Optimization Studies of the CERN-ISOLDE Neutron Converter – Fission Target System

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EURISOL-NET Workshop, June 27-28 2011, CERN

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CERN - ISOLDE

- The ISOLDE facility operates at CERN since 1967
- One of the most important facilities worldwide producing radioactive ion beams using the ISOL method
- More than 1000 radioactive isotopes have been produced at ISOLDE
- These isotopes are produced following the bombardment of various primary targets with a pulsed proton beam from the Proton Synchrotron Booster (PSB)
  - Beam energy: 1.4 GeV
  - Beam Intensity: ~ 2 μA
- Most of these isotopes can be accelerated in REX-ISOLDE to energies up to 2.8 MeV/u

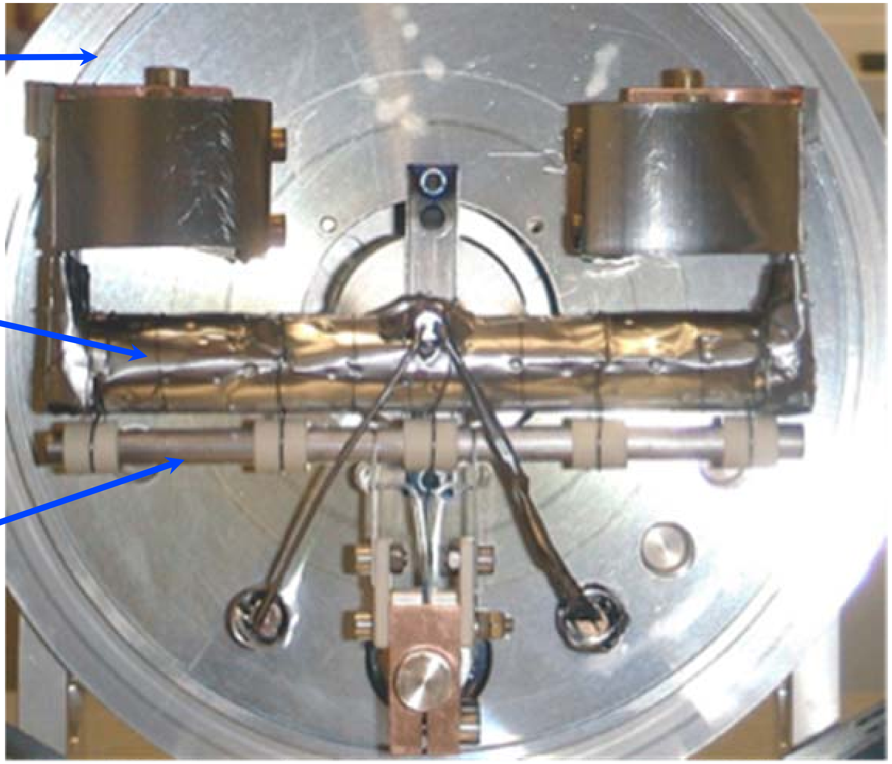
ISOLDE Target System Layout

aluminum base

Spallation / fission target (uranium carbide)

proton beam

Converter



- ISOLDE will have a major upgrade - HIE-ISOLDE
  - proton beam intensity upgraded to ~6 μA (PS-Booster upgrade)
  - possibility of a further upgrade to ~20 μA (10Hz, 1e13 ppp, 2GeV)
- This work is already for ISOLDE and will apply directly to future upgrades

Radioactive Ion Beam Intensity

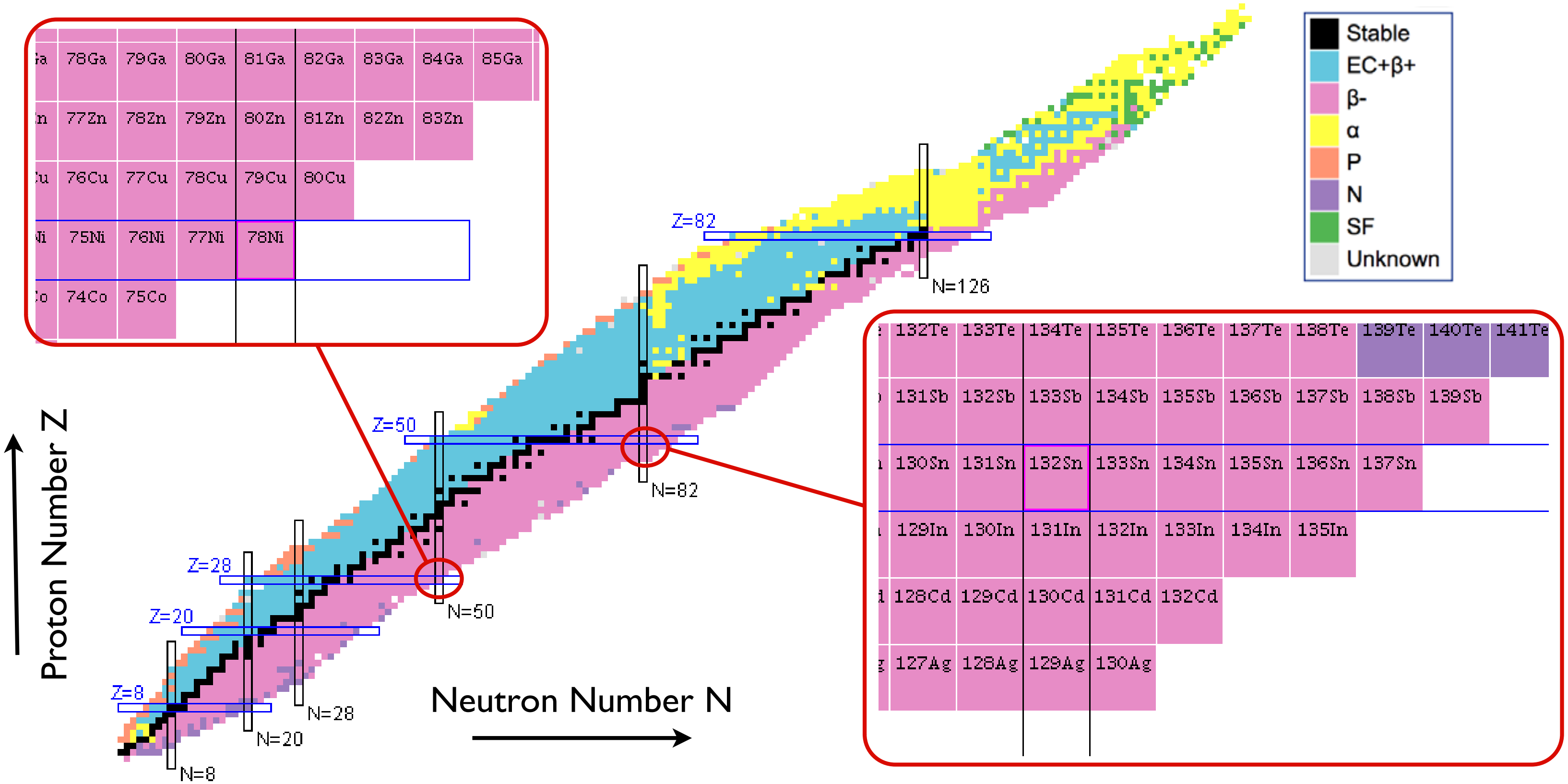
- Main figures of merit for a RIB facility:
  - beam intensity
  - beam purity

In-Target Production

$$i = \Phi \cdot \sigma \cdot N \cdot \epsilon_{\mathrm{target}} \cdot \epsilon_{\mathrm{source}} \cdot \epsilon_{\mathrm{sep}} \cdot \epsilon_{\mathrm{transp}}$$

- Φ: flux of primary particles
- σ: isotope production cross section
- N: number of atoms in the target
- $\epsilon_{\mathrm{target}}$: release efficiency from the target
- $\epsilon_{\mathrm{source}}$: ionization efficiency
- ϵ_{sep}: transmission of the mass separator
- $\epsilon_{\mathrm{transp}}$: transmission to the detection system

Nuclides of Interest for this Study



- A lot of physics interest in the regions of double shell closure (^{78}Ni and ^{132}Sn), in nuclides that lie in and near the path of r-process nucleosynthesis
- In these regions, Zn, Ga, Cu, and Cd isotopes have the most appropriate release properties for the target materials
- In this study, emphasis is given to Zn and Cd isotopes

Proton-rich Isobars Background

- Fission in ^{238}U by GeV protons:
  - strong contribution of spallation-fission
    - neutron evaporation before fission in part of the target nuclei
  - shift of the fission yields towards neutron-deficient species
  - background of proton-rich isobars when producing neutron-rich species
    - these can be difficult to suppress through chemical selection
- Low-energy fission can be used to reduce the background
  - use of a tungsten spallation target to convert the protons in neutrons with energies mainly in the MeV region
  - production of mainly neutron-rich species

Objectives

In-Target Production

$$i = \underbrace{\Phi \cdot \sigma \cdot N} \cdot \epsilon_{\text{target}} \cdot \epsilon_{\text{source}} \cdot \epsilon_{\text{sep}} \cdot \epsilon_{\text{transp}}$$

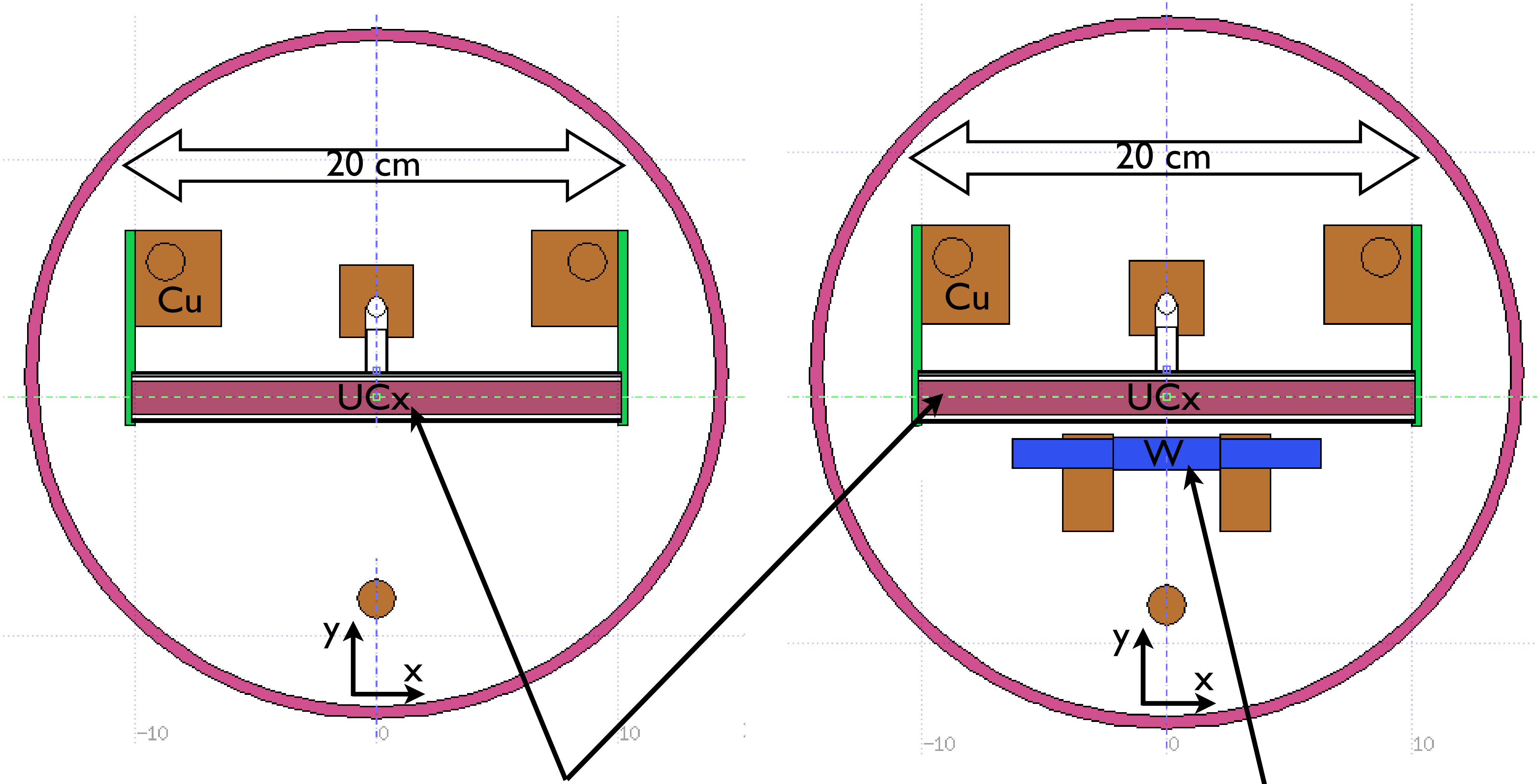
- Maximize in-Target Production of important neutron-rich nuclides:
  - ^{80}Zn (and beyond, if possible)
  - ^{130}Cd (and beyond, if possible)
- Reduce the contamination by proton-rich isobars, namely:
  - ^{80}Rb (^{80}Zn)
  - ^{130}Cs (^{130}Cd)

Results

Optimization Studies using FLUKA

Direct Beam Configuration

Converter Configuration



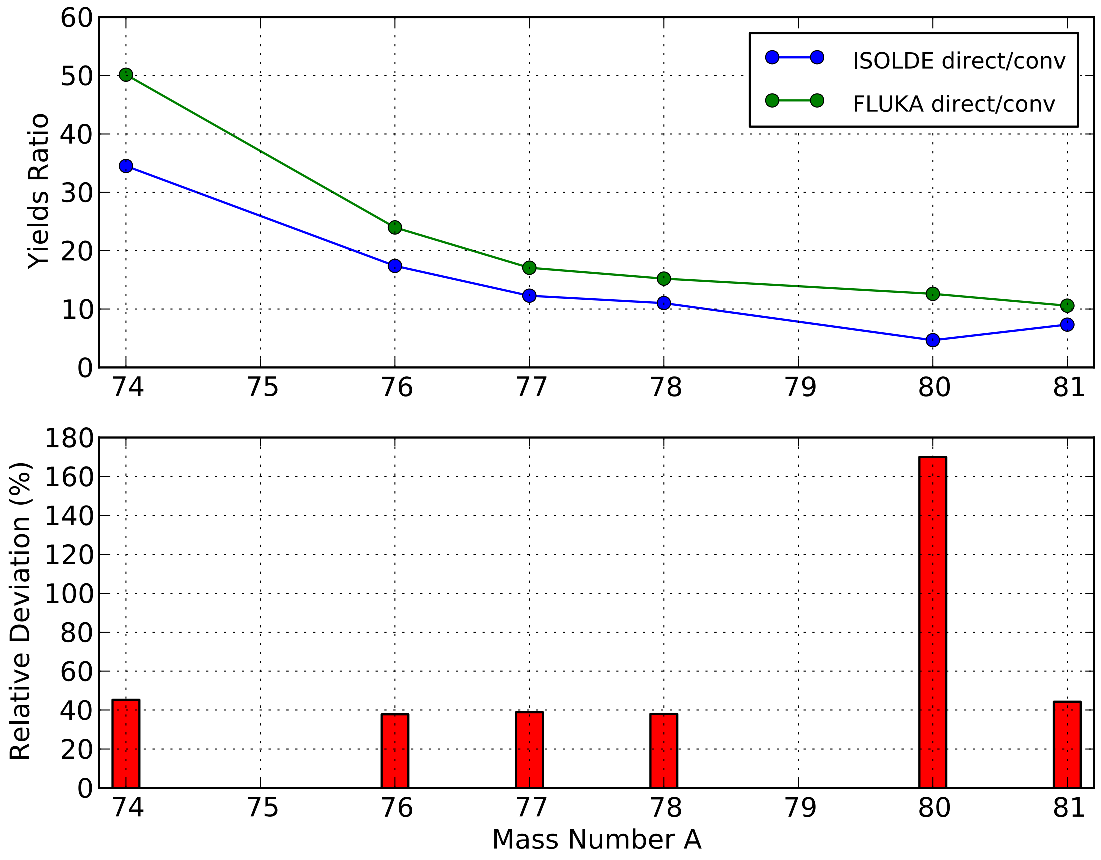
uranium carbide target tungsten spallation target

Benchmarks

$$i = \Phi \cdot \sigma \cdot N \cdot \epsilon_{\mathrm{target}} \cdot \epsilon_{\mathrm{source}} \cdot \epsilon_{\mathrm{sep}} \cdot \epsilon_{\mathrm{transp}}$$

In-Target Production

difficult to quantify experimentally



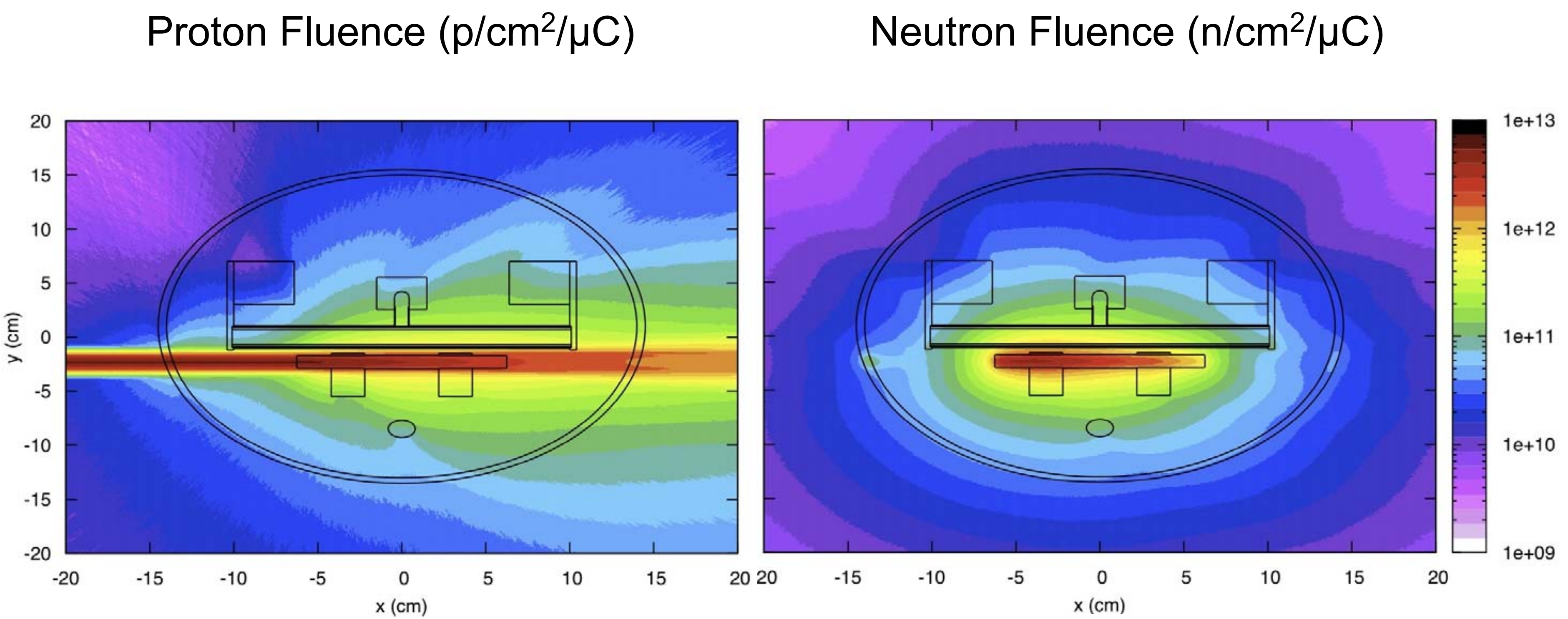
- Experimental RIB intensities cannot be compared with in-target production obtained with FLUKA
- Instead, the following ratios were compared (the efficiencies cancel out):

$$\frac{\mathrm{ISOLDE}_{\mathrm{Direct\ Configuration}}}{\mathrm{ISOLDE}_{\mathrm{Converter\ Configuration}}}$$

$$\frac{\mathrm{FLUKA}_{\mathrm{Direct\ Configuration}}}{\mathrm{FLUKA}_{\mathrm{Converter\ Configuration}}}$$

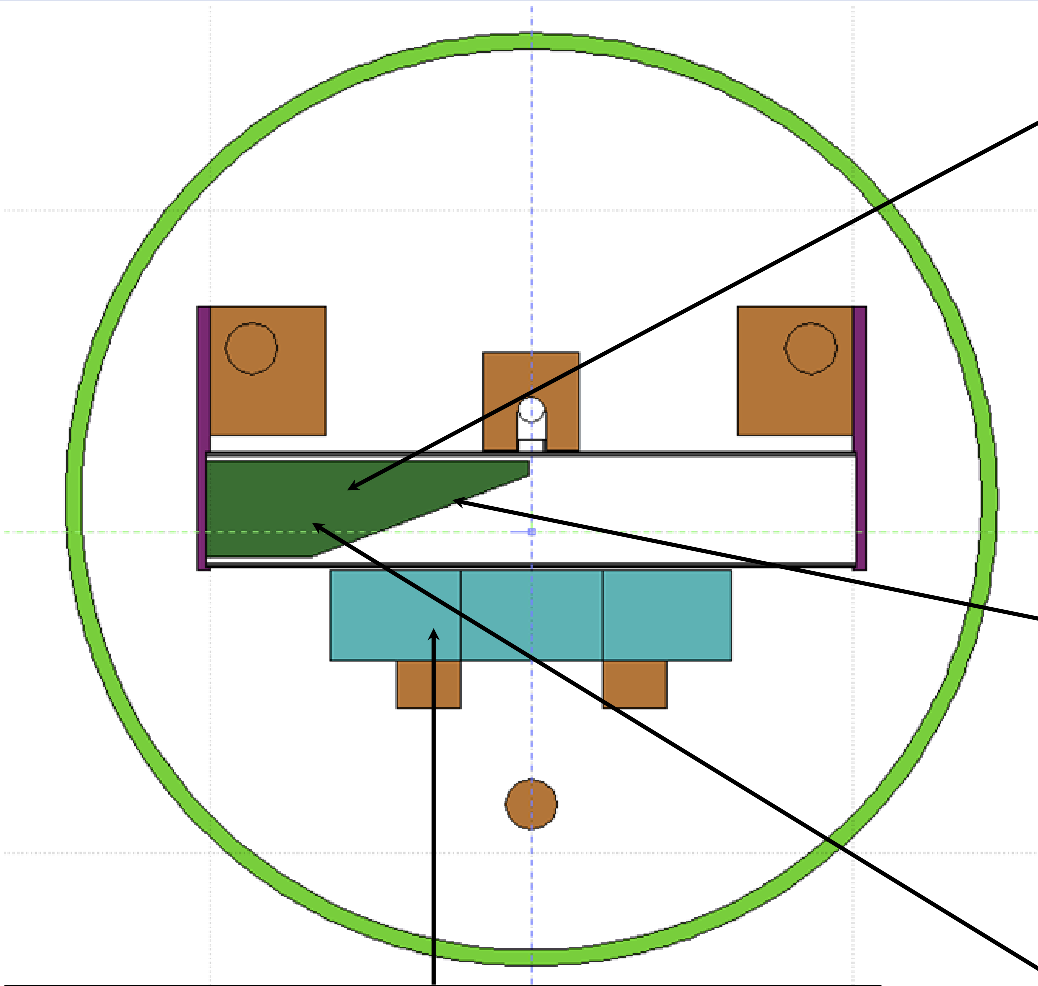
- For most isotopes, the relative deviation between the ratios is of about 40 %

Neutron and Proton Fluences (with converter)



- There are significant proton fluences reaching the uranium carbide target
- The proton fluences spread with an approximate “conical shape” after dispersion in the spallation target
- The neutron fluences have approximately an isotropic distribution around the spallation target

Optimized Geometry



Shorter UCx target

to remove the region with higher proton fluences

old length = 20 cm

new length = 10 cm

Diagonal cut in the UCx Target

to avoid the highest proton fluencies

Thicker UCx target

to increase the ^{238}U mass

old radius = 0.7 cm

new radius = 1.5 cm

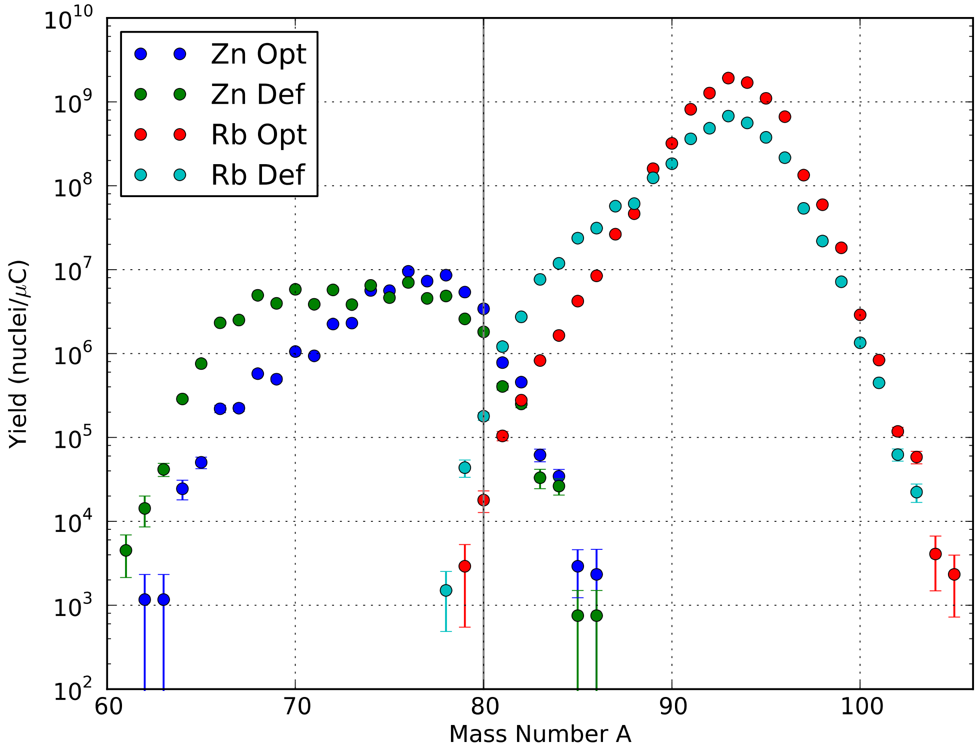
Thicker spallation target

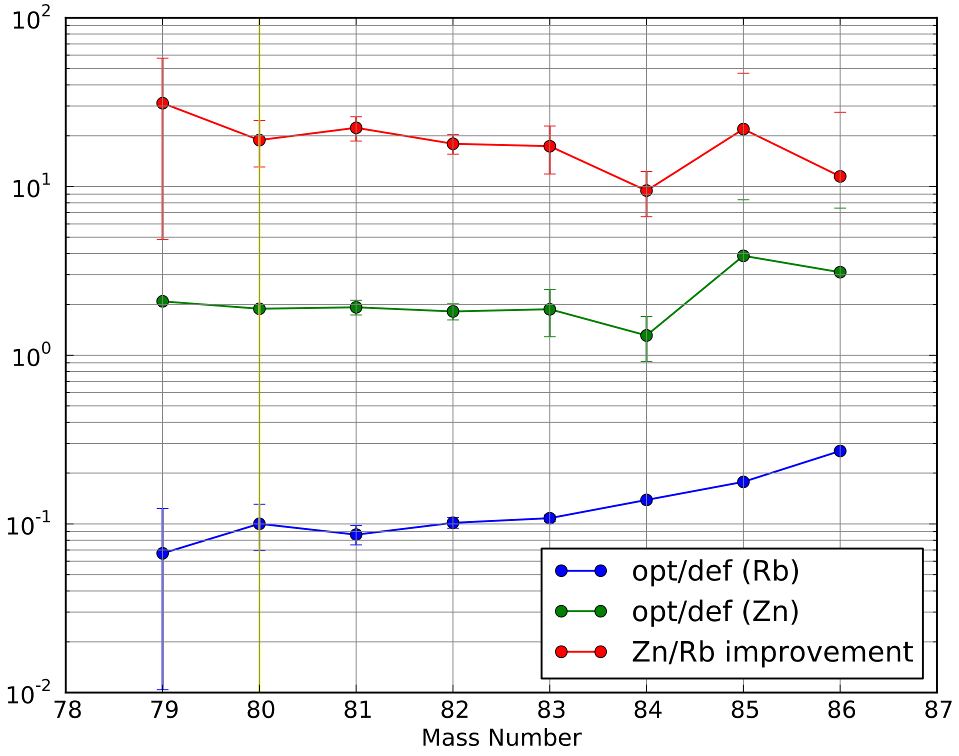
to better “contain” the proton fluences

old radius = 0.6 cm

new radius = 1.4 cm

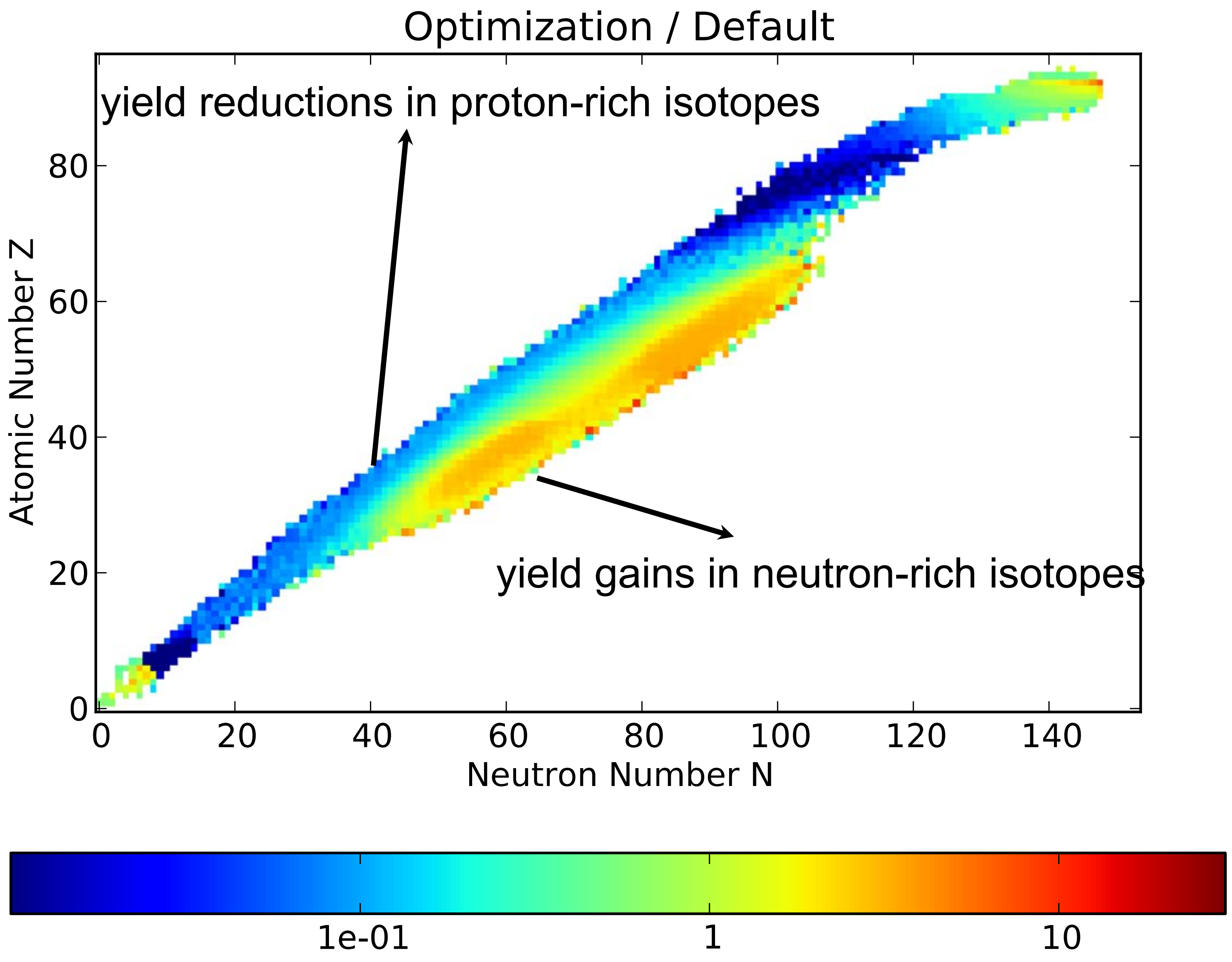
Optimization - Zn and Rb Yields



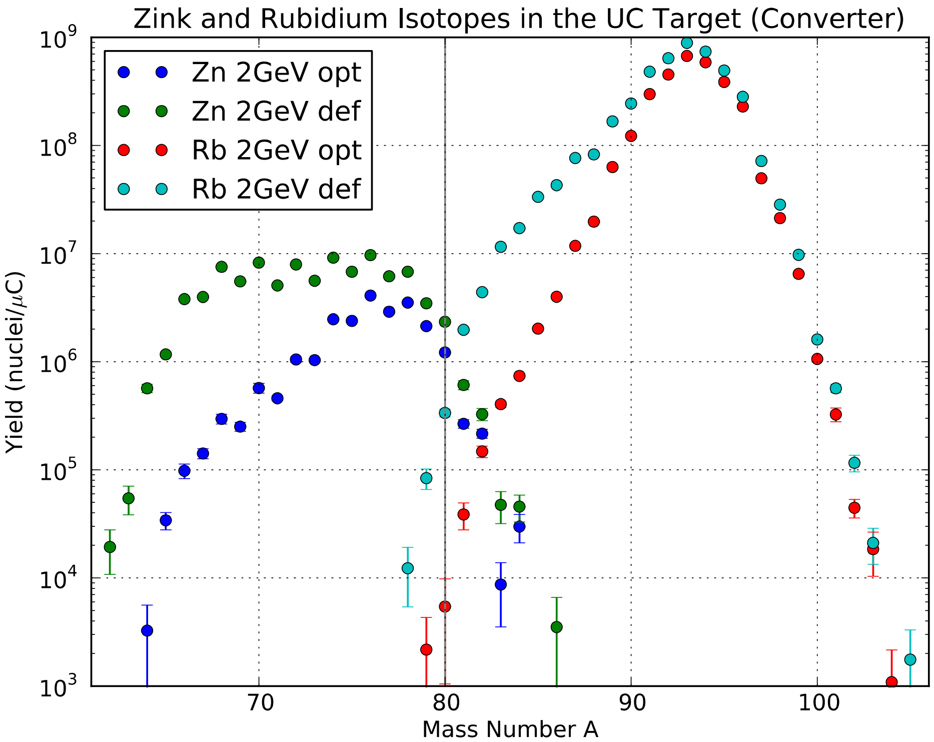


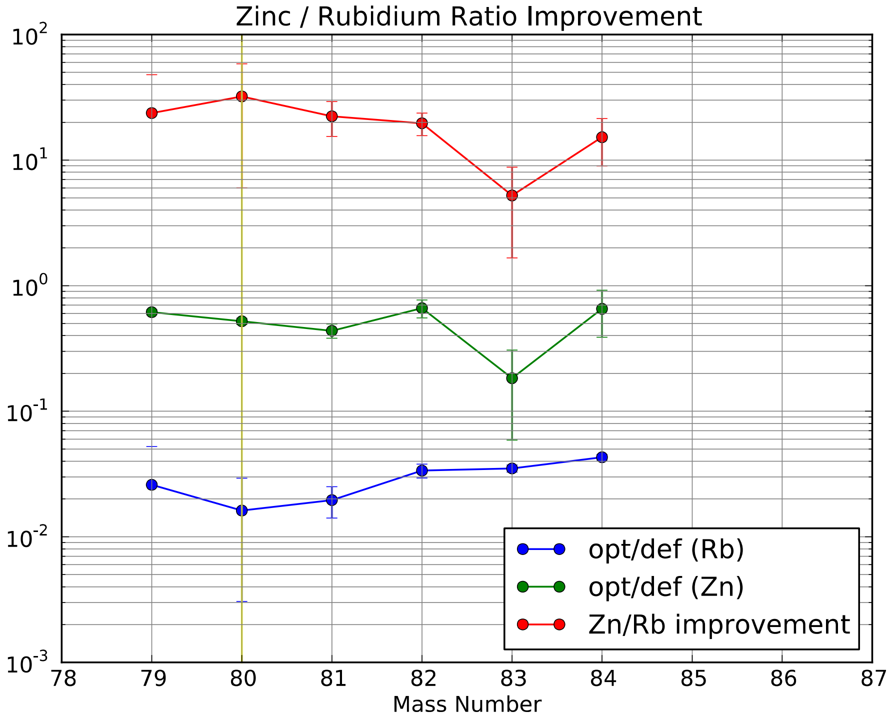
- The production of ^{80}Zn is approximately doubled
- The production of ^{80}Rb (contaminant) is decreased by a factor of 10
- The optimized ratio ^{80}Zn / ^{80}Rb is increased by a factor of ~20
- A similar improvement is obtained for the ratio ^{130}Cd/^{130}Cs

Yields - Optimized / Default Ratio



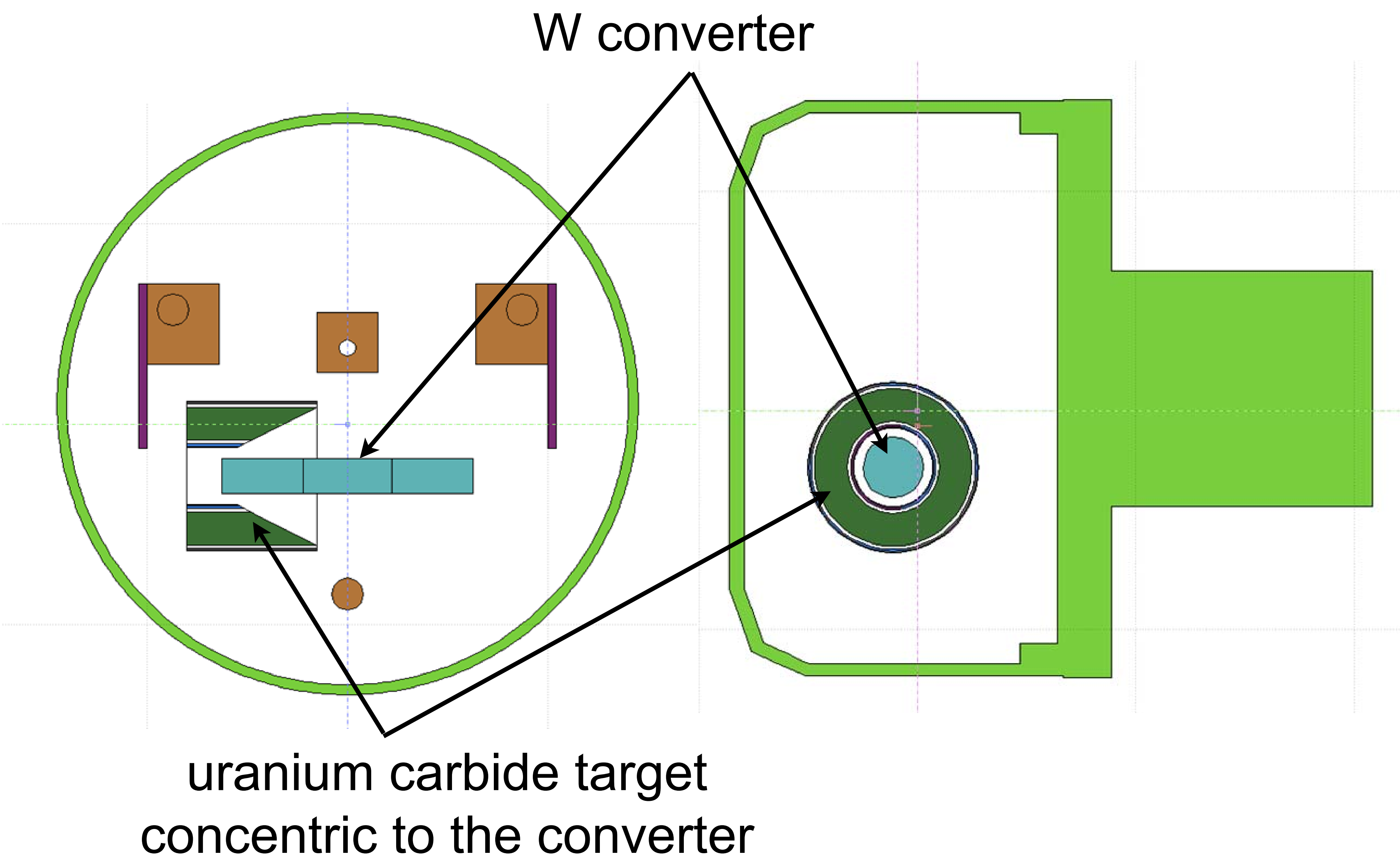
Optimization - Zn and Rb Yields for a 2 GeV Proton Beam (preliminary results)



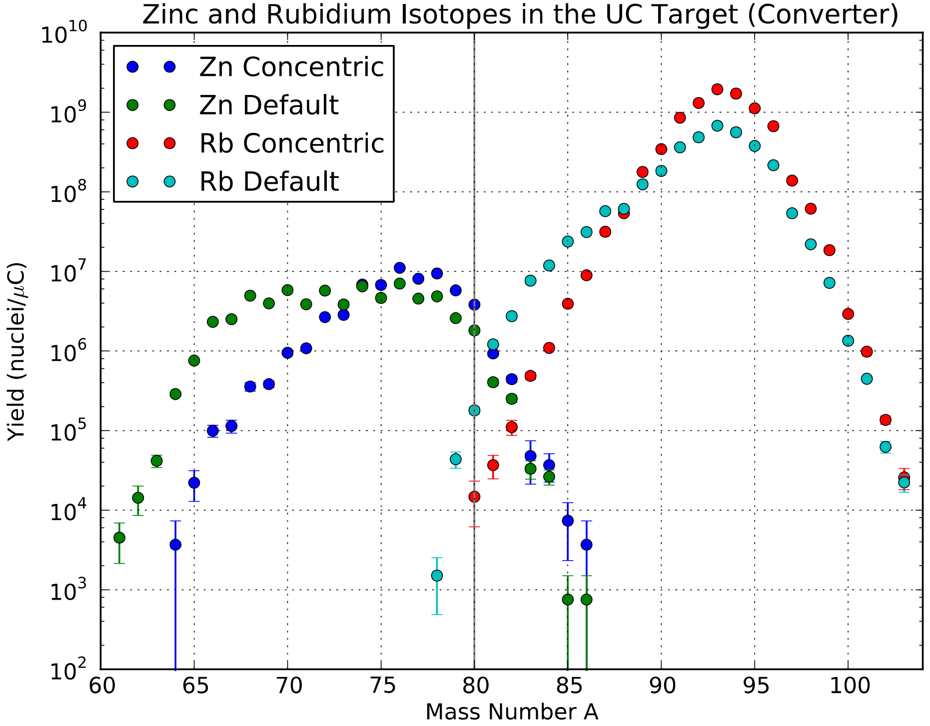


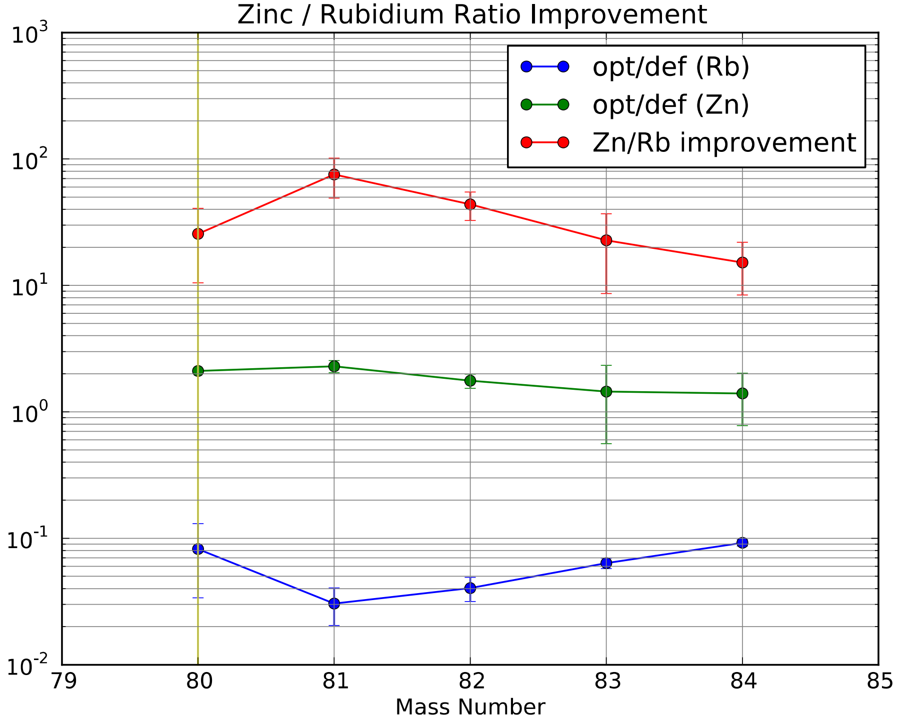
- For a 2 GeV proton beam, the contamination issues become even more important
- Preliminary results indicate that the improvement by a factor of ~20 for the $^{80}Zn/^{80}Rb$ ratio is possible with no further optimization
- A specific optimization for the 2 GeV proton beam will increase this factor

UCx Target Concentric to the Converter



Concentric UCx Target – Zn and Rb Yields (preliminary results)





- ^{80}Zn/^{80}Rb ratio is improved ~25 times (slightly more than in previous optimization)
- ^{81}Zn/^{81}Rb ratio is improved ~70 times
- A conservative uranium carbide target density was assumed - increasing the target density will provide yield gains if the release characteristics are maintained

Conclusions

- The current configuration of the ISOLDE target system can be optimized for the production of neutron-rich isotopes
- Results from this work indicate that
  - the in-target production of neutron rich isotopes of Zn and Cd can be increased while the contamination by proton-rich isobars can be lowered
  - the ratio neutron-rich isotope / proton-rich contaminant can be increased by a factor of 20 or more
- In-target yield gains will translate into RIB intensity gains
  - The gain in the ratio beam of interest / impurity will be preserved in the final RIB
  - This will be of special importance for HIE-ISOLDE when a 2 GeV proton beam is used
- This factor 20 will hopefully increase with future optimizations

- Thank you for your attention