Beam Thermalization at the National Superconducting Cyclotron Laboratory

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Outline

- ❖ Overview of Stopped Beam Facility at NSCL
- ❖ Gas catcher operation
- ❖ Experimental results

Stopped Beam Facility at NSCL

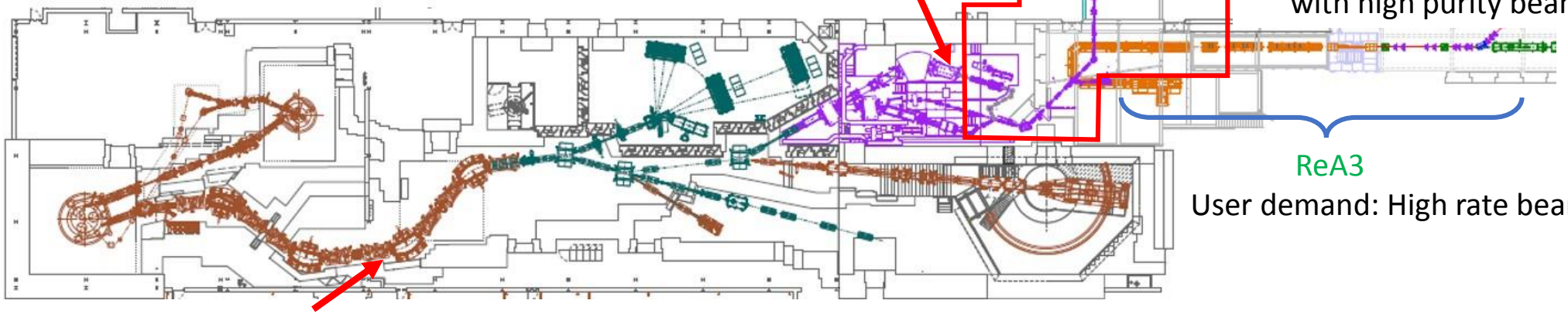
Low energy beam area

Stopped beam facility (N4 vault)

Decay experimental stations
User demand: High purity beams

BECOLA (Laser Spectroscopy)
User demand: High rates with bare ion beams

LEBIT (Mass measurements)
User demand: Very low rates with high purity beams

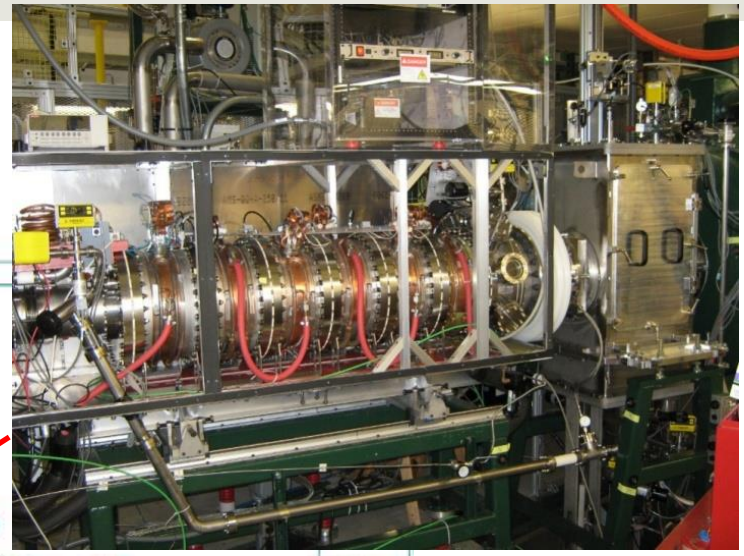


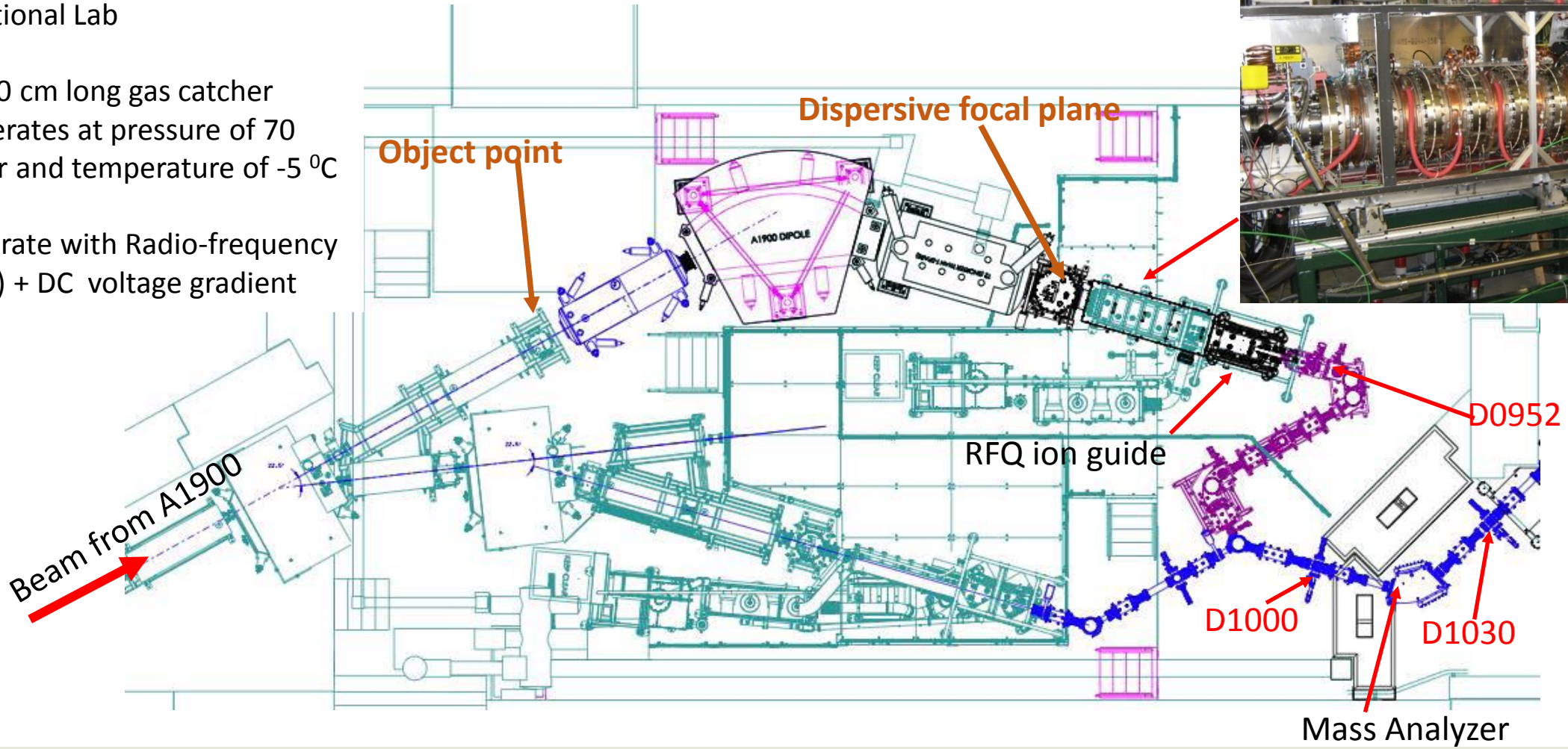
ReA3
User demand: High rate beams

A1900 fragment separator

Stopped Beam Facility at NSCL

- Large linear gas catcher constructed by Argonne National Lab
- 140 cm long gas catcher operates at pressure of 70 Torr and temperature of -5 ^{0}C
- Operate with Radio-frequency (RF) + DC voltage gradient





Low Energy Area Operations Overview

- Present linear gas catcher installed : Aug 2012
- Total number of low energy radioactive beams = 76
- Number of beams with different elements = 23
- Gas catcher delivers beams to experiments about 35% of total hours of NSCL operation

- **Beams for LEBIT (22)**
  - Fe-62,63,67,51
  - Co-63,64,65,68,69,52
  - Br-72
  - O-14
  - N-13
  - C-11
  - Cl-31
  - Si-24
  - P-29
  - Na-21
  - Cu-58,56
  - As-65, 67

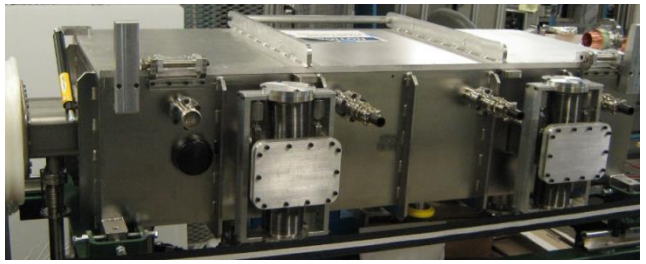
- **Beams for BECOLA (12)**
  - Fe-51,52,53
  - K-35,36,37
  - Ca-36,37,38,39
  - Ni-55, 56

- **Beams for structure (4)**
  - Ga-76
  - Mn-60
  - S-42
  - Rb-91

- **Gas Catcher experiments (23)**
  - Ga-76
  - K-37,47
  - P-29
  - Cl-33
  - S-40
  - Ni-55
  - Se-83,84
  - Si-27
  - Mg-22,23,29
  - O-14
  - Si-26
  - Br-72,78
  - Kr-73
  - Ar-46,34
  - Co-54
  - Sc-50,49

- **Beams for ReA3 (15)**
  - Ga-76,75
  - Ar-34,37,46
  - K-37,46,45,47
  - Cl-34
  - Br-77
  - Mg-22, 23
  - Se-71,72

New Addition to Stopped Beam Facility

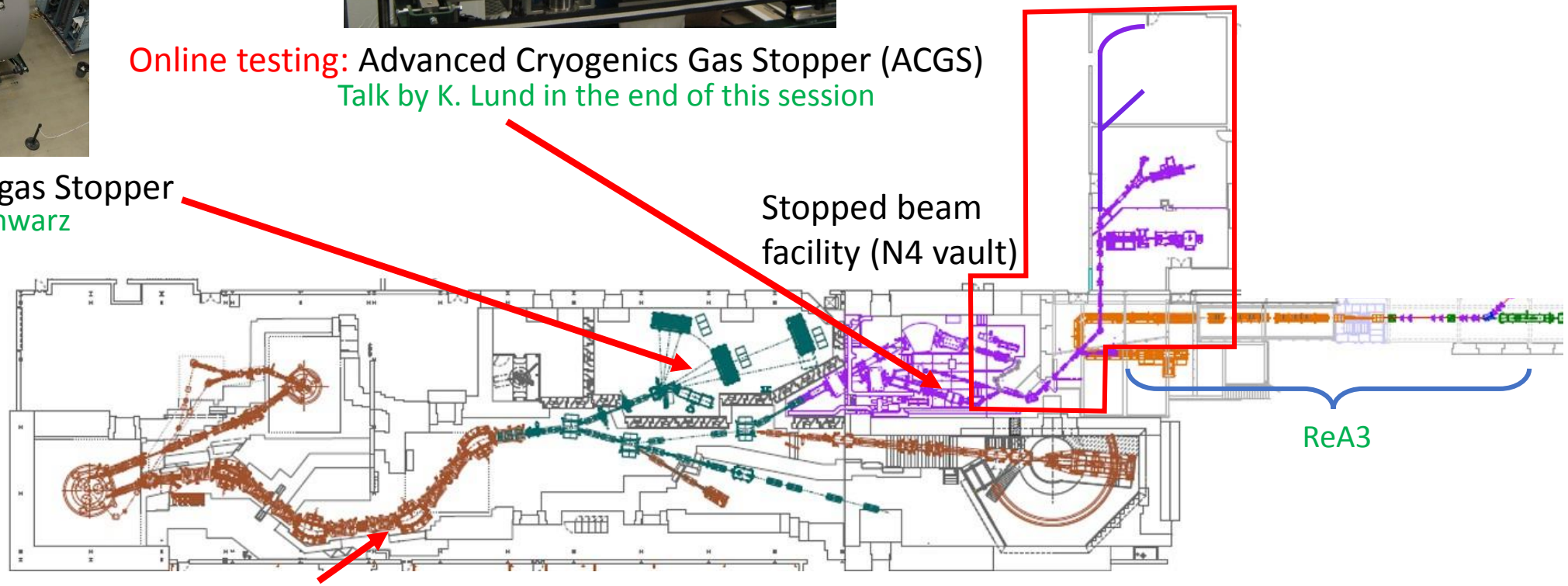


Low energy beam area

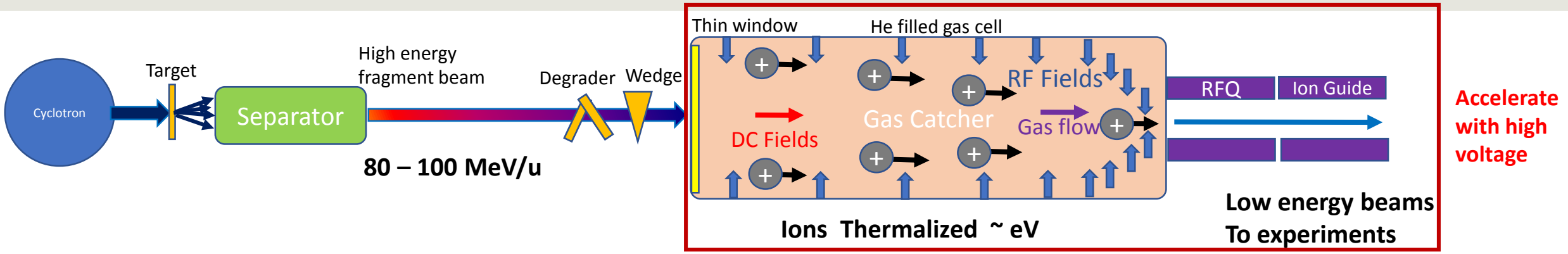
Online testing: Advanced Cryogenics Gas Stopper (ACGS)
Talk by K. Lund in the end of this session

Future: Cyclotron gas Stopper
Poster (90) by S. Schwarz

Stopped beam facility (N4 vault)



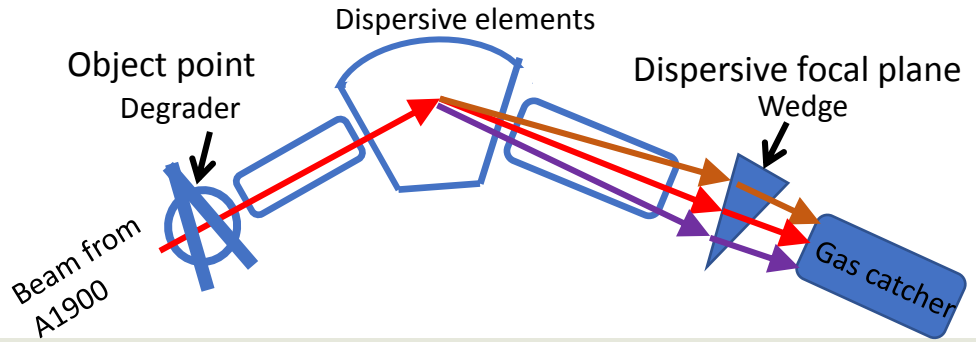
Scheme for Thermalization of Projectile Fragmentation



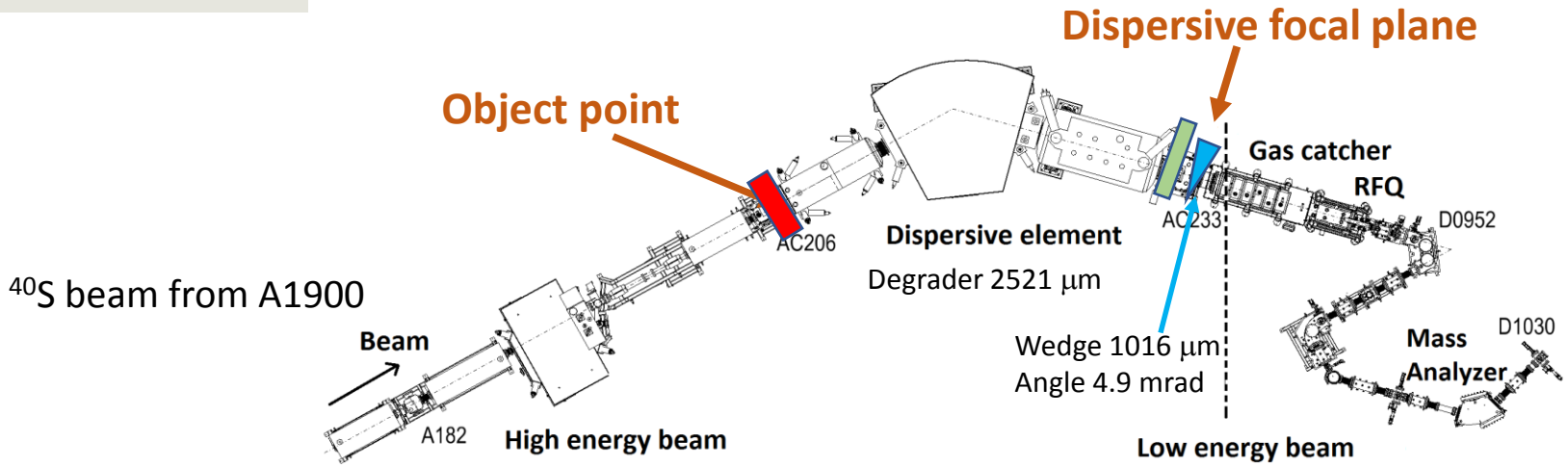
- Production of fragments from high energy beam
  - Large momentum spread due to reaction mechanism and production target.
- Bρ and ΔE separation
  - A1900 separator (High acceptance: 5% Δp/p) , achromatic wedge
- Momentum compression and thermalization
  - Narrow momentum spread beams lead to high stopping efficiency (L. Weissman et al. NIM A 522 (2004) 212)
- Gaseous ions collection
- Low energy beam transport

Method for producing an ideal incident beam:

- Degrade 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)

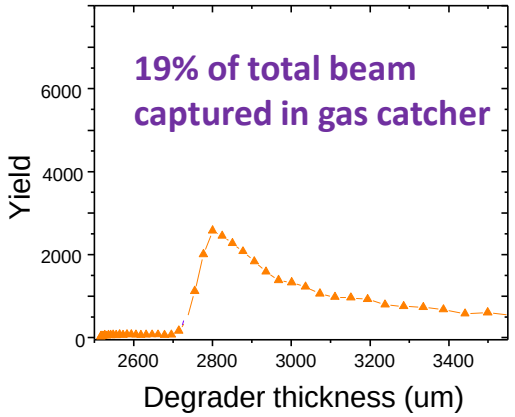


Momentum compression scheme: ^{40}S fragment



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

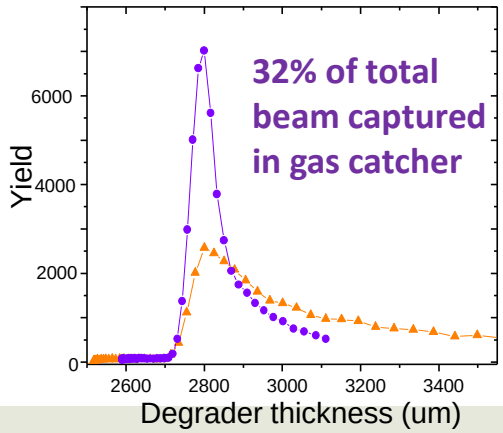
^{40}S range distribution



➢ **Rate increased by 1.7 times for ^{40}S beam**

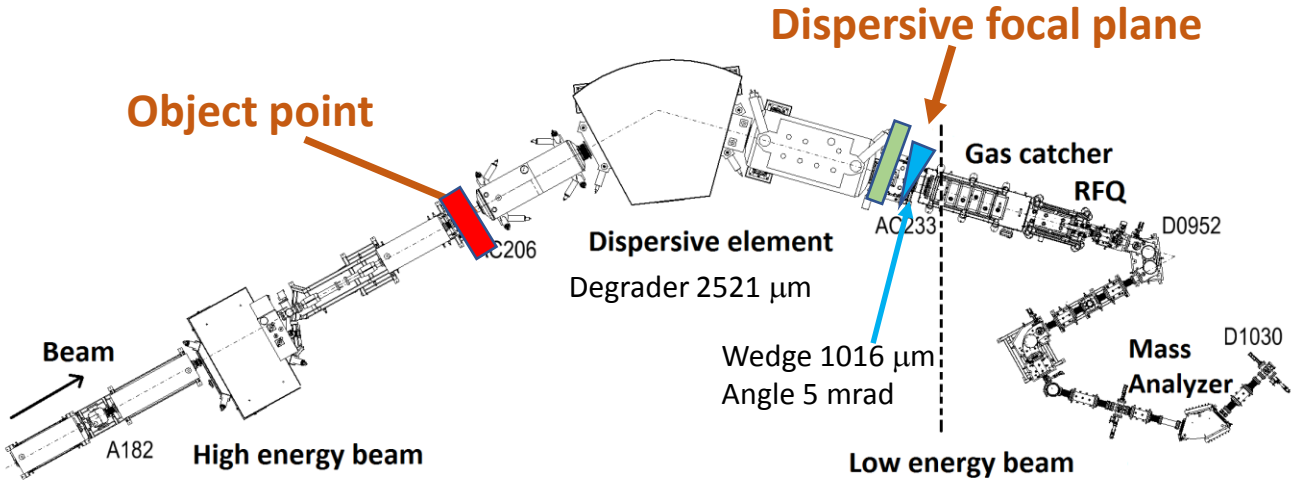
^{40}S Fragment thermalized with: 1) first degrader at the object point 2) second adjustable degrader and fixed angle wedge at the dispersive focal plane

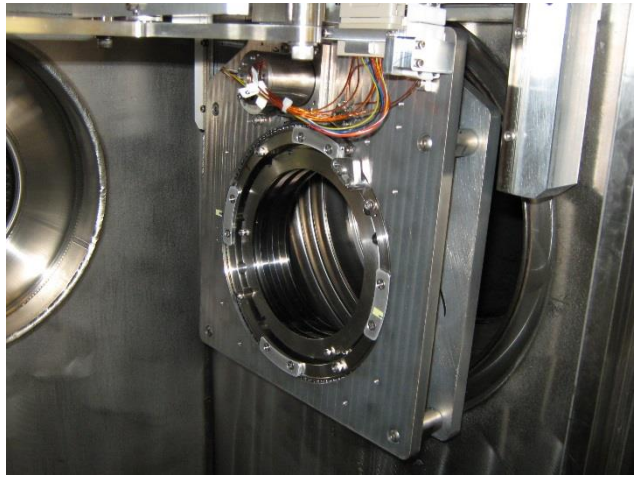
^{40}S range distribution

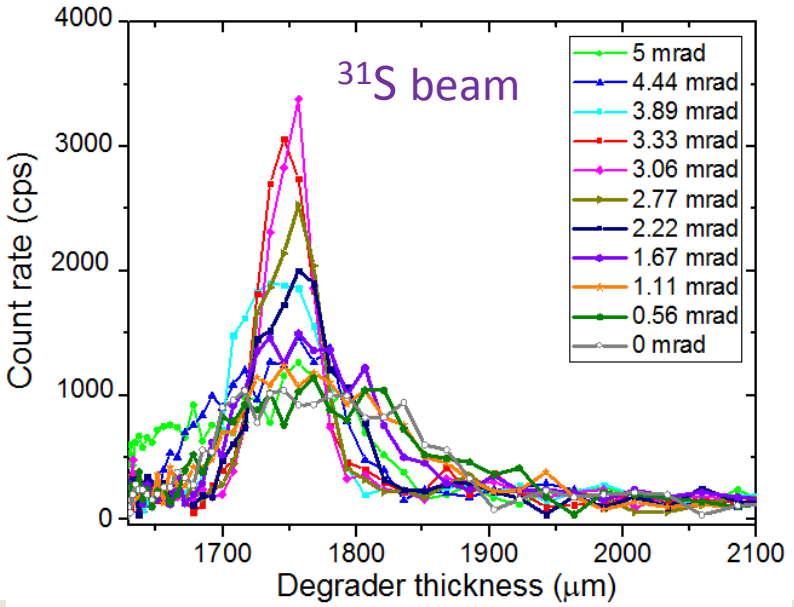


Improvement: Tunable Wedge System

- **Stopping efficiency increases due to the angle tunable wedge system**



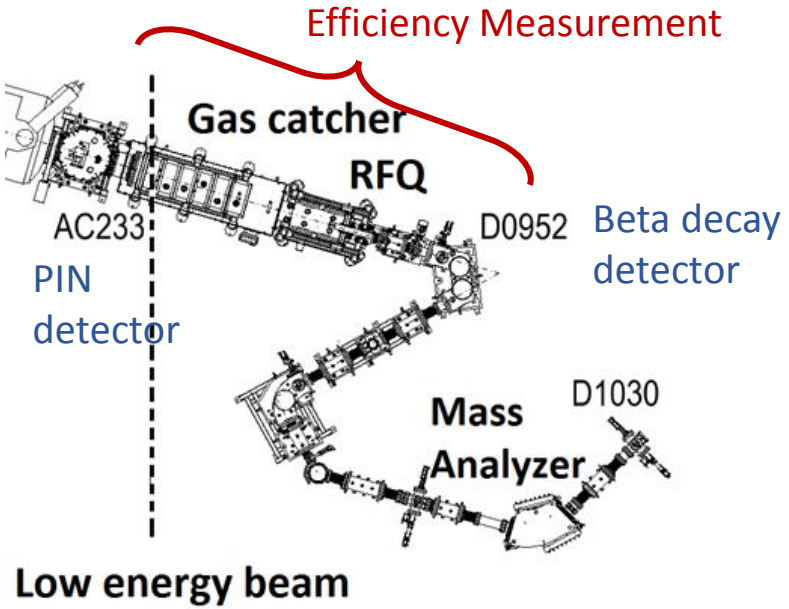




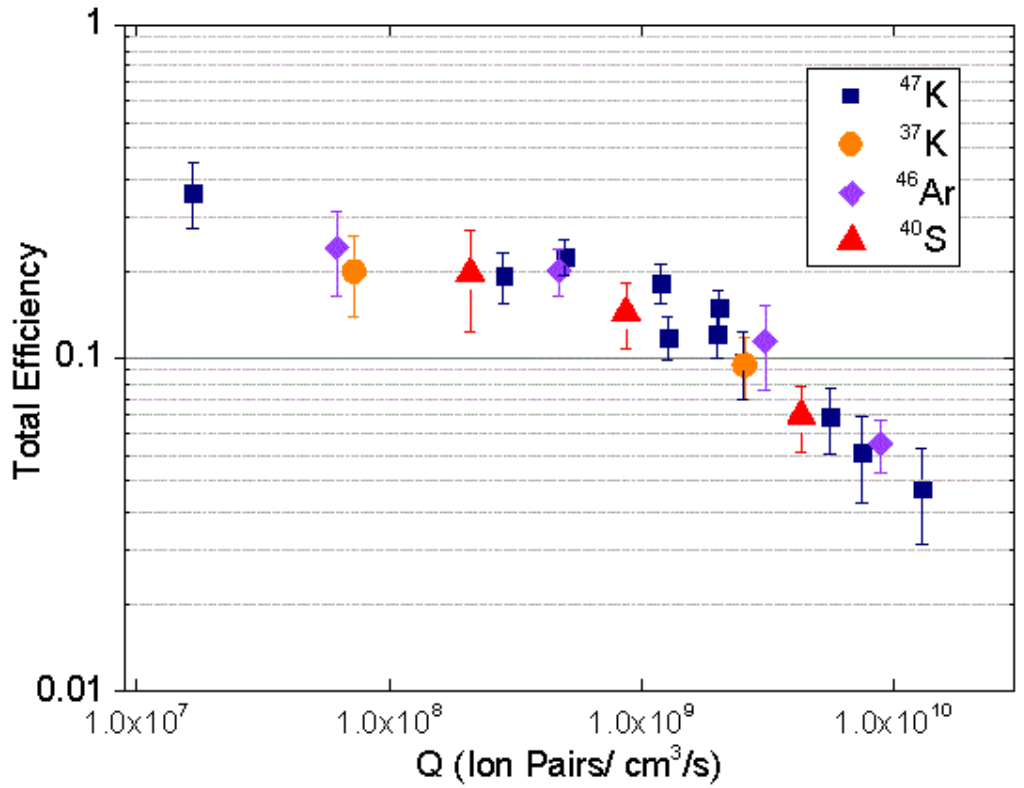
Angle tunable wedge system installed recently.

- 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 ^{31}S beam

Stopping and Extraction Efficiency



Total Efficiency Measurement



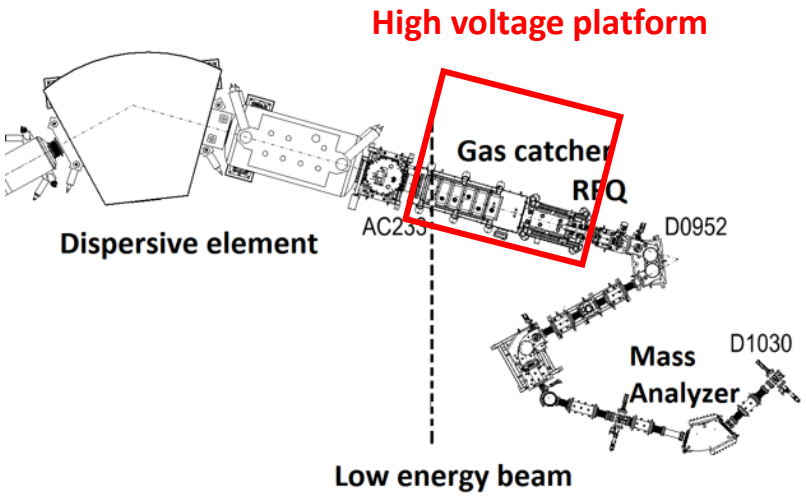
- Total Efficiency Includes stopping and extraction efficiencies of the gas catcher, and RFQ efficiency.
- RFQ extraction efficiency ~ 80 %
- Incoming particle rate to the gas catcher varies from 10^2 to 10^8 pps.

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

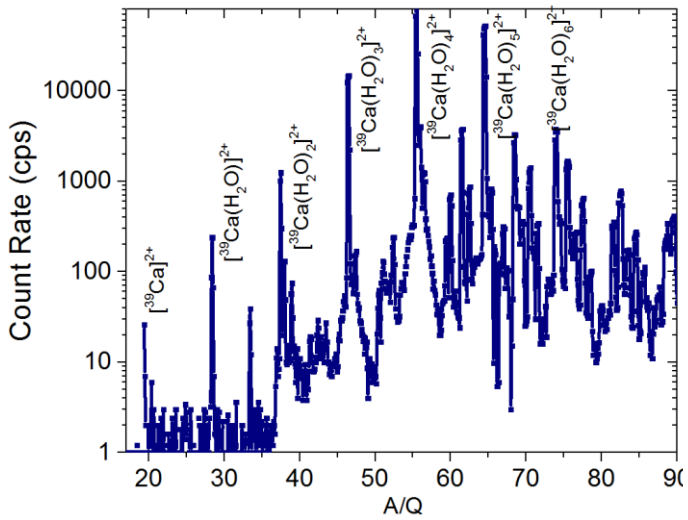
Molecular Ion Formation with Fragments

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

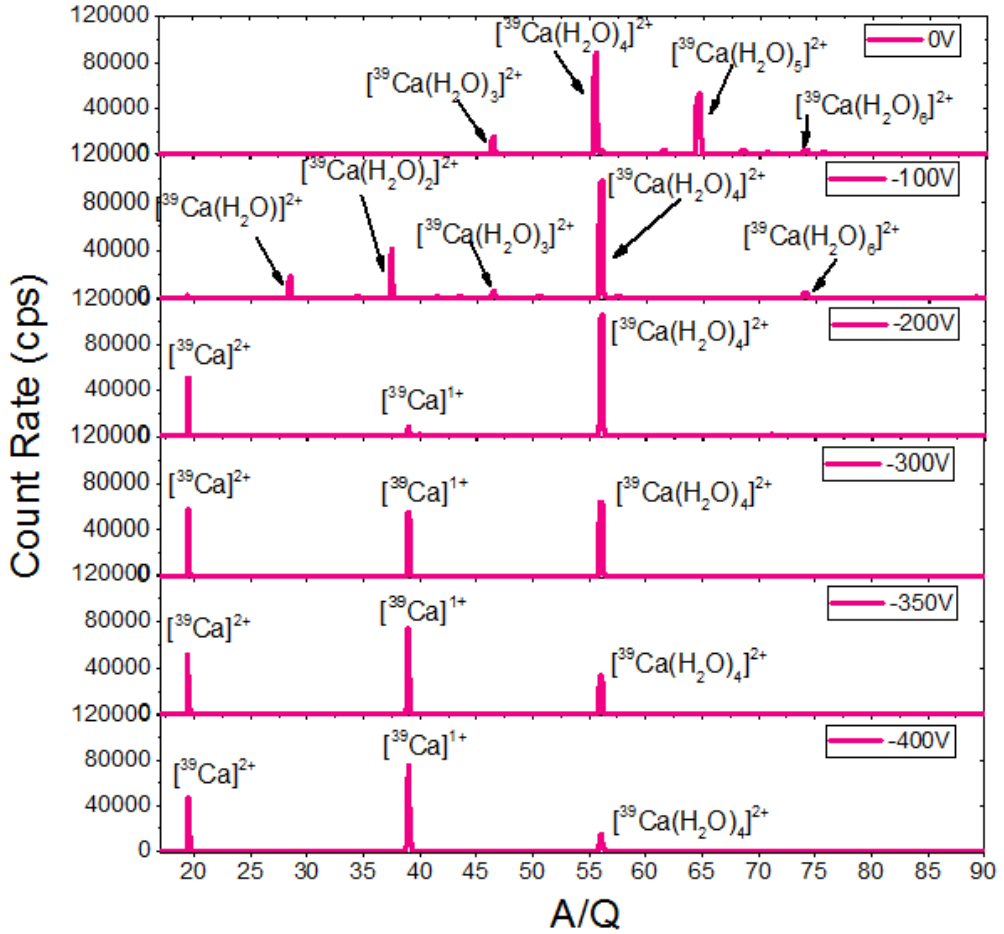
- lower the beam rate for experiments and some experiments can't use beams in molecular ion form.



^{39}Ca Molecular Ion Distribution



^{39}Ca Collision Induced Dissociation



- Apply negative offset voltage at RFQ

- Compensate the offset voltage by increasing the platform voltage

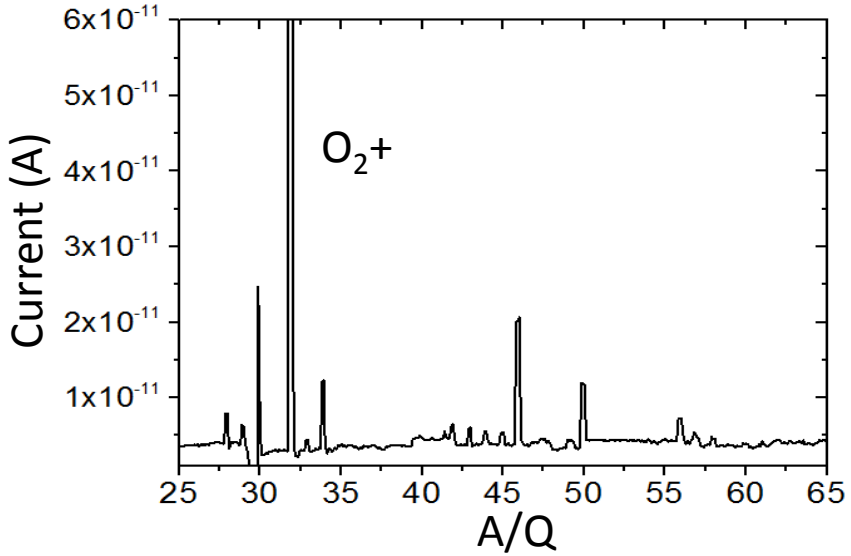
- 2^+ molecular ions breaks when offset voltage increases.
- Produces bare $^{39}Ca^{2+}$ and $^{39}Ca^{1+}$

Stable Ion Contaminants with Low Energy Radioactive Beam

- Stable ions are formed during thermalization process.
- Contribute to high beam current (depends on incoming rate); Increase space charge in gas catcher

^{37}K experiment

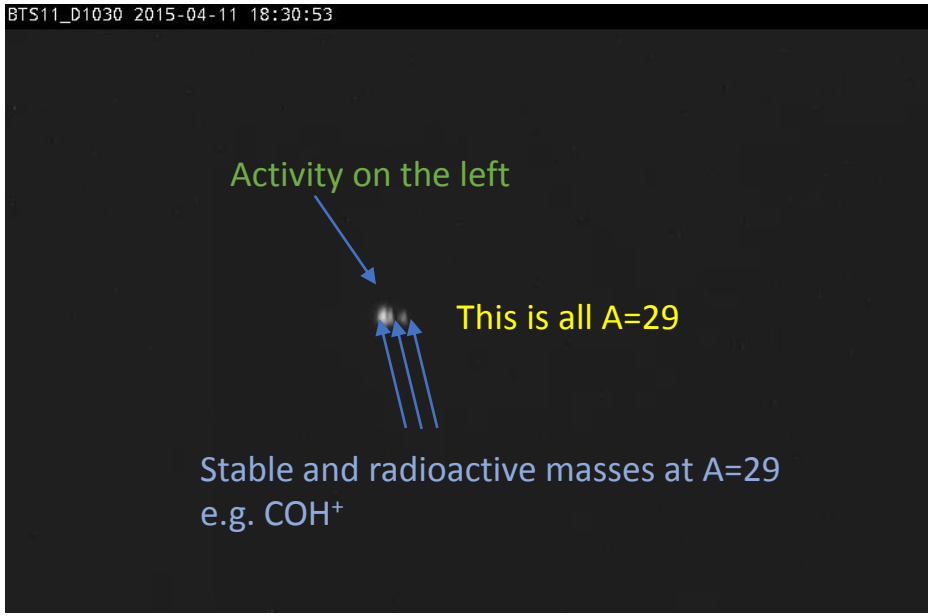
Stable ions mass distribution



Major contribution come from oxygen molecular ions

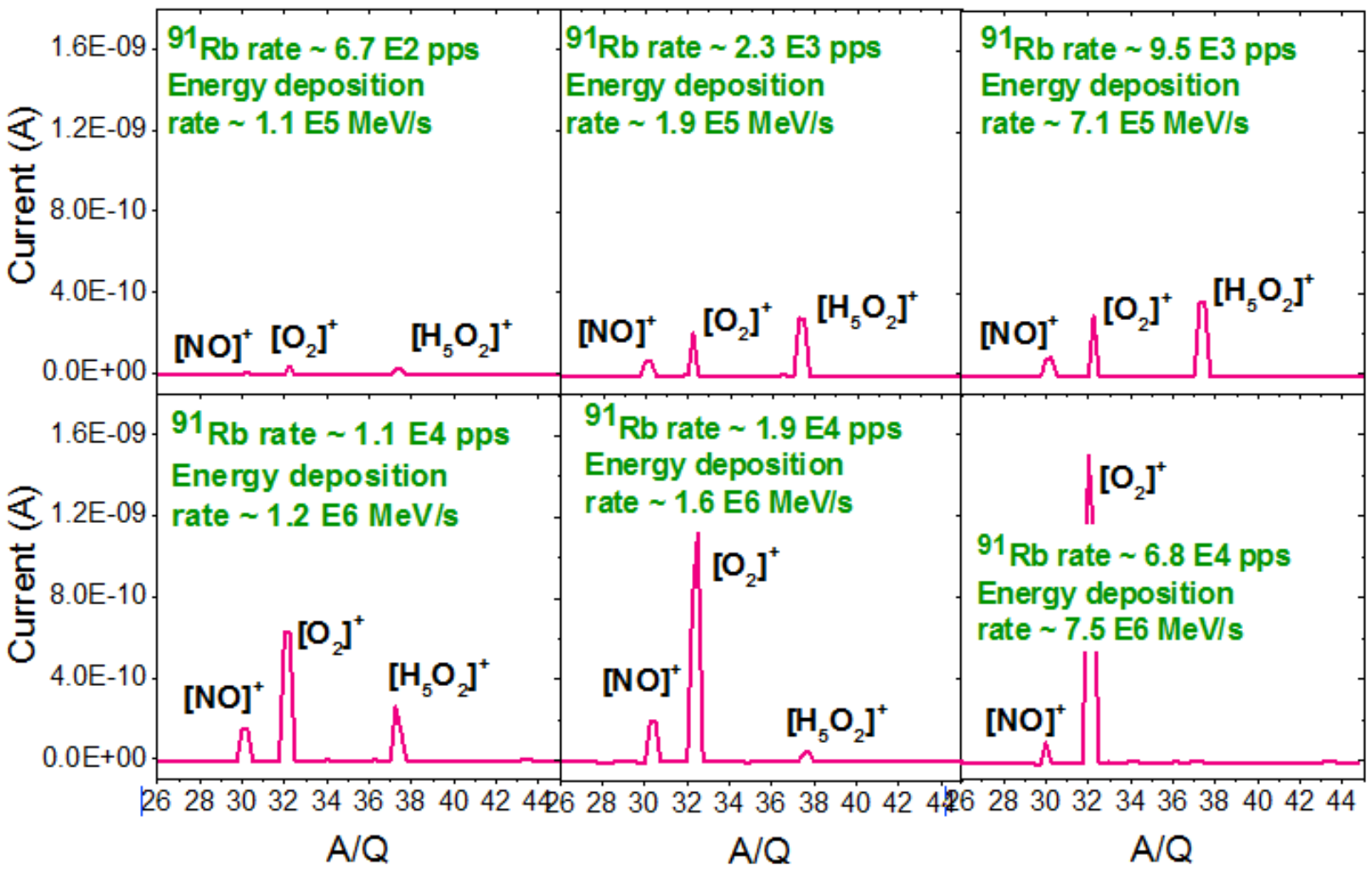
^{29}P experiment : Mass measurements

MCP image after mass separation (set for mass = 29)



- Major issue for low rate experiments
- Mass analyzer resolution (R) $m/\Delta m \sim 1500$
- Some cases, stable ions can be rejected with slits

Water Dissociate to Produce Oxygen ions

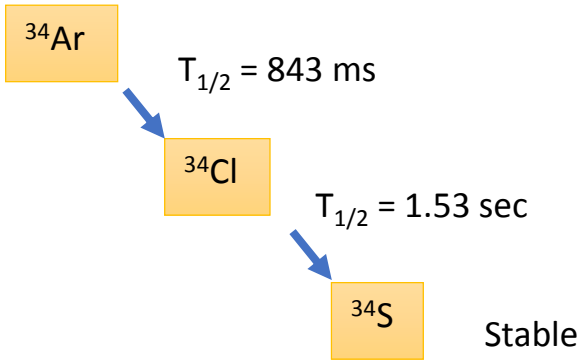


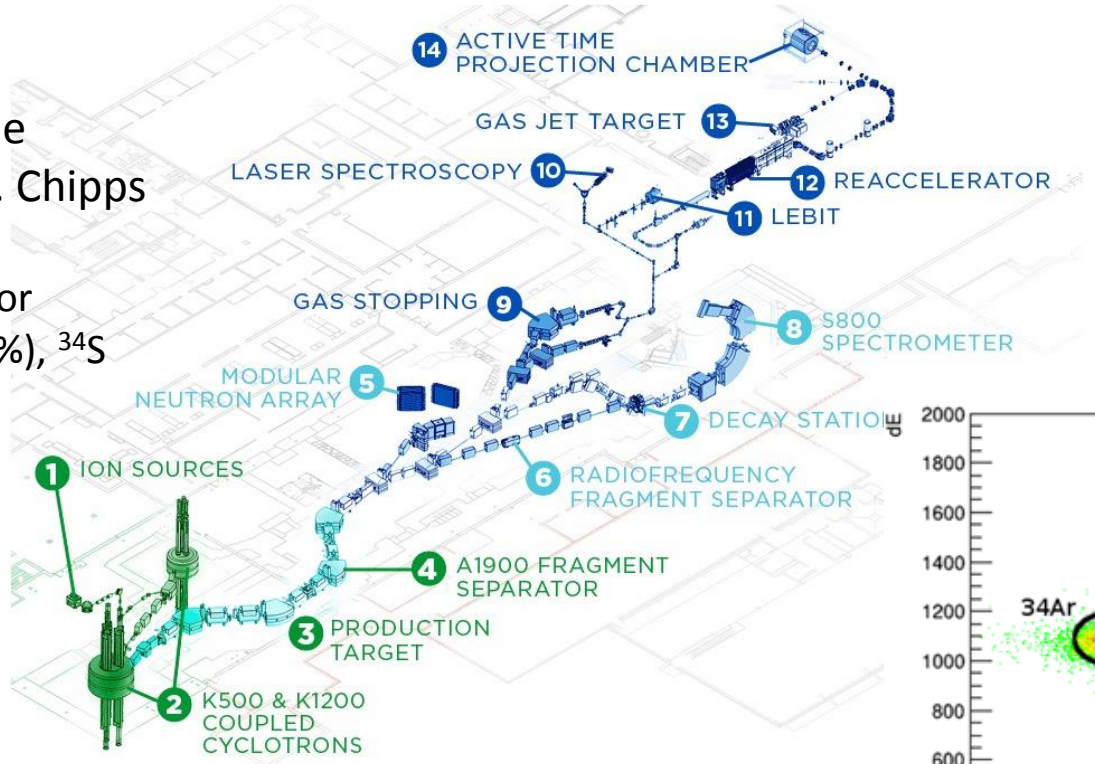
- Stable ion output rates were measured as a function of incoming incoming beam rates
- Incoming beam rate controlled by attenuation and momentum slits (dp/p = 0.5, 1.0 & 2.0%)
- Water dissociates to produce oxygen ions when increasing the energy deposition rate.

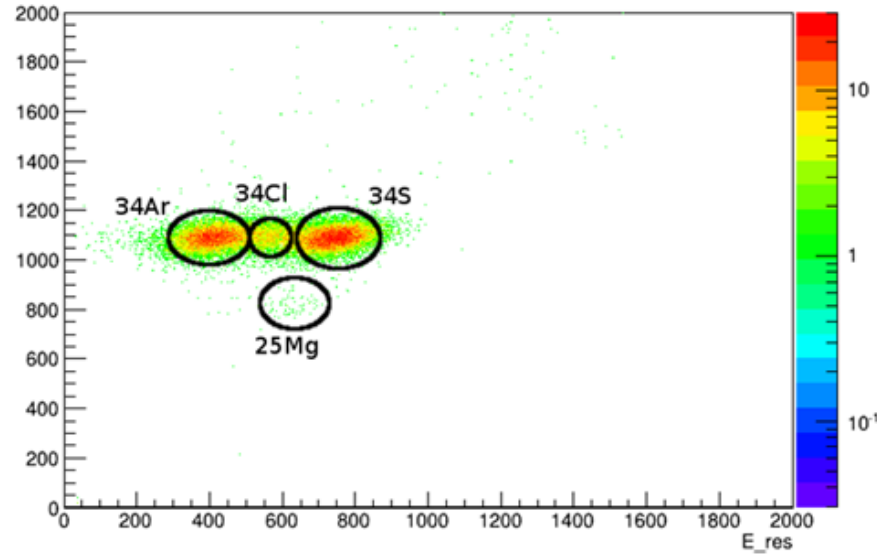
Decay Products as Contaminants

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

- ^{34}Ar beam was delivered to reaccelerator
- Beam composition: ^{34}Ar (38%), ^{34}Cl (16%), ^{34}S (46%)

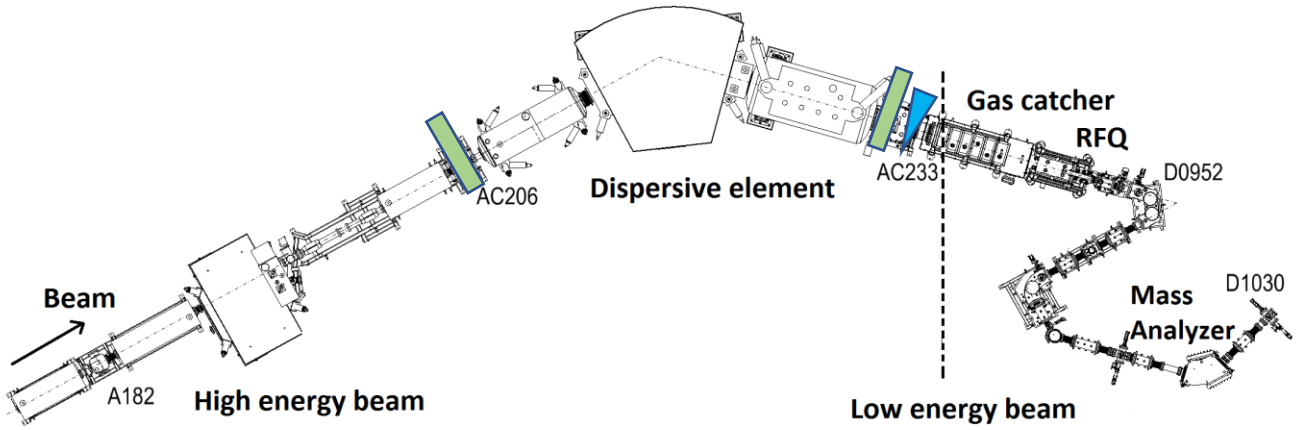


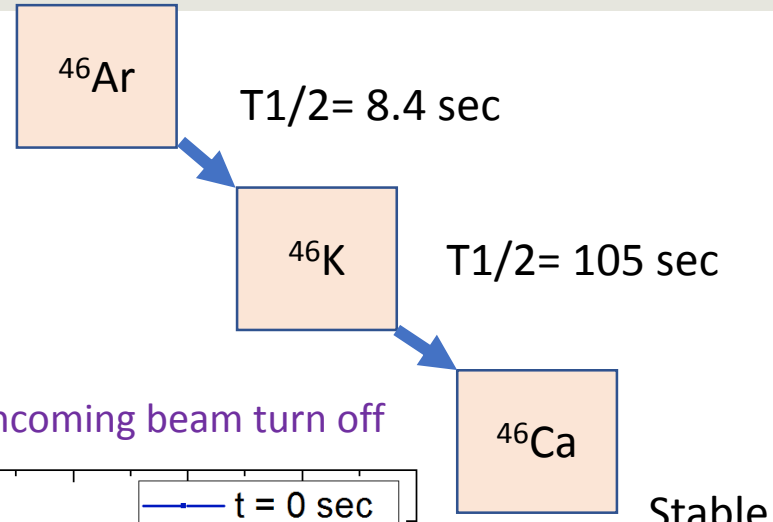




➢ **Decay products delivers with low energy beams**

Decay products in low energy radioactive beams



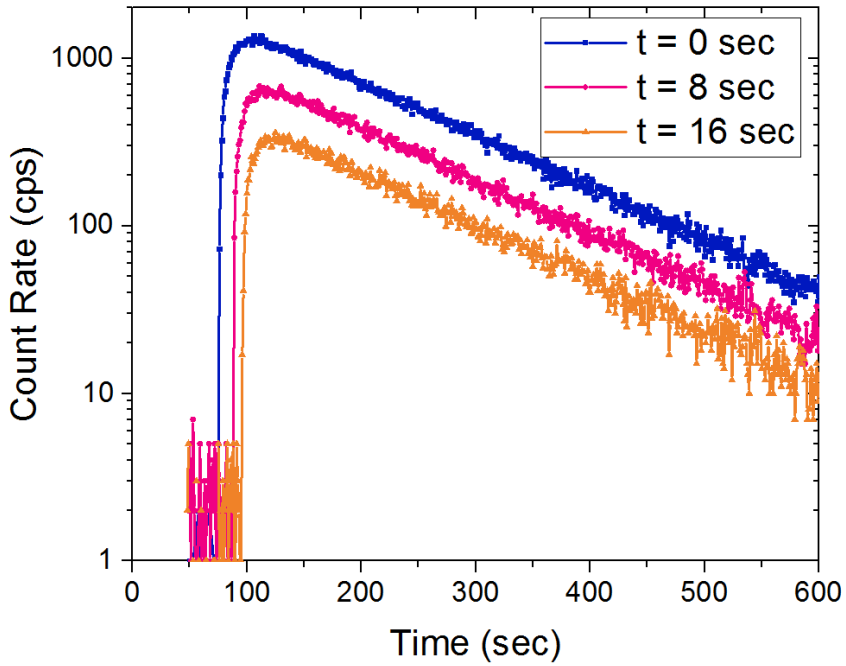


Daughter products were observed after incoming beam turn off

eg. Decay of 46K was observed after turning off incoming 46 Ar radioactive beam.

Fragments stopped on the back wall of gas catcher decay and eject the recoil nucleus from the wall.

^{46}Ar decay after incoming beam turn off



Outlook

- Stopped Beam facility at NSCL provides beams to low energy experimental programs successfully (35% of total operation time)
- Improve beam stopping efficiency by momentum compression
- Application of Collision Induced Dissociation technique provides beams without molecular ion form
- Identify oxygen ion production mechanism in the gas catcher
- Decay products from fragments stopped on the wall of gas catcher comes out with the low energy beam
- New beam thermalization capabilities are on the way to reality soon (ACGS, Cyclotron Stopper)

Thank You for Your Attention