Science & Technology Facilities Council
Daresbury Laboratory

EMMA

Project Status and Overview

BASROC
CONFORM

Contents

- BASROC and CONFORM
- EMMA Objectives
- ERLP injector
- EMMA Technology status
- Project specification, cost and timescales
- Conclusions and next steps

BASROC

- British Accelerator Science and Radiation Oncology Consortium
- BASROC is an umbrella group of academic, medical and industry specialists in accelerator and medical technology with the aim of promoting the use of accelerators in science, industry and medicine. More detail at www.basroc.org.uk/
- BASROC will sponsor and provide oversight to projects, such as the CONFORM Project

CONFORM

- BASROC has been successful in being awarded its first grant from RCUK BASIC TECHNOLOGY RESEARCH PROGRAMME
- Project Name is CONFORM (COnstruction of a Nonscaling FFag for Oncology, Research, and Medicine) www.conform.ac.uk/
- Total funds £6.9m over 3.5 year project lifecycle
- Project start date 1st April ? 2007
- Project leader is Professor Roger Barlow, University of Manchester and The Cockcroft Institute
- 3 parts to the project are funded
  - EMMA design and construction
  - PAMELA design study
  - Applications study

CONFORM

- EMMA: The Electron Model of Many Applications. It is a design and construction project for a 20 MeV electron accelerator. It will be an entirely experimental machine used to learn how to design NS-FFAGs for a variety of applications. It will be built at Daresbury Laboratory using the Energy Recovery Linac Prototype (ERLP) as the electron injector
- PAMELA: The Particle Accelerator for MEdicaL Applications. It is a design study for a proton NS-FFAG that we can submitted to a funding agency. “Energy/No. of rings under discussion”. It will be a prototype(s) to demonstrate biological experiments leading to a medical NS-FFAG to be realised in practice for hadron therapy. With the intention to build a complete facility for the treatment of patients using hadron beams. It is planned to construct PAMELA it in a new building on the Churchill Hospital site in Oxford for the Department of Radiation Oncology and Biology and strengthen the case for hadron therapy in UK
- Applications: Work package to focus on exploitation of FFAG technology in a wider context than just medical applications

Project Management

- CONFORM Project leader and Principle Investigator is Professor Roger Barlow, University of Manchester and The Cockcroft Institute
- Chair of Project Board and Project Sponsor is Professor Mike Poole, STFC, Director of ASTeC and The Cockcroft Institute
- EMMA - Sub Project leader: Dr Rob Edgecock, STFC RAL, funding - £5638k
- PAMELA - Sub Project leader: Professor Ken Peach John Adams Institute for Accelerator Science, University of Oxford *and* Royal Holloway, University of London funding - £865k
- Applications - Sub Project leader: Dr Karen Kirkby, University of Surrey funding - £273k

EMMA Collaboration

- We are holding regular phone meeting (every 2 or 3 weeks)
- Project Reviews held at Daresbury
  - Hardware review on 1 July 06
  - Design Reviews on 4 Jan 07 and 26 Feb 07
- Active participation:
  - Brookhaven National Laboratory US
  - CERN France/Switzerland
  - Fermi National Accelerator Laboratory US
  - LPSC France
  - STFC UK
  - The John Adams Institute UK
  - The Cockcroft Institute UK
  - TRIUMF Laboratory Canada
  - ………..
- Presentations stored on the CONFORM web page at https://www.conform.ac.uk/documents/emma/ec%20-%20emma%20collaboration%20meetings/

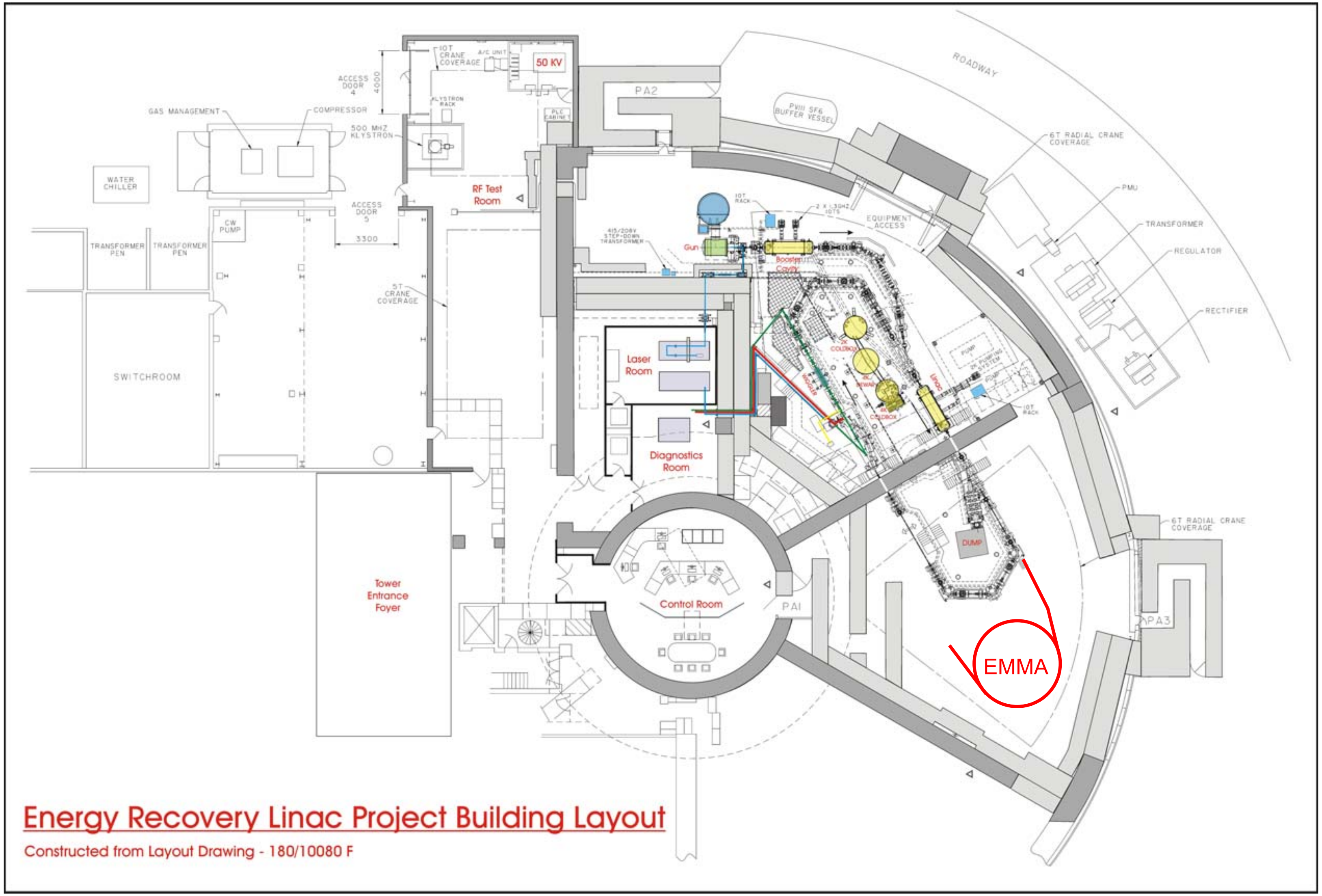
Aims & Objectives of EMMA Project

- Prove that a NS-FFAG can successfully accelerate particles
- Study linear non-scaling FFAGs under particular circumstances
  - Rapid acceleration
  - Relativistic energies
  - Main application currently: muon acceleration
- Two important characteristics of non-scaling FFAG lattices
  - Rapid acceleration through many resonances
  - Unique longitudinal dynamics

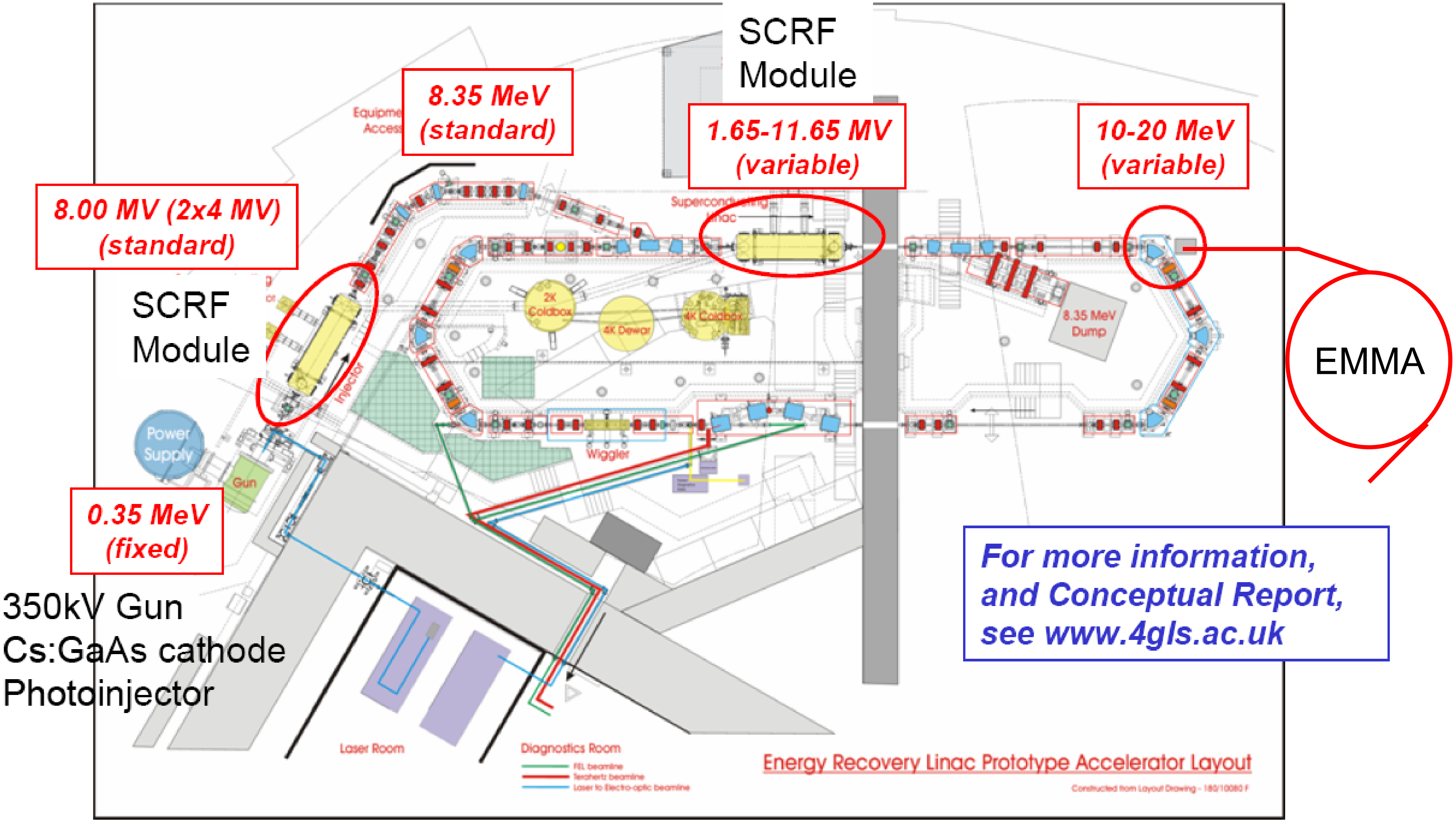
Aims & Objectives of EMMA Project cont.

- To test our understanding of the underlying dynamics
  - How does emittance growth depend on which resonances we cross?
  - How does longitudinal behaviour change with machine parameters
    - RF frequency
    - Energy where machine is isochronous
  - Coupling of transverse and longitudinal motion
  - What effect do errors have on performance
    - Magnet position
    - Field strength
    - RF phase errors
- Use the information gained to inform the design of PAMELA and Applications sub projects

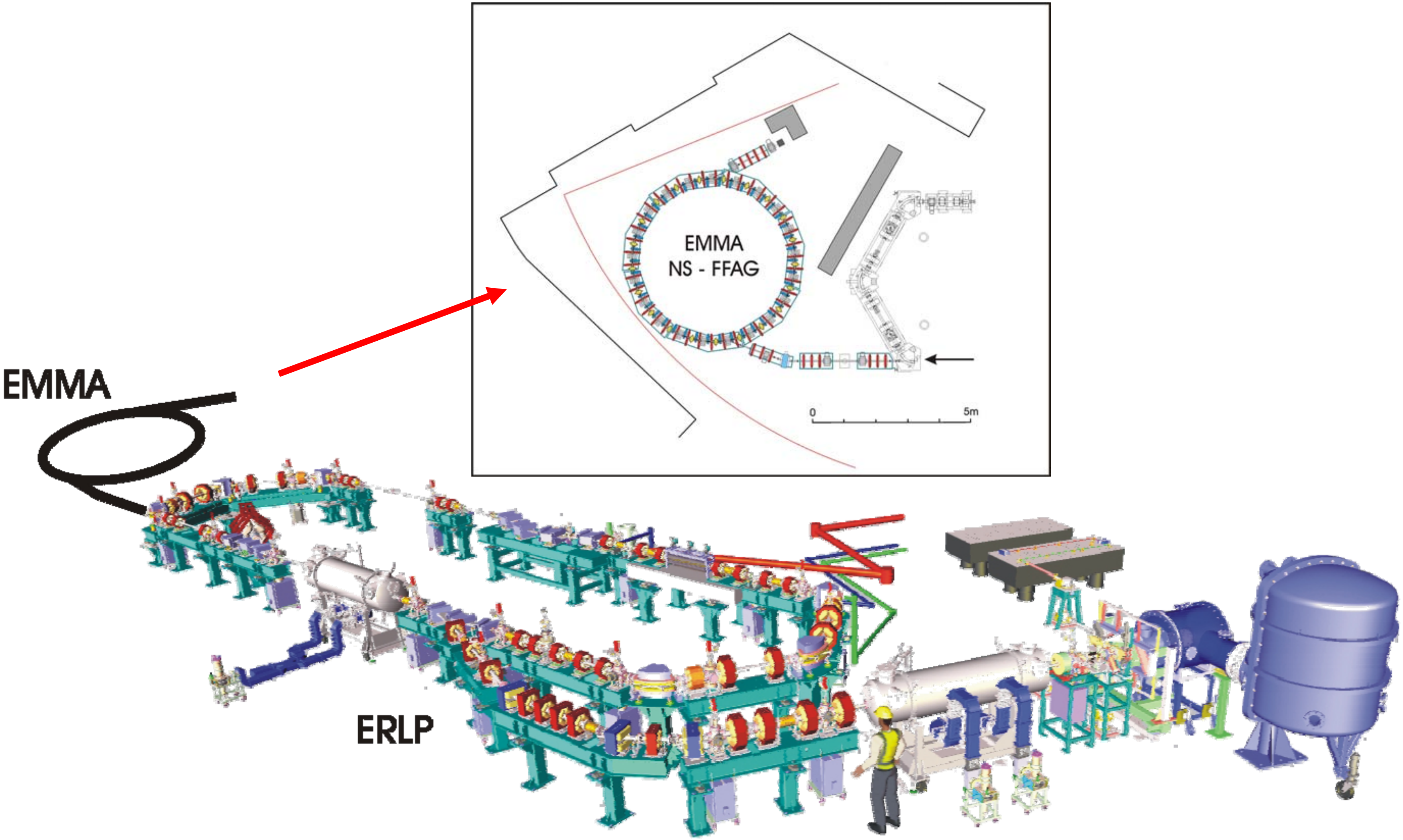
EMMA on ERLP


ROADWAY
PA2
50 KV
RF Test Room
GAS MANAGEMENT
COMPRESSOR
500 MHZ KLYSTRON
WATER CHILLER
CW PUMP
ACCESS DOOR 5
3300
TRANSFORMER PEN
TRANSFORMER PEN
5T CRANE COVERAGE
SWITCHROOM
6T RADIAL CRANE COVERAGE
PMU
TRANSFORMER
REGULATOR
RECTIFIER
EQUIPMENT ACCESS
Gun
Laser Room
Diagnostics Room
Control Room
PA1
PA3
DUMP
Tower Entrance Foyer
EMMA
Energy Recovery Linac Project Building Layout
Constructed from Layout Drawing - 180/10080 F

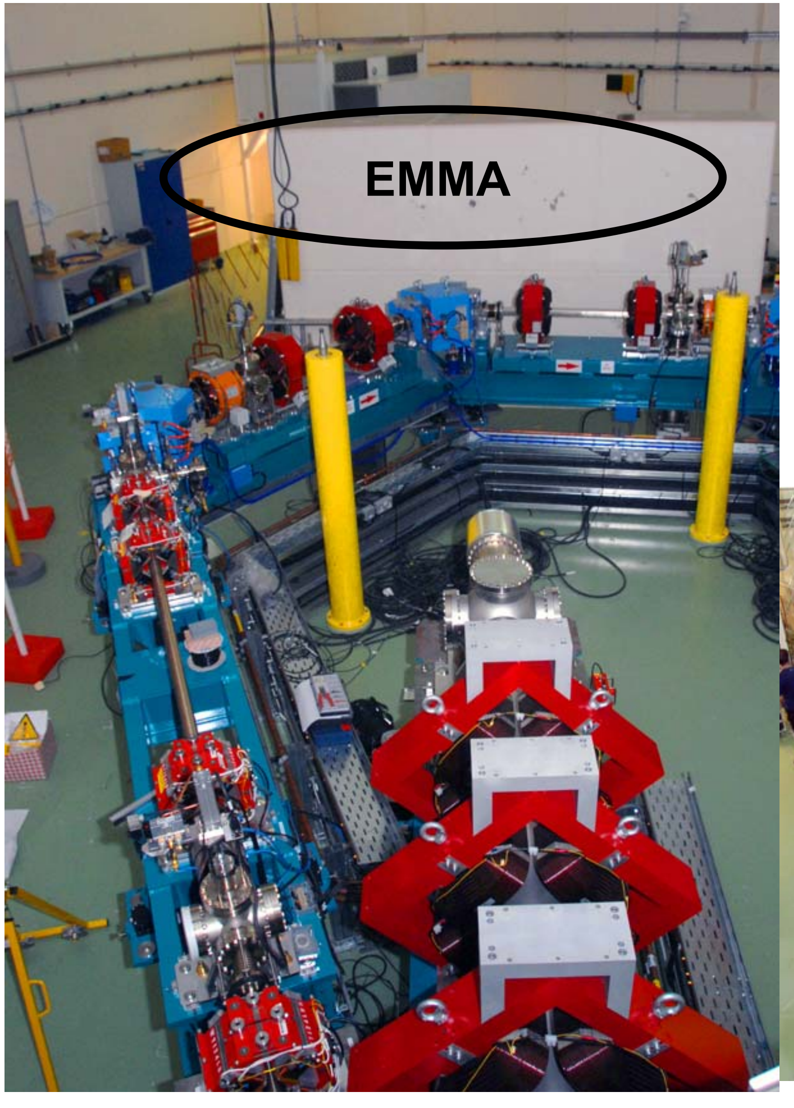
ERLP Injector

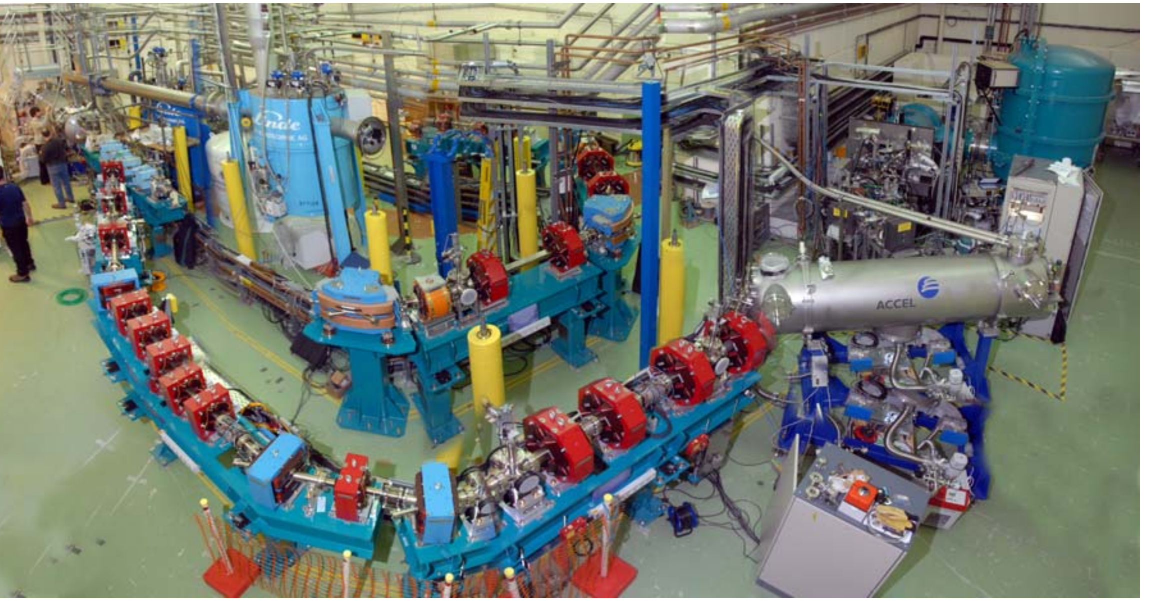


EMMA on ERLP



ERLP Injector





ERLP Parameters

Parameter	Value
Nominal Gun Energy	350 keV
Max. Booster Volts	8 MV
TL 2 Energy	8.33 MeV
Max. Linac Volts	26.67 MV
Max. Energy	35 MeV
Linac RF Frequency	1.300 GHz (+/- 1 MHz)
Bunch Repetition Rate	81.25 MHz
Bunch Spacing	12.3 ns
Max Bunch Charge	80 pC
Particles per Bunch	5×10^8

ERLP Timescales

- Currently commissioning the photoinjector with 20 pC beams
- All modules are now installed, under vacuum and being commissioned
- Currently commissioning the cryogenic systems for the SCRF modules
- RF Systems ready 12 Jul 07
- Beam through Module 1 (8.35 MeV) 14 Aug 07
- Beam through Module 2 (35 MeV) 11 Sep 07
- **Energy recovery demonstrated** 6 Nov 07

- Install wiggler
- Energy recovery from FEL-disrupted beam
- Produce output from the FEL, CBs and THz

EMMA Parameters

Lattice - Scott Berg

https://www.conform.ac.uk/documents/emma/acc%20-%20accelerator%20physics/lattice.html

Parameter	**Value**
Kinetic Energy range	10 – 20 MeV
Injection	10 – 20 MeV
Number of cells	42
Lattice	F/D Doublet
Cell length	394.481 mm
Circumference	16568.202 mm
Average beam current	13 μA
Injected emittance	5-20 mm mrad (norm.)
Model acceptance	3000 mm mrad (norm.)
Orbit swing	3 cm
Bunch charge	16-32 pC single bunch 1 – 2 E8
Repetition rate	1, 5, 20 Hz
RF Frequency	1.3 GHz
RF Frequency range	(1.295981 to 1.301554)
RF voltage	20 – 120 kV/cavity
Number of RF cavities	19

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BASROC CONFORM

Cell Drawing

Scott's going to talk about the lattice in detail on Saturday, so no detail of how we got here

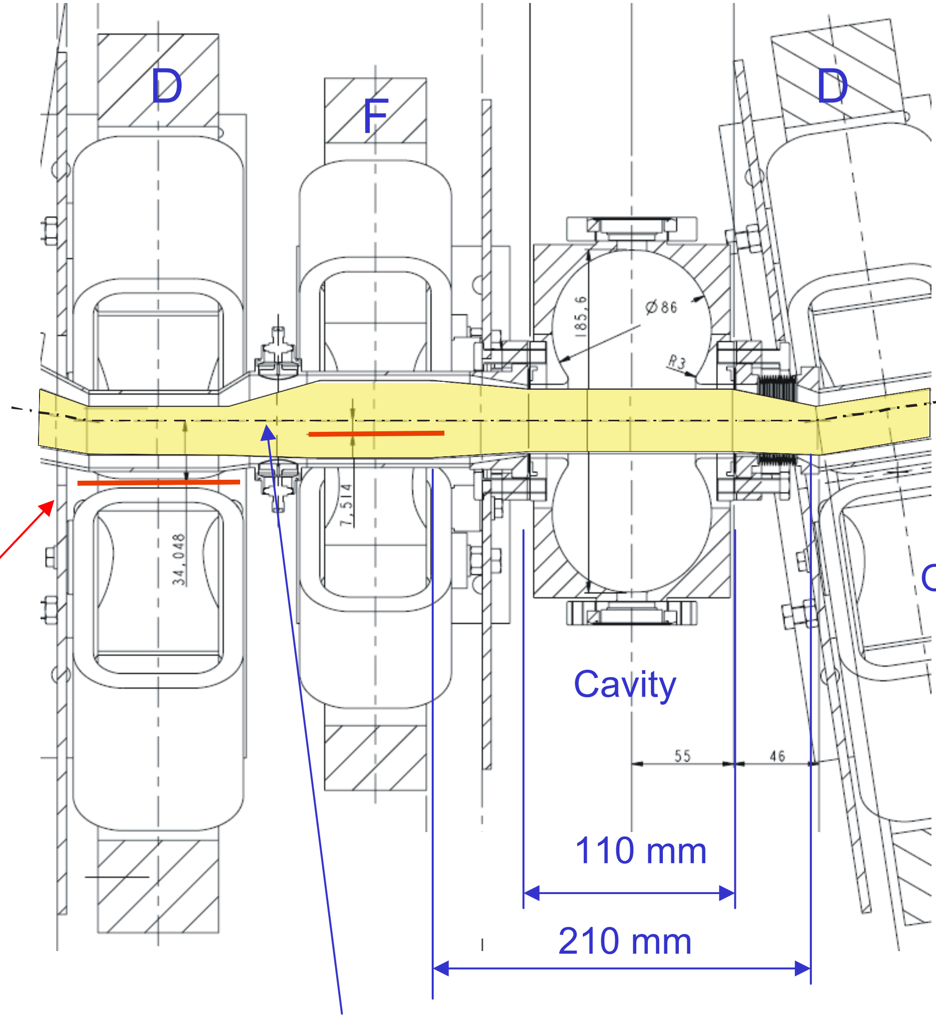
D, F magnet and Cavity all parallel

Geometry consisting of 42 cells @ 394.481 mm
Circumference = 16568.202 mm

Long drift	210.000 mm
F Quad	58.782 mm
Short drift	50.000 mm
D Quad	75.699 mm

Magnet Reference Offsets
D = 34.048 mm
F = 7.514 mm

Magnet Yoke Lengths
D = 65 mm
F = 55 mm



Beam Aperture Requirements

MAGNET DISPACEMENT AND GRADIENT

	D	F
Displacement	34.048 mm	7.514 mm
Minimum Shift	28.751 mm	4.903 mm
Maximum Shift	48.559 mm	10.212 mm

+ ve towards outside of ring
- ve towards inside of ring

BEAM STAY CLEAR APERTURES

	D	F	Cavity
Min. hor. chamber	-7.416 mm	-21.638 mm	-16.936 mm
Max hor. chamber	+18.789 mm	+20.700 mm	+17.814 mm
Half height	± 11.676 mm	± 8.906 mm	± 10.571 mm

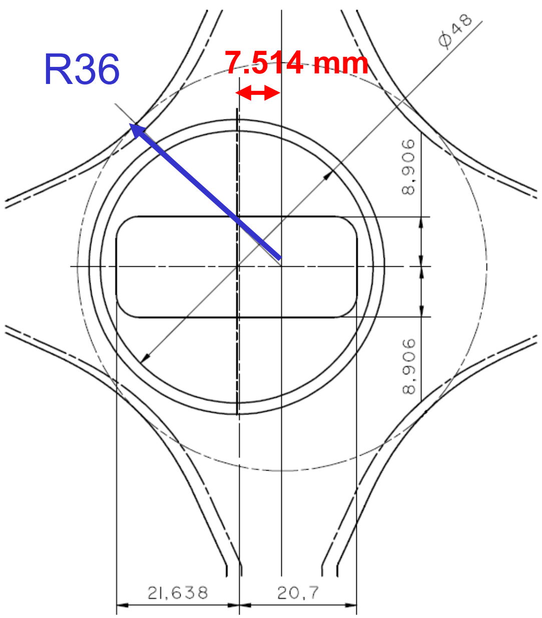
FURTHER APERTURE REQUIREMENTS

	D	F	Cavity
Max. hor. in magnet	-55.975 mm	-31.850 mm	
Cavity centre position			0.439 mm
Cavity aperture diameter			34.751 mm

Vacuum Chamber Apertures

Magnet translation

- 2.611 mm +2.698 mm

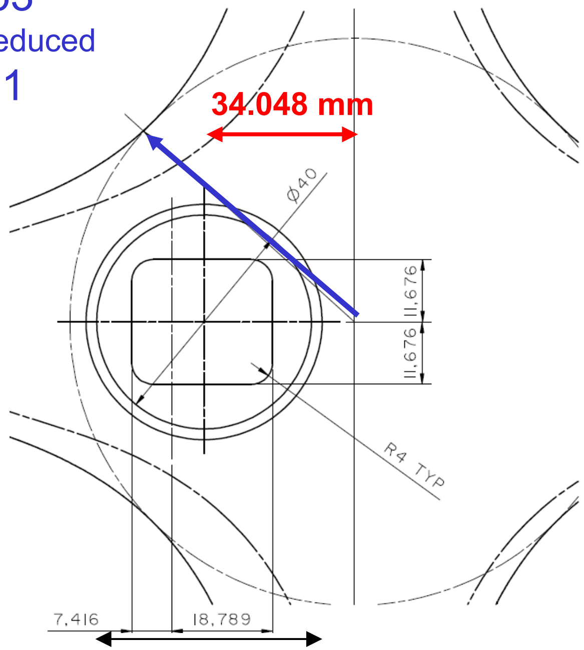


F Magnet Section
Tube OD 52 mm, ID 48 mm
Seamless tube St. St. 316L

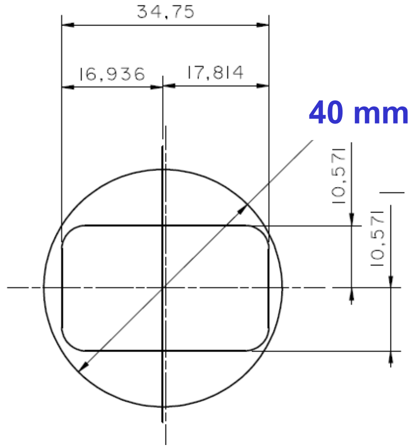
Drawn here
at R53
Now reduced
to R51

Magnet translation

- 5.297mm +14.511mm



D Magnet Section
Tube OD 44 mm, ID 40 mm
Seamless tube St. St. 316L



Section thro. Cavity
ID 40 mm

207-10130-B-cell-layout 3D

Without field clamp plates shown

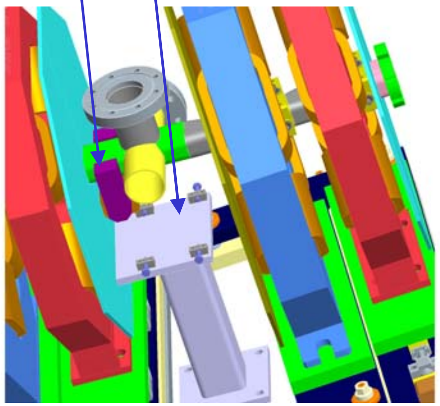
Vertical corrector
16 per ring

Vacuum Chamber Support

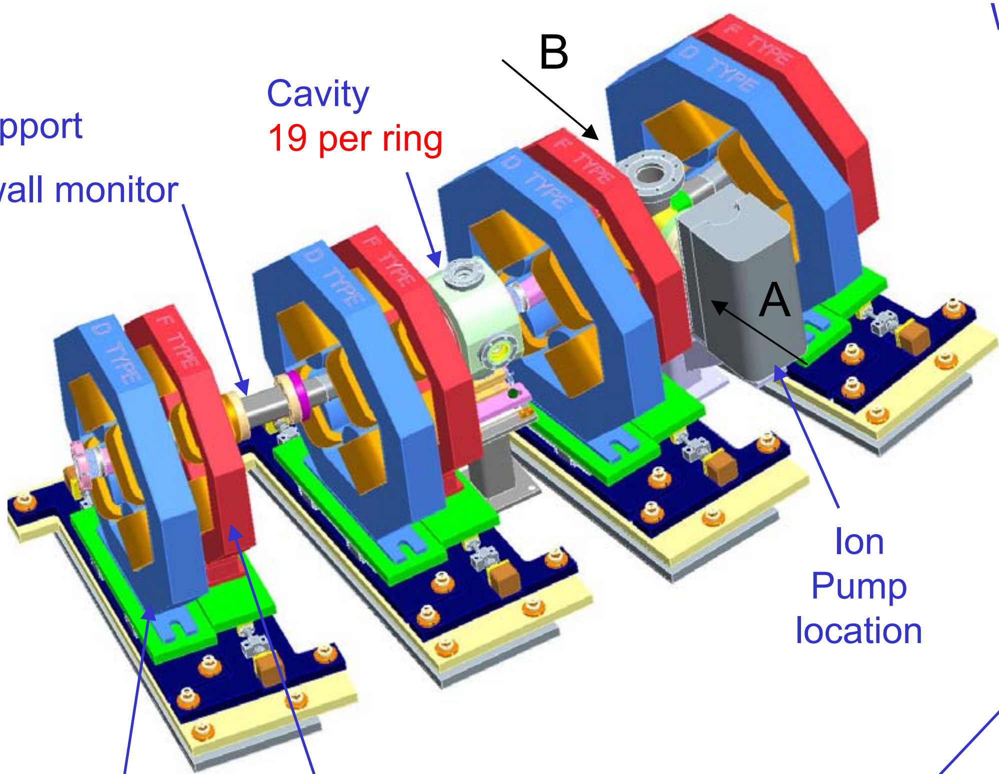
Resistive wall monitor
1 per ring

Cavity
19 per ring

Pop in Diagnostics
Screens 2 per ring
Wire scanners 2 per ring



View on A
with Ion Pump removed
Field clamp plates shown

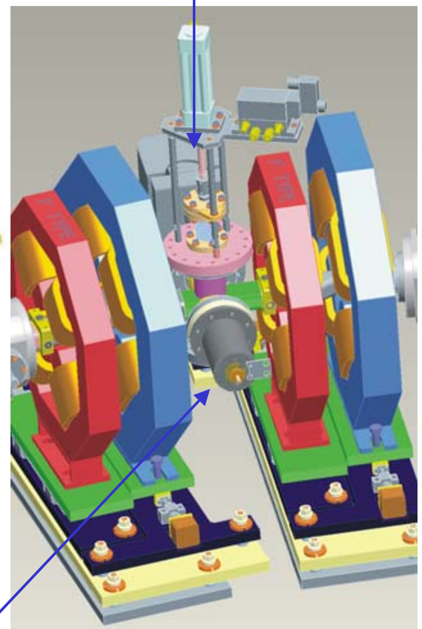


Ion
Pump
location

D Magnet
42 per ring

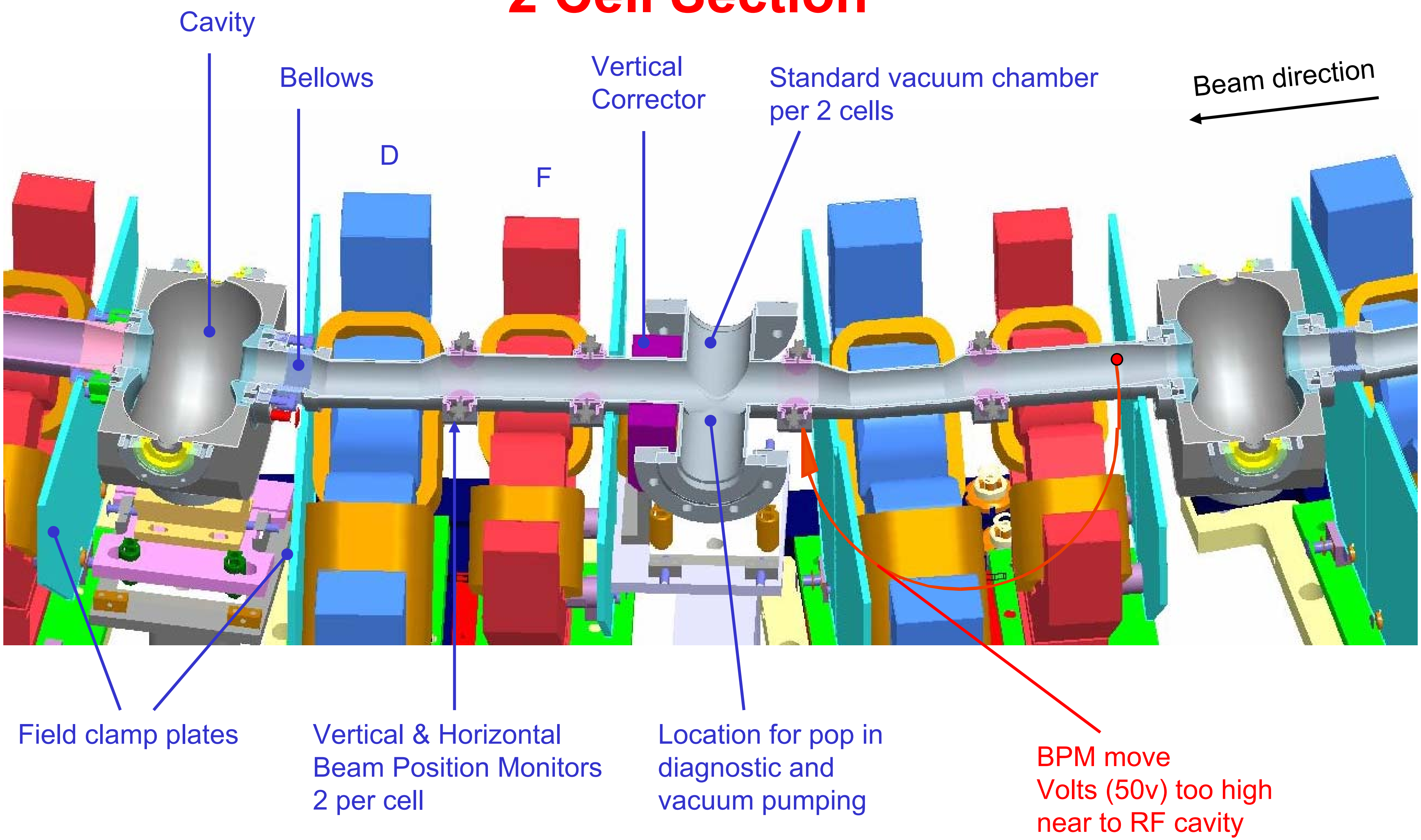
F Magnet
42 per ring

Screen Camera



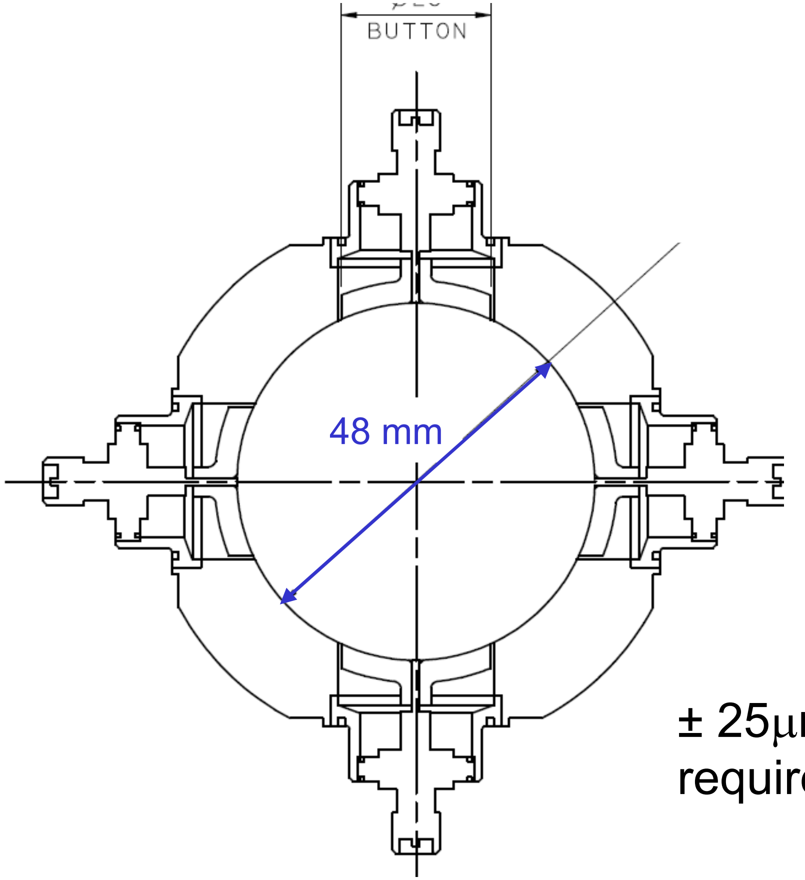
View on B
with screen shown

2 Cell Section



BPM Detail

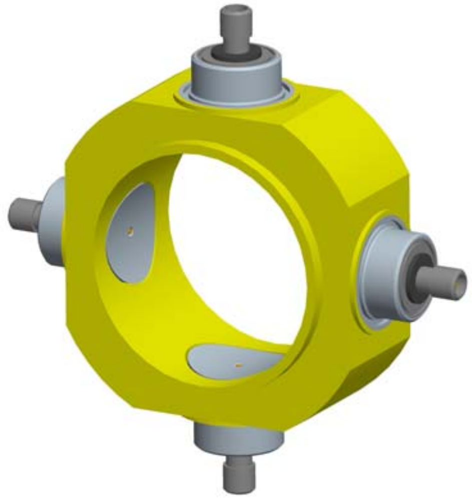
20 mm (~πd/8)



Cross-section

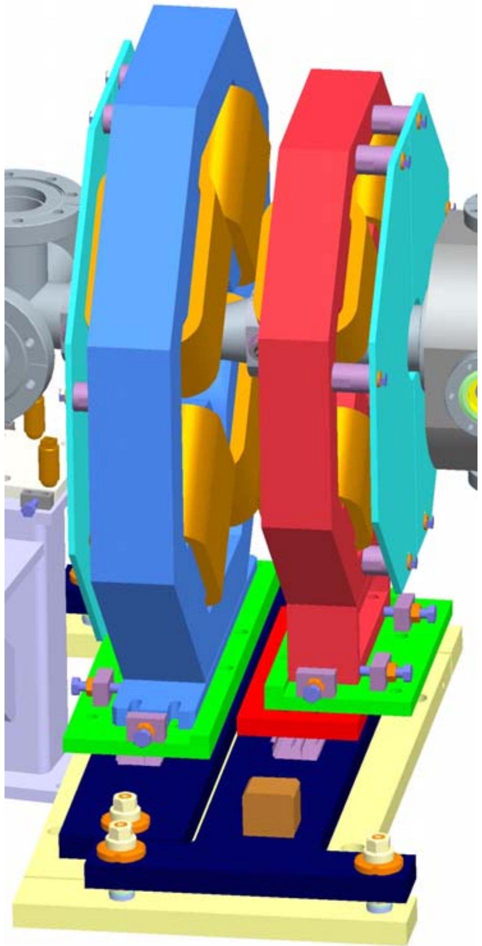
± 25μm r.m.s.
required resolution

Standard vacuum chamber
for 2 cells. Circular cross-section
Material stainless steel



4 x BPM bodies, accurately machined and welded into vacuum chamber

Magnets



Magnet Type	Units	QD	QF
Quantity		42	42
Inscribed radii	mm	51.0	36.0
Good gradient region	**mm**	**-56.0, -9.9**	**+15.8, -32.0**
Good gradient quality	**%**	**± 0.1**	**± 0.1**
Gradient strength (standard)	**T**	**0.367**	**0.403**
Gradient strength (max)	**T**	**0.440**	**0.483**
Translation	mm	+14.5 -5.3	+2.7 -2.6

Magnet Status

More detailed presentation on magnets tomorrow from Ben Shepherd

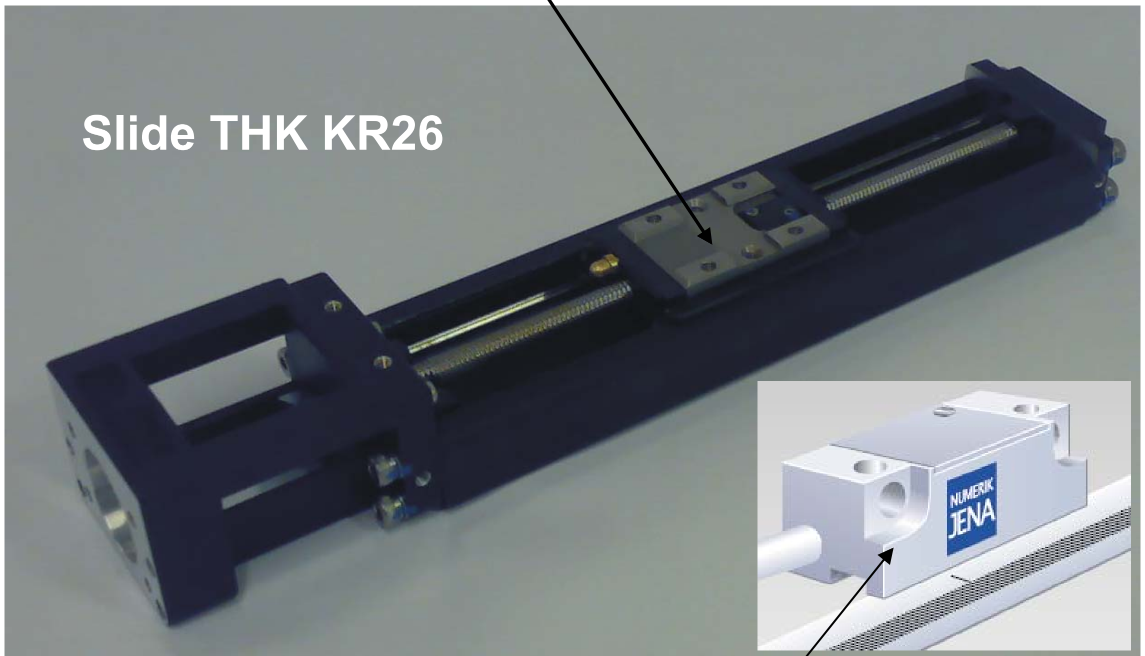
- Exact detail of pole shape and end chamfers still to be defined
- Decision made that field clamp plates are required
- Field clamp plates reduce BF by 11% and BD by 18%
- Field clamp plates are attached to and move with the magnets
- Optimum shape of hole in field clamp plate still to be confirmed
- We need to calculate the turning moment effect on the 2 magnets on a relatively slim bearing platform. Fall back position is an additional slide at the top of the magnets
- We have gone out to suppliers for prices for the F and D prototype on 6 April
- Return of bids by 23 April
- Place contract by 11 May
- Asking for delivery of 1st magnet by 24 August (15 weeks)
- 2nd Magnet by 7 September (17 weeks)

Magnet Linear Slide

Model Type	Rail Length (mm)	Positioning Accuracy reproducibility over 300mm (mm)	Running Parallelism over 300mm (mm)
THK KR26	300	±0.003	0.01

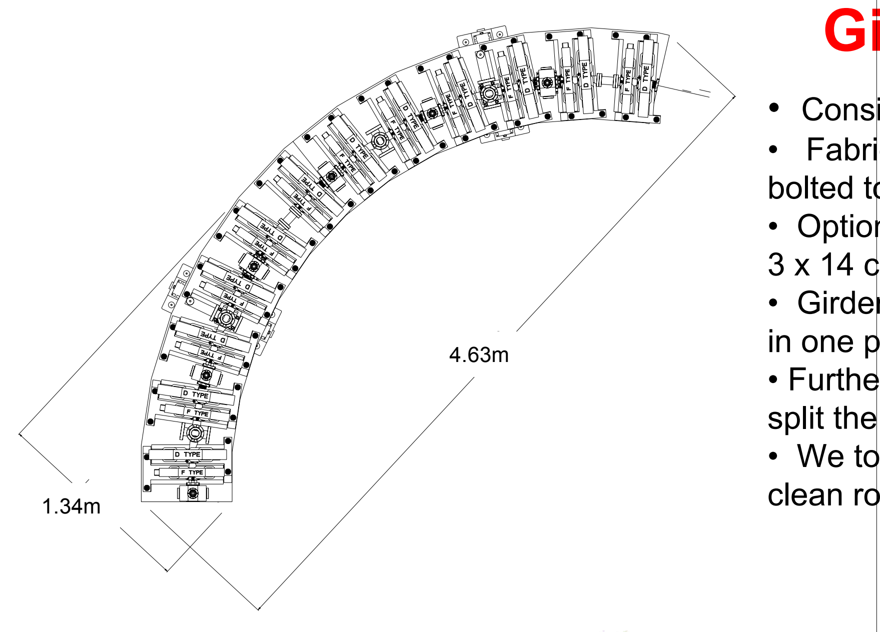
Ordered with 2 bearing guide blocks
1st block containing linear guidance and ballscrew nut,
2nd block containing linear guidance only

- Closed loop drive
- All components specified
- Planning to measure the accuracy of these slides over the magnet movement range (D = 20 mm, F = 6 mm)
- Budget for assembly – slide, motor, limit switches, belt drive, encoder and motion controller only £1.84k

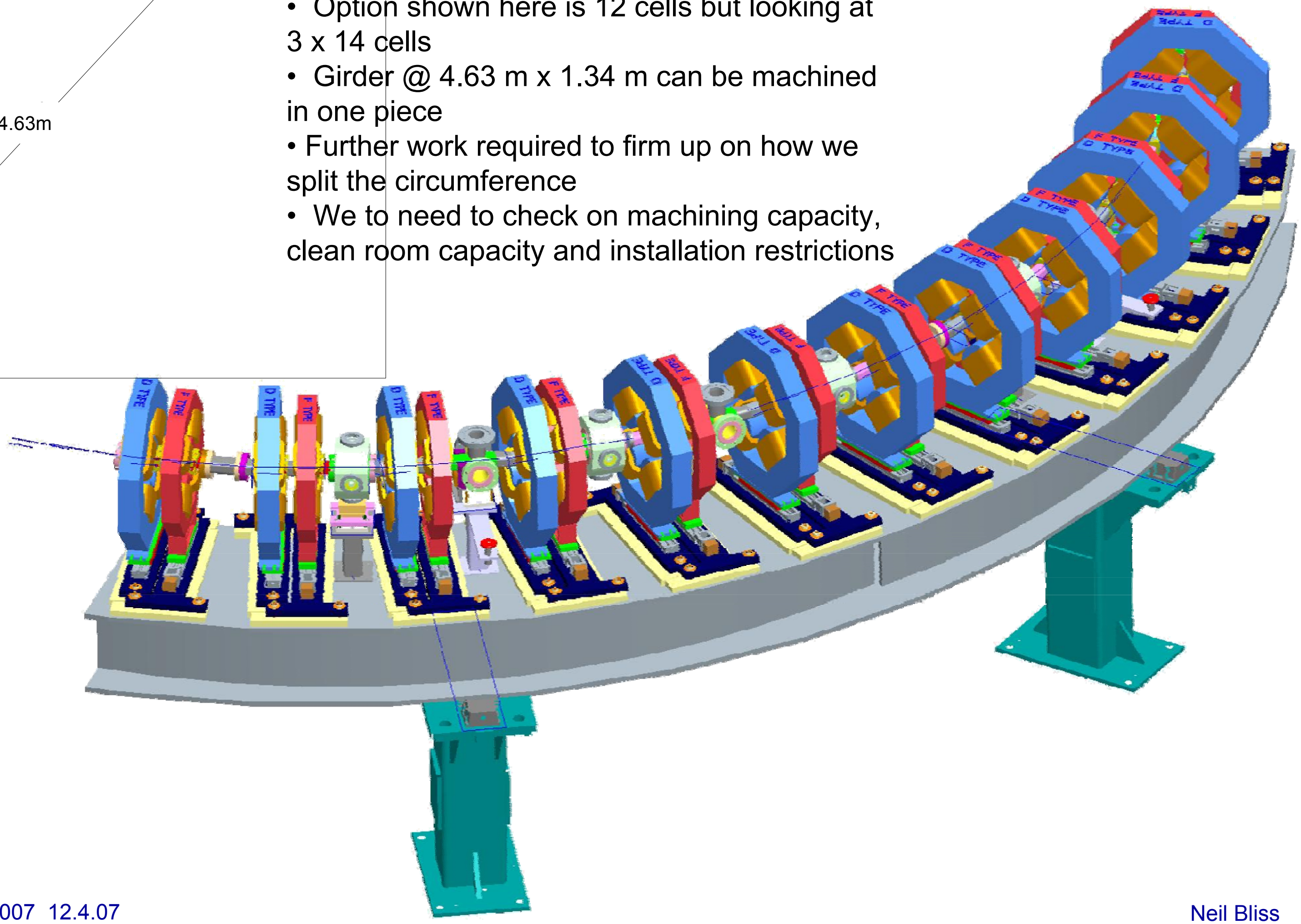


Encoder NUMERIK JENA 1 micron repeatability

Girder Assembly

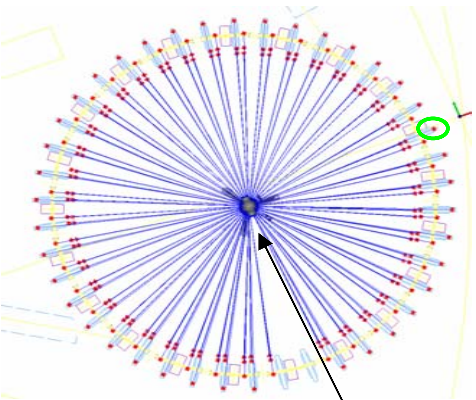


- Considering 1 girder support approach
- Fabricated from 3 or 4 pieces, machined an bolted together to make a rigid ring
- Option shown here is 12 cells but looking at 3 x 14 cells
- Girder @ 4.63 m x 1.34 m can be machined in one piece
- Further work required to firm up on how we split the circumference
- We to need to check on machining capacity, clean room capacity and installation restrictions

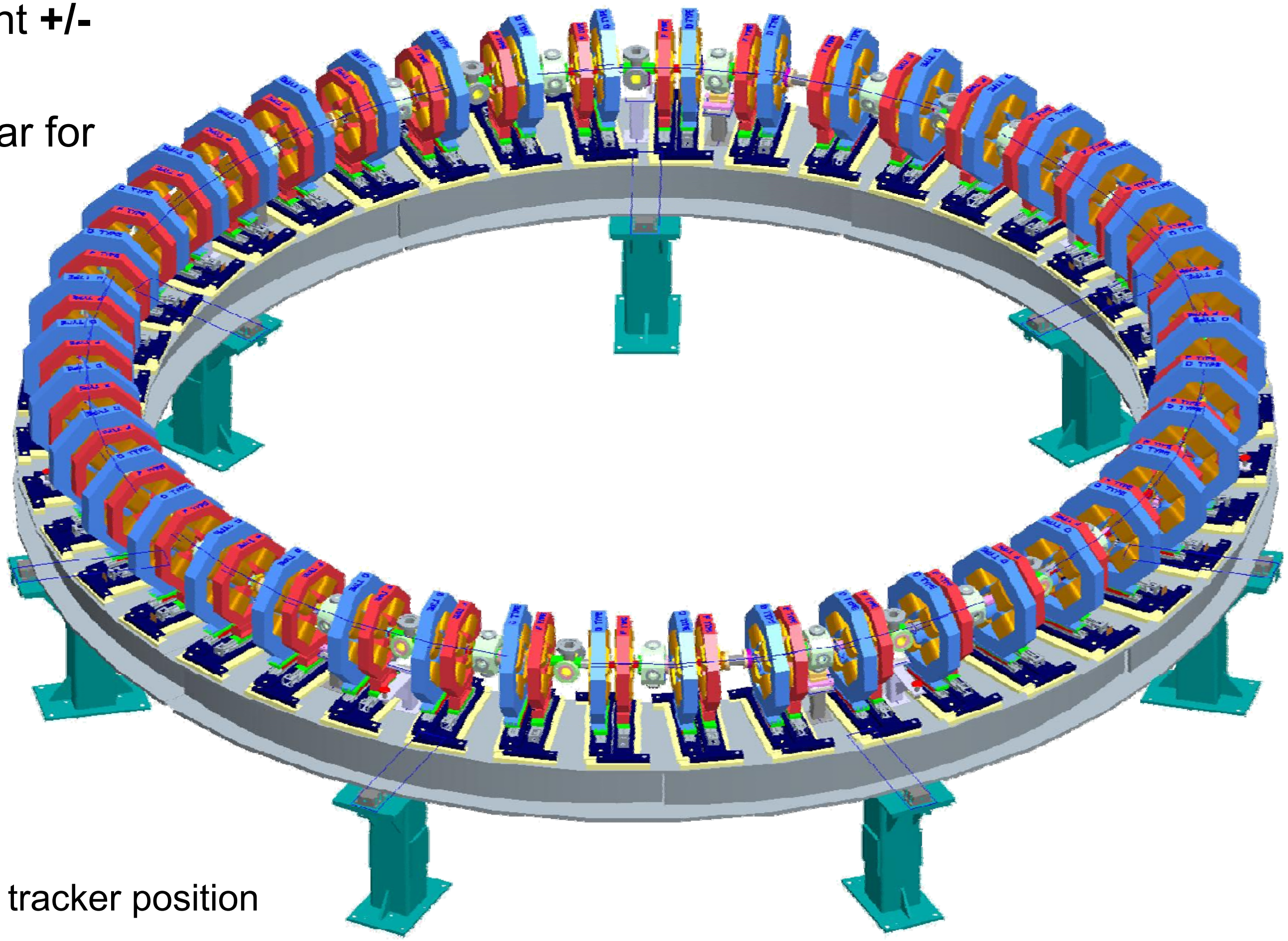


EMMA Ring

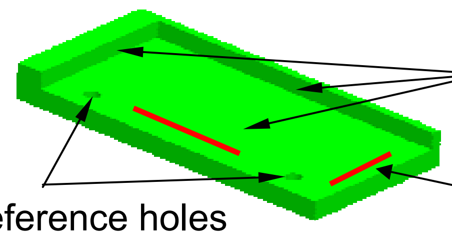
- Magnetic centre fiducialisation **+/- 25µm (1σ)**
- Individual Magnet alignment **+/- 25µm (1σ)**
- Keep centre of the ring clear for laser tracker lines of site

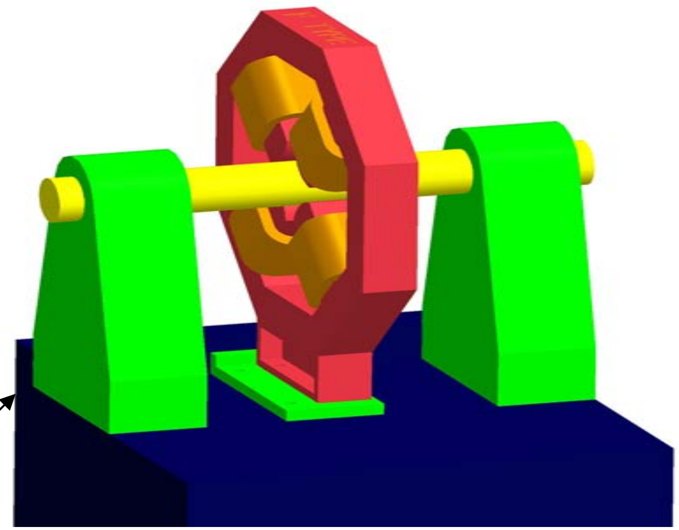


Single laser tracker position



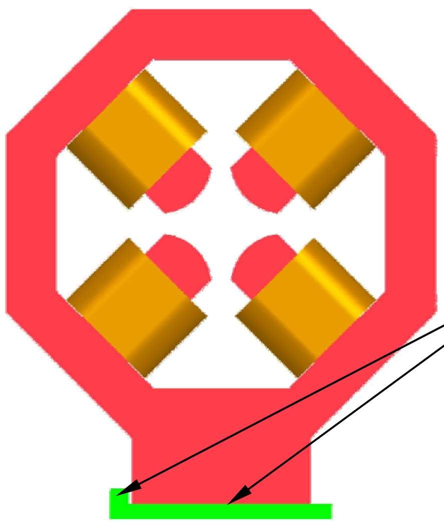
Magnetic centre fiducialisation





Survey plates under magnets with holes that take the laser tracker reflector spheres

- Alignment edges on rotating coil bench
- Survey plates aligned to rotating coil centre with shims



+/- 25µm (1σ)

RF Requirements

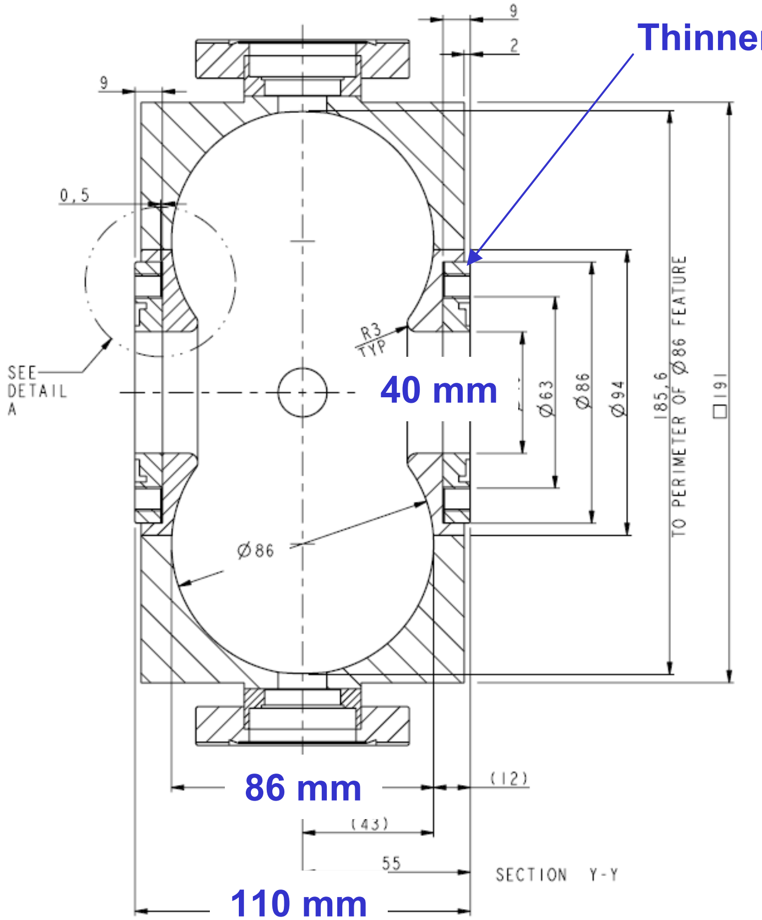
- Voltage:
  - Voltage required 20 - 120 kV/cavity, based on 19 cavities (parameter a=1/6)
  - Up to 180kV is desirable but not essential (parameter a=1/4)
  - 360 kV un-necessary (parameter a=1/2)
- Frequency:
  - Chosen frequency for the RF system is 1.3GHz, to both match the ERLP RF systems and also allow for the use of developed and mature LLRF systems at this frequency
  - Range requirement 5.6 MHz (1.295981 to 1.301554 GHz)
- Cavity phase:
  - Remote and individual control of the cavity phases is essential
- Available length: 110 mm flange to flange
- Aperture: diameter 34.7 mm min. We have chosen diameter 40 mm to simplify vacuum chamber by removing offsets + some clearance

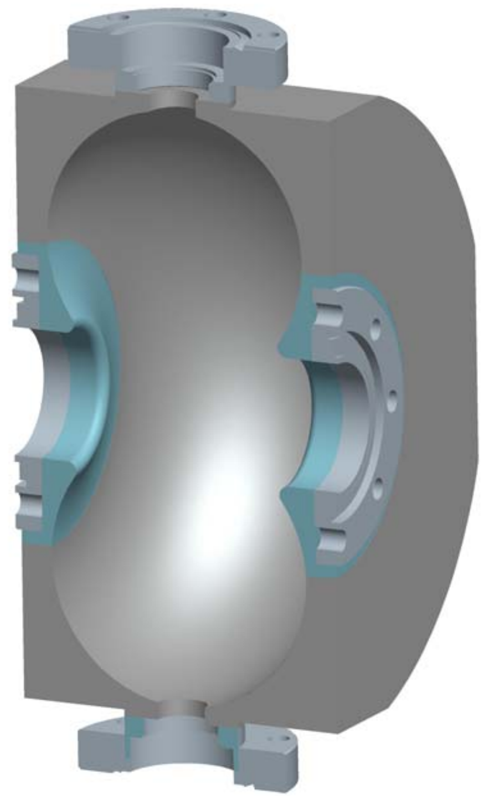
RF Cavity Design

	ELBE Cavity	ELBE Like Design	PEP II Like Design	Toroid Design
Shunt Impedance / MΩ	1.4	2.52	2.53	3.41
Practical Shunt Impedance / MΩ	1.12	2.016	2.024	2.728
Power Requirements @ 135 kV / kW	8.14	4.52	4.50	3.34
Power Requirements @ 200 kV / kW	17.86	9.92	9.88	7.33

- Started with ELBE cavity design initially, which fits the space requirements, but a need to increase the shunt impedance
- A further 3 designs considered with the toroid giving the best results
- Further work confirms we can increase the internal diameter of the toroid by designing a slimmer vacuum flange has increased the shunt impedance to 4.4 Ohms (x3 on original value)
- Thermal and structural analysis of cavity to do
- Optimised construction method to do

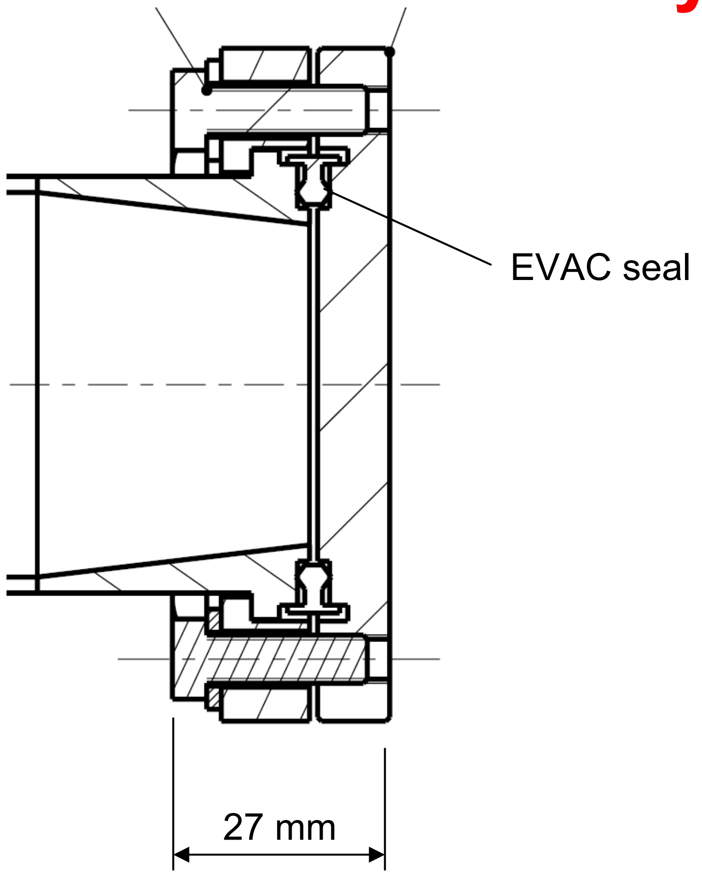
RF Cavity – Toroid Design

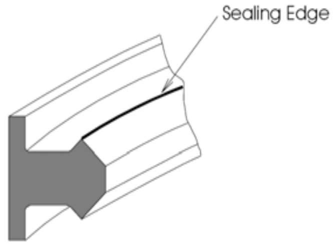


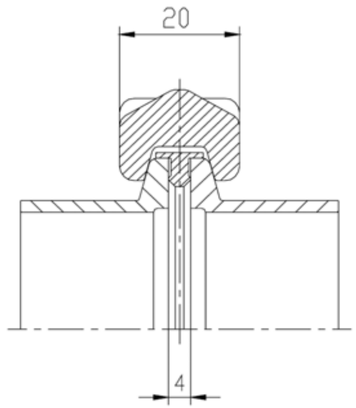


3D Section

Cavity Flange Design







Normal KF flange arrangement with chain clamping ring

37 mm for equivalent CF flange
10 mm saving per cell
required to fit in field clamp plate, larger BPM and increased internal size of RF cavity

EVAC gasket Pt No: 34.142.140-az
Seal material soft aluminium
Seal has an outer aligning ring
Leak rate = <1x 10 $^{-11}$ mbar litre s-1
Temperature range = -271°C to 150°C
Flange material stainless steel 316L

RF Work in progress

Carl Beard presenting RF update in more detail tomorrow:

- Finalise cavity design
- Update on cavity design, coupler and tuner designs to ensure optimum coupling at high powers and the required 5.6 MHz bandwidth
- Describe the latest RF power delivery options and power distribution
  - Pros /Cons
- Options being considered are
  - 20 kW IOT e2v integrated amplifier
  - 30 kW IOT Thales/CPI (non-integrated)
  - 160 kW Klystron e2v

Injection

Takeichiro Yokoi will talk in more detail on Saturday

- Many injection layout schemes considered
- Baseline design is 1 septum and 2 kickers injecting from the outside of the ring. Outside injection preferred:
  - We would like to keep the inside clear of obstructions clear for survey
  - Injection angle is steeper on inside injection due to the geometry of the magnets and less room to thread the injected beam through the quadrupoles
  - Additional bends required for internal injection resulting in additional cost and sources of dispersion
- Further work needed to include the septum design to improve the injection distribution point
- High angle septum considered at present. Low angle injection by threading the beam through the quadrupoles to be studied

Fast Switching

- Beam injection (extraction) needs to cope with a broad varieties of injection conditions - Energy10~20 MeV, phase advance: 0.1~0.4/cell, various operation modes
- For the 2 kicker with a septum injection from the outside of the ring:
- Maximum available kicker field set at 0.06T
- Maximum deflection angle at 10MeV = 157mR and at 20MeV =88mR
- Kicker aperture can be: 45(Hor.) × 25mm(Vert) window frame
- Kicker magnet length 100mm
- Assuming a 70ns half sinewave, with a single bunch kicked
- Max kick at 20MeV at 88mR peak rating is 1.23kA & 13.8kV
- Including estimated inductance peak volts at power supply = 22.6kV
- Max DdI/dt = 55A/ns Power supply rating 23kV 1.3kA + rise time of 35nS
- Combination of 3 values in red is demanding
- Looking at 2 switching options a) Solid State switch b) Thyratron Valve. Best achievable jitter (repeatability of pulse) with option b) is (5ns possible, maybe 2ns)
- No solution yet but discussions in progress with suppliers
- Engineering design of vacuum chamber and kicker due to start shortly

The FFEMMAG Computer Code

Stephan Tzenov

- The FFEMMAG Code, which is under development at DL is a computer programme to simulate the reference orbit, the accelerated orbit, dispersion and lattice functions of EMMA. It:

1) Calculates the accelerator modes of the reference orbit map;
2) Solves the equations for the accelerated orbit and determines the median plane beam footprint;
3) Calculates the dispersion function;
4) Calculates the generalized Twiss parameters, as well as the betatron tunes.
5) Future plans to extend the code include simulations of the dynamic aperture and resonance crossings.

Window between EMMA & ERLP

- Considering a window between ERLP and EMMA
- Advantage of separate vacuum systems for the 2 machines
- Quicker and lower cost for assembly of EMMA due to less stringent vacuum procedures (ERLP has requirement for very low particle count for SCRF modules)
- Location of window to be at double waist with small beta and alpha =0 to minimise the transverse emittance blow up
- Work to do on design of the transfer line

Diagnostic Beamline

- Design of diagnostic beamline not started but debate on diagnostics requirements in progress:
  - BPMs x 4 for beam position
  - Commissioning screen immediately downstream of the septum
  - Wall current monitor
  - 2 wire scanners for H & V profiles at large Twiss-beta
  - Deflecting mode cavity and screen
  - 2 or 3 wire scanners per plane for emittance measurement
  - Spectrometer for extracted momentum

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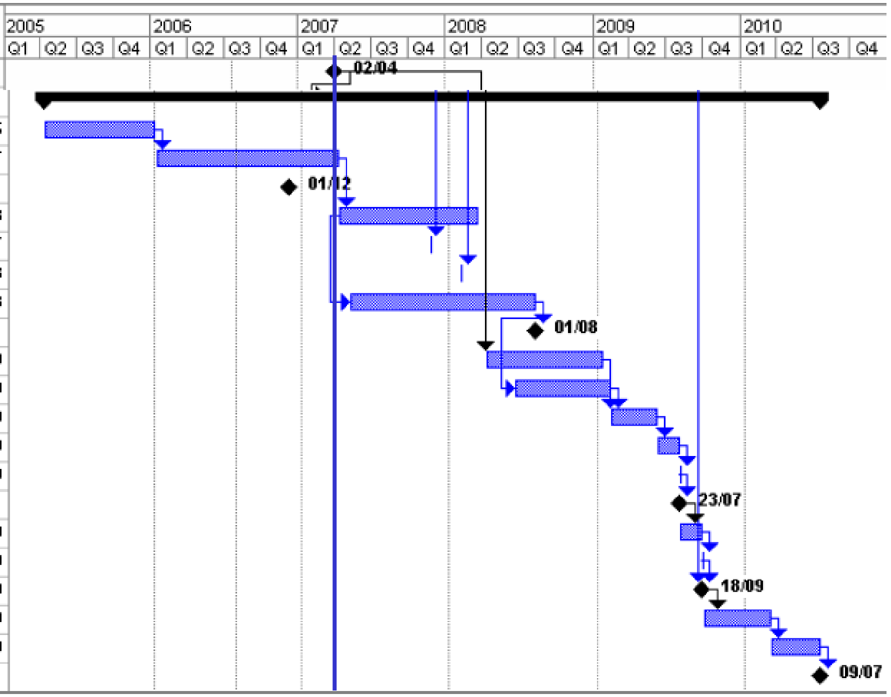
BASROC CONFORM

Timescales

ID		Task Name	Duration	Start	Finish
1		Funding available	0 days	Mon 02/04/07	Mon 02/04/07
23		**EMMA Project Plan**	**1363 days**	**Fri 01/04/05**	**Fri 09/07/10**
24		Conception	9.8 mons	Fri 01/04/05	Fri 30/12/05
25		Feasibility Phase	16.25 mons	Mon 02/01/06	Fri 30/03/07
26		**Project approval notified**	**0 days**	**Fri 01/12/06**	**Fri 01/12/06**
27		Design	12 mons	Mon 02/04/07	Mon 10/03/08
28		Design review 1	1 day	Mon 12/11/07	Mon 12/11/07
29		Design review 2	1 day	Tue 29/01/08	Tue 29/01/08
30		Procurement	16.2 mons	Mon 30/04/07	Fri 01/08/08
31		**All major components on site**	**0 days**	**Fri 01/08/08**	**Fri 01/08/08**
32		Infrastructure upgrade	10 mons	Tue 01/04/08	Wed 14/01/09
33		Off line assembly and test sub systems	8.2 mons	Mon 09/06/08	Mon 02/02/09
34		Installation in Accelerator Hall	4.1 mons	Tue 03/02/09	Wed 27/05/09
35		Test systems in Accelerator Hall	2 mons	Thu 28/05/09	Wed 22/07/09
36		Construction project close out review	1 day	Thu 23/07/09	Thu 23/07/09
37		**EMMA construction complete**	**0 days**	**Thu 23/07/09**	**Thu 23/07/09**
38		Commission with electrons	2 mons	Fri 24/07/09	Thu 17/09/09
39		Construction project post implementation review	1 day	Fri 18/09/09	Fri 18/09/09
40		Detailed experimental programme	0 days	Fri 18/09/09	Fri 18/09/09
41		Full ring studies	6 mons	Mon 21/09/09	Fri 05/03/10
42		Advanced ring studies	4.5 mons	Mon 08/03/10	Fri 09/07/10
43		**EMMA phase 1 beam studies complete**	**0 days**	**Fri 09/07/10**	**Fri 09/07/10**



ID		Task Name	Duration	Start	Finish
1		**Funding available**	**0 days**	**Mon 02/04/07**	**Mon 02/04/07**
23		**EMMA Project Plan**	**1363 days**	**Fri 01/04/05**	**Fri 09/07/10**
24		Conception	9.8 mons	Fri 01/04/05	Fri 30/12/05
25		Feasibility Phase	16.25 mons	Mon 02/01/06	Fri 30/03/07
26		**Project approval notified**	**0 days**	**Fri 01/12/06**	**Fri 01/12/06**
27		Design	12 mons	Mon 02/04/07	Mon 10/03/08
28		Design review 1	1 day	Mon 12/11/07	Mon 12/11/07
29		Design review 2	1 day	Tue 29/01/08	Tue 29/01/08
30		Procurement	16.2 mons	Mon 30/04/07	Fri 01/08/08
31		**All major components on site**	**0 days**	**Fri 01/08/08**	**Fri 01/08/08**
32		Infrastructure upgrade	10 mons	Tue 01/04/08	Wed 14/01/09
33		Off line assembly and test sub systems	8.2 mons	Mon 09/06/08	Mon 02/02/09
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35		Test systems in Accelerator Hall	2 mons	Thu 28/05/09	Wed 22/07/09
36		Construction project close out review	1 day	Thu 23/07/09	Thu 23/07/09
37		**EMMA construction complete**	**0 days**	**Thu 23/07/09**	**Thu 23/07/09**
38		Commission with electrons	2 mons	Fri 24/07/09	Thu 17/09/09
39		Construction project post implementation review	1 day	Fri 18/09/09	Fri 18/09/09
40		Detailed experimental programme	0 days	Fri 18/09/09	Fri 18/09/09
41		Full ring studies	6 mons	Mon 21/09/09	Fri 05/03/10
42		Advanced ring studies	4.5 mons	Mon 08/03/10	Fri 09/07/10
43		**EMMA phase 1 beam studies complete**	**0 days**	**Fri 09/07/10**	**Fri 09/07/10**

Cost Breakdown

	Item	Cost (Incl. VAT)	
	EMMA		
1	RF CAVITY SYSTEM	£	1,641,500
2	DIAGNOSTICS	£	492,400
3	MAGNETS	£	502,430
4	MECHANICAL & VACUUM CHAMBERS	£	391,250
5	VACUUM EQUIPMENT	£	134,300
6	CONTROLS	£	121,662
7	ELECTRICAL	£	442,450
8	COOLING & SERVICES	£	70,000
9	CIVIL	£	34,000
10	**sub total**	**£**	**3,829,992**
11	EMMA Staff	**£**	**1,808,000**

£ 5,637,992

Conclusions Next Steps

- Funding in place
- Definition phase now well advanced
- More cost planning needed now that we are better defined
- More detailed work breakdown structure needed for planning
- A lot of work to do
  - Make decision of RF power delivery scheme
  - Firming up on injection and extraction scheme
  - Engineering of injection and extraction devices
  - Matching ERLP to EMMA
  - Design of transfer line from ERLP to EMMA
  - Design of diagnostics beamline
- We aim to have an operating NS-FFAG at DL in September 2009

Acknowledgements

- All the team
  - Internal staff
  - All the collaborators