Permanent Magnet Quadrupoles for the CLIC Drive Beam

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CERN-UK Kick Off Meeting, April 2011

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)
- Started 2009 – funded by STFC (ASTeC)

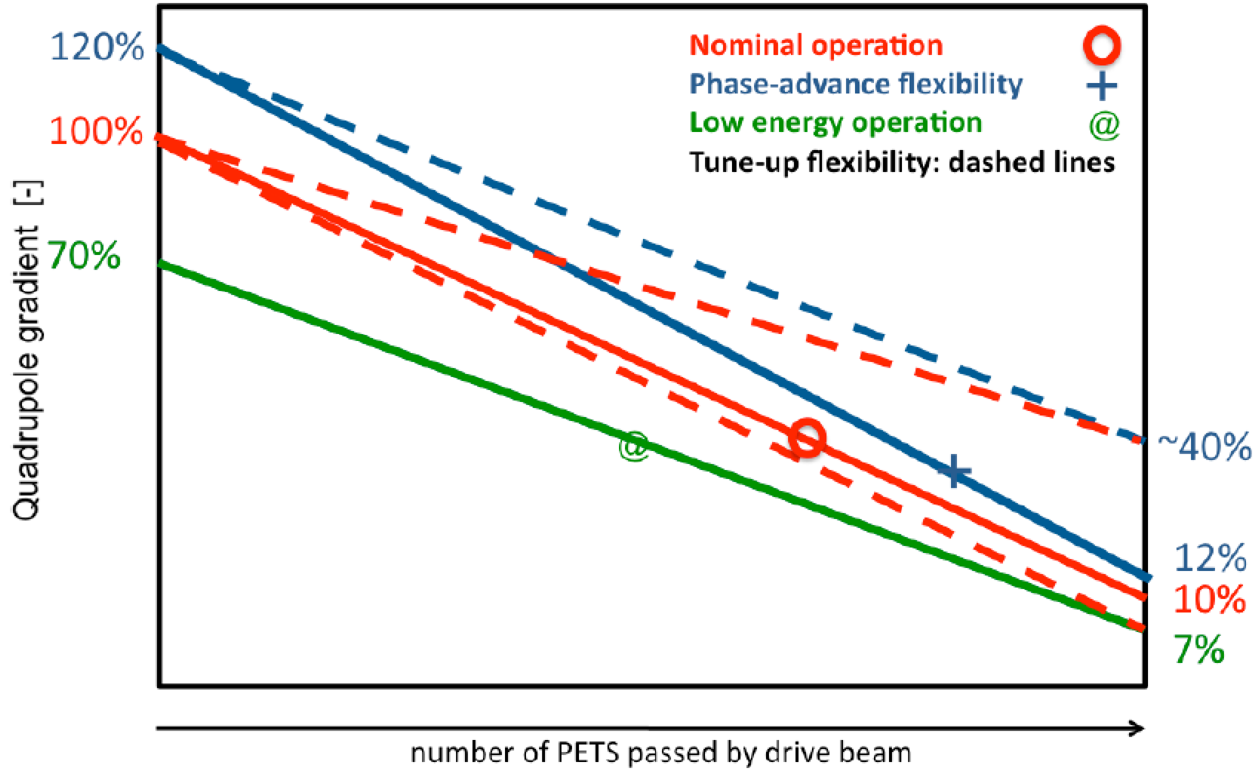
Why PM Quads?

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

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 ±11.5 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

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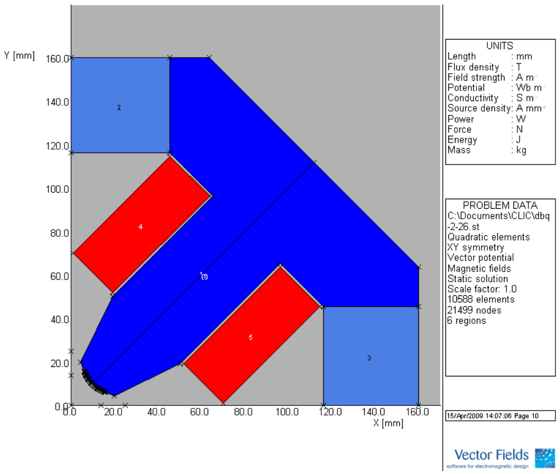
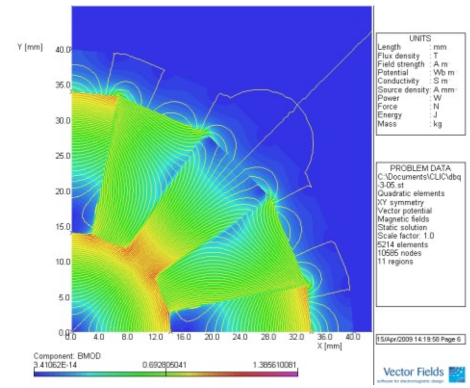
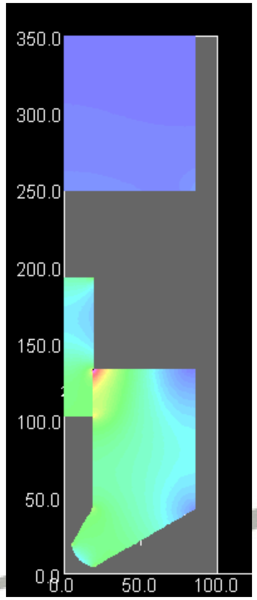
Options Considered

- 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







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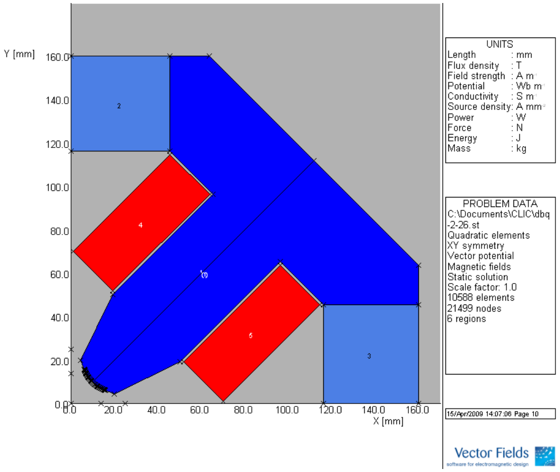
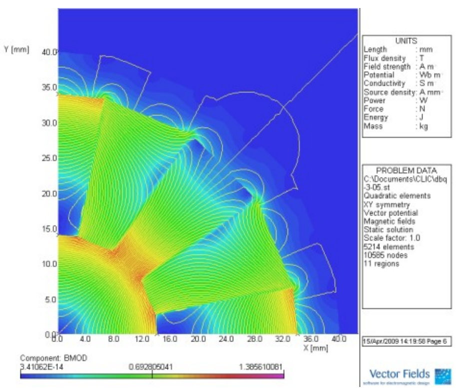
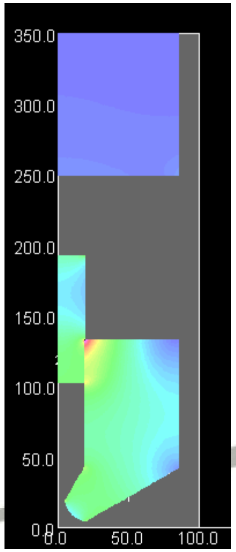
Assessment

- 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







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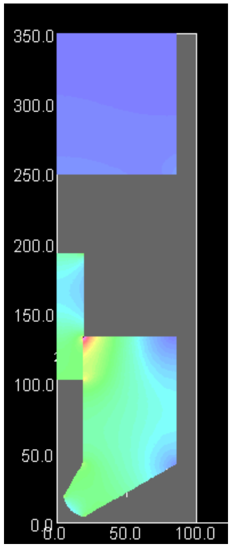
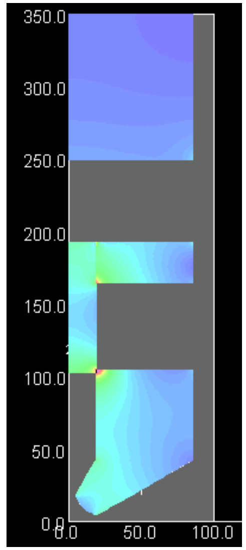
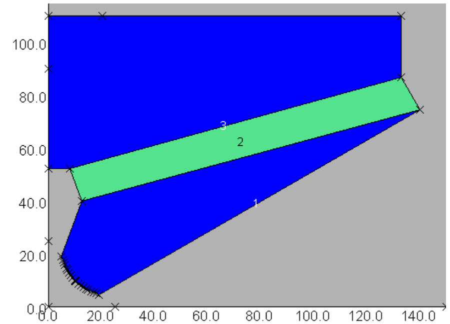
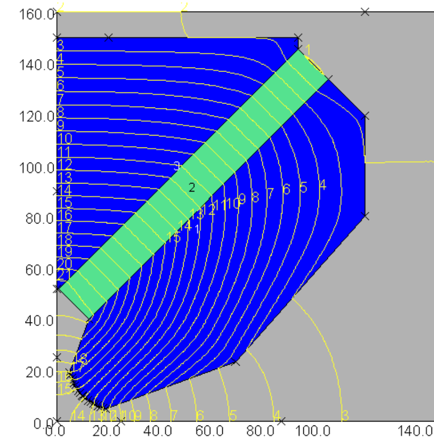
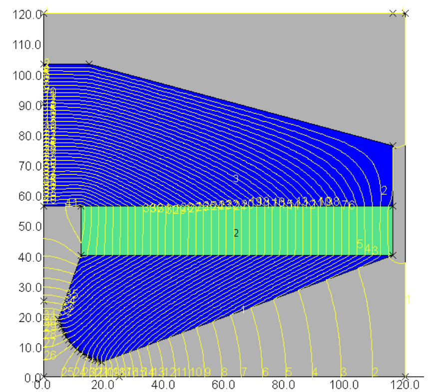
Many Geometries Assessed

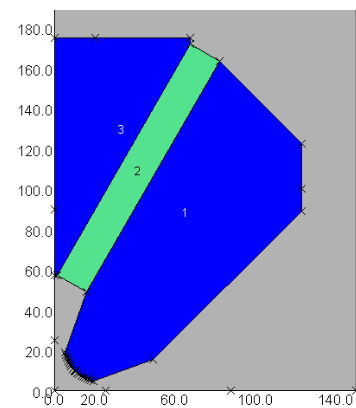


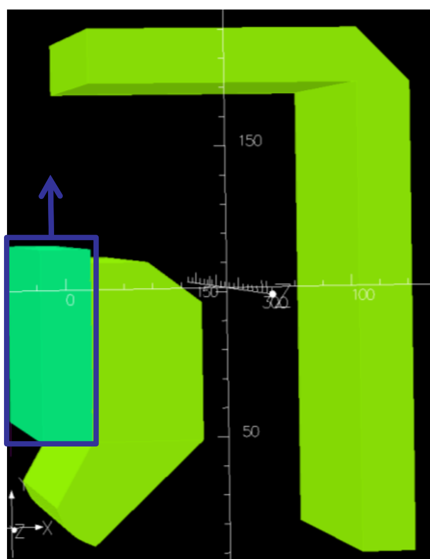




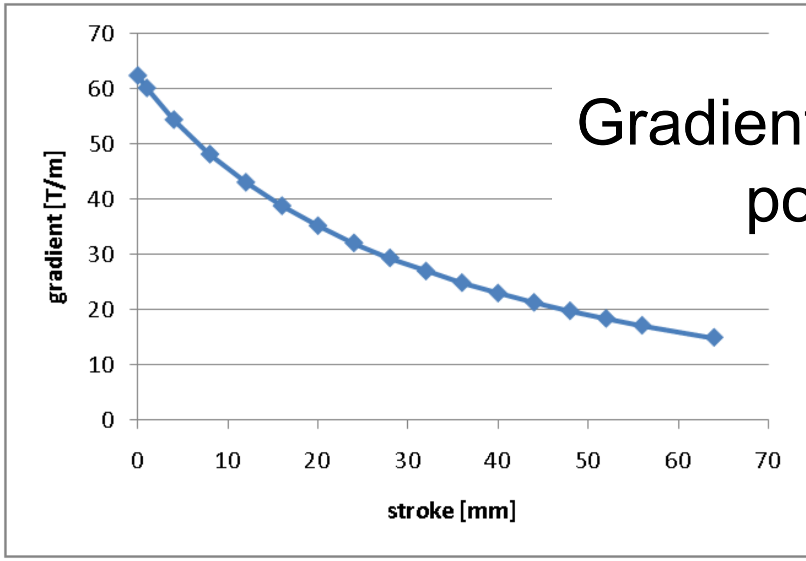






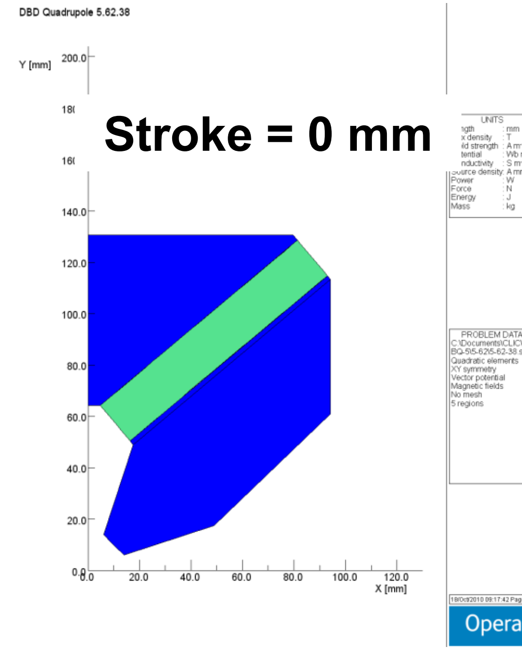


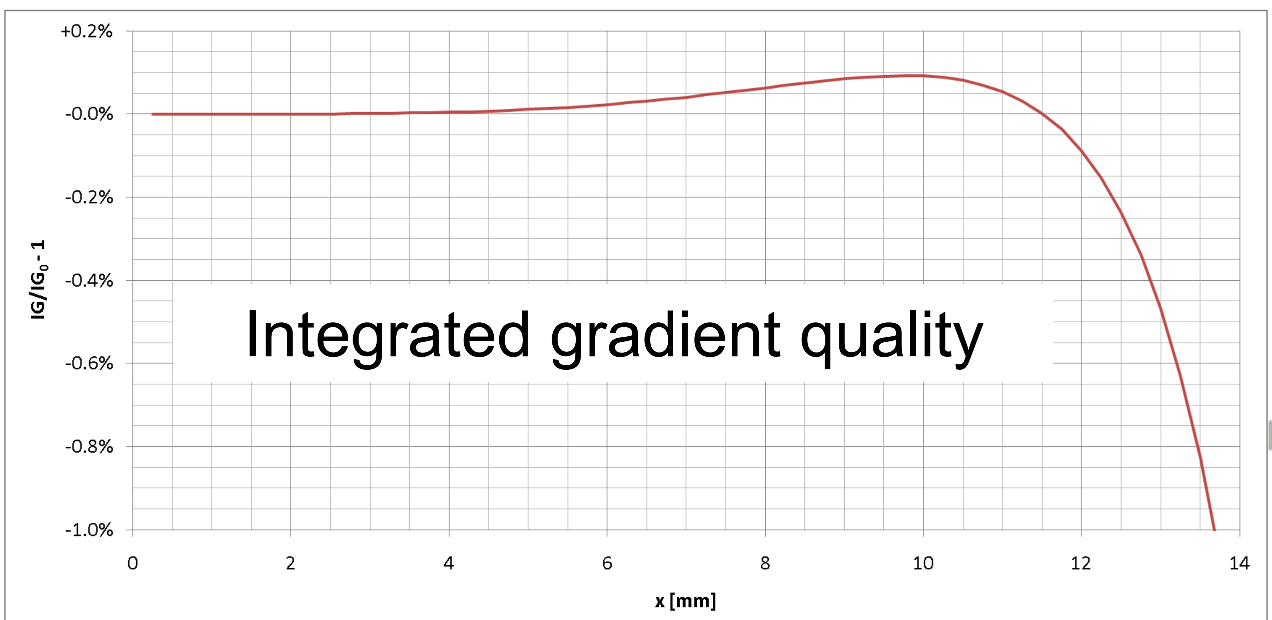
Preferred Solution



Gradient vs magnet position

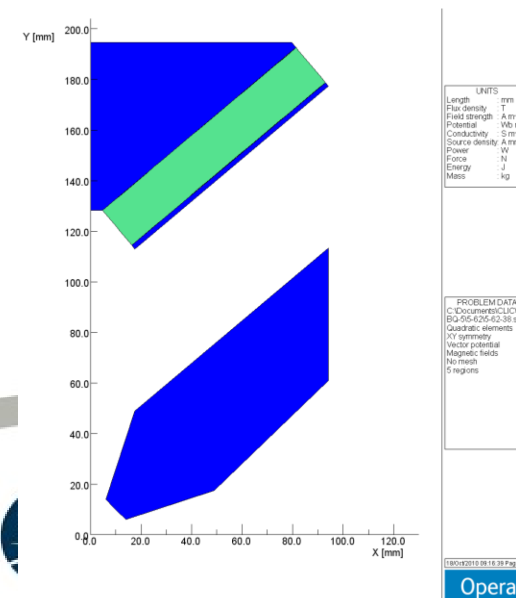
Stroke = 0 mm





Integrated gradient quality

Stroke = 64 mm



Parameters

Parameter	Value	
Inscribed radius	13.6 mm	
PM size	18 x 100 x 230mm	
PM angle	40°	
Magnet Pole Length	230 mm	
Maximum stroke	64 mm	
Integrated gradient	14.6 T (max)	4.4 T (min)
Relative to nominal	120%	30%
Good gradient region	±12.0 mm	

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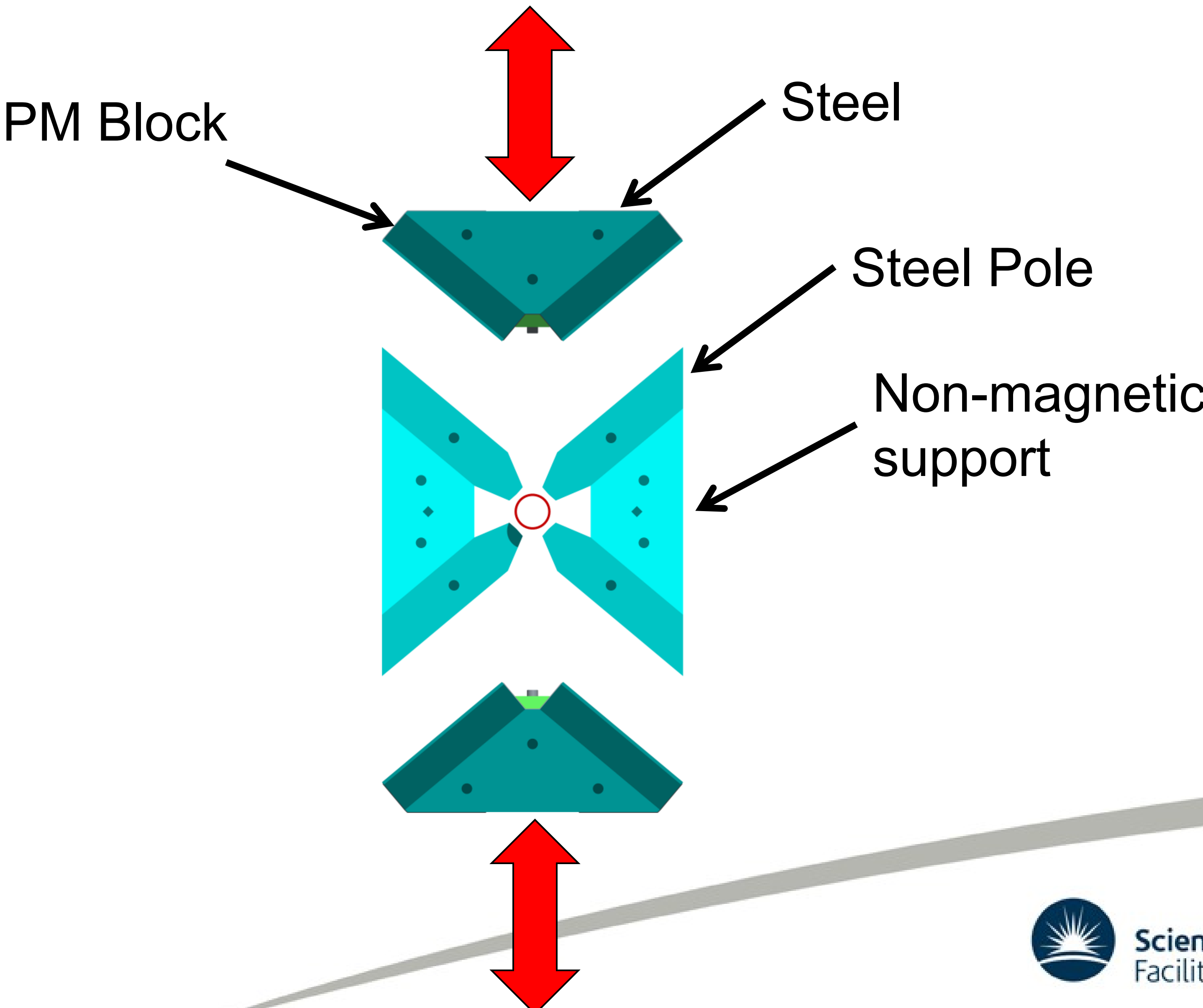
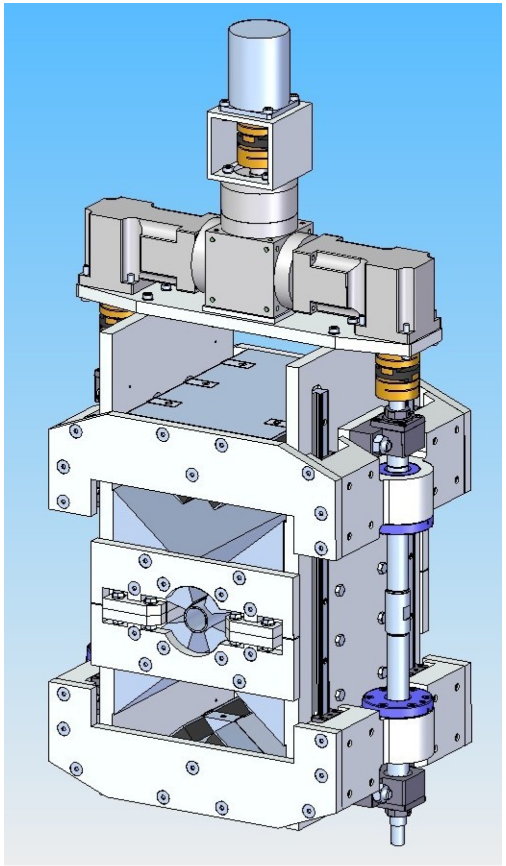
Basic Engineering Concept



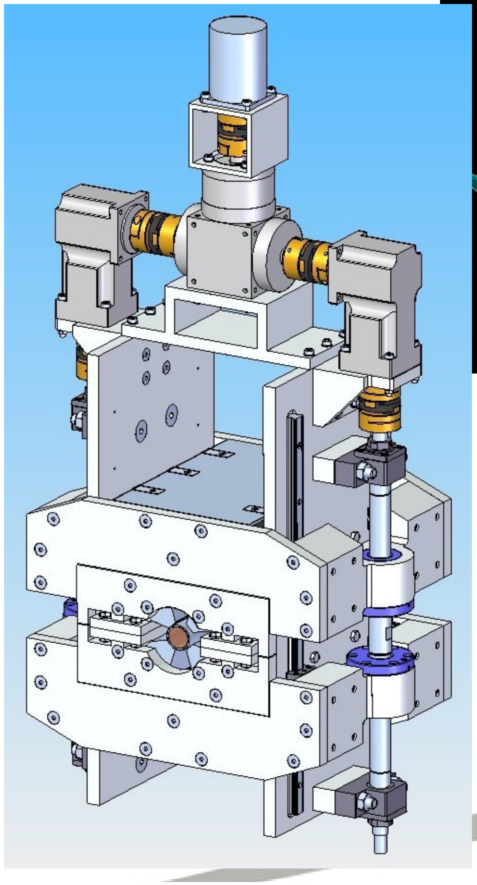
Design has been patented

Engineering

PM Block secured to steel yoke



Fully Open



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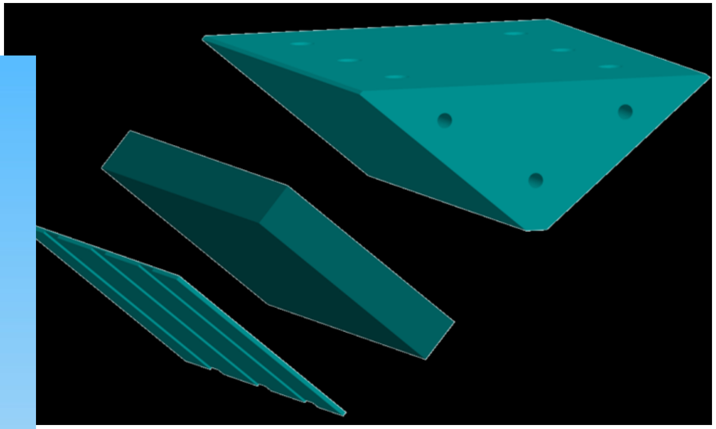

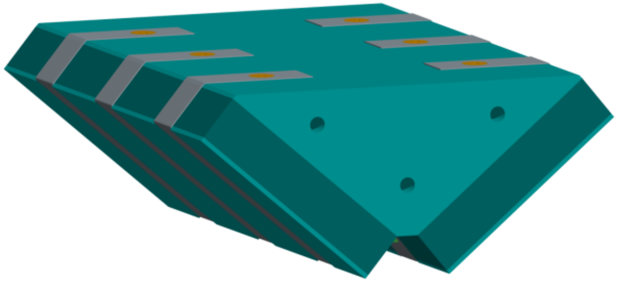

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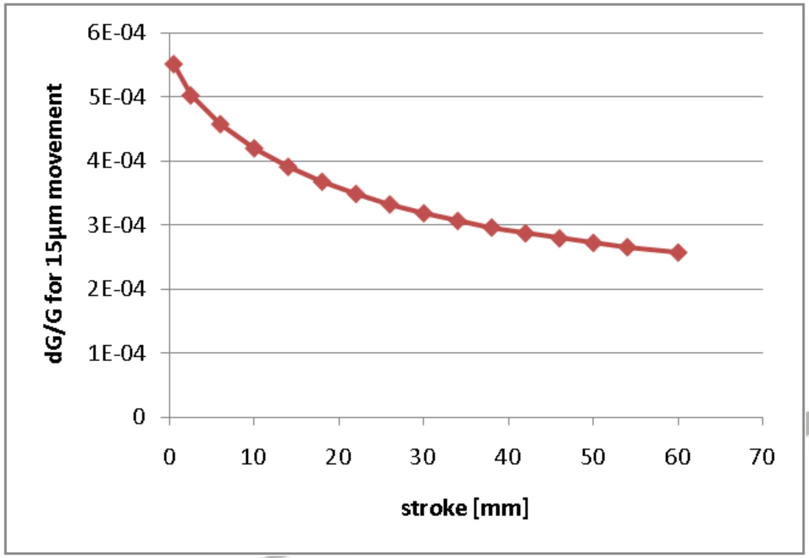
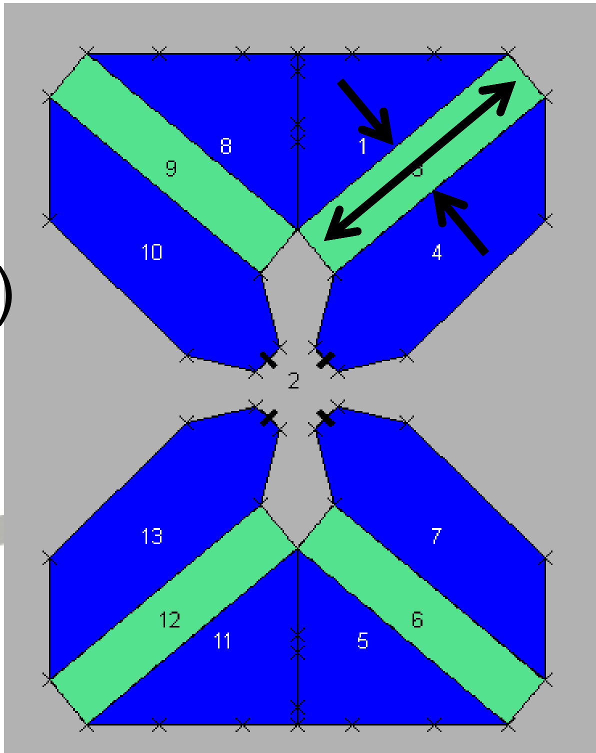
Motion Control

- Step size of 15 μm changes strength by <6 x 10^{-4}
- PM Undulator and wiggler motion control
  - Similar forces
  - Similar motion/drive system
  - Typically 1 μm step size achieved
- Max force 17.2kN



PM size tolerance study

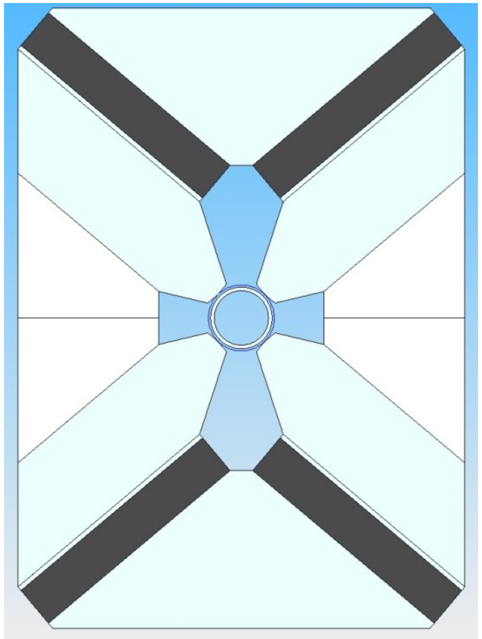
- Modelled complete magnet (not quadrant) in 2D
- Adjusted dimensions of one PM by 0.1mm; measured relative effect on gradient
- Same for PM length in 3D
- Relative changes:
  - 0.2%/mm for width (nominally 100mm)
  - 1.0%/mm for height (nominally 21mm)
  - 0.1%/mm for length (nominally 228mm)
- Length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

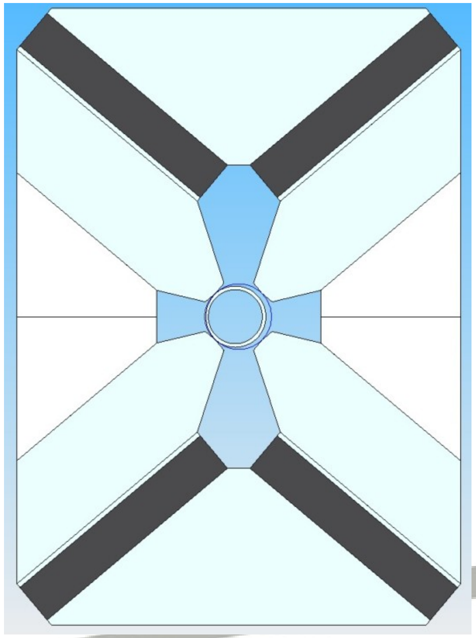


Dipole Correction

- Require 12 mTm in either x or y
- Most easily achieved by moving magnet by up to 0.8 mm – current design makes allowance for this

Magnet on axis





Magnet moved to the right

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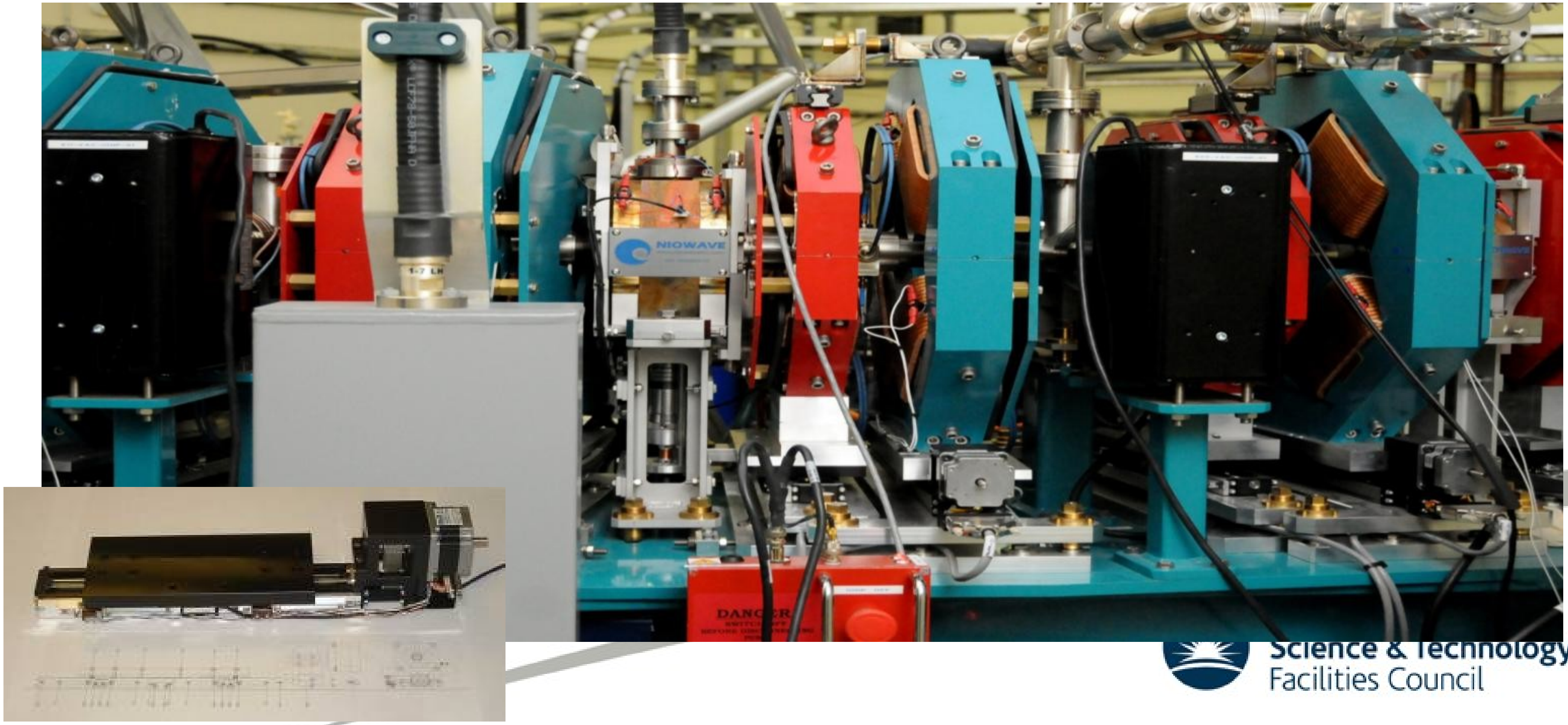
EMMA Quadrupoles

- 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



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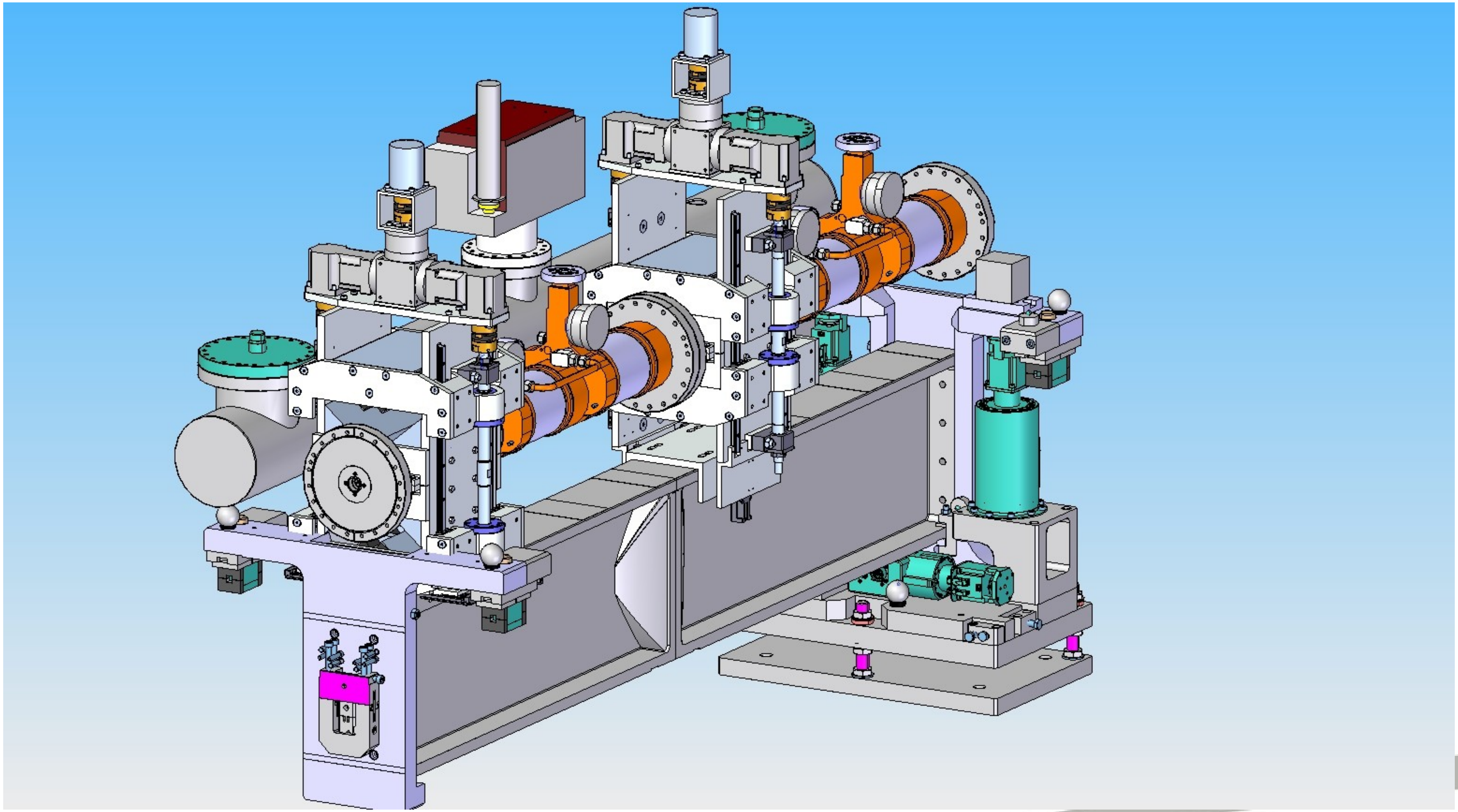
PM Quads in CLIC



Planning & Deliverables

- Detailed engineering design of **high strength quadrupole**
- Procure components and assemble prototype (31/3/12)
- Magnetic and mechanical testing (DL & CERN), write report (30/09/12)
- Design **low strength quadrupole** for lower energy drive beam
- Procure components and assemble prototype (30/9/13)
- Magnetic and mechanical testing (DL & CERN), write report (31/03/14)

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Resources

	(Year 0)	Year 1	Year 2	Year 3
ASTeC Staff (STFC Contribution)	~2	0.5	0.5	0.5
Engineering Staff (CERN Contribution)		1.5	1.5	1.5

Material Costs £47k
Travel Costs £12k

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