EMMA RF System

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BASROC and CONFORM

- 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

Project Overview

- EMMA is using the ALICE as the injector (Accelerators and Lasers In Combined Experiments)
- Electron Model for Many Applications
- Part of a larger Project called CONFORM (COnstruction of a Nonscaling FFag for Oncology, Research, and Medicine) www.conform.ac.uk/
- 3 parts to the project are funded
  - EMMA design and construction
  - PAMELA design study funding - £865k
  - Applications study funding - £273k
- Total funds for EMMA are £5.75m over 3.5 year project lifecycle

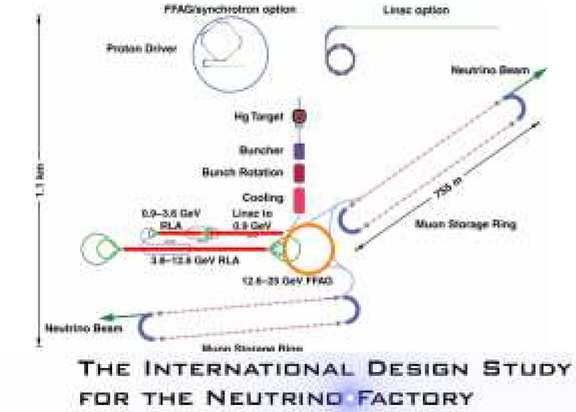
EMMA Collaboration

- STFC recognise and appreciate the active collaboration from:
  - Brookhaven National Laboratory
  - CERN
  - Fermi National Accelerator Laboratory
  - Laboratoire de Physique Subatomique et de Cosmologie
  - Science & Technology Facilities Council UK
  - John Adams Institute UK
  - Cockcroft Institute UK
  - TRIUMF
  - ………..
- Technical presentations stored on the CONFORM web server at https://www.conform.ac.uk/documents/emma/ec%20-%20emma%20collaboration%20meetings/

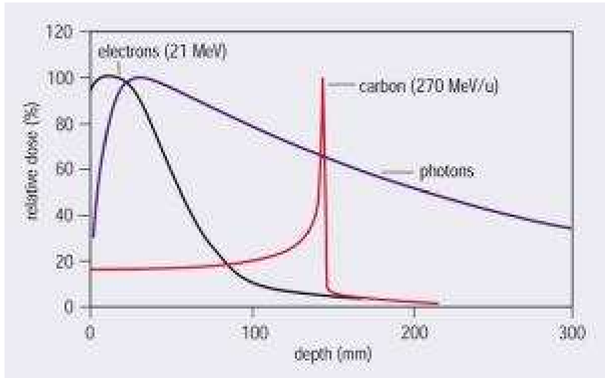
Motivation for constructing EMMA

BASROC CONFORM

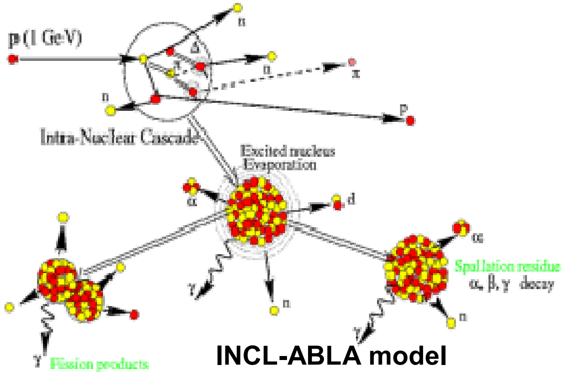
– Muon Acceleration



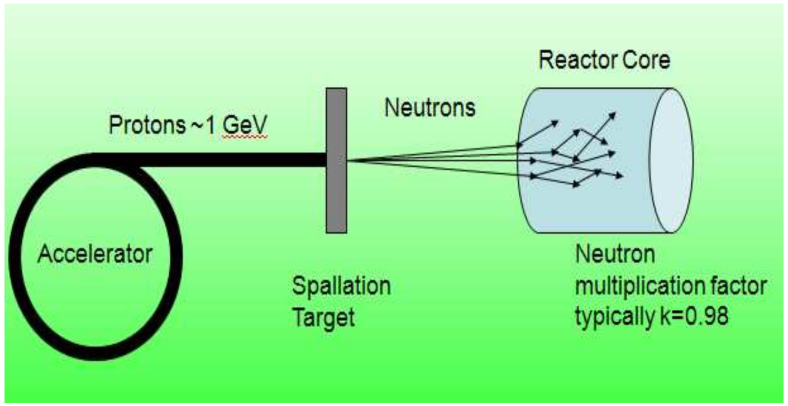
– Proton & Carbon Therapy



– Muon Sources



– Energy & Environment



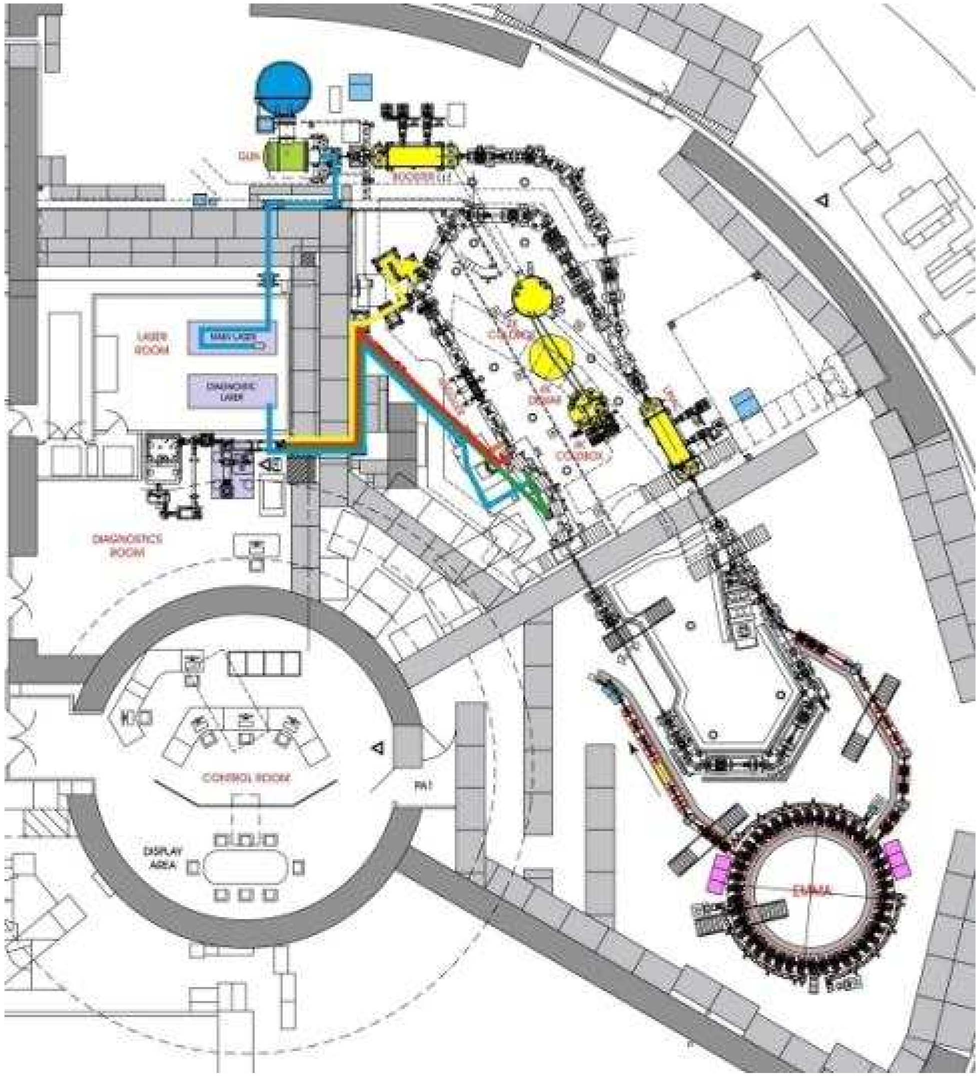
Aims & Objectives of EMMA Project

- Prove that a NS-FFAG can successfully accelerate particles – EMMA is a proof of principle demonstration
- Study linear non-scaling FFAGs under particular circumstances
  - Rapid acceleration
  - Relativistic energies
- 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

Accelerators and Lasers In Combined Experiments (ALICE)



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
Bunch Repetition Rate	81.25 MHz
Bunch Spacing	12.3 ns
Max Bunch Charge	80 pC
Particles per Bunch	5×10^8

ALICE

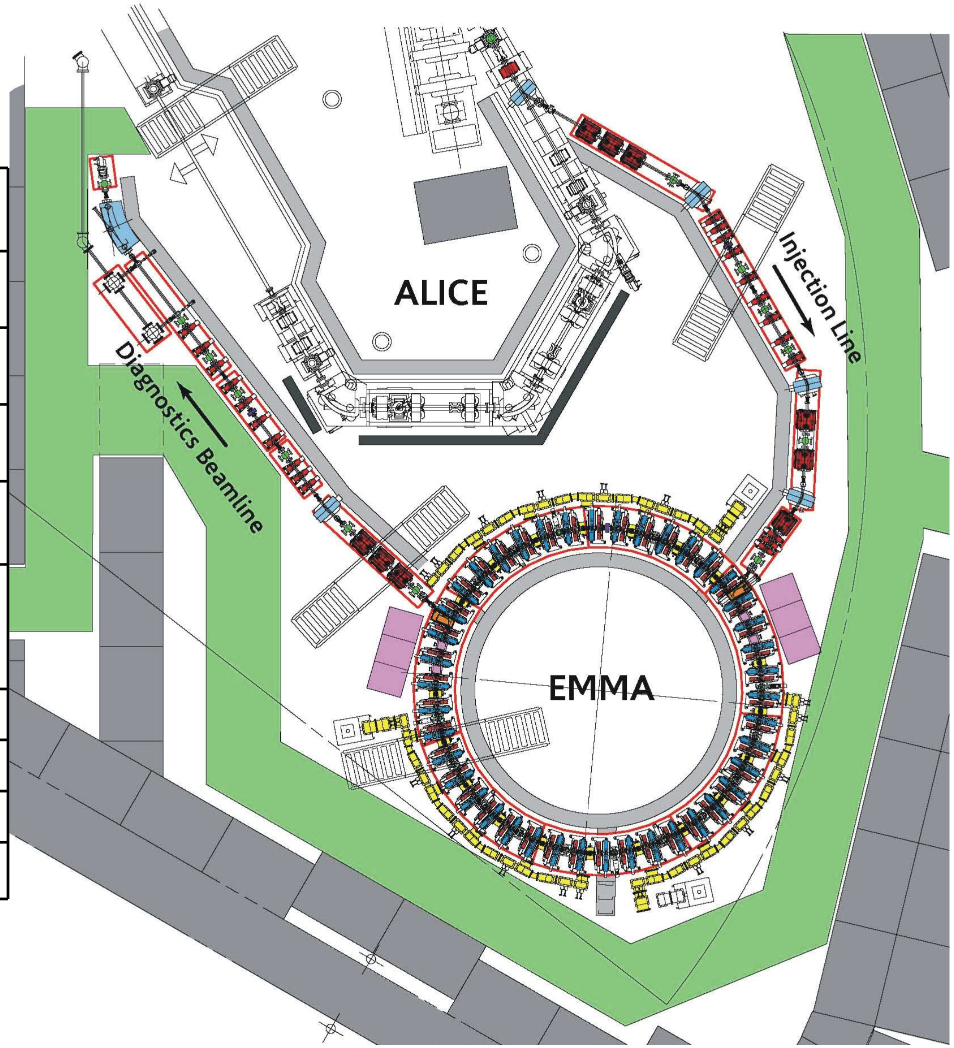
ALICE

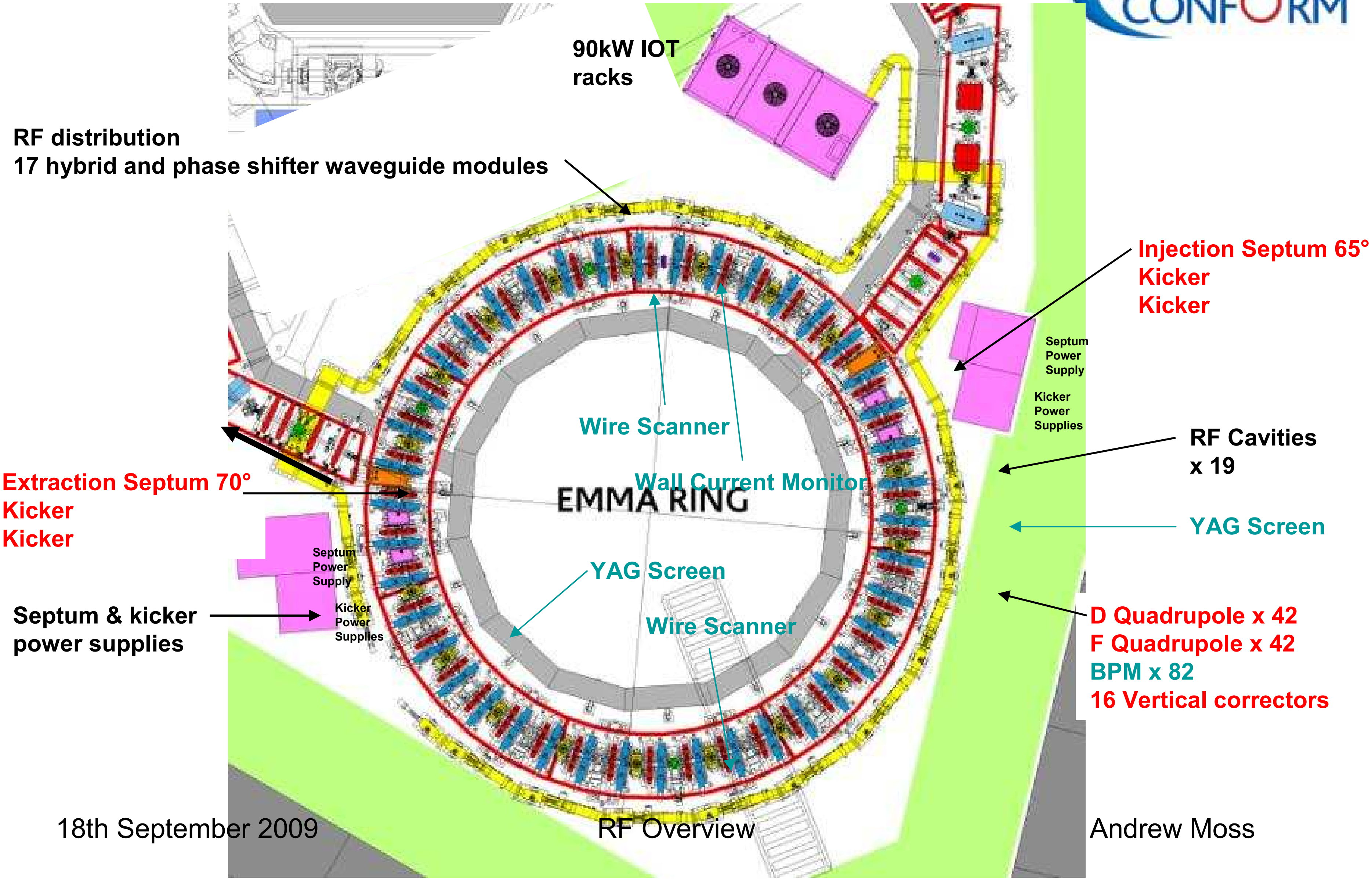
ALICE RF

- Low noise Wenzel oscillator – 10Mhz in, 81.25Mhz and 1.3Ghz out
- Rossendorf analog LLRF cards running in pulsed mode at 1-20Hz 4 - 20mS
- 3 different types of IOTs power ALICE SC Tesla type cavity's
  - 2 e2v IOT's combine to give 32kW booster 1
  - CPI 21kW IOT booster 2
  - e2v 16kW IOT linac 1
  - Thales 16kw IOT linac 2
- ALICE has been in operation for 1 year with electron beam
- Energy recovery achieved, work on Terra-Hertz and Compton Back Scattering continuing, FEL being installed

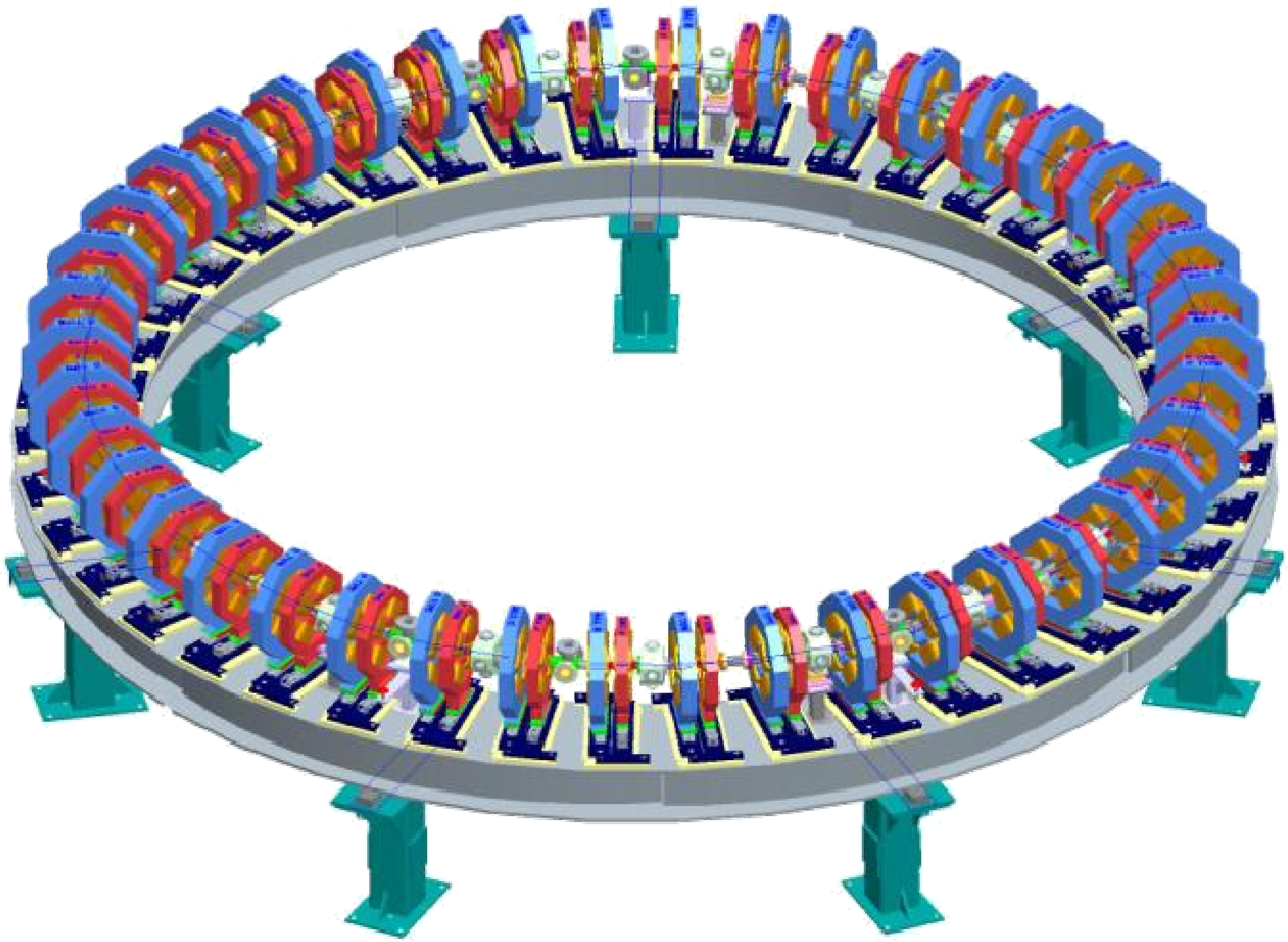
EMMA Layout & Basic Parameters

Energy range	**10 – 20 MeV**
Lattice	**F/D Doublet**
Circumference	**16568.202 mm**
No of cells	**42**
Normalised transverse acceptance	**3π mm-mrad**
Frequency (nominal)	**1.3 GHz**
No of RF cavities	**19**
Average beam current	**13 μA**
Repetition rate	**1, 5, 10, 20 Hz**
Bunch charge	**16-32 pC single bunch**

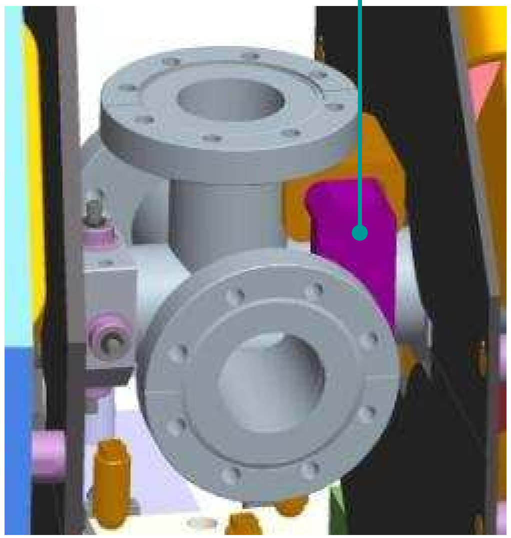



90kW IOT
racks
RF distribution
17 hybrid and phase shifter waveguide modules
Injection Septum 65°
Kicker
Kicker
Septum
Power
Supply
Kicker
Power
Supplies
Wire Scanner
RF Cavities
x 19
Extraction Septum 70°
Kicker
Kicker
Wall Current Monitor
EMMA RING
YAG Screen
Septum
Power
Supply
YAG Screen
Kicker
Power
Supplies
Septum & kicker
power supplies
Wire Scanner
D Quadrupole x 42
F Quadrupole x 42
BPM x 82
16 Vertical correctors

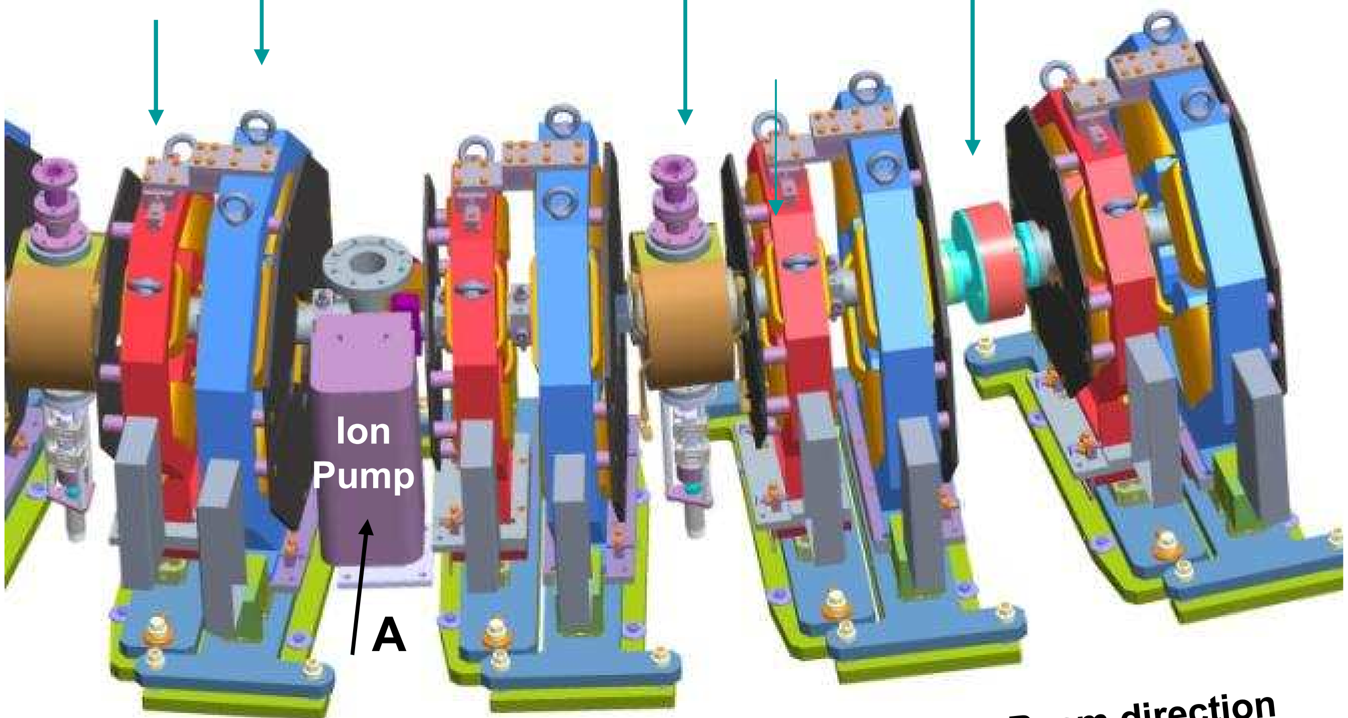
EMMA Ring



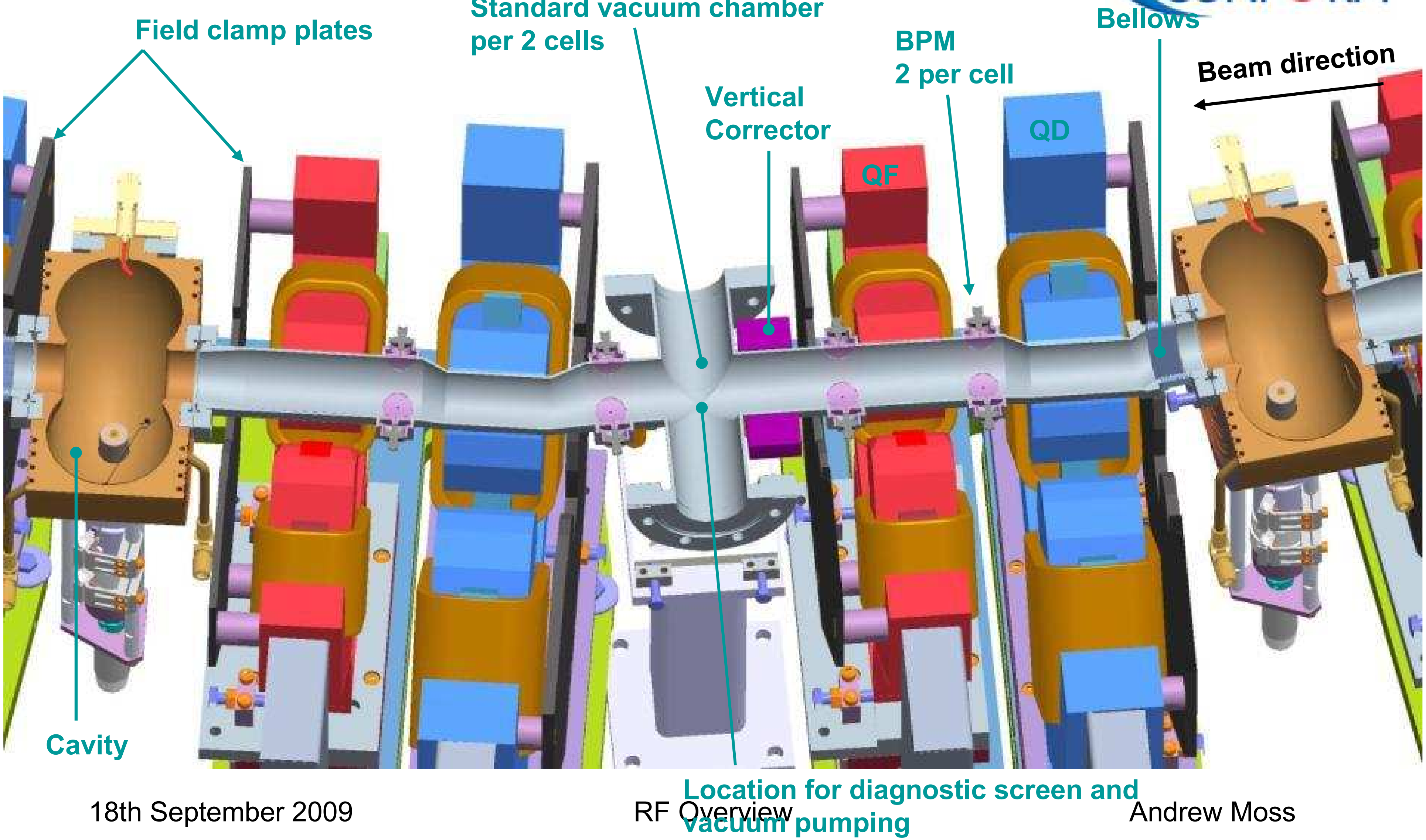
4 Cells



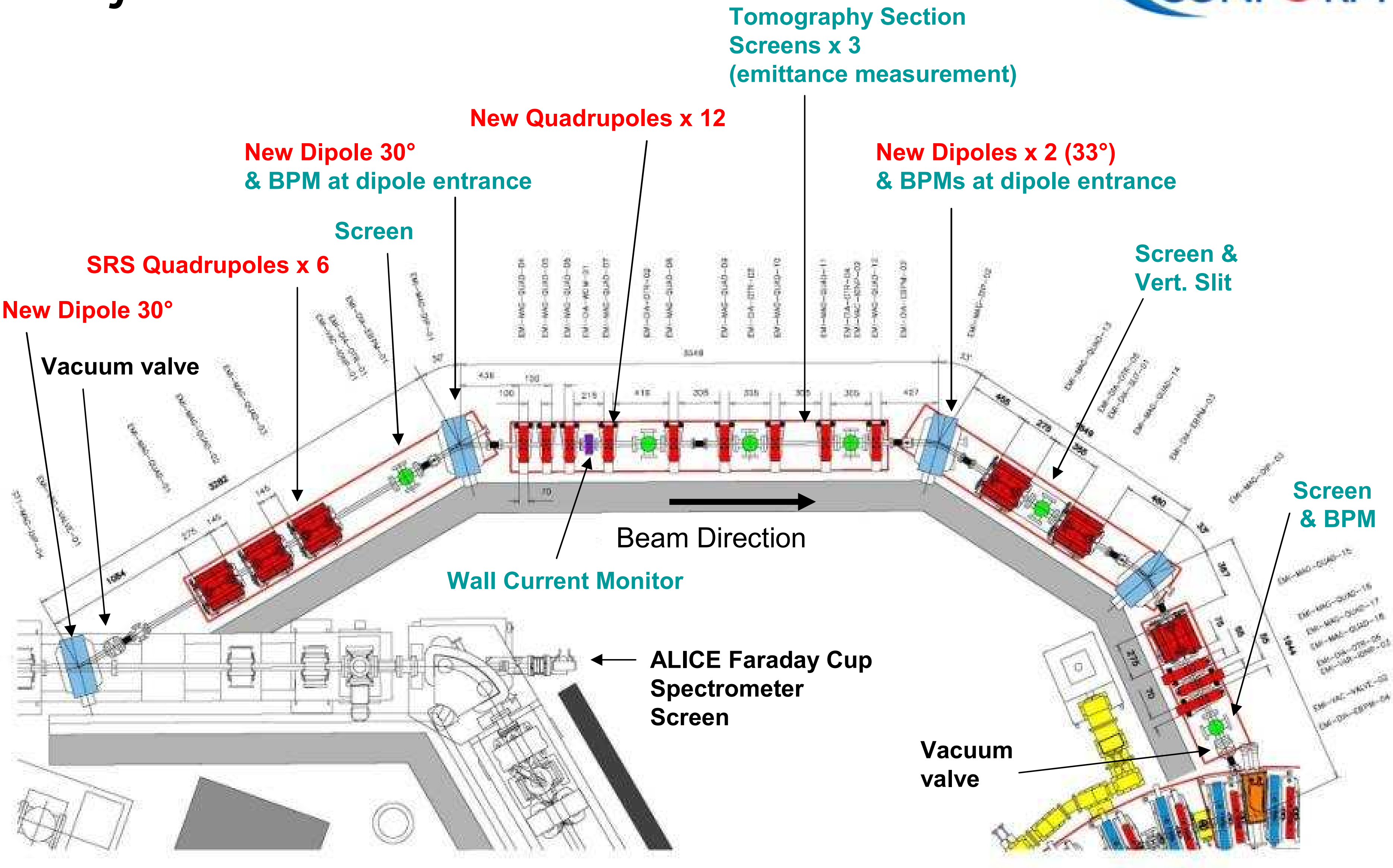
View on vertical corrector
with Ion Pump removed



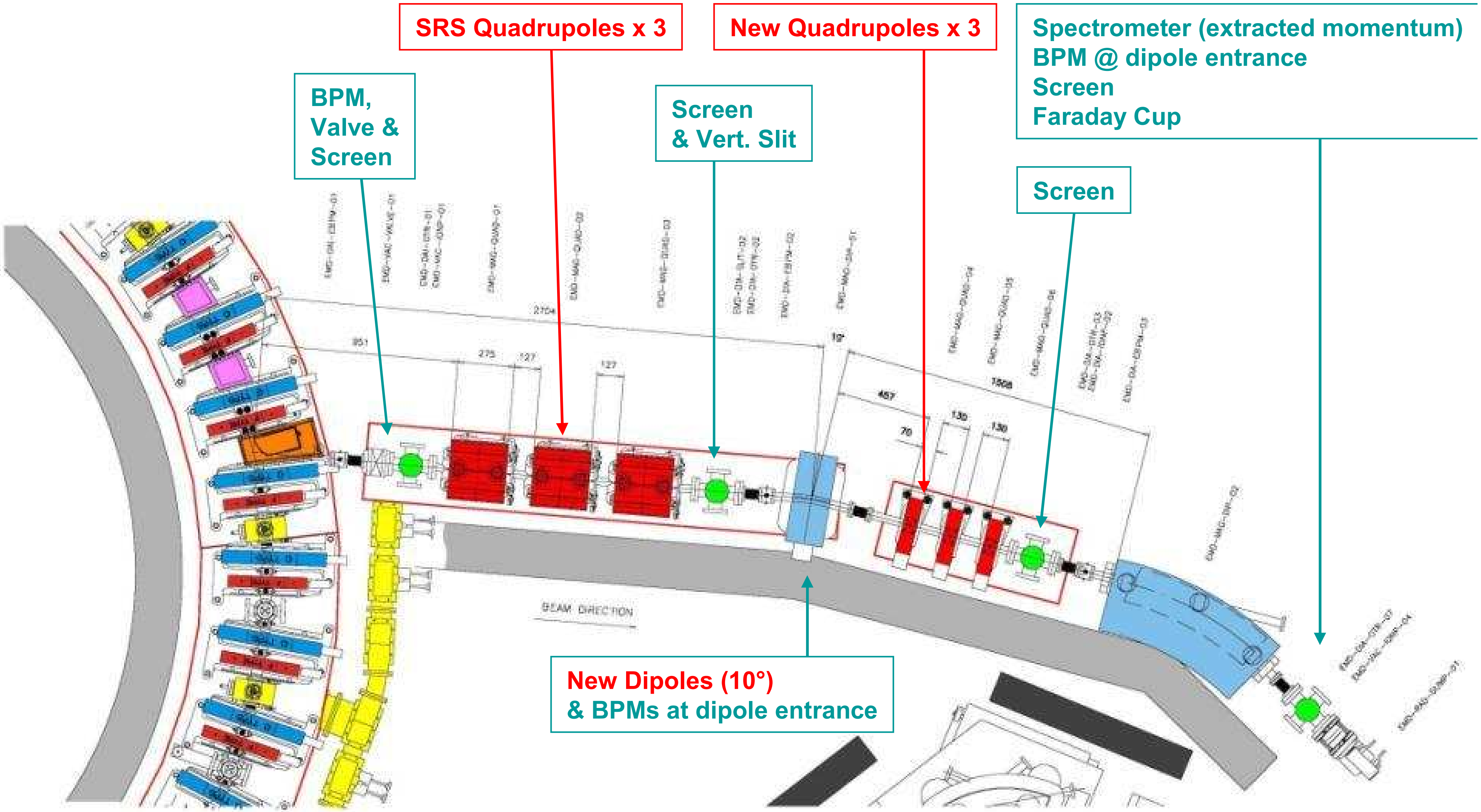
2 Cell Section (Standard Vacuum Chamber)



Injection Line



Diagnostic Phase Line 1



Diagnostic Phase Line 2

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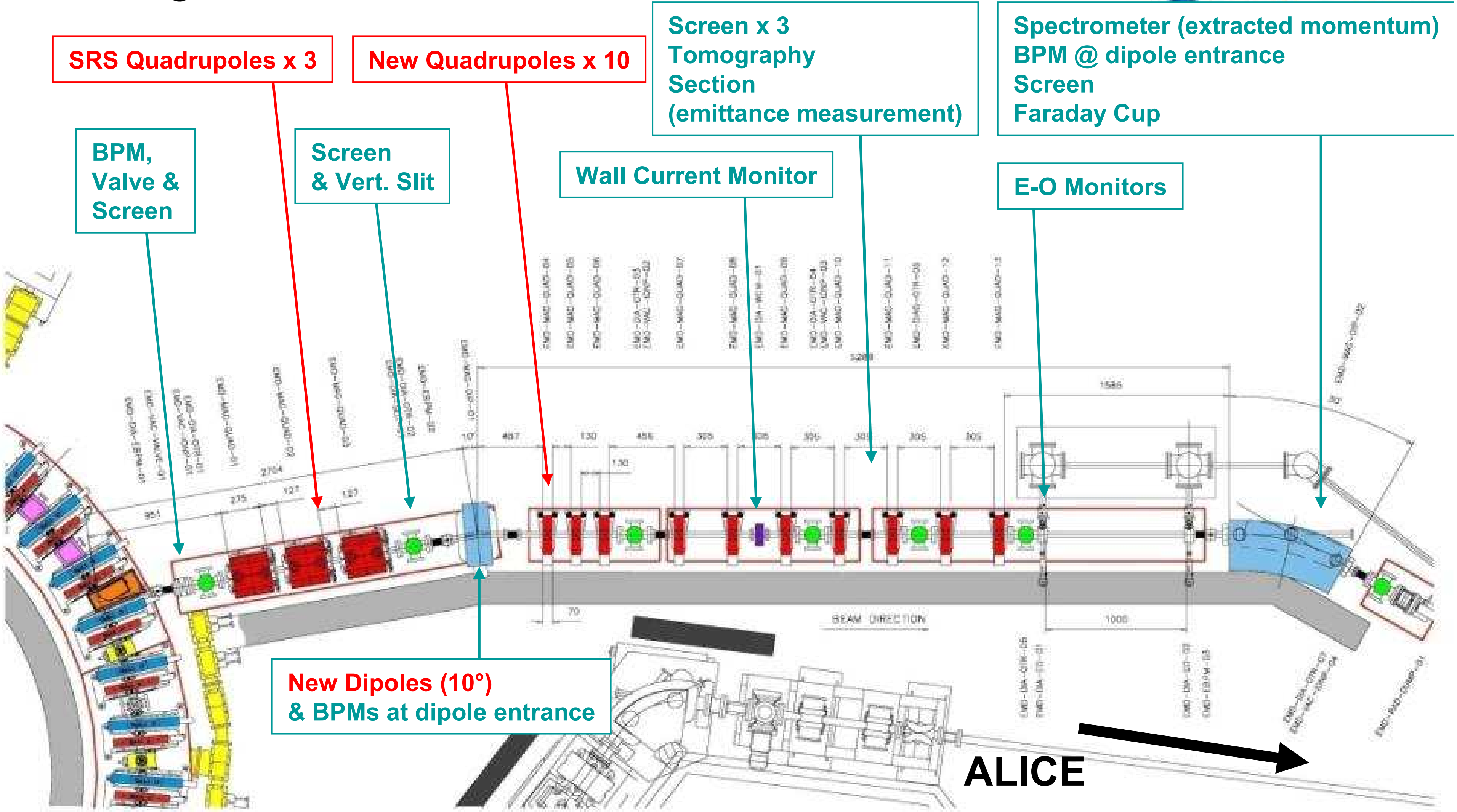
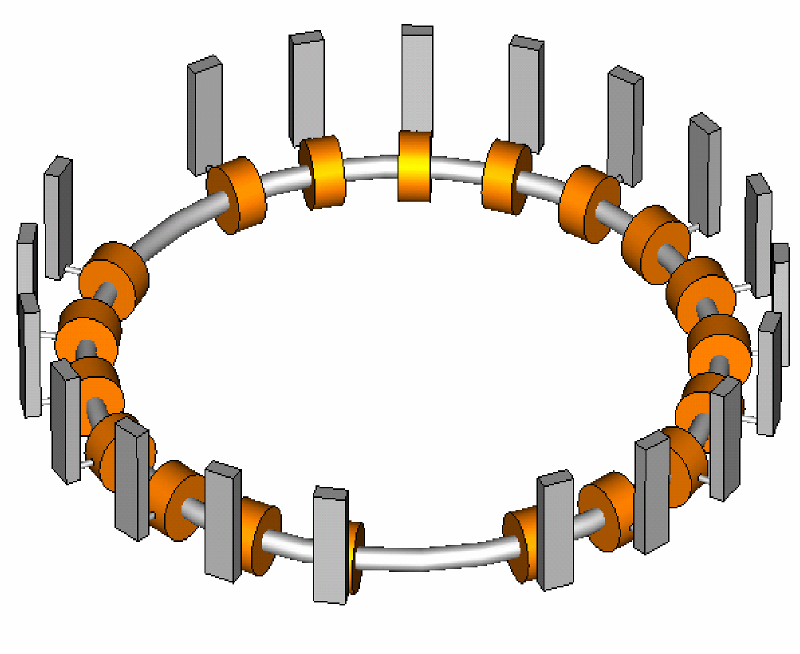


EMMA RF Specification

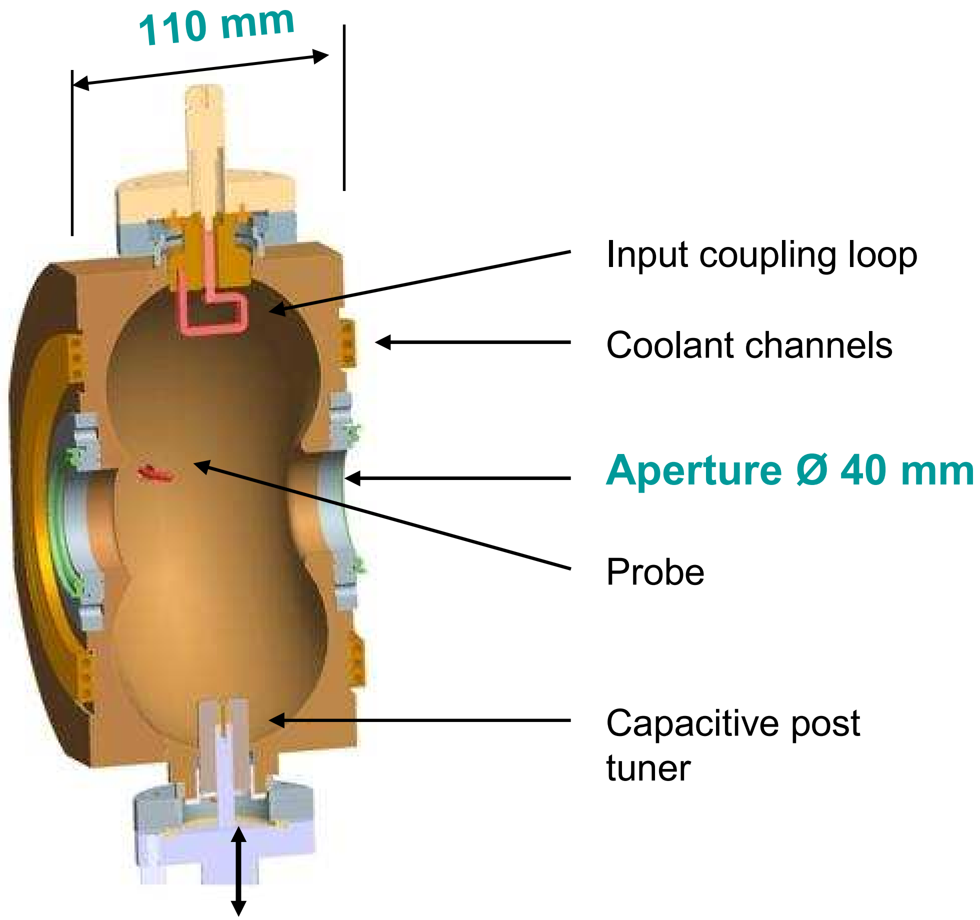
Machine Parameters	Value
Frequency (GHz)	1.3
Number of Straights	21
Number of Cavities	19
Total Acc per turn	2.3 MV
Upgrade Acc per turn	3.4 MV
Beam Aperture	40mm
RF Bunch Length	1.6 ms
RF Repetition rate	5 -20 Hz
Phase Control	0.3 D
Amplitude Control	0.3 %



RF Design

- Voltage:
  - 20 - 120 kV/cavity essential, based on 19 cavities
  - Up to 180 kV/cavity desirable
- Frequency:
  - 1.3 GHz chosen, to both match the ALICE RF systems and also allow for the use of developed and mature LLRF systems at this frequency
  - Range requirement 5.6 MHz
- Cavity phase:
  - Remote and individual control of the cavity phases is essential

Cavity Design

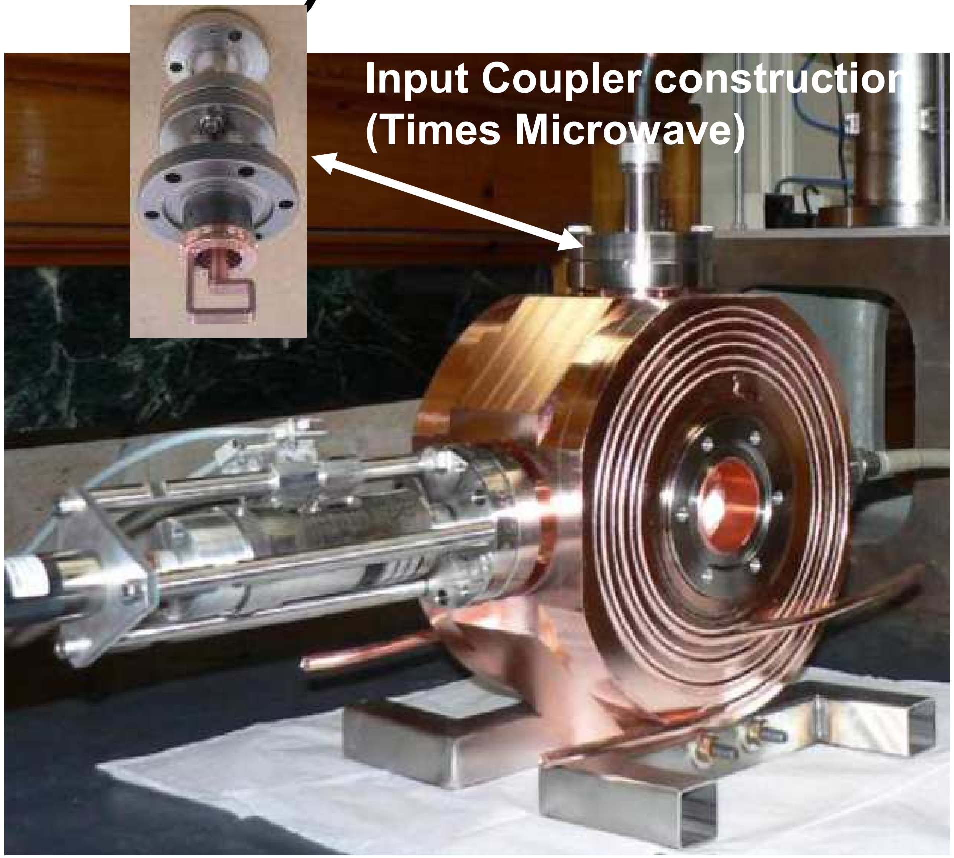


Normal conducting single cell re-entrant cavity design optimised for high shunt impedance

Parameter	Value	
Frequency	1.3 GHz	
Theoretical Shunt Impedance	2.3 MΩ	
Realistic Shunt Impedance (80%)	**2 MΩ**	
Qo	20,400	
R/Q	100 Ω	
Tuning Range	-4 to +1.6 MHz	
Accelerating Voltage	120 kV	180 kV
Total Power Required (Assuming 30% losses in distribution	**90 kW**	200 kW
Power required per cavity	3.6 kW	8.1 kW

Cavity manufacture

BASROC CONFORM

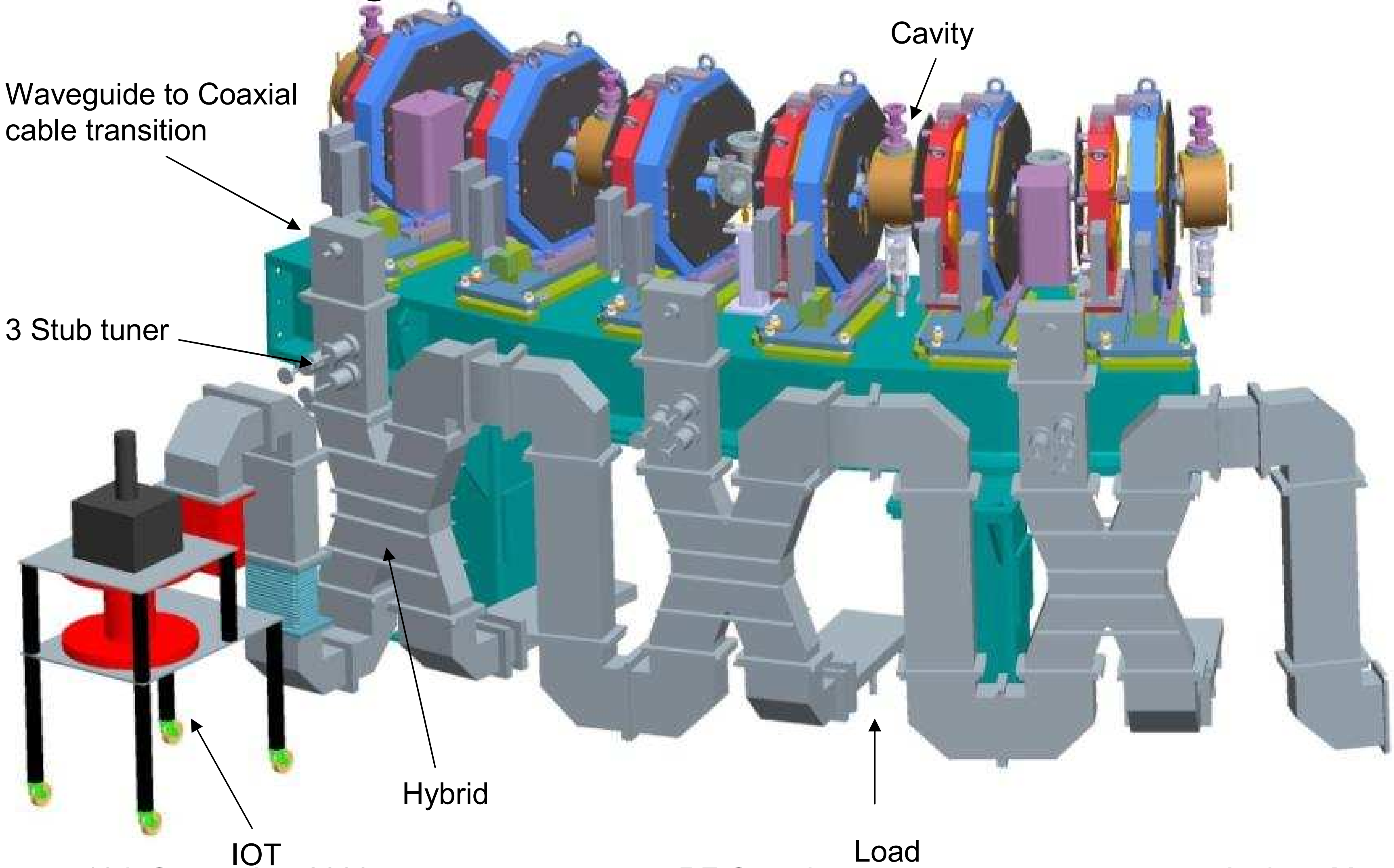


- All cavities now received
  - Final 4 awaiting input couplers from Times Microwave
  - 2 input couplers have been delivered
- Input couplers
  - Leaks discovered on 2 of the feed-throughs
  - Poor response from Times Microwave
  - Alternatives from SLAC or Niowave being sought
- Cavity evaluation
  - Four cavities successfully conditioned
  - $Q_0 \approx 20000$ achieved
  - Crosstalk seen on the pick-up probe
  - Responses to be checked and coupler to be adjusted by 180 degrees

Cavity construction

NIOWAVE, INC.

RF Waveguide Distribution



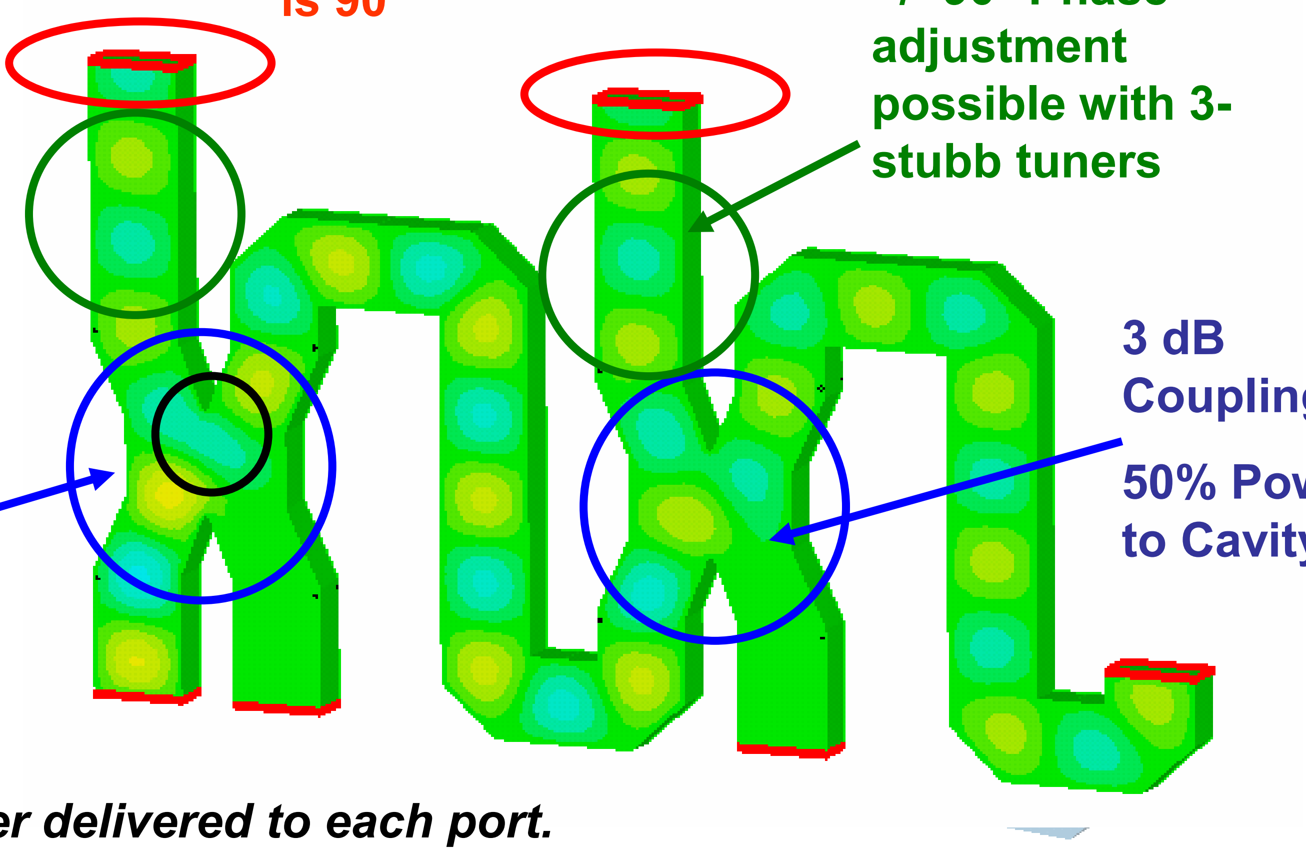
Phase Assessment

Phase Difference between 2 ports is 90°

+/- 90° Phase adjustment possible with 3-stubb tuners

4.8 dB Coupling

33% Power to Cavity

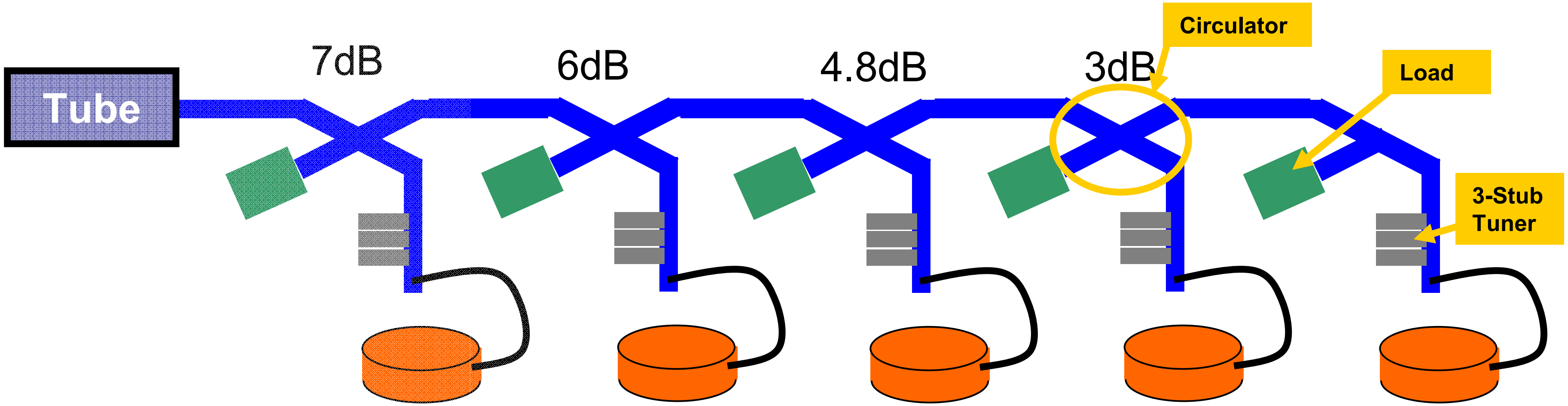


3 dB Coupling

50% Power to Cavity

Equal power delivered to each port.

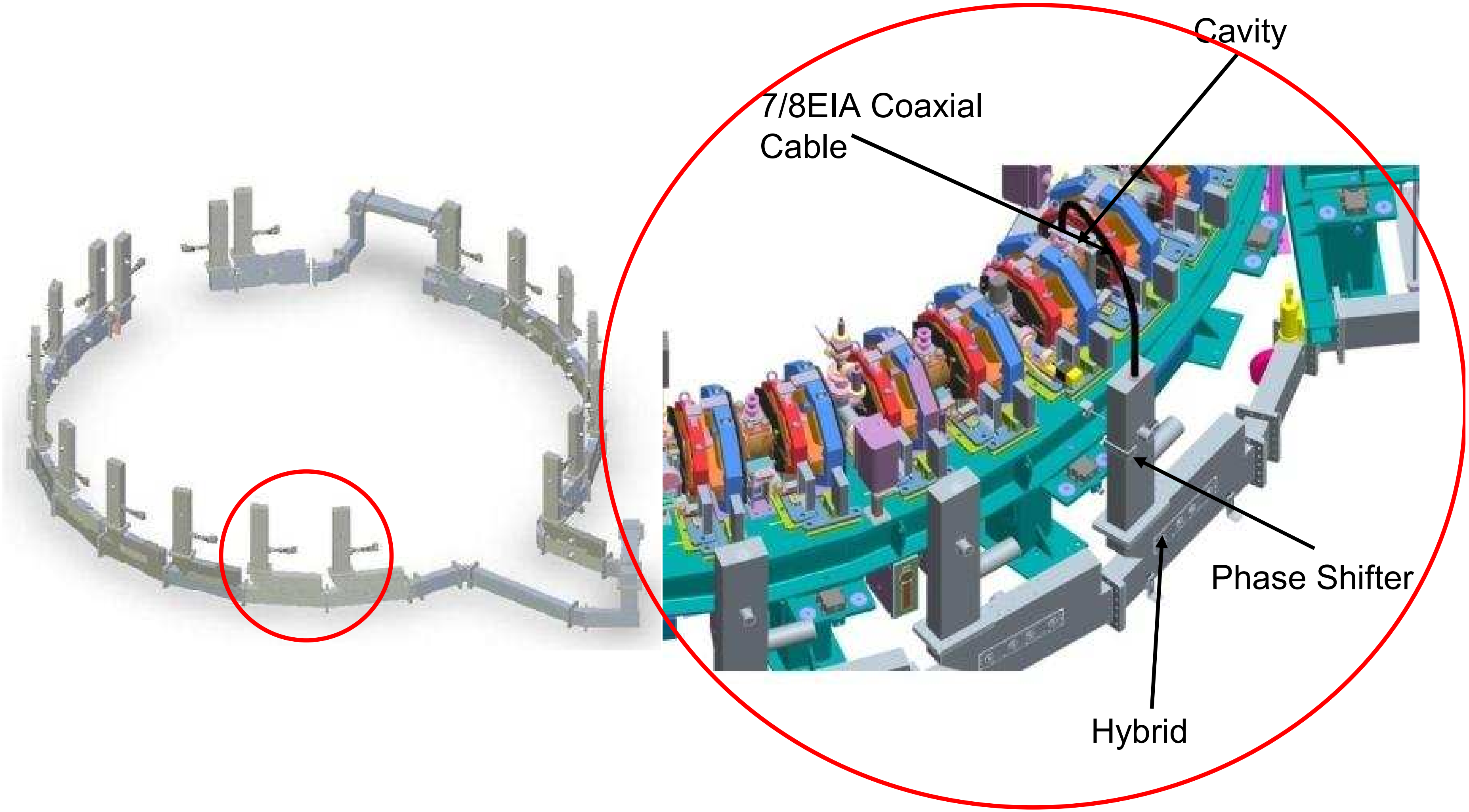
Cascaded Distribution Scheme



2	3	4	5	6	7
50%	33%	25%	20%	16.6%	14.3%
3 dB	4.8 dB	6 dB	7 dB	7.8 dB	8.4 dB

- The same regardless of number of splits.
- Compact System

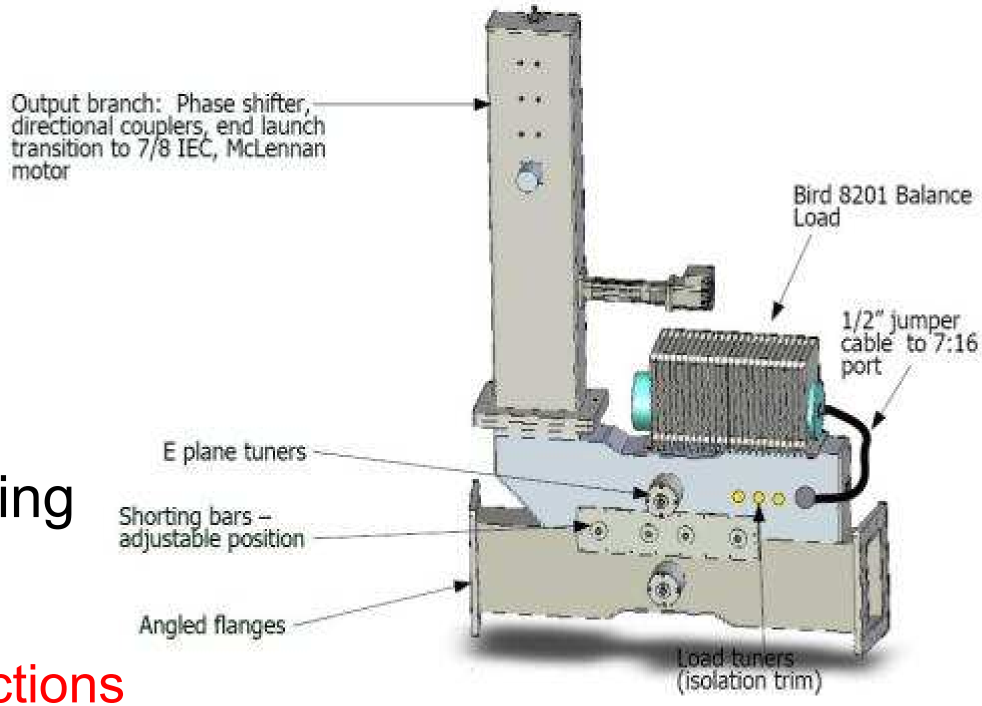
Waveguide Distribution Scheme



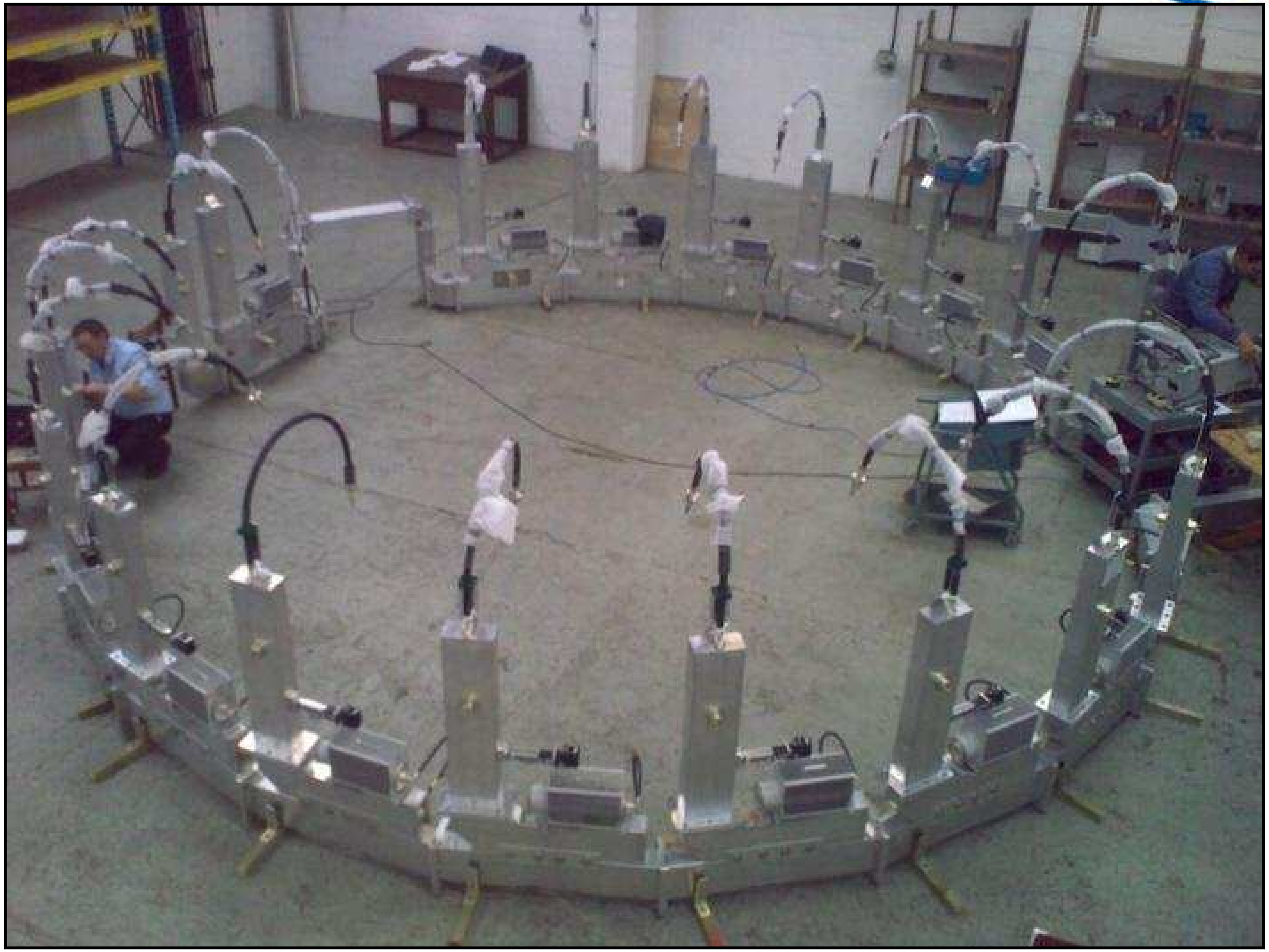
Waveguide Distribution Scheme

- Power split from the IOT with a 3dB hybrid
  - 10 RF cavities anti-clockwise
  - 9 RF cavities clockwise
- Amplitude control
  - RF power from the IOT
  - Cavity frequency
- Phase control
  - Cable length (fixed)
  - Phase shifter
- Complete system undergoing final tests
  - 3dB hybrid required
  - No flexible waveguide sections
    - Straight length of WR650 still to be defined

Hybrid & Phase Shifter

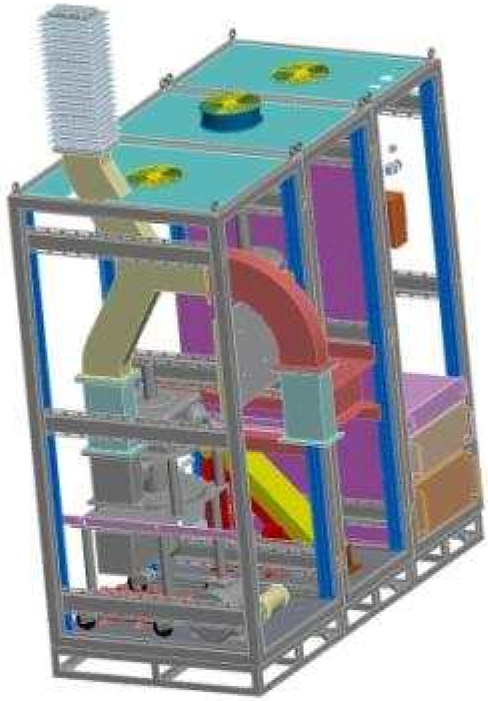


Waveguide test assembly at Qpar Angus



RF Power amplifier

- Contract placed with CPI for supply of the RF source
- VIL409 high power RF amplifier system in 3 racks
- A single 100kW (pulsed) IOT supplying the 19 RF cavities distributed around EMMA
- Utilises a Bruker solid state amplifier up to 1.8kW
- Similar unit to that already being used on ALICE but with a larger bandwidth
- Software and system tests are in progress
- Delivery immanent



LLRF system

- LLRF system needed to stabilise the amplitude and phase of 19 cavities to 0.3% and 0.3 degrees
- ALICE will be operated in single bunch mode,1 to 20 Hz to inject into EMMA at 10mEV
- EMMA requires ability to run over frequency variation +1.5 to – 4Mhz from 1.3GHz while maintaining synchronisation with ALICE bunch timing
- LLRF system has the task of generating the frequency offset the operators pick, then tuning the cavity's to the correct frequency and setting the waveguide phase shifters to correct for phase length errors
  - It is expected this that this process will need to be done daily

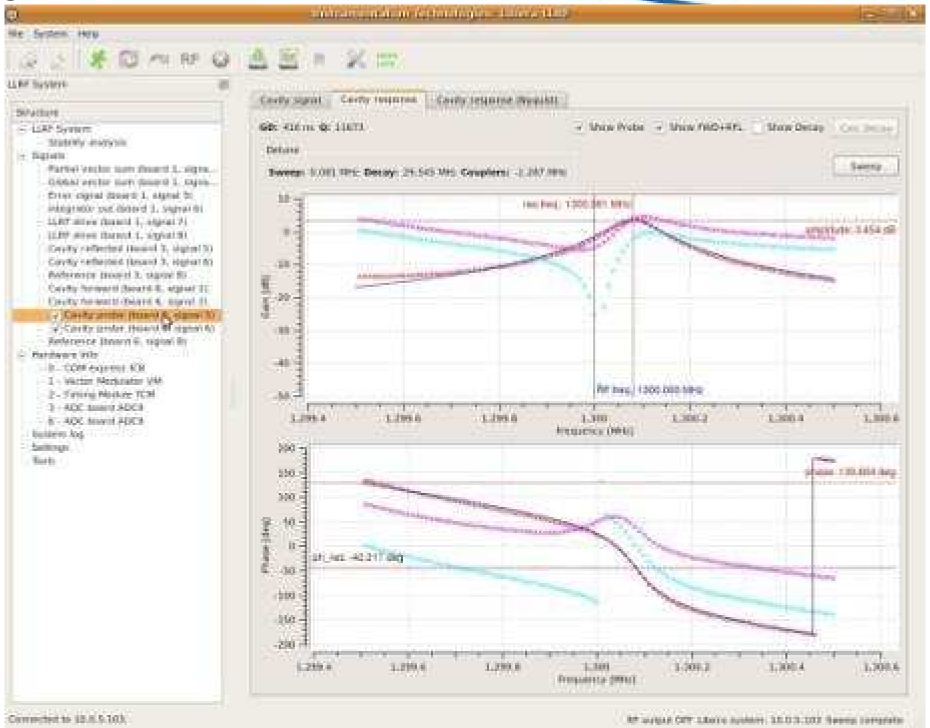
LLRF decisions

- The LLRF system is unusual due to the need to vary the frequency of the machine while maintaining synchronisation with the injector at a fixed frequency
- However the topology suits a vector sum layout used at many accelerator machines
- A tender for the LLRF system was released and a number of proposals where received leading to the option to purchase the I Tech Libera system

LLRF test layout

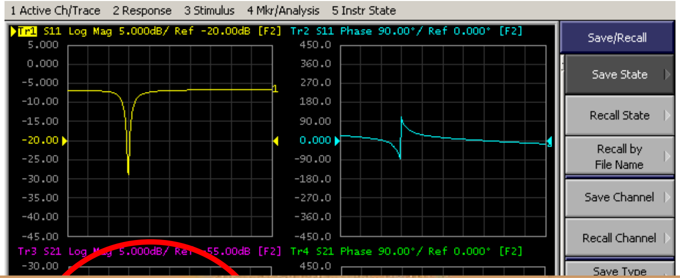
LLRF 'network analysis mode'

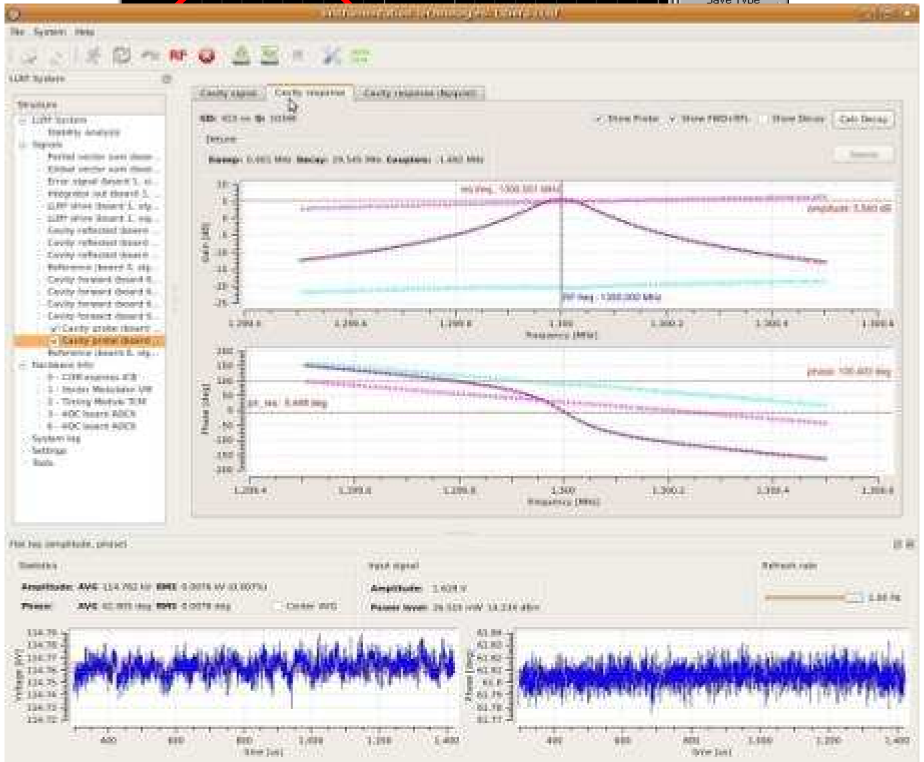
- Testing of a prototype Libera LLRF system using two EMMA cavities, Qpar hybrid splitter and phase shifter to simulate conditions on the EMMA machine
- Intial 'network analysis' mode of Libera showed problems with cavity response



Clean room checks

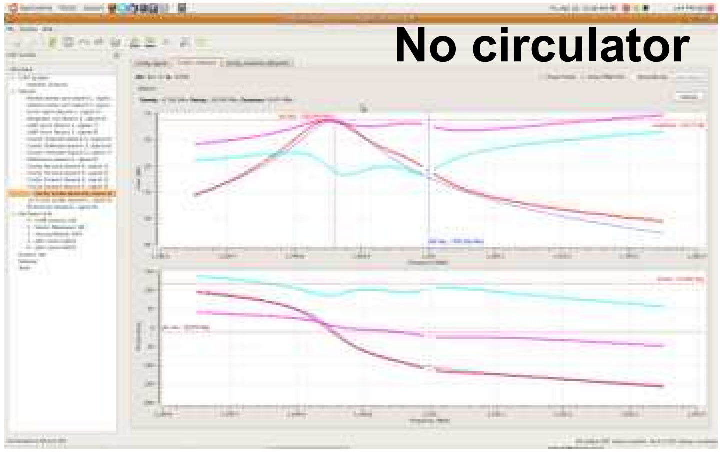
- In the clean room cavity's were checked with a Network Analyser
- Showed over coupling of the field probe
- Field probe was rotated 180 degrees
- All 19 cavity's have now been changed to give the correct response

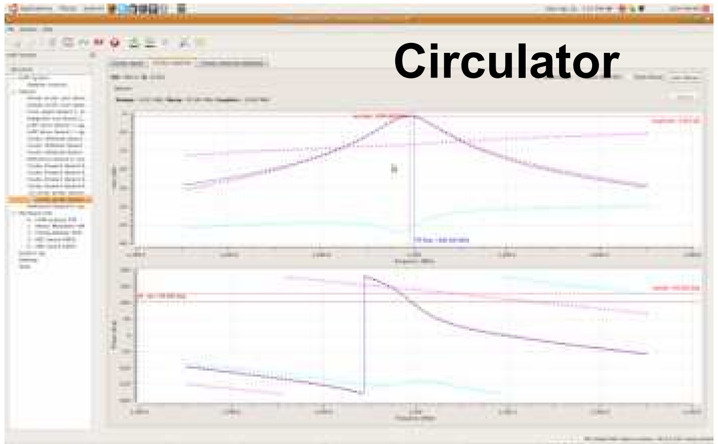




LLRF high power tests in to cavity

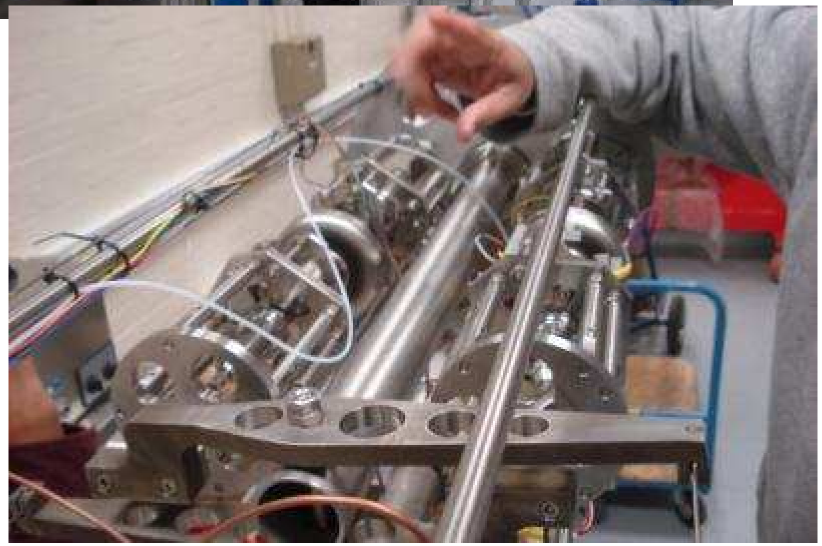
- Frequency sweep mode used to tune cavity frequency
- Double hump found in response
- Eventually traced to interaction between the cavitys and the output of the IOT (itself a cavity)
- Inclusion of a circulator on the output of the IOT resolved this
- Performance achieved at 5kW (~150kV) per cavity
  - Phase: 0.0093º (spec is 0.3º)
  - Amplitude: 0.006% (spec is 0.3%)



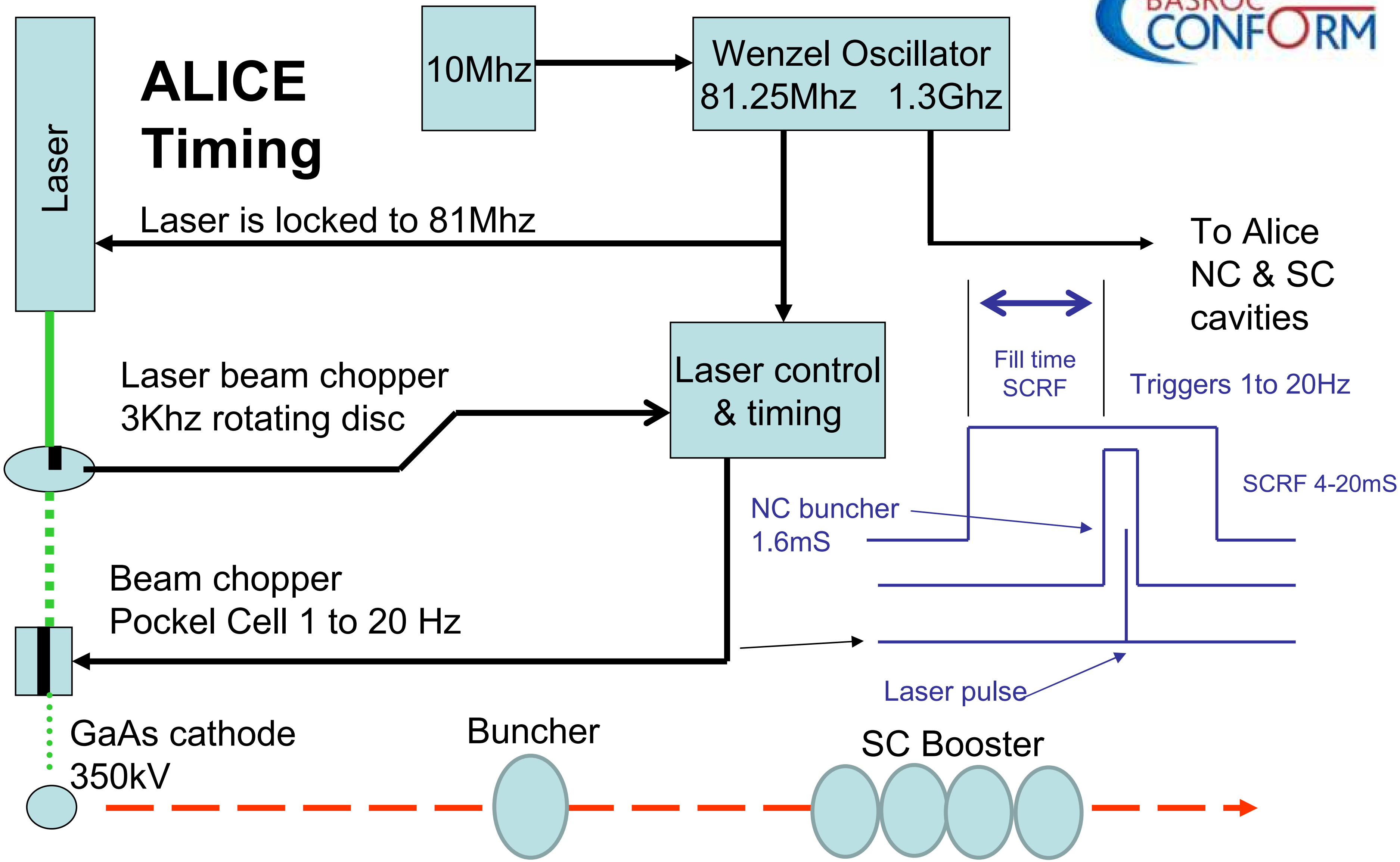


SCRF test

- During tests of EMMA cavities, two SC 3.9Ghz ILC crab cavities were cold in our vertical test stand
- 2 hour ‘window’ to test
- Libera system had front end components changed and then was connected and setup within 1 hour to perform first test on SCRF
- Phase locked across the cavitys
- No microphonics compensation at that time, however system was very stable
- Impressive !



ALICE Timing



EMMA Set up procedure

- Initial Set-Up
  - No beam
  - Low power mode - Cavities tuned to resonant frequency
  - Phase shifters adjusted to give desired phase map
- RF Power Set-Up
  - No beam
  - Desired output power from IOTs set
    - Determined by the power for the 10 cavities
  - Amplitude adjusted and locked
    - Detune the 9 cavity section
  - Phases adjusted and locked
  - Apply beam
    - Beam loading negligible

Set up continued

- Phase Adjustment
  - RF system is phase locked to the master oscillator at 1.3Ghz
    - Injection phase control is a matter of setting a fixed offset between the master oscillator and the cavity vector sum.
  - All cavity phases will be referenced to a defined cavity
- However when the EMMA frequency is changed the synchronisation with the injector must be maintained
- Working towards a good solution with ITech

Schedule

- The EMMA machine is currently being installed into the experimental hall
  - Cavitys and magnet components are installed on machine support girders
  - Waveguide system has arrived on site
  - RF power supply is having acceptance test in USA this week
  - LLRF system is on site awaiting installation
- Components will be installed during a 3 week shutdown during October
- Beam tests will begin in November 09

Conclusion

- The EMMA machine is a novel exciting project, rapid acceleration is interesting to many fields of accelerator design
- The RF system is complex in layout and in some ways unusual
- We know the LLRF system will provide us with many diagnostics and aid us in the operation of the machine
- It is perhaps very wise that we have chosen a LLRF system that is so flexible, which can be developed and changed to meet new challenges as they are found, extremely important in this machine