Power Source Development Activities at CERN

HG2018

G. McMonagle

Shanghai 8/06/2018

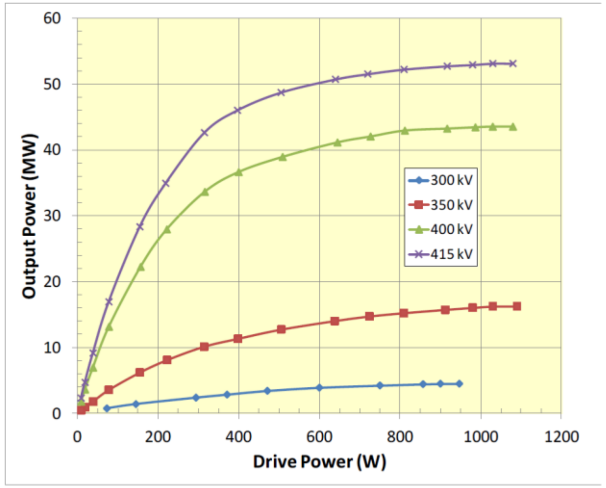
OUTLINE

- Objectives
  - Multiple RF power sources to test components for CLIC and high gradient requirements
- Xbox1 and Xbox2
  - Existing setup
  - Proposed modulator upgrade
  - Structure testing with beam in CLEAR, Possible change to RF network to test 2 structures
- Xbox3
  - Original design goal, existing setup
  - Needed upgrade
    - higher power klystrons
- High efficiency objectives for CLIC 380 GeV
  - CERN initiative
  - SLAC klystron Study
  - Collaboration with industry
  - Solenoid replacement
  - Compact two klystron modulator
- Need for RF windows

Xbox1 and Xbox2

Scandinova solid state modulators

CPI Klystron (commercial SLAC XL5)



Parameters	Specifications	units
	VKX-8311A	
RF Frequency	11.9942	GHz
Peak RF power	50	MW
RF pulse length	1.5	µs
Pulse repetition rate	50 (100)	Hz
Klystron voltage	410-470	kV
Micro perveance	1.15E-6	

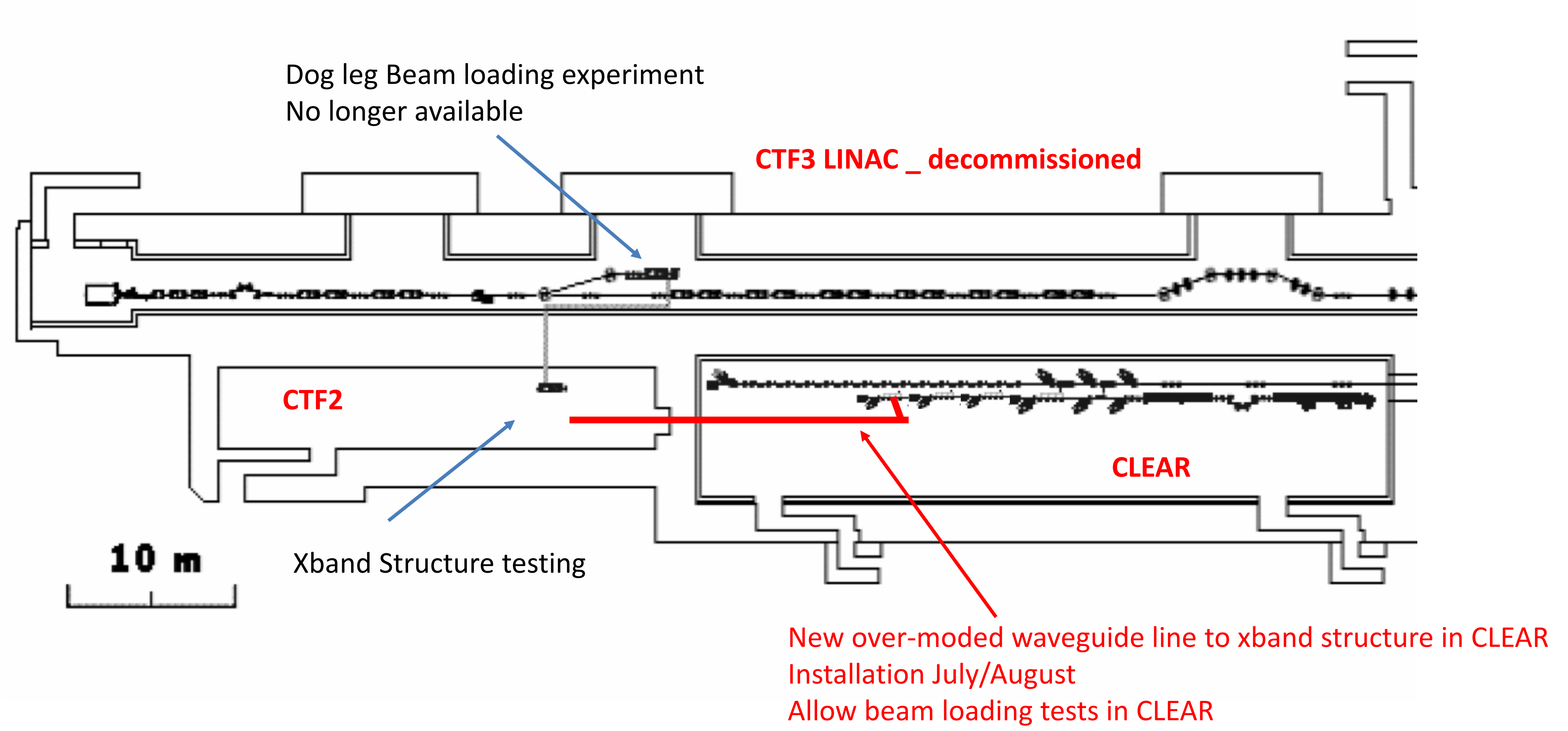
Xbox1 and Xbox2

- **Xbox1**
  - Modulator installed since 2010 in CERN
  - Initially with XL5 klystron now CPI
  - LLRF getting ‘tired’, pulse compressor difficult to tune
  - Using solid state 1.2KW klystron driver, more stable and reliable than original TWT

- Possible upgrades
  - Install extra charging supplies to increase repetition rate to 100Hz
  - Old LLRF system upgrade to same as Xbox2

Xbox1 and Xbox2

- Xbox1



Xbox1 and Xbox2

- **Xbox2**
  - same configuration as Xbox1 for modulator and klystron, (modulator more recent generation)
  - LLRF, National Instrument PXI development
  - New generation pulse compressor
- has been running very reliably this year, really good pulse to pulse stability

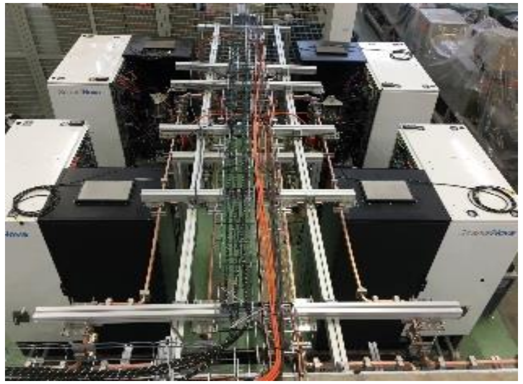
- Possible upgrades
  - Install extra charging supplies to increase repetition rate to 100Hz

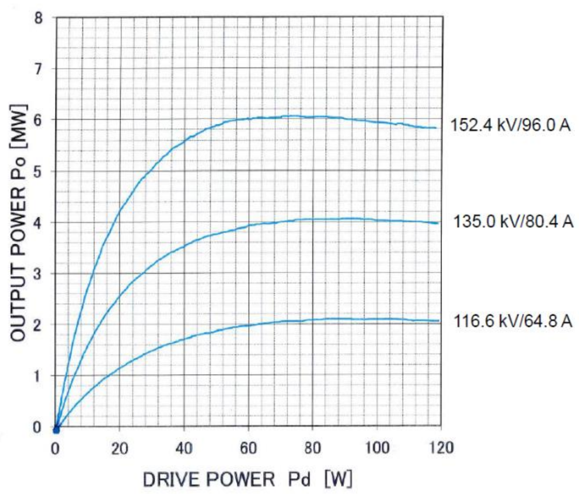
Xbox3

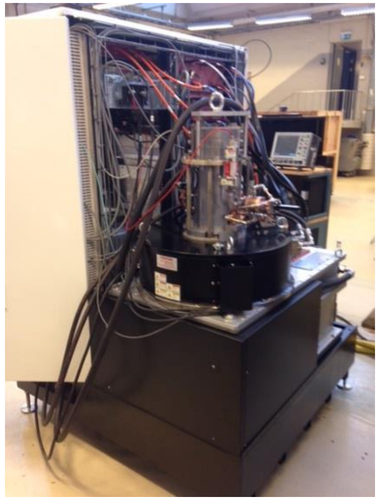
multi slot High Gradient Test Facility

Turnkey solution

Toshiba E37113 klystrons
Scandinova solid state modulators

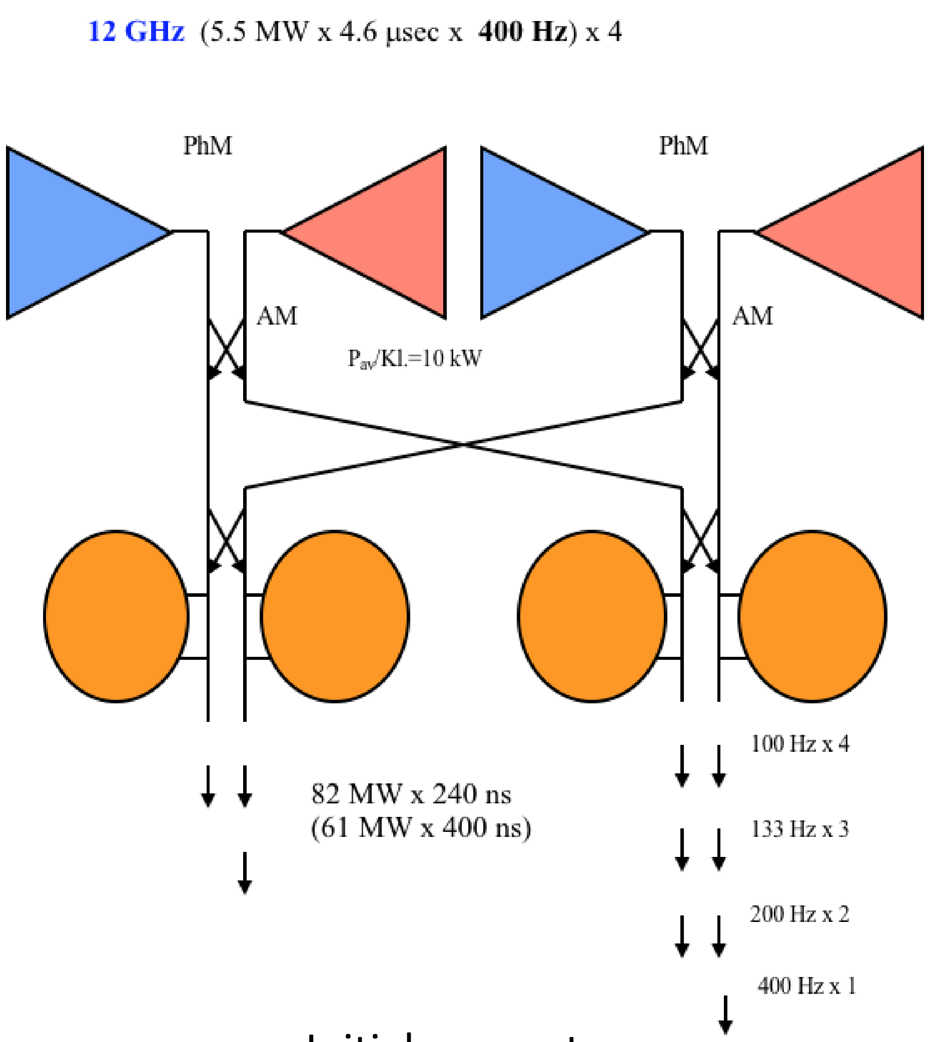




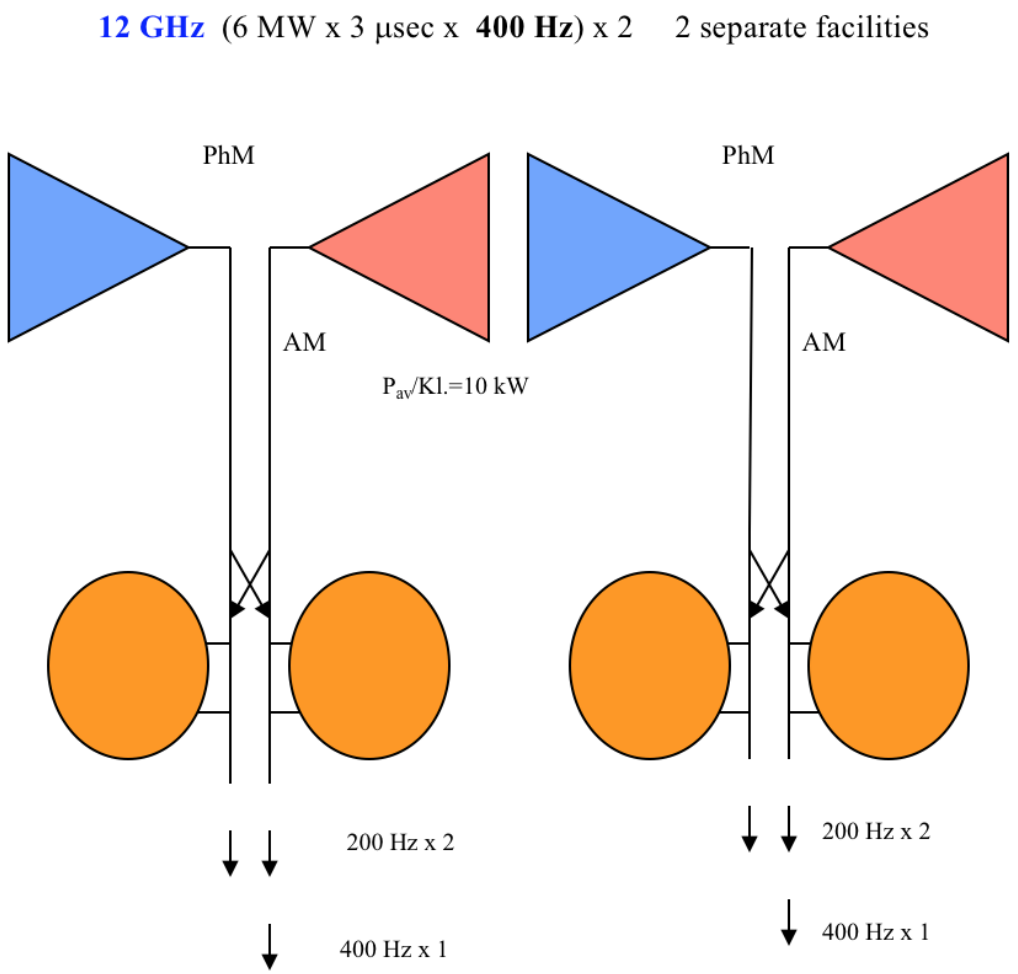


Parameters	Specifications	units
	E37113	
RF Frequency	11.9942	GHz
Peak RF power	6	MW
RF pulse length	5	µs
Pulse repetition rate	400	Hz
Klystron voltage	150	kV
Micro perveance	1.5	

Xbox3



Initial concept



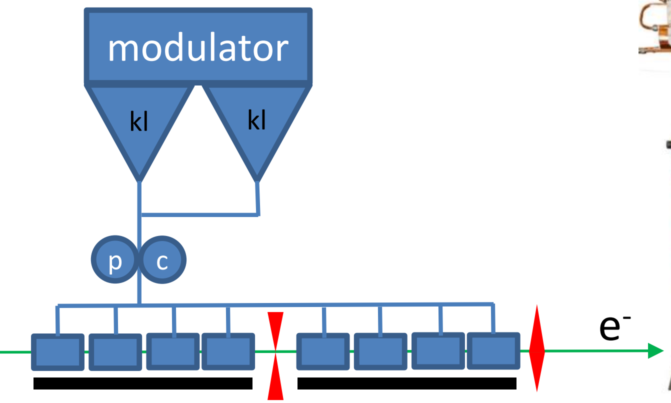
Actual configuration

Missing some peak power to achieve full conditioning program

Higher power klystrons for same modulators?

High efficiency objectives for CLIC 380 GeV

- Klystron based first stage CLIC 380 GeV
- Technical study and cost compared to two beam solution
- Will need high efficiency klystron development, (same peak power)
- Klystrons and modulators need to be installed in tunnel



Would need two klystrons per 2 m of LINAC
Total 5800 klystrons !!

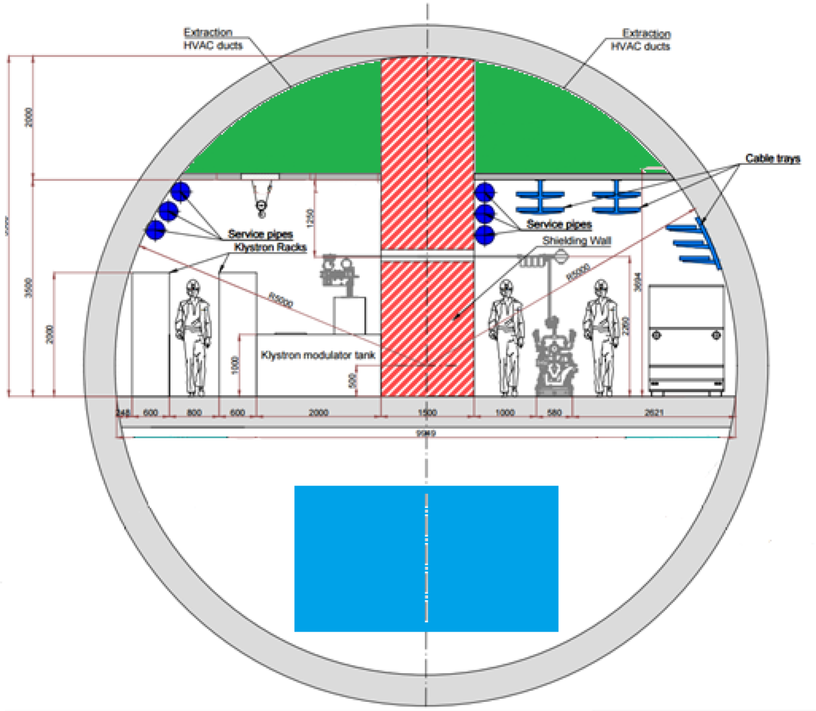
Klystron

+

Modulator

Power consumption important
existing solenoids
(20kW x 5800 = 116 MW)

Existing modulator footprint for 1 klystron
Study needed for two pack klystron with similar footprint



High efficiency objectives for CLIC 380 GeV

- **SLAC study using COM method to increase efficiency of existing XL5**
  - **financed by CERN**

Design	# Cavities	Beam Voltage	Beam Current	Output Power	Efficiency
XL-5	7	420 kV	335 A	~ 50 MW	~ 38%
0.9 µK COM	**9 – 11**	**363 kV**	**197 A**	**> 50 MW**	**> 70%**

- **Final paper design conclusions expected soon**

High efficiency objectives for CLIC 380 GeV

- **In parallel CERN continue high efficiency klystron study (see previous talk Jinchi Cai)**
  - ESS/FFC (collaboration ongoing with industrial partner)
  - LHC klystron (study started for higher efficiency, higher power)
    - needed for HiLumi LHC
  - **CLIC klystron**
    - Initial study on low power Xband (Xbox 3) ,
    - RF design completed instigating collaboration with klystron manufacturers to design and manufacture complete klystron
    - Will continue in same way for 50 MW tube

Replace existing solenoid with super conducting solenoid - Study instigated by Akira Yamamoto (KEK)

A reference

IEEE TRANSACTIONS ON MAGNETICS, VOL. 32, NO. 4, JULY 1996 2633

Cryogen Free Conduction Cooled NbTi Superconducting Magnet for a X-band Klystron

S. Yokoyama, T. Minato, Y. Imai, T. Inaguchi T. H. Kim, T. Umemura
Mitsubishi Electric Corp.,Tsukaguchi-Honmachi,Amagasaki,Hyogo,661 Japan

T. Ogitsu, H. Mizuno
National Laboratory for High Energy Physics,Oho,Tsukuba,Ibaragi,305 Japan

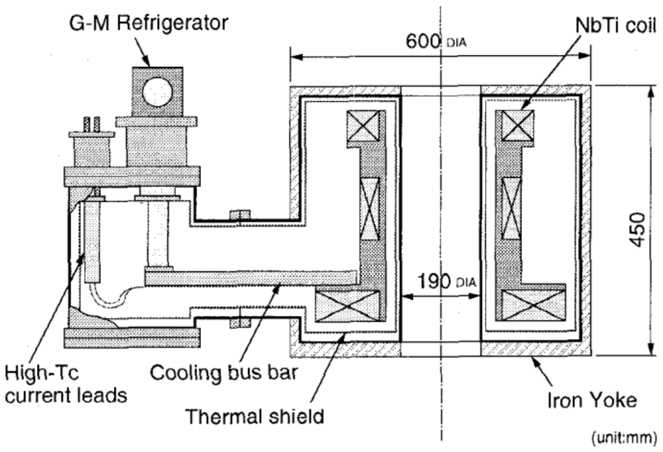


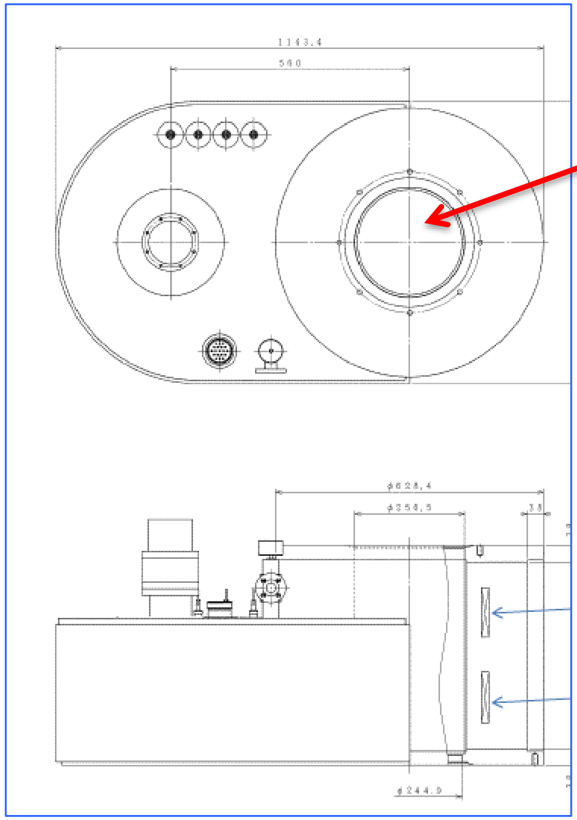
Fig. 1. Schematic structure of the conduction cooled superconducting magnet for the X-band klystron.

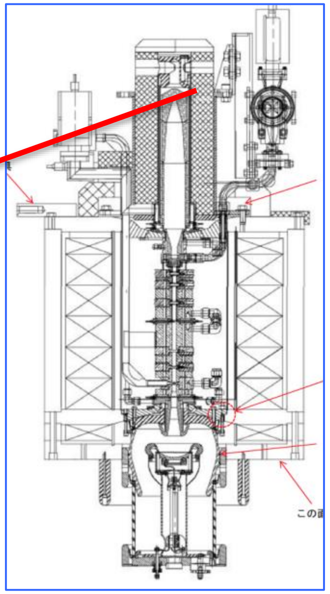
Table 1. Main parameters of the magnet.

Coil		
Dimensions(mm)	inner diameter	250
	outer diameter	400
	height	280
Magnetic field (T)		0.7
Operating current(A)		17.6
Inductance(H)		36
Stored energy (kJ)		5.6
Conductor of the coil		
Superconducting wire		Nb-Ti/Cu
Matrix ratio		4.5
Current lead		
Superconducting material		$Bi_2Sr_2Ca_2Cu_3O_8$
Dimensions(mm)		width 10, thickness 1,length 200
Support material		GFRP(EL-GEM)
Dimensions(mm)		width 16, thickness 2,length 250
Refrigerator		
Type		2-staged Gifford-McMahon cycle
Regenerator material		$Ho_{1.5}Er_{1.5}Ru$
Capacity (W)	1st stage	30 W at 40 K
	2nd stage	1.1 W at 6 K

A SC Model Magnet proposed

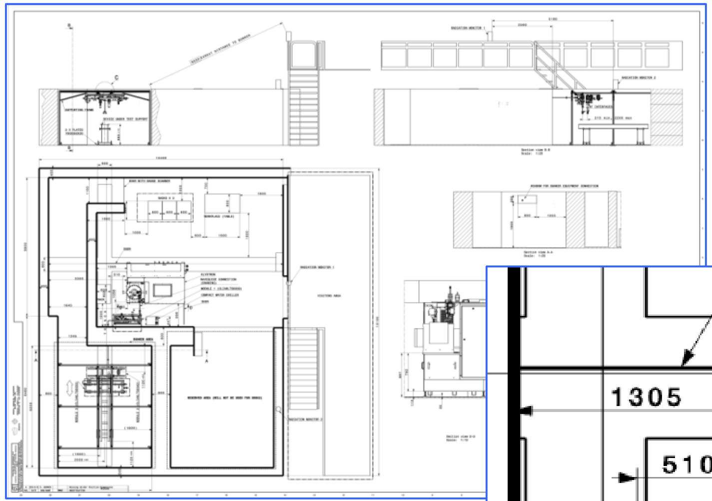
Design Parameters	
Superconductor (T-operation)	MgB_2 (@ 20 K)
Current	50 A
Central field	0.7 T
Stored energy	~ 10 kJ
Cryo-cooler applied	6.7 W @ 20 K 13.5 W @ 80 K
AC Plug Power	≤ 3 kW (< 1,5 kW/Klystron in case of a pair)

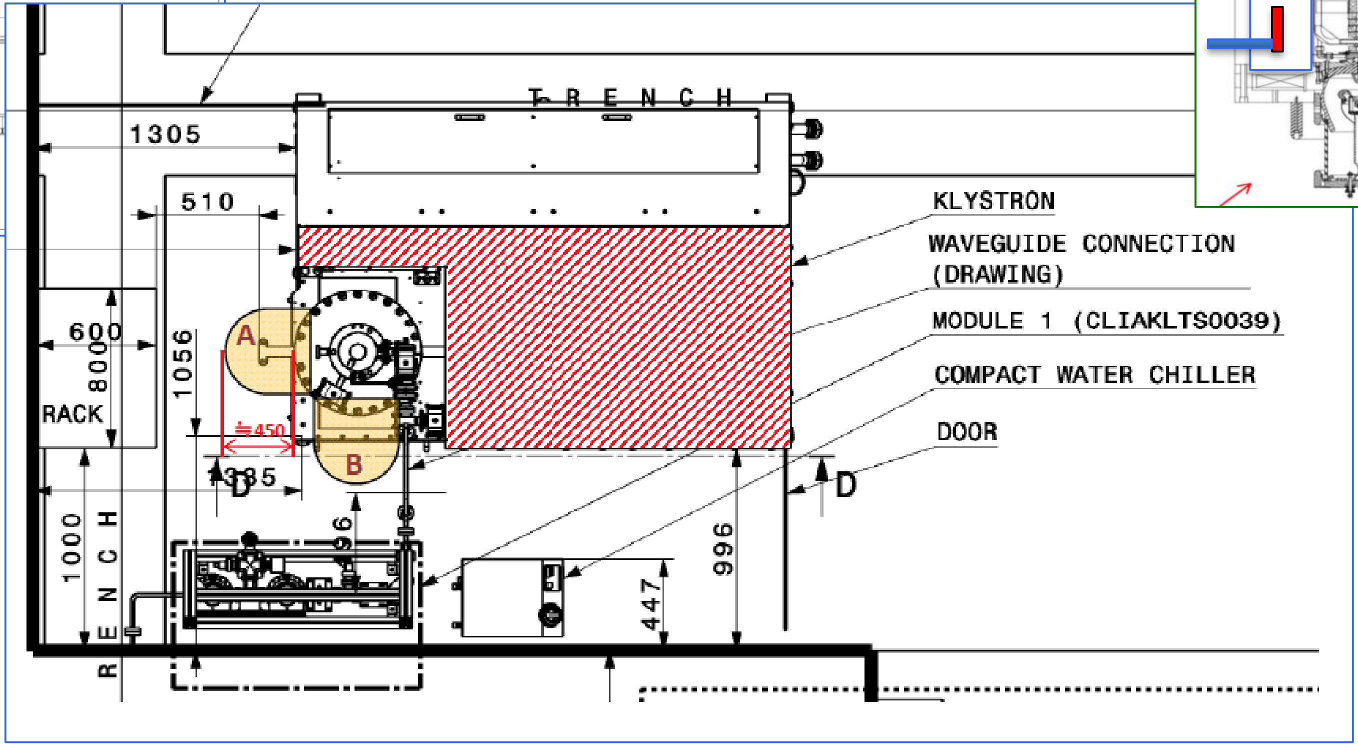


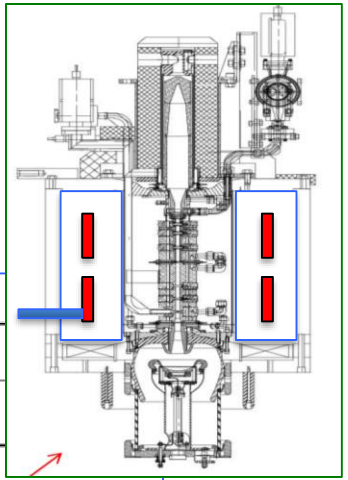


Already ~100 MW saving

A Possible Setup with the Klystron in Xbox2 at the CERN







Cooperative Work

KEK:

- Design and construct a prototype superconducting magnet compatible with the 50 MW klystrons used in the CERN high-gradient test facilities and providing a significant energy saving compared to the existing normal-conducting solenoid;
- Demonstrate the magnet performance and characteristics prior to the test with the klystron at CERN;
- Deliver the prototype klystron to CERN; and
- Undertake further design study for applications in future accelerator and other programs.

SC Prototype Planning

- **2018 (Feb. – August)**
  - Magnet design
  - MgB2 superconductor fabrication and performance test
- **2018 (May – Dec.)**
  - Coil component fabrication and winding (Sept. ~)
  - Assembly into cryostat
  - Performance test
- **2019**
  - Magnet delivery and combined tests with Klystron at CERN

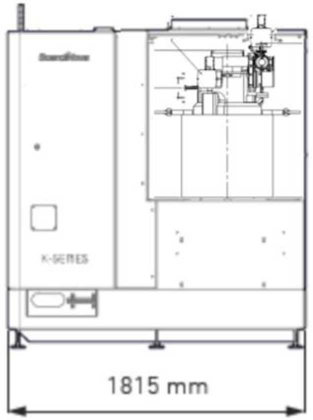
Two klystron modulator

Must fit into tunnel for 380 GeV solution (compact)

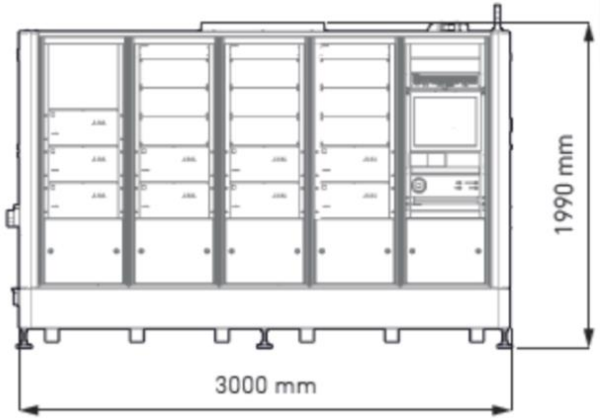
How can we do this ?

High efficiency objectives for CLIC 380 GeV

BASED ON K500 PLATFORM

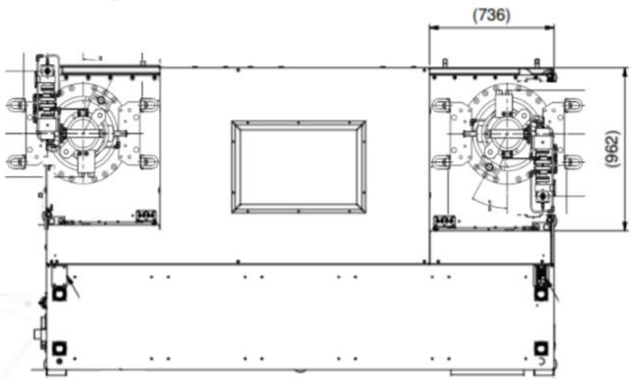


Side View



Front View

K500 Platform front/side view



Top View

Main Parameters	Values
Peak Power	100 MW (2x50)
Average Power	7.5 kW
Pulse Width	1.5 μs
Pulse repetition	50 Hz
Pulse Voltage	410 kV
Pulse Current	310 A

High efficiency objectives for CLIC 380 GeV

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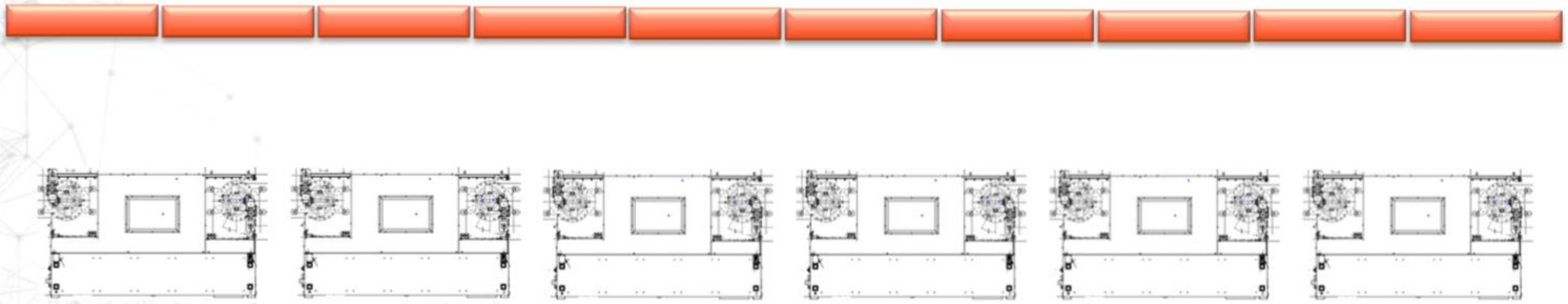
DUAL X-BAND 2X 50MW RF UNIT
LAYOUT1: INDIVIDUAL UNITS (TOP VIEW)

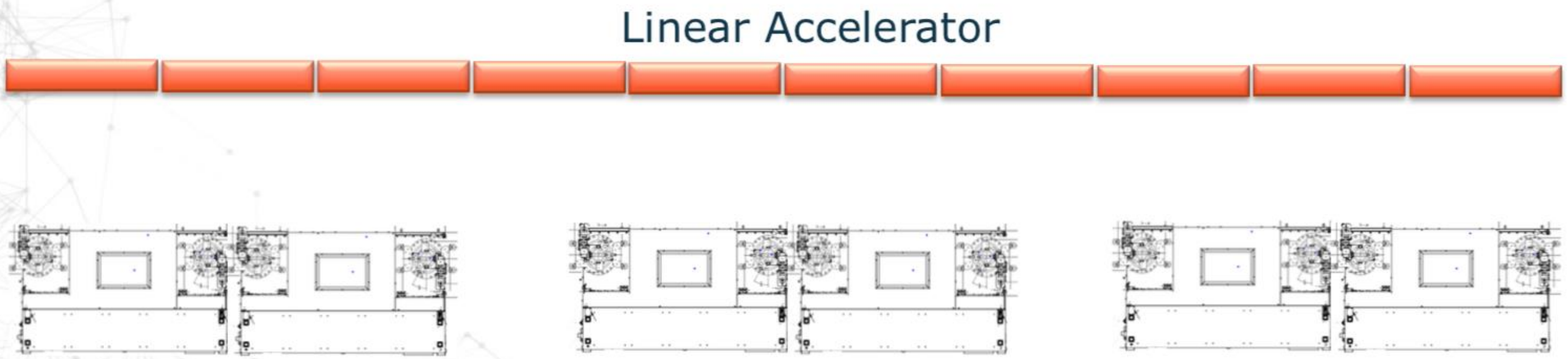
Linear Accelerator



Dual RF Units with equal spacing
-narrow space between units

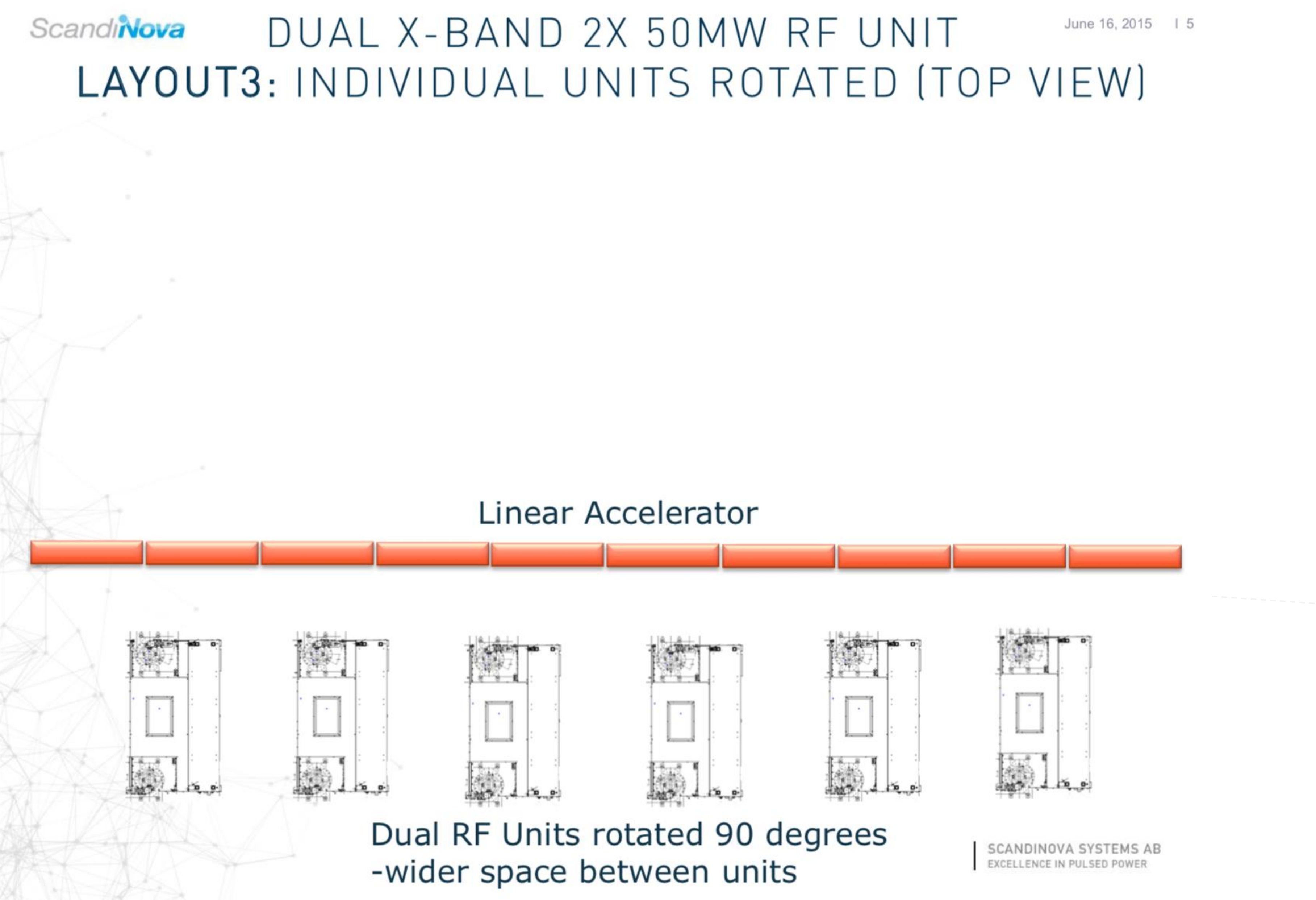
DUAL X-BAND 2X 50MW RF UNIT

LAYOUT2: TWO UNITS SIDE BY SIDE (TOP VIEW)

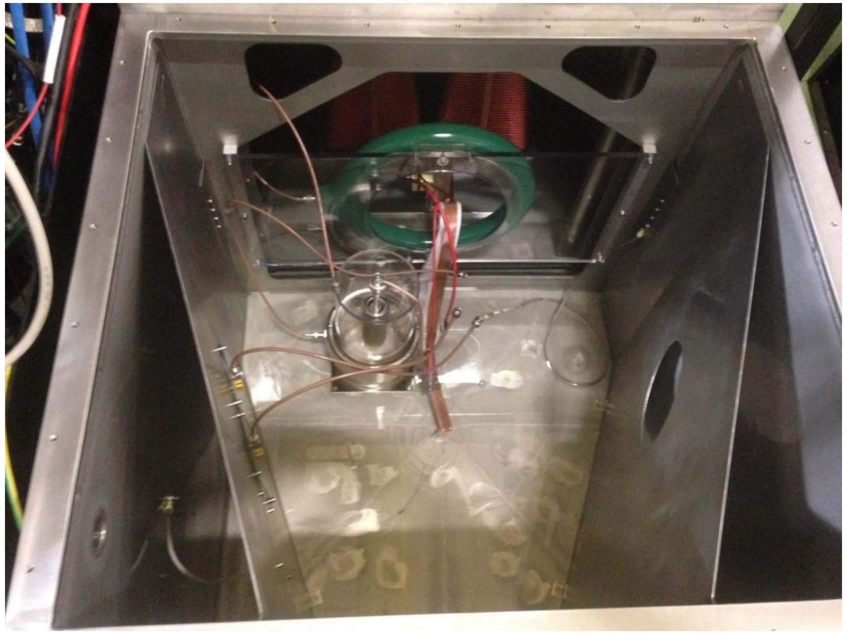


Dual RF Units side by side
-more space between units

High efficiency objectives for CLIC 380 GeV



High efficiency objectives for CLIC 380 GeV



High efficiency klystron , same power , lower voltage

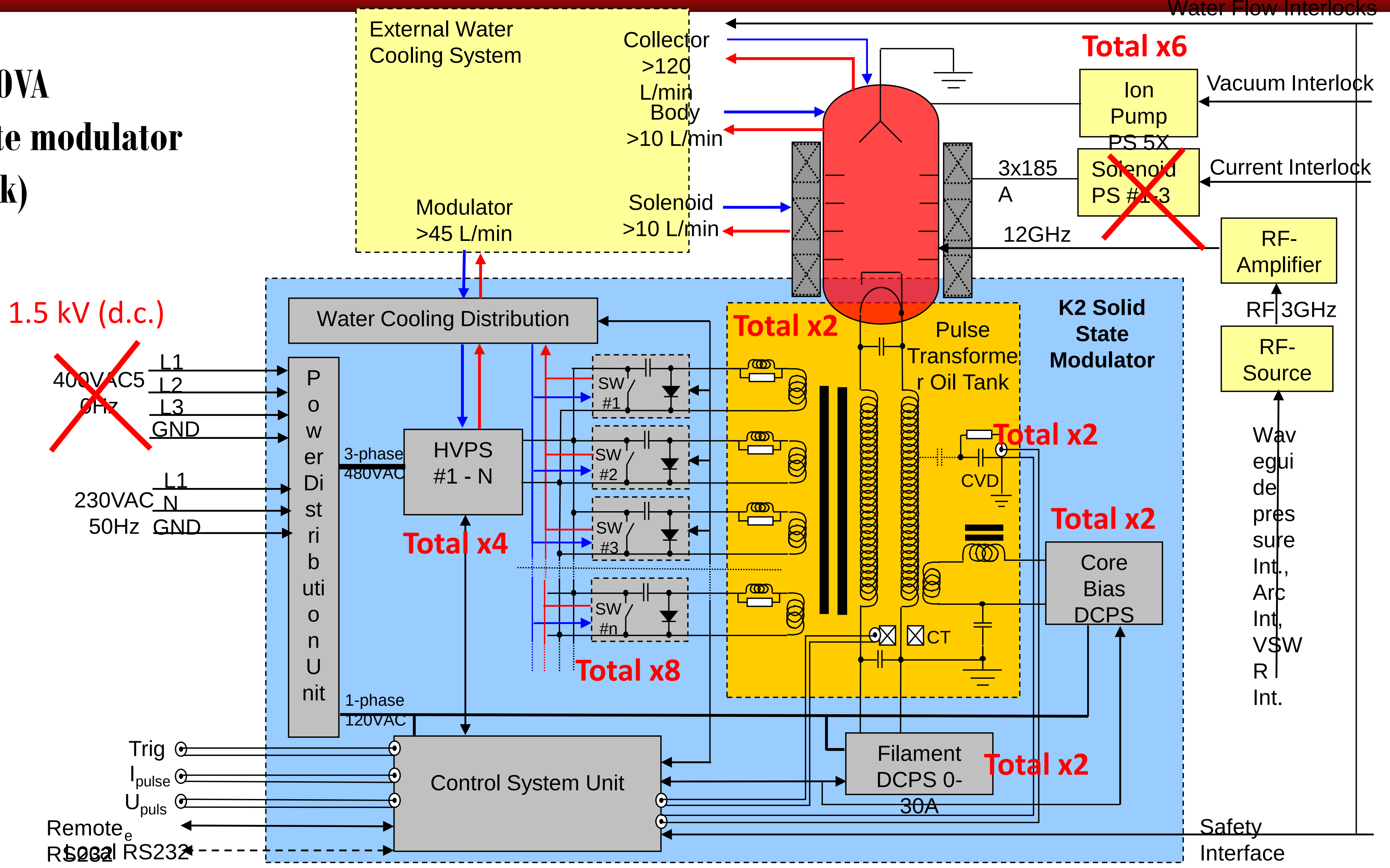
Less volt seconds means smaller pulse transformer

Optimise space in high voltage tank

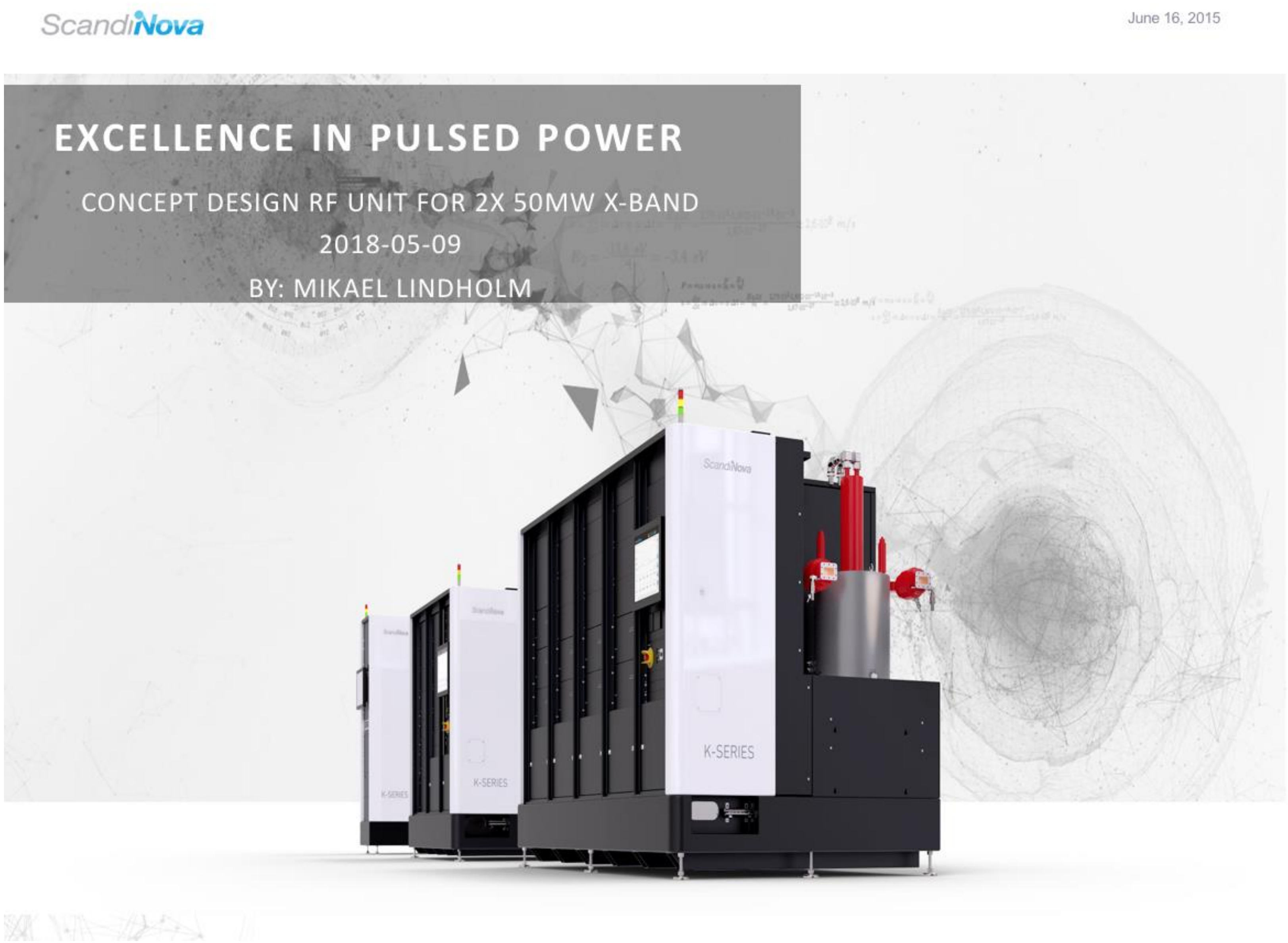
SC Magnet (no integrated power supplies in modulator)

High efficiency objectives for CLIC 380 GeV

SCANDINOVA solid state modulator (two pack)



High efficiency objectives for CLIC 380 GeV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June 16, 2015

EXCELLENCE IN PULSED POWER

CONCEPT DESIGN RF UNIT FOR 2X 50MW X-BAND

2018-05-09

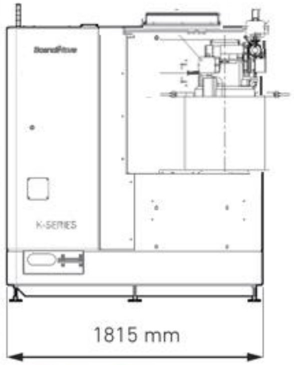
BY: MIKAEL LINDHOLM

High efficiency objectives for CLIC 380 GeV

ScandiNova

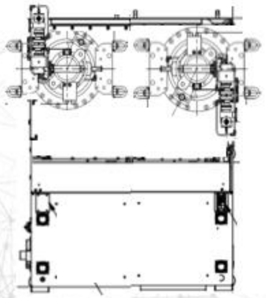
DUAL X-BAND 2X 50MW RF UNIT BASED ON K200 EXTENDED PLATFORM

June 16, 2015 I 2

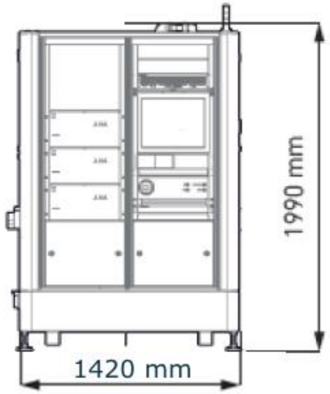


Side View

K200 Platform front/side view



Top View

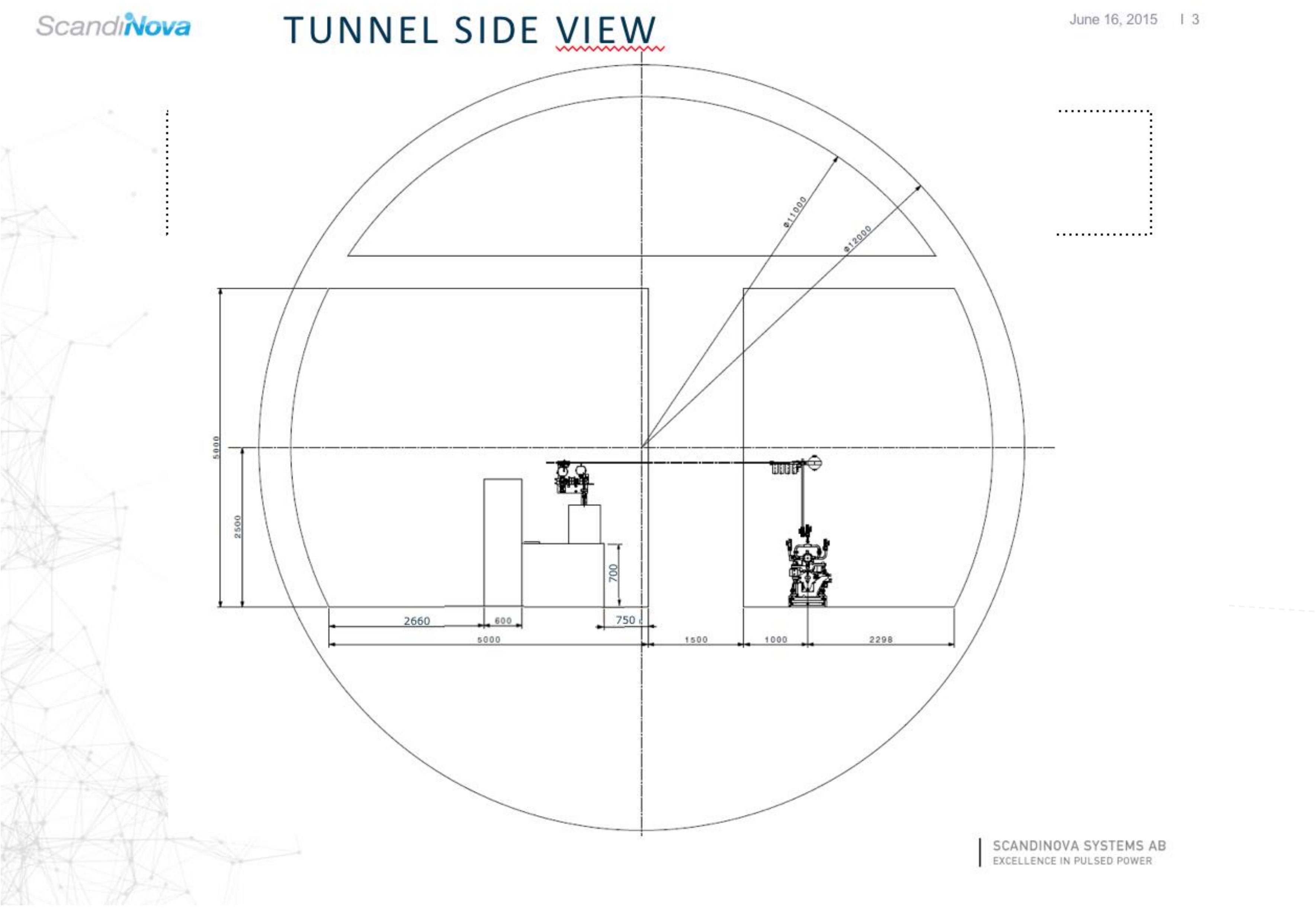


Front View

Main Parameters	Values
RF Peak Power	100 MW (2x50)
RF Average Power	7.5 kW
Pulse Width	1.5 μs
Pulse repetition	50 Hz
Klystron Efficiency	70%
Perveance	0.9 μperv
Pulse Voltage	363 kV
Pulse Current	197 A
Mod. Average Power	22 kW
Length	1420 mm
Depth	1815 mm
Height	1990 mm

SCANDINOVA SYSTEMS AB
EXCELLENCE IN PULSED POWER

High efficiency objectives for CLIC 380 GeV



High efficiency objectives for CLIC 380 GeV

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TUNNEL TOP VIEW

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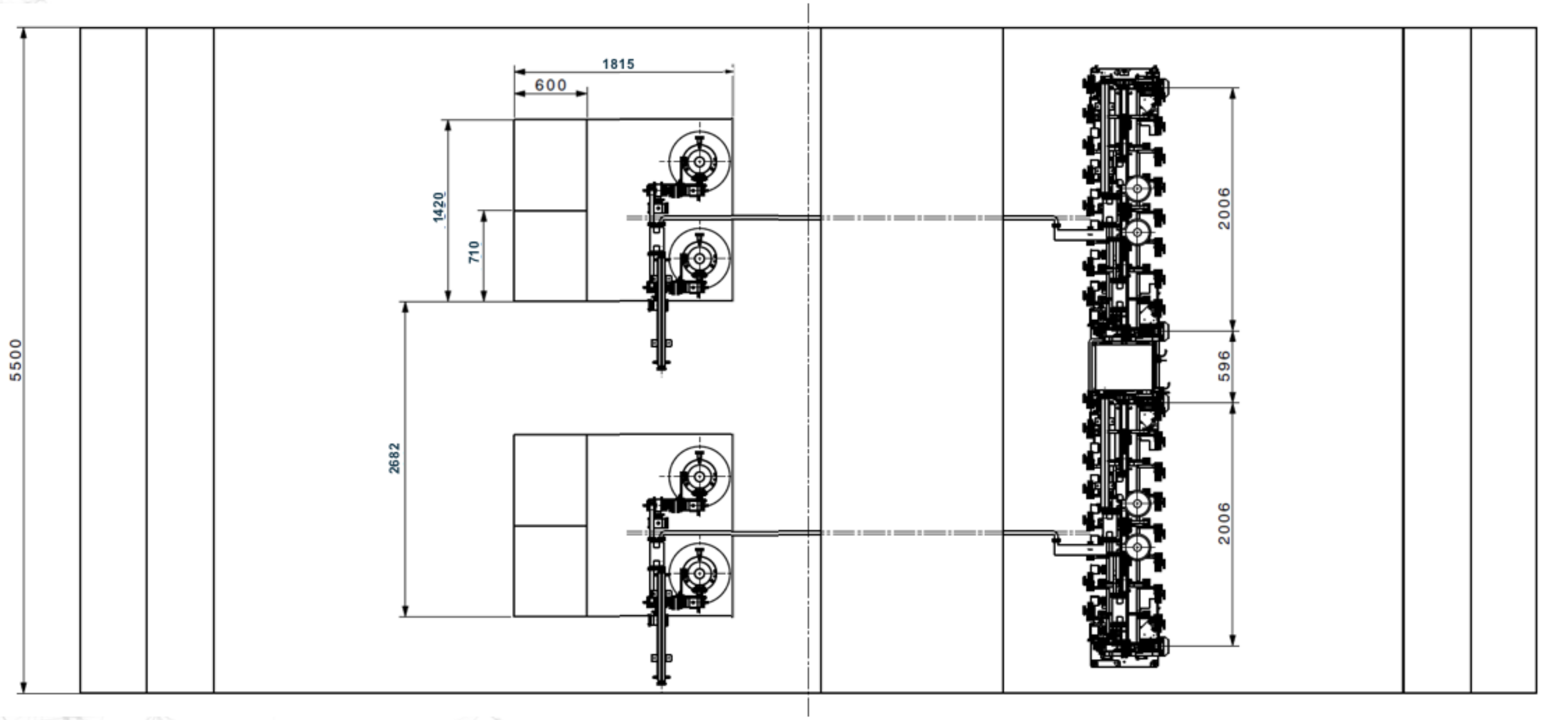

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EXCELLENCE IN PULSED POWER

High efficiency objectives for CLIC 380 GeV

Many other issues to consider
e.g. ~4500 m3 of oil in 11 km tunnel (fire risk)

Prospects and timeline

complete

- High efficiency klystron design completion
- SC solenoid testing at CERN

- Prototype CLIC module test stand .... 2020 ->

- This may be accelerated if 3.5 GeV gets approved (A. Grudiev talk)
- But with existing klystron and solenoid

RF Windows

Need RF windows to reduce reconditioning time of RF networks in the test stand after removal and replacement of components (structures, klystrons, loads)

No high power Xband window commercially available (unless attached to klystron)

SLAC have made their own model

Tentative commercial enquiries were made

High NRE and unit price cost
Some manufacturers gave very long delivery with no guarantee of performance

CERN and Synchrotron Trieste collaboration to develop and build prototype at CERN

TRAVELING WAVE WINDOW FOR X-BAND

RF DESIGN

08/05/2018

C. Serpico, I. Syratchev

PRELIMINARY CONSIDERATIONS

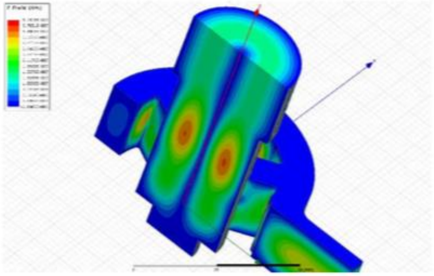
- Peak power of 75 MW has to be considered.
- Field lines crossing the brazing joint (between the ceramic and the copper) must be avoided.
  - ⇨ A mode convertor from TE_{10} (in rectangular wg) to TE_{01} (in circular wg) will be used
- Electric field at the ceramic window shall be lower than 3.4 MV/m.
  - ⇨ To lower the peak field, a diameter of 65 mm will be considered for the ceramic

WRAP-AROUND MODE CONVERTER

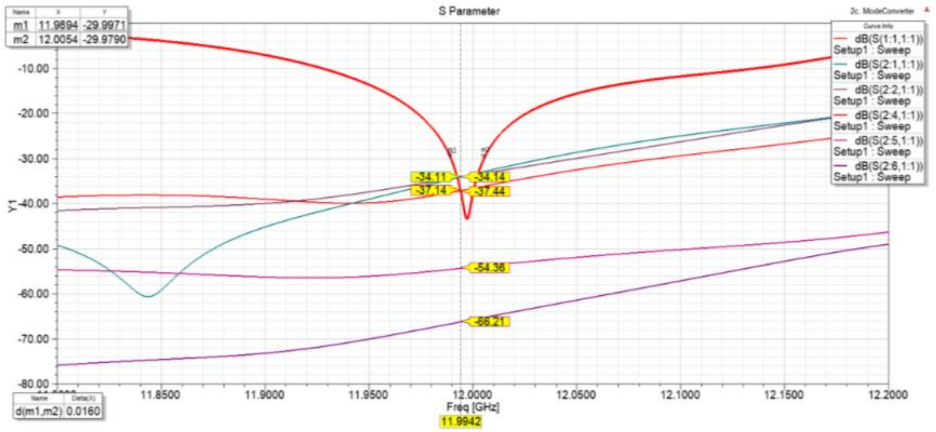
Also considering
double height WR-90 Kasakov type mode converter design
Bandwidth considerations
Fabrication tolerances (cost)

RF Parameters

E-field



Bandwidth



Freq [GHz]	dB(S(1:1,1:1)) Setup1 : LastAdaptive	dB(S(2:3,1:1)) Setup1 : LastAdaptive	dB(S(2:1,1:1)) Setup1 : LastAdaptive	dB(S(2:2,1:1)) Setup1 : LastAdaptive	dB(S(2:4,1:1)) Setup1 : LastAdaptive	dB(S(2:5,1:1)) Setup1 : LastAdaptive	dB(S(2:6,1:1)) Setup1 : LastAdaptive
11.994200	-37.434919	-0.005000	-34.114219	-34.138679	-37.144315	-54.360527	-66.209075

	Value	Units
f_0	11.9942	GHz
s_{11}	-37.4	dB
s_{21}	-34.1	dB
s_{31}	-34.1	dB
s_{41}	-37.1	dB
s_{51}	-54.3	dB
s_{61}	-66.2	dB

High Order Modes (s_{21} – s_{61})

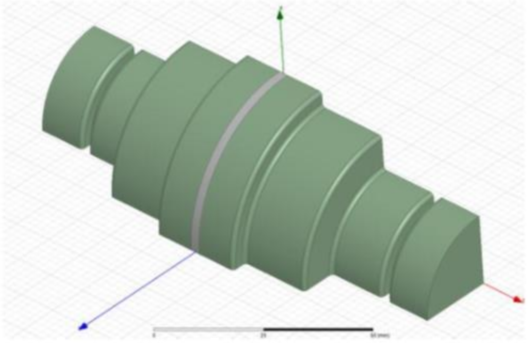
RF parameters are not the final ones, optimization still in progress….

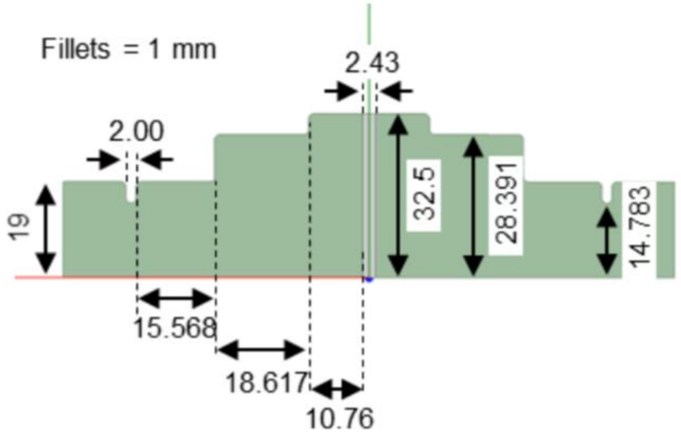
08/05/2018

C. Serpico, I. Syratchev

RF WINDOW

- The TE_{01} circular waveguide mode will be launched with the wrap-around mode converter
- The input and output ports for this window design are 38 mm in diameter.
- The transitions from 38 mm to 65 mm are two-stage step to preserve the required TE_{01} mode purity.

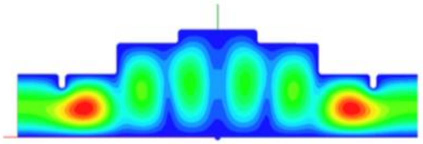




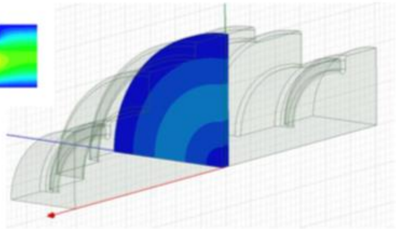
RF WINDOW

RF Parameters

E-field

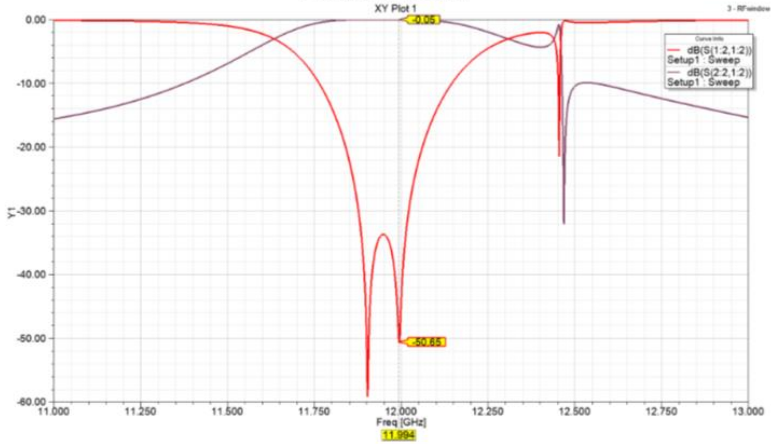


E-field on Ceramic



	Value	Units
f_0	11.9942	GHz
P_{IN}	75	MW
Material	Alumina 96%	
Relative Permittivity	9.4	
Dielectric Loss Tangent	0.006	
s_{11}	-50.7	dB
s_{21}	-0.0491	dB
$E_{Max\ Ceramic}$	3.4	MV/m

Bandwidth



	S:1:1	S:1:2	S:1:3	S:1:4	S:1:5	S:1:6	S:2:1	S:2:2	S:2:3	S:2:4	S:2:5	S:2:6
1:2	-83.1	-50.7	-106	-108	-106	-35.5	-94.3	-0.0491	-113	-136	-135	-35.5

RF Parameters at f_0 = 11.9942 GHz

08/05/2018

C. Serpico, I. Syratchev

RF Windows

Next Steps

- ✓ Discuss brazing of ceramic disc to copper methods with CERN experts
- ✓ Re-evaluate RF design after discussion on brazing method (Claudio)

- Manufacturing drawings at CERN
- Order raw material
- Prototype braze of window to copper cylinder
- Build full prototype

Summmary

Thank you for your attention