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

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

Piotr Tracz
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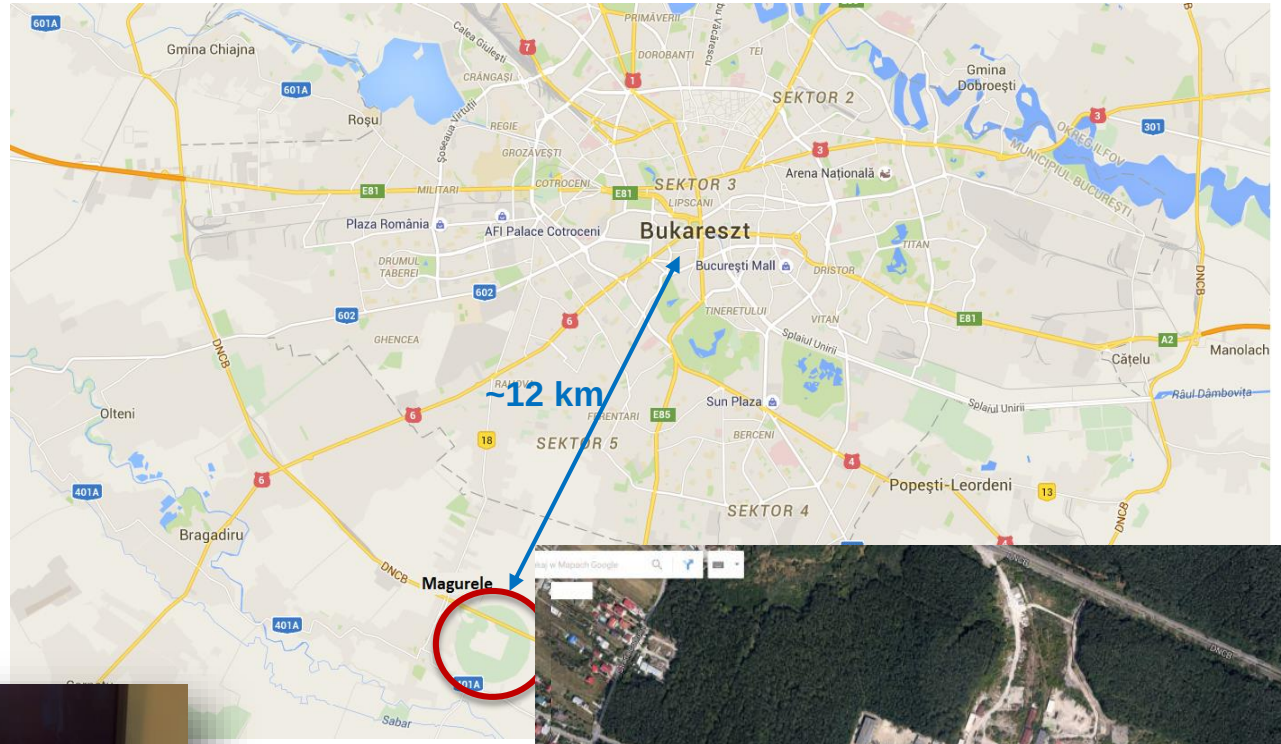
For the ELI-NP team

ELI-NP Gamma Beam System

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),

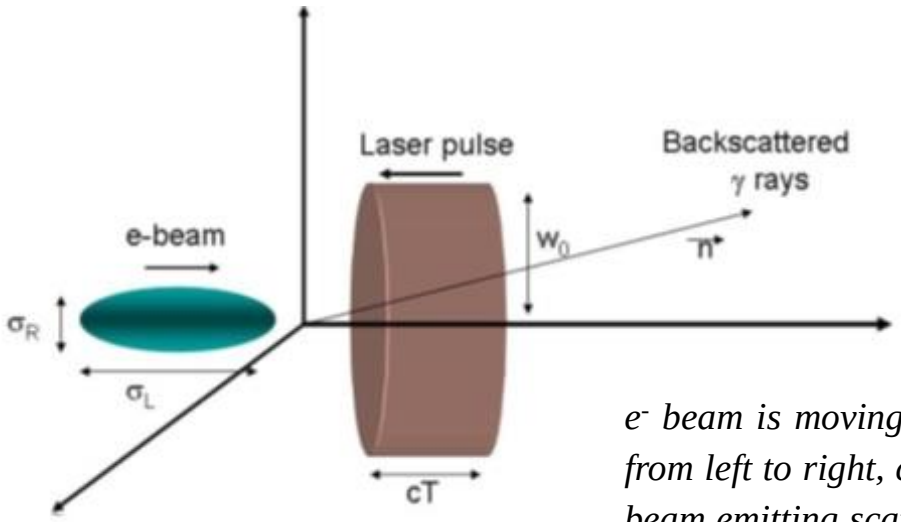


Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH)

Gamma Beam System – Basic Concept

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

Compton backscattering geometry



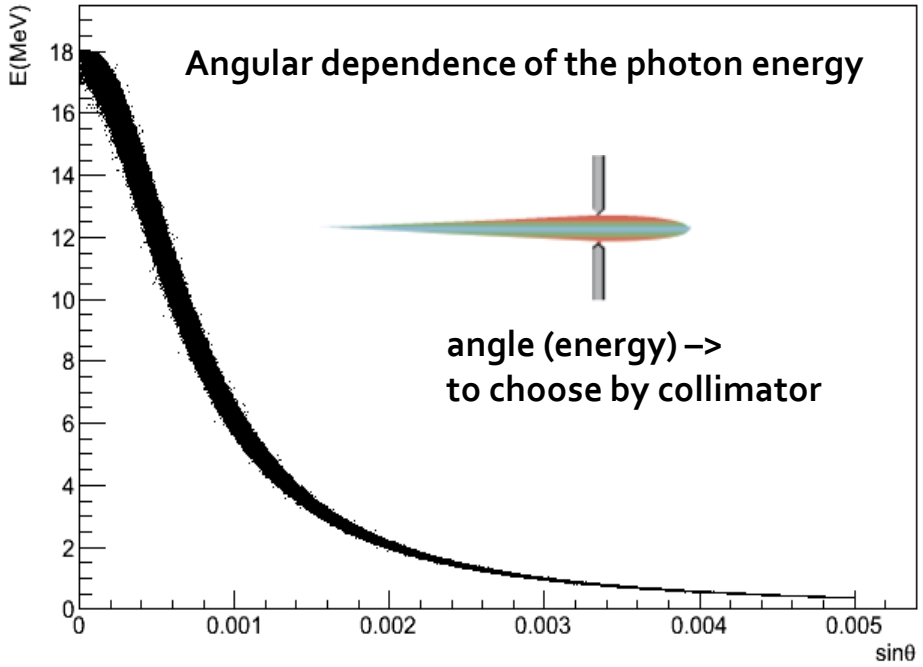
e^- beam is moving at a relativistic speed from left to right, colliding with a photon beam emitting scattered radiation mainly in the direction of motion of the e^- beam.

Laser pulse (*3.5ps*) energy:

0.2J
$(2.4eV, 515nm$ – green)
2 x 0.2J

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

$E_e \sim 720\ MeV$ ⇒ $E_\gamma \leq 19\ MeV$ (High Energy Branch)



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

Gamma Beam System – Basic Concept

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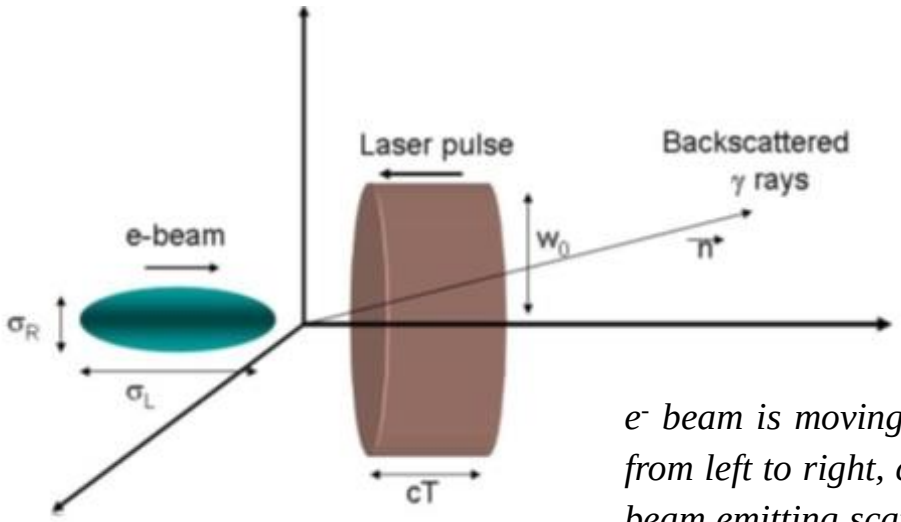

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Low cross section (~ 10^{-25} cm^2)
→ need of high density of electron and photon beams

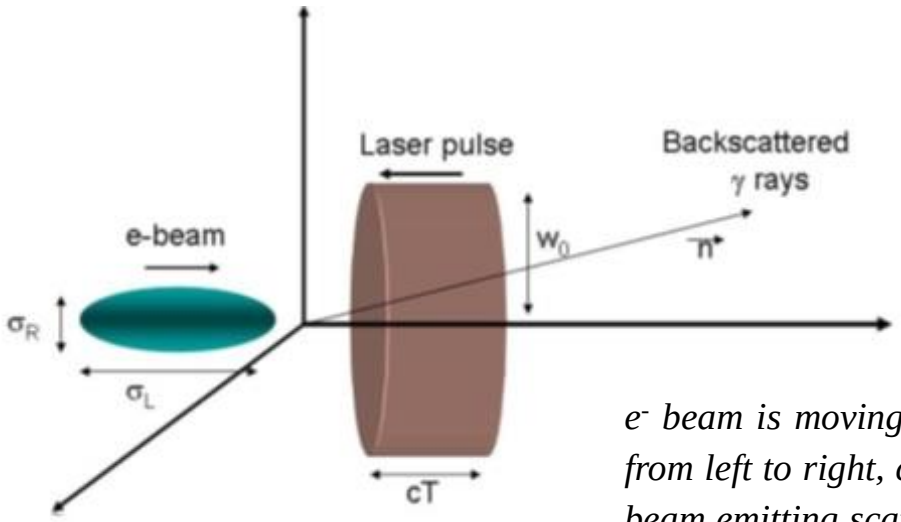
Result:
generation of high brilliance γ-ray beam with number of advantages over the more conventional bremsstrahlung sources, which are based on impinging the electron beam onto a solid target of high Z material:

- 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



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Branch)

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%)	$10^{20} \div 10^{23}$
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

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

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.

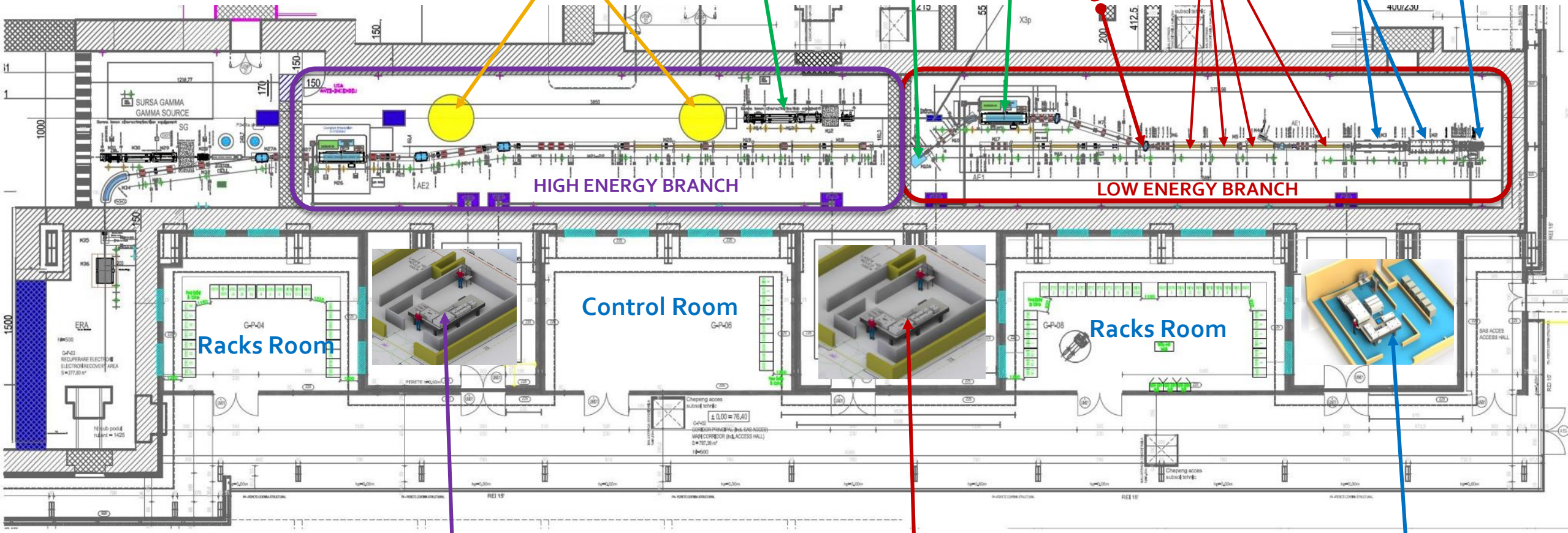
b) laser beam of high intensity, very brilliant, high repetition rate.

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



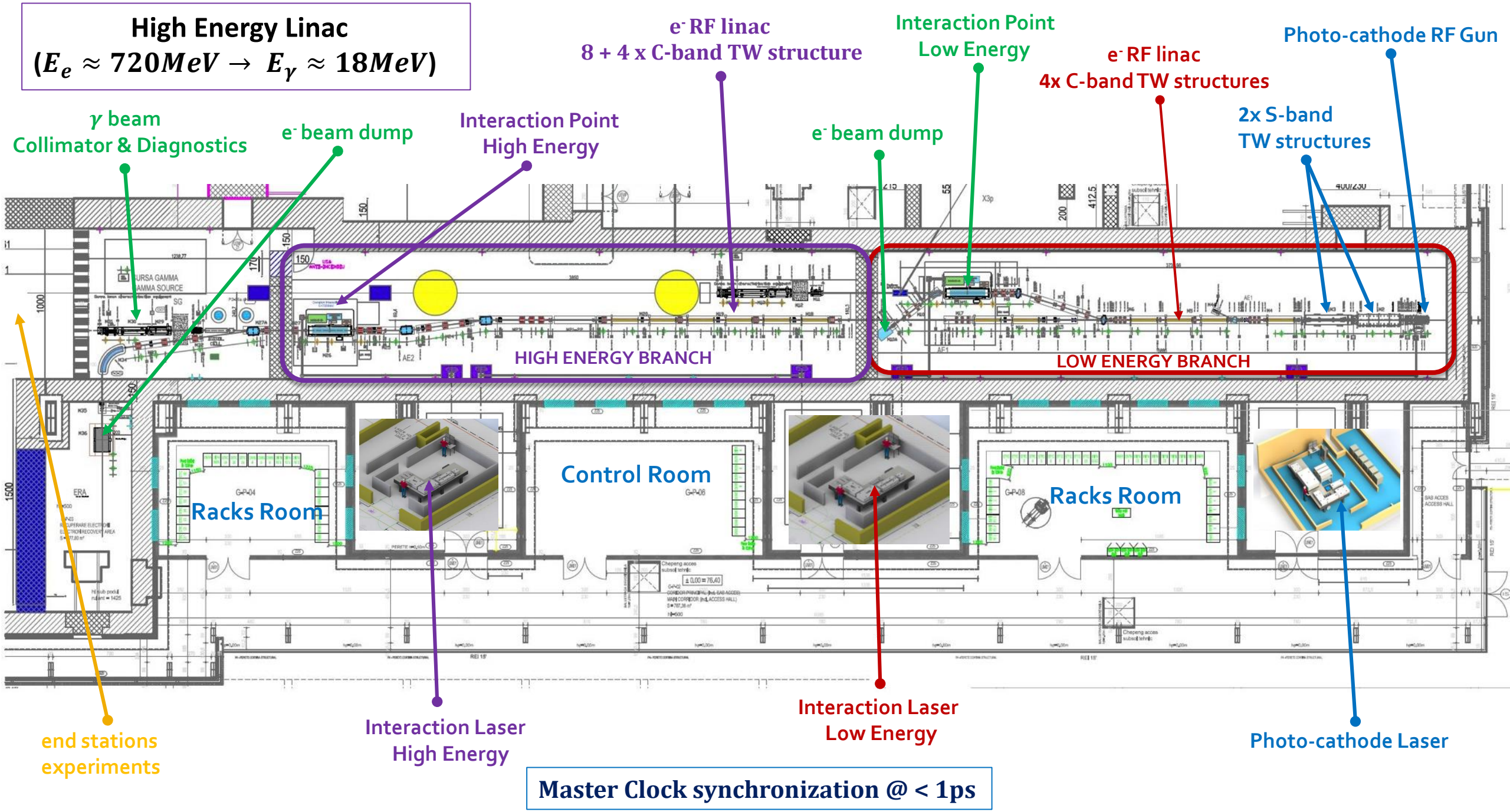
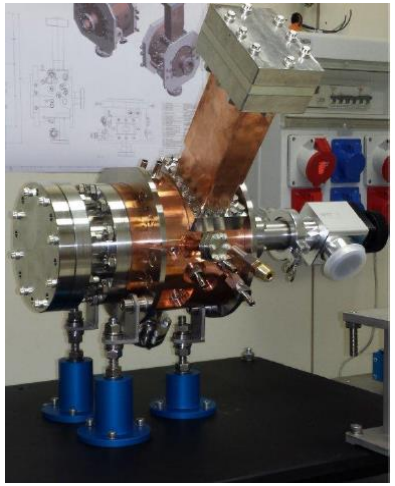

High Energy Linac
$(E_e \approx 720MeV \rightarrow E_\gamma \approx 18MeV)$
γ beam
Collimator & Diagnostics
e- beam dump
Interaction Point
High Energy
e- RF linac
8 + 4 x C-band TW structure
Interaction Point
Low Energy
e- beam dump
e- RF linac
4x C-band TW structures
2x S-band
TW structures
Photo-cathode RF Gun
HIGH ENERGY BRANCH
LOW ENERGY BRANCH
Racks Room
Control Room
Racks Room
end stations
experiments
Interaction Laser
High Energy
Interaction Laser
Low Energy
Photo-cathode Laser
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

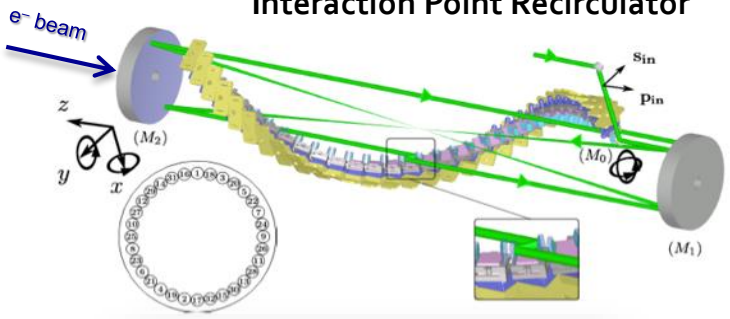
Dual-symmetric feeding – min. of multipole effects.
Long bunch at the photo-cathode (10ps) => to control the emittance growth due to space charge effects.
S-band injector – reduction of the bunch length (1ps) by the velocity bunching technique.

C-band linac – 12 x TW acc. structures

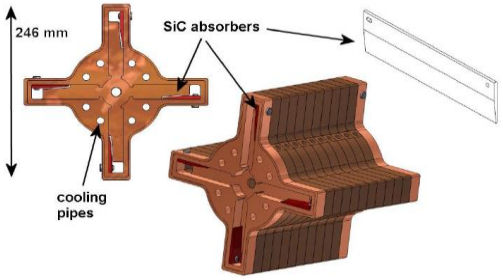
Effective damping of HOM dipole modes

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

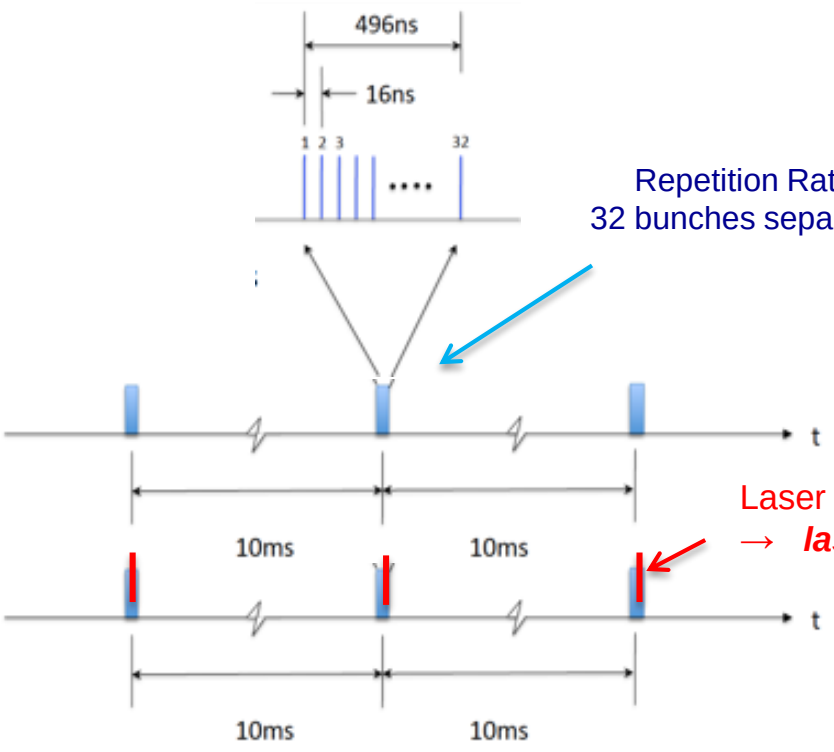
Interaction Point Recirculator



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***

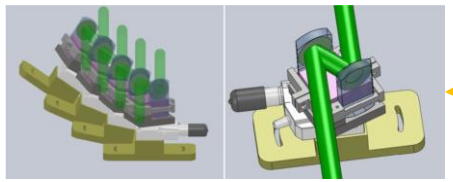
Laser Recirculator -> Single laser pulse is recirculated 32 times, synchronized with RF clock.

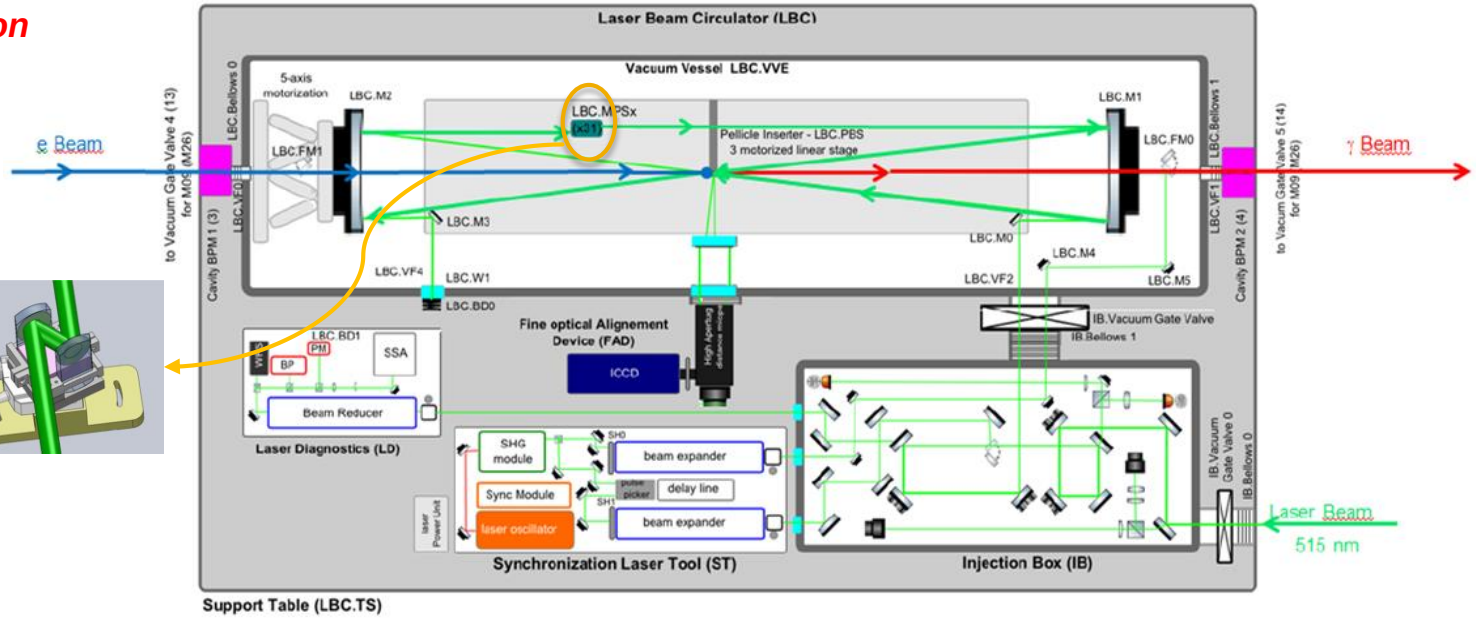
The laser beam is reflected and focused to the Interaction Point (IP) with the parabolic mirrors (sharing the same focal point.).

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

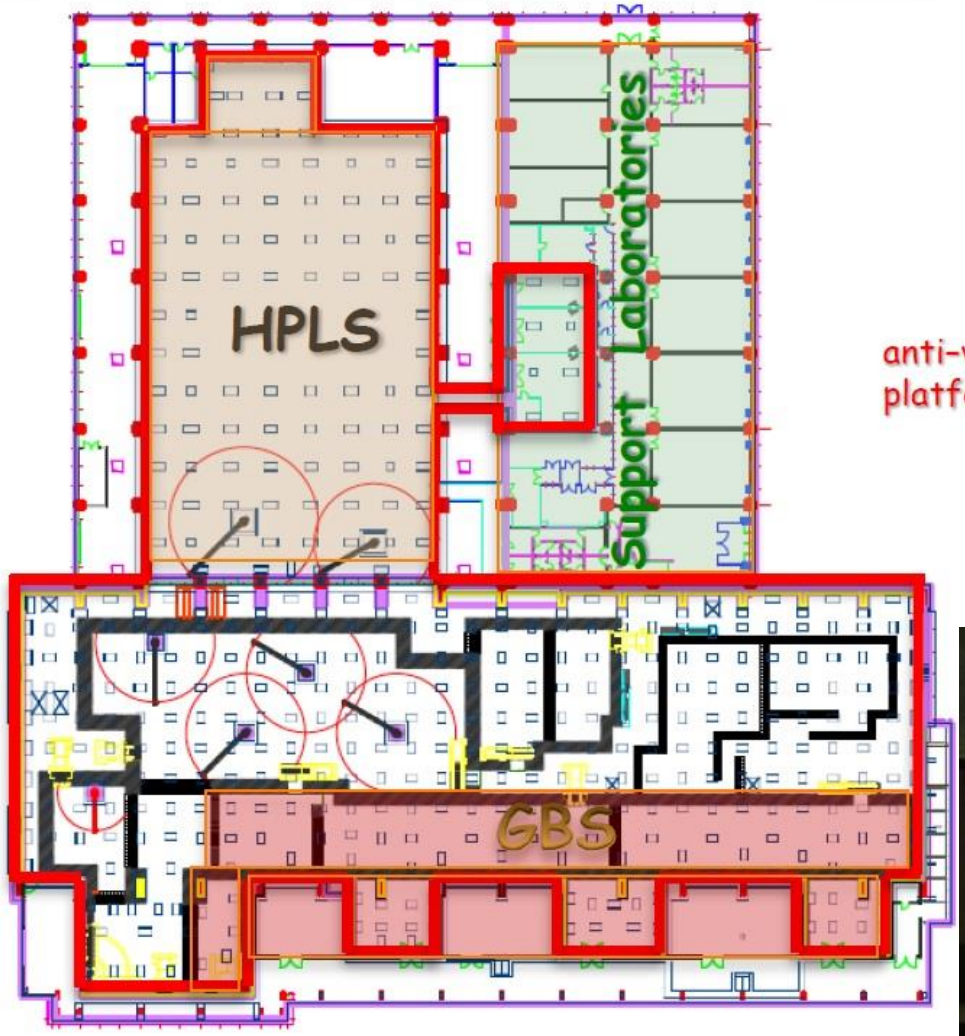


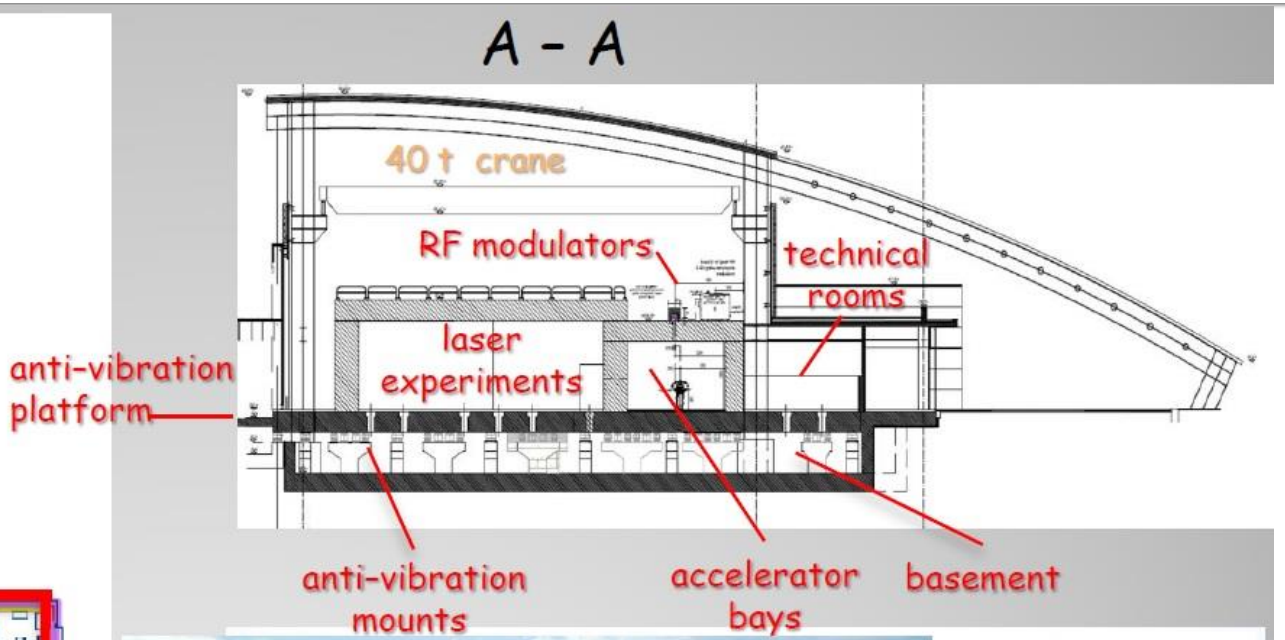


Laser Recirculator:

- Highly complex optical implementation

ELI–NP Facility Concept





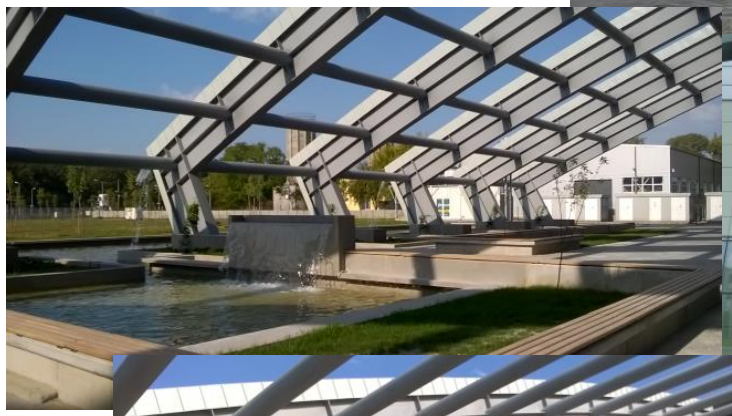
ELI -NP Main Experimental Building ~ 15,000 m

ELI–NP Facility

July-August 2016

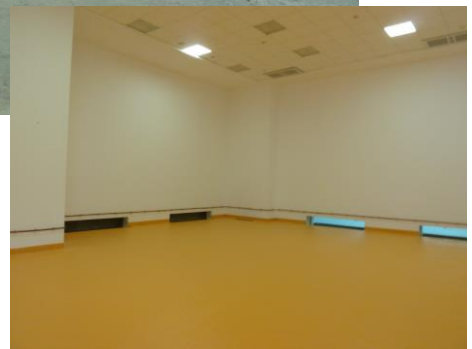






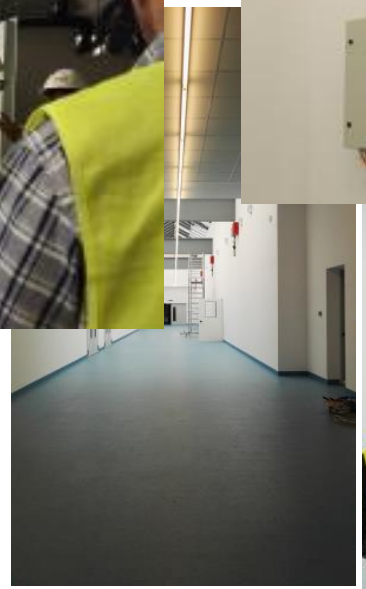






Building Acceptance

June-September 2016

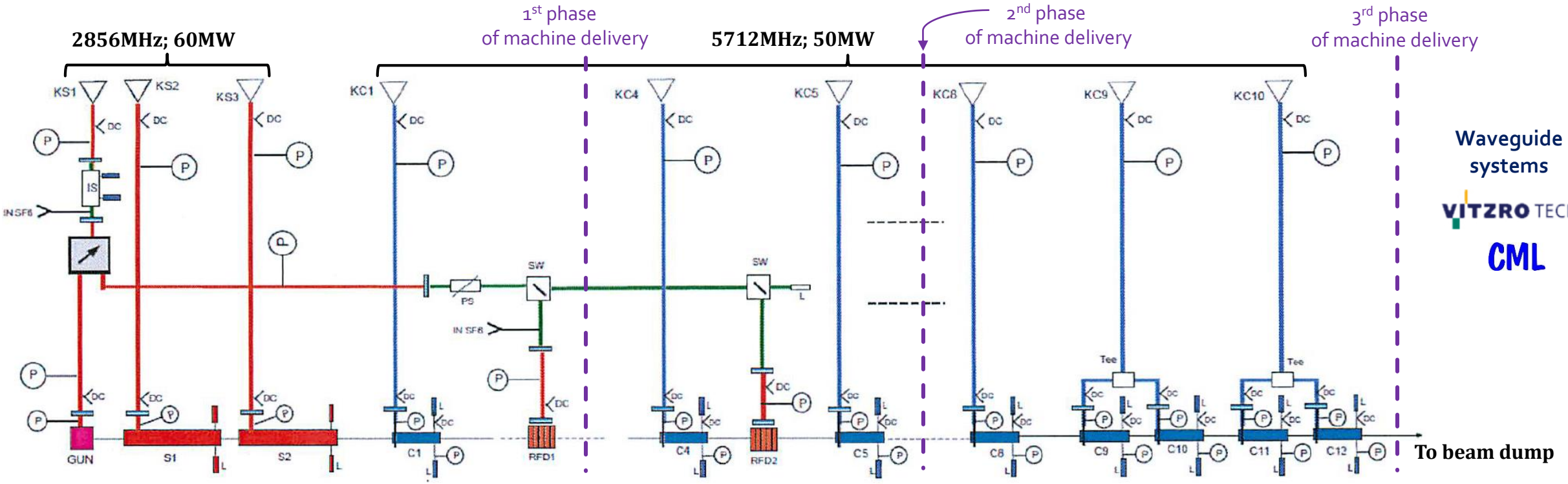








Vibration Measurements – Gerb Engineering GmbH
Laser tracker 3D scanning for check the real dimensions and volumes of the rooms. Location of all openings etc.
Electrical measurements – grounding parameters, short-circuit current, grid voltage monitoring.
Tests of BMS, Ventilation System, Alarm system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

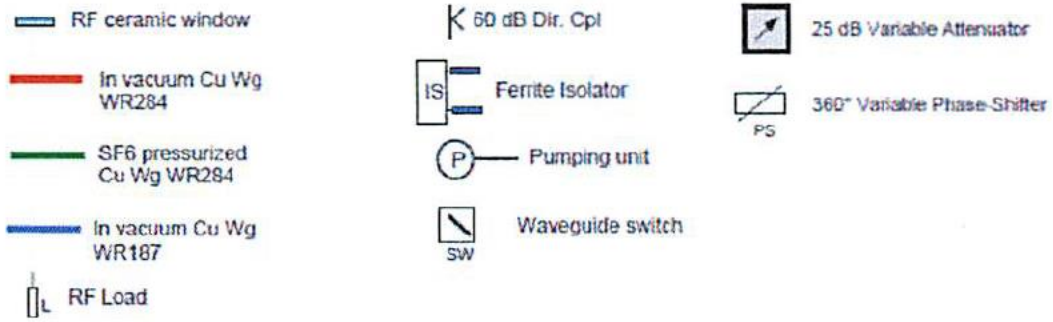
RF power distribution



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

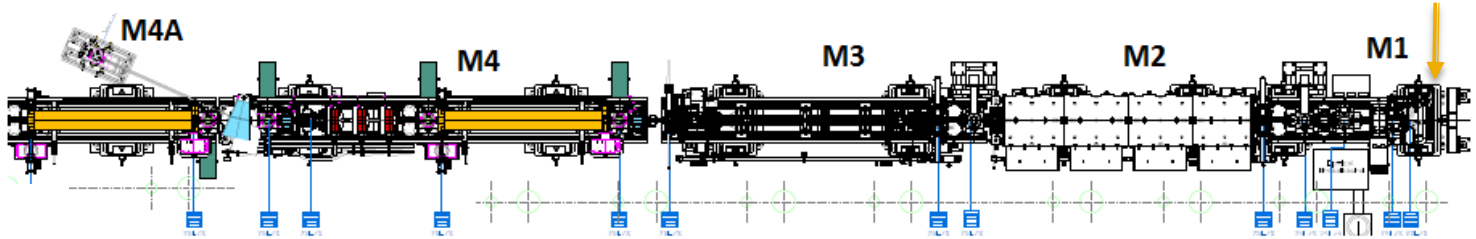
TOSHIBA Leading Innovation >>>

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 (Bossey)
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 (C
14	EXT	Photocathode Laser Transport line	LAL (C
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	
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		
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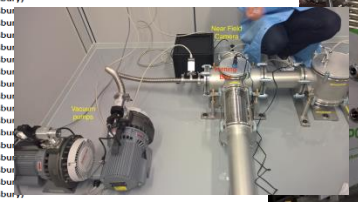
151	M4		
152	M4		
153	M4		

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)



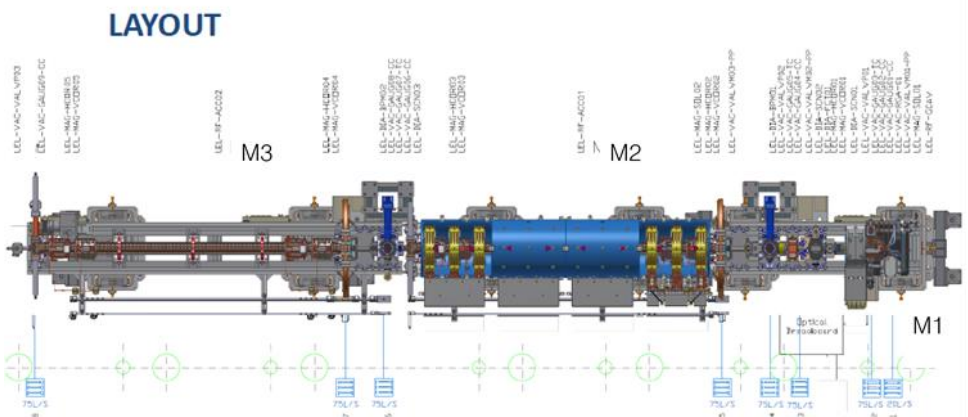
3/4

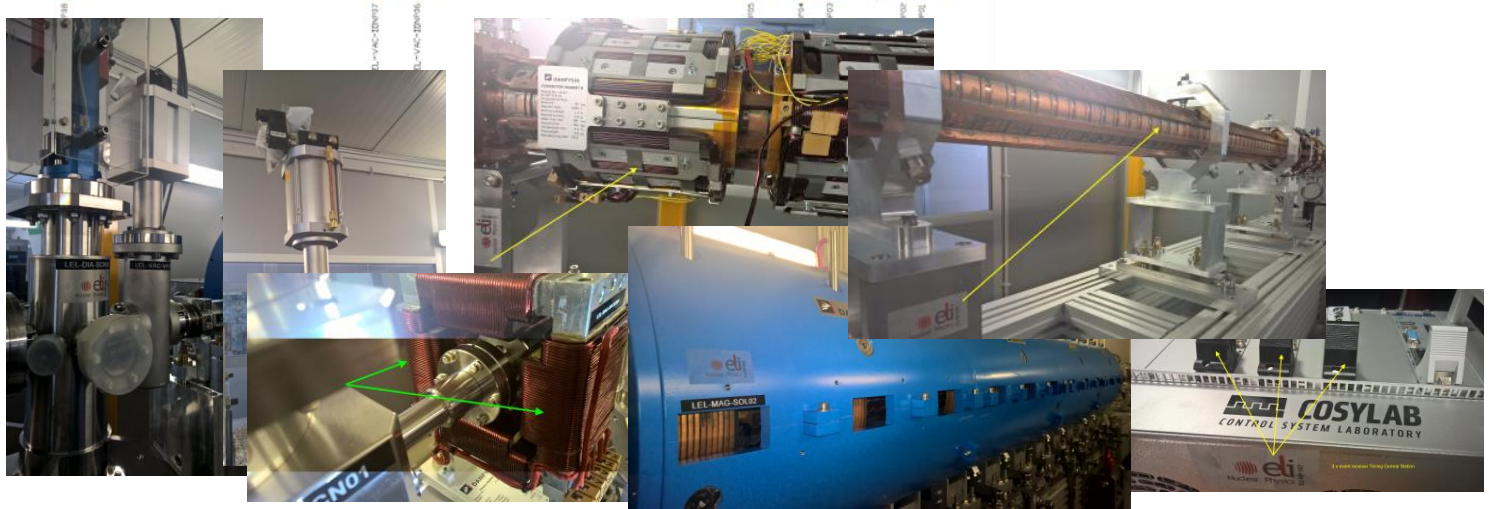
Acceptance of GBS devices/components

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





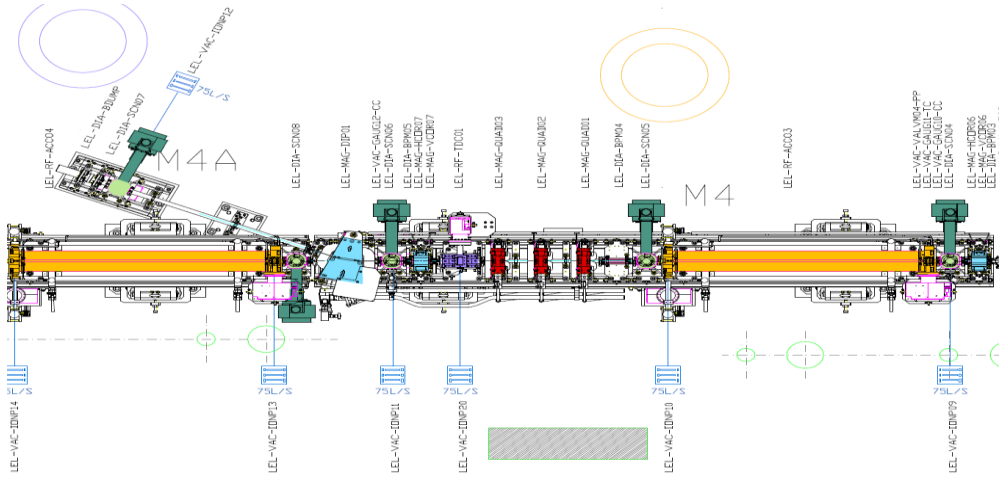
STFC, Daresbury, UK

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.)



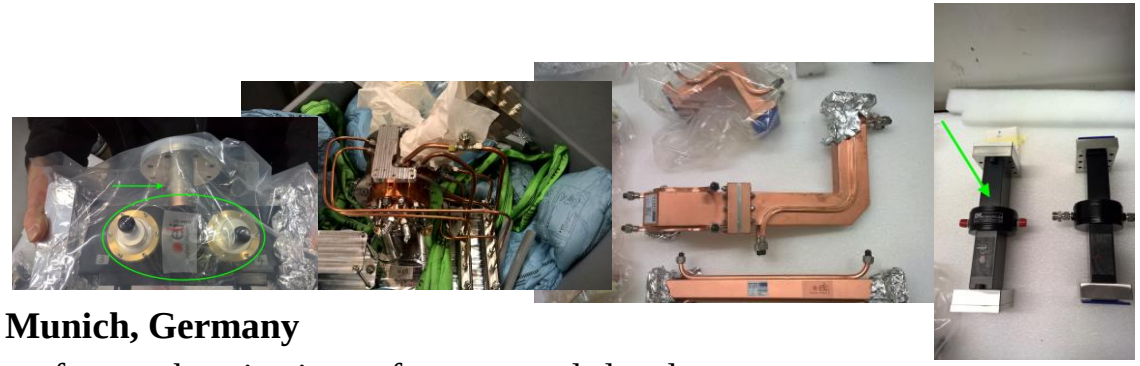
Acceptance of GBS devices/components

Scandinova, Uppsala, Sweden

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

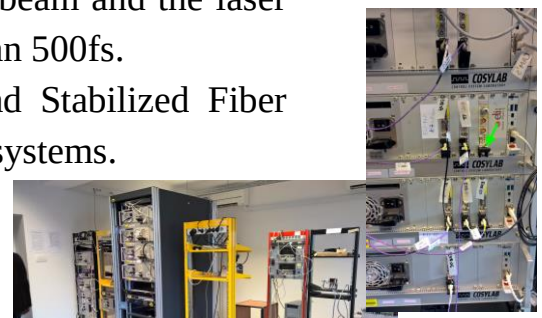
Research Instruments, Bonn/Bergish Gladbach, Germany

- 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.



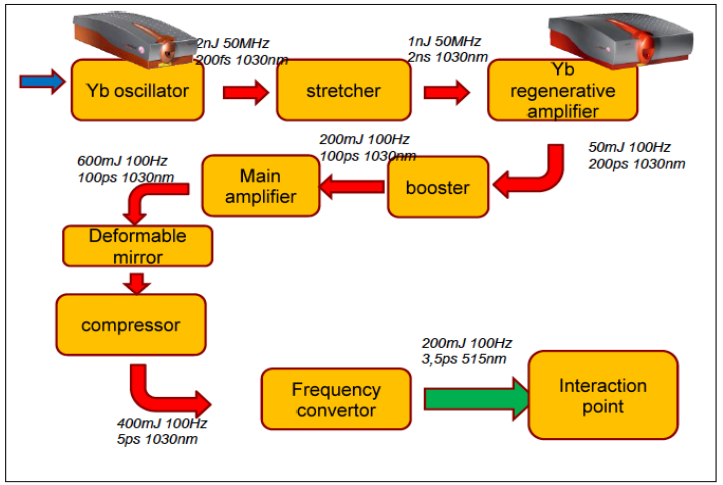
Cosylab, Ljubljana, Slovenia

- 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.



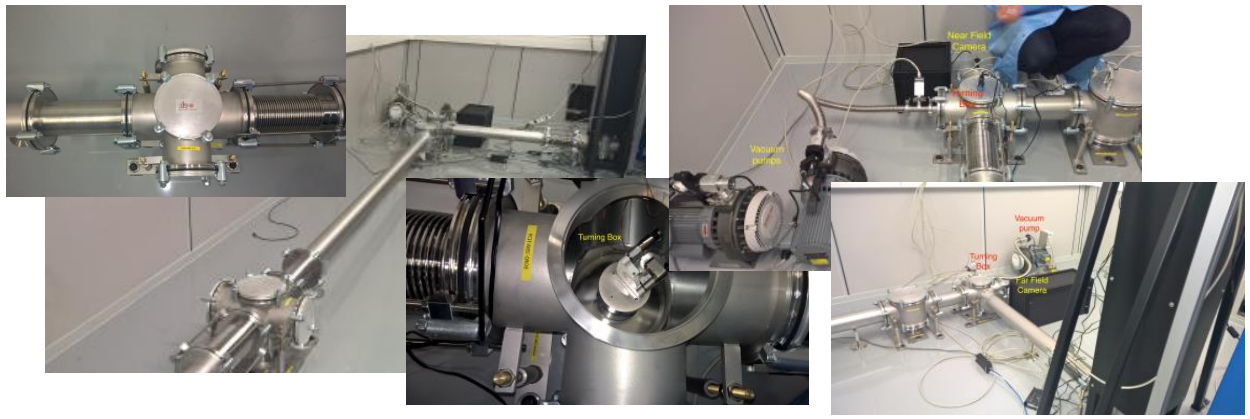
Amplitude Technologies, Lisses, France

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

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