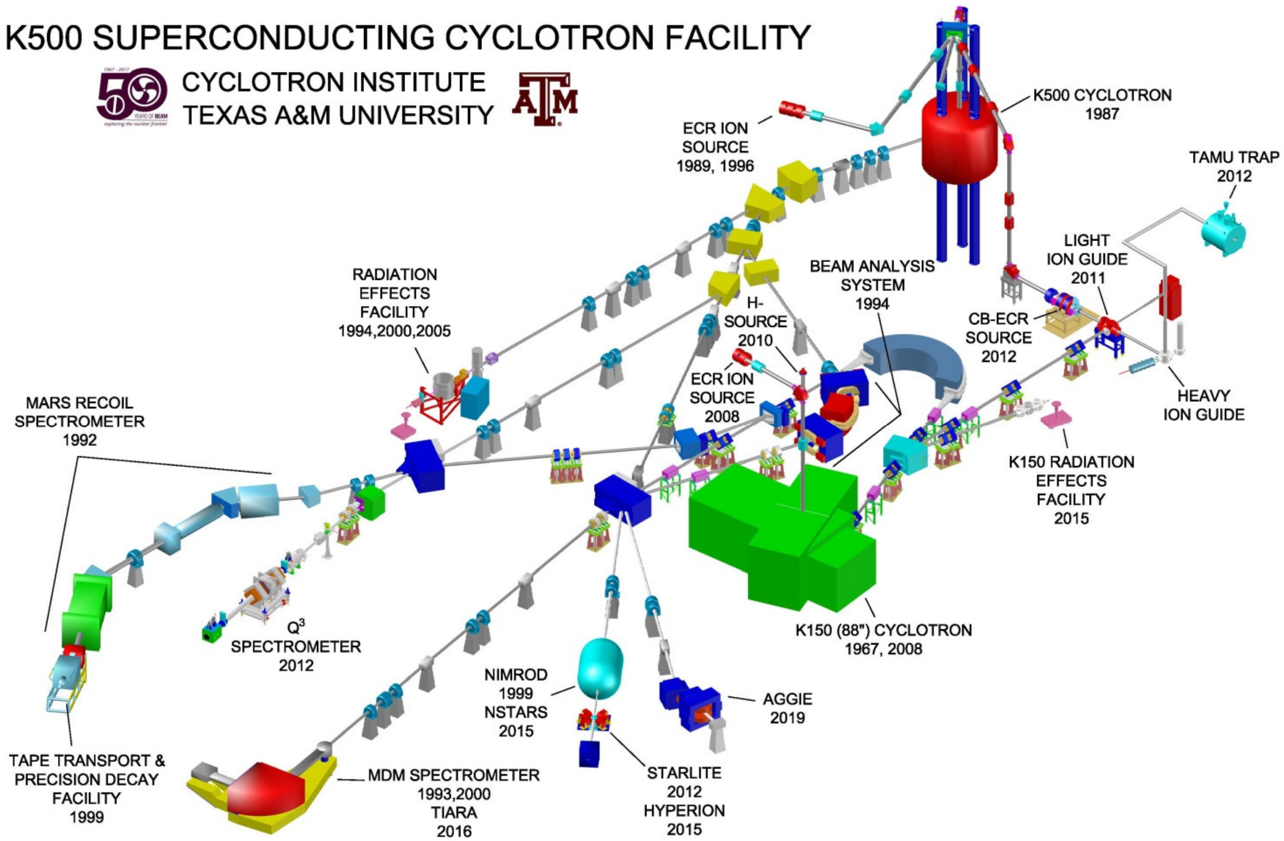
CYCLOTRON INSTITUTE
Texas A&M University

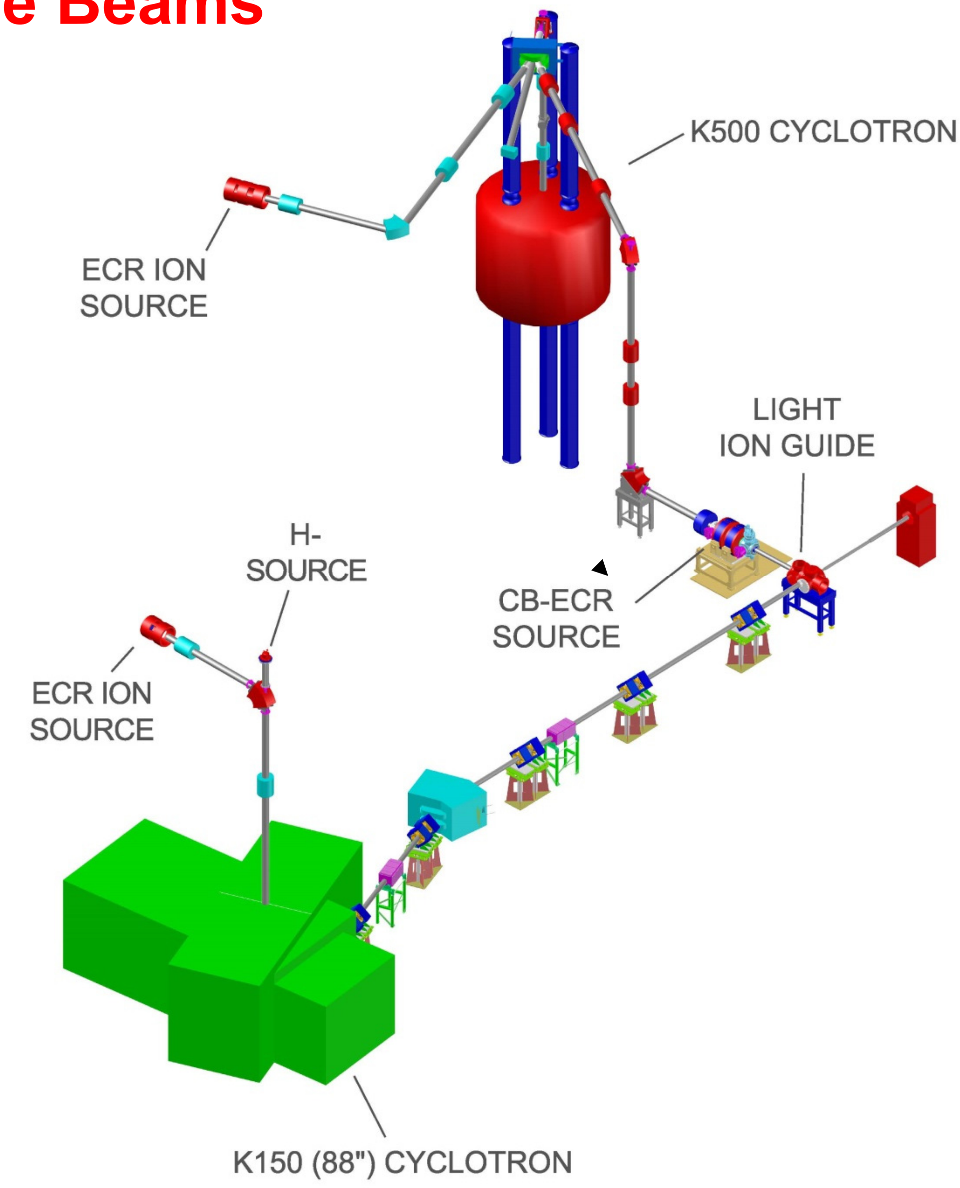
FIRST BEAMS PRODUCED BY THE TEXAS A&M UNIVERSITY RADIOACTIVE-BEAM UPGRADE

D.P. May, F.P. Abegglen, J. Ärje, H. Clark, G. J. Kim, B.T. Roeder, A. Saastamoinen, and G. Tabacaru



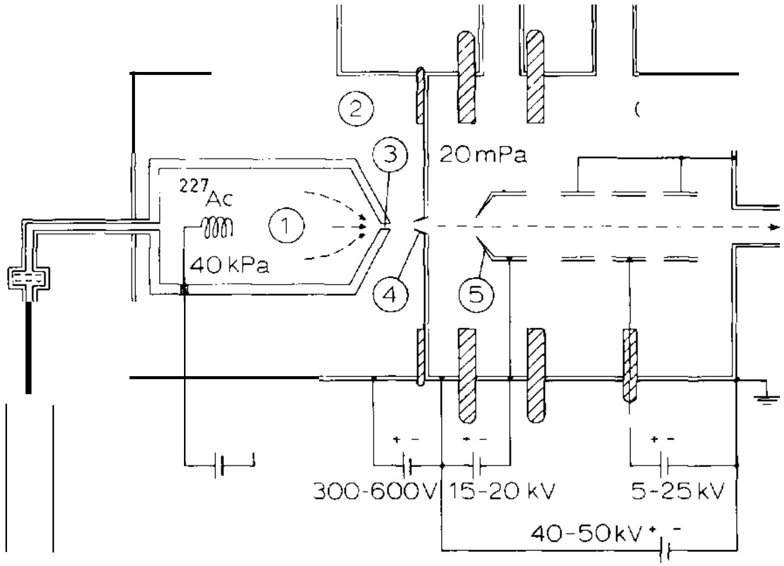
Steps for Radioactive Beams

- *Intense light-ion beams from the K150: p and d from negative-ion source, also ^{3}He and α*
- *High production of radioactive 1+ beams from the light-ion guide (LIG).*
- *Efficient boosting to high-charge states by an electron-cyclotron-resonance ion source (CB-ECRIS).*
- *Tuning of the K500 cyclotron aided by analogs and detector stations.*



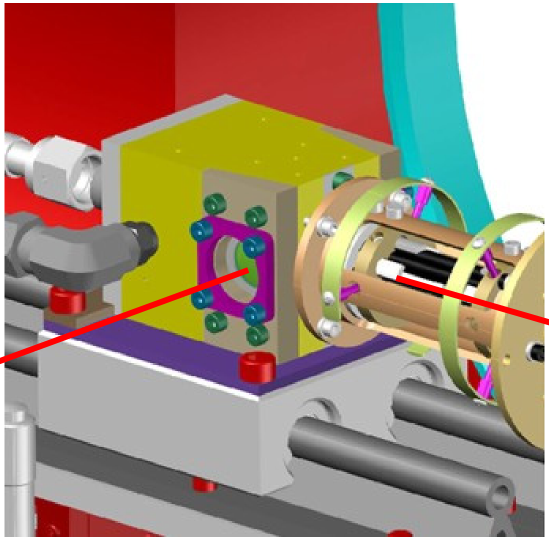
Basis for the LIG is the ion-guide on-line (IGOL) method developed at JYFL.

Juha Ärje, 1981

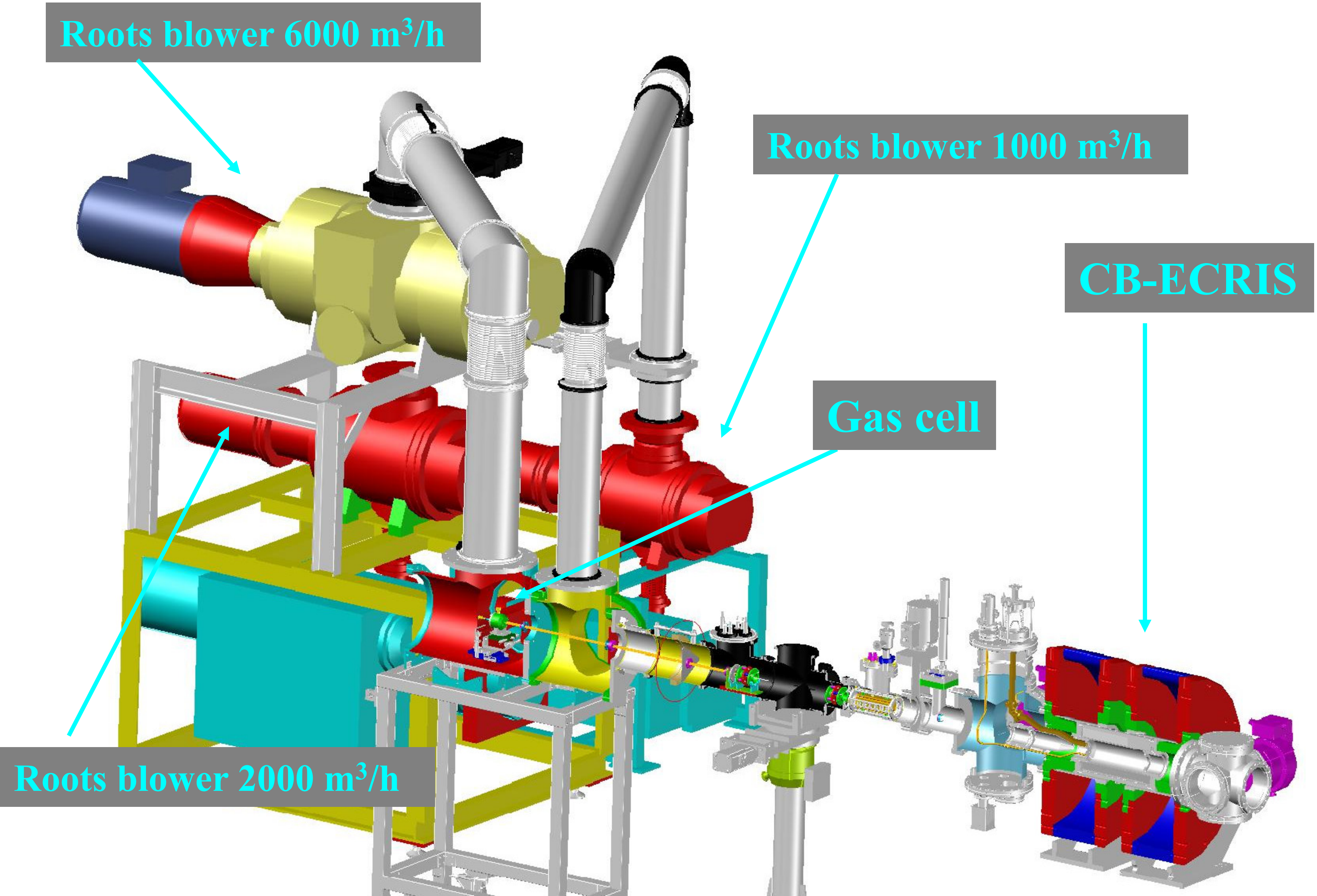


RIB Production via Light-Ion Guide

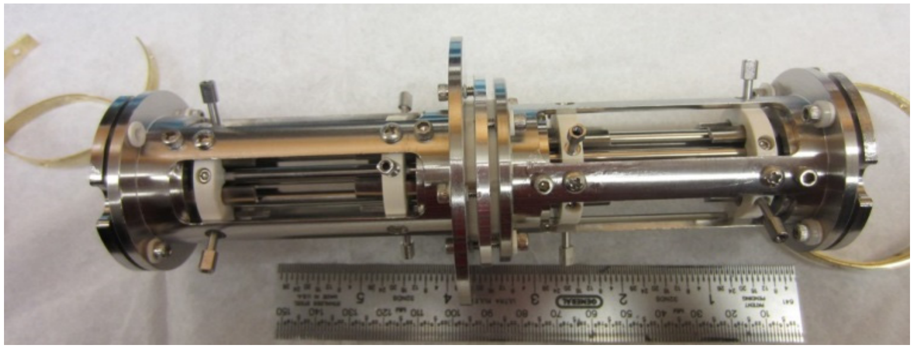
- **The K150 provides an intense beam of light ions (p, d, ^{3}He, α) to a target mounted on the side of the LIG chamber.**
- **Products from the target directly enter a helium gas flow.**
- **Products in the chamber are stopped by the helium, remain singly charged, and are guided by the helium flow through an aperture of one to two millimeters diameter.**
- **For K500 acceleration the low-charge-state beam of products is transported to the CB-ECRIS. In the ECRIS the products are stopped in the plasma and further ionized by the energetic electrons.**
- **Extracted beam from CB-ECRIS is analyzed, and a beam of one charge-state is injected into the K500.**

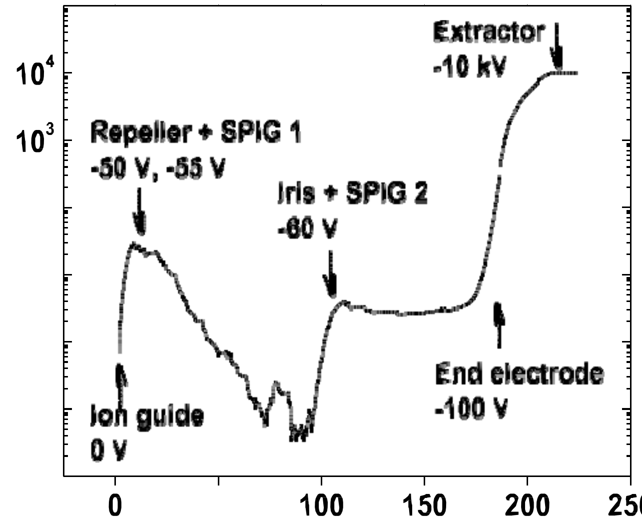


Pumping to handle the helium flow



One significant improvement from 1981 was the introduction of an RF-only sextupole ion-guide (SPIG) following the target chamber.





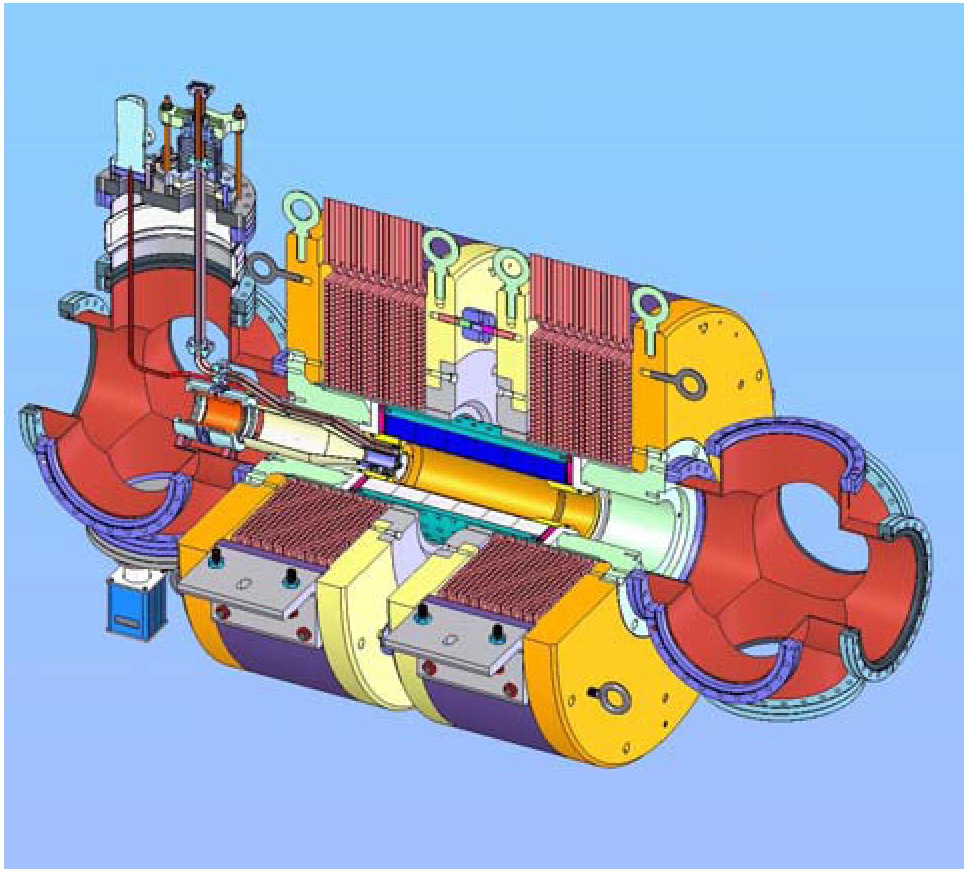
Inner diameter	*10 mm*
Rod diameter	*4 mm*
Length	*16.5 cm*
RF frequency	*~ 3 MHz*

Three apertures for control of helium flow

Apertures separately DC biased

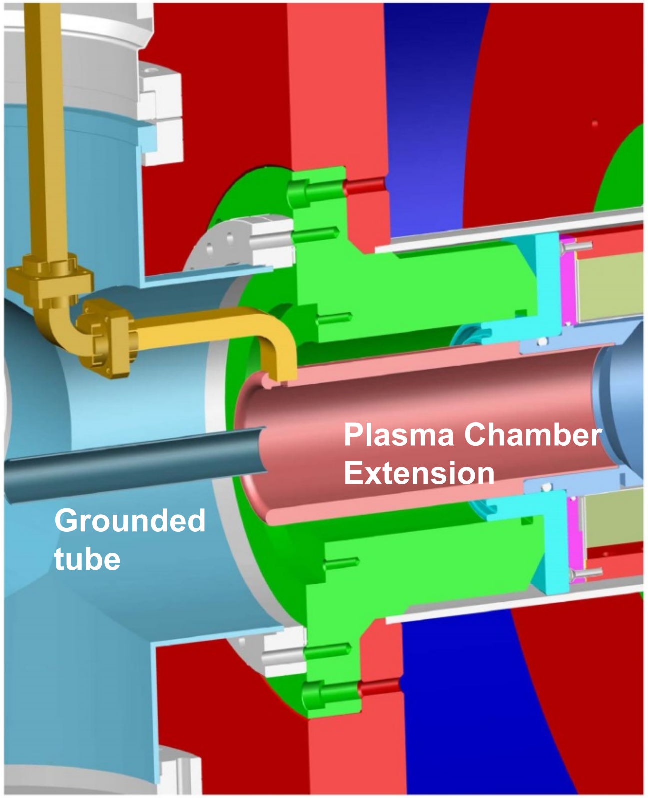
1+ ions are cooled and confined into a small volume along the SPIG while helium is pumped away

The 14.5 GHz CB-ECRIS built on a DOE SBIR grant by Scientific Solutions (W. Cornelius)



The Accel-Decel Option for 1+ CB-ECRIS Injection.

Injection-end electrodes discarded



Accel-Decel charge-breeding tests with radioactive beams

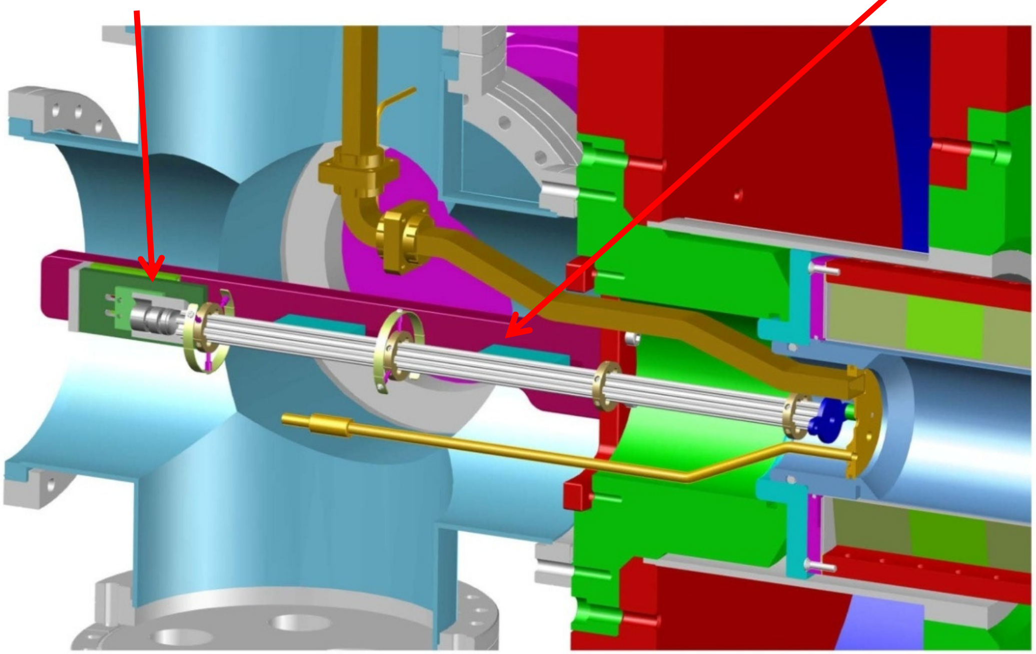
Reaction studied	History
$^{58}Ni(p,n)^{58}Cu$	$^{58}Cu^{14+}$ was separated with a total yield of **21 ions/μC.**
$^{27}Al(p,n)^{27}Si$	$^{27}Si^{5+}$ first time observed and separated with a very low efficiency **0.03 ions/μC**.
$^{64}Zn(p,n)^{64}Ga$	Multiple experiments were performed on this reaction. $^{64}Ga^{17+}$ had a total yield of approximately **62 ions/μC**. Contaminants in CB-ECRIS made it impossible to separate radioactive ^{64}Ga after acceleration.
$^{64}Zn(p,d)^{63}Zn$	Radioactive $^{63}Zn^{17+}$ was separated and an attempt to accelerate was made. Contaminants from CB-ECRIS (^{63}Cu) made it impossible to clearly identify radioactive ^{63}Zn after acceleration.
$^{114}Cd(p,n)^{114}In$	$^{114}In^{19+}$ was separated with an estimated charge-breeding efficiency of **1%.**

Discouraging!

Perhaps increased beam-energy dispersion by the helium, or alignment, or lack of injection symmetry was spoiling the charge-breeding.

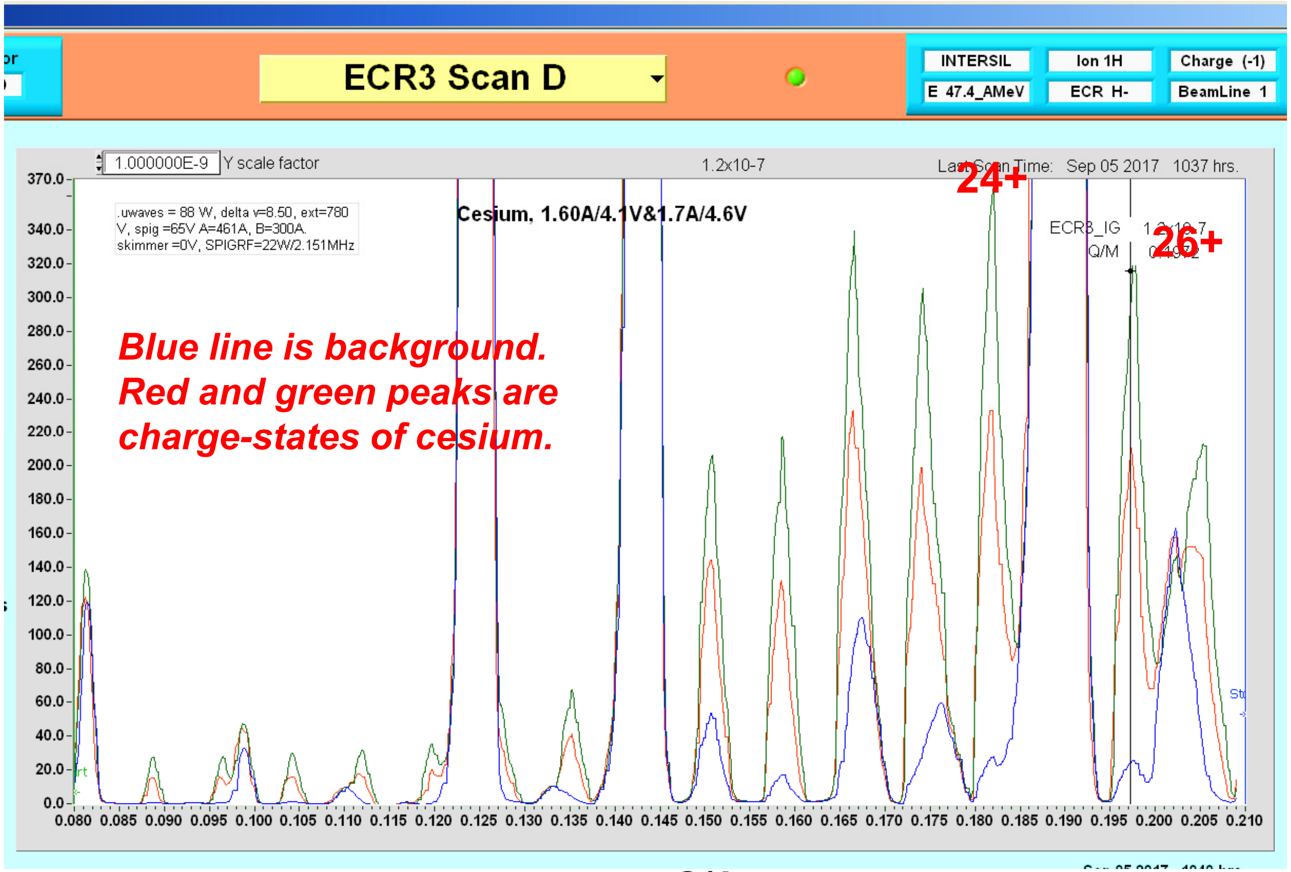
Fortunately we had been testing direct SPIG injection into CB-ECRIS

Alkali ion source (HeatWave) and 0.4 meter SPIG



Scan of charge-bred cesium using 0.4 m SPIG for direct injection

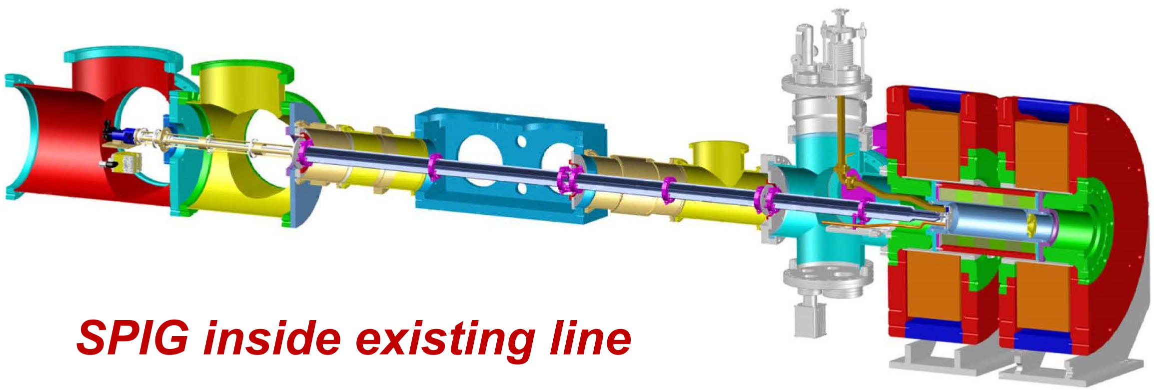
Heater = 0A (Blue), 1.6A (Red), 1.7A (Green)



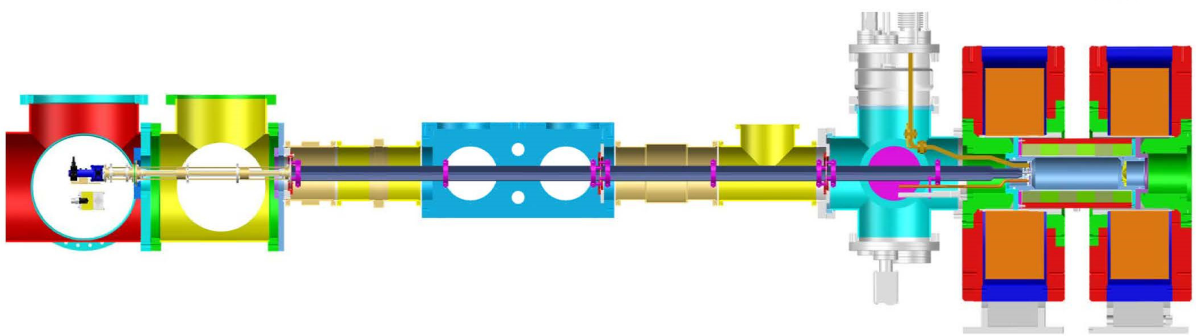
Estimate of 10% efficiency into the 24+

So it was decided to develop a SPIG that would span the whole 2.5 meters between the target chamber and the CB-ECRIS (no accel-decel).

This would be more tolerant of alignment error and also eliminate helium flow down the line by using multiple apertures with small DC biases.

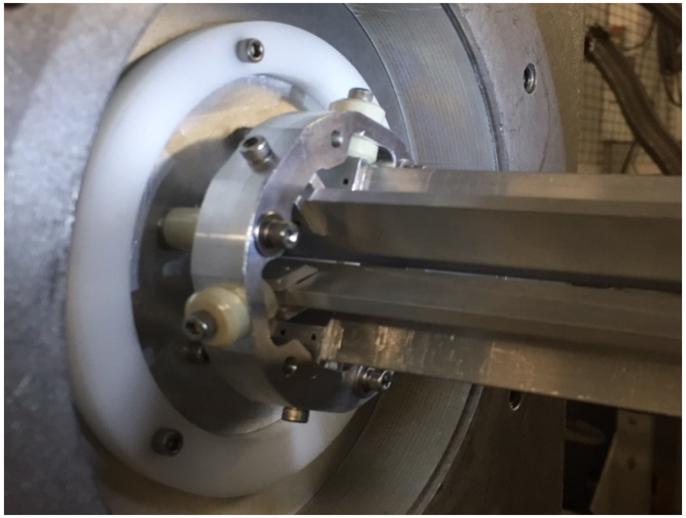


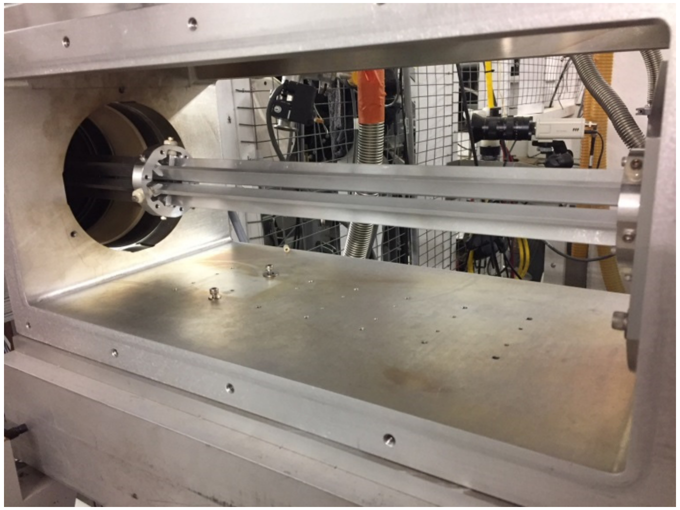
SPIG inside existing line



Vaned 2.5 m Sextupole Ion-Guide

SPIG and insulated pumping aperture

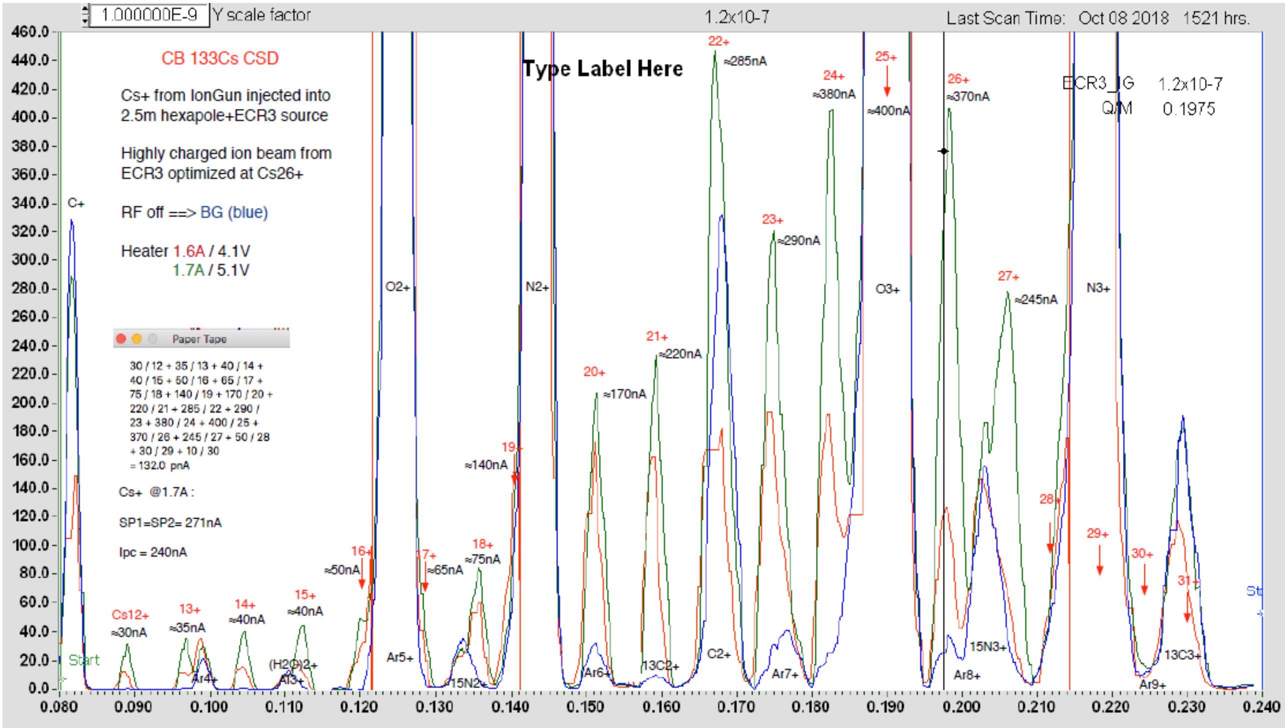




Middle SPIG section – fitted into existing chamber

Scan of charge-bred cesium, 2.5 m SPIG

Heater = 0A (Blue), 1.6A (Red), 1.7A (Green)

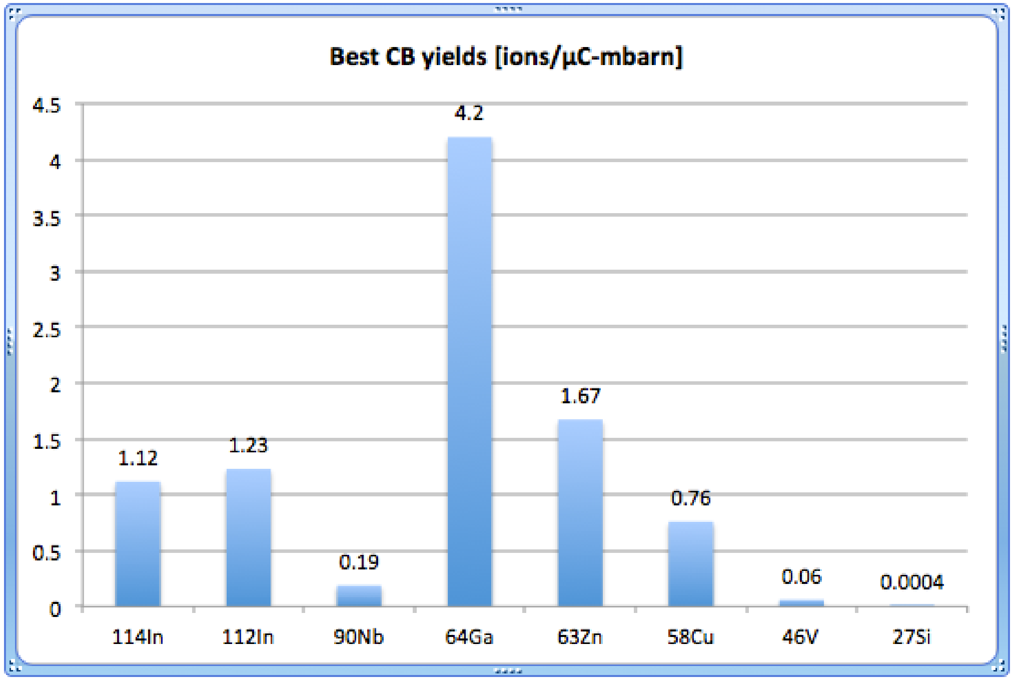


~50% global efficiency estimated

Next a 228 Th source placed inside the target chamber with <u>helium</u> flow provided 1+ ions of 220 Rn and 216 Po (alpha emitters). The charge-breeding global efficiency was ~50%, as well.

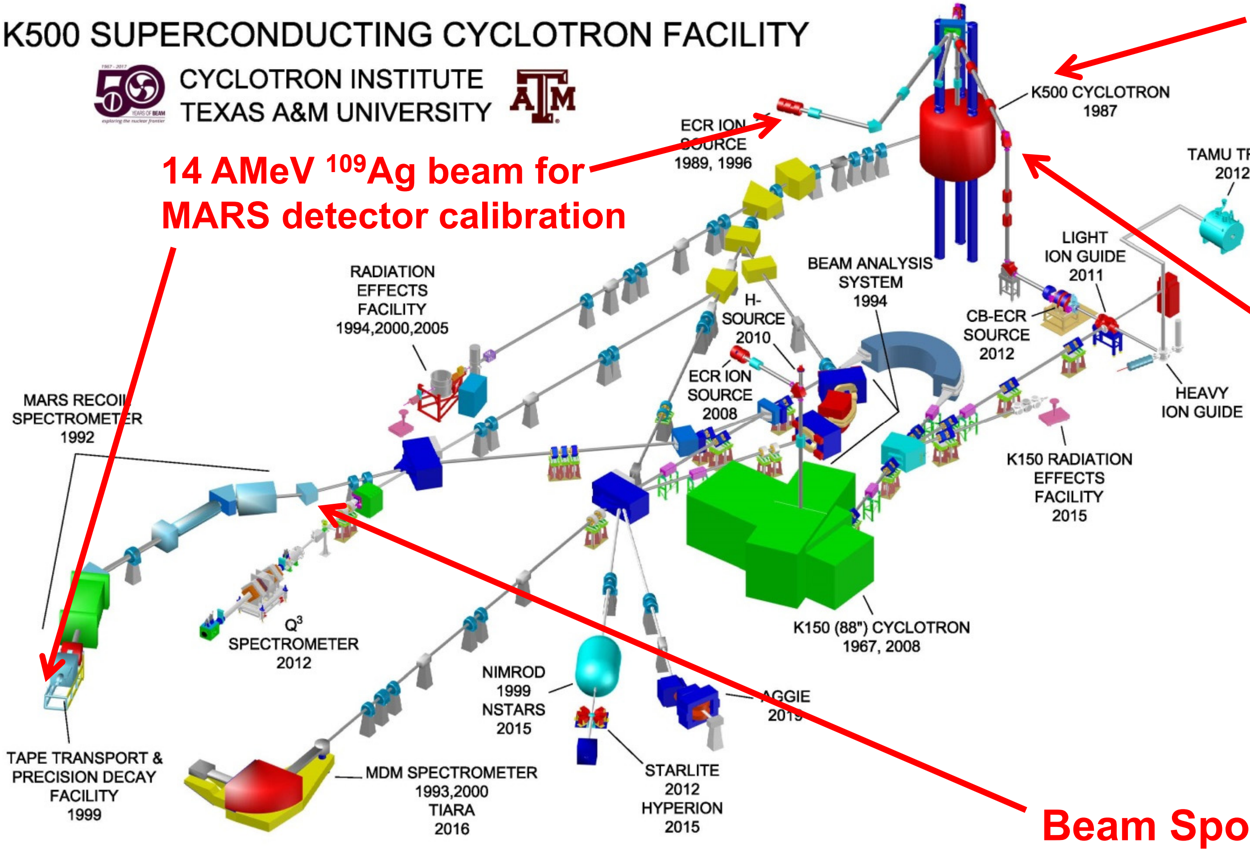
Charge-bred yields from proton-induced reactions

Recoil ion	Yield [ions/μC-mbarn]
114In	1.12
112In	1.23
90Nb	0.19
64Ga	4.2
63Zn	1.67
58Cu	0.76
46V	0.06
27Si	0.0004



Intensities of $^{64}Ga^{14+}$, $^{63}Zn^{14+}$, $^{114}In^{20+}$ and $^{112}In^{21+}$ were 680, 897, 610 and 974 ions/μC, respectively. So, two orders of magnitude improvement.

Tuning the K500 and its beam-lines for the ^{112}In RIB



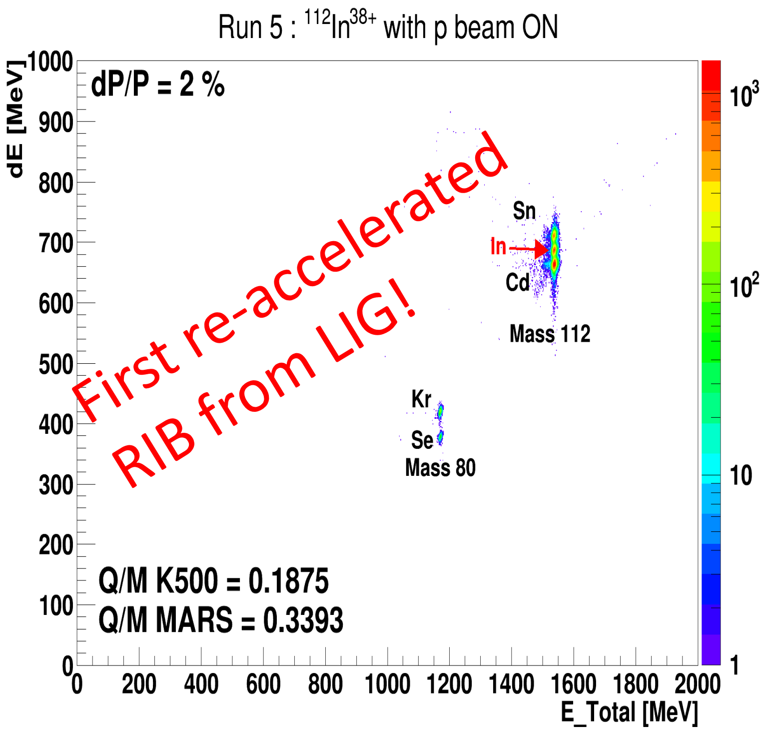
Change the K500 field and tune14 AMeV $^{16}O^{3+}$ (.18758)

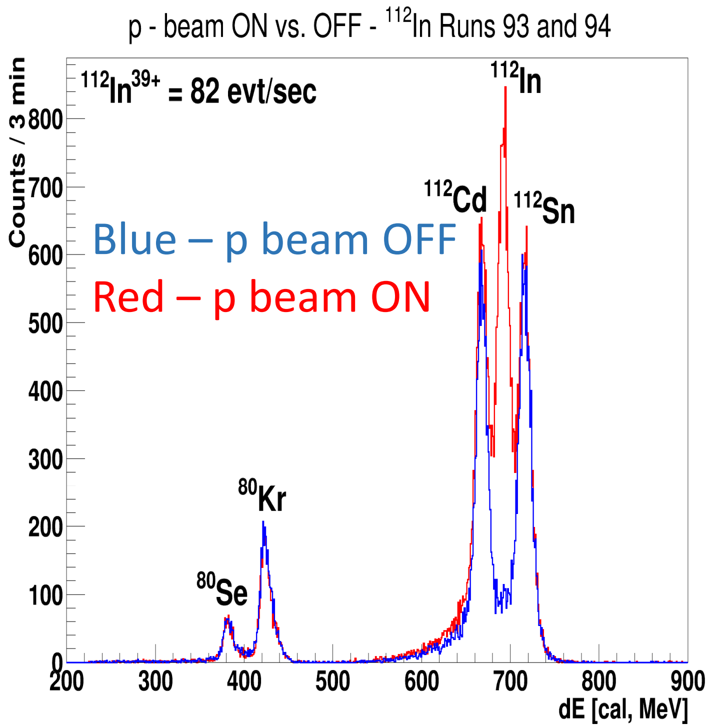
14 AMeV ^{109}Ag beam for MARS detector calibration

Change only the RF by +6.5 KHz for 14 AMeV $^{112}In^{21+}$ (.18768)

Beam Spot. Here the beam is stripped for injection into MARS.

Results for ^{112}In re-acceleration



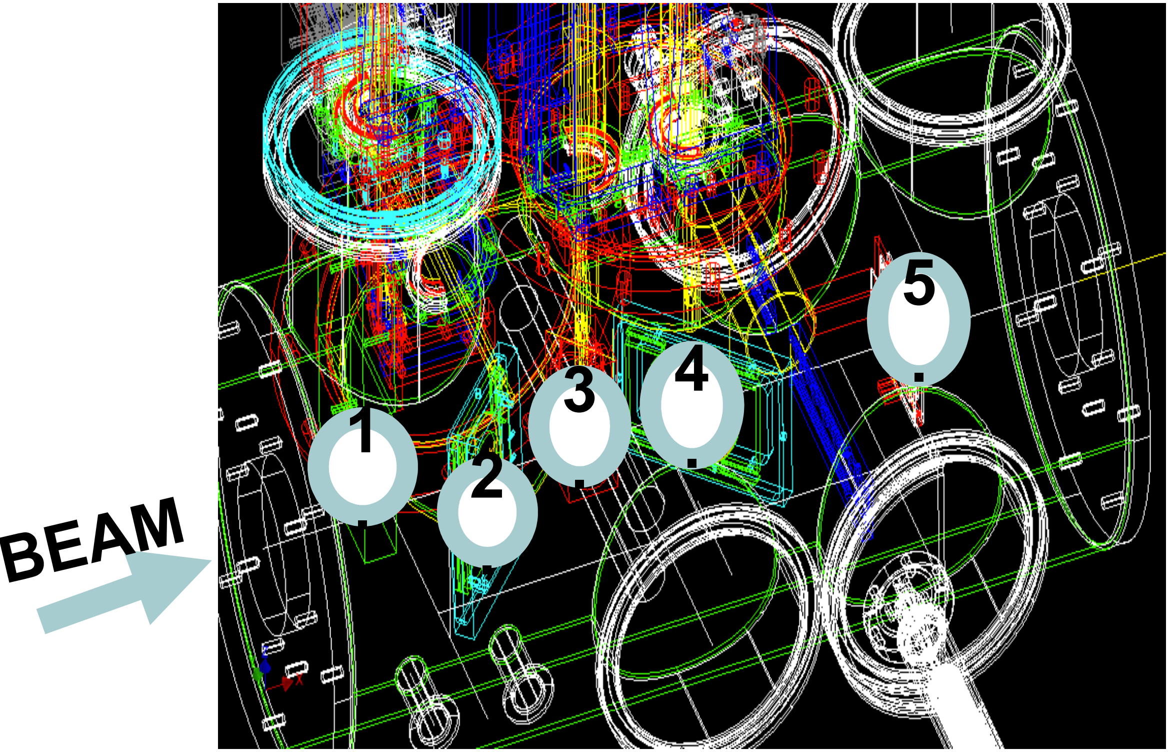


- *$^{112}In^{21+}$ produced with $^{114}Cd(p,3n)$ reaction with LIG and CB-ECRIS.*
- *With $^{16}O^{3+}$ pilot beam at 14 MeV/u and a K500 frequency shift of 5.5-6.5 kHz, observed ^{112}In at MARS focal plane.*
- *$^{112}In^{39+}$ had the best result (after stripper foil). Up to 100 p/s was observed, typical was ~ 80 / sec. (I_{proton} = 2 μA)*

Outlook – Efficiency estimates

- How much ^{112}In did we make (best result) ?
  - 0.3 (MARS)*0.1 (K500) estimated transport to end of MARS for $^{112}In^{39+}$
  - If 100 particle/sec observed at MARS, implies ~ $3*10^3$ p/s $^{112}In^{21+}$ after CB-ECR.
- For ^{112}In, we were limited to about 2 μA protons on target (water leak). ~10x more beam now available.
- Estimate 10^3 p/s re-accelerated (after K500) in reach for ^{112}In.
- Will soon try other beams with > 100 mb cross- section and need to work towards lighter nuclei. Some possible beams:
  - ^{57}Ni – from $^{58}Ni(p,d)$, E_p = 26 MeV – σ (TALYS) = 293 mb.
  - ^{45}Ti – from $^{46}Ti(p,d)$, E_p = 26 MeV – σ (TALYS) = 455 mb.
  - ^{30}P – from $^{27}Al(\alpha,n)$, E_α = 11 MeV – σ (TALYS) = 200 mb.
  - ^{34}Cl – from $^{35}Cl(p,d)$, E_p = 24 MeV – σ (TALYS) = (g+m) (83+119) mb.
  - ^{37}Ar – from $^{37}Cl(p,n)$, E_p = 9 MeV – σ (TALYS) = 465 mb.

Particle ID station in K500 vault

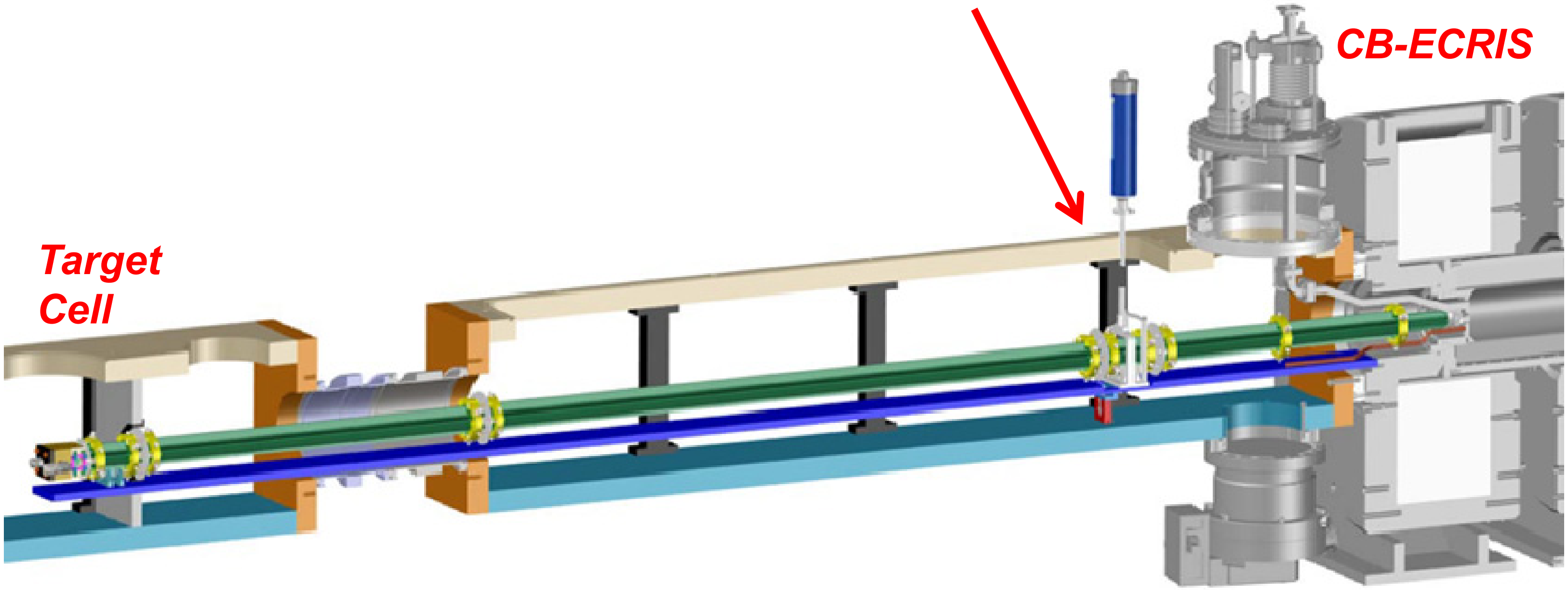


1. FC
2. High intensity viewer
3. Plastic + 1/2 PMT for ion counting
4. Low intensity viewer
5. Rotatable Si dE-E telescope with target ladder

- Plan to install Particle ID station in K500 vault. Most likely placed on the existing BAS line.
- Will consist of viewers (low-light cameras), scintillator PMTs (counting) and a Si-telescope.
- Diamond Detectors – under development
- Plan to charge-strip the beam at the exit of the K500, separate with beamline, and identify with PID station.
- Once beam is tuned, can swing resulting beam into any beam line.

New chamber being designed for SPIG

With easier access and a diagnostic position



Thank you!