# The Bern medical cyclotron as a facility for radiation hardness studies

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SiPM Radiation: Quantifying Light for Nuclear, Space and Medical Instruments under Harsh Radiation Conditions

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# Outline

- The Bern medical cyclotron and its beam transfer line.
- The Bern cyclotron as an irradiation facility.
- Production of controlled neutron beams.

The Bern medical cyclotron and its beam transfer line.

# A machine for production of radiopharmaceuticals… And for research!

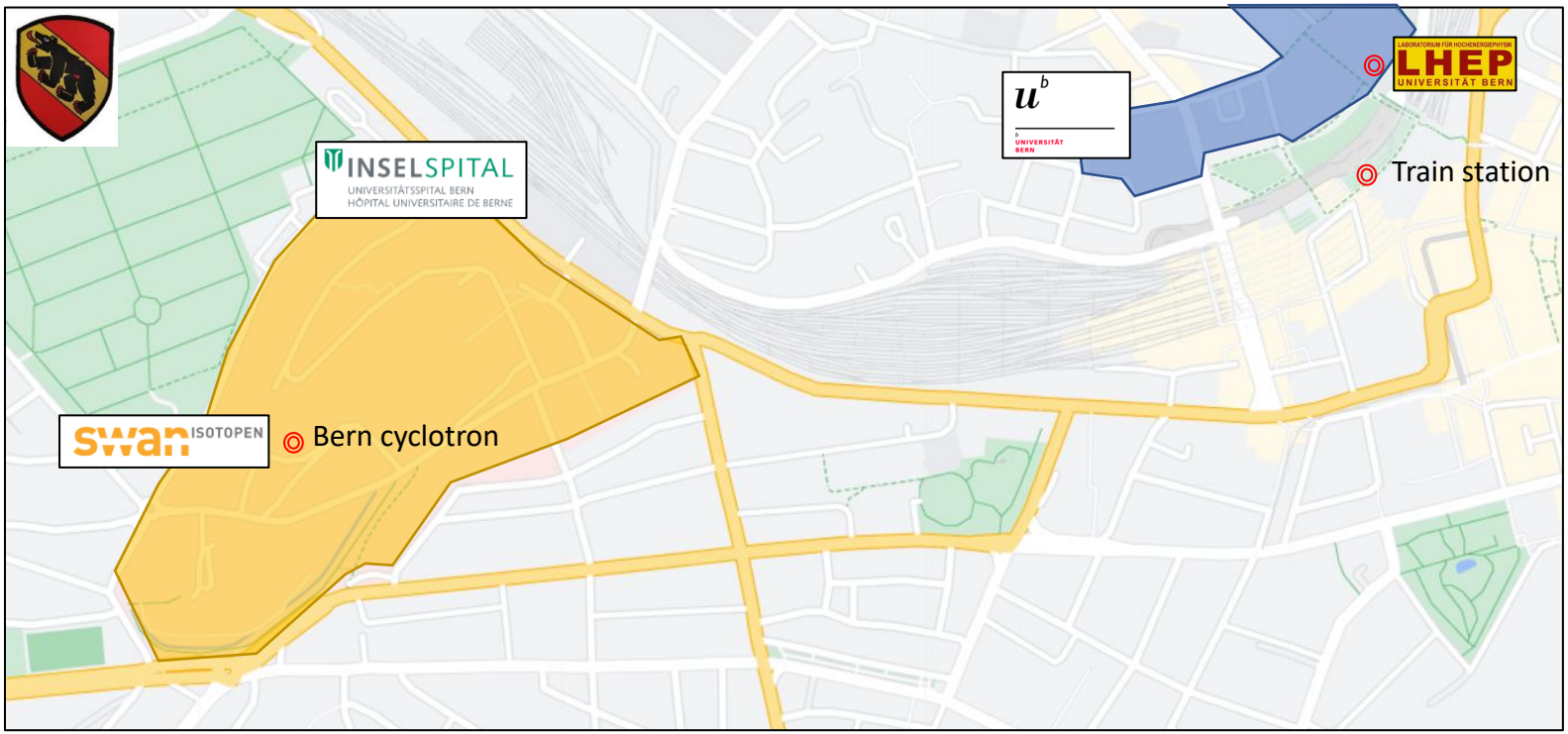
SWAN Isotopen AG

Commercial production of radiophamaceuticals (overnight).

Laboratory for High-Energy Physics (LHEP)

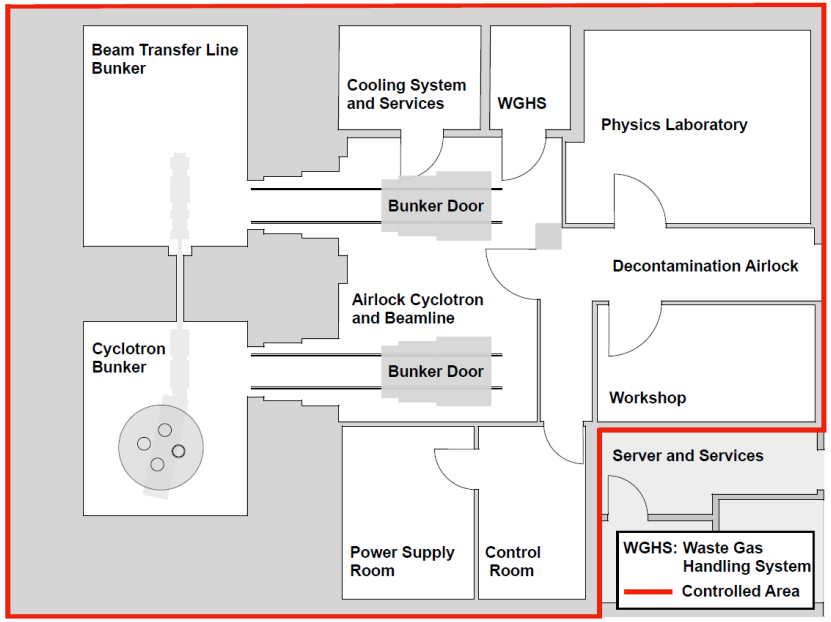
Research and Development (daytime):

- Medical applications.
- Beam monitoring.
- **Radiation hardness studies.**
- Collaborations with CERN, ESA, PSI, TRIUMF…



# The facility

- 2 bunker structure with a dedicated Beam Transfer Line (BTL) to transport the beam from the Cyclotron bunker to the adjacent bunker.
  - Fully dedicated to research activities.
  - Shielding from highly radioactive environment in the cyclotron bunker.
- Physics laboratory, within the Radiation Controlled area, hosts data acquisition systems for active irradiations and post-irradiation studies.
  - Avoiding shipping of radioactive material.
  - Minimizing annealing on irradiated samples.

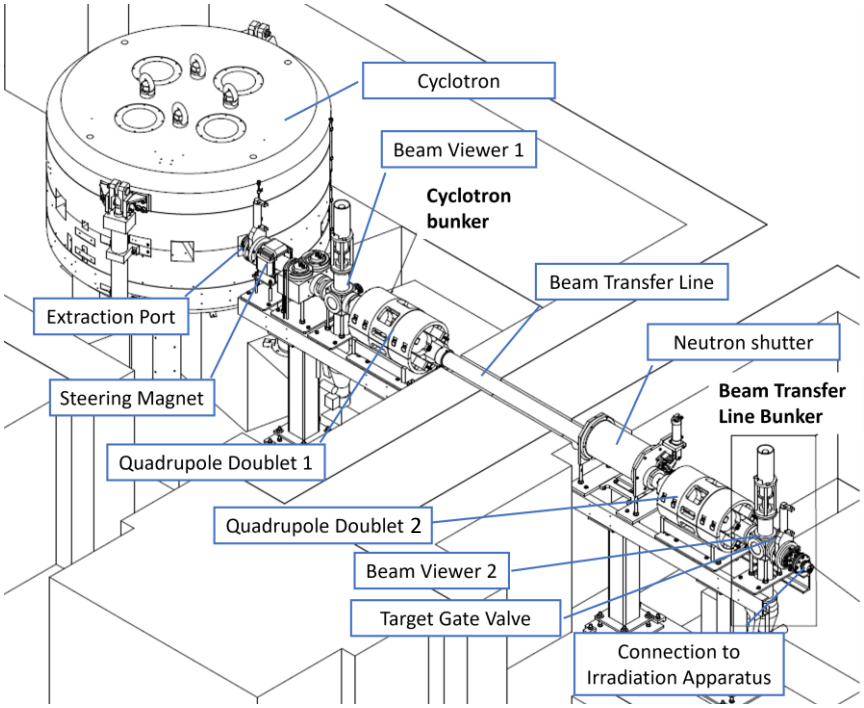


# The cyclotron

- Cyclone 18/18 from IBA - Radiopharma Solutions.
- Accelerates $H^-$ ions to 18 MeV.
- Proton extraction after electron stripping.
- Beam current up to 150 µA.
- 8 extraction ports (1 dedicated to the BTL).

# The Beam Transfer Line.

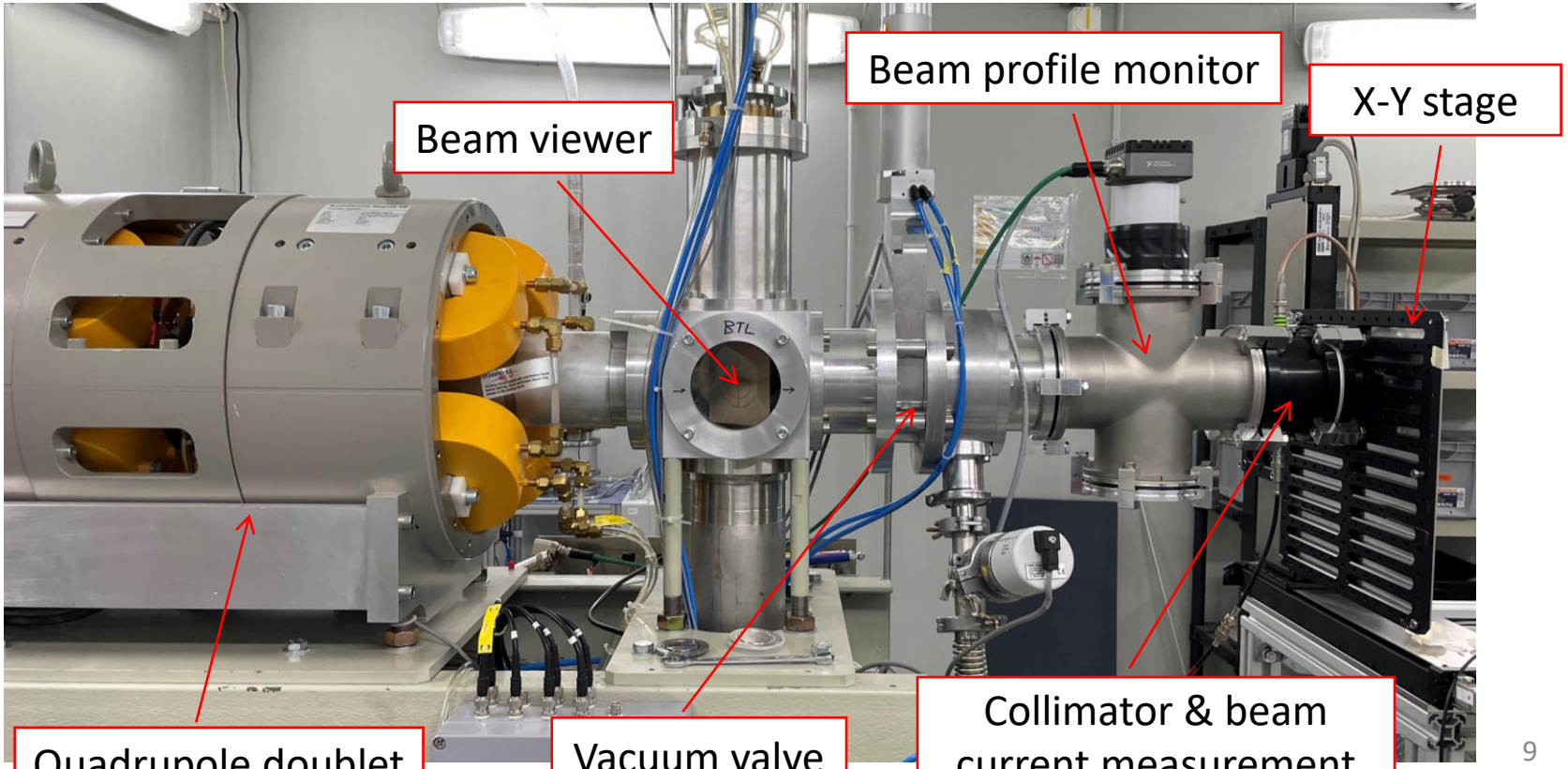
- 6.5 m long beamline.
- 1 dipole doublet for horizontal/vertical steering.
- 2 quadrupole doublets for focusing.
- Neutron shutter to stop neutron flux during radiopharmaceutical production.
- 2 beam viewers provide a destructive beam current measurement.




# The cyclotron as an irradiation facility.

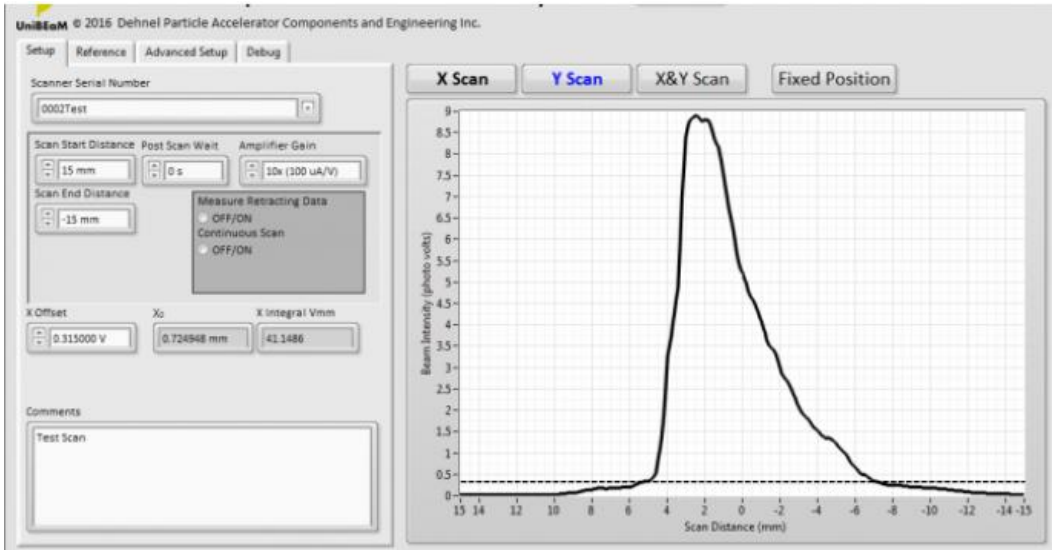
# Irradiation setup

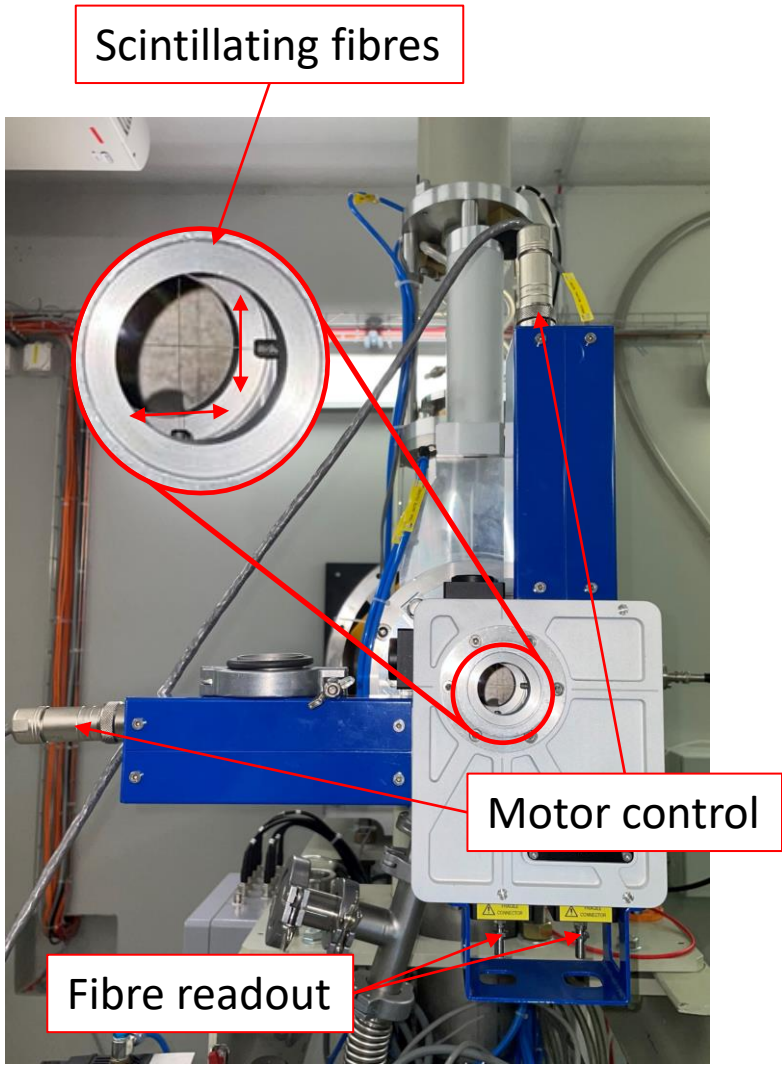
- 2nd quadrupole doublet switched off to obtain a quasi-uniform beam profile.
- Irradiations typically performed in air.
  - 300 um Al extraction window – Extracted energy: 16.7 ± 0.5 MeV
- Different collimators available (from 1x1 $cm^2$ to 3x3 $cm^2$).
- Adjustable proton flux ($10^9$ – $10^{12}$ $p/cm^2/s$).



# Beam profile monitoring - UniBEaM

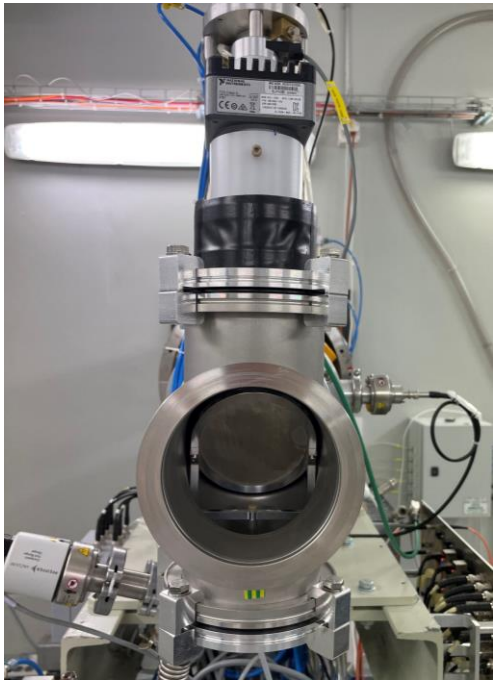
- Based on scintillating cerium-doped silica fibers scanning the beam to obtain the horizontal and vertical beam profile projections.
- Developed at LHEP and commercialized by D-PACE under license from University of Bern.

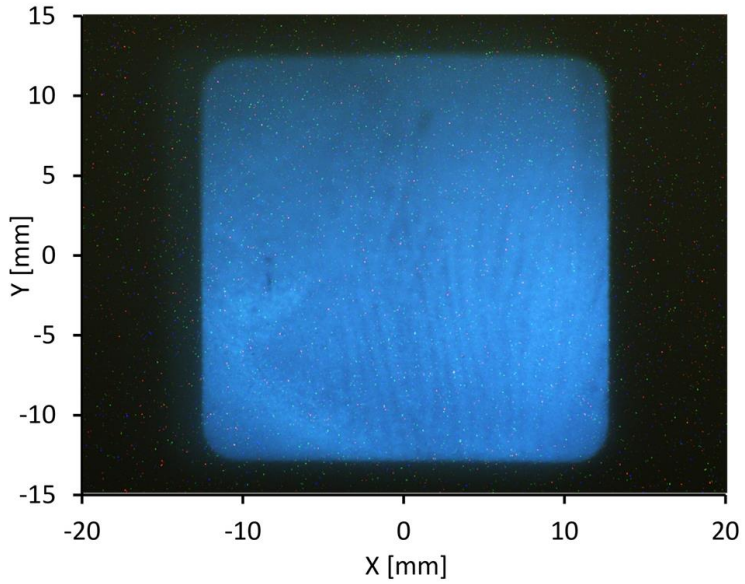


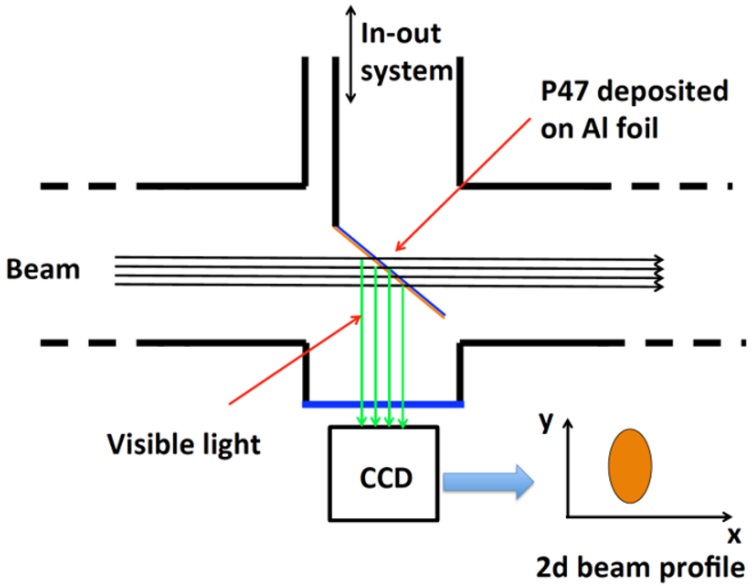



# Beam profile monitoring - $\pi^2$

- 15 µm thick Al foil coated with P47 scintillating compound, placed at 45° with respect to the beam.
- Beam image recorded with commercial camera.
- Recorded image is processed to correct for perspective effects.

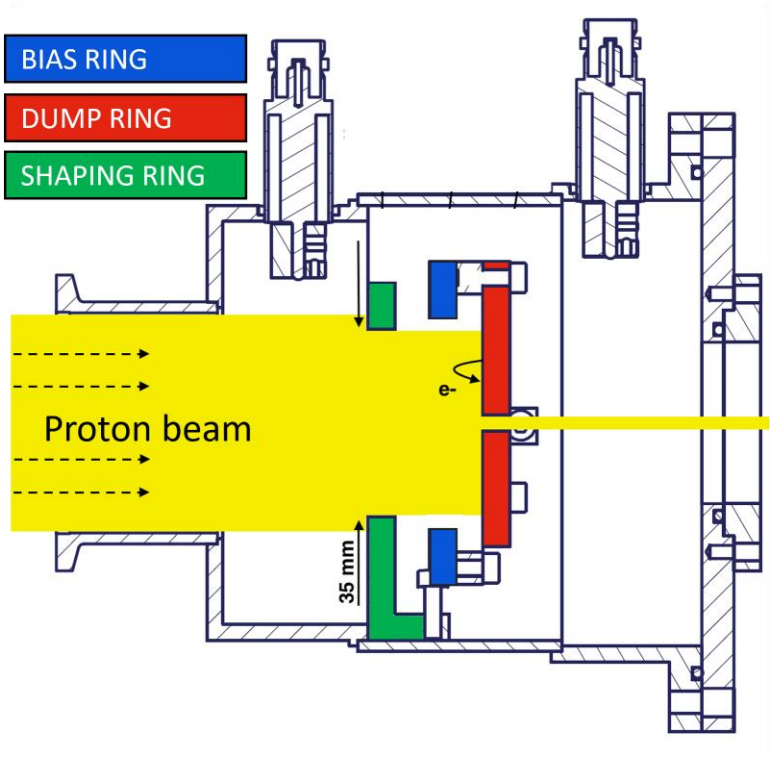


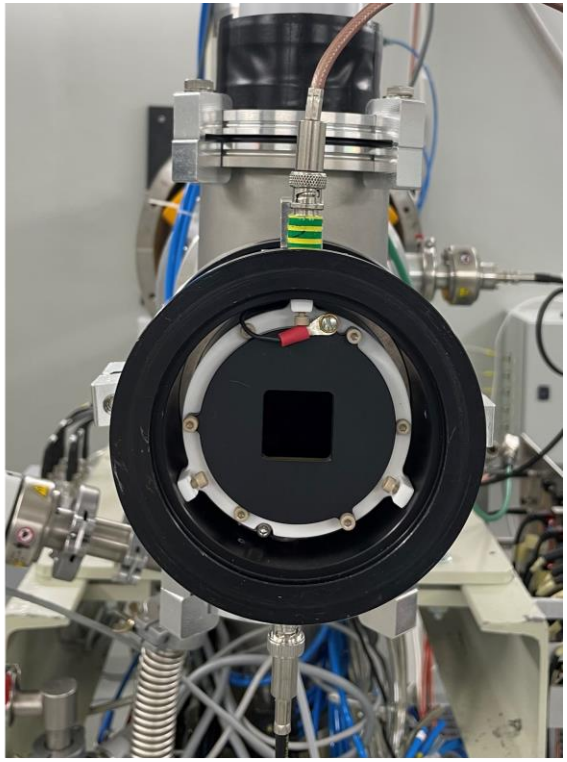


# Beam current measurement

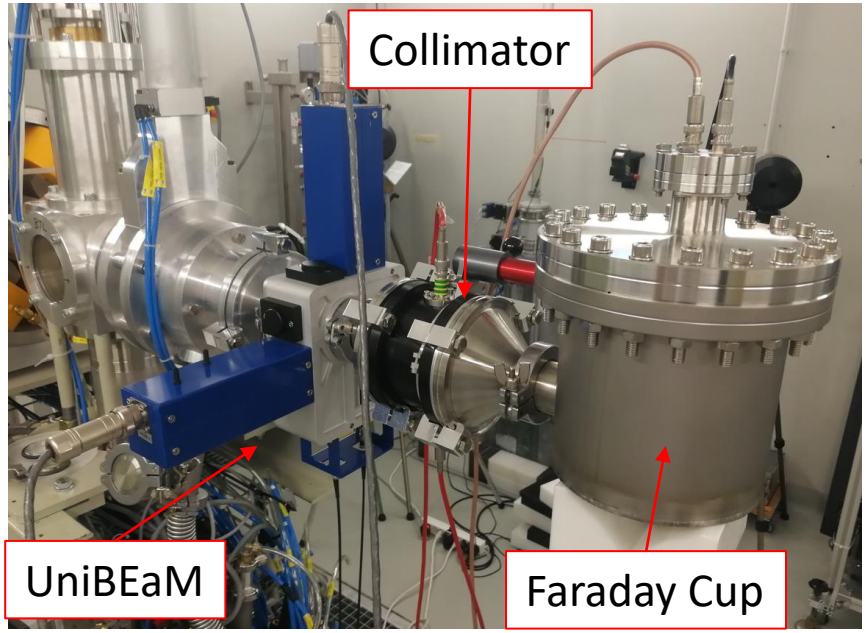
- Collimator used as beam current monitor`.
- Current dumped on the collimator, combined with beam profile, used to infer extracted proton flux.
- Biasing electrode to prevent secondary electron emission.

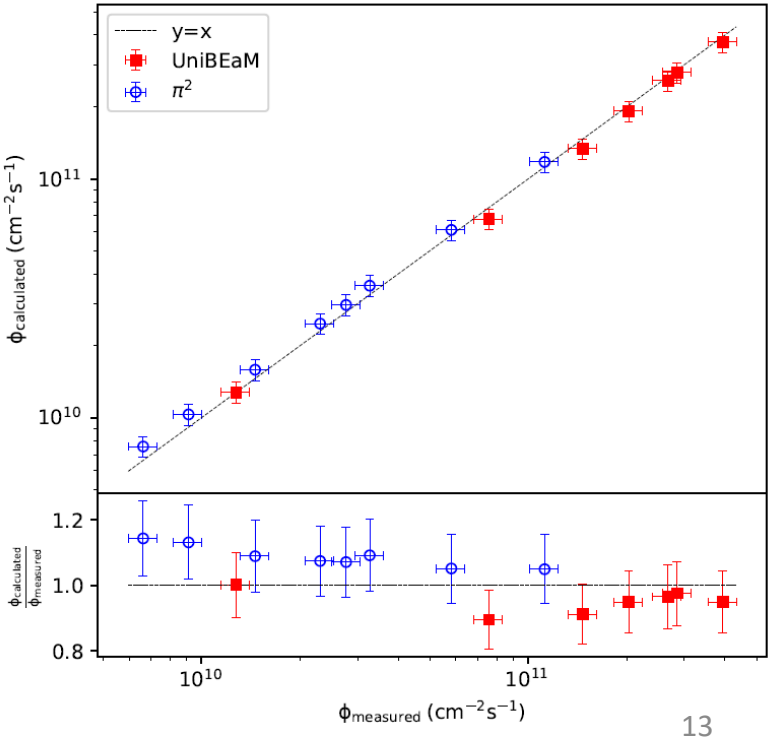


# Irradiation setup validation

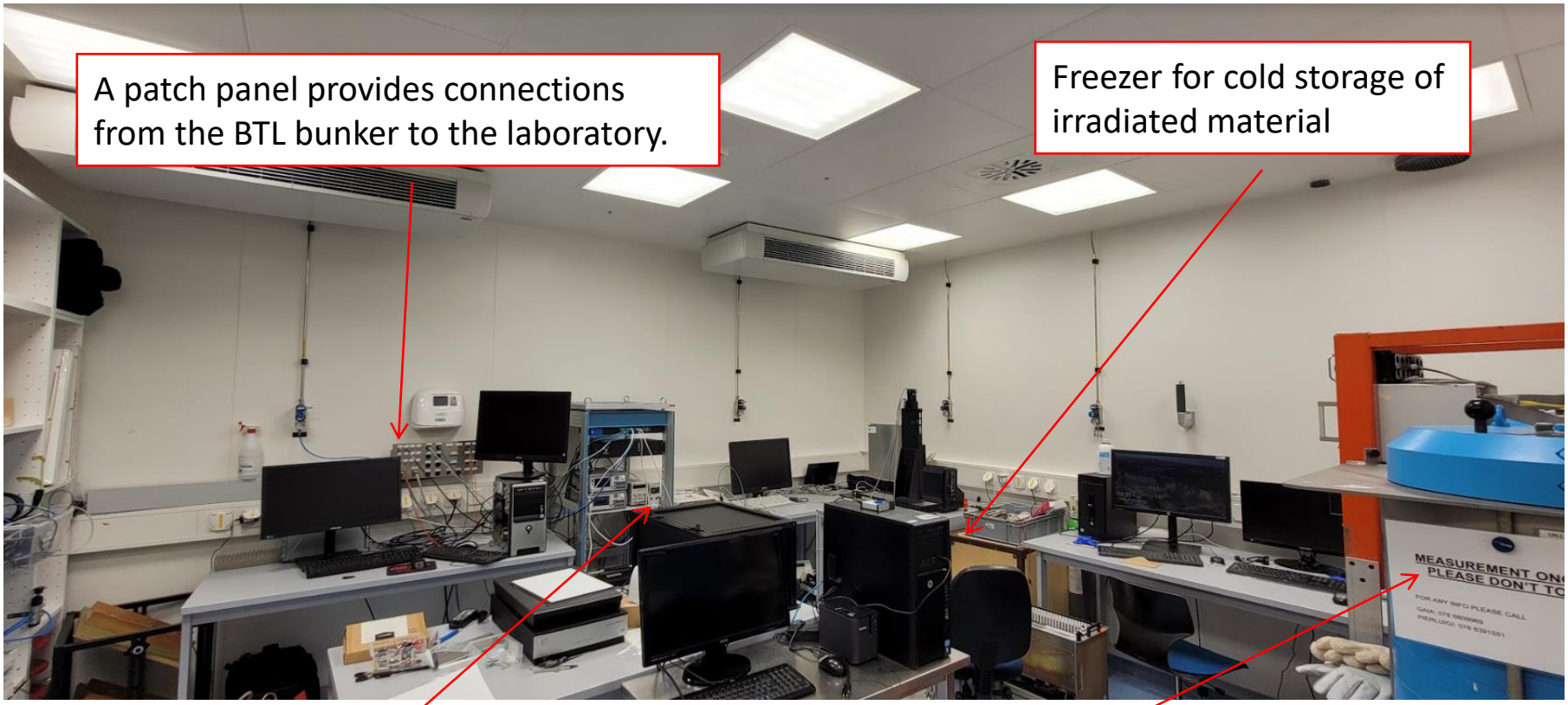
- Faraday Cup downstream of irradiation setup to validate the proton flux measured using the beam profile monitor and the collimator.
- Agreement within 10% for a proton flux ranging from $5 \times 10^9$ p/cm$^2$/s to $4 \times 10^{11}$ p/cm$^2$/s.
- Validated using both the Pi-2 and the UniBEaM.



# The Physics laboratory

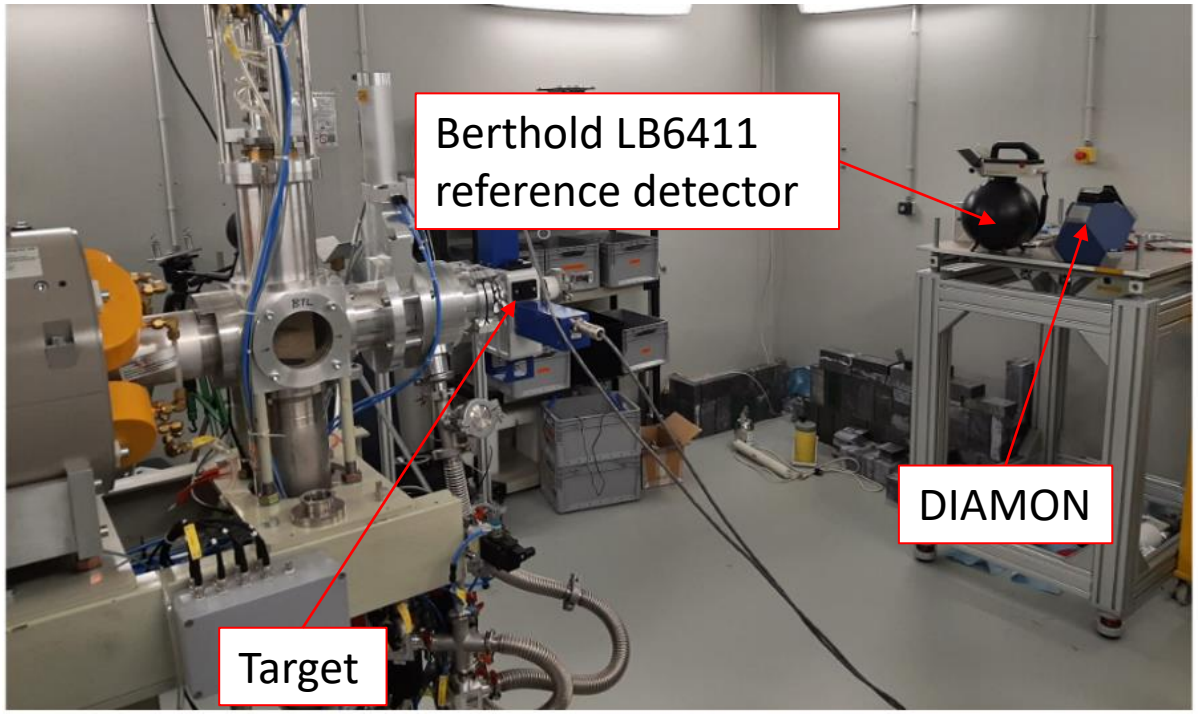
Dedicated laboratory to host Data Acquisition equipment during active irradiations or post-irradiation studies.



# Production of controlled neutron beams.

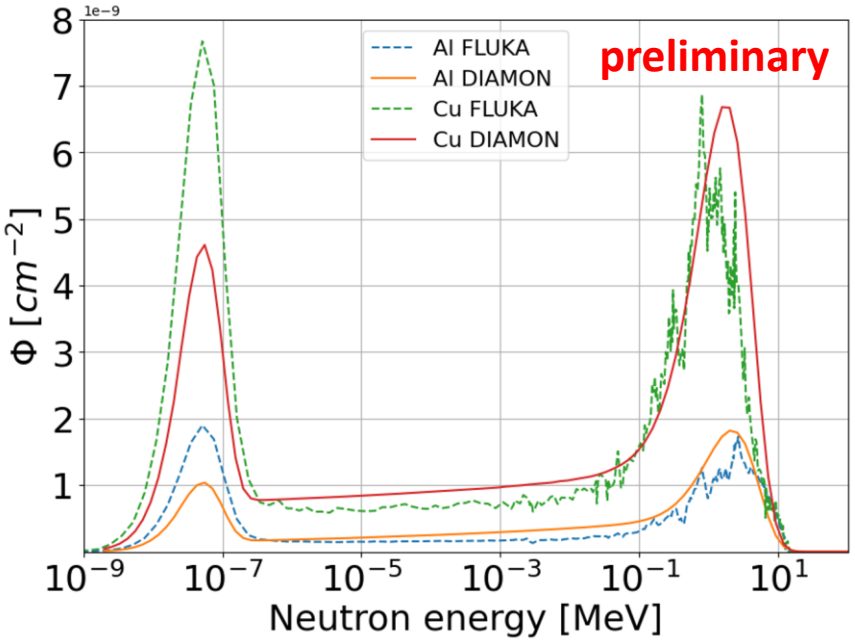
# Project overview

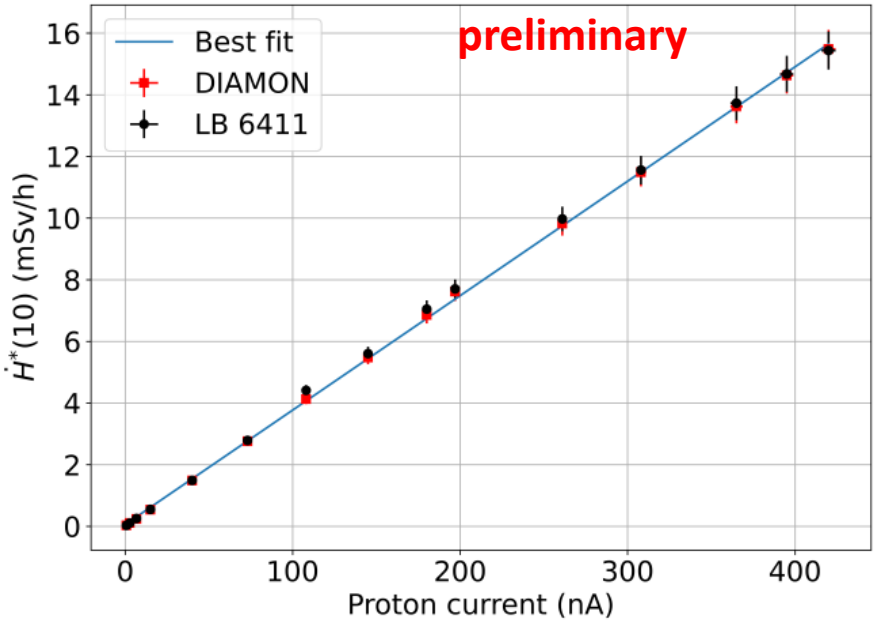
- R&D project aiming at generating a controlled neutron beam using converter targets at the end of the BTL.
- Ongoing work on the characterization of the neutron spectrum using different target materials.
- DIAMON neutron spectrometer used for this study.



# Status

- Validated DIAMON detector
  - Neutron spectra are consistent with FLUKA simulations.
  - Dose rate measurements are comparable to well-established reference detector (Berthold LB 6411).
- Neutron flux of the order of ~$10^{-9}$ n/cm$^2$/primary can be achieved. Potentially higher with further development.
  - Reduction of distance from target to detector.



# Conclusions

- Bern medical cyclotron available as a 18 MeV proton irradiation facility for radiation hardness studies.
- Well established irradiation setup, able to deliver a well controlled proton flux in the $10^9 – 10^{12}$ p/cm$^2$/s range.
- Laboratory for post-irradiation characterization available on-site.
- Ongoing R&D to also produce controlled neutron beams in the facility.
- For more details about the irradiation facility, see our publication in JINST (in print).
- **Collaborations are welcome!** If interested in performing an irradiation, please contact saverio.braccini@lhep.unibe.ch or isidro.mateu@lhep.unibe.ch.

# Thank you for your attention!

# Published work on past irradiation campaigns.

- High-Voltage CMOS sensors for the ATLAS HL-LHC upgrade.
- Qualification of materials for the data transmission system of the ATLAS ITk pixel upgrade.
- Testing of resistors for ESA's JUICE mission.
- Radiation effects on optical windows for GEM-based detectors.