4GLS

4GLS Status

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Contents

- ERLP
  - Introduction
  - Status (Kit on site…)
  - Plan
- 4GLS (Conceptual Design)
  - Concept
  - Beam transport
  - Injectors
  - SC RF
  - FELs
  - Combining Sources

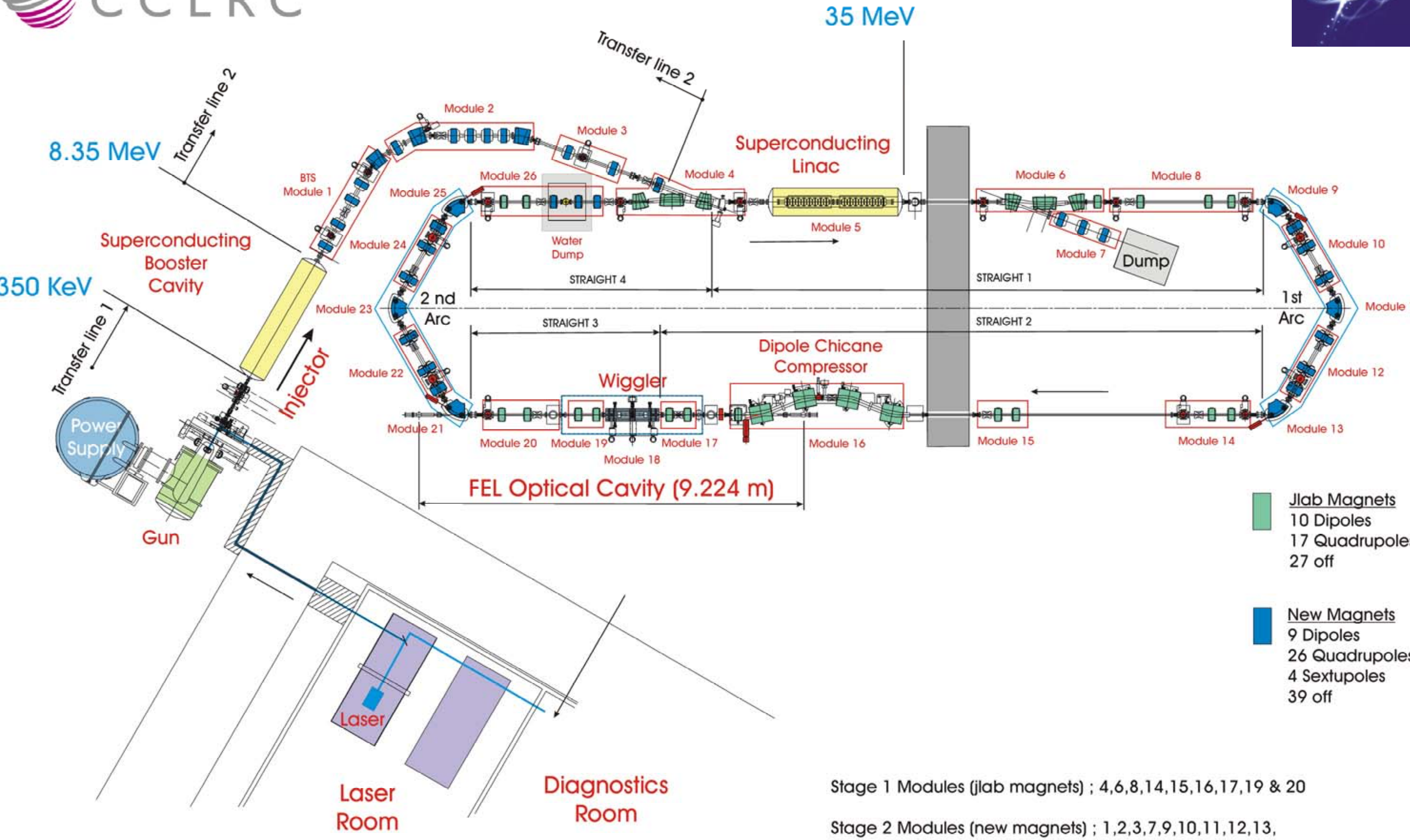
Introduction to ERLP

- Energy Recovery Linac Prototype
- Demonstrating skills and technologies for 4GLS
- Operation of photo injector electron gun
- Operation of superconducting electron linac
- Energy recovery from a FEL-disrupted beam
- Synchronisation of gun and FEL output

Main Parameters

Nominal Gun Energy	350 keV
Injector Energy	8.35 MeV
Circulating Beam Energy	35 MeV
Linac RF Frequency	1.3 GHz
Bunch Repetition Rate	81.25 MHz
Max Bunch Charge	80 pC
Max Average Current	13 µA

Constructed from Layout Drawing -



Stage 1 Modules (jlab magnets) ; 4,6,8,14,15,16,17,19 & 20

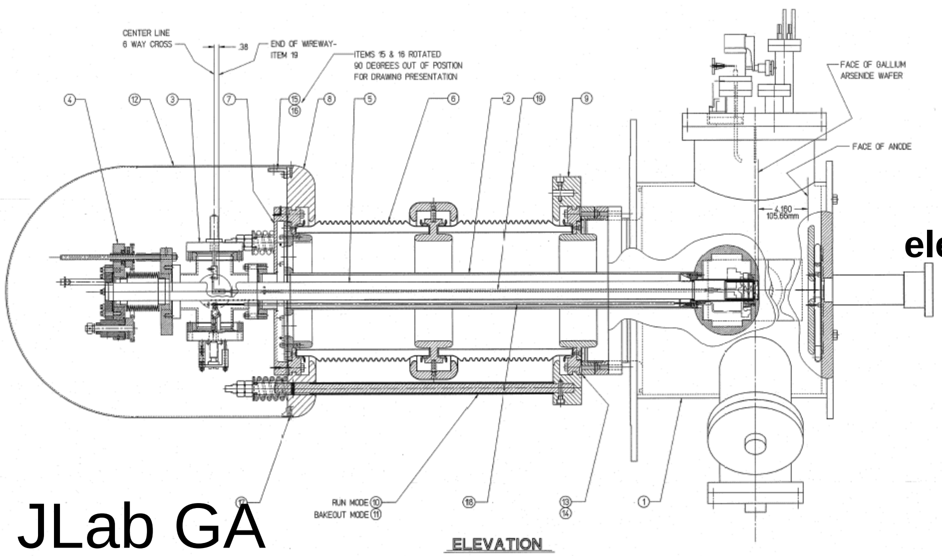
Stage 2 Modules (new magnets) ; 1,2,3,7,9,10,11,12,13, 21,22,23, 24, 25 & 26

Stage 3 Module (Wiggler) : 18

Photoinjector Laser – Collaboration with CLF

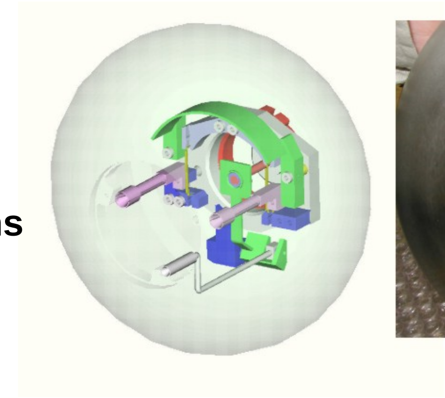
- Wavelength: 1.05μm, multiplied to 0.53μm/0.26μm (NdYvanadate)
- Pulse energy: 80nJ on target
- Pulse duration: 10ps FWHM
- Pulse repetition rate: 81 MHz
- Macropulse duration: 20 ms
- Duty cycle: 0.2%
- Timing jitter: <1ps
- Spatial profile: circular (top hat) on photocathode

ERLP: Gun



JLab GA

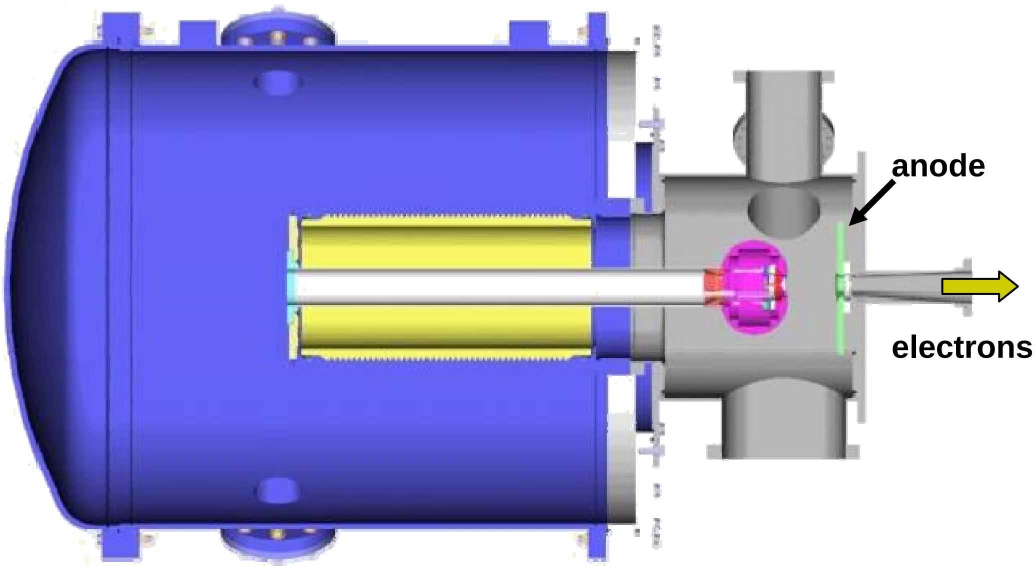
electrons



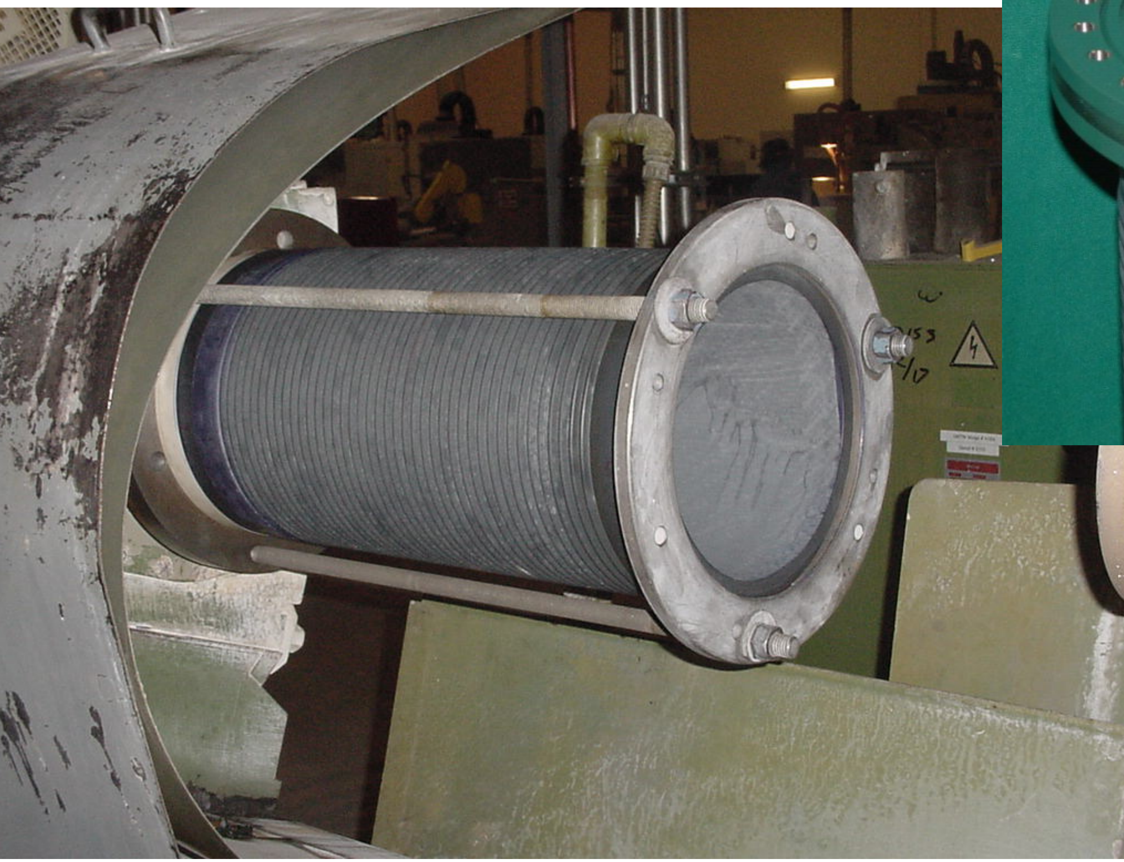
transverse emittance
~3 mm mrad

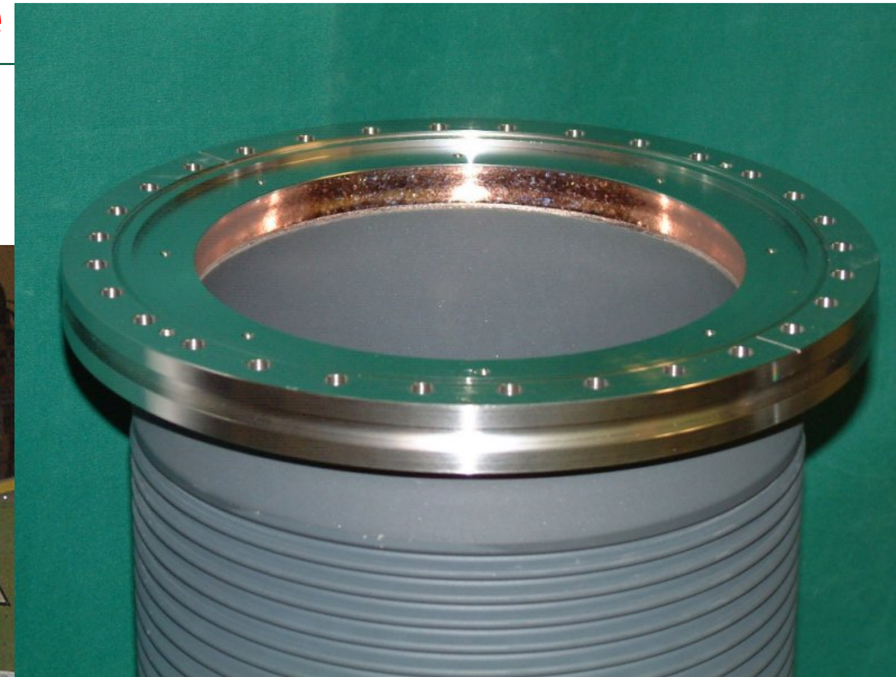
Ceramic having flanges welded, delivery to DL March 06

Pro/E

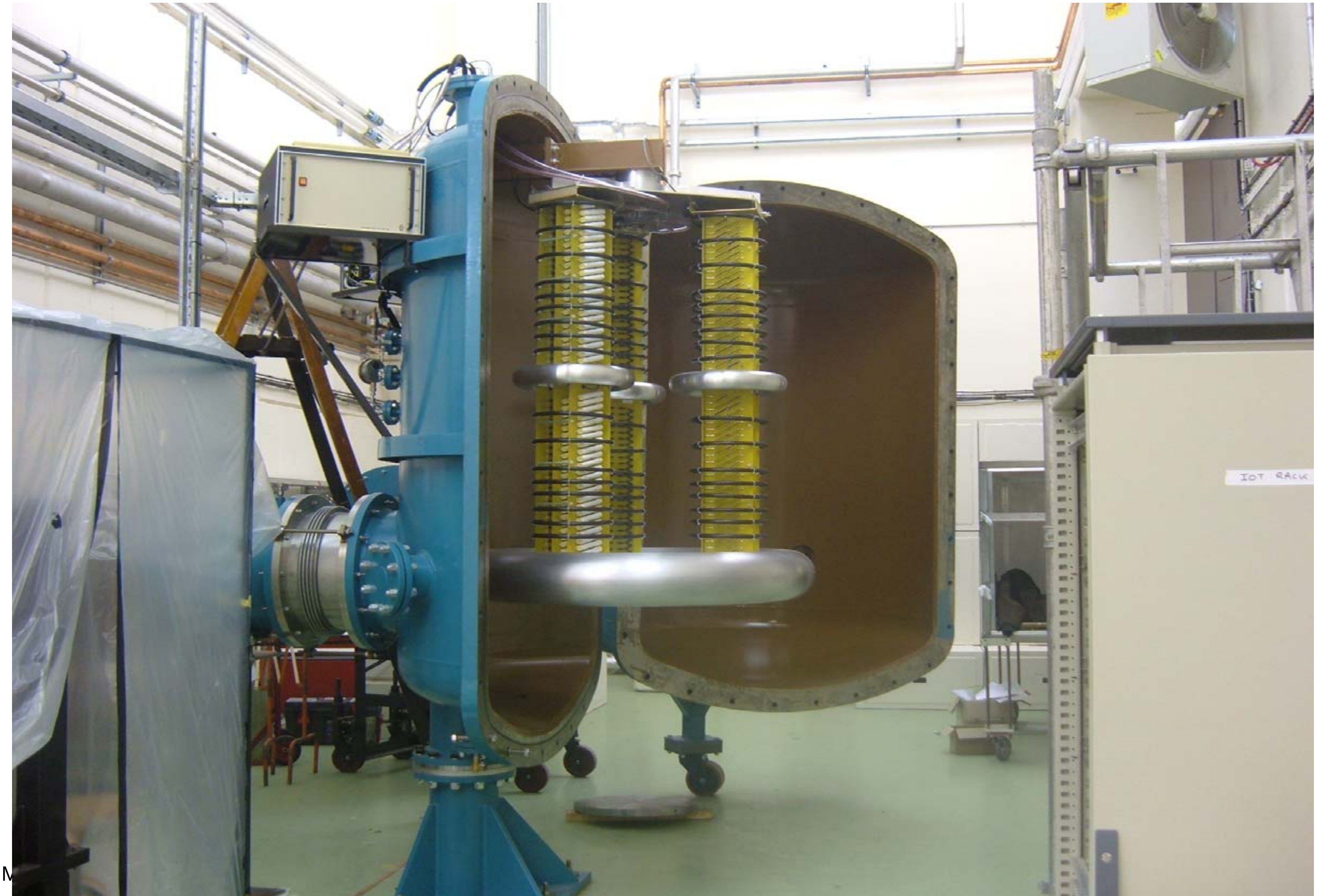


Gun Ceramic Manufacture





Gun Power Supply



ERLP Cryo system

Superconducting Booster Module

ERLP Booster to Linac Transfer Path

Machine Status/Milestones

- Laser system ready
- IOTs under test on site
- Gun ceramic – major source of delay – at Daresbury (~1 year late)
- Accelerator modules arrive April/June 2005 (~6 months late)
- 4 K commissioning May 06
- Gun commissioning June-August 06
- 2K commissioning Sept 06
- Complete machine ready October 06
- Energy Recovery Spring 07
- Exploitation 2007...

4GLS

Science

- understanding the function of single biomolecules in living systems and membrane transport;
- determining reaction pathways in areas as diverse as enzyme processes, reactions contributing to atmospheric pollution or reactions occurring in the interstellar medium;
- studies of electron motion in atoms/molecules and developing ‘coherent control’ of reactions and intense laser-matter interaction leading to new physics;
- developing new nano-scale devices through understanding electron charge and spin transport; and
- development of new dynamic imaging techniques to improve early diagnosis of conditions such as cancer and prion based diseases.

Output

- Optimised continuous radiation in the IR to XUV region of the spectrum;
- Optimised pulsed sources of radiation in the IR, VUV and XUV regions of the spectrum;
- Multiple, synchronised sources to enable pump-probe and two-colour experiments;
- Both ultra-high brightness and ultra-high flux to enable the study of very dilute or nanoscale samples, and to allow the development of new nanoimaging techniques;
- Pulse lengths which are variable from the ps to the fs regime, with variable pulse spacing for investigation of dynamic processes.

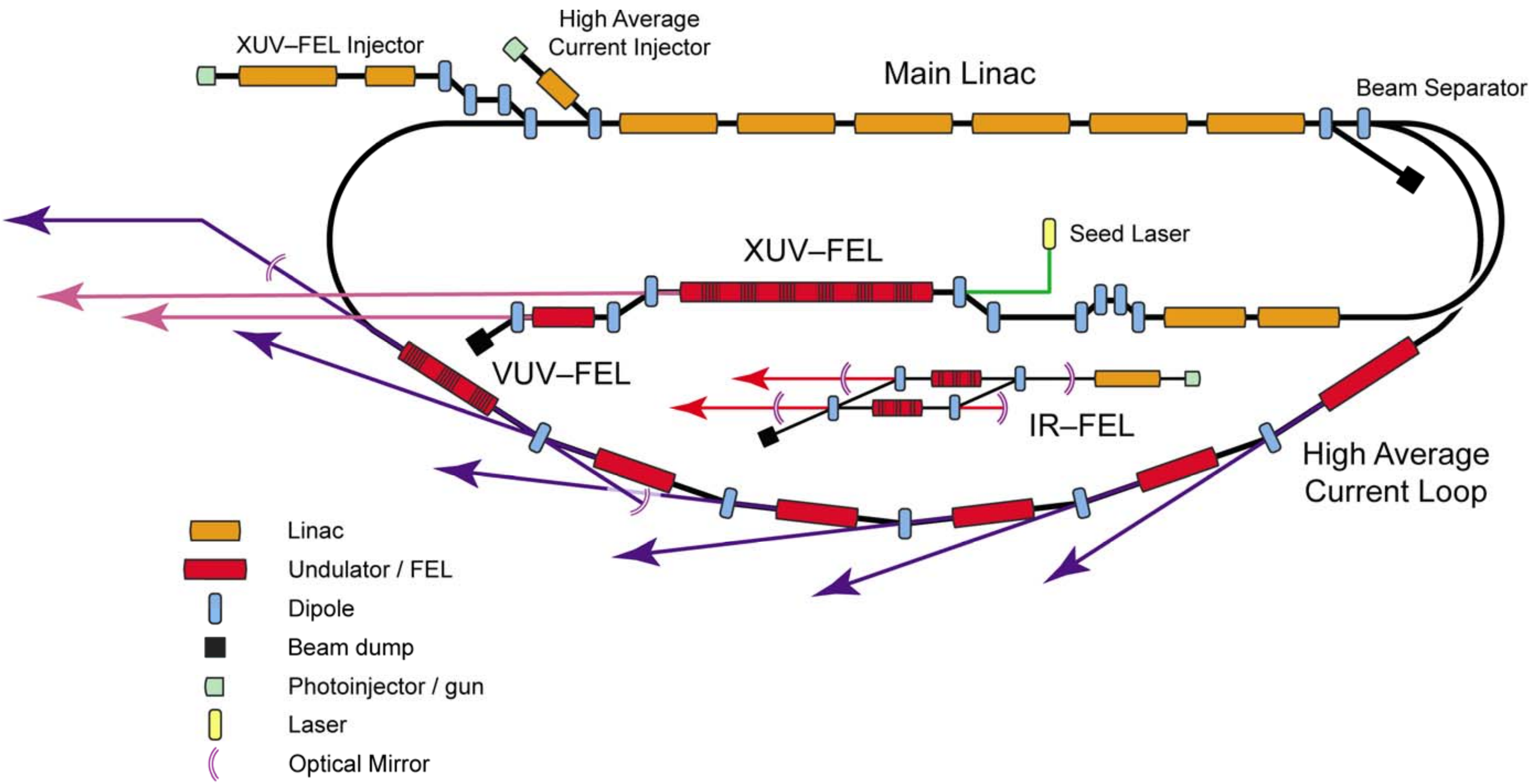
Key Features

- THz to soft X-Ray (<1keV) light source
- Very short pulses (<< 1ps)
- Combination of pulses for pump-probe experiments
- Multiple experiments
- Very small emittance
- Pulse timing flexibility
- Electrons not stored – continually refreshed
- Energy recovery linac system
- Three distinct types of Free Electron Laser
- Conventional undulators
- Coherent SR

4GLS-Three Inter-related accelerators

- High average current loop
  - ERL, 600 MeV delivering 77pc @ 1.3 GHz = 100 mA
  - Distribute compression giving 1ps – 100 fs SR
  - Low Q VUV FEL
- XUV-FEL Branch
  - 1.5 kA, 750-950 MeV
  - 1 nC, 1kHz
  - XUV FEL using HHG seed laser scheme
- IR-FEL
  - 25-60 MeV SC linac
  - Integrated & synchronised IR-FEL

Conceptual Layout of 4GLS



4GLS Beams

- 600 MeV, 77 pC bunches with short bunch lengths down to ~100 fs RMS, operating at 1.3 GHz for a suite of spontaneous sources or operating at some multiple, n, of 4.33 MHz for a VUV-FEL. The peak current at the VUV-FEL must be over 300 A
- 750-950 MeV, 1 nC bunches with peak current >1.5 kA driving an XUV-FEL at 1 kHz, with RMS bunch lengths less than 270 fs
- 25-60 MeV, 200 pC bunches for an IR-FEL, delivered at 13 MHz with RMS bunch lengths between 1 and 10 ps.

Challenges

- **Electron Beam Transport**
  - Preservation of small emittance
  - Generation of <<ps bunches at the correct locations
  - Minimisation of instabilities (CSR, wakes, …) – long bunches!
  - Merge and separation of different beams
  - Minimise losses
    - Collimation
    - **60 MW beam power –** ILC is 11 MW !
  - 1MW Dump

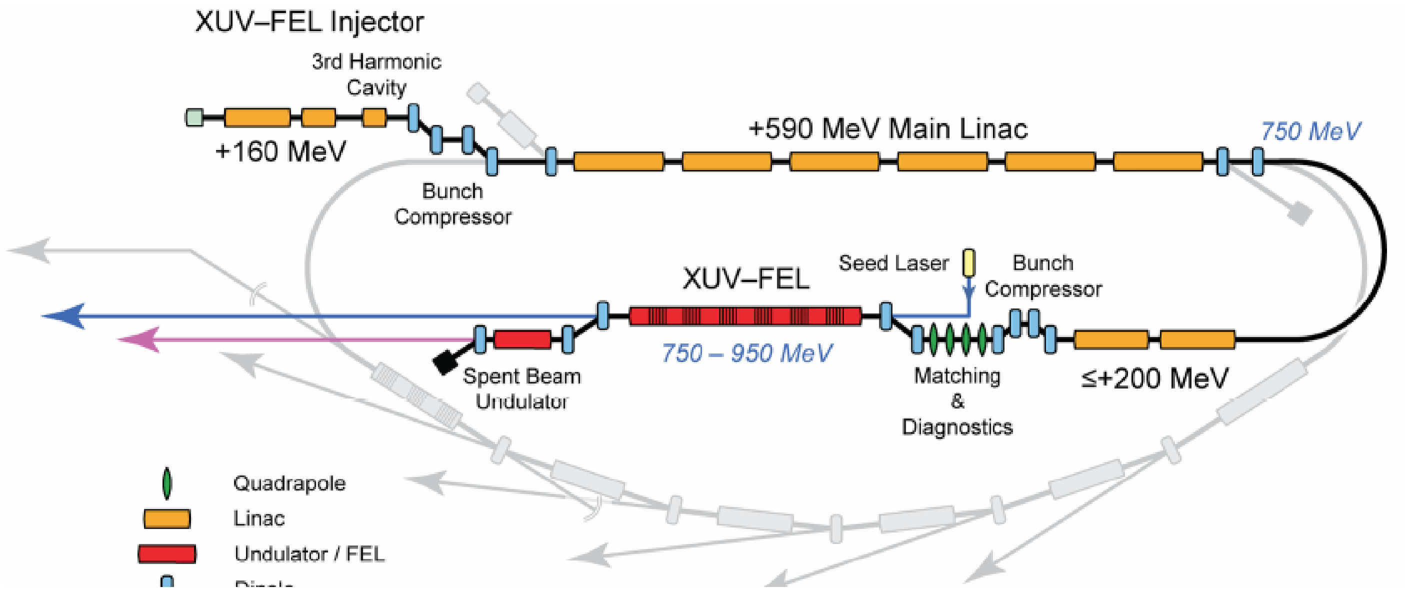
CDR Beam Transport Studies

- Identify possible show stoppers….
- From defined science case parameters
  - Define concept for accelerator complex capable of broadly delivering science vision
  - Confirm that basic physics driving disruptive processes are understood and parameterised to a degree that confirms that a suitable solution will be tractable during TDR phase
  - Define a clear enough geometry, component list and specification to allow a costing exercise to progress at a basic level of accuracy for the CDR
  - Confirm a target set of beam parameters

Beam Transport CDR Issues

- Layout/Concept
- Modelling of longitudinal gymnastics/compression
  - CSR
  - LSC
  - Wakefield estimates
  - ID wakefield estimates (apertures)
- BBU limits and understanding of linac focussing issues etc.
- Ion effect

FEL Branch

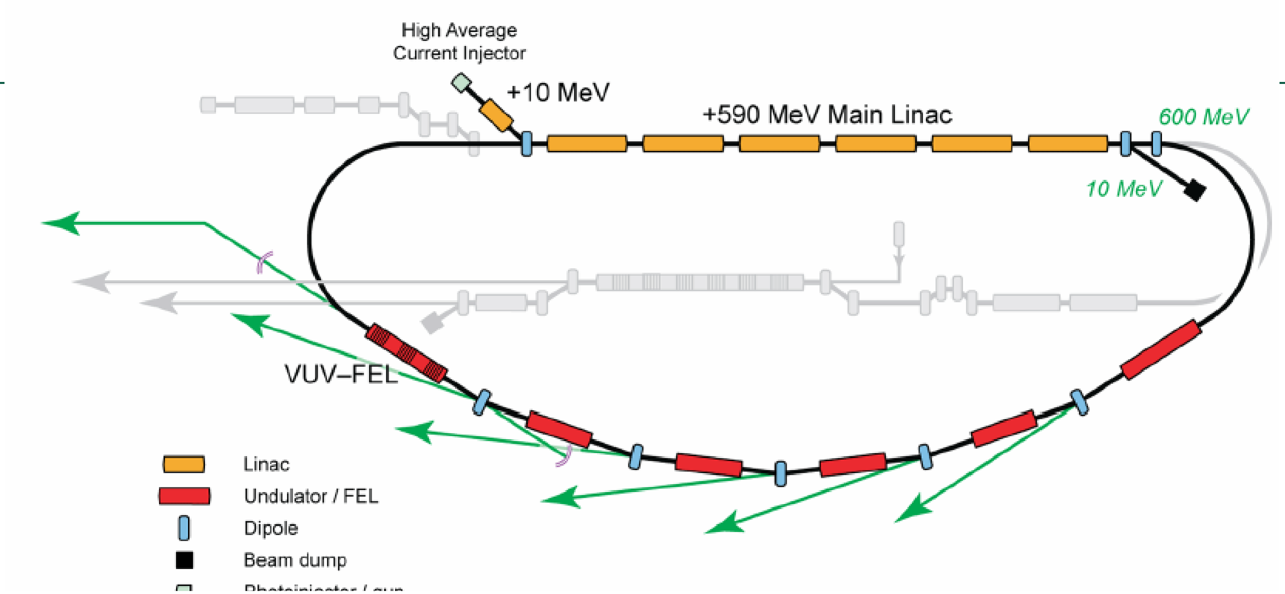


- Positive phase acceleration
  - Helps to cancel large wakefields from 1nC bunch charge
- Positive compression (chicane-like) – 2-stage BC1/BC2
  - Spreader R_{56} is inherently positive
  - Arc R_{56} must be negative - cancels spreader
  - Linac-2 provides final chirp
  - Final bunch compressor provides compression

XUV-FEL Bunch Parameters

Energy	750 to 950 MeV
Normalised Emittance	2 mm mrad
RMS Projected Energy Spread at XUV-FEL	0.1%
RMS Bunch Length at XUV-FEL	< 270 fs
Bunch Charge	1 nC
Bunch Repetition Rate	1 kHz
Electron Beam Average Power at XUV-FEL	1 kW
Energy at start of Main Linac (Linac5)	160 MeV

CW Branch

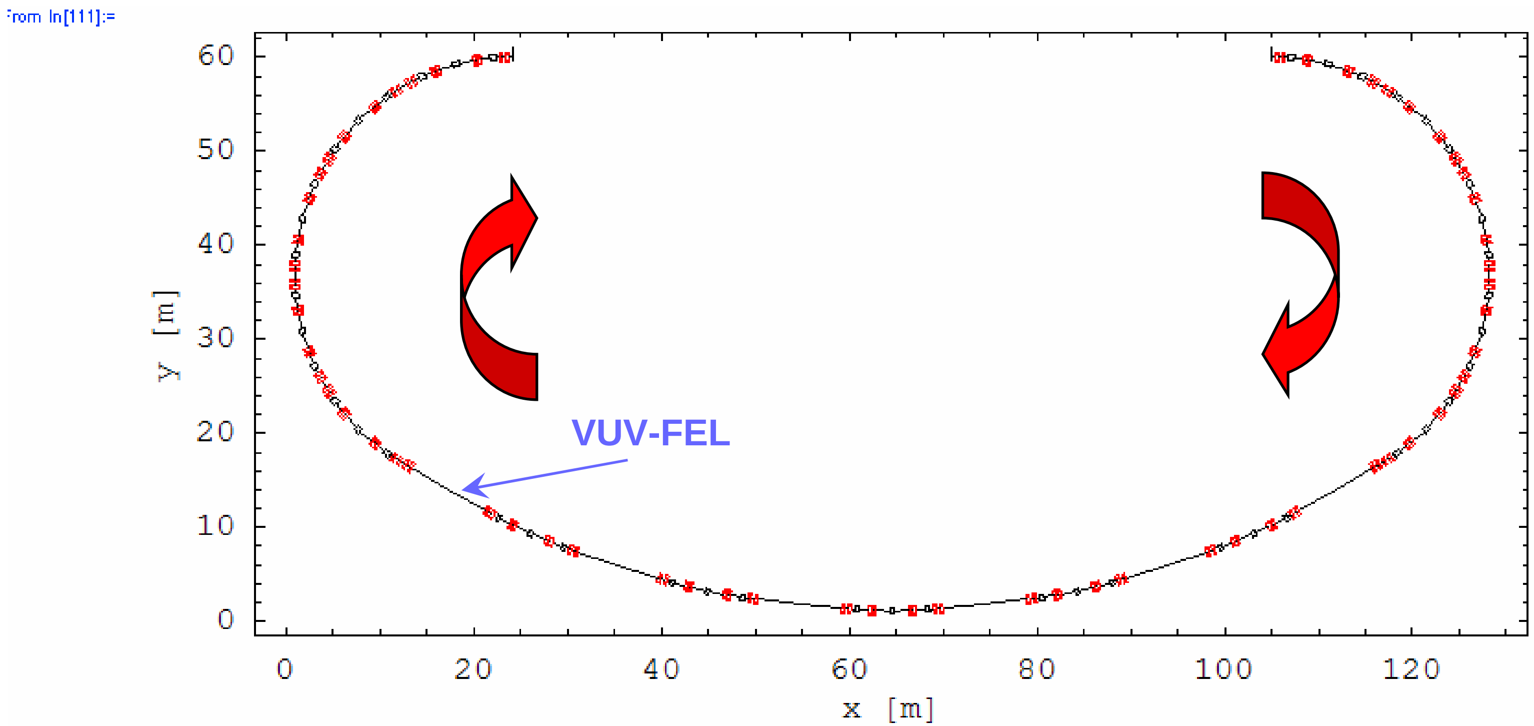


- Bunch must be short in many ID straights separated by arcs
- Wakefields/apertures limit total straight length where bunch is fully compressed
  - Therefore must have some compression from straight to straight
  - Therefore compression must be negative (arc-like)
- Therefore negative phase acceleration
  - OK since 77pC bunch has small associated wakefield.
- Spreader has positive R_{56}
- Loop arc (5xFODO cell) cancels spreader R_{56} and performs main compression
- Final (small) compression performed in 5x TBA cells (6 ID straights)

High Average Current Bunch Parameter

HACL Bunch Parameter	100 mA Operation	VUV-FEL Operation
Energy at Source	600 MeV	600 MeV
Normalised emittance	2 mm mrad	2 mm mrad
RMS Projected Energy Spread	0.1 %	0.1 %
RMS Bunch Length at Device	100-900 fs in 6straights	100 fs
Bunch Charge	77 pC	77 pC
Bunch Repetition Rate	1.3 GHz	n x 4.33 MHz
Beam Power at 600 MeV	60 MW	n x 200 kW
Injector Energy	10 MeV	~ 10 MeV
Dump Energy	~ 10 MeV	~ 10 MeV

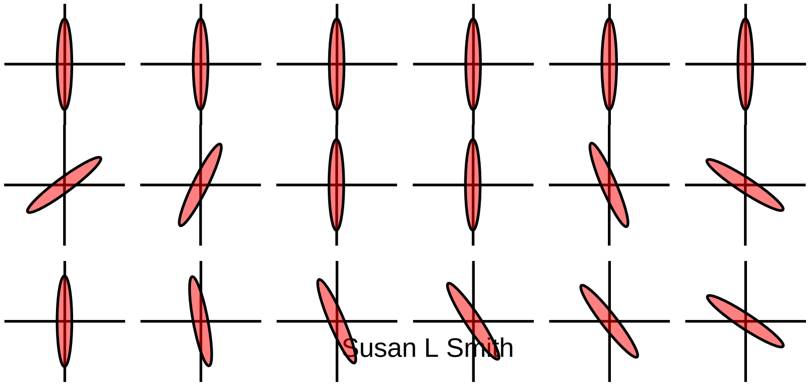
Progressive Compression – Loops + ID



Mode 1: All Short
(Probable wakefield limit)

Mode 2: Centre Short

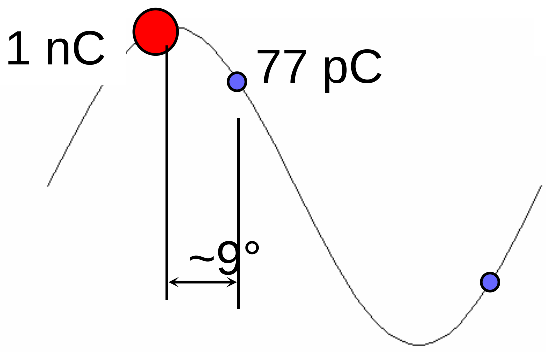
Mode 3: VUV Short



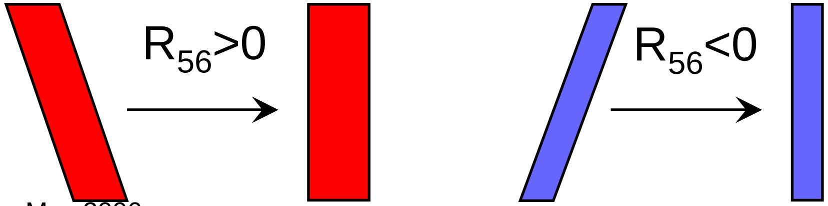
Golden Rule:
beam 'compression' (i.e. shear) only goes one way.

Beam Propagation

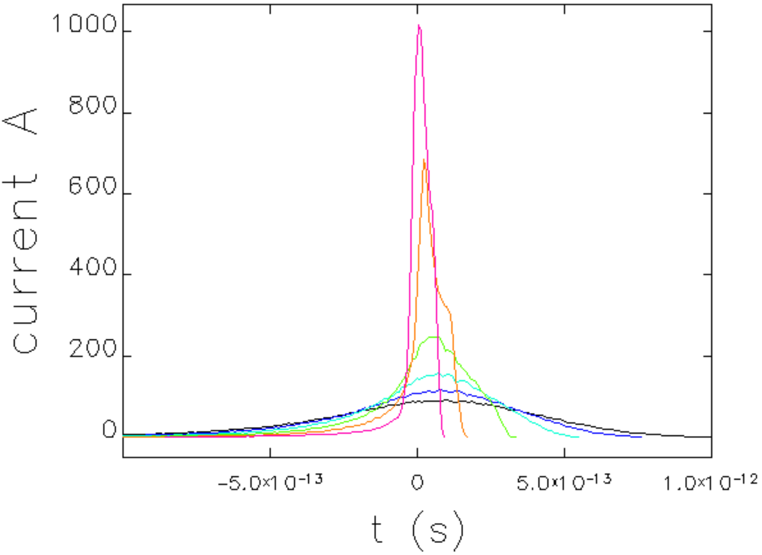
FEL vs. CW Compression

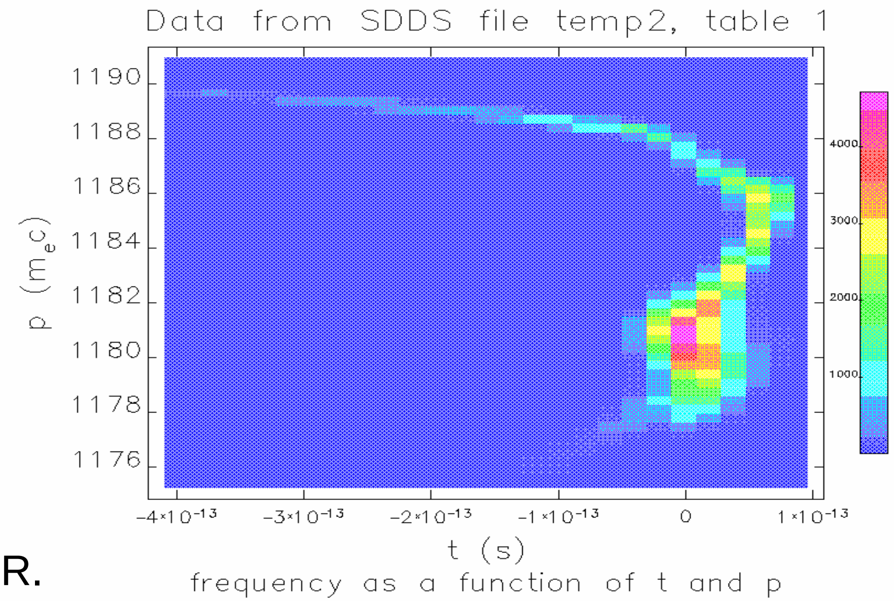


- FEL and CW Compression are carried out with opposite phases
- FEL compression requires positive phase/R56 to cancel wakefield effects
- CW compression requires negative phase/R56 to allow progressive compression in the IDs (TBAs are negative)



High Average Current Loop Near Start to FEL Simulation





Bunch profiles at each of the ID straights, with CSR.

CSR	LSC	Linac phase	Rms length (fs)	Rms energy spread
No	no	97.3	96	0.21%
No	yes	97.2	104	0.22%
yes	no	97.0	80	0.27%

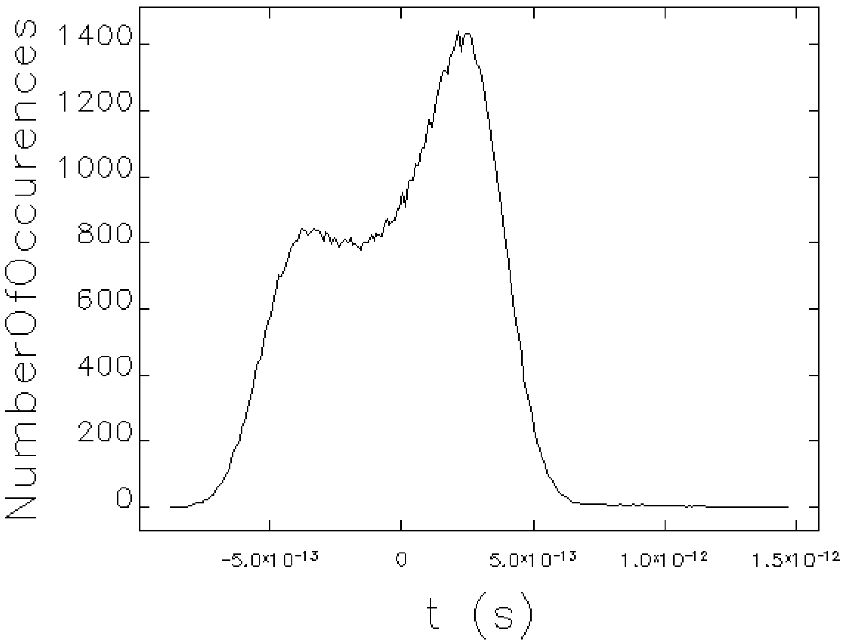
Status of XUV-FEL Branch modelling.

2ps 140MeV gaussian beam CSR, LSC in the linacs and straights and wakefields in the linac were included.

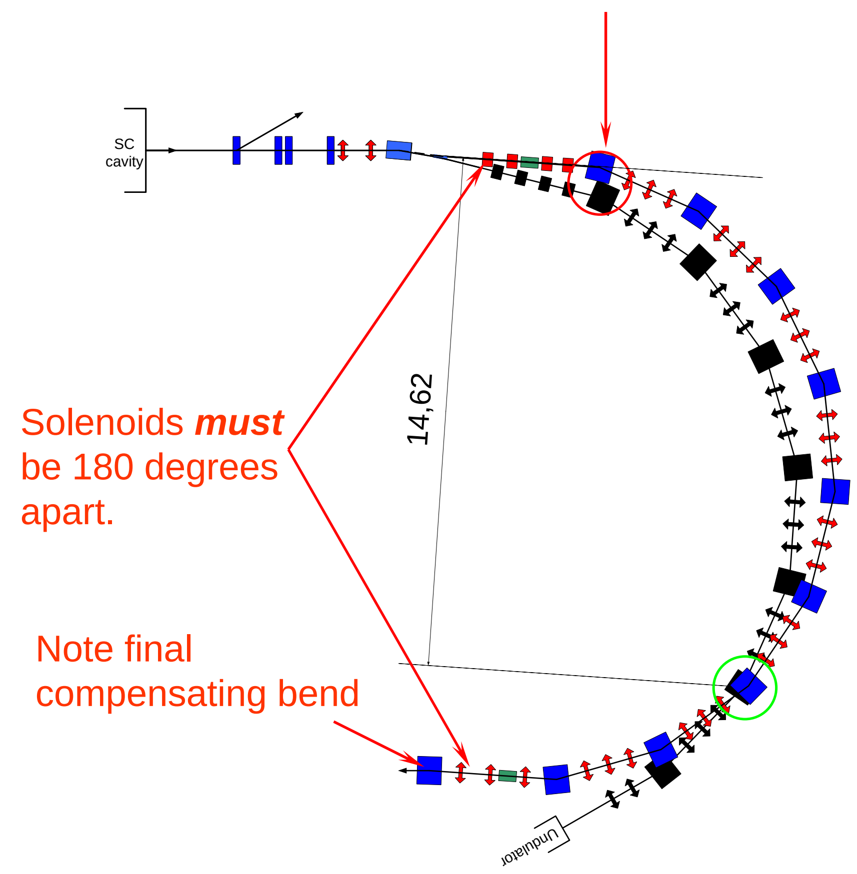
Phase of the linac had to be changed to allow mainly for the change in energy chirp due to the wakefield and LSC.

Without any linearisation from 3rd harmonic cavity or sextupoles included, a peak current of 1.4 kA was obtained, just short of the 1.5 kA target.

Further simulations using a more realistic input bunch distribution will be performed in future design work.

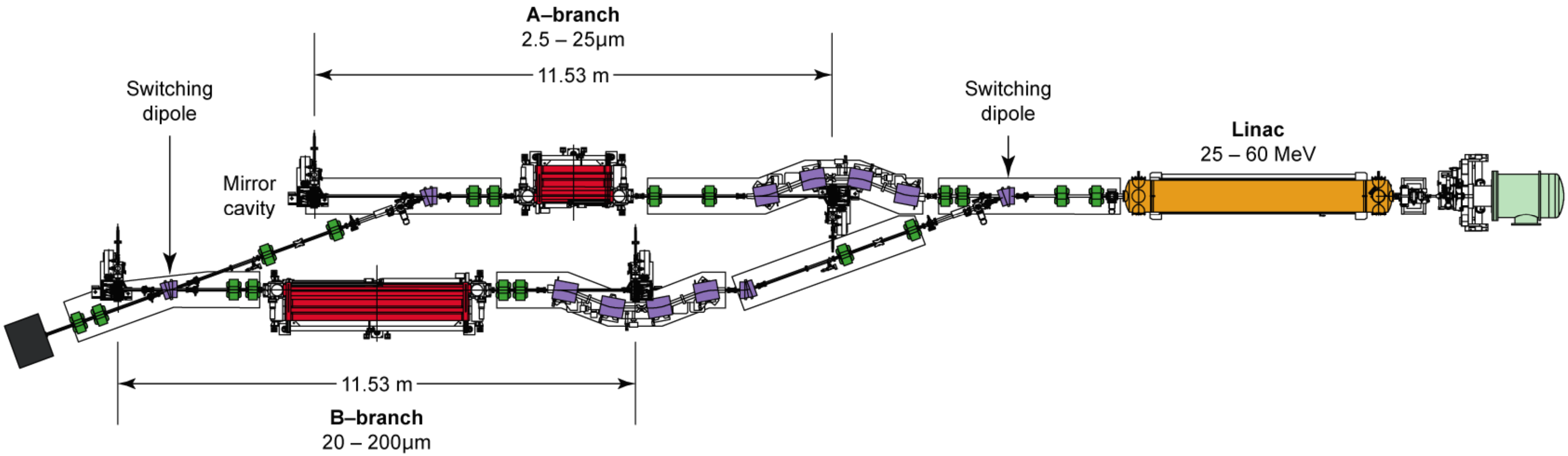


ARCs



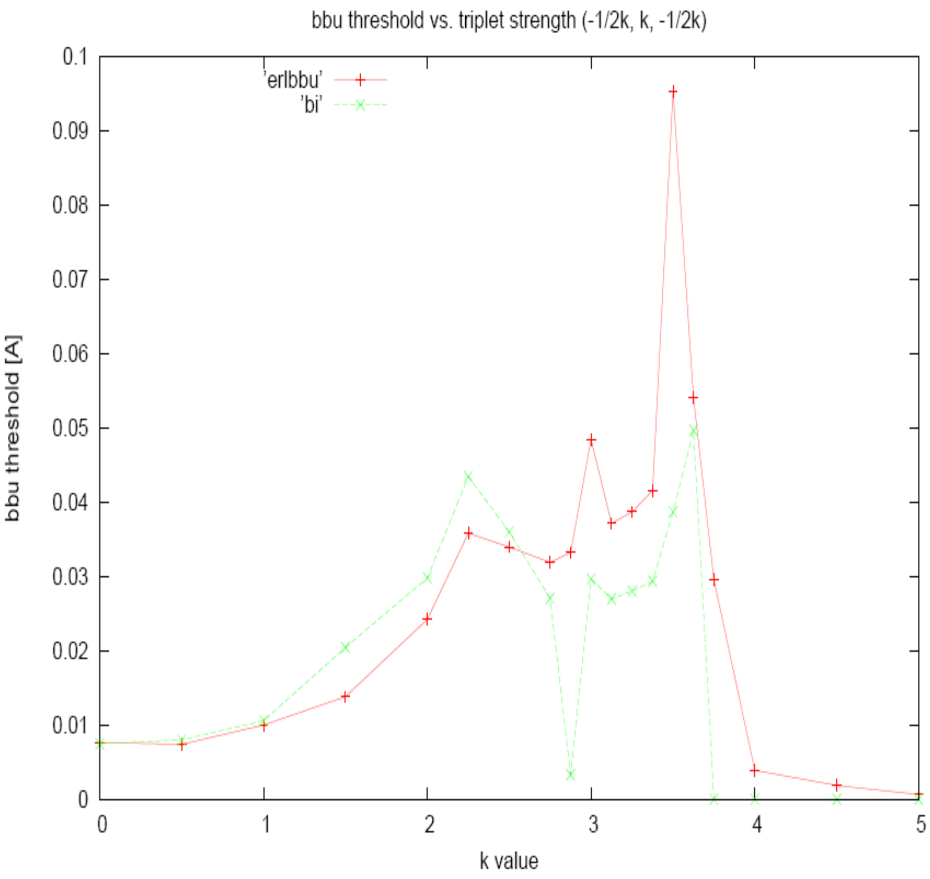
- FEL arc now outside of CW arc
- Advantages:
  - Keeps FEL arc radius large for CSR management
  - Eliminates opposing bends
- Disadvantages:
  - Vertical offset to transport to pass FEL arc under CW Loop arc – 60 cm in present iteration
  - Uses solenoids to achieve vertical matching – no flat beams for FEL branch!!
  - Optically complex

IR FEL



Normalised Emittance 10 mm-mrad
Projected Energy spread 0.1%
RMS Bunch length 1-10 ps
Bunch charge 200 pC
Bunch rep rate Bunch Repetition Rate 13 MHz
Avg. Power 60 MeV 156 kW
Branch switching 100 Hz

BBU



- Thresholds in the 20-40 ish mA

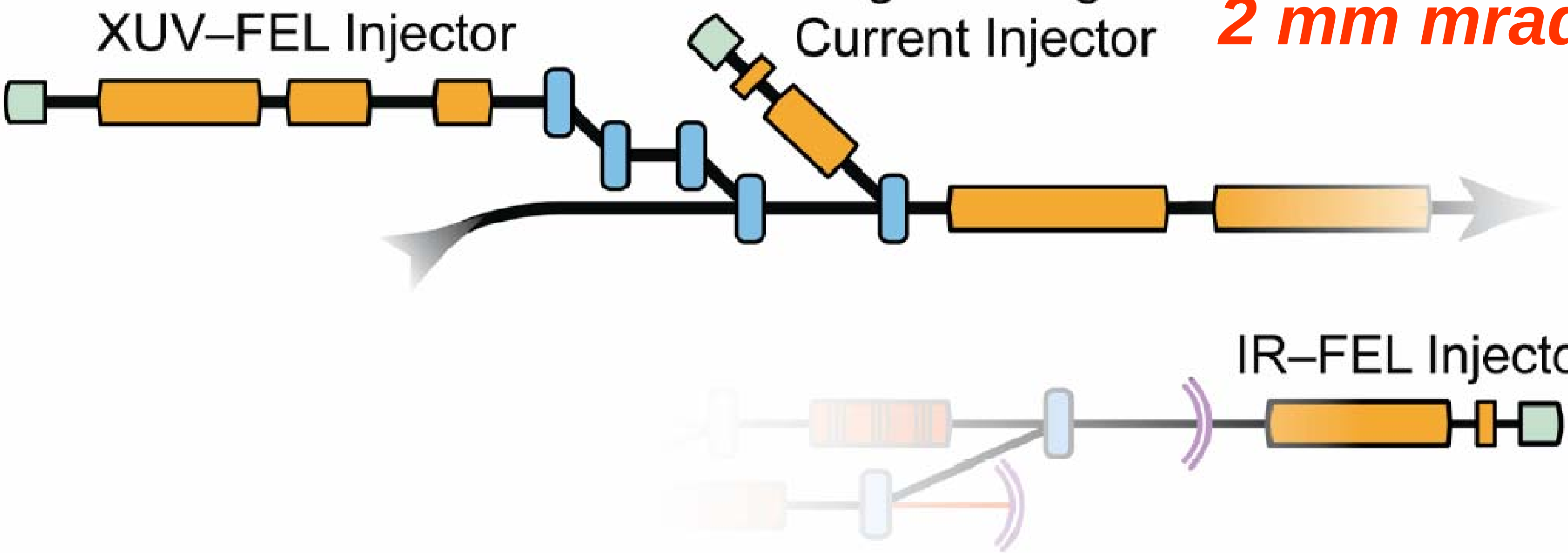
But we don't have a detailed LINAC cavity design and…

- We have not optimisation of "single turn" optics
- Fully explored the linac focussing effects
- HOM spectrum as for TESLA cavities
- not modelled skew quadrupoles scheme Etc.

Injectors

1nC, 1kHz, 2ps,
<2 mm mrad

100 mA, 77pC,
1.3 GHz, 2 ps
2 mm mrad



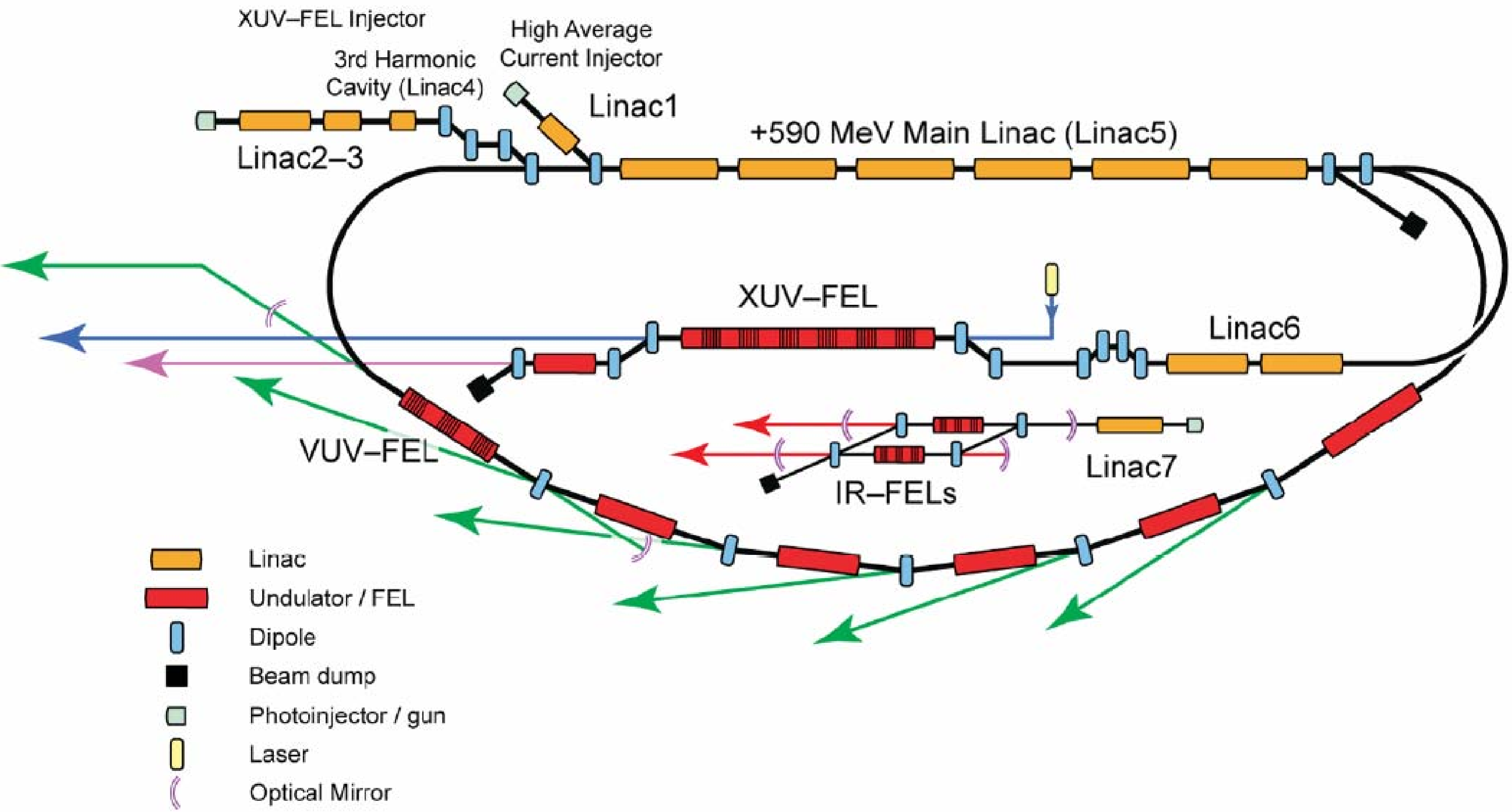
200 pC, 13 MHz,
<10 mm mrad,
1-10 ps

Challenges

- **Photoinjectors**
  - 1nC, 1kHz **has never been built before**
    - Demanding laser
    - Thermal problems from RF losses
    - Other groups are active: BESSY/DESY & LBNL ….
  - 77pC, 1.3 GHz (100mA) **has never been built before**
    - Even more demanding laser
    - DC version has issues with power supply, high voltages
    - SCRF version has issues with photocathodes
    - Other groups are active: Cornell, BNL & JLab…..

EUROFeL Activities

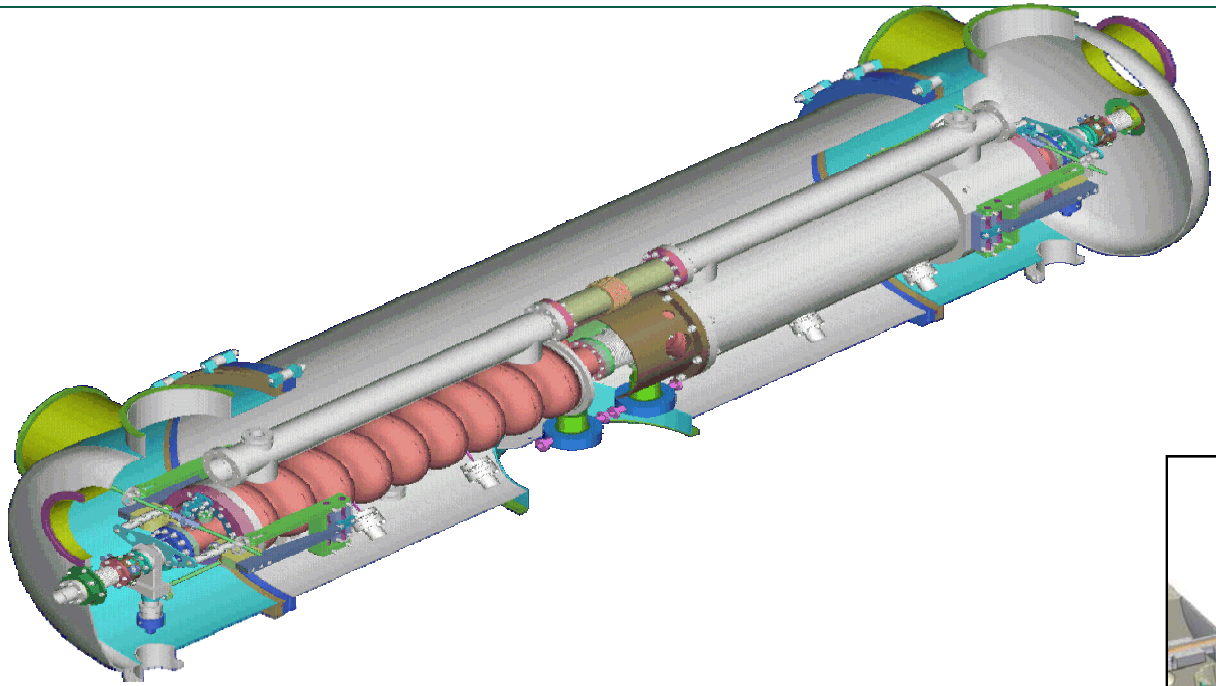
Seven Distinct Superconducting Linac Modules



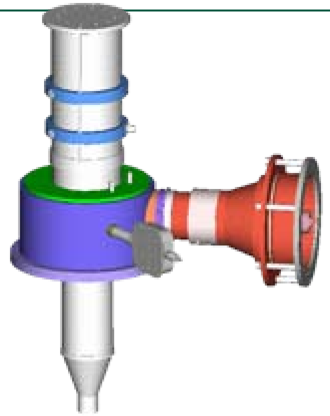
Challenges

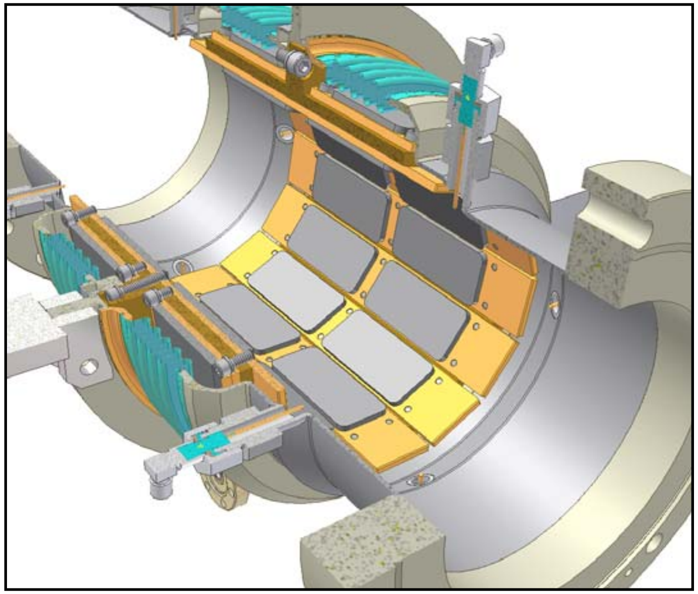
- Linacs
  - 7 different SC RF Linacs
  - Based upon 1.3GHz (3.9 GHz 3rd harmonic)
  - High input powers (10MeV, 100mA = 1MW)
  - Three distinct beams in main linac
  - Complex pulse trains
  - Need to minimise HOMs & extract power at correct temperature – Beam Break Up
  - Phase and amplitude control: 0.01°, 0.01% - state of the art
  - Need largest ever UK cryogenic plant

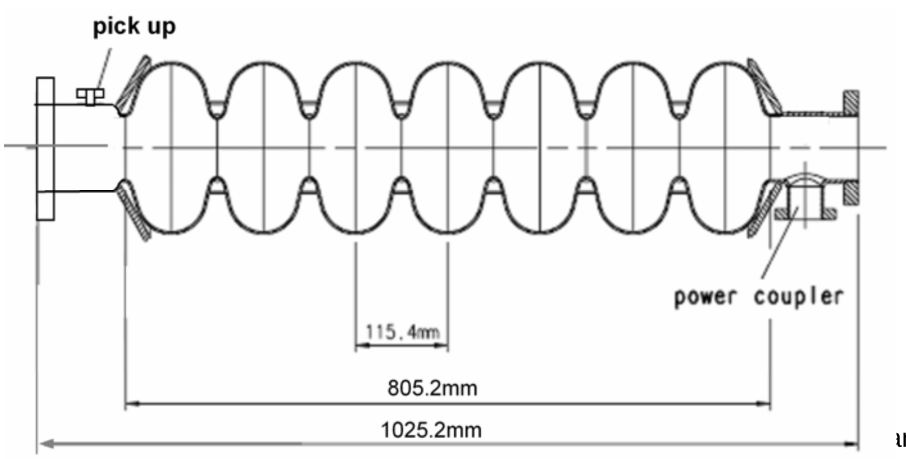
Modified 7 Cell TESLA type Cavity



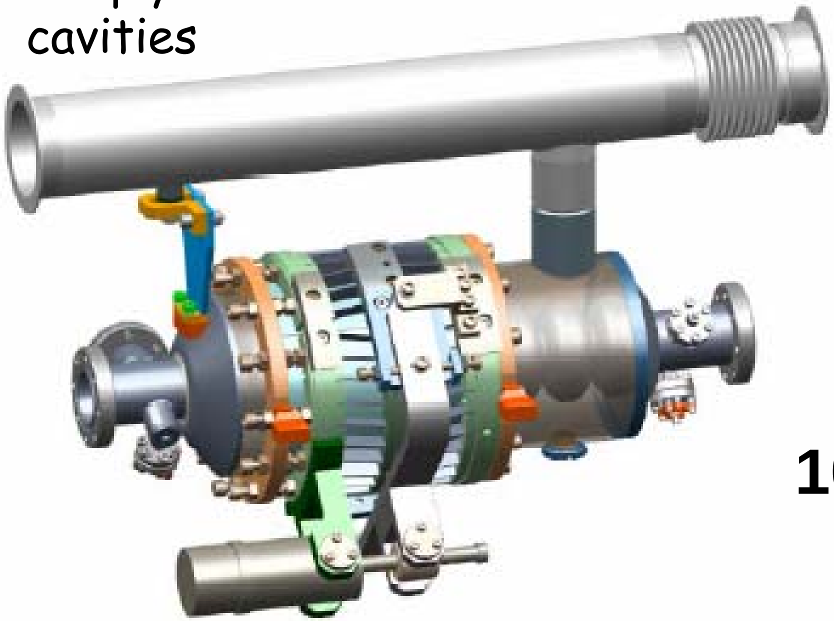
IOT





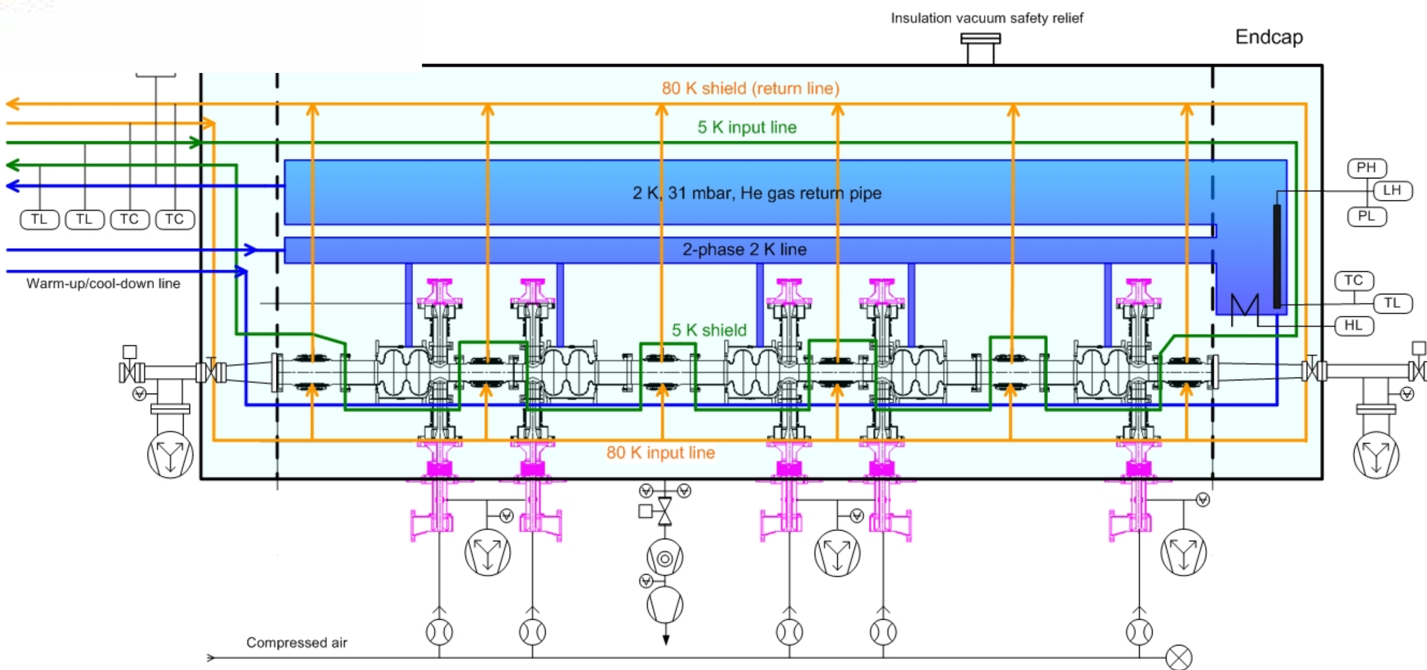


Simply 2 x scaled 9-cell TESLA/TTF cavities

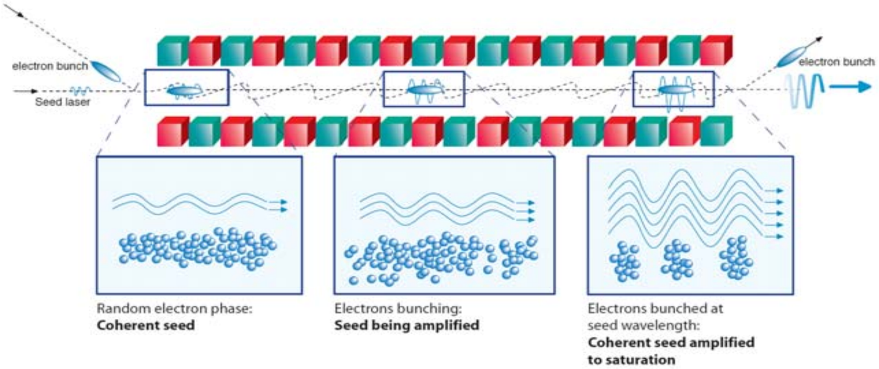


100 mA, 10 MeV Booster

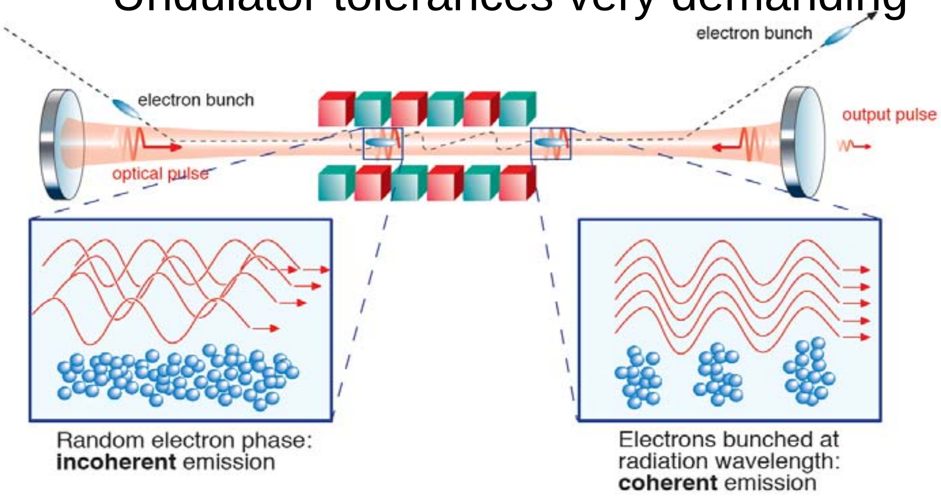
3rd Harmonic



3 distinct FEL designs

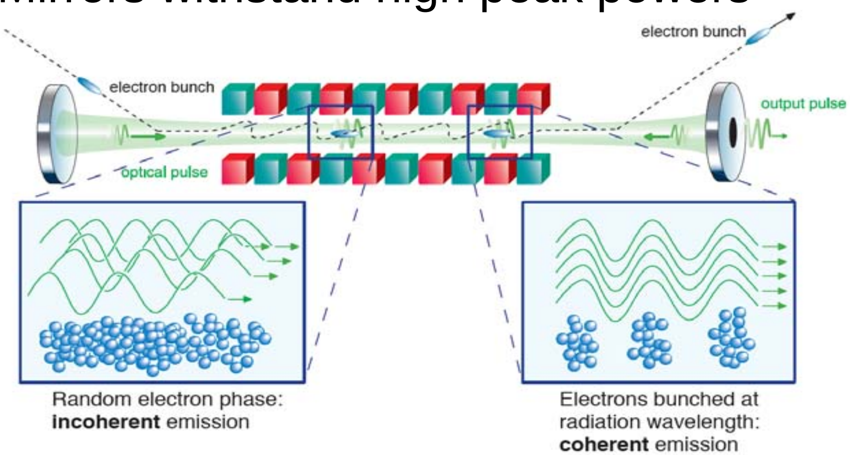


Single pass seeded amplifier
(eXtreme Ultra Violet
Seed laser state of the art (HHG system)
Undulator tolerances very demanding



Low Q cavity (Vacuum Ultra Violet)

Mirrors withstand high peak powers



High Q cavity (Infra Red)

4GLS FEL Output

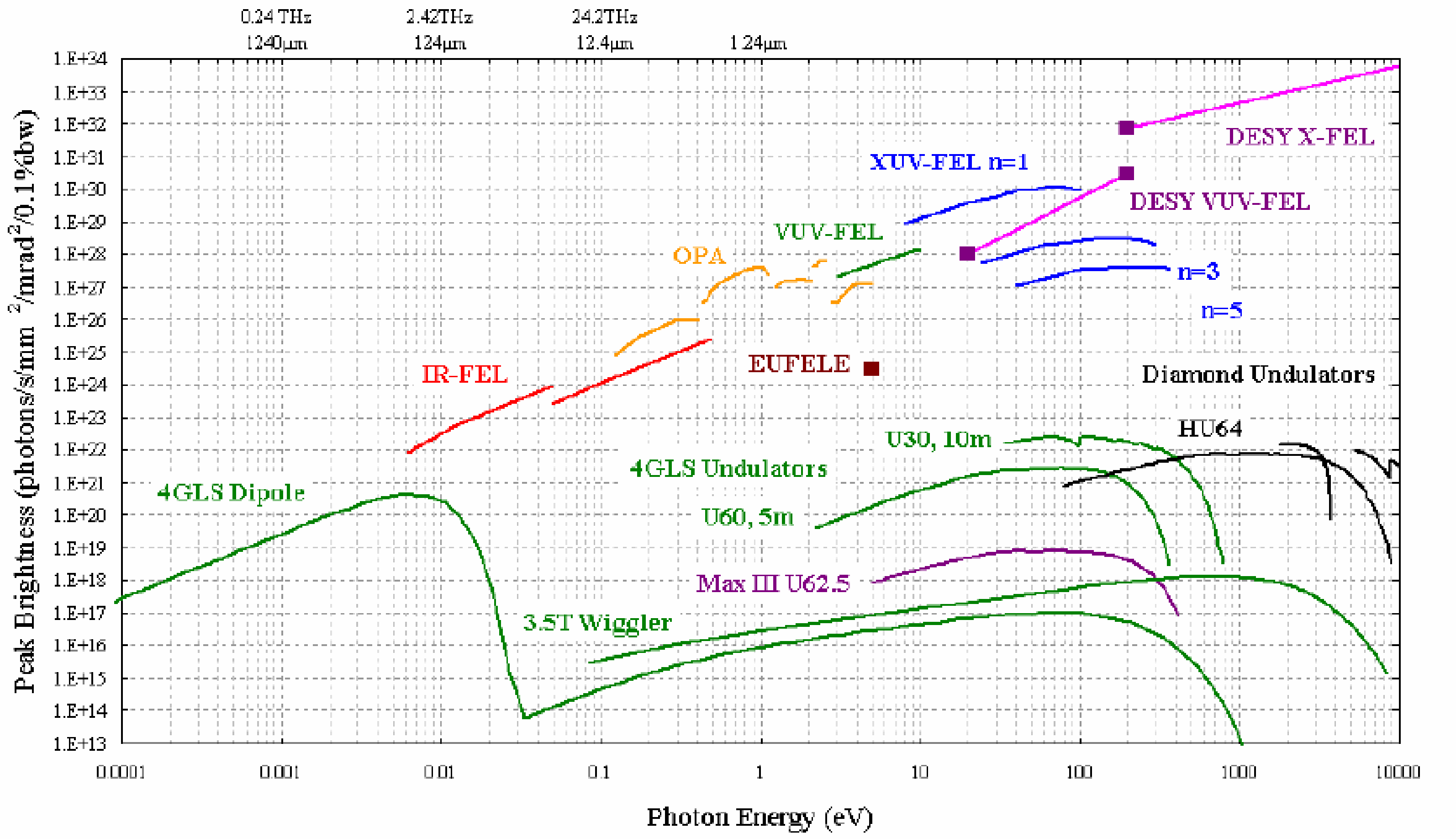
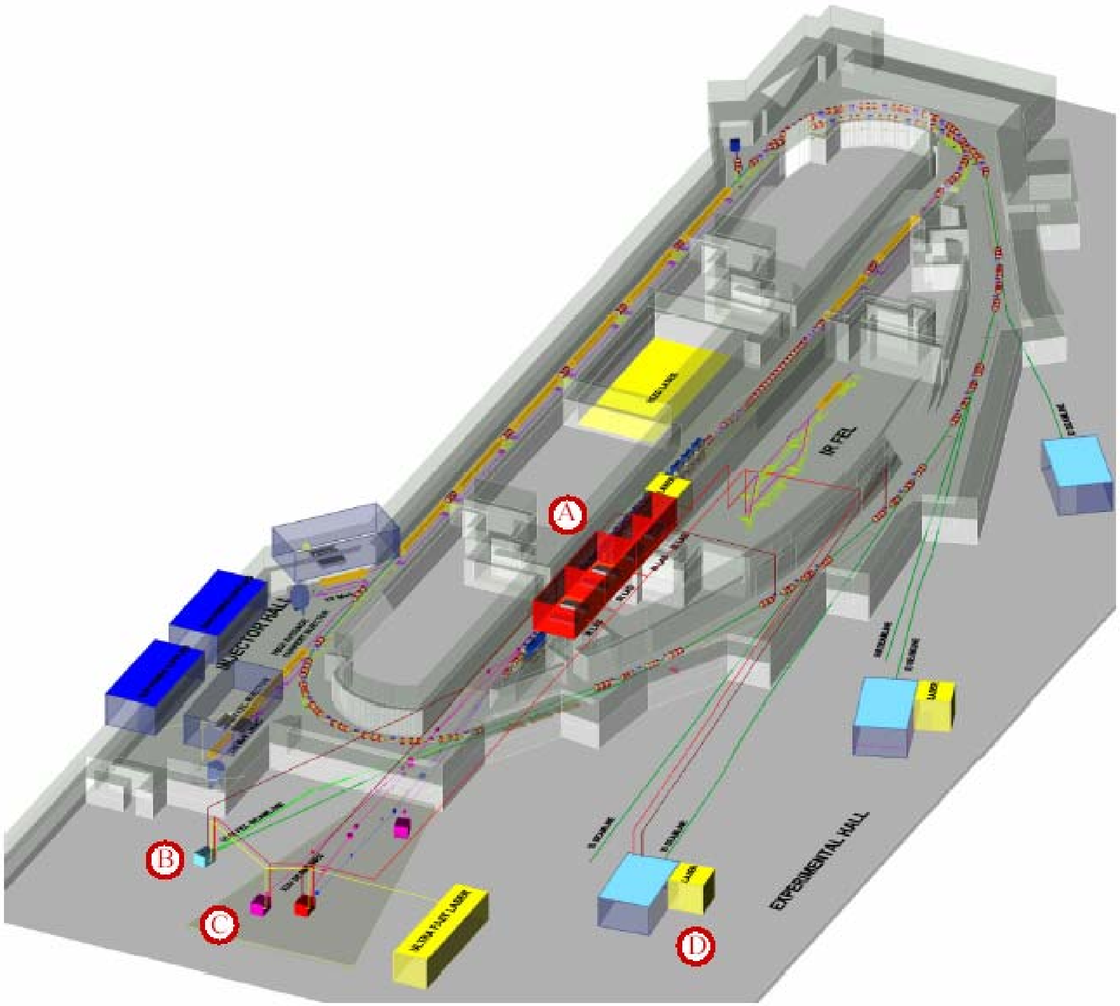


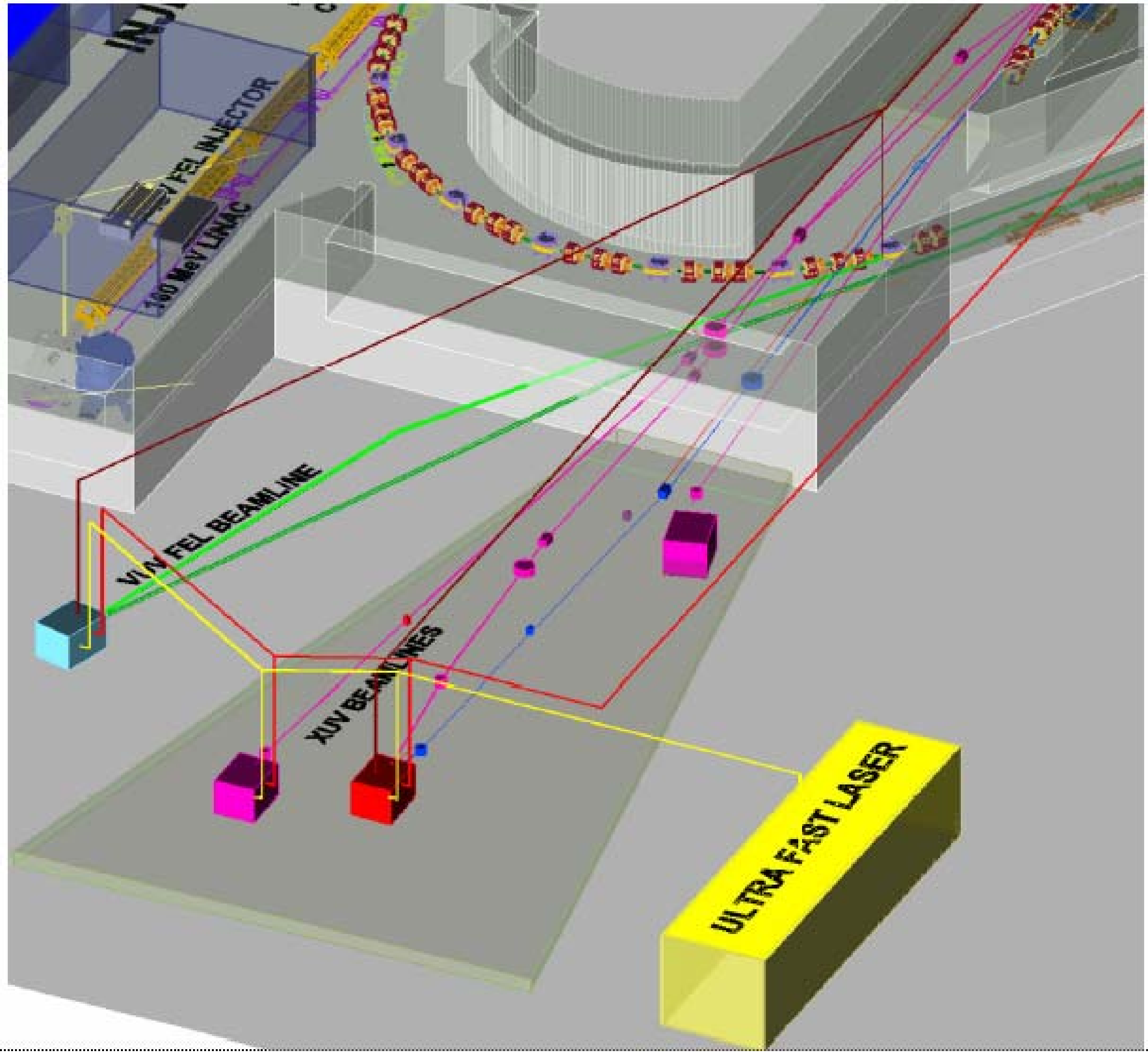
Figure 3.9 Peak brightness for 4GLS FELs, undulators, wiggler, OPA and dipoles compared with EUFELE, X-FEL, Diamond and Max III undulators

Combining Sources



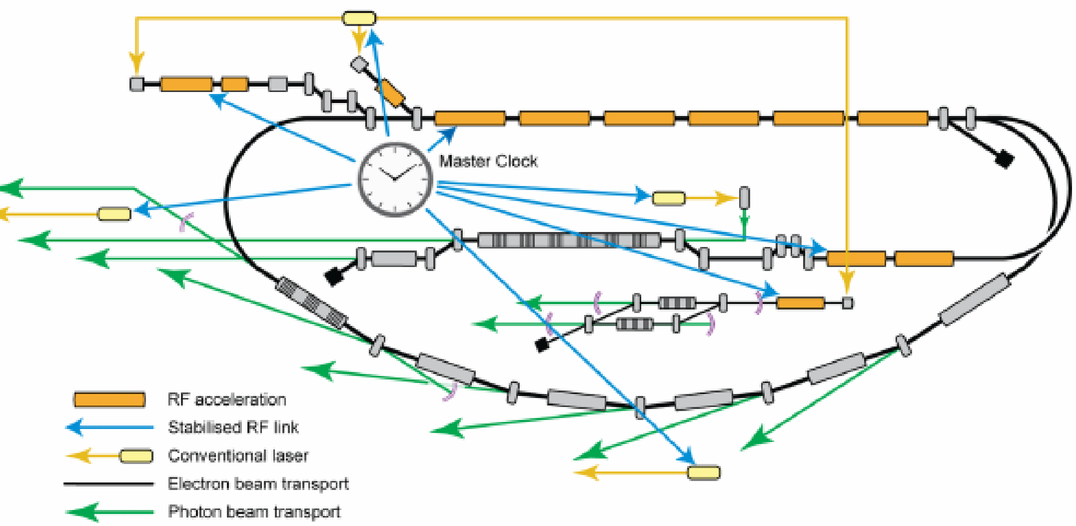
Three dimensional diagram showing some multibeam stations

Some details!

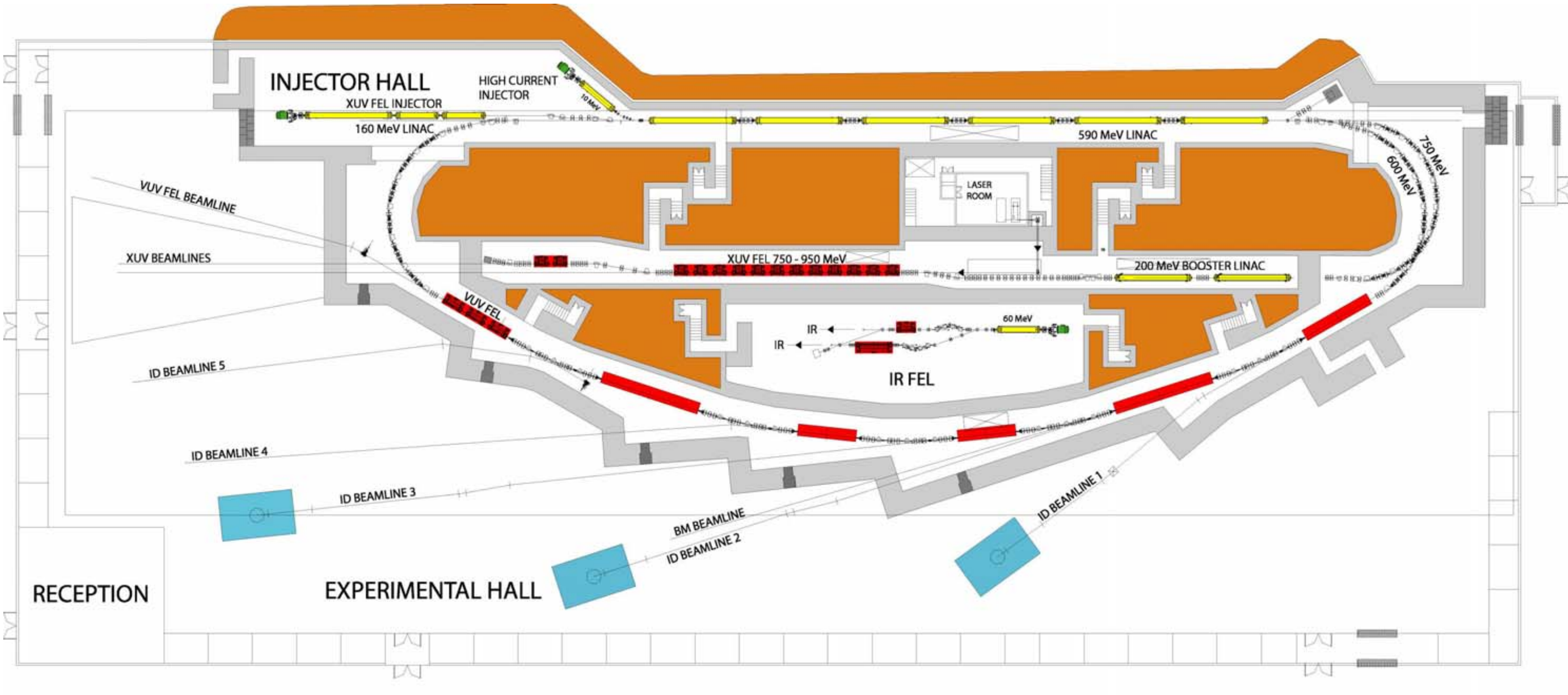


Challenges

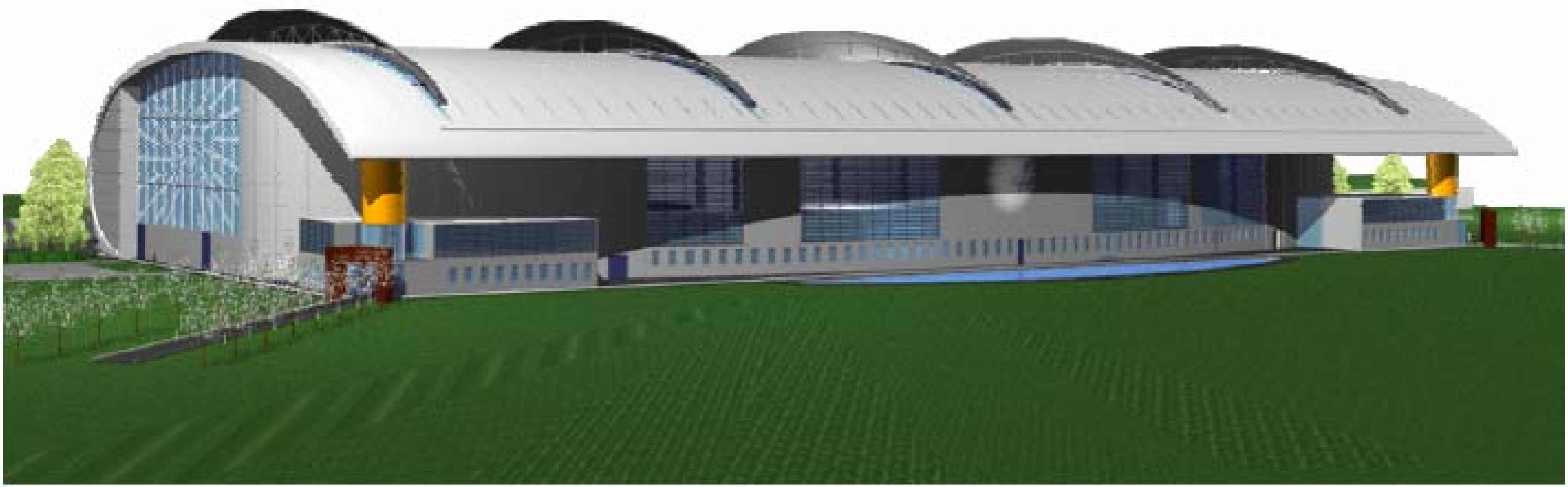
- **Timing & Synchronisation**
  - All combined sources to have synchronisation better than 100fs
  - Particular combinations require 10fs
  - Many sources of jitter
    - Laser
    - RF signals
    - RF acceleration
    - Electron transport
    - Photon transport



Present Layout



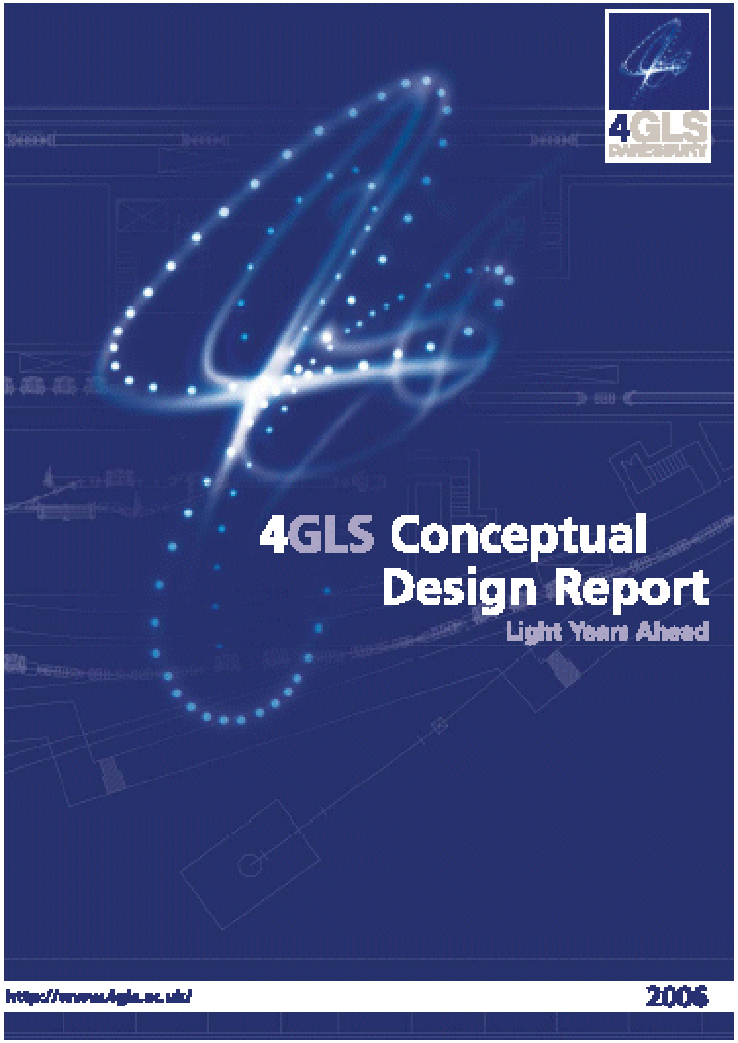
External View



Status & Milestones

- ERLP Commissioning (2006-2007)
- Exploitation of ERLP (2007……)
  - Accelerator science
  - Photon science THz & X-rays (CBS)
- CDR April 2006   www.4gls.ac.uk
- TDR March 2007
  - Costing
  - High priority technical work
- Prototyping (SC RF, Photoinjector) 3 years
- Bid for 4GLS funding late 2007

Thanks….



The 4GLS Team

International Advisory Committee