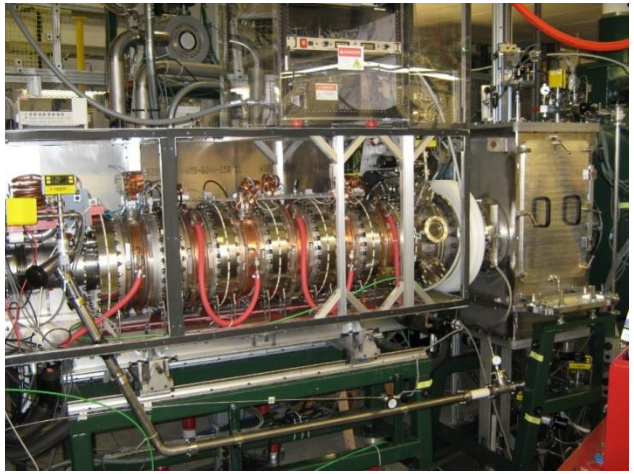
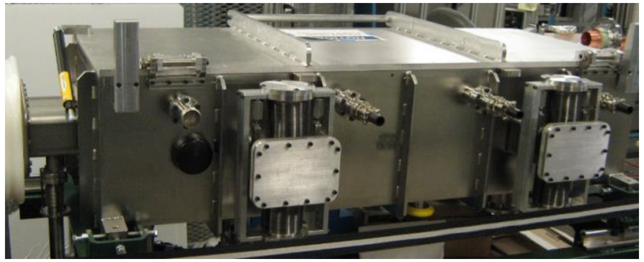
Thermalization and Extraction of Projectile Fragments

Chandana Sumithrarachchi





Future: Advanced Cryogenics Gas Stopper (ACGS)

Future: Cyclotron Stopper

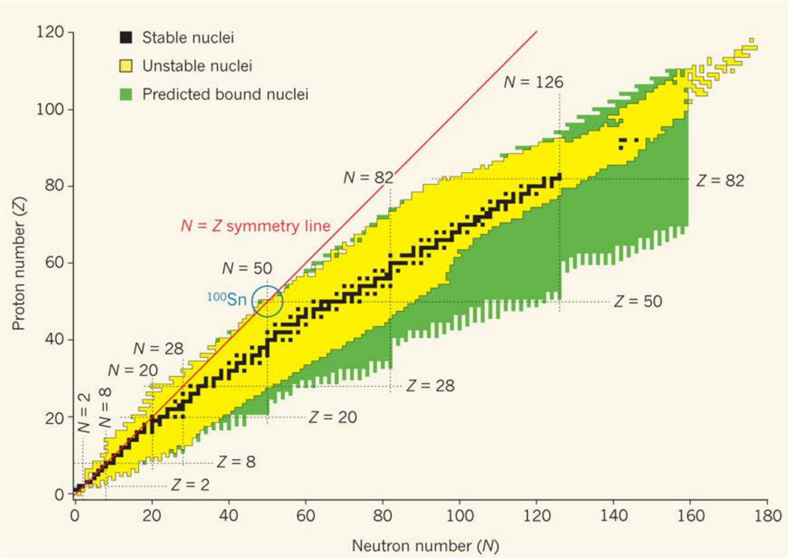
Outline

- ❖ 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.

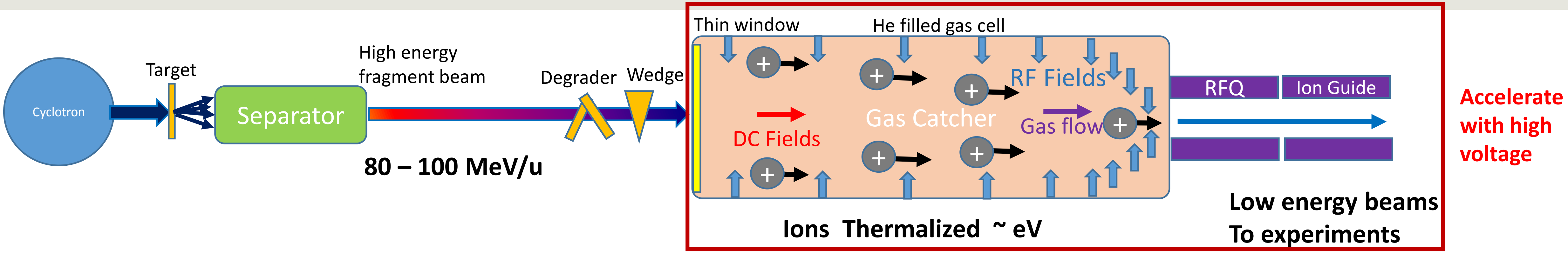
- ❖ Study properties of exotic nuclei far from stability
- ❖ Search for driplines



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



❖ Production of fragments from high energy beam
- Large momentum spread due to reaction mechanism and production target.

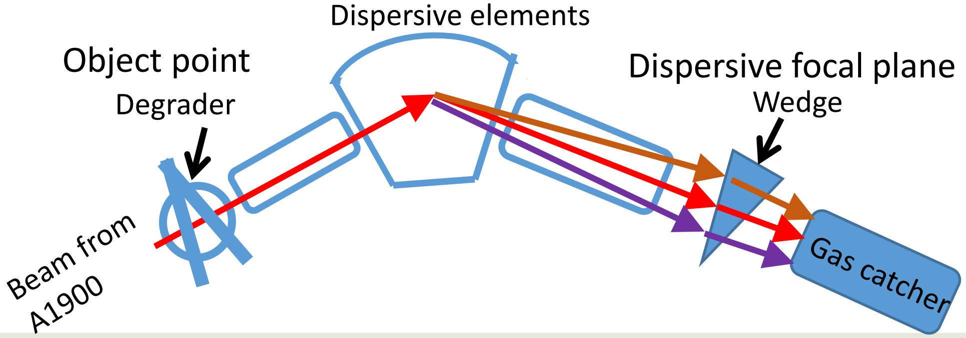
❖ Bρ and ΔE separation
- A1900 spectrometer (High acceptance: 5% Δp/p) , achromatic wedge

❖ Momentum compression and thermalization
- Narrow momentum spread beams lead to high stopping efficiency (L. Weissman et al. NIM A 522 (2004) 212)

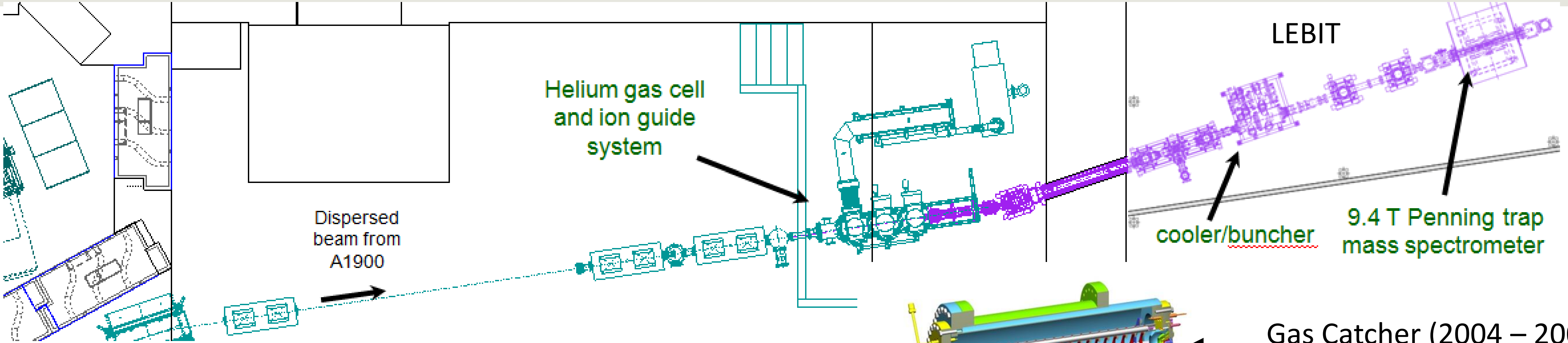
❖ Gaseous ions collection

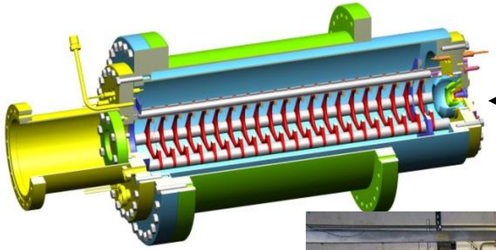
❖ Low energy transport

Method for producing an ideal incident beam:
- Thermalize beam at the object point
- Bunch momentum spread with wedge at the dispersive focal plane (H. Weick, et al., NIM B164-5(2000)168; H. Geissel, et al., NIM A282(1989)247)



History of Beam Thermalization at NSCL





Gas Catcher (2004 – 2009)
by D. J. Morrissey

NSCL has pioneered the beam thermalization in gas since 2002.

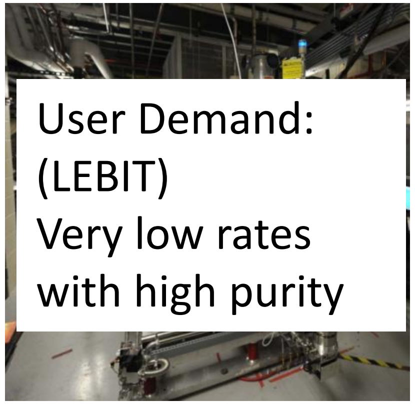
- Operated 25 L volume gas catcher, 1 bar, 298 K
- Delivered thermalized beams to LEBIT for Penning trap mass measurements
- First high precision mass measurement: $^{38}Ca^{2+}$

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

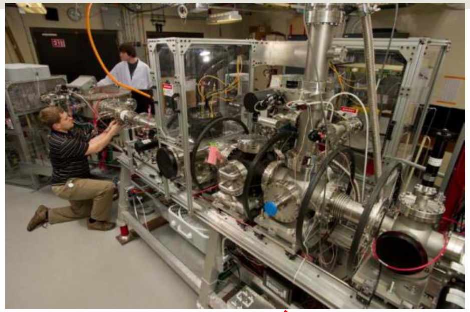
Low Energy Beam Area at NSCL

Beam thermalization facility (N4 vault)

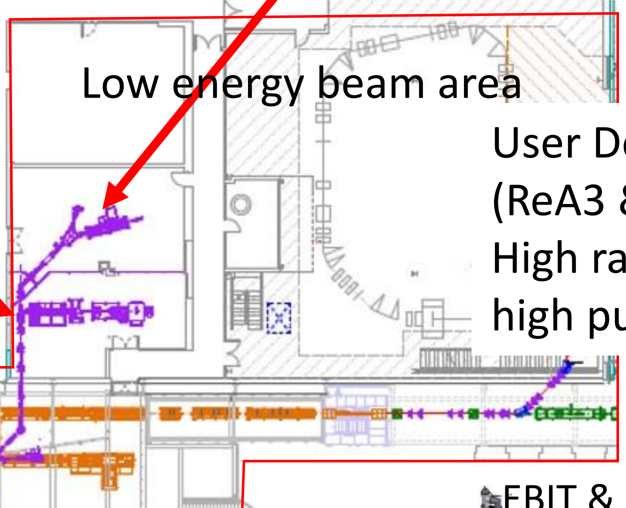
LEBIT (Mass measurements)

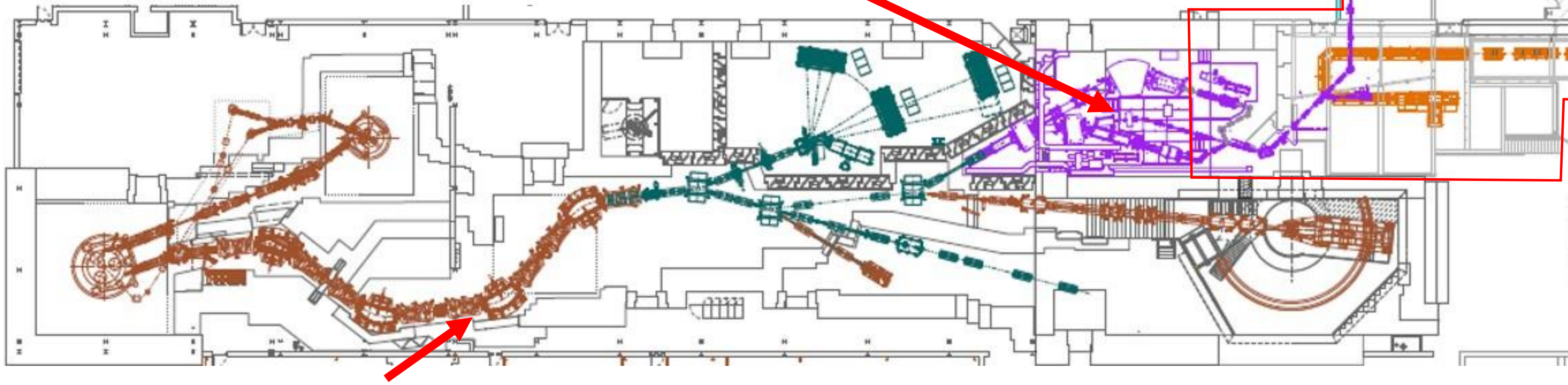


User Demand:
(LEBIT)
Very low rates
with high purity



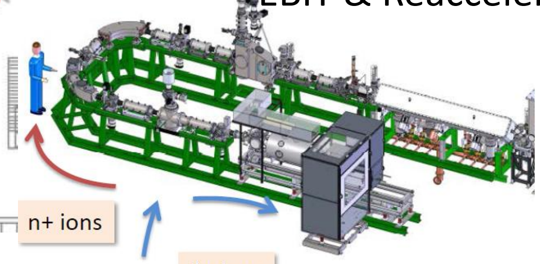
BECOLA (Laser Spectroscopy)





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

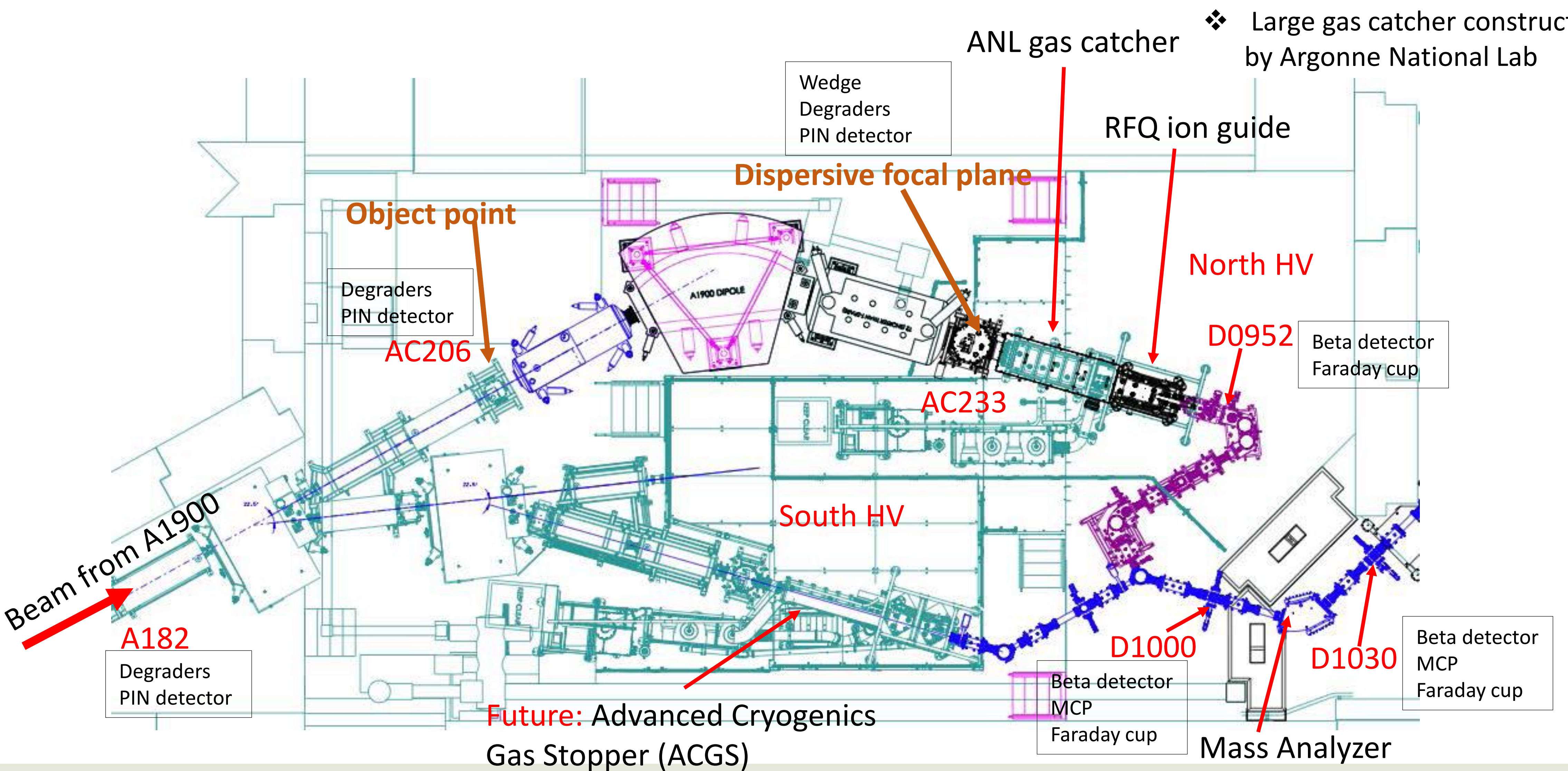
EBIT & Reaccelerator



A1900 fragment separator

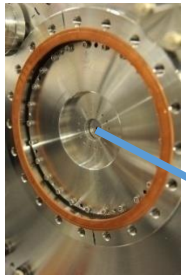
Beam Thermalization Facility

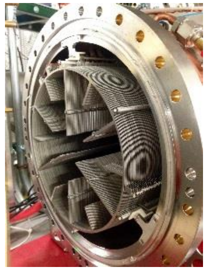
- Large gas catcher constructed by Argonne National Lab

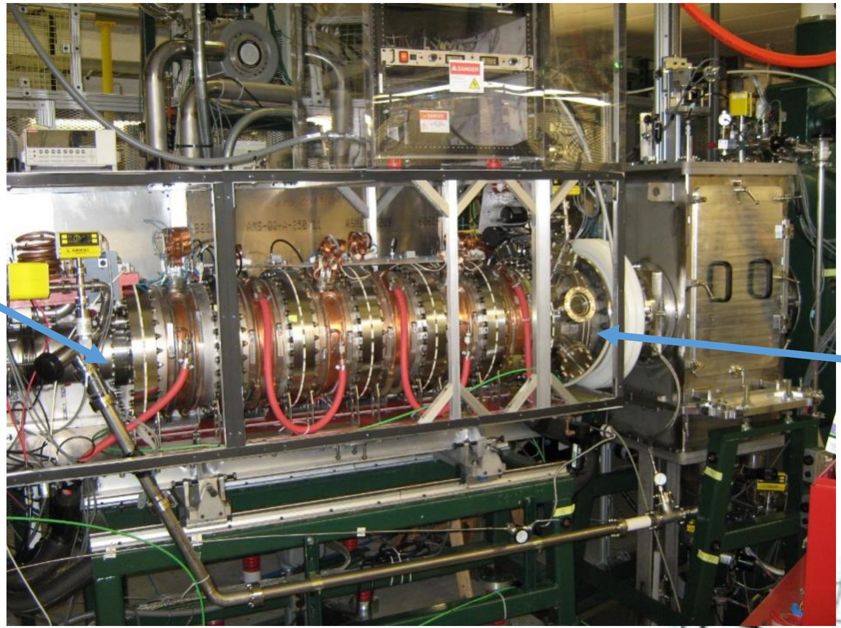


ANL Gas Catcher

Nozzle
1.3 mm diameter

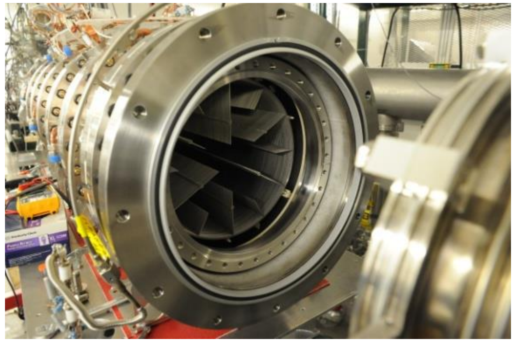






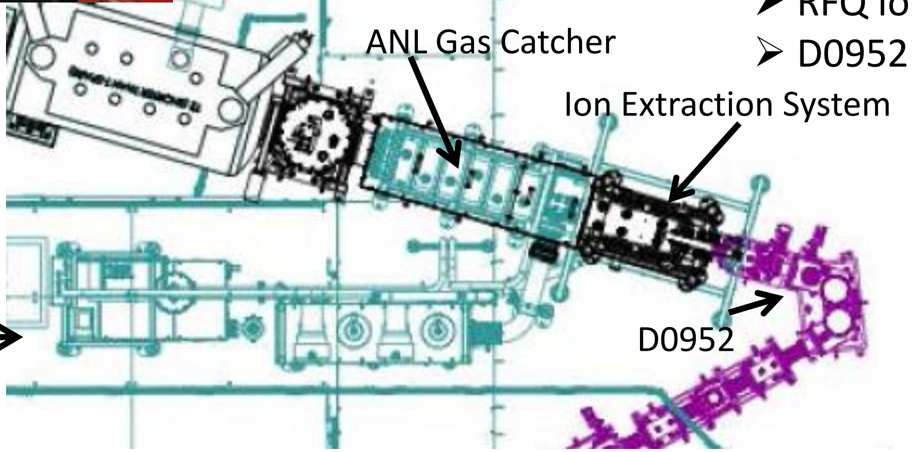
Al thin Window

- ❖ 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
- ❖ Current measurements capabilities:
  - ➢ Window current ((-) ions)
  - ➢ RFQ ion guide electrode current
  - ➢ D0952 Faraday Cup Current

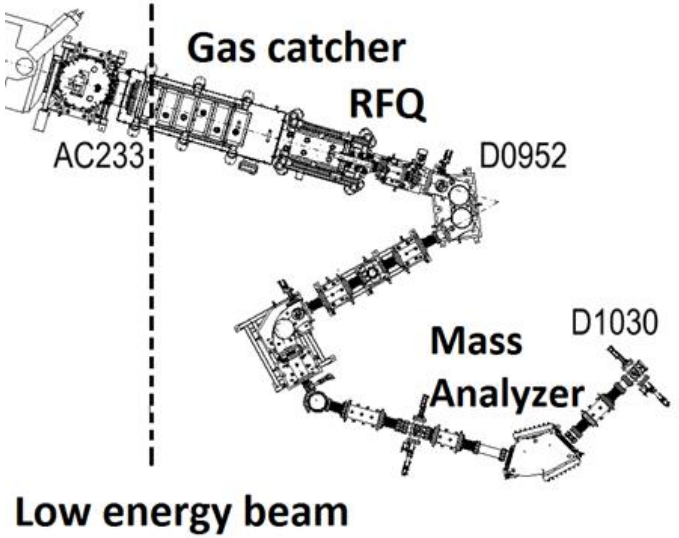


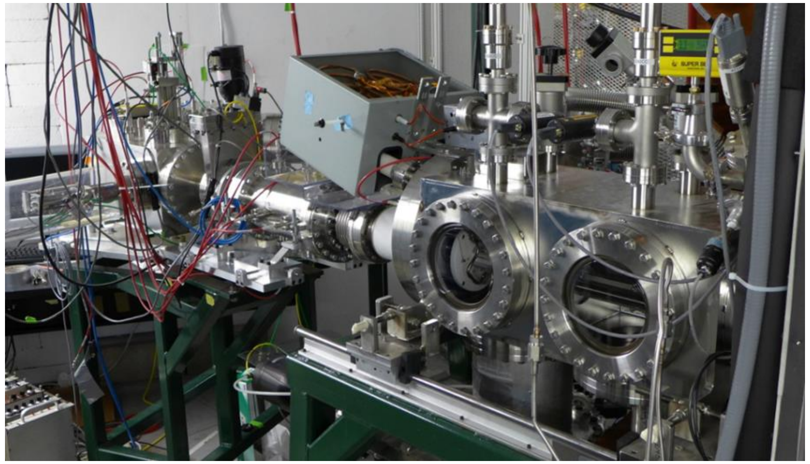
RF electrodes in Gas Catcher

Differential Pumping Station

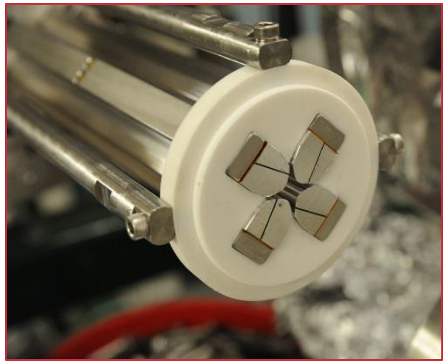


RFQ Ion Guide





RFQ electrodes



- Beam cooling with He
- Transverse confinement with RF quadrupole electric field
- Axial drag field with DC voltage gradient

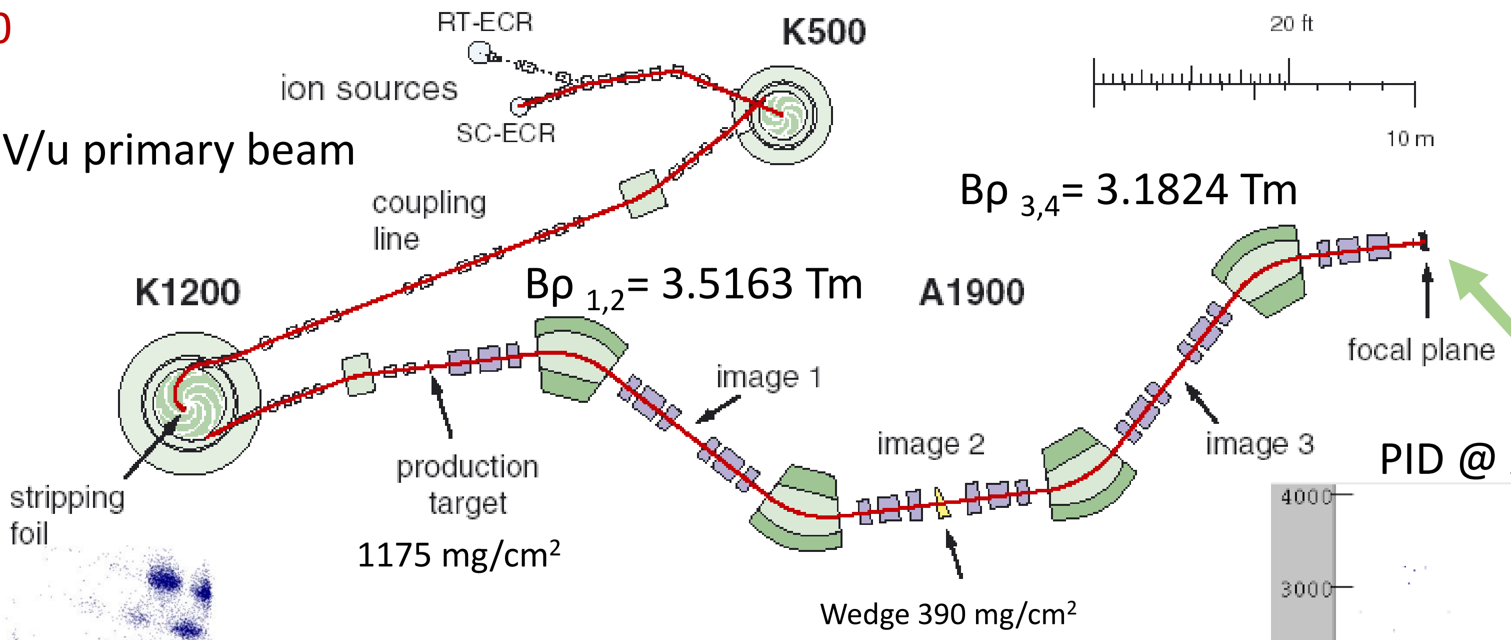
RFQ operates at:

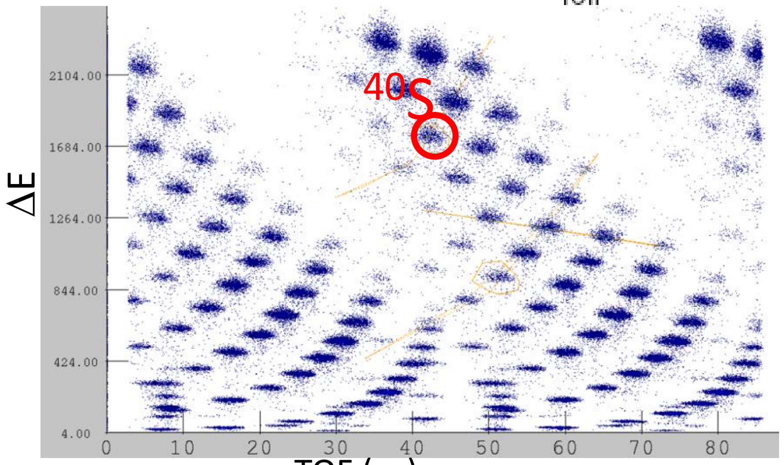
- RF frequency range of 3 -4.5 MHz
- Peak-to-peak amplitude ~ < 500 V

Beam Thermalization: ^{40}S fragment

^{40}S Fragment
Production @ A1900

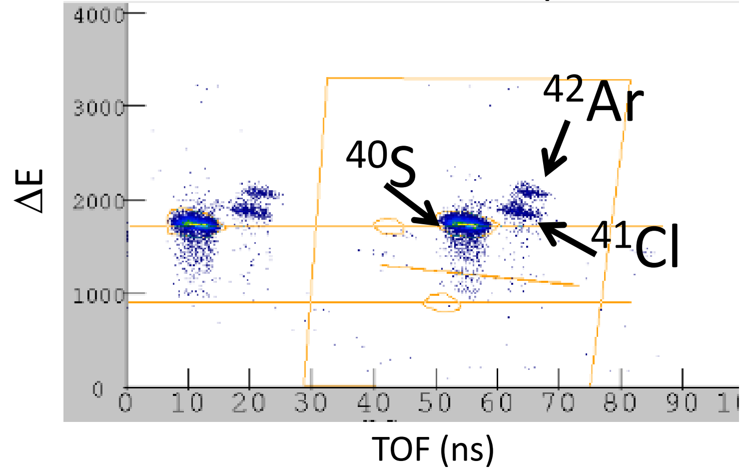
^{48}Ca 140 MeV/u primary beam





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

PID @ A1900 focal plane

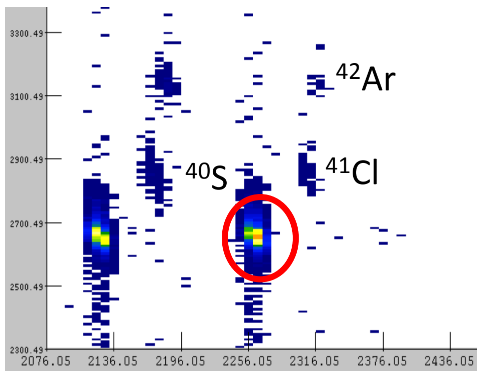


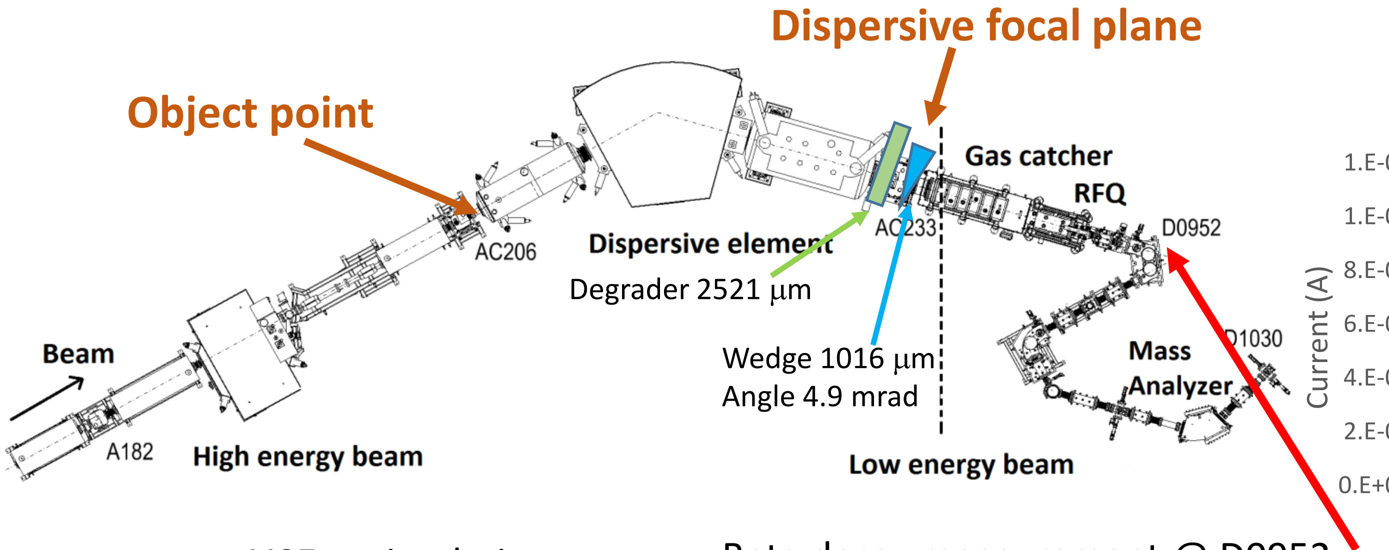
Beam Thermalization: ^{40}S fragment

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

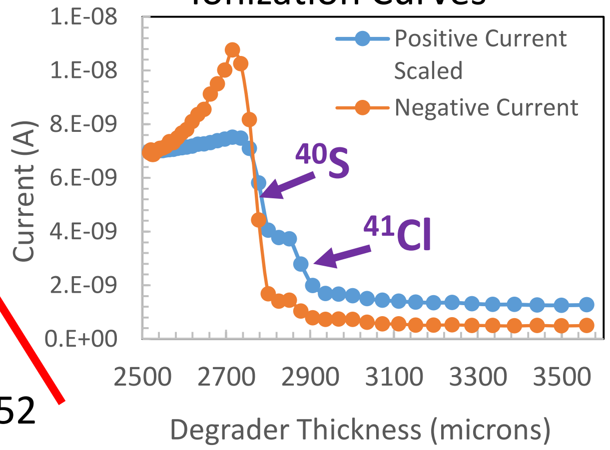
Incoming rate ~ 5.9 E5 pps
Ions: ^{40}S, ^{41}Cl & ^{42}Ar

PID @ AC233

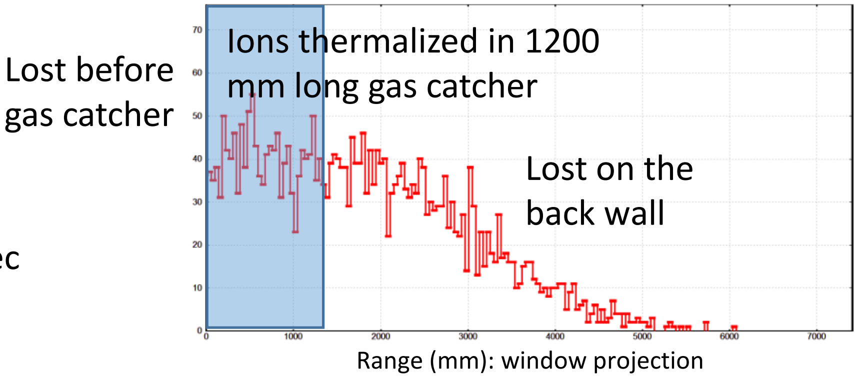




Ionization Curves

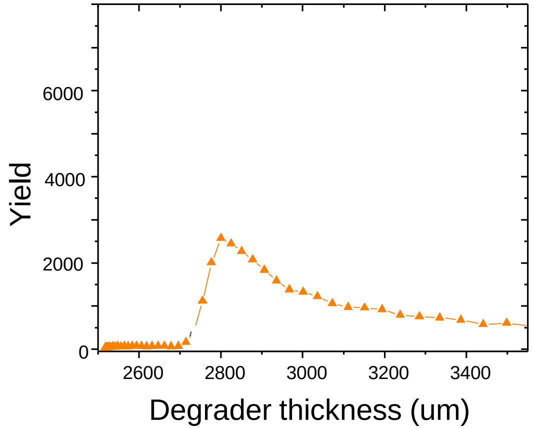


LISE++ simulation

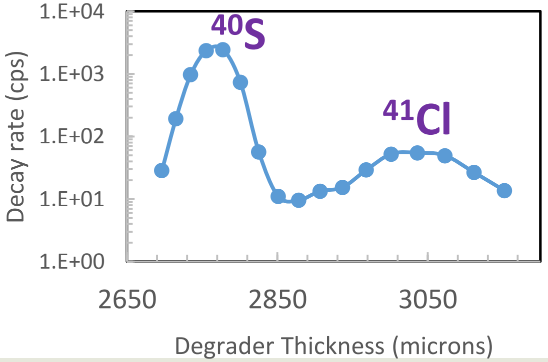


19% of total beam captured in gas catcher

Beta decay measurement @ D0952



Range Measurement



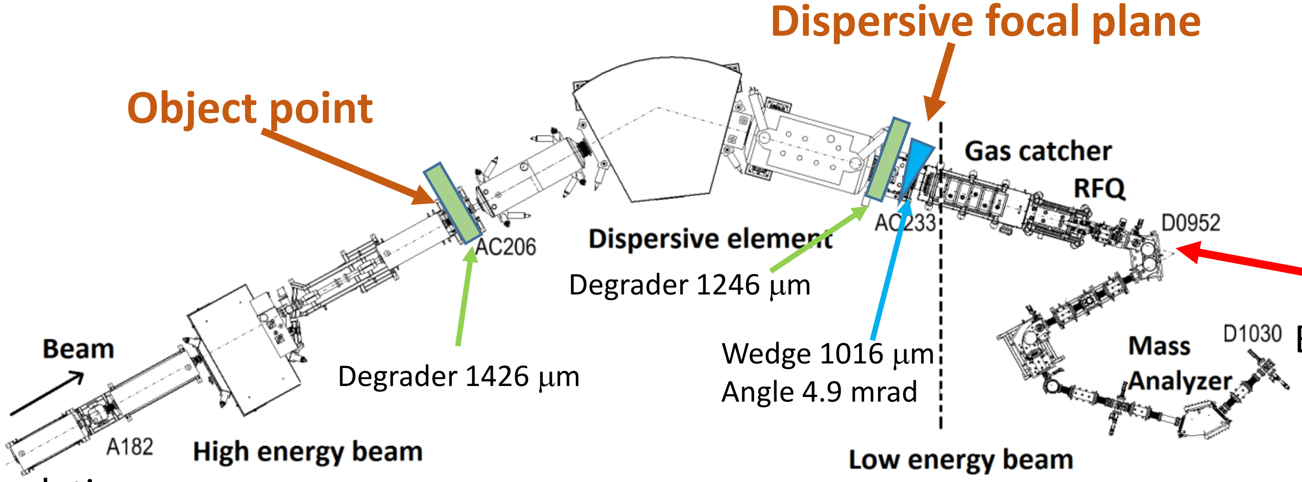
^{40}S → $T_{1/2}$ = 8.8 sec → ^{40}Cl → $T_{1/2}$ = 95 sec → ^{40}Ar

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

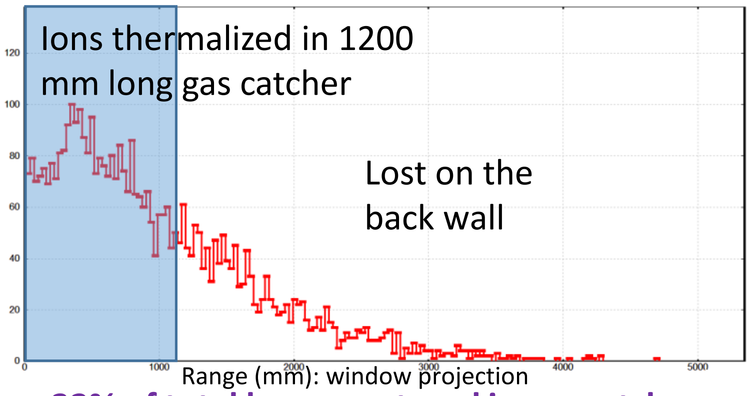
Incoming rate ~ 5.9 E5 pps
Ions: ^{40}S, ^{41}Cl & ^{42}Ar

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

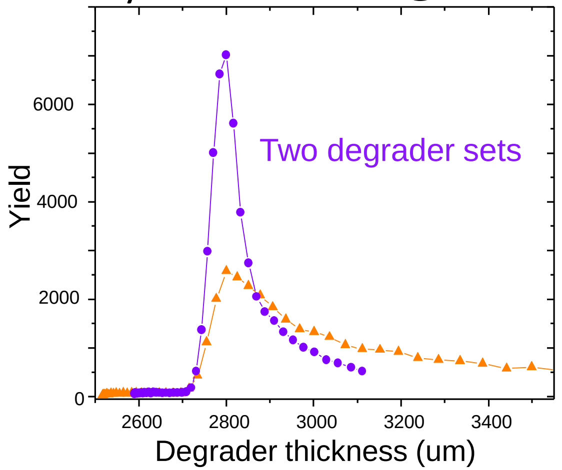


Beta decay measurement @ D0952

LISE++ simulation



32% of total beam captured in gas catcher



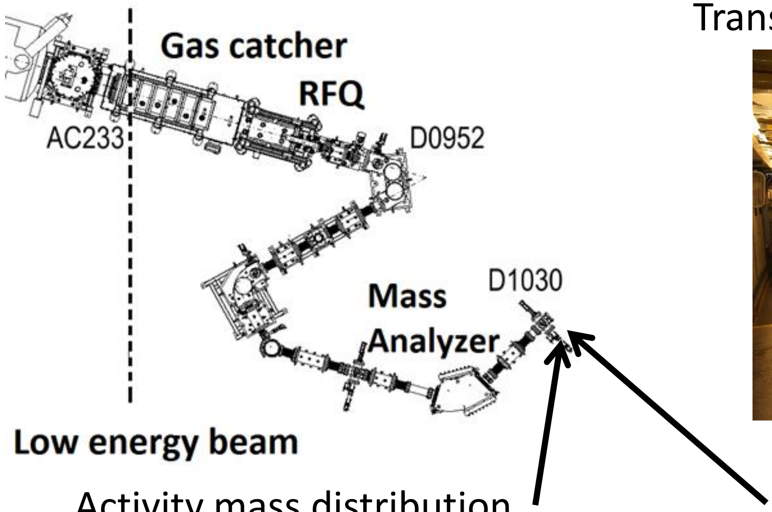
- Rate increased by 1.7 times
- Dispersion match to wedge

Beam Thermalization: ^{40}S fragment

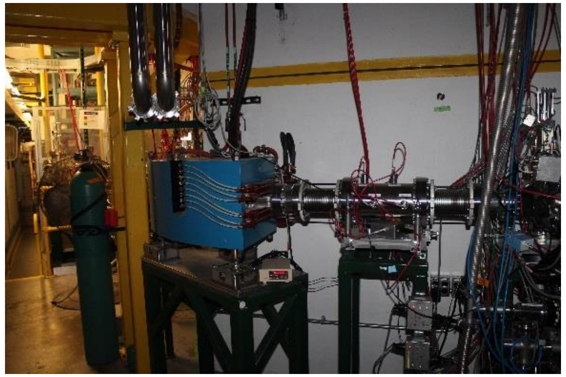
Mass distribution of ^{40}S Fragment after thermalization

Processes inside the gas catcher:

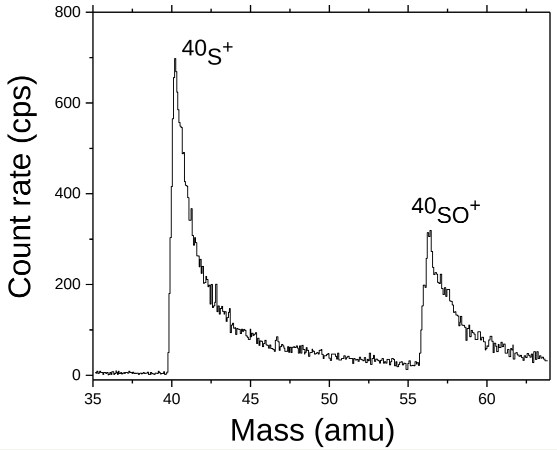
- Thermalization process produces ions and electron pairs. (He_2^+)
- Form stable molecular ions from impurity molecules in the gas.
- Transport of thermalized ions in the buffer gas is affected by the interactions with molecular ions in the gas. (Drift time ~ 70 ms, Depends on impurity concentration, fragment chemistry)



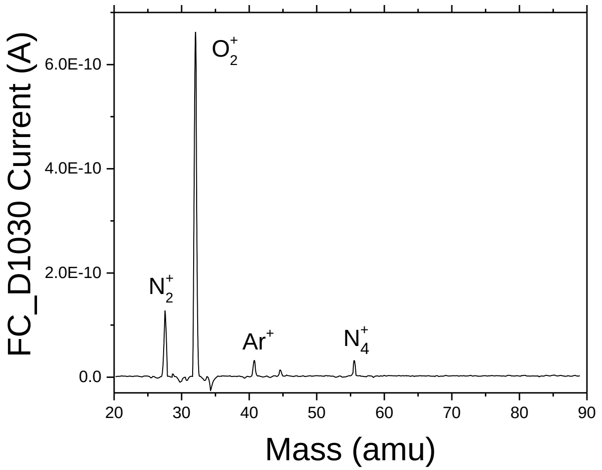
Transport through low energy beamline



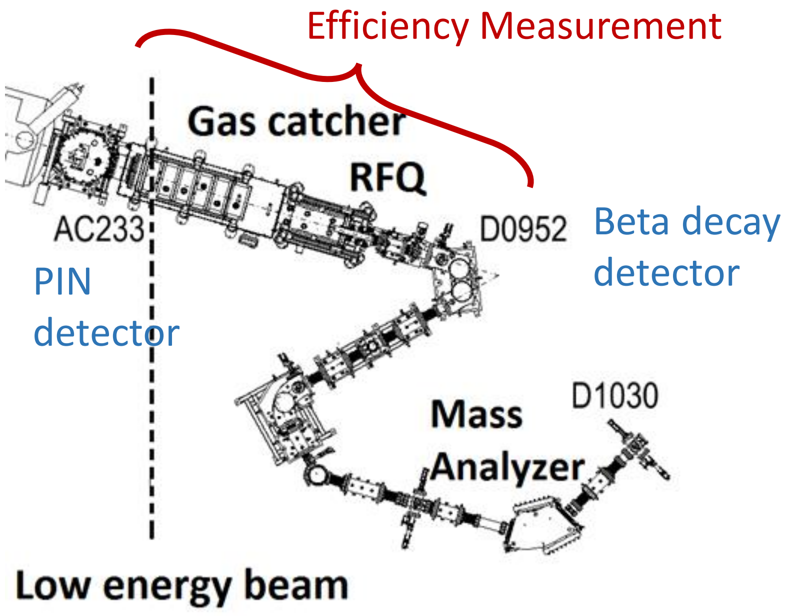
Activity mass distribution

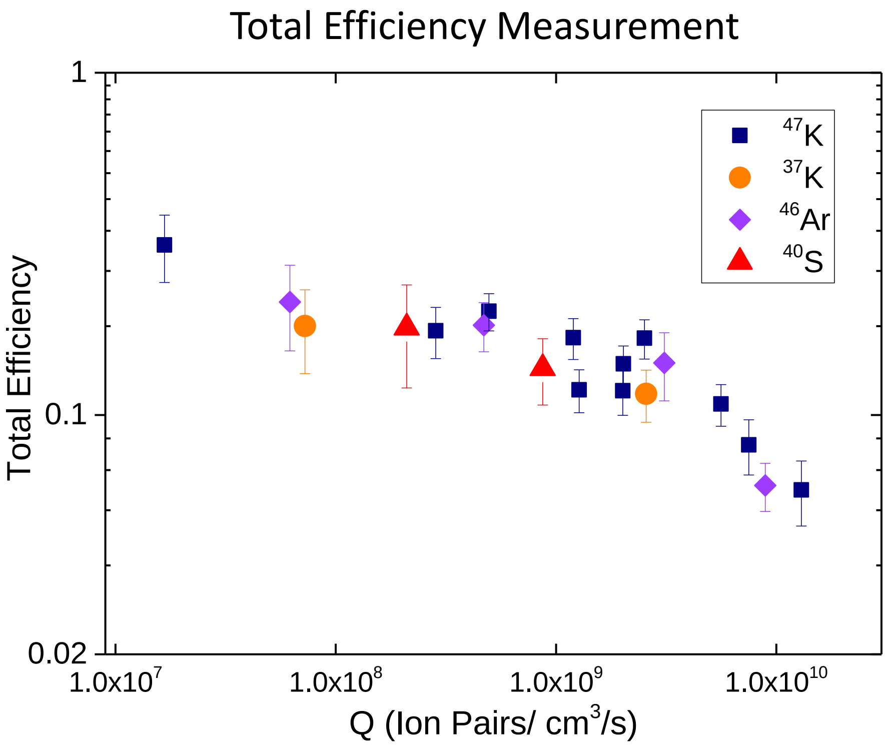


Stable ion mass distribution



Thermalization and Extraction Efficiency





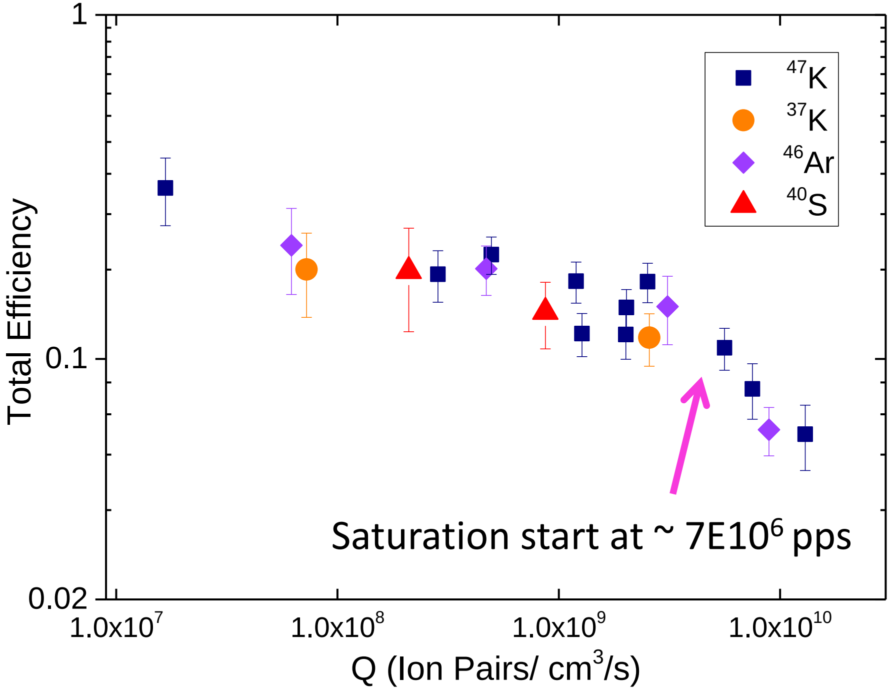
- Measurements were made between AC233 and D0952 detectors. (corrected for beam currents and decay.)
- Total Efficiency Includes stopping and extraction efficiencies of the gas catcher, and RFQ efficiency.
- RFQ extraction efficiency ~ 80 %
- Incoming particle rate to the gas catcher varies from 10^2 to 10^8 pps.

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

Challenges in Beam Thermalization Process

- Total efficiency of thermalization and extraction reduces with incoming beam rate and start saturation.
  - Space charge build up
    - Nozzle size (diameter ~1.3 mm)
    - Higher DC gradient
    - Fast extraction methods (Ion surfing on RF carpet – Future ACGS, Cyclotron Stopper)
- Chemical adducts formation with fragments
- Stable ion contaminants
- Decay product as contaminants

Total Efficiency Measurement



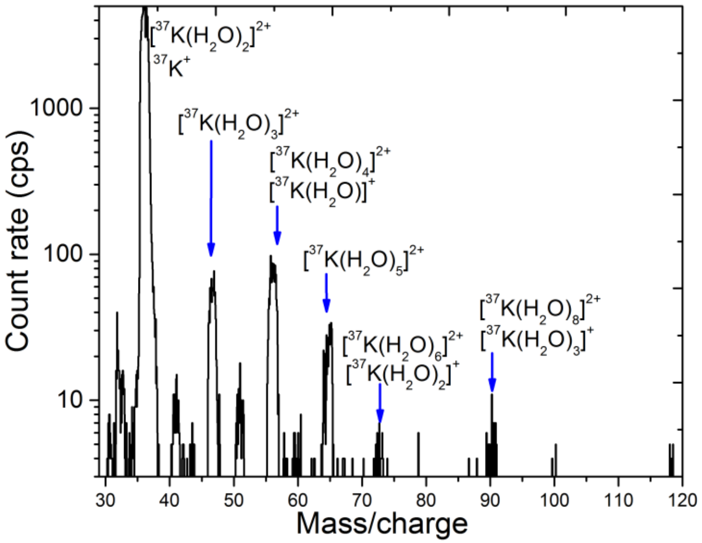
$$Q - \text{Ionization rate density} = \frac{\text{\# of ion pairs * Incoming beam rate}}{\text{Stopping volume}}$$

Chemical Adducts Formation

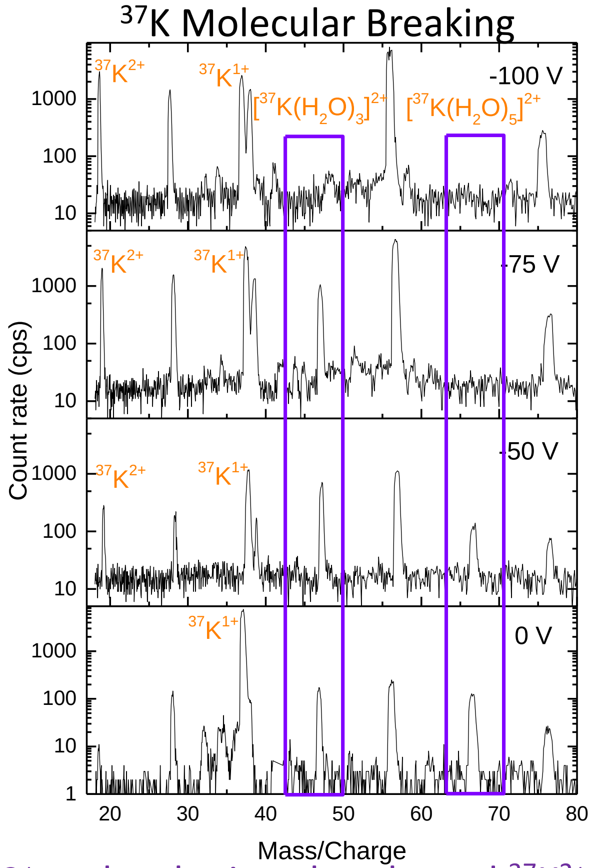
- Impurity molecules in buffer gas form molecular ions with fragments (Depends on impurity concentration & fragment chemistry).

- Reduce thermalized beam rate for low energy experiments

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

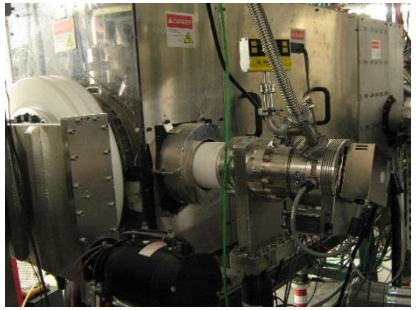


- Apply additional voltage at RFQ

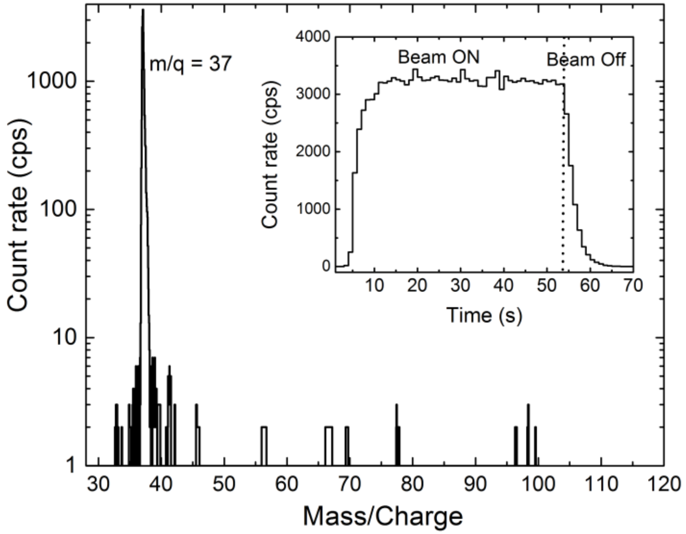


2^+ molecular ions breaks and $^{37}K^{2+}$ produces when offset voltage increases.

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



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

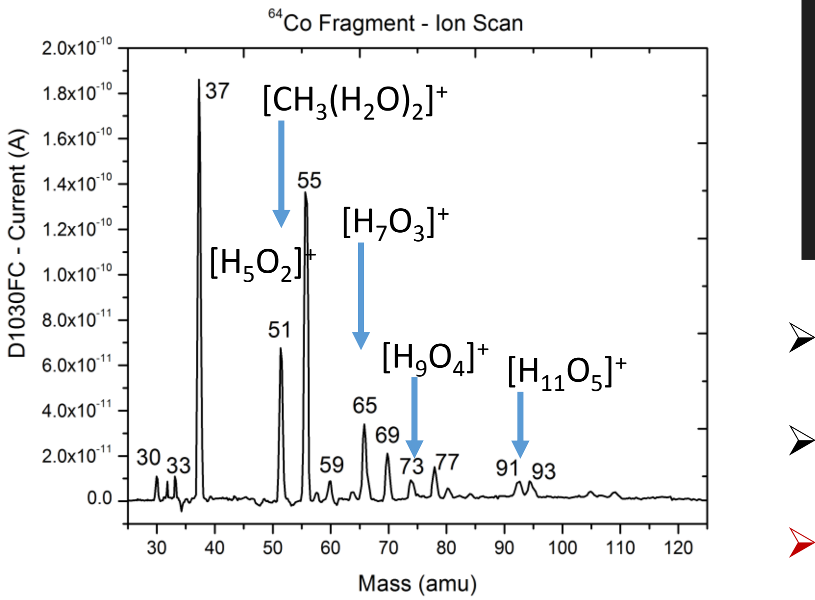


Stable Ion Contaminants

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

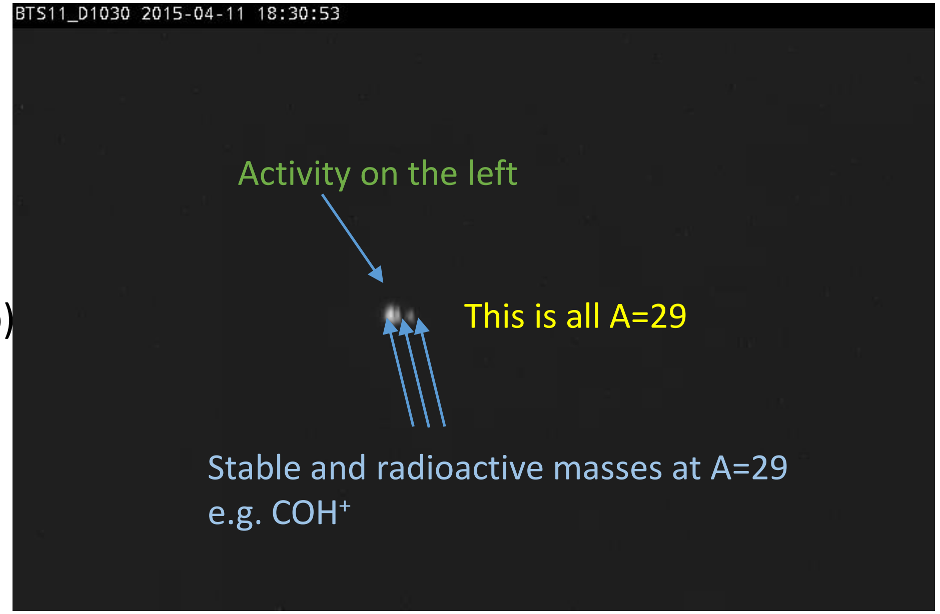
^{37}K experiment

Stable ions mass distribution (before clean up)



^{29}P experiment : Mass measurements

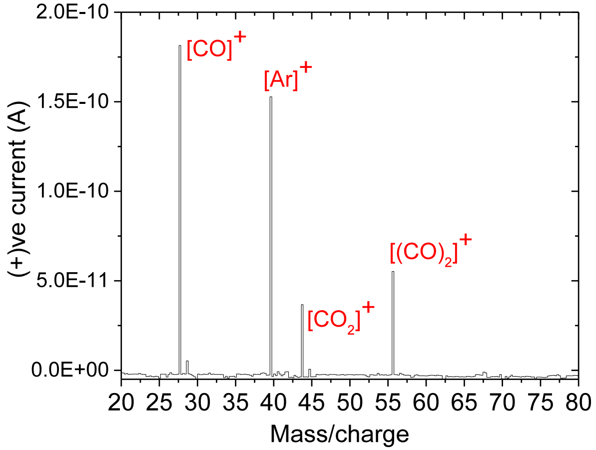
MCP image @ D1030 (set for mass = 29)



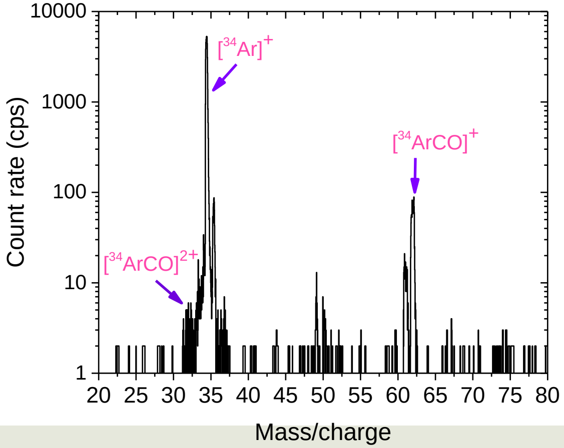
- Activity identify from beta detector and slits
- Mass analyzer resolution (R) $m/\Delta m$ ~ 1500
- Some cases, stable ions can be rejected with slits

^{34}Ar experiment

Stable ion mass distribution (after clean up)



- CO groups show: gas catcher become very clean



Decay Products as Contaminants

➢ Thermalized beams are some time contaminated with decay products.

ReA3 Experiment: Measurement of the $^{75}Ga(a,n)$ and $(a,2n)$ cross sections important for neutrino driven wind nucleosynthesis – Z. Meisel

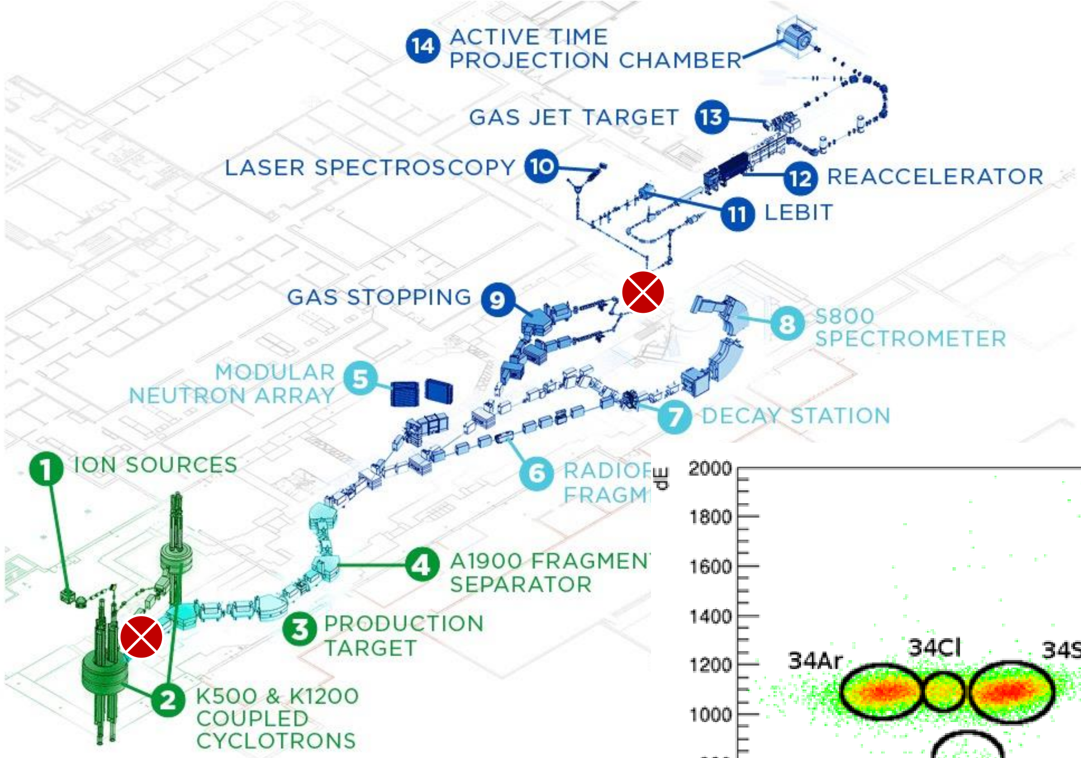
- ^{75}Ga beam was thermalized in ANL gas catcher and delivered to reaccelerator.
- Stable ion contaminants were expected from EBIT, BCB and gas catcher.
- Beam is 95% pure ^{75}Ga and found 1.1% of ^{75}Ge (daughter of ^{75}Ga)
- Decay products come from gas catcher

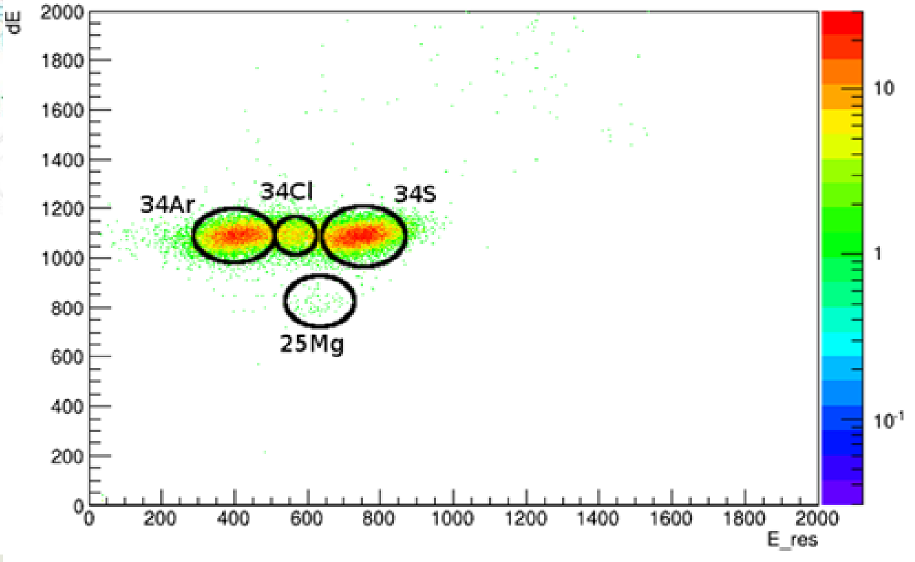
^{75}Ga → $T_{1/2}$ = 126 sec → ^{75}Ge → $T_{1/2}$ = 82.8 min → ^{75}As Stable

ReA3 Experiment: Measurement of the $^{34}Ar(a,p)^{37}K$ reaction cross section – K. Chipps

❖ ^{34}Ar beam was delivered for reacceleration
❖ Beam composition: ^{34}Ar (38%), ^{34}Cl (16%), ^{34}S (46%)
❖ Decay products come from gas catcher

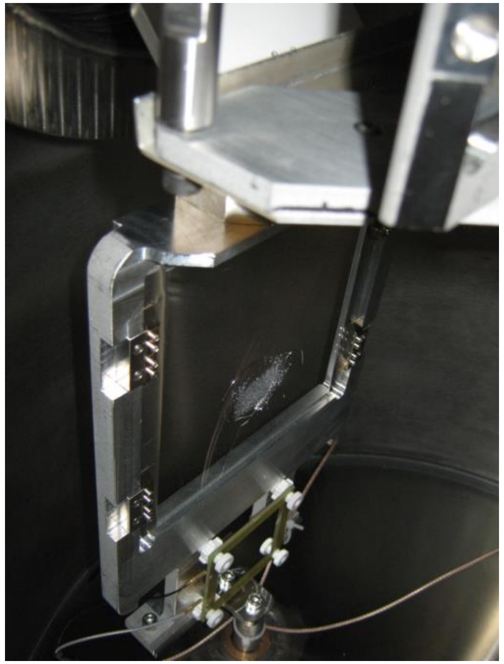
^{34}Ar → $T_{1/2}$ = 843 ms → ^{34}Cl → $T_{1/2}$ = 1.53 sec → ^{34}S Stable





Wedge for High Intense Beam

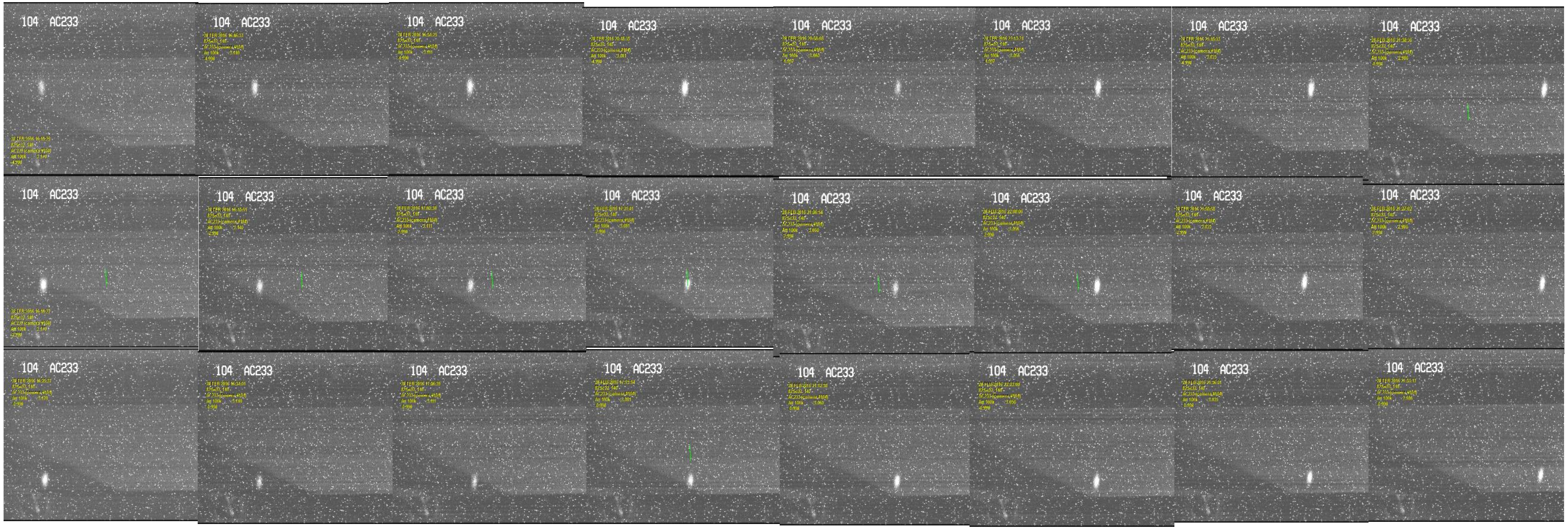
- Homogeneous wedges can be manufactured with glass
- High intense beams can damage fused silica glass wedges



Damage glass wedge

Wedge for High Intense Beam

- In-house built Al wedge (size: 15 cm X 15 cm; angle = 5 mrad; middle thickness = 1.0 mm)
- Check the wedge for homogeneity with ^{82}Se beam

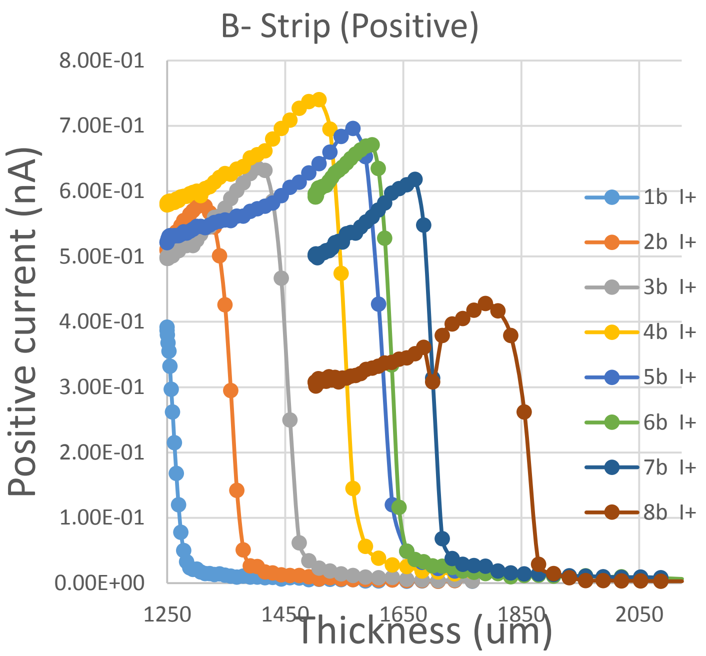


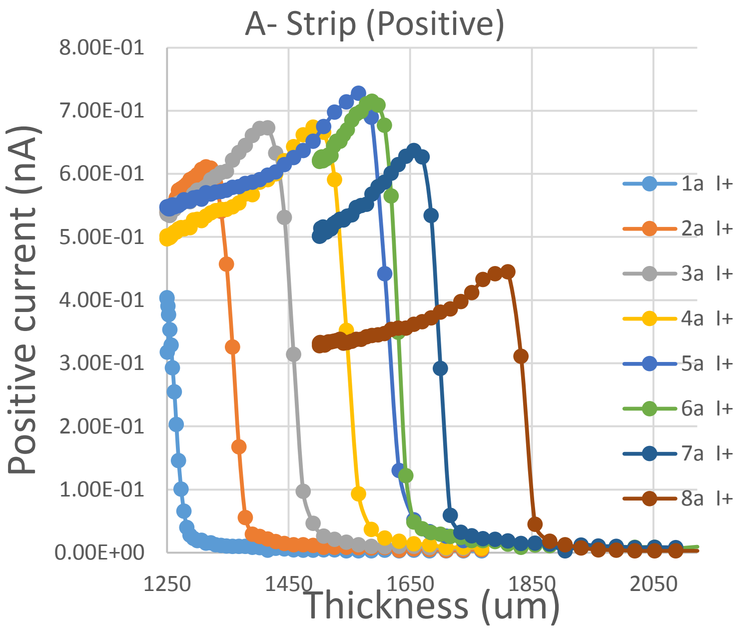
Thicker

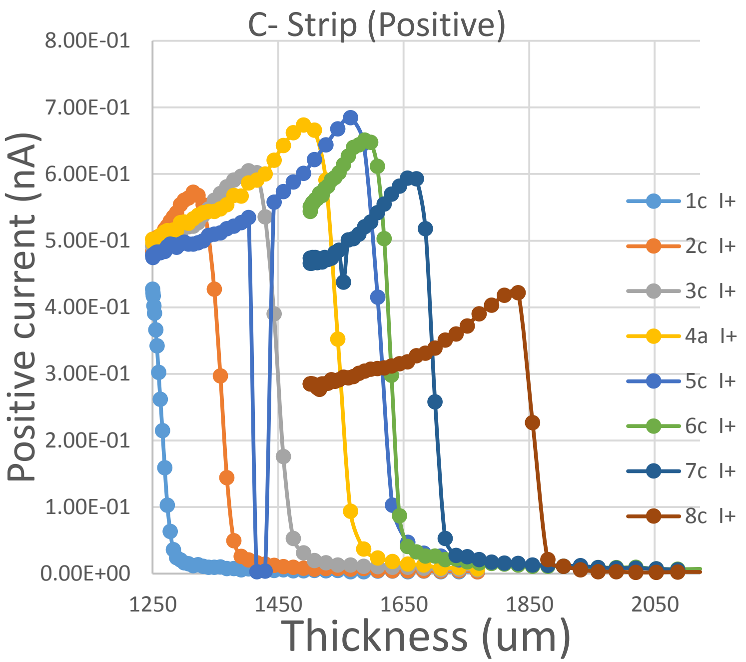
Beam position on the wedge →

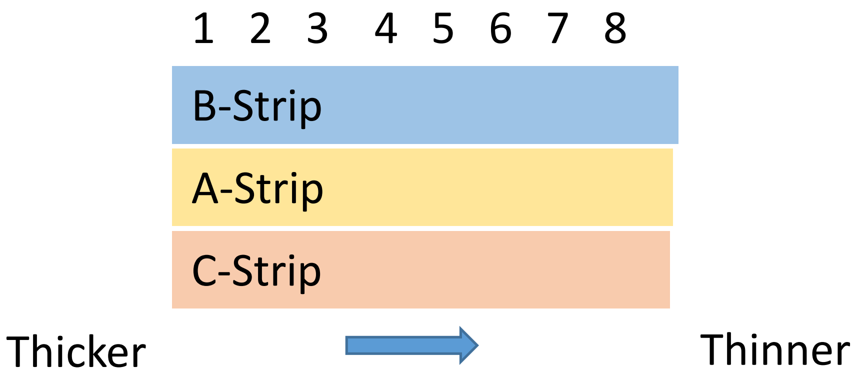
Thinner

Wedge for High Intense Beam





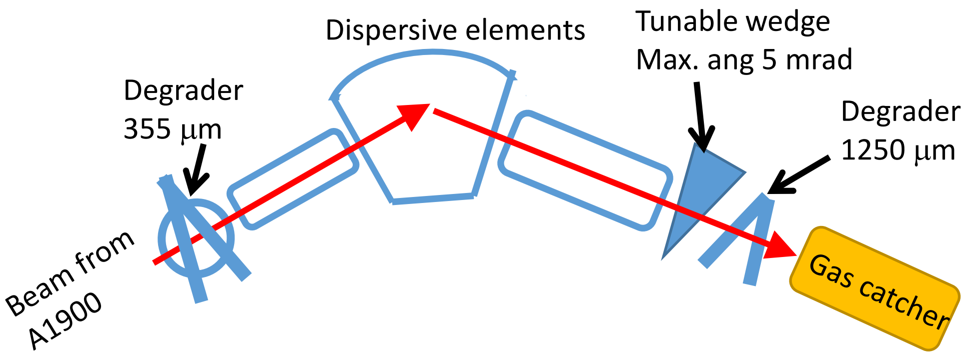


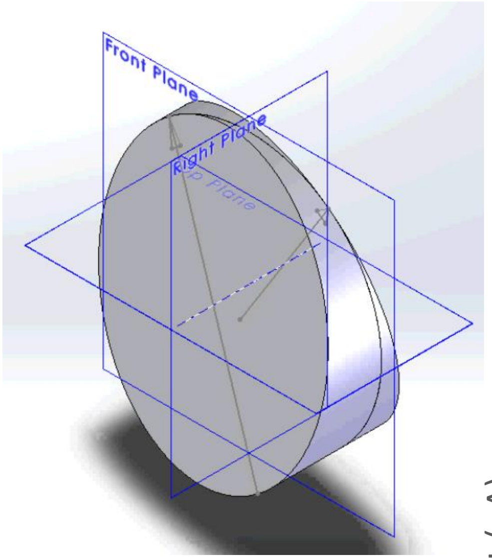


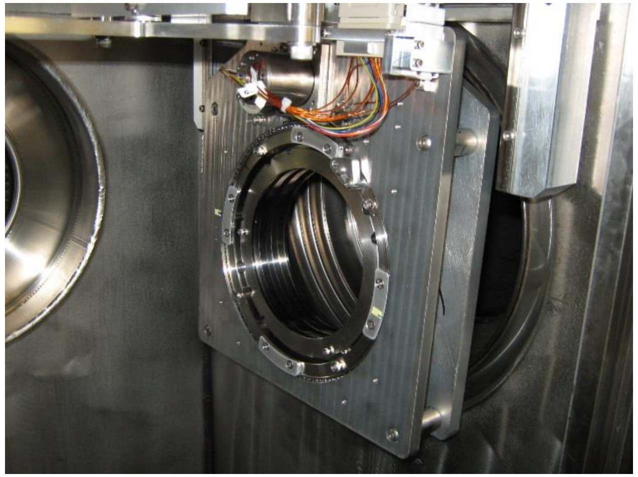
Improvement: Tunable Wedge System

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

^{75}Ga experiment

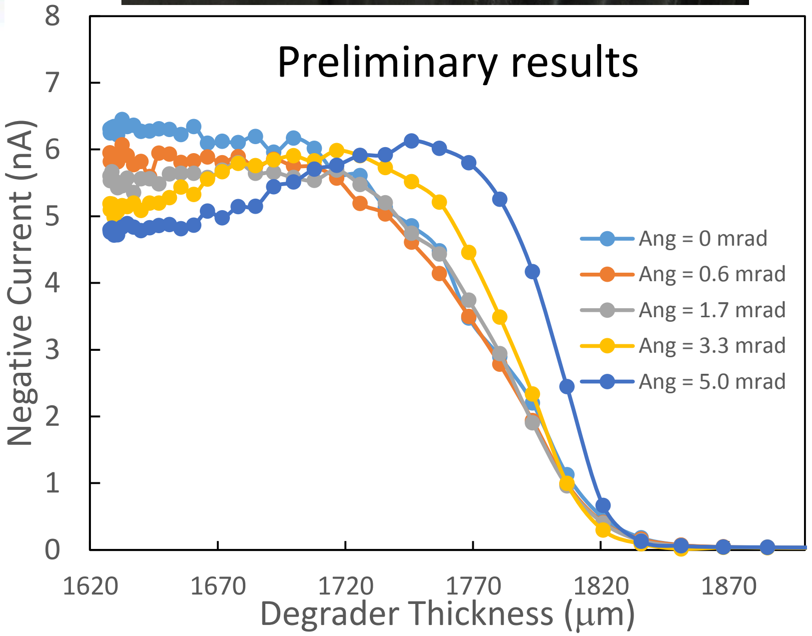






Tunable wedge system installed recently.

- 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



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