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EMMA Kickers

Topical Workshop on Injection and Injection systems (TWIIS)

30/08/2017

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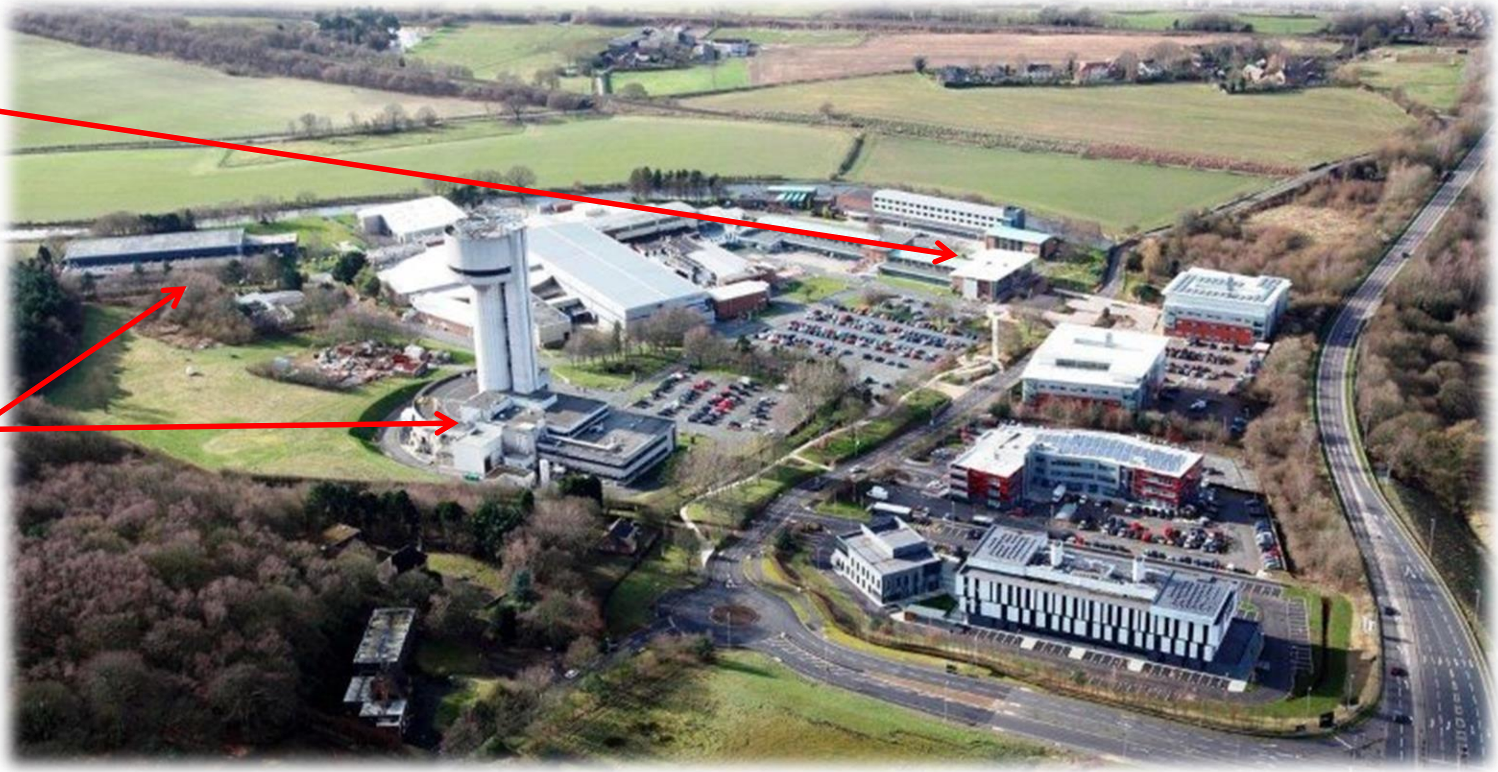
Daresbury Laboratory

ASTeC

Technology at Daresbury



ASTeC – Accelerator Science and Technology Centre: Accelerator Physics, Diagnostics, Lasers, Magnets and Vacuum Science

Technology at Daresbury: Electrical, Mechanical, Controls, Electronics and Vacuum Engineering

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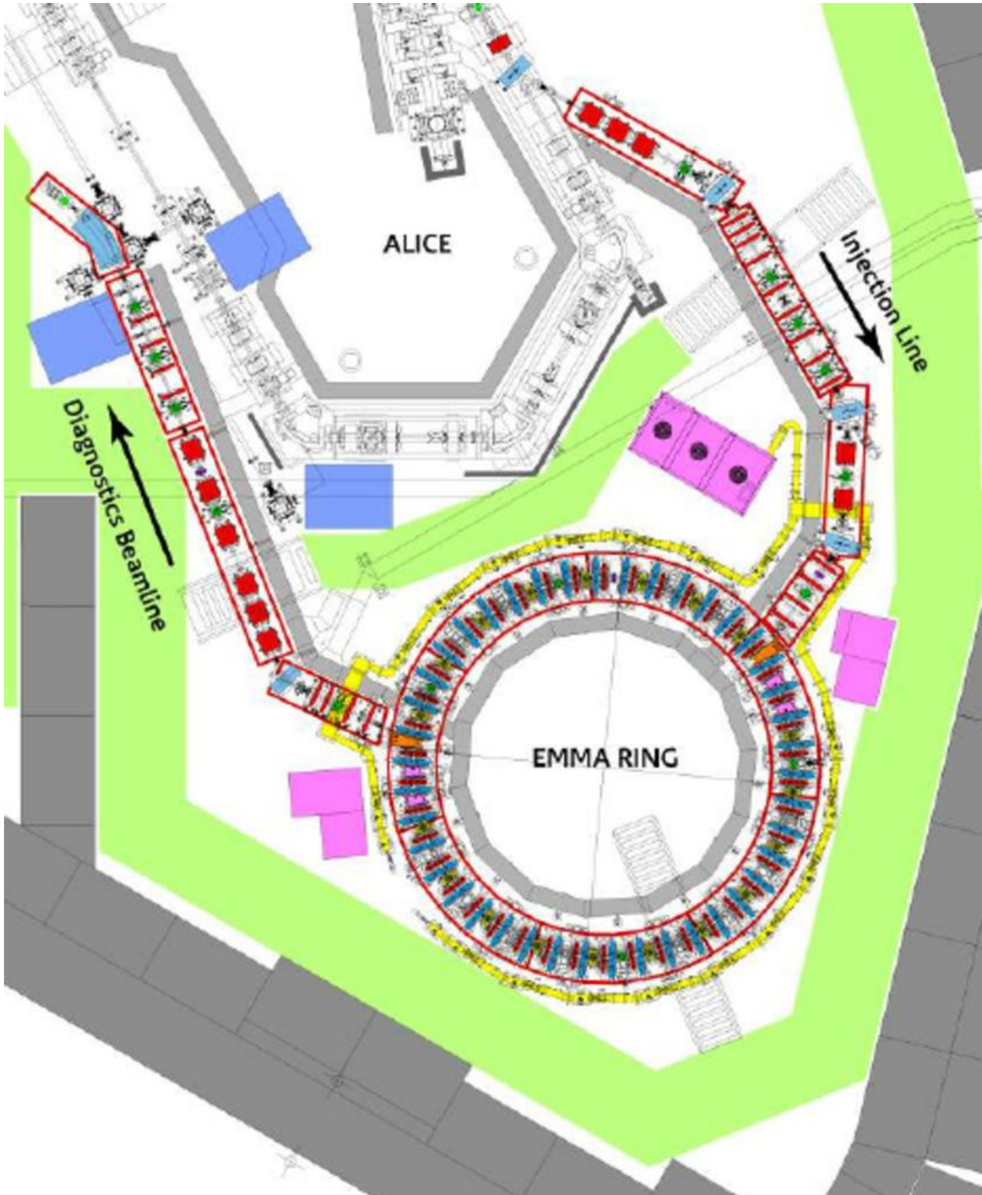
EMMA

- £8.6M Funded by the UK under the CONFORM project (COnstruction of a Non-scaling FFAG for Oncology, Research and Medicine)
- £5.6M for EMMA - Electron Machine for Many Applications
- First Non Scaling Fixed Field Alternating Gradient Machine (NS-FFAG)
- A proof-of-concept machine to explore in detail the beam dynamics to gain experience in the design and construction of NS-FFAGs
- Areas of possible use of NS-FFAGs are:
  - Medical - Hadron and Ion Therapy for cancer treatment
  - Energy generation – Accelerator driven reactor
  - Neutrino factory - muon accelerator

EMMA



Parameter	Value
Energy Range	10 – 20 MeV
Lattice	F/D Doublet
Circumference	16.57m
No. of cells	42
Normalised transverse acceptance	3mm
No. of RF cavities	19
Average beam current	13uA
Repetition rate	20 Hz
Bunch charge	16 – 32 pC, single bunch

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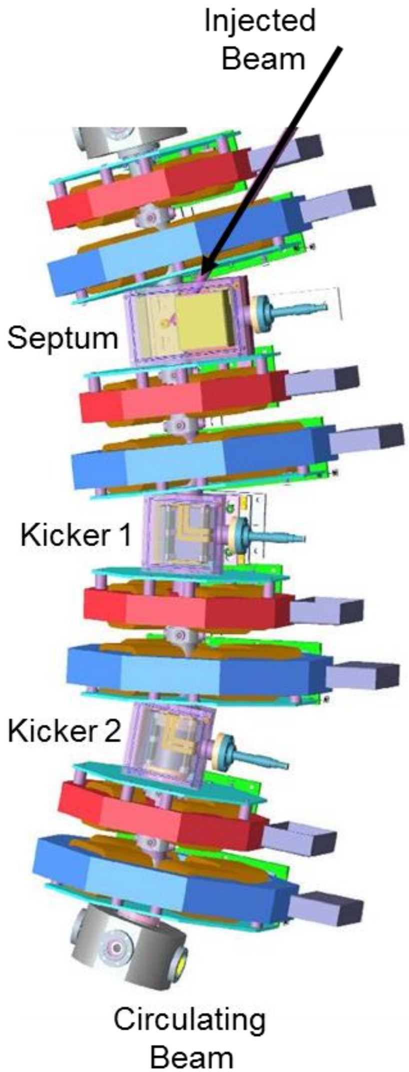
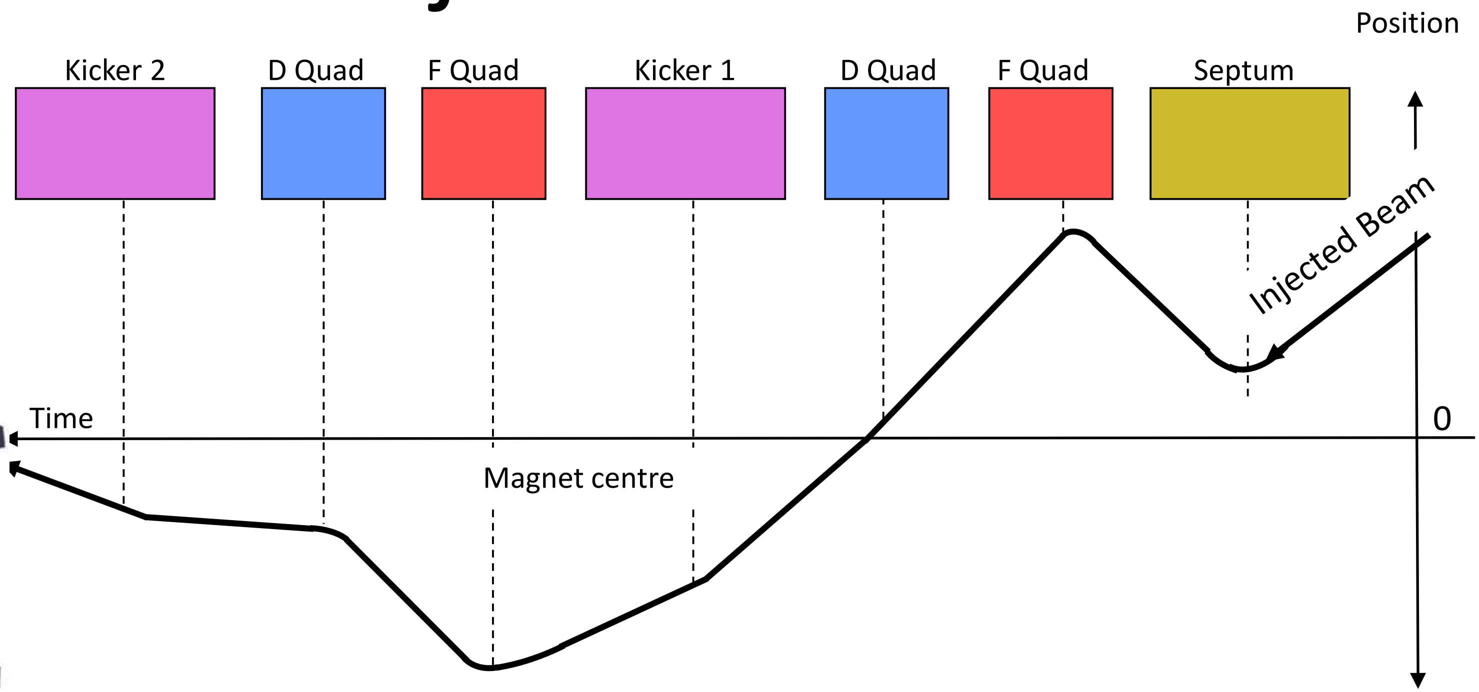
Injection





Large Septum magnet bending angles required (65° injection and 70° extraction)

Reducing angle passes the beam through preceding quadrupole magnets.

The focusing or defocusing effects from the quadrupoles are balanced with appropriate septum and kicker magnet adjustments.

Beam must be on the correct orbit after the second kicker.

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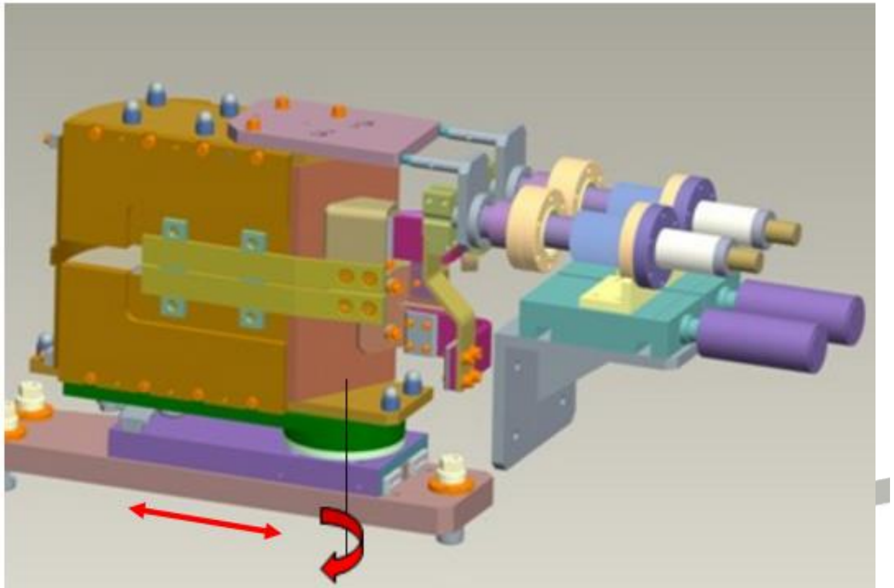
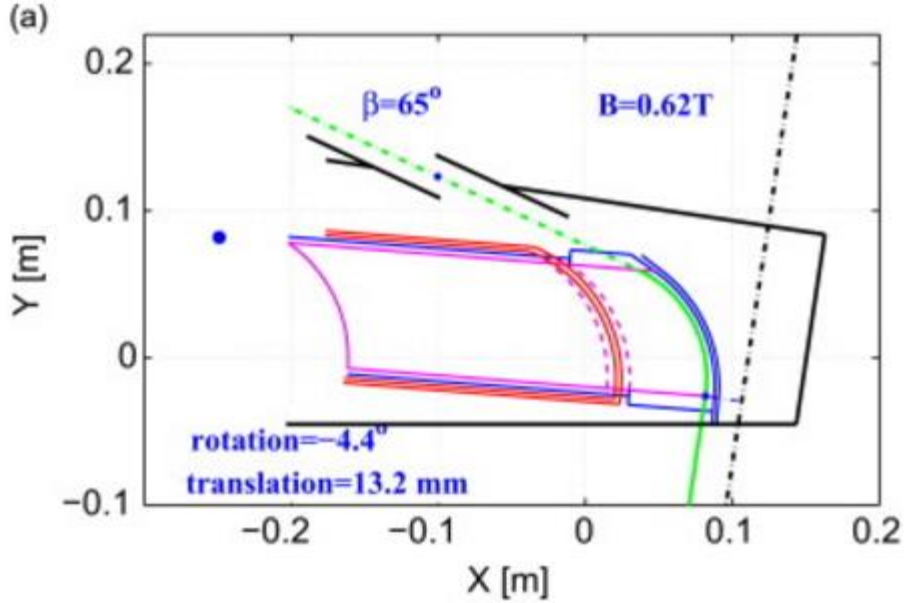
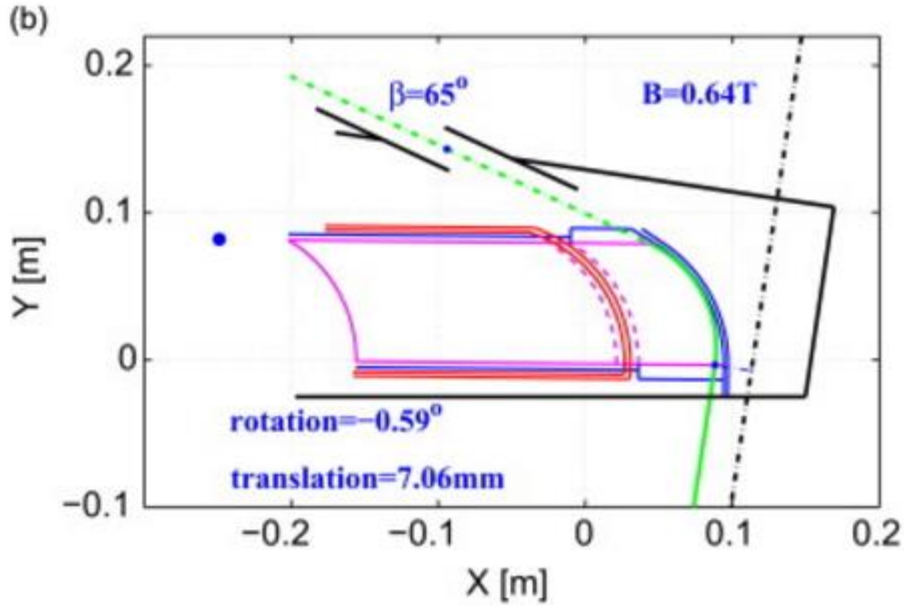
Design of EMMA Septum Magnet

- Very large bending angle required (65° for injection and 70° for extraction)
- Longitudinal space available for the magnets only ~100 mm in the straights.
- Also the magnets must inject and extract in the entire energy range (10–20 MeV)
- Solution is an eddy-current septum, capable of translation and rotation around a moving pivot point



ISO view of septum with vacuum chamber removed

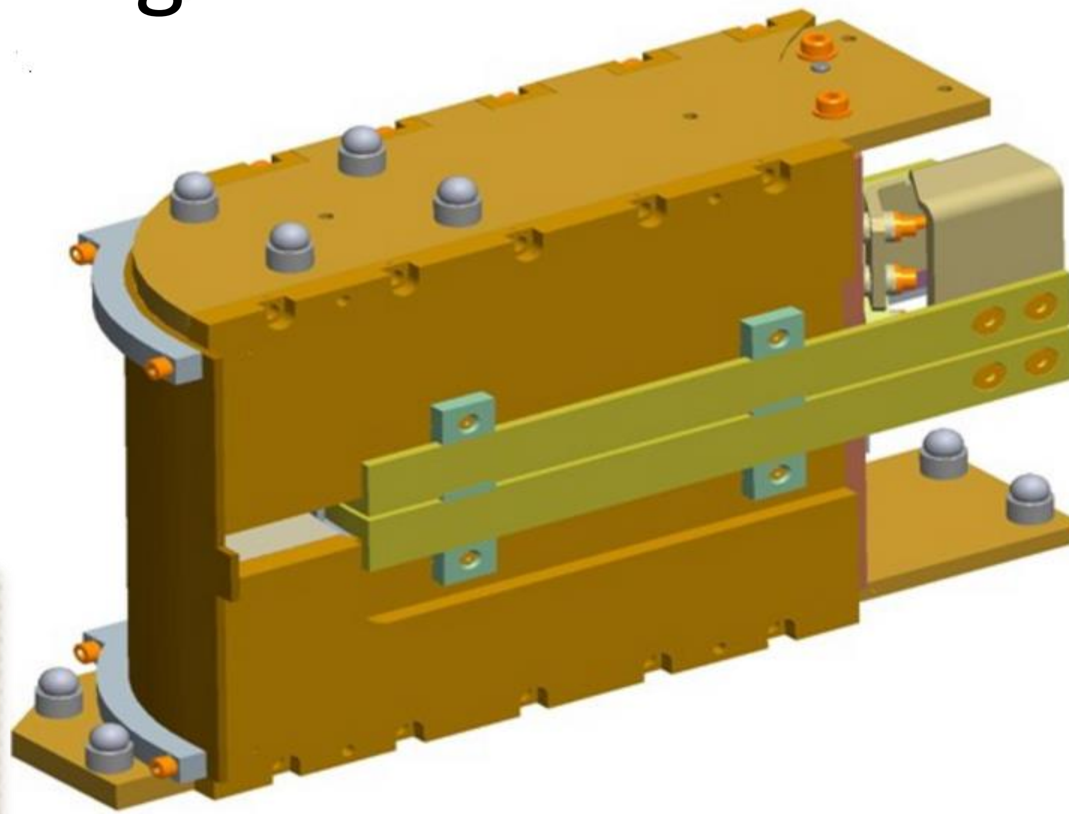


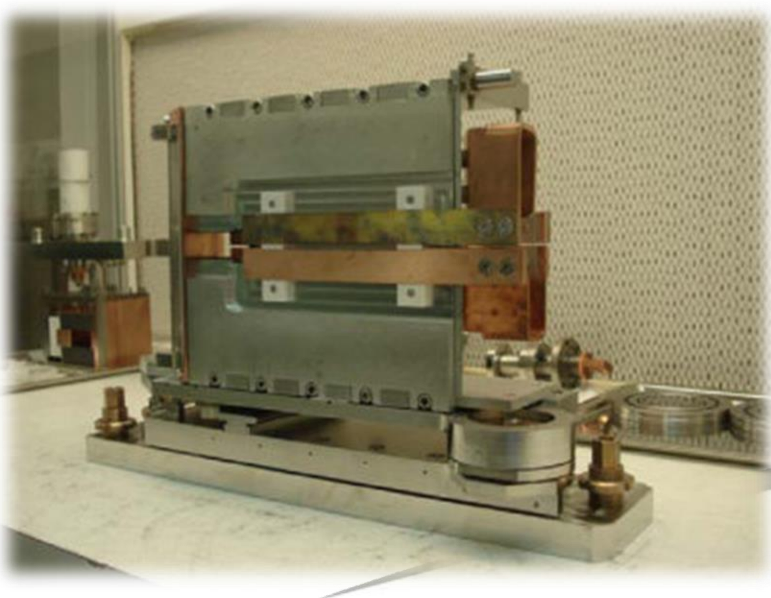


Production of the EMMA Septum Magnet

Inner Steel Yoke assembled from 0.1mm thick Silicon Steel laminations insulated with 0.2µm coatings on each side.

Magnet Assembled by Tesla Storrington, UK





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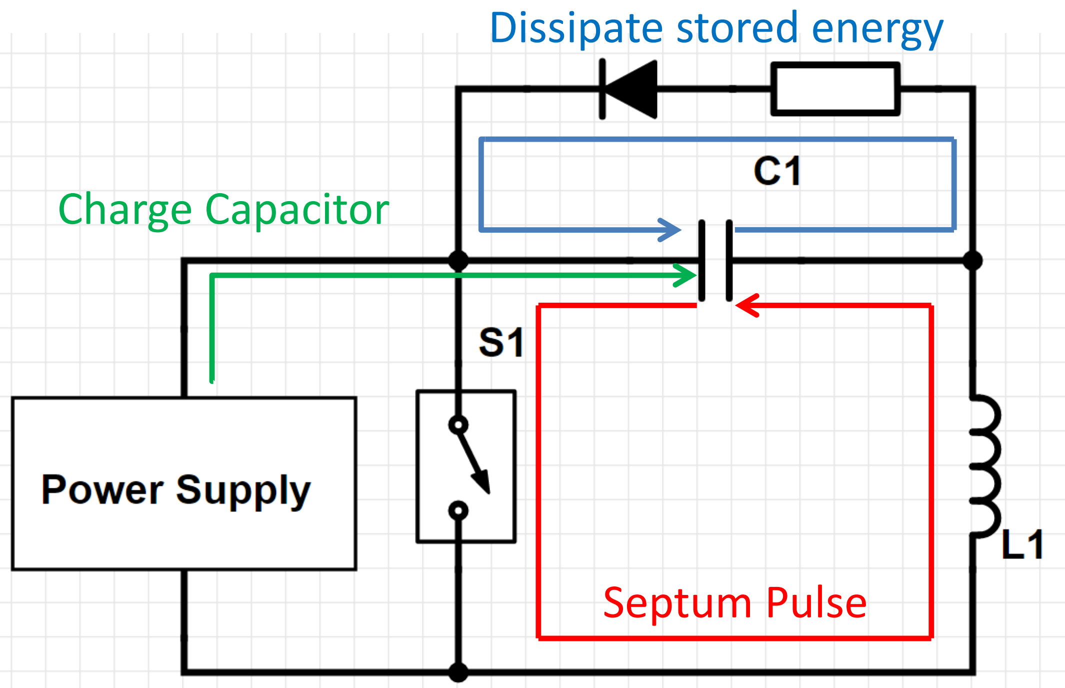
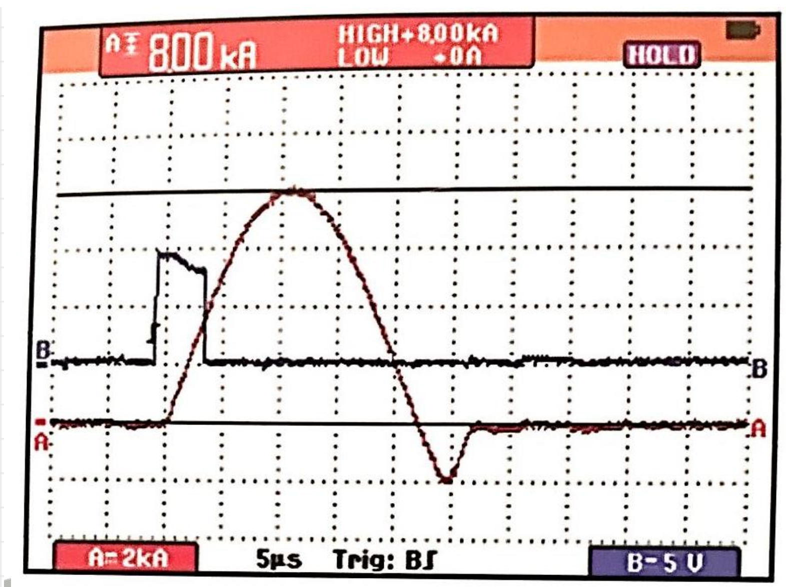
Septum Power Supply

- Specification was for a 8000A, 25us half sinusoidal pulse.
- A closely coupled LC circuit with L being the septum magnet load was utilised, a proven and understood design.
- The capacitor is chosen to match the pulse width required.
- The Switch was a CX1154C thyratron valve is a proven technology with switching speeds in excess of 150kA/us. MA2709A thyratron trigger system.





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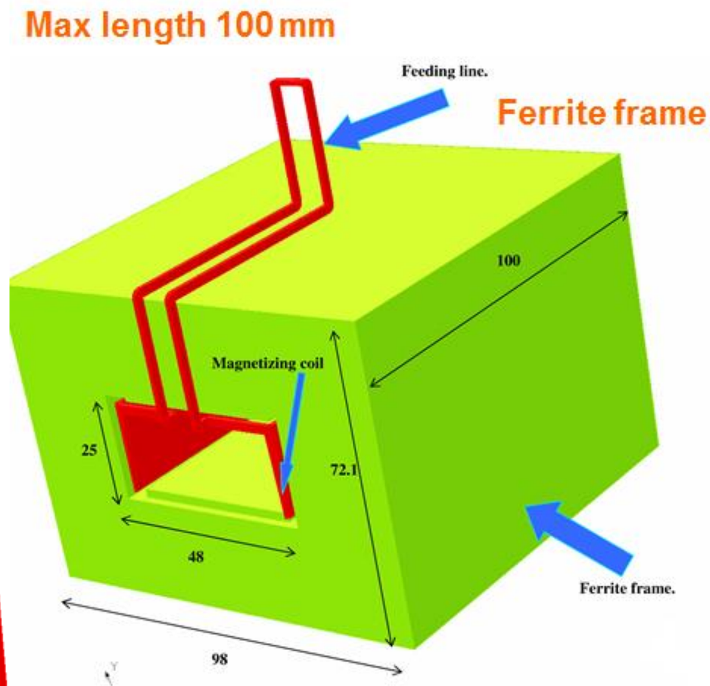
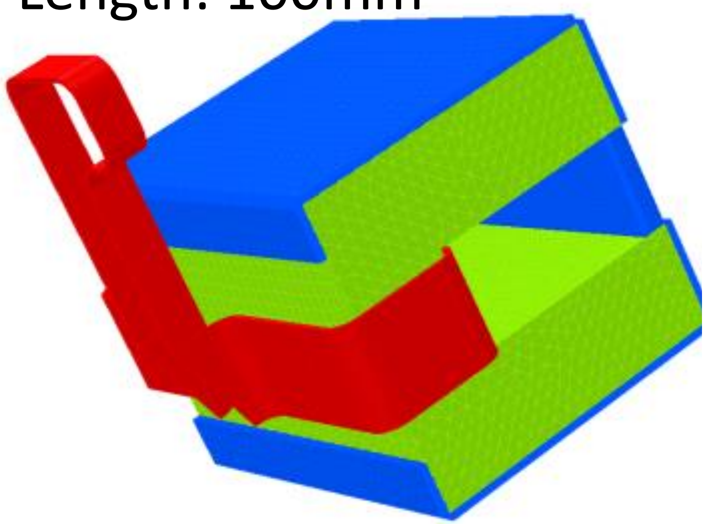
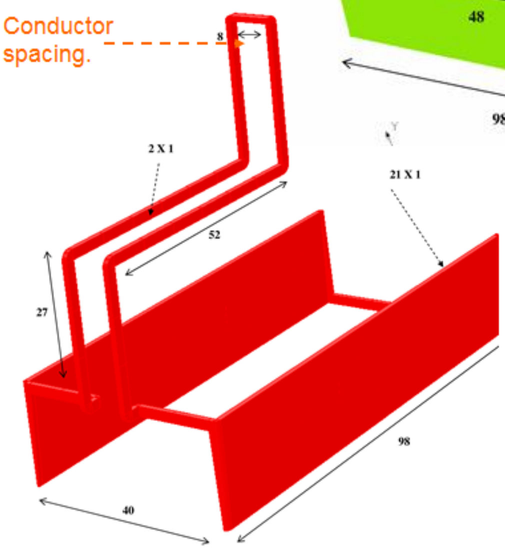
Kicker Magnet Design

- Designed at Daresbury Laboratory.
- Delay Line Kicker was considered, however it was decided it would be too electrically and structurally complex
- Lumped (inductive) Kicker type
- Horizontal aperture: 46mm
- Vertical aperture: 25mm
- Length: 100mm







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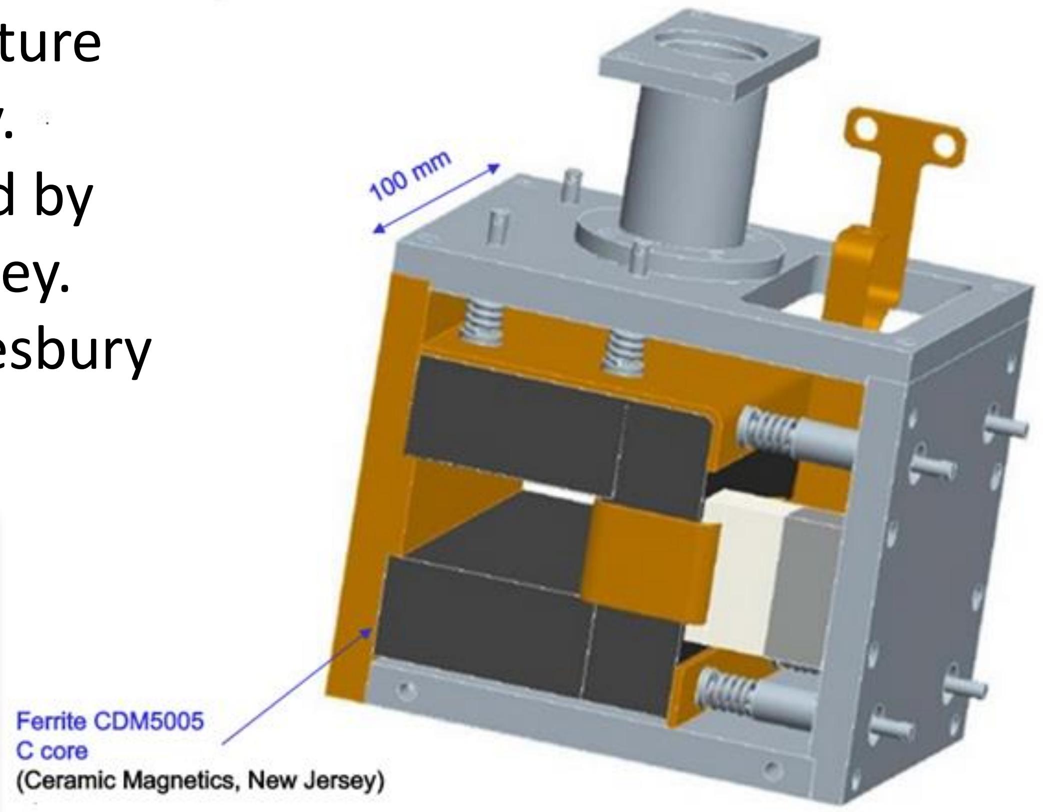
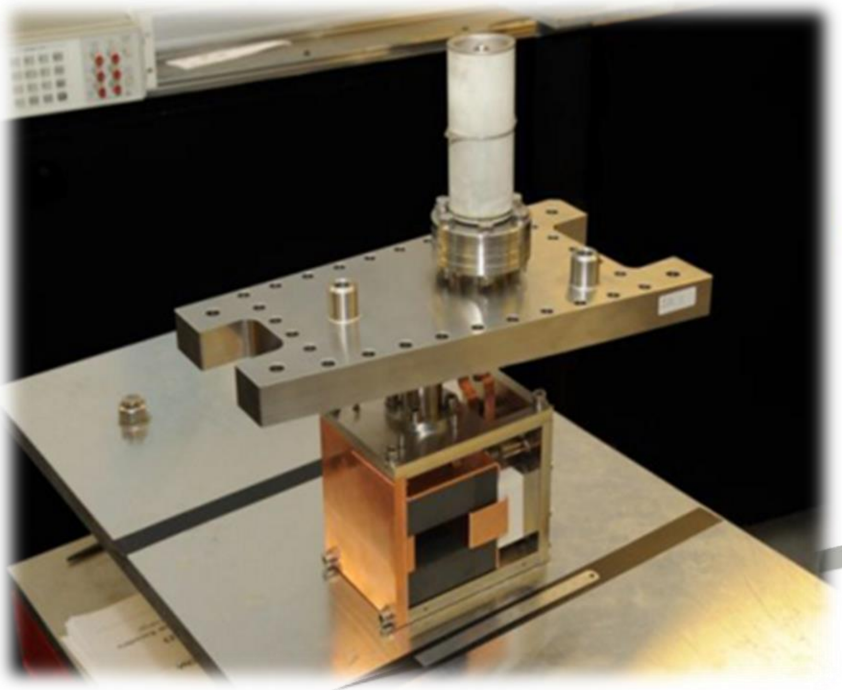
Production of the EMMA Kicker Magnet

- Kicker component manufacture by Brite Precision, Newbury.
- Ferrite Blocks manufactured by Ceramic Magnets, New Jersey.
- Magnets assembled at Daresbury Laboratory.





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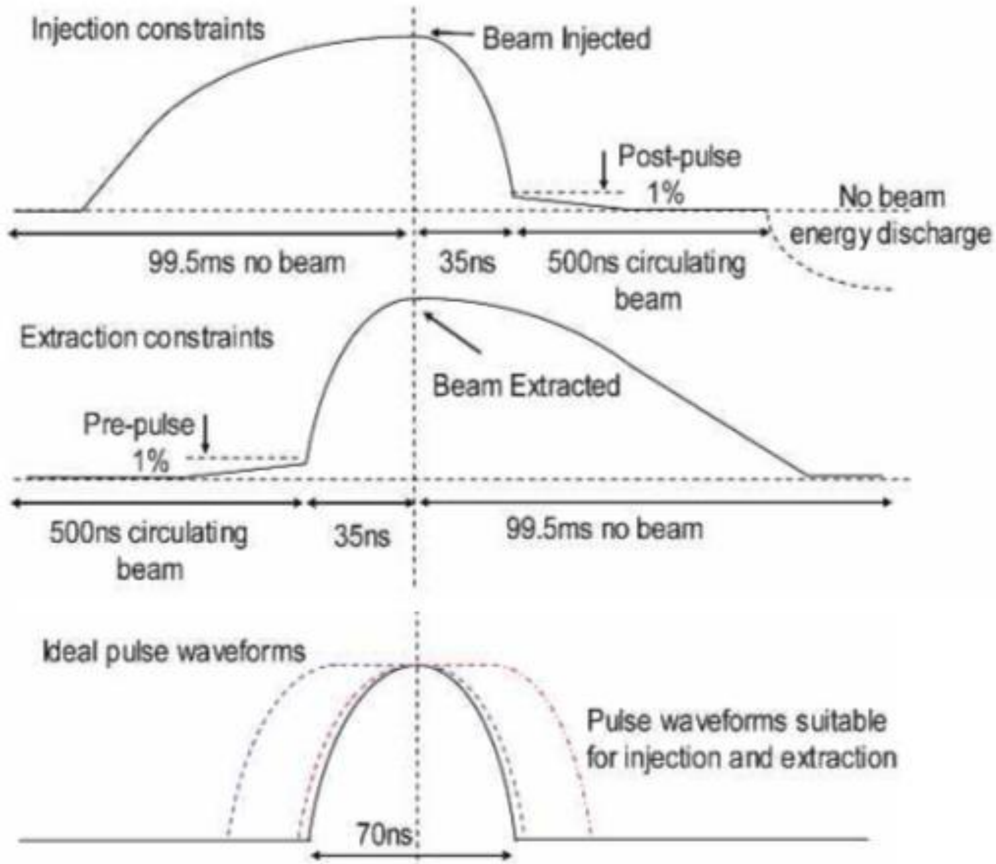
Kicker Power Supply Specification

Parameter	Value
Magnet length	0.1m
Field at 10MeV (injection)	0.035T
Field at 20MeV (extraction)	0.07T
Magnet Inductance	0.25uH
Lead Inductance	0.16uH
Peak Current at 10/20MeV	1.3kA
Peak Voltage at Magnet	14kV
Rise/Fall Time	35ns
Jitter pulse to pulse	<2ns



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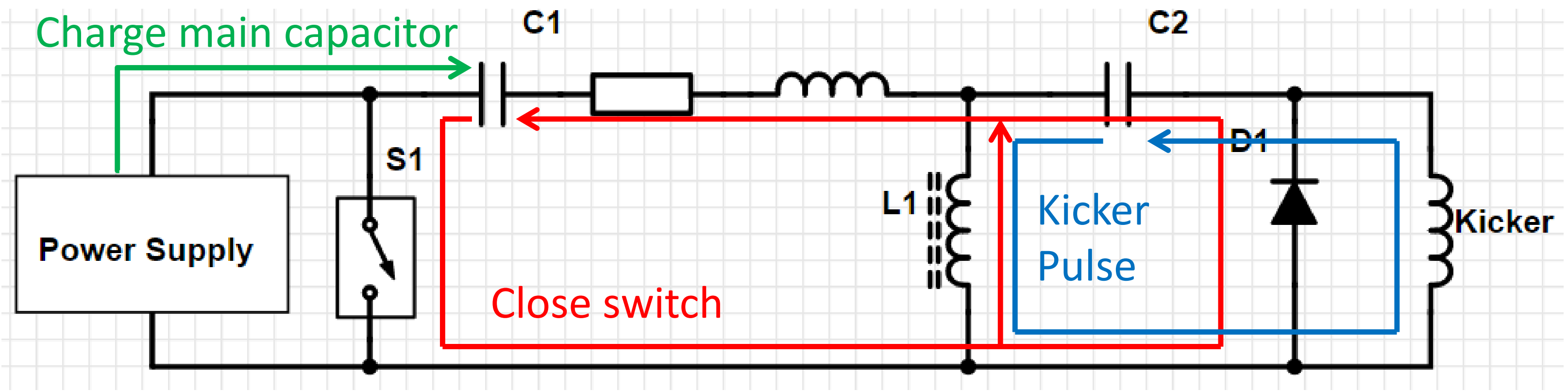
Kicker Power supply design



This concept was developed in collaboration with Applied Pulse Power*:

- L1 is optimised magnetic switch.
- C1 main charging capacitor.
- C2 charges on closure of S1.
- L2 saturates when C2 at voltage required.
- C2 then discharges through L2 and magnet.

Circuit performance optimised was to improve di/dt rate and pre-pulse current.

**Applied Pulse Power Inc. Freeville, New York.*

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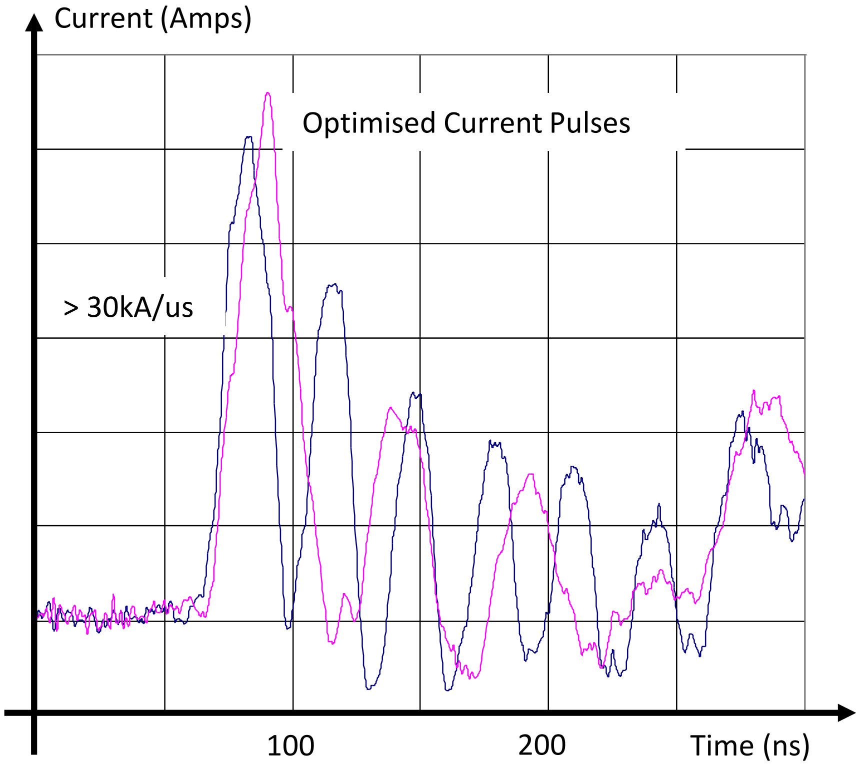
Kicker Power Supply design

- After computer simulation and prototype testing, circuit suitable for extraction only.
- The desired pre-pulse and di/dt rate has been achieved.
- Further work is required to increase peak current from 600Amps to 1.2kAmps.
- Unfortunately the post pulse oscillation was not acceptable for an injection magnet.



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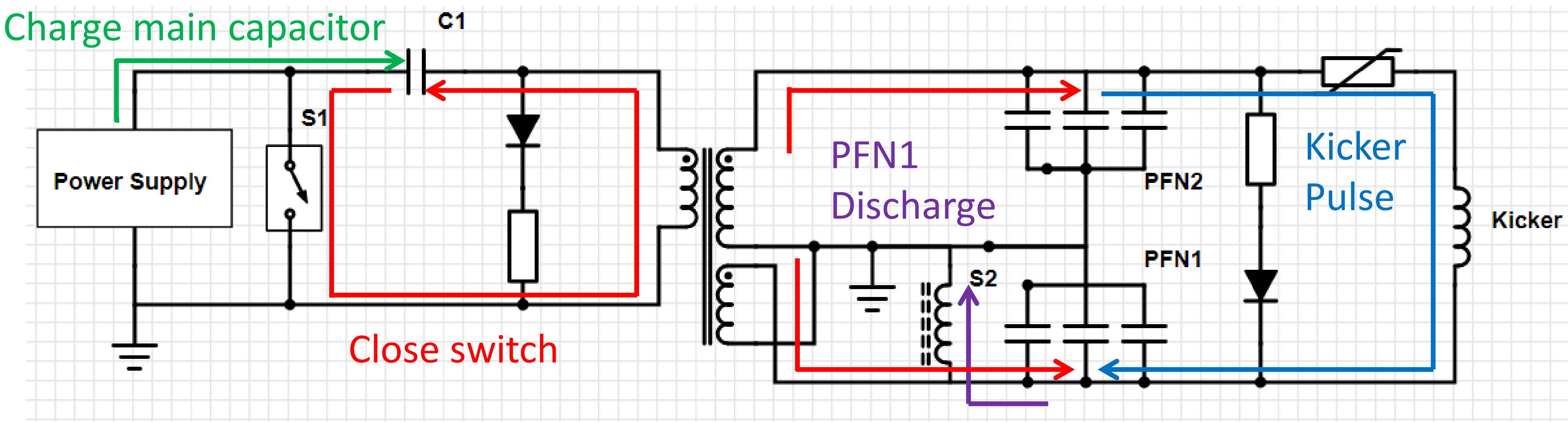
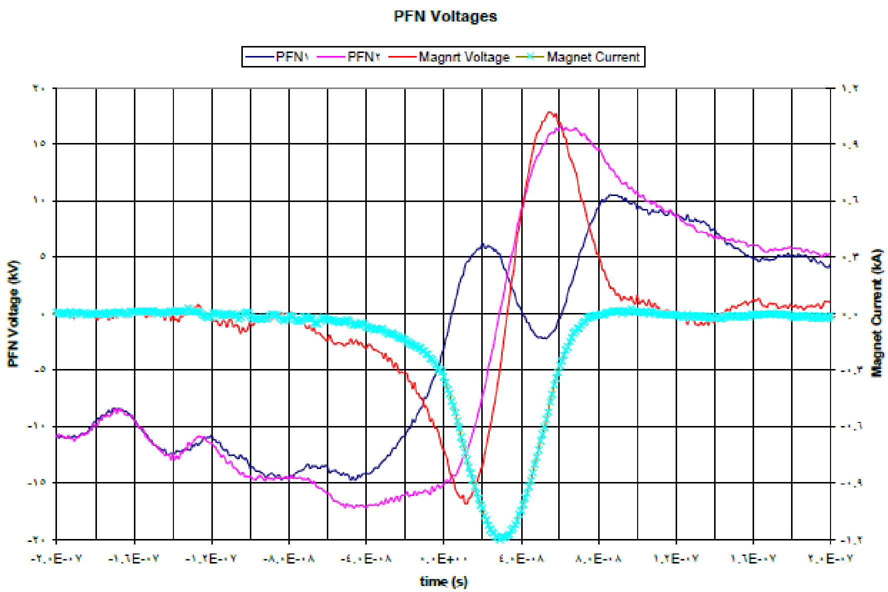
Kicker Power supply design

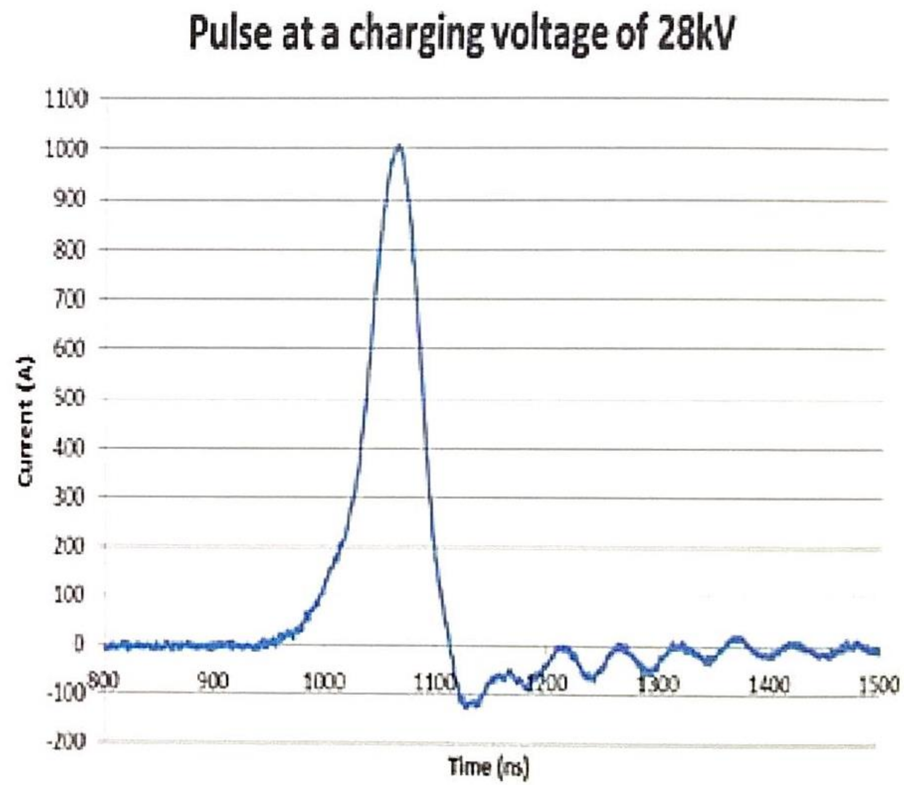


Again in Collaboration with APP We developed and tested this circuit. It operates as follows:

- The PFNs are charged on an ~ 200ns timescale through step-up transformer, using the model S33A-8 32kV solid state switch S1.
- When S2 saturates, the voltage across one PFN1 discharges
- In turn PFN2 is able to discarge through the magnet

Kicker Power Supply design





It appeared possible to meet the requirements for both injection and extraction kickers with a relatively simple and inexpensive system that uses proven solid state switch technology.

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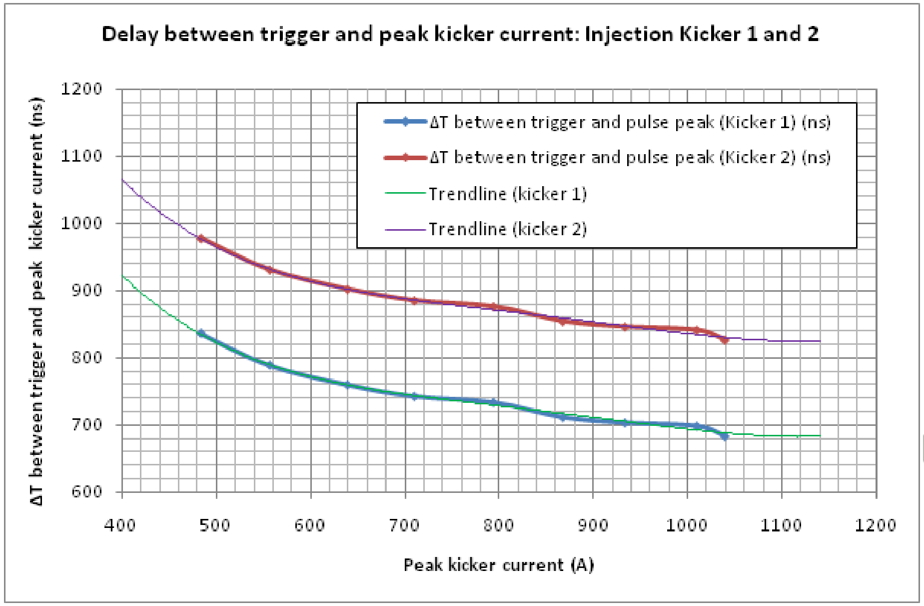
Features

- Due to the importance of impedance matching, the pulse power supply had to sit on top of the magnet. This provided significant mechanical limitations.
- We provided a complete additional level of screening for our pulse current transformers to obtain a clean current trace.
- Delay between the control signal pulse and current pulse varied with kicker current and was different for each kicker!



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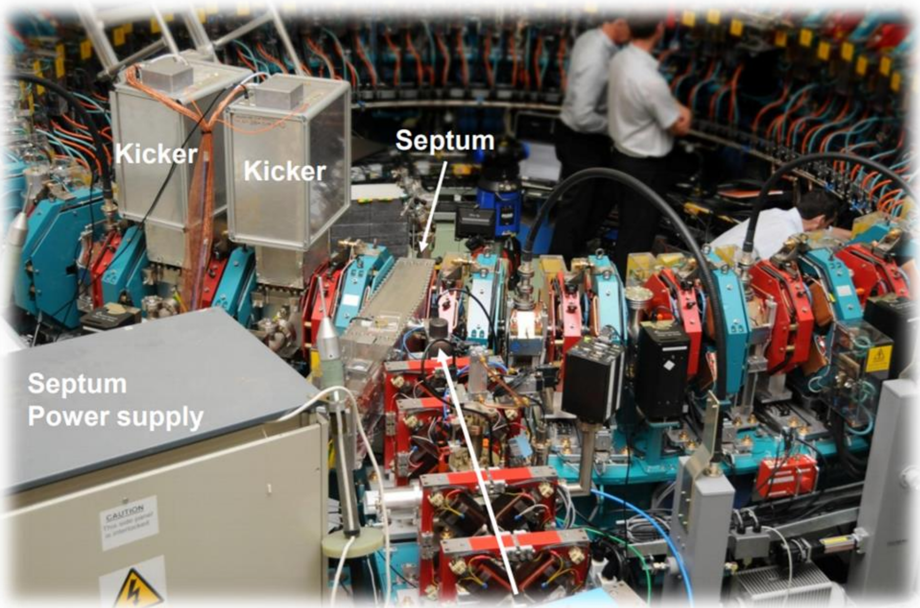
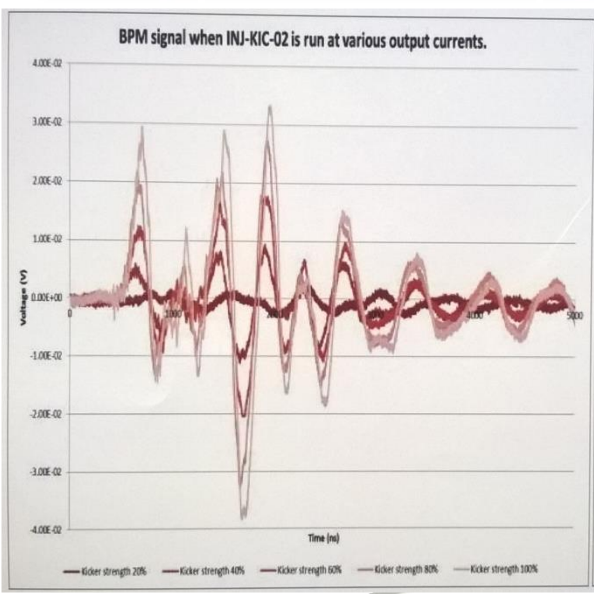
Problem with the BPMs

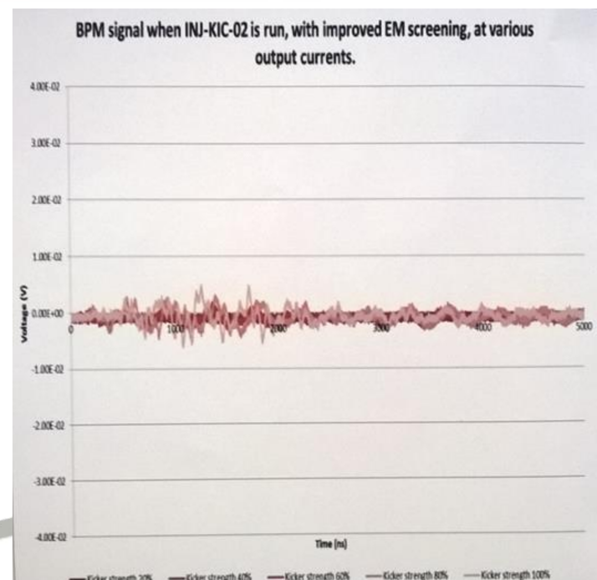


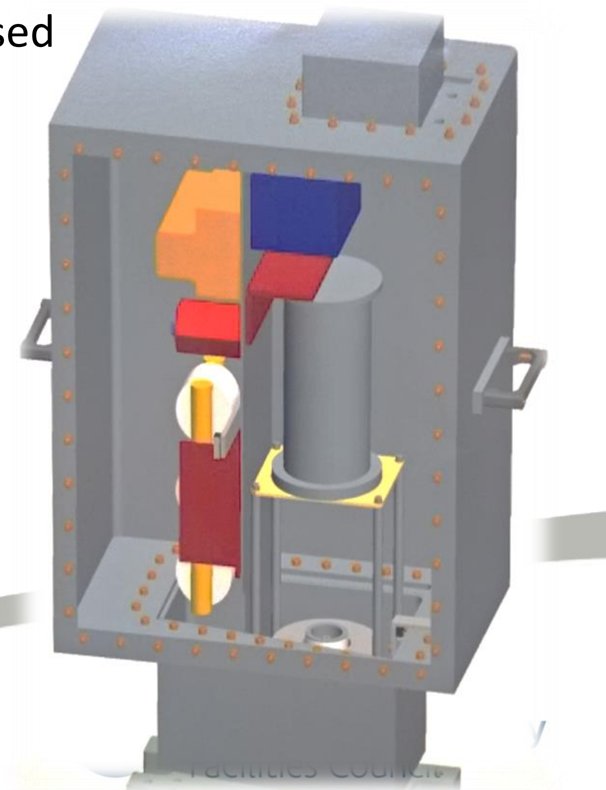
Interference from the kickers was such that the Beam could not be detected after injection.

Careful grounding and shielding methods improved this.

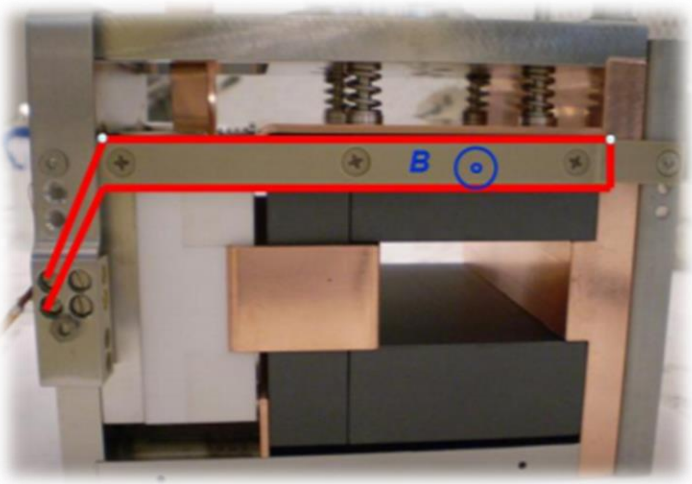
A new enclosure rectified the issue sufficiantly to allow the BPM to be correctly utilised



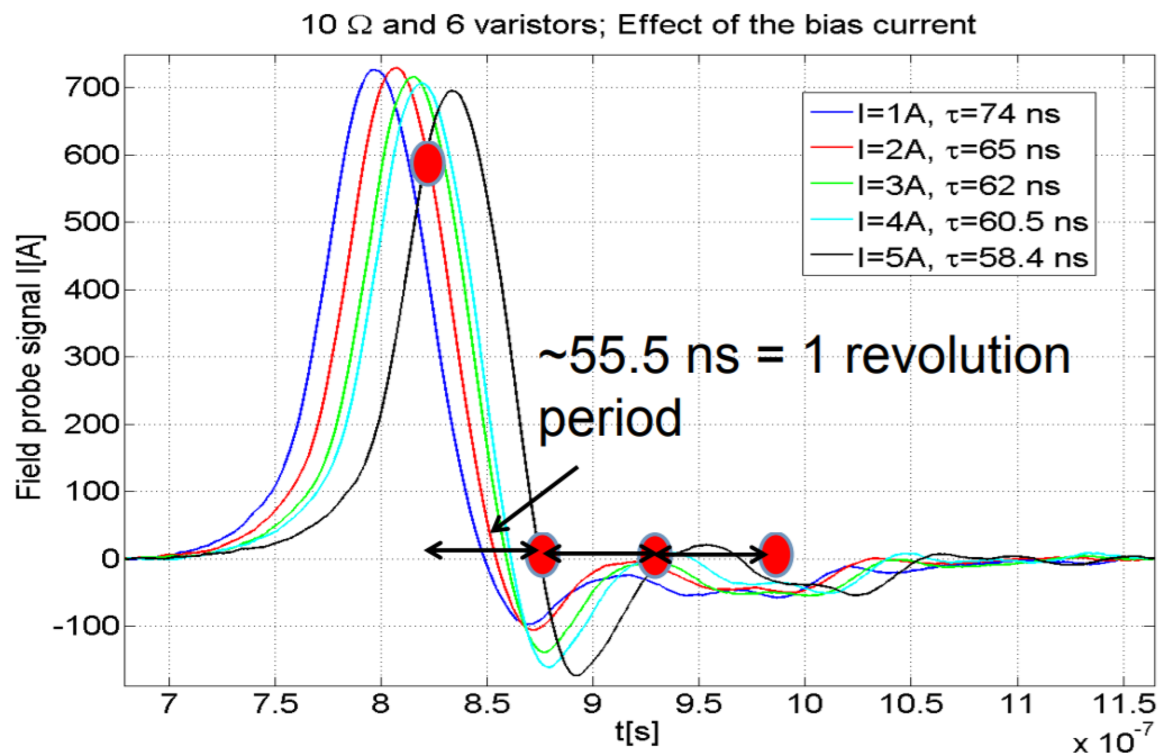




Performance



An in-situ field probe was mounted on the kicker magnet to measure performance.
This was used to verify that the system post pulse overshoot was much larger than acceptable



There were 3 main parameters to vary; resistance of the energy dampener, number of varistors or saturatable choke current.
However we were unable to meet specification.
The only remaining choice was multiple turn injection.
This was not ideal however it was achieved and EMMA was successfully operated and met it required deliverables.

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Lessons Learned

- Benefits:
  - Technology is relatively cheap - Cost in 2009 for 4 kicker units including testing and shipping was $100k (USD).
  - Technology is relatively straight forward to support – the topology is relatively simple.
- Disadvantages:
  - It is very difficult to design a match impedance between the pulse power supply and the magnet without the magnet present.
  - Capacitor charger requires suitable protection from short circuit and reverse currents within the pulse power supply

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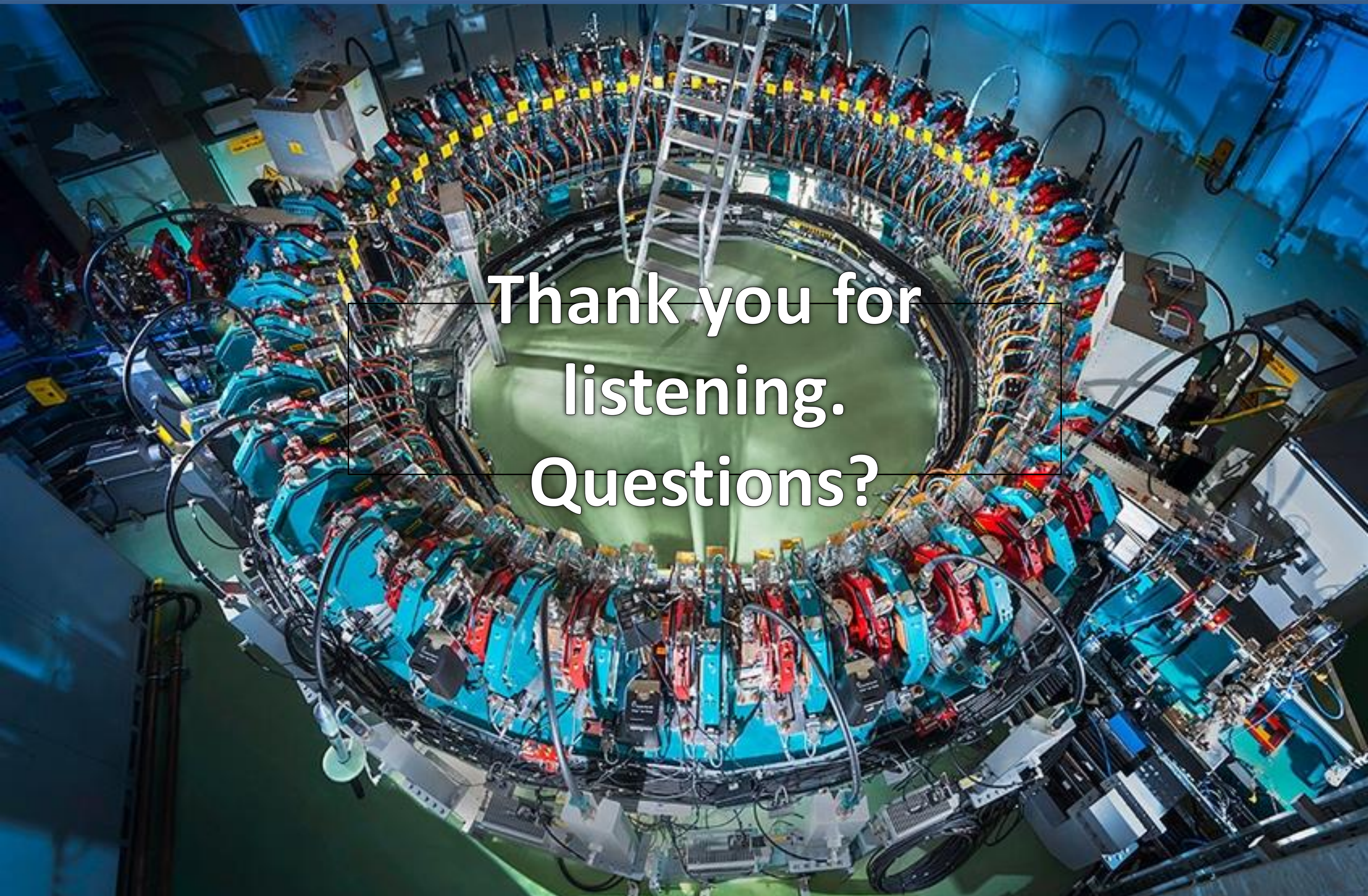

Thank you for listening. Questions?