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The ALICE Accelerator R&D Facility

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

Alice

ASTeC

IOP Institute of Physics
Nuclear and Particle Physics Divisional Conference (NPPD)
4–7 April 2011, University of Glasgow, UK

Introduction

- Outline of ALICE as unique and important development in UK accelerator science
- Successes and challenges
- Facility capabilities and current/future research programme

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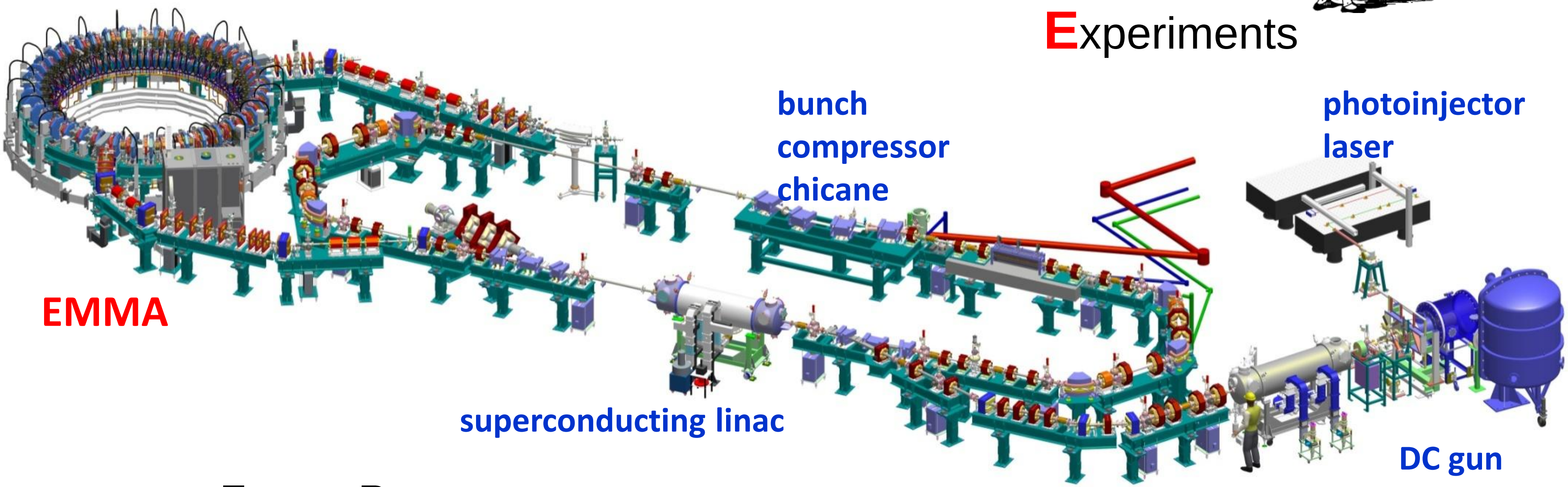
The ALICE Facility @ Daresbury Laboratory

An accelerator facility based on a superconducting energy recovery linac prototype

Accelerators and
Lasers
In
Combined
Experiments



Energy Recovery

Electrons returning to linac are decelerated and the energy is extracted → lower power consumption

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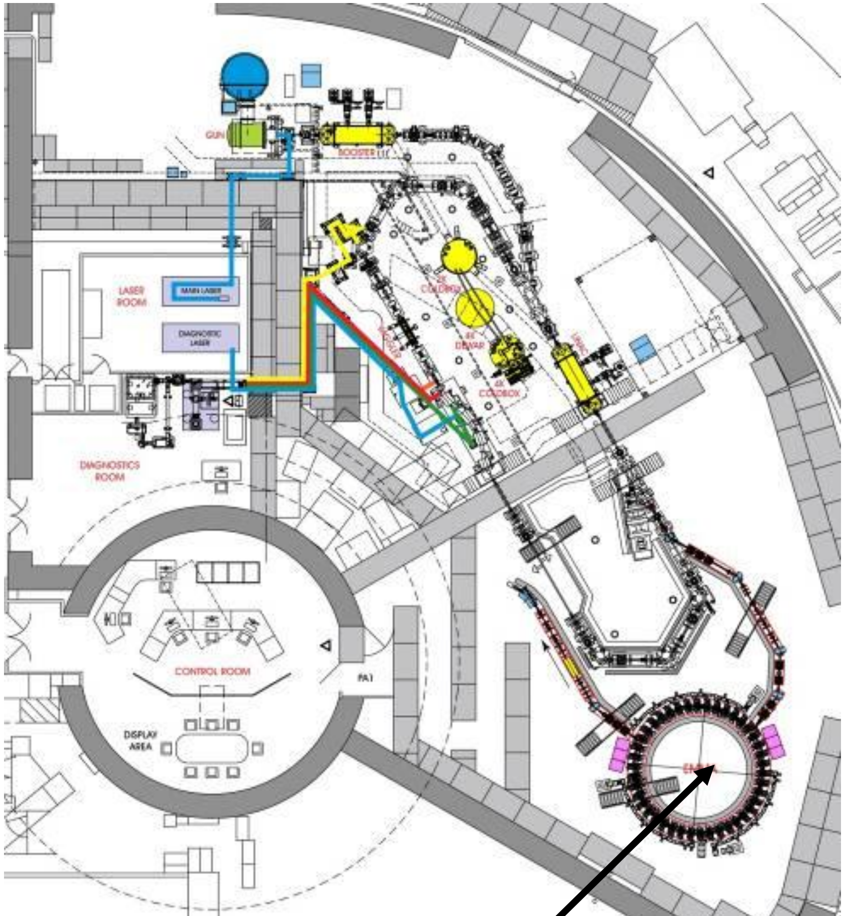
The ALICE Facility @ Daresbury Laboratory



EMMA

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ALICE History & Context

Original conceived as a prototype machine for 4th generation light source.

- 2003 Project conceived and funded.
- 2006 First electrons from gun.
- 2008 Energy recovery established.
- 2009 Compton backscattered X-ray photons generated
- 2010 IR-FEL lasing achieved

A step in UK accelerator science from 2nd-3rd generation into the 4th generation of light source.

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

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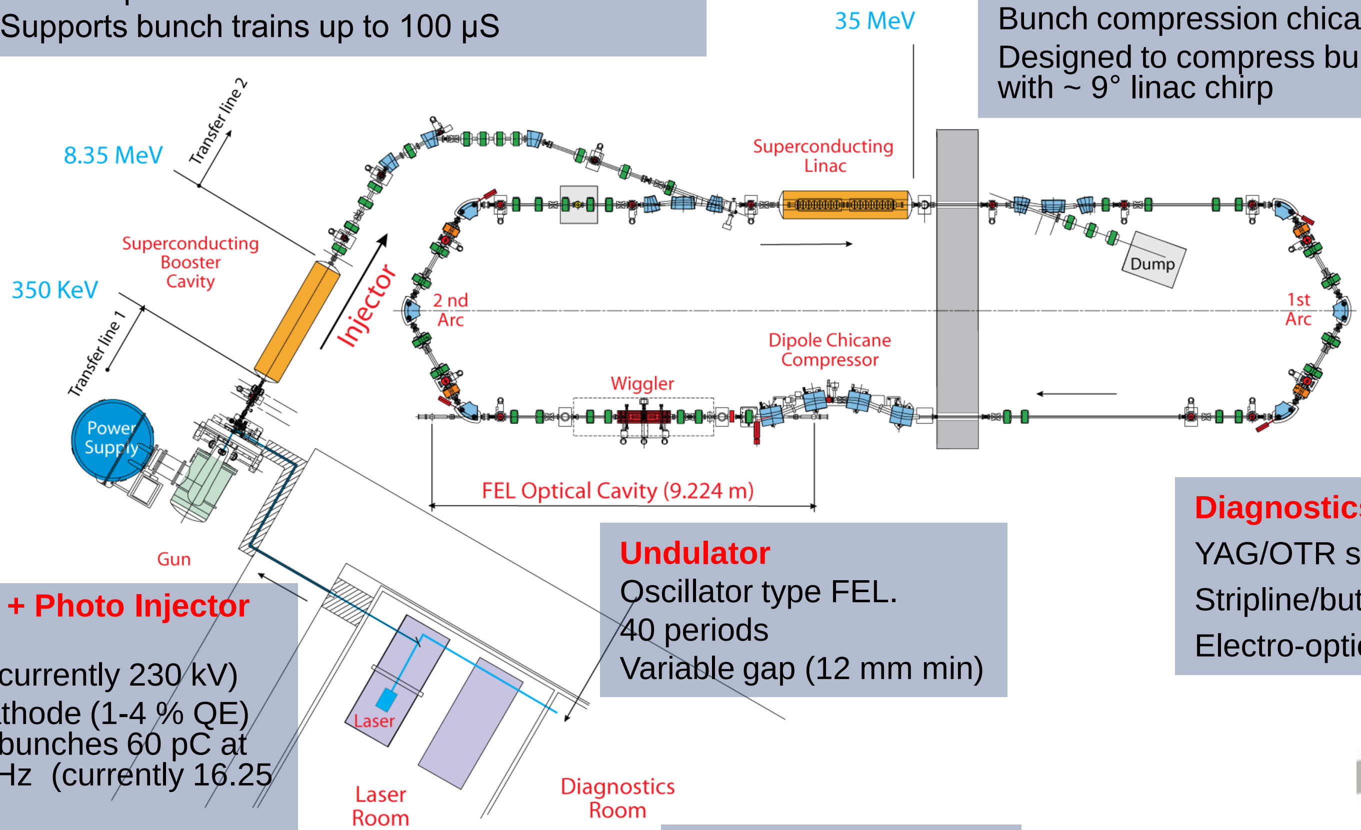
ALICE Machine Description

RF System
Superconducting booster + linac
TESLA/ILC/XFEL-Type 9-cell cavities. 1.3 GHz
Linac gradients ~10 MV/m.
Pulsed up to 10 Hz
Supports bunch trains up to 100 μS

Beam transport system.
Arcs are isochronous triple bend achromats, first arc translatable for energy recovery phase adjustment
Bunch compression chicane R_{56} = 28 cm
Designed to compress bunch length to < 1 pS with ~ 9° linac chirp



Diagnostics
YAG/OTR screens
Stripline/button BPMs
Electro-optic bunch profile monitor

Undulator
Oscillator type FEL.
40 periods
Variable gap (12 mm min)

DC Gun + Photo Injector Laser
350 kV (currently 230 kV)
GaAs cathode (1-4 % QE) delivers bunches 60 pC at 81.25 MHz (currently 16.25 MHz)
Vacuum (~1e-11 mbar)
Solenoid for emittance compensation/focussing

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

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ALICE Beam Physics

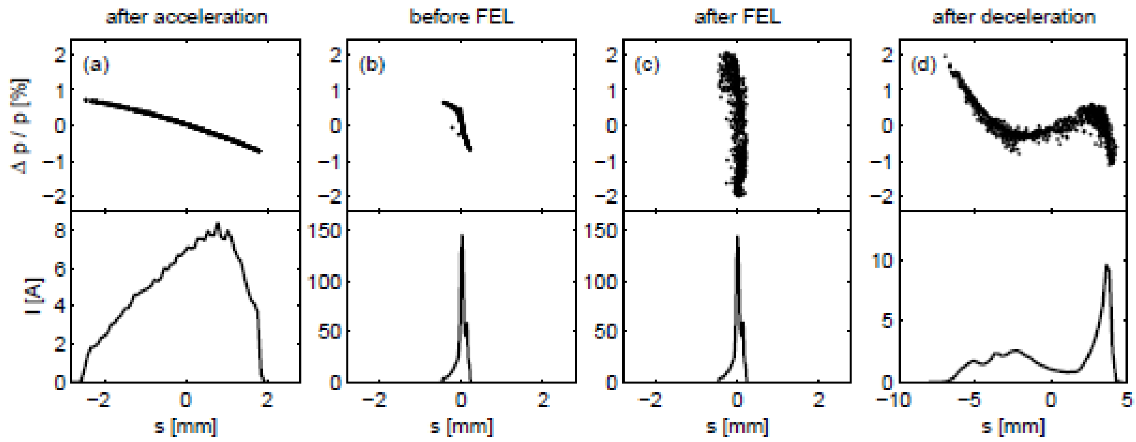
longitudinal dynamics are the most crucial for FEL

Injector

• Minimise uncorellated bunch length and energy spread (< 1 mm, < 0.5 %)
• Emittance around 5 µm

Main Loop

• Bunch compression via linac chirp and compressor chicane.
• Arc sextupoles provide linearisation of longitudinal phase space.



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

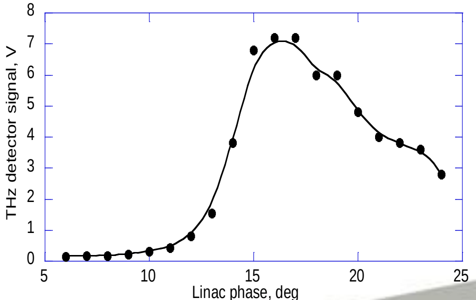
Measurements

• Not the top priority to achieve fine grained control of whole beam phase space (particularly transverse).

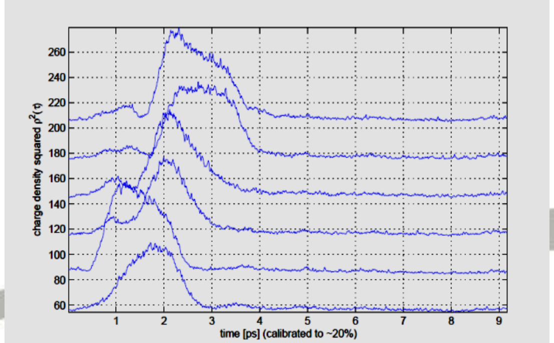
• THz + electro-optic diagnostic used to tune bunch compression to required level.

• Some chirp evident from booster

• The effect of sextupoles linearisation is not yet clear.



THz signal as function of phase



EO work by S. Jamison, T. Ng

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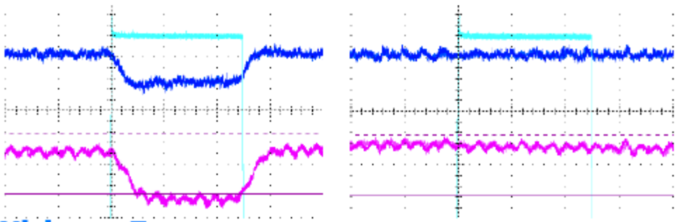
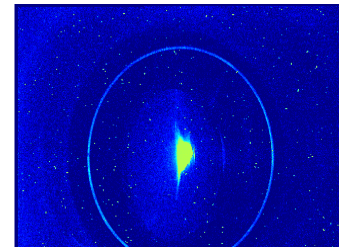
ALICE Early Achievements

Energy recovery achieved Christmas 2008



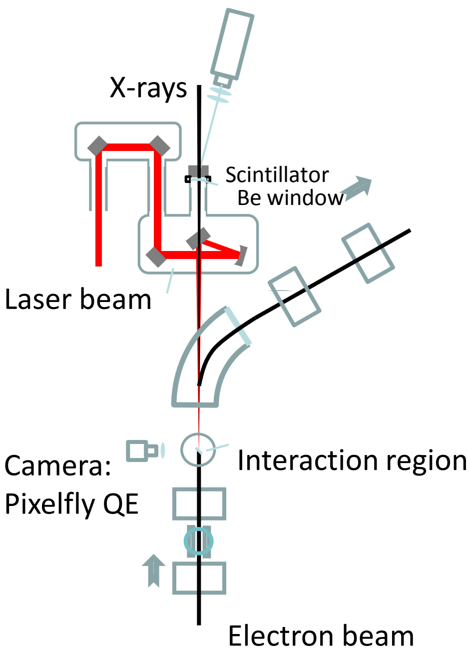
Without Energy Recovery | **With Energy Recovery**

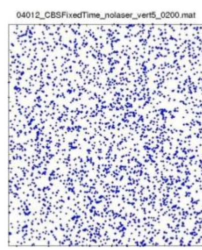
LLRF (power demand) signals without (left) and with (right) energy recovery



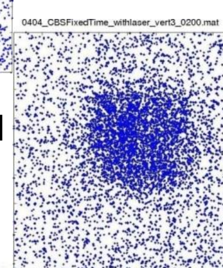
Compton backscattering achieved November 2009

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

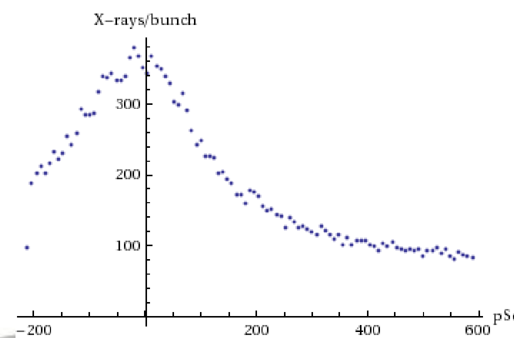




Background:
Electron beam ON
Laser OFF



Electron beam ON
Laser beam ON



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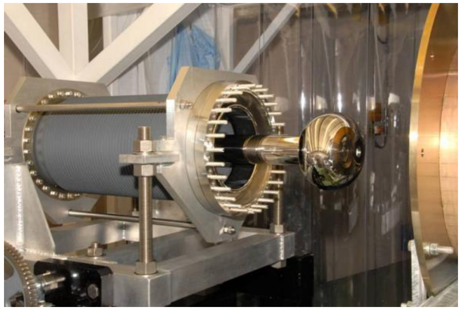
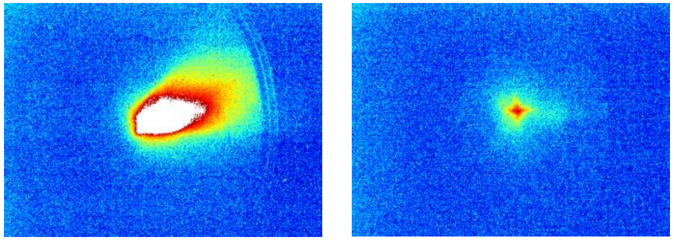
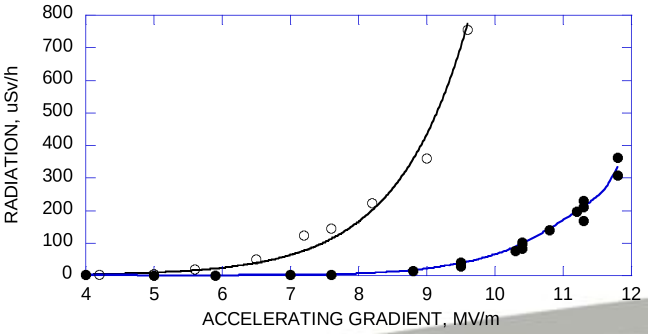
ALICE Challenges and Solutions

- ALICE uses several novel and difficult technologies.
- **DC Gun** was technically challenging.
  - Ceramic insulator problems. Gun presently limited to 230 kV
  - 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** due to LLRF limitations caused energy droop across bunch train
  - Effect suspected even at 40 pC, 81.25 MHz
  - 'Burst generator' solution. An additional pockels cell to reduce bunch rep frequency to 16 MHz, increase bunch charge to 60-80 pC.







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

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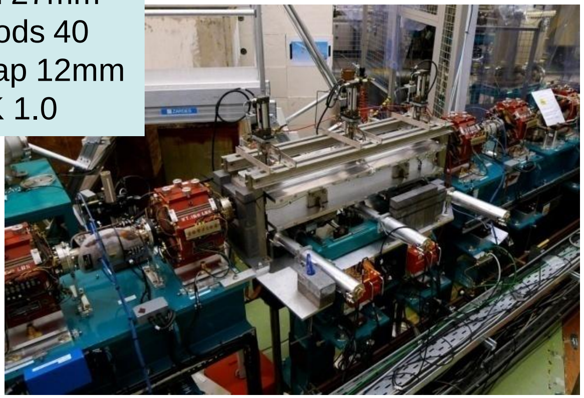
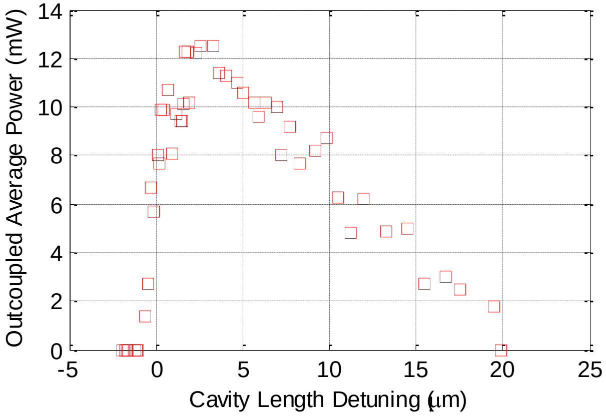
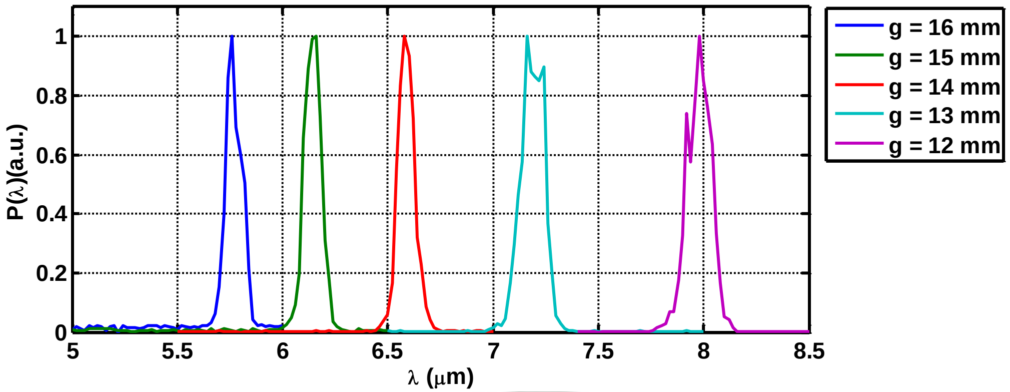
Infra-Red Free Electron Laser

- Oscillator IR-FEL with undulator borrowed from Jefferson Lab
- Spontaneous IR synchrotron radiation seen soon after wiggler installed (Dec 2009)
- Efforts towards lasing continued alongside installation, EMMA commissioning, and other projects
- First lasing October 2010
  - One week after burst generator installed – 80 pC, 16 MHz
- Lasing first achieved at 8 μm, average power ~10-30 mW.
- Adjusting undulator gap to achieve lasing 5.7-8.0 μm
- Gain is lower than expected. Beam dynamics not optimal.

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







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

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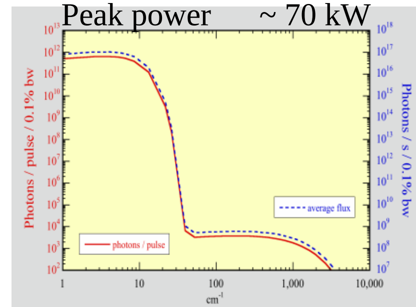
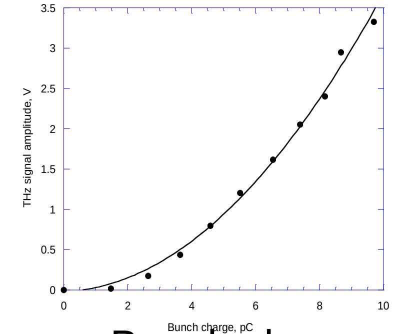
ALICE THz Source

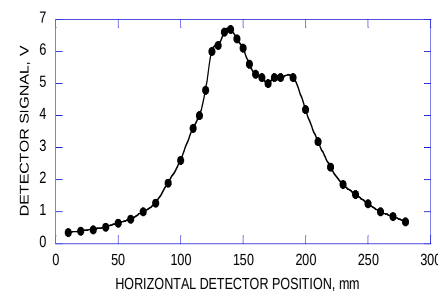
- ALICE is a rare source of high power broadband THz radiation
  - Coherent enhancement of synchrotron radiation through bunch compression chicane.
- Many orders of magnitude more powerful than conventional sources
  - Laboratory instruments 100 μW, ALICE ~ kW.
  - High peak power, low average power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

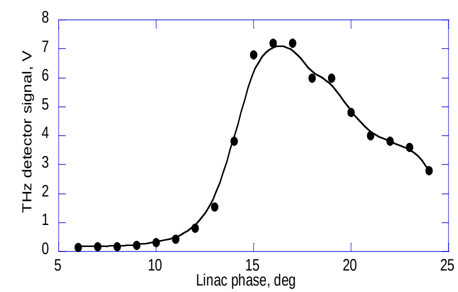
Average power ~ 24 mW
Peak power ~ 70 kW

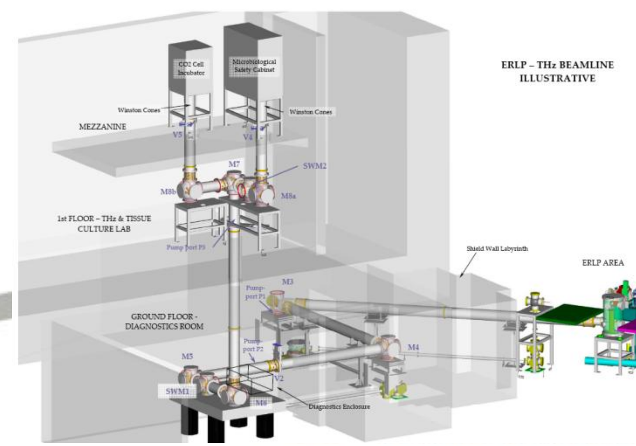




Bunch charge



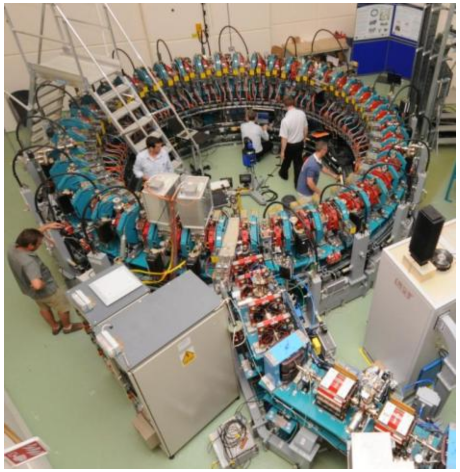




THz diagnostics: M. Surman.
Liverpool Univ. THz group. P. Weightman, R. Williams G. Holder, A. Schofield, C. Turner, P. Harrison

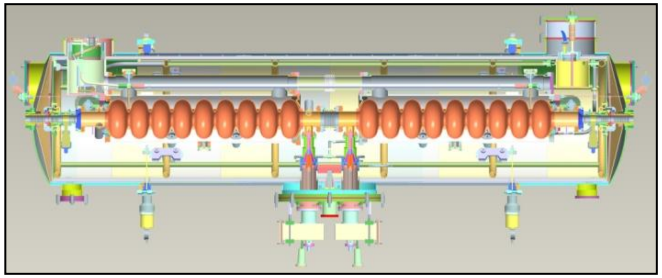
Other Applications of ALICE

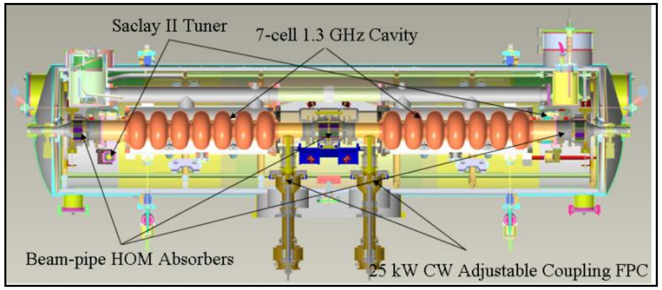
- EMMA non-scaling FFAG injector
  - Novel type of accelerator suitable for many applications
- Timing and synchronisation experiments
  - FP7/IRUVX-PP funding for demonstration on ALICE:
  - Development of beam arrival monitoring and timing distribution
  - Goal is **sub-10fs** timing distribution (as required by future light sources)



ALICE Plans

- THz and FEL beam lines presently under construction
  - Tissue culture laboratory for THz experiments
- Digital LLRF upgrade
- Cryomodule upgrade (international collaboration)
- Diagnostics
  - OTR streak camera and arrivial time monitors for R_{56} measurements and better measurement of longitudinal phase space
- ASTeC is now looking beyond ALICE





Will be installed into ALICE later in 2011

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ALICE Summary

- Achievements, experience and skills gained
  - IR-FEL lasing with energy recovery for first time in Europe
  - DC photo gun challenges and solutions
    - Gun and photocathode development
  - SCRF + cryogenics
  - Synchronisation techniques (EO and CBS)
- Other ALICE related presentations at this conference
  - ALICE facility poster in Wed afternoon coffee
  - Talks in this session on ALICE FEL, photoinjectors, FFAGs by D. Dunning, B. Militsyn, S. Sheehy (+ posters)
  - "Commissioning of EMMA, a Novel FFAG" Professor S. Smith. Thurs 7th 11:15 Senate Room

Alice

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

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Supplementary Slides

Energy Recovery Linacs

- DL only energy recovery linac in Europe
- In US existing ERL IR/UV-FEL @ JLab which was a pioneer (if not the first ever demo). CEBAF investigations into higher energy ERL.
- Several US proposals for ER machines
  - Cornell CESR upgrade to GeV Synchrotron-ERL (pre-construction prototyping of different components taking place)
  - APS (Argonne) considering similar upgrade
  - BNL considering e-RHIC driven by FEL
- Japan has 17 MeV ERL @ JAEA and building 200 MeV prototype for GeV scale ERL (Kentaro visit to DL)
- China (Peking) building 30 MeV ERL same scale as ALICE
- Novosibirsk FEL (BINP) 40 MeV

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History and Context

- ALICE pre-history
  - Daresbury global pioneer of the SR machine in the UK in 1980s
  - New 3rd Gen Machine DIAMOND went to Rutherford Lab
  - Daresbury considered new light sources beyond DIAMOND
  - Some different options considered (see e.g. J. Clarke PAC ’01)
  - Decided to go for FEL IR-VUV with ERL.
  - ERLP was the prototype.

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History and Context

- Delays.
- Electron source
  - Several parts of gun/laser not ready until April 2006.
  - First beam was August 2006.
  - Through 2007 gun conditioning and beam characterisation continued with various failures of the gun.
  - In Jun 2008 switched to Stanford ceramic.
- RF
  - Linac and booster cooled to 2K in late 2006
  - Booster was sent back for repair in Jan 2008
  - Booster returned to DL in Mar 2008.
- Machine ready (stanford ceramic in place + booster fixed + gun conditioned), Oct 2008
  - Took about 1-2 months from this point to get energy recovery.

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Machine Parameters

- Beam current
  - Design average current 80 pC × 81.25 MHz = 6.5 mA
  - Have achieved 6.5 mA within a train, but due to duty factor of RF real average current is 13 uA.
  - 4th generation user machine envisaged high beam currents 100 mA CW.
- Emittance
  - Goal was a few um
  - Measured about 6 um in recent AEMITR shifts.
- FEL requirements.
  - Peak current requirement. Gain as function of bunch length and charge given in \\dlfiles03\Apsv4\Astec\IDs and Magnets\ALICE_FEL_references\erlp-ofel-rpt-0001 ERL Prototype Free-Electron Laser.pdf

ALICE Machine Features (Laser)

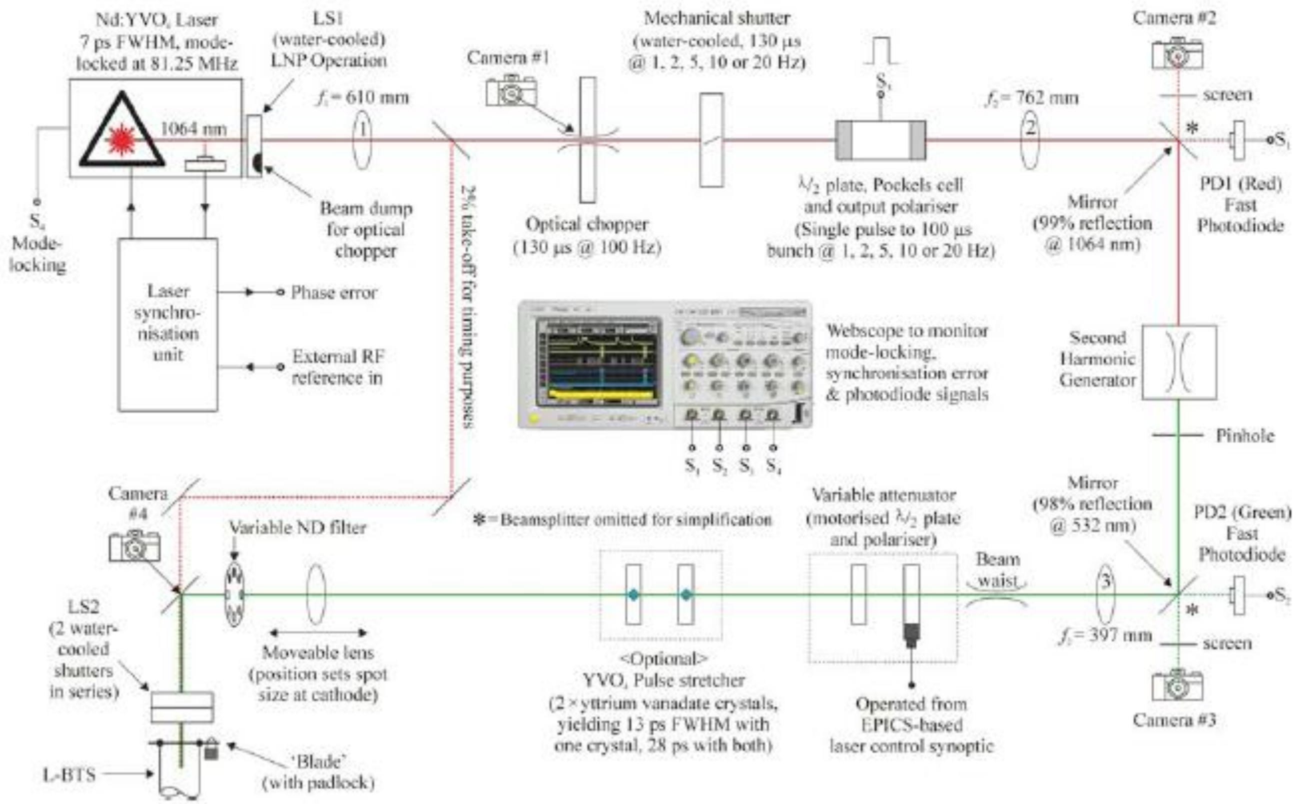

Figure 2: Schematic showing the layout of the optical system for the ERLP photoinjector drive laser.

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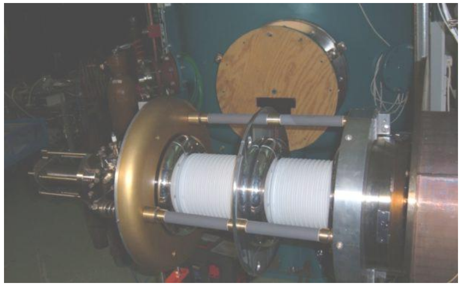
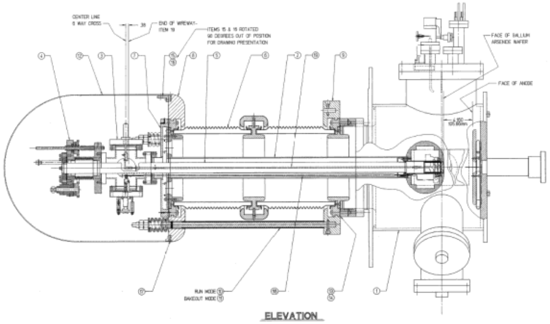
ALICE Machine Features (Gun+ Cathode)





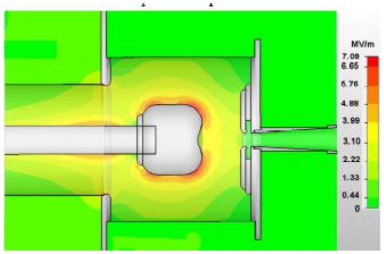
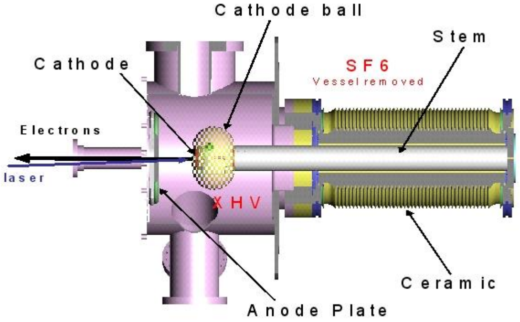
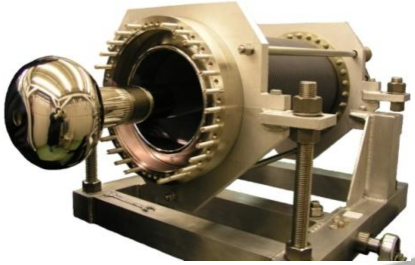


Figure 2: The electric fields in the gun chamber.

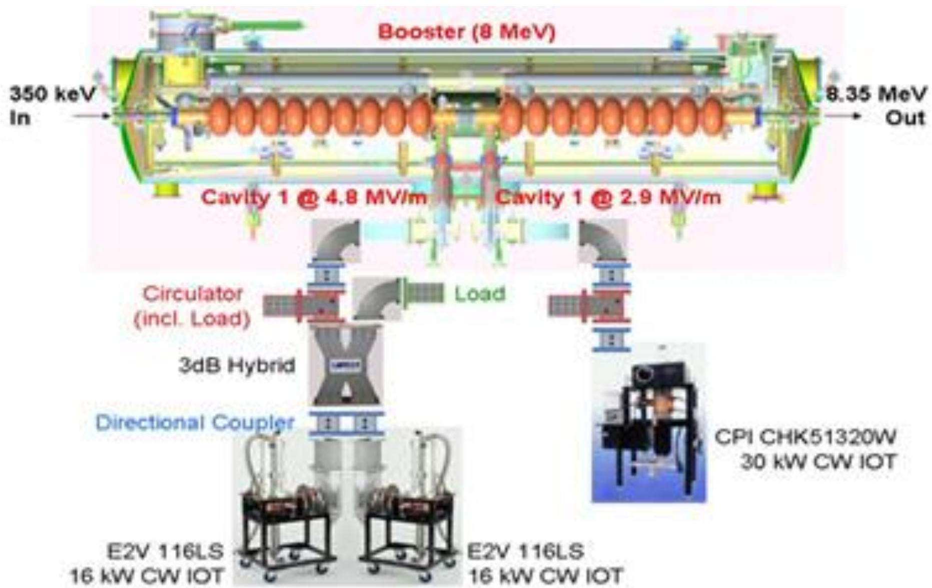


Ceramic insulator electrically insolates HV cathode ball and stem.



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



<u>ELBE facility@Rossendorf</u>

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

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>Stanford Picosecond Free Electron Laser Center</u>

• *<u>not</u>* SLAC
•W.W. Hansen Experimental Physics Laboratory, Stanford University
•40 MeV linac (same cryomodule as ALICE)

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ALICE Beam Dynamics

PAC ‘07 Quick and dirty emittance measurement vs charge, not minimizing emittance at each point

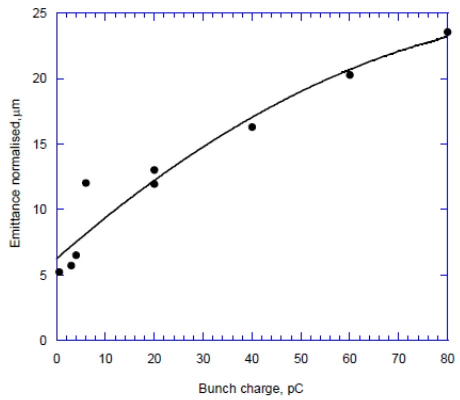
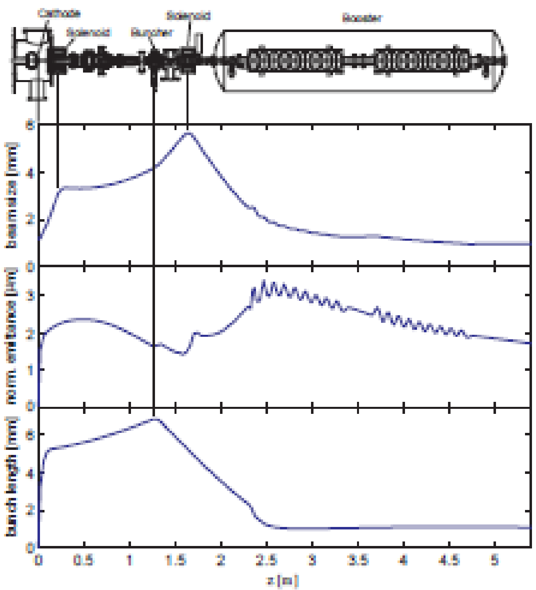
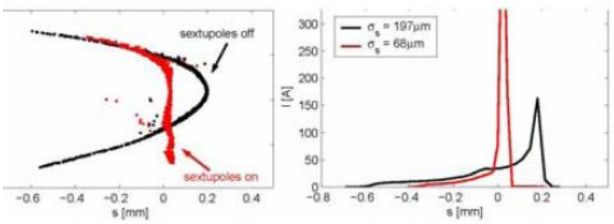


Figure 3: First estimates of the transverse emittance as a function of the bunch charge.

Injector



sextupoles



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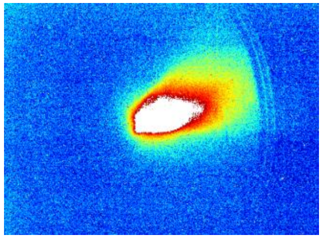
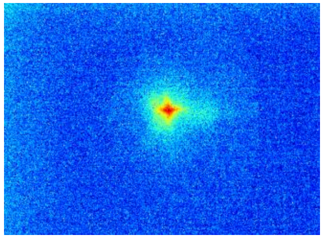
ALICE Problems and Solutions

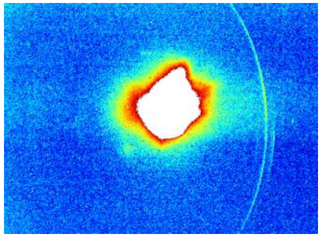
- Ceramic was only part of gun different to JLAB. Our ceramic body is better than JLAB but the braze was the problematic bit.
- Field emission



FE SOL-01 =2.6A



FE SOL-01 =3.3A

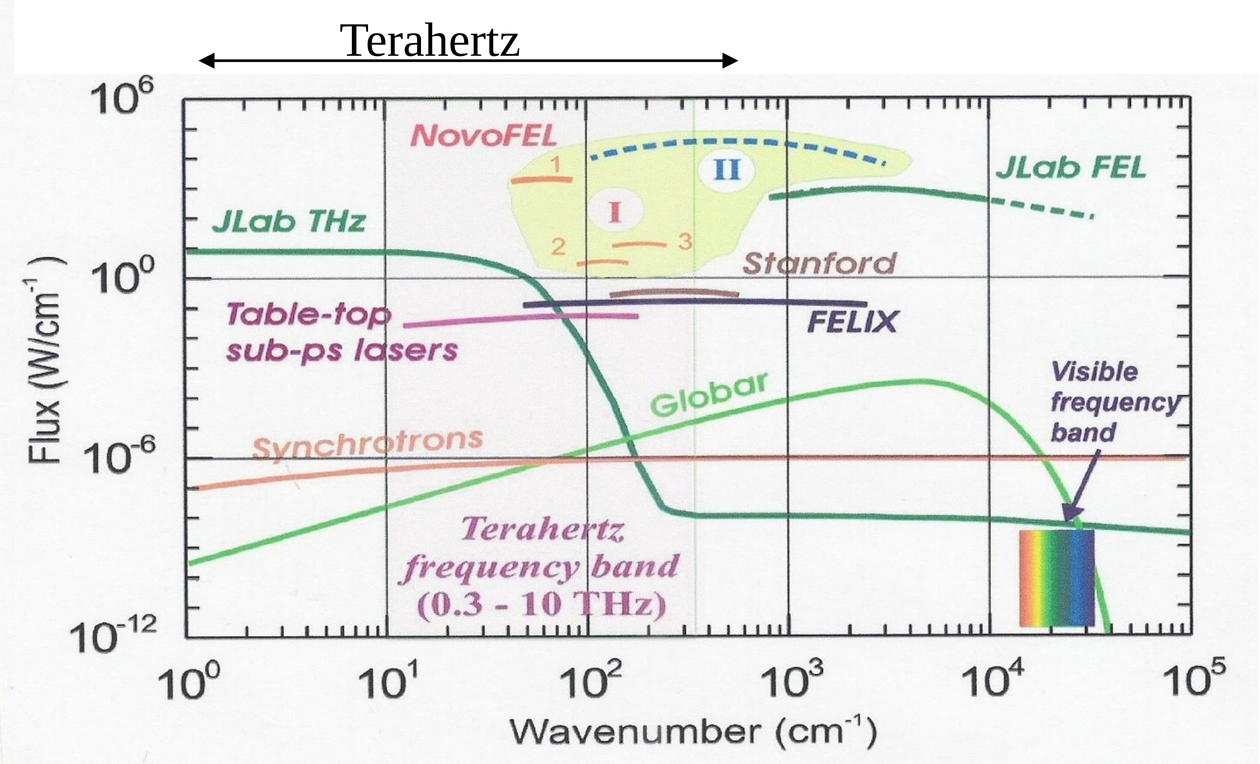


20 pC beam SOL-01 =3.3A

Images on YAG screen after booster at various SOL-01. The FE after the booster becomes acceptable at SOL-01 setting above ~3.3A.

Sources of THz Radiation

Laboratory sources	~ 100 μW
Synchrotrons (varies a lot)	~ 100 mW
Energy recovery linacs	~ 70 kW (ALICE at Daresbury peak power)



Principle of Energy Recovery Linac

When the length of the electron bunch is less than the wavelength emitted there is a massive increase in intensity. (Coherent emission)

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G. L. Carr et al Nature **420** 153 (2002)