National Institute of Nuclear Physics
Frascati National Laboratories

the past, the present and the future

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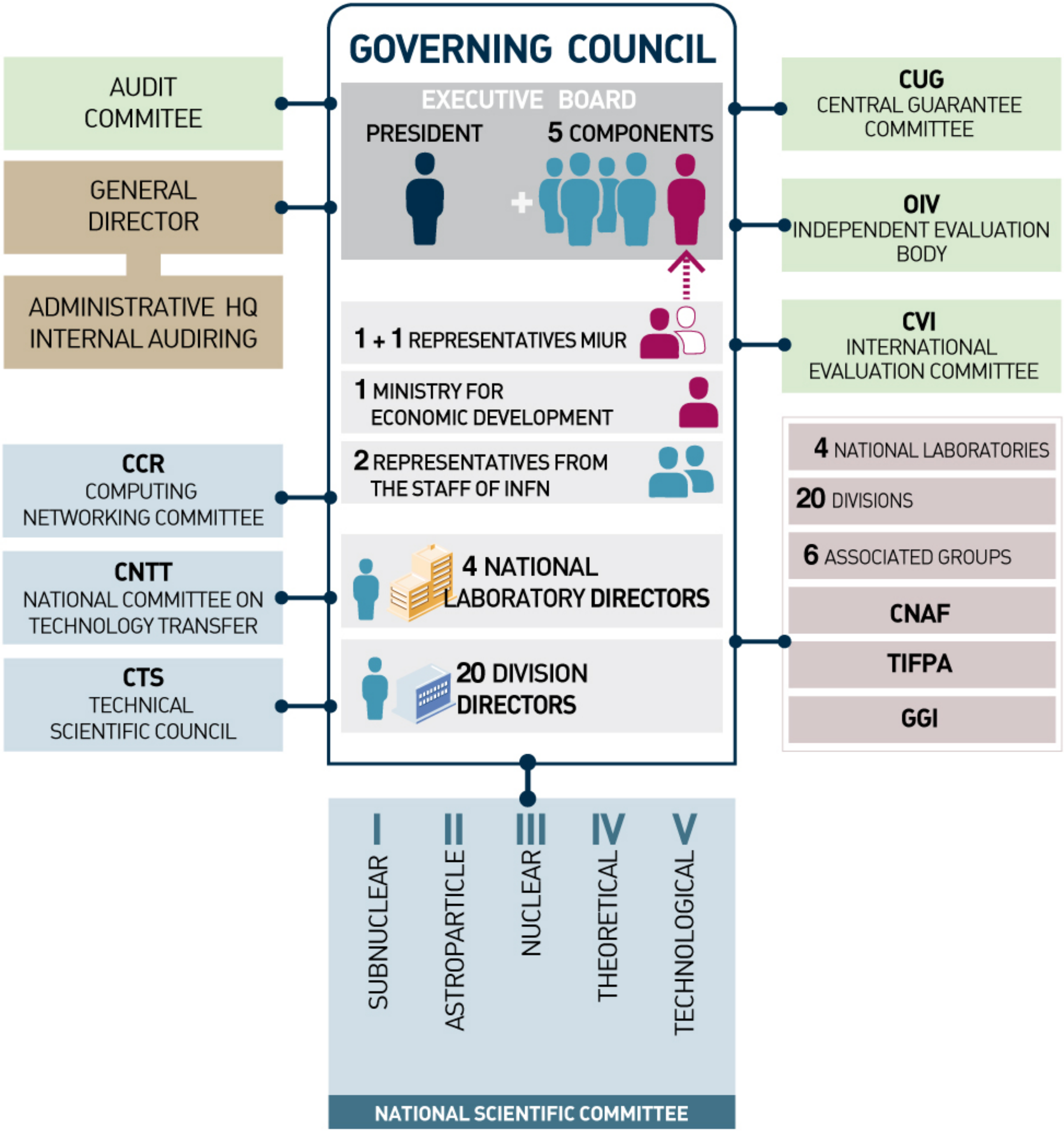
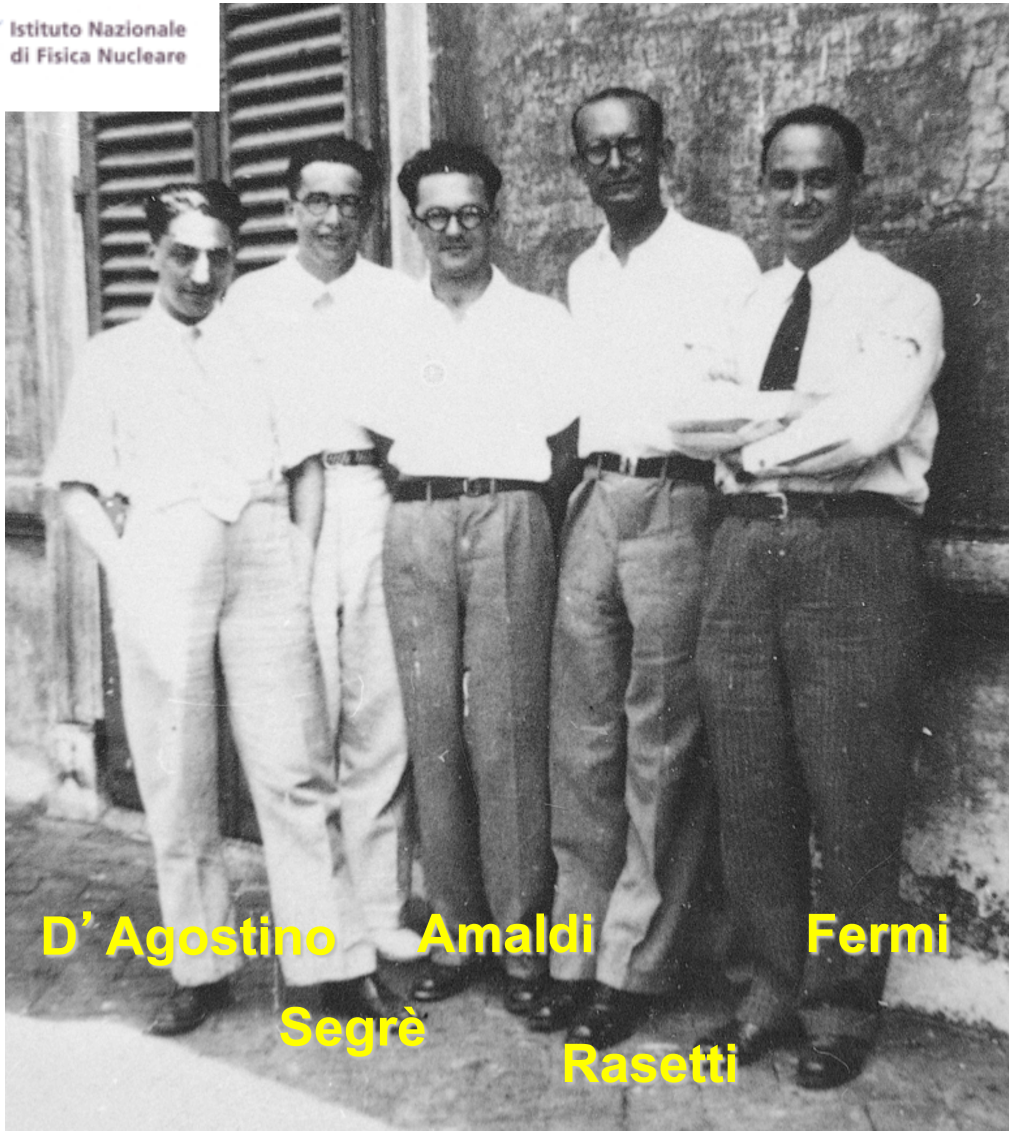
The INFN:

- promotes, coordinates and performs scientific research in subnuclear, nuclear and astroparticle physics,
- as well as the research and technological development necessary for activities in these sectors,
- in close collaboration with universities,
- and within a framework of international cooperation and comparison



The origins of the INFN



Enrico Fermi and the “Boys of Via Panisperna” conducted a series of fundamental nuclear physics experiments at the Istituto di Fisica at the University of Rome in the 1930s.

Fermi realized that continuing progress in the field would require costly instruments and technical infrastructure (e.g., accelerators). Fermi (in Rome) and Bruno Rossi (in Florence) sought to establish an “Istituto Nazionale di Fisica” in the 1930s.

Because of the war, this was impossible until Edoardo Amaldi worked to found the INFN in 1951.

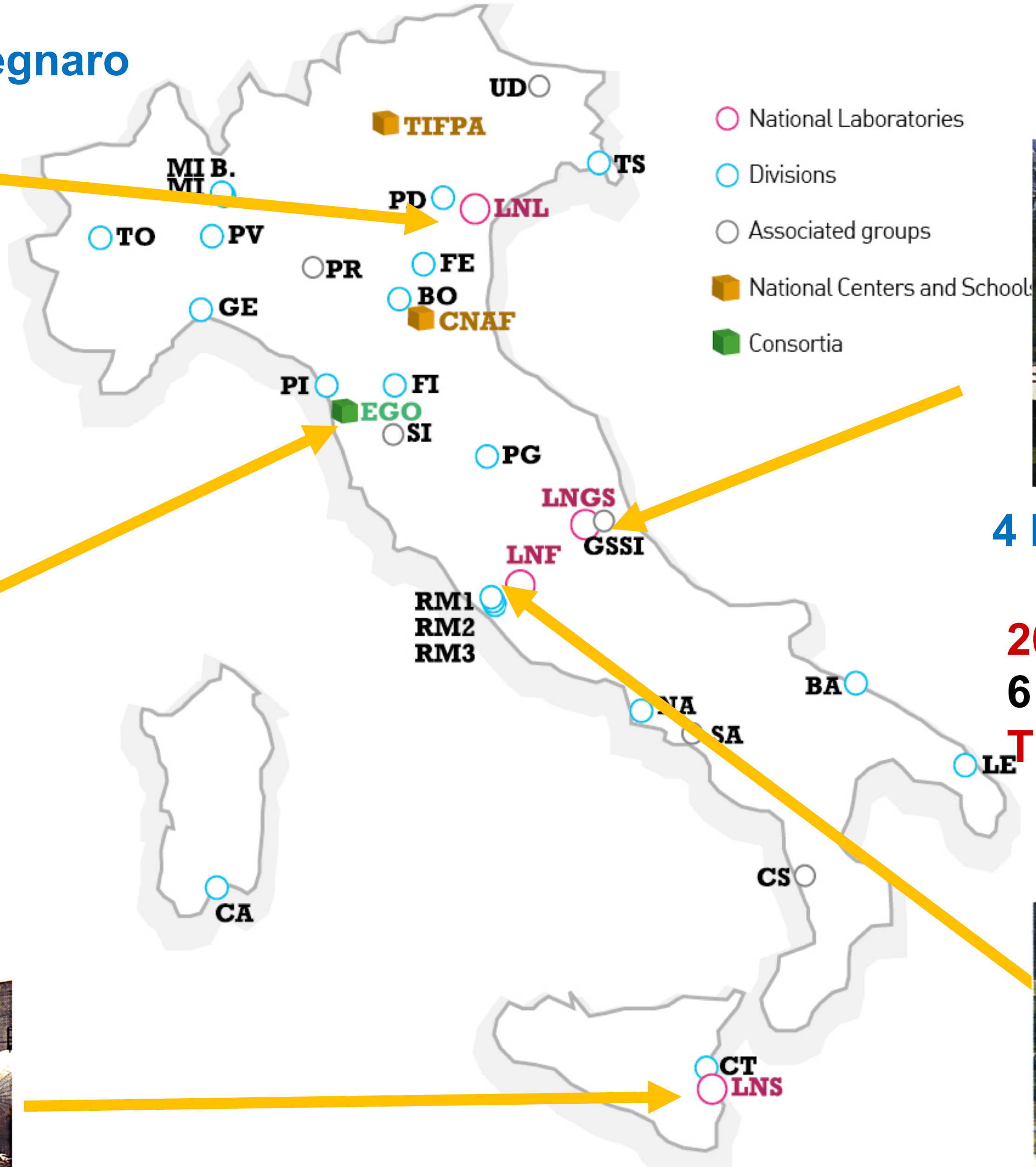
INFN
Istituto Nazionale di Fisica Nucleare

1951
4 Division
Milan, Turin, Padua, and Rome

1957
Laboratori Nazionali di Frascati

Frascati

Legnaro



Gran Sasso

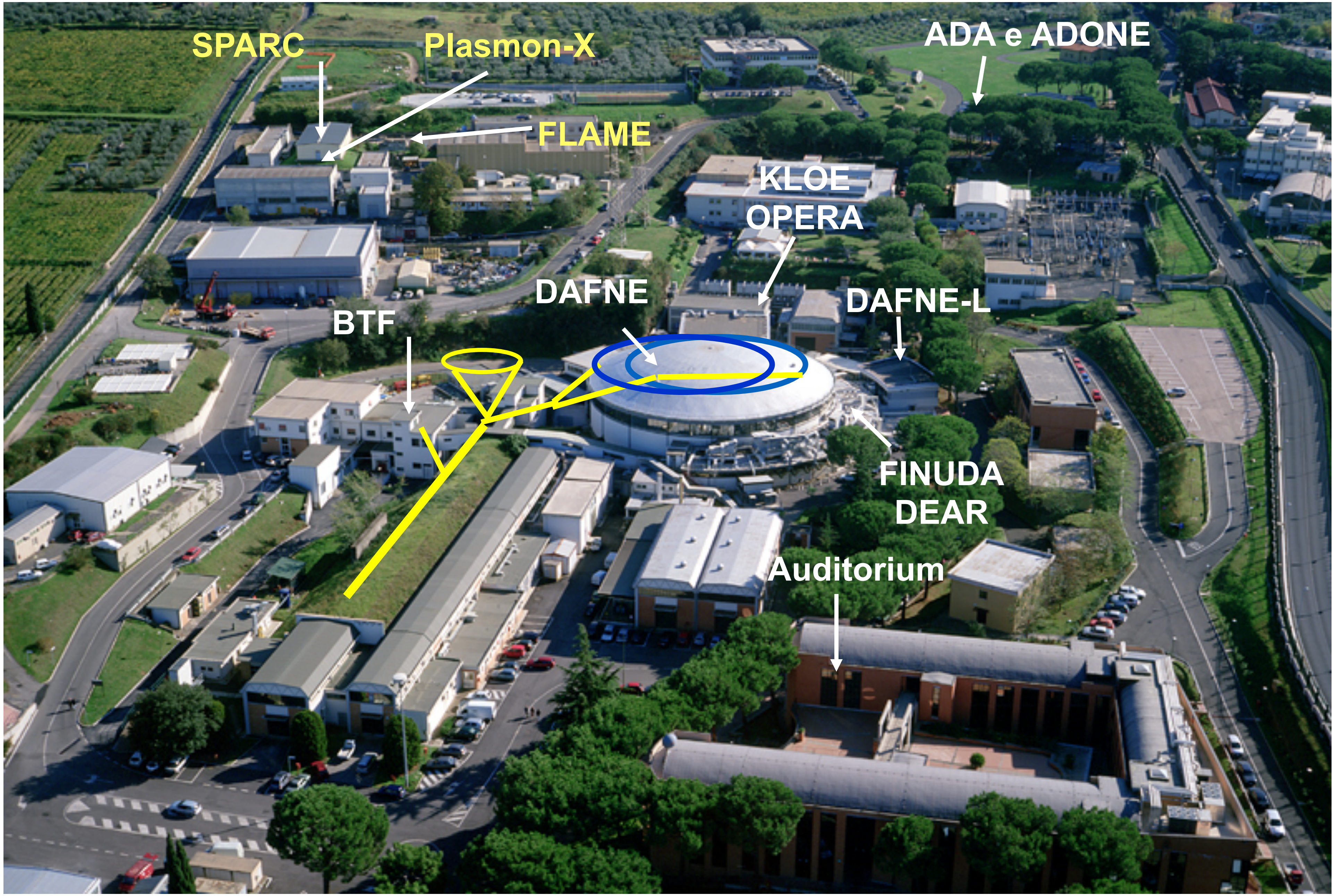
4 National Laboratories

20 Divisions

6 associated groups CNAF, TIFPA, GGI

VIRGO-EGO
European
Gravitational
Observatory

Laboratori del Sud (Catania)


SPARC
Plasmon-X
FLAME
ADA e ADONE
KLOE
OPERA
DAFNE
DAFNE-L
BTF
FINUDA
DEAR
Auditorium

What do we do at the Laboratori Nazionali di Frascati?

- *Fundamental research*
- *Develop and construct particle detectors*
- *Study and develop accelerating techniques*
- *Perform material studies and biomedical research with synchrotron light*
- *Develop and support computing systems and networks*
- *Research activities in the fieldof high energy particle dosimetry*

The main characteristic of LNF consists in knowing how to build particle accelerators.

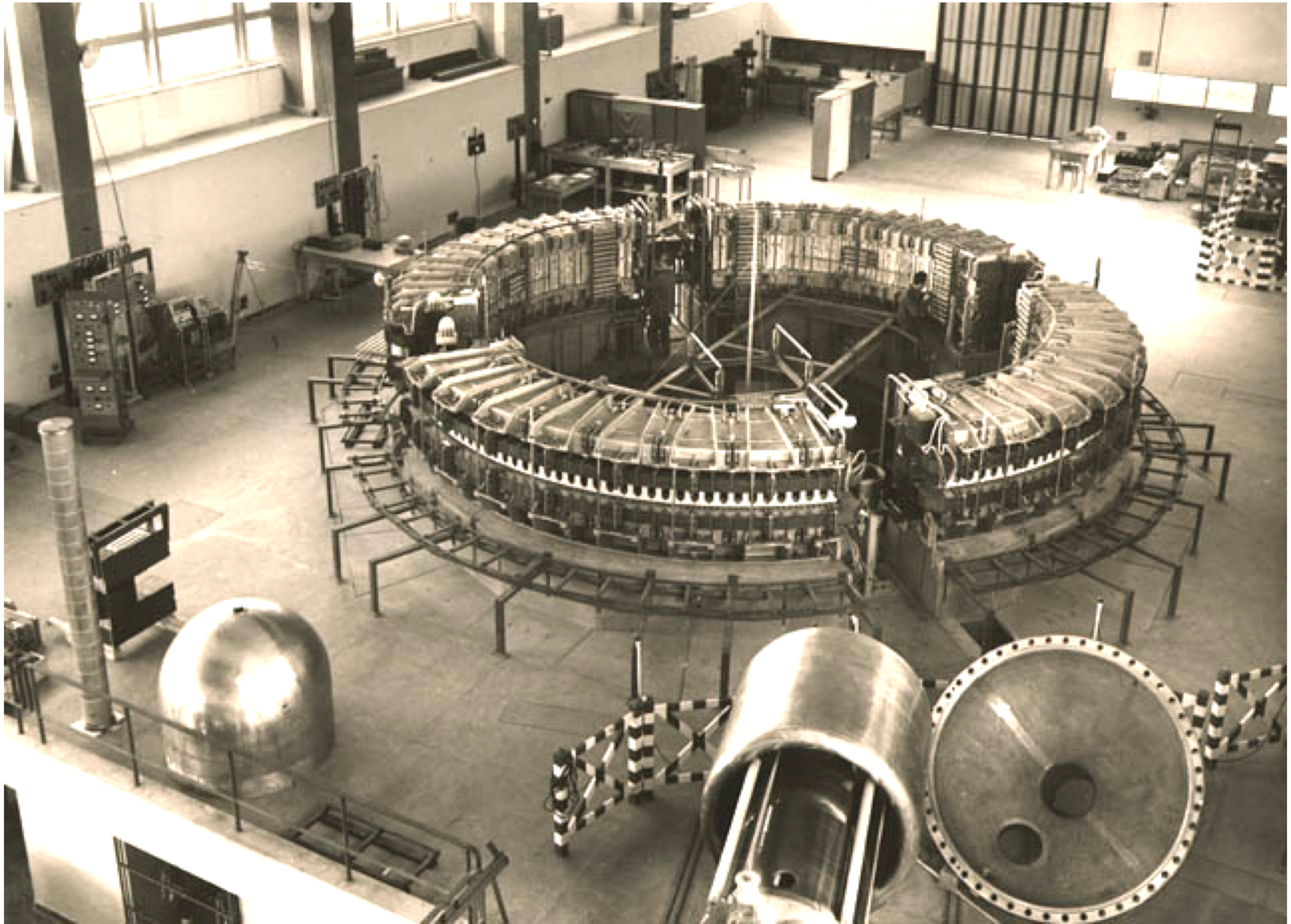
This activity started in 1957 with the 1.1 GeV electron synchrotron, the most powerful machine at the time, continued with AdA (1961), the first electron-positron collider ever built, and its successor ADONE (1969) and culminated in 2000 with the construction of DAΦNE, the collider still in operation that holds the world record of low energy instantaneous luminosity.

LNF hosts

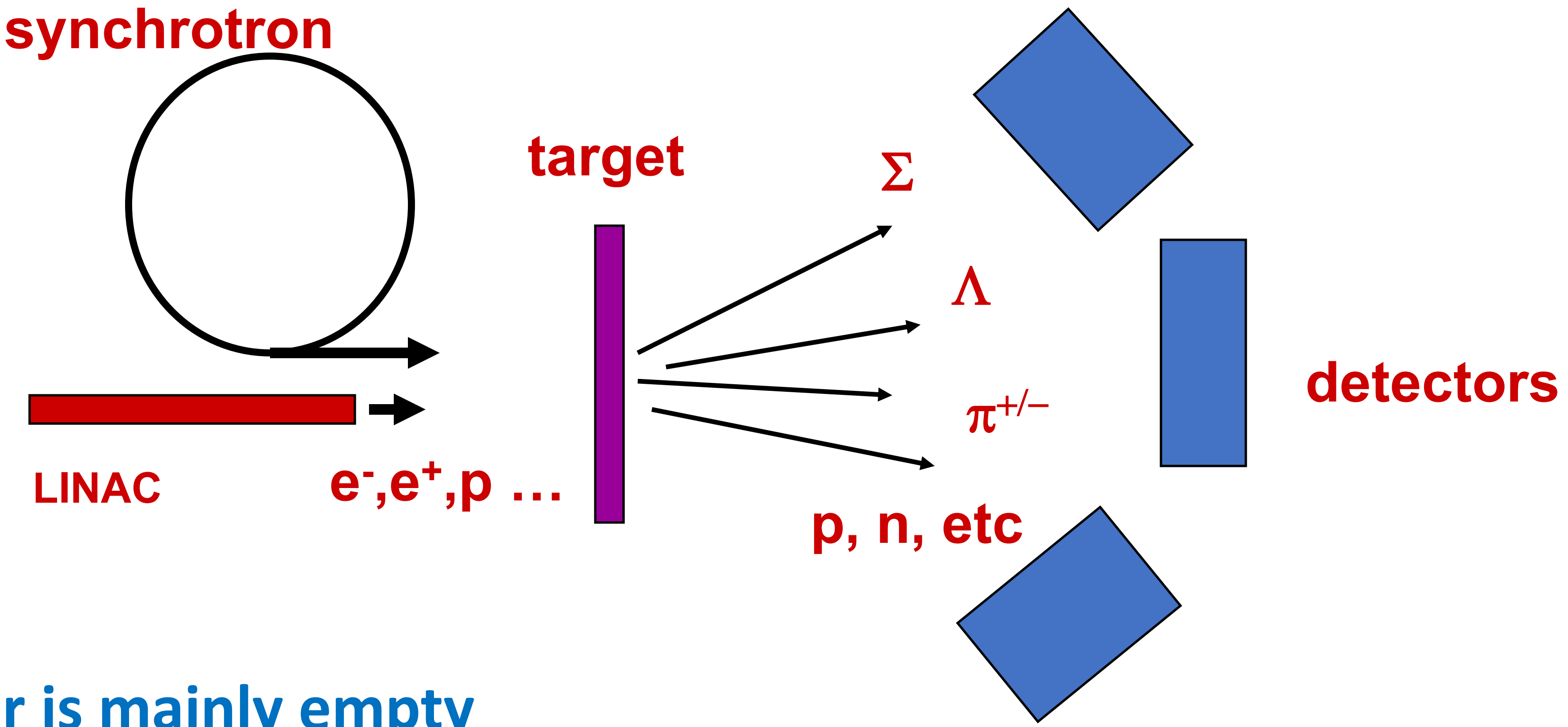
- the SPARC free-electron laser
- the extremely high power FLAME laser for the study of innovative particle acceleration techniques

LNF new project EuPRAXIA@SPARC_LAB

The Frascati Electron Synchrotron 1959-1975

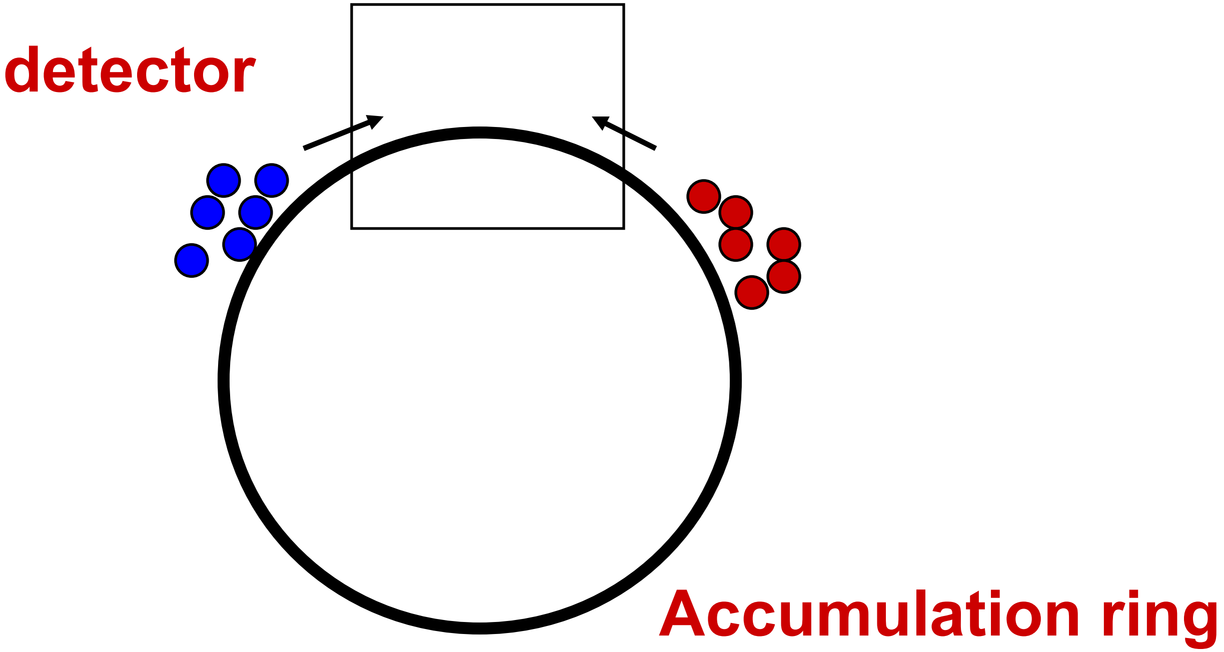


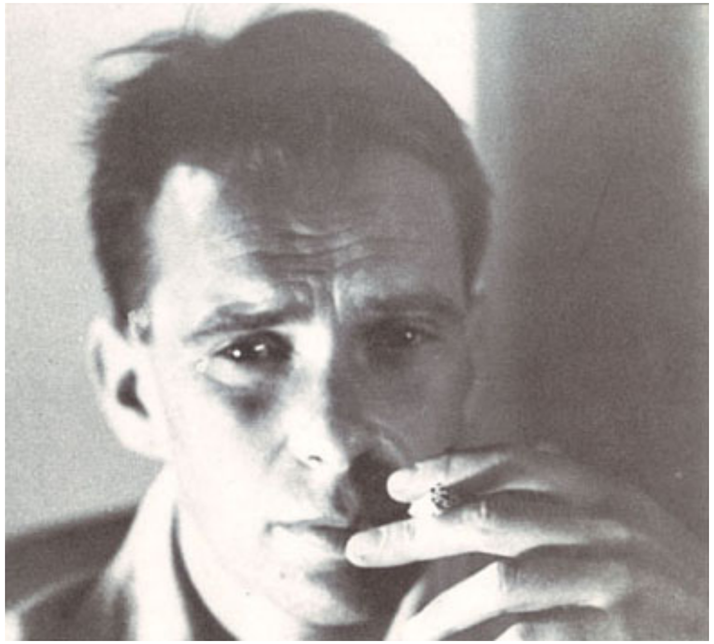
Experiments using fixed targets



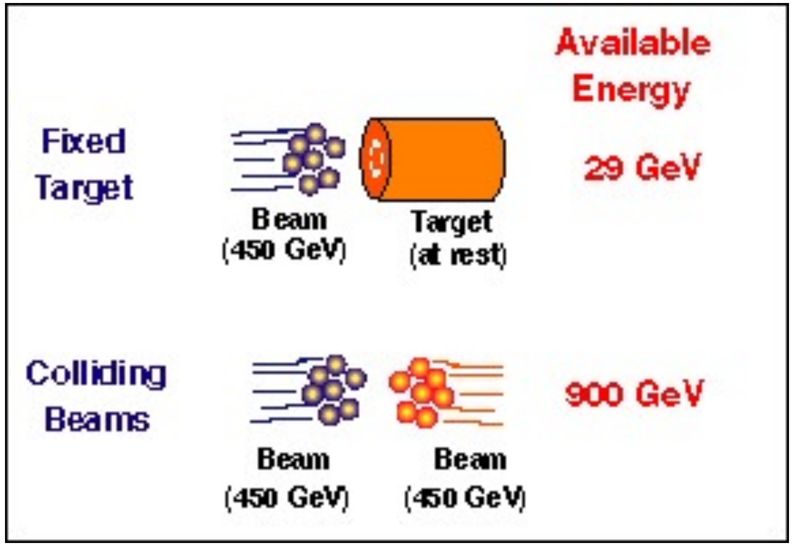
- Matter is mainly empty
- All particles which do not interact are lost
- Energy is lost to moving the center of mass
- “Target” is a nucleus, with a complex structure

A new approach: Use colliding beams



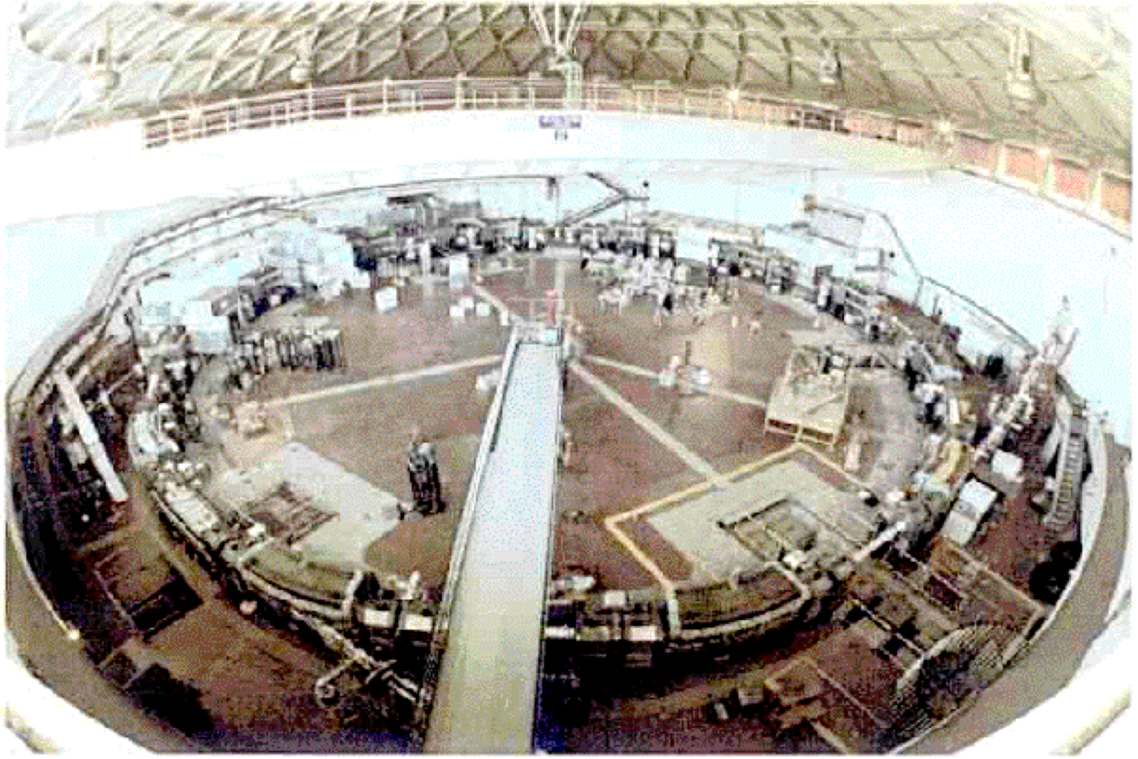


Bruno Touschek, Frascati, 1960



- The non-interacting particles can be reused in successive rounds
- Collisions are performed in the center-of-mass frame
- The circulating particles can be either elementary or complex (nuclei or atoms)

ADONE (1969-1993)



AL
NUOVO CIMENTO
A CURA DELLA SOCIETÀ ITALIANA DI FISICA

VOL. I, N. 15 | Serie prima | 21 Maggio 1969

Two-Beam Operation of the 1.5 GeV Electron-Positron Storage Ring Adone.

F. AMMAN, R. ANDREANI, M. BASSETTI, M. BERNARDINI, A. CATTONI, V. CHIMENTI, G. F. CORAZZA, D. FABIANI, E. FERLENGHI (*), A. MASSAROTTI, C. PELLEGRINI, M. PLACIDI, M. PUGLISI, F. SOSO, S. TAZZARI, F. TAZZIOLI and G. VIGNOLA

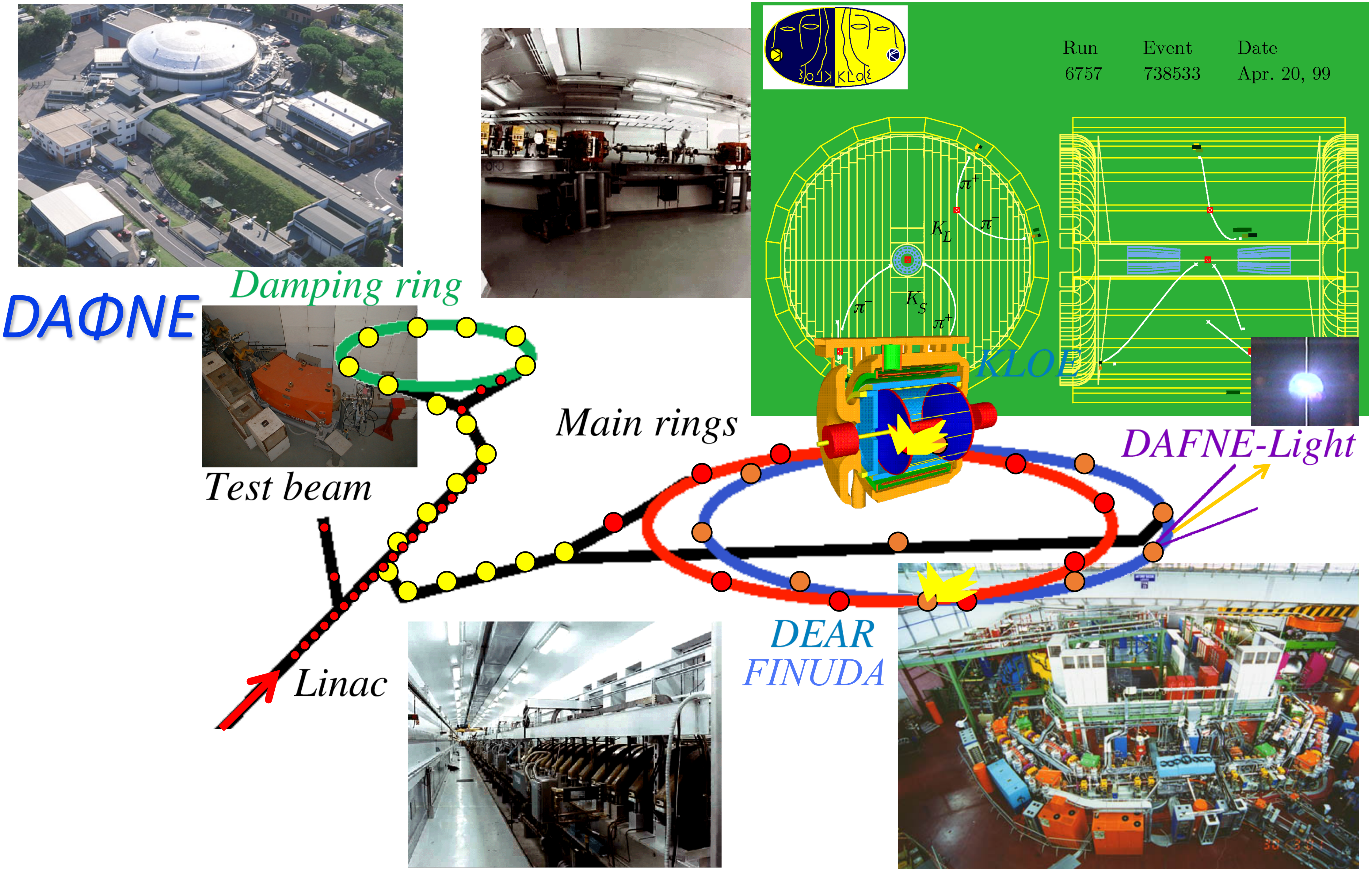
Laboratori Nazionali di Frascati del CNEN - Frascati

(ricevuto il 12 Maggio 1969)

DAΦNE

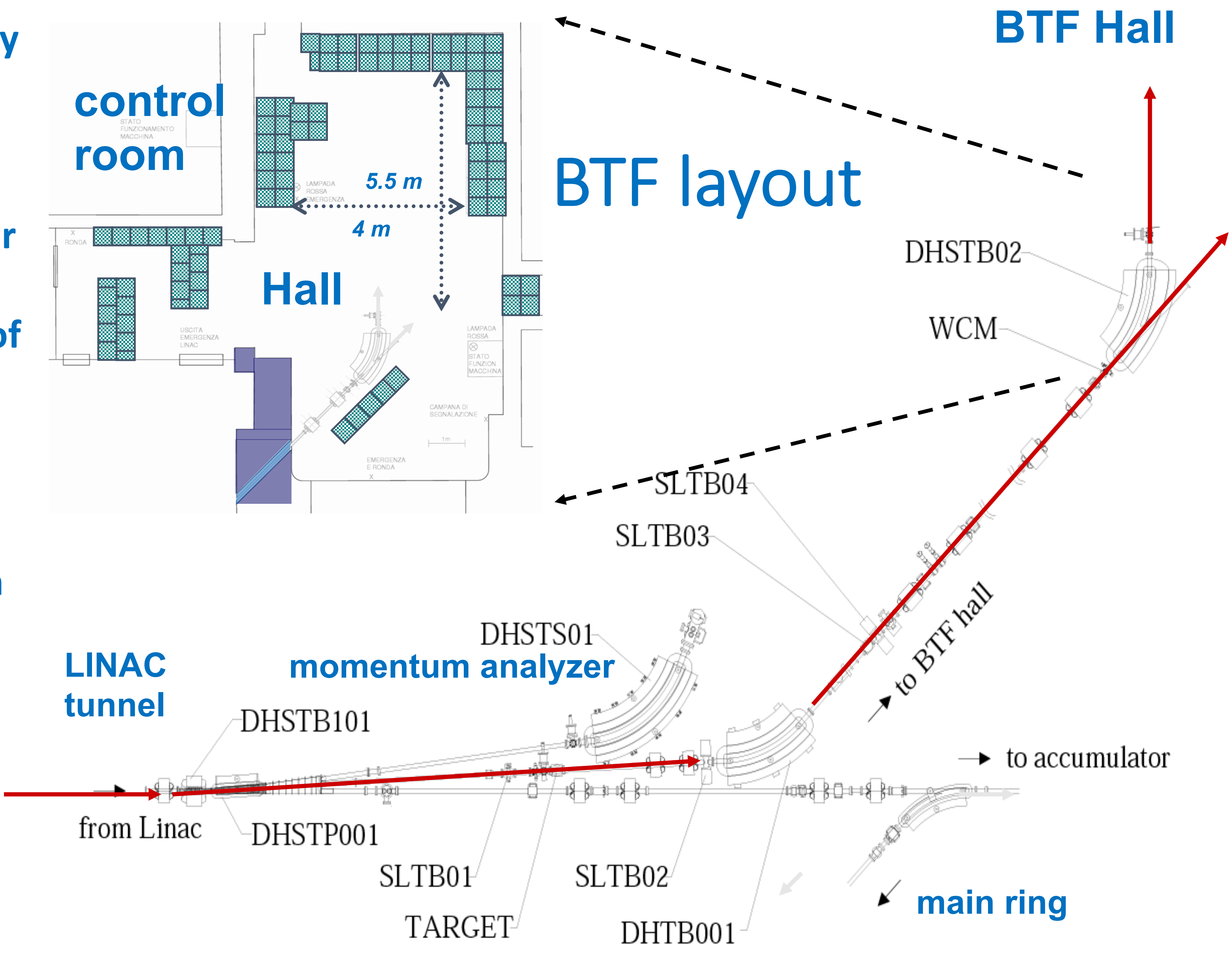
The Frascati National Laboratories operates a DAΦNE accelerator complex for fundamental and applied physics. The DAΦNE (Double Annular Φ Factory for Nice Experiments) consists of a Linac for electrons and positrons with energy 800 and 550 MeV, respectively, an Accumulator for topping up and Main Rings with energy 510 MeV per beam.

The aim is to accumulate, into the Main Rings, two electron/positron beams with a maximum intensity 10^{13} particles/beam, divided in 120 bunches (average current 5A) at 510 MeV.


DAΦNE
Damping ring
Main rings
Test beam
Linac
Run 6757
Event 738533
Date Apr. 20, 99
K_L
K_S
π^+
π^-
π^-
π^+
KLOE
DAFNE-Light
DEAR
FINUDA

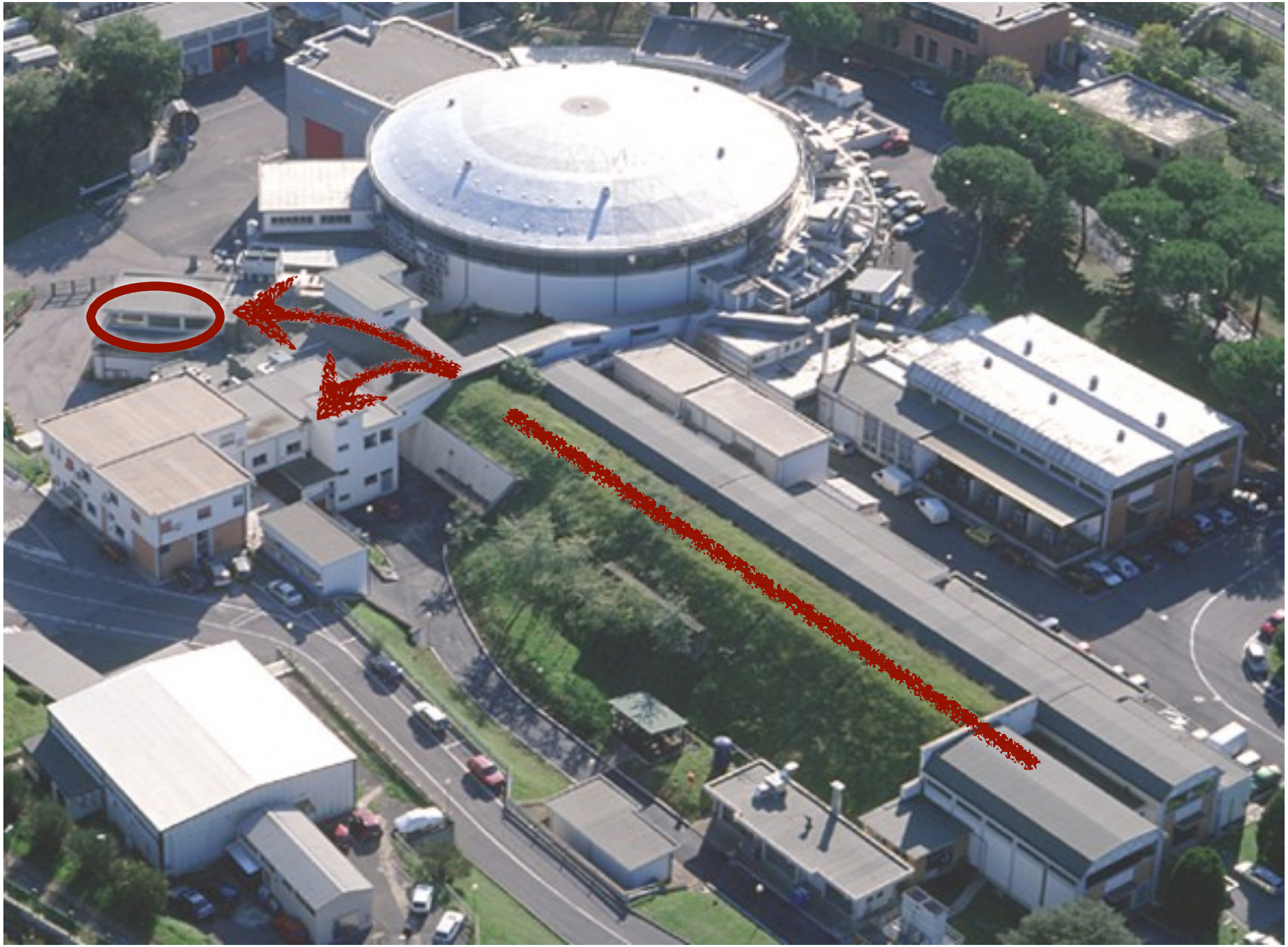
The DAFNE Beam-Test Facility (BTF) is a beam transfer line designed for the optimized, stochastical production of single electrons/positrons for detector calibration purposes, or the extraction of the DAFNE LINAC electron/positron beam.

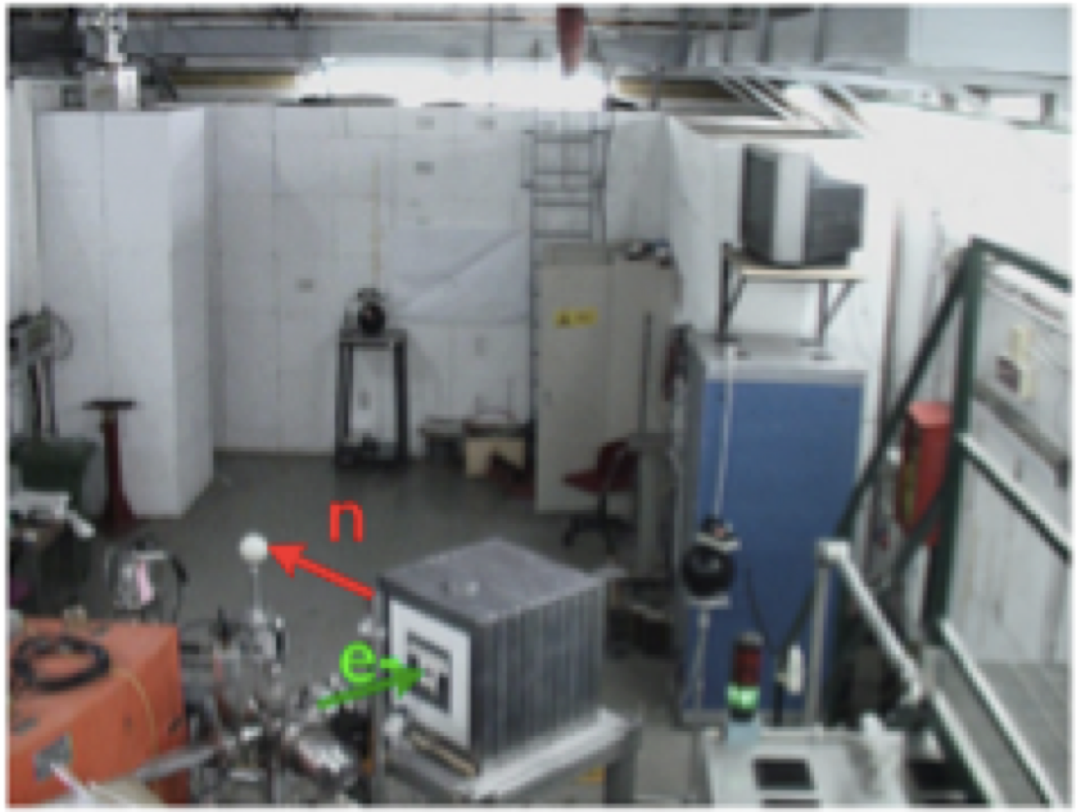
Beam characteristics (spot size, divergence, momentum resolution), are strongly depended by multiplicity (number of particles/spill) and energy requested.

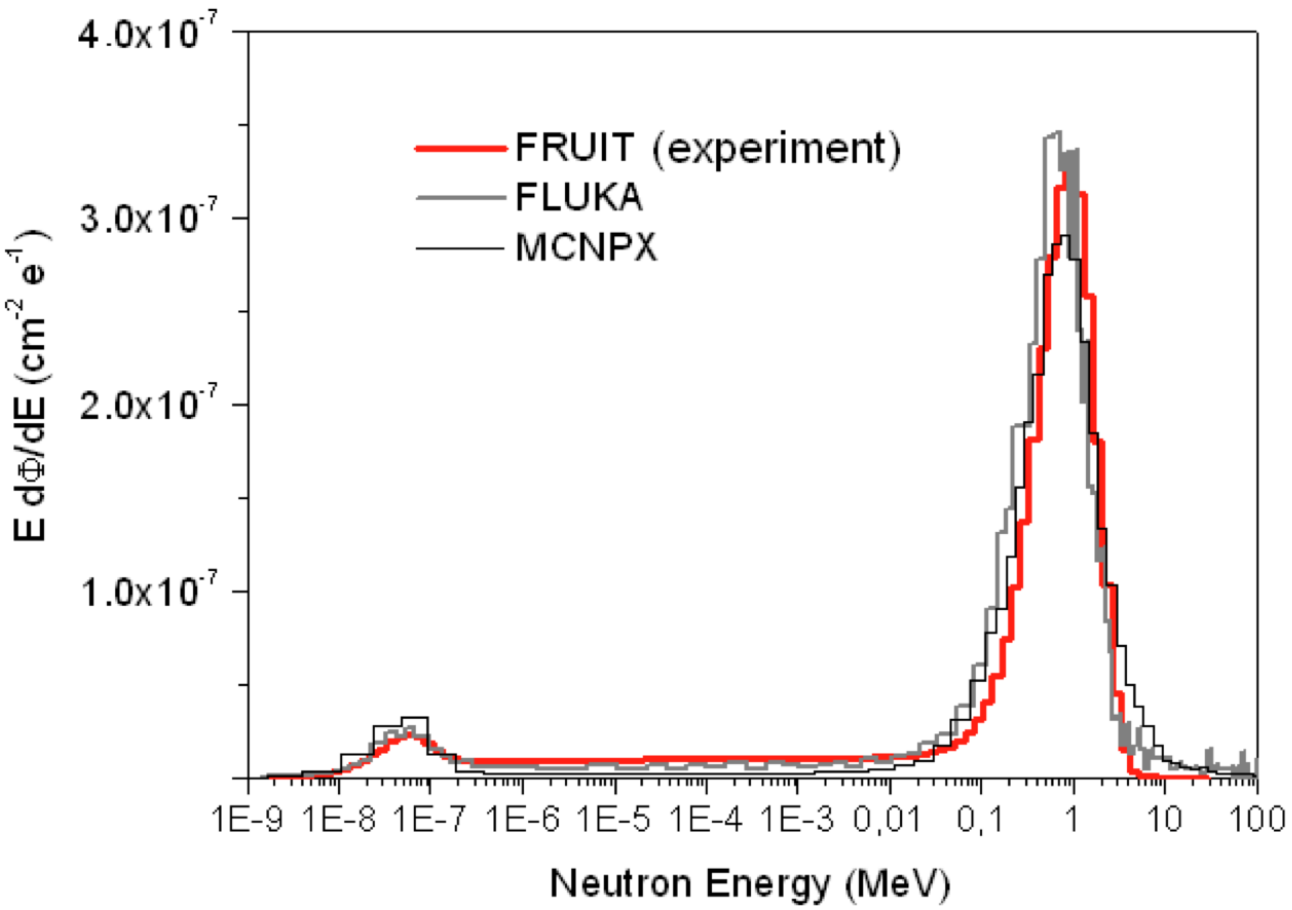


The BTF activity is essentially dedicated to the testing and calibration of detectors for use in high-energy physics experiments. It is addressed to both experimental groups operating within the National Laboratory of Frascati, as well as Italian and foreign external researchers.

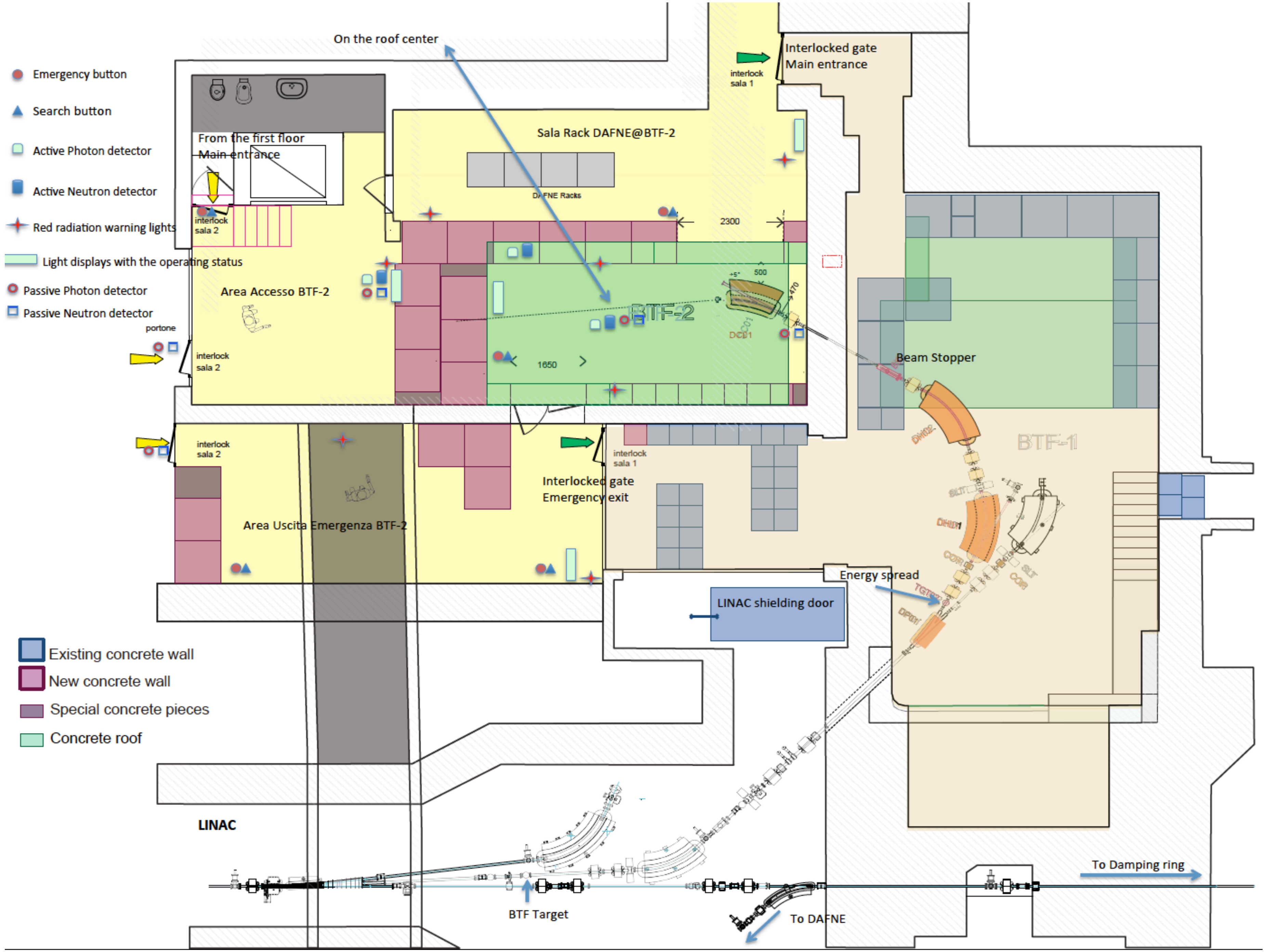
Parameter	Values			
Maximum average flux	3.125 10^{10} particles/s			
Spot size	1–25 mm (y) 1–55 mm (x)			
Divergence	1–2 mrad			
	Parasitic mode		Dedicated mode	
Pulse duration	10 ns		1.5–40 ns Selectable	
Repetition rate	Variable between 10 Hz and 49 Hz Depending on DAFNE mode		1–49 Hz Selectable	
	With target	Without target	With target	Without target
Particle species	e^+ or e^- Selectable by user	e^+ or e^- Depending on DAFNE mode	e^+ or e^- Selectable	
Energy	25–500 MeV	510 MeV	25–700 MeV (e^-) 25–500 MeV (e^+)	250–730 MeV (e^-) 250–530 MeV (e^+)
Energy spread	1% at 500 MeV	0.5%	0.5%	
Intensity (particles/bunch)	1–10^5	10^7–1.5 10^{10}	1–10^5	10^3–3 10^{10}





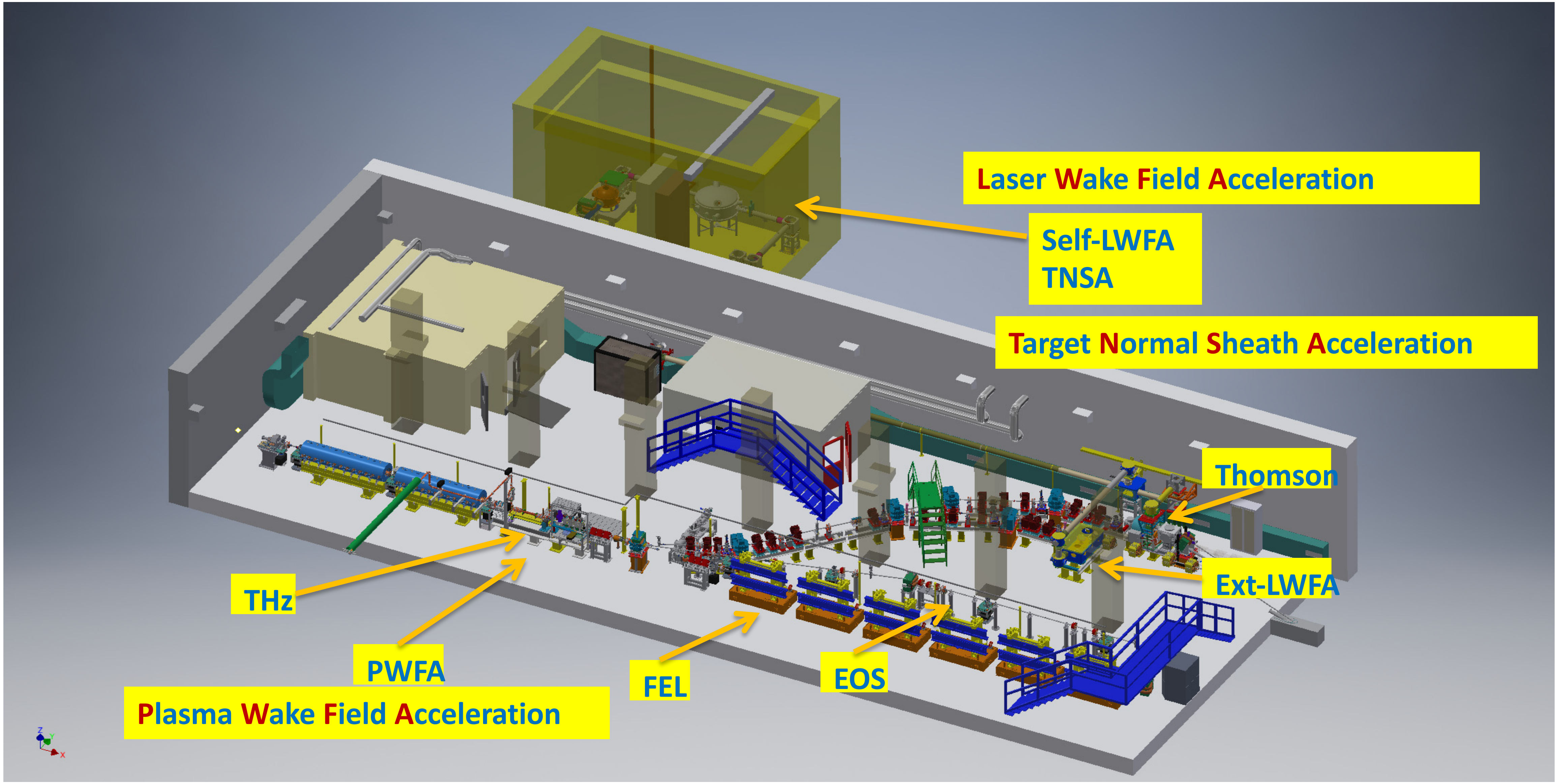


Neutron Flux at 1.5m from shield = 4E+5 n/cm^{2}s^{-1} corresponds to Equivalent Dose=45 mSv/h

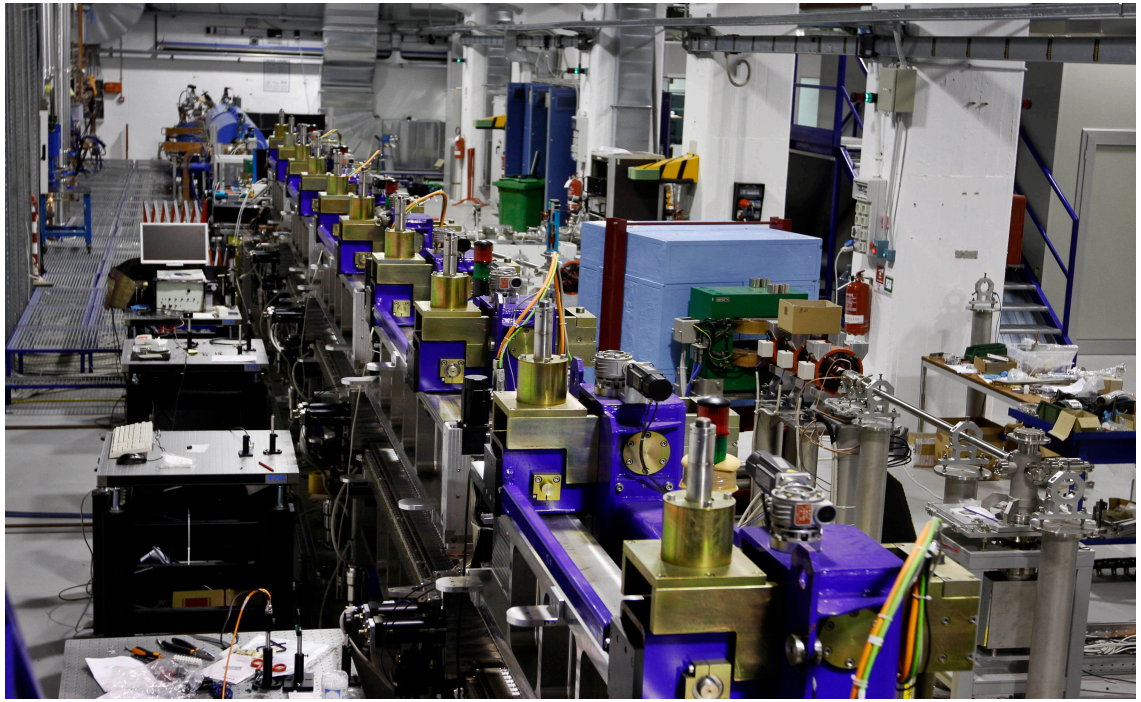


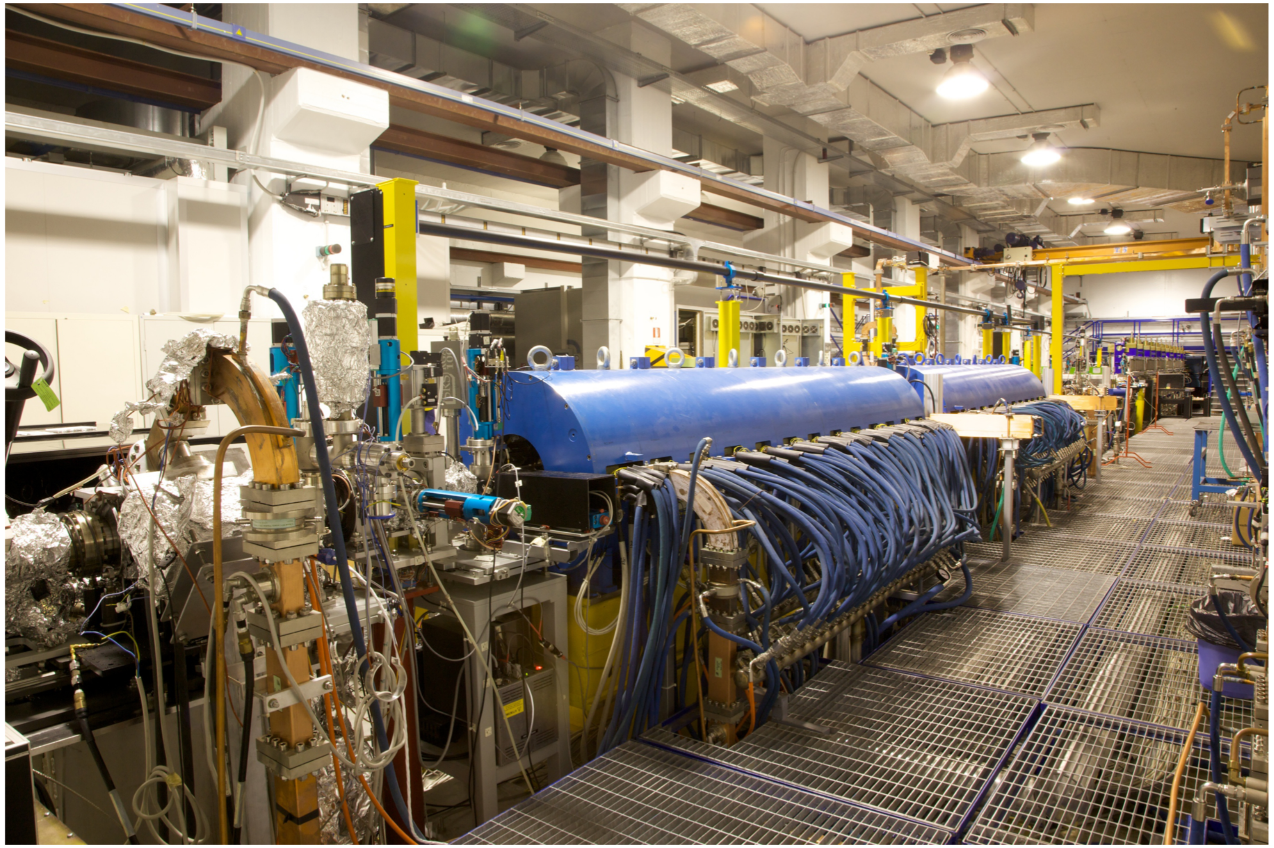
Emergency button
Search button
Active Photon detector
Active Neutron detector
Red radiation warning lights
Light displays with the operating status
Passive Photon detector
Passive Neutron detector
portone
On the roof center
From the first floor
Main entrance
interlock sala 2
Sala Rack DAFNE@BTF-2
DAFNE Racks
2300
Interlocked gate
Main entrance
interlock sala 1
Area Accesso BTF-2
BTF-2
1650
500
470
DCD1
Beam Stopper
BTF-1
Area Uscita Emergenza BTF-2
Interlocked gate
Emergency exit
Energy spread
LINAC shielding door
Existing concrete wall
New concrete wall
Special concrete pieces
Concrete roof
LINAC
BTF Target
To DAFNE
To Damping ring

The LNF operates the SPARC_Lab (Source for Plasma Accelerators and Radiation Compton With Laser and Beams)



SPARC 150 MeV Advanced Photo-Injector





A facility based on the unique combination of high brightness electron beams with high intensity ultra-short laser pulses is available for the entire accelerator community, such to allow the investigation of all the different configurations of plasma accelerator and the development of a wide spectrum inter-disciplinary leading-edge research activity.

The Frascati Laser for Acceleration and Multidisciplinary Experiments (FLAME)

300 TW, 20fs, 10 Hz

The main purpose of the facility will consist in R&D activity aimed at the following objectives:

The PLASMONX project

The aim of the PLASMONX project is to provide the LNF with a world-class, high-power laser facility suitable for the development of an innovative, high-gradient acceleration technique based upon super-intense and ultra-short laser pulses, and X/gamma-ray tunable sources using Thomson scattering of optical photons by energetic electrons.

demonstration of high-gradient acceleration of electrons injected into electron plasma waves excited by ultra-short, high-power laser pulses;

development of a monochromatic and tuneable X-ray source in the 20-1000 keV range, based upon Thomson scattering of laser pulses by relativistic electrons.

The ultra-intense laser pulses are employed to study the interaction with matter for many purposes:
electron acceleration through LWFA, ion and proton generation exploiting the TNSA mechanism,
study of new radiation sources and developmentof new electron diagnostics.

Frascati Laser for Acceleration and Multi-disciplinary Experiments

SPARC (pulsed self-amplified source of coerent radiation)

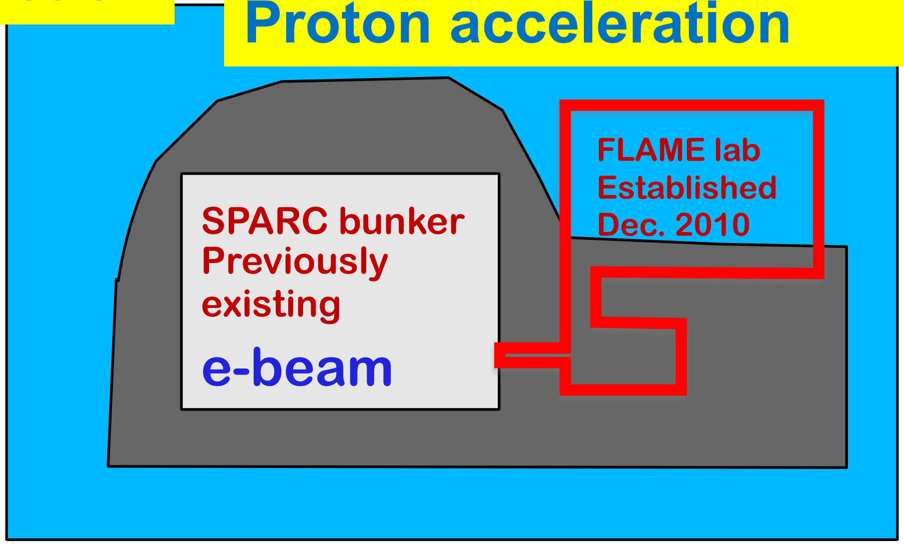
E_{max}	150 MeV
I_p	200A
Pulse	duration 10ps
Repetition Rate	10Hz

LWFA with external injection

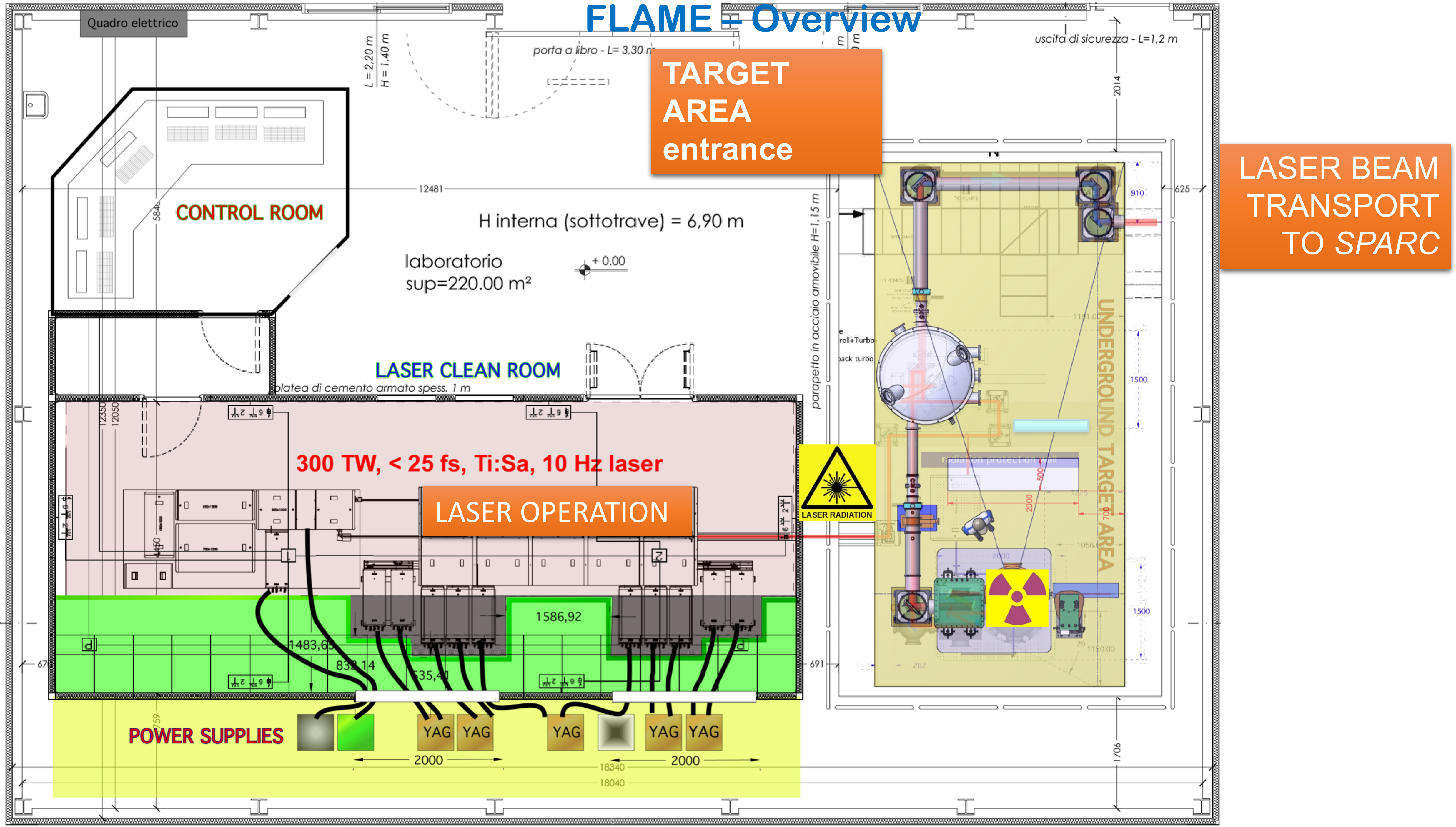
FLAME

nominal peak power	300 TW
pulse length	≥ 20fs
repetition rate	10 Hz
output energy	8J
laser intensity	~ 10^{20} Wcm^{-2}

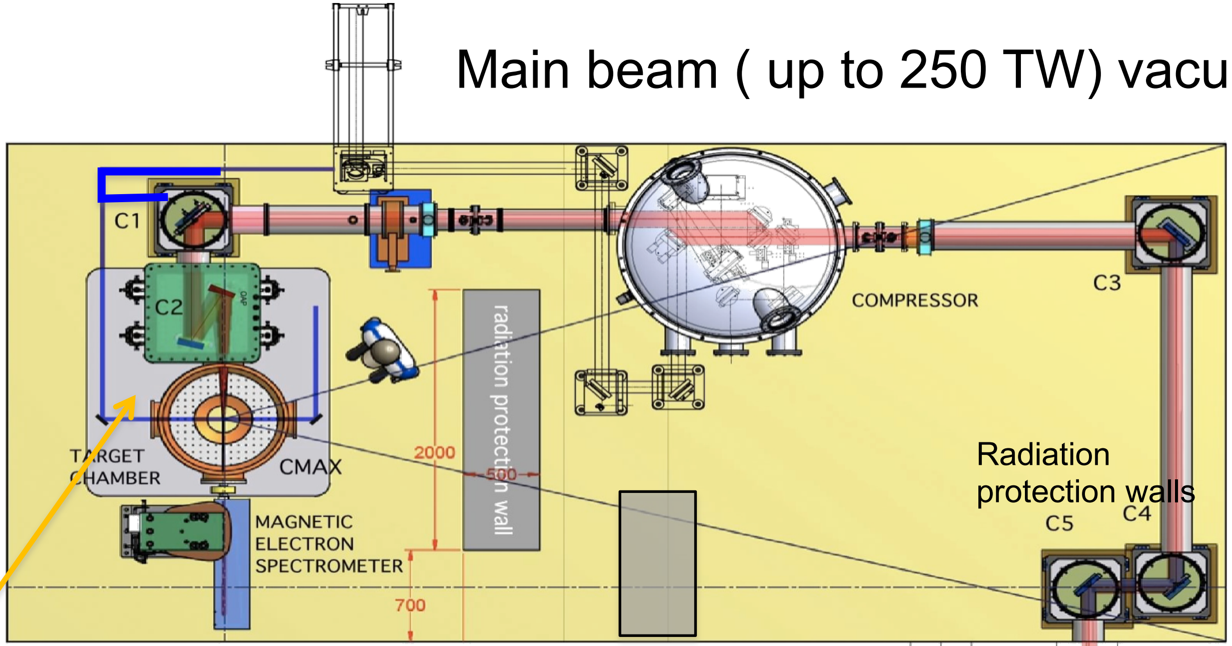
LWFA with self-injection
Proton acceleration



FLAME – Overview



Main beam (up to 250 TW) vacuum transport line

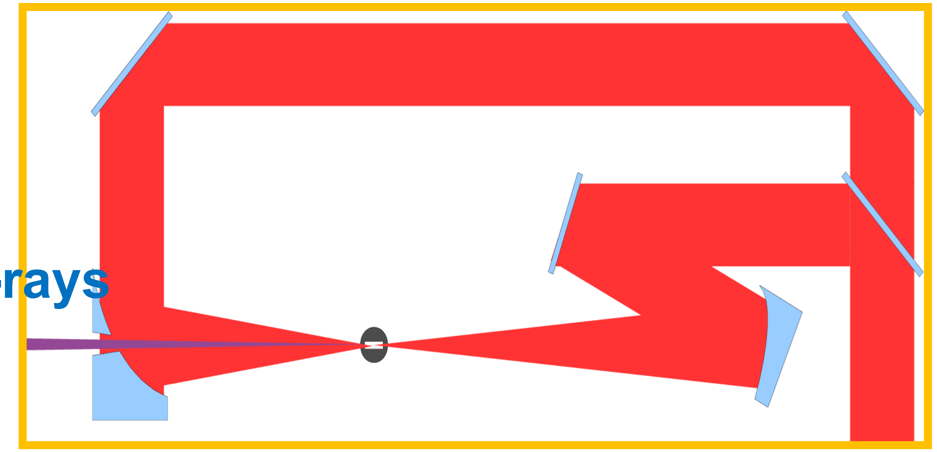


Aux “probe” beam up to 100 mJ

To SPARC bunker

Plasma acceleration

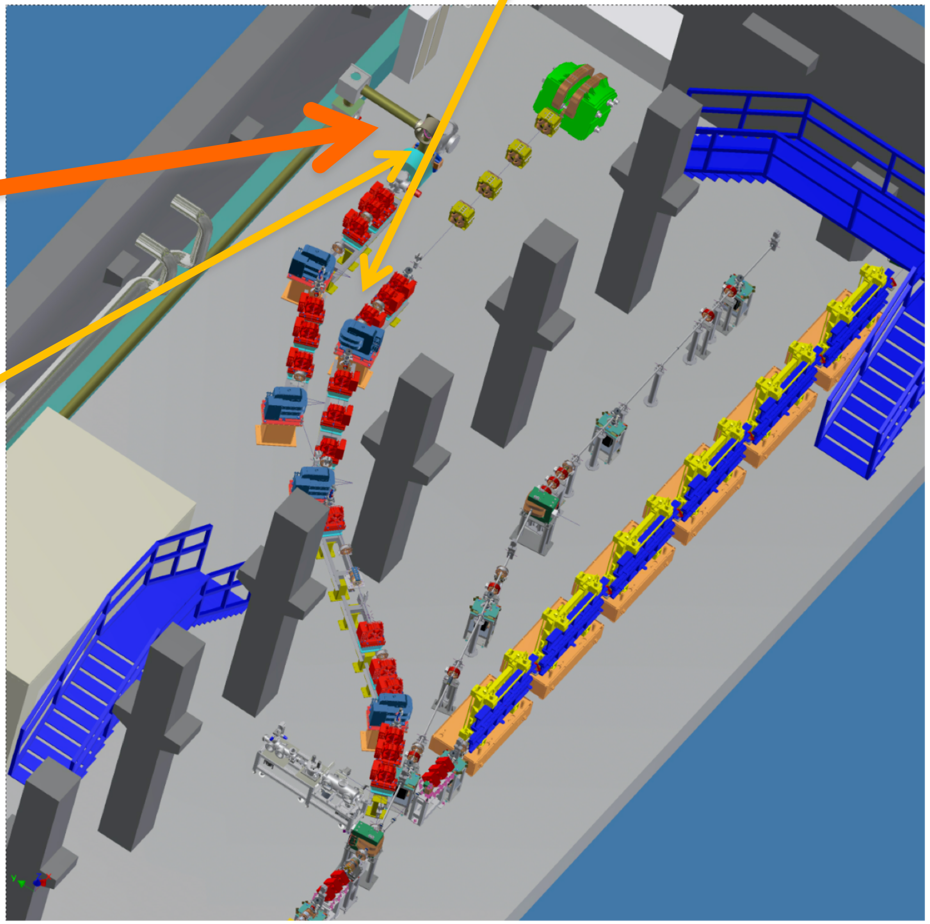
Thomson scattering laser pulse



splitter

γ-rays

Thompson source



Main laser pulse from FLAME

Plasma Acceleration laser pulse

For the shielding evaluation

$$\sum \dot{H}_i = \sum_i \frac{s}{r^2} e^{-d/\lambda i}$$

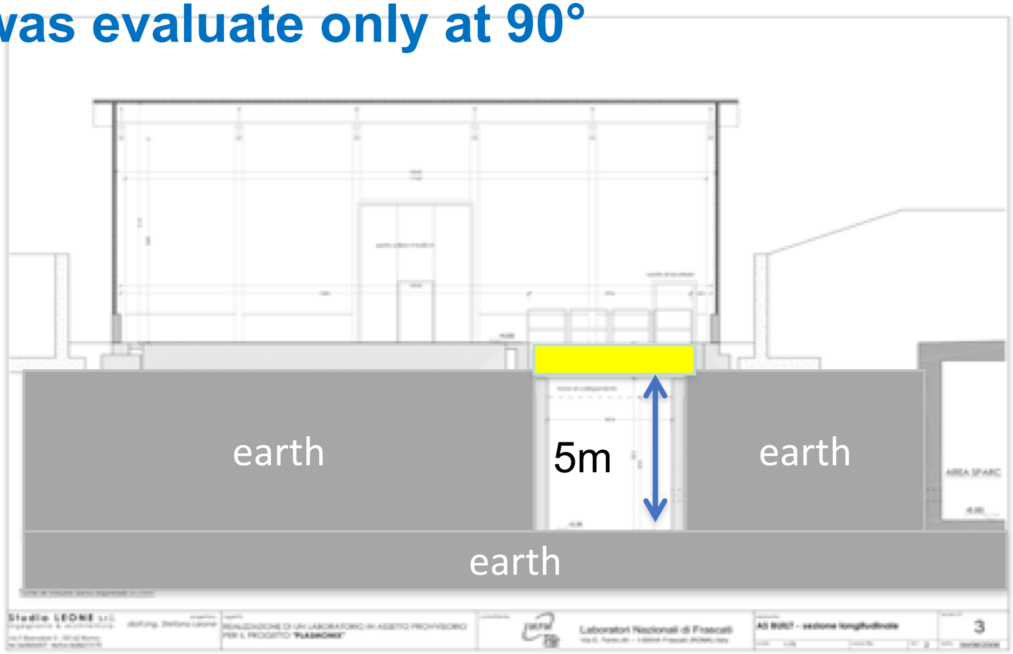
We reported only the values obtained in most conservative case from the point of radiation protection view (200 MeV, 1 nC/shot, 10Hz)

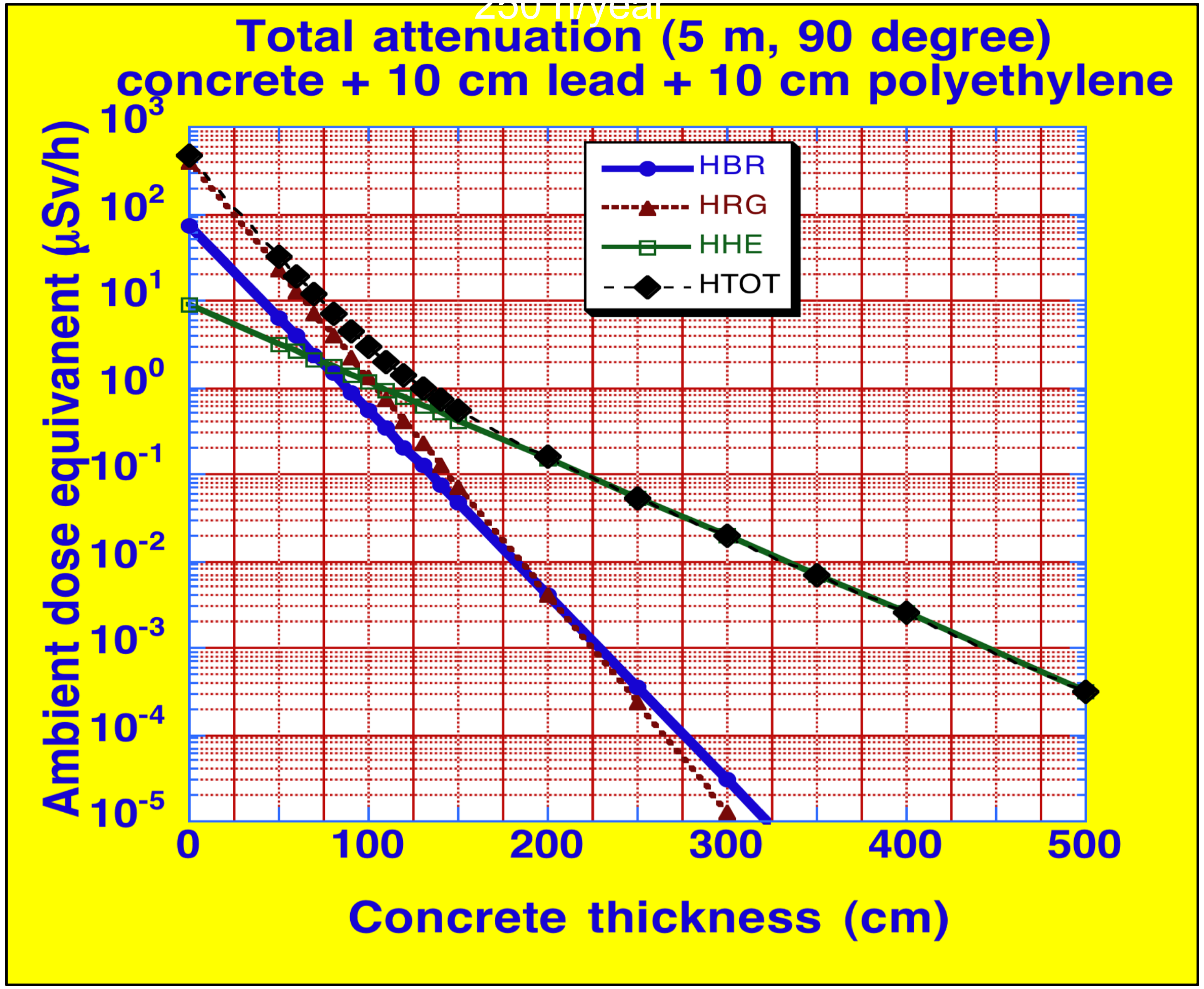
Operation for 250h/year

H*(10) < 1mSv/year

ambient dose equivalent rate

The ambient dose equivalent rate was evaluate only at 90°





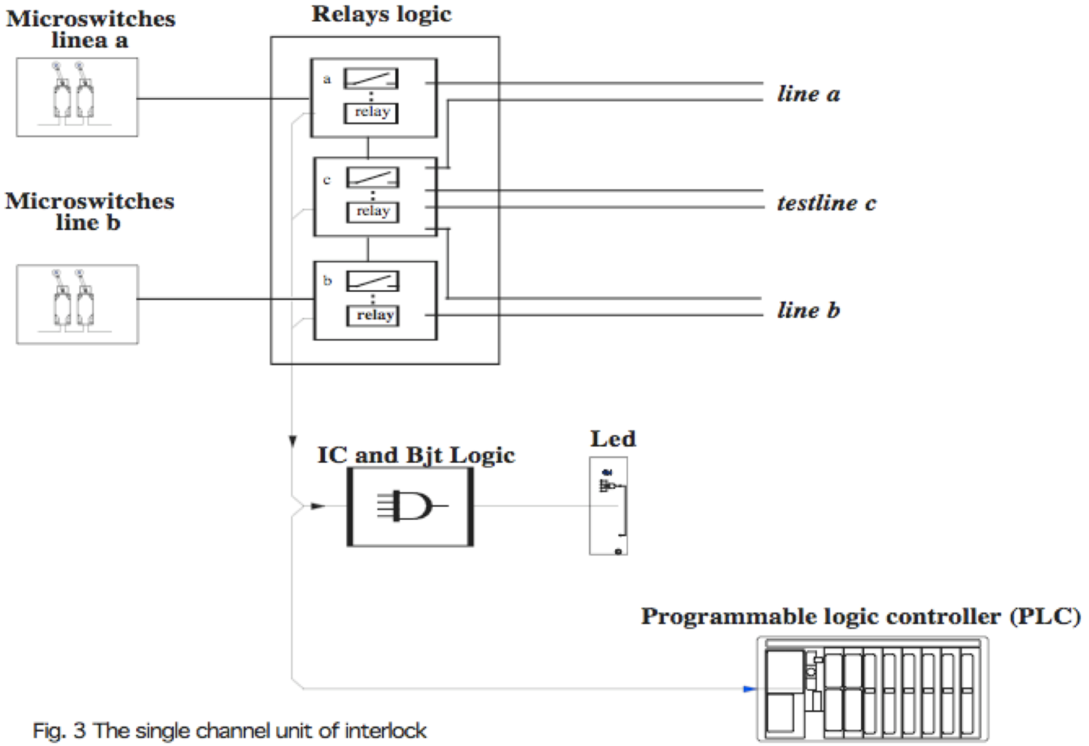


Fig. 3 The single channel unit of interlock

The door of FLAME experimental area is equipped with a lock with a key imprisoned. The access door is equipped with two independent chains of interlocks, each interlock consisting of two microswitches in series and each microswitch consisting of two contacts.

Emergency-off buttons, clearly visible in the darkness and readily accessible, are installed inside and outside the pit area . The reset of emergency-off buttons must be done locally.

Warning lights and audible warning are given inside radiation areas when the laser is ready to give a shot.

Any violation of the radiation areas must cause the stop of the machine. In this case
a shutter is inserted along the main laser beam transport;
a valve is inserted between the compressor and the interaction chamber;
a mirror in the compressor is rotated to avoid any transport of the main beam to experimental chamber. Start again require a new area search.

Radiological risk for the workers and the members of public from the prompt radiation.

Normal working condition

The ambient dose equivalent rates in the various areas of FLAME laboratory as well as in the external areas are quite negligible and however difficult to measure with the radiation protection instruments used in routine monitoring.

Accident condition

The only accident condition consists in the irradiation of person close to the target area during the FLAME operation. This event is quite unlikely taking into account of the redundancy of the radiation safety system. The evaluation of the effective dose is not an easy job because of the impossibility to take into account the distance from the source, the condition of the exposition, the numbers of shots and so on.
Only one shot can in principle give at 1m from the target an ambient dose equivalent of 3-4 mSv in the worst conditions

Area classification

Target area

Controlled area during the operation. Access forbidden.

Area interlocked @ laser on.
Free access area @ laser off unless of residual radioactivity

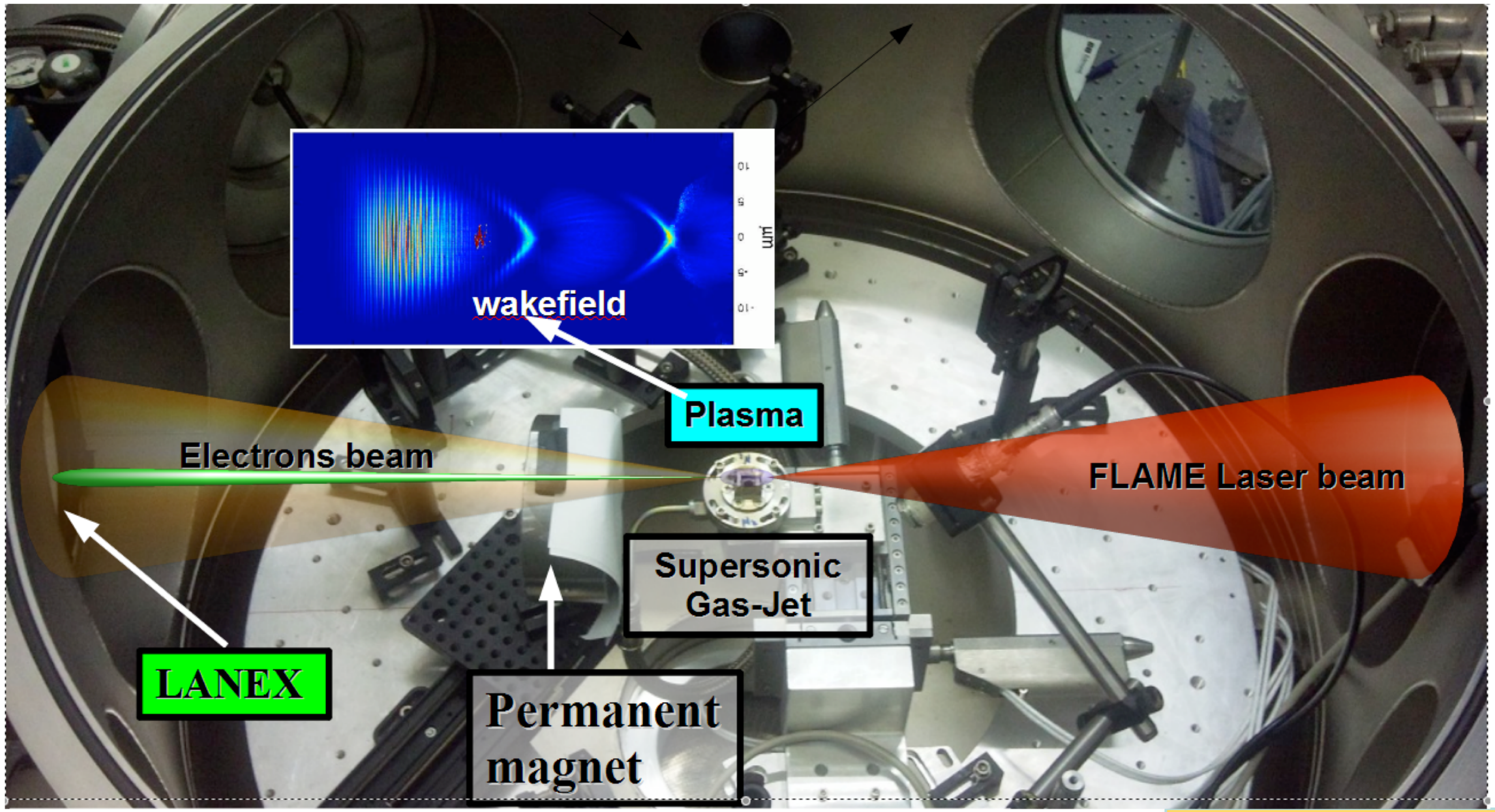
Control room and clean room

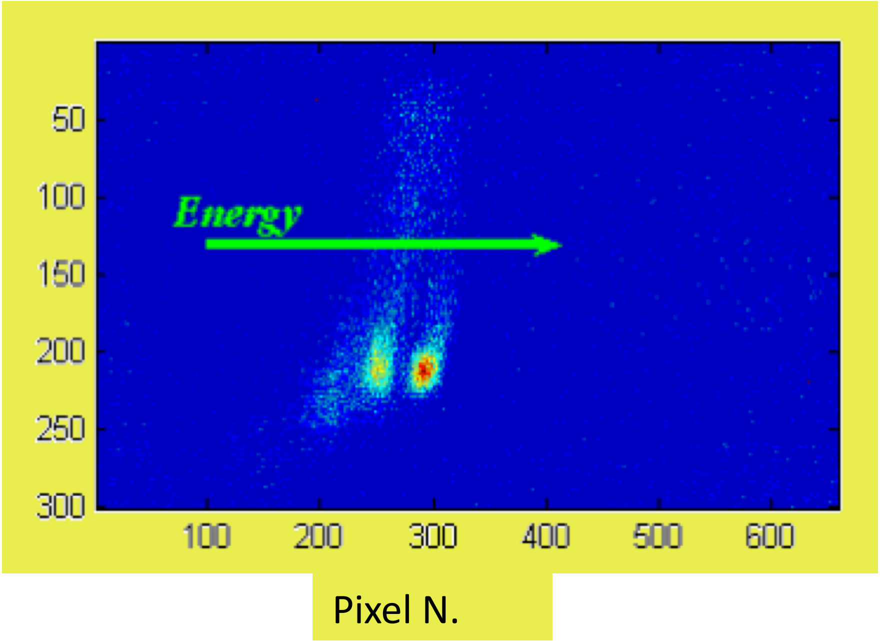
Free access area. No restrictions or requirements from the radiation protection point of view

Worker classification

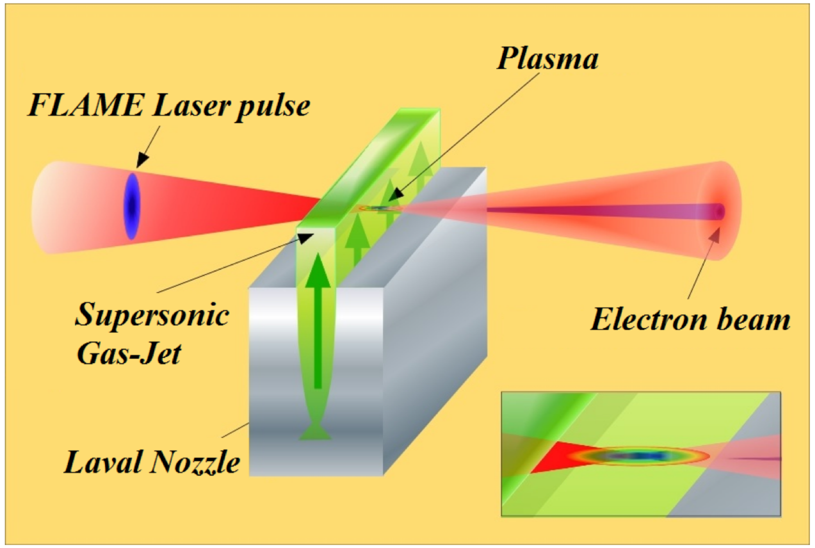
All the workers will be classified "non exposed" workers

According with the Italian law in force the annual exposure limit for non exposed workers is 1 mSv equal to the limit for the members of public.





Gd_2O_2S:Tb inorganic scintillator



Laser peak power = 250Terawatt

Lgasjet = 4 - 10 mm

Plasma density = 1 10^{18} -1 10^{19} cm^{-3}

Pulse duration = 35 fs

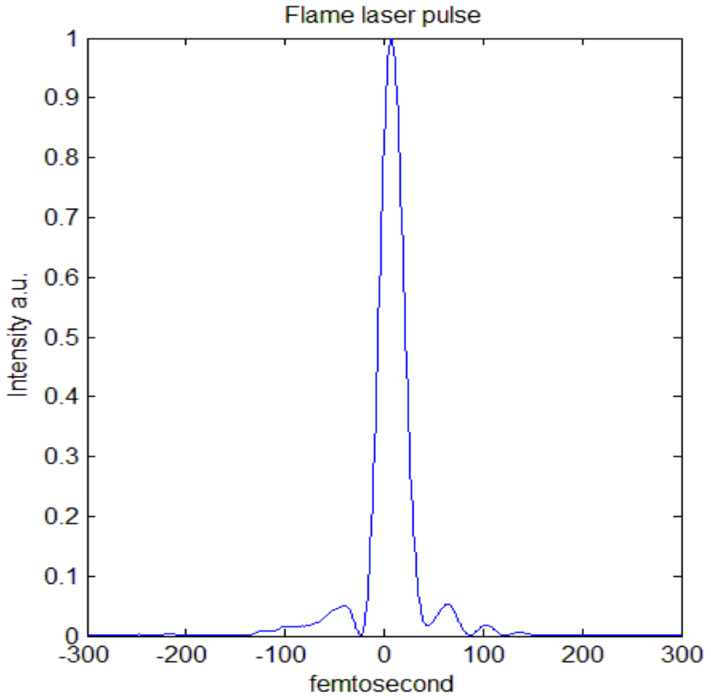
Laser intensity ≤ 5 10^{19} W/cm^2

Laser focal spot = 9 - 17 μm

Laser energy = 1 J

In order to characterize the radiation field of FLAME laboratory the Radiation Protection Group of LNF installed a network of passive detectors mainly inside but also outside radiation shield. In each positions were installed different TLD detectors (TLD 400 bulb detectors, TLD 600, TLD 700, from Thermo Company previous Harshaw Company) plus a stack of PADC detectors.

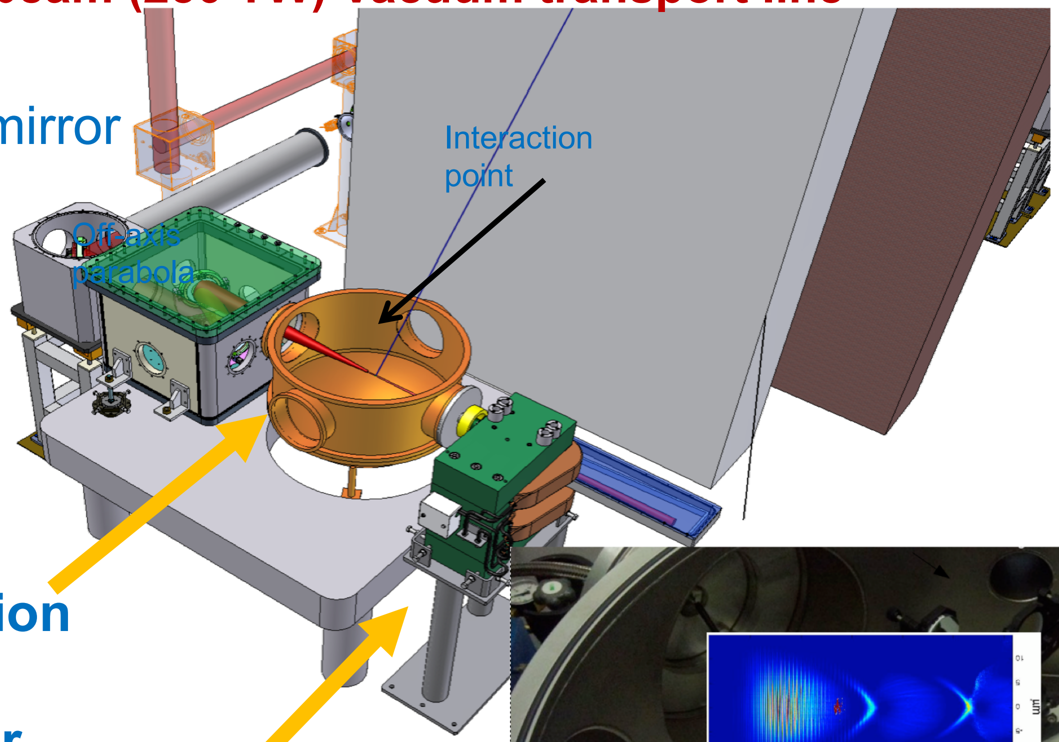
Detectors were exposed 55 hours
For a 2980 effective shots (~10shot/min) plus 10% for setting



Main beam (250 TW) Vacuum transport line

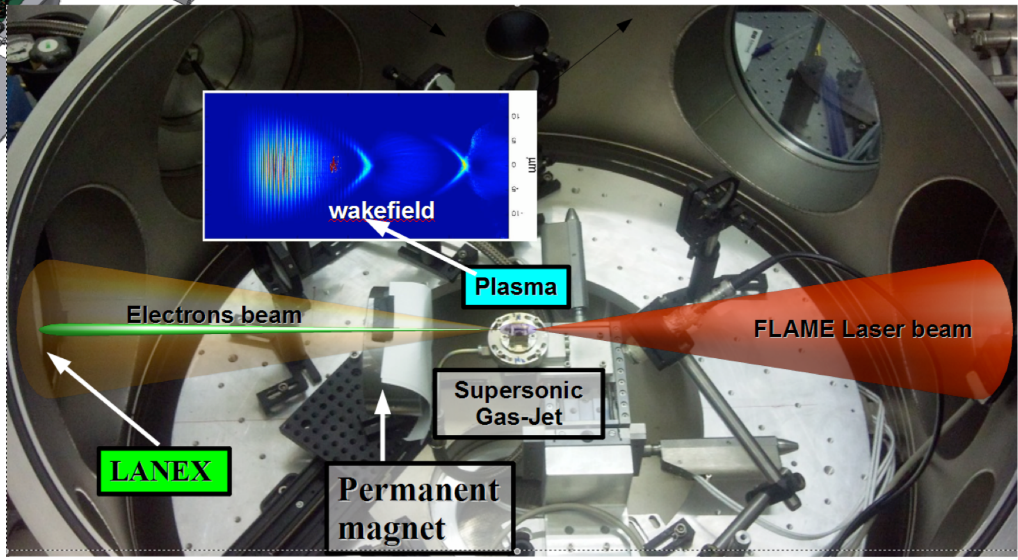
Main **turning** mirror

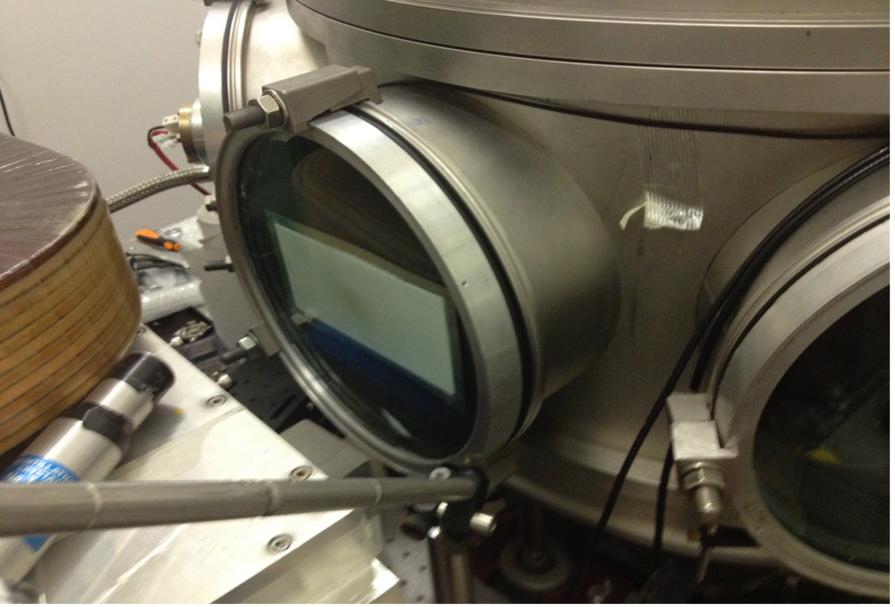
Radiation protection walls



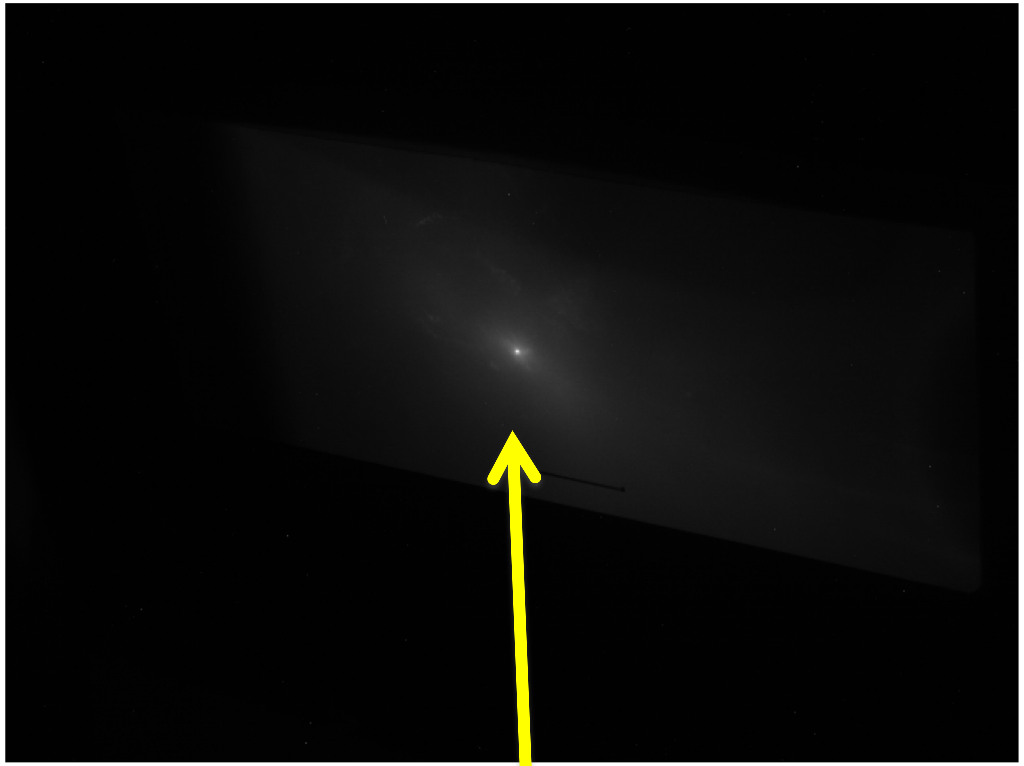
Interaction vacuum chamber

Electron spectrometer





Lanex screen with and without magnetic field



Electron beam divergence about 1 mrad

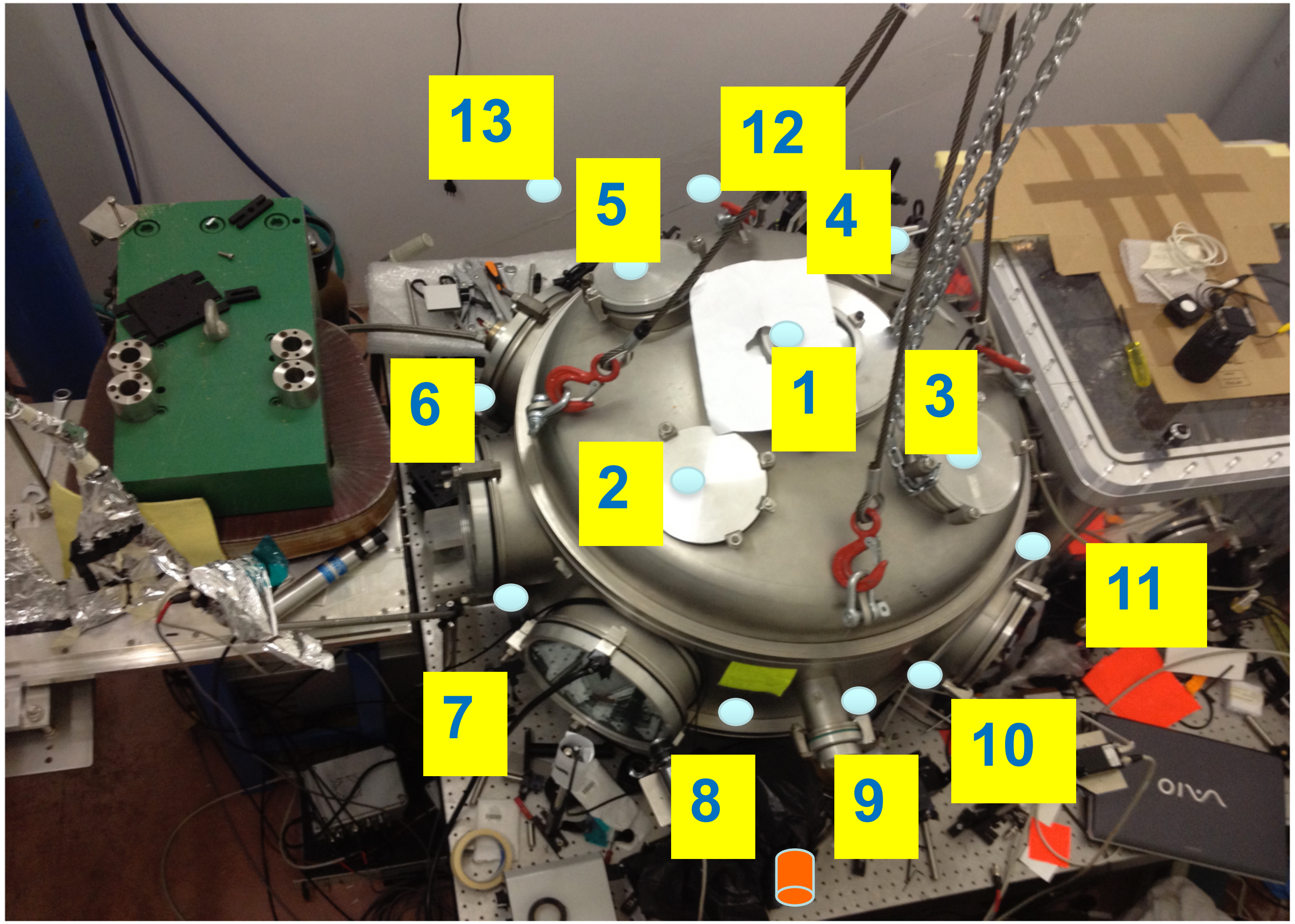
Electron energy dispersion with a 0.9 Tesla of permanent magnetic dipole

Estimation of electron energies ranges up to 500 MeV and more.

In about 2 days of exposition were obtained from TLD 400 and 700 the values reported in a table.

Measurement points around the interaction chamber.

Automess Scintillator Probe 6150AD-b

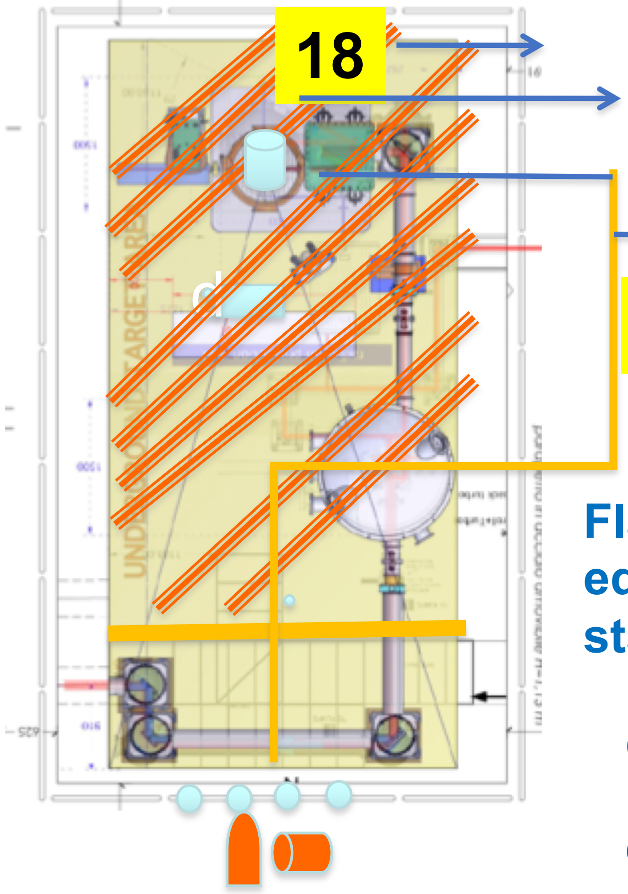


Measurement positions	Ambient dose equivalent (mSv)	Ambient dose equivalent (mSv)
1	0.55	0.84
2	0.84	1.99
3	0.56	1.01
4	0.34	0.56
5	1.05	2. 31
6	611	497.22
7	65	174.00
8	4.8	1.29
9	3.27	1.35
10	2.3	0.99
11	1.3	0.52
12	0.06	0.04
13	0.05	0.04

10% up to 20%

Uncertainties

The Automess Scintillator Probe 6150AD-b in integration mode of operation measured a value of 1 microSievert in an hour of operation at a rate of about 10 shots per minute.
The value is consistent with the value obtained with TLD 400 and 700, taking into account the different position and size of both detectors



Passive network detectors after half a meter of ordinary concrete

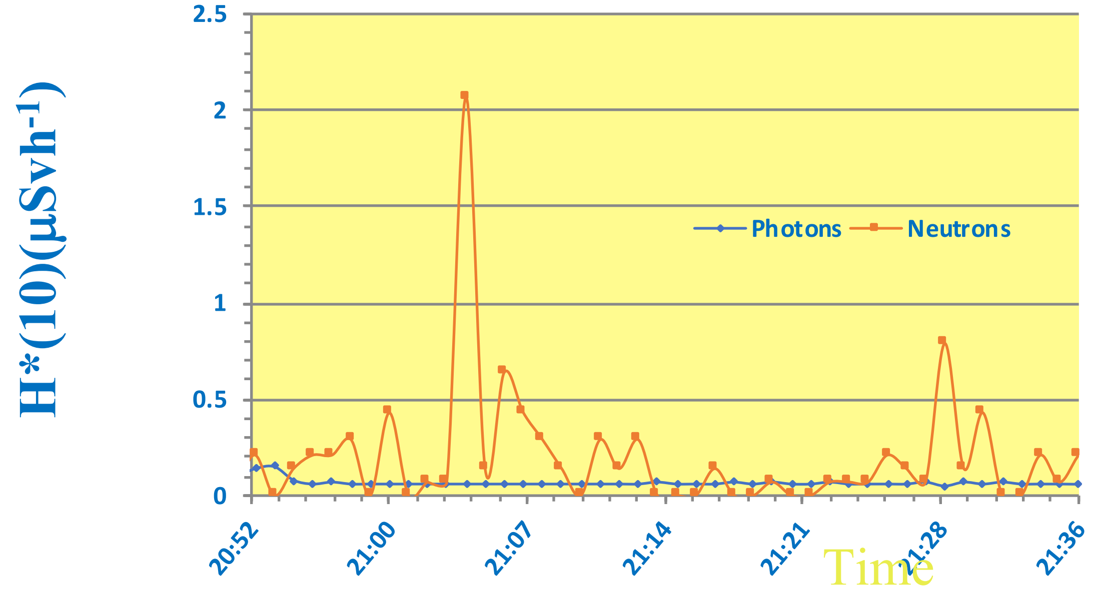
14 15 16 17

Flame pit entrance equipped with two stairs

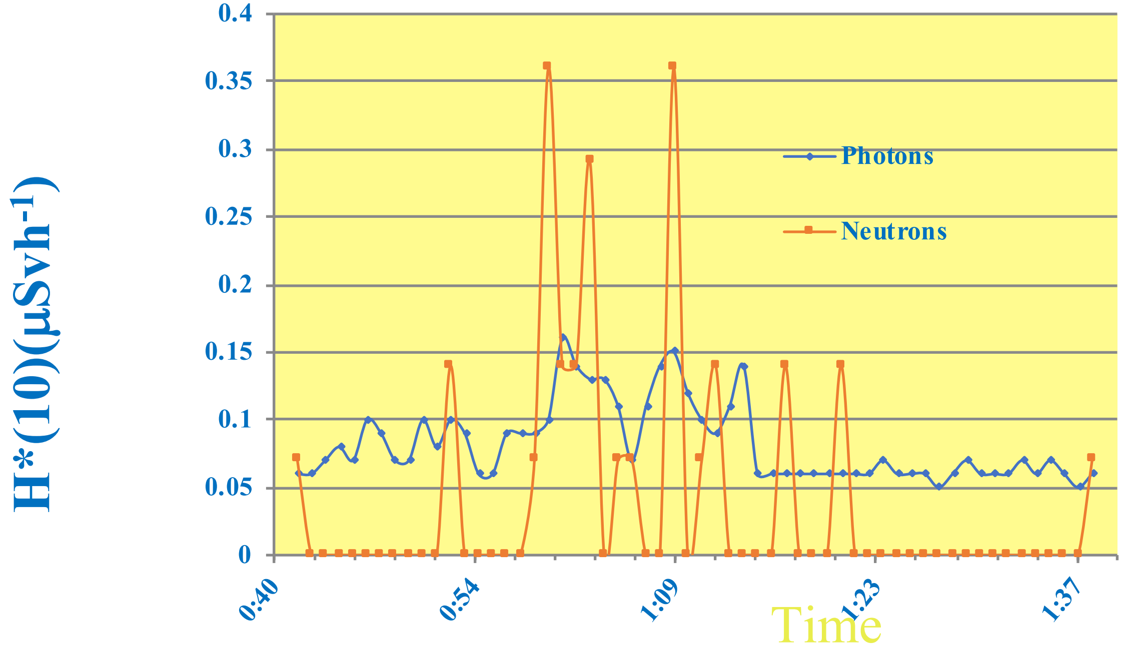
Gamma and neutron active detectors

Measurement positions	Ambient dose equivalent (mSv)	Ambient dose equivalent (mSv)
14	0.05	0.04
15	0.06	0.04
16	0.06	0.04
17	0.06	0.04
18	0.07	0.04

A person close to interaction chamber (point 6) during the operation in such conditions could receive in one minute about 2 mSv. This value is consistent with maximum credible accident.



Ambient dose equivalent rate just outside FLAME pit as shown in the previous figure.
Each point represents the ambient dose equivalent obtained averaging samples on each minute of operation and scaling for an hour.



A contemporary gamma and neutron emission not always were detected.

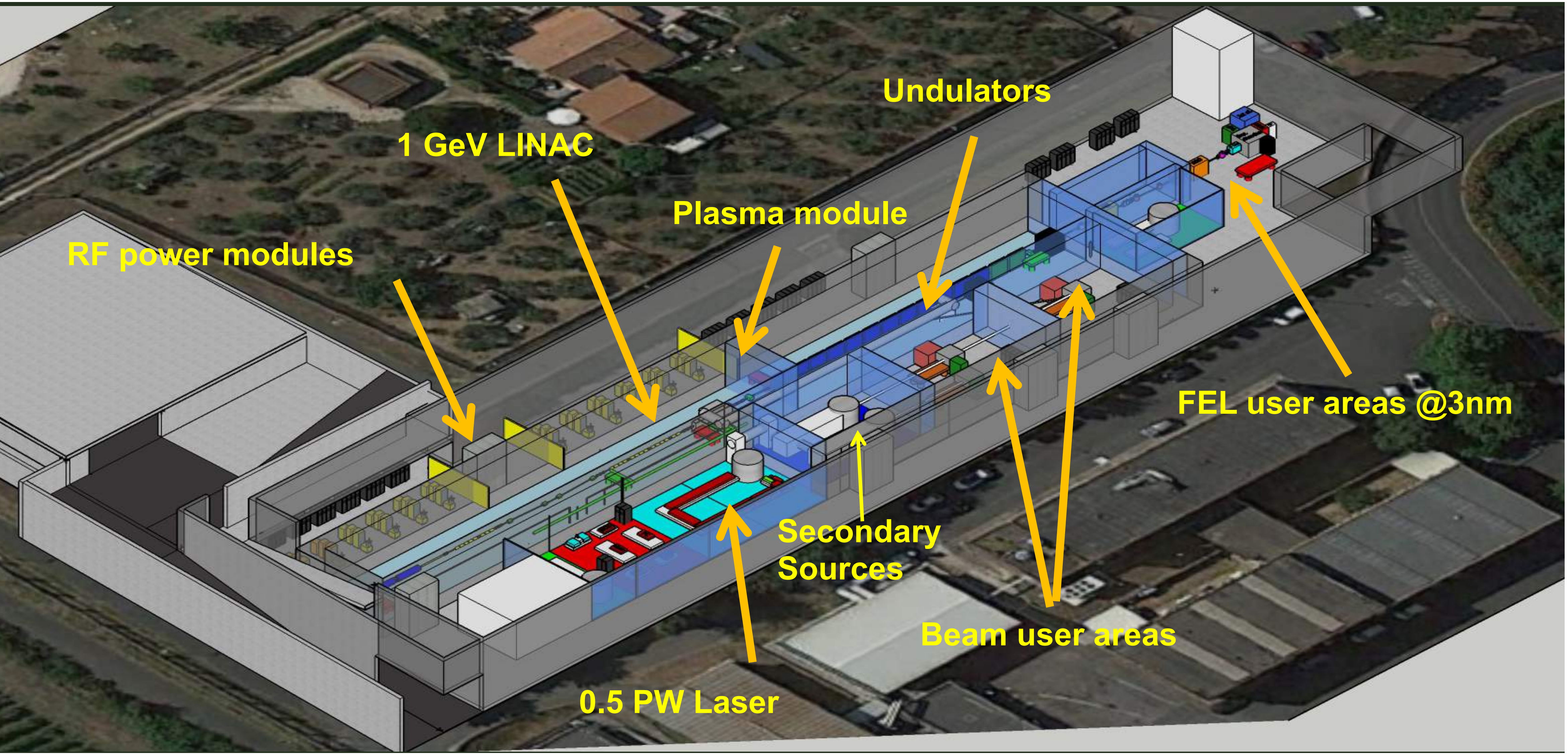
Neutron background is negligible in practice, while photon background is ~0.06 mSv/h

Annual exposure to natural radiation sources is ~3.3mSv equal 0.38 mSv/h.

Conceptual Design Report Readyfor the LNF site

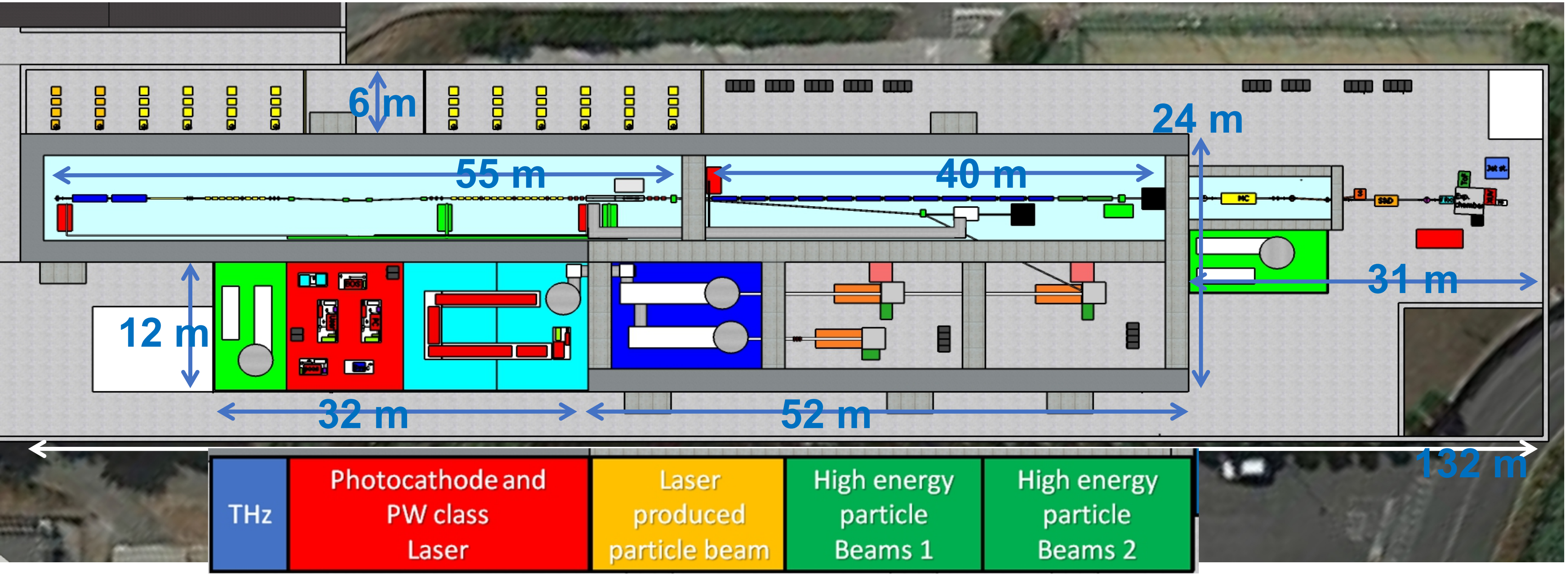
http://www.lnf.infn.it/sis/preprint/pdf/getfile.php?filename=INFN-18-03-LNF.pdf

Courtesy Massimo Ferrario



Courtesy Massimo Ferrario

- Candidate LNF to host EuPRAXIA (1-5 GeV)
- FEL user facility (1 GeV – 3nm)
- Advanced Accelerator Test facility (LC) + CERN



- 500 MeV by RF Linac + 500 MeV by Plasma (LWFA or PWFA)
- 1 GeV by X-band RF Linac only
- Final goal compact 5 GeV accelerator

Courtesy Massimo Ferrario

Main Goals

- X-band RF technology implementation,➔ CompactLight
- Science with short wavelength Free Electron Laser (FEL)
- Physics with high power lasers and secondary particle source
- Compact Neutron Source
- R&D on compact radiation sources for medical applications
- Detector development and test for X-ray FEL and HEP
- Science with THz radiation sources
- Nuclear photonics with g-rays Compton sources
- R&D on polarized positron sources
- R&D in accelerator physics and industrial spin – off

Courtesy Massimo Ferrario

MariX: design study of a
Multi-disciplinary Advanced Research Infrastructure for the generation and application of X-rays

MariX is a research infrastructure optimized for matter analysis carried out using techniques based on coherent X-ray diffusion and photo-electric effect, with a temporal resolution at the femtosecond level and MHz-class pulse repetition rate.

The Mission

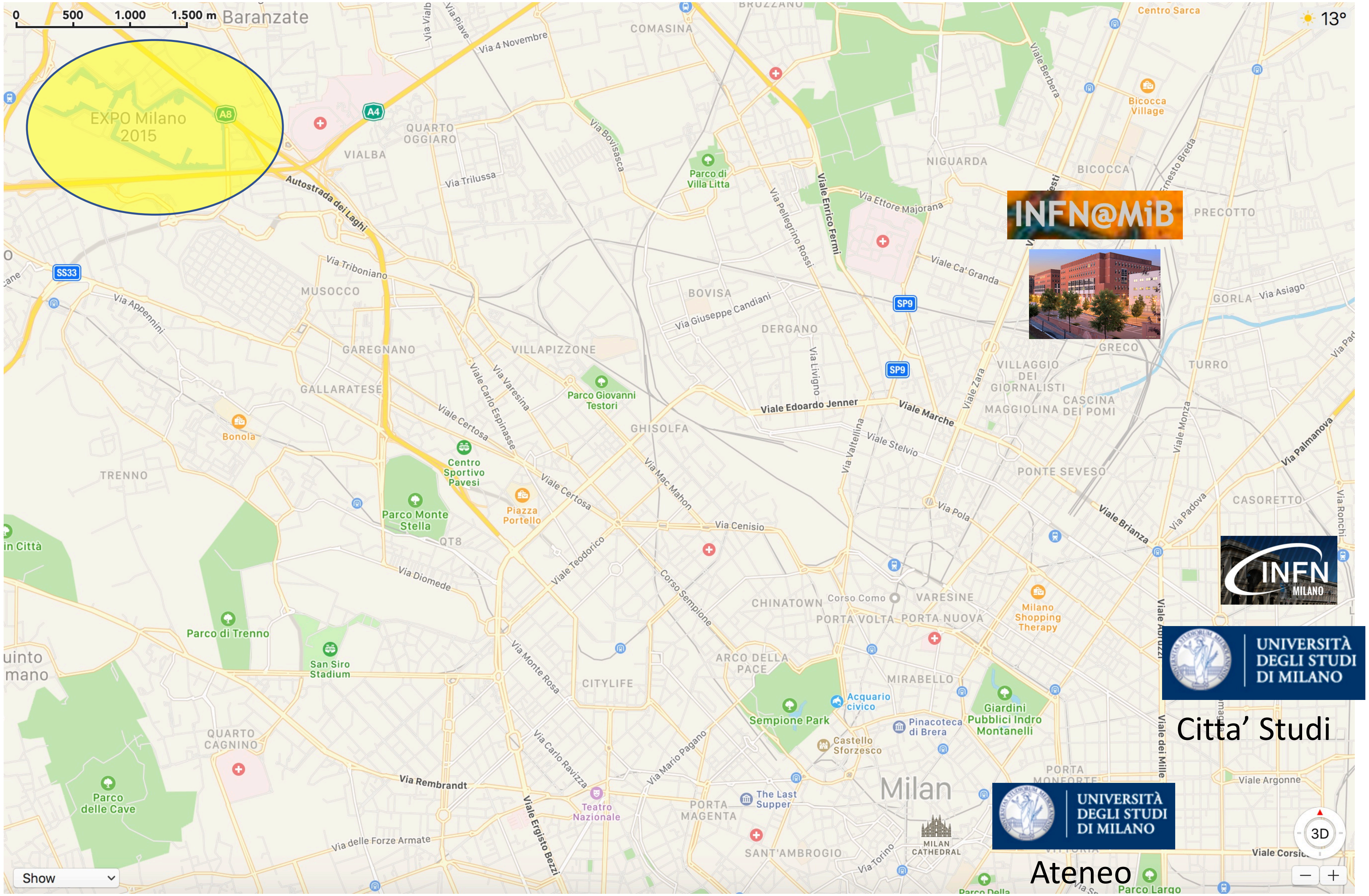
coherent femto-second X-rays @ (0.1-8) keV

ultra-high brilliance hard X-rays @ 20-180 keV

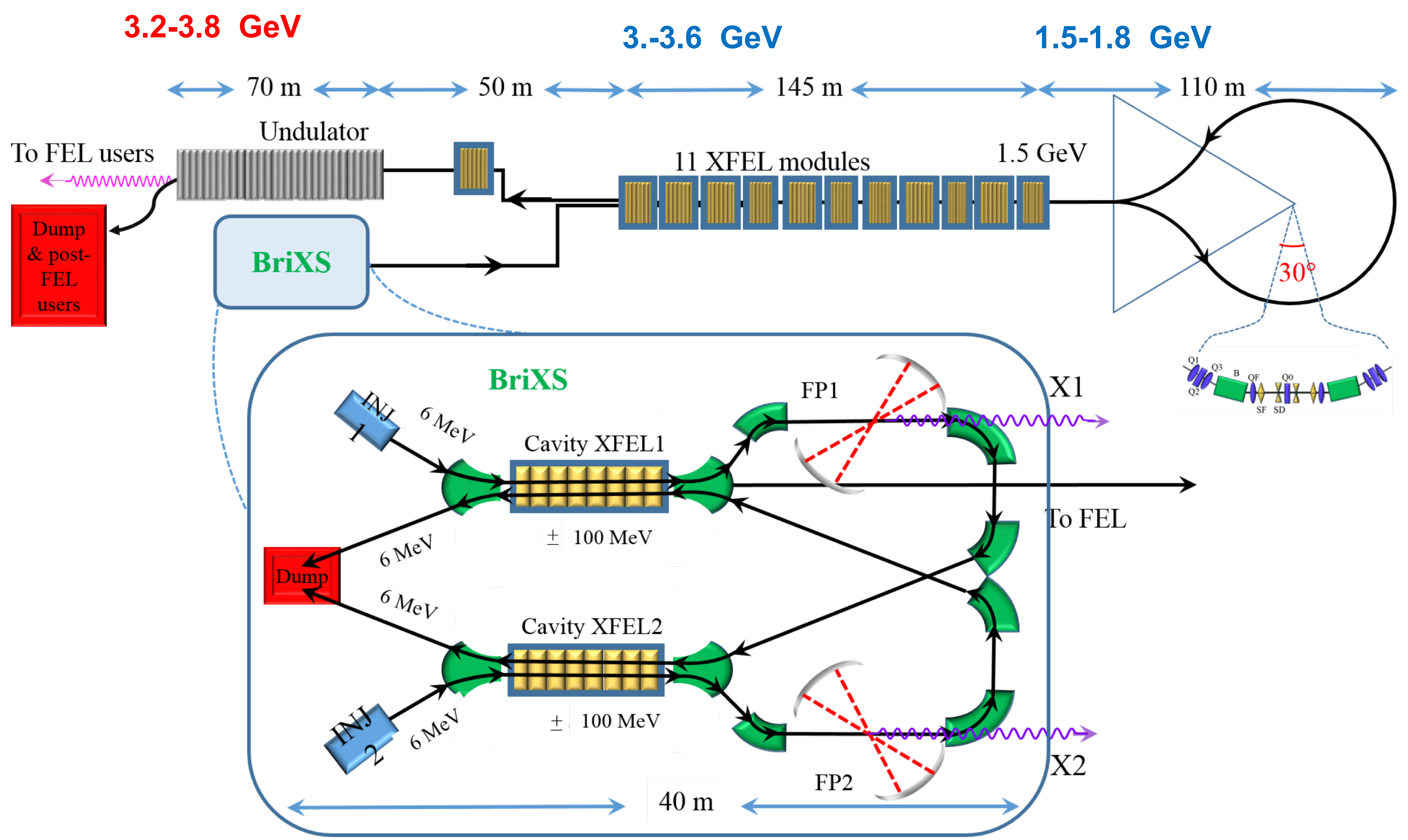
FEL fully coherent diffraction limited X-ray photon beam: $10^{9\text{-}12}$ $h\nu$/pulse @ 1 MHz in 0.05% $\Delta\nu/\nu$, 0.1-8 keV, σ_t < 50 fsec, 10^{18} $h\nu$/s

Compton X-ray photon beam: 10^{12} - 10^{13} $h\nu$/s (@ 100 MHz) in 5% $\Delta\nu/\nu$, 20-180 keV, tunable, polarized, σ_t = 2 psec, 10 μm round source spot size, mrad divergence

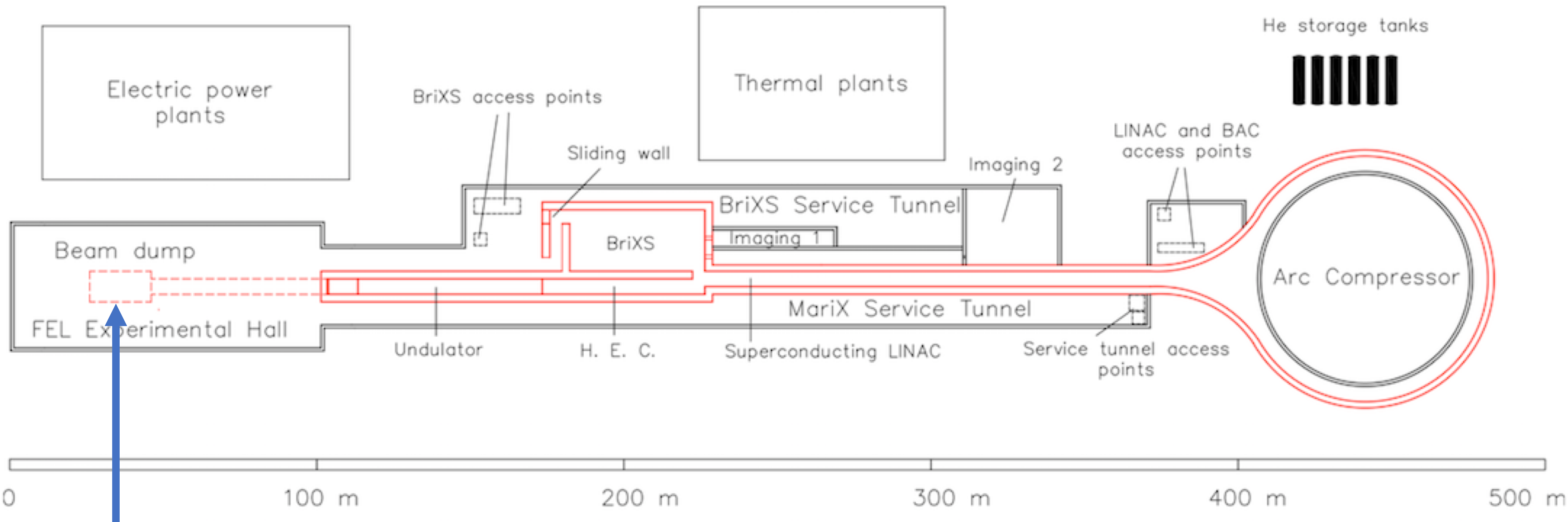
Where? Milano north of Italy in the area of the **World Exposition Milan 2015, Italy**



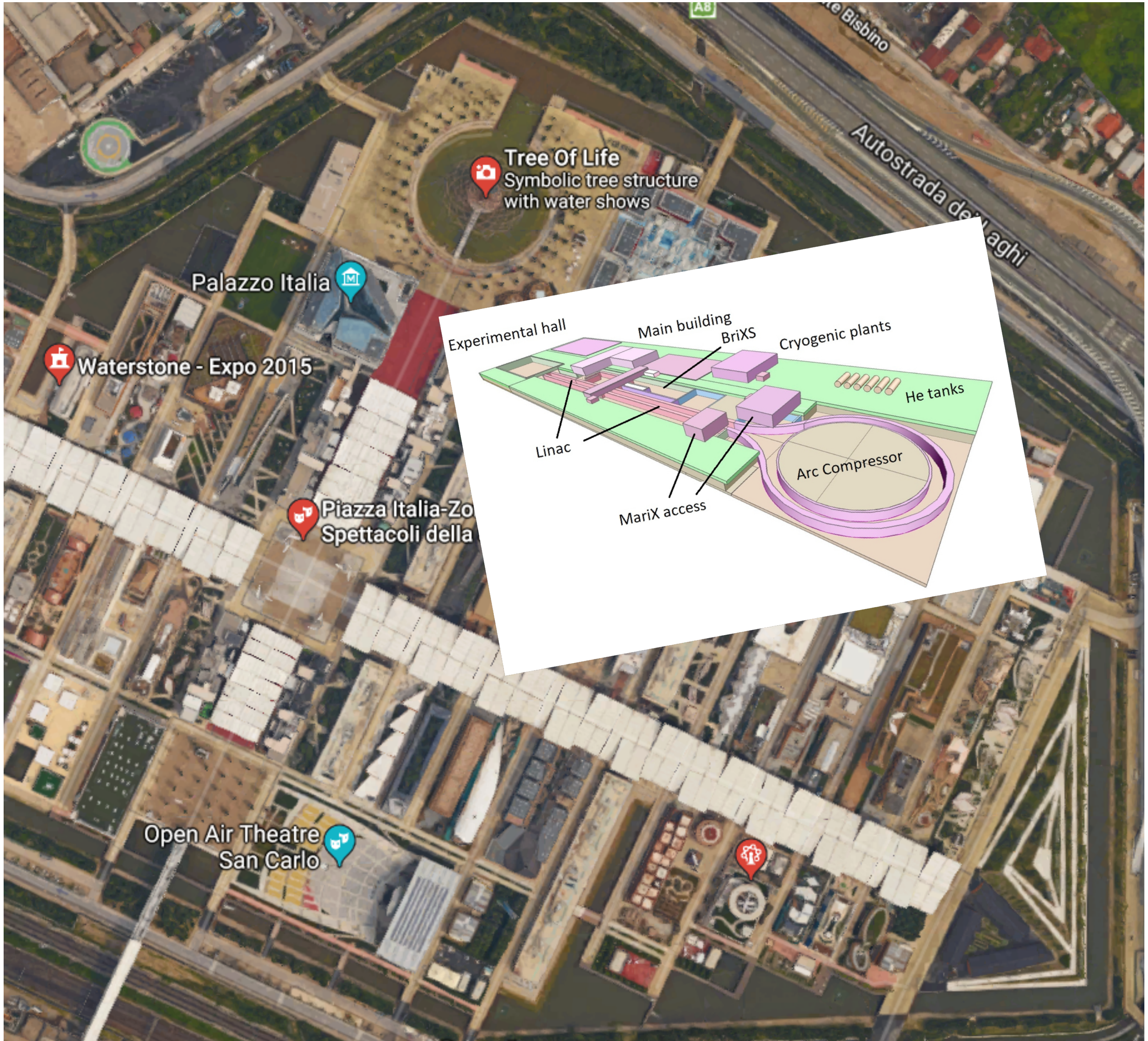
Courtesy Luca Serafini



3.2-3.8 GeV
3.-3.6 GeV
1.5-1.8 GeV
70 m
50 m
145 m
110 m
Undulator
To FEL users
Dump & post-FEL users
11 XFEL modules
1.5 GeV
30°
BriXS
Q1
Q2
Q3
B
QF
Q0
SF
SD
BriXS
INJ 1
6 MeV
Cavity XFEL1
FP1
X1
± 100 MeV
To FEL
6 MeV
Dump
6 MeV
Cavity XFEL2
INJ 2
6 MeV
± 100 MeV
FP2
X2
40 m



200 kW underground beam dump @ 3.8 GeV



Environmental impact

Beam dumps

Material activation

Dose constraints

Area classification	Area description	Design requirement	Dose limit
Controlled areas	Linac Tunnel when accessible, Restricted areas around Beam dumps and/or any other activated, Restricted areas around klystrons	5 mSv/year	20 mSv/year
Free access areas	Experimenal areas Neighboring areas	0.1 mSv/year	1 mSv/year
Border areas	Constraint from licencing authorities = trivial dose	10 micro Sv/year	

At the end of this list of present and future activities of the LNF, I would just like to underline that the LNF Radiation Protection Group is involved in all those competence activities related to the design and operation of accelerator machines and not only at home.

One of the major problems faced was the measurement of neutron dose and spectra around high energy accelerators

Dosimetry of neutron radiation

For area monitoring ICRU recommends the use of H*(10) which is to provide a conservative estimate of effective dose.

H*(10) is not a measurable quantity)

$$H^*(10) = \int_0^{Emax} \Phi_E(E) h^*_{\Phi}(E)\, dE$$

$\Phi_E = \Phi \cdot \varphi(E)$

$\varphi(E)$ is the energy distribution of the neutron fluence normalized to 1 cm^{-2}

h^*_{Φ} neutron fluence to dose equivalent conversion factor

Two approaches are possible to determining the value of the Ambient Dose Equivalent H*(10) in a neutron field.

- Using an instruments with flat energy response in terms of H*(10)
- Deriving $\Phi(E)$ by means of spectrometric techniques

Dosimetry of neutron radiation

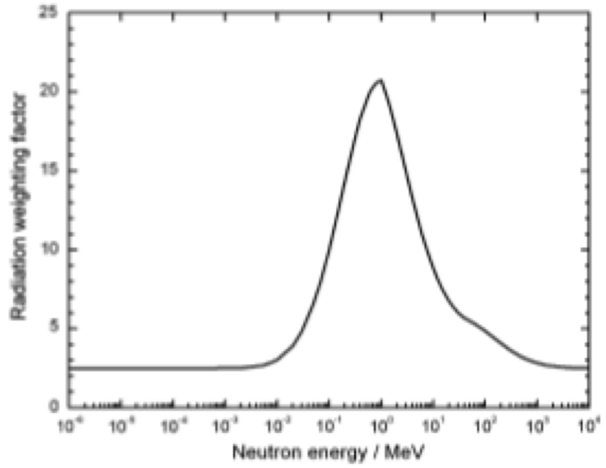
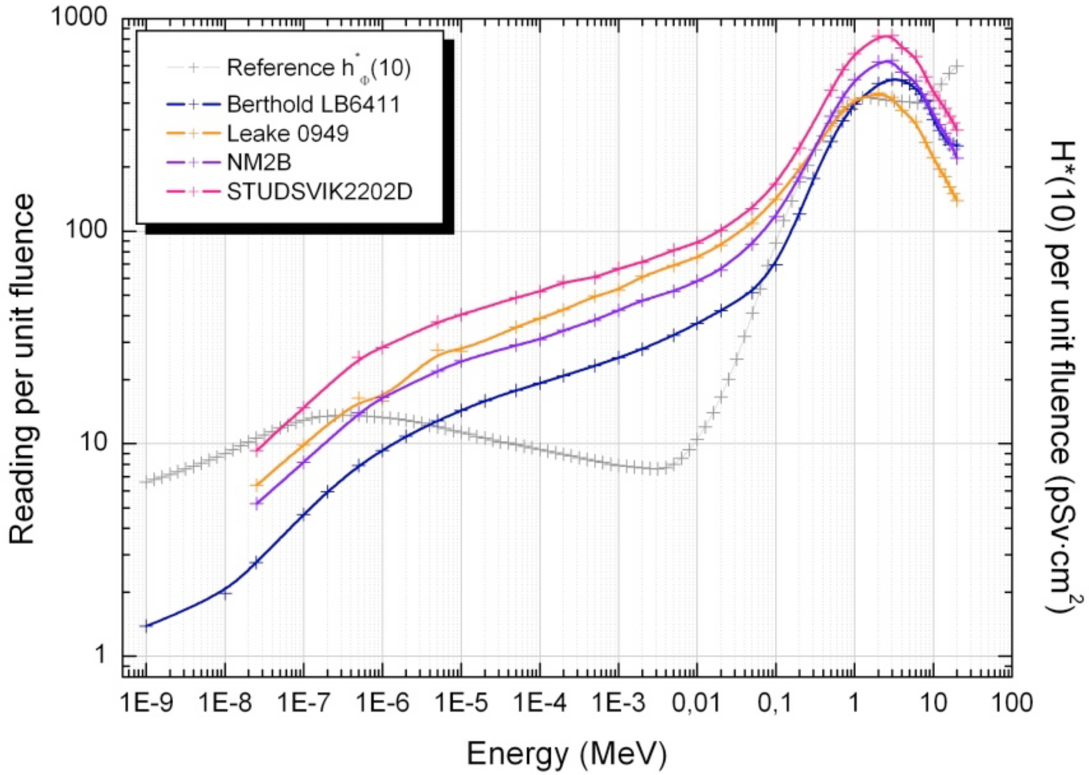


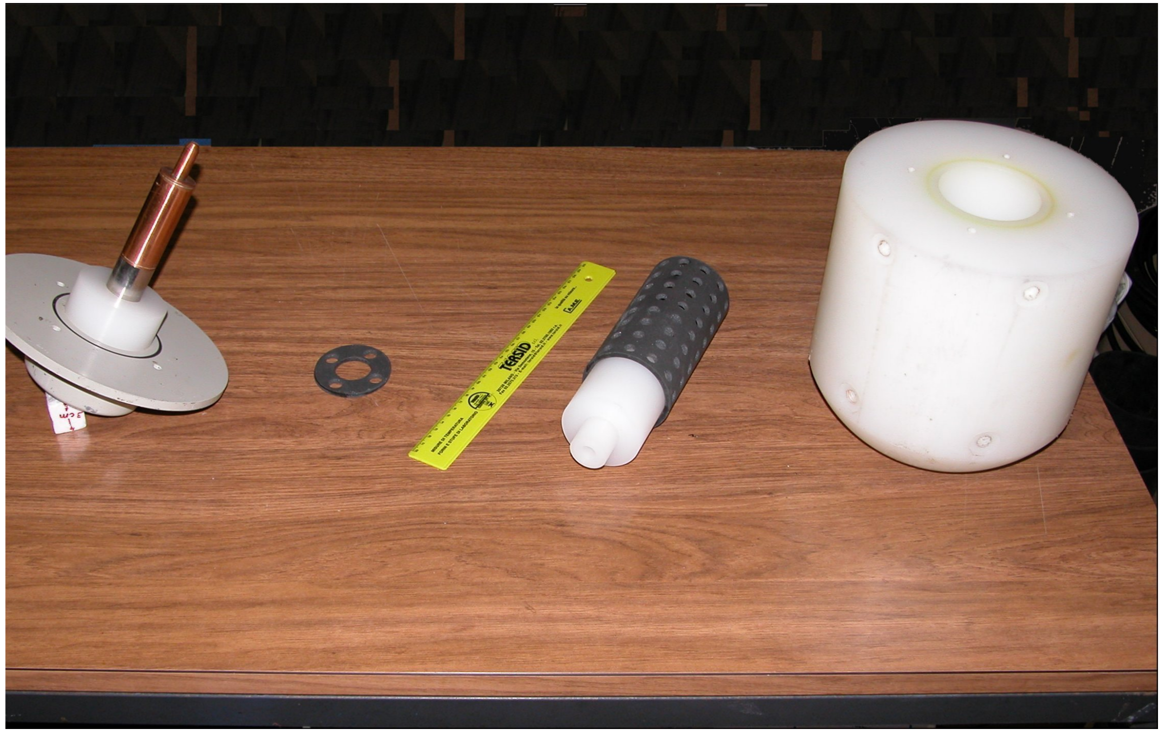
Fig. 1. Radiation weighting factor, w_R, for neutrons versus neutron energy.

This first approach is possible in a limited energy range.

Due to high energy variability of the fluence-to-ambient dose-equivalent conversion coefficients and the diversity of the interaction mechanisms in the human body and the dosimetric material, the instruments responses usually show a very important energy dependence.

Moreover the energy neutrons in the workplace fields can range over 10 order of magnitude



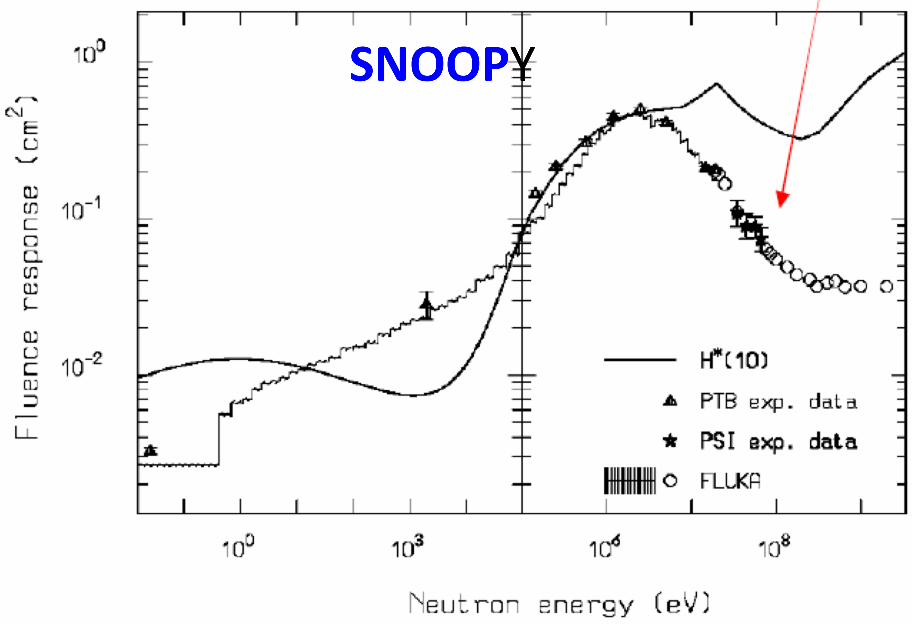


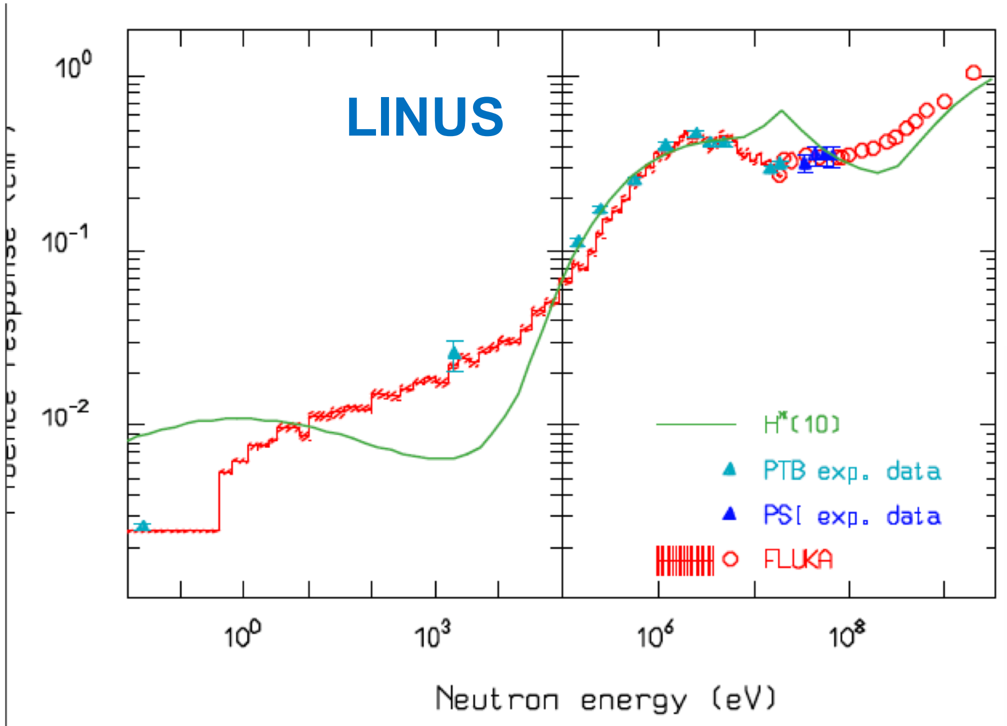
Dosimetry of neutron radiation

As previously shown conventional rem counters are suitable **only** for neutron field up to 14 MeV

The enhancement of instrument response because the reaction (n,xn) Lead attenuator 1 cm thick

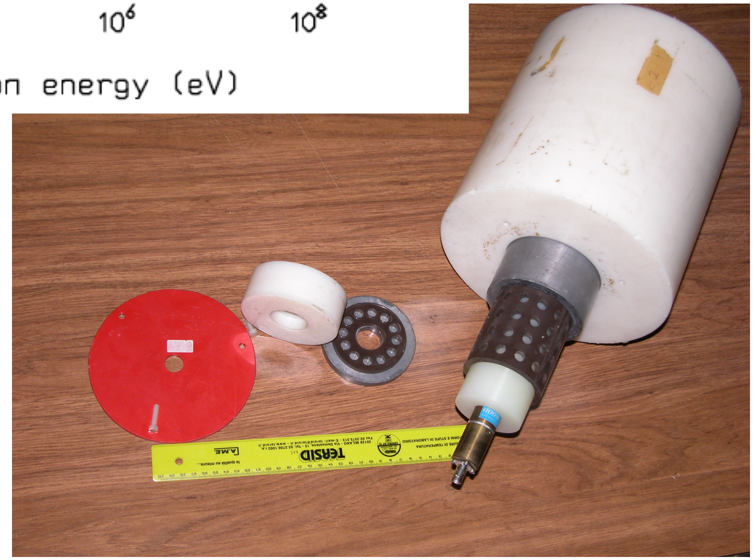
Heavily underestimated above a few MeV





5 MeV	D(d, n)	30.807 ± 1.081	30.586 ± 1.073
14.8 MeV	T(d, n)	21.886 ± 0.767	15.498 ± 0.543
19 MeV	T(d, n)	23.30 ± 0.942	15.18 ± 0.614

The Long Interval NeUtron Survey-meter (LINUS) is a new type of rem counter developed by INFN (LNF Radiation Protection Group and Section of Milan)



Birattari, Esposito, Ferrari, Pelliccioni , Silari,NIM A324 (1993) 232-238
Birattari, Esposito, Ferrari, Pelliccioni,Rancati, Silari, RPD 76 (1998) 135-148

Dosimetry of neutron radiation

An accurate determination of H*(10) in workplace field of unknown direction distribution can be achieved through the use of suitable neutron spectrometer.

- ◆Neutron scattering and measurement of the energies of recoil nuclei.
- ◆Measurement of the energies of charged particles released in neutron-induced nuclear reactions.
- ◆Methods in which the velocity of neutrons is measured TOF
- ◆Threshold spectrometry

The most used neutron spectrometry technique in workplaces is the so called Bonner Sphere Spectrometer (BSS).

Dosimetry of neutron radiation

The advantages of such type of spectrometer are

- the isotropy of the response,
- the possibility to extend the energy range up to GeV neutrons
- the availability of different active or passive central detectors (TLD's, PADC, Activation foils) to be chosen according to the field intensity and time structure.

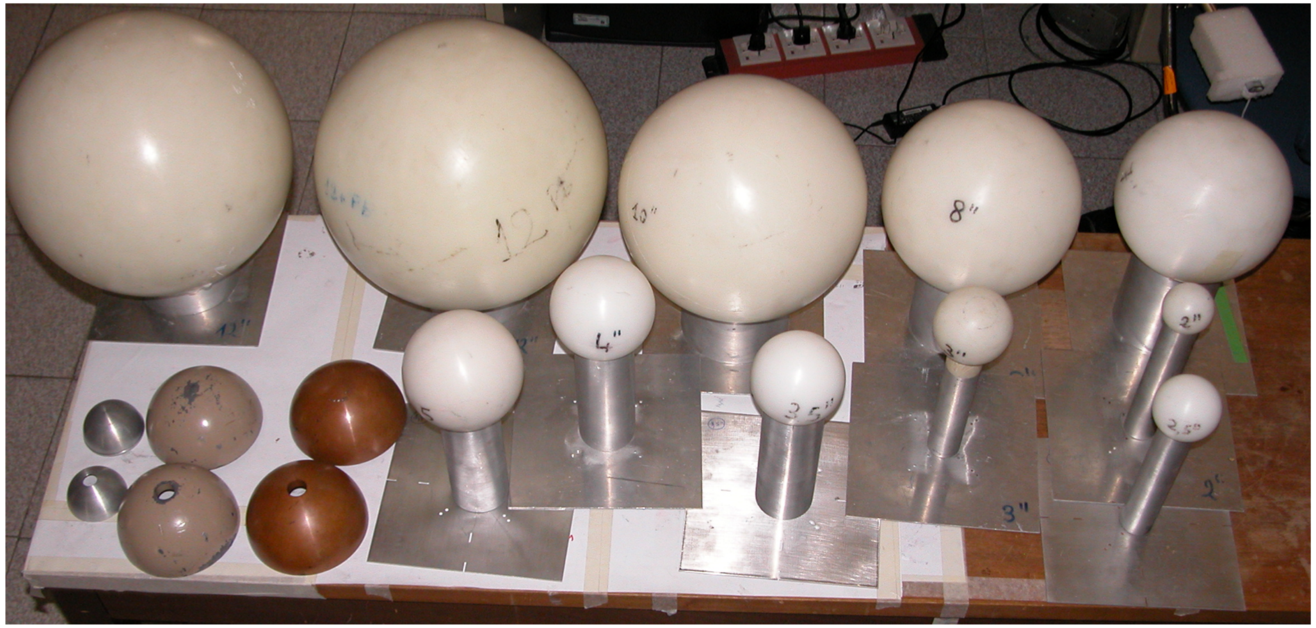
Nevertheless, the unfolding process remains the most difficult task in Bonner Sphere spectrometry, because unfolding codes are usually very complex and require quite detailed "a priori" information on the spectrum to be measured.

With the aim of providing a useful and friendly tool for spectrometry in workplaces, the INFN-LNF Radiation Protection Group developed FRUIT, a new unfolding code specially designed for routine applications where no detailed pre information on the neutron field are available.

The LNF-ERBSS, available from Ludlum Measurements, USA, includes

- eleven polyethylene spheres (density 0.95 g·cm^{-3})
  (2", 2.5", 3",3.5", 4.5", 5", 7",8", 10", 12")
- three polyethylene spheres (density 0.95 g·cm^{-3}) loaded with copper and lead
  (7" Cu, 7" Pb, 12" Pb)
- one sphere sourrounded by a Cd shell
- a 4x4 ^{6}LiI(Eu) active scintillator

Special aluminum holders were designed to expose TLD pairs and a gold or dysprosium foil in the same time



All spheres are designed to hold the scintillator

Dosimetry of neutron radiation

When a set of *m* Bonner spheres is exposed to the same neutron fluence, a set of readings C_1, i=1,..,m is collected. The neutron fluence Φ and its energy distribution φ(E) may be derived by inverting a set of *m* equations, that for computer calculation purposes can be expressed in the following discrete form:

$$C_i = f\Phi \sum_{j=1}^{N_g} R_{i,j}\varphi_j \Delta E_j \qquad i = 1 \ldots \ldots \ldots n$$

***φ(E)* is the energy distribution of the neutron fluence normalized to 1 cm^{-2} (also termed "unit spectrum").**

***$R_i(E)$* is the response function of the sphere (in cm^{-2}). It is usually derived with Monte Carlo calculations and represents the reading per unit fluence as a function of the monoenergetic neutron energy, E.**

$\Phi_E = \Phi \cdot \varphi(E)$

The unfolding problem in Bonner Sphere Spectrometry is under-determined, i.e. the number of independent measurements, *m,* is largely lower than the number of unknowns, N_g.

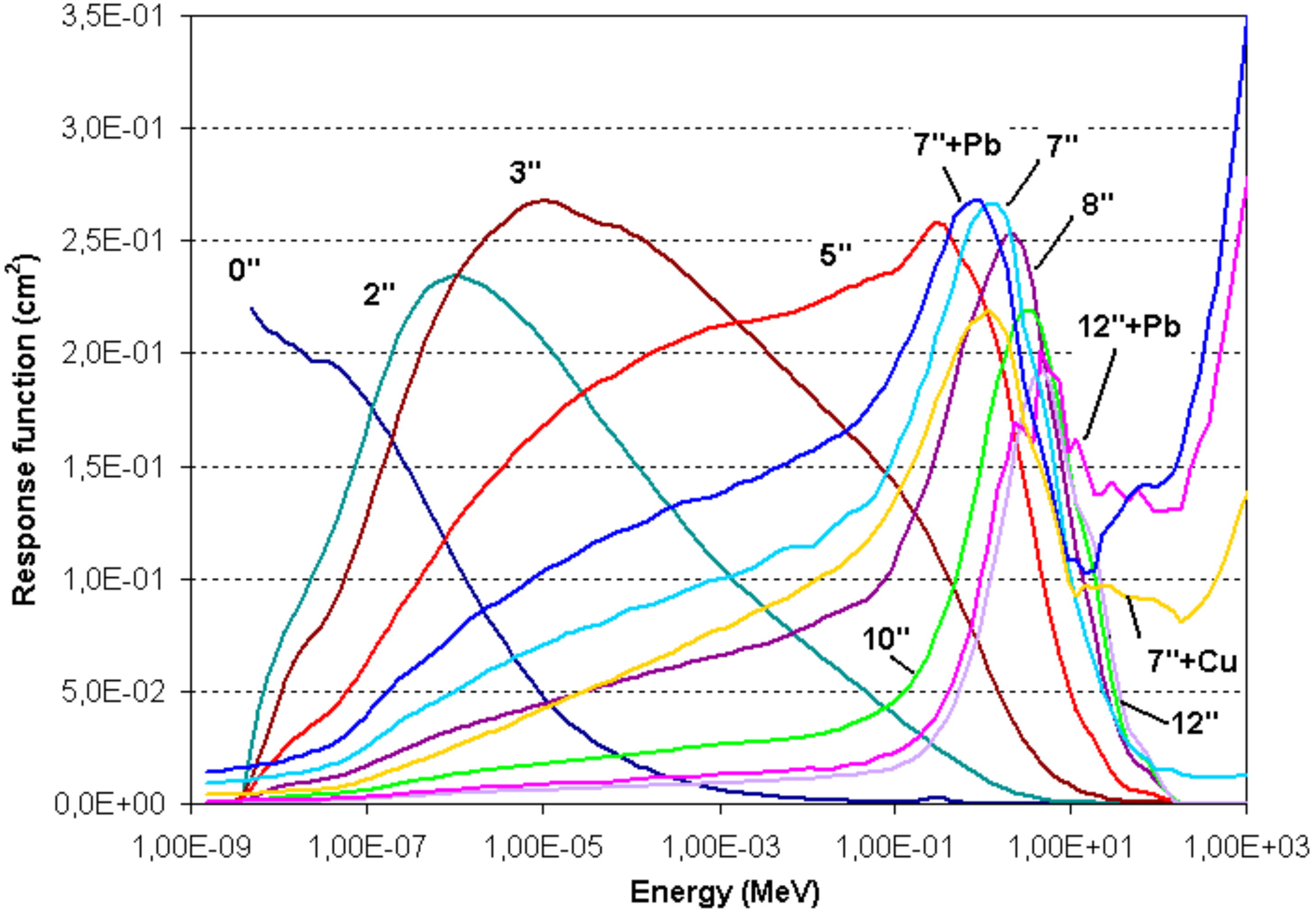
This implies that a set of infinite mathematical functions could satisfy the equation. Nevertheless, only a limited number of them is physically acceptable.

Many codes have been developed for unfolding neutron spectra (Gravel, Maxed, Mitom, Sand)

At LNF we developed the **FRUIT (FRascati Unfolding Interactive Tool)**

The response functions of the active ERBSS were calculated with MCNPX Monte Carlo transport code.

The data were interpolated to produce a response matrix with 120 logarithmic equidistant intervals from 1.5 meV to 1.16 GeV.



The LNF-ERBSS response matrix

The response matrix of the ERBSS was validated in reference neutron fields (PTB, TSL, CERF) and its overall uncertainty was estimated to be σ_{matrix} = ±3%.

Thank you for your attention