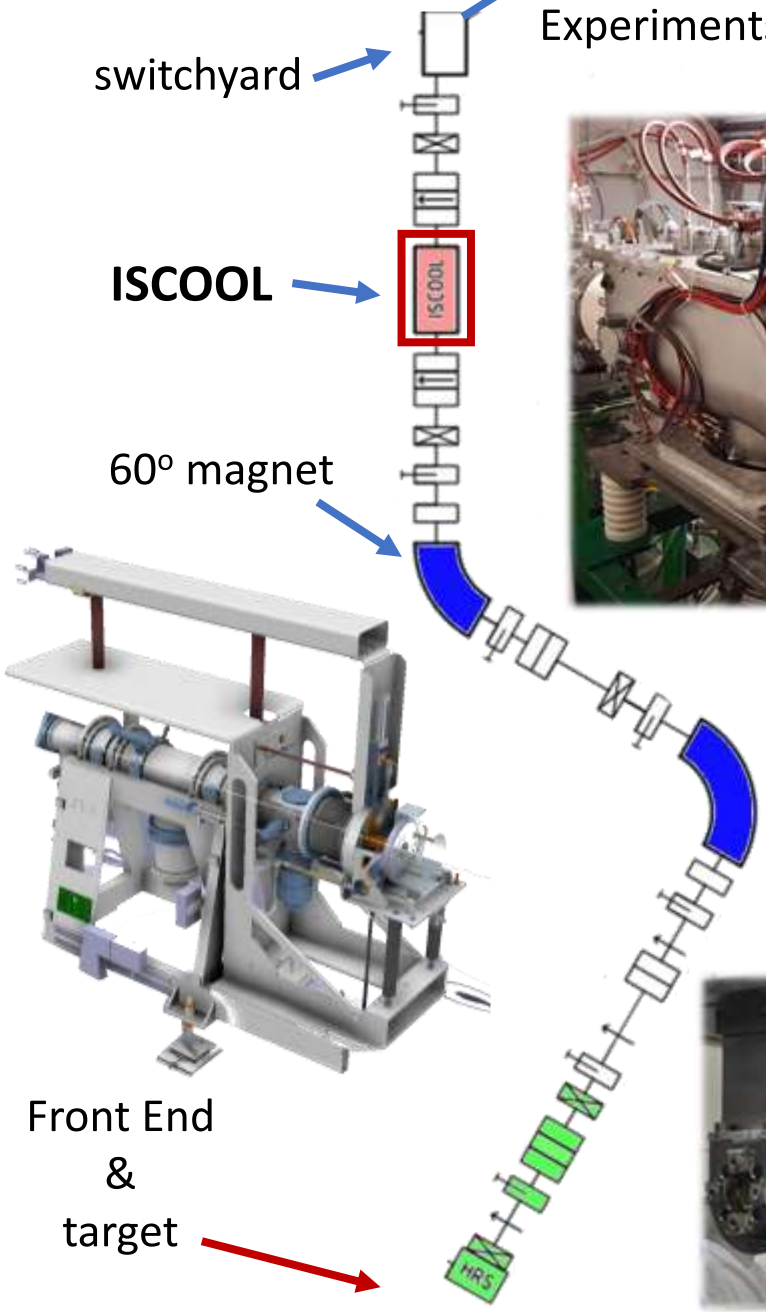
Radio-Frequency waveform investigation for ion transport within the RFQcb at Offline 2

ISOLDE workshop 2020

Stuart warren



RFQcb role:

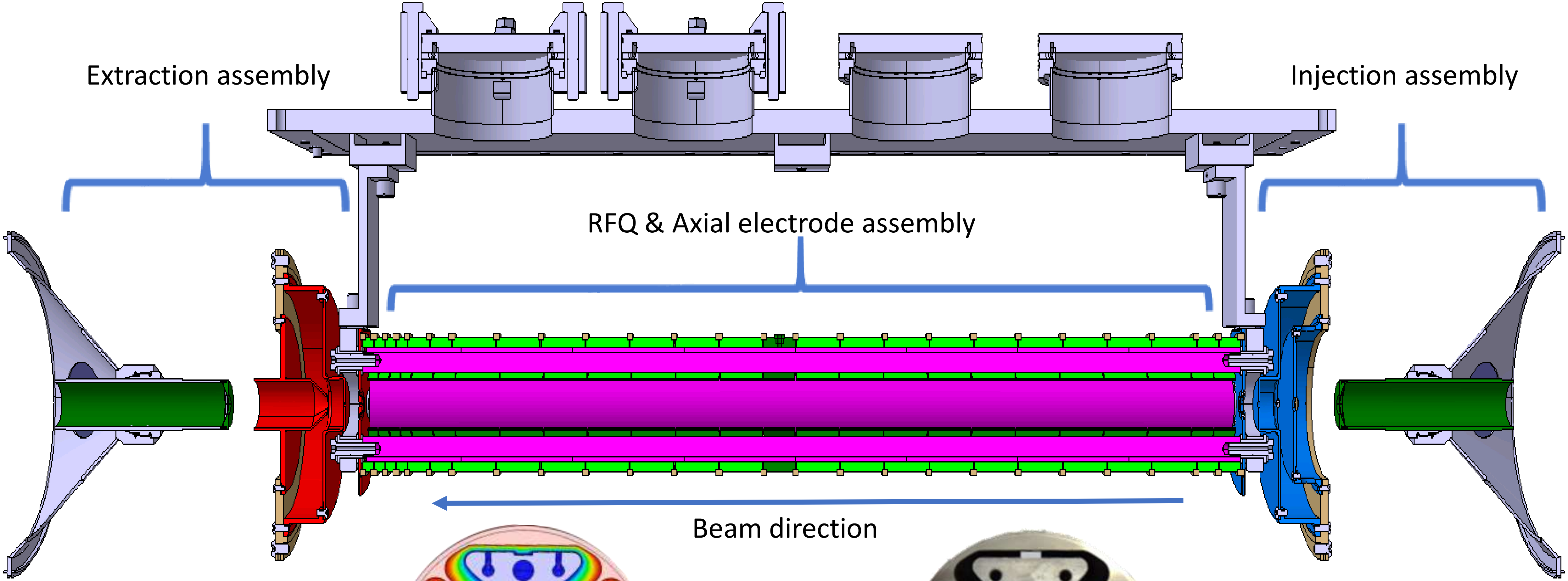
Radio-Frequency Quadrupole cooler buncher

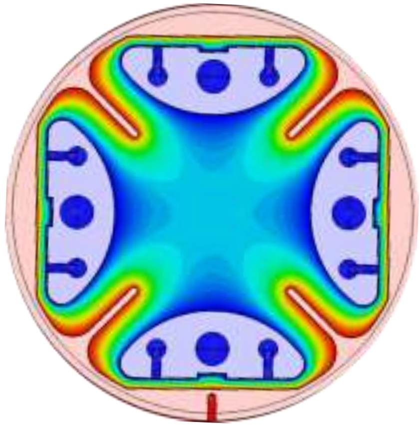
- Emittance reducing device
  - Transverse $\sim 3\,\pi\, mm\, mRad^{\dagger}$
  - Temporal $\sim 1\, eV\, us^{*}$
- Bunching beams
  - High instantaneous flux
  - Additional cooling time.
- Installed 2007, modified…
  - Replaced RF 2012
  - Replaced Gas inj. Systems ?
  - Realigned in 2012
  - HV stability increased (60 kV) 2016

*Dependent on space charge, gas pressure and RF & +/- 0.6V PSU stability
† tuned correctly and low space charge

https://ab-div-op-iso-rfqcb.web.cern.ch/photographs.htm

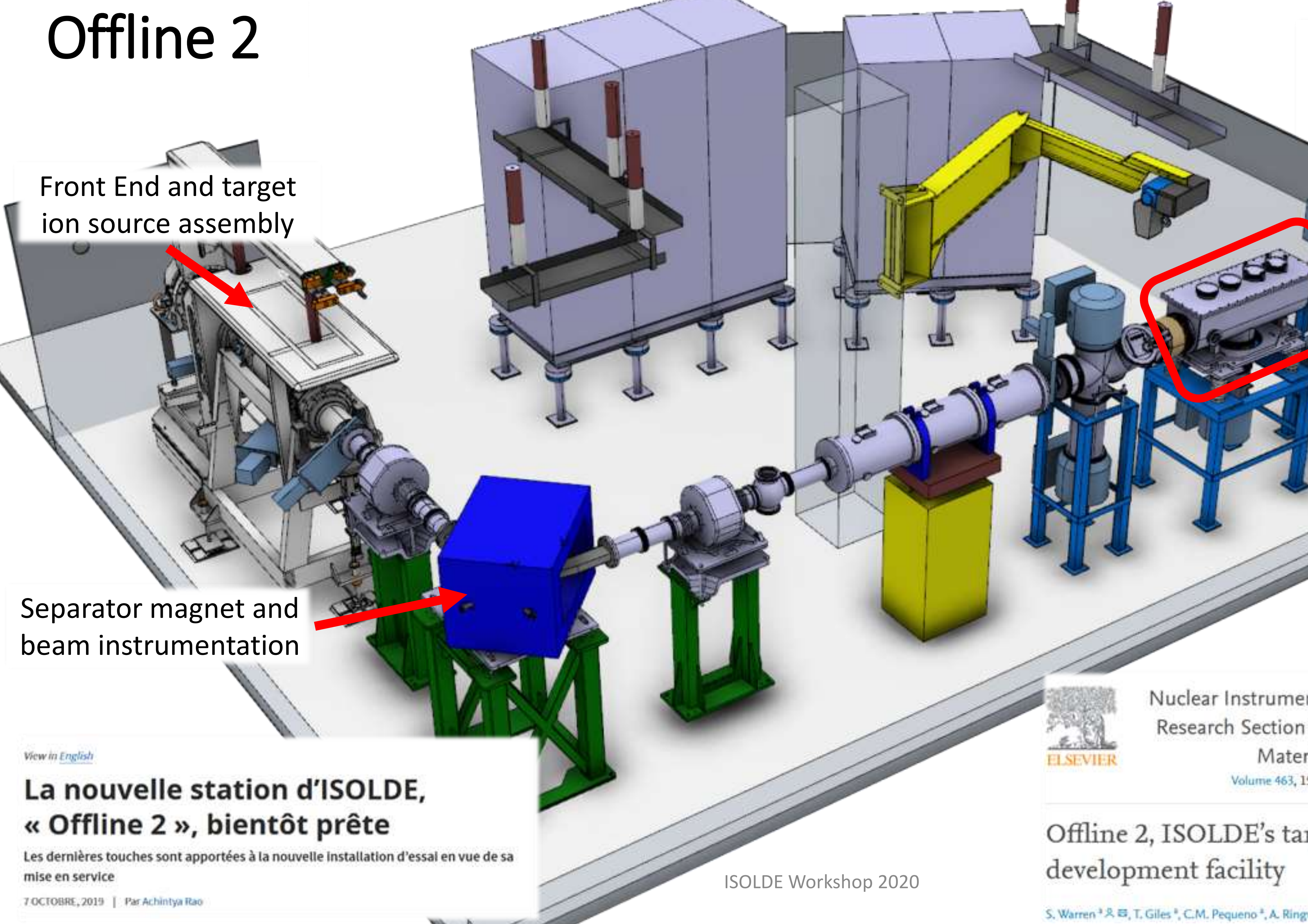
RFQ Structure





Very Idea QP,
$C_{1,3,4} \approx 0$,

Offline 2



View in English

La nouvelle station d'ISOLDE, « Offline 2 », bientôt prête

Les dernières touches sont apportées à la nouvelle installation d'essai en vue de sa mise en service

7 OCTOBRE, 2019 | Par Achintya Rao

Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms
Volume 463, 15 January 2020, Pages 115-118

Offline 2, ISOLDE's target, laser and beams development facility

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OL2 RFQcb

High performance controls

Beam Diagnostics

- Injection SC &FC
- Extraction FC
- 1.5 m down-stream SEE MCP detector

Operational Sep 2019

Vacuum

4x 1200 l/s
1x 1600 l/s
Turbos Operate Independently

Platform offset potential control +/- 0.1 w.r.t. F.E.

RF:

- RMS 6kWatt
- 0.01-10 MHz flat
- V_{0P} 1 kV
- Z matched to Rods Cap.
- 16 bit Arb. Wave. Gen

RFQ Core:

- Improved rod rigidity
- 0.1mm Alignment
- > V_{0P} @10MHz
- Peek & Macor insulators

The tune (Xe129)

- For simple transport a=0 no DC component
- Look at the already computed solutions from Mathieu and map… 0.5q value

m [u]	f_{RF} [MHz]	U_{RF} (0-peak) [V]
10	0.80	130
20	0.60	147.5
50	0.42	180
100	0.30	185
120	0.28	192.5
140	0.26	192.5
160	0.24	190
180	0.22	180
200	0.21	180
220	0.21	200
240	0.20	195
250	0.20	200

*Ivan Podadera Aliseda thesis 2006

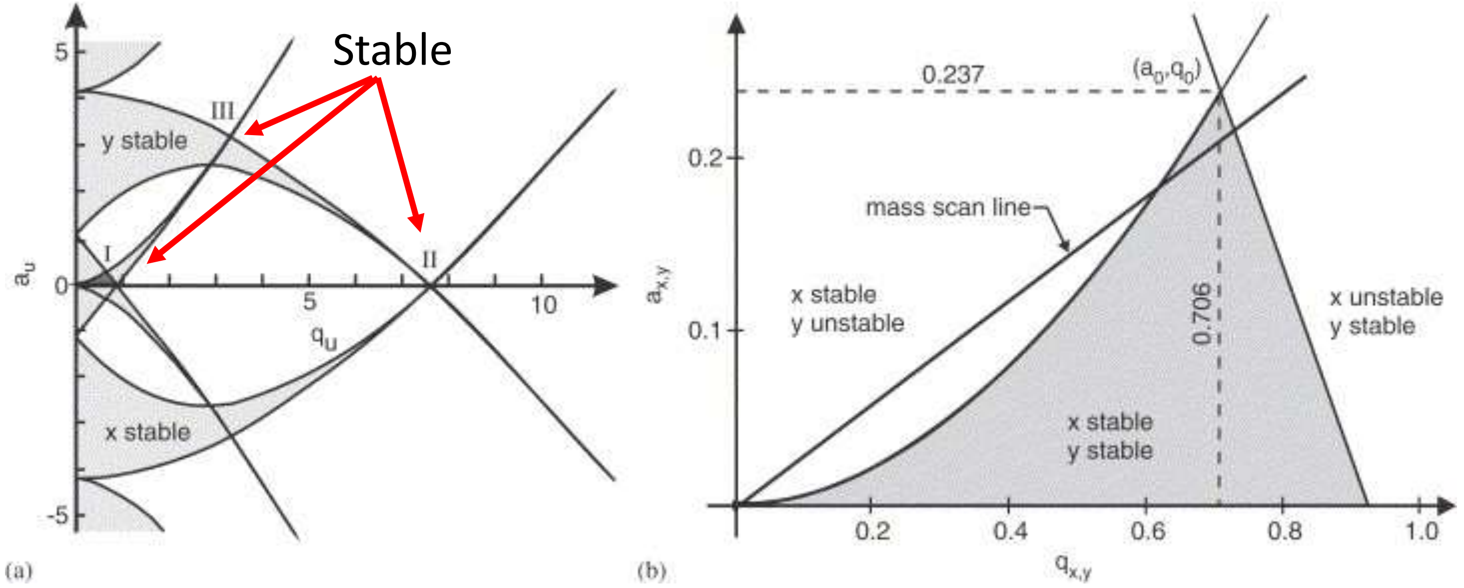
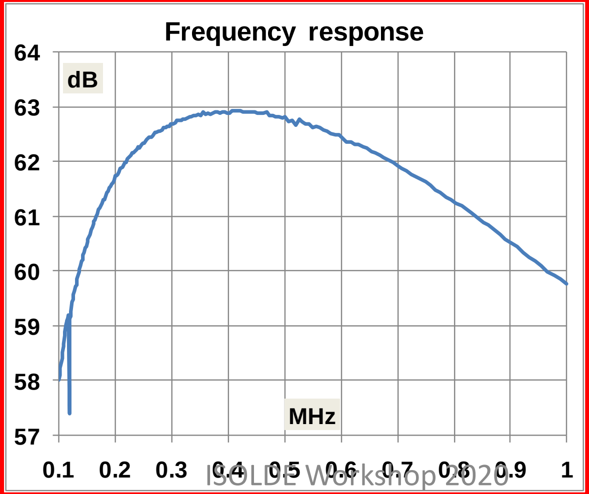


Image from : https://ars.els-cdn.com/content/image/1-s2.0-S0370157305004643-gr7.jpg

Changed 2012
&
not the same Amps @OL2



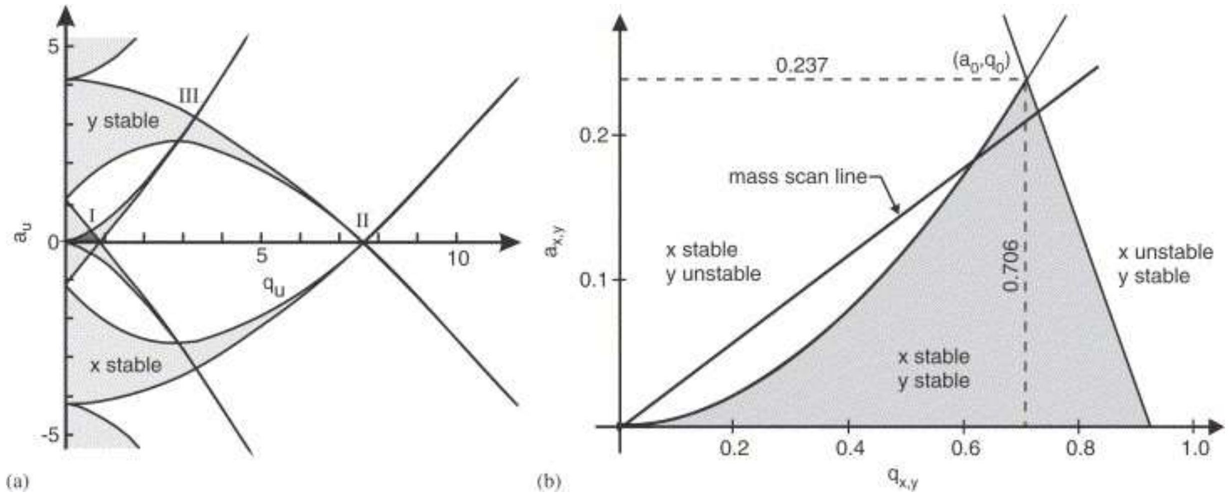
$$\ddot{u} + \left(\theta_0 + 2\sum_{n=1}^{\infty}\theta_n Cos(2nt) + \sum_{m=1}^{\infty}\phi_m sin(2mt)\right) u = 0$$

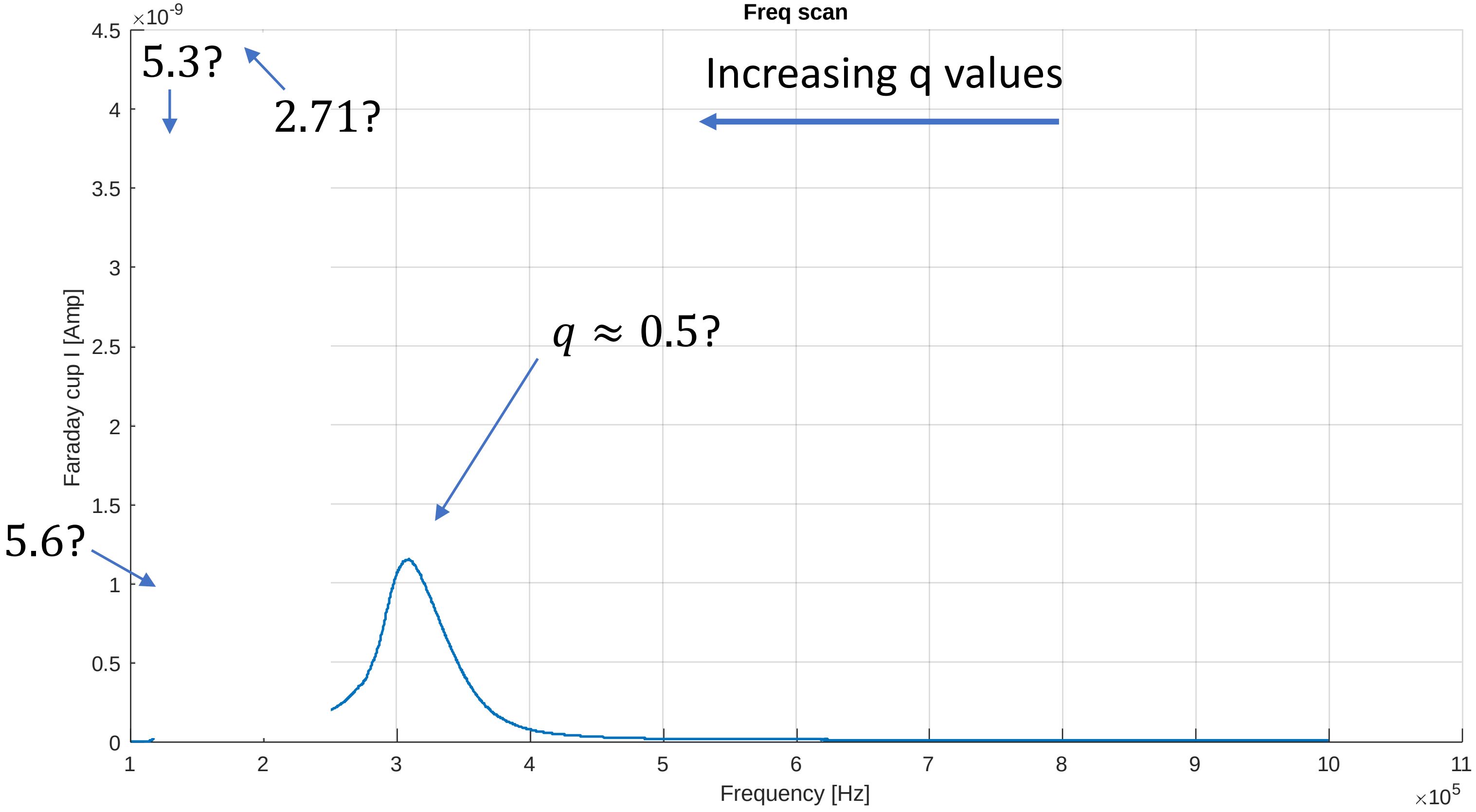
$$\frac{d^2x}{d\xi^2} + (a - 2qCos(2\xi))\, x = 0$$

$$q = 4\frac{eZ_iV}{mr_0^2\omega^2} \quad \text{and} \quad a = \frac{8eZ_iU}{mr_0^2\omega^2}$$

$$q = 4\frac{eZ_iV}{mr_0^2\omega^2}$$

M = 129 AMU
$V_{0\text{-}p}$ = 500 V
r_0 = 0.02 m
Z = 1
Q = 0.5
Ideal Freq = 435 kHz





$$q = 4\frac{eZ_iV}{mr_0^2\omega^2}$$

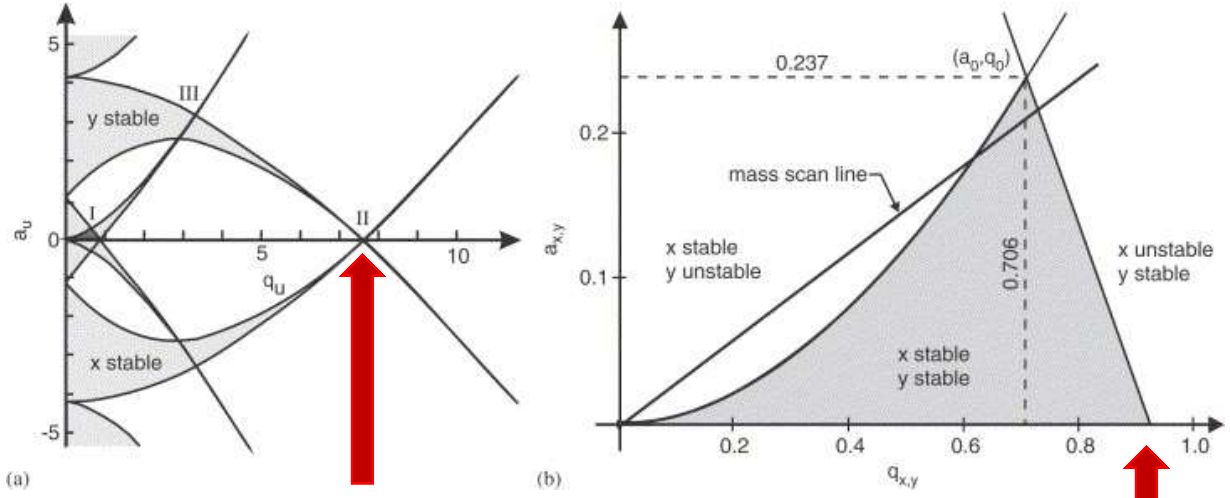
M = 132 AMU

$V_{0\text{-}p}$ = 500 V ← 90 V

r_0 = 0.02 m

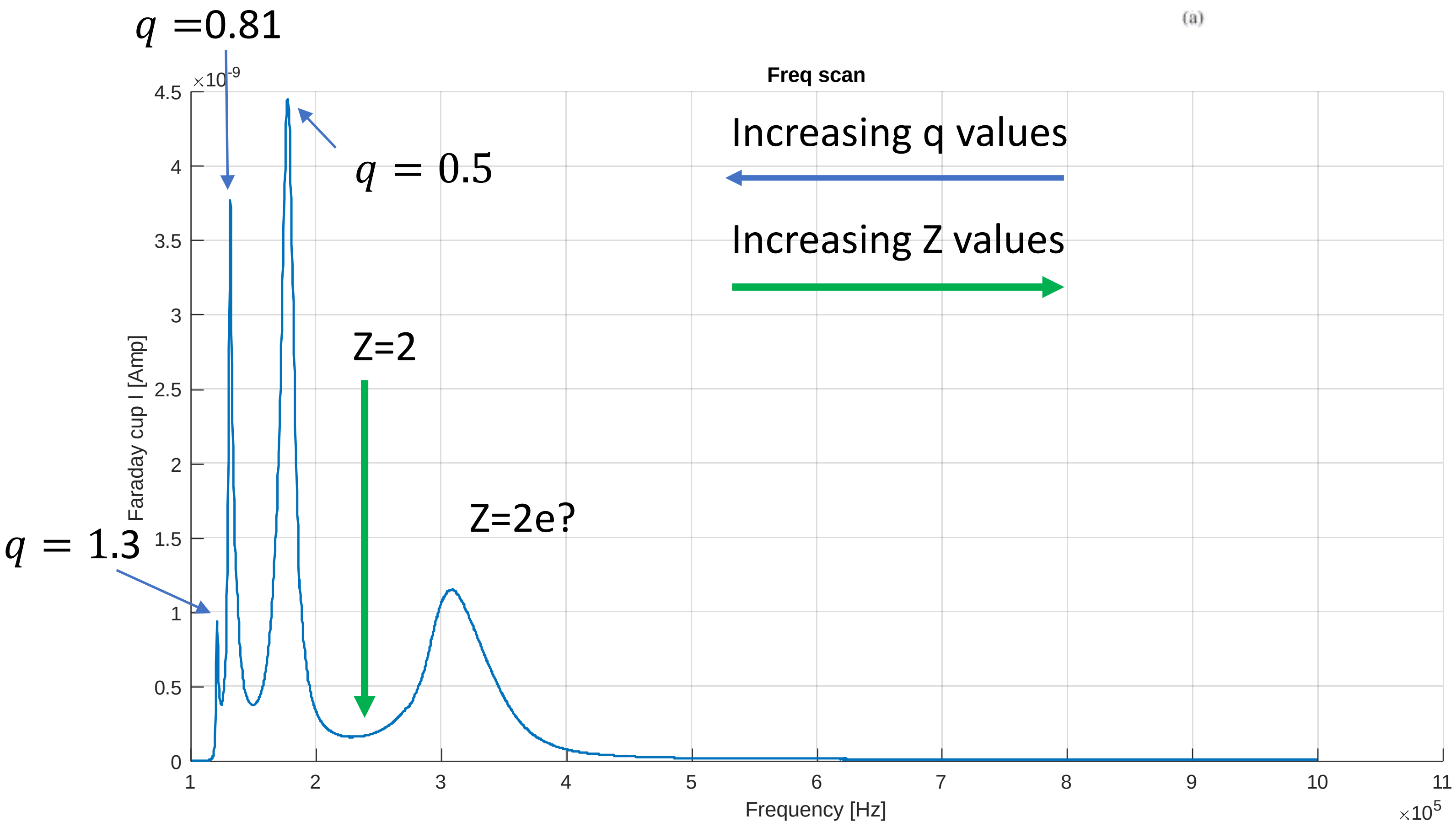
Z = 1e ← 2e

Q = 0.5



Q=7.6

Should not be stable > 0.9 !?

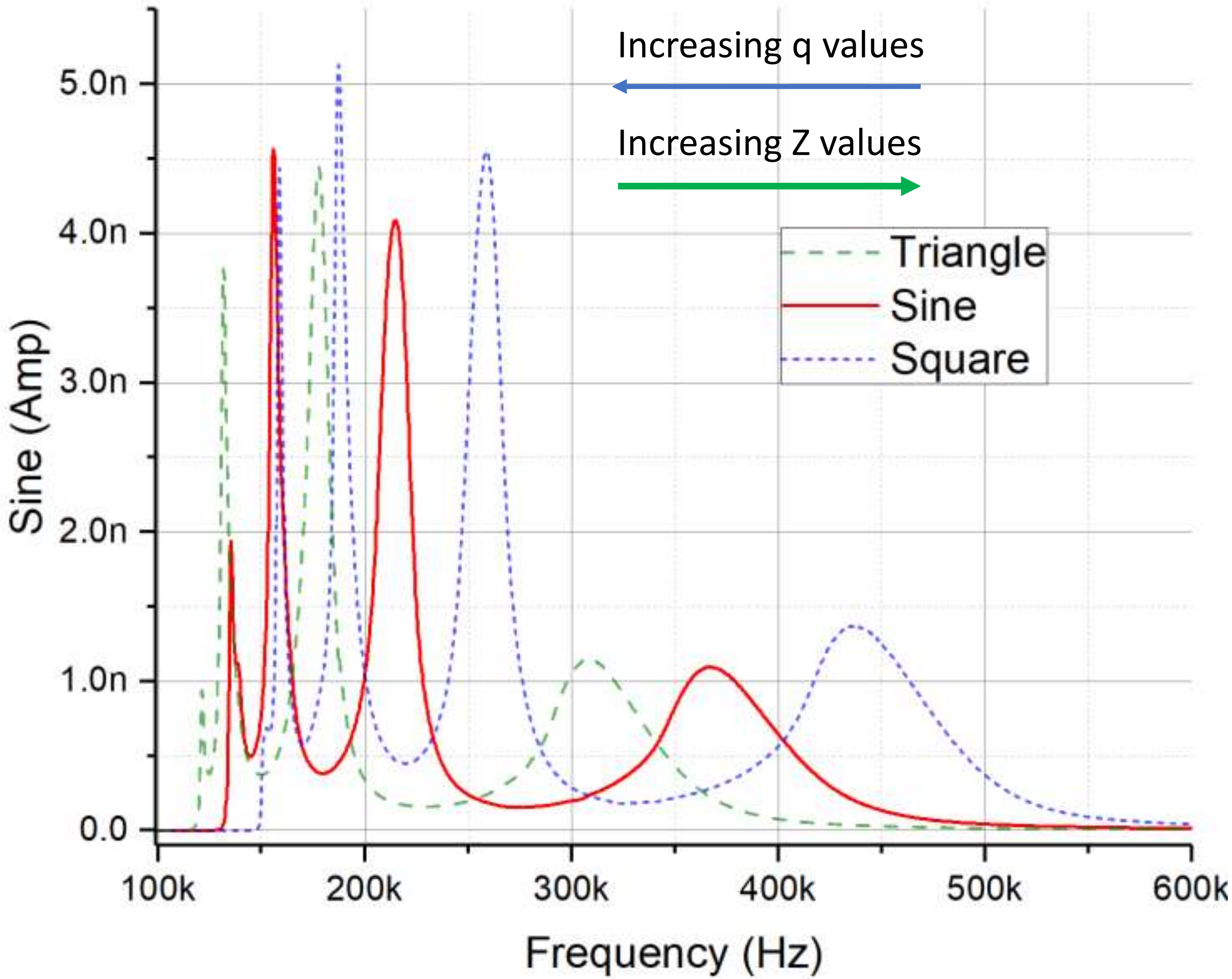


Continue to investigate the effect of waveform, **Stable point (~q=0.5) shouldn't change much** between **Mattheu** solutions (sine)

And

Meissner (square)

RF scans with alternate wave forms



- Repeated with different masses :
  - Ne20, Ar40, Kr84, Xe129
- Next step is to solve the hill equation for more than just the sine and square solutions and for more than just q upto 25 :

$$\ddot{u} + \left(\theta_0 + 2\sum_{n=1}^{\infty}\theta_n Cos(2nt) + \sum_{m=1}^{\infty}\phi_m sin(2mt)\right) u = 0$$

Sine: $$\frac{d^2x}{d\xi^2} + (a - 2qCos(2\xi))\,x = 0$$

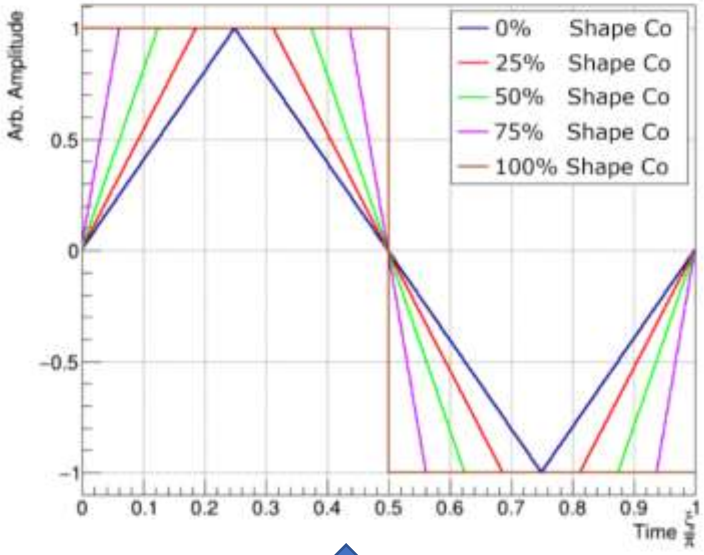
Square: $$\frac{d^2y}{dt^2} + (\alpha^2 + \omega^2 \operatorname{sgn}\cos(t))y = 0$$

Arb: ……..

BUT
Comes later, only 5 days of fellowship left.

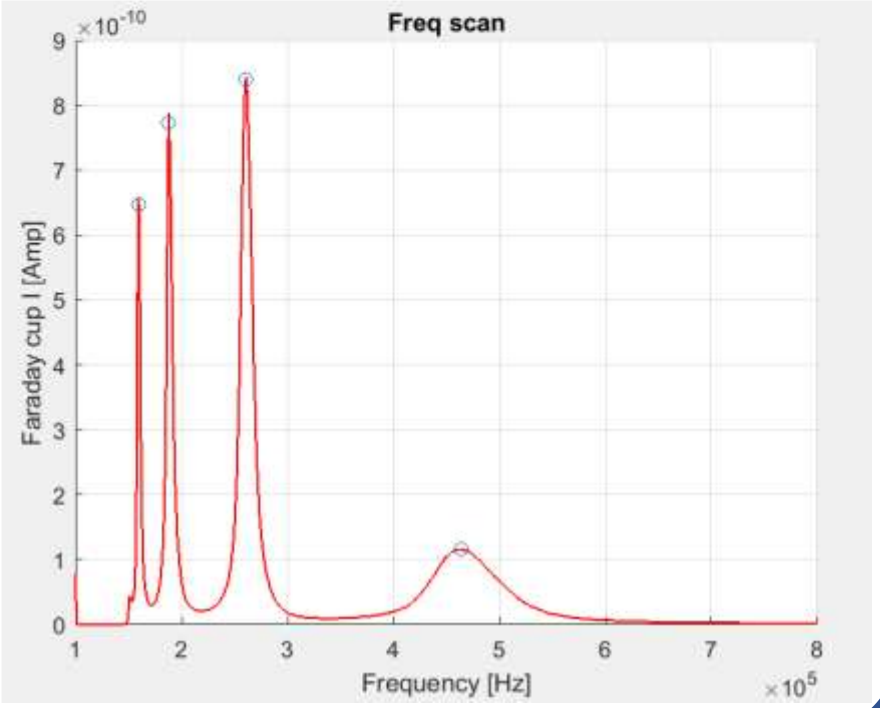
RF scans with alternate wave forms

Experimental while(-1) loop:



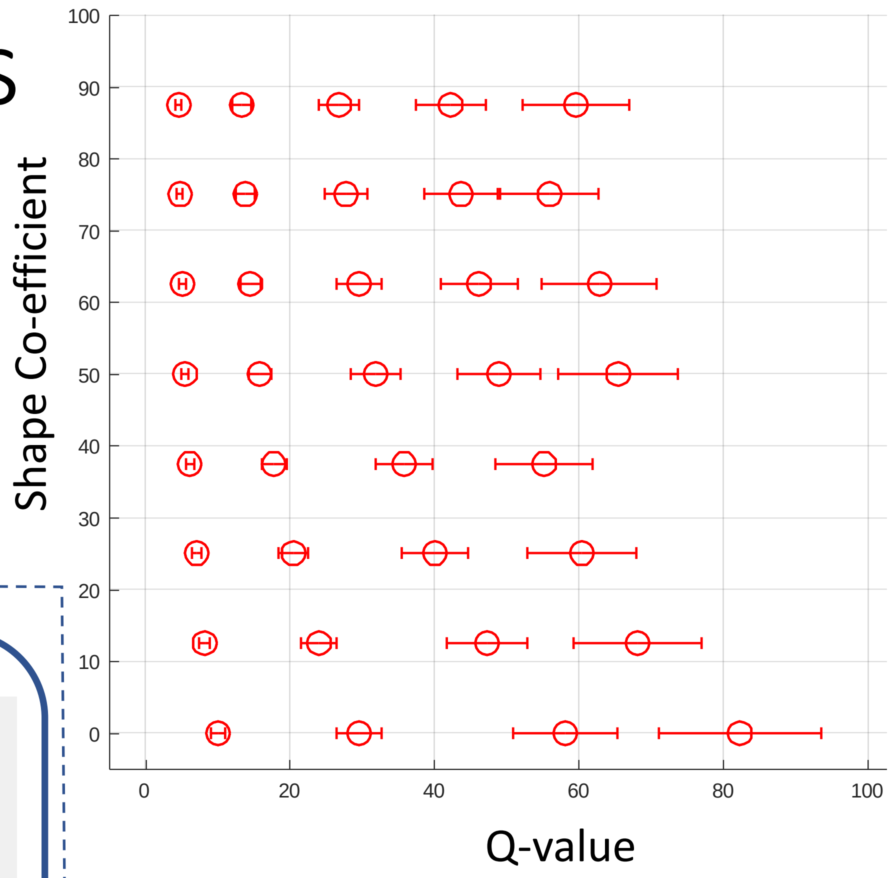
Change ADC waveform amplitude

Scan over 100 to 800 kHz



Save and extract peak data

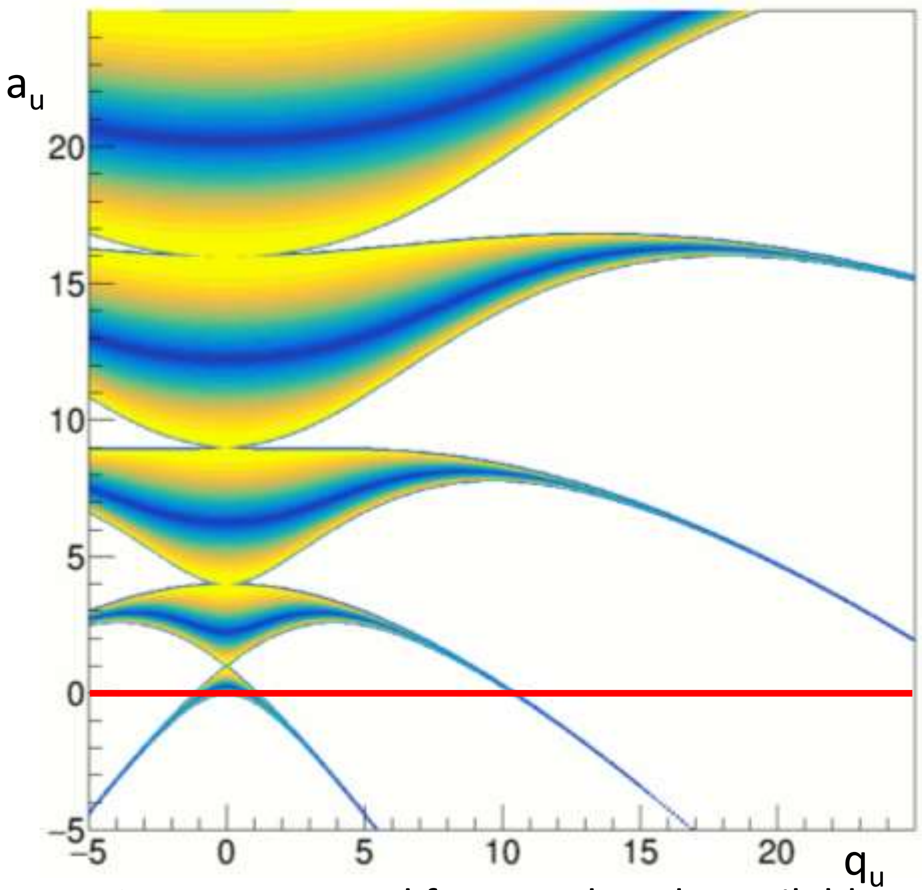
Compute q values



Offline 2 checks:

- Magnet stability
- Ion source drain current
- RF cooling
- Platform potential
- Injection Pressure

Stable ion motion computed (COVID-19 lockdown)



- CUDA computed for speed, code available upon requested.
- Coloured regions are stable < 1 , darker = more stable
- Redline is the a_u=0, no DC trapping present.

Solve for any continuous waveform

$$\ddot{u} + \left(\theta_0 + 2\sum_{n=1}^{\infty}\theta_n Cos(2nt) + \sum_{m=1}^{\infty}\phi_m sin(2mt)\right)u = 0$$

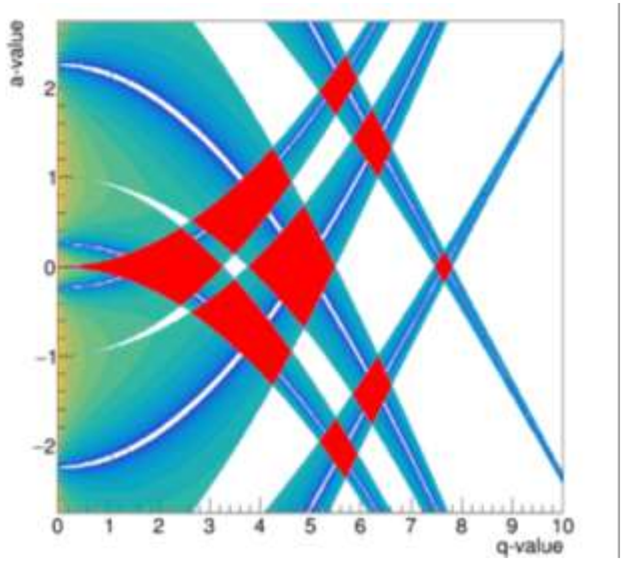
Maths, madness and whisky later*

$$M_i(f_i,\Delta_i) \times \begin{bmatrix} Cos(\Delta\sqrt{f_i}) & \frac{1}{\sqrt{f_i}}Sin(\Delta\sqrt{f_i}) \\ -\sqrt{f_i}Sin(\Delta\sqrt{f_i}) & Cos(\Delta\sqrt{f_i}) \end{bmatrix} \Rightarrow$$

$$\frac{|Tr(M)|}{2} \leq 1 \quad \text{stable}$$

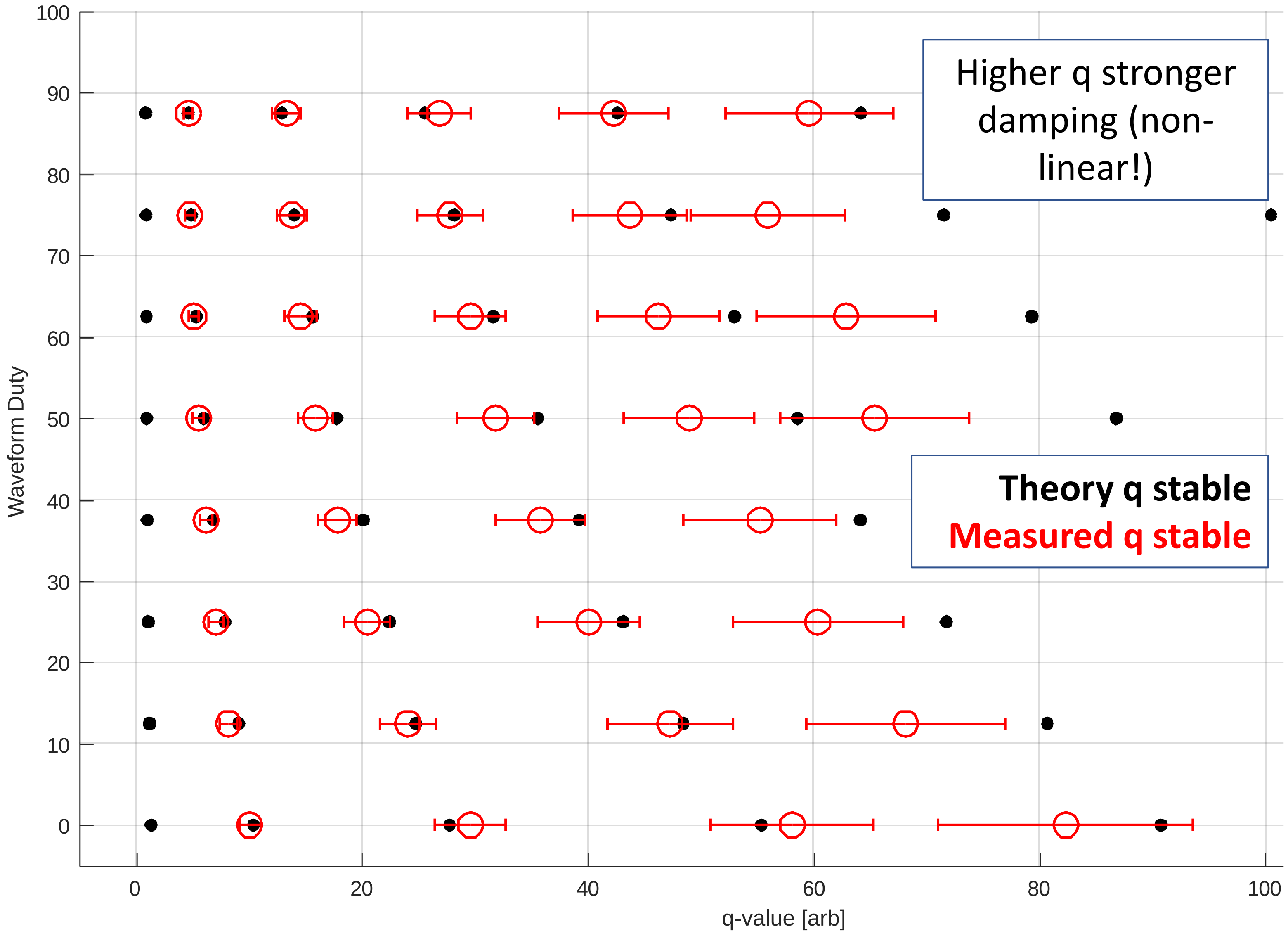
$$\frac{|Tr(M)|}{2} > 1 \quad \text{Unstable}$$

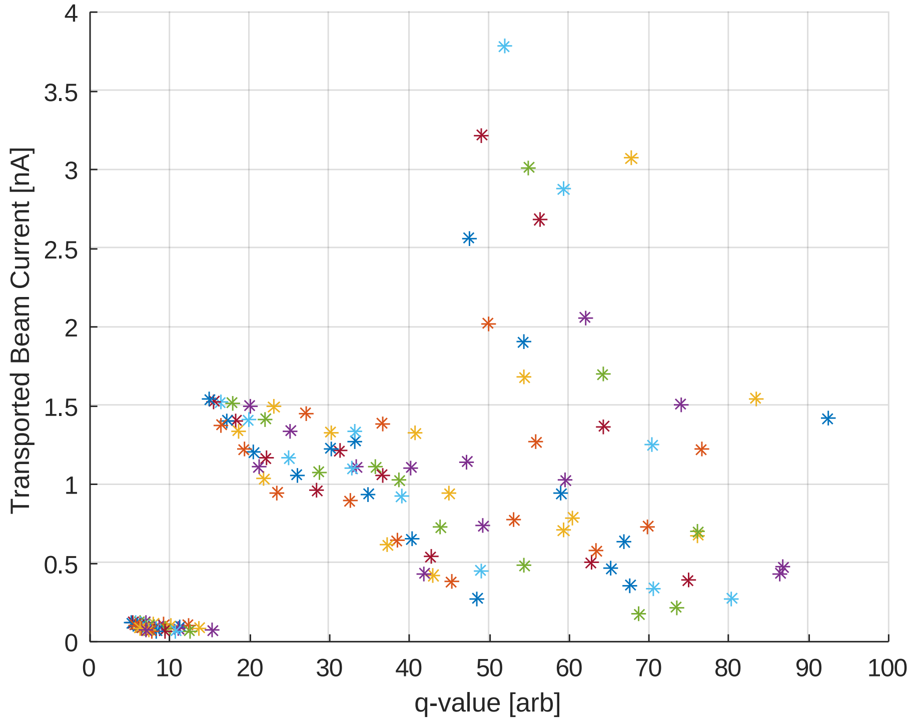
Since:
$q_x = -q_y$
Can get stable points for ANY waveform inc. DC offsets



* L.A.Pipes **Matrix Solution of Equations of the Mathieu-Hill Type**
https://aip.scitation.org/doi/pdf/10.1063/1.1721400

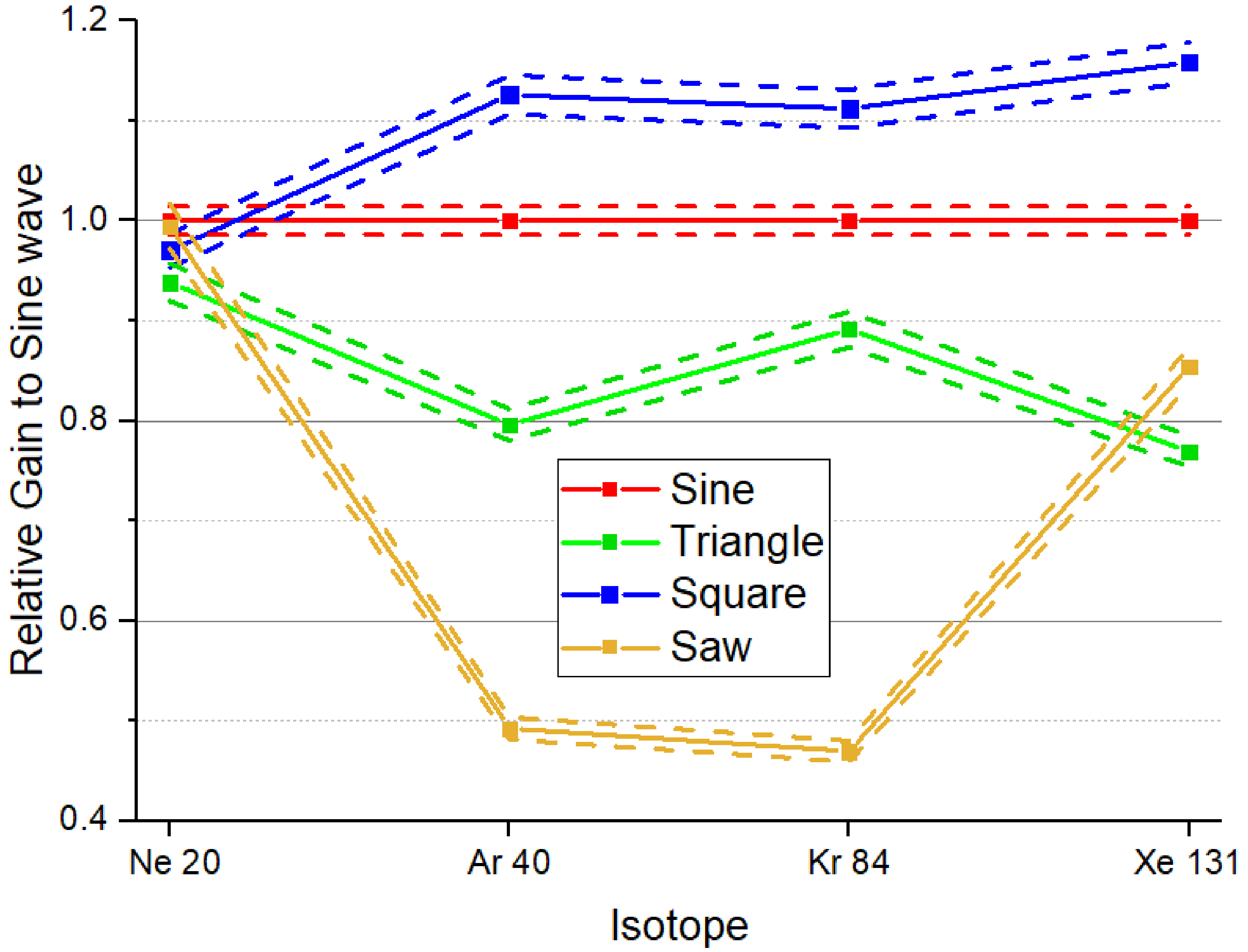
Computed values Vs measured





- Error dominated by:
  - QP sag internally +/- 0.2mm
  - FWHM of peak fitting
- Note ion source stability issue over long scan duration (24 hours)

Maximised for transport

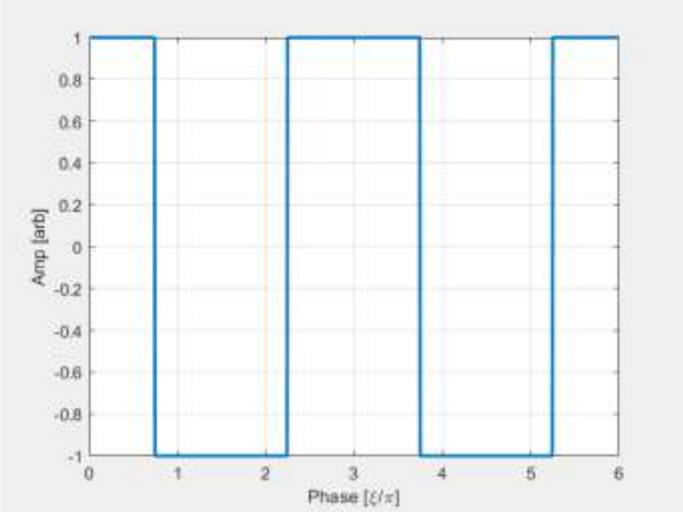


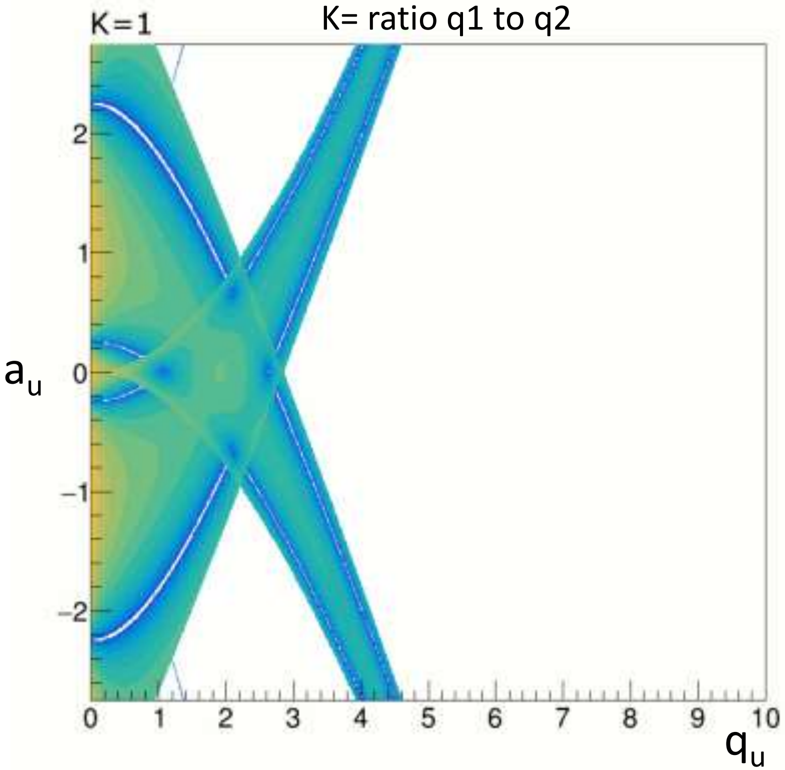
- Any peak with max transport taken in quick succession.

- PHYSICS: Transport better for heavier masses with square wave:
  - Longer time in deeper potential well
  - Stronger cooling
  - Better injection

- PRACTICAL:
  - Much cheaper to produce Square wave generator
  - No amplifiers → Mosfet and low precision DAC with High current PSUs

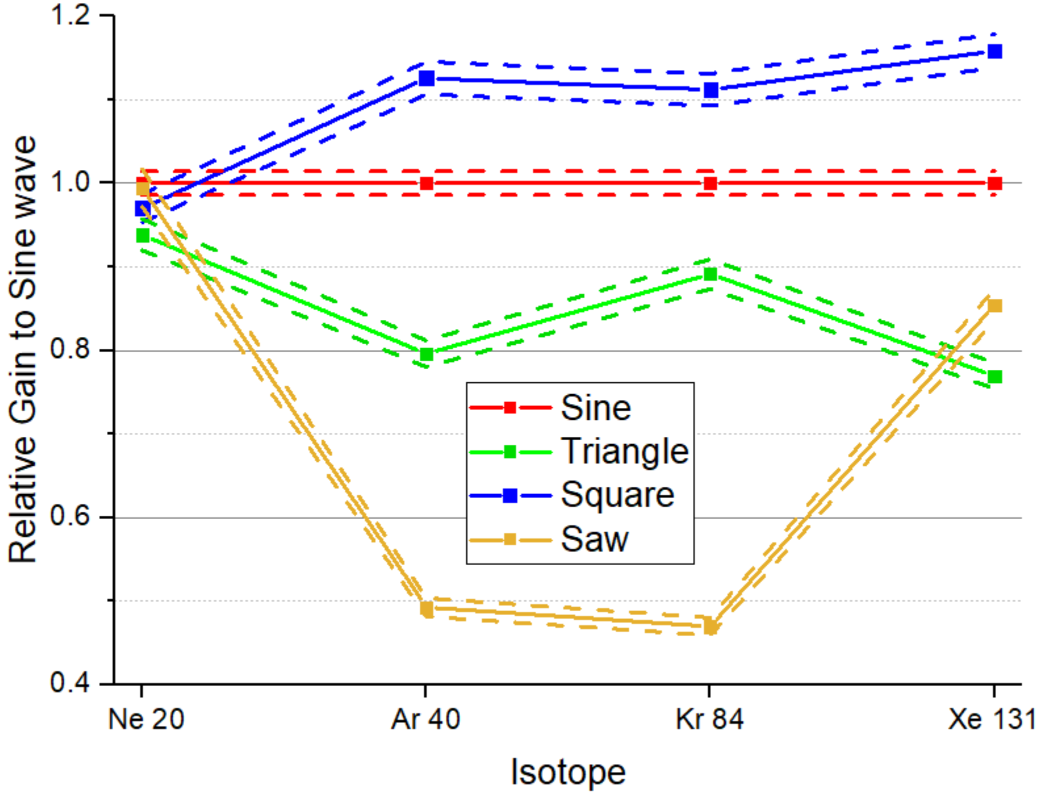
Future Possibilities

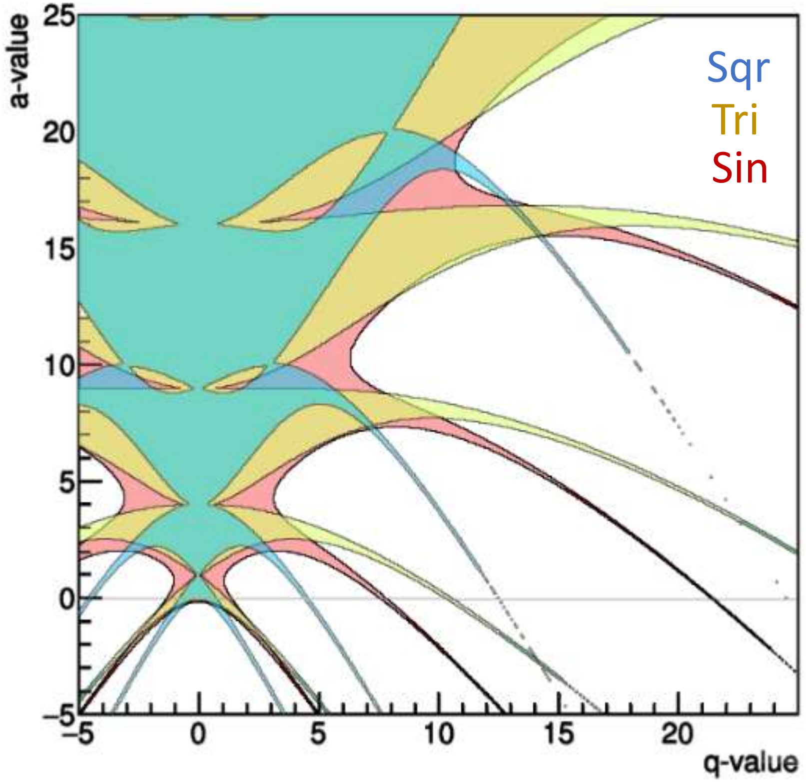




- Mother Daughter Molecular breakup capture
  - Use RF Summing and excitations to capture both then remove mother from daughter products with K advance
- Improve the Bunching Vs Transport Beam transmission
  - Use tune suited to capture then advance V and RF to better accommodate the a_u!=0 DC offsets
- Improve cooling via reduced RF heating influence due to collisional 'dragging'
- **Would very much like to verify the results with more testing !!!!**

Thank you for your attention





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  - T. Giles, R. Catherall, S. Rothe, C.M Pequeno, A. Ringvall-Moberg, B. Crepieux and the rest of the RBS group
  - Cern services who helped out, BE-RF, TE-VAC, BE-BI, TE-EPC
  - M. Kowalska for giving me the time to do this work!