



HIGH POWER TEST RESULTS OF THE SPARC C-BAND ACCELERATING STRUCTURES

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OUTLINE

- 1. C-BAND @ SPARC**
- 2. DESIGN AND REALIZATION**
- 3. HIGH POWER TEST**
- 4. *NEXT STEP: HOM DAMPED-HIGH REP. RATE C-BAND ACCELERATING STRUCTURES FOR ELI-NP GAMMA BEAM SYSTEM***



(Sources for Plasma Accelerators and Radiation Compton with Lasers And Beams)

SPARC_LAB is a facility @ LNF-INFN based on the unique combination of **high brightness electron beams** with high intensity **ultra-short laser pulses** oriented to a wide spectrum inter-disciplinary leading-edge research activities.

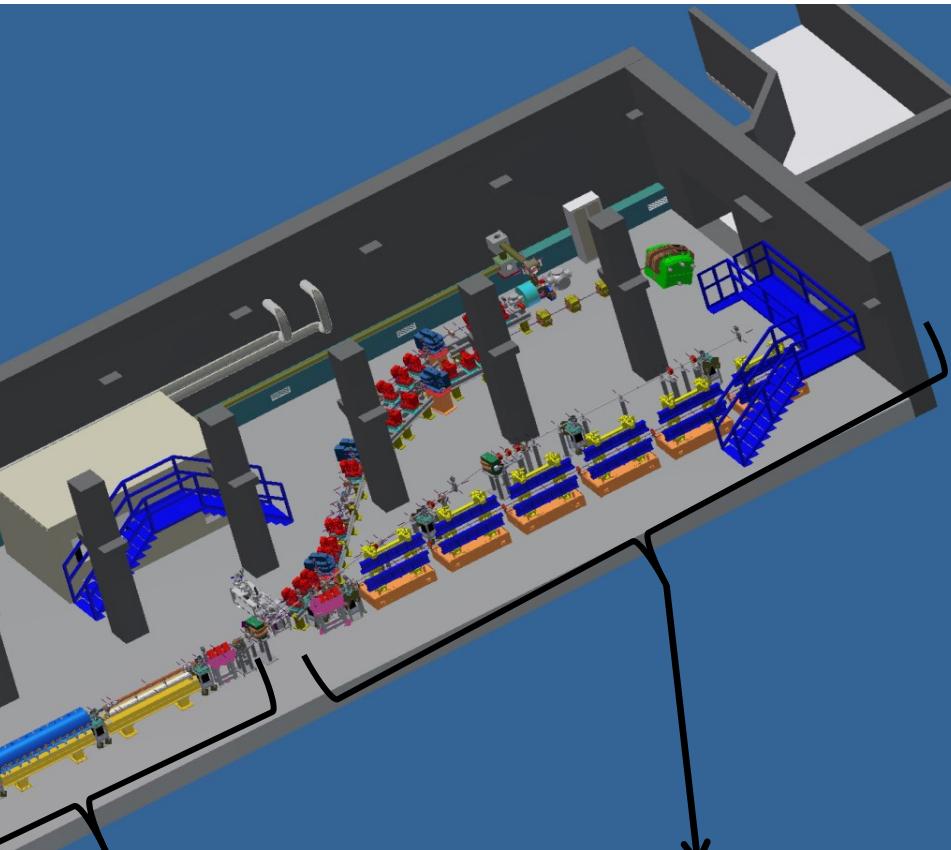
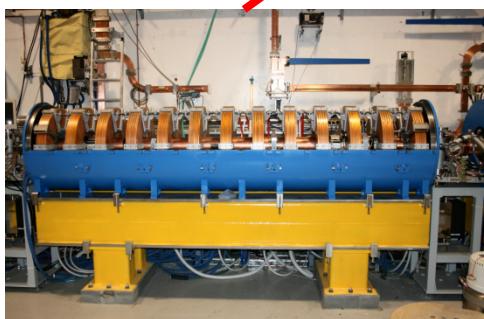
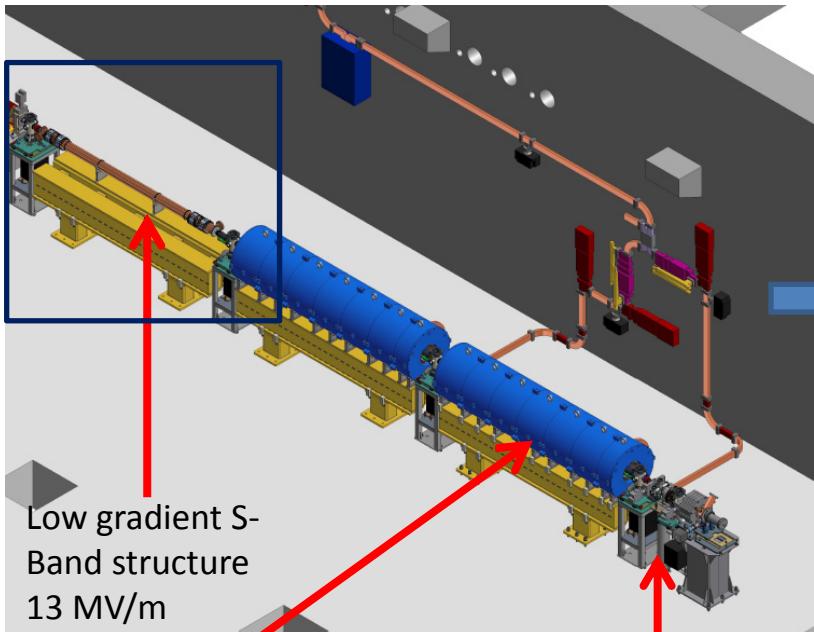


Photo-injector

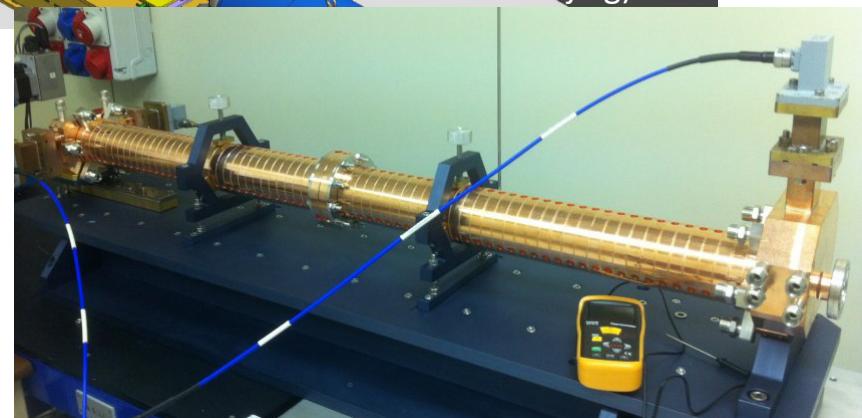
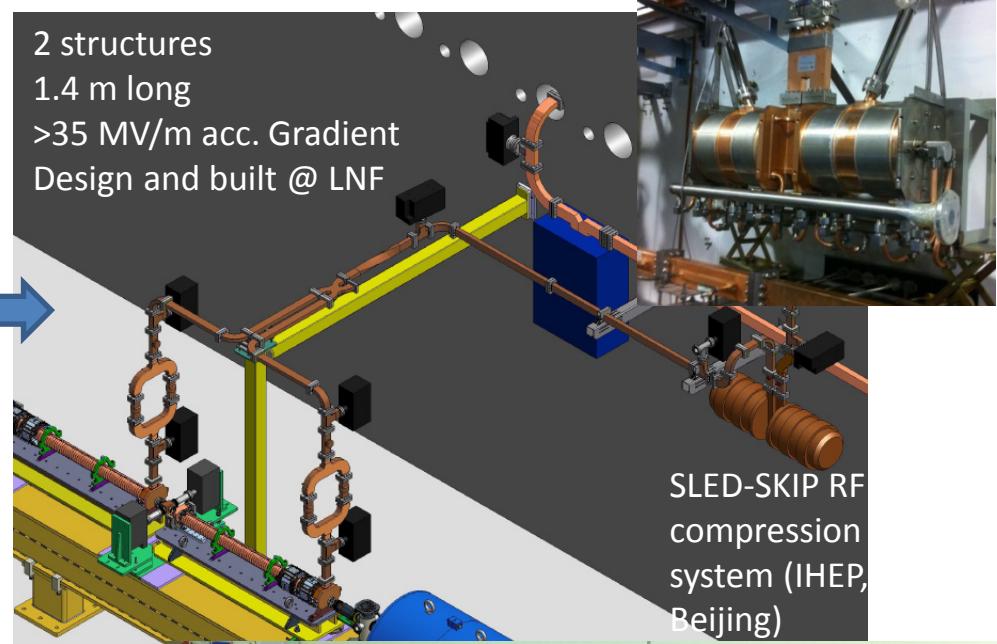
Experimental beam lines for FEL,
Laser plasma acceleration, THz radiation,
Compton source,...

C-BAND ACCELERATING SYSTEM @ SPARC

The **energy upgrade** of the SPARC photo-injector at LNF-INFN from 170 to more than 240 MeV will be done by replacing a low gradient S-Band accelerating structure with two C-band structures. The structures are **TW and CI**, have symmetric axial input couplers and have been optimized to work with a SLED RF input pulse. In the SPARC photoinjector the choice of the C-band for the energy upgrade was dictated by the opportunity to **achieve a higher accelerating gradient**, enabled by the higher frequency, and to **explore a C-band acceleration combined with an S-band injector** that, at least from beam dynamics simulations was very promising in terms of achievable beam quality.



S-Band SLAC-type structure
22 MV/m



S-Band gun 120 MV/m

DESIGN OF C-BAND TW STRUCTURES FOR SPARC

(D. Alesini, et al, JINST, 8, P05004, 2013)

Structure design criteria:

-**CONSTANT IMPEDANCE** (all equal irises) to simplify the fabrication and to reduce the unbalance between the accelerating field at the entrance and at the end of the structure, due to the combination of power dissipation along the structure and SLED pulse profile.

-**LARGE IRISES WITH ELLIPTICAL SHAPE** to

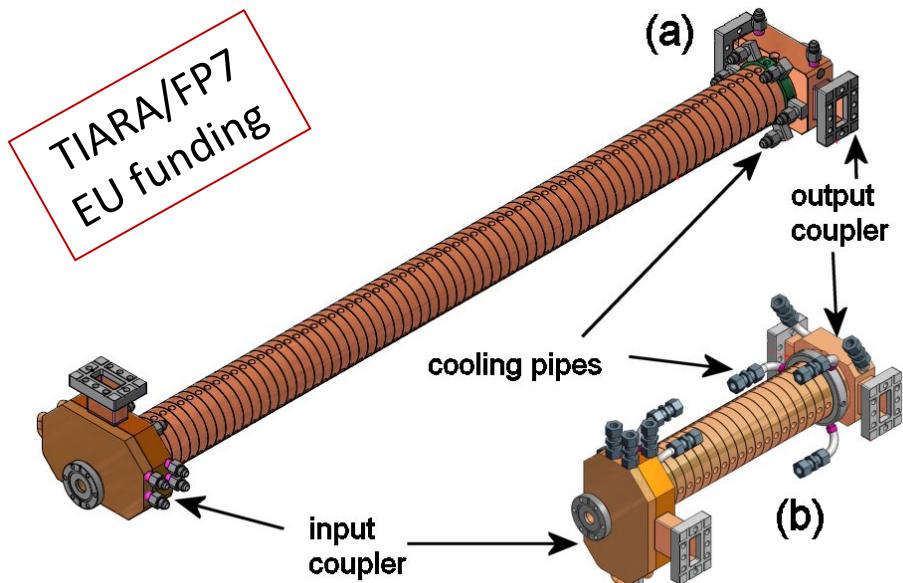
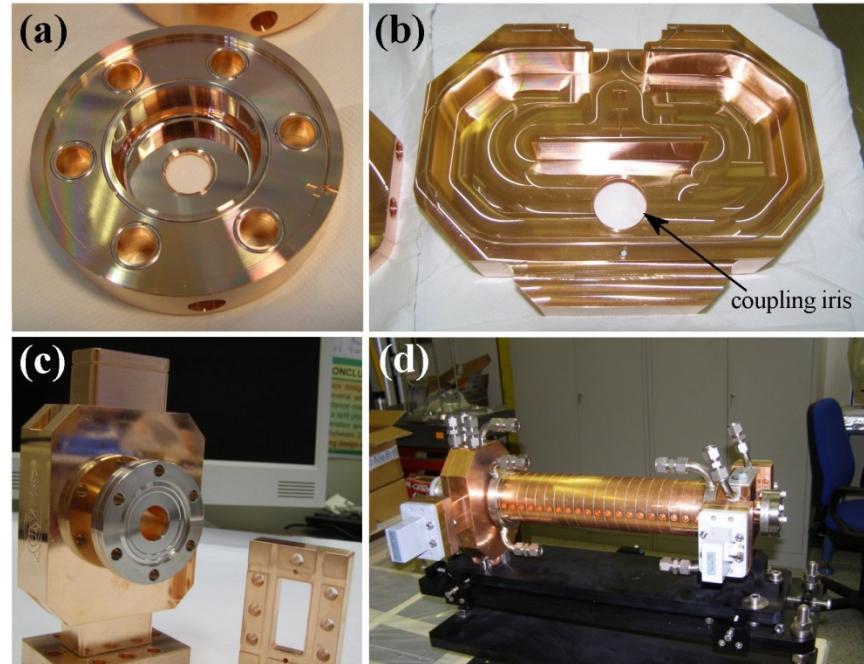
-reduce the peak surface field obtaining at the same time **an average accelerating field >35 MV/m** with the available power from the klystron;

-reduce the filling time of the structure and, consequently, the RF input pulse length thus reducing the breakdown rate;

-reduce the dipole wake intensity

-increase the pumping speed.

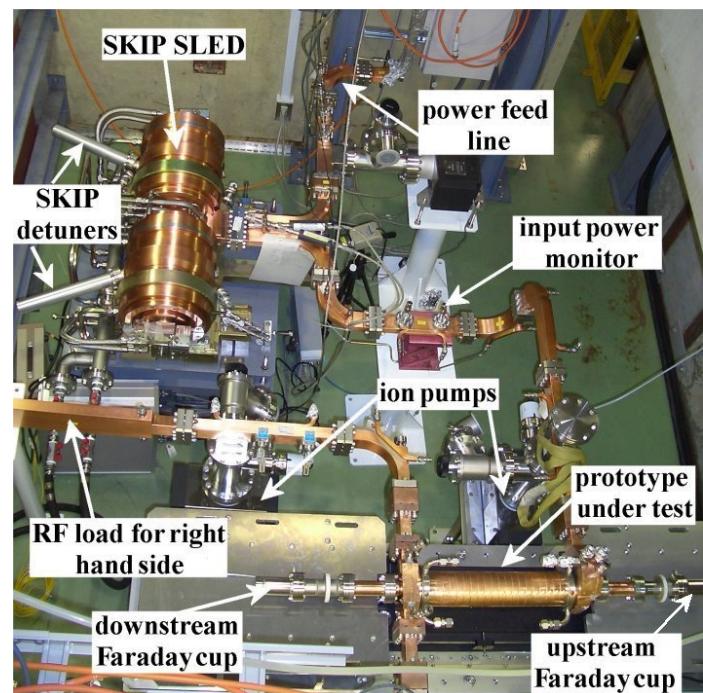
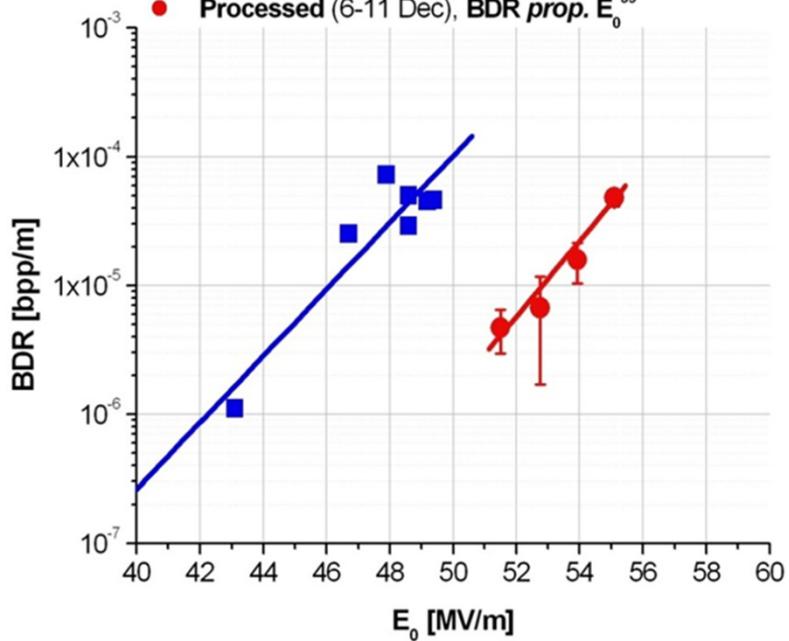
-**WAVEGUIDE COUPLER** design based on “low pulsed heating” couplers for high gradient operation of X Band structures (SLAC).



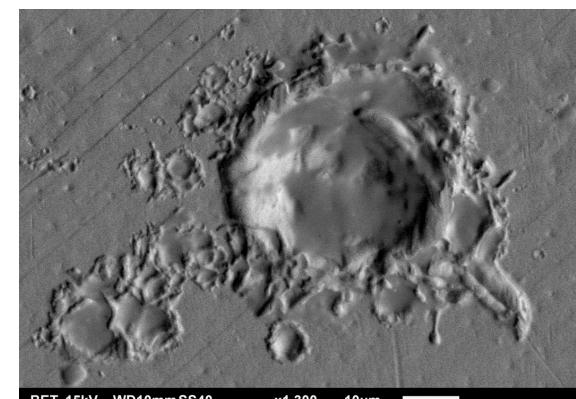
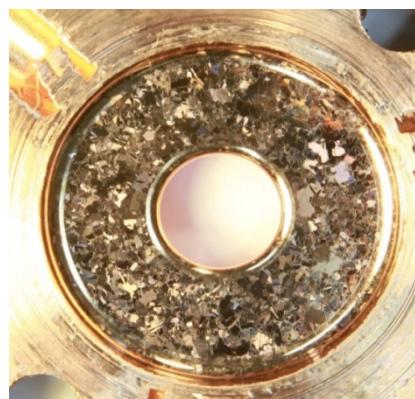
TEST AT HIGH POWER (@KEK) OF THE PROTOTYPE

The high-power test started on November 5, 2010 and was completed on December 13, 2010. For almost one month of processing, from November 5 until December 2, more than **10⁸ RF pulses of 200 ns width** were sent into the structure with a repetition rate of **50 Hz**. For a couple of days the RF pulse length was changed to 300 ns and for one day (November 12) the repetition rate was decreased to 25 Hz. On November 15, SKIP was switched on.

- Not processed (27 Nov - 1 Dec), BDR prop. E_0^{27}
- Processed (6-11 Dec), BDR prop. E_0^{35}



After the high power test the structure has been **cut in slices** for an **internal inspection**. We have identified the signs of craters and discharges mainly in the first accelerating cell after the input coupler, as expected, because the highest field values are excited at the beginning of CI structures.



MAIN PROBLEMS ENCOUNTERED IN THE FINAL STRUCTURE FABRICATION

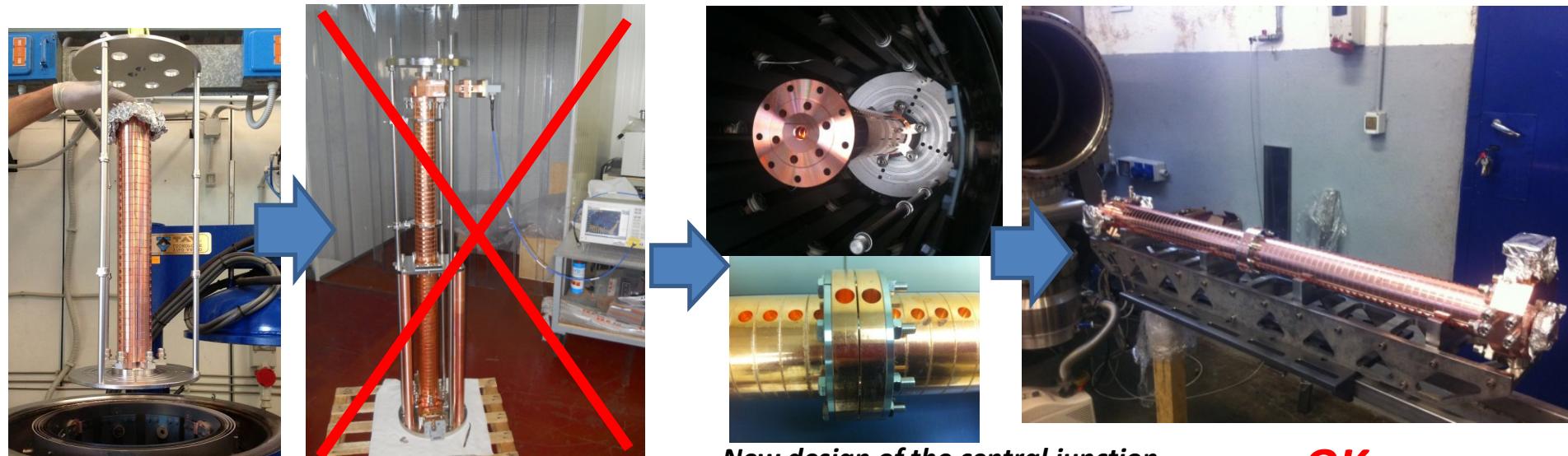
The main problems were related to the fact that we do not have a vertical >1.5 m long oven for brazing and we had to braze the structures in several steps.

Each brazing step is a structure “stress”, requires a full control of the process and introduces unknowns since the success of the brazing cannot be guarantee at 100% even with a long experience.

The design, machining and brazing of a new (complicated) structure (such as the SPARC C-band structures), require a strong activity of R&D and prototyping at least in the first phase to investigate all possible criticalities (RF, mechanical).

For the SPARC C-band structures, we have fabricated only one small prototype before starting the construction of the first complete structure and this is the reason why we had to re-machine and re-cut the first structure a couple of time. In other words the first structure has been a prototype.

At LNF-INFN this experience has been the first experience of a complete in-house design, realization and test of a such long multi-cell TW structure. We gain a lot (a lot) of experience thanks to this work.



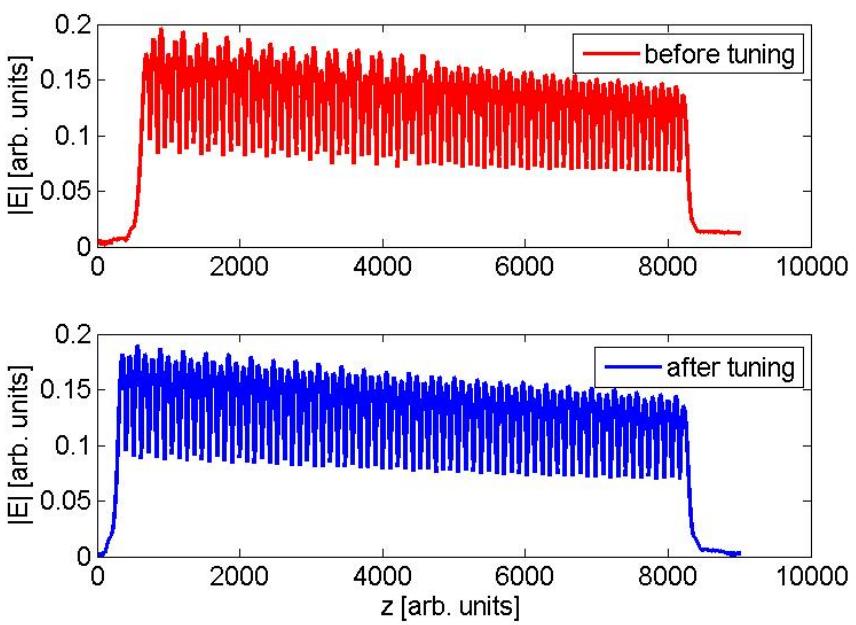
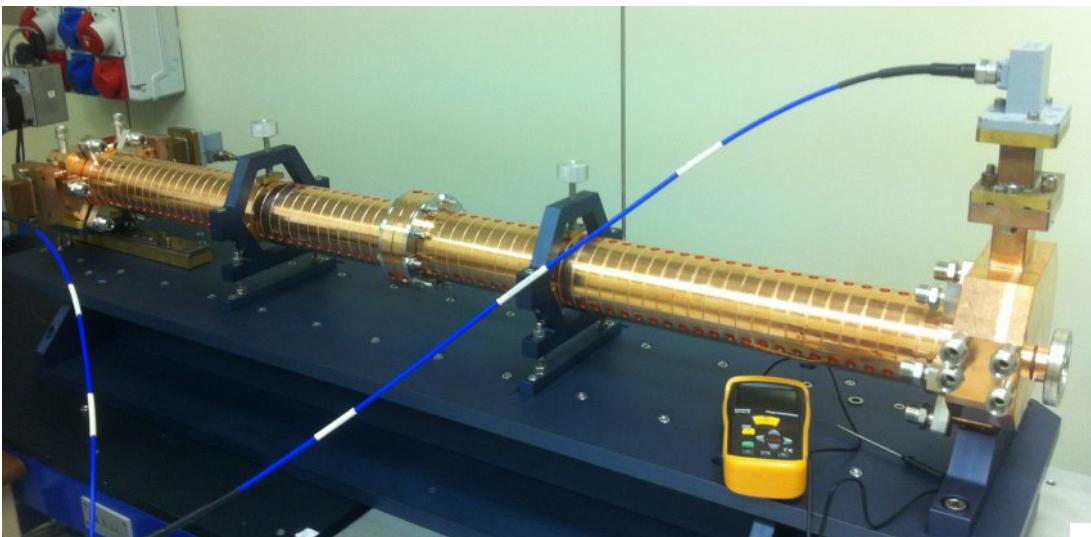
First realization technique

*New design of the central junction,
re-machining and brazing*

OK

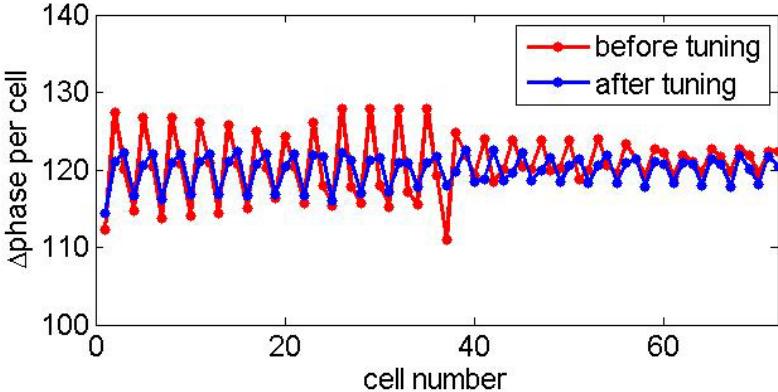
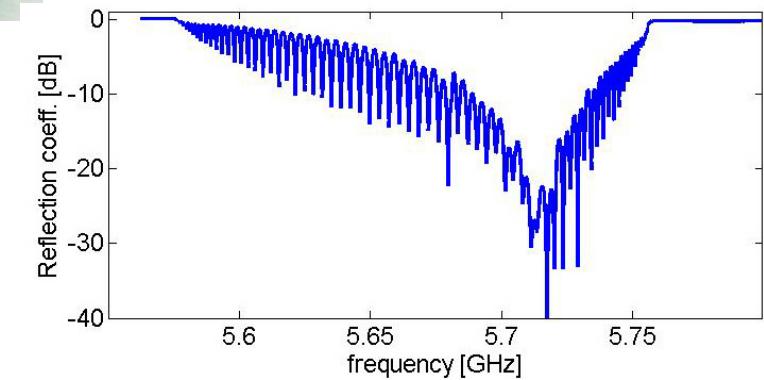
LOW POWER RF MEASUREMENTS ON FINAL C-BAND STRUCTURES

First fabricated C-band structure



(D. Alesini, et al, JINST 8, P10010, 2013)

PARAMETER	final structure
Frequency	5.712 [GHz]
Phase advance per cell	$2\pi/3$
Number of accel. cells	71
Structure length	1.4 [m]
Group velocity/c	0.0283
Field attenuation	0.206 [1/m]
Average accelerating field	>35 MV/m
Shunt impedance (r)	82.9 [$M\Omega/m$]
Filling time	150 [ns]
Surf. peak E field/Acc. field	2.17
Surf. Peak H field@ 35 MV/m	87.2 [kA/m]
Pulsed heating @ 35 MV/m	<1 °C
Av. dissipated power @ 10 Hz	59.6 [W]



C-BAND HIGH POWER STATION @ SPARC

Toshiba ET37202 klystron and solid state modulator by Scandinova



Frequency	5712 MHz
Output RF power	50 MW (max).
RF pulse length	2.5 μ sec
Pulse rep. rate	50 pps max.
Gain	44 dB min
Efficiency	40 % min
Drive power	300 W

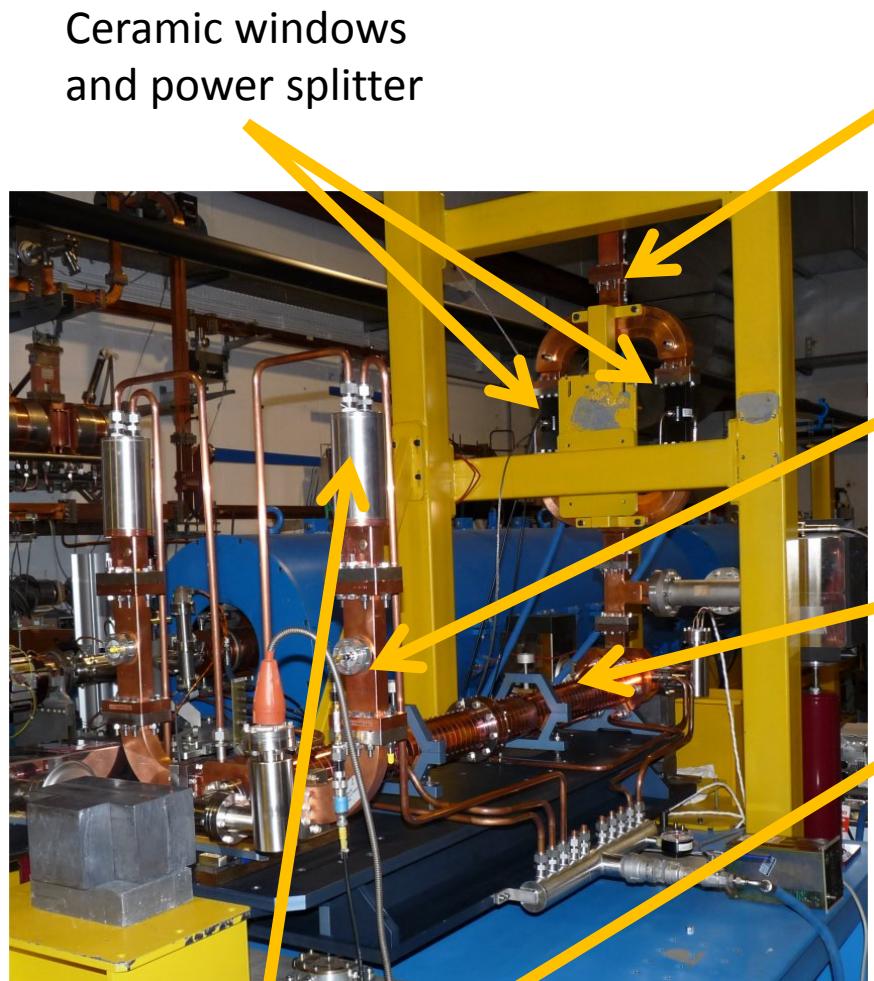
The new C-band power station will consist mainly of:

- C-band klystron, manufactured by Toshiba Ltd (JP)
- Pulsed HV modulator supplied by ScandiNova (S)
- WR187 waveguide system with power pulse compressor.
- 500 W solid state klystron driver supplied by MitecTelecom (CDN)

Test stand for high power test



C-BAND STRUCTURES: HIGH POWER TEST BENCH @SPARC



Ceramic windows
and power splitter

RF Loads

RF pickup
FW-RW

RF Pickup
TRANS

C-Band structure

From KLY



Ion pumps

HIGH POWER TEST @SPARC: RESULTS (1/2)

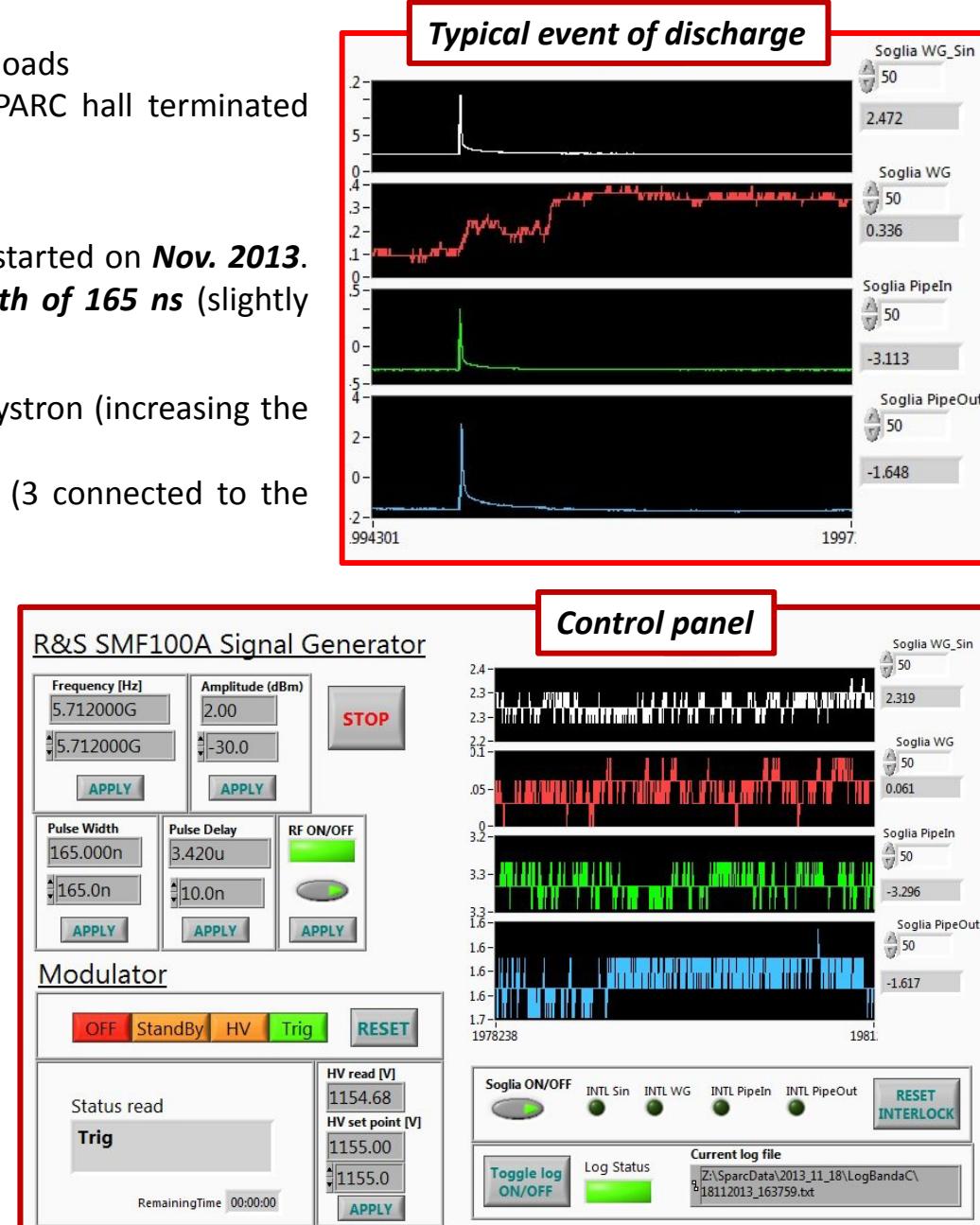
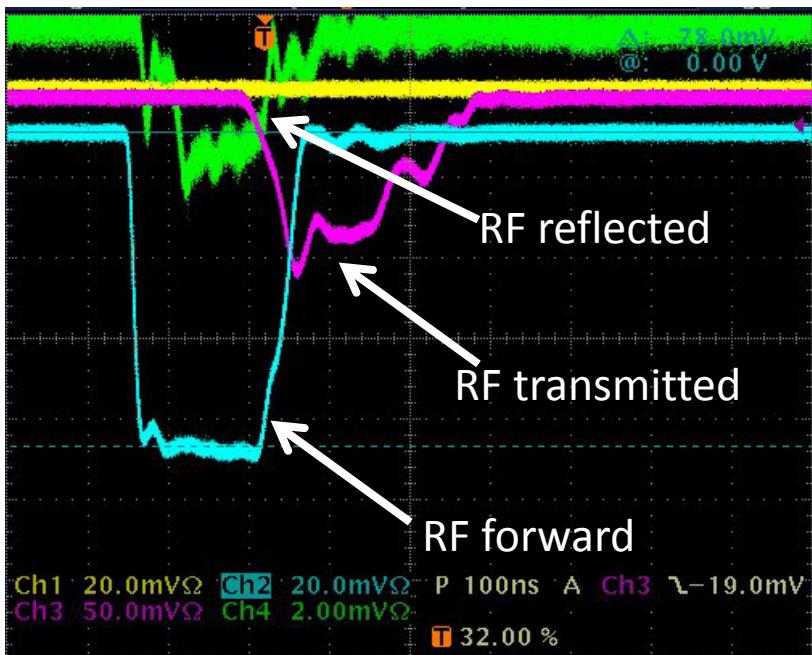
1) The RF conditioning has been done in three steps:

- ⇒ test of the **Klystron system** terminated into a loads
- ⇒ test of the **waveguide system** up to the SPARC hall terminated into a load
- ⇒ test of the **first accelerating structure**

2) The high power test on the first C-band structure started on **Nov. 2013**. We operated at **10 Hz with the nominal pulse width of 165 ns** (slightly longer than the filling time of the structure).

3) We progressively increased the power from the klystron (increasing the HV of the modulator) monitoring:

- ⇒ the **current absorption of the 4 ion pumps** (3 connected to the structure and 1 to the waveguide);
- ⇒ the **RF signals from pickups**.



HIGH POWER TEST @SPARC: RESULTS (2/2)

1) The conditioning procedure was semi-automatic and the switch-off on the HV were caused by:

⇒ operator

⇒ ion pumps current absorption above a certain threshold (50 µA corresponding to a vacuum of 10^{-7} mbar) including the ion pump absorption directly connected to the KLY output;

⇒ KLY interlocks (tube vacuum, modulators interlocks);

2) We normally operate at a vacuum level in the structure between $5 \cdot 10^{-10}$ mbar and $2 \cdot 10^{-9}$ mbar.

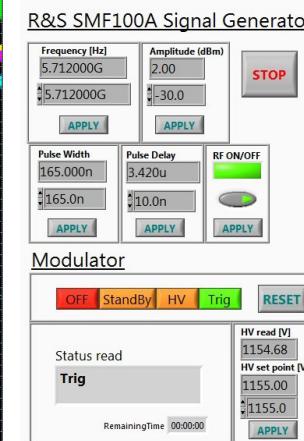
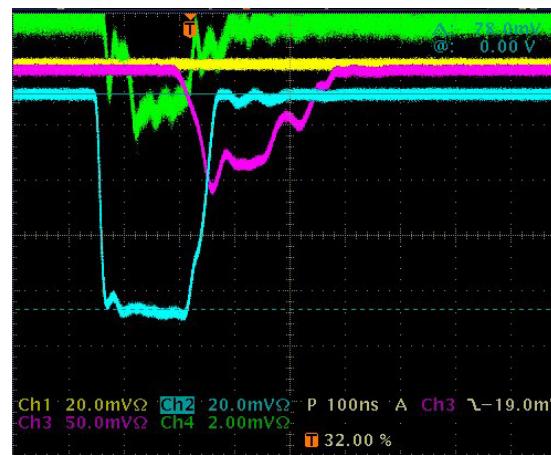
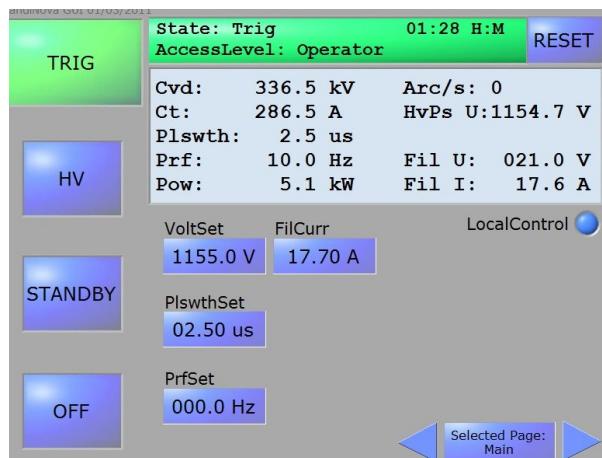
3) The duration of the RF conditioning (not h24) was about 10-15 full days equivalent! We have finally reached:

⇒ **38 MW input power in the structure** (44 MW from the klystron), **nominal rep. rate and pulse length**.

⇒ the corresponding accelerating field was **36 MV/m peak and 32 MV/m average**

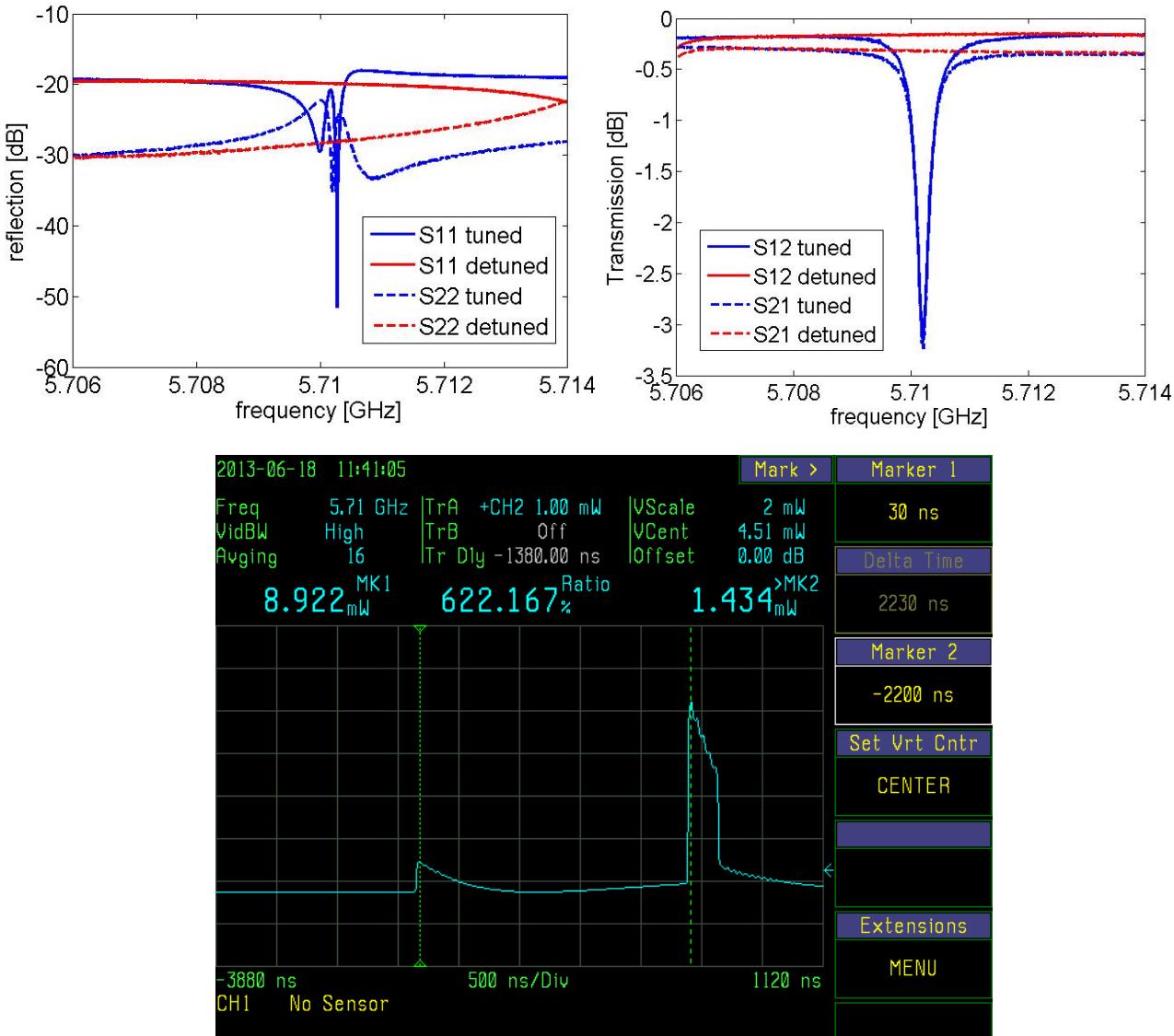
⇒ **BDR <10⁻⁵** but even less because a correct measurements of the BDR require a long time and we would test both structures in a shorter time!

⇒ 340 KV modulator voltage



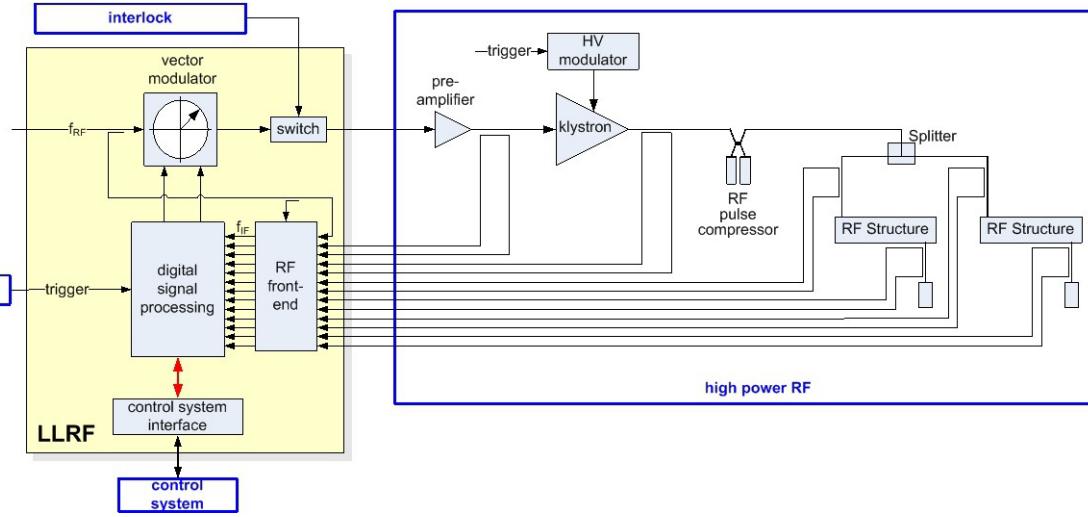
C-BAND SLED LOW POWER MEASUREMENTS

The SKIP SLED has been fabricated in IHEP (Beijing). It has been fixed to the SPARC experimental hall ready for waveguide connection.



C-BAND LLRF

A **stable and flexible digital low level RF system** to control the input to the RF amplifiers and monitor the RF signals of the high gradient C-band accelerating structures at SPARC test facility has been designed and fabricated by PSI Institute in the framework of the **TIARA project**. The **LLRF system has been integrated into the SPARC control system** by implementing an EPICS/LabVIEW interface using the EPICS CA drivers in LabVIEW programming environment that is fully compatible with the SPARC_LAB control system.



Analogue part

Number of RF signal receivers: 12 + 4 spares

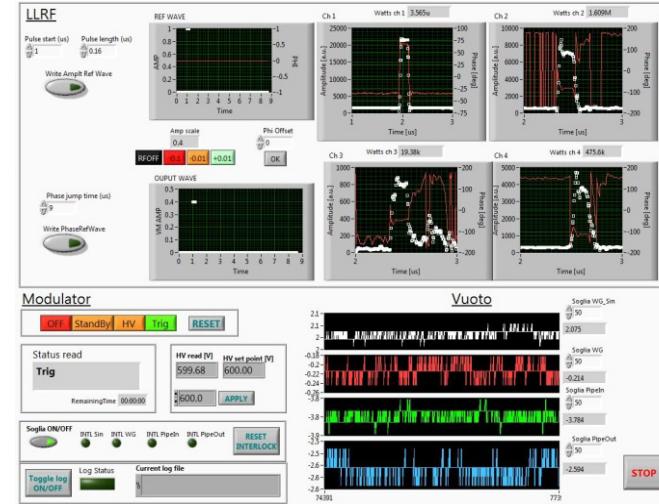
RF Frequency 5.712 GHz

IF Frequency 39.666 MHz

Bandwidth (3dB) ± 18 MHz

Phase resolution < 15 fs or 0.03 deg

Amplitude error ≈ 0.1 dB (10 dB range)



Digital part

16 ADC channels (to sample IF waveforms)

4 DAC channels (for vector modulator control)

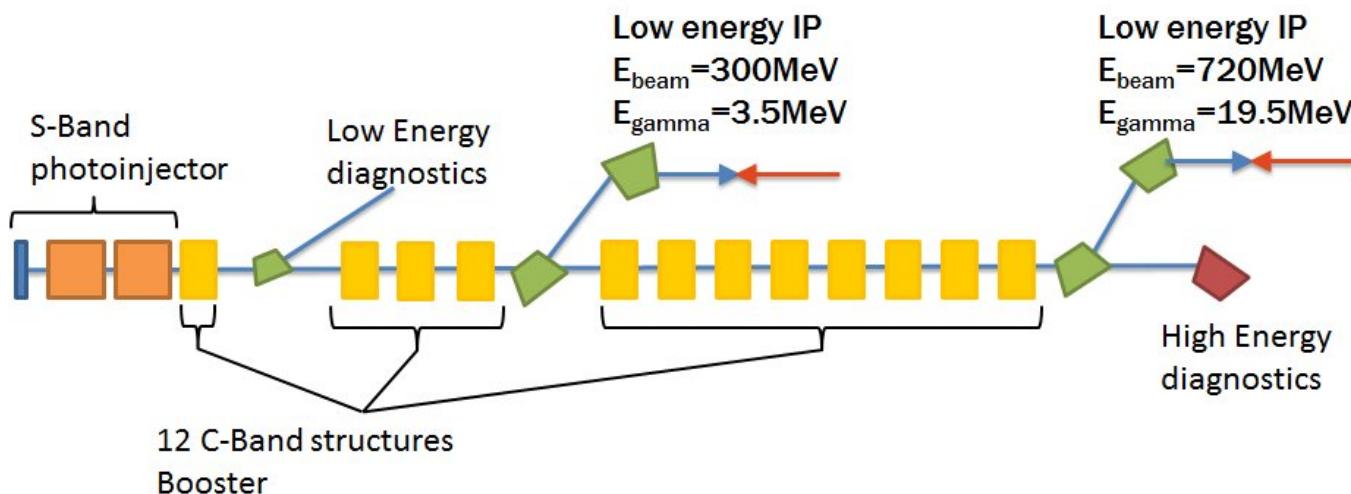
FPGA for signal processing

EPICS server implemented in the main CPU

NEXT STEP: HOM DAMPED-HIGH REP. RATE STRUCTURES FOR ELI-NP GAMMA BEAM SYSTEM

In the **context of the ELI-NP Research Infrastructure**, to be built at Magurele (Bucharest, Romania), an advanced Source of Gamma-ray photons is planned, capable to produce beams of mono-chromatic and high spectral density gamma photons. The **Gamma Beam System is based on a Compton back-scattering source**. Its main specifications are: photon energy tunable in the range 1-20 MeV, rms bandwidth smaller than 0.5% and spectral density larger than 10^4 photons/sec.eV, with source spot sizes smaller than 10-30 microns.

For this LINAC **high gradient/high rep rate and damped structures (for multi-bunch operation)** are required to allow an high gamma flux and a compact source.

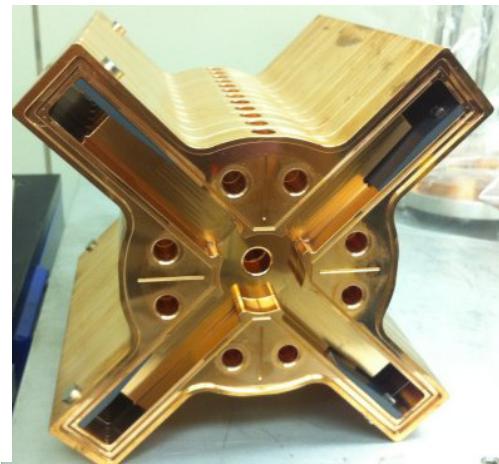
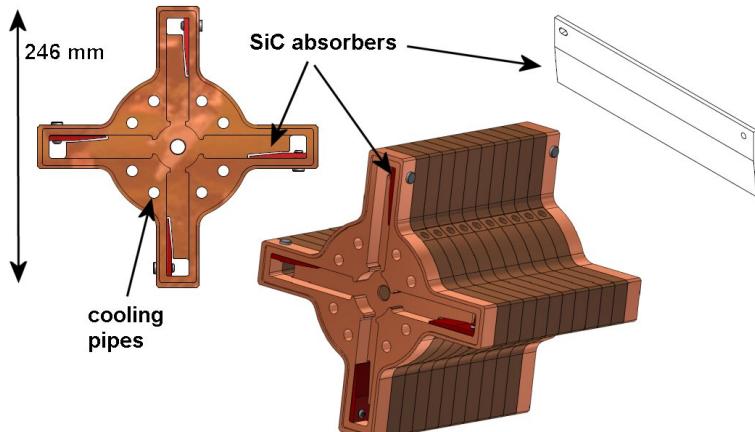
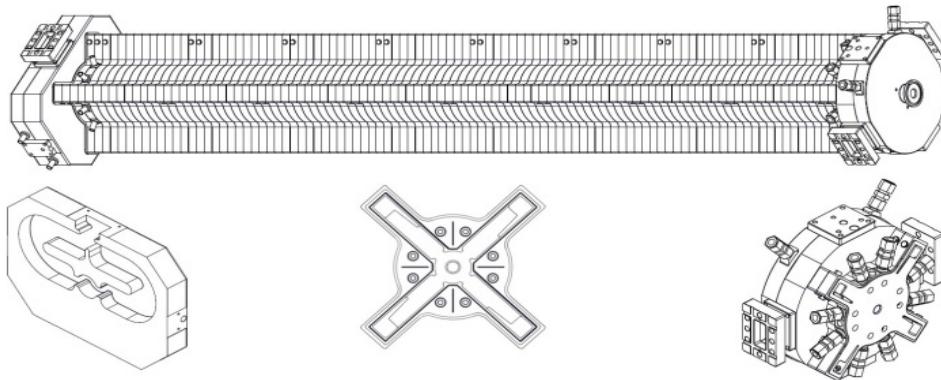


Bunch charge	250 pC
Number of bunches	32
Bunch distance	16 ns
C-band average accelerating gradient	33 MV/m
Norm. emittance	0.2-0.6 mm·mrad
Bunch length	<300 μm
RF rep Rate	100 Hz

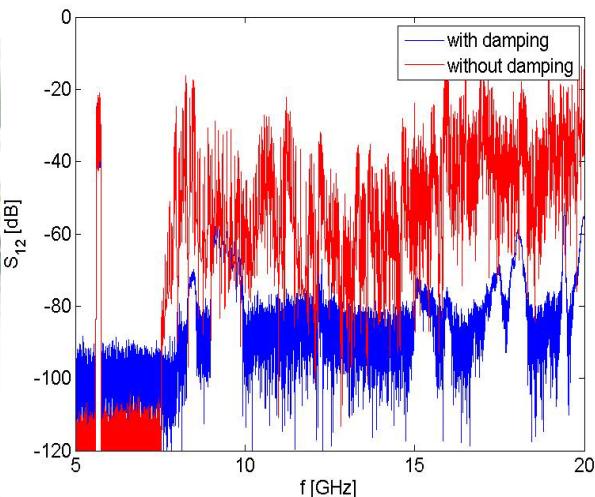
ACCELERATING STRUCTURES FOR ELI-GBS

(THPRI042)

Since the ELI-NP linac operation is necessarily multi-bunch, in order to achieve the requested photon flux, the structures have been designed with an **effective damping of the HOM dipoles modes to avoid BBU instabilities**. The solution adopted for the ELI-NP structures is based on a waveguide damping system, similar to the design adopted for the CLIC structures, but the mechanical design has been strongly simplified with respect to CLIC-type structures to reduce the cost and to simplify the fabrication.



PARAMETER	SPARC	ELI-GBS
Type	TW-CI	TW- quasi CG, HOM damped
Frequency (f_{RF})	5.712 [GHz]	5.712 [GHz]
Phase advance per cell	$2\pi/3$	$2\pi/3$
Structure Length	1.4 m (71 cells)	1.8 m (102 cells)
Iris aperture (a)	7 mm	6.8-5.78 mm
Attenuation constant	0.0283	0.266-0.458
Filling time	150 ns	310 ns
Shunt imp. (r)	83 [$M\Omega/m$]	67-73 [$M\Omega/m$]
RF input power	>40 MW (SLED)	40 MW (constant, 822 ns)
Average accelerating field	>35 MV/m	33 MV/m
Rep. Rate (f_{rep})	10 Hz	100 Hz
Average dissipated power	60 [W]	2.3 [kW]



CONCLUSIONS

1. C-Band “adventure” started @ LNF for the SPARC energy upgrade-single bunch operation.
2. The first prototype (22 cells) has been tested at **gradients >50 MV/m**
3. The two final C-band structures have been designed, fabricated and tested at high power reaching stable operation at gradients of 35 MV/m.
4. **The next and important step is the realization of damped-high rep rate C-band structures for multi-bunch acceleration** developed for the ELI-NP Gamma Beam System.

...THANK YOU FOR YOUR ATTENTION