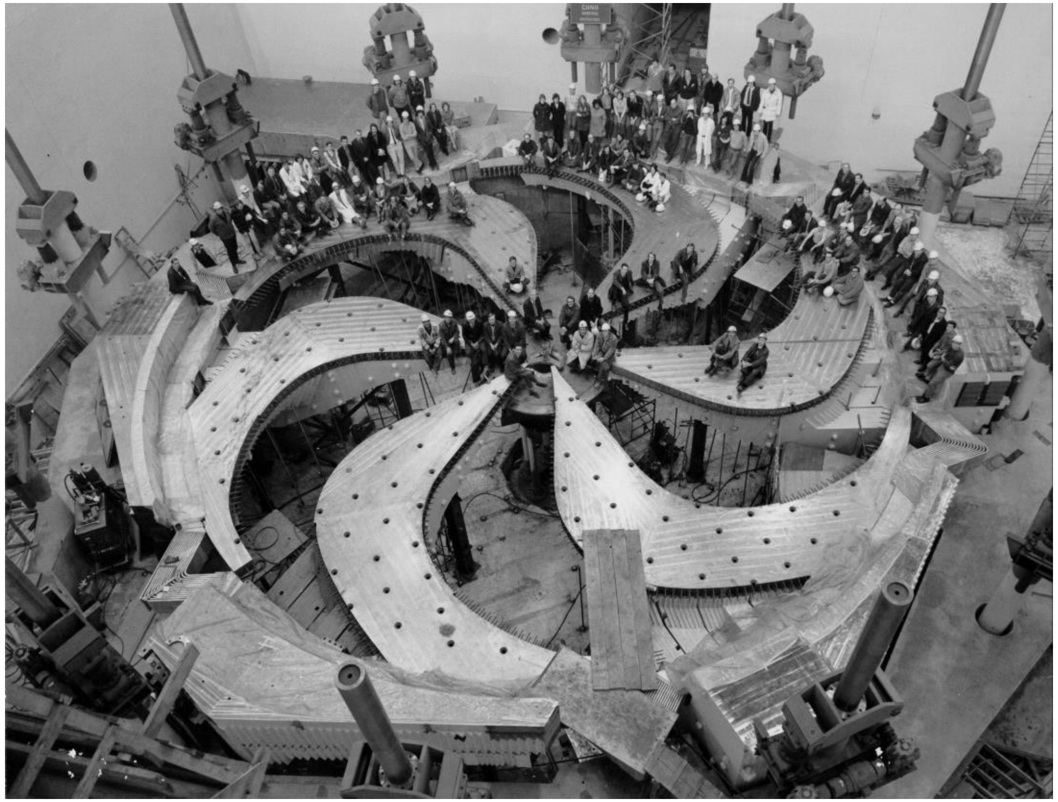
TRIUMF

Improved isotope intensity and purity from a new spallation-driven proton-to-neutron converter at ISAC-TRIUMF

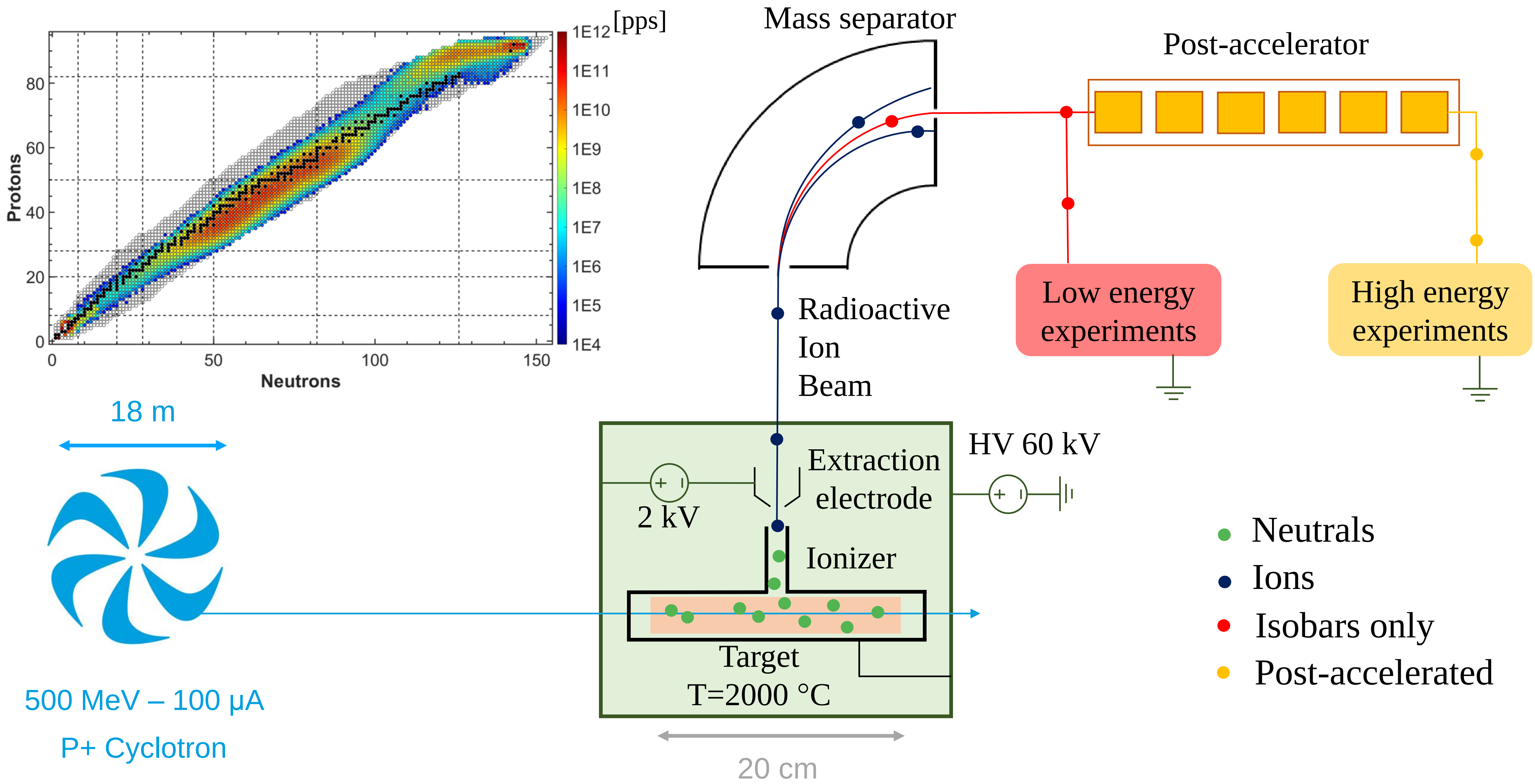
Luca Egoriti

PhD Student

EMIS19 – October 3rd, 2022

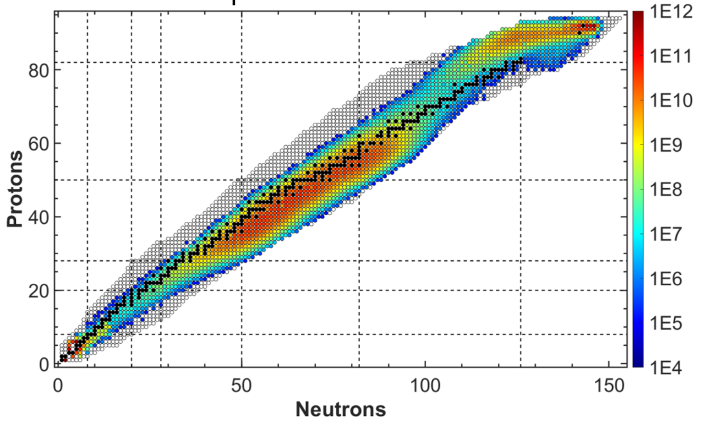


ISOL targets for RIB production

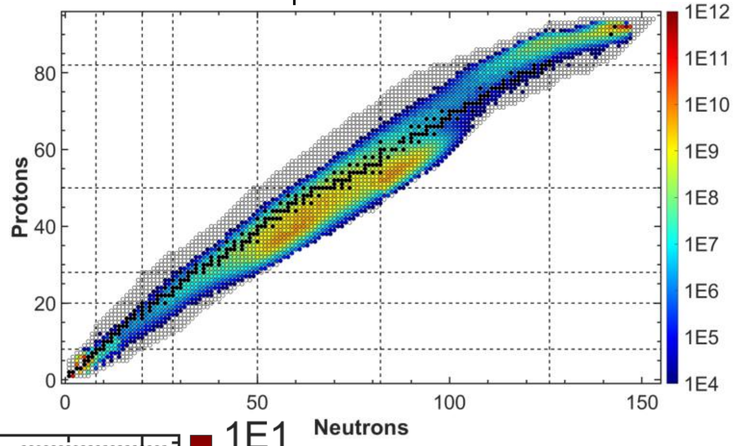


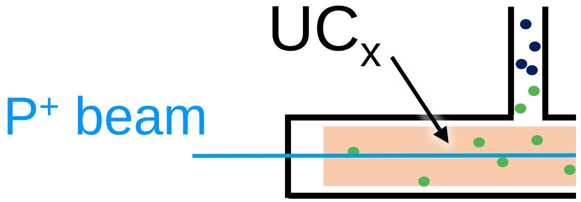
Conventional ISAC and Converter concepts

I_p = 20 μA

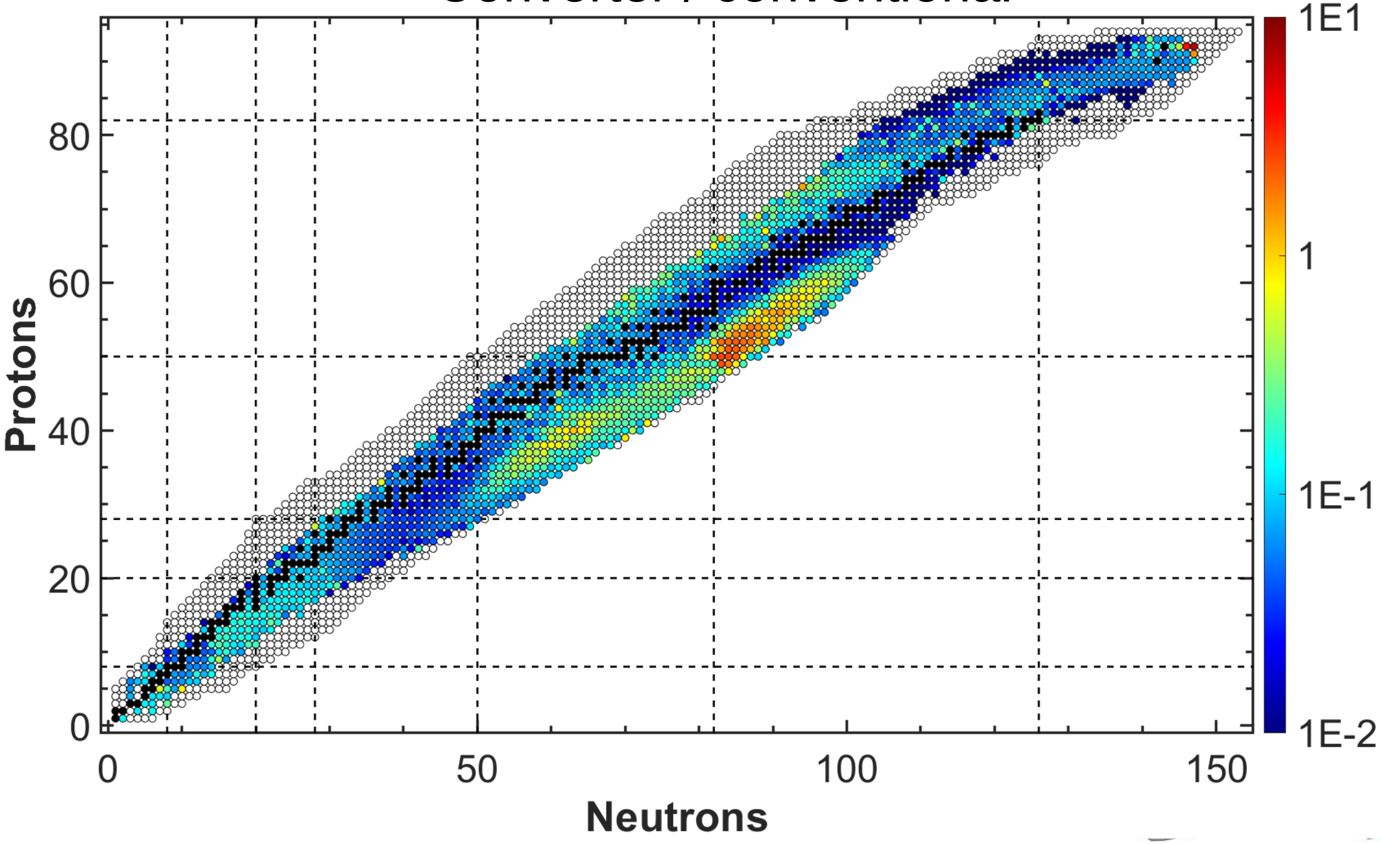


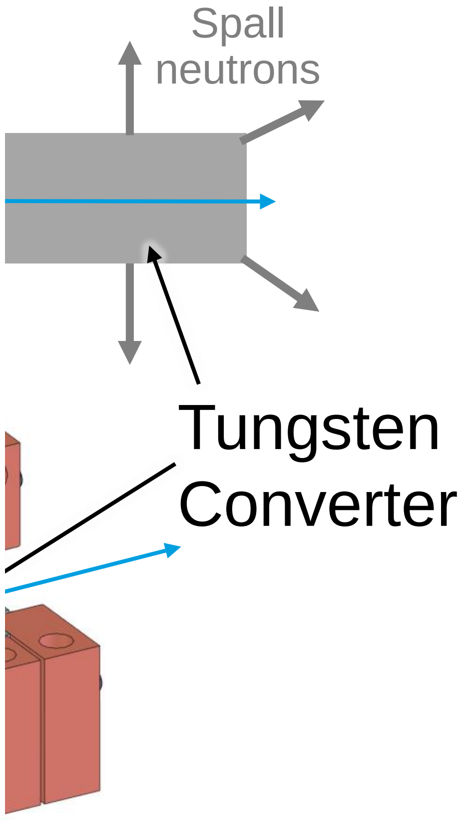
I_p = 100 μA





Converter / conventional



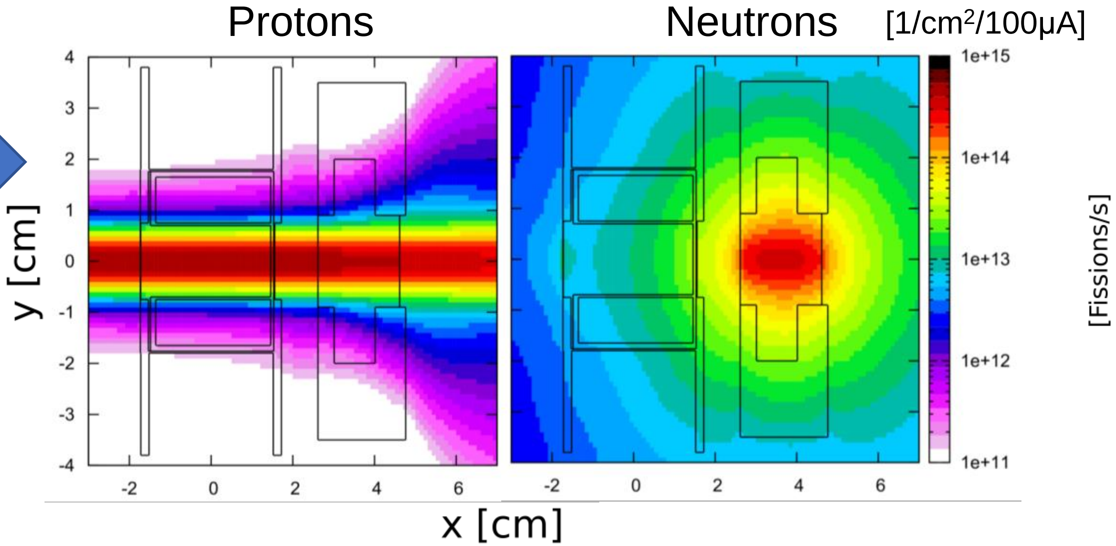


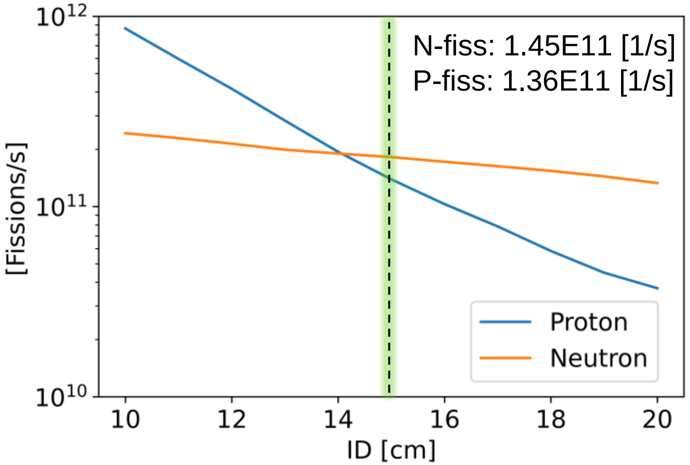
Target optimization

Optimization:
Leg shape
UC_x inner diameter
UC_x outer diameter

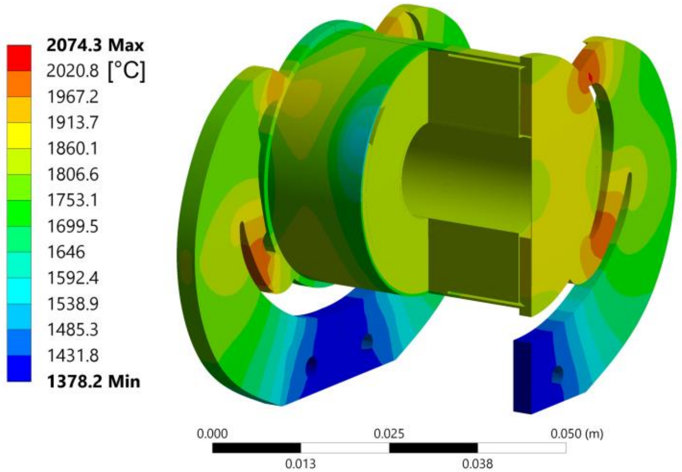
Principle:
Physics design
↕
Numerical validation (MC, multiphysics)
↕
Engineering design (CAD, component prototyping & testing)
↕
Manufacturing, assembly, installation

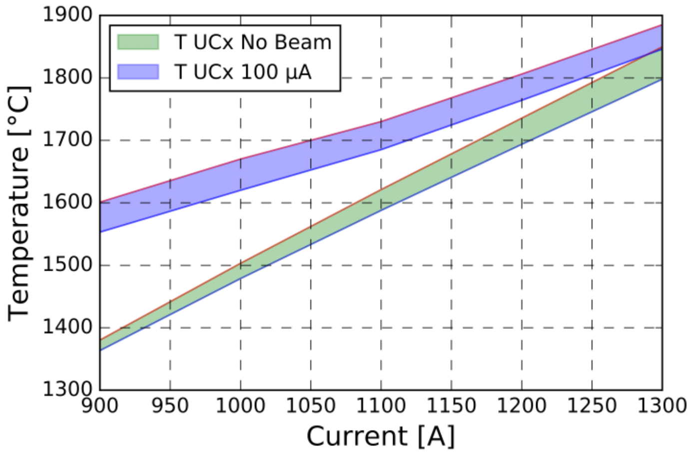
Particle tracking: to optimize n-rich vs n-deficient yield

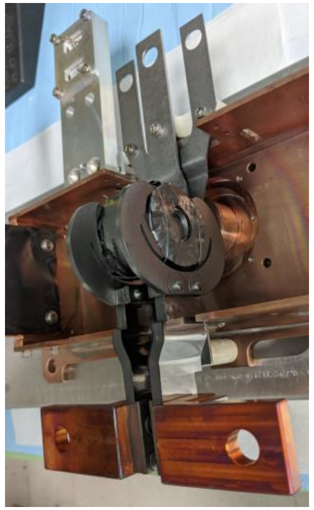




FEA Thermo-mechanical + prototyping: to optimize thermal distribution



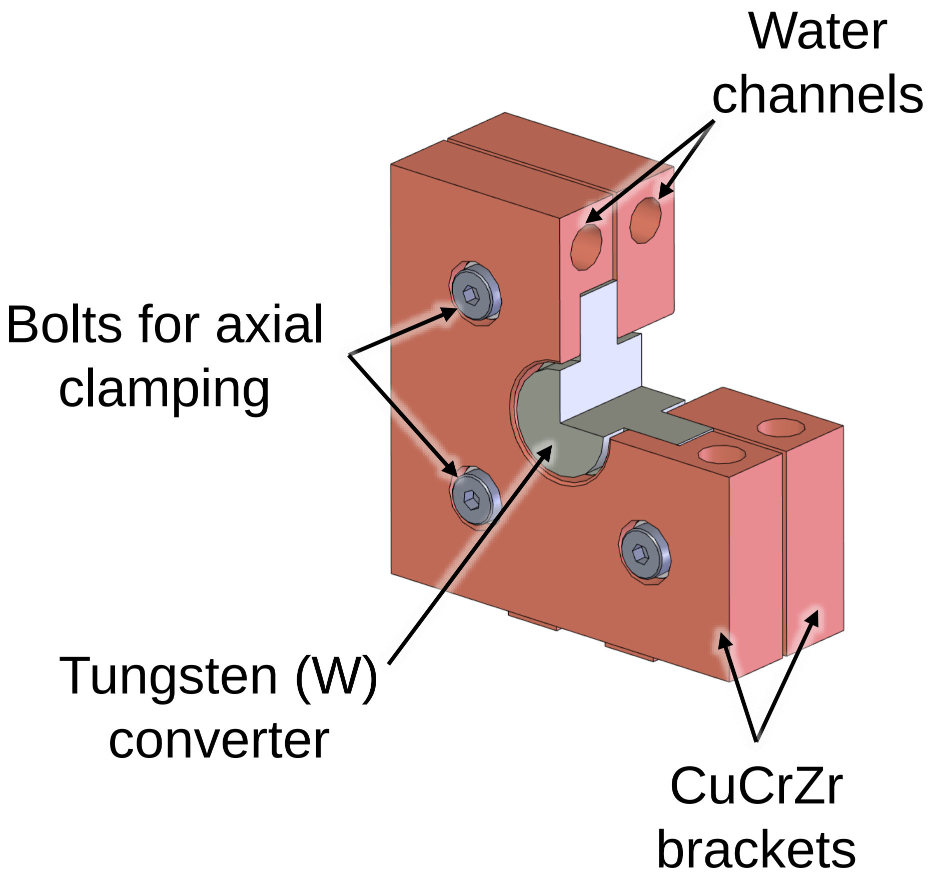


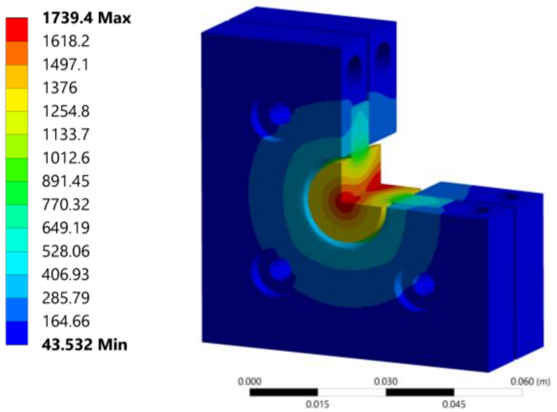


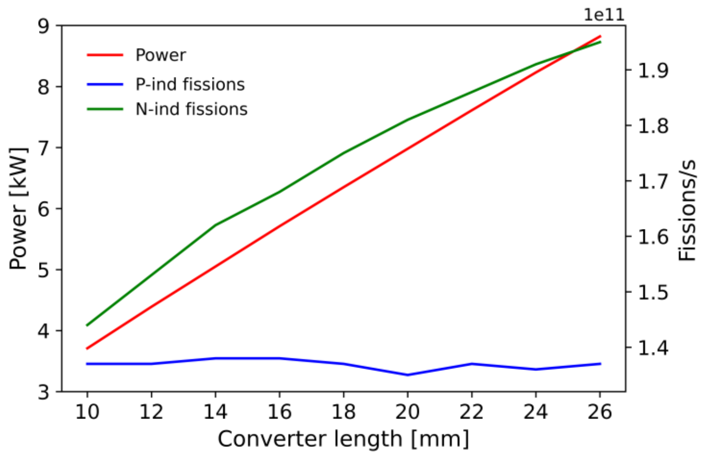
Converter optimization

Objectives:

- Minimize thermal shine to target
  → Active water cooling
- Maximize neutron-induced fissions
  → balancing power vs neutron production







Available conditions:

- Flow H_2O ~ 6 [lpm]
- Pressure H_2O ~ 6.8 [bar]
- T_{evap} (H_2O @ 6.8 [bar]) = 166 °C
- Spring-loaded bolts
- Creep resistant alloy CuCrZr
- Thermal conductance through offline tests

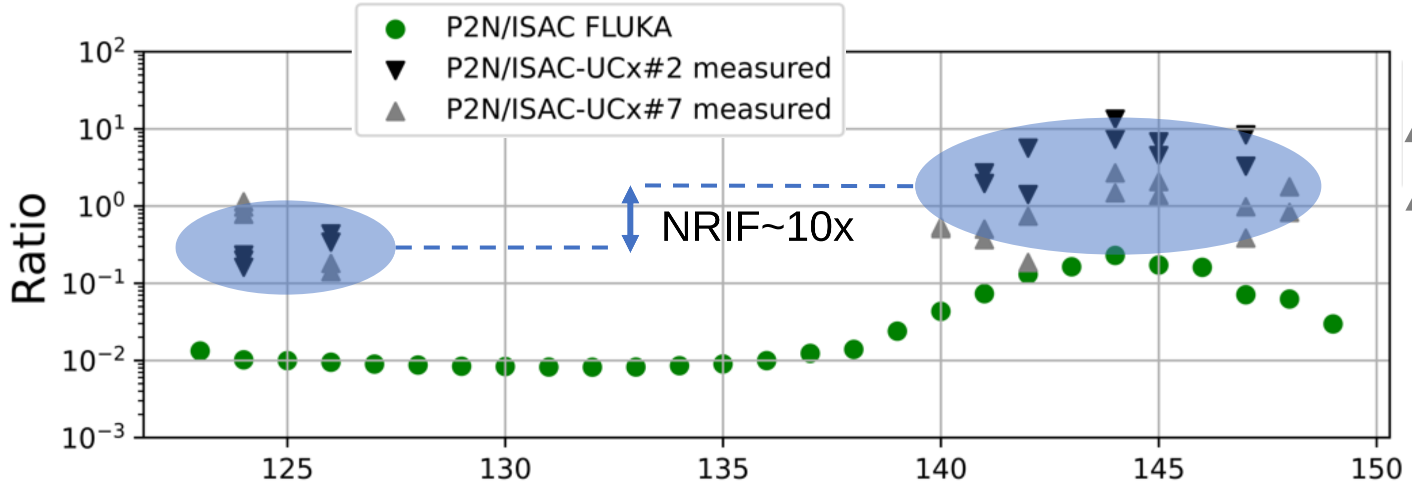
Results:

- Optimum W length = 2 cm
- Power deposited = 7525 W
- T_{max} (W) = 1739 °C
- T_{max} (CuCrZr) = 360 °C
- T_{max} (H_2O) = 149 °C
- Plastic stresses OK

Objectives during P2N on-line runs (June 2021 and June 2022)

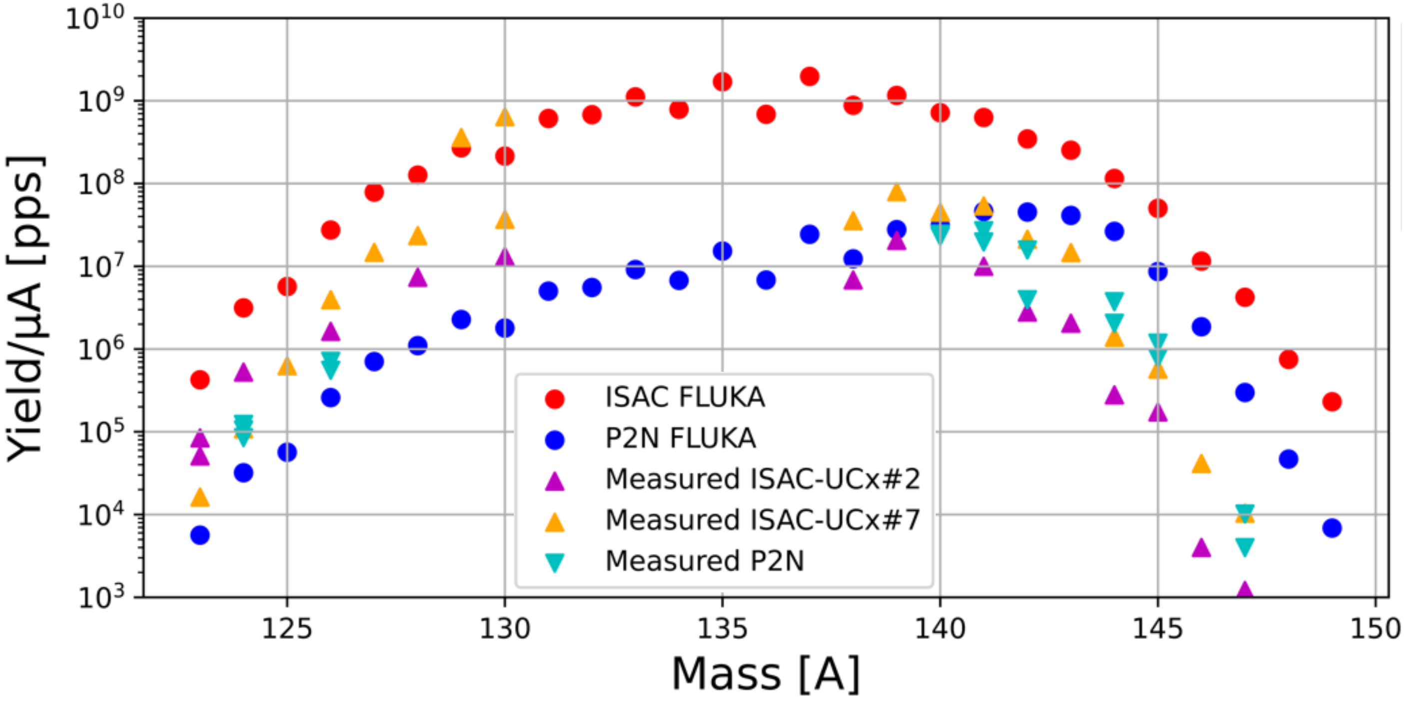
- Neutron rich purity assessment
  → To reduce spallation (n-deficient) contamination for users
  → Comparison with previous conventional ISAC-UC_x targets
- Release efficiency vs half life
  → To assess target thermal performance
  → Comparison with previous ISAC-UC_x targets
- Yield vs proton beam intensity
  → To exploit full proton intensity
  → To explore Radiation Enhanced Diffusion (RED)
- Post Irradiation Examinations (PIEs)
- Yield vs p+ FWHM characterization
- TITAN MR-ToF spectra
  - To measure contaminants ratios
  - Measure new masses

Neutron-rich purity: Cs yield chain



- P2N improves production in n-rich region
- Measured yield ratios P2N / ISAC-UC_x
- Ratios are half-life independent

<u>Neutron-Rich Improvement Factor</u> (NRIF): Quantifies P2N performance to enhance n-rich production.

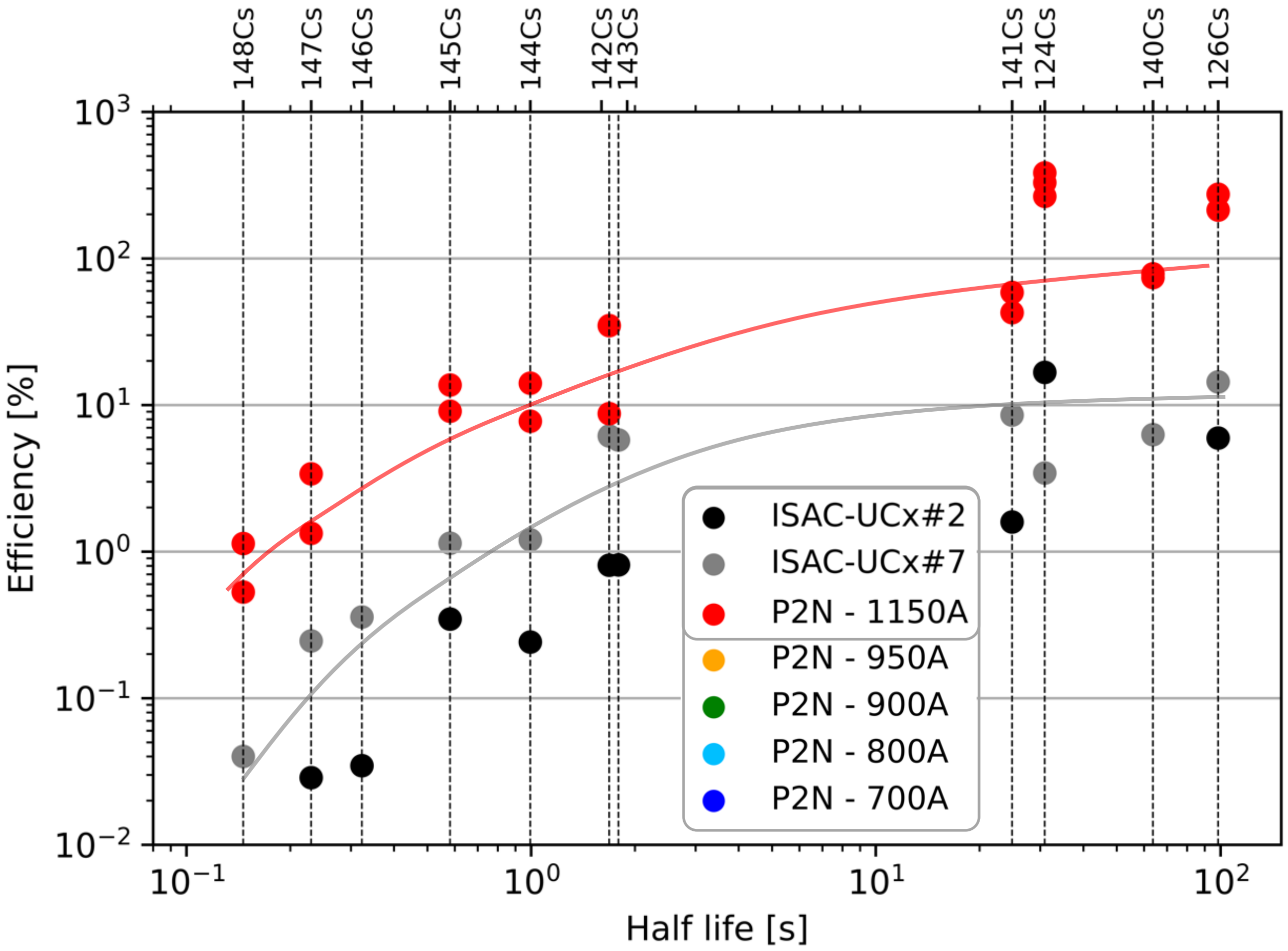


Yields **per μA**! P2N can take ~4x more p^+ current

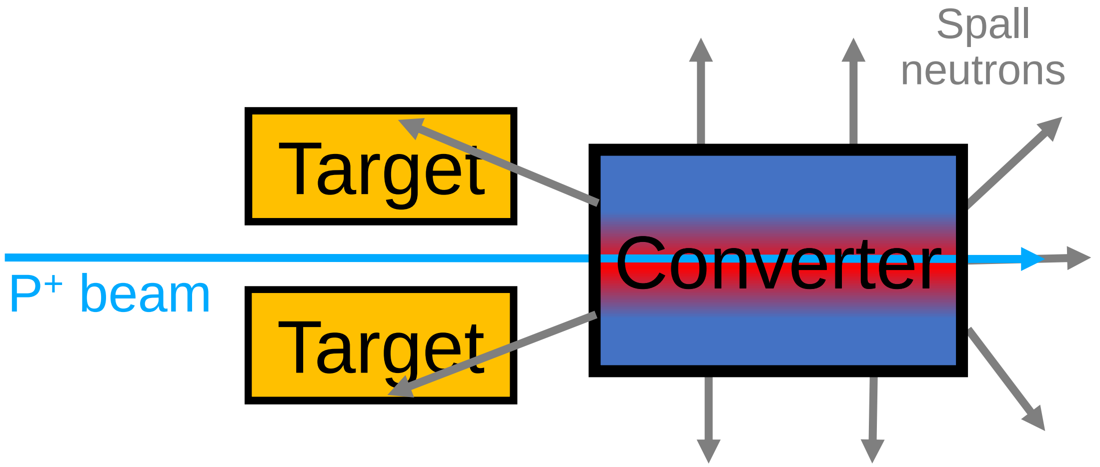
Chains measured for Cs, Rb, Sn, Zn

- Conventional ISAC-UC_x simulation
- Converter simulation: peaks at higher mass value
- Conventional ISAC Yield/μA
- Converter Yield/μA

Release efficiency vs half life: Cs

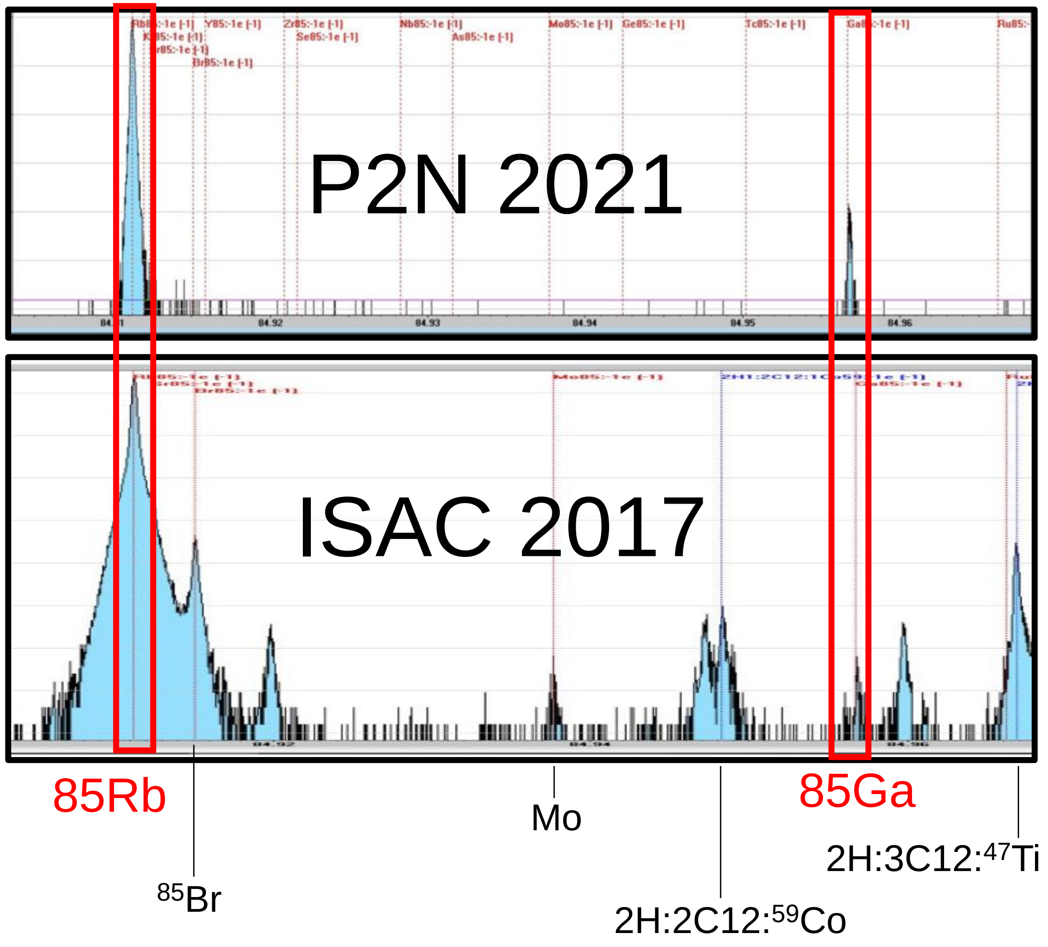


- Trend comparable with ISAC-UC_x
- P2N release efficiency higher
  - Temperature homogeneity
- N-deficient efficiency > 100%
  - P-beam mis-steered
- Cs yields at lower temperature
  - Temperature-controlled mode
  - Enables cleaner Cs, Rb beams by suppressing lanthanides by a factor ~1000

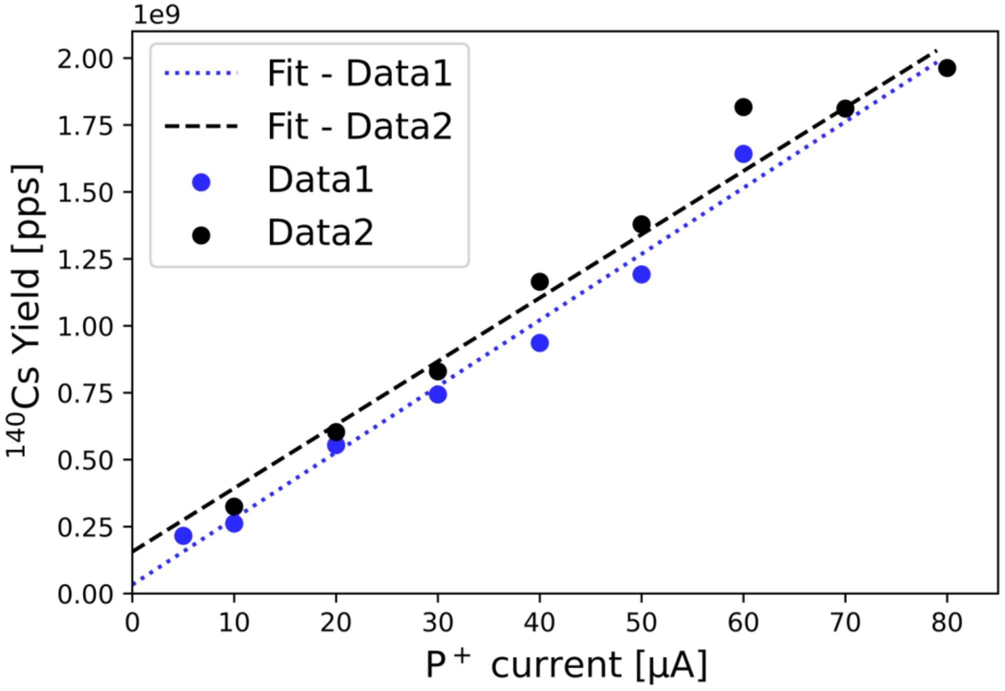


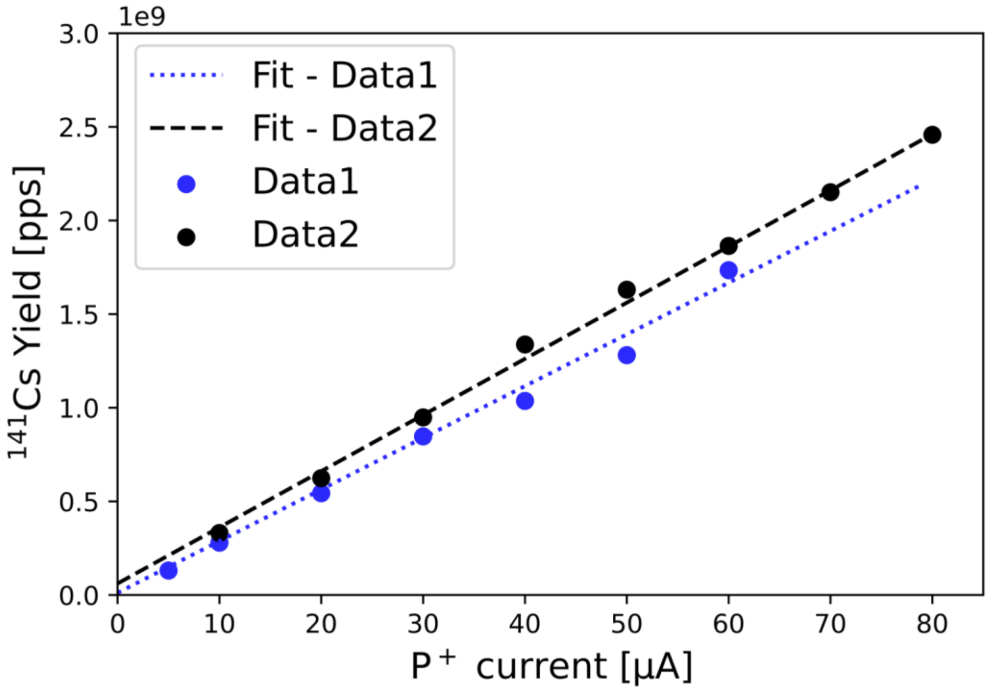
MR-ToF (TITAN) results

- Time split between yield measurements and MR-ToF measurements
  - Assessing relative contaminant yields (50%)
  - Measuring masses for relevant science cases (50%)
- Maximum RIB current in MR-ToF ~ 10^6 pps
- Purity gains enabled measurements of 10 new masses:
  - ^{83}Zn, ^{149}Cs, ^{150}Cs, ^{151}Cs, ^{151}Ba, ^{152}Ba, ^{136}Sn, ^{137}Sn, ^{138}Sn and ^{86}Ga
- Molecular contamination reduced



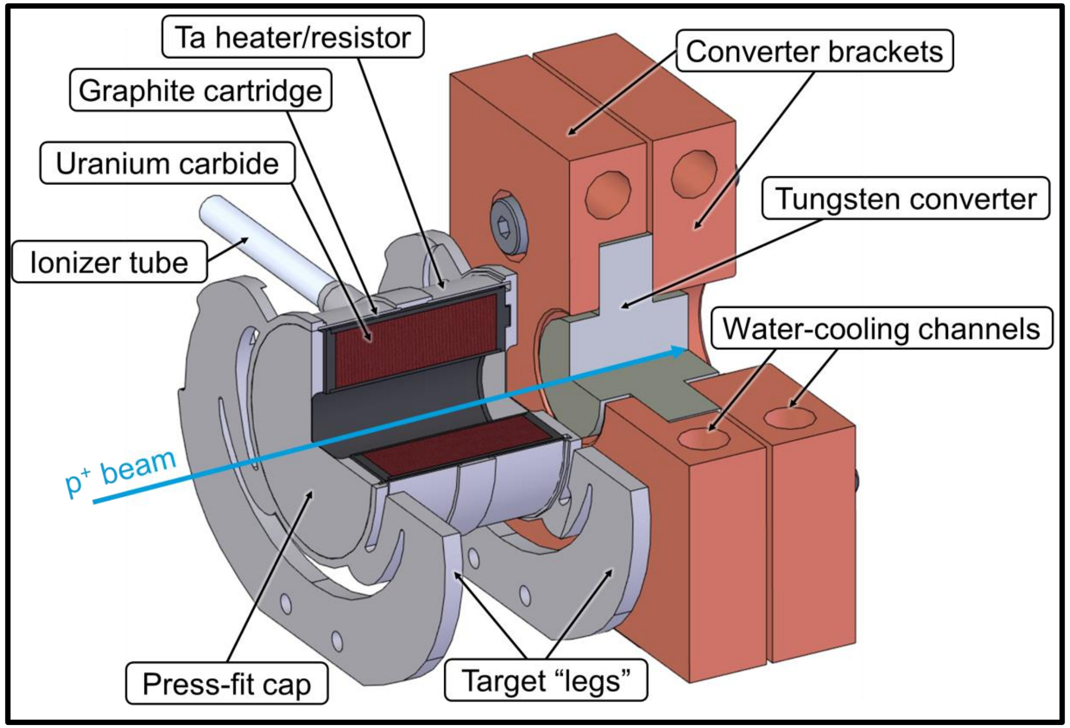
Linearity: Yield vs p⁺ current

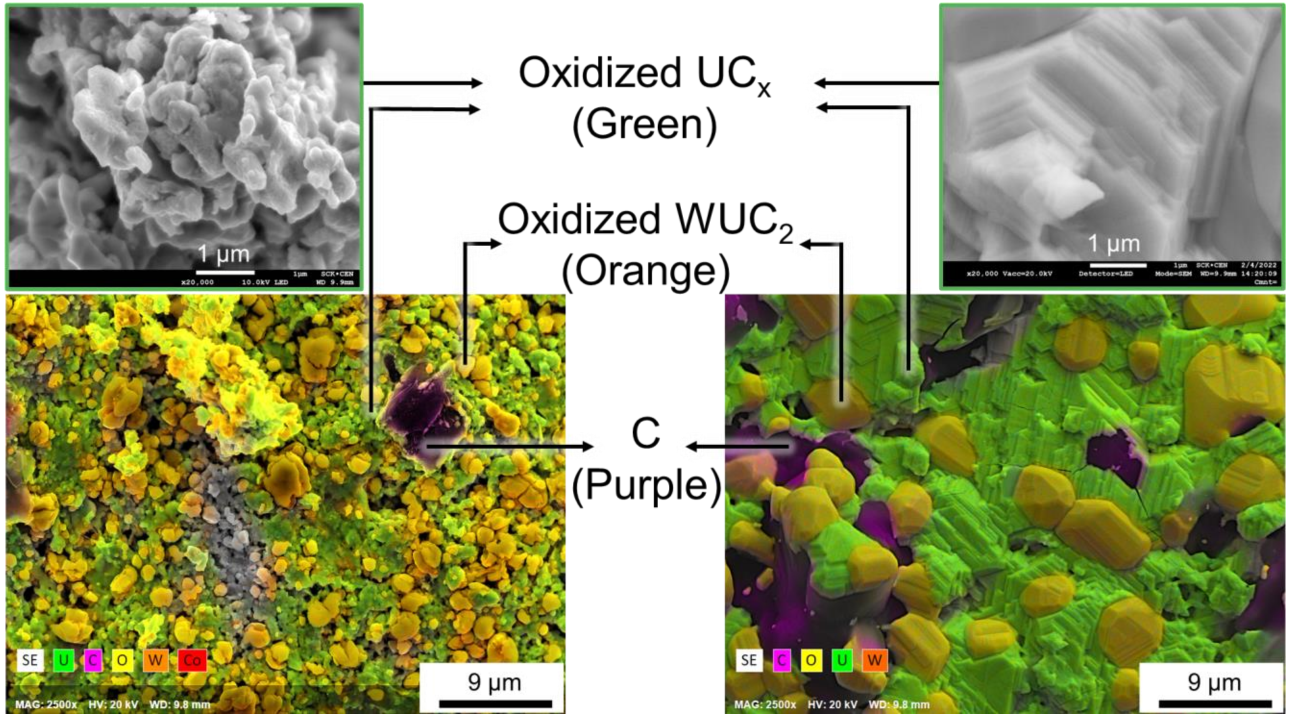


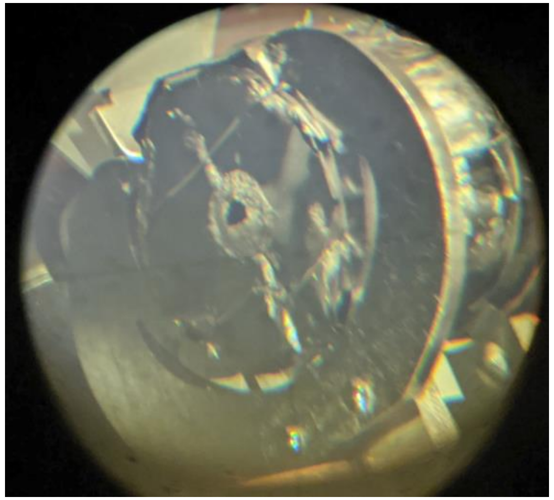


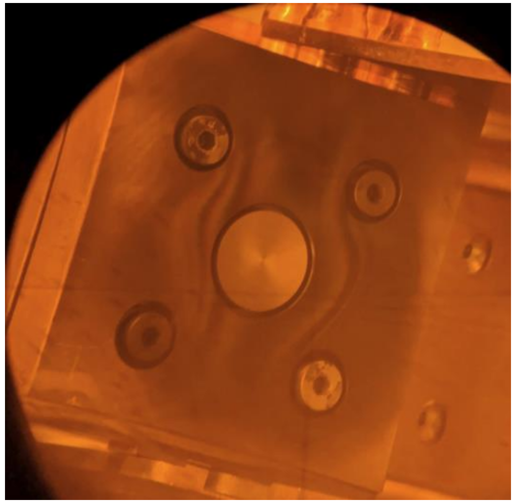
- Confirms that yields can be presented per unit of primary beam [µA p+]
- Confirms little thermal coupling between p+ and target windows
- No Radiation Enhanced Diffusion noticed on broad p^+ range

Post Irradiation Examinations (PIEs)





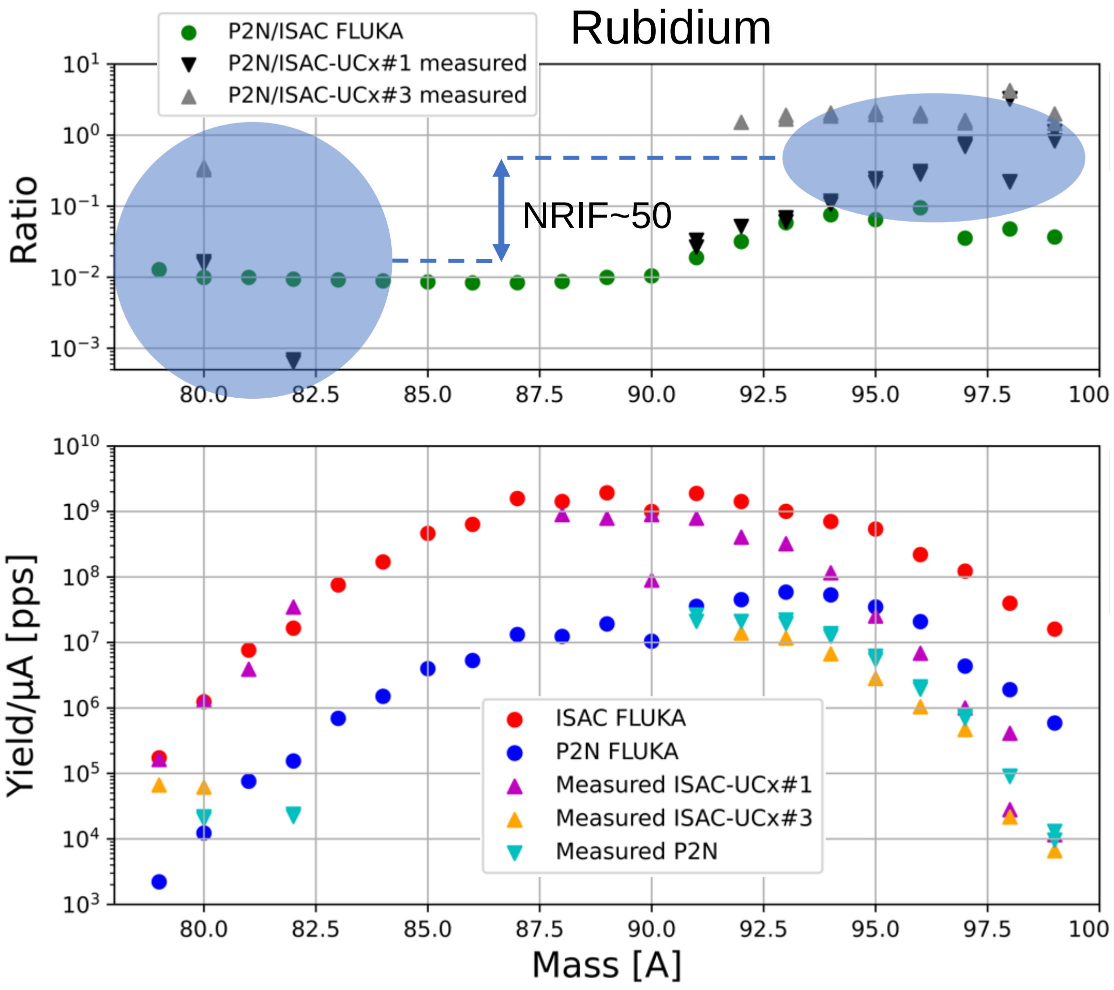


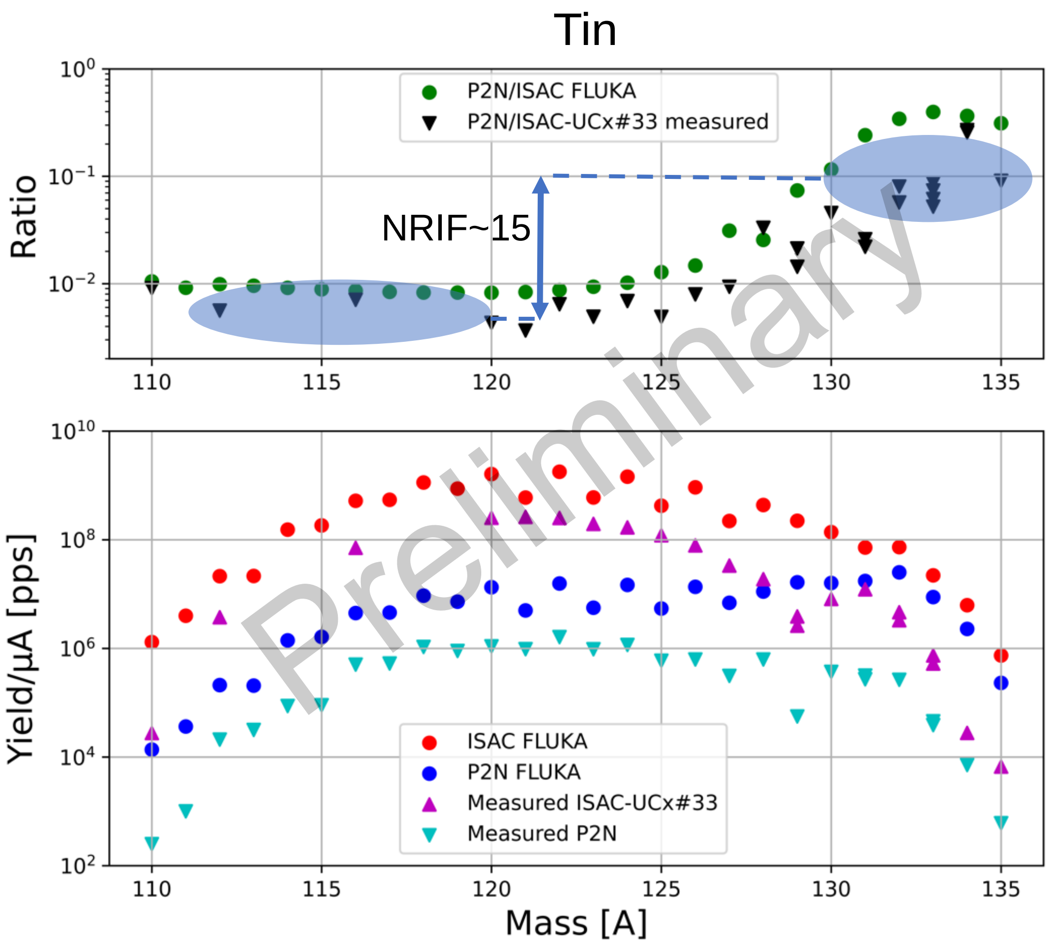


<u>PIE observations</u>

- Converter always withstood beam power
- Target windows broke only with I_{p+} > 50 µA
- SEM and EBSD performed on irradiated UC$_x$ at SCK CEN
    - Carbides were oxidized due to air exposure
    - UC$_x$ particle size grew ~10x

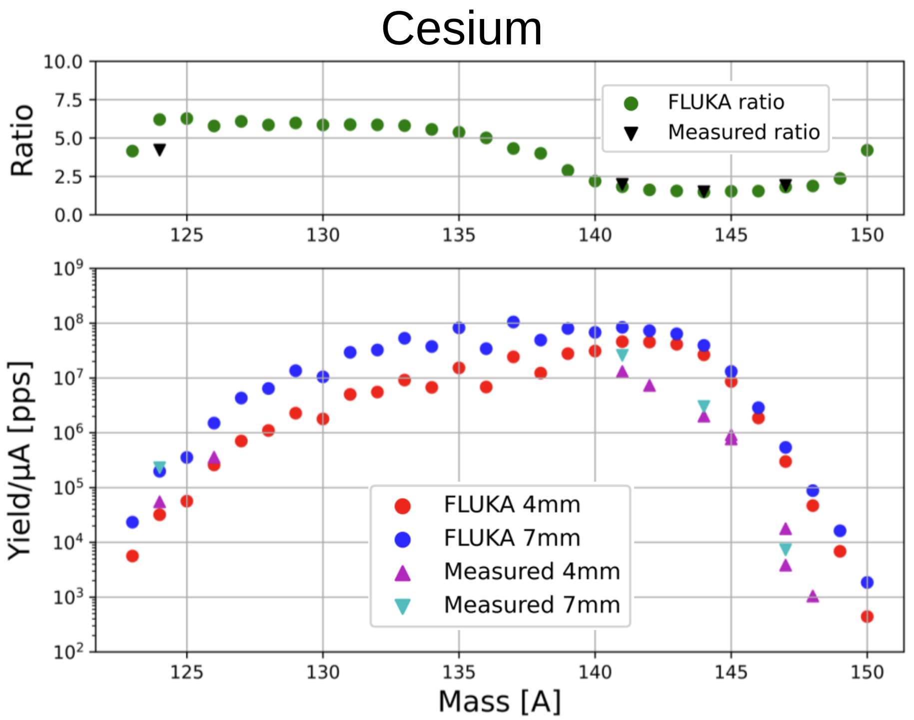
Neutron-rich purity: Rb and Sn yield chains

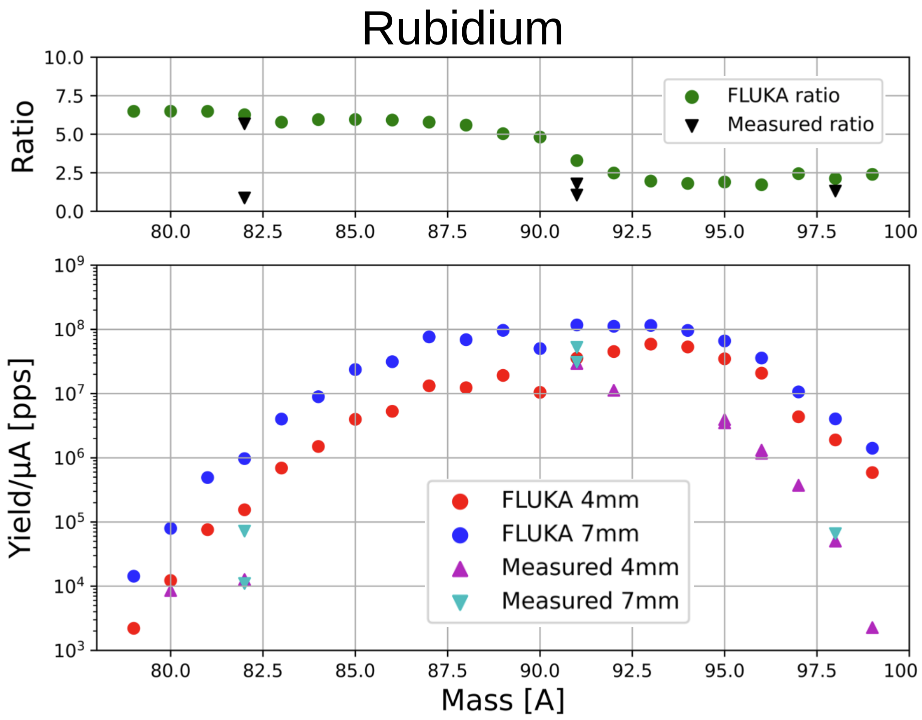


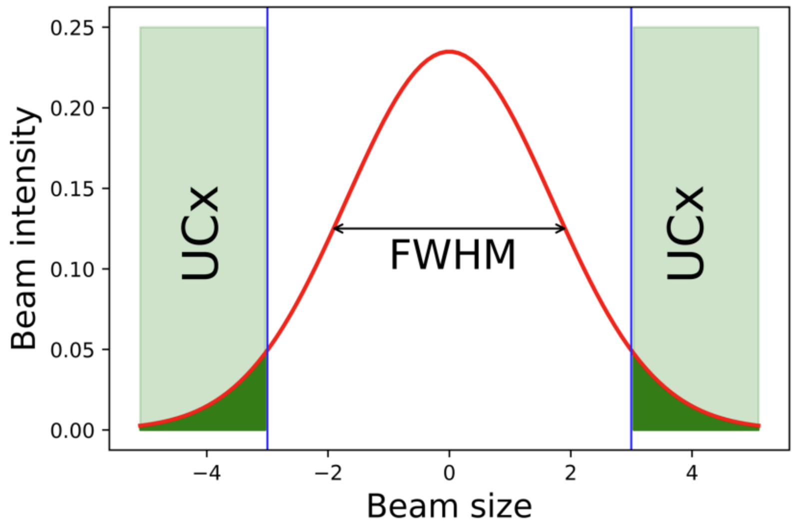


Neutron rich improvements by 15x – 50x at nominal temperature

Effect of beam FWHM on spallation reactions







<u>FWHM considerations</u>:

- Larger beam → Higher spallation on UC_x from “beam tails”
- Conservative operation of target module (Al6061) window:
  - $I_{p+ (max)}$ = 80 μA (@ FWMH = 4 mm)
  - $I_{p+ (max)}$ = 99 μA (@ FWMH = 7 mm)

Summary

- Neutron rich purity assessment
  → To reduce spallation (n-deficient) contamination for users
  → Comparison with previous conventional ISAC-UC_x targets
- Release efficiency vs half life
  → To assess target thermal performance
  → Comparison with previous ISAC-UC_x targets
- Yield vs proton beam intensity
  → To exploit full proton intensity
  → To explore Radiation Enhanced Diffusion (RED)
- Post Irradiation Examinations (PIEs)
  - UC_x material extracted and analyzed with SEM/EBSD
  - General health of target/converter confirmed post irradiation
- Yield vs p+ FWHM characterization
- TITAN MR-ToF spectra
  - To measure contaminants ratios
  - New masses:

^{83}Zn, ^{149}Cs, ^{150}Cs, ^{151}Cs, ^{151}Ba, ^{152}Ba, ^{136}Sn, ^{137}Sn, ^{138}Sn and ^{86}Ga

✓ Purity gain ~ 10-50x

✓ Efficiencies higher for Rb and Cs

✓ Yields linear with p^+ intensity

✓ Small design improvements identified

✓ Yield dependence on FWHM measured

✓ TITAN measured 10 new masses

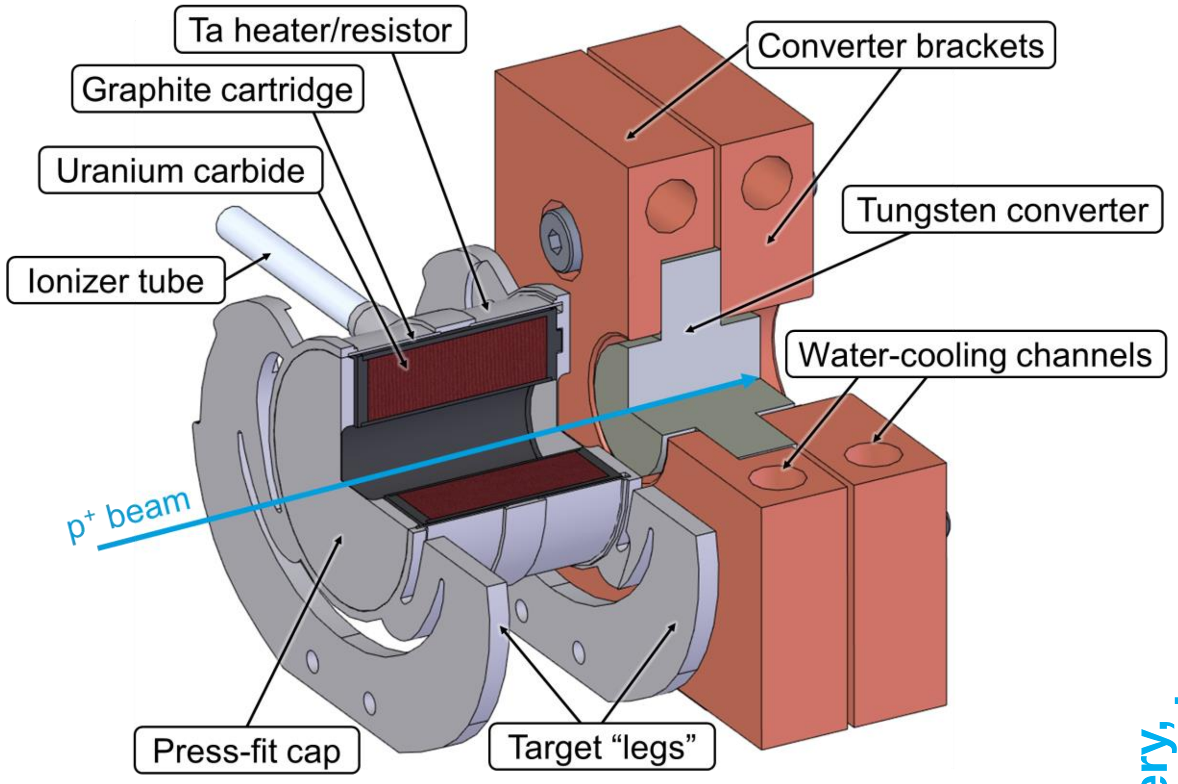
Routine operation of this converter is foreseen

Thank you!
Merci!

Many people involved in several levels:

At TRIUMF: Alex Gottberg, Pierre Bricault, Marla Cervantes, Fernando Maldonado, Ferran Boix-Pamies, Tom Day Goodacre, Carla Babcock, Peter Kunz, Friedhelm Ames, Andres Mjos, Aaron Schmidt, Jens Lassen, Ruohong Li, Darwin Ortiz Rosales, David Wang, Frank Song, John Langrish, Chad Fisher, Matthew Gareau, Navid Noori, Aurelia Laxdal, Sundeep Gosh, Joe Mildenberger, Max Kinakin, Maico Dalla Valle, Dan MacDonald, John Wong, TITAN team.

At SCK CEN and ISOLDE: Joao Pedro Ramos, Donald Houngbo, Jarno Van de Walle, Lucia Popescu, Marc Dierckx, Santiago Ramos Graces, Sebastian Rothe, Thierry Stora.



Discovery, accelerated