The FERMI project @ Elettra: radiation protection and safety issues

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RADSYNCH 2009

elettra

FERMI @elettra

Outline

- Past and present layout of the Elettra facility
- The main features of the FERMI project
- Linac upgrade program
- Undulator and experimental hall
- Radiation protection criteria and dose limits
- The Personnel Safety System
- Radiation monitoring
- First benchmark of Geant4 simulation code

The original layout of Elettra

Linac working parameters:

injection energy: 1-1.2 GeV

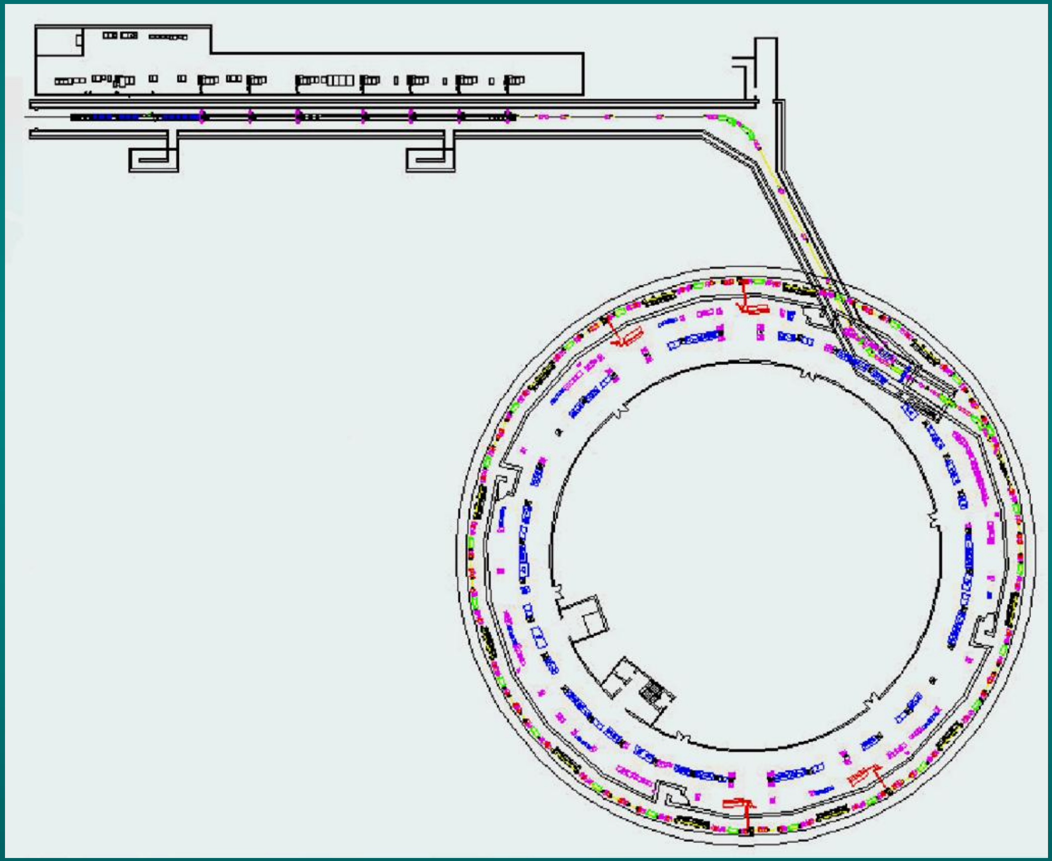
Max. average current: 0.1 μA

Repetition rate: 10 Hz

Ring operation modes (multibunch) :

Energy: 2 GeV, 320 mA

Energy: 2.4 GeV, 140 mA



The full energy injector

Linac pre-injector:

Energy: 100 MeV

Maximum charge/pulse : 3 nC

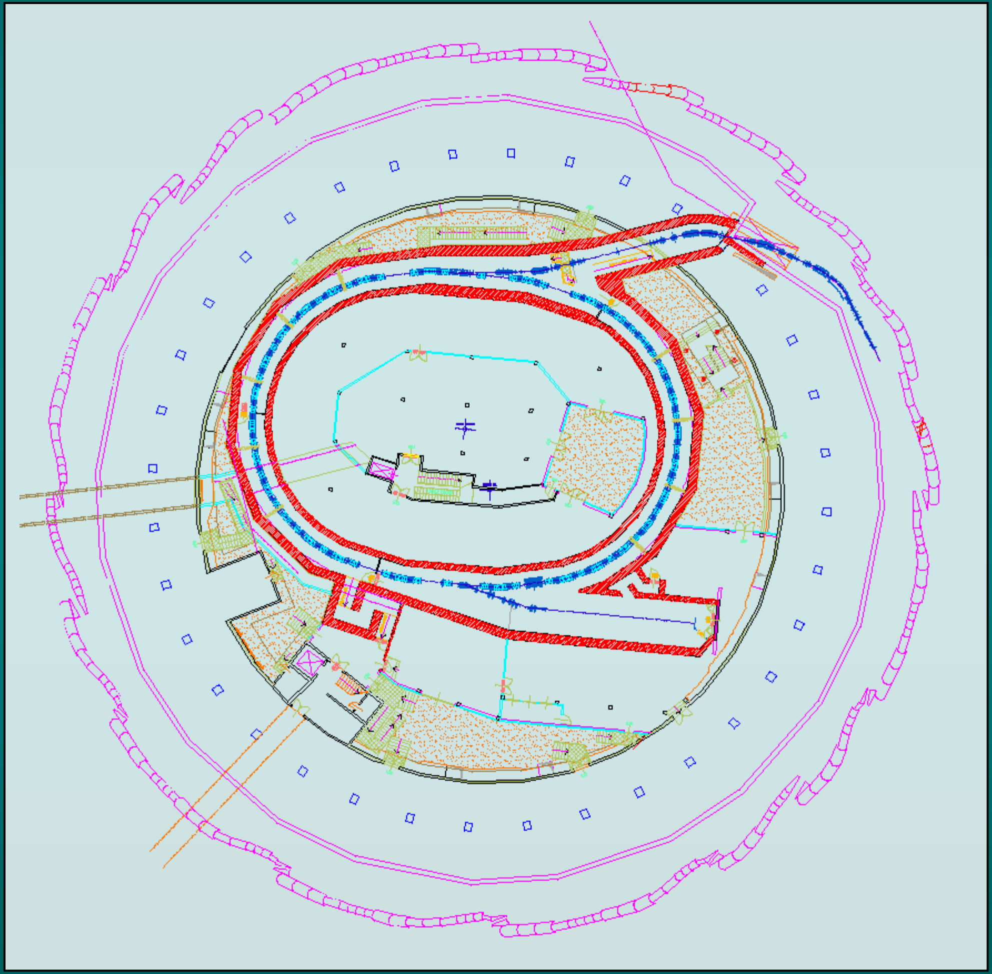
Rep. Rate: 3 Hz

Booster:

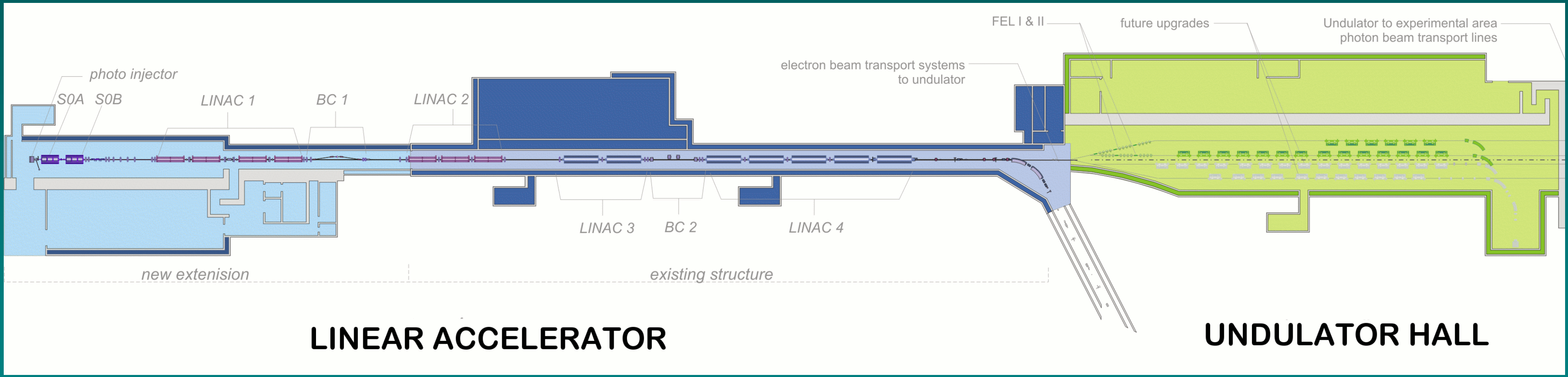
Injection energies: 2 or 2.4 GeV

Maximum injected charge/pulse: 2 nC for refill

Maximum injected charge/pulse: 0.2 nC for top-up

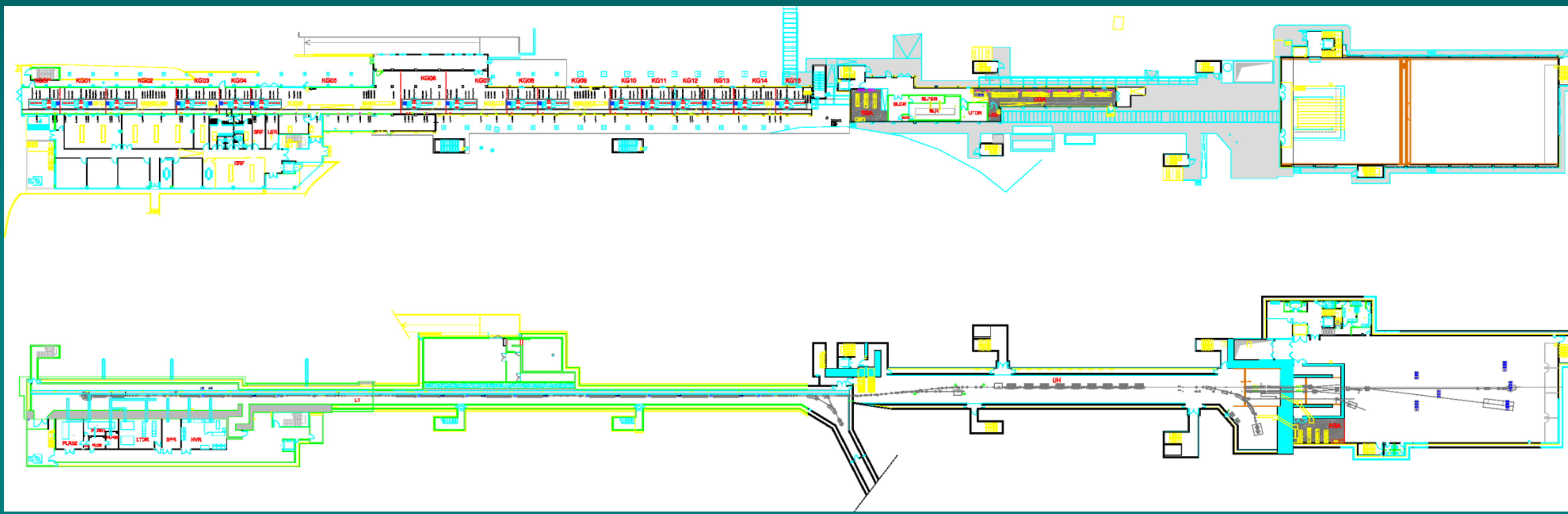


The FERMI project



FERMI - 4th generation source: single-pass seeded FEL, based upon the conversion of the original 1.2 GeV linac.

FERMI general layout



Energy: 1 ÷ 1.8 GeV

Fundamental wavelength range:

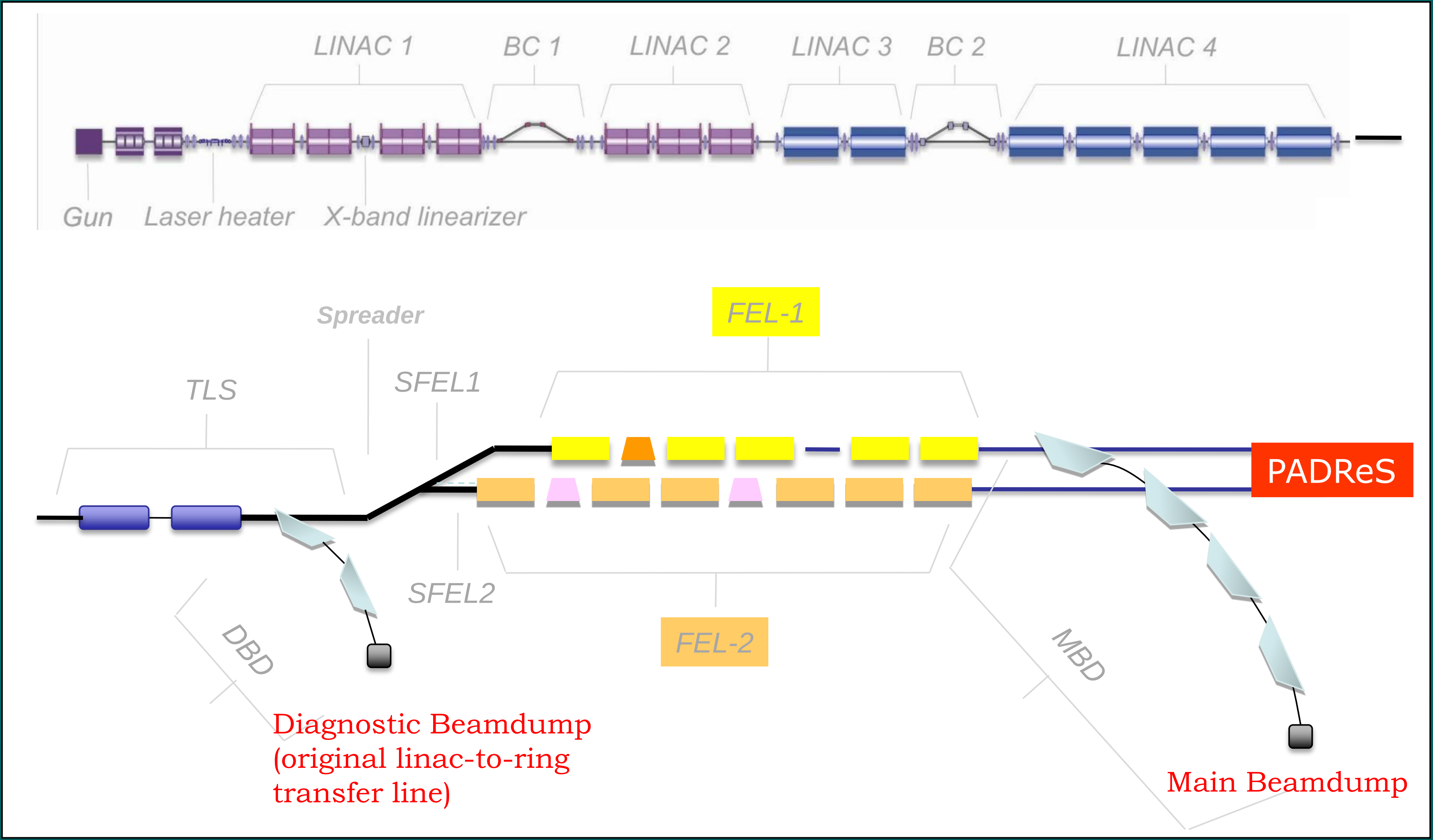
FEL 1: 100 ÷ 20 nm

FEL 2: 20 ÷ 3 nm

The linac tunnel upgrade

- Extension of the original machine tunnel gallery (upstream)
- Substitution of the termoionic gun with a high brightness photoinjector
- Addition of 7 new accelerating sections donated by CERN
- Installation of a X-band accelerating section to linearize the longitudinal phase space
- Installation of two buch compressors to increase the peak current
- Installation of a new LLRF system to stabilize the phase and amplitude of the accelerating field
- Beam energy feedbacks
- 50 Hz repetition rate (instead of the original 10 Hz, new HV modulators and RF plants)

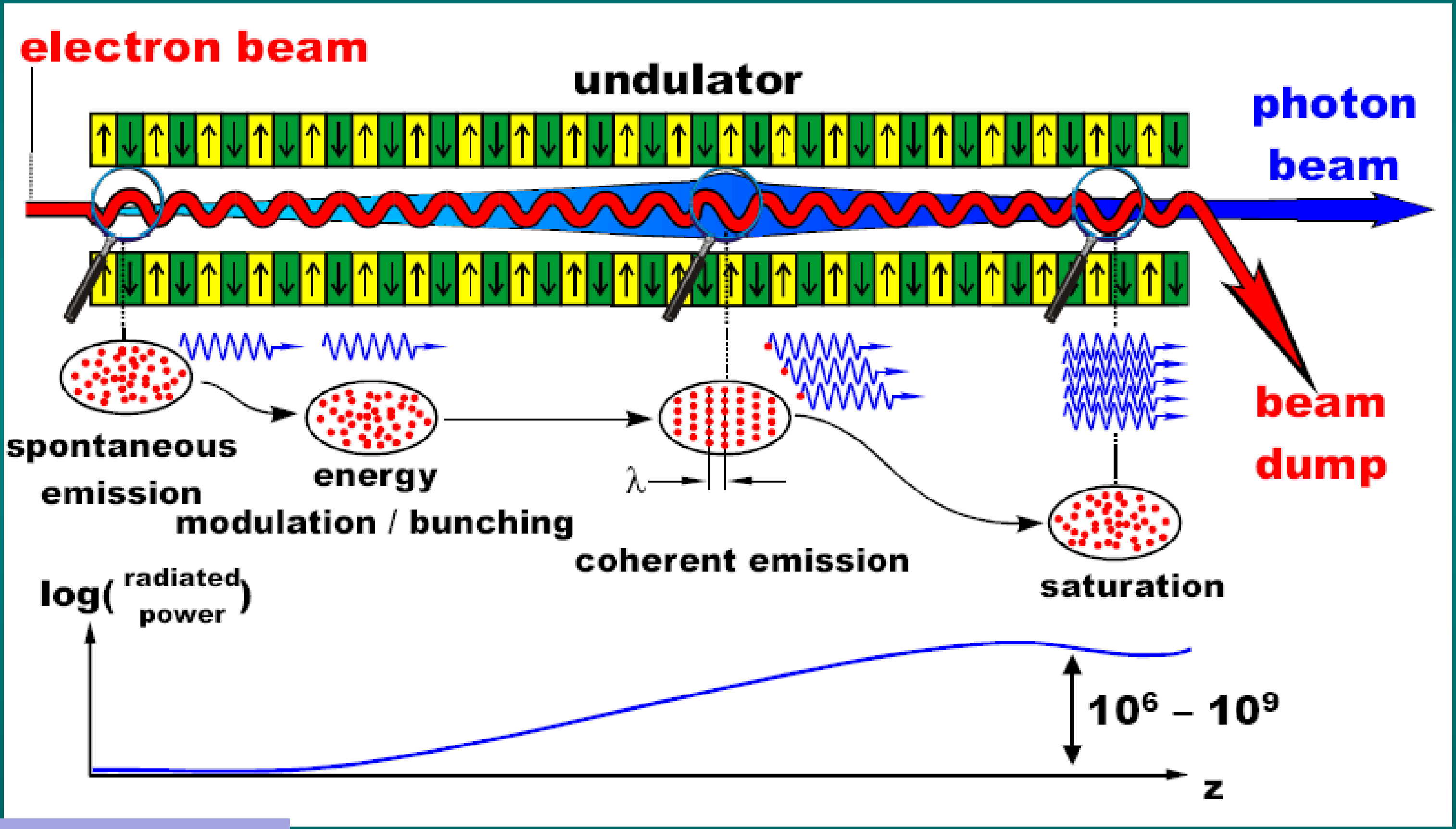
Machine layout: linac and FEL



Courtesy of Simone Di Mitri

FEL Properties – Self Amplified Sontaneous Emission (SASE)

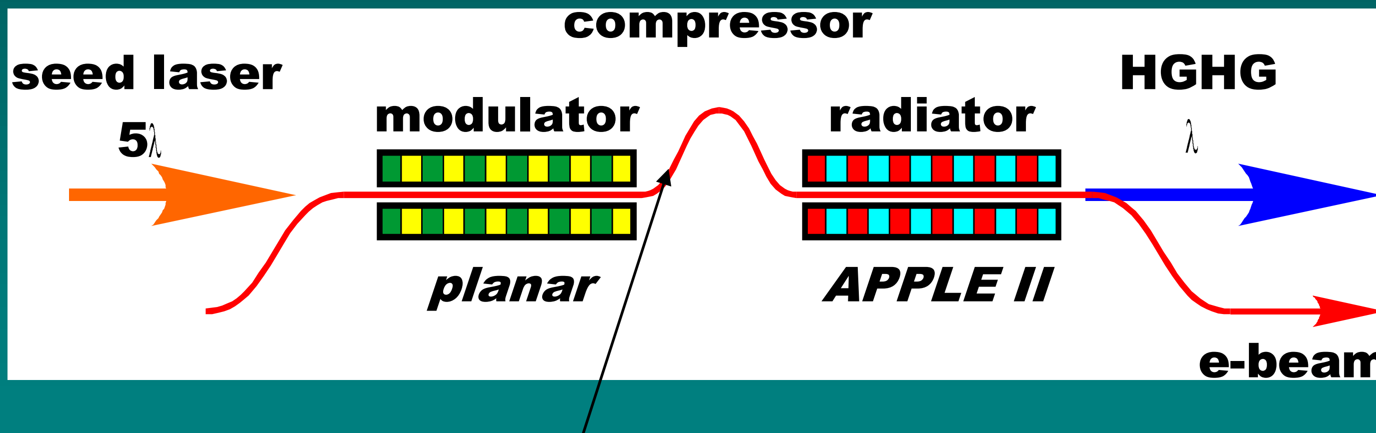
Electrons start to irradiate at the undulator entrance -> spontaneus emission -> modulation -> coherent emission
(SASE needs very long undulators)



Radiated Power:
$P \sim n_e^2$

Courtesy of Simone Di Mitri

FEL Properties High Gain Harmonic Generation - HGHG



Bunching at harmonic λ

- fully temporally coherent source
- control of pulse length
- control of spectral parameters

External seeding laser is used to enhance bunch modulation -> further modulation in undulator -> pulse compressor (to further enhance modulation) -> radiator for coherent emission tuned *at fundamental* ***or higher harmonic frequency***

This approach allows to reduce the undulator length and increase the photon energy

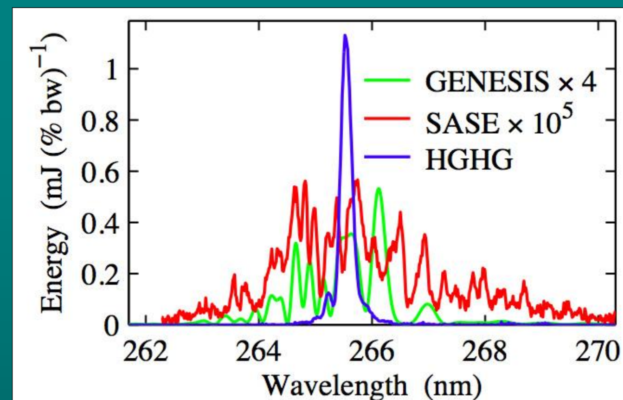


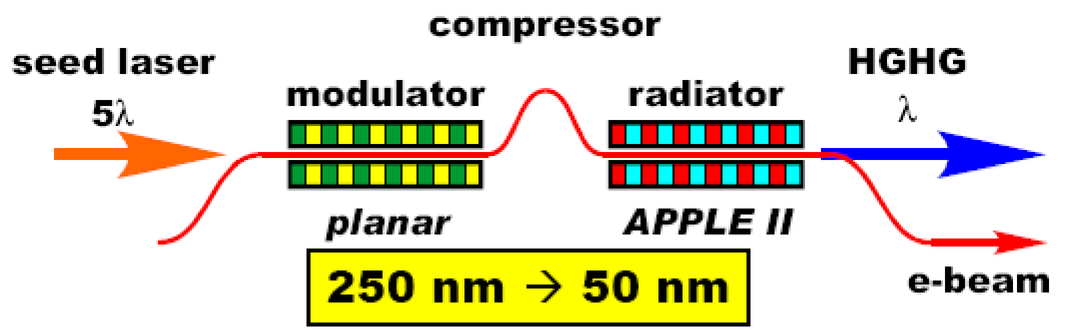
FIG. 4: Single shot HGHG spectrum for 30 MW seed (blue), single shot SASE spectrum measured by blocking the seed laser (red) and simulation the SASE spectrum after 20 m of NISUS structure (green). The average spacing between spikes in the SASE spectrum is used to estimate the pulse length.

Li-Hua Yu
DUV-FEL

Courtesy of Simone Di Mitri

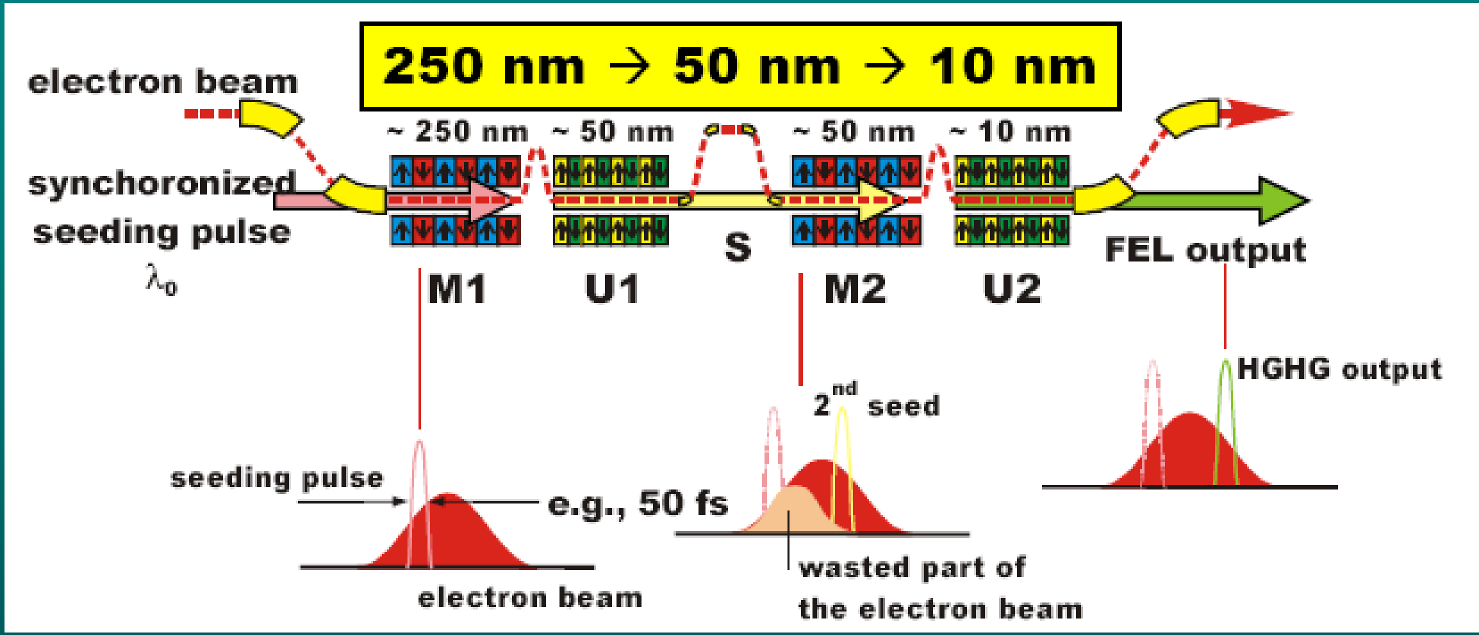
FERMI FEL

FEL1



Cascade to HGHG FELs (to further enhance modulation and emit at higher harmonics) – progressively smaller slices of beam are selected

FEL2



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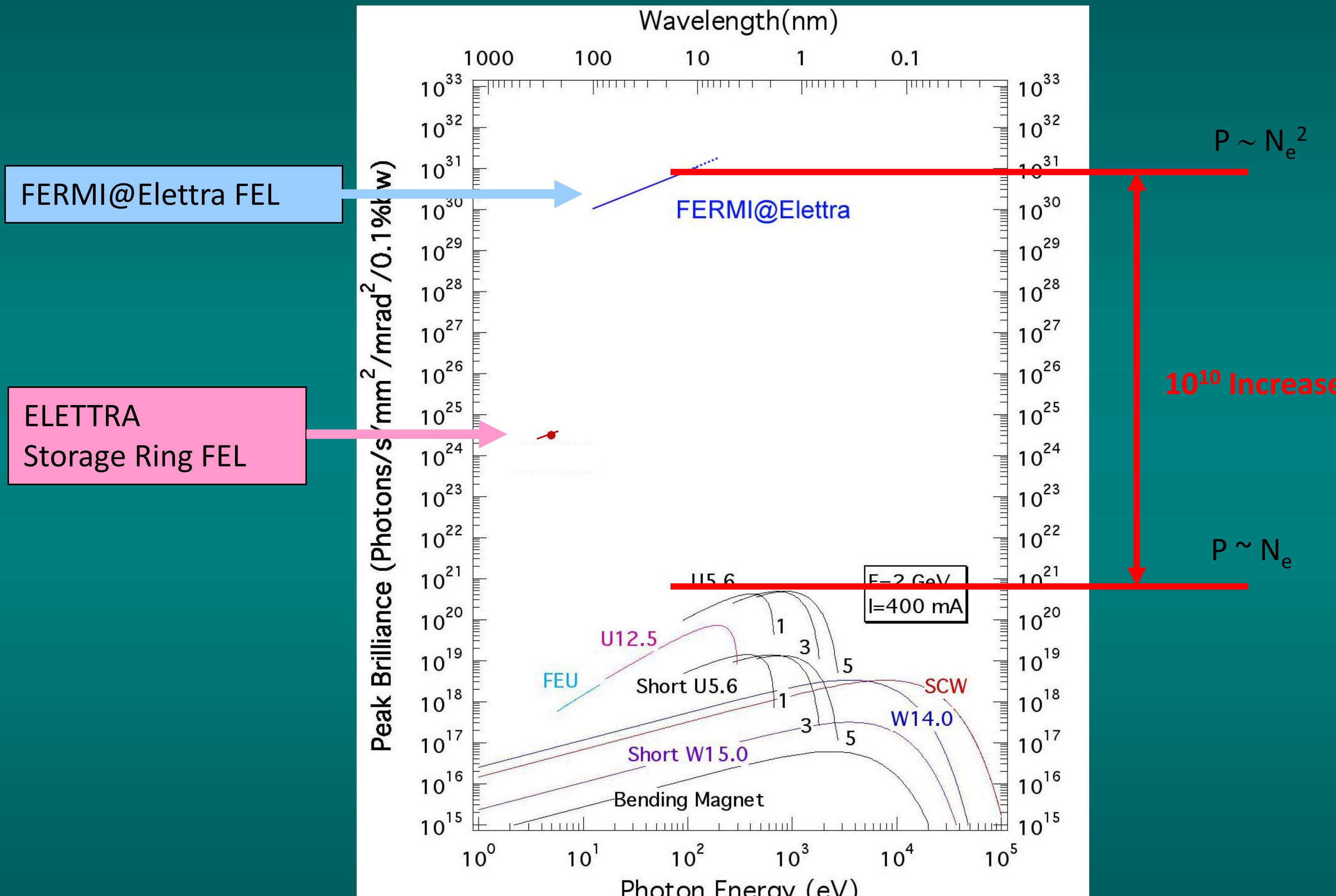
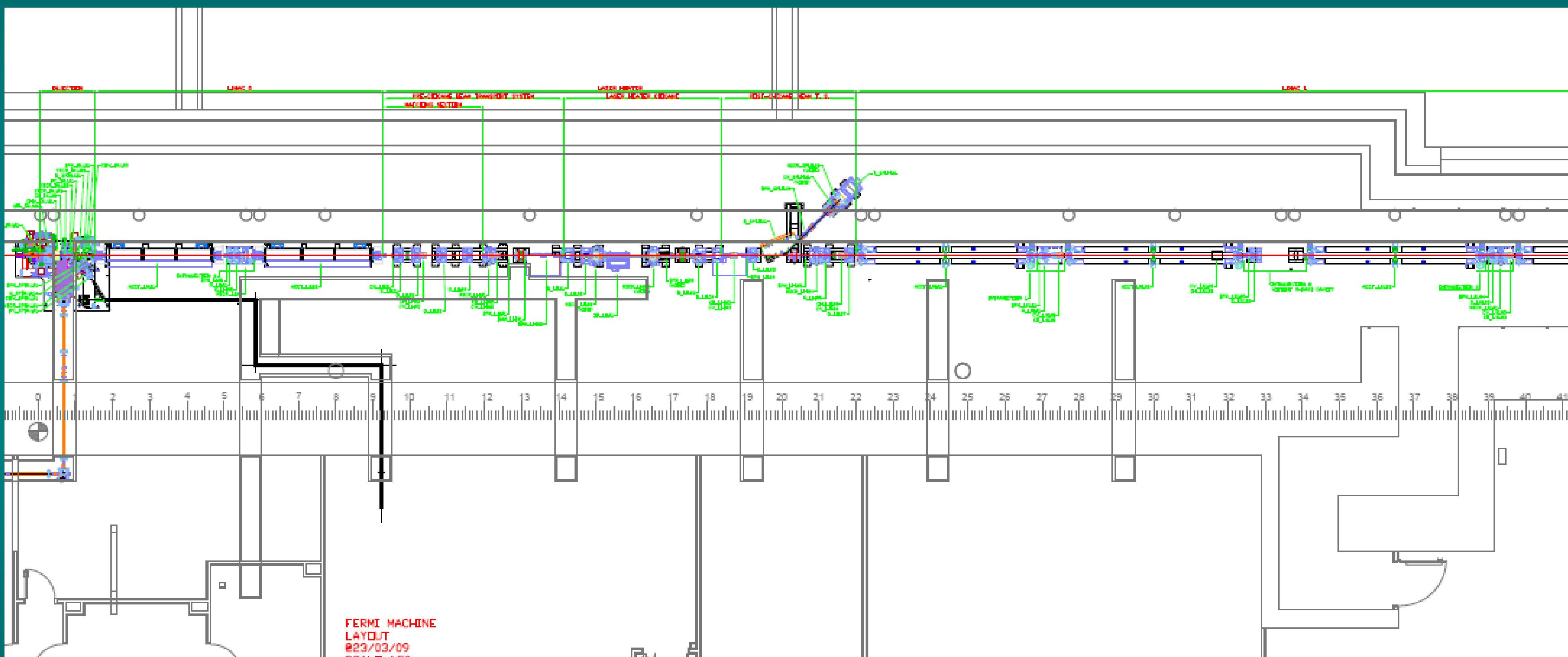
FERMI FEL

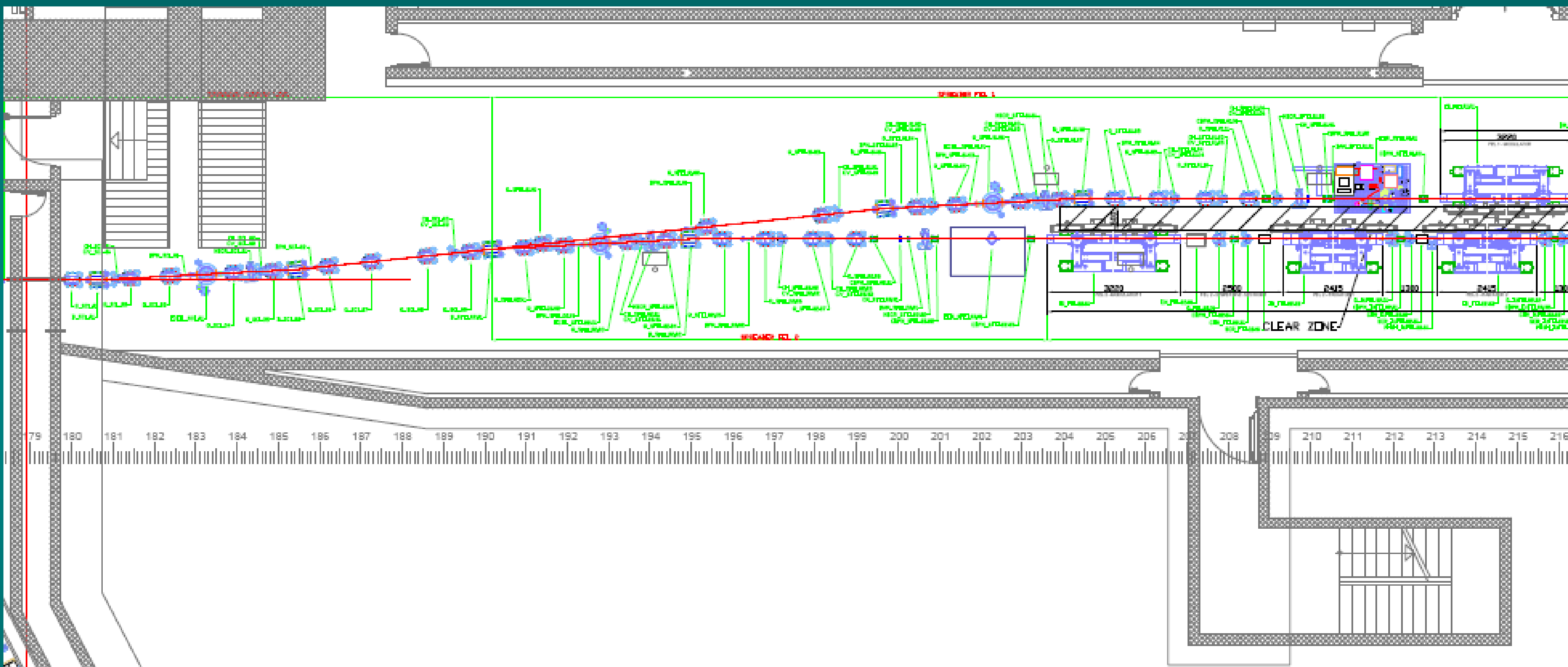


Courtesy of Simone Di Mitri

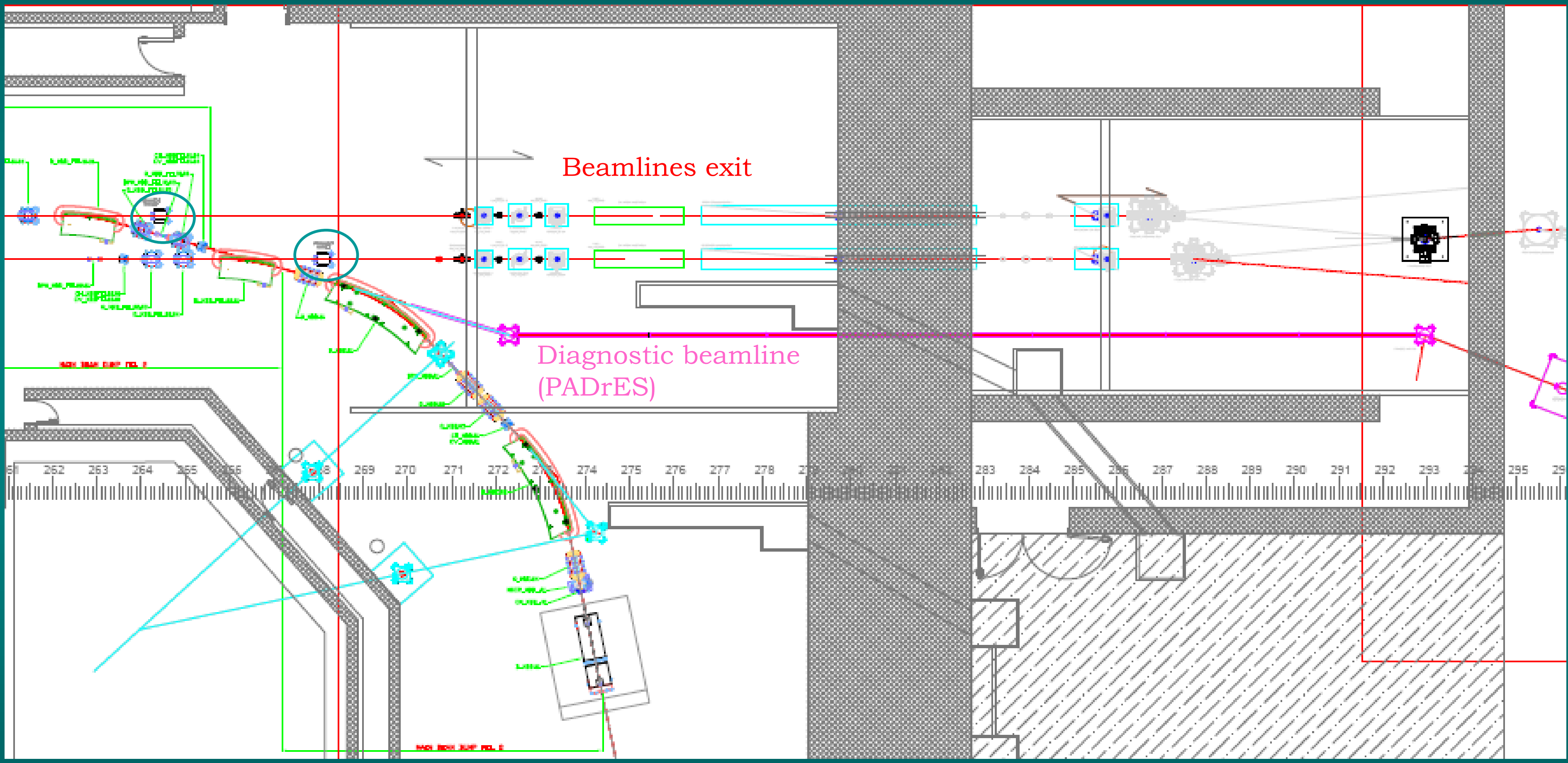
The beginning of the linac with the first 100 MeV diagnostic line



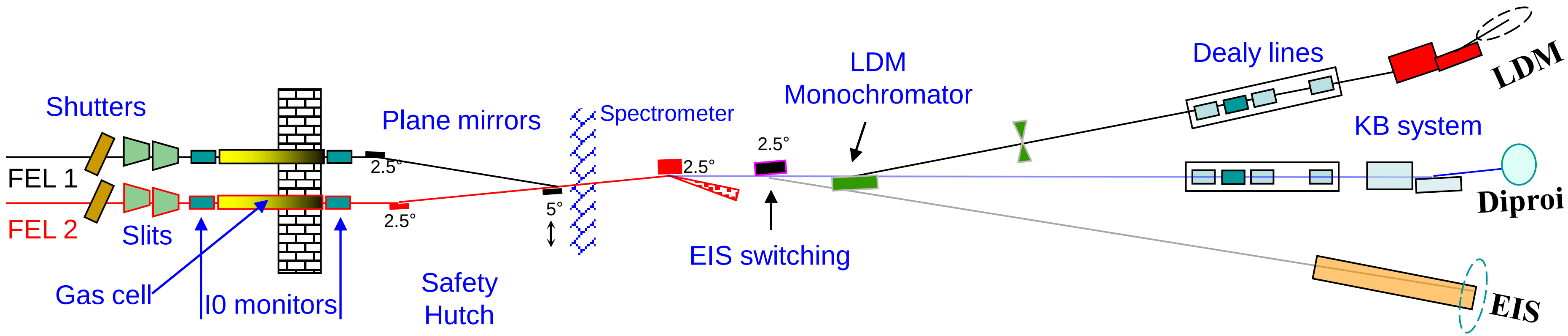
The undulator hall – spreader area



The beamdump and the beamlines frontends



Beamlines and photon diagnostic systems



PADReS (Photon Analysis Delivery & Reduction System) photon diagnostic will measure:

- Intensity: On line; Shot by shot; 1% repeatability, 2-3% precision (calibration dependent)
- Angular position: On line; Shot by shot; ~2 μrad sensibility
- Divergence: NOT On line; NOT Shot by shot; based on YAG crystal meas.
- Photon energy distribution: On line; Shot by shot; Single spectrometer, 12-360 eV sub mV resolution.

Beamlines

DIPROI: Diffraction and Projection Imaging
EIS: Elastic and Inelastic Scattering
LDM: Low Density Mater

The linac shielding design - original

Parameters considered for the Linac as Elettra injector (1992):

- maximum acceleration energy: 2 GeV
- max average current: 0.1 μA
- acceleration efficiency: 20%
- beam loss scenario: continuous total beamloss at the end of the linac and along the linac-to–ring transfer line during beam injection
- free area, full occupancy outside the tunnel. Dose limits: 0.1 mSv/year

Shielding thickness (roof)

0 - 600 MeV -> 2 m ordinary concrete ($\rho = 2.3\ g/cm^3$)

Higher than 600 MeV:

0.65 m ordinary concrete ($\rho = 2.3\ g/cm^3$) +

1.35 m heavy concrete ($\rho = 3.6\ g/cm^3$)

Shielding requirements for FERMI

- Shielding of the upstream extension of the linac tunnel:
  - Kept the same thickness of the first 600 MeV i.e. 2 m ordinary concrete
- Radiation Protection assumptions for the undulator hall:
  - Energy & current: same as for the previous linac (2 GeV, 0.1 μA)
  - Beam loss scenario: 100% beamlosses at beamstopper, scrapers, at spreaders, at BPMs, along the undulator sections……
- Criteria for the shielding power of the tunnel roof:
  - Free area with full occupancy anywhere -> thickness = 2.5 m ordinary concrete
- Criteria for the undulator hall shielding wall:
  - Free access area with low occupancy (1/16) in the vicinities of the shielding wall
  - Free access area with full occupancy at the user stations -> thickness = 3 m ordinary concrete

Areas classification and yearly dose limits

			(*)
Controlled areas	Machine tunnel with linac in *stand-by* *(access controlled by safety system)* Delimited areas close to activated components and beamdumps with linac in *shutdown* Delimited regions around modulators	5 mSv	20 mSv
Supervised areas	Laser hall and Service area during commissioning	2 mSv	6 mSv
Free (not classified)	Experimental hall – low permanence areas	0.5 mSv	1 mSv
Free (not classified)	Experimental hall – user stations Laser hall and Service area during normal operation	0.1 mSv	1 mSv

(*) Limits for personnel and public established by Italian regulations in compliance with the European/Euratom instructions

The FERMI Personnel Safety System (PSS)

- PSS is based on Programmable Logic Circuits (PLCs) of high safety level (class 4).

  Main characteristics:
  - Redundancy
  - Fail safe phylosophy
  - Diversification of actuators/controls

The FERMI Personnel Safety System (PSS)

- **Elements controlled by PSS:**
  - photo-injector modulator
  - klystron modulators feeding the accelerating sections

  Determine the access conditions to machine tunnel

  - beamstopper at the end of the linac
  - beamstopper at the beamlines front-end
  - gamma monitors status

  Define the conditions to enter the beamlines hutch

  - HV power supply of bending magnets
  - Toroids for measuring the beam current in the transfer-line to the dump.

  Give the consent to open the beamlines beamstoppers

- **Additional passive safety elements:** permanent magnets, used (as third level) to prevent accidental beam channeling into the beamlines

Radiation monitors (ELSE)

Gamma dosimeters (interlocked with PSS)

- type: pressurized ionization chamber Ar6.4-N9.6 (16 atm)
- model: Centronic Mod. IG5
- response as a function of energy:
  - 80 keV - 120 keV: ±20%
  - 120 keV - 2 MeV: ±5%
- equivalent doserate range:
  0.01 μSv/h – 0.1 Sv/h (7 decades)
- environmental conditions: 0÷ 50°C
- precision on environmental doserate measurements: ± 5%
- automatic change of scale based on microprocessor
field
- good behavior in a pulsed radiation field (talk by M.Ballerini)

Neutron monitors

- type: Rem counter (BF_3)
- model: FAG Biorem
- energy range: 0.025 eV – 15 MeV
- equivalent doserate range: up to 0.4 Sv/h

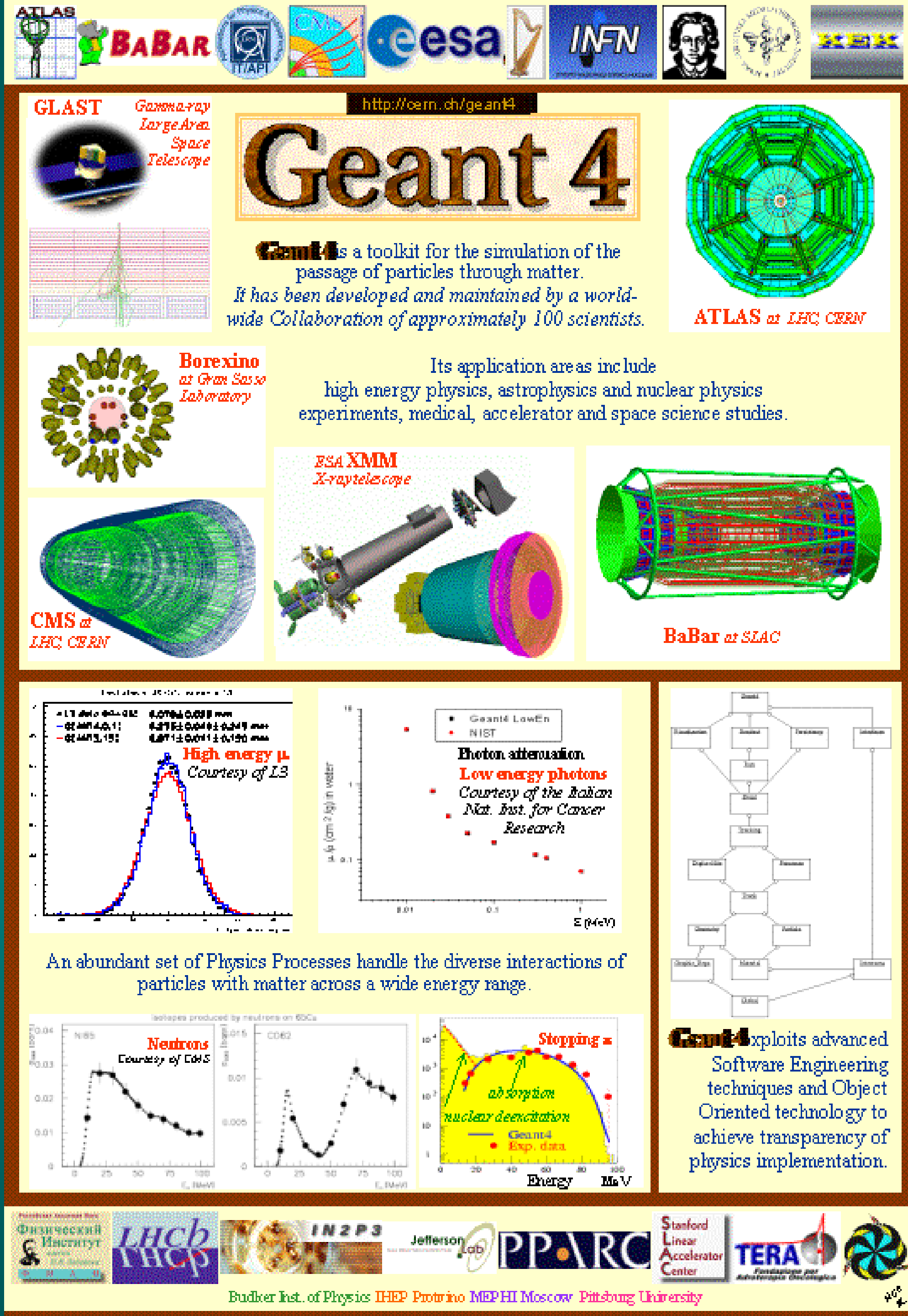
Future activities

- Definition of shielding around the first mirror in the beamlines hutch
- Positioning of local shielding in the tunnel to reduce the channeling of secondaries into the beamlines pipes
- Evaluation of shielding in the vicinities of ducts for lasers and cables
- Estimate of induced radioactivity

Need to validate a Montecarlo code able to simulate complex geometries

Geant 4

- Geant4 is the successor of GEANT3, the world-standard toolkit for HEP detector simulation.
- Geant4 is one of the first successful attempt to re-design a major package of HEP software for the next generation of experiments using an Object-Oriented environment.
- A variety of requirements have also taken into account from heavy ion physics, CP violation physics, cosmic ray physics, astrophysics, space science and **medical applications**.
- In order to meet such requirements, a large degree of functionality and flexibility are provided.
- **G4 is not only for HEP but goes well beyond that.**



Benchmark of semi-empirical formulas vs. experimental measurements and **Geant 4** simulations

(I preliminary validation)

thanks to the support of Francesco Longo

Available approaches for gamma Source Term:

- W. P. Swanson, “Radiological safety aspects of the operation of electron linear accelerators”, Technical Reports Series N. 188, IAEA, 1979
  → utilized for doserate evaluation at 0° and 90°

- G.Tromba, A.Rindi, M.Favretto, “The Shielding of Electron Accelerators : A Montecarlo Evaluation of Gamma Source Terms”, Proc. of 2nd European Particle Acc. Conference, 1990
  → utilized for doserate evaluation at 0° and 90°

- X. S. Mao et al., “90 degrees Bremsstrahlung Source Term Produced in Thick Targets by 50 MeV to 10 GeV Electrons”, SLAC-PUB-7722, January 2000
  → utilized for doserate prediction at 90°

- V. Vylet, J. C. Liu, “Radiation Protection at high energy electron accelerators”, Rad. Prot. Dos., V.96, No. 4, 2001.
  → utilized for doserate prediction at various angles

Experimental measurements layout

50 cm thick concrete shielding

E = 0.91 GeV

Cilindrical Target (BST): Cu

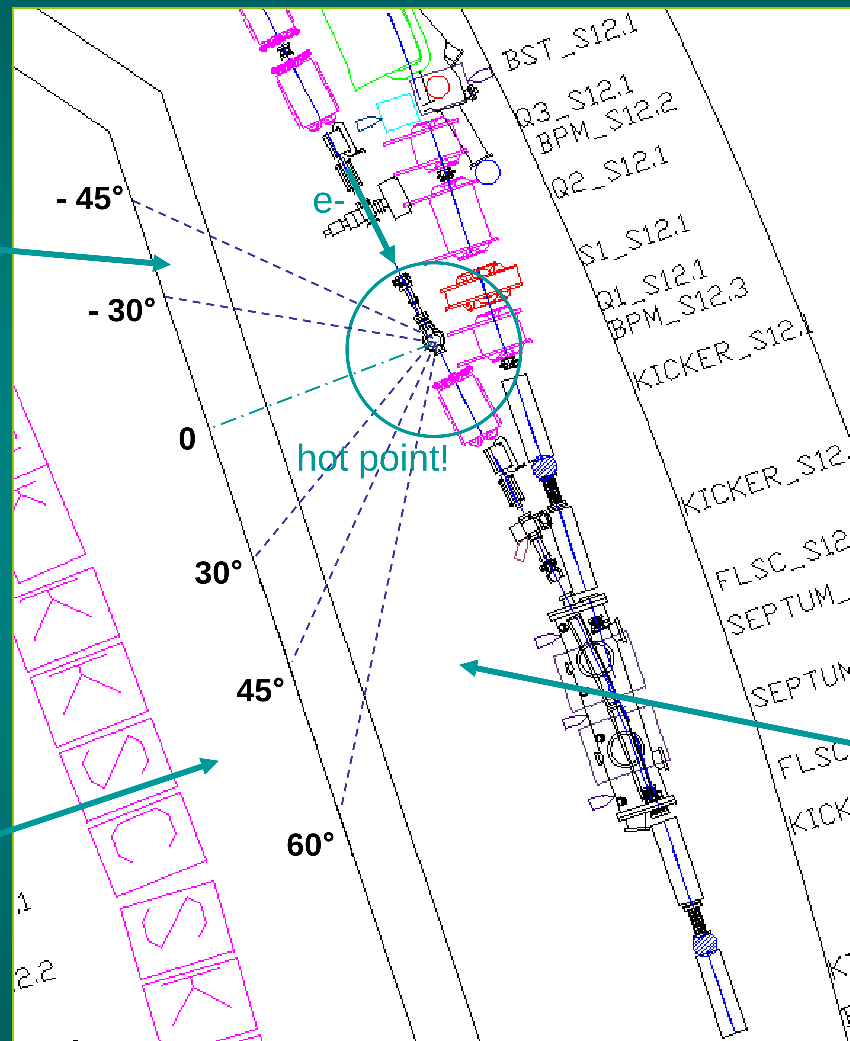
Diameter and height = 8 cm

Pulse length: 70 nsec

Current/pulse: 1 – 8.5 mA

Repetition rate: 10 Hz

(tests performed in 2002 and reported at RADSYNCH02, ESRF)



machine tunnel

Elettra Service Area

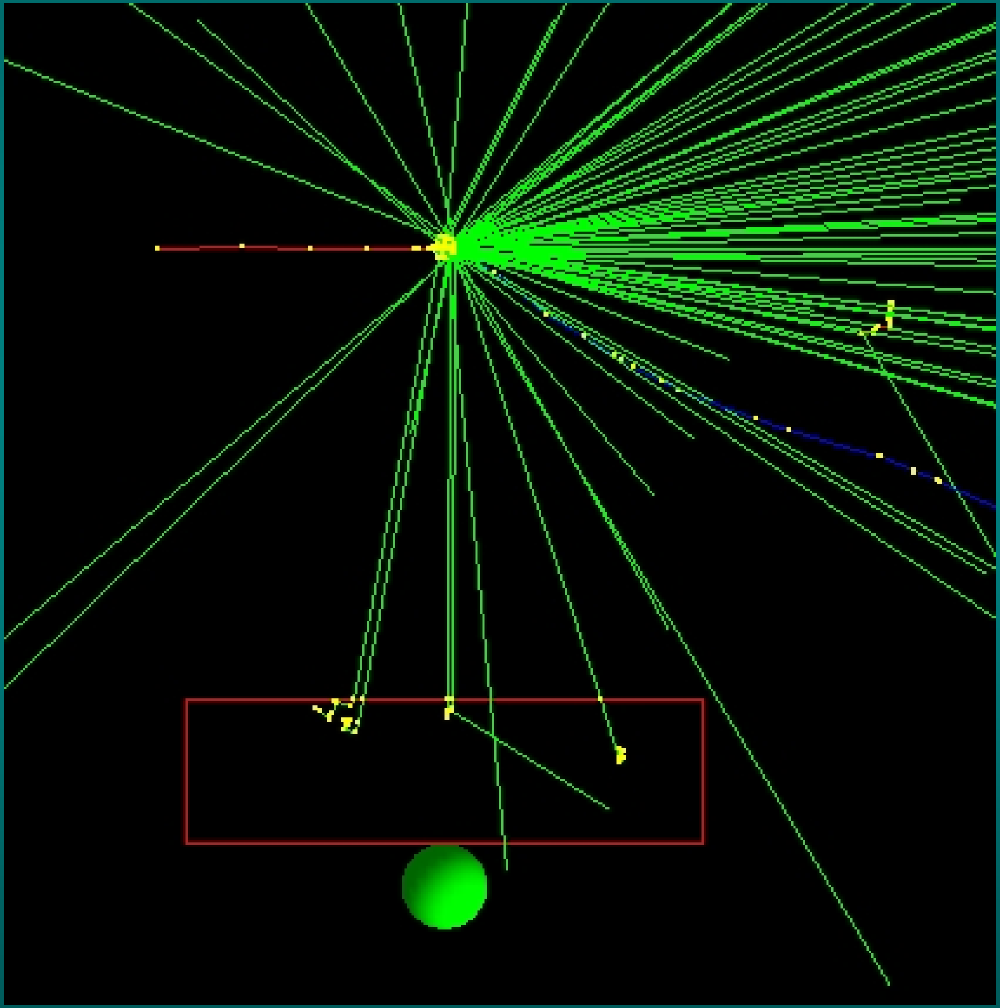
PTW ionization chambers characteristics

	PTW model 32002	PTW model 32003
Volume	1.000 cm^3	10.000 cm^3
Response	$3 \cdot 10^{-5}$ C/Gy	$3 \cdot 10^{-4}$ C/Gy
Leakage	$\pm 1 \cdot 10^{-14}$ A	$\pm 1 \cdot 10^{-14}$ A
Polarizing voltage	max. 400V	max. 400V
Cable leakage	$5 \cdot 10^{-12}$ C/(Gy·cm)	$5 \cdot 10^{-12}$ C/(Gy·cm)
Wall material	POM $(CH_2O)_n$	POM $(CH_2O)_n$
Wall thickness	3 mm	3 mm
Area density	470 mg/cm2	470 mg/cm2
Range of temperature	+ 10° C …. + 40° C	+ 10° C …. + 40° C
Ion collection time	300 V: 52 ms 400 V: 39 ms	300 V: 0.22 s 400 V: 0.16 s

		PTW model 32002		PTW model 32003	
Saturation behaviour	Polarizing voltage	99% saturation	99.5% saturation	99% saturation	99.5% saturation
Max dose rate at continuous irradiation	300 V 400 V	0.25 Gy/h 0.44 Gy/h	0.12 Gy/h 0.22 Gy/h	14 mGy/h 25 mGy/h	7.1 mGy/h 13 mGy/h
Max dose per irradiation pulse	300 V 400 V	2.4 μGy 3.2 μGy	1.2 μGy 1.6 μGy	0.57 μGy 0.76 μGy	0.29 μGy 0.38 μGy

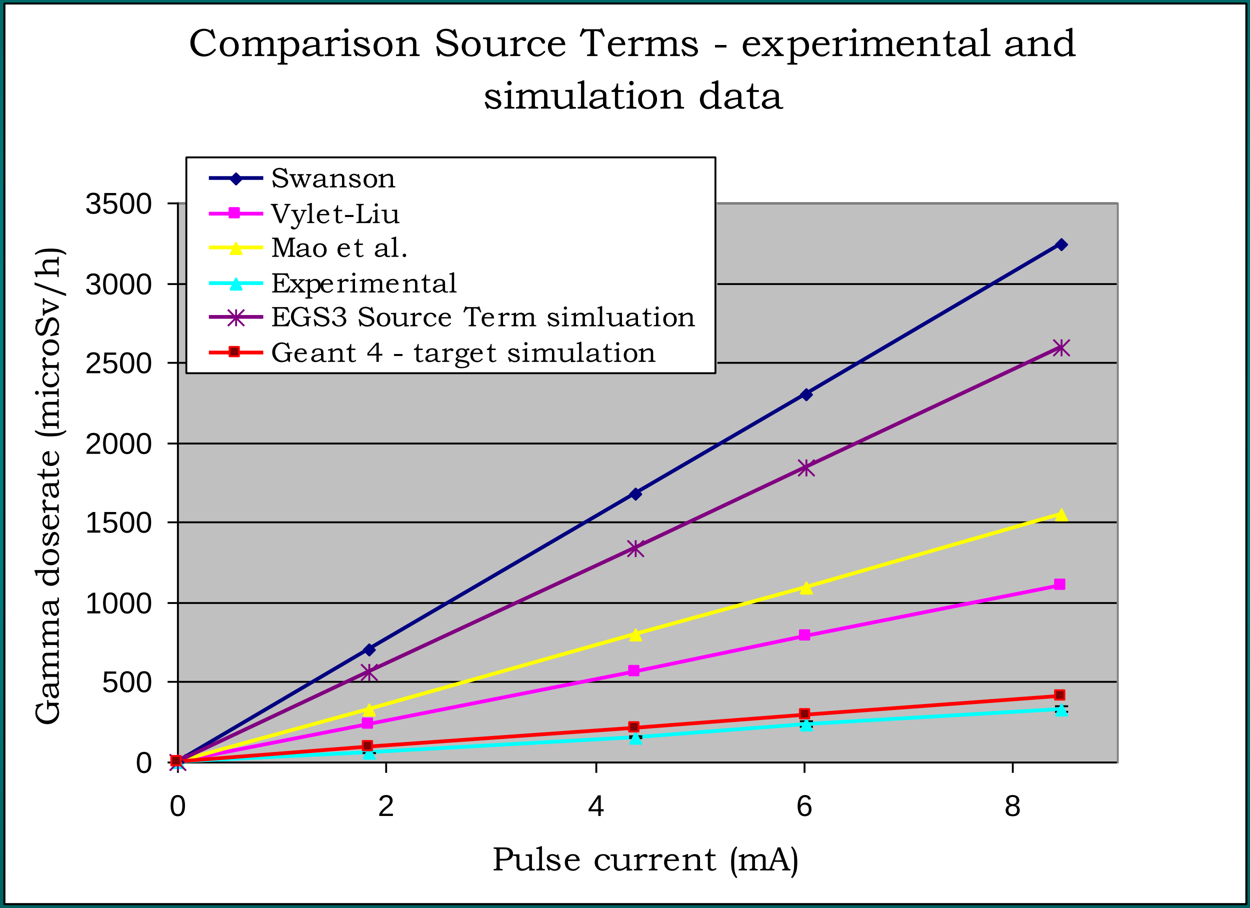
Simulated geometry

1 event



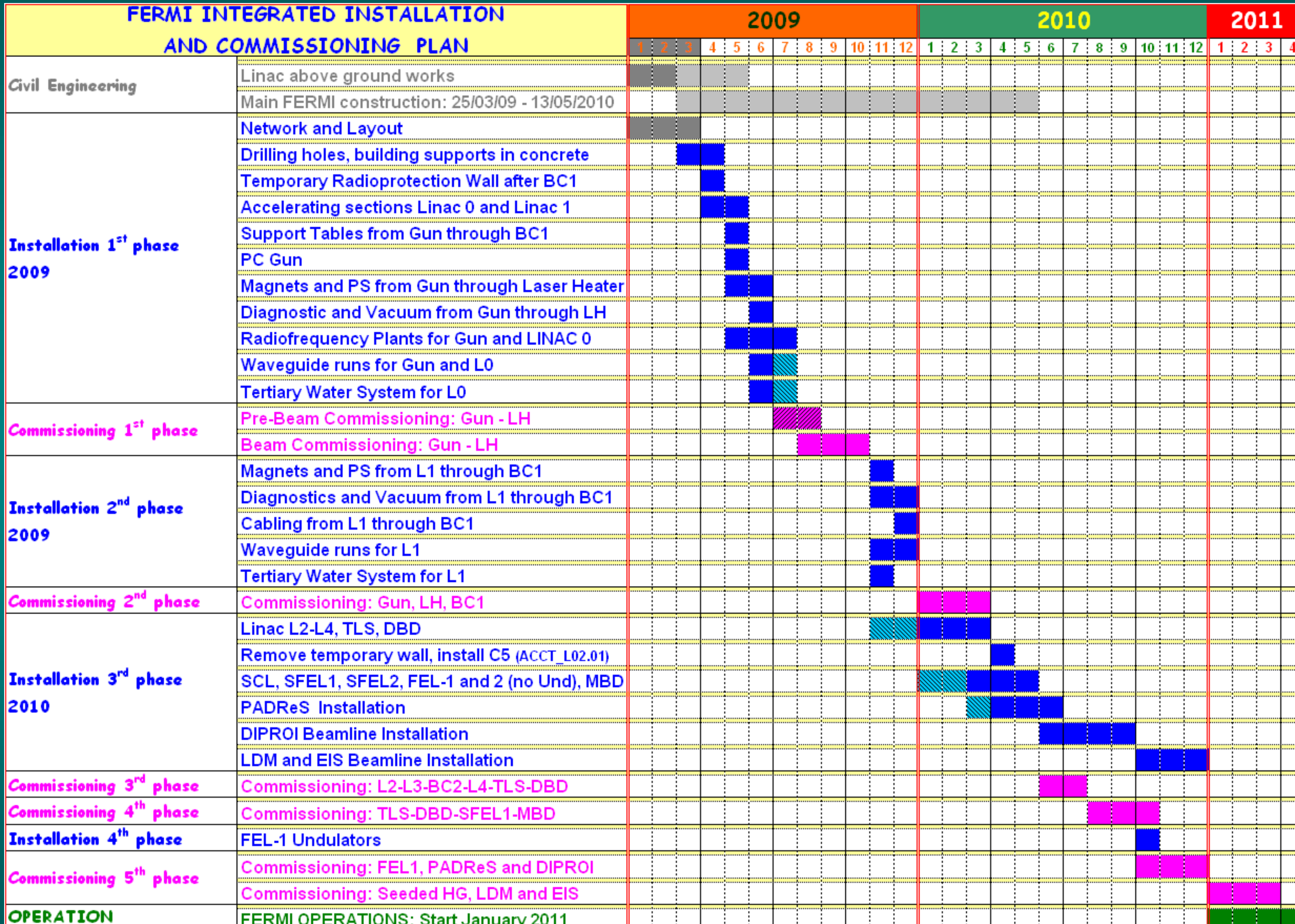
gammas
electrons
positrons

Benchmark results (preliminary)



Method	Ratio (with respect to exp. data)
Swanson	10.4
EGS3 simulation of ST	8.3
Mao et al.	~ 5
Vylet/Liu	~ 3.5
Geant4 simulation of the **real** target (BST)	1.3

FERMI time schedule



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