The neutron production facility at the Lawrence Berkeley National Laboratory

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Lawrence Livermore National Laboratory

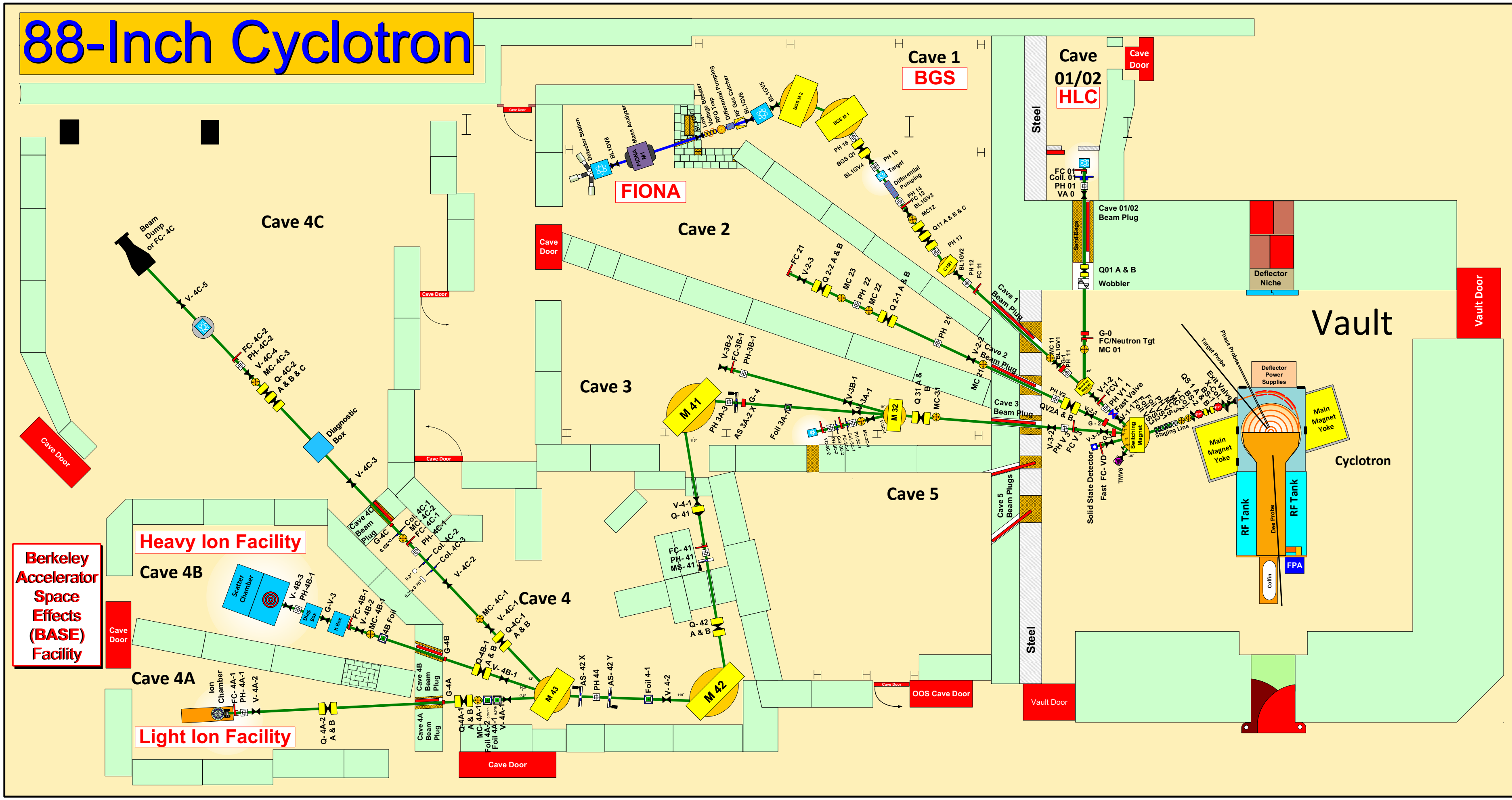
Fast Neutrons for the Next Decade and Beyond
iThemba LABS, South Africa
February 5, 2019

LLNL-PRES-

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

Lawrence Livermore National Laboratory

The 88-inch cyclotron is a K140 accelerator producing Z=1-92 beams (up to 65 MeV p,d's), operating since 1961.



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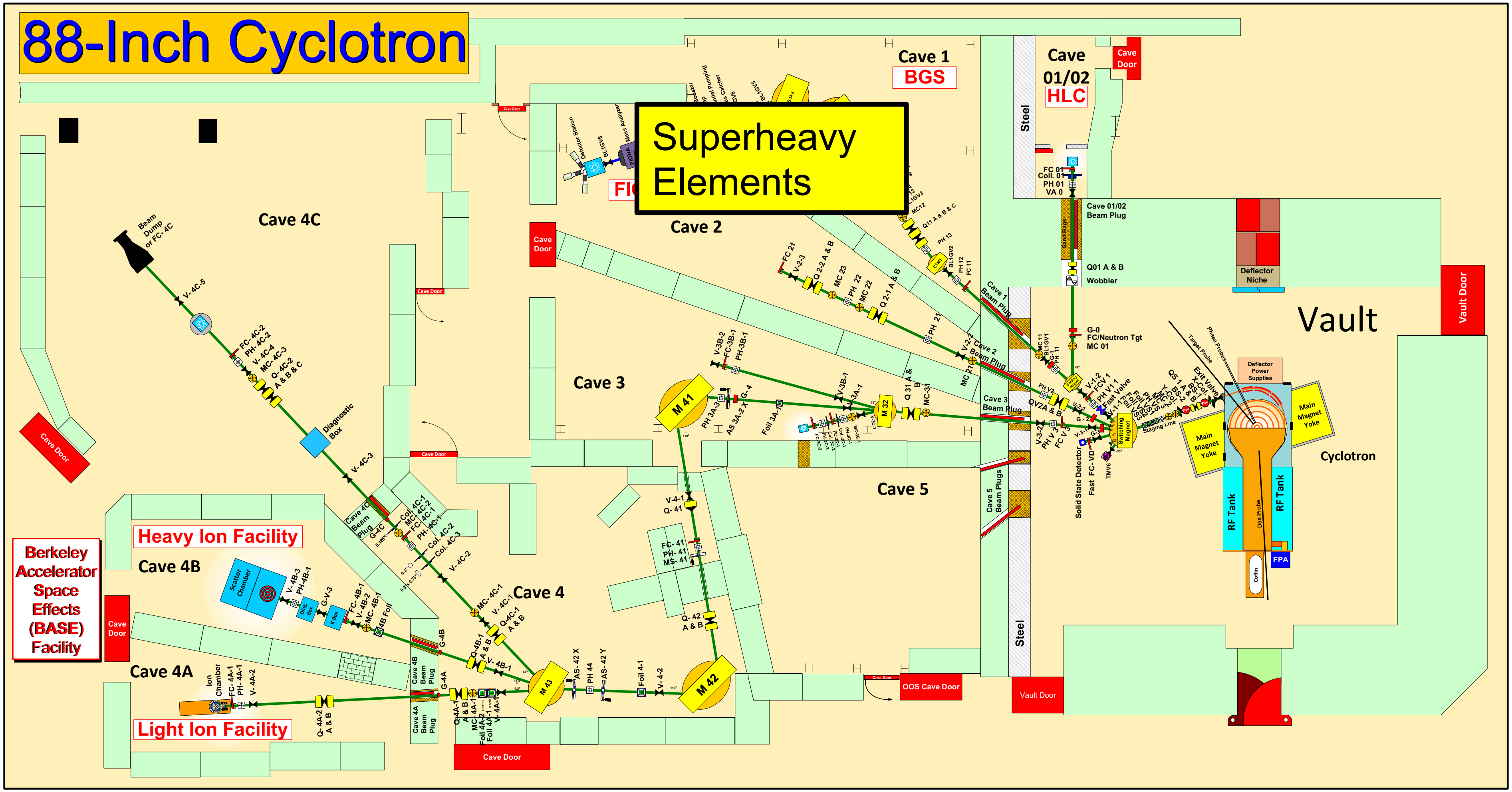

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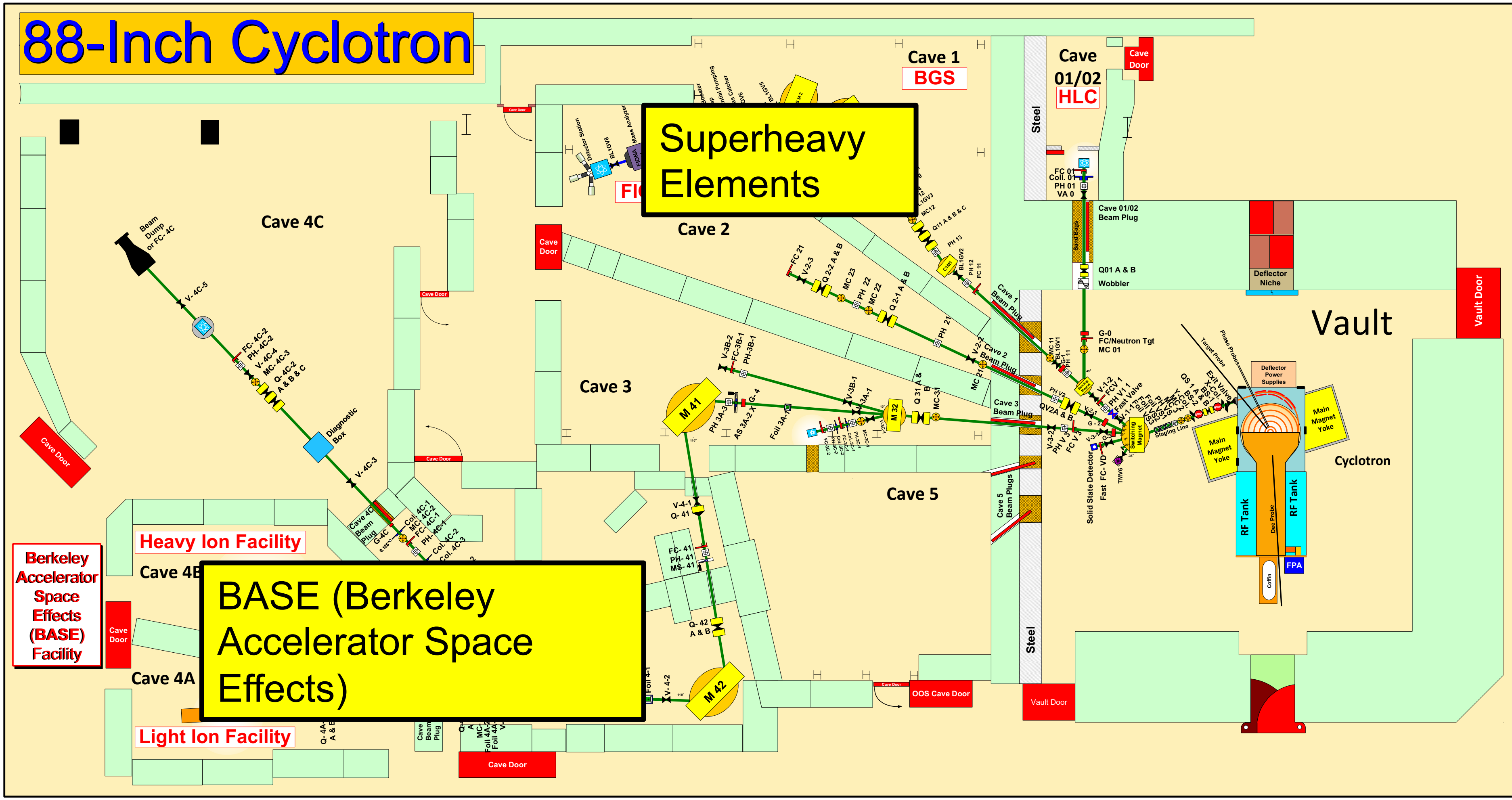

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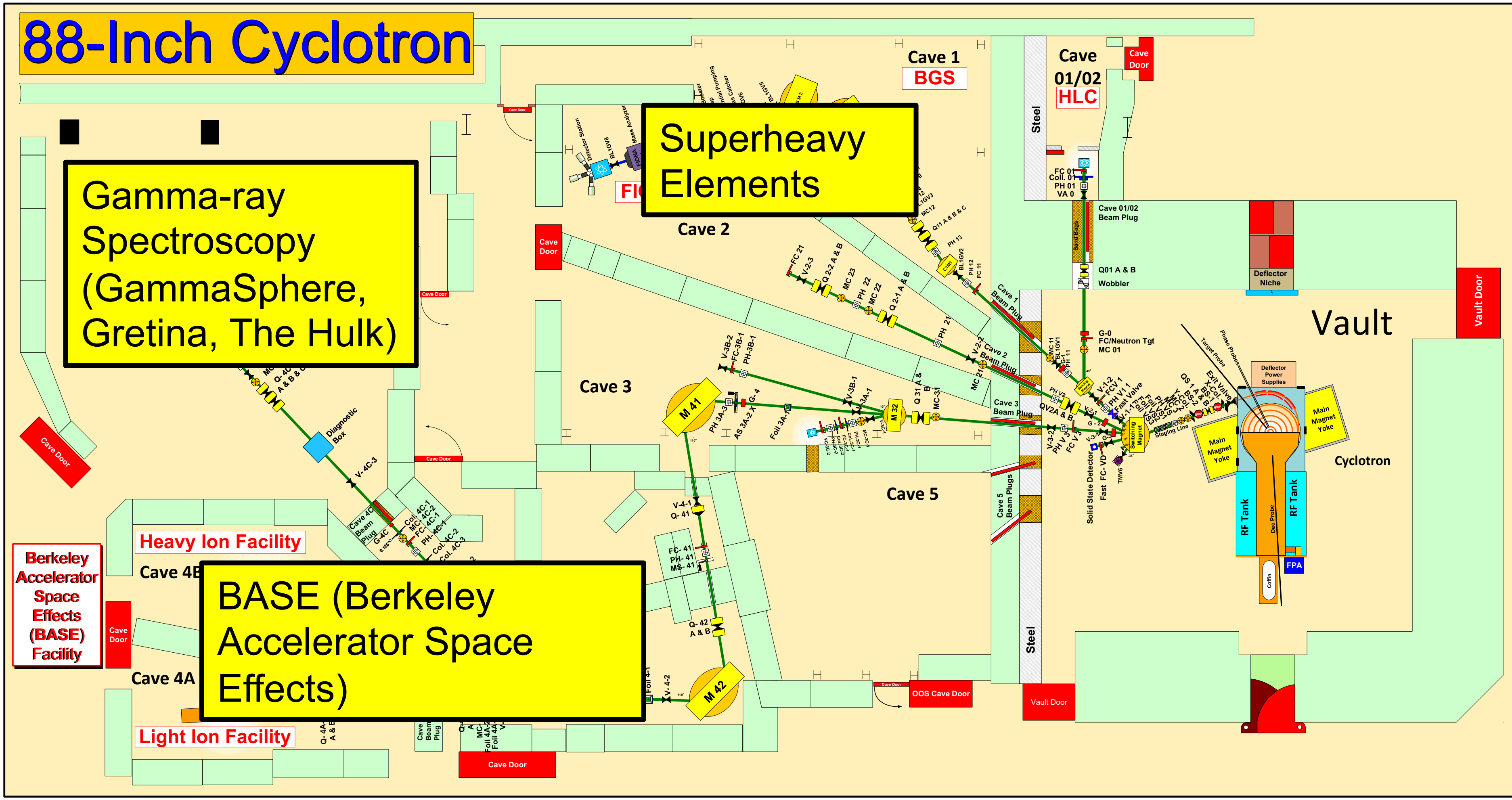

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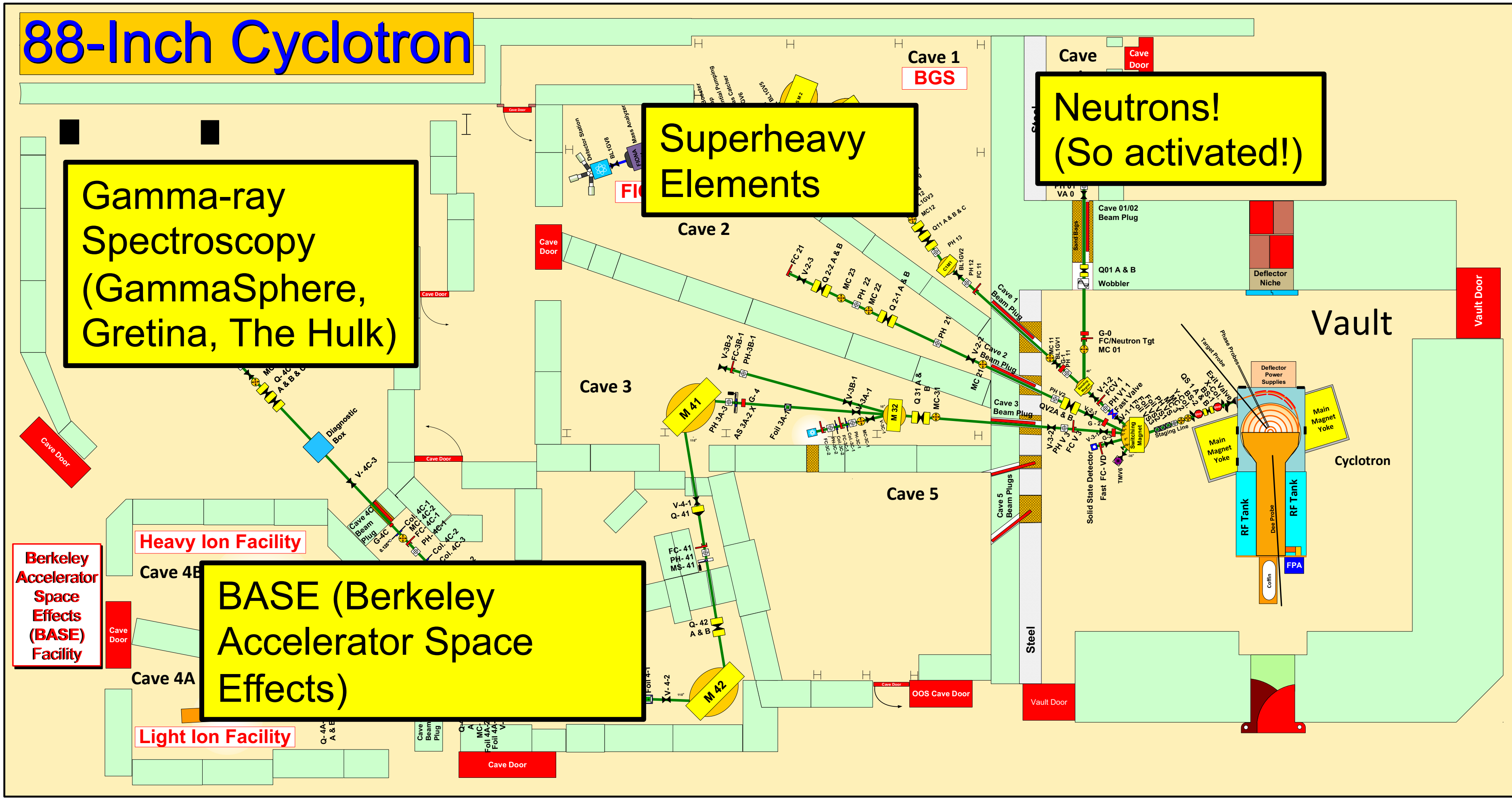

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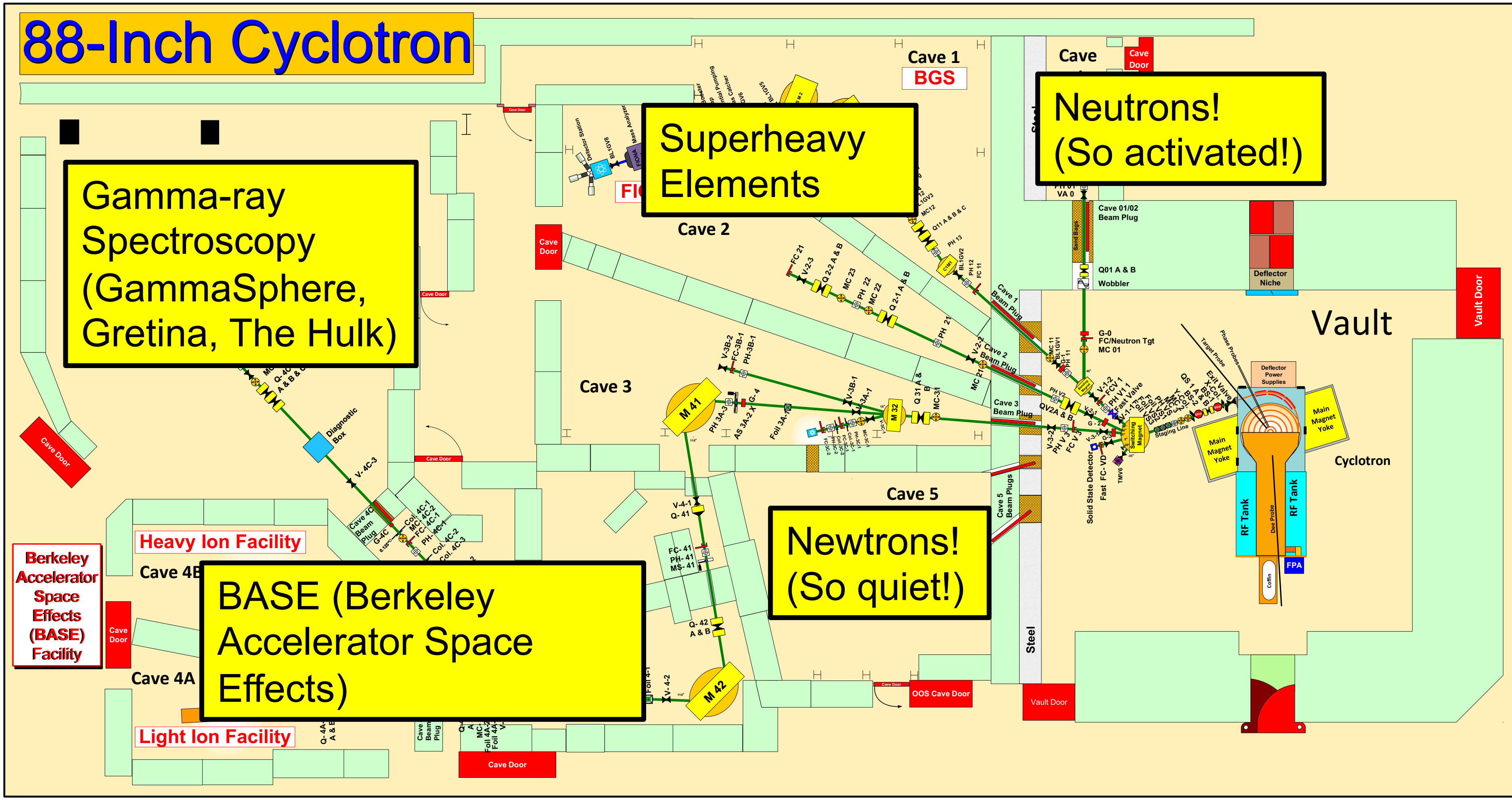
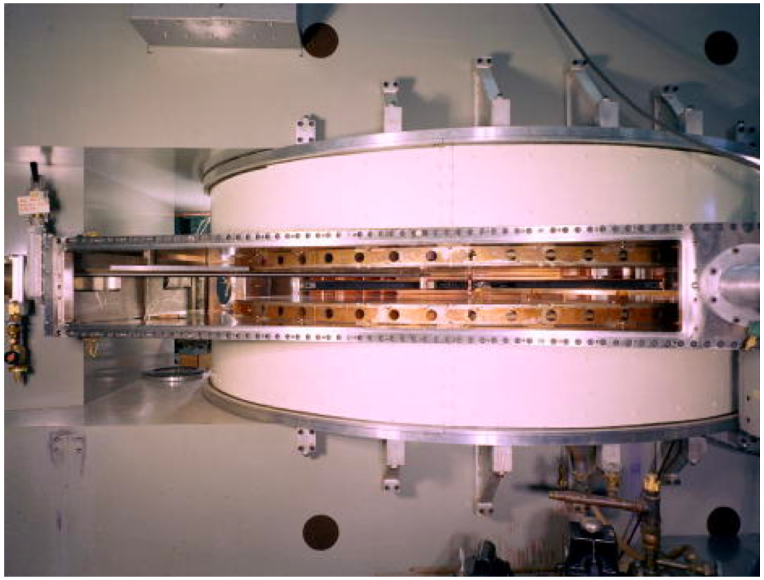


A neutron production facility has been developed at LBNL's 88-inch cyclotron over the past few decades

Sources:
- Deuteron breakup (white)
- ^{7}Li(p,n) (quasi-monoenergetic)

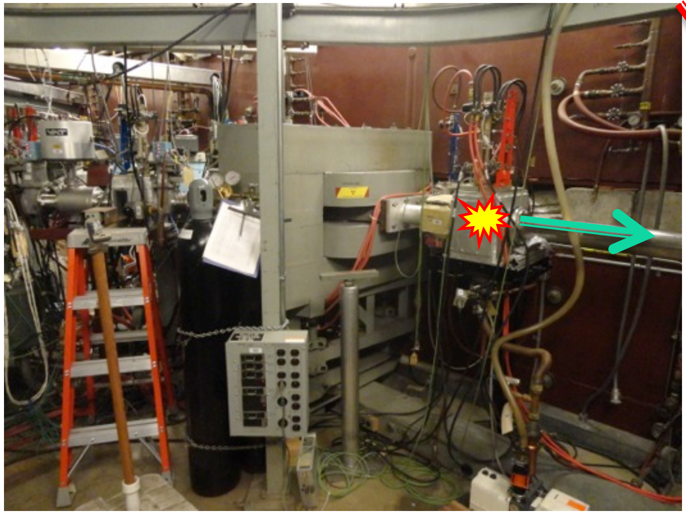
Applications:
- Neutron energy spectral measurements
- Scintillator characterization
  - Timing
  - Light yield
  - Efficiency
- Equipment damage
- Isotope production cross sections

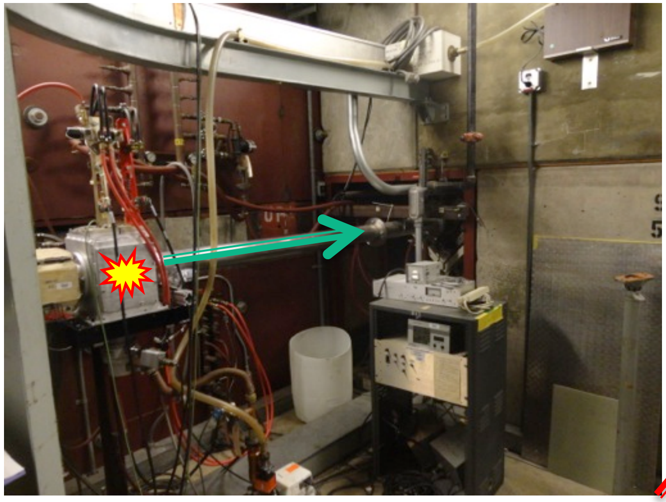
Developing Capabilities (the future!):
- FLUFFY – Short-lifetime fission product yields
- GENESIS – Inelastic scattering

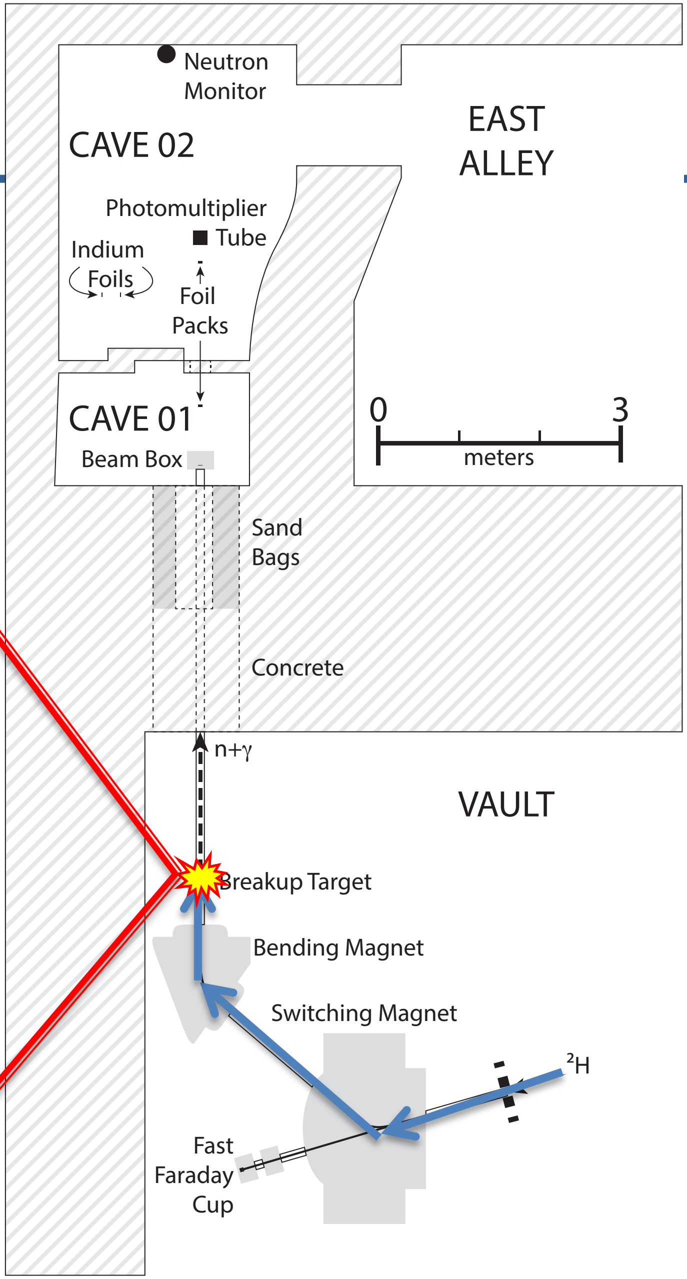


The 88-inch cyclotron

Deuteron breakup in, or into, Cave0 has been our workhorse







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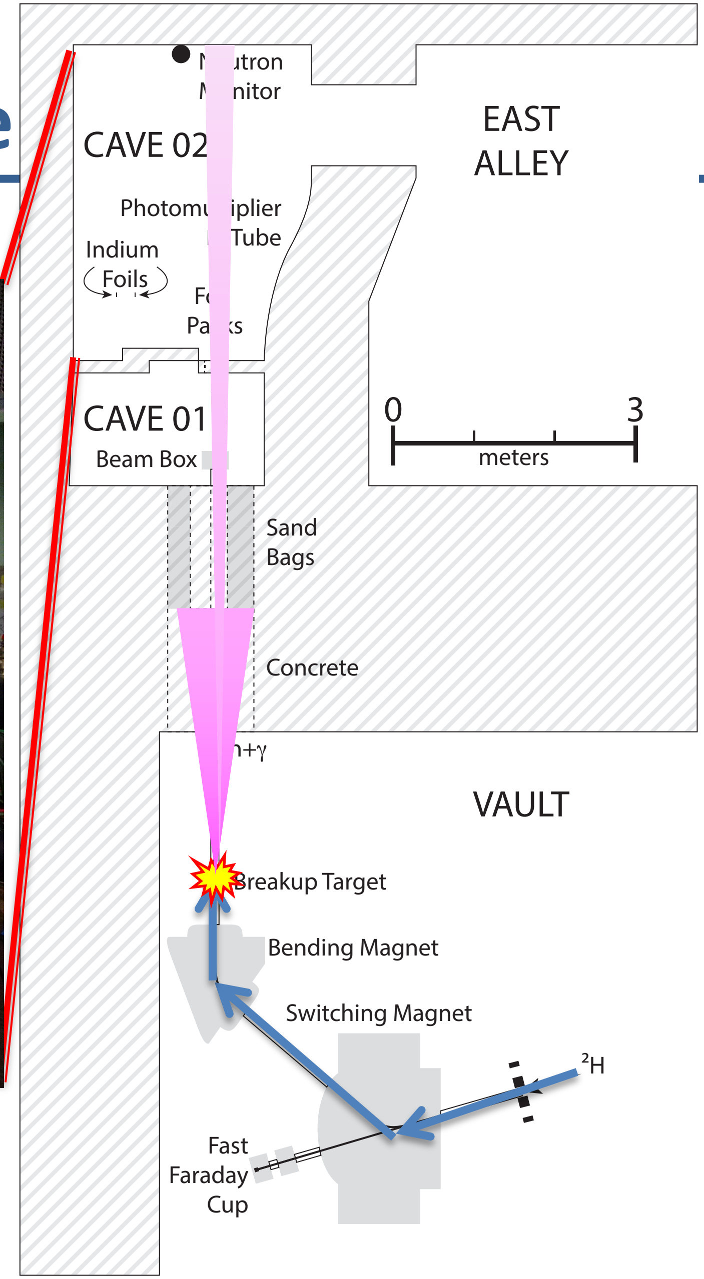

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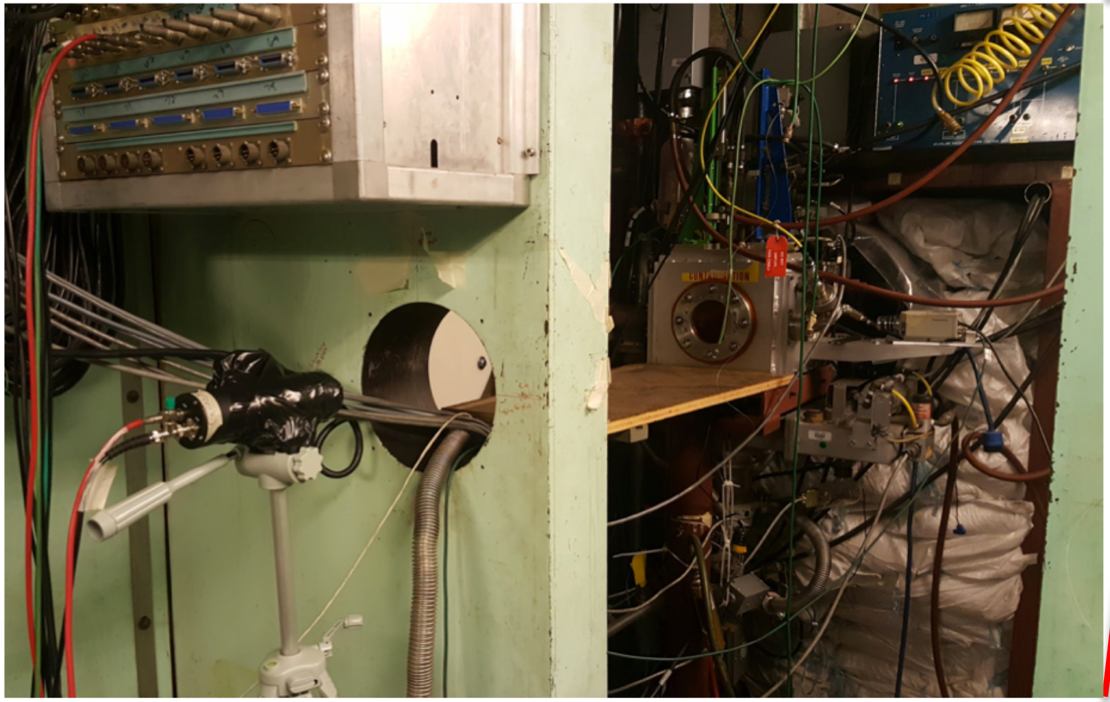

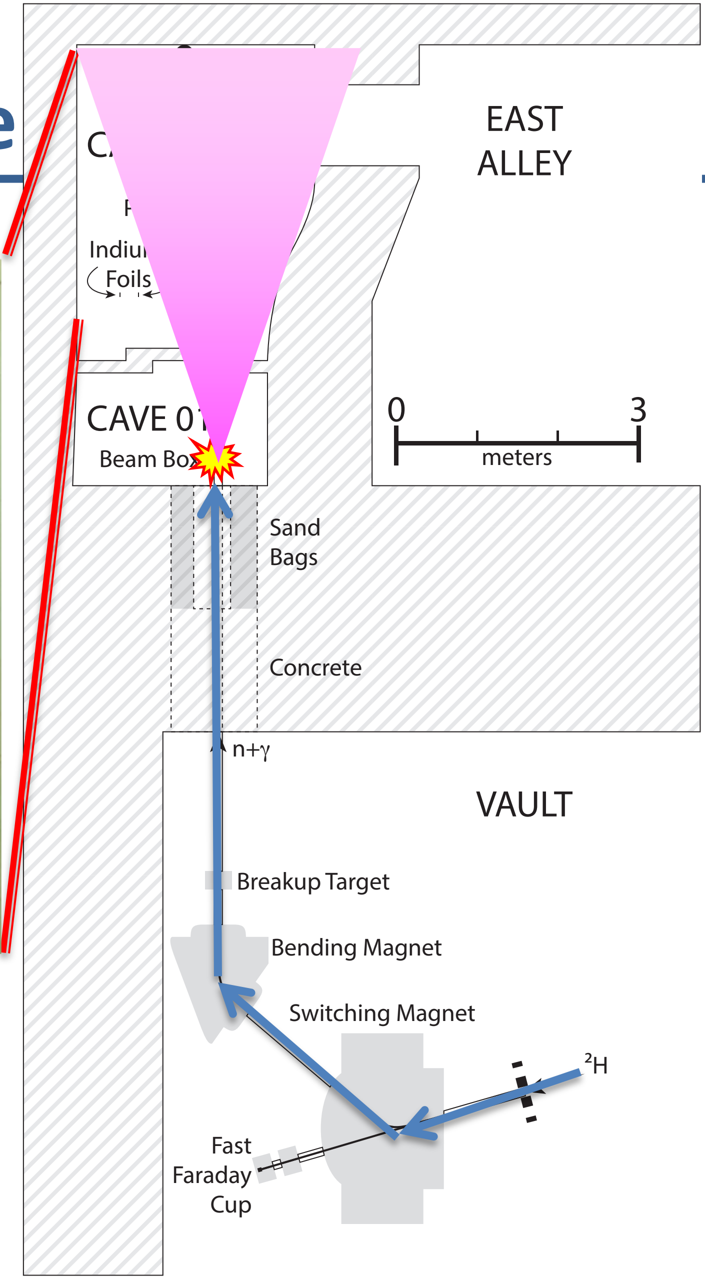

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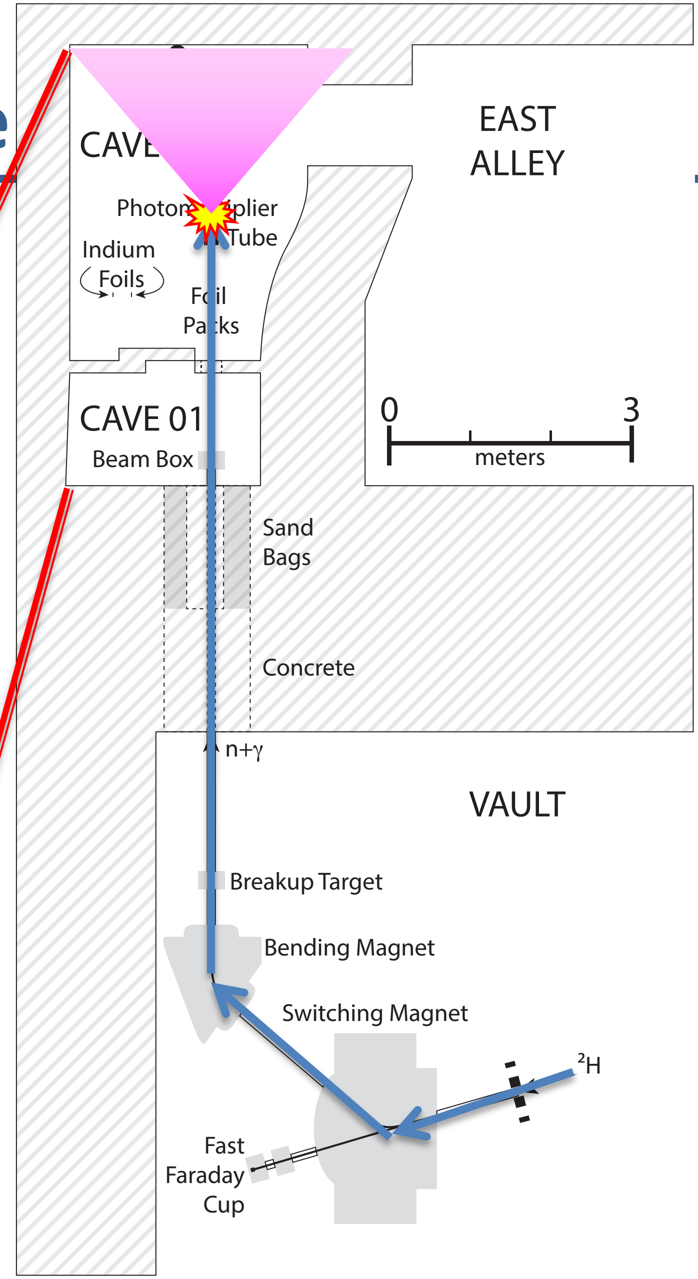
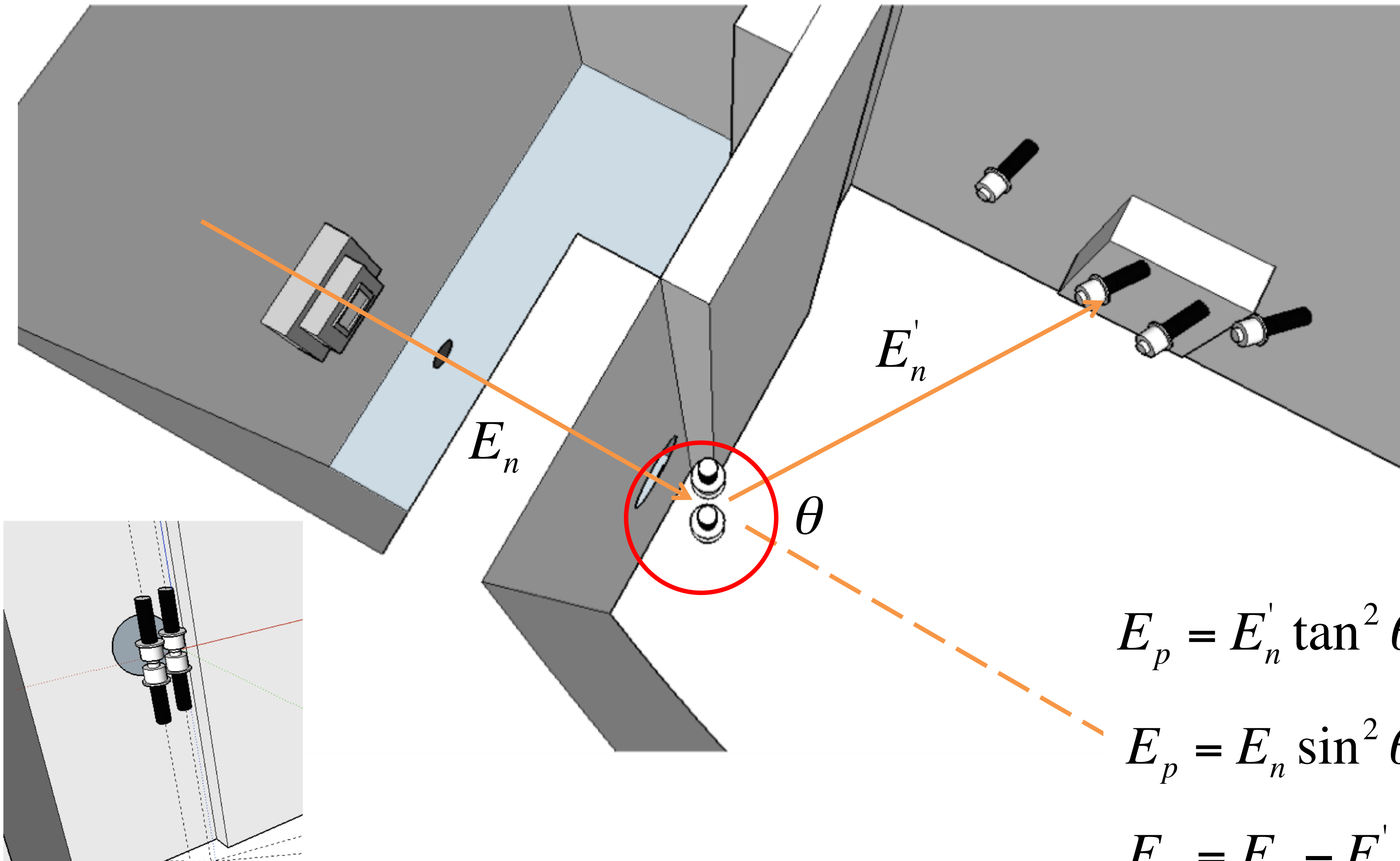


To mitigate frame overlap in energy spectral measurements, we developed a "double time-of-flight" technique



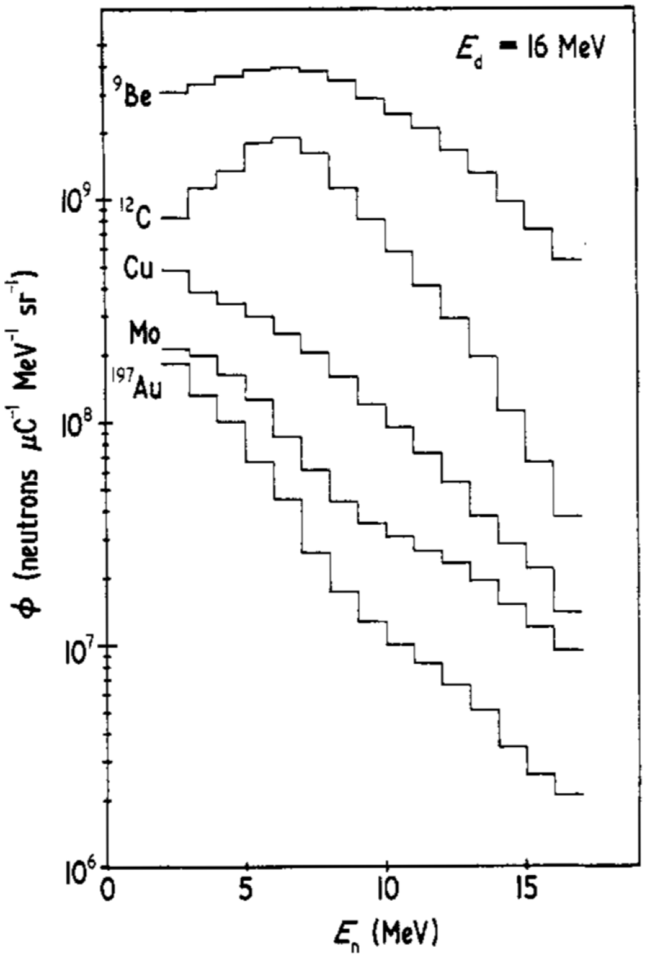
$$E_p = E_n^{'} \tan^2 \theta$$

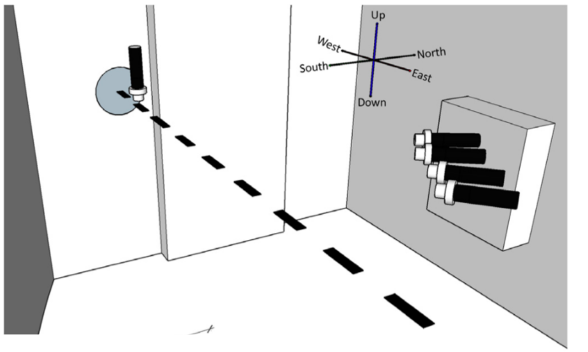
$$E_p = E_n \sin^2 \theta$$

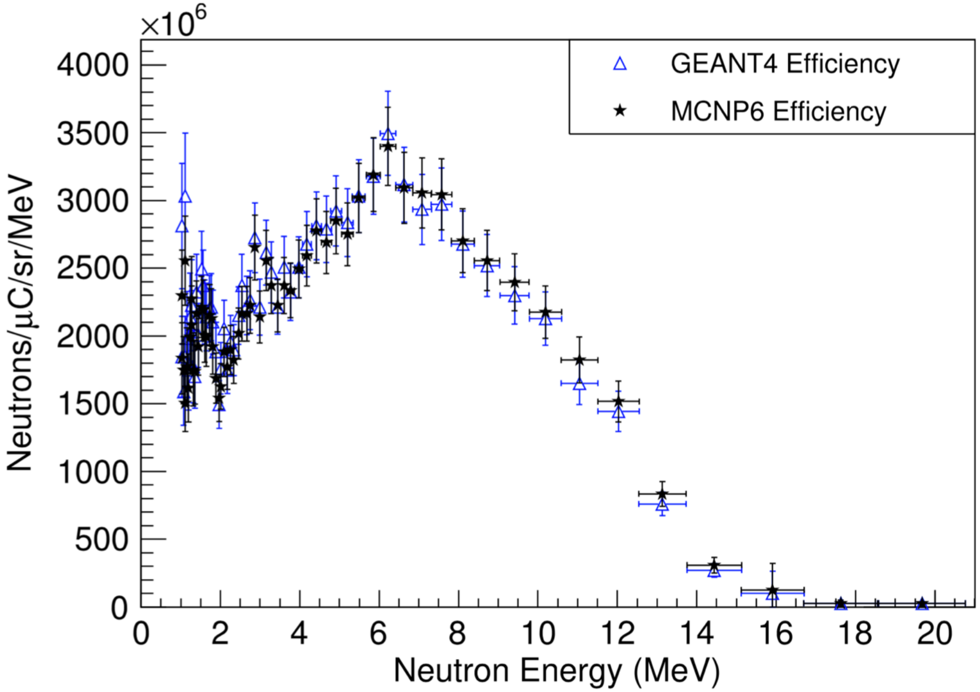
$$E_p = E_n - E_n^{'}$$

Harrig et. al, NIM A 877 (2018) 359.

Using this "dToF" method, we were able to improve the "16 MeV d-on-Be" deuteron breakup measurement



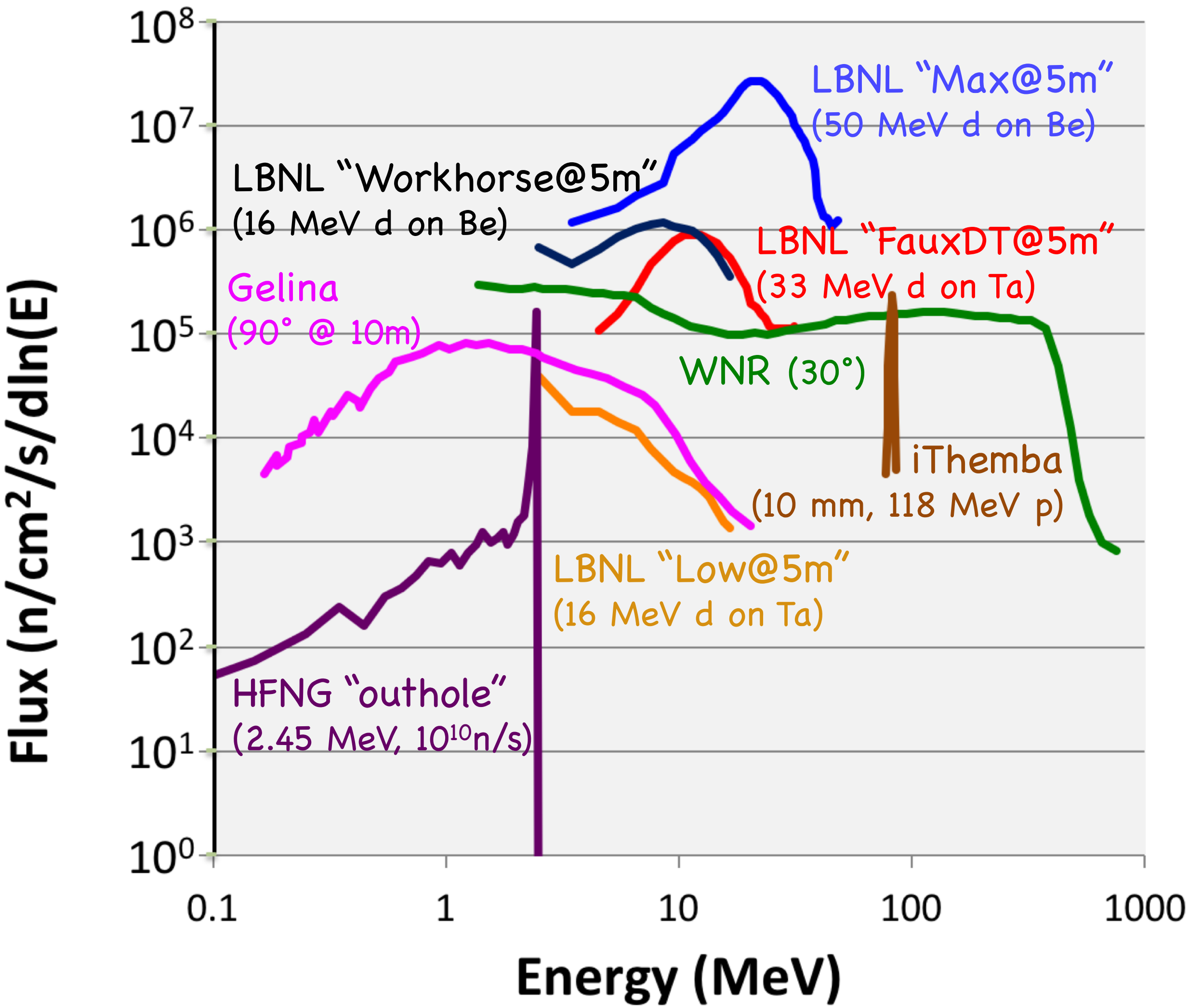




Meulders et. al, Phys. Med. Biol., **20(2)**, 235 (1975).

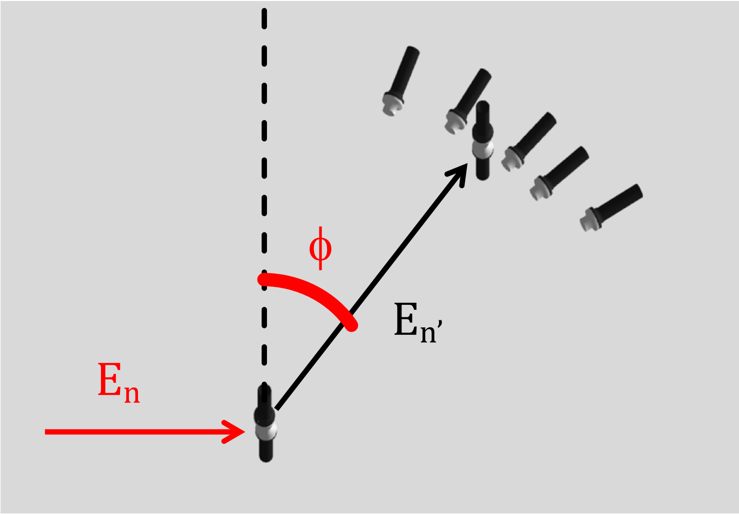
Harrig et. al, NIM A 877 (2018) 359.

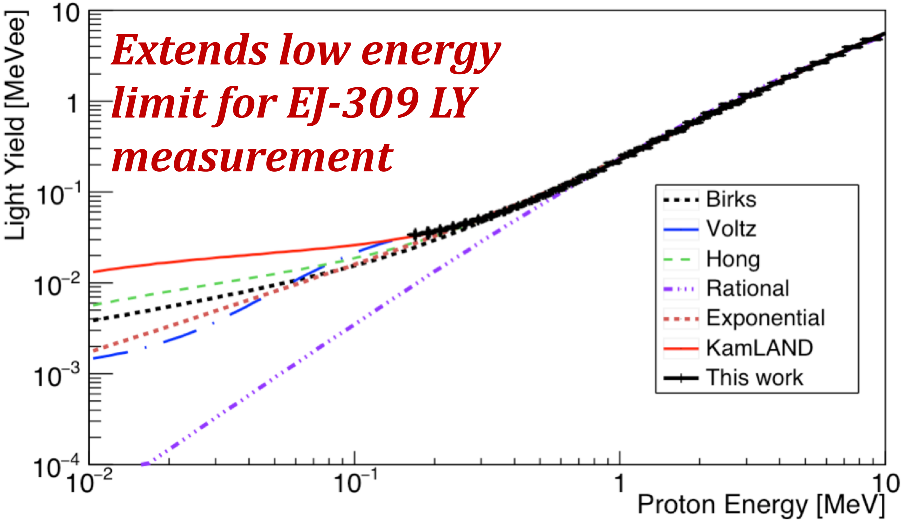
A comparison of (some) neutron sources around the world
(a.k.a., the slide that gets me hate mail)

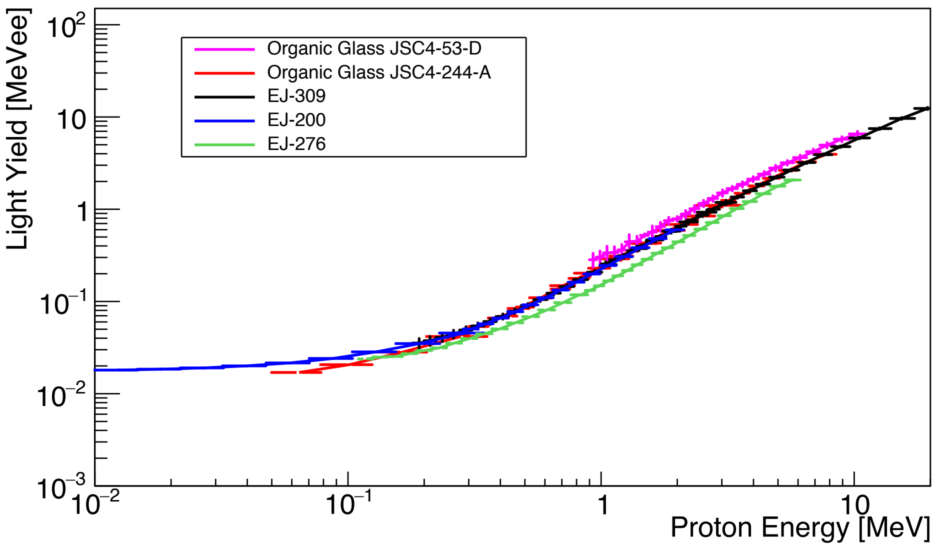


Source	$Flux_{total}$ (n/cm2/s)
50 MeV d on Be (10μA, 5m)	$2x10^7$
WNR (30°)	10^6
16 MeV d on Be (10μA @ 5m)	$2x10^6$
33 MeV d on Ta (10μA @ 5m)	$9x10^5$
Gelina (90°) (@ 10m)	$2x10^5$
16 MeV d on Ta (10μA @ 5m)	$3x10^4$
118 MeV iThemba (10mm tgt @ 8m)	10^4
HFNG (2.27m)	10^4

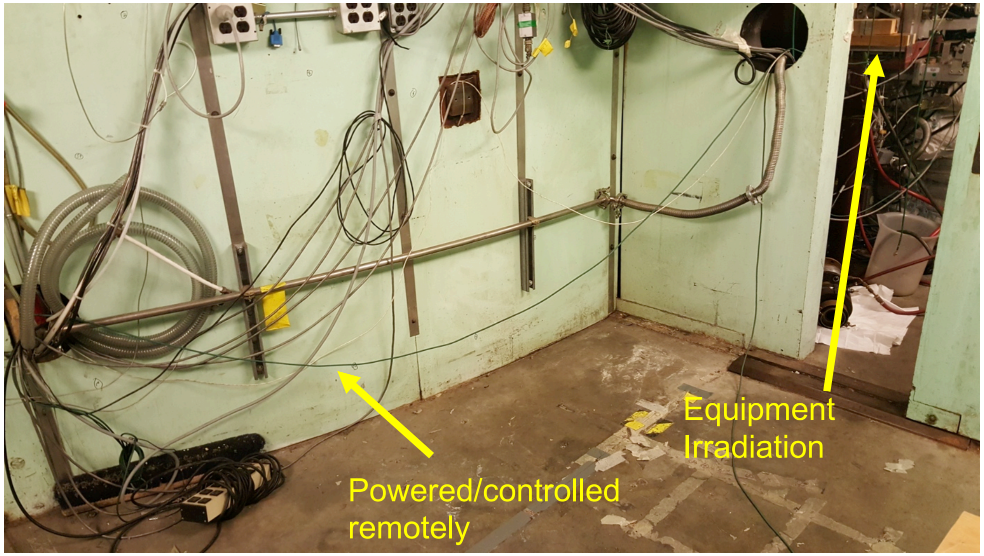
Using the same "dToF" method, we have characterized scintillator light yield lower in energy than ever before

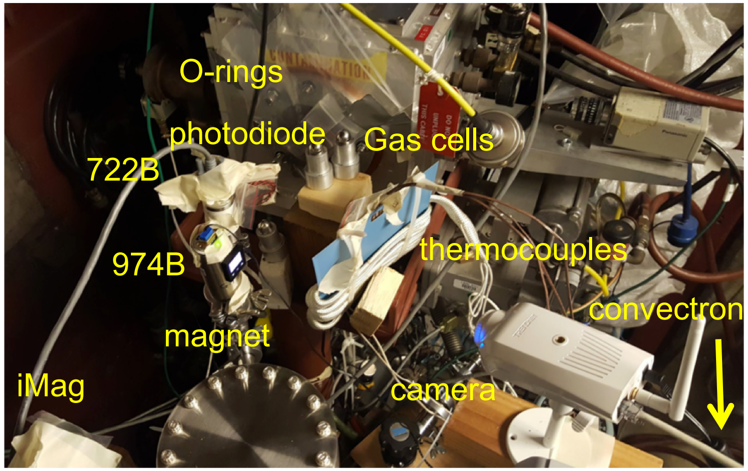


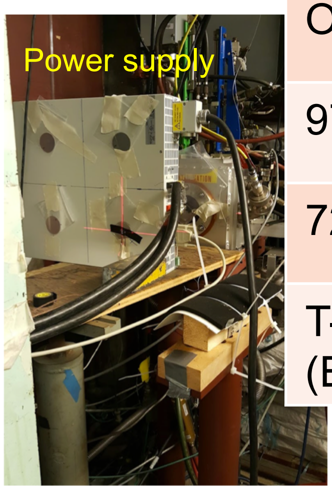




The neutron flux close to the breakup source is high enough to damage equipment (both purposefully and not)

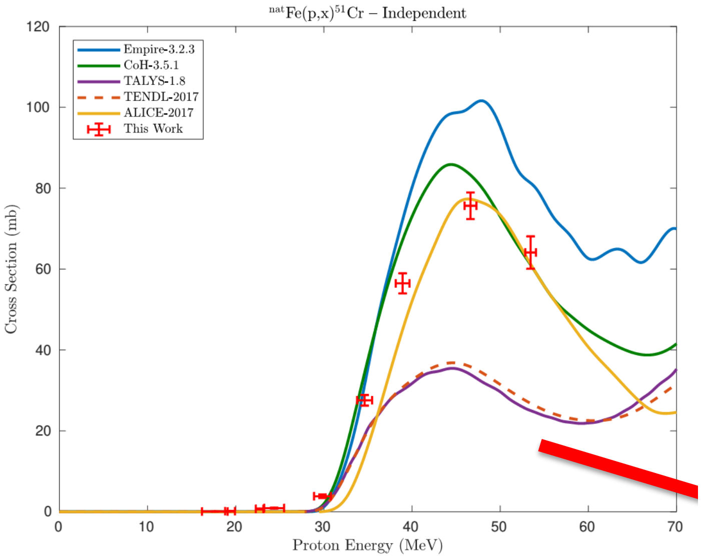


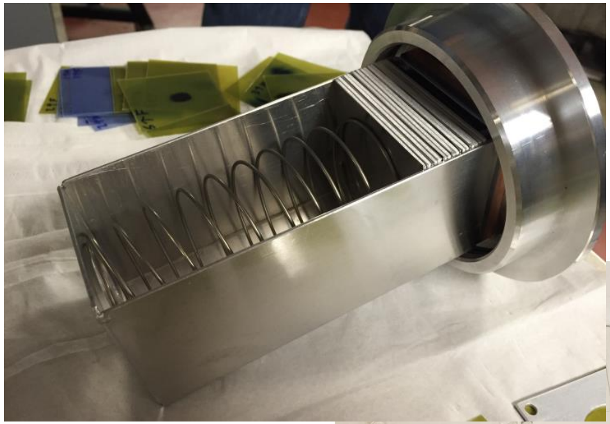




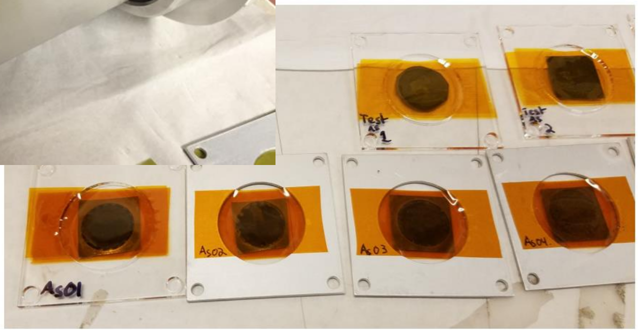
Equipment	Fluence (n/cm^2) [to failure]	Facility-equivalent time	P/F
Pow. Supply	2×10^{10}	1 week	✗
Magnet	9×10^{10}	1.8 week	✓
Photodiode	3×10^{11}	0.6 week	✗
Hall Sensor	1×10^{13}	23 weeks	✓
O-rings	5×10^{13}		✓
974B Gauge	2×10^{11}	0.8 week	✗
722B Gauge	2×10^{11}	0.6 week	✗
T-couples (E,J,K)	5×10^{12}		✓

Lee Bernstein's group has begun a program to measure cross sections important to isotope production





Foil packs use degrader layers to measure full excitation function in one experiment

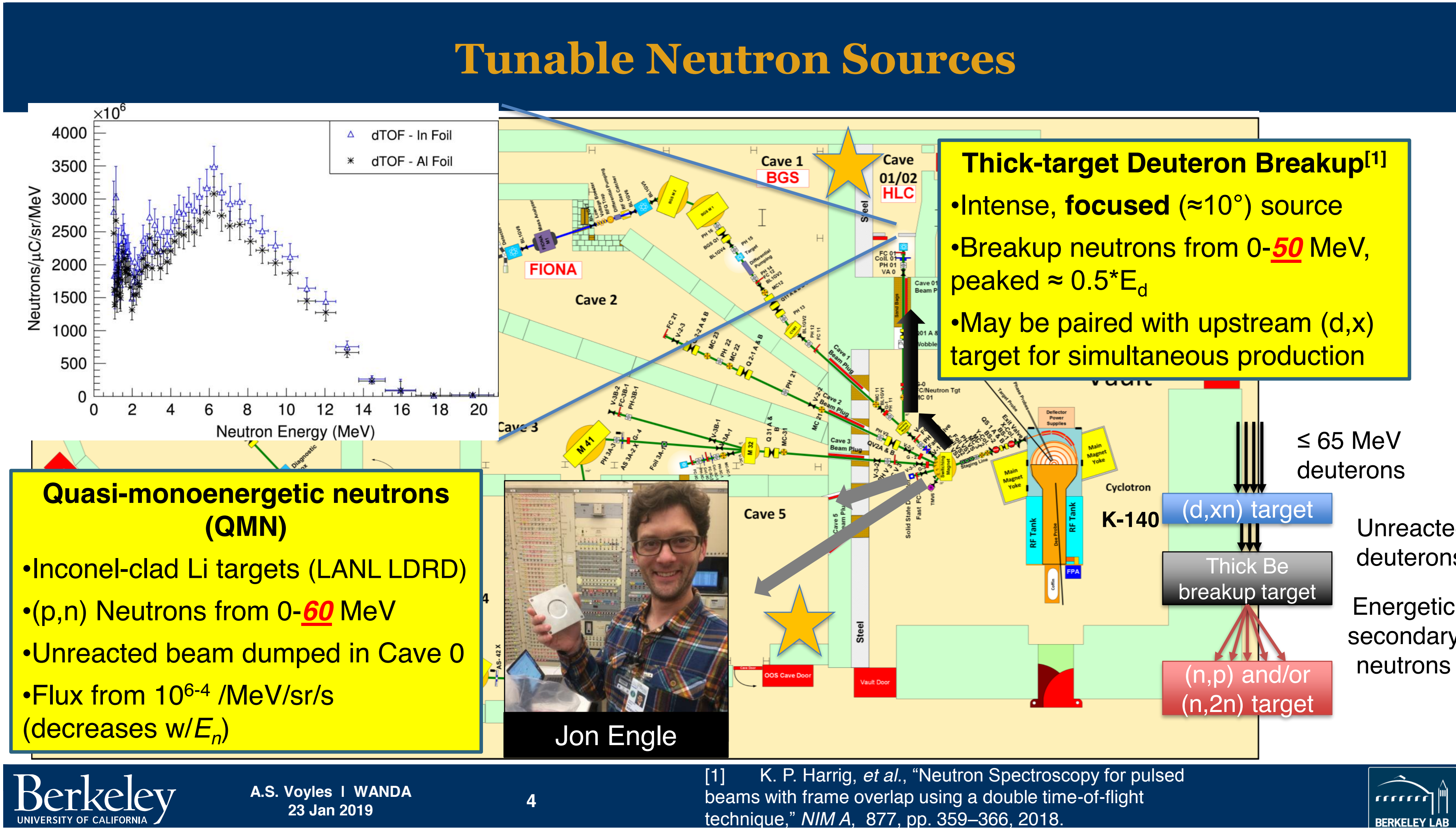


Developing target-platng capabilities

Each Rx is a thesis:
- $Fe(p,x)^{51,52m/g}Mn$
- $Zn(n,x)^{64,67}Cu$
- $Ir(d,x)^{193m}Pt$
- $La(p,x)^{134}Ce$
- $^{235}U(d,x)^{236m}Np$
  $Tm(d,x)^{169}Yb$
- $As(p,x)^{72}Se, ^{68}Ge$
- $^{86}Sr(d/p,x)^{86}Y$

Aiming towards simultaneous production using breakup neutrons from production target!

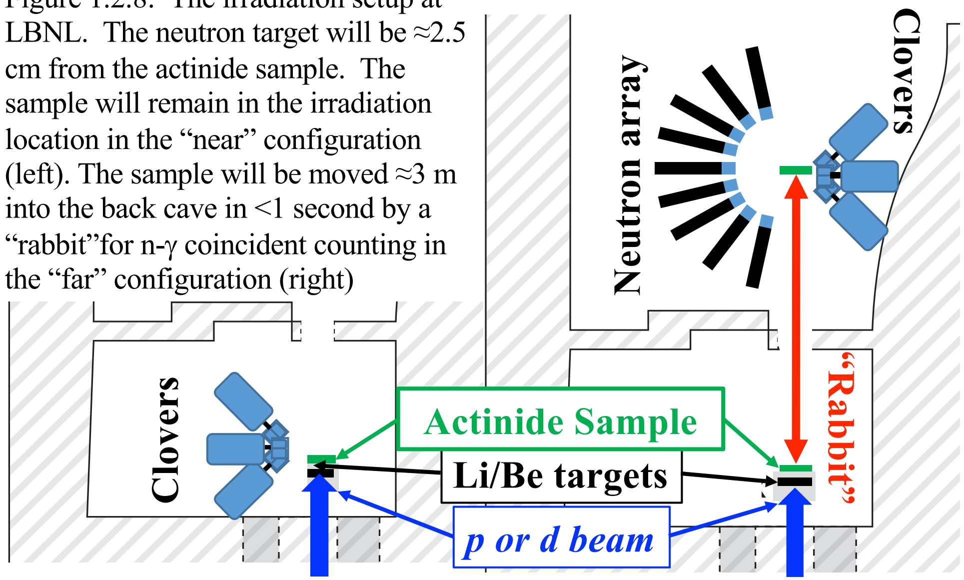
As part of this effort, in cooperation with J. Engle, we have added thin lithium targets (patterned after iThemba's)



We were part of a successful NDIWG grant to assemble FLUFFY to measure short-lived fission product yields

- **FLUFFY:** Fast-Loading User Facility for Fission Yields
- High-intensity, short-burst neutron irradiations of ^{235}U, ^{238}U, ^{239}Pu targets
- Rabbit system to Clover HPGe detectors in neighboring shielded room within 100 milliseconds
- Repeat
- Goal is to measure independent fission product yields with $t_{1/2}$<1s
- In collaboration with TUNL, where longer-lifetime yields are measured as a function of neutron energy

Figure 1.2.8: The irradiation setup at LBNL. The neutron target will be ≈2.5 cm from the actinide sample. The sample will remain in the irradiation location in the "near" configuration (left). The sample will be moved ≈3 m into the back cave in <1 second by a "rabbit" for n-γ coincident counting in the "far" configuration (right)



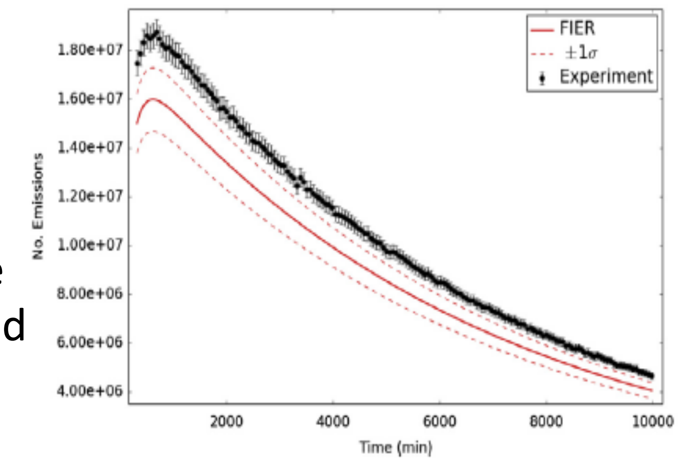
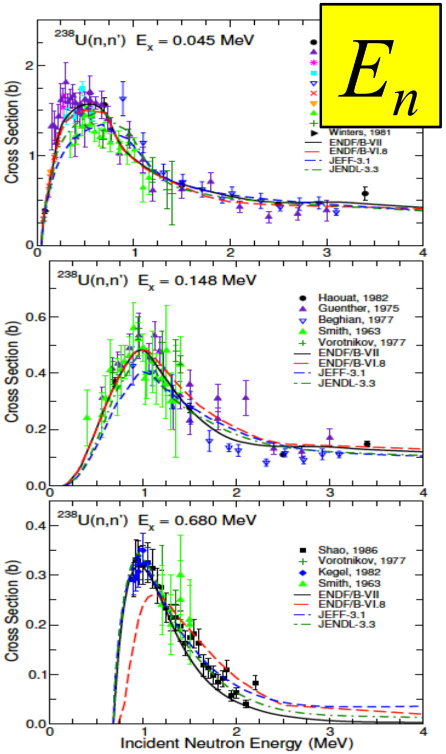
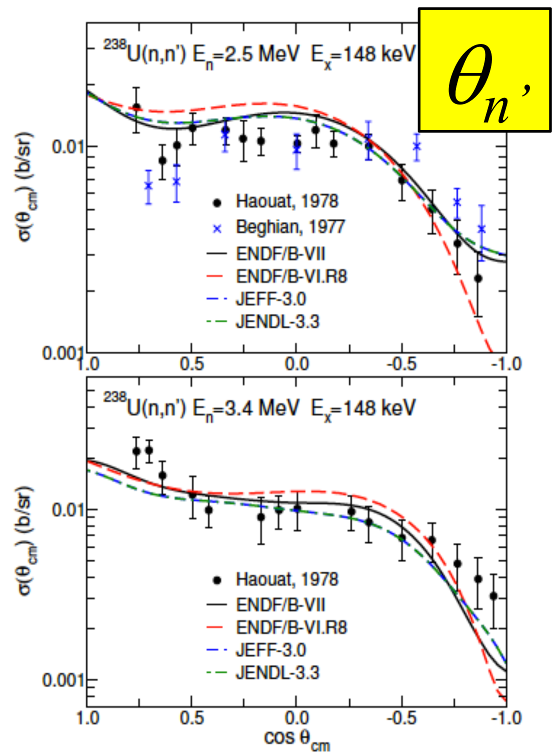


Figure 1.3.10: Difference in the observed and FIER-modeled yield of ^{132}I as a function of time for a ^{235}U sample irradiated at the GODIVA critical assembly from [Mat18].

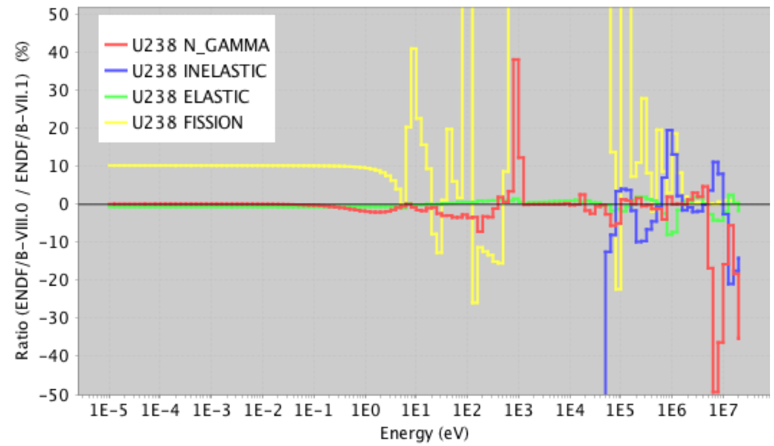
Inelastic scattering has been referred to as "the trash dump of neutron cross sections."

- ^{238}U(n,n) and (n,n') are the most likely initial reactions for a prompt fission neutron
- There are large uncertainties in ^{238}U(n,n') at PFNS energies as a function of $E_{n'}$ and $\theta_{n'}$





ENDF 7.1 → ENDF 8.0



When other (*e.g.* n,γ) cross sections improve, (n,n') is typically altered to maintain (n,tot), such that simulations of historical integral measurements remain valid.

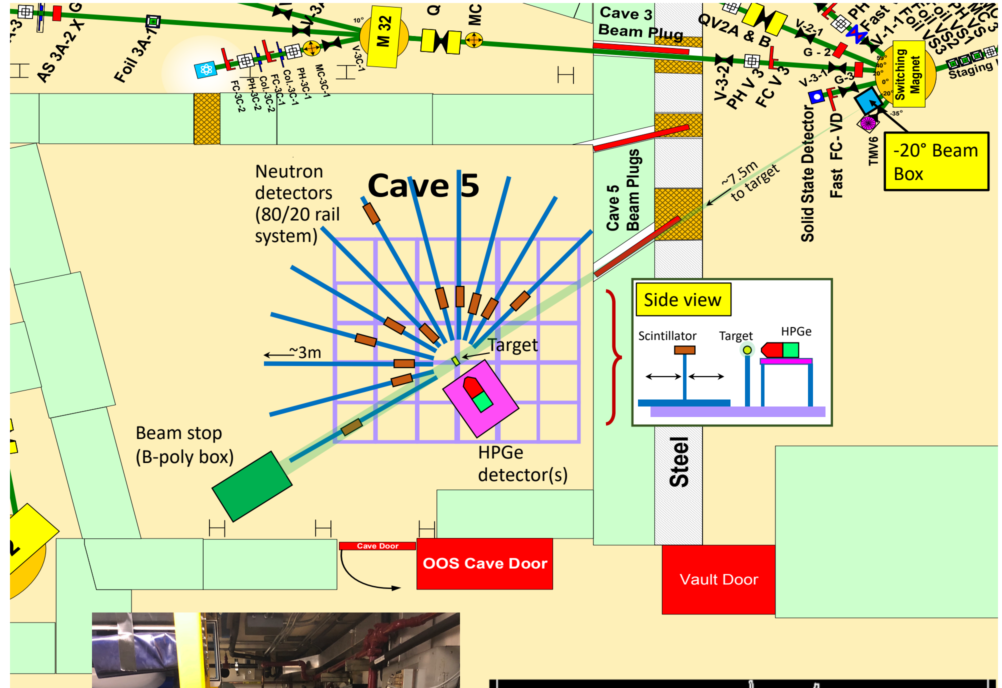
We also received a Nuclear Data grant to assemble GENESIS, a new capability to measure inelastic cross sections

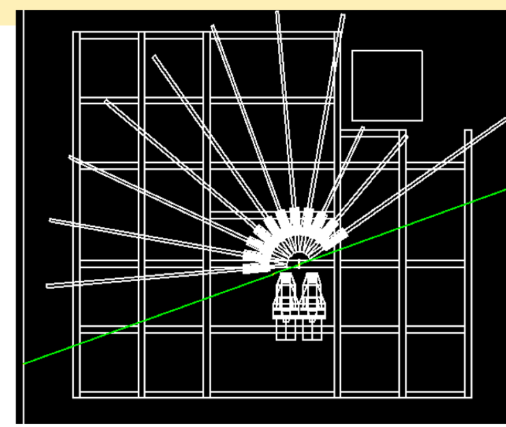
- **GENESIS:** Gamma-Energy Neutron-Energy Spectrometer for Inelastic Scattering

- Use coincident neutron and gamma-ray detection with time-of-flight to measure $d^3\sigma_{n,n'\gamma}/dE_n dE_{n'} d\Omega$ (inelastic cross sections as a function of incoming energy, outgoing neutron energy and angle)

- 12 EJ309 neutron detectors
- 2-3 Clover HPGe
- 1 LEPS
- 1 Gretina module

- Neutron test run: March 2019
- First Benchmark (^{56}Fe) run: June 2019
- NDIWG grant Goal: ^{238}U(n,n')
- LLNL-funded stretch goal: low-Z

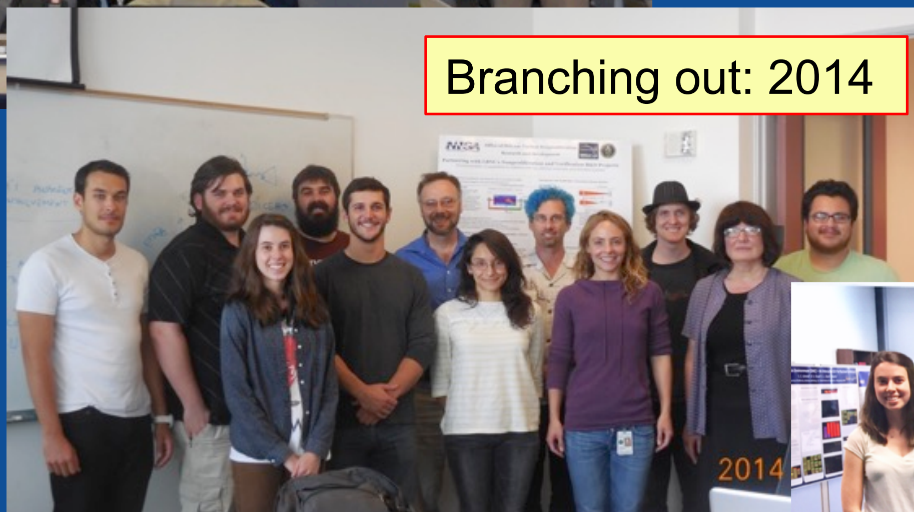




Thanks!

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

Branching out: 2014



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

Realizing we need to take group photos more often: 2018

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