Los Alamos
NATIONAL LABORATORY

RADIATION EFFECTS FACILITIES at LANSCE

KRANTI GUNTHOTI

Irradiation Test Area Workshop
August 9-10, 2022

Outline

- Los Alamos Neutron Science Center (LANSCE)
  - LANSCE Accelerator
  - LANSCE User Facilities
- LANSCE Beam Transport and Time Structure
- Neutron Radiation Effects Facilities at LANSCE
  - ICE Houses
  - WNR 60R
- Proton Radiation Effects Facility at LANSCE
  - Target-2 (aka Blue Room)
  - Target-2 Operation
  - Target-2 Facilities

Los Alamos Neutron Science Center (LANSCE) Facility

- LANSCE is a multi-user, multi-beam facility that produces intense sources of pulsed spallation neutrons and proton beams in support of basic and applied science research.
- LANSCE came to online in 1972.
- Originally known as The Los Alamos Meson Physics Facility (LAMPF).
- In 1995 LAMPF was renamed the Los Alamos Neutron Science Center (LANSCE).

LANSCE ACCELERATOR

LANSCE accelerator consists of:

- 750-keV H+ and H- Sources and Injectors
- 100-MeV Drift Tube LINAC (62 m)
- 800-MeV Side-Coupled Cavity LINAC (731 m)
- 800-MeV Compressor Ring (Proton Storage Ring)

LANSCE Experimental User Facilities

- **The Isotope Production Facility (IPF):** IPF uses 100 MeV protons for production of medical radioisotopes for the US.
- **The Proton Radiography (pRad) Facility**: pRad project uses 800 MeV protons to diagnose dynamic experiments (e.g: explosive and powder gun experiments).
- **The Ultra Cold Neutrons (UCN):** A source of sub-μeV neutrons for fundamental physics research (e.g., neutron life time).
- **Lujan Center:** Lujan facility uses an intense time-compressed proton bunch from the proton storage ring (PSR) to create a short pulse of moderated neutrons (meV to keV range) for neutron scattering experiments.
- **The Weapons Neutron Research (WNR) Facility:** Provides a source of unmoderated neutrons (0.1 to 800 MeV) for irradiation of electronic chips and basic science experiments.
- **Blue Room**: Target 2 is used for proton (250 to 800 MeV) irradiation experiments.

Beam Schedule

CY 2022 LUF Operating Schedule
Version 1.4
10-Jun-2022

Michael R Furlanetto

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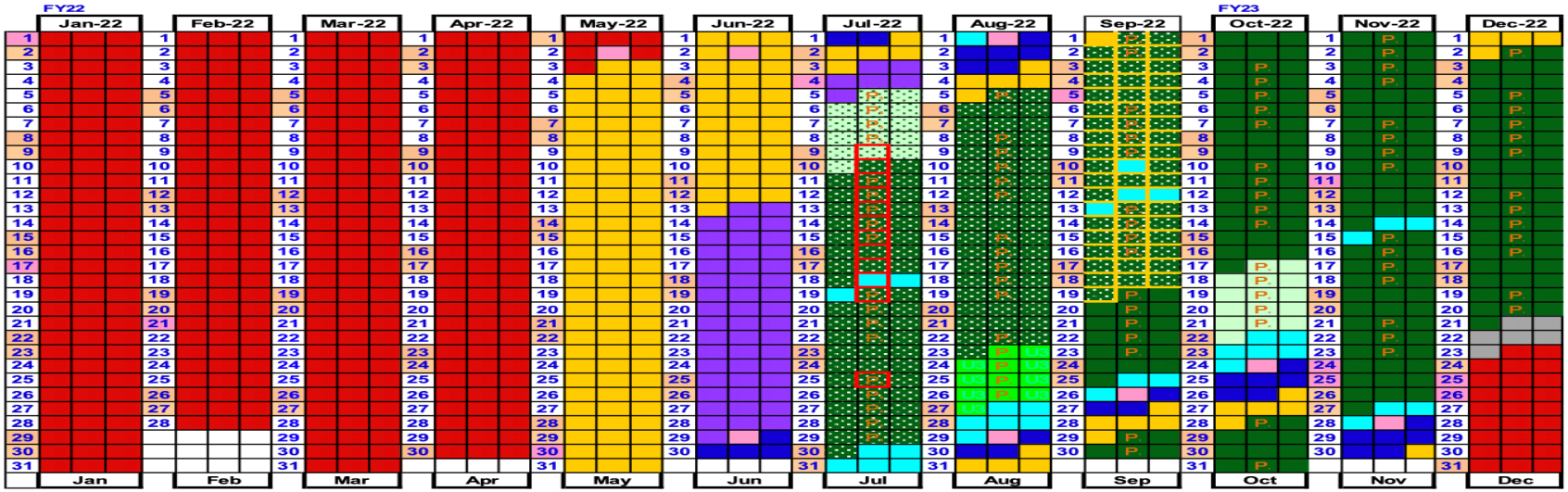


Code	Pattern	Description
0		Outage Maintenance
0		Intra Run Cycle Maintenance
0		H- Ion Source Recycle
0		Documentation / Shut Down
0		Start Up All Areas / Tune Recovery

#	Holiday and/or Laboratory Closure
#	Weekend

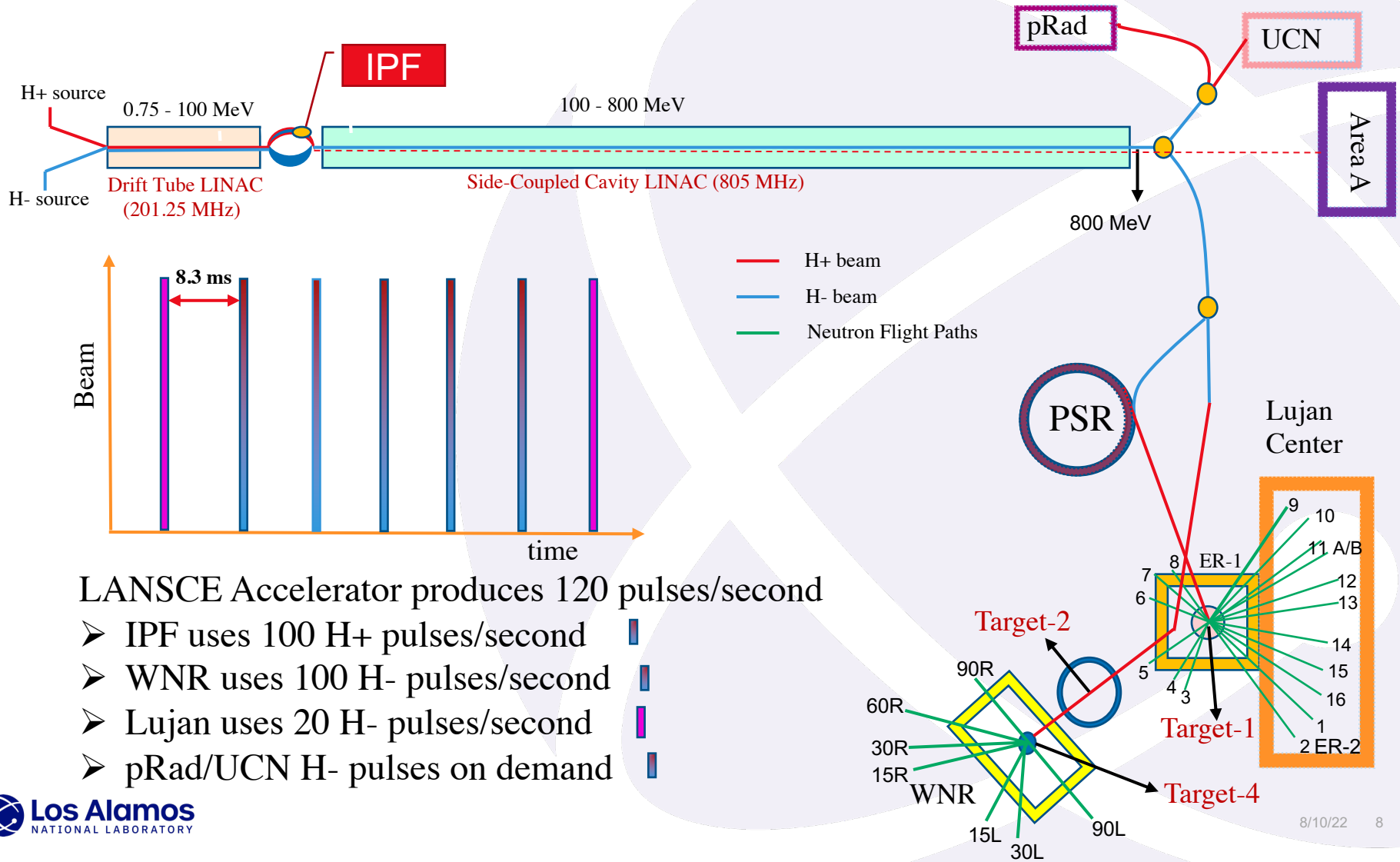
Note:
- Schedule blocks represent 8 hr shifts from 0000-0800, 0800-1600, 1600-2400.
- PRad normal operating hours are typically 0700-1800. PRad and UCN hours are adjusted to account for these typical operating hours.
- The day shift on 10 Sep is reserved for LANSCE Family Day tours. No Beam to any areas.

Code	Pattern	Description	Lujan	T4	T2 linac	T2 PSR	PRAD	UCN	IPF
U1		Production to All Areas with UCN	Y	Y	N	N	N	Y	Y
U2		Tgt 2 Linac Beam, Production Other Areas with UCN	Y	N	Y	N	N	Y	Y
U3	U3	Tgt 2 PSR Beam with IPF & UCN	N	N	N	Y	N	Y	Y
U4		Production to All Areas with UCN EXCEPT LUJAN	N	Y	N	N	N	Y	Y
U5		Tgt 2 Linac, Production Others with UCN EXCEPT LUJAN	N	N	Y	N	N	Y	Y
D		Machine Intervention / Studies	N	N	N	N	N	N	N
I		IPF Production Only	N	N	N	N	N	N	Y
P1	P	Production to All Areas with pRad	Y	Y	N	N	Y	N	Y
P2	P	Tgt 2 Linac, Production Other Areas with pRad	Y	N	Y	N	Y	N	Y
P3	P	Tgt 2 PSR Beam with IPF & pRad	N	N	N	Y	Y	N	Y
P4	P	Production to All Areas with pRad EXCEPT LUJAN	N	Y	N	N	Y	N	Y
P5	P	Tgt 2 Linac, Production Others with pRad EXCEPT LUJAN	N	N	Y	N	Y	N	Y
		Work in 1L Target areas, Production Others EXCEPT LUJAN AND WNR							
		Tuning to 1L Target, Production Others EXCEPT LUJAN							

Duration of Beam Delivery	Shifts	Hours	Start Production
Lujan	231	1848	19-Sep-22
pRad	96	1056	5-Jul-22
UCN	323	2296	5-Jul-22
WNR Sole Use	12	96	Per Schedule
WNR Tgt 4	367	2936	10-Jul-22
WNR Tgt 2	41	328	Per Schedule
IPF	473	3784	13-Jun-22
Machine Intervention	34	272	Per Schedule

Beam Transport and Time Structure

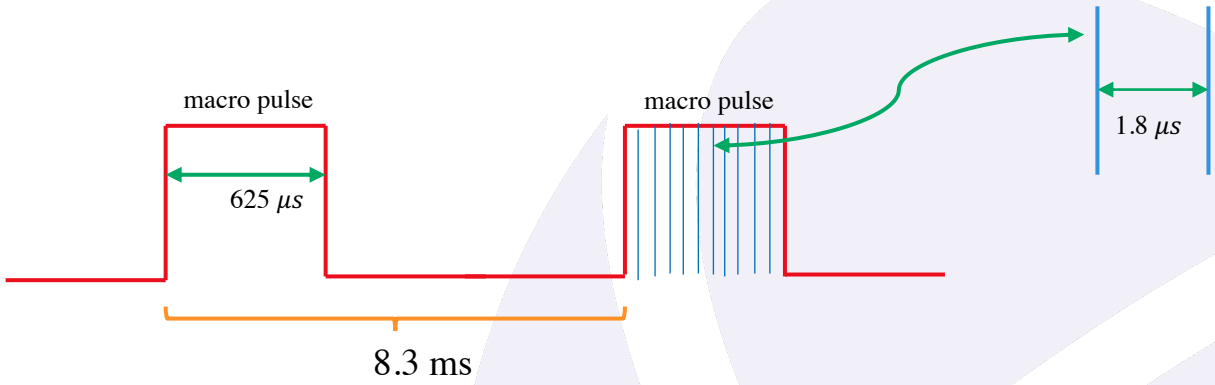
Beam Transport



LANSCE Accelerator produces 120 pulses/second

- IPF uses 100 H+ pulses/second
- WNR uses 100 H- pulses/second
- Lujan uses 20 H- pulses/second
- pRad/UCN H- pulses on demand

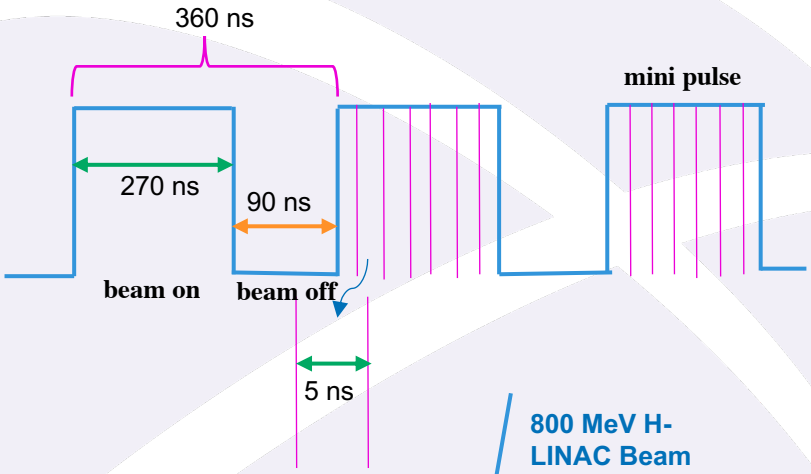
Time Structure of Target-4 Proton Beam

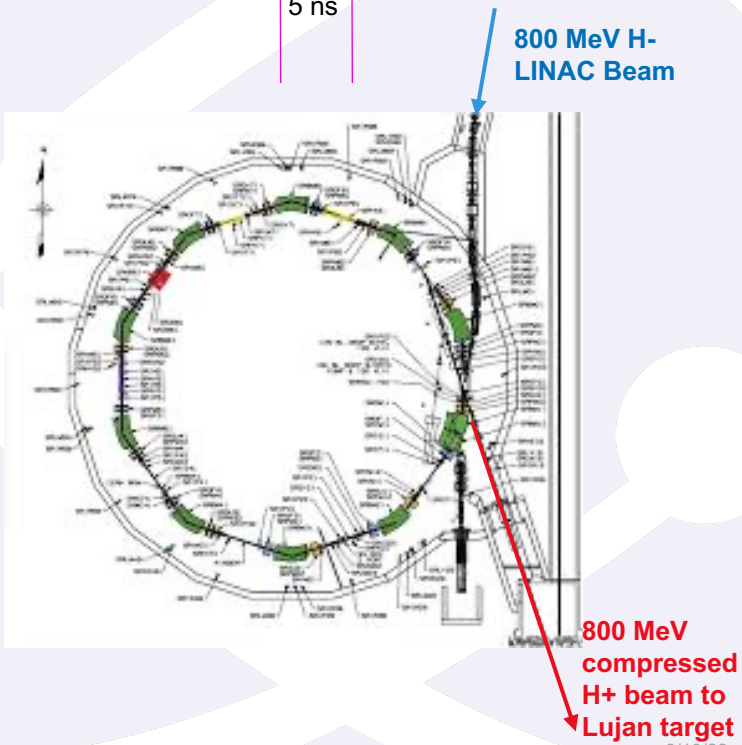


- Linac beam is directly delivered to T-4
- 100 macro pulses/sec (100 Hz)
- Separation between macro pulses = 8.3 ms
- Each macro pulse consists of micro pulses: 1 ns width, 1.8 μs spacing
- Number of micro pulses in each macro pulse = $\frac{625\ \mu s}{1.8\ \mu s} \cong 347$
- Number of micro pulses per sec = $100 \times 347 = 34700$ micro pulses
- Proton beam current: $\left(34700\,\frac{\text{micropulses}}{\text{s}}\right)\left(7\times10^{8}\,\frac{\text{protons}}{\text{micropulse}}\right)(1.6\times10^{-19}C) = 3.8\ \mu A$

Time Structure of Target-1 Proton Beam

- The H+ beam is delivered to Target-1 after passing through the proton storage ring (PSR).
- PSR:
  - Circumference = 90.23 m
  - Rev. freq. / period = 2.795 MHz / 357.8 ns
- Input beam:
  - Energy: 800 MeV
  - macro pulse width: 625 μs
  - mini pulse width: 270 ns,
  - extraction gap: 90 ns
- Output beam:
  - Energy: 800 MeV
  - pulse: triangular pulse ~270-ns wide at the base. 150 ns FWHM
  - Beam current: 100 uA average @ 20 Hz,
  - Charge: 5 μC/pulse (6.2×10^{13} protons/pulse)

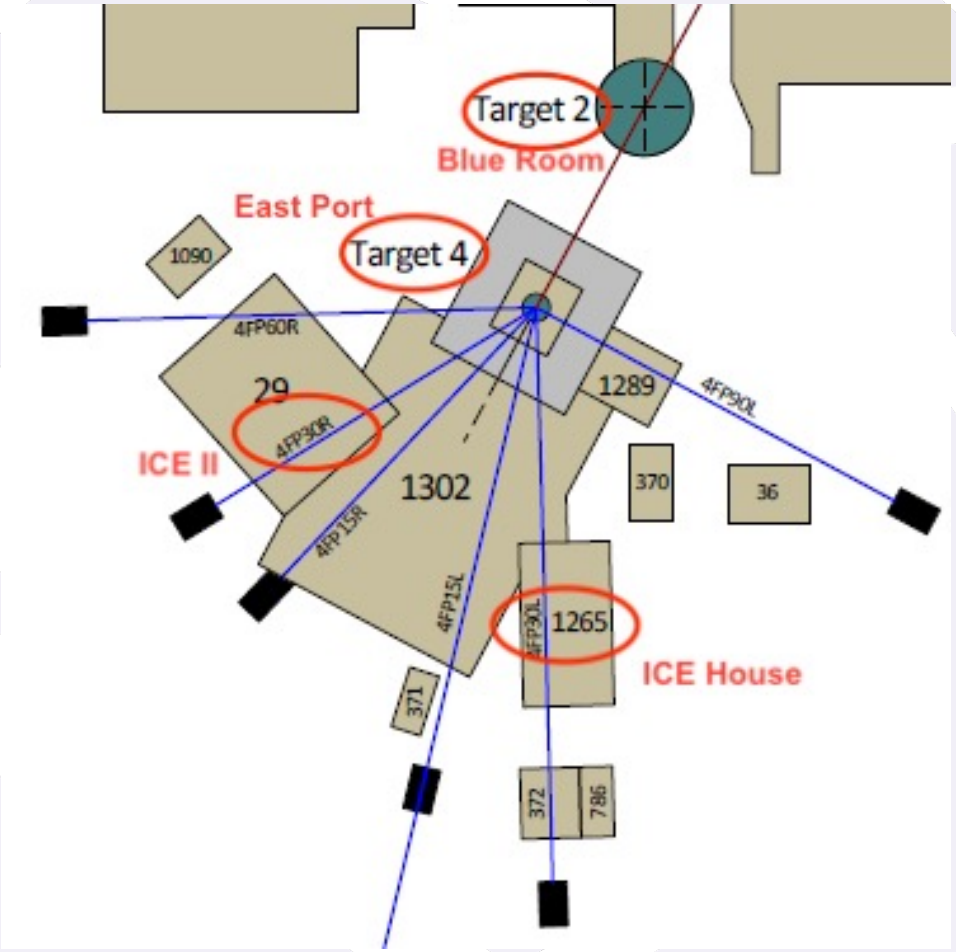




Neutron Irradiation Facilities at LANSCE

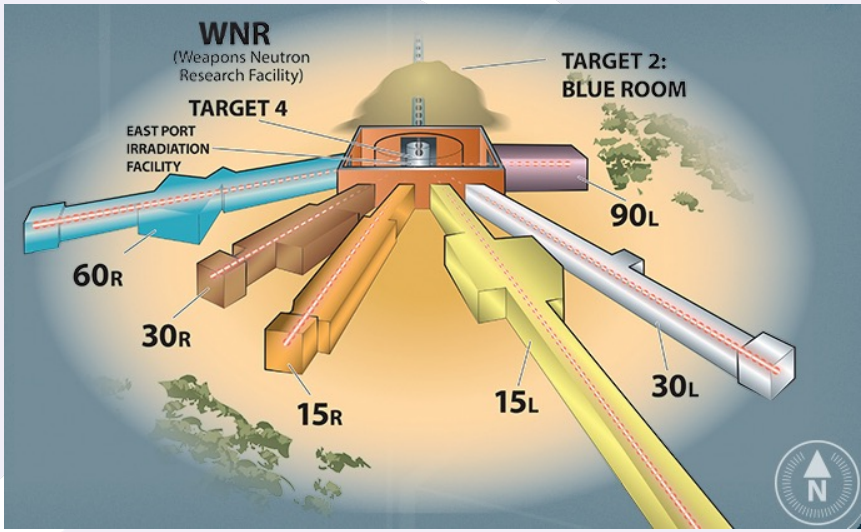
Proton/Neutron Irradiation Facilities at LANSCE

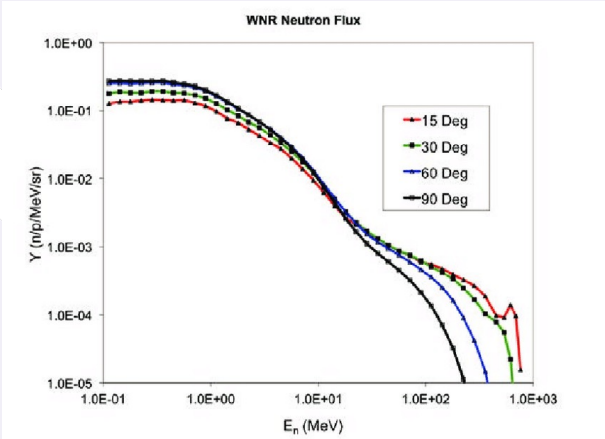
- LANSCE is one of the unique facilities in the world to conduct radiation (protons & neutrons) effects experiments.
- Facilities:
  - Target-2 (Blue Room) – Protons
  - 4FP30R (ICE-II) – Neutrons
  - 4FP30L (ICE-I) – Neutrons
  - 4FP60R (under development) – Neutrons
  - East Port (inactive) – Neutrons
  - Area-A (inactive) – Protons



WNR Neutron Flight Paths

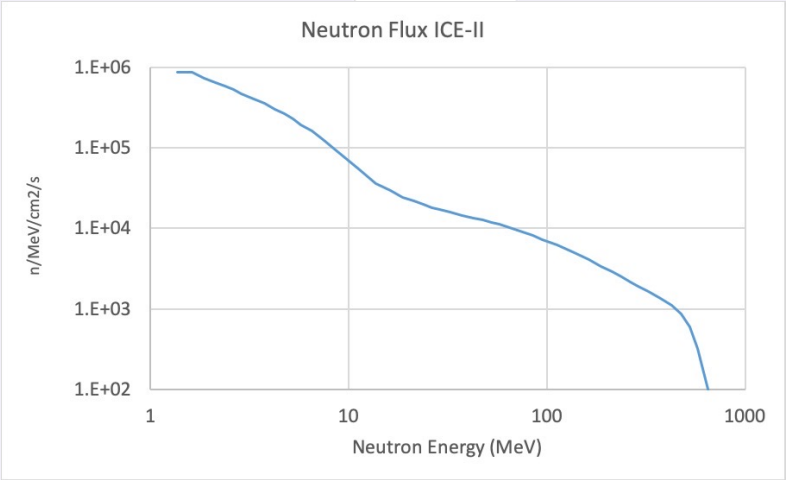
- WNR flight paths names are identified by their angles with respect to the proton beam direction.
- Neutron spectrum depends on the angle of the flight path with respect to the proton beam.
- 15° ($R\ and\ L$) flight paths have the most intensity at high energy and lower intensity at lower neutron energy.
- 90°L flight path has more intensity at lower energy and lower intensity at high neutron energies.
- 60°$R\ and$ 30°(R and L) neutron spectrums fit between 90° and 15° .



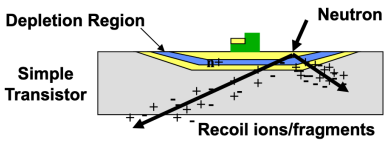


ICE HOUSES

- The ICE (Irradiation of Chips and Electronics) Houses are experimental areas that are primarily used for semiconductor neutron irradiation research and testing.
- Industry, laboratory, and university researchers use these facilities to qualify and test semiconductor devices for single-event effects (radiation-induced-errors).
- ICE-I (30L) and ICE-II (30R) neutron spectrums are very similar to the cosmic-ray-induced atmospheric neutron spectrum but typically 5×10^7 times more intense.
- This large flux allows testing of semiconductor devices at greatly accelerated rates.



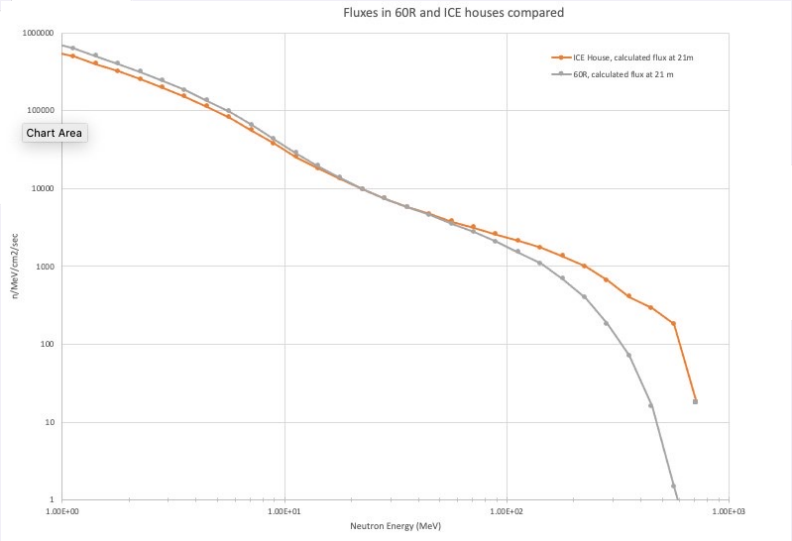
parameters	ICE-I	ICE-II
Distance from T-4 to fission chamber	19.67 m	13.87 m
Integrated neutron intensity above 1.25 MeV	$2.4\times10^6 \frac{n}{cm^2/s}$	$4.7\times10^6 \frac{n}{cm^2/s}$
Integrated neutron intensity above 10 MeV	$1.2\times10^6 \frac{n}{cm^2/s}$	$2.2\times10^6 \frac{n}{cm^2/s}$
Beam spots	1”, 2”, 3”, 4”, 4.5”	1”, 2”, 2.5”, 3”



WNR 60R

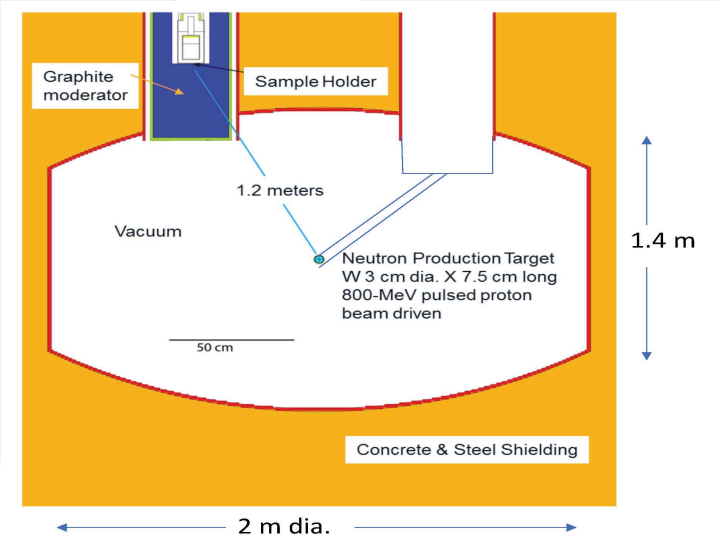
- 60R primarily used for fast neutron imaging.
- ICE Houses are oversubscribed with radiation effects users.
- We are upgrading 60R flight path to provide the same level of support to radiation effects users as the ICE Houses.
- 60R should provide additional capacity for users who can use a neutron spectrum that is not as closely matched to the cosmic induced atmospheric neutron spectrum.
- The neutron spectrum of 60R ranges from 0.6 to 400 MeV.
- Integrated neutron flux above 1 MeV = 3×10^6 neutrons/cm^2/sec

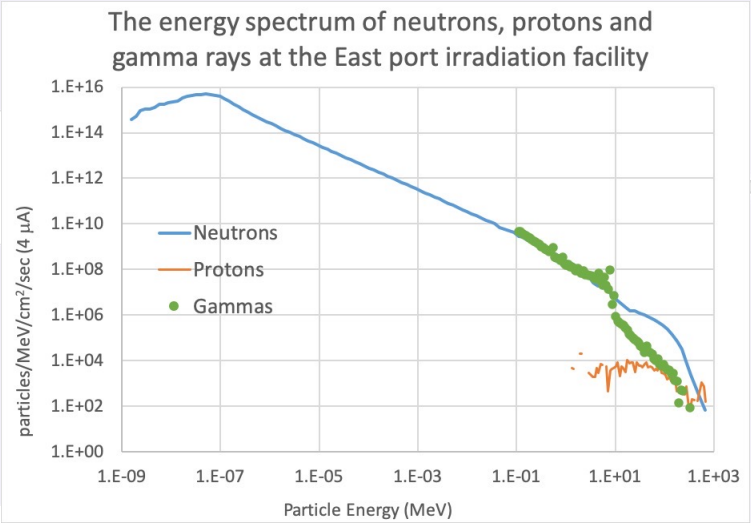
Fast neutron radiograph of the left most portion of the 74.5 million year old skull of the tyrannosauroid dinosaur Bistahieversor sealeyi collected from northwestern New Mexico.



East Port

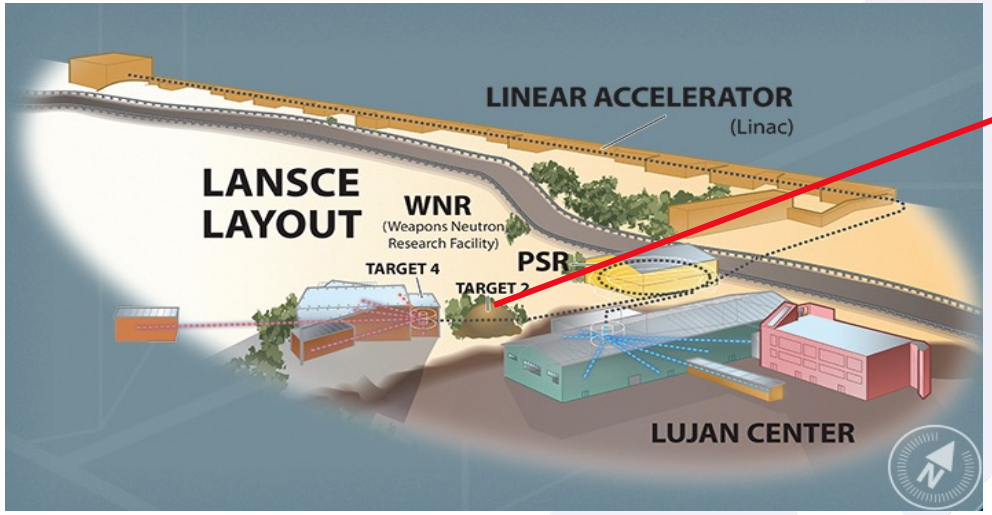
- East Port Irradiation Facility provides intense neutron flux for material irradiation studies and research (e.g.: rad-hard scintillator studies, semiconductor radiation hardness studies)
- The sample cell is located approximately 1.2 m from the neutron production target.
- Samples are loaded in the cell at the top of the access port and can be lowered to the irradiation location.
- Samples are exposed to protons and gamma rays that are produced in the production target.
- Integrated intensity of particles above 1 MeV
  - Neutrons: $4.2\times10^{8}\ \frac{n}{cm^2/s}$
  - Protons: $8.17\times10^{5}\ \frac{p}{cm^2/s}$
  - Gammas: $4.1\times10^{8}\ \frac{\gamma}{cm^2/s}$





Proton Irradiation Facility at LANSCE

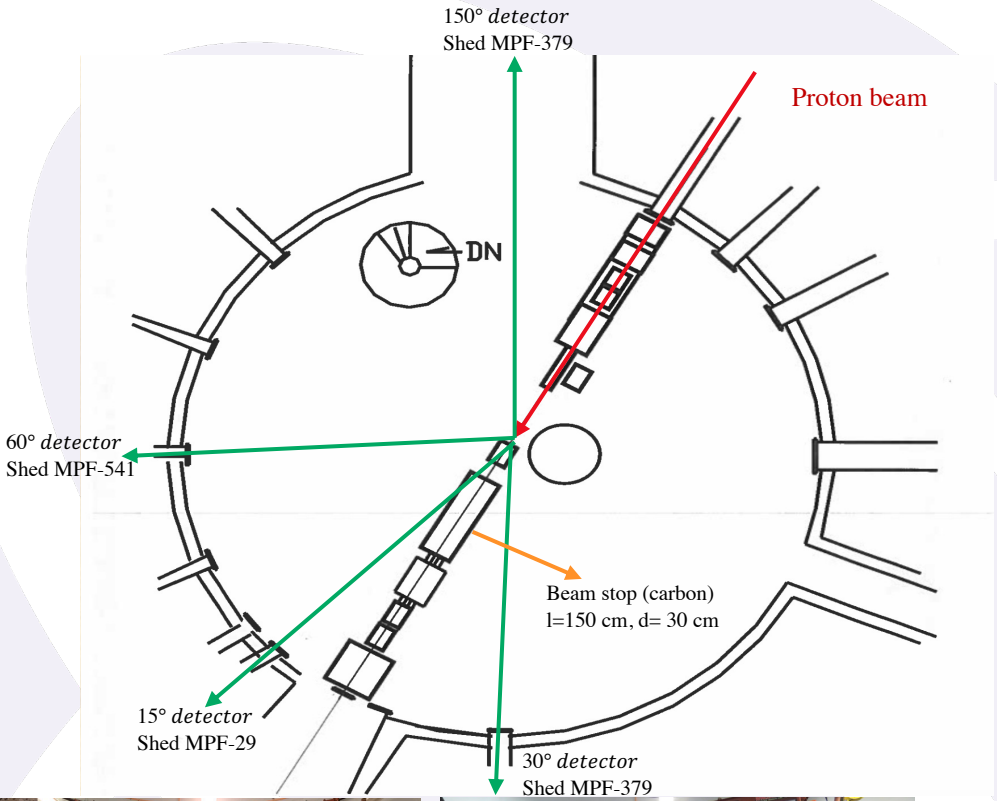
TARGET-2 (aka Blue Room)



- Target-2 aka Blue Room is a unique facility in the world to perform proton irradiation experiments with 250-800 MeV proton beam.
- Based on experiment requirements, Target-2 can use either use the linac beam, or the high peak intensity stacked beam from the Proton Storage Ring.
- Target-2 is operated at an average current of 80 nA.
- PSR can be run from pulse-on-demand up to 40 Hz
- PSR beam pulse intensity can be as high as 5 μC (3 x 10^{13} protons) per pulse.

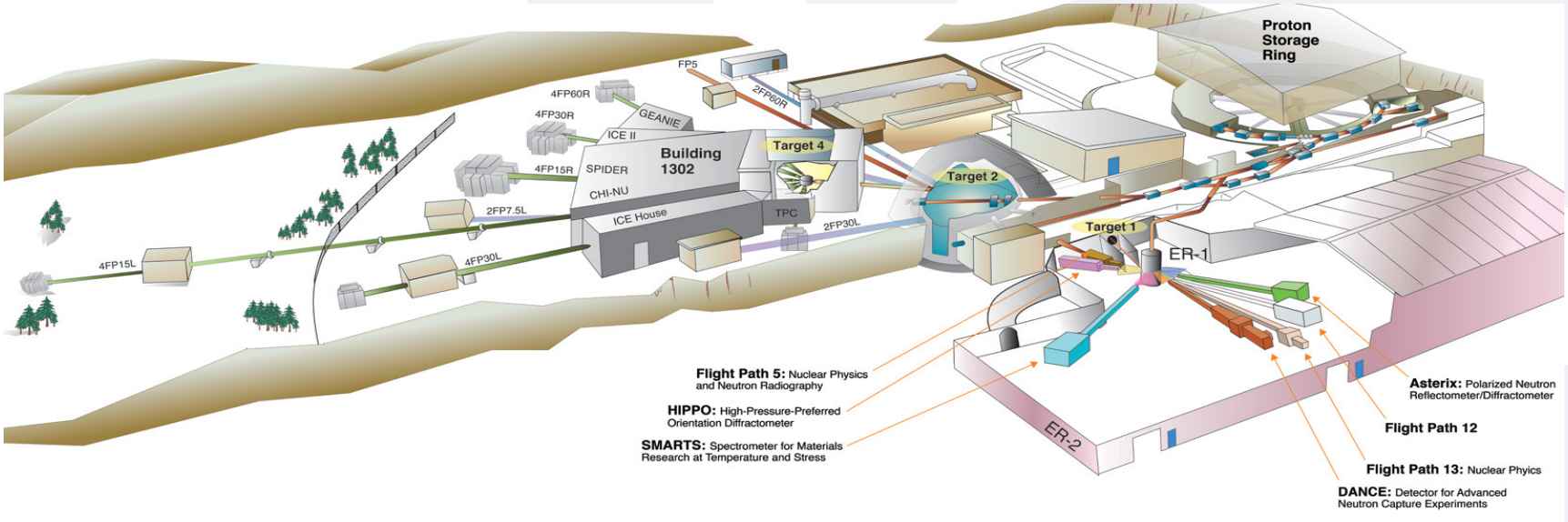
TARGET-2 Layout

- Target-2 is domed room in Building-7 at LANSCE.
- It has a diameter of 40 feet
- Target-2 floor is mainly constructed with aluminum which elevated to 20 feet above the basement floor to reduce room return neutrons.
- It has multiple neutron flight paths extended ~50 m outside the room to detector sheds.
- When Target-2 is in operation, beam line pipe is removed, ~ 4 m space is available along proton beam path to set up Devices Under Test(DUT)/targets.



Target-2 Operational Limitations

- Blue Room operation is limited to 80 nA (5×10^{11} protons/s) to limit radiation environment outside of Blue Room.
- When linac beam is delivered to Target-2, we cannot operate WNR neutron flight paths.
- When PSR beam is delivered to Target-2, we cannot operate Lujan center neutron flight paths.
- Only high scientific merit and high priority experiments are scheduled



Beam Time Requests for Target-2 in 2022

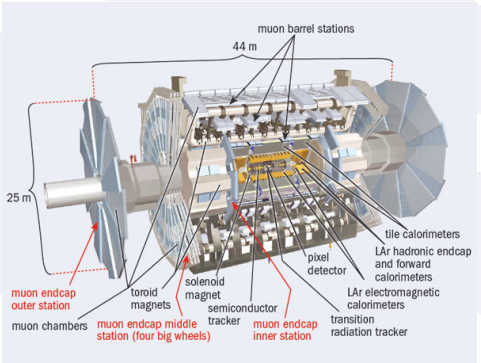
- 6 proposals were received for beam time in the Blue Room.
- A total of 19 days were requested.

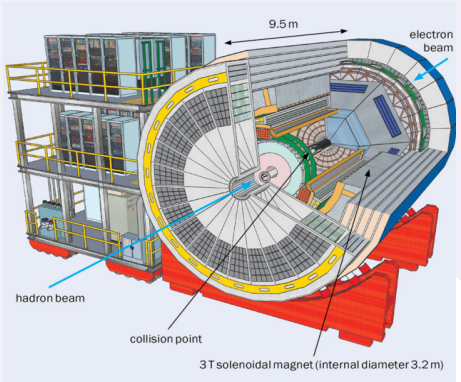
- LINAC beam time: 13 days
  - Irradiation of detector materials for high energy particle collider experiments and other applications [users: UNM, LANL, Caltech]
  - Above experiments scheduled for July 5, 6, 7, 8, 9; Oct 17, 18, 19, 20, 21.
  - LANL and UNM users collaborated and simultaneously ran their experiments in July

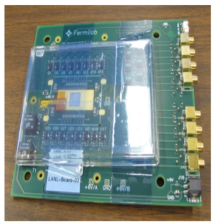
- PSR beam time: 6 days
  - A study of the dynamic strain response in a tungsten target block (ORNL's Second Target Station) due to a high-energy pulsed proton beam impact [users: ORNL]
  - Scheduled for Aug 23, 24, 25, and 26.

UNM-LANL Blue Room Run

- UNM: Radiation tolerance test for sensor/readout silicon detector modules that will operate a few centimeters from the collision point in LHC ATLAS Experiment at CERN.
- LANL: To evaluate radiation damage effects on three new detector technologies under development for EIC and LHCb.
- Beam parameters:
  - LINAC beam
  - Energy: 500 MeV (Due to sector F failure we could not deliver 800 MeV beam)
  - Beam average Current: 76 nA ($4.7\times10^{11} protons/s$)

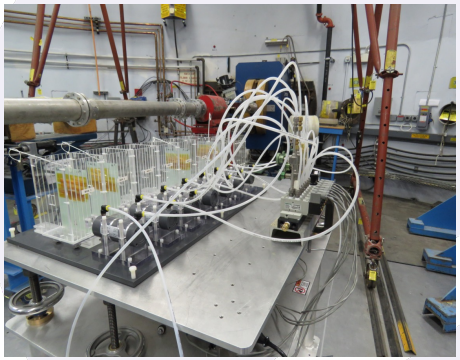


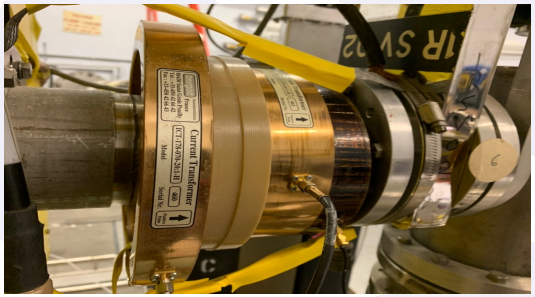




Target-2 Facilities

1. Pneumatic system:
   - users can interface their sample changer with our pneumatic system
   - can operate remotely
2. Translational stage
3. Laser
   - used for DUTs alignment with the beam
3. Three cameras:
   - To see beam spot on phosphor
   - To see beam spot on beam stop phosphor
   - To monitor experiment remotely
4. Bergoz Integrating Current Transformer: The proton current is measured using ICT with appropriate sensitivity.
   - 5:1 for PSR beam
   - 20:1 for LINAC beam
5. Freezers: to store radioactive samples
6. Data Room



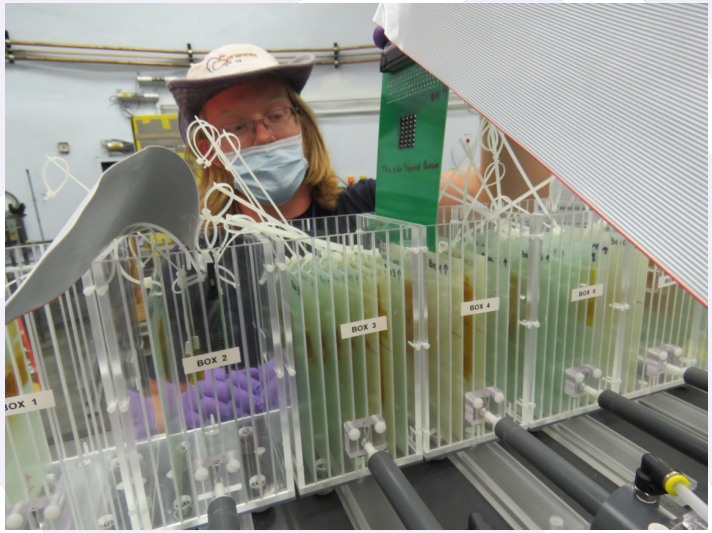


Training required for the Users

- Site Specific
- General Employee Radiological training (GERT)
- Rad Worker II
- Blue room Experiment orientation
- Pre-Job briefing of Integrated Work Document and user checklist by IS/IA
- Pre-job briefing of Radiological Permits (RWP) by RCTs
- Beryllium Awareness training.
- Dosimeters required to access T-2:
  - TLD (Thermoluminescent Dosimeter)
  - TED (Track-Etch Dosimeter)
  - Wrist Extremity Dosimeters (if handling irradiated samples)

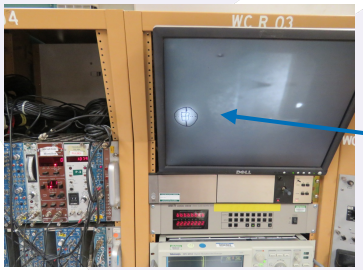
Experimental setup

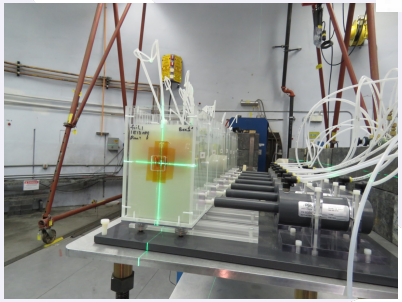
- We will have morning meeting to discuss plans for the day.
- Pre-Job briefing of Integrated Work Document and user checklist by IS/IA
- Pre-job briefing of Radiological Permits (RWP) by RCTs
- Call Central Control Room and request for Blue Room entry
- RCTs will perform initial survey and indicate activated areas.
  - ➢ If necessary wait for area to cool down before entry.
- Remove beamline pipe.
- Start vacuum system (may take ~ 6 h)
- Set up tables and any other experiment-specific equipment.
- Install beam stop.
- Users can start setting up their experiment.

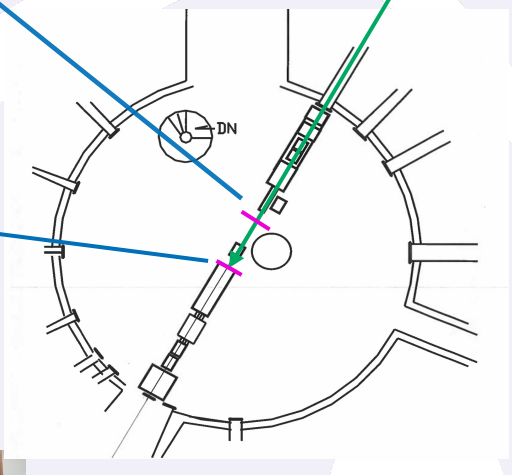


DUT/Target Alignment

- Set up DUT in the Blue Room
- Close the Blue Room
- Close up and sweep Target-2
  - ➢ Call CCR for sweep of Target-2.
- Accelerator operators will tune beam to hit center of the phosphor plates
- Mark beam spot points on the screens in WNR control Room
- Stop beam
- Access Blue Room
- Align samples/targets based on markings using laser
- Close and sweep the Blue Room
- Take beam







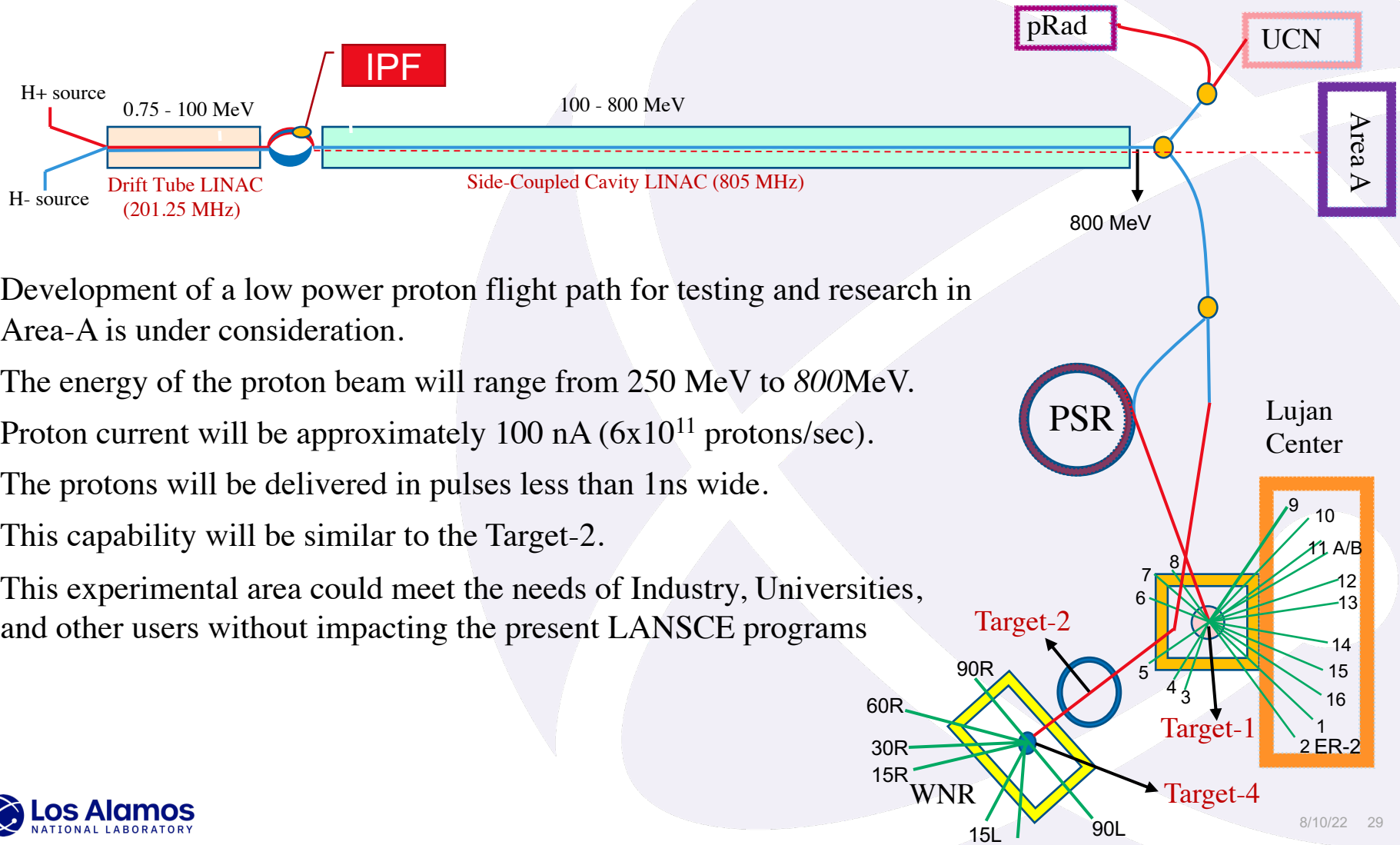
Run Experiment

- We will have morning meeting to discuss plans for the day.
- If necessary to enter the Blue Room:
  - Call CCR and request entry
  - RCTs will survey Target-2 upon first entry after beam has been turned off
  - Results of survey will be posted and briefed to all people entering Target-2.
  - Minimize number of people in the area.
  - If necessary wait for area to cool down before entry.
- Any material exposed to the beam must be surveyed before handling or prior to removal.
- Personal protective equipment (PPE):
  - Use gloves when handling any material that has been exposed to proton beam.
  - Booties, lab coats, gloves as required by RWP or when required by on-site RCTs.
- Perform work in Target-2
- Close up and sweep Target-2
  - Call CCR for sweep of Target-2.
- Use hand and foot monitor when leaving Target-2
- Run beam

Disassembly of Experiment

- We will have morning meeting to discuss plans for the day.
- Enter target -2
  - Call CCR for Entry
  - RCTs will do area survey post radioactive areas
  - If necessary, wait appropriate time before entering
- Wear PPE mentioned in the RWP
- Move as much apparatus (cables, cameras, detectors, Devices Under Test, etc.) from area around proton beamline as possible.
- Stage equipment to be surveyed. We will probably keep most of equipment/samples in Target-2 until it has had time for radioactivity to decay.
- If necessary we can do rad shipment

Area A



- Development of a low power proton flight path for testing and research in Area-A is under consideration.
- The energy of the proton beam will range from 250 MeV to *800*MeV.
- Proton current will be approximately 100 nA ($6x10^{11}$ protons/sec).
- The protons will be delivered in pulses less than 1ns wide.
- This capability will be similar to the Target-2.
- This experimental area could meet the needs of Industry, Universities, and other users without impacting the present LANSCE programs

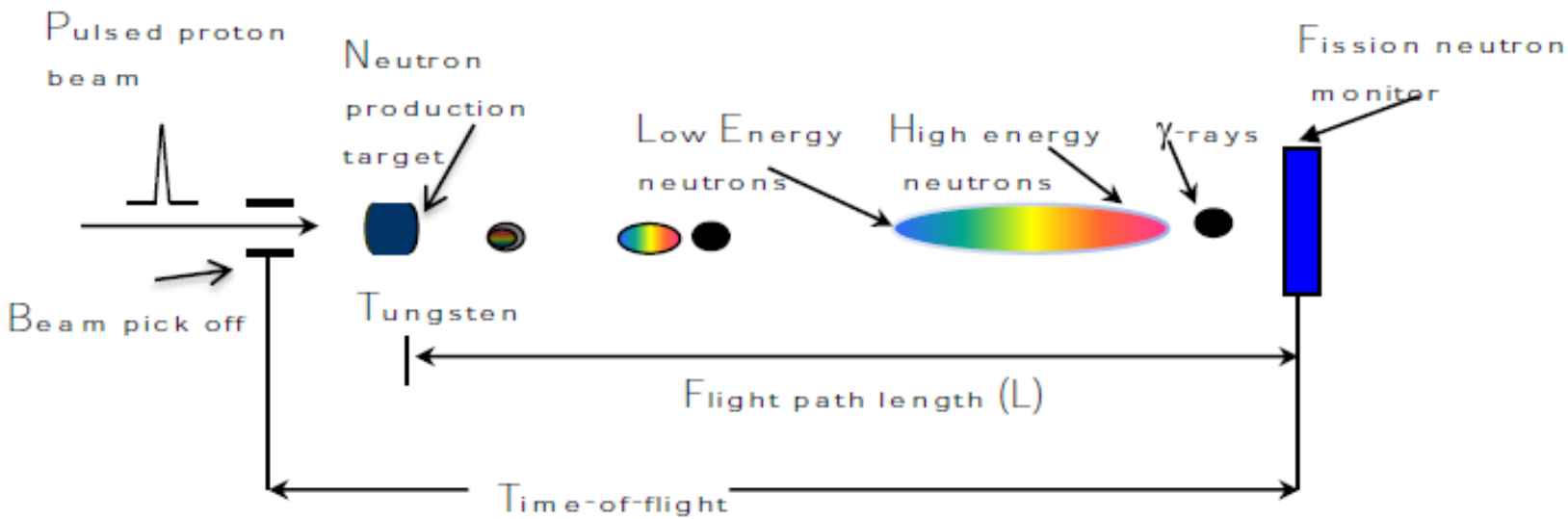
Summary

- LANSCE is an excellent facility for neutron and proton irradiation experiments.
- There are several exciting capabilities at LANSCE for electronics and detector/materials irradiations:
  - High energy neutron (1 - 600 MeV) irradiation facilities: ICE Houses
  - Low-intensity proton beam (80 nA) irradiation facility: Target-2 (aka Blue Room)
  - 60 R high energy neutron (0.6 – 400 MeV) irradiation facility (under development)
  - Area-A proton beam (100 nA) facility (future capability)

Thank You!

Back Up Slides

Time of Flight



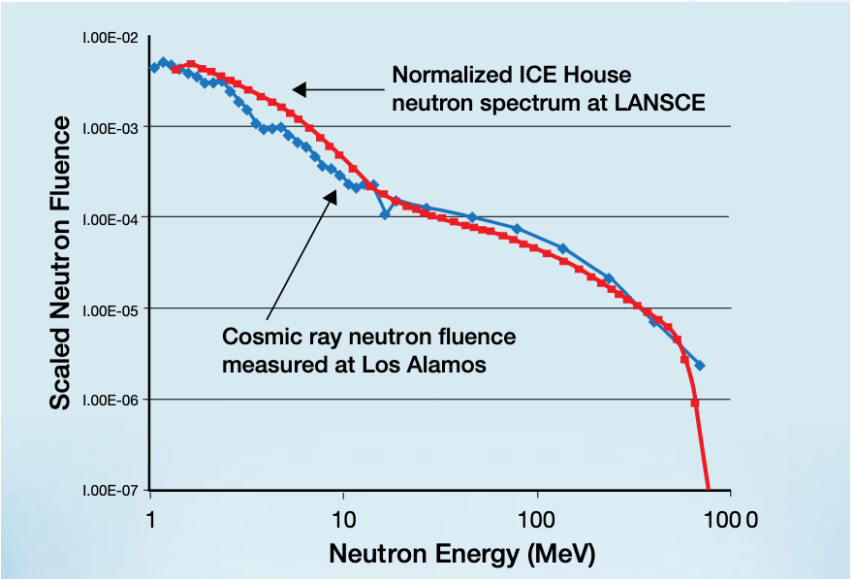
Neutron TOF $= \frac{72.3\,L}{\sqrt{E_n}}$ (non-relativistic)

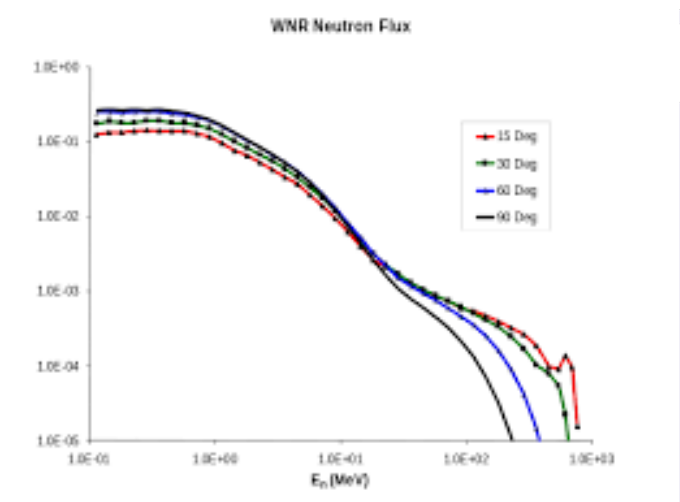
γ-ray TOF $= \frac{L}{c}$ c is velocity of light

Example: L = 20 m TOF_γ = 67 ns E_n = 1 MeV TOF_n = 1.5 μs

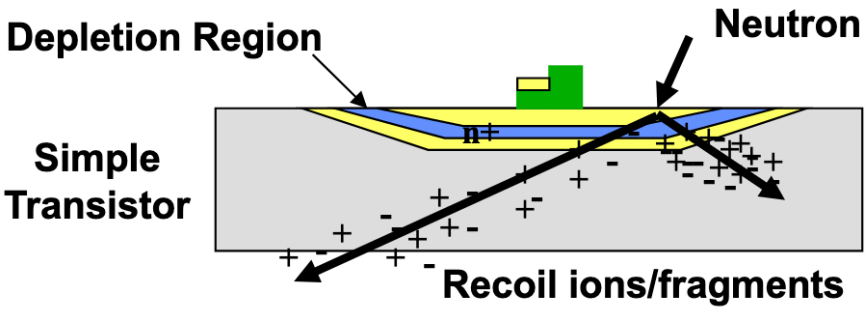
E_n = 100 MeV TOF_n = 150 ns

ICE House Neutron spectrum





Single Event Effects



Neutrons need nuclear reaction to create charged particles. Charged recoil ions (elastic collisions) and fragments (inelastic) ionize device material and deposit charge in the sensitive volume where it can cause an upset.

- The failure rate due to cosmic-ray events is given by:

$$F/t = \Sigma_p \int \sigma_p(E_p) * \Phi_p(E_p)\ dE$$

Particle flux depends on:
- **Particle type**
- **Altitude**
- **Latitude**
- **Solar activity**
- **Local geometry**

Cross section depends on
- **Device characteristics**
- **Particle type**
- **Particle energy**

F/t is the number of fails / time

p is the particle type (neutron, protons, pions,…)

$\sigma_p(E_p)$ is the number of upsets /particle with energy E_p

$\Phi_p(E_p)$ is the number of particles/sec with energy E_p