Research with neutrons at LENS

(CANS in the International Neutron Ecosystem)

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OUTLINE

- Overview of the ADNS landscape:
  - Avenues to neutron production (CANS vs. Spallation)
    - Electron linac-driven facilities
    - Low-energy proton/deuteron machines
- Materials Research with mid-scale to small-scale ADNS
  - Conventional neutron scattering applications
  - Novel applications in materials
  - Unique opportunities for ADNS facilities
- Connections between CANS and Intl. Facilities
- Conclusions

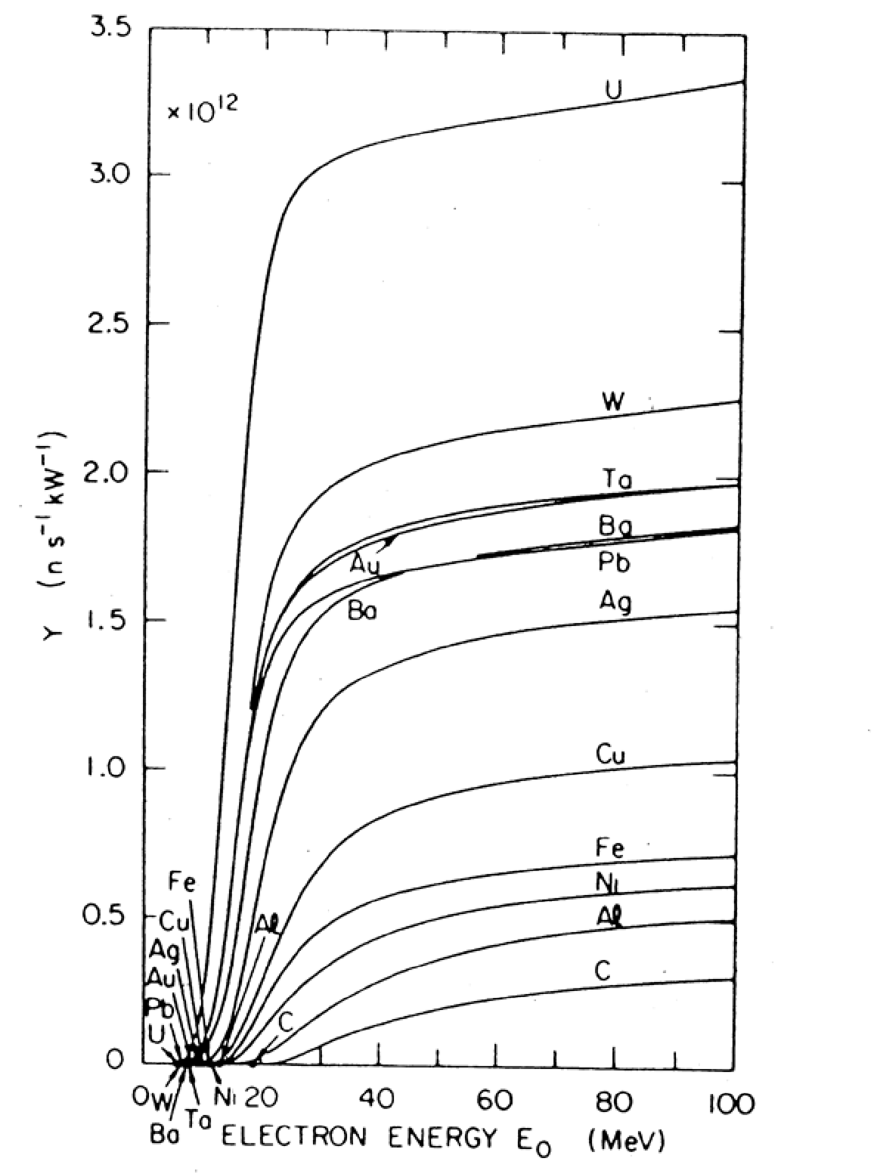
Energy associated with generation:

- Fission (*Dl*): 30x10^9 n/J
- High-E proton spallation (*l*): 200x10^9 n/J
  - ESS, SNS, JSNS, SINQ, ISIS
- Low-E Proton (p,n)Be 13MeV (*ml*): 3x10^9 n/J
  - ESS-B, LENS, RANS, …
- Threshold (d,n)Be (p,n)Li (*ml*): 0.5-1x10^9 n/J
  - NUANS, PKUNFTY, BNCT,…
- Electron on W (*cl*): 2x10^9 n/J
  - HUNS, Bariloche, RPI,…
- D-D, D-T (*nl*): >400x10^9 n/J

Electron-linac facilities (HUNS, Bariloche, RPI, …)

- Advantages:
  - Low cost of the accelerator (both purchase and maintenance)
  - High peak currents are possible (several A).
  - Short pulses easy to produce with good intensity.
- Disadvantages;
  - Gamma background is very severe
  - Activation issues near the target
  - Neutron spectrum /shielding

Photo-neutron production



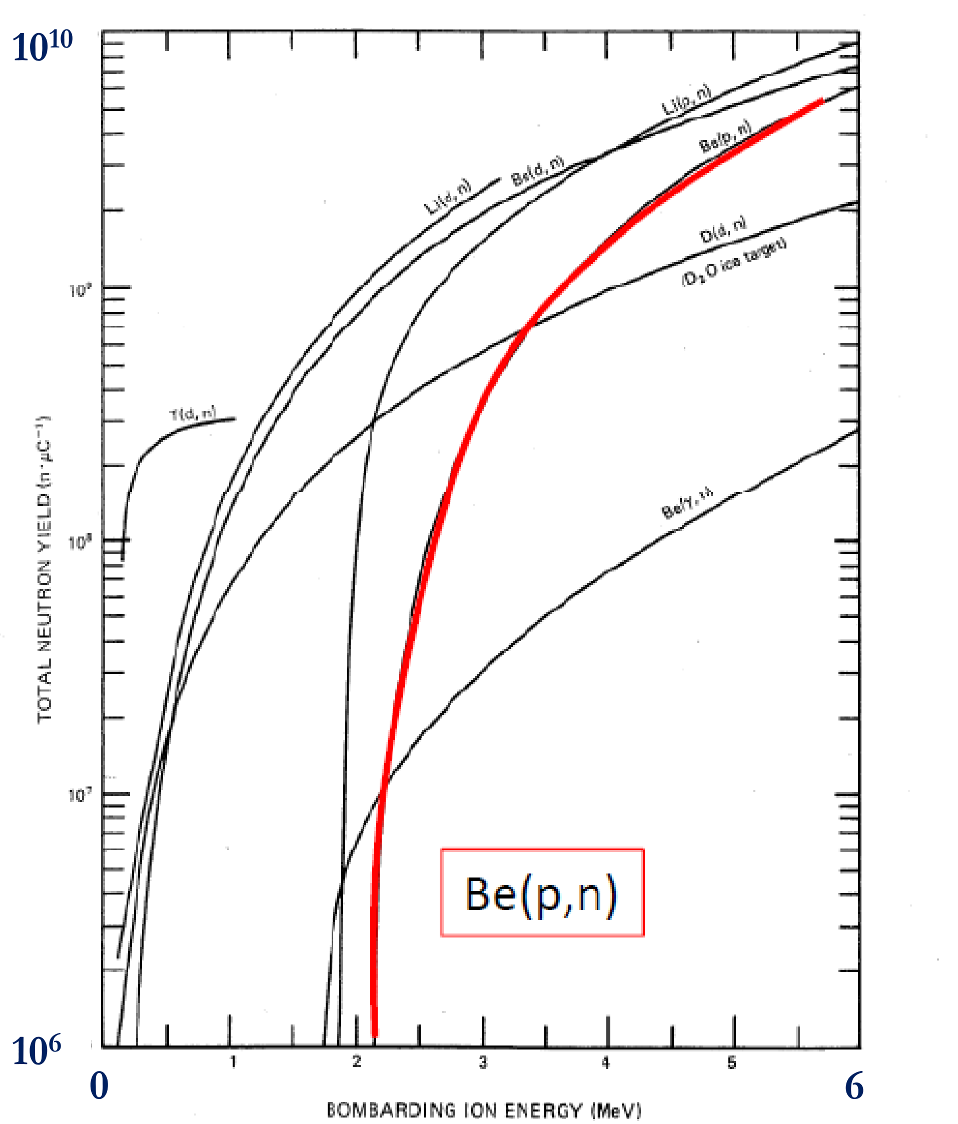
This type of source was popular for nuclear physics applications., but at least two facilities have used it successfully for innovative work in CMP applications (Bariloche and Hokkaido). Need ~35-40MeV e-linac, lots of shielding, several kW beam power

Carpenter, UCANS-V

Proton-linac facilities
LENS, RANS, NUANS, …

- Advantages:
  - Low background (limited E_n, fewer γ)
    - Scattering, BNCT, SEE
  - Slightly higher n production per target power
  - Activation can be quite limited for low enough energy
- Disadvantages;
  - Relatively expensive to build and operate
  - Target can be a challenge
  - Limited peak flux capability.

Low-E Neutron Production

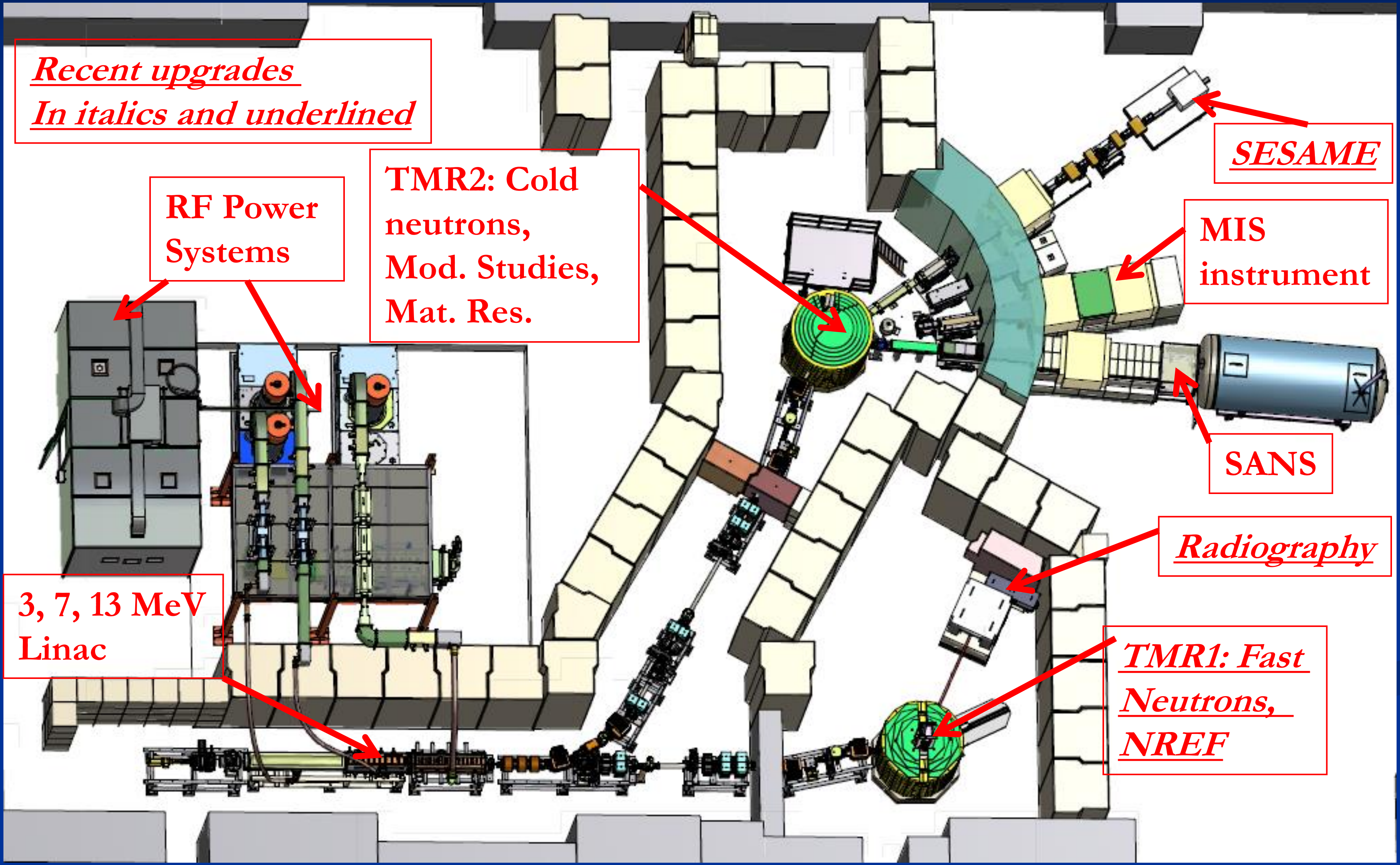


M.R.Hawksworth, Atomic Energy Review 152(1977)

Sources of this type are typically restricted to Li or Be targets.

- Li is attractive for BNCT or very low projectile energy (lower threshold), but has major activation and target issues
- Be also has target issues, but fewer activation issues, particularly if you stay at or below 8 or 13 MeV.

LENS: 2014



Recent upgrades
In italics and underlined

RF Power Systems

TMR2: Cold neutrons, Mod. Studies, Mat. Res.

SESAME

MIS instrument

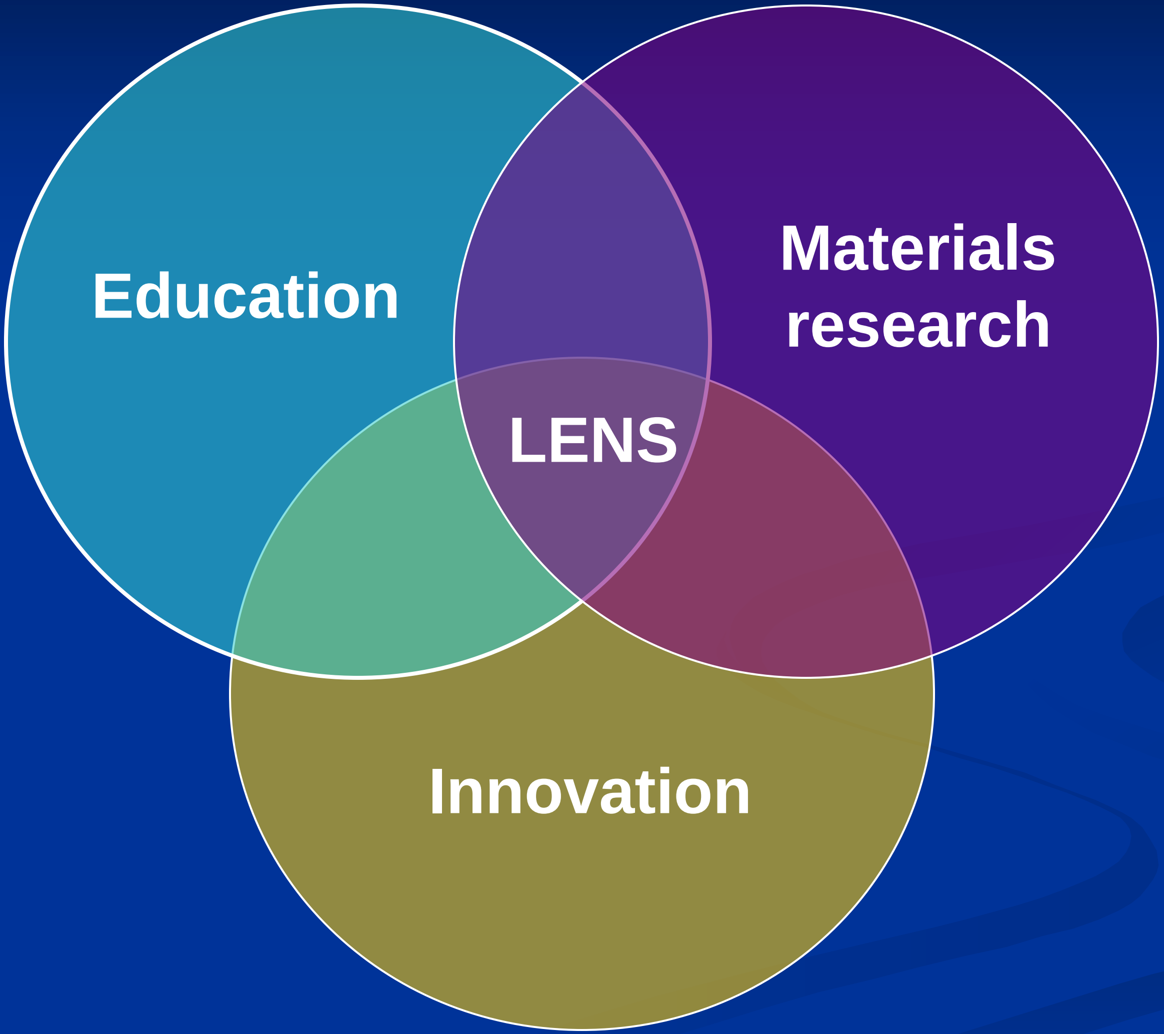
SANS

Radiography

3, 7, 13 MeV Linac

TMR1: Fast Neutrons, NREF

LENS Missions



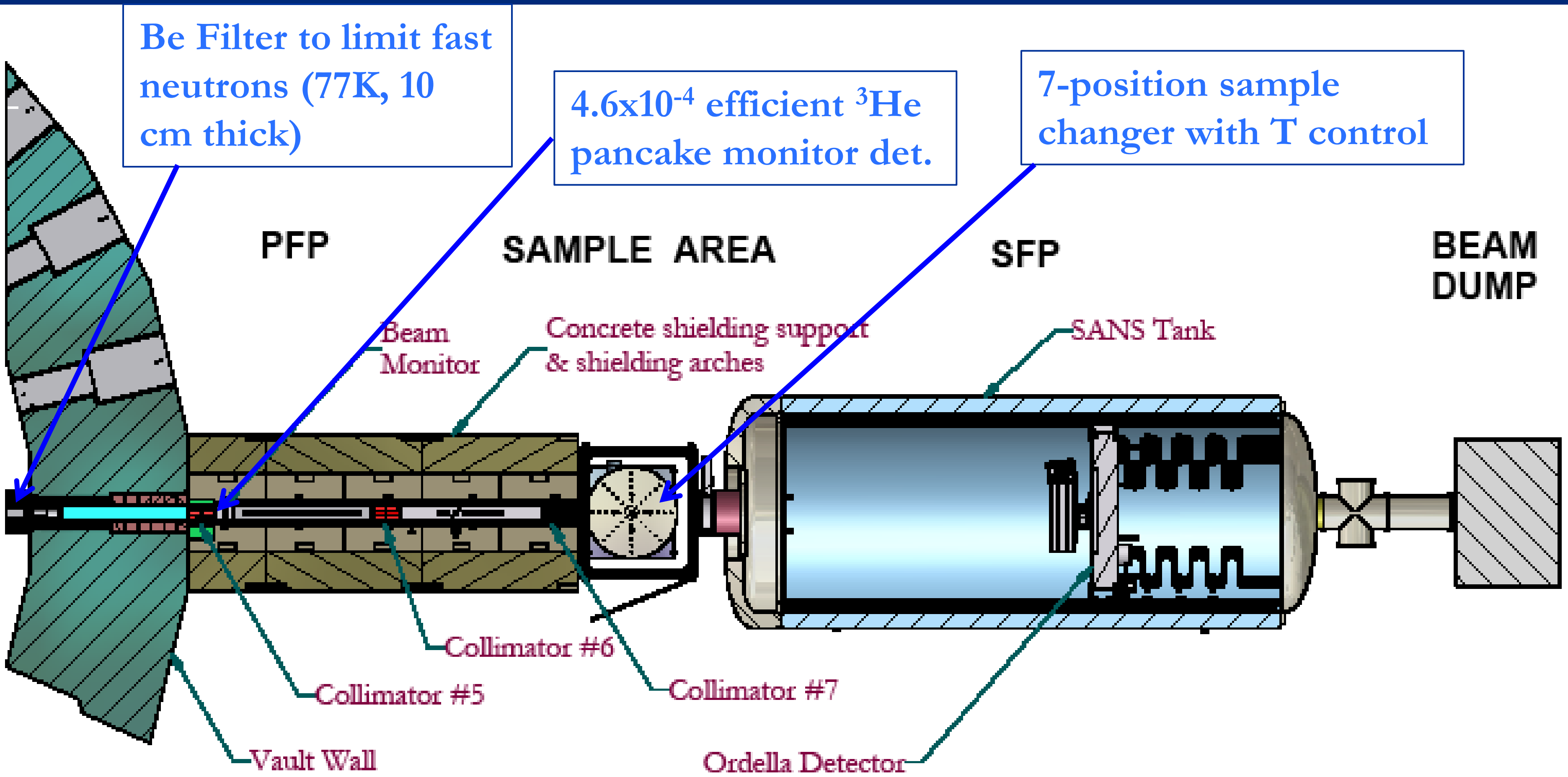
Education

Materials research

LENS

Innovation

SANS instrument

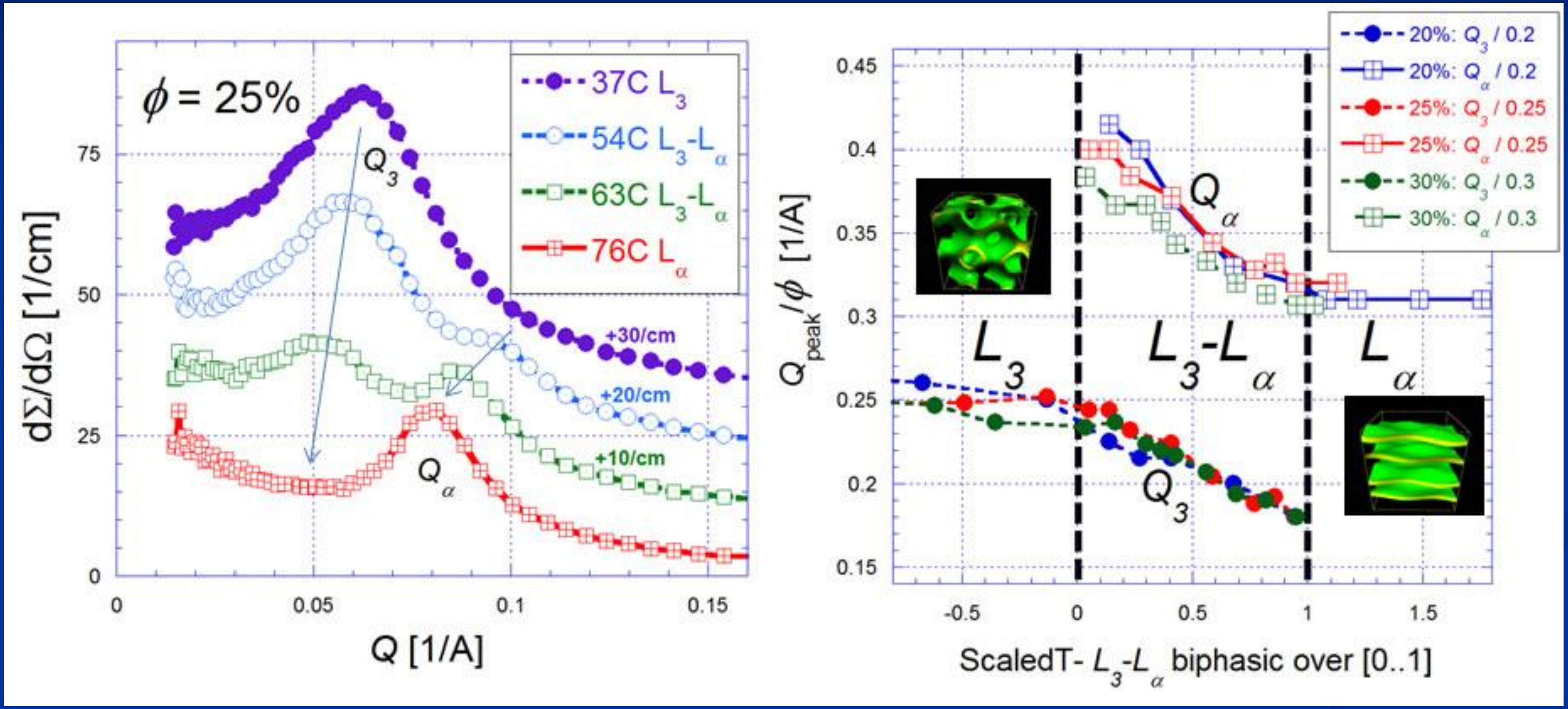


Be Filter to limit fast neutrons (77K, 10 cm thick)

4.6×10^{-4} efficient ^{3}He pancake monitor det.

7-position sample changer with T control

SANS :AOT (Sodium Di-2-ethylhexyl Sulfosuccinate)

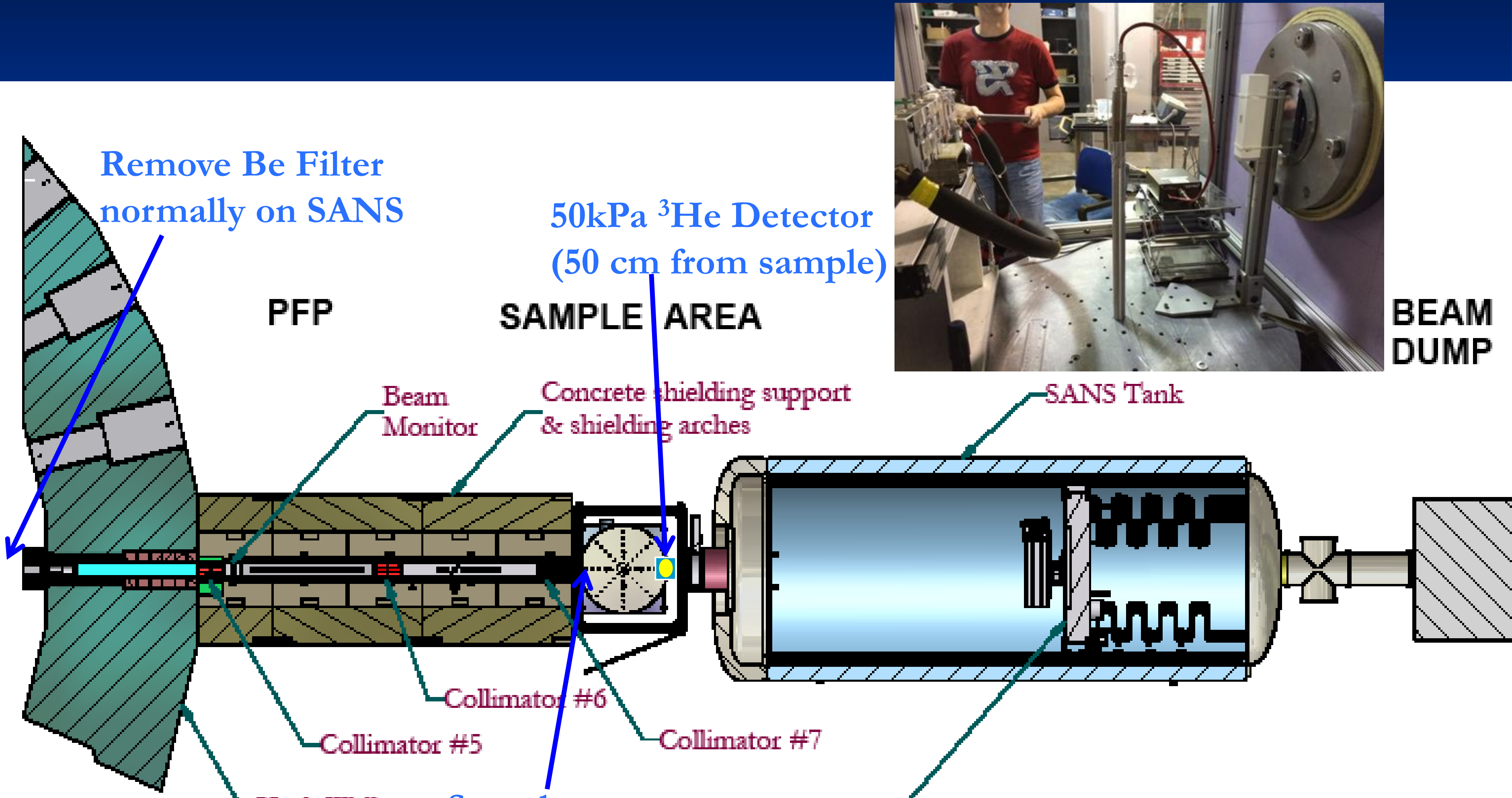


Data from the LENS SANS instrument. 20 minutes per temperature.

W. A. Hamilton and
S. R. Parnell (2014)

- Also preliminary data leading to experiments elsewhere:
  - Weir et al. , Chem Mat. **28**, 1698 (2016), graphene oxide, volume to surface fractal tranisition
  - CO_2 CH_4 in confinement (NIST, SNS)
  - CuMn (experiment scheduled at ISIS).

Total Cross-Section Expt. Setup

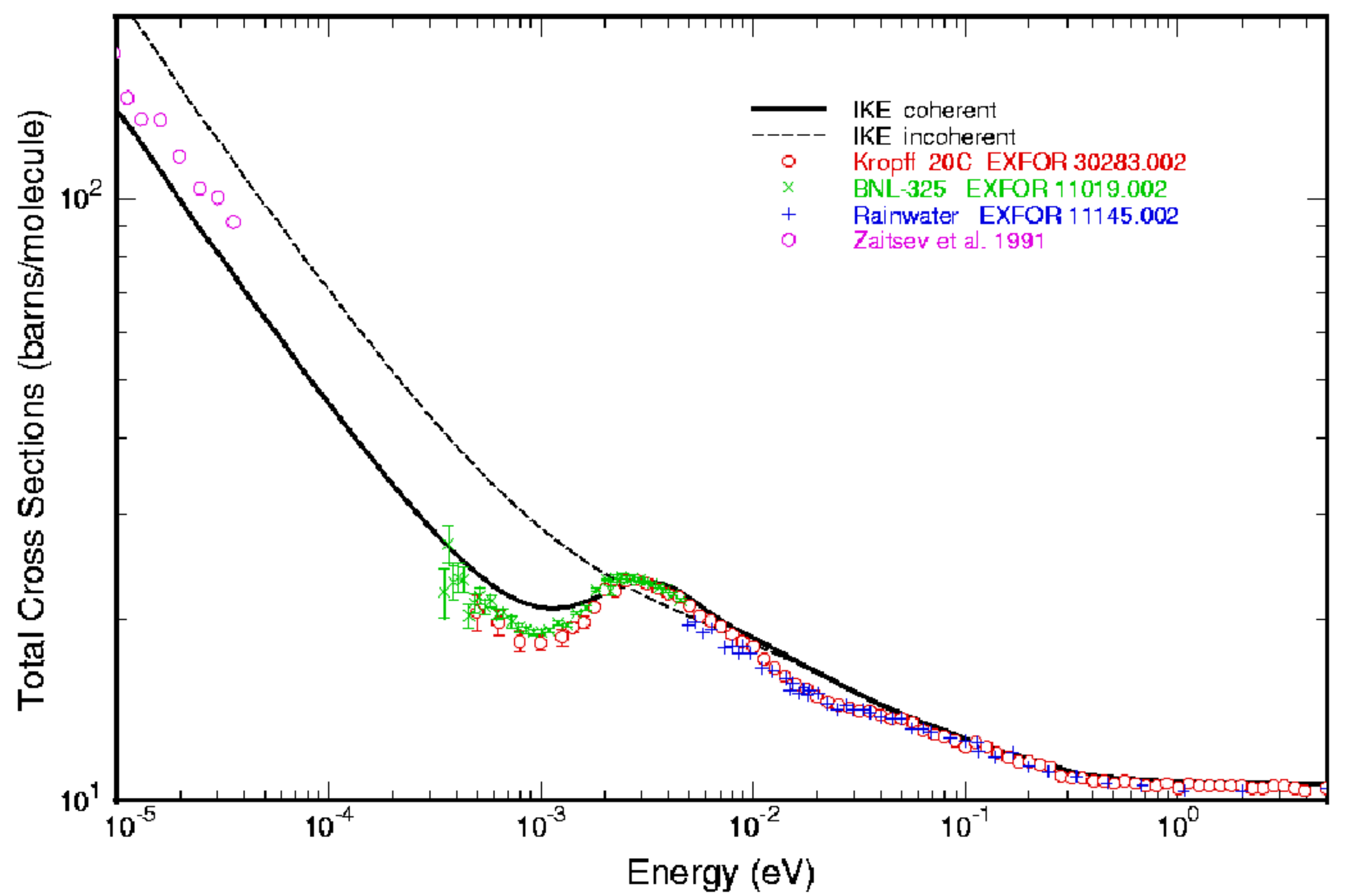


Remove Be Filter normally on SANS

50kPa ^{3}He Detector (50 cm from sample)

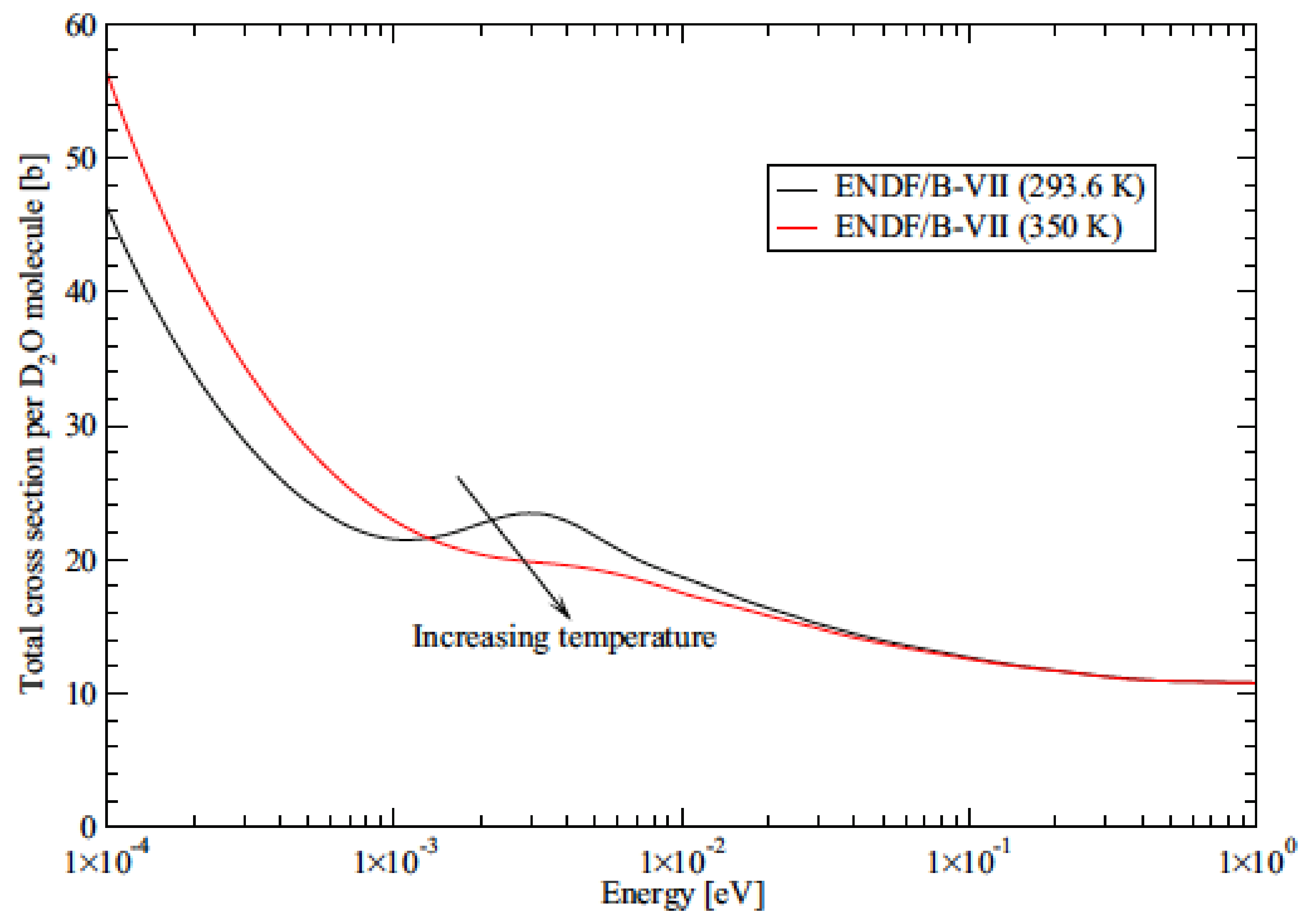
Sample stage moved to front

Kernel deficiencies in VCN regime



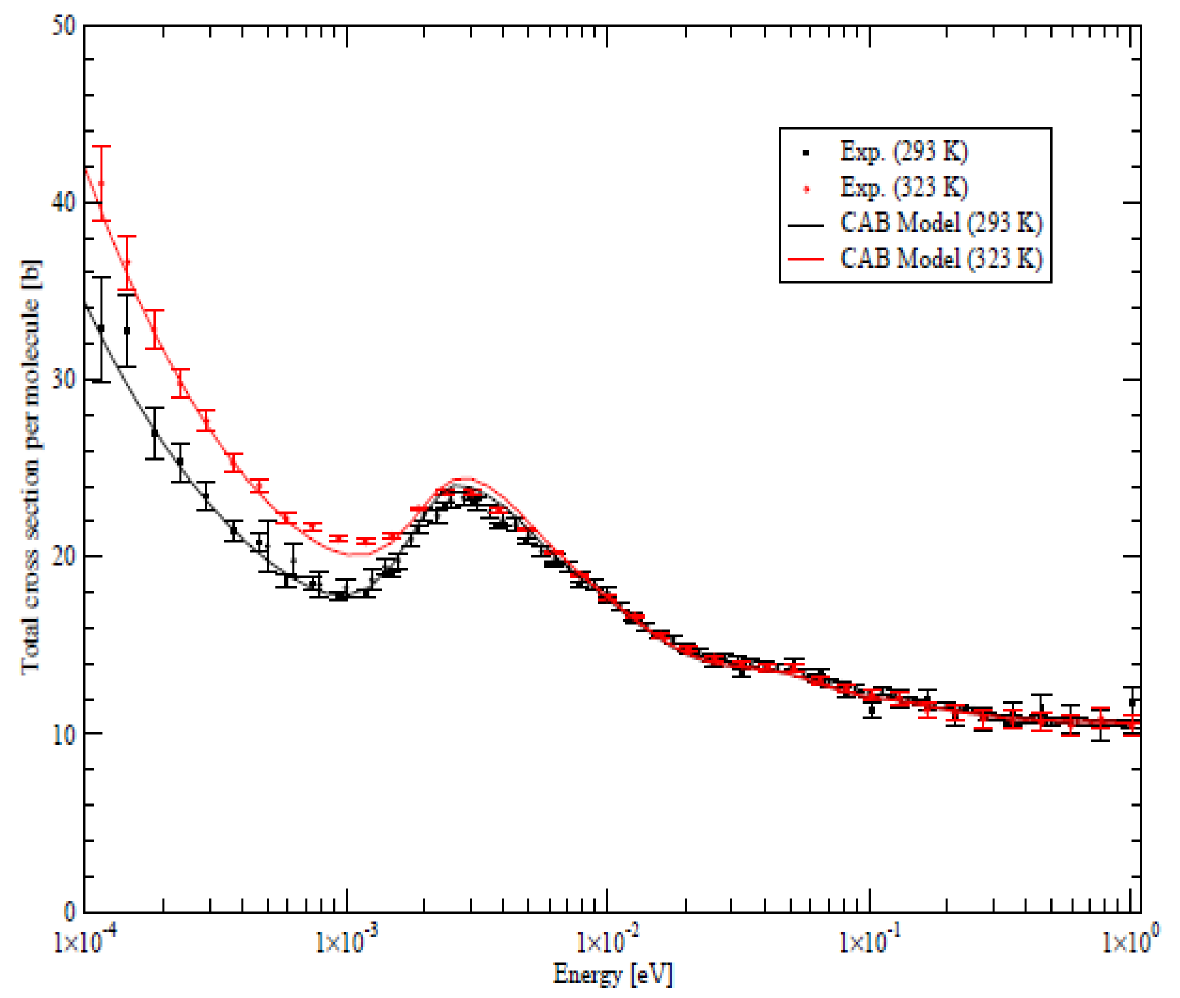
IAEA report: INDC(NDS) -0470

Temperature Dependence



Marquez Damian et al.
Il Nuov. Cim. 38C, 178 (2016)

Total Cross section of D_2O



Marquez Damian et al.
Il Nuov. Cim. 38C, 178 (2016)

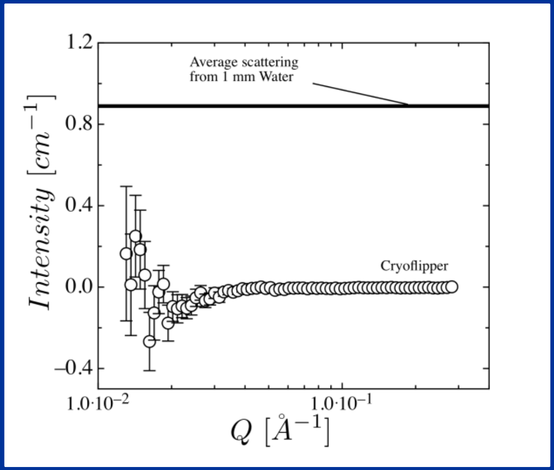
Data collected at 10Hz with 0.15ms pulse width for full energy range.
12 hour data collection(6 hour sample in, 6 hour sample out).

Statistics could be improved by using different accelerator settings for large and small energy portions of the data.

Background rate in the ^{3}He detector is very small.

Novel spin manipulation devices based on high temperature YBCO materials

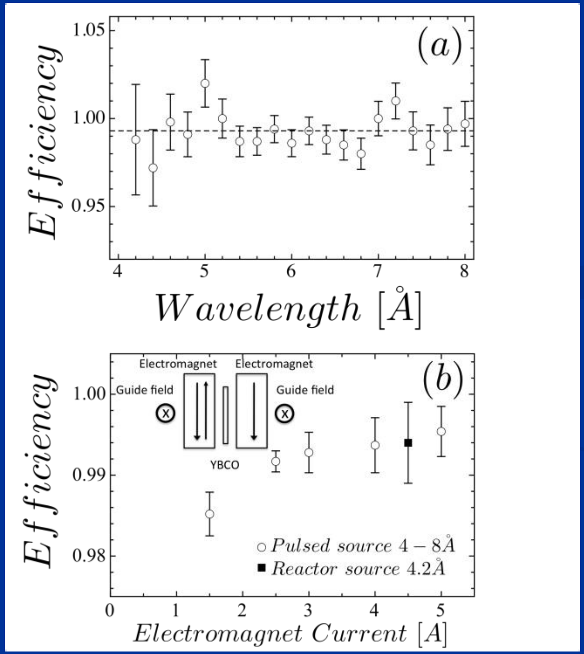
Materials tested on SANS - Proved low background scattering contribution



S.R.Parnell et al. Physics Procedia 42 (2013) 125-129

<u>Cryoflipper</u>: Uses Meissner effect to create abrupt non-adiabatic transition between magnetic field regions

Measurements of efficiency on SESAME – Simple flipper

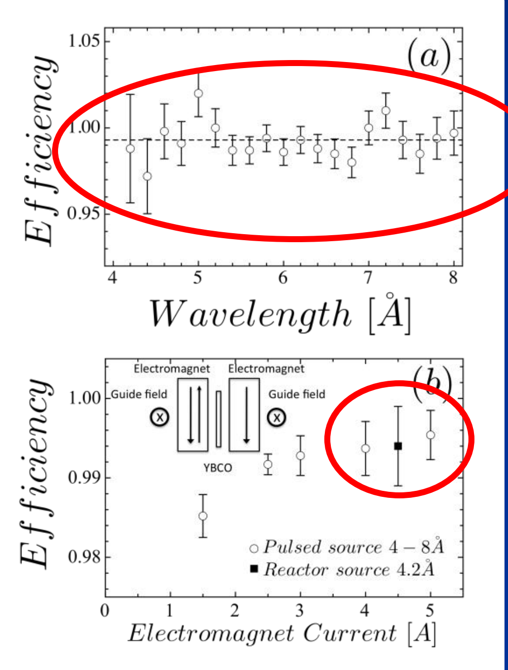


S.R.Parnell et al. Nuclear Instruments and Methods A 722 (2013) 20-23

Recently used at SNS on canted ferromagnet on HySpec instrument

Spin Manipulation - Results

<u>Cryoflipper</u>: Uses Meissner effect to create abrupt non-adiabatic transition between magnetic field regions

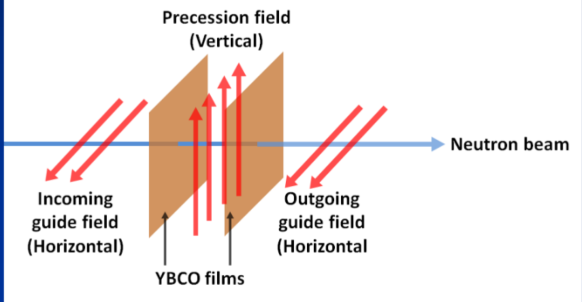


Uniform wavelength efficiency

Optimisation gives 99.5% efficiency

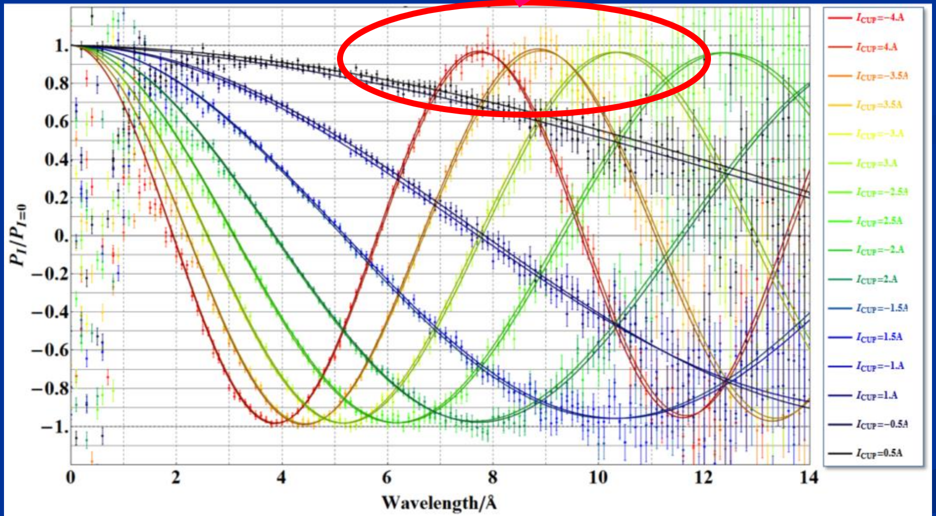
Tested at LENS and HFIR

<u>Cryo-Cup</u>: Compact spin precession device -



- Tested at LENS
- Key component of full SNP

Low depolarisation

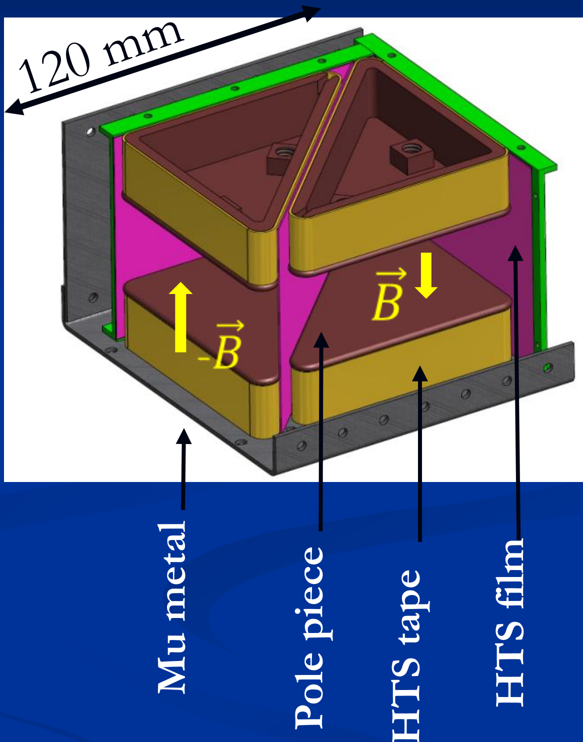


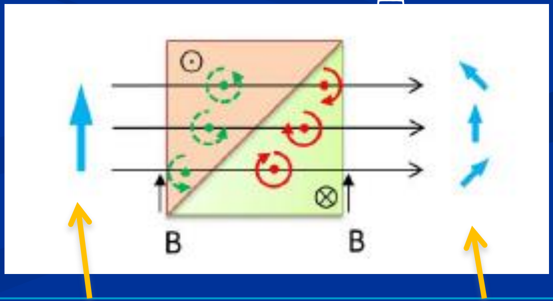
- Above plot shows P/Po as a function of λ for various coil currents (up to 4 A).

S. R. Parnell et al., NIMA **722**, 20 (2013),
Phys. Procedia **42**, 125 (2013)
Rev. Sci. Instr. **85**, 053303 (2014)

High-Temperature Superconducting Wollaston Prism (WP) for Neutrons

- A neutron WP allows you to encode neutron trajectory information into the neutron phase (spin orientation). With this you can decouple momentum resolution from neutron intensity facilitating:
  - Increased energy resolution in neutron scattering
  - Spin-echo approaches to real-space correlations in materials
  - New contrast mechanisms to neutron radiography
  - Introduction of entangled spin states into neutron scattering
- NSF funding was used to develop the concept and first prototype (by 2 NSF-supported grad students).
- Experimental tests at NCNR verify performance calculated using simulation software (MagNet©)
- Will be deployed at National Facilities (SNS, HFIR, NCNR) using follow-on funding from DOC, ORNL.
- A follow-on DOE STTR is leading to commercialization

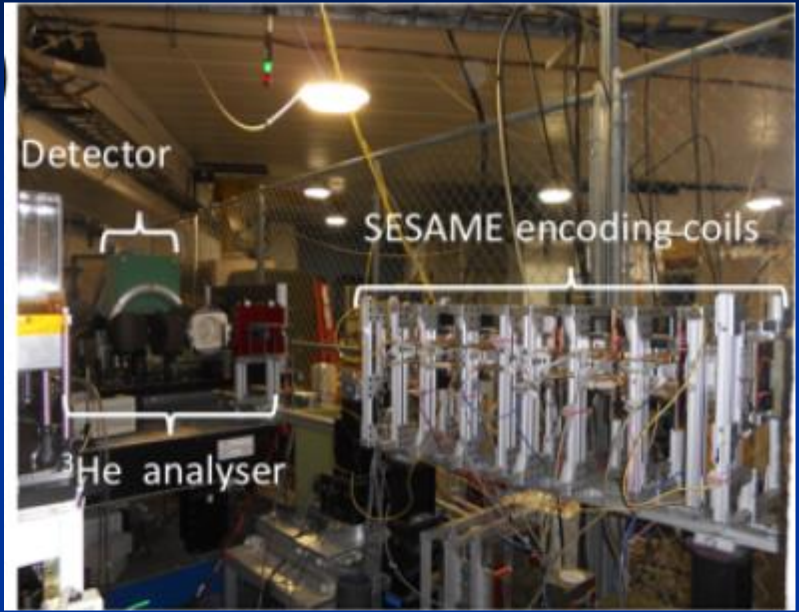


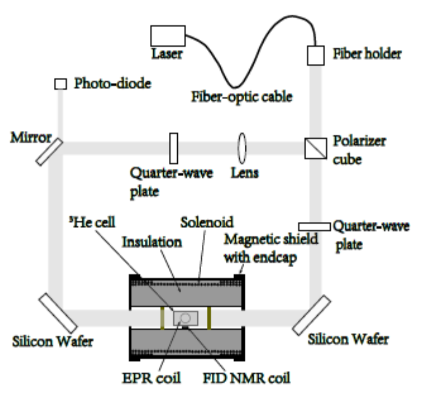


Neutron spin orientations

See Li et al. Rev. Sci. Inst. **86**, 023902 (2014), Li and Pynn, J. Appl. Cryst, **47**,1849 (2014) & perspective by F. Mezei, J. Appl. Cryst **47**,1807 (2014)

SESAME Instrument

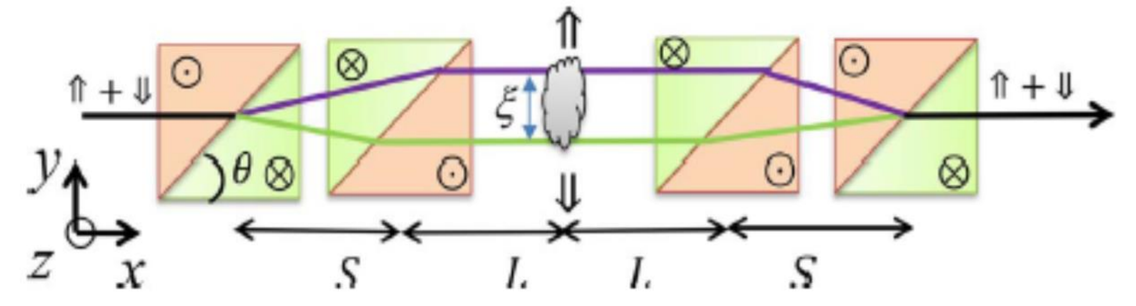




On-line ^{3}He polarization (SEOP) analysis

$$\boxed{P_s(\xi)/P_o(\xi)=\exp(\Sigma_t[G(\xi)-1])}$$

$\xi = cBL\lambda^2 B\cot(\theta)$; $c=2.476\times10^{14}\ T^{-1}\ m^{-2}$



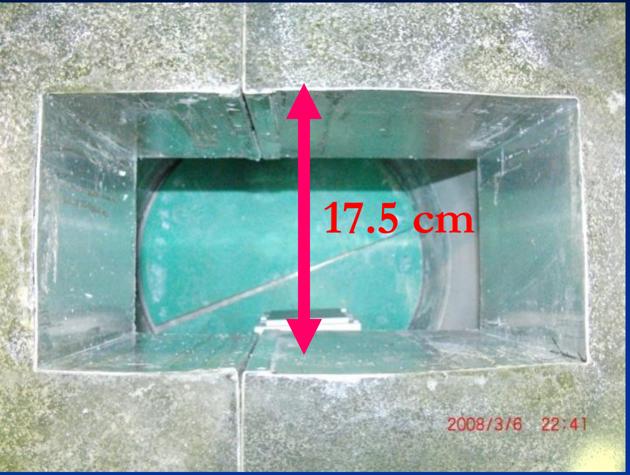
Real space correlations are determined directly from measuring the normalized polarization of the outgoing beam.

S. R. Parnell, Rev. Sci. Inst. (2015)

LENS Connections to the International Neutron Community

- **Technological:**
  - Instrumentation development (MWP, instrument upgrades at Lujan, NCNR,..)
- **Education**
  - NSF-IGERT: neutron grad. Program; emphasizes on hand-on instrumentation exposure and project-based classroom learning (with U. Missouri and SNS).
  - Joint convening of workshops on neutron education (ORNL) and instrumentation development (NIST)
  - Lectures at summer schools
- **Financial/Programmatic/Research**
  - Pynn joint appointment between IU/ORNL
  - LENS/NCNR collaborative agreement
  - Joint research projects/proposals in areas such as ^{3}He neutron polarizer development (NIST/SNS), instrument upgrades (LANL), and moderator development (SNS,LANL,ESS), looking at novel radiography (NIST/ORNL)…

TMR1

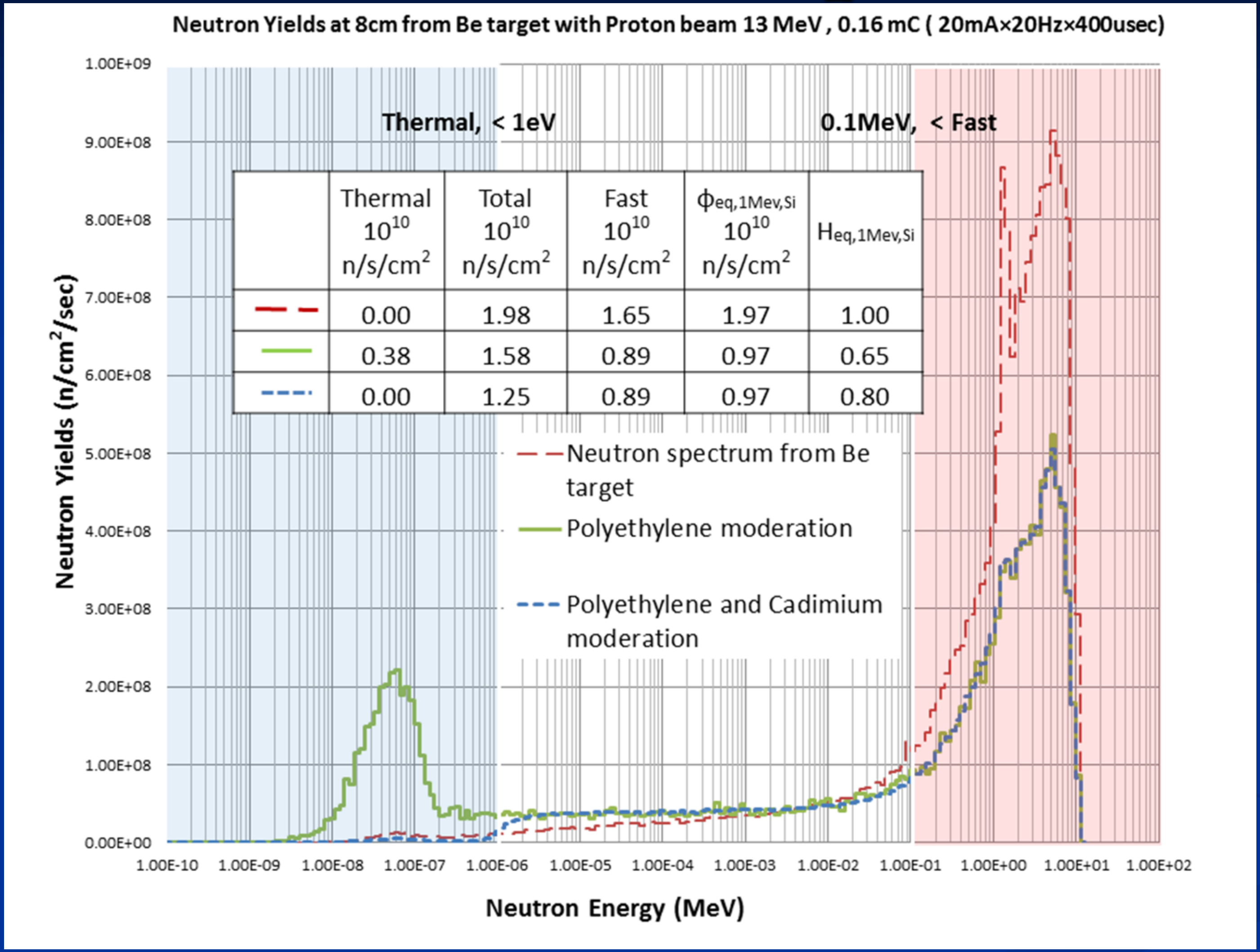


TMR 1 has undergone a couple of upgrades over the last two years.

New dumb-waiter access allows us to accommodate larger circuits and ease access at NREF.

Radiography set up to image lithium batteries. We are also reaching out to Anthropology/Archeology

NREF Spectrum



Neutron Yields at 8cm from Be target with Proton beam 13 MeV , 0.16 mC (20mA×20Hz×400usec)

	Thermal 10^{10} n/s/cm^2	Total 10^{10} n/s/cm^2	Fast 10^{10} n/s/cm^2	$\phi_{eq,1Mev,Si}$ 10^{10} n/s/cm^2	$H_{eq,1Mev,Si}$
— —	0.00	1.98	1.65	1.97	1.00
——	0.38	1.58	0.89	0.97	0.65
- - -	0.00	1.25	0.89	0.97	0.80

NOTE: These numbers are for ~1% duty factor. Peak flux is roughly 100 times as great.

Compare to: TRIUMF (3e6 n/(cm^2.s) at TNF, 5e4 n/(cm^2.s) at BL2C), LANSCE 4.5e5 n/(cm^2.s); ISIS (anticipated at ChipIR ~4e7 n/(cm^2.s) pencil beam, 3e5 n/(cm^2.s) flood) These facilities go to significantly higher maximum energy (100's of MeV).

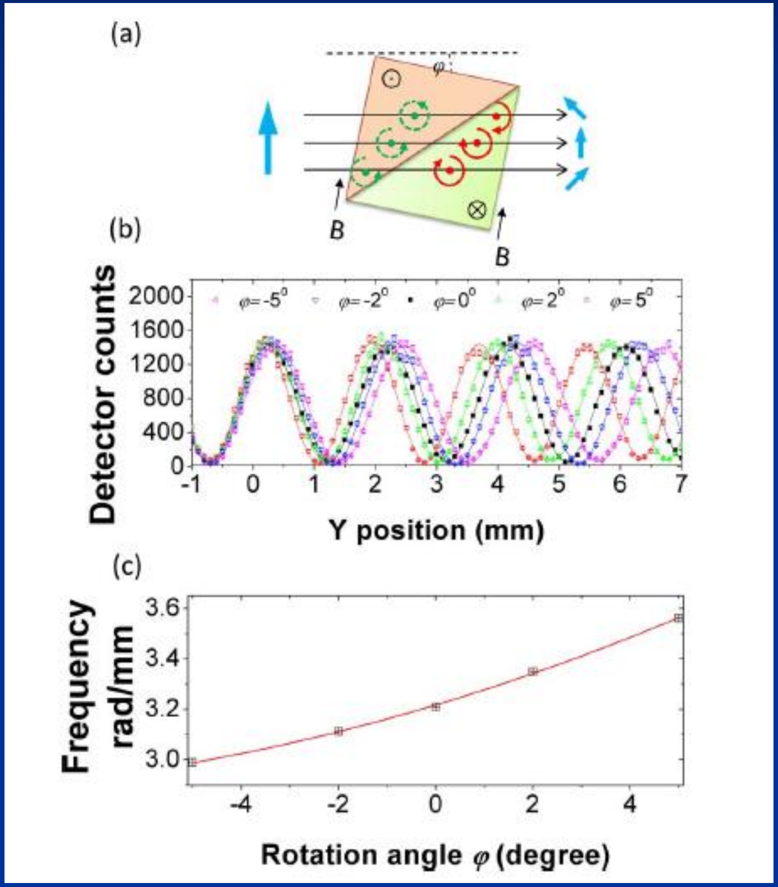
NREF

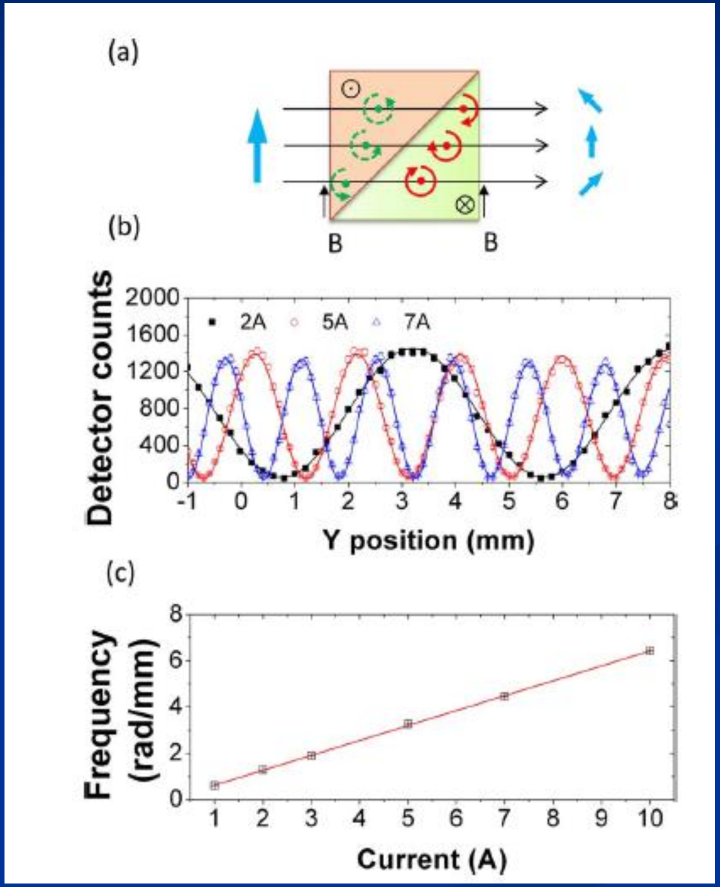
- Neutron-induced Single Event Effects (SEE) are a concern:
    - Cosmic-ray induced effects on commercial electronics
    - “harsh environments” for military electronics
- Military testing traditionally performed at fast burst reactors; these are becoming a dying breed!
- SEE involve processes over a large range of time scales (<ns to months).
- QUESTIONS
    - Can CANS provide equivalent information to reactors?
    - Can CANS provide extra information on time scales from <ms to minutes?

CONCLUSIONS

- ADNS are the flagship sources of the future, but have a role to play at smaller scales as well.
- Examples exist over a wide range of facility scales
  - (ESS, SNS/JSNS, ISIS, ESS-B,LENS, HUNS, RANS)
- CANS-scale facilities have demonstrated track record for innovation, science, and support.
- There are a number of opportunities for continued innovation on the horizon.

Magnetic Wollaston Prisms





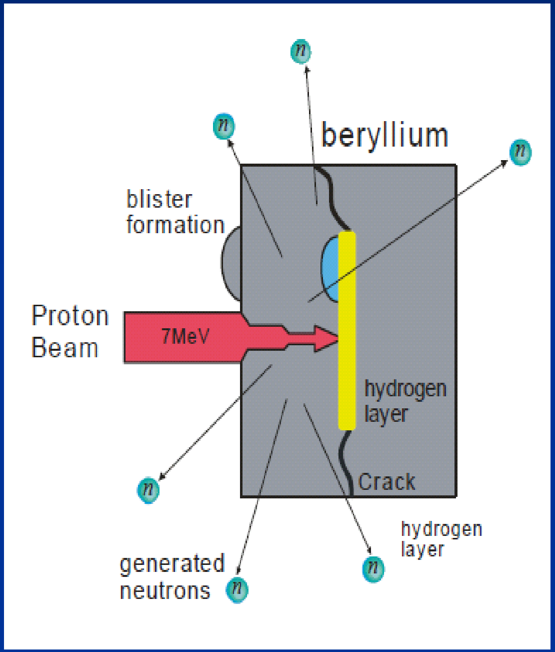
F. Li et al. (2014)

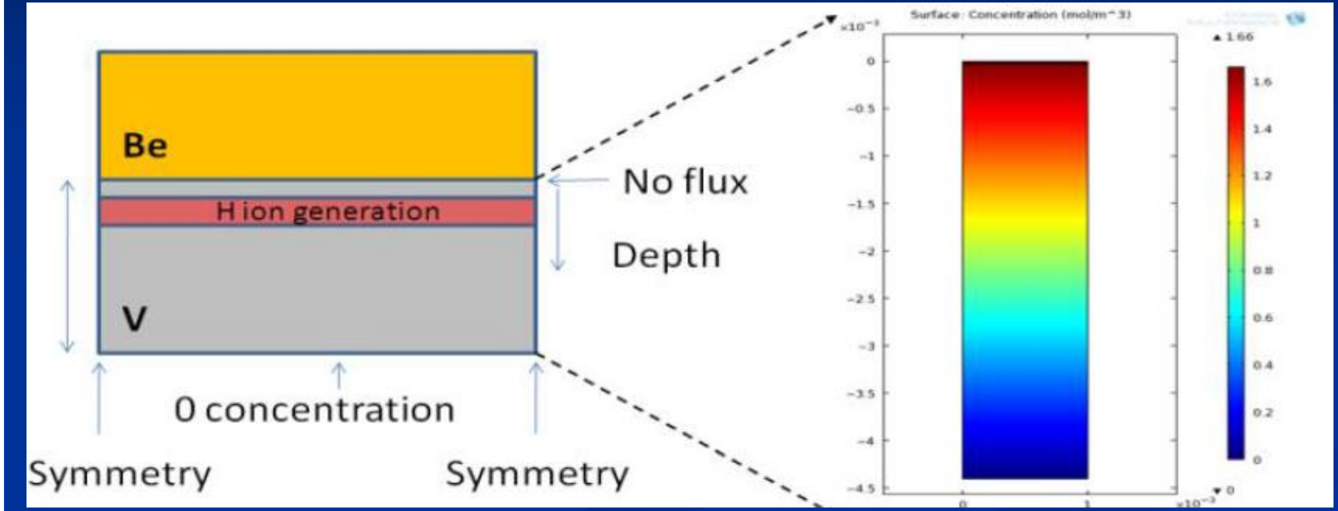
Have working prototypes functioning up to 20 A, expect to have the next generation working to 60 A (more details tomorrow, applications to SANS-like length scales, phase imaging on 0.2 mm scales, phonon-focusing, …

Some LENS Target Failures

Hydrogen embrittlement/blistering is a major issue

Target design limitations



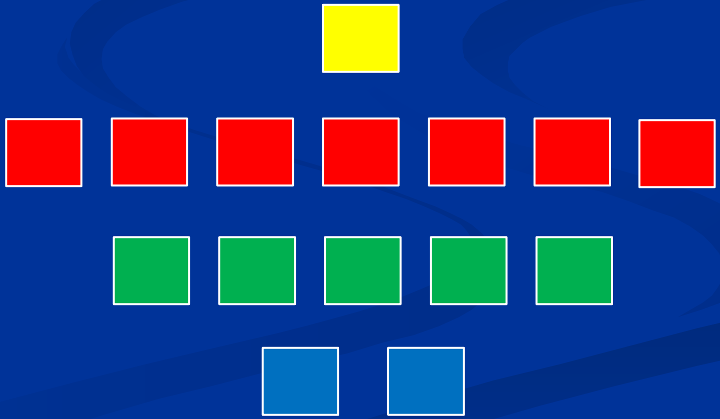


Y. Yamagata et al.

Difficulty with the (p,n)Be target design is the buildup of H within the target at the depth of the Bragg peak.

- Be has little tolerance for H, and the H does not diffuse away.
- A composite design, in which the Be is backed by a layer in which H diffuses rapidly (such as V or Pd) has been implemented at a number of facilities.
- One BNCT project in Japan envisions an 80kW target operating at 8MeV with such a design., HBS is envisaged with a ~30kW target, ESS-B with ~100kW at 50MeV.

Neutrons in Europe 2014



Robert McGreevy, 2015