Classical Stellarators as Sources of Ions for Accelerators – Modeling of Ion Extraction

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Electron Cyclotron Resonance Ion Sources generate high-charge ions for accelerators

- Hot electrons (10keV), cold ions (eV)
- Trend to higher $f_{ECRH}$, improved confinement, reduced electron tails
- State of the art: 28GHz (1T at center, 3T at mirrors). Plans for 50GHz
- Open questions: stochastic heating, two-frequency phenomena
Toroidal ECRIS could improve confinement and make better use of the field

- Bumpy torus + tor. hexapole
- \( l=3 \) classical stellarator
- TF “Mono-coil” inspired by MST
A toroidal ECRIS will make better use of B, allow higher $f_{ECRH}$, $n_e$ and confinement and ionization

- **Toroidal Apparatus for Resonant Absorption of Low Frequency Waves and Generation of highly charged Ions (TARALLO)**

- **Ion extraction**
  - Loss cone
  - Divertor
  - Charge-dependent drifts
  - Pulsed saddle coil
  - Collector at dist.<FLR from plasma boundary
  - e.s.
  - Deflecting magnets

**Possible configuration:**
- $R=35\,\text{cm}$
- $a=75\,\text{cm}$
- $B=2.5\,\text{T}$, $f=70\,\text{GHz}$
- Water-cooled copper, $t\approx 2\,\text{s}$

- Techniques used in accelerators to pass particles from one storage ring or accelerator to the next, of higher energy (ECRIS would be first ring)
COMSOL was used to model fields, particle drifts and trajectories in TARALLO

Magnetic extraction of Bi⁺ from outer midplane

Other ions, charge-states and initial conditions also modeled, to study selectivity in mass, charge and velocity space.
Magnetic configurations considered

Mono-coil TF uniformity

Rotated hexapole

Various $l$ and $n$ considered

Top view for $I_{\text{hex}} = 30 \text{ kA}$ and $300 \text{ kA}$
Helical hexapole bends otherwise vertically drifting particles. Strong fields make boundary 3D.

Use drifts and non-axisymmetries to concentrate ion losses in specific $\theta$ and/or $\phi$, thus facilitating extraction.
Two ion extraction methods numerically demonstrated: 1) ExB

Dielectric used to simulate Debye shielding of capacitor’s fringing field
Two ion extraction methods numerically demonstrated: 2) magnetic deflector/divertor

Inboard extraction seems more efficient. Due to “meniscus”? 
Summary and Conclusions

- ECRIS are EC-heated plasma-based sources of ions (Au, Pb etc.) for accelerators such as LHC, RHIC, FRIB and others.
- Conventional ECRIS are linear (magnetic mirror + hexapole) and have reached high $n_e$ and $T_e$, but need to improve confinement.
- Toroidal ECRIS proposed here. Obvious improvement of confinement expected.
- Challenge will be ion extraction. Various methods proposed. Two were modeled and shown to work, in the limit of validity of single particle trajectories:
  - Electrostatic extraction
  - Magnetic deflector/divertor