Fast Beam-ion Instabilities

Vacuum Specifications in CLIC Main Linac

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Outline

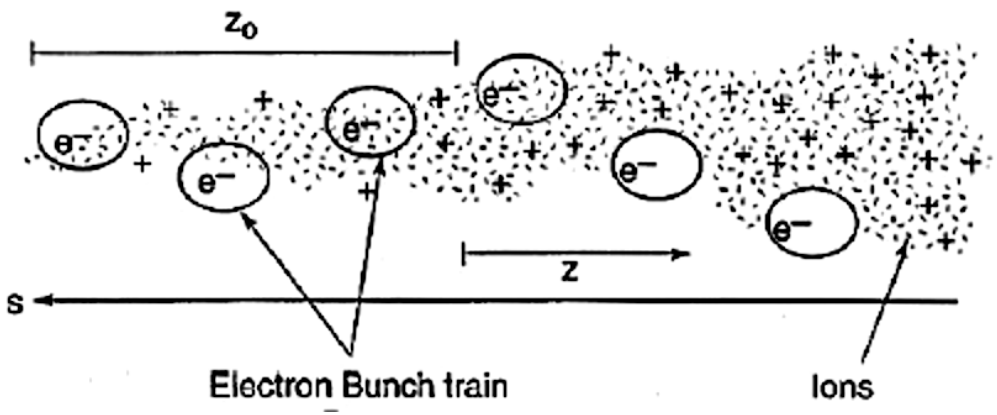
Fast beam-ion instability I

Fast beam-ion instability:

- electron bunches create ions out of residual gases by
  - scattering ionization
  - field ionization – after threshold (beam transversely small enough): currently ∼4km for a final energy of 1.5TeV
- electromagnetic interaction between electrons and ions
  - ions created bunch by bunch and kicked by passing bunches
  - electron bunches feel effect of ion field
- resulting in
  1. extra phase advance shift over bunch train
  2. possible excitation of unstable ion-electron coupled motion (ions do not necessarily need to be trapped)

Fast beam-ion instability II

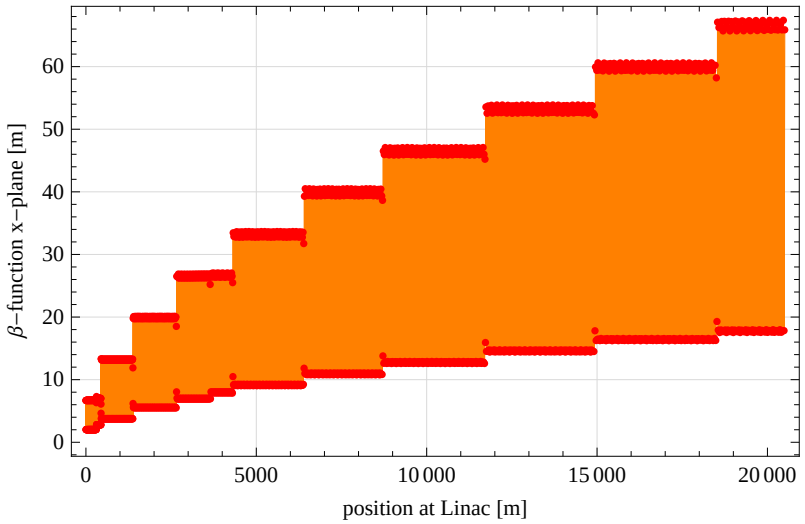
- two-stream instability:
  - accumulation of ions around beam for long enough times $\Longrightarrow$ coupled oscillations between electrons and ions triggered (resonance, grows by its own)



source: http://sps-impedance.web.cern.ch/sps-impedance/USPAS/TwoStream.pdf

FASTION code I

- FASTION code uses PLACET Twiss file to get beta functions and energies (tracking electrons through Main Linac)

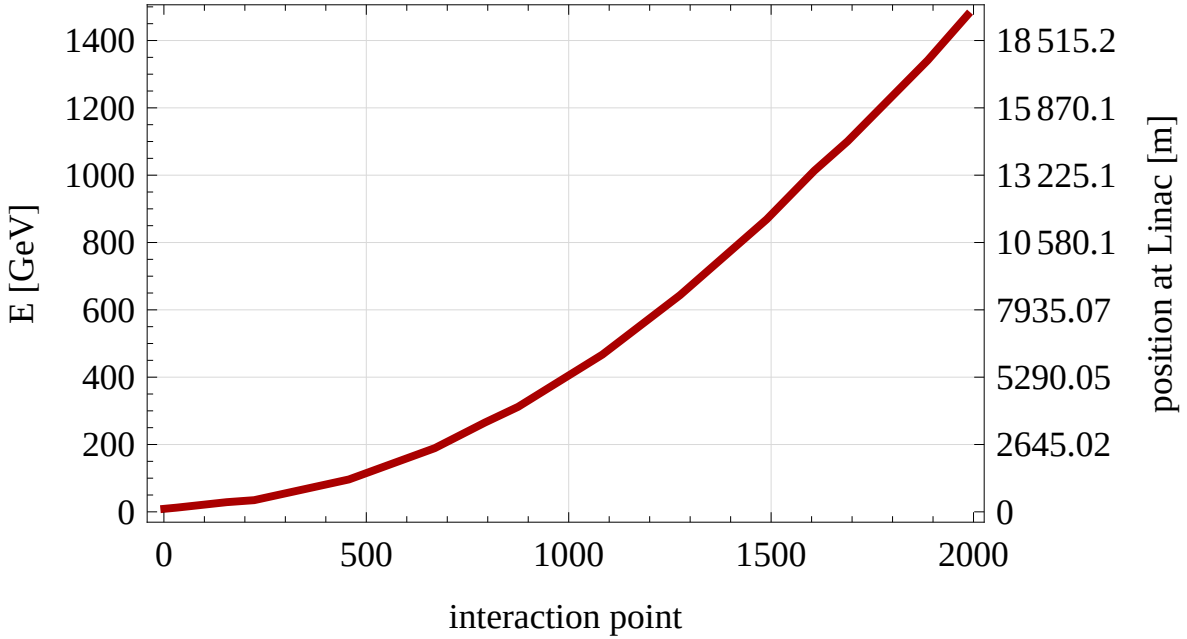


β-functions increase along Main Linac $\Rightarrow$ partial compensation of shrinking beam size due to acceleration

- interactions of ion and electron macro-particles at each lattice point (integrated up to next point)

Energy vs. Interaction Points

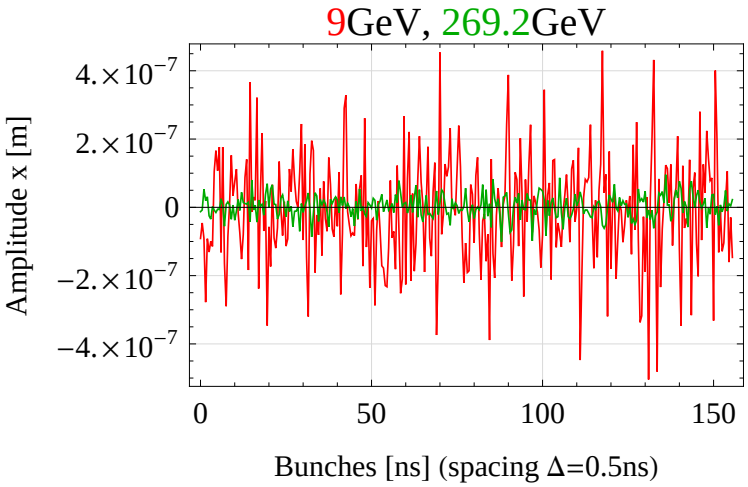
- distribution of interaction points in PLACET Twiss file becomes less dense towards end



FASTION code II

FASTION code produces several output files, e.g.

- bunch by bunch offsets x, x', y, y' over whole train for all lattice points



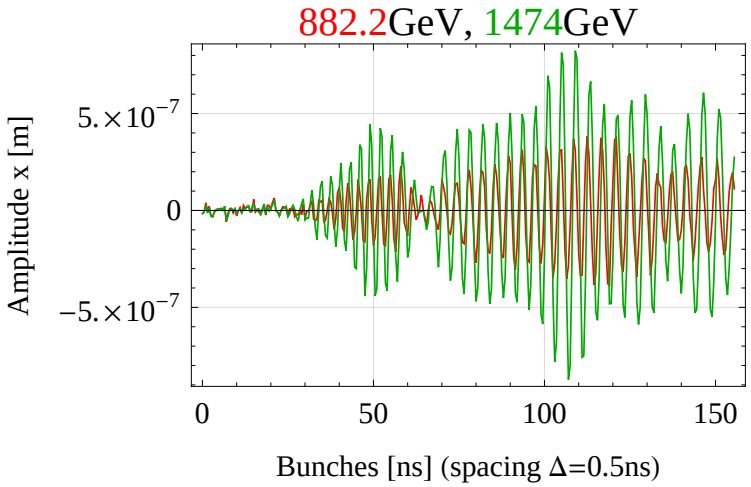


Figure: Bunch offsets – ion species: H_2O, pressure: 20nTorr

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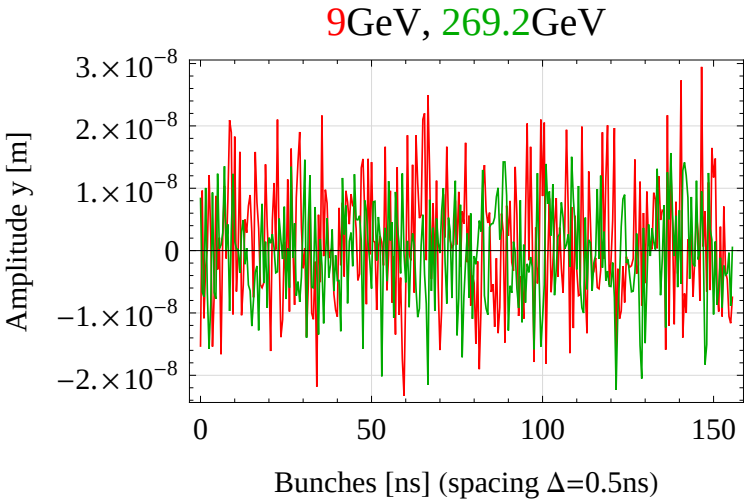

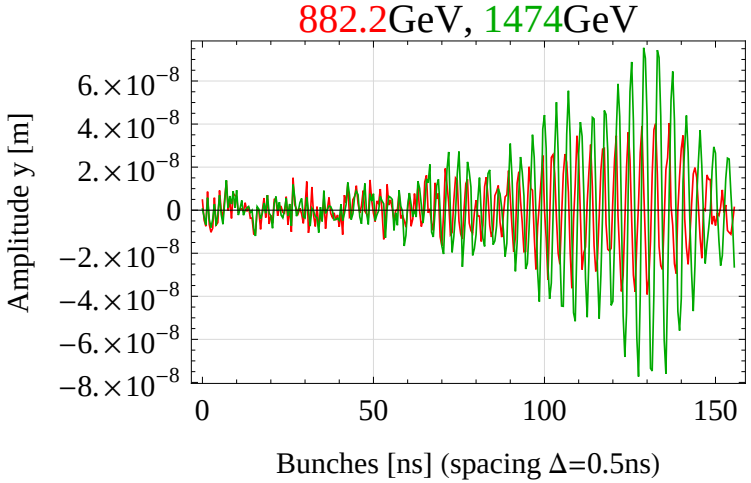

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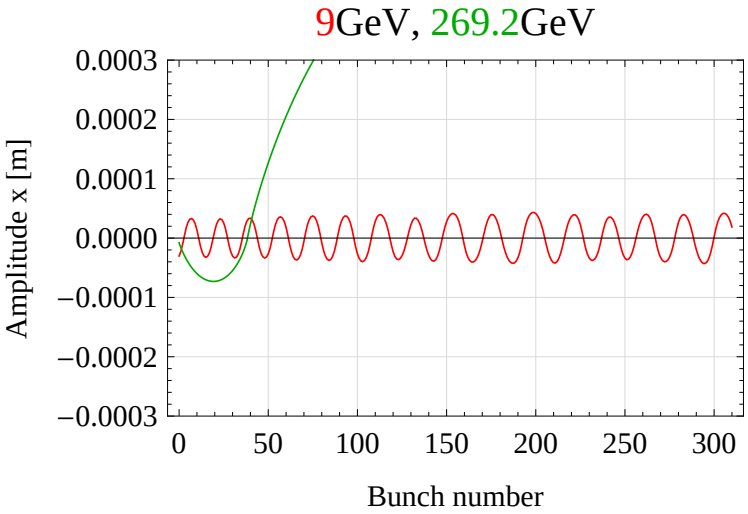
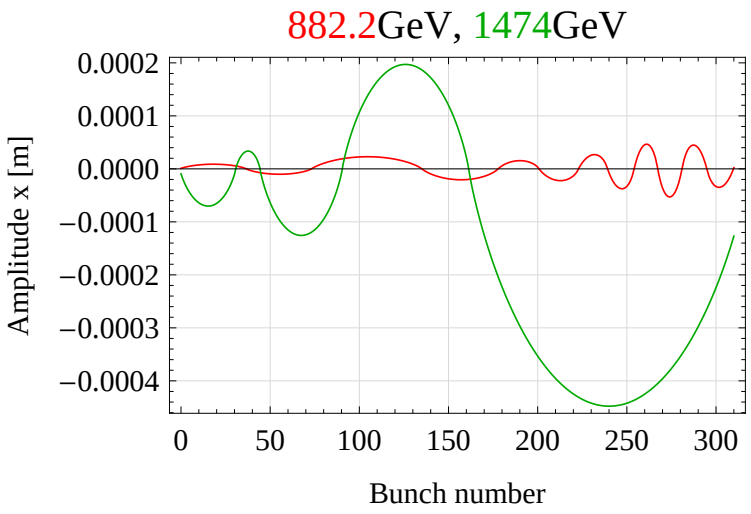
FASTION code produces several output files, e.g.

- bunch by bunch offsets x, x', y, y' over whole train for all lattice points
- sample ion trajectories recorded uniformly distributed





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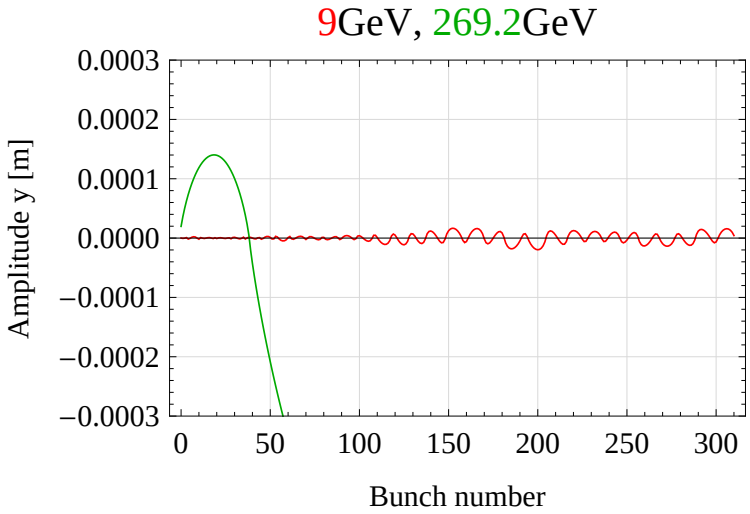


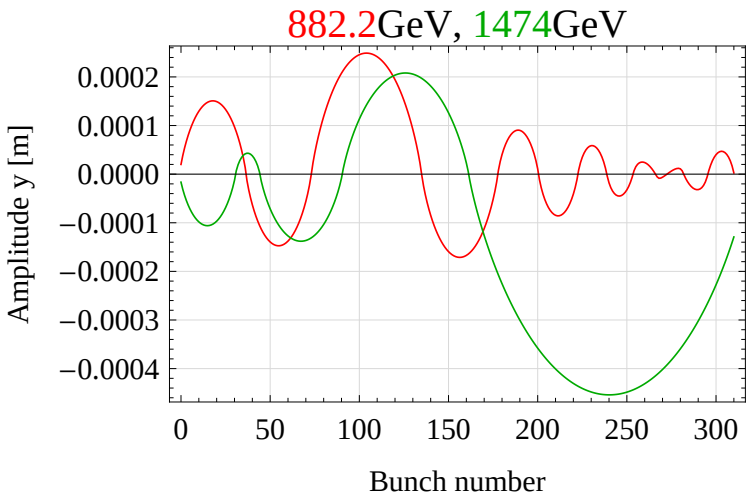


Figure: Ion trajectories – ion species: H_2O, pressure: 20nTorr

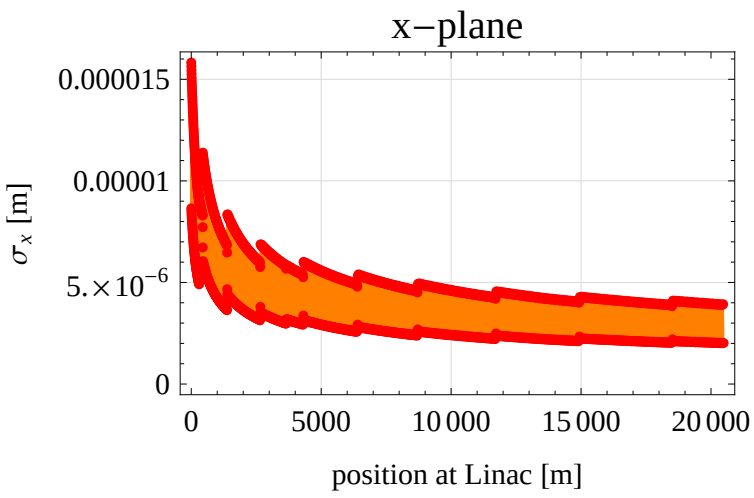
Specifications

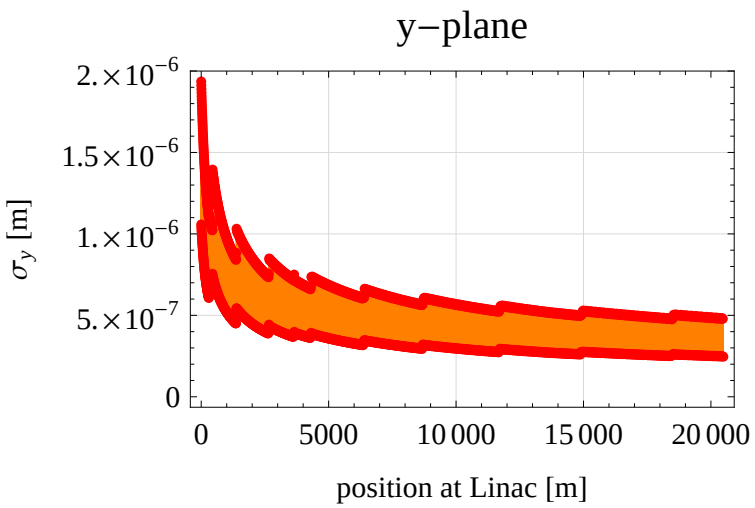
Parameters used in the study of CLIC Main Linac:

Energy	p_0 [GeV]	9 to 1500
Norm. transv. emitt.	$\epsilon_{x,y}$ [nm]	660, 10
Bunch population	N	4×10^9
Number of bunches	N_b	312
Bunch spacing	ΔT_b [ns]	0.5
Bunch length	σ_z [ps]	0.15
Linac length	L [km]	20.5
Gas pressure	P [nTorr]	scanned
Ioniz. cross sect.	σ_{ions} [MBarn]	2
Thresh. electr. field	E_{th} [GV/m]	15

Beam Transverse Size Shrinking

What makes Main Linac special? (compared to transfer line)





- field ionization can start (small transverse beam size)
- trapping condition changing along Main Linac
- excited frequencies different along Main Linac

My tasks

What I finished so far:

- scan of different ion species from 2 (H_2) to 132 (Xe) for
  - starting mass number causing beam instabilities
  - frequency analyses of unstable train oscillations
- investigation on realistic distributions of residual gas
  - main components of the residual gas one by one
  - threshold pressure causing beam instabilities

My tasks

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- scan of different ion species from 2 (H_2) to 132 (Xe) for
  - starting mass number causing beam instabilities
  - frequency analyses of unstable train oscillations
- investigation on realistic distributions of residual gas
  - main components of the residual gas one by one
  - threshold pressure causing beam instabilities

What I would like to accomplish:

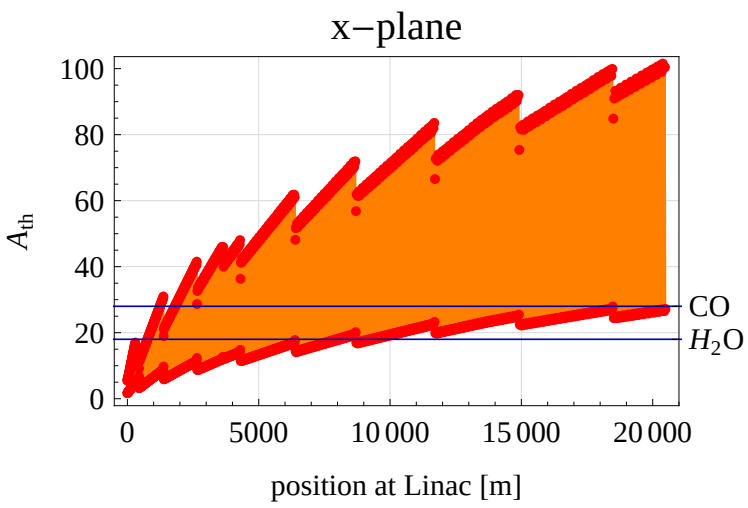
- simulating all ion species of realistic distribution together
- evaluation of pressure threshold for energy scaled Linac
- study the 500 GeV option
- perform some parameter scans

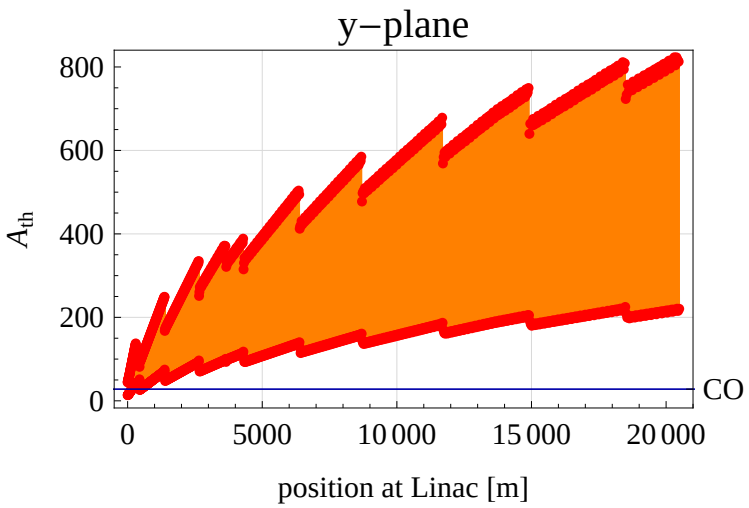
Trapping Condition for Gaussian Beams

Ion species being trapped in x-/y-plane:

$$A > \frac{N_b \, r_p \, T_b \, c}{2 \, \sigma_{x,y} \left(\sigma_x + \sigma_y\right)}$$

with r_p: classical proton radius





- ions have to be trapped in both planes ($\Rightarrow$ can only occur at beginning of Linac)

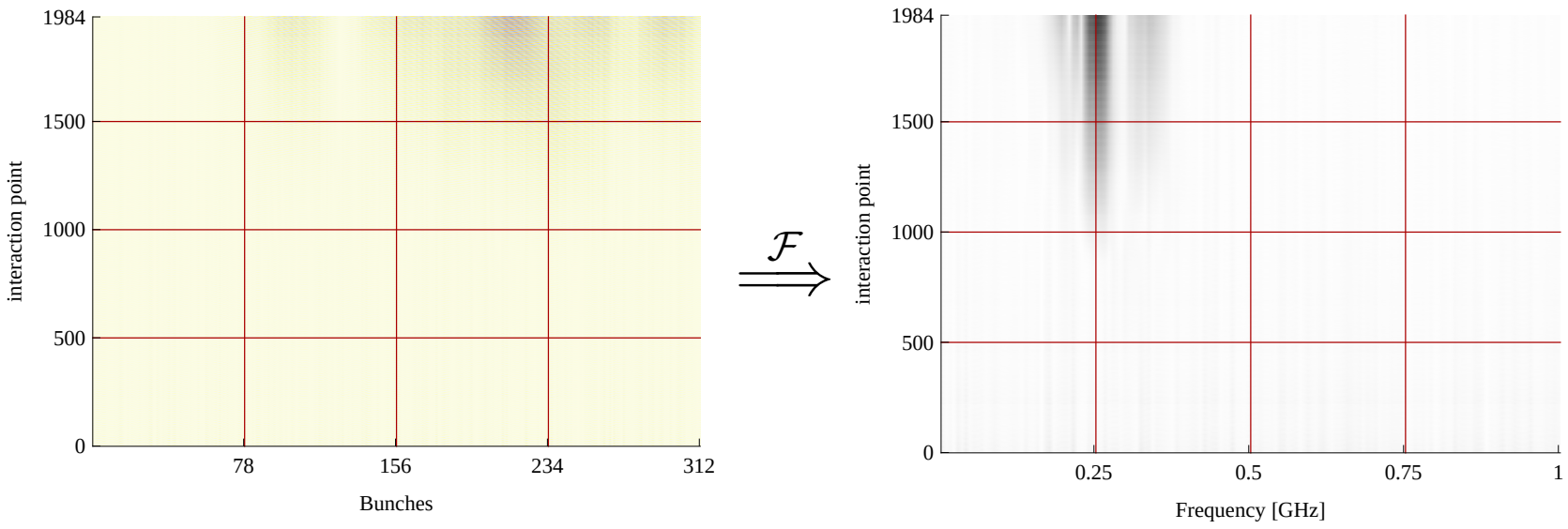
Approach for Scan

- scanned mass numbers: 2 (H_2), 4 (He), 5, 6, 7, 10, 12, 14, 16, 18 (H_2O), 20 (Ne), 28 (CO), 32 (O_2), 44 (CO_2), 70 ($^{35}Cl_2$), 84 (Kr), 132 (Xe)
- pressure set to 20nTorr
- analyzing bunch train motion and its fourier transformed modes

Why scan?

- evaluation of frequency dependencies on ion mass number

Fourier Transformed Modes for $A = 18$ (H_2O)



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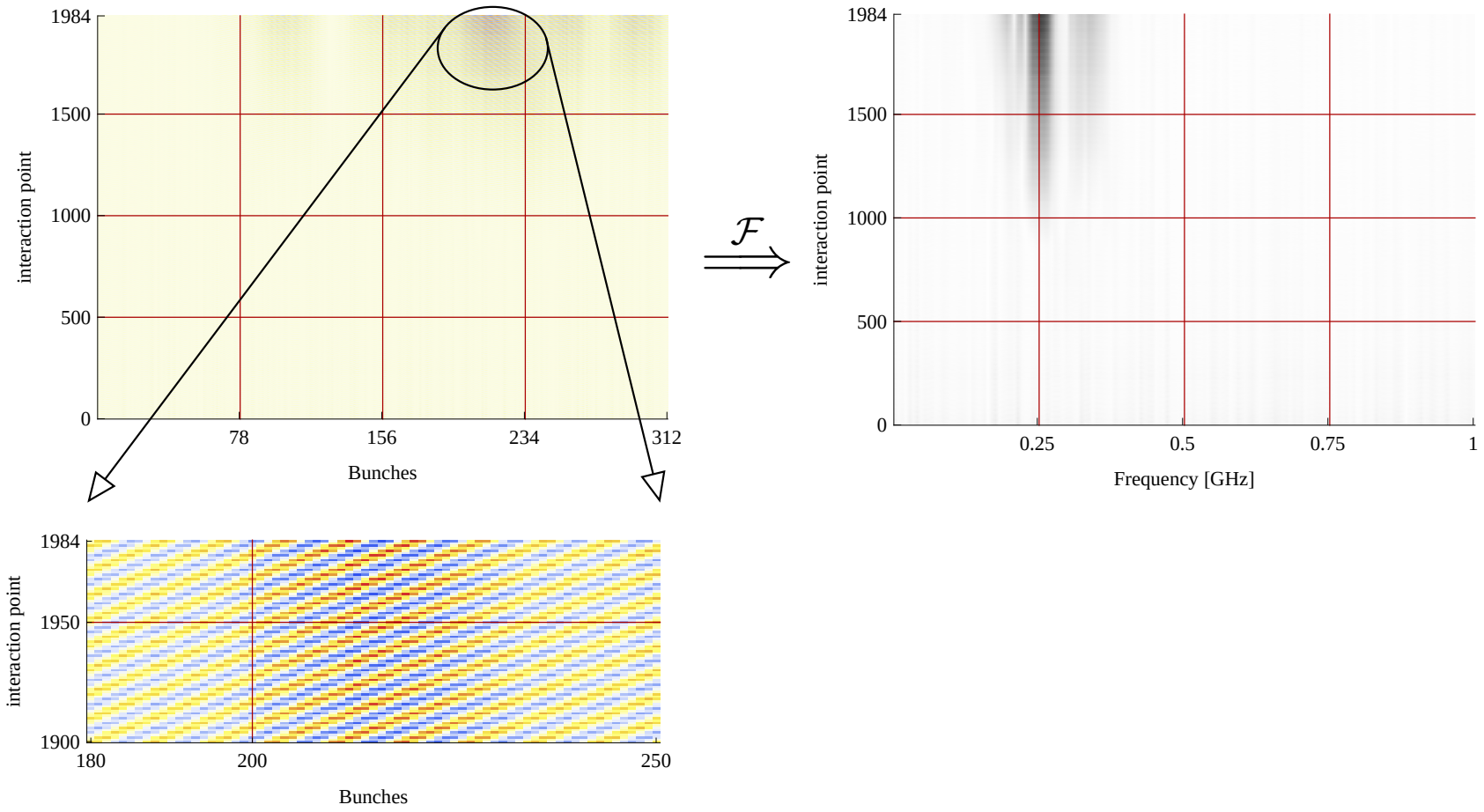

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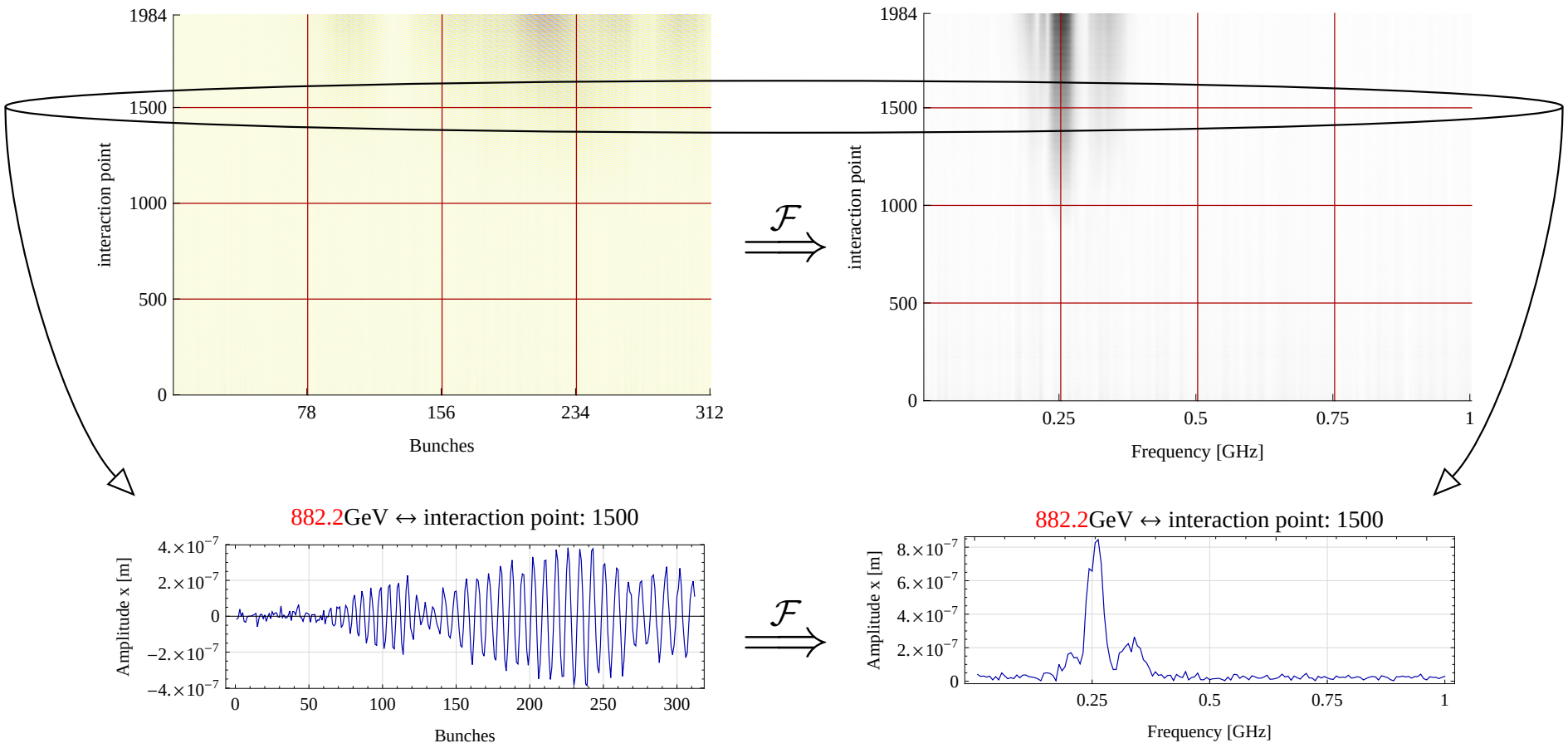
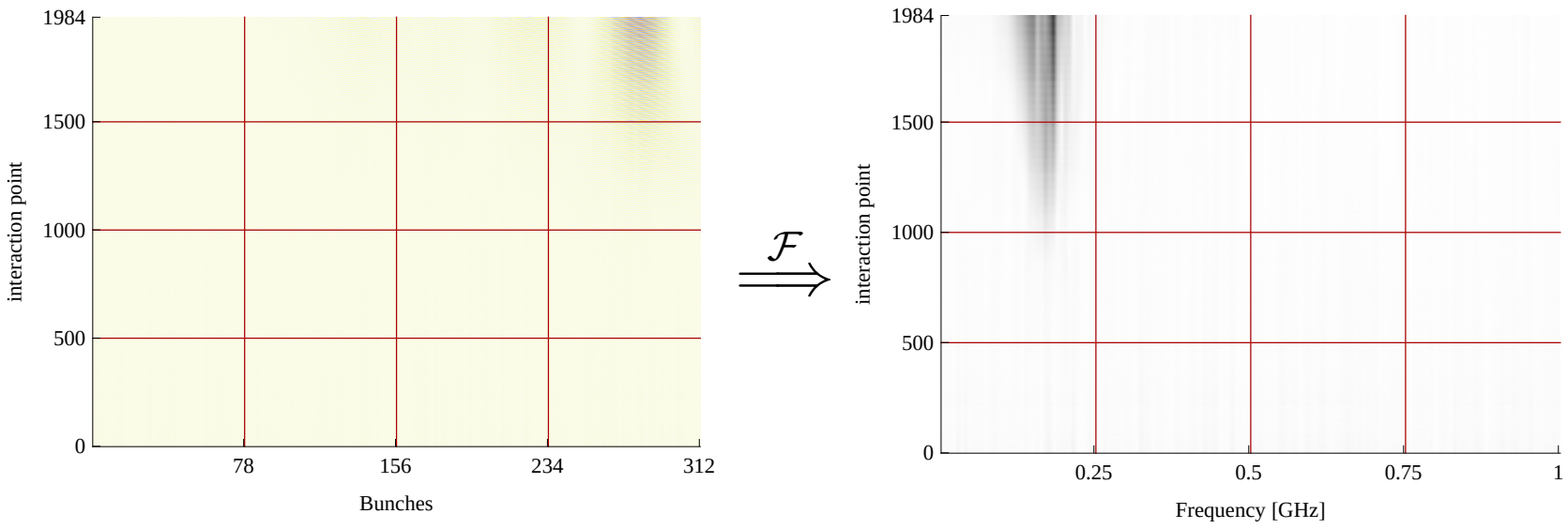


Fourier Transformed Modes for $A = 84$ (Kr)



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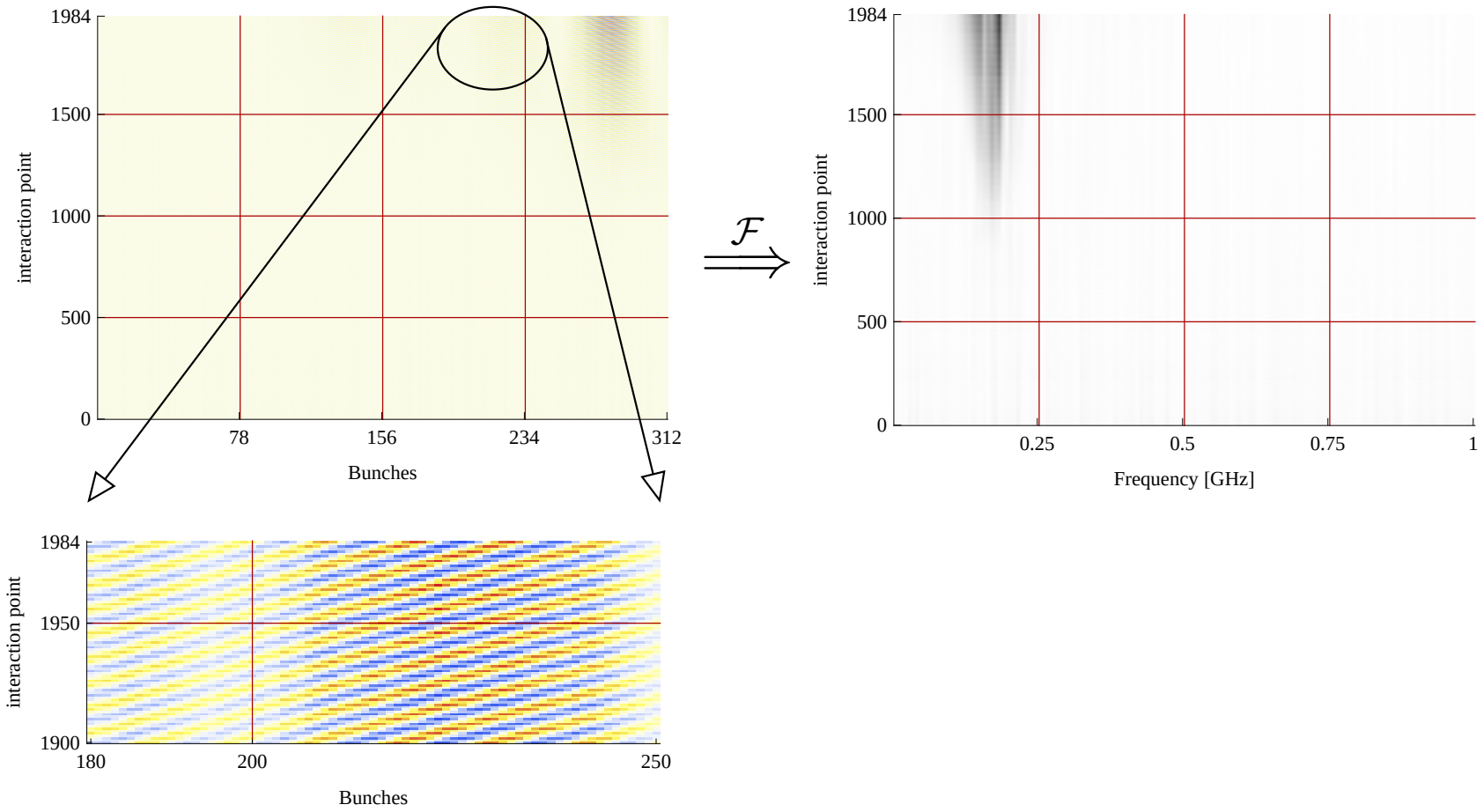

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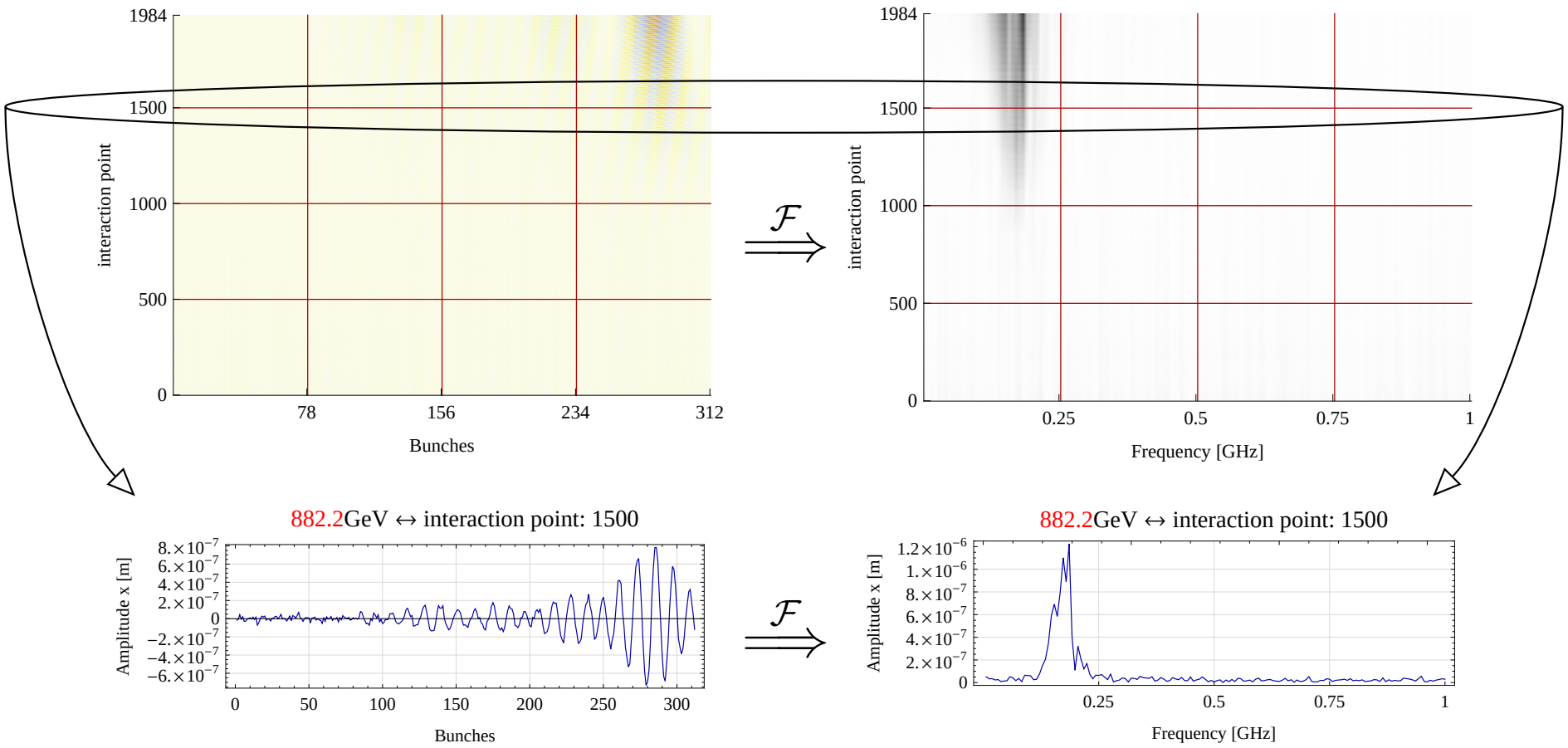
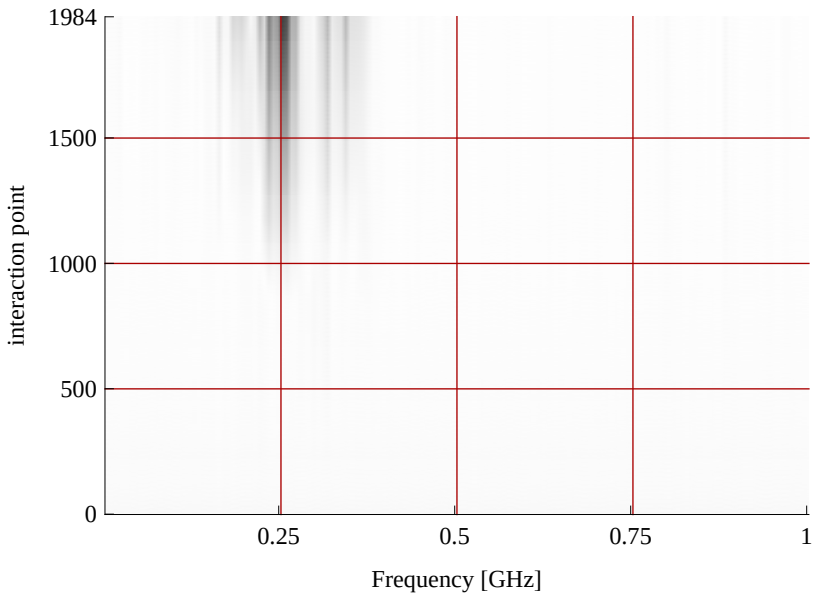


Mode Amplification for $A = 18$ (H_2O)



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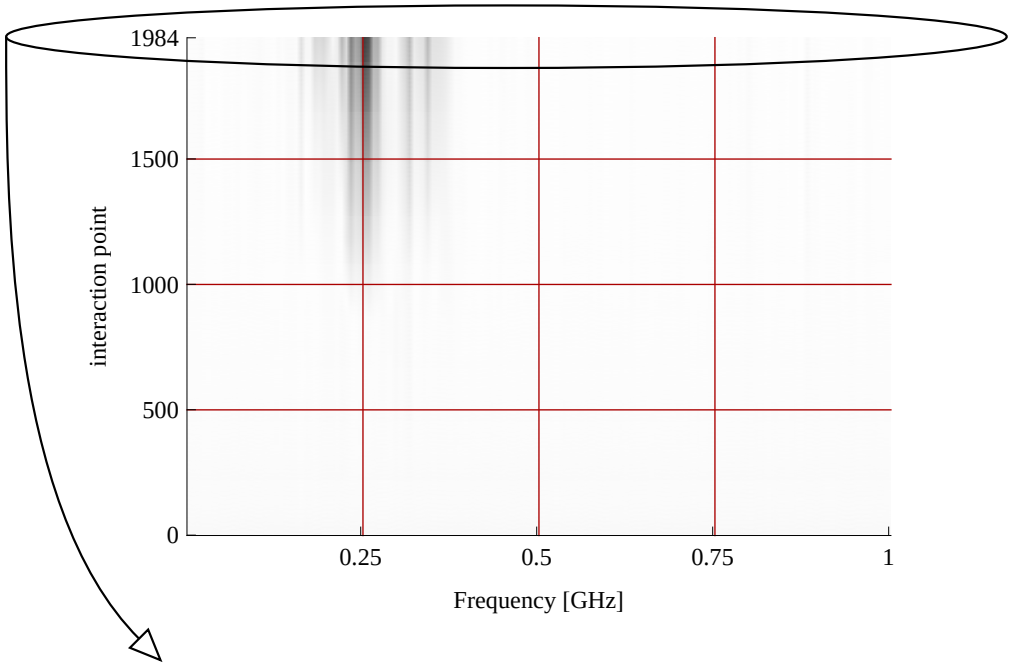

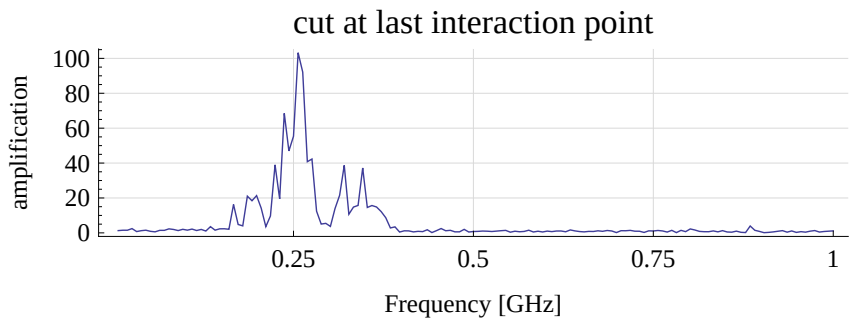

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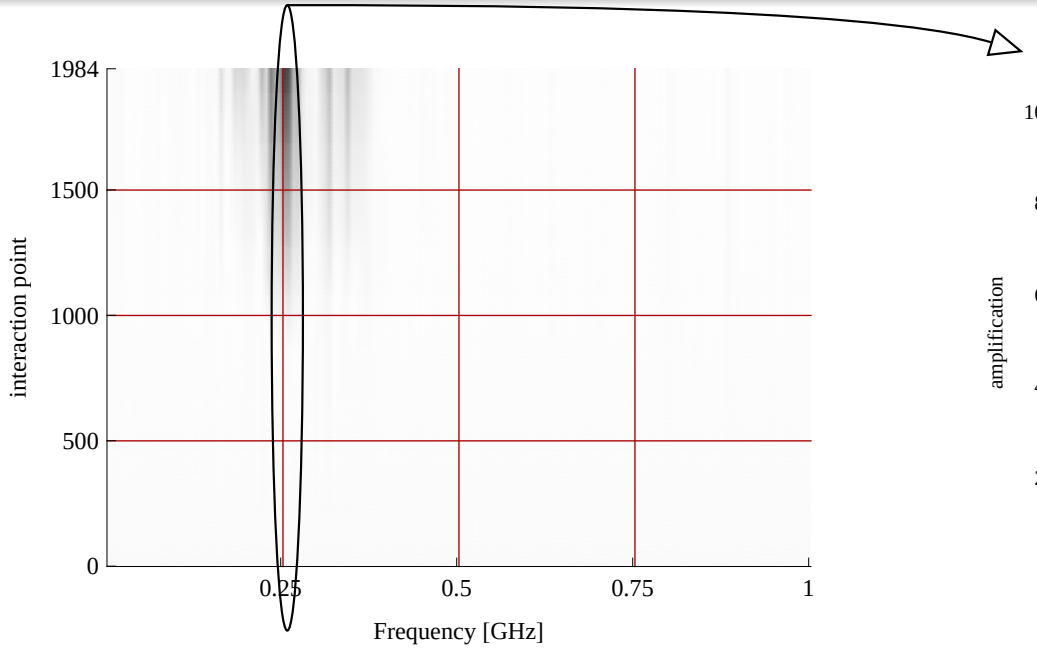

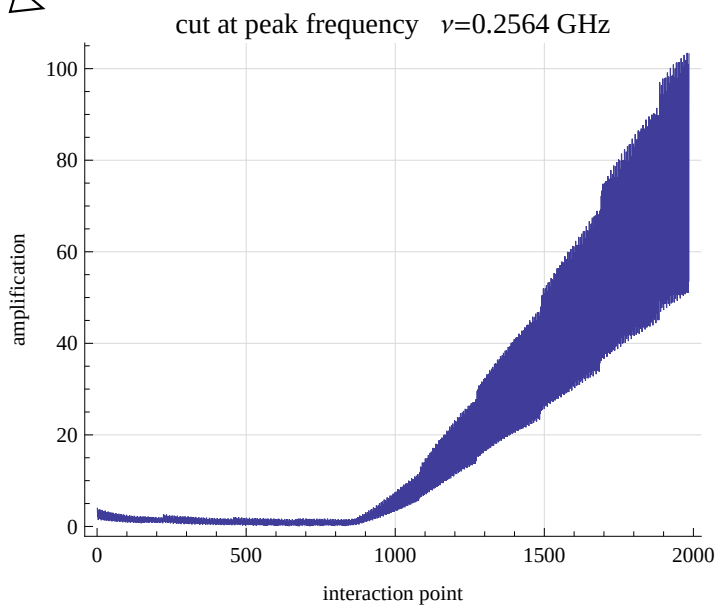

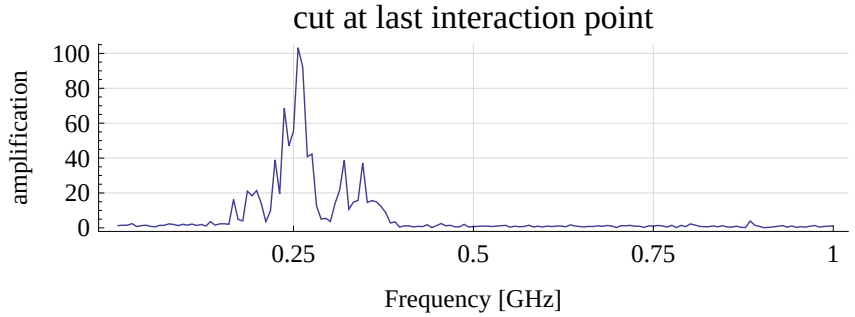

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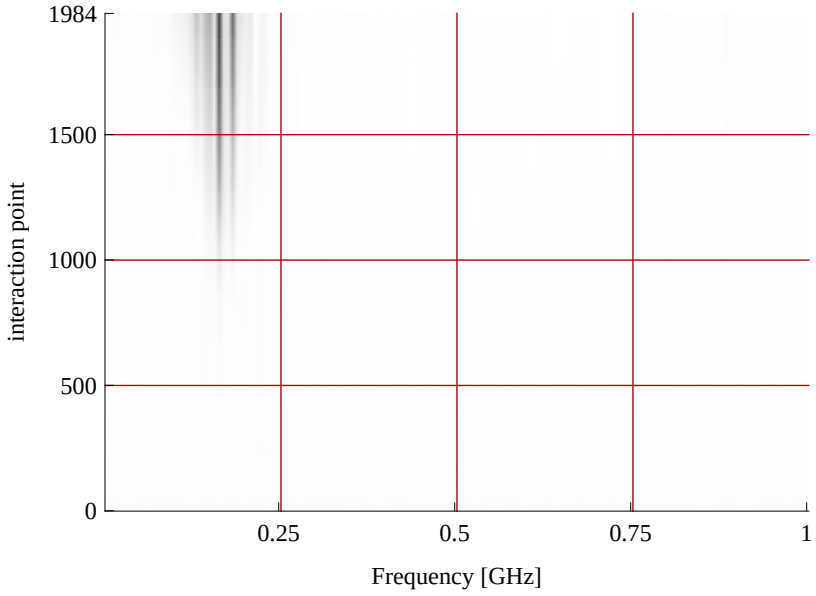

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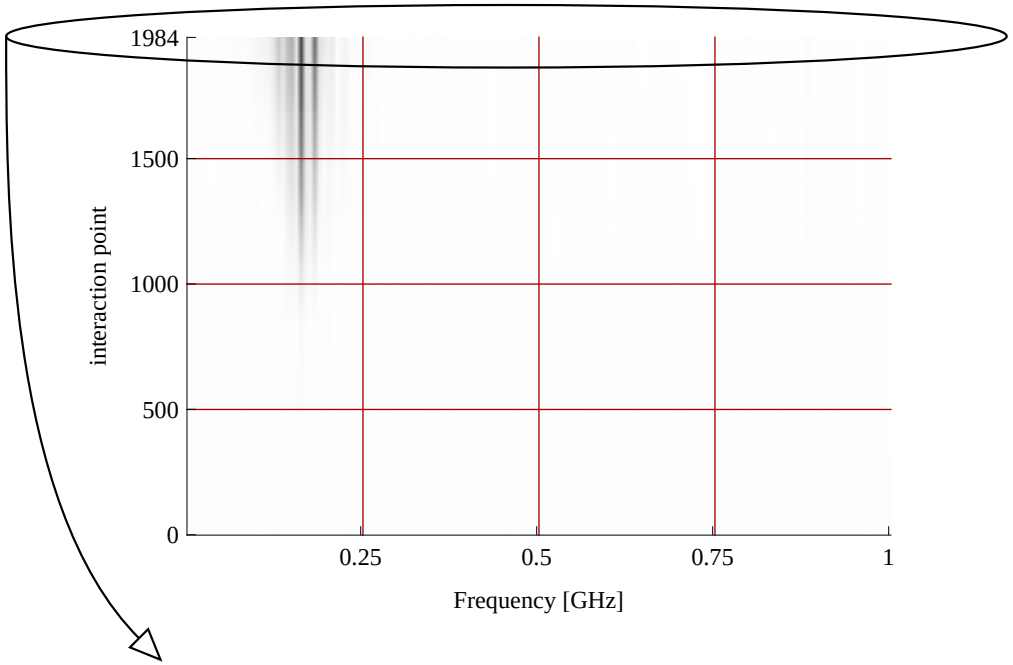

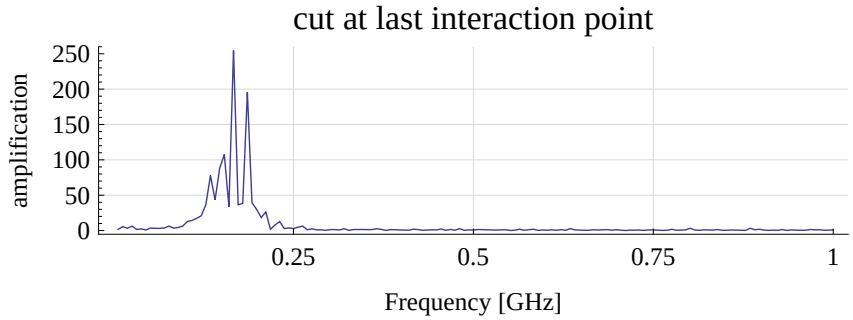

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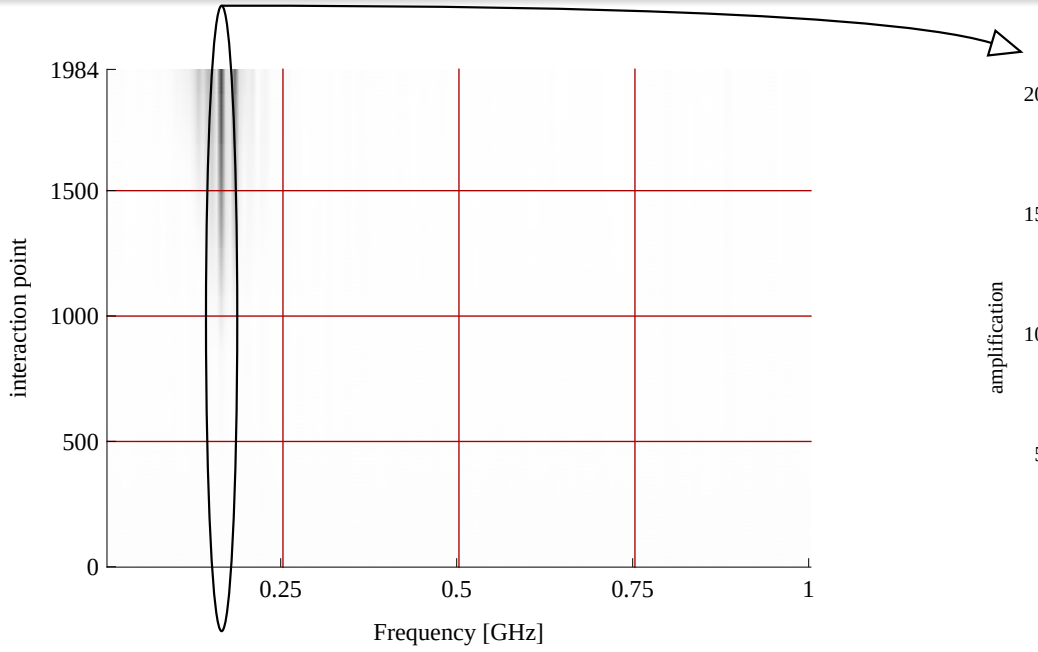
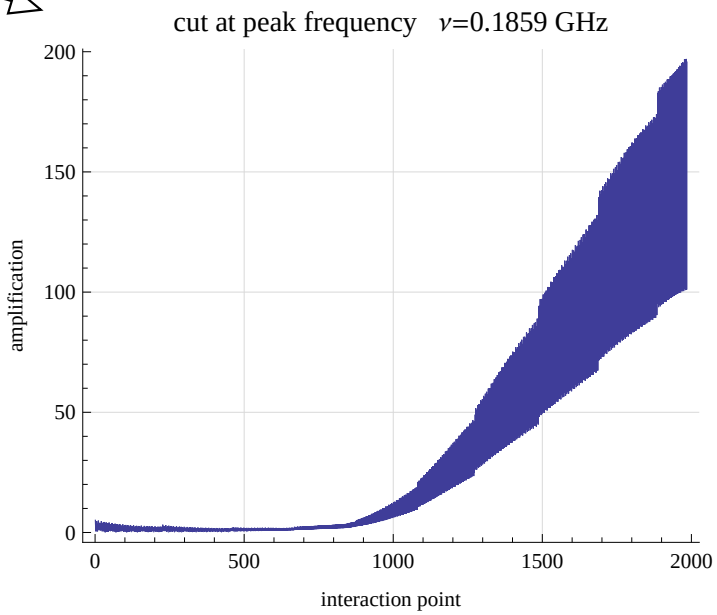
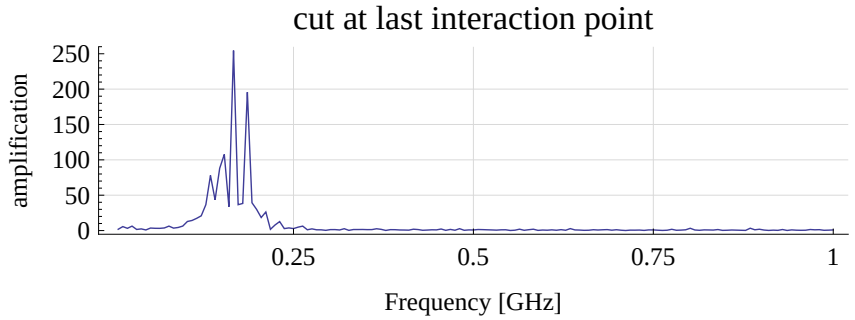


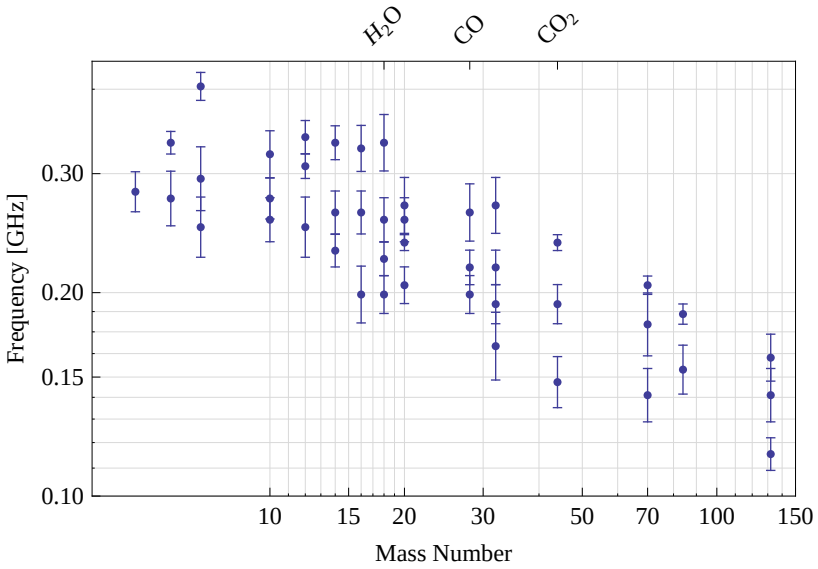




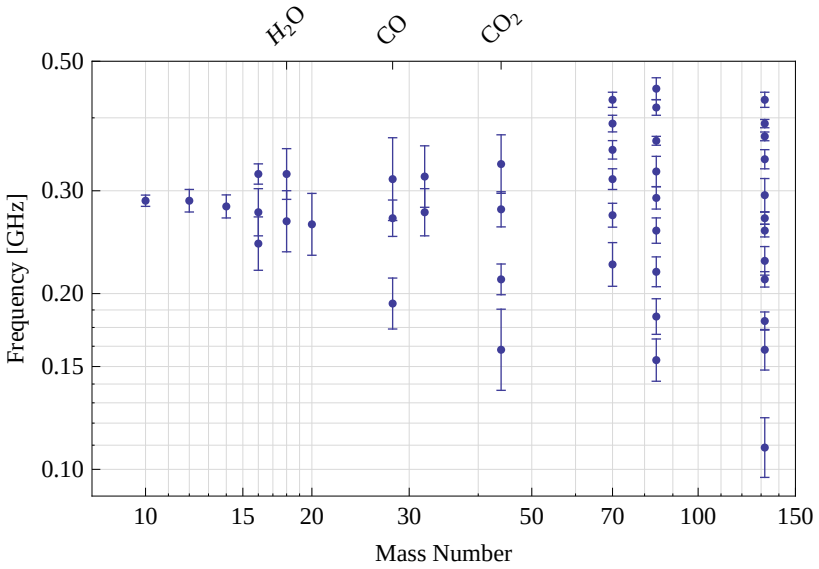
Results

- upcoming unstable resonance frequencies at $A = 5$, clear beam instability from $A = 7$ on (20nTorr)
- frequency peaks from the scanned ion species (cf. ion frequency)

x-plane



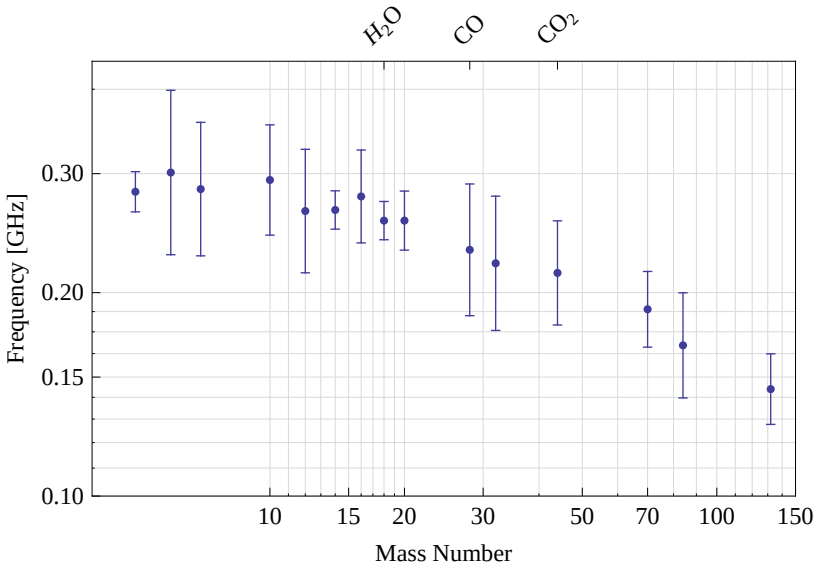
y-plane



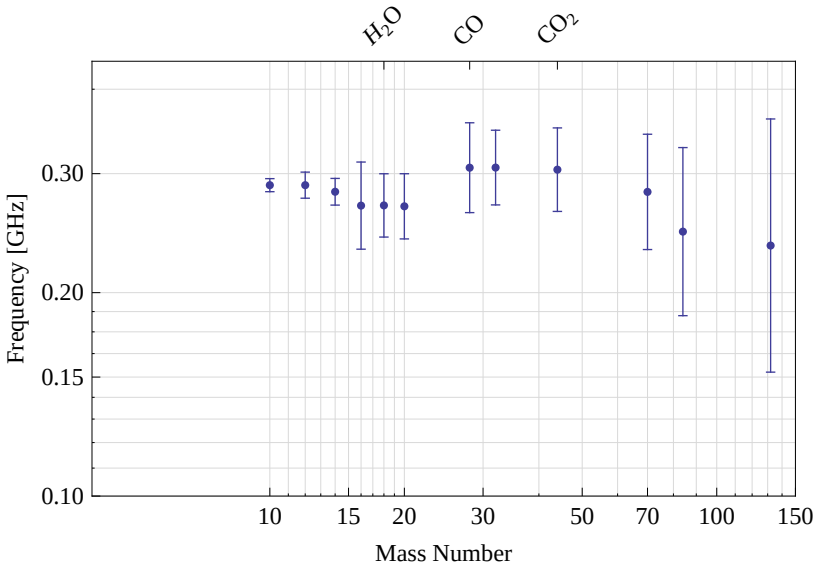
Results

- upcoming unstable resonance frequencies at $A = 5$, clear beam instability from $A = 7$ on (20nTorr)
- frequency peaks from the scanned ion species (cf. ion frequency)
- frequency mean values and standard deviation

x-plane



y-plane



Composition of Vacuum

Three different possibilities for vacuum composition:

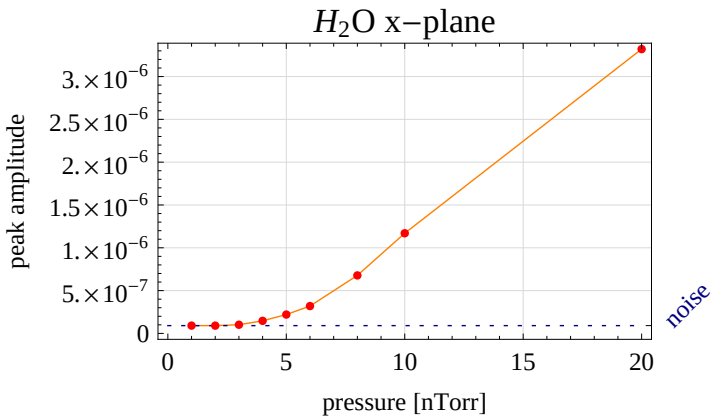
	Unbaked Vacuum	Baked Vacuum	BakedNEG Vacuum
H_2	40%	80%	90%
H_2O	40%	10%	4%
CO	10%	5%	3%
CO_2	10%	5%	3%

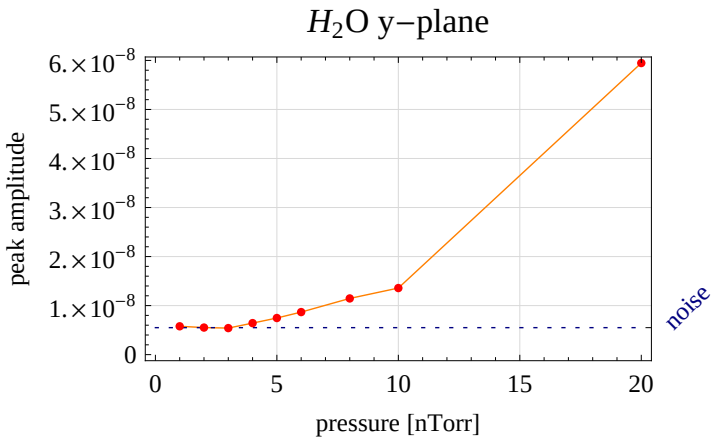
Thanks to S. Calatroni for providing the compositions

Results

- H_2 stable at least until 200nTorr, 2000nTorr is unstable (negligibly high)

Evolution of peak frequency amplitude for H_2O:

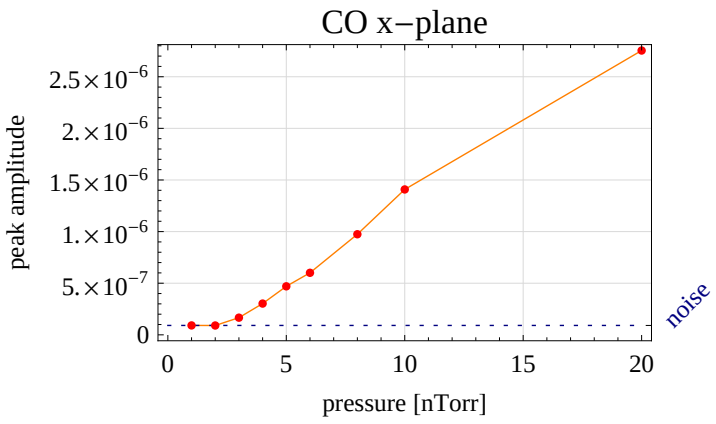


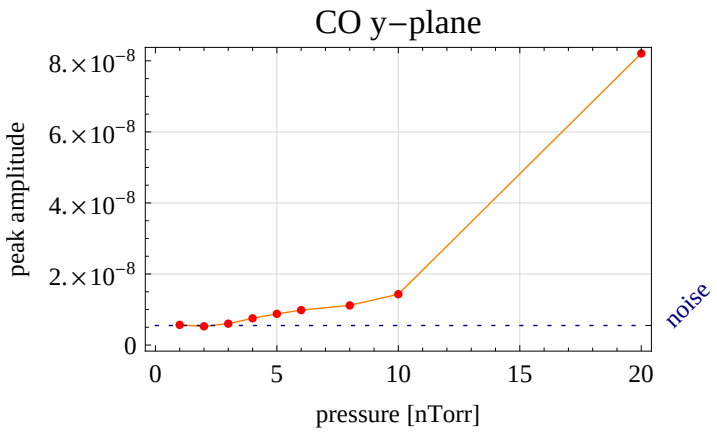


- beam instabilities in both x- and y-plane occur from 4nTorr on

Results

Evolution of peak frequency amplitude for CO:

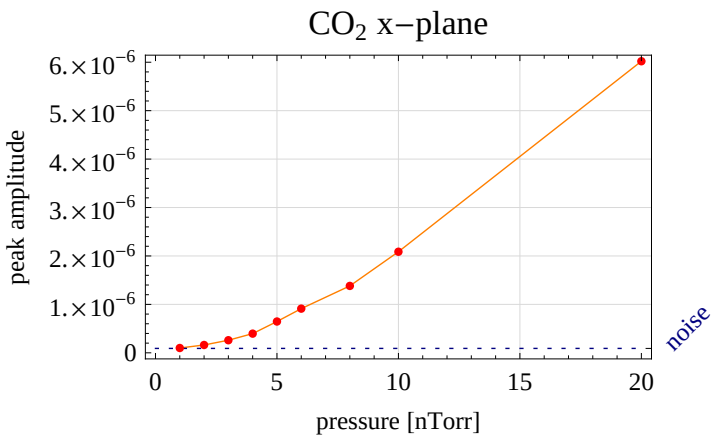


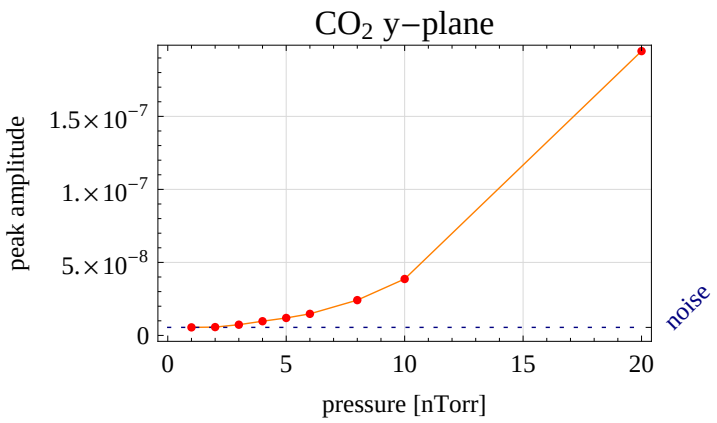


- beam instabilities in both x- and y-plane occur from 3nTorr on

Results

Evolution of peak frequency amplitude for CO_2:





- beam instabilities occur from 2nTorr (x-plane) resp. from 3nTorr (y-plane) on

Summary

- for considerable pressures, beam instabilities occur from $A \geq 5$ on
- ion frequencies range between 0.1 and 0.5 GHz in x- and y-plane
- H_2O becomes unstable from 4nTorr on
- CO becomes unstable from 3nTorr on
- CO_2 becomes unstable from 2nTorr (x-plane) and 3nTorr (y-plane) on

Perspectives

- for combinations of gas species, thresholds could be more relaxed under constant total pressure
- simulations with several ion species (real gas compositions) can be tricky:
  - e.g. for too many H_2 macro-particles, we do not see instabilities at expected pressures compared to simulations without H_2 (due to a numerical problem)
- however, H_2 has no effect on beam $\Rightarrow$ leave it aside (fix total pressure and consider only rest parts of realistic gas composition)