Sapienza Università di Roma

INFN Istituto Nazionale di Fisica Nucleare
Sezione di Roma

Dipartimento di Scienze di Base e Applicate per l'Ingegneria

PhD theses at SBAI (Basic and Applied Sciences for Engineering) – Sapienza and INFN-Roma1

M. Migliorati

Group at Department of Basic and Applied Sciences for Engineering

- Luigi Faillace, Luca Ficcadenti (INFN-Roma1), Mauro Migliorati, Andrea Mostacci, Luigi Palumbo, Massimo Petrarca + some PhD and master students.

- Our group has a long-standing tradition of work in particle accelerators and collective effects. We have close collaborations with UCLA, CERN and INFN.

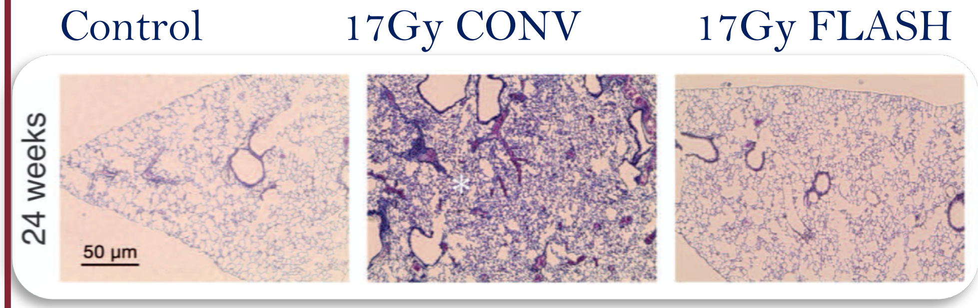
- We have expertise in:
  - design of devices for Linacs and circular accelerators
  - beam dynamics and development of simulation codes
  - collective effects and electromagnetic beam-environment interactions
  - Laser-plasma acceleration
  - RF characterization of accelerator devices

Flash Therapy

FLASH THERAPY is a new method for cancer treatment using Linacs and consisting in delivering very high doses in short time intervals:

- μs pulses of radiation,
- beam-on time < 100-500ms
- high dose per pulse → very high dose rate (>100 Gy/s)

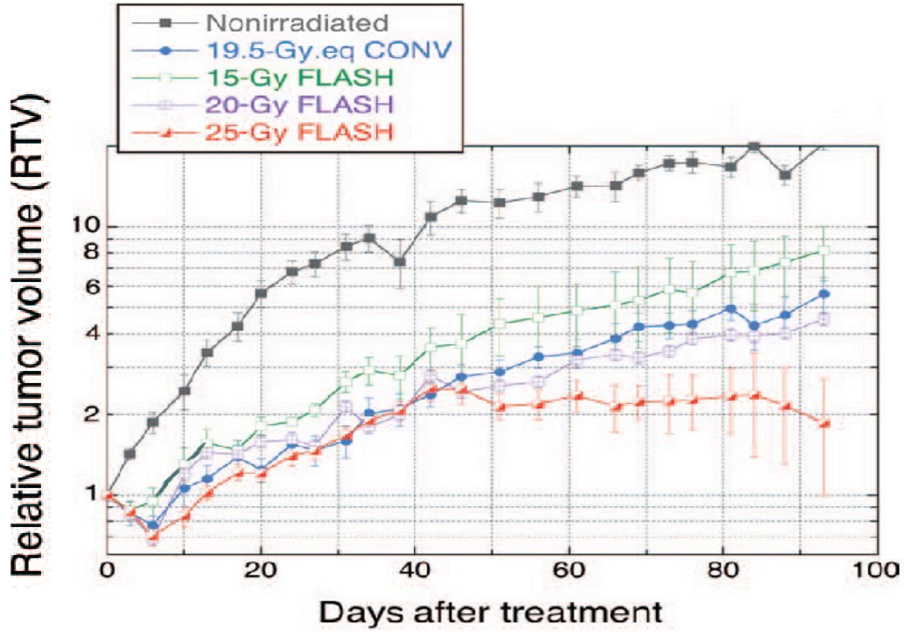
FLASH EFFECT is the improvement of the healthy tissue tolerance to the delivered dose.



Healthy **Fibrosis** **Healthy**

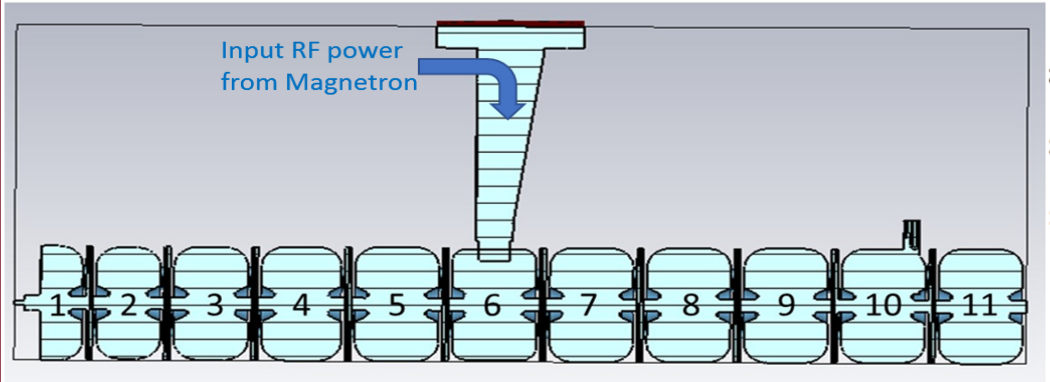
V. Favaudon et al., "Ultrahigh dose-rate FLASH irradiation increases the differential response between normal and tumour tissue in mice", *Science Translational Medicine* 6, 2014

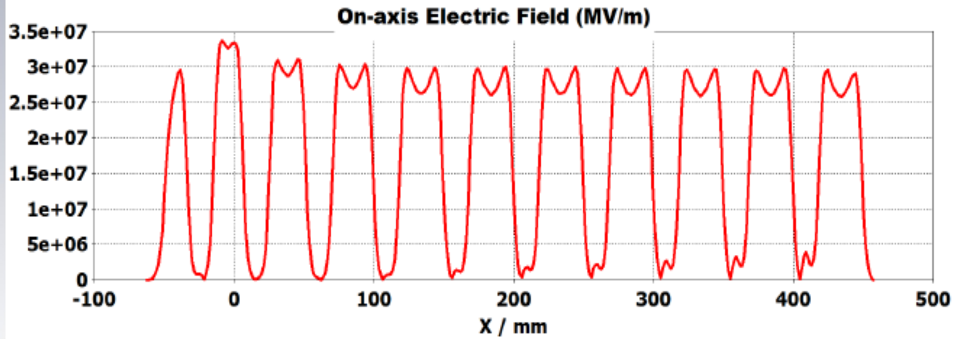
The FLASH therapy is **as efficient as Conventional** irradiation in the repression of tumor growth



Realization of ElectronFlash4000

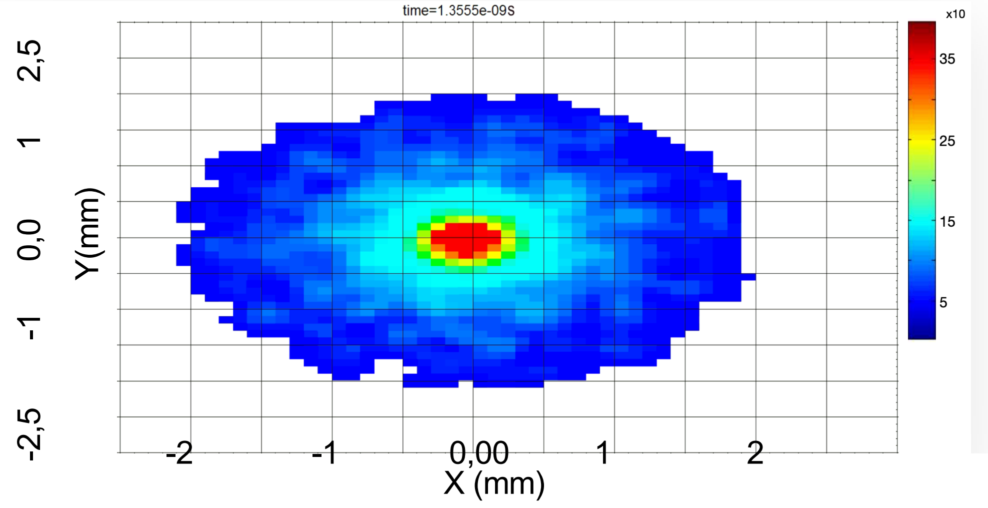
RF design



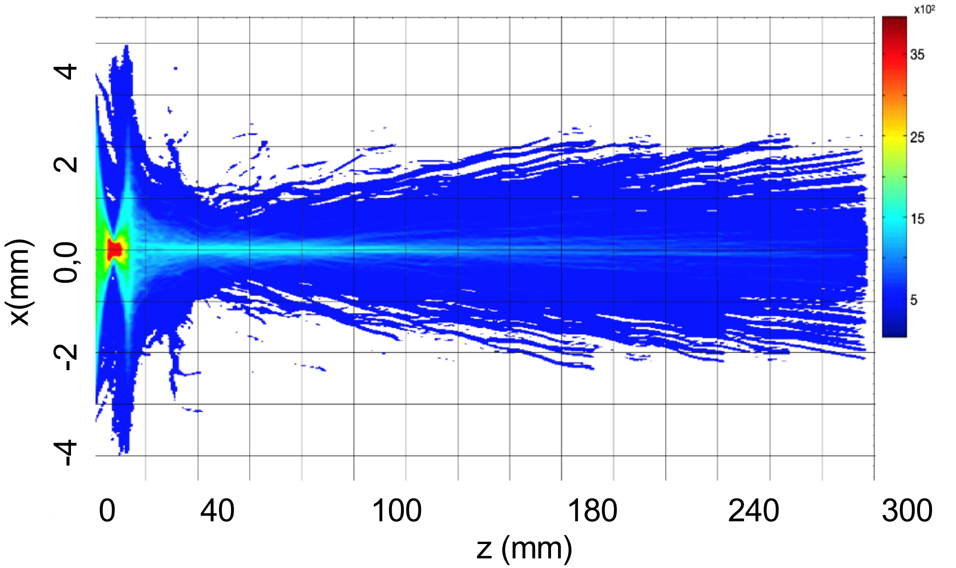


Beam dynamics simulations

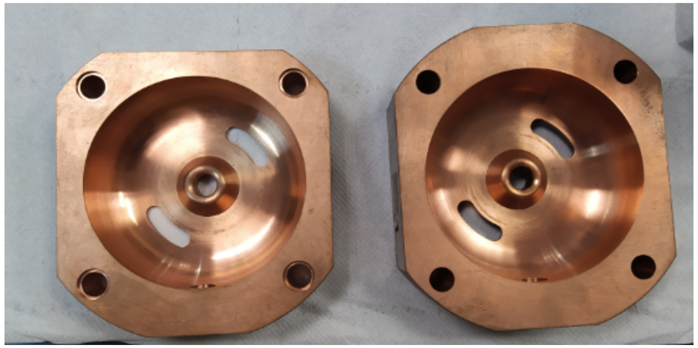
Final beam transverse spot size in cm

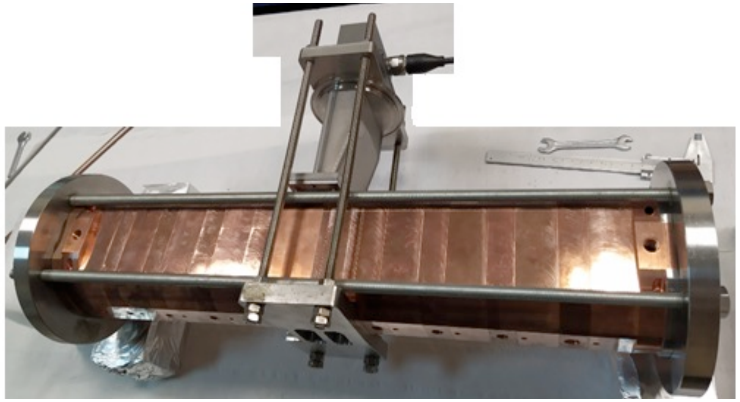


Trajectory



Accelerating cells and clamped linac before brazing





Linac installed at Curie Institute

- Variable energy: 5-7 MeV (for other pre-clinical investigations)
- Samples surface variable: 10x10 cm – 4x4cm (high homogeneity for in-vitro screening)
- Target dose per pulse: 5 Gy
- Pulse width: few μs
- Mean Dose rate: 1000 Gy/s
- 10^6 < Dose-rate in pulse:< 10^7 Gy/s
- Pulse repetition frequency: ν= 300Hz

UCLA, La Sapienza, LNF-INFN, SLAC, LANL

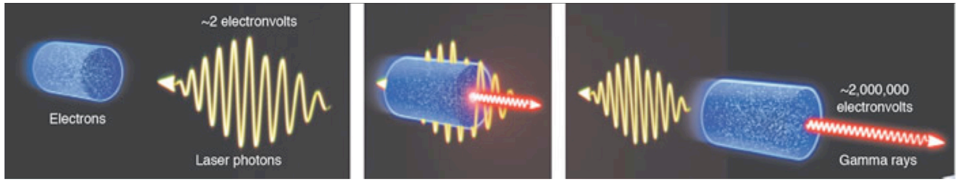
HIGH BRIGHTNESS C-BAND RF PHOTOINJECTORS FOR ELECTRON LINACS

Main Applications and Projects

- High **brightness** (high current, low transverse emittances) electron beams are the key to achieve good performances for advanced radiation sources
- Such beams can be produced by a proper combination of radio frequency (RF) **photoinjectors** and linear accelerators (linacs) sections

Inverse Compton Sources

- Small footprint facility aimed to produce $\boldsymbol{X/\gamma}$ **radiation** from electron-photon scattering
- Design based on a **hybrid photoinjector** electron source and a room temperature C-band $(5.712\ \mathrm{GHz})$ linac

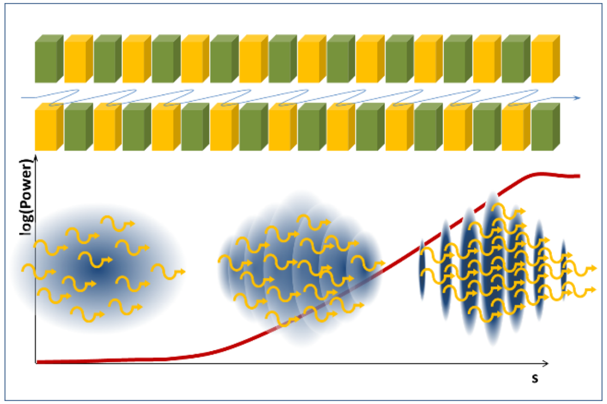


Ultra Compact X-rays Free Electron Laser

- Compact $(\sim 40\ \mathrm{m})$ facility generating high brightness **X-rays**
- Design based on a high field $(240\ \mathrm{MV/m})$ standing wave photoinjector, **cryogenic** (77 K) high gradient RF linacs and **short period** $(3 \div 6.5\ \mathrm{mm})$ MEMS based undulators

MEMS= Micro-Electro-Mechanical Systems

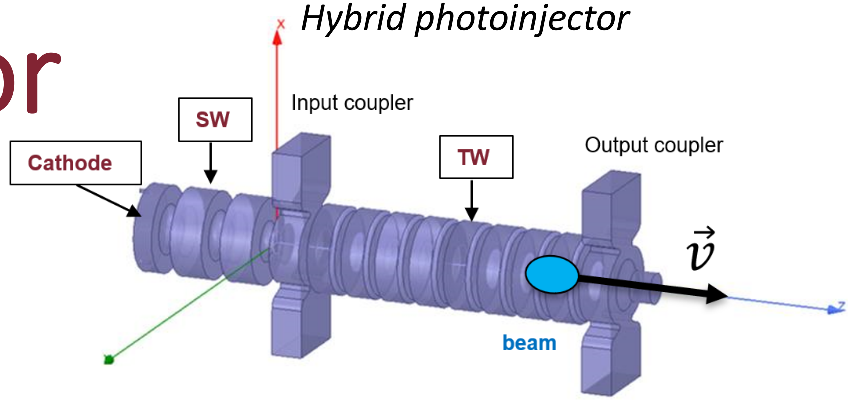
J. B. Rosenzweig, N. Majernik et alia, "An ultra-compact X-ray free-electron laser," 2020.



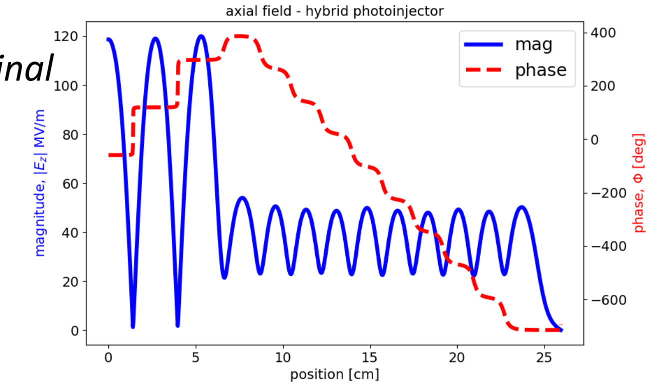
Hybrid RF Photoinjector

- Multicell RF structure combining a **standing wave** (SW) and a **traveling wave** (TW) section fed from a common coupling cell
- C-band RF design: working frequency is 5.712 GHz
- Electrons are extracted from the **cathode** by an UV laser pulse and are accelerated in the SW region
- The TW structure introduces **velocity bunching** which shortens the beam enhancing the peak current
- A proper combination with solenoid coils and a booster linac allows to achieve **emittance compensation** and velocity bunching together
- The latter results in beams of high **5D brightness** (high current, low emittance)

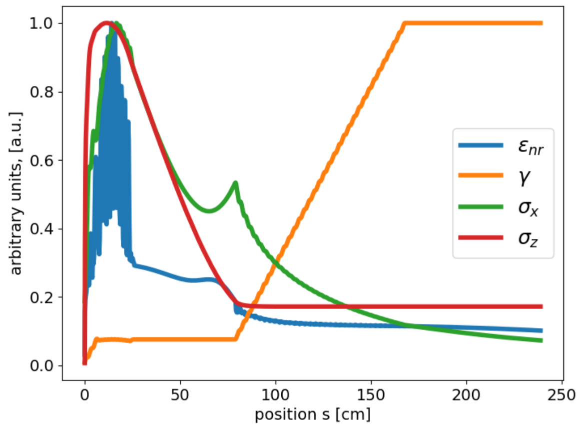
Hybrid photoinjector



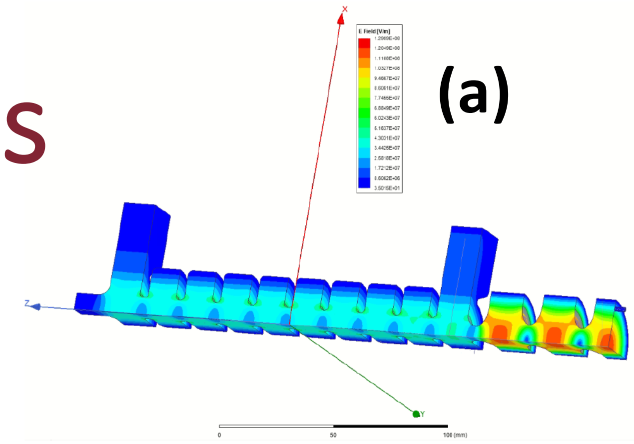
longitudinal on-axis electric field



Beam distribution moments along a hybrid photoinjector-drift-linac system



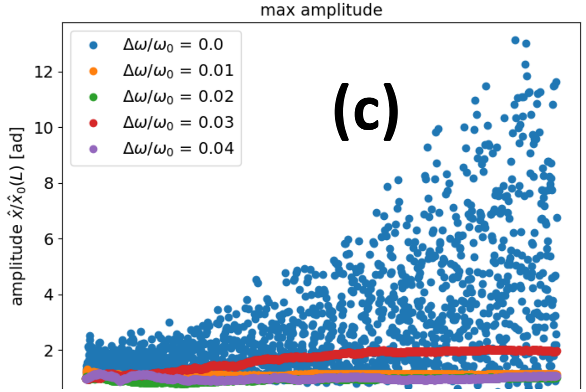
Main Research Activities

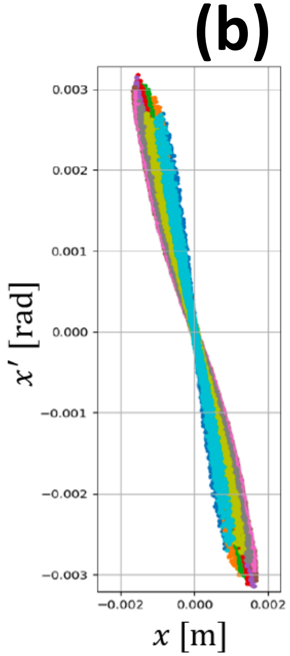


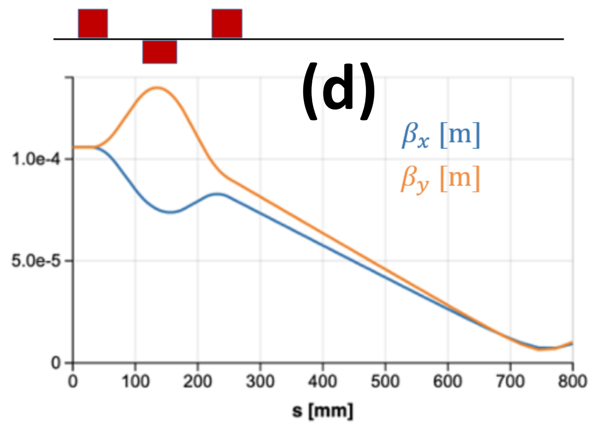
(a) *Electric field*

Activities concerning the hybrid photoinjector

- Design and optimization of the C-band **RF structure (a)**
- Beam **dynamics** studies to achieve the best working point in terms of emittance and peak current **(b)**
- Studies on **instabilities** aimed to keep under control the effects the self-fields generated by the electron beam in the downstream linac sections **(c)**
- Design of the **final focus** optics system for the Compton interaction point **(d)**







Further applications

- The good performances shown by hybrid photoinjectors allow to foresee a wide panorama of applications beyond Compton sources
- Hybrid photoinjectors could be employed to drive **FEL radiation** or to fulfill **THz radiation** sources for medical applications

RF technology for ultra-compact, high gradient Linacs: Laser switch approach for very short RF pulse length (of the order of ns)

- **The major factor limiting nowadays accelerating gradient to reach very high energies in compact accelerators is vacuum RF breakdown.**

- **The probability of such breakdowns increases with pulse length.**

- **For reliable operation, high frequency structures (30-100 GHz → millimeter-wavelength) require nanoseconds-long pulses at the megawatt level.**

- **This power is available from gyrotrons, which have a minimum pulse length on the order of microseconds.**

- **To create shorter pulses and to reliably prevent rf breakdowns, we are investigating the development of a laser-based RF switch capable of selecting short pulses (of the order of 10-30 ns) out of the microseconds long pulses of gyrotron (or of other power sources) for high frequency and high gradient Linacs.**