University of Sheffield

Gas Gains Over 10^4 in Low Pressure SF_6 with a Novel Multi-Mesh ThGEM for Directional Dark Matter Searches

8th CYGNUS Workshop on Directional Recoil Detection

Slade Lecture Theatre, School of Physics, University of Sydney, NSW, Australia
11-15/Dec/2023

A.G.McLean
ali.mclean@sheffield.ac.uk

14/Dec/2023

SCAN ME

Overview

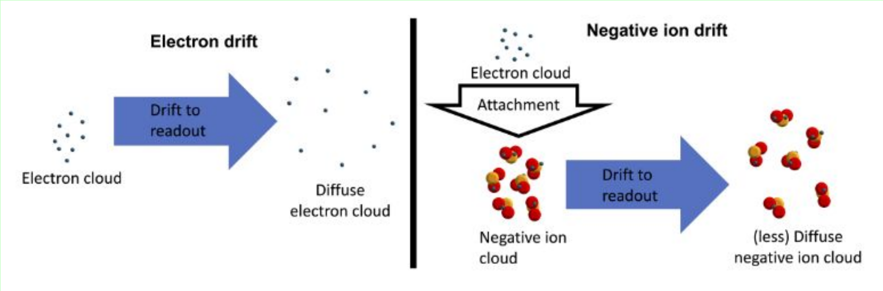
1. Motivation
2. Experimental Setup
3. Calibration Against CF_4 Signals
4. Comparison to Previous Work
5. Field Strength Optimisation
6. Fully Optimisation Run
7. Conclusions

1. Motivation

Why use SF_6 gas?

Pros!

- Fluorine content - possible improvement in WIMP cross section
- Electronegative/Negative Ion Drift (NID) gas
- Not toxic! - previously CS_2 was used as a NID gas but it is toxic



Con...

Very difficult to produce significant gas gains with…

Electron must first be stripped from the NI before amplification can occur

Limits sensitivity of detector to low energy recoils

How can we improve SF_6 gas gain?

Often a single amplification stage device is not sufficient for charge amplification in NID gas SF_6

Several studies have shown that multi-stage amplification is often required

Double/Triple GEM structures might not be the best solution as charge can be lost during transfer between successive GEMs

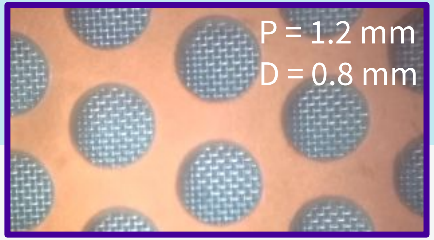
Positive ion backflow can be detrimental

Uniform fields can be beneficial for charge amplification

Ideal charge amplification device?

1. Single "stand-alone" device
2. Multistage amplification
3. Suppression of positive ion backflow
4. Uniform fields

Two stage Multi-Mesh ThGEM (MMThGEM)



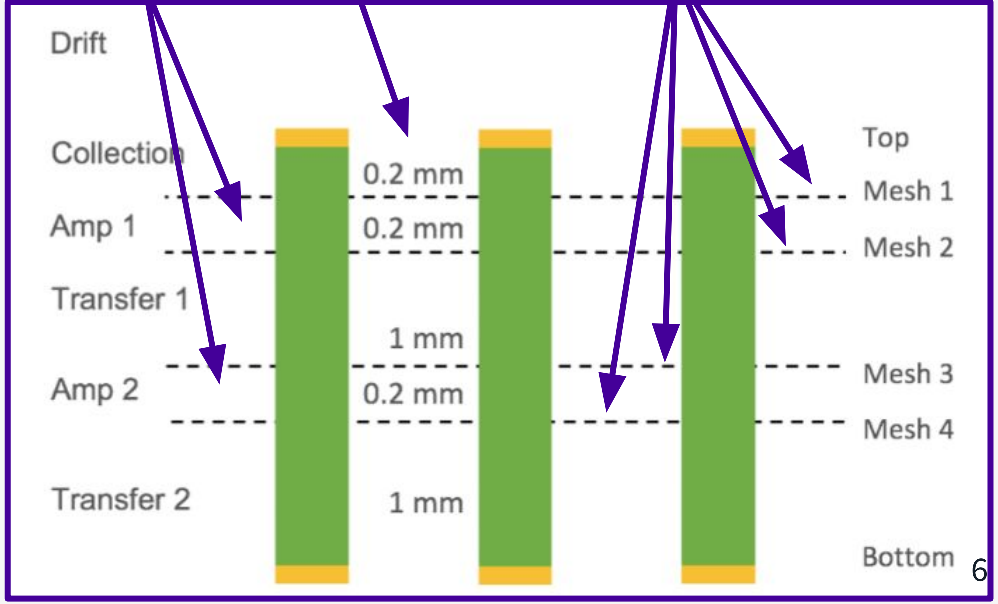
Ideal charge amplification device?

1. Single "stand-alone" device✅
2. Multistage amplification✅
3. Suppression of positive ion backflow✅
4. Uniform fields✅

Charge is only collected once

Charge is amplified twice

Meshes provide uniform fields and suppress positive ion backflow



2. Experimental Setup and Method

Experimental Setup

MMThGEM mounted to acrylic base with 1cm standoff

Cathode mounted 3cm above MMThGEM

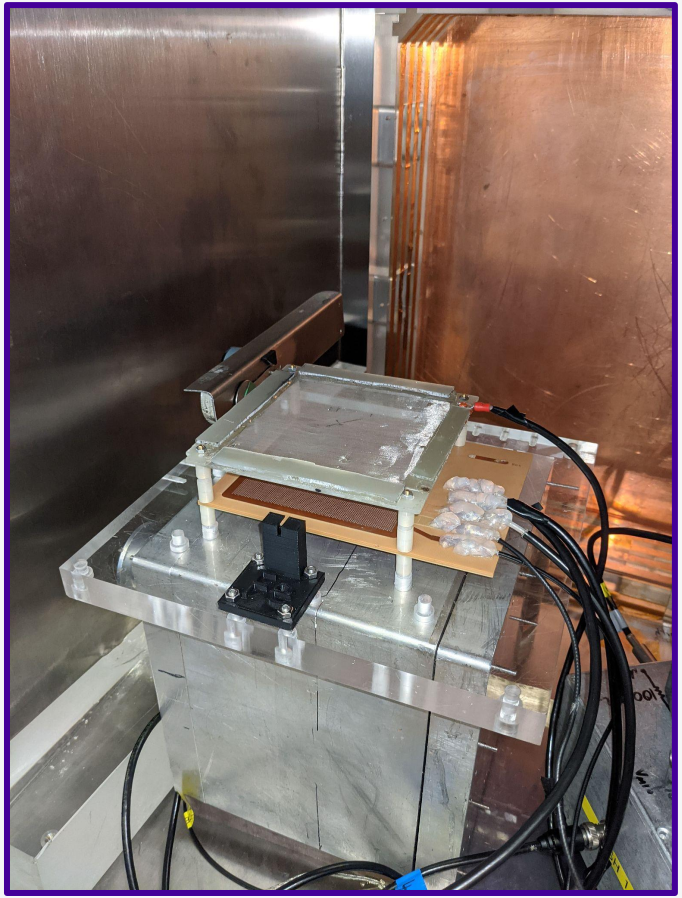
3D printed source holder mounted to acrylic to ensure repeatable exposure

All electrodes biased according to biasing circuit diagram

Signals monitored on M2 and measured on M4

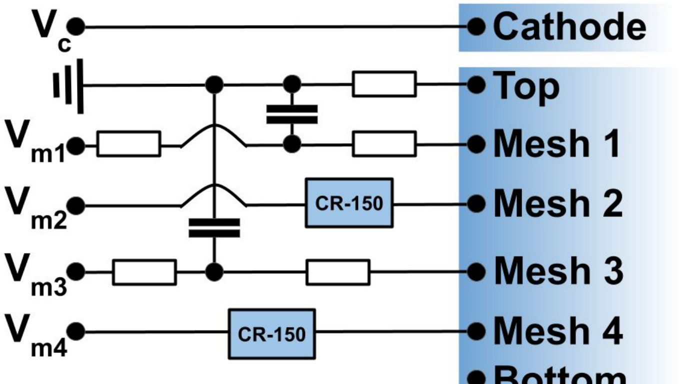
Preamp output connected to shaper externally

Shaper output connected to labview script which records all waveforms in full



HV Biasing Circuit

- Cathode biased with -ve HV supply
- MMThGEM top grounded
- M1 and M3 biased via an RC circuit to reduce capacitive coupling
- M2 and M4 biased via the HV line of CREMAT CR-150 board



Resistors and capacitors are 200 MΩ and 10 nF respectively

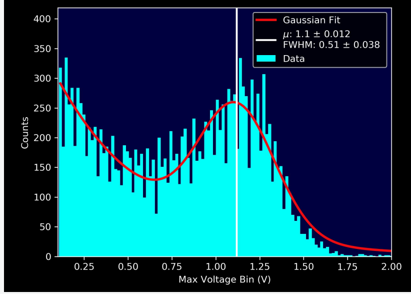
3. Calibration Against CF_4 Signals

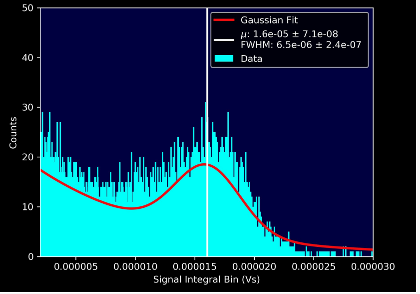
CF_4 Calibration Run

Standard signal amplitude method is suitable for electron drift gases but less appropriate for NID gases

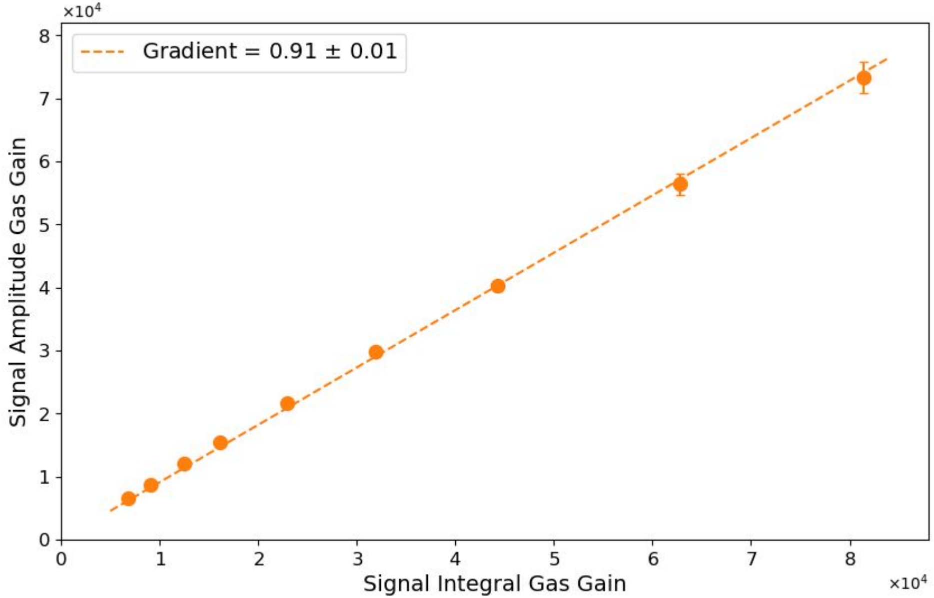
One suitable method for NID gases is signal pulse integration - (Simpson method above a threshold)

Here we calibrated the two methods against each other with well understood electron drift gas CF_4





V_c = -300 V, V_{m1} = 100 V, transfer field 1 = 500 V/cm, and Amp fields = 18500 - 22500 V/cm (increments of 500 V/cm)



Signal amplitude and integral methods did not produce the same gas gain

Integral method provided slight overestimate of the gas gain

Re-calibrate the integral method against the signal amplitude method in order to avoid an overestimate

4. Comparison to Previous Work

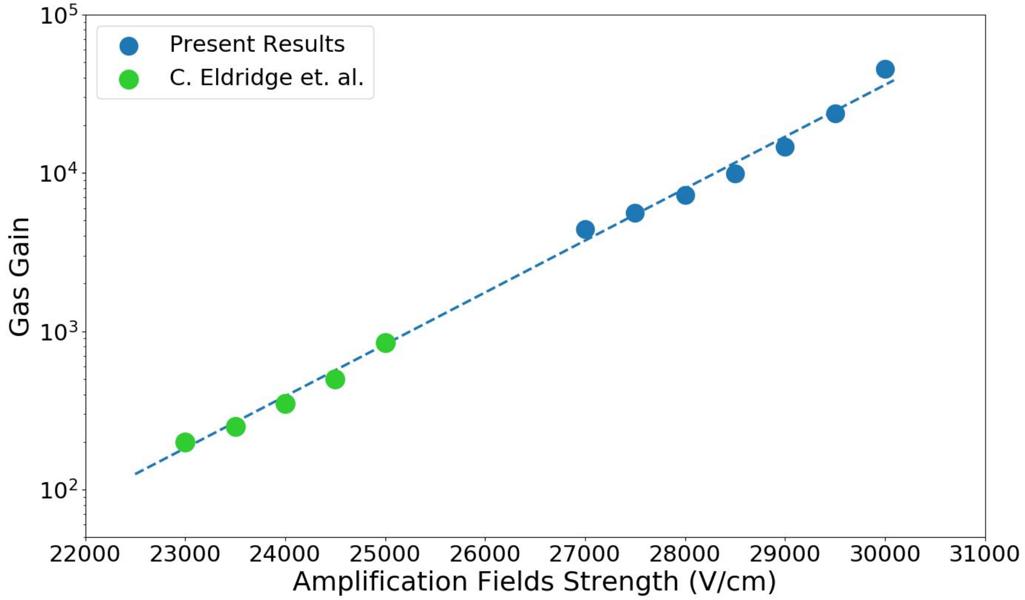
Comparison to Previous Work

V_c = -500 V, V_{m1}= 30 V, and transfer field 1 = 600 V/cm

Previously the MMThGEM was used to amplify charge in low pressure 20, 30, and 40 Torr of SF_6

The device was previously not pushed to its sparking limit in 40 Torr of SF_6 due to ringing phenomena observed at lower pressures

In the present results, similar field strengths were applied to the device and it was pushed to its sparking limit



- Exponential curve was fitted to present results and extrapolated down to lower amplification field strengths..
- Provides good agreement with previous measurements!
- Maximum stable gas gain ~45000
- Ringing effect could be suppressed as pressure increases?

5. Field Strength Optimisation

Collection Field Optimisation

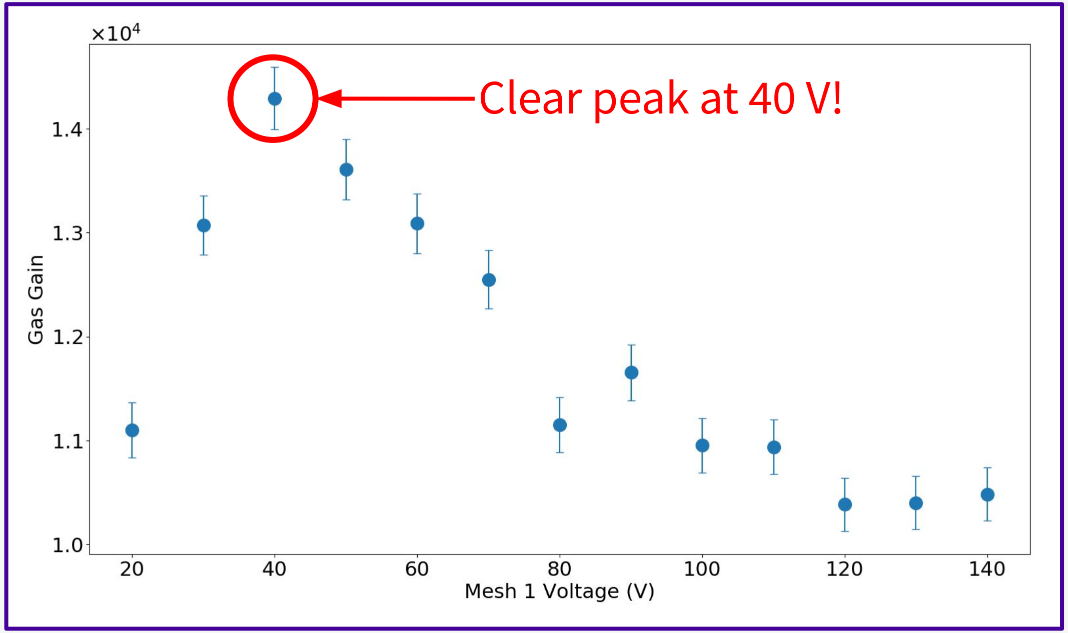
Collection field isolated and varied from 20 V to 140 V

Gas gain increases as M1 voltage increase until 40 V

Clear peak observed at 40 V

Gas gain decreases as M1 increase above 40 V

V_c= -500 V, amp fields = 29000 V/cm, and transfer field = 600 V/cm



Transfer Field Optimisation

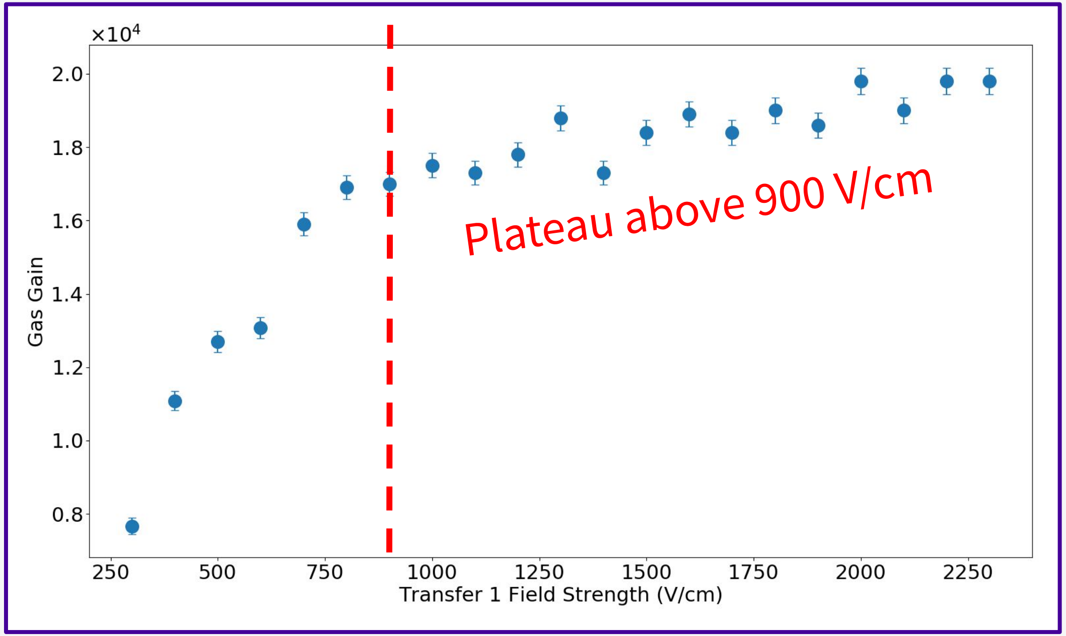
Transfer field isolated in similar fashion and varied from 300 V/cm to 2300 V/cm in increments of 100 V/cm

Gas gain significantly increases with increasing field strength up to 900 V/cm

Plateau observed above 900 V/cm

900 V/cm chosen as optimum transfer field strength

V_c = -500 V, V_{m1} = 30 V, and amp fields = 29000 V/cm



6. Fully Optimised Run

Fully Optimised Run in SF_6 - Gas Gain

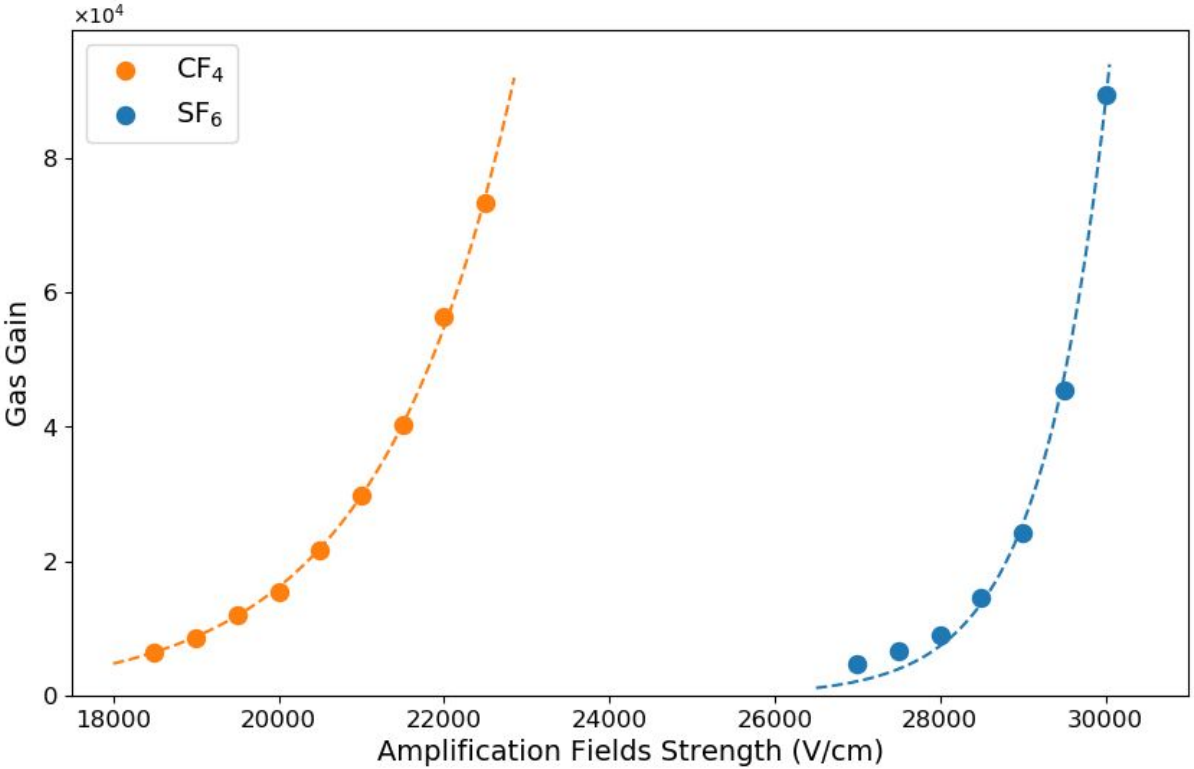
With the collection and transfer fields now optimised, the amplification fields were increased in tandem

Gas gains ranging from 4700 to 89300 were observed!

Some of the highest gas gains ever achieved in low pressure pure SF_6

Beneficial for low energy recoils in the context of a directional DM search

V_c = -500 V, V_{m1} = 40 V, and transfer field = 900 V/cm



Fully Optimised Run in SF_6 - Energy Resolution

Energy resolution also evaluated

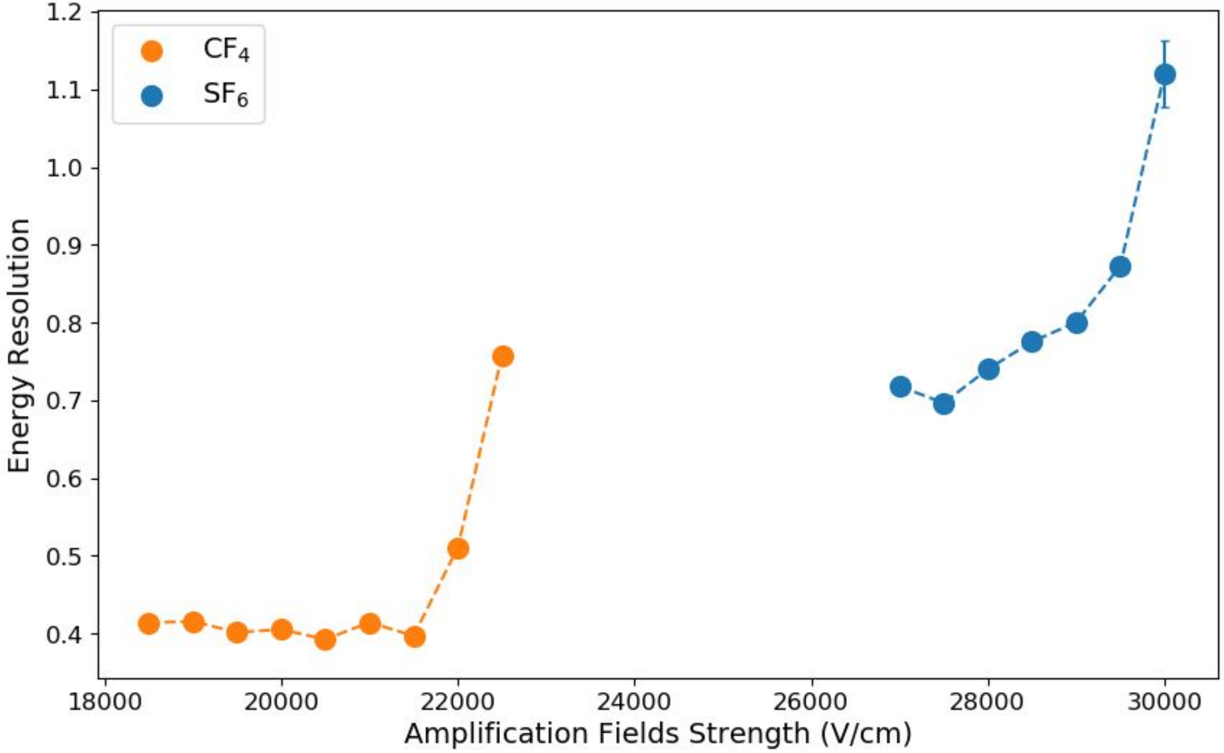
Worst energy resolution found in CF_4 is comparable to the best energy resolution found in SF_6

CF_4 ER ranges from 0.392 to 0.758

SF_6 ER ranges from 0.696 to 1.12

ER could benefit from a similar optimisation procedure…

V_c = -500 V, V_{m1} = 40 V, and transfer field = 900 V/cm



7. Conclusion

Conclusions

The NID gas, SF_6, has favourable properties for future directional dark matter searches however charge amplification is a limiting factor

The two stage MMThGEM has several favourable properties which could aid charge amplification in low pressure SF_6

Building on previous work, the MMThGEM was able to reach gas gains in SF_6 around ~ 45000

The devices collection and transfer fields were isolated and optimised for gas gain

The fully optimised device was tested and compared to the CF_4 calibration run and found to be comparable to CF_4 and achieved a maximum gas gain of ~90000

These gas gain are some of the largest gas gains ever seen with a NID gas and offer significant improvement for low energy recoils in the context of directional DM search

The energy resolution in the device in SF_6 was poor compared to CF_4

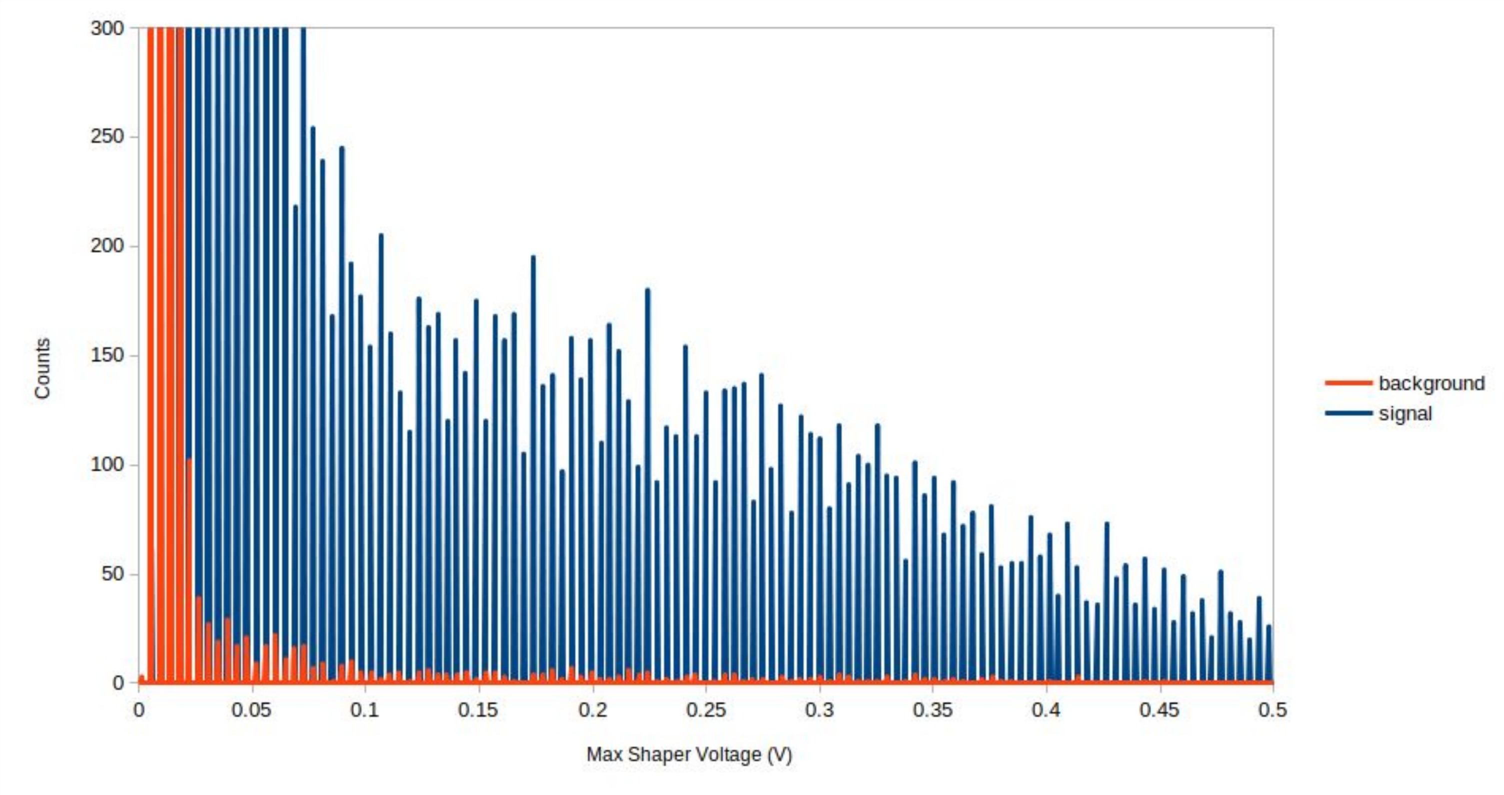
Thank you for your attention

Any questions?

SCAN ME

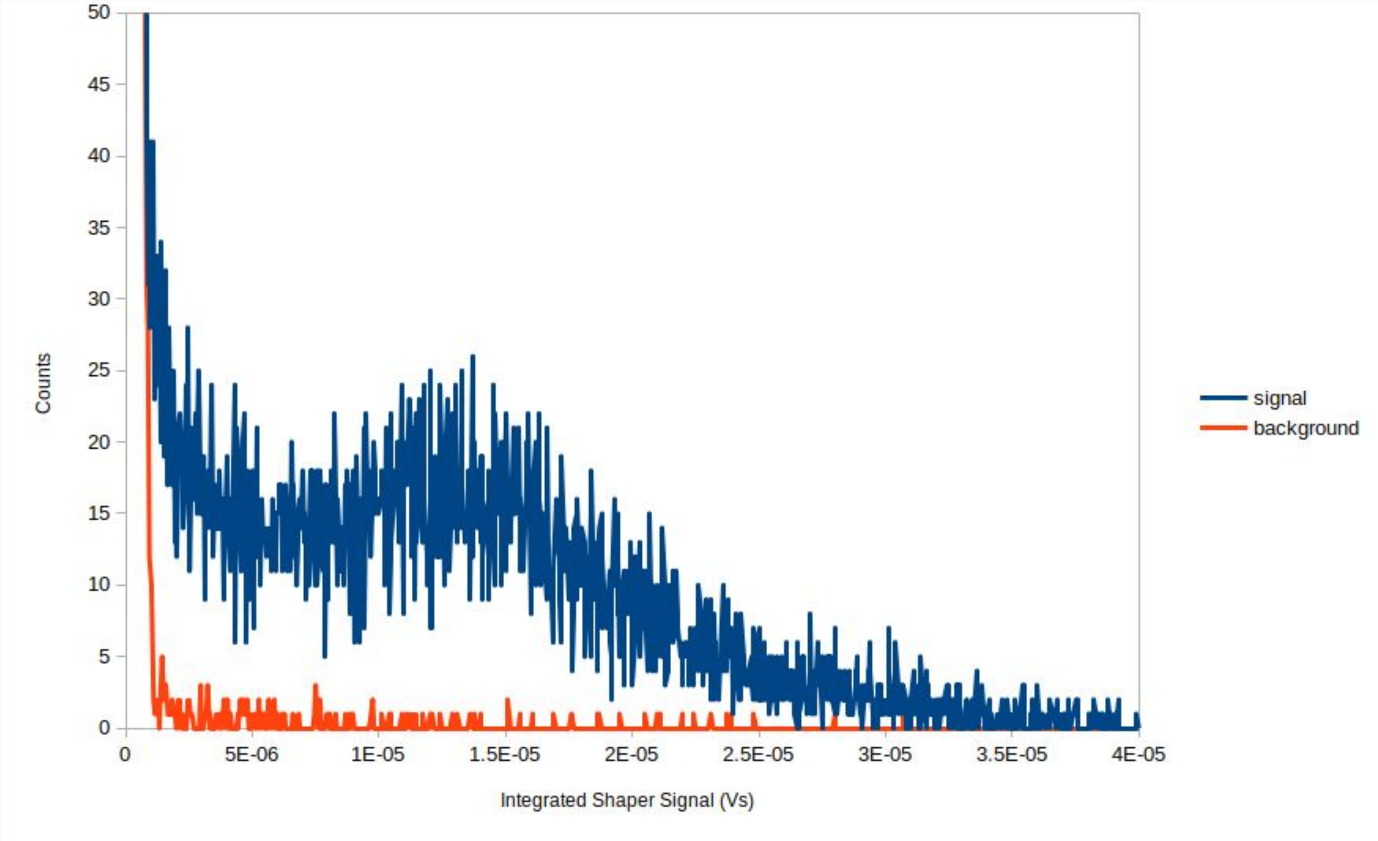
Additional Slides

Fe^{55} Spectrum using Max Voltage



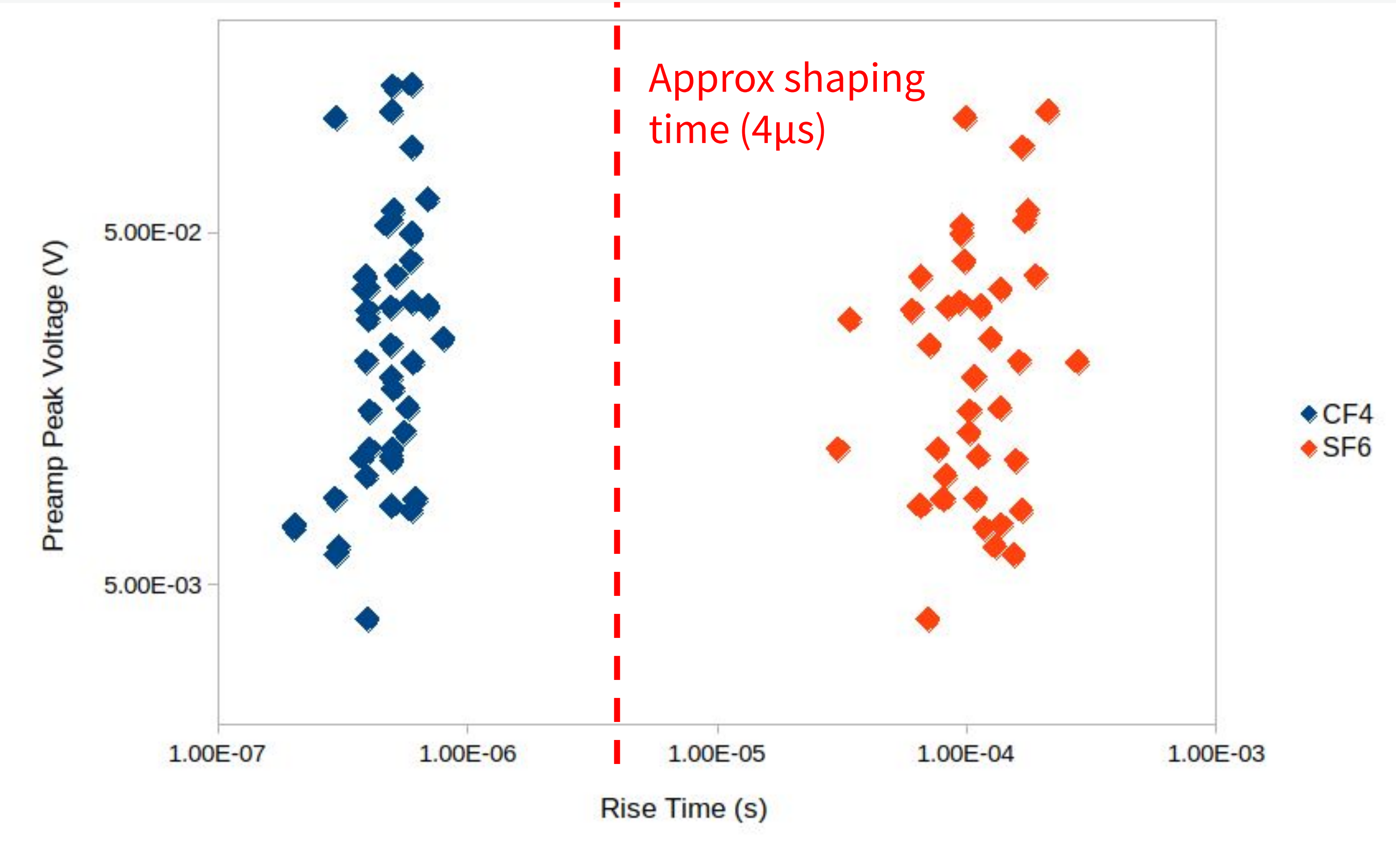
Biasing scheme -> c = -500 V, M1 = 30 V, M2 = 620 V, M3 = 680, M4 = 1270

Fe^{55} Spectrum using Integrated Signal

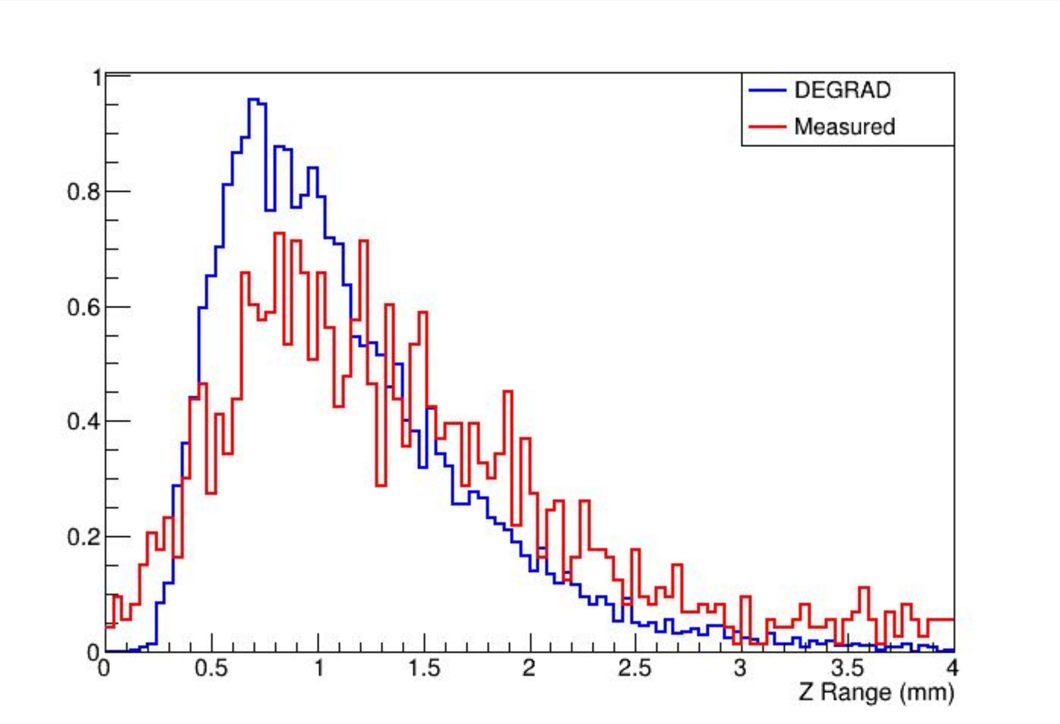


Biasing scheme -> c = -500 V, M1 = 30 V, M2 = 620 V, M3 = 680, M4 = 1270

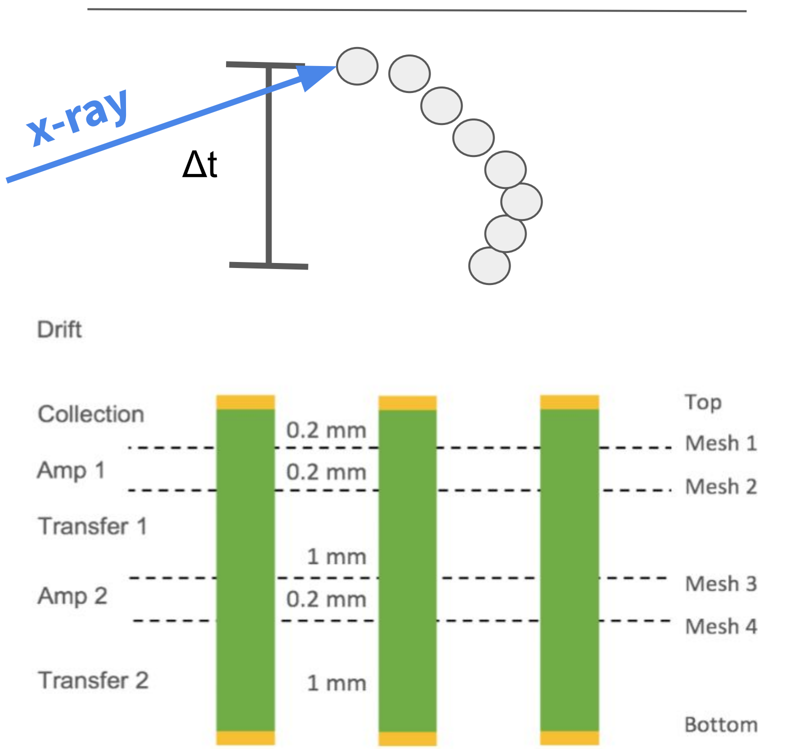
Difference in Preamp Rise Time



Rise Time (z-range calculations/simulations)

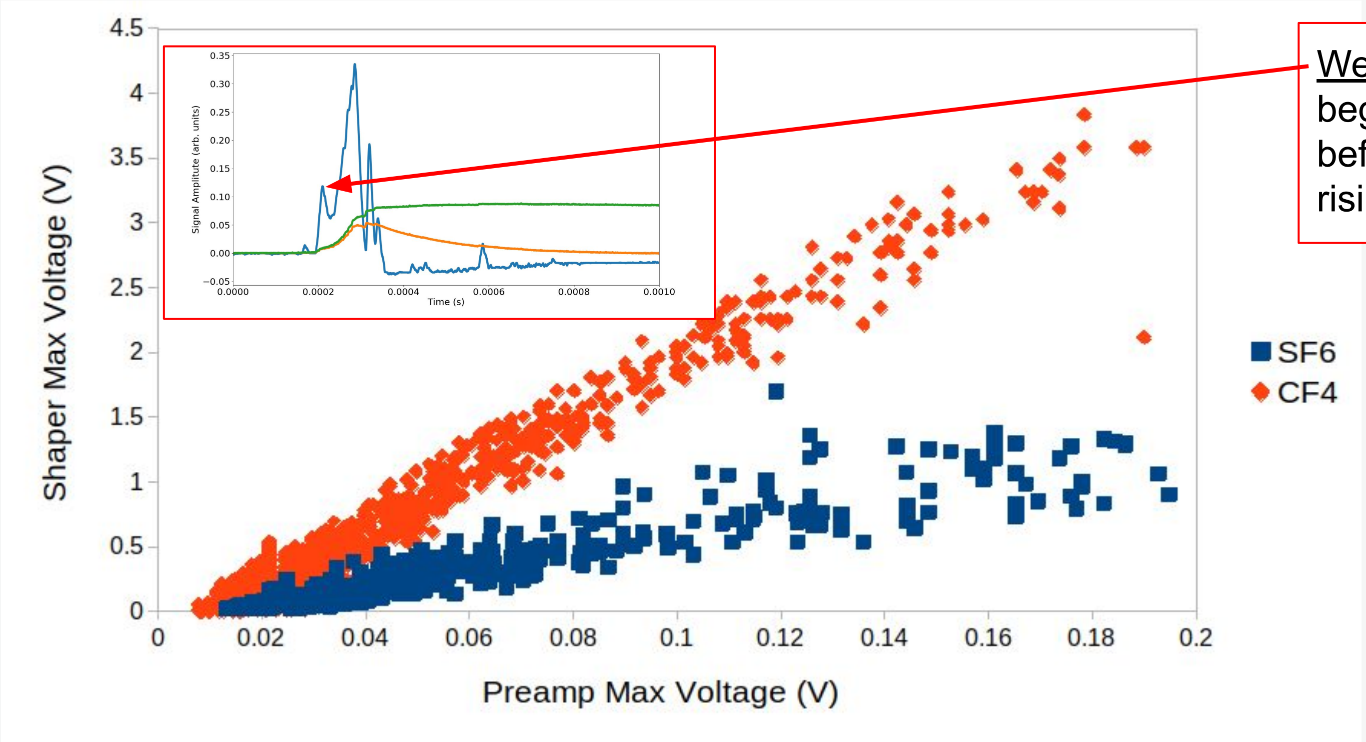


Simulations (adjusted for diffusion) agree with measured z-range



Δt = rise time of preamp (10-90%)

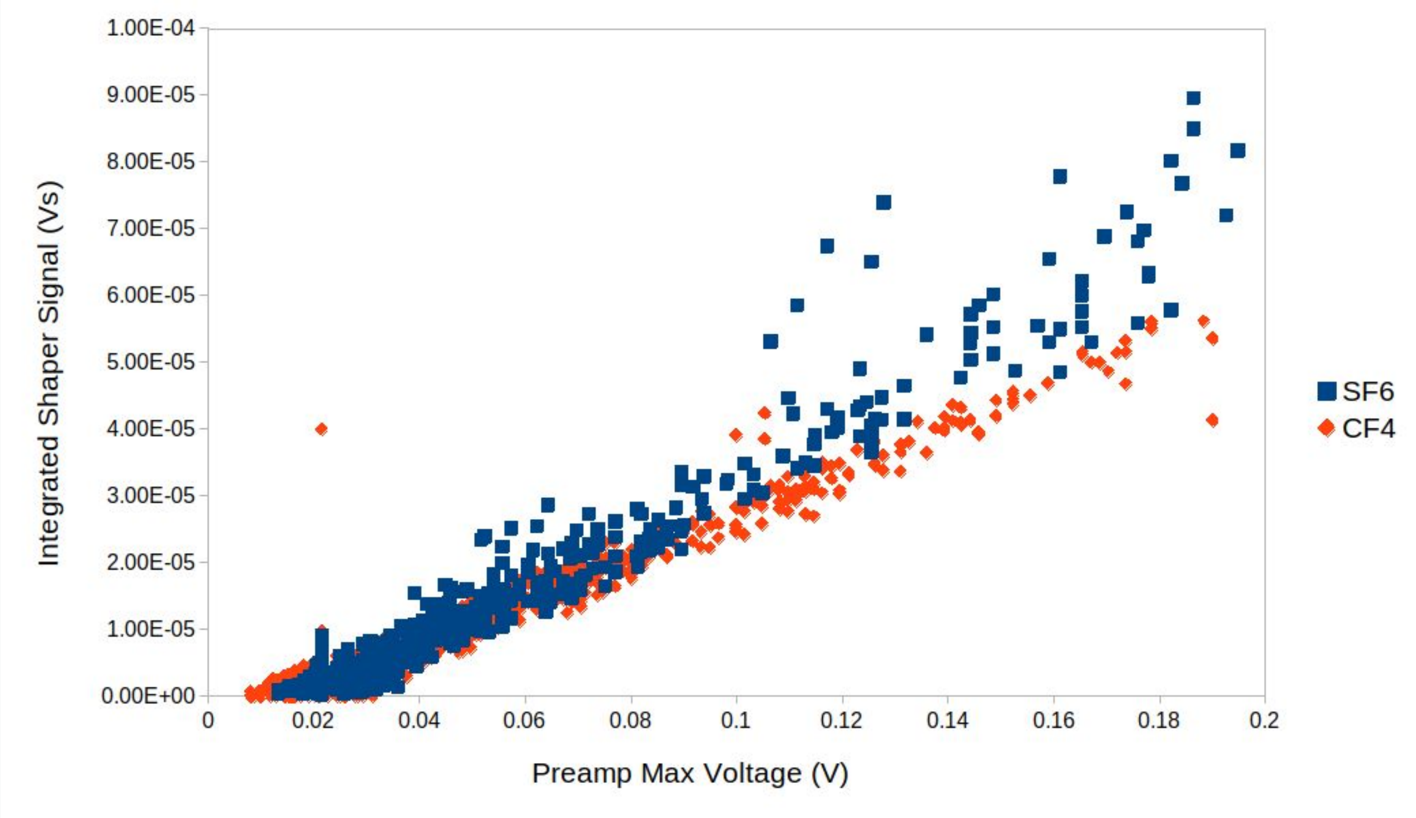
Electronic Gain - Max Voltage of Shaper Signal



We see this here! The shaper begins integrating the signal before the preamp stops rising!

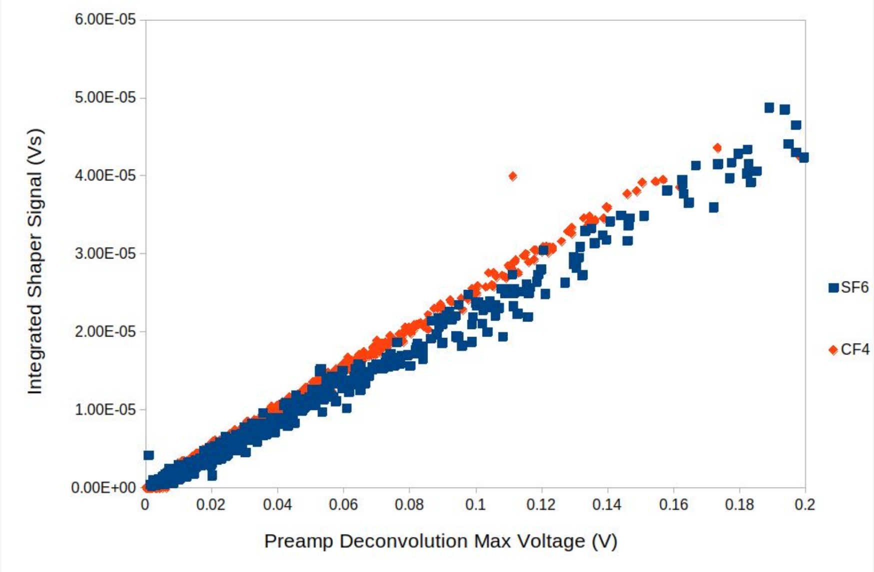
- The electronic gain (amplitude of shaper/amplitude of preamplifier) is not the same for both gasses.
- Smaller for SF_6 but still approximately linear.
- Gradient for CF_4 is 20.95 and 4.69 for SF_6.
- This is because the rise time is longer than the shaper time.

Electronic Gain - Integrated Shaper Signal



- Using the integral method - the electronic gain between the two gases is much more comparable
- Linear regression gives a gradient of 0.0003 s and 0.0004 s - much better agreement
- Still a bit of a discrepancy and larger spread at higher preamp voltages
- Likely an artifact of the decay time of the preamp

Integrated Shaper Signal vs Preamp Deconvolution Signal



By accounting for the decay time of the preamplifier the agreement at larger preamp signals improves.

Gradient CF_4= 0.00025

Gradient SF_6 = 0.00023

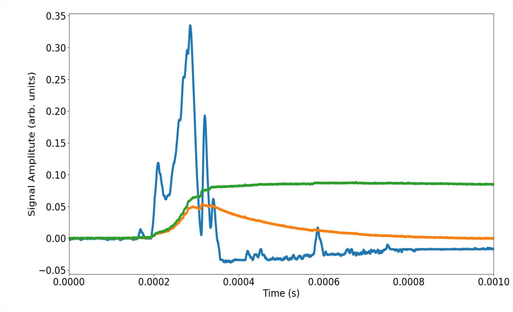
Deconvolution Algorithm

$$V_i^{rec} = \begin{cases} V_i^{av}, & i = 1, \\ V_{i-1}^{rec} + V_i^{av} - V_{i-1}^{av} \times \exp(-\Delta t/\tau), & i > 1. \end{cases}$$

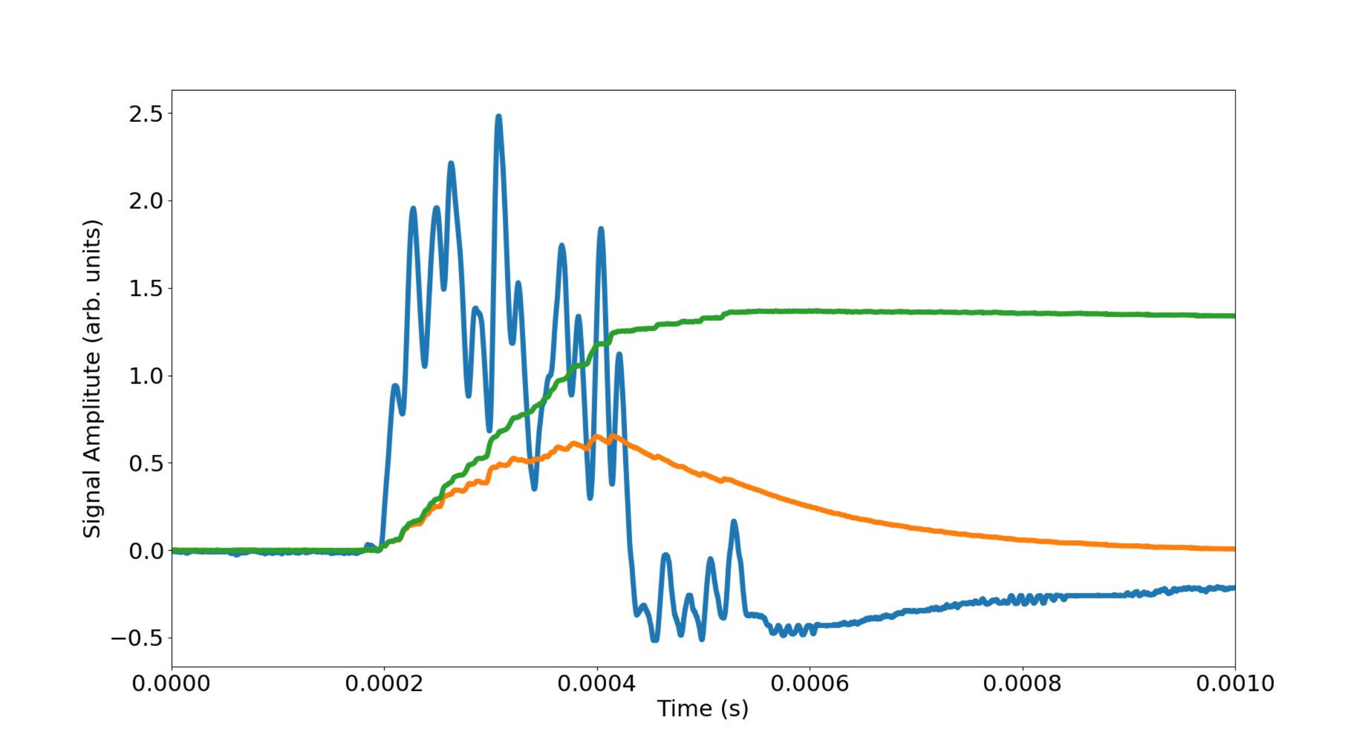
https://arxiv.org/pdf/1508.04295.pdf

The deconvolution algorithm calculates cumulative charge from the preamp signal.

It essentially removes the losses due to the decay time of the preamp.

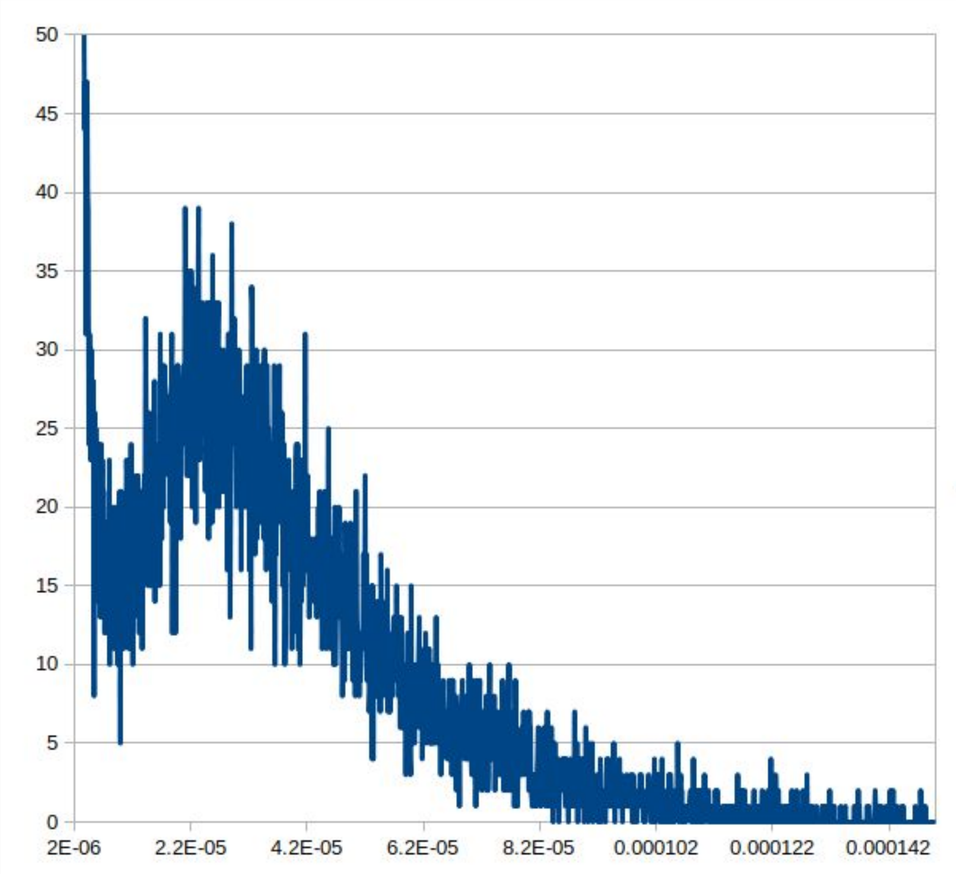


Self Regulating Ringing Events at Largest Amplification Fields



Ringing event found in amp field = 30000 V/cm run - returns to baseline without intervention.
At higher field strengths, ringing events do not return to baseline without intervention.

Spectral Skewing at Largest Amplification Field Strengths

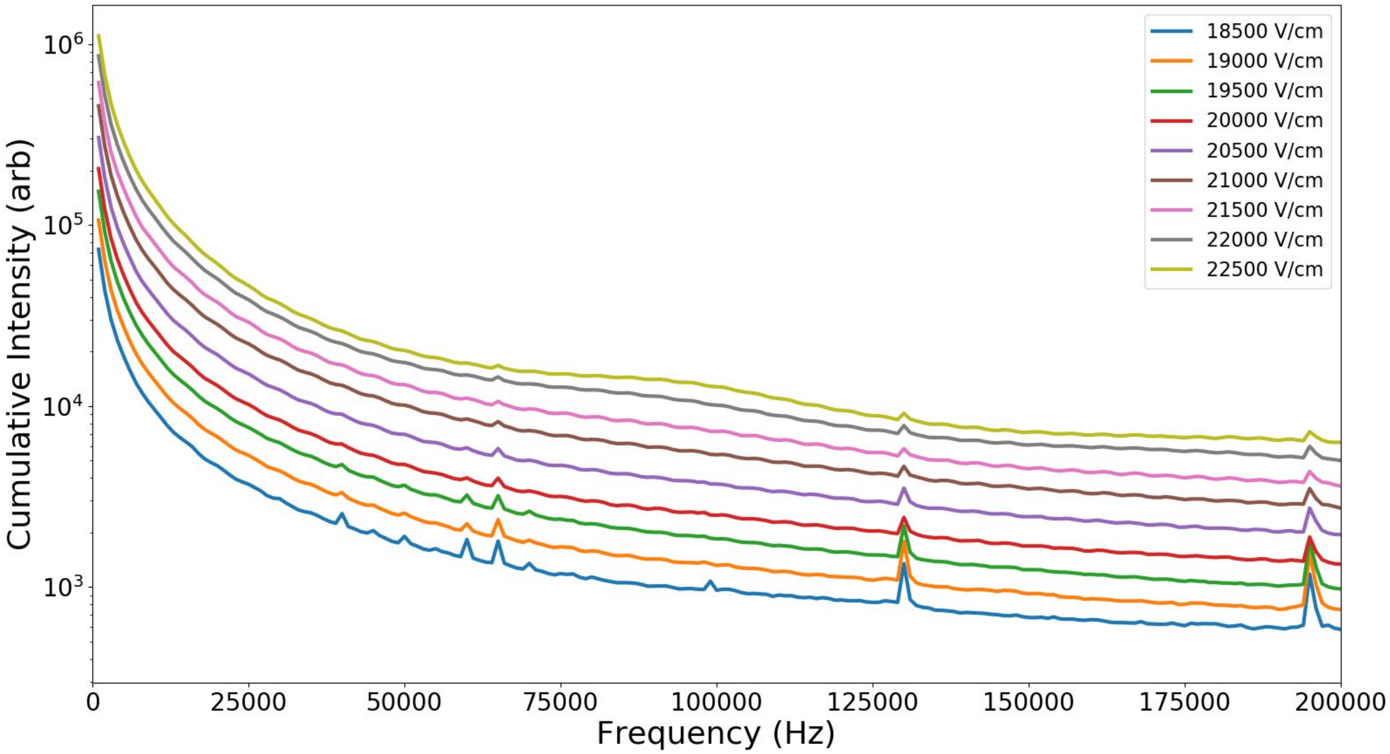


RHS skewing of gaussian spectrum

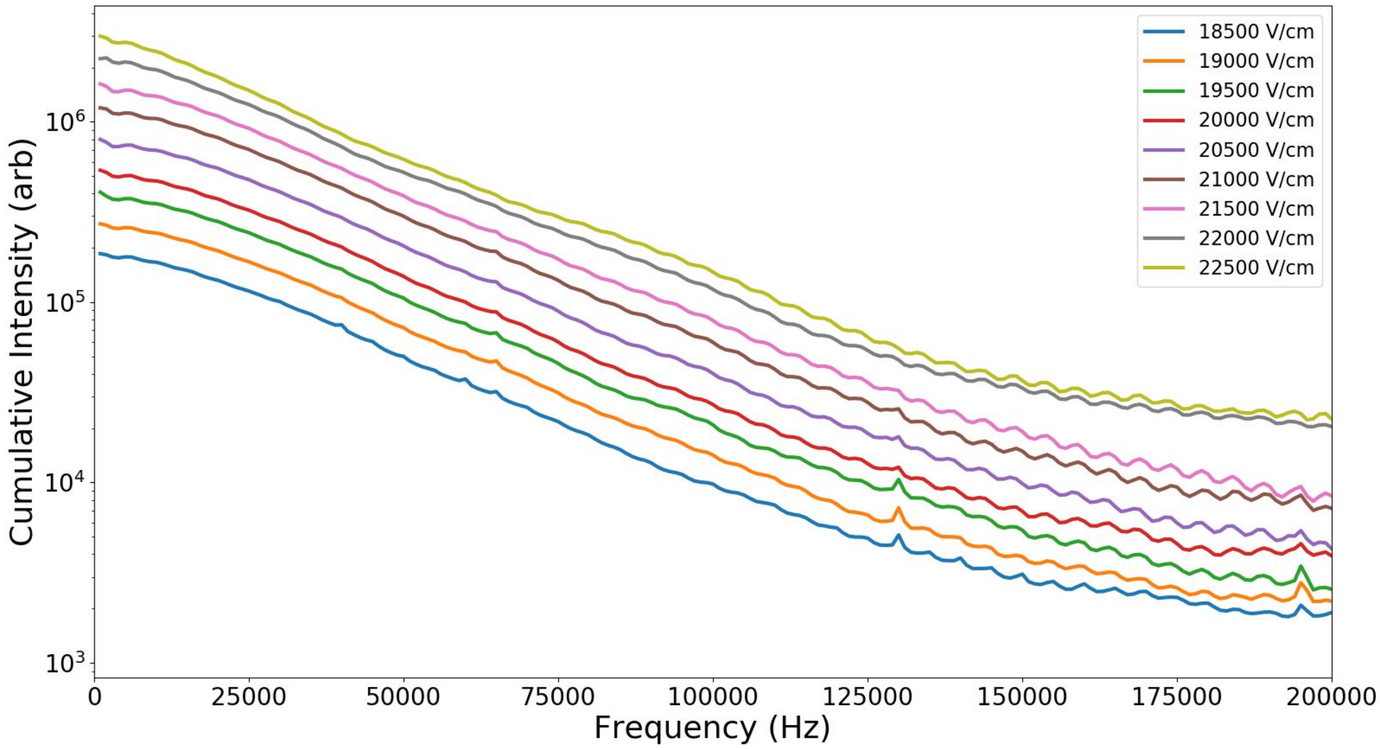
Caused by a minority of ringing events which populate the RHS of the gaussian

Ringing caused by positive ion backflow

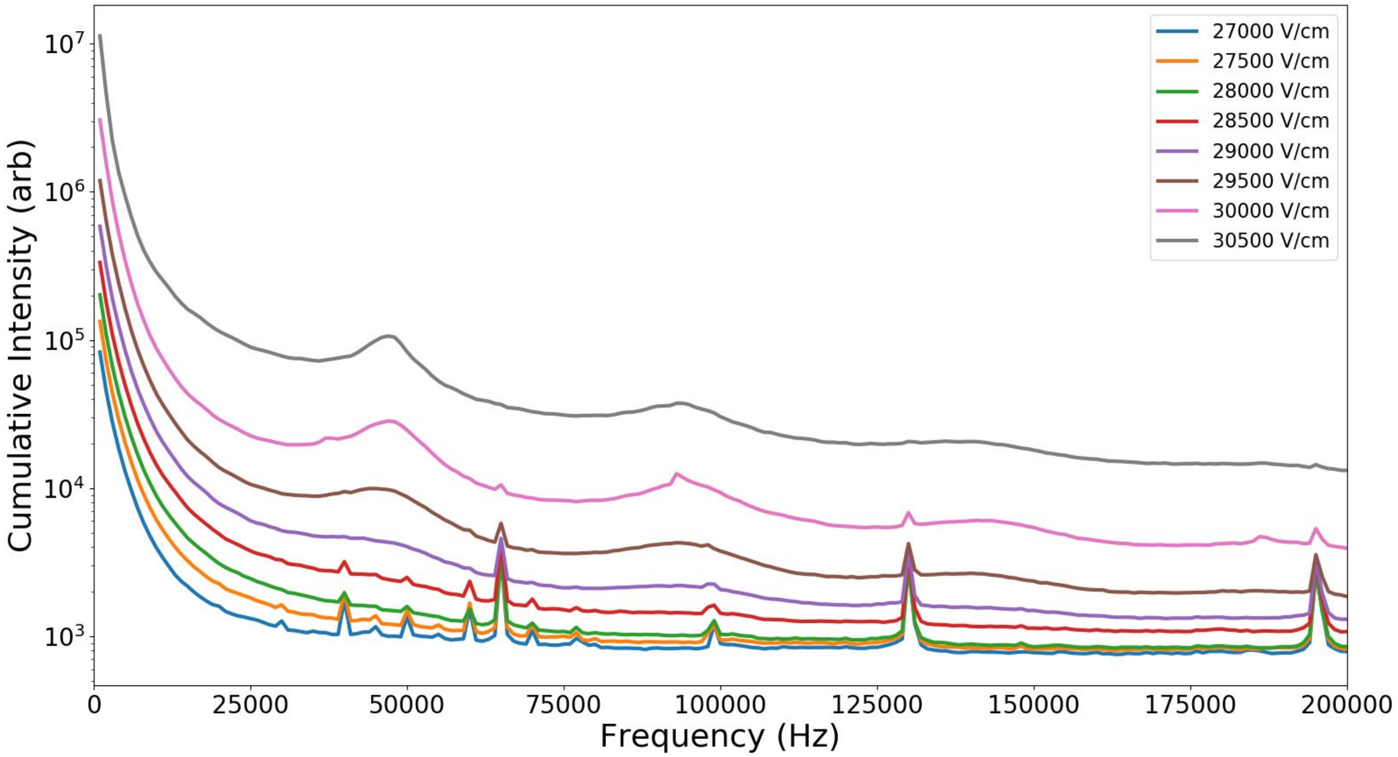
Ringing Analysis CF_4 Preamp



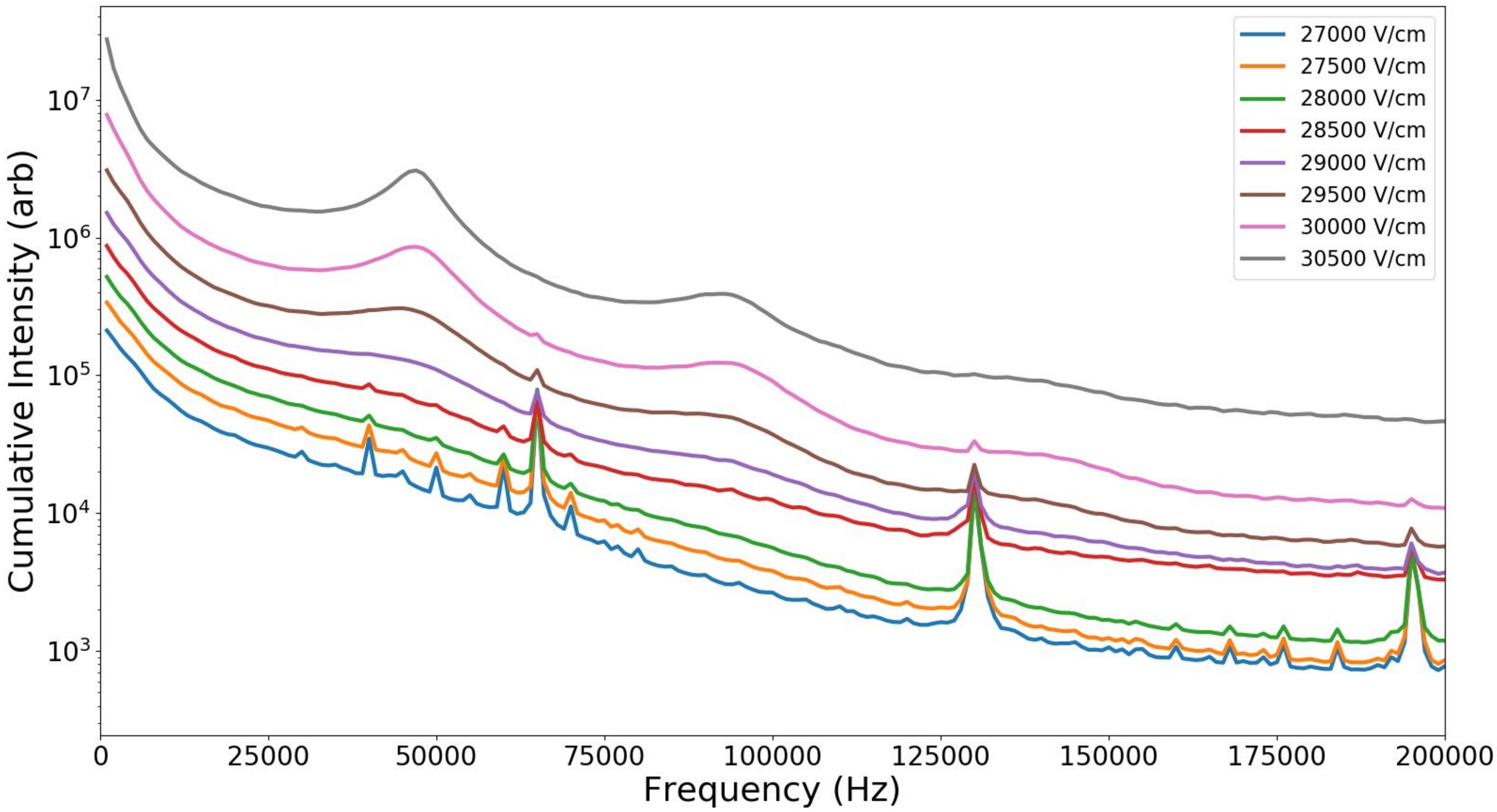
Ringing Analysis CF_4 Shaper



Ringing Analysis SF_6 Preamp



Ringing Analysis SF_6 Shaper



SF_6 Ringing Analysis (+ve Ion Backflow)

- Peaks observed in larger amplification field strengths.
- First peak observed at 47000 ∓ 1000 Hz.
- Second peak observed at 94000 ∓ 1000 Hz.
- Transfer field = 900V/cm -> SF6- ions t = 1mm/90630mm/s and 2t = 2/90630 s => corresponding frequency = 90630/2 Hz = 46170 ∓ 1312 Hz or 46000 ∓ 1000 Hz
- GOOD AGREEMENT WITH RINGING HYPOTHESIS!
- Not all pulses exhibit ringing, this suggests that the skewing observed in spectra of larger amplification fields is likely caused by increase in the number of ringing events, this however does not affect the position of the photo peak and therefore the gain measurements are still valid.
- The fact that the peaks are also observed in preamp frequency spectrum confirms that the peaks are not an artifact of the shaper integration time.