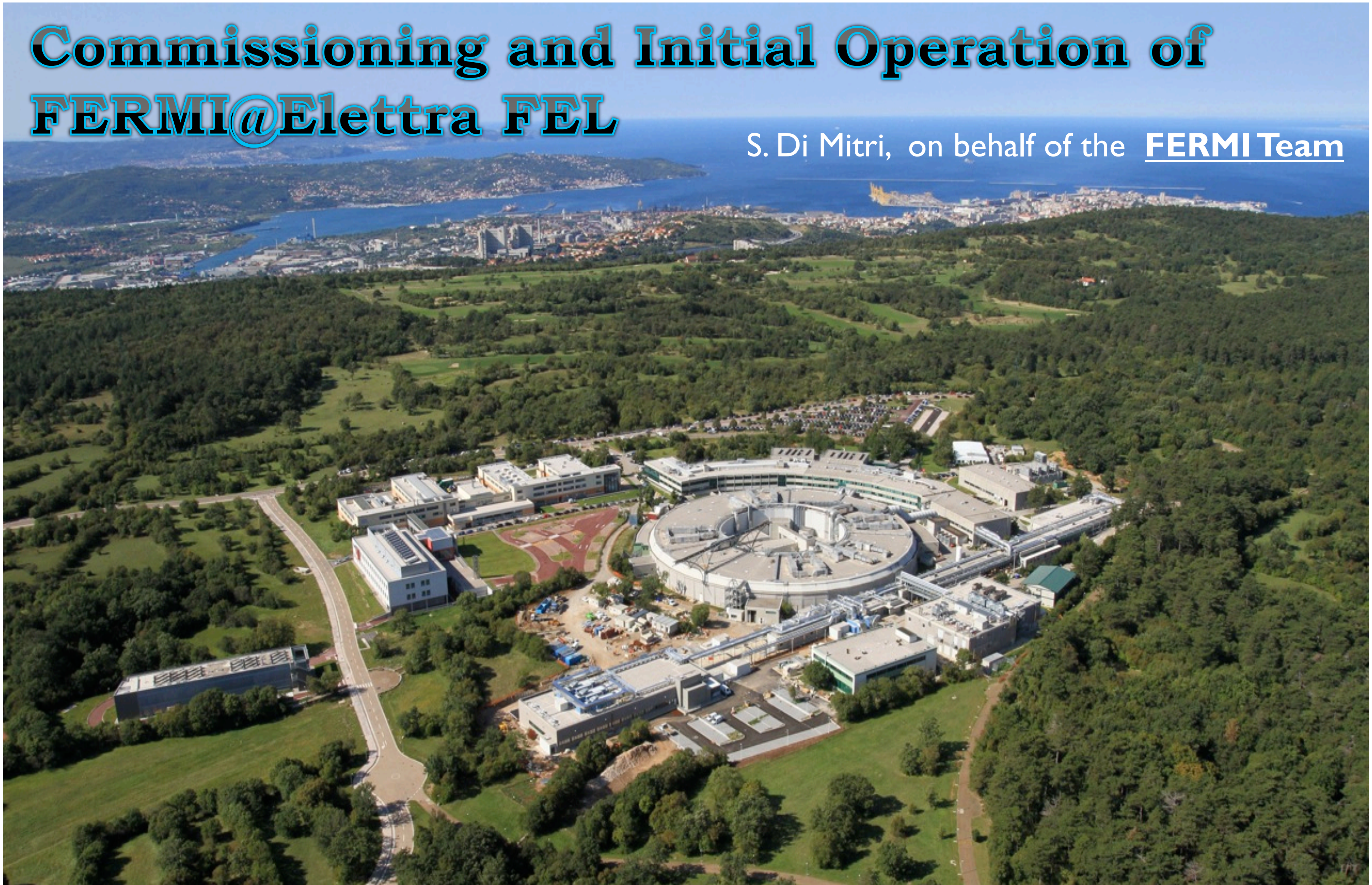
Commissioning and Initial Operation of FERMI@Elettra FEL

S. Di Mitri, on behalf of the **FERMI Team**



BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

LBNL, 17 April 2012

Outline

- Project Overview and Achievements
  - Photon Beamlines, Design Goals and Achievements
- e-Beam Commissioning
  - Extraction, Compression, Emittance, Wakefields
- FEL Commissioning
  - Seeding, Optimization, Coeherence, Recent Studies
- Users Operation
  - Preliminary Results

FERMI Project Overview & Achievements

Science, Design and Achievements

FERMI at the ELETTRA LABORATORY

SINCROTRONE TRIESTE is a nonprofit shareholder company of Italian national interest, established in 1987 to construct and manage synchrotron light sources as international facilities.

FERMI@Elettra FEL:
100 – 4 nm, fully funded

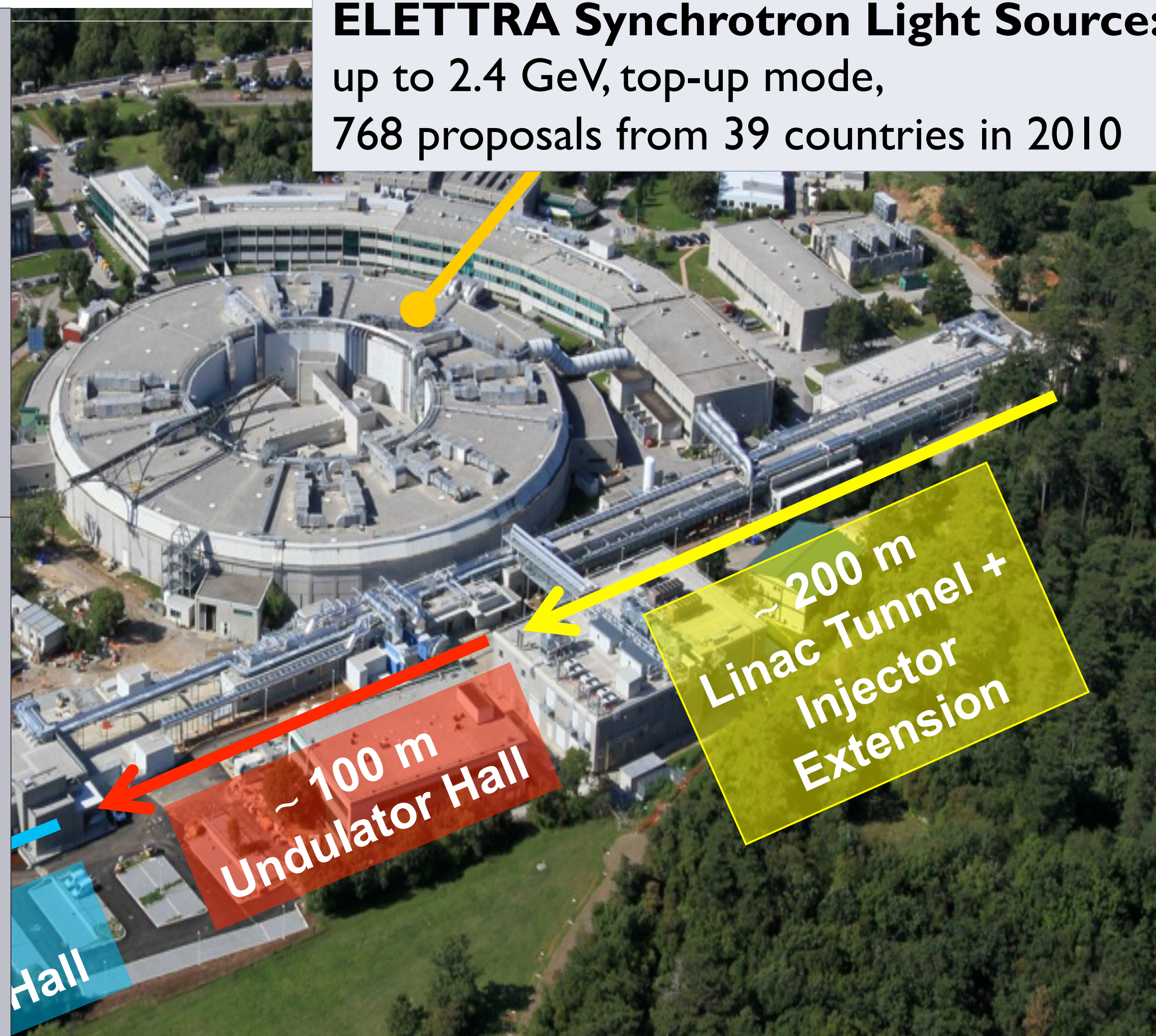
❑Sponsors:

Italian Minister of University and Research (MIUR)
Regione Auton. Friuli Venezia Giulia
European Investment Bank (EIB)
European Research Council (ERC)
European Commission (EC)

❑ Collaborations:

❑ and many others…

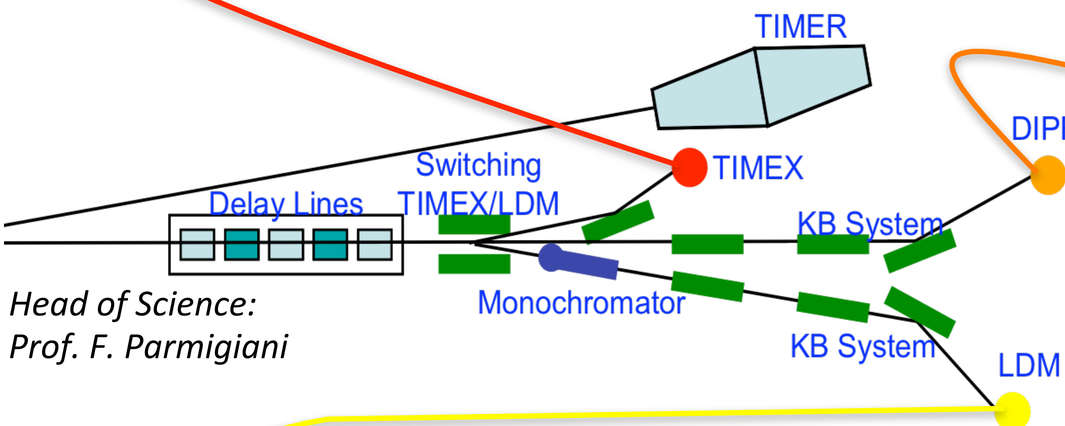
ELETTRA Synchrotron Light Source:
up to 2.4 GeV, top-up mode,
768 proposals from 39 countries in 2010



FERMI PHOTON BEAMLINES

Elastic and Inelastic Scattering *(coord. C.Masciovecchio)*

- **Transient grating spectroscopy** ....transform-limited bandwidth
- **Pump & Probe Spectroscopy, including ultra-fast magnetization dynamics** ....brightness, λ-tunability



Head of Science: Prof. F. Parmigiani

Diffraction and Projection Imaging

DIPROI *(coord.M.Kiskinova)*

- **Single-shot CDI** (bio and solid state structures)
- **Resonant CDI** (chemical and magnetic imaging)
- **Time-resolved CDI** (morphology and internal structure at the nm scale)

...............brightness

............λ-tunability, circular polarization

Low Density Matter *(coord. C.Callegari)*

- **Structure of nano-clusters** ....brightness
- **High resolution spectroscopy** ....narrow bw, λ-tunability
- **Ionization Dynamics** ....circular polarization
- **Catalysis in nano-materials** ....fs pulse and stability

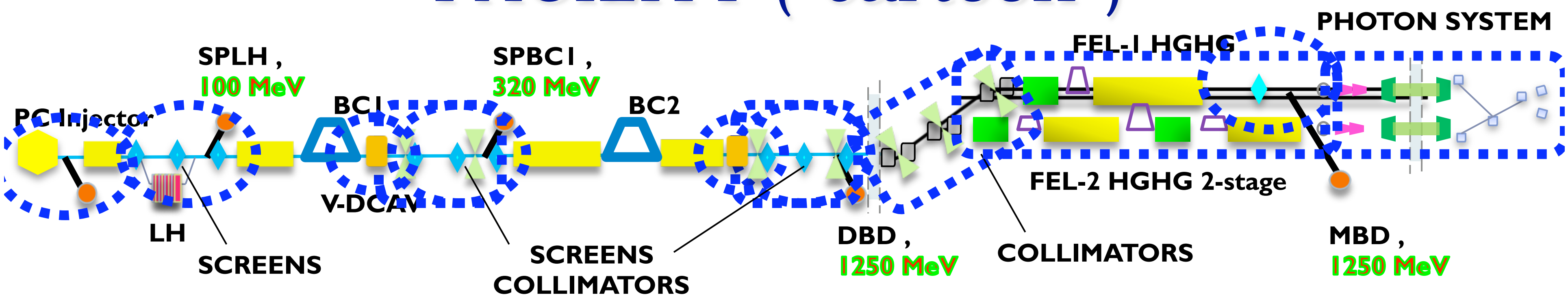
FEL SCHEME

FERMI is a **single-pass, 10/50Hz, externally seeded FEL facility** of **soft X-rays**:

- high peak power .... 0.3 to GW's range
- short temporal structure .... sub-ps to 10 fs time scale
- tunable wavelength .... APPLE II-type undulators
- variable polarization .... horizontal/circular/vertical

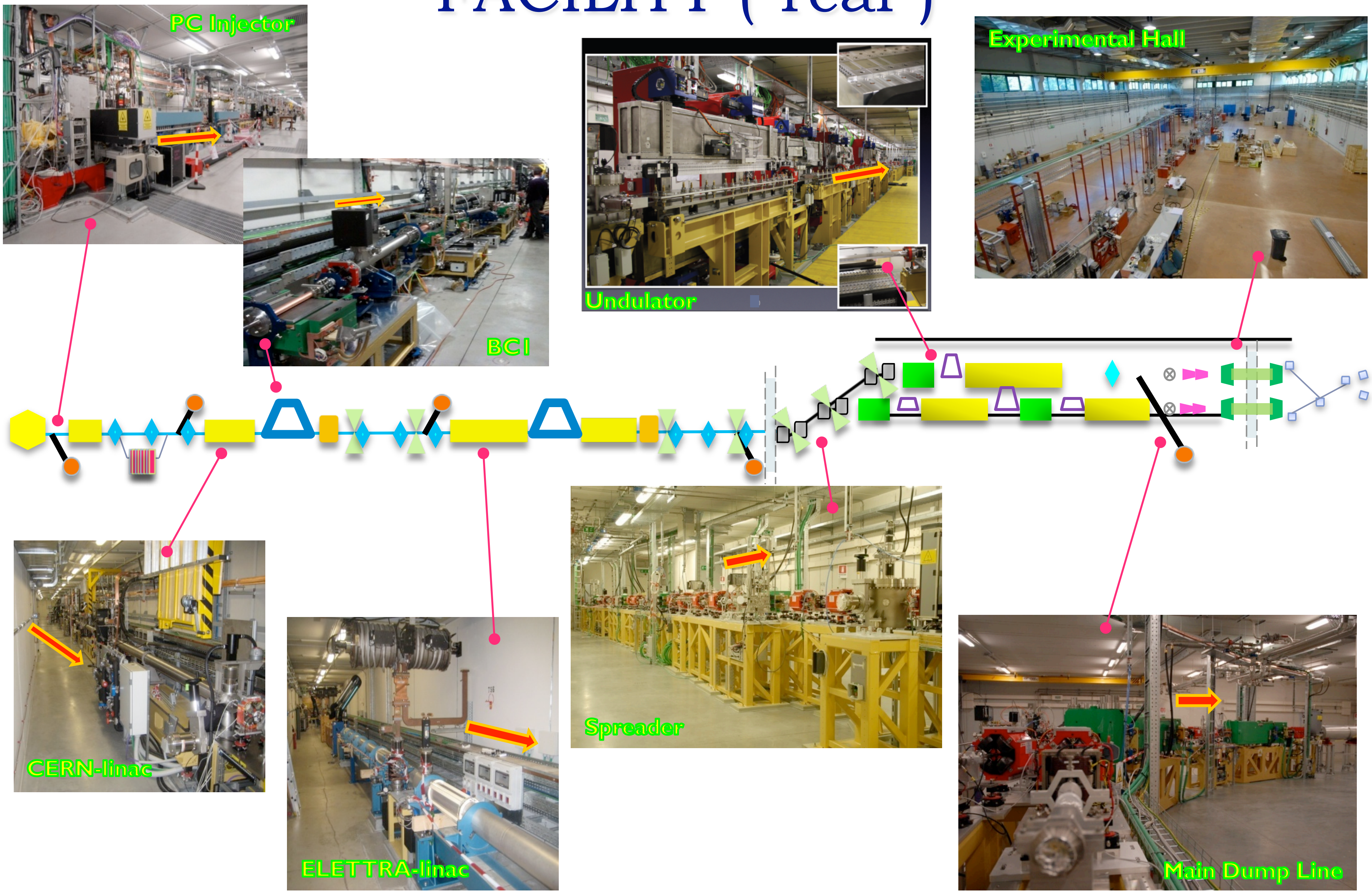
peak brilliance	**$10^{30} – 10^{31}$**	ph/sec/mm^2/mrad^2/0.1%bw
flux	**$10^{12} – 10^{14}$**	ph/pulse
bandwidth	**~ Fourier Transform Limit**	

FACILITY ("cartoon")



- RF Photo-cathode Gun and Injector + up to1.35 GeV Linac
- 2 Magnetic Bunch Length Compressors + 2 Bunch Length Monitors
- 2 RF Vertical Deflectors for time-resolved measurements
- 4 Diagnostic Stations + 5 Spectrometers
- 3 Collimation sections
- Planar/APPLE-type Undulators + RF BPMs + γ/e- Screens + EOS + Quad-movers
- Photon Diagnostics Hutch + X-ray Transport + 3 Beamlines
- Still ***NOT*** fully commissioned (but already in place): **X-band & Laser Heater**

FACILITY (“real”)



OTHER MACHINE SYSTEMS…

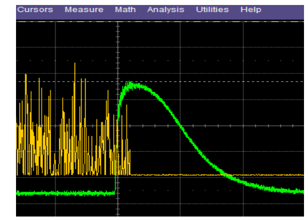
- Controls (news in M. Lonza's, G. Gaio's and L. Pivetta's talk at ICALEPCS 2011)
  - *Tango*-based
  - Real-time framework
  - `elegant`-based on-line optics control
  - MATLAB for Mach. Phys. Applications
  - Scientific Data Management
- Diagnostics (see R. De Monte's talk and "Elettra" contributions at DIPAC 2011)
  - Electro-Optical Sampling
  - Bunch Length Monitor
  - Bunch Arrival Monitor
  - 2μm-res. RF Cavity BPMs
  - Intra-Undulator Screens
- Timing & Synchronization (see M. Ferianis' talk at FEL Conf. 2011)
  - All-optical timing system
  - Synchronization with femtosecond precision
- Machine Protection System (see L. Froehlich's talk at DIPAC 2011)
  - Cerenkov fiber beam loss posit. monitor
  - On-line dosimeter with MOSFETs
  - Ionization chamber beam loss monitor
- Lasers (see M. Danailov' talk at FEL Conf. 2011)

MILESTONES

- PI Laser, Gun & Injector: 2009 **– 2.5 months.**
  (2008, first Gun tests at MAX-lab.)

- Linac & First Bunch Length Compressor: 2010 **– 3.5 months.**

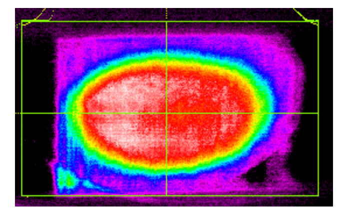
- Transfer Line to Main Beam Dump: 2010 **– 1.5 month.**



- 1st Coherent Emission at 43 nm: 2010 **– 1.5 months.** (13 Dec. 2010)

Coherent X-rays within 9 months after warm-up

- X-ray Transport & Diagnostics: 2011 **– 2 months.**



- FEL Exponential Gain, Polarization & Tunability: 2011 **– 1.5 months.**

- 65 – 32.5 nm to *LDM*, *TIMEX* & *DIPROI* Lines: 2011 **– 1.5 months.**

First user tests 5 months after 1st coherent output

DESIGN GOALS & ACHIEVEMENTS

	Parameter	FEL-1	FEL-2	Units
γ	Output Wavelength (fund.)	80 **(65) – 20**	20 – 4	nm
	Peak Power	**1** – 5	> 0.3	GW
e	Energy	1.2 **(1.35)**	1.5	GeV
	Charge	250 – 800 **(500)**	800	A
	Peak Current (core)	200 – 800 **(350)**	800	A
	Slice Norm. Emittance	**1.5** – 3.0	1.0	mm mrad
	Slice Energy Spread	**~0.20**	0.15	MeV

* achieved

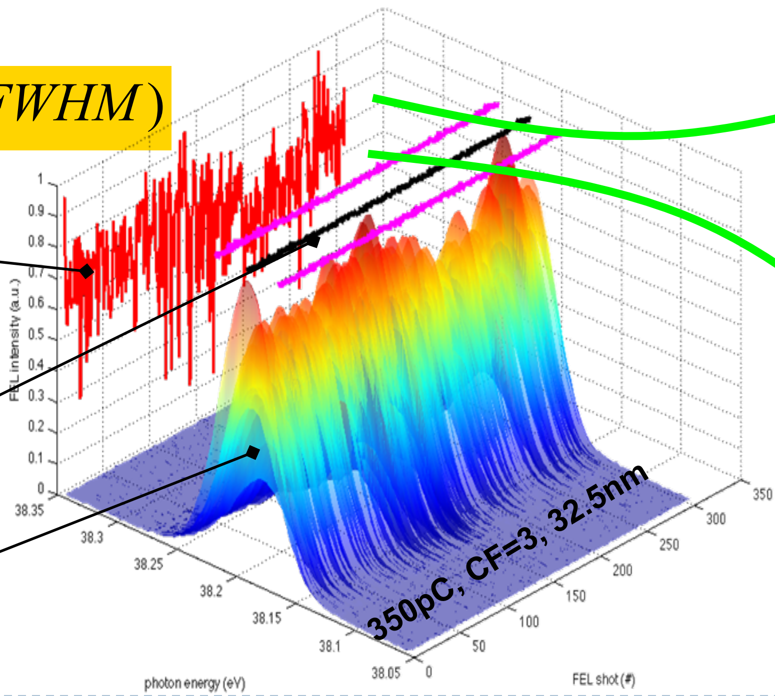
$$\Delta t \Delta \upsilon \approx 1.5 \cdot 0.44 \ \ (FWHM)$$

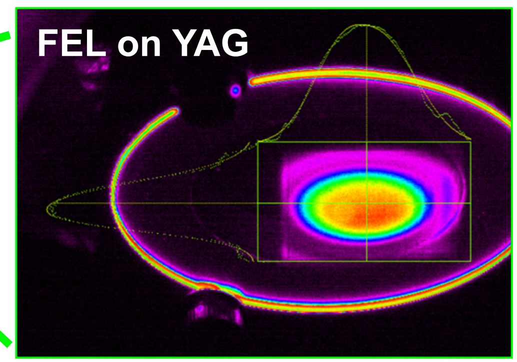
Jitters RMS ~1 hour

$$\frac{\Delta I}{I} \leq 10\%$$

$$\frac{\Delta \lambda_0}{\lambda_0} \leq 5 \cdot 10^{-5}$$

$$\frac{\Delta bw}{bw} \leq 3\%$$





FEL TEM_{00} Gaussian mode. Up to **10^{13} photons per pulse** at 43 nm.

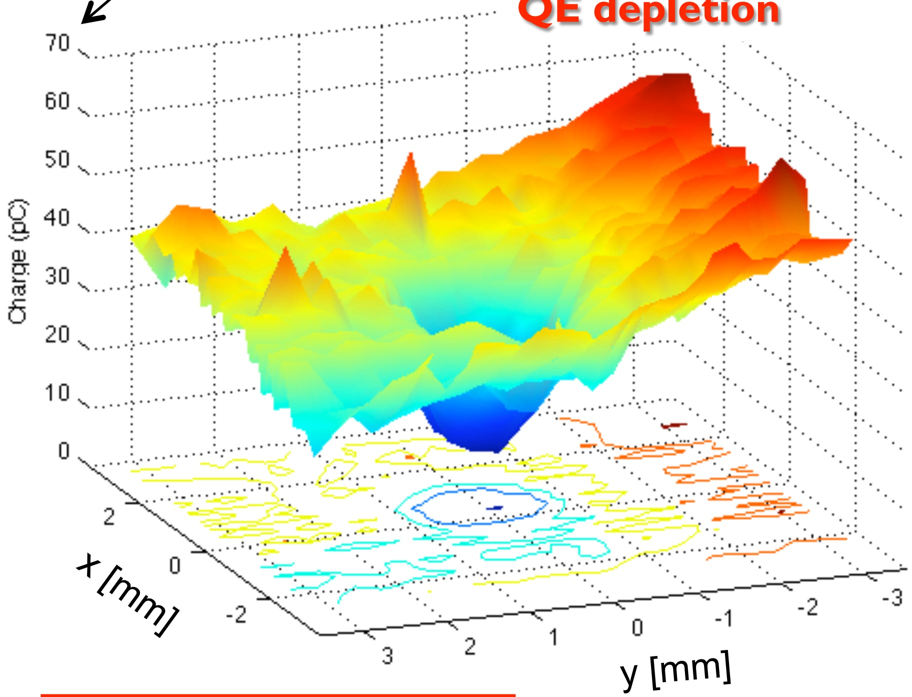
e-Beam Commissioning

Extraction, Compression, Emittance, Wakefields

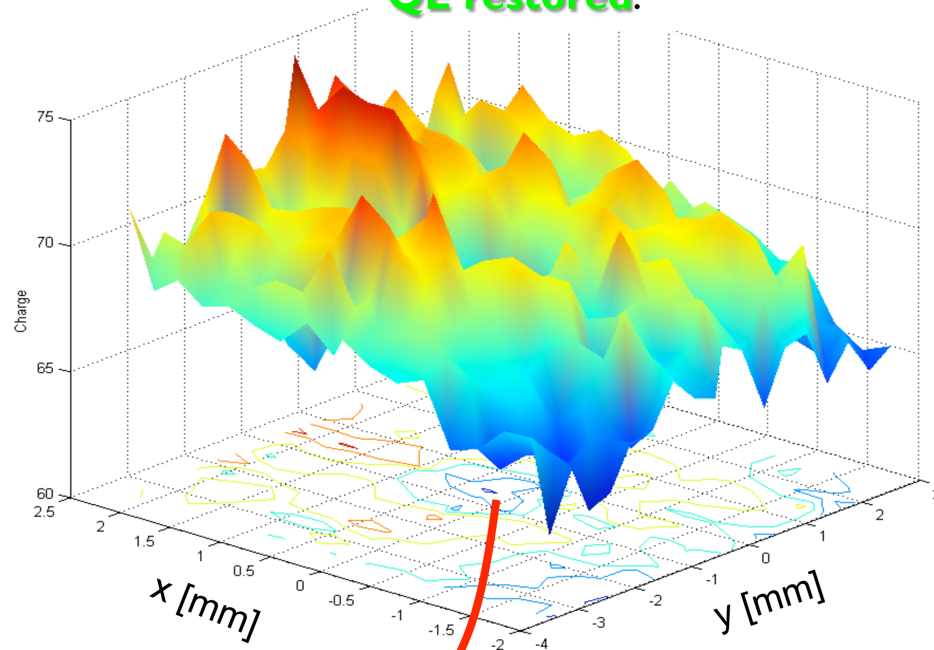
PHOTO-CATHODE

QE=2.5x10^{-5}

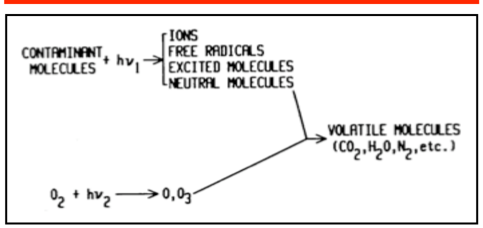
After 2 months operation:
QE depletion

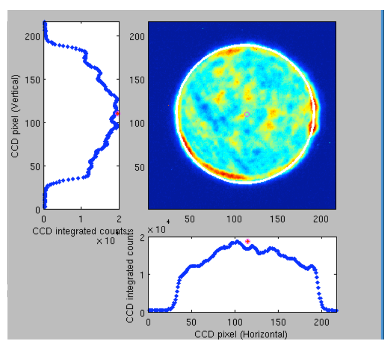


After UV/Ozone cleaning* routinely implemented at machine start-up:
QE restored.



The Cu cathode surface is sampled by a 200 μm, 10 μJ laser.

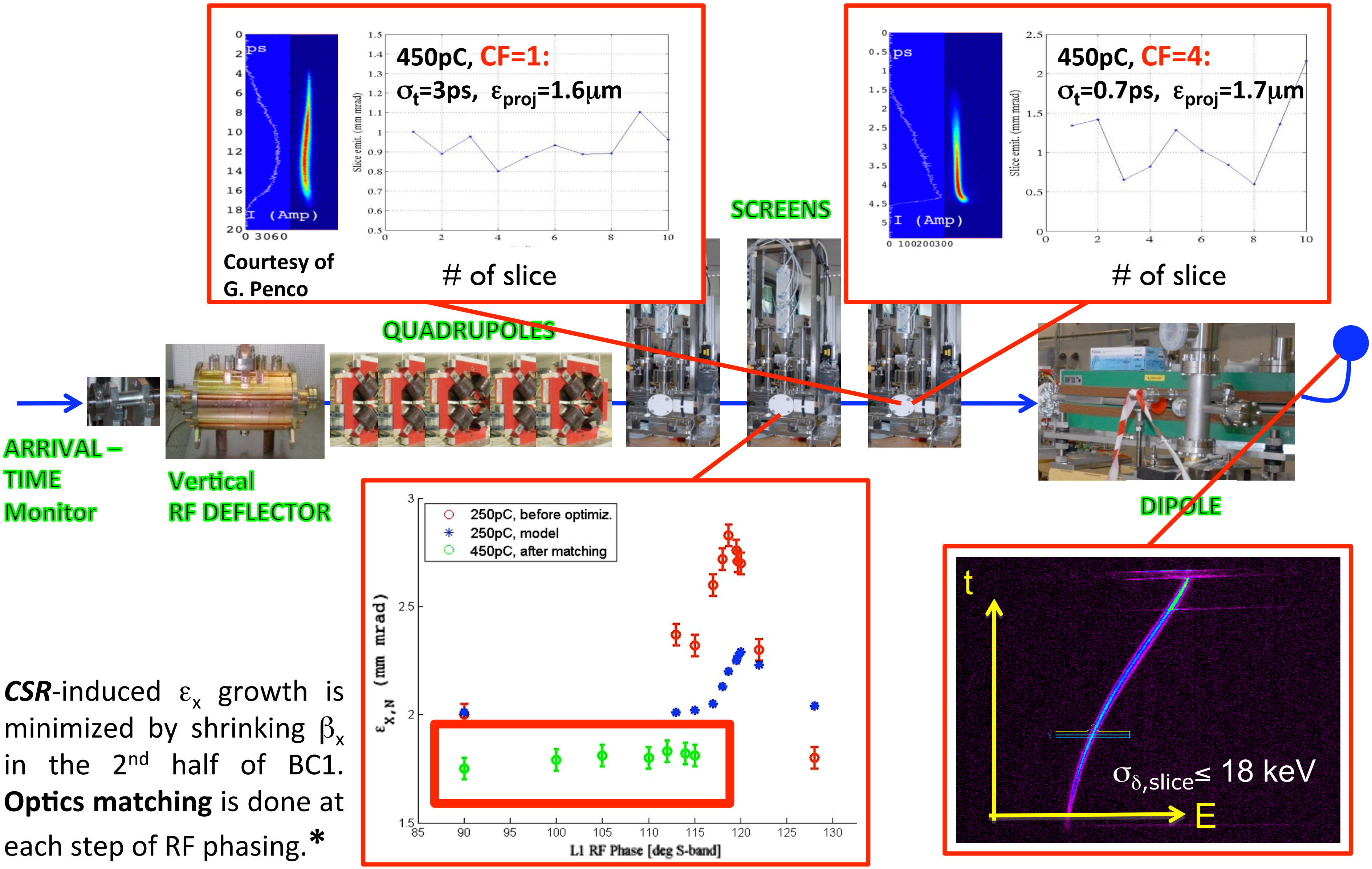




Gaussian spot (r=0.53mm) is the best compromise between cathode surface stress and emittance performance.

* see M.Trovo' et al., *Workshop on PC for RF Guns*, Lecce , Italy (March 2011).

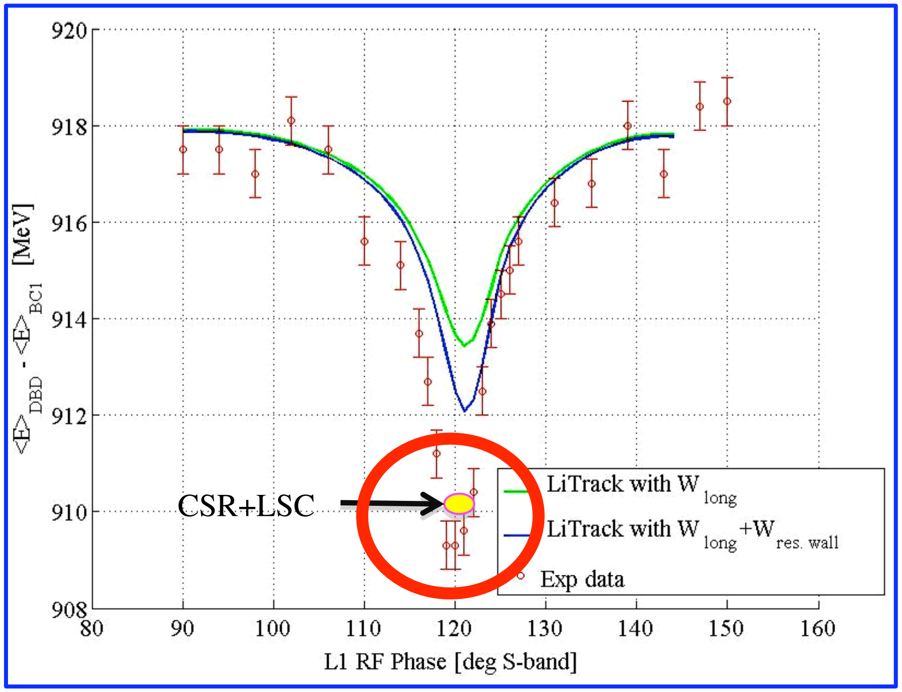
COMPRESSION & DIAGNOSTICS



CSR-induced ε_x growth is minimized by shrinking β_x in the 2nd half of BC1. **Optics matching** is done at each step of RF phasing.*

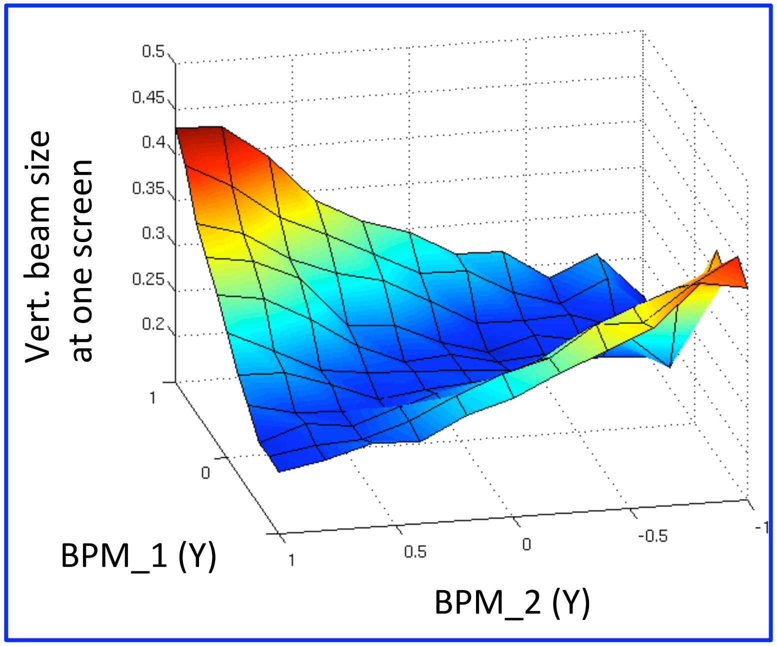
* S. Di Mitri et al., PRST-AB 15, 020701 (2012).

LINAC WAKEFIELDS



- Modeling of the linac **longitudinal wakefields** was experimentally benchmarked with **1 MeV accuracy.**

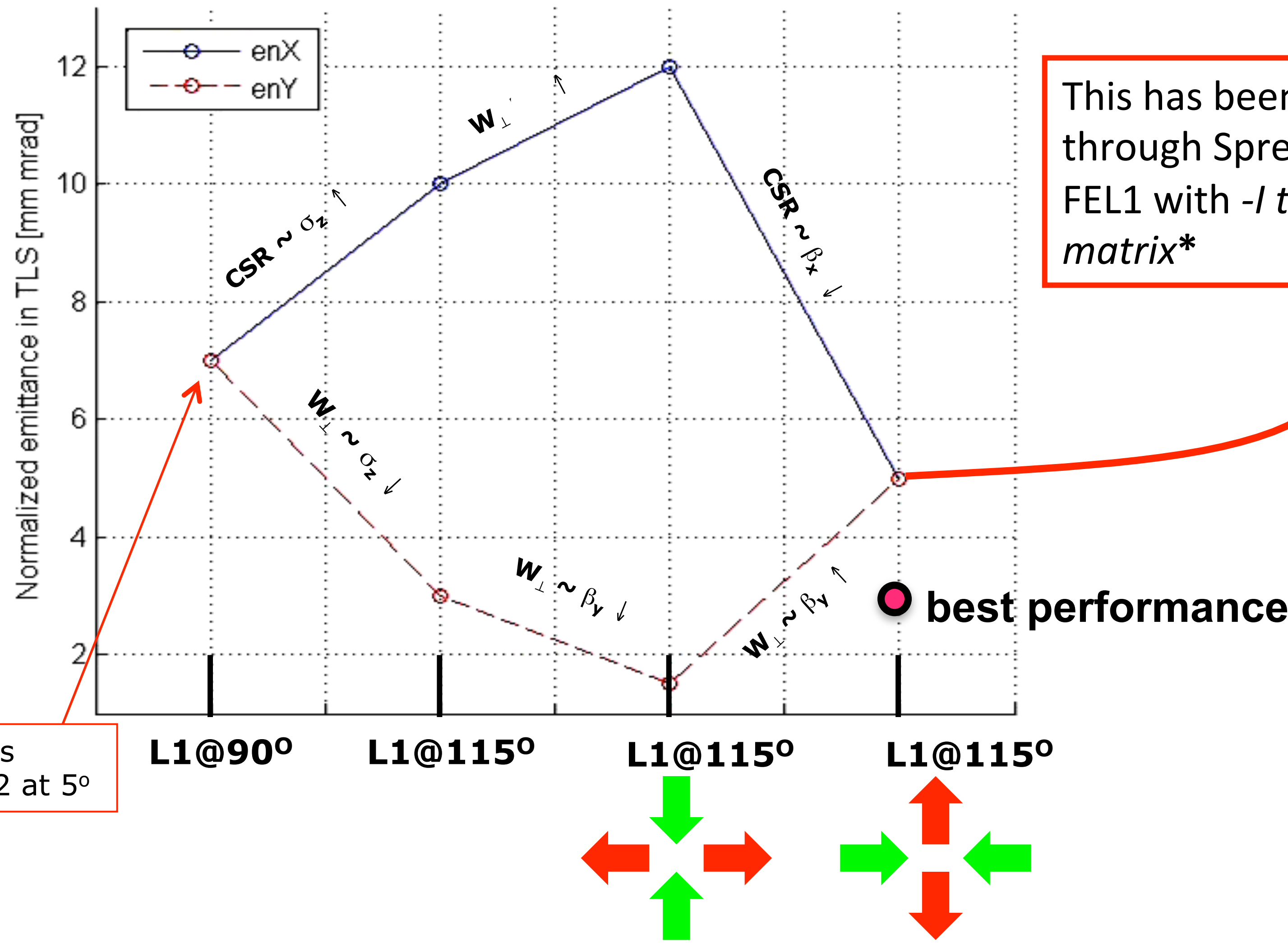
- The linac **transverse wakefields** are minimized with scans of beam size vs. **trajectory offsets**, possibly at different screens.



Courtesy of P. Craievich, E. Ferrari et al.

PROJECTED EMITTANCE

- Final proj. $\varepsilon_{x,y}$ is important for matching into the undulator, finally for a higher FEL gain. Source of degradation: CSR, transverse wakefield. Knob for restore: optics.



350pC, 6.5ps
BC1 and BC2 at 5°

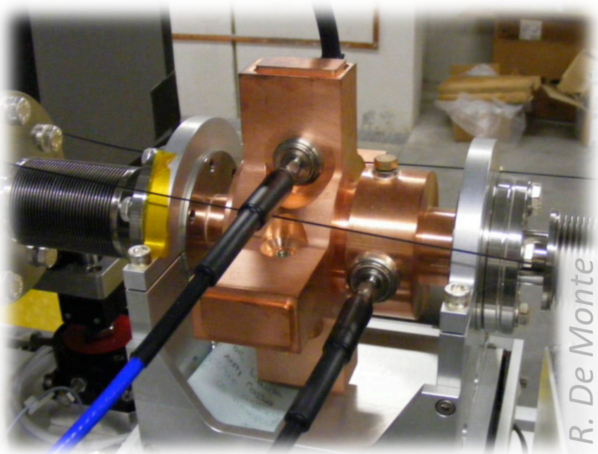
This has been preserved through Spreader and FEL1 with *-I transport matrix**

* D. Douglas, JLAB-TN-98-012 (1998).

SPECIAL DIAGNOSTICS

Cavity BPMs

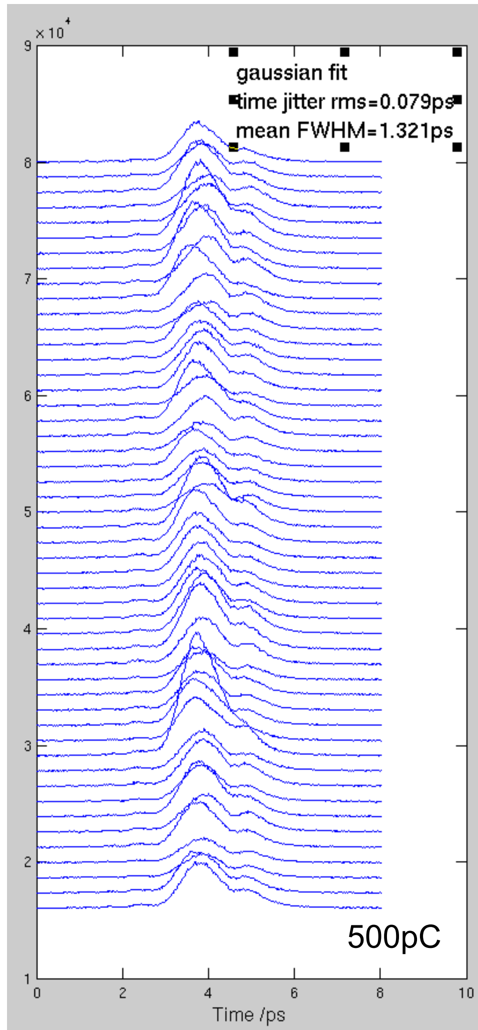
Res. 1.2 µm • Range ±1.5 mm



R. De Monte

Electro-Optical Sampling

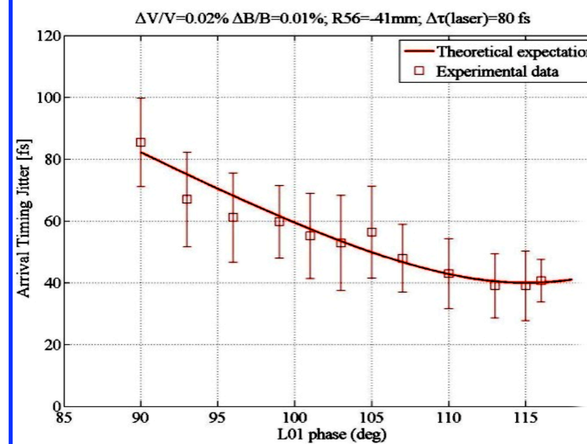
Measured jitter 80 fs



M. Veronese

Bunch Arrival Time Mon.

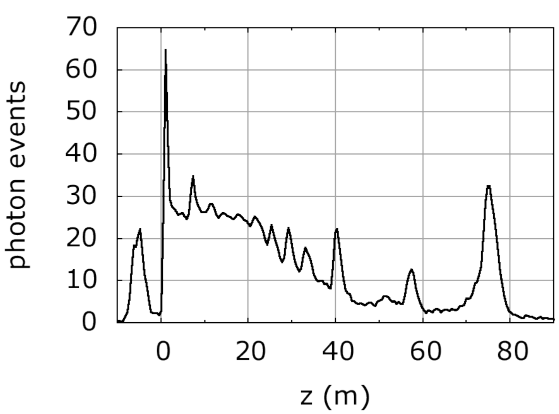
Resolution <20 fs



F. Rossi, G. Penco

Fiber Beam Loss Monitor

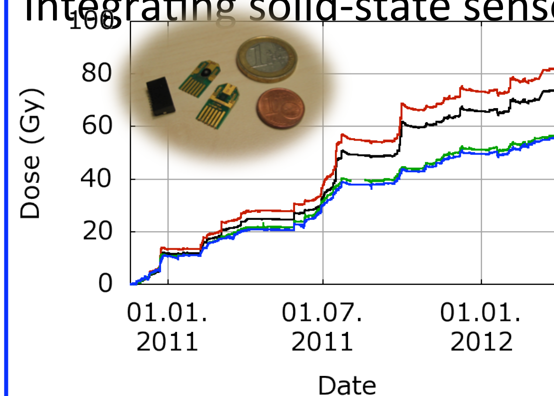
Resolution 50 cm



L. Fröhlich

RADFET Online Dosimetry

Integrating solid-state sensors



L. Fröhlich

Courtesy of L. Froehlich, R. De Monte, M. Veronese, F. Rossi , G. Penco et al.