American Detector Irradiation Facilities

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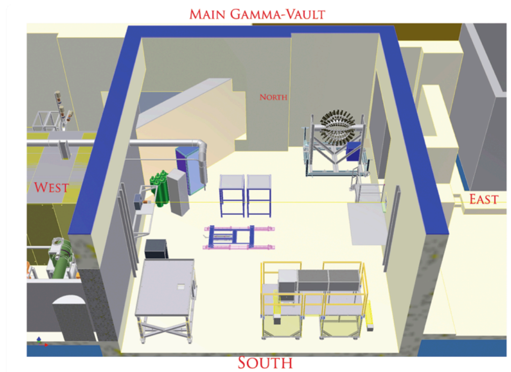
Need for irradiation facilities

- The central detectors at a lepton collider are not an extreme radiation environment. The inner vertex detector, for instance, will see $<10^9$ neutrons/cm^2 in a year, while LHC inner detectors will see more than 10^{12}.
- However, the forward region (BeamCal) at ILC/CLIC is expected to see on the order of 10^{15} neutrons in a year and have an EM dose of up to 100 MRad.
- For studies of detectors in the forward region of ILC, and for studies of radiation effects in generic detector R&D, I'd like to make a database of facilities in North America where irradiation of detectors can be performed on a regular basis.
- Types of radiation facilities to catalog:
  - High intensity, high energy γ (1000 Curie level and above)
  - High intensity, low energy pions or protons ($<$ 1 GeV, $>10^{14}$ particles/cm^2)
  - High intensity, thermal neutrons (>10 MRad)
  - Medium intensity, high energy neutrons (10 MeV, $>10^8$ particles/cm^2)
  - Medium intensity, low energy ions
- I will give examples here of facilities. It is by no means comprehensive. Please suggest other facilities that I've missed.

High Intensity, High Energy γ's

- HIGS ("High Intensity Gamma Source")
  - Duke University
  - Compton Backscattered off of electrons in Duke Electron Storage Ring
  - Energies between 1-100 MeV
  - Order of 5% energy spread
  - Fluxes on the order of 10^8 per sec
  - Removable wall
  - Overhead crane



HIGS flux performance table for high-flux, quasi-CW operation, DFELL/TUNL, Nov. 9, 2010 (Version 2.3).

HIGS Flux Performance Projection (2010 – 2011)		Total Flux [g/s] CW Operation Two-Bunch [*]	Collimated Flux ($\Delta E_\gamma / E_\gamma$ = 5% FWHM) [#], [@]	FEL λ [nm]	Comment
No-loss Mode : < 20 MeV					Linear Pol. with OK-4 Circular Pol with OK-5
E_γ = 1 – 2 MeV	(E_e = 237 – 336 MeV)	$1 \times 10^8 – 4 \times 10^8$	$6 \times 10^6 – 2.4 \times 10^7$	1064	Linear and Circular [a], [b]
E_γ = 2 – 2.9 MeV	(E_e = 336 – 405 MeV)	$4 \times 10^8 – 1 \times 10^9$	$2.4 \times 10^7 – 6 \times 10^7$	1064	Linear and Circular [a], [b]
E_γ = 2 – 3 MeV	(E_e = 288 – 353 MeV)	$2 \times 10^8 – 6 \times 10^8$	$1.2 \times 10^7 – 3.6 \times 10^7$	780	Linear and Circular [a], [b]
E_γ = 3 – 5.4 MeV	(E_e = 353 – 474 MeV)	$6 \times 10^8 – 2 \times 10^9$	$3.6 \times 10^7 – 1.2 \times 10^8$	780	Linear [a]
E_γ = 3 – 6.3 MeV	(E_e = 353 – 512 MeV)	$6 \times 10^8 – 3 \times 10^9$	$3.6 \times 10^7 – 1.8 \times 10^8$	780	Circular [a]
E_γ = 5 – 8 MeV	(E_e = 380 – 481MeV)	$4 \times 10^8 – 1 \times 10^9$	$2.4 \times 10^7 – 6 \times 10^7$	540	Linear and Circular [a]
E_γ = 8 – 11 MeV	(E_e = 481 – 565 MeV)	$1 \times 10^9 – 2 \times 10^9$	$6 \times 10^7 – 1.2 \times 10^8$	540	Linear [a]
E_γ = 8 – 13 MeV	(E_e = 481 – 615 MeV)	$1 \times 10^9 – 4 \times 10^9$	$6 \times 10^7 – 2.4 \times 10^8$	540	Circular [a]
E_γ = 8 – 11 MeV	(E_e = 439 – 516 MeV)	$5 \times 10^8 – 1 \times 10^9$	$3 \times 10^7 – 6 \times 10^7$	450	Linear and Circular [a]
E_γ = 11 – 16 MeV	(E_e = 516 – 624 MeV)	$1 \times 10^9 – 2 \times 10^9$	$6 \times 10^7 – 1.2 \times 10^8$	450	Linear [a]
E_γ = 11 – 18.5 MeV	(E_e = 516 – 671 MeV)	$1 \times 10^9 – 2 \times 10^9$	$6 \times 10^7 – 1.2 \times 10^8$	450	Circular [a]
E_γ = 15 – 25 MeV	(E_e = 533 – 691 MeV)	$2 \times 10^8 – 3 \times 10^8$	$1.2 \times 10^7 – 1.8 \times 10^7$	350	Linear [a]
E_γ = 15 – 30 MeV	(E_e = 533 – 758 MeV)	$3 \times 10^8 – 5 \times 10^8$	$1.8 \times 10^7 – 3 \times 10^7$	350	Circular [a]
Loss Mode: > 20 MeV					Circular Polarization only with OK-5 FEL
E_γ = 21 – 54 MeV	(E_e = 547 – 887 MeV)	$\sim 2 \times 10^8$	$\sim 1.2 \times 10^7$	260	Circular [c]
E_γ = 21 – 60 MeV	(E_e = 526 – 901 MeV)	$\sim 2 \times 10^8$	$\sim 1.2 \times 10^7$	240	Circular [c]
E_γ = 50 – 95 MeV	(E_e = 738 – 1030 MeV)	$\sim 1 \times 10^8$	$\sim 6 \times 10^6$	193	Circular [c], [d]

(a) As mirrors degrade due to wiggler radiation, the gamma flux will be lower than the listed numbers. Operating in circular polarization slows mirror degradation.
(b) With new FEL mirrors, the flux of the circularly polarized gamma beam can be 1.5 to 2 times as the listed numbers.
(c) The flux is limited by the capability of sustaining a high intra-cavity power by the FEL mirrors and electron injection rate.
(d) Total flux is 1×10^7 gamma/sec as of Oct. 2010. A total flux of 1×10^8 gamma/sec is expected as early as Q2, 2012. [1]
(*) The flux numbers are projected for the high-flux operation with two symmetric electron bunches. The gamma flux will be different in other operation modes, including the high-resolution mode, and giant-pulse mode.
(#) The energy resolution of the collimated gamma beam depends on parameters of the electron and FEL beams, as well as the collimator opening aperture. The 5% FWHM flux in the table is used only for the purpose of illustrating the collimated flux. A higher resolution beam can be produced at the expense of a reduced gamma-beam flux. Using a given FEL mirror set, the portion of the flux selected by the collimator is inversely proportional to the gamma beam energy.
(@) It is critical to match the experimental sample and collimated gamma beam. A useful formula to estimate the portion of the gamma-ray beam after collimation is:

$$\frac{\text{Collimated Flux}}{\text{Total Flux}} = a * \left[\frac{Ee\ [\text{MeV}]}{0.511} * \frac{r\ [\text{mm}]}{52.8*10^3}\right]^2, \qquad a \sim 1.2 \text{ to } 1.5,$$

where Ee is the electron energy in MeV and r is the radius of the collimating aperture in mm. The distance between the collision point and the collimator is 52.8 m as of January, 2010.

Modes of HIGS Operation

1. ***High-flux, quasi-CW operation, micropules with sub-ns durations at 5.5796 MHz***
   Typical energy spread (FWHM): 4 – 10%; the flux performance is found in the above table;
2. ***High-resolution, quasi-CW operation, micropules with sub-ns durations at 2.7898 MHz (the main beam)***
   Typical energy spread (FWHM): 0.8 – 1.5%; the flux is lower by a factor of 50 – 100 compared to high-flux mode;
3. ***Pulsed operation***
   Typically, 100 – 300 microsecond macropulses are produced with a reprate of 1 to 15 Hz, depending on gamma energy, the flux performance is lower than quasi-CW modes, and with reduced stability below 10 MeV.

1 Contact for details of HIGS performance: wu@fel.duke.edu

- Other facilities
  - Lowell Radiation Laboratory: 100 rad to 2 Mrad per hour
  - Sandia Lab – 100 kCi Co60 source – 550 rad/sec

High Intensity, Low Energy Protons

- Indiana University ISAT ("Integrated Science and Accelerator Technology")
  - Cyclotron
  - Protons 30-200 MeV
  - Flux 1E02 to 1E11 protons/ cm^2/sec
  - 2 cm – 30 cm diameter beam

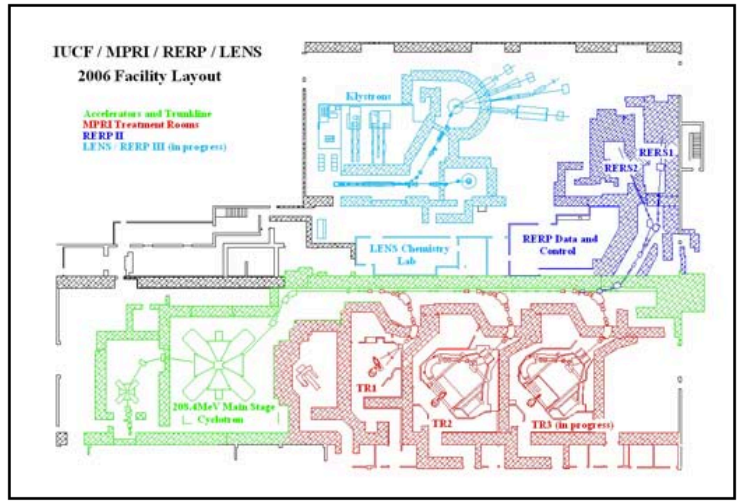
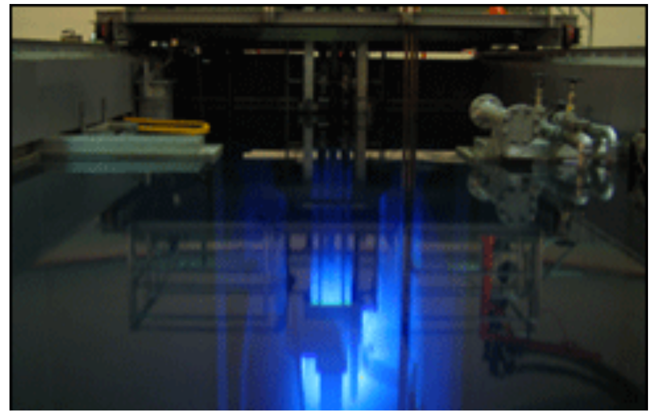


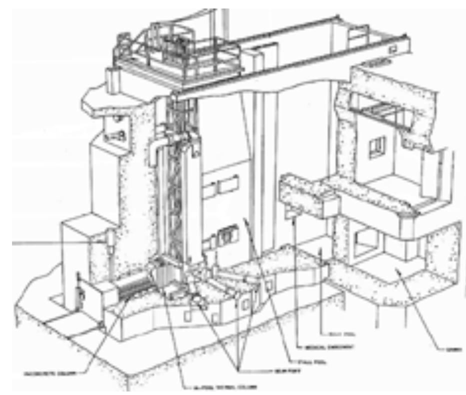
Figure 1: *Indiana University Integrated Science and Accelerator Technology Hall: The cyclotron and so-called trunkline, which runs horizontally across the picture, are shown in green. The medical facility with treatment rooms (TR1-3) is shown in red. Two beamlines for radiation effects research were completed in 2003 (RERS1 and RERS2, dark blue). A NSF funded low energy neutron scattering facility (LENS, light blue) produced its first neutron beam in December 2004. The neutron beam may also be used for radiation effects studies.*

- Other facilities
  - Los Alamos LANSCE: 800 Mev protons; 5E11 protons per pulse at 1 Hz
  - Fermilab MTA: 400 MeV proton beam; 1E13/sec flux; small samples only

High Intensity, Thermal Neutrons

- UMass "Lowell Radiation Laboratory"
  - Research reactor can deliver high doses of neutrons.
  - Supports large sample sizes and can perform neutron radiography.
  - There is a fast neutron flux facility using the 5 MeV Van-de-Graaff, which can deliver 10^{11} n/cm^{2}/sec.

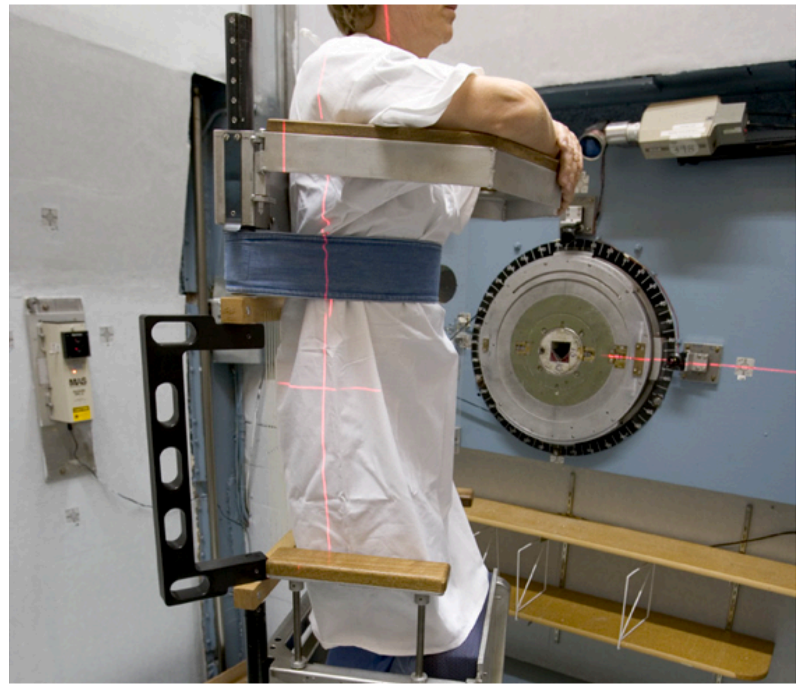




- Other facilities:
  - "LENS" at Indiana University cyclotron; 10^{8} neutrons/cm^{2}/sec
  - Sandia Lab "Annular Core Research Reactor"

Medium Intensity, High Energy Neutrons

- Fermilab "Neutron Therapy Facility"
  - Neutrons average 10-20 MeV
  - Flux of approximately 10^7 neutrons/sec in a collimator of size 10x10 cm^2
  - Easy access to beam



- Other facilities
  - Lowell Radiation Lab
  - University Washington Clinical Neutron Therapy Institute

Medium Intensity, Medium Energy Ions

- LBNL "88 inch Cyclotron"
  - Has multiple sources feeding into 50 MeV cyclotron
  - Can use input of 'cocktail' of ions and tune for each one in sequence.

VENUS Ion Source

- Other facilities
  - University of Washington CNTS
  - Texas A&M Cyclotron Institute

Ion	Cocktail (MeV/nuc)	Energy (MeV)	Z	A	Chg. State	% Nat. Abund.	LET 0° (MeV/(mg/cm^2))	LET 60° (MeV/(mg/cm^2))	Range (µm)	Ion
B	**4.5**	44.90	5	10	+2	19.9	**1.65**	3.30	78.5	**B**
N	**4.5**	67.44	7	15	+3	0.37	**3.08**	6.16	67.8	**N**
Ne	**4.5**	89.95	10	20	+4	90.48	**5.77**	11.54	53.1	**Ne**
Si	**4.5**	139.61	14	29	+6	4.67	**9.28**	18.56	52.4	**Si**
Ar	**4.5**	180.00	18	40	+8	99.6	**14.32**	28.64	48.3	**Ar**
V	**4.5**	221.00	23	51	+10	99.75	**21.68**	43.36	42.5	**V**
Cu	**4.5**	301.79	29	63	+13	69.17	**29.33**	58.66	45.6	**Cu**
Kr	**4.5**	387.08	36	84	+17	17.3	**38.96**	77.92	48.0	**Kr**
Y	**4.5**	409.58	39	89	+18	100	**45.58**	91.16	45.8	**Y**
Ag	**4.5**	499.50	47	109	+22	48.161	**58.18**	116.36	46.3	**Ag**
Xe	**4.5**	602.90	54	136	+27	8.9	**68.84**	137.68	48.3	**Xe**
Tb	**4.5**	724.17	65	159	+32	100	**77.52**	155.04	52.4	**Tb**
Ta	**4.5**	805.02	73	181	+36	99.988	**87.15**	174.30	53.0	**Ta**
Bi	**4.5**	904.16	83	209	+41	100	**99.74**	199.48	52.9	**Bi**
B	**10**	108.01	5	11	+3	80.1	**0.89**	1.78	305.7	**B**
O	**10**	183.47	8	18	+5	0.2	**2.19**	4.38	226.4	**O**
Ne	**10**	216.28	10	22	+6	9.25	**3.49**	6.98	174.6	**Ne**
Si	**10**	291.77	14	29	+8	4.67	**6.09**	12.18	141.7	**Si**
Ar	**10**	400.00	18	40	+11	99.6	**9.74**	19.48	130.1	**Ar**
V	**10**	508.27	23	51	+14	99.75	**14.59**	29.18	113.4	**V**
Cu	**10**	659.19	29	65	+18	30.83	**21.17**	42.34	108.0	**Cu**
Kr	**10**	906.45	36	84	+23	57	**30.23**	60.46	113.1	**Kr**
Y	**10**	928.49	39	89	+25	100	**34.73**	69.46	102.2	**Y**
Ag	**10**	1039.42	47	107	+29	51.839	**48.15**	96.30	90.0	**Ag**
Xe	**10**	1232.55	54	124	+34	0.1	**58.78**	117.56	90.0	**Xe**

Other facilities?

- Please send information to:

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