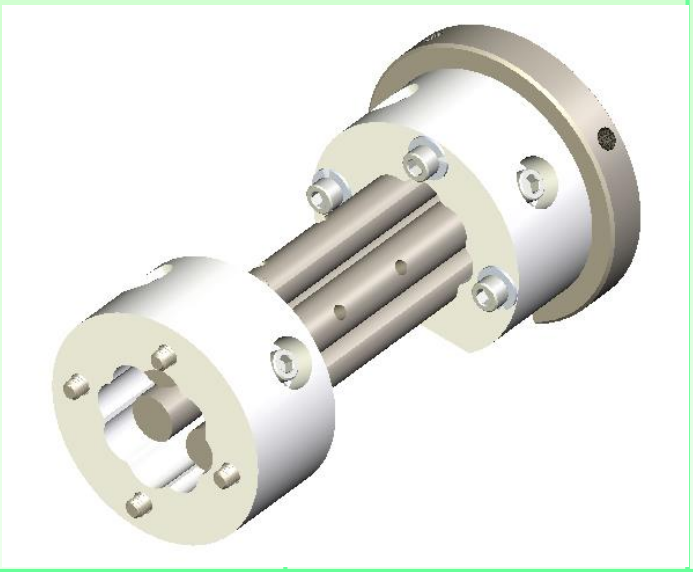
Quadrupole Miniaturization: Revisited



Justin Jacobsky

University of Pittsburgh

Randall E. Pedder, Ph.D.

Michael Klaric

Christopher Taormina, Ph.D.

Ardara Technologies L.P.

Flashback to 2007…

- Eight years ago at the 2007 HEMS, we presented experimental data that predicted that extremely miniaturized quadrupoles will have limited utility due to poor sensitivity.

- But what if we don't get so extreme…

Measured Argon m/z 40 Peak Heights

Normalized to Peak Height on 2 mm Quadrupole with 0.7 amu peak width

	Peak Width (amu)						
Diameter (mm)	**0.18**	**0.35**	**0.7**	**1**	**2**	**5**	**10**
1 (mult)					0.11	3.21	8.24
2 (mult)		0.19	**1**	1.82	14	48	103
2					3	29	87
4		5	**25**	45	99	272	507
6		13	**96**	168	519	1,214	1,957
9	78	253	**736**	1,092	2,141	3,779	
12	50	344	**1,295**	2,141	3,638	5,017	5,370
20	933	1,757	**3,639**	4,802	6,709	7,289	

Conclusions from HEMS 2007 talk:

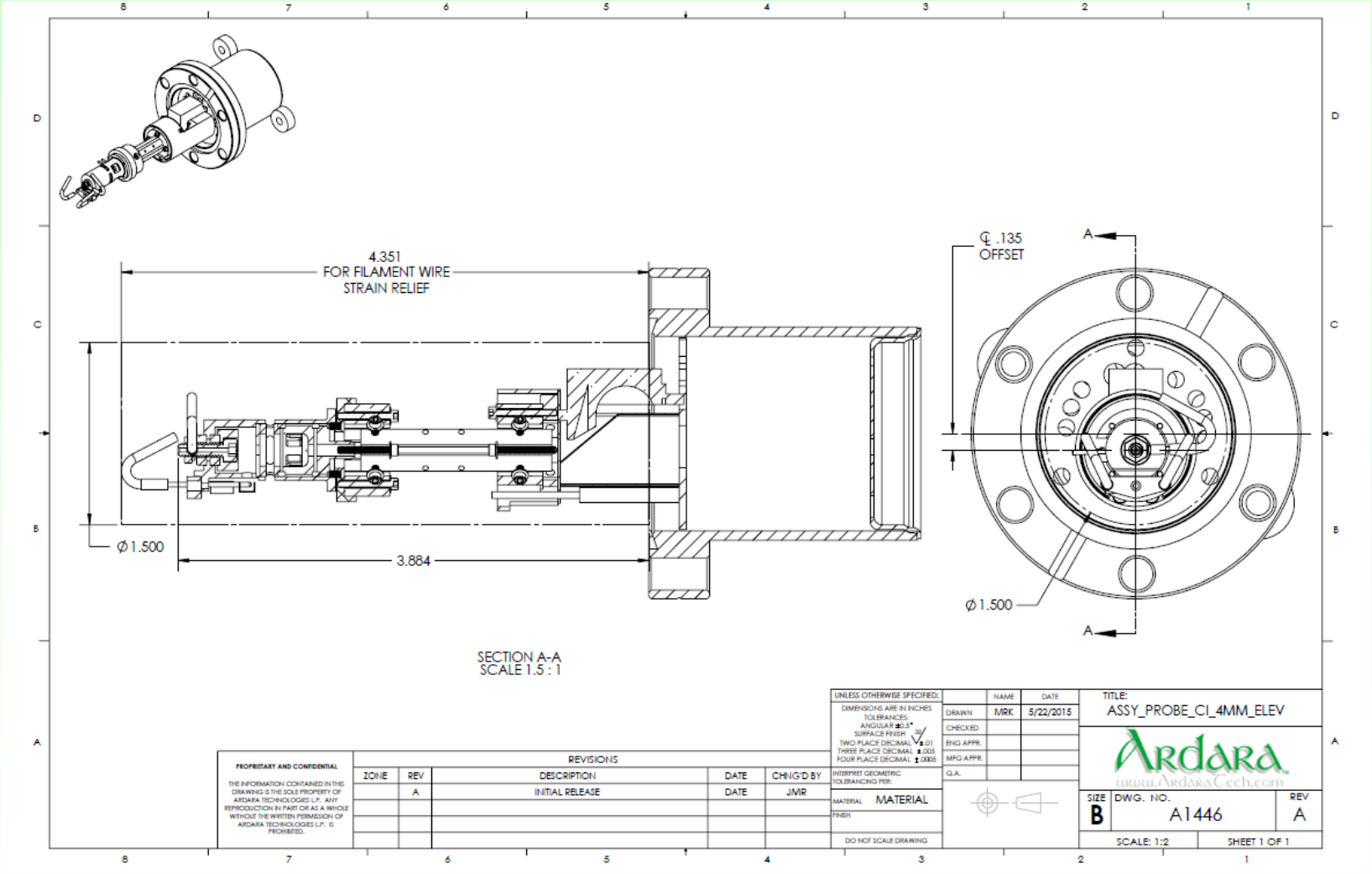
- If the emissive area of the ion source is larger than the acceptance of the quadrupole…
  - Transmission goes with rod diameter to the third and fourth power.
    - Ten-fold reduction in rod diameter yielded 3,600-fold loss in sensitivity.
  - Transmission goes with RF frequency squared.
- Since you can't scale the frequency inversely with the reduction in rod diameter (because of discharge issues), **extreme miniaturization of quadrupoles is unlikely to yield analyzers with anywhere near the performance of conventionally scaled quadrupoles.**

Maybe, we were a little bit hasty…

Fast Forward to 2015 HEMS Talk

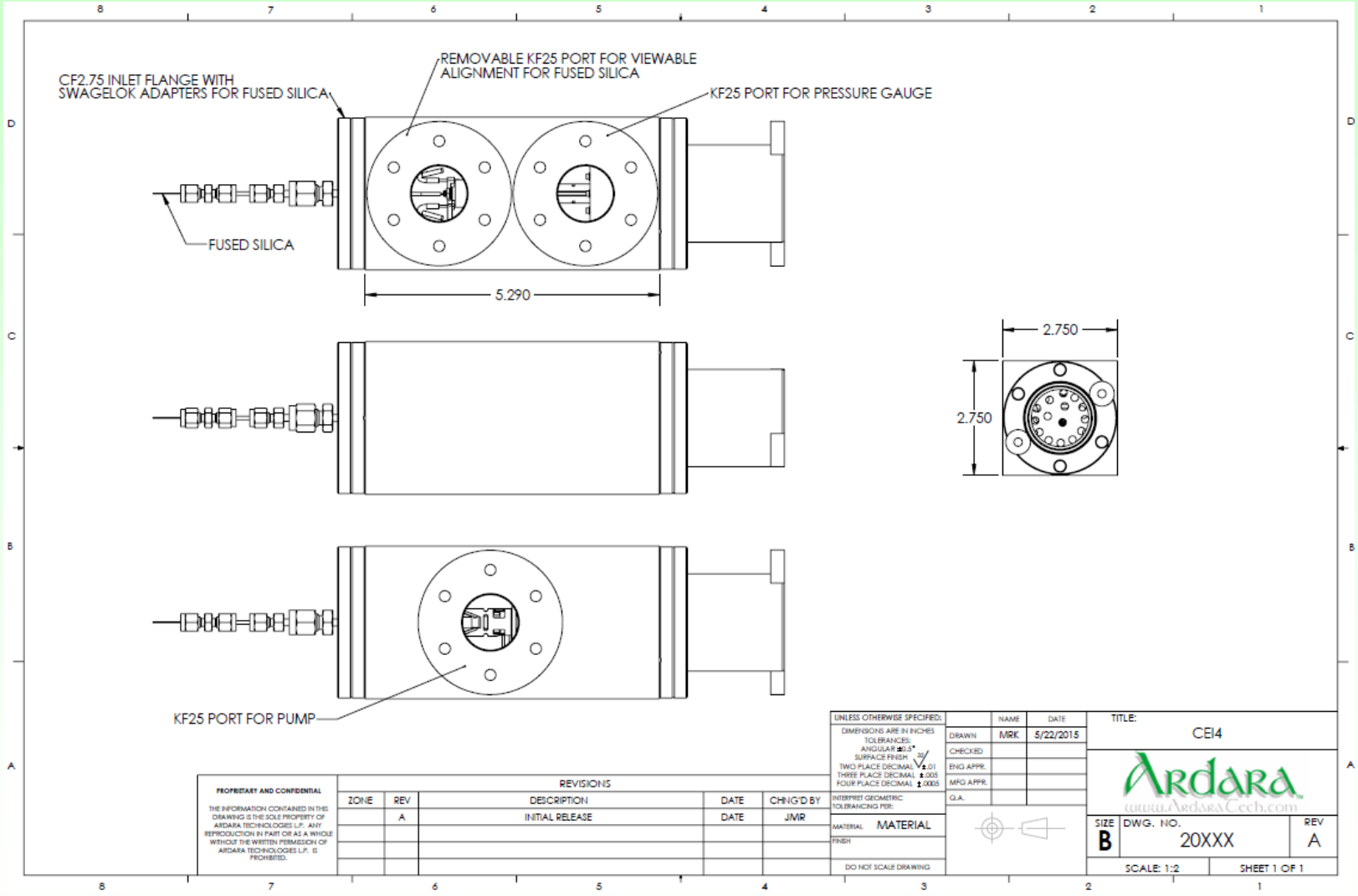
- Quadrupole mass spectrometer system:
  - 4 cm long quadrupole rods
  - 4 mm rod diameter
  - 6.5 MHz RF frequency (~1800 Vpp RF)
  - 100 amu mass range
  - Closed ion source
  - Pfeiffer HiPace 10 turbo pump
  - 2 ¾ Conflat Flange with Multiplier (Extorr)
  - 2 ¾ X 2 ¾ X 5 ¼ inch chamber

Quadrupole Probe on 2 ¾ Conflat Flange



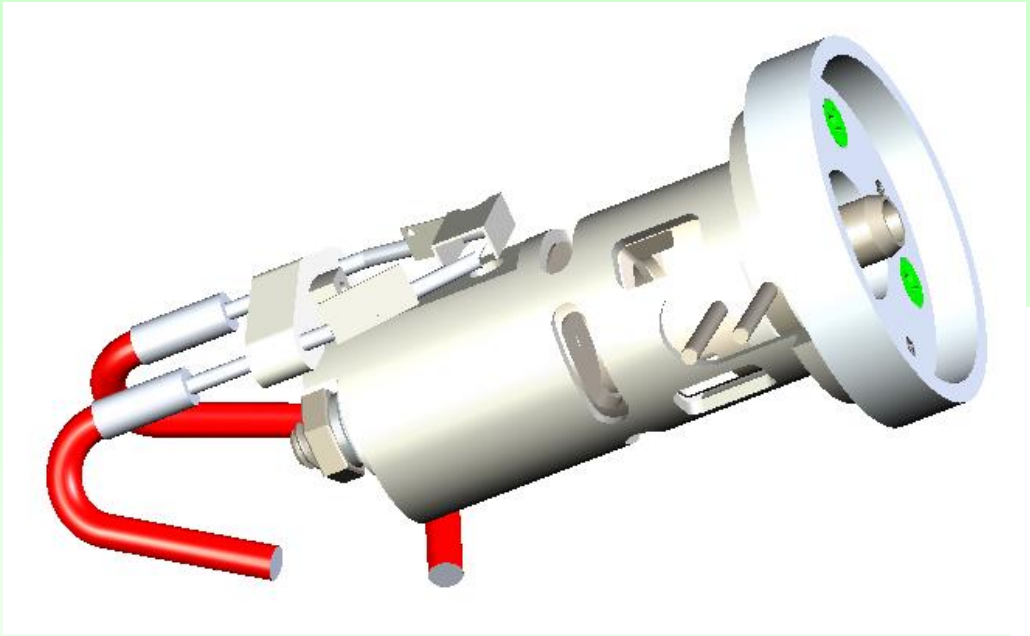
ARDARA
www.ArdaraTech.com

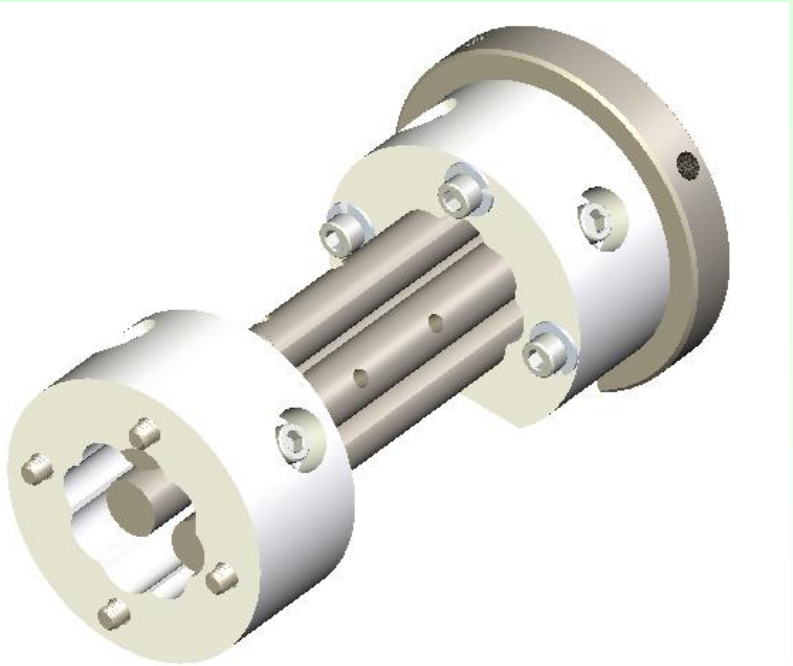
Chamber Assembly with Fused Silica Inlet



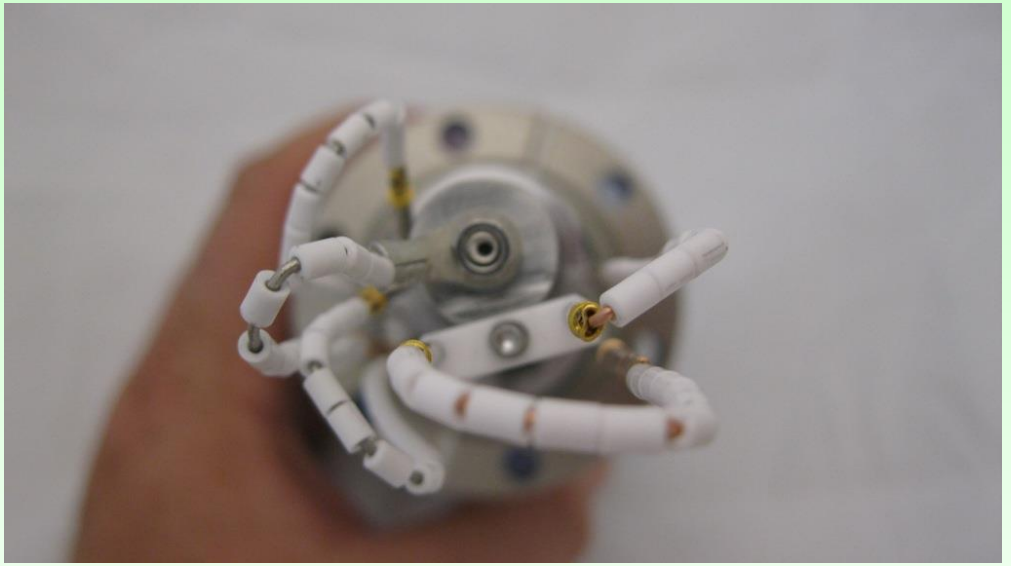
ARDARA™
www.ArdaraTech.com

Closed Ion Source Amazingly Similar to Common GC/MS Design…

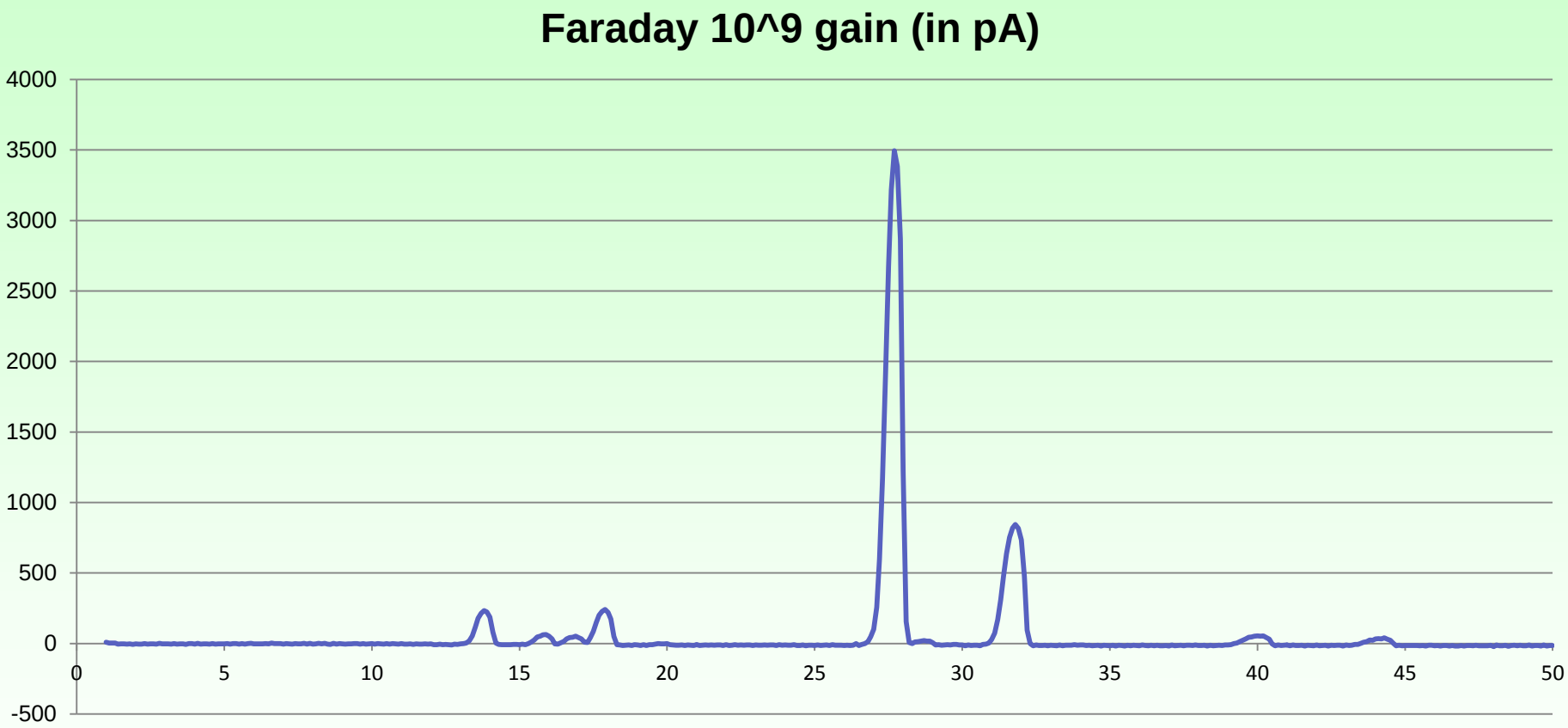




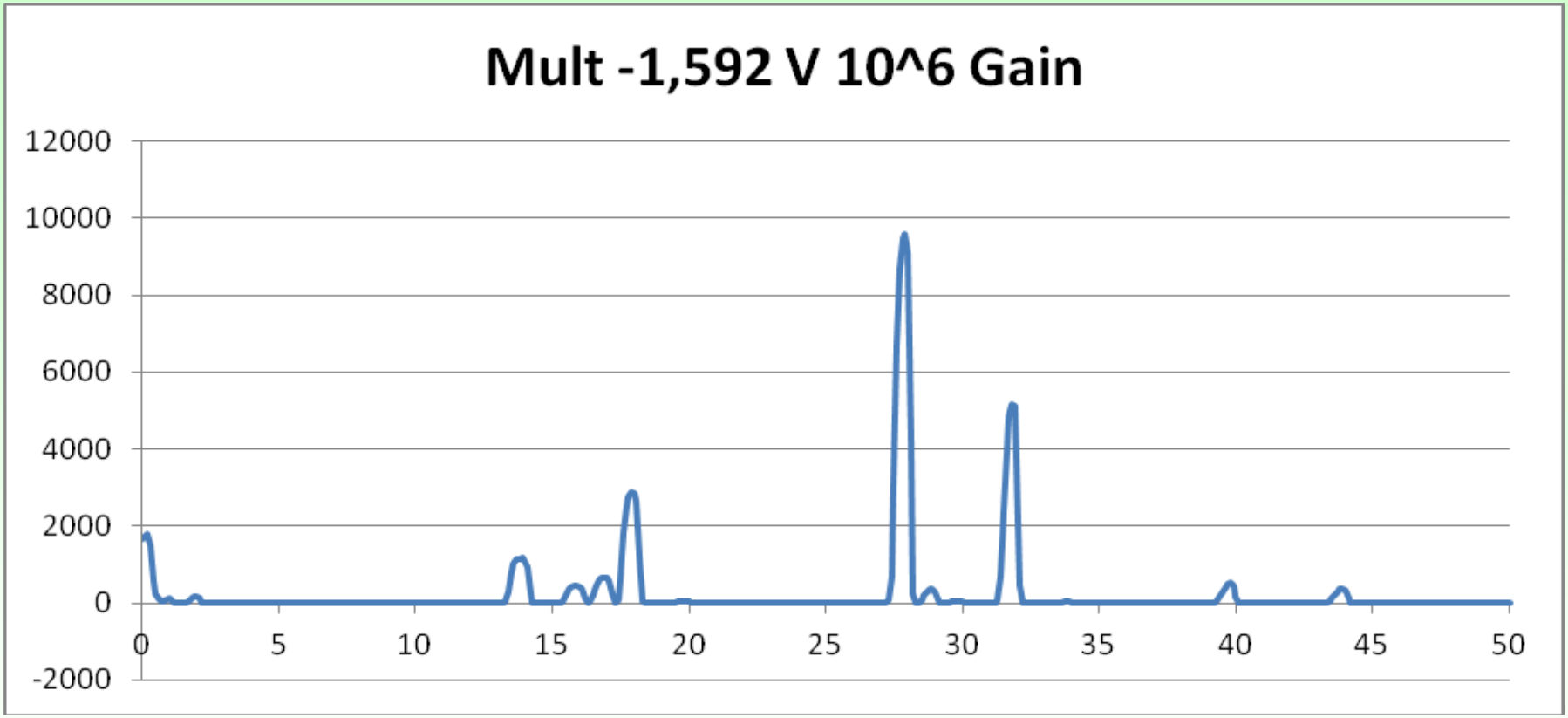
Fused Silica Enters Ionizer Through Repeller



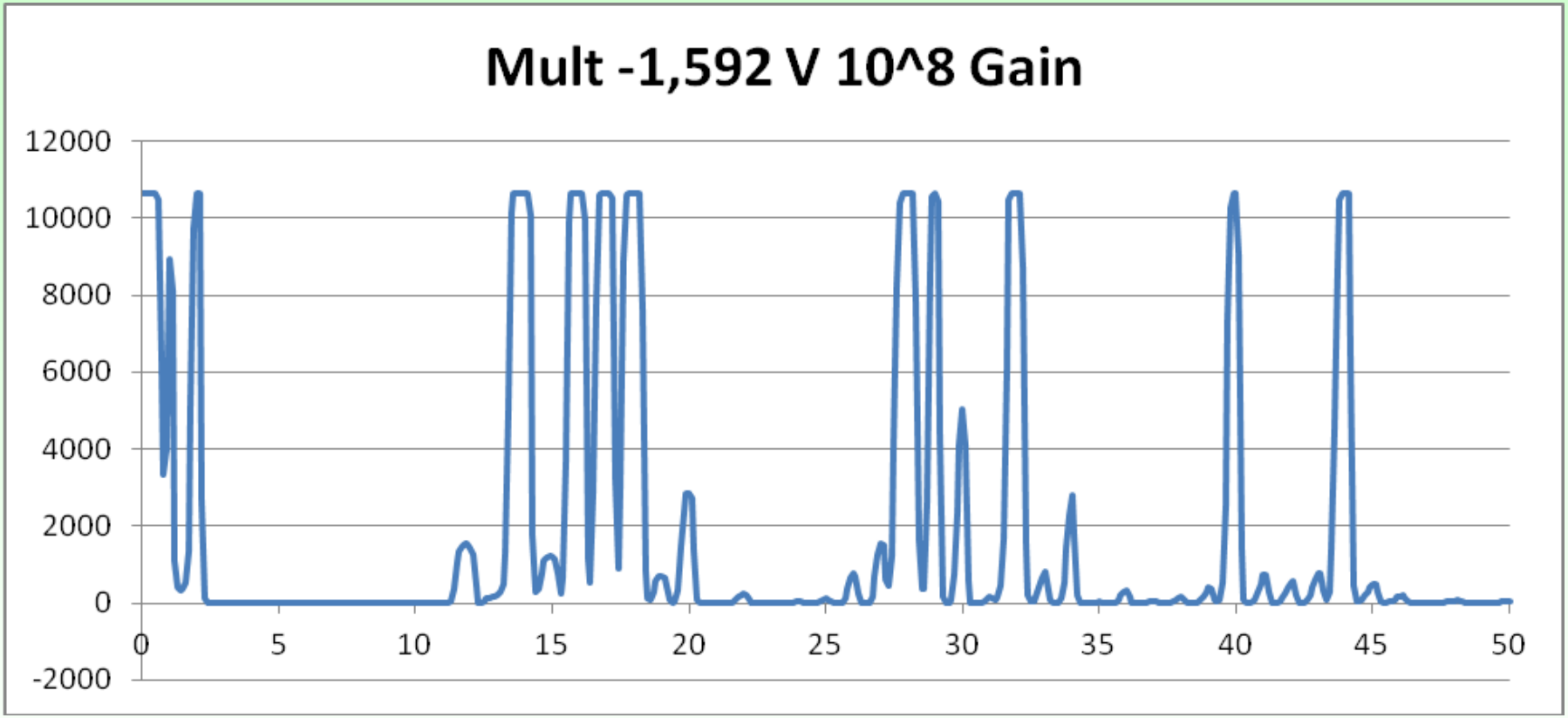
An Early Spectrum: 3.5 nanoAmps!



Series of Spectra with Different Preamp Gains

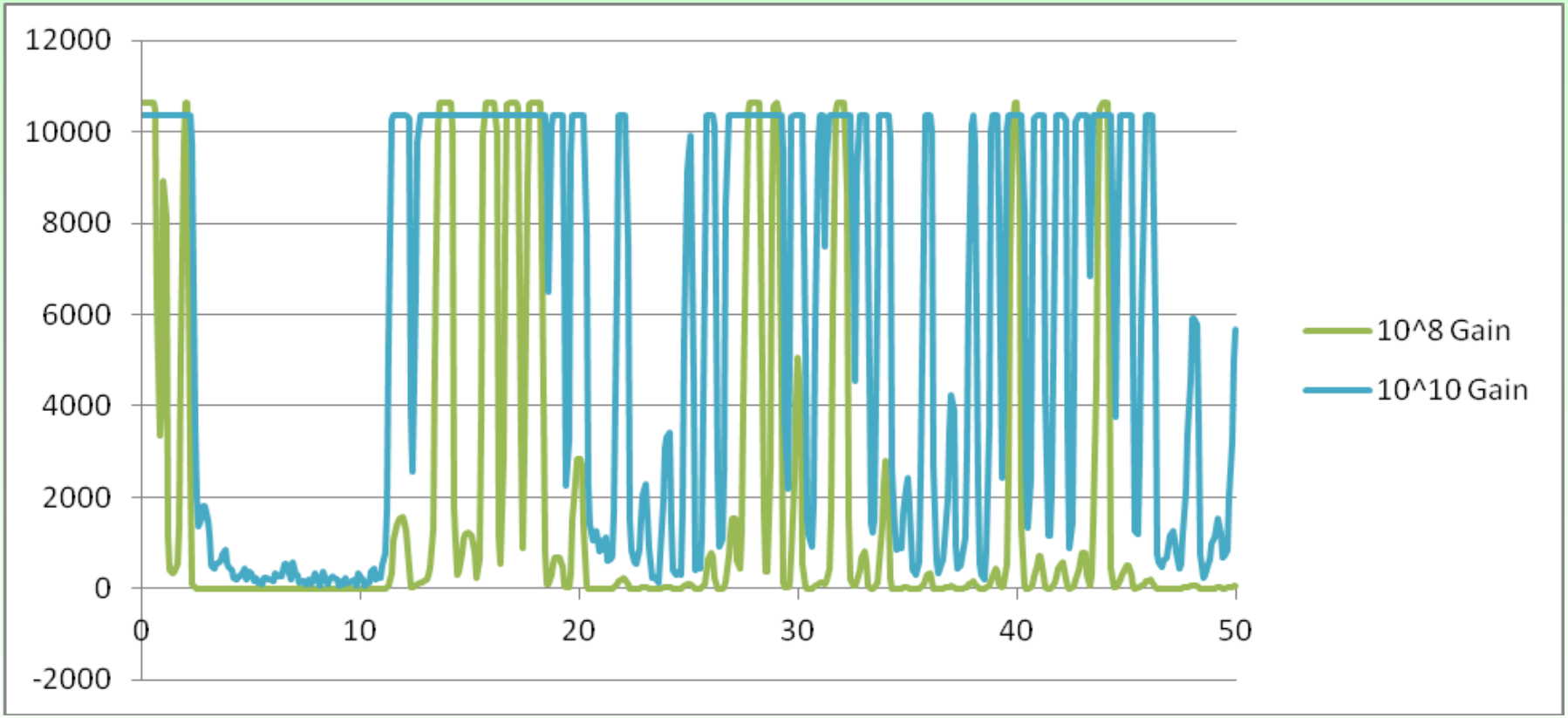


Series of Spectra with Different Preamp Gains



Nitrogen Abundance Sensitivity: m/z 27 peak is 600X lower in intensity than m/z 28, but still resolved.

Series of Spectra with Different Preamp Gains

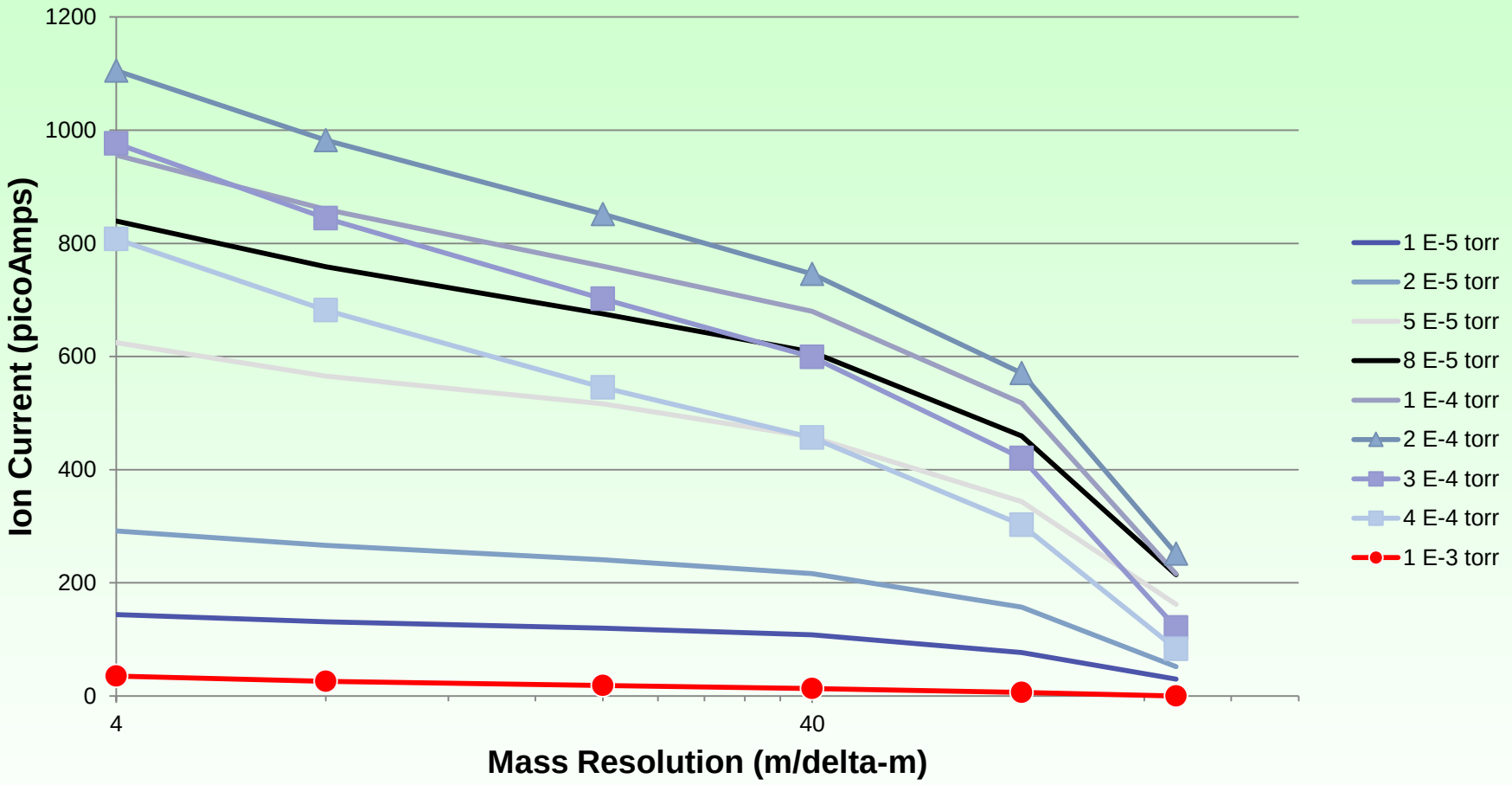


Helium @ m/z 4 with ~6:1 S/N
Equivalent to ~1 ppm LOD

Shorter Analyzer - High Pressure Operation?

- The primary motivation for choosing to go with a shorter analyzer was the hope that the system would be more forgiving with regards to higher pressure operation (i.e. for operation with smaller, less efficient turbo pumps).
- To that end, we gathered spectra for various pressures of Argon leaked into the ionizer (up to a millitorr), at various peak widths (0.3 amu, 0.5 amu, 1 amu, 2 amu, 5 amu and 10 amu at half height).
- One would think that operating at ¼ to 1/5 the length of traditional quadrupoles would allow good operation at 4-5 times higher pressures than normal… But what is normal?
- Of course none of this considers the potential negative consequences of ion molecule reactions in the ion source at higher source pressures…

Argon Resolution – Transmission Curves for Various Partial Pressures



Severe Scattering Losses with Operation above 2 E-4 torr.

Shorter Analyzer - High Pressure Operation?

1 amu wide peaks

Pressure (torr)	microamps per torr
1.0E-05	10.819
2.0E-05	10.804
5.0E-05	9.151
8.0E-05	7.601
1.0E-04	6.799
2.0E-04	3.729
3.0E-04	1.997
4.0E-04	1.142
1.0E-03	0.013

Sensitivity goes down rapidly with Pressure!

Conclusions and Future Work:

- Analyzer system works better than expected. Predicted performance of better than 1 ppm LOD from a single 5 second scan across a 50 amu mass range.
- Operation at higher pressures was disappointing. Perhaps the long focal length optics of the chosen ionizer design is not appropriate for the still higher pressures in the ion source relative to the measured chamber pressures.
- Future work:
  - Investigate performance enhancement when using pre-filters
  - Build longer quadrupole so can operate at lower RF frequency to extend the mass range without sacrificing resolution.
  - Characterize the exact ratio between ionizer partial pressure and chamber partial pressure.

I would like to Acknowledge my Co-Authors for all their hard work on this project:

- Justin Jacobsky – Summer Intern from University of Pittsburgh
- Michael Klaric – Ardara Technologies – Mechanical Designer
- Chris Taormina Ph.D. – Ardara Technologies – Scientist

My Favorite Literature Citation:

International Journal of Mass Spectrometry and Ion Physics, 27 (1978) 31—41 31

A QUADRUPOLE MASS FILTER WITH FLAT ELECTRODES

C.G. PEARCE

Physics Department, University of Aston, Birmingham (Gt. Britain)

D. HALSALL

V.G. Micromass, Road Two, Winsford (Gt. Britain)

(Received 8 August 1977)

In conclusion, the performance of this plane electrode system reminds us of Dr. Johnson's famous remark about women preachers; "Sir, a woman's preaching is like a dog's walking on his hinder legs. It is not well done; but you are surprised to find it done at all" [7].

REFERENCES

1 C.G. Pearce, D. Halsall and J.C. Davies, Resolving Power of Approximate Fields, Proceedings of 7th International Mass spectromentry Conference, Florence, 1976, to be published.
2 T. Hayashi and N. Sakudo, Rev. Sci. Instrum., 39 (1968) 958.
3 T. Hayashi and N. Sakudo, Recent Developments in Mass Spectroscopy, University Park Press, Tokyo 1969, p. 263.
4 T. Chisholm and A.M. Stark, J. Phys. D, (1970) 1717.
5 P.H. Dawson and N.R. Whetten, J. Vac. Sci. Technol. 7 (1970) 440.
6 K.J. Binns and P.J. Lawrenson, Analysis and Computation of Electric and Magnetic Field Problems, MacMillan, New York, 1963, p. 270 ff.
7 Boswell's Life of Johnson Vol. 1, 1763, p. 463.