Alice
Accelerators and Lasers
In Combined Experiments

The status of ALICE

(Energy Recovery Linac Prototype - ERLP)

S.L.Smith,
N.Bliss, A.R.Goulden, D.J.Holder, P.A.McIntosh,
and of course the rest of the ALICE team!

Science & Technology Facilities Council
Daresbury Laboratory

The Cockcroft Institute
of Accelerator Science and Technology

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ALICE introduction

Introduction

- ERLP (**E**nergy **R**ecovery **L**inac **P**rototype) at Daresbury Lab, UK
  - conceived as a prototype of an energy recovery based 4th generation light source

Beyond 4GLS !

- Reviewed Oct 2007
- Best matched ?
- UK requirements
  - Funding ~2011
  - Science ~2015

- ALICE (**A**ccelerators and **L**asers in **C**ombined **E**xperiments)
  - An R&D facility dedicated to accelerator science and technology development
  - Offers a unique combination of accelerator, laser and free-electron laser sources
  - Enables essential studies of beam combination techniques
  - Provides a suite of photon sources for scientific exploitation

New Light Source Project

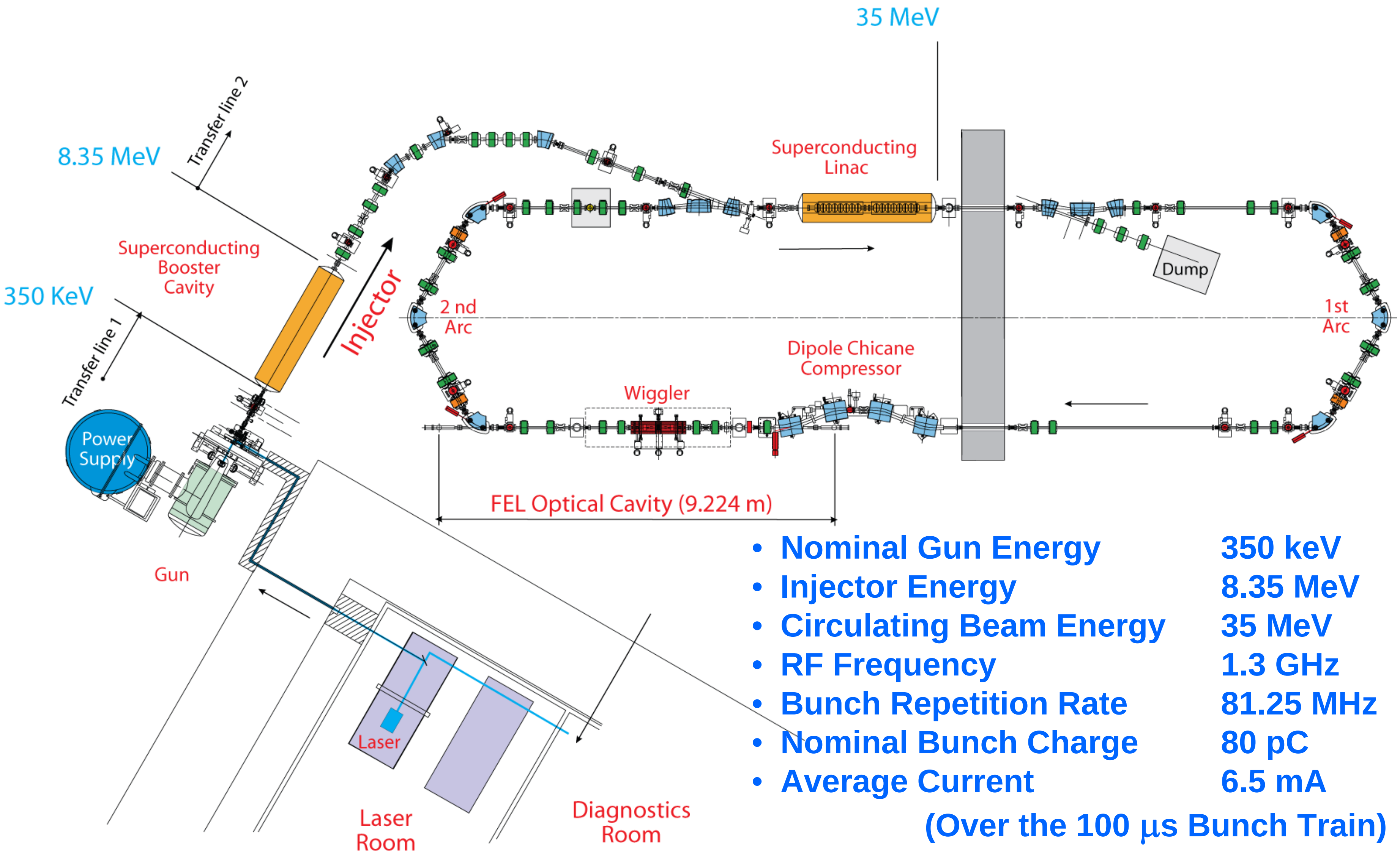
New Light Source Project (NLS)
aiming for unique studies of microscopic motions in matter of all kinds

> "We seek to examine the case for a New Light Source (NLS) Facility, based on advanced conventional and free electron lasers, with unique and world leading capabilities"

http://www.newlightsource.org/

- **MOPC035: "PULSE – A High Repetition Rate Linac Driver as a Possible Option for a Next Generation UK Light Source" Williams…**
- **MOPC033: "Sapphire – An Ultra-fast High Peak Brightness X-Ray Source as a Possible Option for a Next Generation UK Light Source" Walker…**

Accelerator Layout

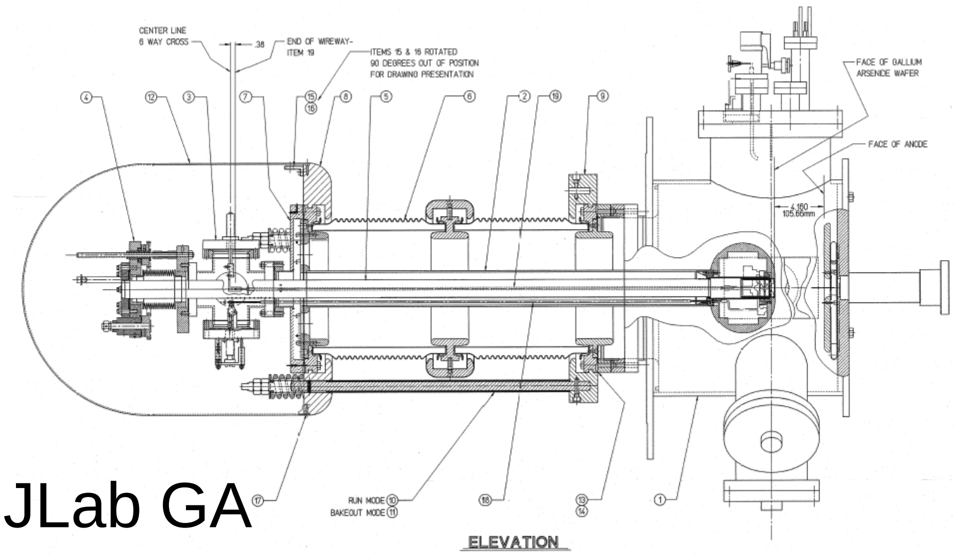


- **Nominal Gun Energy** **350 keV**
- **Injector Energy** **8.35 MeV**
- **Circulating Beam Energy** **35 MeV**
- **RF Frequency** **1.3 GHz**
- **Bunch Repetition Rate** **81.25 MHz**
- **Nominal Bunch Charge** **80 pC**
- **Average Current** **6.5 mA**

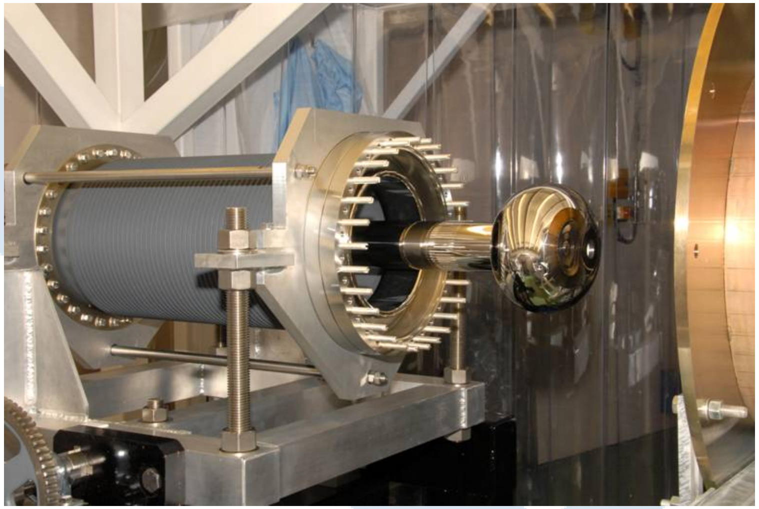
(Over the 100 μs Bunch Train)

Photoinjector

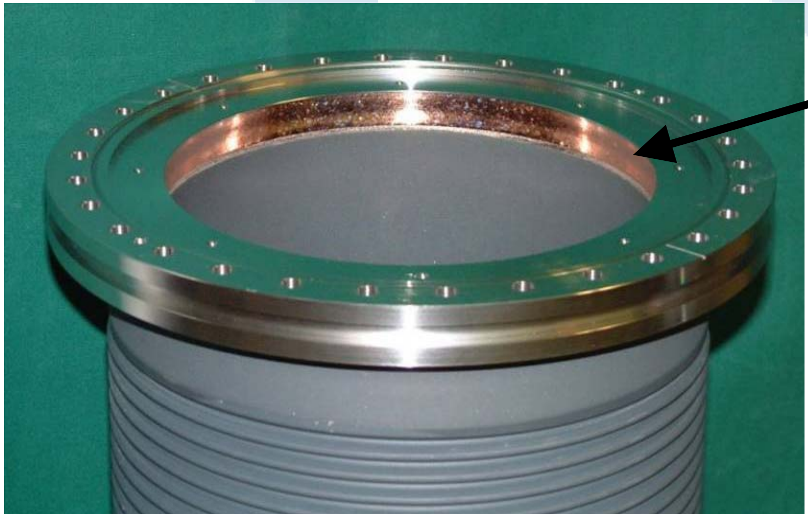
Photoinjector Introduction



JLab GA



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



Copper brazed joint

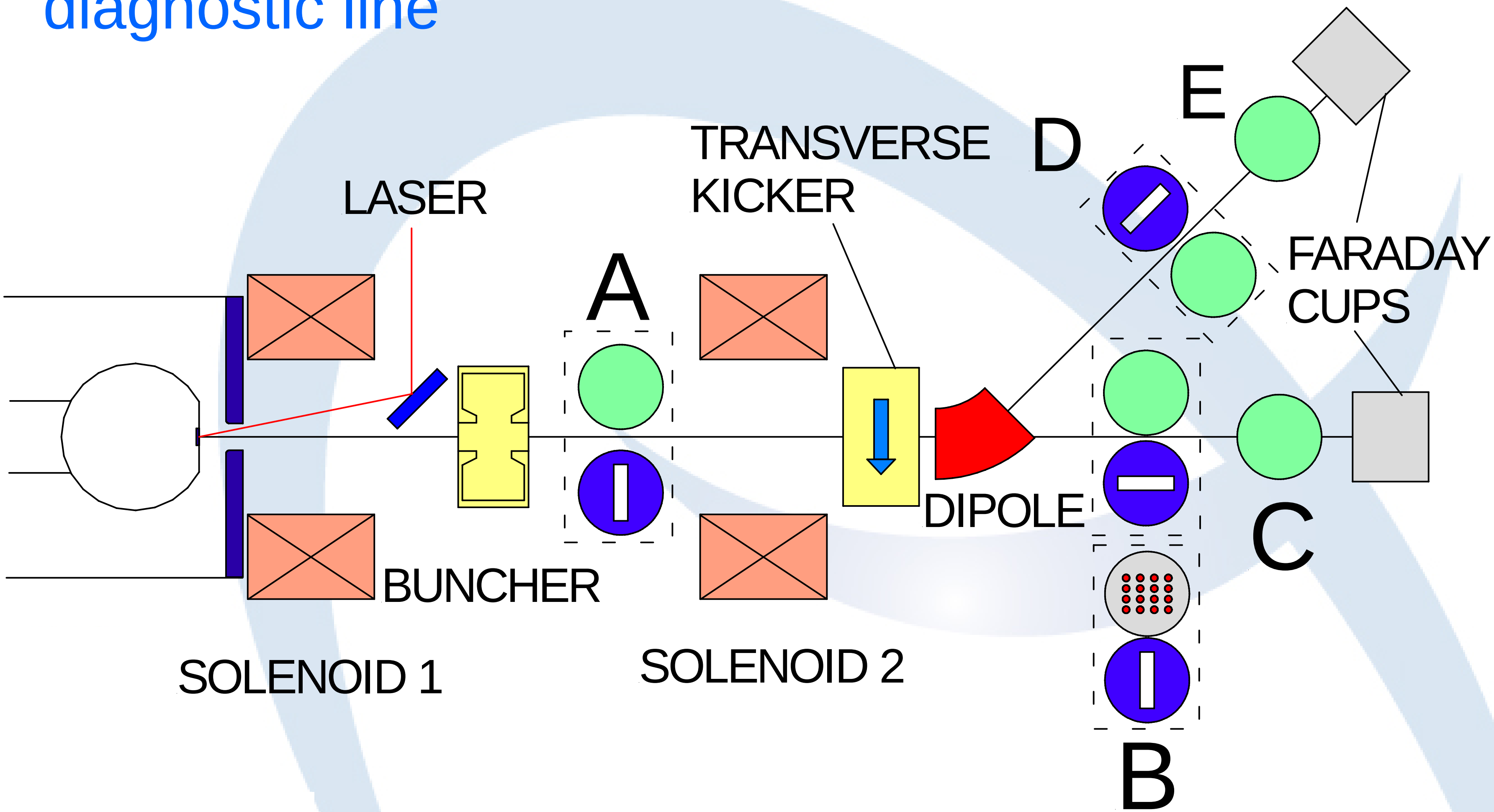
First electrons August 2006

PI Operational Problems

- Still to achieve routine reliable operation
- Major issues
  - High voltage breakdown problems after cathode caesiation
  - Failure during bake-out of the large diameter flange seals
  - Difficulties in achieving XHV vacuum conditions (after HV gun conditioning) and resulting poor cathode lifetime
  - Field emission from the photocathode
  - Failures of the copper brazing of the ceramic to its end flanges

PI Commissioning Highlights

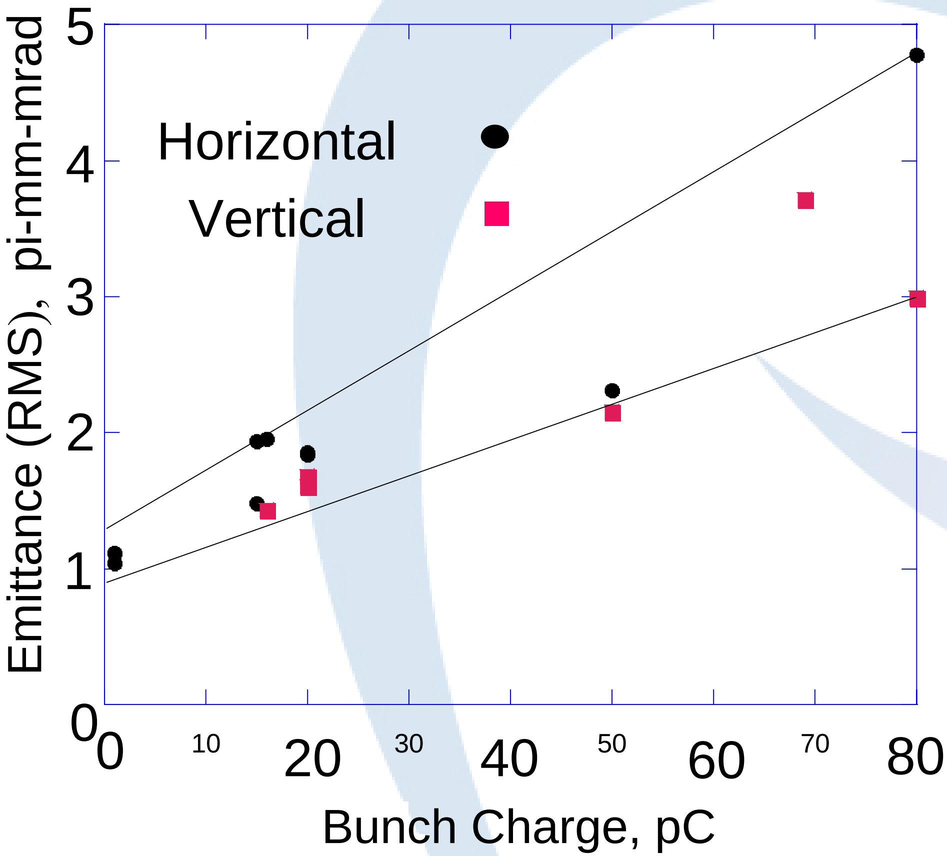
Injector commissioning with dedicated diagnostic line



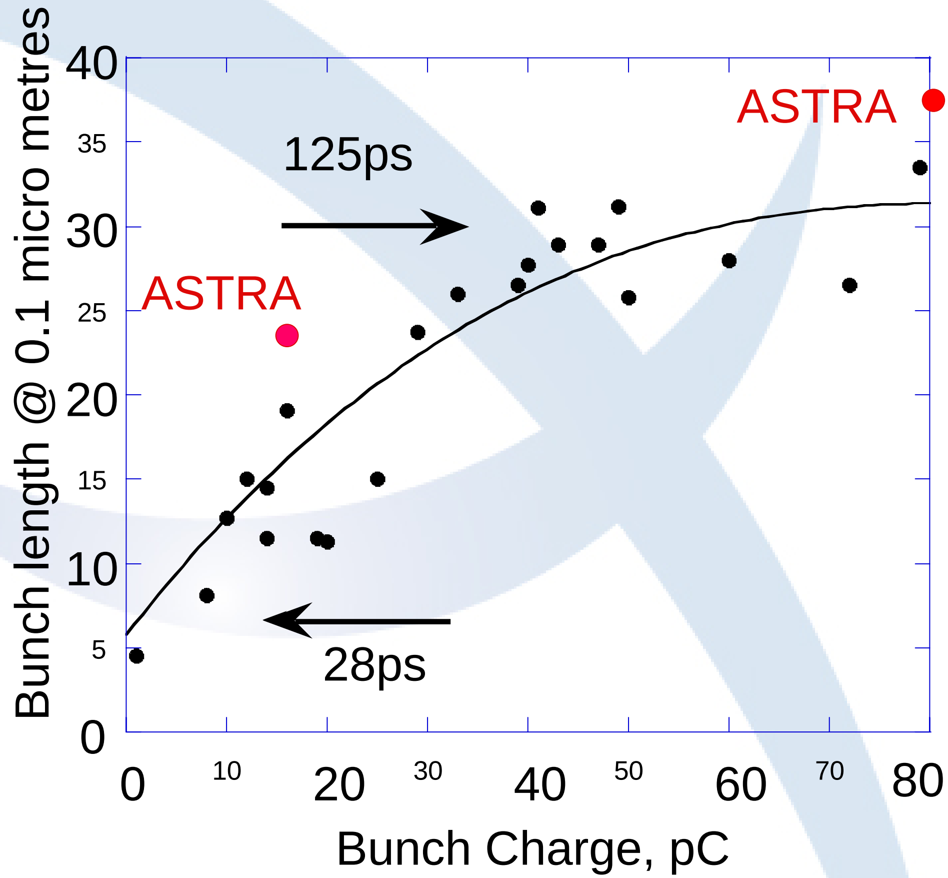
PI Results (1)

MOPC062 "RESULTS FROM ALICE (ERLP) DC PHOTOINJECTOR GUN COMMISSIONING" Saveliev….

RMS geometric emittance
vs.
bunch charge



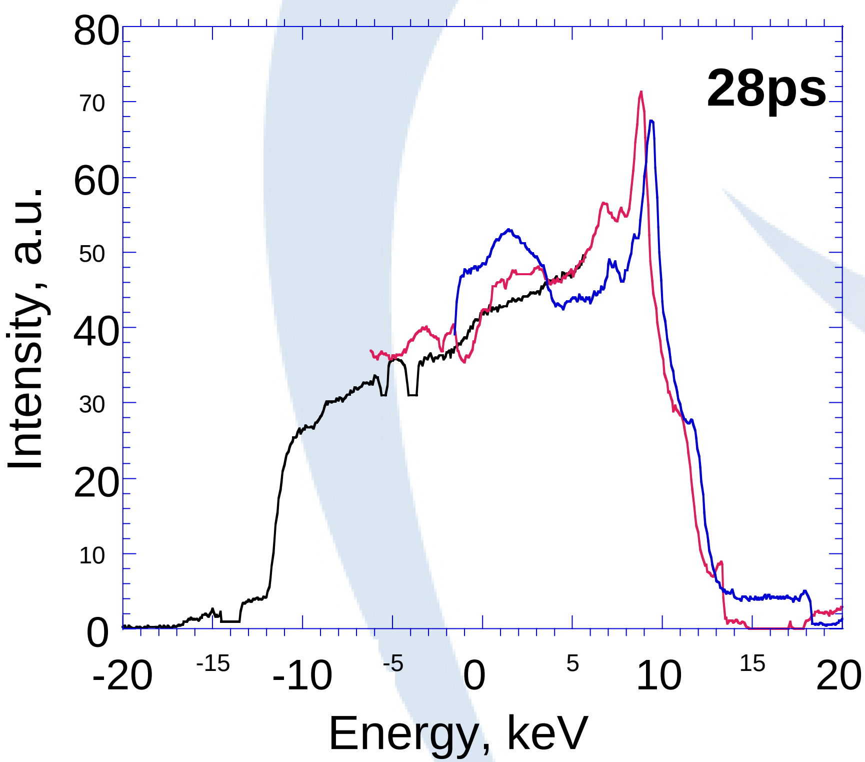
Bunch length at 10% of peak value
vs.
bunch charge

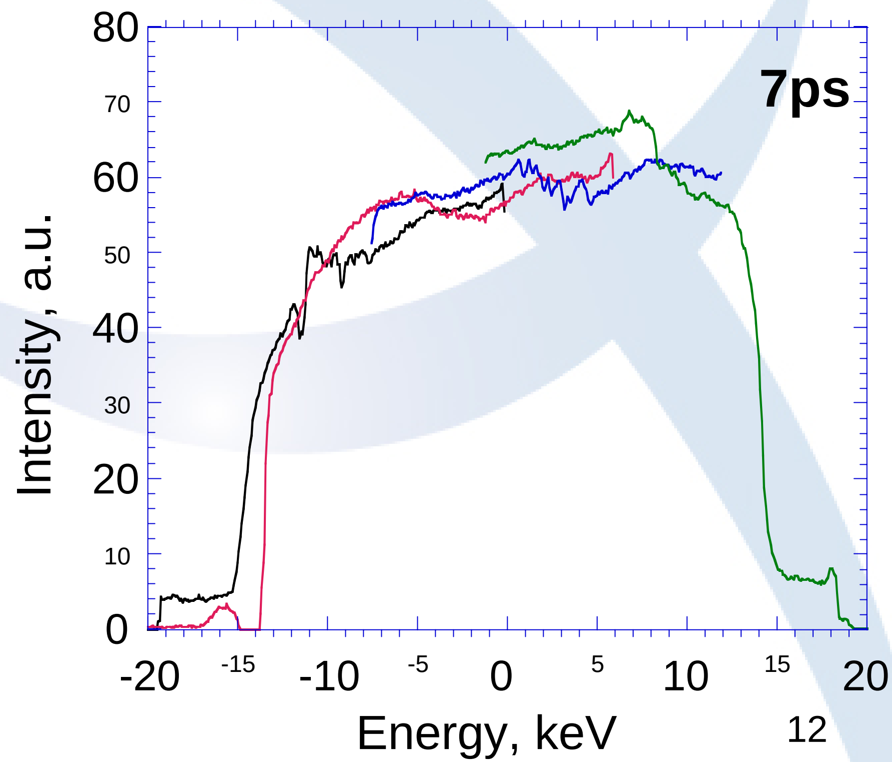


PI Results (2)

MOPC063 "ELECTRON BUNCHES FROM ALICE DC PHOTOINJECTOR GUN AT TWO DIFFERENT LASER PULSE LENGTHS", Saveliev….

Total energy spectra for bunches generated by 28 ps and 7 ps laser pulses.

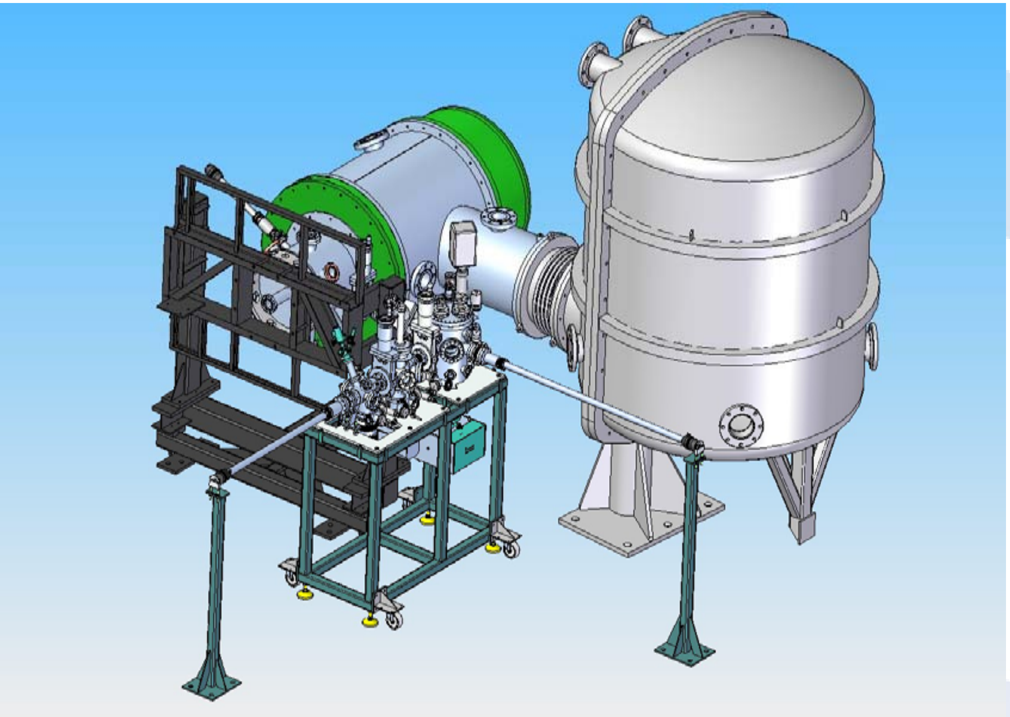




Gun Commissioning Summary

- Results
  - The gun can now be routinely **HV conditioned to 450kV**
  - **QE above ~3%** are normally achieved after cathode activations (bunch charges of well above100pC have been achieved)
  - The beam was **fully characterised** (emittance, bunch length, energy spectra) in a wide range of bunch charges from 1 to 80pC
  - A **good agreement** between the ASTRA simulations and the experimental data was found in terms of the **bunch length** and the **energy spread** but **not for the emittance**.
  - Bunch characteristics were investigated at **two different laser pulses** of 7ps and 28ps.
  - At **low Q<20pC, no significant difference** was observed. An importance of a smooth (i.e. flat-top) laser pulse for minimisation of the beam emittance was demonstrated.
- Remaining gun-related issues
  - Ensure the absence of FE spots on the cathode
  - Increase the cathode lifetime at QE level of >1.5%
  - Transverse emittance is higher than expected (FE ? QE non-uniformity?)

Injector upgrade



ALICE photocathode gun equipped with a photocathode preparation & exchange facility

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

MOPC073: "DESIGN OF AN UPGRADE TO THE ALICE PHOTOCATHODE ELECTRON GUN", Militsyn…

Cryogenics system status

Cryosystem Operation

- Partial system procured from Linde
- 4 K commissioning completed May 06
- SRF Module delivery April and July 06
  - Problems with excessive system heat leaks and heater failure.
- Cryo output
  - Specification 118 W at 2 K with 1 mbar stability.
  - Measured 118 W at 2 K with ± 0.03 mbar stability in May 07
- Static load
  - Specification < 15 W per module
  - Measured 5 W for both modules (i.e. ~2.5 W each)
- System has operated successfully at 1.8 K – needs optimising

Superconducting module status

SC Module Design

ALICE 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

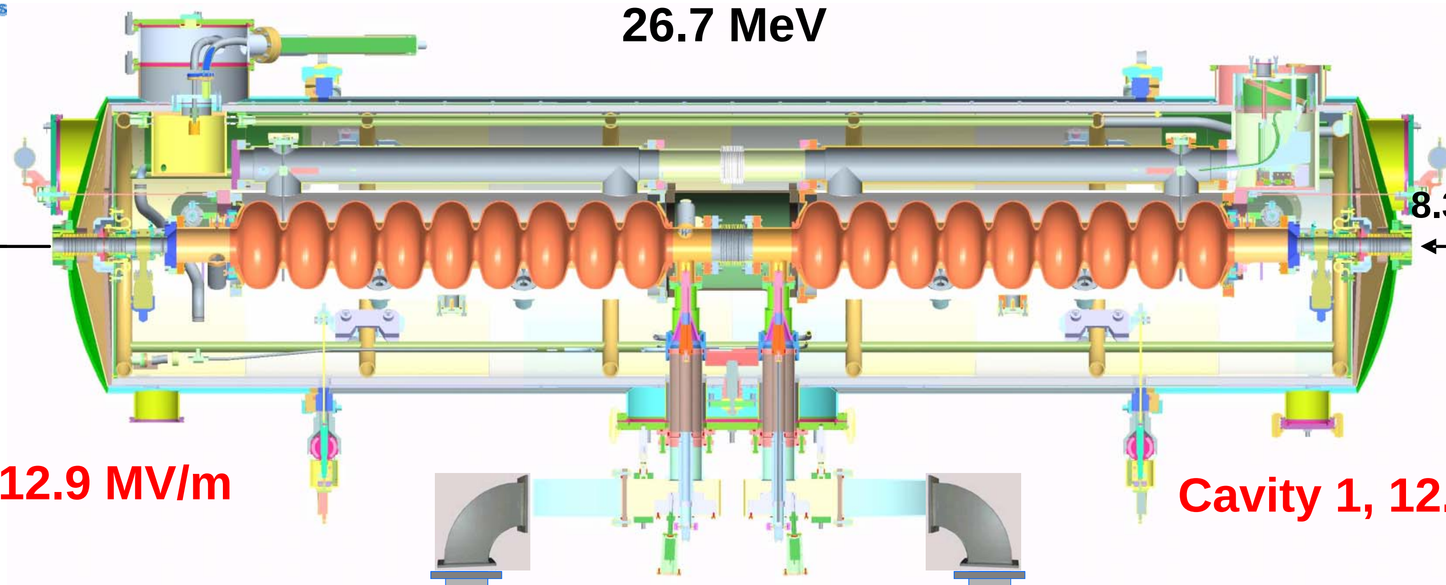
Linac and booster both consist of two TESLA 9 cell cavities in a Rossendorf/Stanford module

Linac layout

26.7 MeV

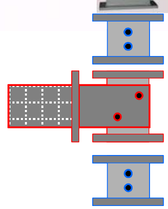
35 MeV Out

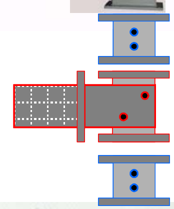
8.35 MeV In



Cavity 2, 12.9 MV/m

Cavity 1, 12.9 MV/m





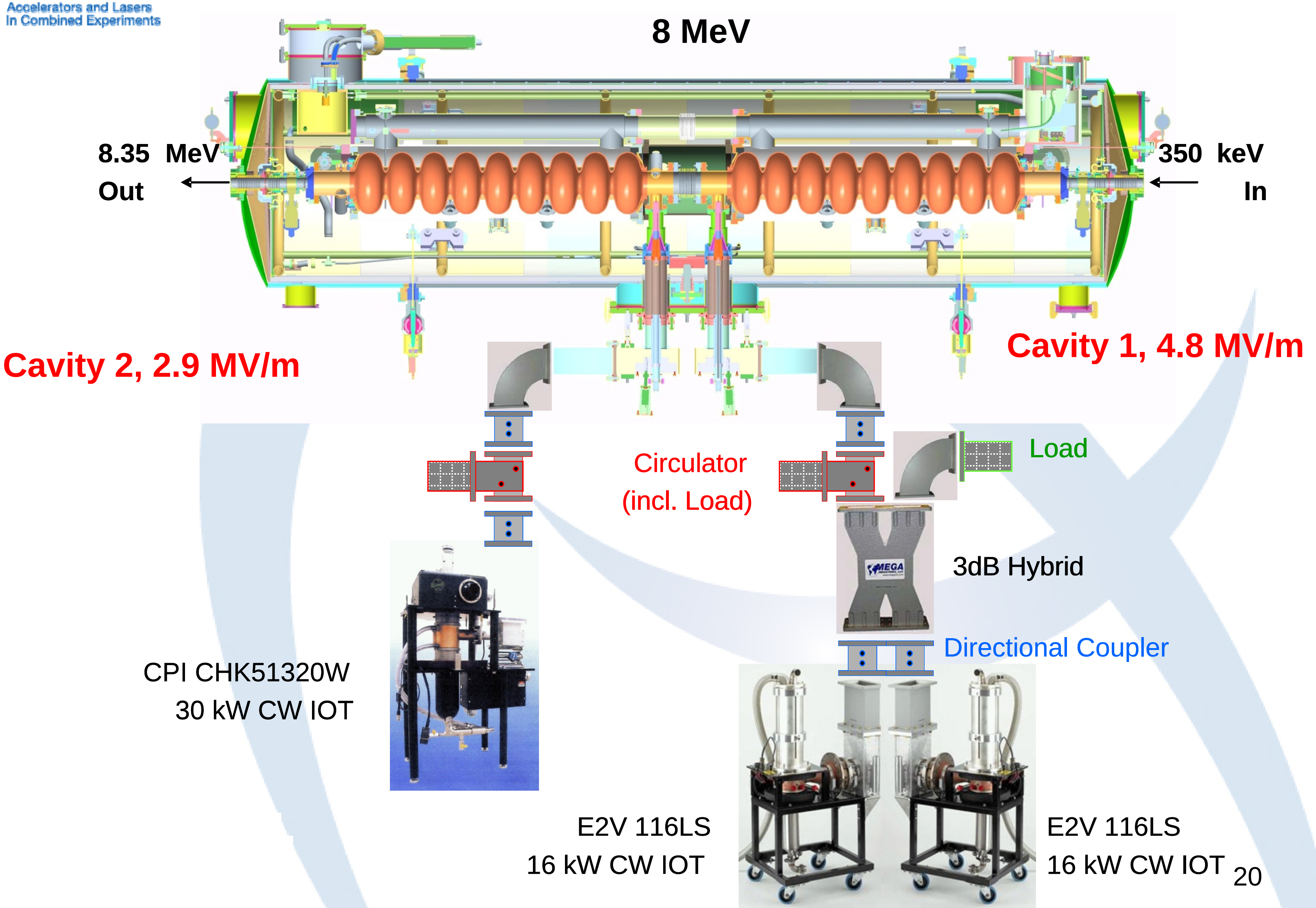
Circulator (incl. Load)

Directional Coupler

Thales TH713
20 kW CW IOT

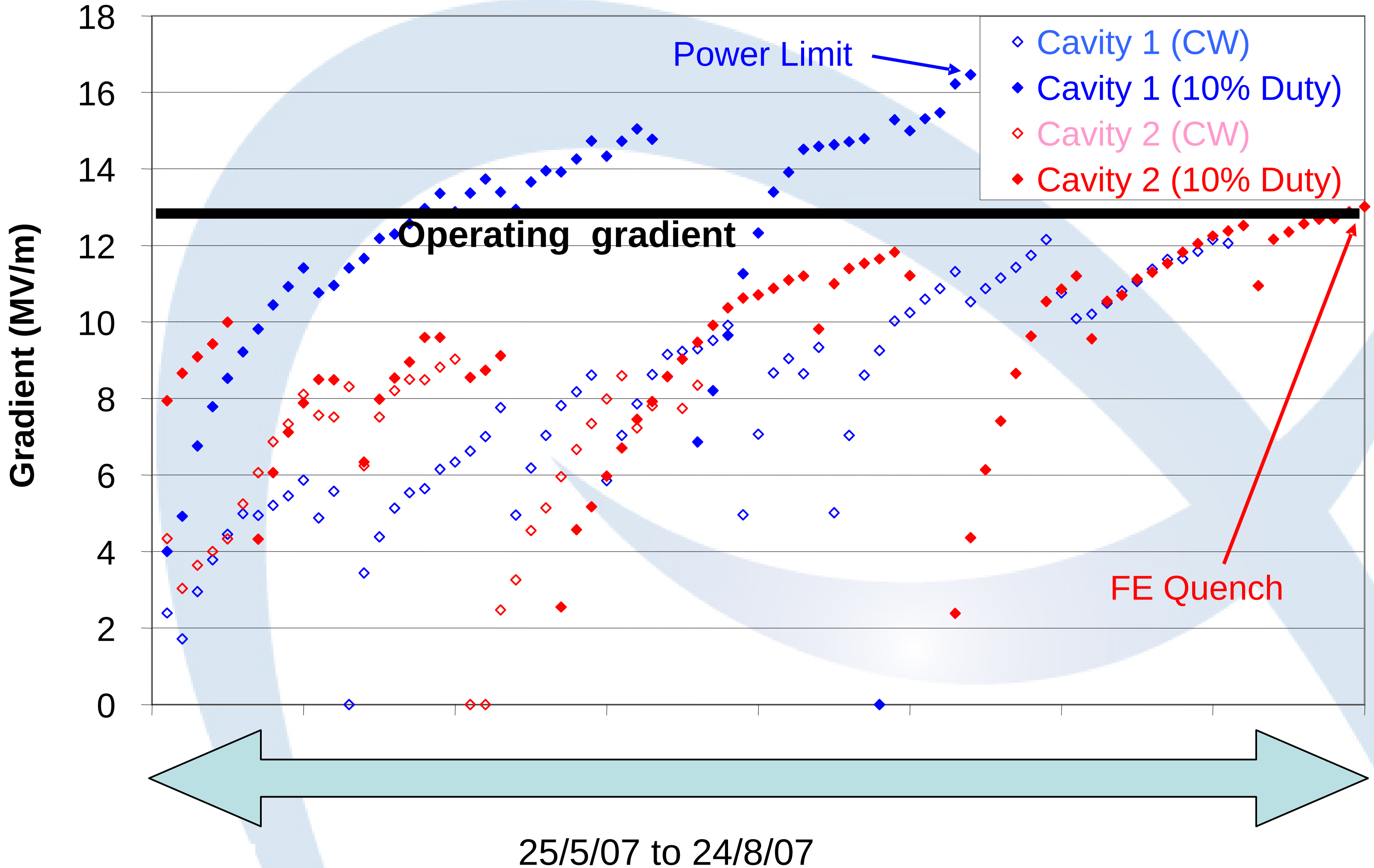
E2V 116LS
16 kW CW IOT

Booster layout

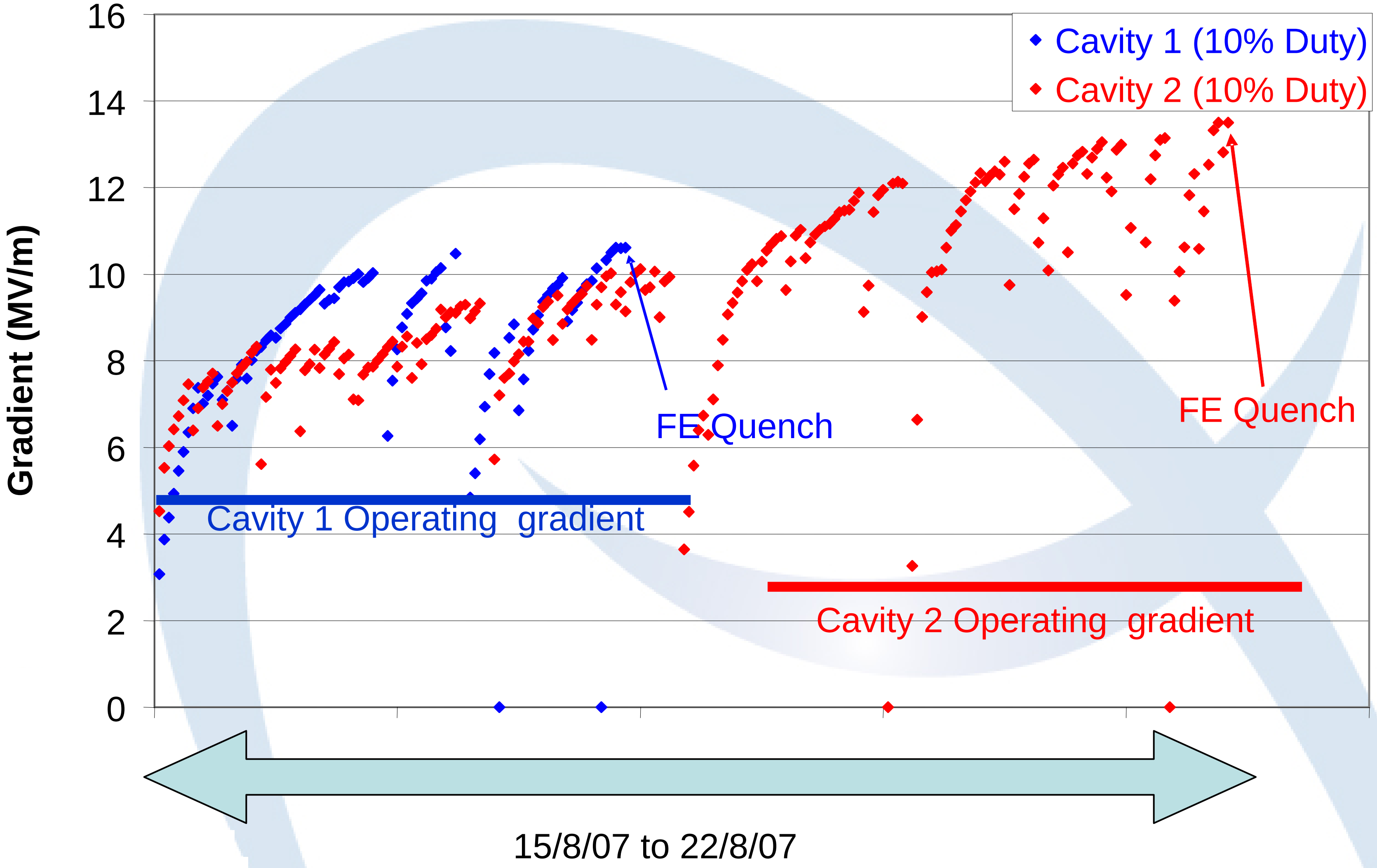


Linac Module Performance

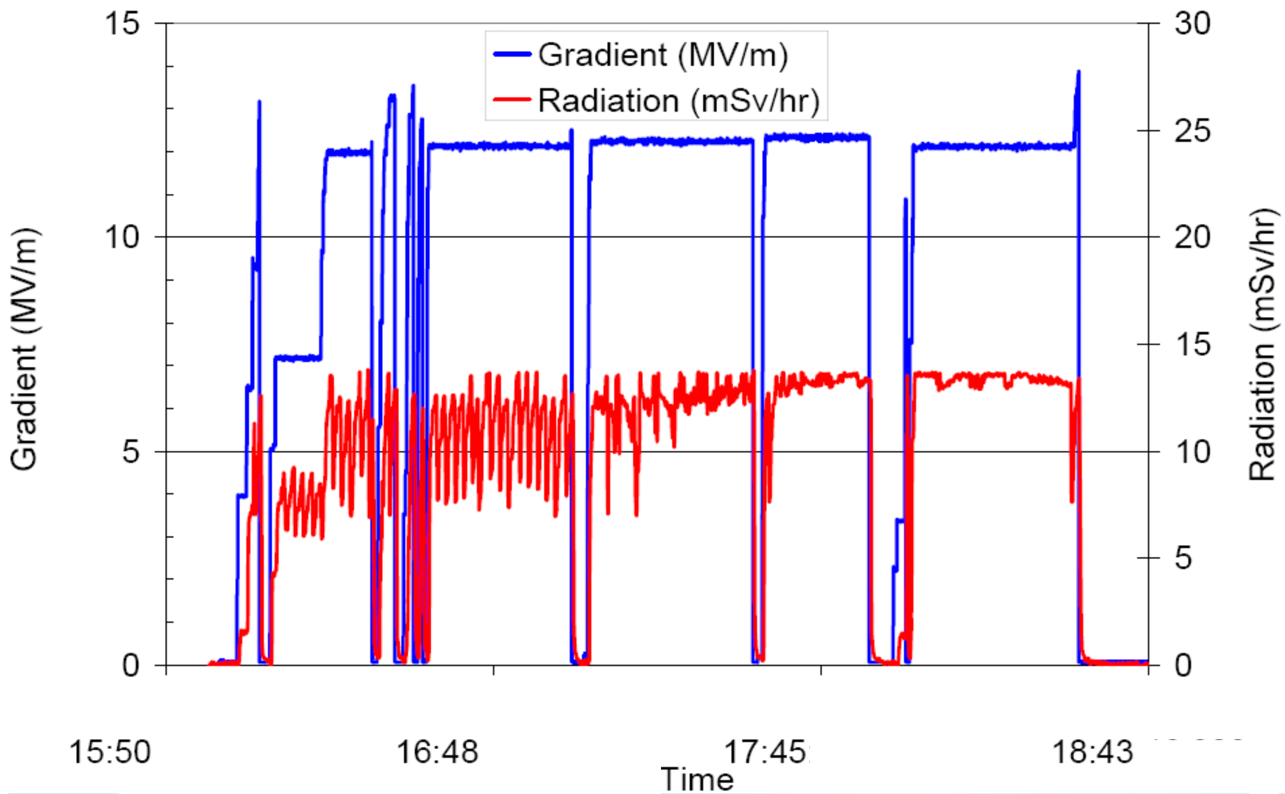
MOPP141 "Commissioning of the ERLP SRF Systems at Daresbury Laboratory", P McIntosh…



Booster Module Performance



Field Emission Radiation Issue



Measurements from an ionisation chamber radiation monitor, which is positioned 7 m away from the Linac module, as the gradient in the cavity is increased .

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

SC Module Commissioning Summary

- All 5 IOTs are successfully commissioned
- All 4 cavities show unexpected limitations due to field emission
- ALICE operation at 35 MeV is still possible
- Measurements of cryogenic losses at intermediate gradients show significant reduction compared with vertical test results.
- Measurements of high levels of FE radiation at electronic components
  - Installation of extensive lead shielding of LINAC module
  - Installation of high average current cryomodule, Summer 09.

CW Vertical tests at DESY (July – Dec 2005)

	Booster		Linac	
	Cavity 1	Cavity 2	Cavity 1	Cavity 2
Eacc (MV/m)	18.9	20.8	17.1	20.4
Qo	$5x10^9$	$5x10^9$	$5x10^9$	$5 x 10^9$

Module acceptance test at 10% duty cycle (May– Sept 2007)

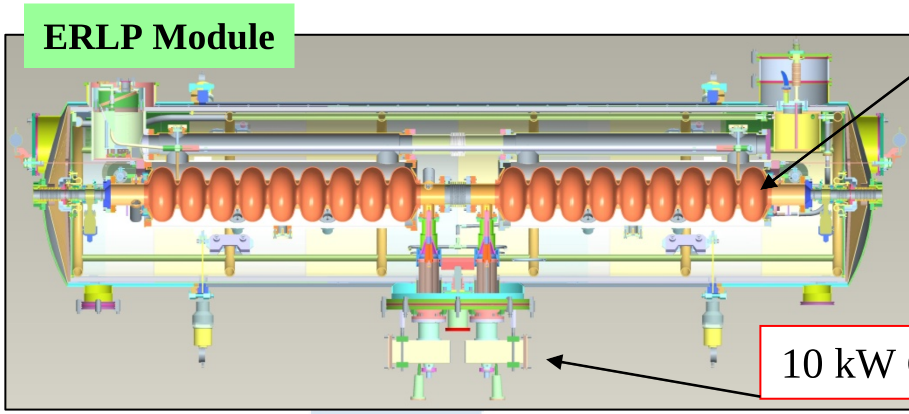
Max Eacc (MV/m)	10.8	13.5	16.4	12.8
Qo at Gradient MV/m	$3.5x10^9$ 8.2	$1.3x10^9$ 11	$1.9x10^9$ 14.8	$7.0x10^9$ 9.8
Qe	$2.5x10^6$	$2.6x10^6$	$6.4x10^6$	$4.7x10^6$
Limitation	Quench	Quench	RF Power	Quench

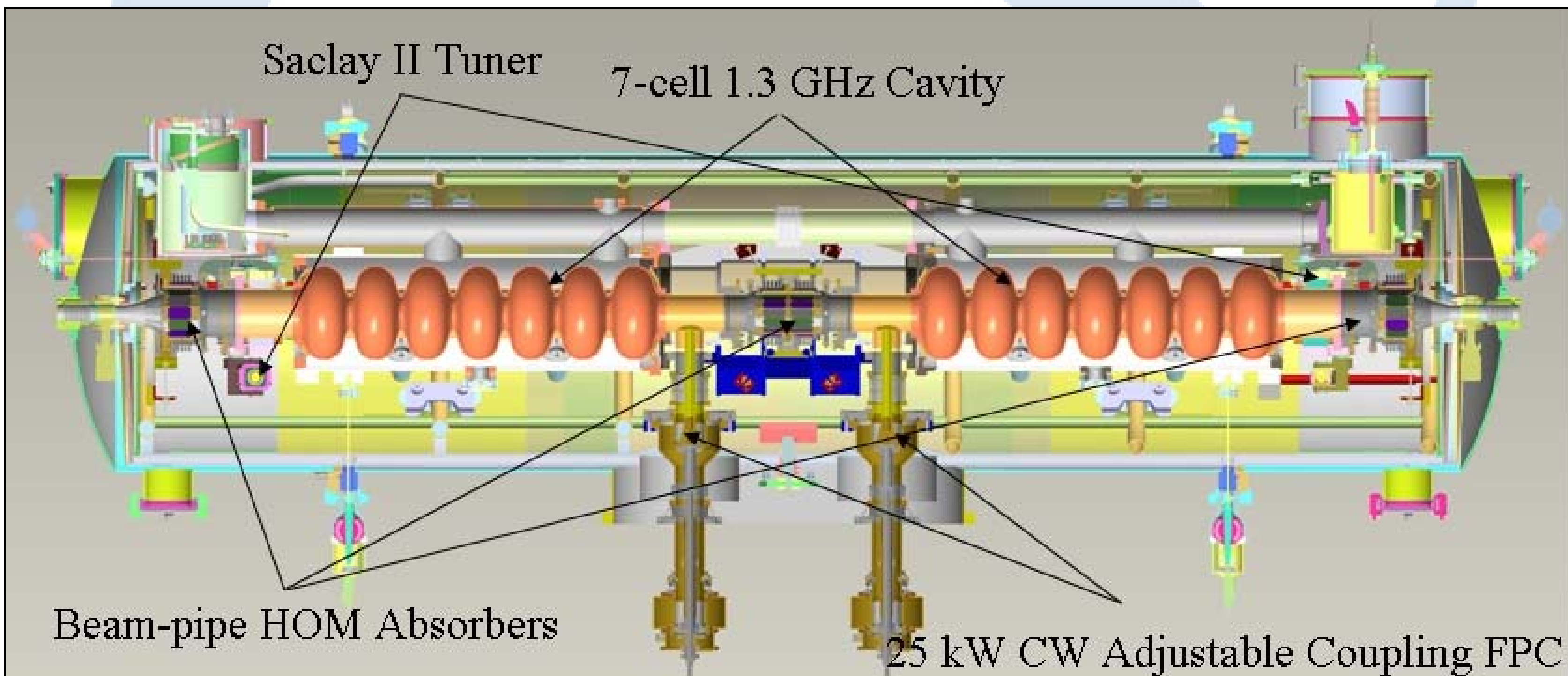
High Current Cryomodule R&D Collaboration

"Realisation of a prototype superconducting CW cavity and cryo module for energy recovery", P McIntosh et al, SRF07 Beijing

- 5 collaborating institutes
  - ASTeC (UK)
  - Cornell University (USA)
  - Stanford University (USA)
  - Lawrence Berkeley Laboratory (USA)
  - FZD Rossendorf (Germany)

Cryomodule


ERLP Module
2 x 9-cell 1.3 GHz cavity
10 kW CW fixed coupling FPC


Saclay II Tuner
7-cell 1.3 GHz Cavity
Beam-pipe HOM Absorbers
25 kW CW Adjustable Coupling FPC

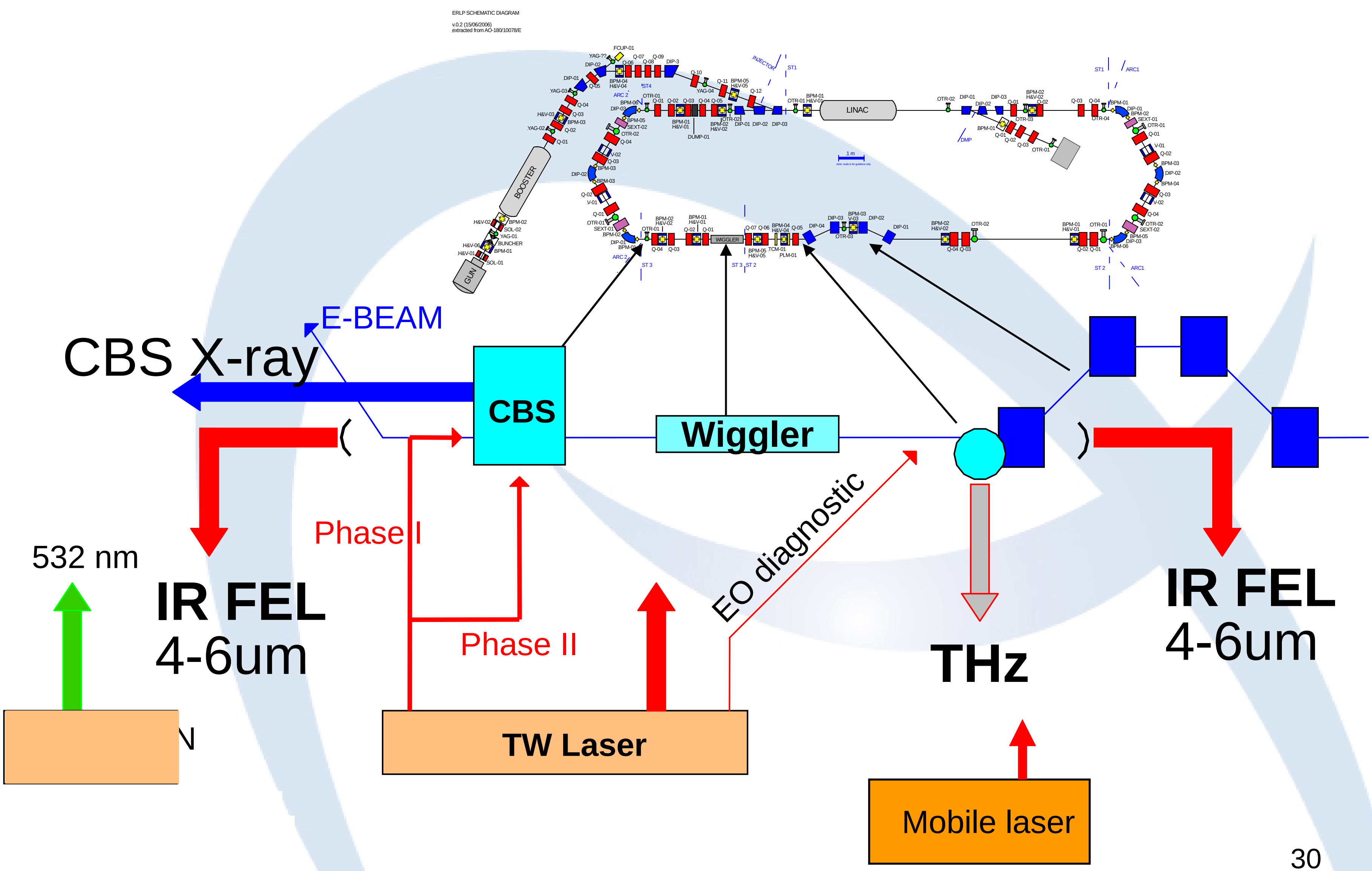
Future Plans

Energy Recovery

- First energy recovery (Summer 2008)
  - Without FEL, installation planned Spring 2009
- Fine tuning
  - injector tuning for minimal emittance
  - optimisation of energy recovery at nominal beam parameters
  - beam diagnostics
- Short pulse commissioning stage
  - longitudinal dynamics, electro-optical diagnostic studies
- Energy recovery with FEL (Spring 2009)
  - first light !
  - recovery of a disrupted beam

Science Beyond Energy Recovery

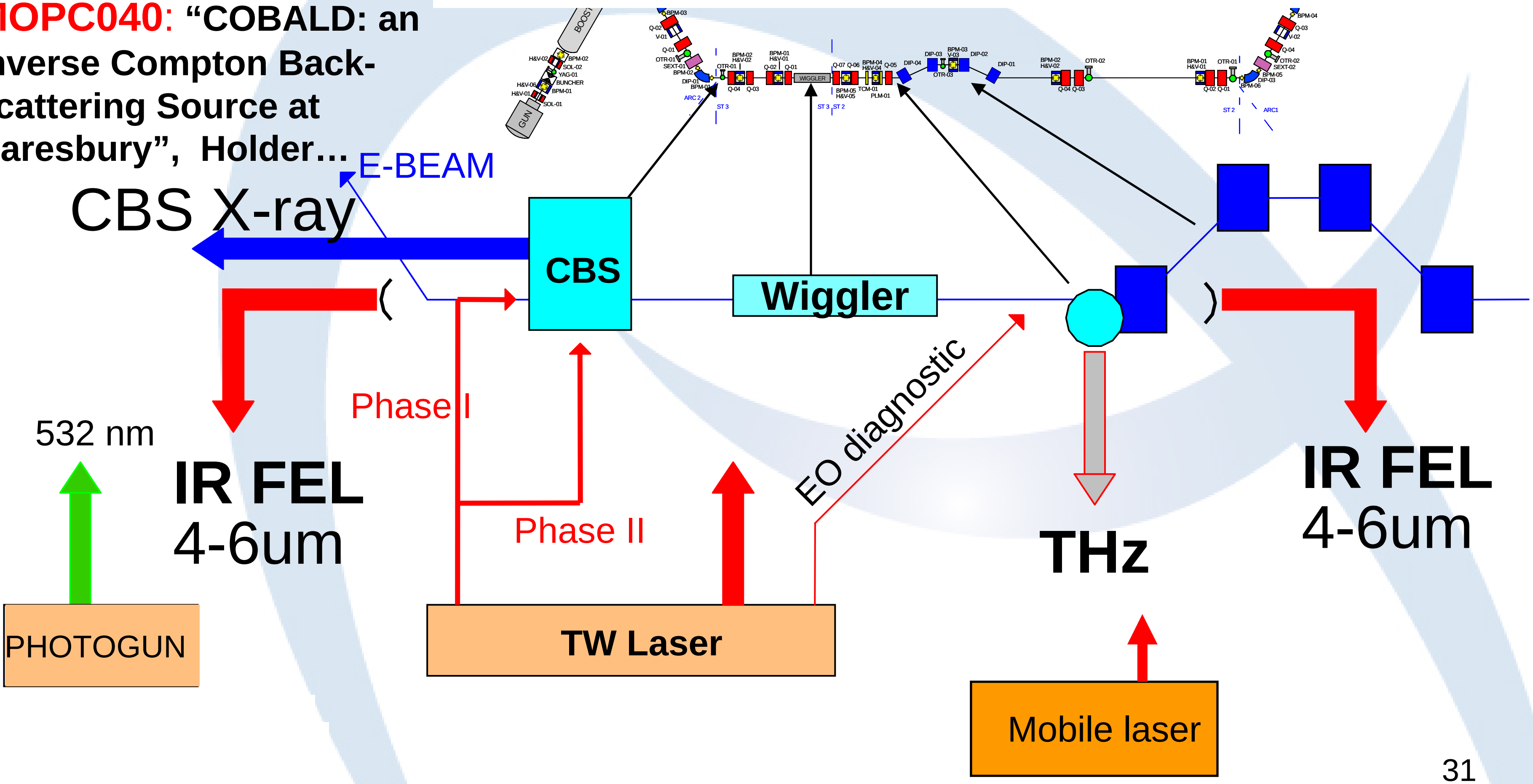
- EMMA – the first NS FFAG
- CBS X-ray source
- IR and THz research programme
- Tissue Culture Laboratory @ ALICE
- Exciting pump – probe research programme with all ALICE light sources:
  - TW laser (10TW, 100 / 35 fs, 10Hz)
  - IR FEL (~4mm, ~15MW peak, ~1ps, ~10mJ)
  - fs tunable laser
  - THz radiation (broadband)
  - CBS X-ray source (15-30keV, 10^7 – 10^8 photons/pulse, <1ps)
- Accelerator physics research
  - Photocathode research and testing (using the upgraded gun)


ERLP SCHEMATIC DIAGRAM
BOOSTER
GUN
LINAC
WIGGLER
E-BEAM
CBS X-ray
CBS
Wiggler
Phase I
Phase II
532 nm
IR FEL
4-6um
EO diagnostic
THz
IR FEL
4-6um
TW Laser
Mobile laser

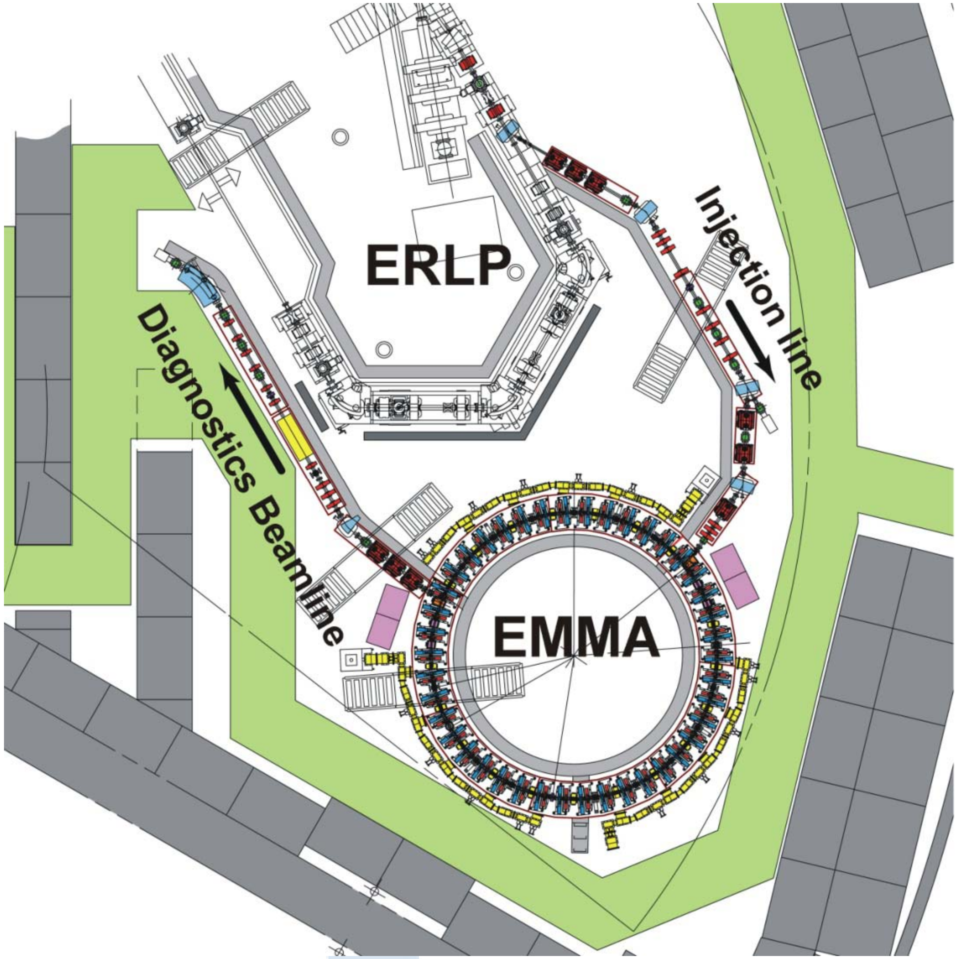
TUPC042: **“Limitations of Electro-optic Longitudinal Electron Bunch Length Measurements” Jamison…**

TUPP069: **“Measurements of the Complex Conductivity of Realistic Vacuum Vessels at THz Frequencies” Scott & Jamison**

MOPC040: **“COBALD: an Inverse Compton Back-scattering Source at Daresbury”, Holder…**



ALICE + EMMA = First NS FFAG



THPP004 "EMMA: the World's First Non-scaling FFAG" Edgecock….

Electron Machine with Many Applications

EMMA: Non Scaling Fixed Field Alternating Gradient Accelerator

Construction of a Non-scaling FFAG for Oncology, Research and Medicine = CONFORM Project
(Basic Technology grant ; international collaboration)

Why FFAG ?

- fast acceleration (e.g. muons)
- high power beam acceleration
- variable electron energy

Why Non Scaling ?

- compact beamline vacuum chamber
- hence, compact magnets

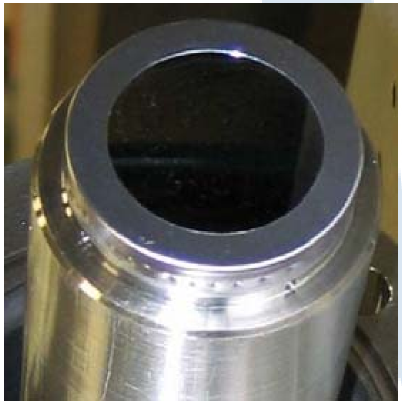
Applications :

- medical (oncology)
- muon acceleration
- Accelerator Driven Sub-critical Reactor (ADSR)

Photocathode Research

Emphasis on GaAs type of the photocathodes (inc GaAsP)

- Photocathode structures for
  - fast response time
  - low energy spread (hence low thermal emittance)
  - low field emission
- Preparation procedures for high QE, high lifetime and low field emission
- Experiments with Positive Electron Affinity photocathodes
  - faster response time
- Photocathode tests on the Photocathode Testing Facility at DL
- Response time measurements (@ University of Mainz)
- Cathode testing and beam characterisation in situ (@ ALICE)
- - enabled by the photogun upgrade



Potential collaborations:

- TJNAF
- Institute of Semiconductor Physics, Novosibirsk
- University of Mainz
- Florida State University (Big Light)

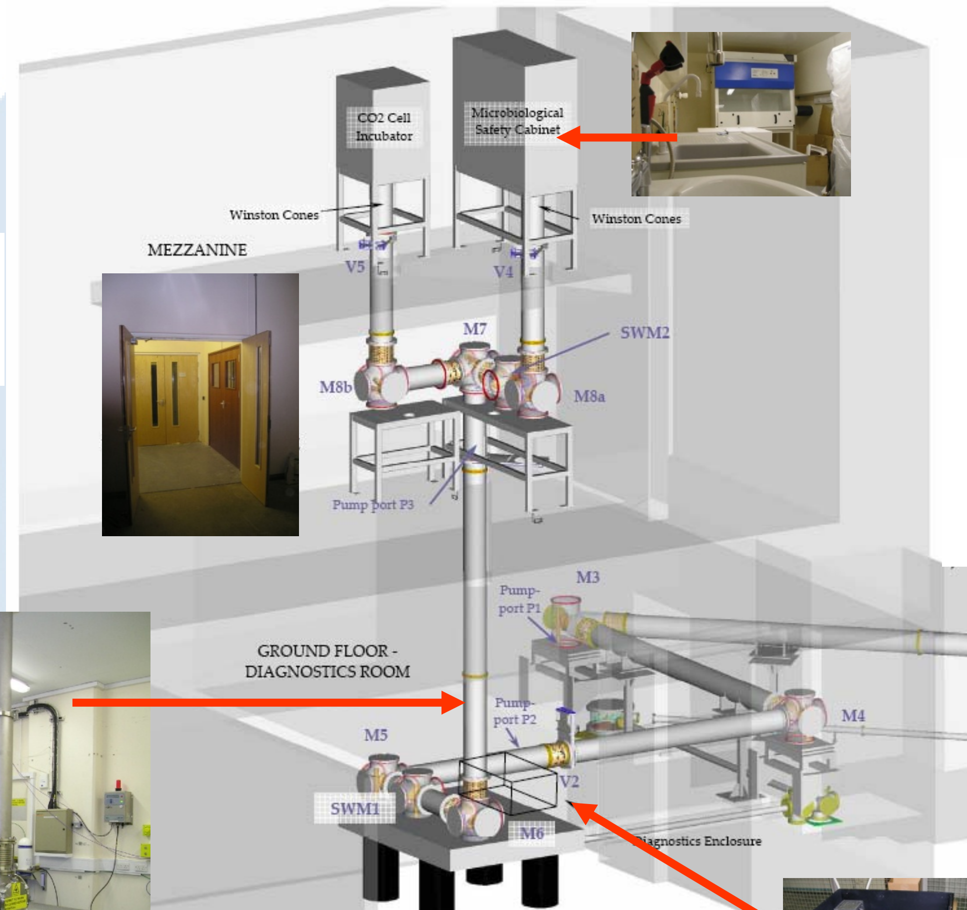
Alice
Accelerators and Lasers In Combined Experiments

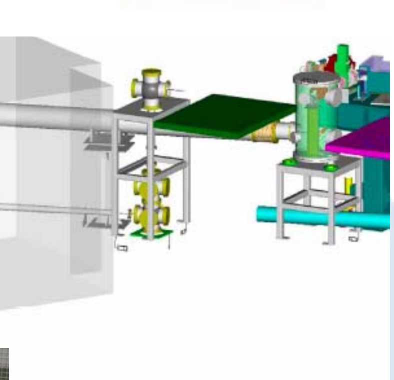
THz Programme & Tissue Culture Facility

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

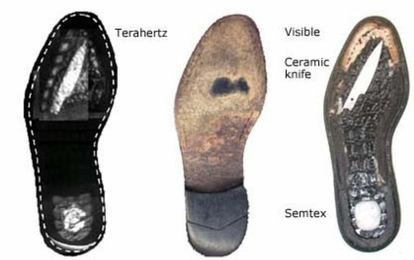
Weightman et al
University of Liverpool
University of Nottingham

Northwest
REGIONAL DEVELOPMENT AGENCY





THz has important role in security screening



TeraView

Summary

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

Credits

Credits

- My Co-authors
  - Radiofrequency etc.: Peter McIntosh
  - Cryogenics: Andy Goulden
  - Injector commissioning: Yuri Saveliev, David Holder
- The Rest of the ALICE Technical Team
  - Controls: Brian Martlew et al
  - Vacuum: Tom Weston & Keith Middleman et al
  - Installation engineering: Phill Atkinson et al
  - Mechanical engineering: Neil Bliss et al
  - Electrical engineering: Steve Griffiths et al
  - Diagnostics: Rob Smith et al
  - FEL: Jim Clarke et al
  - Compton Back Scatter: Gerd Preibe et al
  - THz Science: Mark Surman et al
  - Running, Safety: Cheryl Hodgkinson et al
  - Photoinjector laser: Steve Jamison & Graeme Hirst et al
  - Elaine Seddon, Mike Poole and Paul Quinn

Last but not least…

- Our international collaborators including
  - J Lab (George Neil, Fay Hannon, Kevin Jordon, Carlos Hernandez Garcia, Tom Powers et. al.
  - FZD Rossendorf (Peter Michel, Frank Gabriel et. al.)
  - Cornell (Bruce Dunham)
  - Stanford University (Todd Smith)
  - Institute of Semiconductor Physics, Novosibirsk (Alex Terekhov)
  - The 4GLS advisory committee
- The ALICE Commissioning Teams

  For the nights, evenings and weekends given. So far!!
  - The key commissioning team
  - The RF commissioning team
  - The Cryogenics commissioning team

Thanks for listening!

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- **MOPC033: "Sapphire – An Ultra-fast High Peak Brightness X-Ray Source as a Possible Option for a Next Generation UK Light Source", Walker et al.**
- **MOPC062: "Results from ALICE (ERLP) DC Photoinjector Gun Commissioning", Saveliev et al.**
- **MOPC063: "Electron Bunches from the ALICE DC Photoinjector Gun at Two Different Laser Pulse Lengths", Saveliev et al.**
- **MOPC073: "Design of an Upgrade to the ALICE Photocathode Electron Gun", Militsyn et al.**
- **MOPP141: "Commissioning of the ERLP SRF Systems at Daresbury Laboratory", P McIntosh et al.**
- **TUPP069: "Measurements of the Complex Conductivity of Realistic Vacuum Vessels at THz Frequencies", Scott and Jamison**
- **TUPC042: "Limitations of Electro-optic Longitudinal Electron Bunch Length Measurements" Jamison et al.**
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