WP11.3 Update

WP11.3: Permanent Magnet Quadrupoles and Combined Function Magnets for Ultra-Low Emittance Storage Rings

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I.FAST Open Steering Committee Meeting

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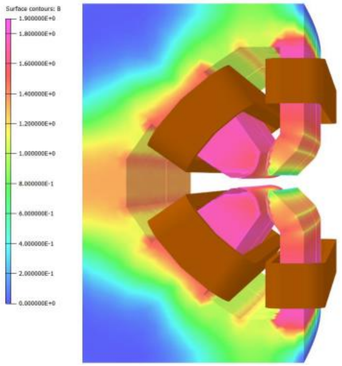
Task description

- ***Task 11.3: Permanent Magnet Quadrupoles & Combined Function Magnets for Ultra Low-Emittance Rings***
  - Partners: UKRI – Diamond Light Source – Kyma
- This task addresses the need for reducing the electricity consumption and carbon footprint in future storage rings
- Two prototypes to be designed, assembled and tested: (**D11.3**)
  - PM-based strong focusing quadrupole magnet
  - PM-based combined function dipole-quadrupole (DQ) magnet
- Parameters similar to Diamond-II and other facilities
- Second-stage prototypes
  - Basic concept already tested
  - Examine requirements for cost-effective series production
- Adjustment using either coils or motors

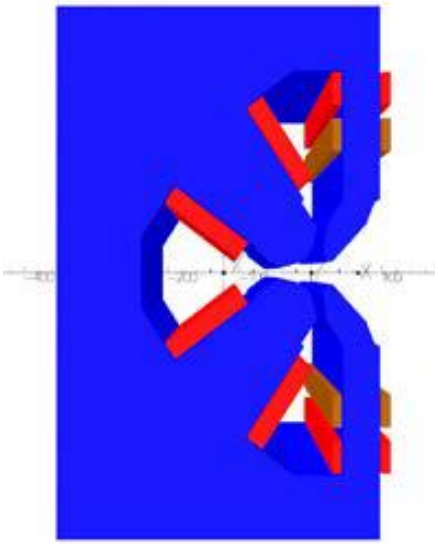
UKRI's ZEPTO tunable PM quadrupole



Diamond combined function DQ magnet

“Diamond-II” prototype

- DQ magnet
- Permanent magnet version
- Tunable over a small range using coils



Parameter	Value	Unit	Parameter	Value	Unit
Field	0.7	T	Curvature Radius	16421	mm
Gradient	-33	T/m	Yoke Material	Low carbon steel	-
Half Gap at 0.7 T	~14.2	mm	Total Yoke Mass	~1150	kg
Int. B	0.607	T m	Good Field Region (GFR)	±10	mm
Int. G	28.6	T	ΔB/B within GFR	5E-04	-
Iron Length	867	mm	ΔG/G within GFR	1E-03	-

2d magnet model

- Dipole Field: **0.70 T**
- Gradient: **32.4 T/m**

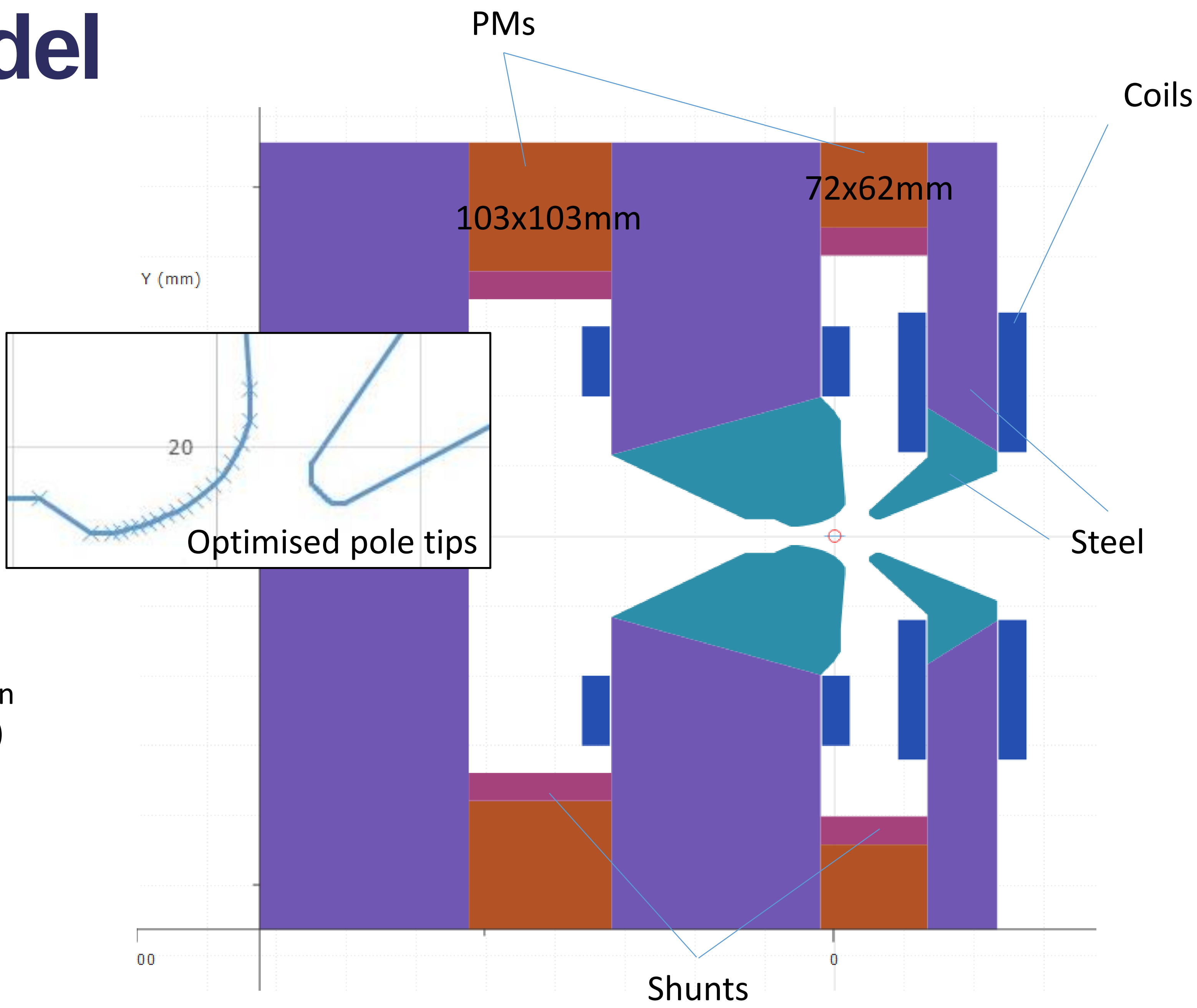
- Good field region: **±7 mm**
- ΔB/B within GFR: **5e-4**
- ΔG/G within GFR: **1e-3**

- Single sided quadrupole design
- Min inscribed radius: **12.8mm**
- Overall size: **566x563mm** (W x H)

- PM material: NdFeB 40EH
- B_r = **1.32 T** at 20°C

- FeNi shunt to reduce temperature variation
- Thickness: **14.7 mm** (main), **12.5 mm** (aux)
- Relative change with temperature
  - **-6e-6/°C** (field); **5e-5/°C** (gradient)

- Current densities of **±2 A/mm²** in the coils
  - **±6%** in field, **±10%** in gradient



3D model

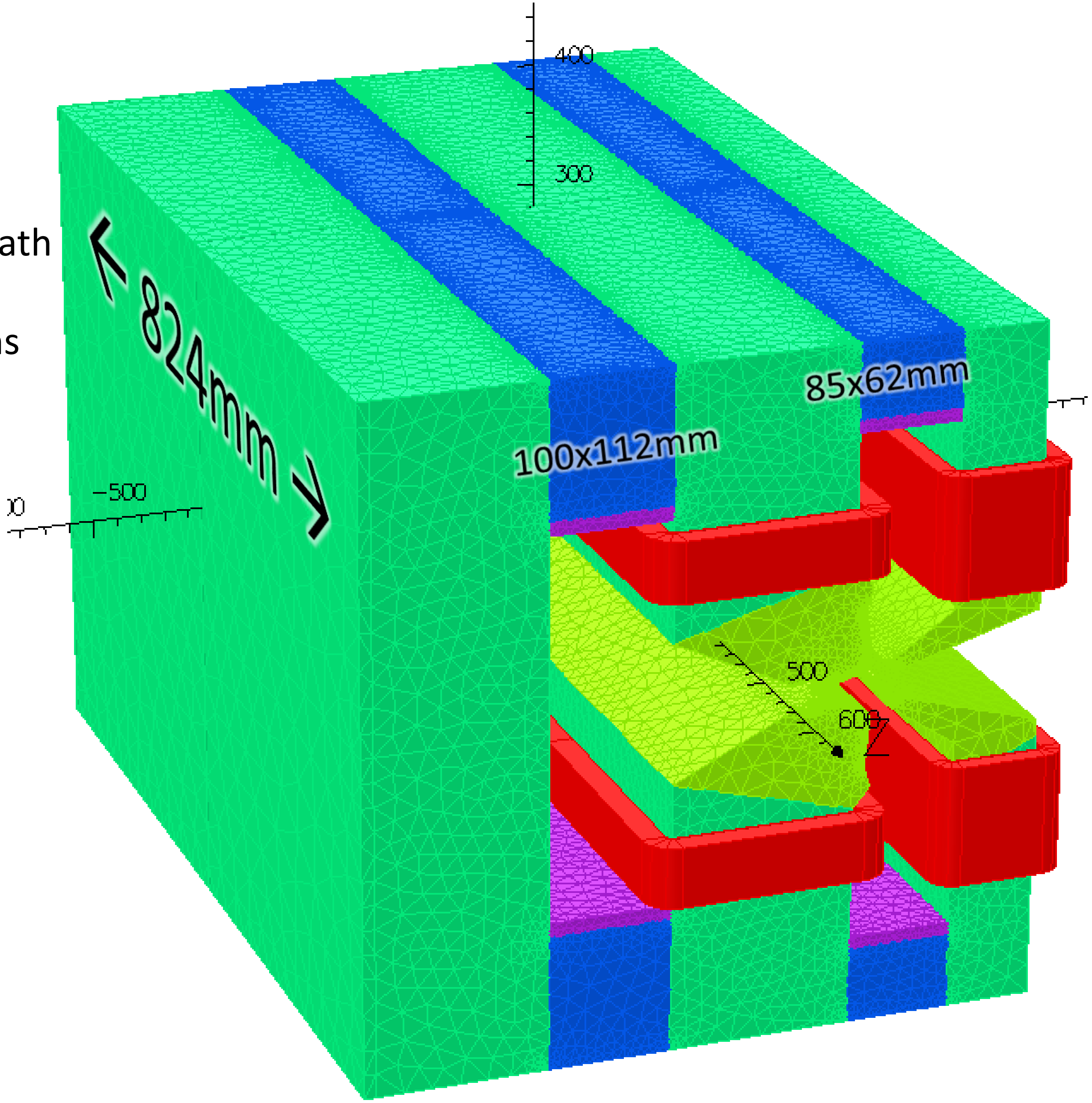
- 3D model with same pole tip profile as 2D model
- Pole tips are **curved** to give constant dipole along beam path
- Magnet dimensions slightly different than 2D model
- Difficult to achieve nominal fields with magnet dimensions to 0.1 mm – small currents required in coils to trim fields

- Dipole Field: **0.70 T**
- Gradient: **32.4 T/m**

- Good field region: **±7 mm**
- ΔB/B within GFR: **2.5e-4**
- ΔG/G within GFR: **2.3e-3**

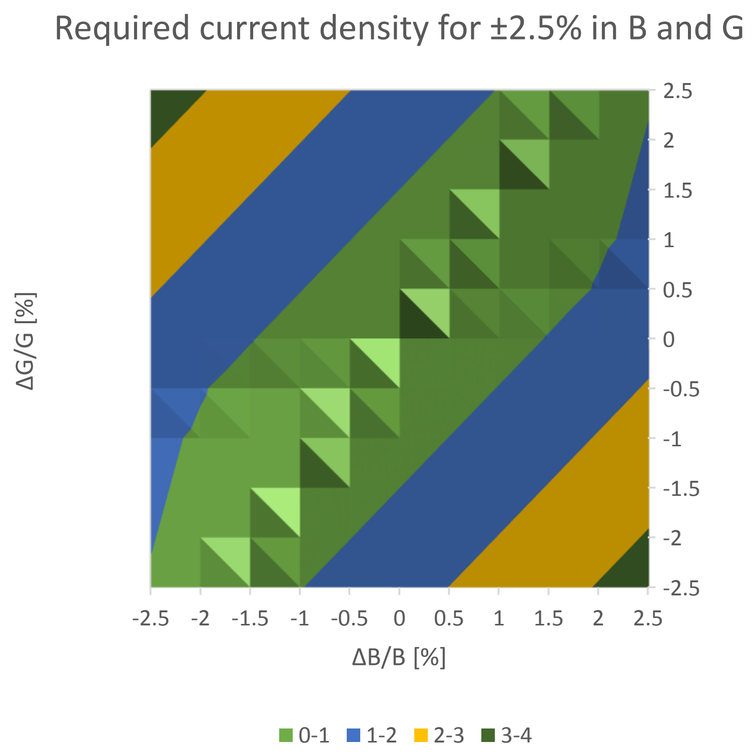
- FeNi shunt to reduce temperature variation
- Thickness: **11.3 mm** (main), **9.8 mm** (aux)
- Relative change with temperature
  - **-6e-6/°C** (field); **5e-5/°C** (gradient)

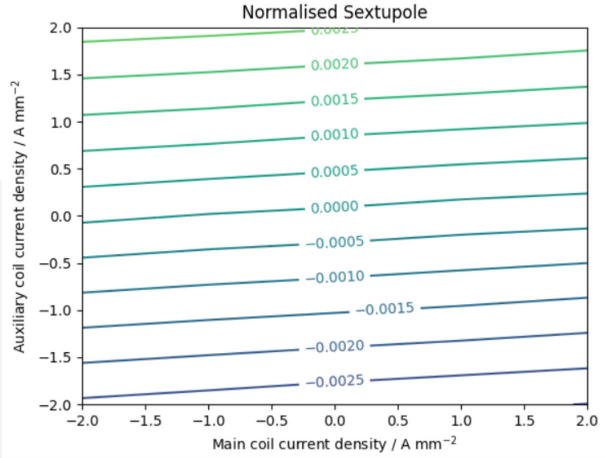
- Current densities of **±2 A/mm²** in the coils
  - **±6%** in field, **±8%** in gradient

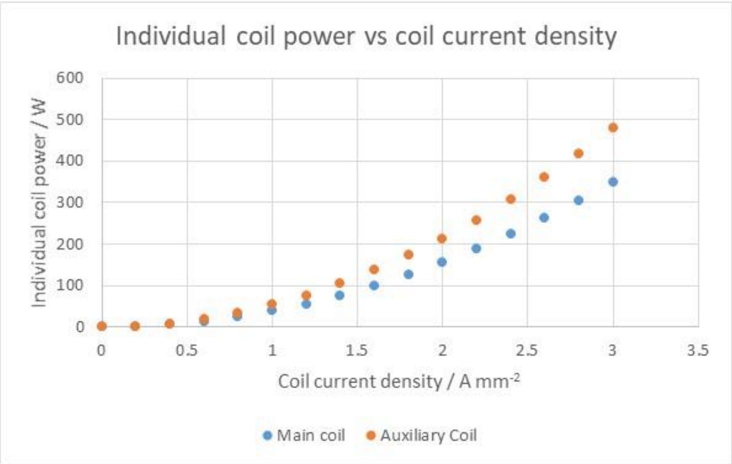


3D Central Field Tuning

- Can expect similar coil current densities (~2 A mm^{-2}) for range of B ± 2.5% and G ± 2.5%
- Most combinations are OK – some need higher currents
- Sextupole mainly dependent on auxiliary coil current density
- Estimate power dissipation of ~200 W per coil at 2 A mm^{-2} assuming copper coils



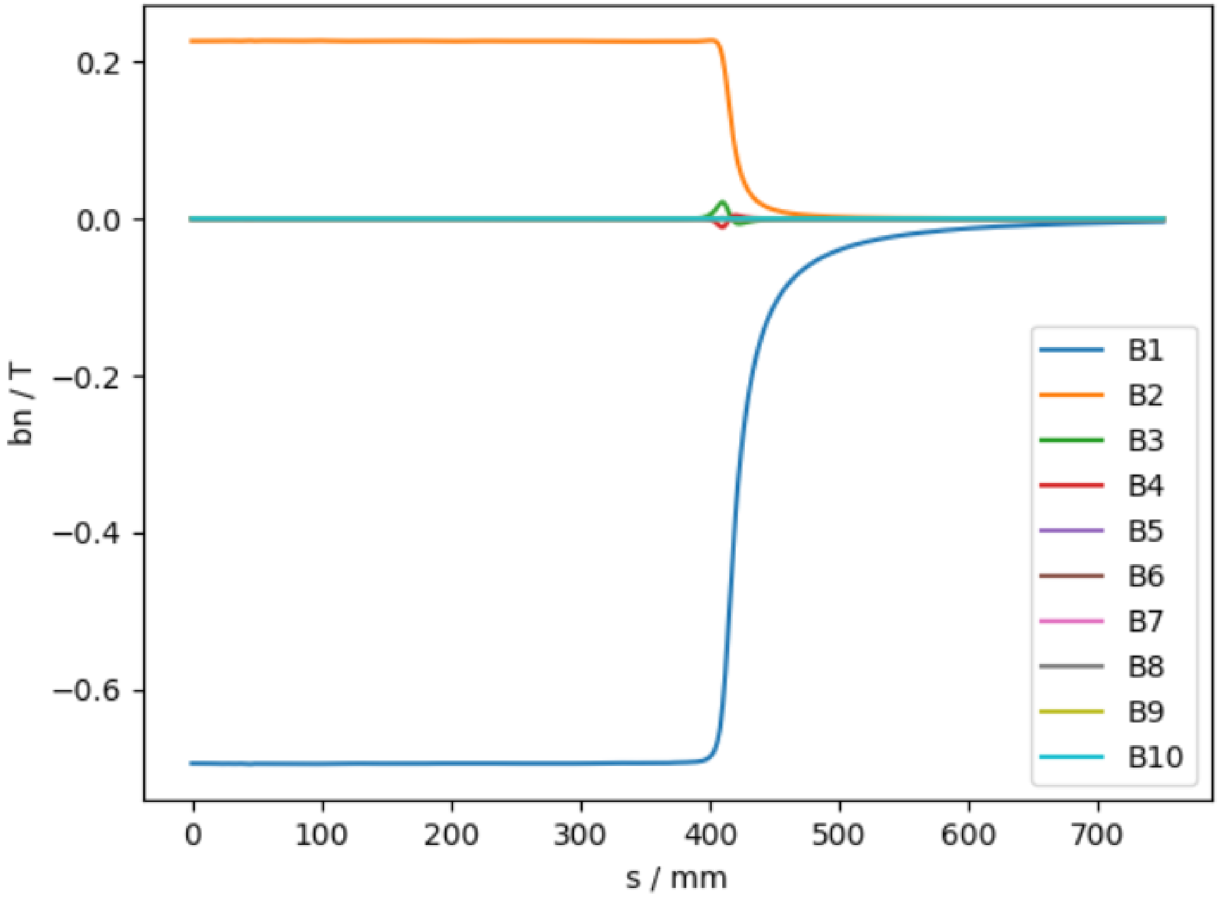




3D Integrated Fields

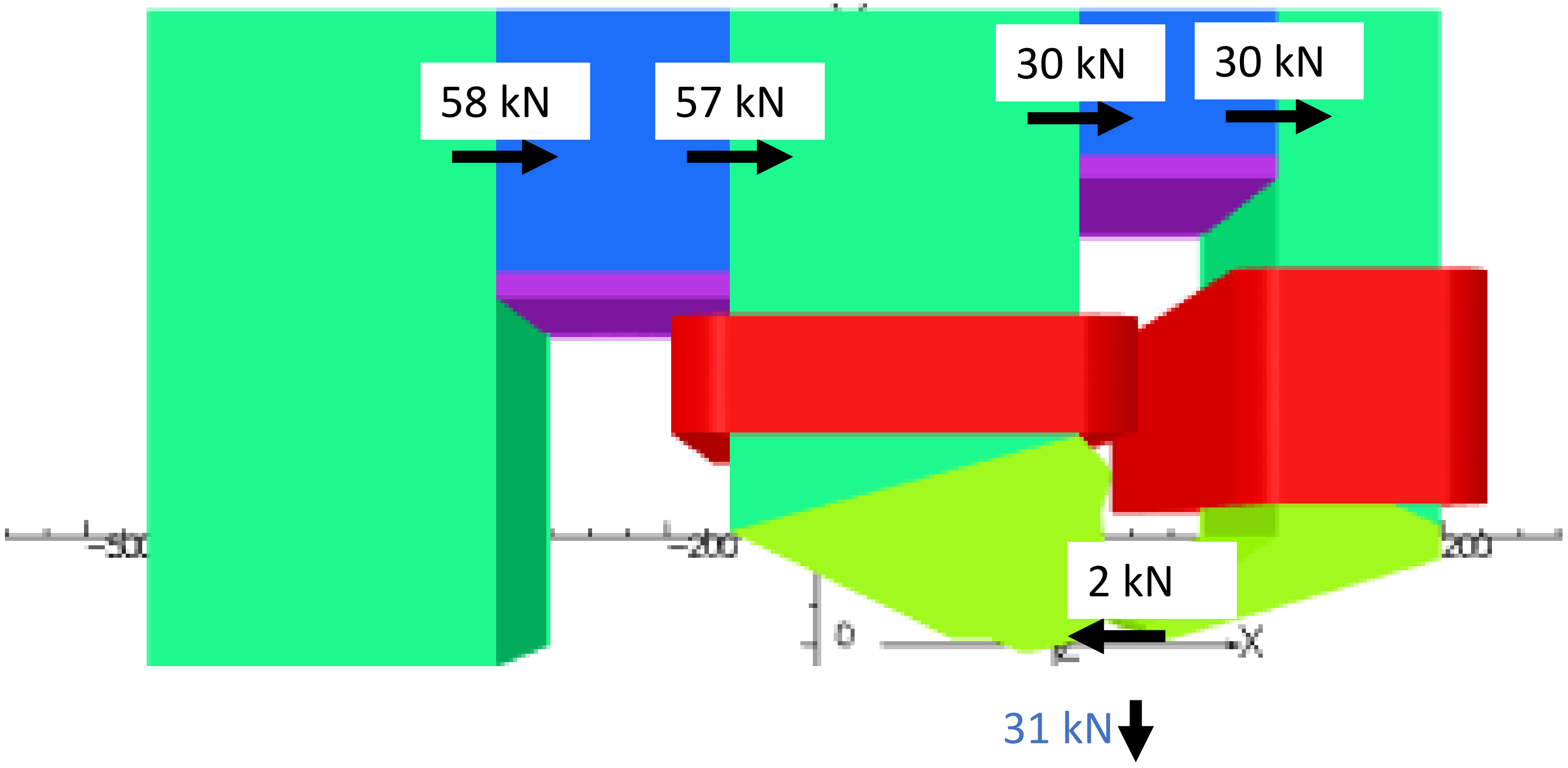
- Model physical length = 824 mm
- Physical length tuned to get target integrated dipole field
- Integrated gradient lower than target due to different effective lengths of dipole and gradient

Component	Unit	Model Value	Nominal
∫ b1 ds	T.m	0.6047	0.6047
∫ b2 ds	T/m.m	27.3526	28.1857
∫ b3 ds	T/m^2.m	0.9956	0
∫ b4 ds	T/m^3.m	-1.036E2	0
∫ b5 ds	T/m^4.m	1.407E4	0



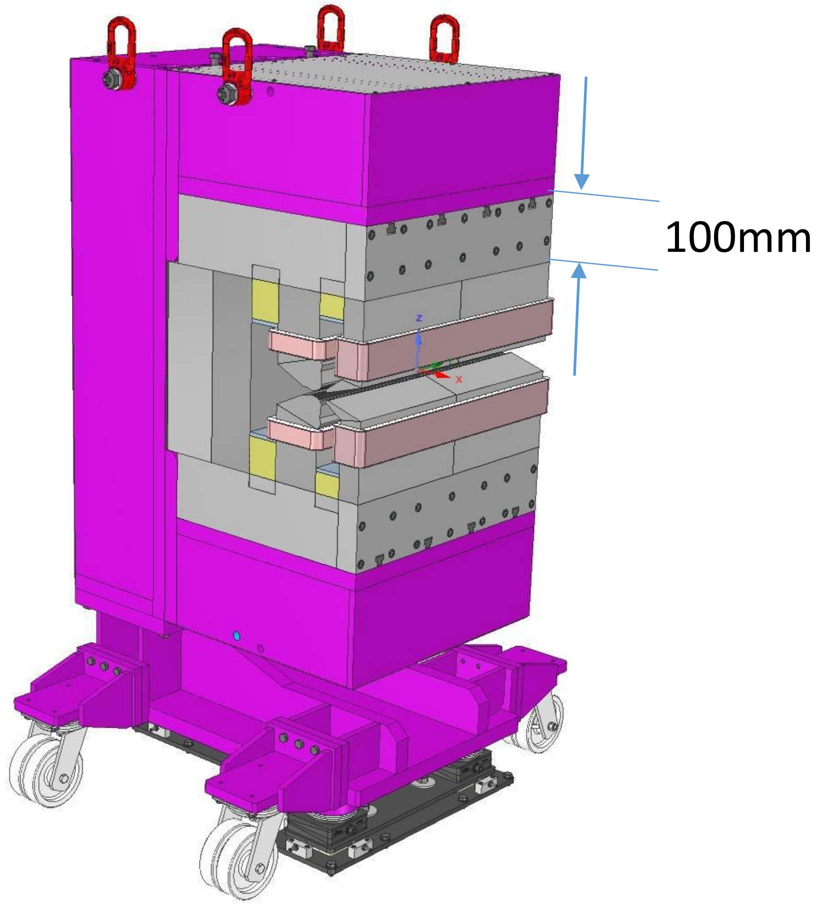
Forces Between Components

- First estimate of magnitude of forces – not 100% accurate
- Forces between magnet blocks and yoke of order 10 kN
- Forces between pole tips of order 1 kN
- Vertical force between upper and lower magnetic structures: **31 kN**



Mechanical Engineering Design

- Treated like an insertion device with a large outer steel strongback structure
- Magnetic modelling indicates minimum gap of **100mm** can be used without significant loss of field
- PM blocks glued onto aluminium supports for assembly
- Assembly procedure proposed using dual screw jacks to safely handle PM components
- Work in progress



Tadej Milharcic @ Kyma

Conclusions

- Magnetic and mechanical design of a combined-function DQ magnet is progressing well
- We have a viable design that meets the specification
- More detailed work needs to be completed on the mechanical design and assembly process
- Future work: decide on PM prototype to build for PETRA-IV