EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments 2007-2013

Sectoral Operational Programme
„Increase of Economic Competitiveness”
“Investments for Your Future”

Extreme Light Infrastructure – Nuclear Physics (ELI–NP)

Project co–financed by the European Regional Development Fund

ELI-NP Gamma Beam System: New Facility for Nuclear Physics Research – Current Status

Piotr Tracz
piotr.tracz@eli-np.ro
For the ELI-NP team

November 16th , 2016
University of Applied Sciences, Brugg/Windisch, Switzerland

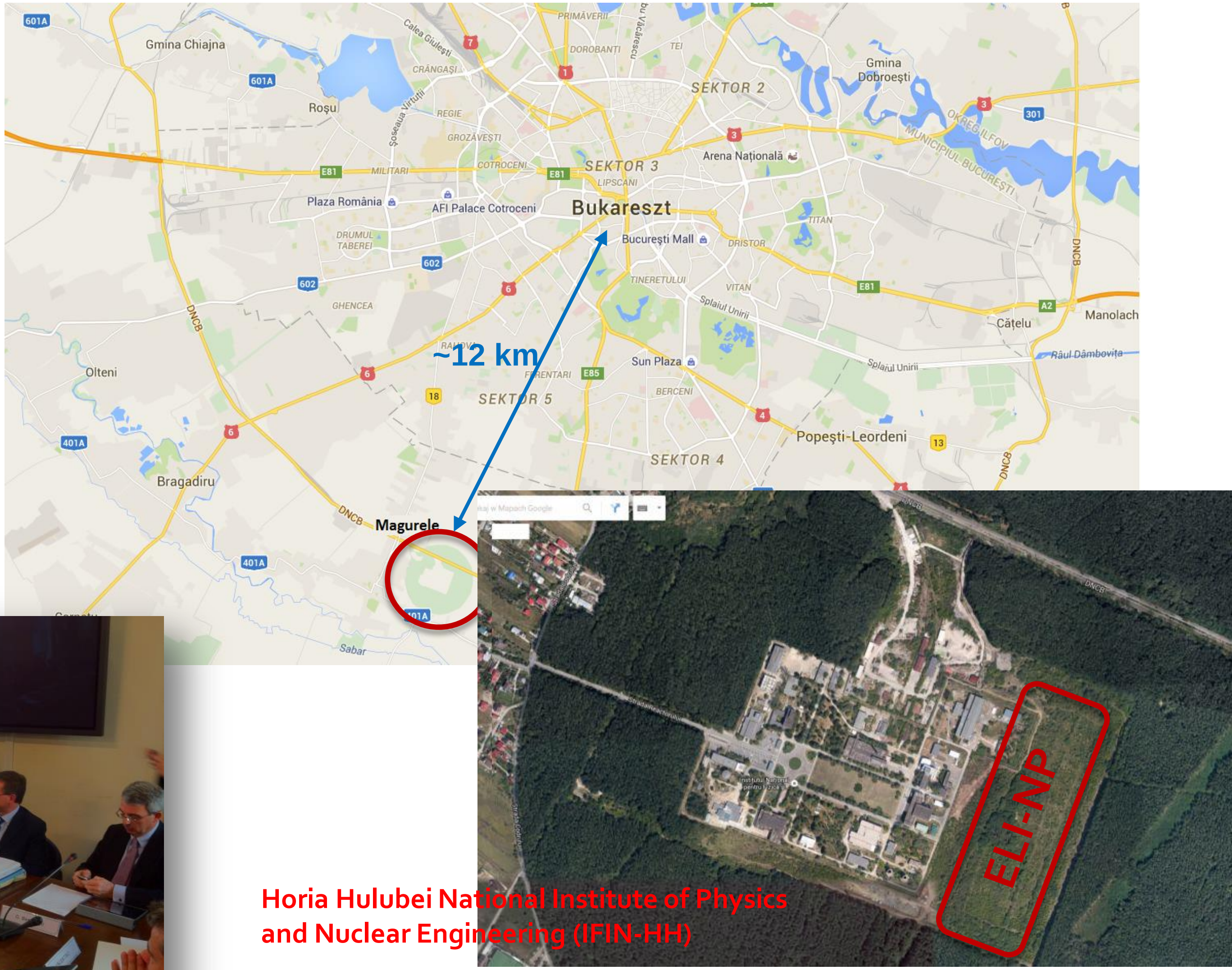
ELI-NP Gamma Beam System

Nuclear Physics

Provider – EuroGammaS Association

Academic Institutions
INFN (Italy), Sapienza University (Italy), CNRS (France)
Industrial Partners
ACP Systems (France), ALSYOM (France),
COMEB (Italy), ScandiNova Systems (Sweden)

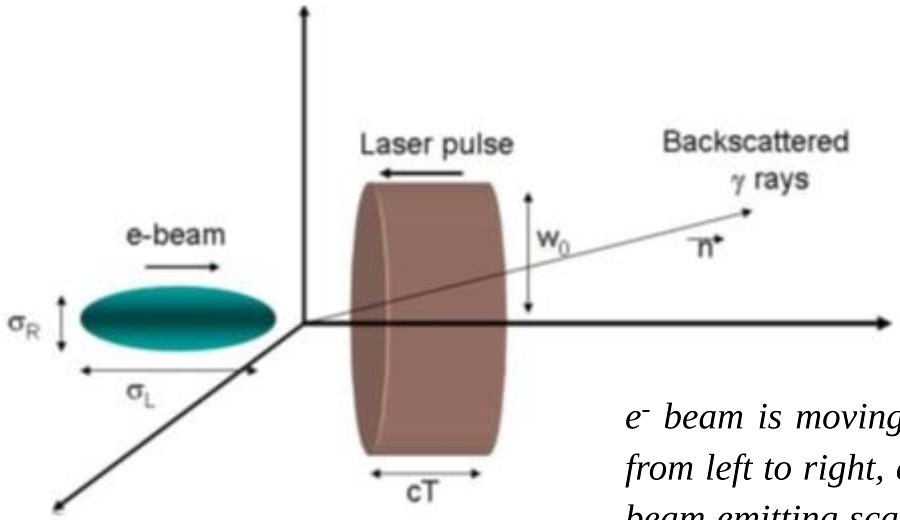
and several Sub-Contractors:
Alba (Spain), STFC (UK)
Amplitude Systems (France), Amplitude Technology (France), iTech (Slovenia), Cosylab (Slovenia), Danfysik (Denmark), M&W Group (Italy), Menlo Systems (Germany), RI (Germany),



Gamma Beam System – Basic Concept

Compton backscattering between a relativistic electron bunch and a high power laser pulse.

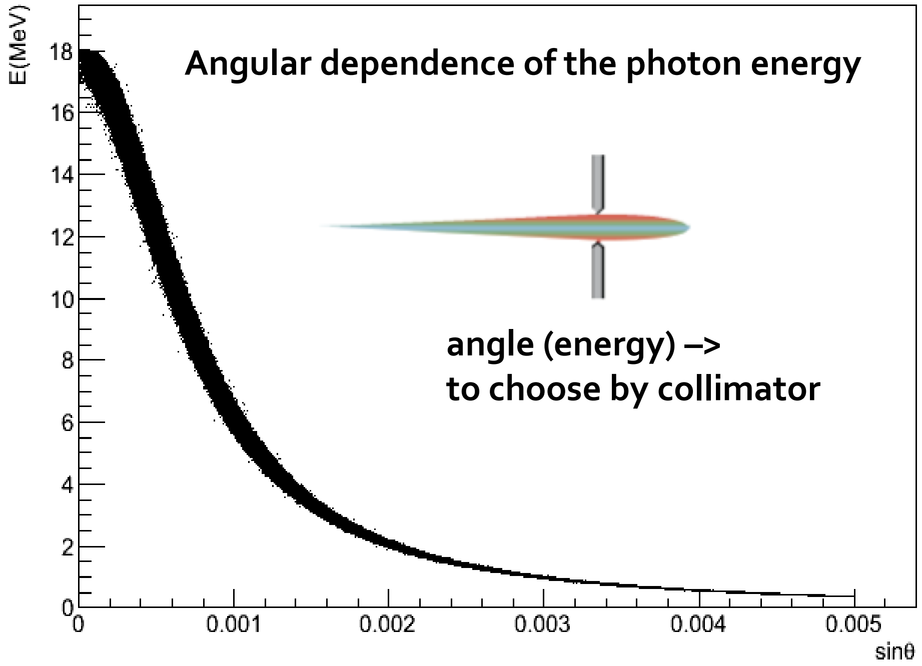
Compton backscattering geometry



Laser pulse (*3.5ps*) energy:

0.2J	$E_e \sim 300 MeV$	$E_\gamma < 3.5\ MeV$	(Low Energy Branch)
($2.4eV, 515nm$ – green)			
2 x 0.2J	$E_e \sim 720\ MeV$	$E_\gamma \leq 19\ MeV$	(High Energy Branch)

e^- beam is moving at a relativistic speed from left to right, colliding with a photon beam emitting scattered radiation mainly in the direction of motion of the e^- beam.



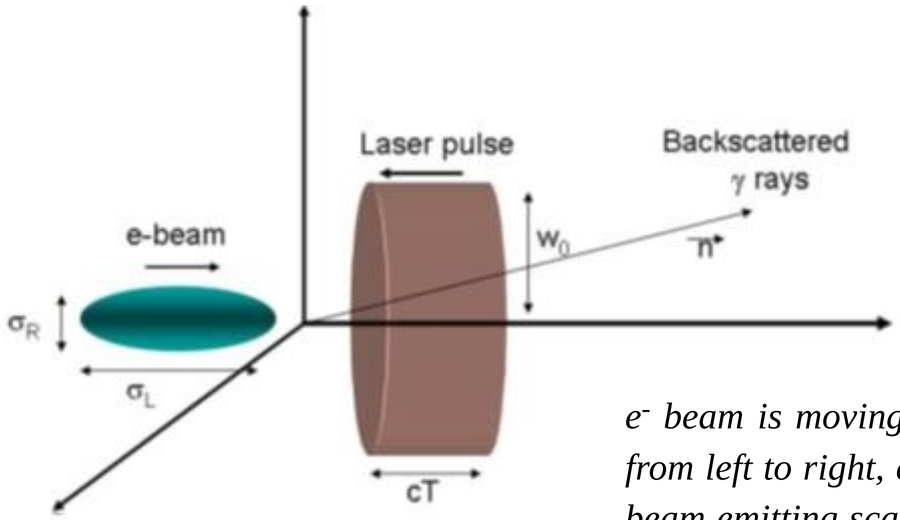
Low cross section (~ 10^{-25} cm^2)

→ need of high density of electron and photon beams

Gamma Beam System – Basic Concept

Compton backscattering between a relativistic electron bunch and a high power laser pulse.

Compton backscattering geometry



e^- beam is moving at a relativistic speed from left to right, colliding with a photon beam emitting scattered radiation mainly in the direction of motion of the e^- beam.

Laser pulse (*3.5ps*) energy:

0.2J (2.4eV, 515nm – green)	$E_e \sim 300 MeV$	⇒ $E_\gamma < 3.5\ MeV$	(Low Energy Branch)
2 x 0.2J	$E_e \sim 720\ MeV$	⇒ $E_\gamma \leq 19\ MeV$	(High Energy Branch)

Low cross section (~ 10^{-25} cm^2)

→ need of high density of electron and photon beams

Result:

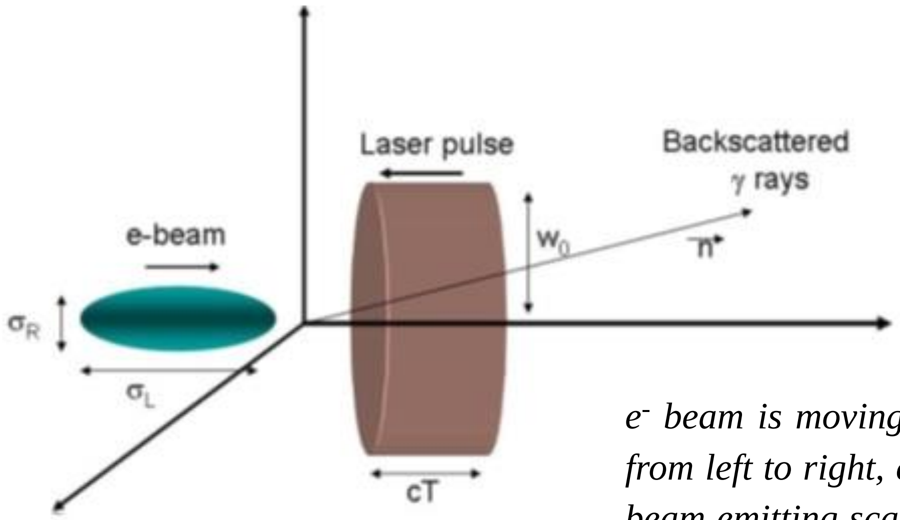
generation of high brilliance γ-ray beam with number of advantages over the more conventional bremsstrahlung sources, which are based on impinging the electron beam onto a solid target of high Z material:

- good and controllable monochromaticity,
- easy tunability,
- higher collimation
- full control of the gamma photon polarization.

Gamma Beam System – Basic Concept

Compton backscattering between a relativistic electron bunch and a high power laser pulse.

Compton backscattering geometry



Laser pulse (*3.5ps*) energy:

0.2J
$(2.4eV, 515nm$ – green)

$E_e \sim 300MeV$ ⇒ $E_\gamma < 3.5\ MeV$ (Low Energy Branch)

2 x 0.2J

Branch)

e^- beam is moving at a relativistic speed from left to right, colliding with a photon beam emitting scattered radiation mainly in the direction of motion of the e^- beam.

Low cross section (~ 10^{-25} cm^2)
→ need of high density of electron and photon beams

Photon Energy	up to 19.5 MeV
Spectral Density	10^4 ph/sec/eV
Bandwidth (rms)	≤ 0.5%
# photons / shot within FWHM bdw.	$2.6 \cdot 10^5$ (max)
# photons / sec within FWHM bdw.	$8.3 \cdot 10^8$ (max)
Source rms size	10 ÷ 30 μm
Source rms divergence	30 ÷ 200 μrad
Peak brilliance (N_{ph}/sec mm^2 mrad^2 0.1%)	10^{20} ÷ 10^{23}
Pulse length (rms)	0.7 ÷ 1.5 ps
Linear polarization	> 99%
Repetition Rate	100 Hz
Source position transverse jitter	< 5 μm
Energy jitter pulse-to-pulse	< 0.2 %
# pulses per macro-pulse	32
Pulse-to-pulse separation	16 ns

ELI-NP-GBS Electron Accelerator

Electron beam parameters at Interaction Points

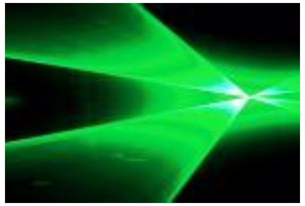
Energy	up to 720 MeV
Bunch charge	250 pC
Bunch length	1 ps
Norm. transverse emittance	0.4 mm·mrad
Bunch energy spread	0.04 ÷ 0.1 %
Focal spot size	~ 15 µm
Number of bunches	32
Bunch-to-bunch distance	16 ns
Energy variation along macro-bunch	0.1%
Energy jitter shot to shot	0.1%
Time arrival jitter	< 0.5 ps
Pointing jitter	1 µm
Bunch rep rate	100 Hz

We need:

a) high brightness (high charge, low emittance, low energy spread) and high phase space density electron beam carrying 250pC per bunch in bunch trains of 32 bunches per RF pulse, focused down to spot sizes of about 15µm.

b) laser beam of high intensity, very brilliant, high repetition rate.

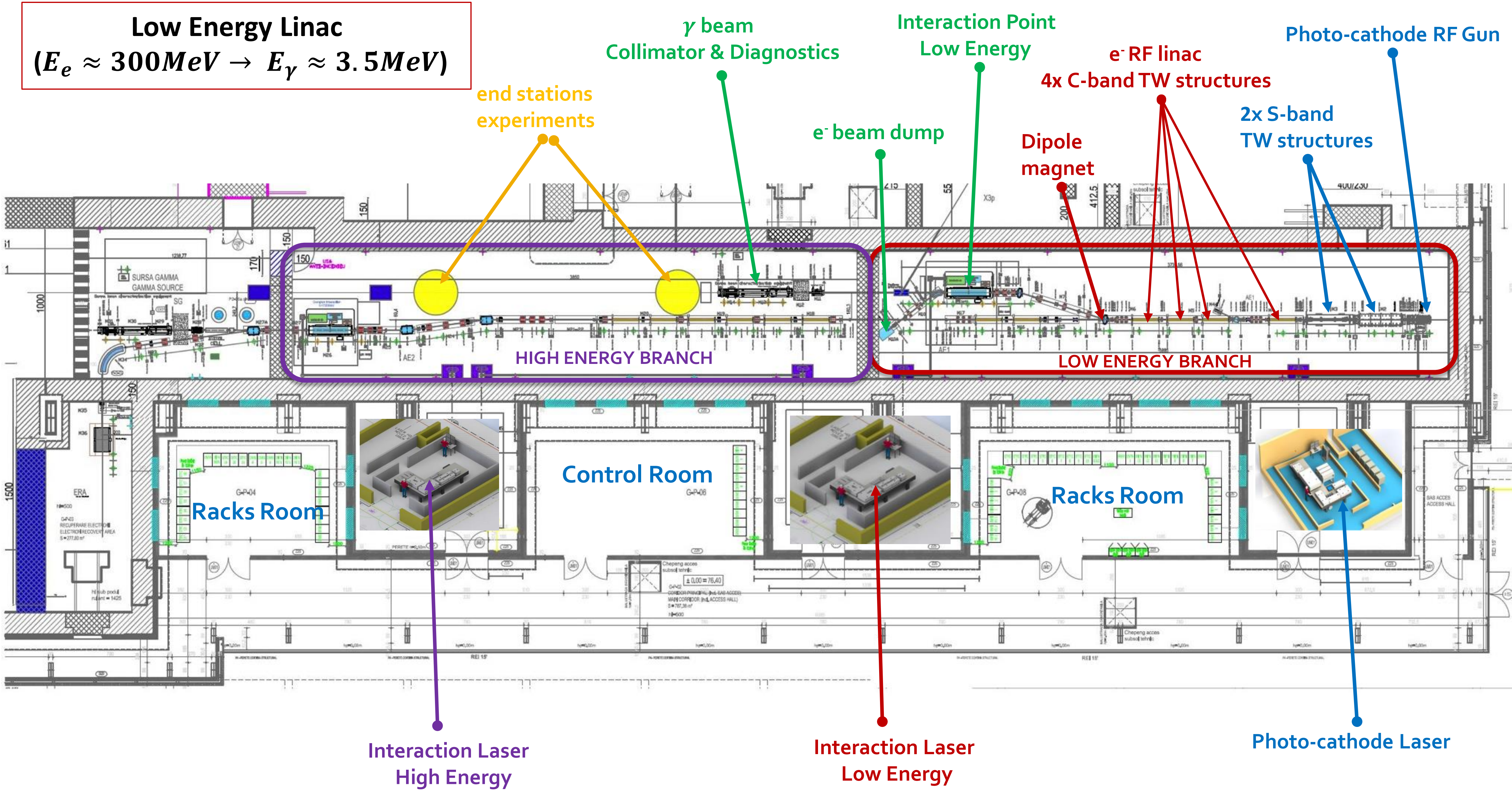
The **G**amma **B**eam **S**ystem is based on warm RF linac operated at C-band with S-band photo-injector.



Ti:sapphire laser for photocathode RF gun
Output: ~10ps pulse duration in UV range (266nm), 150µJ/pulse, sequence of trains made of 32 pulses separated by 16ns @100Hz rep. rate.

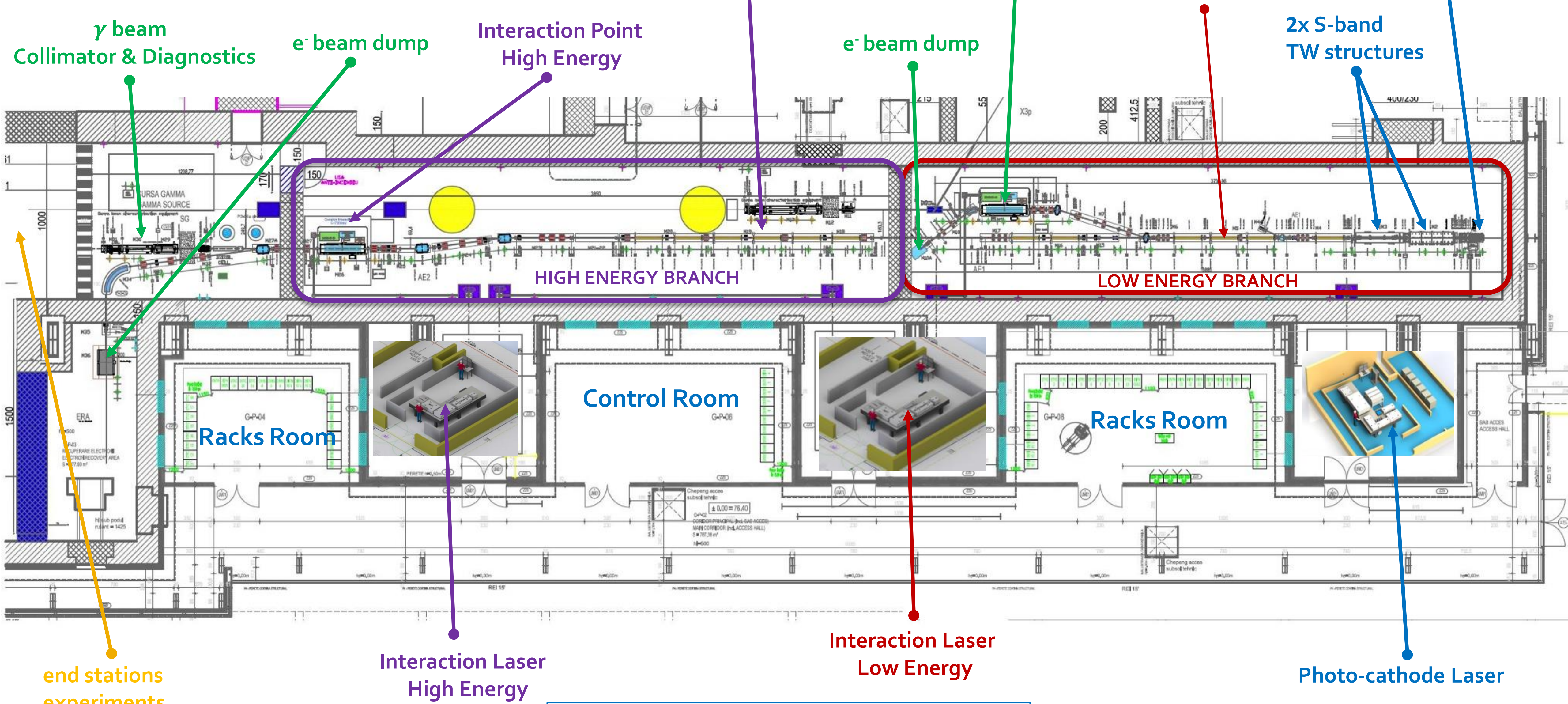
Yb:YAG lasers for Interaction Points with 3.5 ps pulse duration (FWHM) at 515 nm, 0.2J, 100Hz, 0.1% (rms) bandwidth, and pulse energy stability of 1%.

Low Energy Linac
($E_e \approx 300 MeV \rightarrow\ E_\gamma \approx 3.5 MeV$)



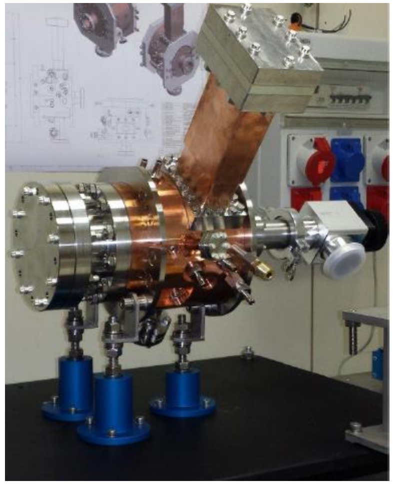
High Energy Linac

$(E_e \approx 720MeV \rightarrow E_\gamma \approx 18MeV)$



Master Clock synchronization @ < 1ps

Photo-cathode RF Gun



1.6-cell standing-wave RF cavity, working in S-band at 2.856 GHz.

high gradient: 120 MV/m; 100Hz
photo-cathode: OFHC Copper

S-band injector – 2 x TW accelerating structures

Dual-symmetric feeding – min. of multipole effects.
Long bunch at the photo-cathode (10ps) => to control the emittance growth due to space charge effects.
S-band injector – reduction of the bunch length (1ps) by the velocity bunching technique.

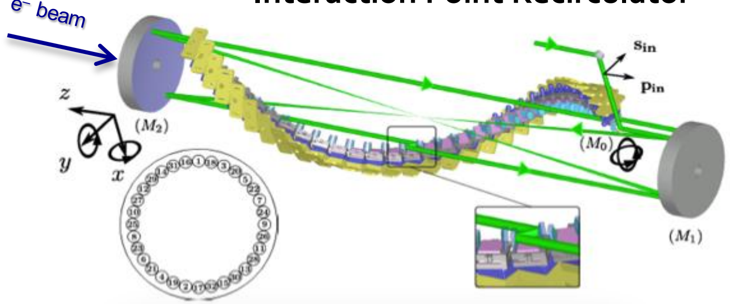
research instruments

C-band linac – 12 x TW acc. structures

Effective damping of HOM dipole modes

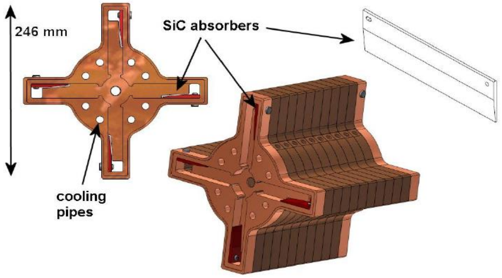
D.Alesini et al., *"Design and RF Test of Damped C-band Accelerating Structures for the ELI-NP Linac"*

Interaction Point Recirculator

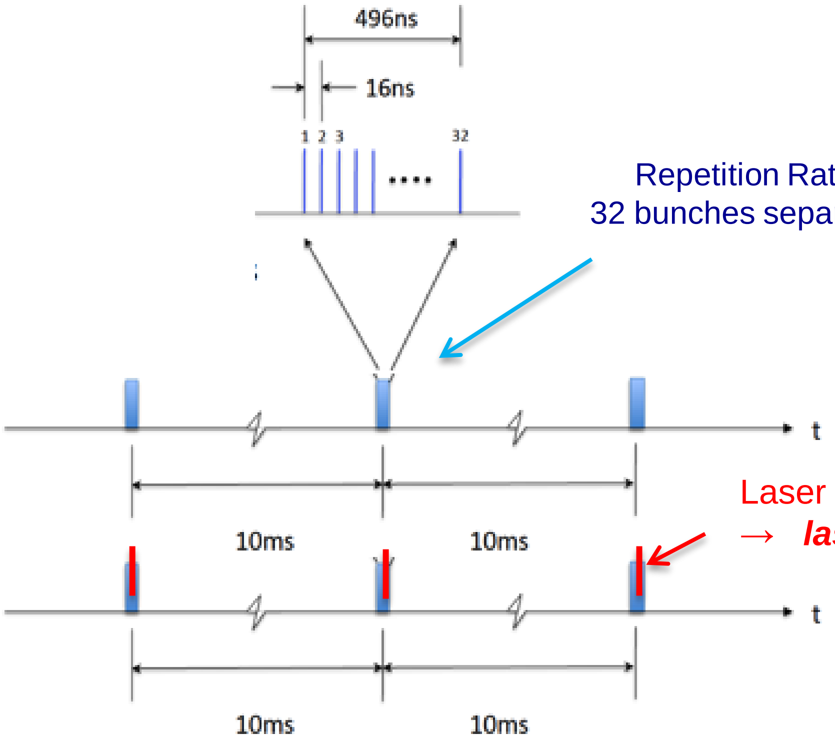


Designed by

Waveguide dumping system => excited dipole modes propagate and dissipate into RF loads



Laser Recirculation at Interaction Points



Repetition Rate – 100 Hz
32 bunches separated by 16 ns

Laser pulse rep. rate – 100 Hz
→ ***laser recirculation***

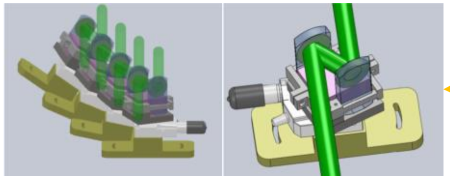
Laser Recirculator -> Single laser pulse is recirculated 32 times, synchronized with RF clock.

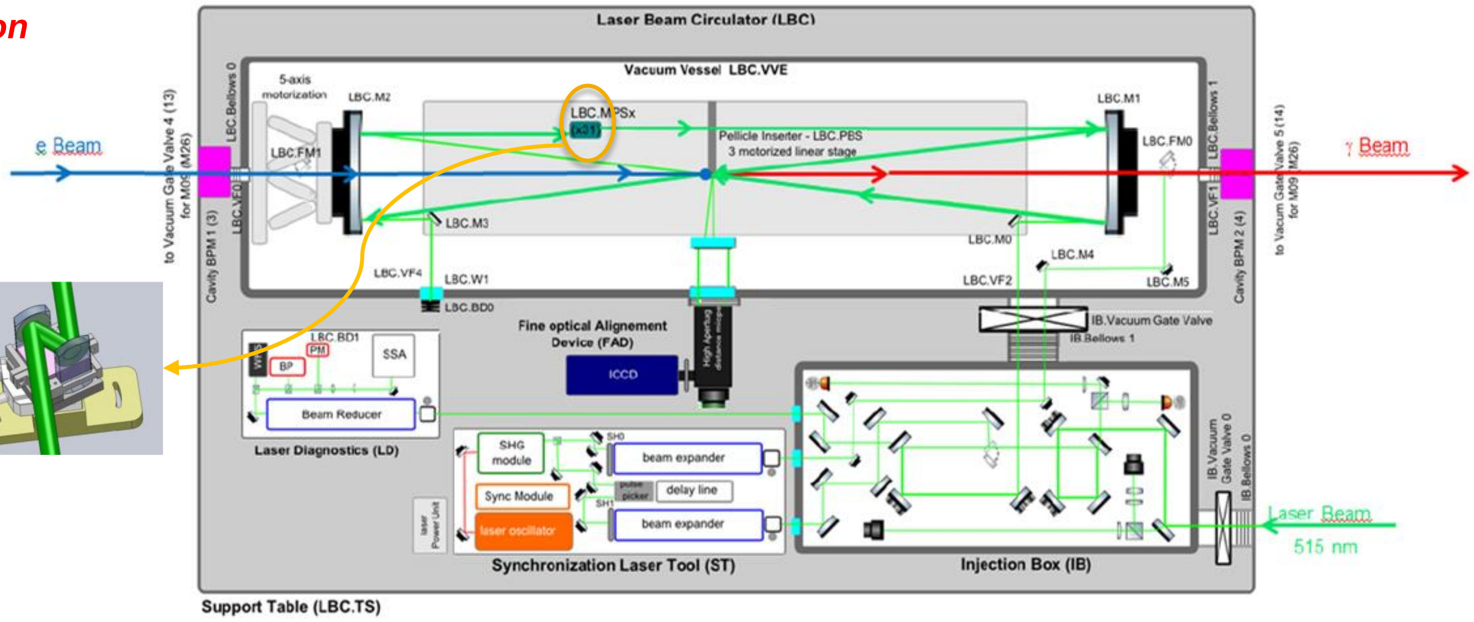
The laser beam is reflected and focused to the Interaction Point (IP) with the parabolic mirrors (sharing the same focal point.).

Mirror Pair System (MPS) - enables to shift the laser beam path in respect to parabolic mirrors and to delay in order to synchronize the laser pulse over the electron bunches.

2 parabolic reflectors M1& M2

- M1 fixed
- M2 : 5 degrees of freedom

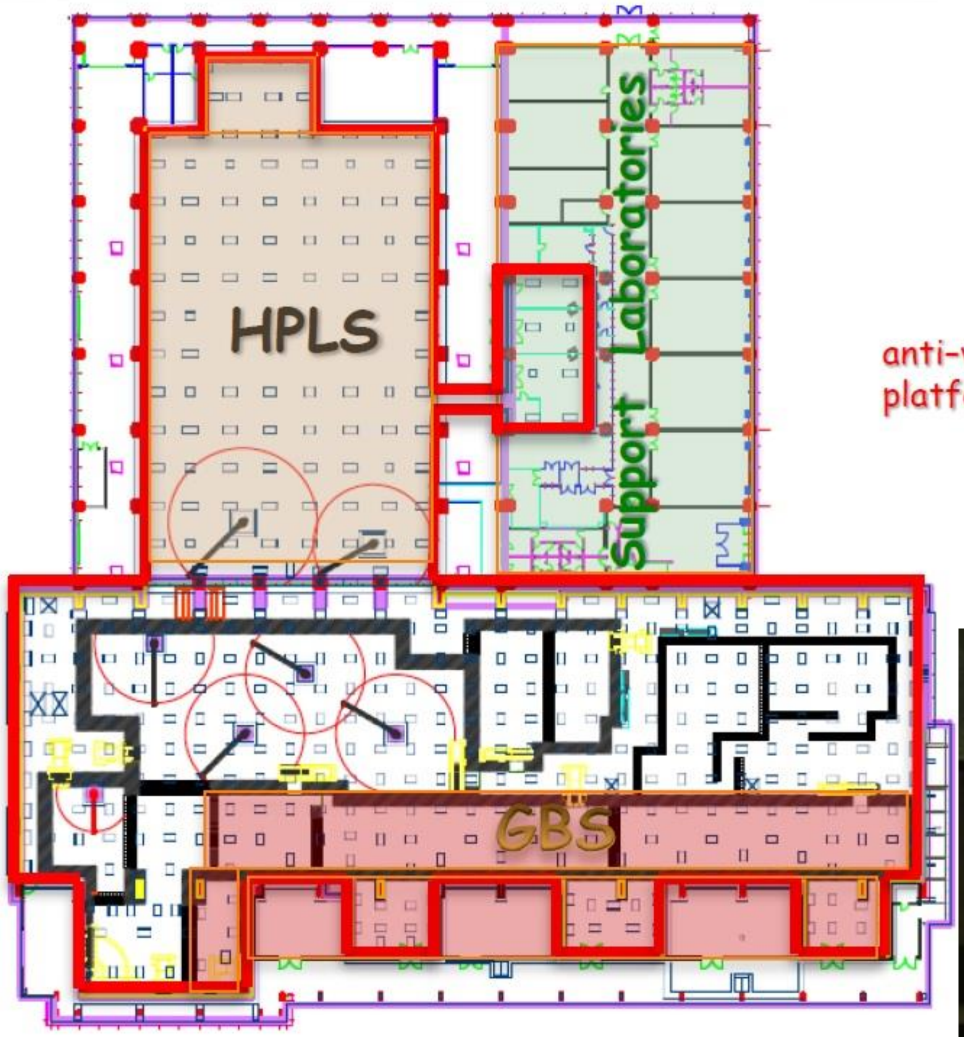




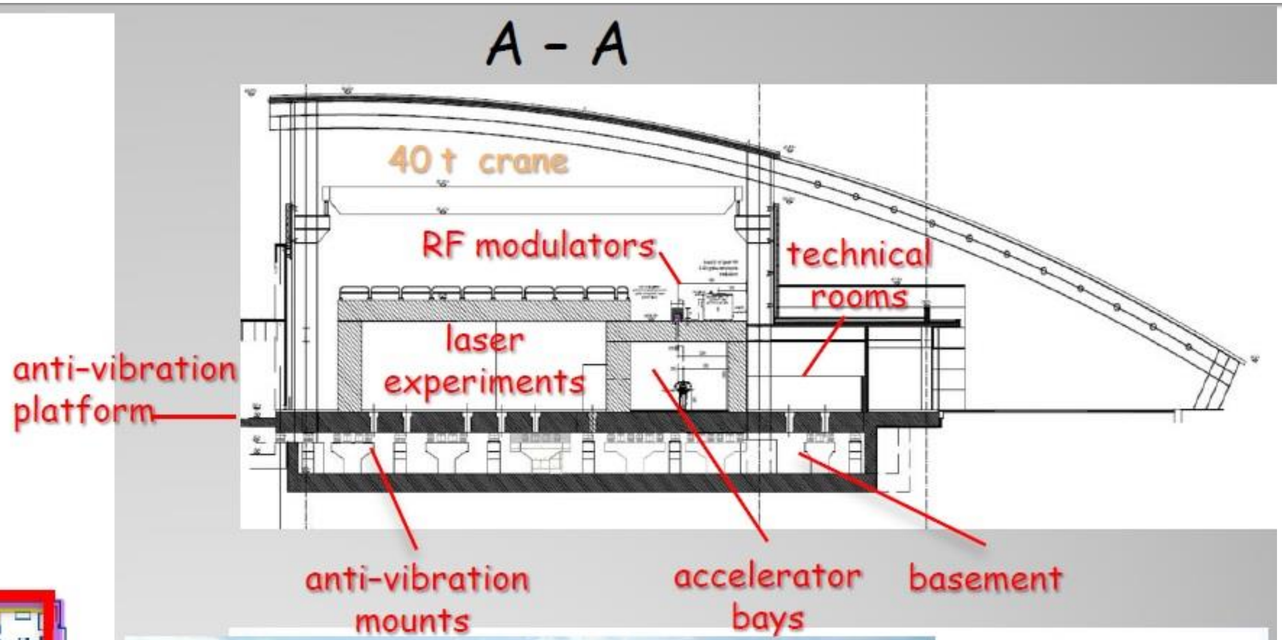
Laser Recirculator:

- Highly complex optical implementation

ELI–NP Facility Concept



ELI -NP Main Experimental Building ~ 15,000 m

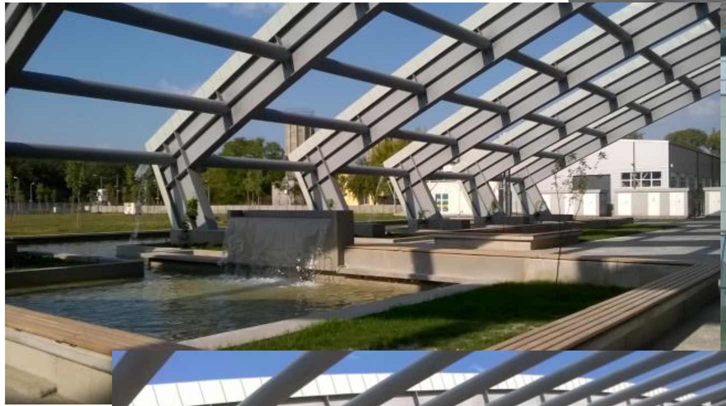


ELI–NP Facility

July-August 2016





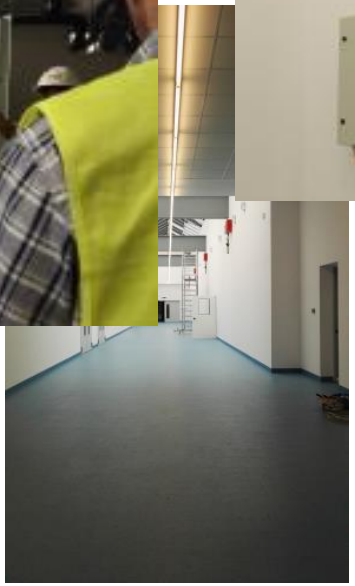






Building Acceptance

June-September 2016

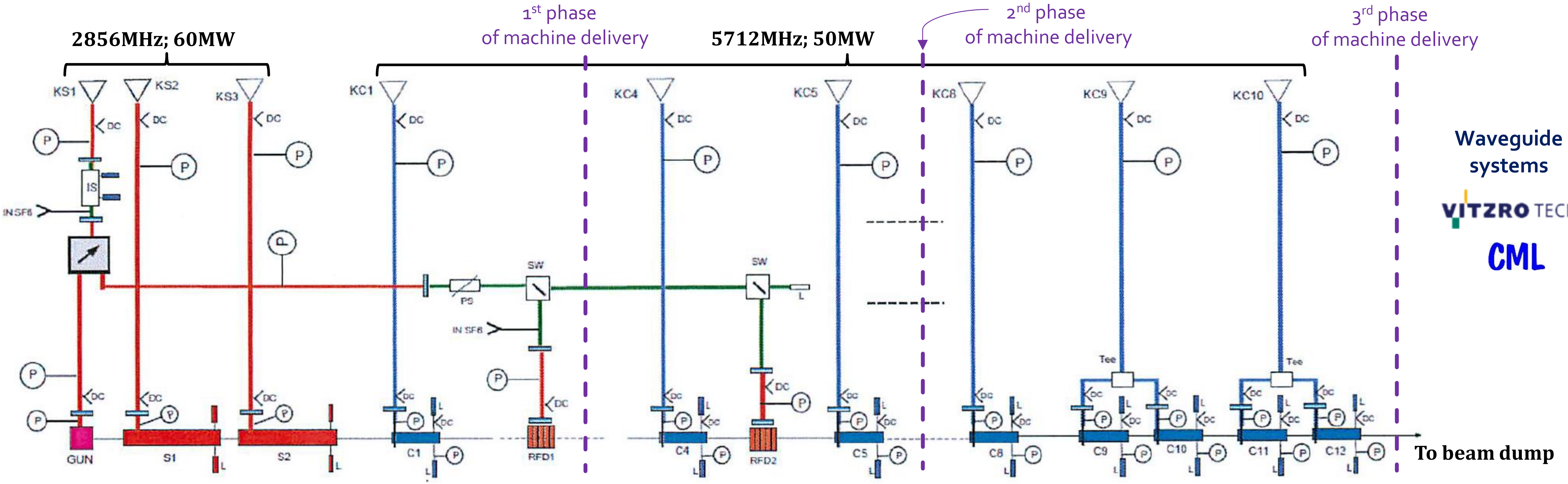








Vibration Measurements – Gerb Engineering GmbH
Laser tracker 3D scanning for check the real dimensions and volumes of the rooms. Location of all openings etc.
Electrical measurements – grounding parameters, short-circuit current, grid voltage monitoring.
Tests of BMS, Ventilation System, Alarm system etc.

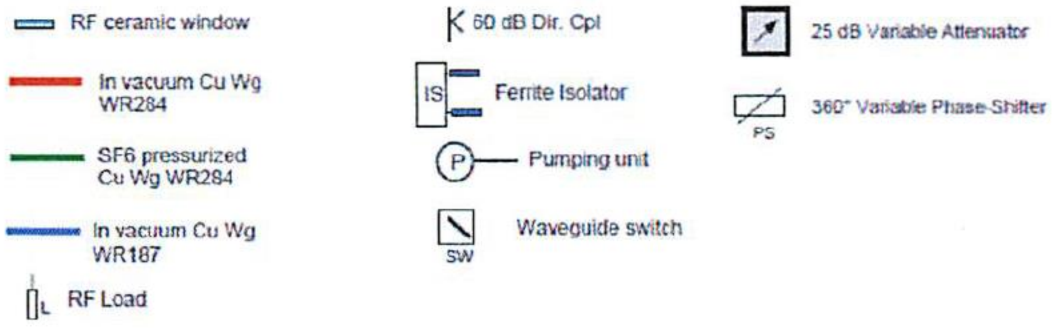
RF power distribution



Waveguide systems

VITZRO TECH

CML



KLYSTRON MODULATORS	Electron Gun	Injector	Booster
Frequency [GHz]	2.856	2.856	5.712
Output Peak Power [MW]	45	60	50
Pulse length [µs]	5	1,5	0,5
Rep. Rate [Hz]	100	100	100

ScandiNova

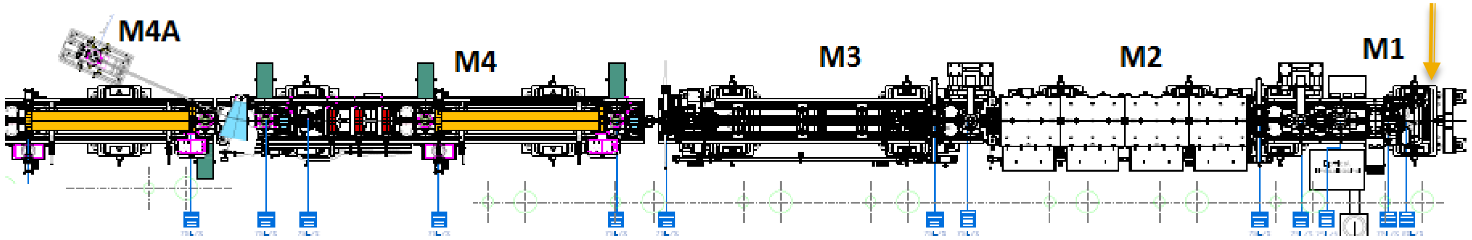
TOSHIBA Leading Innovation

Acceptance of GBS devices/components

Stage I – delivery and tests of system components corresponding to gamma beam energy min. 1MeV (by **November 2015**)

Components were completed with the ELI-NP label numbers, and documented with photographs.

Photo-gun



Attachment to Addendum 3 - End of Stage 1 deliveries.xlsx

#	Module	Equipment Description	Location
1	EXT	Photocathode laser - 1 pulse UV	AMPLITUDE (Lisses)
2	EXT	1 IP Laser	AMPLITUDE (Pessac)
3	EXT	Consolles	COSYL
4	EXT	11x CPU Control	COSYL
5	EXT	Ethernet Converter	COSYL
6	EXT	Ethernet switch	COSYL
7	EXT	Fanout	COSYL
8	EXT	Monitor	COSYL
9	EXT	PLC	COSYL
10	EXT	Digitizer	COSYL
11	EXT	1 event generator Timing Central Station	COSYL
12	EXT	11 event receiver Timing Central Station	COSYL
13	EXT	Low Energy IP laser Transport line	LAL (O
14	EXT	Photocathode Laser Transport line	LAL (O
15	EXT	Synchronization Main Enclosure	MENL
16	EXT	OMO related electronics	MENL
17	EXT	SFLspools and related electronics	MENL
18	EXT	SFL terminations and front end devices	MENL
19	M1	BPM Libera channel	INFN (
20	M1	BPM	INFN (
21	M1	FCT	INFN (
22	M1	Screen chamber	INFN (
23	M1	Screen chamber	INFN (
24	M1	H & V Corrector Magnet Type A - Hor. coil	INFN (
25	M1	Steerer Power Supply	INFN (
26	M1	Solenoid Power Supply	INFN (
27	M1	Steerer Power Supply	INFN (
28	M1	Solenoid A (2 coils)	INFN (
29	M1	H & V Corrector Magnet Type A - Vert. coil	INFN (
30	M1	Girder	INFN (
31	M1	Mechanical Support	INFN (
32	M1	Vacuum chamber	INFN (
33	M1	Cold cathode vacuum gauge - Agilent IMG300	INFN (
34	M1	Cold cathode vacuum gauge - Agilent IMG300	INFN (
35	M1	Thermal conductivity vacuum gauge - Agilent TC536 Pirani	INFN (
36	M1	Cold cathode vacuum gauge - Agilent IMG300	INFN (
37	M1	Thermal conductivity vacuum gauge - Agilent TC536 Pirani	INFN (
38	M1	Ion pump 75 l/s	INFN (
39	M1	Ion pump 75 l/s	INFN (
40	M1	4 channels Power Supply (for 4 pumps)	INFN (
41	M1	Pump Power Supply	INFN (
42	M1	Residual gas analyser	INFN (
43	M1	Pumping & Vent valve (MANUAL)	INFN (
44	M1	Pumping & Vent valve (MANUAL)	INFN (
45	M1	Sector Vacuum valve (PNEUMATIC)	INFN (
46	M1	Sector Vacuum valve (PNEUMATIC)	INFN (
47	M1	RF window	RI (Be
48	M1	S-band RF Gun cavity	RI (Bo
49	M1	MSB1 (Modulator)	RI (Bo
50	M1	MSB1 (Klystron)	RI (Bo
51	M1	Directional coupler	RI (Bo

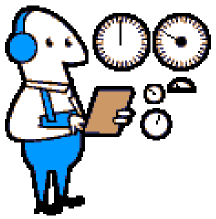
Attachment to Addendum 3 - End of Stage 1 deliveries.xlsx

#	Module	Equipment Description	Location
52	M1	Directional coupler	RI (Bonn)
53	M1	Waveguides S-band, T pumping	RI (Bonn)
54	M1	RF window	
55	M1	Ion pump 20 l/s	
56	M1	Ion pump 75 l/s	
57	M1	Pump	
58	M1	Pump	
59	M2	H Corrector Type B1 Single plane	
60	M2	H Corrector Type B1 Single plane	
61	M2	Power Supply	
62	M2	Power Supply	
63	M2	1 Solenoid Power Supply	
64	M2	Power Supply	
65	M2	Power Supply	
66	M2	Solenoid B (12 coils)	
67	M2	V Corrector Type B1 Single plane	
68	M2	V Corrector Type B1 Single plane	
69	M2	Girder	
70	M2	Mechanical support	
71	M2	S-band Accelerating Structure	
72	M2	2 Loads (section termination)	
73	M2	Directional coupler	
74	M2	Ion pump 75 l/s	
75	M2	4 channels Power Supply	
76	M2	Directional coupler	
77	M2	1 T pumping S-band	
78	M2	Waveguide S-band	
79	M2	1 Pump	
80	M2	1 RF window	
81	M2	MSB2 (Modulator)	
82	M2	MSB2 (Klystron)	
83	M3	BPM Libera channel	
84	M3	BPM	
85	M3	Screen chamber	
86	M3	H Corrector Type B2 Single plane	
87	M3	H Corrector Type B2 Single plane	
88	M3	Steerer Power Supply	
89	M3	Steerer Power Supply	
90	M3	Steerer Power Supply	
91	M3	Steerer Power Supply	
92	M3	V Corrector Type B2 Single plane	
93	M3	V Corrector Type B2 Single plane	
94	M3	Girder	
95	M3	Mechanical support	
96	M3	Directional coupler	
97	M3	S-band Accelerating Structure	
98	M3	2 Loads (section termination)	
99	M3	Vacuum chambers	
100	M3	Cold cathode vacuum gauge - Agilent IMG300	
101	M3	Thermal conductivity vacuum gauge - Agilent	
102	M3	Cold cathode vacuum gauge - Agilent IMG300	

1/4

Attachment to Addendum 3 -

#	Module	Equipment Description
154	M4	Quadrupole vacuum chamber 271-10651
155	M4	4 way cross DN40
156	M4	Agilent vacuum gauge controller
157	M4	Cold cathode vacuum gauge - Agilent IMG
158	M4	Thermal conductivity vacuum gauge - Agil
159	M4	Cold cathode vacuum gauge - Agilent IMG
160	M4	Ion pump 75 l/s
161	M4	Ion pump 75 l/s
162	M4	Ion pump 75 l/s
163	M4	Ion pump 75 l/s
164	M4	Tee DN40
165	M4	Power Supply for 4 ION pumps
166	M4	Pumping & Vent valve (MANUAL)
167	M4A	140 MeV Beam Dump
168	M4A	Screen chamber
169	M4A	DN63CF Ceramic break 63,5 mm tube /8K
170	M4A	Mechanical Support
171	M4A	Vacuum chamber 271-10652
172	M4A	Ion pump 75 l/s



Attachment to Addendum 3 - End of Stage 1 deliveries.xlsx

#	Module	Equipment Description	Location
103	M3	Cold cathode vacuum gauge - Agilent IMG300	INFN (Frascati)
104	M3	Ion pump 75 l/s	INFN (Frascati)
105	M3		
106	M3		
107	M3		
108	M3		
109	M3		
110	M3		
111	M3		
112	M3		
113	M3		
114	M3		
115	M3		
116	M4		
117	M4		
118	M4		
119	M4		
120	M4		
121	M4		
122	M4		
123	M4		
124	M4		
125	M4		
126	M4		
127	M4		
128	M4		
129	M4		
130	M4		
131	M4		
132	M4		
133	M4		
134	M4		
135	M4		
136	M4		
137	M4		
138	M4		
139	M4		
140	M4		
141	M4		
142	M4		
143	M4		
144	M4		
145	M4		
146	M4		
147	M4		
148	M4		
149	M4		
150	M4		
151	M4		
152	M4		
153	M4		

Attachment to Addendum 3 - End of Stage 1 deliveries.xlsx

#	Module	Equipment Description	Location
103	M3	Cold cathode vacuum gauge - Agilent IMG300	INFN (Frascati)
104	M3	Ion pump 75 l/s	INFN (Frascati)
105	M3	Ion pump 75 l/s	INFN (Frascati)
106	M3	Ion pump 75 l/s	INFN (Frascati)
107	M3	Pumping & Vent valve (MANUAL)	INFN (Frascati)
108	M3	Sector Vacuum valve (PNEUMATIC)	INFN (Frascati)
109	M3	Directional coupler	RI (Bergisch Gl
110	M3	1 T pumping S-band	RI (Bergisch Gl
111	M3	Waveguide S-band	RI (Bergisch Gl
112	M3	1 RF window	RI (Bergisch Gl
113	M3	1 Ion pump	RI (Bergisch Gl
114	M3	MSB3 (Modulator)	SCANDINOVA
115	M3	MSB3 (Klystron)	SCANDINOVA
116	M4	BPM Libera channel	INFN (Frascati)
117	M4	BPM Libera channel	INFN (Frascati)
118	M4	MCB1 (Modulator)	SCANDINOVA
119	M4	MCB1 (Klystron)	SCANDINOVA
120	M4	DELL R220 EPICS Vacuum IOC	STFC (Daresbu
121	M4	BPM	STFC (Daresbury)
122	M4	BPM	STFC (Daresbury)
123	M4	BPM	STFC (Daresbury)
124	M4	Screen chamber	STFC (Daresbu
125	M4	Screen chamber	STFC (Daresbu
126	M4	Screen chamber	STFC (Daresbu
127	M4	Dipole A	STFC (Daresbu
128	M4	H & V Corrector Magnet Type C - Hor. coil	STFC (Daresbu
129	M4	H & V Corrector Magnet Type C - Hor. coil	STFC (Daresbu
130	M4	Magnet Power Supply	STFC (Daresbu
131	M4	Steerer Power Supply	STFC (Daresbu
132	M4	Steerer Power Supply	STFC (Daresbu
133	M4	Magnet Power Supply	STFC (Daresbu
134	M4	Magnet Power Supply	STFC (Daresbu
135	M4	Magnet Power Supply	STFC (Daresbu
136	M4	Steerer Power Supply	STFC (Daresbu
137	M4	Steerer Power Supply	STFC (Daresbu
138	M4	QUAD Type D	STFC (Daresbu
139	M4	QUAD Type D	STFC (Daresbury)
140	M4	QUAD Type D	STFC (Daresbury)
141	M4	H & V Corrector Magnet Type C - Vert. coil	STFC (Daresbury)
142	M4	H & V Corrector Magnet Type C - Vert. coil	STFC (Daresbury)
143	M4	Girder	STFC (Daresbury)
144	M4	Mechanical Support	STFC (Daresbury)
145	M4	DELL R220 EPICS Magnet IOC	STFC (Daresbury)
146	M4	C-band Accelerating Structure	STFC (Daresbury)
147	M4	RF loads for C1	STFC (Daresbury)
148	M4	Transverse Deflecting Cavity 1	STFC (Daresbury)
149	M4	Direction Coupler C band	STFC (Daresbury)
150	M4	RF pumping tee waveguide for C band	STFC (Daresbury)
151	M4	RF pumping tee waveguide for TDC01	STFC (Daresbury)
152	M4	RF waveguide elbow for C1	STFC (Daresbury)
153	M4	Dipole A Vacuum chamber 271-10278	STFC (Daresbury)

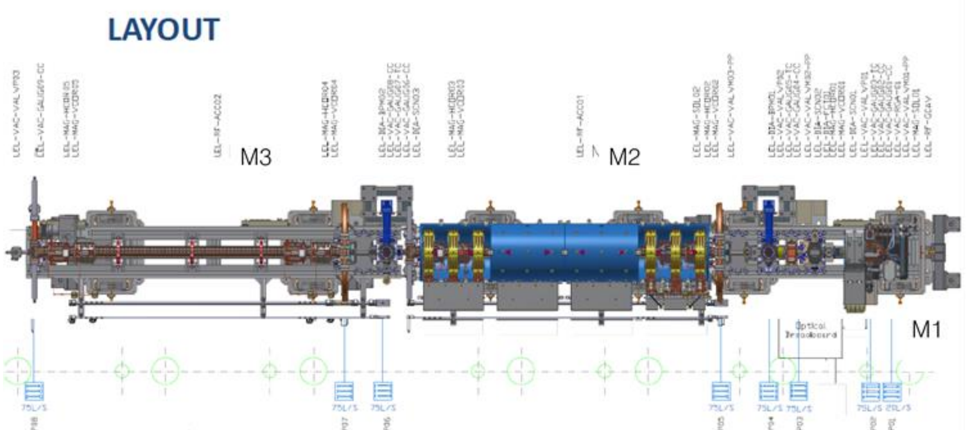
3/4

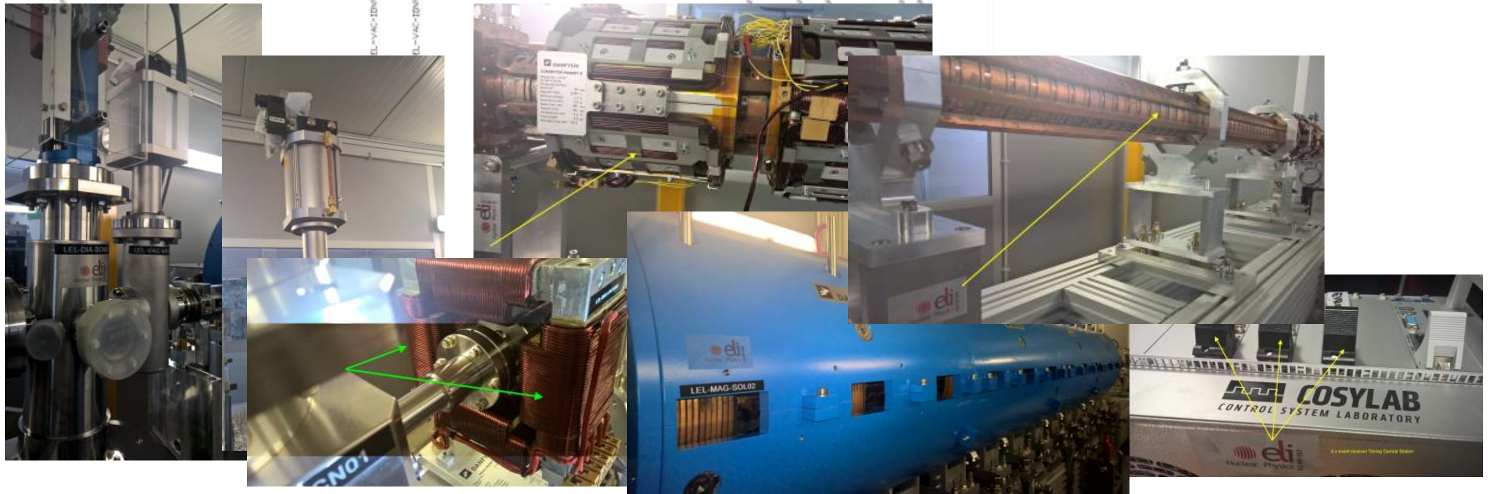
Acceptance of GBS devices/components

INFN, Frascati, Italy

Modules M1, M2, M3 (components mounted and aligned with laser tracker)

Every module is completed with horizontal and vertical steerers for beam position adjustment, beam position monitor system (BPM) and screens for beam profile analysis, vacuum elements, power supplies





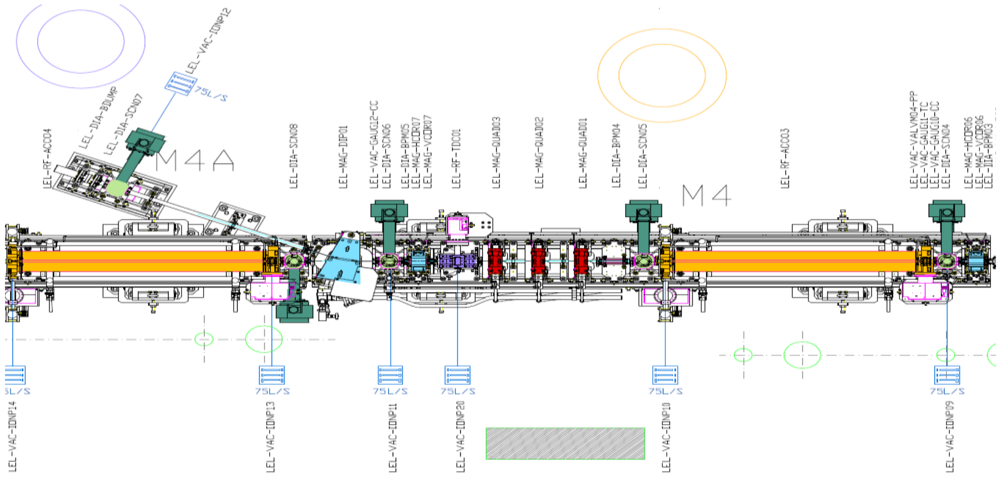
STFC, Daresbury, UK

Provided two modules M4 and M4A (mounted components and aligned with laser tracker)

M4 – C-band accelerating structure, 3x quadrupole magnets and a dipole magnet. M4A – beam dump.

Every module is completed with horizontal and vertical steerers for beam position adjustment, beam position monitor systems (BPM) and OTR screens for beam profile analysis, vacuum elements (gauges, ion pumps, manual an automatic valves), power supplies.

(Stage II – modules M5 to M8 were in advanced stage of mounting.)



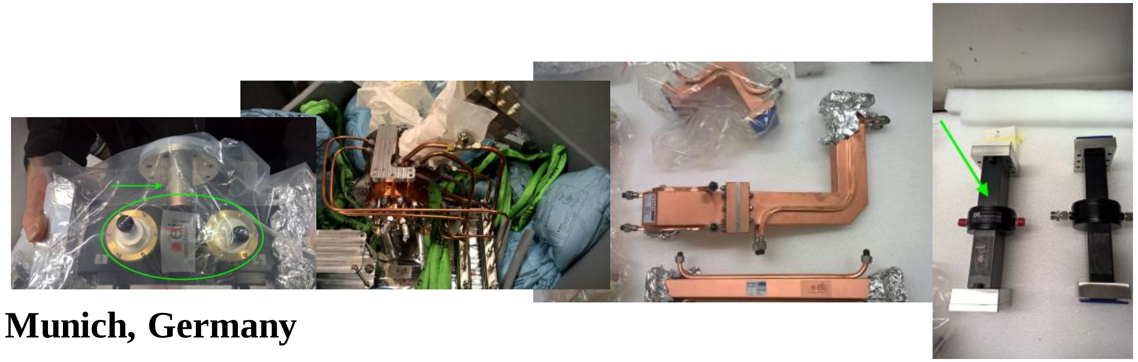
Acceptance of GBS devices/components

Scandinova, Uppsala, Sweden

- Modulators and klystrons – modulators MSB1, MSB2, MSB3, MCB1

Research Instruments, Bonn/Bergish Gladbach, Germany

- Power conditioning of S- and C-band accelerating structures, and photo-gun
- Photo-gun, S-band structures, RF waveguides, vacuum components, directional couplers, RF windows.
- RI will install RF components in the ELI-NP building,
- Takes care of the implementation of the network of reference points for the accelerator alignment in the ELI-NP building.

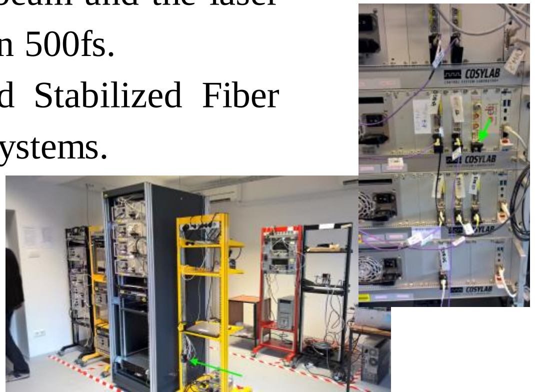


Menlo Systems, Munich, Germany

- Timing systems for synchronization at femtoseconds level
- Timing distribution needed to synchronize the electron beam and the laser pulses at the interaction point with an accuracy better than 500fs.
- The system is based on Optical Master Oscillator and Stabilized Fiber Links, ensuring the synchronization of the RF and laser systems.

Cosylab, Ljubljana, Slovenia

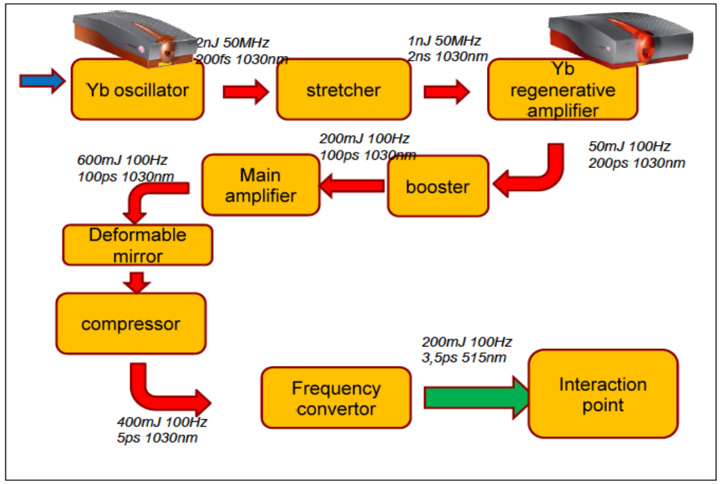
- Delivery of the software and hardware necessary to control the modules M1 to M4

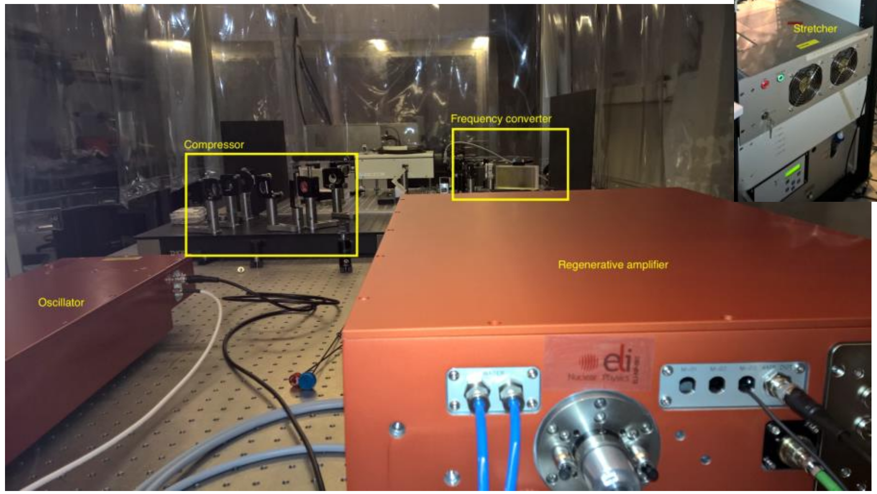


Acceptance of GBS devices/components

ACP Systems, Amplitude Systems, France

Interaction laser IP1 – delivery of configuration able to provide pulses of 100μJ at 100Hz repetition rate and 515nm wavelength.





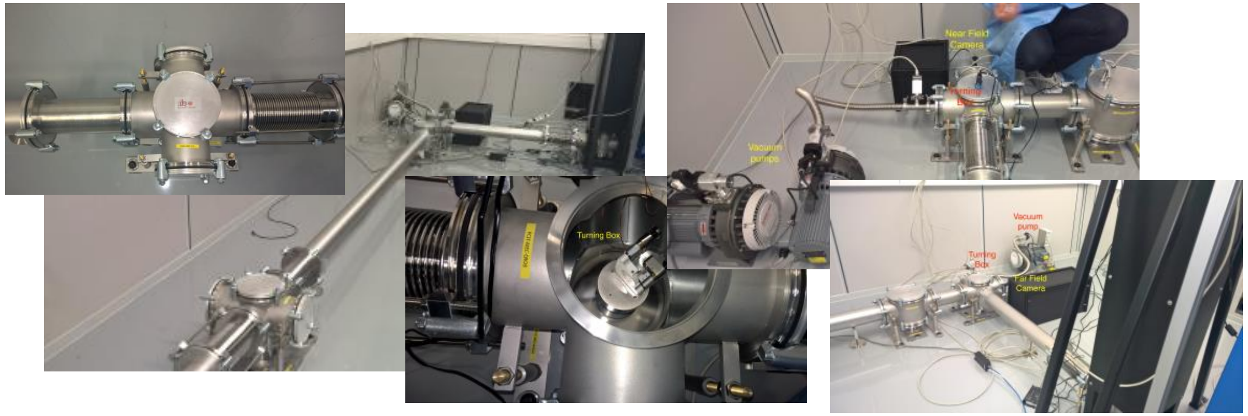
Amplitude Technologies, Lisses, France

Photocathode laser: stretcher, 100Hz regenerative amplifier, 100Hz multi-pass pre-amplifier, 2 x 100Hz multi-pass amplifiers, compressor, pump lasers.

Tests of module were successful being able to produce the 32 pulses separated at 16ns with an intensity fluctuations below 5%.

LAL CNRS, Orsay, France

Laser beam transport lines for photocathode laser and IP1.



Thank You for Your Attention

www.eli-np.ro

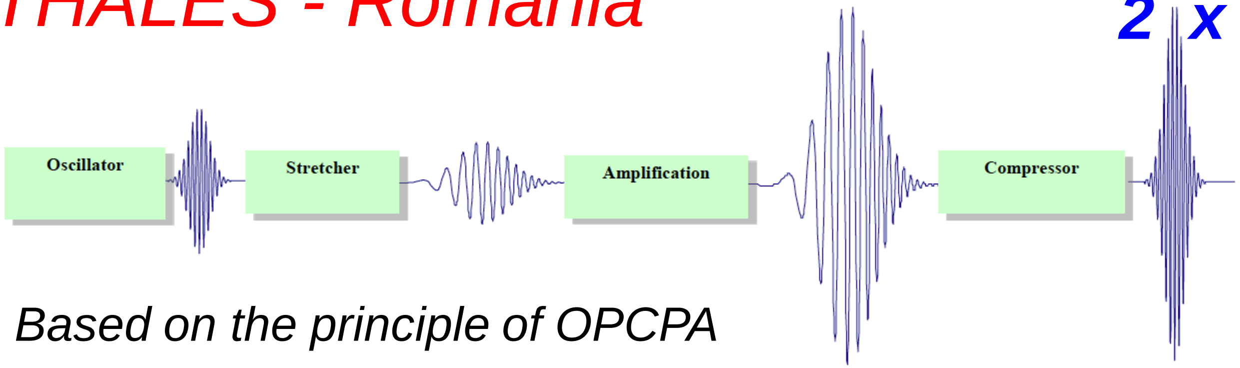
ELI–NP High Power Laser System

Nuclear Physics

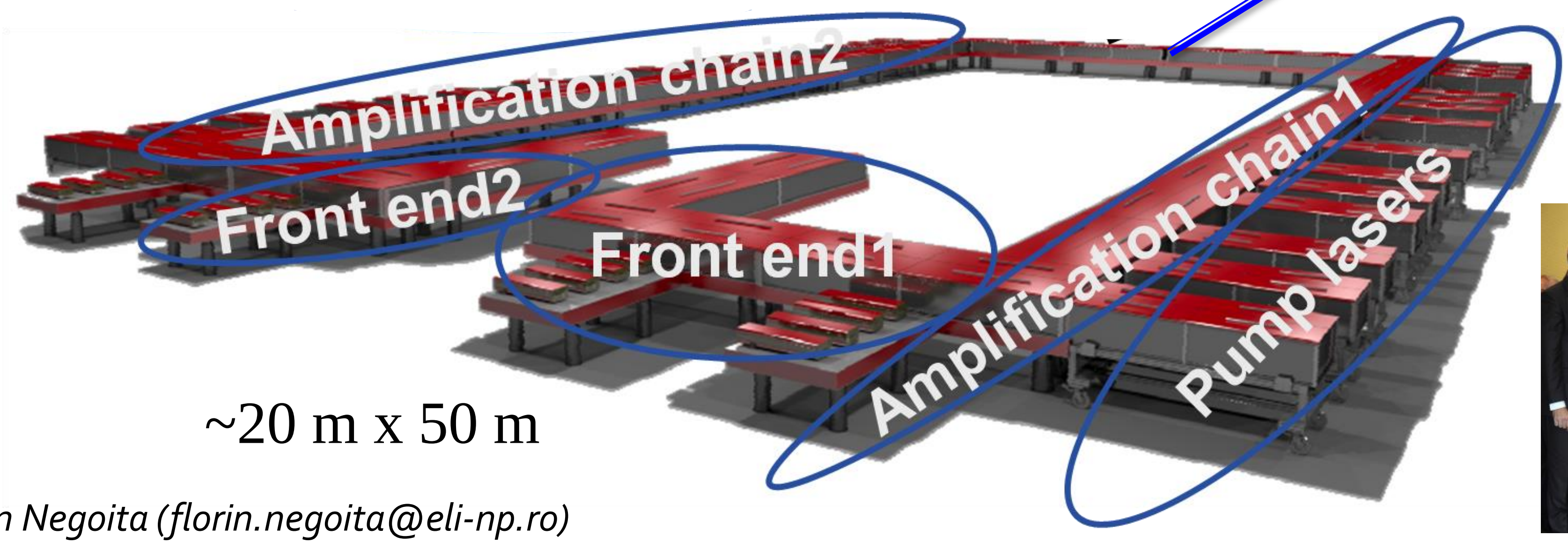
THALES – France
THALES - Romania

2013-2018

2 x 0.1 PW		**10Hz**
2 x 1 PW		**1 Hz**
2 x 10 PW		**0.1 Hz**

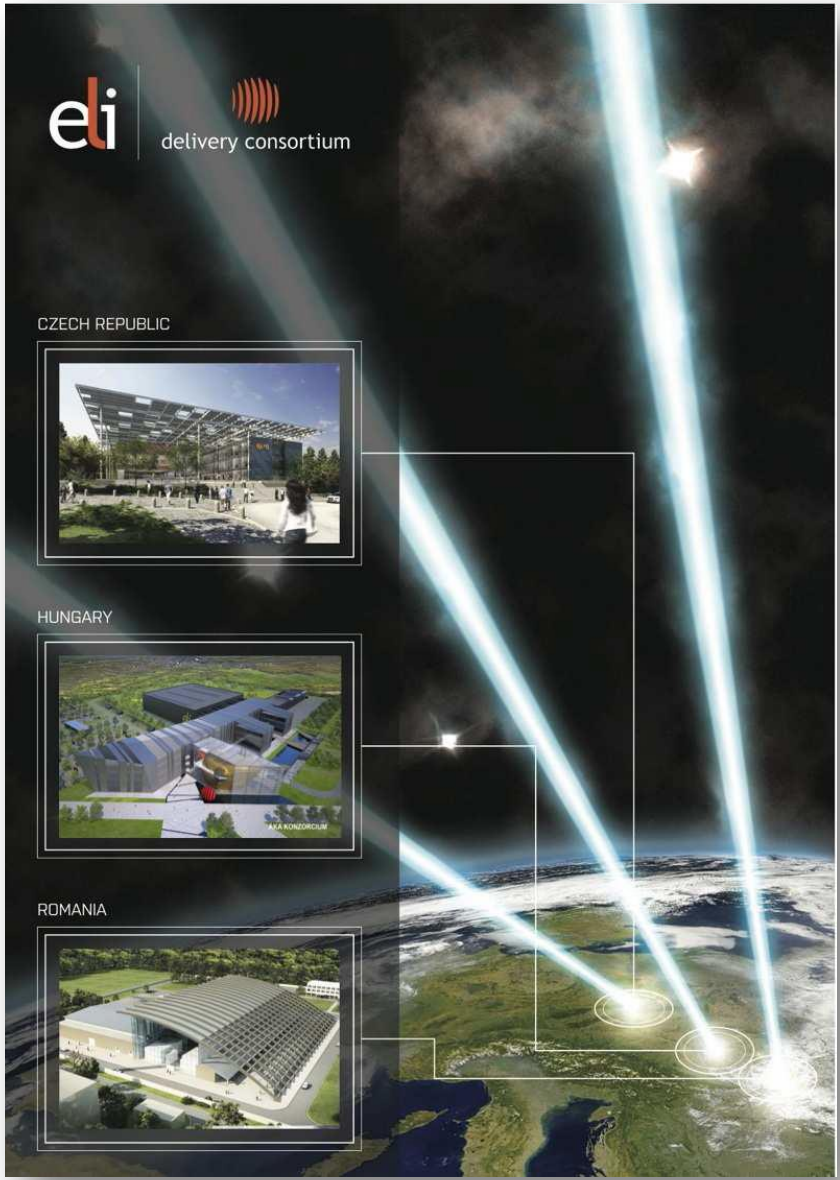


Based on the principle of OPCPA



Courtesy of Florin Negoita (florin.negoita@eli-np.ro)

Extreme Light Infrastructure (ELI)



the world’s first international laser research infrastructure

pan–European distributed research infrastructure based presently on 3 facilities in CZ, HU and RO

ELI–Beamlines, Prague, CZ

High–Energy Beam Facility

development and application of ultra–short pulses of high–energy particles and radiation

ELI–ALPS, Szeged, HU

Attosecond Laser Science Facility

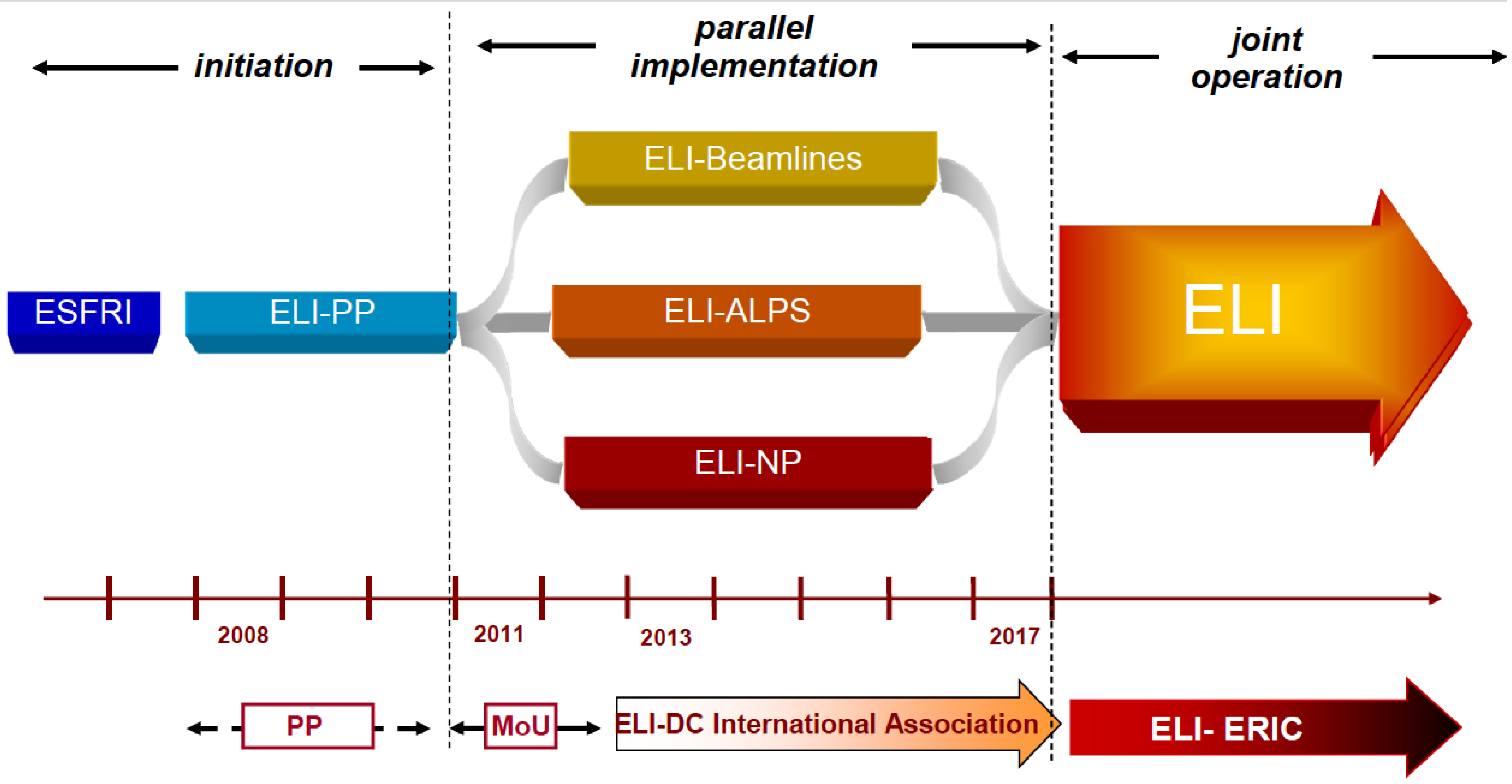
new regimes of time resolution

ELI–NP, Magurele, RO

Nuclear Physics Facility with ultra–intense laser and brilliant gamma beams (up to 20 MeV)

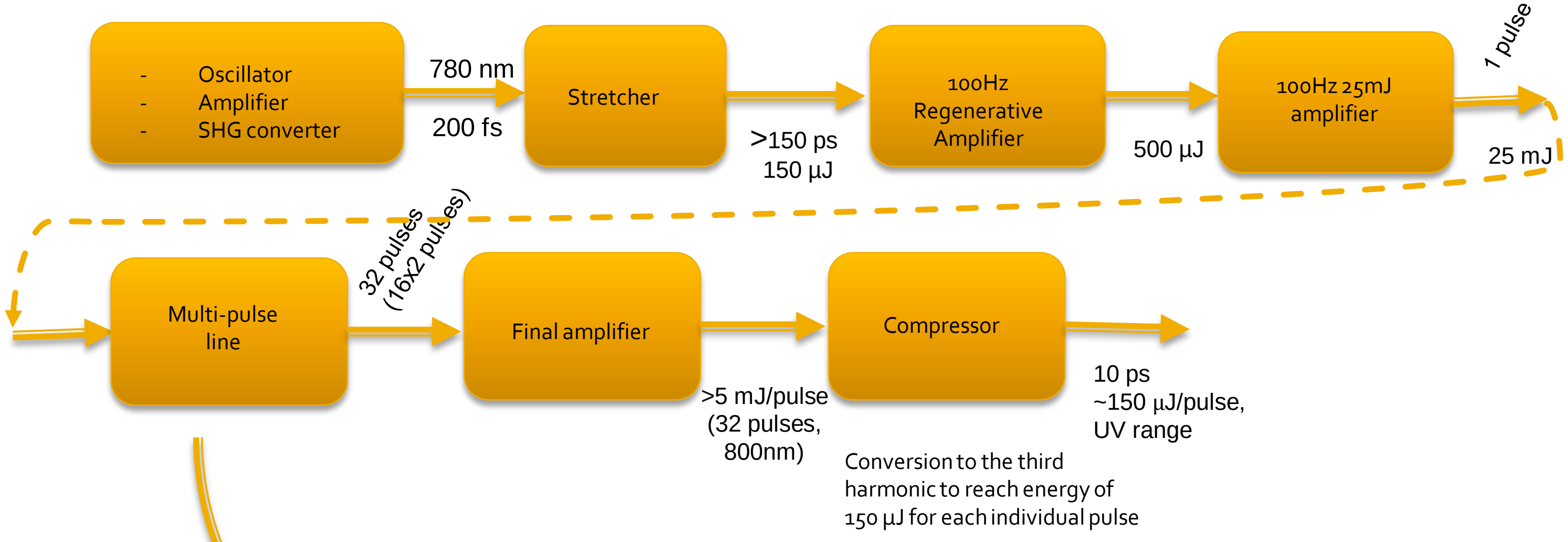
novel photonuclear studies

ELI Roadmap

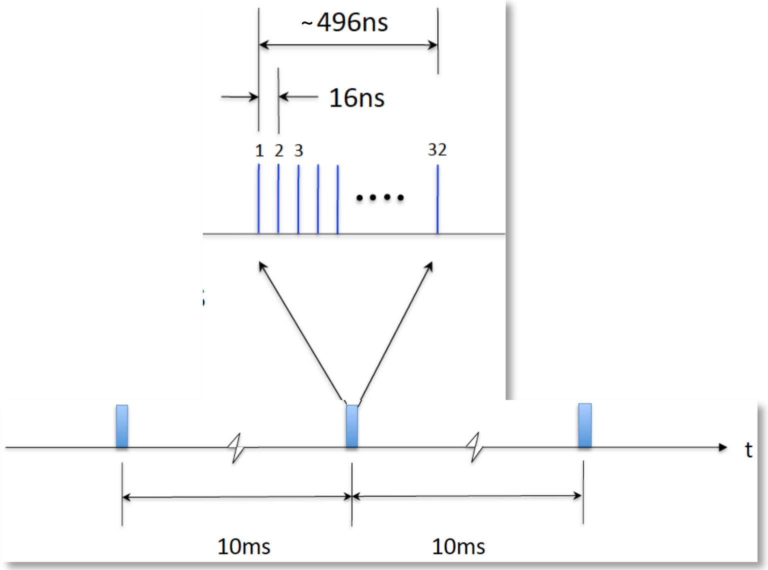


ELI Delivery Consortium

Photo-gun laser

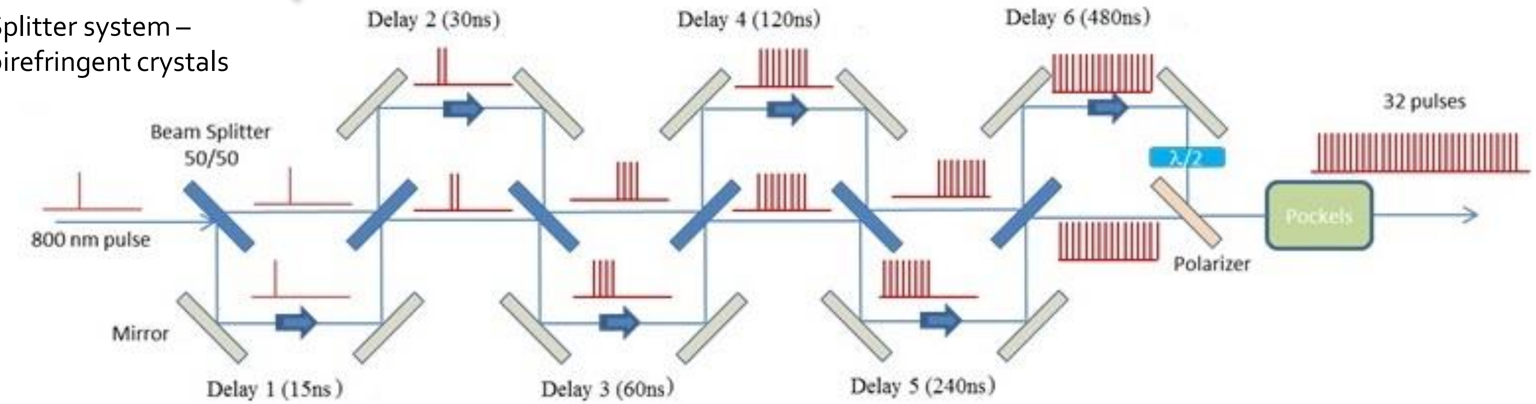


Time structure of the electron beam



producing 32 replica (before the last amplifier)

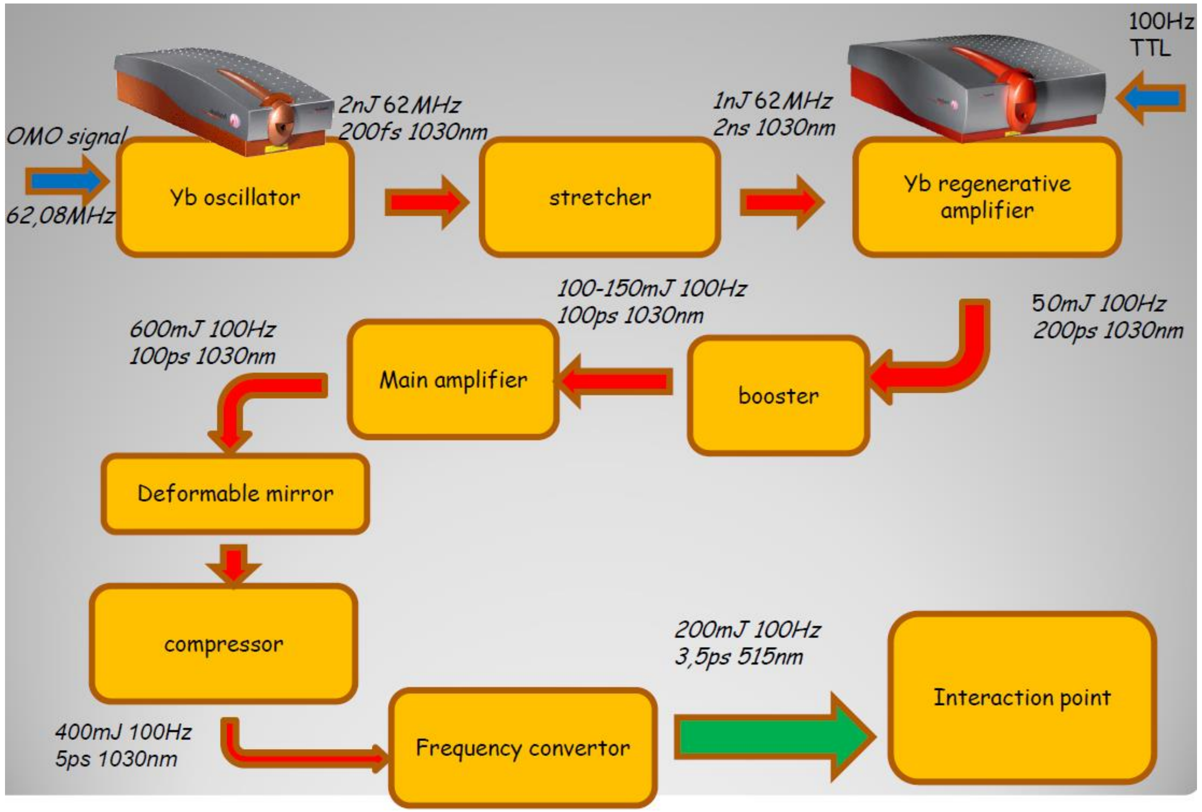
Splitter system – birefringent crystals



32 laser pulses separated by 16ns @ 100Hz repetition rate with ~10ps pulse duration

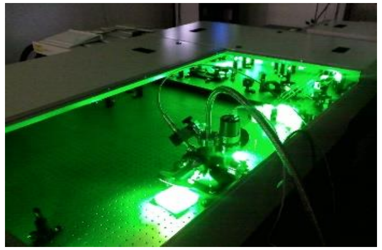
Interaction Points Lasers

Interaction Laser Architecture



Interaction Lasers: cryo–cooled Yb:YAG

	Low Energy Interaction	High Energy Interaction
Pulse Energy [J]	0.2	2 x 0.2
Wavelength [nm]	515	515
FWHM Pulse length [ps]	3.5	3.5
Repetition Rate [Hz]	100	100
M^2	≤ 1.2	≤ 1.2
Focal spot size w_o [µm]	28	28
Bandwidth [rms]	0.1%	0.1%
Pointing Stability [µrad]	1	1
Synchronization to external clock	< 1 ps	< 1ps
Pulse energy stability	1%	1%



Gamma Beam vs. Energy

Simulated gamma beams for different energies

Photon Energy [MeV]	2.00	3.45	9.87	19.5
# photons / shot within FWHM bdw.	$< 1.2 \cdot 10^5$	$< 1.1 \cdot 10^5$	$< 2.6 \cdot 10^5$	$< 2.5 \cdot 10^5$
# photons / sec within FWHM bdw.	$< 4.0 \cdot 10^8$	$< 3.7 \cdot 10^8$	$< 8.3 \cdot 10^8$	$< 8.1 \cdot 10^8$
Source rms size [μm]	12	11	11	10
Source rms divergence [μrad]	≤ 140	≤ 100	≤ 50	≤ 40
Pulse length (rms) [ps]	0.92	0.91	0.95	0.90

GBS Linac

High quality gamma beam -> requires high quality electron beam

- Low emittance, low energy spread, and high beam charge
- To increase the gamma flux we need to increase the number of collision per second.

100 Hz repetition rate

Multi bunch

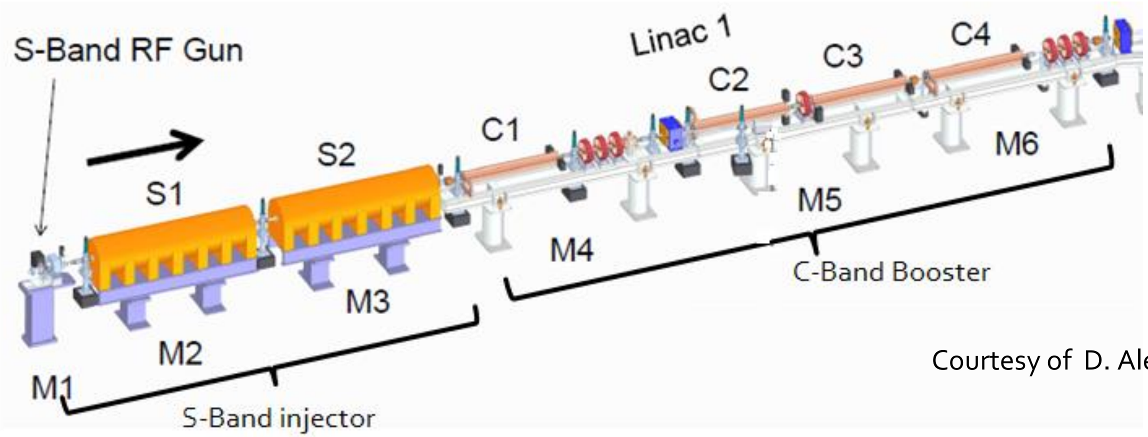
- Dumping of HOM dipole modes in RF structures to avoid BBU (beam break-up) instabilities
- Compensation of beam loading effects
- Accurate thermal design (high average dissipate power)

-> Waveguide dumping system with silicon-carbide (SiC) RF loads

-> amplitude modulation of the input RF power along the e^- beam train to reduce the energy spread

-> each structure has 14 water cooling channels for temperature stabilization; water flow of 66 litre /min

compact system → **High gradient** → **C-band linac combined with S-band Injector**



Courtesy of D. Alesini

Multi-bunch mode -> **wakefields** (both longitudinal and transverse components $\boldsymbol{F} \equiv \boldsymbol{F}_{||} + \boldsymbol{F}_{\perp}$) -> affect the longitudinal (changes energy) and transverse (deflects trajectory) beam dynamics.

Longitudinal components -> **beam loading effects ->** increase of energy spread and decrease of accelerating field gradient in the structure.

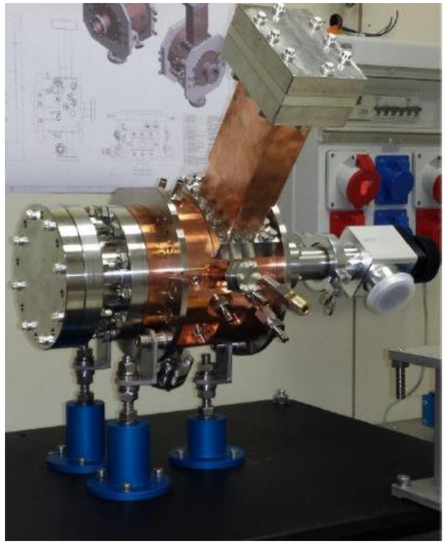
Transverse components (BBU) -> drive instability along the train generating the **HOM dipole modes**. (off-axis beam trajectories)

Electron Gun

Gun sector – module 1

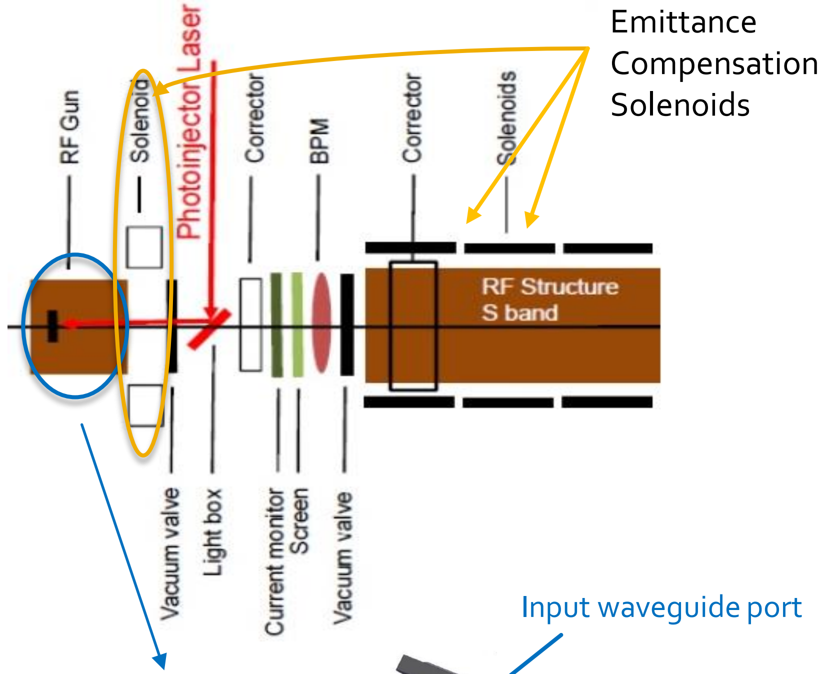
Laser-driven photocathode
1.6-cell standing-wave RF cavity, working in S-band at 2.856 GHz.

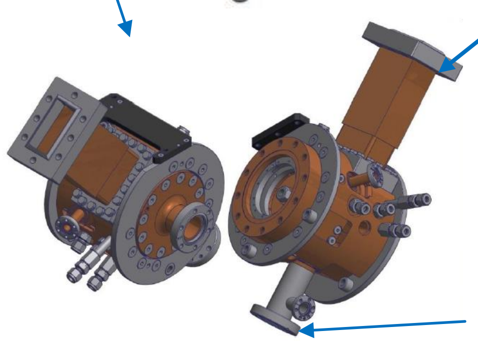
Photocathode – (oxygen-free high thermal conductivity) OFHC Copper



Ti:Sa laser –

output: UV range (266nm), 10ps, 150μJ/pulse, sequence of trains made of 32 pulses separated by 16ns @ 100Hz repetition rate.





high gradient: 120 MV/m;
100Hz

Photo-gun laser parameters at cathode:

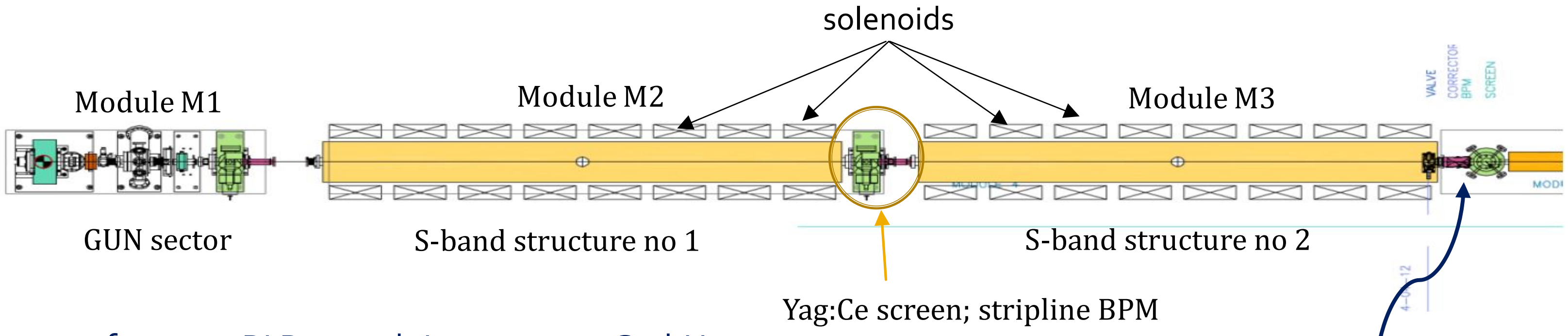
Laser pulse length (flat-top)	10 [ps]
Laser pulse rise/fall time FWHM	0,7 [ps]
Energy per pulse at 266 nm	150μJ
Laser spot size RMS radius on cathode	100-400 [μm]
Laser pulse energy jitter	2%
Time arrival jitter	<0.5 [ps]
Pointing jitter	<20 [μm]

Electron beam parameters:

Beam energy	5.7 [MeV]
Bunch charge	250 [pC]
Bunch length	~10 [ps]

S-band injector

S-band injector – 2 x Travelling Wave accelerating structures



manufacturer: RI Research Instruments GmbH

e^- beam energy: ~100 MeV
bunch length: ~1 ps (~300μm)
transverse normalized emittance ~0.4 μrad

S-band acc. structure parameters

Structure type	Constant gradient, TW
Working Frequency	2.856 [GHz]
Number Cells / Structure length	86 / 3m
Phase advance between cells	2π/3
Nominal RF input power / Average dissipated power	40 [MW] / ~3.5kW
Accelerating gradient	22 [MV/m]
Quality factor (Q)	13000
Shunt Impedance per unit length	55 [MΩ/m]
RF input pulse length	1.5 [μs]
Filling time	~850 [ns]

Long bunch at the photo-cathode -> to control the emittance growth due to space charge effects.
S-band injector – reduction of the bunch length by the velocity bunching technique.

Dual-symmetric feeding structures – minimization of the multipole effects generated by asymmetric feeding.

Beam loading effects - compensated with modulation of input RF power.
No evidence of HOM dipole modes in experimental measurements.

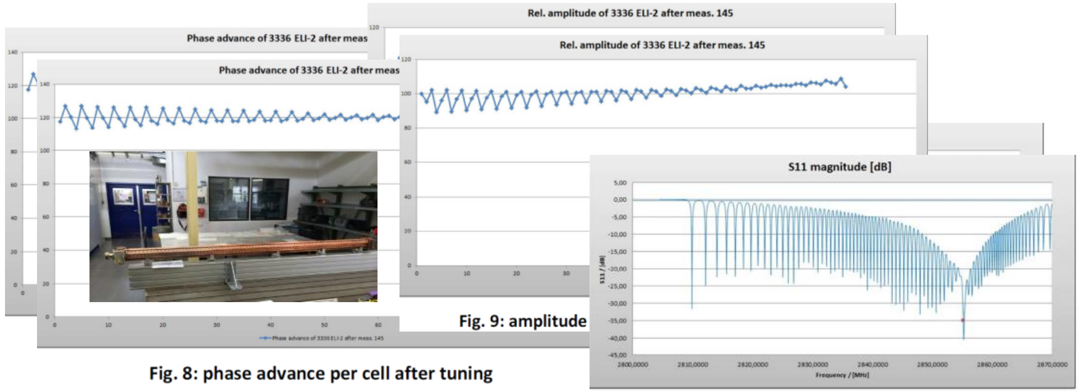


Fig. 8: phase advance per cell after tuning

Fig. 9: amplitude

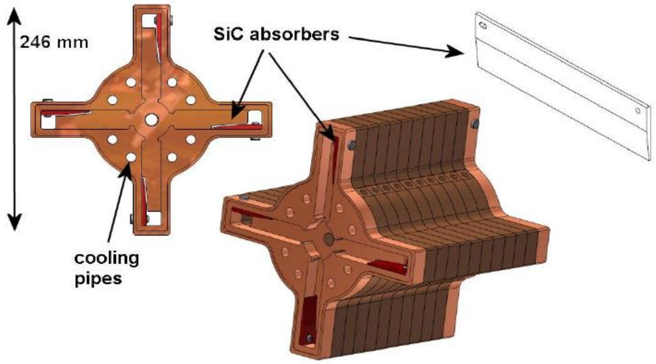
Fig. 10: reflection coefficient at the input port after tuning

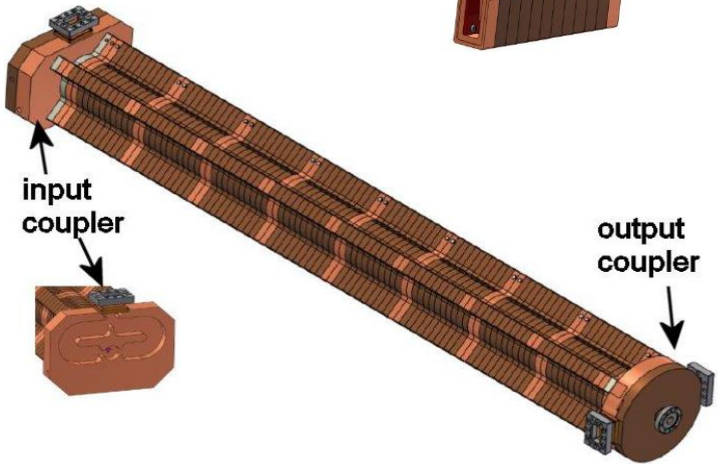
C-band LINAC

C-band linac – 12 x TW acc. structures

Effective damping of HOM dipoles modes

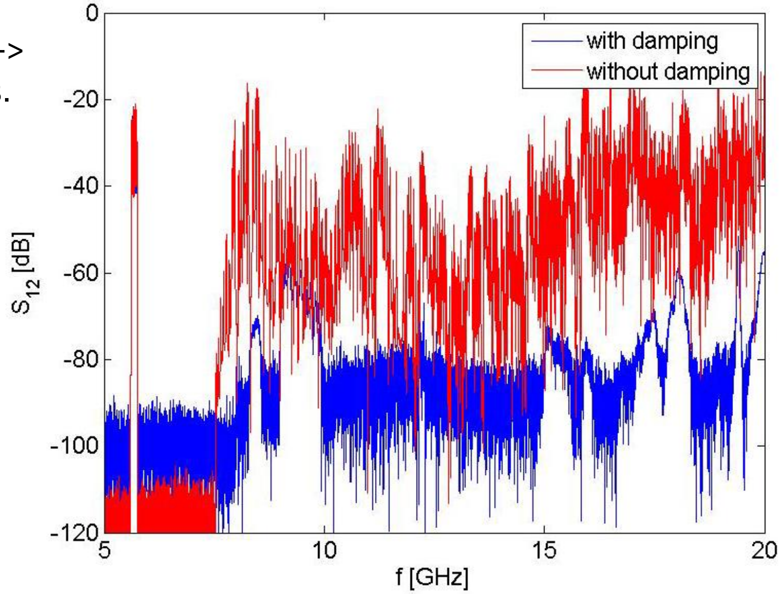
Waveguide dumping system - four waveguides in each cell -> excited dipole modes propagate and dissipate into RF loads.

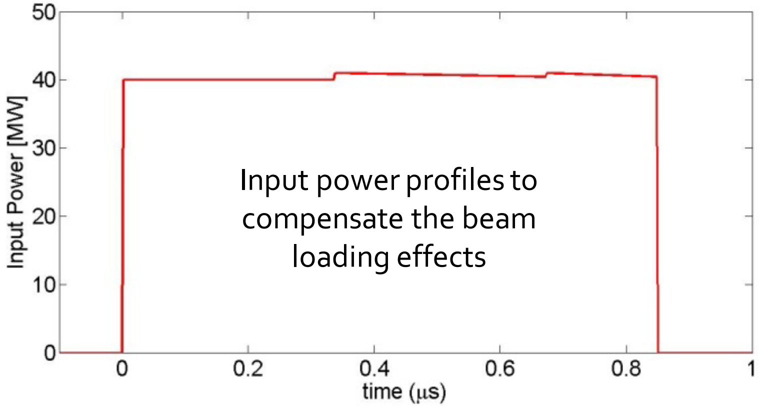




Dual-symmetric feeding structures

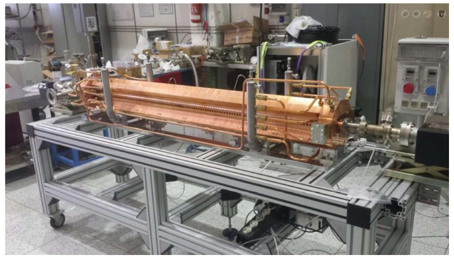
Transmission Coefficient





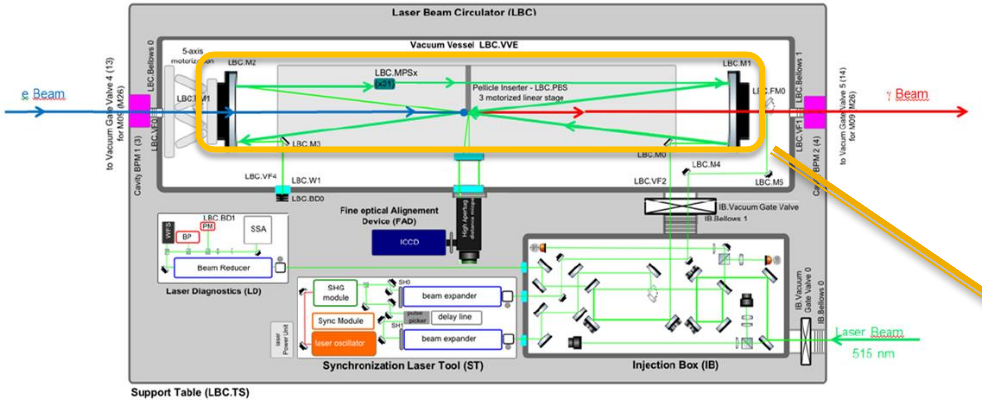
C-band acc. structure parameters

Structure type	Quasi-constant gradient, TW
Working Frequency	5.712 [GHz]
Number Cells / Structure length	102 + 1in + 1 out coupler / 1.8m
Phase advance between cells	2π/3
Nominal RF input power / Average dissipated power	40 [MW] / ~2.3kW
Average accelerating gradient	33 [MV/m]
Quality factor	8800
Shunt Impedance per unit length	74.5 [MΩ/m]
Max. RF input pulse length	0.8 [μs]
Filling time	310 [ns]
Working temperature	30 [°C]

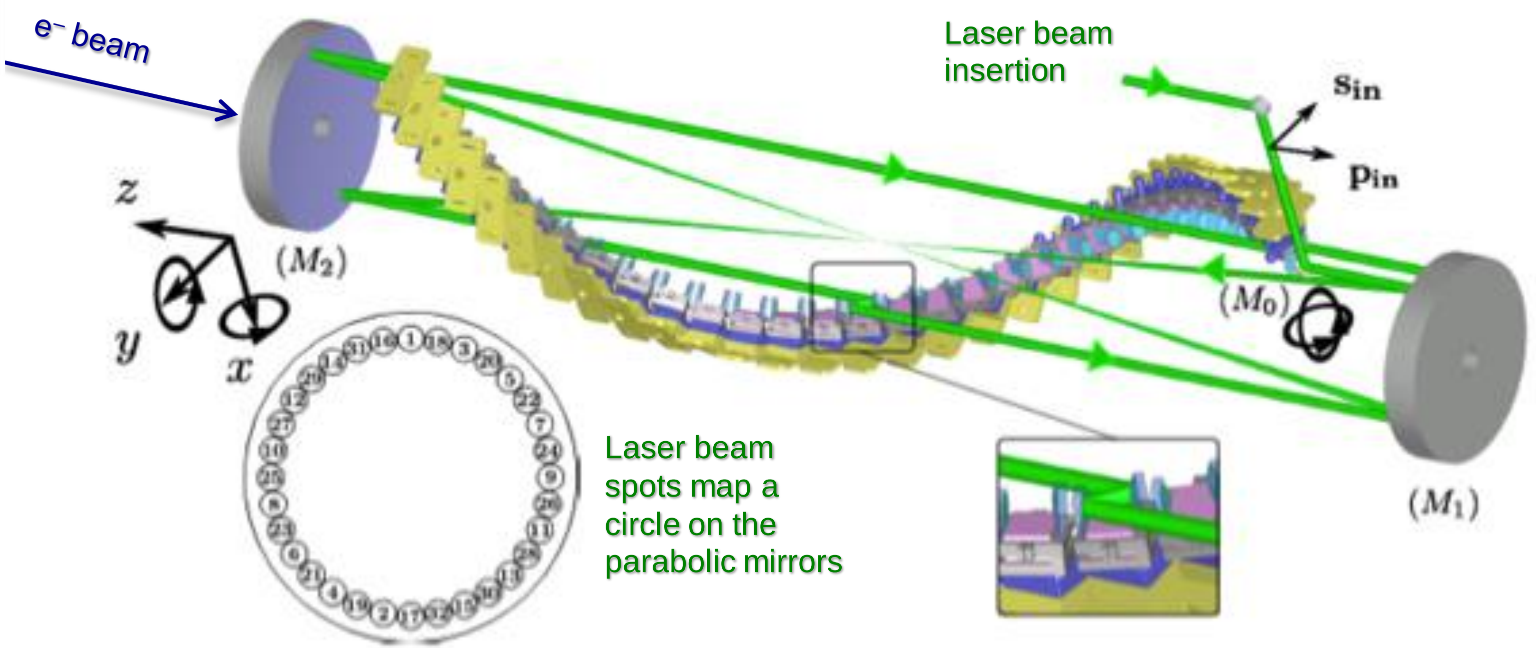


D.Alesini et al., *"Design and RF Test of Damped C-band Accelerating Structures for the ELI-NP Linac"* THPRI042, proceedings of IPAC2014, Dresden, Germany

Laser Recirculation at IP



'Dragon–shaped' Laser Recirculation



Provide 32 passes of an intense laser pulse @ 100 Hz

- Focusing the laser beam on the electron beam without optical aberrations
- Keeping a constant crossing angle between laser and electrons (7.5°)
- Synchronization to an ext. clock <1 ps
- Extreme mechanical precision –

  mirrors parallelism ≤10 μrad; mirrors

  alignment tolerance ≤10 μm
- High damage threshold optics, high level of cleanness and high vacuum required

K.Dupraz et al., Phys.Rev. STAB 17 (2014) 033501

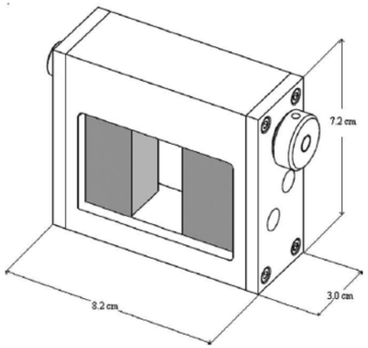
Gamma Beam Collimation and Diagnostics

Collimator System to obtain narrow bandwidth main requirements are:

- **Low transmission of gamma photons** (high density and atomic number)
- **Continuously adjustable aperture** (to adjust the energy bandwidth in the entire energy range)
- **Avoid contamination of the primary beam** with production of secondary radiation

Collimation aperture varies from 20mm to less than 1mm

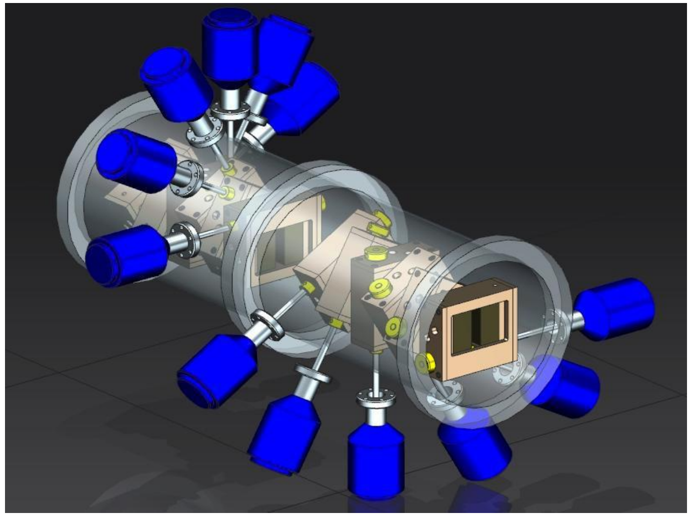
Tungsten slits – 20 mm thick

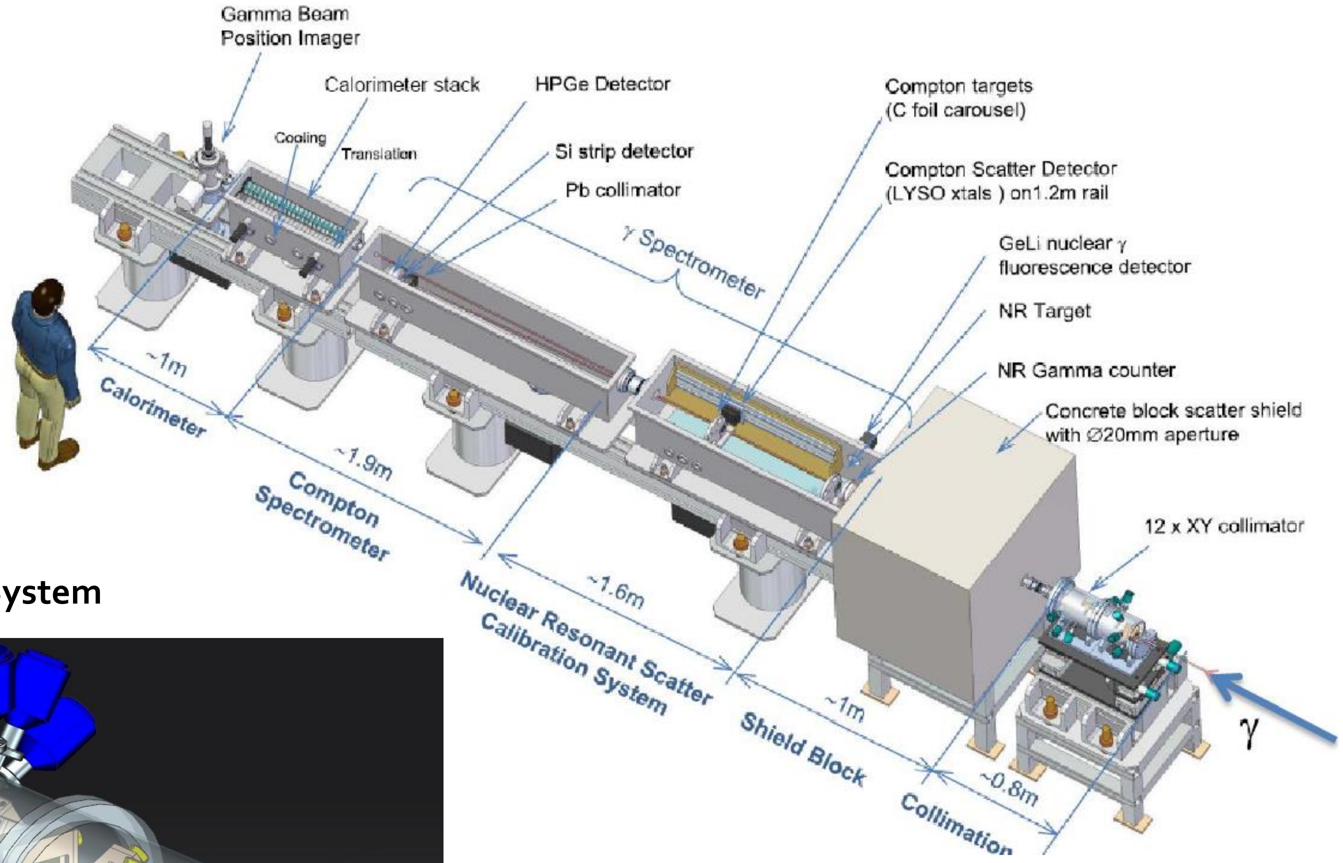


Low-energy configuration:
12 independent slits with 30º relative angle

High-energy configuration:
14 independent slits with 25.7º relative angle

Collimator System



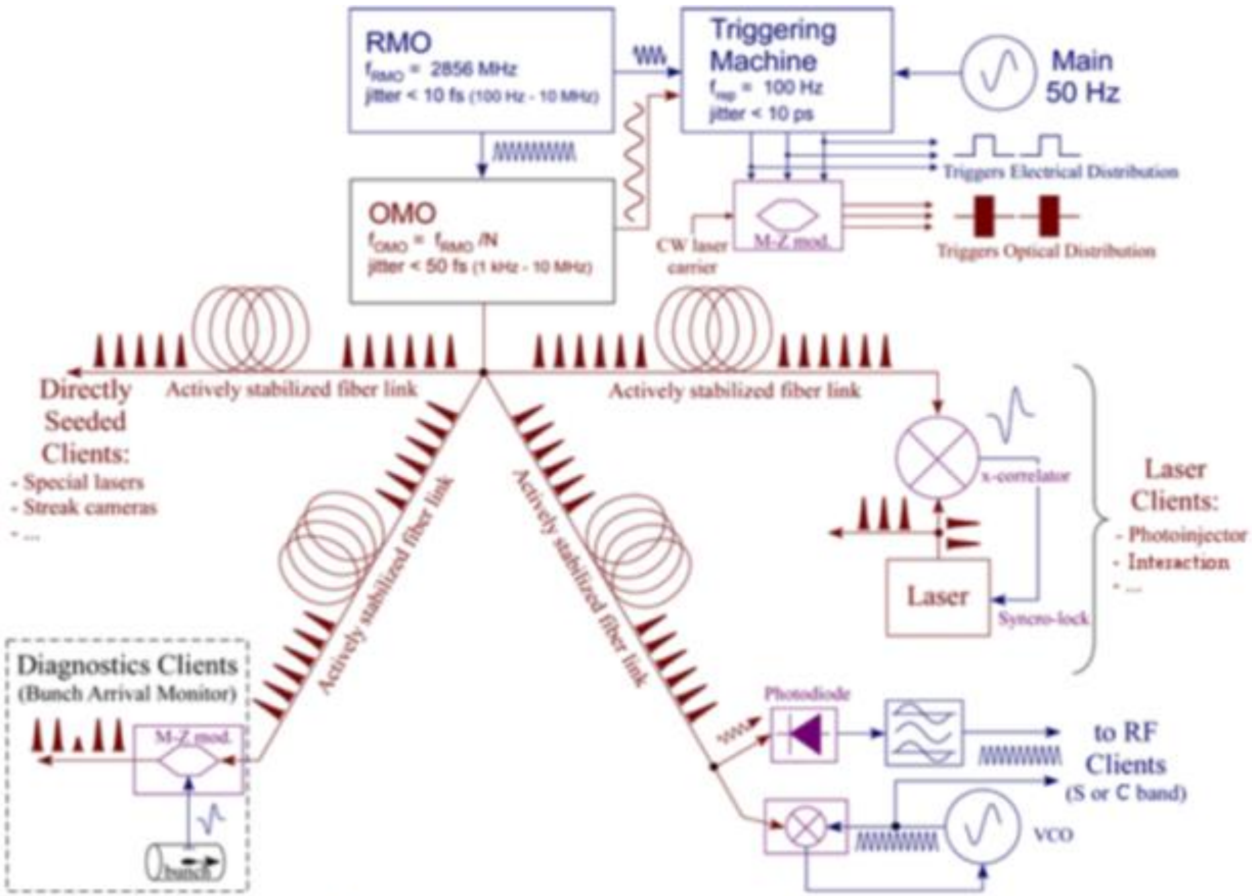


Gamma Beam Diagnostic System for:

γ Beam characterization

- energy, intensity, profile

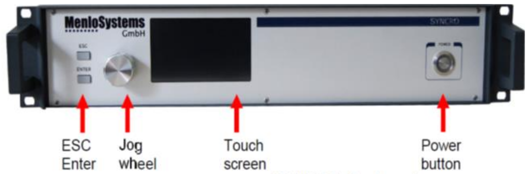
Timing and Synchronization System



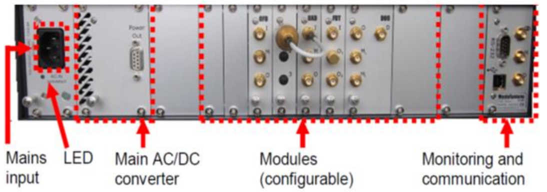
Timing and synchronization system layout

RMO - μ-wave crystal oscillator with ultra-low phase noise characteristics
OMO – highly stable fiber-laser oscillator that encodes the reference timing information in the repetition rate of short optical pulse in the IR spectrum
Ultra-stable reference signal will be distributed to the clients through actively stabilized links. The stability of each link is ≈70fs over any time scale.
Each individual clients will be locked to the local reference provided by the timing distribution systems. MENLO

Together with a continuous reference signal, low repetition rate trigger signals must be provided to some clients, which contain essentially the information on the timing of the macro pulses needed to prepare all the systems to produce and monitor the bunches and the radiation pulses (laser amplification pumps, klystron HV, bema diagnostics,….) The triggering system is a coarser timing line (≈10ps stability, that can be distributed either optically or electrically.
COSYLAB (MRF)



SYNCRO's front panel



SYNCRO's rear panel

Timing and Synchronization System

Laser systems synchronization

The reference signal is generated by an optical master oscillator (OMO) and transmitted to the end users by a stabilized fibre optic link.

The phase error is measured by optical mixing (cross-correlator). One pulse from the laser oscillator and one from the OMO overlap. The measured phase noise error is used to drive actuator to active control the oscillator’s cavity length -> high frequency piezo-electric transducer (PZT) is associated to a lower frequency stepper motor driven optical delay line.

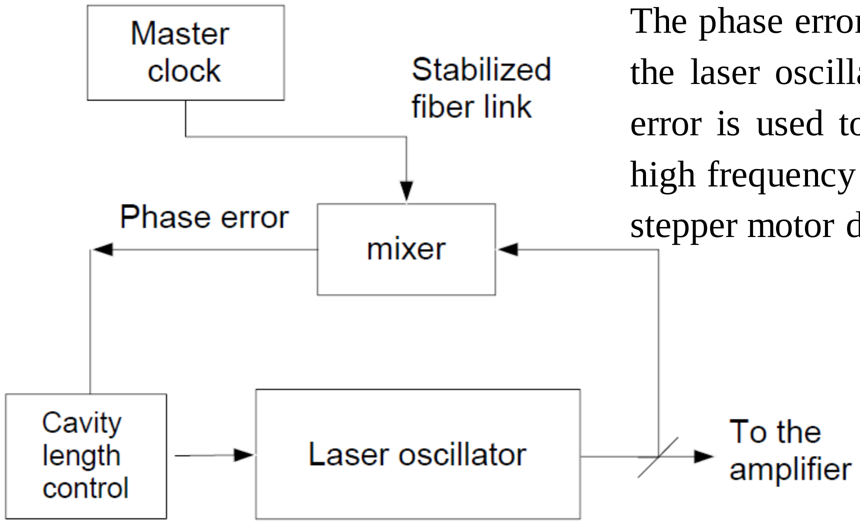


Fig. 102. Schematic of the laser oscillator phase locked loop

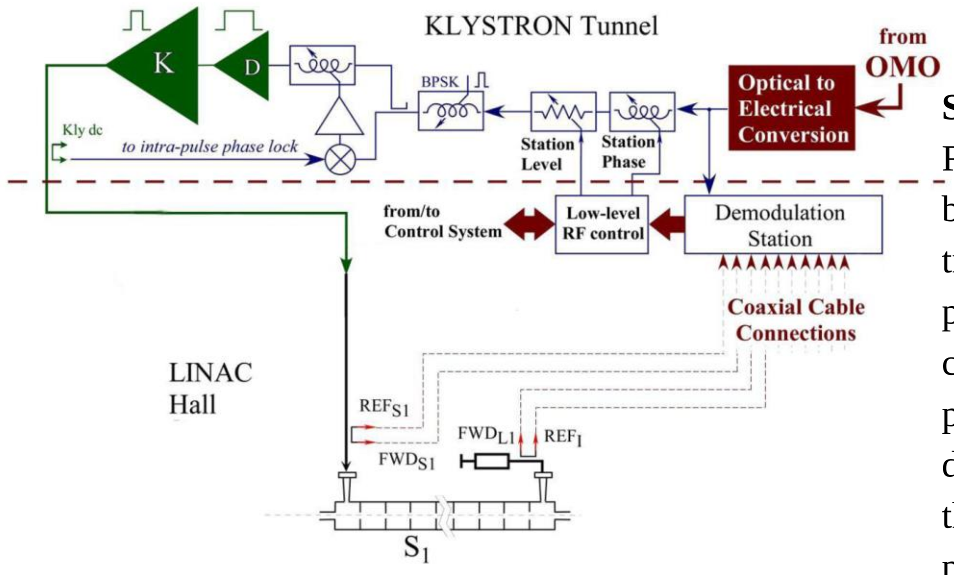


Fig. 104. Sketch of the ELI-NP single power station

Synchronization of the RF clients

RF driving signal for all power sources will be locally extracted from the OMO reference transported to each station by stabilized phase links. The optical to electrical conversion will be accomplished by photodiodes. The same reference is used to demodulate various RF pulses sampled over the network, and the whole station is re-phased in real time on the base of the measured values.

ELI–NP Nuclear Physics Research

Research Activities

- HPLS
- GBS
- Experiments with HPLS
- Experiments with GBS
- Combined experiments

Experiments with HPLS

1. Laser–driven nuclear physics

2. Strong field QED

2. Irradiated materials sciences

Experiments with GBS

1. Nuclear Physics experiments

- Nuclear Resonance Fluorescence Experiments

- Photo-fission & Exotic Nuclei

- Photo-disintegration and Nuclear Astrophysics (γ,n) experiments; (γ,p) experiments

2. Positron source for material science

3. Applications based on very brilliant γ beams

- Nuclear materials and radioactive waste management *(isotope-specific identification; scan containers for nuclear materials and explosives)*

- Food contamination

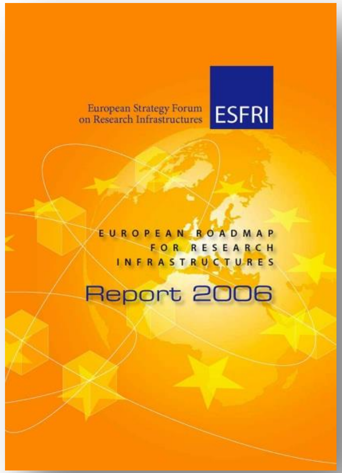
- Radioscopy and tomography *(new methods for producing medical radioisotopes for diagnostic medical imaging and radiotherapy)*

Combined experiments

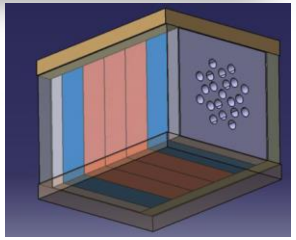
1. Probing the Pair Creation from the Vacuum in the Focus of Strong Electrical Fields with a High Energy γ Beam

2. The Real Part of the Index of Refraction of the Vacuum in High Fields: Vacuum Birefringence

3. Cascades of e^+e^- Pairs and γ – Rays triggered by a Single Slow Electron in Strong Fields



Si DSSSD



4PIN – neutron ^{3}He counter array