Beam Thermalization at The National Superconducting Cyclotron Laboratory

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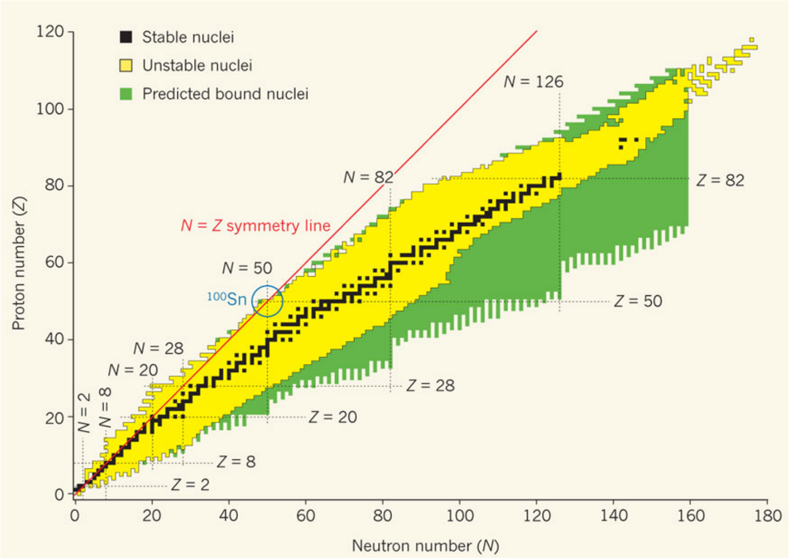
Outline

- ❖ Introduction to beam thermalization at NSCL
- ❖ Experimental results
- ❖ Challenges and improvements

Why Thermalized beams

Projectile Fragmentation provides wide range of very exotic nuclei at high energies without decay losses and without chemical separation.

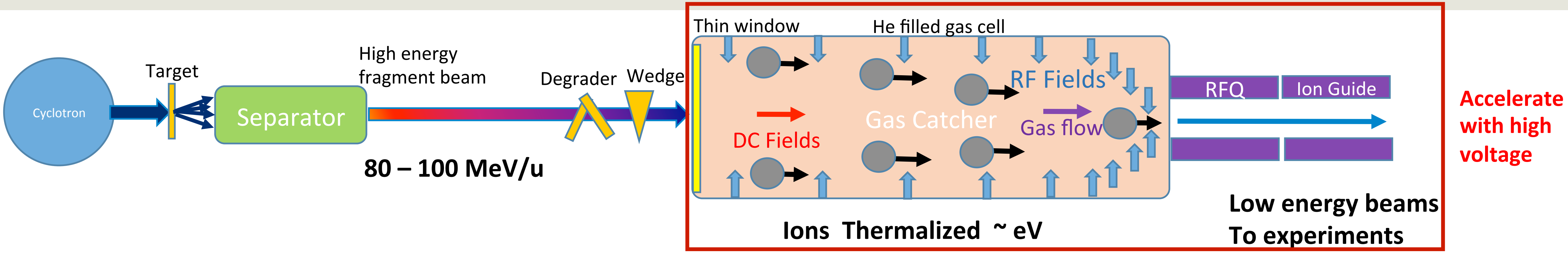
- ❖ Study properties of exotic nuclei far from stability
- ❖ Search for driplines



Some experiments are only possible with low energy beams (0 – 100 keV).

- ❖ High precision mass measurements
- ❖ Laser spectroscopy (Charge radii, nuclear moments)
- ❖ Nuclear astrophysics experiments (Safe coulomb excitation, transfer reactions)

Scheme for Thermalization of Projectile Fragmentation

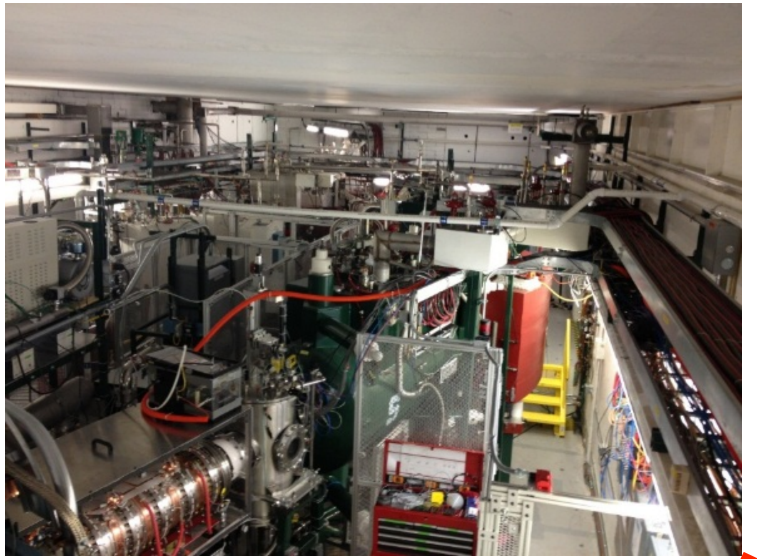


Processes inside the gas catcher:

- Thermalization process produces ions an
  (He_2^+)
- Form stable molecular ions from impurit
  gas.
- Transport of thermalized ions in the buf
  the interactions with molecular ions in tl
  radioactive molecular ions. (Depends on i
  fragment chemistry)

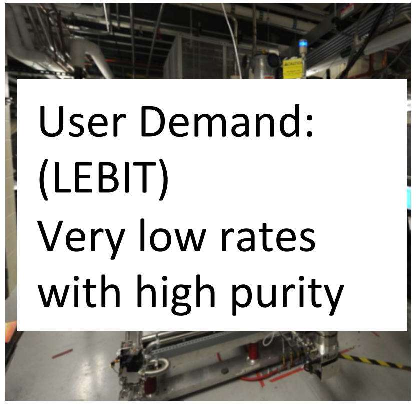
Low Energy Beam Area at NSCL

NSCL expand capabilities to provide thermalized beams to low energy experimental areas (since 2012).



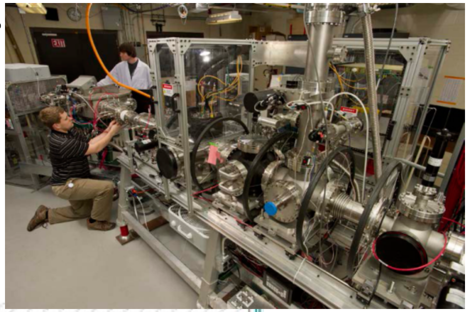
Beam thermalization facility (N4 vault)

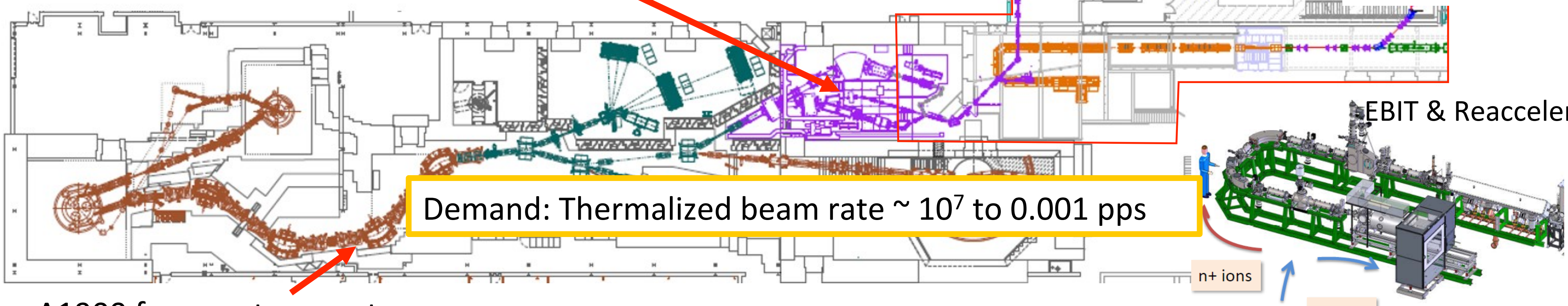
LEBIT (Mass measurements)



User Demand:
(LEBIT)
Very low rates with high purity

BECOLA (Laser Spectroscopy)





Low energy beam area

User Demand:
(ReA3 & BECOLA)
High rates and high purity

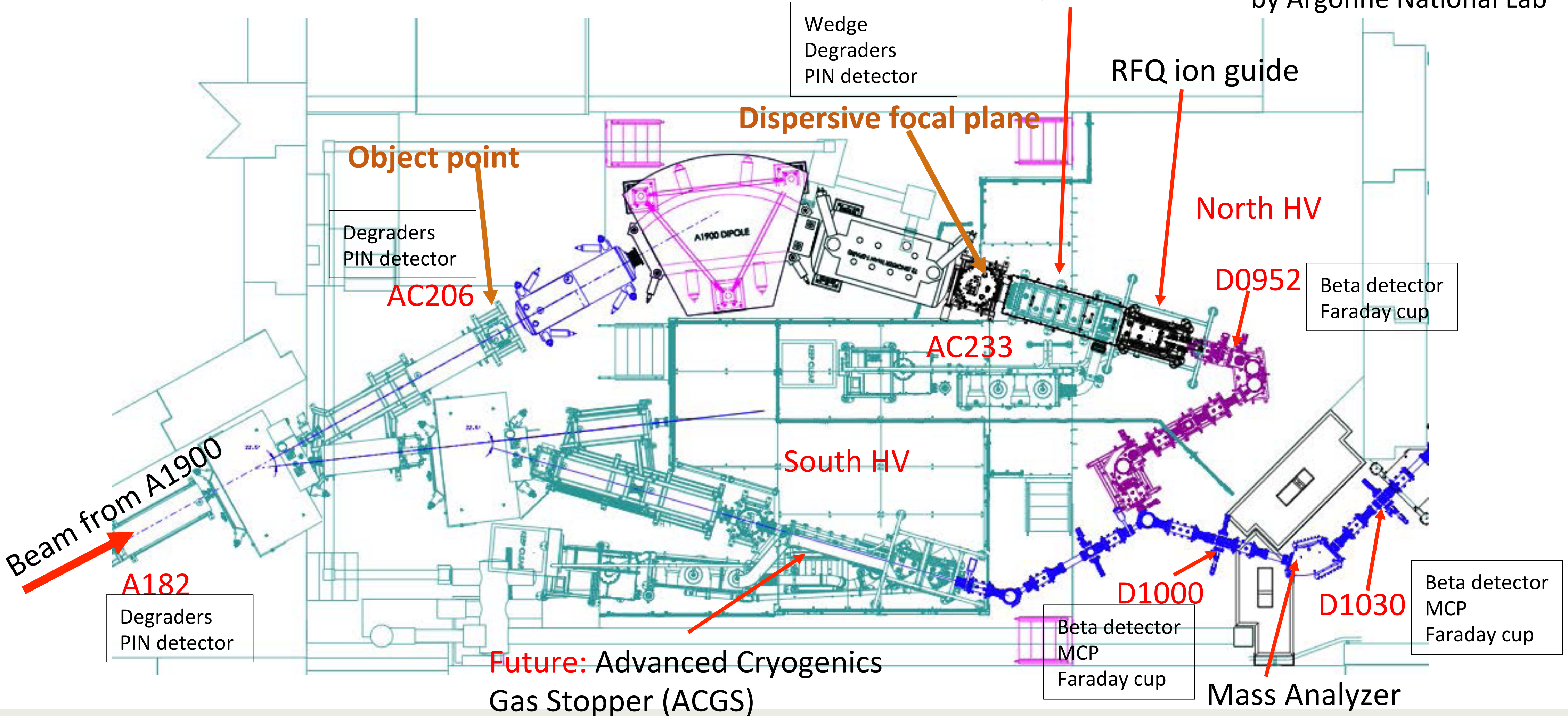
EBIT & Reaccelerator

Demand: Thermalized beam rate ~ 10^7 to 0.001 pps

A1900 fragment separator

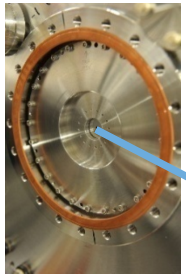
Beam Thermalization Facility

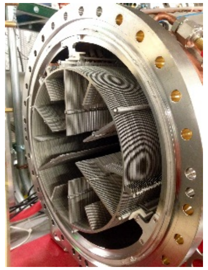
❖ Large gas catcher constructed by Argonne National Lab

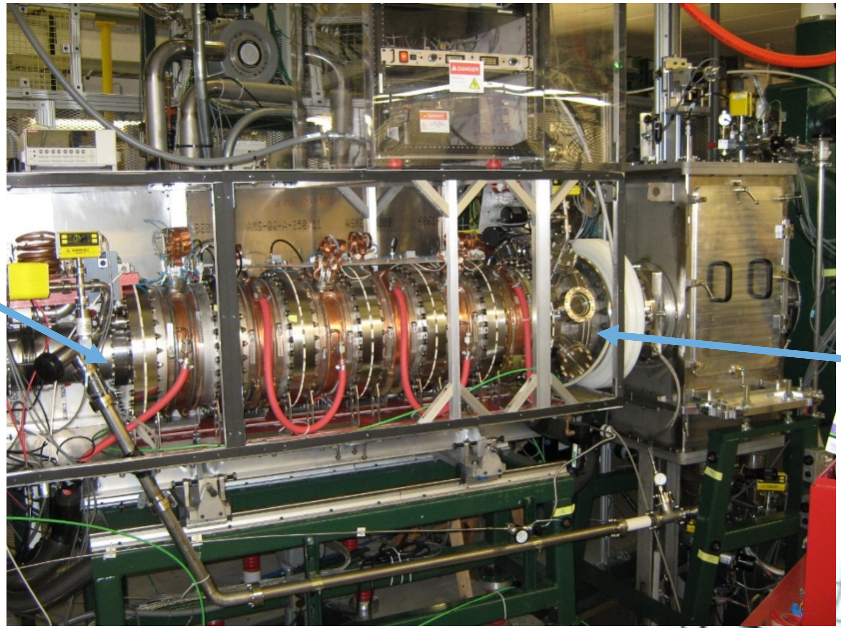


ANL Gas Catcher

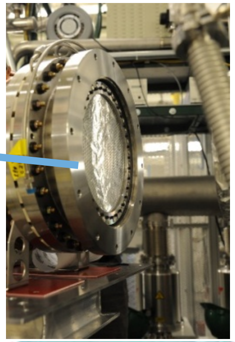
Nozzle
1.3 mm diameter



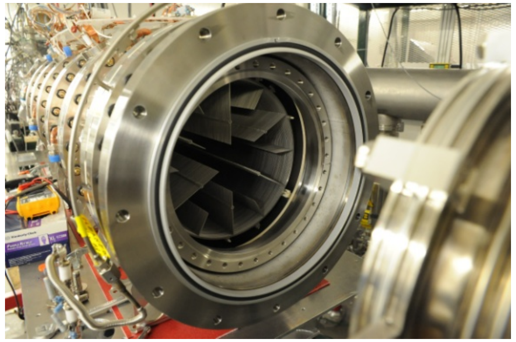




Al thin Window

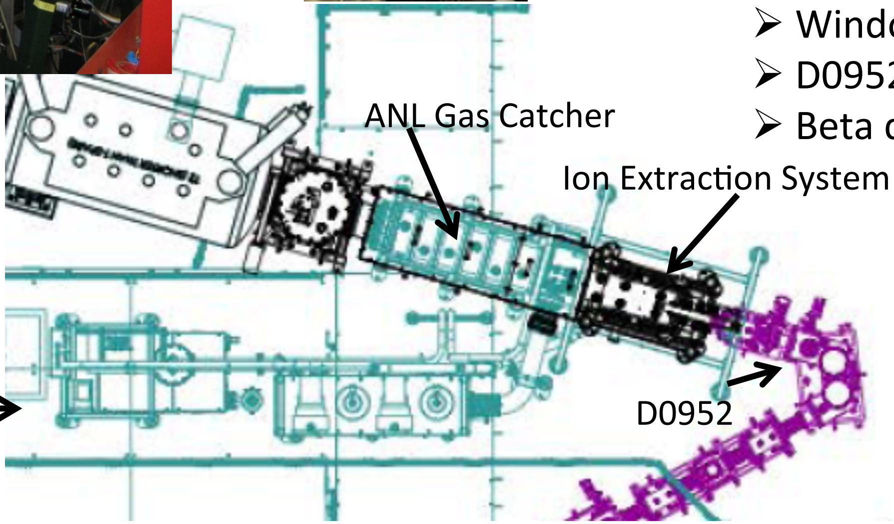


- ❖ Large linear gas catcher constructed by Argonne National Lab
- ❖ 120 cm long gas catcher operate at pressure of 70 Torr and temperature of -10 ^{0}C
- ❖ Operate with Radio-frequency (RF) + DC voltage gradient
- ❖ Measurements capabilities:
  - ➢ Window current ((-) ions)
  - ➢ D0952 Faraday Cup Current
  - ➢ Beta detector

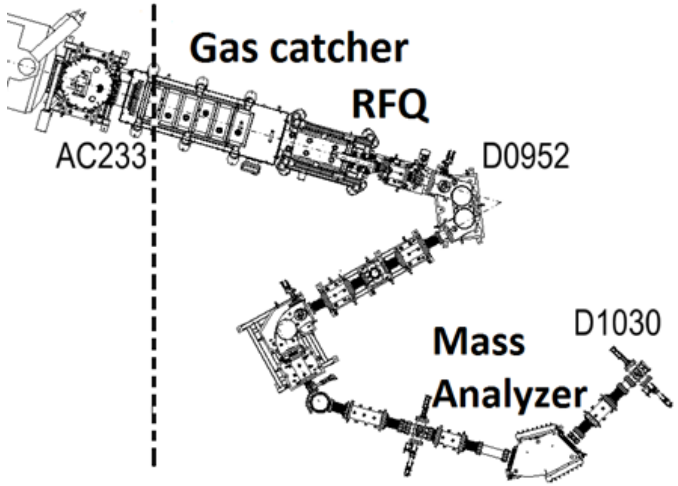


RF electrodes in Gas Catcher

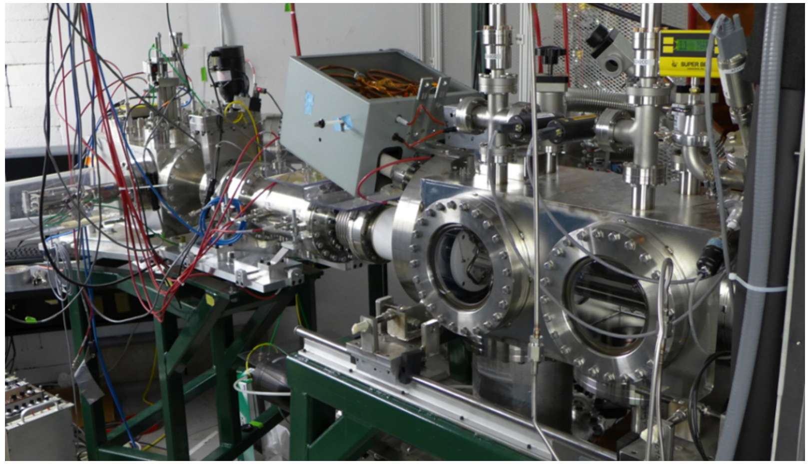
Differential Pumping Station



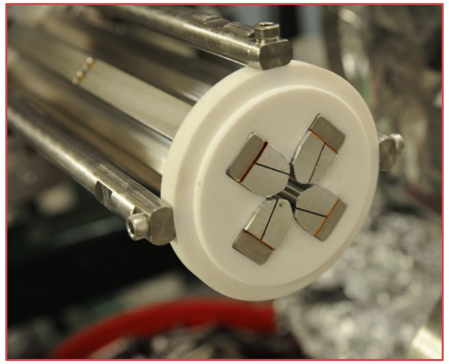
RFQ Ion Guide



Low energy beam



RFQ electrodes



- Beam cooling with He ~ eV energy beam
- Transverse confinement with RF quadrupole electric field
- Axial drag field with DC voltage gradient
- Low emittance

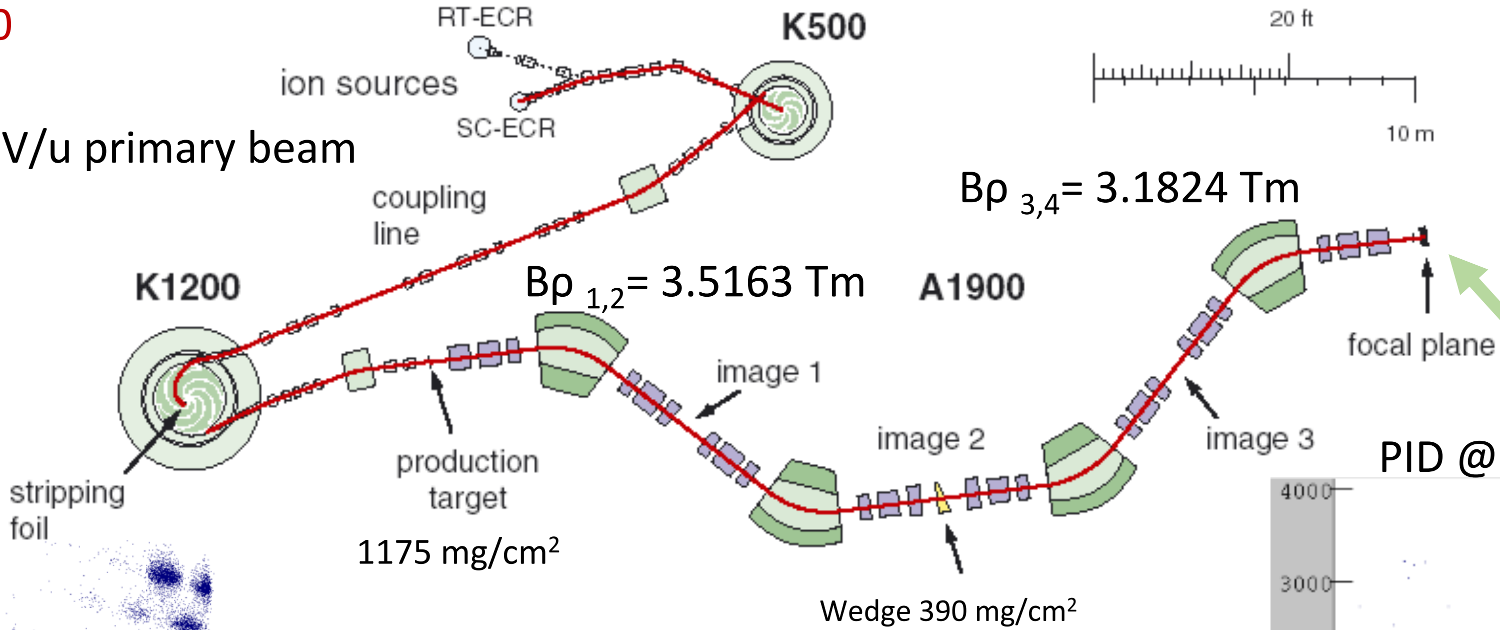
RFQ operates at:

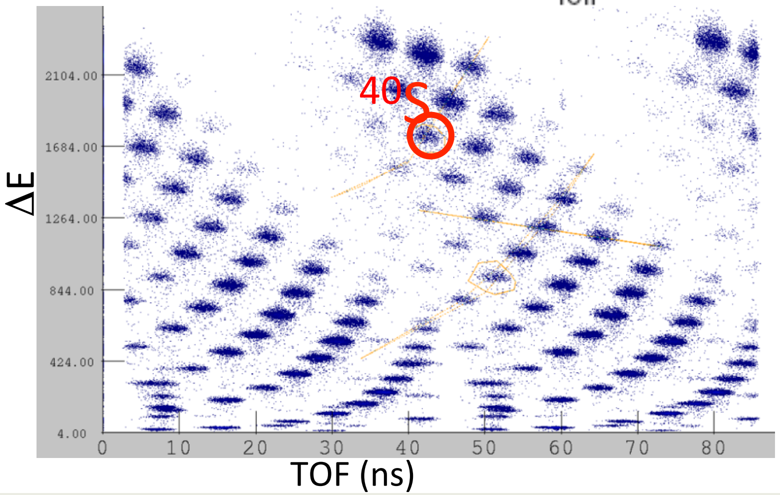
- RF frequency range of 3 -4.5 MHz
- Peak-to-peak amplitude ~ < 500 V

Beam Thermalization: ^{40}S fragment

^{40}S Fragment
Production @ A1900

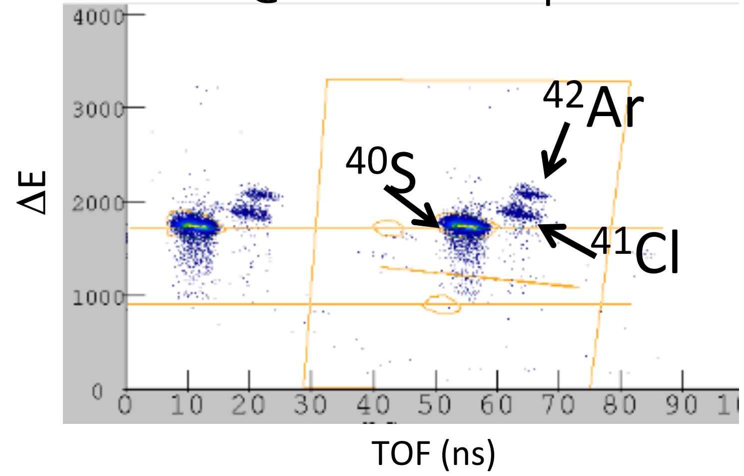
^{48}Ca 140 MeV/u primary beam





Production Rate ~ 5.9E5 pps
Incoming beam energy ~ 75 MeV/u
Purity = 92%
dp/p = 2%

PID @ A1900 focal plane

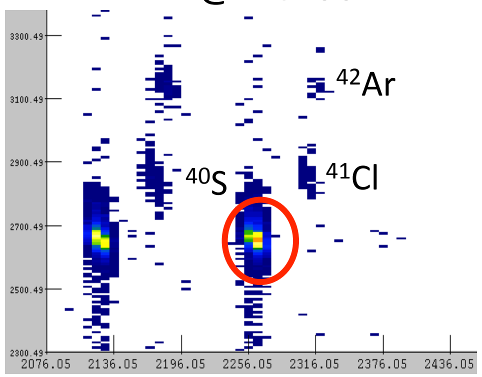


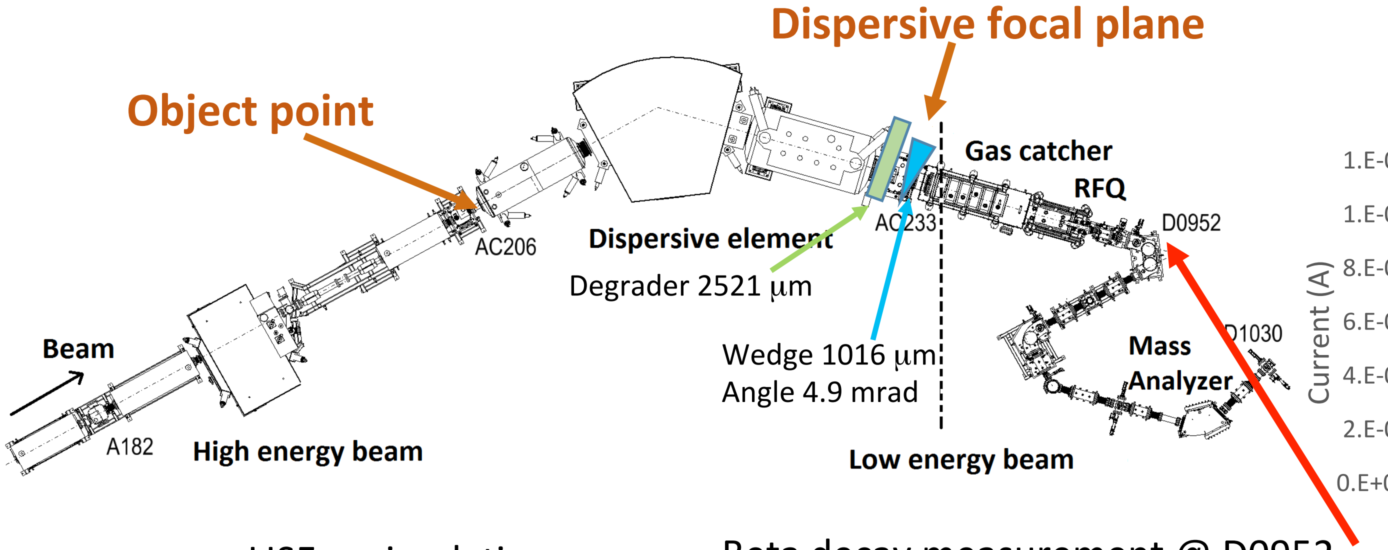
Beam Thermalization: ^{40}S fragment

^{40}S Fragment thermalized with adjustable degrader and fixed angle wedge at the dispersive focal plane

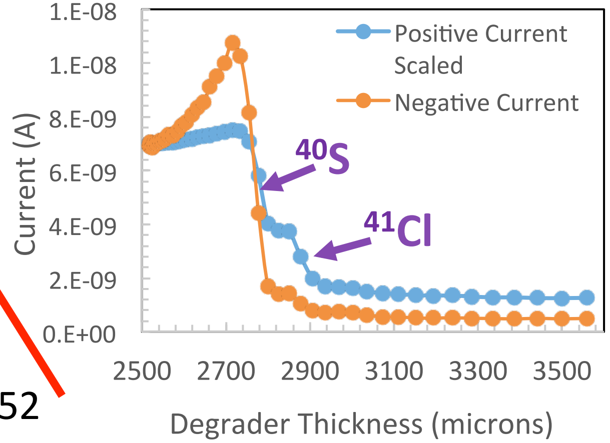
Incoming rate ~ 5.9 E5 pps
Ions: ^{40}S, ^{41}Cl & ^{42}Ar

PID @ AC233



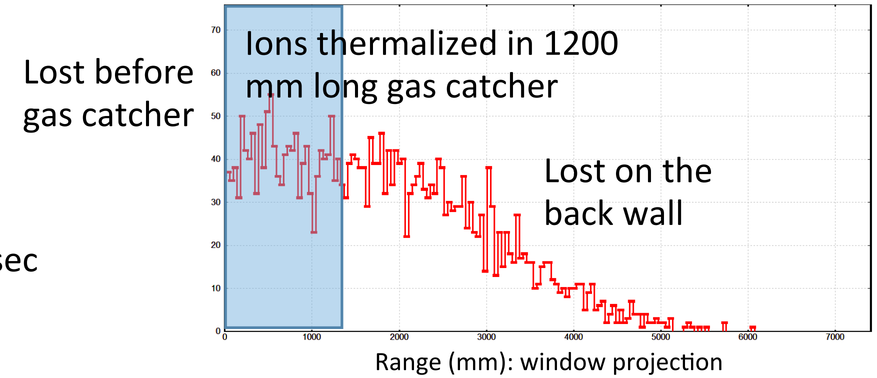


Ionization Curves



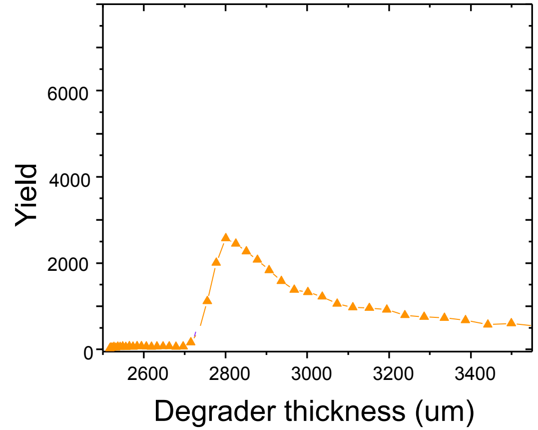
^{40}S → $T_{1/2}$ = 8.8 sec → ^{40}Cl → $T_{1/2}$ = 95 sec → ^{40}Ar

LISE++ simulation

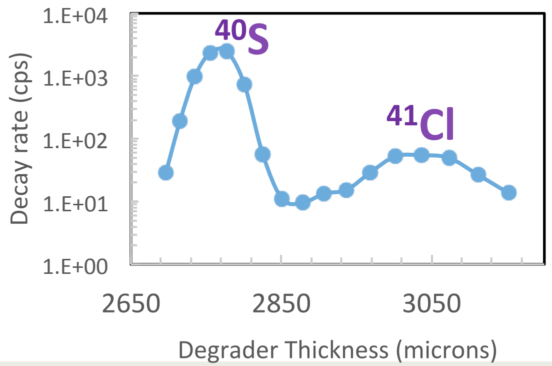


19% of total beam captured in gas catcher

Beta decay measurement @ D0952



Range Measurement

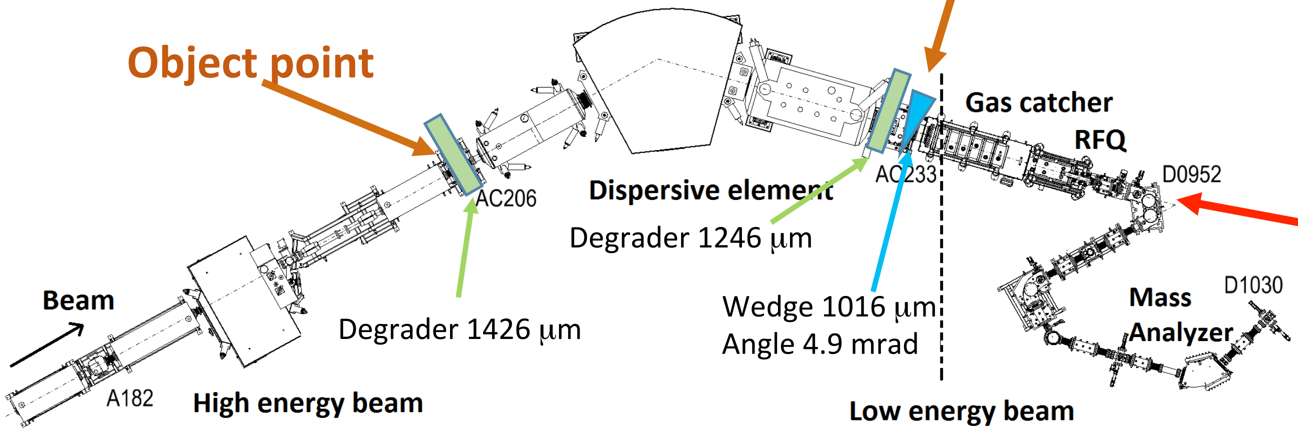


Beam Thermalization: ^{40}S fragment

^{40}S Fragment thermalized with: 1) first degrader at the object point
2) second adjustable degrader and fixed angle wedge at the dispersive focal plane

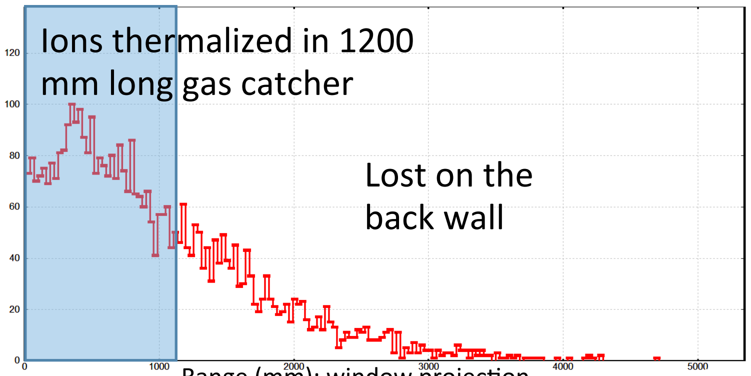
Incoming rate ~ 5.9 E5 pps
Ions: ^{40}S, ^{41}Cl & ^{42}Ar

^{40}S → $T_{1/2}$ = 8.8 sec → ^{40}Cl → $T_{1/2}$ = 95 sec → ^{40}Ar



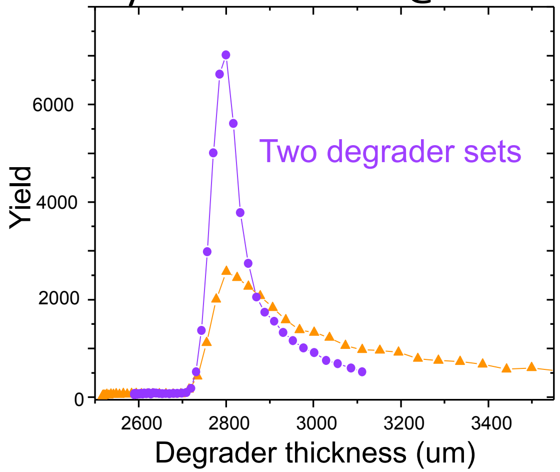
Beta decay measurement @ D0952

LISE++ simulation



32% of total beam captured in gas catcher

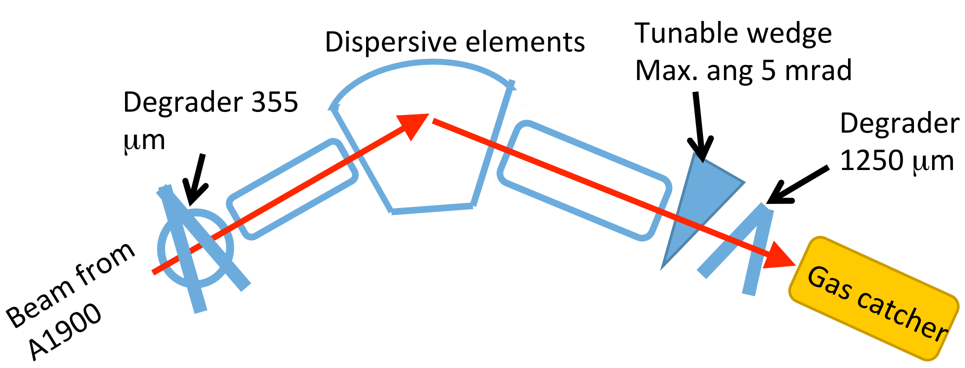
- Rate increased by 1.7 times
- Dispersion match to wedge

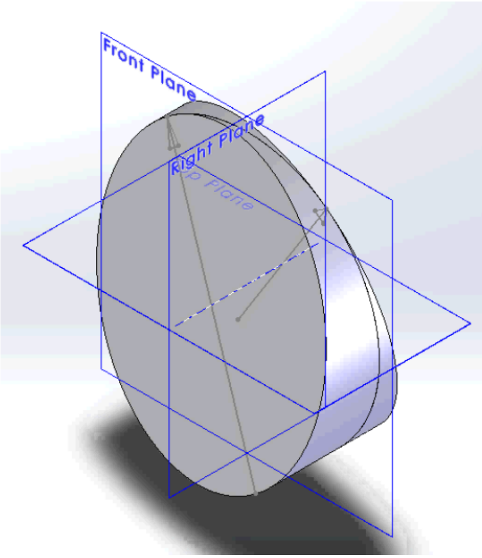


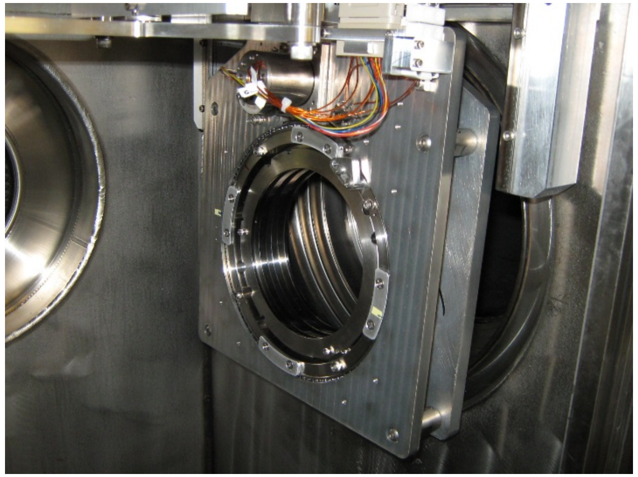
Improvement: Tunable Wedge System

- Stopping efficiency can be increased by having tunable wedge system.

^{75}Ga experiment

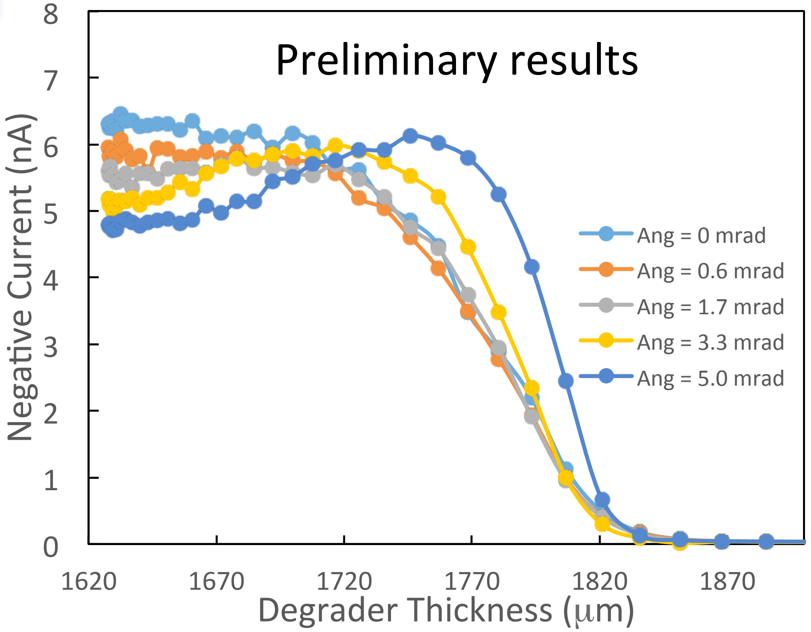






Tunable wedge system installed recently.

- Two fused silica wedges rotate opposite direction to get the desired angle
- Angle per wedge = 2.5 mrad; middle thickness = 0.5 mm; Max wedge angle = 5 mrad
- Tested with ^{75}Ga beam

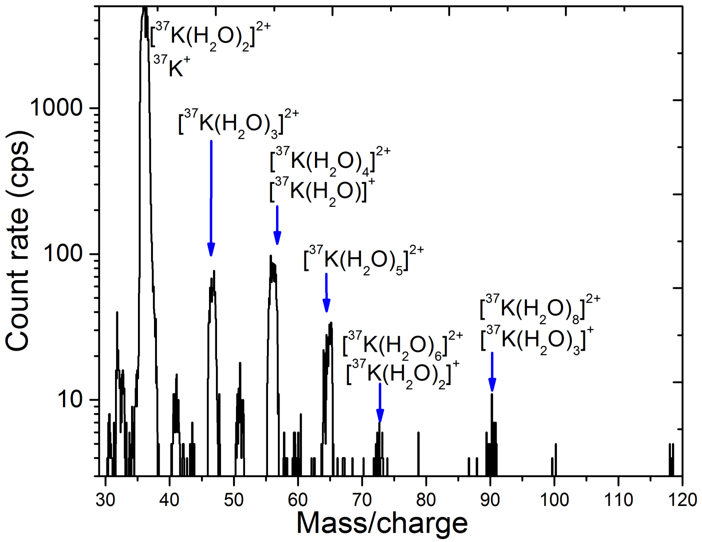


Chemical Molecular Ions Formation with Fragments

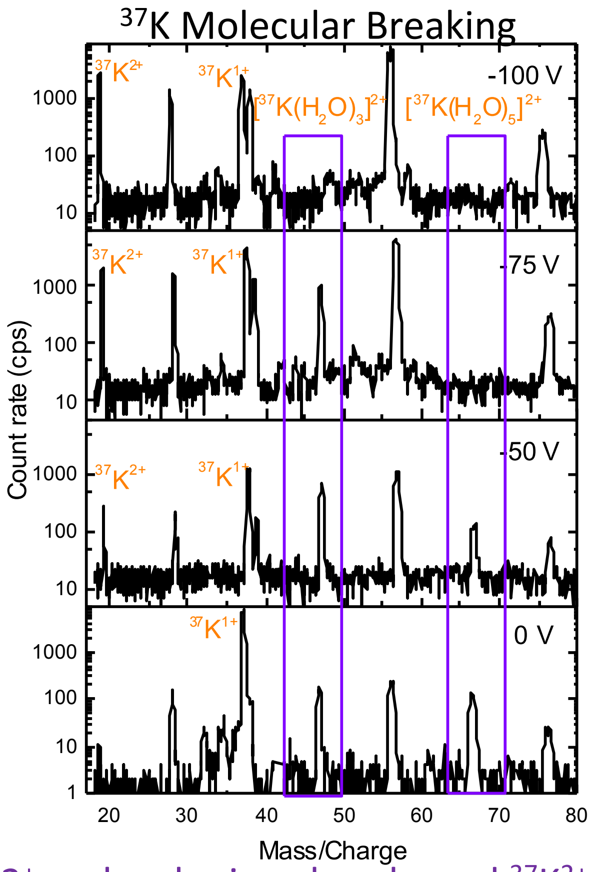
- Impurity molecules in buffer gas form molecular ions with fragments (Depends on impurity concentration & fragment chemistry).

- Reduce thermalized beam rate for low energy experiments

Mass distribution of ^{37}K (before clean up)

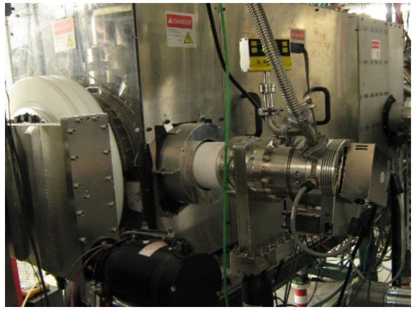


- Apply additional voltage at RFQ

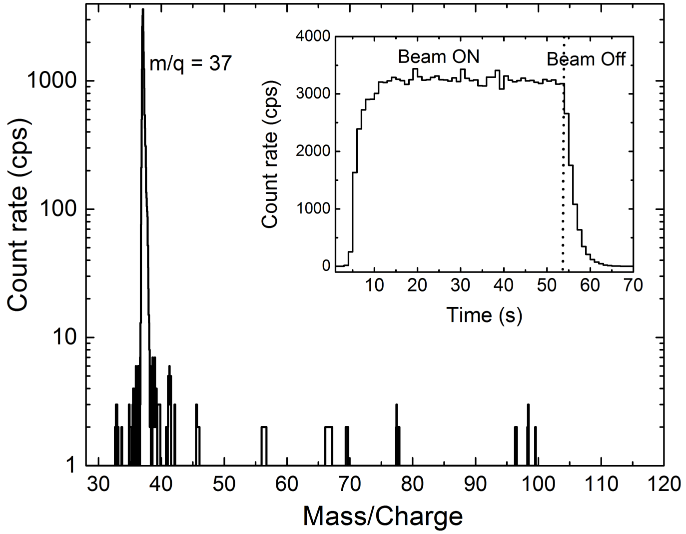


2^{+} molecular ions breaks and $^{37}K^{2+}$ produces when offset voltage increases.

- Install a pump directly attached to the gas catcher (Clean up purpose)



Mass distribution of ^{37}K (after clean up)

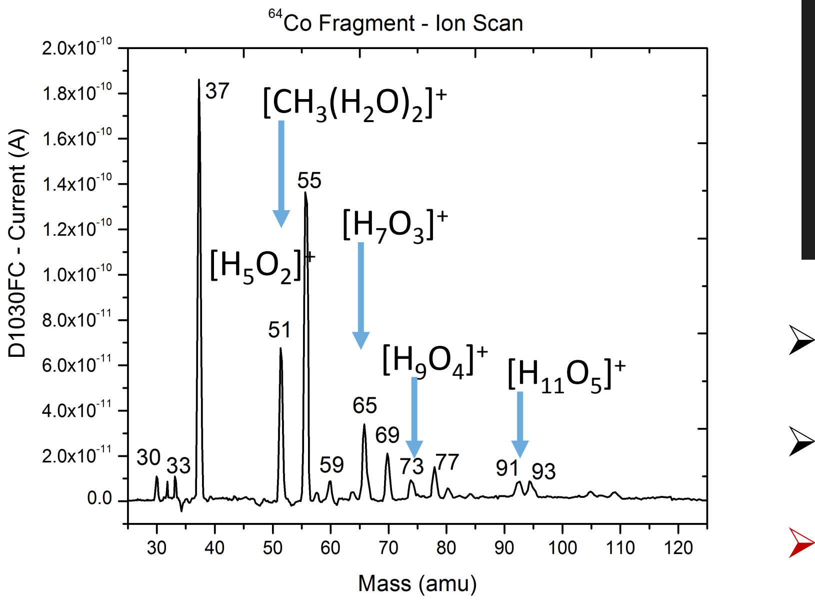


Thermalized Beam Contaminates With Stable Ions

- Stable ions are formed during thermalization process (Depends on impurity concentration).
- Contribute to high beam current (~ 600-800 pA)
- Major issue for low rate experiments

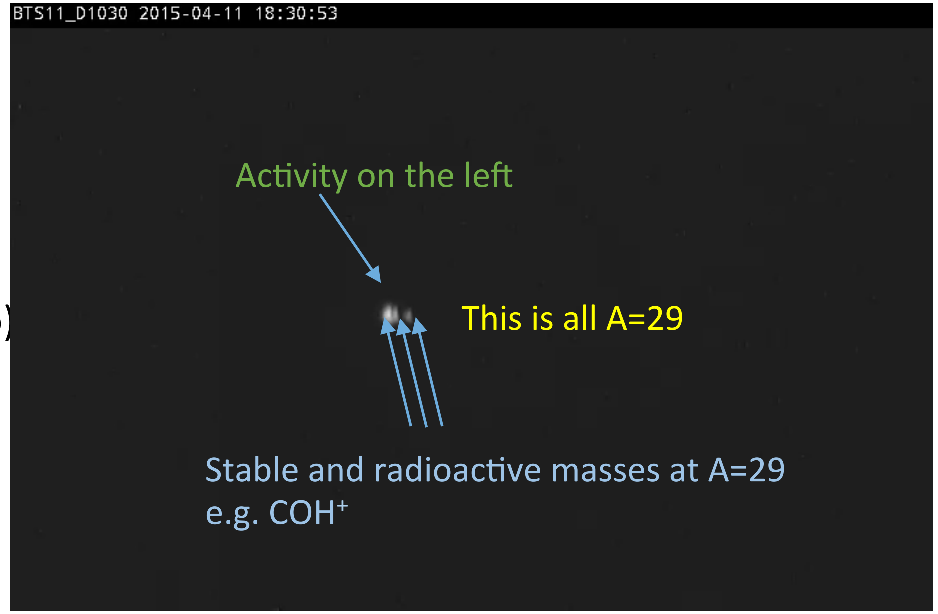
^{37}K experiment

Stable ions mass distribution (before clean up)



^{29}P experiment : Mass measurements

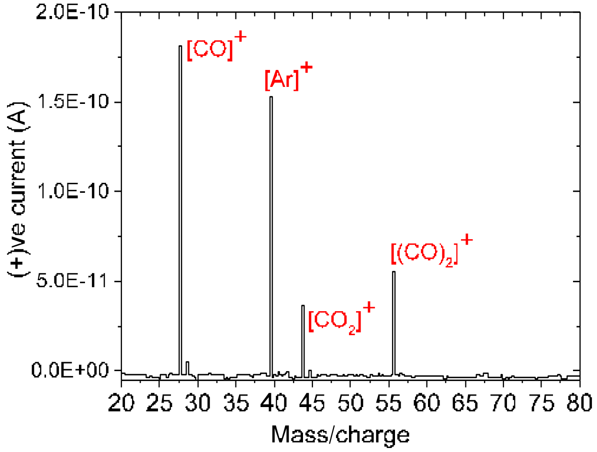
MCP image @ D1030 (set for mass = 29)



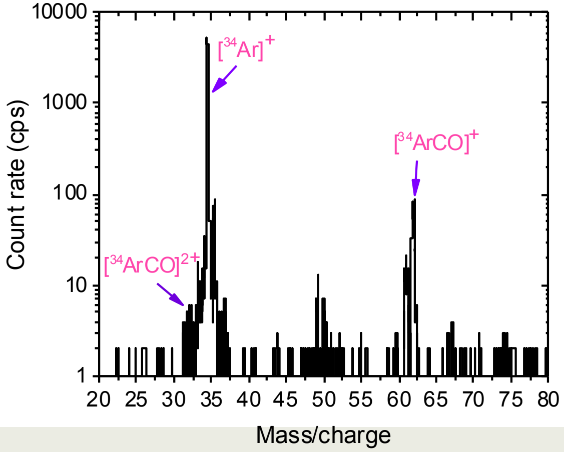
- Activity identify from beta detector and slits
- Mass analyzer resolution (R) $m/\Delta m \sim 1500$
- Some cases, stable ions can be rejected with slits

^{34}Ar experiment

Stable ion mass distribution (after clean up)



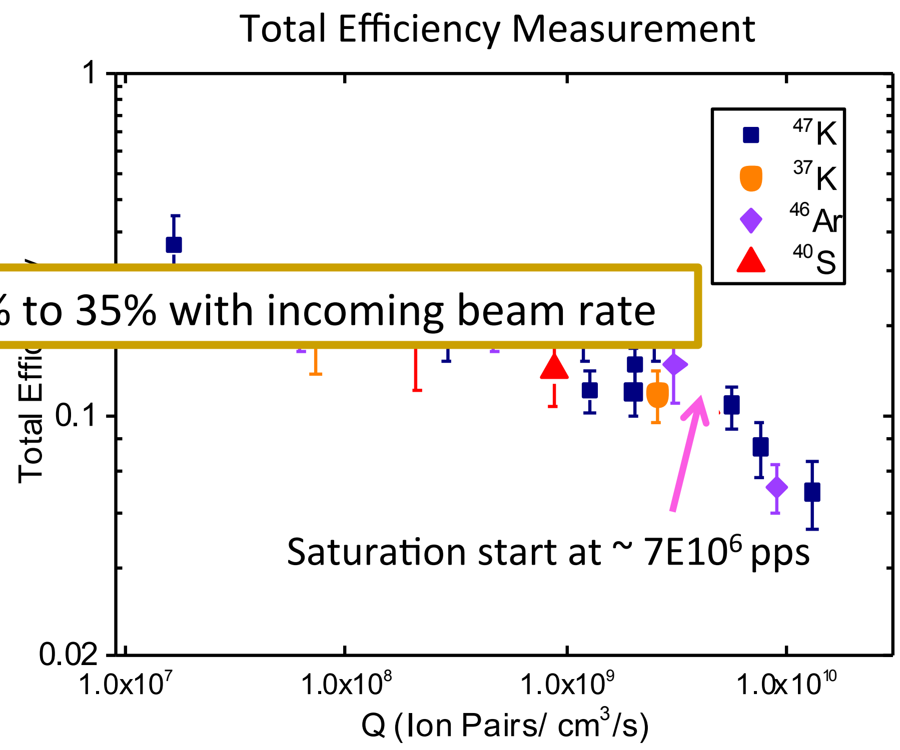
- CO groups show: gas catcher become very clean



Thermalization and Extraction Efficiency

To minimize the space charge effect:

- Increase nozzle diameter (0.6 mm to 1.3 mm)
- Higher DC gradients (discharge limited)
- Beam pulsing
- Fast extraction methods (Ion surfing on RF carpet-Future ACGS)



ange of 2% to 35% with incoming beam rate

e gas

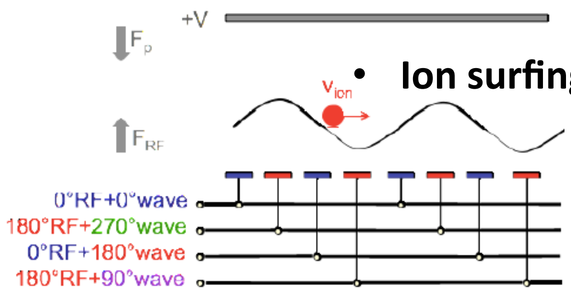
$$Q – \text{Ionization rate density} = \frac{\text{\# of ion pairs * Incoming beam rate}}{\text{Stopping volume}}$$

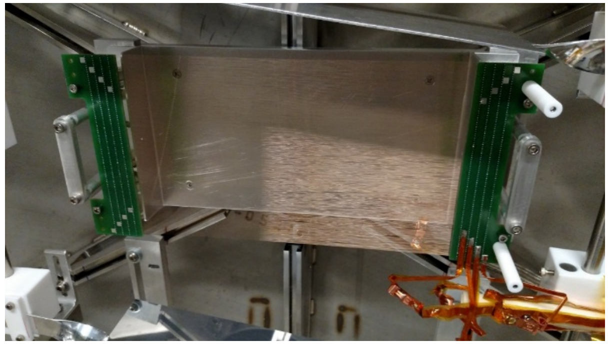
Advanced Cryogenics Gas Stopper (ACGS)

❖ Potential gradient is replaced using a travelling wave to transport ions

- Wire carpet

- Ion surfing



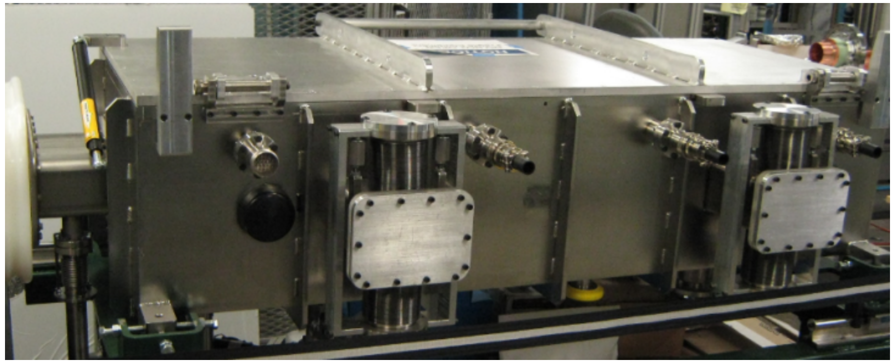


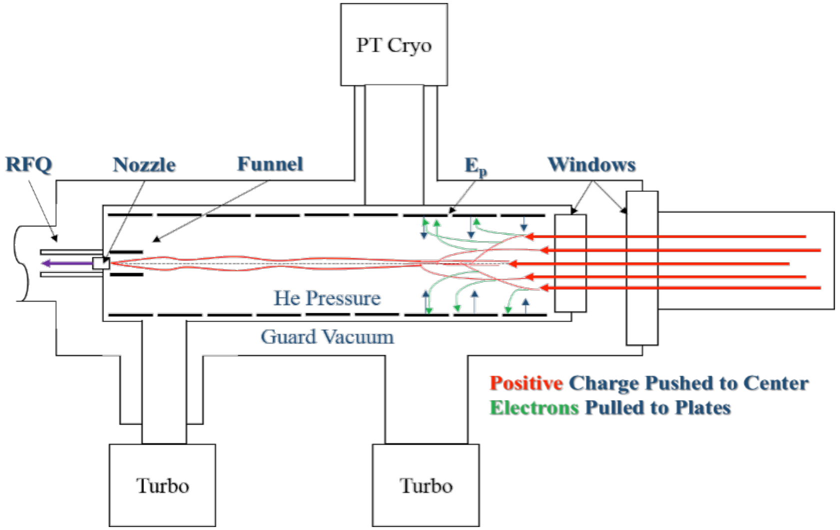
❖ Operates at liquid helium temperature (Stable ion formation is limited)

❖ Ion transport is not discharge limited (Can extract shorter-lived isotopes)

❖ High extraction efficiency

ACGS under construction





Outlook

- ❖ Beam thermalization facility at NSCL provides beams successfully to low energy experimental programs
- ❖ Momentum compression improves beam thermalization efficiency
- ❖ Challengers for beam thermalization were identified and some of improvements were implemented
- ❖ New beam thermalization capabilities are on the way to reality soon (ACGS, Cyclotron Stopper)

ANL Gas Catcher Operation

- First Beam to ANL gas catcher : Aug 2012

- **Beams for LEBIT**
  - Fe-62,63,67
  - Co-63,64,65,68,69
  - Br-72
  - O-14
  - N-13
  - C-11
  - Cl-31
  - Si-24
  - P-29
  - Na-21
- **Beams for BECOLA**
  - Fe-51,52,53
  - K-35,36,37
- **Beams for ReA3**
  - Ga-76
  - K-37
  - Ar-46
  - K-46
  - Ar-34
  - Ga-75
- **Gas Catcher experiments**
  - Ga-76
  - K-37,38,47
  - P-29
  - Cl-33
  - S-40
  - Mg-29
  - O-14
  - Si-26
  - Br-72
  - Kr-73
  - Ar-46

Thank you