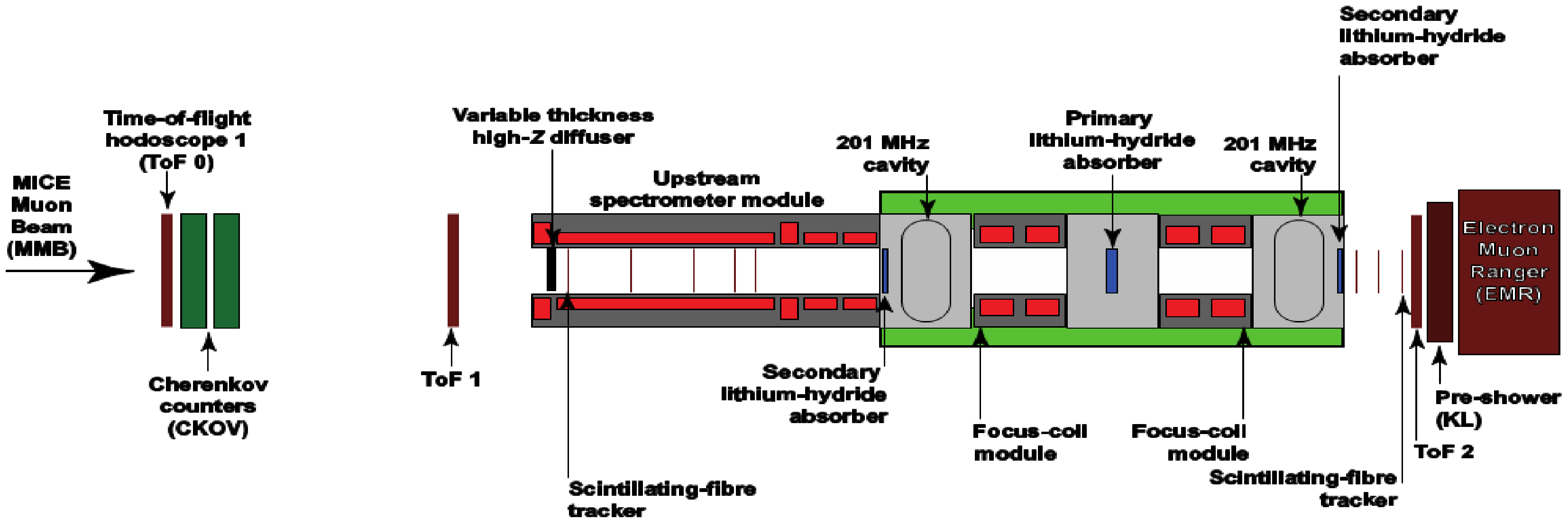
MICE RF Drive and Diagnostics

The MICE RF team

MICE High Power RF system: Requirements

- MICE High Power RF system
  - Two cavities, driven by ONE RF power amplifier- 2MW output
    - Estimated gradient 7.2 MV/m
      - Allowing for realistic LLRF overhead and losses
  - 1st Amplifier proven and installed @ RAL(triode stage remains installed)
  - Cavity proving complete @ MTA
    - At much higher gradients (up to 14.3MV/m)
    - Cavity performance risk enormously mitigated
  - Cavity construction in hand @ LBNL

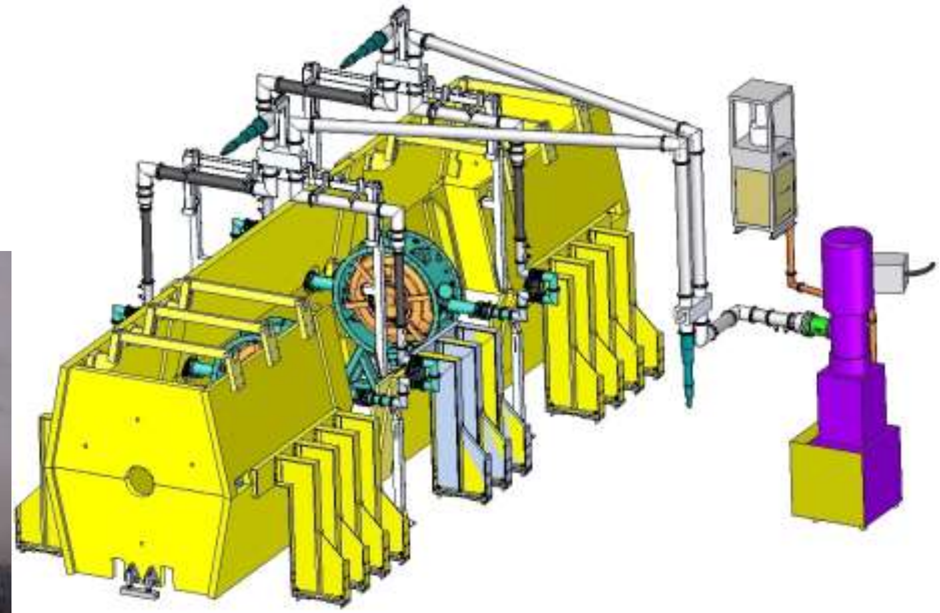


Status Summary

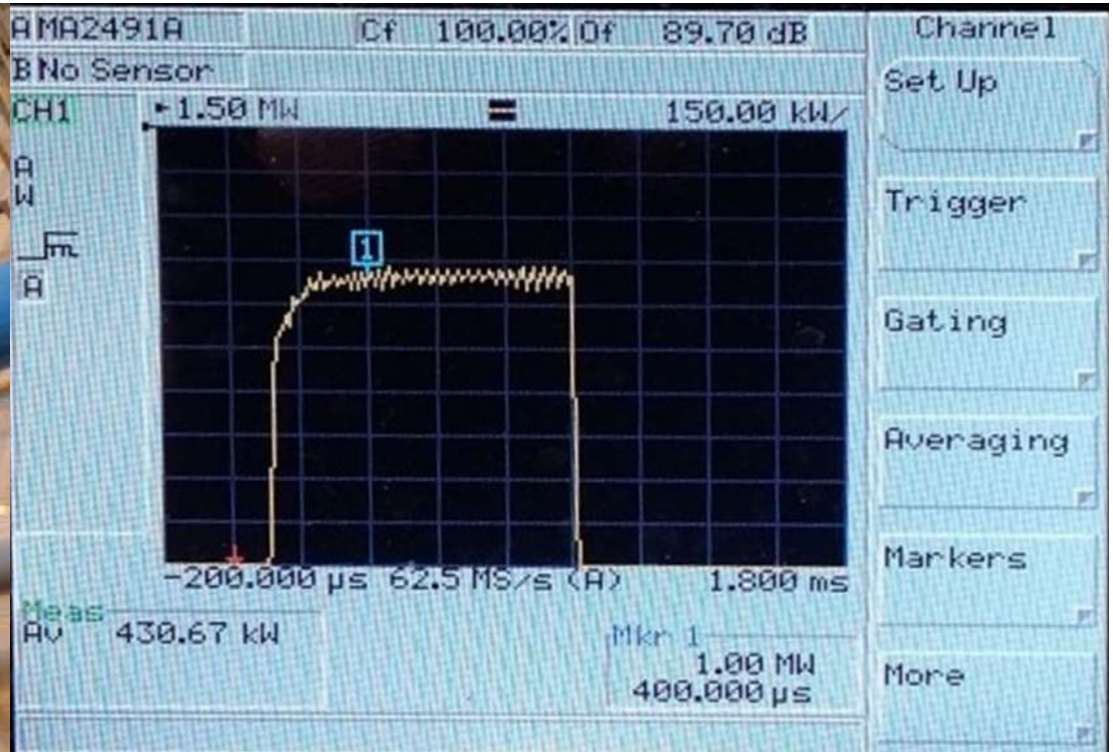
- RF Funding halted summer '16
  - Limited opportunities to advance this year
  - Some work completed before 'halt' order, others work as risk mitigation
- Distribution network
  - Components assembled into distribution network at DL
  - Components delivered to RAL from DL for installation
  - Adapted from components procured under NSF-MRI for earlier configuration
- Status of RF drive system
  - Triode No. 2 under test, started mid March
    - Exploiting 1st tetrode, and upgraded No. 1 modulator racks
    - Triode achieved 1MW using ex-ISIS valve (close to limit of valve)
    - Modulator/RF glitches noted when tetrode > 50kW into triode
    - These are now understood
  - Interface channels for RF controls defined
    - Work underway to complete control crates (DL subcontracted work)
  - LLRF system demonstrated on ISIS debuncher (at low power)

RF Distribution Network

- Must Support 2MW in 6” line and 500 kW in 4” line with full reflect
  - 4” lines rated to 1.12MW at 1 atmosphere in dry air
  - Therefore will be pressurised by N_2 (with slow ramp) or SF_6 or gas
    - Will be treated as pressure vessels
  - Some of the 6” and 4” line from the NSF MRI procurement modified
  - All components/devices will be drawn from the NSF procured stock
  - Calibration components procured
  - Distribution network components now at RAL

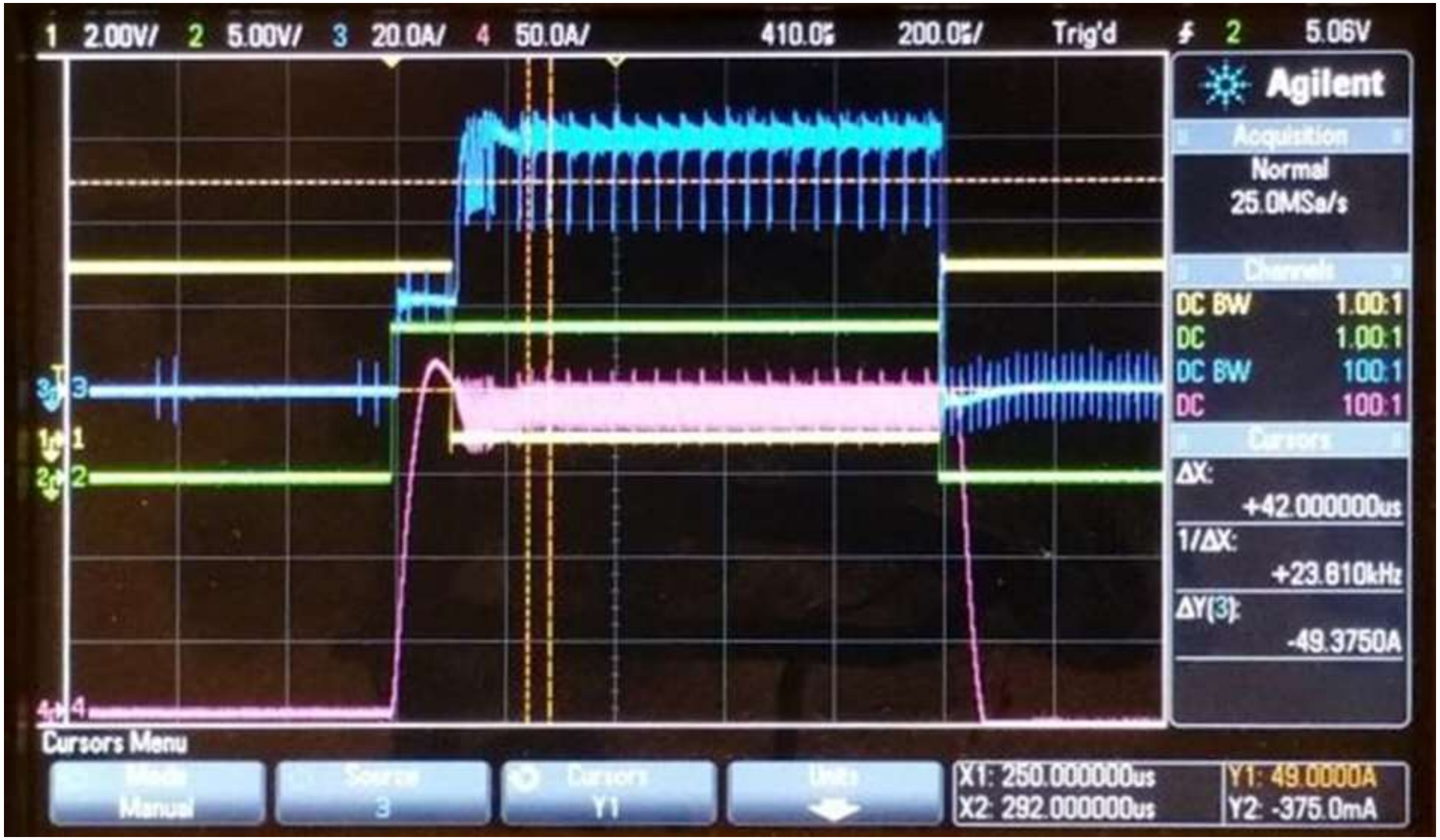


RF Drive Systems



- 1st Modulator set and Tetrode recommissioned at Daresbury
- 2nd Triode is under test
  - 1MW achieved using ex ISIS triode valve at 25kV
  - η: 57%, Gain: 8.6 dB, Tetrode: 136kW, η: 52%, Gain: 19 dB
  - Triode input return loss 11.5 dB
  - At MICE duty and pulse duration

RF Drive System

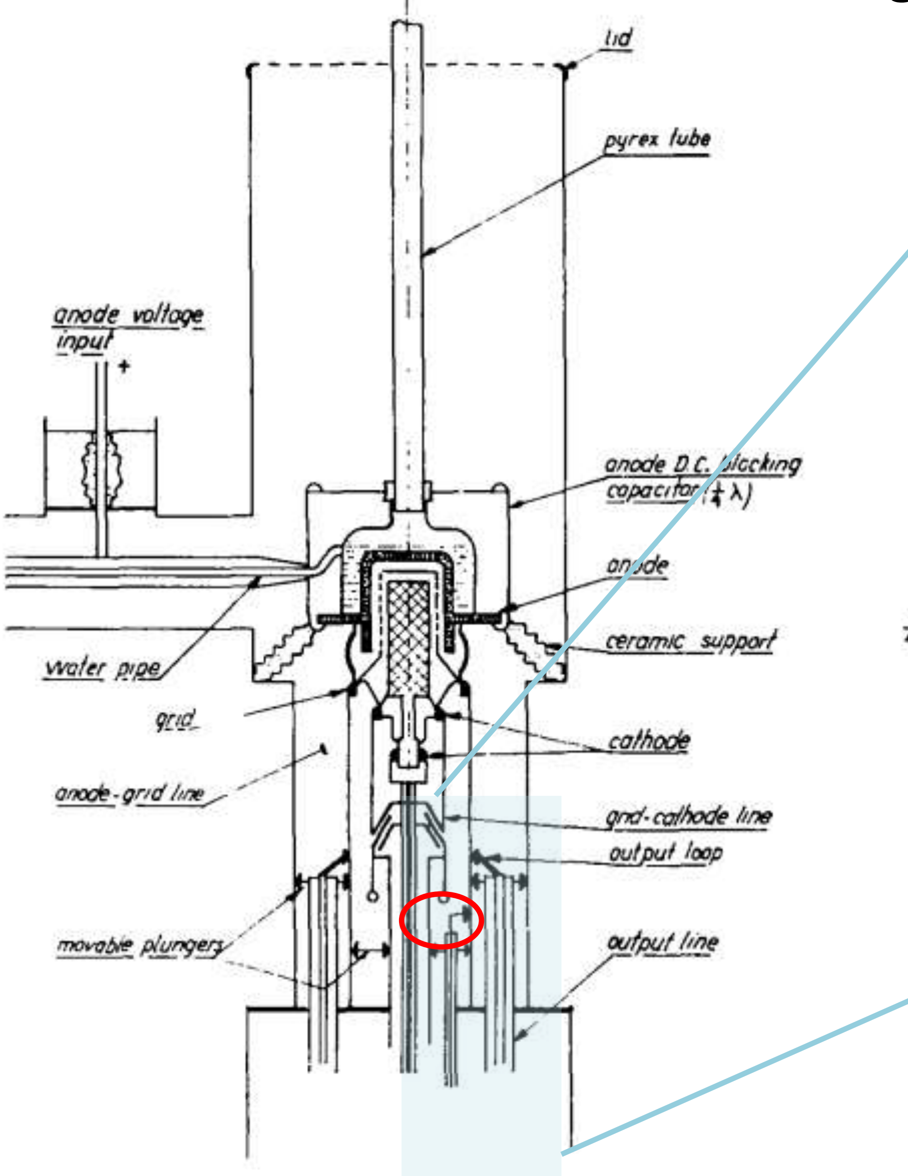


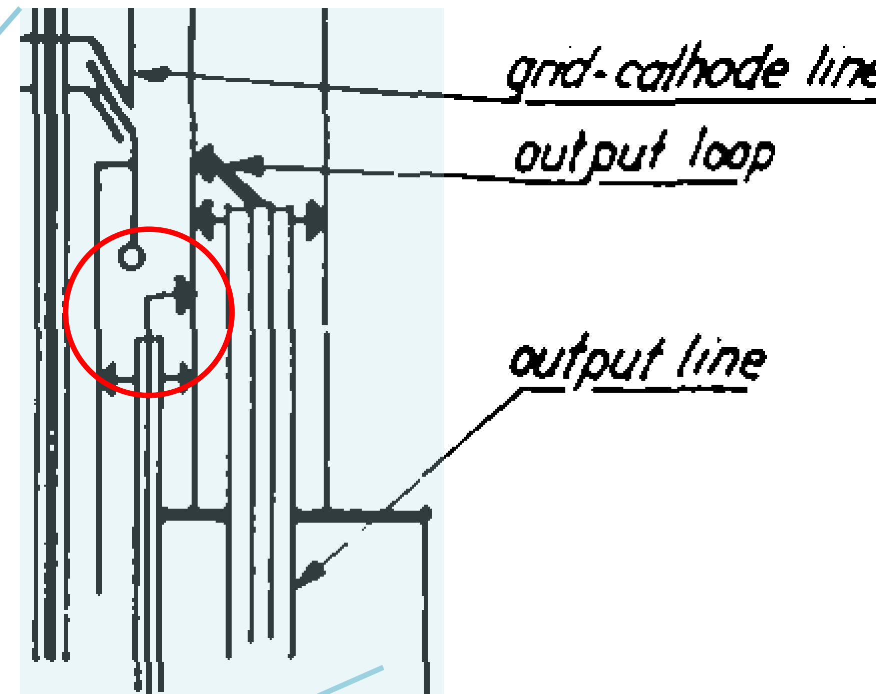
- Glitches observed in modulator current traces when Tetrode operated above 50 kW output
- Completely independent of RF output tuning of tetrode, triode, bias voltages on triode
- Maps to modulation of output signal of both triode and tetrode
- Does not happen when tetrode drives resistive load at MUCH higher power

Understanding the Glitches

- Possible causes of the glitches considered
  - Capacitor charger ‘noise’ annoying the HT electronics
    - Problem got worse if charger switched off and system run in capacitor run-down mode- so not that
  - Unlucky line resonance – stored energy in tetrode output line modulating the tetrode anode swing-
    - Looked like the tetrode output spiked up then dipped at a glitch
    - But should improve with increased tetrode anode bias and eliminated with output coupler tuning- but no effect seen
  - New solid state crowbar ‘twitching’ triode HT circuit
    - Hard to see how this would not result in a full crowbar event
  - Sparking in the triode input
    - Surprisingly regular process for sparking
- Further tests
  - Eventually the glitches stopped, but the input match to the triode became very poor at all power levels
  - This implies a spark was the cause. Prize to Andy Moss for suspecting this.

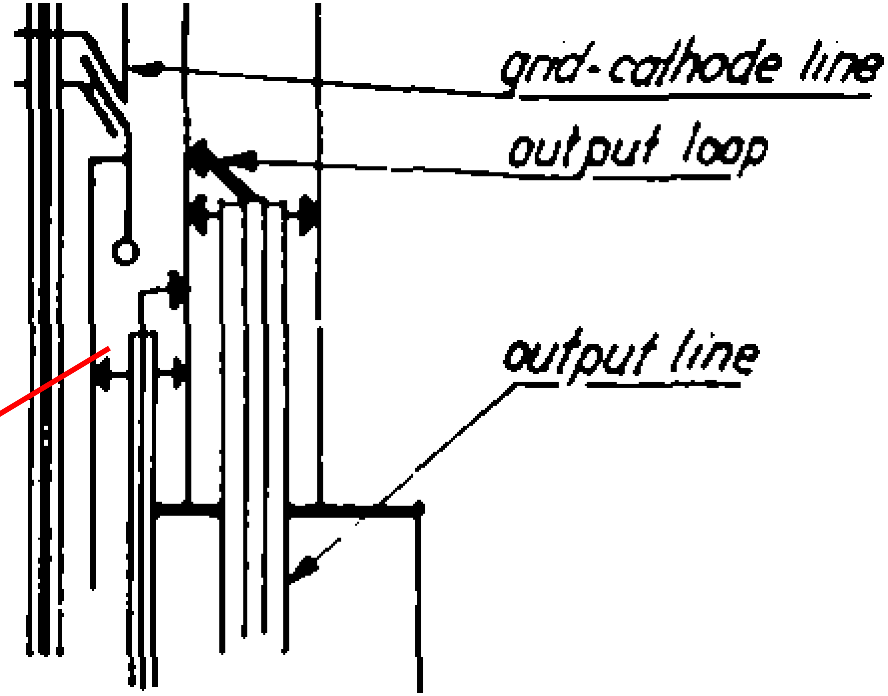
Understanding the Glitches





- Suspect location
  - Matching Resistors in input line
  - Drawing from *E Zaccheroni et al, NIM,* ***5****, 78-89*

Understanding the Glitches



- Suspect location
  - Only accessible by fully stripping the amplifier
  - This triode is only needed to shake down controls,
  - Scheduling considerations suggest we NOT do this
  - Drawing from *E Zaccheroni et al, NIM,* ***5****, 78-89*

RF Controls and Monitoring Systems

- Channel list and State Machine Defined for RF amplifier controls
  - Enable the build of the controls hardware at Daresbury- Underway by Daresbury Electrical Engineering
  - Also defines the logical interaction with the system states
  - Software development commenced: associating channels with variables for EPICS control

- Daresbury TD have made major progress in building controls rack
  - In present FY funds available to complete Controls Rack
  - Commitments at DL mean that this is being undertaken by subcontractors
  - Programming of the software will remain to be done

LLRF

- LLRF development has continued due to ISIS interest
  - Has been controlling tuners on ISIS debuncher cavity based on feedback signals
  - Low power tests only so far: Bob Anderson @ ISIS Injector RF Group

RF Team and Equipment Status

- RF development continued only as risk mitigation
  - Has had very limited amount of effort available on MICE RF
  - Tim Stanley (formerly MICE RF Engineer) now with ISIS RF
  - Limited effort available at Daresbury
  - Slowed progress where the project plan would have liked to increase effort

- Looking forward: if Cooling Demo Approved
  - Daresbury RF and TD groups heavily committed to CLARA
  - Dissipation in skill base- In addition to redeployment, there are possible retirements to consider
    - We will need to make sure we can secure adequate RF resources
    - There may be a steep learning curve
  - We have a lot of (valuable) spare parts
  - We have most major capital equipment required
    - Limited procurement, clock and LLRF reference source hardware
    - Also cavity support infrastructure

Work Needed for Cooling Demo

- Distribution network
  - Installation, calibration
  - Gas insulation scheme needs to be built
  - Adjustment of relative phase
- RF drive system
  - Resolution of the glitches issue on the test stand at Daresbury on Triode No 2
  - Completion of controls system- do we need such a ‘hands off’ system?
    - Tests of controls system
  - Installation in Hall and commissioning- provision of cooling water and controls cabling
  - LLRF system modified for MICE
- Cavities
  - Provision of auxiliary systems for cavities (cooling/air/vacuum)
  - Installation, integration with controls/monitoring/LLRF
  - Online commissioning
- Funding bid to access STFC underspend in FY 17-18
  - News due soon: Could fund completion of RF drive system
  - Would need prompt action to resource if successful

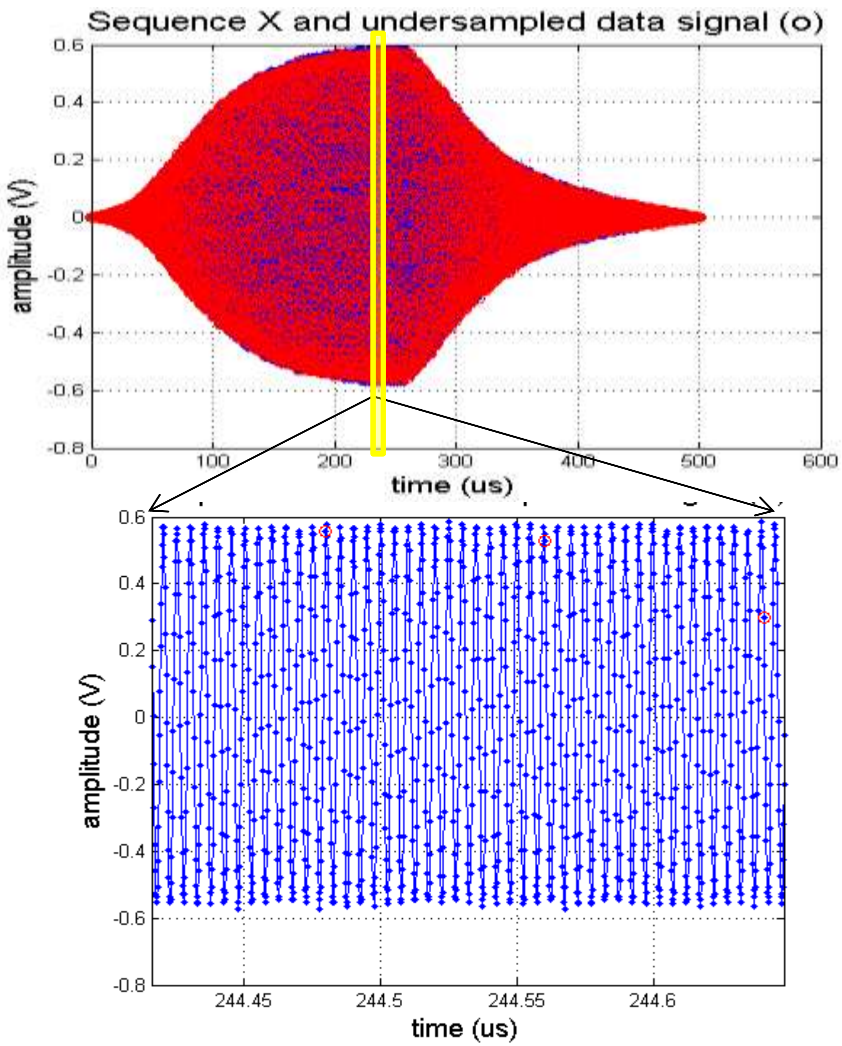
Muon Transit Phase Detection

- Need to be able to select particles for analysis by their RF transit phase
  - Allows the ‘bundling’ of particles for coherent analysis
  - i.e. As if we are considering the interactions of a real particle ‘bunch’

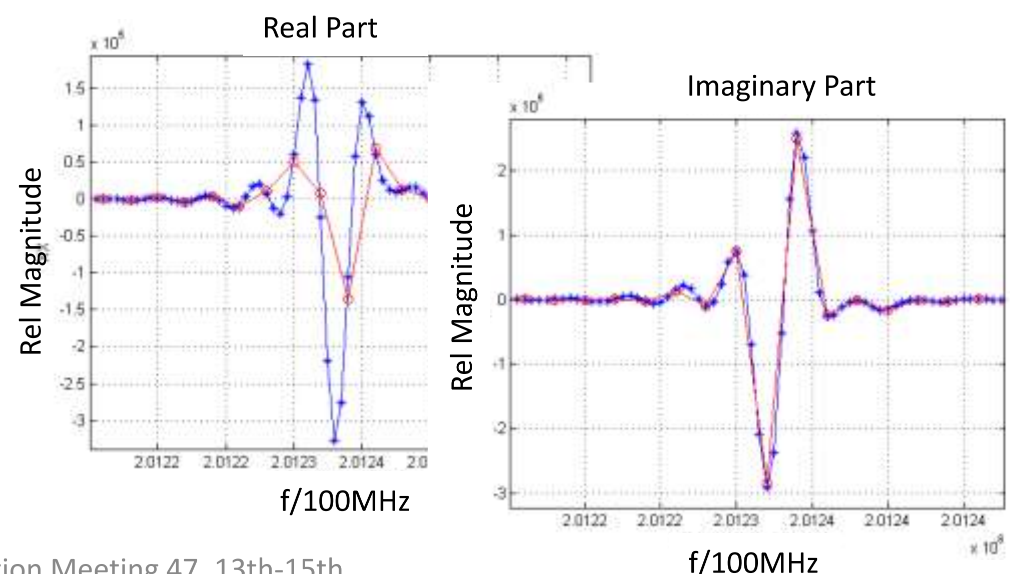
- Cavity transit time inferred by the ToF transit time and the tracker measurement of momentum
  - Combining ToF resolution and Momentum projection resolution ~ +/- 51.5ps
  - Desire to know RF phase to better than 0.3 of this ~ 17ps

- Two Approaches
  - Digitisation (subsampled) of the RF waveform on the pickup probes
  - Direct recording of the wave inside the cavity
  - TDC recording of the RF waveform
  - Records zero crossings of a reference oscillator/Cavity waveform - provides RF phase reference for TDC particle events

Muon Transit Phase Detection

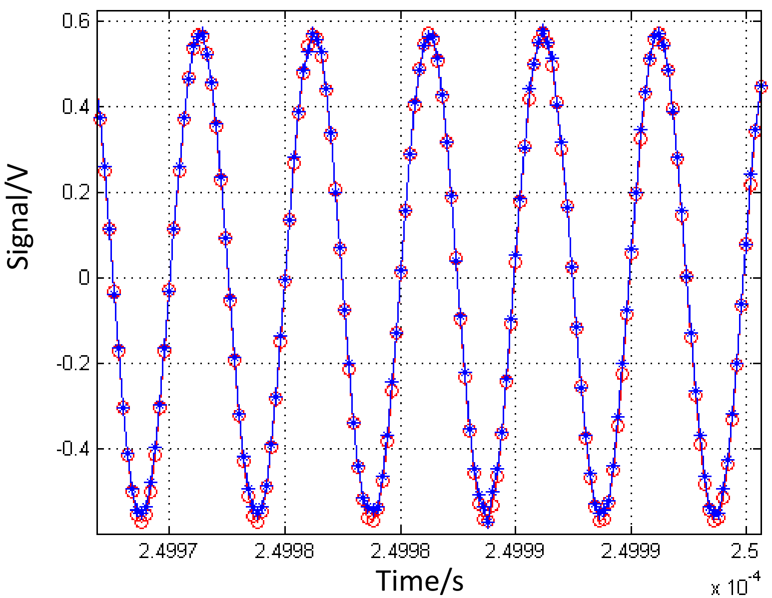


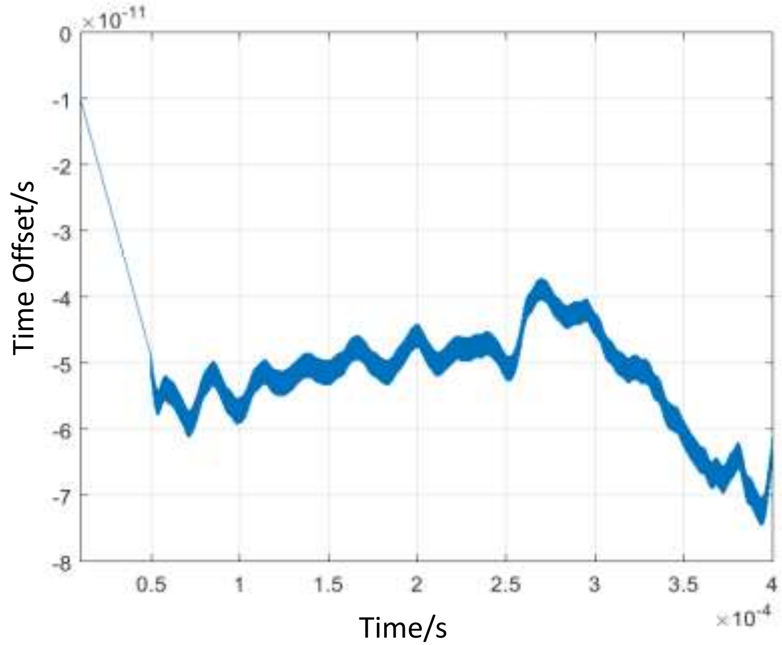
- Time domain: signal (blue) from FNAL cavity tests - 500μs window sampled at 5G.Sa/sec
- Subsample (red) at 12.5M.Sa/sec, reduce data by x400, and 48x < Nyquist @ 200MHz
- Note time domain signal ‘windowed’: New data from MTA will remove this process
- Freq. domain: Red fft of entire recorded data, Blue enhanced dft of subsampled data



Muon Transit Phase Detection

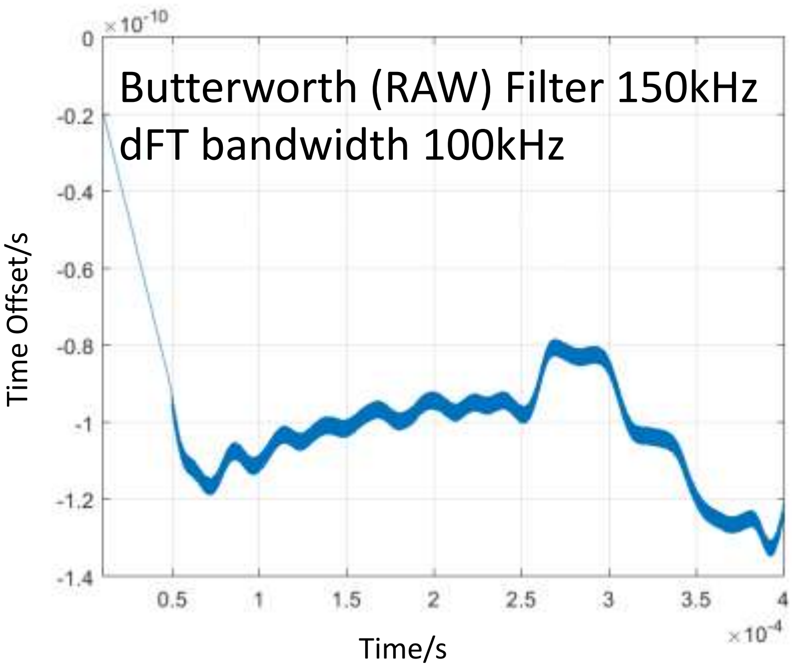
- Freq. domain reconstructions: high fidelity to raw signal over entire pulse duration (no spark)
- Blue is original data through Butterworth filter, Red is reconstructed subsample data
- Note dft here is effectively a (hard edged) 100kHz filter
- 10ps precision achieved on pulses from MTA tests

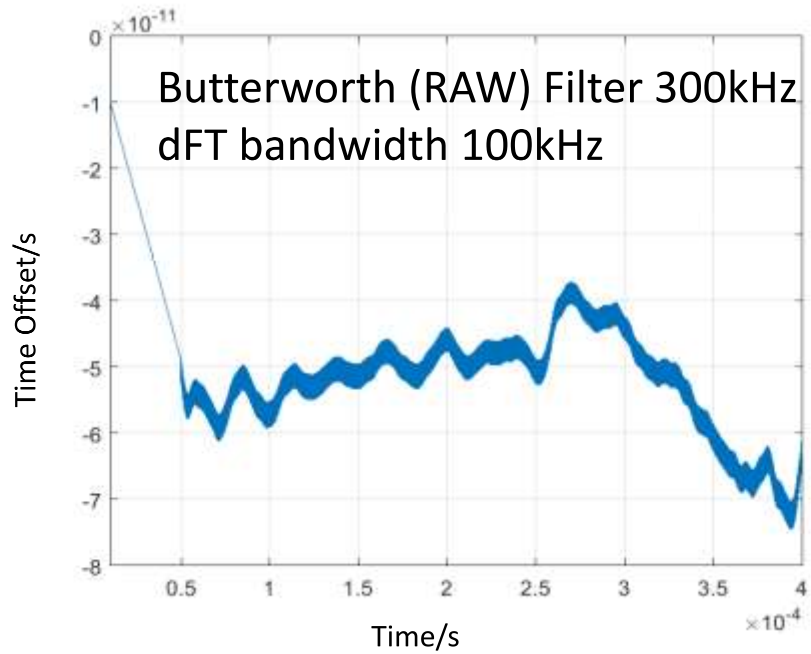




Muon Transit Phase Detection

- The effects of the filter bandwidths were considered:
  - Both dft used for the FD reconstruction and
  - Butterworth applied to the raw data
- Width of Butterworth filter: Minor impact on noise at 5ps level, significant impact on systematic offets
- Width of dFT- affected resolution of fine scale variation in signal- no significant impact on systematic offsets





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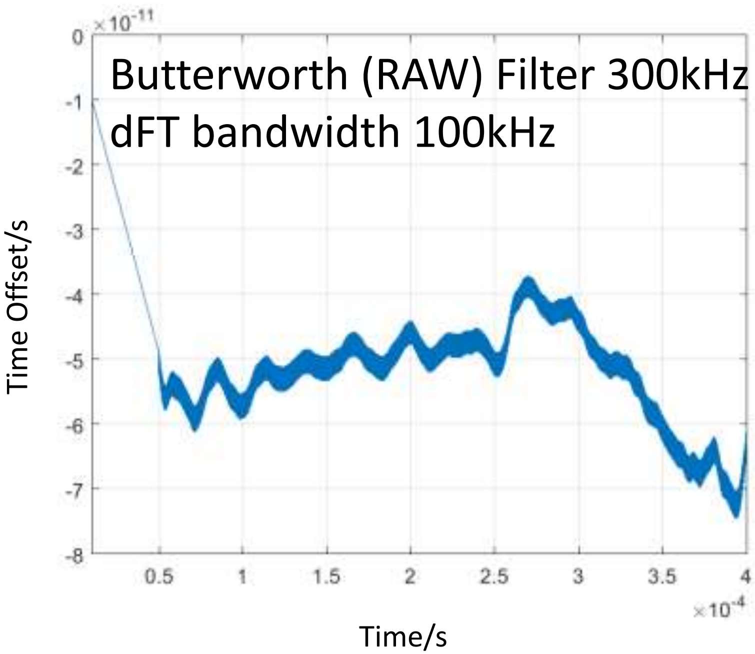
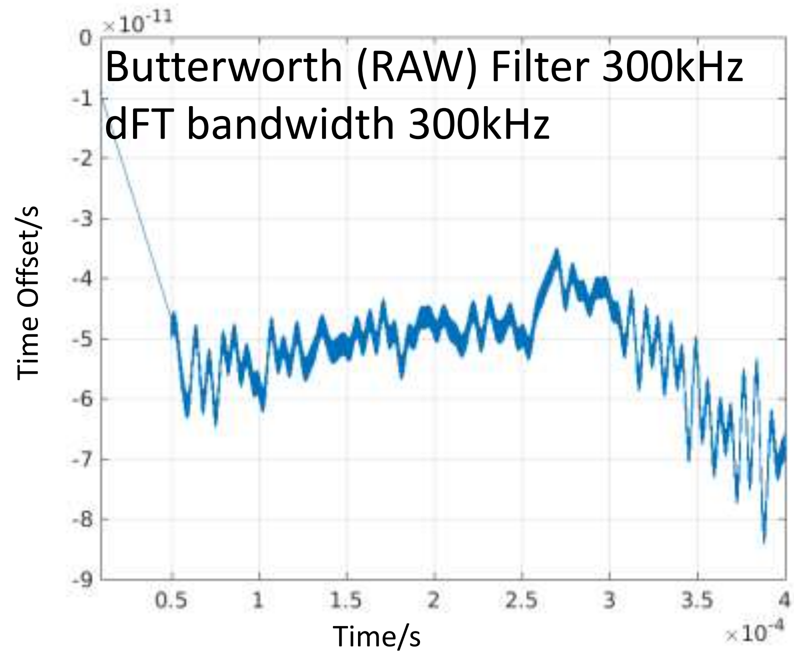
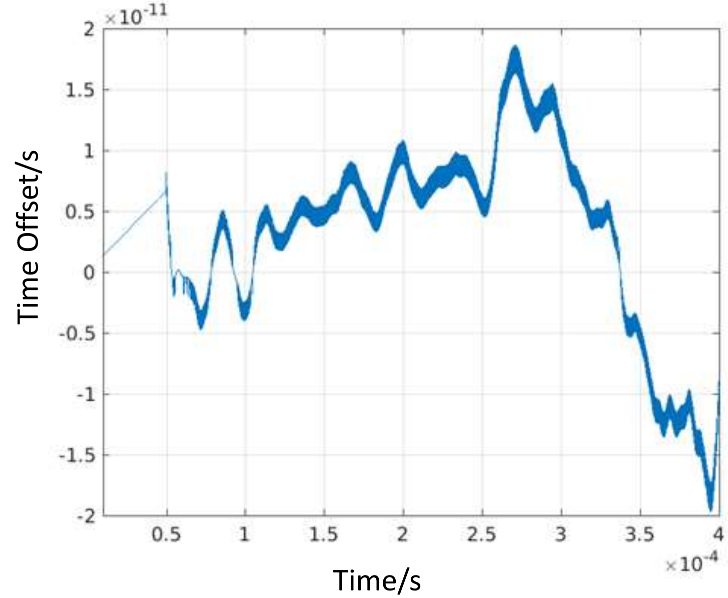




Muon Transit Phase Detection

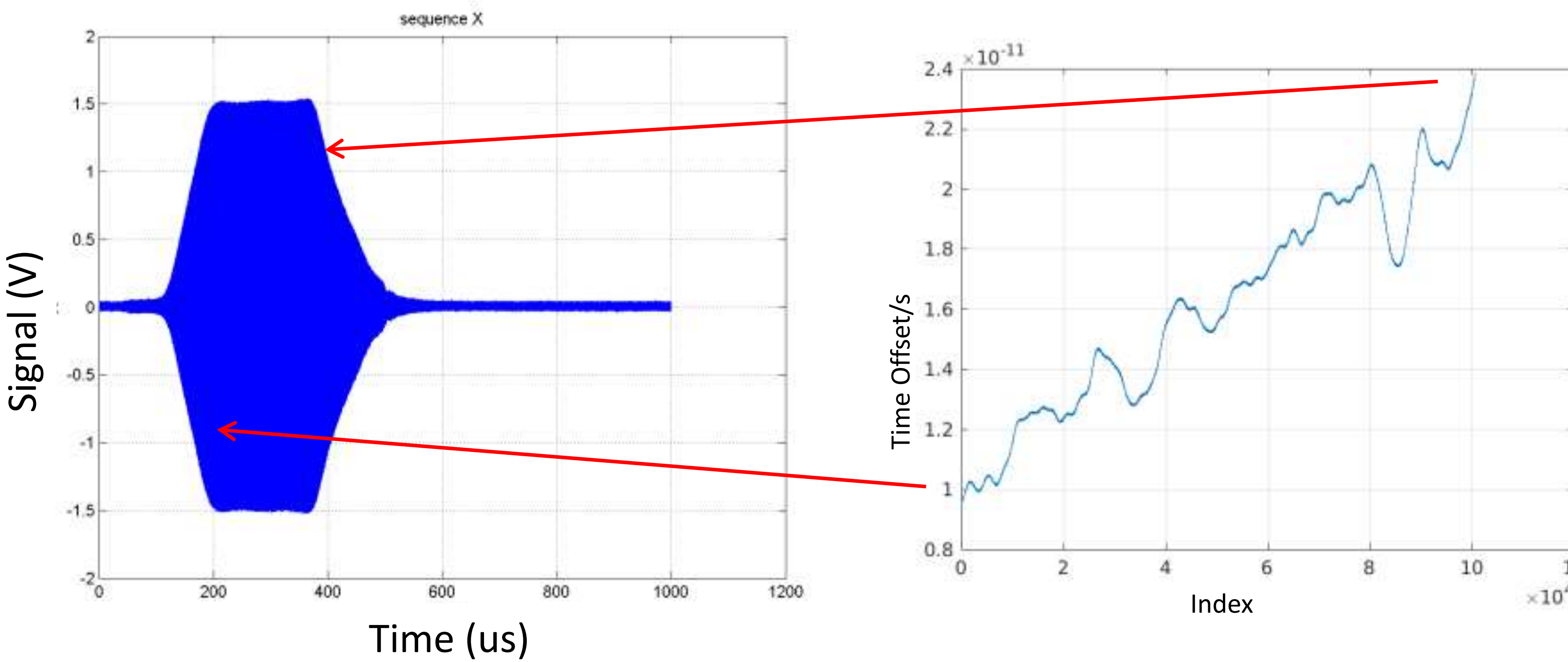
- At previous meetings, tests showed good random walks in the reconstructed signals BUT
- Some variation in the systematic offsets
- The majority of the MTA tests did not attempt to hold the cavity on resonance
- Rather the drive amplifier followed the natural tuning of the cavity as the cavity temperature evolved
  - Freq. shifts over 32 valid datasets (i.e. no valve/cavity arcs) of ~4 kHz noted
- MICE will not run like this
- New analysis approach, first perform a very precise dFT, then use this to centre all freq sensitive processing
- Significantly reduces the offsets

Butterworth (RAW) Filter 300kHz
dFT bandwidth 300kHz
Corrected centre frequency



Muon Transit Phase Detection

- Same analysis approach being applied to new data received last year from MTA
- Much longer record lengths- very large data sets
- No longer need to 'window' the data save to suppress noise at the acquisition edges
- Similar performances being observed over all 3 datasets



Summary

- Subsample method shows good performance
  - Note variation in the traces from the initial dataset arise where the cavity amplitude is changing rapidly- this will NOT be an interesting condition for MICE
  - Slew in the long, high resolution datasets probably a result of insufficient ‘enhancement’ of the Fourier resolutions

- Digitiser Hardware Status
  - 4GSa/s 2 Ch VME digitiser in hand- can record entire pulse at > Nyquist at need
  - Has 10 bit resolution (instruments used to date are 8 bit)
  - Can be programmed to run with 40MHz external clock (shared by the TDC’s)
  - Work required to capture waveforms at 1Hz at whatever subsample rate we choose
    - 12.5MSa/sec or 25MSa/s seem likely candidates

- TDC hardware status
  - 300MHz Discriminator available and running tests (others are available)
  - Spare MICE TDC is at Strathclyde and installed in VME crate
  - VME bus on crate at Strathclyde now communicating with TDC- thanks to Ed

- Integration
  - Acquisition software routines need to be produced
  - Clock required to sync TDC’s and digitiser
  - Trigger alignment needs to be done between TDC’s and Digitiser
  - Bench tests using Arbitrary Wave Generators and 50ps transient generators

MICE High Power RF system: Requirements

- MICE High Power RF system
  - Two cavities, driven by ONE RF power amplifier- 2MW output
  - Lower gradient means less risk/lower cost at cost of reduced p_z uplift
    - Not without its own issues
    - No longer have electronic control of relative phase
    - Either predefined fixed phase setting or increments by mechanical adjustment of the transmission lines
    - Alternative: Quote received $25k US for 1.5m trombone phase shifter
  - Note: Means we lose control of the impedance presented at the amplifier