The Front End Test Stand at RAL

Alan Letchford

Presenting the work of the FETS collaboration:

Saad Alsari, Morteza Aslaninejad, John Back, Stewart Boogert, Gary Boorman, Alessio Bosco, Mike Clarke-Gayther, Richard D'arcy, Mike Dudman, Rob Edgecock, Charles Evans, Dan Faircloth, Christoph Gabor, Alberto Garbayo, Stephen Gibson, Simon Jolly, Pavel Karataev, Konstantin Kruchinin, Ajit Kurup, Scott Lawrie, Mike Perkins, Ciprian Plostinar, Piero Posocco, Juergen Pozimski, Pete Savage, Jordan Taylor, Philip Wise

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Motivation for FETS

- FETS will demonstrate front end technologies for future high power proton drivers
- High power means 20 kW @ 3 MeV

  = 1 MW @ 180 MeV
- FETS is at RAL because infrastructure and support services are available
- FETS is generic – many possible applications

FETS Collaboration

Science & Technology Facilities Council ISIS

Science & Technology Facilities Council ASTeC

Imperial College London

THE UNIVERSITY OF WARWICK

JAI John Adams Institute for Accelerator Science

ROYAL HOLLOWAY UNIVERSITY OF LONDON

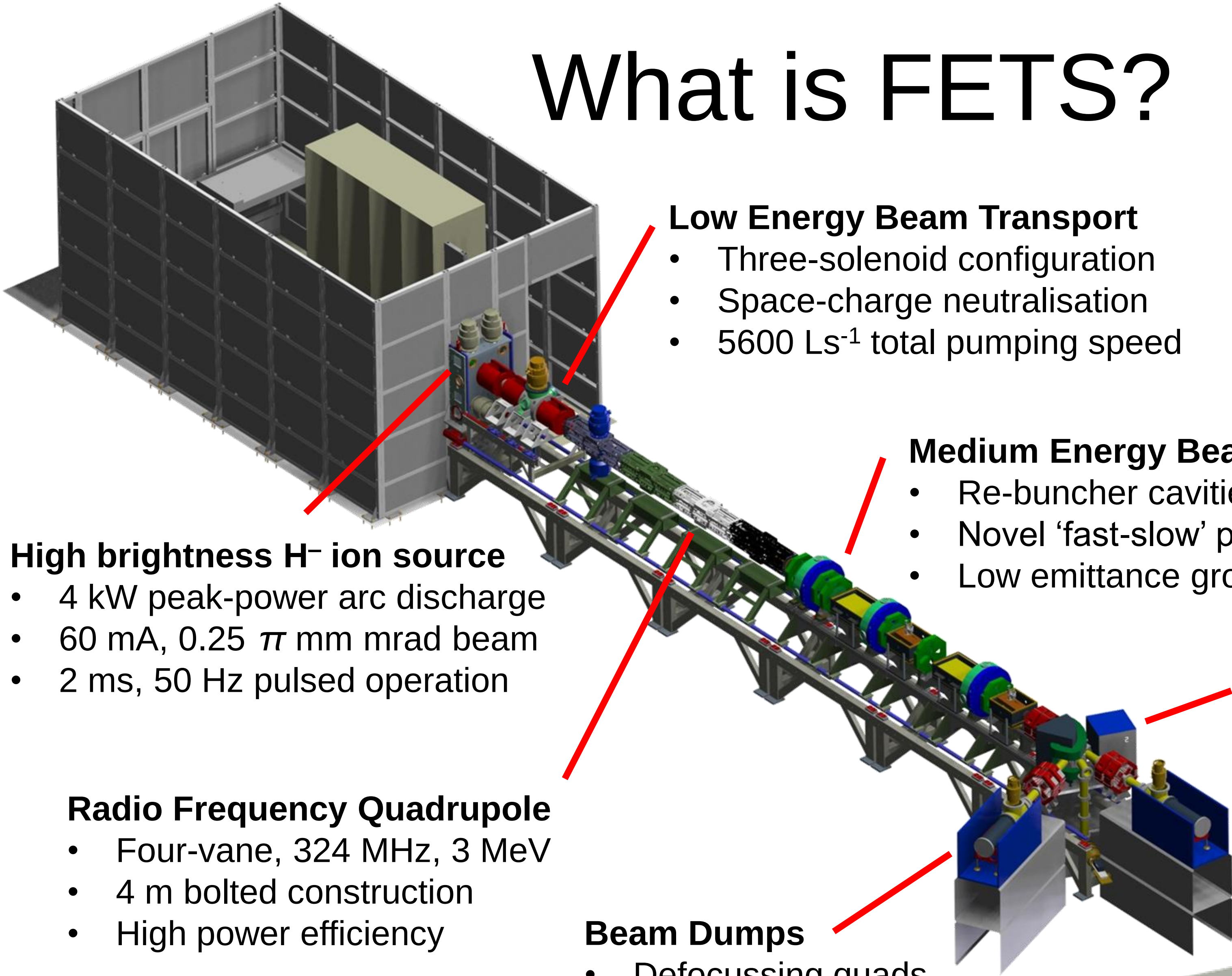
CERN

UCL

ESS bilbao


R8

What is FETS?



Low Energy Beam Transport
- Three-solenoid configuration
- Space-charge neutralisation
- 5600 Ls^{-1} total pumping speed

Medium Energy Beam Transport
- Re-buncher cavities and EM quads
- Novel ‘fast-slow’ perfect chopping
- Low emittance growth

High brightness H^{-} ion source
- 4 kW peak-power arc discharge
- 60 mA, 0.25 π mm mrad beam
- 2 ms, 50 Hz pulsed operation

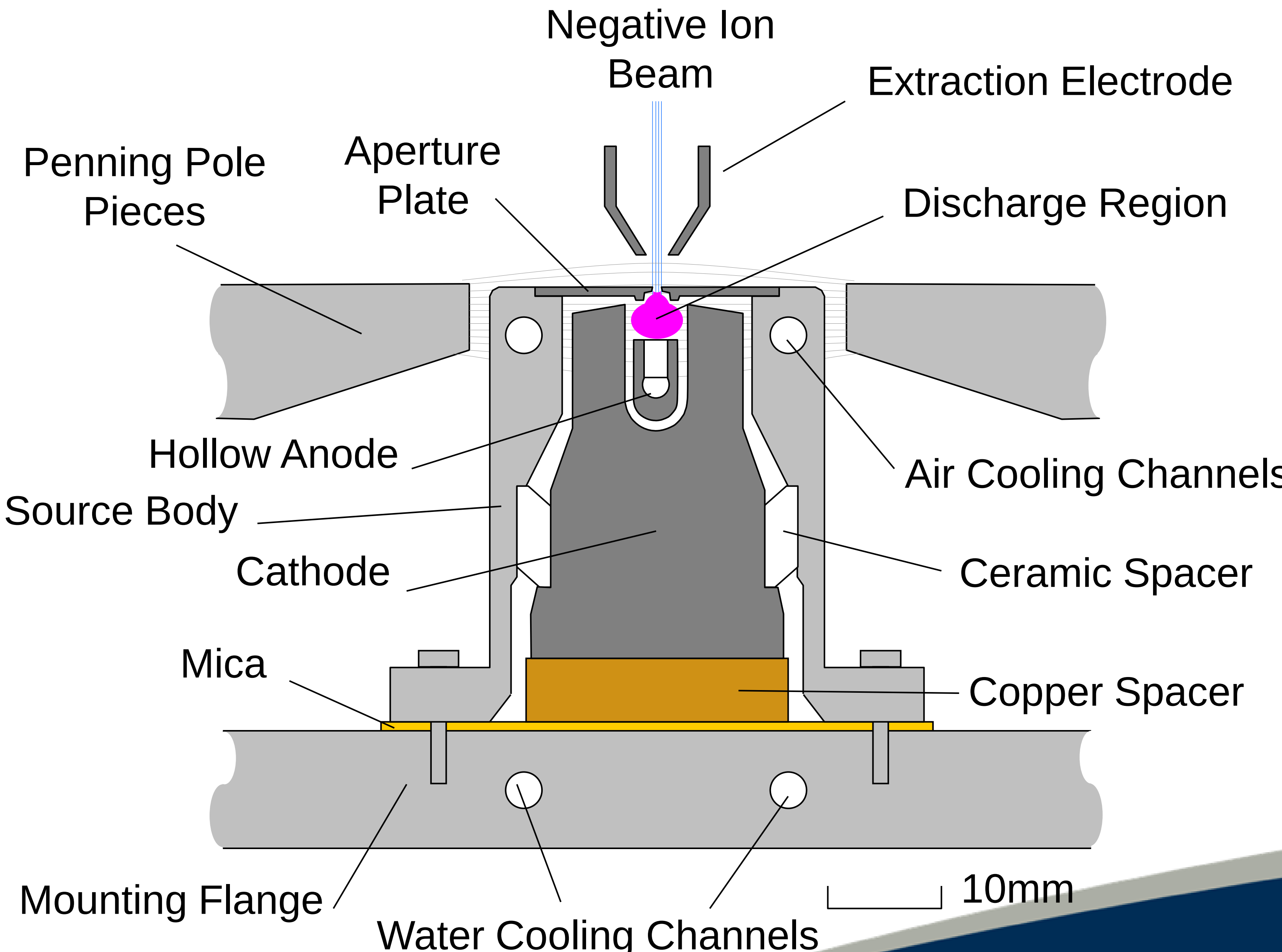
Diagnostics
- Non-interceptive
- Well distributed
- Laser-based

Radio Frequency Quadrupole
- Four-vane, 324 MHz, 3 MeV
- 4 m bolted construction
- High power efficiency

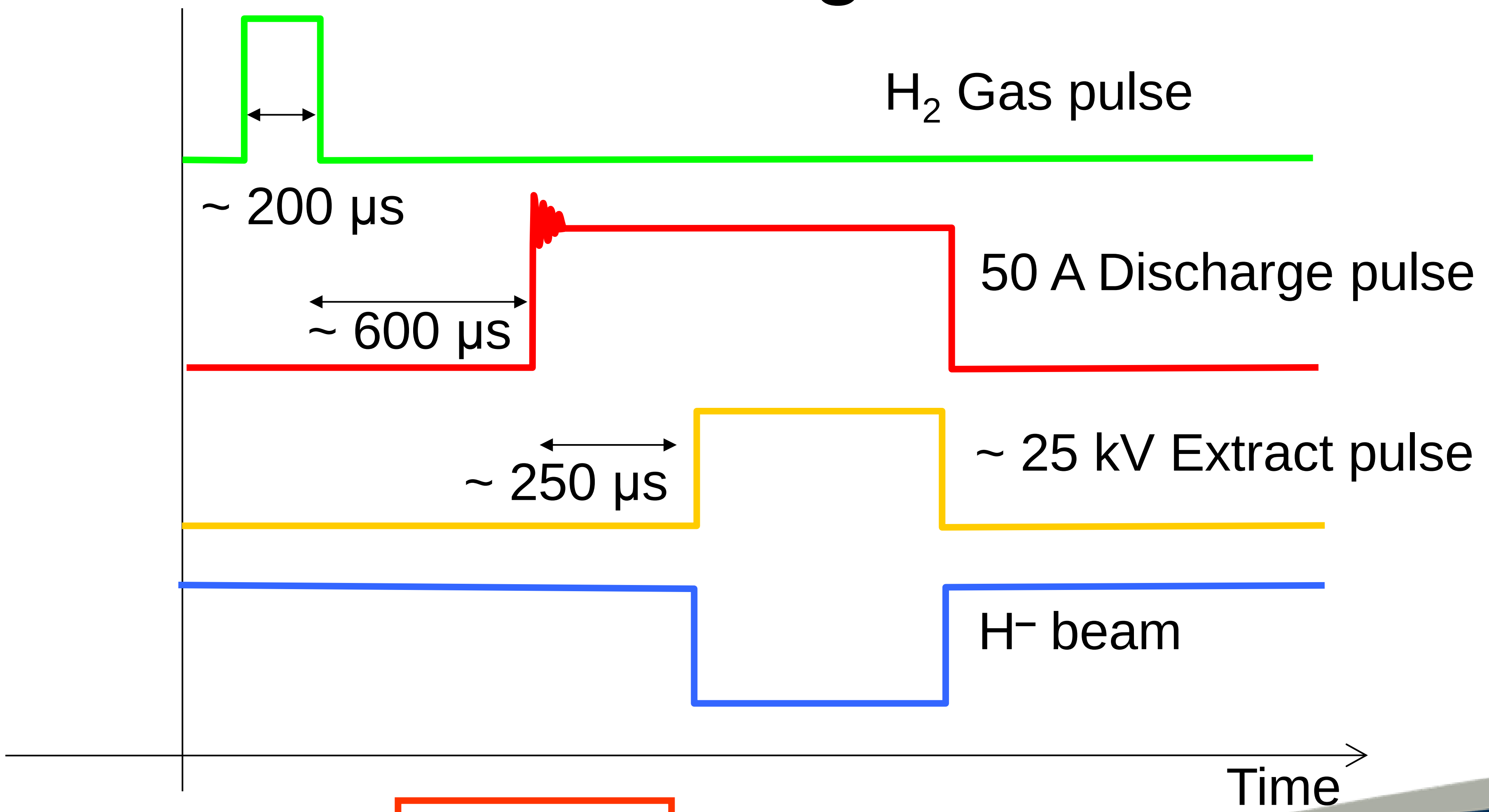
Beam Dumps
- Defocussing quads
- Water cooled cones
- Pure Al

H^- Ion Source

- High brightness Penning Surface Plasma Source (SPS)
- Very high emission current density >1Acm^{-2}
- Based on ISIS operational source


Negative Ion Beam
Extraction Electrode
Penning Pole Pieces
Aperture Plate
Discharge Region
Hollow Anode
Source Body
Cathode
Air Cooling Channels
Ceramic Spacer
Mica
Copper Spacer
Mounting Flange
Water Cooling Channels
10mm

Timing



Source Runs at 50 Hz Rep Rate

New 25 kV 2ms 50 Hz Extraction Power Supply

Dumping system

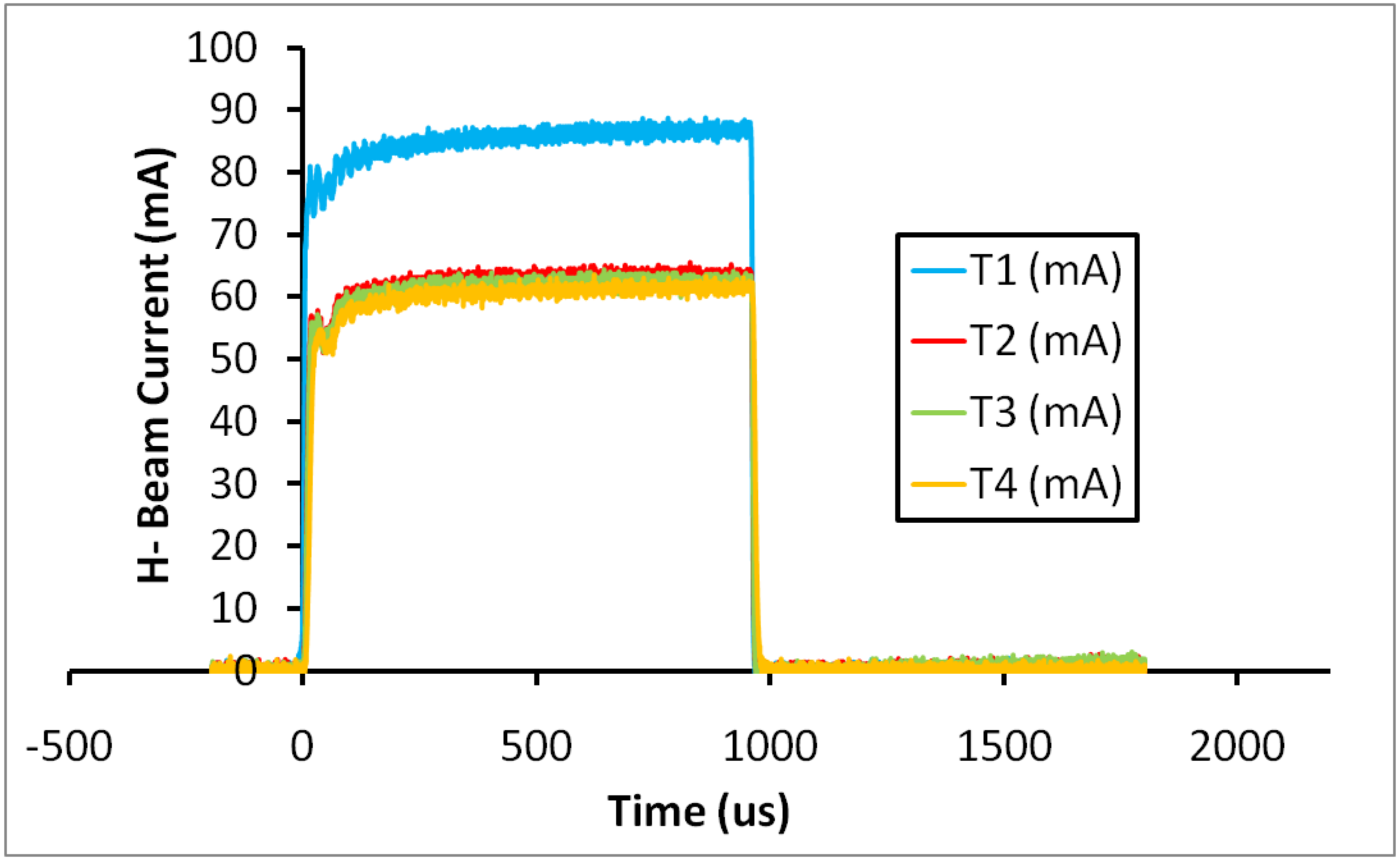
Reservoir capacitor

High power tetrode

Isolation transformer

Maximum LEBT output:

60 mA 1ms 50 Hz



1.2 ms 60 A discharge, 19.6 kV extraction voltage, 65 keV beam, 180°C caesium oven, 16 $mLmin^{-1}$ H_2

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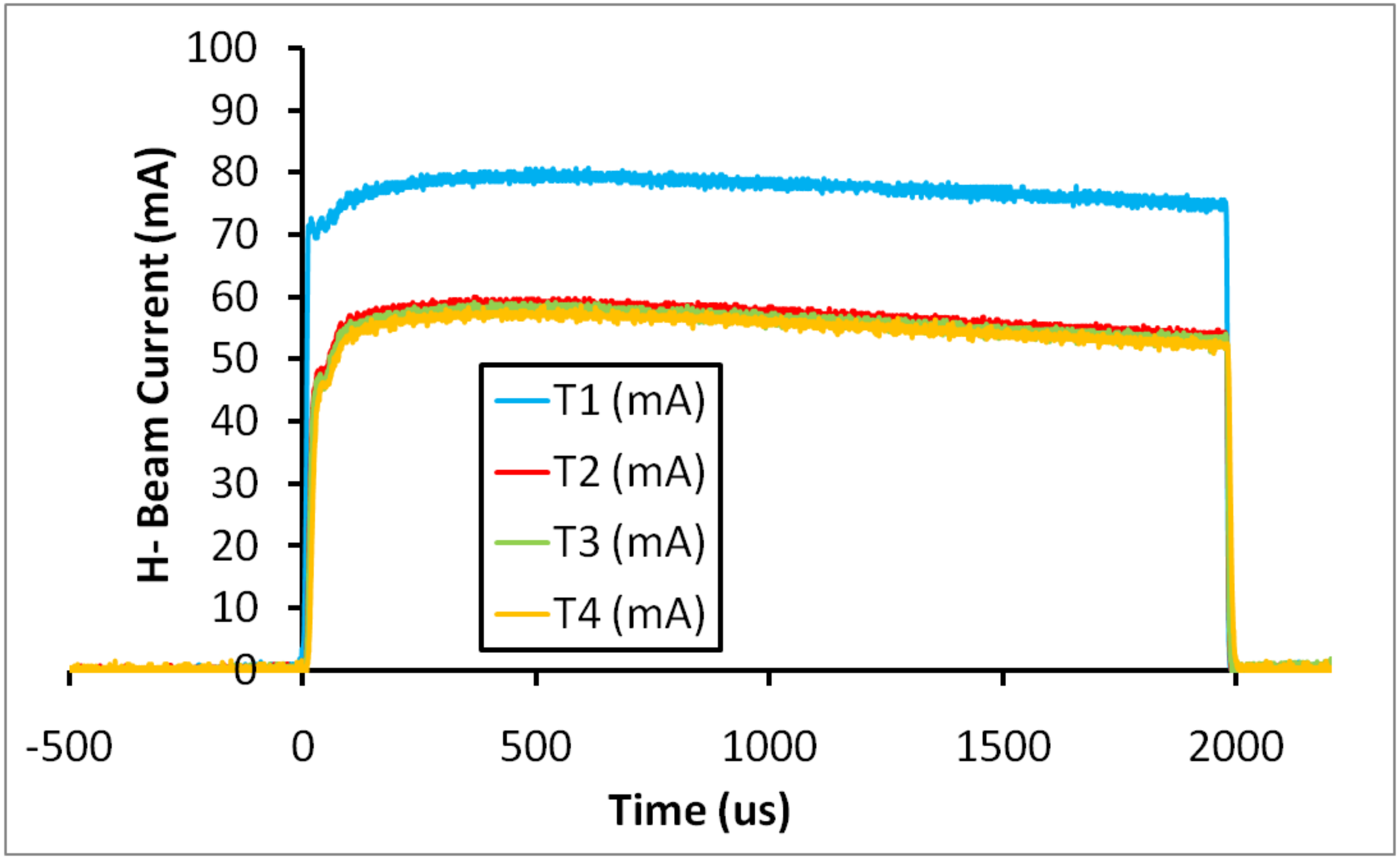
OR

60 mA 2ms 25 Hz



2.2 ms, 64 A discharge, 19.6 kV extraction voltage, 65 keV beam, 190°C caesium oven, 16 mLmin^{-1} H_2

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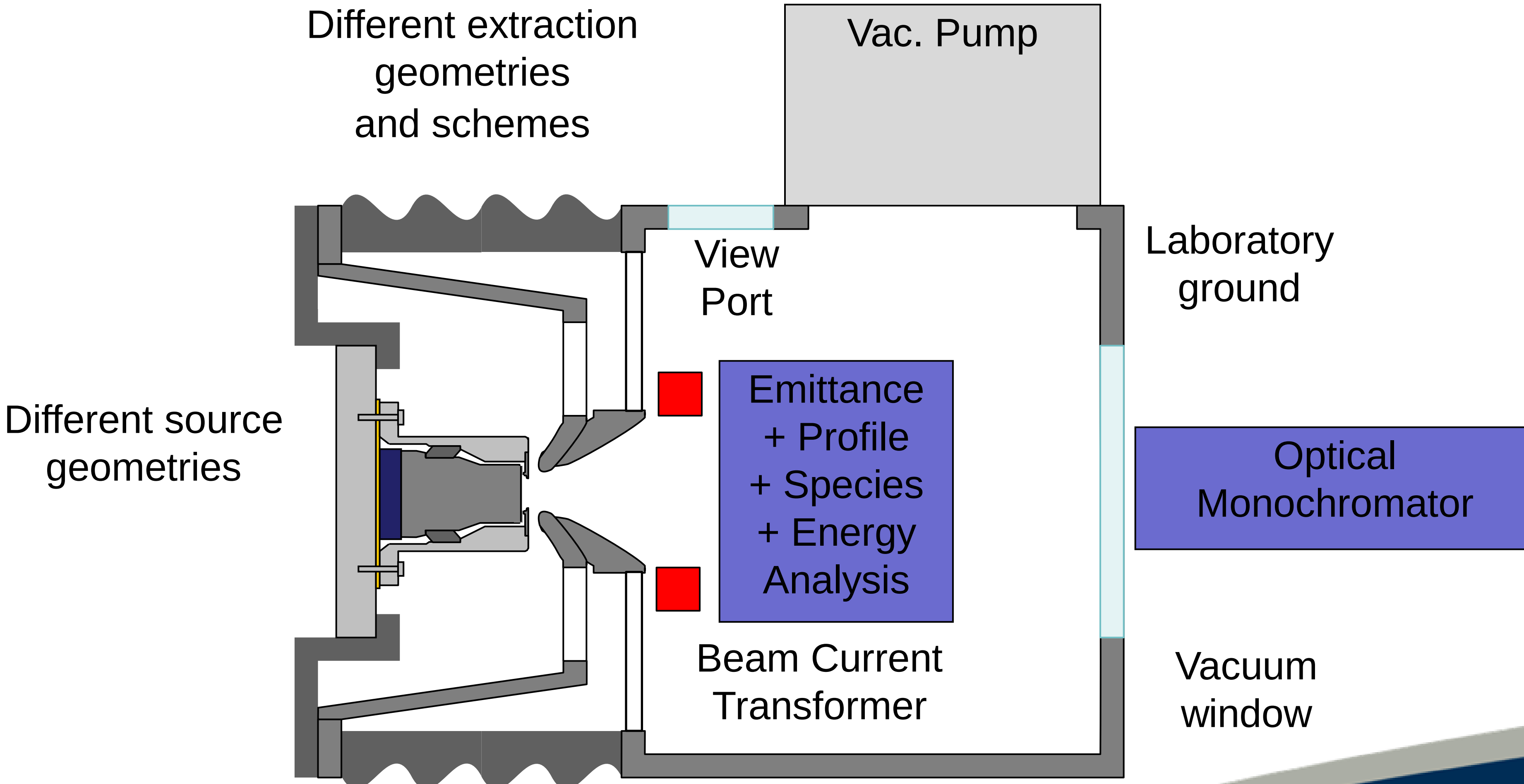
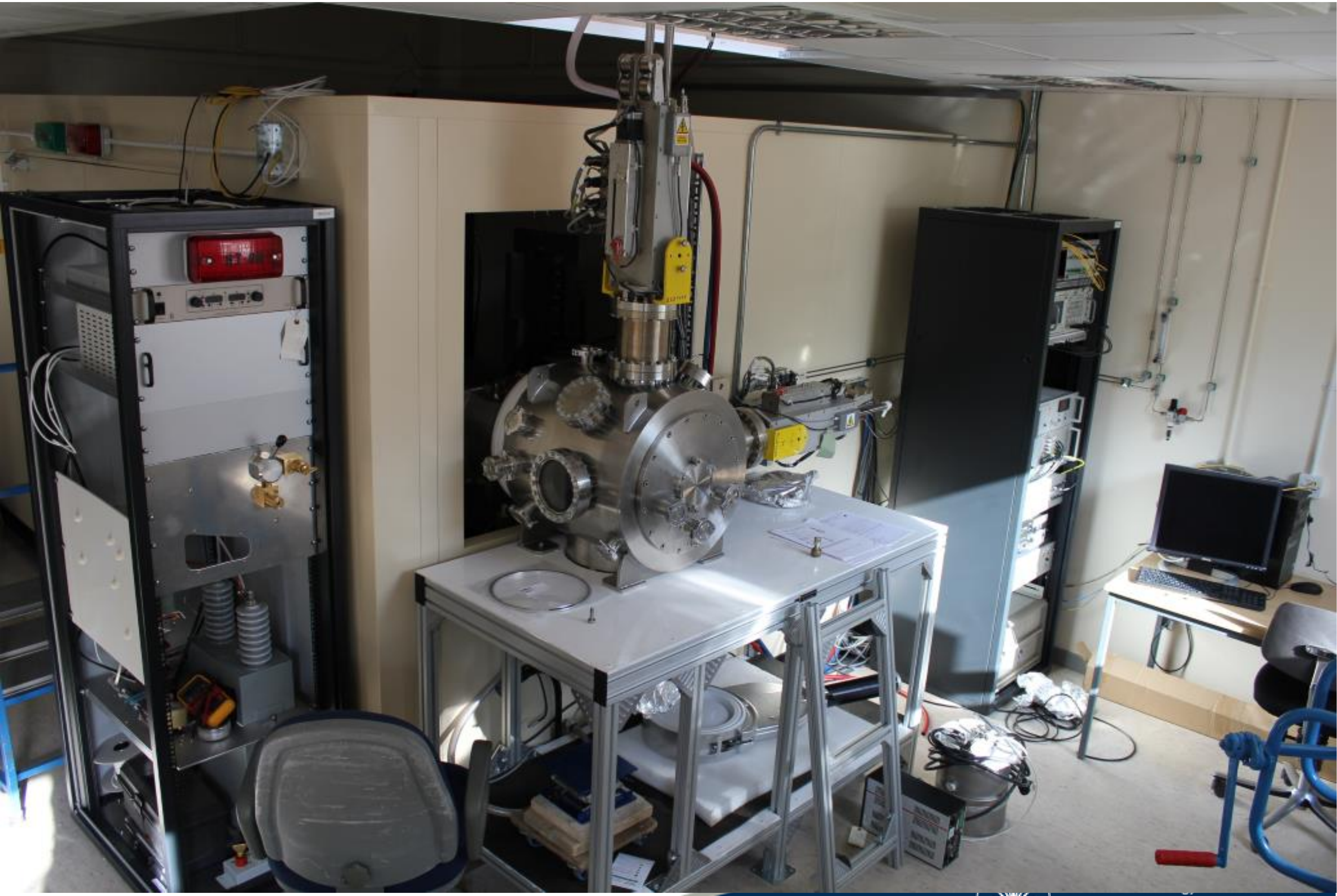
This appears to be a fundamental limit of the present source design.

In order to fully meet the FETS beam requirements we must modify the plasma geometry.

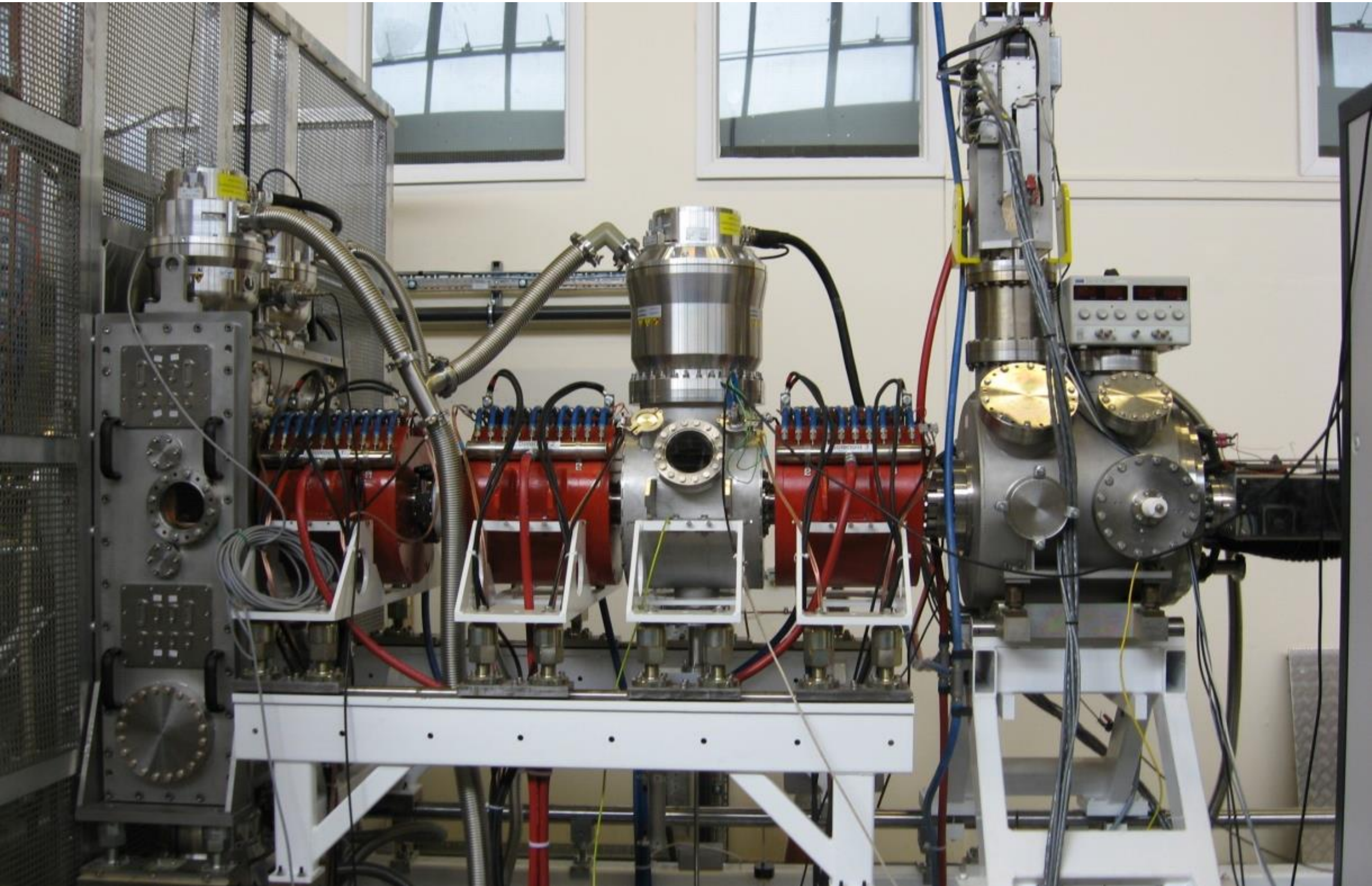
This has led to the VESPA experiment - Vessel for Extraction and Source Plasma Analyses.

VESPA Design

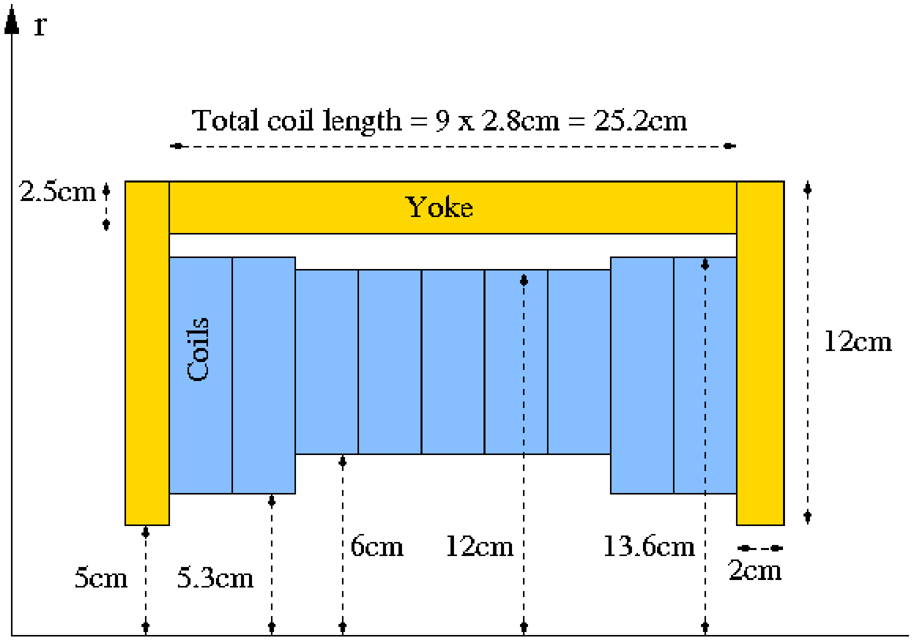


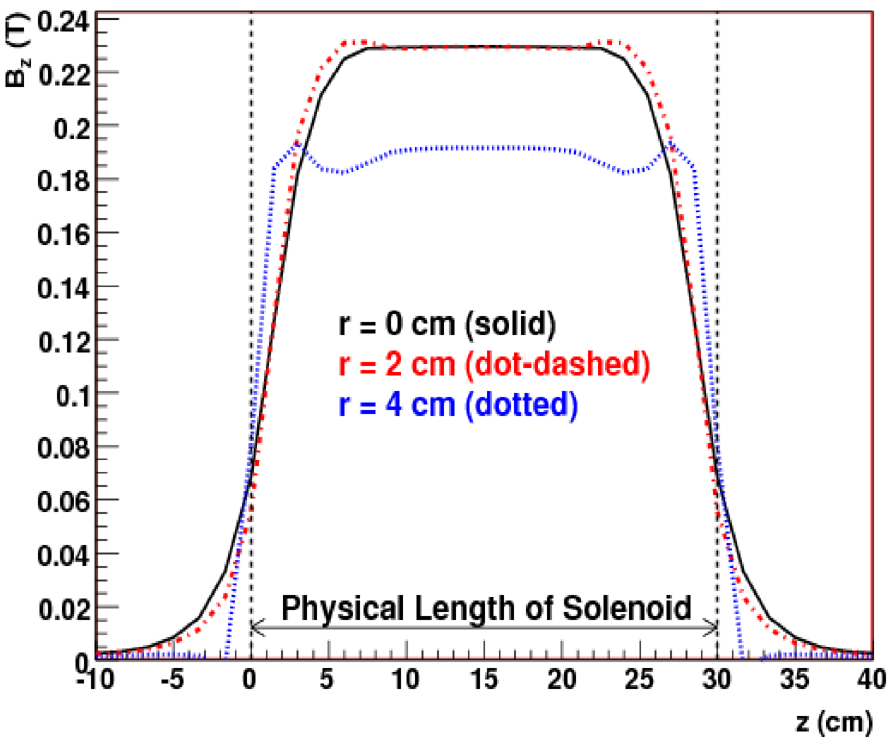


Low Energy Beam Transport (LEBT)



Solenoid Design

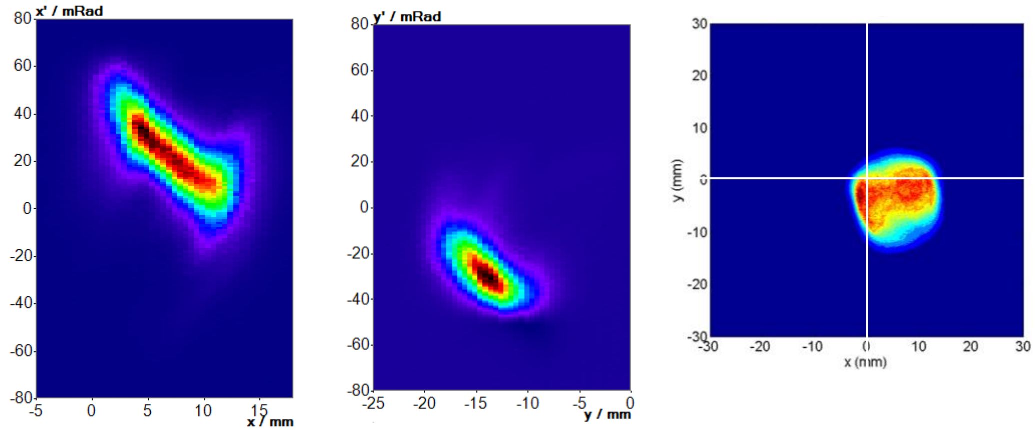


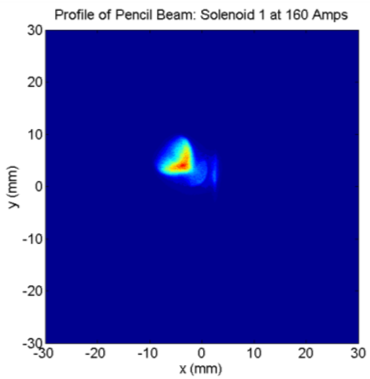


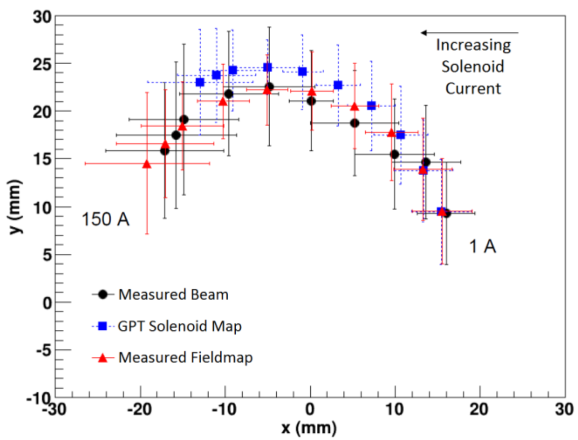
300 A Solenoid power supplies

LEBT Beam Transport Studies

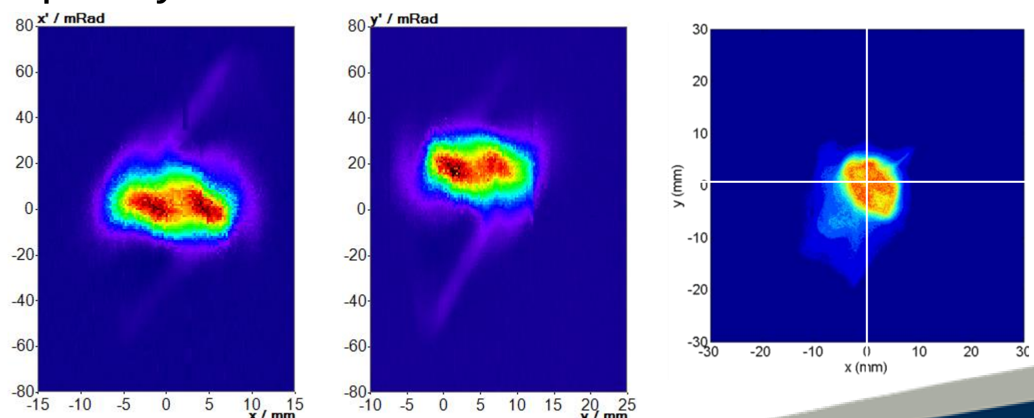
Although good transmission was achieved, a major concern was significant misalignment of the beam:







Configuring the LEBT for a pencil beam coupled with particle tracking has allowed this to be almost completely corrected:



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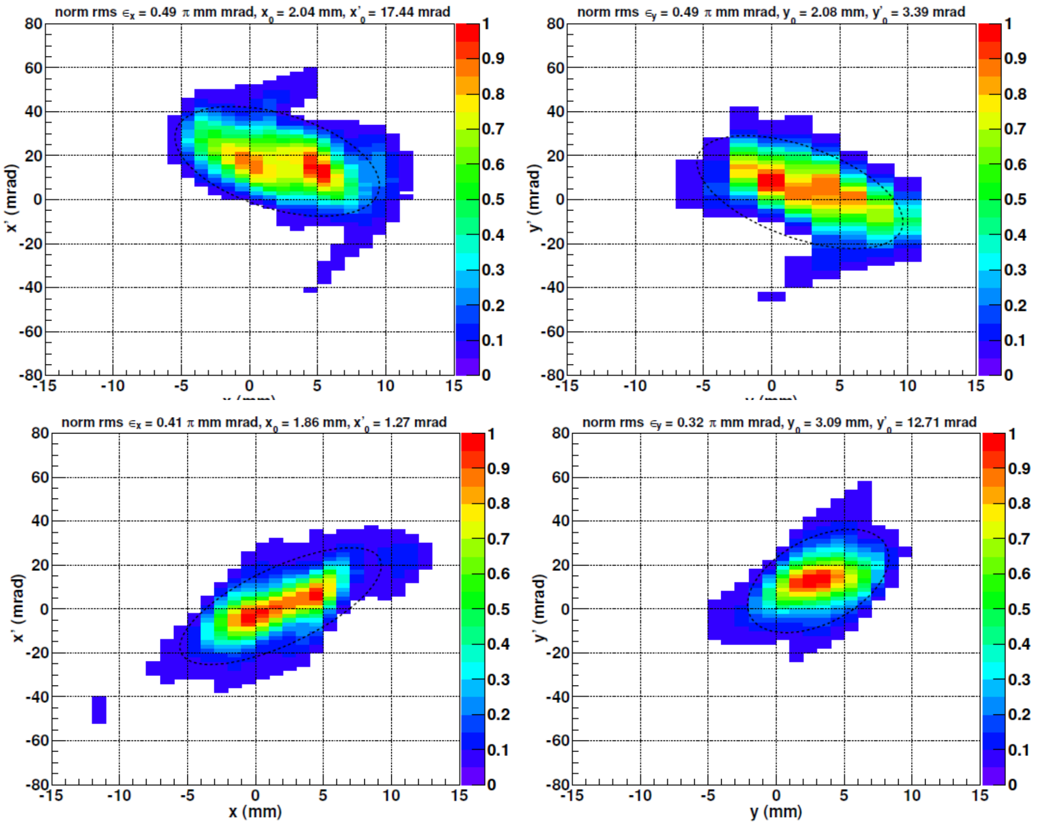
LEBT Matching

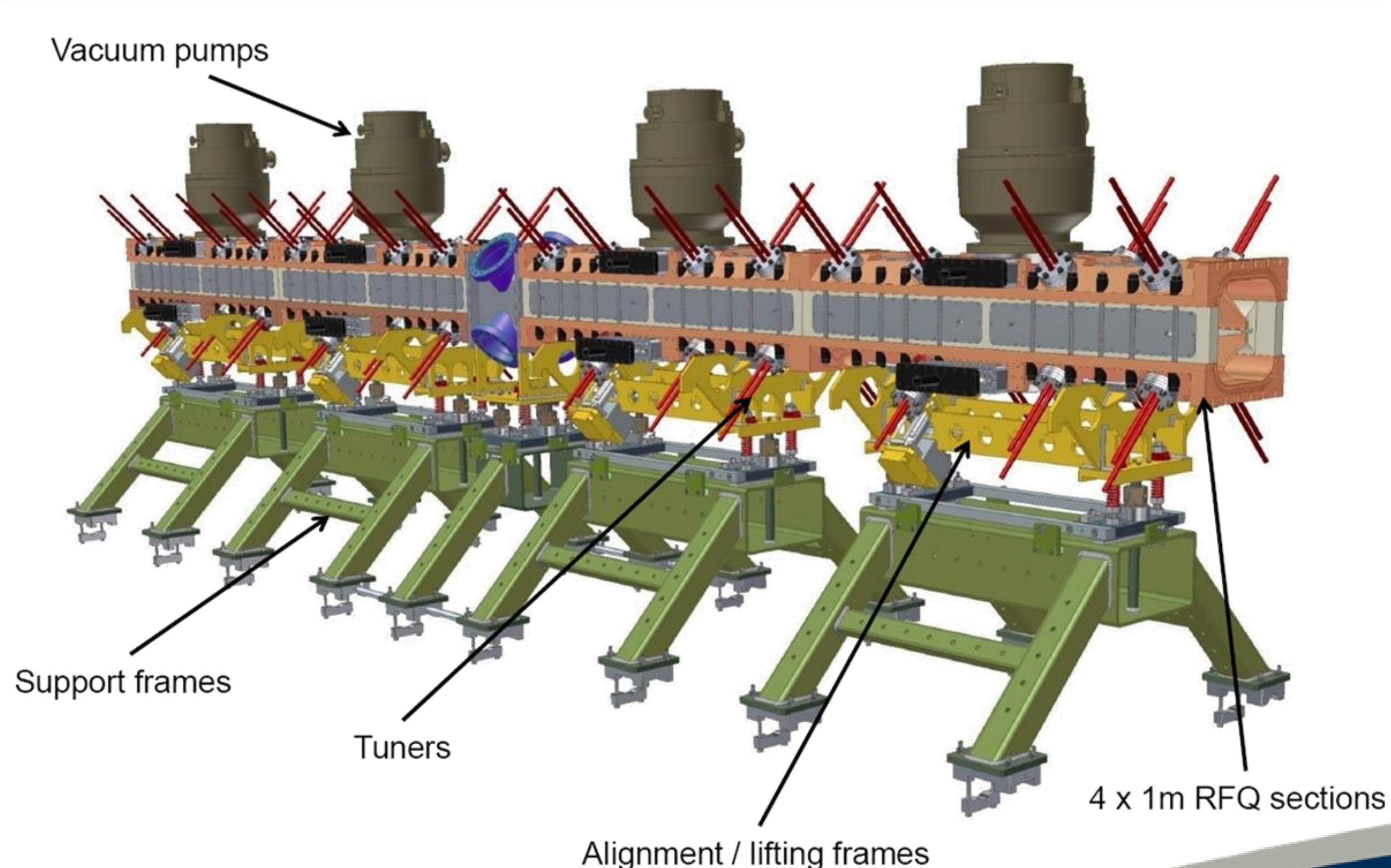
Following successful realignment of the ion source beam and reliability improvements to hardware, further parametric studies of the LEBT have been performed to demonstrate the ability to match into the RFQ.



The LEBT beam can be taken through a focus at the RFQ matching plane. Although the emittance is still large this result gives confidence of being able to achieve a reasonable match.

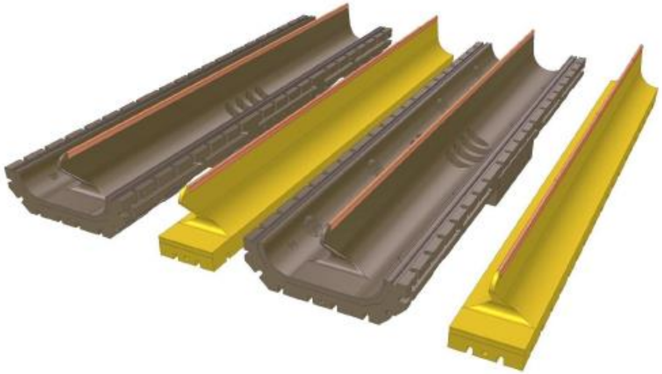
Radio Frequency Quadrupole (RFQ)

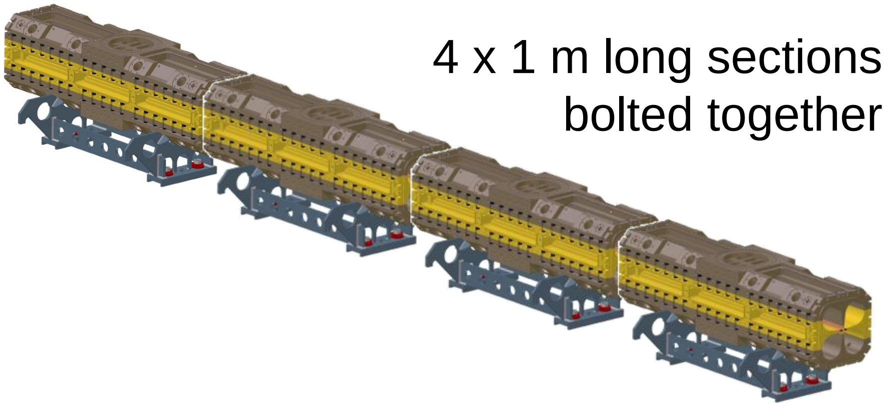
The FETS RFQ
324 MHz, 3 MeV, 4 vane, 4m long



RFQ Construction

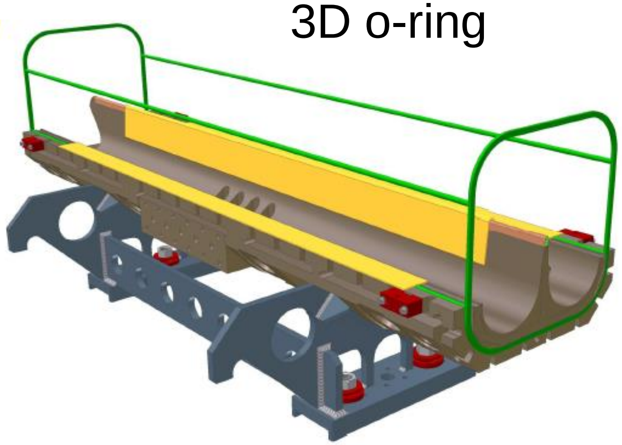
Sections made of 2 major and 2 minor vanes

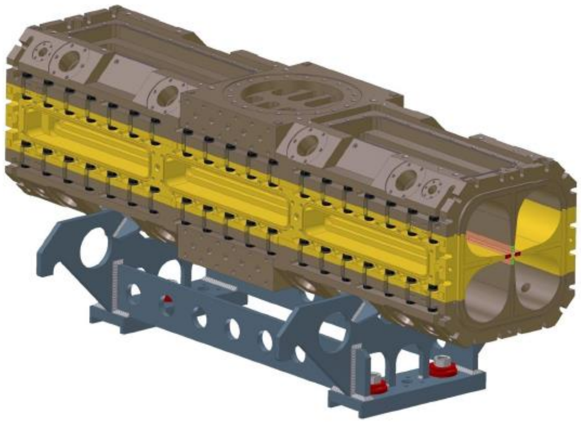




4 x 1 m long sections
bolted together

3D o-ring





Vanes bolted together to
make 1 m sections

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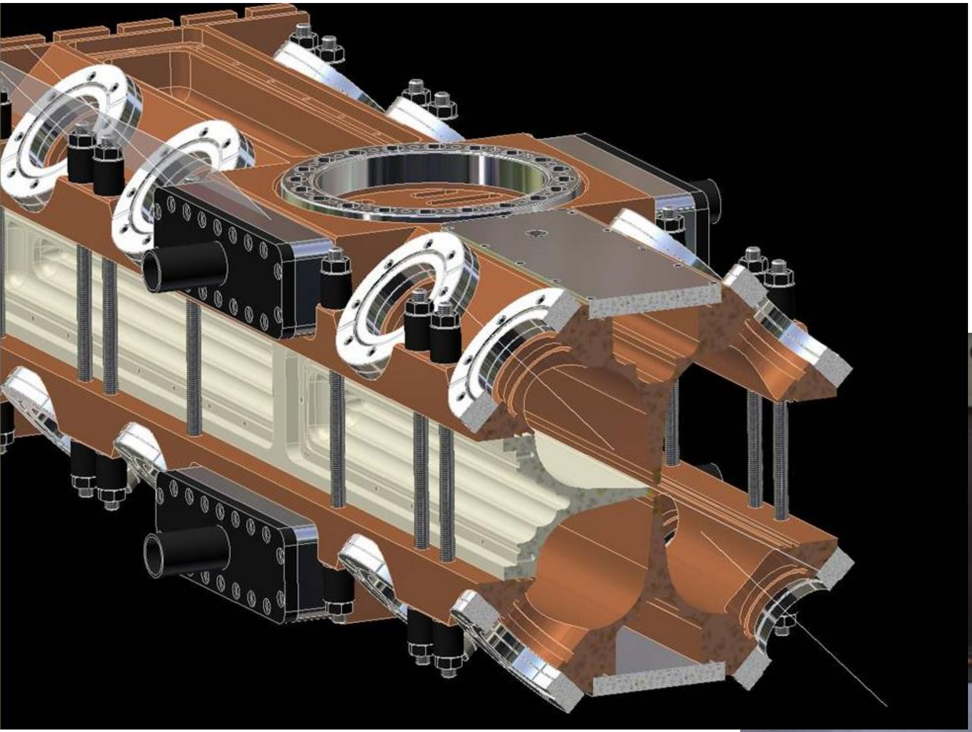
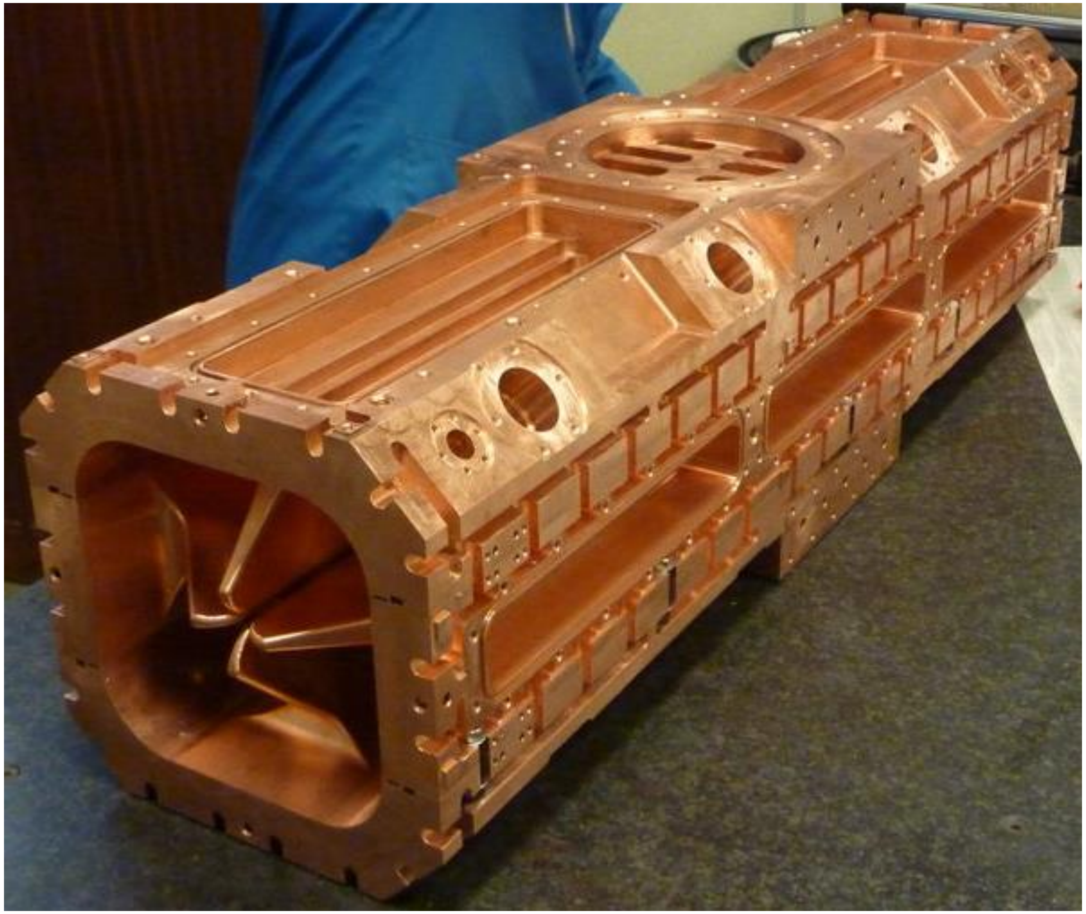
RFQ Construction

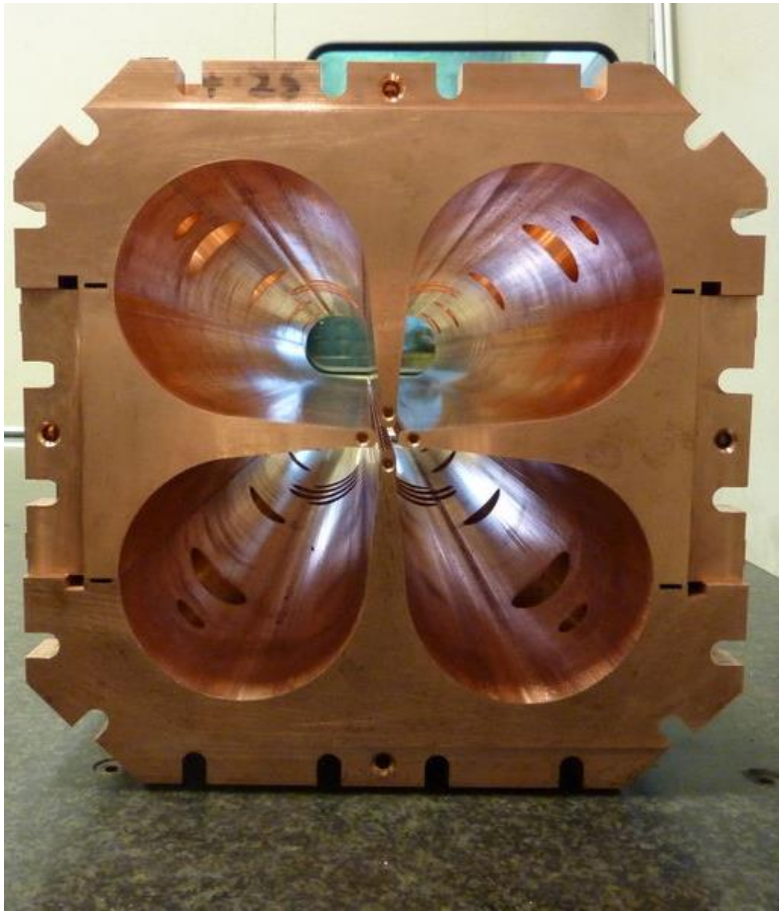


Novel cooling pocket design

Machined without using cutting lubricant

Completed first section of the RFQ





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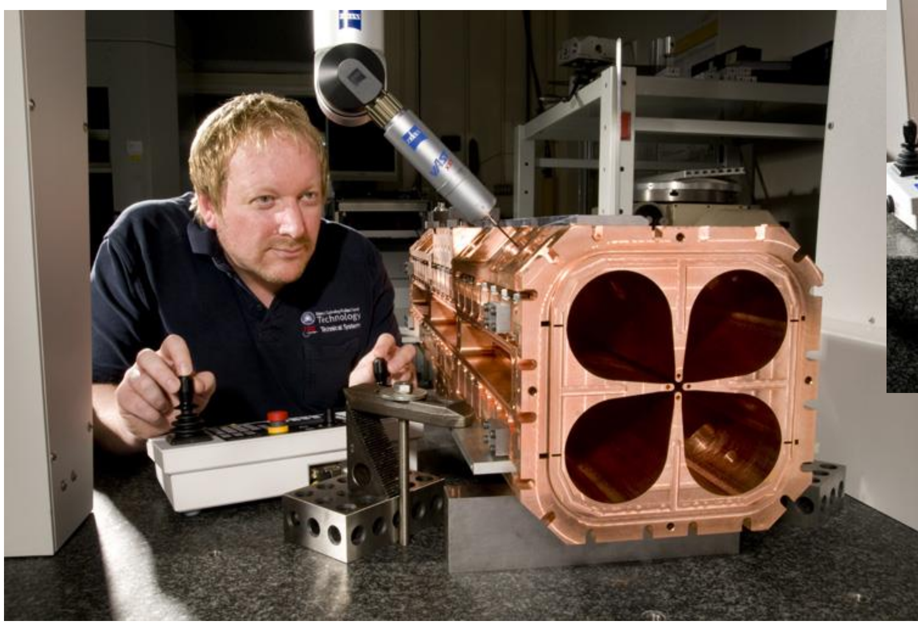
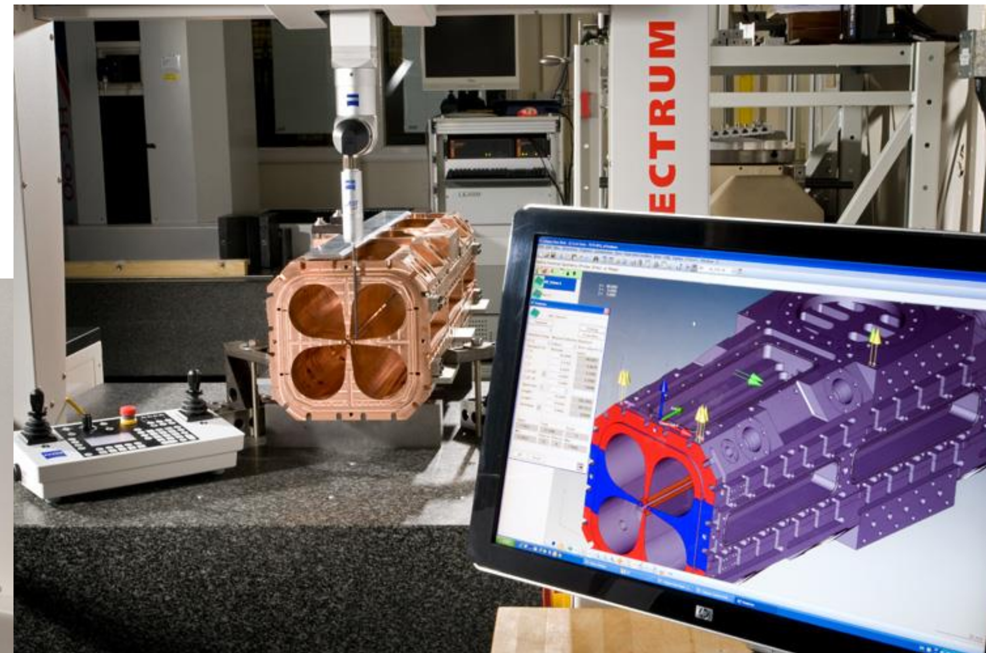
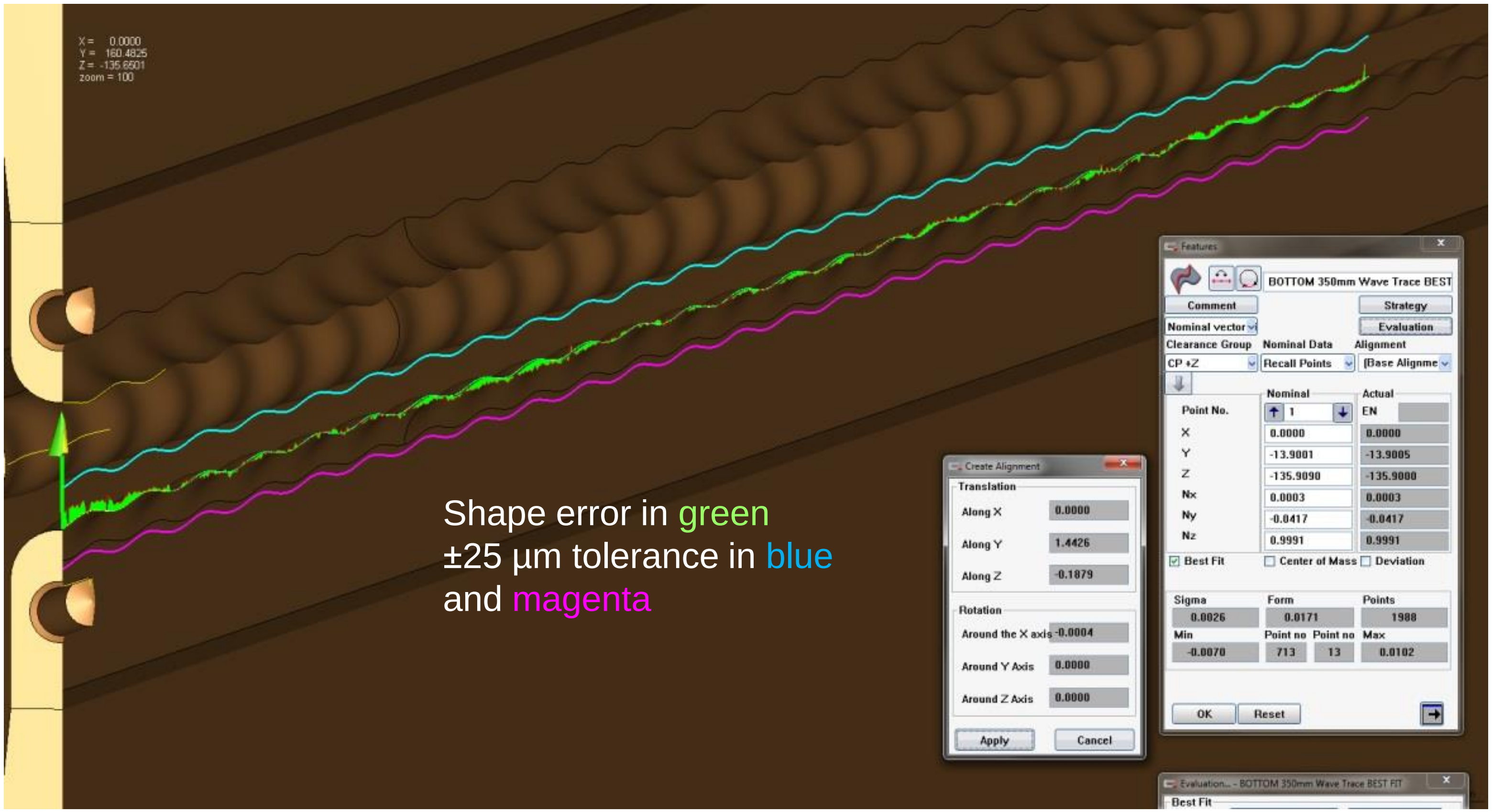
RFQ alignment survey at RAL metrology





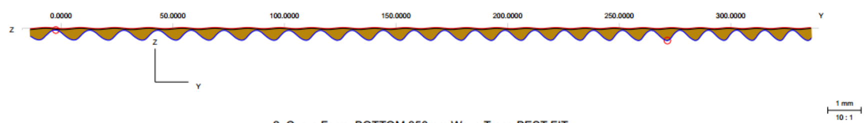
The modulations are ‘perfect’…



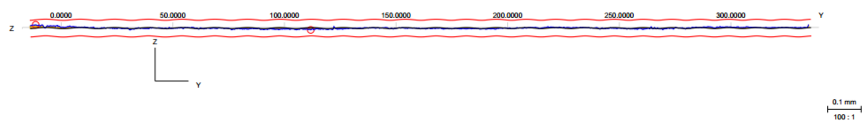
… but they are in the wrong place

ZEISS Calypso 5.2.20	Carl Zeiss	Date	February 6, 2014
		Order	
Part Number: Shimmed_Sectio… / CMM Type: SPECTRUM	Drawing No.: FETS_RFQ Section…	Department:	
		Operator	Master
Meas. Plan Name	FETS RFQ_M Dudman_FINAL CAD	Signature:	

1: Curve Form_BOTTOM 350mm Wave Trace



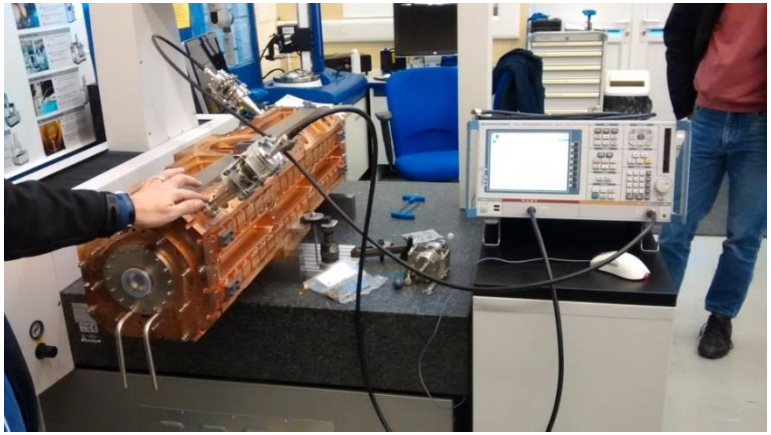
2: Curve Form_BOTTOM 350mm Wave Trace BEST FIT



	Identifier	Sigma [mm]	Form [mm]	Number of Points	Lower Tol. [mm]	Upper Tol. [mm]	MinInd	Min Dev. [mm]	MaxInd	Max Dev. [mm]	Best Fit	X [mm]	Y [mm]	Z [mm]		X	Y	Z
	Curve Form_BOTTOM 350mm Wave Trace	0.2235	0.3558	2000	-0.0250	0.0250	1629	-0.3558	67	-0.0291	Translation	0.0000	0.0000	0.0000	Rotation	0.0000	0.0000	0.0000
	Curve Form_BOTTOM 350mm Wave Trace BEST FIT	0.0026	0.0171	1988	-0.0250	0.0250	713	-0.0070	13	0.0102	Translation	0.0000	1.4430	-0.1917	Rotation	-0.0011	0.0000	0.0000

10 µm max shape error

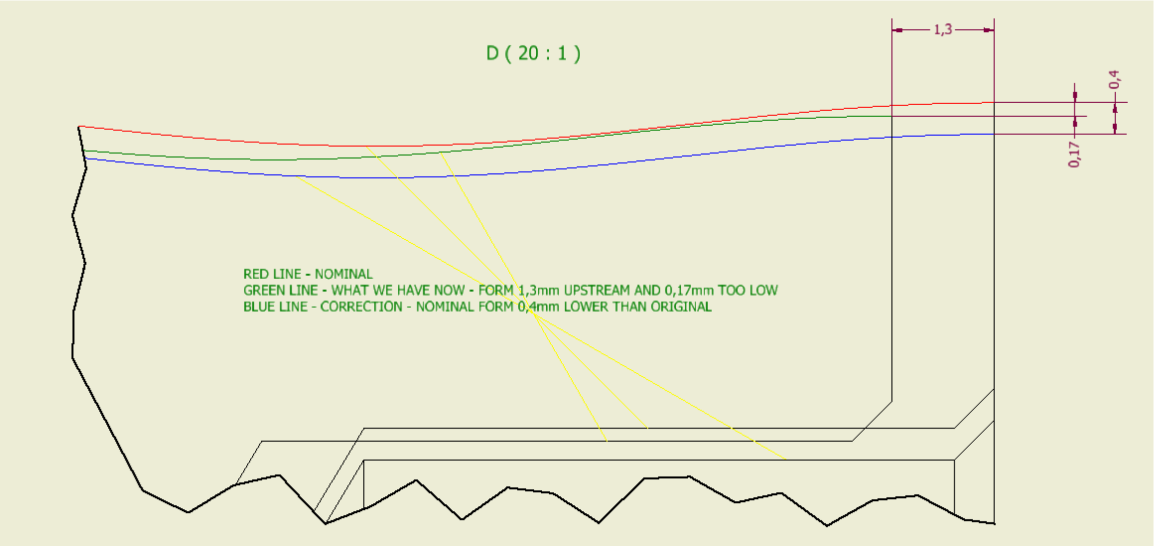
1.4 mm & 0.2 mm offsets!



CST simulations predicted a 6 MHz frequency shift. Confirmed by measurement.
Outside of the acceptable tuning range.

Solution

Machining of test pieces confirmed the cause - a tool tip radius setting in the CNC software.
Due to the shallow modulation in section 1 the error can be corrected by a minor re-machining of the internal surfaces.



With the error satisfactorily explained, final machining of sections 2, 3 & 4 is well underway.

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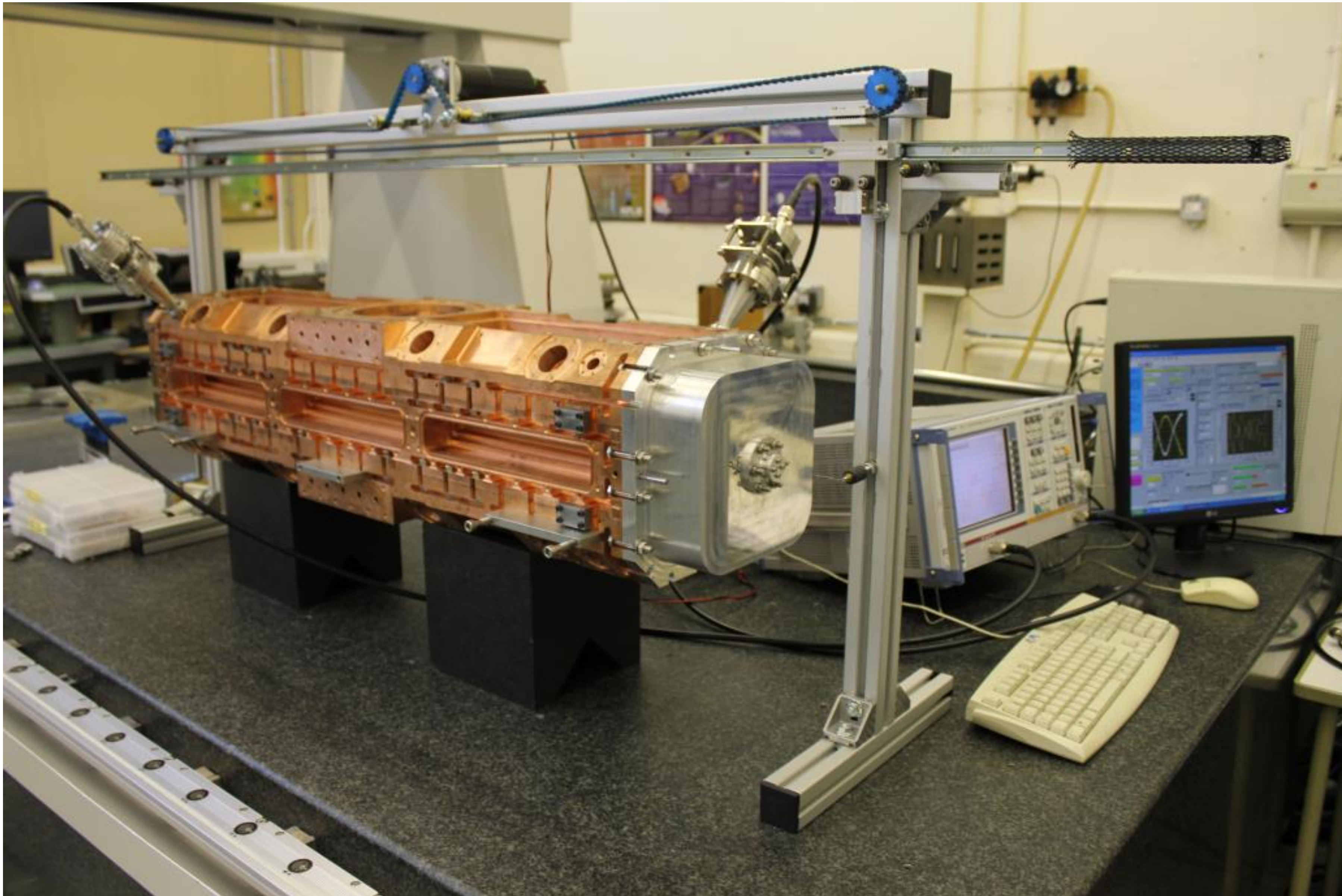
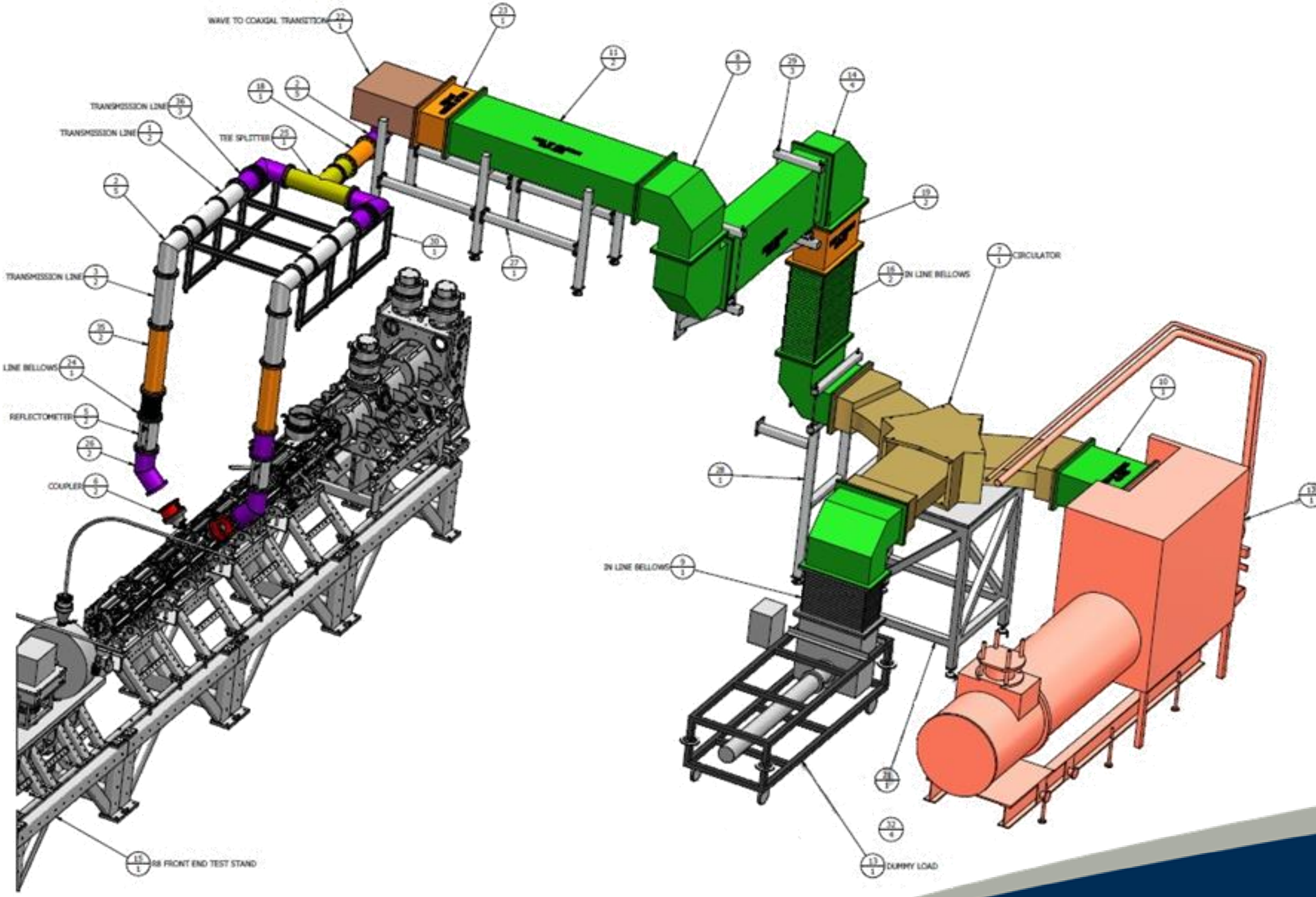


RF System



WAVE TO COAXIAL TRANSITION
TRANSMISSION LINE
TRANSMISSION LINE
TEE SPLITTER
TRANSMISSION LINE
LINE BELLOWS
REFLECTOMETER
COUPLER
CIRCULATOR
IN LINE BELLOWS
IN LINE BELLOWS
DUMMY LOAD
RB FRONT END TEST STAND

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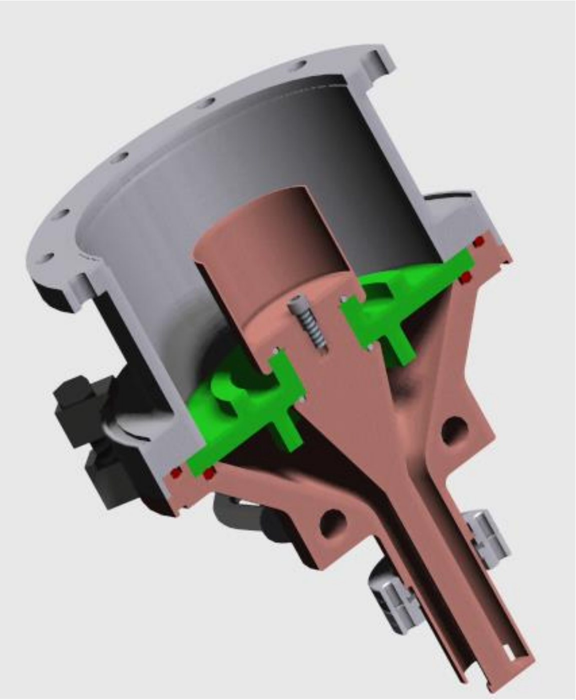
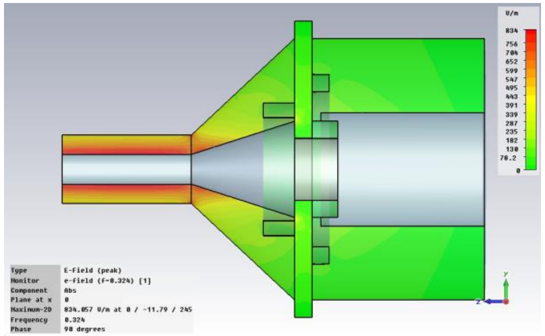
RFQ Power Coupler





The high power RFQ coupler engineering design is complete and its performance confirmed by simulation. It will soon go for manufacture.

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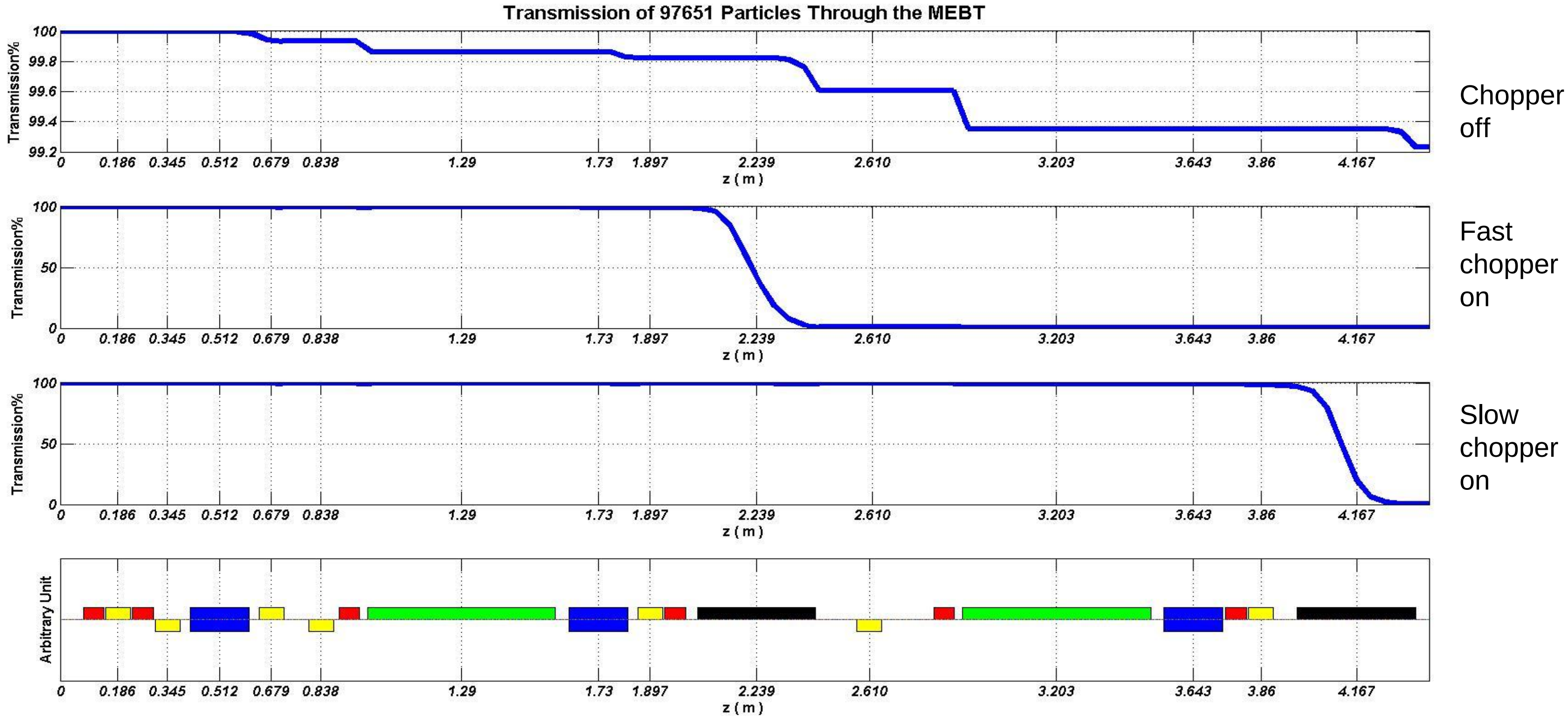
MEBT
Medium Energy Beam Transport

Lattice Requirements:

- Perfect chopping
- Low beam loss: 3 MeV causes activation
- Low emittance growth
- Space for diagnostics
- Minimize cost i.e. reduce:
    - Number of components
    - Magnet & RF power

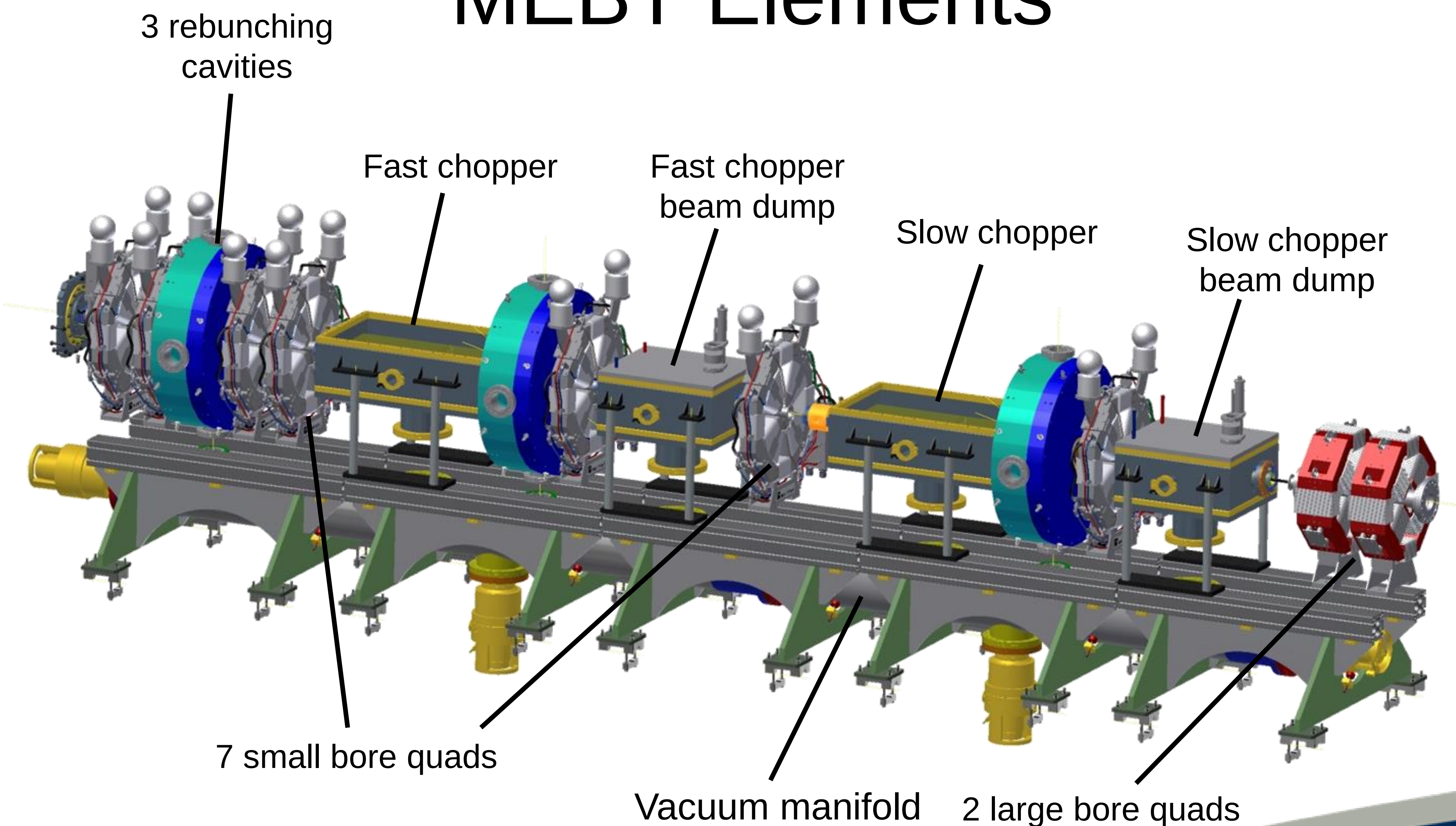
Achieving all of the lattice requirements simultaneously has proved challenging and time consuming.

MEBT Design Optimisation



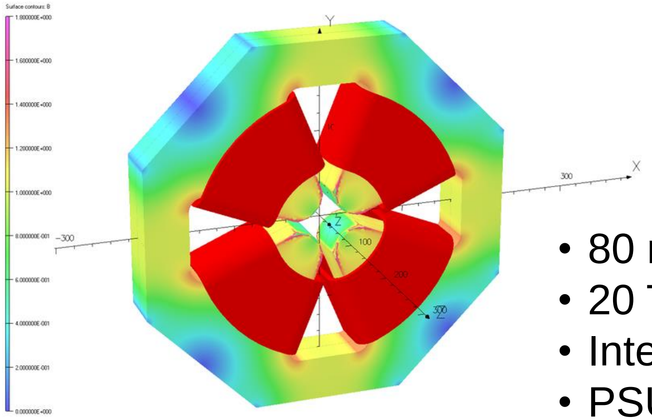
Parameter	2011	2013	Parameter	2011	2013
Beam Loss	*2.5%*	*0.8%*	*MEBT Length (m)*	*3.8*	*4.4*
Quad Strength(T/m)	*6-30*	*5.3-18.3*	*Emittance Growth(x-y-z)*	*20%*	*37% / 15% / -3.5%*
Cavity Voltage (kV)	*50-150*	*<100*	*Extinction*	*99%*	*99.2%*
Chopper Length (mm)	*450*	*604*			

MEBT Elements

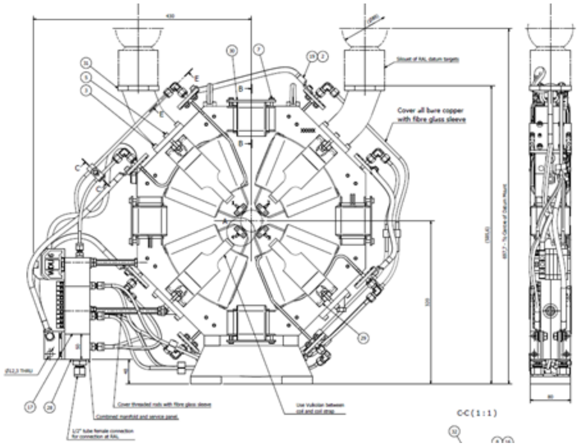


MEBT Quadrupoles

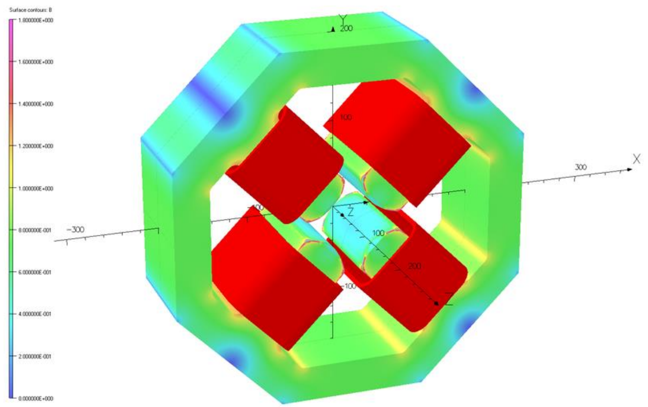
Small Bore



- 80 mm total length
- 20 Tm^{-1} gradient
- Integrated steering
- PSUs ordered
- Manufacture underway at Danfysik



Large Bore



- 160 mm total length
- 20 Tm^{-1} gradient
- Tender complete

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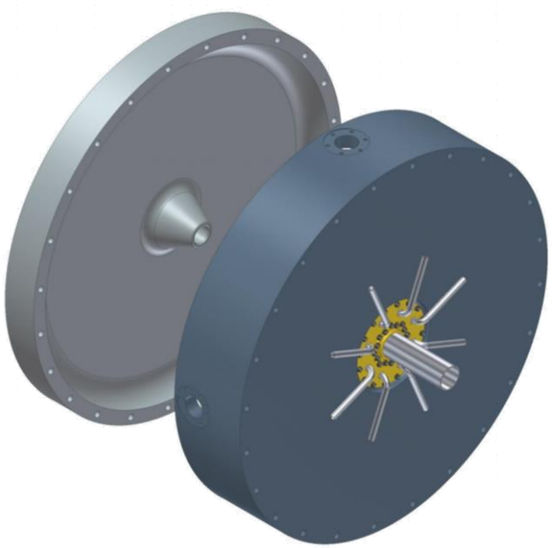
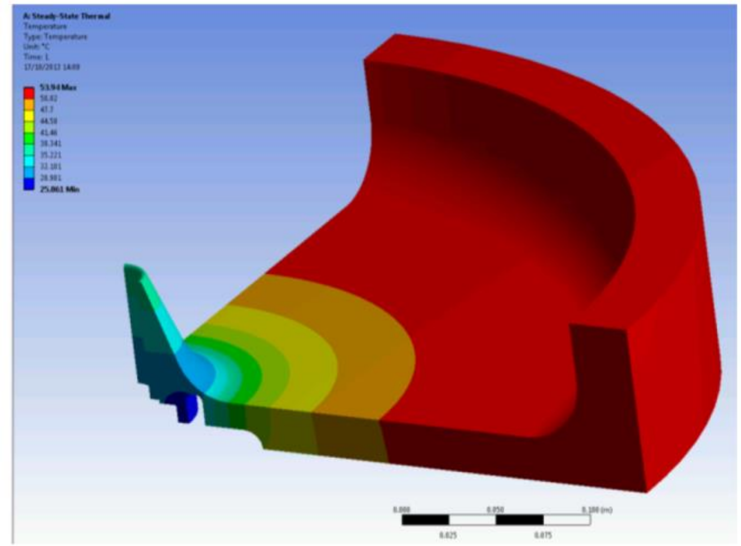
MEBT Rebunching Cavities





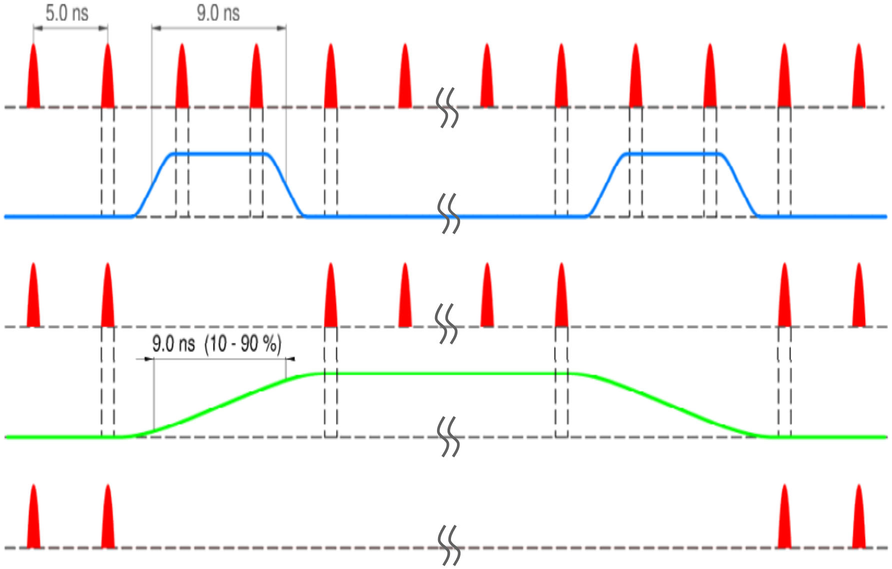
Re-bunching cavities:

- Pill-box with re-entrant nose cones
- 324 MHz, ~8 kW peak power
- 100 kV effective voltage
- Detailed engineering completed
- Copper plated stainless steel for lower cost

FETS Chopper

‘Perfect’ Electrostatic Chopping

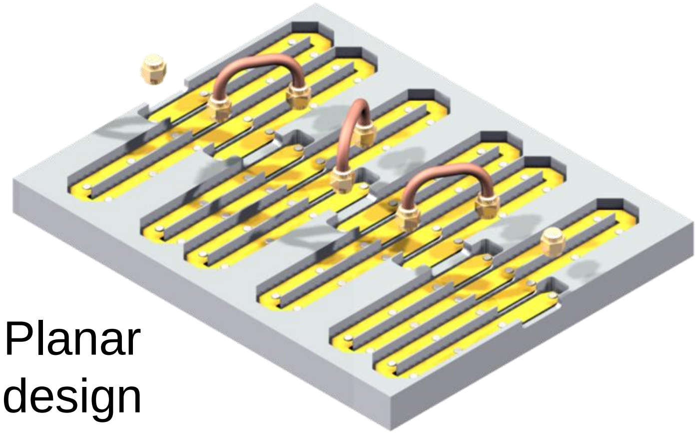
‘Fast-slow’ chopping scheme:



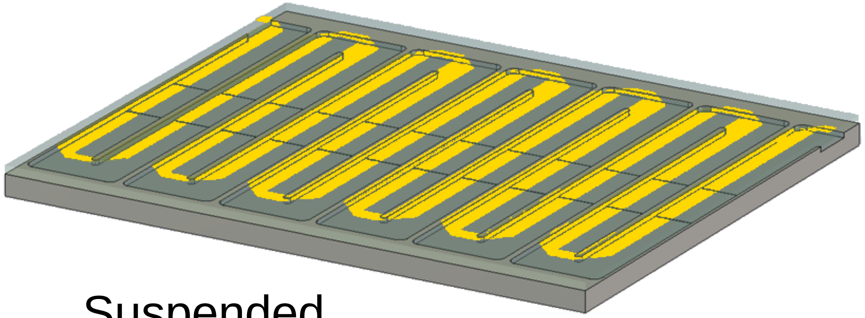
Specification:

- No partially chopped bunches
- <2 ns rise time: between bunches
- ~150 μs gap in bunch train
- 6 kW dumped beam power

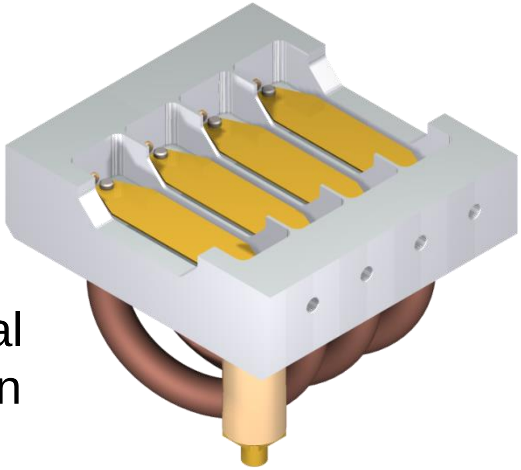
3 Fast Chopper Designs



Planar design



Suspended micro-strip design



Helical design

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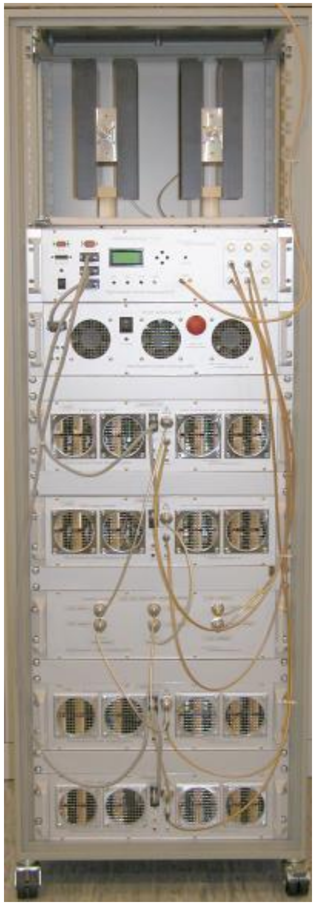
Chopper Power Supply



High peak power loads

Control and interface

Power supply

9 x Pulse generator cards

9 x Pulse generator cards

Combiner

9 x Pulse generator cards

9 x Pulse generator cards

1.7 m

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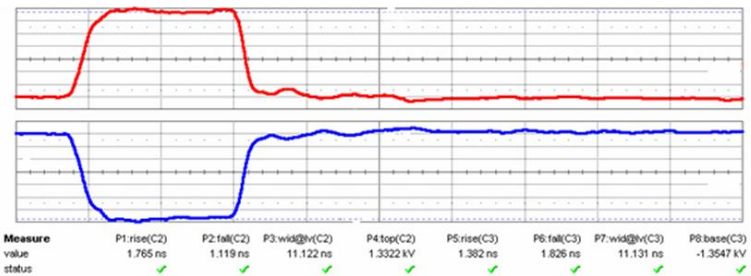
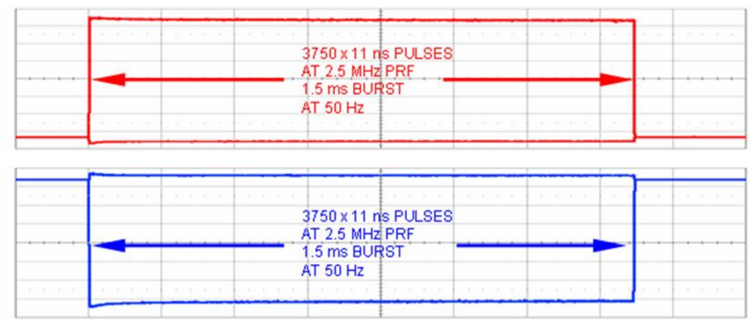
Chopper Power Supply



FPG Waveforms at ± 1.4 kV peak & 5 ns / div.

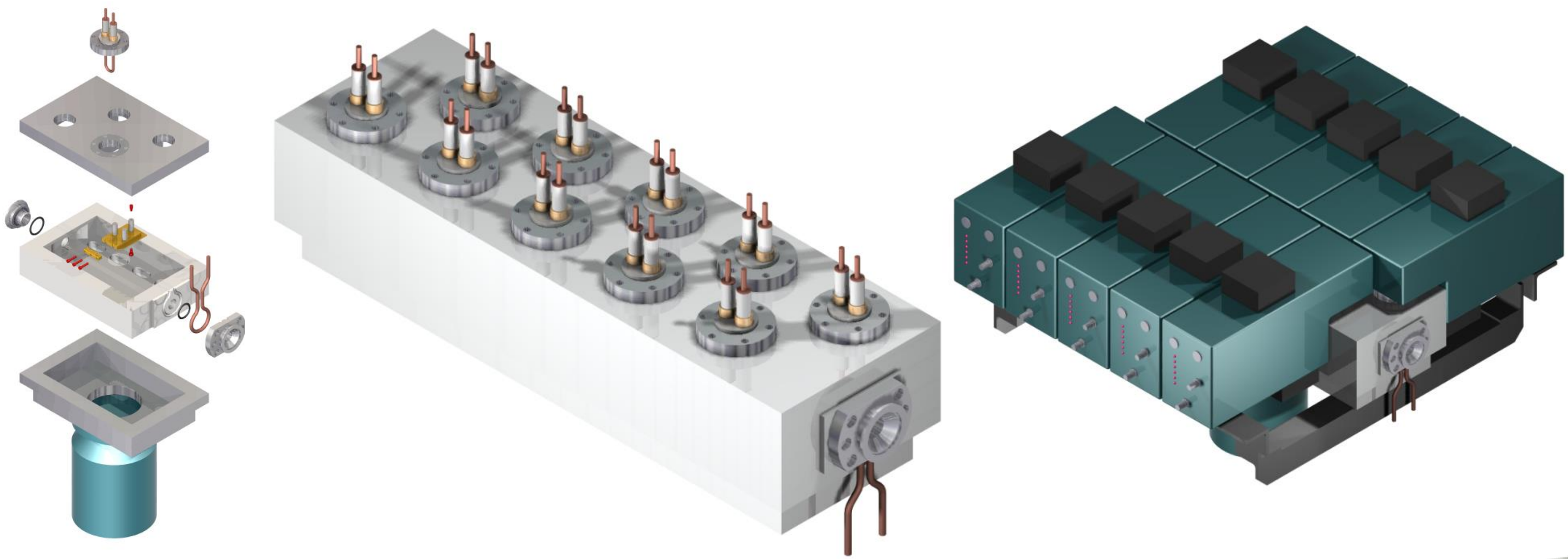


FPG Waveforms at ± 1.4 kV peak & 0. 2 ms / div.

Pulse Parameter	FETS Requirement	Measured	Compliancy	Comment
Amplitude (kV into 50 Ohms)	± 1.4	± 1.5	Yes	Scalable
Transition time (ns)	≤ 2.0	T_{rise} = 1.8, T_{fall} = 1.2	Yes	10 – 90 %
Duration (ns)	10 - 15	10 - 15	Yes	FWHM
Droop (%)	2.0 in 10 ns	1.9 in 10 ns	Yes	F_{3dB} ~ 300 kHz
Repetition frequency (MHz)	2.4	2.4	Yes	
Burst duration (ms)	0.3-1.5	1.5	Yes	
Burst repetition frequency (Hz)	50	50	Yes	Duty cycle ~ 0.27 %
Post pulse aberration (%)	± 2	± 5	No	Reducible
Timing stability (ps over 1 hour)	± 100	± 50	Yes	Peak to Peak
Burst amplitude stability (%)	+ 10, - 5	+ 5, - 3	Yes	

Slow Chopper

The slow chopper deflector and feed-through design is nearing completion. Design of the complete assembly with drivers is well underway.



Diagnostics

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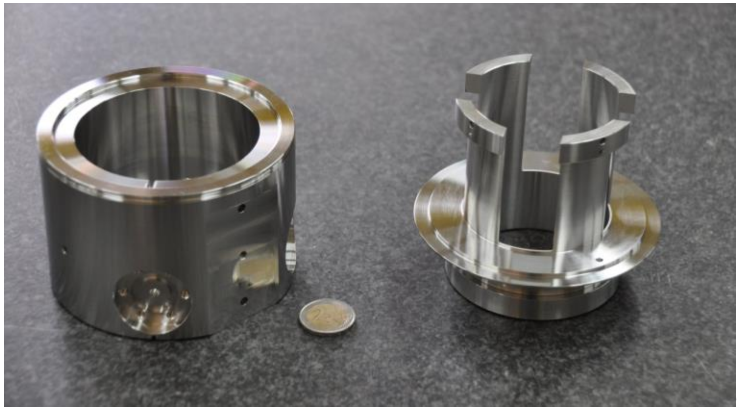
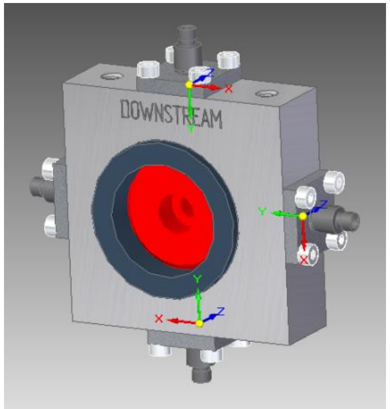
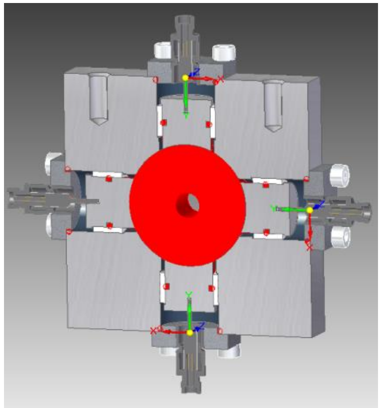
MEBT BPMs

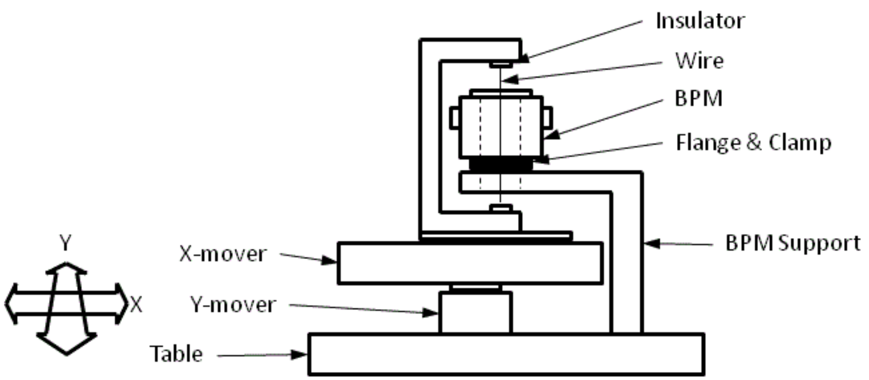
The FETS MEBT will utilise both CERN shorted stripline BPMs and an in-house designed compact button BPM.

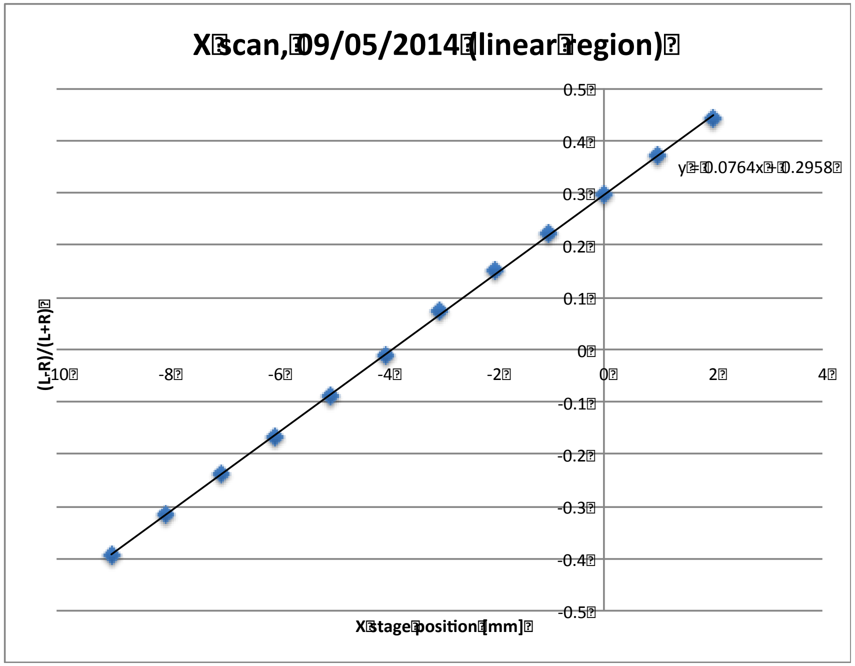


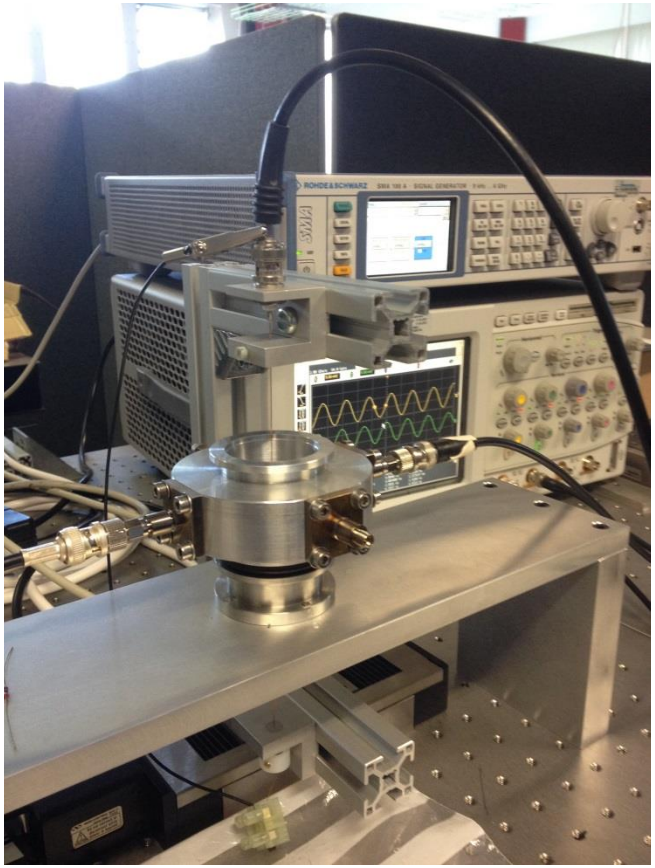




BPM Testing

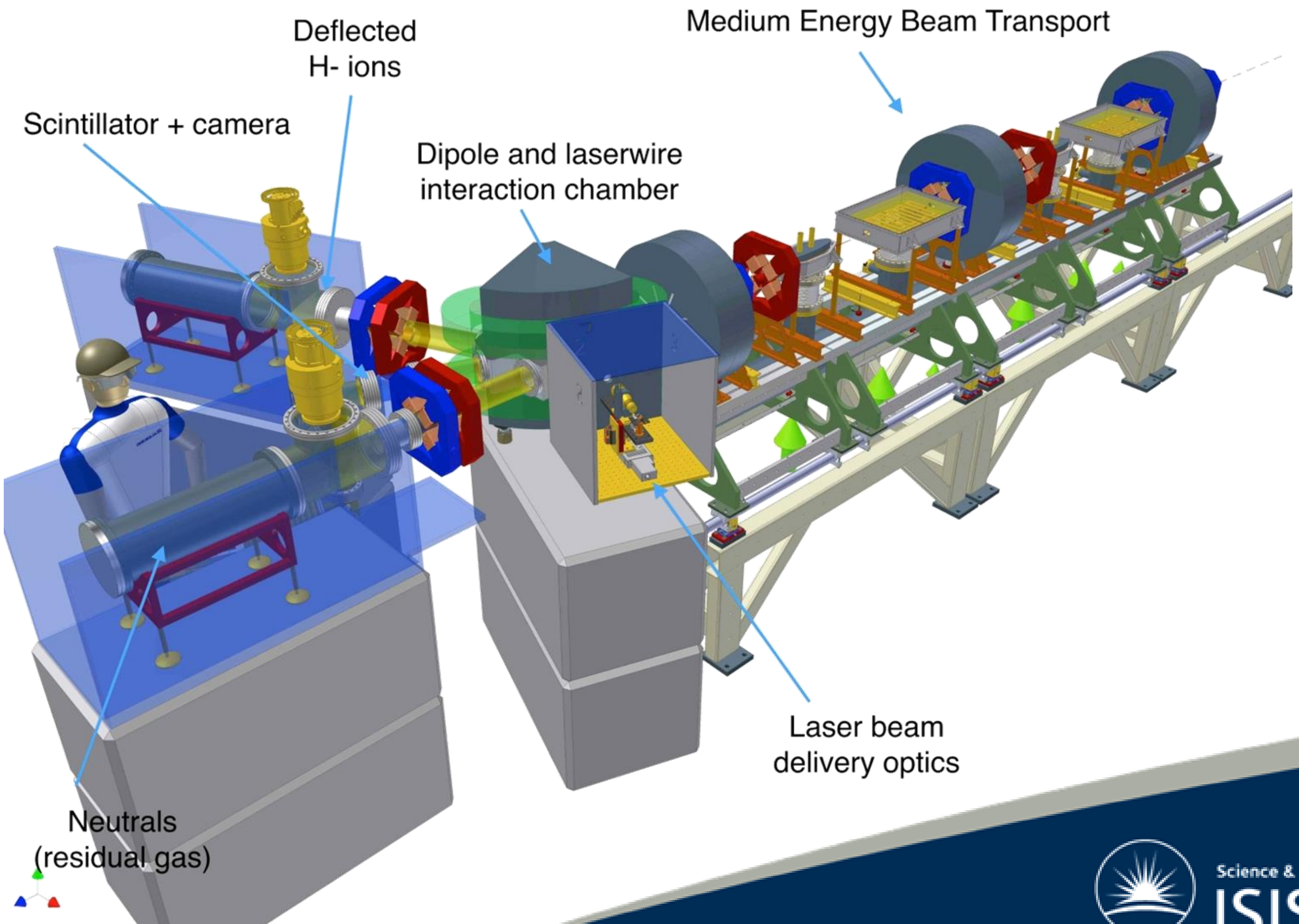






Button BPMs are being evaluated on a wire test rig.

Laser Photo-detachment Diagnostic



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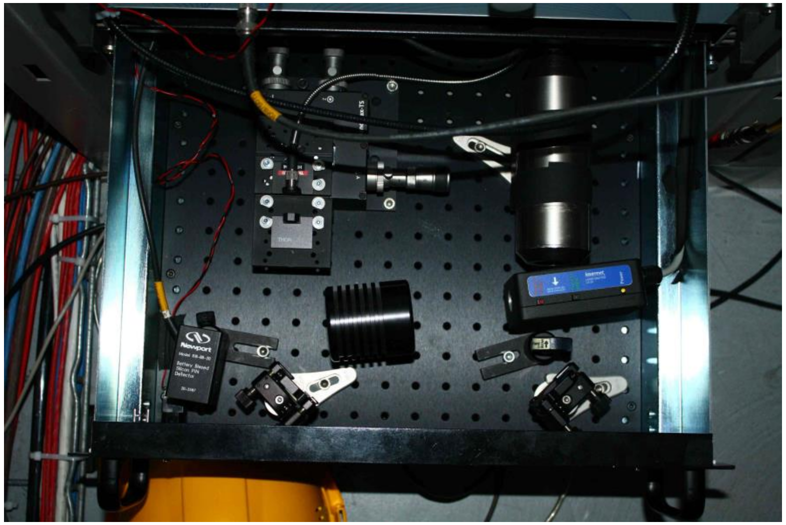
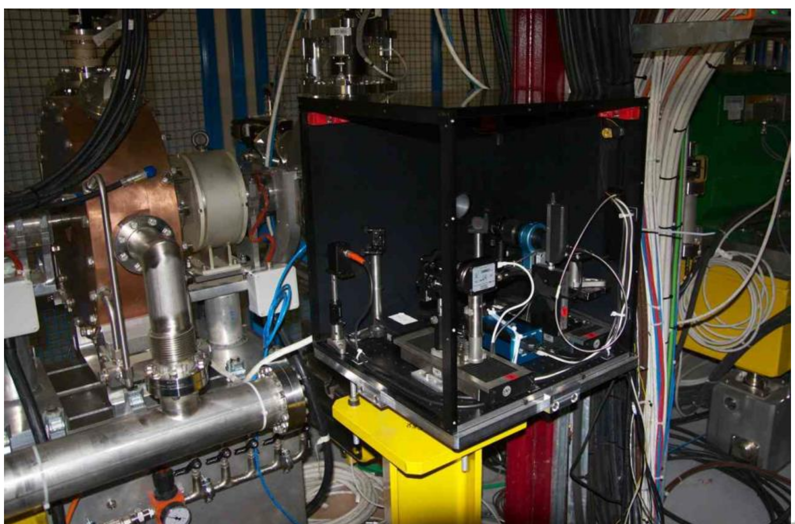
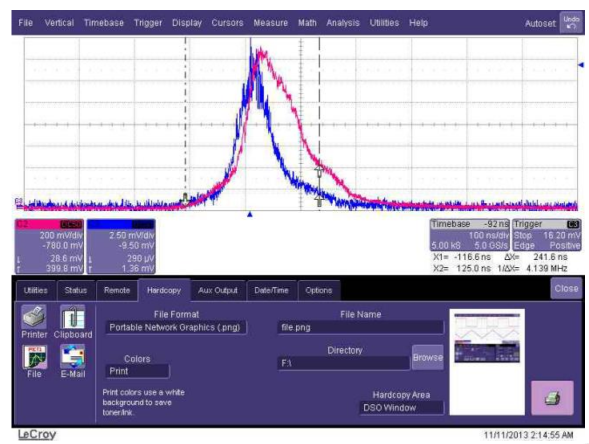
CERN Collaboration





- CERN are also pursuing an H^- laser diagnostic for Linac4.
- Linac4 are more advanced with their front end, FETS are more advanced with our laser system.
- A perfect opportunity for collaboration.
- The FETS laser system is at CERN and installed on the Linac4 front end.



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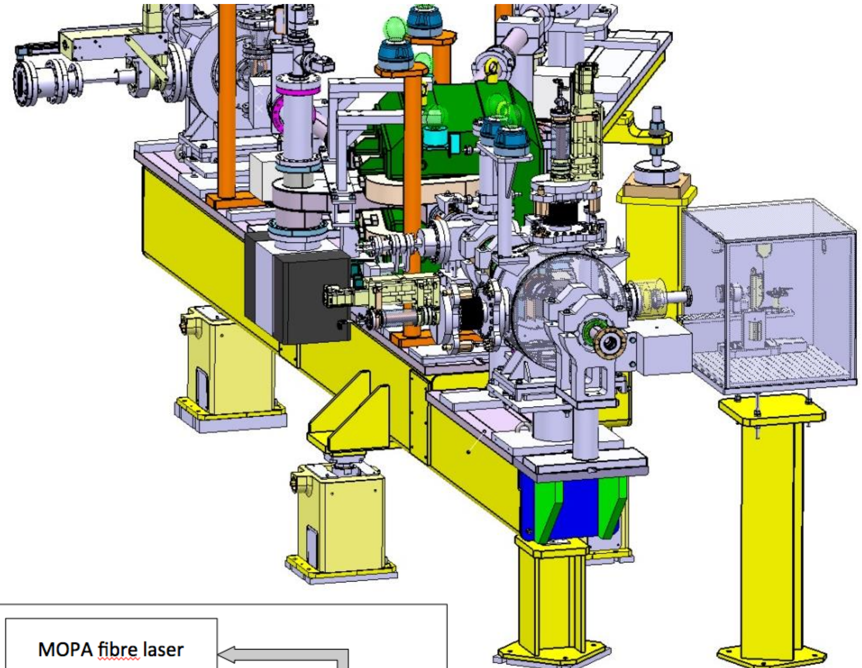

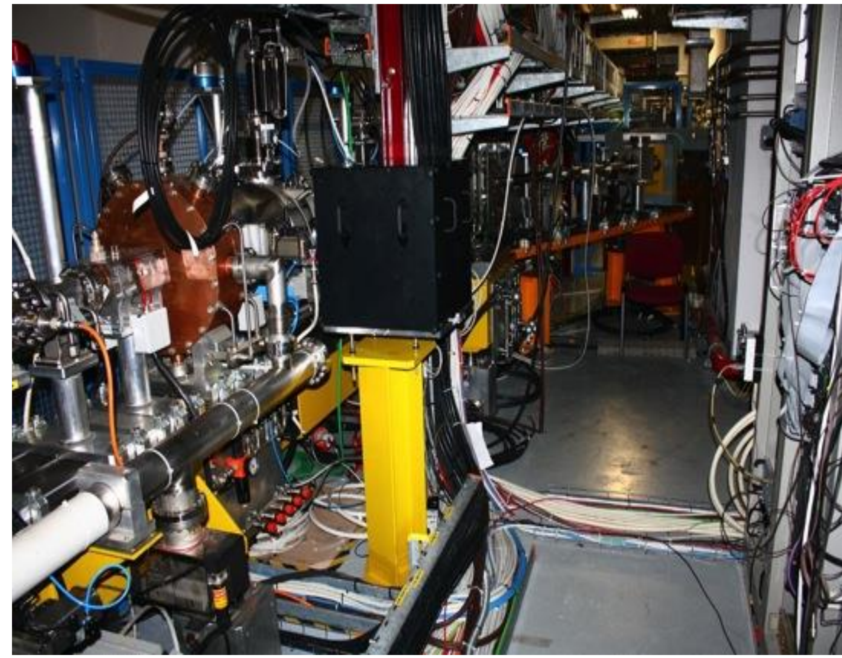

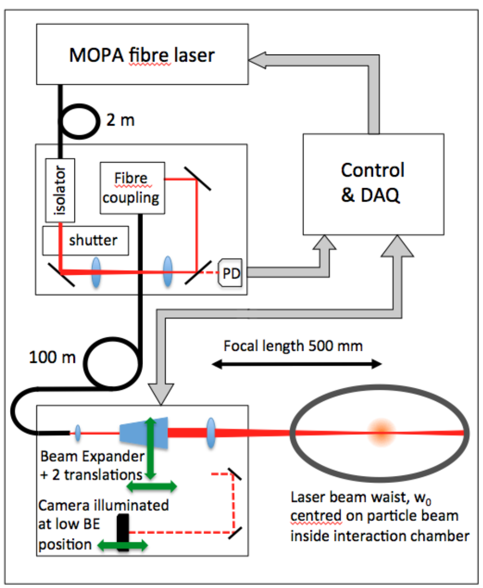

The beam energy and current are the same as FETS. Only the duty factor differs.

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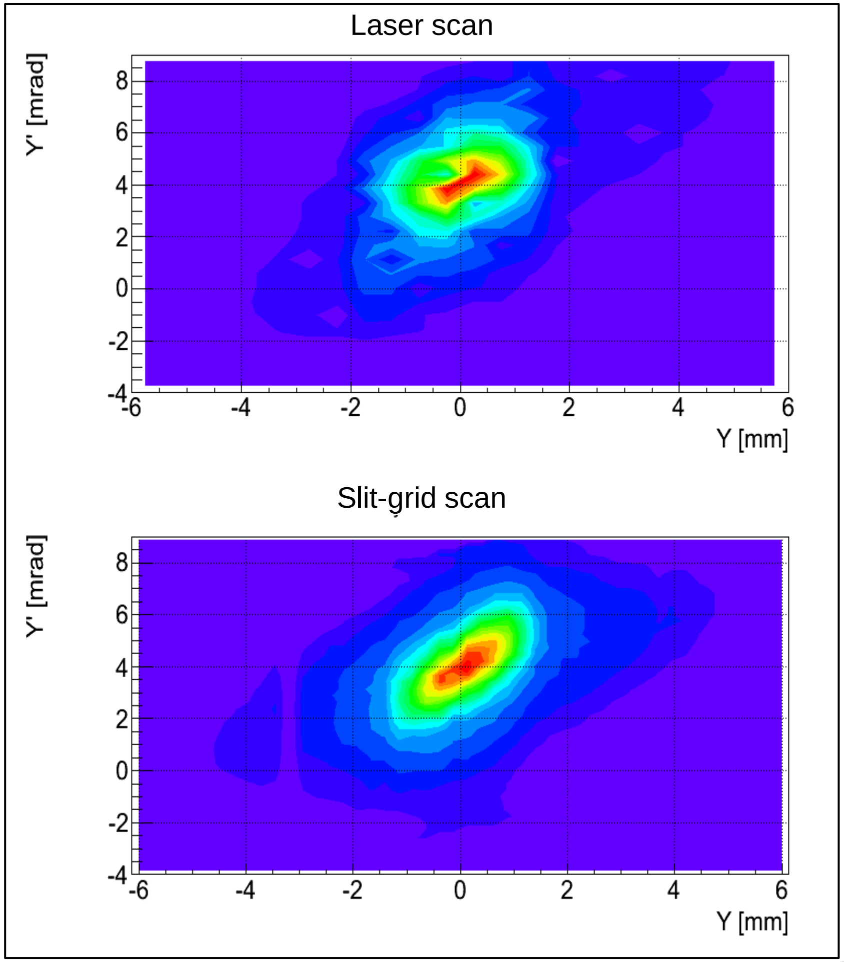
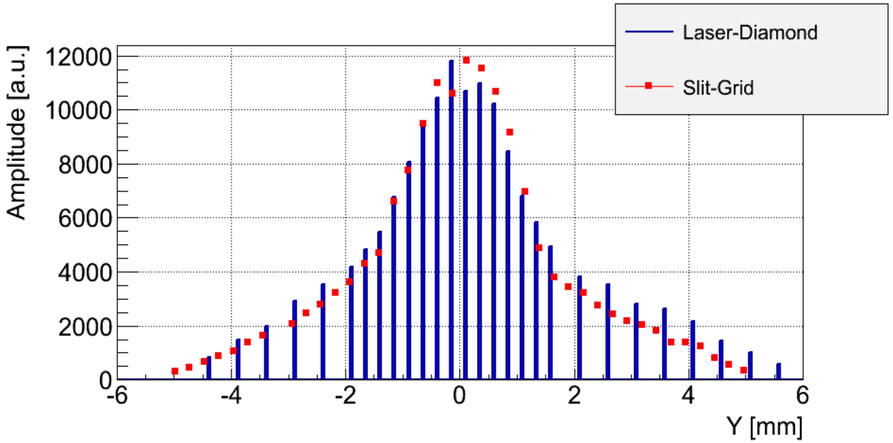
First Laser Emittance Measurement

Laserwire profiles compare well with grid profiles.
Photo-detachment emittance measurement shows very good agreement with slit-grid.



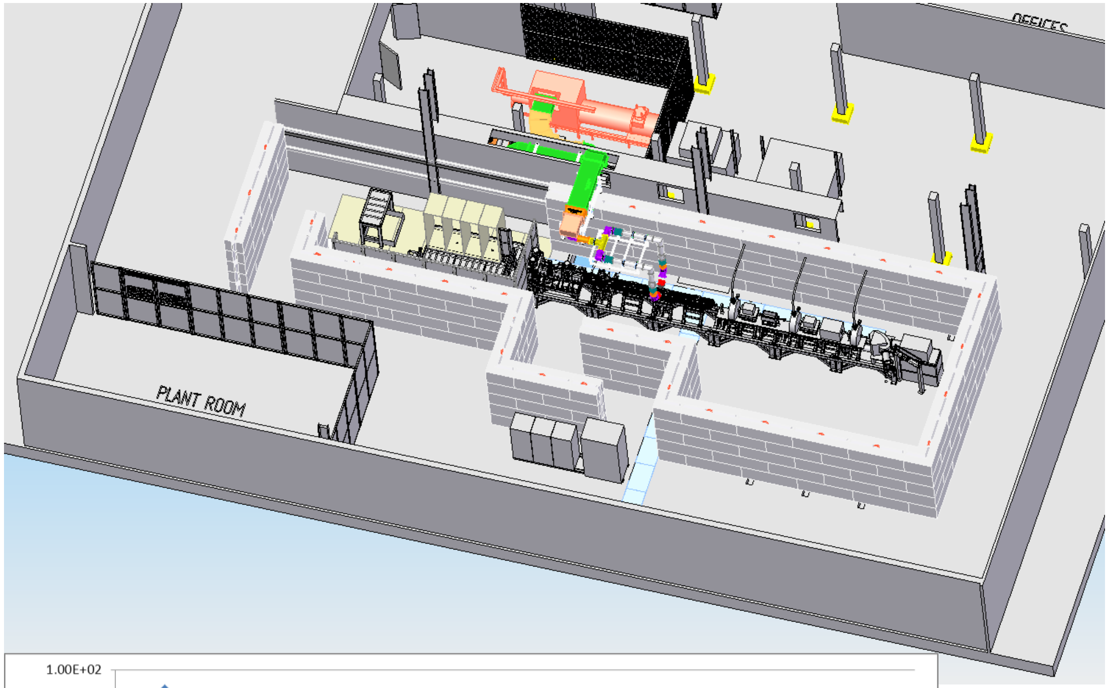


These measurements are now being repeated at 15MeV after installation of the next section of Linac4.

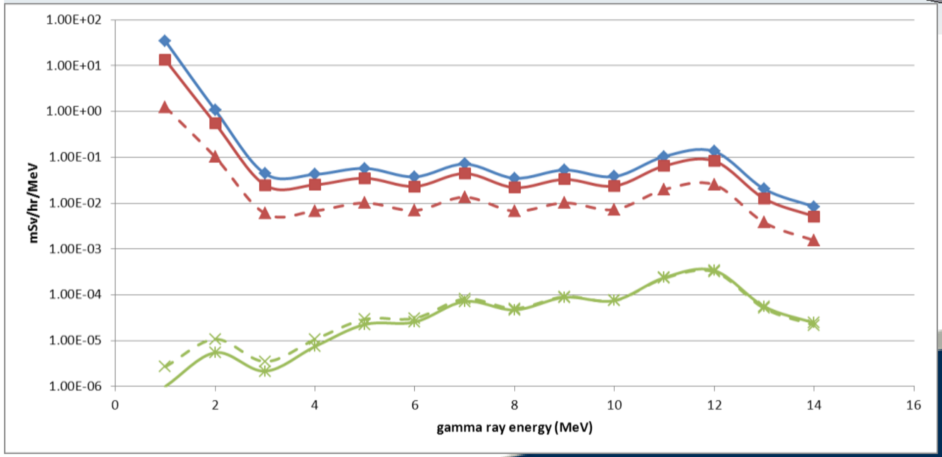
Radiation Protection

- Every effort made to exclude radiologically ‘bad’ materials from FETS.
- Even so significant shielding required to protect personnel from expected mSv/h levels of neutrons and gammas.

Radiation shielding



- A shielding concept has been developed and approved by RAL RPA
- Most of the concrete blocks procured
- Roof design complete



Gamma ray attenuation by various shielding scenarios

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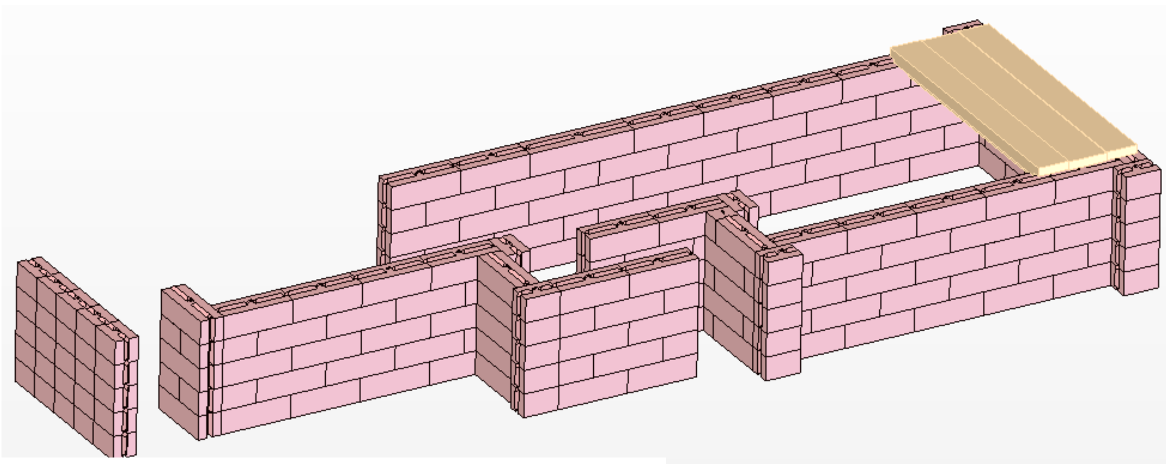
Hall cleared for shielding installation.

Shielding Installation



The last additional blocks needed to complete the enclosure are in manufacture.

A complete personnel interlock system compliant with all appropriate regulations will be supplied by ISIS ESSO group.

Hire of a specialist crane is required for installation of the north shield wall.

Cooling Plant


industrialcooling
CLIMAVENETA

Control Systems

- **Primary equipment:**
  - ISIS Control System
  - CompactPCI crates
  - X-windows/Exceed user interface
- **Experiments and diagnostics:**
  - PXI crates
  - Labview user interface
- **Personnel Interlocks:**
  - Hardwired relays and PLC systems
  - Compliant with safety standards

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The reasons for FETS

From the beginning FETS was seen as more than simply an accelerator R&D project for RAL or ISIS.

It was always hoped that the project could be a means of encouraging accelerator R&D activities in UK university groups and greater collaboration between RAL and those groups.

It has been very successful in meeting those aims.

The university groups are an integral part of and full stakeholders in the FETS project.

RAL accelerator experts now lecture on university courses.

Structure of the FETS project

FETS is a 'laboratory project' in the sense that it needs a lab. to host it.

However the participation of the university groups is essential to its success.

- FETS is directly funded by the Science and Technology Facilities Council, the UK funding agency.
- Funding includes all hardware and most staff costs.
- Some staff costs are covered by university groups' rolling grants.
- FETS is hosted by ISIS which covers some of the infrastructure costs.
- FETS relies on some specialist groups within RAL/ISIS such as HSE, vacuum, health physics, metrology, etc …

Management of the FETS project

Alan letchford
Project leader

Juergen Pozimski
Principal investigator

Management of the FETS project

Alan letchford
Project leader

Juergen Pozimski
Principal investigator

Laboratory

Universities

Management of the FETS project

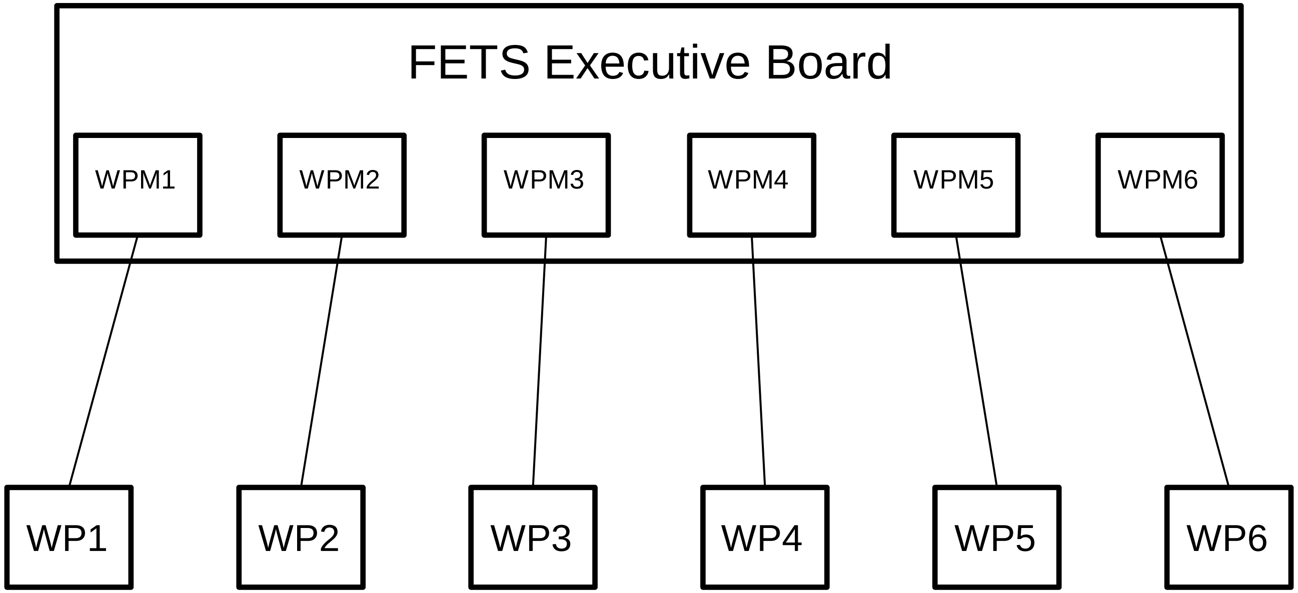
FETS Executive Board

Alan letchford
Project leader

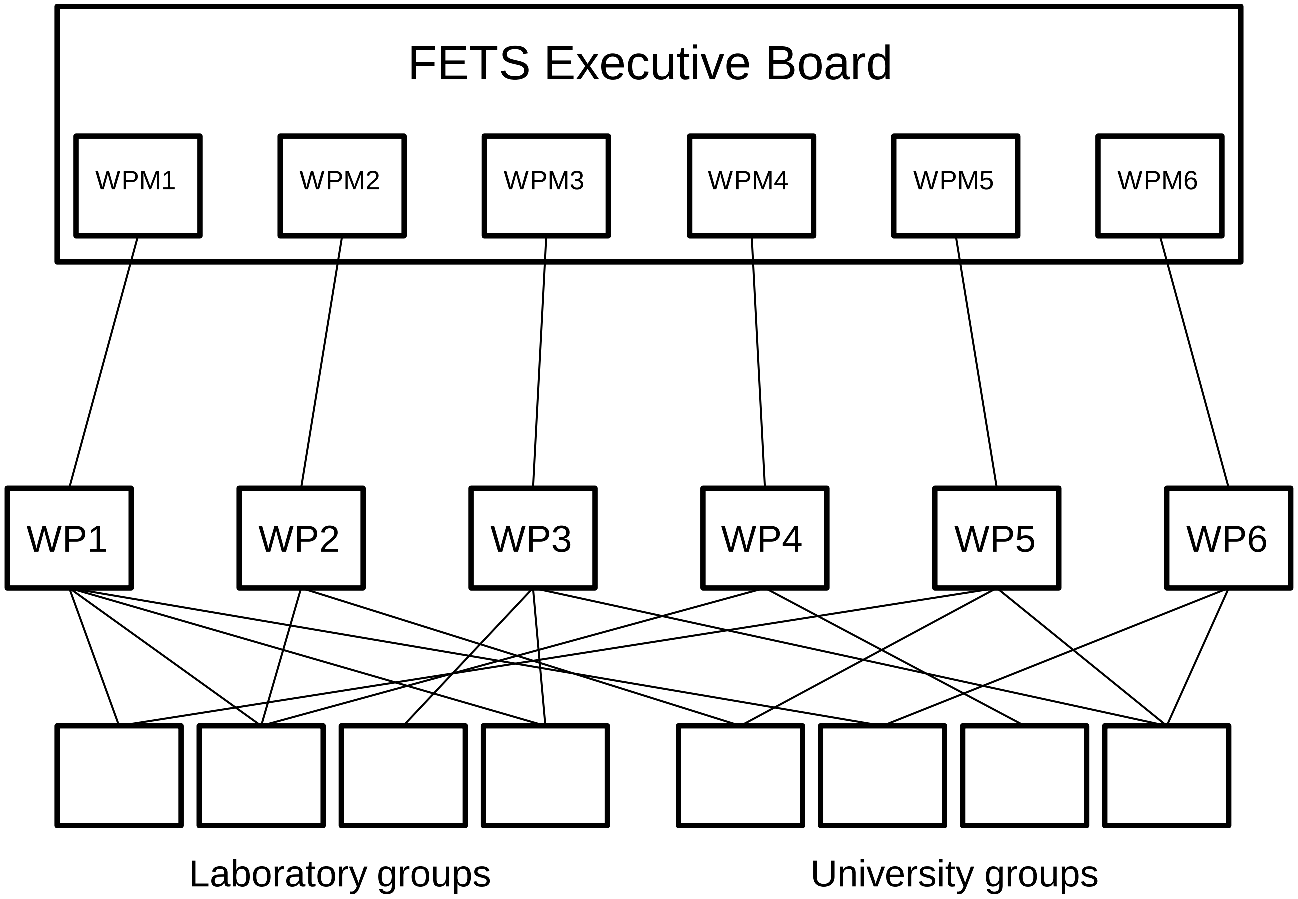
Juergen Pozimski
Principal investigator

Work package managers
(RAL & Universities)

Management of the FETS project



Management of the FETS project



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Pros and cons of a lab/university collaboration

From the perspective of a career laboratory person

Pros

- Manpower
- Specialist knowledge
- A different approach
- New ideas
- ‘Young blood’ – the next generation
- Different funding opportunities
- Alignment with higher management strategy
- Other interactions beyond the FETS project

Cons

- Managing a distributed team
- Occasional reluctance to step away from the computer and get hands dirty
- Not always aligned with the ‘big picture’

Does it work?

Overwhelmingly YES!

The distributed nature of the FETS team is not without management challenges compared to a purely laboratory based project
and
Satisfying the universities' agendas and priorities occasionally complicates the route to the project goals

However these minor disadvantages are relatively insignificant compared to the overwhelmingly positive aspects of the lab/university interactions.

FETS is a high priority accelerator project identified as of high strategic importance in the UK.
It is doubtful if its status and progress could have been achieved without the active participation of the university collaborators.
Other projects within RAL/ISIS could benefit from similar participation.

Thank you for your attention.