Alice
Accelerators and Lasers
In Combined Experiments

LINAC

First Results from the ERL Prototype (ALICE) at Daresbury

David Holder, on behalf of the ALICE team.

LINAC'08 Victoria, BC

Science & Technology Facilities Council
Daresbury Laboratory

The Cockcroft Institute
of Accelerator Science and Technology

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- **Introduction:**
  - **New Name**
  - **ALICE & EMMA Layout**
- Overview of Gun Commissioning
- Cryogenics, Superconducting Modules & RF System Status
- Next Steps
- Summary
- Credits

New Name

ERLP (Energy Recovery Linac Prototype)

- conceived as a prototype of an energy recovery-based 4th generation light source…

now called…

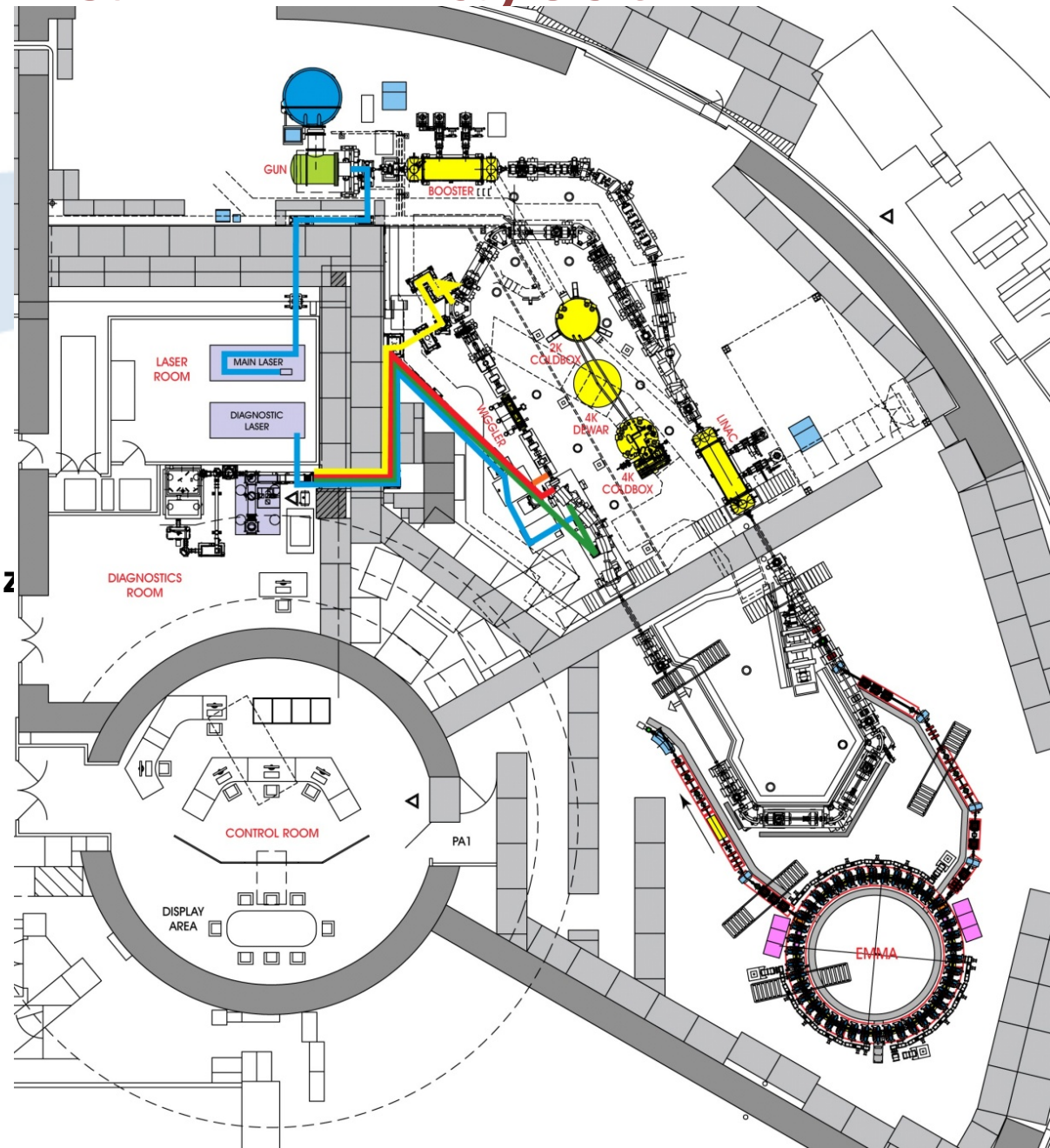
ALICE (Accelerators and Lasers In Combined Experiments)

- An R&D facility dedicated to accelerator science and technology development;
- Offering a unique combination of accelerator, laser and free-electron laser sources;
- Enables studies of photon beam combination techniques;
- Provides a suite of photon sources for scientific exploitation.

No, not THAT ALICE…

ALICE & EMMA Layout

- **Nominal Gun Energy** **350 keV**
- **Injector Energy** **8.35 MeV**
- **Beam Energy** **35 MeV**
- **RF Frequency** **1.3 GHz**
- **Bunch Rep Rate** **81.25 MHz**
- **Nom Bunch Charge** **80 pC**
- **Average Current** **6.5 mA**
(over the 100 µs bunch train)



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- Introduction
- **Overview of Gun Commissioning**
  - **Photoinjector**
  - **Gun Problems**
  - **Gun Diagnostic Layout**
  - **Gun Commissioning Results**
  - **Gun Commissioning Summary**
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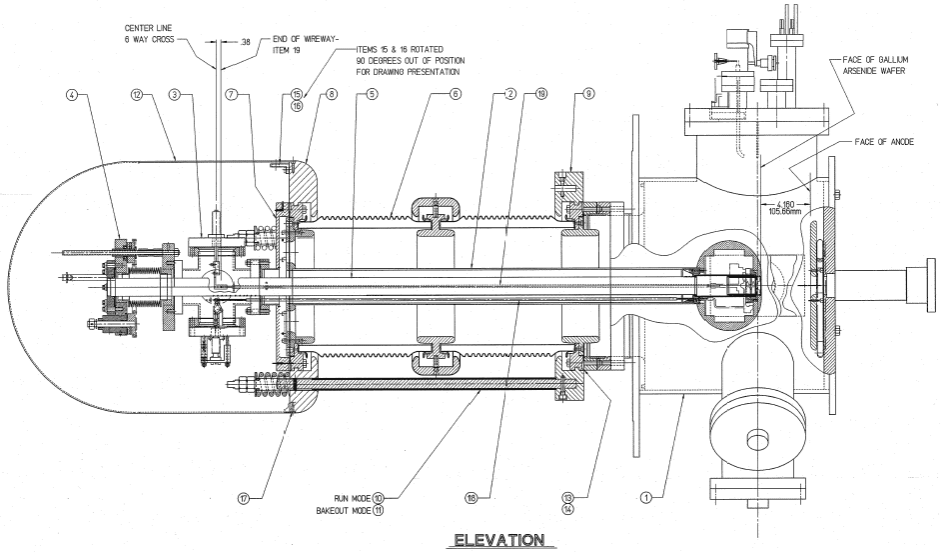
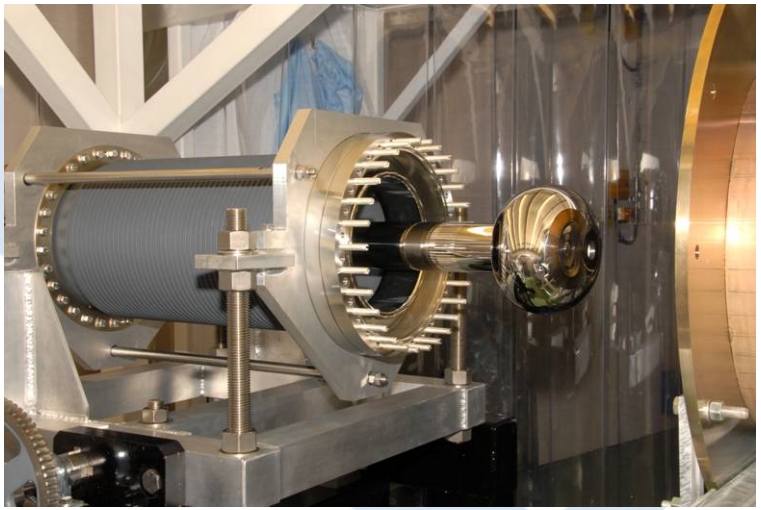
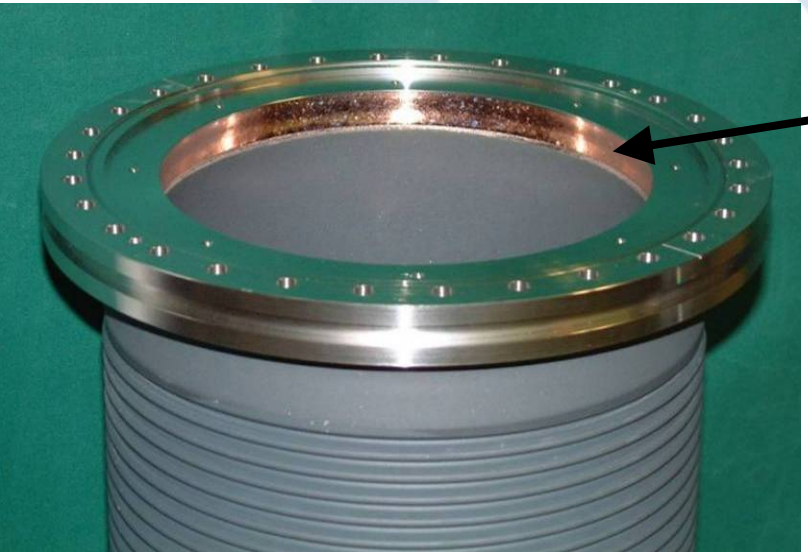
Photoinjector





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

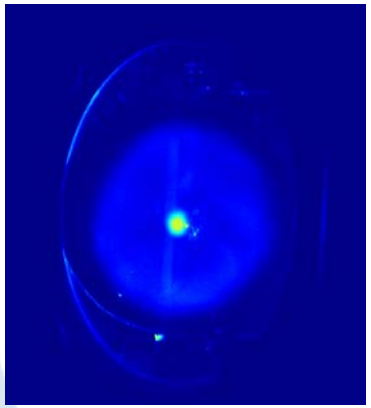


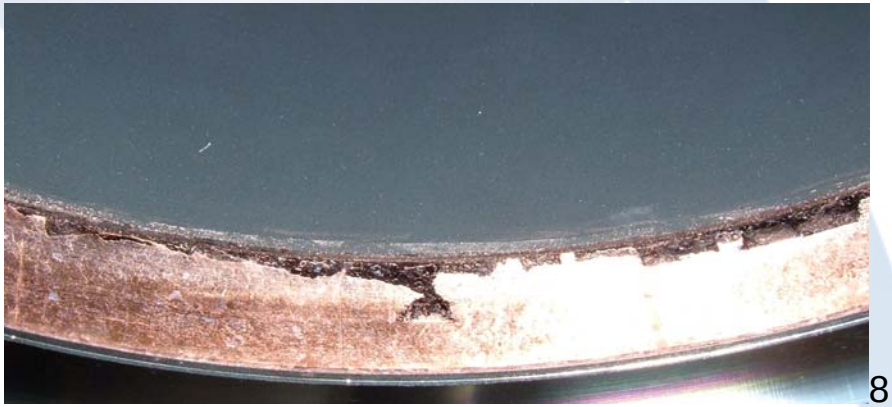
Copper brazed joint

(First electrons August 2006)

Gun Problems

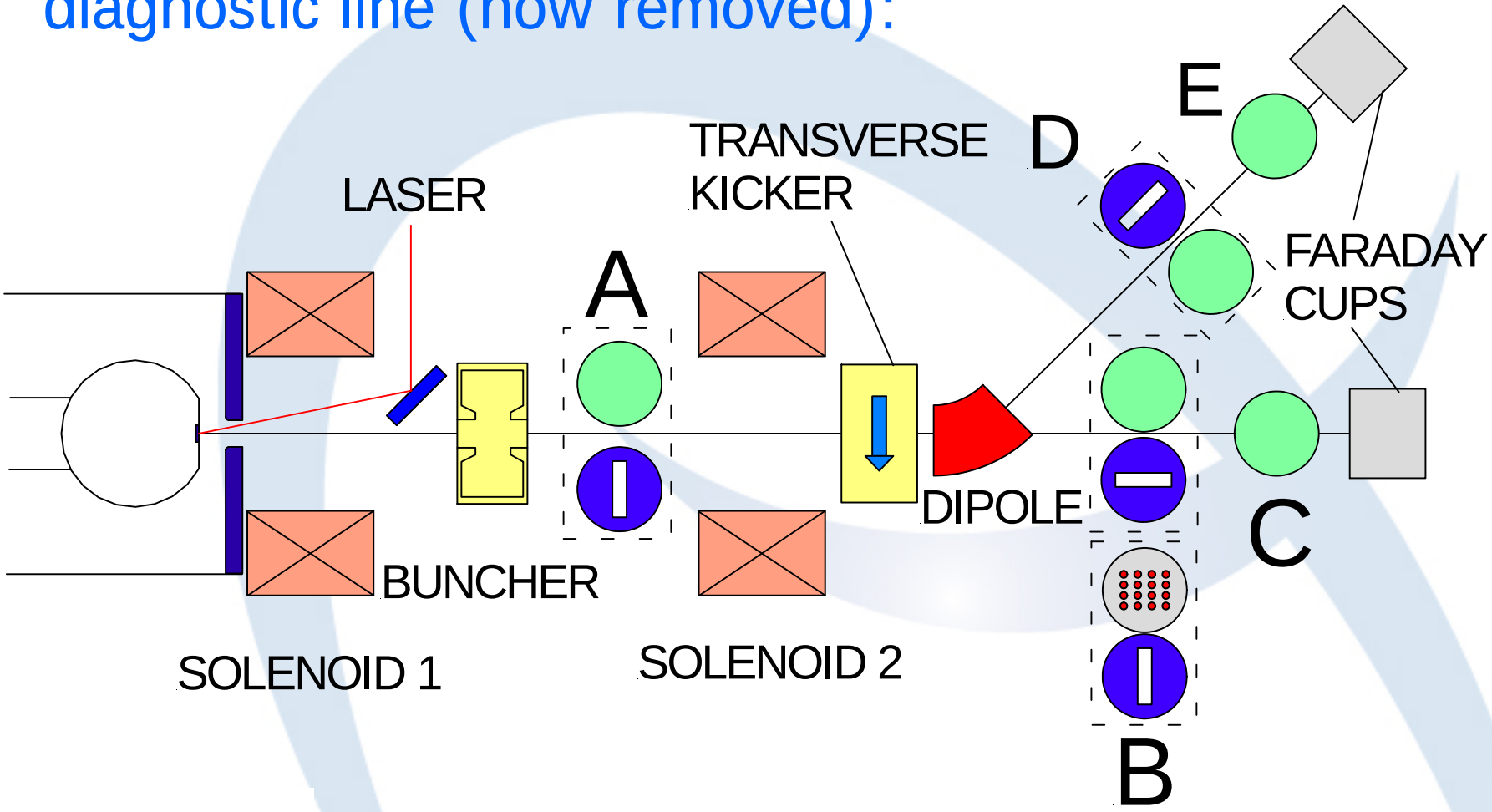
- High voltage breakdown problems after cathode caesiation and from braze disintegration;
- Vacuum failures during bake-out of large diameter flange seals, feedthrough, valve and braze (again!);
- Contamination (caesium again?) and hydrocarbons;
  - impaired XHV conditions, field emission, halo, poor cathode lifetime.





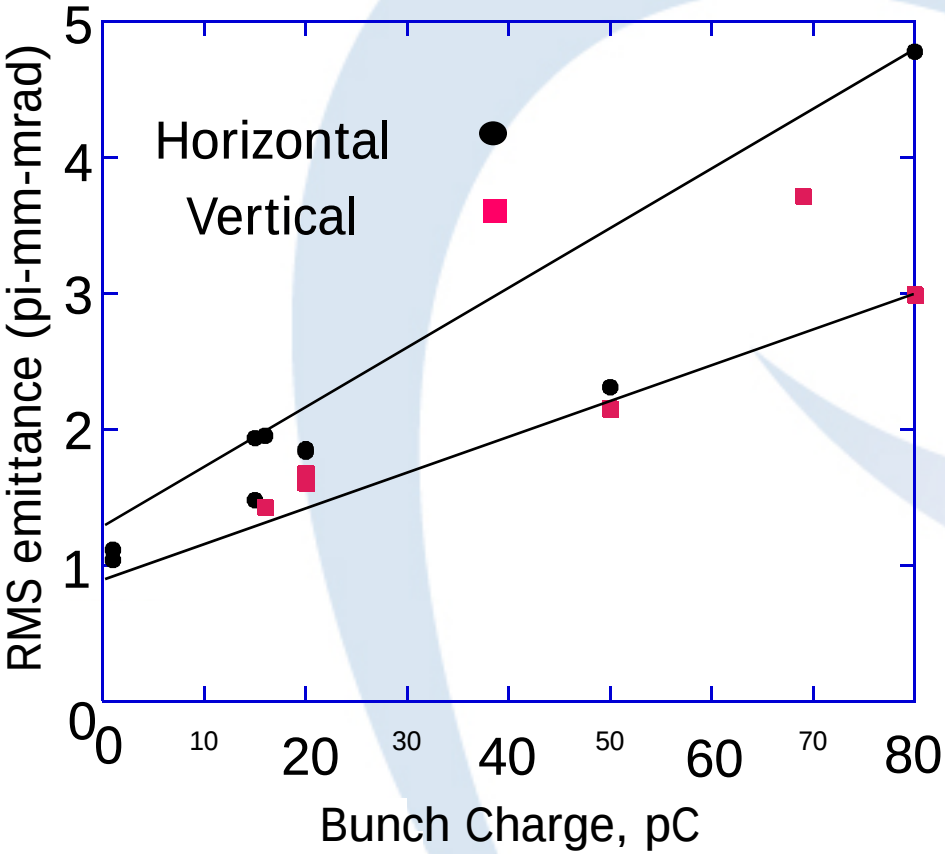
Gun Diagnostic Layout

Injector commissioned with dedicated diagnostic line (now removed):

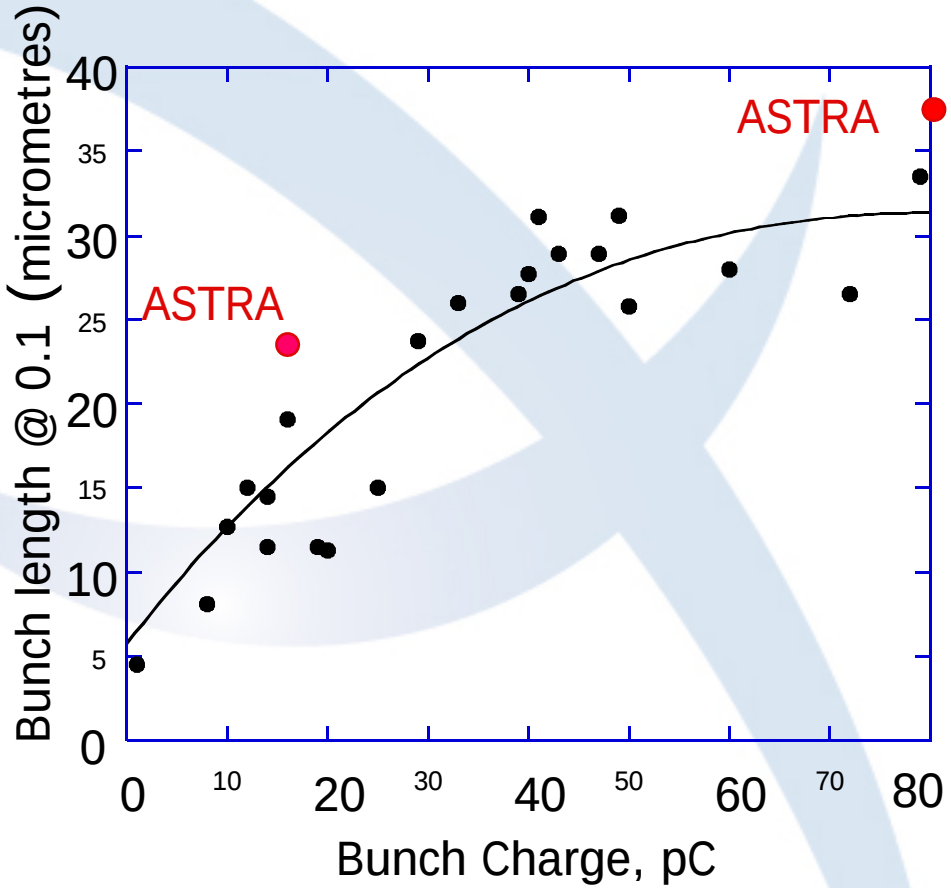


Gun Commissioning Results (1 of 3)

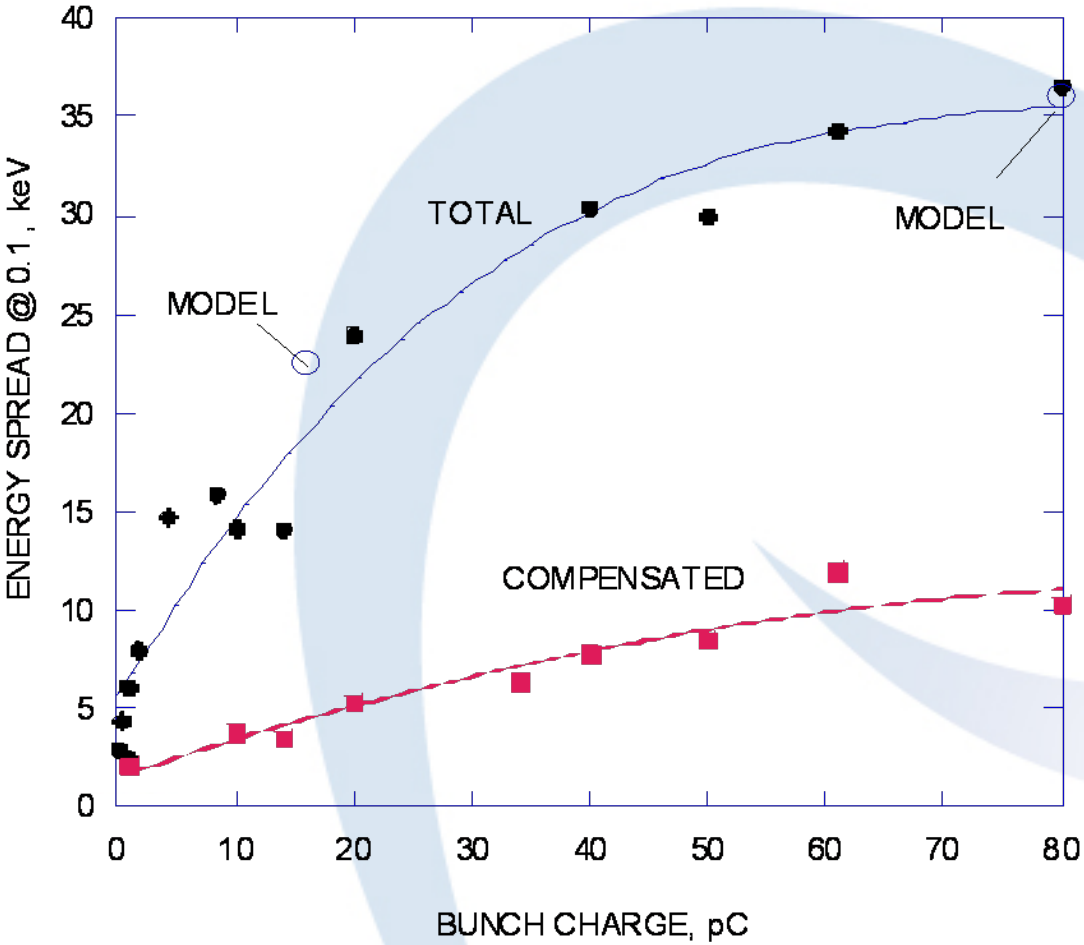
RMS emittance vs. bunch charge



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



Gun Commissioning Results (2 of 3)

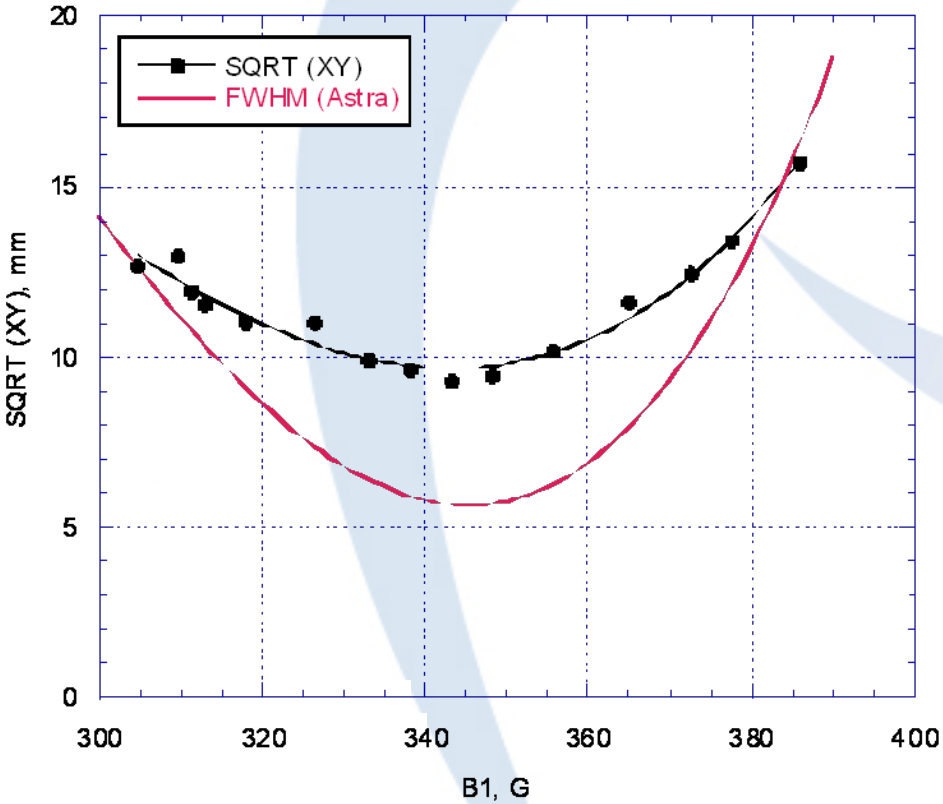


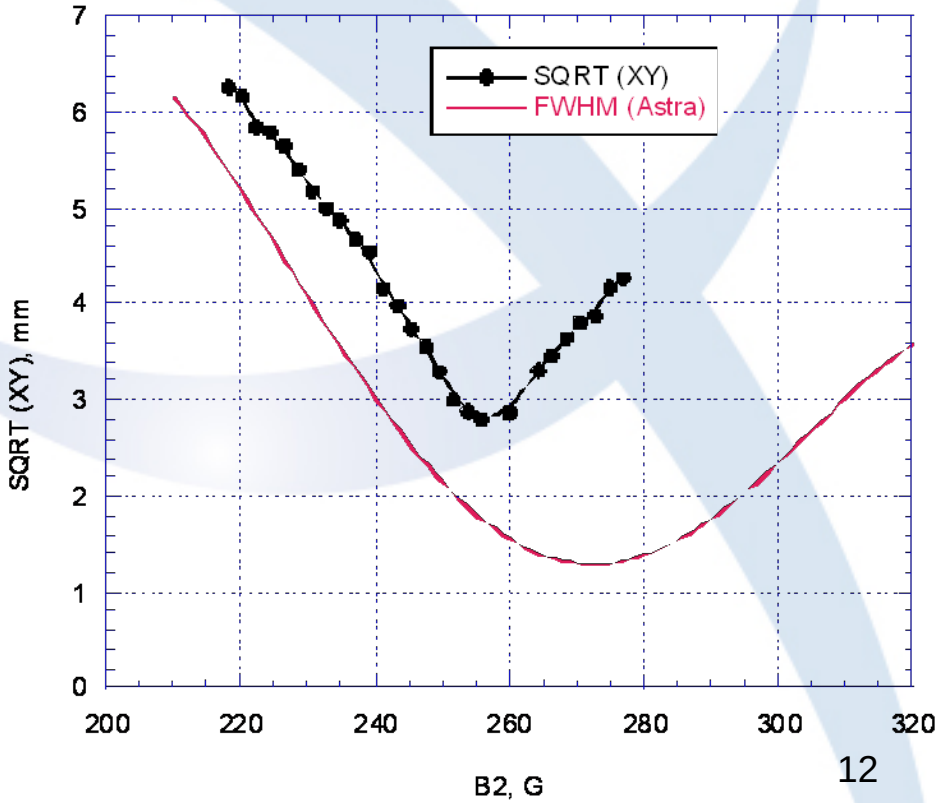
Energy spread (at 10% of peak value) vs. bunch charge

Compensated = buncher ON

Gun Commissioning Results (3 of 3)

Beam size vs. solenoid 1 & 2 current, at Q=54 pC, compared to ASTRA model





Gun Commissioning Summary

- Results:
  - The gun can now be routinely **HV conditioned** to **450kV**;
  - **QE above ~3%** is normally achieved after cathode activations (bunch charges of well above 100pC have been achieved);
  - The beam was **fully characterised** (emittance, bunch length, etc.) for bunch charges between 1 to 80pC;
  - A **good agreement** between the ASTRA simulations and the experimental data was found for 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**;
  - The importance of a smooth longitudinal laser profile 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 with QE >1.5%;
  - Resolve transverse emittance discrepancy (FE? QE non-uniformity?)

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- Overview of Gun Commissioning
- **Cryogenics, Superconducting Modules & RF System Status:**
  - **Cryosystem Commissioning**
  - **Booster Module & RF Layout**
  - **Module Commissioning Results**
  - **Field Emission Radiation Issue**
  - **Mitigating Strategies**
- Next Steps
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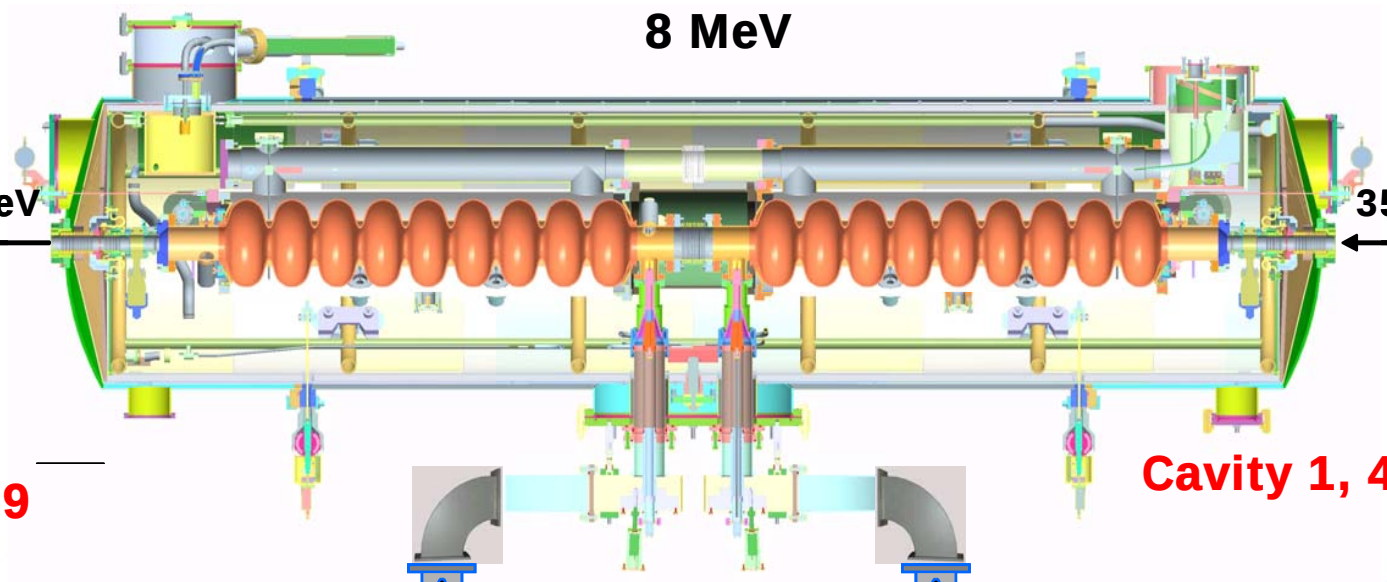
Cryosystem Commissioning

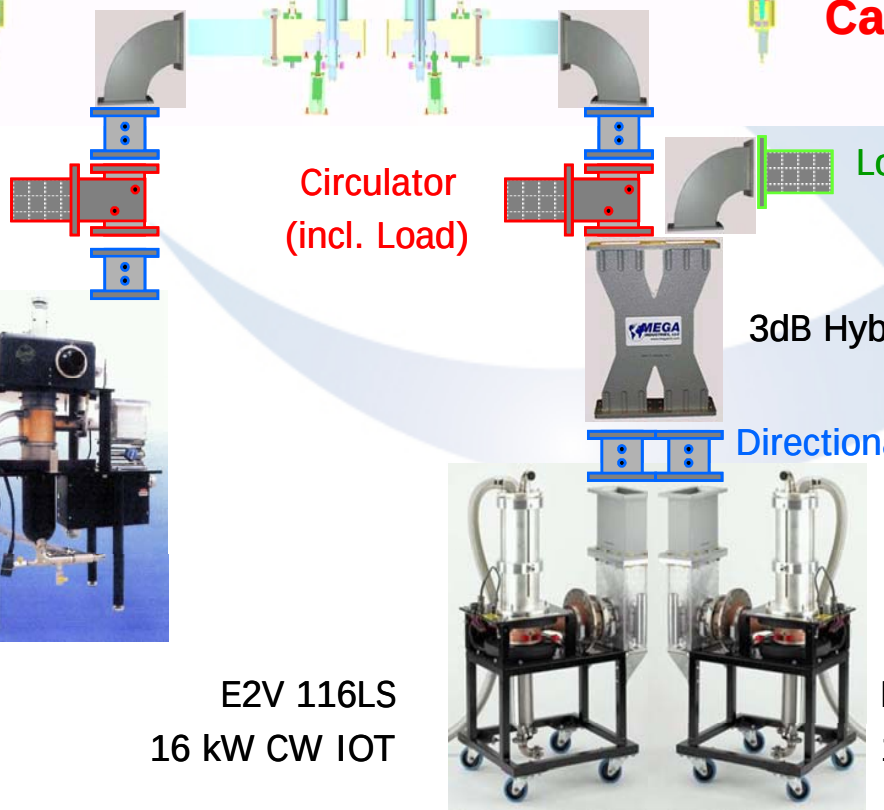
- Partial system procured from Linde;
- 4 K commissioning completed May 06;
- SRF Module delivery April and July 06;
- Problems with excessive system heat leaks (lack of capacity) and heater failure;
- Cryosystem output:
  - Specification 118 W at 2 K with 1 mbar stability;
  - Measured 118 W at 2 K with $\pm$ 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 further optimisation.

Booster Module & RF Layout



Cavity 2, 2.9 MV/m

Cavity 1, 4.8 MV/m



Module Commissioning Results

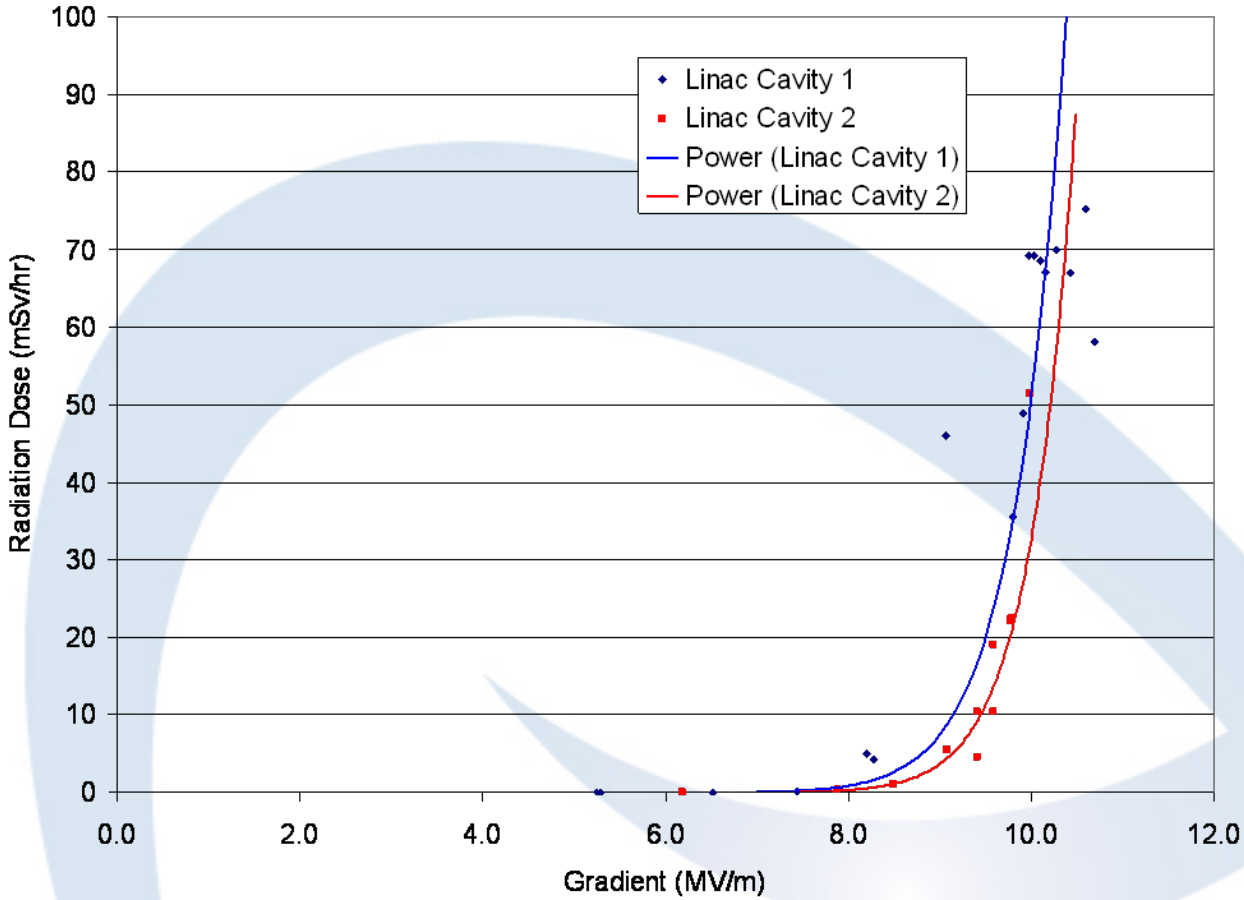
Vertical Tests at DESY (Jul – Dec 2005)

	Booster		Linac	
	Cavity 1	Cavity 2	Cavity 1	Cavity 2
E_{acc} (MV/m)	18.9	20.8	17.1	20.4
Q_o	5×10^9	5×10^9	5×10^9	5×10^9

Module Acceptance Tests at Daresbury (May – Sept 2007)

Max E_{acc} (MV/m)	10.8	13.5	16.4	12.8
Q_o	3.5×10^9 @ 8.2 MV/m	1.3×10^9 @ 11 MV/m	1.9×10^9 @ 14.8 MV/m	7.0×10^9 @ 9.8 MV/m
Limitation	FE Quench	FE Quench	RF Power	FE Quench

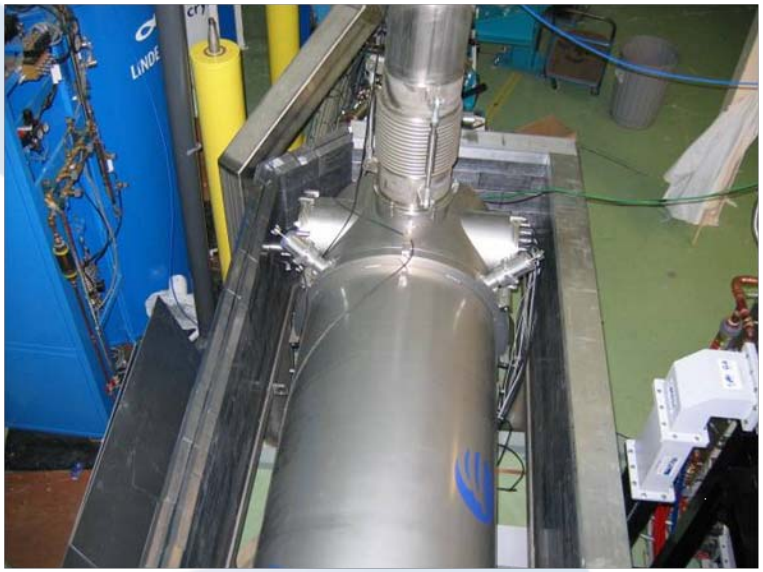
Field Emission Radiation Issue



- At 9 MV/m (c.f. required value of 13.5), radiation monitor in linac LLRF rack goes into saturation.
- Predicted electronics lifetime only around 1000 hrs.

Mitigating Strategies

- Lead shielding installed around linac;
- New linac module (collaborative design);
- Further aggressive processing:



  - Over longer conditioning periods;
  - Varying frequency, pulse width and pulse repetition rate;
  - CW conditioning (only possible at lower power levels);
  - Possibly condition the cavity when warm;
  - Introduce helium into the vacuum (risky!)

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;
- High levels of FE radiation measured and mitigating strategies implemented.

		Maximum measured	**Required**	
Booster	Cavity 1	10.8	4.8	MV/m
	Cavity 2	13.5	2.9	MV/m
Linac	Cavity 1	16.4	13.5	MV/m
	Cavity 2	12.8	13.5	MV/m

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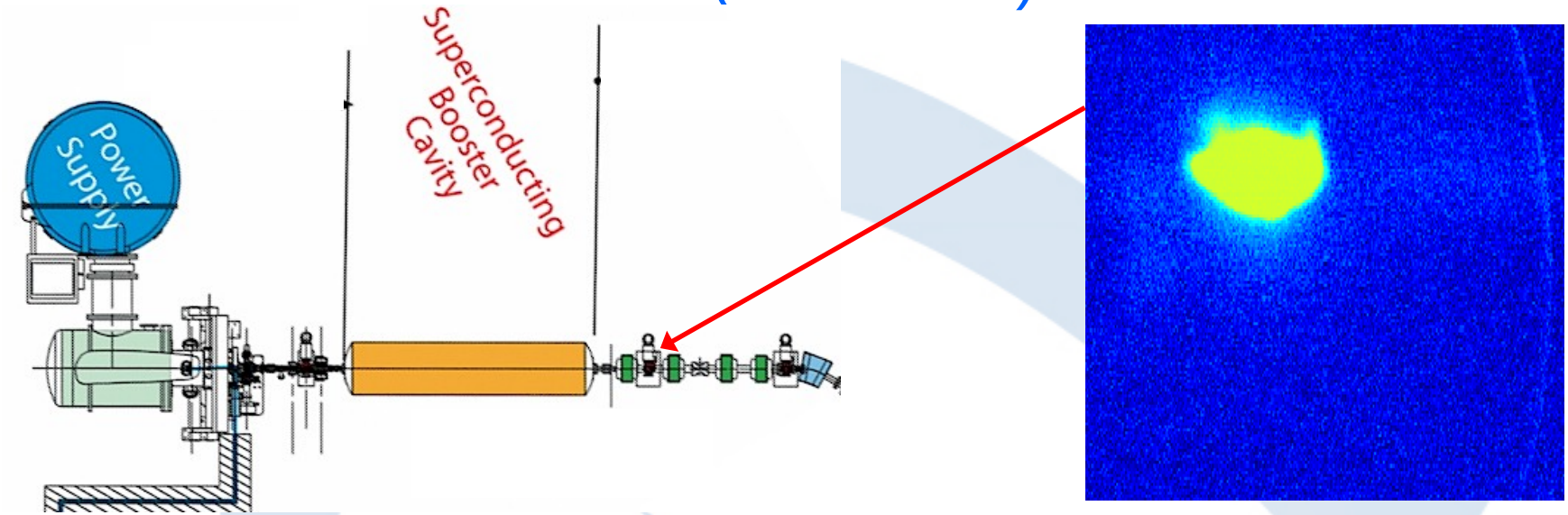
- **Next Steps:**
  - **Accelerator (short term)**
  - **Science Programme**
  - **Accelerator Developments**
  - **EMMA**
- Summary
- Credits

Accelerator Plan (original)

- First energy recovery (Fall 2008):
  - Without FEL, installation planned Spring 2009;
- Fine tuning:
  - Injector tuning for minimum 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!
  - Energy recovery of a disrupted beam.
- Then the fun really starts…

Revised schedule (October)

- First accelerated beam (~4.35 MeV) 24th October 2008:



- Shutdown 25th October – end November:
  - Power off, cryogenics work, installation of CBS components;
- First energy recovery (December 2008):
  - Without FEL.

Revised schedule (October)

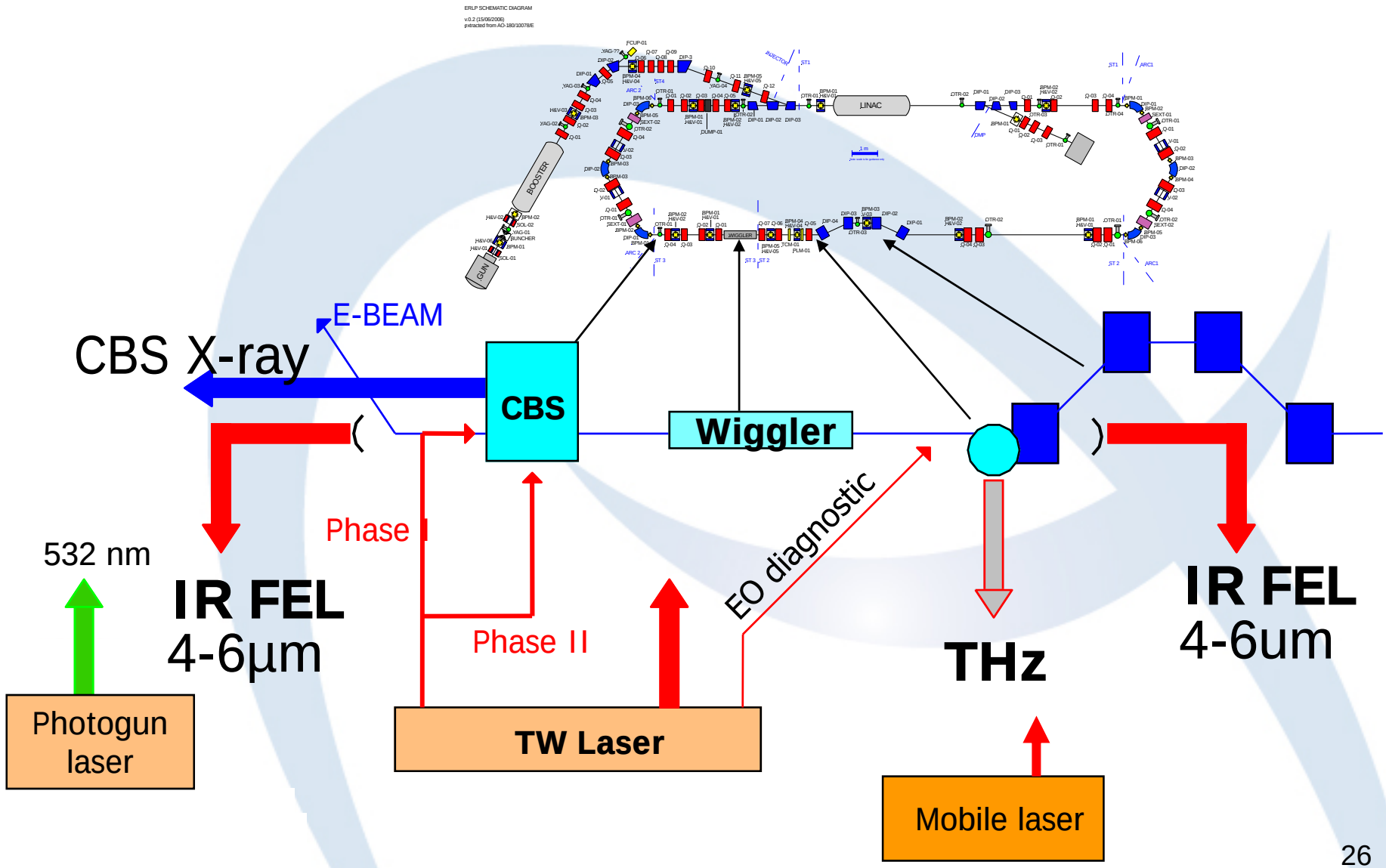
- Fine tuning:
  - Injector tuning for minimum emittance;
  - Optimisation of energy recovery at nominal beam parameters;
  - Beam diagnostics;
- Short pulse commissioning stage:
  - Longitudinal dynamics, electro-optical diagnostic studies;
- FEL installation planned early 2009;
- Energy recovery with FEL (2009):
  - First light!
  - Energy recovery of a disrupted beam.
- Then the fun really starts…

Science Programme

IR FEL, CBS x-ray source and terahertz radiation research programme, including pump–probe research programme with all ALICE light sources:

- Terawatt laser (~10TW, 100 / 35 fs, 10Hz);
- Infrared FEL (~4µm, ~15MW peak, ~1ps, ~10mJ);
- Femptosecond tunable laser;
- Terahertz radiation (broadband);
- CBS x-ray source (15-30keV, 10^7 – 10^8 photons/pulse, <1ps);
- Tissue Culture Laboratory (TCL).

Science Programme



Accelerator Developments

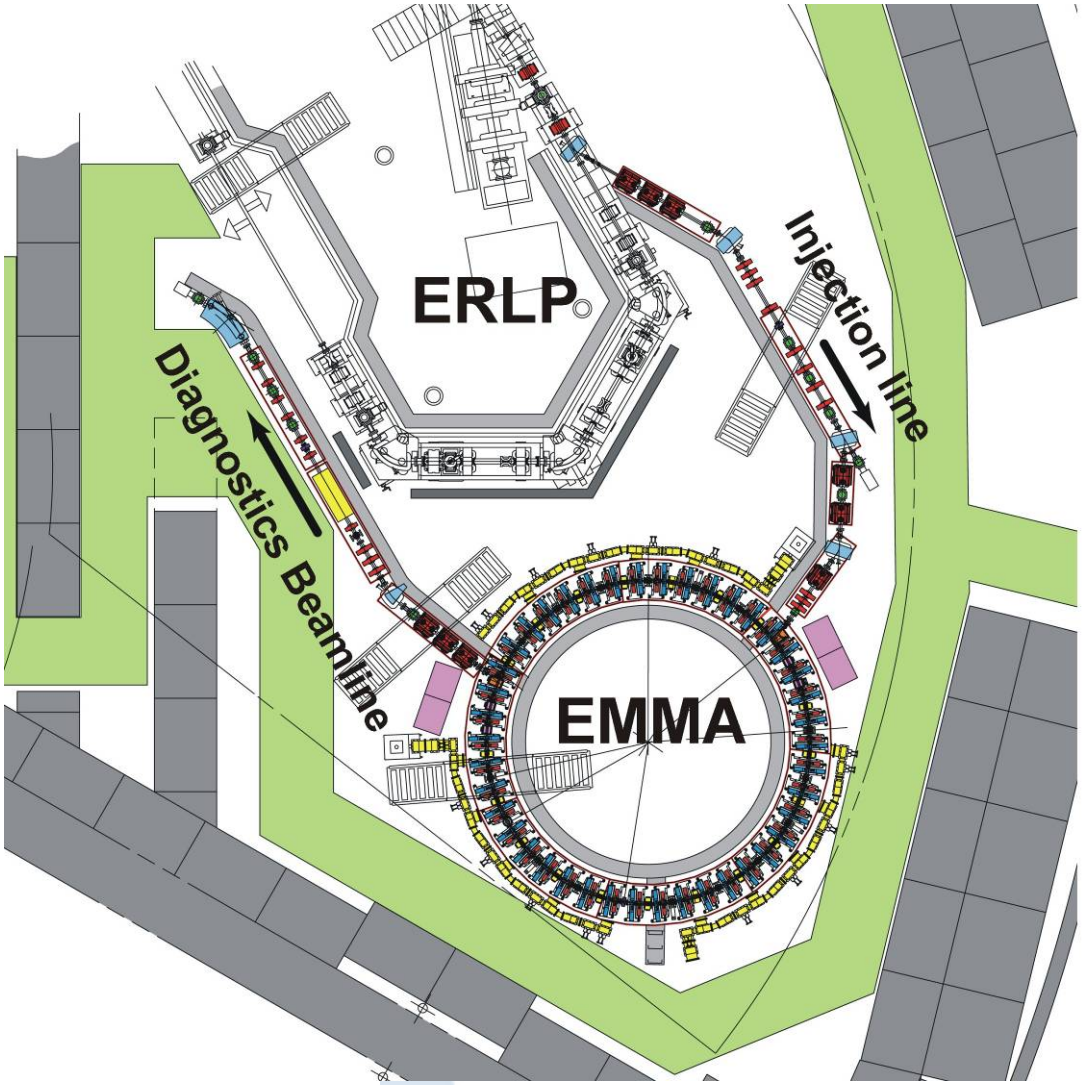
- Accelerator physics research:
  - Photocathode research and testing (upgraded load-lock system for cathode exchange & activation);
  - New linac module;
  - Re-establishment of gun diagnostic line.

- EMMA - Electron Machine with Many Applications:
  - Non-scaling fixed field alternating gradient accelerator;

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

Why Non-Scaling ?
- compact beamline vacuum chamber
- hence, compact magnets

EMMA



Applications :

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

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Summary

- Accelerator commissioning has now reached a critical stage;
- ALICE has provided the UK with an opportunity to develop generic technologies and skills important for the delivery of advanced accelerator-driven facilities, including:
  - Photoinjector, SCRF, cryogenics, diagnostics, synchronisation 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.

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Credits

- The ALICE technical team:
  - Controls: Brian Martlew et al.
  - Vacuum: Tom Weston & Keith Middleman et al.
  - Installation engineering: Phil 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: Stephen Hill et al.
  - Photoinjector laser: Steve Jamison & Graeme Hirst et al.
  - Elaine Seddon, Mike Poole and Paul Quinn
- 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)

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Thanks for listening

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Daresbury Laboratory

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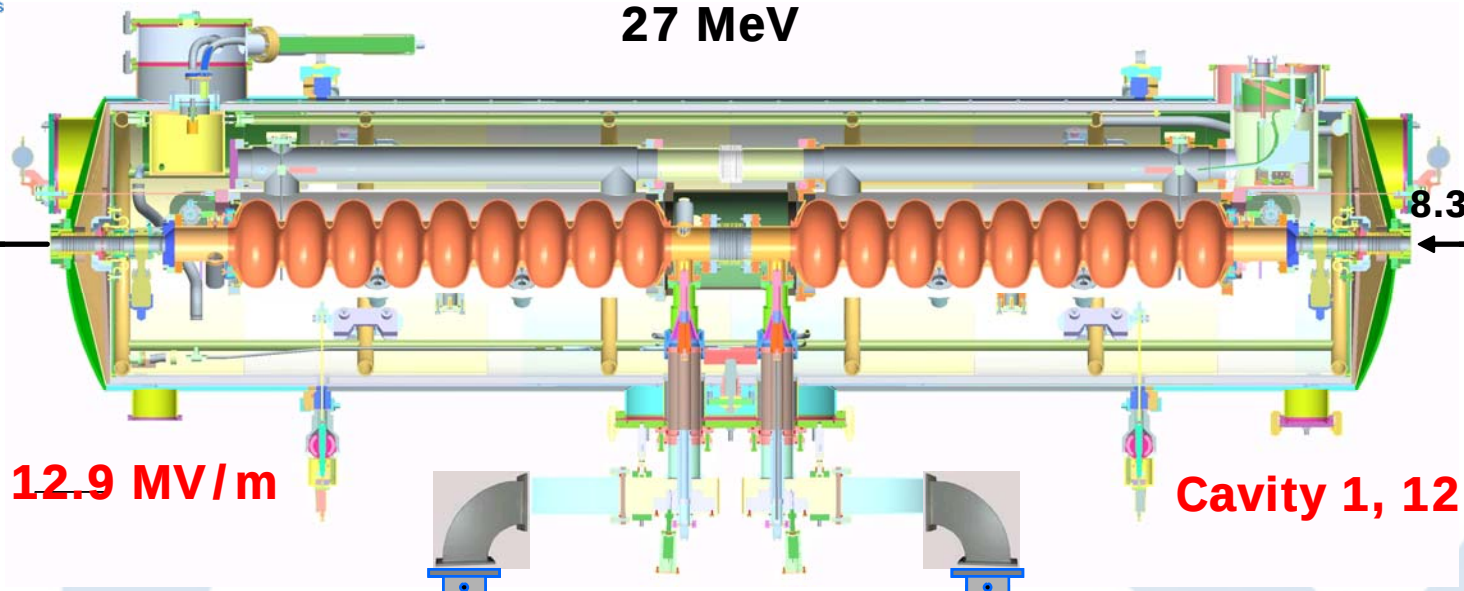
Spare slides

Linac layout



Circulator (incl. Load)

Directional Coupler

Thales TH713
20 kW CW IOT

E2V 116LS
16 kW CW IOT