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The Status of the ALICE R&D Facility at STFC Daresbury Laboratory

Frank Jackson, Accelerator Science and Technology Centre, and Cockcroft Institute, Daresbury Laboratory on behalf of the ALICE team

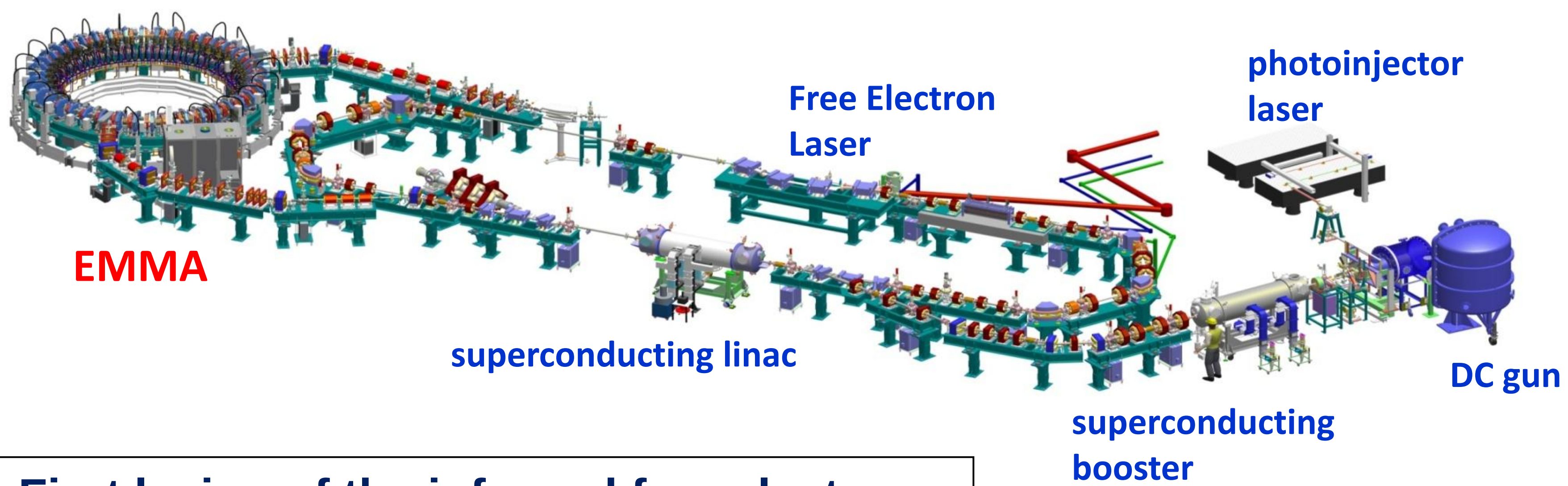
Alice

The Cockcroft Institute
of Accelerator Science and Technology

The ALICE Facility @ Daresbury Laboratory

Accelerators and **L**asers **I**n **C**ombined **E**xperiments

An accelerator R&D facility based on a superconducting energy recovery linac



First lasing of the infra red free electron laser was achieved in Oct 2010

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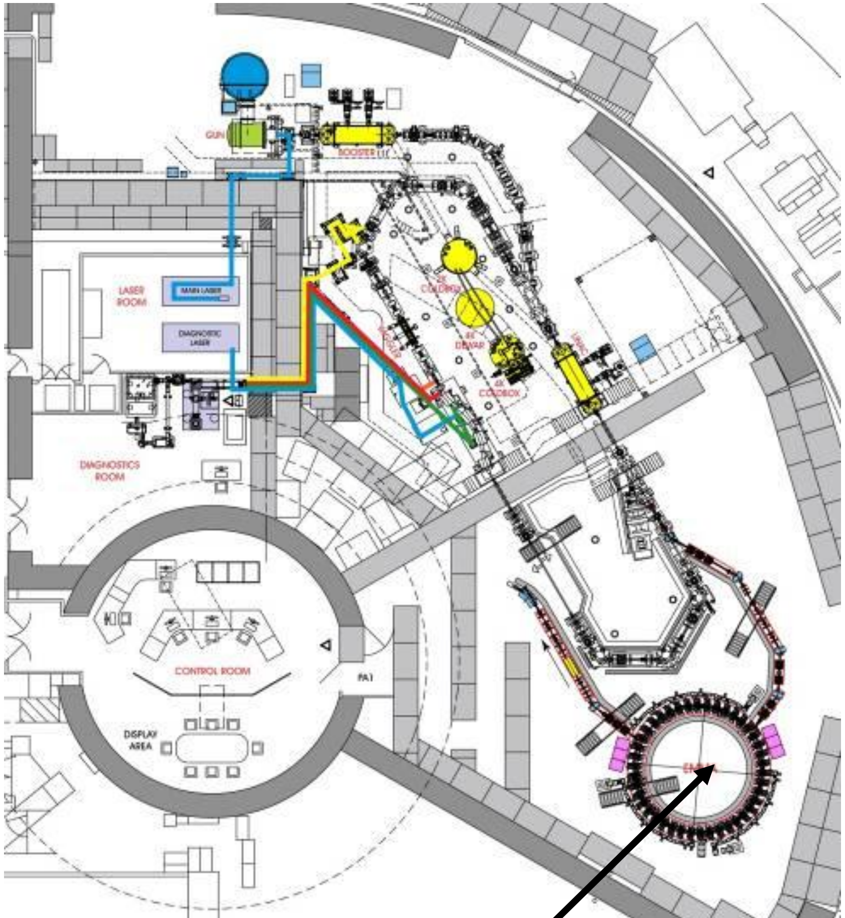
The ALICE Facility @ Daresbury Laboratory



EMMA

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ALICE History & Context

- 2003 Project conceived and funded.
- 2006 First electrons from gun.
- 2008 Energy recovery established.
- 2010 IR-FEL lasing achieved

New accelerator technologies for the UK

First SCRF linac operating in the UK

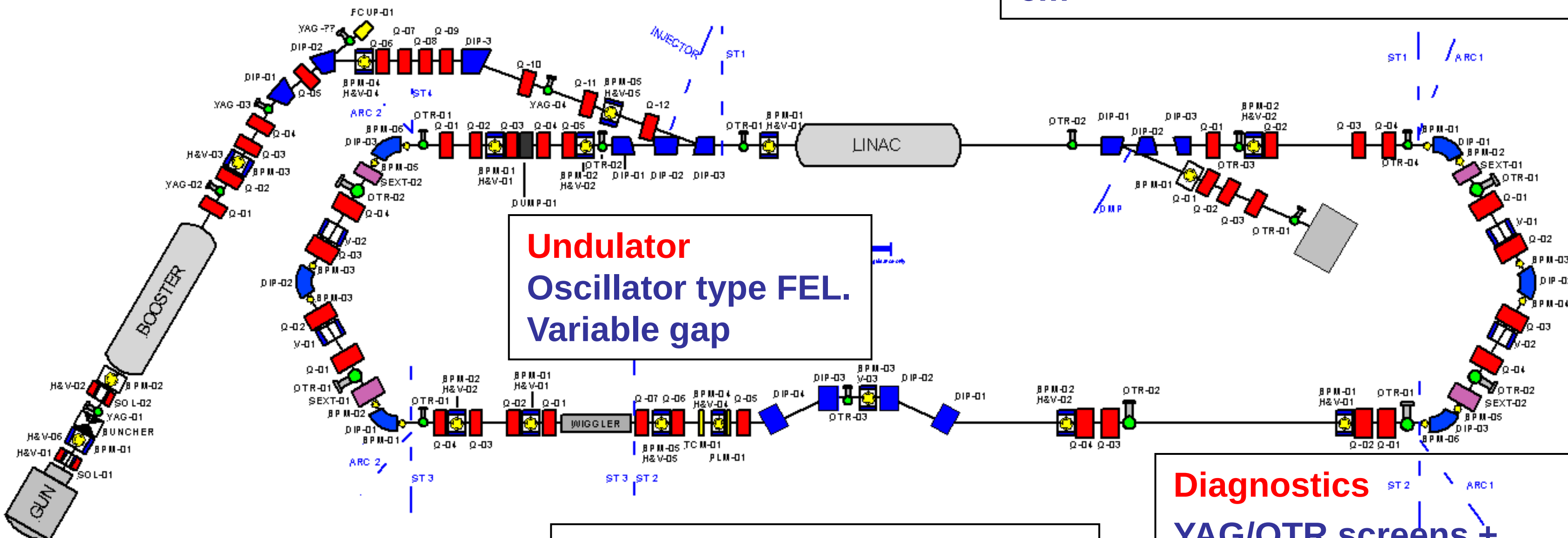
First DC photoinjector gun in the UK

First free electron laser driven by energy recovery accelerator in Europe

ALICE Machine Description

RF System
Superconducting booster + linac
9-cell cavities. 1.3 GHz, ~10 MV/m.
Pulsed up to 10 Hz, 100 μS bunch trains

Beam transport system.
Triple bend achromatic arcs.
First arc isochronous
Bunch compression chicane R_{56} = 28 cm



Undulator
Oscillator type FEL.
Variable gap

DC Gun + Photo Injector Laser
230 kV
GaAs cathode
Up to 100 pC bunch charge
Up to 81.25 MHz rep rate

TW laser
For Compton Backscattering and EO
~70 fS duration, 10 Hz
Ti Sapphire

Diagnostics
YAG/OTR screens + stripline BPMs
Electro-optic bunch profile monitor

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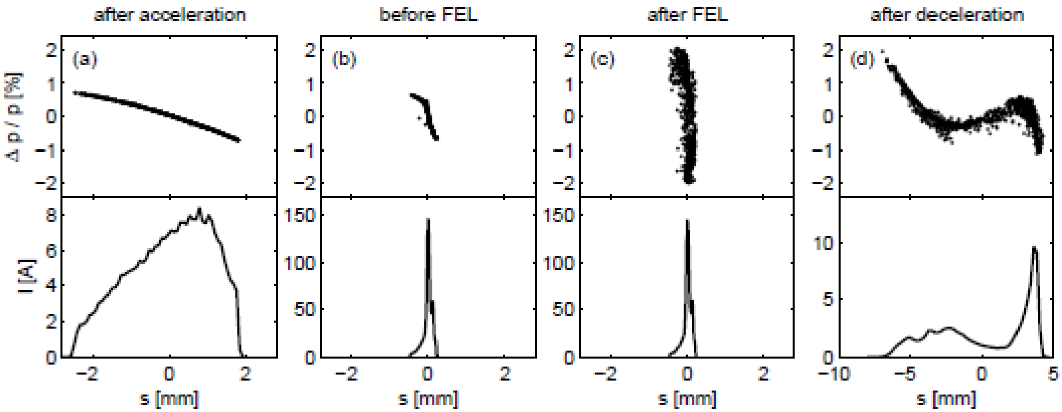
ALICE Beam Physics

FEL requires good control of longitudinal dynamics



Simulations and lattice design by C. Gerth, M. Holder, B. Muratori, H. Owen

Sufficent FEL gain requires 1 pS bunch length and 0.5 % energy spread

Injector

• Minimise intrinsic energy spread and bunch length (< 5 pS, < 0.5 %)

Main Loop

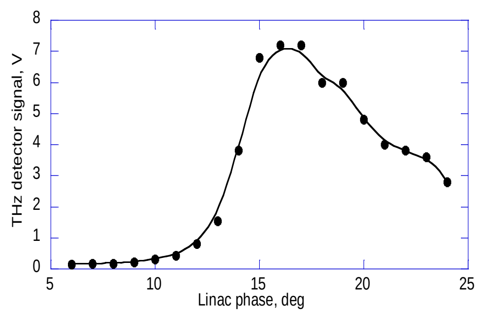
• Bunch compression via linac chirp and compressor chicane.

• Arc sextupoles provide linearisation of longitudinal phase space.

Measurements

•THz + electro-optic diagnostic used to tune bunch compression to required level.

•The effect of sextupoles linearisation is not yet clear.

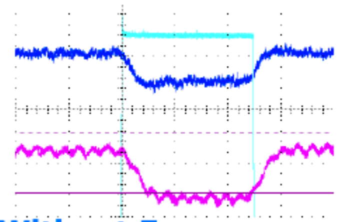


THz signal vs linac phase

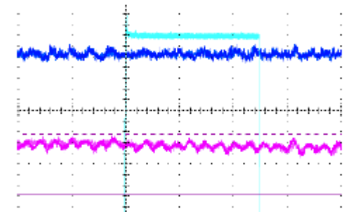
Past ALICE Milestones

Energy recovery achieved Christmas 2008

ER is required for FEL operation, typically over 90% efficiency



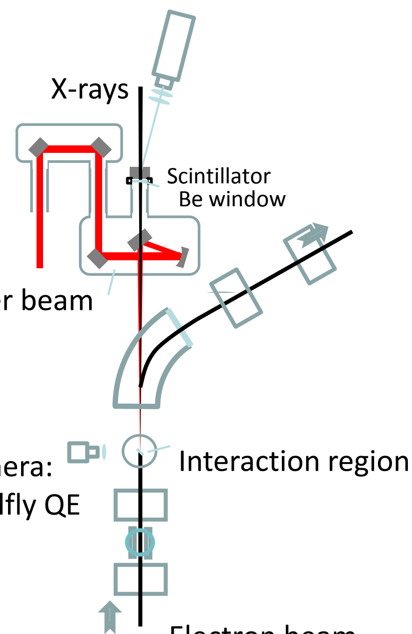
Without Energy Recovery

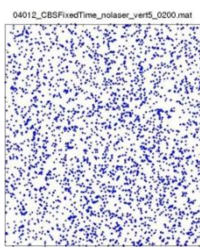


With Energy Recovery

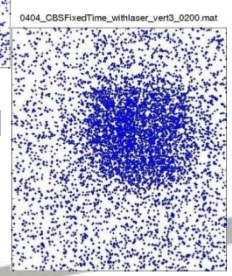
LLRF (power demand) signals without (left) and with (right) energy recovery

Compton backscattering achieved November 2009

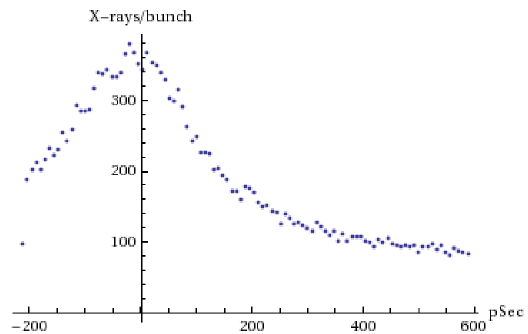




Background:
Electron beam ON
Laser OFF



Electron beam ON
Laser beam ON



S. Jamison, G. Priebe
D. Laundy, E. Seddon
et al

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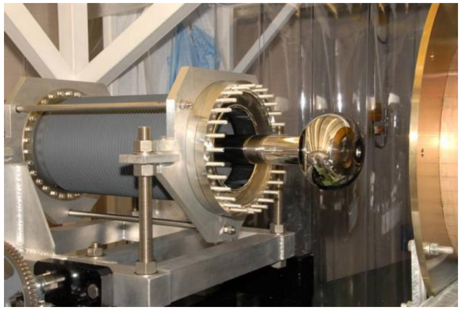
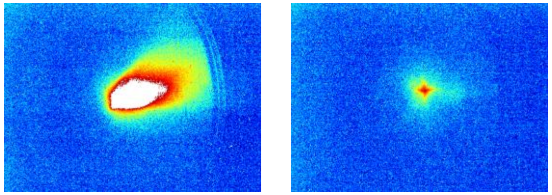
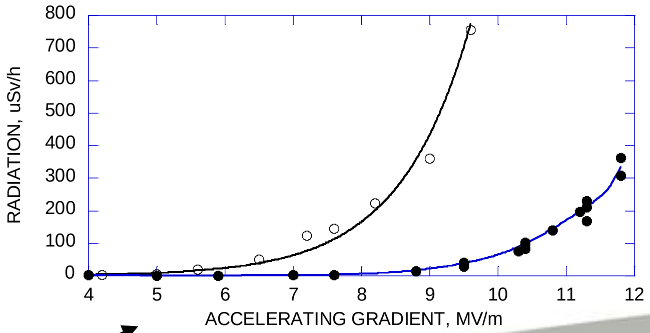
ALICE Challenges and Solutions

- ALICE uses several novel and difficult technologies.
- **DC Gun** was technically challenging.
  - Ceramic insulator problems. Gun presently limited to 230 kV (small diameter ceramic insulator borrowed from Stanford)
  - Field emission (FE) from cathode.
- **SCRF linac** also required optimisation
  - Field emission problems after final linac assembly limited gradient
  - Mitigated with Helium processing, and reduced RF pulse length to achieve ~27 MeV beam energy.
- **Beam loading** caused energy droop across bunch train







He processing by ASTeC RF + cryogenic groups with assistance from T. Powers (Jlab)

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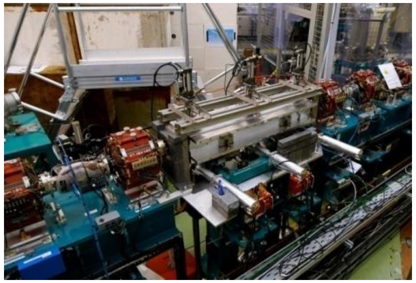
IR-FEL

IR-FEL

First commissioning period
40 pC @ 81.25 MHz

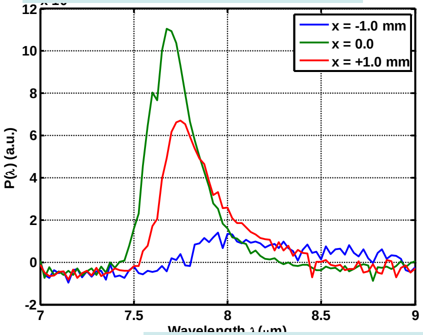
- Spontaneous radiation detected February 2010 (shortly after undulator installation) but no gain initially
- First spectra of SR were obtained at time of IPAC 2010 (May-Jun 2010)
  - Spontaneous spectra indicated sufficient energy spread, correct undulator alignment.
- Electro-optic bunch profile measurement indicated sufficiently small bunch length
- Some evidence of enhancement after optimising electron beam
  - Indicated coherent emission from subsequent bunches and sufficiently low timing jitter.
- Beam loading
  - Booster beam loading mitigated by 40pC operation
  - Linac beam loading less precisely measured.

Undulator borrowed from Jefferson Lab

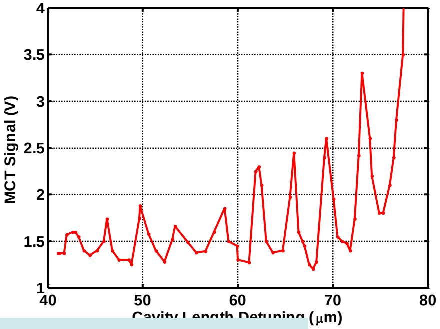


period 27mm
periods 40
min gap 12mm
max K 1.0

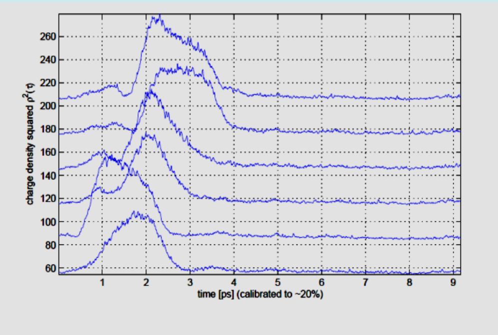
Spontaneous spectra



Spontaneous signal Cavity Scan



Electro-optic bunch length measurement



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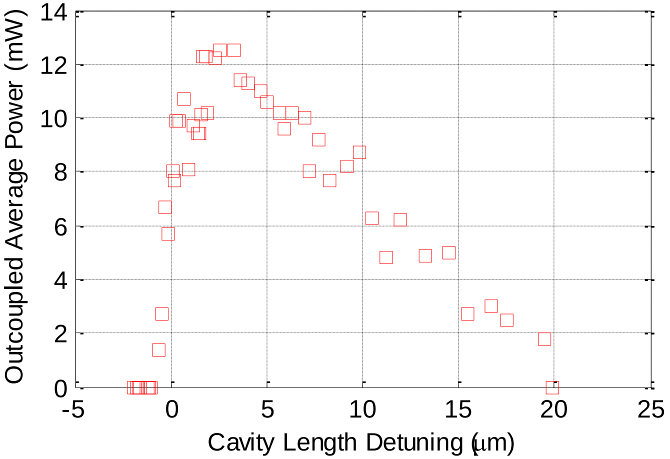
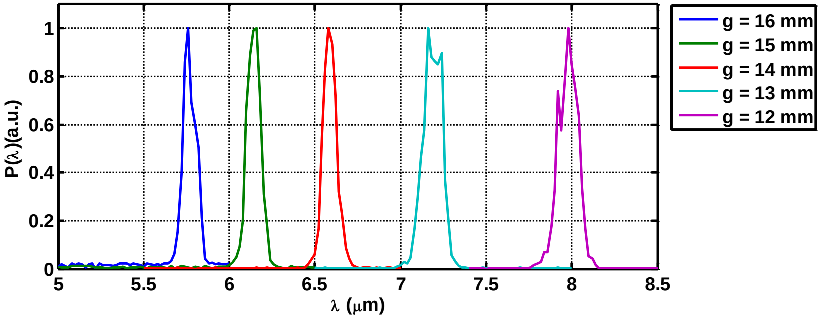
IR-FEL

Lasing
100-40 pC @ 16.25 MHz

- 'Burst generator'. Modification of PI laser to divide bunch rep freq to 16 MHz
  - Increase bunch charge to 60-100 pC.
- 1 week after modification, lasing was achieved at 80 pC (8 µm, average power ~10-30 mW)
- Continuous tuning demonstrated 5.7-8.0 µm, varying undulator gap.
- The FEL pulse duration has been inferred from the spectral width to be ~1 ps. The peak power is therefore ~3 MW
- Single pass gain measured at ~20 %.
- Gain limited by relatively large energy spread of beam





FEL group: J.Clarke, N.Thompson, D. Dunning
Diagnostics+ Beamline: M. Surman, A. Smith, M.Roper

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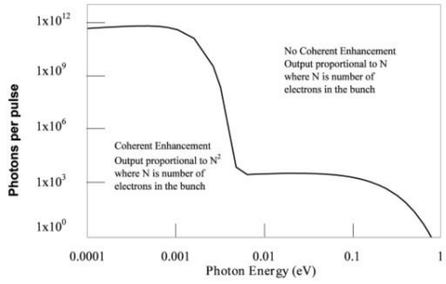
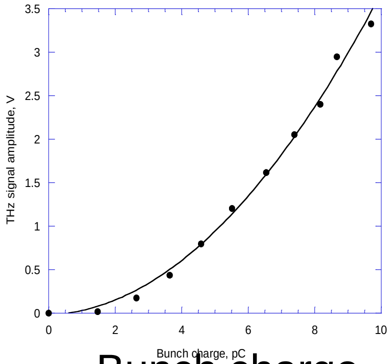
Terahertz Source

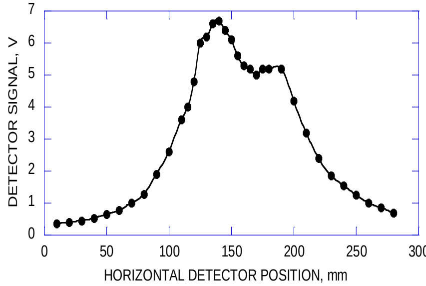
ALICE THz Source

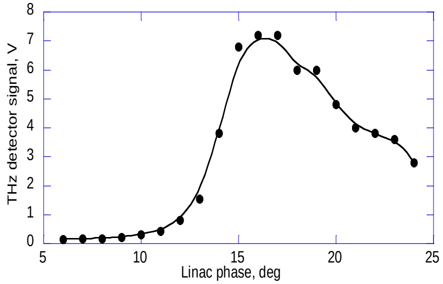
- ALICE is a source of high power broadband THz radiation
  - Coherent enhancement of synchrotron radiation through bunch compression chicane.
- Many orders of magnitude more powerful than conventional sources
  - Laboratory instruments 100 µW, ALICE ~ kW.
  - High peak power, low average power
- Used in biological experiments. Effect of THz on living cells in culture. Initially using in-situ incubator.
- Also useful as bunch length diagnostic





Bunch charge





THz diagnostics: M. Surman.
Liverpool Univ. THz group. P. Weightman, R. Williams G. Holder, A. Schofield, C. Turner, P. Harrison

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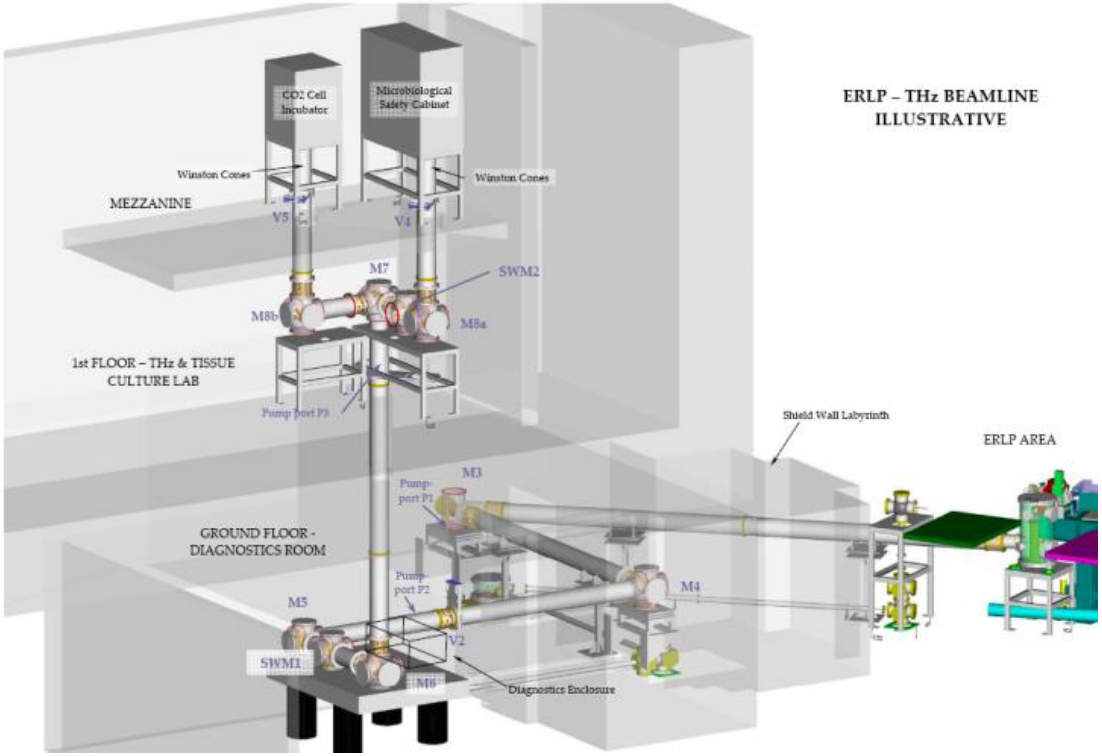
THz Tissue Culture Laboratory

In 2011 progress in characterising transmission of THz and transport to TCL, 30 m away from accelerator

Electron beam optimsation of THz beamline transport using detectors close to first periscope and in diagnostics room

THz power per bunch train measured close to accelerator and in TCL

Estimate > 10 KW in single THz pulse close to accelerator and 20% transport efficiency to TCL



Research program to determine safe limits of exposure of human cells to THz and effect of THz on differentiation of stem cells

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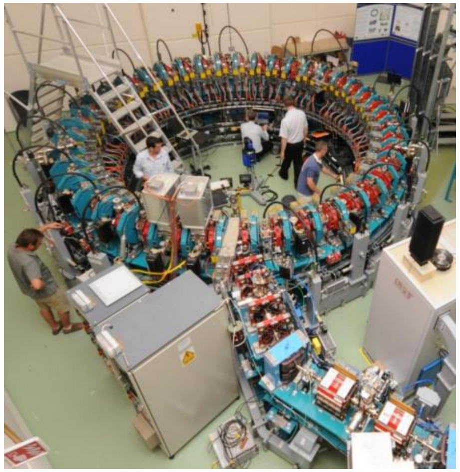
Other Applications of ALICE

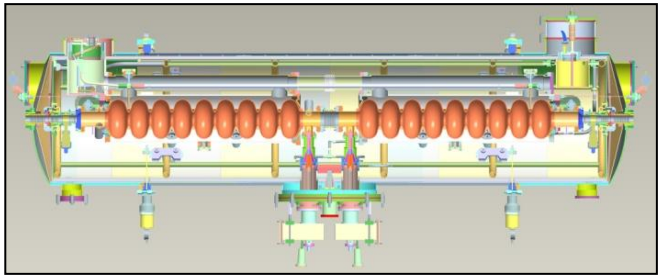
- EMMA non-scaling FFAG injector
  - Novel type of accelerator suitable for many applications
  - Acceleration demonstrated in April 2011
  - S. Machida ‘First Results from the EMMA Experiment’ TUYB01, Tues 11:00, Chamber Hall

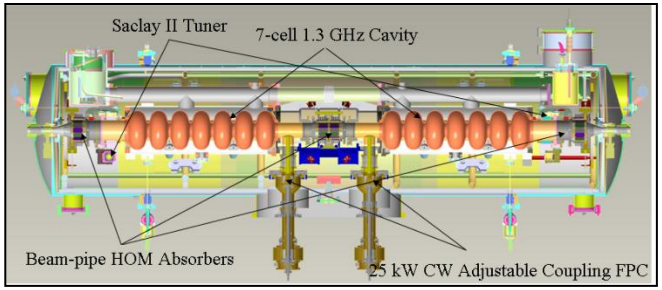


- Timing and synchronisation experiments
  - Development of beam arrival monitoring and timing distribution (fibre-ring-laser-based system)
  - Goal is **sub-10fs** timing distribution (as required by future light sources)

ALICE Plans

- IR-FEL
  - Free Electron Laser integration with Scanning Near-field Optical Microscope (FELIS)
- THz
  - Continuing TCL program
  - Quantum dot research for novel solar cells.
- Cryomodule upgrade (Daresbury International Cryomodule Collaboration)
- Diagnostics
  - OTR streak camera and arrivial time monitors for R_{56} measurements and better measurement of longitudinal phase space





Plan to be installed into ALICE later this year

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ALICE Summary

- Achievements, experience and skills gained
  - IR-FEL lasing with energy recovery for first time in Europe
  - SCRF + cryogenics
  - DC gun, photocathode, vacuum science
  - Timing and synchronisation techniques
  - Beam diagnostics
  - …
- Other ALICE related contributions in this conference
  - MOPC148 Optical Clock Distribution System at the *ALICE* Energy Recovery Linac
  - MOPC165 Digital Low Level RF Development at Daresbury Laboratory
  - TUPO035 Beam Dynamics at the *ALICE* Accelerator R&D Facility
  - TUPC149 Measurements at the *ALICE* Tomography Section
  - TUPC151 Cherenkov Fibre Optic Beam Loss Monitor at *ALICE*
  - WEPC176 Beam Loss Monitoring and Machine Protection System Design and Application for the *ALICE* Test Accelerator at Daresbury Laboratory

http://alice.stfc.ac.uk/

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Extra Slides

ALICE PI Laser

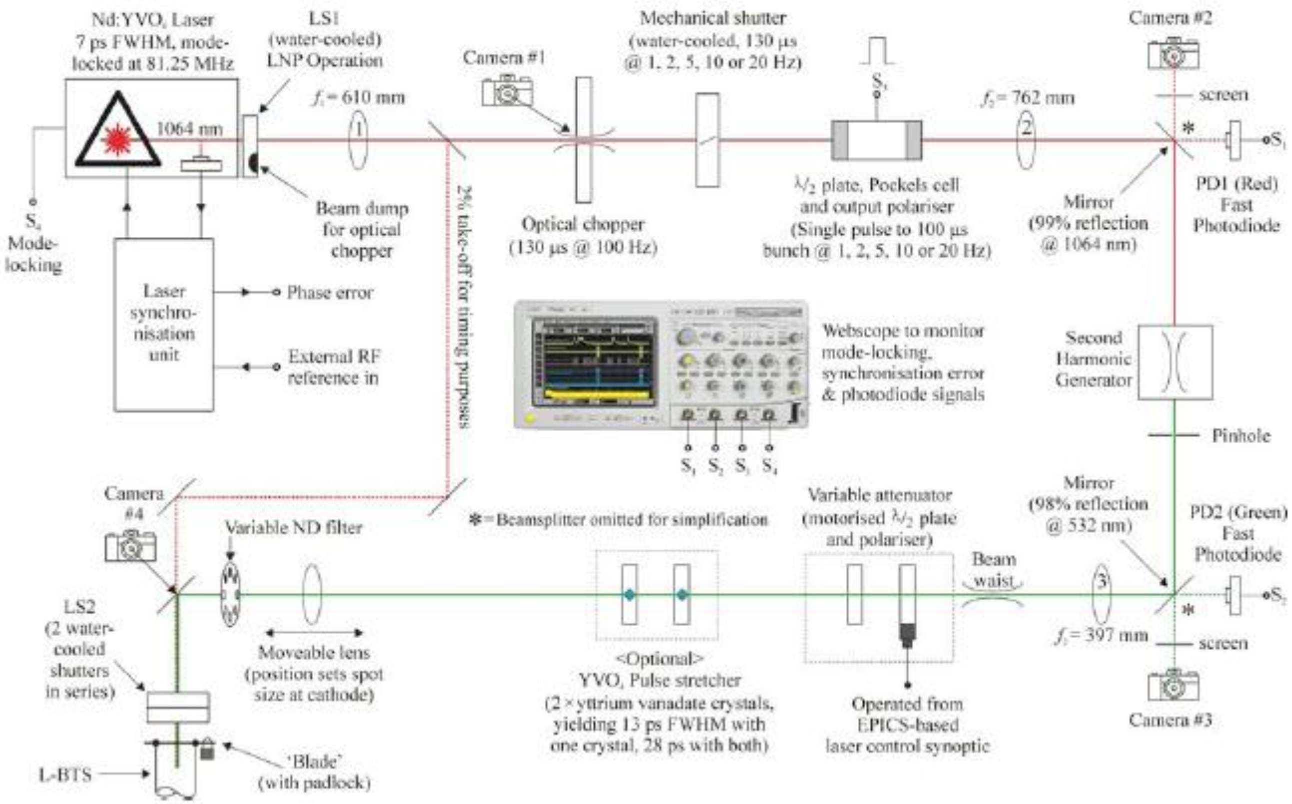

Figure 2: Schematic showing the layout of the optical system for the ERLP photoinjector drive laser.

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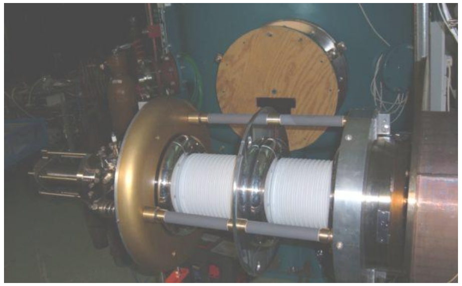
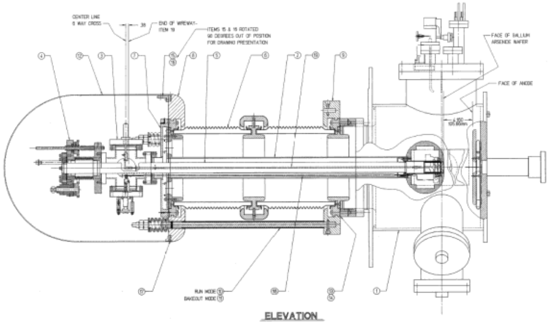
ALICE Gun + Ceramic





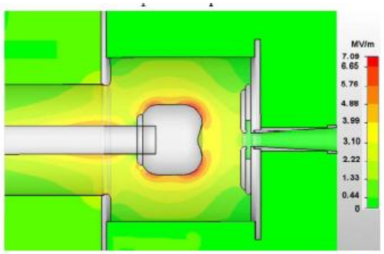
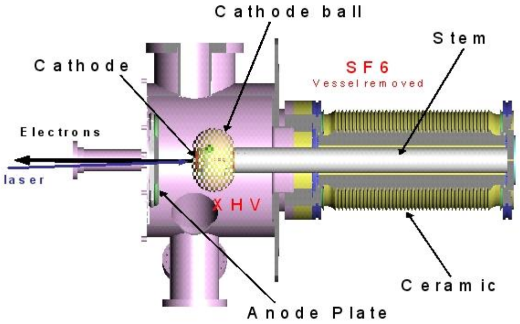
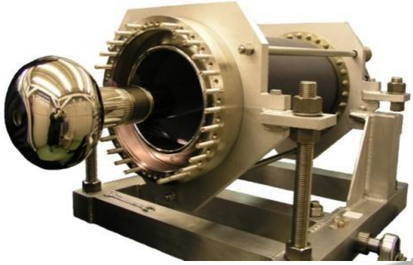


Figure 2: The electric fields in the gun chamber.



Ceramic insulator electrically insolates HV cathode ball and stem.



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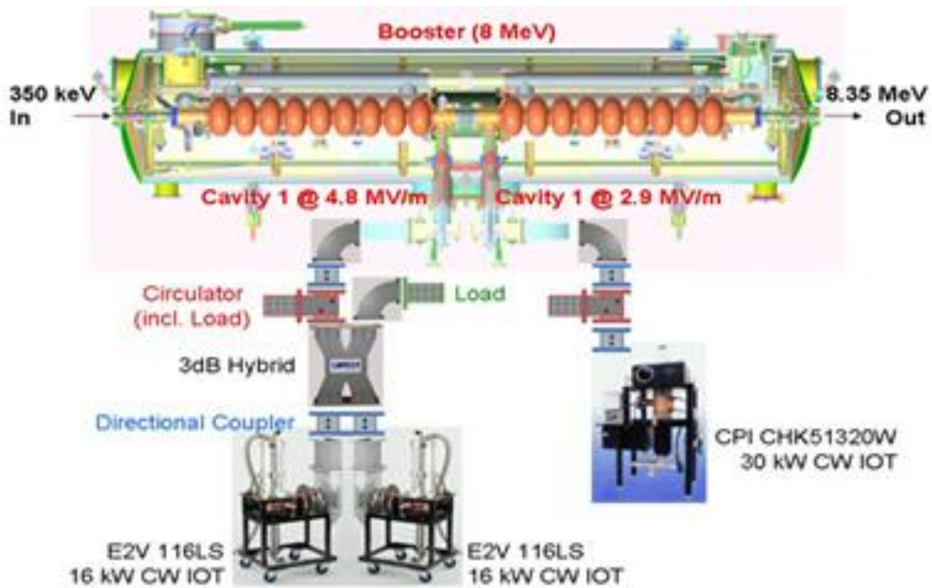
ALICE Machine Features RF

- 2 (SRF) cryomodules, and a normal conducting Buncher cavity.
- Each SRF cryomdule has 2 identical cavities operating at 1.3 GHz and are powered by 5 IOTs
- Booster cavity 1 is powered by 2 E2V IOTs, Booster cavity 2 has a CPI IOT
- Linac cavity 1 has an e2v IOT and Linac cavity 2 has a Thales IOT
- Buncher cavity has a single 2.5 kW solid state amplifier provided by Microwave Amplifiers.
- Analogue low level RF (LLRF) system sets and maintain the phase and amplitude all cavities. The LLRF reacts to: phase changes due to cavity detuning, reduction in gradient due to accelerating beam, cryomodule microphonics etc



ALICE SRF SYSTEM

Table 2: ALICE RF System Requirements

	Booster		ERL Linac	
	Cav1	Cav2	Cav1	Cav2
Eacc (MV/m)	4.8	2.9	12.9	12.9
Qo	$5x10^9$	$5x10^9$	$5x10^9$	$5x10^9$
Qe	$3x10^6$	$3x10^6$	$7x10^6$	$7x10^6$
Power (kW)	32	20	6.2	6.2
Power Source	2 x e2v	CPI	e2v	Thales

0.1ms bunch trains @ 20 Hz repetition rate

<u>ELBE facility@Rossendorf</u>

- 40 MeV linac (same cryomodule as ALICE)
- Driven by 10 kW klystrons non ER
- Drives 2 x IR-FELs

<u>Stanford Picosecond Free Electron Laser Center</u>

- W.W. Hansen Experimental Physics Laboratory, Stanford University
- 40 MeV linac (same cryomodule as ALICE)

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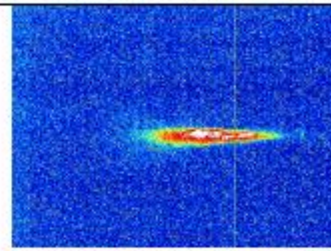
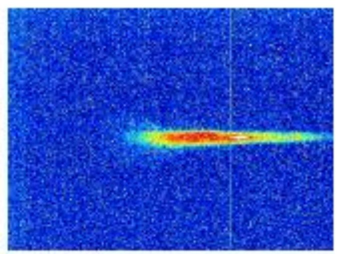
ALICE Lasing and Energy Recovery

Images taken on AR2-1

NO LASING σ_x=9.65mm	
LASING σ_x=12.32mm Increase in energy spread due to FEL $\frac{\sigma_{E1}}{\sigma_{E0}} = 1.82$ using $\sigma_{E1} = \frac{153\text{keV}}{27.5\text{MeV}}$ Change in position of centroid = 2.56mm giving ΔE=78keV, or for bunch charge of 65pC energy loss per bunch of 65pC × 78keV = 5μJ. Relative energy loss per bunch is 0.3%.	

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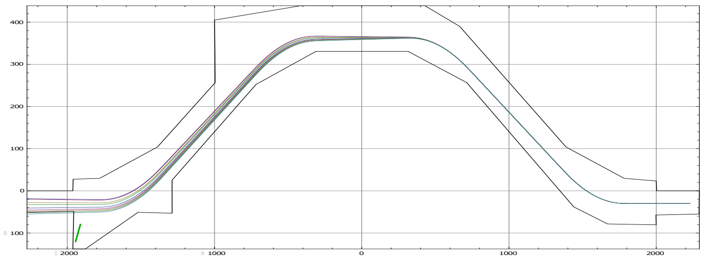
$$\frac{\sigma_{E1}}{\sigma_{E0}} = \sqrt{1+\frac{(\sigma_{b1}^2-\sigma_{b0}^2)}{\sigma_{E0}^2 D^2}}.$$

D = 0.9 m

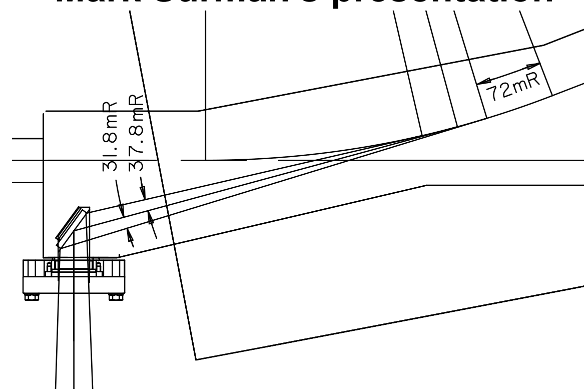
measured on AR1-1 where β is small

THz Beamline

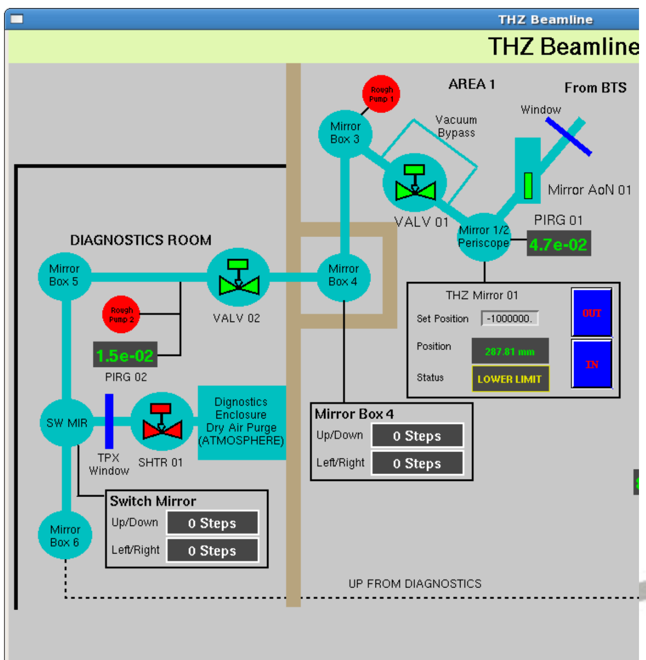
Bunch Compressor Chicane Geometery



DIAMOND WINDOW
From \\Dlfiles03\alice\Talks\Stakeholder Meeting, Feb 2009
Mark Surman's presentation



THZ beamline schematic



HeNe laser used for THz beamline alignment.

HeNe alignment used to position external THz detectors (AON and AP) for optimisation of e-beam

M1 (first mirror in periscope) is a focussing mirror

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