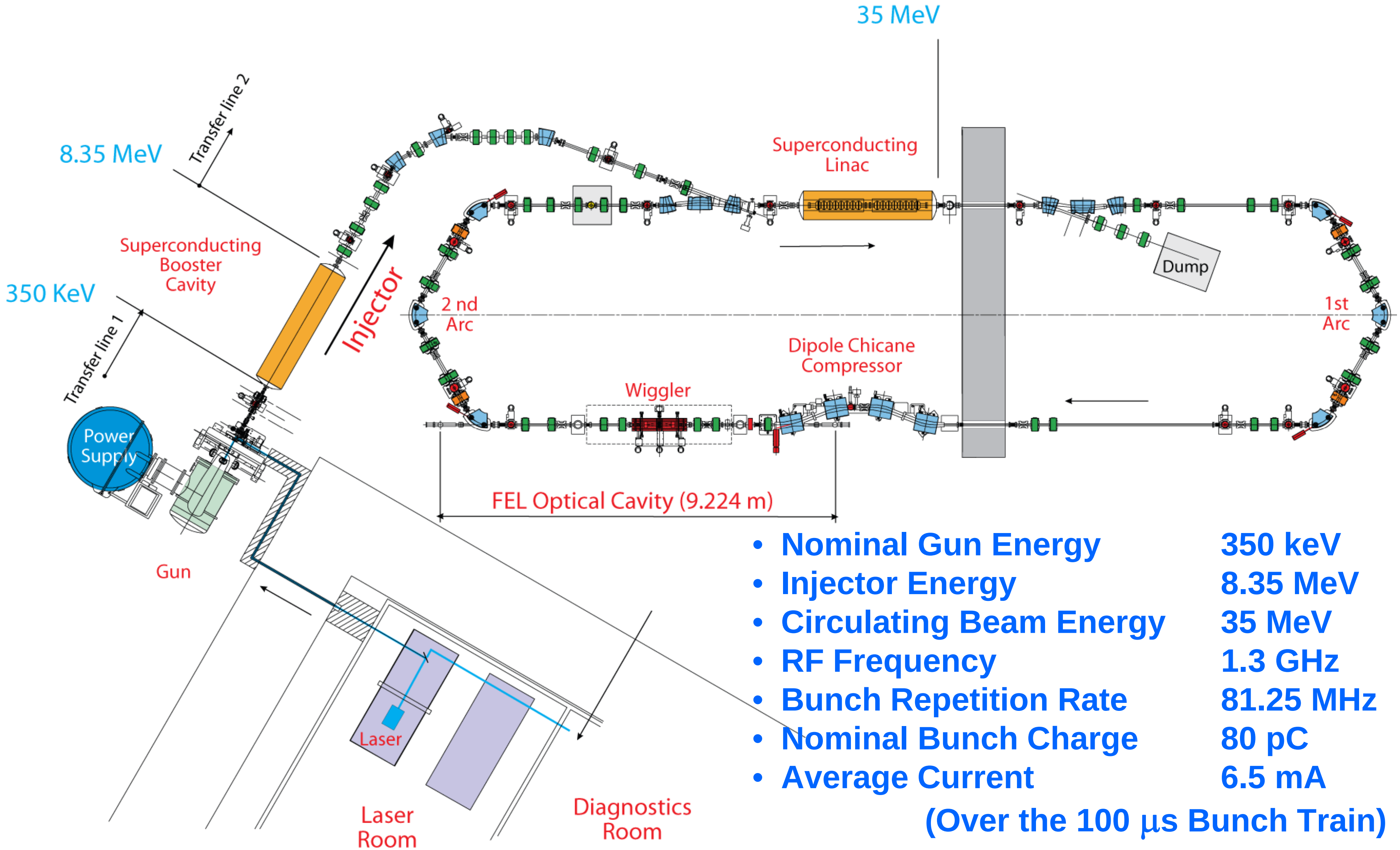
Contents

- ALICE introduction
- Photoinjector commissioning
- Superconducting module status
- Commissioning
- EO and synchronisation
- Science beyond energy recovery
- Programme
- Summary

Accelerator Layout

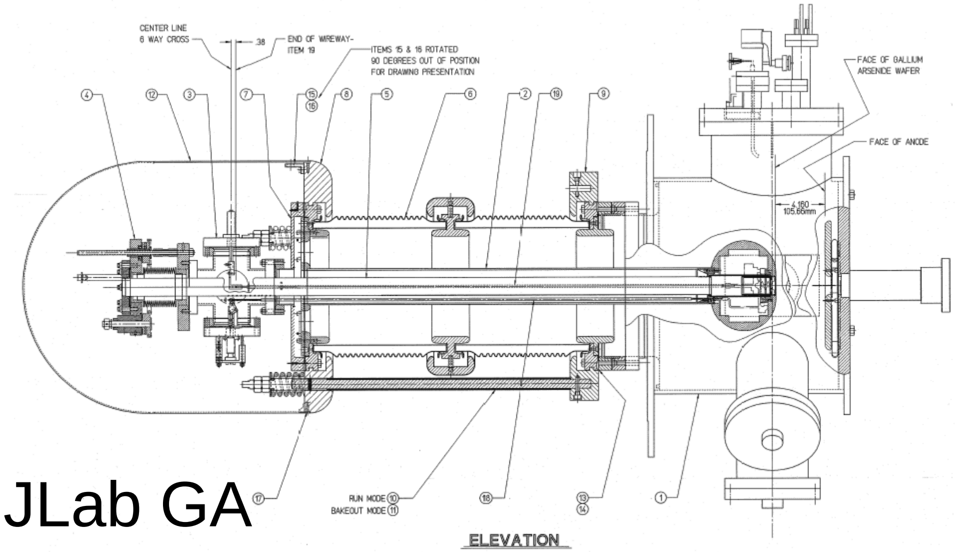


• **Nominal Gun Energy**	**350 keV**
• **Injector Energy**	**8.35 MeV**
• **Circulating Beam Energy**	**35 MeV**
• **RF Frequency**	**1.3 GHz**
• **Bunch Repetition Rate**	**81.25 MHz**
• **Nominal Bunch Charge**	**80 pC**
• **Average Current**	**6.5 mA**

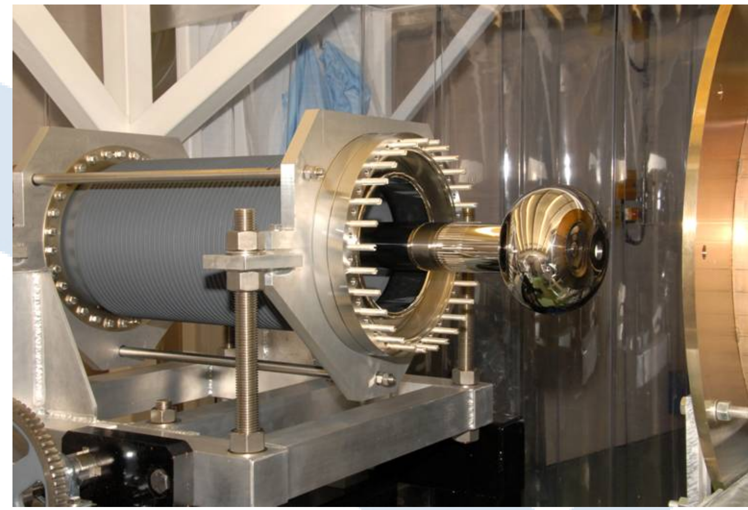
(Over the 100 μs Bunch Train)

Photoinjector

Photoinjector



JLab GA



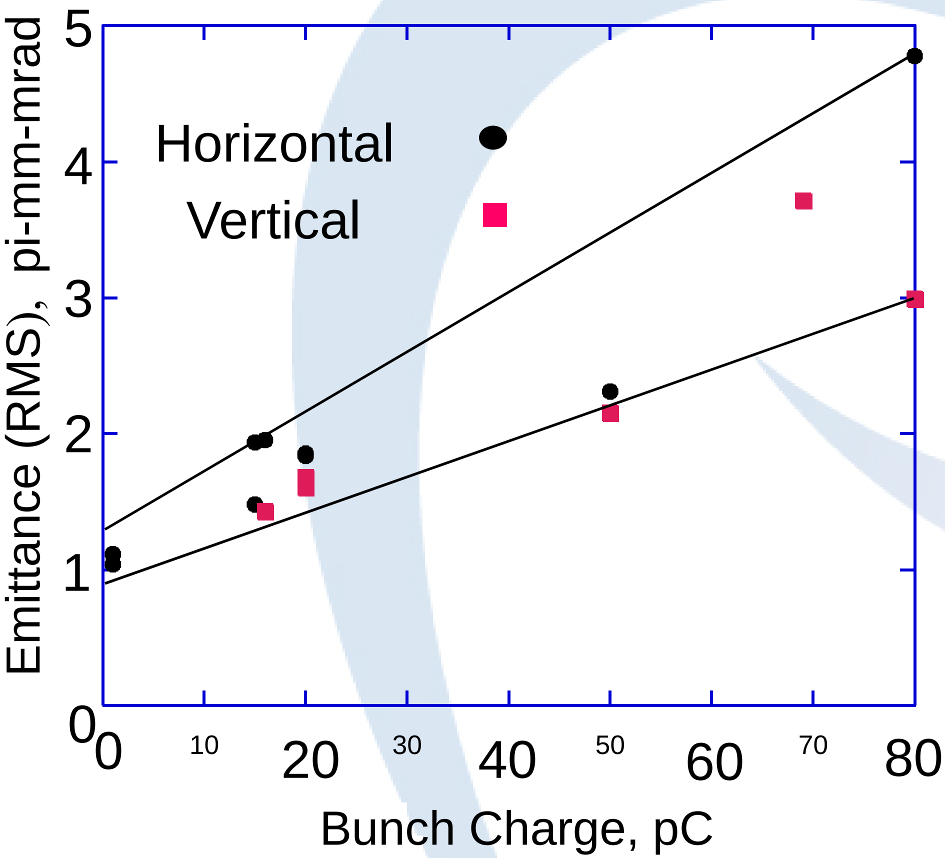
Gun ceramic – major source of delay – at Daresbury (~1 year late)

Copper brazed joint

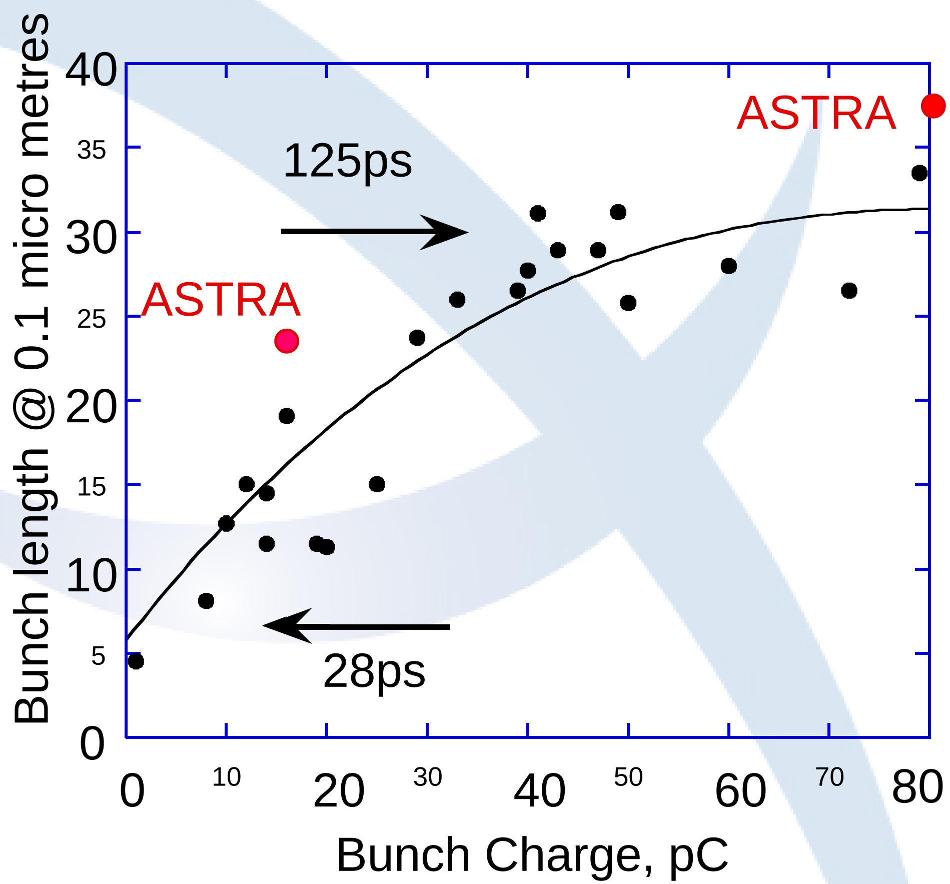
First electrons August 2006

PI Results

RMS geometric emittance
vs.
bunch charge

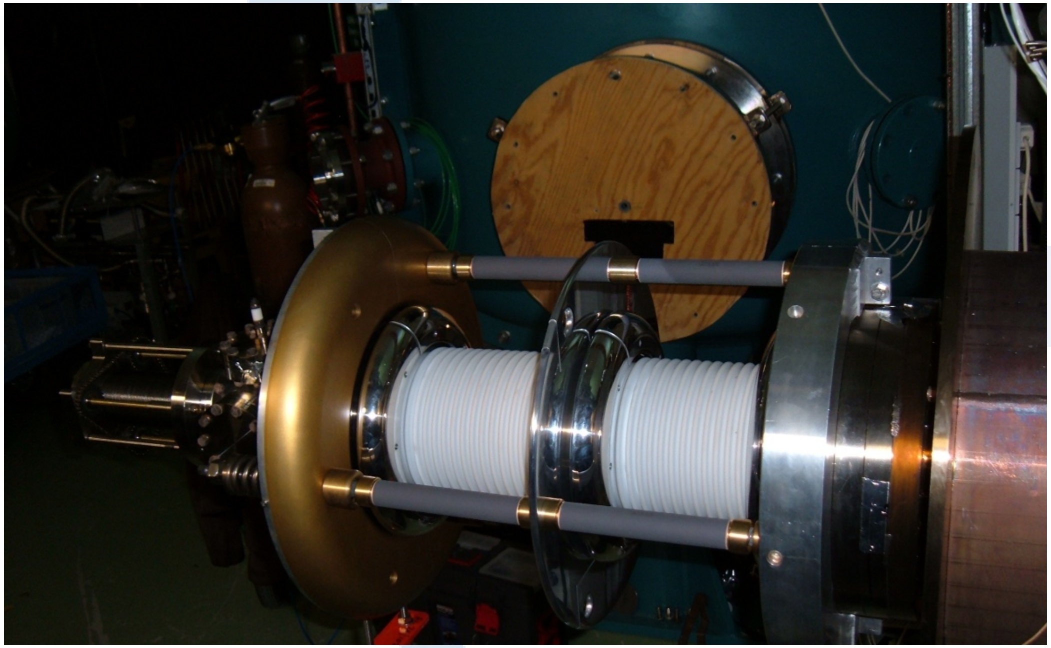


Bunch length at 10% of peak value
vs.
bunch charge



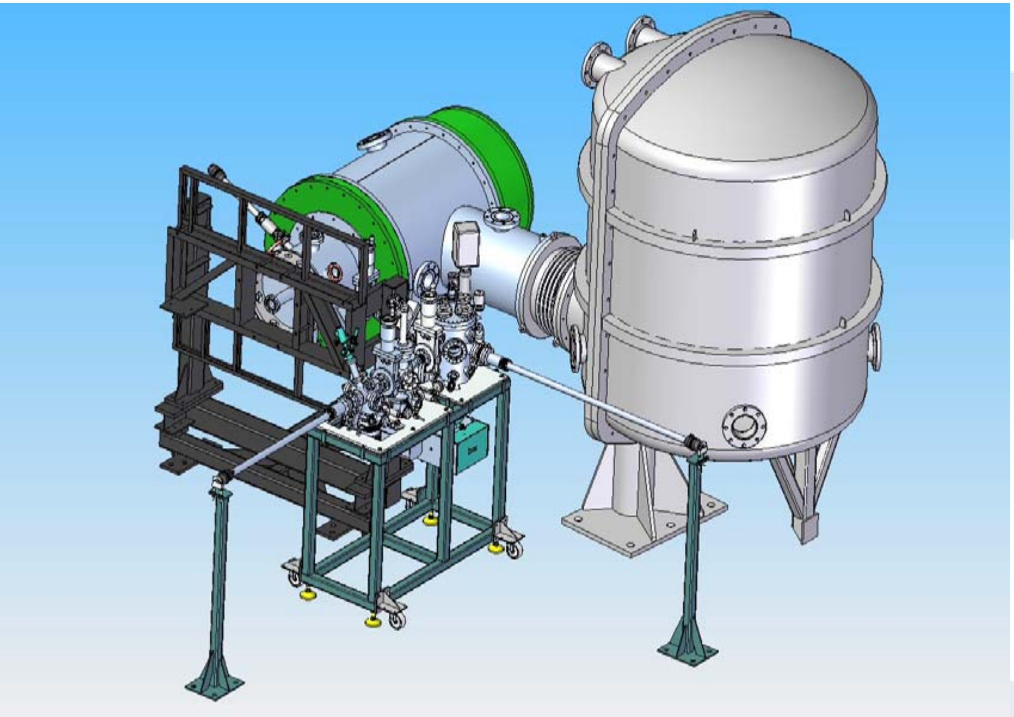
Photoinjector: Leaks, leaks and more leaks and even more leaks!

- Since February 2007 we have had 6 leaks
- In 2008 we had 2 more major failures of the ceramic to metal braze joints
- A contamination of the whole injector assembly through cross contamination of a neg pump component in the vacuum cleaning facility!!
- 2 leaks on a pirani gauge (1 capped on present assembly)
- Leak on a bleed valve
- We have yet to have manufactured a reliable large ceramic but 2 on order



Operational October 2008!

Injector upgrade

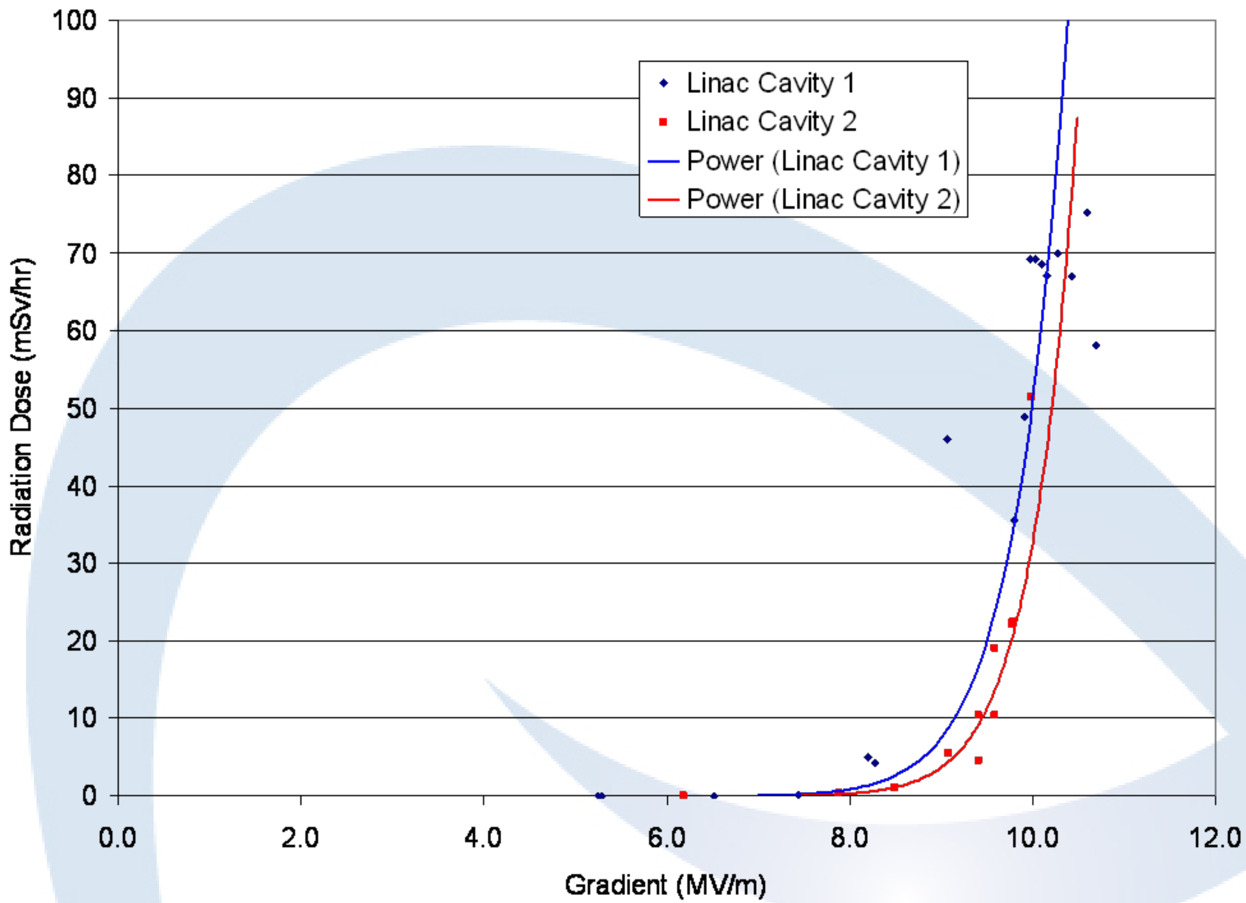


ALICE photocathode gun equipped with a photocathode preparation & exchange facility

- Improved vacuum conditions
- Reduction of contamination from caesium ions
  - Improved gun stability under high voltage
- Reduced time for photocathode changeover, from weeks to hours
- Higher quantum efficiency
  - Allows practical experiments with photocathodes activated to different electron affinity levels

Superconducting modules

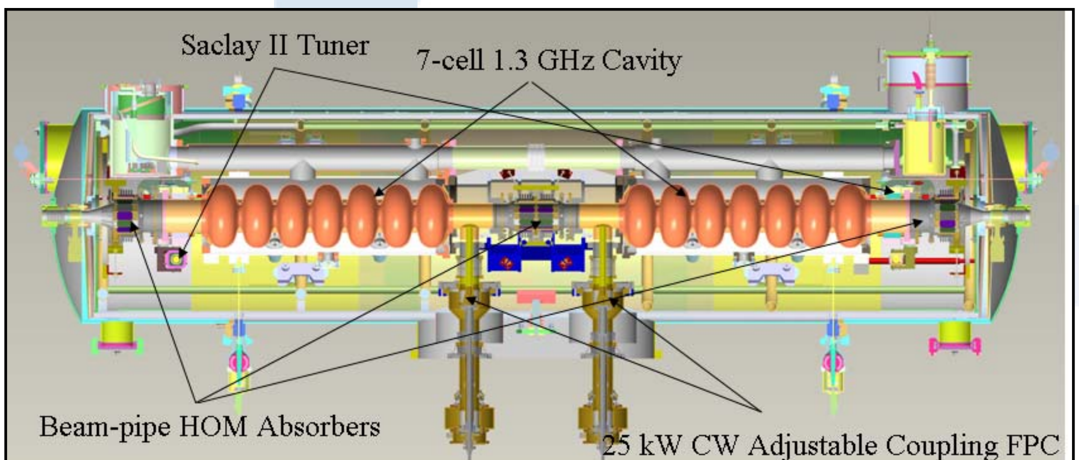
Field Emission Radiation Issue

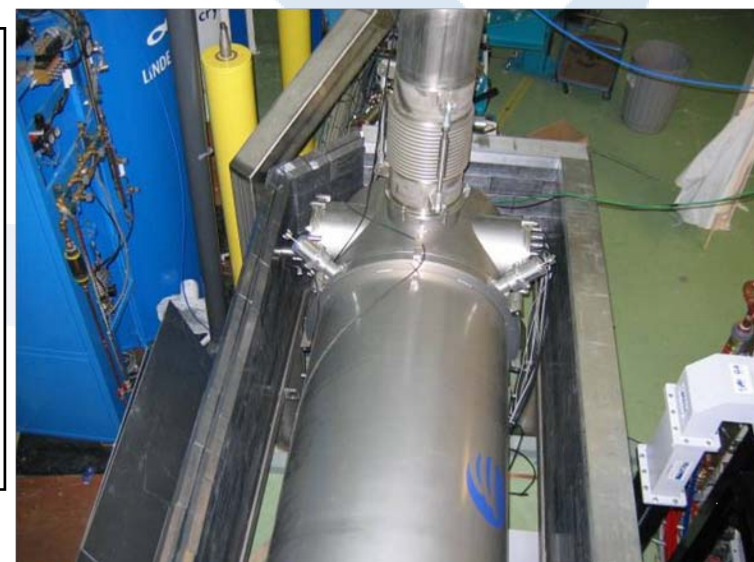


Even at 9 MV/m, which is the saturation point of the radiation monitor, it is predicted that the low-level RF electronics, close to the linac, would have a lifetime of only around 1000 hrs. At the operational gradient the lifetime would be much shorter!

SC Cavity Processing Plan

- Further aggressive processing is now planned:
  - Over longer conditioning periods;
  - Varying frequency, pulse width and pulse repetition rate;
  - CW conditioning (only possible at lower power levels);
  - Possibly condition the cavity when warm;
  - Introduce helium into the vacuum (risky!)
- **High average current module installation (2010)**



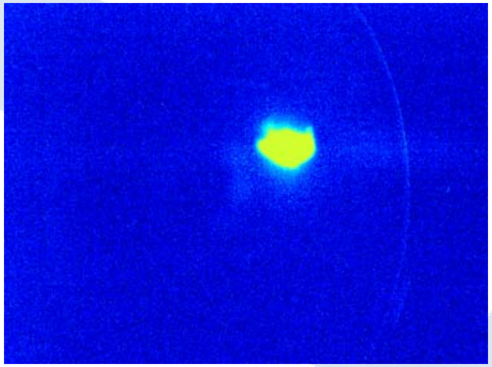


Commissioning ALICE

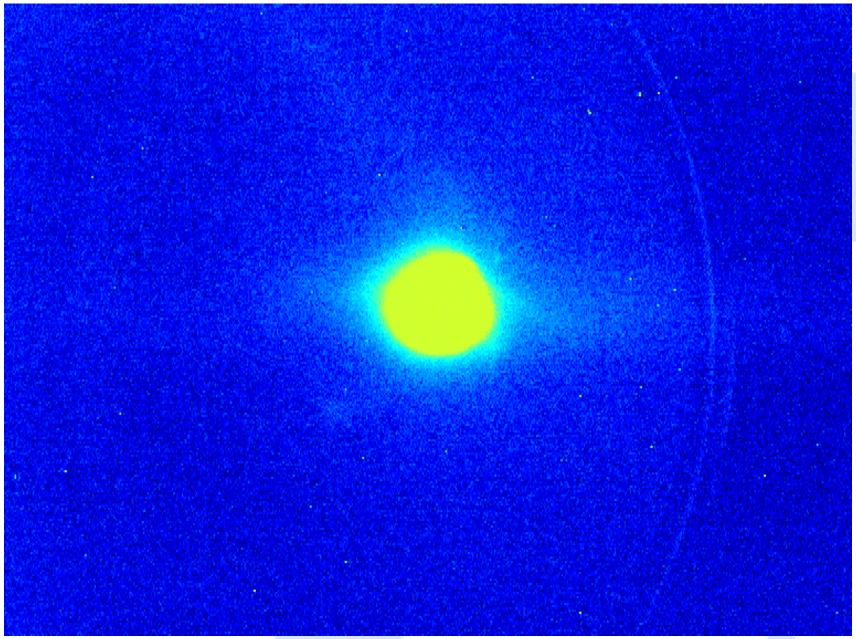
ALICE Accelerates Towards Energy Recovery

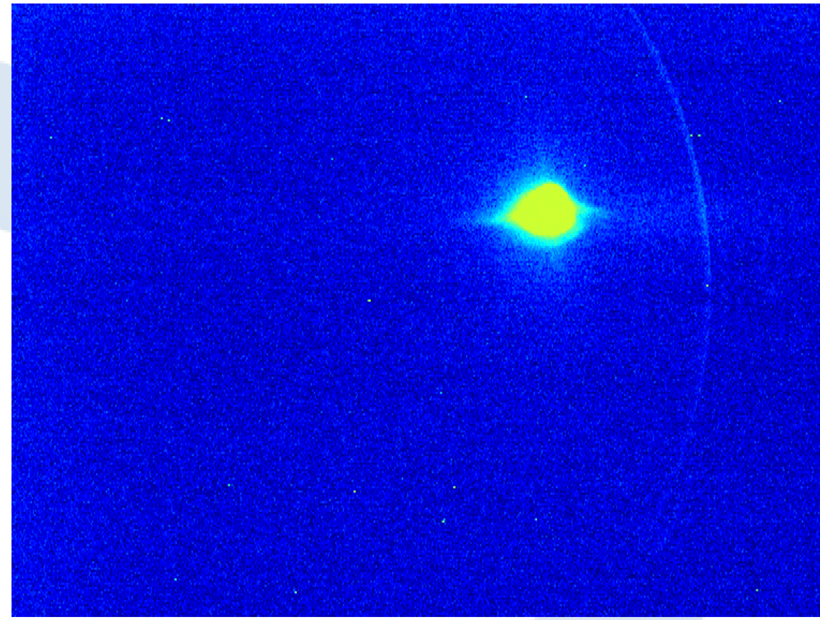
24/10/08 Midnight at start of a 1 month shutdown

- **ALICE commissioning team successfully accelerated an electron beam through the superconducting booster module.**
- **The electron beam was accelerated through the module to around 4 MeV.**

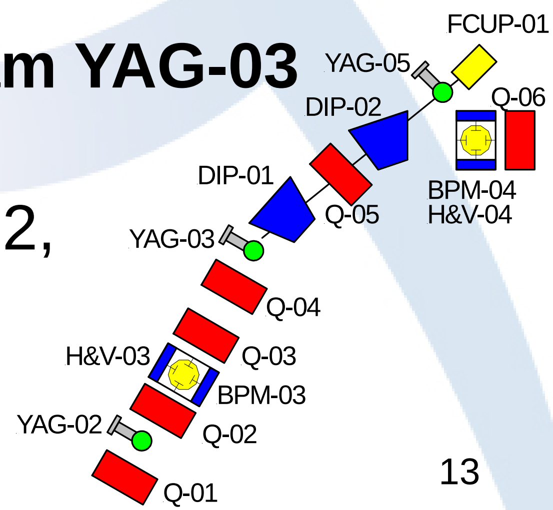


Acceleration through both booster cavities





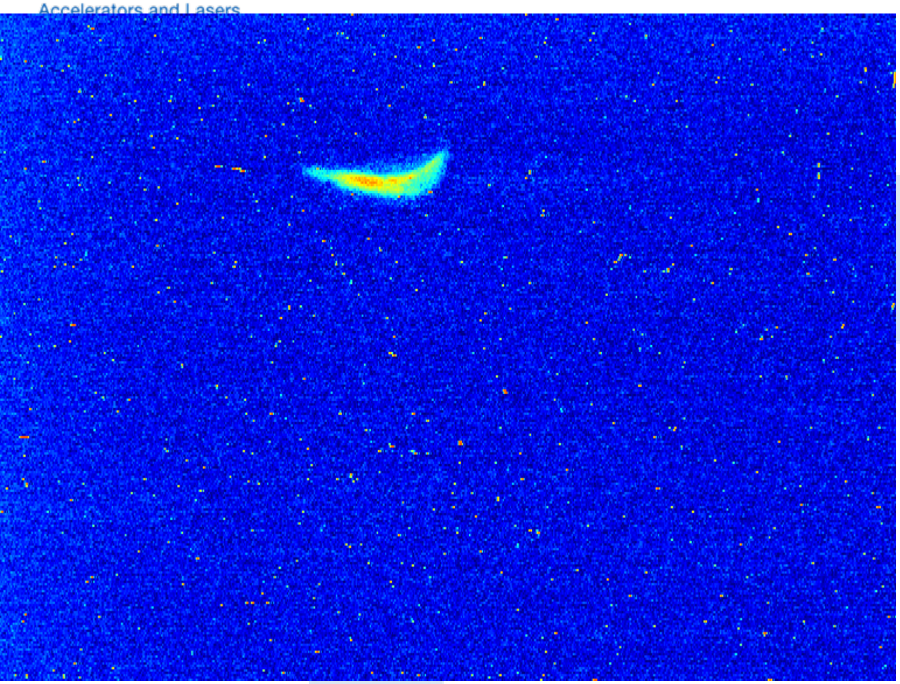
YAG-02 **First Beam YAG-03**

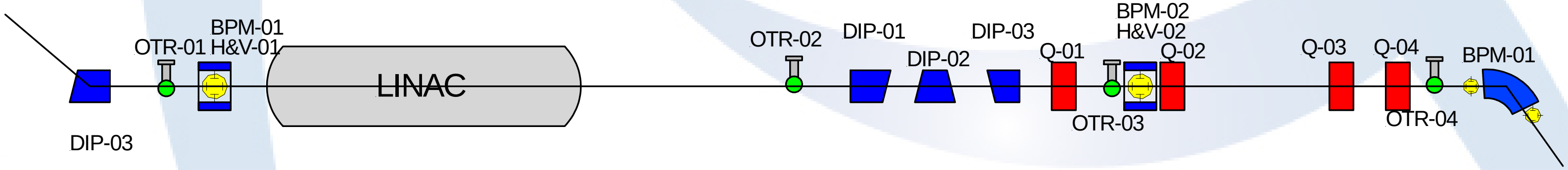


cavity 1 at 5.5 MV/m, phase shift position at 2.2,
cavity 2 at 4.9 MV/m

Sunday 23rd November Shift 3 (#862)

Acceleration Through The LINAC

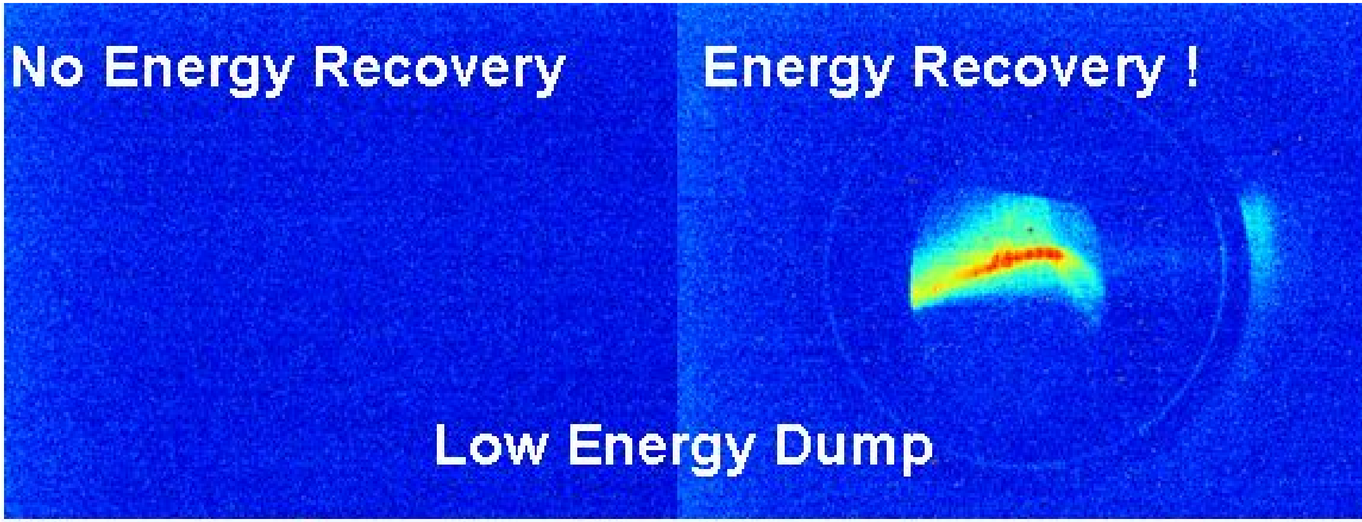




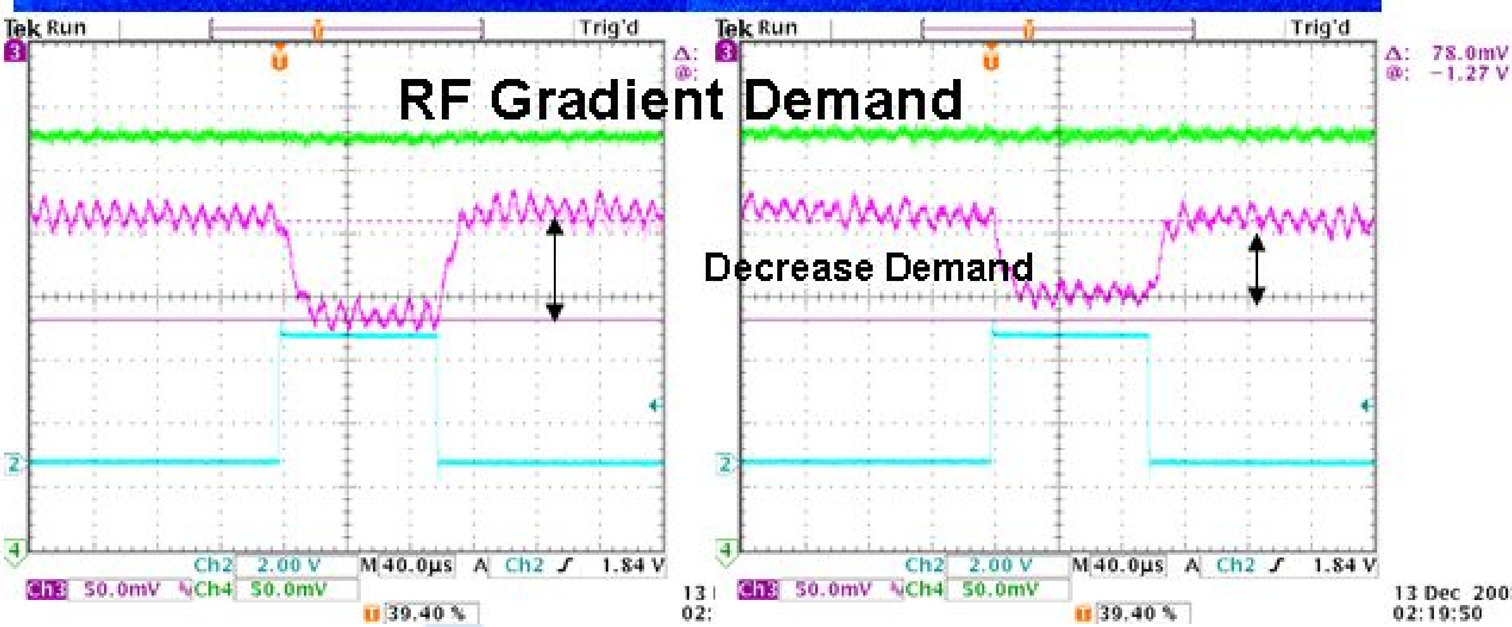
Sunday December 7th

First Circulation

Success on 13 December

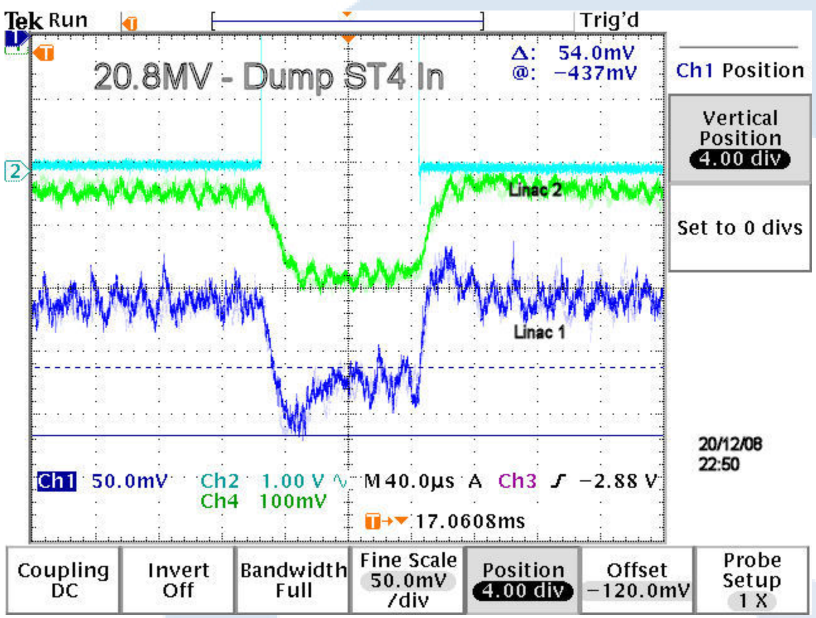


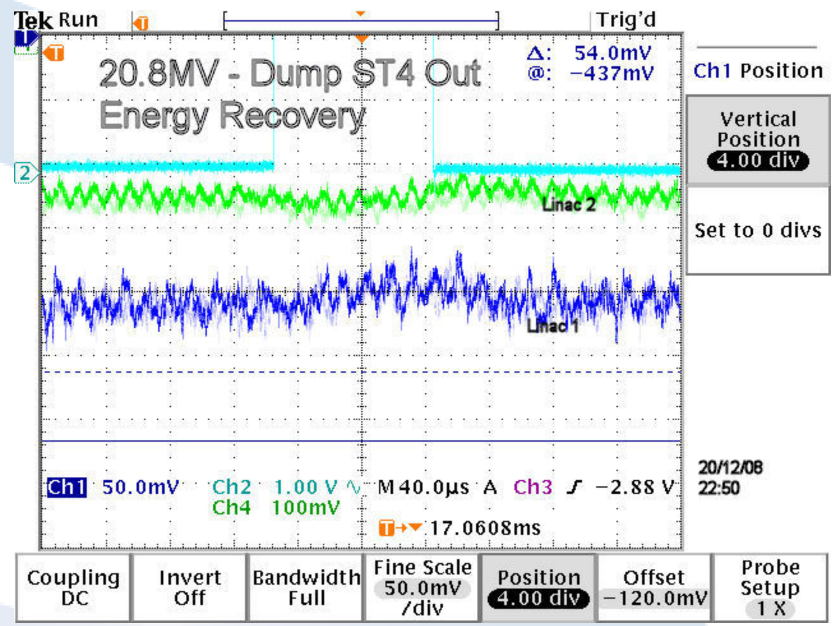
11 MeV operation



Full Energy Recovery

20.8 MeV operation





Full energy recovery demonstrated on ALICE 20 December 2008.

The accelerator has been tuned for transport of the 20.8 MeV beam. The green and dark blue traces show the reduction to “zero” in RF demand on both linac cavities when the (pale blue) beam is decelerated through the cavities.

Commissioning ALICE

- First energy recovery (Dec 2009)
  - Without FEL, installation planned Summer 2009
- Fine tuning
  - injector tuning for minimal emittance
  - optimisation of energy recovery at nominal beam parameters
  - beam diagnostics
- Short pulse commissioning stage
  - longitudinal dynamics, electro-optical diagnostic studies
- Energy recovery with FEL (Summer 2009)
  - first light !
  - recovery of a disrupted beam

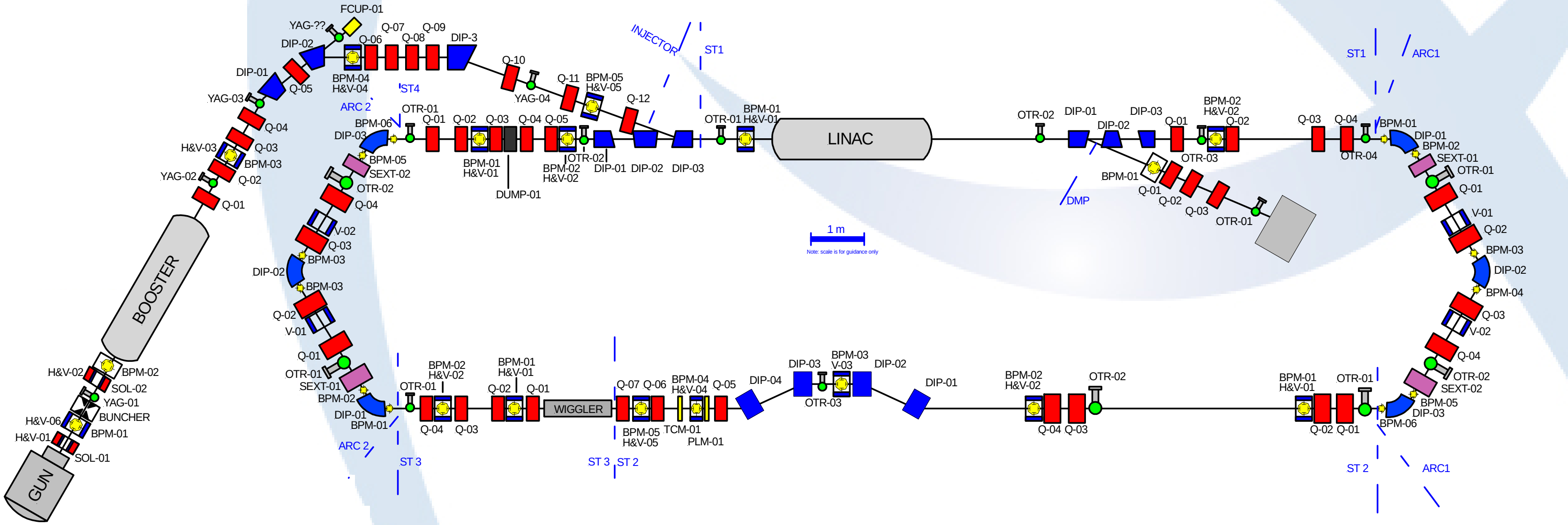
ALICE : First Energy Recovery

ALICE first energy recovery

- no undulator installed
- minimal energy spread (acceleration on crest)
- not concerned with longitudinal phase space, bunching and de-bunching
- nothing particularly difficult here
- major ALICE milestone

ERLP SCHEMATIC DIAGRAM

v.0.2 (15/06/2006)
extracted from AO-180/10078/E



Commissioning to Energy Recovery

- Injector voltage 235 keV (350 keV) (Smaller Stanford cermaic)
- Booster energy gain 5.4 MeV (8 MeV) (Matched to conservative LINAC gradient)
- Total Energy 21 MeV (35 MeV) (Limited by FE/Conditioning)
- Bunch charge 6 pC (80pC) (Qe lifetime)

ALICE : Fine Tuning

- Achieving "full" energy and beam power (25?MeV, 80pC)

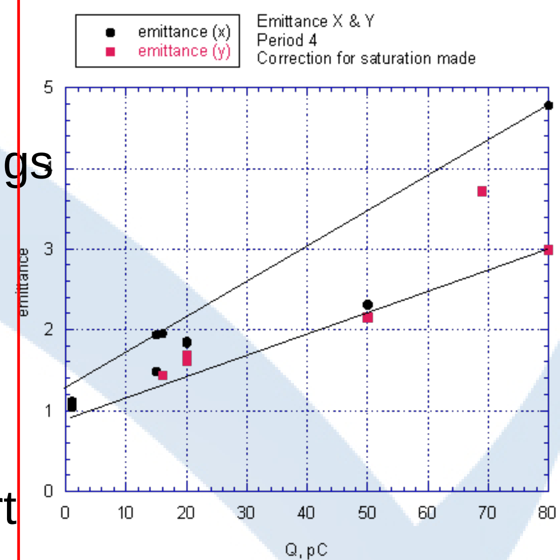
- Injector tuning
  - minimal emittance (slit & quad scans)
  - optimisation of booster cavities phases settings
  - buncher electric field optimisation
  - etc…

- Difference orbit measurements

- Setting the required linac phases and beam transport
- Optimising beam transport

- Measurements
  - emittance
  - Twiss parameters
  - bunch length (zero-crossing and E/O methods)
  - energy spectra

- Matching with the model



Transverse emittance as measured during the gun commissioning

(too high due to field emission from the cathode and non-uniform QE map ?)

ALICE : Short Pulse Commissioning

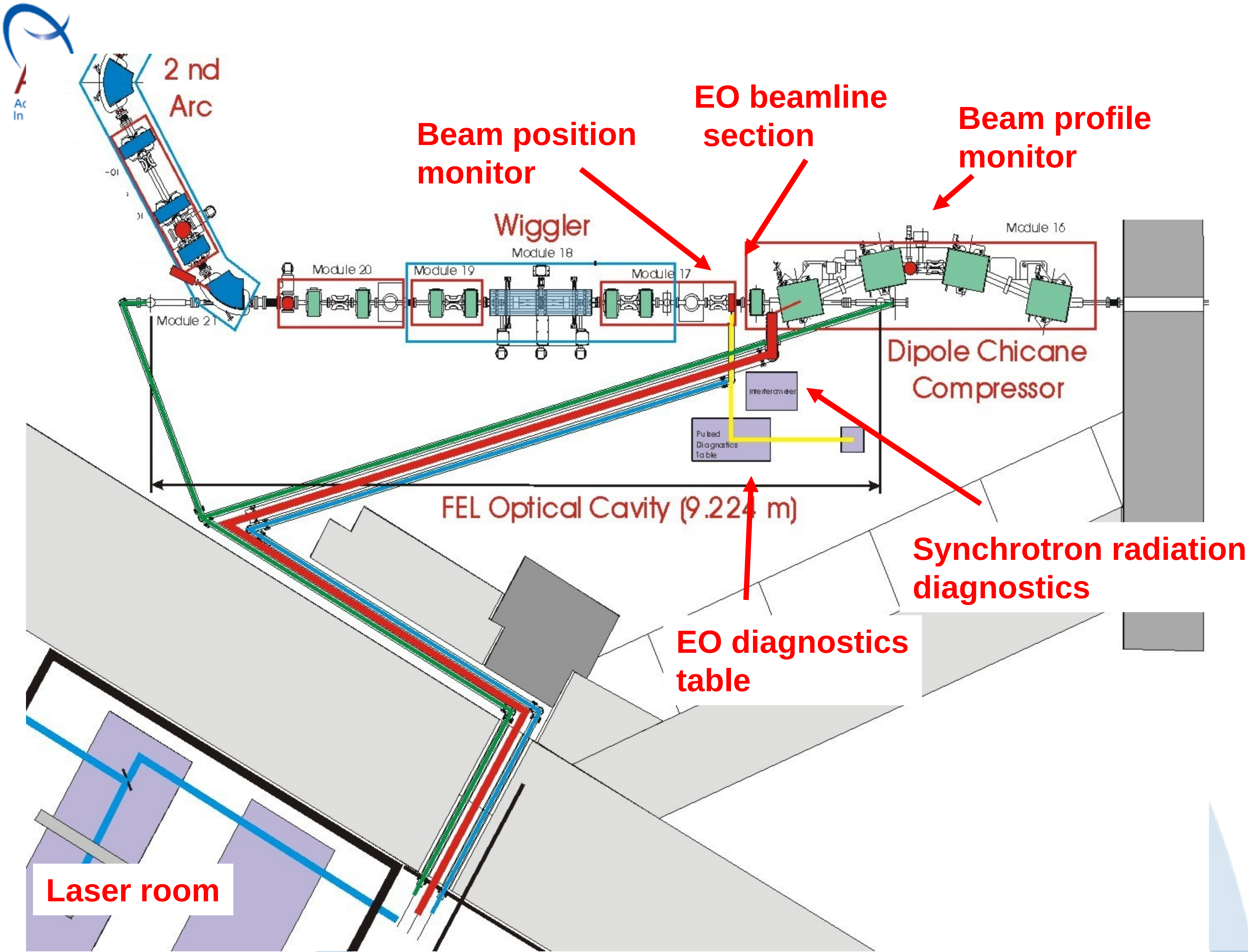
- Initially, no FEL still not installed yet …

- Longitudinal dynamics
  - Linac phases tuning
  - R56 tuning in ARC 1 & ARC 2
  - sextupole tuning
  - longitudinal bunch compression setup
  - min bunch length

- Phase transfer measurements
  - using either BPMs or E/O

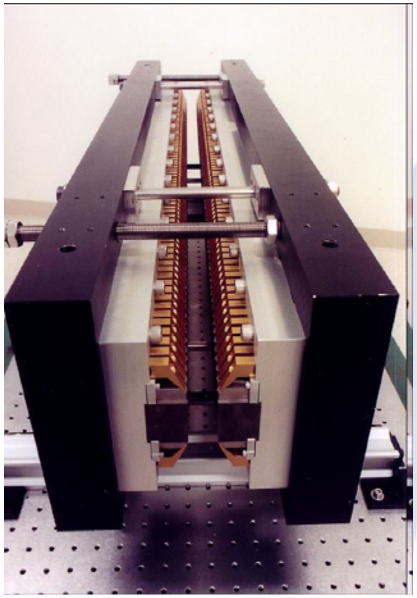
- THz measurements

- E/O bunch length measurements

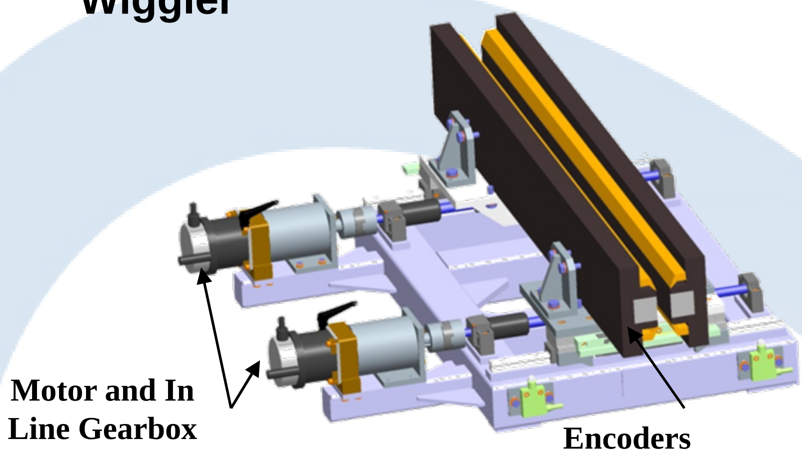


2 nd
Arc
Beam position
monitor
EO beamline
section
Beam profile
monitor
Wiggler
Module 18
Module 20
Module 19
Module 17
Module 16
Module 21
Dipole Chicane
Compressor
Interferometer
Pulsed
Diagnostics
Table
FEL Optical Cavity (9.224 m)
Synchrotron radiation
diagnostics
EO diagnostics
table
Laser room

Tunable IR FEL



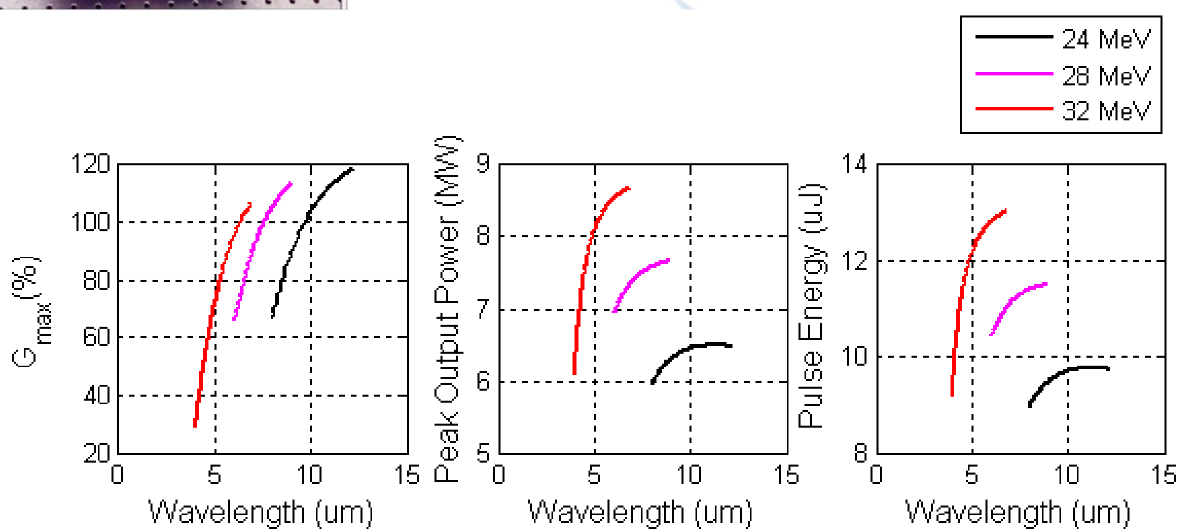
JLAB IR Demo Wiggler



Tunability by varying :

- electron energy (24-35MeV)
- undulator gap (12-20mm)

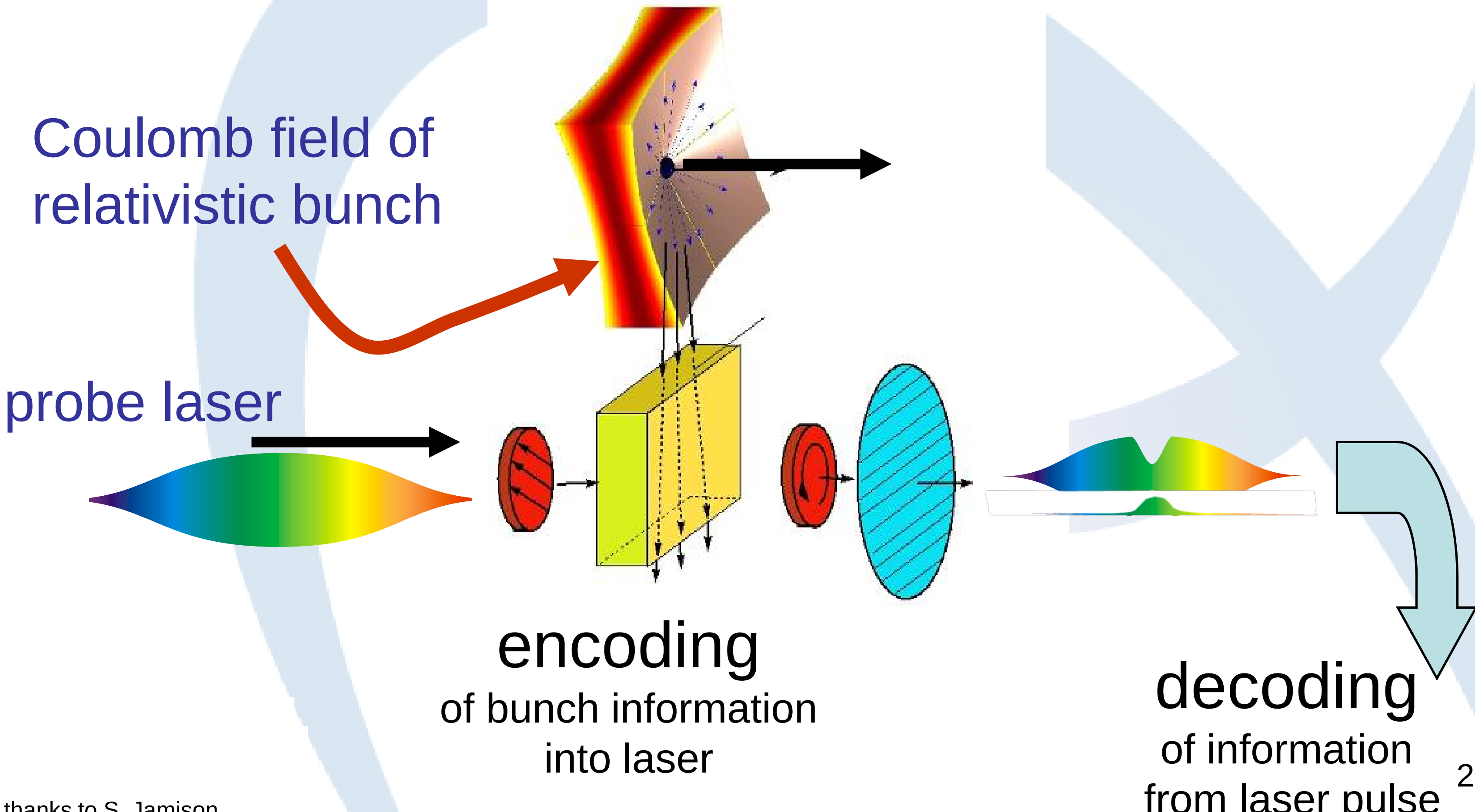
λ = 4-12 μm



EO Diagnostics and Synchronisation

Electro-optic sampling of Coulomb field

probe laser co-propagates with bunch (with transverse offset)



thanks to S. Jamison

Electro-optic technique for bunch profile and time-of-arrival measurements

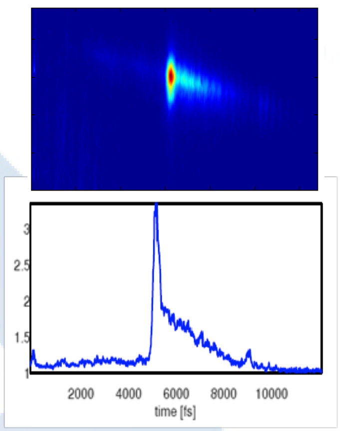
UK has leading position in EO longitudinal diagnostics

highest time resolution demonstrated by UK/Dutch/German collaboration at FLASH

ALICE test-bed

For testing of modified concepts for real system integration

- cost-vs-capability becoming a driver
  >£200k for our best resolution system! (cost mostly in the laser)
- investigate migration of techniques to fibre laser systems
- integration with timing distribution systems
  -profile info highly desirable for even arrival time diagnostics



EU-IRUVX funding for further prototype of EO system on ALICE

Tests for external laboratories...

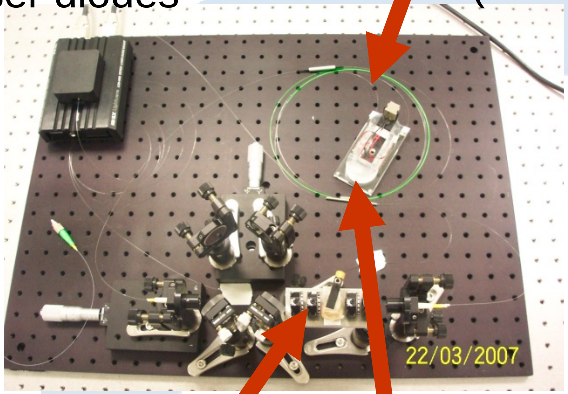
thanks to S. Jamison

ALICE: Fibre Lasers Oscillators / Clocks R&D

in-house build...

pump laser diodes

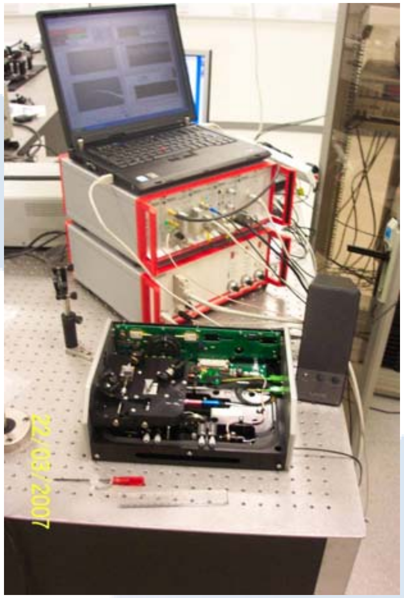
gain medium
(Er: fibre)



polarising elements

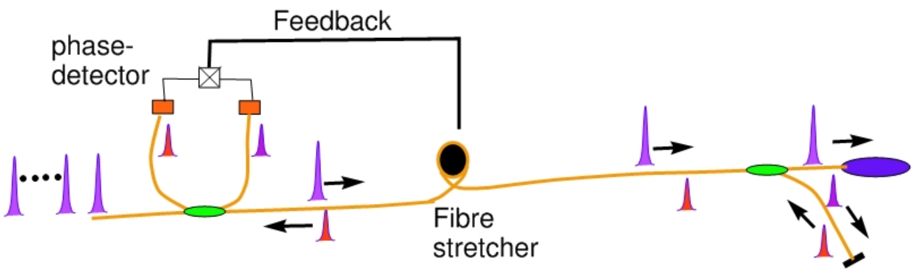
fibre stretcher
(cavity length feedback)

commercial system...



plus..

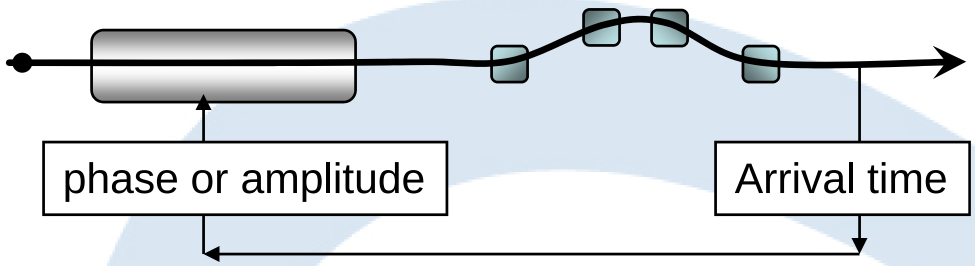
Active length stabilisation of distribution optical fibre..



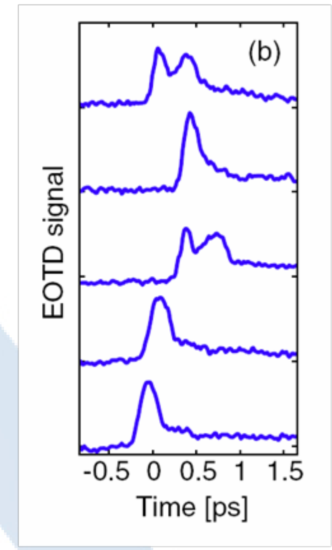
Compare arrival time of outgoing and round trip pulses
- RF phase detection ~20fs sensitivity
- optical cross-correlation ~1fs (?)

thanks to S. Jamison

ALICE: Longitudinal profile feedback studies

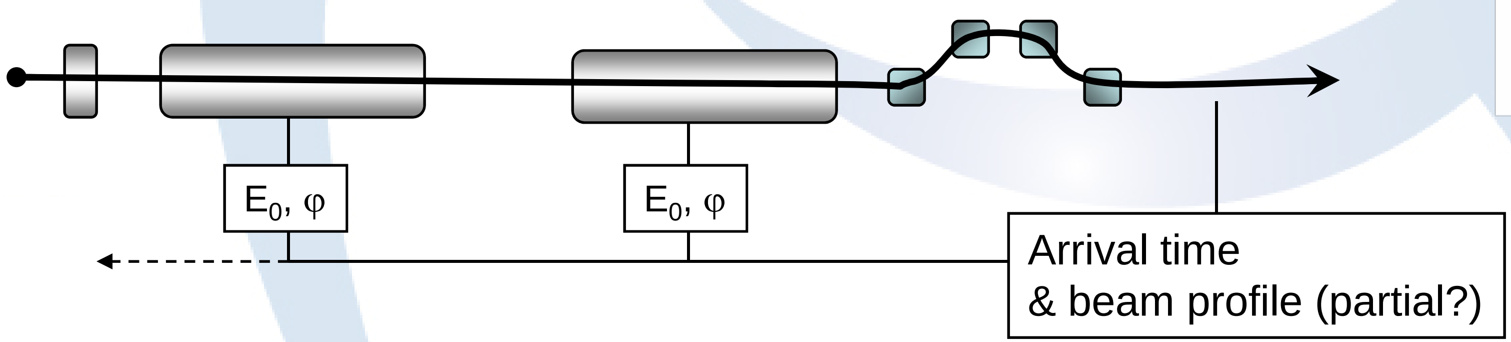


concept recently
proven at FLASH



Arrival of what? charge mean or peak current ?

development through EU/Marie Curie (in proposal stage)



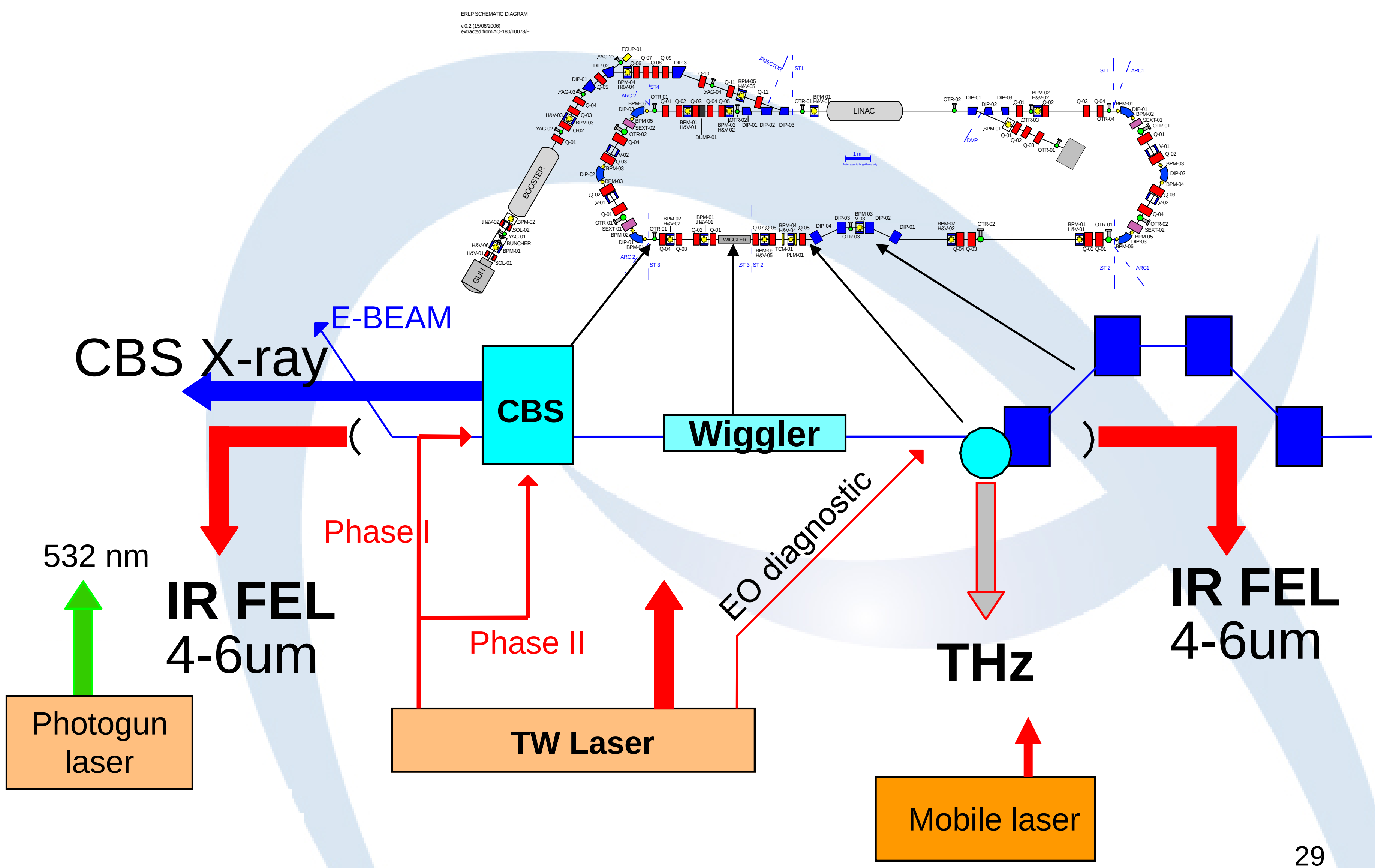
more profile data ⇔ more “knobs” available

We can do it on ALICE !

motivation behind IR-UVX
EO profile investigations

thanks to S. Jamison

ALICE - not just an Energy Recovery Linac



Future Plans

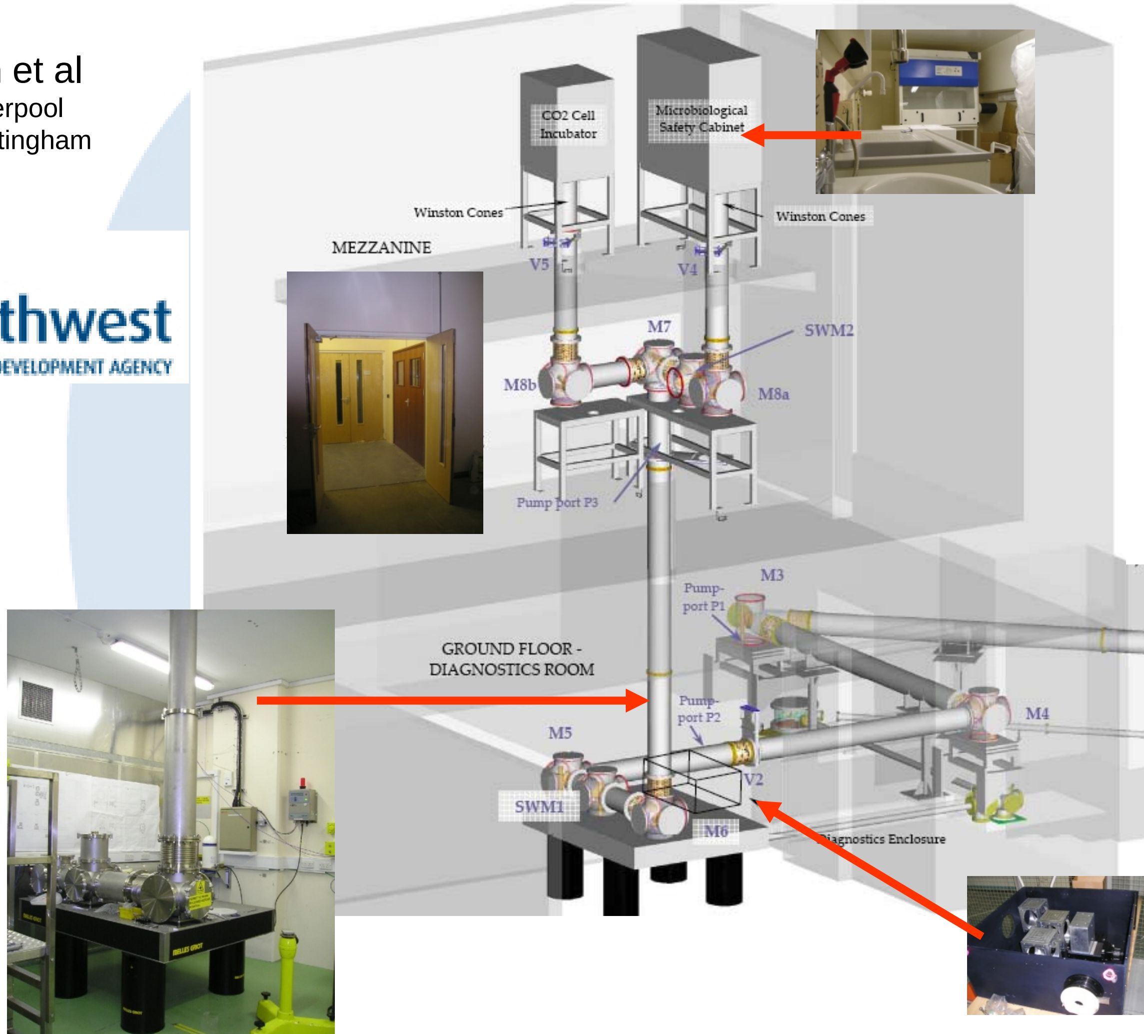
Science Beyond Energy Recovery

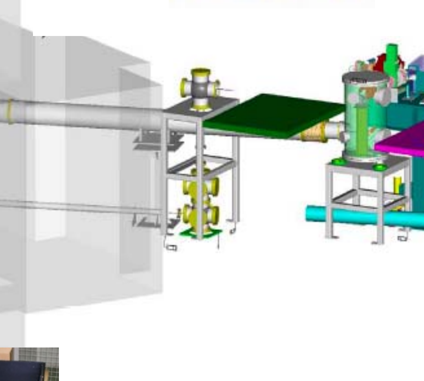
- EMMA – the first NS FFAG
- Accelerator physics research
  - Photoinjector upgrade, load lock system and diagnostics line
  - High average current accelerator module
  - Photocathode research and testing (using the upgraded gun)
  - Linac Transfer Matrix Investigation
  - Beam Tomography @ High Bunch Charges and Low Energy
  - Laser slicing
  - Micro-bunching?
  - Laser Wakefield Acceleration (LWFA) on ALICE
- CBS X-ray source
- IR and THz research programme
- Tissue Culture Laboratory @ ALICE
- Exciting pump – probe research programme with all ALICE light sources:
  - TW laser (10TW, 100 / 35 fs, 10Hz)
  - IR FEL (~4mm, ~15MW peak, ~1ps, ~10mJ)
  - fs tunable laser
  - THz radiation (broadband)
  - CBS X-ray source (15-30keV, 10^7 – 10^8 photons/pulse, <1ps)

THz Programme & Tissue Culture Facility

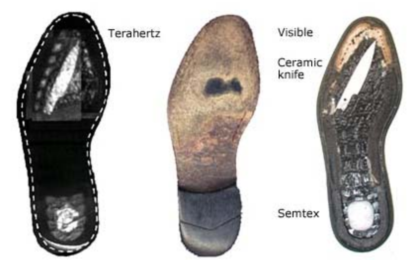
A world-unique facility allowing the effect of high peak power / high rep rate THz on living cells to be investigated.

Weightman et al
University of Liverpool
University of Nottingham





THz has important role in security screening

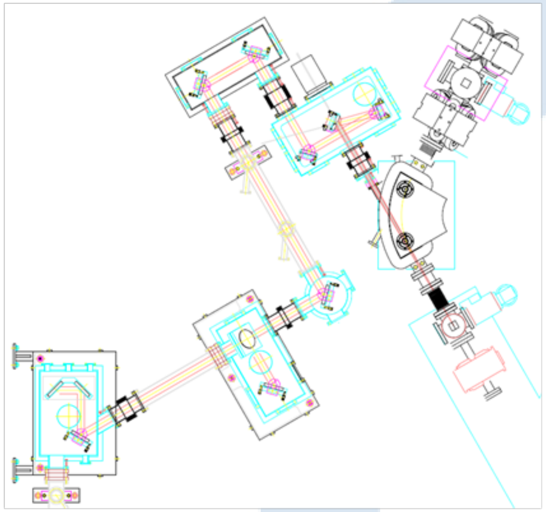


TeraView

CBS experiment : Phase I

Head on 180^o
photon-electron collisions

(relaxed synchronisation requirements)



- X-ray source characterisation
  - spectrum
  - X-ray pulse duration
  - brightness (number of photons N_p)
- Electron bunch / laser pulse time jitter
  - shot-to-shot variations in energy spectra and N_p
  - **better resolution expected in phase II**
- First pump/probe experiment
  - (but this more likely to be done during phase II)

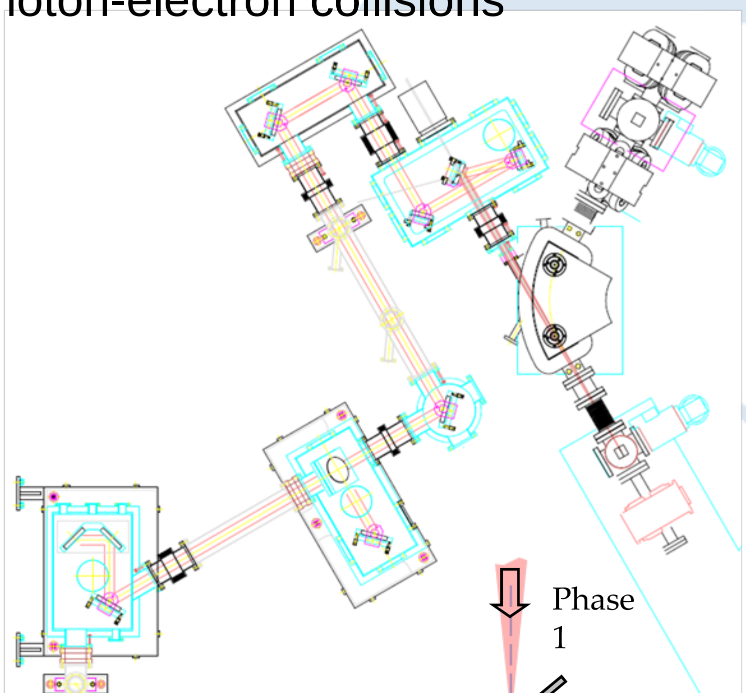
-Laser pulse travels through the length of the electron bunch
- **X-ray pulse length ~ electron bunch length**
- **relaxed synchronisation requirements**

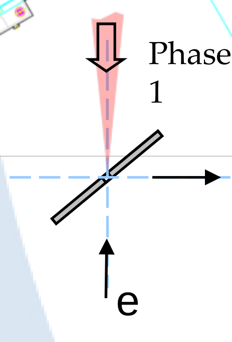
First X-ray pulses April 2009

CBS: Phases I & II

PHASE I

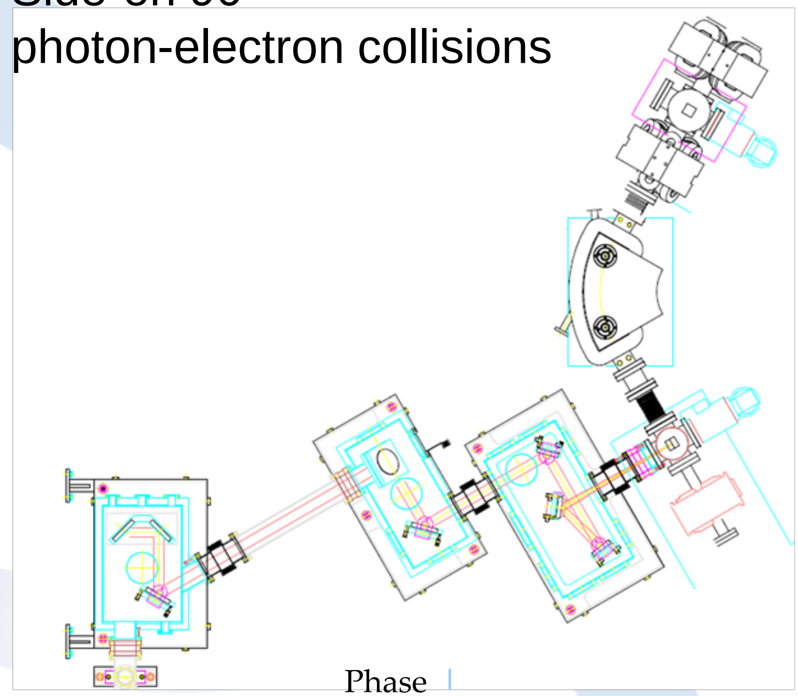
Head on 180º
photon-electron collisions

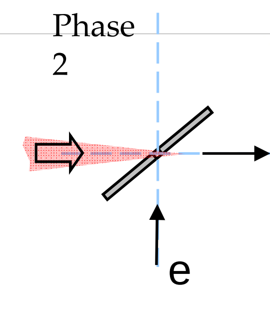




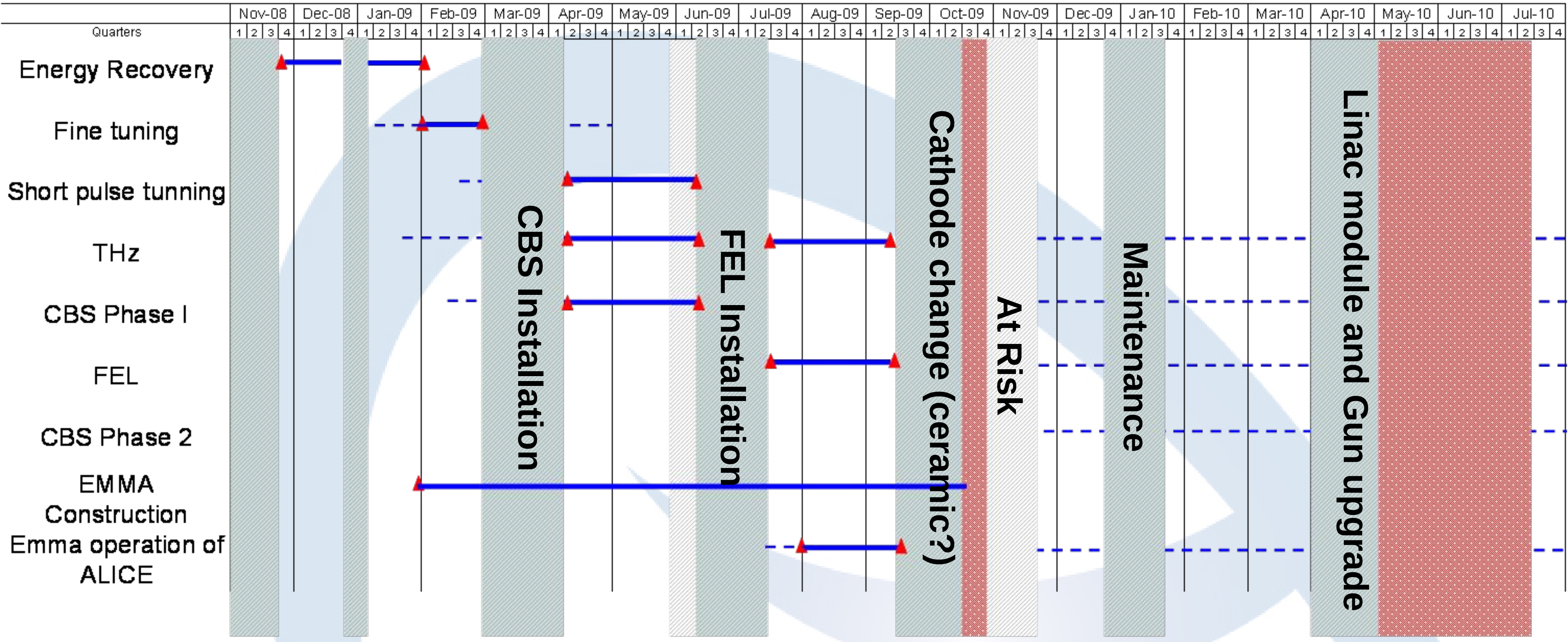
PHASE II

Side-on 90º
photon-electron collisions





ALICE Programme



Summary

- Accelerator commissioning has now reached a critical stage
- ALICE has provided the UK with an opportunity to develop generic technologies and skills important to delivery of advance accelerator driven facilities
  - Photoinjector, SC RF, cryogenics etc.
- ALICE will provide a unique R&D facility in Europe, dedicated to accelerator science & technology development
  - Offering a unique combination of accelerator, laser and free-electron laser sources
  - Enabling essential studies of beam combination techniques
  - Providing a suite of photon sources for scientific exploitation

Many thanks to all contributors to this presentation

EMMA STATUS

Neil Bliss, STFC Technology, Daresbury Laboratory
6th January 2009

Thomas Jefferson National Accelerator Facility

Science & Technology Facilities Council

BASROC CONFORM

CONTENTS

Project Overview

- Electron Model for Many Applications (EMMA)
- 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 - £5.75m over 3.5 year project lifecycle. Project start was 2nd April 2007
  - PAMELA design study - £865k
  - Applications study - £273k
- EMMA is using ALICE as the injector
- EMMA will be the worlds 1st non-scaling FFAG

Science & Technology Facilities Council

BASROC CONFORM

EMMA Collaboration

- EMMA design is an international effort and we 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
  - ………..

FFAGs are circular, strong-focusing accelerators having:

- d.c.-powered magnets, and are suited to rapid acceleration
- some reverse bending (radial-sector type)
- closed orbits whose average radii (mostly) increase with beam momentum
- large 6D acceptance.

FFAG type	Fixed βtron tunes	Compaction $(\Delta p/p)/(\Delta R/R)$
Classical, scaling	Yes	Normal
1st Gen linear-field NS	No	Very large

The NS-FFAG properties, resonance crossing, small apertures, parabolic ToF and serpentine acceleration, lead to novel, unproven accelerator physics. Hence the demonstration model.

Effect of resonances are minimized by:

- Symmetry: all cells identical
- Linear magnets: nonlinear resonances weak
- Accelerate rapidly: fast crossing
- Magnet errors: keep them small, $\delta G/G < 2\times10^{-4}$

Slide courtesy of Shane Koscielniak, TRIUMF

Muon Acceleration Model

- EMMA was originally conceived as a model of a 10-20 GeV muon accelerator
- EMMA has developed from a simple “demonstration” objective to a sophisticated instrument for accelerator physics investigation –with operational demands far in excess of the NFMC application

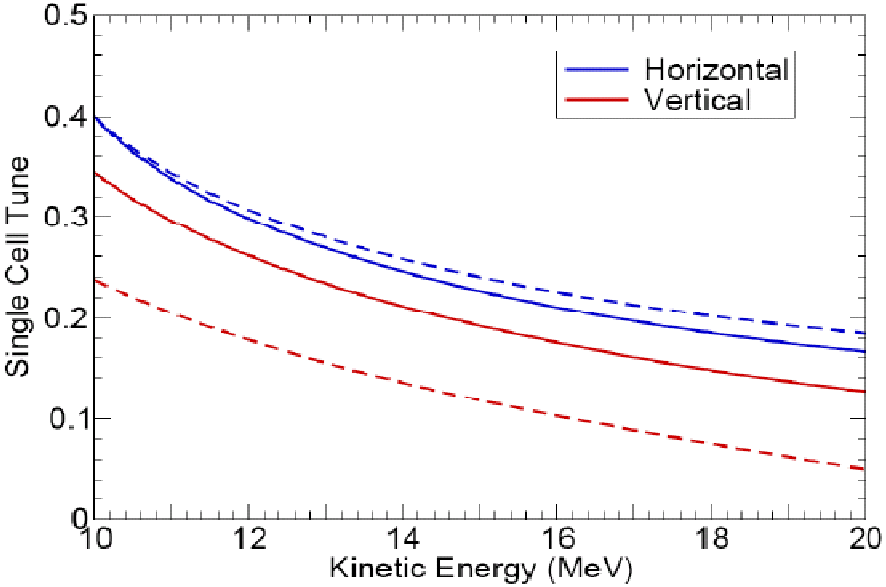
	NFMC	EMMA
Particle type	muon	electron
Energy range	10-20 GeV	10-20 MeV
Circumference	≈ 440 m	16.6 m*
# doublet cells	≈100	42
Cell length	4.4 m	38 cm
Pole-tip field	≈ 2.5 T	≈ 0.25 T
Magnet type	Combined-function	Quadrupoles
RF	200 MHz	1.3 GHz
# acceleration turns	≈ 15	≈ 15
Acceptance (normalized)	≈30 mm	≈3 mm

Slide courtesy of Shane Koscielniak, TRIUMF

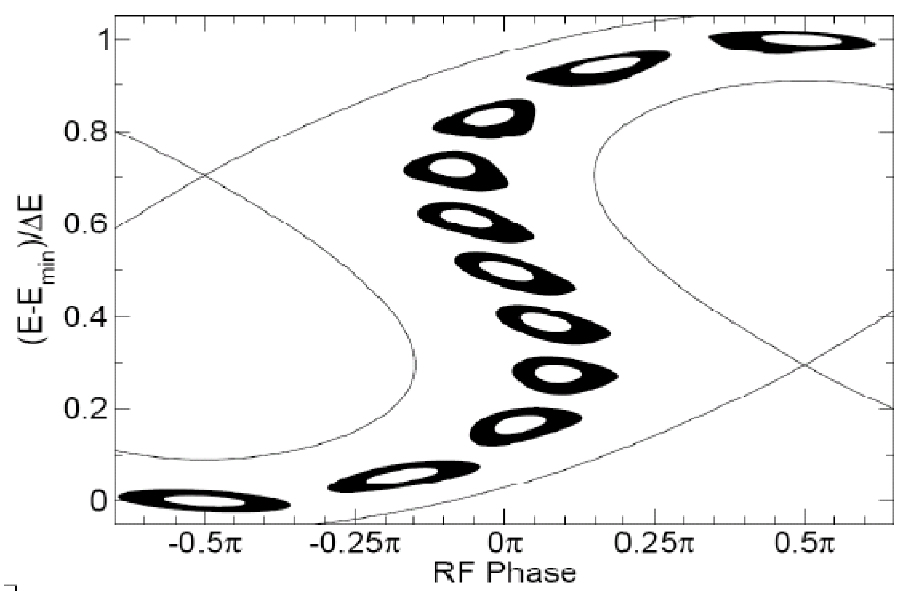
Aims & Objectives

EMMA goals are to study:

(1) Rapid acceleration with large tune variation (natural chromaticity)



(2) Serpentine acceleration (results from parabolic ToF)



(3) Map the transverse and longitudinal acceptances.

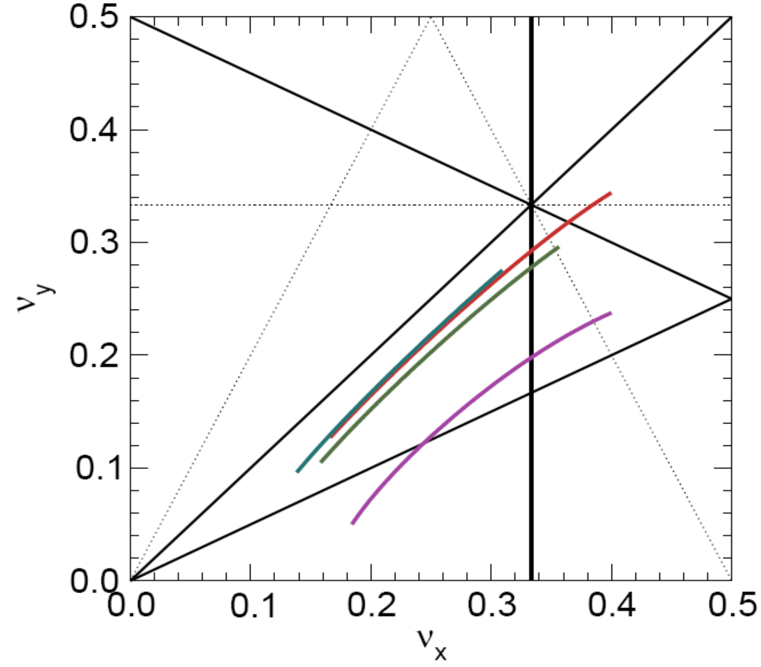
Graphs courtesy of Scott Berg BNL

Aims & Objectives

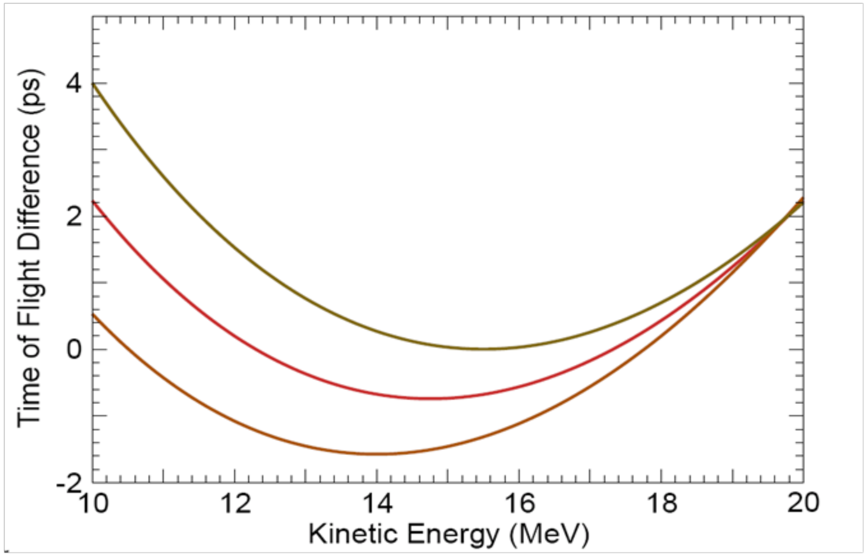
An EMMA objective: to understand the NS-FFAG beam dynamics as function of lattice tuning and RF parameters

- Example: retune lattice to vary resonances crossed during acceleration

Tune plane



Time of Flight vs Energy



- Example: retune lattice to vary longitudinal Time of Flight curve, range and minimum

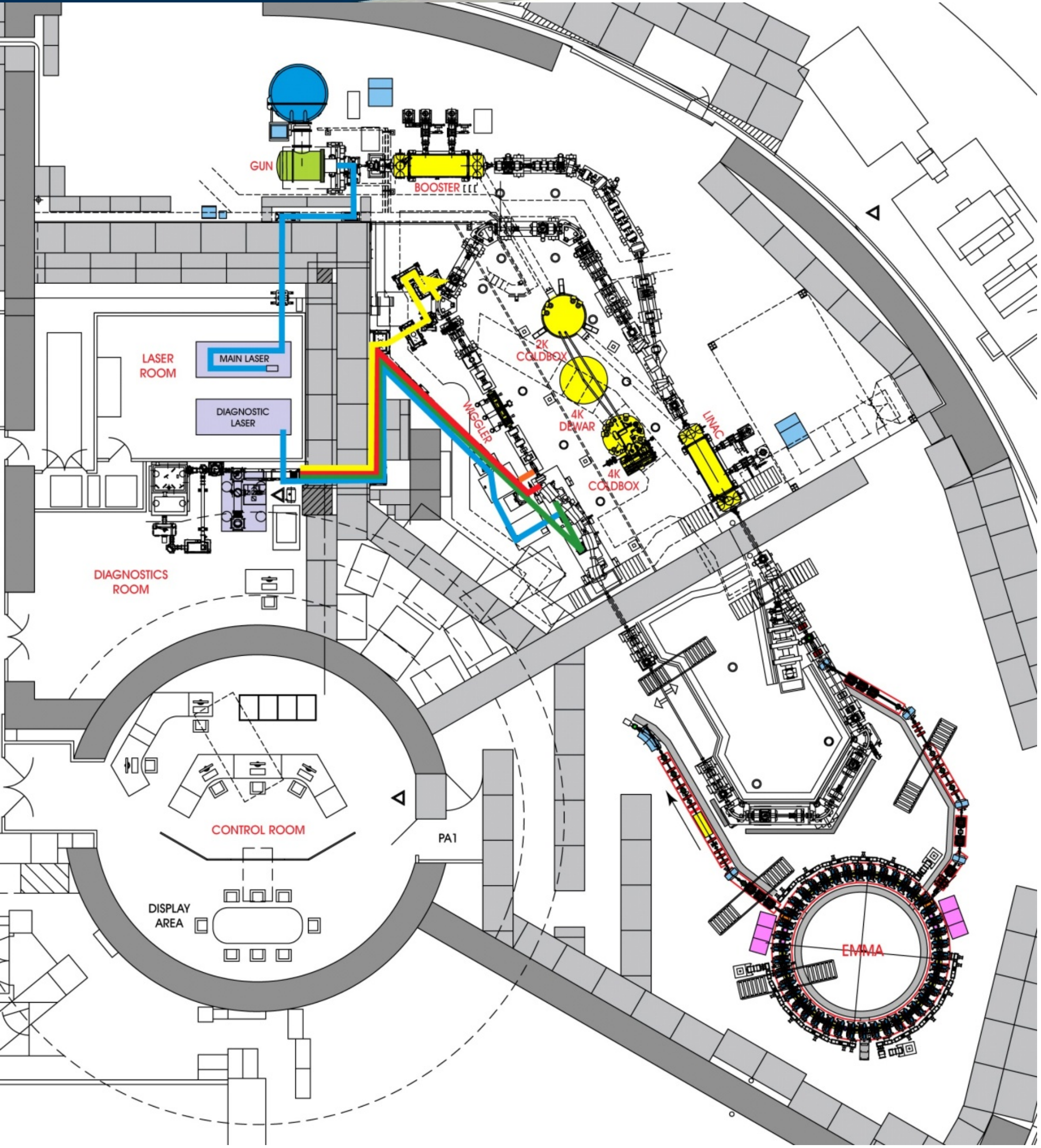
Graphs courtesy of Scott Berg BNL

BROOKHAVEN NATIONAL LABORATORY

Requirements

- Full aperture injection and extraction at all energies 10 – 20 MeV
- Many lattice retunings (vary ratio of dipole to quadrupole fields)
- Vary frequency, amplitude and phase of RF cavities
- Non-accelerated operation to map closed orbits and tunes vs momentum
- Map longitudinal and transverse acceptances with probe beam
- To be heavily instrumented with beam diagnostics, etc.

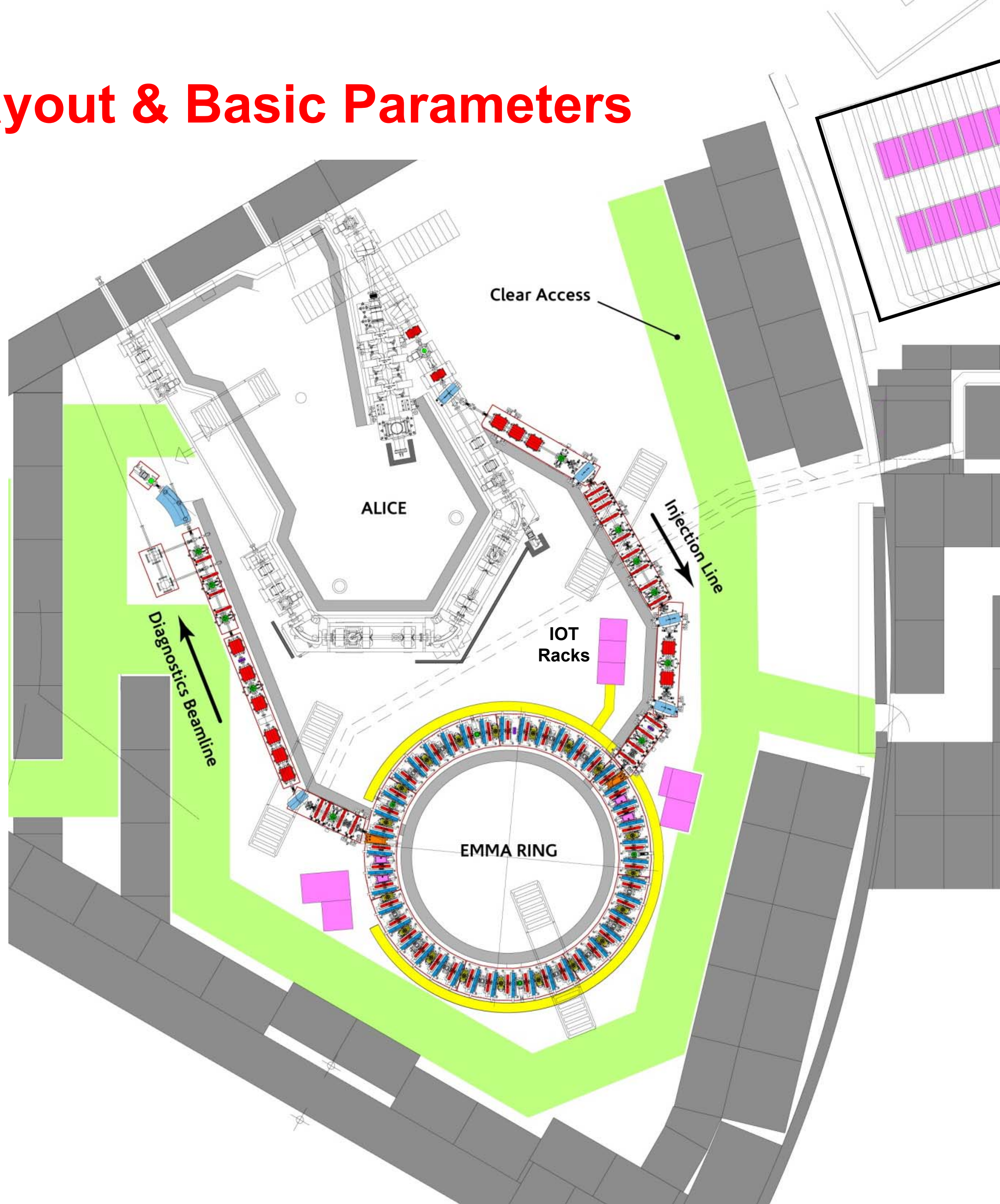
ALICE



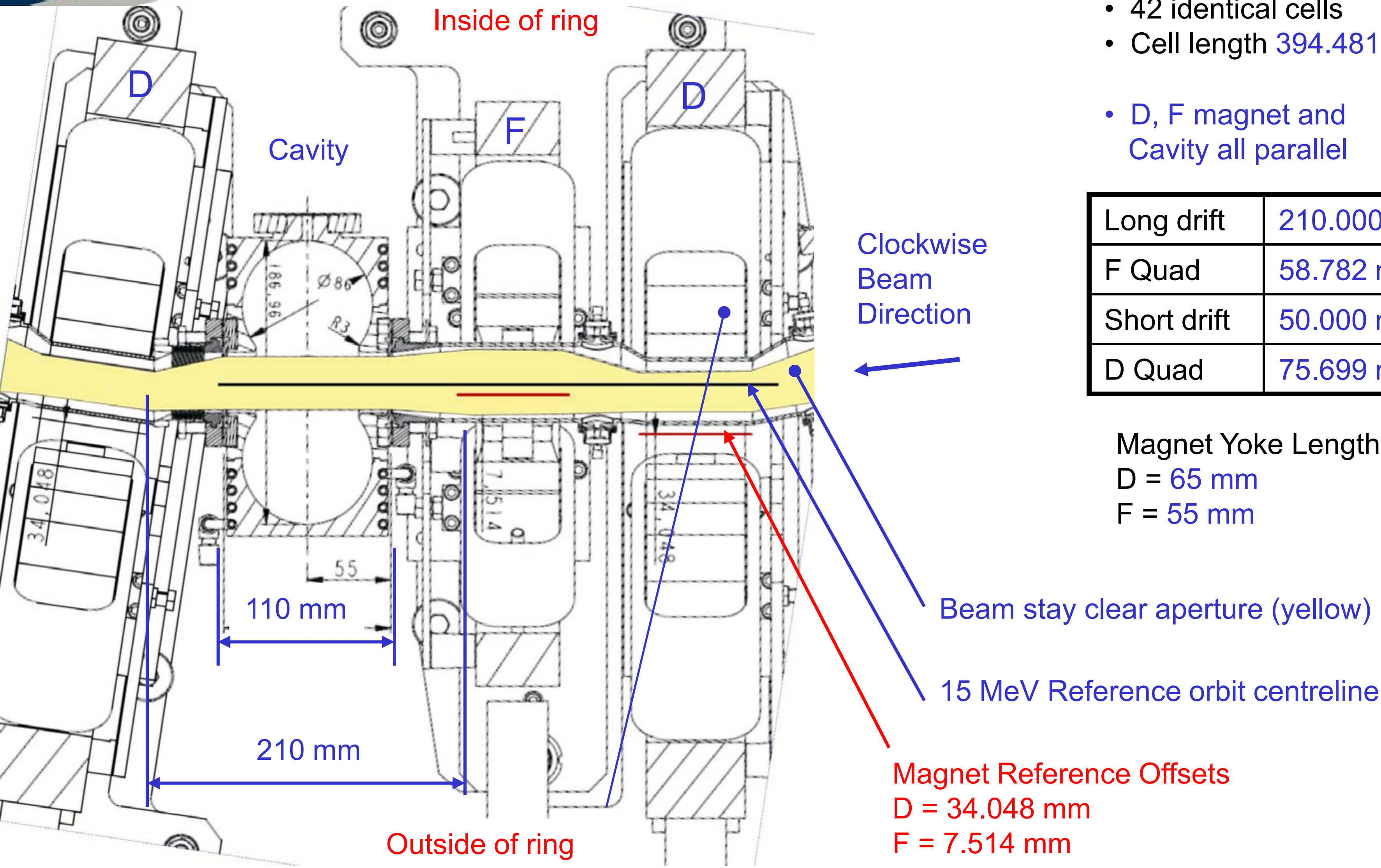
Parameter	Value
Nominal Gun Energy	350 keV
Max. Booster Volts	8 MV
TL 2 Energy	8.33 MeV
Max. Linac Volts	26.67 MV
Max. Energy	35 MeV
Linac RF Frequency	1.300 GHz
Bunch Repetition Rate	81.25 MHz
Bunch Spacing	12.3 ns
Max Bunch Charge	80 pC
Particles per Bunch	5×10^8

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



EMMA Ring Cell Layout



- 42 identical cells
- Cell length 394.481 mm

- D, F magnet and Cavity all parallel

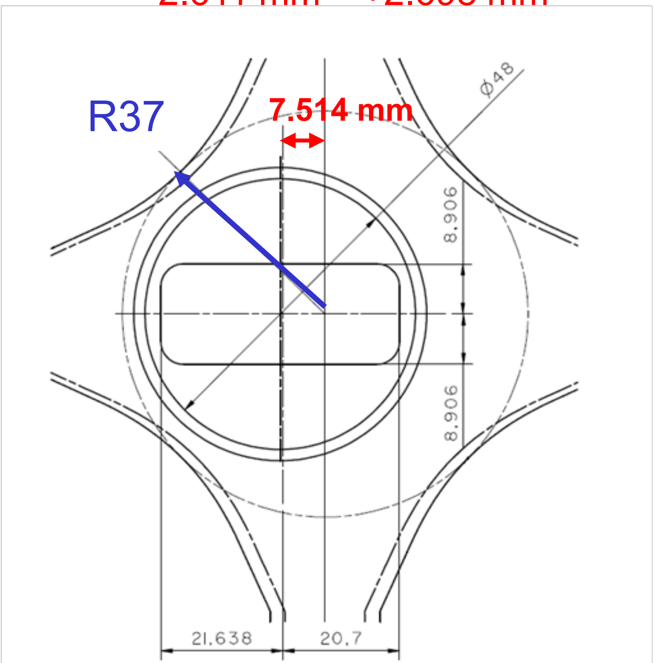
Long drift	210.000 mm
F Quad	58.782 mm
Short drift	50.000 mm
D Quad	75.699 mm

Magnet Yoke Lengths
D = 65 mm
F = 55 mm

Vacuum Chamber Apertures

Magnet translation

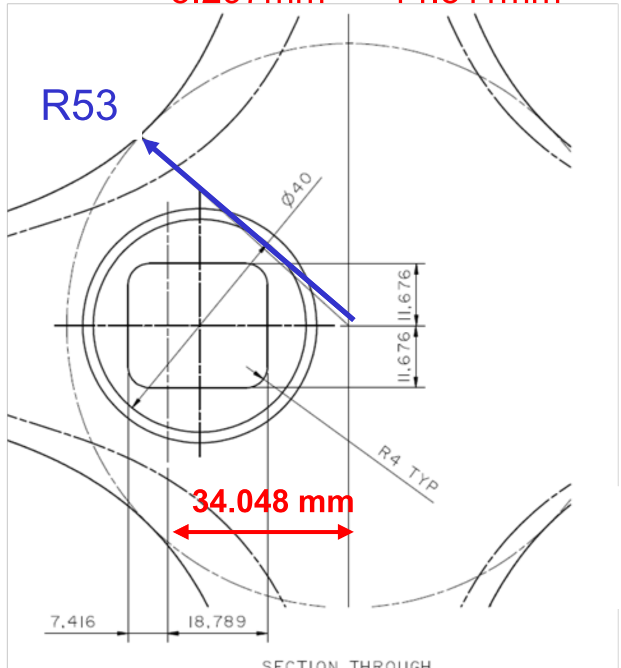
- 2.611 mm +2.698 mm



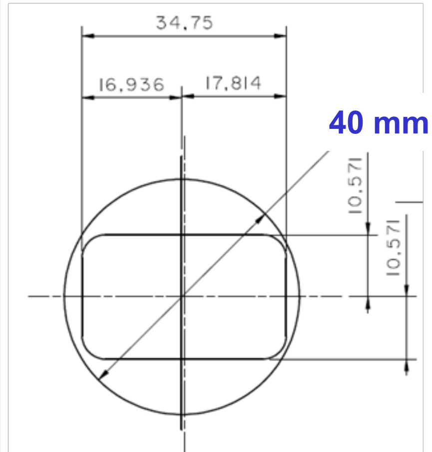
F Magnet Section
Vacuum Chamber
OD 52 mm, ID **48 mm**

Magnet translation

- 5.297mm +14.511mm

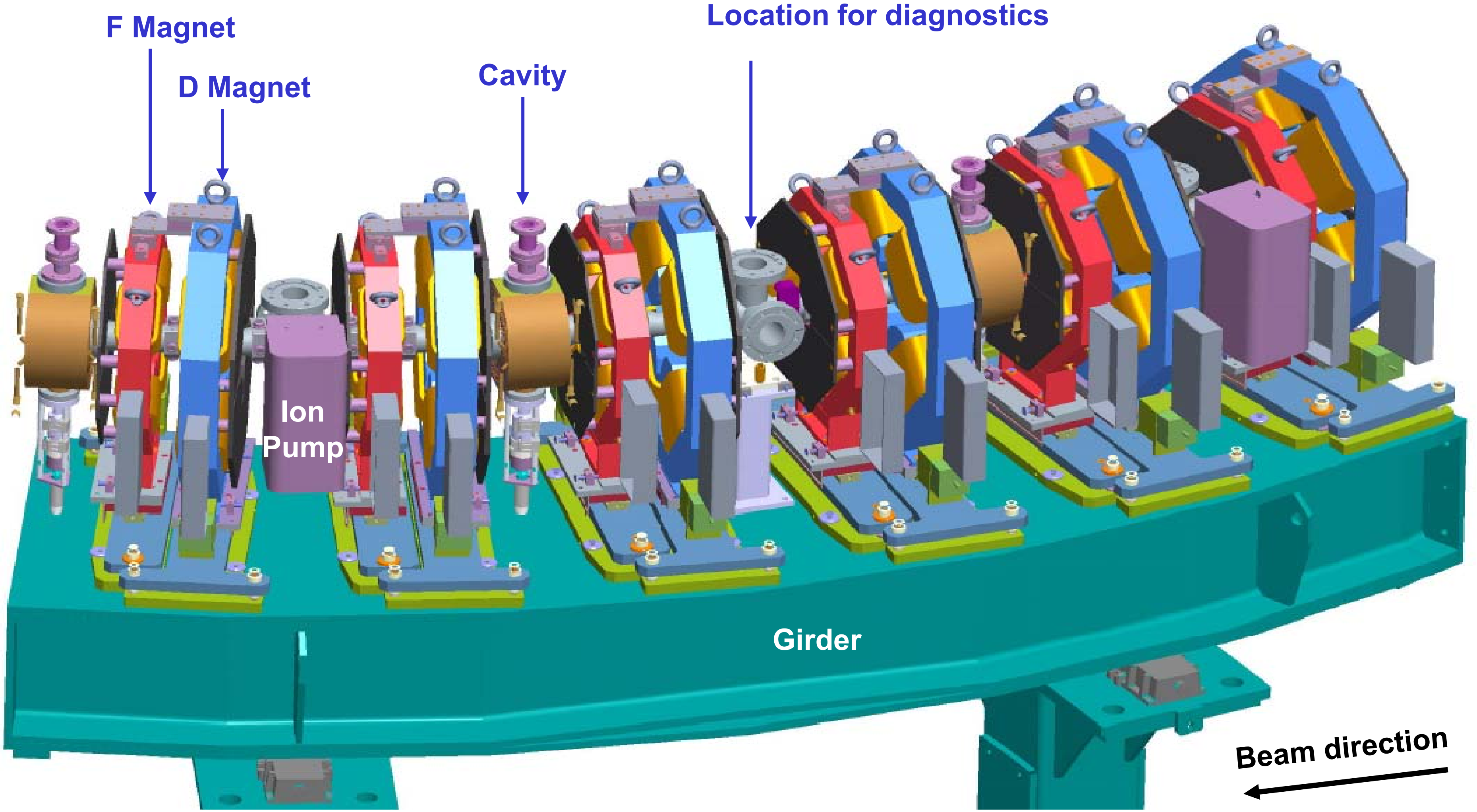


D Magnet Section
Vacuum Chamber
OD 44 mm, ID **40 mm**

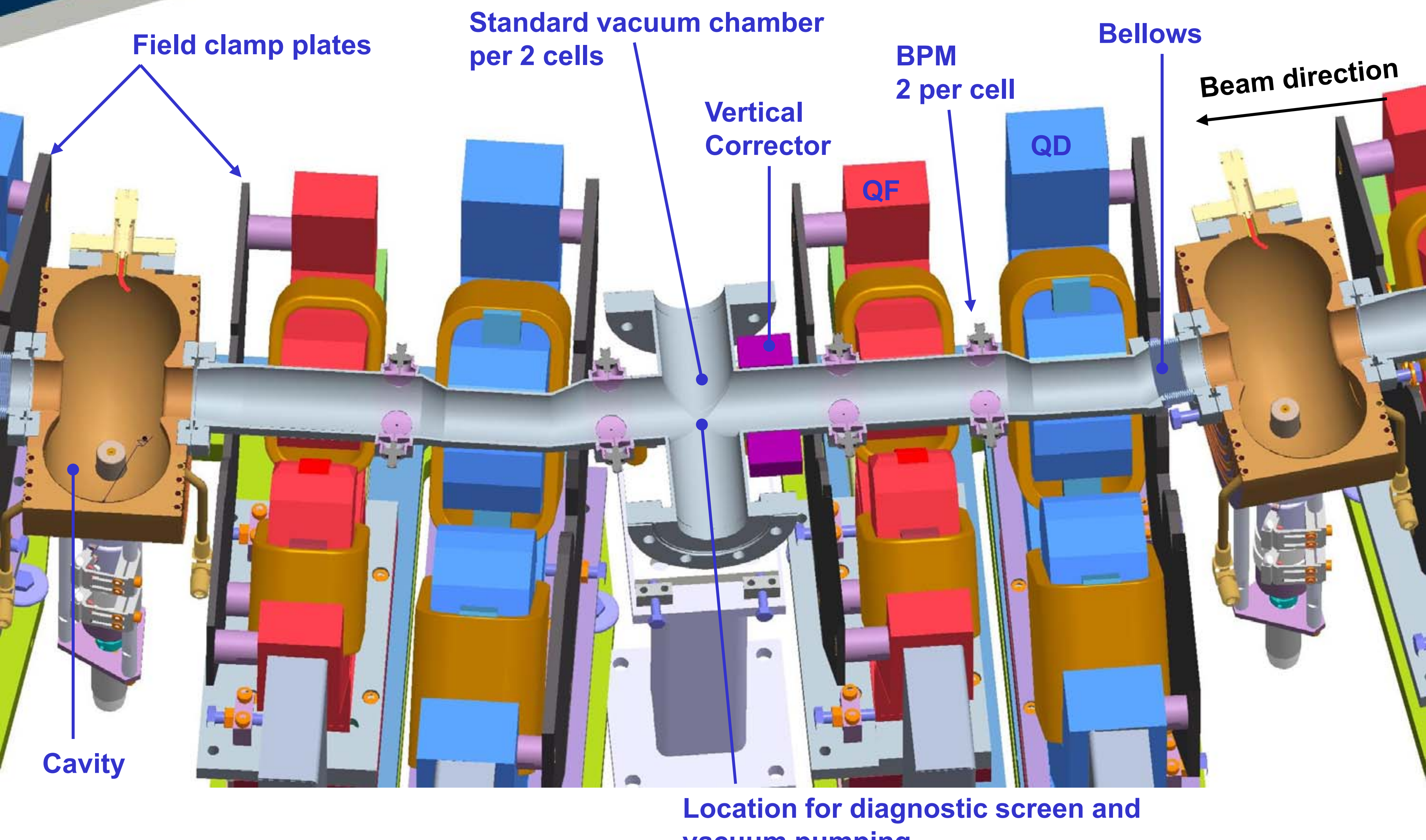


Section thro. Cavity
ID **40 mm**

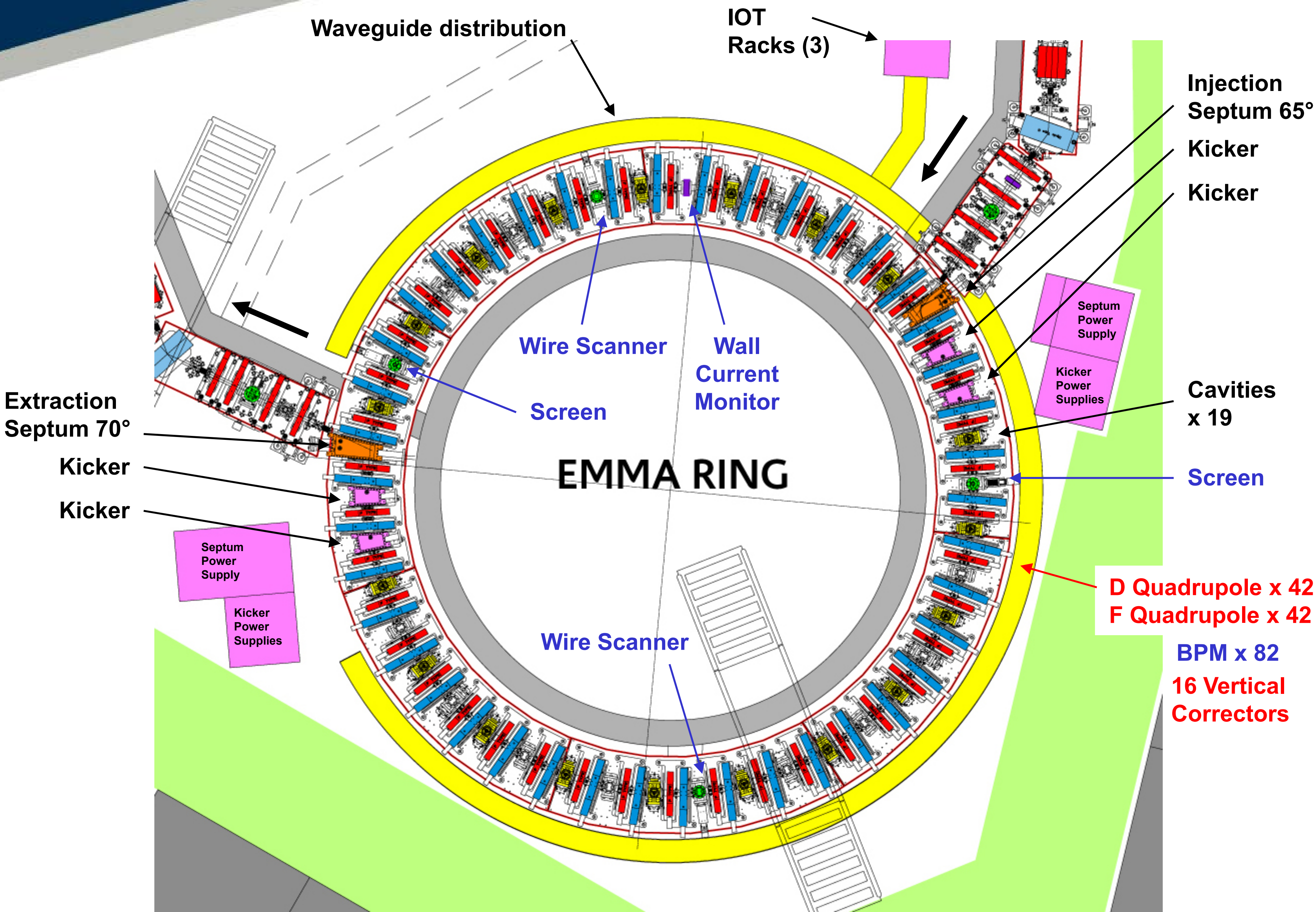
6 CELL Girder Assembly



EMMA Ring Section



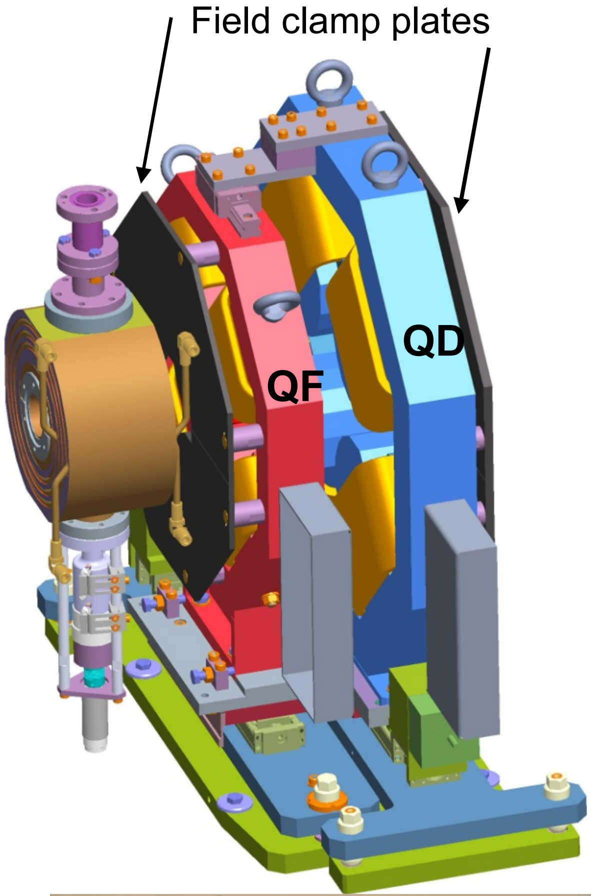
EMMA Ring

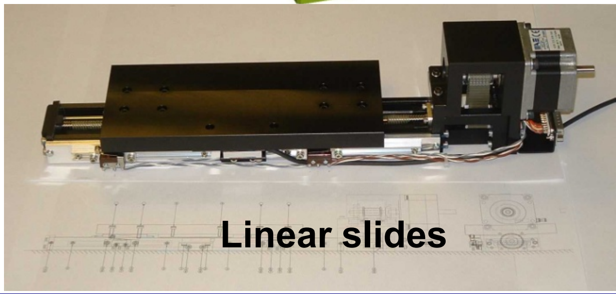

Waveguide distribution
IOT
Racks (3)
Injection
Septum 65°
Kicker
Kicker
Septum
Power
Supply
Kicker
Power
Supplies
Cavities
x 19
Screen
Wire Scanner
Wall
Current
Monitor
Screen
EMMA RING
Extraction
Septum 70°
Kicker
Kicker
Septum
Power
Supply
Kicker
Power
Supplies
Wire Scanner
D Quadrupole x 42
F Quadrupole x 42
BPM x 82
16 Vertical
Correctors

Ring Quadrupole Magnets

Requirements / Solution

- Adjust dipole & quadrupole components independently - Mount magnets on independent radial linear slides
- Fields identical in every cell despite kickers and septum - Field clamps at cell entrance face of QD & exit face of QF
- Very large good field region for range of closed orbits - Optimised pole profile implemented, abandon hyperbola & use 6 facet approach

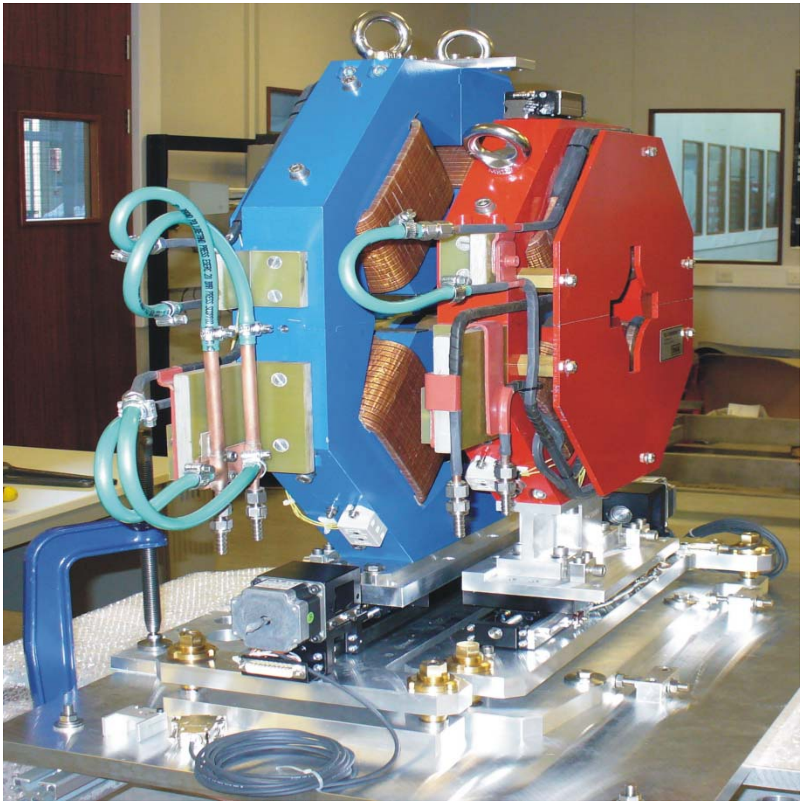


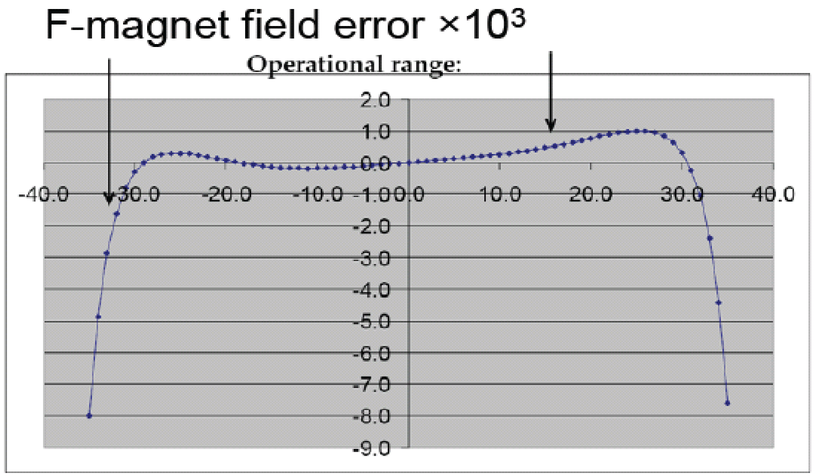


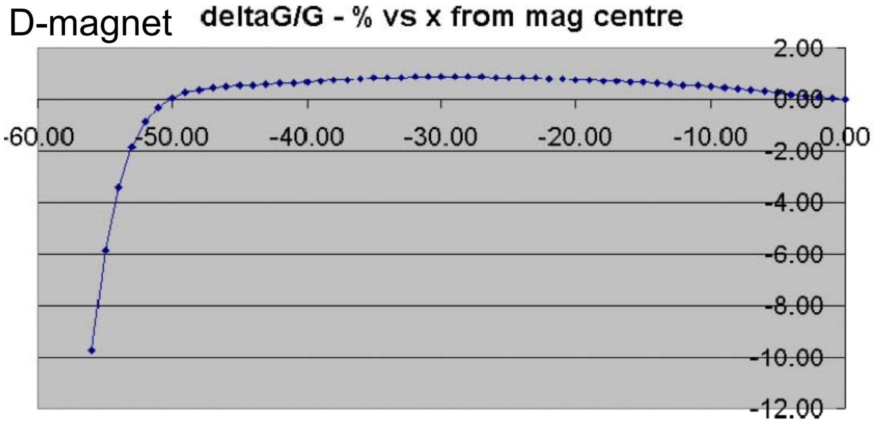
Due to extreme compactness of lattice, D & F magnets

- Are in very close proximity. Consequence: field computation and measurement with both magnets in place has been essential. Results from the prototype measurements have been implemented in the lattice simulations
- Are short compared with aperture. Consequence: integrated strength is dominated by end-field contributions

Prototype Ring Magnets



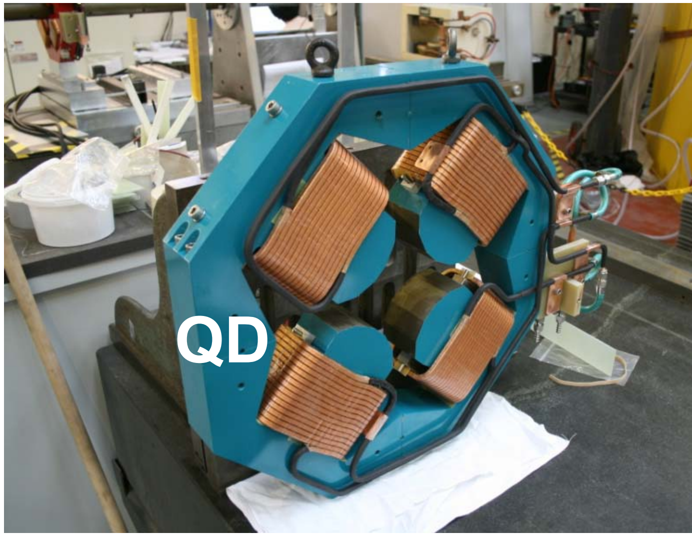


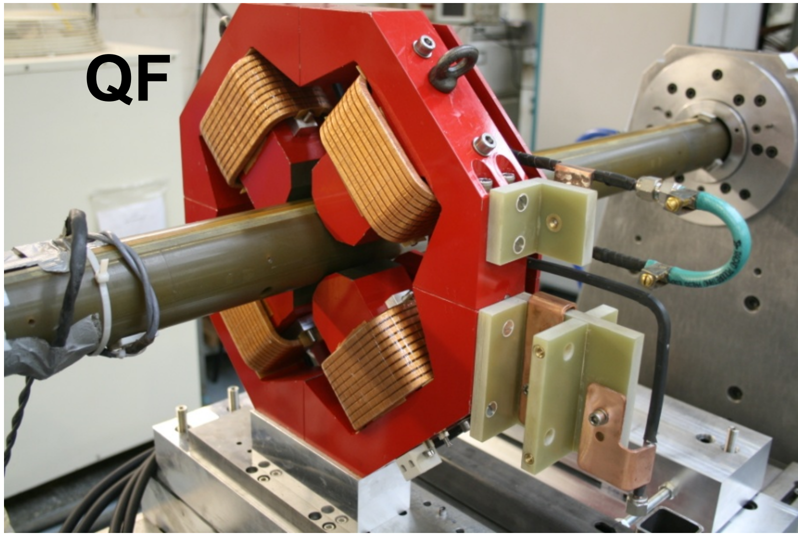


- Good field gradient quality requirement is ± 1.0% over a good gradient region of
  - QF +15.8, -32.0
  - QD - 56.0 , -9.9 mm

Production Quadrupoles

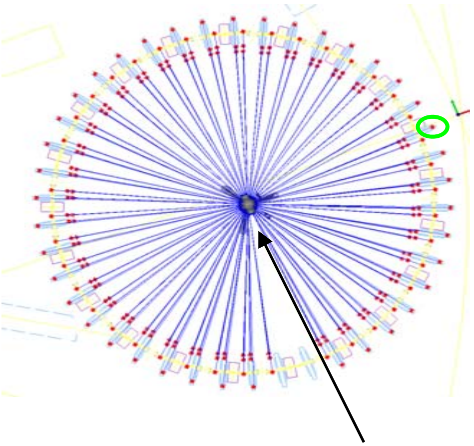
- Magnet construction is complete and magnet measurements are in progress
- Delivery of 1st batch of QF magnets ere received in December 08



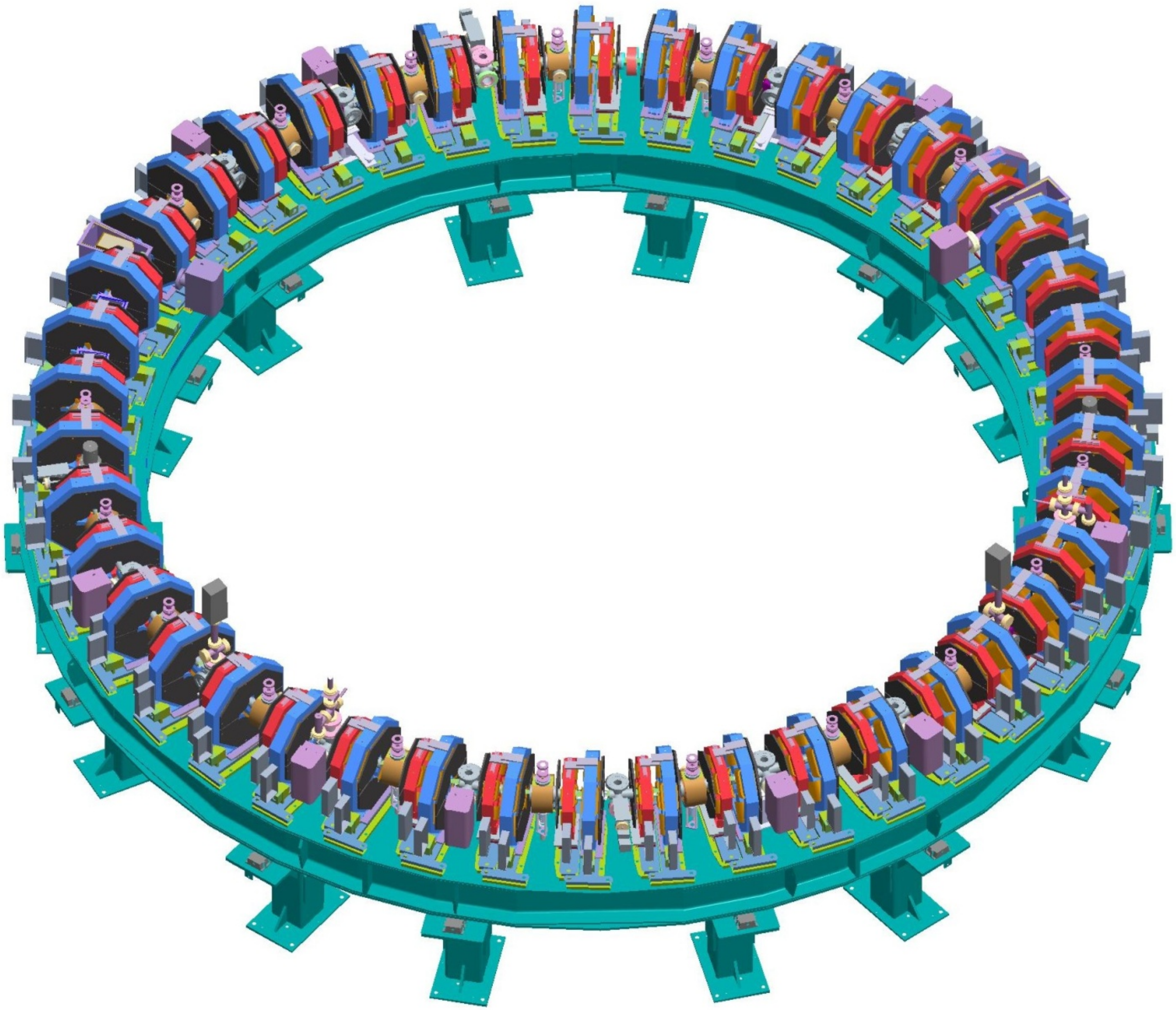


Magnet Alignment

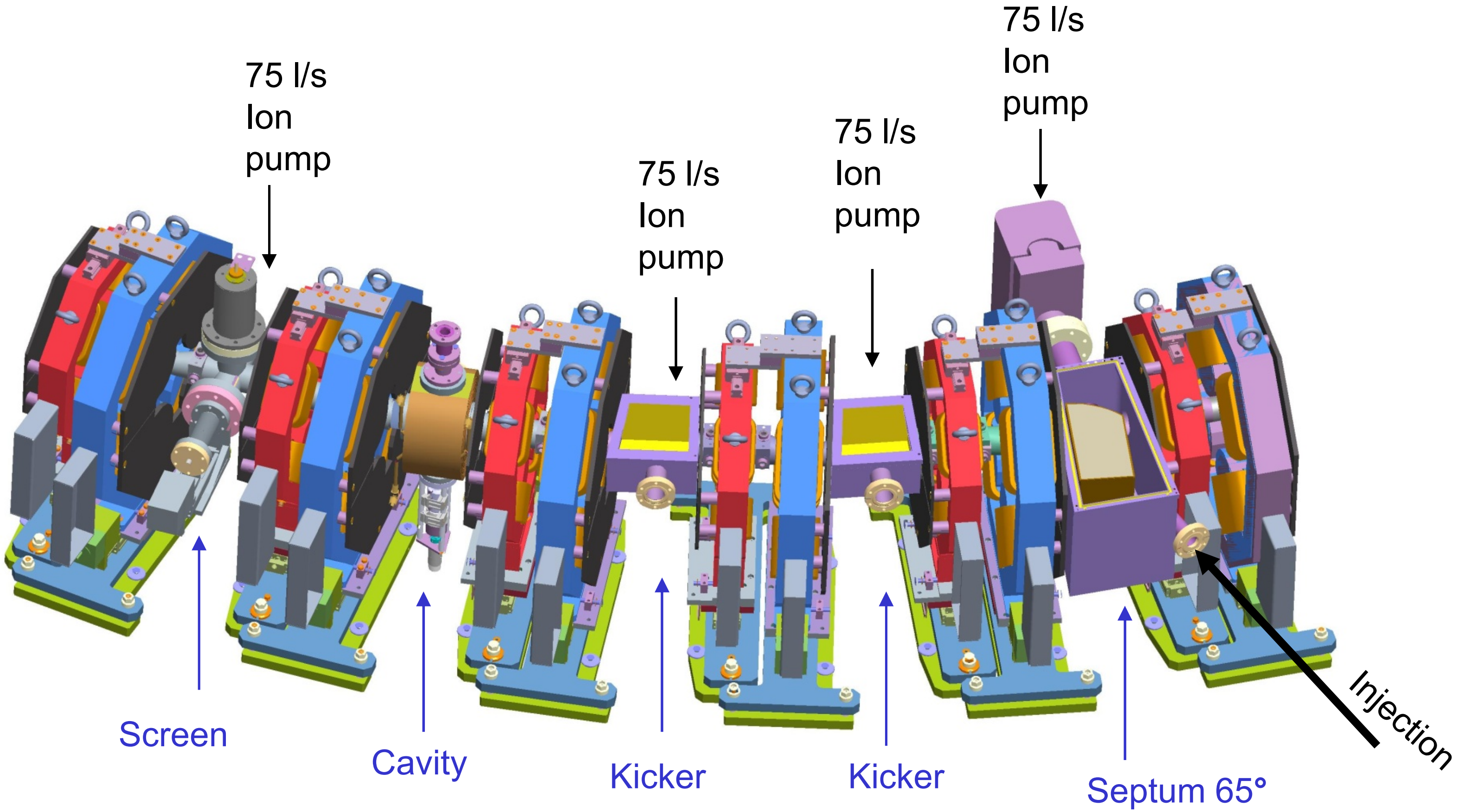
- Magnetic centre fiducialisation **+/- 25µm (1σ)**
- Individual Magnet alignment **+/- 25µm (1σ)**
- Accurate transfer of magnetic centre to the survey fiducials on the EMMA magnets is essential
- Keep centre of the ring clear for laser tracker lines of site



Single laser tracker position



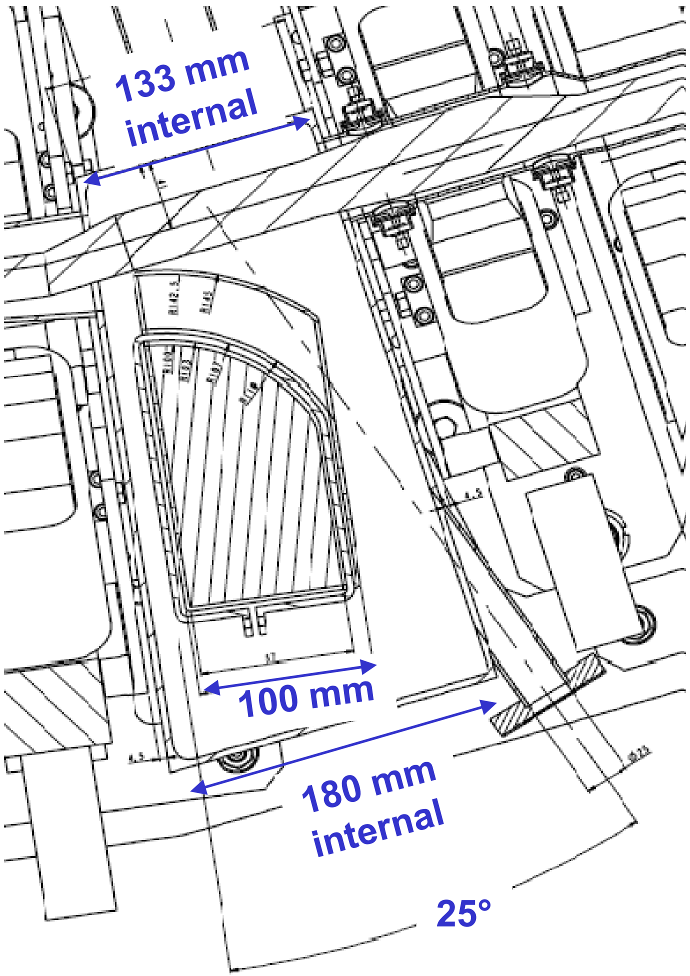
Injection Region



Opposite kicker, kicker septum arrangement for extraction

Injection Septum 65°

- Large angle for injection (65°) and extraction (70°) very challenging !!
- Injection/Extraction scheme required for all energies 10 – 20 MeV, all lattices and all lattice configurations
- Minimise stray fields on circulating beam
- Space very limited between magnet clamp plates for the septum construction



Parameters

Current pulse: 25 μs half-sine-wave
Radial aperture w=40 mm
Vertical aperture h=25 mm
Pole area S=3862 mm^2
Max. flux density Bmax=0.83T

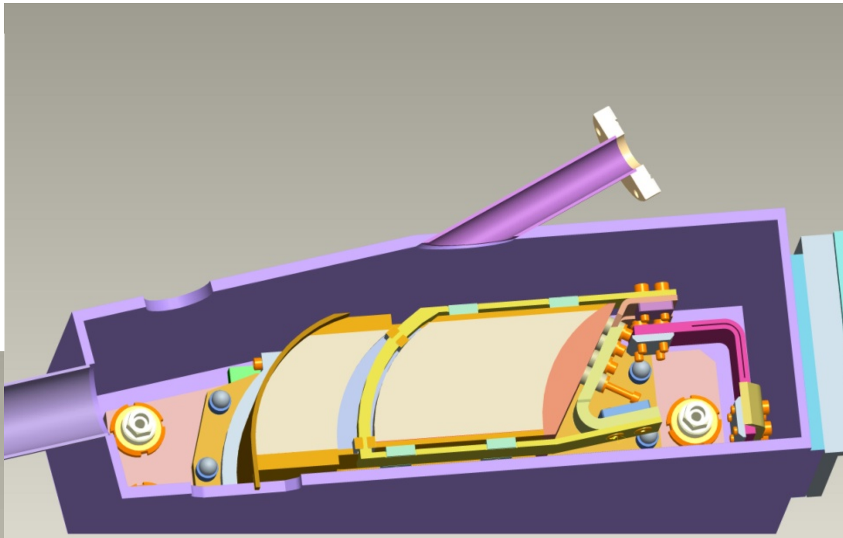
Max current (@ Bmax) $I_{max} = \frac{Bh}{\mu_0} = 16.5kA$

Septum inductance $L_s = \frac{\mu_0 S}{h} = 0.19\mu H$

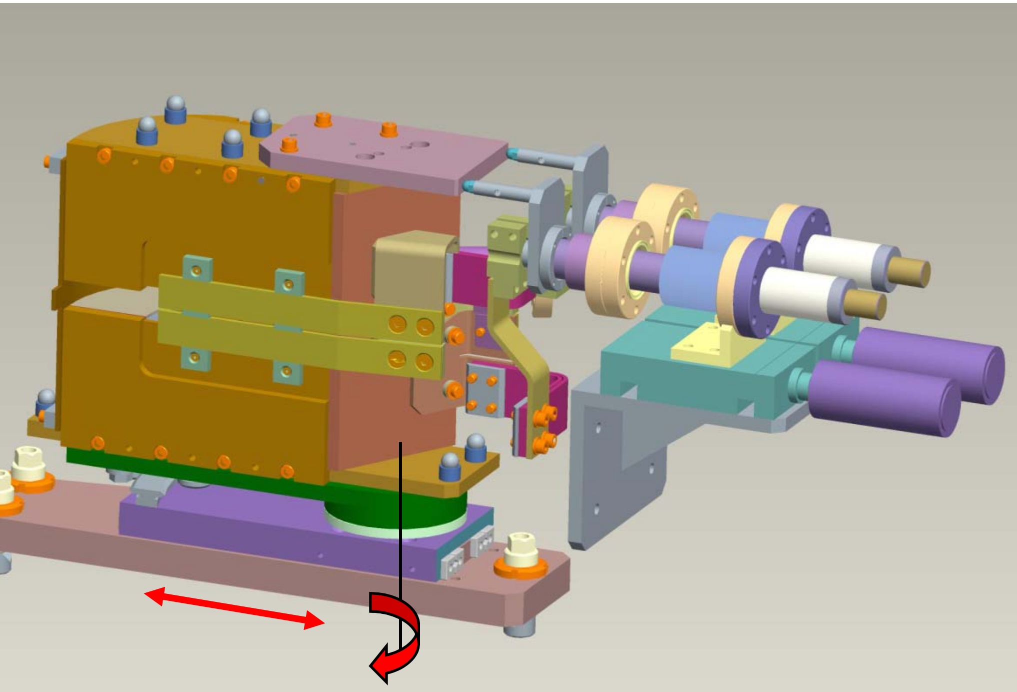
Max. voltage (@ Bmax) $V_{max} = I_{max} \frac{10^6 \pi}{25} L = 403V$

Septum Design

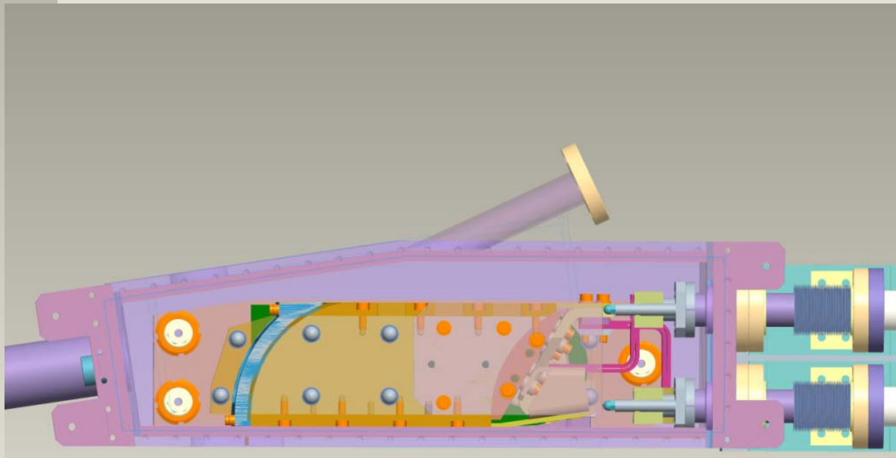
- In house design of septum and vacuum chamber in progress
- Wire eroding of lamination stacks scheduled for February, steel delivered.
- Magnet measurements scheduled for April 09



Section view of septum in vacuum chamber

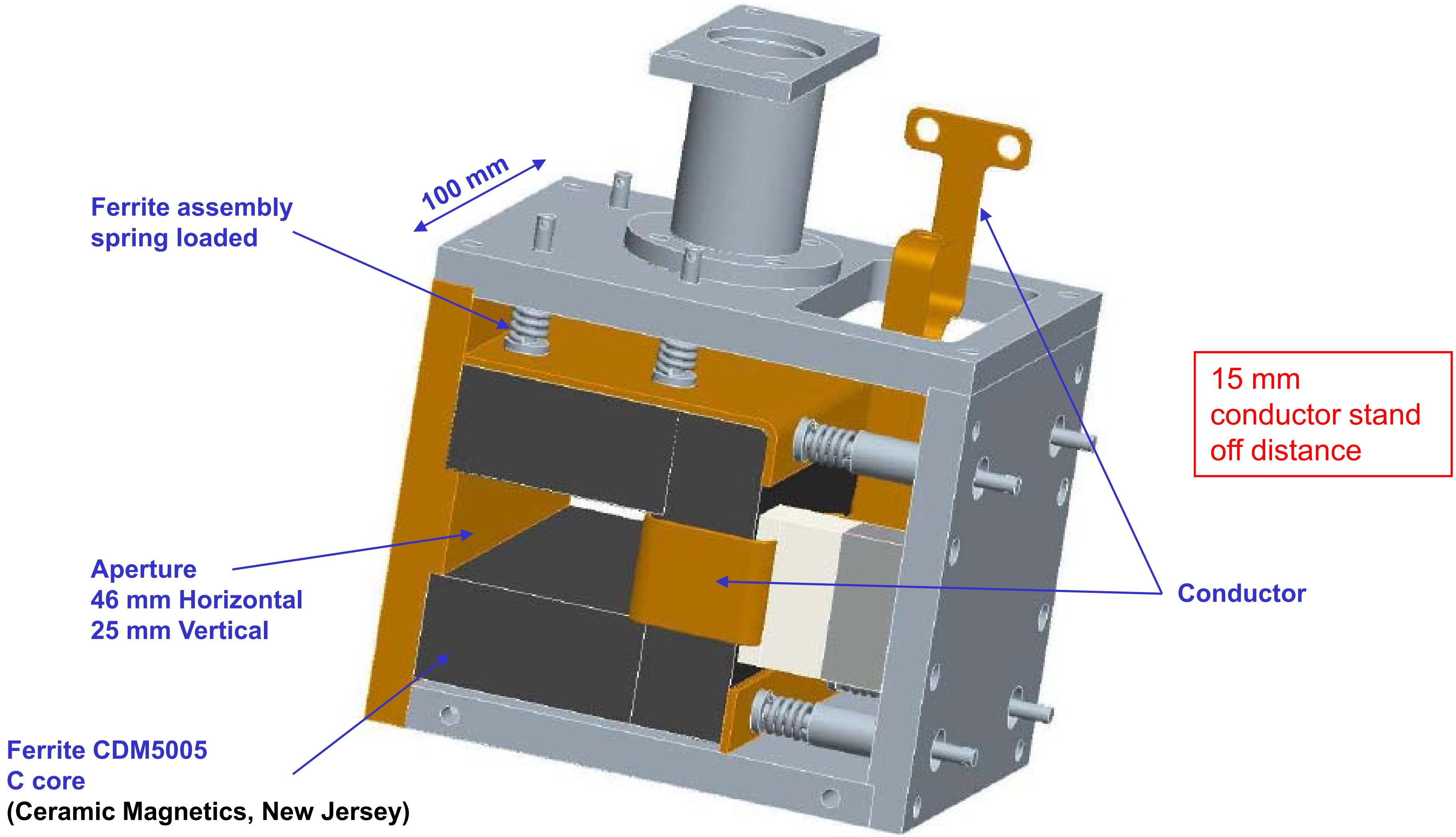


ISO view of septum with vacuum chamber removed



Plan view of septum in vacuum chamber

Kicker Magnet Design

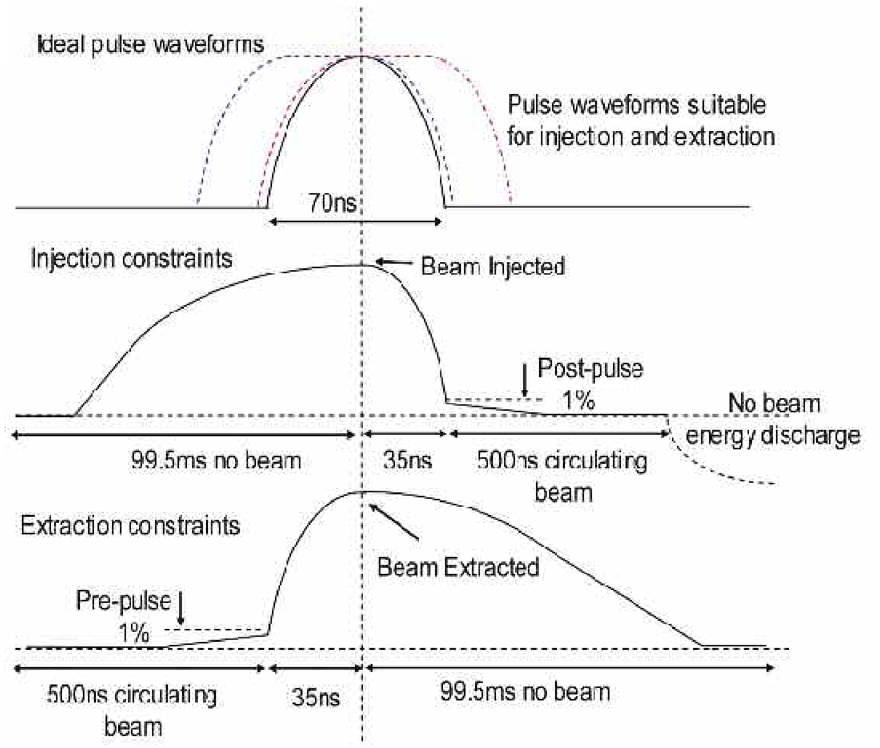


EMMA Kicker Magnet Fast Switching

Magnet length	0.1m
Field at 10MeV (Injection)	0.035T
Field at 20MeV (Extraction)	0.07T
Magnet Inductance	0.25μH
Lead Inductance	0.16μH
Peak Current at 10/20MeV	**1.3kA**
Peak Voltage at Magnet	14kV
Peak Voltage at Power Supply	23kV
Rise / Fall Time	**35nS**
Jitter pulse to pulse	**>2nS**
Pulse Waveform	Half Sinewave

Kicker Magnet Power Supply parameters are directly affected by the compact design and require:

- Fast rise / fall times 35 nS
- Rapid changes in current 50kA/μS
- Constraints on Pre and Post Pulses



Applied Pulse Power Collaboration

Design and construction of thyristor prototype units using magnetic switching and Pulse Forming Network techniques

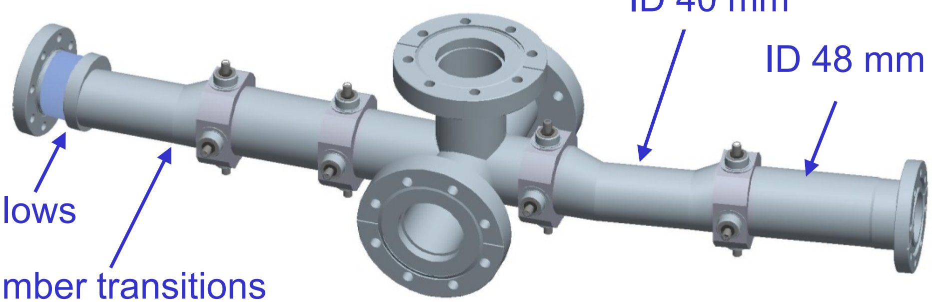
Science & Technology Facilities Council

BASROC CONFORM

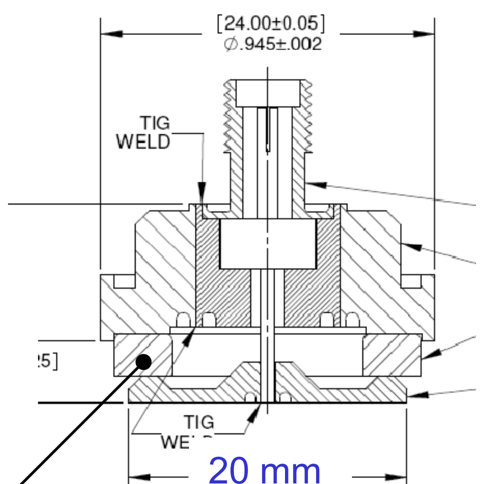
Vacuum chamber & BPM

- Contract placed for BPM pickups with Testbourne. Delivery November 2008
- Contract placed with VG Scienta for the vacuum chambers. Manufacture in progress – Delivery – Jan 2009
- Clean vacuum testing & RGA cleanliness tests at the factory before delivery to Daresbury
- Particle processing at Daresbury

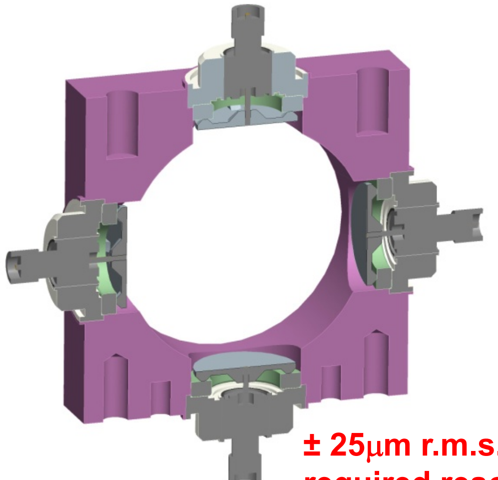
Standard vacuum chamber
for 2 cells. Circular cross-section
Material - stainless steel



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



BPM pickup cross-section

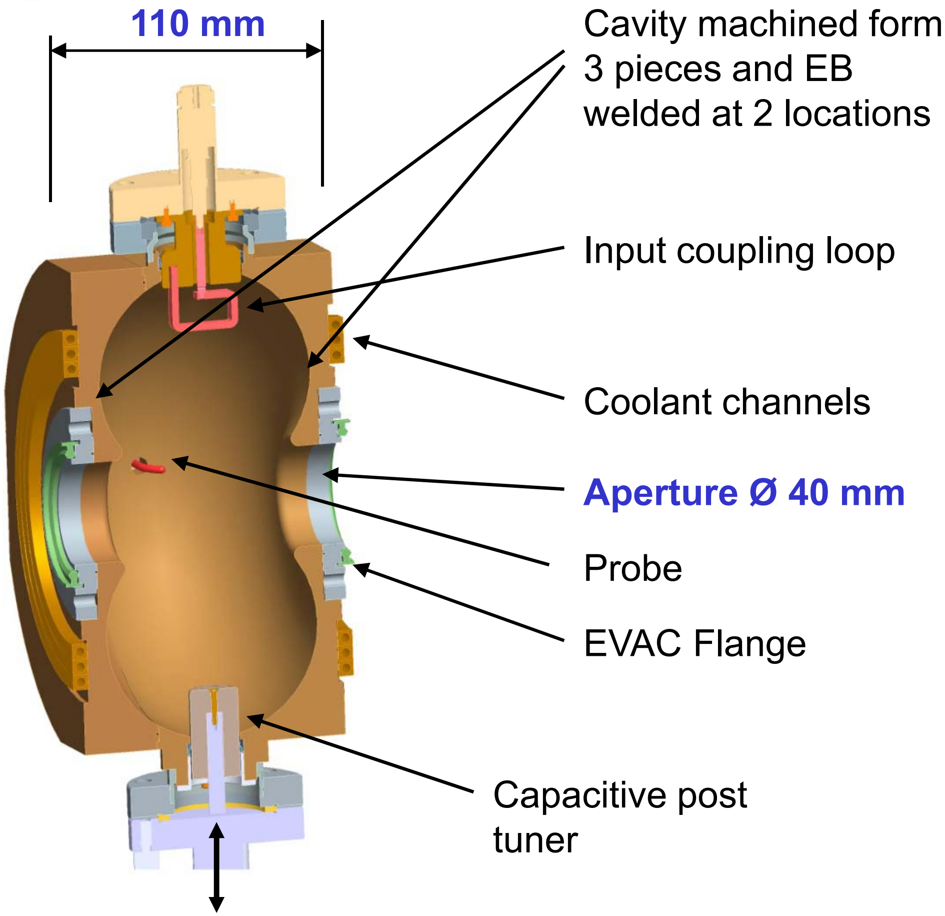


BPM block cross-section

RF Requirements

- Voltage:
  - 20 - 120 kV/cavity, based on 19 cavities
- 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 (1.295981 to 1.301554 GHz)
- Cavity phase:
  - Remote and individual control of the cavity phases is essential

Cavity Design



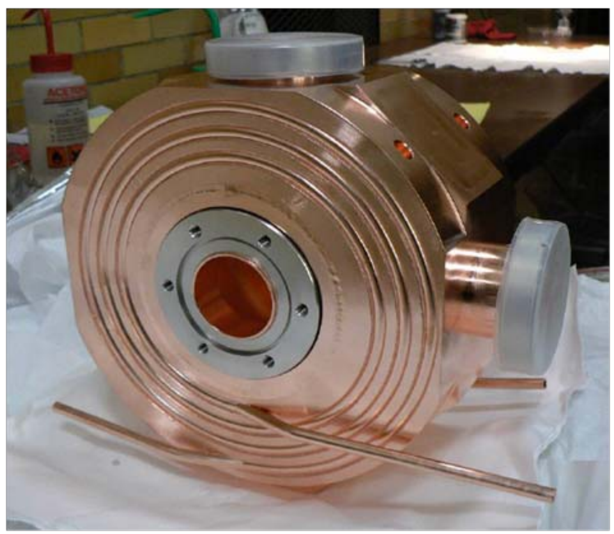
Normal conducting single cell re-entrant cavity design optimised for high shunt impedance

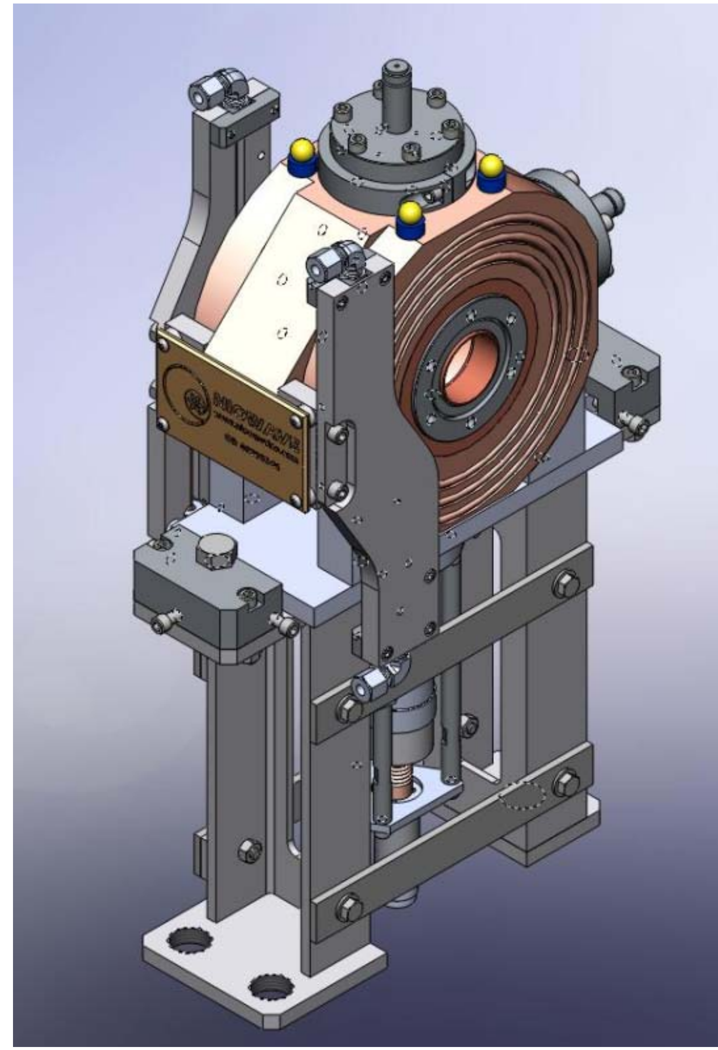
Parameter	Value	
Frequency	1.3 GHz	
Theoretical Shunt Impedance	2.3 MΩ	
Realistic Shunt Impedance (80%)	2 MΩ	
Qo (Theoretical)	23,000 (23000)	
R/Q	100 Ω	
Tuning Range	-4 to +1.6 MHz	
Accelerating Voltage	120 kV	180 kV
Total Power Required (Assuming 30% losses in distribution	90 kW	200 kW
Power required per cavity	3.6 kW	8.1 kW

Cavity Construction

Manufacture of prototype cavities complete

- Aluminium alloy cavity delivered in Jan 2008
- Copper cavity delivered in March 2008





Frequency
Tuning range
R/Q verification

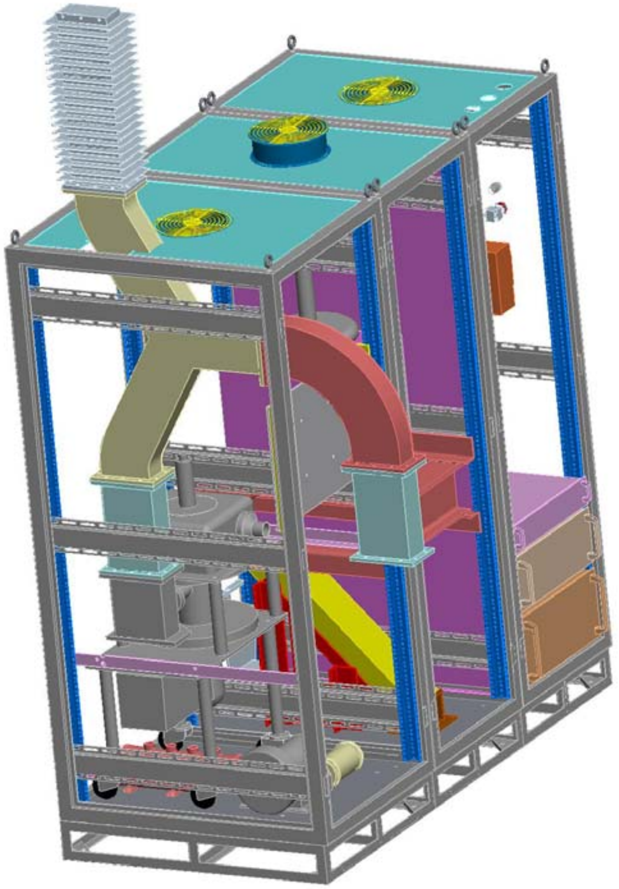
Production Cavities

20 (19 + spare) production cavity construction in progress

- Machining - complete
- EB welding - complete
- Brazing - complete
- Re measure Frequency & Q - complete
- Dimensional checks - complete
- Chemical etching – complete (Qo 18,500 to 20,400)
- Clean - complete
- Assemble and pump down - complete
- Measure F & Q - in progress
- Leak Check - in progress
- Bakeout - in progress
- RGA & vacuum measurement - in progress
- Delivery in batches from 7th Sep – 5th Feb 2009
- 3rd batch of 4 cavities complete

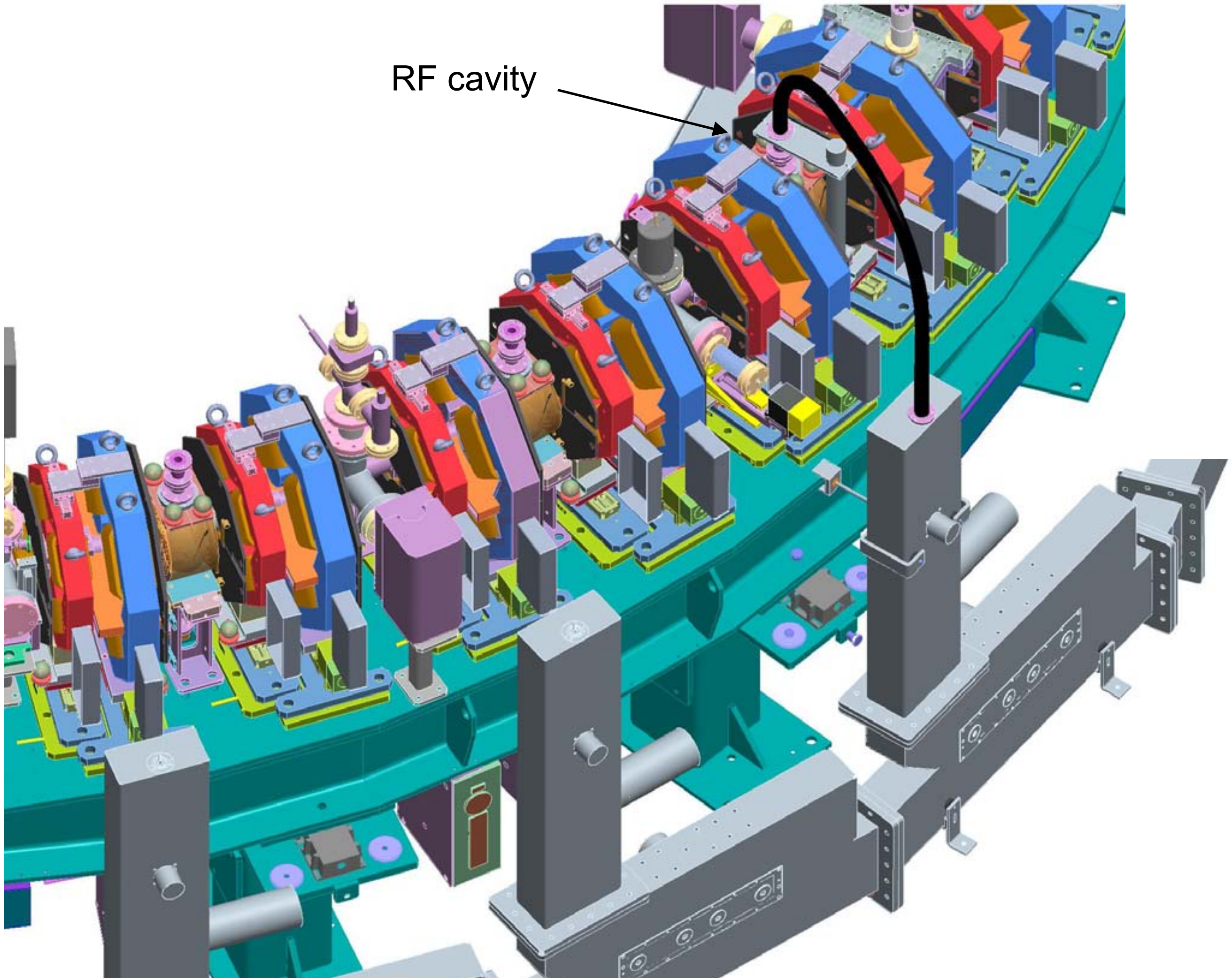
Input Coupler construction
(Times Microwave)
Delivery to Niowave - Complete

CPI IOT

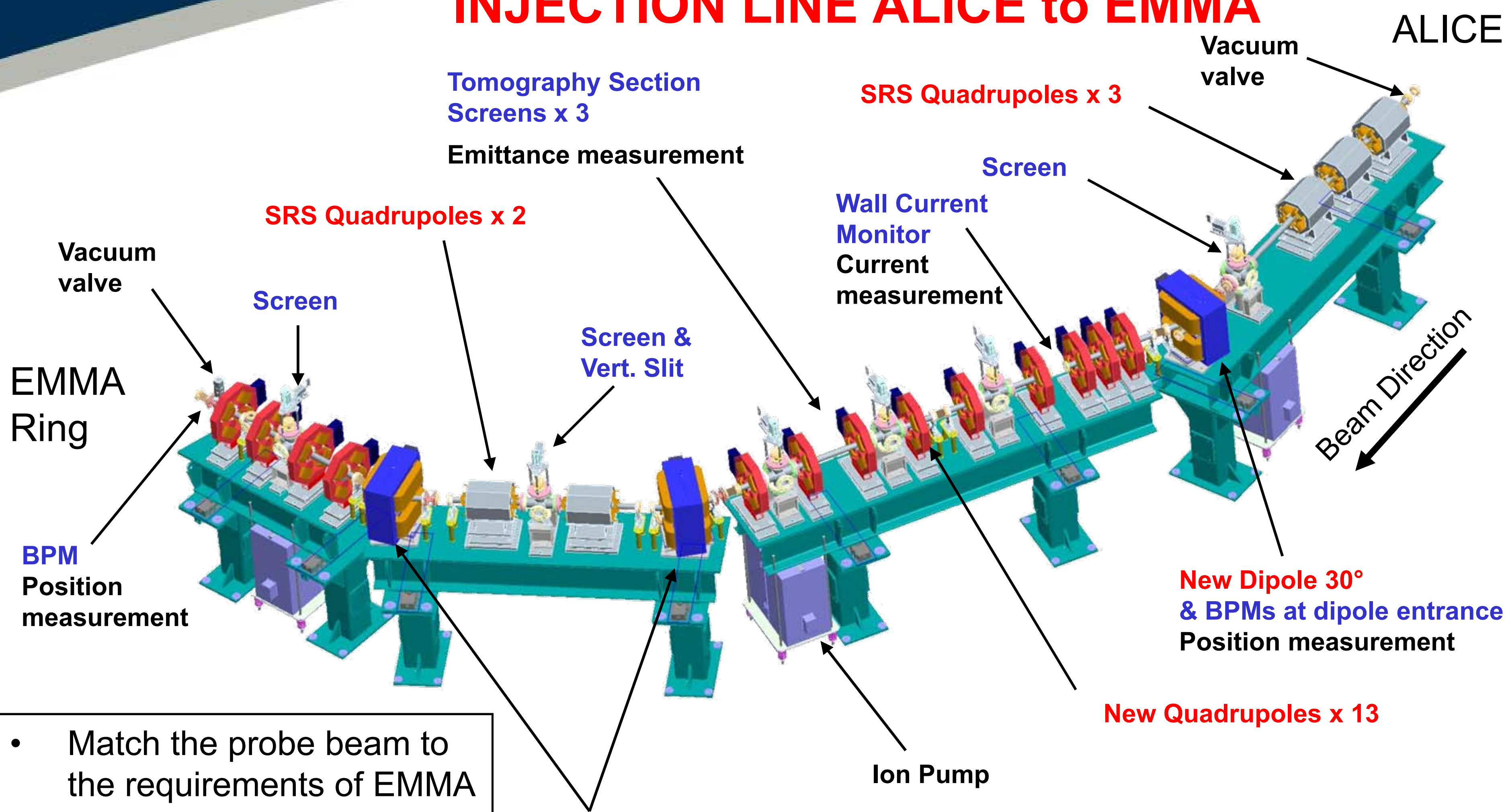


90 kW (pulsed)

Cascade RF Distribution



INJECTION LINE ALICE to EMMA



- Match the probe beam to the requirements of EMMA
- Measure the properties of the probe beam

DIAGNOSTICS BEAMLINE LAYOUT

New Quadrupoles x 4

SRS Quadrupoles x 6

Screen x 3
Tomography
Section
Emittance measurement

Spectrometer **Extracted momentum**
BPM @ dipole entrance
Screen
Faraday Cup

Screen
& Vert. Slit

BPM &
Valve

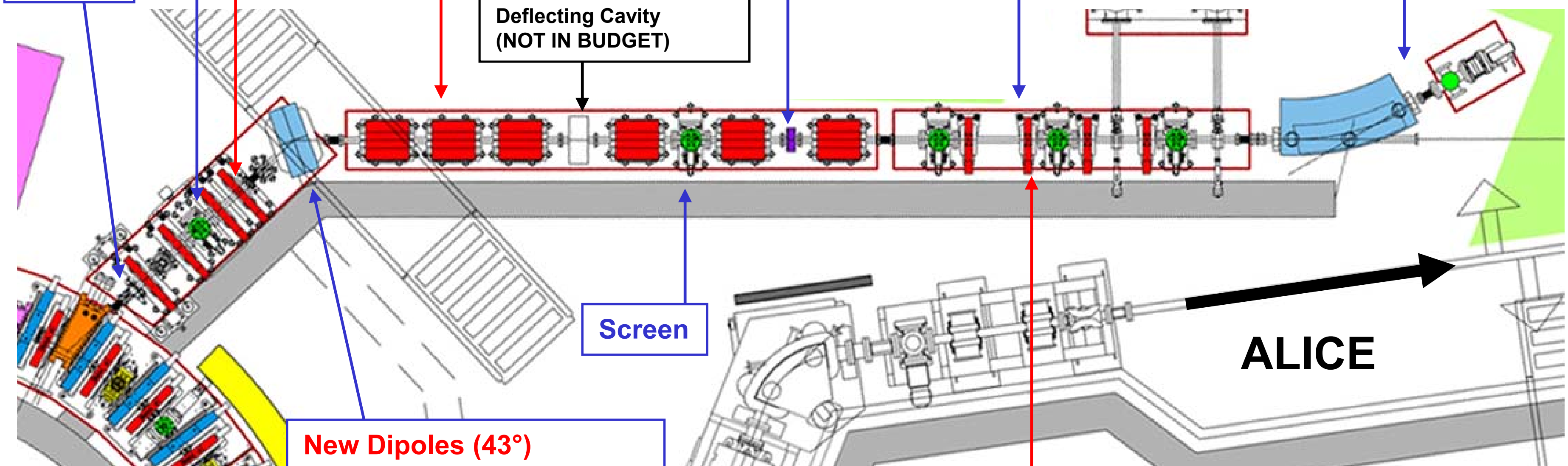
Wall Current Monitor

Current measurement

E-O Monitor

Longitudinal profile

Location for Transverse
Deflecting Cavity
(NOT IN BUDGET)



Screen

New Dipoles (43°)
& BPMs at dipole entrance

Position measurement

New Quadrupoles x 4

Milestones

ALICE shutdown (Cable management installation) Diamond drilling of ALICE wall, cable tray installation	25 Oct – 21 Nov 2008	1 month
Off line build of modules	Oct 2008 – Jun 2009	9 months
ALICE shutdown	1st Mar – 12th Apr 2009	6 wks
ALICE shutdown	8th Jun – 13th Jul 2009	5 wks
Installation in Accelerator Hall	Mar – Aug 2009	6 months
Test systems in Accelerator Hall	May - Oct 2009	6 months
Injection line and ring complete	31st Oct 09	
Commission with electrons starting	Nov 2009	

Summary

- Design phase is now well advanced
- Procurement is underway with major contracts placed
- Major components started to arrive in October 08, off-line build is in progress at Daresbury
- We aim to be commissioning with electrons at DL in November 2009
- Aim to demonstrate that non scaling FFAG technology works and compare results with the theoretical studies performed to gain real experience of operating such accelerators

Acknowledgements

- All the team
  - Internal STFC staff and
  - All the international collaborators
  - Commercial suppliers

ASTeC

Accelerator Science and Technology Centre

New Light Source Project

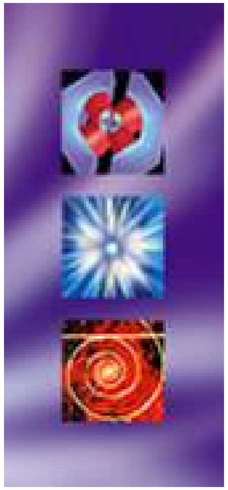
Design Options for the New Light Source

Susan Smith

ASTeC, STFC Daresbury Laboratory

& Cockcroft Institute

(on behalf of the NLS design team)



The Cockcroft Institute of Accelerator Science and Technology

Science & Technology Facilities Council Daresbury Laboratory

New Light Source Project

New Light Source Project

- STFC-led project to examine and propose a 4th Generation synchrotron user facility for the UK with unique and world leading capabilities (NLS is a working title)
- Three stages:
  1. *Science Case*
  2. *Technical Design Study*
  3. *Funding and Location*
- Science Case presented to STFC - PALS on 15rd Oct (www.newlightsource.org). From executive summary…
  - **IMAGING NANOSCALE STRUCTURES:** Instantaneous images of nanoscale objects can be recorded at any desired instant allowing, for example, nanometer scale resolution of sub-cellular structures in living systems.
  - **CAPTURING FLUCTUATING AND RAPIDLY EVOLVING SYSTEMS:** Rapid intrinsic evolution and fluctuations in the positions of the constituents within matter can be characterized.
  - **STRUCTURAL DYNAMICS UNDERLYING PHYSICAL AND CHEMICAL CHANGES:** The structural dynamics governing physical, chemical and biochemical processes can be followed by using laser pump- X-ray probe techniques.
  - **ULTRA-FAST DYNAMICS IN MULTI-ELECTRON SYSTEMS:** New approaches to measuring the multi-electron quantum dynamics, that are present in all complex matter, will become possible.
- Outcome: Phase 2 Technical Design Study to go ahead ☺

New Light Source Design Team

New Light Source Project

- STFC-led collaboration involving (pretty much) all players in the UK (named persons contributed directly to this talk)

Science & Technology Facilities Council Daresbury Laboratory

• P Williams, S. Appleton, P. McIntosh, J. McKenzie, B. Militsyn N. Thompson

diamond

• R. Bartolini, Jang-Hui Han, R. Walker

MANCHESTER 1824 The University of Manchester

The Cockcroft Institute of Accelerator Science and Technology

• H. Owen

Science & Technology Facilities Council Rutherford Appleton Laboratory

University of Strathclyde

• B. McNeil

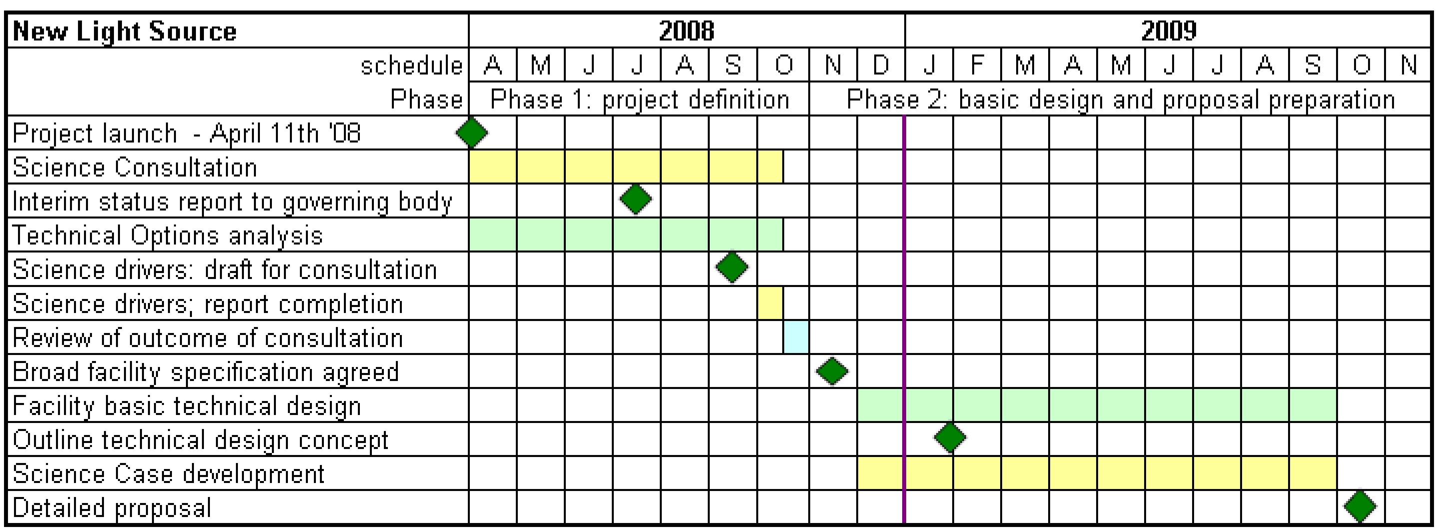
NLS Technical Design Study

New Light Source Project

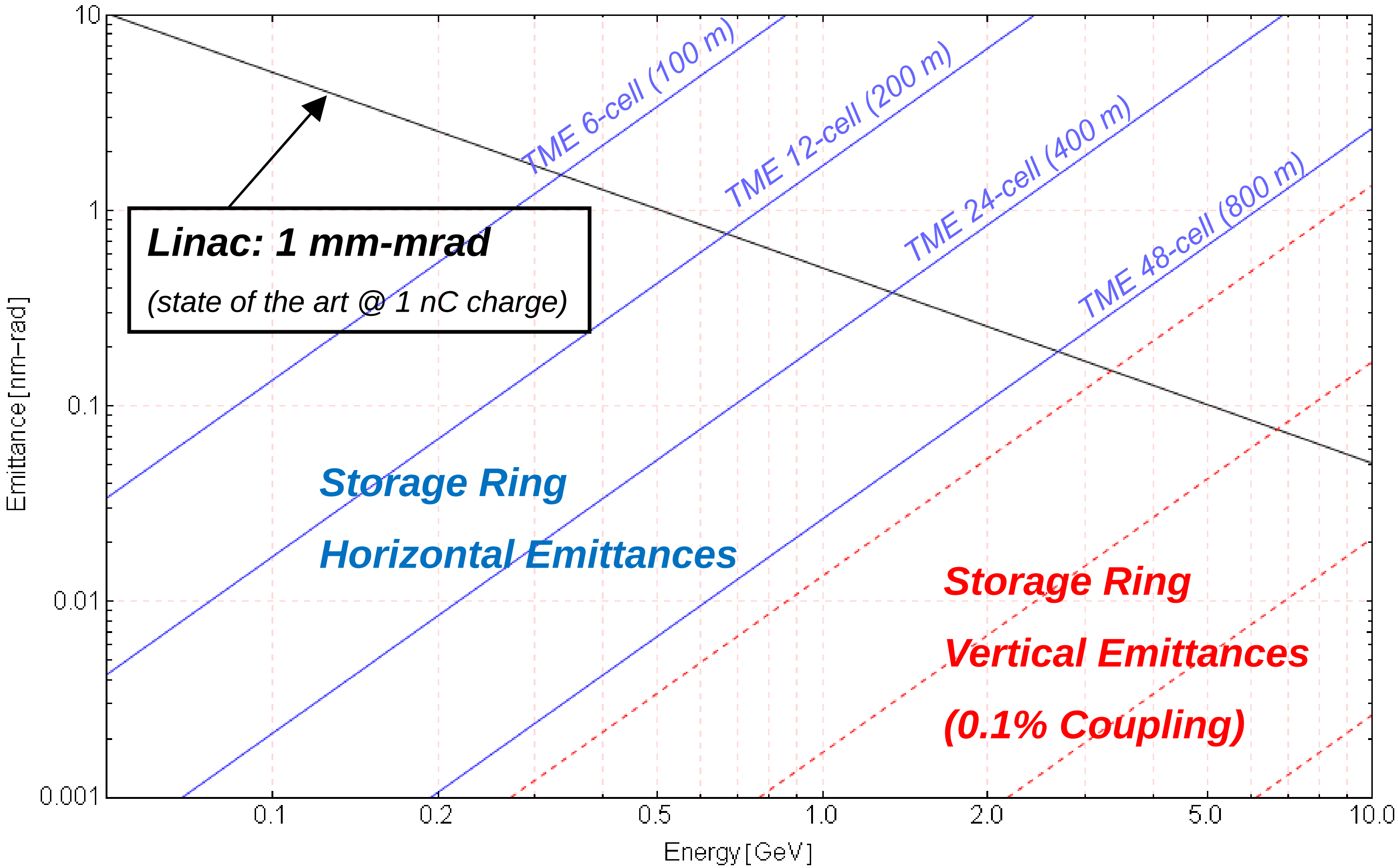
- NLS is likely to be a coupled set of facilities including conventional lasers (high field/ultra-short pulse), long wavelength sources and at its core a short wavelength (<100nm) free electron laser

- Facility requirements presented in Science Case
  - *Photon energies tuneable over the range from THz/IR through to soft X-ray*
  - *Two-colours (i.e. UV/Vis or IR/THz synchronised with soft X-ray pulses)*
  - *Ultra-fast pulses with duration down to sub-femtosecond range*
  - *High temporal and transverse coherence*

- Decision Nov to propose a high rep. rate machine (>1kHz) based upon a Superconducting Linac – high rep rate pushed by users.



Transverse Brightness $\Rightarrow$ Not a Storage Ring!

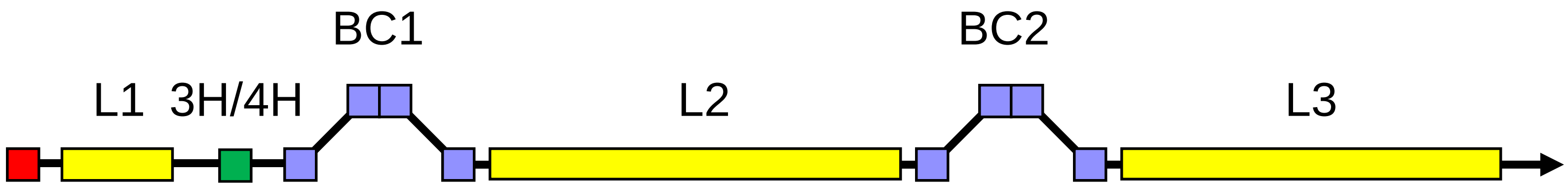


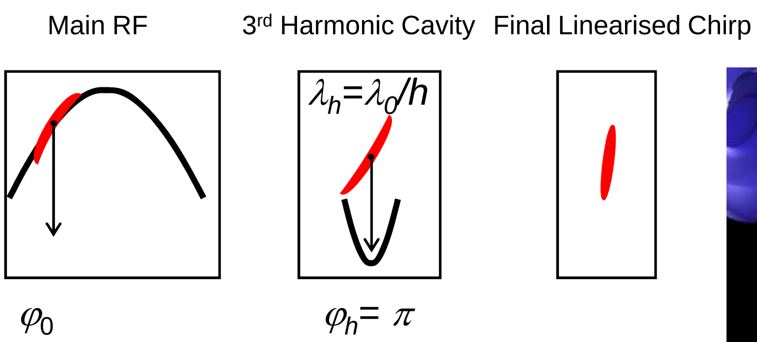
TME (theoretical minimum emittance) is the smallest emittance possible in a ring, based on minimising $H = \gamma D_x^2 + 2\alpha D_x D'_x + \beta D'^2_x$

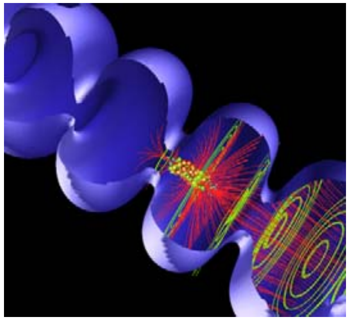
$$I_5 = \oint \frac{H}{\rho^3} ds \qquad \epsilon_x = C_q \frac{\gamma^2}{J_x} \frac{I_5}{I_2}$$

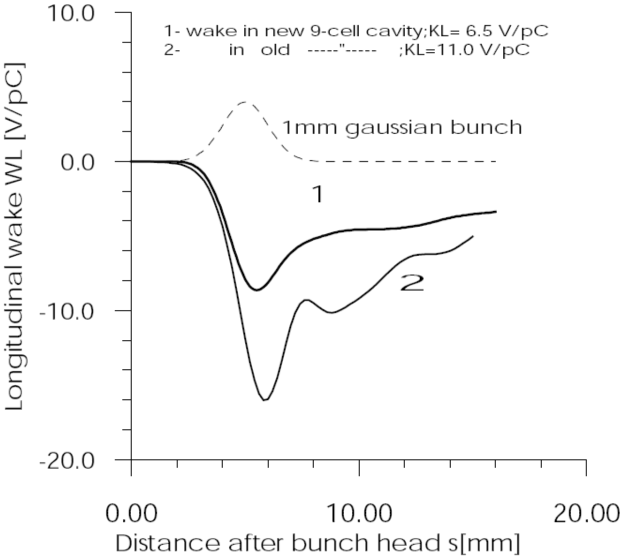
Courtesy Hywel Owen

Compression Scheme Design Non-Trivial

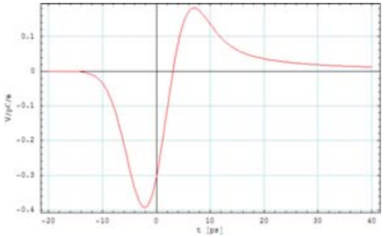




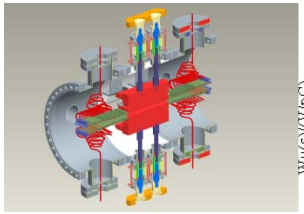




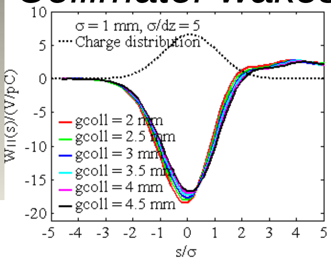
$$W \sim -d\lambda(s)/ds$$



Resistive wall wakes



Collimator wakes



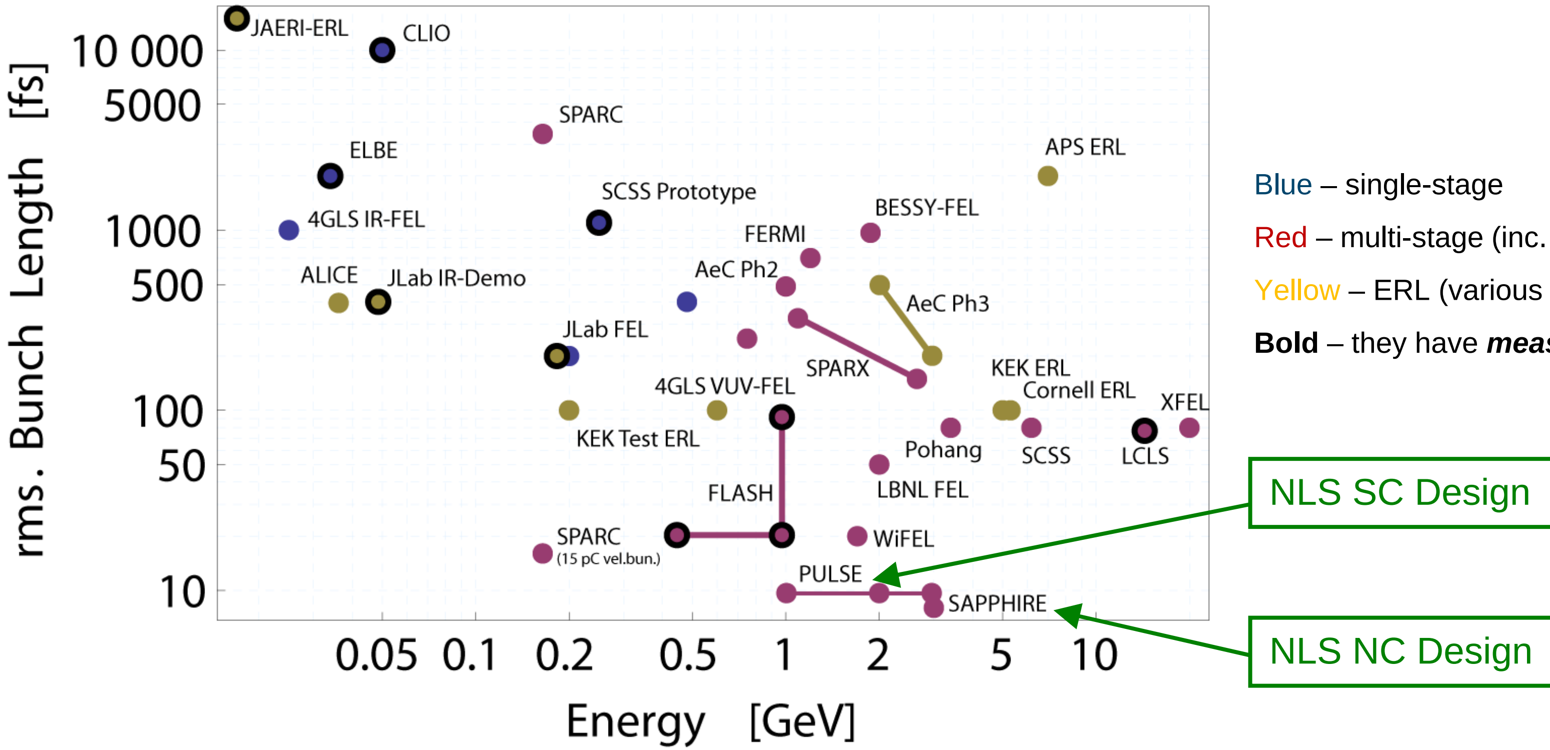
Longitudinal cavity wake

E.g. Trade off large CSR in transporting short bunch with jitter caused by large R56

Courtesy Hywel Owen

4th Generation Machines Worldwide

New Light Source Project



Blue – single-stage

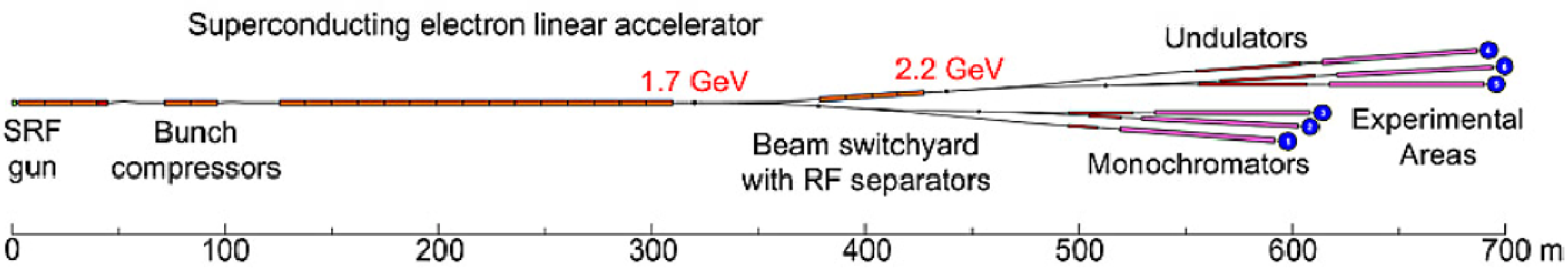
Red – multi-stage (inc. harmonic correction)

Yellow – ERL (various methods)

Bold – they have ***measured*** that bunch length

- Users want 1kHz rep. rate, 20fs pulses, 3 GeV ideally
- Our initial interpretation, a ~1 GeV SC linac, upgradable to 3 GeV
- Other approach, a 3 GeV NC linac (R. Bartolini)
- Recirculating option being developed

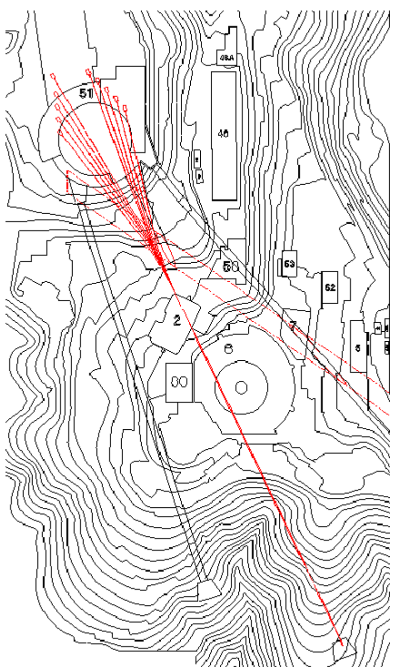
Similar Schemes to a SC NLS



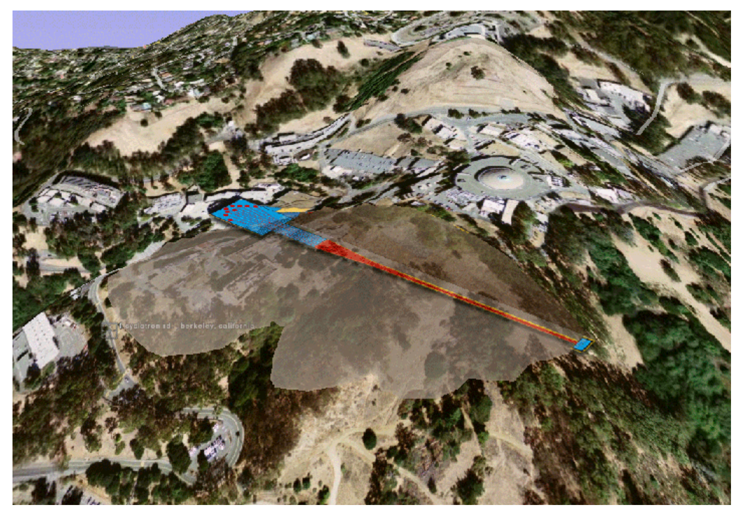
Both about 2 GeV

WiFEL

Both about 600 m (facility)

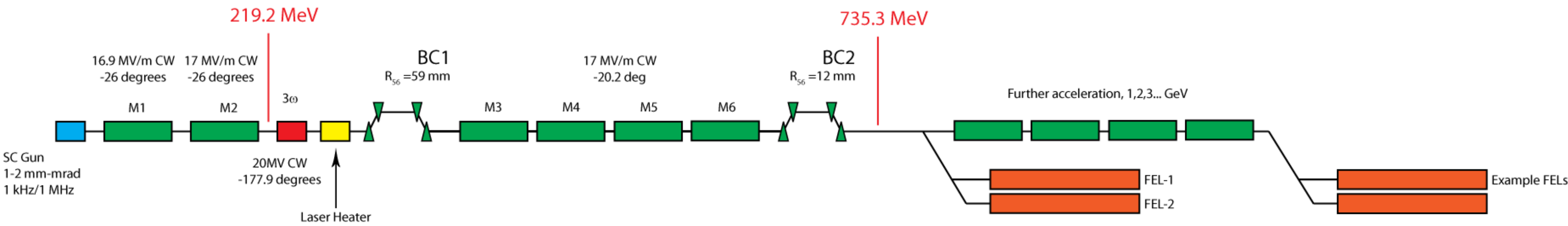


LBNL



An NLS SC Design (Hywel Owen and Peter Williams)

New Light Source Project



• 735 MeV chosen as it corresponds to 1 nm, the limit for HHG seeding i.e. this is a possible extraction energy where we want short bunches

• Compression scheme must be carefully designed – linearisation, cavity wakefield compensation, CSR, LSC

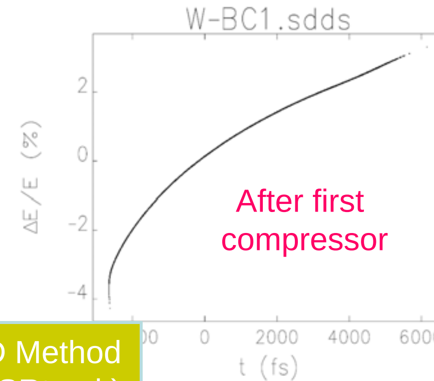
• 200 pC bunch charge chosen, based injector on XFEL

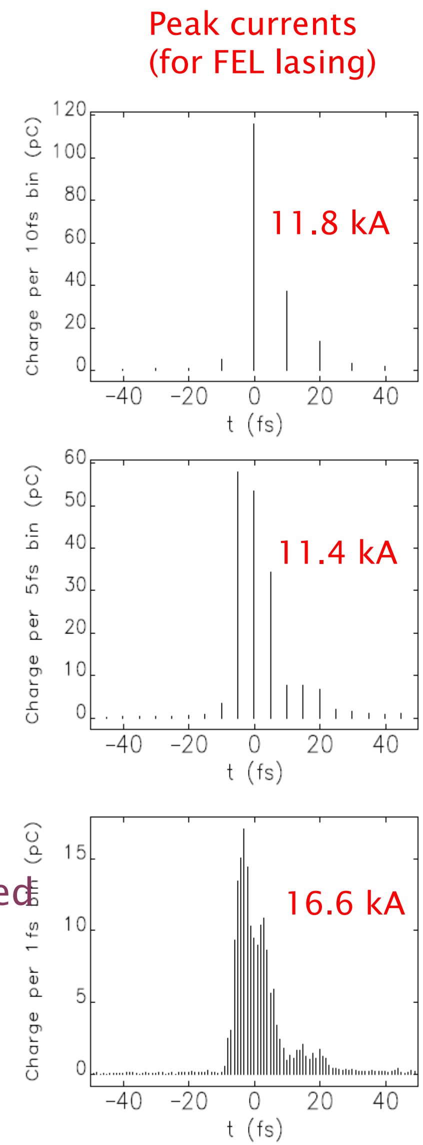
EPAC08: MOPC034, MOPC035 available at www.jacow.org
PR-STAB in preparation

Parameter	Value
Bunch Charge	200 pC
Fundamental RF	1.3 GHz
Bunch Rate	1 kHz to 1 MHz
Gradient	17 MV/m
3.9 GHz Total Voltage	20 MV
Transverse Slice Emittance	< 2 mm-mrad
rms Energy Spread	4.1 MeV
Bunch Length	10 fs

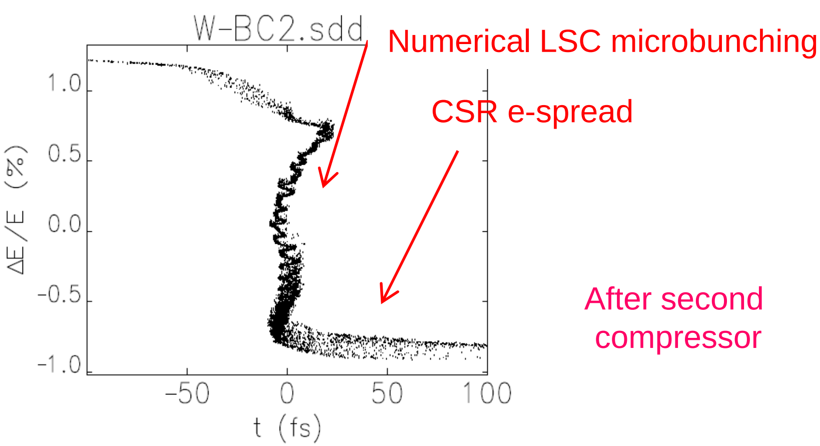
An NLS SC Simulation – The Upright Bunch

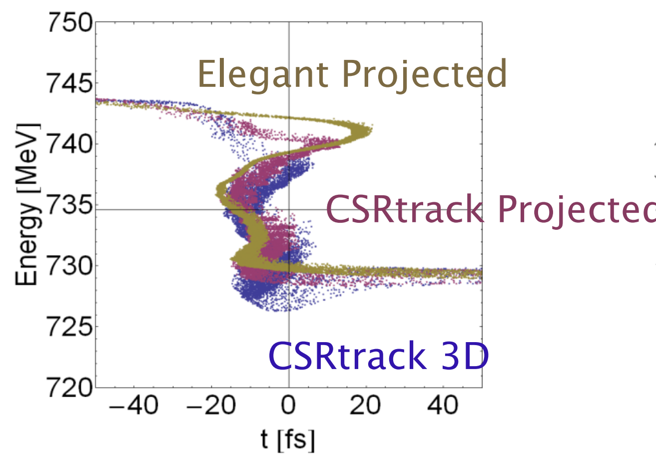
Central Bin Width	Slice Emittance	Charge	Equivalent Current
1 fs	1.32 mm-mrad	16.9 pC	16.9 kA
5 fs	1.43 mm-mrad	57.5 pC	11.5 kA
10 fs	1.91 mm-mrad	104 pC	10.4 kA





Parameter	Projected (ELEGANT)	3D Method (CSRtrack)
Projected Emittance	2.98 mm-mrad	4.95 mm-mrad
Slice Emittance (5 fs)	1.43 mm-mrad	1.85 mm-mrad
Slice Energy Spread (5 fs)	0.29 %	0.27 %
Peak Current (1 fs)	16.6 kA	14.5 kA



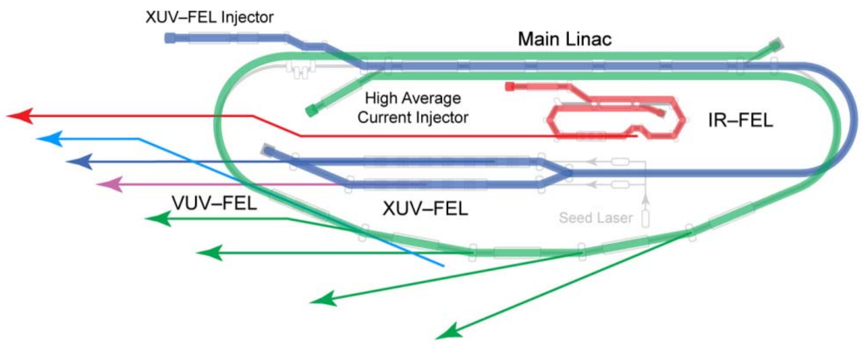


NLS Future Work: Questions For Upright Bunch

- How does the current spike survive misalignments? (probably not well)
- What about timing jitter? Keep BC2 R56 low, but still…
- How does microbunching limit an upright bunch? After all, the microbunching is now ‘sideways’.
- 200 pC was used in these simulations – what is the best charge to use? It seems that there is a weak scaling of peak current with total bunch charge.
- What is the best way of managing wakefields when compressing?
- Might it be sensible to consider a multi-frequency design, to benefit from higher gradients at higher frequency? (e.g a C-band or X-band light source). Not favoured at present

NLS Current Work: Recirculation

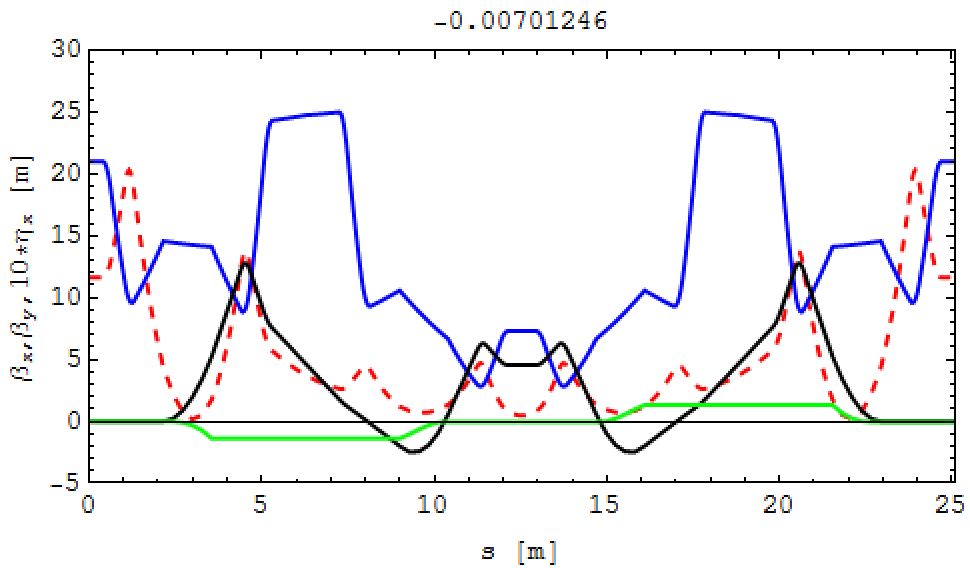
- Users want high rep. rate (> 1 kHz) ⇒ superconducting machine ⇒ capital expense
- Mitigation strategy – Recirculation
- Example: Build a 1 GeV SC linac as a first stage, recirculate to 2 (3) GeV.
- Possible issues:
    - Compression Scheme (no ~10 fs bunches at high energy – do we need this)
    - Emittance Degradation (CSR, ISR, LSC) due to arcs
    - Beam Break Up
    - High Energy Diagnostics
    - Linearisation
    - Jitter due extra transport

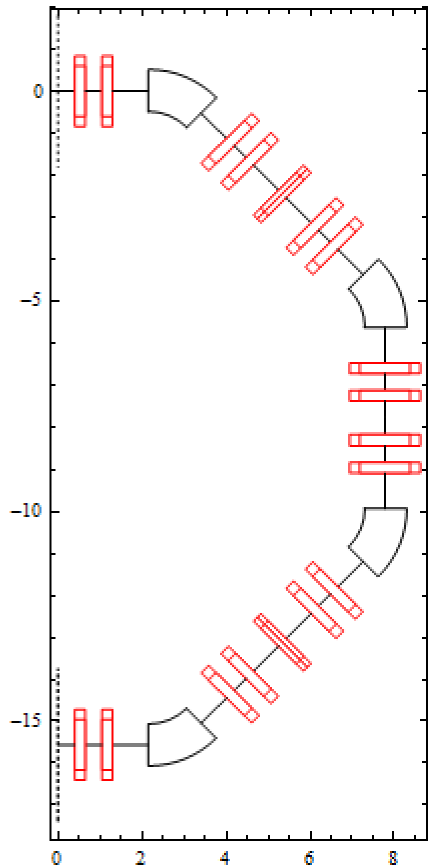


- Investigation of these underway based on 4GLS-XUV arcs

NLS Current Work: Recirculation

- Regular FODO channel – eventually rejected for 4GLS-XUV (size, non-zero R56)
- Went to a zero R56 compact QBA design
- GA optimisation algorithm by James Jones, Daresbury





NLS Current Work: Recirculation

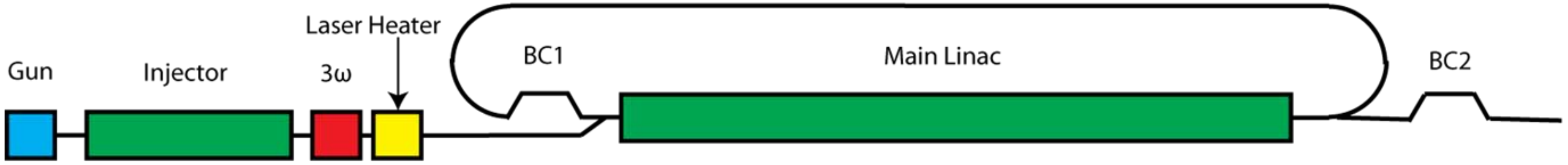
• Do some simple-minded 1-d longitudinal phase space transformations… an example…

• Assume a transport rather than dog-bone to start with. Should we minimise CSR in arc by keeping bunch as long as possible in the first pass by putting first compression after all arcs?

• Answer is no! Cannot linearise. However microbunching MAY require BC1 @ > 250 MeV

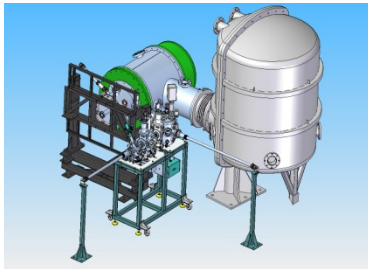
• Why? See Yujong Kim's talk at microbunching instability II workshop *"Solutions against COTR in LCLS and design concepts of XFEL driving Linacs"*

• Also 1st pass = 1 GeV, but 2nd pass = 1.7 GeV



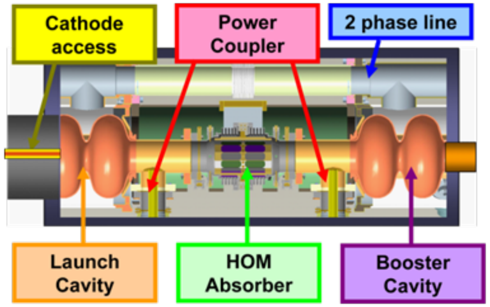
NLS High Rep. Rate (to GHz) Photoinjector Options

1. HV DC gun: Status - operational in user facilities. Experience with technology at DL. Lower emittance due to lower field strength (10MV/m) at cathode. Need XHV vacuum and have HV issues ie ceramic insulator. Can use GaAs photocathodes + others.



2. VHF NC RF gun: Status - design studies (LBNL). ~100MHz gun, similar beam transport/dynamics to DC gun but due to higher field strength (20MV/m) at cathode have lower emittance. NC-RF technology is well established. Cannot use GaAs so use multi-alkali photocathodes such as K2CsSb.

3. SRF gun: Status - under commissioning (ELBE). Don't require a buncher/booster. Therefore less timing jitter but less tuneability. Perfomance limit is the amount of power you can couple in. Up to 50MV/m should be possible giving very low emittance beam. Cannot use GaAs, probably use Cs2Te

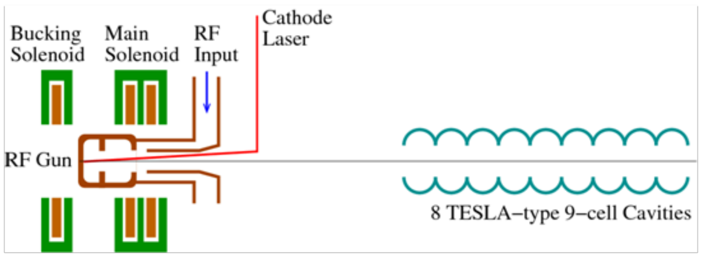


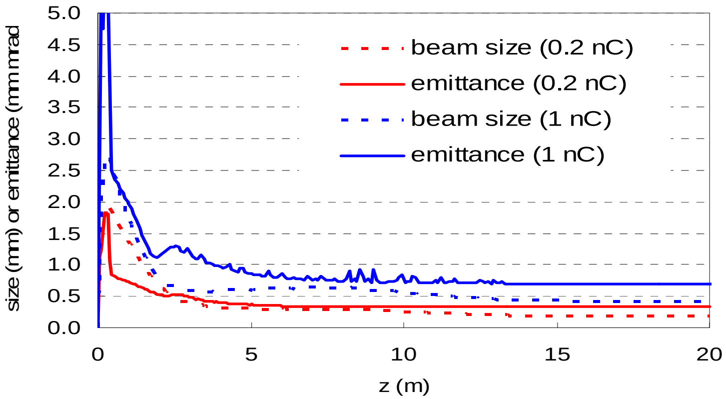
	DC	VHF	SRF
Projected emittance (mm·mrad)	1.95	1.08	0.84
Slice emittance (mm·mrad)	1.2	0.8	0.4
Bunch length (mm)	1.72	1.3	1.67
Longitudinal emittance (keV·mm)	295	115	198
Beam energy (MeV)	120	117	118

Linac 2008 TUP042: Boris Militsyn, Carl Beard, Julian McKenzie – Daresbury

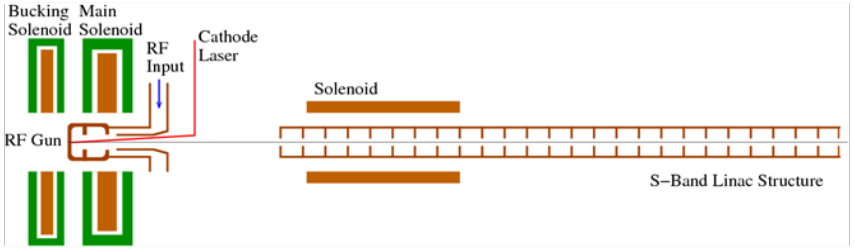
NLS Low Rep. Rate (to kHz) Photoinjector Options

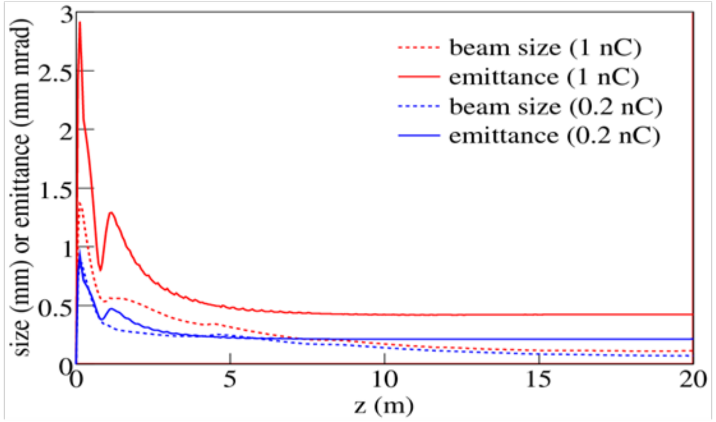
1. NC RF gun at L-Band well proven at PITZ. Up to 50MV/m, upgradable to 1kHz. Transverse emittance: 0.68 mm mrad @ 1 nC and 0.33 mm mrad @ 0.2 nC





2. NC RF gun at S-Band scaled down from DESY L-band gun. Cooling-water channel redesigned → 400 Hz rep. rate. Up to 120MV/m field strength at cathode. Transverse emittance: 0.42 mm mrad @ 1 nC and 0.21 mm mrad @ 0.2 nC.





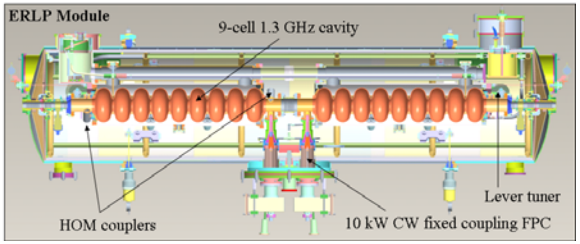
3. SCSS style thermionic gun with CeB6 cathode. Only 60Hz at present.

Thanks to Jang-Hui Han, Diamond

NLS Linac Module Options

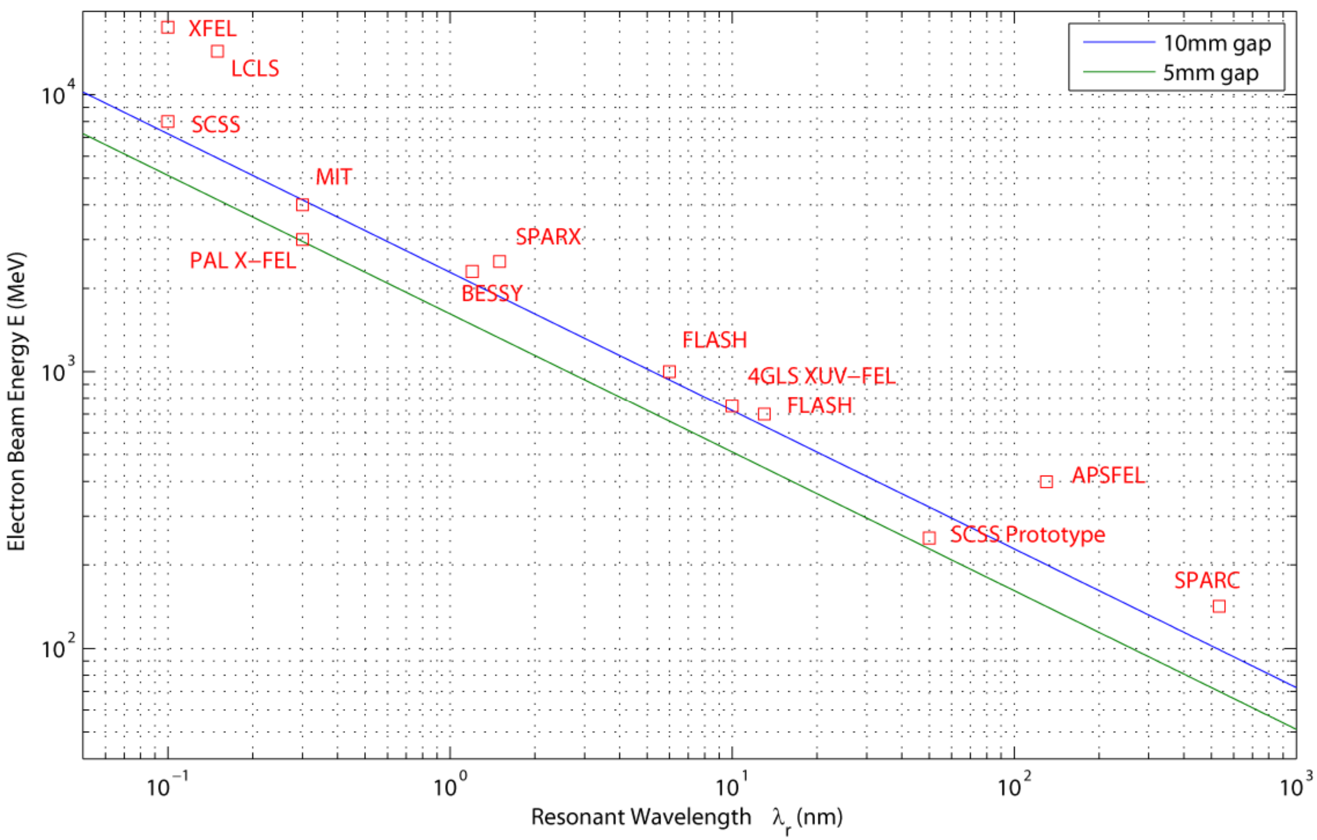
- SC cryomodule options: CEBAF, XFEL, BESSY-FEL, ALICE / ELBE, Daresbury International Cryomodule (Daresbury, Stanford, Cornell, LBNL, Rossendorf)

Accelerator	*CEBAF Upg.*	*XFEL*	*BESSY-FEL*	*ELBE*	*DICC*
Average Cavity Gradient (MV/m)	19.2	23.6	15.4	10	20
Frequency (GHz)	1.5	1.3	1.3	1.3	1.3
Qo	8e9	1e10	2e10	5e9	1e10
Input coupler Qe	2e7 (fixed)	4.6e6 (variable)	3e7 (variable)	5e6 (fixed)	1e7 – 1e8 (variable)
Max Input Coupler Power (kW)	13	169 (pulsed)	5	10	25
Cavities per cryomodule	8	8	8	2	2
Module Energy Gain (MeV)	108	196	128	21	32
Length (m)	10	12.0	12.0	3.0	3.0
CW Operation (>15 MV/m)	Yes	No	Yes	No	Yes
Tuner/motor type	cold/cold	cold/cold	cold/cold	cold/warm	cold/cold
Piezo Tuner	Yes	Yes	Yes	No	Yes
2K Dynamic Heat Load per CM (W)	240	3	150	45	<30



Thanks to Pete McIntosh, Daresbury

NLS FEL Options : Resonance Condition



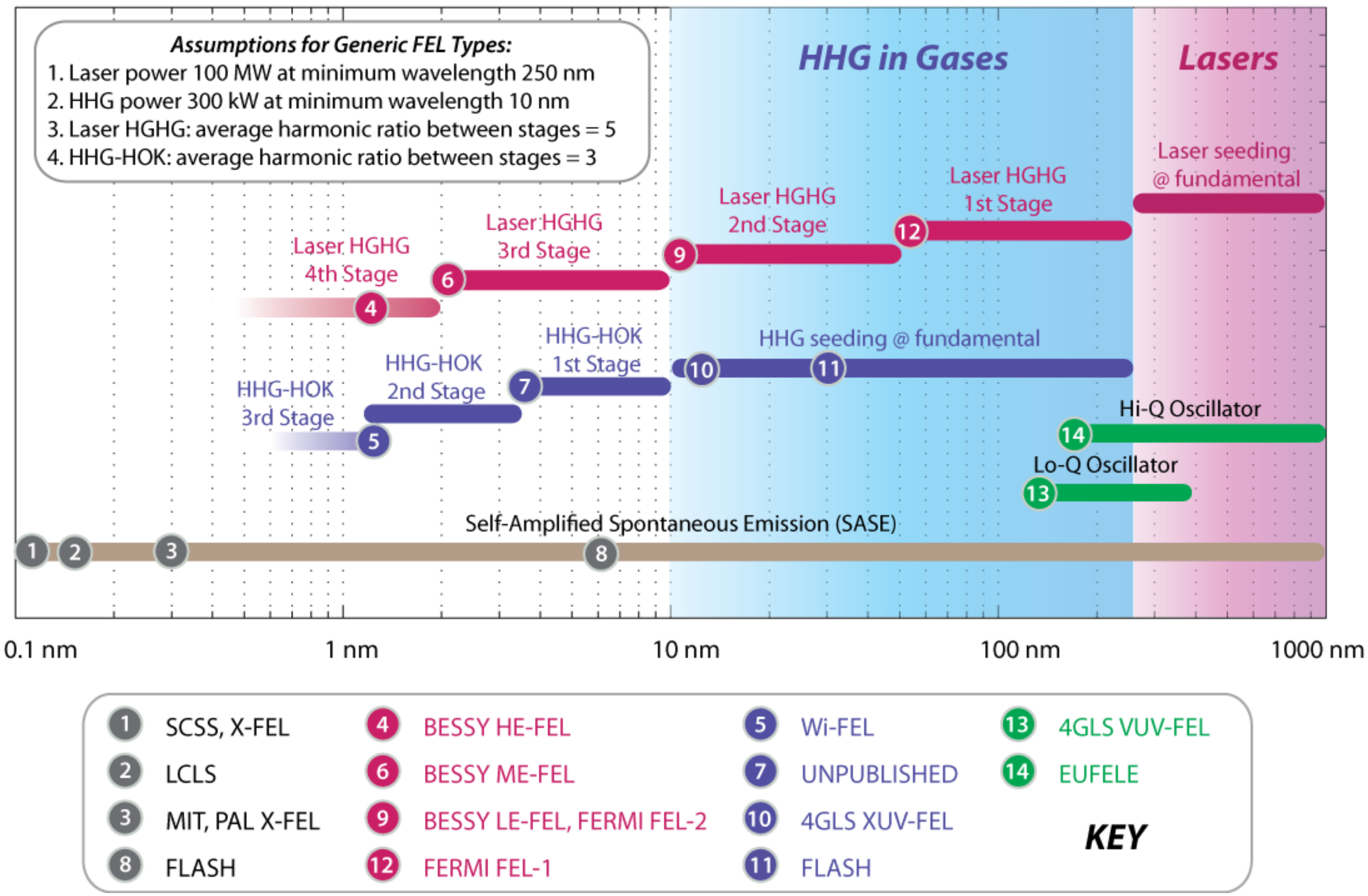
Approximate minimum beam energy required for a given FEL wavelength,
for 10mm and 5mm undulator gap. Also shown are data from current and proposed FEL projects

Thanks to Neil Thompson, Daresbury & Brian McNeil, U. Strathclyde

NLS FEL Options: Seeded + Exotic

Wavelength coverage for the generic FEL types:

Self-Amplified Spontaneous Emission,
High Harmonic Generation gas seeded / Harmonic Optical Klystron,
High Gain Harmonic Generation (modulator + radiator) (laser seeded)
Oscillator FEL e.g. 4GLS-VUV Regenerative Amplifier



NLS Source Requirement (1)

1. Photon energy range and tunability

Complete coverage is required from 50 eV to 1 keV.

3 FELs, nominally (subject to feasibility):

- FEL1: 50-300 eV
- FEL2: 250-850 eV
- FEL3: 430-1000 eV

FEL1 should definitely be seeded, as well as part of the range of FEL2. The rest of FEL2 and FEL3 will therefore either be SASE or HHG seeded followed by a harmonic scheme, however they must be compatible with direct seeding at a later date as seeding sources develop.

NLS Source Requirement (2)

- **2. Polarisation**
  - FEL1&FEL2: complete polarisation control (including arbitrary elliptical and rotatable linear).
  - FEL3: undulator capable of complete polarisation control as above, but parameters can be compromised such that only horizontal and circular (R/L) polarisation is achievable over the full range 430-1000 eV.
  - Degree of polarisation: must be as good as possible, certainly much better than 0.8, ideally > 0.9-0.95.
- **3. Pulse length & pulse energy**
  - 20 fs FWHM at all photon energies.
  - No specific target on pulse energy, except as high as reasonably practicable. At 1 keV 1011 photons/pulse is acceptable.
  - Source design team to specify what is achievable at different energies and feed back to Science Coordinators
- **4. Contrast ratio (for seeded operation)**
  - Must be "good", however no specific target has been set, as it is highly experiment specific: source design team to specify what is achievable at different energies and feed back to Science Coordinators.
- **5. THz/IR**
  - For each FEL, a coherent radiation source is required which is synchronised (FEL pulse to THz/IR phase), with coverage from 20 mm – 500 mm.
  - Pulse energy ideally in the mJ range, higher if possible.
- **6. Experimental stations**
  - Capacity for 2 stations per FEL. 3 time-preserving monochromators to be considered, one for each FEL.

Summary

- NLS project now in technical design phase
- Wide range of options for major systems being studied (injectors, linac, FELs, layout)
- Technology selections will be made in next few months → Detailed proposal by October 2009