

**EuroGammaS**

Corso

«Operazione di acceleratori di elettroni e positroni»

21-22 Giugno 2018

INFN-LNGS



# Il Progetto ELI

**Stefano Pioli**

2018/06/21

# ELI Nuclear Physics - Romania

## Fisica nucleare fotonica:

- Metodi di fisica nucleare per studiare le interazioni tra laser e bersagli
- Incrementare la precisione della spettroscopia nucleare
- Nuova fisica nucleare fondamentale basata su interazioni con fotoni



# ELI Nuclear Physics – In che modo?

❖ **Intensità (laser)** – Si entra in un regime dove i campi sono talmente intensi che si producono particelle in regime relativistico. Per esempio: accelerazione di ioni, interazioni con la materia, indice di rifrazione del vuoto, creazione di coppie, ...

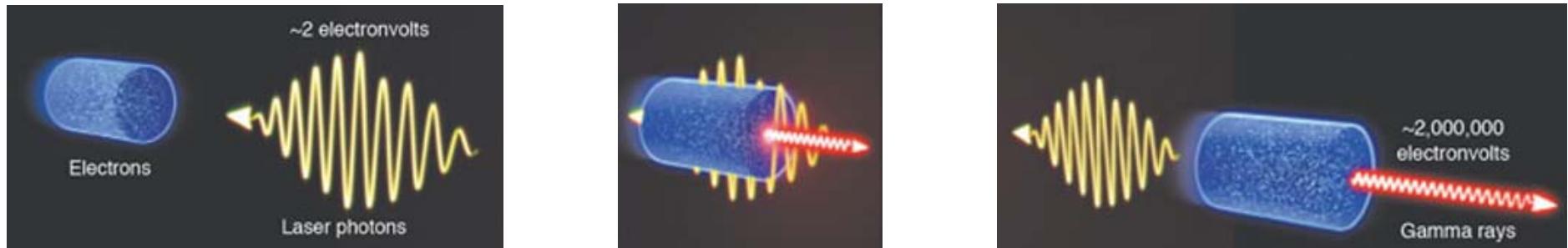


❖ **Frequenza (sorgente gamma)** – Ogni fotone «sonda» lo spazio con dettagli dell'ordine della sua lunghezza d'onda e può eccitare reazioni con energia pari alla sua frequenza. Per eccitare stati nucleari servono energie dell'ordine del MeV. Può servire per: produzione isotopi medicali, tomografia dei materiali radioattivi, ...

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# ELI-NP Gamma Beam Source

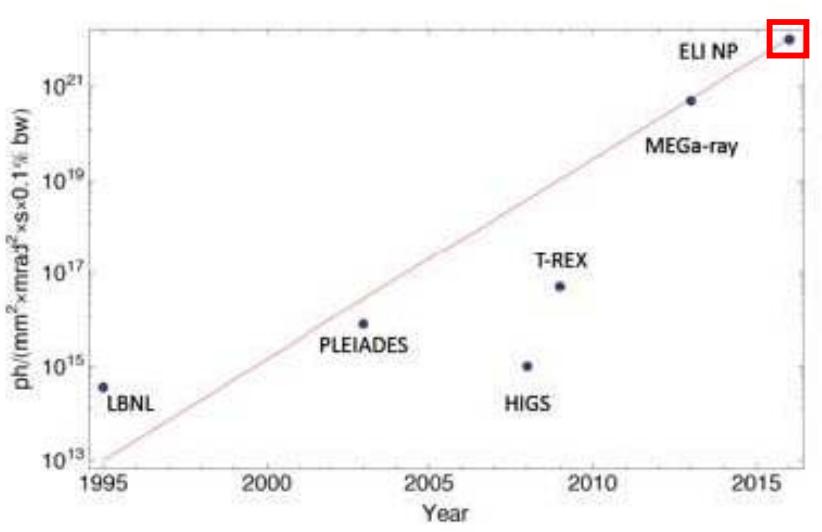


Compton back-scattering gamma source from the interaction of an high brightness electron beam and high power laser pulse.

Gamma beam params	
Energy	0.2 – 20 MeV
Spectral density	$0.8 - 4 * 10^4 \frac{ph}{s * eV}$
Bandwidth (RMS)	< 0.5 %
Peak brilliance	$> 10^{20} \frac{ph}{s * mm^2 * mrad^2 * 0.1\%}$
Spot size	10 – 30 $\mu m$

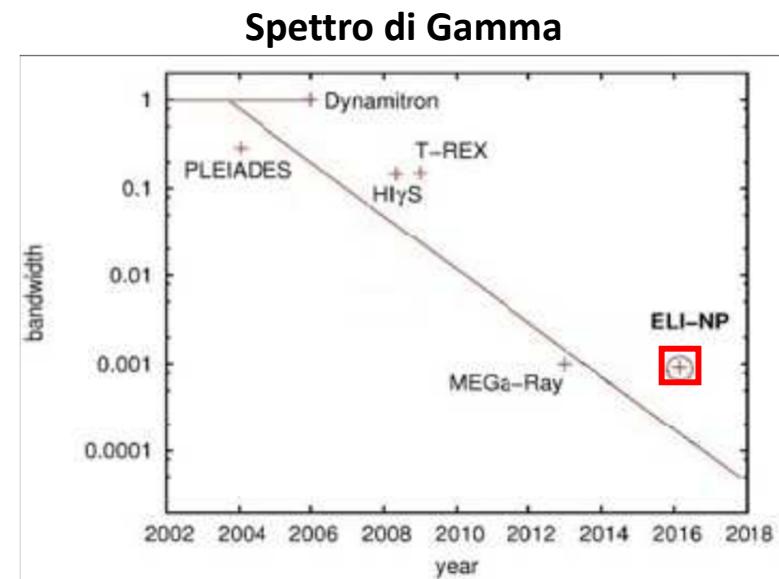
Electron beam params	
Energy	75 – 740 MeV
Bunch charge	25 – 400 pC
Number of bunches/pulse	32
Bunch distance	16 ns
Bunch length	100 – 400 $\mu m$
Pulse length	512 ns
Energy spread (RMS)	0.04 – 0.1%
Norm. Emittance	0.4 mm * mrad
RF repetition rate	100 Hz

# ELI-NP Gamma Beam Source

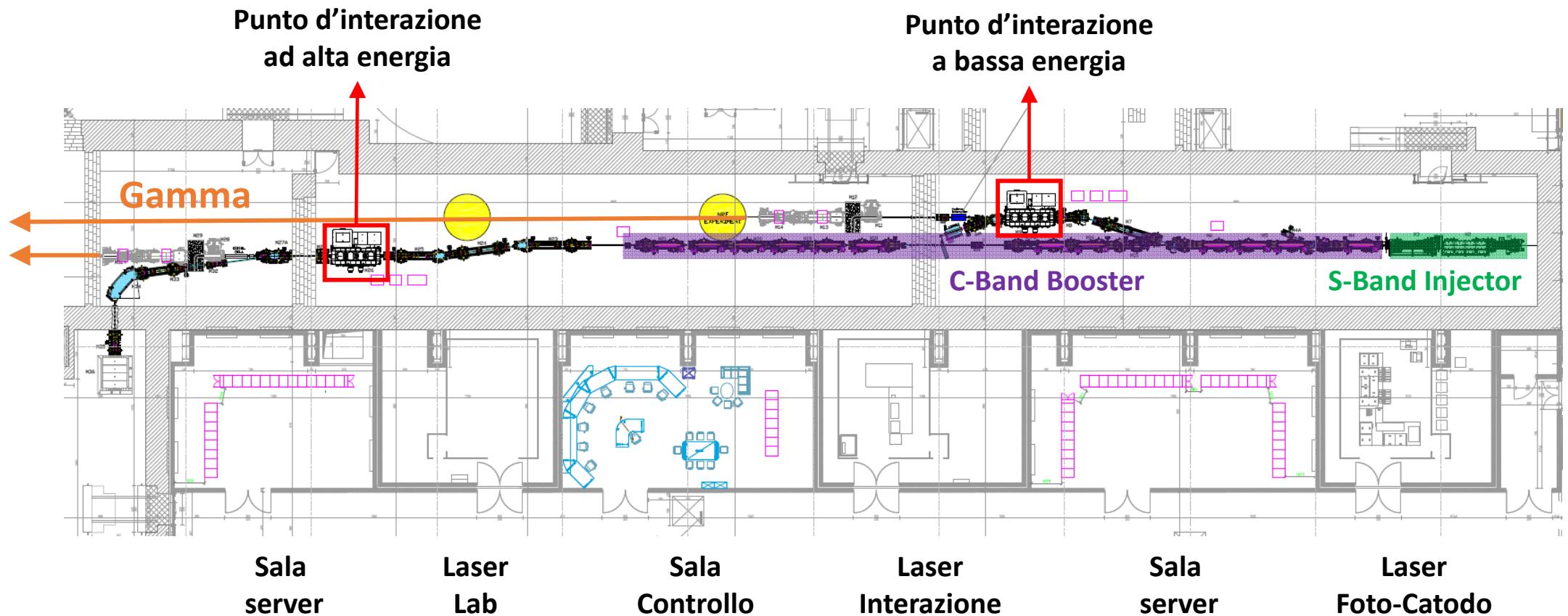


Flusso di Gamma

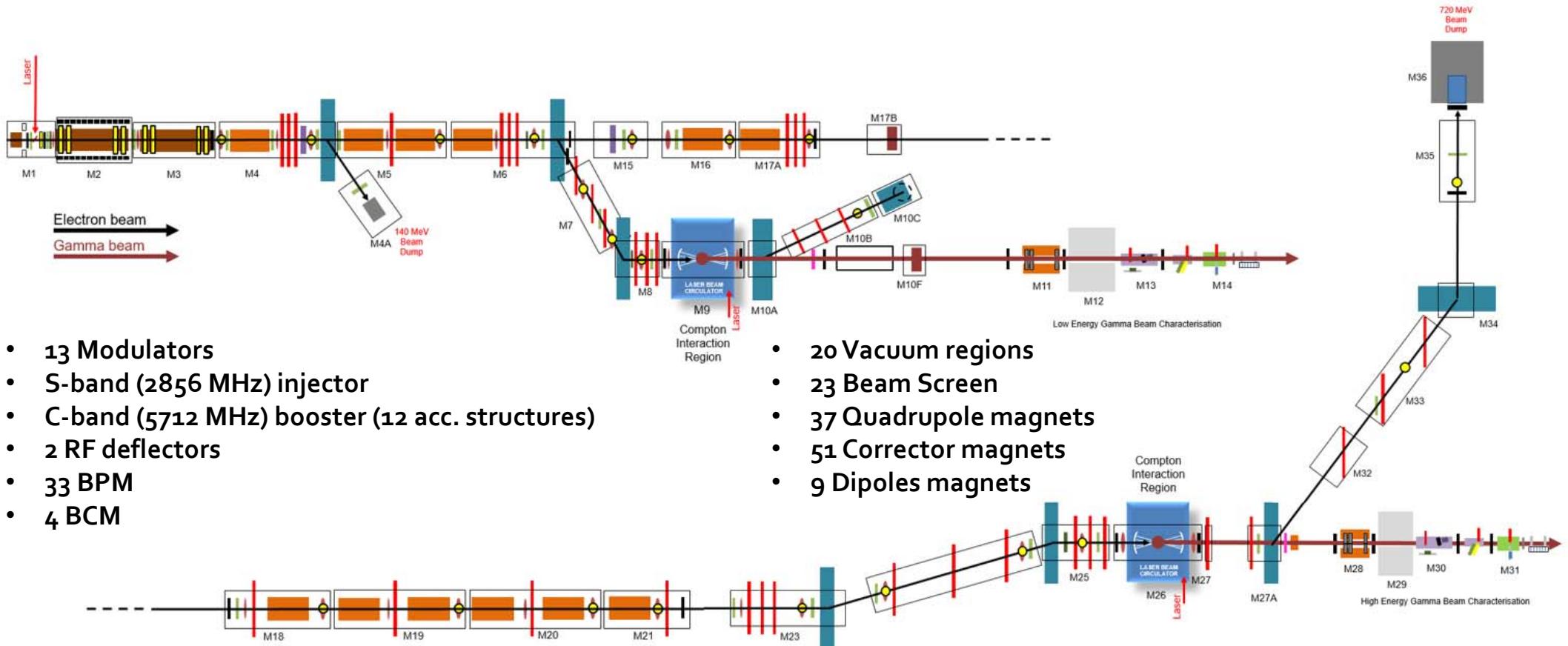
Due ordini di grandezza oltre lo stato dell'arte.



# ELI-NP Gamma Beam Source

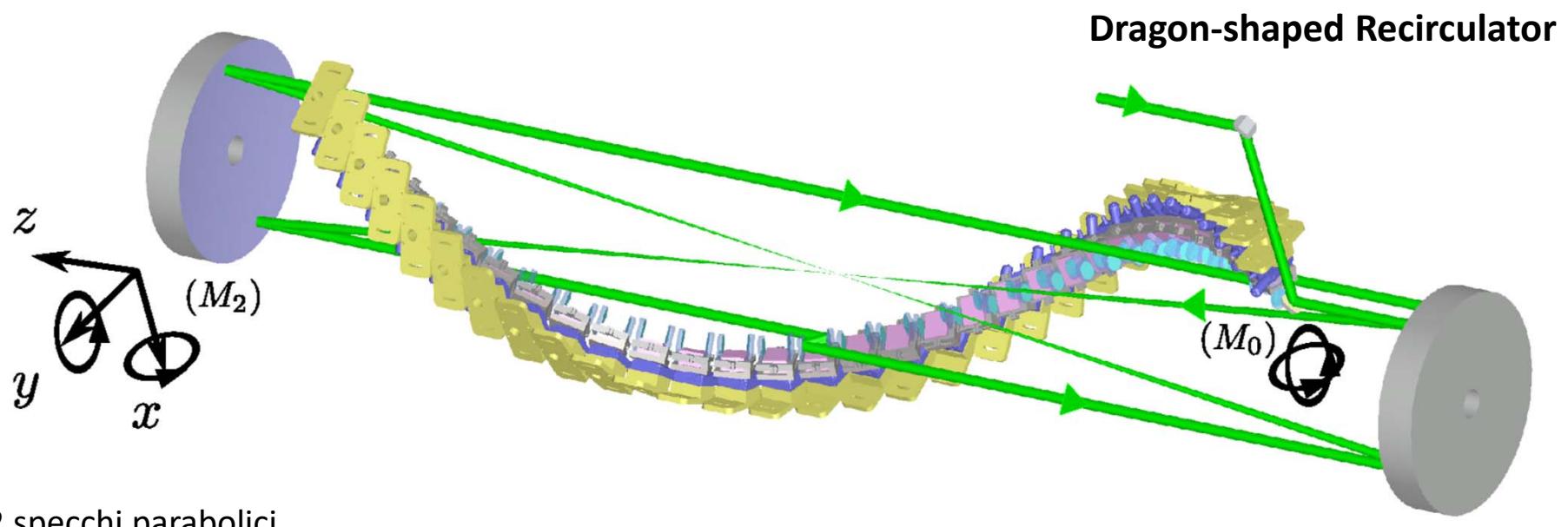


# ELI-NP Gamma Beam Source



- **13 Modulators**
- S-band (2856 MHz) injector
- C-band (5712 MHz) booster (12 acc. structures)
- 2 RF deflectors
- 33 BPM
- 4 BCM
- **20 Vacuum regions**
- **23 Beam Screen**
- **37 Quadrupole magnets**
- **51 Corrector magnets**
- **9 Dipoles magnets**

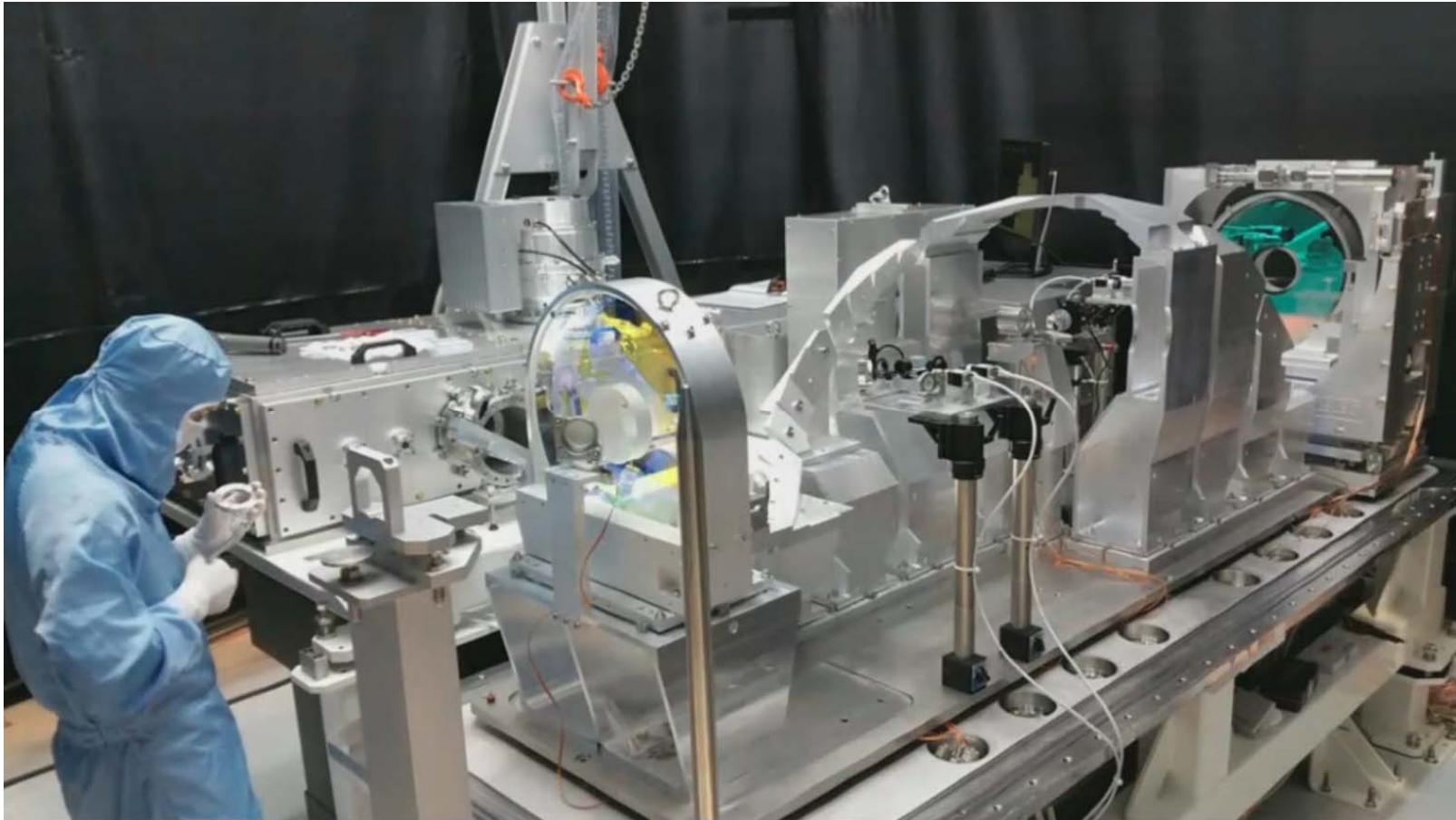
# ELI-NP-GBS: Interaction Point



- 2 specchi parabolici
- 31 coppie di specchi per sincronia con i 32  $\mu$ bunch di elettroni
- Allineamento specchi di 10  $\mu$ m
- Impulso laser da 200 mJ (100 Hz, 3.5 ps, 515 nm)

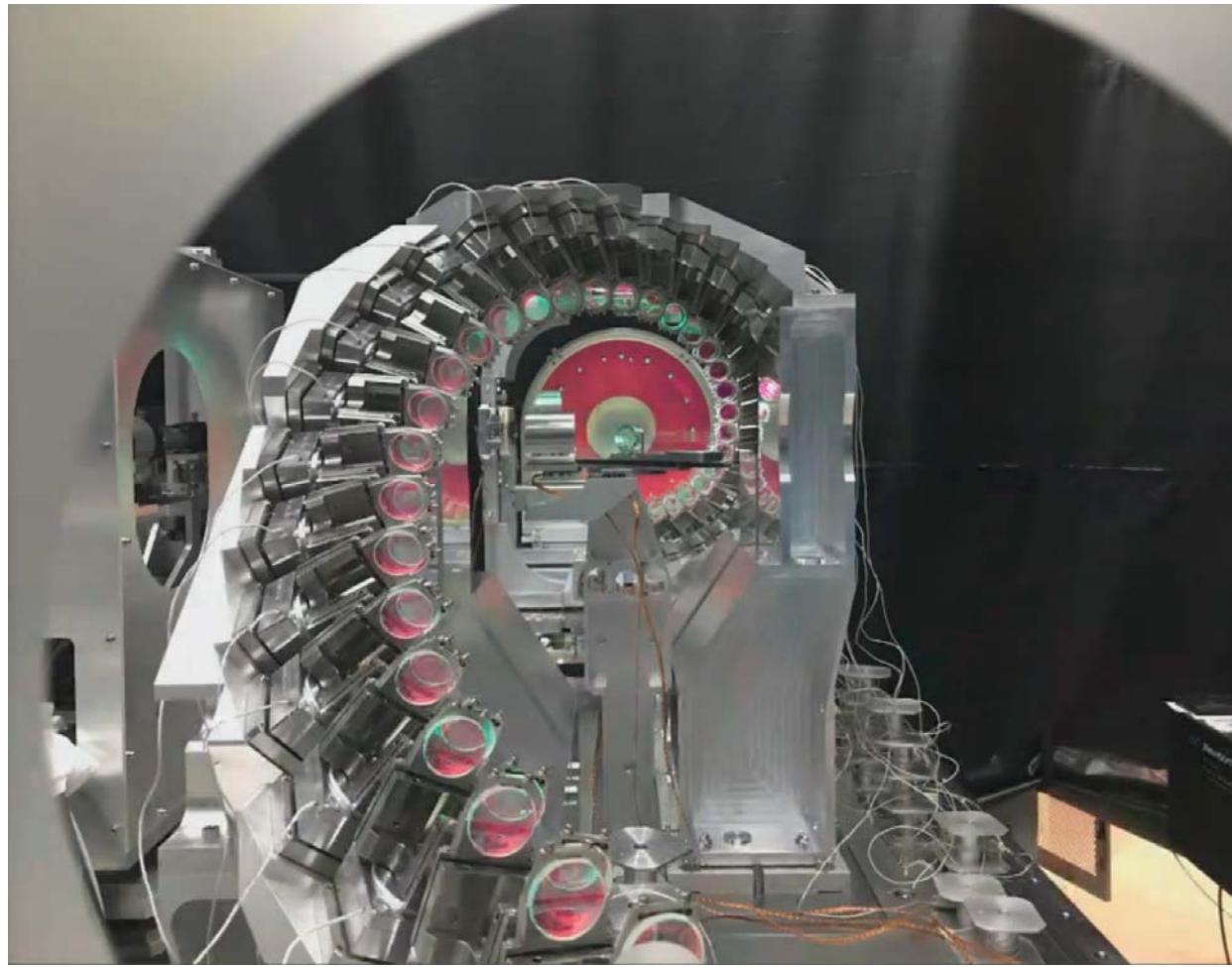
Courtesy of Kevin Cassou

# ELI-NP-GBS: Interaction Point



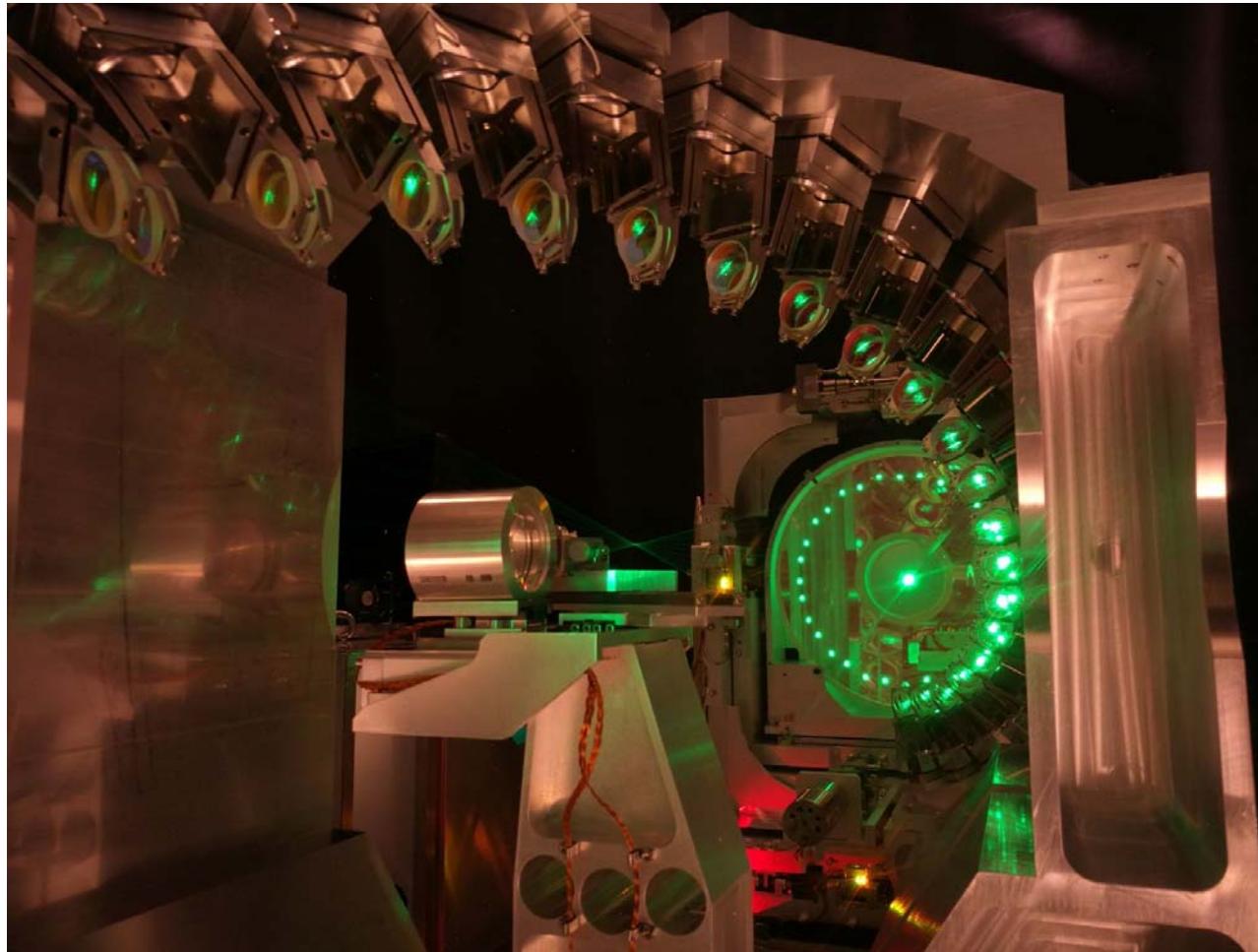
Courtesy of Kevin Cassou

# ELI-NP-GBS: Interaction Point



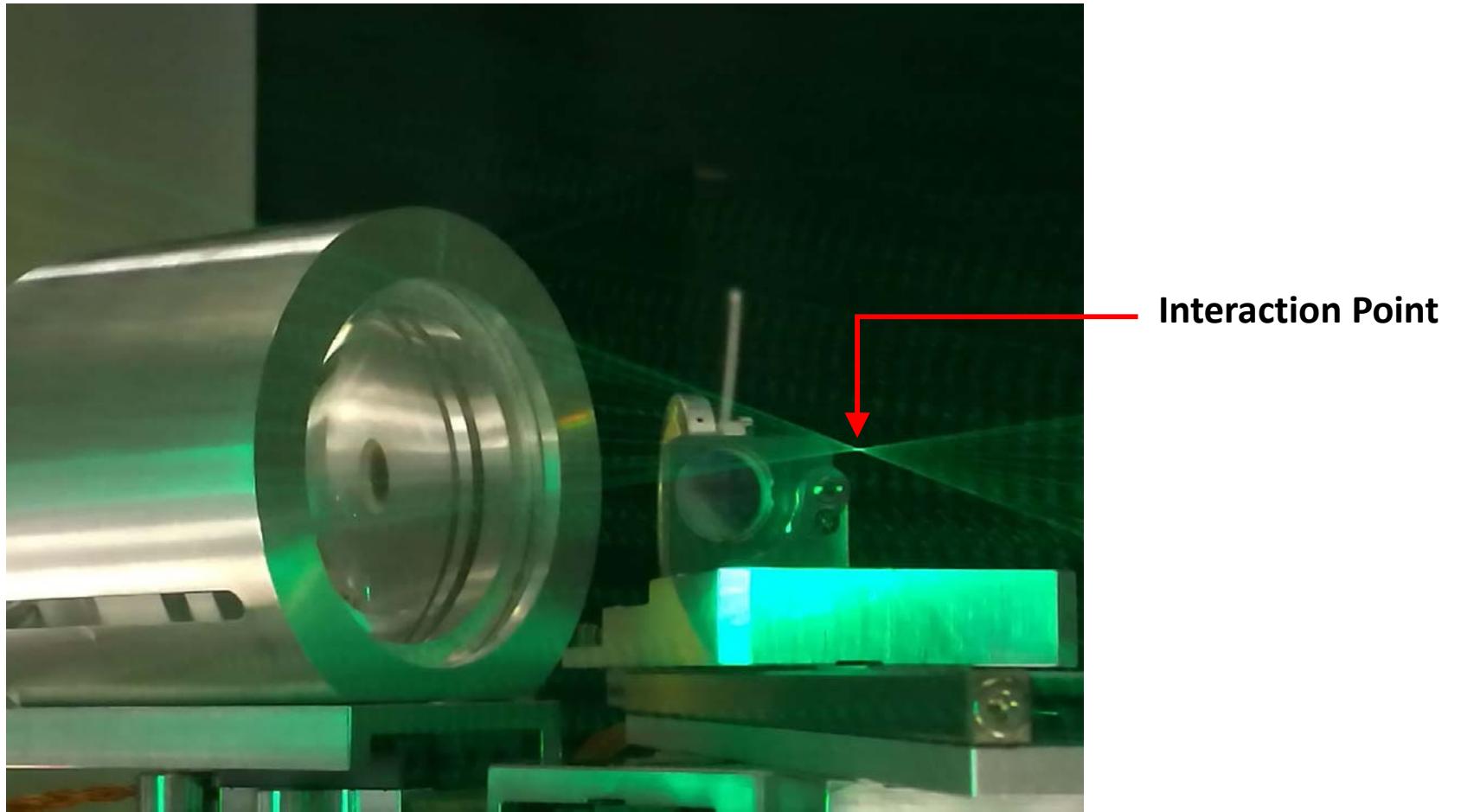
Courtesy of Kevin Cassou

# ELI-NP-GBS: Interaction Point



Courtesy of Kevin Cassou

# ELI-NP-GBS: Interaction Point



Courtesy of Kevin Cassou

# ELI-NP-GBS: Accelerating Structures

## I problemi della RF

- **Alto flusso di gamma**



- Frequenza di ripetizione a 100 Hz.
- Treno Multi-Bunch.



- Dump modi di ordine superiore per evitare instabilità.
- Compensazione beam loading.
- Attenzione al carico termico.

- **Acceleratore compatto**

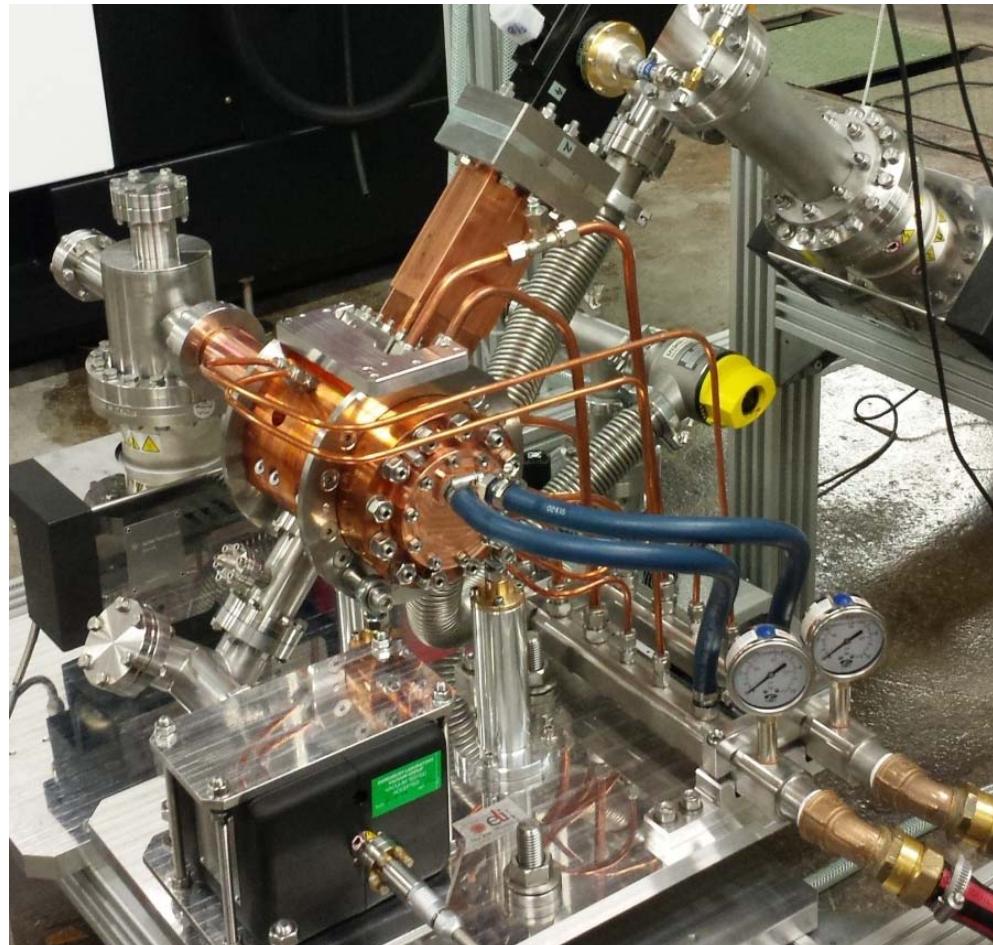


- Alto gradiente accelerante.



- Dinamica di fascio per gestire iniettore in banda-S con booster in banda-C.

# ELI-NP-GBS: Accelerating Structures



RF Gun

<b>RF frequency</b>	GHz	2.856
<b>Repetition frequency</b>	Hz	100
<b>Working mode</b>		$\pi$ SW
<b>Max RF input power</b>	MW	16 (shaped)
<b>RF peak field at the cathode</b>	MV/m	120
<b>Max RF pulse duration</b>	$\mu$ sec	2 (1.5 nominal)
<b>RF pulse duration for beam</b>	$\mu$ sec	0.5
<b>Unloaded Q factor</b>		14600
<b>Average dissipated power</b>	kW	1.3
<b>Working temperature</b>	degrees	34
<b>Coupling coefficient</b>		3
<b>Filling time</b>	$\mu$ s	420
<b>Shunt impedance</b>	$M\Omega$	1.64
<b>Operating vacuum pressure</b>	mbar	$1\text{-}5 \cdot 10^{-9}$
<b>Number of cells</b>	#	1.6
<b>Type of cathode</b>		copper
<b>Cathode quantum efficiency @ 266 nm</b>		$1\text{-}3 \cdot 10^{-5}$

Courtesy of David Alesini

# ELI-NP-GBS: Accelerating Structures

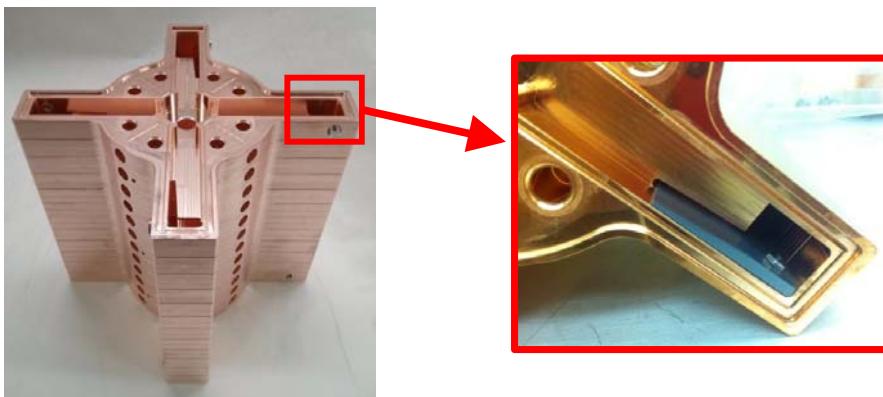


## S-Band structures

<b>RF frequency</b>	GHz	2.856
<b>Repetition frequency</b>	Hz	100
<b>Number of cells</b>	#	84+1in+1out coupler
<b>Working mode</b>		$2\pi/3$ TW
<b>Phase velocity / c</b>		1
<b>Group velocity / c</b>		2%-0.6%
<b>Attenuation constant</b>	neper	0.6
<b>Max RF input power</b>	MW	45
<b>Average accelerating gradient</b>	MV/m	23.5
<b>Average dissipated power</b>	kW	4.5
<b>Q factor per unit length</b>		12300
<b>Working temperature</b>	degrees	30
<b>Operating vacuum pressure</b>	mbar	$5 \cdot 10^{-9} \text{--} 10^{-8}$
<b>Filling time</b>	$\mu\text{s}$	0.8
<b>Average Shunt impedance</b>	$M\Omega/\text{m}$	53
<b>Max RF pulse duration</b>	$\mu\text{sec}$	1.3
<b>RF pulse duration for beam</b>	msec	0.5
<b>Total length</b>	m	3
<b>Iris aperture</b>	mm	26-19 (2a)
<b>Type</b>		CG

Courtesy of David Alesini

# ELI-NP-GBS: Accelerating Structures

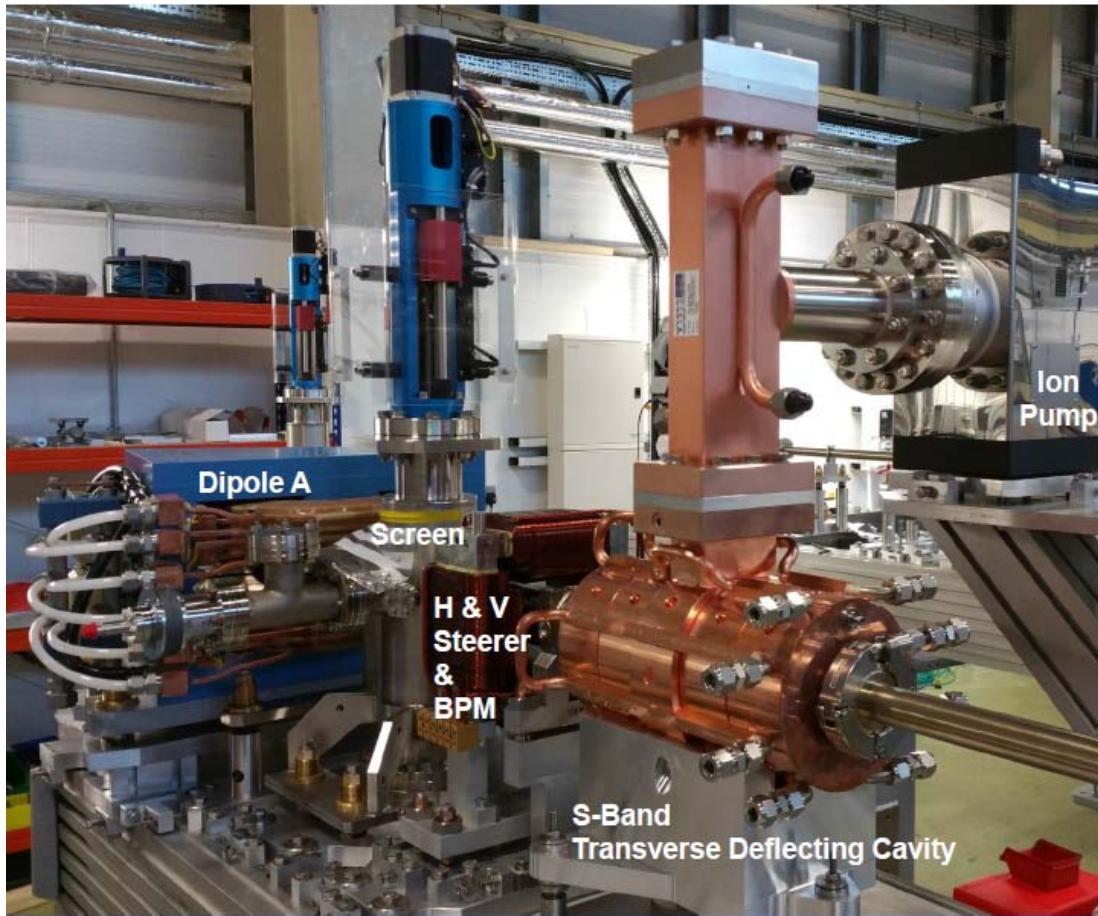


## C-Band structures

<b>RF frequency</b>	GHz	5.712
<b>Repetition frequency</b>	Hz	100
<b>Number of cells</b>	#	102+1in+1out coupler
<b>Working mode</b>		$2\pi/3$ TW
<b>Phase velocity / c</b>		1
<b>Group velocity / c</b>		2.5%-1.4%
<b>Attenuation constant</b>	Neper	0.7
<b>Max RF input power</b>	MW	40
<b>Average accelerating gradient</b>	MV/m	33 (38-28)
<b>Average dissipated power</b>	kW	2.3
<b>Unloaded Q factor</b>		8800
<b>Working temperature</b>	Degrees	30
<b>Operating vacuum pressure</b>	Mbar	$5 \cdot 10^{-9} \text{--} 10^{-8}$
<b>Filling time</b>	$\mu\text{sec}$	0.31
<b>Shunt impedance</b>	$M\Omega/m$	67-73
<b>Max RF pulse duration</b>	$\mu\text{sec}$	0.82
<b>RF pulse duration for beam</b>	$\mu\text{sec}$	0.5
<b>Total length</b>	m	1.8
<b>Iris aperture</b>	mm	6.8-5.78 (half aperture)
<b>type</b>		Quasi CG

Courtesy of David Alesini

# ELI-NP-GBS: Accelerating Structures



## RF Deflectors

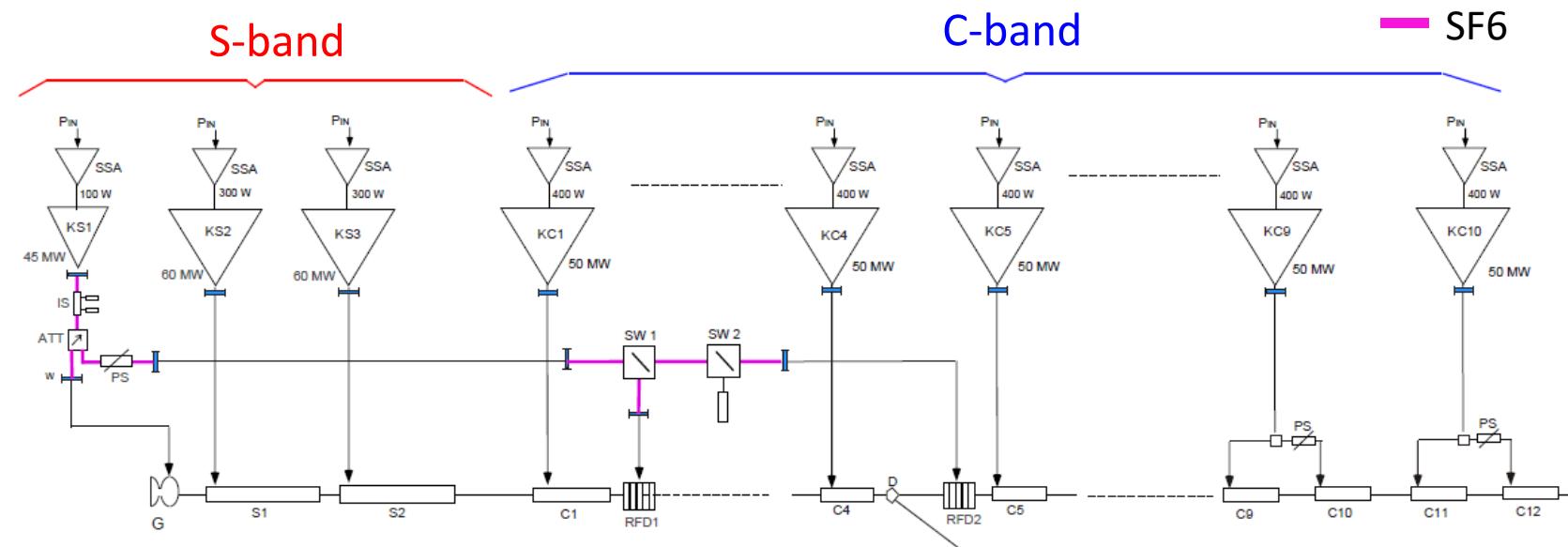
RF frequency	GHz	2.856
Repetition frequency	Hz	100
Number of cells	#	5
Working mode		$\pi$ (SW)
Max RF input power	MW	10
Maximum deflecting voltage	MV	6
Max Average dissipated power	kW	750
Unloaded Q factor		16000
Coupling coefficient	$\beta$	3
Working temperature	degrees	30
Transverse Shunt impedance	$M\Omega$	2.5
Operating vacuum pressure	mbar	$5 \cdot 10^{-9} - 10^{-8}$
Filling time	ns	450
Transverse Shunt impedance	MW	2.5
Max RF pulse duration	$\mu$ sec	2
RF pulse duration for beam	$\mu$ sec	0.5
Total length	m	0.3
Iris aperture	mm	40 (2a)

Courtesy of David Alesini

# ELI-NP-GBS: RF System

RF-Unit: klystron (Toshiba) + pulsed HV Solid State Modulator (ScandiNova) + RF driver (Microwave Amplifier)

- 1x 45MW S-band Unit → RF Gun + 2 Deflecting SW cavities
- 2x 60MW S-band Unit → 2x S-band 3m TW structures
- 10x 50MW C-band Unit → 12x C-band 1.8m TW structures



Courtesy of Fabio Cardelli

# ELI-NP-GBS: RF System

	60MW S-band K2-3 Modulator	50MW C-band K2-2 Modulator
RF Frequency	2856 MHz	5712 MHz
RF peak power	60 MW	50 MW
RF Average power	12 kW (15kW)	5 kW
RF driver power	400 W	300 W
Operational Voltage range	0 – 380 kV	0 – 370 kV
Operational Current range	0 – 430 A	0 – 340 A
Modulator Peak power	163 MW	111 MW
Modulator Average power	65 kW	32 kW
Repetition rate	1-100 Hz	1-100 Hz
Beam Pulse length (top)	2 $\mu$ sec (2.5 $\mu$ sec)	2 $\mu$ sec
Top flatness (dV)	< $\pm$ 1 %	< $\pm$ 0.5 %
Amplitude stability	< $\pm$ 0.005 %	< $\pm$ 0.005 %
Pulse to pulse time jitter	< $\pm$ 4 ns	< $\pm$ 4 ns
Rate of Rise	250 – 350 kV/us	250 – 300 kV/us



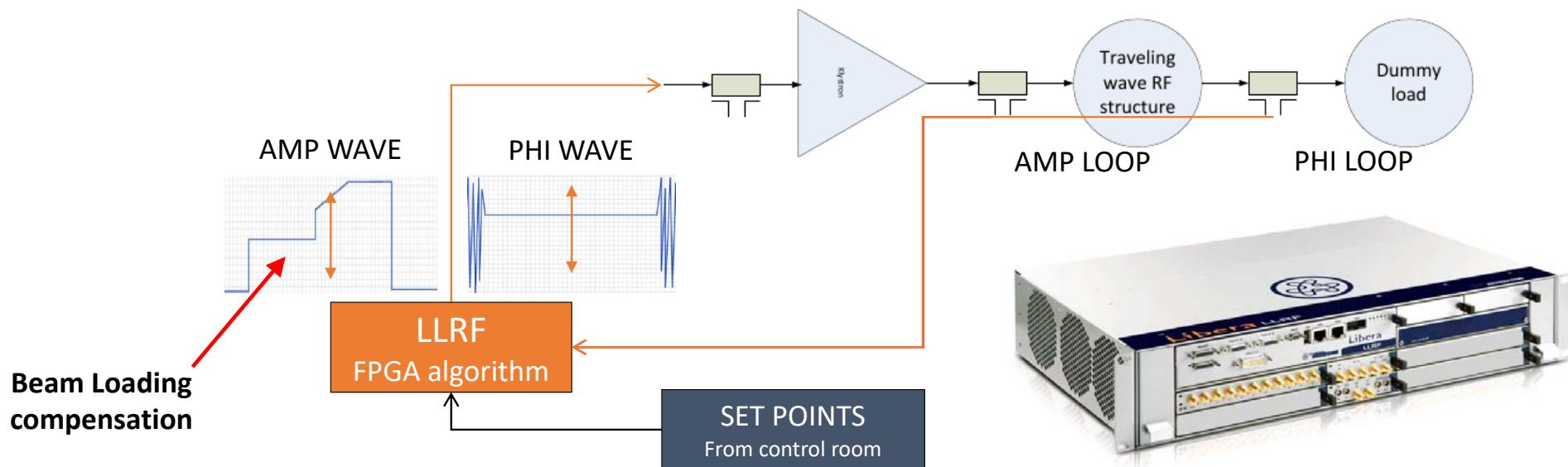
S-band: Model k2-3 4HVPS, 12SU  
C-band: Model k2-2 3HVPS, 8SU

Courtesy of Fabio Cardelli

# ELI-NP-GBS: RF System

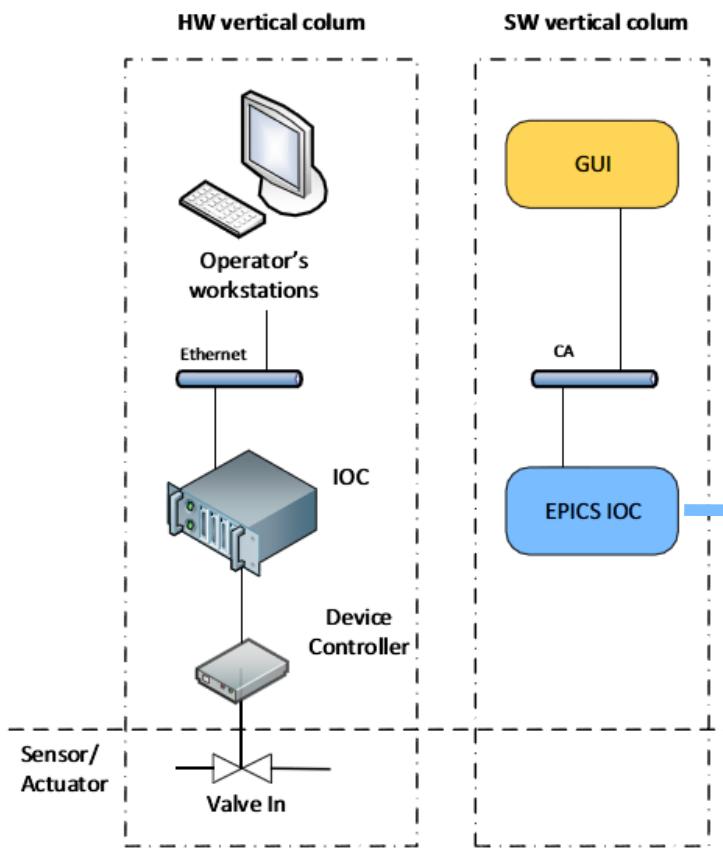
## LLRF purposes:

- RF pulse generation and distribution to klystron pre-amplifier (modulation) and RF signals monitoring (demodulation);
- For each klystron two independent loops have been foreseen: amplitude and phase;
- Once the pulse shapes have been set by the user and feed the structures, the feedback trim the amplitude and phase waveforms leaving their shapes unperturbed.

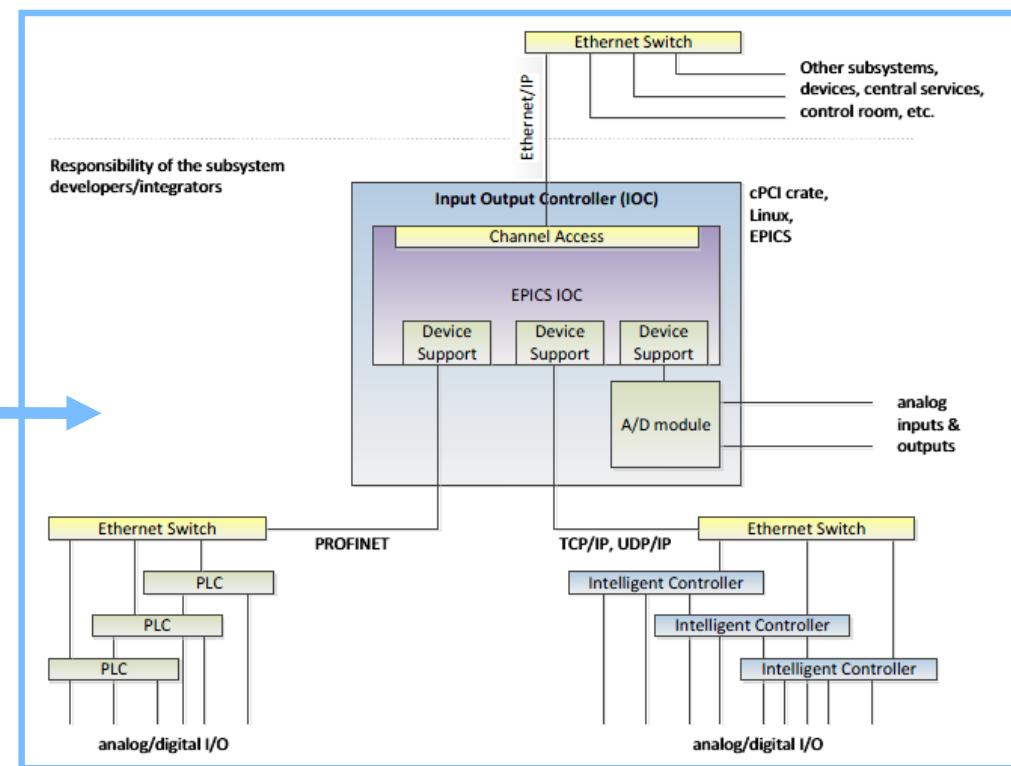


Courtesy of Luca Piersanti

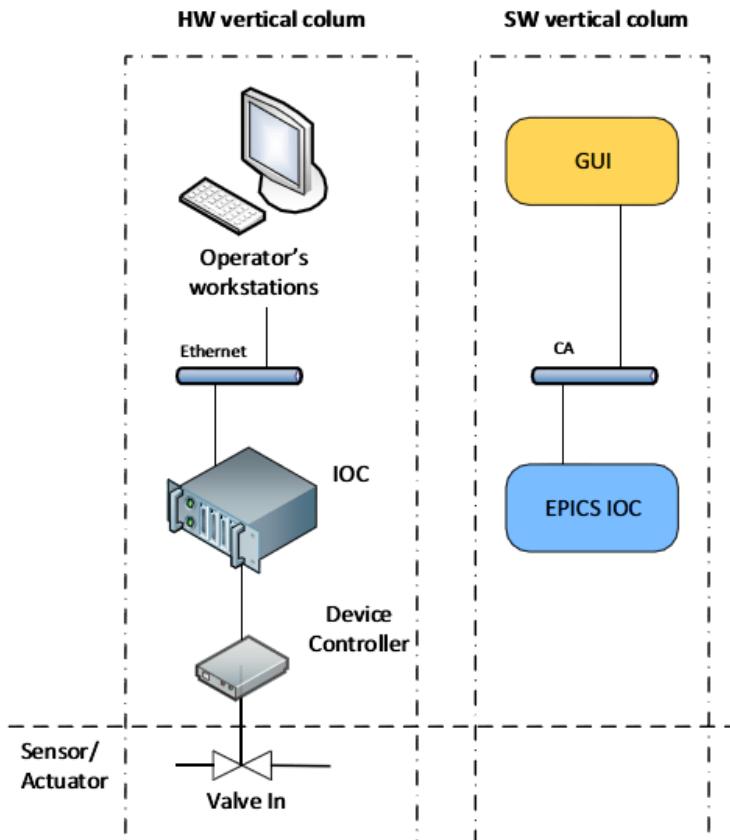
# ELI-NP-GBS: Control System



**EPICS (Experimental Physics and Industrial Control System)**



# ELI-NP-GBS: Control System



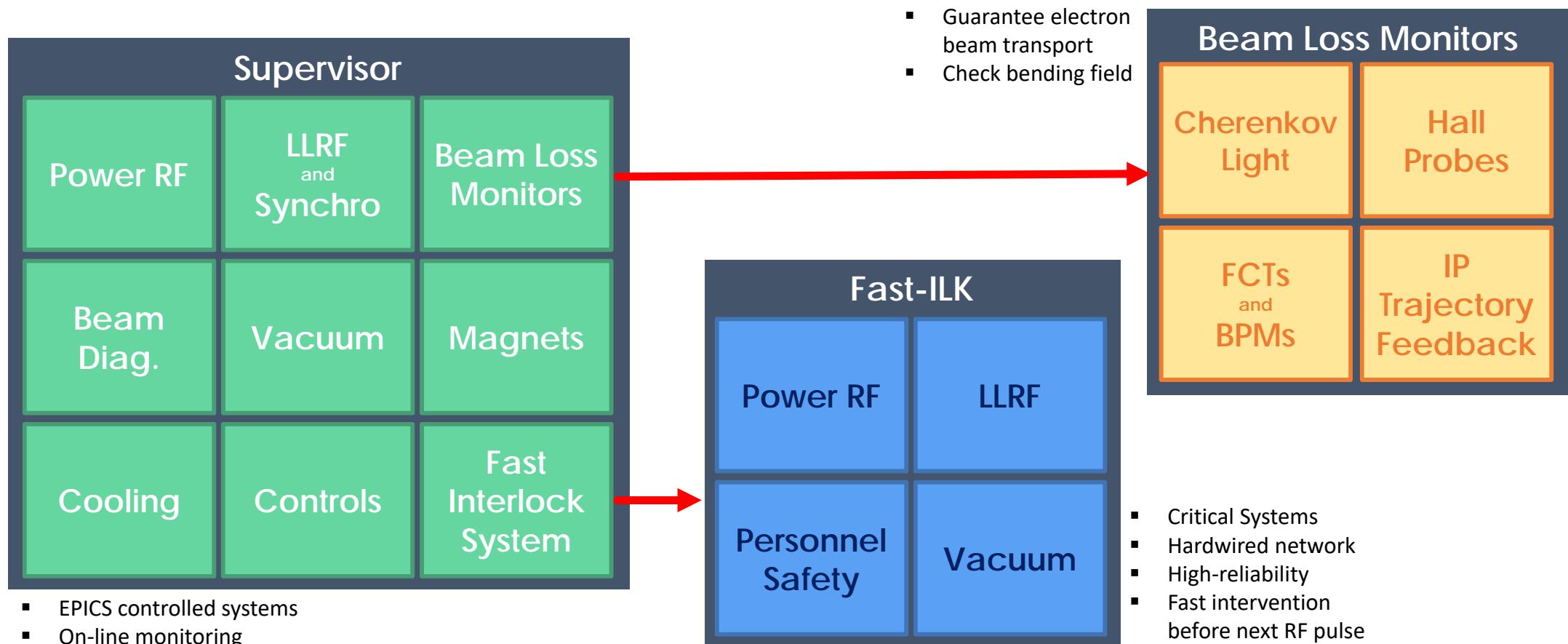
## More than 60 IOCs:

- 3x RF systems IOCs
- 13x LiberaLLRF
- 8x Vacuum IOCs
- 9x Beam Diagnostics IOCs
- 8x LiberaBPM
- 1x Cooling and Chillers IOC
- 1x Synchronization IOC
- 1x Timing EVG IOC
- 6x Magnets IOCs
- 2x LiberaCBPM
- 11x Laser systems IOCs

## CS Hardware:

- 23x IOCs on 1U DELL server
- 17x IOCs with timing EVR on 3U cPCI chassis
- 23x IOCs on Libera systems

# ELI-NP-GBS: Machine Protection System



Grazie per  
l'attenzione.