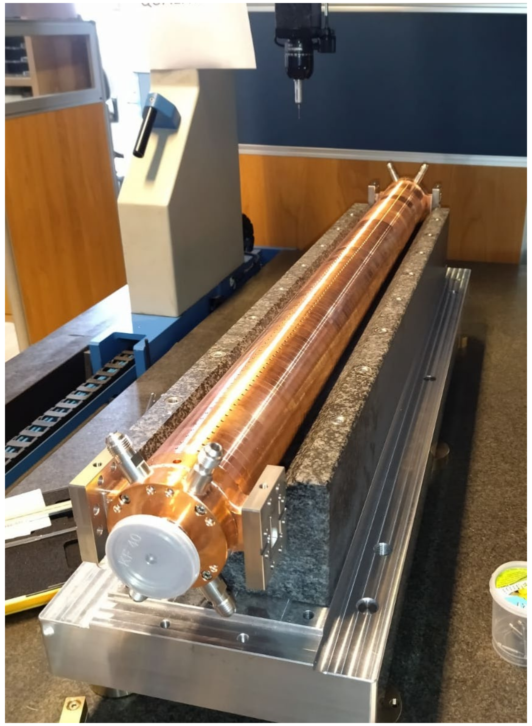
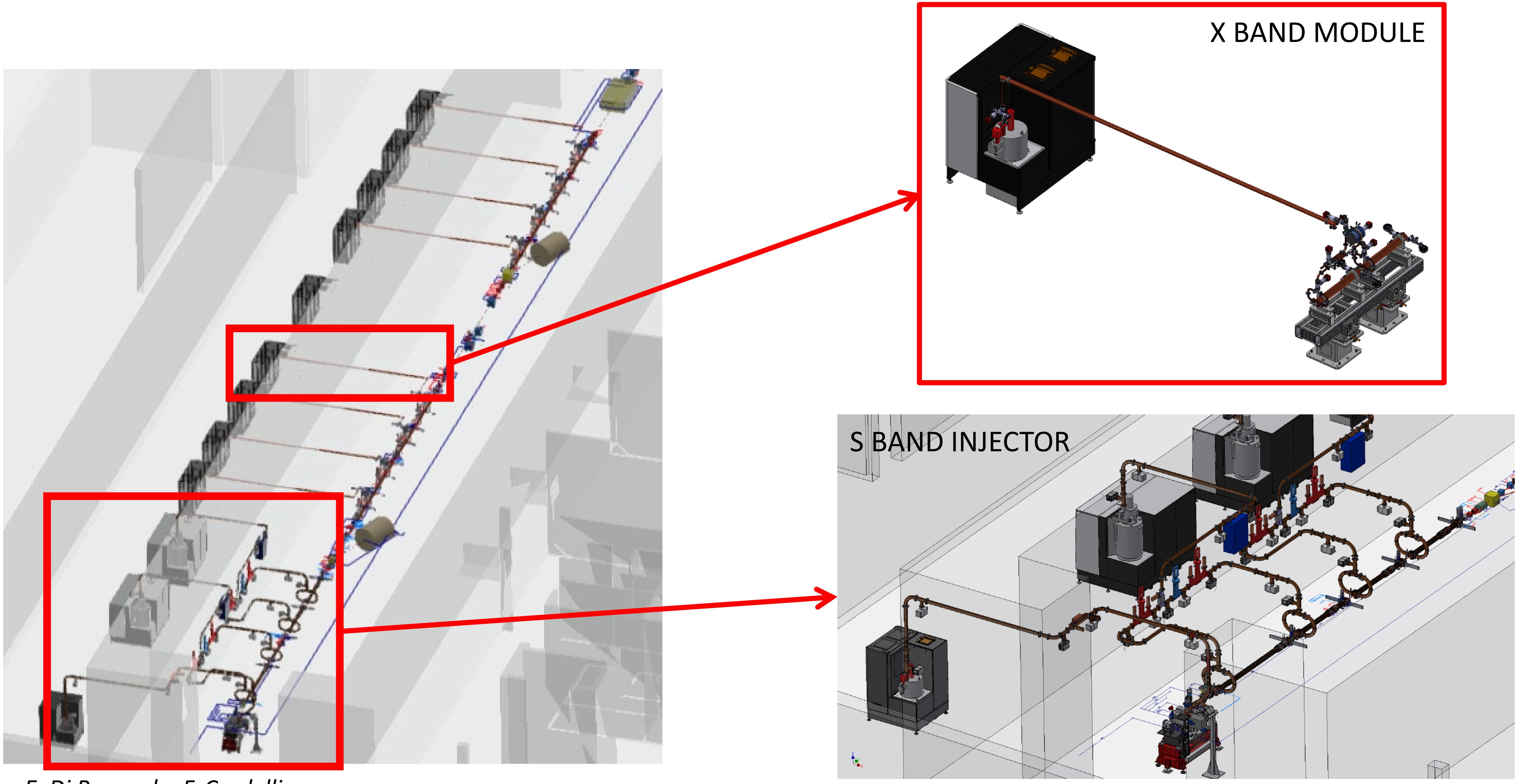
EuPRAXIA@SPARC_LAB TDR Review Committee, 30 Nov-2 Dec 2022

RF SECTIONS AND RF POWER

David Alesini

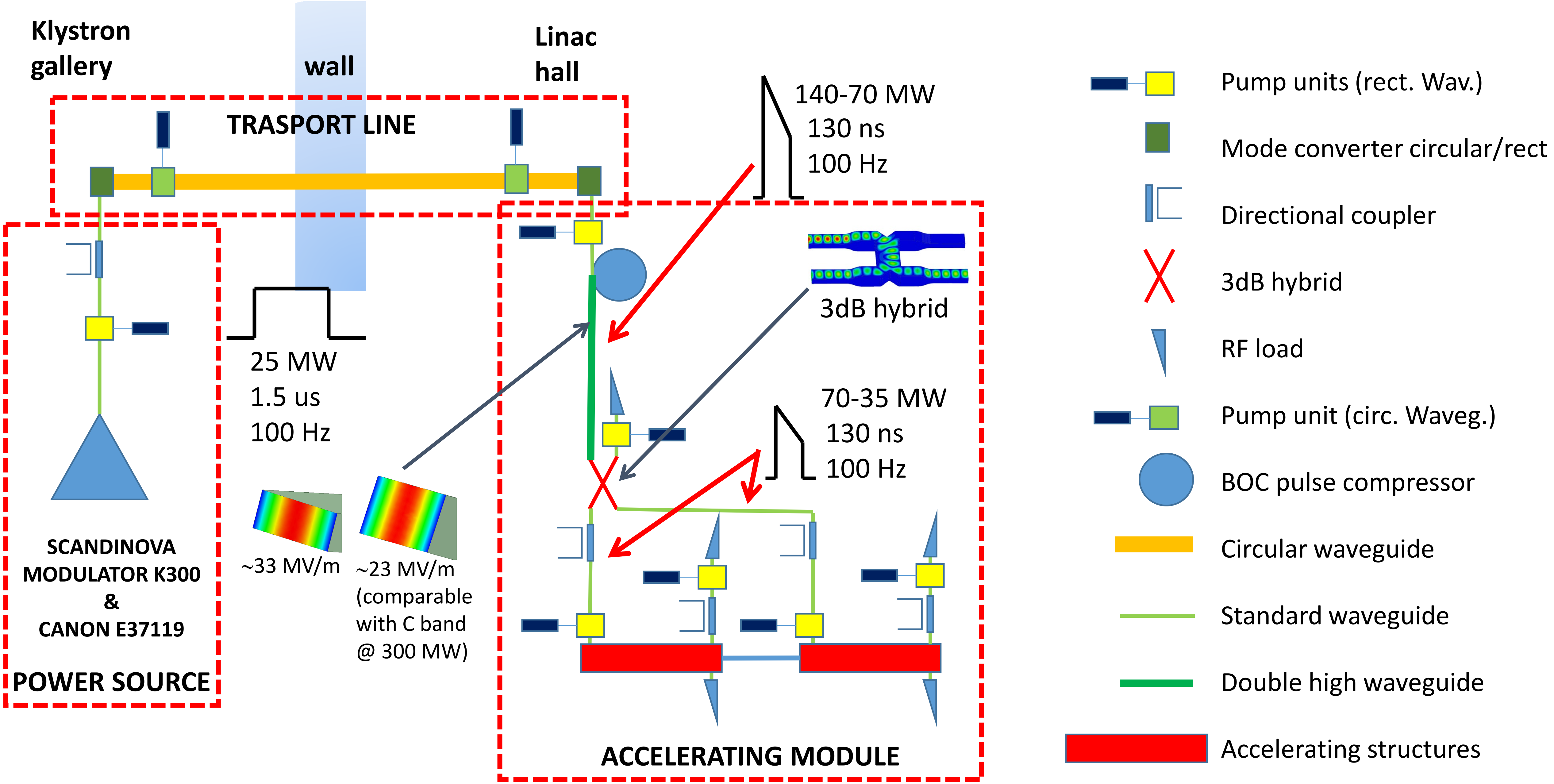


RF SECTIONS AND POWER SOURCES: GENERAL LAYOUT

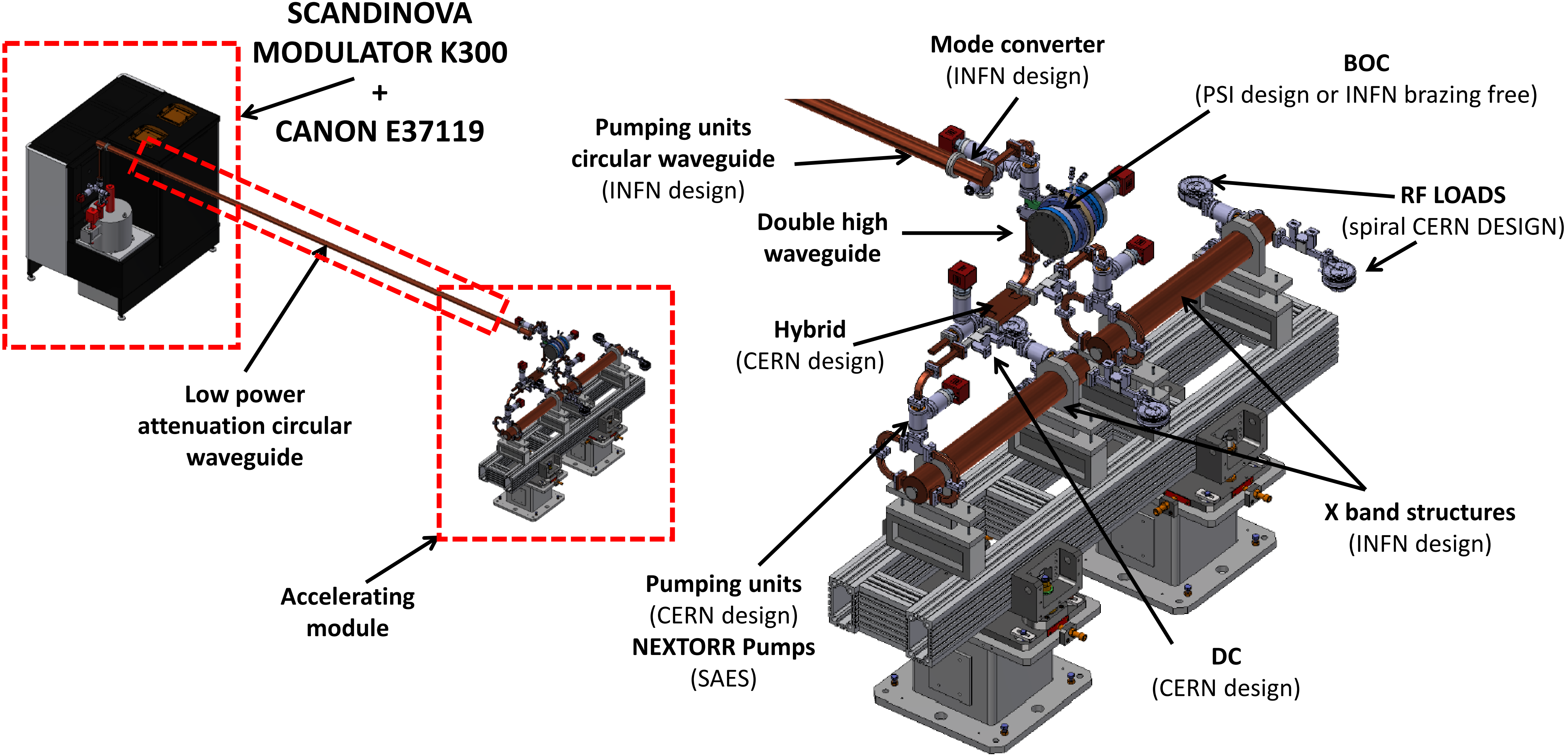


Courtesy E. Di Pasquale, F. Cardelli

X BAND RF MODULE: SCHEMATIC LAYOUT



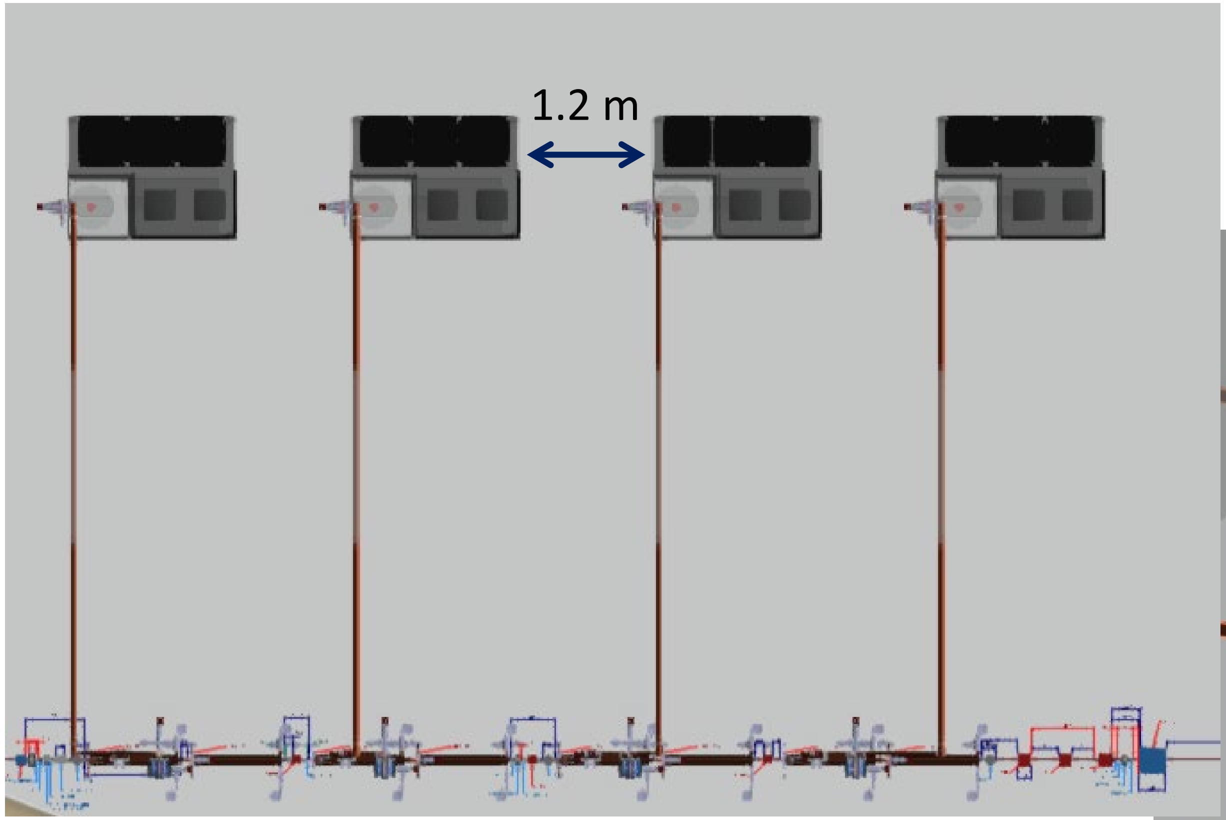
X BAND RF MODULE: MECHANICAL LAYOUT

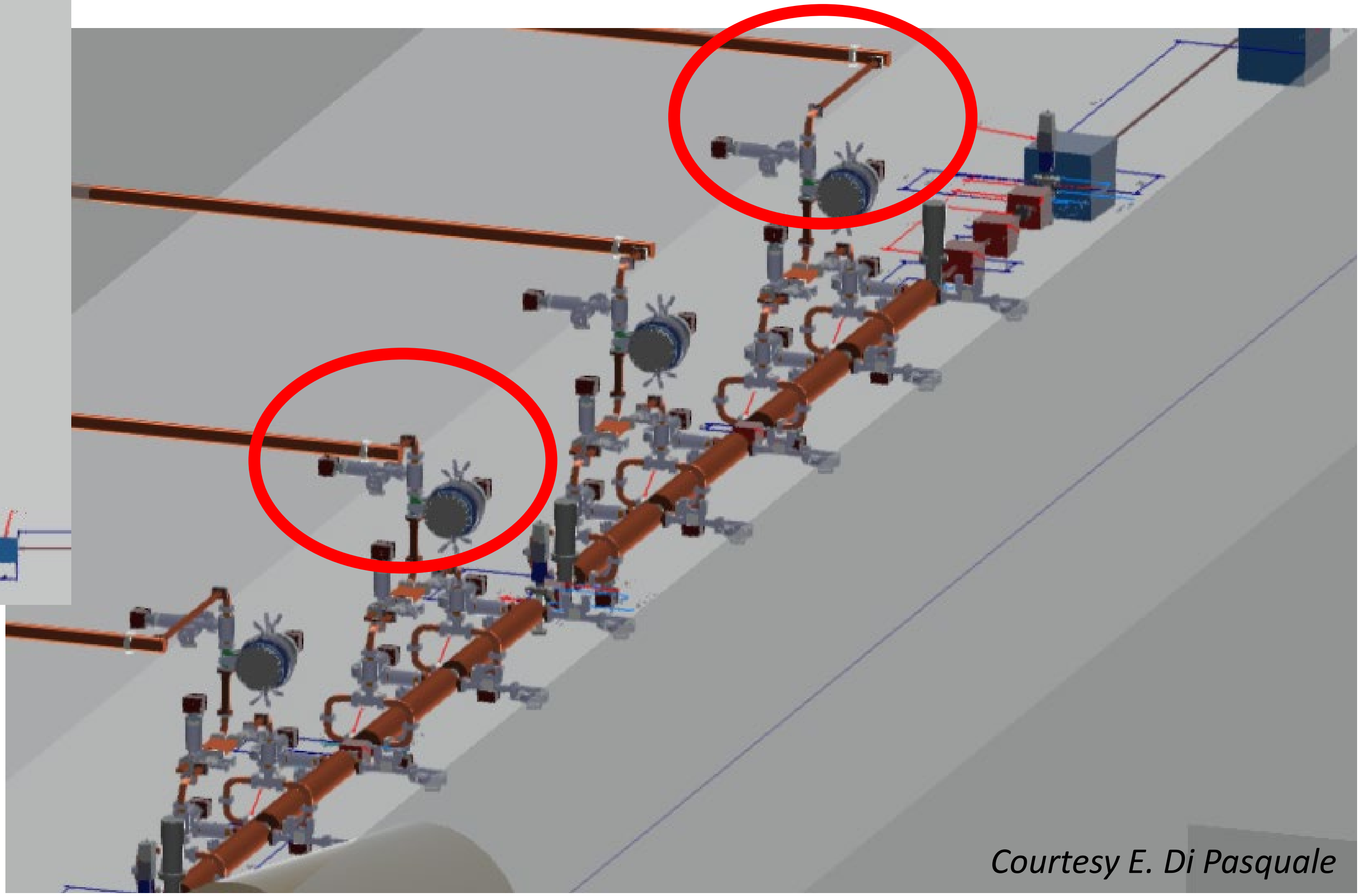


Courtesy E. Di Pasquale, F. Cardelli

X BAND RF MODULES DISTRIBUTION

All the **modulators are distributed** in order to guarantee a reasonable space of 1.2 m between them. Variable RF waveguide straight sections allow to feed all the modules with the same inputs having the **same module configuration**.



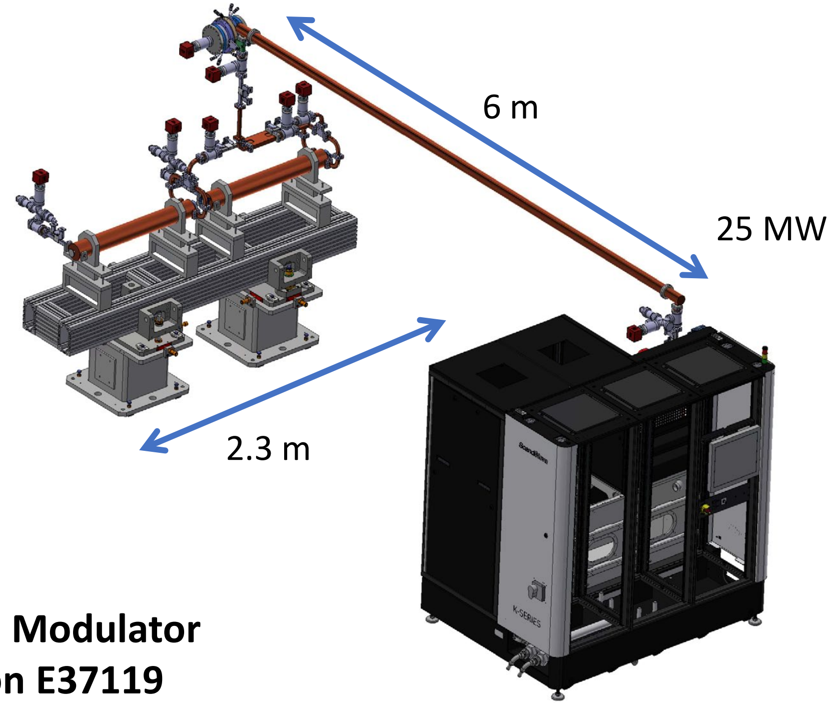


Courtesy E. Di Pasquale

RF MODULE POWER SOURCES: OPTIONS

CANON - BASELINE

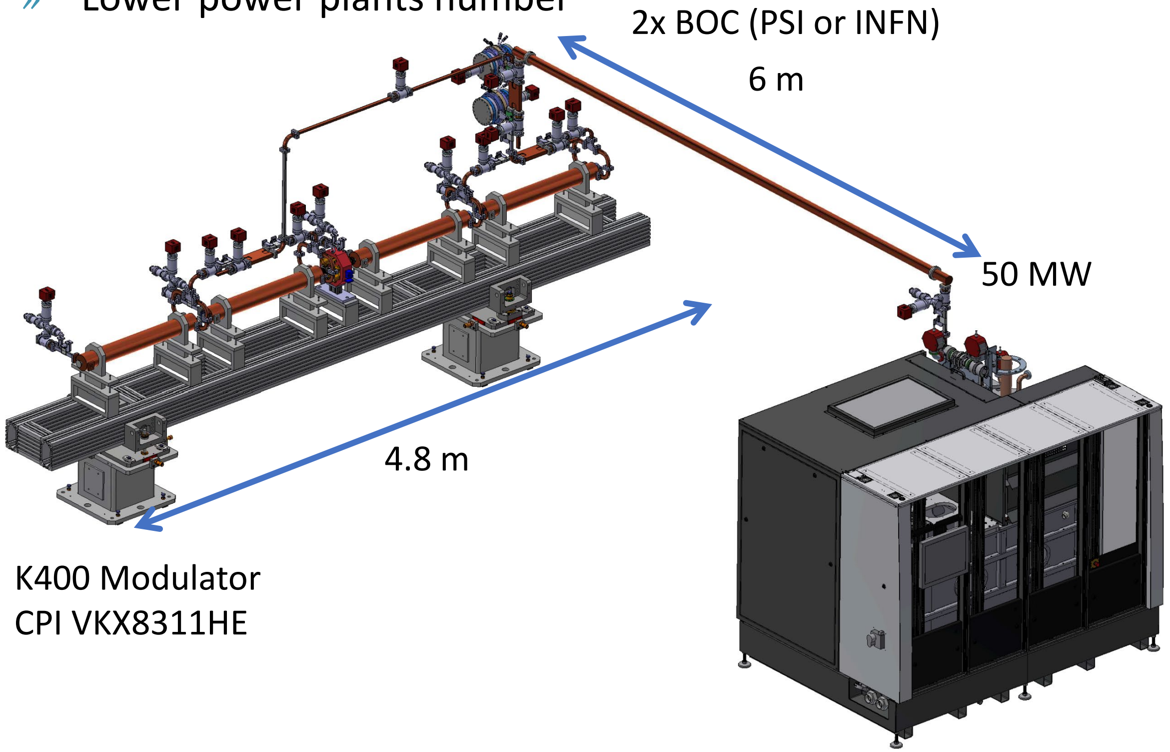
- 1x BOC on one line
- Higher flexibility
- Lower Modulator power requirements
- Possible upgrade at high rep. rate of the Linac (400 Hz)



K300 Modulator
Canon E37119

CPI – OPTION (HIGH EFFICIENCY)

- 2x BOC on one line
- Less flexibility
- Different LE and HE module layout
- Lower power plants number



K400 Modulator
CPI VKX8311HE

RF MODULE POWER SOURCES: OPTIONS

	Unit	Klystron Canon E37119	klystron CPI VKX8311HE
Frequency	MHz	11994	
Heater Voltage	V	20	30
Heater Current	A	20	30
Vk beam voltage	kV	318	415
Ik cathode current	A	197	201
Peak drive power	W	500	
Peak RF output Power	MW	25	50
Average RF output power	kW	15	7,5
Modulator peak power	MW	62,6	83,4
Modulator Average power	kW	75,2	25
Modulator flat pulse	us	3	
RF pulse length	us	1,5	
Repetition Rate	Hz	400	100
Gain	dB	47,0	50
Efficiency	%	40	55

Operational Parameters	Unit	VKX8311A
RF frequency	GHz	11.994
RF Peak Power	MW	50
Gain	dB	48
Modulator Peak Power	MW	140
Operational voltage	kV	420
Operational current	A	320
PRF	Hz	100
Pulse length (top)	us	1.5
Efficiency	%	40

Procurement High Rep. Rate Canon Klystron through Scandinova is ongoing: to be finalized beginning of 2023. We placed the order through Scandinova that will provide the modulator K300 and because it is difficult to directly buy from CANON.

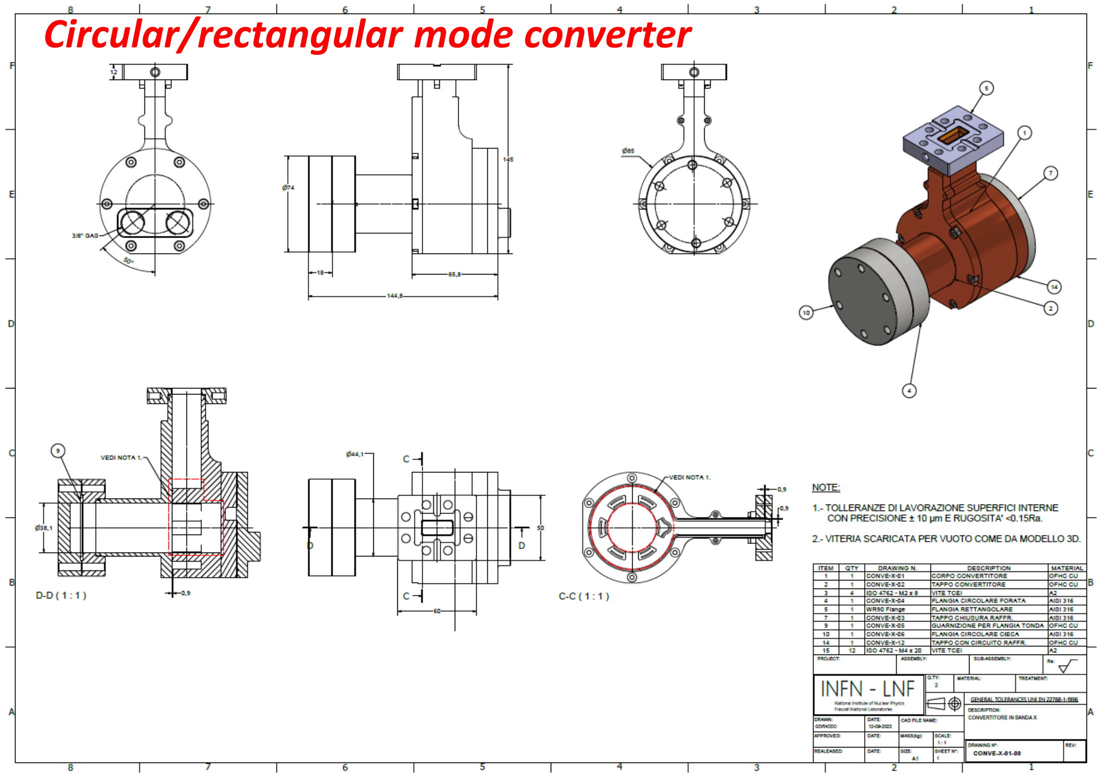
Procurement High Efficiency High Power CPI Klystron concluded. Kickoff in the following weeks. CPI klystron is high efficiency and is a prototype. However, they guarantee the performance of the standard one.

STATUS OF THE WAVEGUIDE COMPONENTS REALIZATION AND TEST

COMPONENT	DESIGNED BY	STATUS	LEVEL OF POWER TO BE TESTED	COMMENTS
Pump units (rect. Wav.)	CERN	Fabricated and installed @ TEX	25 MW 1.5 μs and 70-35 MW 0.13 μs Compressed pulse 100 Hz	
Directional coupler	CERN	Fabricated and installed @ TEX	25 MW 1.5 μs and 70-35 MW 0.13 μs compressed pulse 100 Hz	
RF load	CERN	Fabricated and installed @ TEX	18-9 MW 0.13 μs compressed pulse 100 Hz	Currently, realization is by additive manufacturing. We are developing a design that can be implemented by milling
BOC pulse compressor	PSI	To be ordered (1st half 2023)	140-70 MW 0.13 μs Compressed pulse 100 Hz	We also have a preliminary brazing free design
Mode converter circular/rectangular	INFN	To be ordered (1st half 2023)	25 MW 1.5 μs 100 Hz	We are also looking at CERN design (many versions)
Pump unit (circ. Waveg.)	INFN	To be ordered (1st half 2023)	25 MW 1.5 μs 100 Hz	
3dB hybrid	CERN	To be ordered	140-70 MW 0.13 μs Compressed pulse 100 Hz	

RF COMPONENTS DEVELOPMENTS

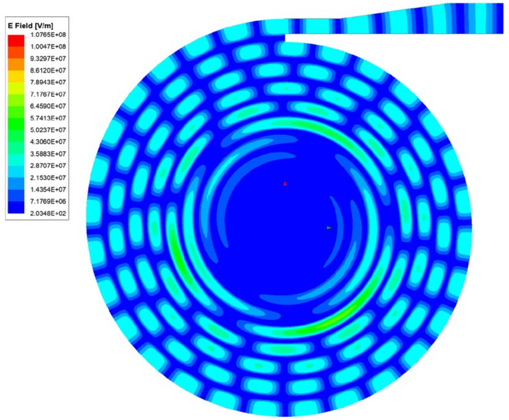
Circular/rectangular mode converter

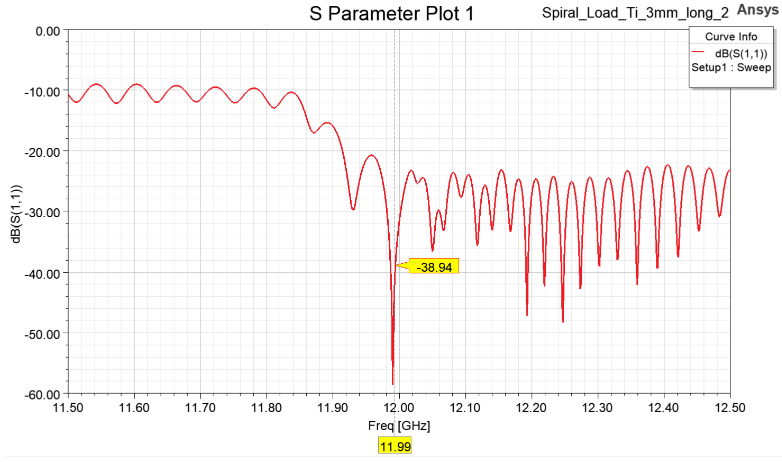


Currently, realization is by **additive manufacturing**. We are developing a design that can be implemented by **milling**:

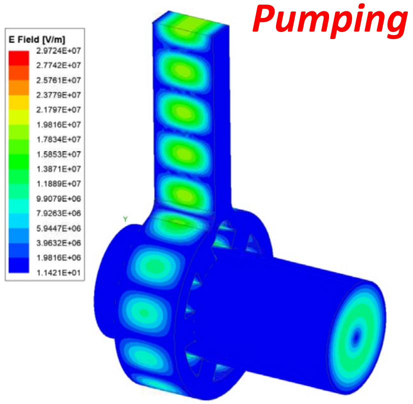
- **Motivation**: the aim is to allow other companies to be able to realize this type of load even without the use of additive manufacturing
- The idea is to replace the vacuum pumping holes by «cutting» the entire load transversely leaving a 1 mm thick gap along the entire length of the waveguide.
- To do this, the thickness of the waveguide walls have been increased from 2 mm to 3 mm to decouple the field between the waveguide windings. The windings of the spiral have been recalculated to keep the overall length of the waveguide as in the original design.

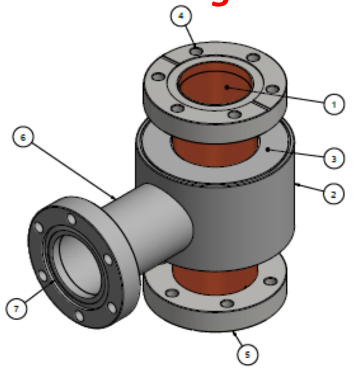
Spiral load





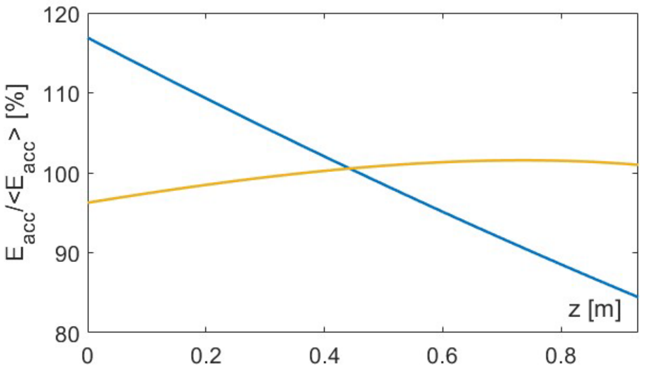
Pumping port on circular waveguide

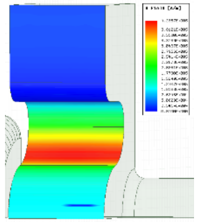




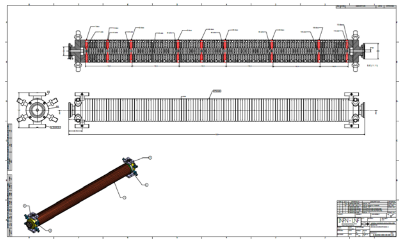
Courtesy F. Cardelli and G. Di Raddo

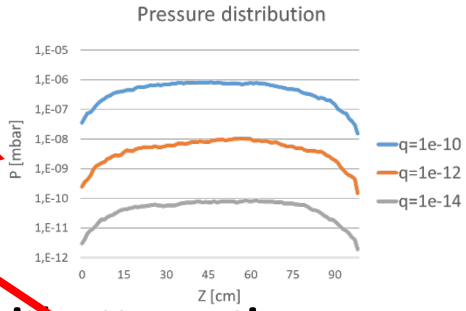
X BAND ACCELERATING STRUCTURES DESIGN: RECAP

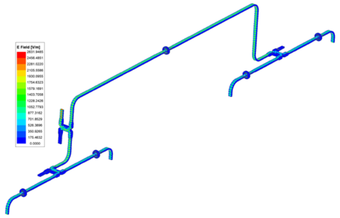


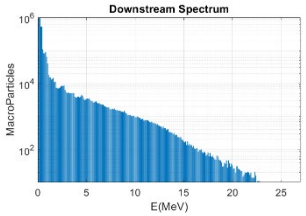


1. **E.m. design**: *done*
2. **Thermo-mechanical analysis**: *done*
3. **Mechanical design**: *done*
4. **Vacuum calculations**: *done*
5. **Dark current simulations**: *done*
6. **Waveguide distribution simulation with attenuation calculations**: *done*







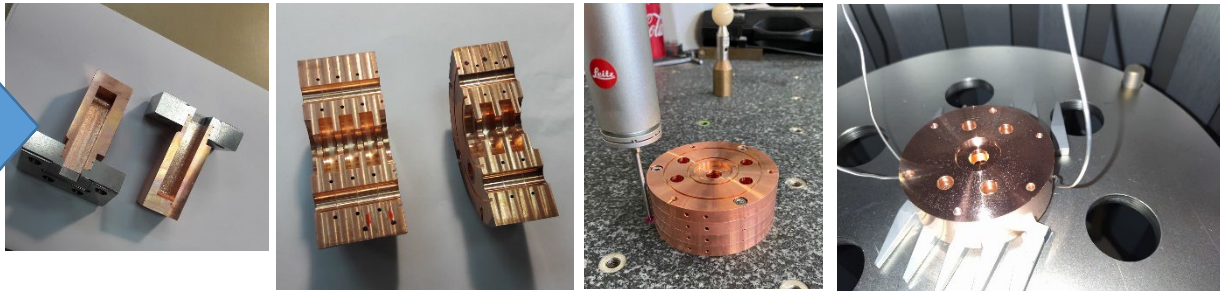


PARAMETER	Value	
	with linear tapering	w/o tapering
Frequency [GHz]	11.9942	
Average acc. gradient [MV/m]	**60**	
Structures per module	2	
Iris radius a [mm]	**3.85-3.15**	**3.5**
Tapering angle [deg]	0.04	0
Struct. length L_s act. Length (flange-to-flange) [m]	**0.94 (1.05)**	
No. of cells	112	
Shunt impedance R [MΩ/m]	93-107	100
Effective shunt Imp. R_{sh_eff} [MΩ/m]	350	347
Peak input power per structure [MW]	70	
Input power averaged over the pulse [MW]	51	
Average dissipated power [kW]	1	
P_{out}/P_{in} [%]	25	
Filling time [ns]	130	
Peak Modified Poynting Vector [W/μm^2]	3.6	4.3
Peak surface electric field [MV/m]	160	190
Unloaded SLED/BOC Q-factor Q_0	150000	
External SLED/BOC Q-factor Q_E	21300	20700
Required Kly power per module (w/o att.)[MW]	**20**	
RF pulse [μs]	**1.5**	
Klystron maximum available power [MW]	**25**	
Rep. Rate [Hz]	**100**	

X BAND ACCELERATING STRUCTURES PROTOTYPING: RECAP

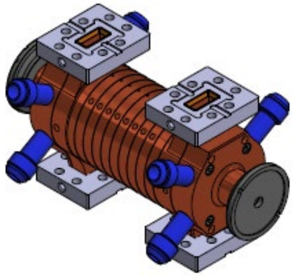
Four main steps of prototyping:

1. **Pre-prototypes** on few cells and simplified couplers to test the brazing procedure, cells assembly, alignment etc: *done*



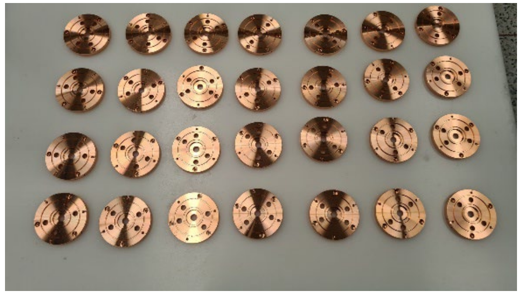
2. **Full scale mechanical prototype**: to test the overall brazing process of the full structure and the cell-to-cell alignment before and after brazing: *done*

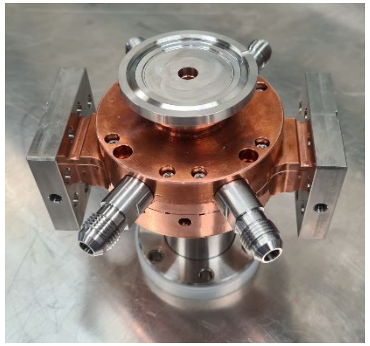
3. **15 cells RF prototype for high power test** w/o tuning, constant impedance: *currently ongoing.*



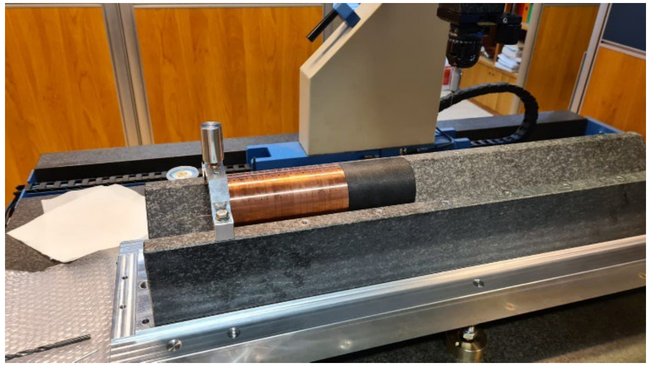
4. **Final full scale structure prototype** constant impedance: *order to be assigned*.

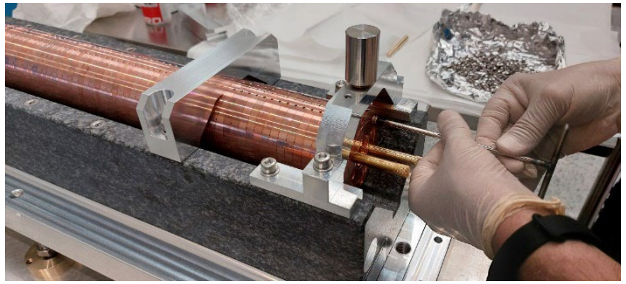
X-BAND STRUCTURE PROTOTYPING ACTIVITIES:
MECHANICAL PROTOTYPE ASSEMBLY AND CHARACTERIZATION



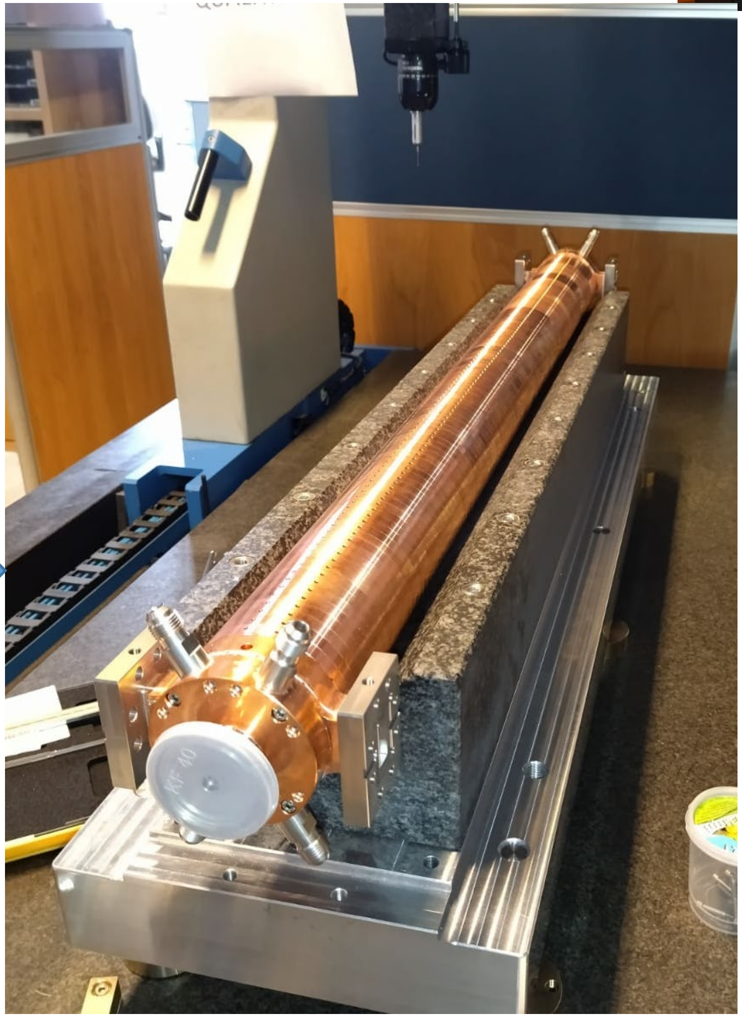


Assembly procedure and dimensional characterization

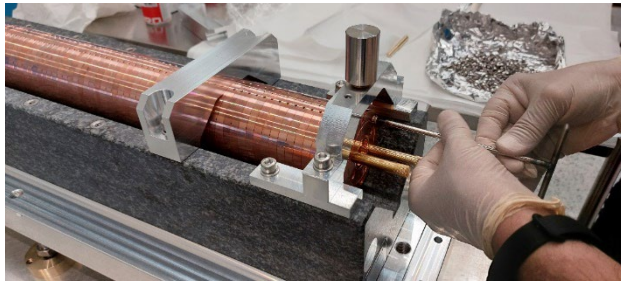


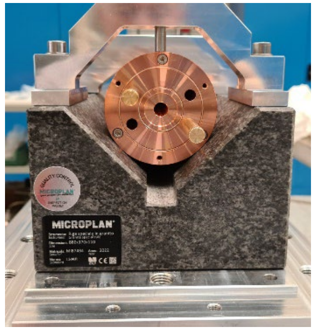


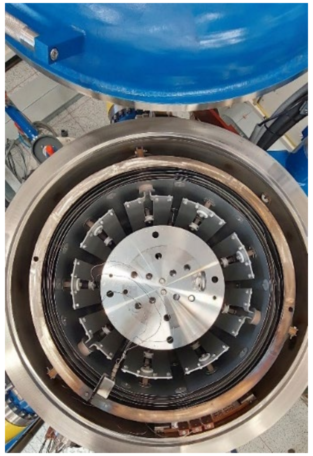
Final structure
(**straightness ±15 μm, before brazing**)

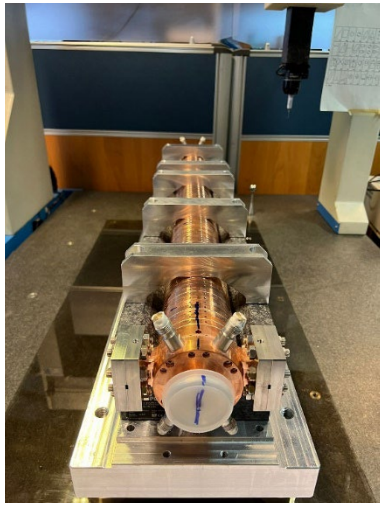


X-BAND STRUCTURE PROTOTYPING ACTIVITIES: MECHANICAL PROTOTYPE BRAZING





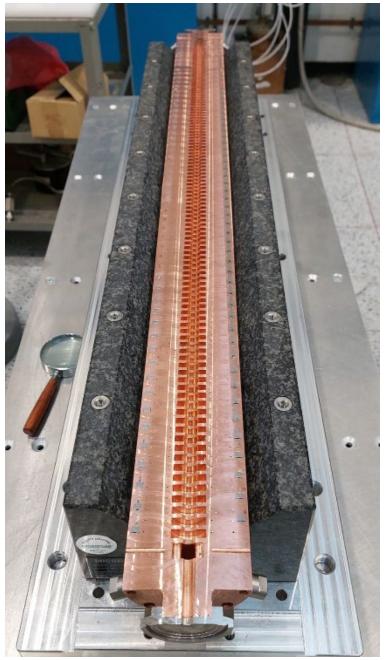




RESULTS

-Straightness ±15 µm, after brazing (±30 µm required by BD)

-Vacuum test OK (except one coupler for a miss-positioning of the brazing alloy)



NOW:

-RF Prototype (15 cells) expected by January/February 2023
-FINAL structure: expected by September 2023

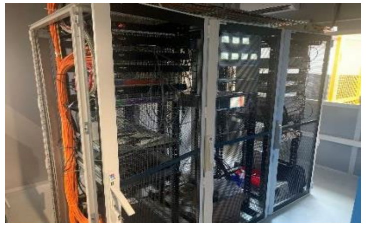
TEX FACILITY STATUS

1. The **TEst-stand for X-band** (TEX) is a facility conceived for **R&D and test on high gradient X-band accelerating structures** and waveguide components in view of Eupraxia@SPARC_LAB project. TEX is located in bld. 7 of LNF, which is being fully refurbished and upgraded to host the RF source and bunker.
2. It has been **co-funded by Lazio regional government in the framework of the LATINO** project (Laboratory in Advanced Technologies for INnOvation). The setup has been done in **collaboration with CERN** that provided the **CPI klystron** and it will be **also used to test CLIC structures**.
3. Not only a facility for accelerator structures but also R&D for: high power tests on RF components, LLRF systems, Beam Diagnostics, Vacuum and Control System
4. The **authorization bureaucracy required many months** but we are now ready to start the high power tests

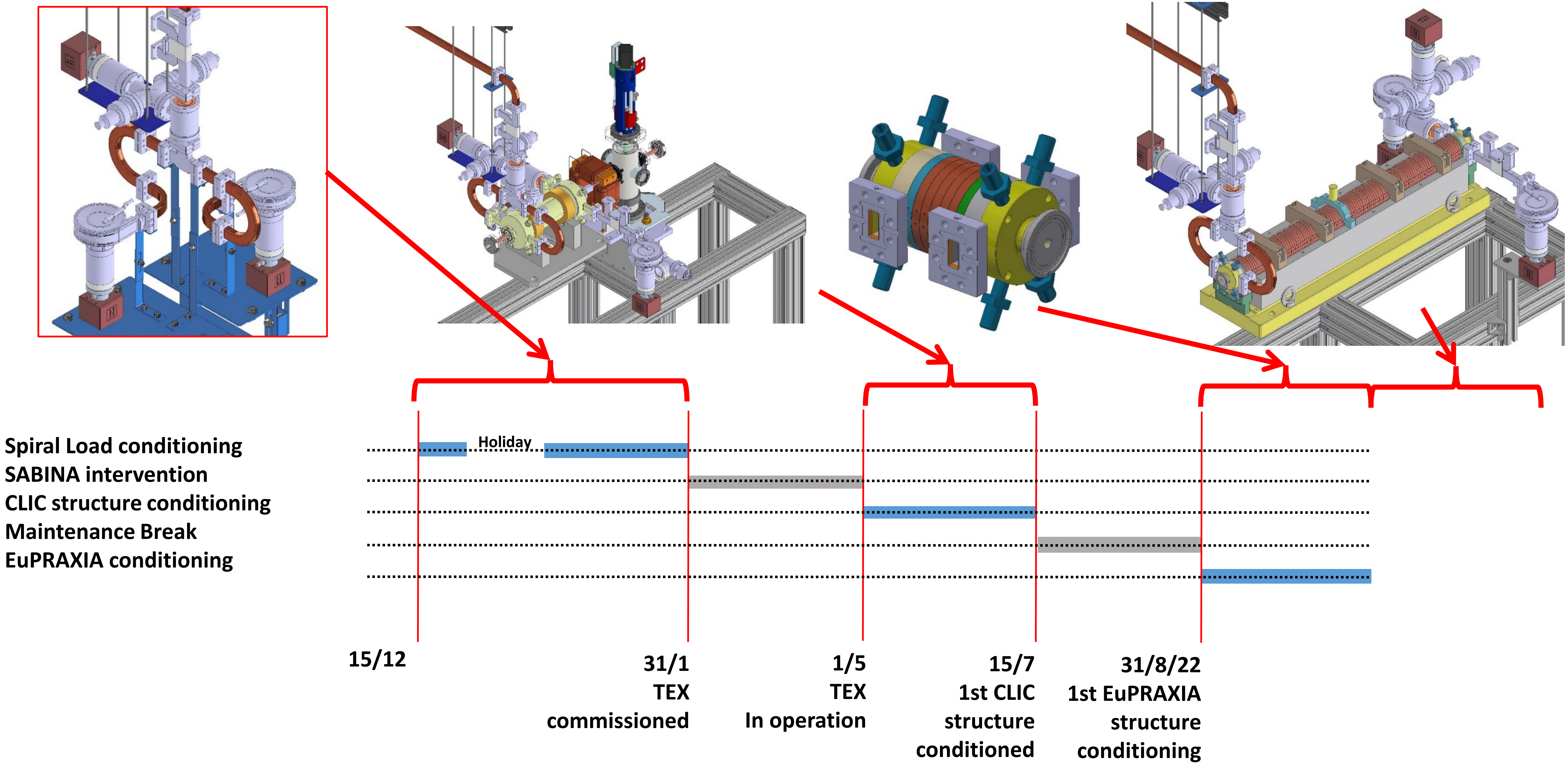
Courtesy F. Cardelli and S. Pioli

Concrete Bunker and Modulator Cage with the RF Source

Control room and Rack room



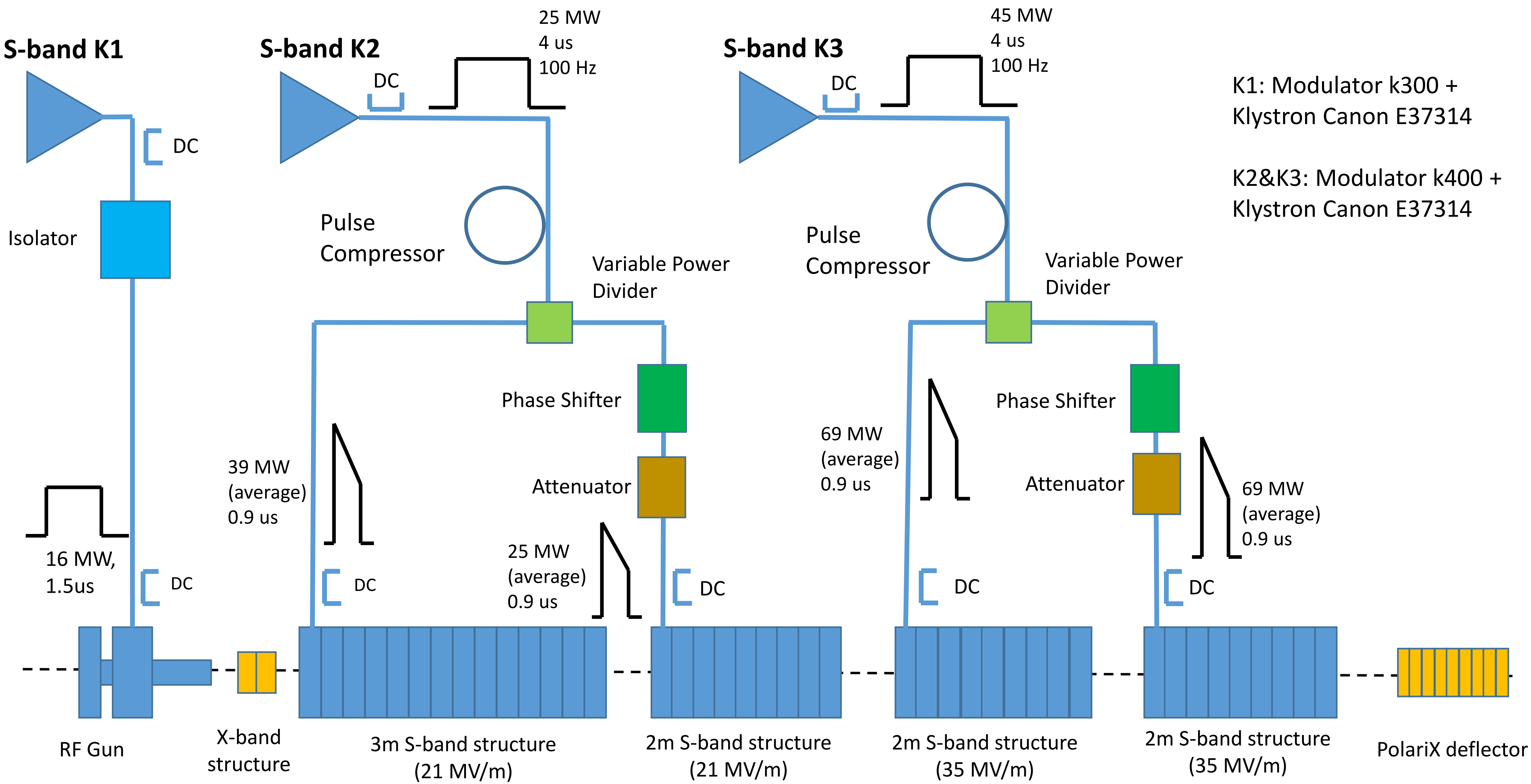
TEX FACILITY SCHEDULE



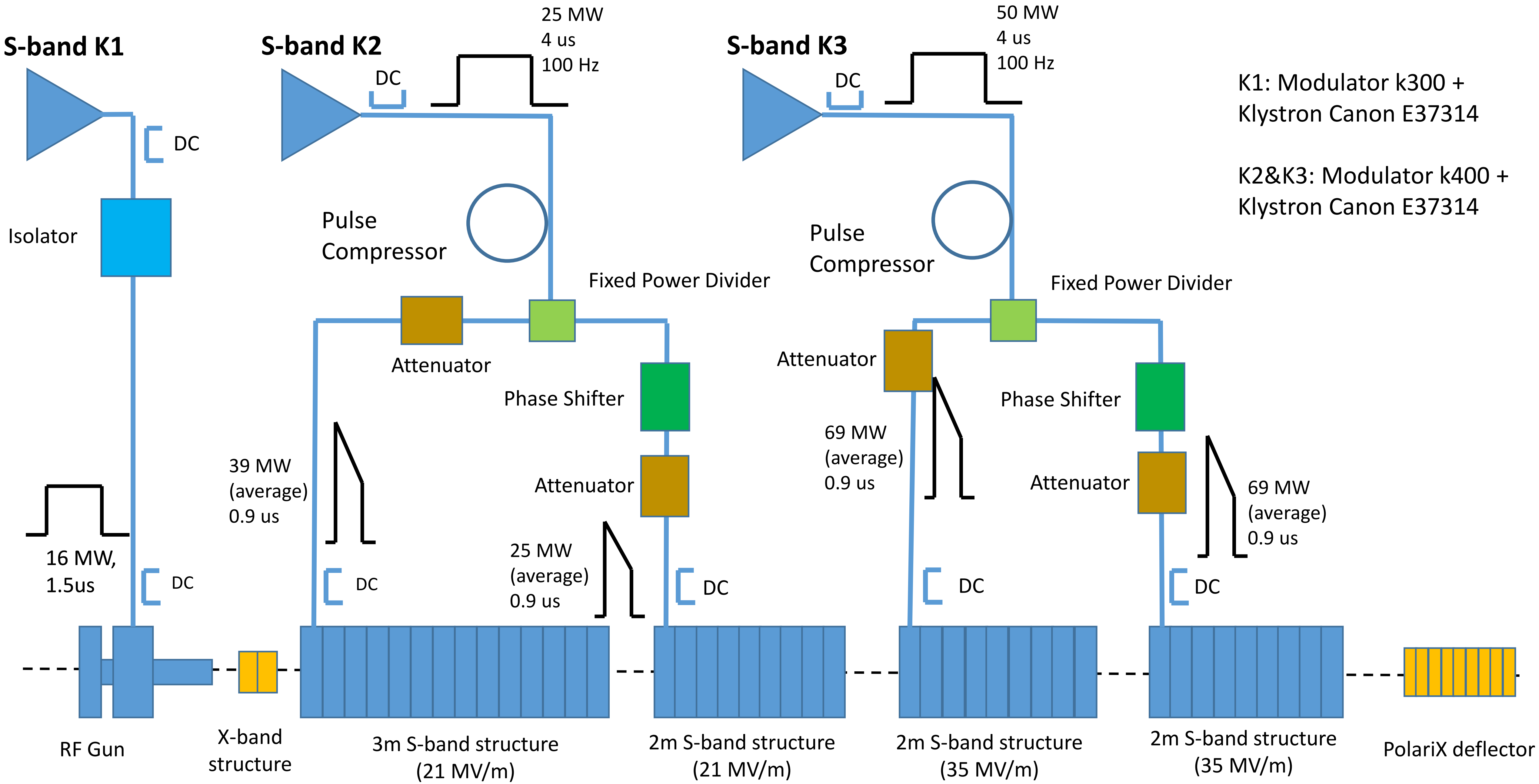
* Radioprotection authorithies will allow TEX operations within first half of December

Courtesy of S. Pioli, E Di Pasquale

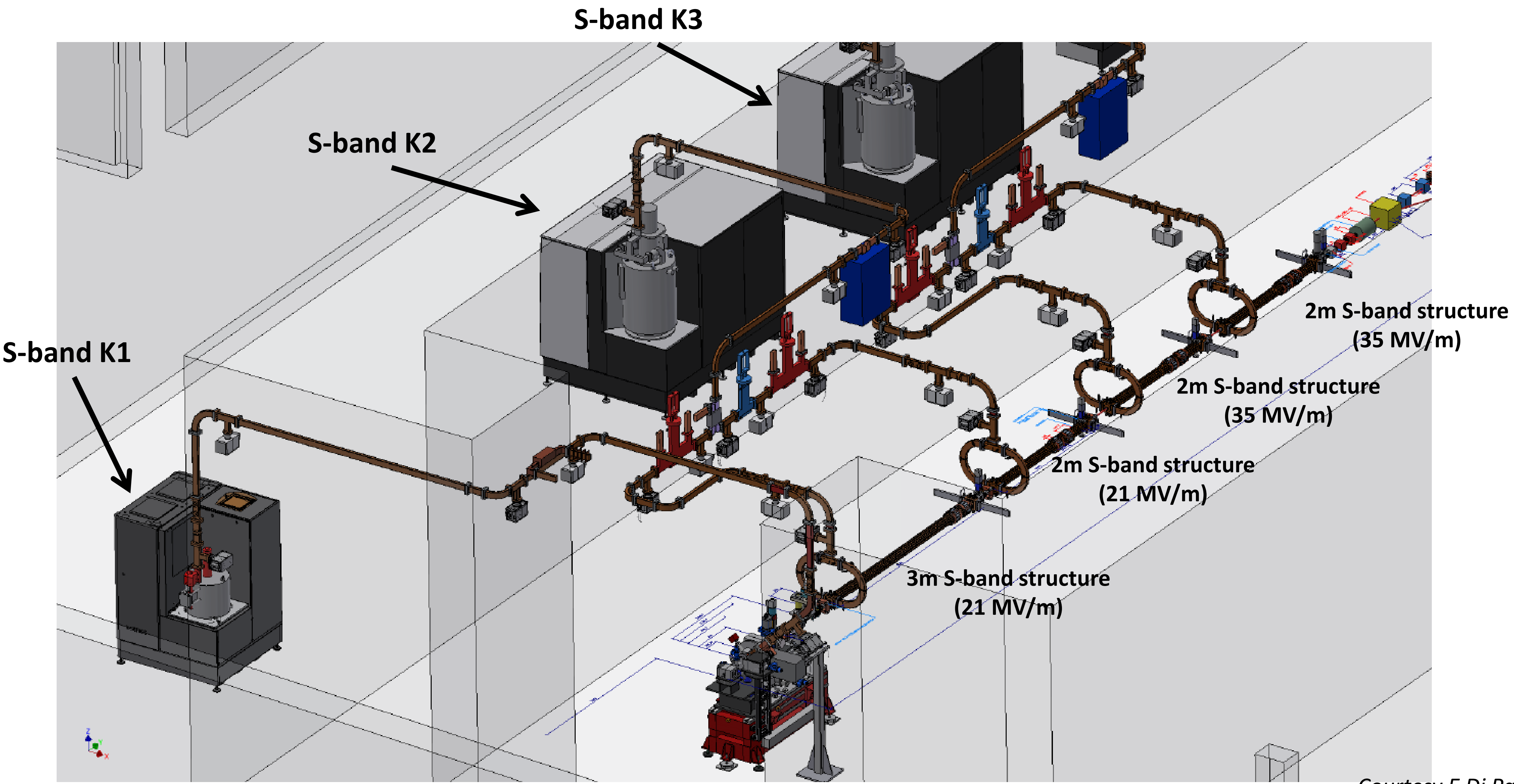
S BAND INJECTOR RF SCHEMATIC LAYOUT 1



S BAND INJECTOR RF SCHEMATIC LAYOUT 2



S BAND INJECTOR MECHANICAL LAYOUT



Courtesy E Di Pasquale

S BAND STRUCTURES PARAMETERS

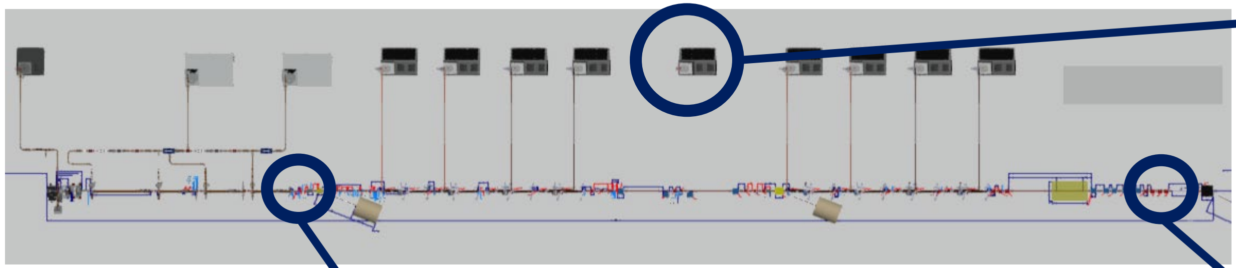
PARAMETER	Structure lenght		
	3 m	2 m	2 m
Frequency [GHz]	2.856		
Average acc. gradient [MV/m]	**21**	**21**	**35**
Number of Structures	1	1	2
Iris radius a [mm]	11.76	10.65	
Tapering of structure	$2\pi/3$ C.I.		
No. of cells	85	57	
Shunt impedance R [MΩ/m]	56	59	
Effective shunt Imp. R_{sh_eff} [MΩ/m]	109	114	
Peak input power in the structure [MW]	67.2	43.5	120
Input power averaged over the pulse [MW]	38.6	25	69
Average dissipated power [kW]	3	2	5.1
P_{out}/P_{in} [%]	32		
Filling time [ns]	920		
Peak Modified Poynting Vector [W/μm^2]	0.43	0.37	1
Peak surface electric field [MV/m]	70	69	115
Unloaded SLED/BOC Q-factor Q_0	150000		
External SLED/BOC Q-factor Q_E	21000		
Required Kly input power (w/o att.)[MW]	12.1	7.8	21.5
RF pulse [μs]	4		
Rep. Rate [Hz]	100		

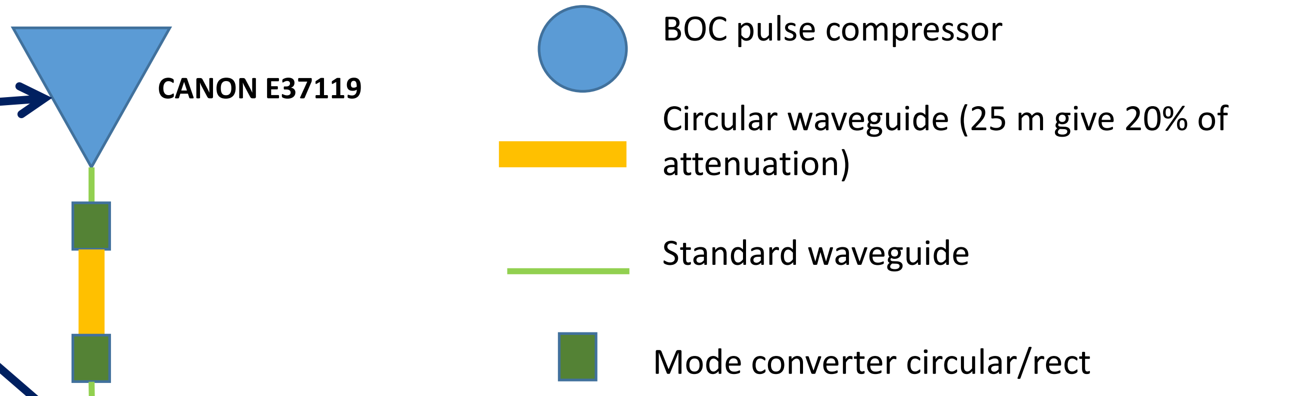
Klystron Canon E37314

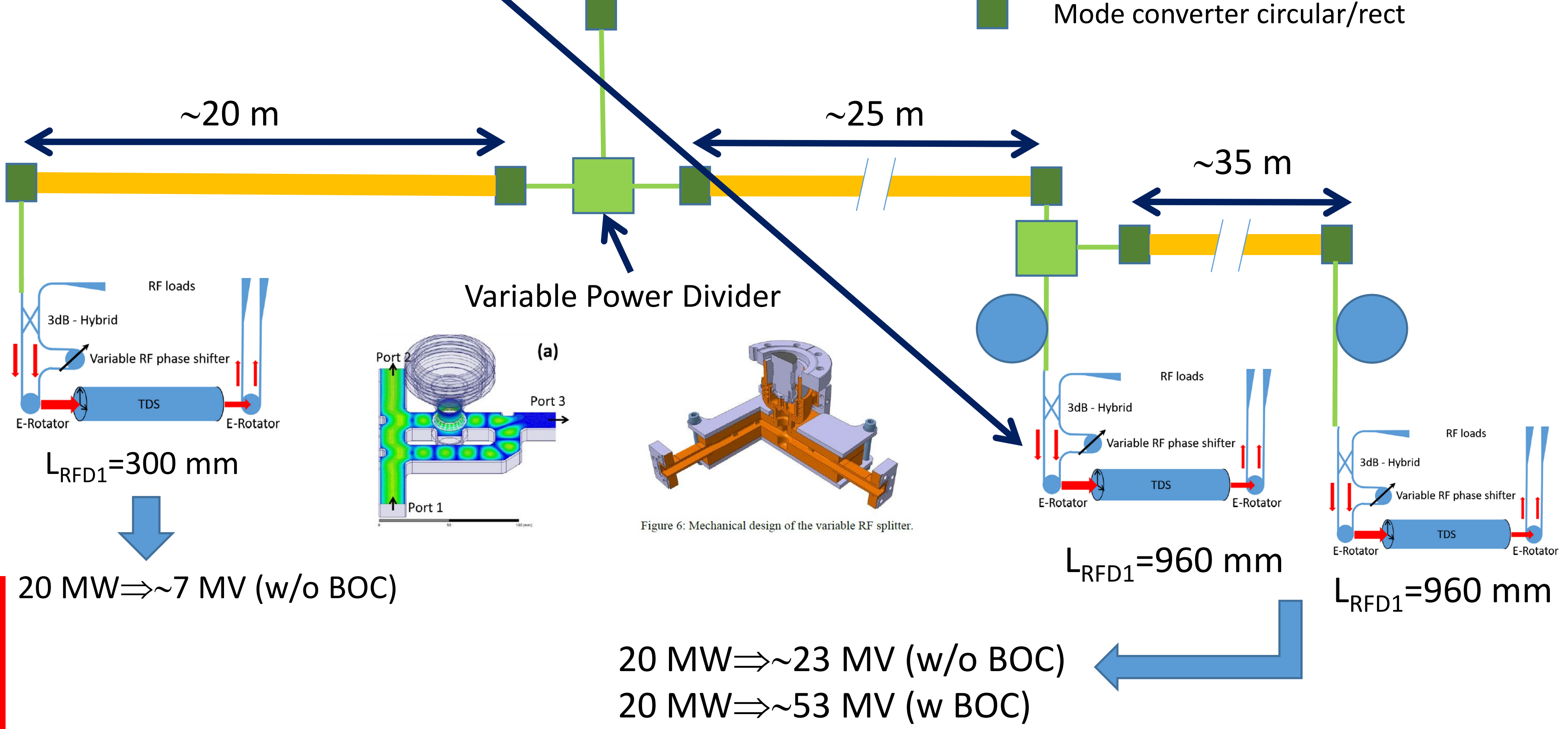
PARAMETER	Value E37314
Frequency [GHz]	2,856
Maximum ouput power [MW]	60
Average power [kW]	24
Efficiency (%)	41
Gain (dB)	53
Pulse Length (μs)	4
Rep. Rate [Hz]	100
Beam Voltage [kV]	360
Beam current [A]	412

Required klystron powers
(w/o considering the waveguide attenuation):
K2 $\Rightarrow$20 MW
K3 $\Rightarrow$43 MW

X BAND RF DEFLECTORS POWERING: PRELIMINARY







P. CRAIEVICH et al. PHYS. REV. ACCEL. BEAMS 23, 112001 (2020)

TABLE V. rf parameters for short and long *X*-band TDS. For operation of the TDS with BOC the following parameters are assumed: $Q_0 = 150000$, $Q_e = 19800$, $t_k = 1500$ ns.

TDS parameter	Short	Long	Unit
Number of cells	96	120	
Filling time	104.5	129.5	ns
Attenuation	−5.21	−6.48	dB
Active length	800	1000	mm
Total length	960	1160	mm
TDS alone			
$R_{\perp,TDS}$	27.3	37.5	MΩ
Power-to-voltage	5.2	6.1	MV/MW$^{0.5}$
TDS + BOC			
$R_{\perp,TDS}$	142	178	MΩ
Power-to-voltage	11.9	13.3	MV/MW$^{0.5}$

THANK YOU

FOR YOUR ATTENTION