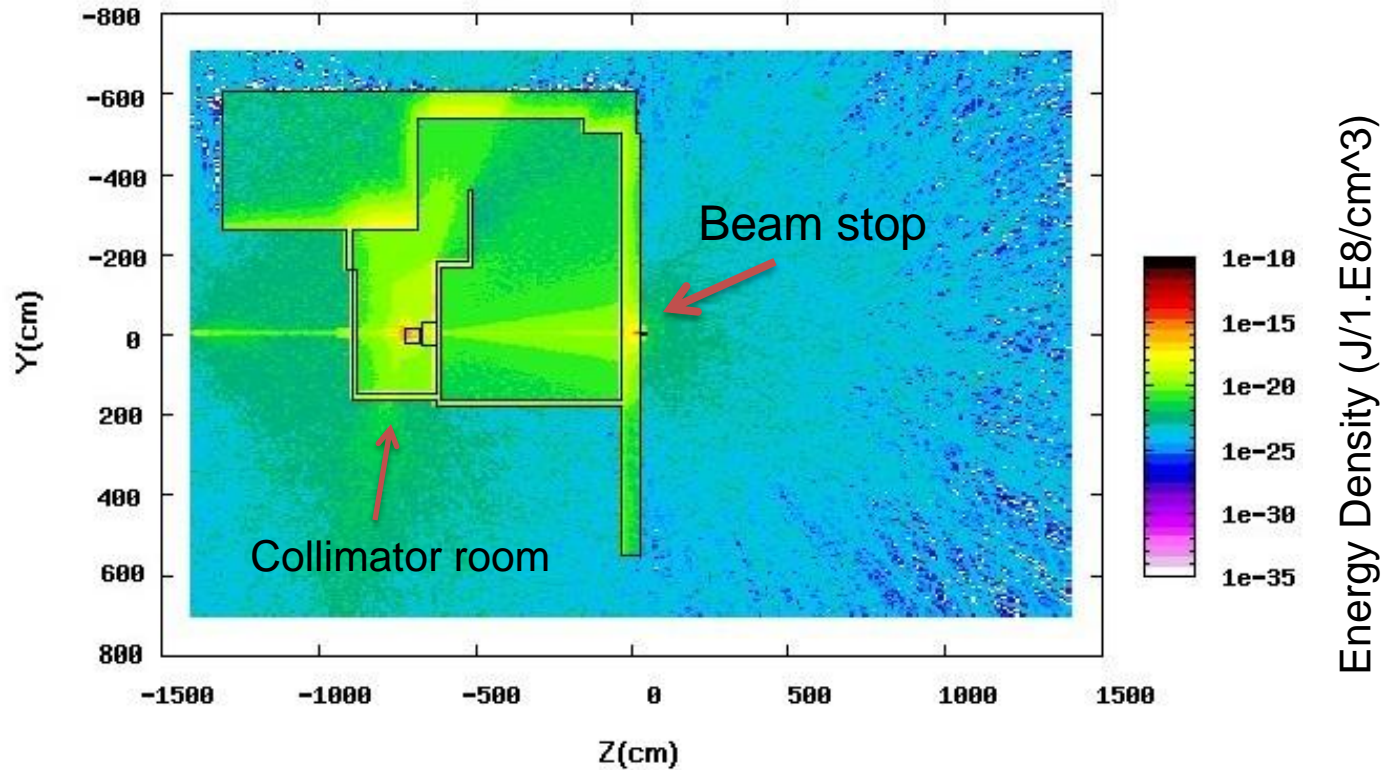
FLUKA TLD LOCATIONS

Beam line enters collimator room

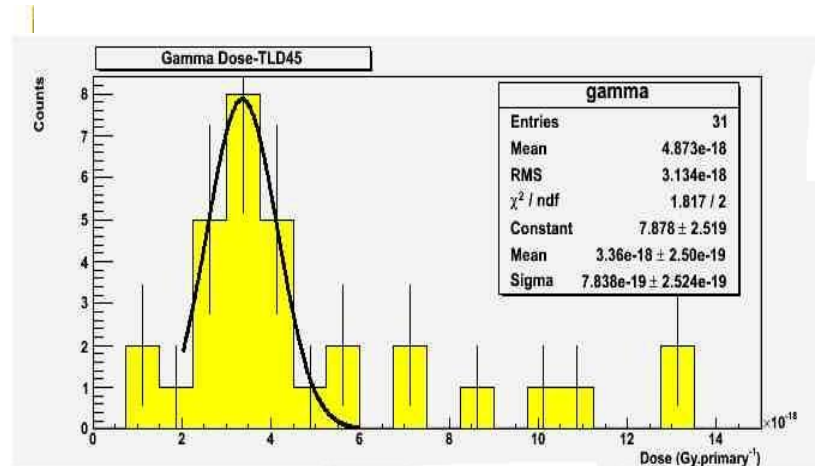
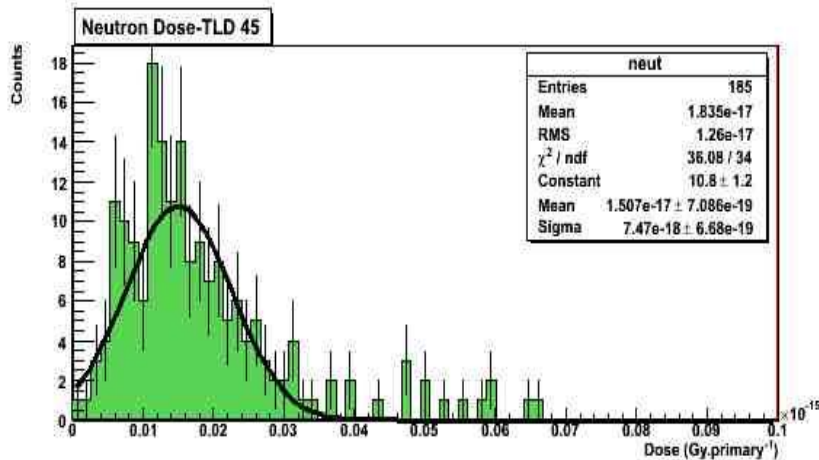


FLUKA Results

Radiation Density – FLUKA (MC)

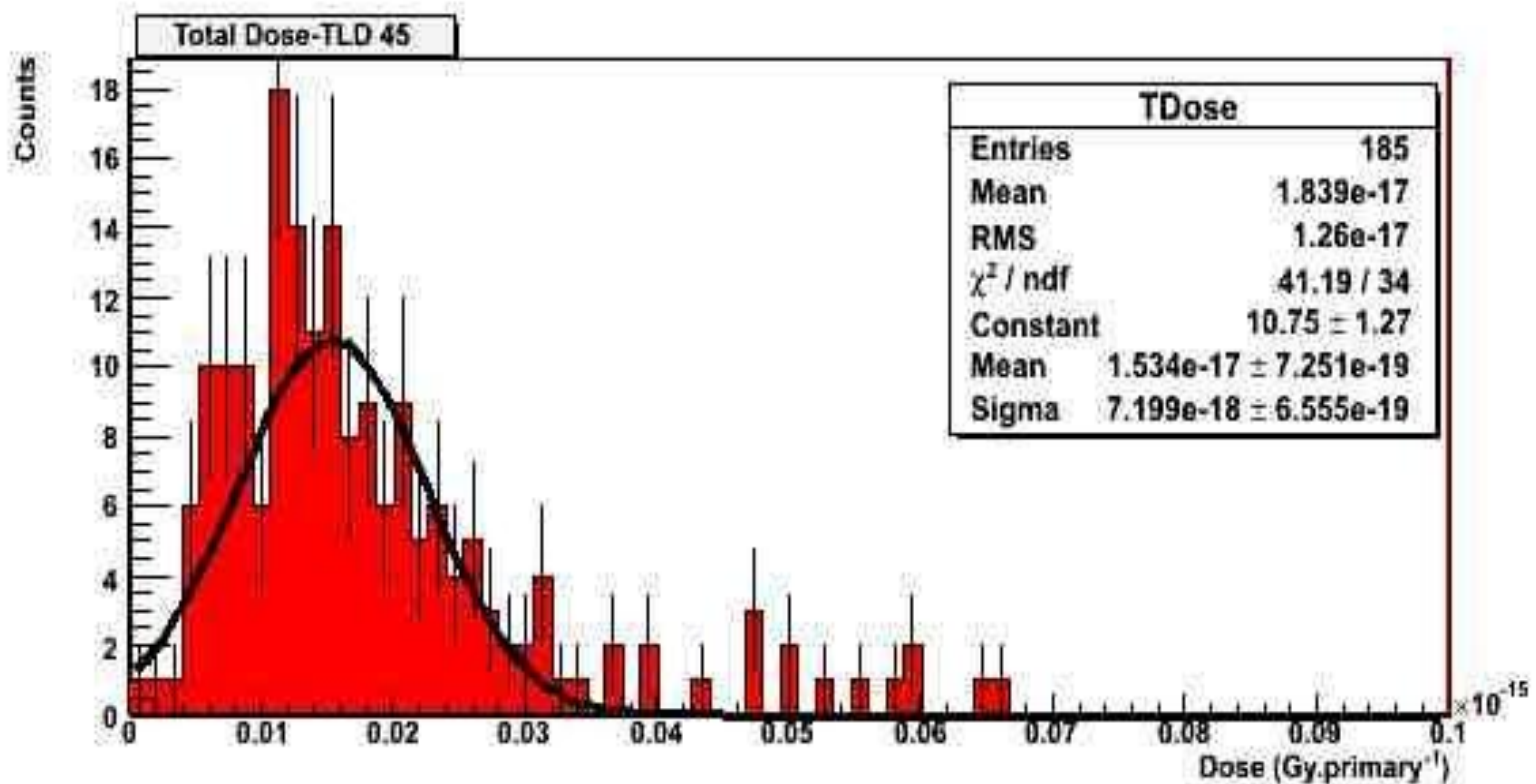


Neutron and Photon data (MC)



Number of primaries on the collimator = 5×10^8 gamma/sec
Neutron dose mean = $1.507 \text{ E-}17$ Gy/gamma
Gamma dose mean = $3.36 \text{ E-}18$ Gy/gamma

Neutron and Photon data (MC)

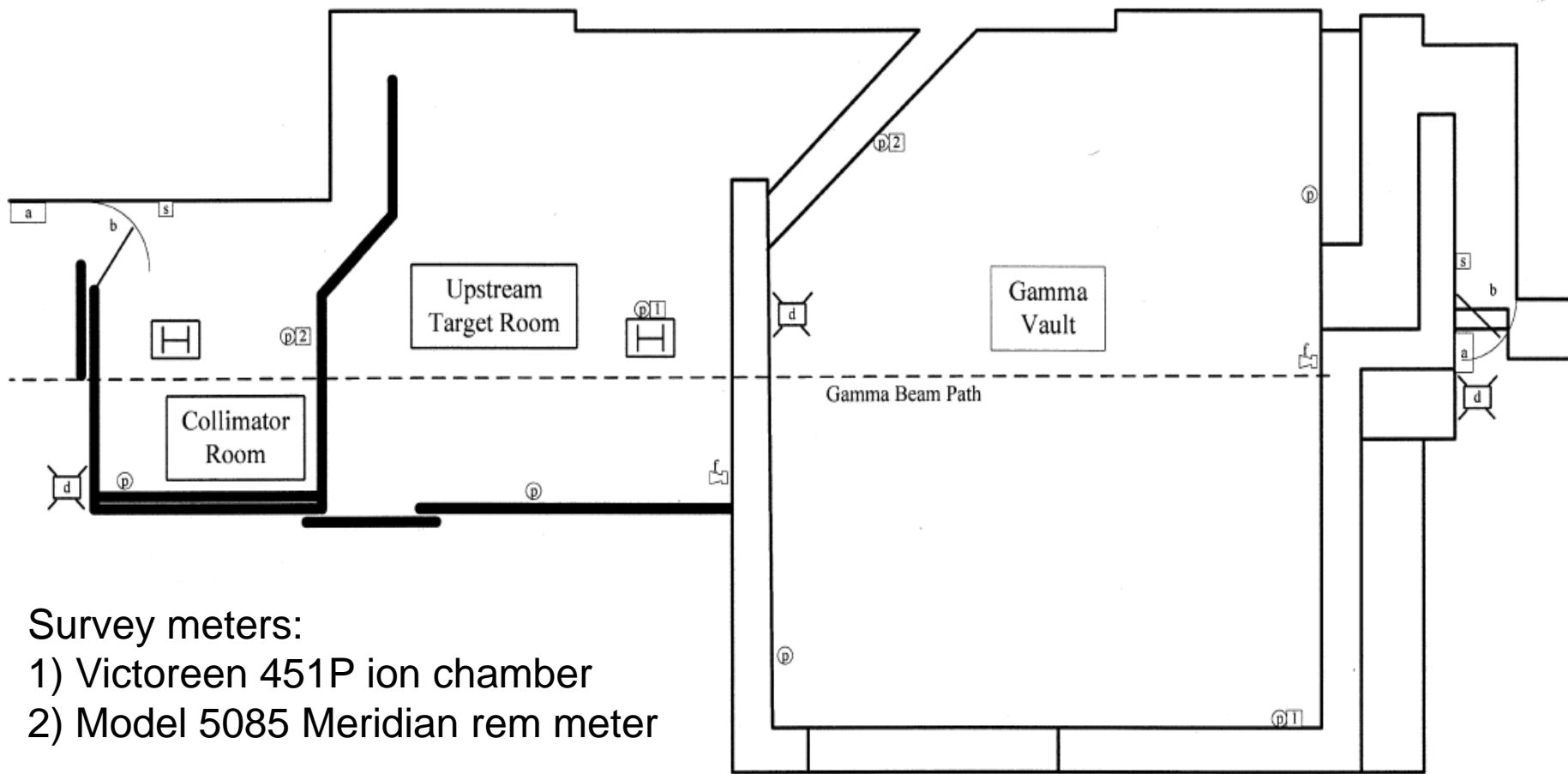


Number of primaries on the collimator = 5×10^8 gamma/sec
Total dose mean = $1.53 \text{ E-}17$ Gy/gamma

Neutron and Photon Doses (MC)

TLD	Total Dose Rate (mrad/hr)	Photon Dose Rate (mrad/hr)	Neutron Dose Rate (mrad/hr)
Beam line enters Collimator Shack (#45)	2.77 (+/- 0.16)	0.60 (+/- 0.01)	2.70 (+/- 0.14)
Beam line enters Collimator Shack (#46)	2.23 (+/- 0.12)	0.77 (+/- 0.09)	2.21 (+/- 0.14)
Various locations	0.30 to 1.521	0 to 1.01	0.29 to 1.45

Survey & Results



Survey meters:

- 1) Victoreen 451P ion chamber
- 2) Model 5085 Meridian rem meter

Note: drawing not to scale

Survey Results

(running at 14 MeV)

Location	Total Dose Rate (mrem/hr)	Photon Dose Rate (mrem/hr)	Neutron Dose Rate (mrem/hr)
Beam line enters Collimator Shack	2.99	0.49	2.50
Other locations	BKG to 0.447	BKG to 0.097	BKG to 0.350

Comparison of Results

TLD #/ Location	Neutron Calculated dose rate (mrem/hr)	Neutron Measured dose rate (mrem/hr)	Photon Calculated dose rate (mrem/hr)	Photon Measured dose rate (mrem/hr)
# 45/Beam line enters Collimator Shack	2.70	2.50	0.60	0.49
# 46/Beam line enters Collimator Shack	2.21	2.5	0.77	0.50

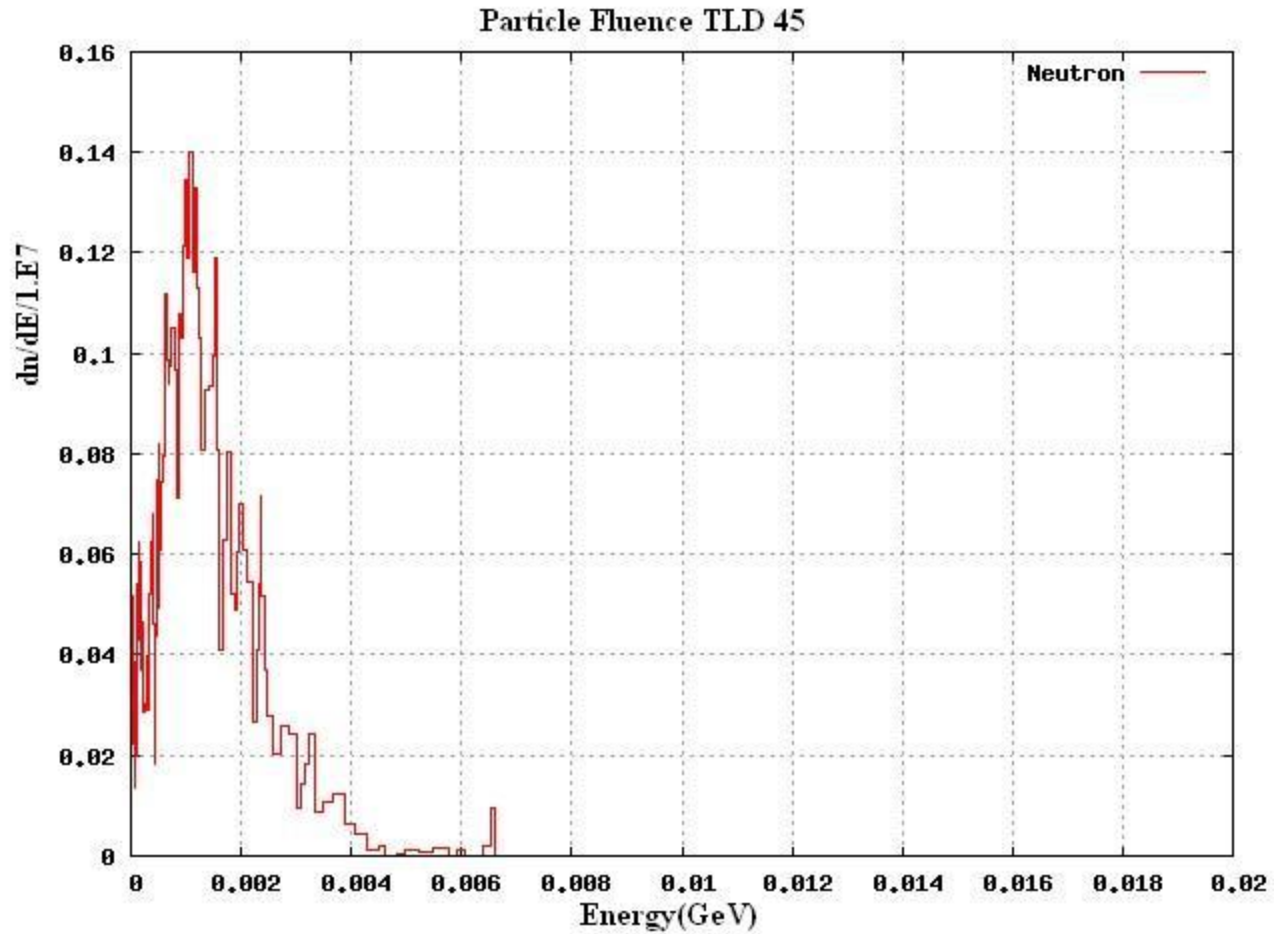
Conclusion

- Survey confirmed Monte Carlo results
- Monte Carlo simulation can be a helpful tool for HPs
- Recommendations for protection can be determined prior to experiments

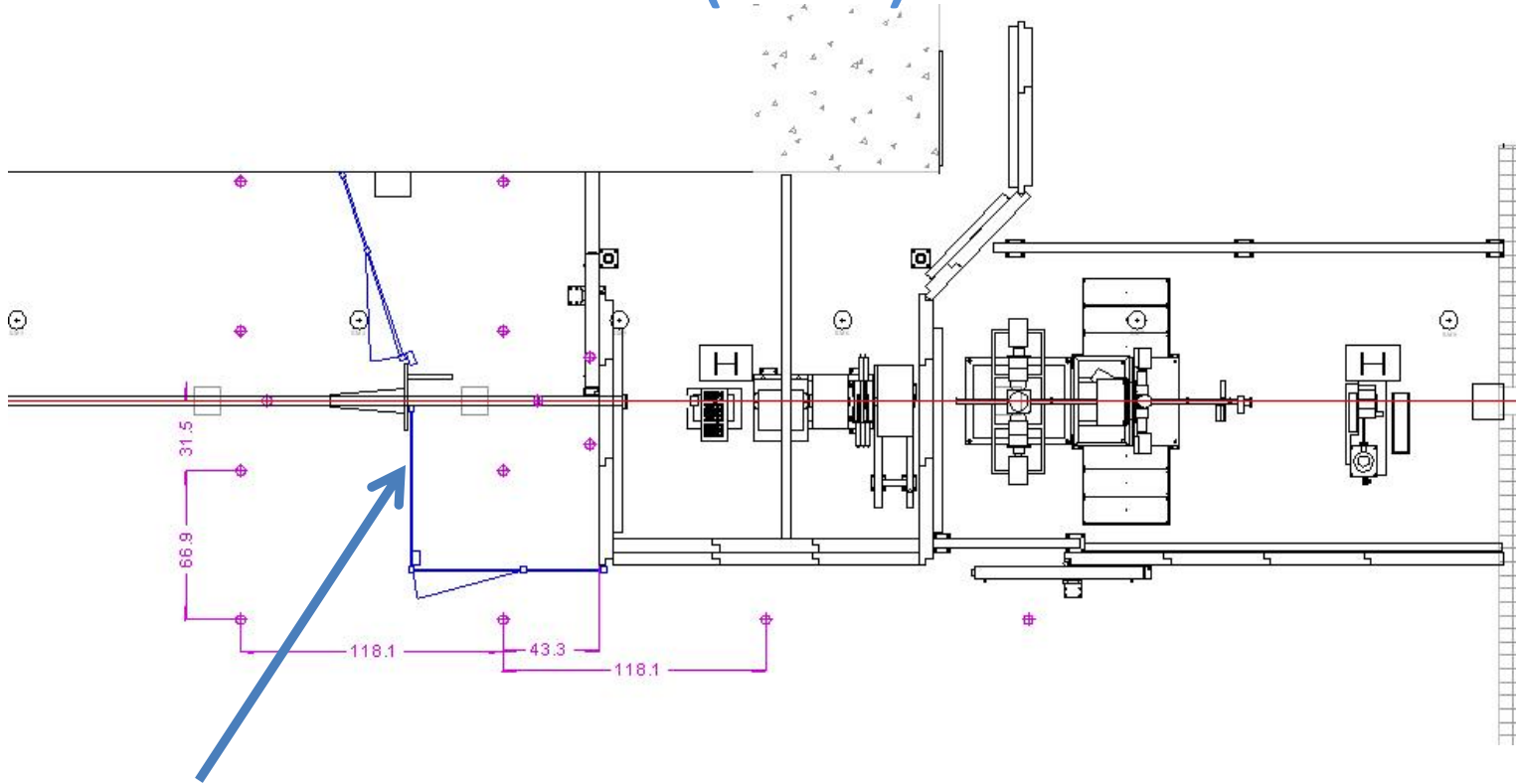
The End!



Neutron Fluence(MC)



Personnel Protection System (PPS)



Fence added

DFELL Beam Stop (FLUKA)

