Science & Technology Facilities Council
ASTeC

Electron Beam Test Facility (EBTF) and Proposed FEL Test Facility CLARA at Daresbury Laboratory

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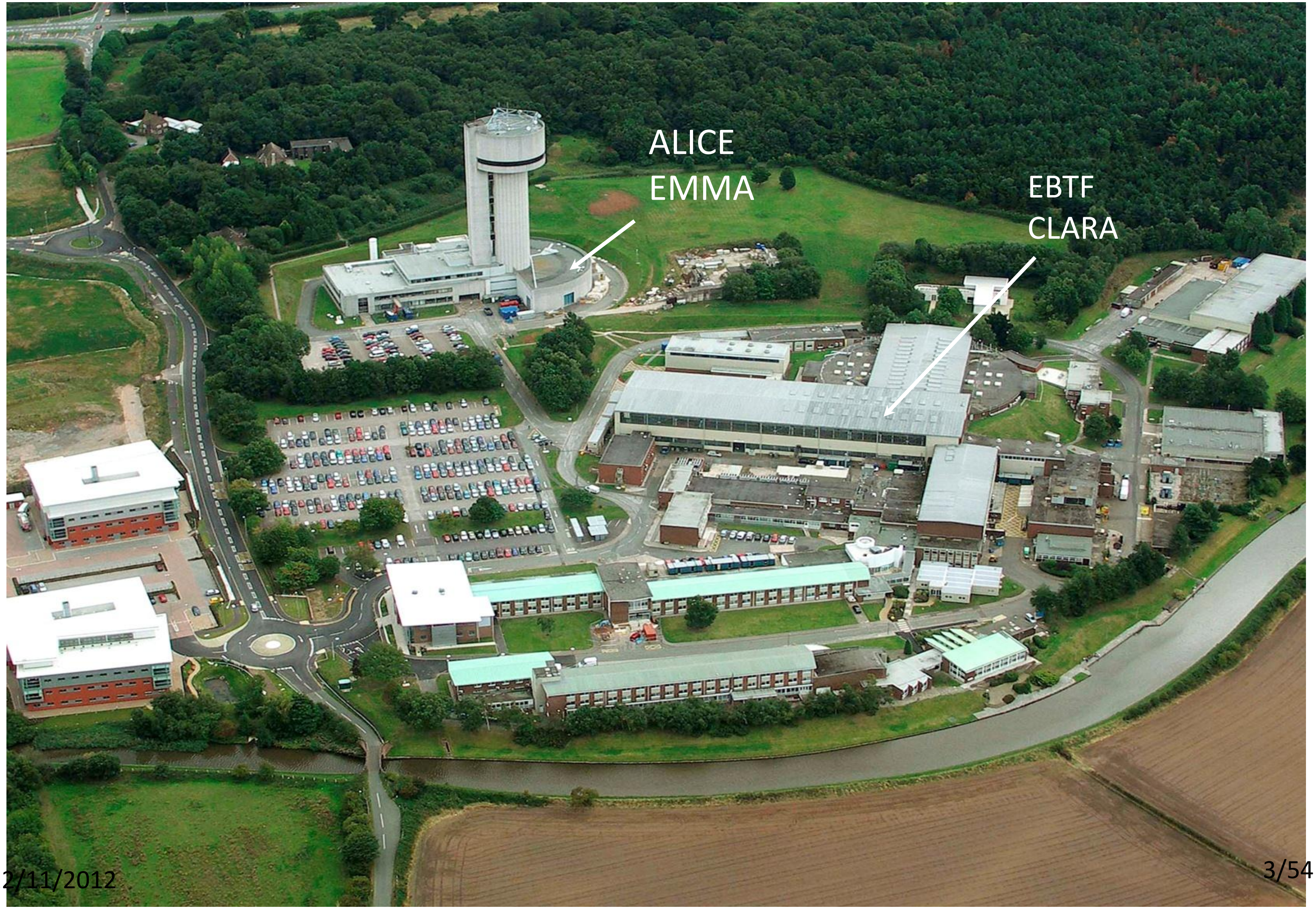
JAI Lecture, 22nd November 2012

Accelerator Test Facilities at Daresbury

- **ALICE** (**A**ccelerators and **L**asers **I**n **C**ombined **E**xperiments)
  - Energy Recovery Linac
  - Experimental Exploitation
- **EMMA** (**E**lectron **M**achine for **M**any **A**pplications)
  - NS-FFAG
  - Acceleration Demonstration
- **EBTF** (**E**lectron **B**eam **T**est **F**acility)
  - Industrial Test Facility – under construction
  - High brightness injector for CLARA
- **CLARA** (**C**ompact **L**inear **A**ccelerator for **R**esearch and **A**pplications)
  - Proposed FEL Test facility
  - Unique Developments
  - High energy beam for research and industrial applications

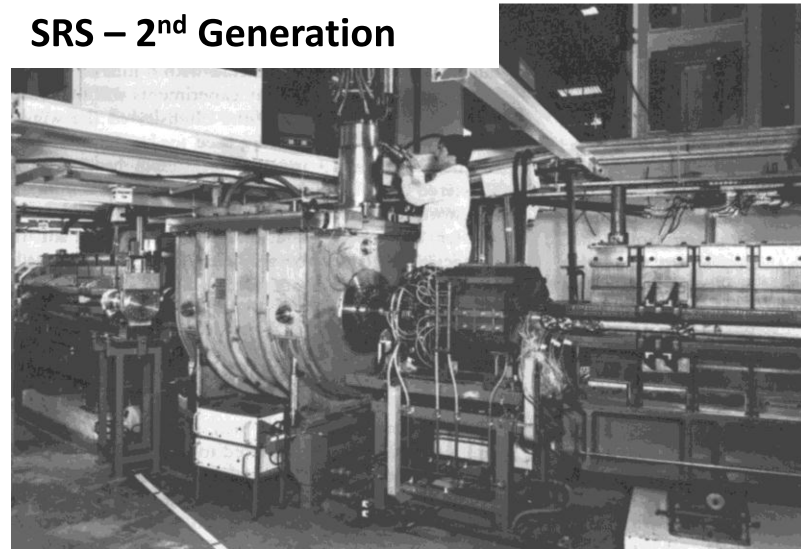
Accelerator Test Facilities at Daresbury



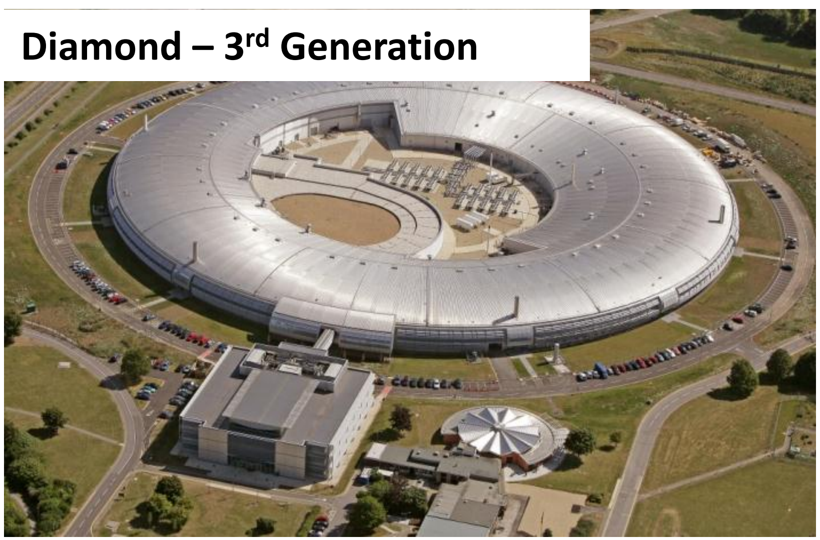
Light Source Generations

NINA – 1st Generation

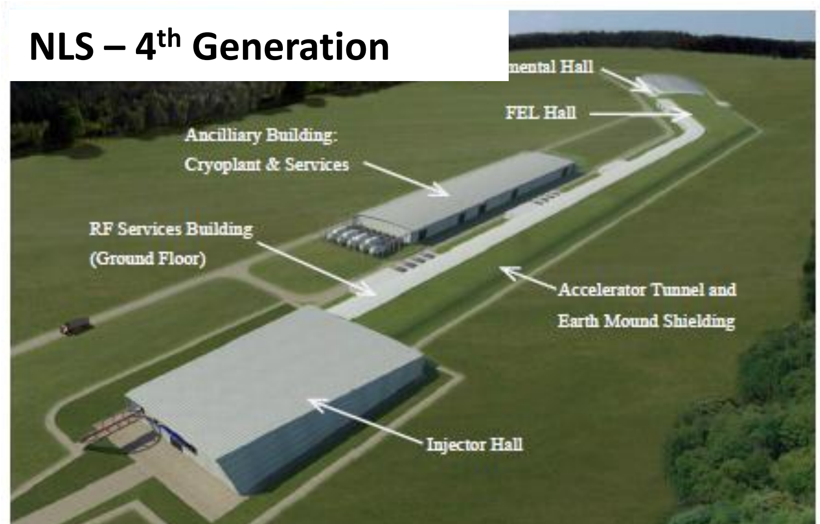
SRS – 2nd Generation



Diamond – 3rd Generation



NLS – 4th Generation



Injector and Beam Quality

- In the 1st, 2nd and 3rd generation light sources, electron sources are part of the injector chain that typically includes a linac and a "booster" ring.
- The beam generated by the electron gun goes through the linac and is then accelerated and stored in the booster for a time long enough that the 6D beam phase-space distribution is fully defined by the characteristics of the booster and not of the electron source.
- In Linac based 4th generation light sources, such as free electron lasers, the final beam quality driving the FELs is dictated by its injector and electron source.
- The ultimate value of the beam brightness depends upon beam manipulations through Linacs and compression chicanes but the ultimate limit comes from the electron source.

Production of High Brightness Electron Beams

Generation

- Thermionic cathode
- Photocathodes
- Field emission cathodes
- Other…

Acceleration

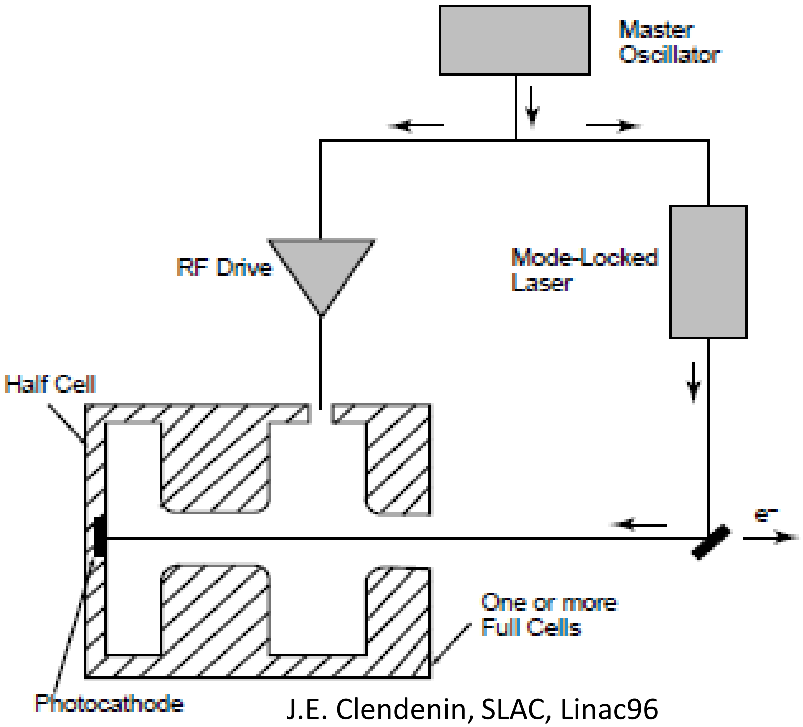
- DC gun
- NC RF guns
- SRF guns

Compression

- Velocity bunching
- Magnetic compression

CLARA = EBTF + Compression + Acceleration + Undulators + FEL

Principle Components of RF Photoinjector



J.E. Clendenin, SLAC, Linac96

The basic components of an RF photoinjector consist of :

- RF gun with a photocathode
- Laser and optical system producing the desired pulse structure
- RF source
- Timing and synchronisation system

Electron Beam Test Facility EBTF

- **Objective:** To provide a suite of accelerator testing facilities which can be utilised in partnership with industry, academic and scientific collaborators
- **Scope:** The provision of a common high performance and flexible injector facility comprising an RF gun, associated RF power systems, beam diagnostics and manipulators, a high power photo-injector drive laser and associated enclosures
- **Costs:** £2.5M capital from DBIS has been assigned for this facility(August 2011). This investment was supplemented by ~£500k capital allocation from STFC's baseline capital allocation for the accelerator test facilities
- **Timescales:** Purchase the majority of the equipment in financial year 2011/12, with build in 2012. First electrons expected in December 2012.

EBTF Parameters to User Areas

	Parameter range*	Comments
Beam Energy	4 - 6 MeV	Operating mode may be dictated by dark current
Bunch Charge	10 - 250 pC	Experimental modes
Bunch length ($\sigma_{t,rms}$)	1-10 psec	Bunch length changes along the line. (Laser 78 fs rms)
Normalised emittance	1-4 μm	Varies along the beam line
Beam size ($\sigma_{x,y,rms}$)	1-5 mm	Varies along the beam line
Energy spread ($\sigma_{e,rms}$)	1-5%	Varies along the beam line
Bunch repetition rate	1-10 Hz (Stage I gun) 1-400 Hz (Stage II High rep rate gun)	Klystron Modulator & Laser specified at 400 Hz

*Not all beam parameters are possible to achieve simultaneously. Due to space charge effects, some beam parameters vary along the beam line.

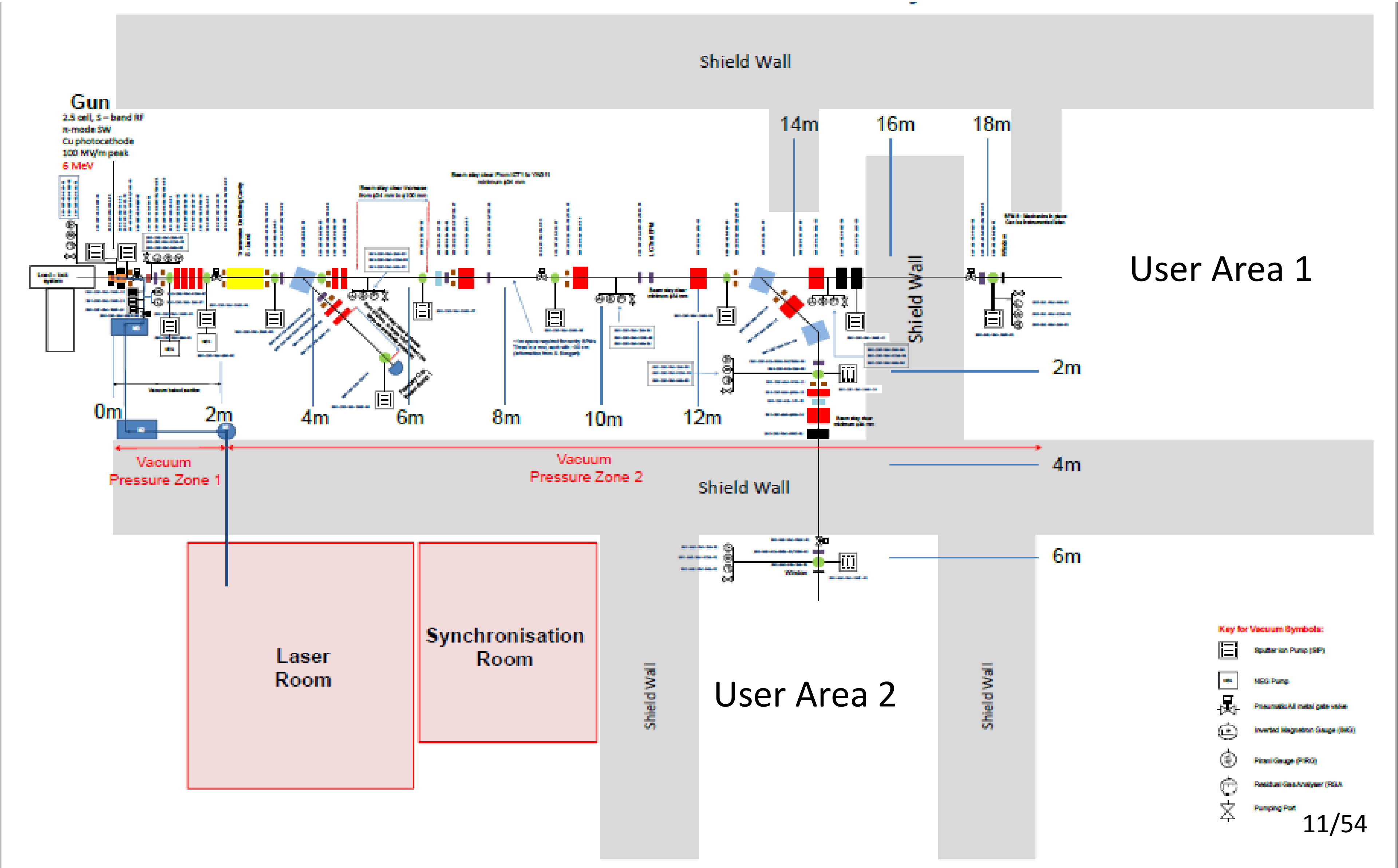
EBTF Synergies

Application Area	Energy (MeV)	Repetition Rate (Hz)	Beam Power (kW)
Security			
Cargo Scanning	1 - 6	100 - 400	≤0.1
Medical			
X-Ray Radiotherapy	5 - 25	≤ 500	≤2
Isotope Production	10 - 100	150	≥10
Sterilisation			
Food	5 -10	250	≤1
Medical	≤10	250	≤10

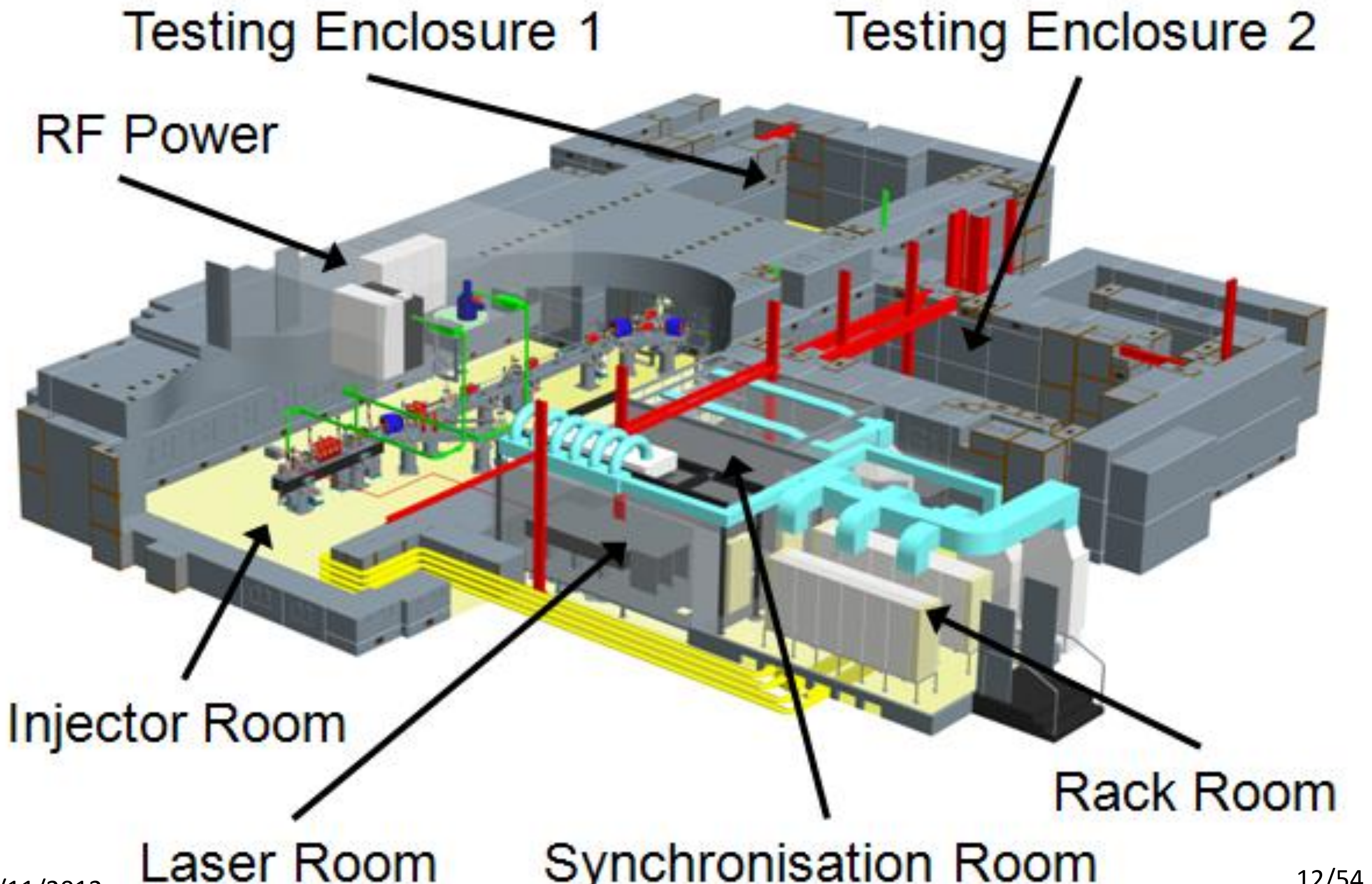
Accelerating Structures & RF Power Sources (Energy column)

Beam Diagnostics & Control Systems (Repetition Rate column)

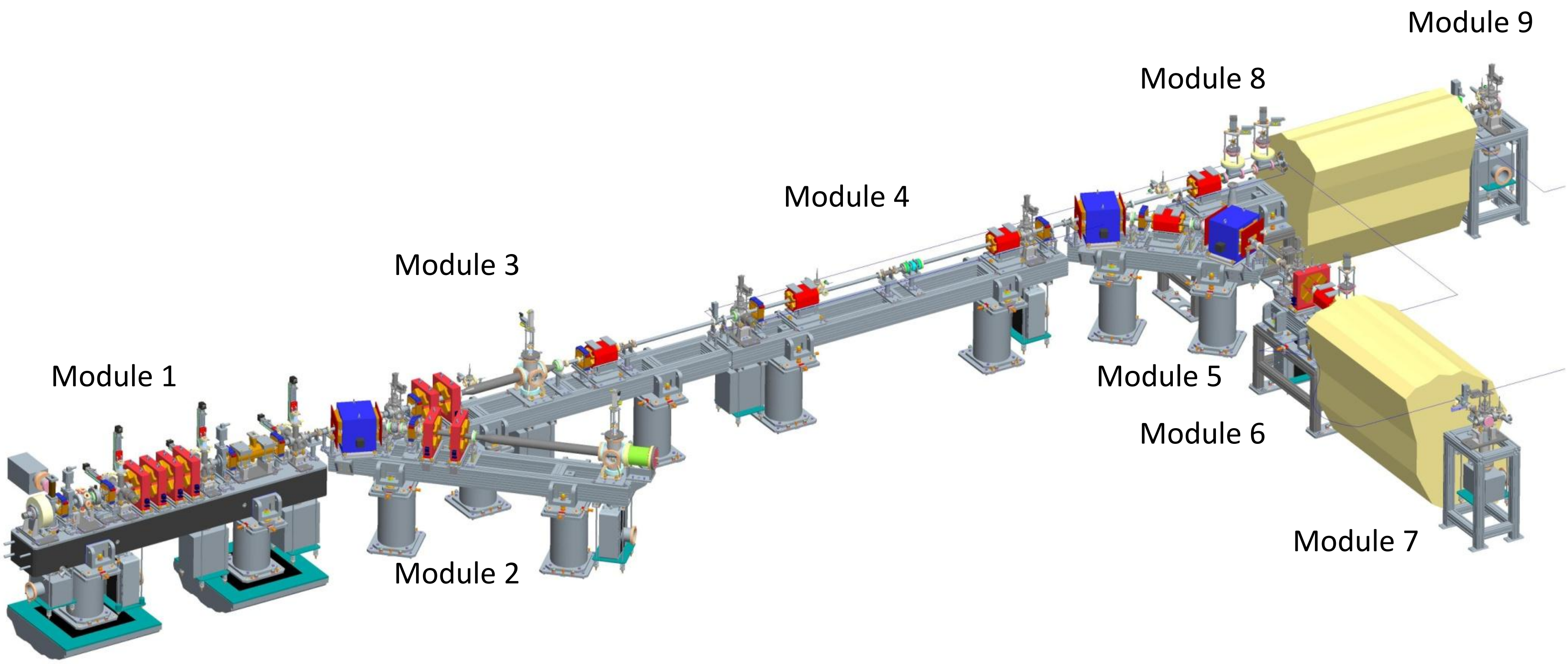
EBTF Schematic Layout



EBTF

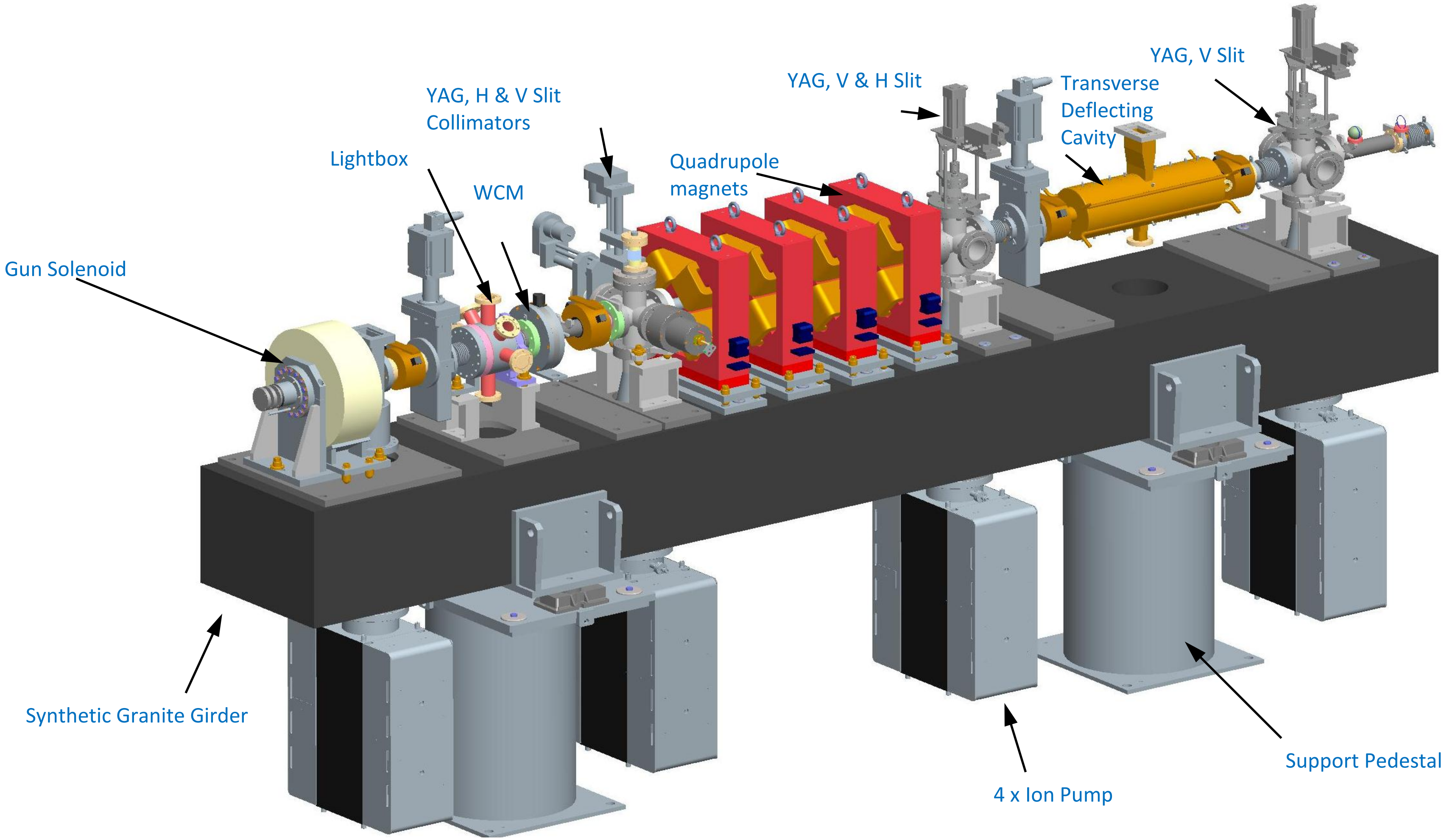

Testing Enclosure 1
Testing Enclosure 2
RF Power
Injector Room
Rack Room
Laser Room
Synchronisation Room

Construction Modules



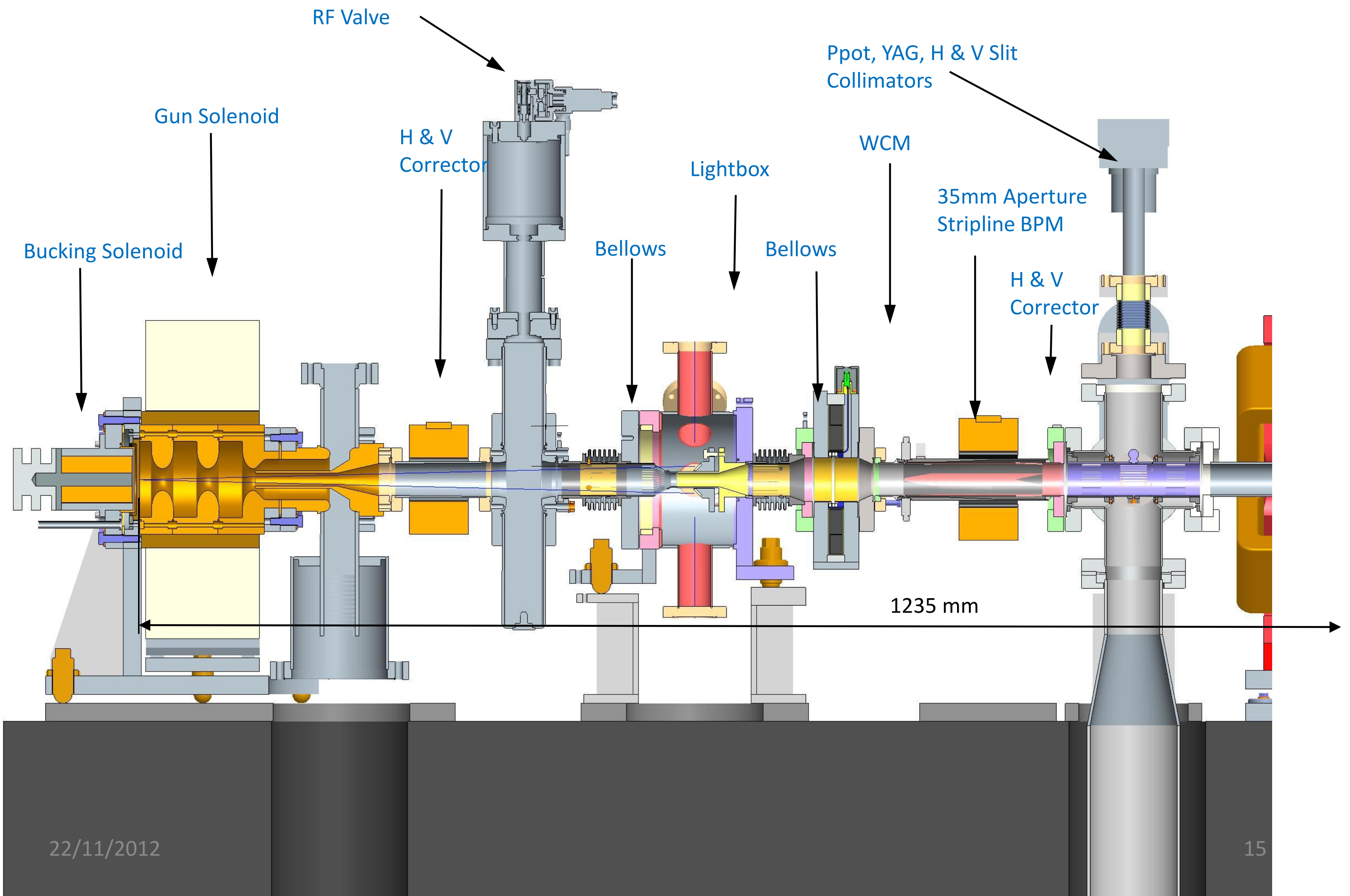
- Aluminium alloy support girders, which gives increased relative stability between components, and reduced time to re-align.
- The girders are supported by sand-filled aluminium alloy pedestals giving increased damping against vibration transmitted through the floor. Particularly, noisy equipment will be locally damped at source.

Photoinjector Module

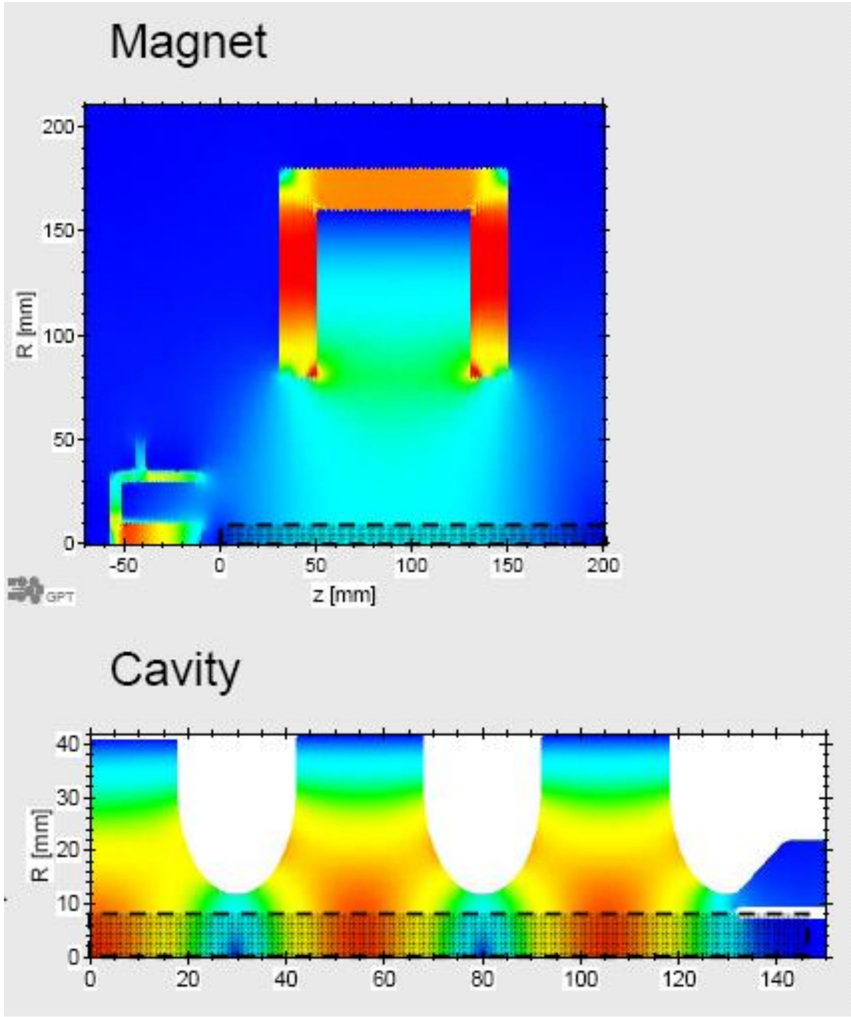


The photoinjector module is supported by a temperature stabilised, synthetic granite girder due to its low co-efficient of thermal expansion, and improved vibration dampening performance.

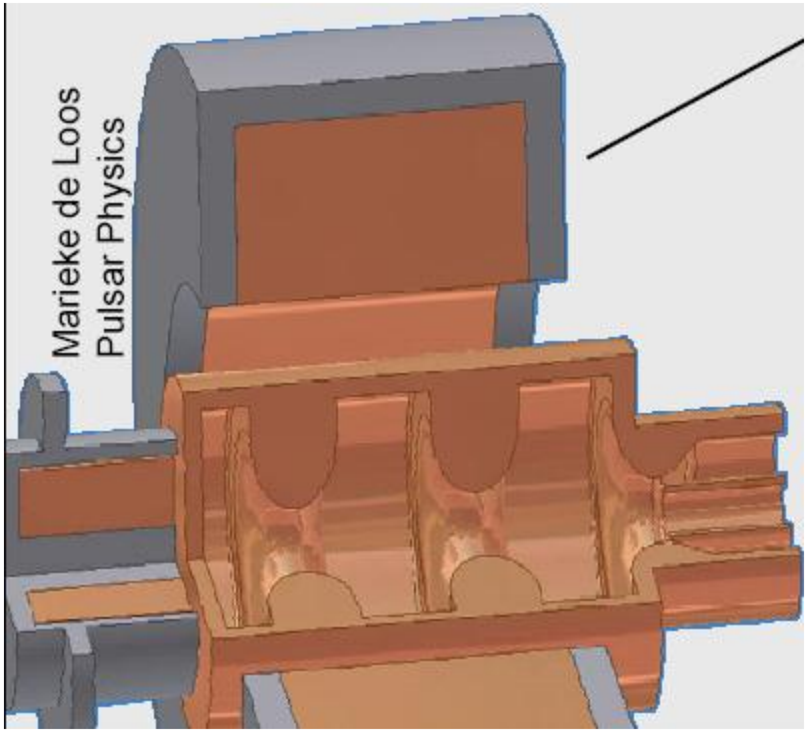
EBTF Gun Beamline



S-band RF gun

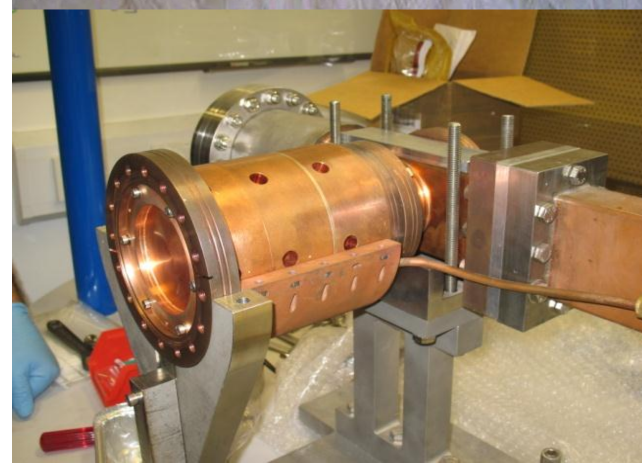


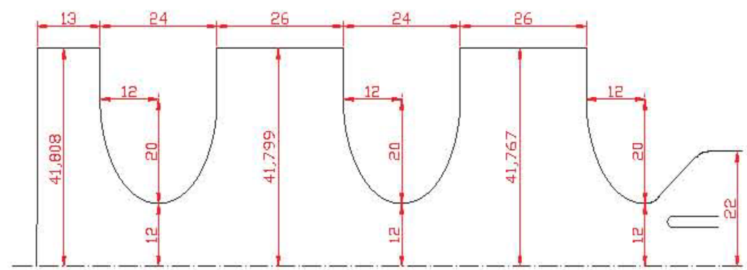
EBTF photoinjector based on the ALPHA-X 2.5-cell S-band gun (TU/e-Strathclyde-LAL)



Photocathode gun cavity

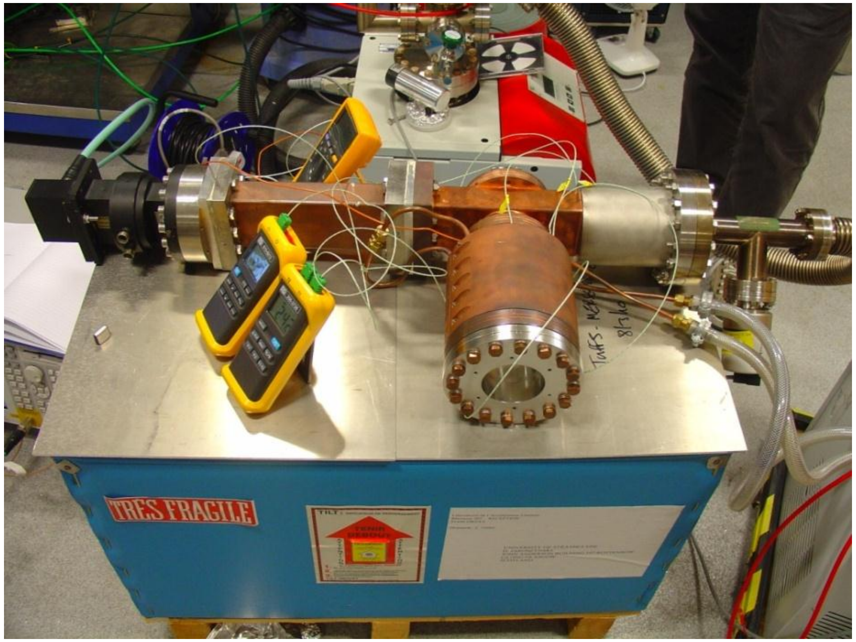
Parameter	Value	Units
Frequency	2998.5	MHz
Bandwidth	< 5	MHz
Maximum beam energy	6	MeV
Maximum accelerating field	100	MV/m
Peak RF Input Power	10	MW
Maximum repetition rate	10	Hz
Maximum bunch charge	250	pC
Operational Temperature	30 - 45	°C
Input coupling	WR284	



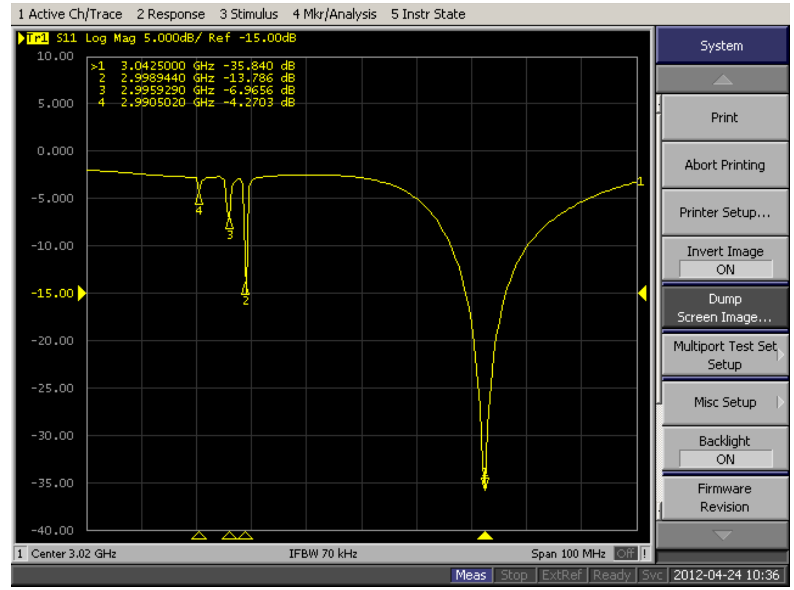


Schematic of RF Gun Cavity

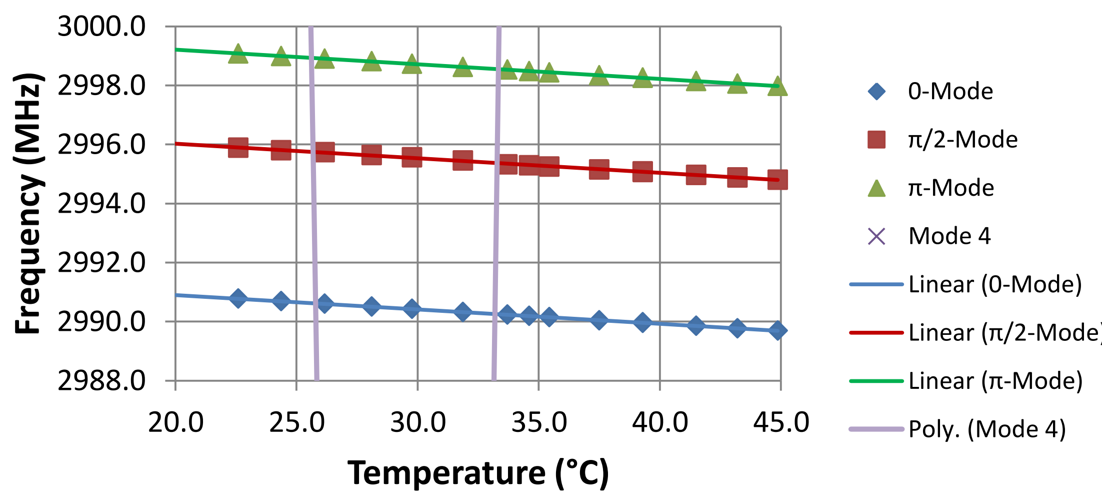
Photocathode Gun Cavity Low Power RF test



Spectrum of the reflected power

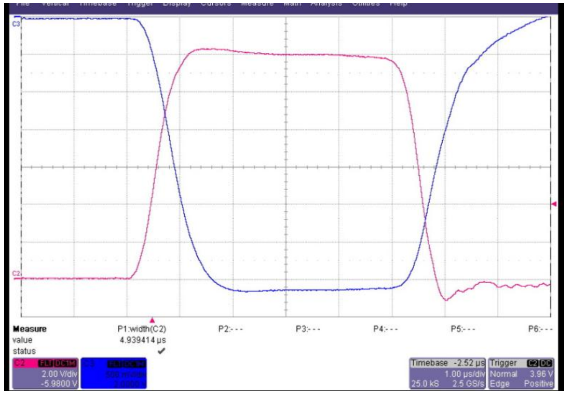


- Vacuum 1.0 x 10^{-7} mBar
- Cavity modes characterised with respect to cavity temperature
  - Chiller unit used to vary the cavity temperature
- 3 accelerating modes
- Additional parasitic mode



RF Gun Klystron Modulator

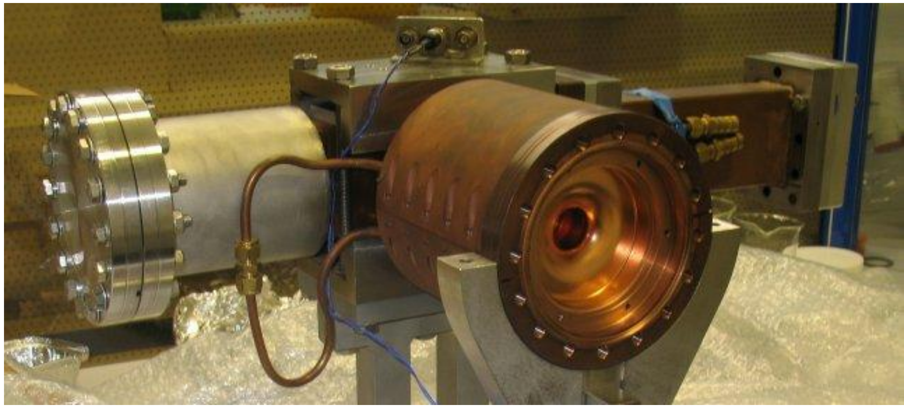
- ScandiNova K2 klystron modulator
  - 250 kV, 150 A
  - PRF 1 – 400 Hz
  - Pulse flat top 0.5 – 3 µs
  - Rate of rise 150 – 215 kV/ µs
- Thales TH2157 klystron
  - 10 MW Pk, 3 kW Ave



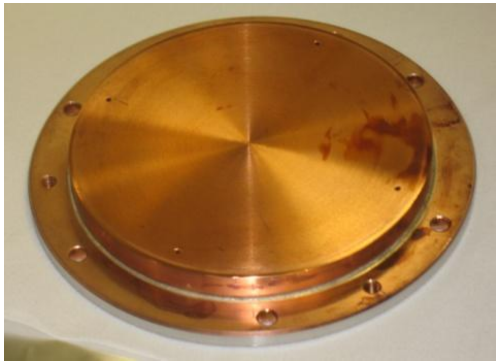
120 A 167 kV 3 µs pulse

Metal Photocathodes

- Metal cathodes have fast response time10^{-15} to 10^{-14} seconds.
- They are robust and can survive months at high surface fields to produce high brightness beam
- However due to the high work function an UV drive laser is required to achieve reasonable *QE.*
- With extensive surface science tools (XPS, AES, ISS, UPS, SEM) and direct access to universities (high resolution SEM,EDS,EBDS,XRD) as well as unique expertise within ASTeC, an extensive metal photocathode R&D has been planned.

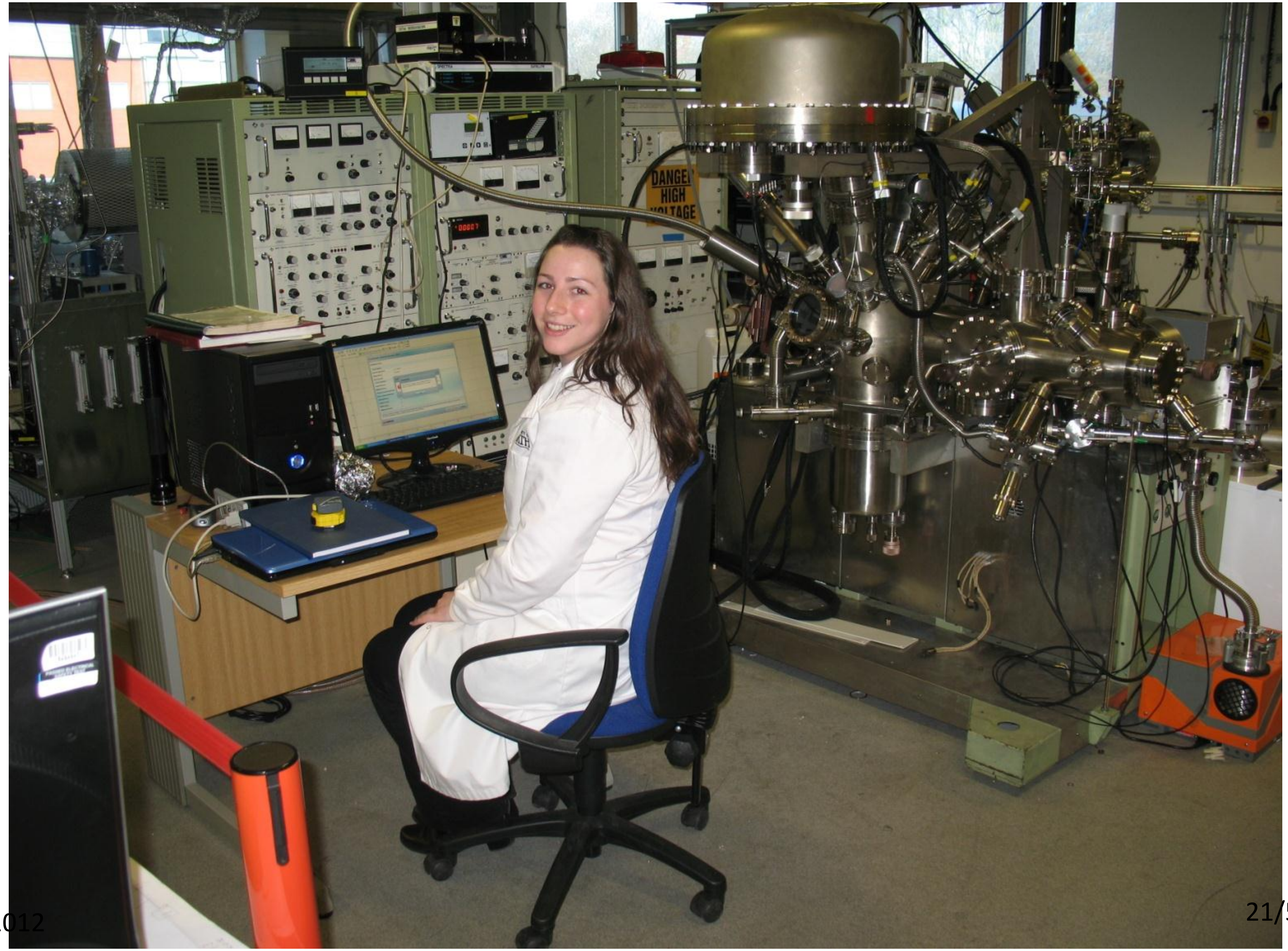


EBTF photocathode gun with dismounted photocathode

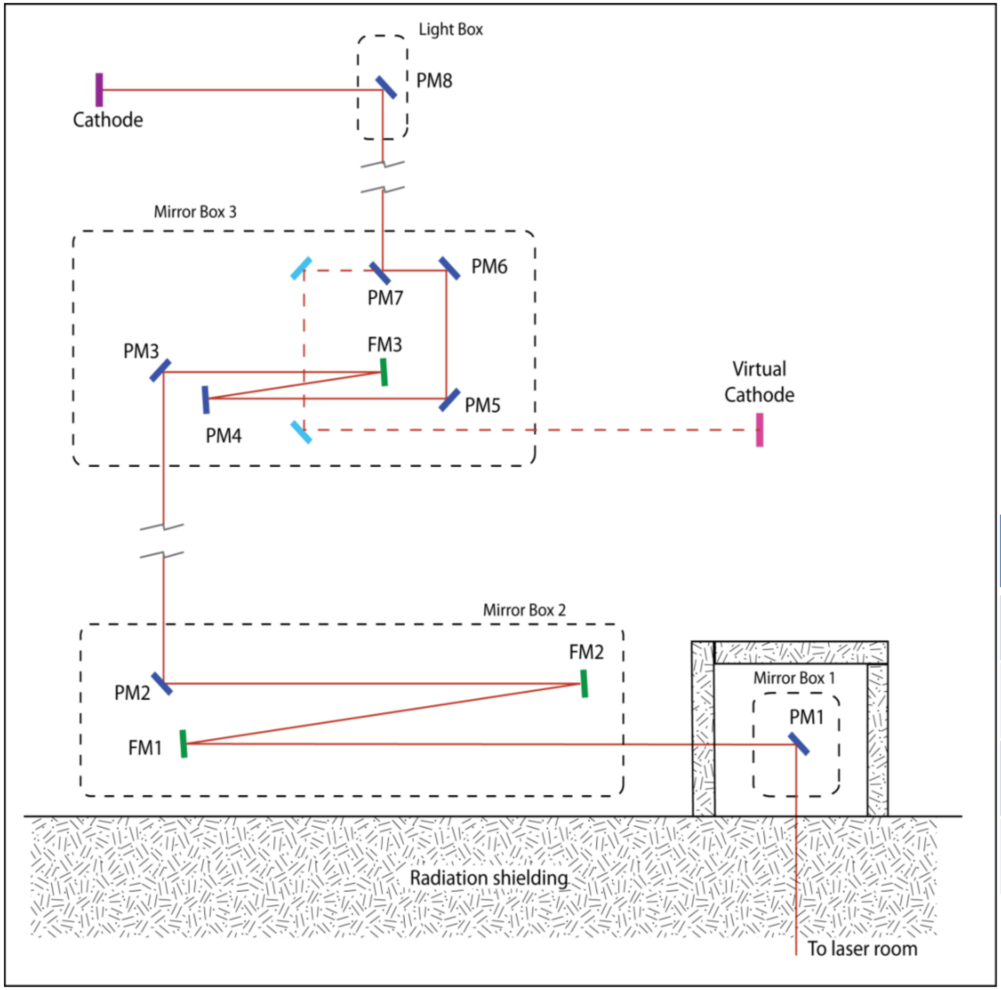


Copper photocathode plate ; polycrystalline, oxygen-free, copper disc, polished to 1µm roughness.

Photocathode Preparation & Characterisation Facility



EBTF Ti:Sapphire Drive Laser System



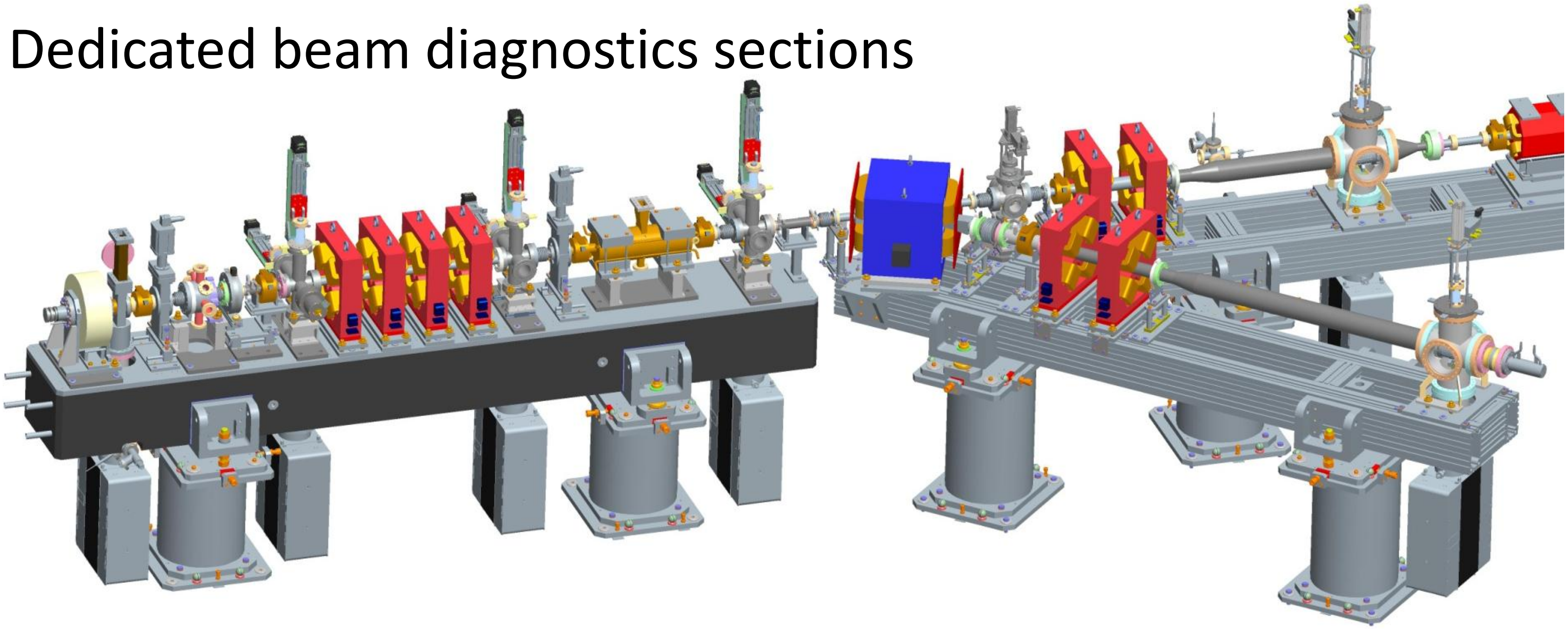
Wavelength , nm	266
Pulse energy, mJ	>1
Pulse duration, fs	<200 FWHM
Pulse repetition rate, Hz	400
Transverse beam quality M^2	<1.5

Drive Laser Specification

		Factory Test Result
Pulse energy at 800 nm	>10 mJ	**10.75 mJ**
Pulse energy Stability	<1% rms	**IR: 0.15%** **THG: 0.88%**
Base repetition rate	400 Hz	**400 Hz**
Pulse duration IR	<40 fs	**36fs**
Pulse energy at 266 nm	>1 mJ	**>2mJ**
Bandwidth at 266 nm	>1 nm	**2.5nm**
Pulse duration at 266 nm	<200 fs	**180fs**
Transverse beam quality (over distance)		
M_x^2 and M_y^2 after compressor	< 1.5	**M_x^2: 1.33** **M_y^2: 1.22**
Beam pointing	$\varepsilon=\Delta\phi.(D/\lambda)$, D is the $1/e^2$ beam diameter, λ is the wavelength, and $\Delta\phi$ is the rms beam-pointing stability in radians, $\varepsilon<0.5$	**ε_x=0.076** **ε_y=0.285** **(Tested with 0.6m focus lens and CCD camera)**
Laser operating at 10 Hz	Determining jitter between laser operating at 10 Hz and external source. Same source that will be fed to the Vitara oscillator. To ensure that there was no +/-12ns ambiguity or jitter.	**10 Hz jittering: <500ps**

Beam Diagnostics

Dedicated beam diagnostics sections



- YAG screens
- Wall Current Monitor (WCM)
- Faraday Cups (FC)
- Strip Line Pickups
- Beam Arrival Monitor
- Slits, collimators, Pepper-pot or Slit mask on first three YAG stations
- Transverse Deflecting Cavity

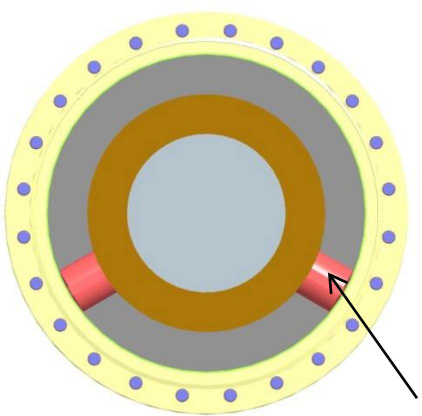
Charge Measurement

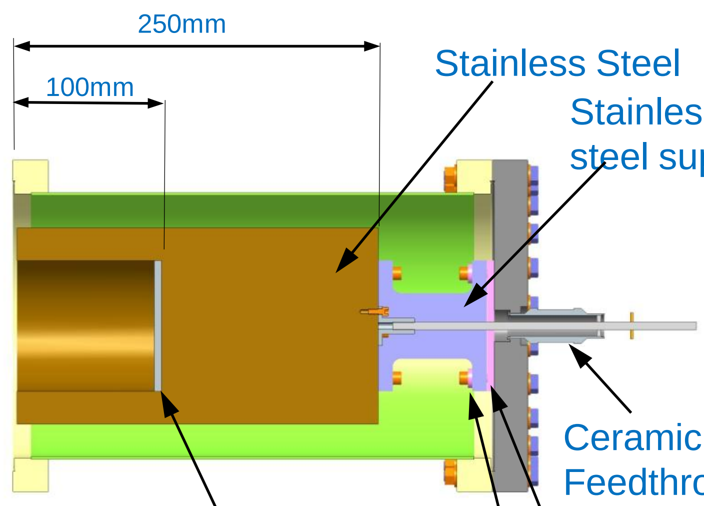
- The WCM (made in Fermilab) has 2Ohm resistance and about 4GHz bandwidth. Its signal (a bunch current & a gun dark current) is supposed to be directly observed on a broadband oscilloscope. The bunch charge can be measured as an integral taken by the scope. The charge can also be measured by the FC integrating electronics (next slide) connected to WCM.

- The ICT (5:1, equipped with a BCM card) are commercial devices (from Bergoz). The scale is 60 pC/V.

Charge Measurement

- The FC is designed to have bunch charge error about 1% in the EBTF energy range. It is made as a somewhat coaxial line to minimise short pulse reflection. After a set of LP filters, its signal comes to an Integrator the output signal of which is a F~30MHz decaying ringing.
- The bunch charge is equal to $V_{ampl}/2\pi F \cdot R \cdot \xi$ where R=50Ohm is the Integrator load, $\xi=1-\varepsilon$, $\varepsilon<<1$ is a coefficient which takes into account the decay, a common-base transistor error, etc. The scale is 5pC/V. For low common mode interference, signal transmission to the Integrator is done using a symmetrical cable.





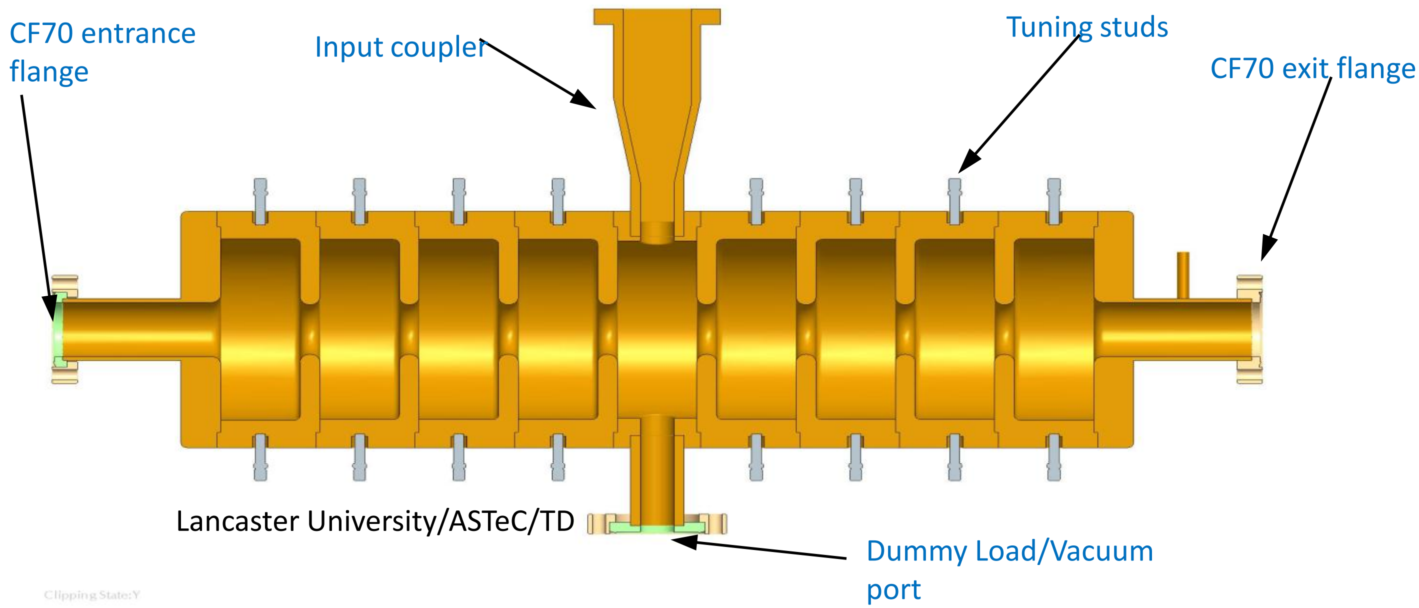
Beam Position Measurement

- The strip line pickups are equipped with EPICS BPMs designed for the EMMA where they are used for single-bunch/turn-by-turn measurements. The BPM consists of a Front-End and a VME card. In the Front End, each pickup signal is converted into a compact 700MHz three-wave packet. Two packets of opposite pickups are time-domain multiplexed (spacing is 55.2ns) and transmitted to a two-channel VME card where they are amplified, detected, measured with a fast ADC and finally stored in a memory. The measurement is triggered by the bunch signal itself.

- BPM software designed for EMMA for its Injection Line as well as for the ring, and for its ALICE injector as well (where EMMA BPMs were also used for some tasks).

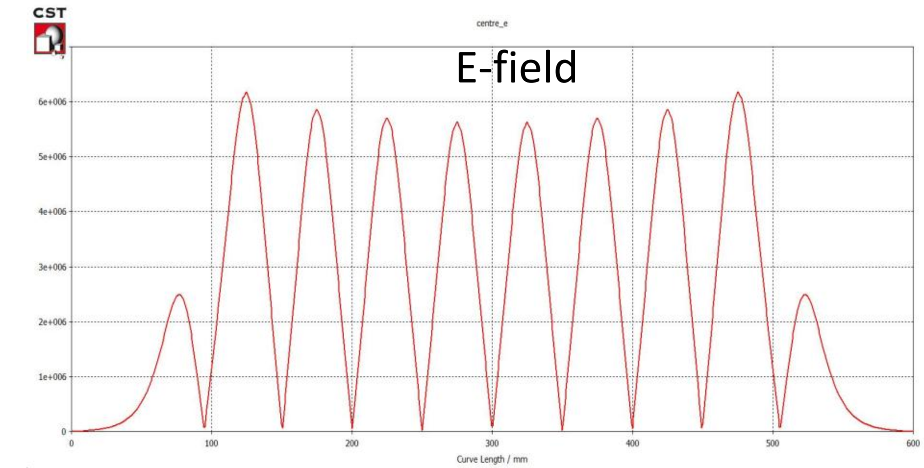
- On EMMA, with button pickups, the BPM resolution was measured as about **30um for bunch charge 20pC**. To extend the BPM range down to several pC which is necessary on EBTF, we improve the signal-to-noise ratio by use of strip line pickups with optimal length equal to [c/700MHz]/4. The gain obtained is about 6 times.

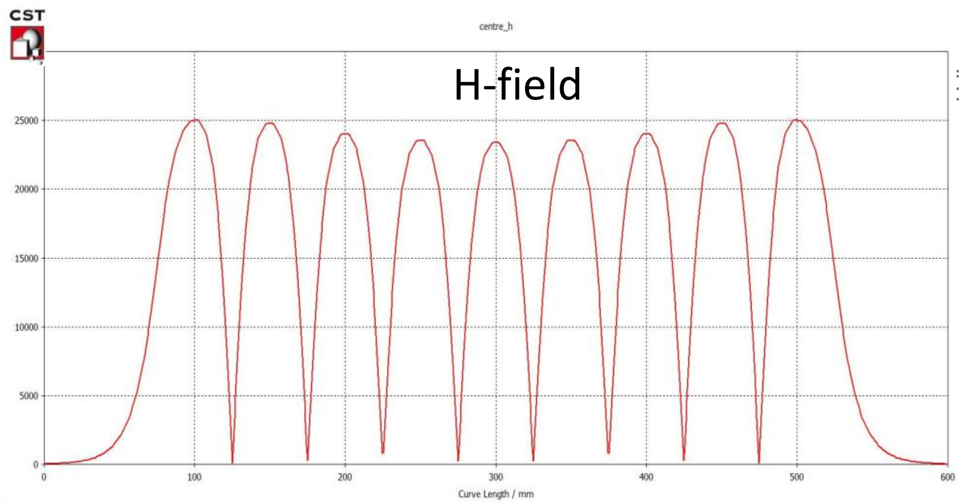
Transverse Deflecting Cavity



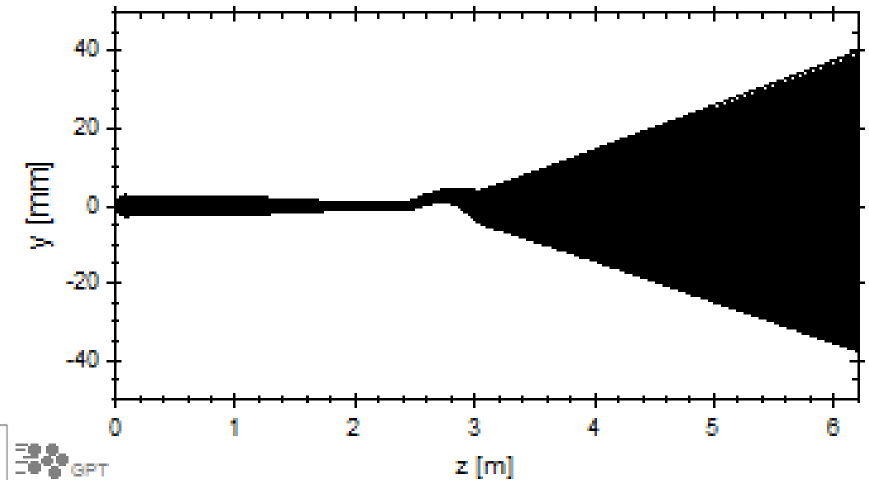
- Provides kick based on longitudinal position within the bunch.
- Beam is streaked in vertical plane so that vertical beamsize after the TDC is proportional to the bunch length at the TDC.
- Passing this beam around a horizontal dipole causes horizontal beamsize to be proportional to energy spread. Thus longitudinal phase space can be viewed directly on a screen.

Transverse Deflecting Cavity

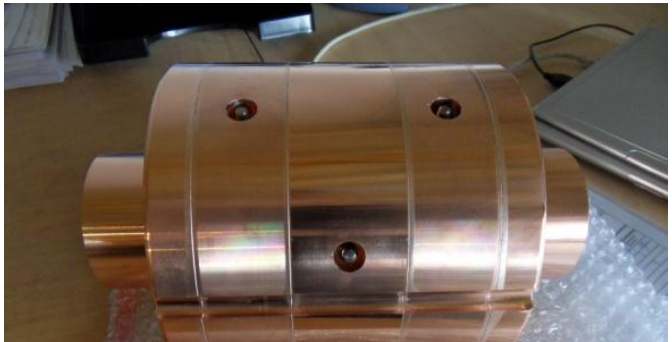




Vertical trajectories with the transverse deflecting cavity providing a streak



Estimated peak transverse voltage 5MV (limited by available RF power)



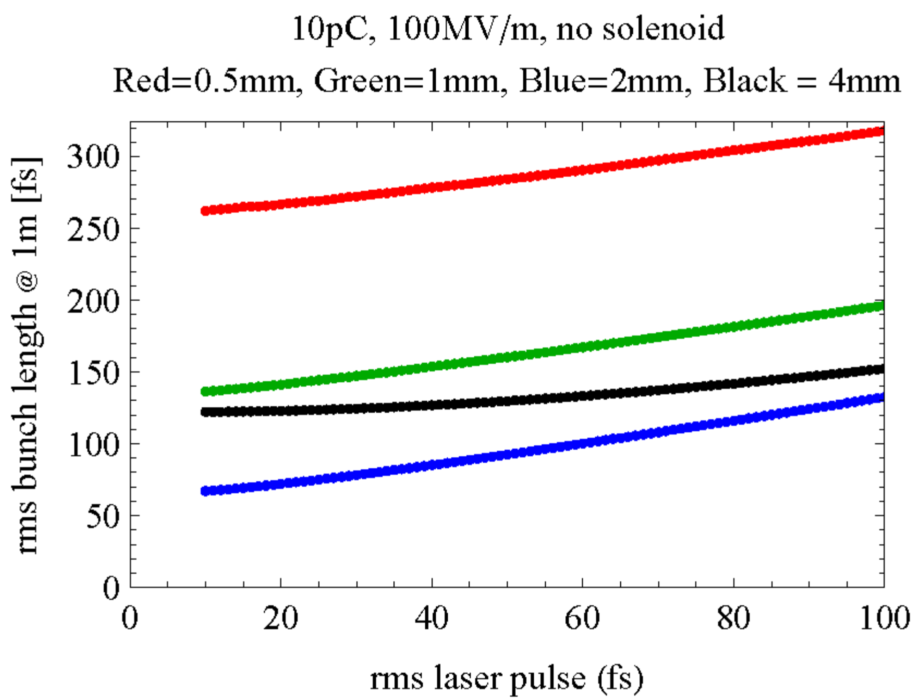
3-cell TDC prototype – for benchmarking against simulations

Shortest Bunch From Gun

Shortest bunch from gun is determined by:

- laser pulse length (78 fsec)
- cathode response time (10^{-15}-10^{-14} sec with metal)
- space charge

- Trade-off between transverse laser spot size and pulse length.
- Intrinsic emittance from the cathode scales linearly with spot size.

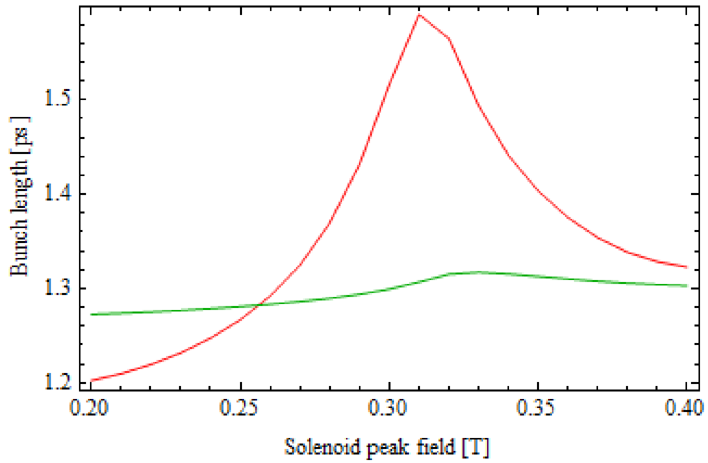


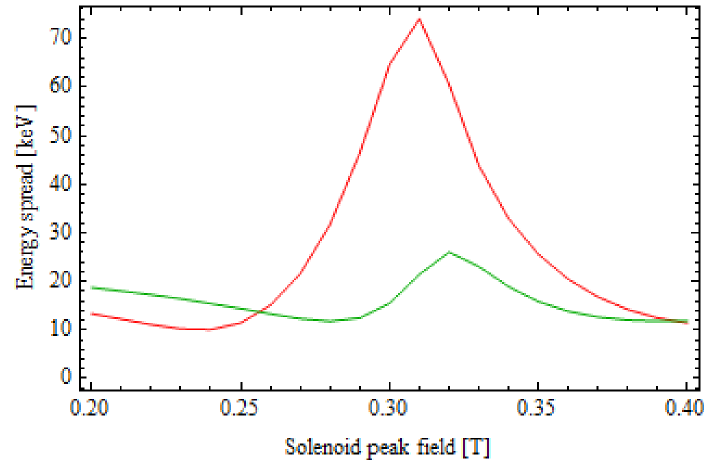
EBTF Gun Simulations

ASTRA/GPT

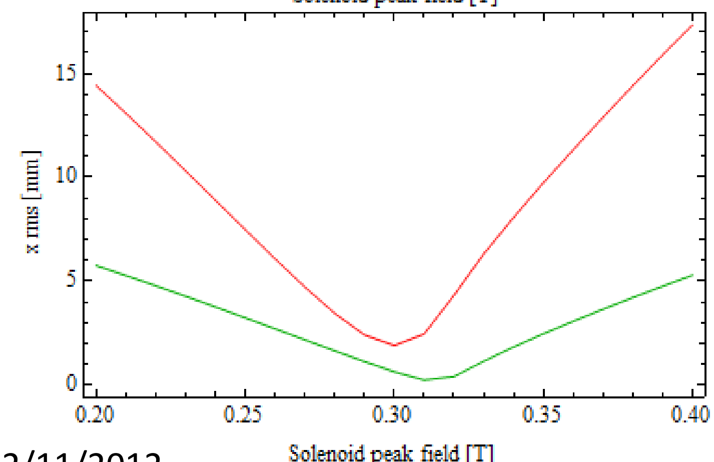
Laser:
1 mm diameter
76 fs Gaussian

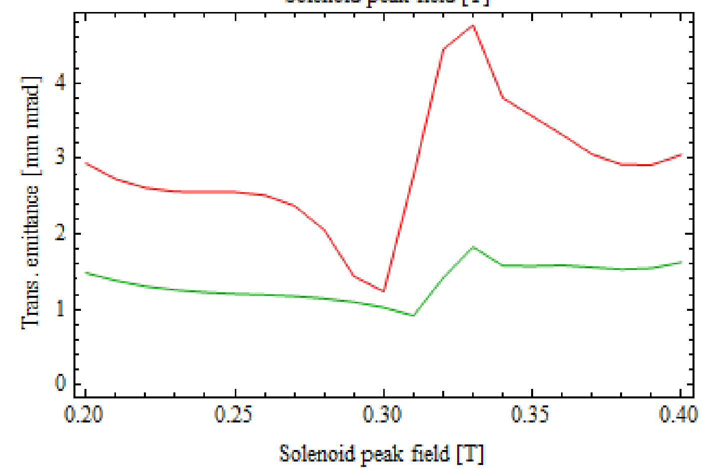
250 pC
Gun peak field: 100 MV/m
Gun phase: -25





Distance from cathode:
Green = 1.1 m
Red = 3.0 m

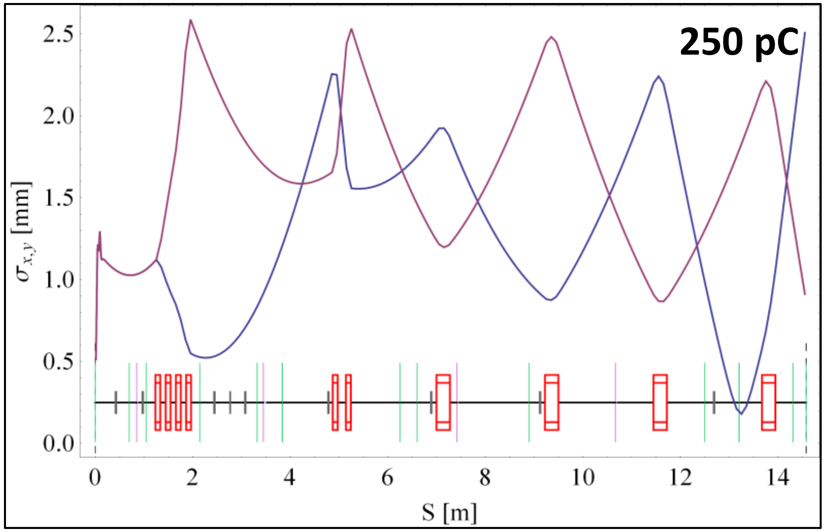


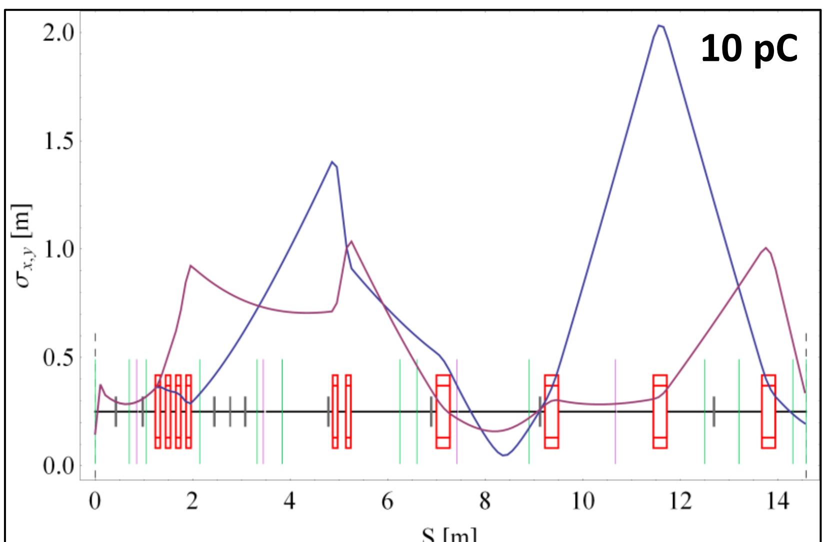


Laser beam size – varied in simulations at different bunch charges.

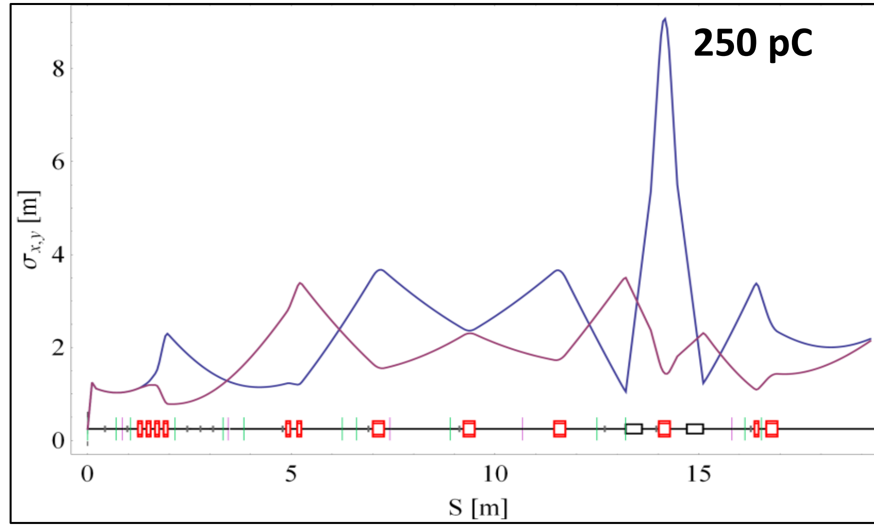
Beam Sizes to User Areas : an example

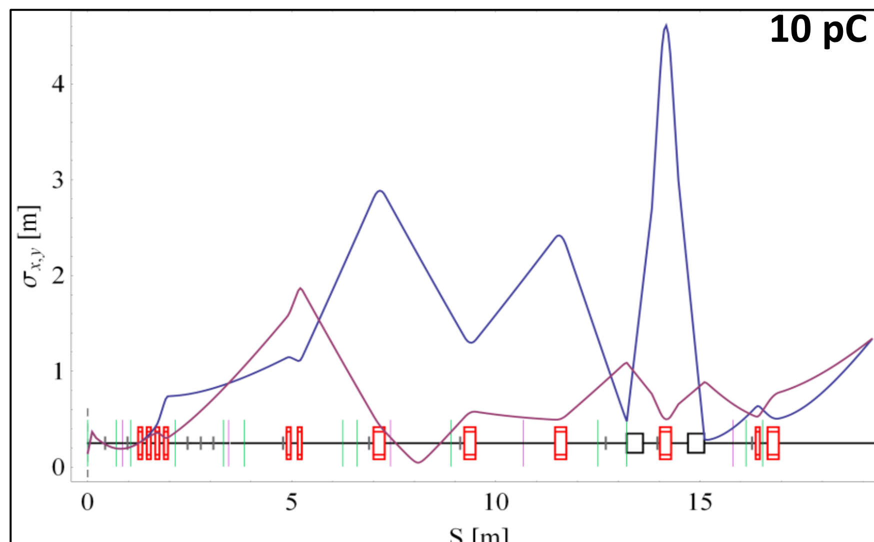
User Area 1





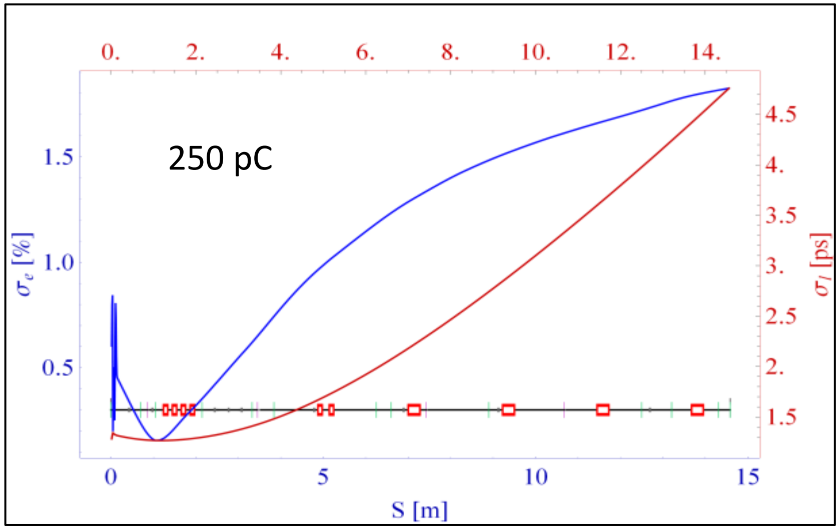
User Area 2

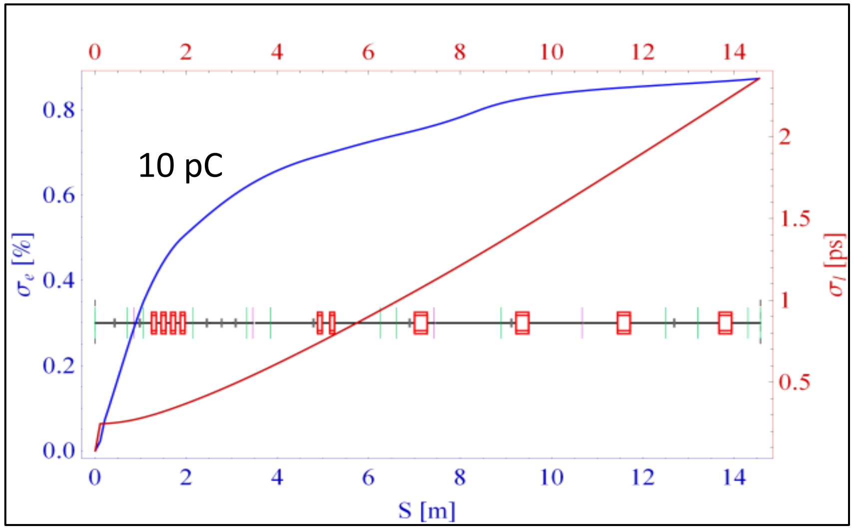




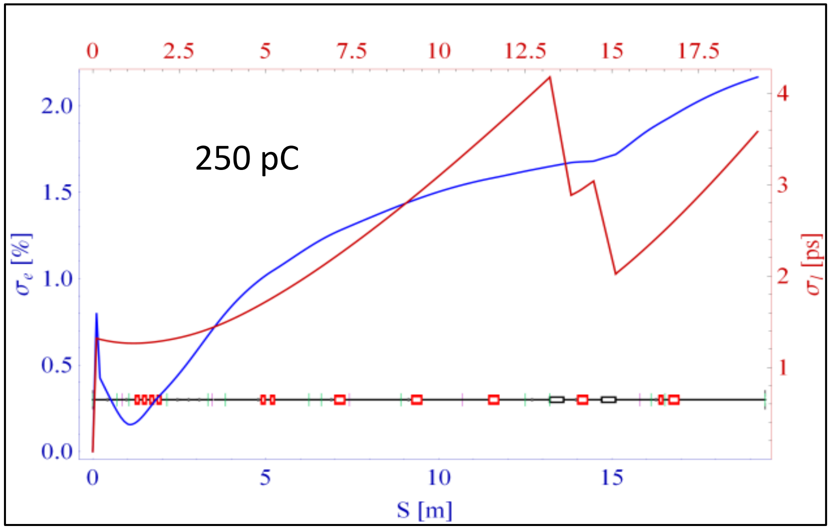
Long. Parameters to User Areas : an example

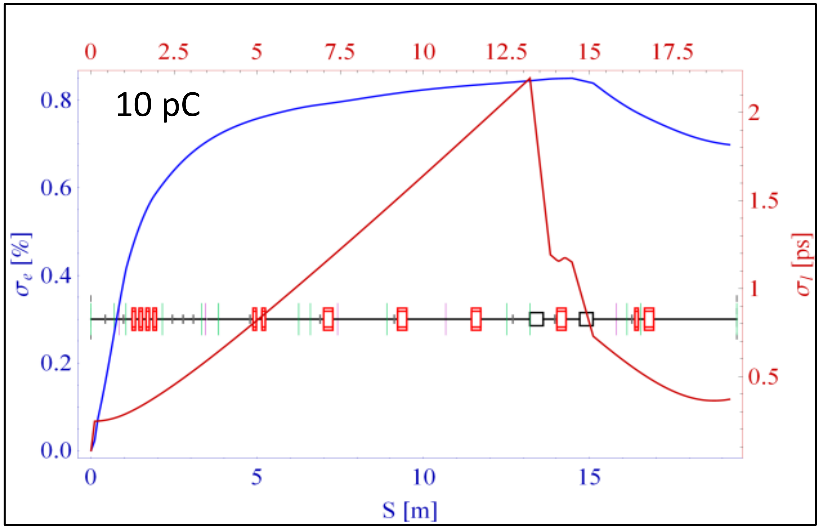
User Area 1





User Area 2

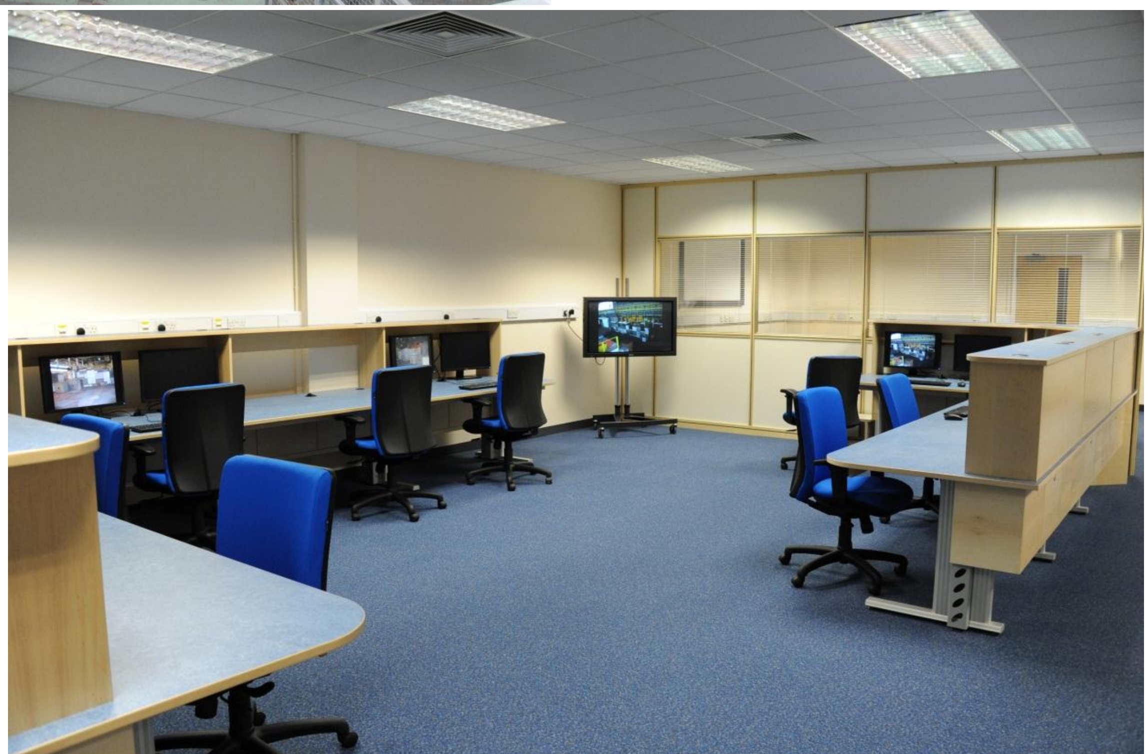




David Cameron Confirmed £10M of investment

Prime Minister David Cameron announces new Enterprise Zones
at the Daresbury Science and Innovation Campus

17 August 2011

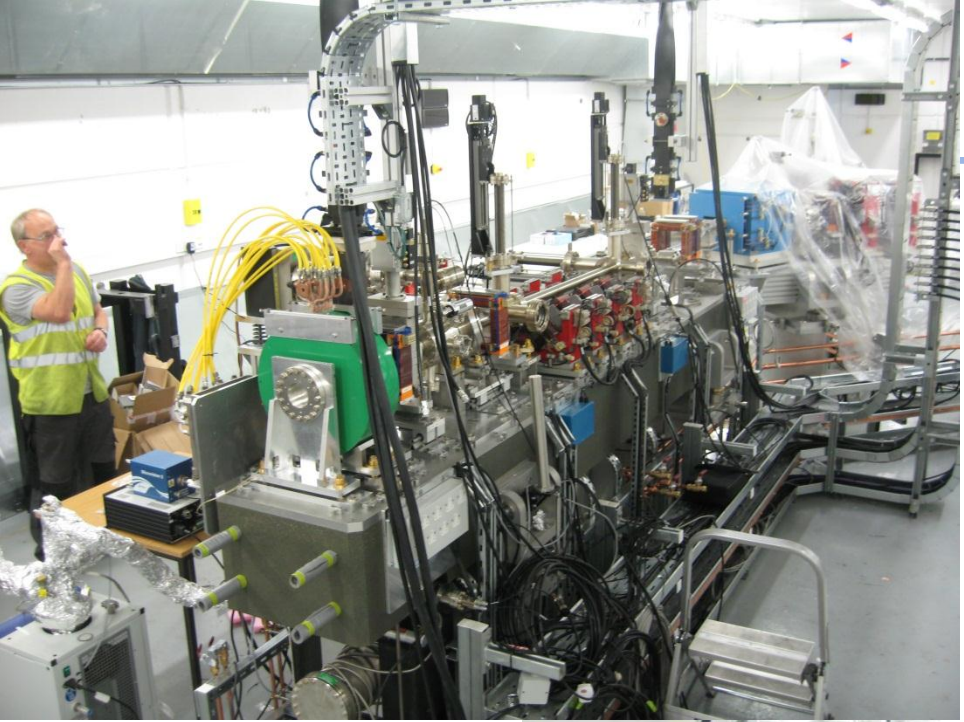


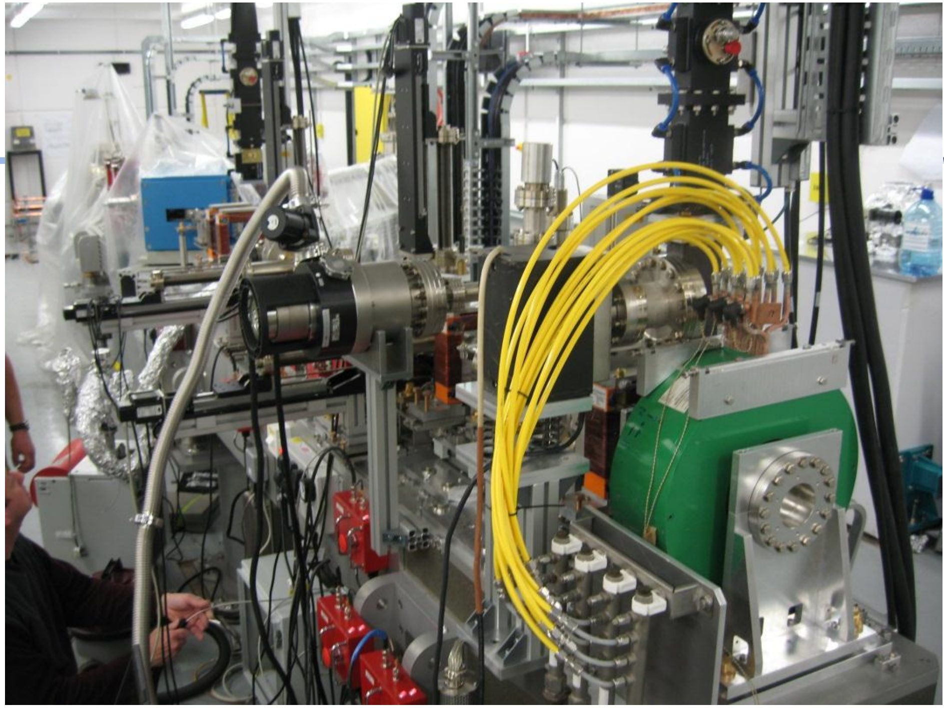
EBTF Control Room


29/03/2012


29/03/2012


16/07/2012





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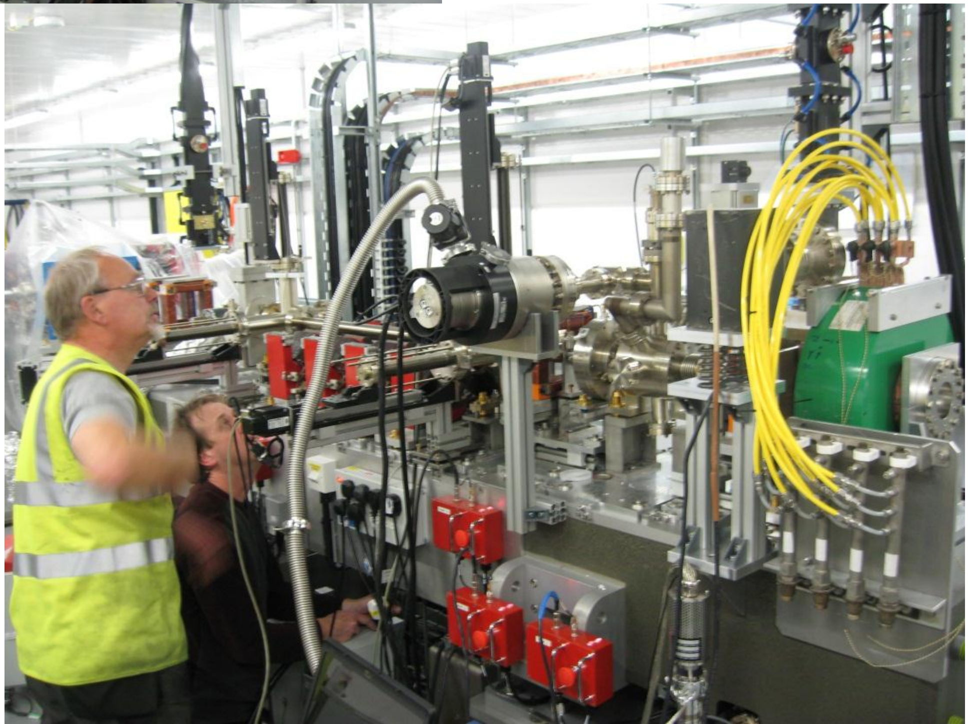
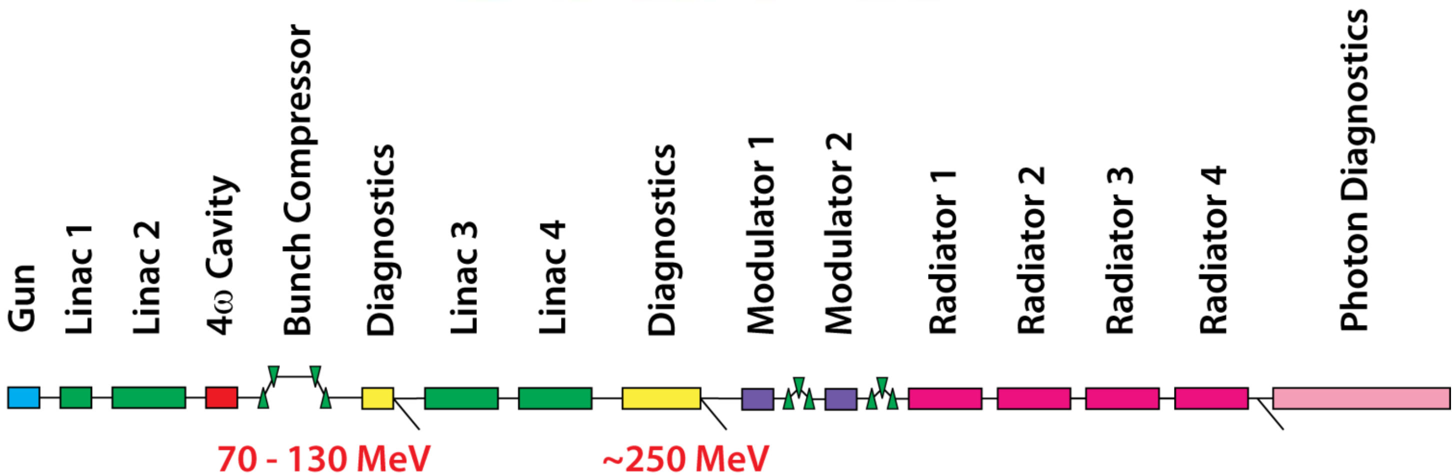
Final checks before RF conditioning starts





Major upgrade of Electron Beam Test Facility

4^{th} Generation Light Sources

- **Free Electron Lasers**
  - Ultra high peak intensity
  - Very short pulses of light
  - Tuneable
  - Basic FEL unstable in intensity and wavelength
  - Immature as a technology, plenty of scope for improvement
  - ***Fortunately lots of ideas exist for improving FEL stability and to make even shorter pulses of light but very few have been tested***
  - ***Can't propose a major new facility based on an untested idea! Need test facility***

➡ **CLARA**

CLARA

- ***A world class FEL test facility that can try out new ideas so they can be implemented directly into a future light source facility***
- ***In parallel we will also be able test advanced accelerator technologies***
- *The relatively small investment required for CLARA will pay for itself by reducing future risk and timescales*
- **More importantly, it will also make any national future light source a world beater !**

Ultimate aims of CLARA

To develop a normal conducting test accelerator able to generate longitudinally and transversely bright electron bunches and to use these bunches in the experimental production of **stable**, **synchronised**, **ultra short** photon pulses of coherent light from a single pass FEL with techniques directly applicable to the future generation of light source facilities.

- **Stable** in terms of transverse position, angle, and intensity from shot to shot.
- A target **synchronisation** level for the photon pulse ‘arrival time’ of better than 10 fs rms is proposed.
- In this context “**ultra short**” means less than the FEL cooperation length, which is typically ~100 wavelengths long (i.e. this equates to a pulse length of 400 as at 1keV, or 40 as at 10 keV). A SASE FEL normally generates pulses that are dictated by the electron bunch length, which can be orders of magnitude larger than the cooperation length.

Other Aims and Prerequisites

To deliver the ultimate objectives of CLARA will encompass development across many areas:

Low charge single bunch diagnostics

NC RF photoinjectors and seed laser systems

Generation and control of bright electron bunches
- manipulation by externally injected radiation fields
- mitigation against unwanted short electron bunch effects

Synchronisation systems

High temporal coherence and wavelength stability through seeding or other methods

Generation of coherent higher harmonics of a seed source

Advanced low level RF systems

Photon pulse diagnostics for single shot characterisation and arrival time monitoring

Novel short period undulators

Reviewing the field – Facilities

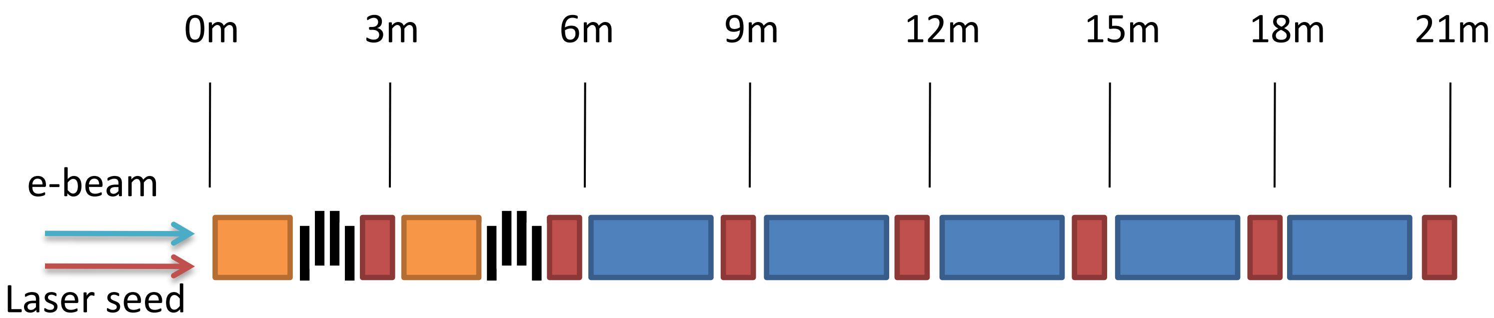
- Many facilities involved in FEL test experiments but perhaps only 5-6 might be considered ***dedicated*** FEL test facilities.
- Highest current priority for FELs is improving temporal coherence.
- Reducing size and cost is another common theme.
- Opportunity for a FEL test facility looking at next frontiers.

Extract from:
A Review of Worldwide Test Facilities for Free Electron Lasers

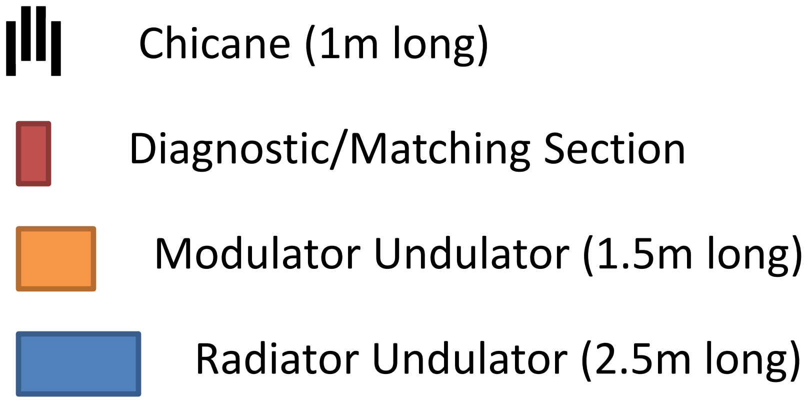
David Dunning, ASTeC

Location	Facility	E [MeV]	Experiments	FEL Frontiers	Running mode/capacity
SLAC	LCLS	3500-15000	Self-seeding, slotted foil, double pulses	Short wavelength, peak power, temporal coherence, short pulses, tailored pulse structures	User facility, limited test time
	NLCTA	120	ECHO-7 (EEHG), Beatwave THz, Inverse FEL.	Temporal coherence – extending range of seeding	Dedicated test facility
JLab	IR/UV upgrade	150	ERL, IR oscillator, UV oscillator, user experiments. + proposals to increase energy for shorter wavelengths (RAFEL, recirculation).	Average power, range of oscillators	FEL development + user experiments
Brookhaven	SDL	300	Laser seeded FEL amplifier, HGHG, E-SASE, Intense coherent THz generation and applications, Ultrafast Electron Diffraction, DUVFEL, COUR, Edge Radiation.	Temporal coherence - range and tunability of seeding	Dedicated test facility
Soleil	LUNEX5	300	HHG seeding, EEHG, in-vacuum undulators, LWFA.	Compact FELs - LWFA, temporal coherence	Proposal for a dedicated test facility, including demonstrator user expts.
PSI	SwissFEL injector test facility	250 (-> 280)	Generation, transport and compression of high brightness beams. Possibly EEHG seeding.	Compact FELs - beam quality, temporal coherence?	Possibly some FEL experiments, limited lifetime
DESY	FLASH	1250	HHG seeding (sFLASH), possibly EEHG.	Temporal coherence, synchronisation	User facility, limited test time
MAX-Lab	Test FEL	380	Seeding and harmonic up-conversion utilizing an optical klystron, HHG, re-circulation.	Temporal coherence	Limited running time?
Frascati	SPARC	150 (->250 ->900?)	Velocity bunching, SASE, HHG seeding, harmonic cascades, short pulses (energy chirp + undulator tapering).	Short pulses, temporal coherence	Dedicated test facility, plans to upgrade to user facility?
Trieste	FERMI@elettra	1500	Laser seeding, HGHG, polarisation control.	Temporal coherence, polarisation control	User facility, limited test time
SINAP	SDUV	210	SASE, seeded FEL experiments, HGHG (2-stage cascades), EEHG.	Temporal coherence	Dedicated test facility
RIKEN	SCSS	300	SASE with short-period in-vacuum undulators, C-band linac and single-crystal thermionic cathode (prototype for SACLA) HHG seeding	Compact FELs, temporal coherence	FEL development + user experiments?

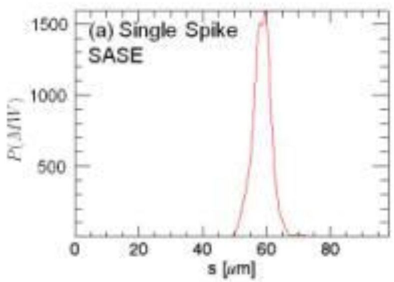
Flexible FEL Layout



- By implementing a flexible FEL layout, especially in the modulator region, it will be possible to test several of the most promising schemes.
- We are carefully comparing the various schemes and their detailed requirements – ***we do not anticipate testing them all!***
- **We aim to design in this flexibility from the start.**

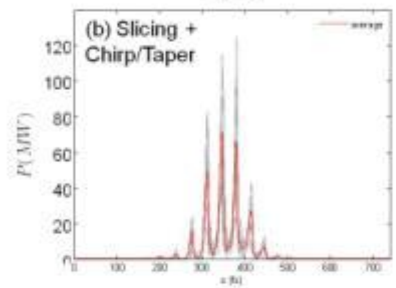


Examples of FEL Schemes on CLARA



SINGLE SPIKE SASE

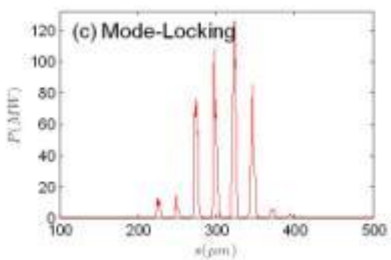
100pC tracked bunch compressed via velocity bunching



SLICING + CHIRP/TAPER

Short pulse generation using an energy chirped electron bunch and a tapered undulator

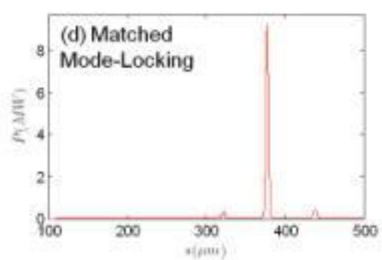
E. L. Saldin et al, Phys. Rev. STAB 9, 050702, 2006



MODE-LOCKING

Mode-locked amplifier FEL using the standard CLARA lattice with electron beam delays between undulators

N. R. Thompson and B. W. J. McNeil, Phys. Rev. Lett. 100, 203901, 2008

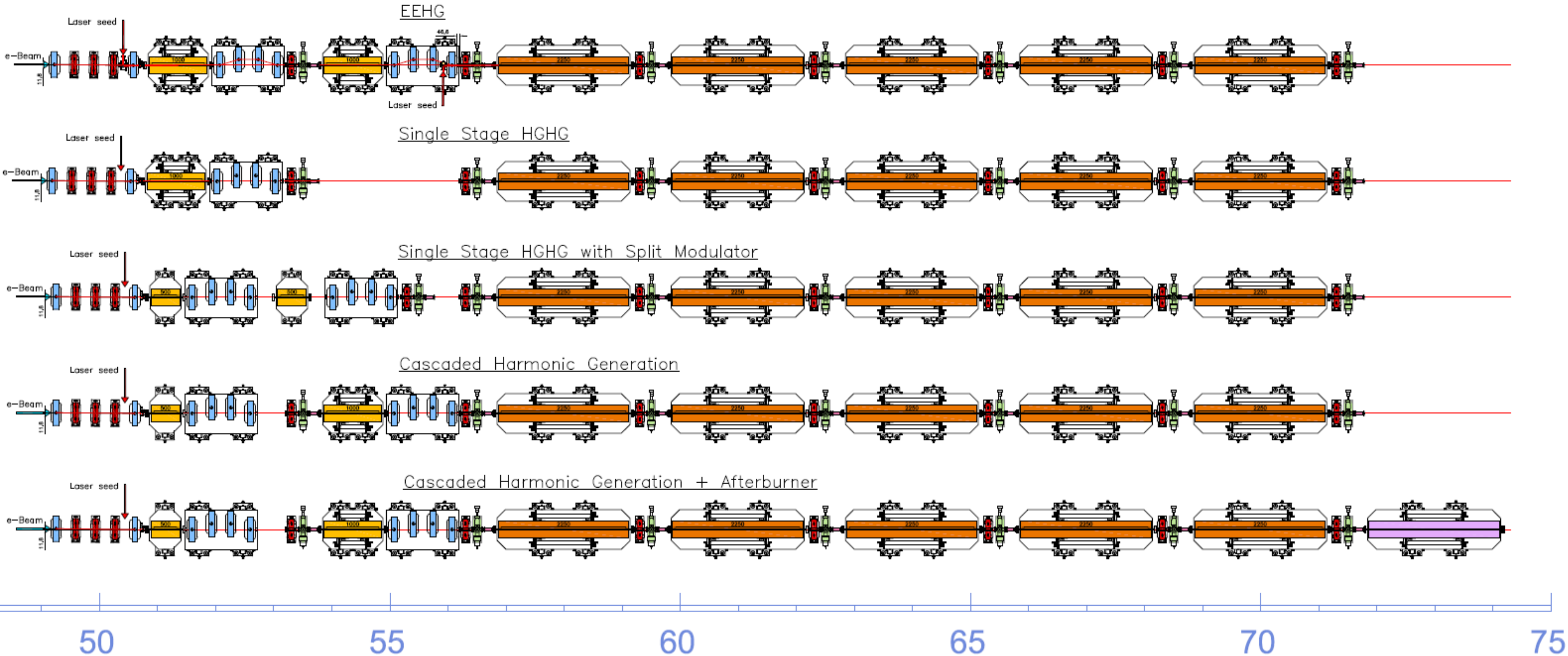


MATCHED MODE-LOCKING

Electron beam delays matched to the rms electron bunch length to distinguish a single spike from the pulse train

Plots courtesy of Ian Martin and Neil Thompson

Modulator / Radiator Example Configurations



CLARA Parameters

The parameters have now been broken down to cover **5 different operating modes**. This helps us understand what parameters we need simultaneously.

	Operating Modes				
Parameter	Seeding	SASE	Single Spike SASE	RAFEL	Industrial
Max Energy (MeV)	250	250	250	250	100
Macropulse Rep Rate (Hz)	100	100	100	100	400
Bunches/macropulse	1	1	1	20	tbc
Bunch Charge (pC)	250	250	20–100	250	250
Peak Current (A)	125–400	400	1500	400	tbc
Bunch length (fs)	250–800 (flat)	250 (rms)	<30	250	tbc
Normalised Emittance (mm-mrad)	≤ 1	≤ 1	≤ 1	≤ 1	≤ 1
RMS Energy Spread (keV)	25	100	150	100	tbc
Radiator Period (mm)	27	27	27	27	-

SASE: Self-Amplified Spontaneous Emission
RAFEL : Regenerative Amplifier FEL

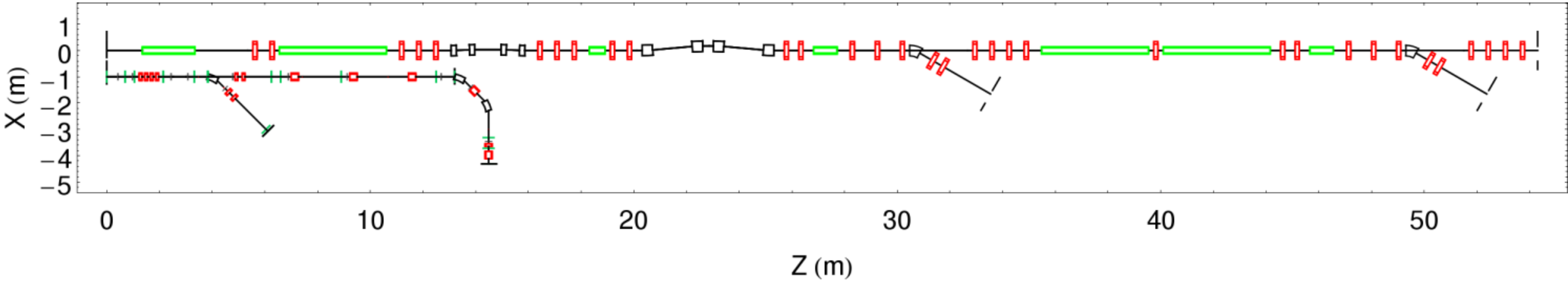
High Repetition Rate NCRF

- The NLS baseline operating rep rate was 1.1 kHz, utilising a NCRF photoinjector
  - Modified FLASH/XFEL gun, 1.3 GHz, 50 MV/m
  - Cooling water channels improved for better cooling efficiency
- EBTF/CLARA gun will be 3 GHz (S_{EU})
- Initial EBTF gun cavity (Strathclyde/LAL) will operate at up to **10 Hz** repetition rate
- **High Rep Rate Gun Development**
  - Scaled NLS model gun cavity fabricated by DLS could be tested at up to 400 Hz with CLARA (no pick up, modification to cathode exchange required)
  - Also looking at new design
- **CLARA Linac**
  - SwissFEL offer of 3 existing linac structures (100 Hz @ 20 to 25 MV/m, 4.3 m long)
  - Scoping study on practical realisation of 20 to 25 MV/m, 400 Hz linac structures has been funded and contract placed on AES
- **X-Band RF Source Collaboration initiated with CERN**

CLARA layout – Work in Progress

CLARA is shown from the cathode with...

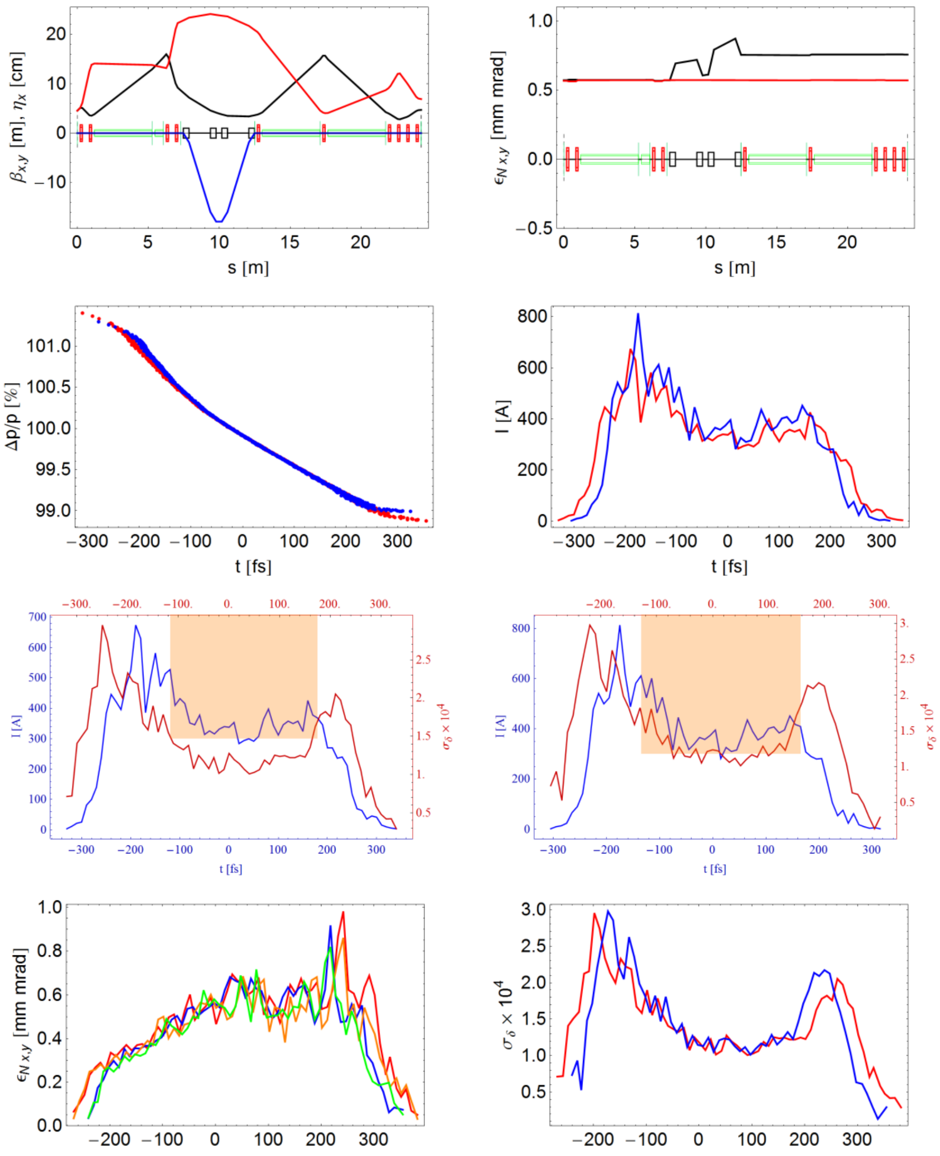
- Linac 1 (2m)
- Linac 2 (4.3m)
- Matching – Laser Heater – Matching
- 4th Harmonic cavity – Matching
- Variable bunch compressor – Matching
- Diagnostics 1 – TDC, Matching, Spectrometer
- Linacs 3 & 4 (4.3m each)
- Diagnostics 2 – TDC, Matching, Spectrometer
- Matching to undulators



- **FEL not shown – total available length ~90m (inside shielding)**
- **EBTF shown alongside**

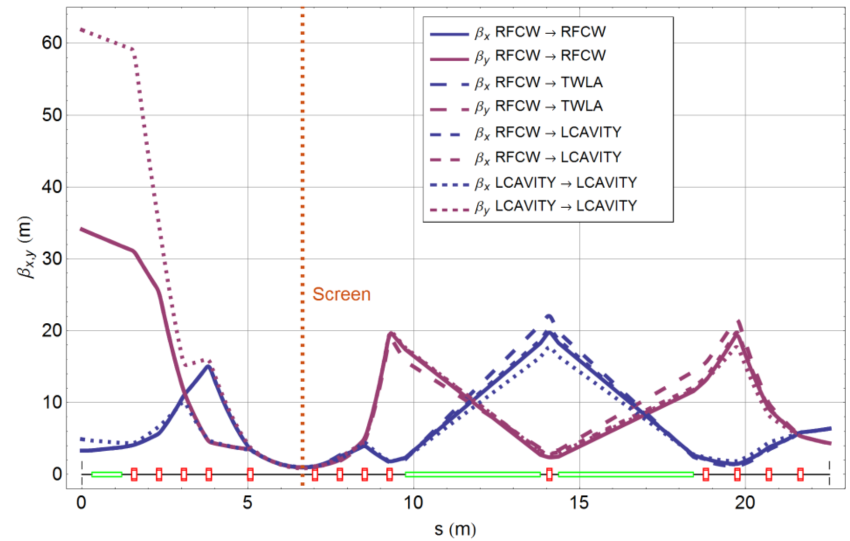
CLARA Design – Work in Progress

Long Pulse Bunch Optimisation



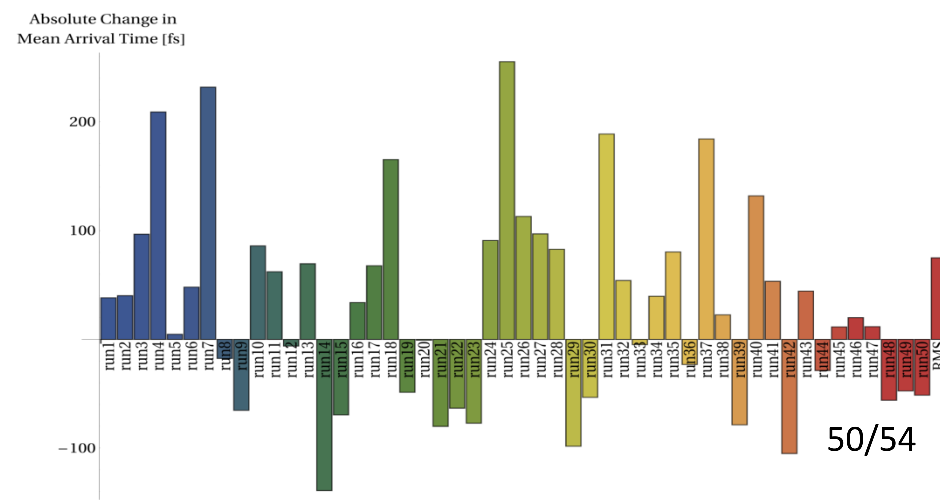
Low energy diagnostics /matching

Twiss Functions – 9 Quadrupoles in S5



Preliminary jitter estimate studies

Change In Mean Arrival Time For 50 Mechines With Randomly Distributed Errors
On All Element Parameters With σ_V=0.1%, σ_ϕ=0.1^o (X Band Linac σ_ϕ=0.3^o) and σ_{DIP}=0.01%,
RMS= 74.9532 fs



Other Opportunities

- Electron Diffraction Facility
  - Can the low energy beam be used for ED experiments?
  - Discussions initiated with UK communities
- Plasma accelerator research
- THz source for science
  - Very high peak power possible
- Compton fs X-ray source
- High energy beamline for industrial exploitation
- …

Summary

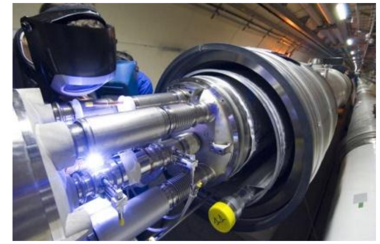
- EBTF offers flexible, high brightness photoinjector facility for industrial, academic and scientific collaborations. Direct synergies with other projects (ELI-NP, AWAKE injector).
- High power RF conditioning starts today and we expect to get first electrons out next month, starting beam characterisation early 2013.
- EBTF will allow the UK to establish skills in operation and commissioning of the RF photoinjector and testing of advanced diagnostics concepts essential for future 4th Generation Light Source.
- Plans are being drawn up for future UK FEL test facility CLARA – already in discussions with JAI on cavity BPM tests and testing of advanced FEL concepts. New contributions and collaborations welcome.
- We are aiming to complete outline design report with costing for CLARA by end of March'13. Aiming for construction in 2013-2015, with commissioning in 2016. ***(subject to funding).***

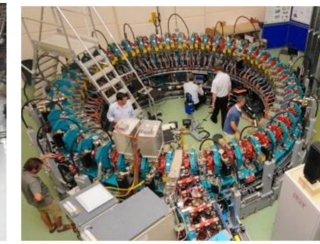
Acknowledgement

Many thanks to colleagues from ASTeC, Technology Department, Strathclyde University, LAL, PITZ, the Cockcroft Institute, the John Adams Institute, and Diamond Light Source for their contributions to this talk and to the EBTF and CLARA projects.


Thank you for your attention
EBTF & CLARA

Do you want to build the world's most exciting physics experiments?





PhD Opportunities at the Cockcroft Institute of Accelerator Science and Technology

Would you like to work on the LHC and produce Higgs bosons, design next generation cancer therapy, develop safe nuclear reactors or build the worlds most advanced scientific instruments? If so the Cockcroft Institute is the place for you.

The Cockcroft Institute is a collaboration between Lancaster, Manchester, and Liverpool Universities with the Science and Technology Facilities Council to develop the next generation of particle accelerators. We are currently looking for PhD students to join us in this venture.

More details can be found at:
http://www.cockcroft.ac.uk/education/informationPhd.htm