Permanent Magnet Quadrupoles for the CLIC Drive Beam

Jim Clarke, Norbert Collomb, Neil Marks, James Richmond, and Ben Shepherd

STFC Daresbury Laboratory, UK

Background

- The CLIC drive beam needs a quadrupole every meter (~42,000)
- The electromagnet option will consume ~400W per magnet
- Want to maintain heat load in tunnel to <150W/m
- Daresbury Lab was asked to look at Permanent Magnet options and also to assess new techniques for building ~50 quads/day

Science & Technology Facilities Council

Why PM Quads?

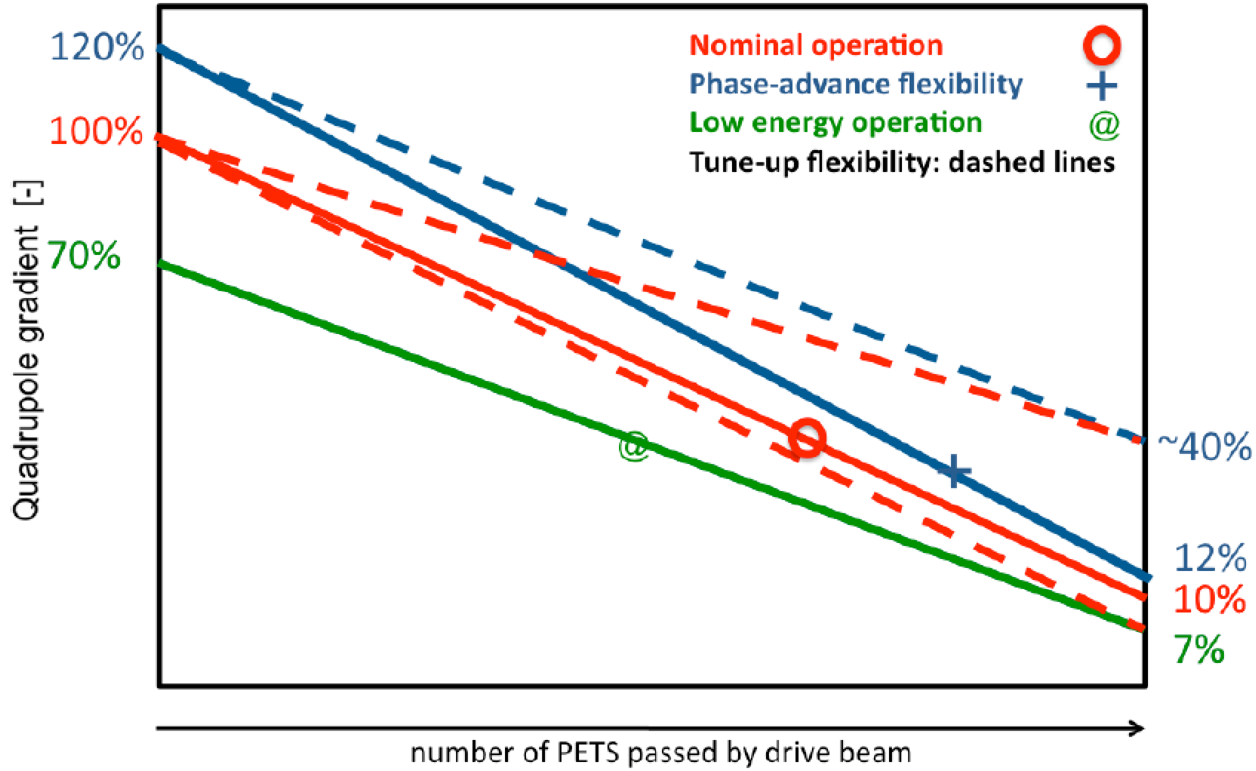
- No direct power consumption
- No heatload in the tunnel
- Low running costs
- Higher integrated gradient (potentially)
- Possible issues
  - Radiation Damage?
  - Is large tuneability feasible?
  - Is required motion control precision feasible?
  - Sensitivity to material errors & temperature?
  - Sufficient magnet quality?
  - ...

Science & Technology
Facilities Council

Specification

- Max Integrated gradient 14.6 T (120% setting)
- Inner radius of vac chamber 11.5 mm
- Outer radius of vac chamber 13.0 mm
- Field quality within ±0.1% over ±5.75 mm
- Max dimensions of magnet:
  - 391 x 391 x 270 mm (H x V x L)
- Adjustability of integrated gradient
  - 120% to ~60% at high energy
  - ~43% to 7% at low energy
- Need dipole correction also of 12 mTm (max) in both planes (not simultaneous)

Tuneability



100% corresponds to a quadrupole gradient of 81.2 T/m (assuming a magnet active length of 0.15 m)

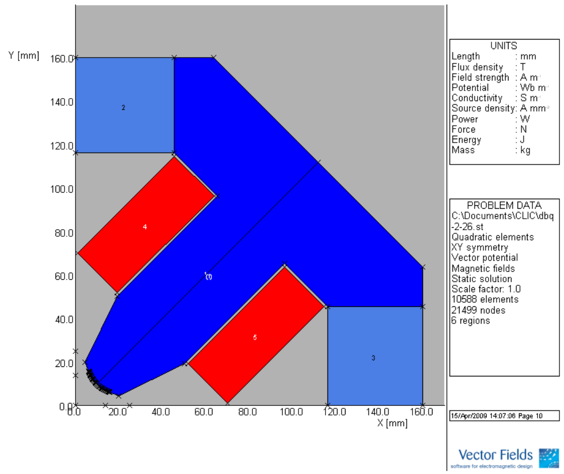
Erik Adli & Daniel Siemaszko

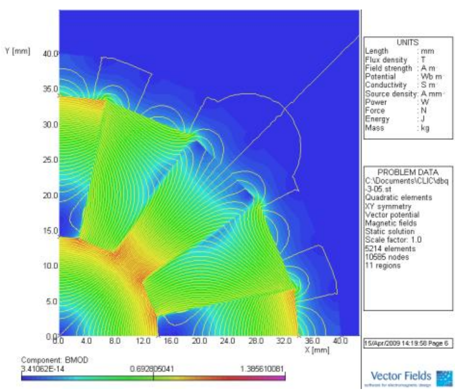
Low energy end more demanding in terms of adjustable range of magnet

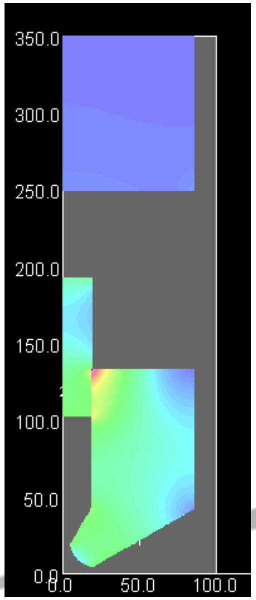
Science & Technology Facilities Council

Options Considered

- Combination of PM and coils
  - Use coils to adjust field
- Circular PM (Halbach) geometries
  - Use motion to adjust field
- Steel pole with PM excitation only
  - Use motion to adjust field



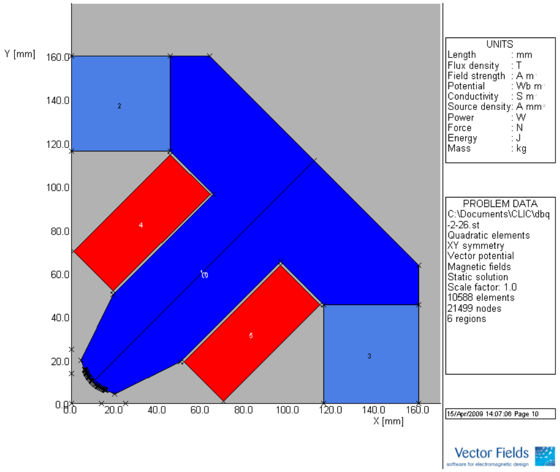


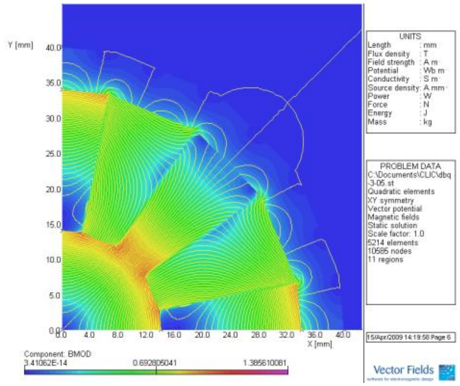


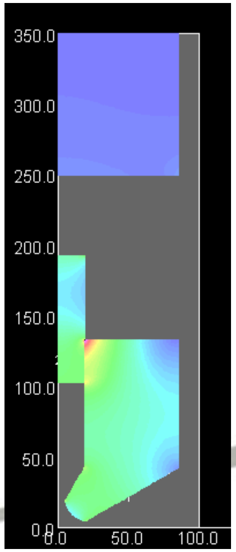
Science & Technology Facilities Council

Assessment

- Combination of PM and coils
  - Little advantage over pure EM
  - Coils have to be of similar rating
- Circular PM geometries
  - Field quality poorer than other options
- Steel pole with PM excitation only
  - Best option, can meet spec

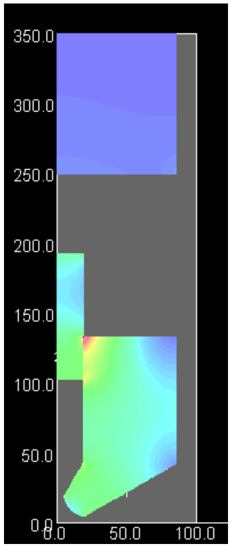


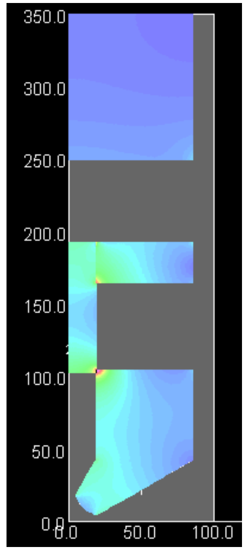


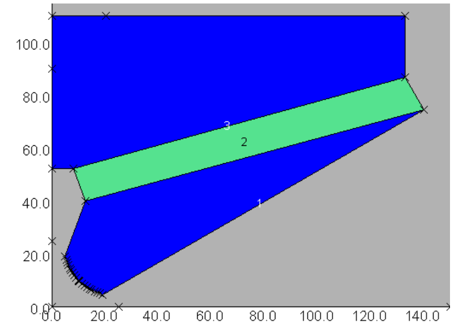


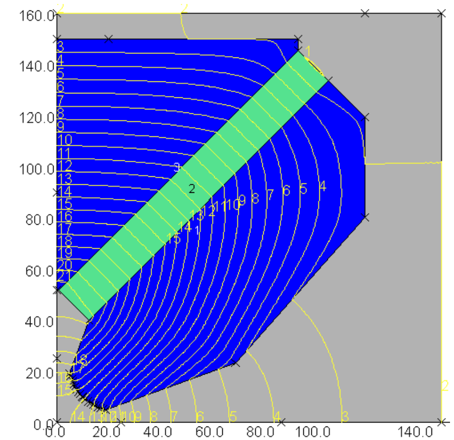
Science & Technology Facilities Council

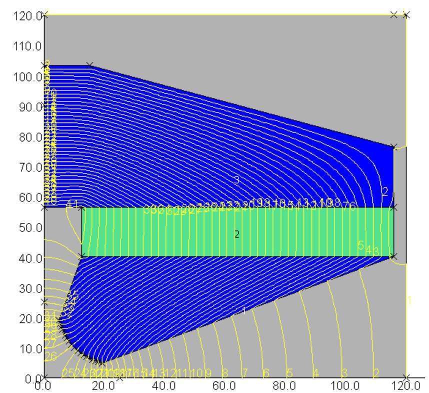
Many Geometries Assessed

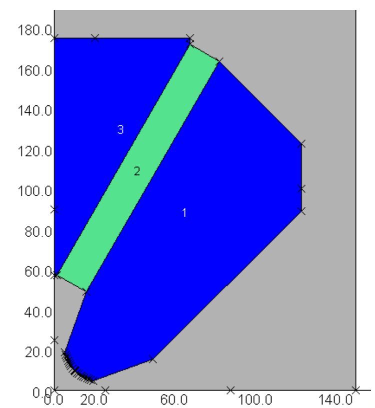


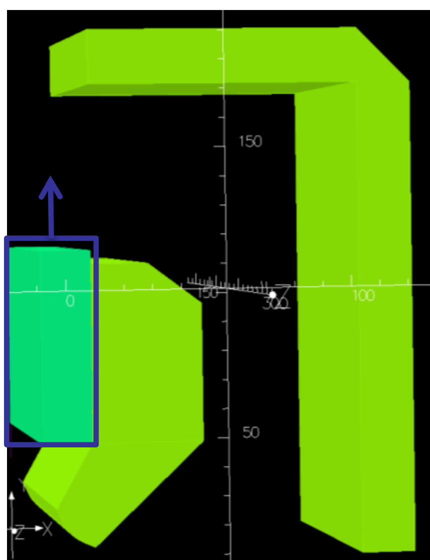




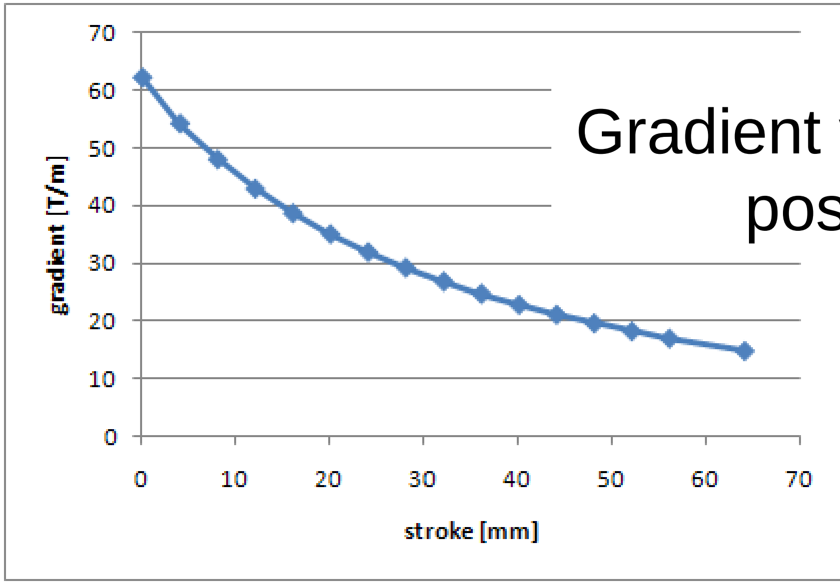


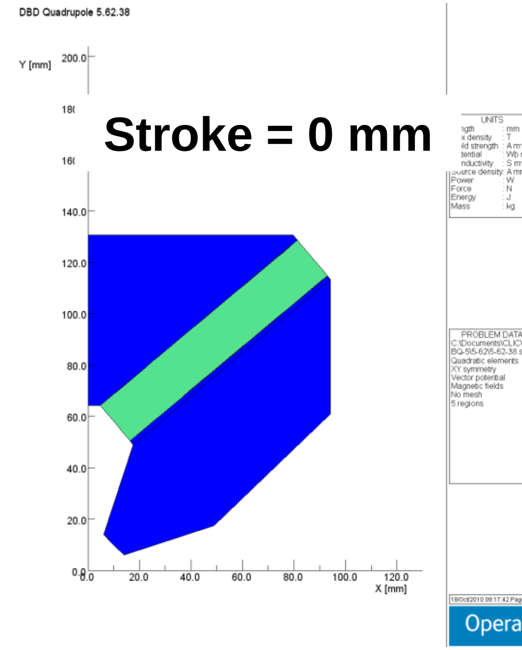


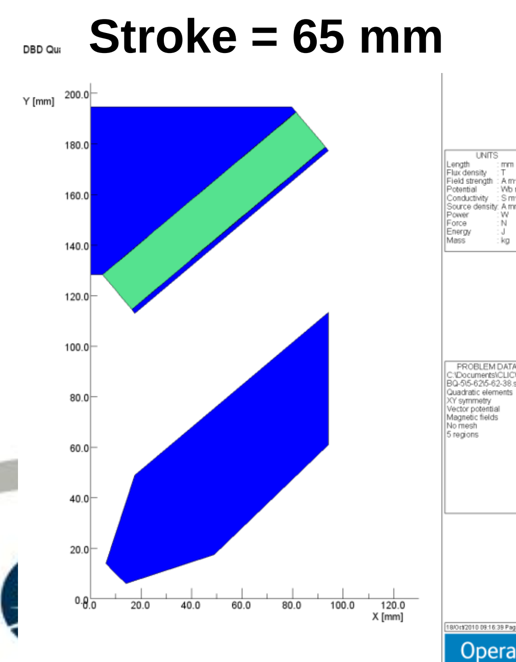


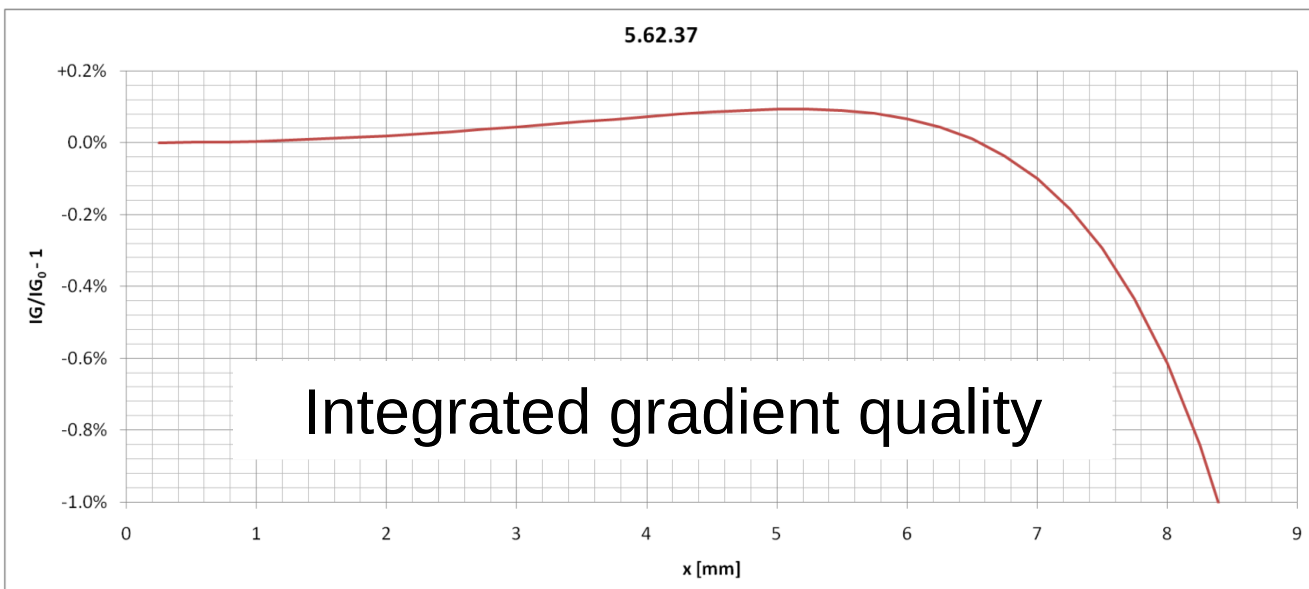


Preferred Solution





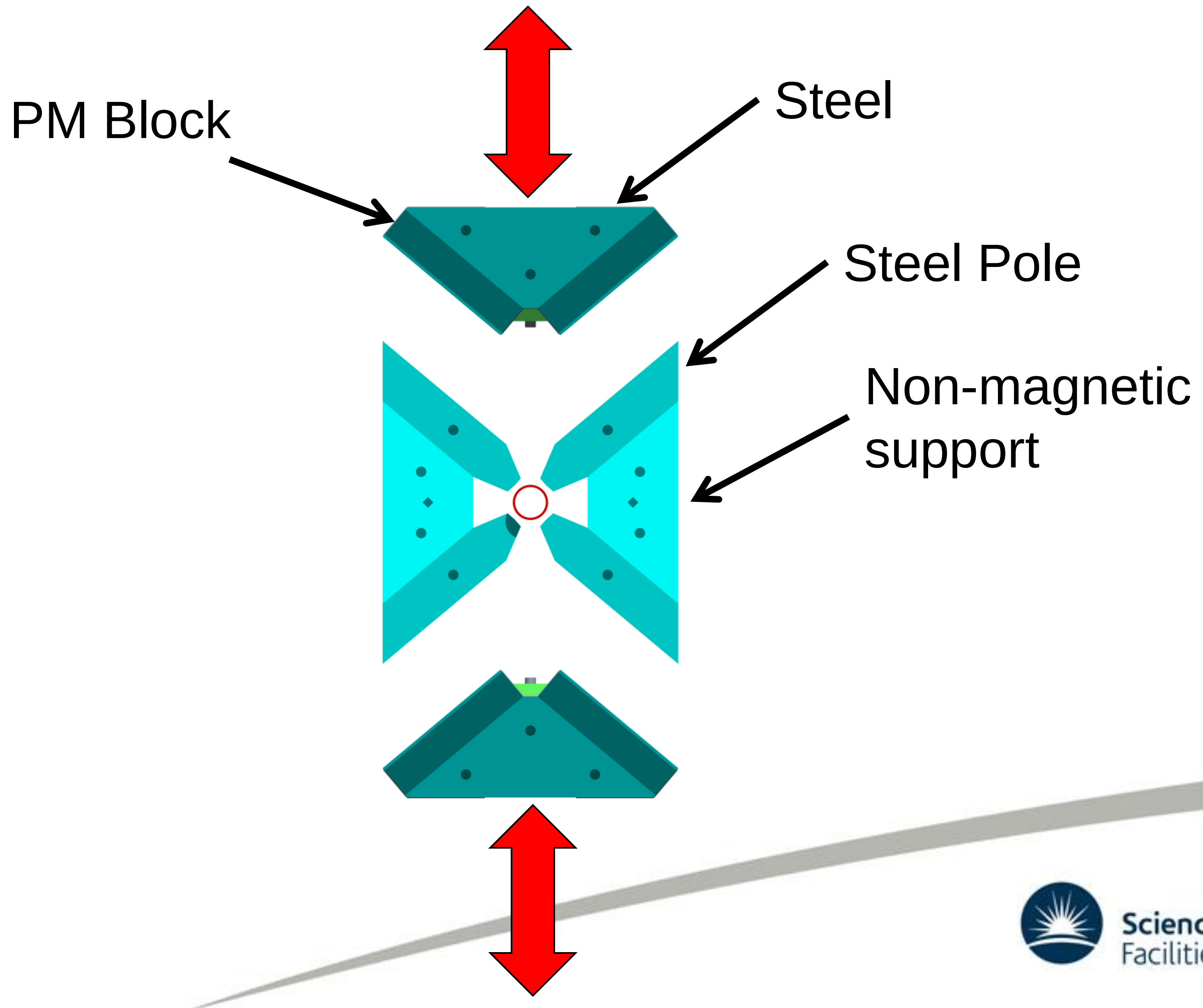




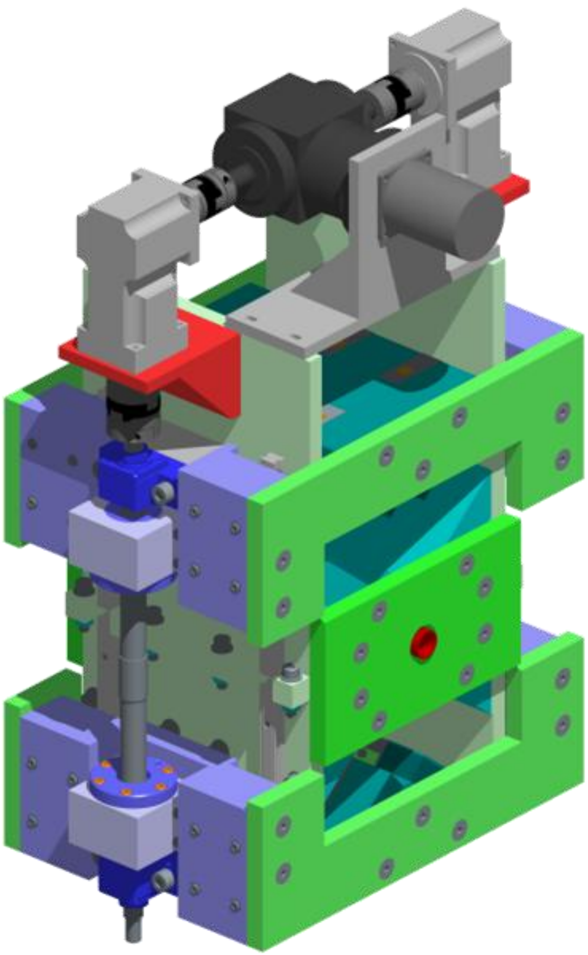
Parameters

Parameter	Value	
Inscribed radius	14 mm	
PM size	18 x 100 mm	
PM angle	40°	
Magnet length	230 mm	
Maximum stroke	64 mm	
Gradient	62.3 T/m (max)	15.0 T/m (min)
Integrated gradient	15.0 T (max)	3.6 T (min)
Relative to nominal	123%	30%
Magnetic length	241 mm	
Good gradient region	±7.0 mm	

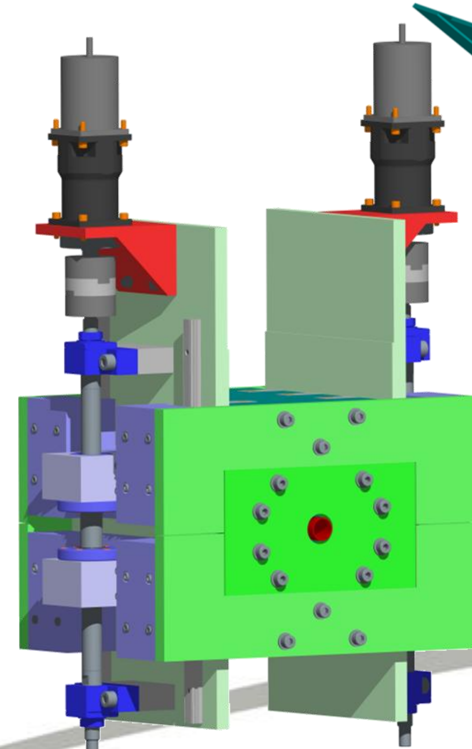
Basic Engineering Concept



Engineering

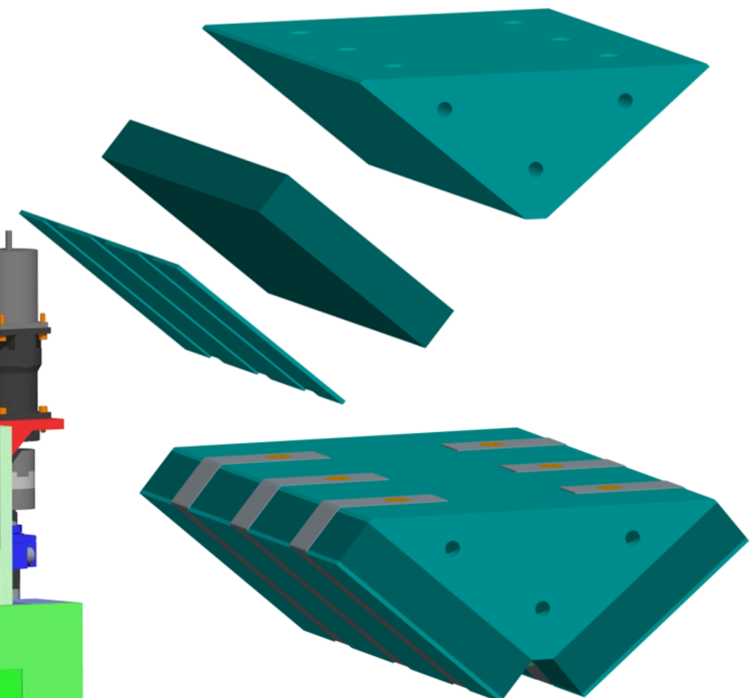


Fully Open



Fully Closed

PM Block secured to steel yoke



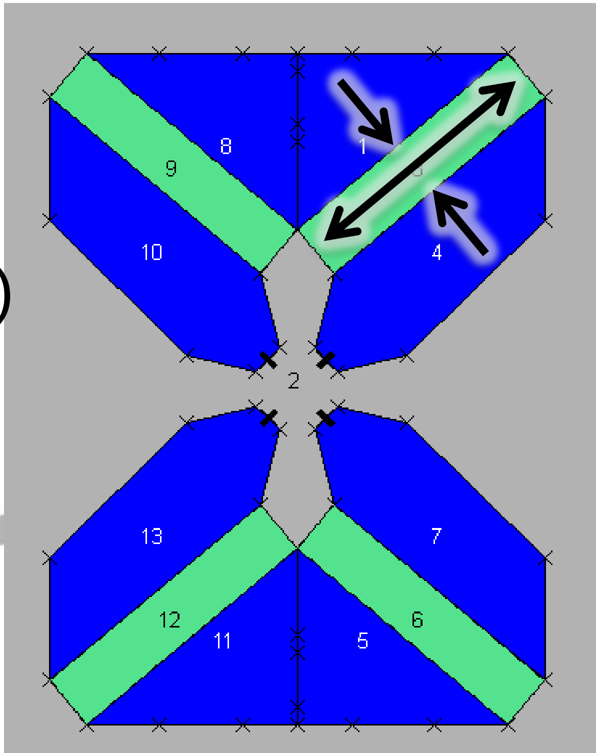
Science & Technology Facilities Council

Motion Control

- Step size of 15 μm changes strength by 5 x 10^{-4}
- PM Undulator and wiggler motion control
  - Similar forces
  - Similar motion/drive system
  - Typically 1 μm step size
- Max force 17.2kN

PM size tolerance study

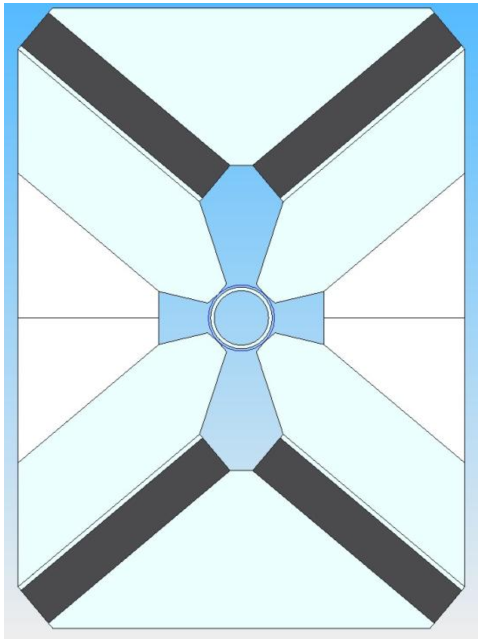
- Modelled complete magnet (not quadrant) in 2D
- Adjusted dimensions of one PM by 0.1mm; measured relative effect on gradient
- Same for PM length in 3D
- Relative changes:
  - – 0.2%/mm for width (nominally 100mm)
  - – 1.0%/mm for height (nominally 21mm)
  - – 0.1%/mm for length (nominally 228mm)
- Length tolerance:
  ~0.1% of each dimension

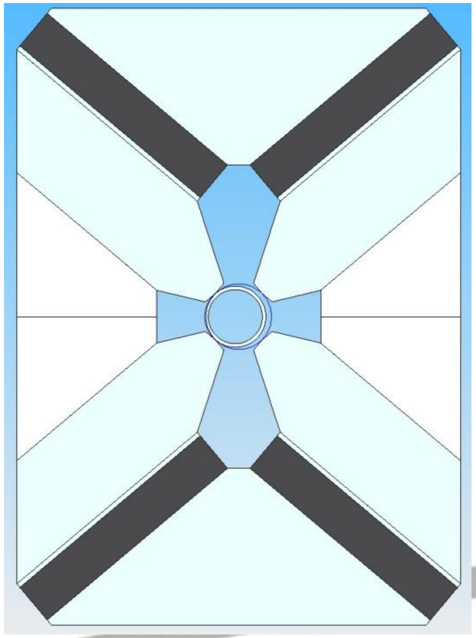


Dipole Correction

- Require 12 mTm in either x or y
- Most easily achieved by moving magnet by up to 1 mm – current design allows up to 1.4mm

Magnet on axis



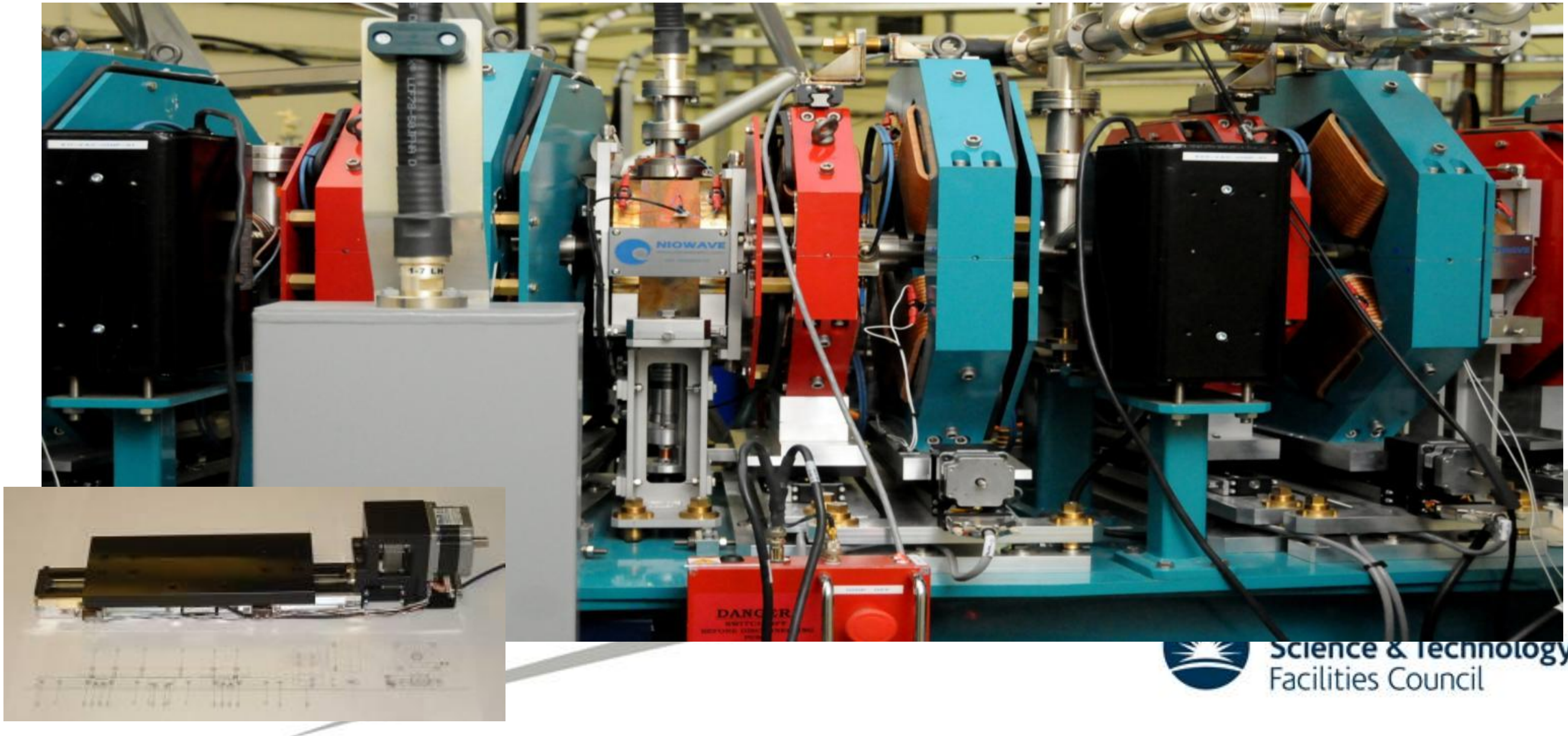


Magnet moved to the right

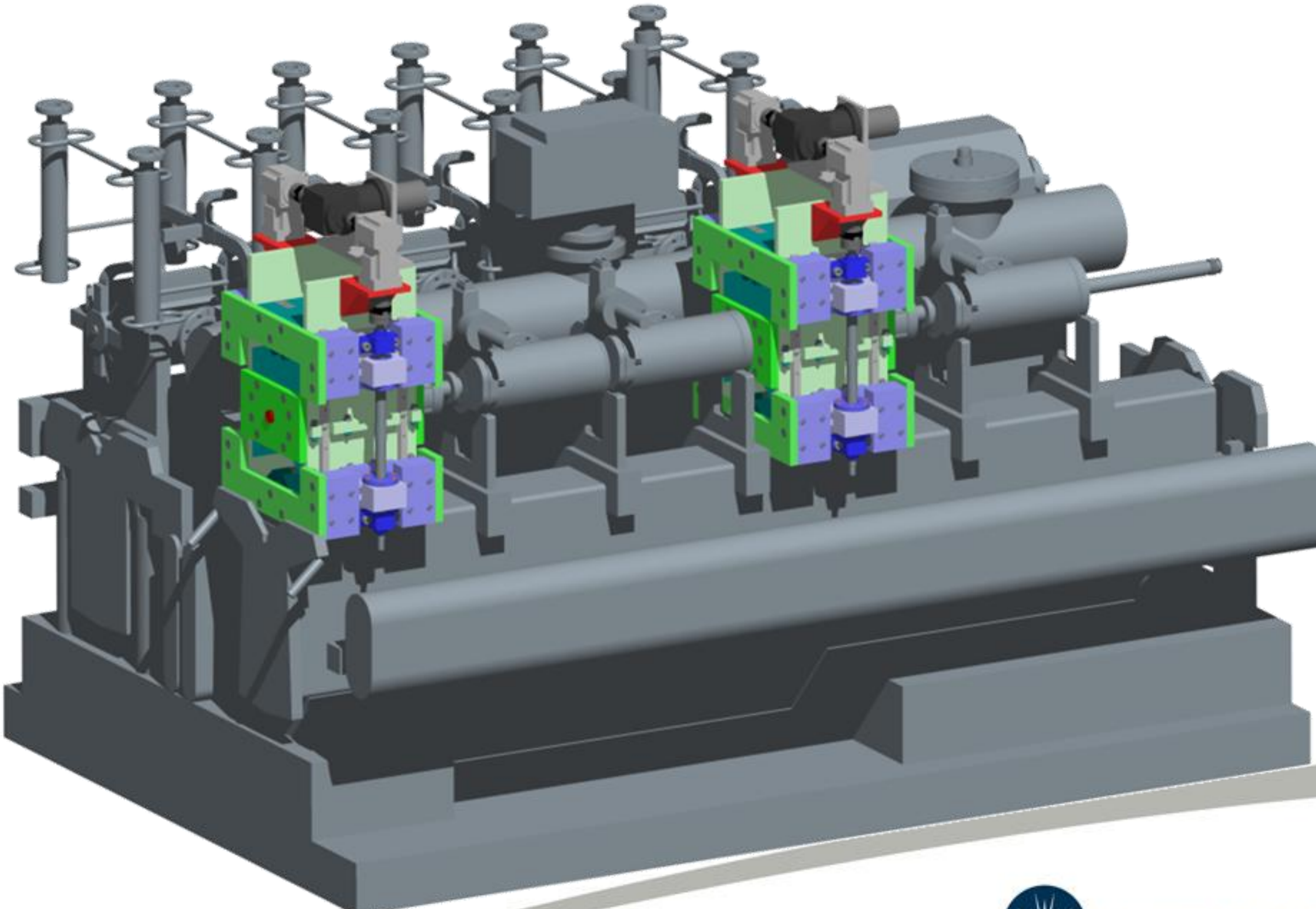
Science & Technology Facilities Council

EMMA Quadrupoles

- The quadrupoles in EMMA (nsFFAG) at Daresbury are mounted on **horizontal slides** to provide independent control of the dipole term
- A similar arrangement could be used to provide CLIC drive beam steering



PM Quads in CLIC



Science & Technology
Facilities Council

Next Steps

- Detailed engineering design
- Assemble and test prototype
- Assess impact of radiation damage
- Assess thermal effects
- Weaker versions for low energy drive beam need to be designed and optimised
  - Will reoptimise design for greater tuneability
- Challenge of automation of production

Science & Technology Facilities Council