

First Results from the ERL Prototype (ALICE) at Daresbury

David Holder, on behalf of the ALICE team.

LINAC'08 Victoria, BC

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- Introduction
- Overview of Gun Commissioning
- Cryogenics, Superconducting Modules & RF System Status
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- Credits

- **Introduction:**

- **New Name**
- **ALICE & EMMA Layout**

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New Name

ERLP (Energy Recovery Linac Prototype)

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

now called...

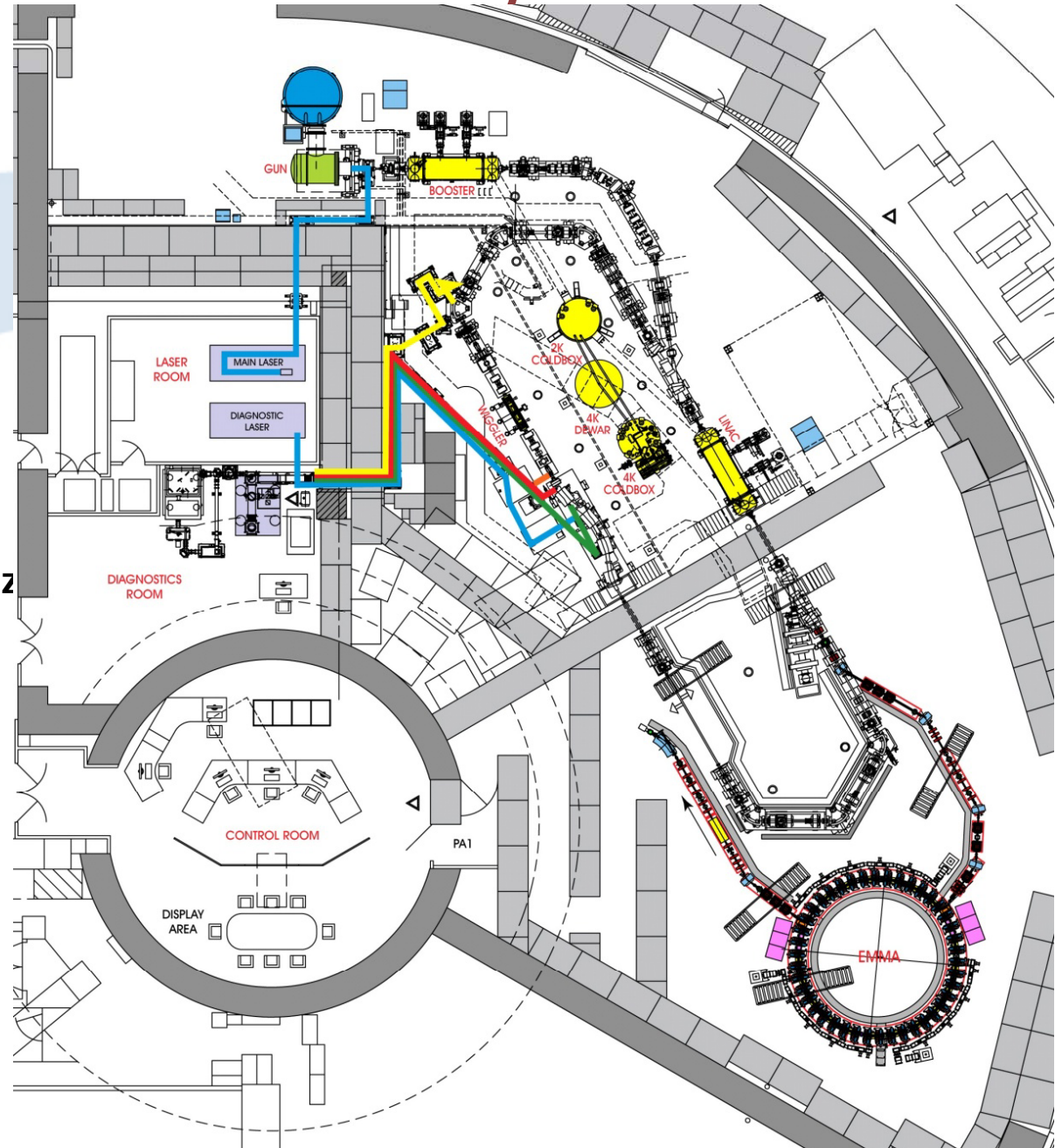
ALICE (Accelerators and Lasers In Combined Experiments)

- 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...

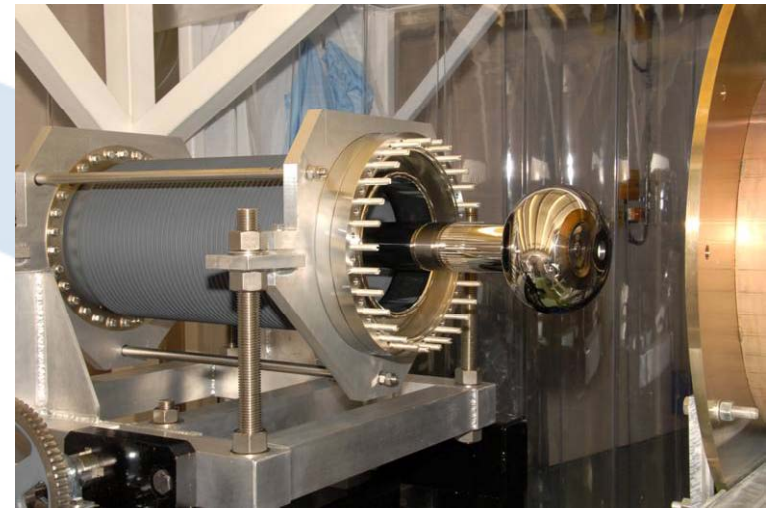
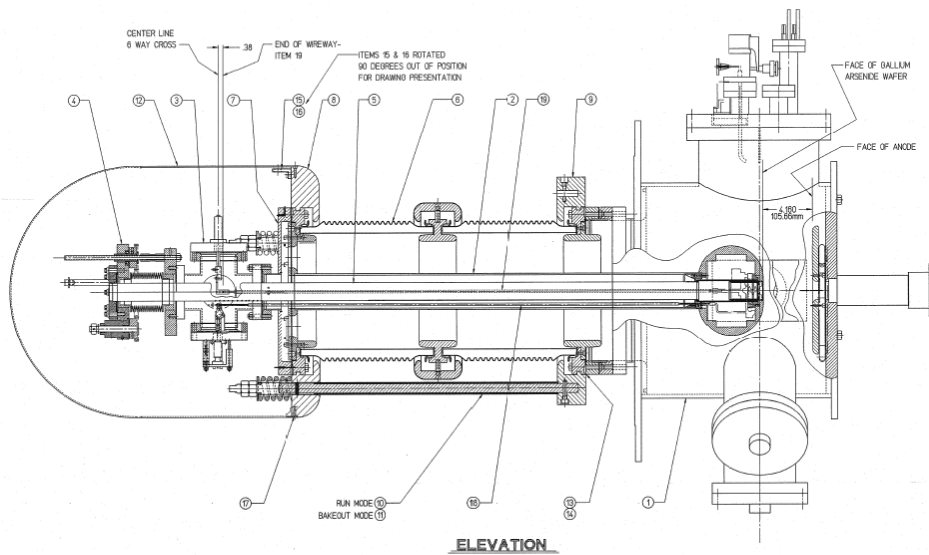
ALICE & EMMA Layout

- 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 μ s bunch train)



- 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)



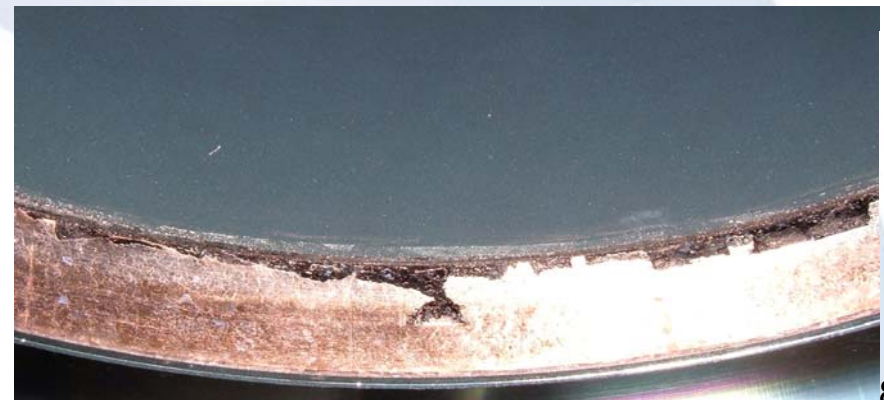
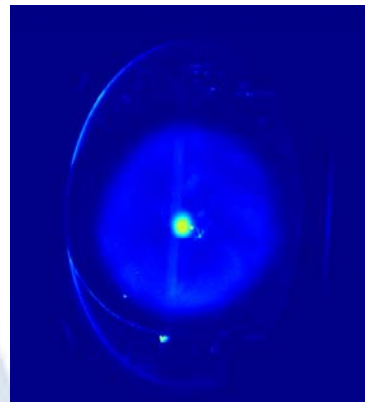
Copper brazed joint

(First electrons
August 2006)



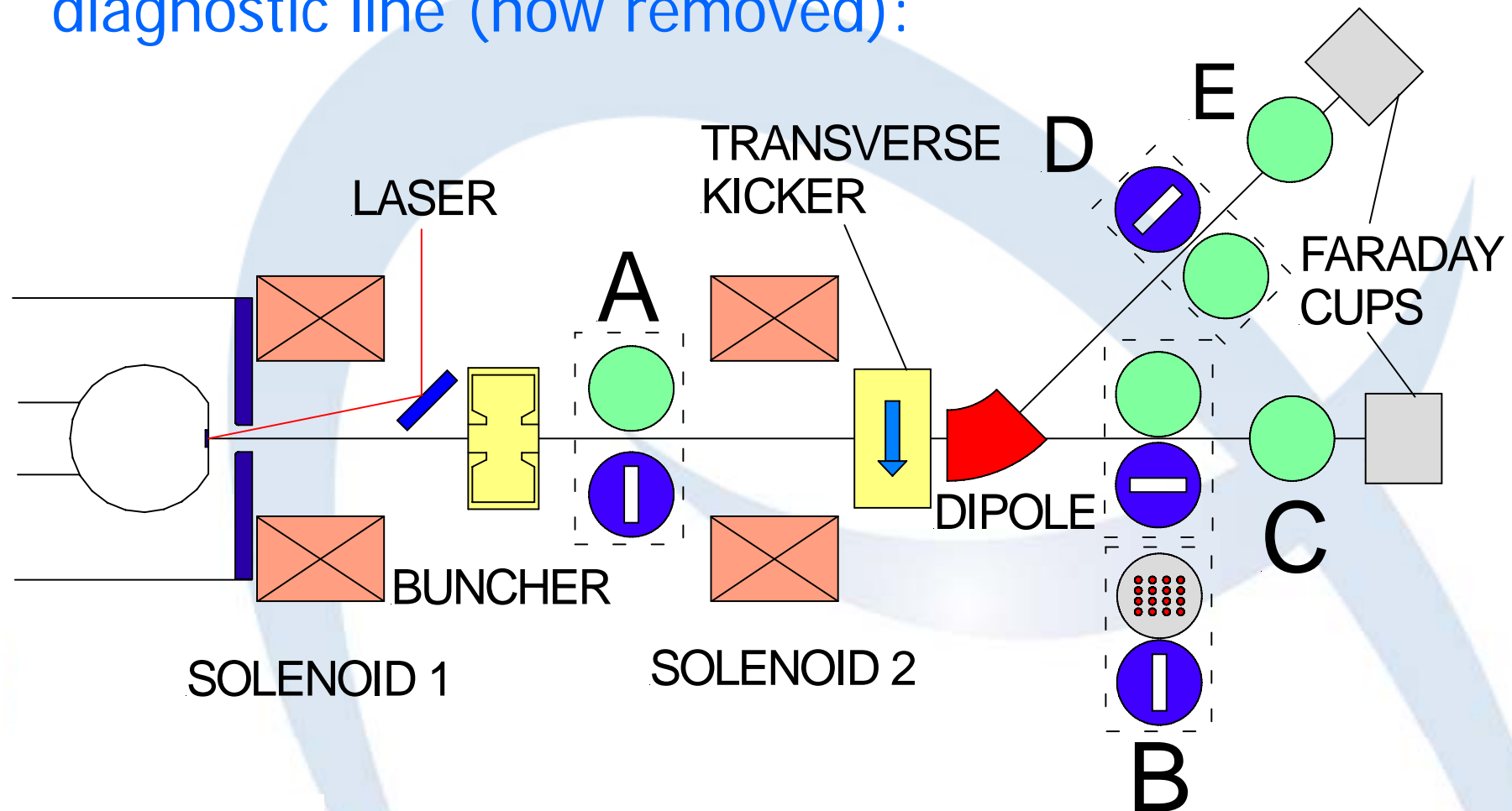
Gun Problems

- 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.



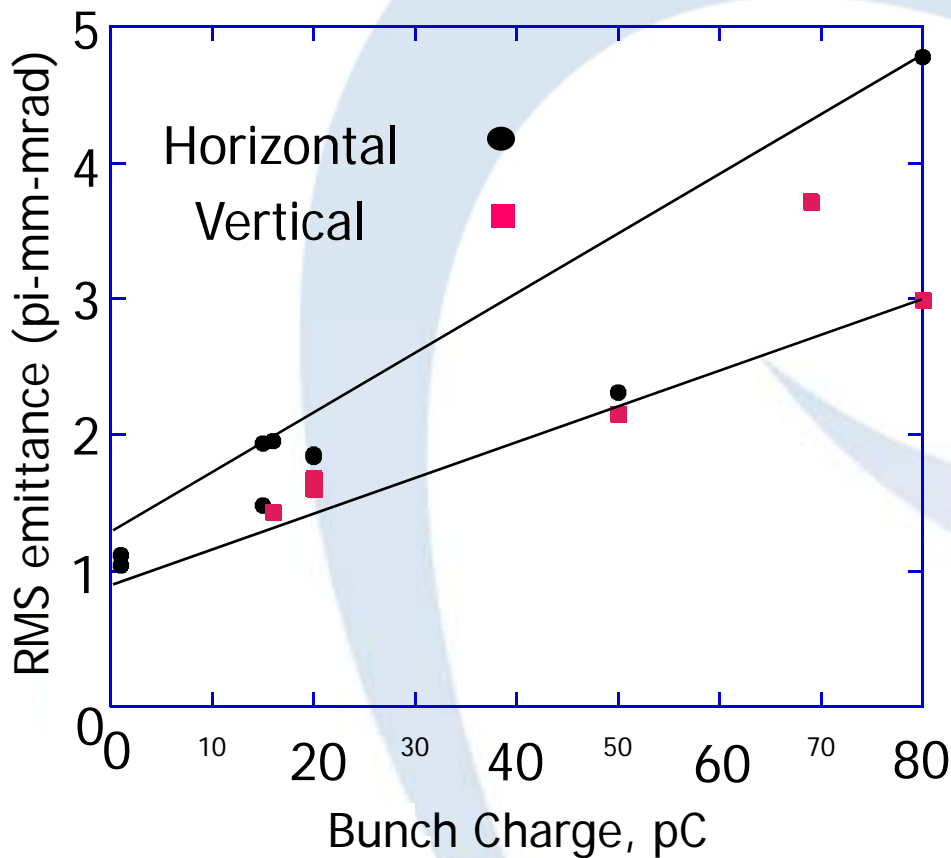
Gun Diagnostic Layout

Injector commissioned with dedicated diagnostic line (now removed):

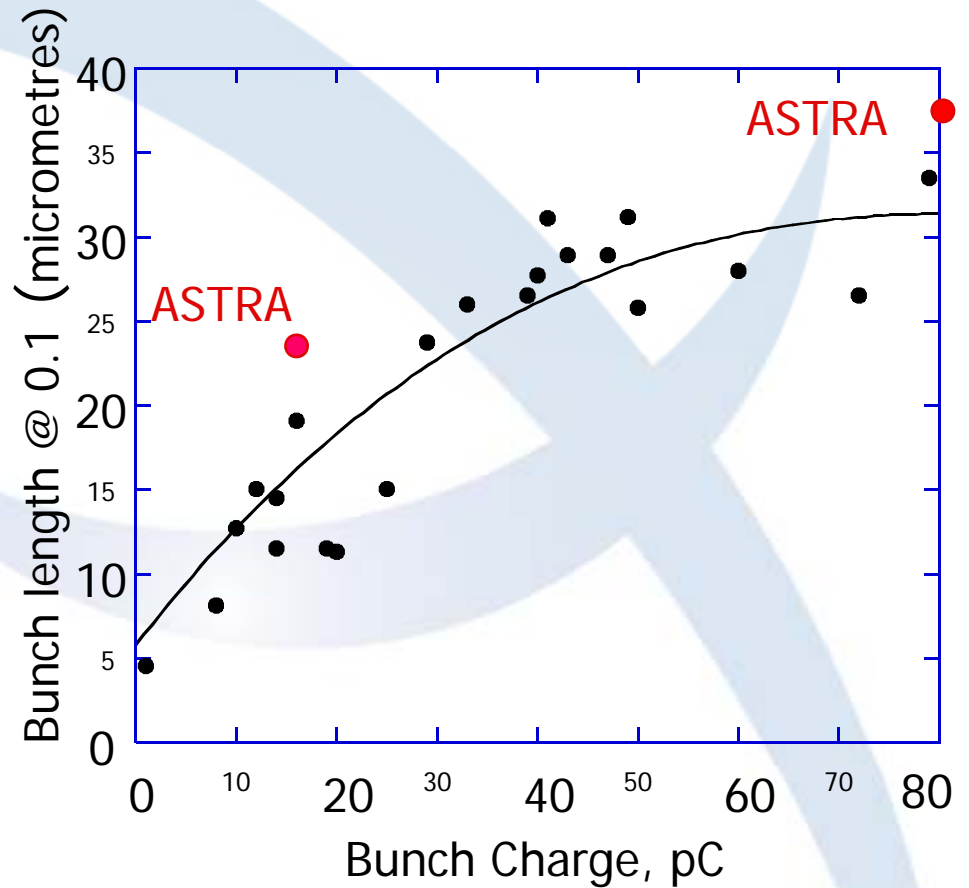


Gun Commissioning Results (1 of 3)

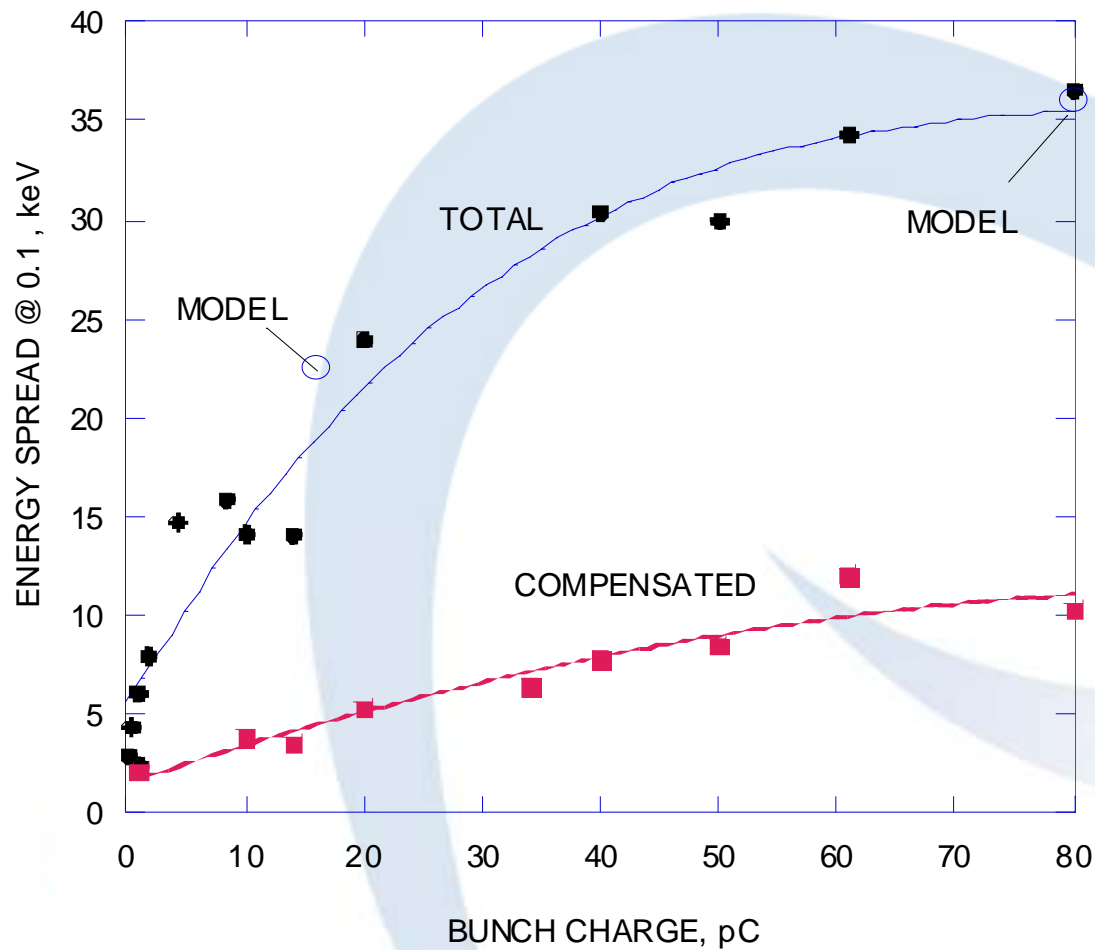
RMS emittance
vs. bunch charge



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



Gun Commissioning Results (2 of 3)

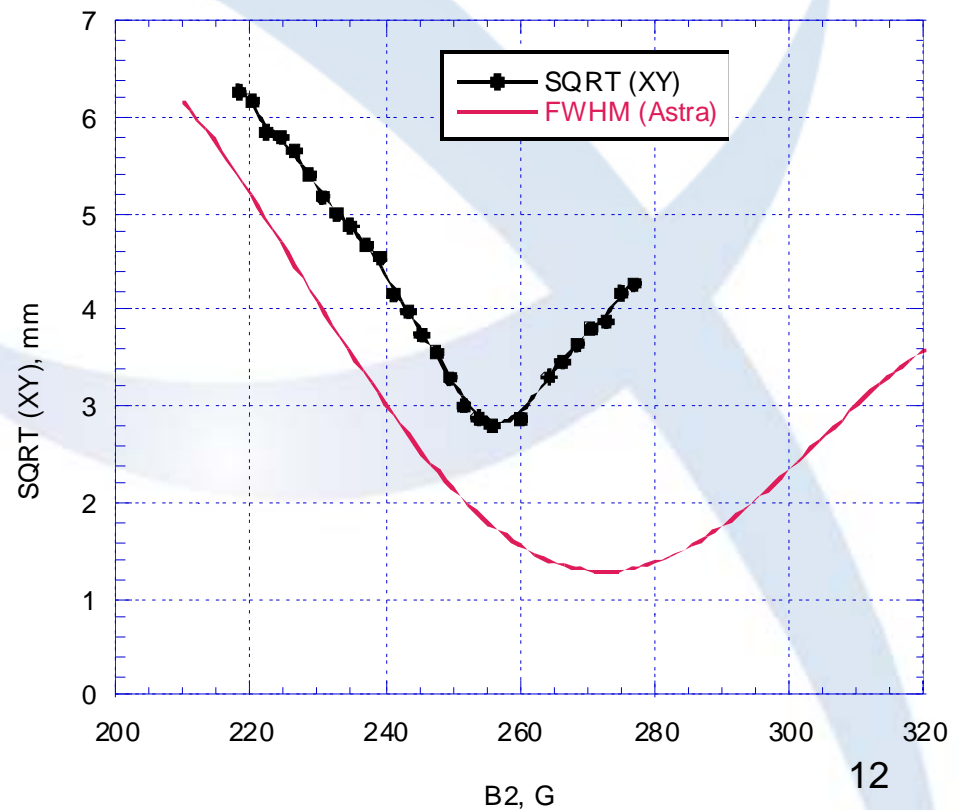
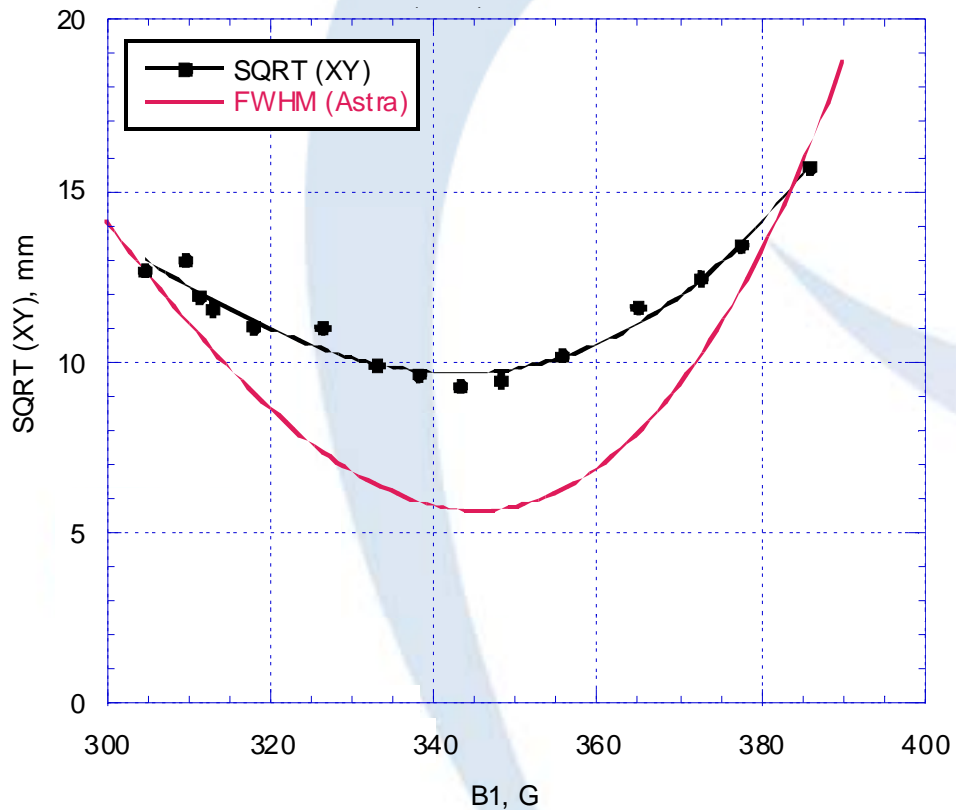


Energy spread (at
10% of peak value)
vs. bunch charge

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

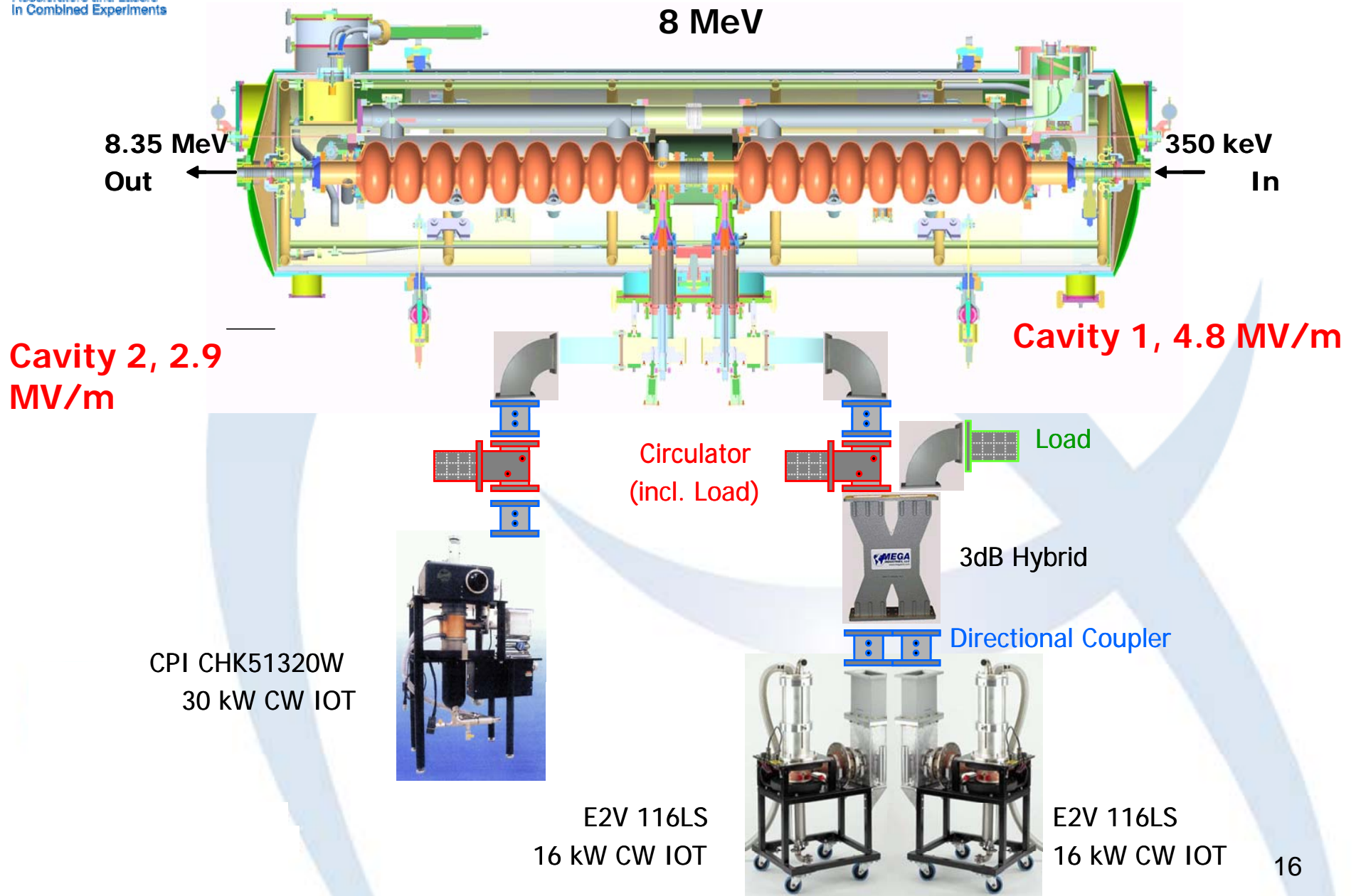
- Results:
 - The gun can now be routinely **HV conditioned to 450kV**;
 - **QE above ~3%** is normally achieved after cathode activations (bunch charges of well above 100pC have been achieved);
 - The beam was **fully characterised** (emittance, bunch length, etc.) for bunch charges between 1 to 80pC;
 - 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 $Q < 20\text{pC}$, 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 $\text{QE} > 1.5\%$;
 - Resolve transverse emittance discrepancy (FE? QE non-uniformity?)

- Introduction
- 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 ± 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



Module Commissioning Results

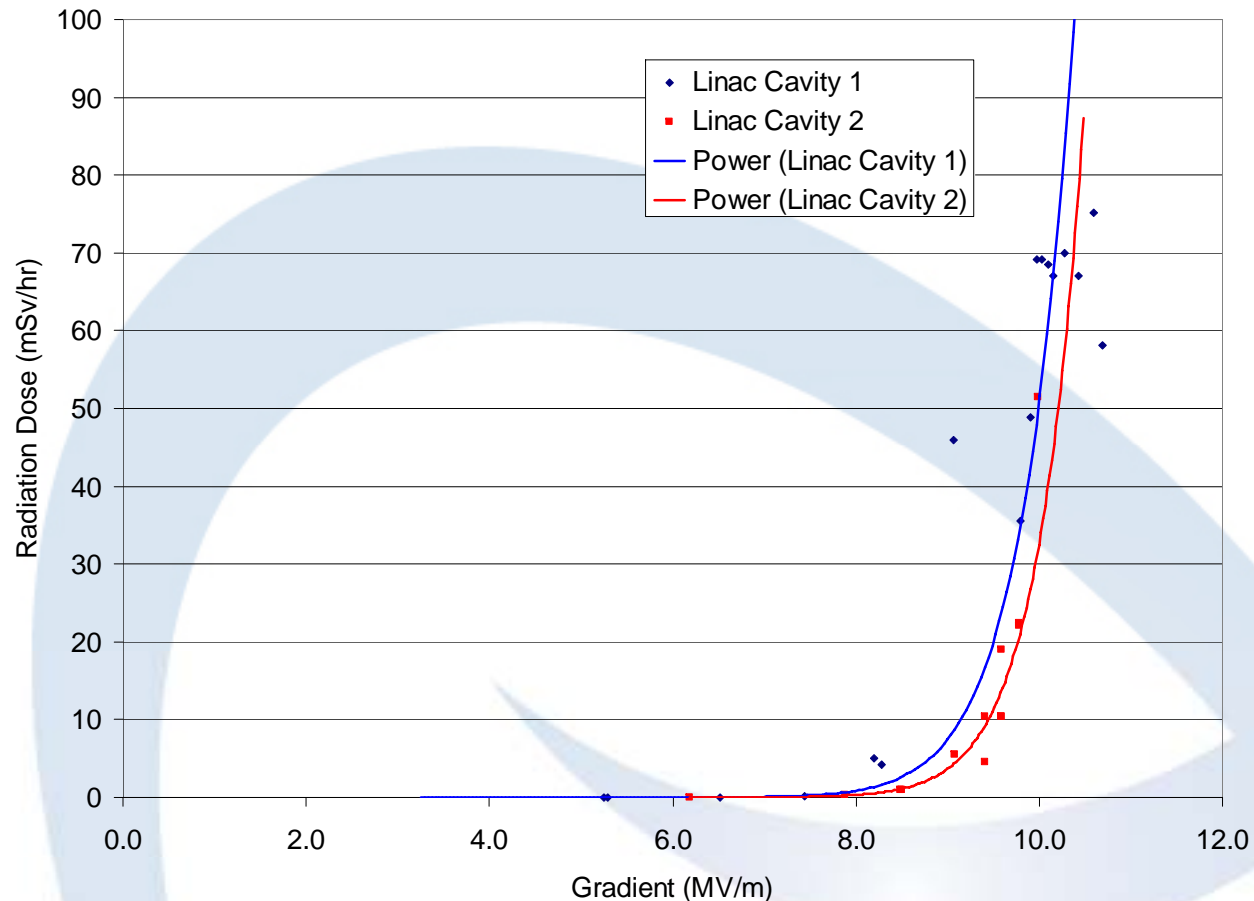
Vertical Tests at DESY (Jul – Dec 2005)

	Booster		Linac	
	Cavity 1	Cavity 2	Cavity 1	Cavity 2
E_{acc} (MV/m)	18.9	20.8	17.1	20.4
Q_0	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_0	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

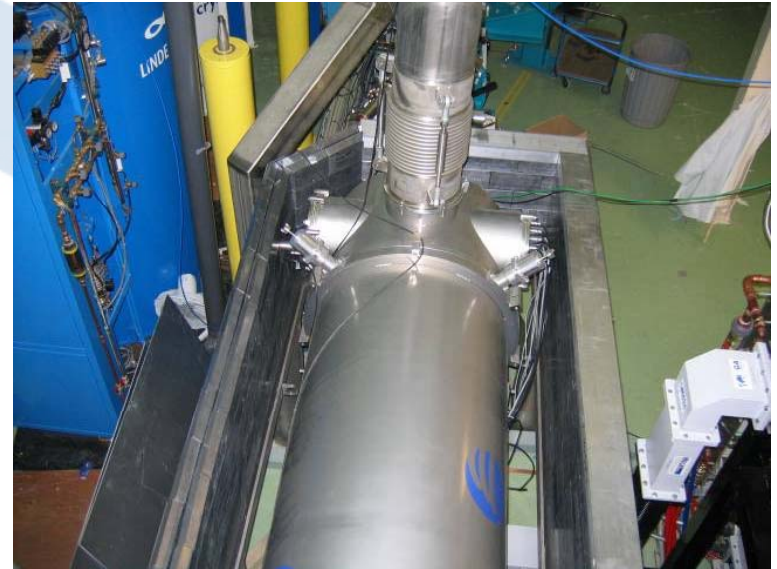
Field Emission Radiation Issue



- 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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 - Accelerator (short term)
 - Science Programme
 - Accelerator Developments
 - EMMA
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Accelerator (short term)

- 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...

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 ($\sim 10\text{TW}$, 100 / 35 fs, 10Hz);
- Infrared FEL ($\sim 4\mu\text{m}$, $\sim 15\text{MW}$ peak, $\sim 1\text{ps}$, $\sim 10\text{mJ}$);
- Femtosecond tunable laser;
- Terahertz radiation (broadband);
- CBS x-ray source (15-30keV, $10^7 - 10^8$ photons/pulse, $< 1\text{ps}$);
- Tissue Culture Laboratory (TCL).



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;

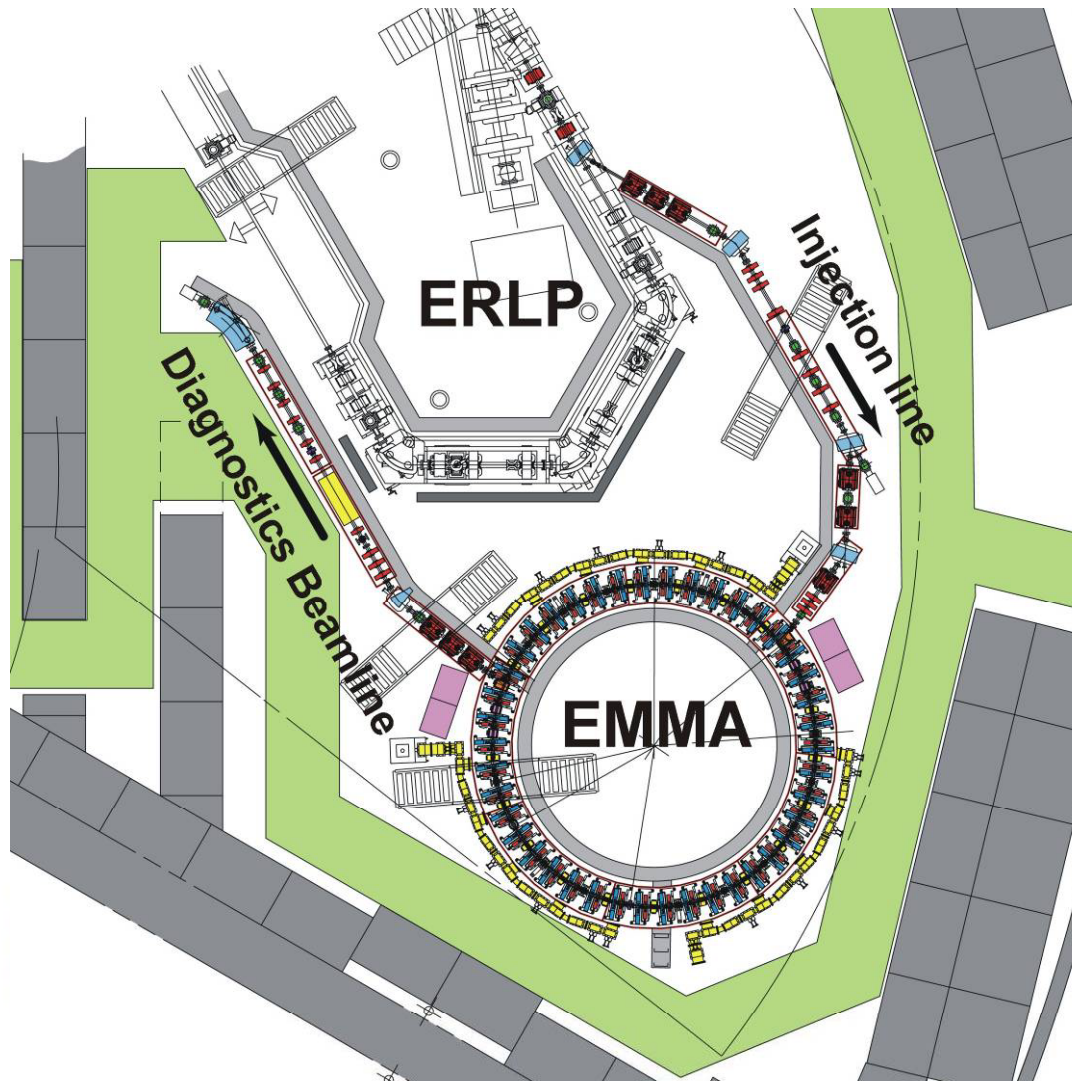
Why FFAG ?

- 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)

Thanks for listening

Spare slides

Linac layout

