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FETS Technical Report

Alan Letchford

Oversight Committee, RAL, 5th December 2012

Contents

- Considerable technical progress has been made towards the FETS goal of delivering a chopped, 3 MeV beam in R8.

- A summary of the highlights of most recent progress and status will be given.

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Front End Test Stand (FETS)

High brightness H^- ion source

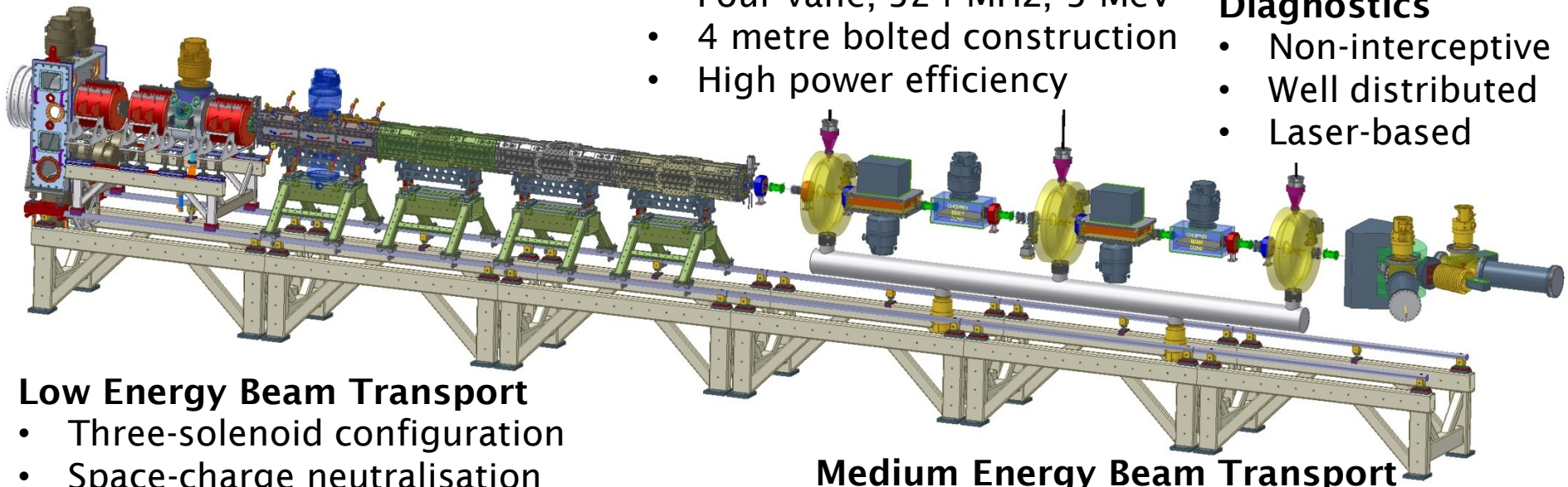
- 4 kW peak-power arc discharge
- 60 mA, 0.25 π mm mrad beam
- 2 ms, 50 Hz pulsed operation

Radio Frequency Quadrupole

- Four-vane, 324 MHz, 3 MeV
- 4 metre bolted construction
- High power efficiency

Diagnostics

- Non-interceptive
- Well distributed
- Laser-based



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

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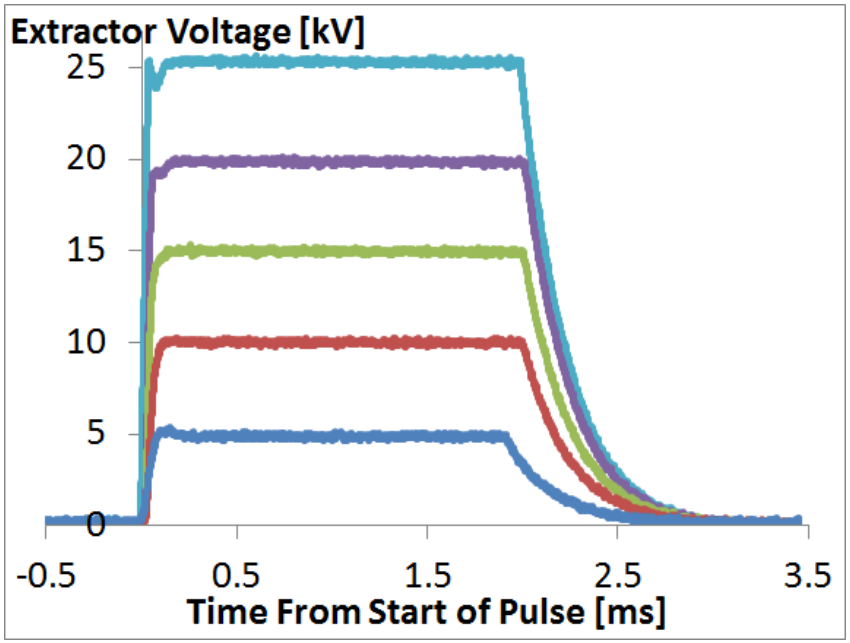
High Duty Cycle Extract Power Supply

A new higher voltage, long pulse extract power supply has been developed for the ion source. An improved magnet design allows for beam extraction at higher voltages.



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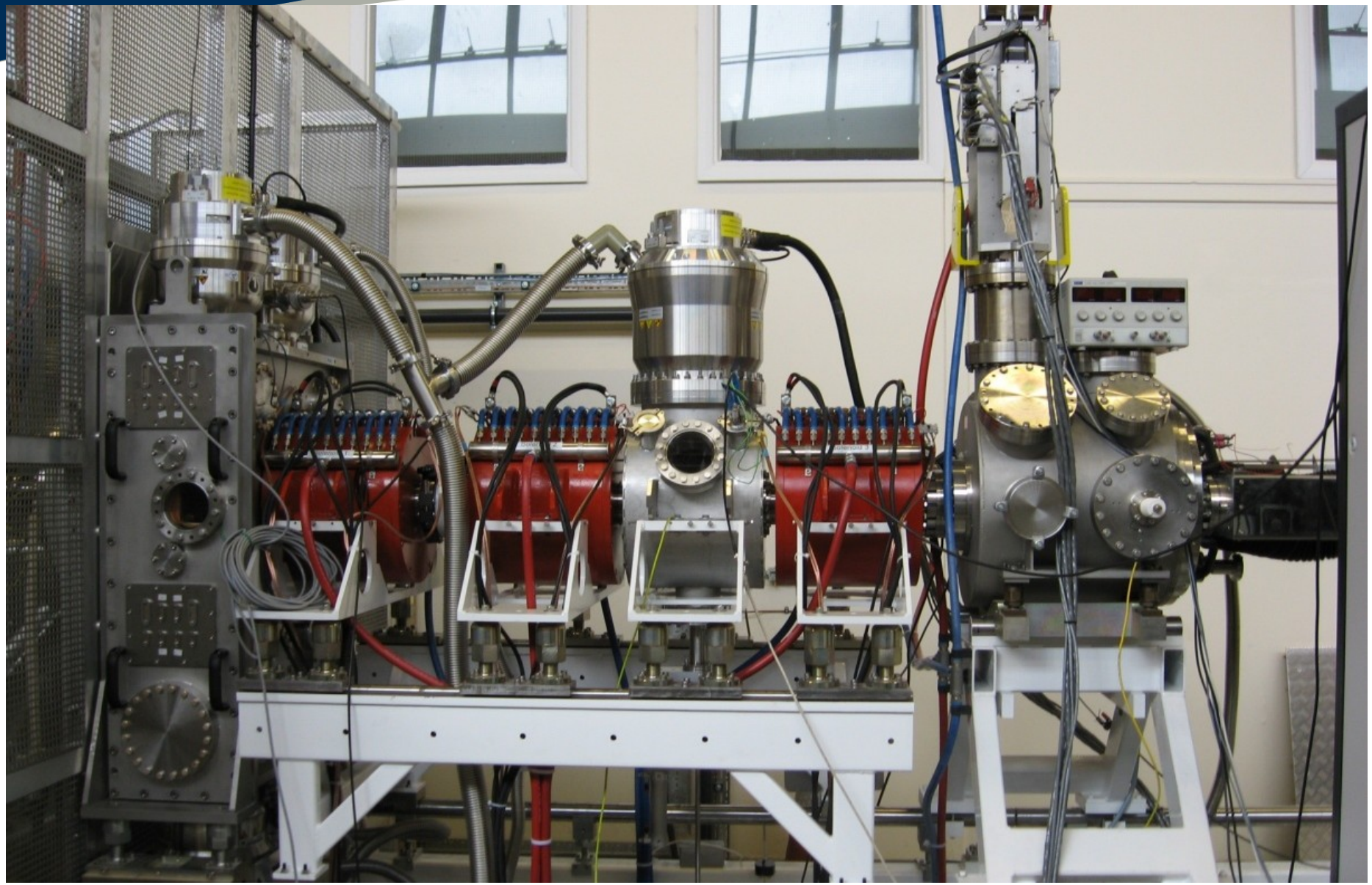
Low Energy Beam Transport (LEBT)



LEBT Beam Transport Studies

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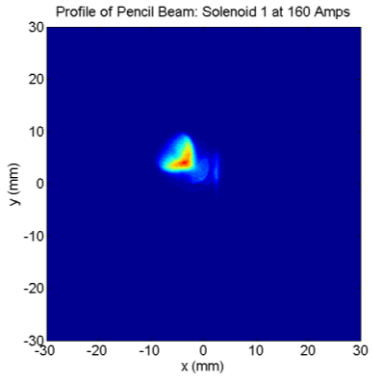
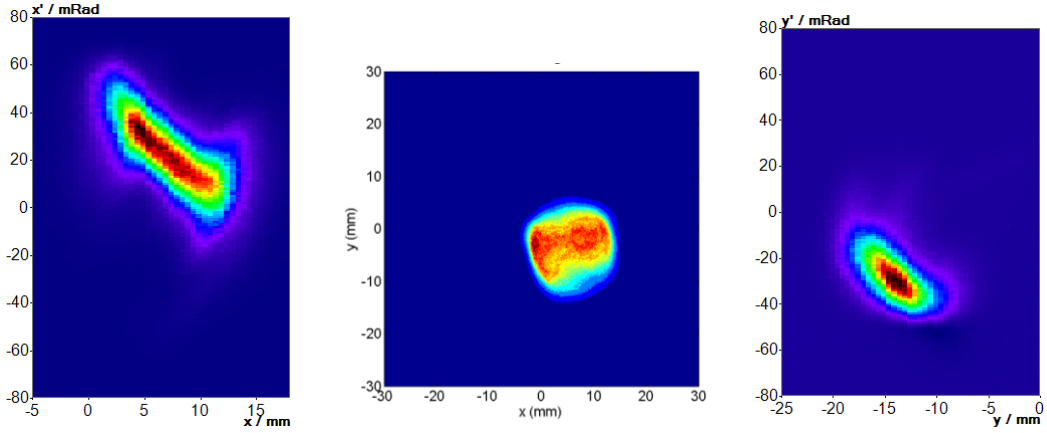
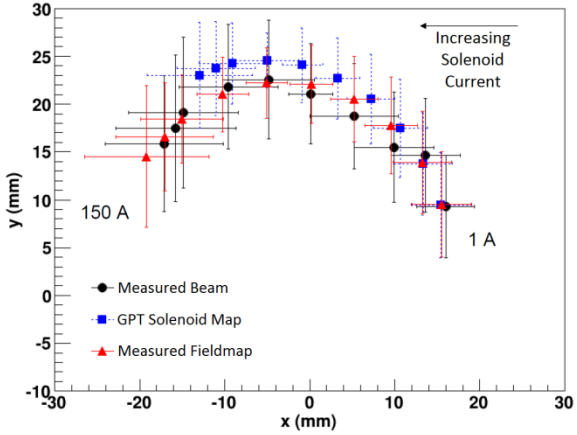
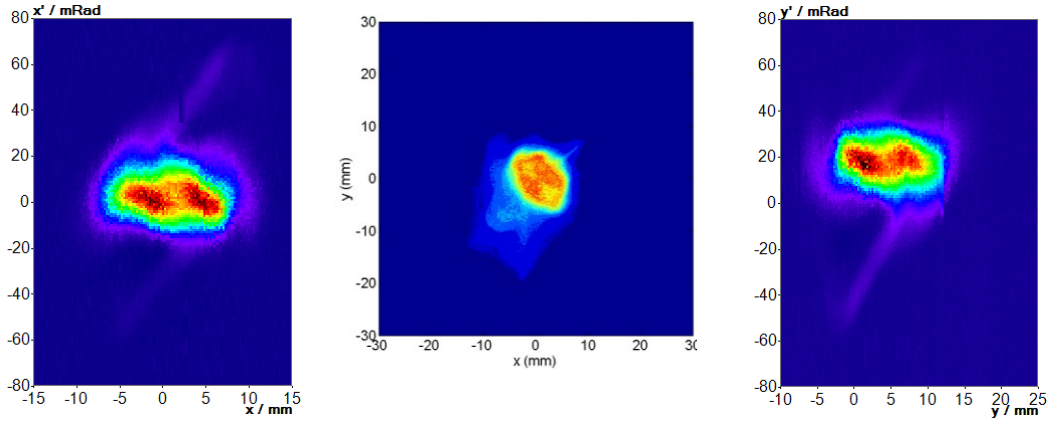
Although good transmission was achieved a major concern was significant misalignment of the beam





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





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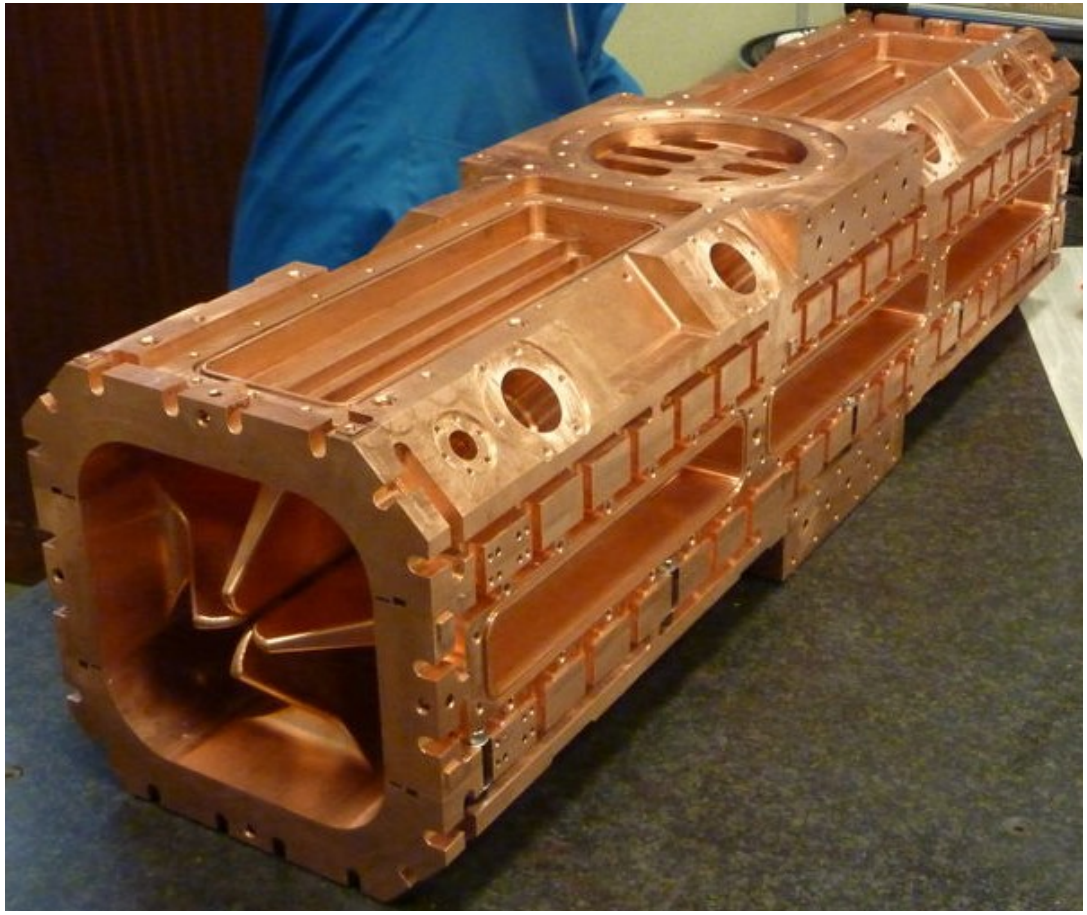
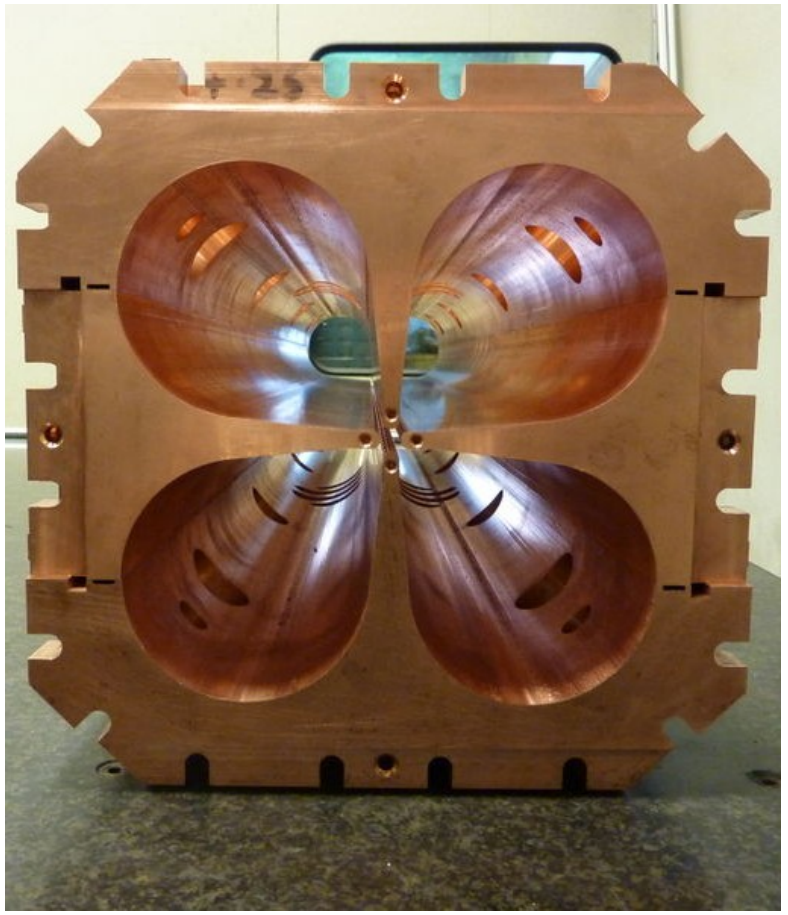
FETS Radio Frequency Quadrupole (RFQ)

- 4 sections, each made of 2 major + 2 minor vanes
- Bolted construction, novel cooling, circular cross-section
- Section 1 complete: undergoing CMM survey in R12
- Sections 2, 3 & 4 in final machining phase





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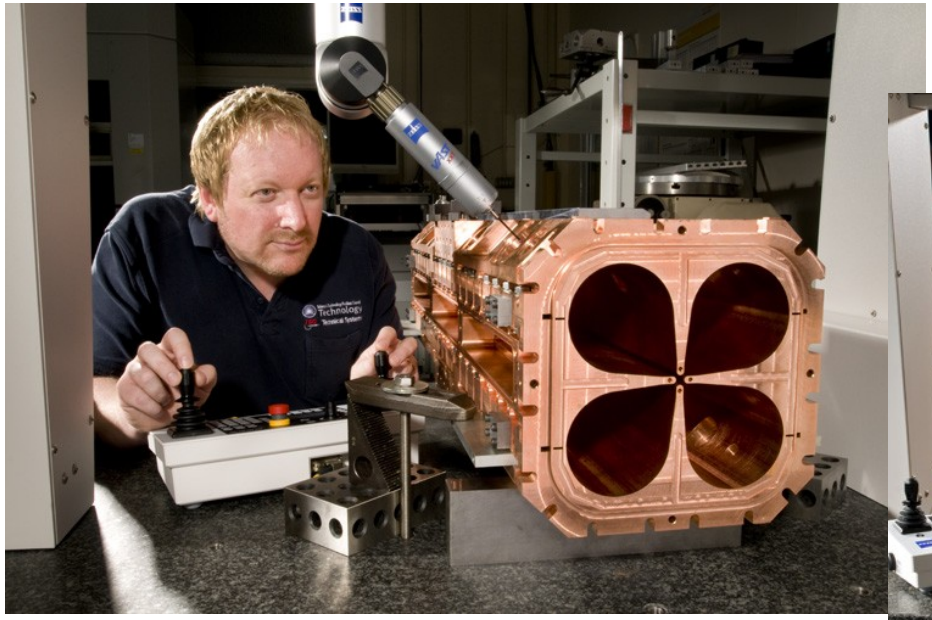
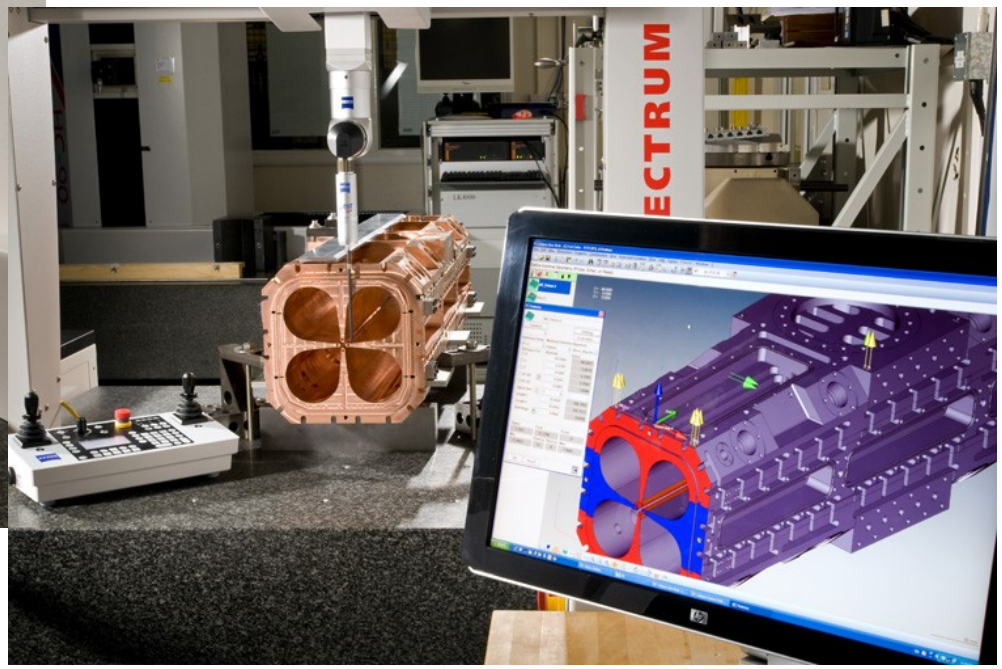
RFQ alignment survey

Due to some delays out of the team's control and an ultra conservative approach to proceeding when unsure, the first section of RFQ is over 1 year late arriving at RAL compared to early expectations.

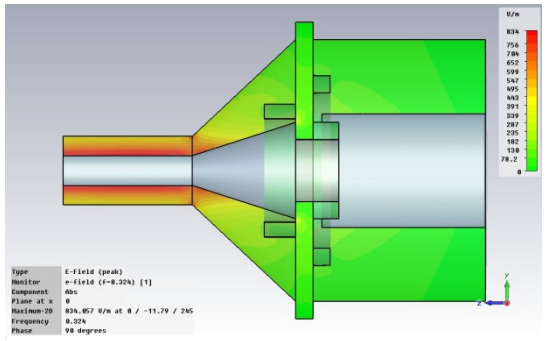




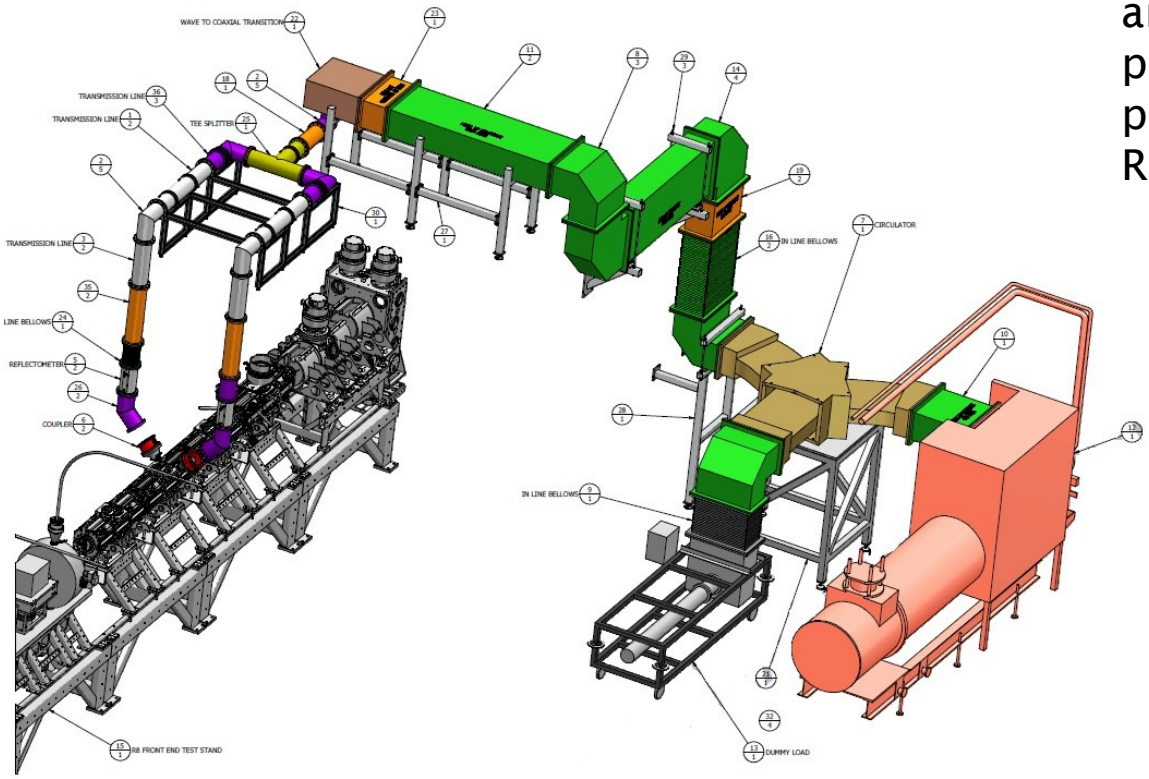
Proceeding cautiously has however resulted in the difficult tolerances being achieved or bettered.

Completion of the final sections can now proceed with more confidence.

RFQ Power Distribution

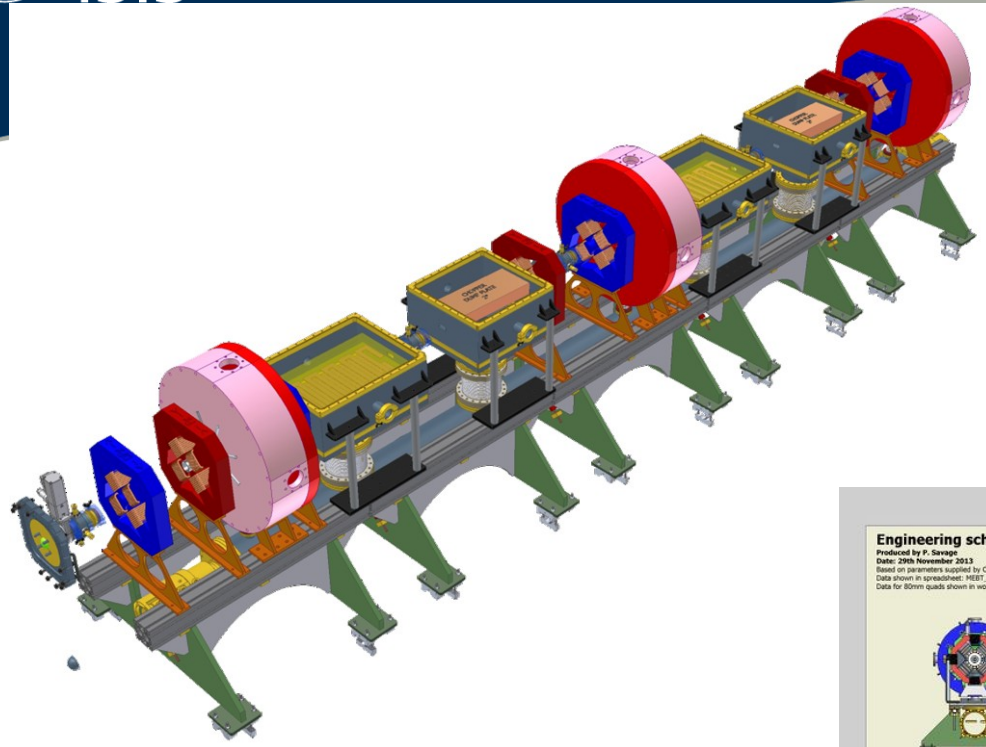


- RF power distribution by waveguide and coax
- Split to feed two couplers on RFQ
- Coupler engineering underway
- High power circulator to protect klystron
- All system components on site or ordered



Our colleagues at ESS Bilbao are loaning us a second high power water load to allow full power system tests without RFQ early in 2014

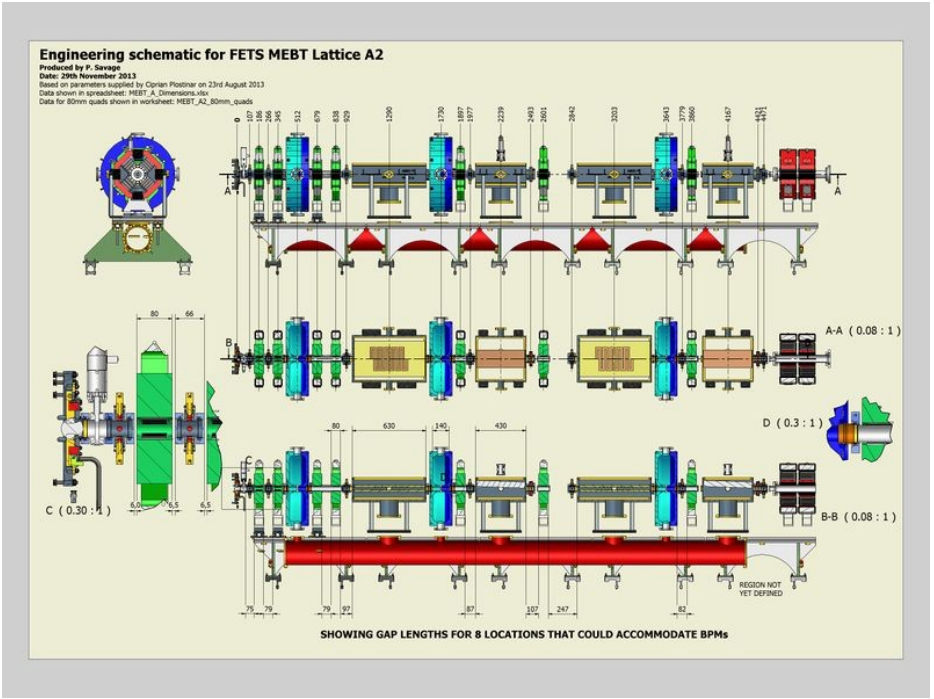
Medium Energy Beam Transport (MEBT)



Lattice Requirements:

- Perfect chopping
- Low beam loss: 3 MeV activates
- 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.
After much work the lattice has been finalised and engineering has begun in earnest…



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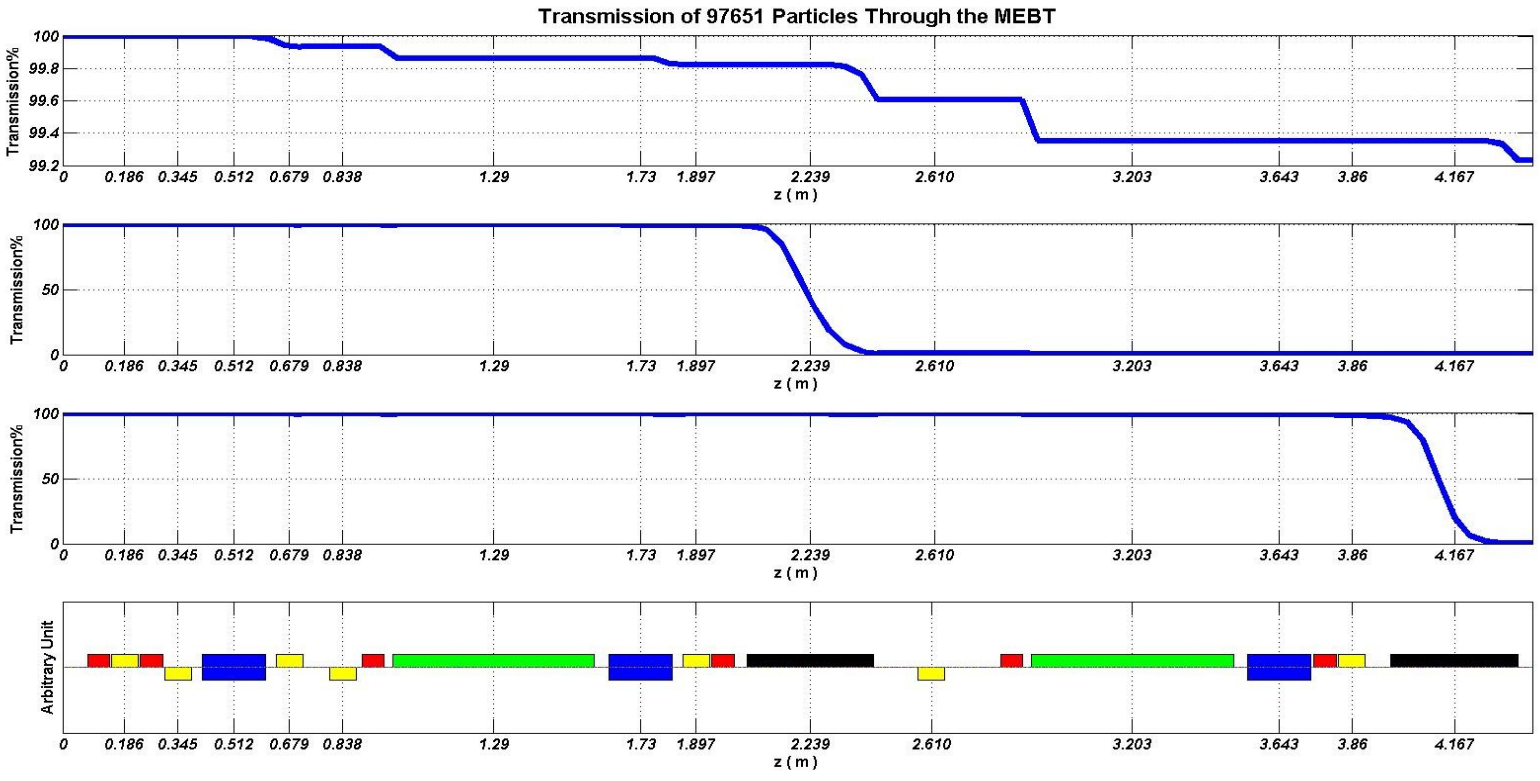
MEBT Performance evolution



Chopper off

Fast chopper on

Slow chopper on

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			

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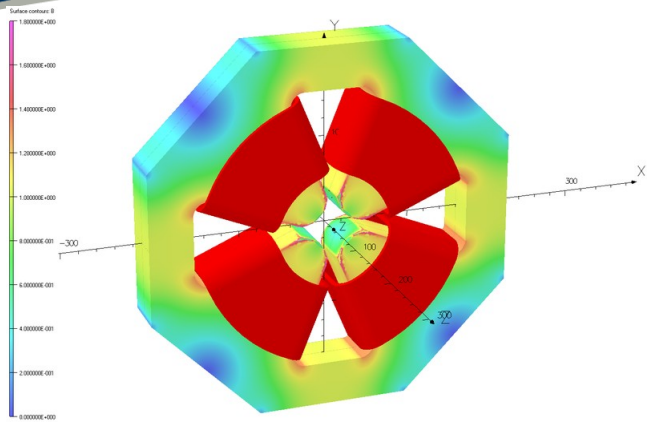
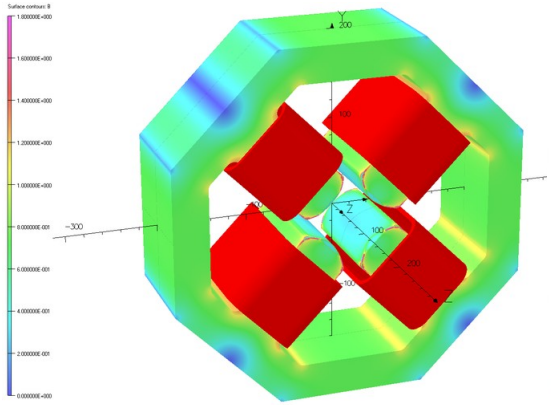
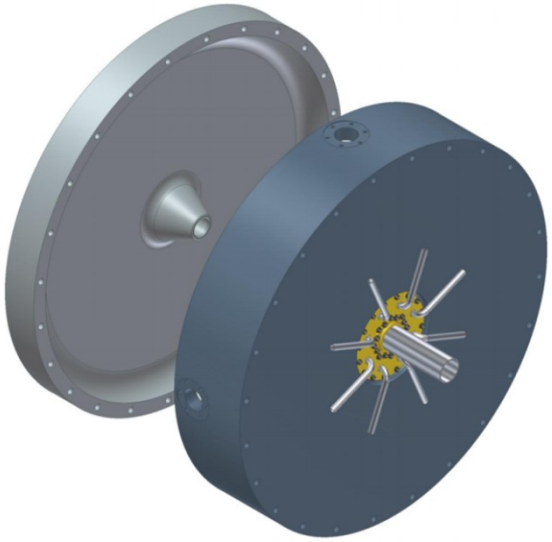
MEBT lattice elements

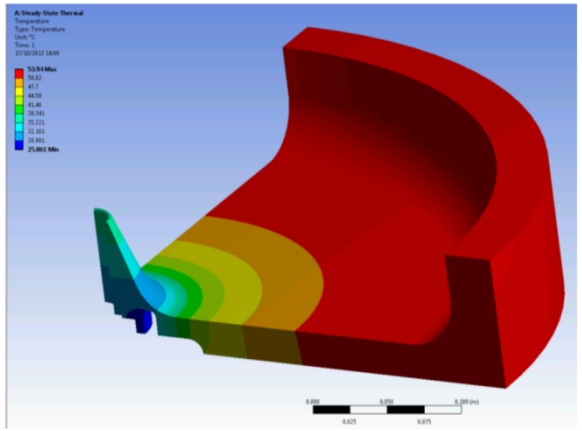




Quadrupoles:
- 80 mm total length
- 20 Tm^{-1} gradient
- Large and small bore
- Integrated steering
- Tendering complete, PSUs ordered

Re-bunching cavities:
- Pill-box with re-entrant nose cones
- 324 MHz, ~10 kW peak power
- 100 kV effective voltage
- Copper plated mild steel
- Detailed engineering underway





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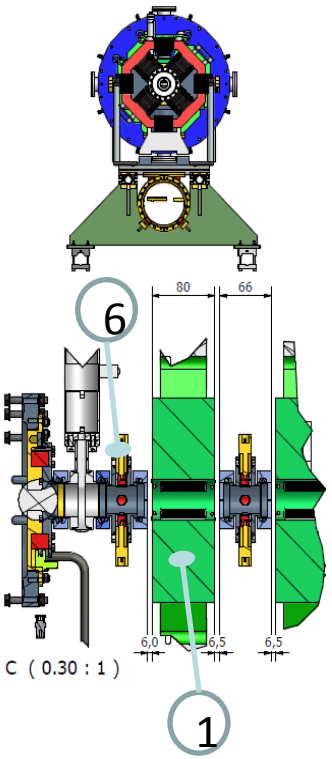
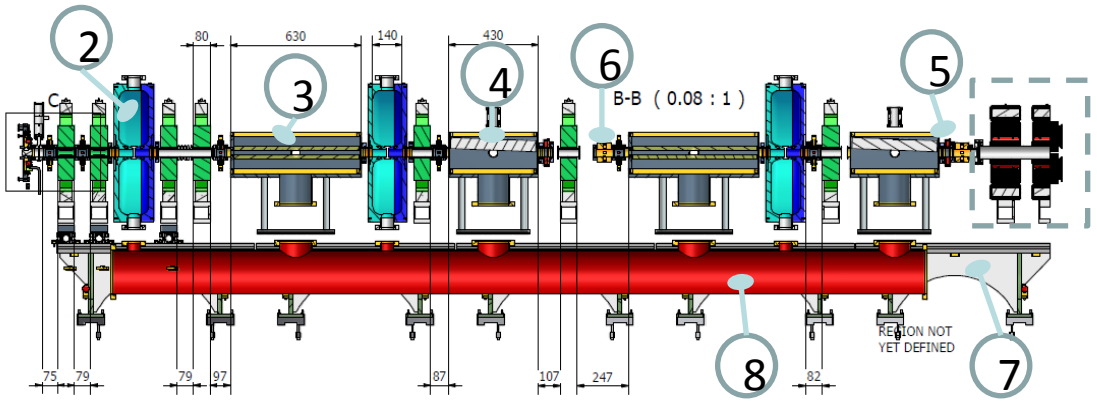
MEBT Engineering status

Component	Change	Status
1. Quadrupole	Increased length from 70mm to 80mm	Magnetic modelling complete. Quotes received from three manufacturers.
2. Rebunching cavity	Decreased internal length to 140mm.	3D concept design advanced. Cooling, vacuum and frequency simulations complete. Plating test model being manufactured.
3. Chopper	Increased length from 450mm to 600mm.	Chopper electrodes advanced. Ready to finalise vessel design.
4. Chopper beam dump	-	Initial thermal calculations made by summer student. Thermal shock calculations to follow. Vessel design will be in parallel to chopper vessel design.
5. Toroid	-	Complete. Prototype housing vacuum tested.
6. Beam position monitor (BPM)	Space made for button type and CERN strip-line type BPM	Button type under development at RAL. Strip-line type being progressed via collaboration between UCL and CERN.
7. Support framework	Modular design enables any MEBT configuration.	Detailed drawings complete. Ready for tender. Alignment system being designed now.
8. Vacuum manifold	3D design complete.	Next in-line for detailing by RAL contractor starting end December 2013.





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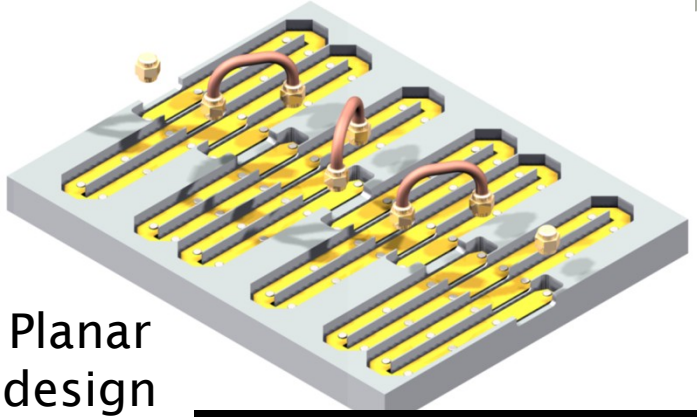
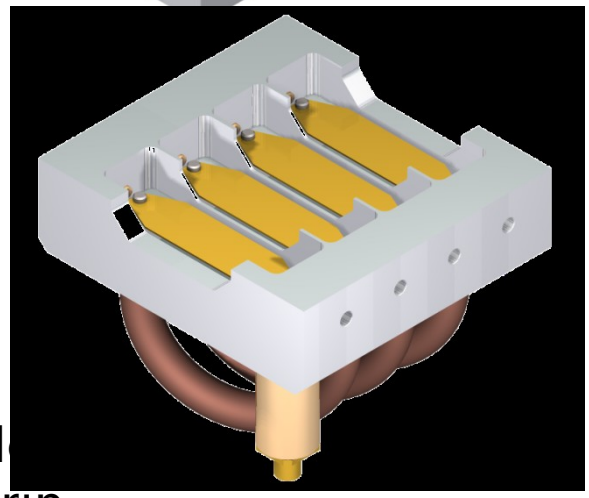
Perfect Electrostatic Chopping

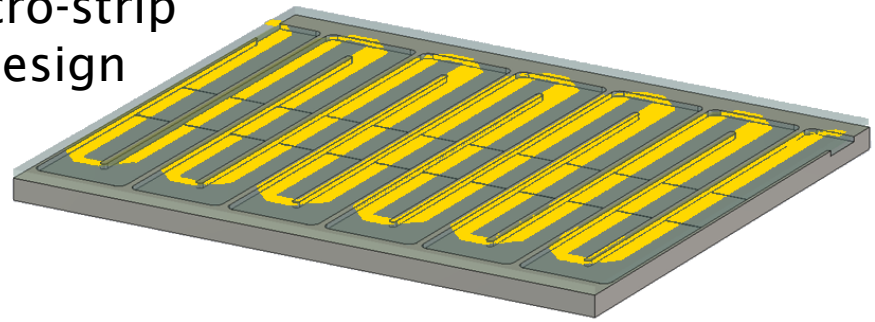


Planar design

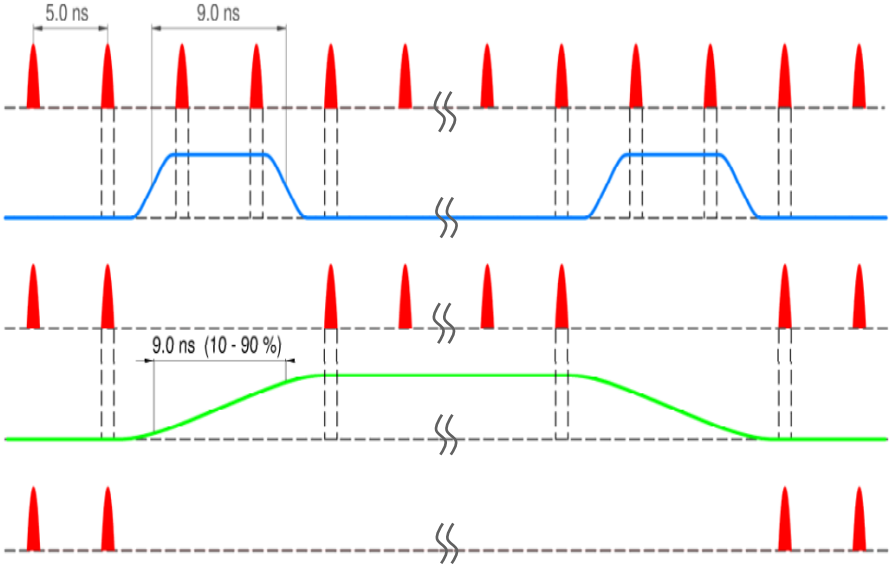


Helical design

Suspended micro-strip design



'Fast-slow' chopping scheme:



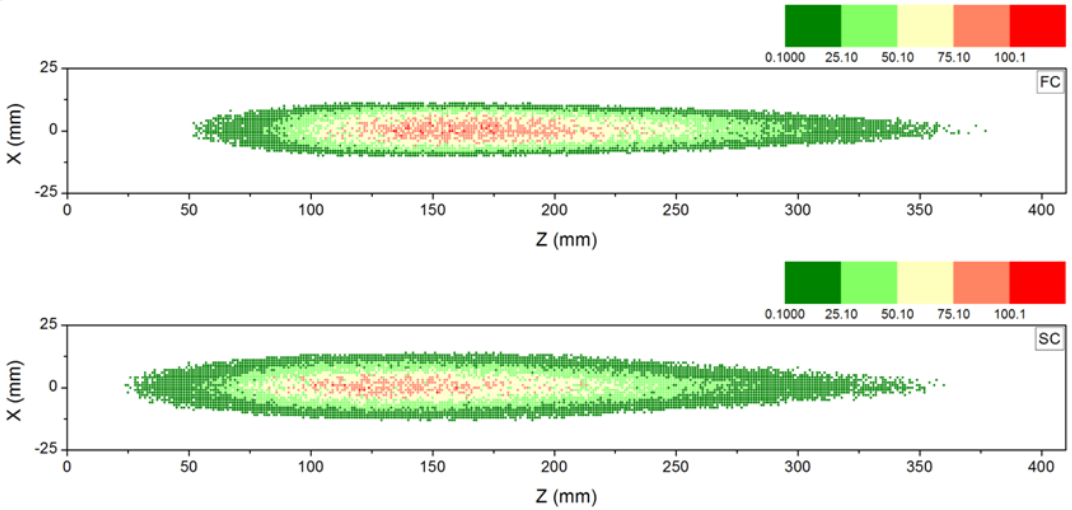
Specification:

- 3 ns rise time: between bunches
- ~150 μs gap in bunch train
- → 'Fast-slow' technique
- 6 kW dumped beam power

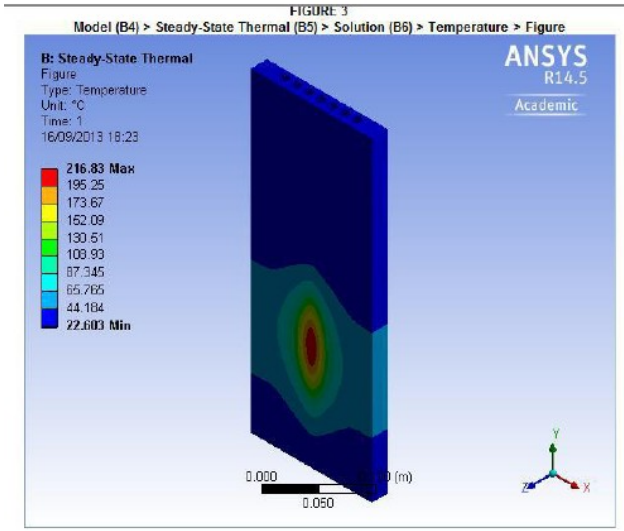
Status:

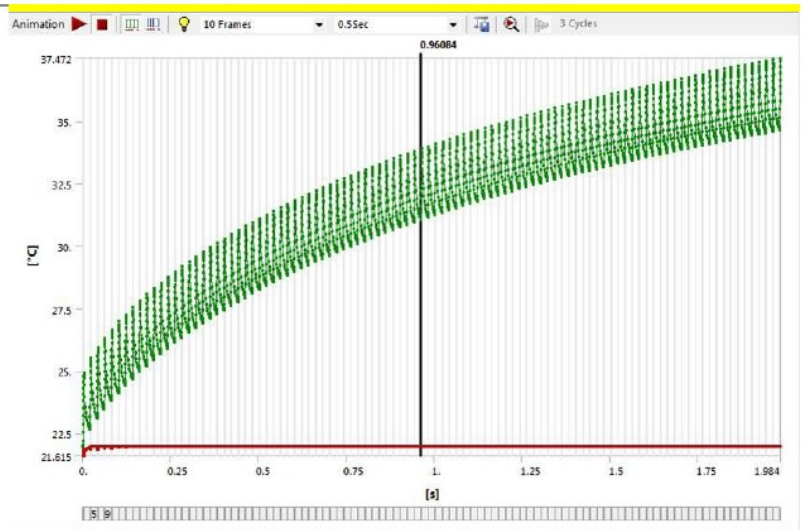
- Fast & slow switching PSUs delivered
- Thorough simulation campaign
- Short test pieces manufactured
- System to be fully complete by 2015

Chopper Beam Dumps

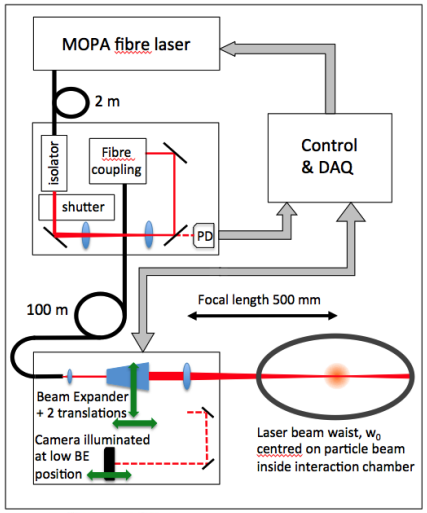


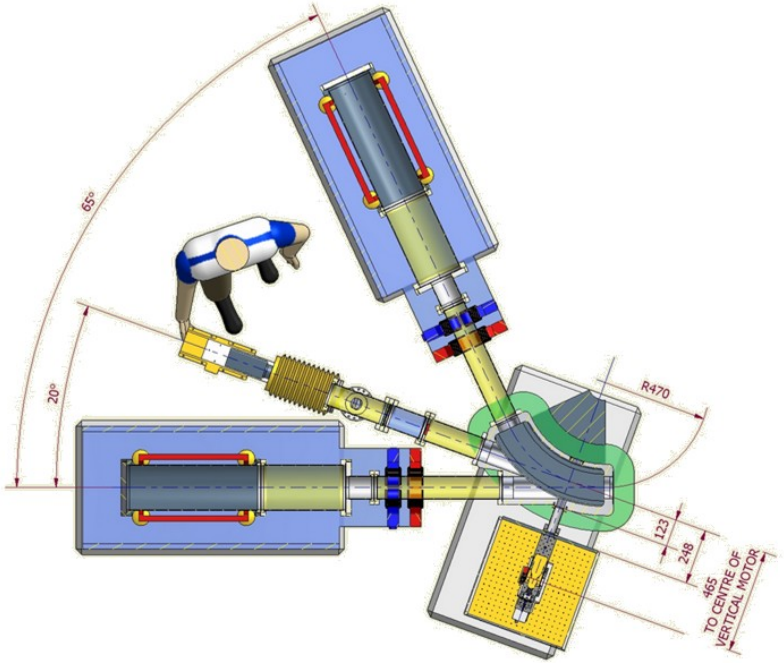
- Peak power dissipation in the chopper dumps is up to 100W/mm^2
- Quite a challenge to cool
- Initial thermal analysis suggests solutions are feasible
- Full engineering design study needs to start





Laser Photo-detachment Emittance



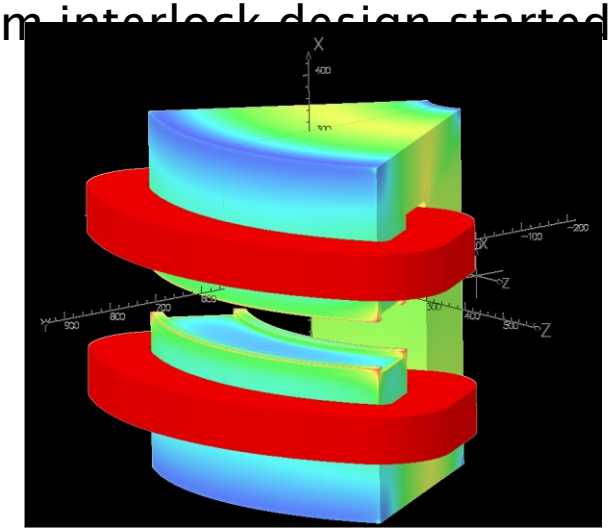


Specification:

- Laser interaction in dipole: reduce background from stripped neutrals
- Scintillator intercepts laser-sliced H^0
- Measure variable beam phase space
- Transport 18 kW of H^- to beam dump

Status:

- Laser optics and fibre transport complete
- Dipole magnet design underway
- Vacuum vessel drawings underway
- Laser safety case complete and system interlock design started



Laser diagnostic particle tracking

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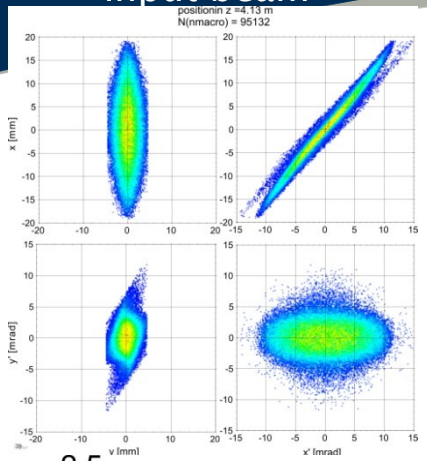
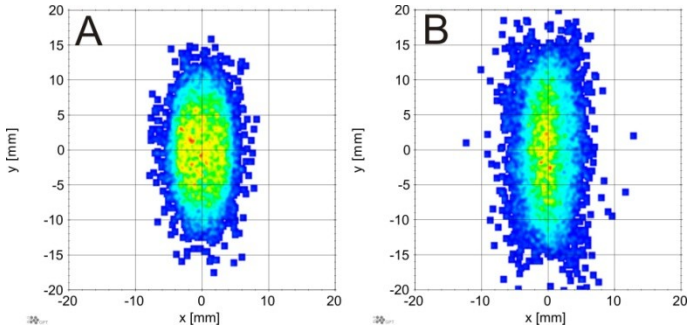
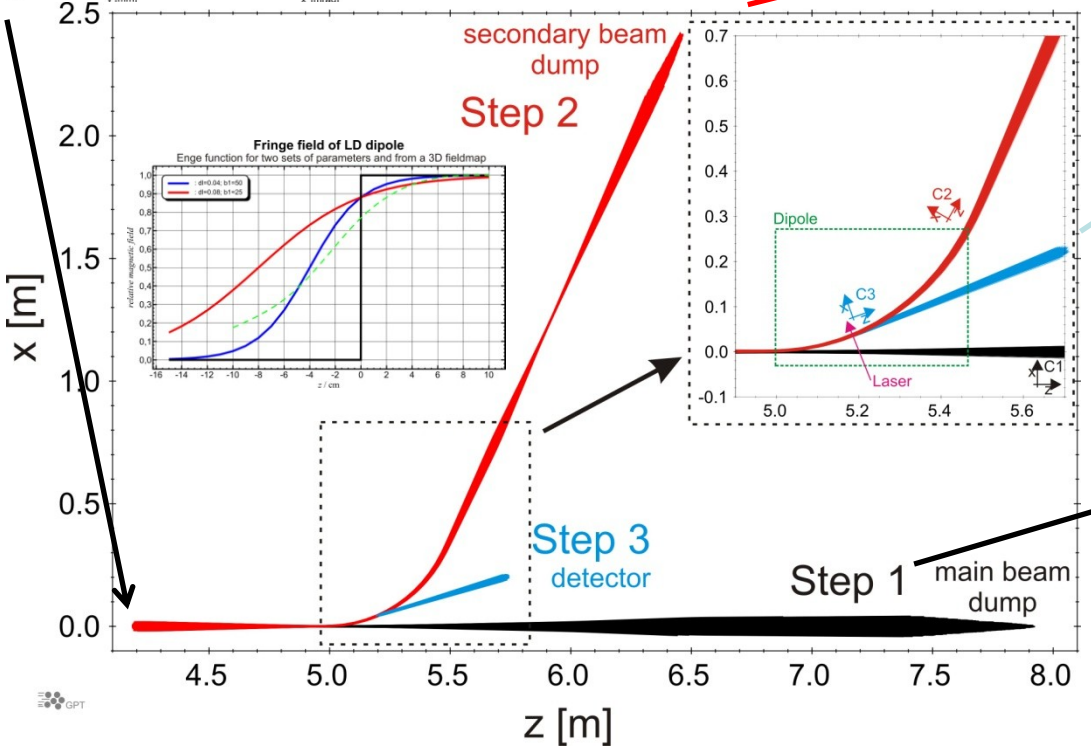
Input beam

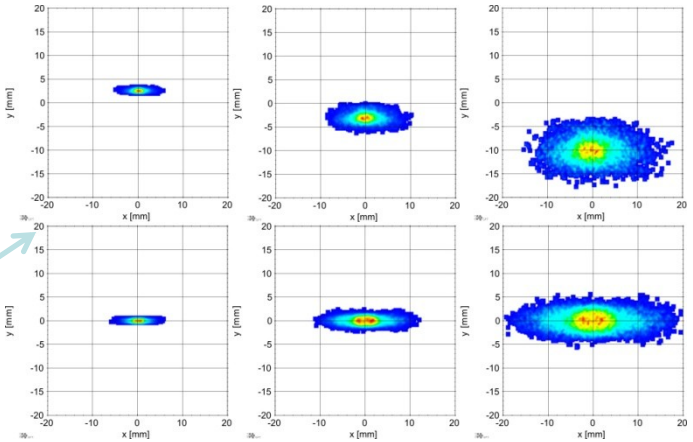


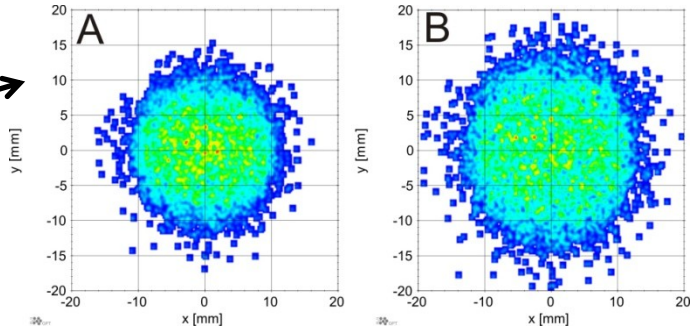
Extensive particle tracking simulations have been performed for various settings of the MEBT quadrupoles to investigate the best placement and size of the 2D scintillating detector, to determine the range and resolution of the instrument and to finalize the lattice

Output beam









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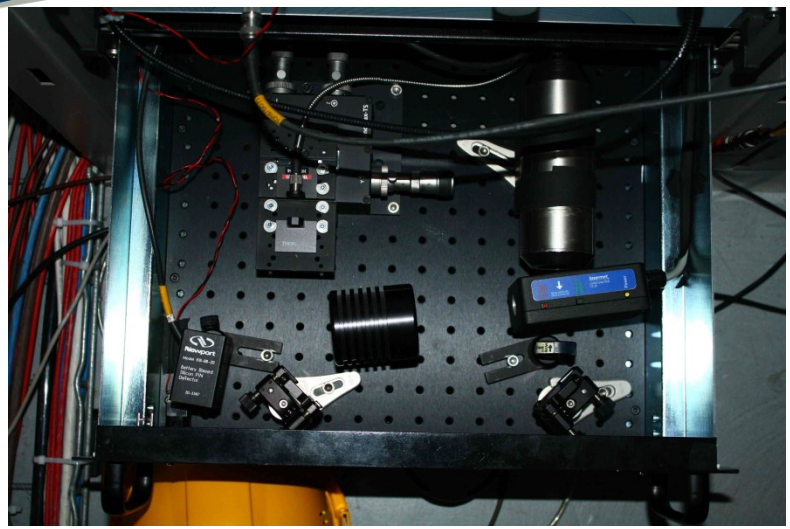
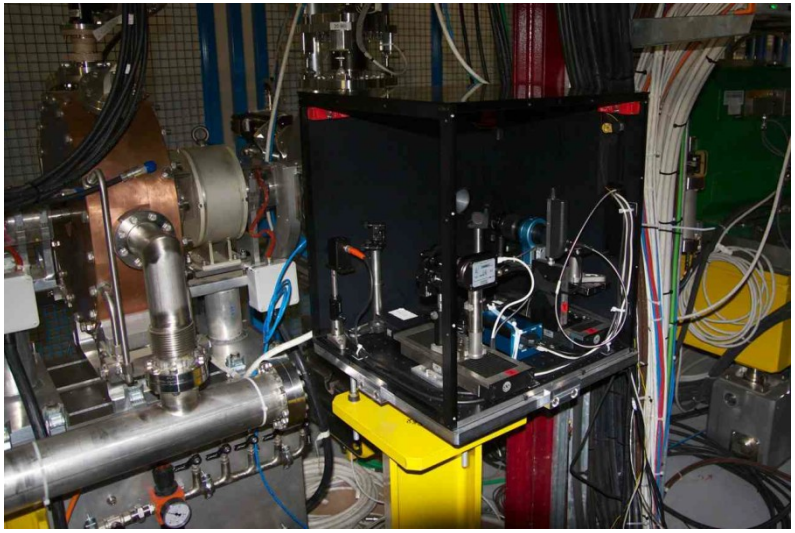
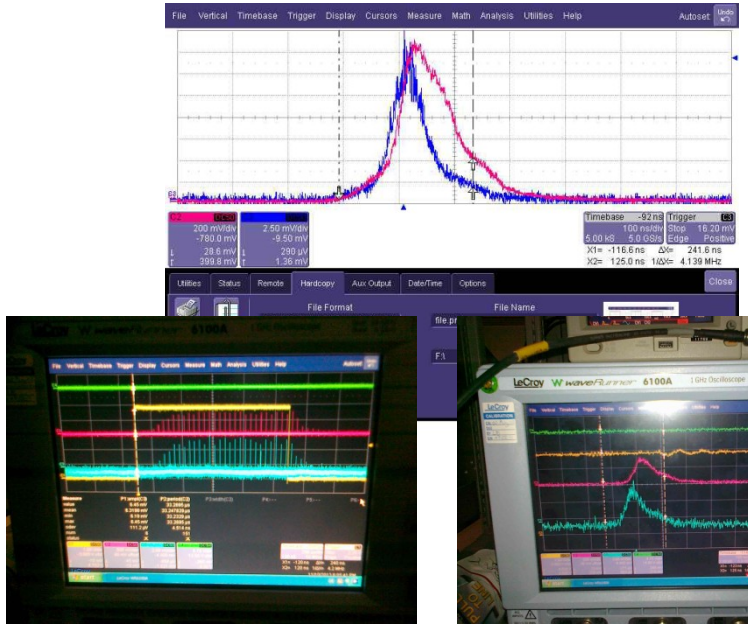
CERN Collaboration

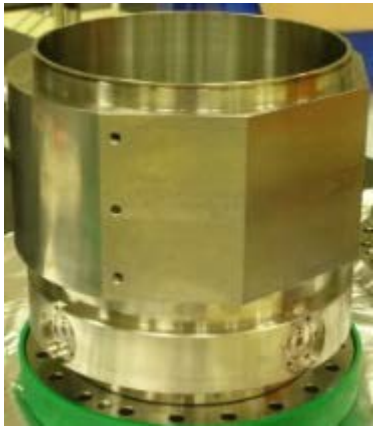


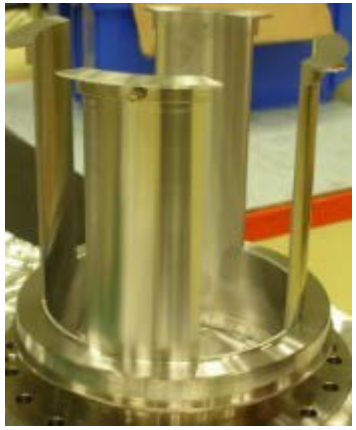


- CERN are also pursuing an H^- laser diagnostic for Linac4.
- Linac4 are more advanced with their front end, FETS are more advanced with our laser system.
- A perfect opportunity for collaboration.
- The FETS laser system is at CERN and installed on the Linac4 front end.

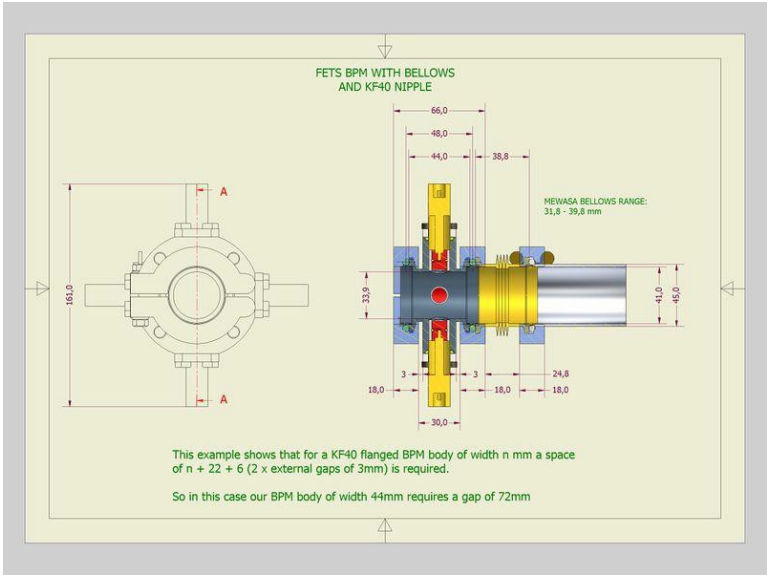


MEBT BPMs





- CERN collaboration also covers use of their stripline BPM on FETS
- Hardware and front end electronics designs shared



- Due to severe space constraints in the MEBT a compact button BPM is also under consideration
- Engineering design nearing completion
- Comparative performance studies will be performed

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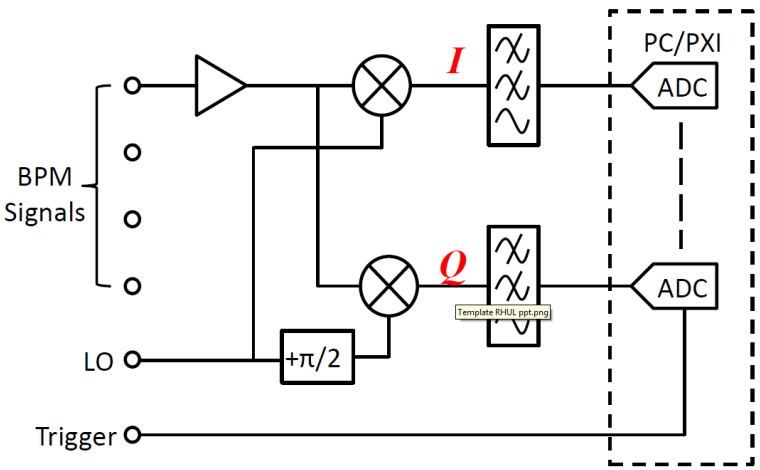
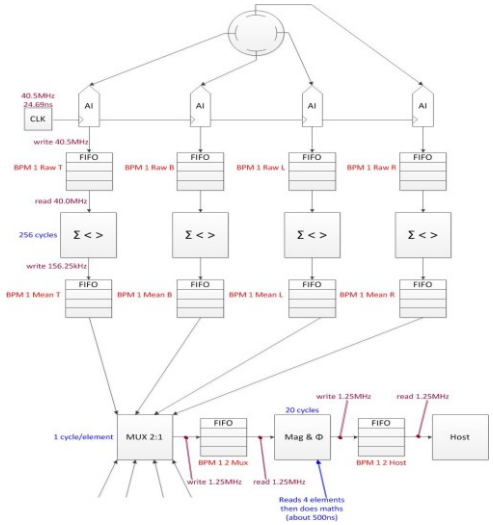
BPM Signal Processing

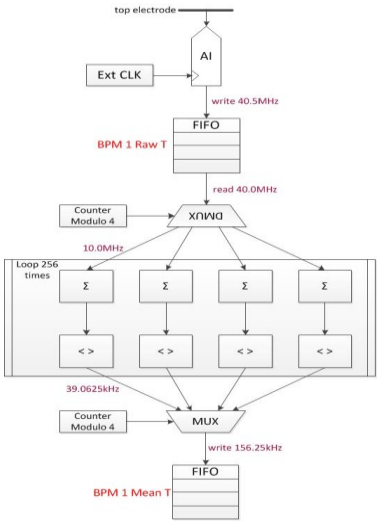


- The front end RF and signal processing has been tested
- V2 of front end card being produced
- CERN to supply PCBs

Next Steps:

- Test FPGA with RF
- Complete system test
- Measure performance on CERN test jig

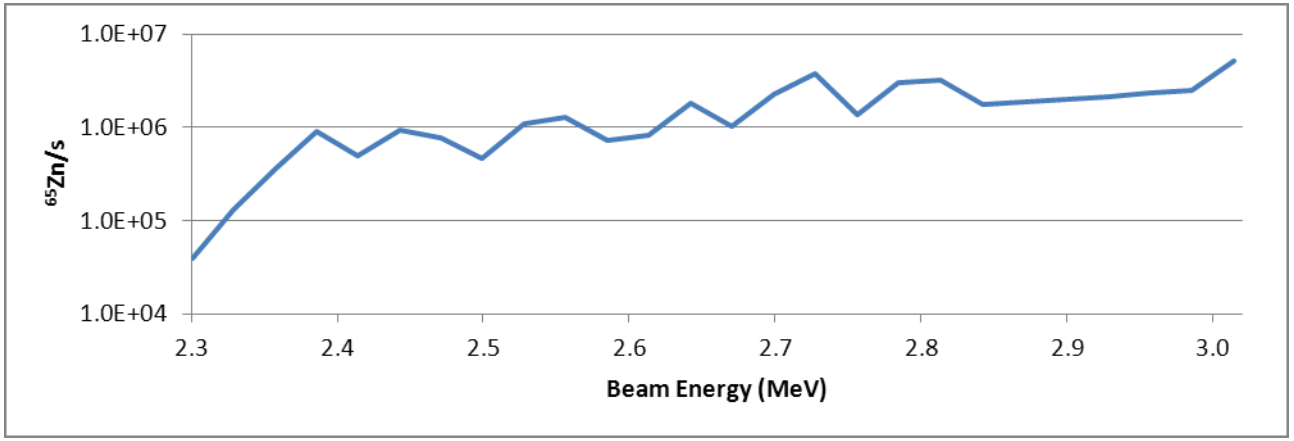


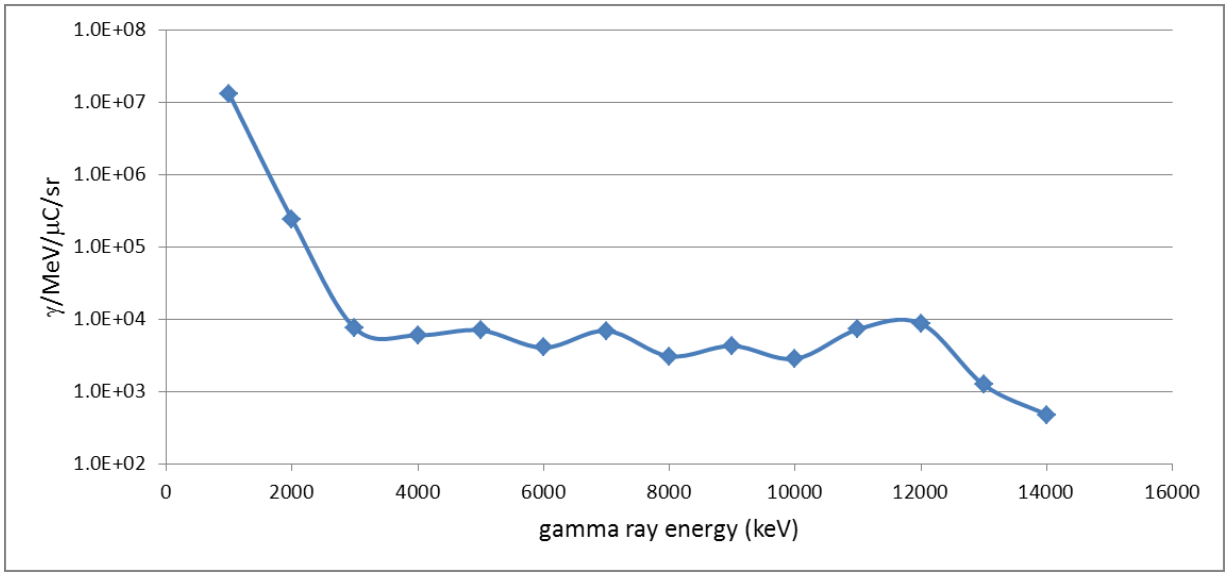


Radiation protection

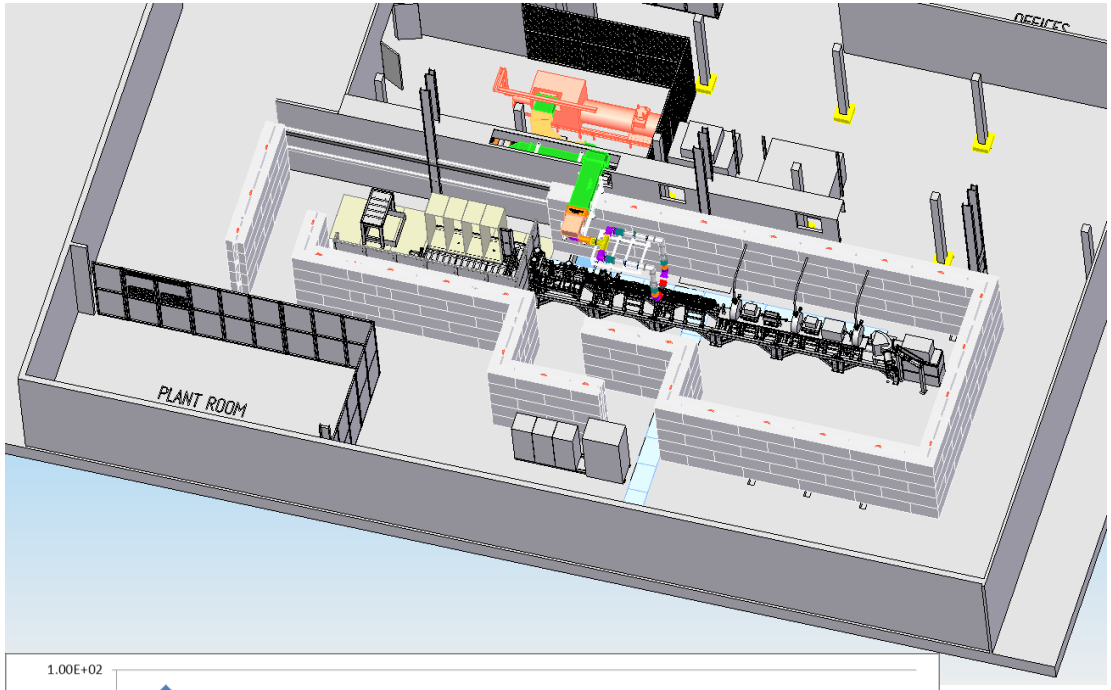
- Every effort made to exclude radiologically 'bad' materials from FETS
- Even so significant shielding required to protect personnel from mSv/h levels of neutrons and gammas expected from FETS

Neutron and gamma ray fluxes due to worst case beam loss in FETS RFQ and MEBT

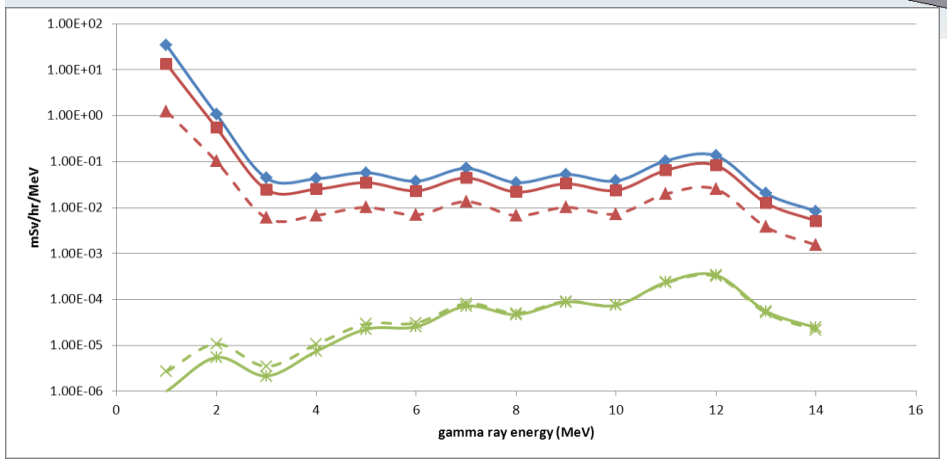




Radiation shielding



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

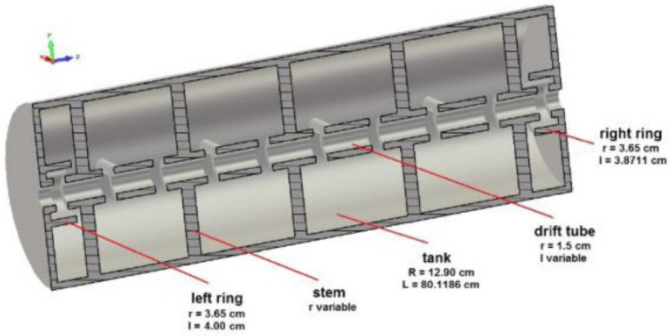


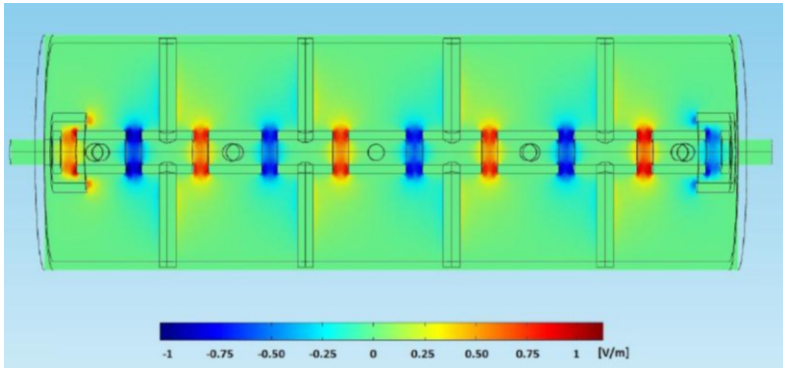
Gamma ray attenuation by various shielding scenarios

Future of FETS

• Within the Proton Accelerator Alliance proposals for exploiting FETS are being prepared.
• Ideas range from a new linac for ISIS to a multi-beam experimental facility.
• Most options currently under consideration require the beam energy to be increased.

• Investigations of CH resonators, which may offer increased efficiency, have been undertaken.





• FETS has provisionally signed up for the Test Infrastructure and Accelerator Research Area (TIARA) preparatory phase

Novel RF sources

- Proton accelerators require large amounts of radio frequency (RF) power
- Traditional sources have common drawbacks:
  - large and expensive
  - complex high voltage power supplies
  - limited lifetimes
  - x-ray radiation.

- STFC and members of the FETS team have been working closely with Siemens who are developing a solid state microwave generator for accelerator applications based on Silicon Carbide transistor technology.
- STFC are the technical consultants and providing expert advice from the end user perspective.
- First prototypes are in the early stages of manufacture.
- FETS will be the beta test site for when the first MW scale generators become available.

Summary

- Good progress is being made in all areas of FETS
- The designs for most parts of the beamline are now finalised
- Physics is well understood with no show stoppers in sight
- Delivery of the first RFQ section a major milestone
- Engineering now the main bottleneck in progress
- Considerable activity in R8 over the next 6 – 9 months