An overview of facilities for measuring prompt neutron-induced gamma-rays

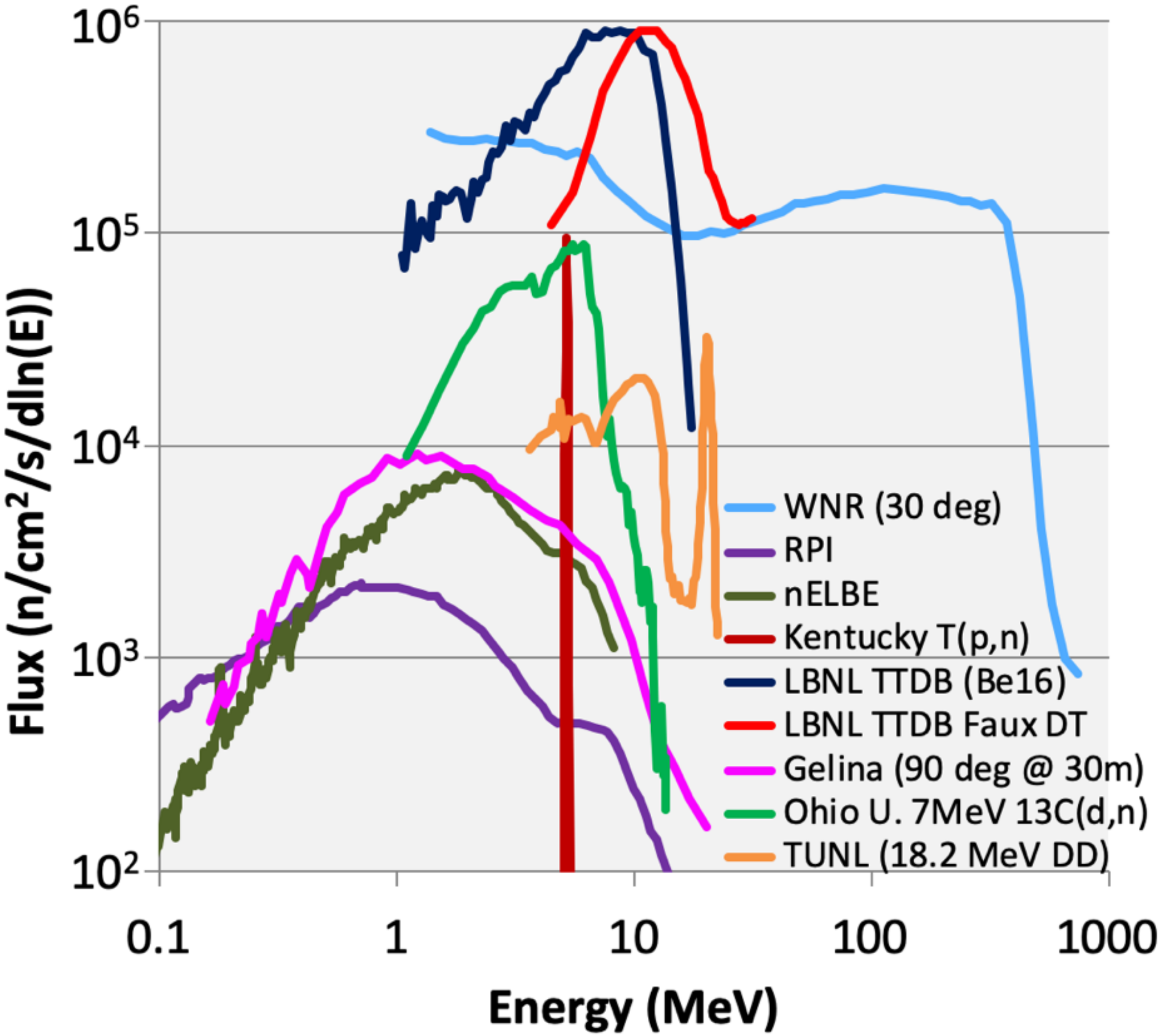
(Or: How to make frenemies and confuse lots of people)

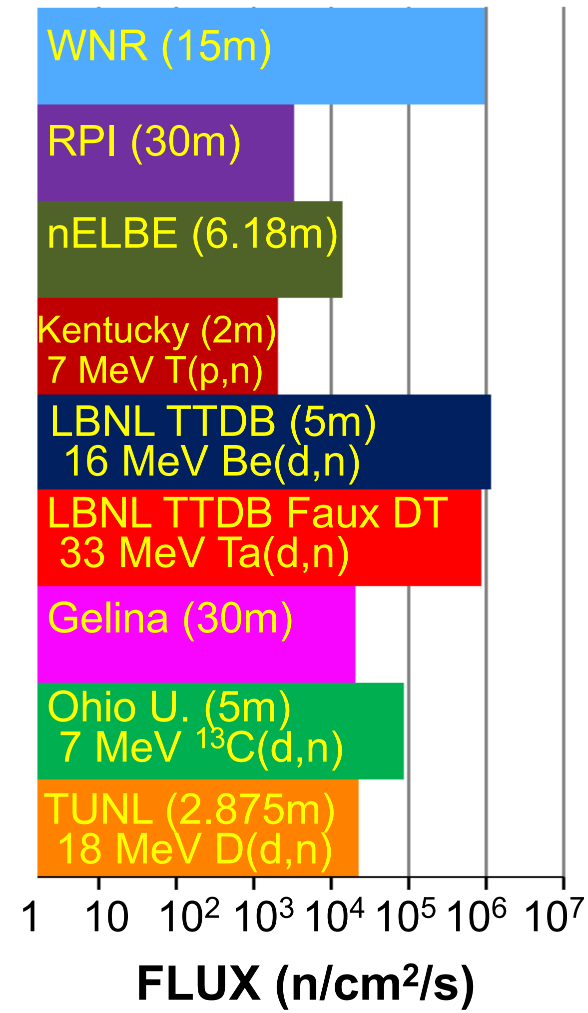
Darren L. Bleuel
Lawrence Livermore National Laboratory

Workshop for Applied Nuclear Data Activities
March 4, 2020

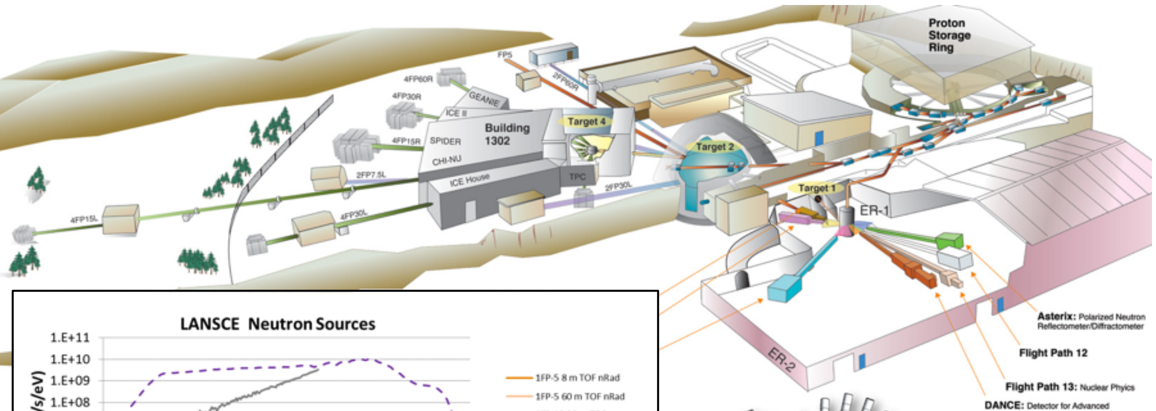
LLNL-PRES-780137
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

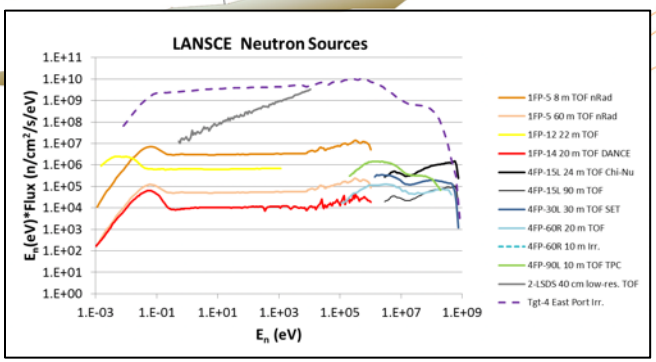
A comparison of (some) neutron sources around the world
(a.k.a., the too-busy slide that gets me hate mail)

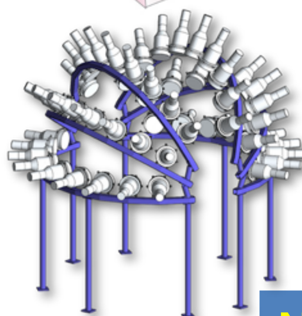


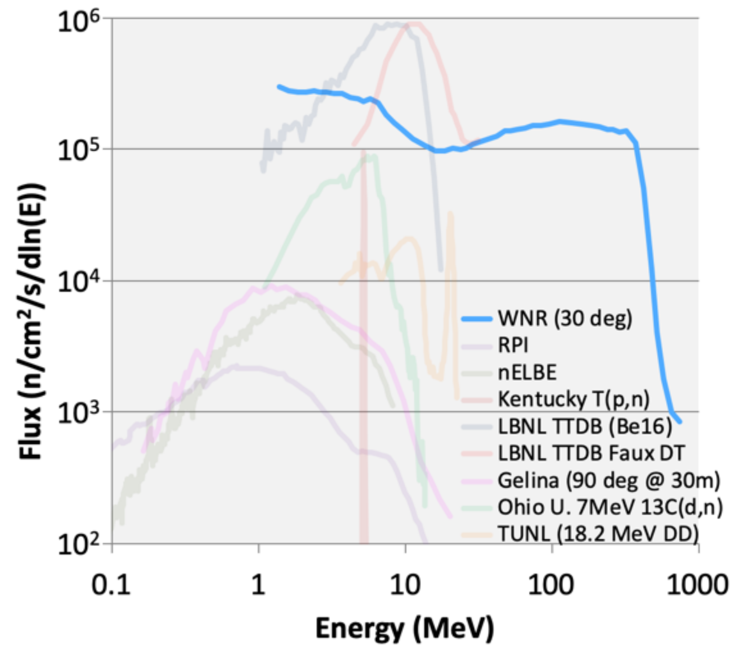


LANSCE (Los Alamos National Lab) (Spallation neutron source)





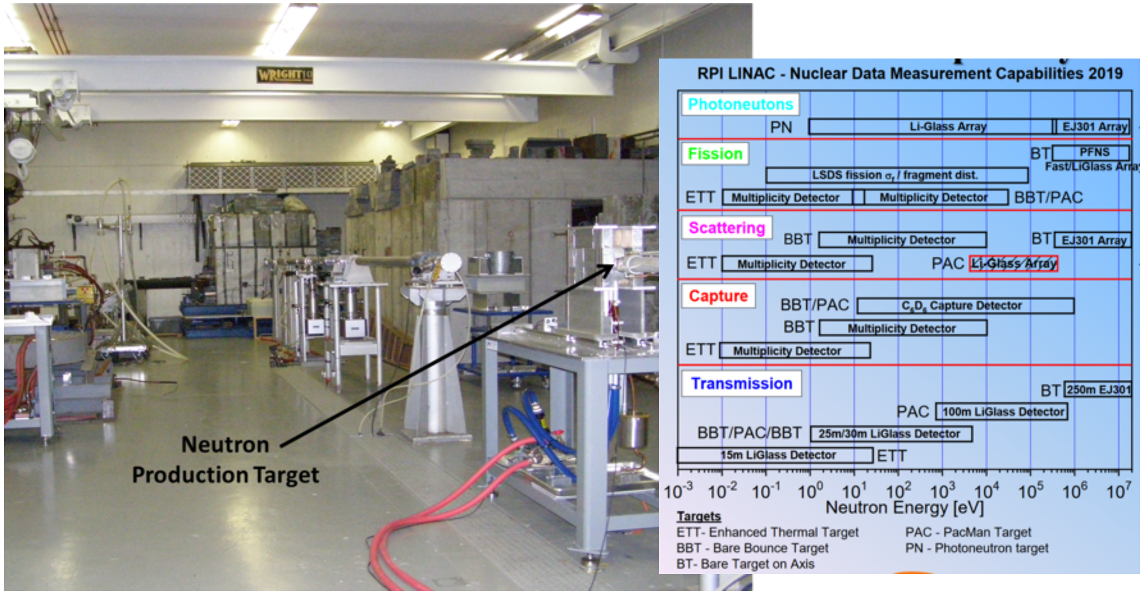


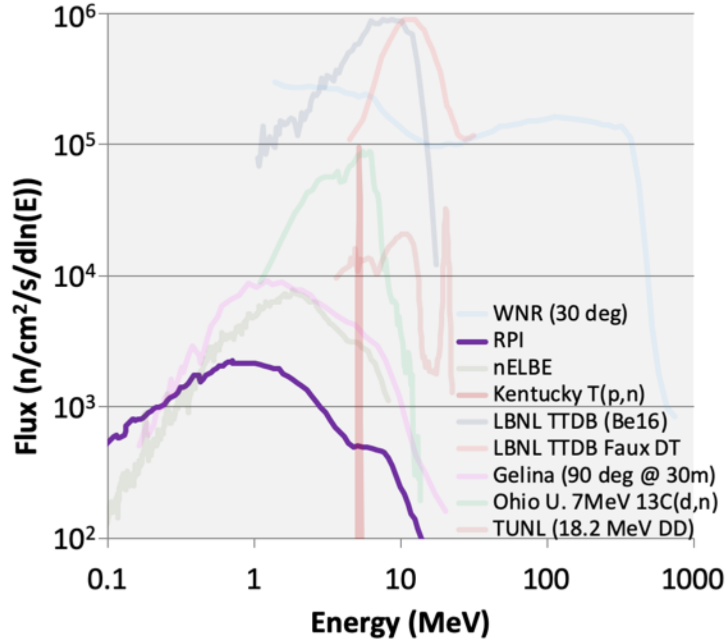


<u>Notable capabilities:</u>
- Many beam lines
- GENESIS partner (Chi-nu)
- Reaction/fission studies
- Activation/decay
- Neutron imaging
- Isotope production
- …

Neutron Source(s):	800 MeV Spallation
Beam spectrum:	(up to 800 MeV)
Target distances	8m - 90m
n Flux (n/cm²/s)	$1\times10^{6\text{-}9}$+ (?)
γ-ray detectors	DANCE, HPGe…

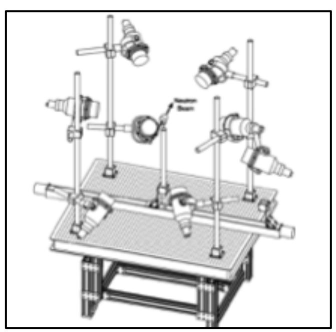
Gaerttner Linear Accelerator Laboratory (RPI) (Electron LINAC, photoneutron source)





Notable capabilities:

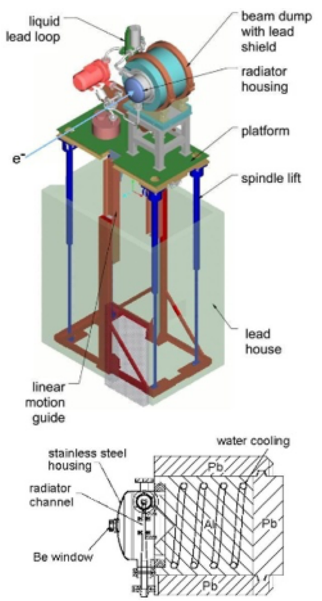
- Multiple stations
- $e^- \rightarrow$ Ta $\rightarrow$ brem $\rightarrow (\gamma,n)$
- Nuclear data
- Rad damage
- Radioisotopes
- LSDS

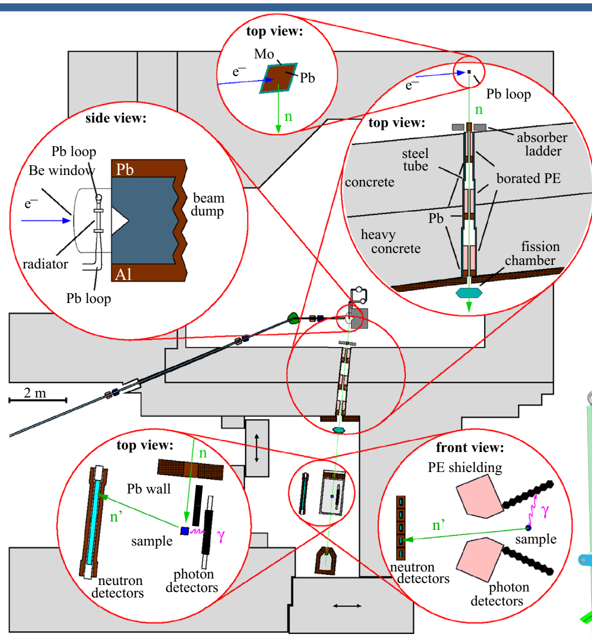


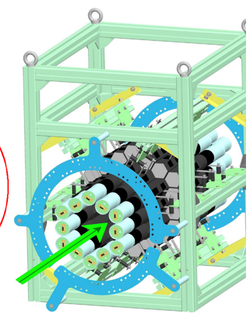
Neutron Source(s):	Photonuclear
Beam current:	8 μA (60 MeV e's)
Target distances	15m - 250m
n Flux (n/cm^2/s)	3.5×10^4 (30m)
γ-ray detectors	NaI, BaF_3, C_6D_6

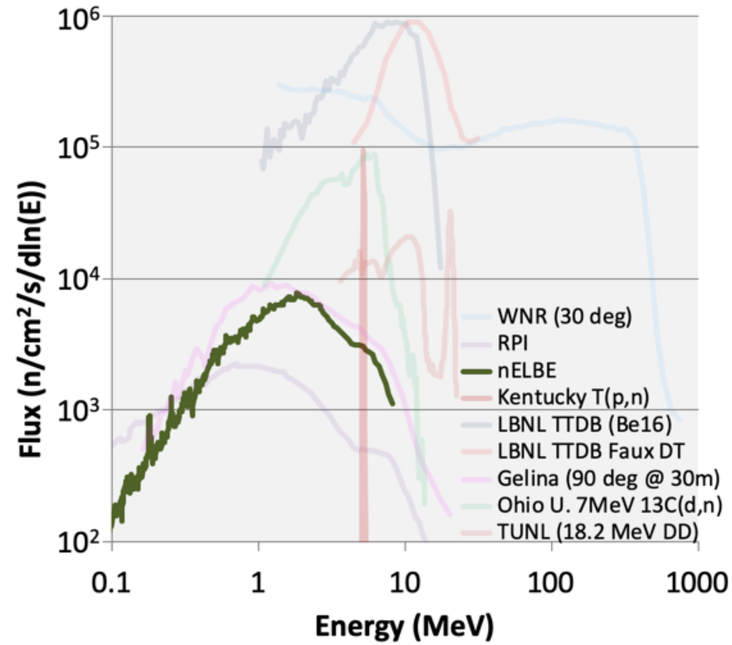
Overberg et. al., NIM A 438 (1999) 253-264

nELBE (Helmholtz-Zentrum Dresden-Rossendorf) (Electron LINAC, photonuclear source)









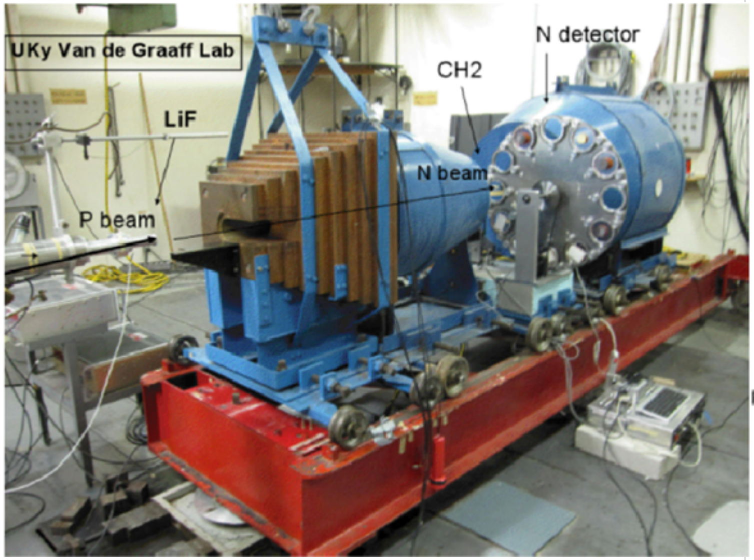
Notable capabilities:

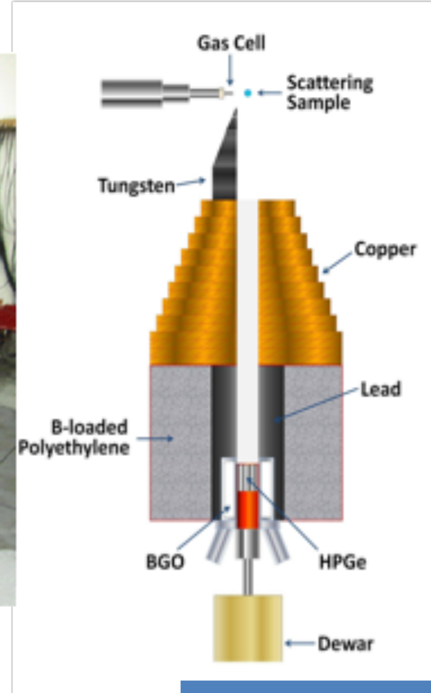
- $e^- \rightarrow Pb_{liq} \rightarrow$ brem $\rightarrow (\gamma,n)$
- Very short pulse (5ps!)
- Close match to fission spectrum
- Fission, capture, inelastic studies
- $^{56}Fe(n,n'\gamma)$ including $\gamma(\Omega)$

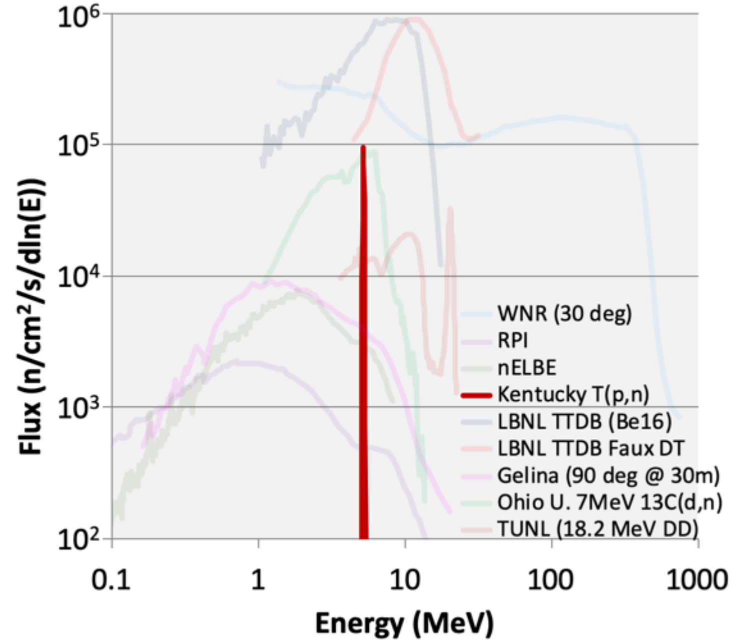
Neutron Source(s):	Photonuclear
Beam current:	1 mA (40 MeV)
Target distances	6.18m
n Flux ($n/cm^2/s$)	$4x10^4$ (6.18m)
γ-ray detectors	HPGe, $LaBr_3$, BaF_2

Beyer et. al., NIM A 723 (2013) 151–162

UKAL – University of Kentucky Accelerator Laboratory (7 MV Van de Graff Accelerator)





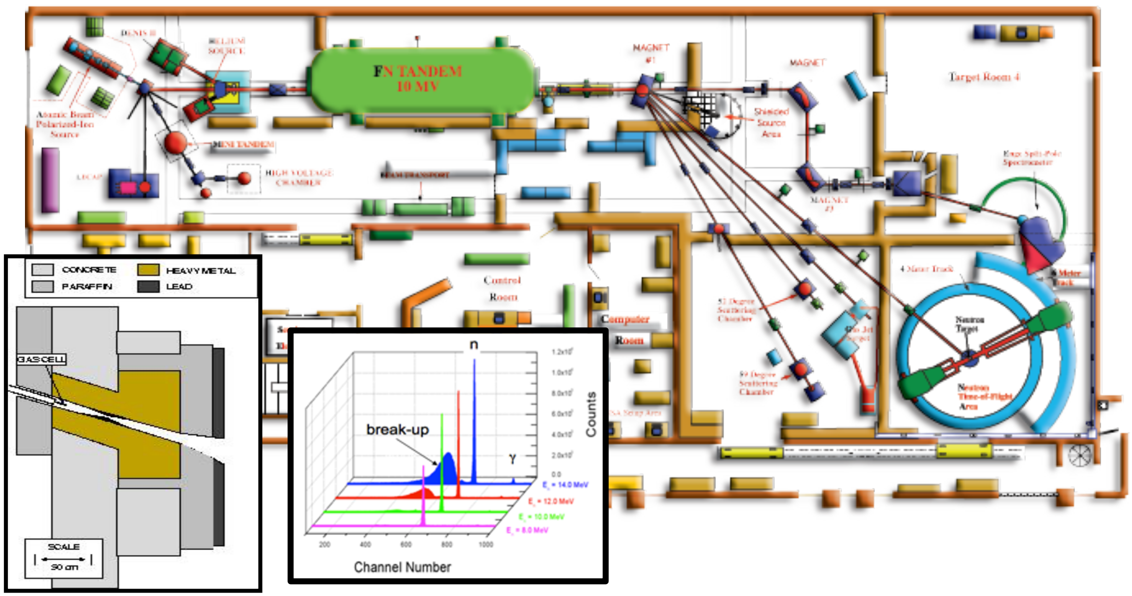


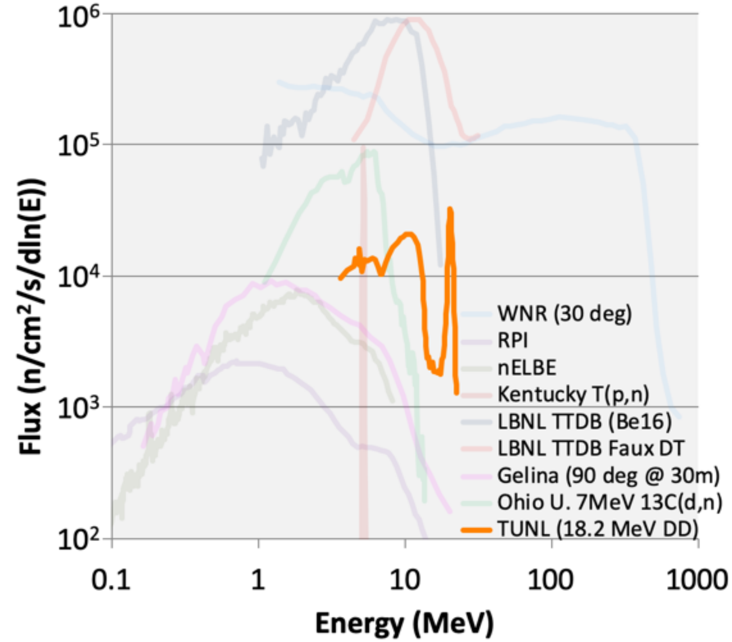
Notable capabilities:
- Monoenergetic beams (0.1-23 MeV)
- Spectroscopy
- Scattering studies
- γ-ray production cross sections ($0\nu\beta\beta$)

Neutron Source(s):	D(d,n), T(p,n)
Beam current:	1-2 μA (<7 MeV)
Target distances	4cm - 2m
n Flux ($n/cm^2/s$)	2×10^3 (2m)
γ-ray detectors	HPGe, BGO

Garrett et. al., J. Res. Natl. Inst. Stand. Technol. 105, 141 (2000).

TUNL – Triangle Universities Nuclear Laboratory (10 MV Tandem accelerator)





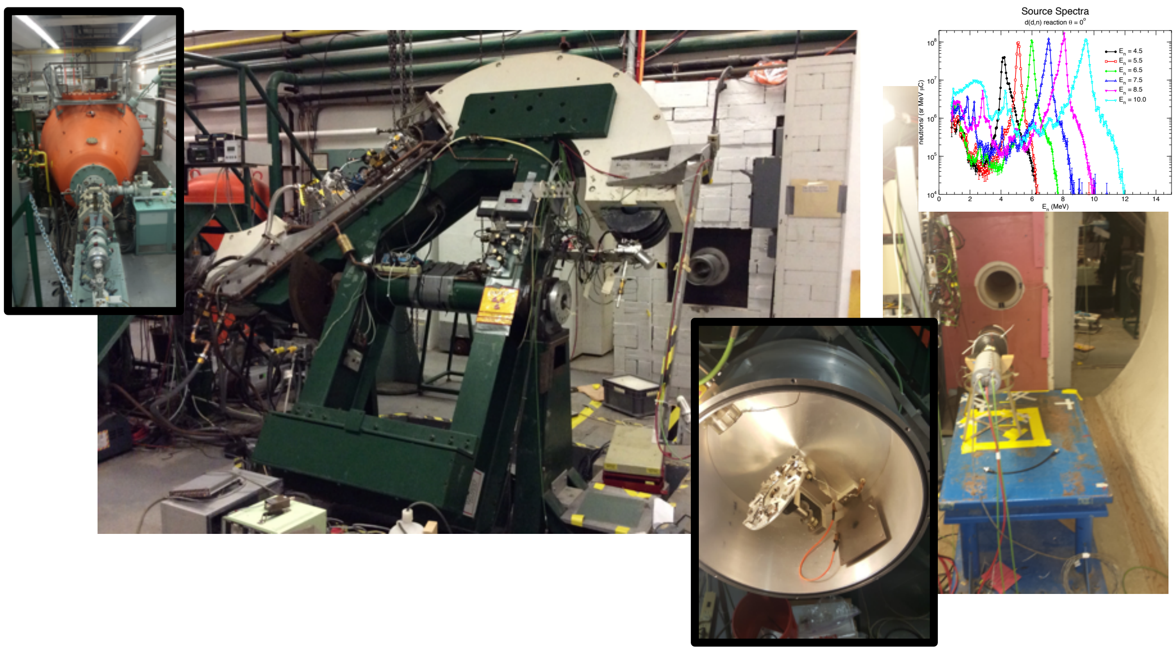
<u>Notable capabilities:</u>

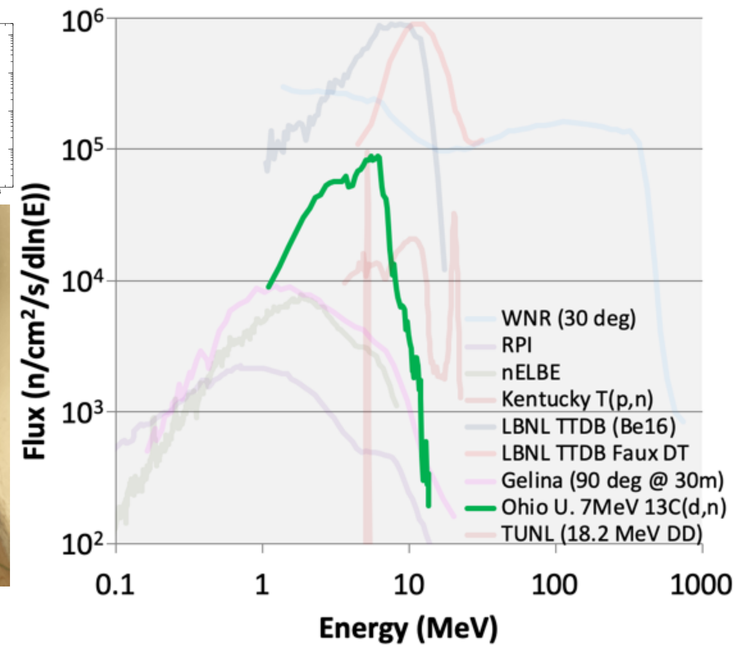
- Monoenergetic n (25 keV - 20.5 MeV)
- Low-background experimental area
- Fission yields (Y_{Nb} vs. E_n)
- Cross sections
- Activation/decay ($^{169}Tm(n,3n)$)
- Rabbit system (~seconds)

Neutron Source(s):	DD, DT, pT, $^{7}Li(p,n)$
Beam current:	1-2 μA
Target distances	2.15m, 4.27m…
n Flux ($n/cm^2/s$)	$2x10^4$ (2.875m)
γ-ray detectors	BEGe, HPGe, NaI, $CeBr_3$, $LaBr_3$

Bhatia et. al., NIM A 757 (2014) 7–19

Edwards Accelerator Laboratory – Ohio University (4.5 MV Tandem accelerator)





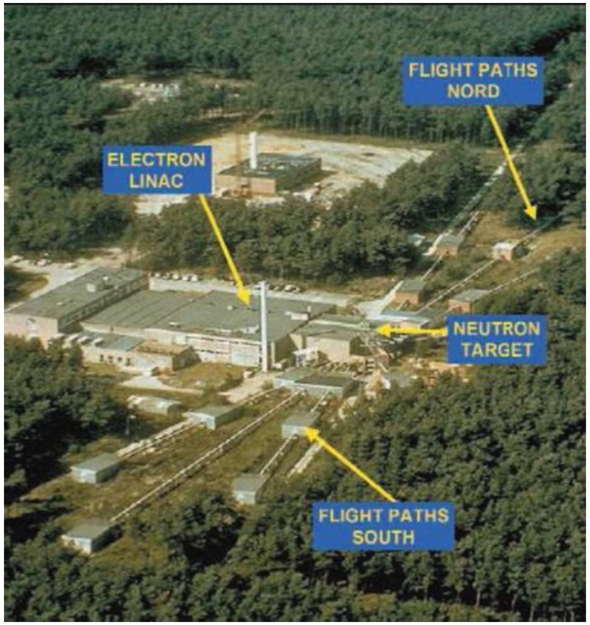
<u>Notable capabilities:</u>

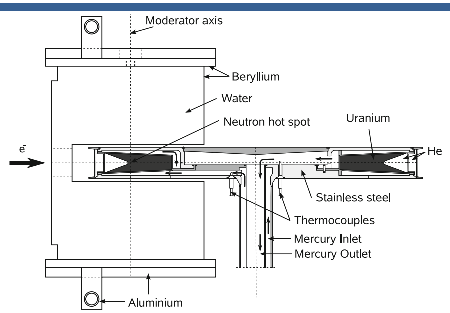
- Swinger arm (0º-155º)
- Beam pulser/buncher (tunable pulse frequency—eliminates wrap-around)
- Long, collimated time-of-flight cave
- Solid/Gas targets
- Monoenergetic+

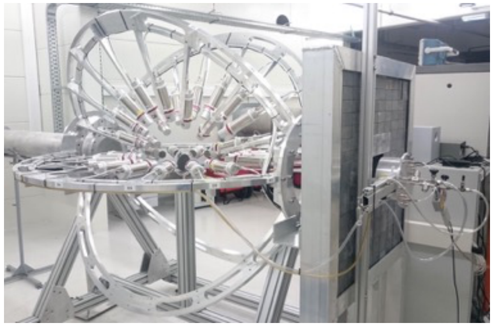
Neutron Source(s):	DD, DT, pT, X(d,n)…
Beam current:	5-10 μA
Target distances	4-30m
n Flux ($n/cm^2/s$)	1×10^5 (5 m)
γ-ray detectors	HPGe, NaI, BGO, $LaBr_3$

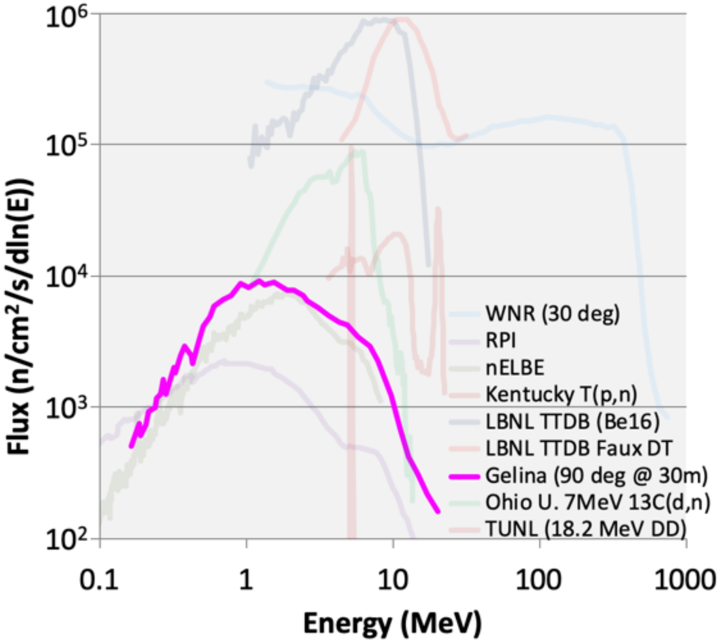
Meisel et. al., Physics Procedia 90, 448-454 (2017).

Gelina – Geel Electron LINear Accelerator (70-140 MeV electron linac, photonuclear/fission)









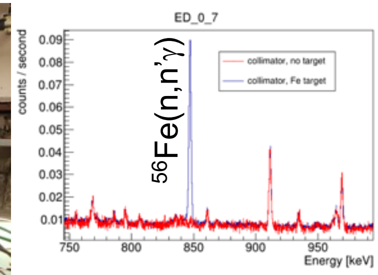
Notable capabilities:

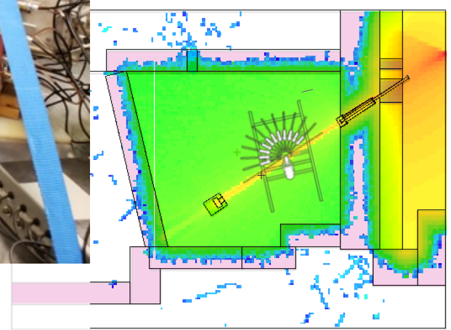
- $e^- \rightarrow U \rightarrow$ brem $\rightarrow (\gamma,n)$
- Water tanks (above/below) to produce low-E neutrons
- Eighteen flight paths
- Long (200m) flight paths
- LONG irradiations (1000's hours)

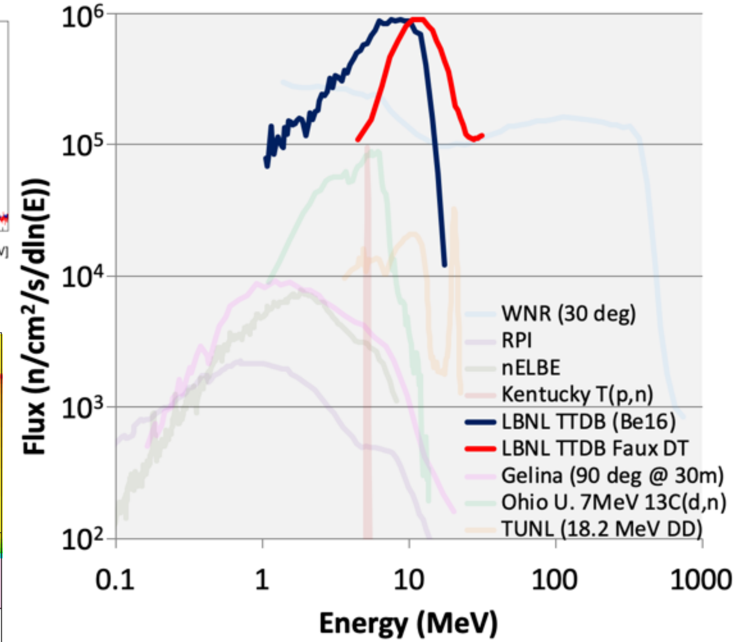
Neutron Source(s):	Photonuclear/fission
Beam current:	70 μA (avg)
Target distances	8-400m
n Flux (n/cm²/s)	2x10⁴ (30 m)
γ-ray detectors	HPGe

Ene, et. al., NIM A 618 (2010) 54–68

GENESIS – 88-inch cyclotron @ Lawrence Berkeley Nat'l Lab (K140 cyclotron)







Notable capabilities:

- γ-tagged inelastic cross sections ($d^3\sigma/d_{En}d_{En'}d\Omega$)
- 22+ EJ309 neutron scintillators
- High flux (>10^{11} n/cm^2/s in Cave 0)
- Tunable spectrum/beam size (<20cm)
- FLUFFY (<1s rabbit system)
- Radioisotope production cross sections

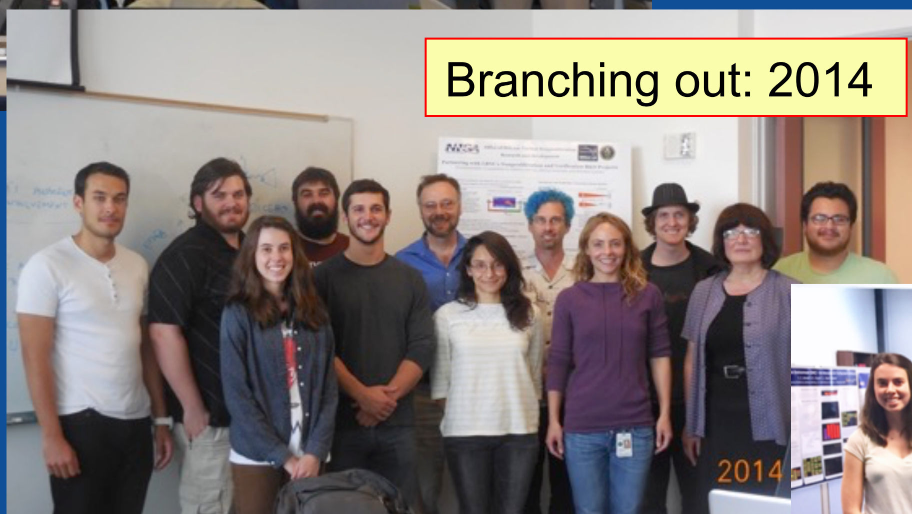
Neutron Source(s):	Deuteron breakup
Beam current:	10 μA (14-55 MeV)
Target distances	5-10m
n Flux (n/cm^2/s)	1×10^6 (5 m)
γ-ray detectors	HPGe, $LaBr_3$, LEPS

Harrig et. al, NIM A 877 (2018) 359.
Meulders, et. al., Phys. Med. Biol., 1975, 20(2), 235, (1975)

Thanks!

UC Fee NPI@NIF grant launches UCB/LLNL collaboration: 2012

Branching out: 2014



This vast variety of neutron capabilities at LBNL are the result of many dozens of students' and postdocs' efforts through a very successful collaboration (BANG) between LBNL, LLNL, and UCB over the past eight years.

Realizing we need to take group photos more often: 2018

Lawrence Livermore National Laboratory