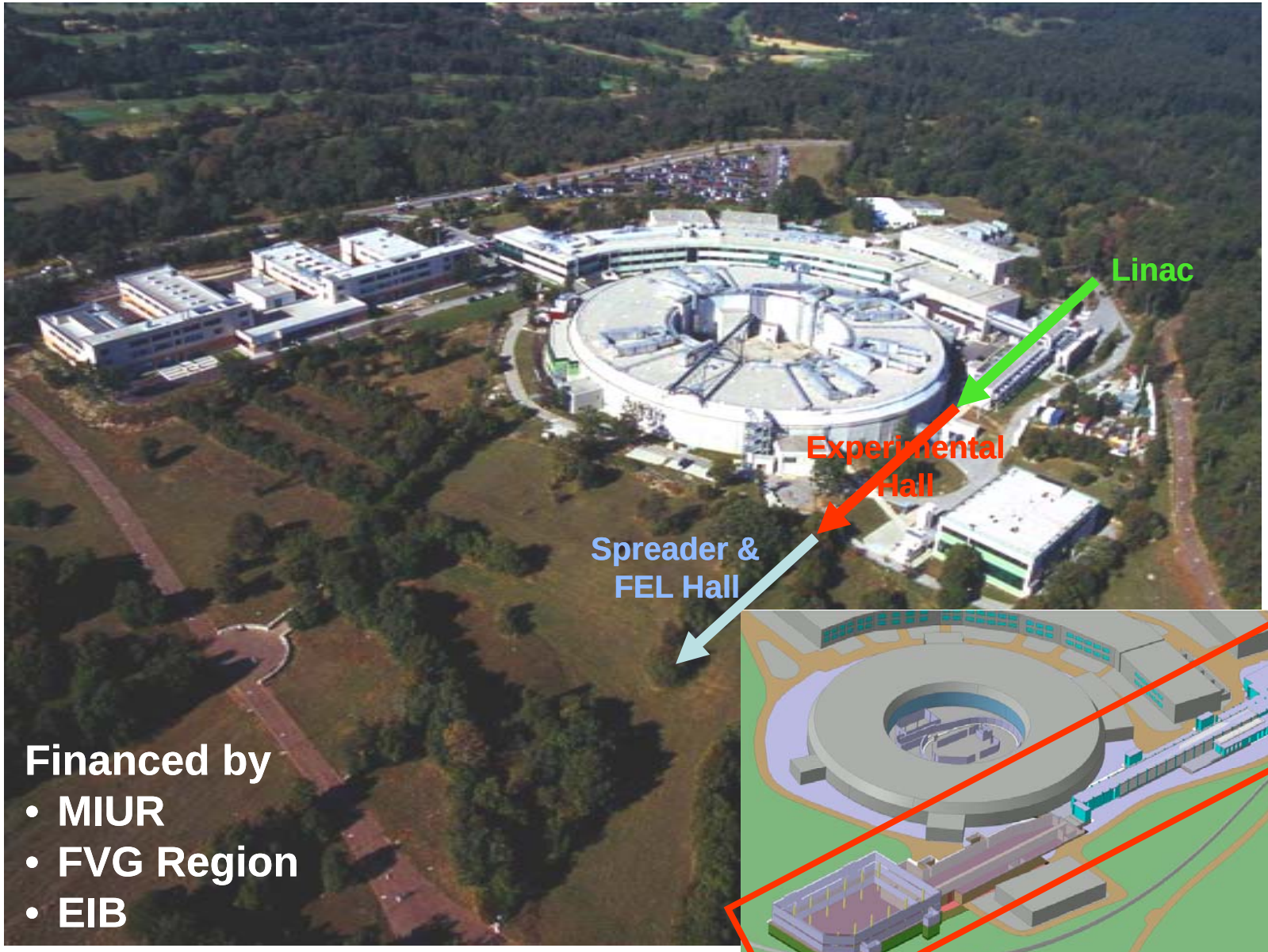
FERMI@ELETTRA

A Single-Pass Free-Electron Laser User Facility

Gerardo D'Auria

X-Band RF Structure & Beam Dynamics Workshop

Cockcroft Institute 1-4 December 2008

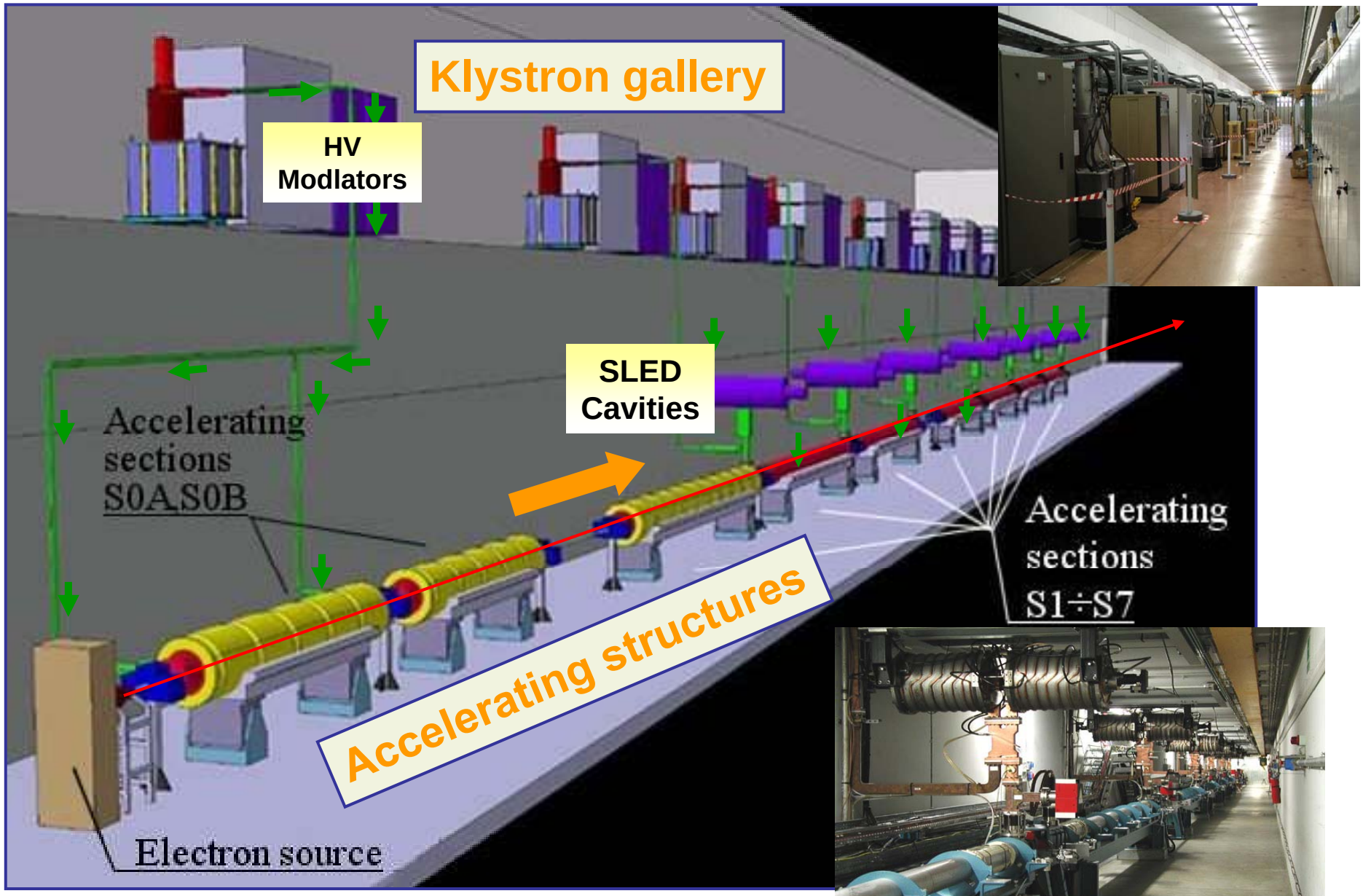

Linac
Experimental Hall
Spreader & FEL Hall
Financed by
• MIUR
• FVG Region
• EIB

FERMI objectives

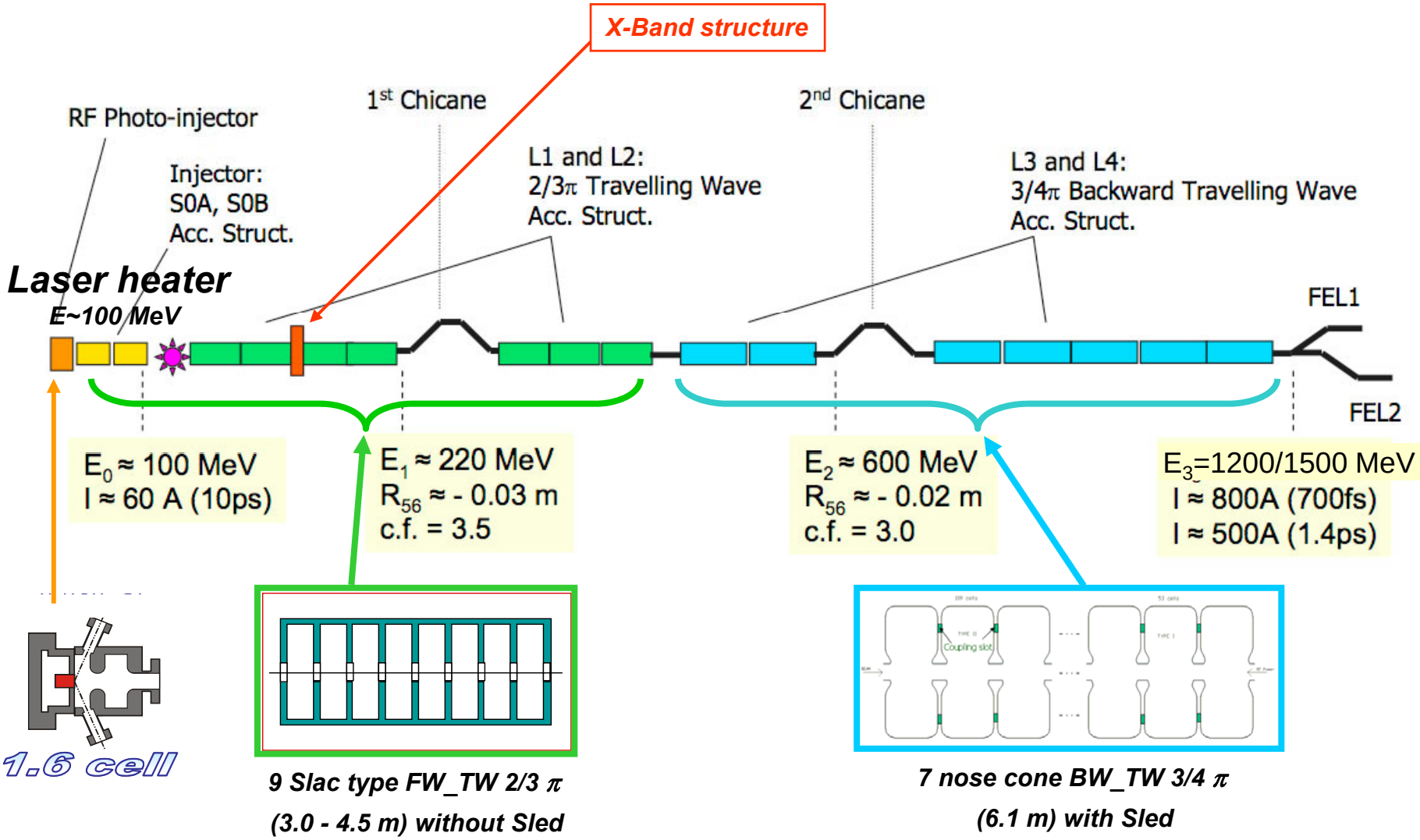
Construction of a single-pass FEL User Facility, in the soft X-ray region, based on the existing Normal Conducting S-band Linac.

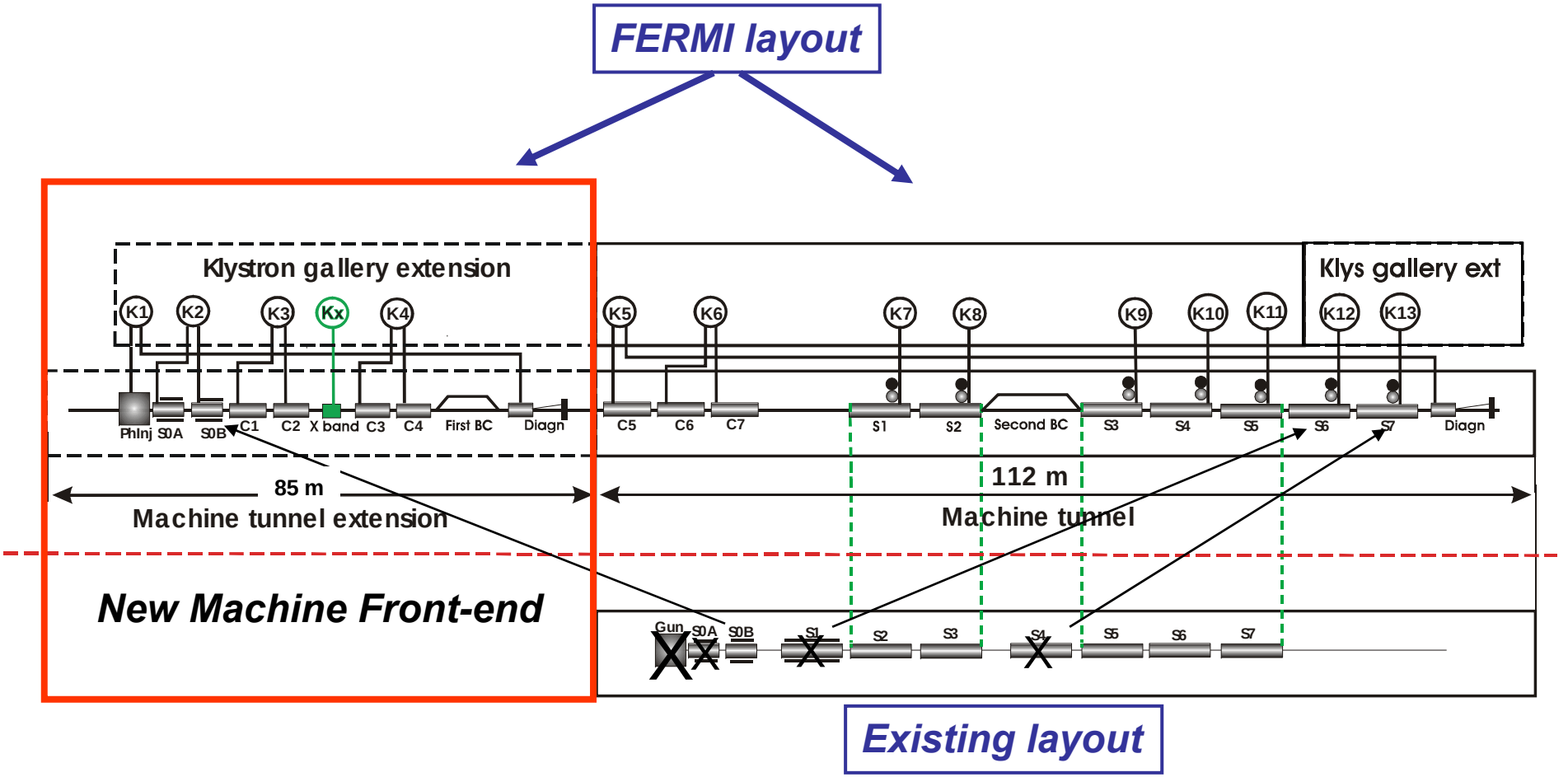
- Beam energy 1.2 GeV (Phase I), 1.5 GeV (Phase II)
- 10-50 Hz pulse repetition rate, 1 e-bunch/pulse
- Seeded operation with Harmonic Generation
- Spectral range:
  - Phase I 100 (80) – 40 (20) nm, single stage
  - Phase II 40 (20) – 10 (5) nm, two stages
- Short sub-ps pulses ≤ 200 fs
- Flexible polarization, gap tuning, apple type undulators

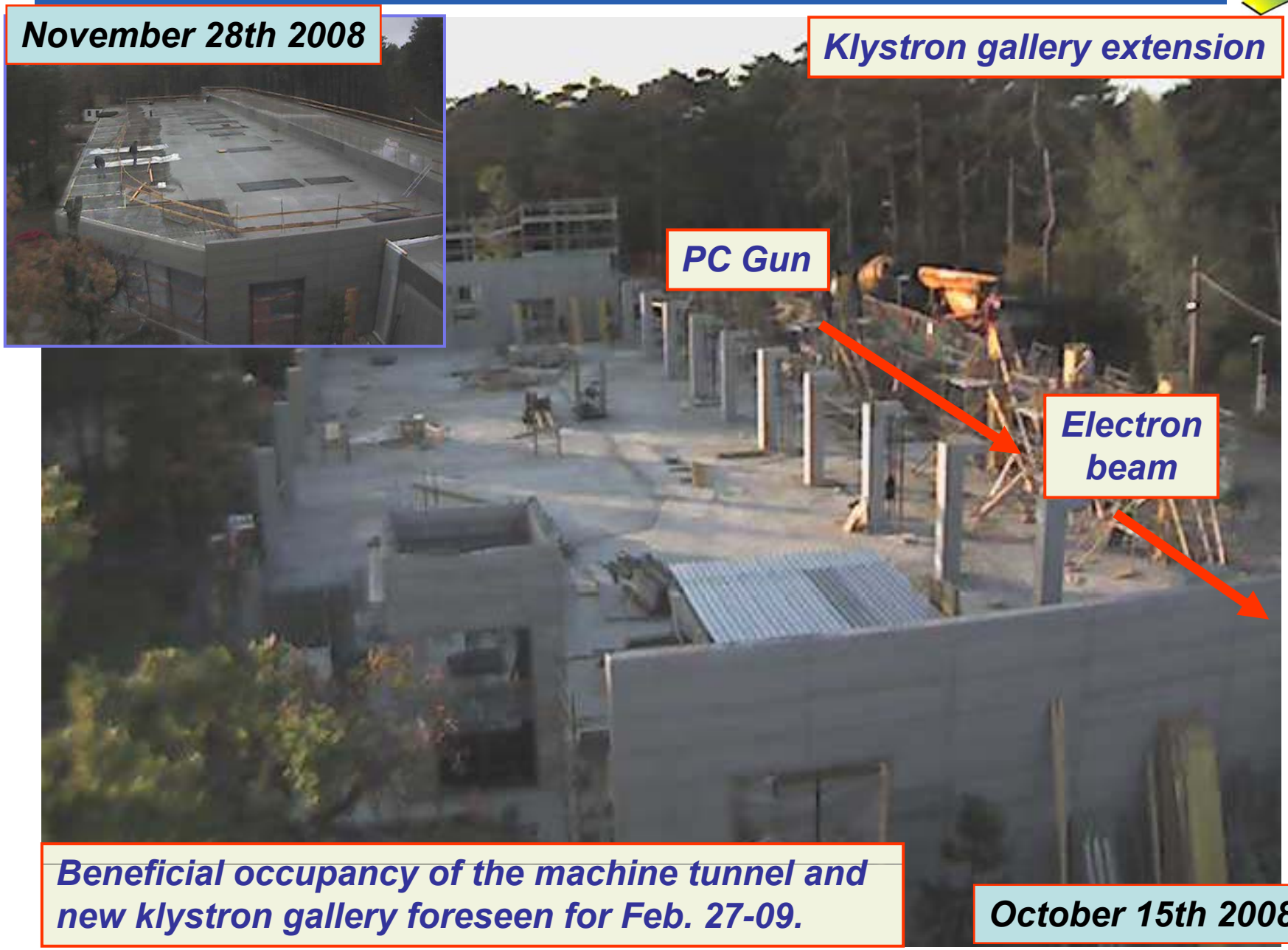
Elettra linac layout



FERMI machine layout




FERMI layout
Klystron gallery extension
Klys gallery ext
K1
K2
K3
Kx
K4
K5
K6
K7
K8
K9
K10
K11
K12
K13
PhInj
S0A
S0B
C1
C2
X band
C3
C4
First BC
Diagn
C5
C6
C7
S1
S2
Second BC
S3
S4
S5
S6
S7
Diagn
85 m
Machine tunnel extension
112 m
Machine tunnel
New Machine Front-end
Gun
S0A
S0B
S1
S2
S3
S4
S5
S6
S7
Existing layout



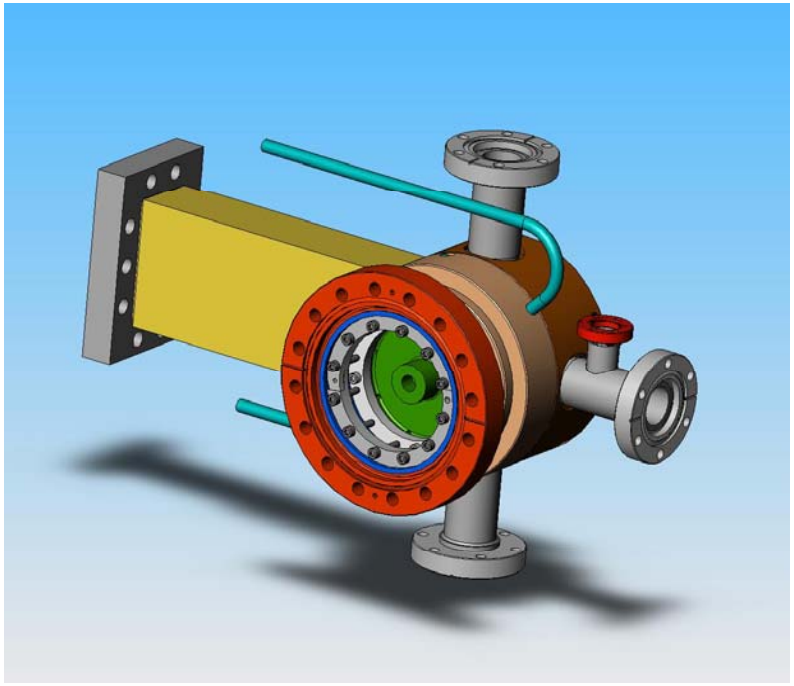
Beneficial occupancy of the machine tunnel and new klystron gallery foreseen for Feb. 27-09.

- To greatly reduce the risks, and to meet the challenging time schedule of the FERMI project, we have chosen to use a proven technology (the 1.6 cell design developed by UCLA-SLAC-BNL).
- We established a collaboration with UCLA-PBPL group (J. Rosenzweig and al.) for the development of a state of the art photo-injector (RF Gun, emittance compensation solenoid and mounting apparatus)
- The solution proposed by UCLA and adopted on FERMI PC gun includes all the most recent improvements tested on the SPARC and FINDER projects.

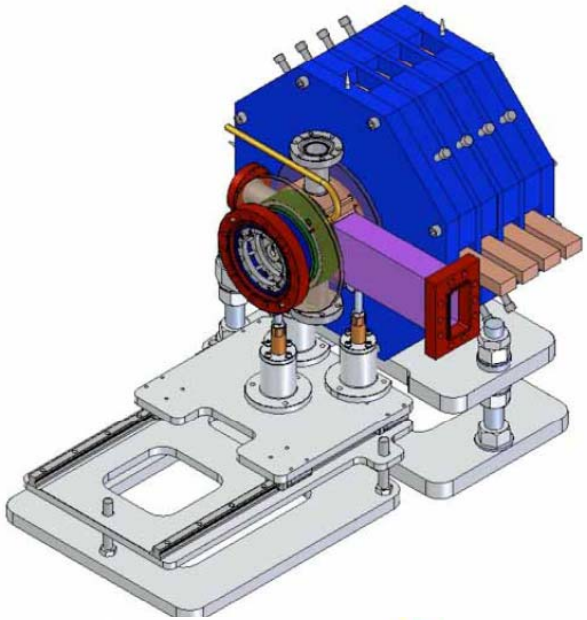
Improvements with respect to existing PC guns

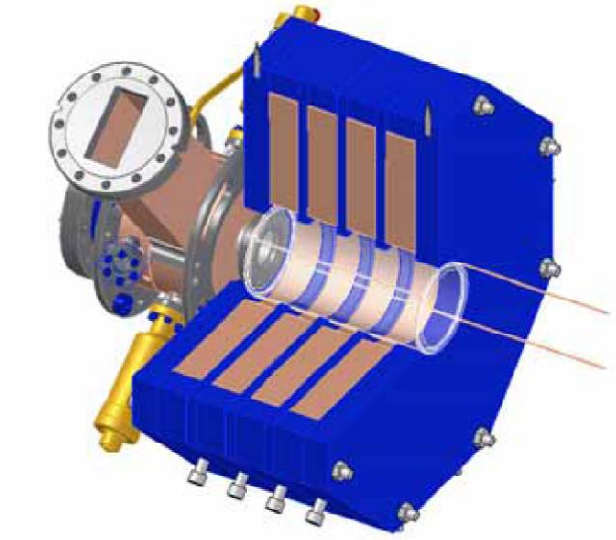
- Enhanced 0-π mode separation (12 MHz) for improved acceleration.
- Removal of the RF tuners to reduce limits to the gun operating voltage (essentially arc free up to 11-12 MW).
- Symmetrization of the gun full cell to limit both the dipole and quadrupole components of the RF field.
- Flexible solenoid design, up to 5 KG in the “pancake” geometry.
- Improved yoke design and multipole field correctors.
- Monolithic copper piece cathode.
- Improved pumping conductance for better RF and QE performance.

Cavity and solenoid designs



Gun Cavity

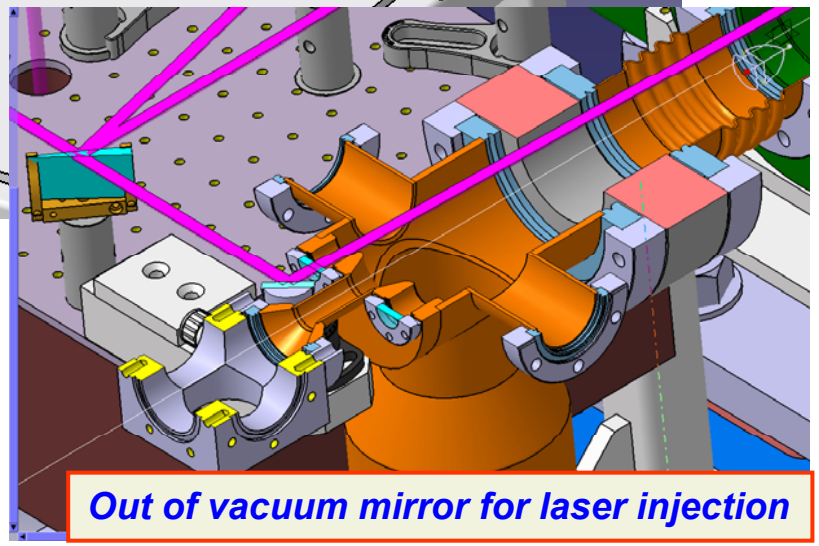




Cavity and solenoid

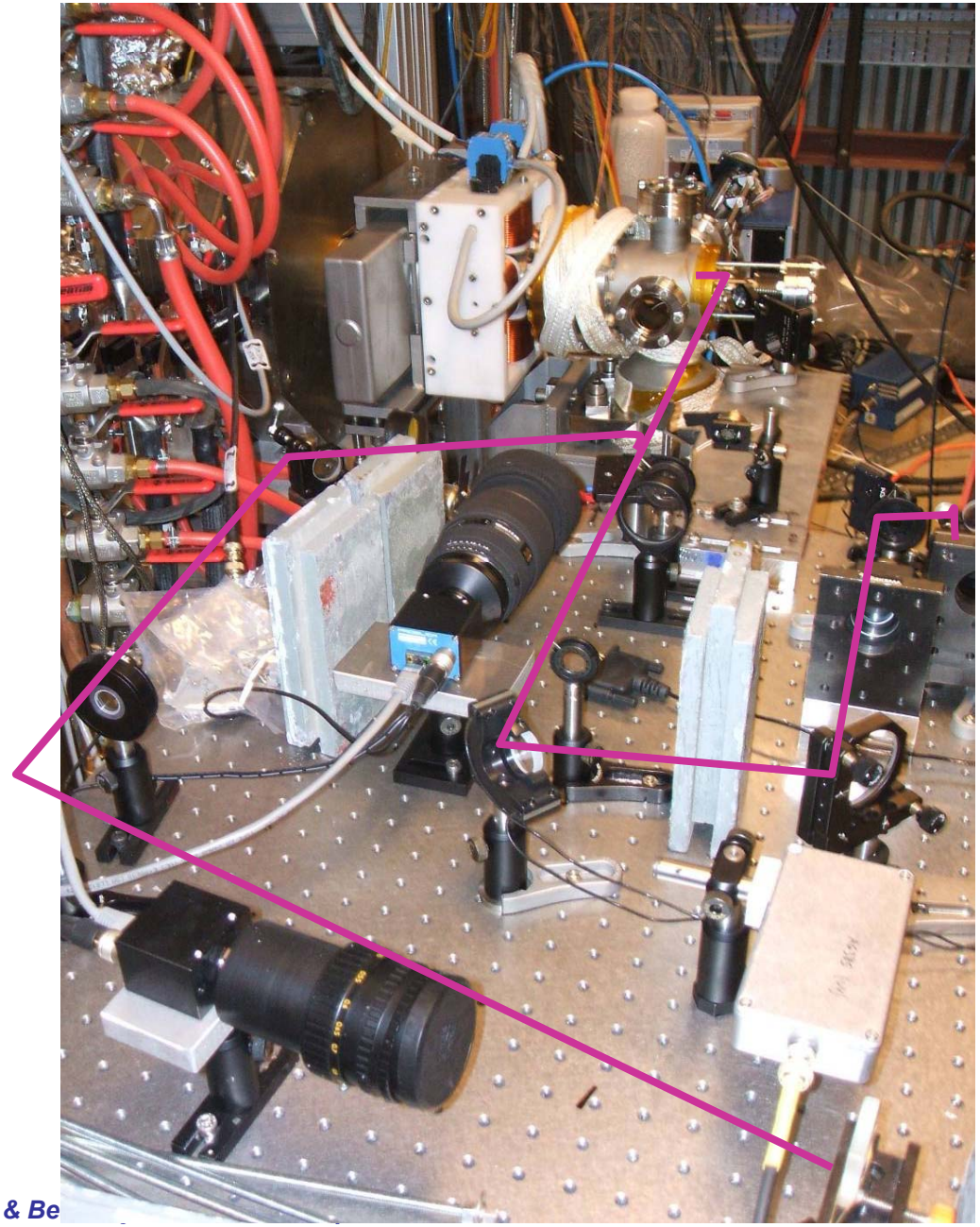
Photo-injector design

Cut view of the Photo-injector



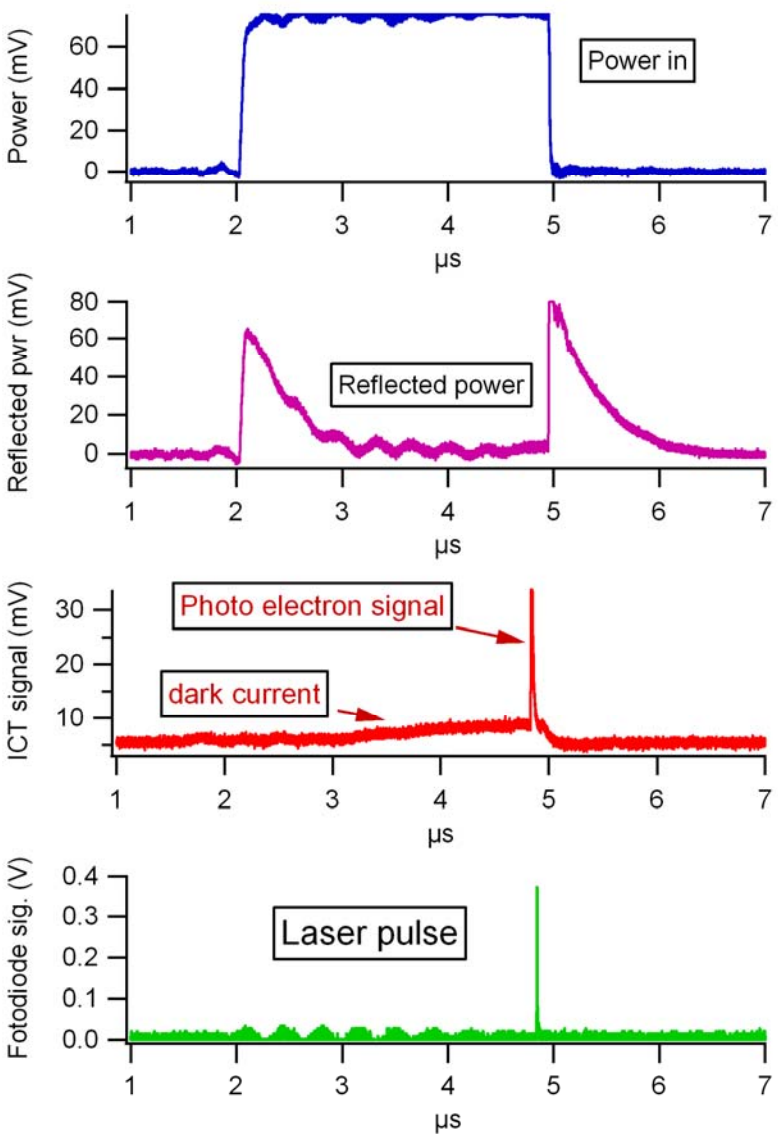
Out of vacuum mirror for laser injection

Laser optical transport



Courtesy of M. Danailov

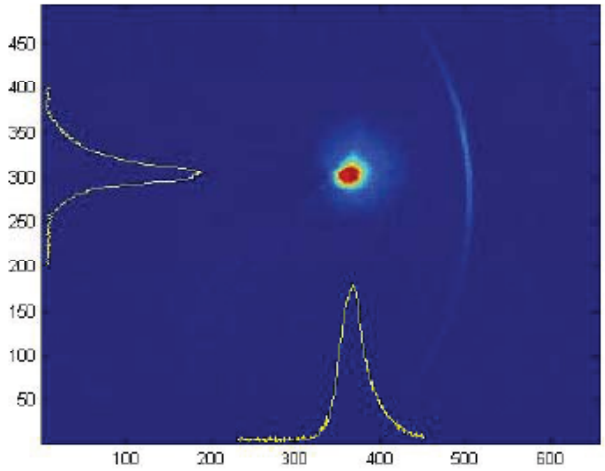
First photoelectrons



28 May 08:

First photoelectron beam extraction!

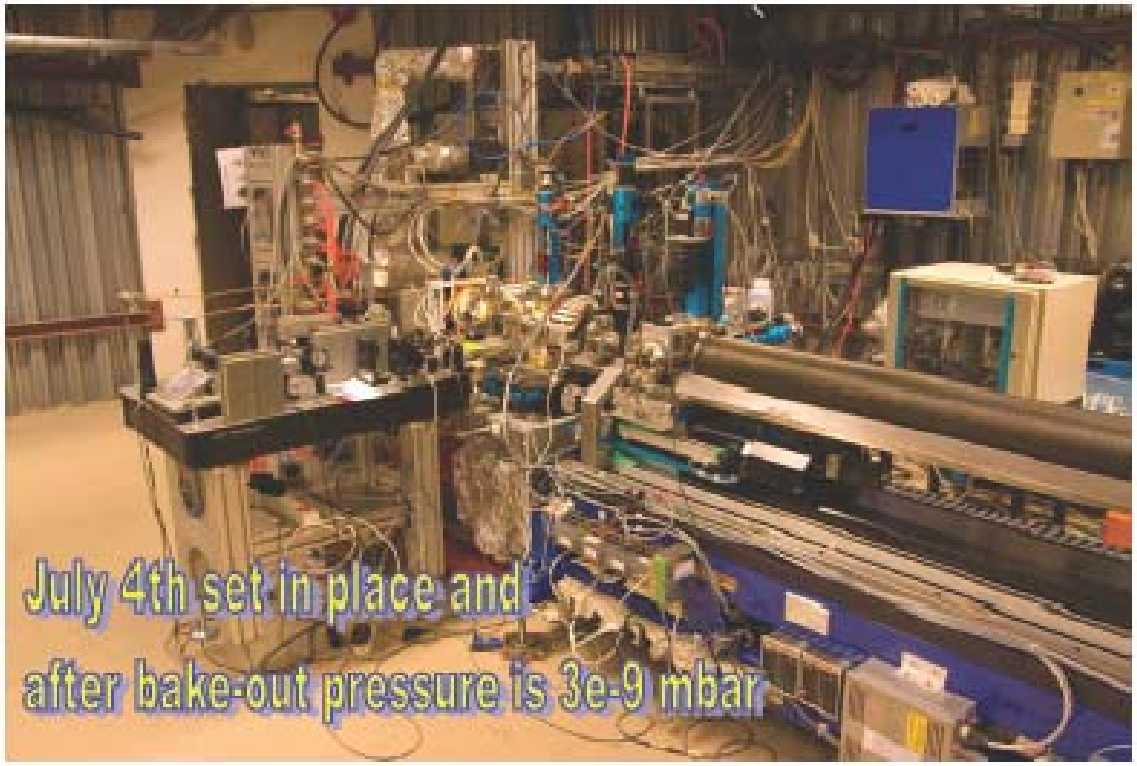
180 pC by 50 μJ



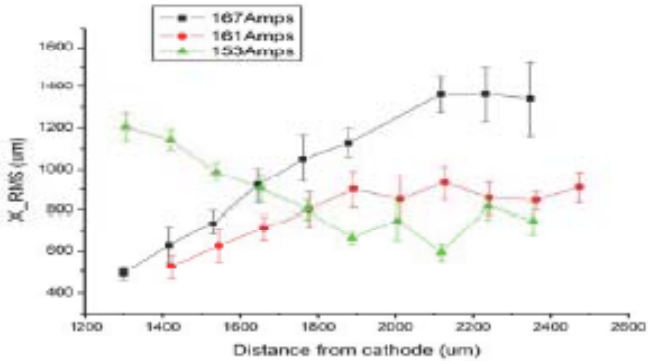
Electron beam on the YAG screen with 80 MV/m RF gradient and $I_{solenoid}$ = 110 A (the horizontal and vertical scales represent the number of the CCD pixel).

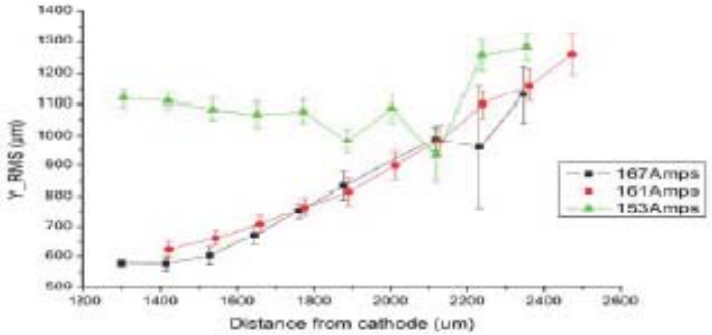
Courtesy of M. Trovo'

Emittance meter installation and measurements



Measurement campaign has been started to characterize the beam as a function of the solenoid and the gun phase.





Emittance measurement:

Q_{bunch} = 200 pC

Energy = 5.2 MeV (115 MV/m)

$Emittance_y$ (@1.5 m) = 2.2 mm mrad

Courtesy of M. Trovo'

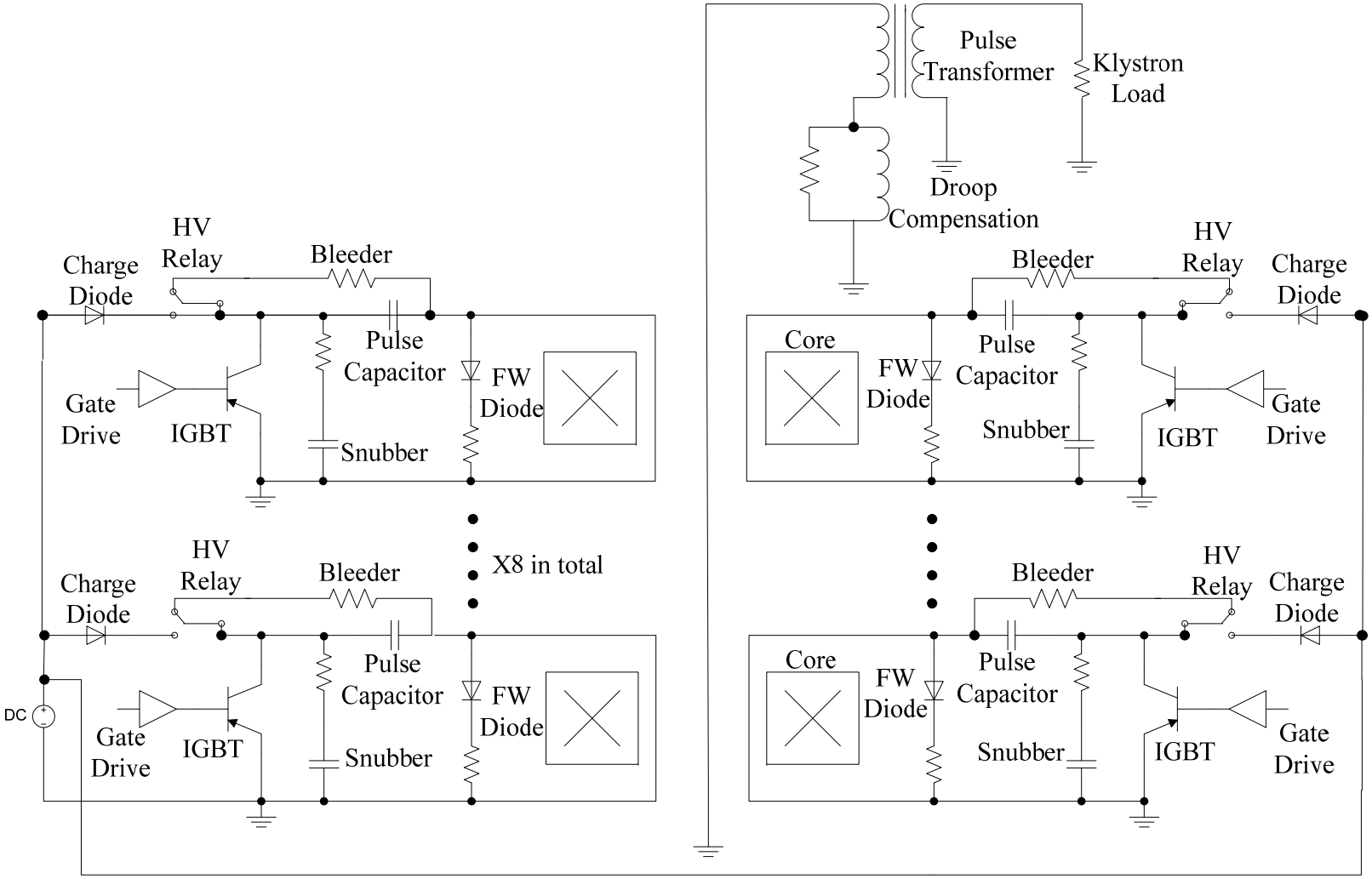
HV modulator development_PFN 50 Hz prototype

Pulse transformer tank

HV power supply
pulse to pulse stability
≤ 1.0 E-4

The 50 Hz PFN modulator assembly has been completed end of February. The system has been tested with good results and now is being used for component characterization.

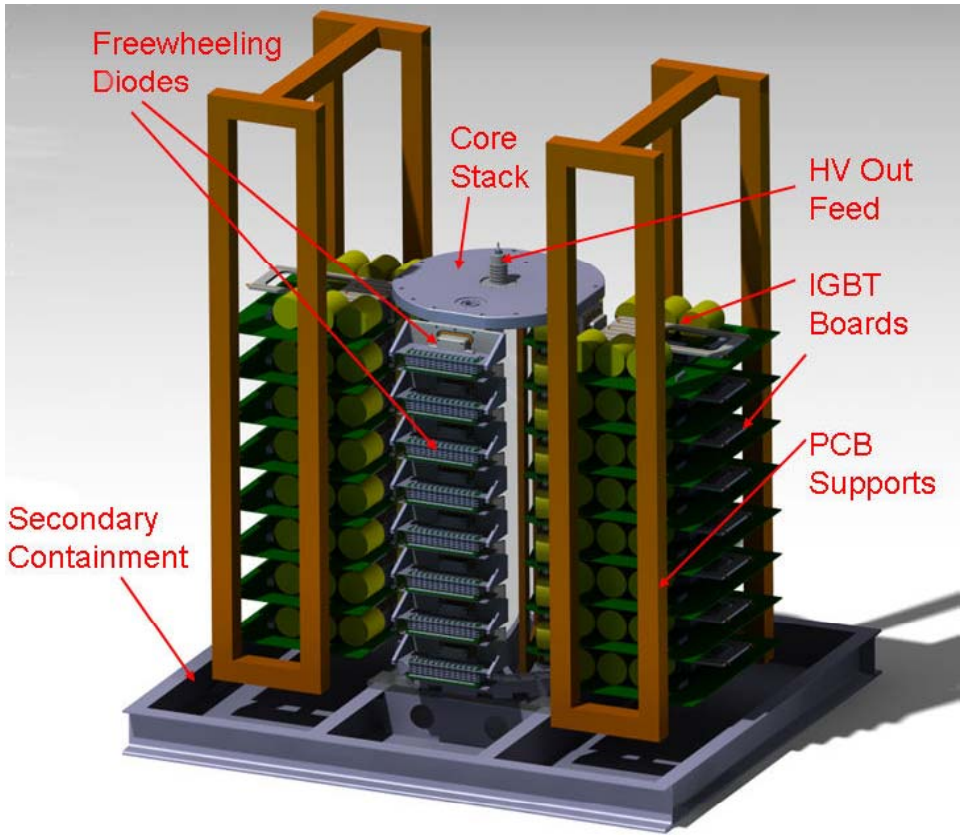
Courtesy of N. Sodomaco



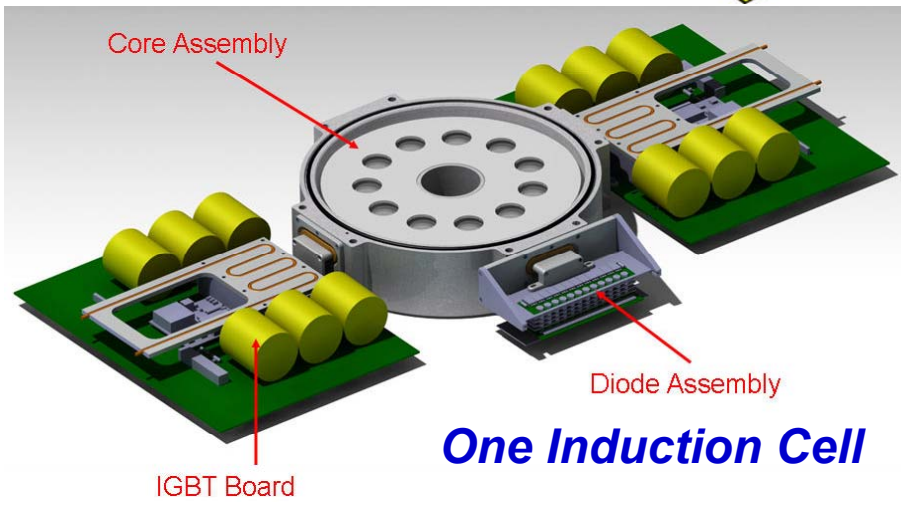
Modulator schematics

Courtesy of C. Pappas

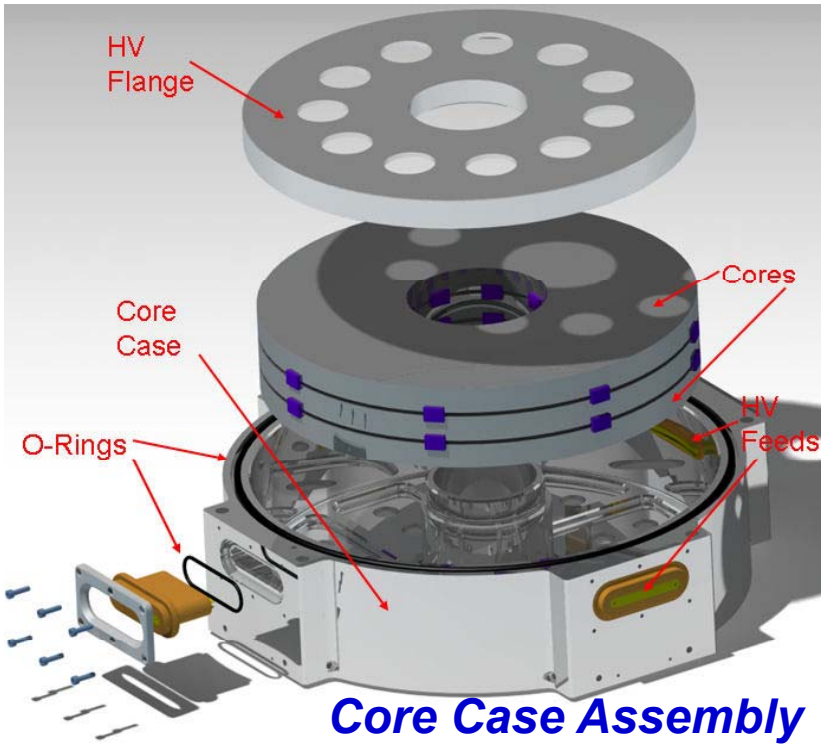
SSM components



The Inductive Adder

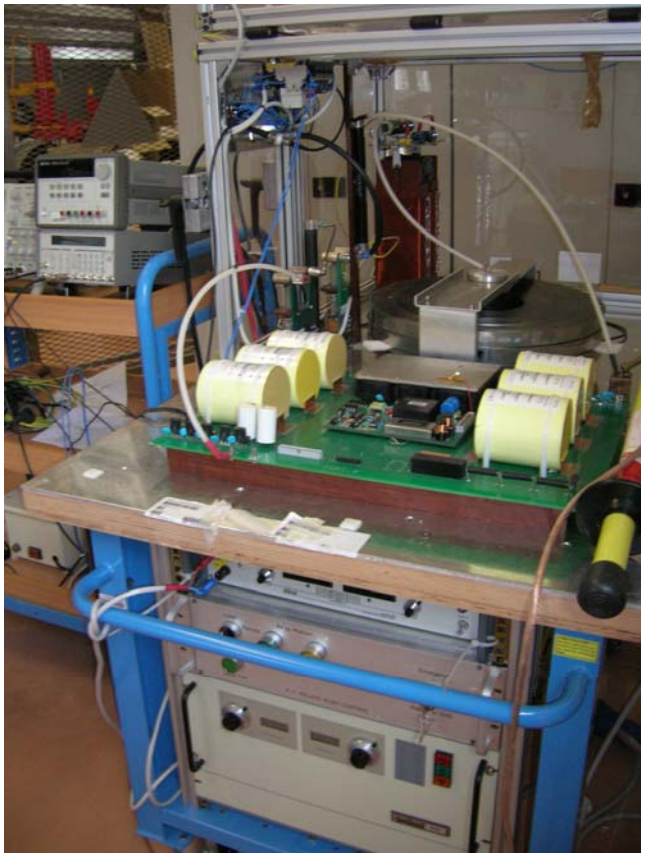


One Induction Cell



Core Case Assembly

Courtesy of C. Pappas



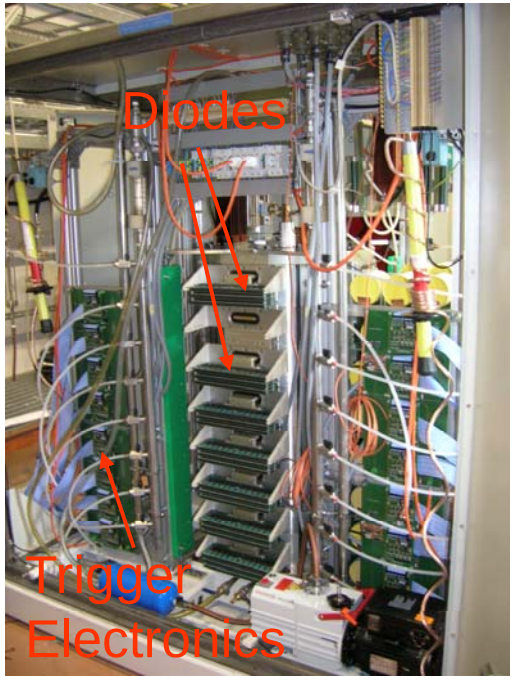
Single Cell Test Stand

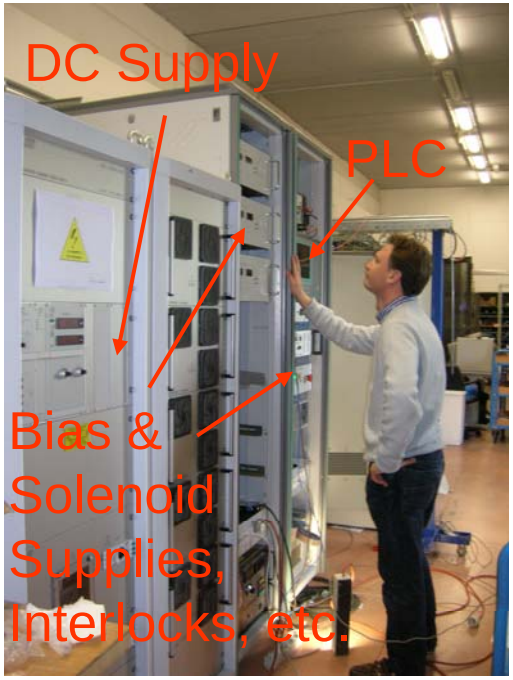
PLC Crate

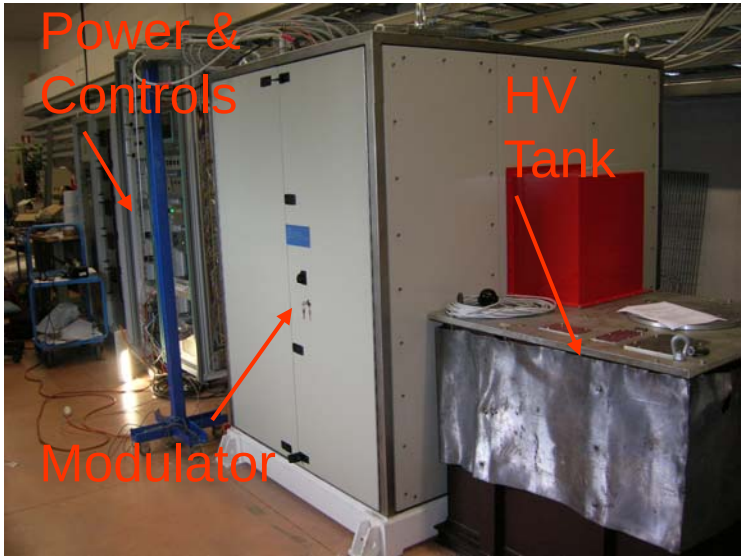
IGBT PCBs Installed

Assembling the Modulator

Courtesy of C. Pappas

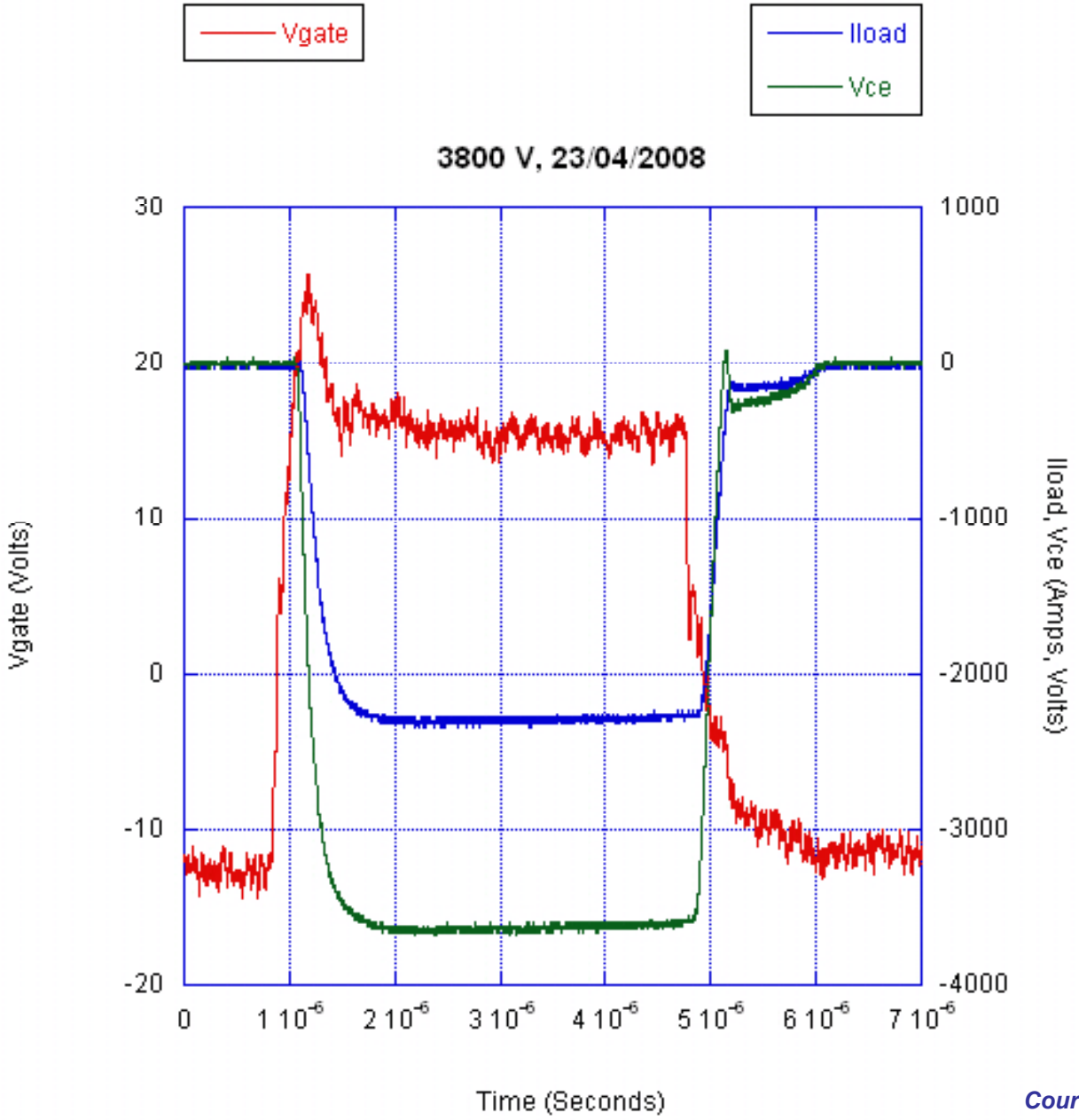






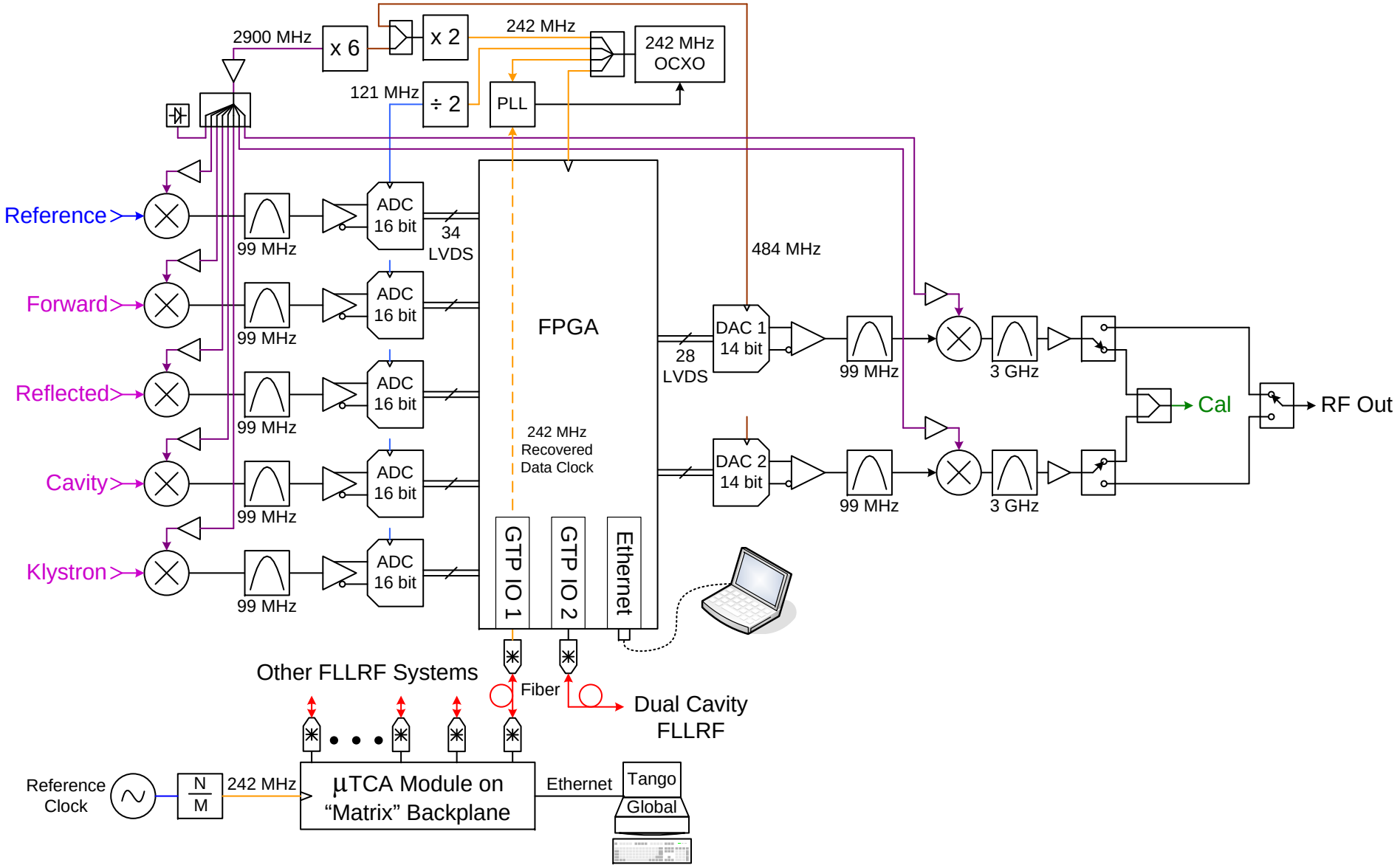
Courtesy of C. Pappas

IGBT power tests



Courtesy of C. Pappas

LLRF System



Courtesy of T. Rohlev

X-band system

- *Contacts and documents exchange with SLAC. A proposal of a MoU has been prepared and is now under discussion.*
- *A strong connection with CERN and PSI has been established (both Labs have already signed a MoU with SLAC).*
- *The first klystron (scaled at 11.992 GHz) could be delivered in the second quarter of 2010.*
- *A request for Regional grants for the development of X-band componets has been presented on March 2008 and received approval in October 2008.*

X-band plant requirements

Parameter		Unit
Max structure length	0.8	m
Active structure length	0.6	m
Working frequency	11.99204	GHz
Nominal structure voltage	20 (24 max.)	MV
Phase	-120	deg
Repetition rate	10-50	Hz
Electron pulse length (full width)	5-15	ps
Phase stability (rms)	0.5	X-deg
Amplitude stability (rms)	0.5	%

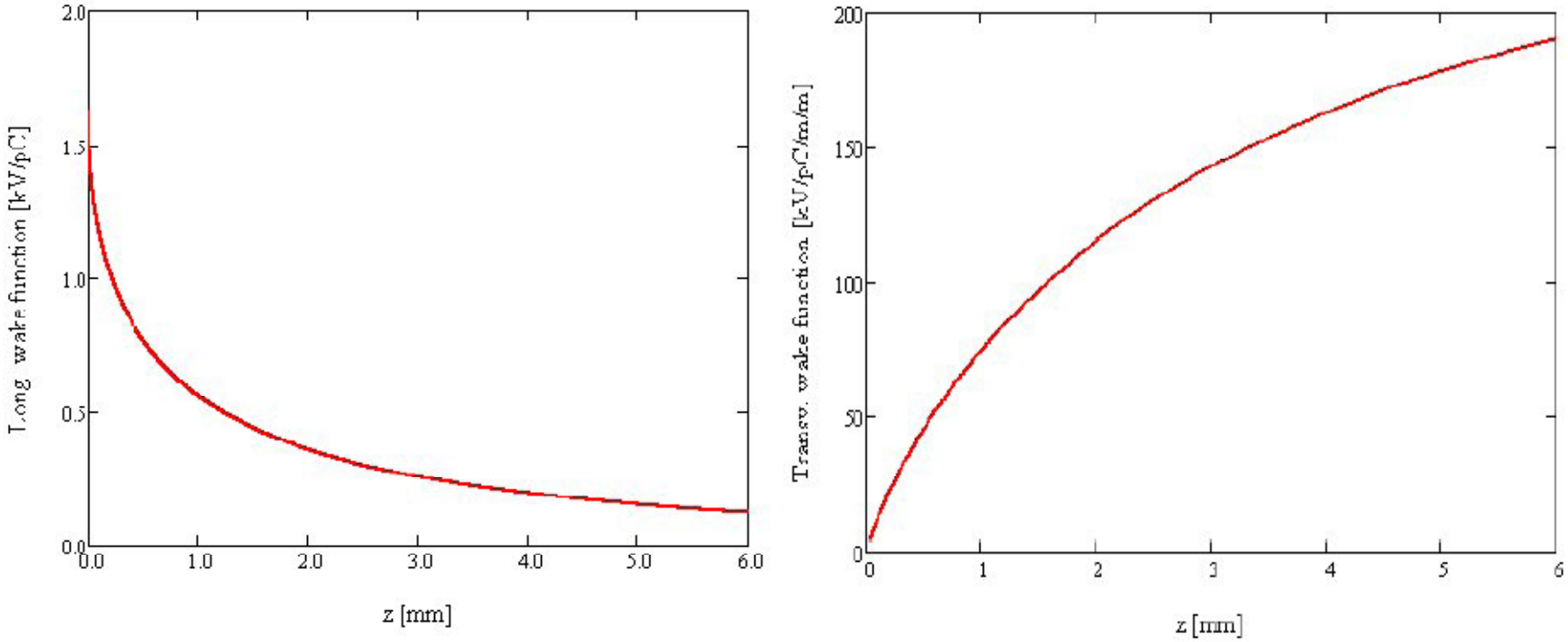
Accelerating section operating parameters

Klystron Operating parameters

	FERMI	*SLAC XL-4*	
Parameter	***Value***		***Units***
RF Frequency	11.99204	11.424	GHz
Peak RF power	≥ 50	50-70	MW
Average RF power	≥ 4.5	6.3	kW
RF pulse width (at – 3dB)	1.5	1.5	μs
Pulse repetition rate	60	60	Hz
Gain at peak power*	≥ 50	52 @ 50 MW	dB
Bandwidth (at – 3 dB)	≥ 50	100	MHz
Efficiency at saturation*	≥ 40	40	%
Peak beam voltage (typ.) V_{beam}*	450	410 @ 50 MW 440 @ 70 MW	kV
Perveance (typ.)*	1.0-1.2	1.2	$\mu A/V^{1.5}$
Maximum output VSWR	1.15:1	1.15:1	
Fraction of RF power in 2nd harmonic*	-20 max	~ 20	dB

* More precise values to be discussed and agreed with SLAC.

Wake functions



Long. and Transv. wake functions used in tracking simulations

Courtesy of P. Craievich

Tolerance budgets for MEDIUM and LONG case (L2)

Using tolerance budgets in table all the following requirements will be met in the same time:

$|\Delta I/I0|<10\%$ $|\Delta E/E0|<0.1\%$ $|\Delta t|<150$fsec (RMS values)

Parameter	Sy.	Unit	Medium	Long
C1-C4 RF phase (L1)	$\varphi 1$	deg	0.10	0.09
X band phase (LX)	φx	deg	**0.50**	**0.50**
C5-C7 RF phase (L2)	$\varphi 2$	deg	0.20	0.20
S1-S2 RF phase (L3)	$\varphi 3$	deg	0.15	0.15
S3-S7 RF phase (L4)	$\varphi 4$	deg	0.20	0.15
C1-C4 RF voltage (L1)	$\Delta V_1/V_1$	%	0.15	0.10
X band voltage (LX)	$\Delta Vx/Vx$	%	**0.50**	**0.50**
C5-C7 RF voltage (L2)	$\Delta V_2/V_2$	%	0.15	0.12
S1-S2 RF voltage (L3)	$\Delta V_3/V_3$	%	0.10	0.10
S3-S7 RF voltage (L4)	$\Delta V_4/V_4$	%	0.08	0.08
Gun timing jitter	Δt_0	psec	0.30	0.30
Initial bunch charge	$\Delta Q/Q$	%	4.00	3.00

RMS values

Leading output parameter is relative mean energy jitter

Leading output parameters are relative mean energy and final timing jitters

Courtesy of P. Craievich