Development of ECR high purity liners for reducing K contamination for AMS studies of ^{39}Ar

By Chris Schmitt

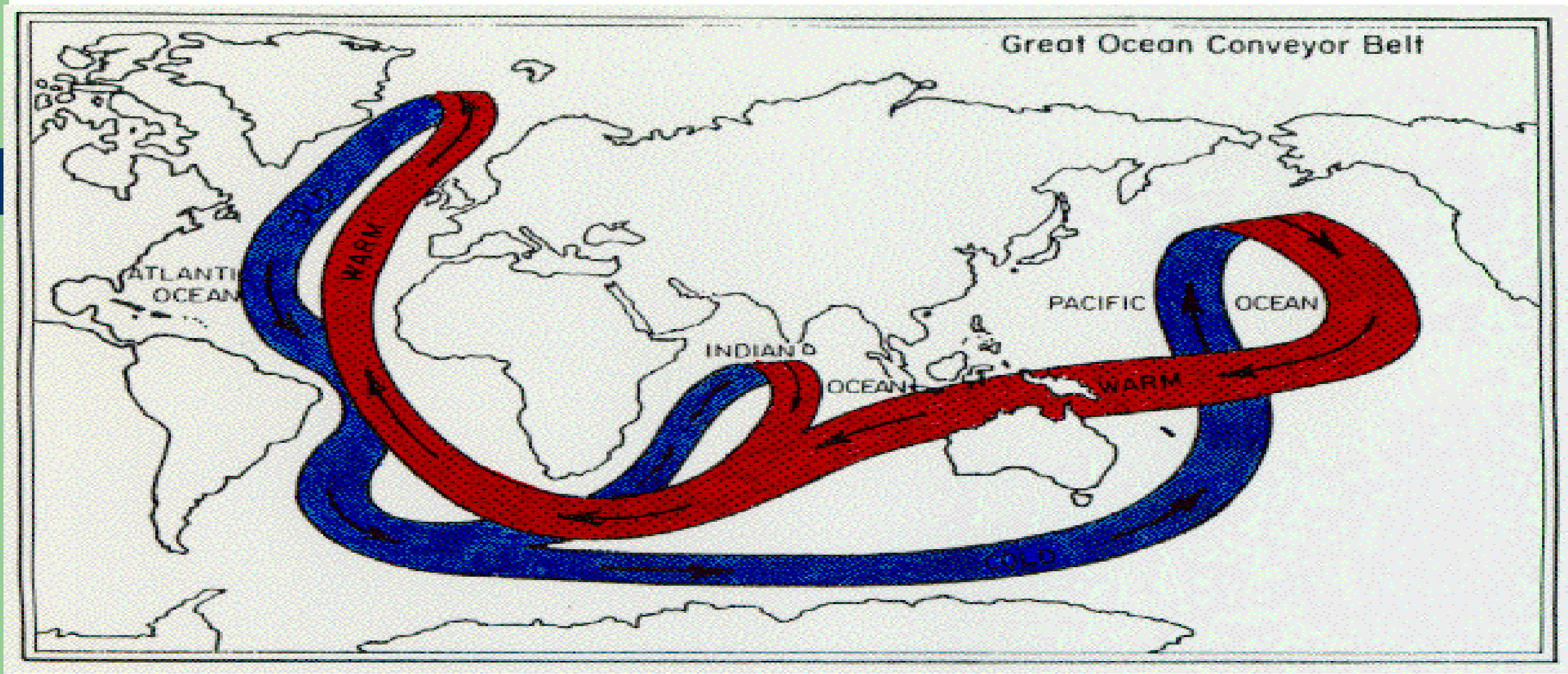
Collaborations.

- **Philippe Collon, M Bowers, D Robertson, C Schmitt** - *Nuclear Science Laboratory, University of Notre Dame, Notre Dame IN 46556, United States*
- **F Calaprice, C Galbiati** - *Department of Physics, Princeton University, Princeton NJ 08540, United States*
- **C.L Jiang, D Henderson, R Pardo, K.E Rehm, R Scott, R Vondrasek** - *Physics Division, Argonne National Laboratory, Argonne IL 60439, United States*
- ***W Kutschera*** - *Vienna Environmental Research Accelerator, Institut fuer Isotopenforschung und Kernphysik, Universitaet Wien, Waehringer Strasse 17, Wien A-1090, Austria*
- **M Paul** - *Racah Institute of Physics, Hebrew University of Jerusalem, Jerusalem 91904, Israel*

Setting the Stage.

- Not the first group to work with liners or cleaning techniques but perhaps one of the few to look at K reduction.
- Where others are trying to remove contaminants at the nanoamp/picoamp level we need to go beyond that.
  - Natural levels of $^{39}Ar/Ar$ are a thousand times smaller than $^{14}C/C$. We need to go much further.
- The levels of concentration are in the 10^{-16} reaching toward the 10^{-19} range. It can be described as looking for a “bottle of wine in Lake Michigan.” (Volume: 4920 km^{3})

Driving Force I: Oceanography, dating ocean water samples.



- As long as large ocean water samples for ^{14}C were routinely collected, low level counting (LLC) of ^{39}Ar of 1000L was feasible. With the advent of AMS only 1L samples of water were needed for ^{14}C thus killing the availability of the large sample sizes needed for ^{39}Ar.
- With ~17 ^{39}Ar decays per year from a 1 L of ocean water it became vital to develop an AMS technique for ^{39}Ar measurements at facilities such at ATLAS.
- The best measurements were <u>$^{39}Ar/Ar = 4.3 \times 10^{-17}$</u>. The levels of sensitivity we are trying to achieve are akin to looking for a <u>"bottle of wine in Lake Michigan."</u>

Driving Force II: The Search for Dark Matter WIMPS.

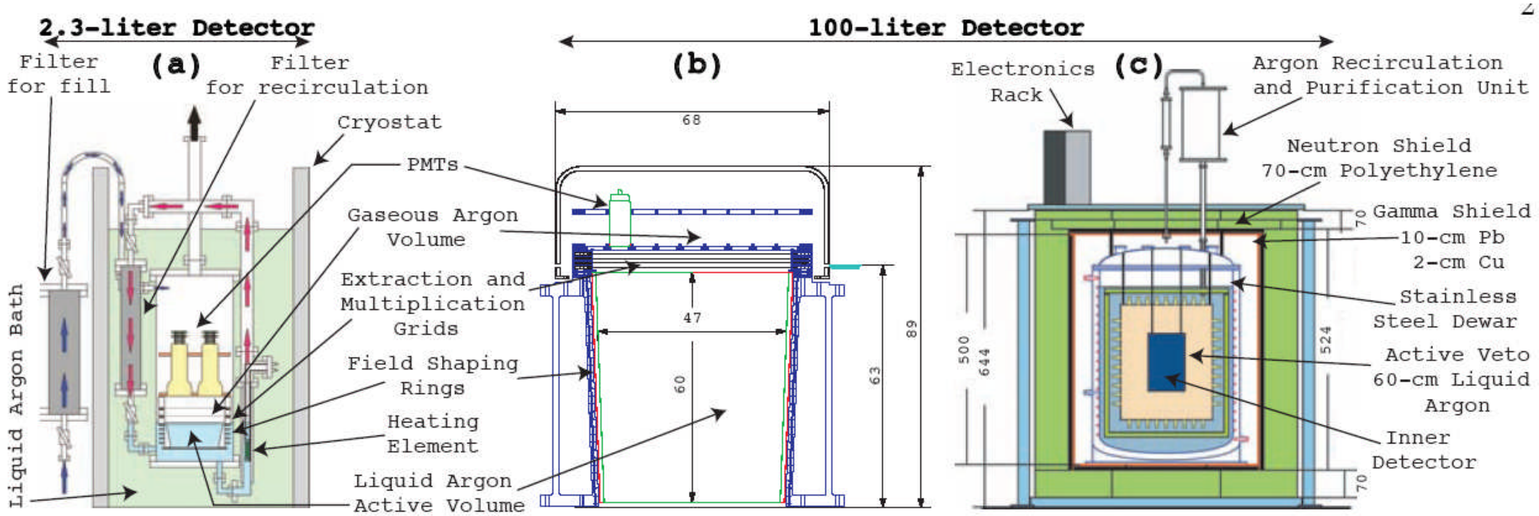
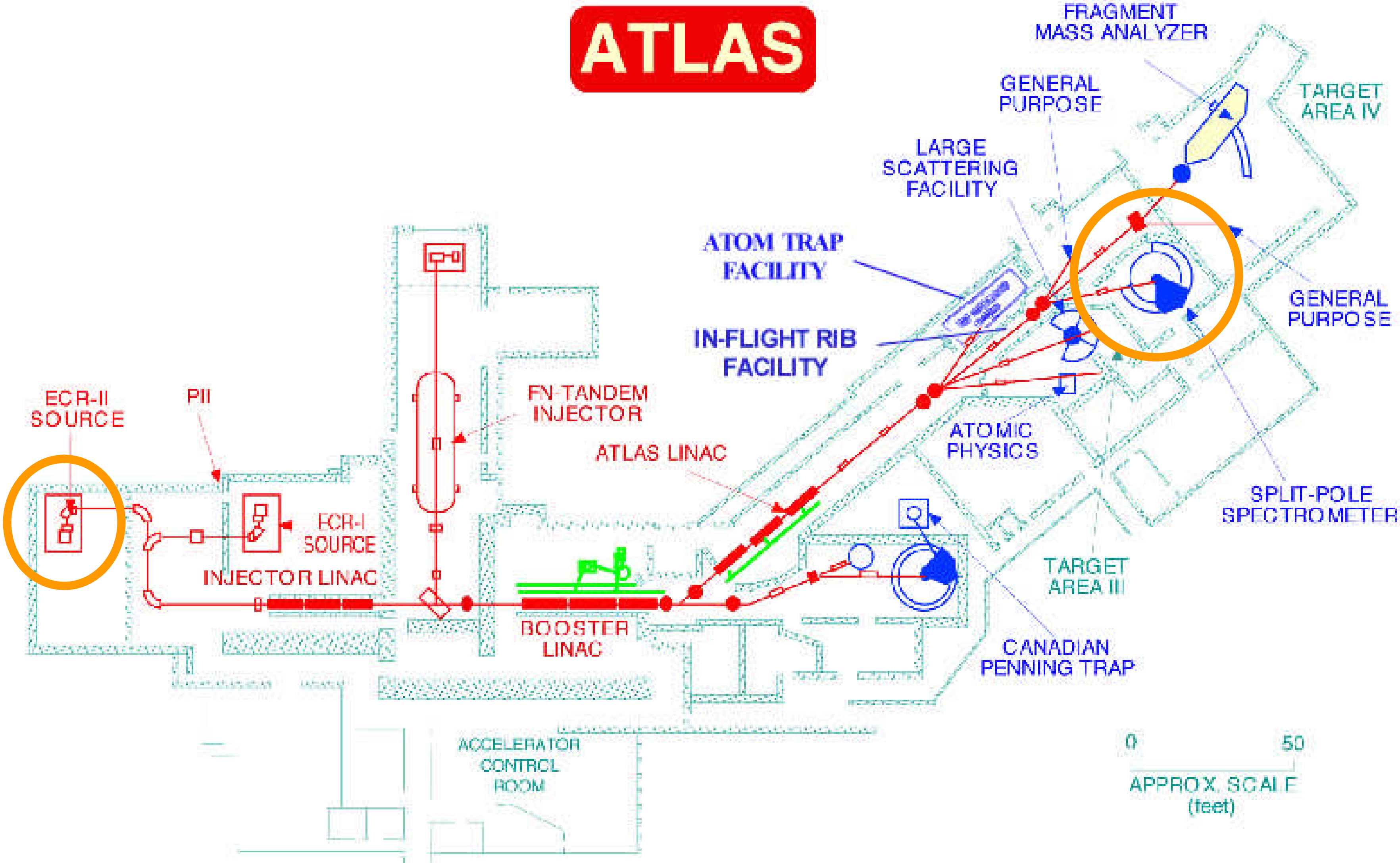


FIG. 1: (a) artist rendition of the 2.3 liter detector. The blue arrows indicate the flow of argon during the detector filling. The red arrows indicated the flow during the online purification.
(b) assembly drawing of the 100-liter inner detector. All quotes in cm.
(c) layout of the 100-liter detector support structure and neutron and gamma shields. All quotes in cm.

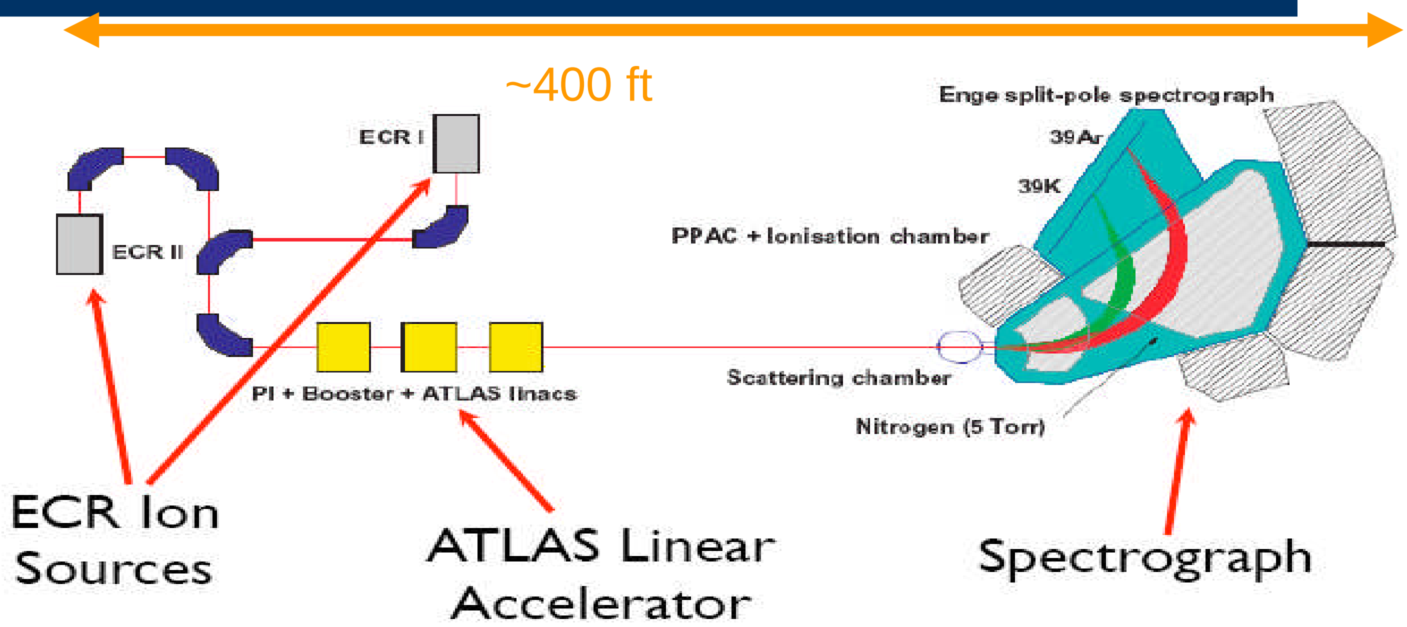
- F. Calaprice has an interest in these ^{39}Ar studies to try and achieve even more sensitivity. More specifically to measure ^{39}Ar to search for a source of argon that has a low concentration of ^{39}Ar. Such a source of argon would be useful for a new liquid argon detector searching for WIMP (Weakly Interacting Massive Particles) dark matter.
- Technical challenges for both studies is separating the ^{39}K isobar.

Argon Stats + Properties

- Commercial argon is obtained from the atmosphere, it contains ^{39}Ar, which is produced by cosmic ray interactions with ^{40}Ar.
- Argon found as a trace component in gas found in deep underground wells. Even though shielded from cosmic rays ^{39}Ar can be formed through nuclear reaction mechanisms as $^{39}K(n, p)$ when U and Th are present with K.
- ^{39}Ar decays via beta emission with an end point energy of 560 keV and $t_{1/2}$ of 269 years.
- Atmospheric concentration: $^{39}Ar/Ar = 8.1 \times 10^{-16}$, which corresponds to a beta decay rate of ~1 Bq/kg of argon.
- Low levels of argon can be expected from well deposits because 1) cosmic ray suppression and 2) low abundance of U and Th compared to the earth's crust.


ATLAS
FRAGMENT MASS ANALYZER
GENERAL PURPOSE
TARGET AREA IV
LARGE SCATTERING FACILITY
ATOM TRAP FACILITY
IN-FLIGHT RIB FACILITY
GENERAL PURPOSE
FN-TANDEM INJECTOR
ECR-II SOURCE
PII
ATLAS LINAC
ATOMIC PHYSICS
SPLIT-POLE SPECTROMETER
ECR-I SOURCE
INJECTOR LINAC
TARGET AREA III
BOOSTER LINAC
CANADIAN PENNING TRAP
ACCELERATOR CONTROL ROOM
0
50
APPROX. SCALE (feet)

Brutal Part 1: Stability.



- For long term use we need to rely on the stability of the source, accelerator, and magnets.
- Spectrograph: The thin windows that allow for GFM, thin mylar windows in the detectors and gas pressures.

Brutal Part 2: Estimated ^{39}Ar Counting Rate.

- Atmospheric concentration: $^{39}Ar/Ar = 8.1 \times 10^{-16}$ and 20% transmission from ECR II to spectrograph focal plane.
- Given a source output of 133 eμA then we can estimate the following:

100% atmospheric Argon = one ^{39}Ar count per minute

10% atmospheric Argon = one ^{39}Ar count in 10 minute

1% atmospheric Argon = one ^{39}Ar count in 1.7 hours

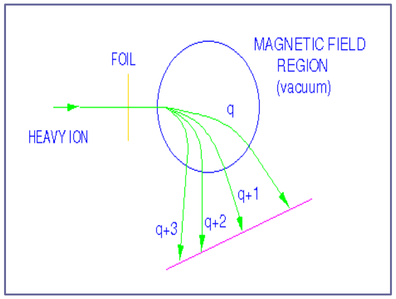
0.1% atmospheric Argon = one ^{39}Ar count in 17 hours

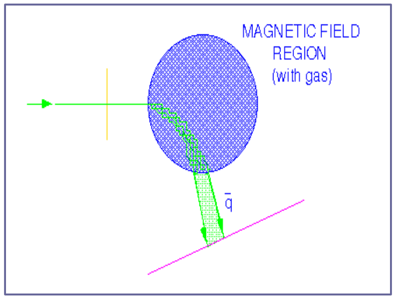
-Calculations done by W. Kutschera

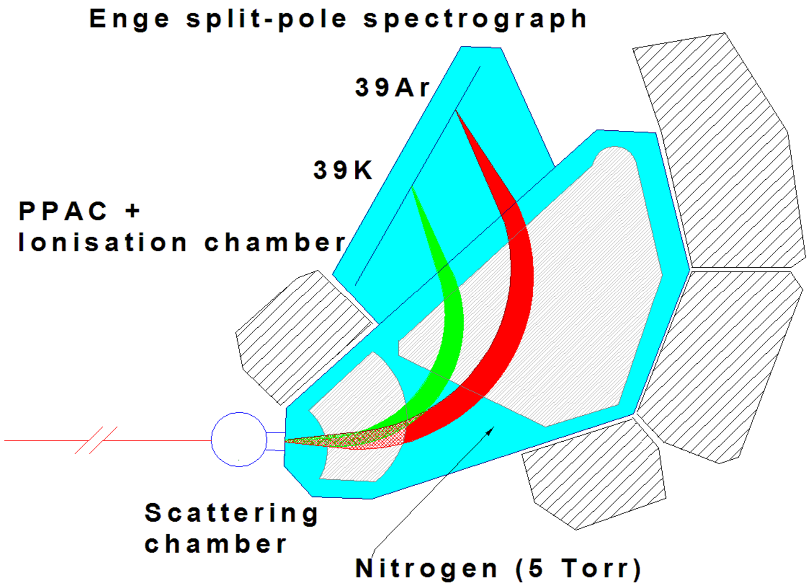
- Time is money and stability. Standard run time is a week so to be efficient we need high beam currents and low background. Having a high purity liner is crucial for success.

The Gas-Filled Magnet Technique.

In the gas filled magnetic region, the discreet charge states coalesce around a trajectory defined by the mean charge state of the ion in the gas

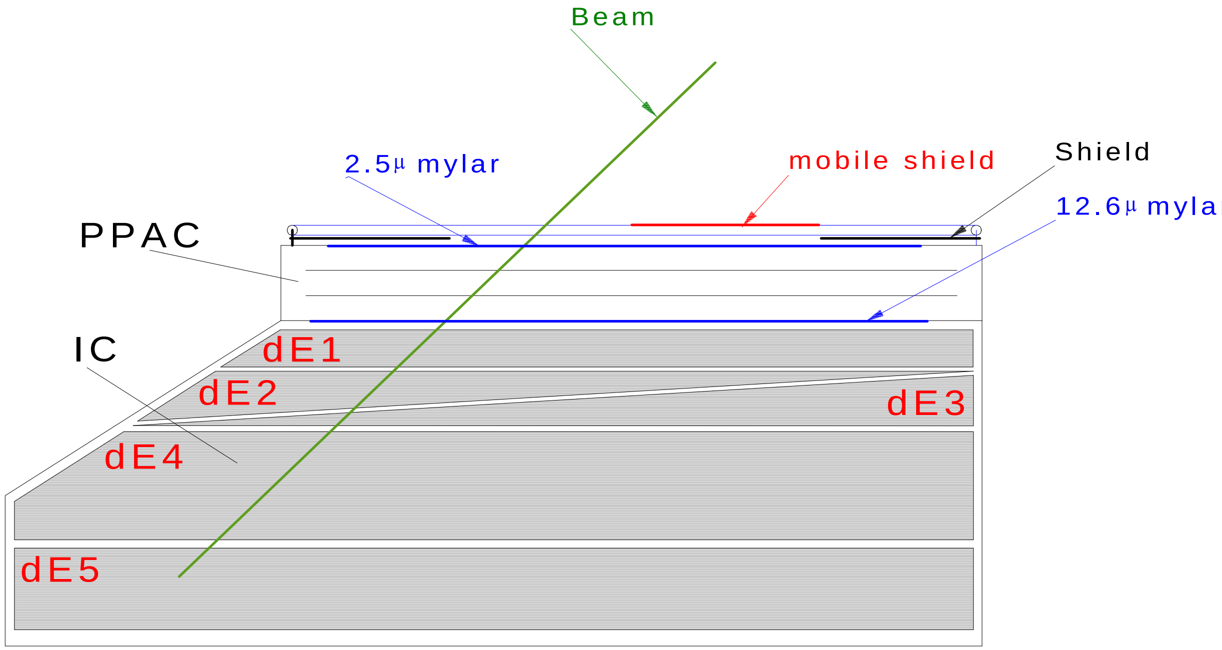






This techniques allows the separation of the ^{39}K (1.3 x 10^6 cps) - ^{39}Ar (0.004 cps) isobar separation (^{39}K/^{39}Ar = 3.2 x 10^8)

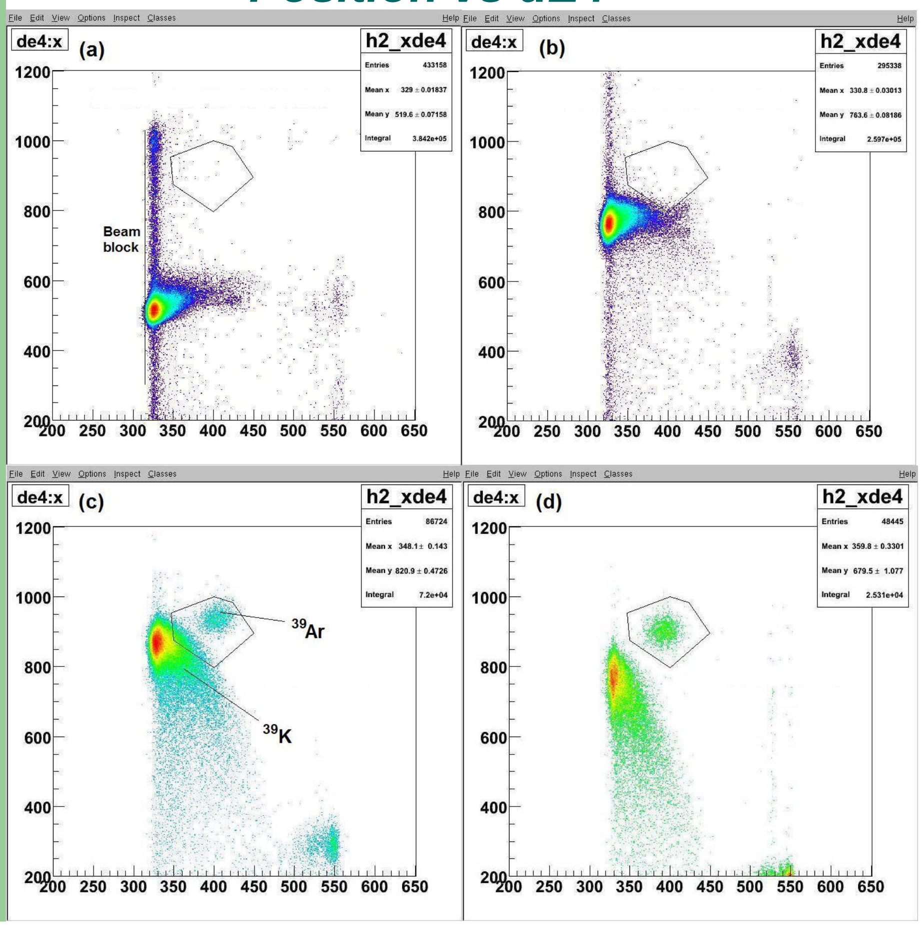
Detector Sensitivity.



Adjusting gas pressures in both the spectrograph and the detectors will allow us to optimize the separation between ^{39}K tail from ^{39}Ar. Adding support Grids to the mylar windows will help with that.

Detector Sensitivity.

Position vs dE4



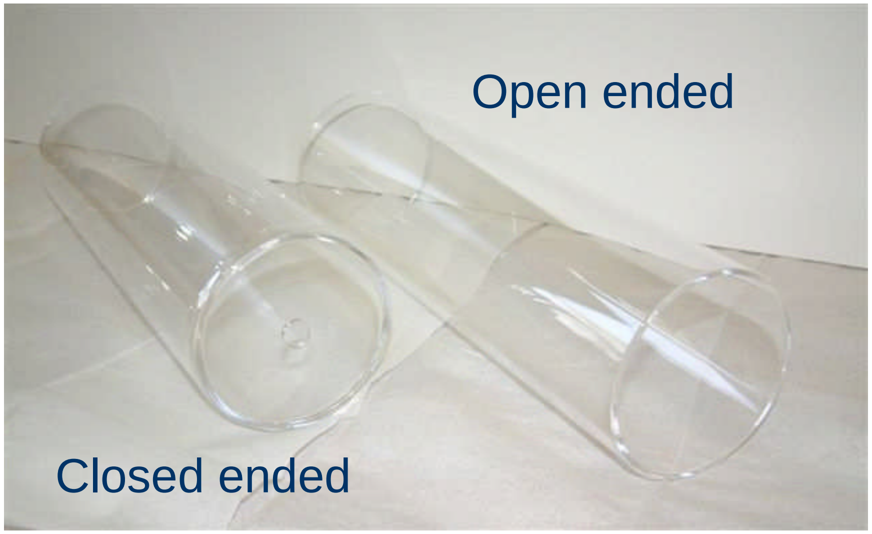
- ***Accelerator and source conditions were the same for a – d. Open Quartz Liner was used.***

- ***(a, b) P_{IC} = 14.8 torr and P_{IC} = 20.8 torr, respectively. A beam block was placed to block most of the 39K peak and only the tail-end of the peak is observed.***

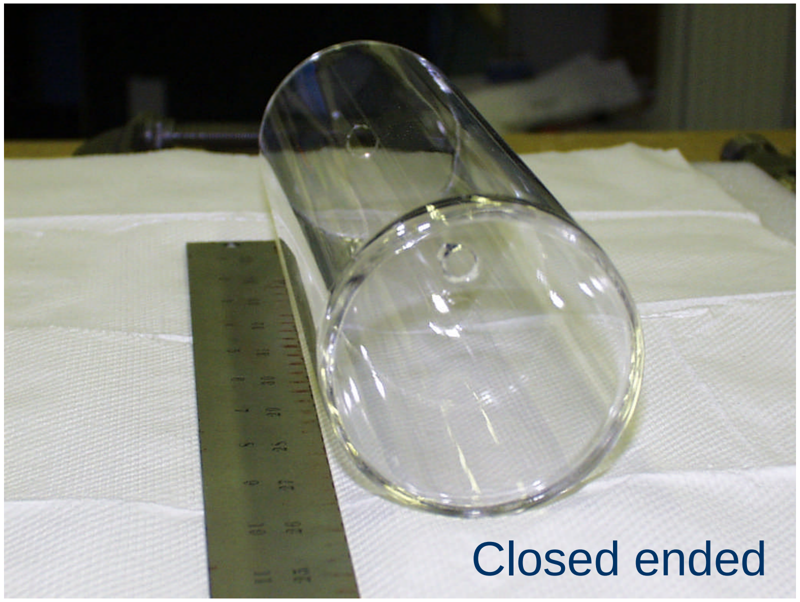
- ***(c) P_{IC} = 24.7 torr***

- ***(d) N_2 pressure (P_{SPEC}) increased from 12 to 13 torr.***

Quartz Liners.



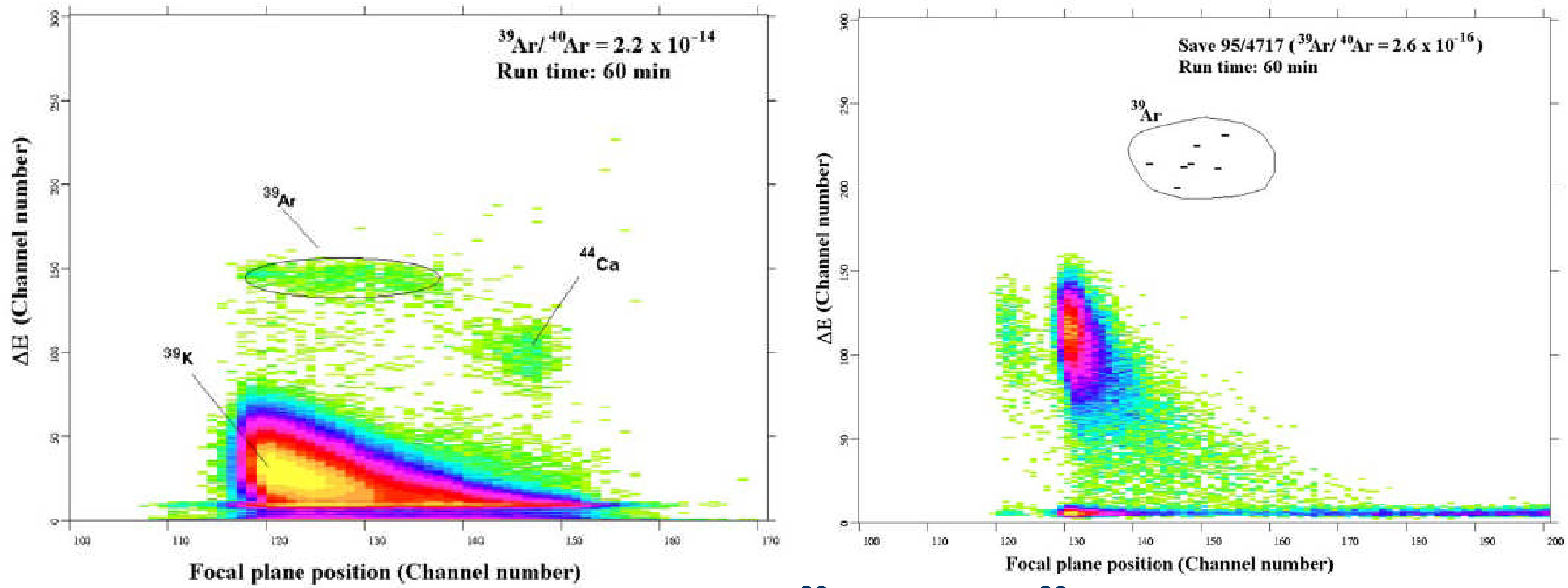
Closed Liner: 10mm opening on axis to allow for beam extraction and the other end a 5mm hole to allow for the introduction of a sample gas.



Limitation: source output, overheating will damage the liner by melting it.

Reference: Rev. Scientific Instrum Vol 75 (2004)	Quartz Liner insertion Argonne (14 GHz ECR-II)
Source performance: $^{40}Ar^{8+}$ current (open liner)	83 uA
$^{39}K^{8+}$ contamination (open liner)	1.3 x 10^6 cps
Treatment method	Insert closed quartz liner
Source performance: $^{40}Ar^{8+}$ current (closed liner)	83 uA
$^{39}K^{8+}$ contamination (closed liner)	9800 cps Reduction factor 130 $^{39}K/^{39}Ar = 2.4 \times 10^6$

What can a liner provide?



Left: (open liner) The clear separation of the ^{39}Ar from the ^{39}K background can be seen. The $^{44}Ca^{9+}$ contribution cannot be separated because of the similar M/Q to $^{39}Ar^{8+}$. Signal pile-up induced in the detector by the high intensity of the ^{39}K count rate can be observed between the two peaks. **Right:** (closed liner) The consequences of the reduction of the intensity of the ^{39}K Background and signal pile-up can clearly be seen.

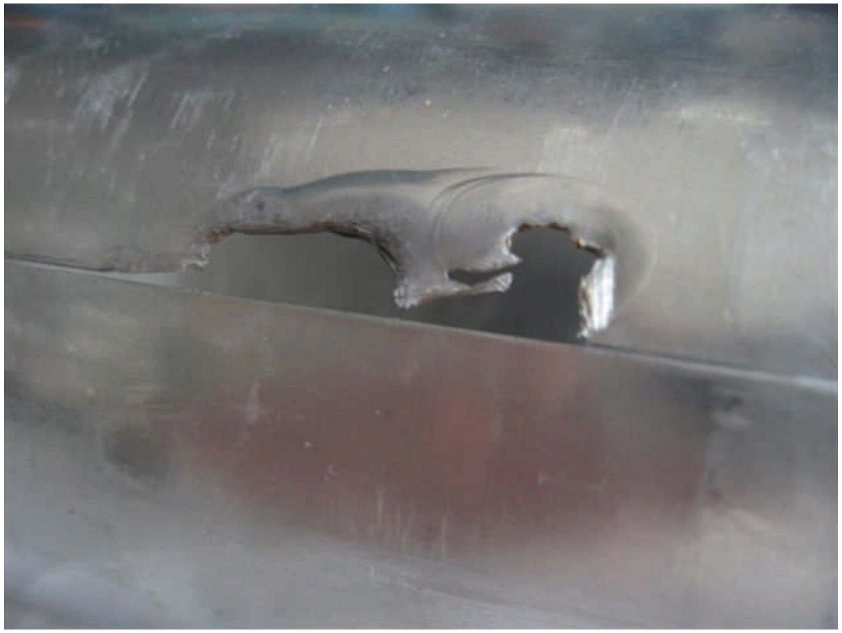
Improving the Method.

- We are currently working on improving the AMS method by following different development paths to allow for i.) higher Ar beam currents to be ii.) coupled with lower ^{39}K rates.
- Ultimate goal: < 1% atmospheric concentration.

Experiment: June 2007.

- Tested an ultra pure Al liner resulting in $^{40}Ar^{8+}$ output of 210 eμA, factor of 3 increase.
- Lower levels of ^{39}K were 3.6×10^4 cps with a source output of 98 eμA.
- Tests hampered by high levels of $^{34}S^{7+}$. Cause: The Al liner melting when it lost thermal contact with the plasma chamber wall.

Ultra Pure Al Liner.



Testing Conditions.

1. Replaced the following from the ECR plasma chamber with ultra pure aluminum:

- bias disc
- extractor
- injector snout

The original aluminum parts of the chamber have a K contamination at the level of 1 ppm where the ultra pure aluminum from Hydro has K at less than 1 ppb.

2. Precision cleaning of the ion source parts with low potassium content soap that's used by the semiconductor industry.

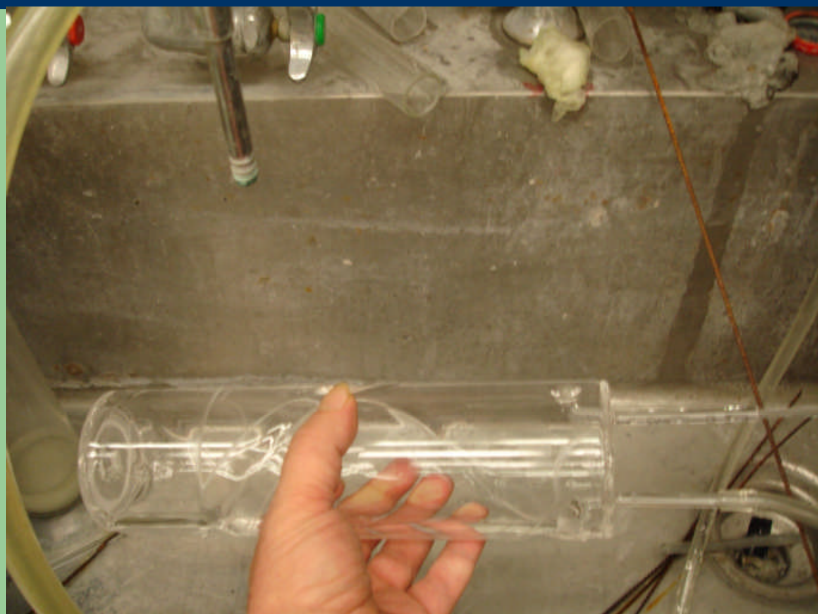
Experiment: April 2008.

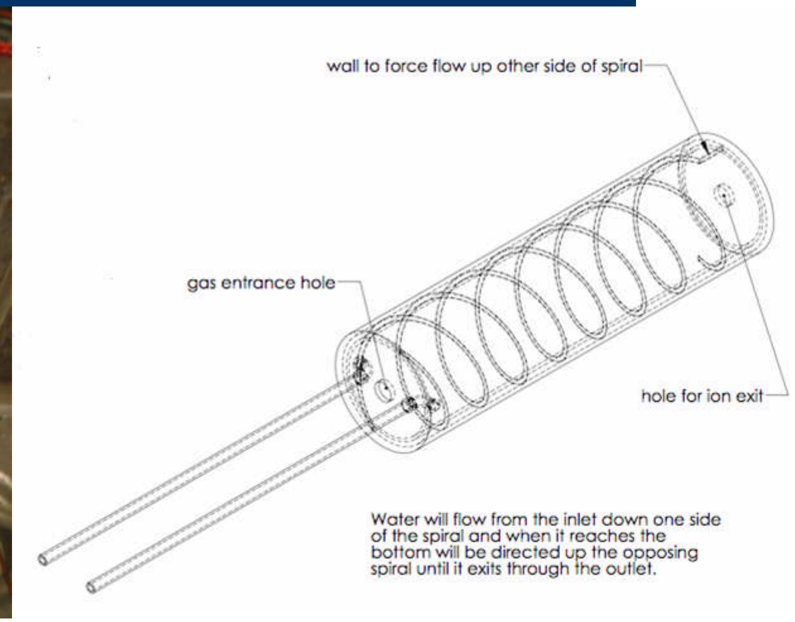
- Spare plasma chamber from ECR II was sent to Princeton for cleaning and to be coated with ultra pure Al. This avoids the thermal contact problem.
- Open ended quartz liner was tested in combination with ultra pure Al parts.
- First step was to look for the ^{34}S contamination from the 2007 run and found no significant trace even though in years past running with no liner had shown some hints of S.
- ^{39}K levels showed a noticeable amount of decrease when ultra pure Al was in use.
- No liner, ultra pure Al coated chamber - 1.5×10^6 cps, compared to the best result with an open ended quartz liner was 1.3×10^6 cps.

Summary.

	Date	^{39}K full peak	IECR ($^{40}Ar^{8+}$)	
^{39}K no treatment	June 07	$4.2x10^6$ cps	83 eμA	Baseline
Open Quartz	Aug 01	$1.3x10^6$ cps	83 eμA	Factor 3.2
Closed quartz	May 01	9800 cps	83 eμA Max output	Factor 430, Best ever But limited in current
Open ultra-pure Al	Jun 07	$4.5x10^4$ cps	98 eμA	Factor 110 Higher beam
	Jun 07		210 eμA	Max beam output In these cond.
Ultra-pure Al coated chamber	Apr 08	$1.5x10^6$ cps	55 eμA	Factor 1.8 (norm. to 83 eμA)
	Apr 08		130 eμA	Max beam output In these cond.

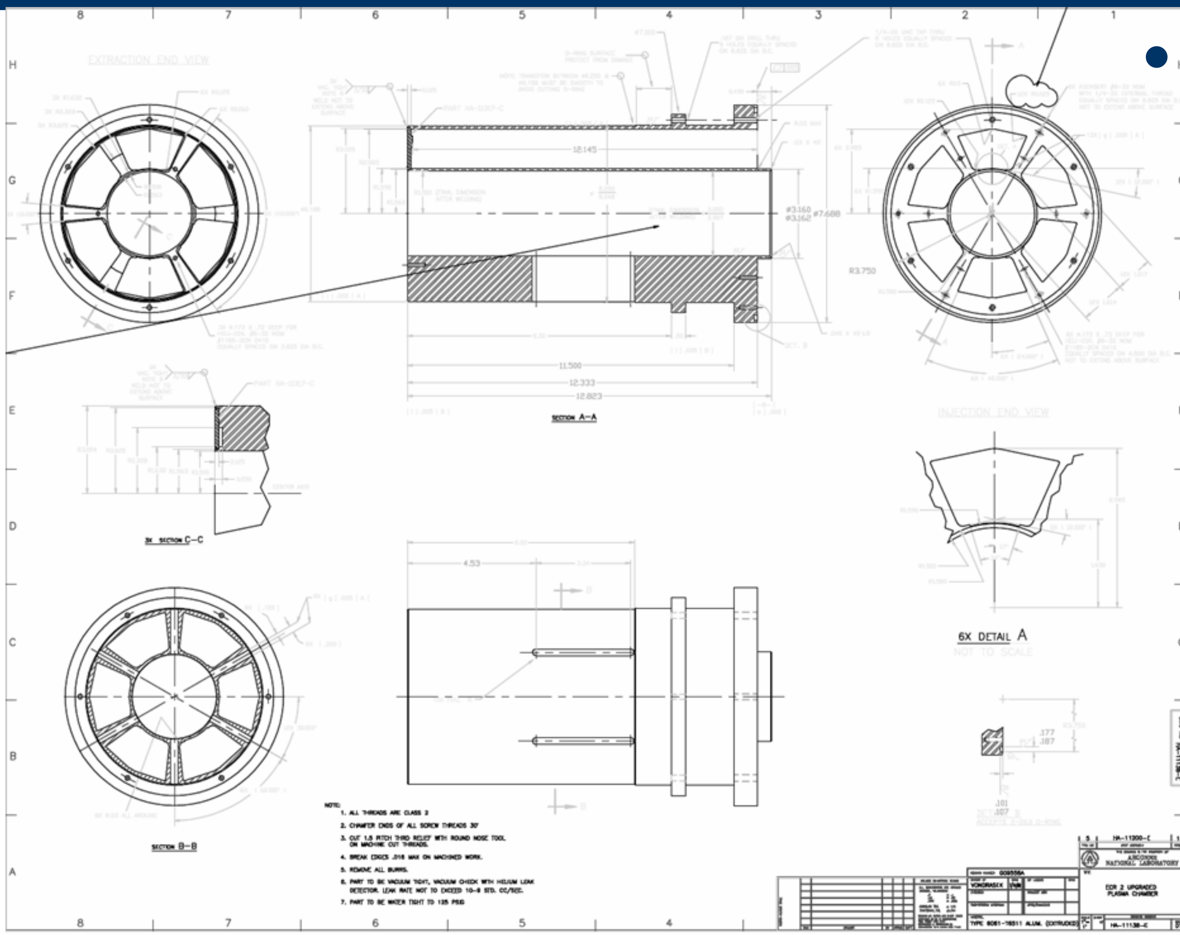
Development Path 1.





- Modifying the design of the quartz liner to provide for active cooling.
- Best results have been with a closed quartz liner, but increasing the current output isn't possible.

Development Path 2.



- A several mm thick ultra pure Al liner will be constructed with an interference fit. The chamber will be heated and the liner chilled with LN2. When the liner warms up it will make maximum surface contact to ensure continuous cooling.