Rydberg atom field ionizer for low-intensity radioactive isotope beams

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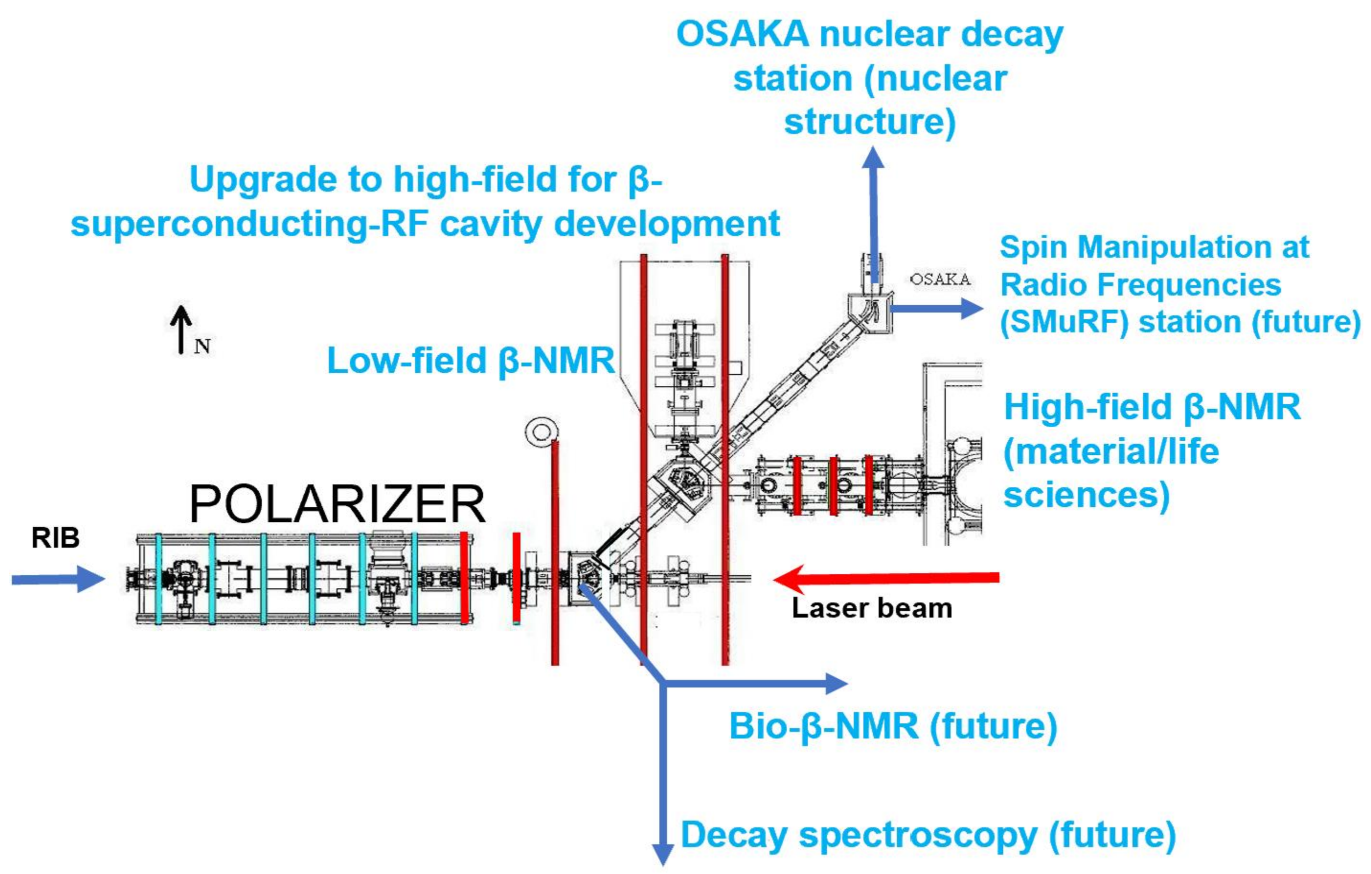
Laser Polarizer

The TRIUMF polarizer facility provides highly **nuclear-spin-polarized radioactive beams** (> 80% polarization), produced through **optical pumping** with lasers [1], to various experiments nuclear spectroscopy experiments (particularly beta-detected nuclear magnetic resonance spectroscopy).

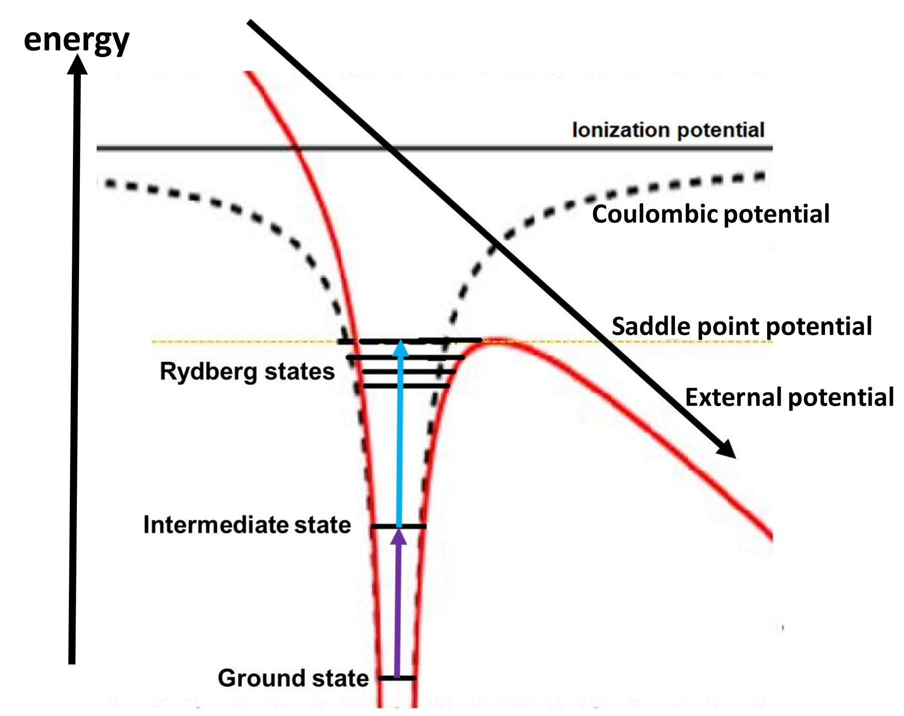
Efficient optical pumping requires knowing an isotope's **hyperfine structure** and **optical isotope shifts.** Traditional fluorescence-based detection is limited by beam intensity. For **low-production isotopes** (< 10^4 s^{-1}), such as ^{32}Na and ^{230,232}Ac (required for research into nuclear structure for radio-pharmaceuticals and β-NMR), more sensitive methods are required.

To improve the sensitivity of collinear laser spectroscopy and polarize low-intensity RIB, we are developing a **Rydberg atom field ionizer** with **charged particle detection** instead of photon counting. This will significantly improve detection efficiency and pave the way to determining the hyperfine structures of exotic nuclei proposed for use in spin-polarized beams.



The polarizer beamline uses optical pumping in a collinear laser-atom beam geometry to spin-polarize β-decaying isotopes for use at a variety of experimental end stations. Current upgrades aim to increase the variety of nuclear-spin-polarized species.

Rydberg Atom Field Ionization



The saddle point model of electric field ionization. An external potential deforms the atom's potential well, creating a saddle point that allows the electron to escape.

The electric field E_{crit} required to ionize an electron with **effective** principal quantum number n^* is

$$E_{crit} = \frac{3.214 \cdot 10^8}{n^{*4}} \; V \cdot cm^{-1}$$

E_{crit} is only practically attainable for **n > 10 (Rydberg states)**. The created ions can be detected with near-unit efficiency. We require:

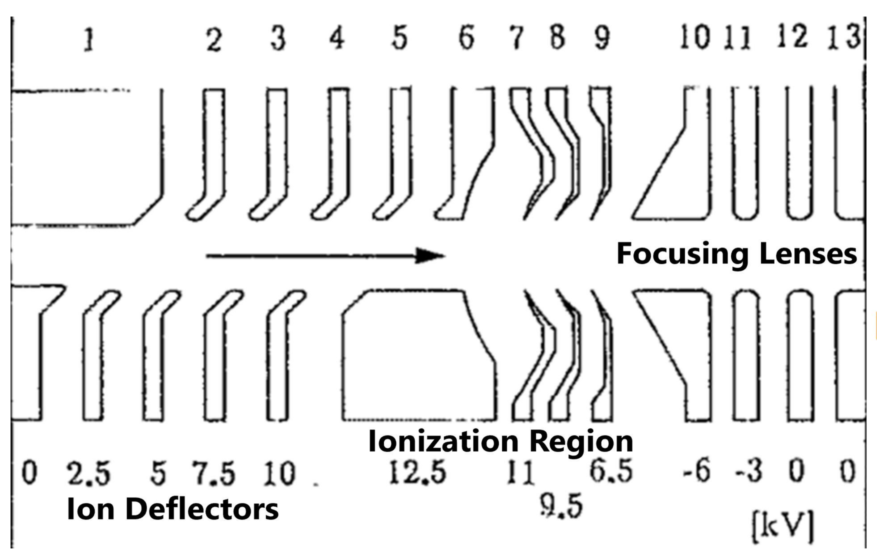
- ❑ resonant excitation of the atoms to a Rydberg state
- ❑ ionization by a suitable electric field
- ❑ suppression of background ions

Field ionization provides **isotope selectivity** as the ions produced from Rydberg atoms can be **marked with a specific energy** as the electric field post-ionization interacts with the ion. Scanning laser frequencies and counting ions with ion beam energy discrimination will allow us to perform hyperfine structure and optical isotope shift measurements of low-intensity RIB.

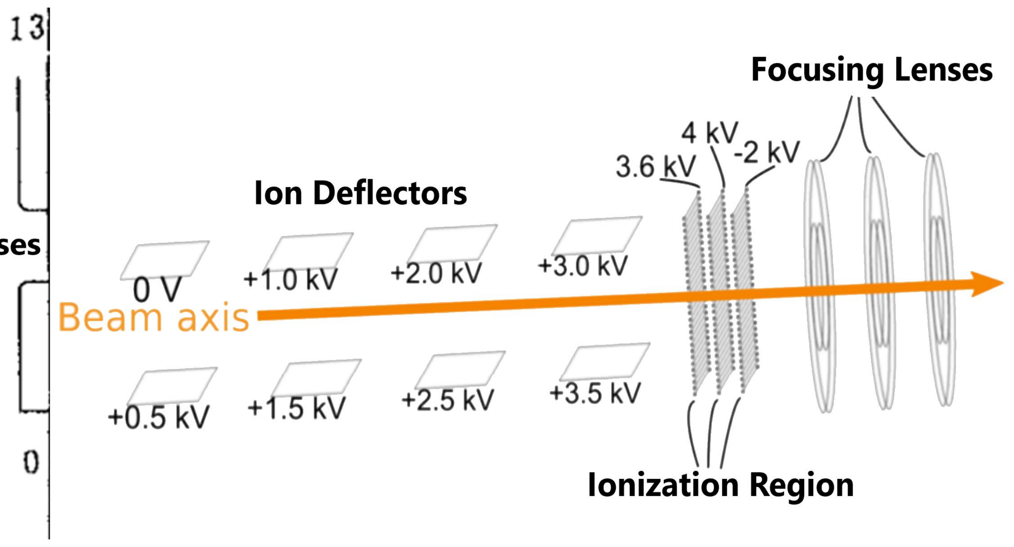
Field Ionizer Geometries

We evaluated two field ionizer geometries with axial electric fields that allow for energy labeling of the field-ionized ions:

- Classical electrode stack with ion filter and **spherical potential** geometry (below left)
- Ion filtering-plates and high-transparency **wire grids** with linear potential geometry (below right)

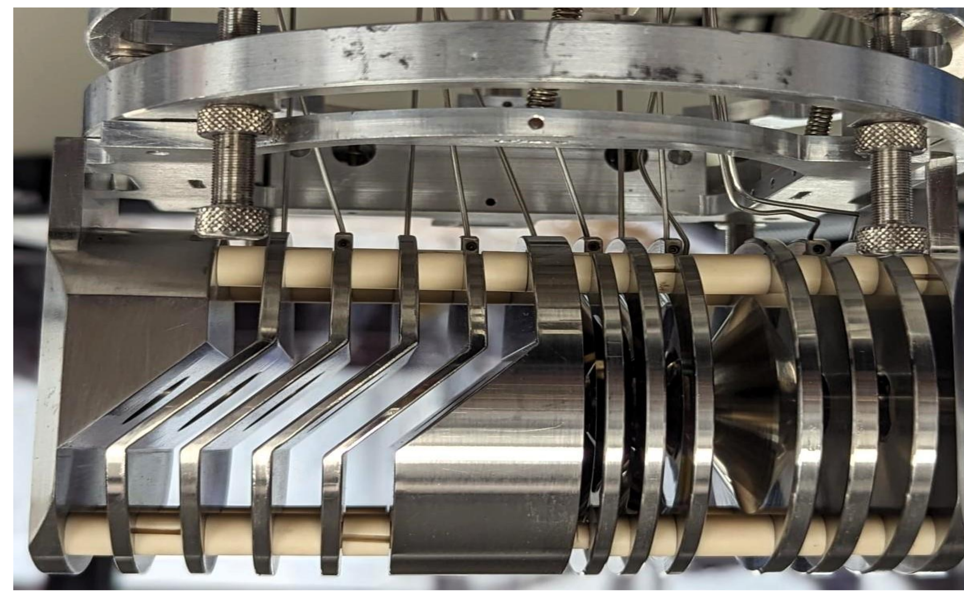


Stacked electrodes design with ion filter and spherical potential for beam focusing and energy labelling [2]. This design is open to atom/ion beams.

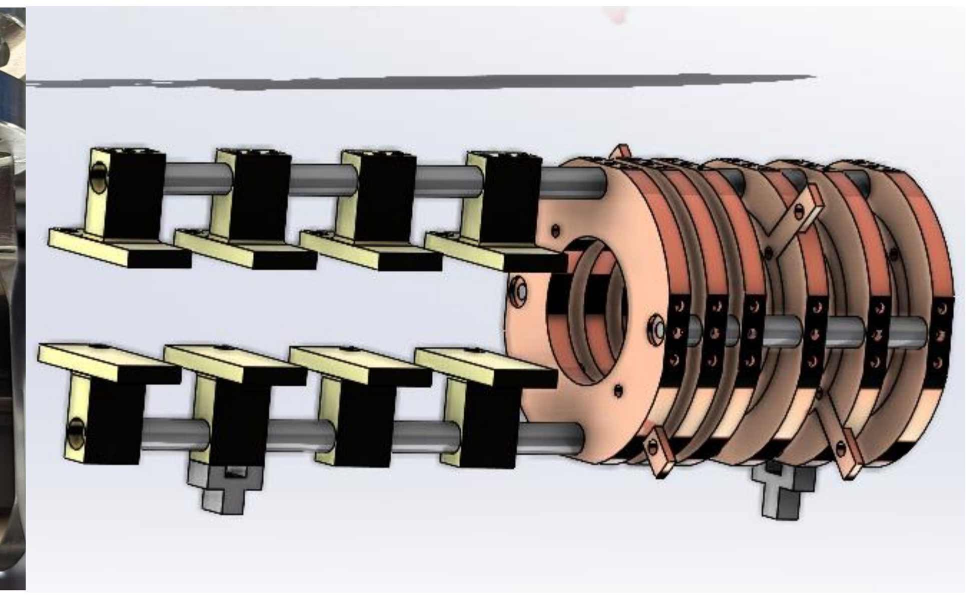


Mesh grid design producing a uniform electric field with minimal focusing [3]. A high transparency grid is required, which will be subject to interaction with the atom/ion beam.

Simulations and Results



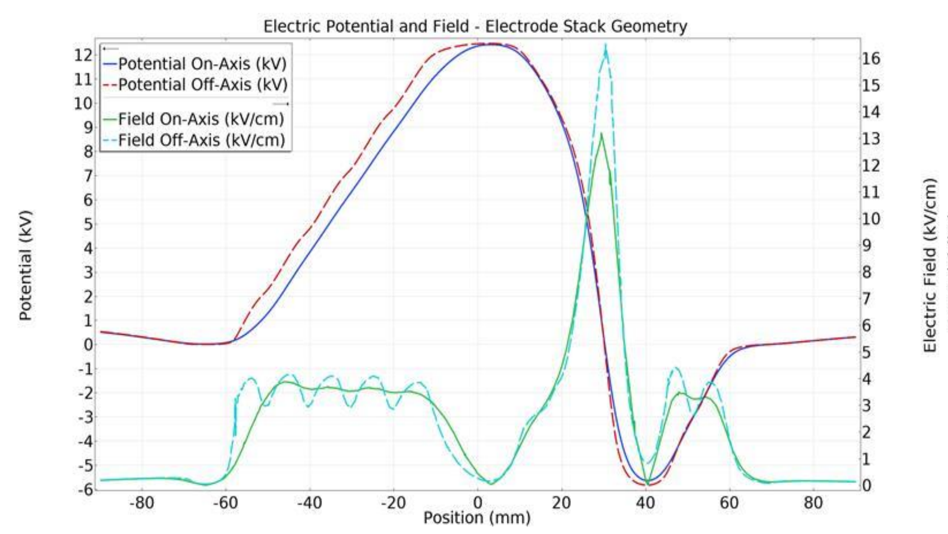
The electrode stack design built and mounted with an efficient voltage distribution system



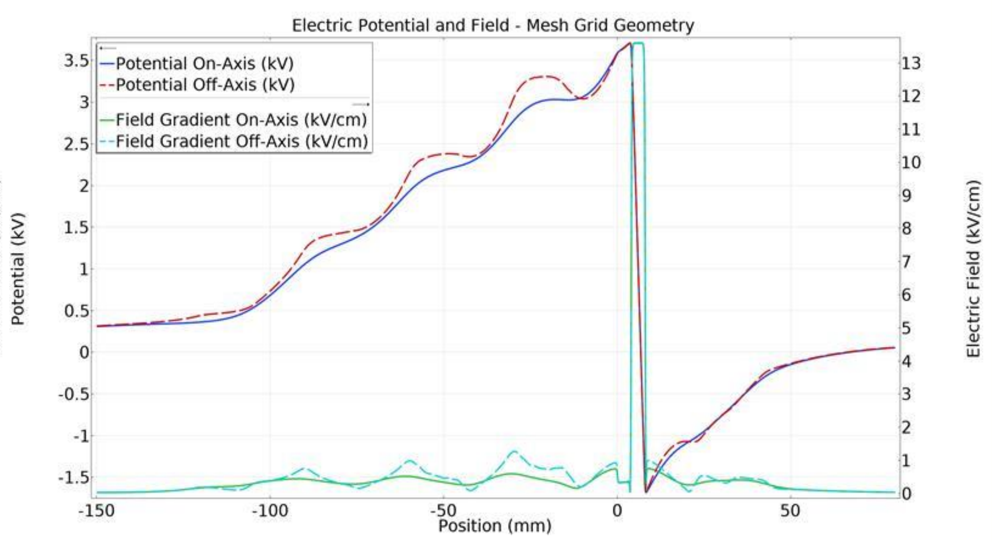
A CAD model of the mesh grid design (without meshes implemented). The mounting rods are based on the electrode stack design on the left.

The goal is to evaluate existing solutions with regards to:

- ❑ deflection of background ions produced by collisional ionization of Rydberg atoms
- ❑ variation in energy signature of field-ionized Rydberg states
- ❑ suitability for use in the ISAC polarizer facility



Fields and potentials of the electrode stack design



Fields and potentials of the mesh grid design

Both geometries had a **gradual rise in potential** followed by a **steep drop**, producing a **localized region** of **high field** where Rydberg atoms are ionized.

The **location of ionization** in the first design **depends on Rydberg state**, whereas in the second design, all field ionization occurs at once. The former is useful for **Rydberg spectroscopy** while the latter is optimized for ionization efficiency.

The **second design** has a far **smaller potential spread** than the first, two-to-three orders of magnitude lower per our calculations.

Outlook

For spectroscopy and analysis of Rydberg states, we will use the older stacked-electrode field ionizer**.** We are currently **finalizing a design** to adapt the mesh ionizer onto our beamline and using **particle trajectory simulations** to optimize the design for successful deflection of incoming ions and field ionization of the entire atom beam. Once built, we will deploy this system to conduct collinear laser spectroscopy of low-intensity RIB, ultimately delivering unique spin-polarized beams to experiments.

Acknowledgements

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References

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Discovery, accelerated