STATUS OF ELI-NP GBS PROJECT

EXTREME LIGHT INFRASTRUCTURE
NUCLEAR PHYSICS
GAMMA BEAM SYSTEM

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University of Rome "La Sapienza" and INFN, Italy

SIF - Roma - September 23, 2015

ESFRI, the European Strategy Forum on Research Infrastructures,
is a strategic instrument to develop the scientific integration of Europe and to strengthen its international outreach.

The **mission of ESFRI is to support a coherent and strategy-led approach to policy-making on research infrastructures in Europe**, and to facilitate multilateral initiatives leading to the better use and development of research infrastructures, at EU and international level.

ESFRI covers:
Social sciences and humanities,
Materials and physical sciences **(ESS, XFEL, FAIR, ELI, ….. € 7.5 billion)**
Energy and engineering
Environmental, Earth
Life sciences.

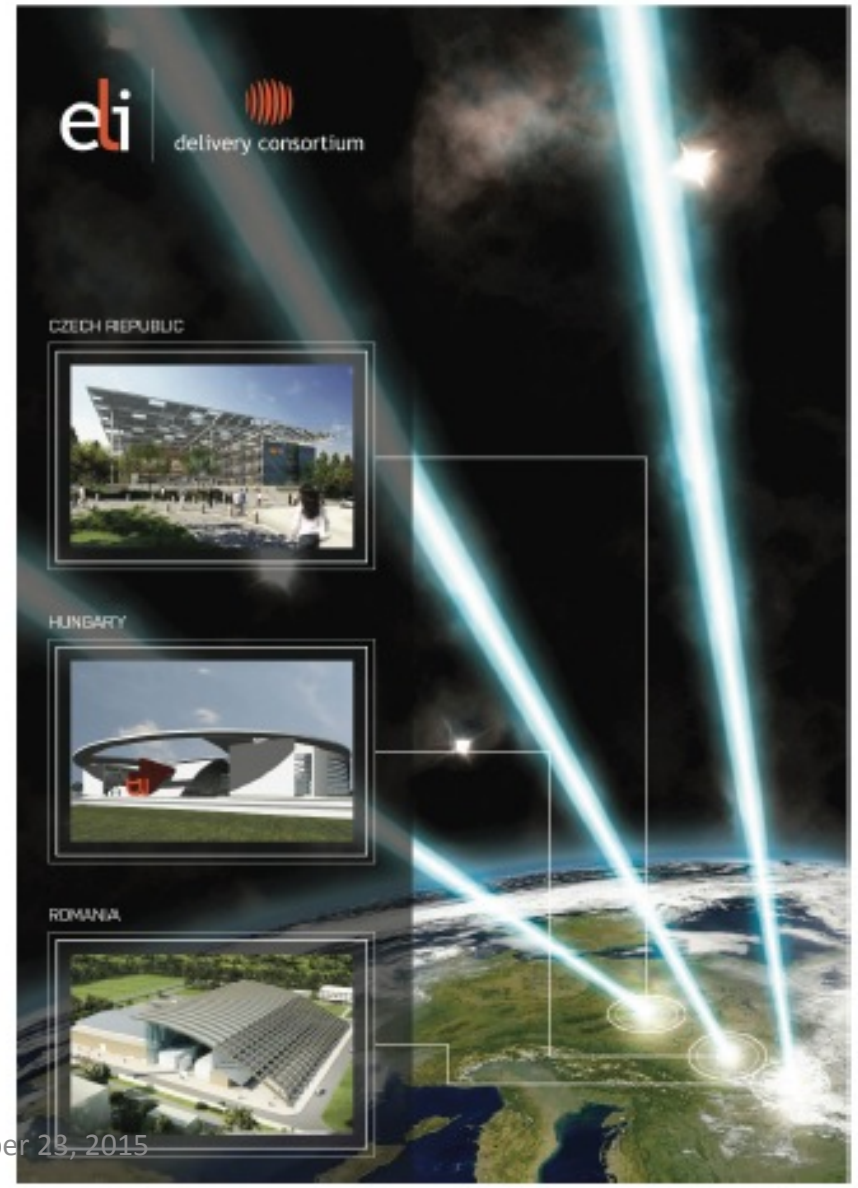
ELI: Implementation Phase

Three Pillars

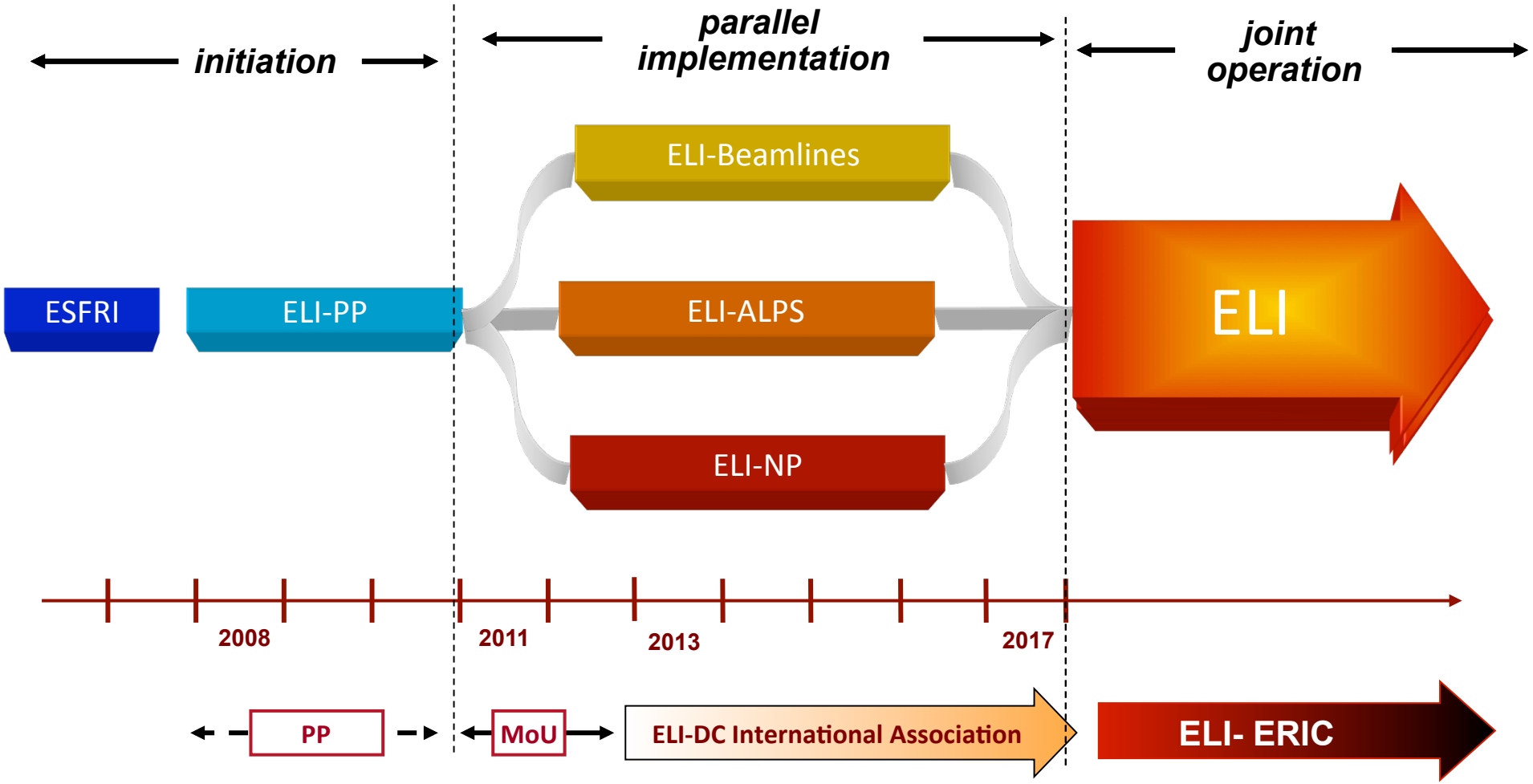
- **ELI High Energy Beam-Line Facility (ELI-Beamlines) (Czech Republic):** highly competitive source of extremely short pulse X-rays, accelerated electrons, or protons for applications (also biomedical).

- **ELI Attosecond Light Pulse Source (ELI-ALPS) (Szeged, Hungary):** ultrafast light sources (coherent XUV and X-ray radiation) including single attosecond pulses, to investigate electron dynamics in atoms, molecules, plasmas and solids.

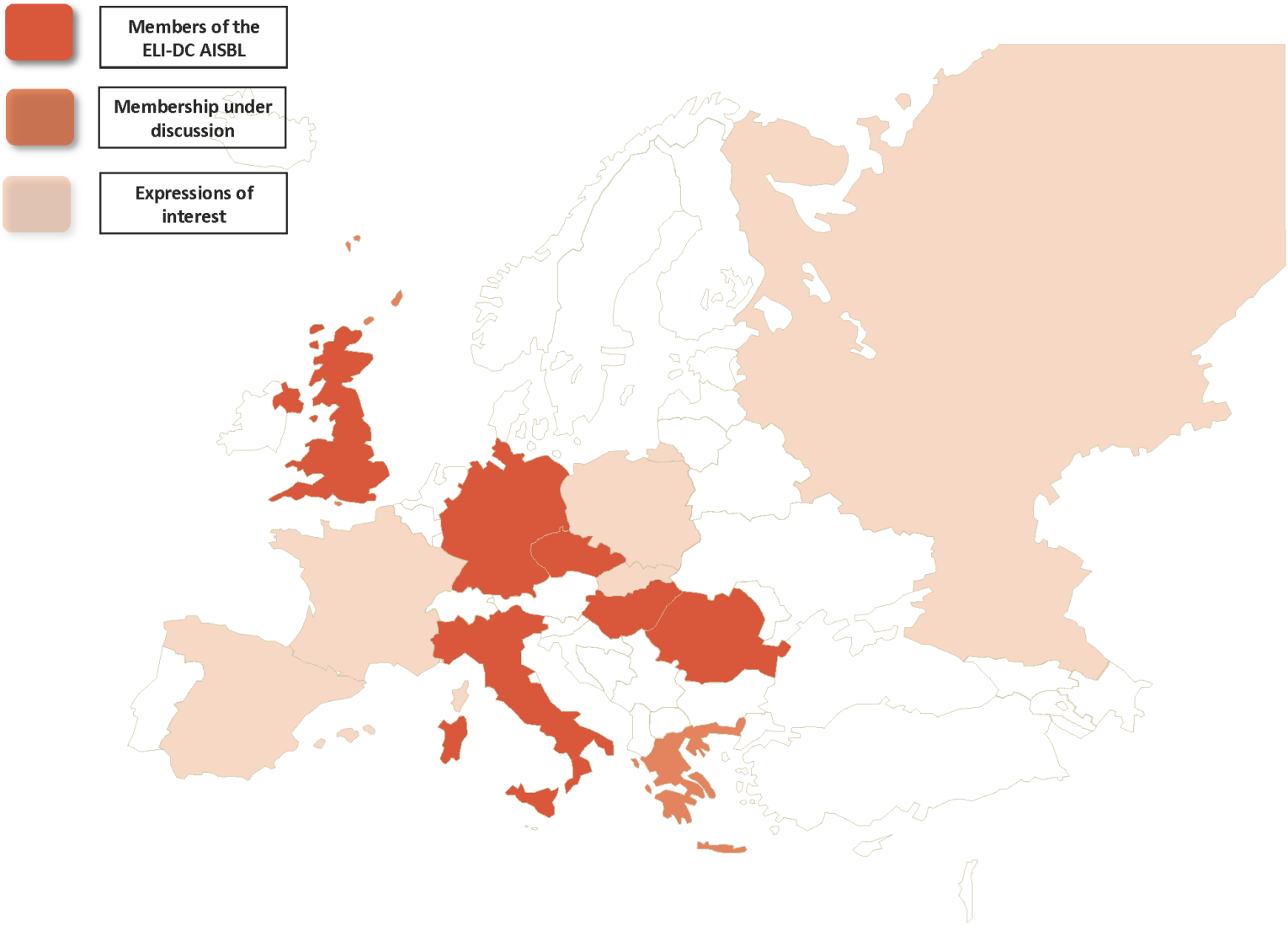
- **ELI Nuclear Physics Facility (ELI-NP) (Magurele, Romania):** laser and gamma beams (low bandwidth, energies in the 20 MeV range) with unique characteristics perform frontier laser, nuclear and fundamental research.



Timeline and milestones



ELI Consortium members and expression of interest



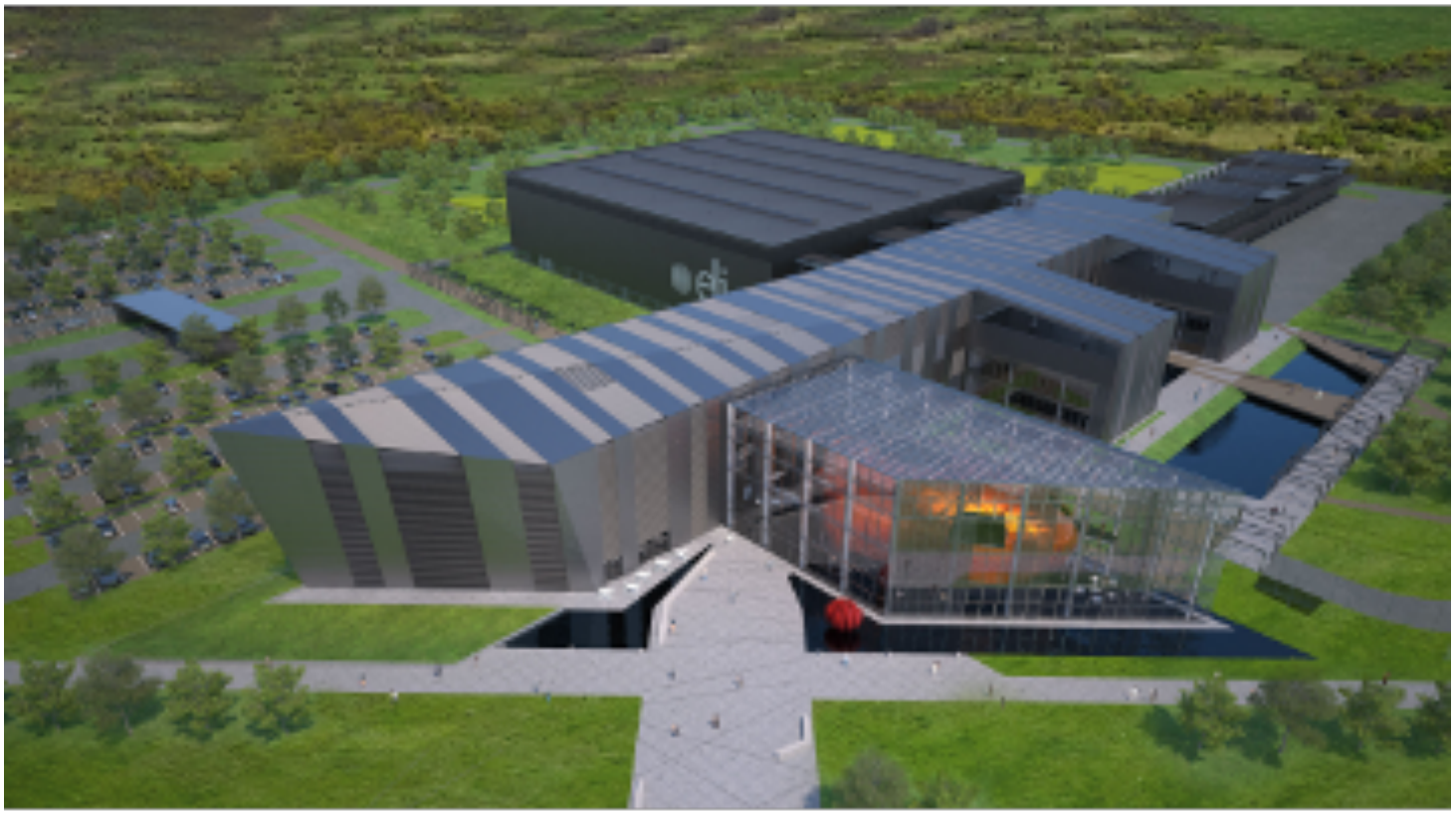
ELI Beamlines (Czech Republic)

High Energy Beam Science

development and usage of dedicated **laser-driven beam lines** with ultra short pulses of high energy radiation and particle acceleration

ELI-Attosecond

Ultrafast radiation source Science

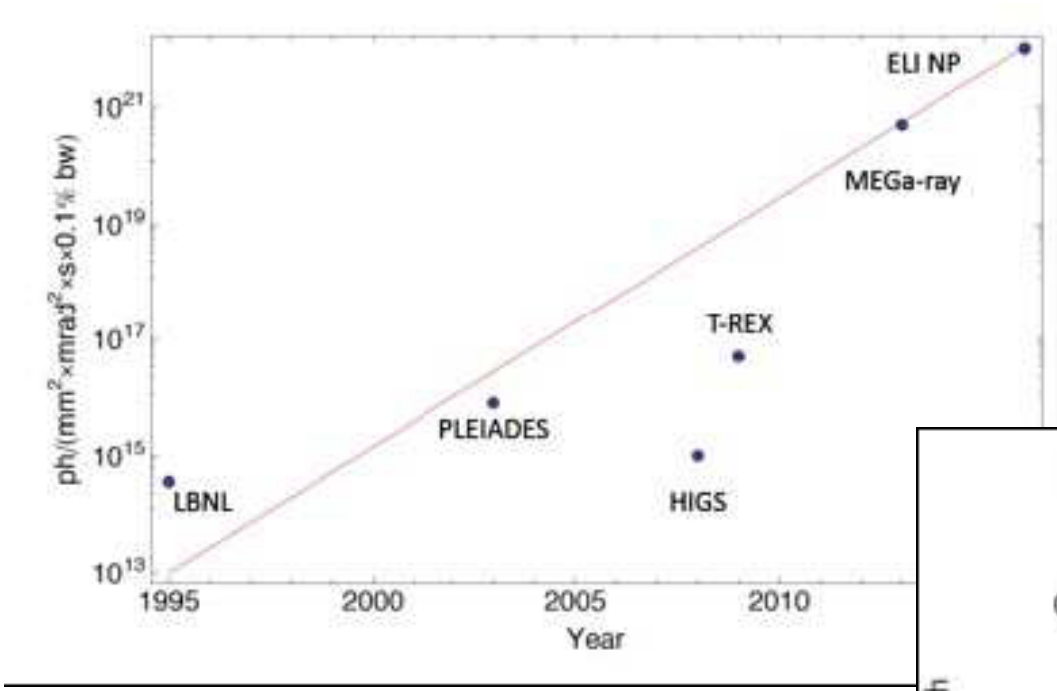


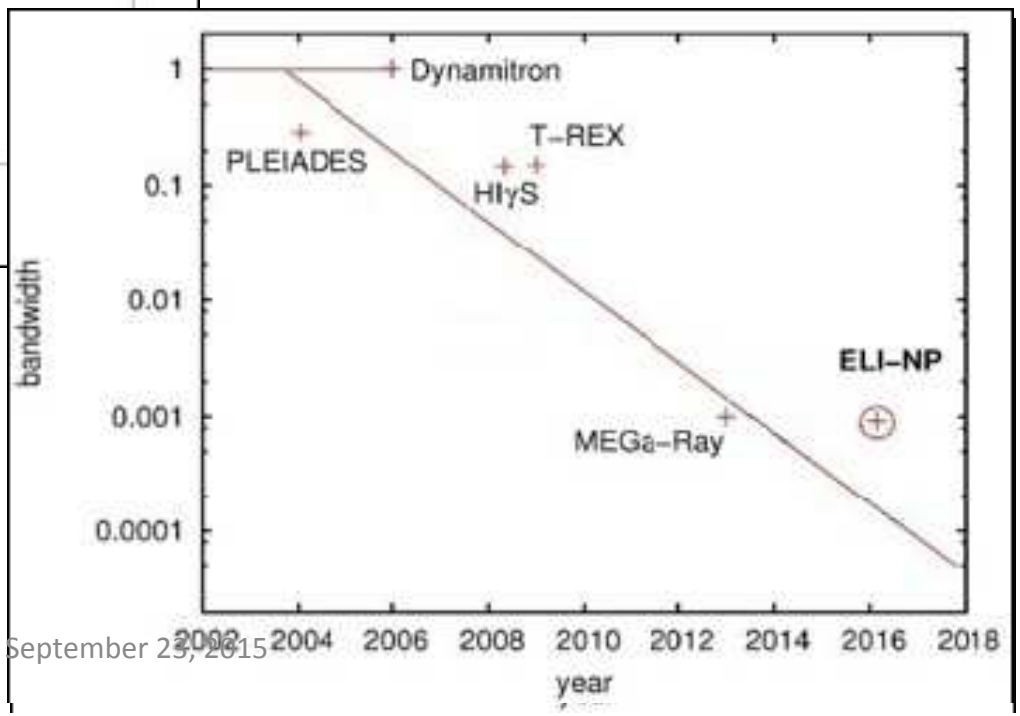
ELI Nuclear Physics (Romania)

Laser-Induced Photonuclear Physics

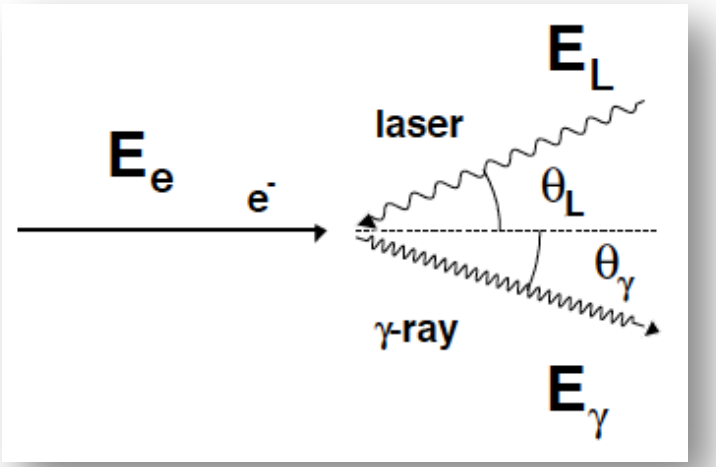
nuclear physics methods to study laser-target interactions, new nuclear spectroscopy, new photonuclear physics

ELI-NP γ beam: the quest for higher flux and narrow bandwidths

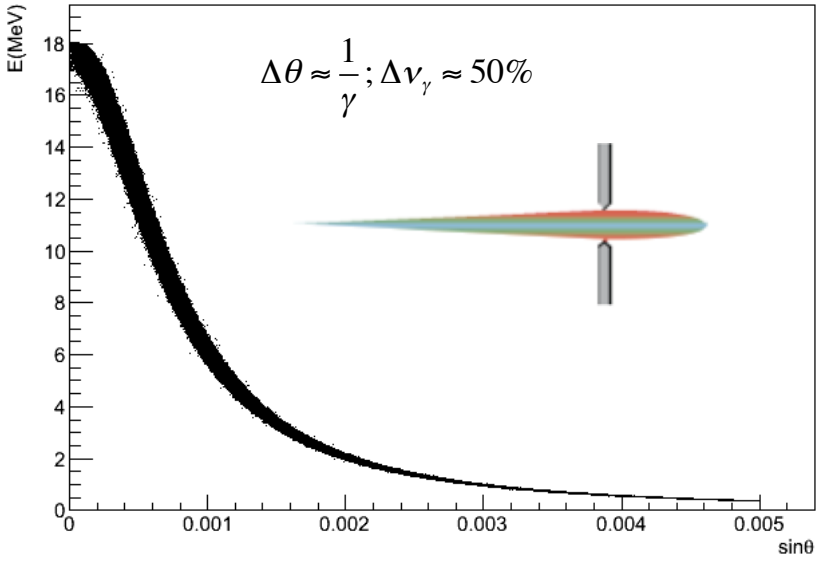




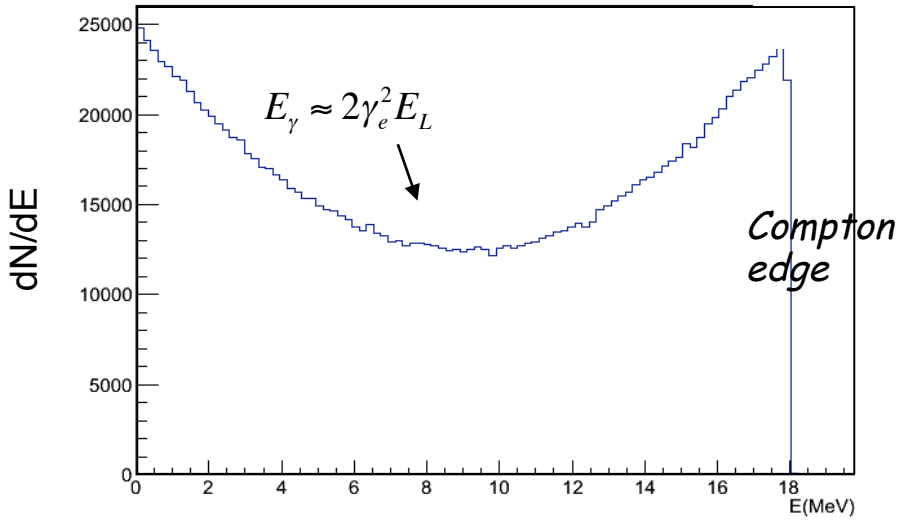
Courtesy V. Zamfir – ELI-NP

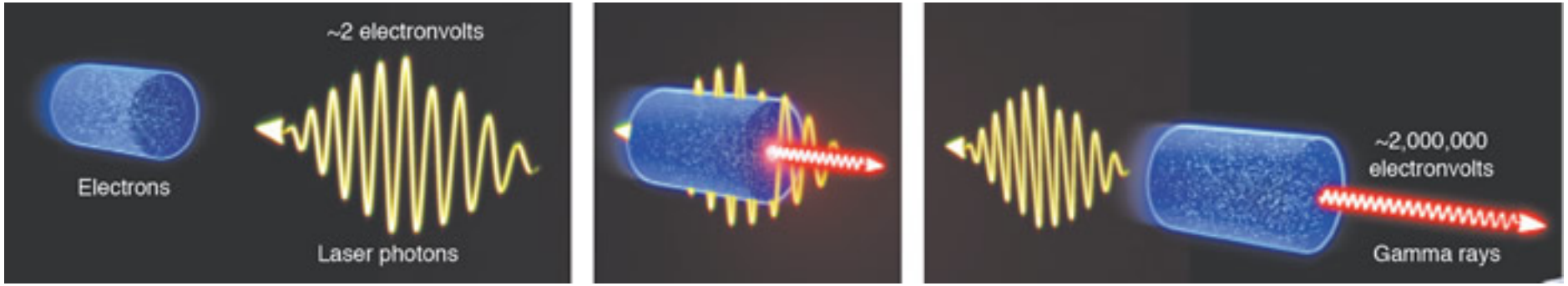


$$E_\gamma = 2\gamma_e^2 \cdot \frac{1+\cos\theta_L}{1+\left(\gamma_e\theta_\gamma\right)^2 + a_0^2 + \frac{4\gamma_e E_L}{mc^2}} \cdot E_L$$



$$\theta_\gamma = 0 \quad E_\gamma \approx 4\gamma_e^2 E_L$$





$$Gamma-ray\ Energy: 1-20\ MeV$$

$$rms\ \ Bandwidth: \ \ 0.3\%$$

$$Spectral\ \ Density: \ \ 10^{4}\ \ photons/s\cdot eV$$

Outstanding electron beam @ 720 MeV with high phase space density (all values are projected, not slice!)

$$Q = 250\,pC\ ;\ \varepsilon_n = 0.4\ \ mm\cdot mrad\ ;\ \frac{\Delta\gamma}{\gamma} = 8\cdot 10^{-4}$$

Scattering off a high quality J-class psec laser pulse

$$U_L = 400\ \ mJ\ ;\ M^2 = 1.2\ ;\ \frac{\Delta\nu}{\nu} = 5\cdot 10^{-4}$$

Technical Design Report

E-Gammas proposal for the ELI-NP Gamma beam System

With 79 tables and 252 figures

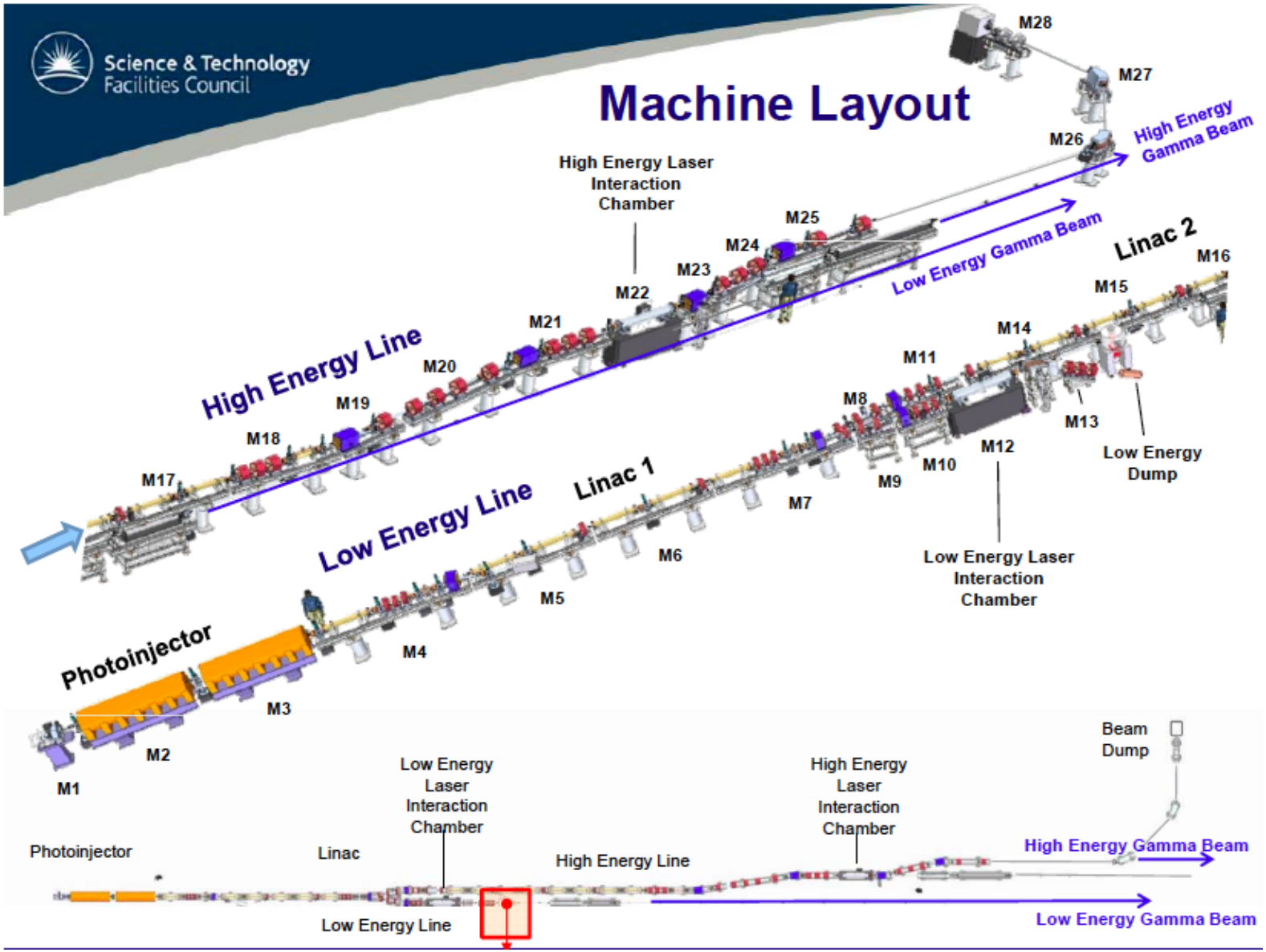
O. Adriani, S. Albergo, D. Alesini, M. Anania, D. Angal-Kalinin, P. Antici, A. Bacci, R. Bedogni, M. Bellaveglia, C. Biscari, N. Bliss, R. Boni, M. Boscolo, F. Broggi, P. Cardarelli, K. Cassou, M. Castellano, L. Catani, I. Chaikovska, E. Chiadroni, R. Chiche, A. Cianchi, J. Clarke, A. Clozza, M. Coppola, A. Courjaud, C. Curatolo, O. Dadoun, N. Delerue, C. De Martinis, G. Di Domenico, E. Di Pasquale, G. Di Pirro, A. Drago, F. Druon, K. Dupraz, F. Egal, A. Esposito, F. Falcoz, B. Fell, M. Ferrario, L. Ficcadenti, P. Fichot, A. Gallo, M. Gambaccini, G. Gatti, P. Georges, A. Ghigo, A. Goulden, G. Graziani, D. Guibout, O. Guilbaud, M. Hanna, J. Herbert, T. Hovsepian, E. Iarocci, P. Iorio, S. Jamison, S. Kazamias, F. Labaye, L. Lancia, F. Marcellini, A. Martens, C. Maroli, B. Martlew, M. Marziani, G. Mazzitelli, P. McIntosh, M. Migliorati, A. Mostacci, A. Mueller, V. Nardone, E. Pace, L. Palumbo, A. Pelorosso, F.X. Perin, G. Passaleva, L. Pellegrino, V. Petrillo, M. Pittman, G. Riboulet, R. Ricci, C. Ronsivalle, D. Ros, A. Rossi, L. Serafini, M. Serio, F. Sgamma, R. Smith, S. Smith, V. Soskov, B. Spataro, M. Statera, A. Stecchi, A. Stella, A. Stocchi, S. Tocci, P. Tomassini, S. Tomassini, A. Tricomi, C. Vaccarezza, A. Variola, M. Veltri, S. Vescovi, F. Villa, F. Wang, E. Yildiz, F. Zomer

2012

108 Authors, 327 pages

Luca Serafini Editor

http://arxiv.org/abs/1407.3669


Science & Technology Facilities Council
Machine Layout
M28
M27
M26
High Energy Gamma Beam
High Energy Laser Interaction Chamber
M25
M24
M23
M22
Low Energy Gamma Beam
Linac 2
M16
M15
M14
M11
M8
M13
Low Energy Dump
High Energy Line
M21
M20
M19
M18
M17
M12
M10
M9
M7
Linac 1
Low Energy Line
M6
M5
M4
Low Energy Laser Interaction Chamber
Photoinjector
M3
M2
M1
Beam Dump
Low Energy Laser Interaction Chamber
High Energy Laser Interaction Chamber
Photoinjector
Linac
High Energy Line
High Energy Gamma Beam
Low Energy Line
Low Energy Gamma Beam

EuroGammaS Consortium

- INFN (I) (Consortium Leader)
- CNRS (F)
- La Sapienza (I)
- Amplitude (F) - Laser Technology
- ScandiNova (SE) - Accelerator Power Sources
- Comeb (I) - Accelerating Structures and Diagnostics
- Alsyom (F) - Opto-Mechanical Systems

EuroGammaS Consortium - Subcontractors

STFC - ASTeC
ALBA CELL

Scientific Institutions

Research Instruments (D)

M+W (I)

Danfysik (DK)

CosyLab (SL)

Instrumentation Technology (SL)

MenloSystems (D)

Industries

SIF - Roma - September 23, 2015

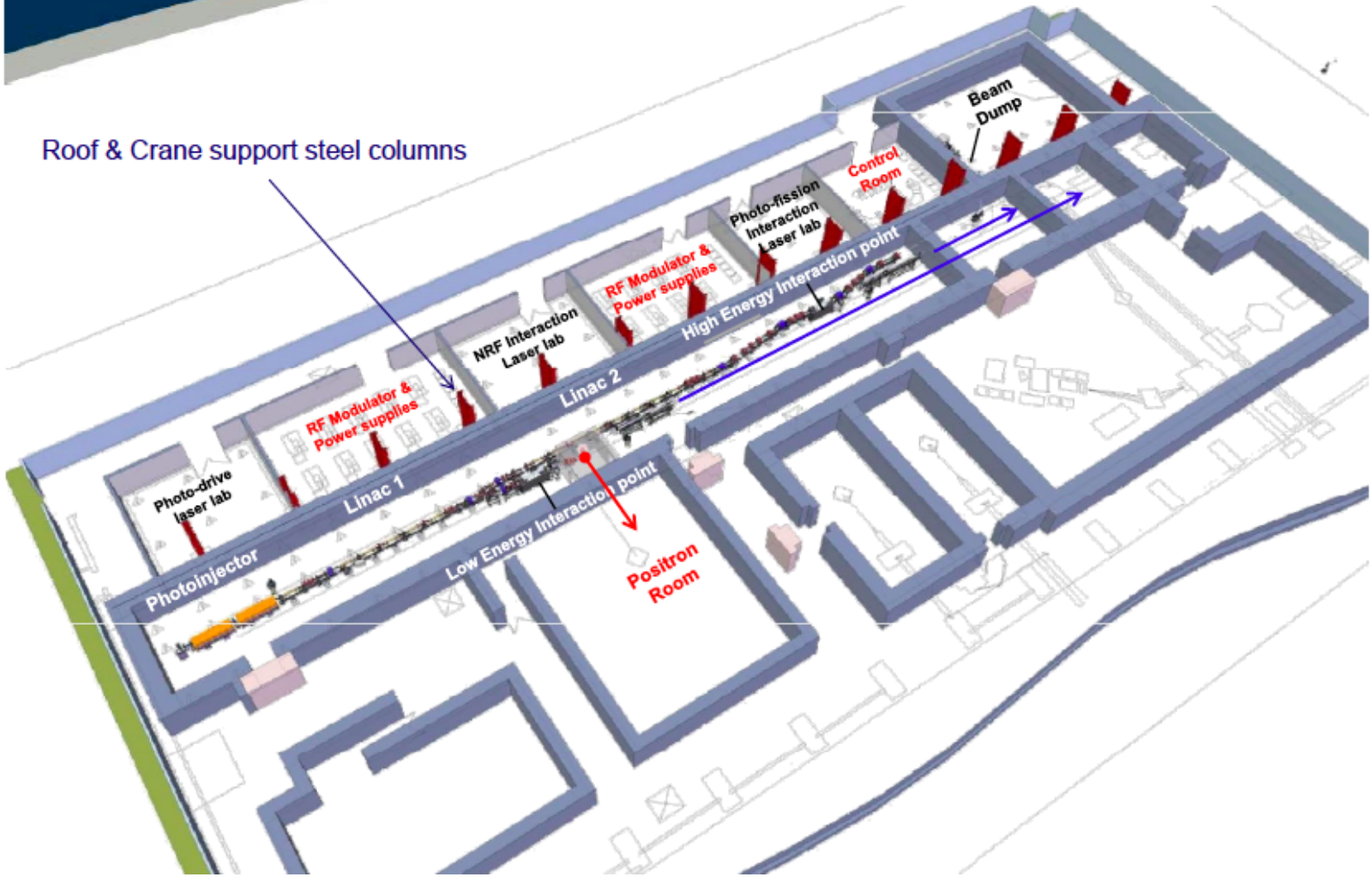
CIF - Roma - September 23, 2009

Energy [MeV]	0.2 – 19.5
Spectral Density [ph/s·eV]	$0.8 – 4 \cdot 10^4$
Bandwidth rms [%]	≤ 0.5
# photons/pulse within FWHM bdw.	$\leq 2.6 \cdot 10^5$
# photons/s within FWHM bdw.	$\leq 8.3 \cdot 10^8$
Source rms size [mm]	10 – 30
Source rms divergence [mrad]	25 – 200
Peak brilliance [N_{ph}/s·mm^2·mrad^2·0.1%]	$10^{20} – 10^{23}$
Radiation pulse length rms [ps]	0.7 – 1.5
Linear polarization [%]	> 99
Macro repetition rate [Hz]	100
# pulses per macropulse	32
Pulse–to–pulse separation [ns]	16
Polarization axis wiggling [deg]	< 1
Synchronization to an external clock [ps]	≤ 0.5
Source position transverse jitter [mm]	< 5
Energy jitter pulse–to–pulse [%]	< 0.2
# photons jitter pulse–to–pulse [%]	≤ 3

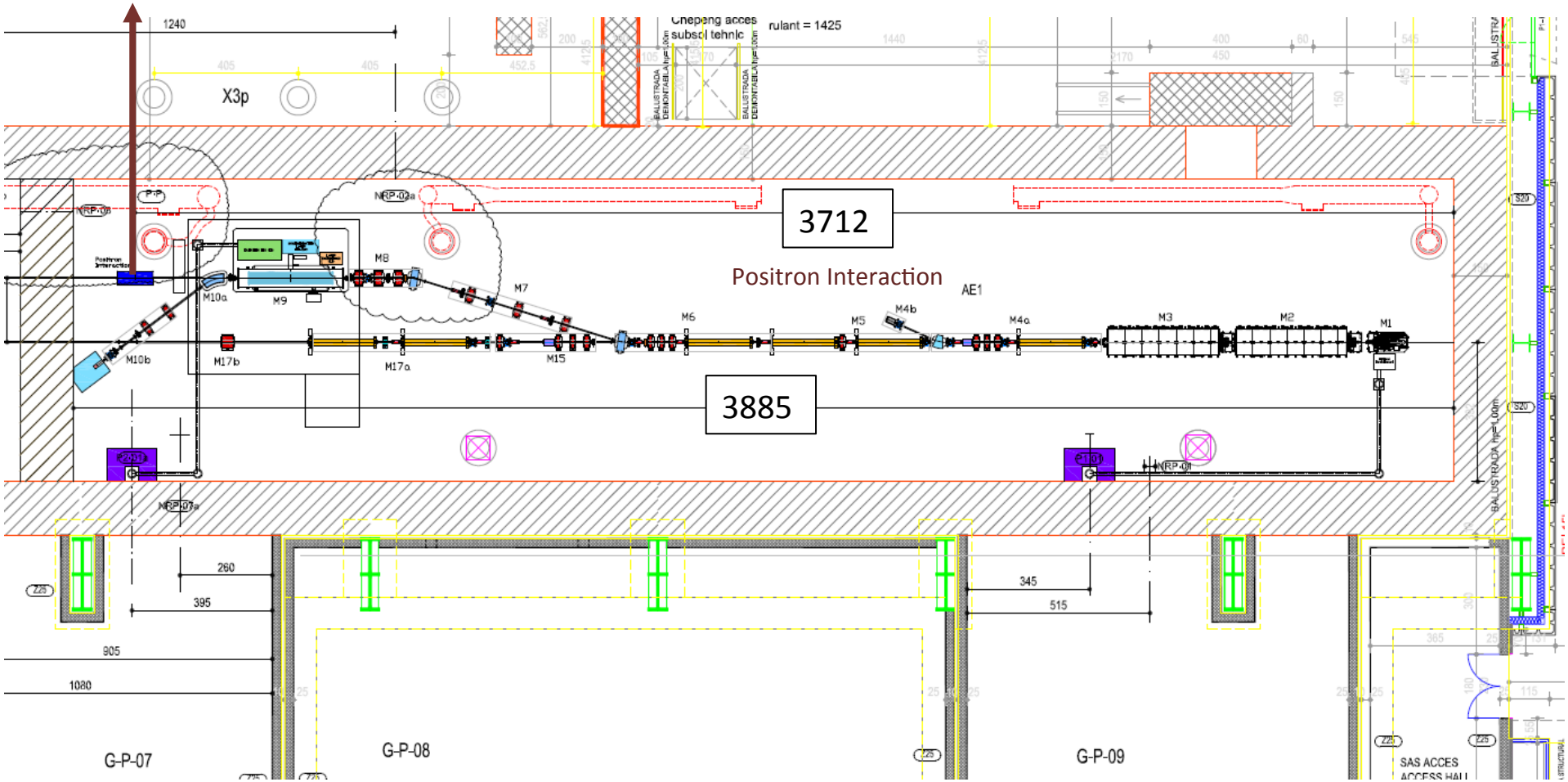
Nuclear Physics

Science & Technology Facilities Council

Building Layout

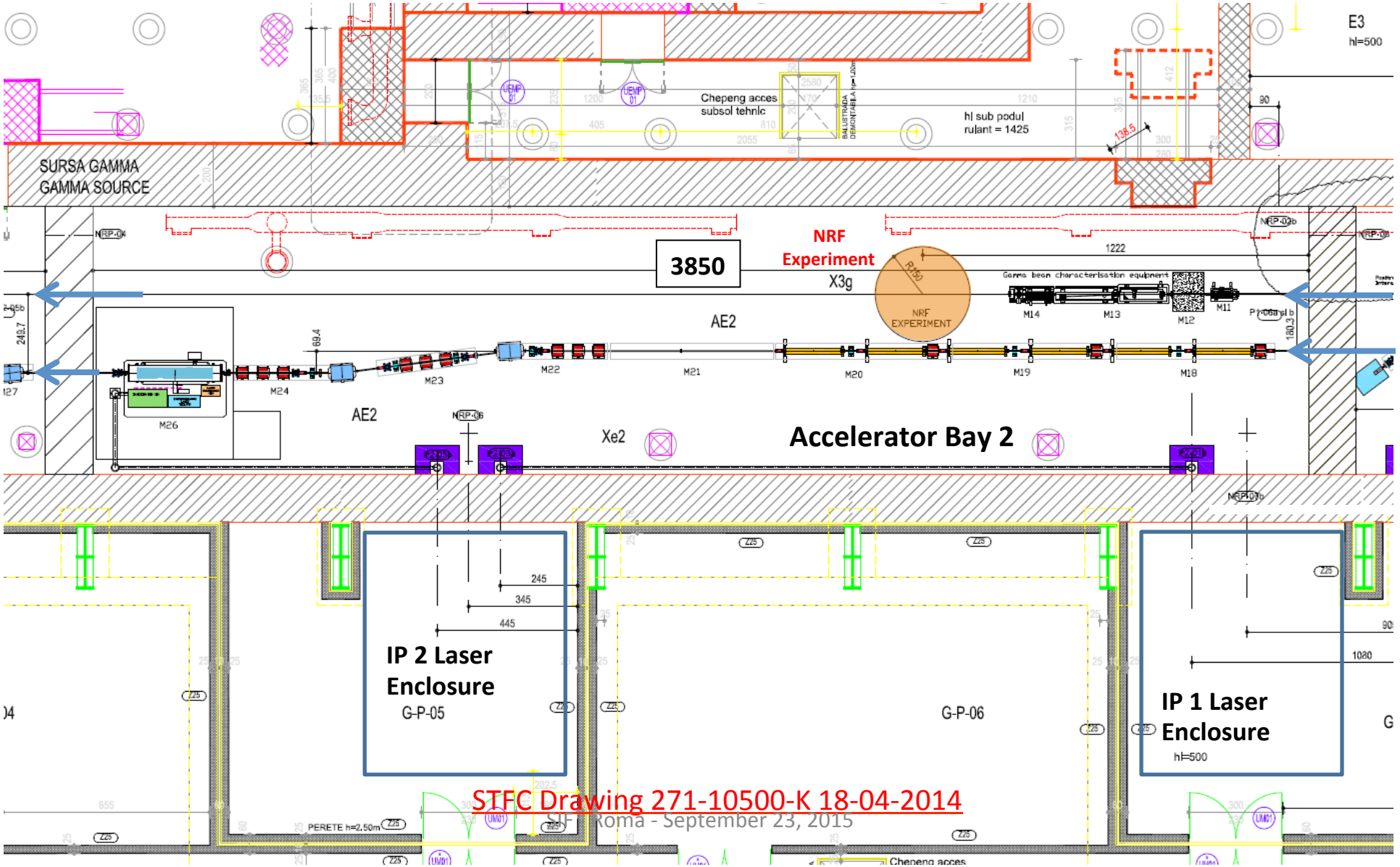


Accelerator Layout - Bay 1



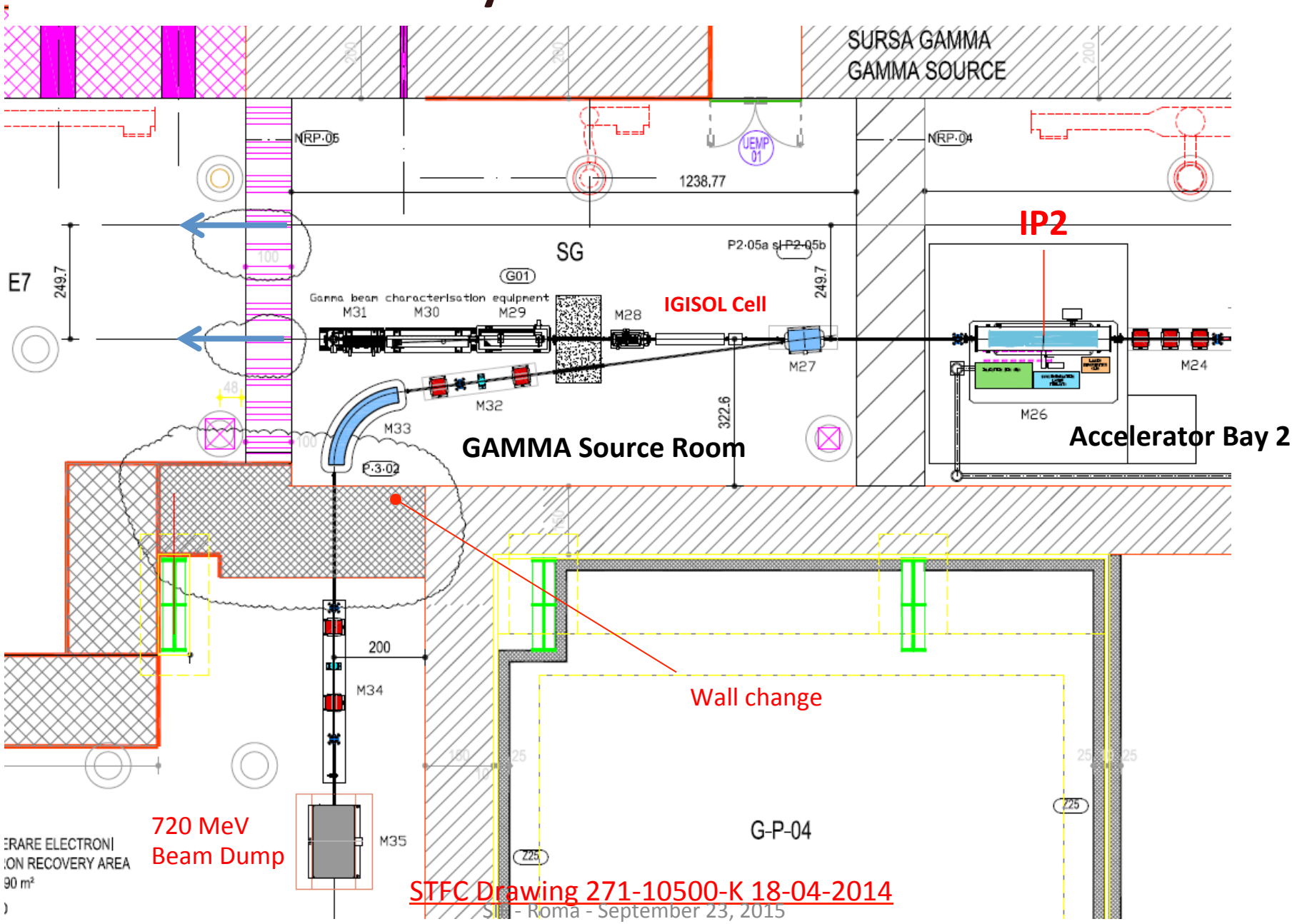
STFC Drawing 271-10500-K 18-04-2014

Accelerator Layout - Bay 2



STFC Drawing 271-10500-K 18-04-2014

Accelerator Layout – Gamma Source Room



STFC Drawing 271-10500-K 18-04-2014

How can we make 100 times better than the state of the Art?

DEVELOP a SOUND and FEASIBLE PROPOSAL for the PROJECT

- **Based mainly on "state of the Art" Technology.**
- **Relying on a short term R&D compatible with the schedule of construction**
- **Able to garantee the generation of a "gamma radiation beam" with unique features of interest to the experimental nuclear physics community.**
- **A system thought to further improvement of performances**

MOTIVATION OF THE TECHNOLOGY CHALLENGES IN THE ELI-NP GBS ACCELERATOR PROJECT

To increase the gamma flux we need to **increase the number of collision per second**

→ **100 Hz** repetition rate

→ **Multi bunch** in the RF pulse

-Damping of HOM in RF structures to avoid BBU instabilities

-Compensation of **beam loading effects**

-accurate thermal design

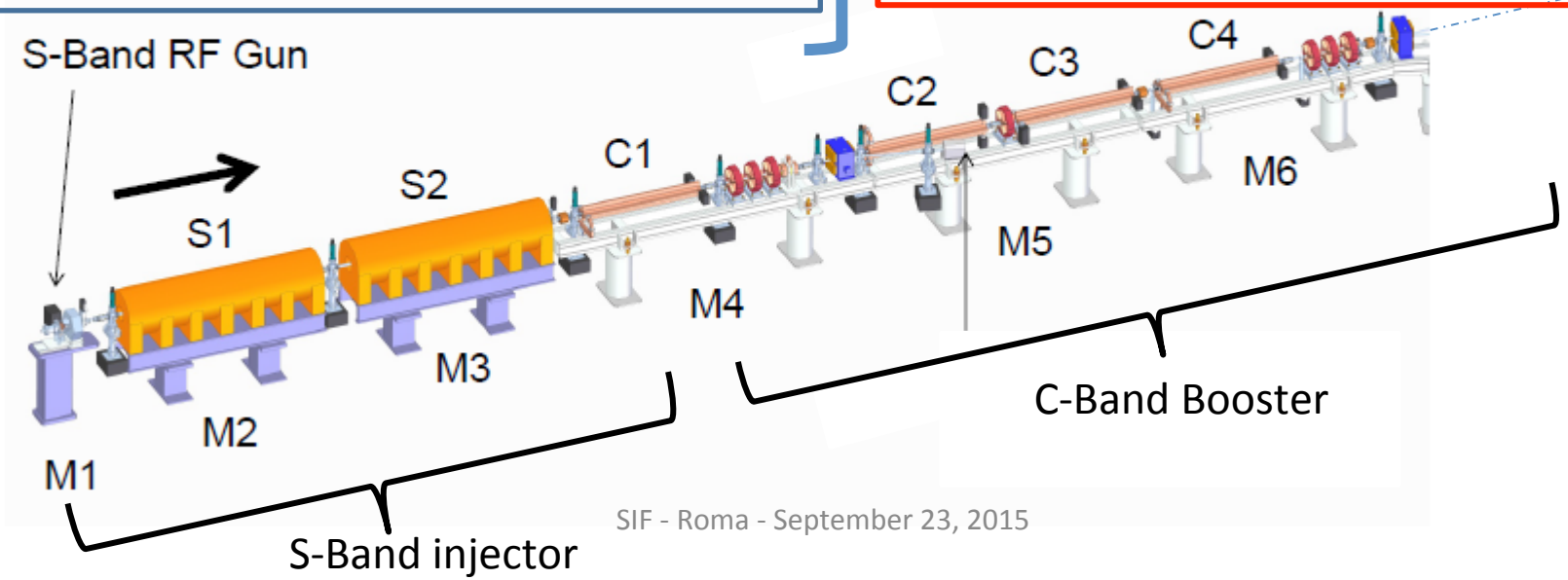
To reduce the accelerator overall dimensions: **compact system**

→ **High gradient**

→ **High frequency**

-C-band LINAC combined with an S-band Injector: the "state of the art" in last generation accelerators technology and RF power sources

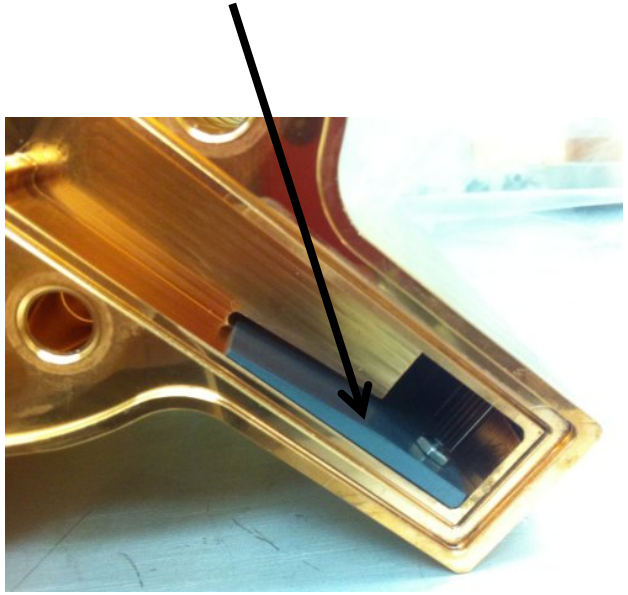
-accurate **RF design and mechanical realization**

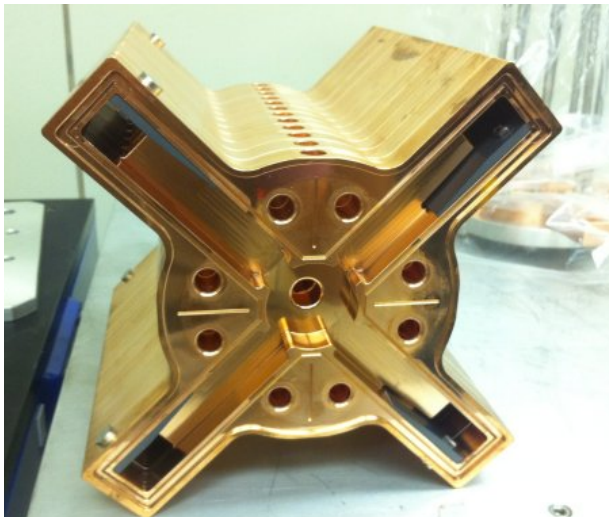


C-BAND STRUCTURES: PROTOTYPES REALIZATION

An intense activity of prototyping has been started to setup and optimize the realization process of the structures. First prototypes have been fabricated to verify both feasibility of copper cells machining and effectiveness of brazing process. We are now focalizing in the realization of two prototypes previous the realization of the first complete structure. The first prototype ("**mechanical prototype**") is a full scale device, under construction, without precise internal dimensions conceived to test the full brazing process, verifying structure deformations and vacuum leaks. This prototype does include SiC absorbers to test also the vacuum performances of the structure. The second prototype ("**RF prototype**") is a device with a reduced number of cells that we would like to fabricate to test the RF properties of the structure at low and high power. Also this second device includes the SiC absorbers and has precise internal dimensions with tuners.

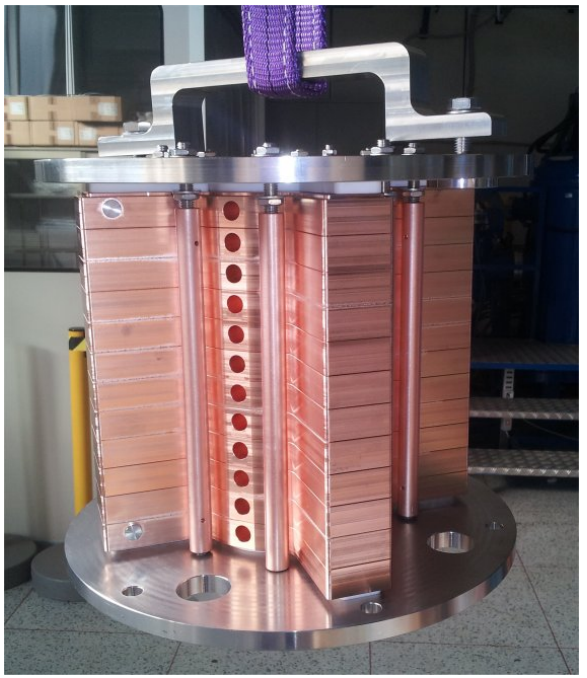
SiC Absorber

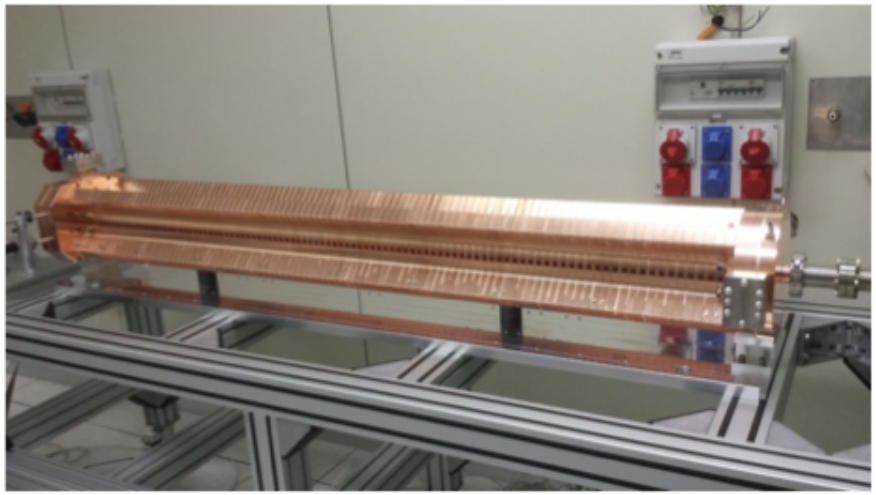


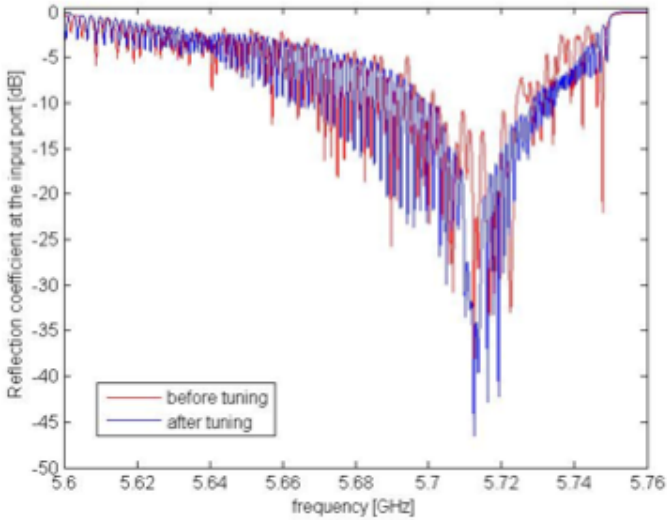


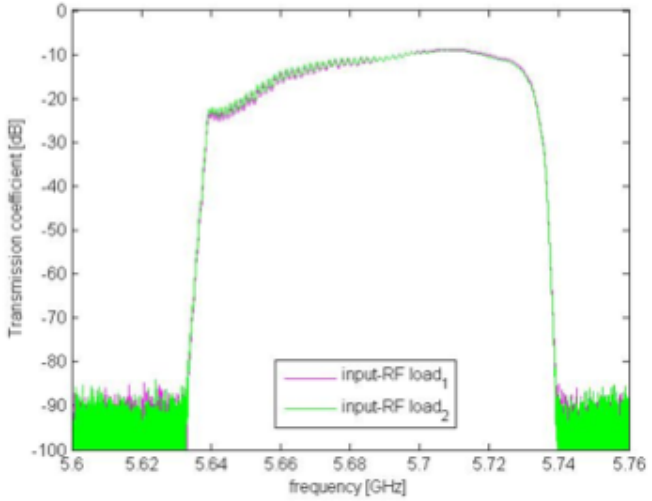
It has been necessary a strong R&D program in close collaboration with Italian Companies (COMEB, CERINCO, ANDALOGIANNI, TSC)

12 cells module



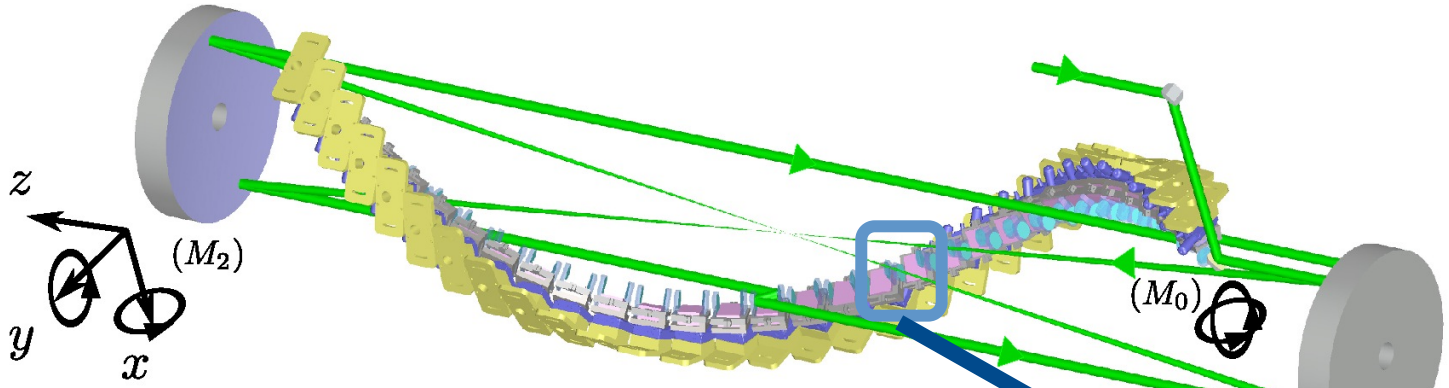






D.Alesini, COMEB
V. Lollo, R. Di Raddo, P. Chimenti, M.Magi, F. Pellegrino,
A. Mostacci, L. Ficcadenti, L.Piersanti, F. Cardelli

Technical solution: the *dragon shape* circulator



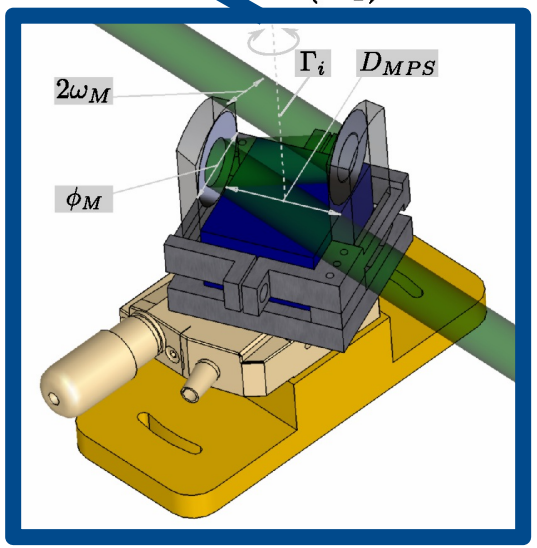
2 parabolic reflectors M1 & M2

- M1 fixed
- M2: 5 degrees of freedom
- M0: 2 tilts for injection

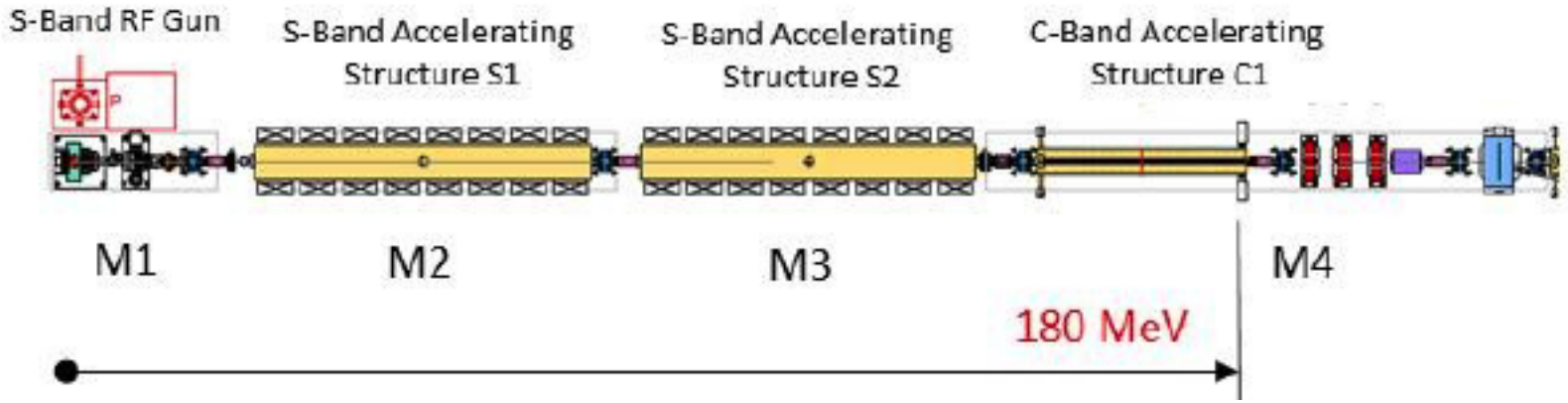
Mirror-pair system

- For interaction plane switch
- Rotation for synchronization

➔Alignment issues



1st STAGE: 31 OCTOBER 2015

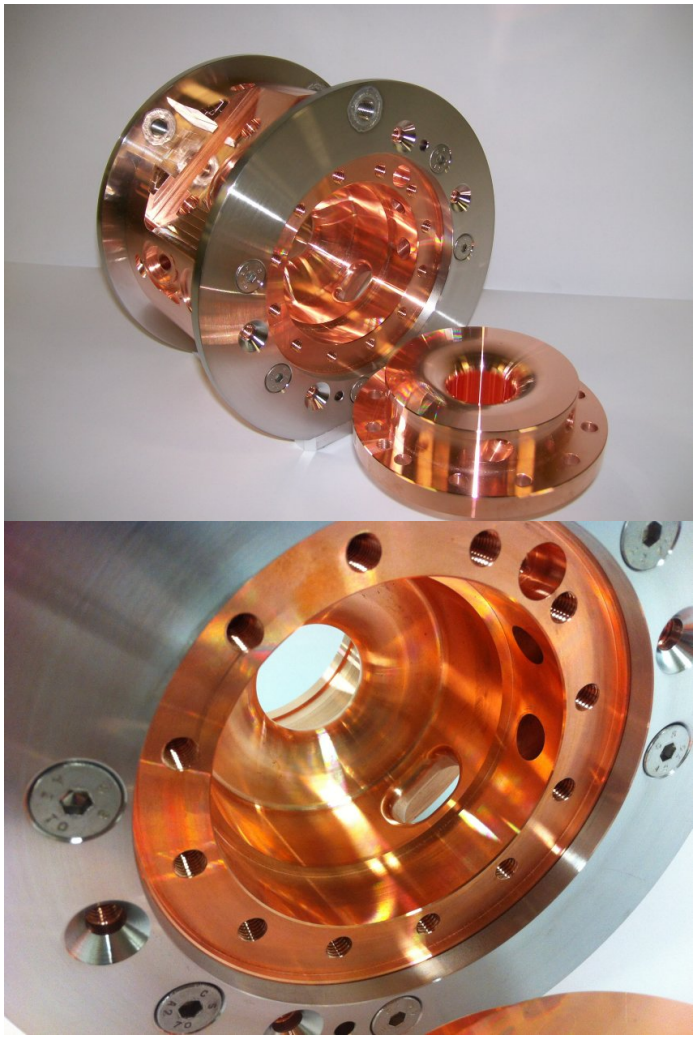


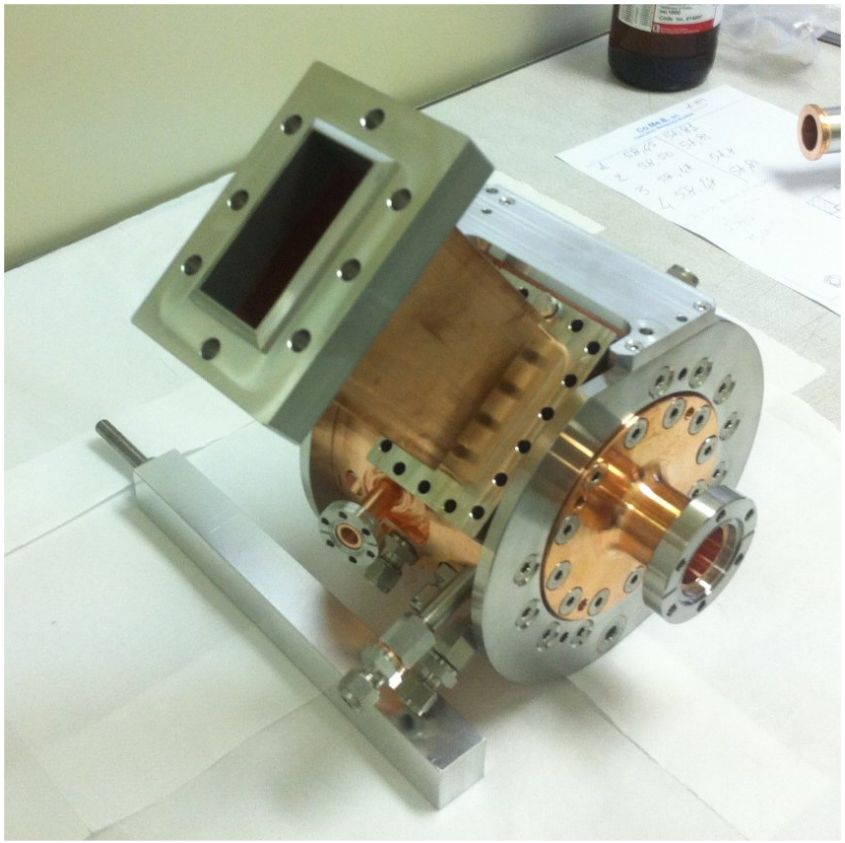
2nd STAGE: 31 August 2016 (350 MeV)

3rd STAGE: 28 February 2017 (720 MeV)

4th STAGE: 54 months from signature (15 September 2018) Commissioning

S BAND GUN: PROTOTYPES

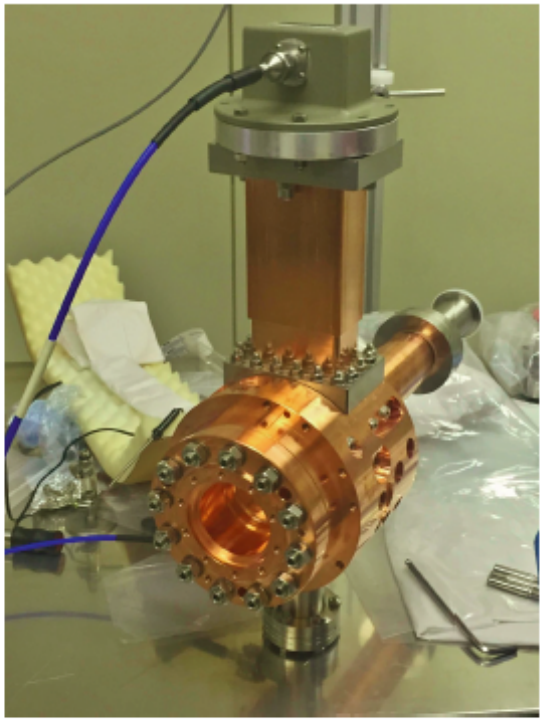


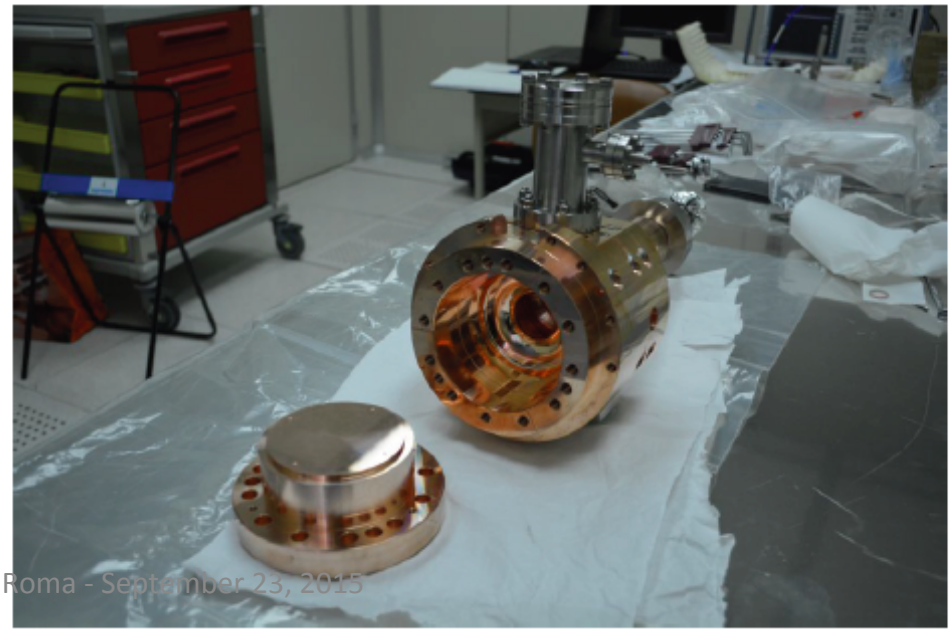


Cannone: necessario un programma di R&D in stretta collaborazione con l'industria

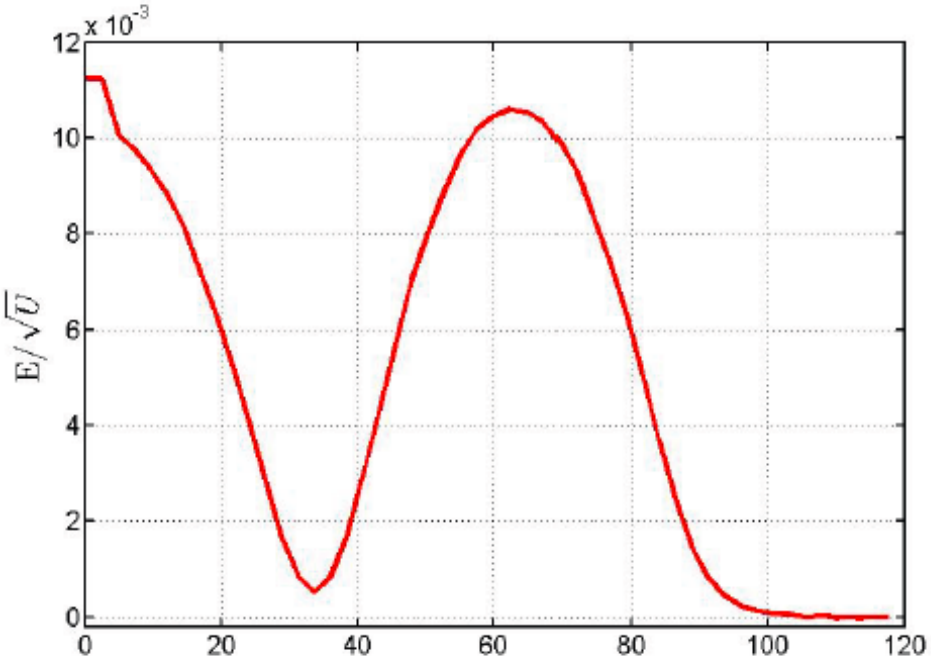
WP03 - Accelerating Structures

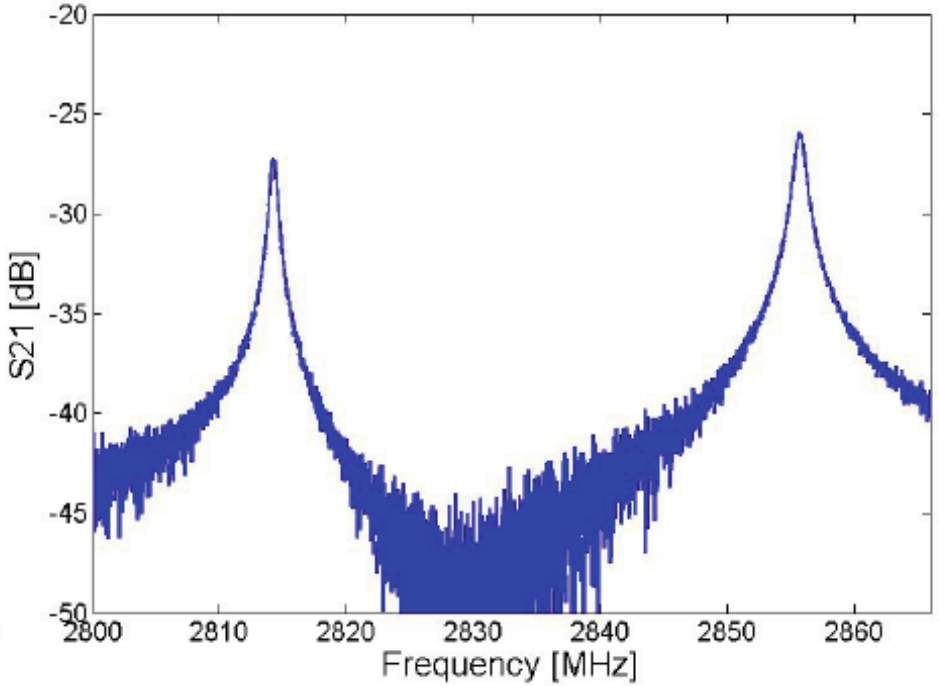
RF Gun





RF Gun measurements



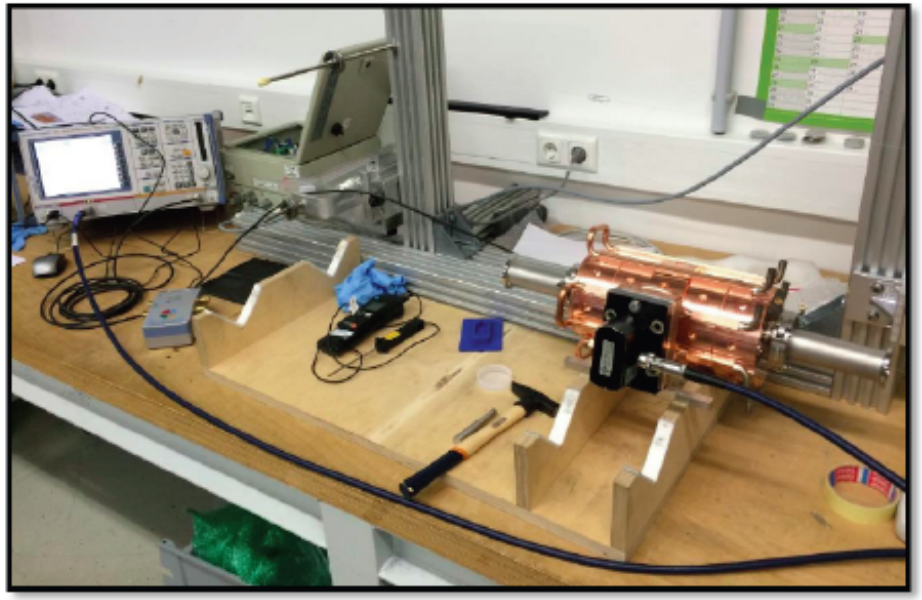


WP03 - Accelerating Structures

TDC1 (now @ STFC)

Parameter	Value	Unit
$f_{meas,amb}$	2555.425	MHz
$f_{meas,vac}$	2855.977	MHz
beta	3.3	-
amplitude flatness B	98.3	%
pickup coupling	-61.4	dB

Table 2-3 RF properties after tuning



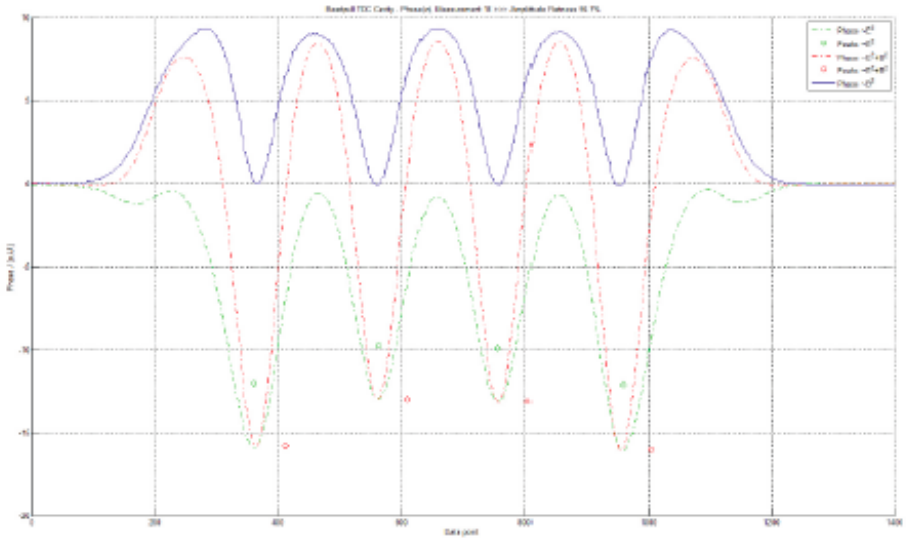
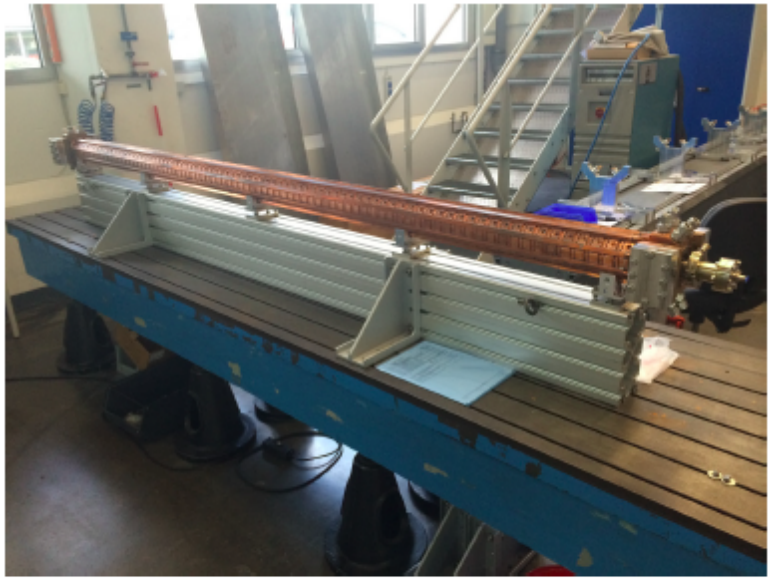


Figure 2-2 Measured field data (metallic and dielectric bead, calculated B^2-field)

WP03 - Accelerating Structures

S-Band 1 : Tuned and fully conditioned

Peak Power	RF Pulse length	Repetition Rate
45 MW	1.5 µs	100 Hz



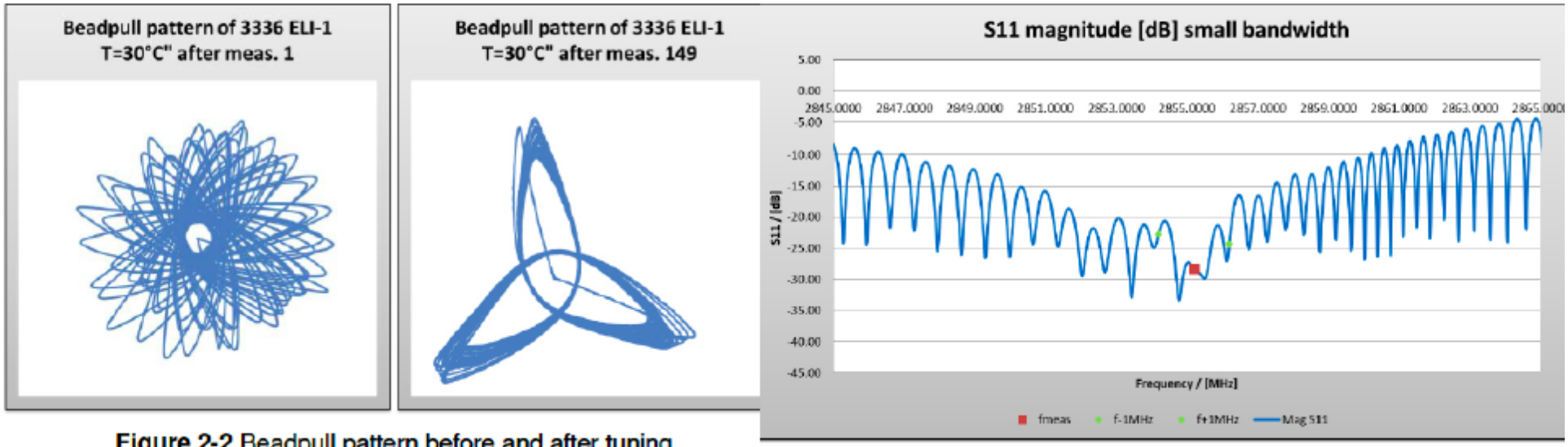
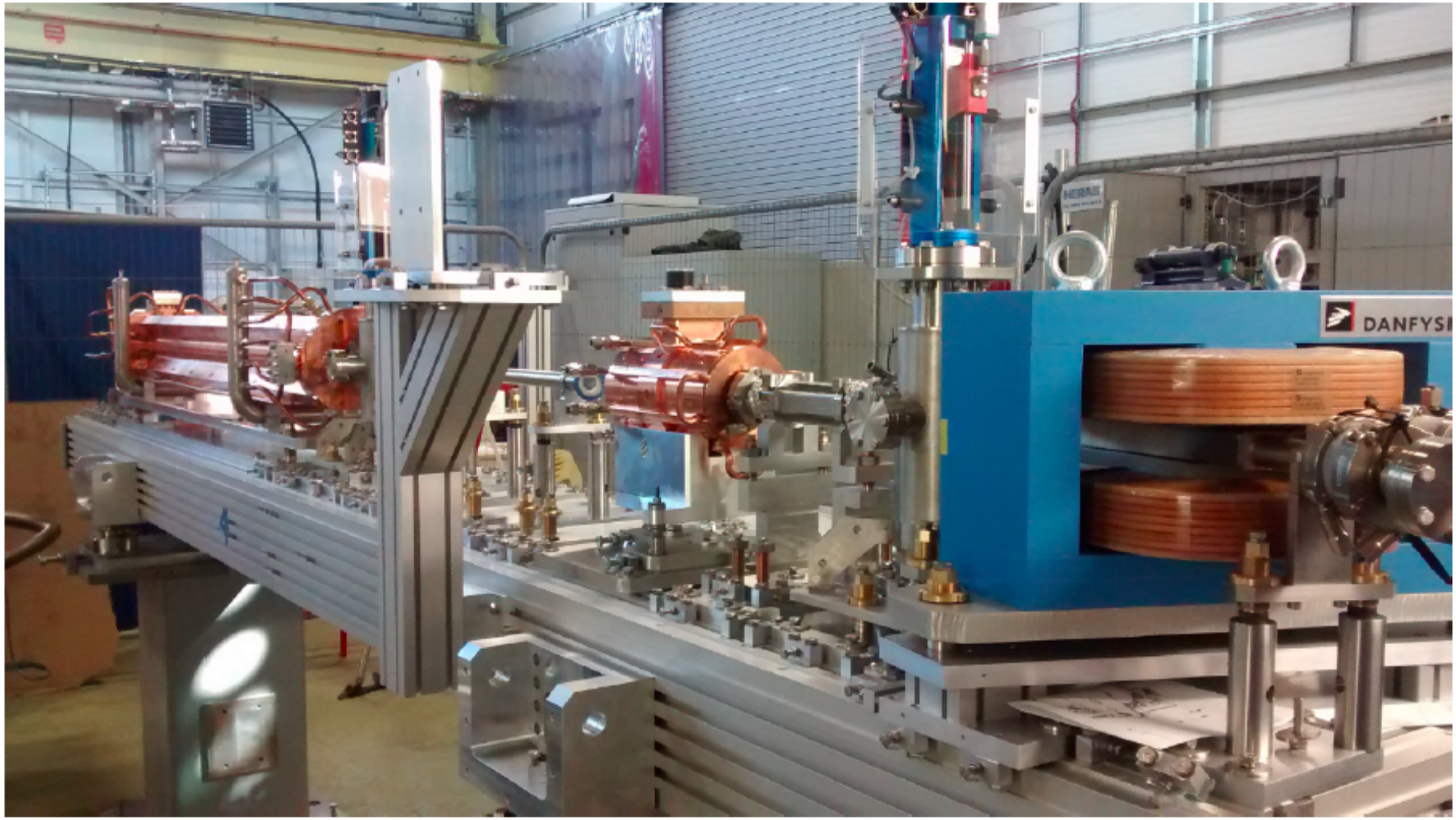


Figure 2-2 Beadpull pattern before and after tuning

WP04 - RF System

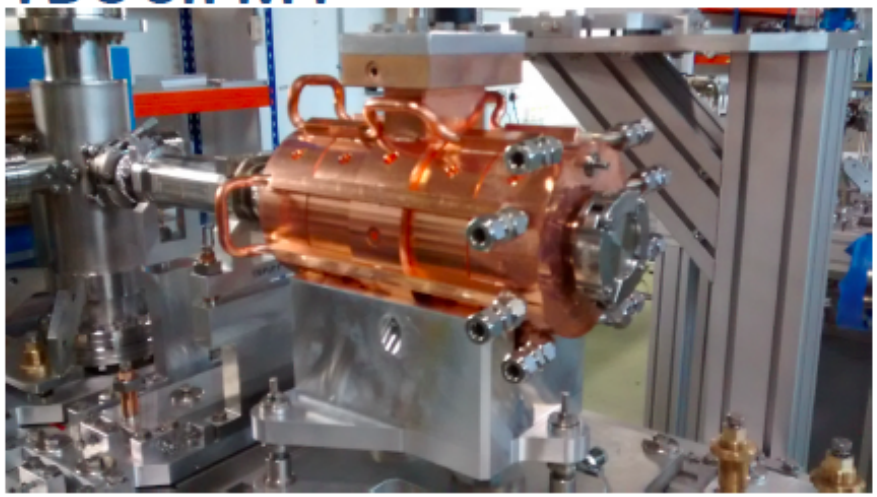
WP05 - STFC Modules

Module 4



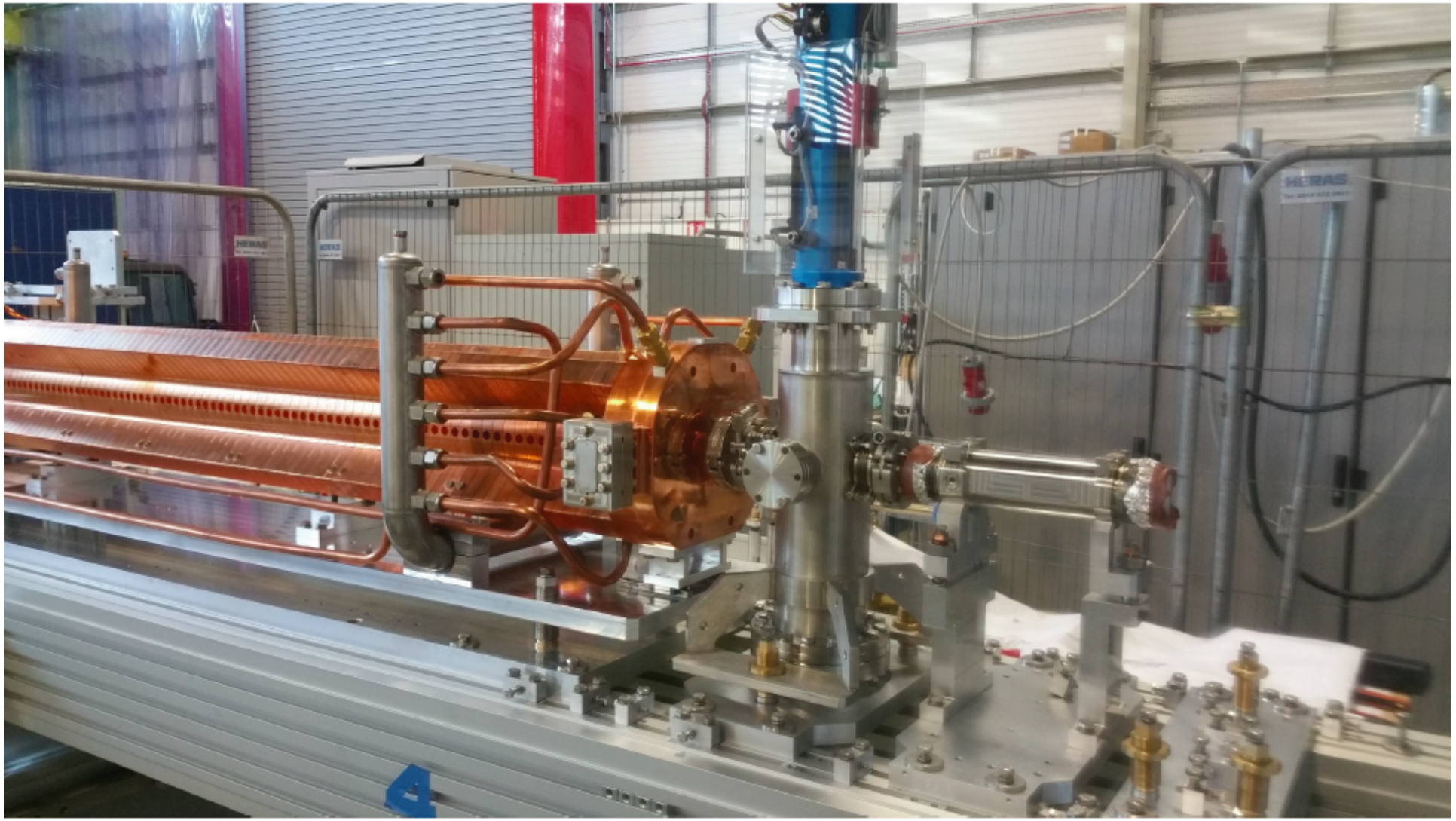
WP05 - STFC Modules

TDC on M4

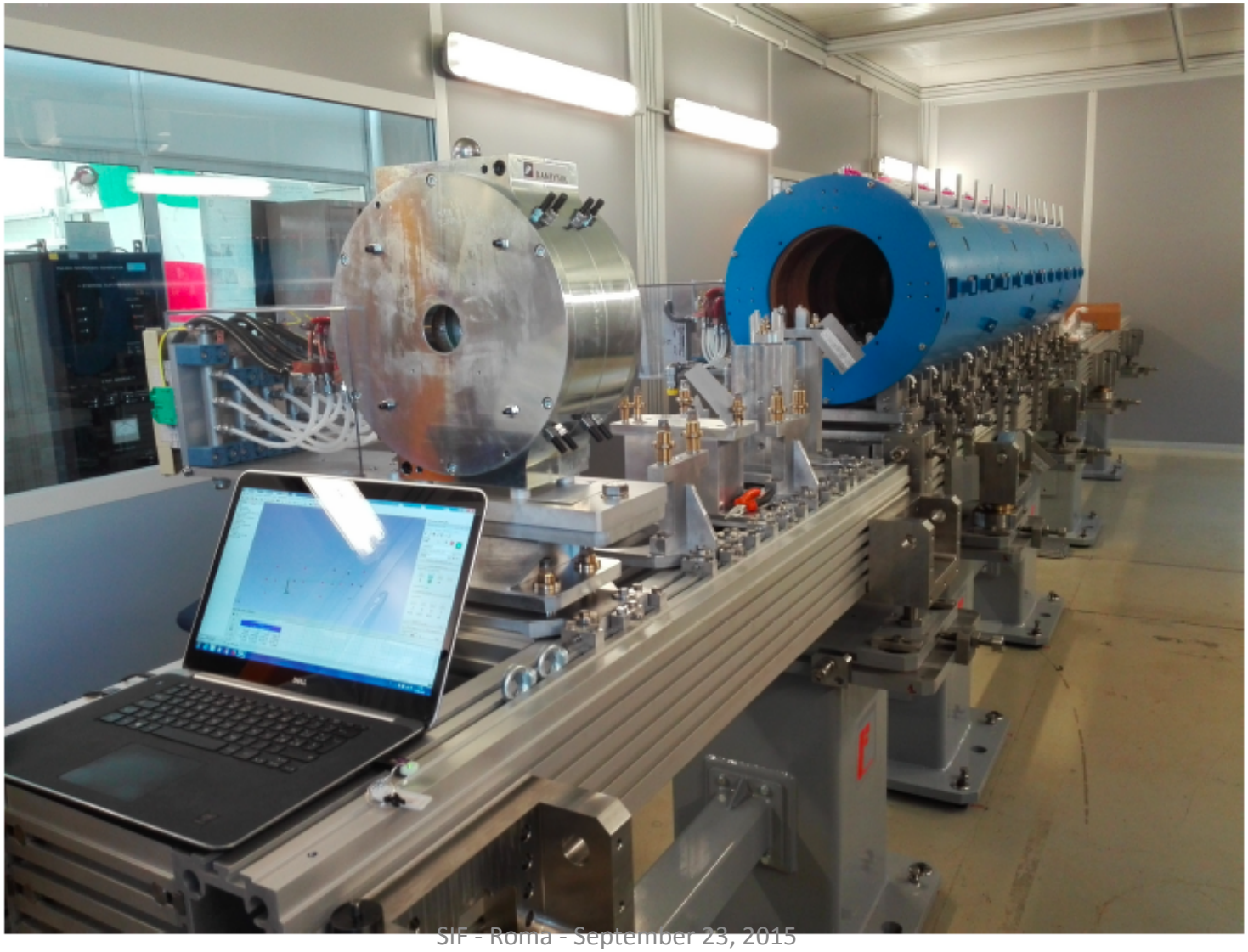


Assembly of M4, M4a, M5, M7 and M8

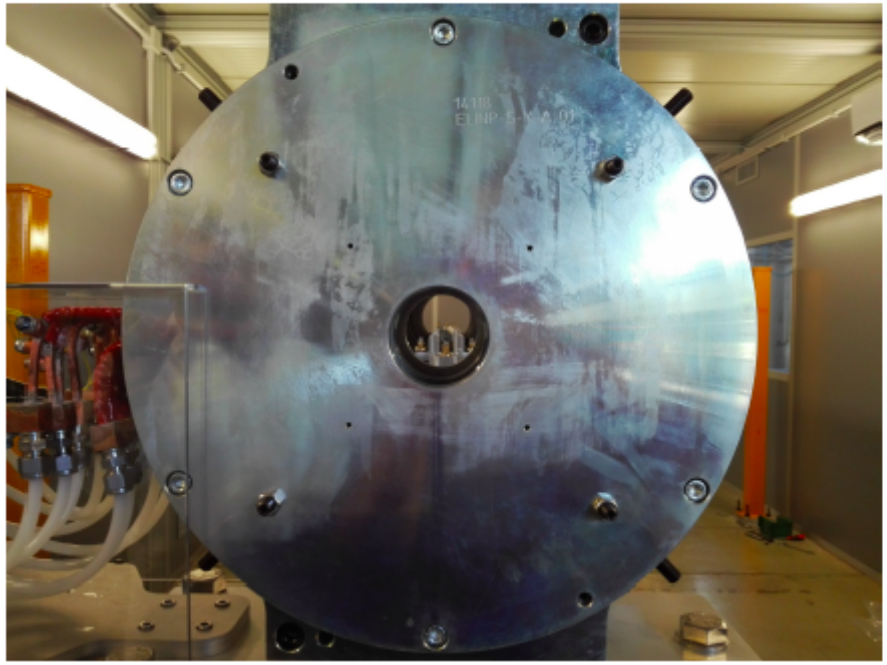
WP05 - STFC Modules

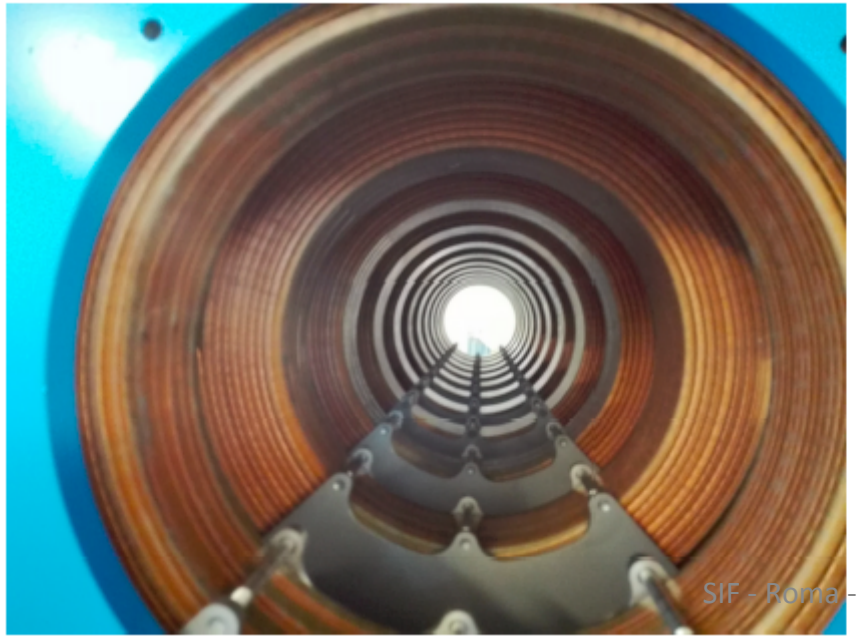


WP06 - INFN Modules

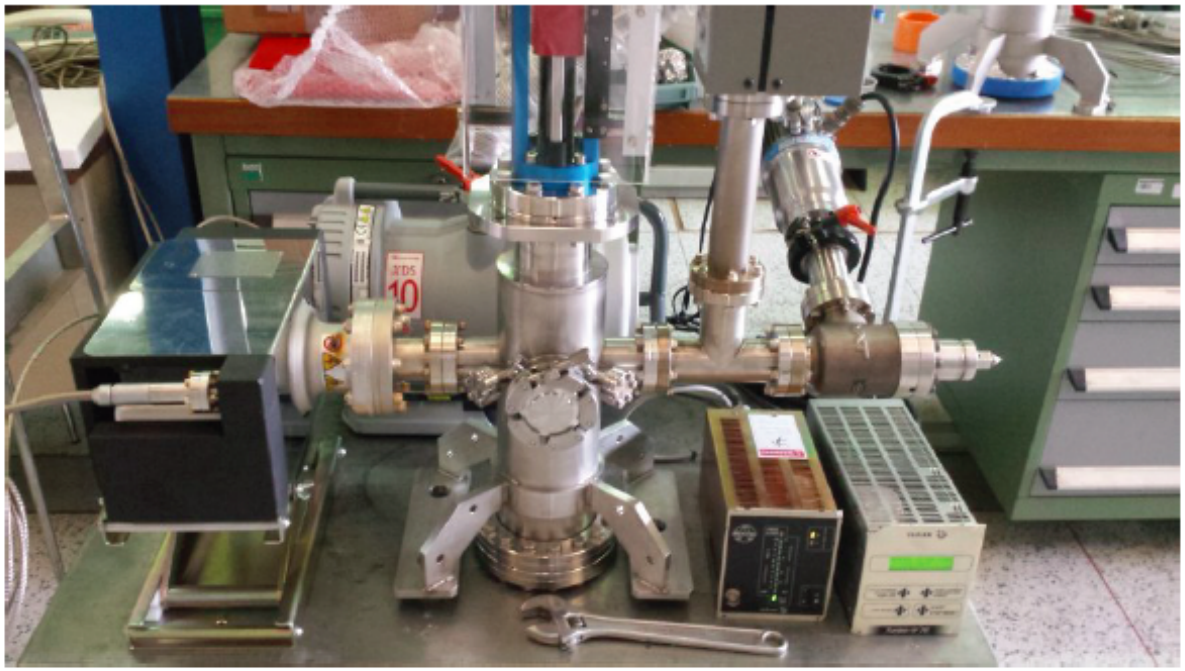


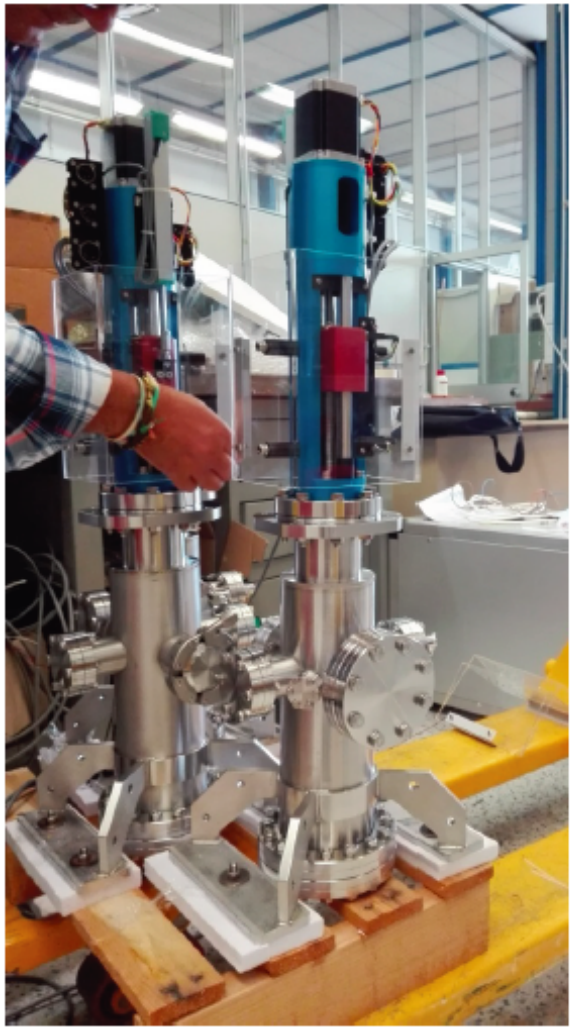
WP06 - INFN Modules



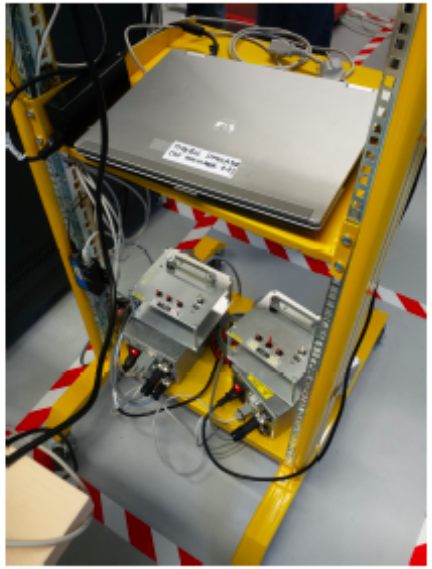


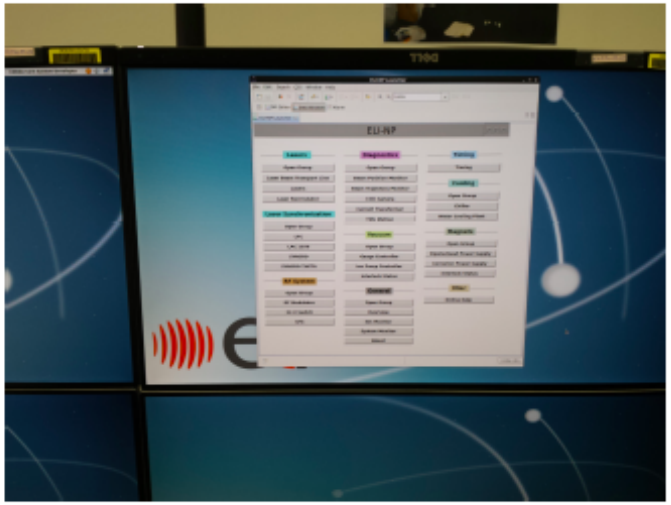
WP07 - Diagnostics - Beam screen





WP08 - CONTROL SYSTEM





STATUS OF THE BUILDING


aros 40t

SIF - Roma - September 23, 2015

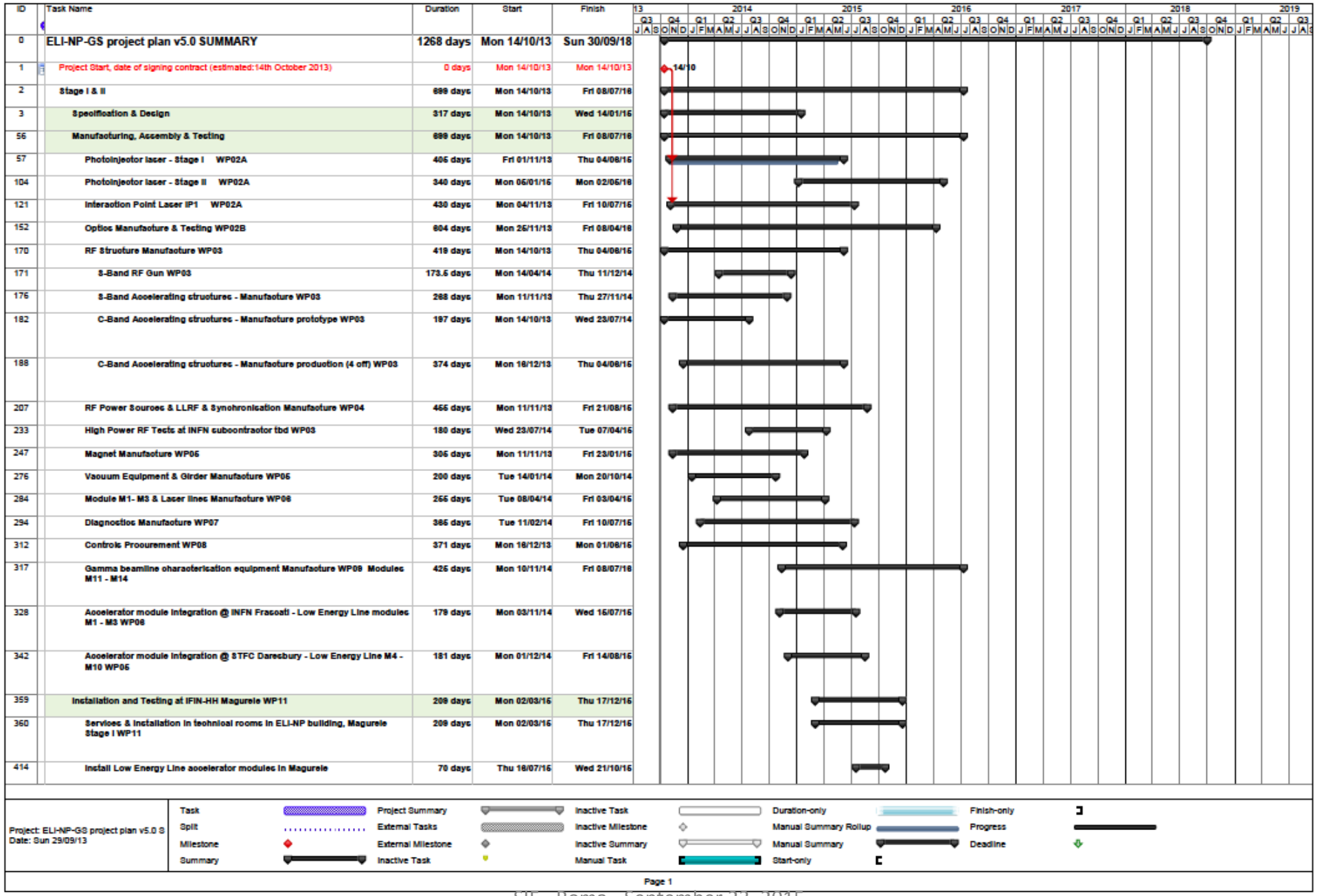
CONCLUSION STATUS OF THE PROJECT

EuroGammaS Consortium is ready to delivery the components of the 1 st stage of the project

CRITICAL ISSUES:

The building is not ready yet, expected 6-8 months delay

A new installation plan and contract consequences will be soon discussed with IFIN-HH



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0	ELI-NP-GS project plan v5.0 SUMMARY	1268 days	Mon 14/10/13	Sun 30/09/18
1	Project Start, date of signing contract (estimated:14th October 2013)	0 days	Mon 14/10/13	Mon 14/10/13
2	Stage I & II	699 days	Mon 14/10/13	Fri 08/07/16
3	Specification & Design	317 days	Mon 14/10/13	Wed 14/01/15
56	Manufacturing, Assembly & Testing	699 days	Mon 14/10/13	Fri 08/07/16
57	PhotoInjector laser - Stage I WP02A	406 days	Fri 01/11/13	Thu 04/08/16
104	PhotoInjector laser - Stage II WP02A	340 days	Mon 06/01/16	Mon 02/05/16
121	Interaction Point Laser IP1 WP02A	430 days	Mon 04/11/13	Fri 10/07/15
152	Optics Manufacture & Testing WP02B	604 days	Mon 25/11/13	Fri 08/04/16
170	RF Structure Manufacture WP03	419 days	Mon 14/10/13	Thu 04/08/16
171	S-Band RF Gun WP03	173.5 days	Mon 14/04/14	Thu 11/12/14
176	S-Band Accelerating structures - Manufacture WP03	268 days	Mon 11/11/13	Thu 27/11/14
182	C-Band Accelerating structures - Manufacture prototype WP03	197 days	Mon 14/10/13	Wed 23/07/14
188	C-Band Accelerating structures - Manufacture production (4 off) WP03	374 days	Mon 16/12/13	Thu 04/08/16
207	RF Power Sources & LLRF & Synchronisation Manufacture WP04	455 days	Mon 11/11/13	Fri 21/08/15
233	High Power RF Tests at INFN subcontractor tbd WP03	180 days	Wed 23/07/14	Tue 07/04/15
247	Magnet Manufacture WP05	305 days	Mon 11/11/13	Fri 23/01/15
276	Vacuum Equipment & Girder Manufacture WP05	200 days	Tue 14/01/14	Mon 20/10/14
284	Module M1- M3 & Laser linac Manufacture WP06	255 days	Tue 08/04/14	Fri 03/04/15
294	Diagnostics Manufacture WP07	385 days	Tue 11/02/14	Fri 10/07/15
312	Controls Procurement WP08	371 days	Mon 16/12/13	Mon 01/08/16
317	Gamma beamline characterisation equipment Manufacture WP09 Modules M11 - M14	425 days	Mon 10/11/14	Fri 08/07/16
328	Accelerator module integration @ INFN Frascati - Low Energy Line modules M1 - M3 WP06	179 days	Mon 03/11/14	Wed 15/07/15
342	Accelerator module integration @ STFC Daresbury - Low Energy Line M4 - M10 WP05	181 days	Mon 01/12/14	Fri 14/08/15
359	Installation and Testing at IFIN-HH Magurele WP11	209 days	Mon 02/03/15	Thu 17/12/15
360	Services & Installation in technical rooms in ELI-NP building, Magurele Stage I WP11	209 days	Mon 02/03/15	Thu 17/12/15
414	Install Low Energy Line accelerator modules in Magurele	70 days	Thu 16/07/15	Wed 21/10/15

Project: ELI-NP-GS project plan v5.0 S
Date: Sun 29/09/13

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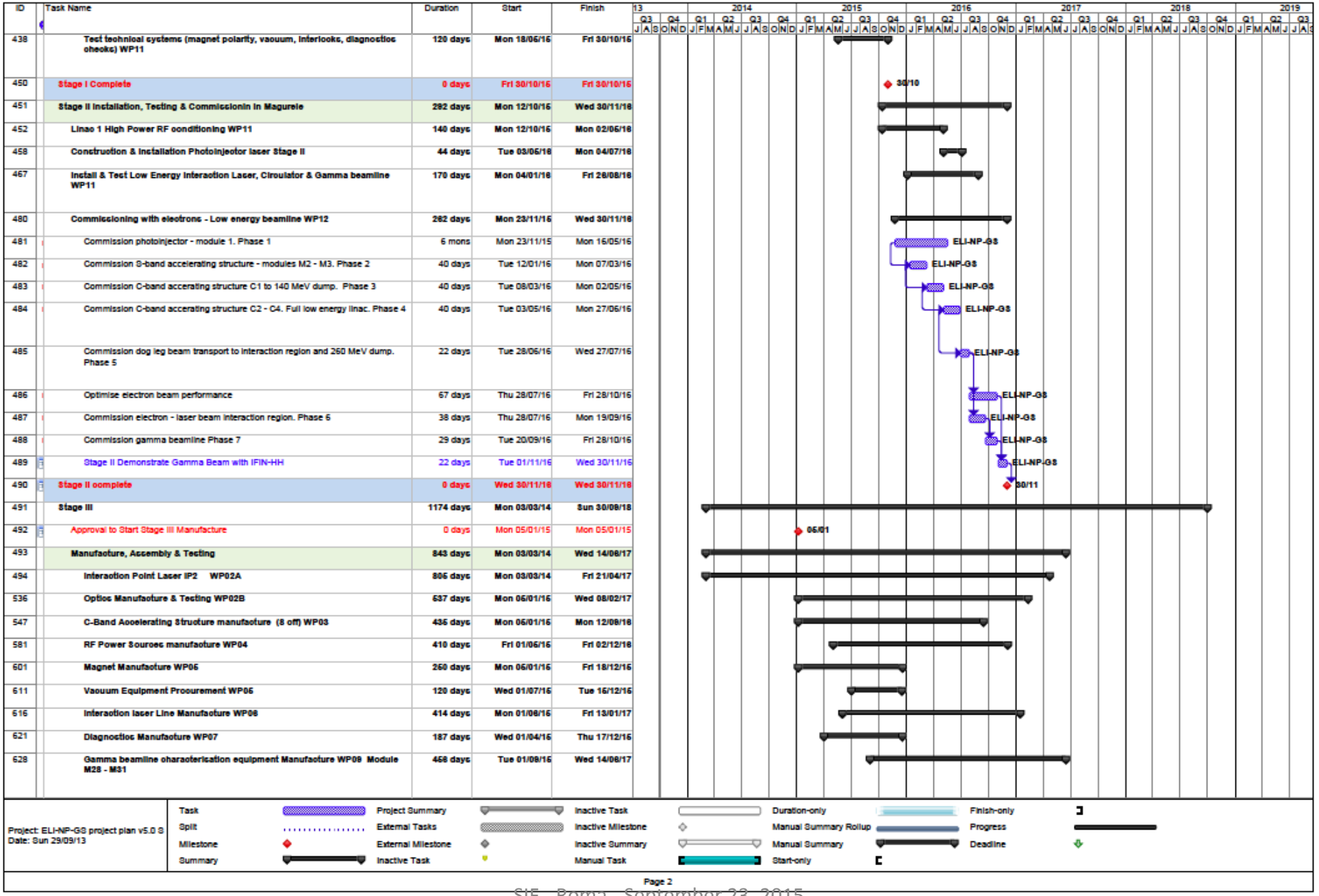
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450 Stage I Complete 0 days Fri 30/10/15 Fri 30/10/15
451 Stage II Installation, Testing & Commissionin in Magurele 282 days Mon 12/10/15 Wed 30/11/16
452 Linac 1 High Power RF conditioning WP11 140 days Mon 12/10/15 Mon 02/05/16
458 Construction & Installation Photoinjector laser Stage II 44 days Tue 03/05/16 Mon 04/07/16
467 Install & Test Low Energy Interaction Laser, Circulator & Gamma beamline WP11 170 days Mon 04/01/16 Fri 26/08/16
480 Commissioning with electrons - Low energy beamline WP12 282 days Mon 23/11/15 Wed 30/11/16
481 Commission photoinjector - module 1. Phase 1 6 mons Mon 23/11/15 Mon 16/05/16
482 Commission S-band accelerating structure - modules M2 - M3. Phase 2 40 days Tue 12/01/16 Mon 07/03/16
483 Commission C-band accerating structure C1 to 140 MeV dump. Phase 3 40 days Tue 08/03/16 Mon 02/05/16
484 Commission C-band accerating structure C2 - C4. Full low energy linac. Phase 4 40 days Tue 03/05/16 Mon 27/06/16
485 Commission dog leg beam transport to interaction region and 260 MeV dump. Phase 5 22 days Tue 28/06/16 Wed 27/07/16
486 Optimise electron beam performance 67 days Thu 28/07/16 Fri 28/10/16
487 Commission electron - laser beam interaction region. Phase 6 38 days Thu 28/07/16 Mon 19/09/16
488 Commission gamma beamline Phase 7 29 days Tue 20/09/16 Fri 28/10/16
489 Stage II Demonstrate Gamma Beam with IFIN-HH 22 days Tue 01/11/16 Wed 30/11/16
490 Stage II complete 0 days Wed 30/11/16 Wed 30/11/16
491 Stage III 1174 days Mon 03/03/14 Sun 30/09/18
492 Approval to Start Stage III Manufacture 0 days Mon 05/01/15 Mon 05/01/15
493 Manufaoture, Assembly & Testing 843 days Mon 03/03/14 Wed 14/06/17
494 Interaotion Point Laser IP2 WP02A 805 days Mon 03/03/14 Fri 21/04/17
536 Optios Manufaoture & Testing WP02B 537 days Mon 06/01/16 Wed 08/02/17
547 C-Band Aooelerating Structure manufaoture (8 off) WP03 435 days Mon 06/01/16 Mon 12/09/16
581 RF Power Sources manufaoture WP04 410 days Fri 01/05/16 Fri 02/12/16
601 Magnet Manufaoture WP05 260 days Mon 06/01/16 Fri 16/12/16
611 Vaouum Equipment Proourement WP05 120 days Wed 01/07/15 Tue 15/12/15
616 Interaotion laser Line Manufaoture WP06 414 days Mon 01/08/16 Fri 13/01/17
621 Diagnostios Manufaoture WP07 187 days Wed 01/04/15 Thu 17/12/15
628 Gamma beamline oharaoterisation equipment Manufaoture WP08 Module M28 - M31 458 days Tue 01/09/15 Wed 14/06/17
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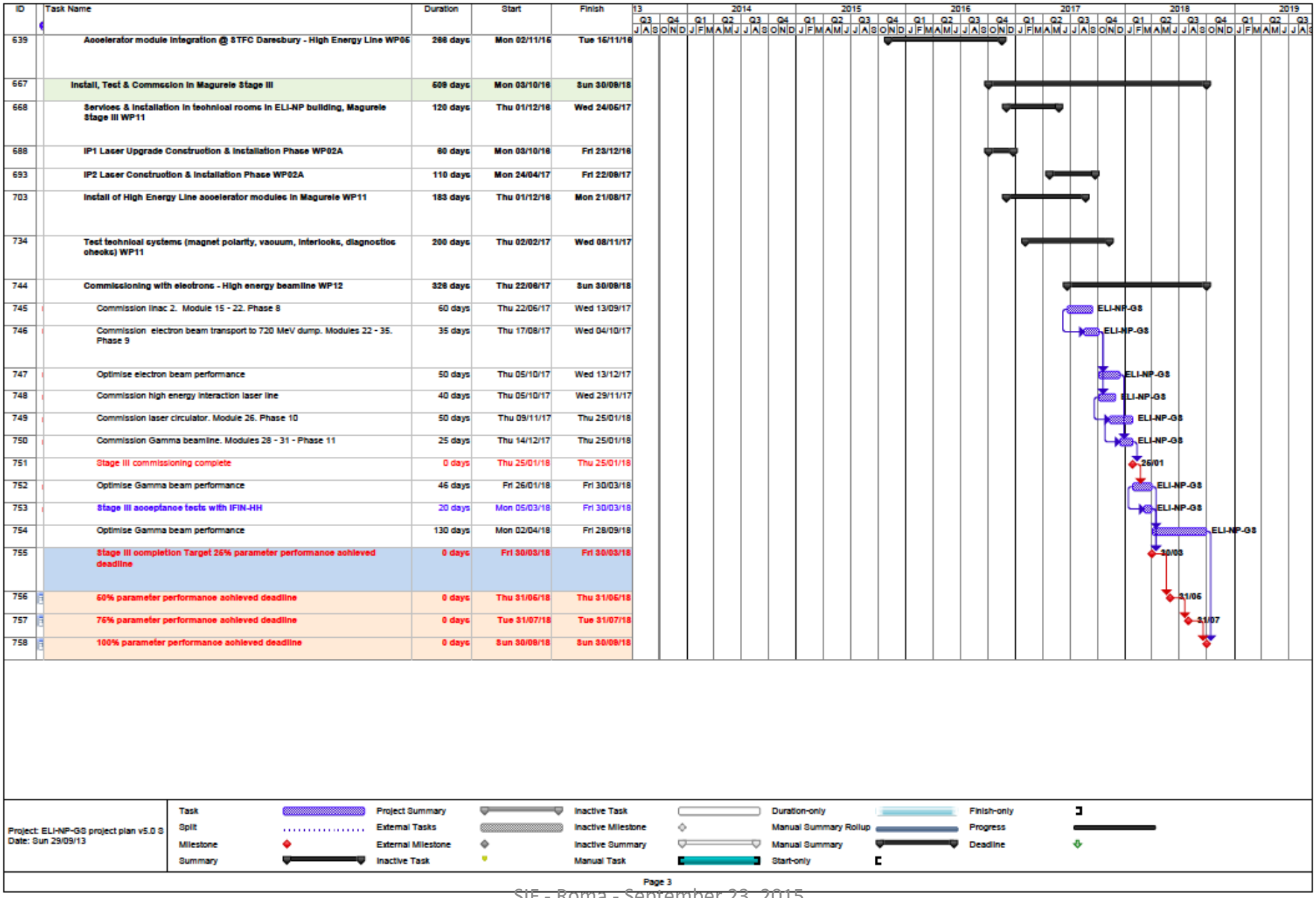
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639 Accelerator module integration @ ŞTEFC Magurele - High Energy Line WP06 268 days Mon 02/11/15 Tue 15/11/16
667 Install, Test & Commssion in Magurele Stage III 609 days Mon 03/10/16 Sun 30/09/18
668 Services & installation in technical rooms in ELI-NP building, Magurele Stage III WP11 120 days Thu 01/12/16 Wed 24/05/17
688 IP1 Laser Upgrade Construction & installation Phase WP02A 60 days Mon 03/10/16 Fri 23/12/16
693 IP2 Laser Construction & installation Phase WP02A 110 days Mon 24/04/17 Fri 22/09/17
703 Install of High Energy Line accelerator modules in Magurele WP11 183 days Thu 01/12/16 Mon 21/08/17
734 Test technical systems (magnet polarity, vacuum, interlocks, diagnostics checks) WP11 200 days Thu 02/02/17 Wed 08/11/17
744 Commissioning with electrons - High energy beamline WP12 328 days Thu 22/06/17 Sun 30/09/18
745 Commission linac 2. Module 15 - 22. Phase 8 60 days Thu 22/06/17 Wed 13/09/17
746 Commission electron beam transport to 720 MeV dump. Modules 22 - 35. Phase 9 35 days Thu 17/08/17 Wed 04/10/17
747 Optimise electron beam performance 50 days Thu 05/10/17 Wed 13/12/17
748 Commission high energy interaction laser line 40 days Thu 05/10/17 Wed 29/11/17
749 Commission laser circulator. Module 26. Phase 10 50 days Thu 09/11/17 Thu 25/01/18
750 Commission Gamma beamline. Modules 28 - 31 - Phase 11 25 days Thu 14/12/17 Thu 25/01/18
751 Stage III commissioning complete 0 days Thu 25/01/18 Thu 25/01/18
752 Optimise Gamma beam performance 46 days Fri 26/01/18 Fri 30/03/18
753 Stage III acceptance tests with IFIN-HH 20 days Mon 05/03/18 Fri 30/03/18
754 Optimise Gamma beam performance 130 days Mon 02/04/18 Fri 28/09/18
755 Stage III completion Target 25% parameter performance achieved deadline 0 days Fri 30/03/18 Fri 30/03/18
756 50% parameter performance achieved deadline 0 days Thu 31/05/18 Thu 31/05/18
757 75% parameter performance achieved deadline 0 days Tue 31/07/18 Tue 31/07/18
758 100% parameter performance achieved deadline 0 days Sun 30/09/18 Sun 30/09/18
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Table 3. Yb:Yag Collision Laser beam parameters

	Low Energy Interaction	High Energy Interaction
Pulse energy (*J*)	0.2	2x0.2
Wavelength (*eV,nm*)	2.3,515	2.3,515
FWHM pulse length (*ps*)	3.5	3.5
Repetition Rate (*Hz*)	100	100
M^2	$\leq$ 1.2	$\leq$ 1.2
Focal spot size w_0 (μm)	> 28	> 28
Bandwidth (*rms*)	0.1 %	0.1 %
Pointing Stability (μrad)	1	1
Sinchronization to an ext. clock	< 1 *psec*	< 1 *psec*
Pulse energy stability	1 %	1 %

Table 4. Laser beam Recirculator parameters

	Low Energy Interaction	High Energy Interaction
Distance between the two Parabolic Reflectors	2.38 *m*	2.38 *m*
Collision Angle	7.5°	7.5°
beam waist w_0	28 μm	28 μm
rotation at IP of linear laser polarization (along 32 passes)	$\geq$ 1°	$\leq$ 1°
integrated luminosity over 32 passes	> 90 %	> 90 %
Mirrors parallelism default	$\leq$ 10 μrad	$\leq$ 10 μrad
Mirrors alignment tolerance	$\leq$ 10 μm	$\leq$ 10 μm
Sinchronization to an ext. clock	< 1 *psec*	< 1 *psec*