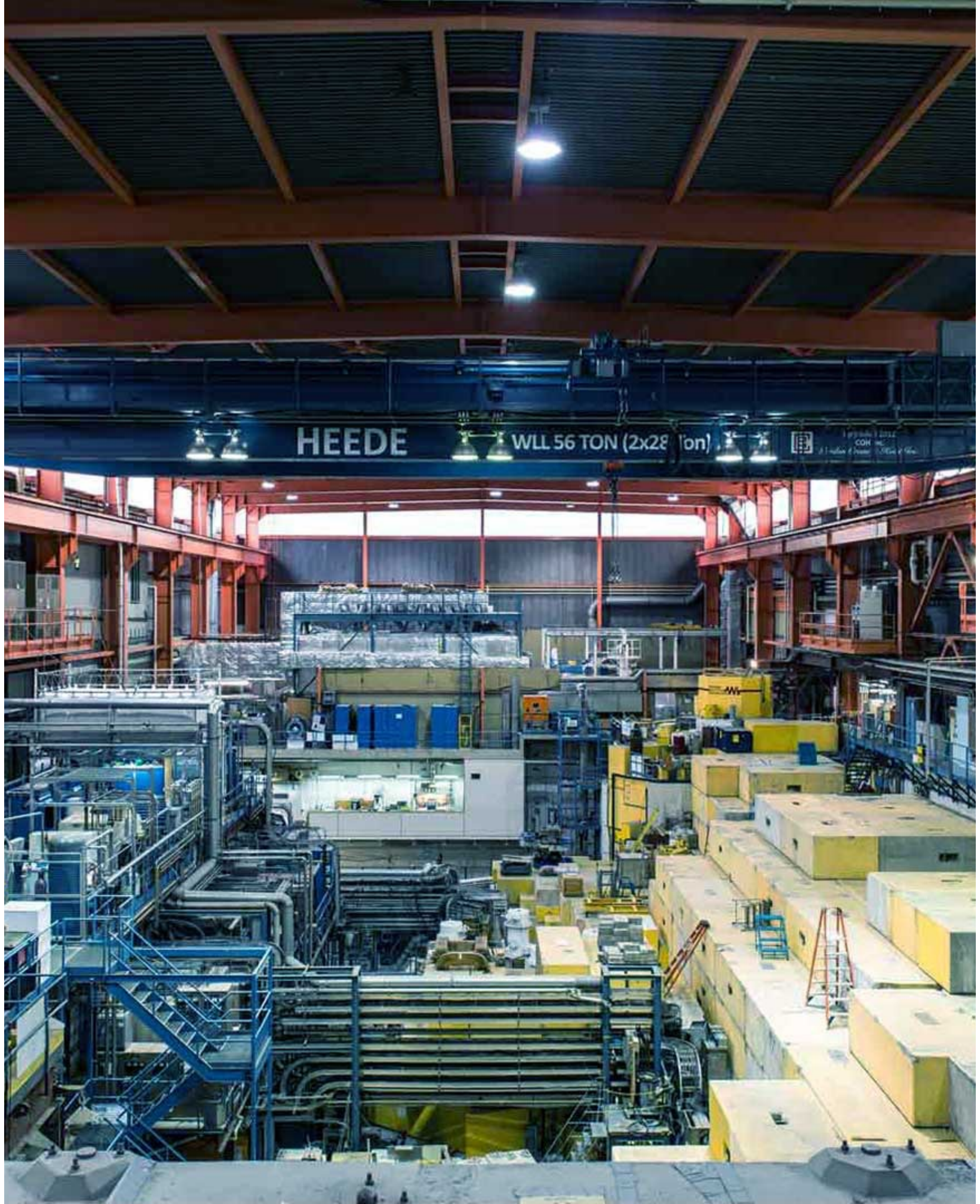
TRIUMF

Muon and atmospheric neutron facilities in RADNEXT
(with a focus on TRIUMF's capabilities)

Camille Bélanger-Champagne
Irradiation Facilities Coordinator, TRIUMF
RADNEXT WP09 deputy leader

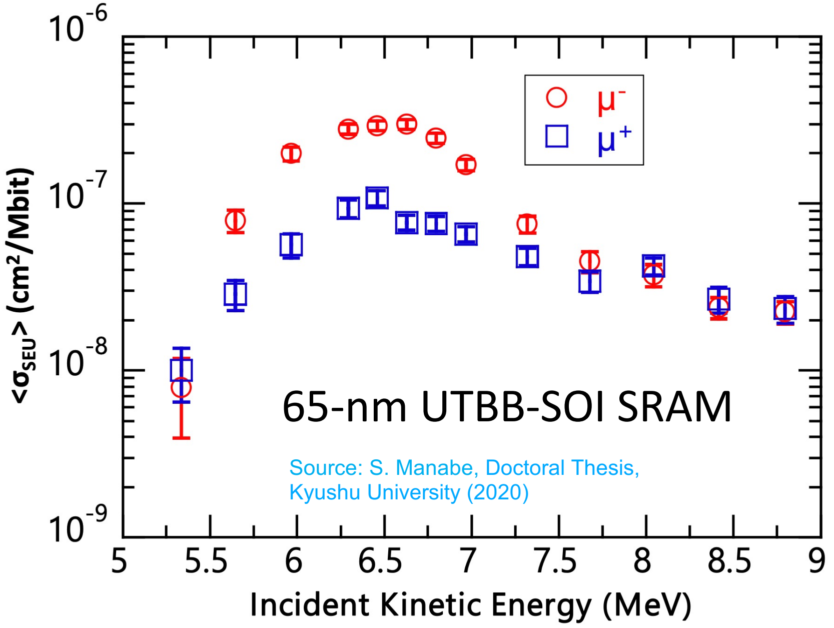
with thanks to C. Cazzaniga, E. Blackmore and M. Trinczek



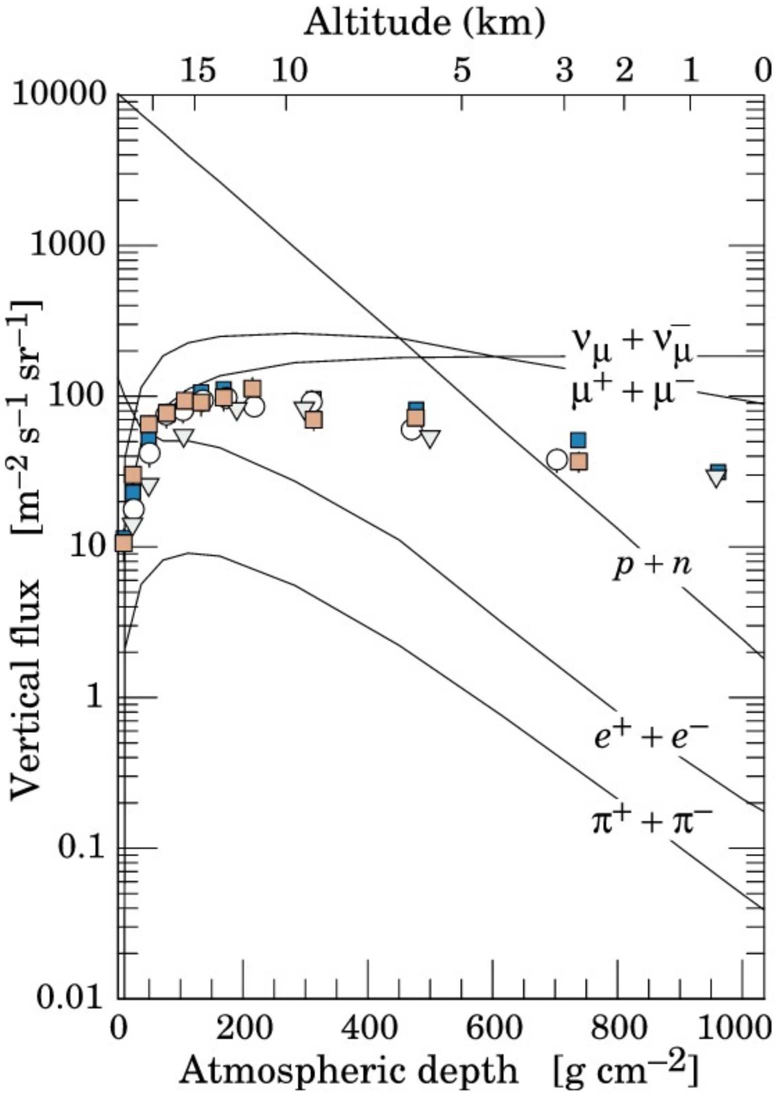
Discovery,
accelerated

Muons in atmospheric cascades

- Very abundant in air showers but low LET – with new technologies and smaller structure size, reduced Q_c can increase rate of muon-induced SEE
- Negative muon capture process can create high LET secondaries – interesting recent results
- Muon test beam capability worldwide is limited to a few facilities (**TRIUMF**, **RAL**, PSI, RCNP, J-PARC) but they are all already involved with the radiation effects community

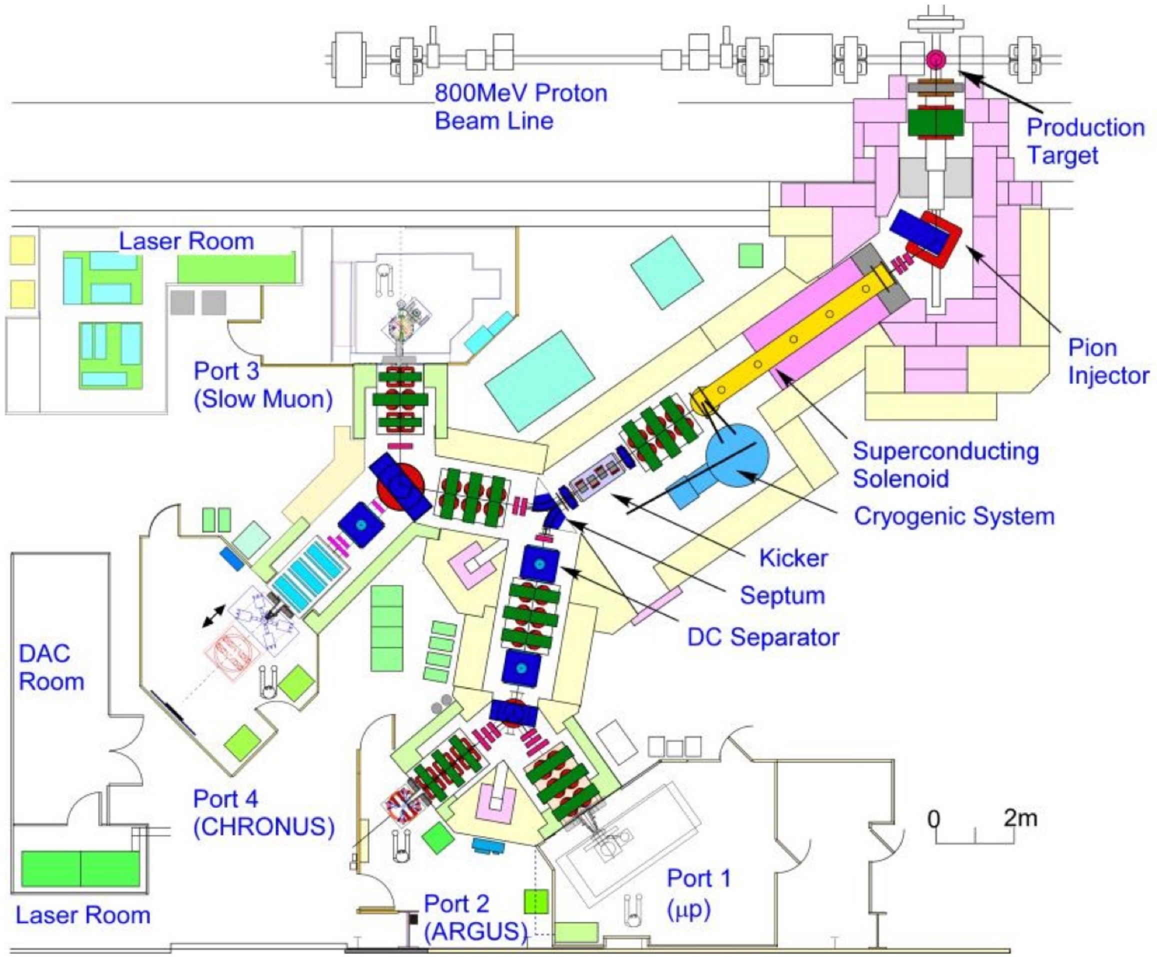


Source: S. Manabe, Doctoral Thesis, Kyushu University (2020)

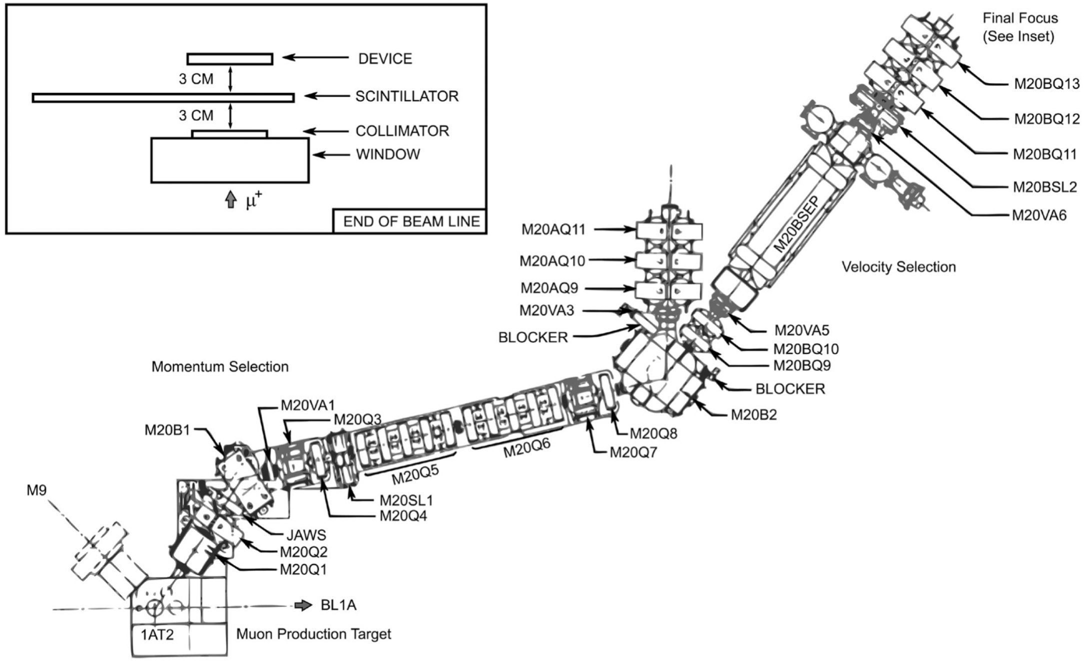


Source: L. Bonechi et al. *Reviews in Physics* 5 (2020) 100038

Muons testing at RADNEXT-affiliated facilities



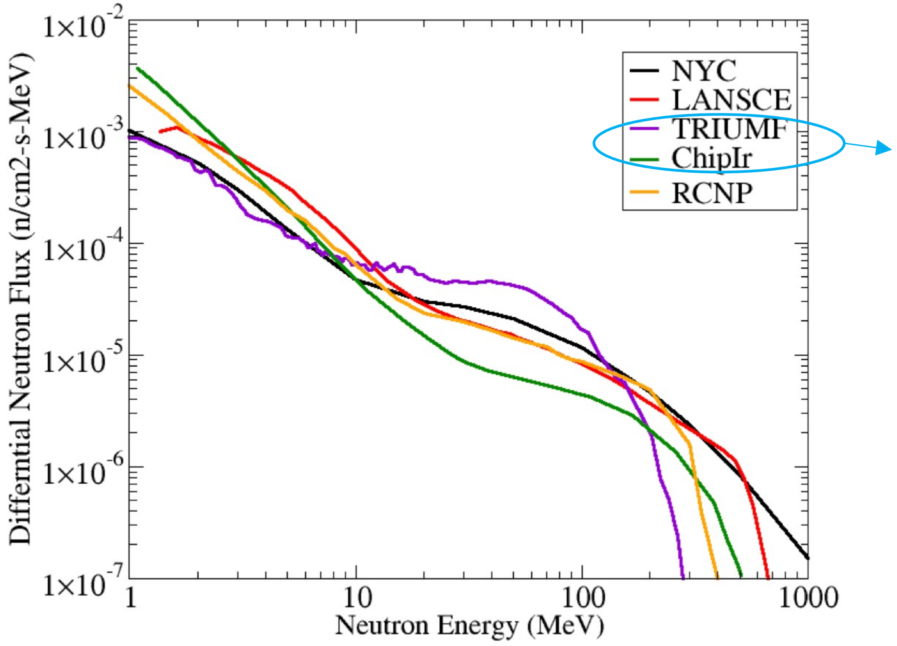
RAL-RIKEN muons up to 60 MeV/c
140 hours available through RADNEXT



TRIUMF-M20 positive muons up to 30 MeV/c

Neutrons in atmospheric cascades

- Dominant contribution to SEEs in atmosphere
- Flux strongly dependent on altitude, latitude
- Atmospheric neutron spectrum well-reproduced at spallation neutron sources, up to energy endpoint of primary beam



RADNEXT facilities

Fig. 1. Neutron spectra are shown for a reference environment in New York City (NYC) and several broad spectrum neutron sources.

Source: H. Quinn et al., *TNS* 66, no 1 (2019) 140

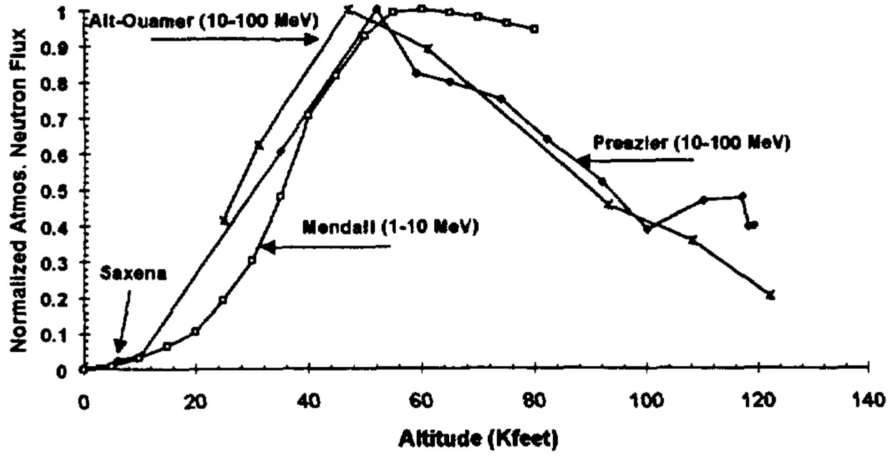
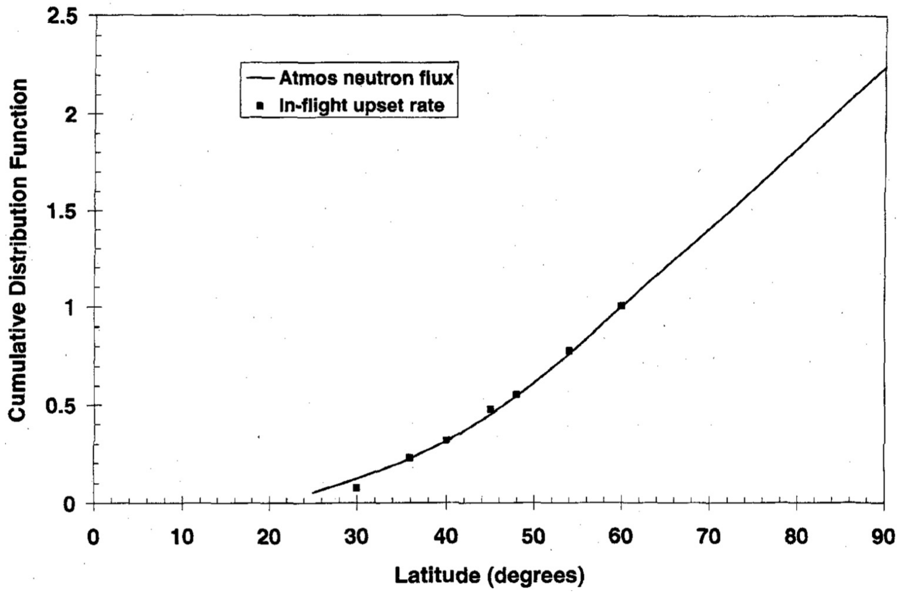


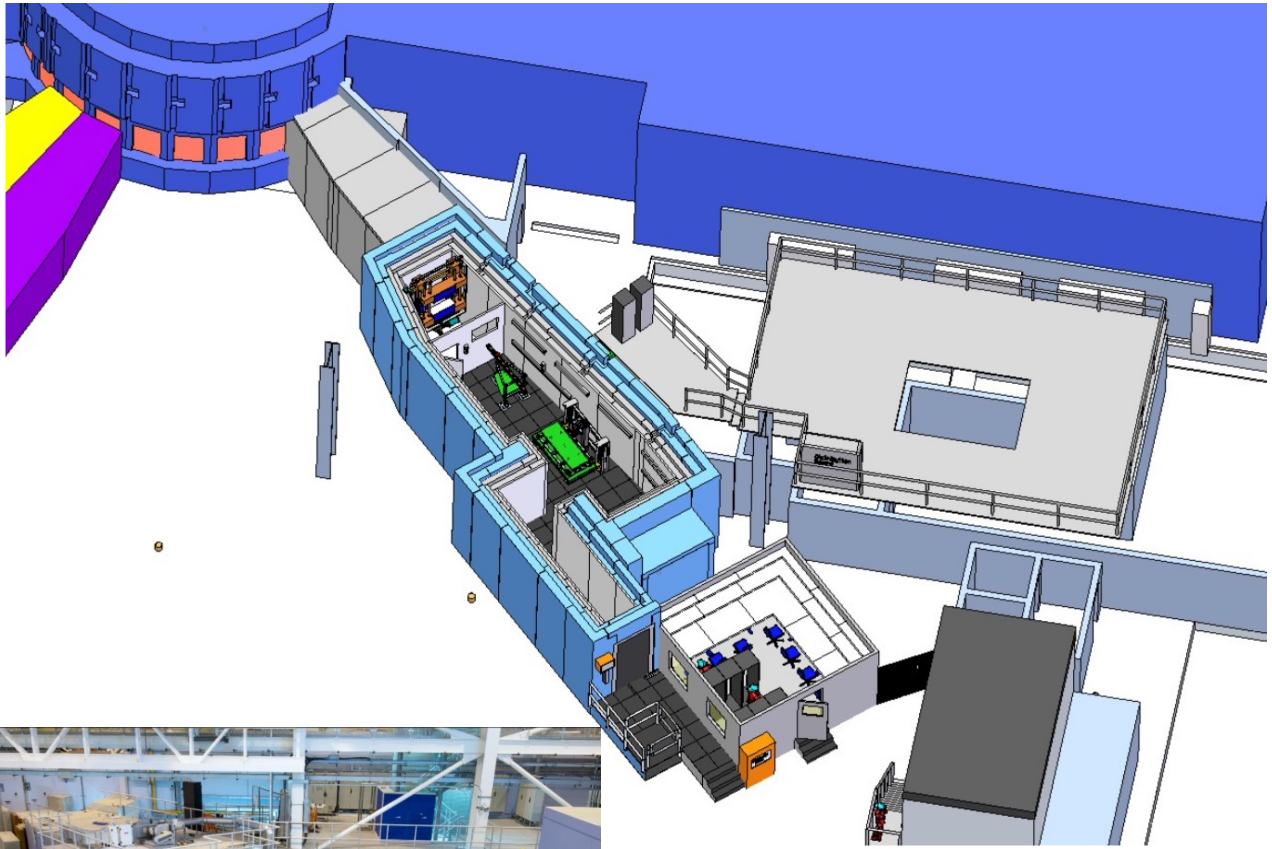
Figure 7. Comparison of the Atmospheric Netron Flux Variation with Altitude in the 1-10 MeV and 10-100 MeV energy Ranges

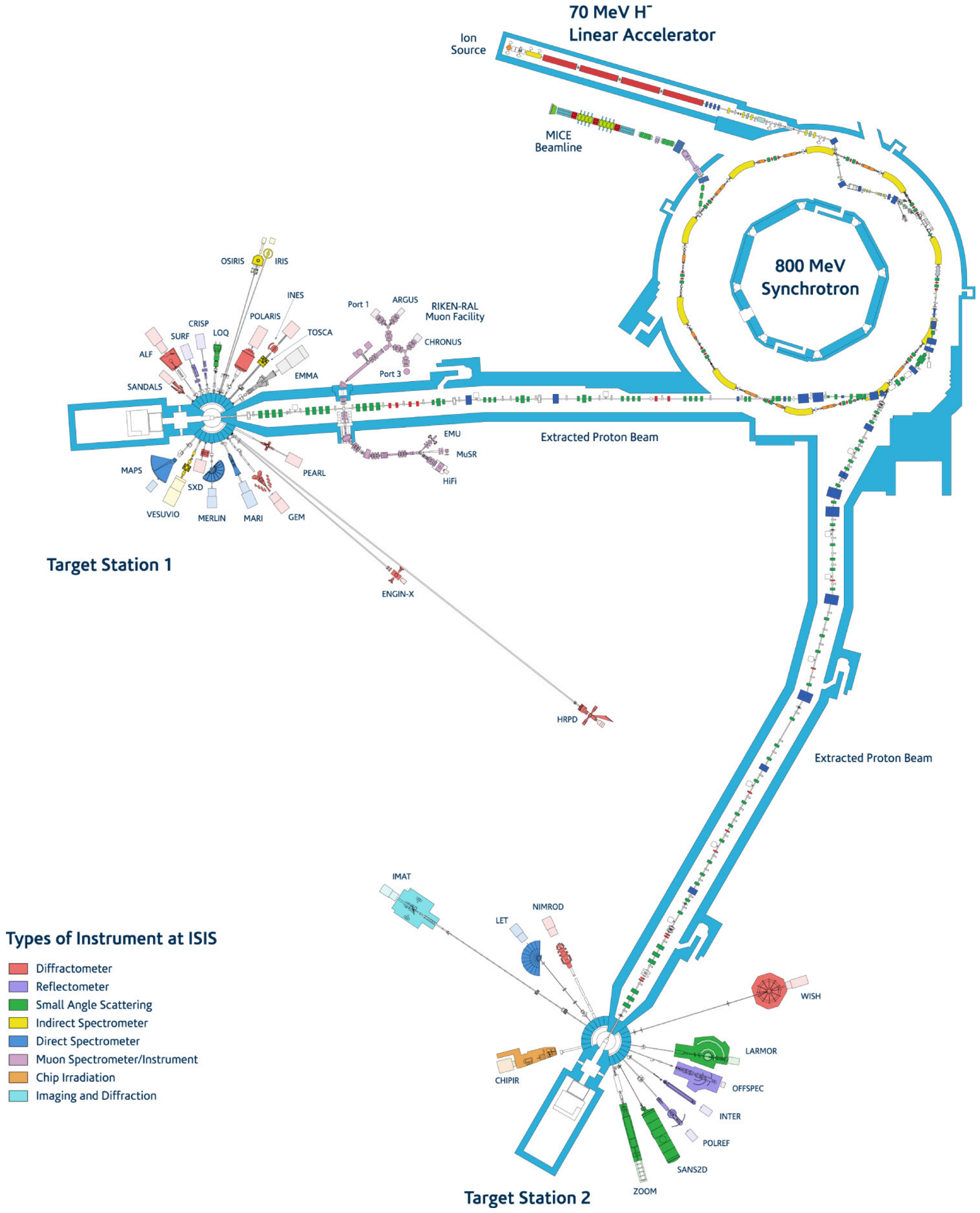
Source: E. Normand and T.J. Baker, *TNS* 40, no 6 (1993) 1484



Source: E. Normand, *TNS* 43, no 2 (1996) 461

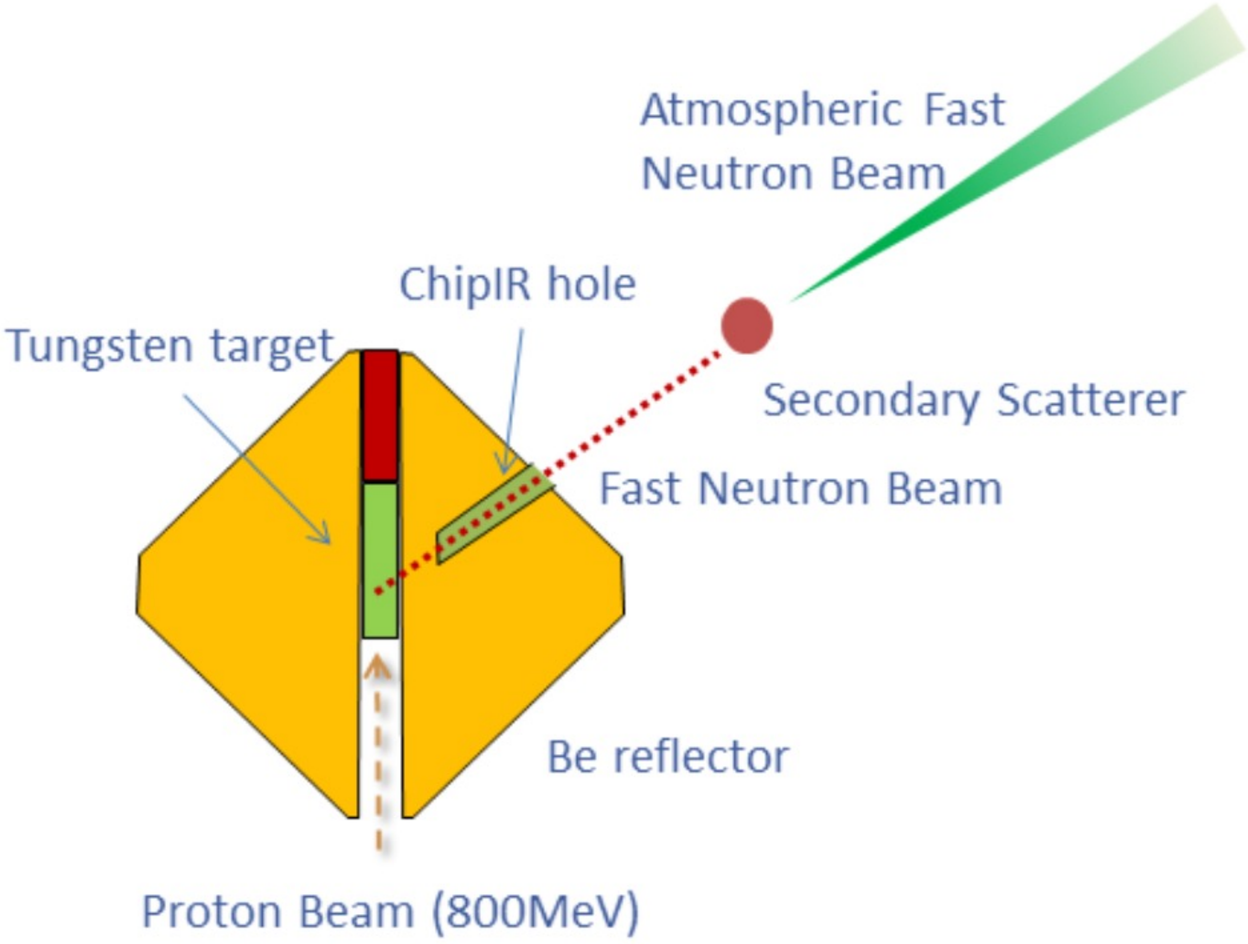
ChipIR at the ISIS Muon and Neutron Source at RAL



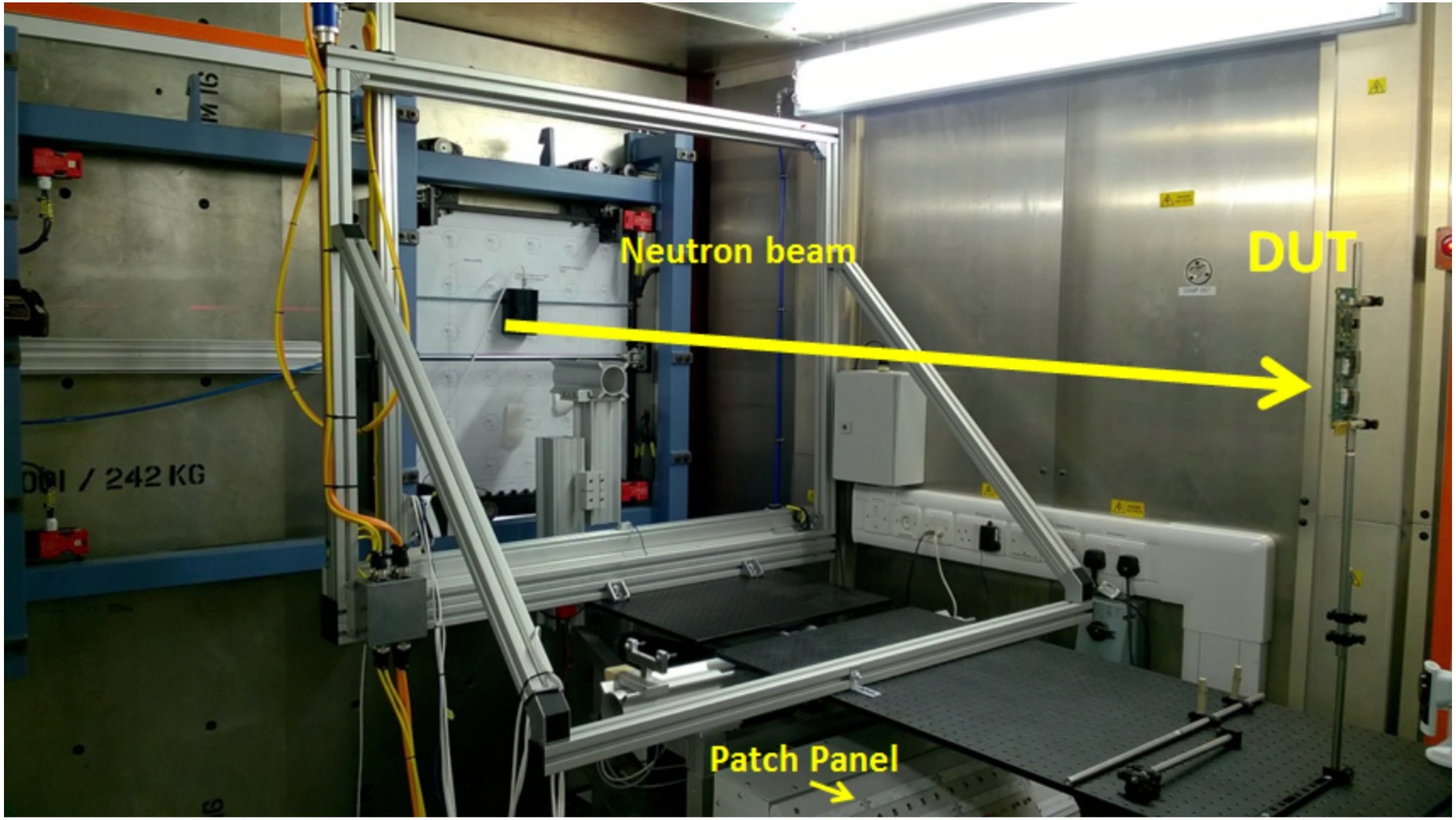


ChipIR at the ISIS Muon and Neutron Source at RAL

- In operation since 2017
- Primary protons at 800 MeV, pulsed beam operation
- Flux: up to 5×10^6 $n_{>10\ MeV}/cm^2/s$
- Variable collimation:
  - As low as a few cm^2
  - Up to 40 cm x 40 cm
- 2 test positions, designed to make it easy to test both small boards and big, heavy systems
- Cadmium filters available to remove thermal and epithermal neutrons
- 620 beam hours available through RADNEXT

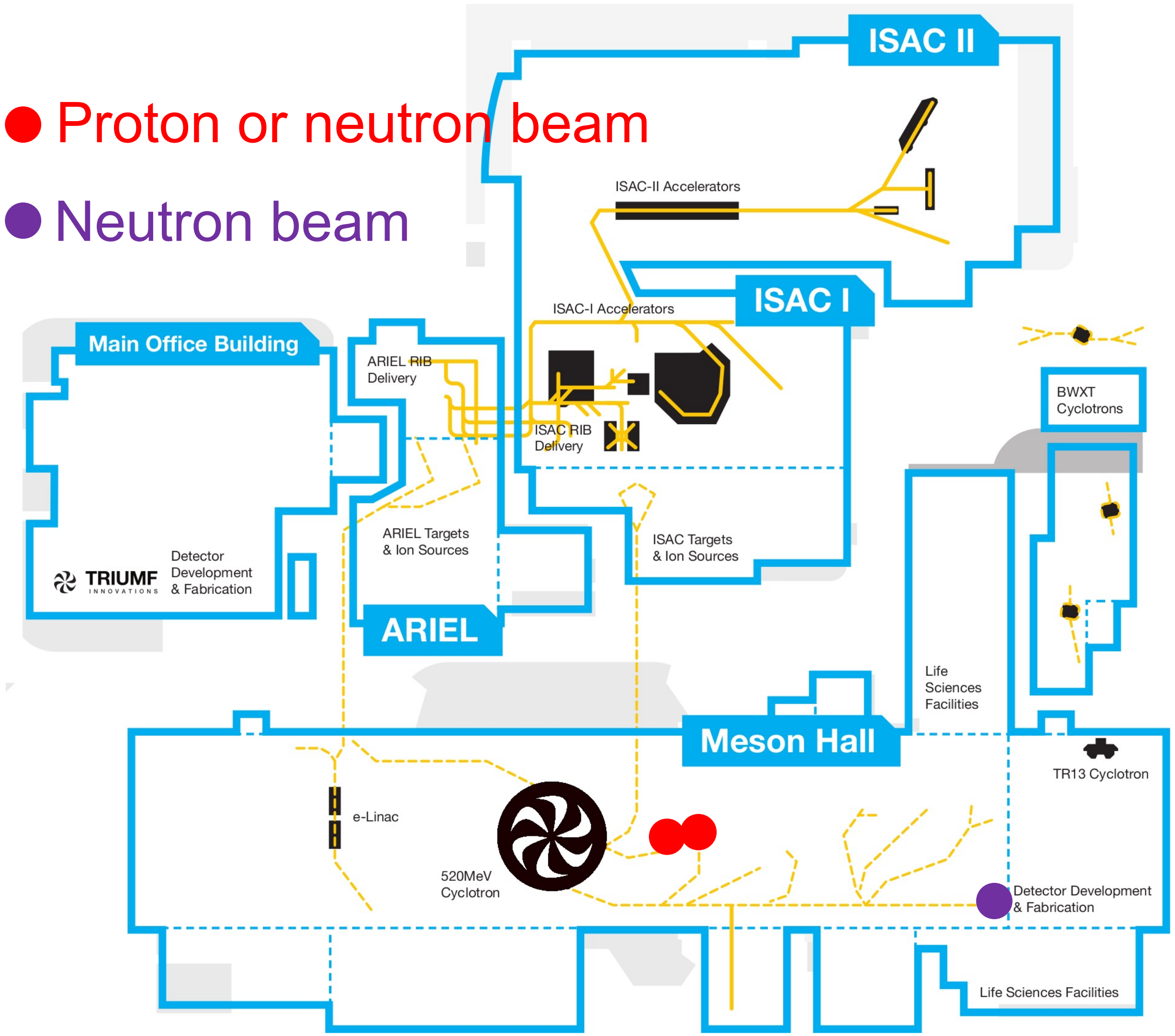


ChipIR at the ISIS Muon and Neutron Source at RAL



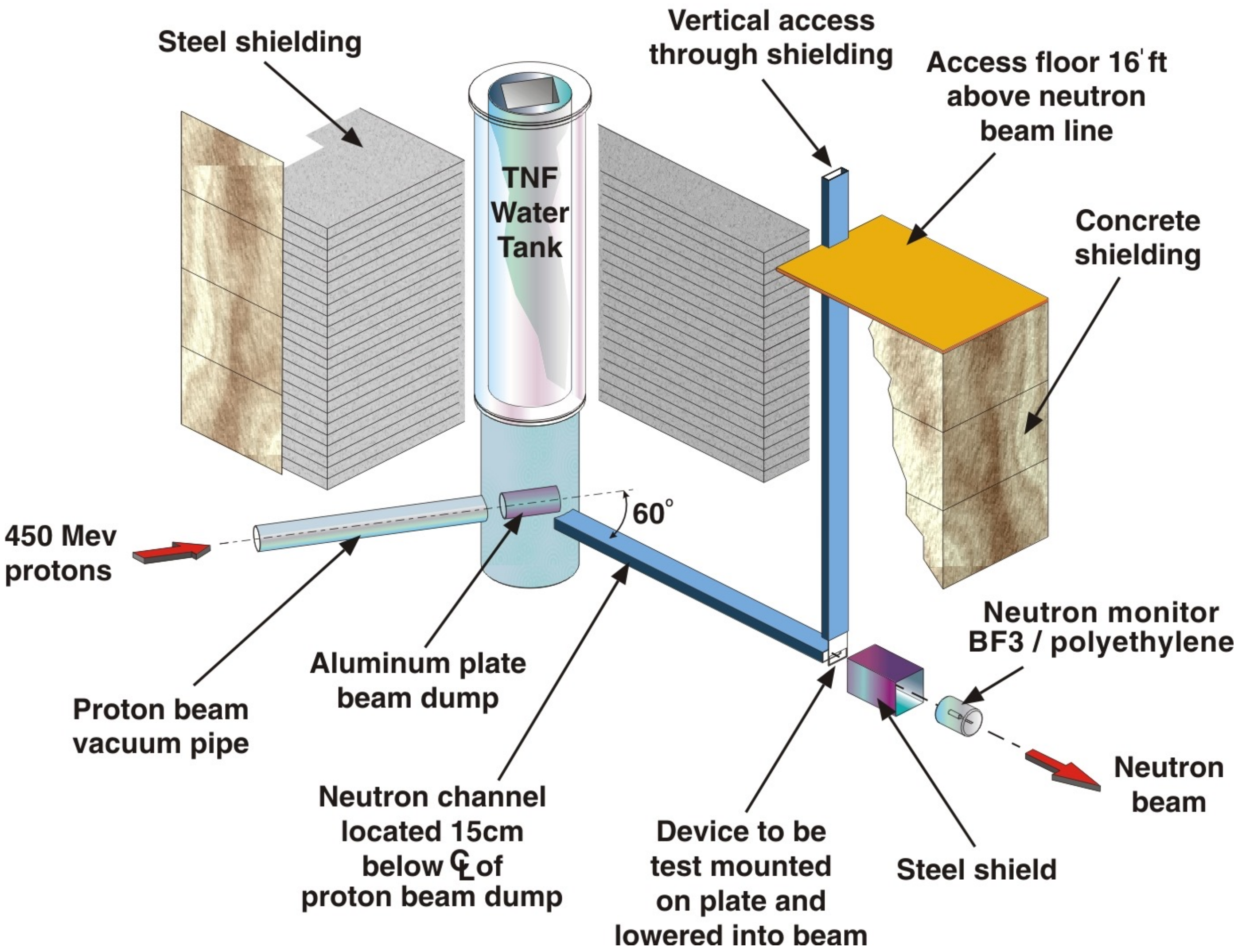
TRIUMF Proton and Neutron Irradiation Facilities

- H- cyclotron, extracted max proton energy: 520 MeV
- Typical operation:
  - 3 or 4 simultaneous beams extracted
  - Multiple energies 63 to 480 MeV
  - >200 μA total circulating beam
  - Continuous-wave beam
- Proton beams available for commercial radiation tests since 1995
- Neutrons beams since 2002

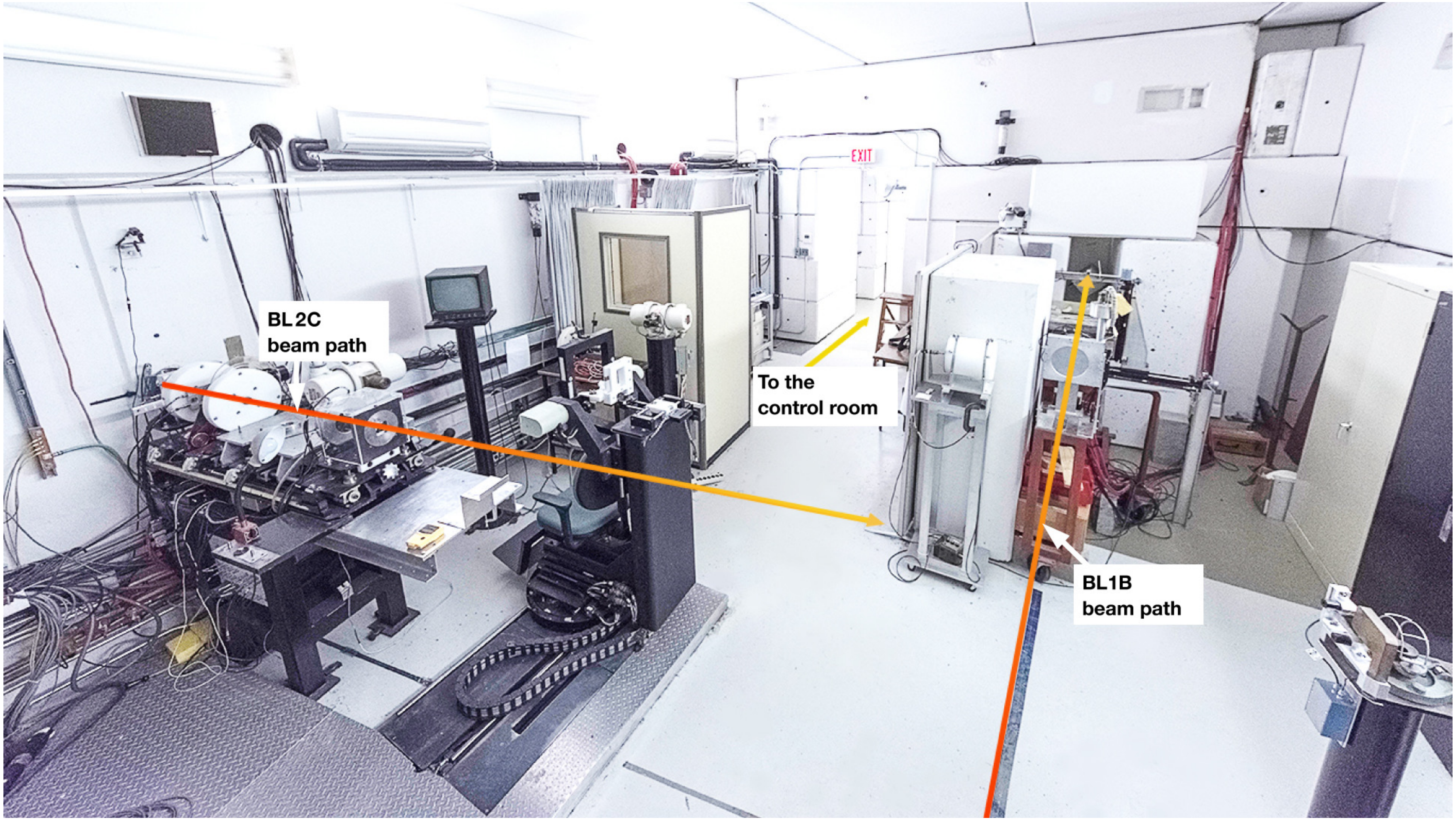


High-intensity neutron beam at TNF

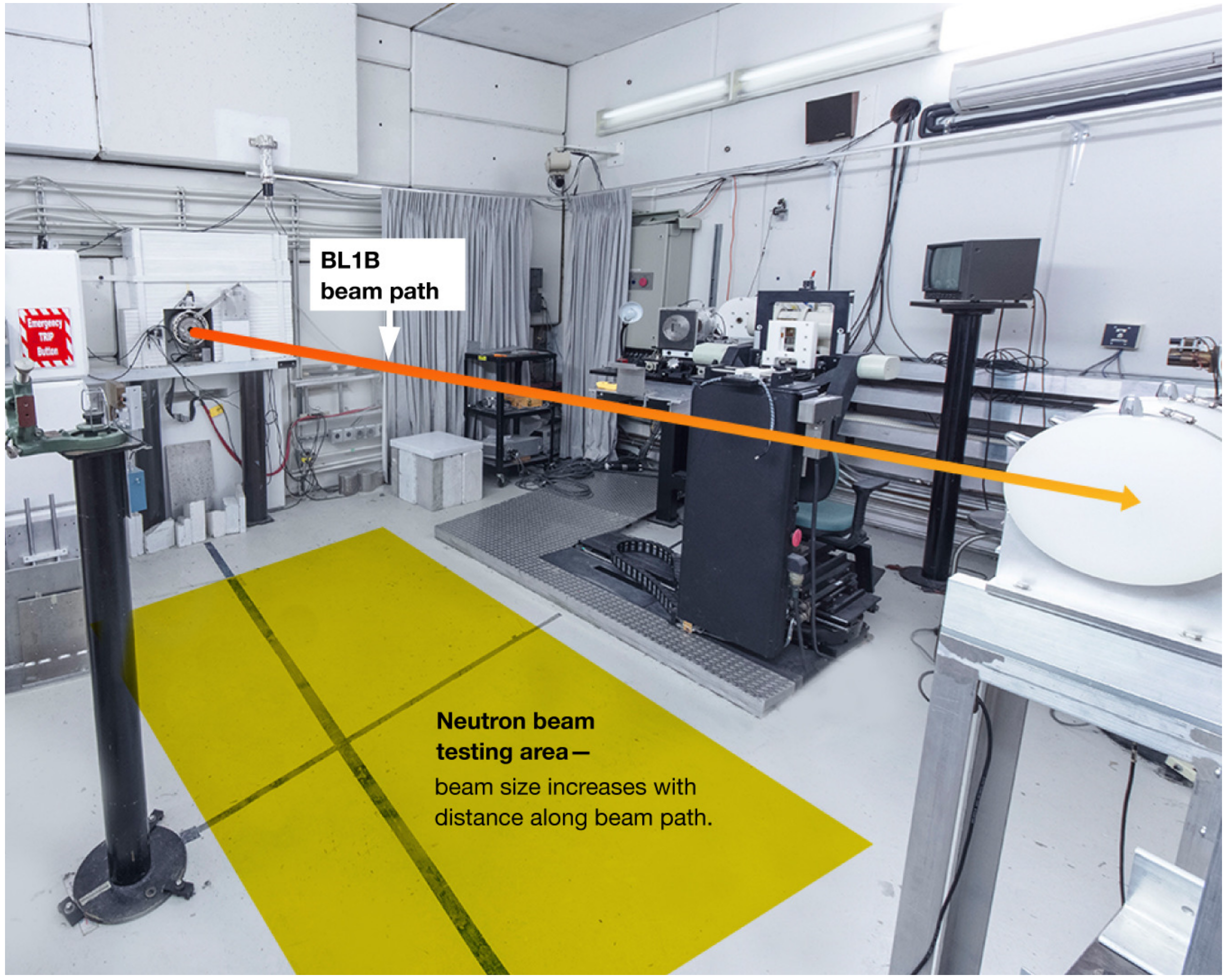
- Symbiotic operation with high-current beamline 1A, 420-450 MeV protons
- Neutrons created in the 1A beam dump (water-cooled aluminium)
- Flux fixed by 1A proton beam users, typically 2-3 x10^6 $n_{>10\ MeV}/cm^2/s$
- Fixed beam size 5 cm x 15 cm
- Narrow channel, trolley plate access
- 92 beam hours available through RADNEXT



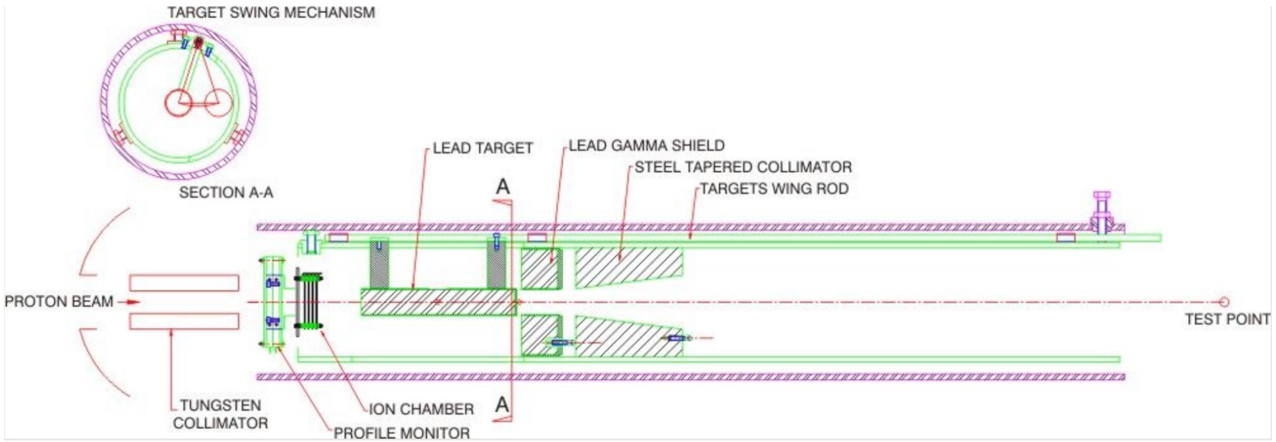
Main radiation test room – proton and neutron test beams



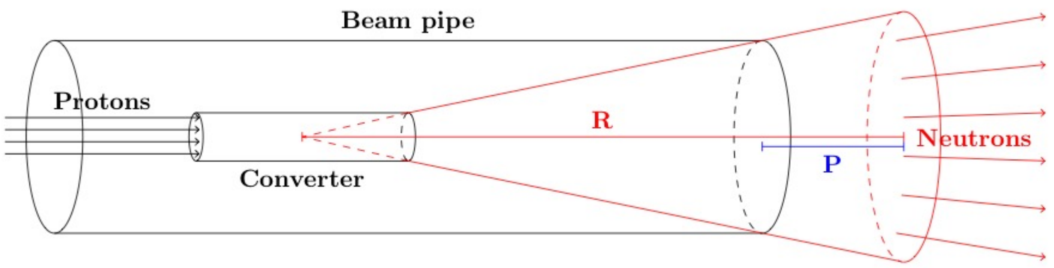
Beamline 1B – neutron mode



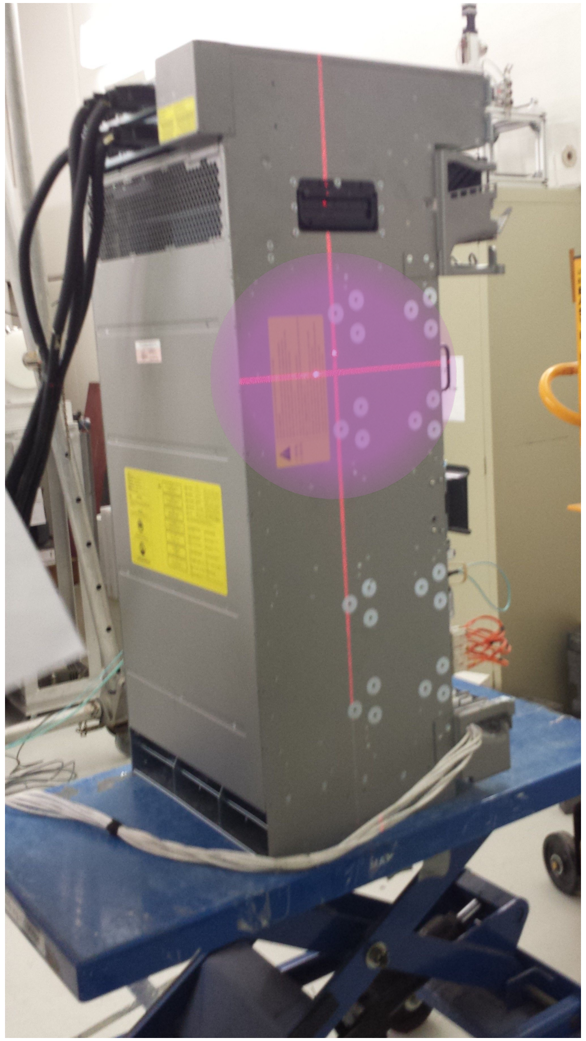
- Atmospheric-like neutron energy spectrum
- Neutron beam created by striking thick lead target with 480-MeV proton beam
- 120 beam hours available through RADNEXT



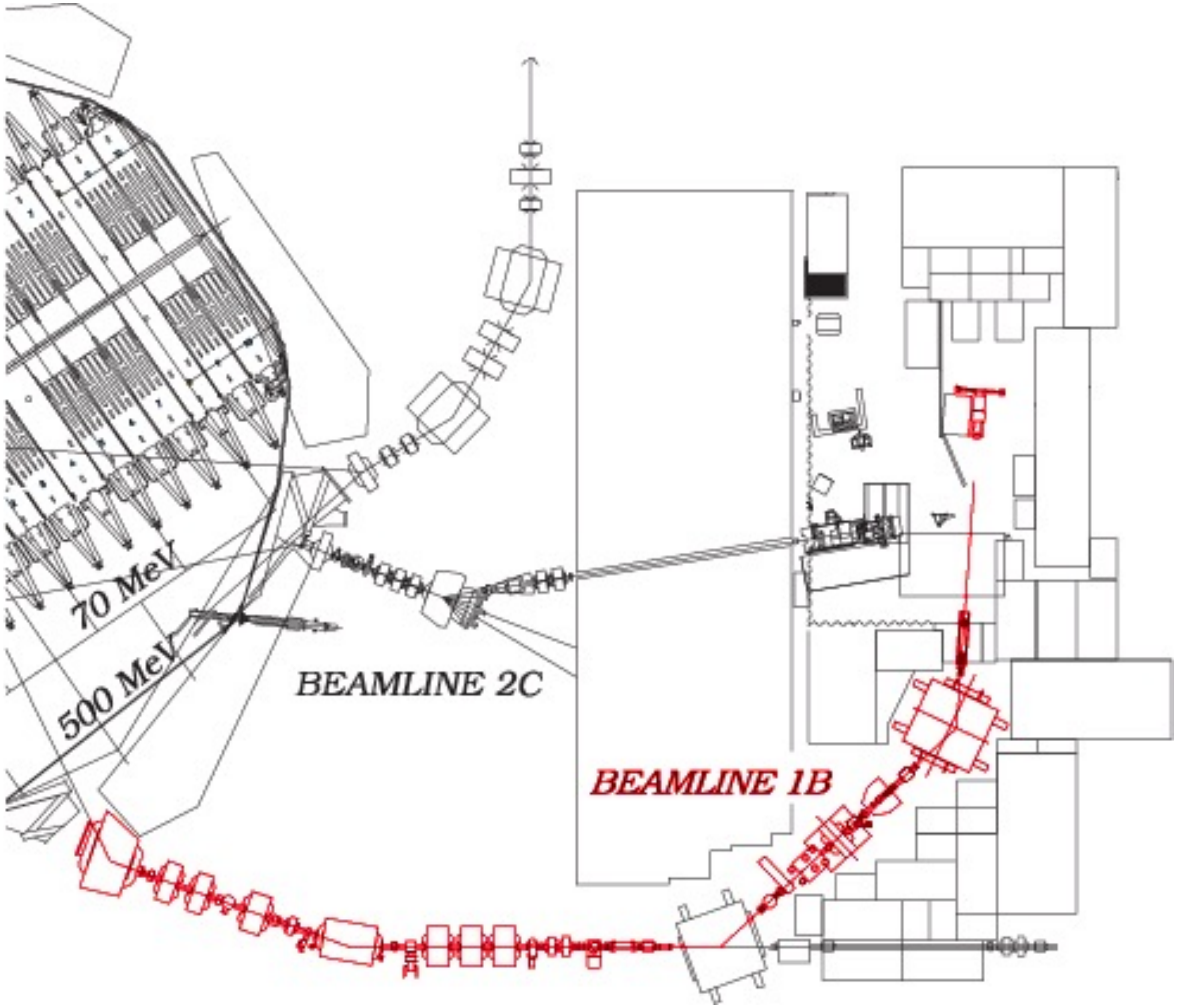
Beamline 1B – neutron mode



Distance from beam entrance in room (cm)	Beam diameter (cm)	Max neutron flux ($cm^{-2}s^{-1}$)
4	16	5.2×10^5
104	32	1.3×10^5
204	48	5.6×10^4
354	72	2.6×10^4

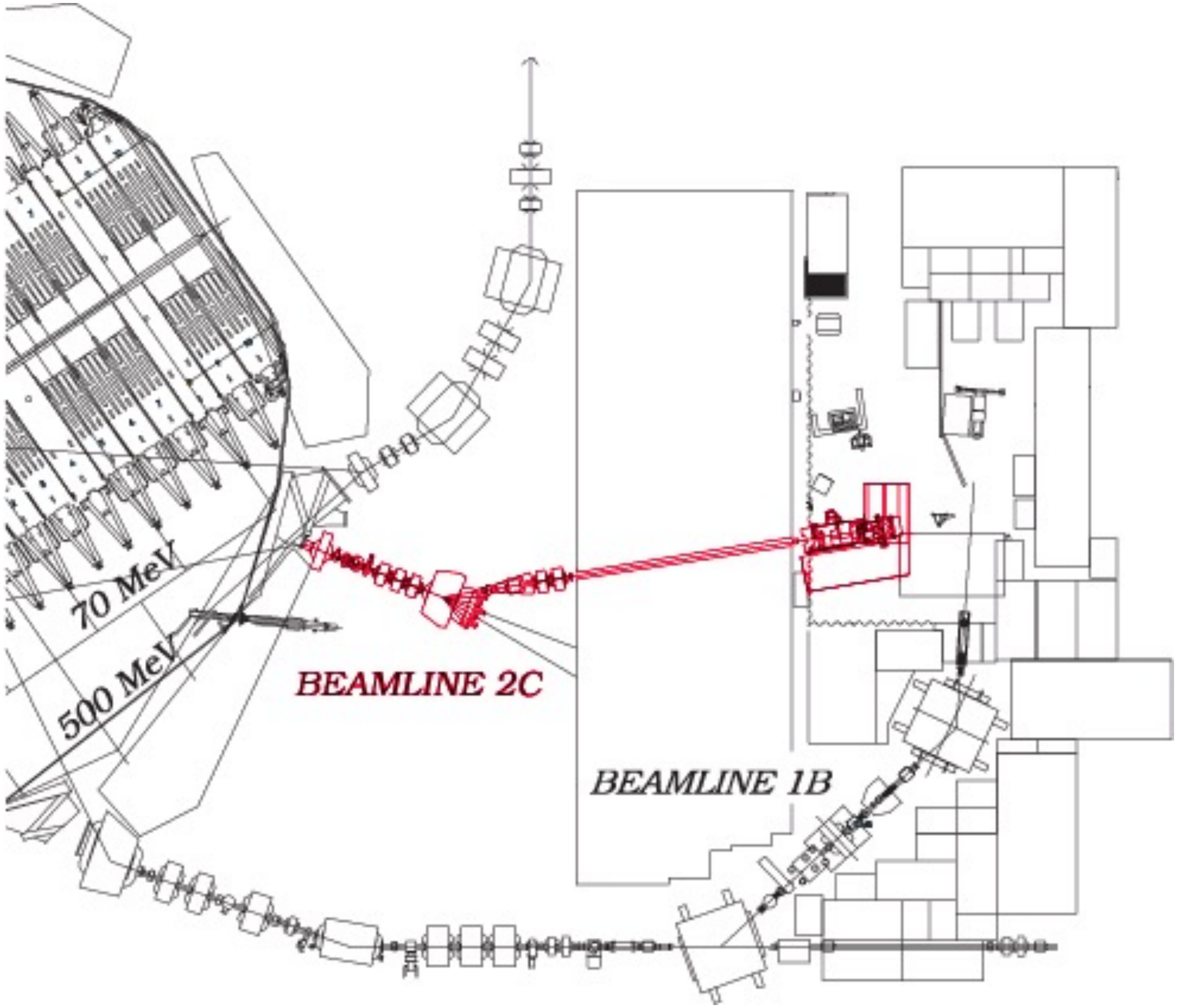


Proton testing on beamline 1B



- 2 standard extracted proton energies:
  - 480 MeV (preferred)
  - 355 MeV
- Max proton flux approx. $4x10^7$ p/cm^2/s
  - Flux adjustable down to 10^2 p/cm^2/s, by user request to cyclotron control room
- Max beam size at standard location
  - 7.5 cm x 7.5 cm
- No degrader capability, limited collimation options: highly penetrative beam

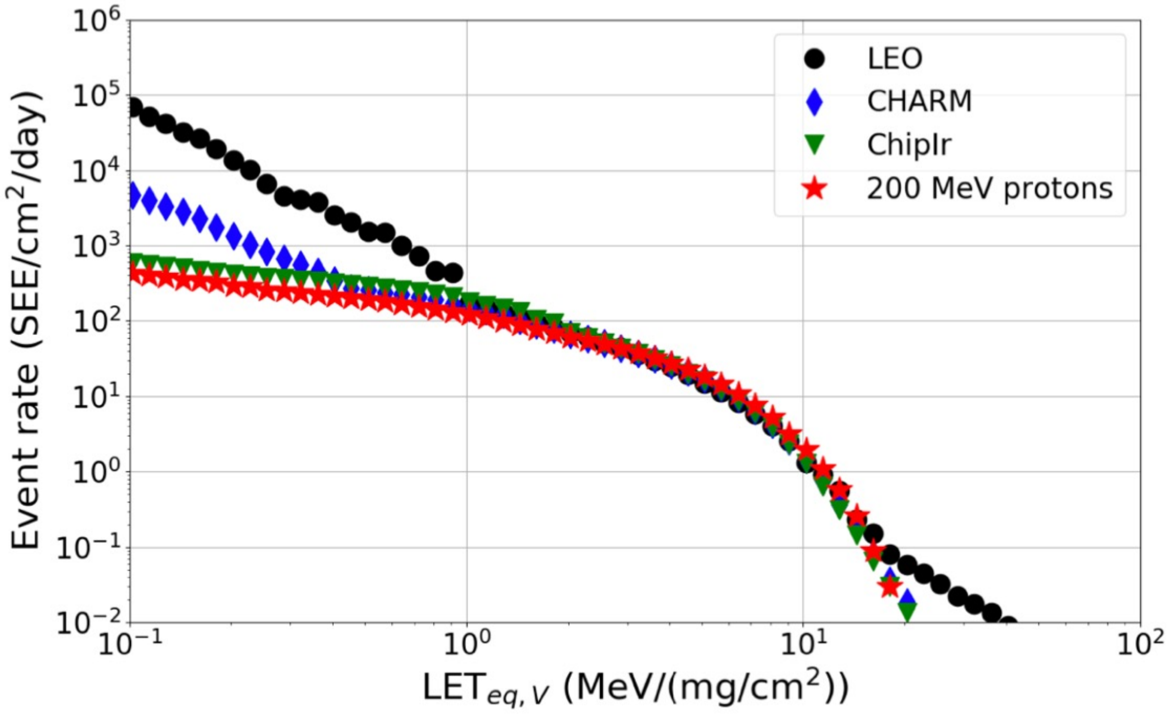
Proton testing on beamline 2C1



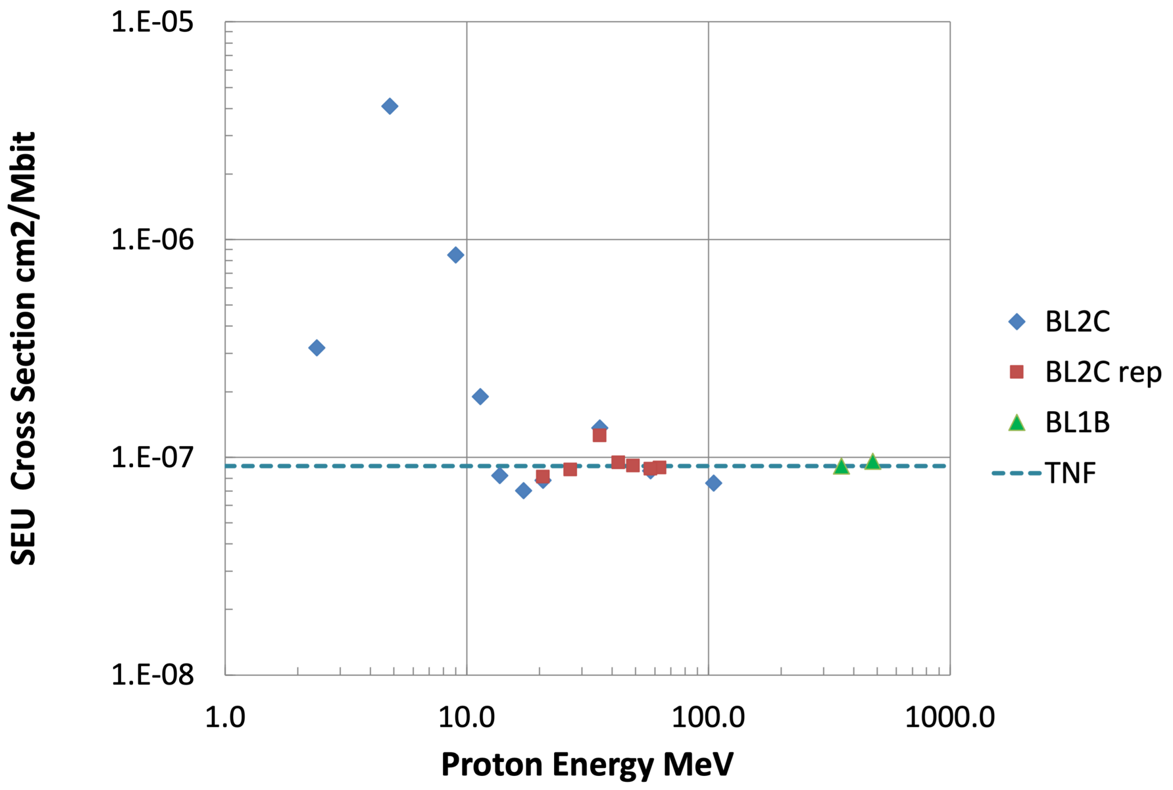
- Initially developed for proton radiotherapy
  - Ocular melanoma cancer treatments
  - Clinical treatments 1995-2018
- 2 standard extracted proton energies:
  - 63 MeV
  - 105 MeV
- Remote-controlled continuous-energy degrader system down to ~15 MeV
- Max proton flux approx. 1×10^8 p/cm^2/s
  - Flux adjustable down to 10^2 p/cm^2/s, by user request to cyclotron control room
- Max beam size at standard location
  - 5 cm x 5 cm
  - 7.5 cm diameter
- Beam parameters highly customizable (size, energy, flux) to support testing for a wide range of applications

Proton beams to support neutron beam testing

- In proton beams of sufficient energy (> 50 MeV), the overlap in available nuclear reaction processes means mono-energetic proton beams can be substituted to broad spectrum neutron beams for certain tasks



Source: A. Coronetti et al. *TNS* 68, no 5 (2021) 958



- Allows faster screening of individual components with good accuracy, increasing confidence that system-level test will be successful

Summary

- Main source of SEEs in avionics and aerospace applications are neutrons created in atmospheric cascades
- Spallation neutron facilities like ChipIr and TRIUMF provide broad-spectrum neutron beams with excellent energy spectrum matching for electronics testing and qualification
- Acceleration factors as high as 10^9
- Spallation neutron facilities have dedicated areas for electronics testing and expert support staff

- Muons are also present in abundance in atmospheric showers
- Low LET - low likelihood to create SEEs
- Interest in electronics testing with muons beams mostly driven by academic groups, understanding of basic mechanisms of radiation effects
- Facility capability exists, but no dedicated infrastructure like what exists for other types of test beams