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EMMA RF commissioning and stabilisation

the World's First Non-Scaling FFAG Accelerator

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STFC, ASTeC

Contents

- What is EMMA
- Layout and Lattice
- Components of the machine
- Radiofrequency
- Beam Commissioning
- Summary

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What is EMMA

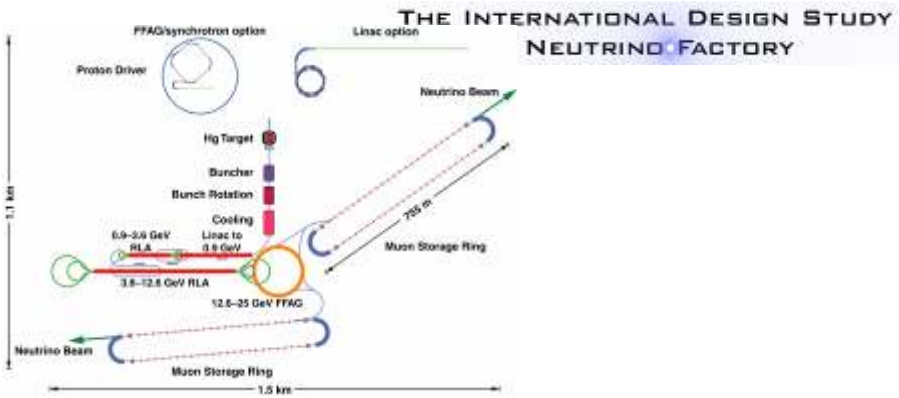
Being funded by **BASROC** (The British Accelerator Science and Radiation Oncology Consortium, BASROC)

- CONFORM project (**CO**nstruction of a **N**on-scaling **F**FAG for **O**ncology, **R**esearch, and **M**edicine)
- 4 year project April 2007 – March 2011
- 3 parts to the project
  - EMMA design and construction ~ £6.5m (~$9M)

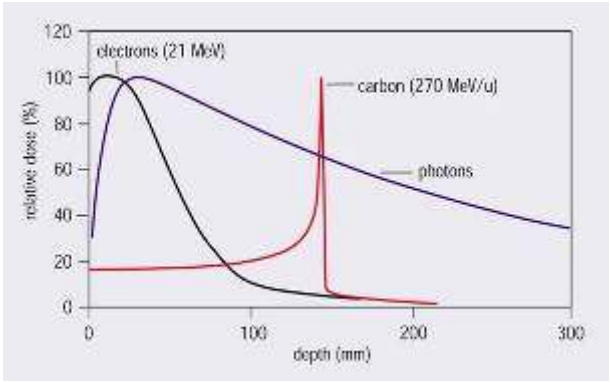
    Electron **M**odel for **M**any **A**pplications (EMMA)
  - PAMELA design study
  - Applications study

Applications of ns-FFAGs

Neutrino Factory

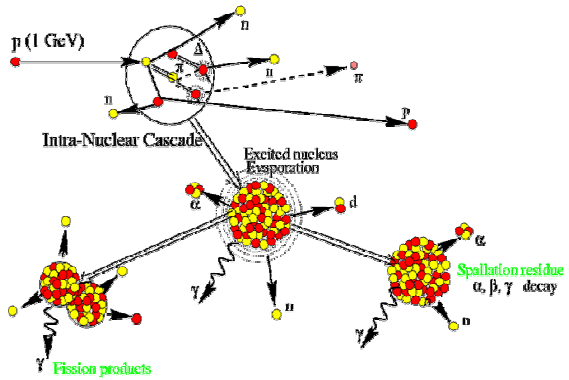


Proton & Carbon Therapy

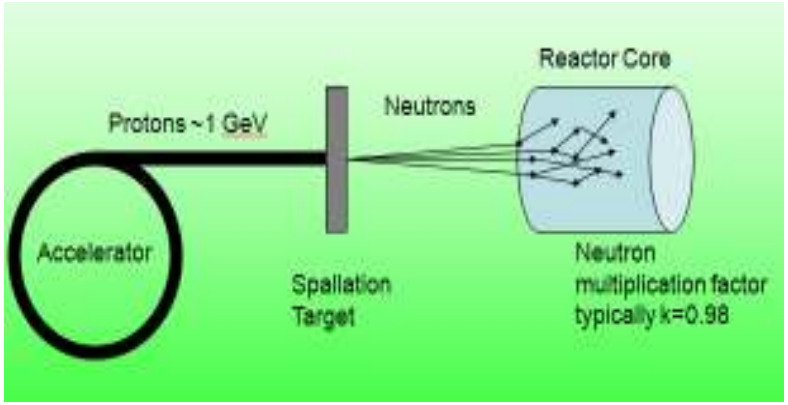


High power proton driver

Dedicated Muon Source



Sub-critical Thorium Reactor



LAYOUT AND LATTICE

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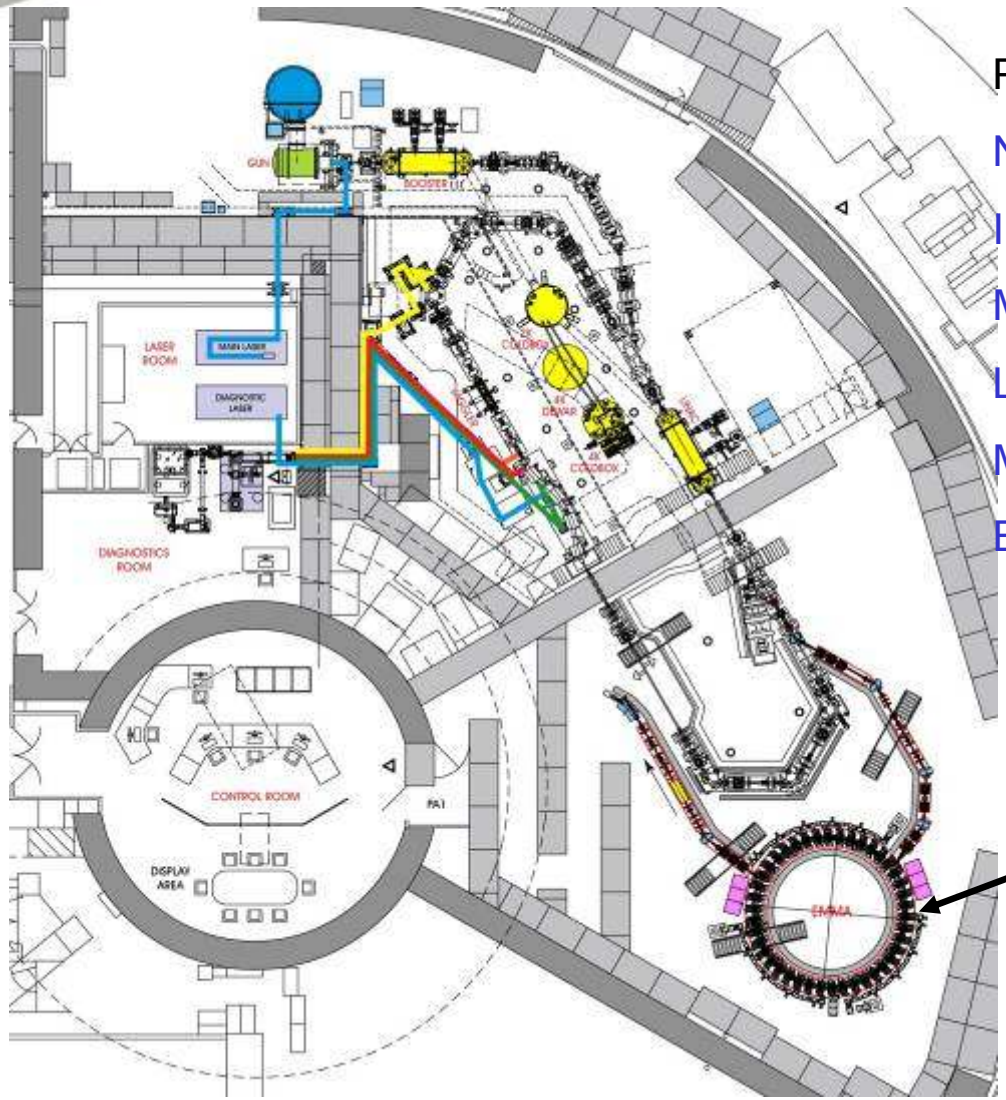
ALICE

Accelerators and Lasers In Combined Experiments



Parameter	Value
Nominal Gun Energy	350 keV
Injector Energy	8.35 MeV
Max. Energy	35 MeV
Linac RF Frequency	1.3 GHz
Max Bunch Charge	80 pC
Emittance	5-15 mm-mrad

EMMA

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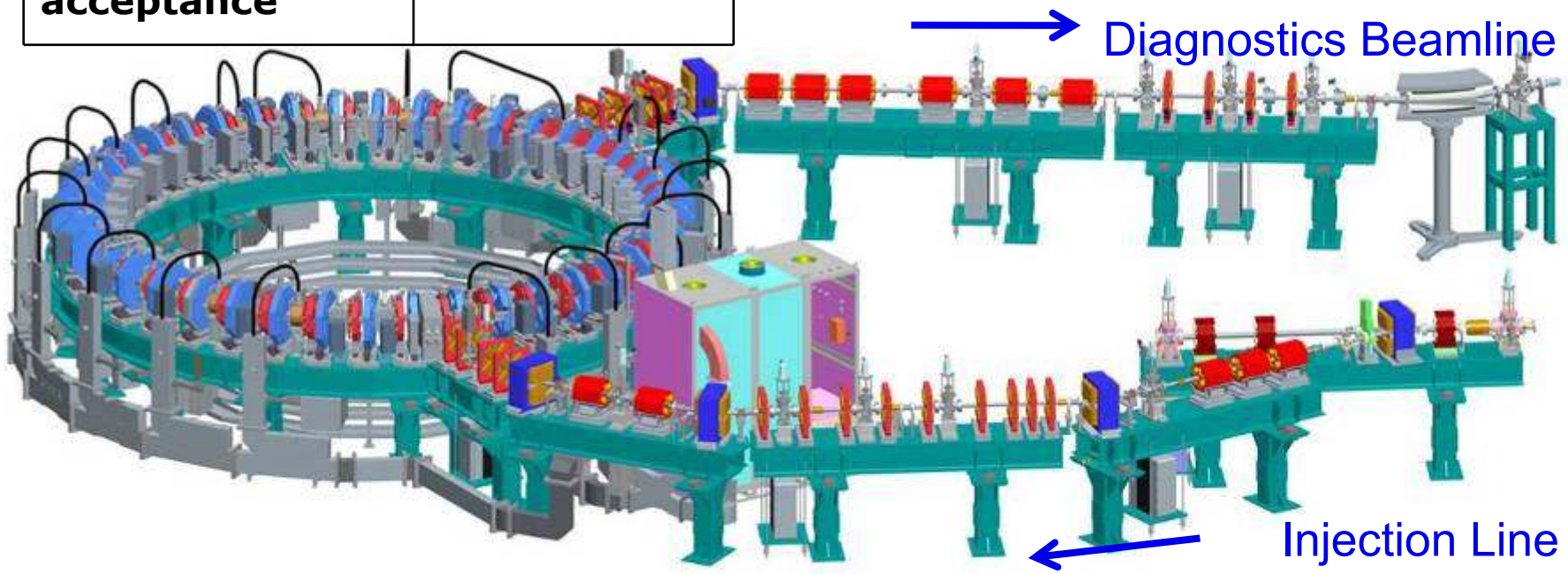
EMMA Parameters & Layout

Energy range	**10 – 20 MeV**
Lattice	**F/D Doublet**
Circumference	**16.57 m**
No of cells	**42**
Normalised transverse acceptance	**3π mm-rad**

Frequency (nominal)	**1.3 GHz**
No of RF cavities	**19**
Repetition rate	**1 - 20 Hz**
Bunch charge	**16-32 pC single bunch**



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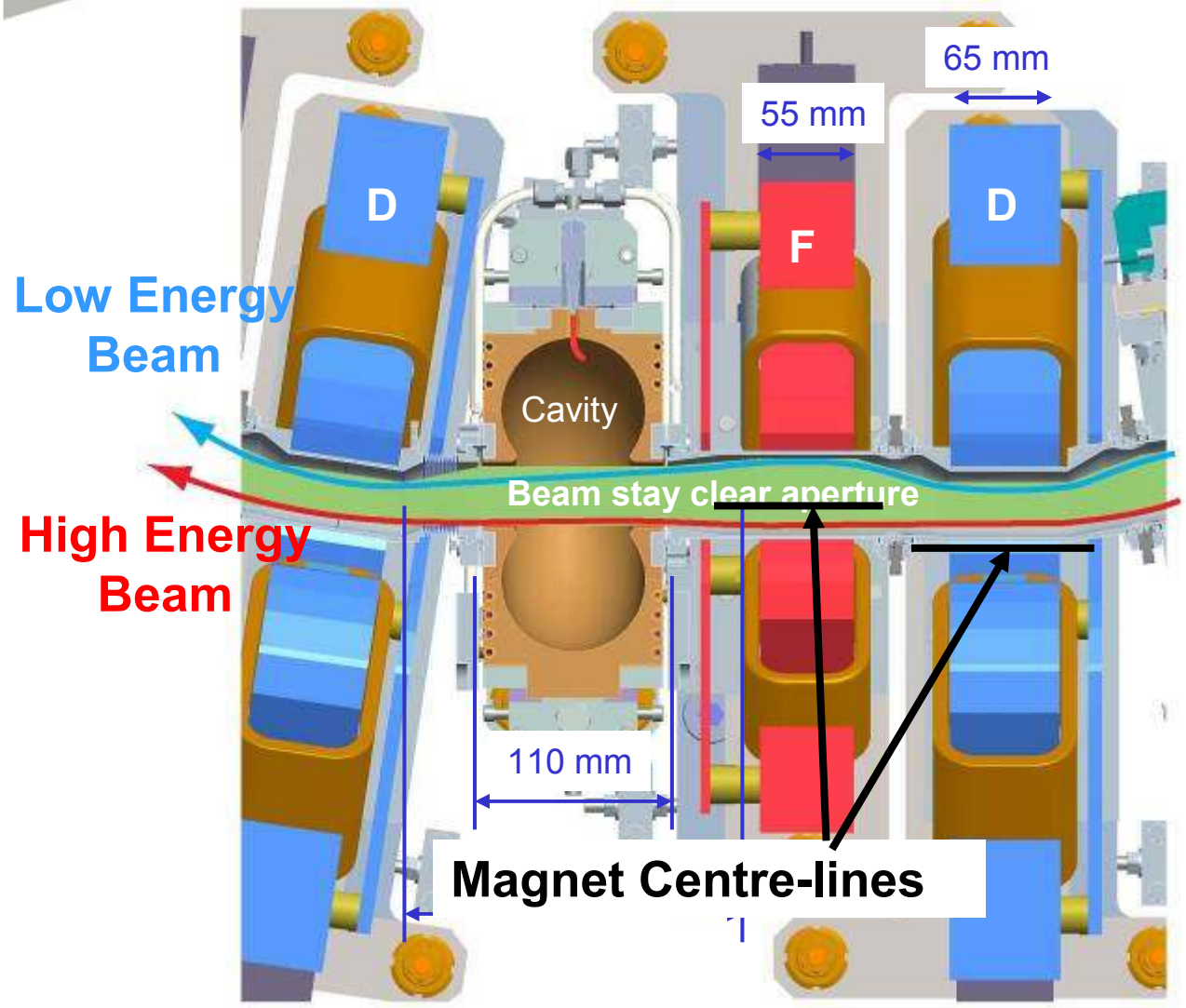
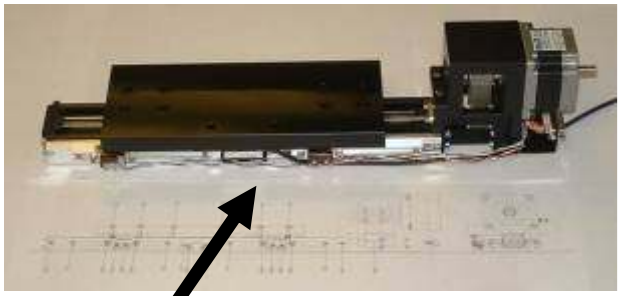
EMMA Ring Cell



Long drift	210 mm
F Quad	58.8 mm
Short drift	50 mm
D Quad	75.7 mm

42 identical doublets



Independent slides

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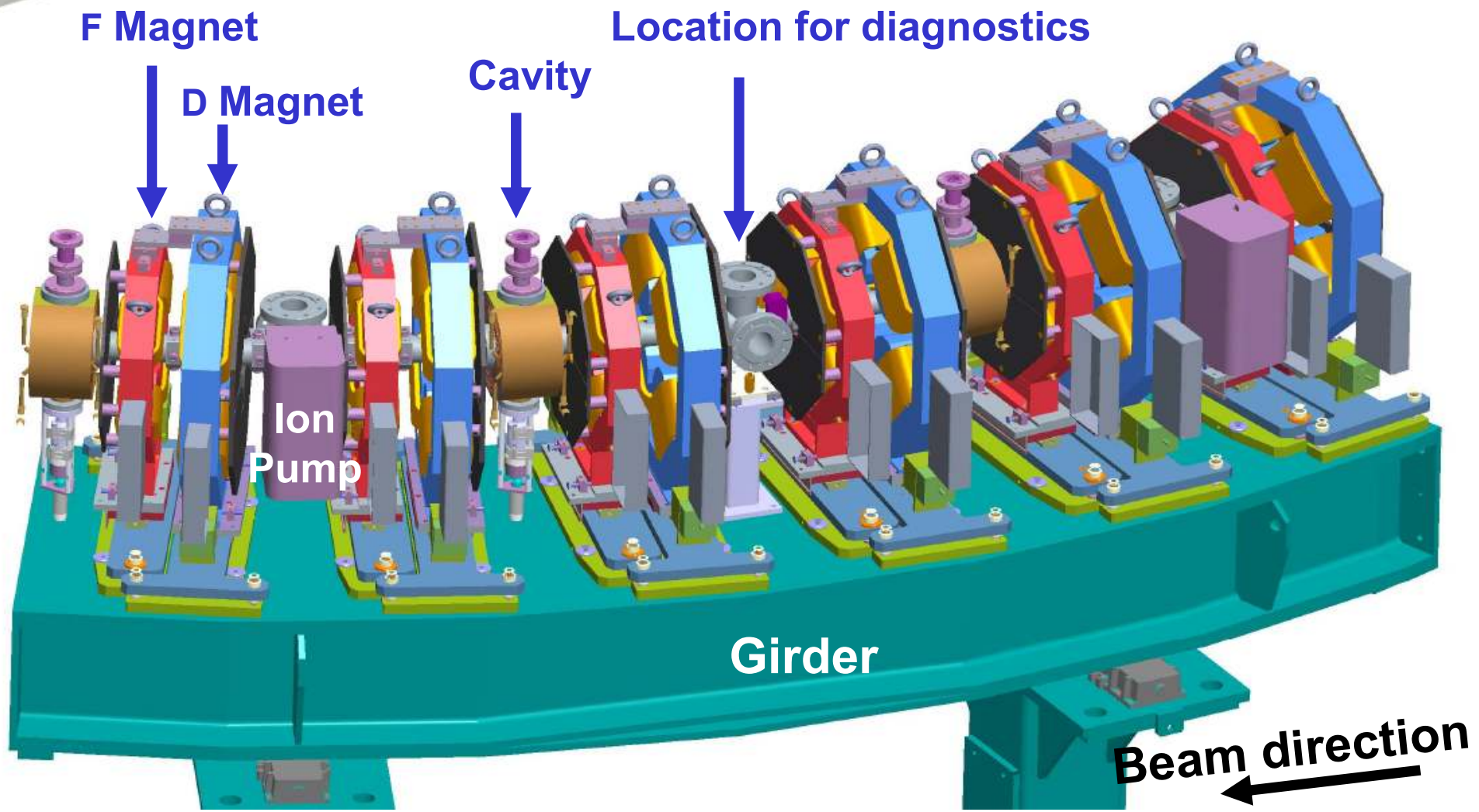
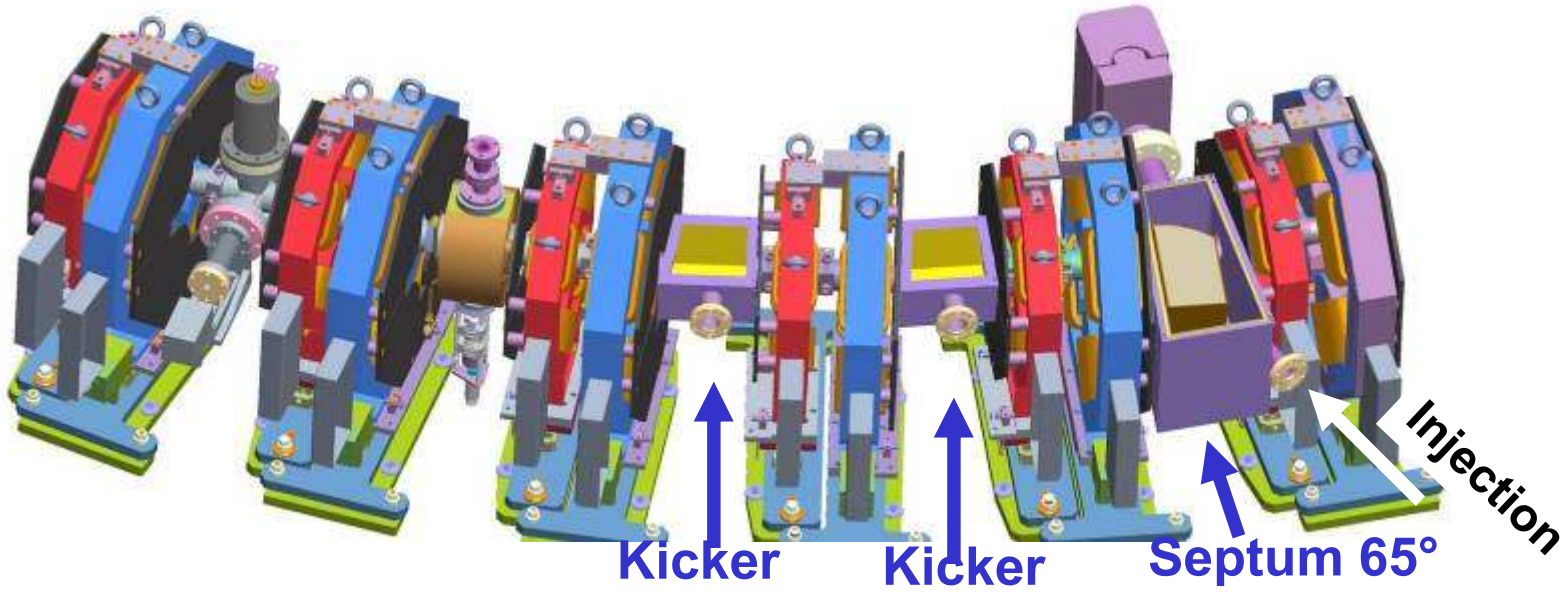
A 6 Cell Girder Assembly



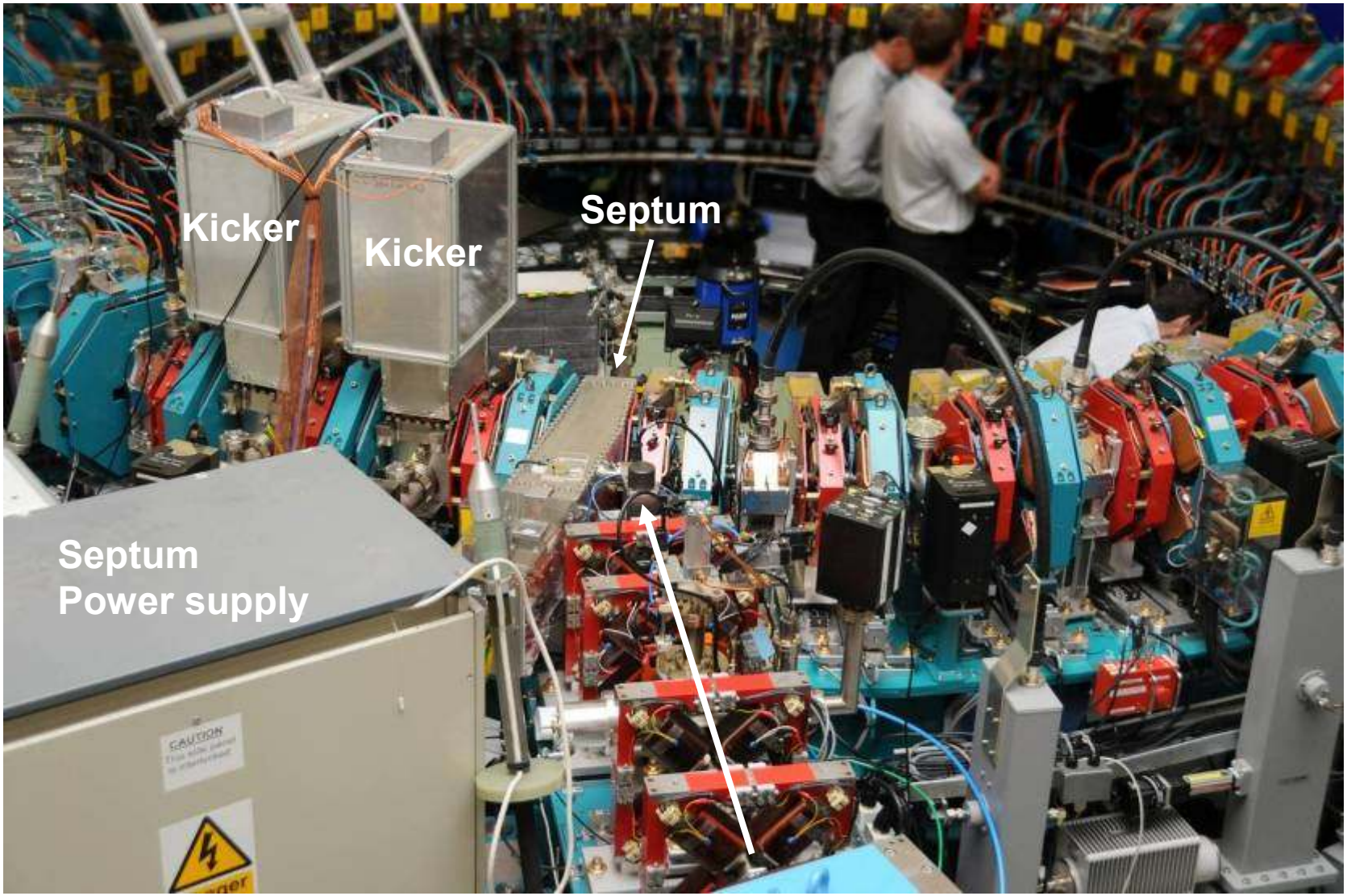
Injection & Extraction

- Large angle for injection (65°) and extraction (70°) very challenging !!
- Injection/Extraction scheme required for all energies (10 – 20 MeV)
- Many lattices and many configurations of each lattice required
- Very limited space between quadrupole clamp plates for the septum and kickers construction

Extensive 3D magnet modelling conducted to minimise the effect of stray septum fields on circulating beam



Injection



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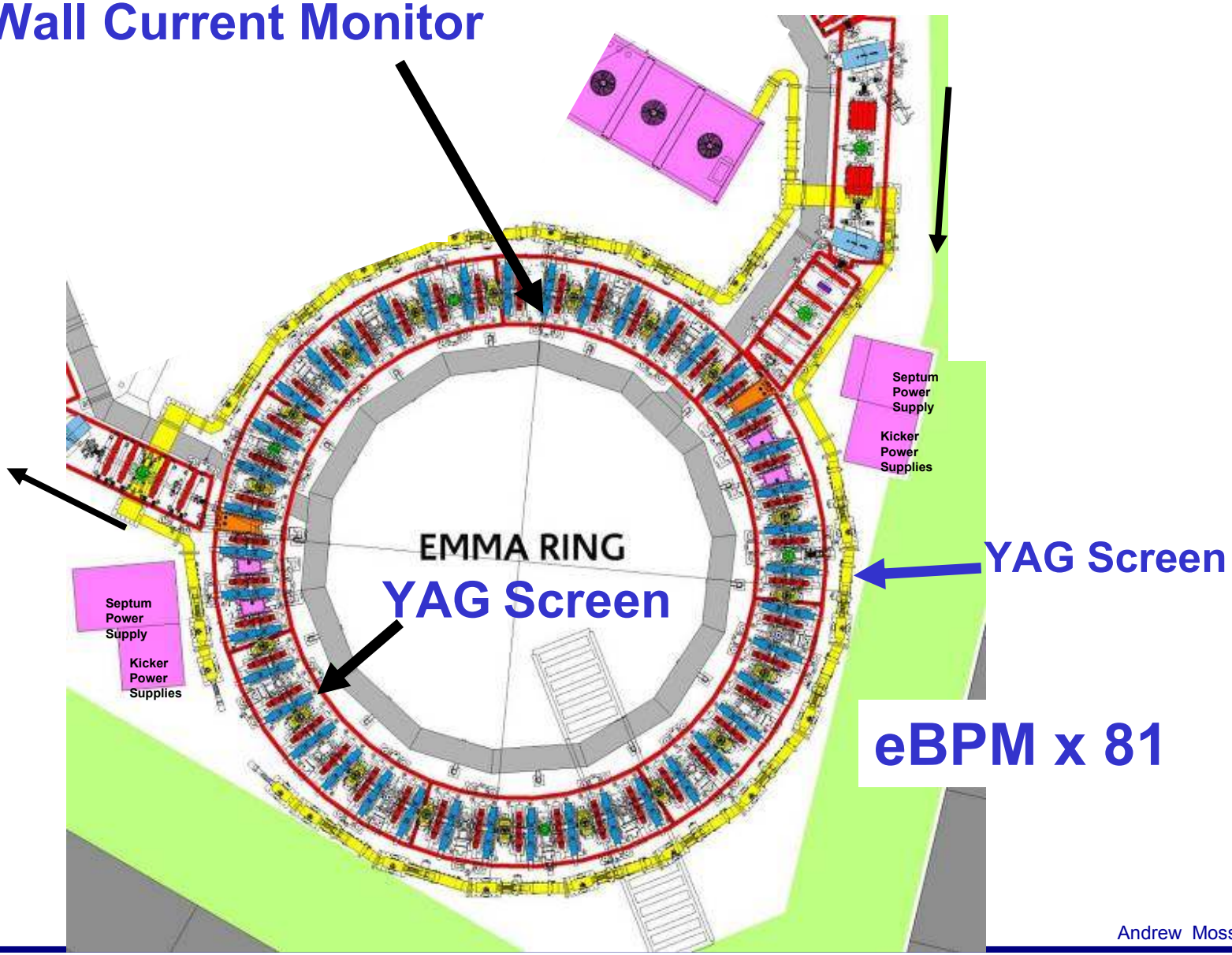
EMMA Ring



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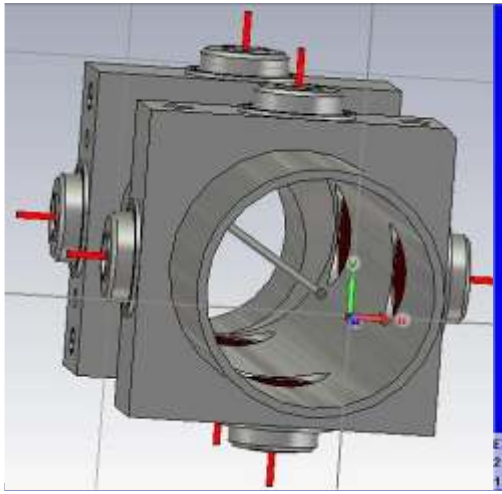
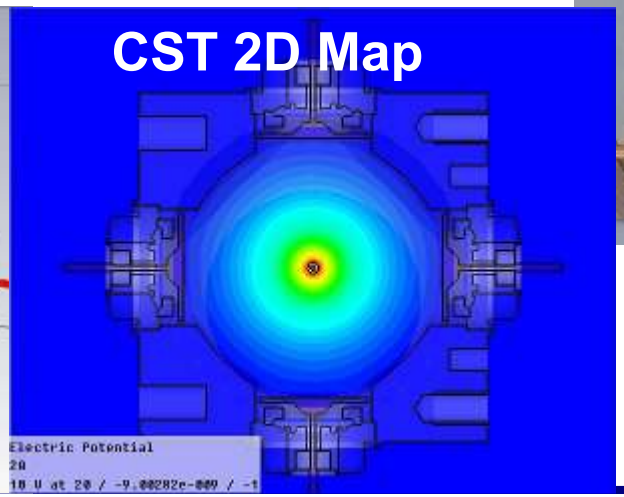
Electron Beam Position Monitors

- 50 μm resolution over a large aperture
- Locally mounted coupler cards
  - Amplifies signals from opposite buttons, coupler and strip line delay cables provides two pulses with ¼ rev. period delay on same cable
- VME Detector card in rack room outside of shielded area digitised

Coupler

Detector card



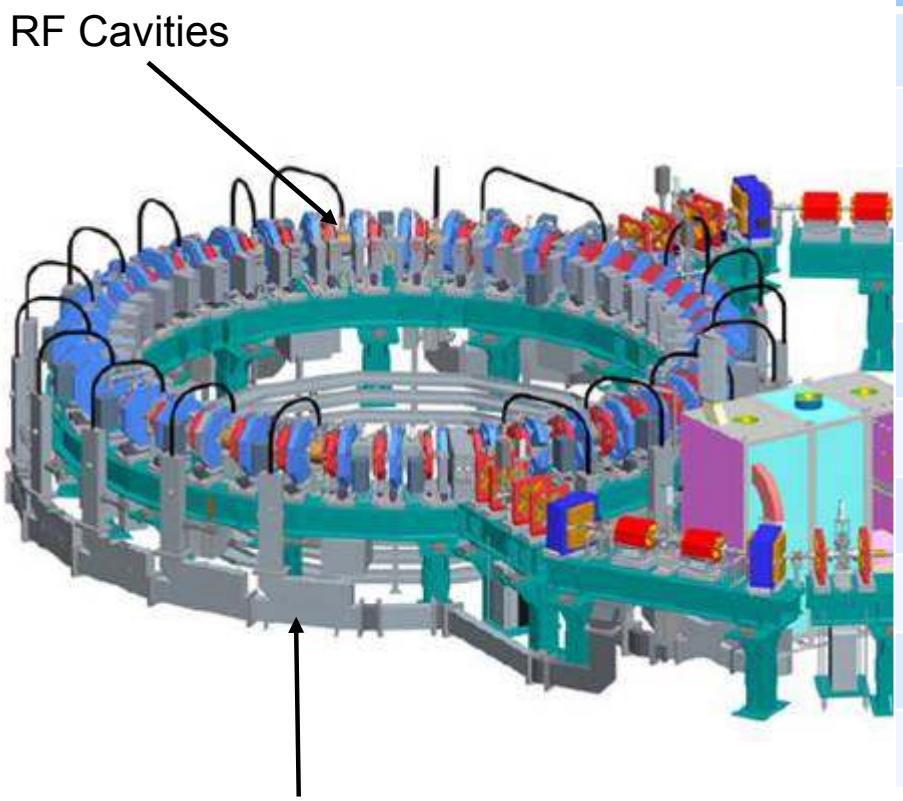


RADIO FREQUENCY

RF Requirements

- Voltage:
  - 20 - 120 kV/cavity essential for serpentine acceleration, based on 19 cavities
  - Upgrade possible to 180k
- Frequency:
  - 1.3 GHz, compact and matches the ALICE RF system
  - Range requirement 5.6 MHz
- Cavity phase:
  - Remote and individual control of the cavity phases is essential – 19 waveguide phase shifters

RF System Overview

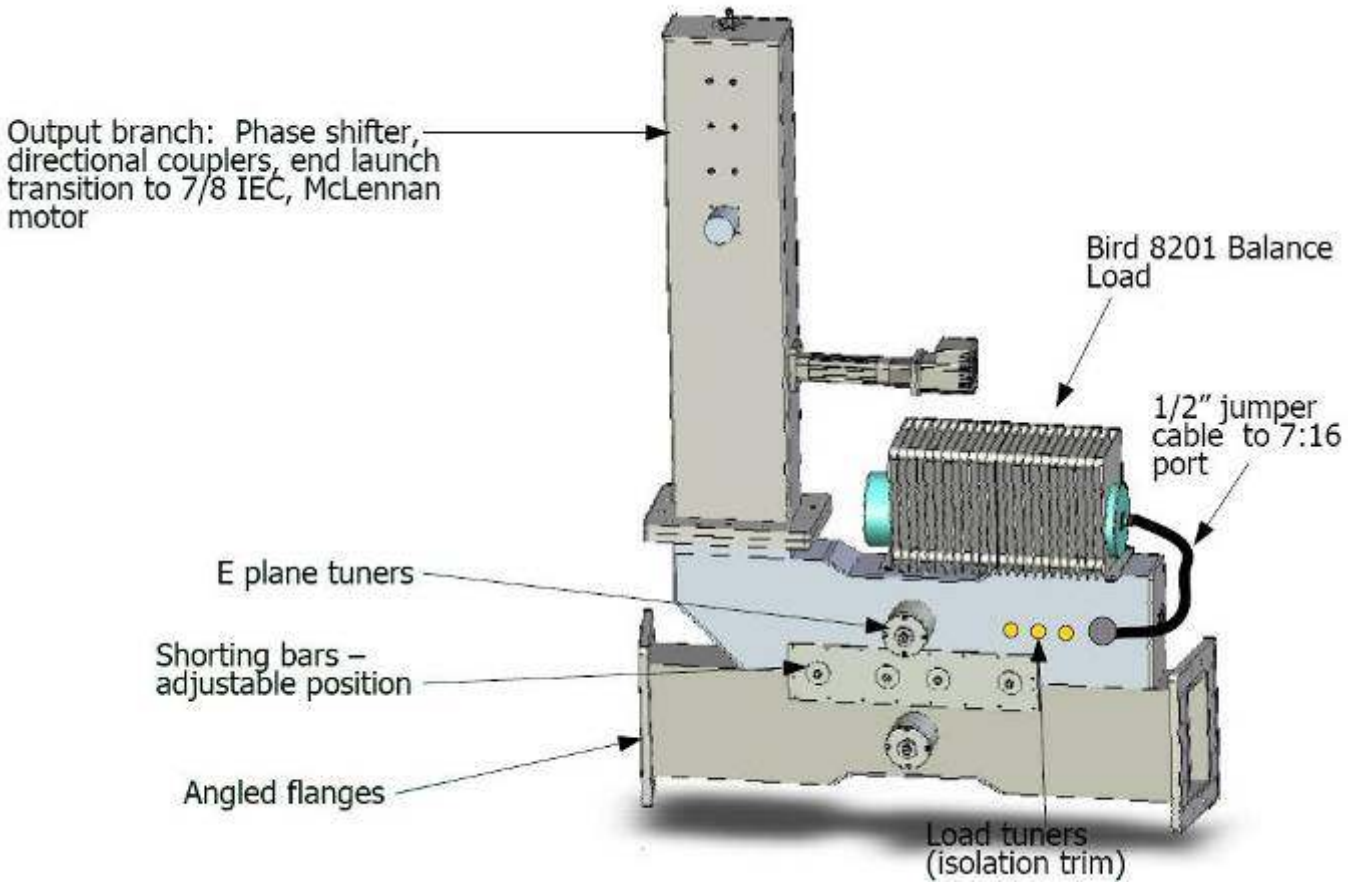


Machine Parameters	Value	Units
Frequency	1.3	GHz
Number of Straights	21	
Number of Cavities	19	
Total Acc per Turn	2.3	MV
Upgrade Acc per Turn	3.4	MV
Beam Aperture	40	mm
Beam Length	1.6	mS
RF Repetition Rate	3-20	Hz
Phase Control	0.3	°
Amplitude Control	0.3	%

Libera is mounted ~ 30 m from machine

Waveguide distribution

Phase shifter



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EMMA LLRF

- **Instrumentation Technologies Libera LLRF system provides**
  - Initial cavity setting conditions
  - Control of the cavity amplitude and phase to ensure stable control the acceleration
- **Diagnostic monitoring**
  - Cavity pick-up loops
  - Forward and reverse power monitoring to each cavity
  - IOT power levels before and the circulator
- **Novel synchronisation of the accelerators**
  - A 200μs beam pre-trigger used to reset LLRF phase accumulators every beam pulse:
  - The LLRF synchronises itself on every trigger pulse, preserve the relationship between ALICE 1.3 GHz and EMMA offset frequ.

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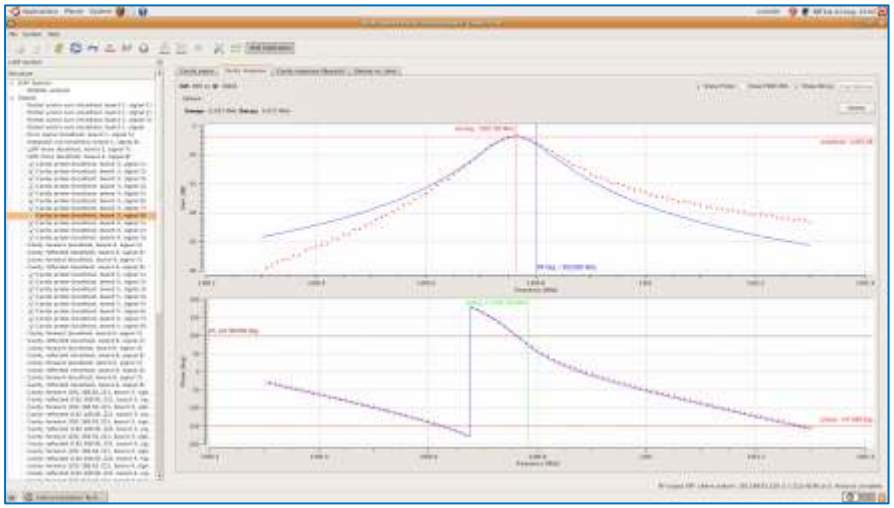
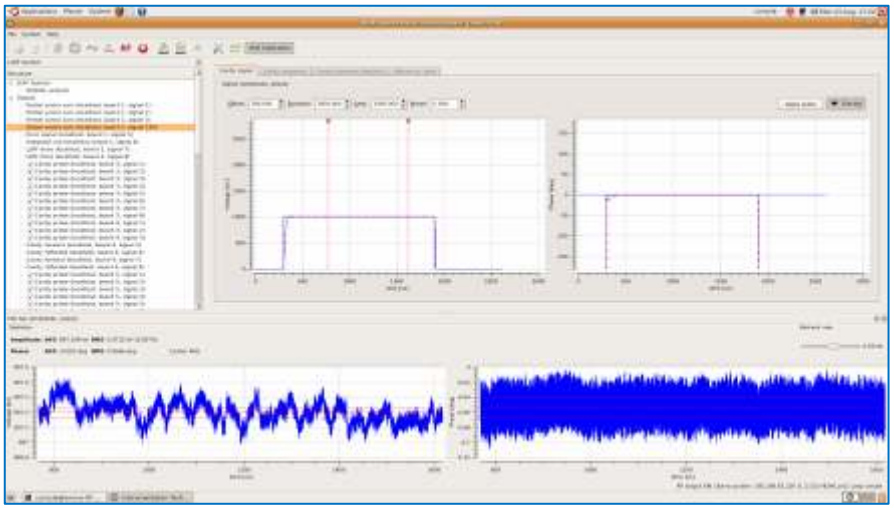
First high power commissioning

Started17/8/10

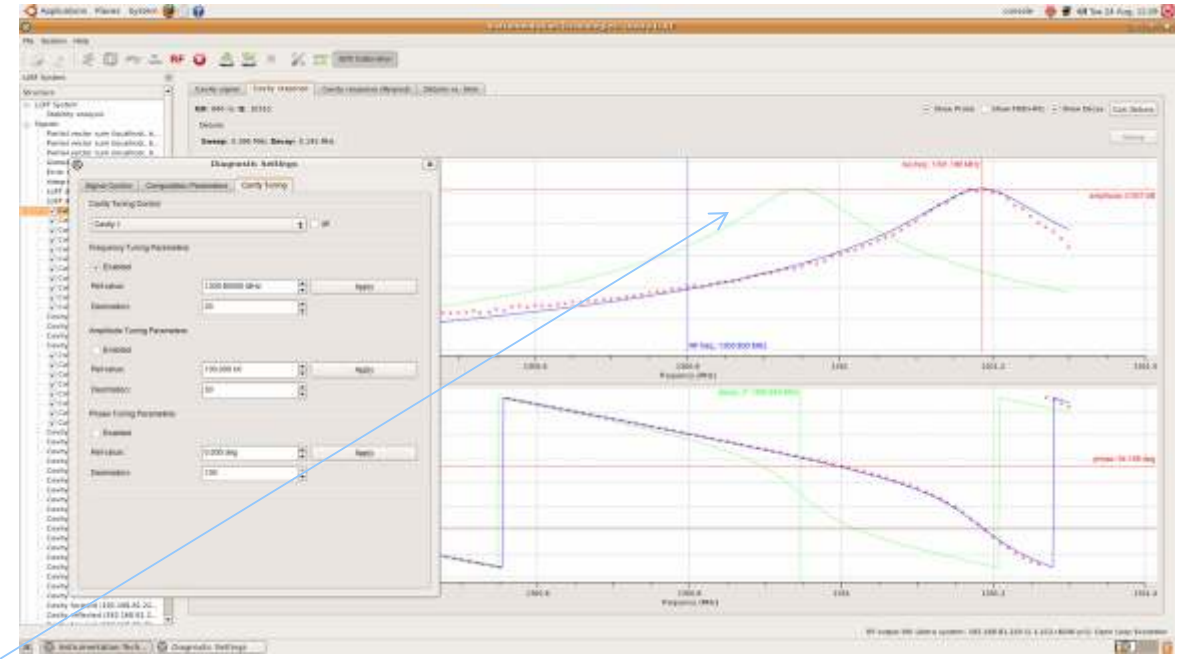




- Excellent cavity control stability (up to 40 kW so far)
  - 0.007% rms voltage
  - 0.027^{o} phase
- Many issues with tuner and phase shifter motors, comms, slipping motor shafts etc
- Ability to ‘ignore’ bad cavities from the GVS
- Further work planned during shutdown to understand and fix all motor problems
- Libera system will then take control motors with updated control software

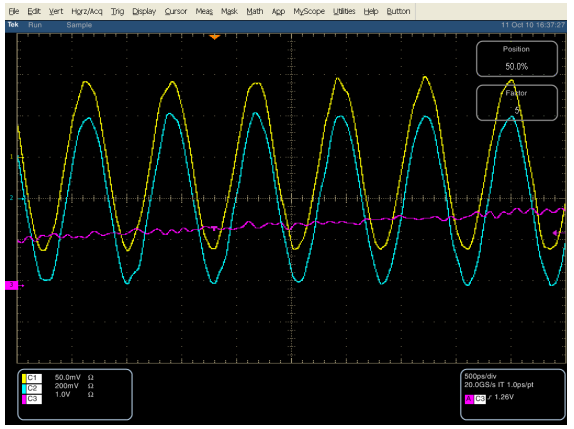
Frequency tuning

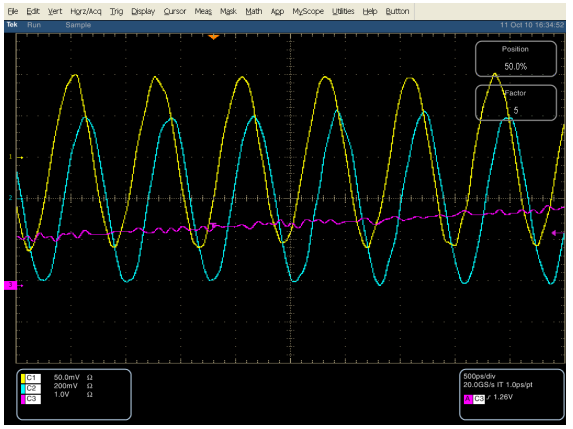
- Changing cavity frequency takes – 30 minutes
- Currently using epics system to move motors in open loop
- Using centre frequency and bandwidth controls ‘sweep analysis’ locates resonance of each cavity in system
- A new centre frequency can then be set and the tuner motors driven
- Calc detune shows new resonance of cavity
- Low reflected power response used to fine tune each cavity



synchronisation

- Yellow = ALICE 1300GHz
- Blue = EMMA 1301Ghz
- Trigger on laser pre injection pulse
- Measured on 12GHz scope while varying GVS phase and also amplitude
  - Can see that the global phase of EMMA being moved while maintaining lock during this simple test
  - Beam based analysis of the synchronisation will be performed as soon possible





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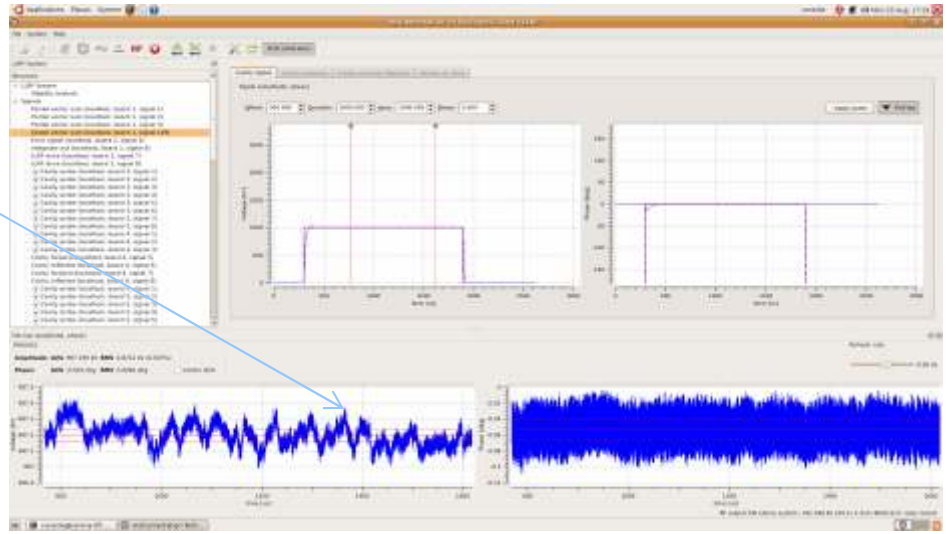
Optimising RF for acceleration

- Zero cross of each cavity to find optimum phase angle
- During recent experiment beam loading effects could be seen on Libera
- Possibility to zero cross each cavity, tune for max acceleration - needs testing
- Close loop on ‘new RF system’ and find the correct phase of system again – phase accumulator is reset during sweep
- RF acceleration essential goal before shutdown for maintenance



BEAM COMMISSIONING

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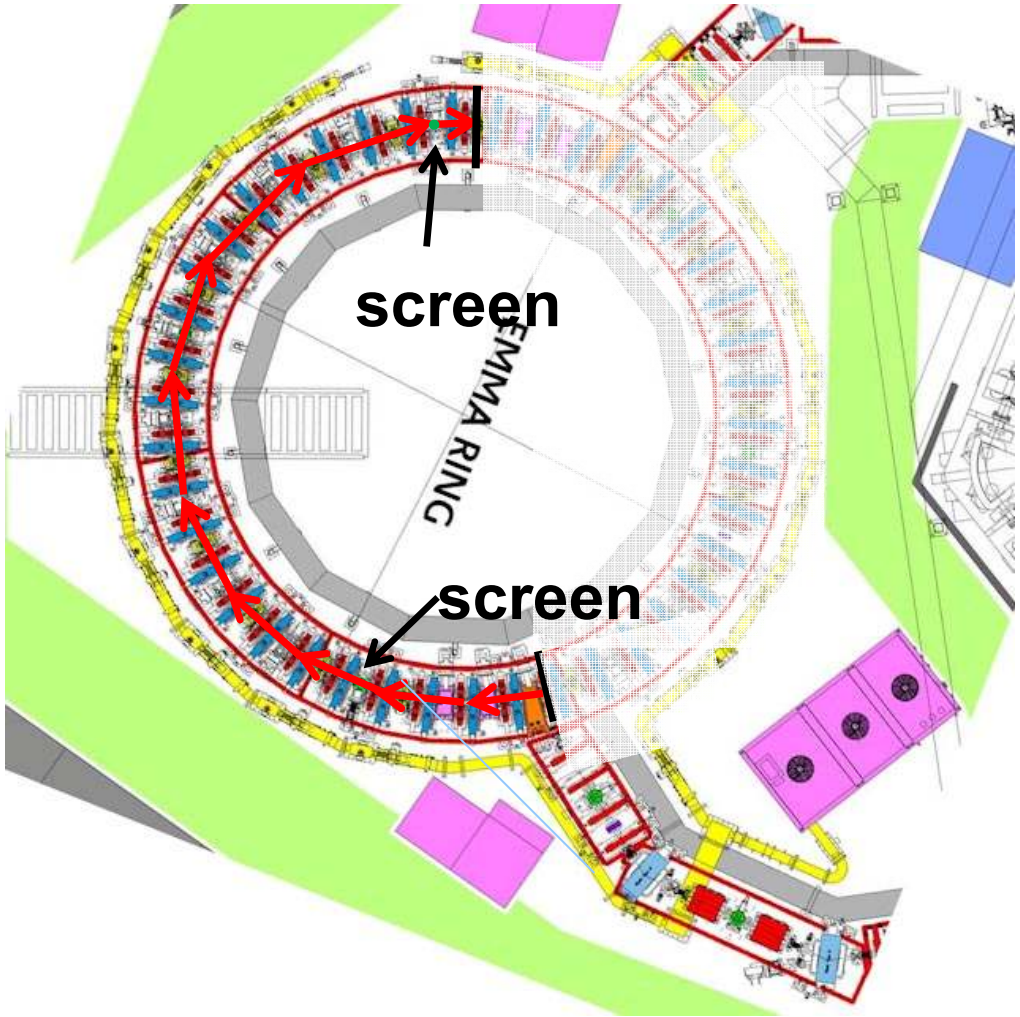
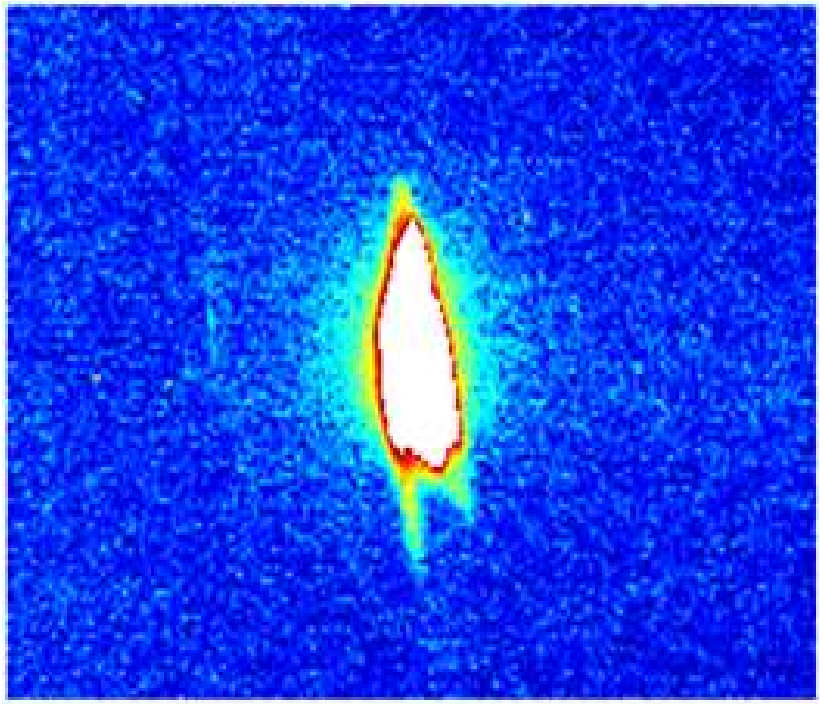
4 Sector Commissioning





Beam image on screen
At the end of 4 sectors
22 cells
22:37 on 22.6.2010

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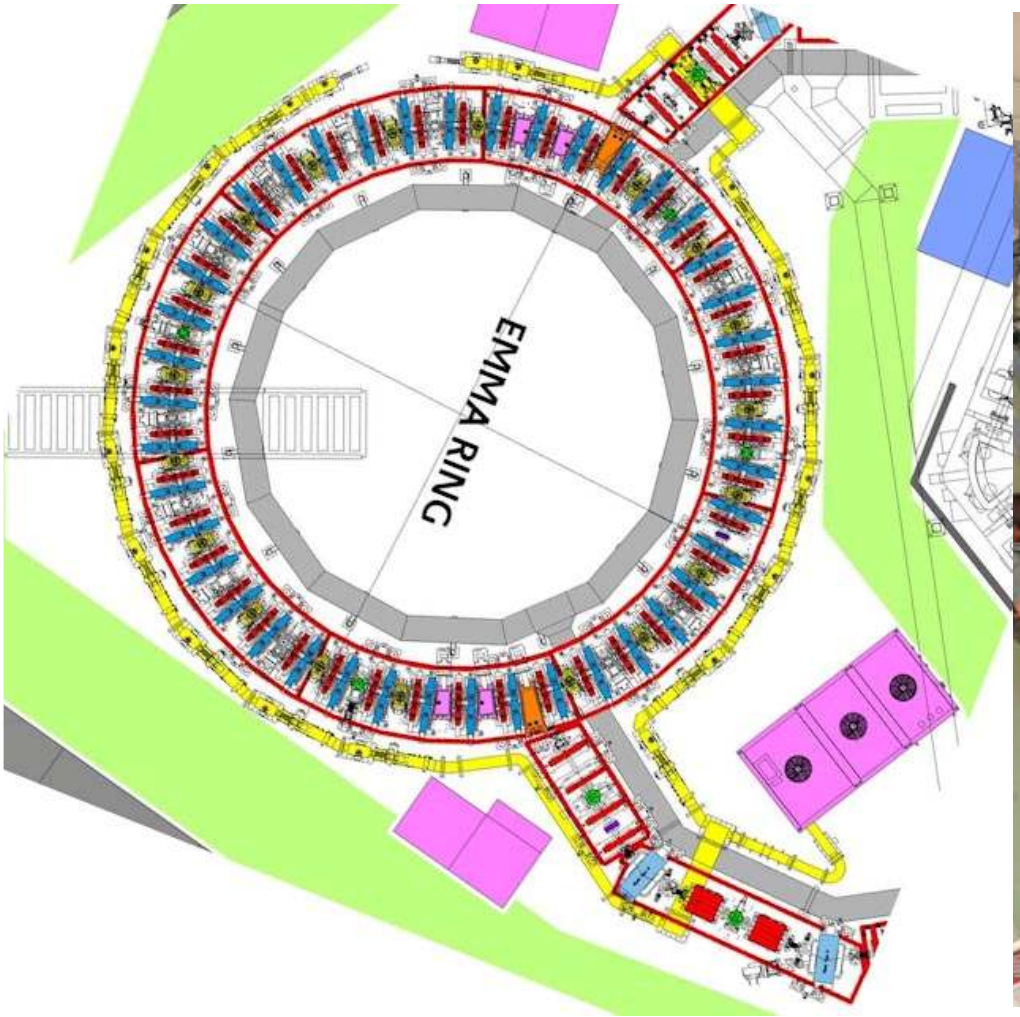
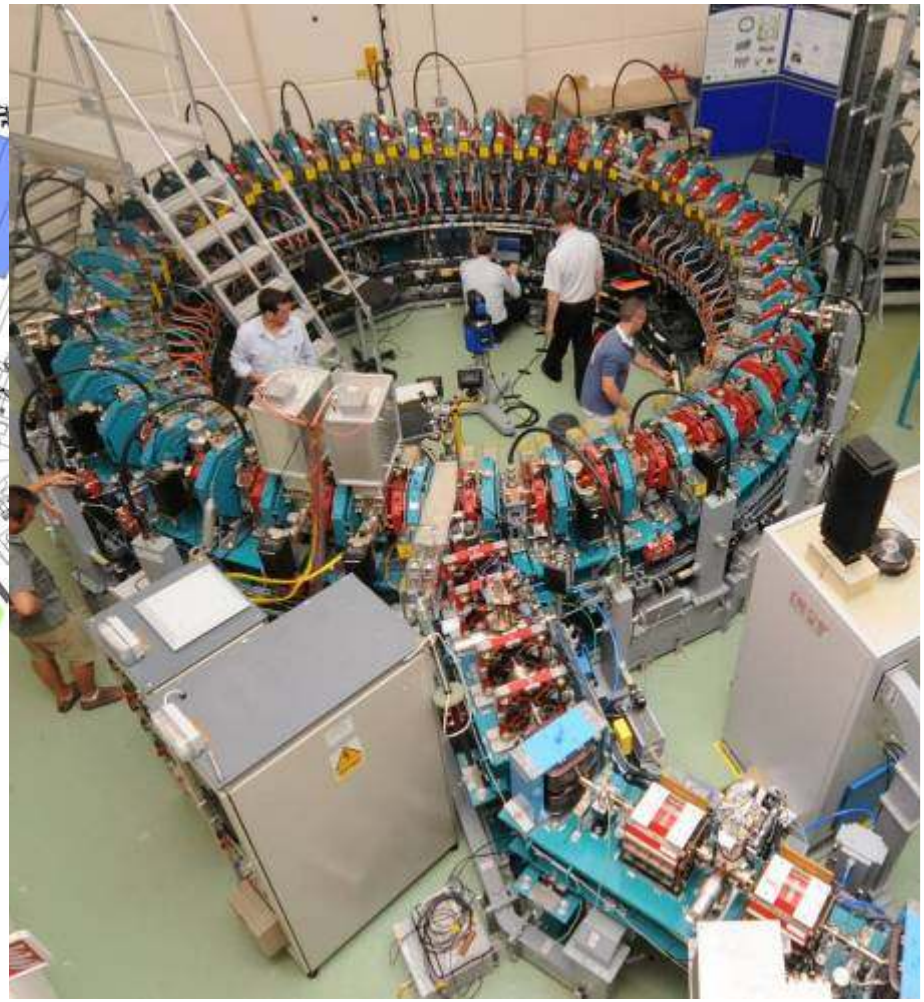
Realisation of EMMA August 2010



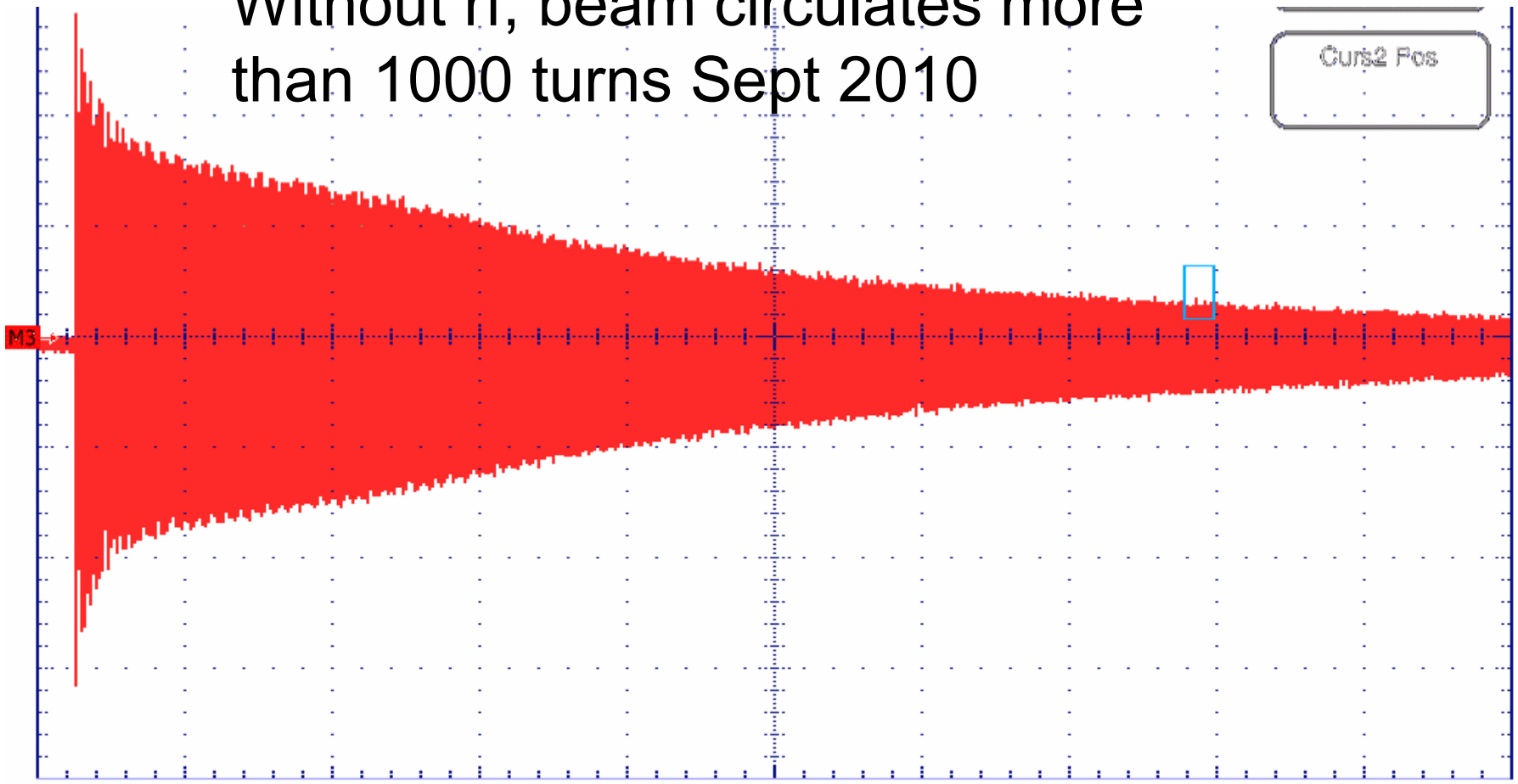


Complete Ring

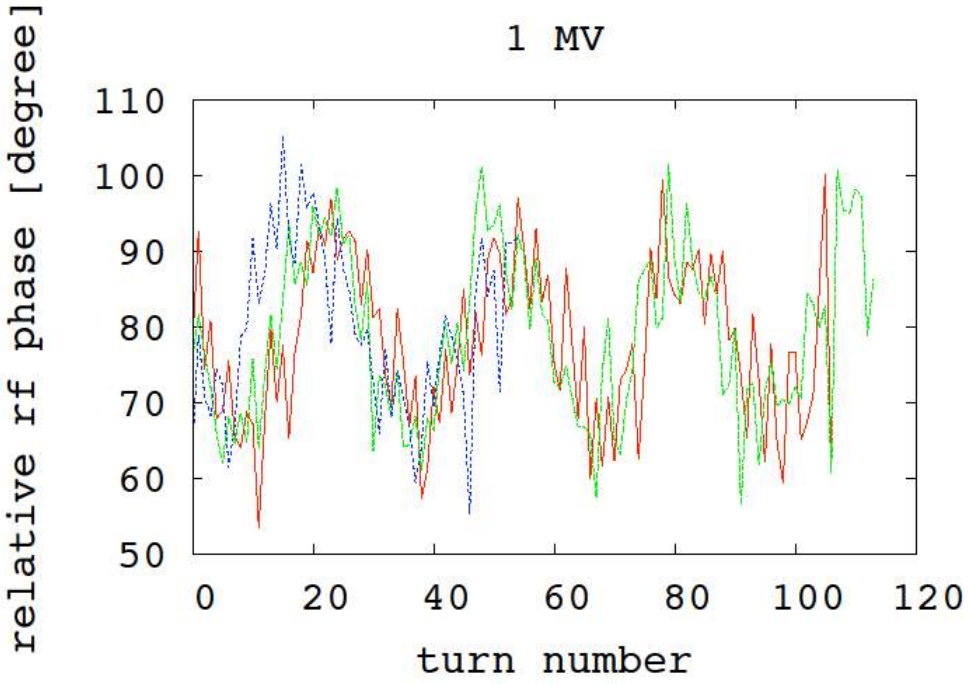
16th Aug 2010

Coasting beam no RF

Without rf, beam circulates more than 1000 turns Sept 2010



Beam with RF



Synchrotron Oscillations

- RF cavity phase set to 154 degrees separation (ToF)
- Result on RF voltage on beam is half of expected change in ToF
- RF buckets around transition momentum still separated – not enough voltage for serpentine acceleration
- Seen RF bucket & synchrotron oscillations inside it
- Next step adjust each cavity phase separately use beam as diagnostic

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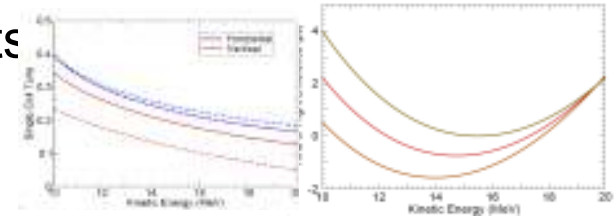
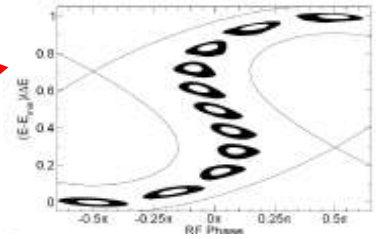
RF summery

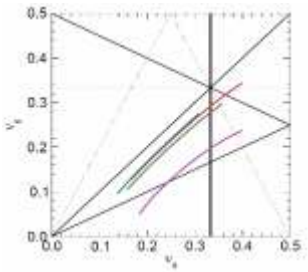
- RF system fully operational at matched frequency and off frequency mode – much more testing to be done using beam
- Motor systems for tuning and phase shifting will be fixed for more controlled operation
- Libera LLRF will then take charge of frequency tuning and phase again
- Synchronisation between ALICE and EMMA RF systems looks to be good, beam will be used for final analysis
- GVS voltage not the same as seen by the physics team, possibility that phase angles of cavities is not well understood yet

Next Steps

- Commissioning now
  - LLRF system fully functional and tested at ALICE & off frequency
  - Verification of successful accelerator, inside/outs
- Characterisation
  - Tunes and ToF fn of E ~ 1MeV steps
  - Tune accelerator to match required lattice
- "EMMA Experiment"
  - Acceleration 10 – 20 MeV
  - Resonance crossing







  - Detailed bench marking with codes
  - Scan aperture in phase space (both longitudinally and transversely)
  - Benchmark measured dynamic aperture with and without acceleration against the simulations .....

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Milestones

Project start	Apr 2007
Design phase	Apr 2007 – Oct 2008
Major procurement contracts	May 2007 – Aug 2009
Off line build of modules	Oct 2008 – 15th Jun 2010
Installation in Accelerator Hall	Mar 2009 - Sep 2009
Test systems in Accelerator Hall	Jul - Oct 2009
1st Beam down the Injection line	26th Mar 2010
1st Beam through 4 sectors	22nd Jun 2010
1st Circulating beam in EMMA	16th Aug 2010
1st Accelerated beam in EMMA	**Sep/Oct 2010**
ALICE & EMMA shutdown	Nov 2010
EMMA Experiments	Jan 2010 – Mar 2011
UK Basic Technology Grant completion	Mar 2011