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

By Chris Schmitt
Collaborations.

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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$^3$)
As long as large ocean water samples for $^{14}\text{C}$ were routinely collected, low level counting (LLC) of $^{39}\text{Ar}$ of 1000L was feasible. With the advent of AMS only 1L samples of water were needed for $^{14}\text{C}$ thus killing the availability of the large sample sizes needed for $^{39}\text{Ar}$.

With ~17 $^{39}\text{Ar}$ decays per year from a 1 L of ocean water it became vital to develop an AMS technique for $^{39}\text{Ar}$ measurements at facilities such as ATLAS.

The best measurements were $^{39}\text{Ar}/\text{Ar} = 4.3 \times 10^{-17}$. The levels of sensitivity we are trying to achieve are akin to looking for a “bottle of wine in Lake Michigan.”
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 $^{39}\text{Ar}$, which is produced by cosmic ray interactions with $^{40}\text{Ar}$.
- Argon found as a trace component in gas found in deep underground wells. Even though shielded from cosmic rays $^{39}\text{Ar}$ can be formed through nuclear reaction mechanisms as $^{39}\text{K}(n, p)$ when U and Th are present with K.
- $^{39}\text{Ar}$ decays via beta emission with an end point energy of 560 keV and $t_{1/2}$ of 269 years.
- Atmospheric concentration: $^{39}\text{Ar}/\text{Ar} = 8.1 \times 10^{-16}$, 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.

- 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: $^{40}$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 minutes
  - 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.
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 technique 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 $^{39}$K 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.
Quartz Liner insertion Argonne (14 GHz ECR-II)

| Source performance: $^{40}\text{Ar}^{8+}$ current (open liner) | 83 $\mu$A |
| $^{39}\text{K}^{8+}$ contamination (open liner) | $1.3 \times 10^6$ cps |
| Treatment method | Insert closed quartz liner |
| Source performance: $^{40}\text{Ar}^{8+}$ current (closed liner) | 83 $\mu$A |
| $^{39}\text{K}^{8+}$ contamination (closed liner) | 9800 cps Reduction factor 130 $^{39}\text{K}/^{39}\text{Ar} = 2.4 \times 10^6$ |

Left: (open liner) The clear separation of the $^{39}\text{Ar}$ from the $^{39}\text{K}$ background can be seen. The $^{44}\text{Ca}^{9+}$ contribution cannot be separated because of the similar M/Q to $^{39}\text{Ar}^{8+}$. Signal pile-up induced in the detector by the high intensity of the $^{39}\text{K}$ count rate can be observed between the two peaks. Right: (closed liner) The consequences of the reduction of the intensity of the $^{39}\text{K}$ 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 $^{40}\text{Ar}^{8+}$ output of 210 e$\mu$A, factor of 3 increase.
- Lower levels of $^{39}\text{K}$ were $3.6 \times 10^4$ cps with a source output of 98 e$\mu$A.
- Tests hampered by high levels of $^{34}\text{S}^{7+}$. 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 $^{34}\text{S}$ 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.
- $^{39}\text{K}$ levels showed a noticeable amount of decrease when ultra pure Al was in use.
- No liner, ultra pure Al coated chamber - $1.5 \times 10^6$ cps, compared to the best result with an open ended quartz liner was $1.3 \times 10^6$ cps.
## Summary.

<table>
<thead>
<tr>
<th></th>
<th>Date</th>
<th>$^{39}$K full peak</th>
<th>IECR ($^{40}$Ar$^{8+}$)</th>
<th>Remarks</th>
</tr>
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<tbody>
<tr>
<td>$^{39}$K no treatment</td>
<td>June 07</td>
<td>$4.2 \times 10^6$</td>
<td>83 eµA</td>
<td>Baseline</td>
</tr>
<tr>
<td>Open Quartz</td>
<td>Aug 01</td>
<td>$1.3 \times 10^6$</td>
<td>83 eµA</td>
<td>Factor 3.2</td>
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<tr>
<td>Closed quartz</td>
<td>May 01</td>
<td>9800 cps</td>
<td>83 eµA</td>
<td>Factor 430, Best ever</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Max output</td>
<td>But limited in current</td>
</tr>
<tr>
<td>Open ultra-pure Al</td>
<td>Jun 07</td>
<td>$4.5 \times 10^4$</td>
<td>98 eµA</td>
<td>Factor 110</td>
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<td></td>
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<td></td>
<td></td>
<td>Higher beam</td>
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<tr>
<td></td>
<td>Jun 07</td>
<td></td>
<td>210 eµA</td>
<td>Max beam output</td>
</tr>
<tr>
<td></td>
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<td>In these cond.</td>
</tr>
<tr>
<td>Ultra-pure Al coated chamber</td>
<td>Apr 08</td>
<td>$1.5 \times 10^6$</td>
<td>55 eµA</td>
<td>Factor 1.8 (norm. to 83 eµA)</td>
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<tr>
<td></td>
<td>Apr 08</td>
<td></td>
<td>130 eµA</td>
<td>Max beam output</td>
</tr>
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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.