A Superconducting Solenoid applicable for X-band Klystrons

Akira Yamamoto（KEK and CERN)

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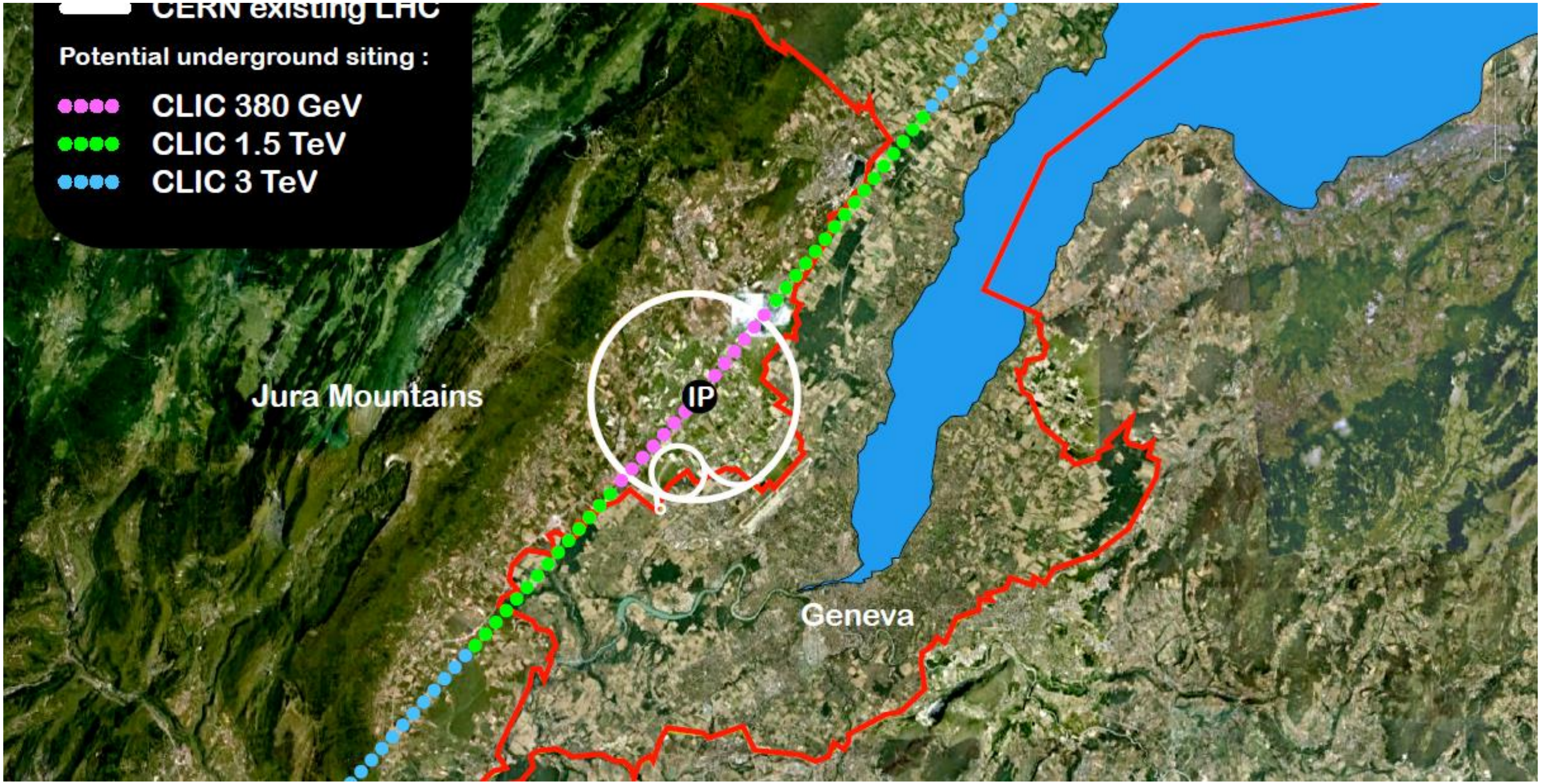
2017-12-01

CLIC Staging Scenario being Studied



Background and Objectives

- The CLIC-380 staging scenario is being studied at CERN, and the X-band (12 GHz) klystron-based accelerating scheme may be a cost-effective option.

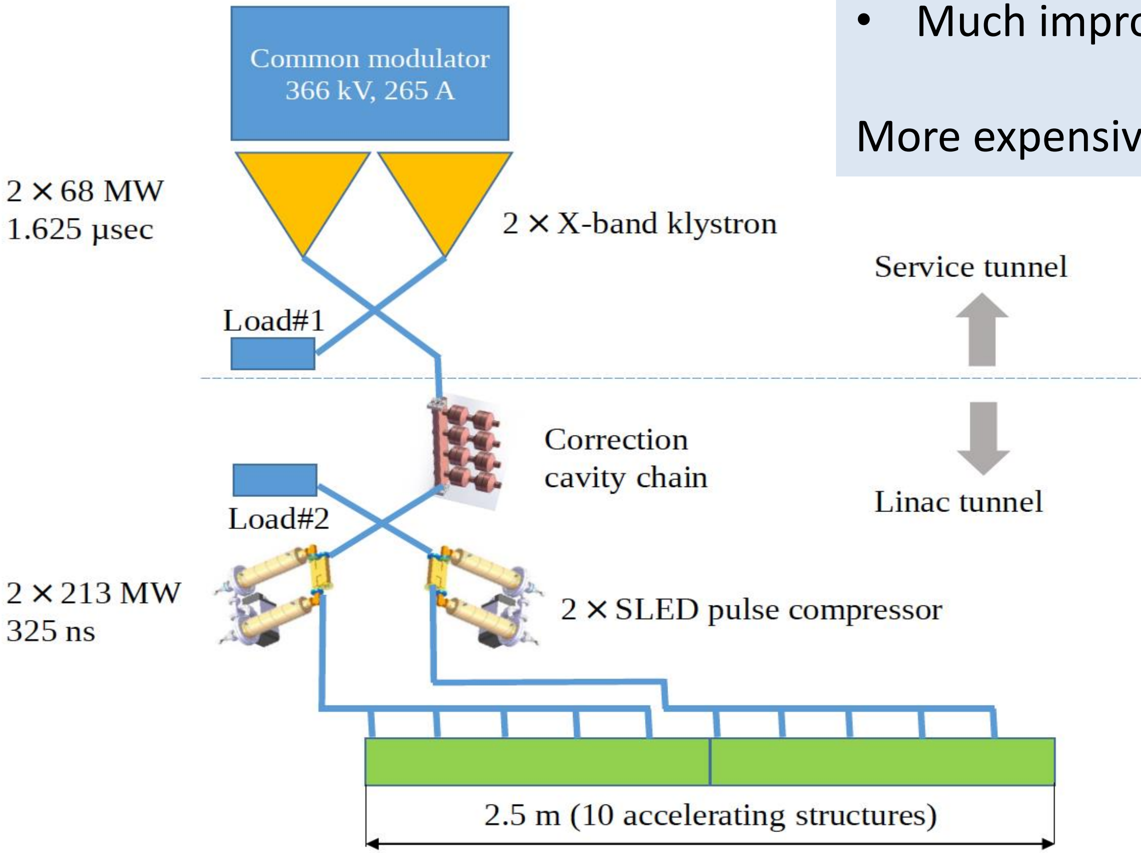
- The klystron requires a solenoid magnet field for beam focusing with
  - Bc = **~ 0.6** T in a bore-diameter of 0.48 m

- A Cu-based solenoid magnet, currently used, is consuming
  - AC-plug power of **~20 kW** per Klystron,

- The superconducting magnet option will result in
  - Total AC-plug power saving of **> ~80 MW** for ~4,500 klystron in CLIC-380.

Klystron-based First Stage (380 GeV)

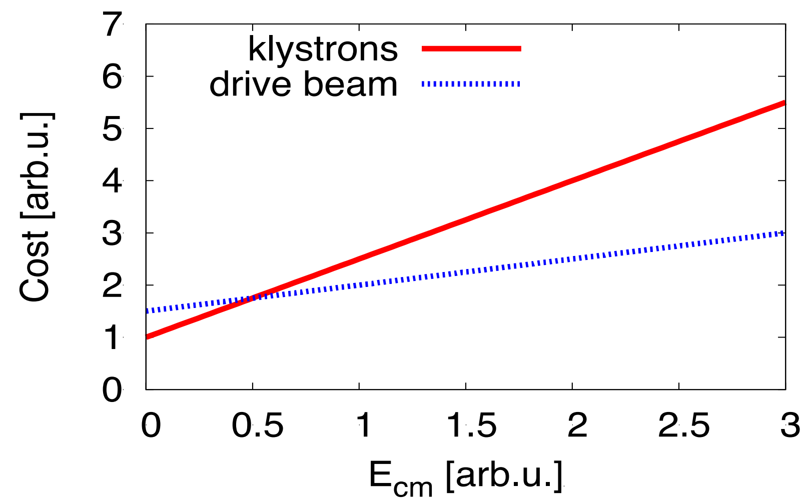
Example RF unit design
(I. Syratchev)



With simple cost model find similar cost than drive beam-based design at 380GeV

- Much improved RF unit design

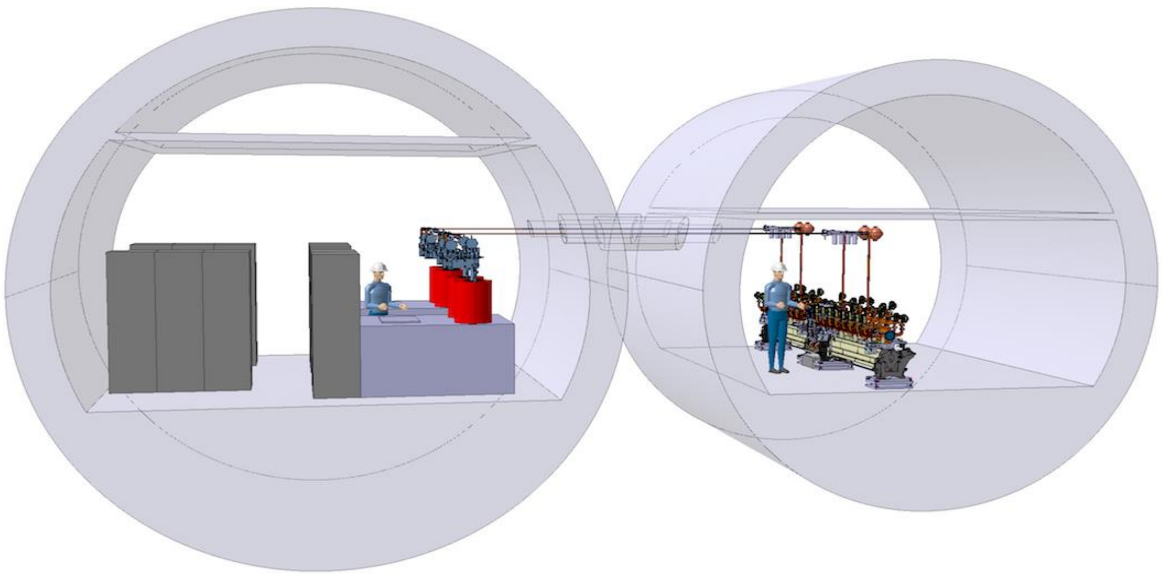
More expensive at 3TeV

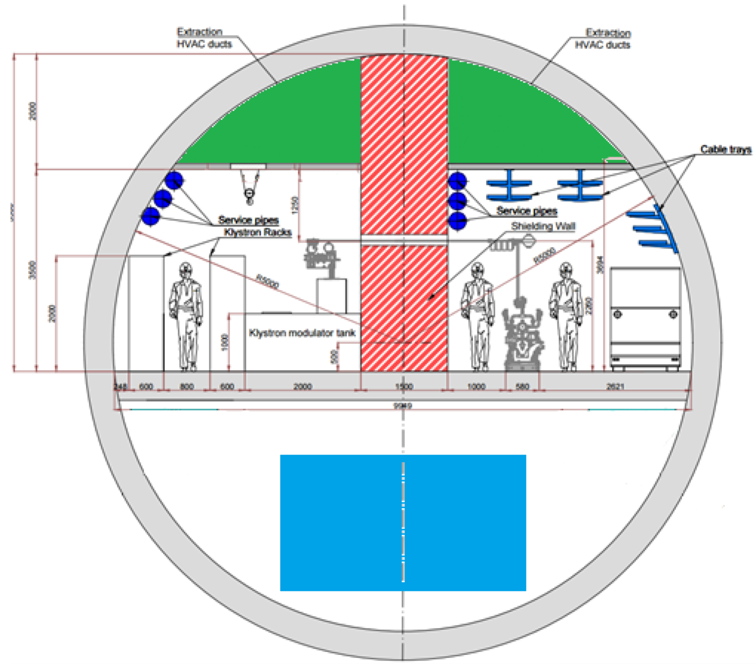


1076 units /beam

The pulse compressor used for parameter determination in the Baseline Report has been still a previous version
But used updated model

380 GeV Klystron Tunnel View

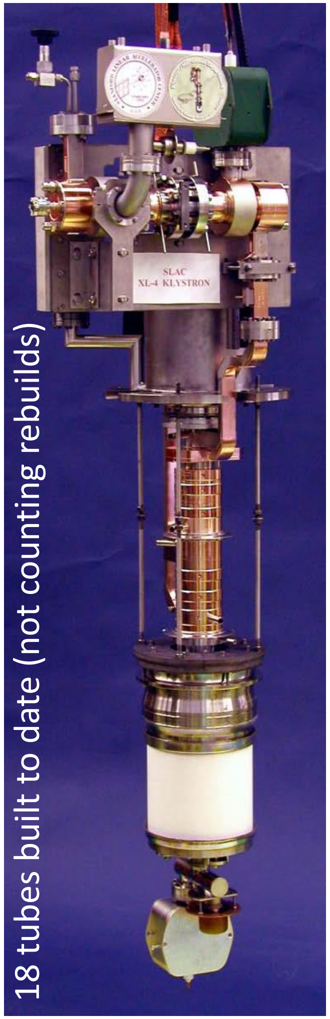




4,482 Klystron strings
(2,241 pairs) required

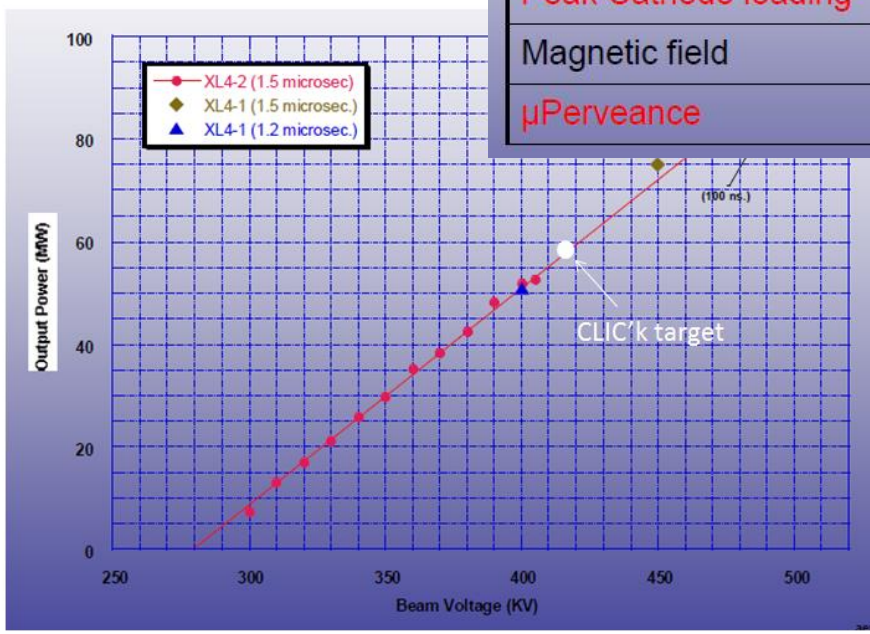
X-band klystrons (industrialized)

Courtesy: Igor.Syratchev



CLIC’k klystron:
59 MW
418 kV, 324 A (μK=1.2)
Efficiency 0.436

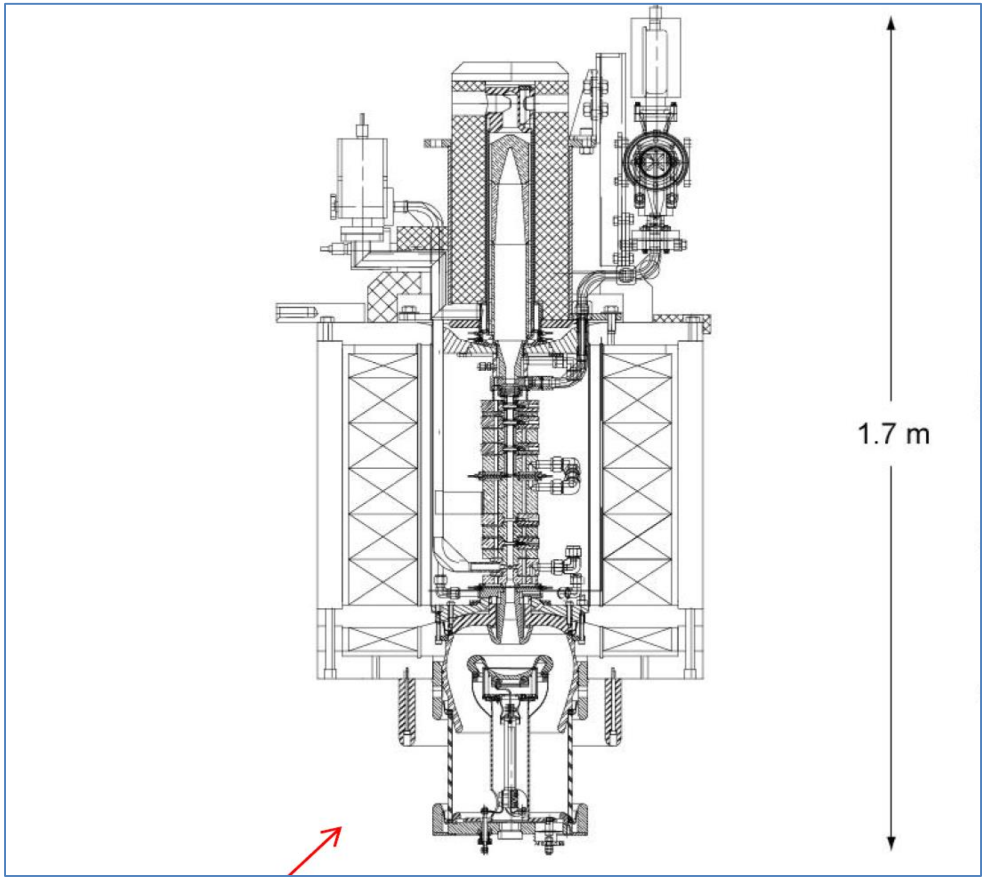
Beam Voltage	440 KV
Beam Current	350 A
Peak Output Power	50 MW
RF Pulse width	1.5μs
Cathode Diameter	71.4 mm
Beam areal compression	125:1
Peak Cathode loading	12.8 A/cm^2
Magnetic field	0.47 T
μPerveance	1.2



Klystron XL4 series
(Design)

KMD and X-Band Overview,
January 5, 2011 Erik Jongewaard

Cross Section and Photos of X-band Klystron at CERN



F. Peauger *et al.*; A 12 GHz RF POWER SOURCE FOR THE CLIC STUDY; Proceedings of IPAC'10

Cu solenoid: Power Consumption: ~ 20 kW

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

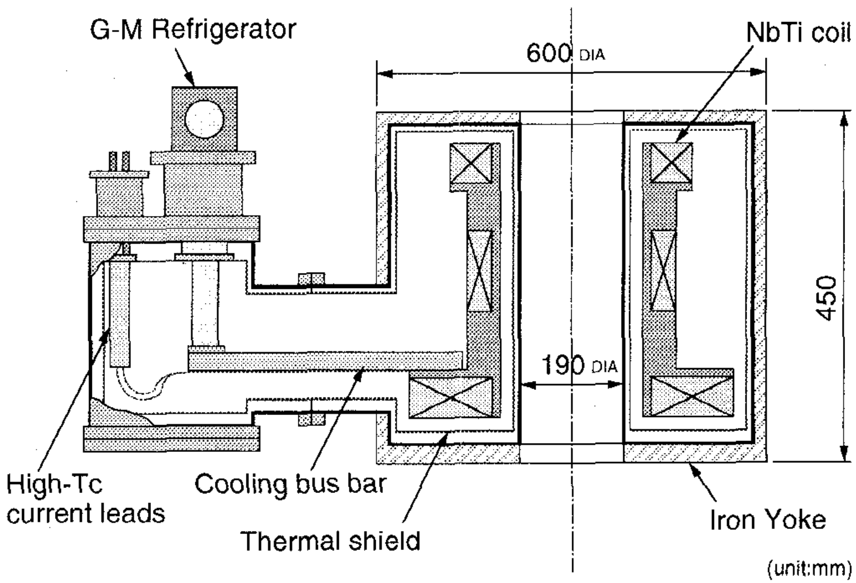
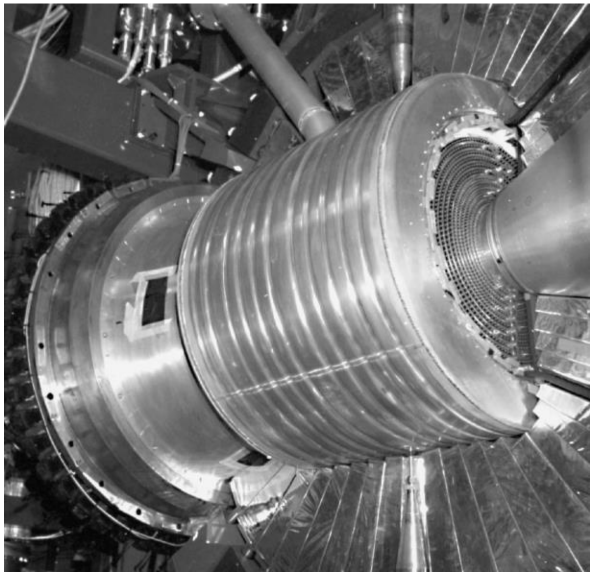


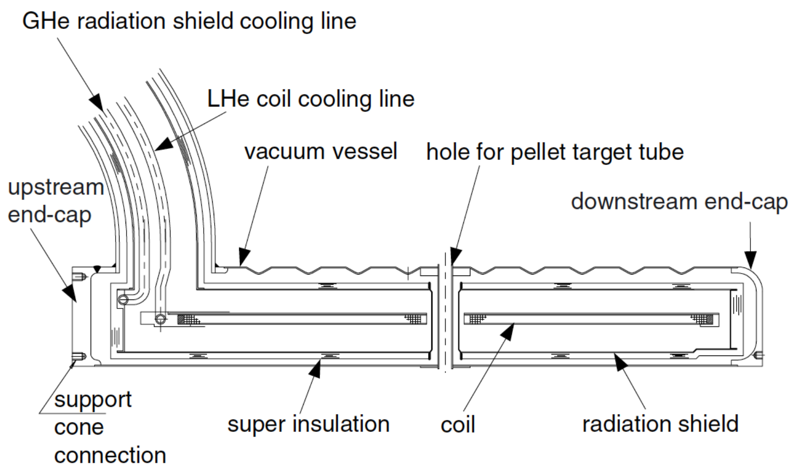
Fig. 1. Schematic structure of the conduction cooled superconducting magnet for the X-band klystron.

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	

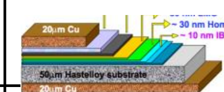
A NbTi SC Solenoid developed for WASA Experiment in cooperation with KEK-Uppsala, in 1990's





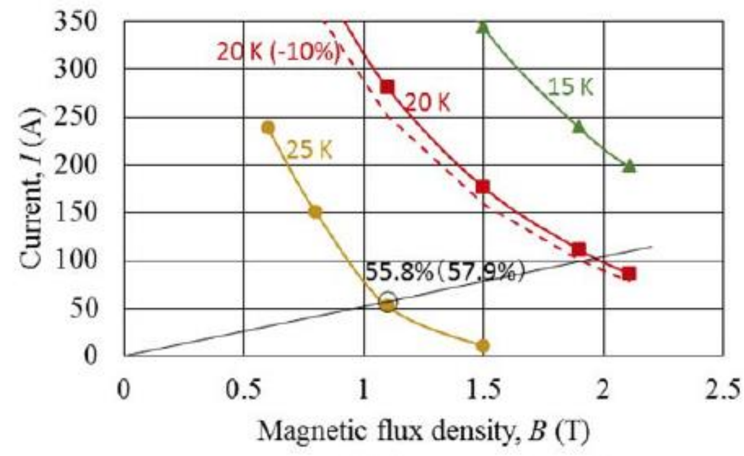
Superconducting Wire	
Superconductor	NbTi in Cu-matrix
Stabilizer	aluminium (RRR = 1500)
Outer dimensions (excl. insulation)	1.2 mm × 1.8 mm
Insulation	Formvar (0.05 mm)
$I_{critical}$ at 2 T, 4.2 K	1415 A
Yield strength $\sigma_{0.2}$ at 77 K	117×10^6 Pa
Coil	
Radius	276.8 – 288.8 mm
Length	465 mm
Gap between windings	40 mm
Winding length on each side of the gap	190 mm
Cold mass	22.9 kg
Maximum central magnetic field	1.3 T
Maximum operational current	903 A
Energy to mass ratio	6 kJ/kg
Inductance	0.30 H
Cooling technique	thermo-syphon
Coil Cryostat	
Radius	245 – 325 mm
Length	555 mm
Hole for the pellet target tube	10×25 mm (oval)

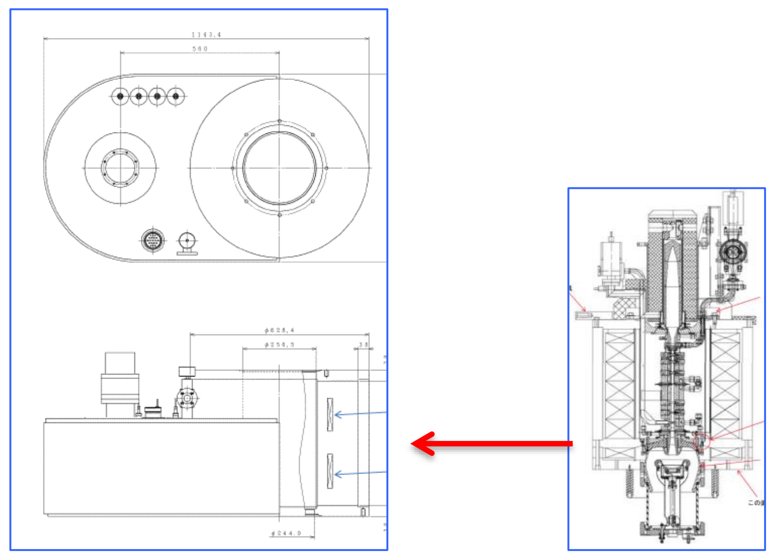
Possible Choices among SC Materials

Material	T_c [K]	$B_{c1}(0)$ [T]	$B_{sh}(0)$ [T]	$B_c(0)$ [T]	$B_{c2}(0)$ [T]	Pen. depth $\lambda(0)$ [nm]	
Nb	9.2	0.18	0.21	0.25	0.28	40	
NbTi	9.2 ~9.5	0.067	--	--	11.5 ~ 14	60	
NbN	17.3	(0.02)	--	--		150-200	
Nb_3Sn	18.3	(0.05)	0.43	0.54	28 ~30	80	
MgB_2	39	(0.03)	0.31	0.43	39	140	
$YBa_2Cu_3O_7$ (REBCO family)	92	0.01	--	1.4	100	150	
$Bi_2Sr_2Ca_1Cu_2O_8$ (BSCCO-2212)	94	0.025	--	--	>100/30	1800	
$Bi_2Sr_2Ca_2Cu_3O_{10}$ (BSCCO-2223)	110	0.0135	--	--	>100/30	2000	
Note Important for:		RF			Magnet		

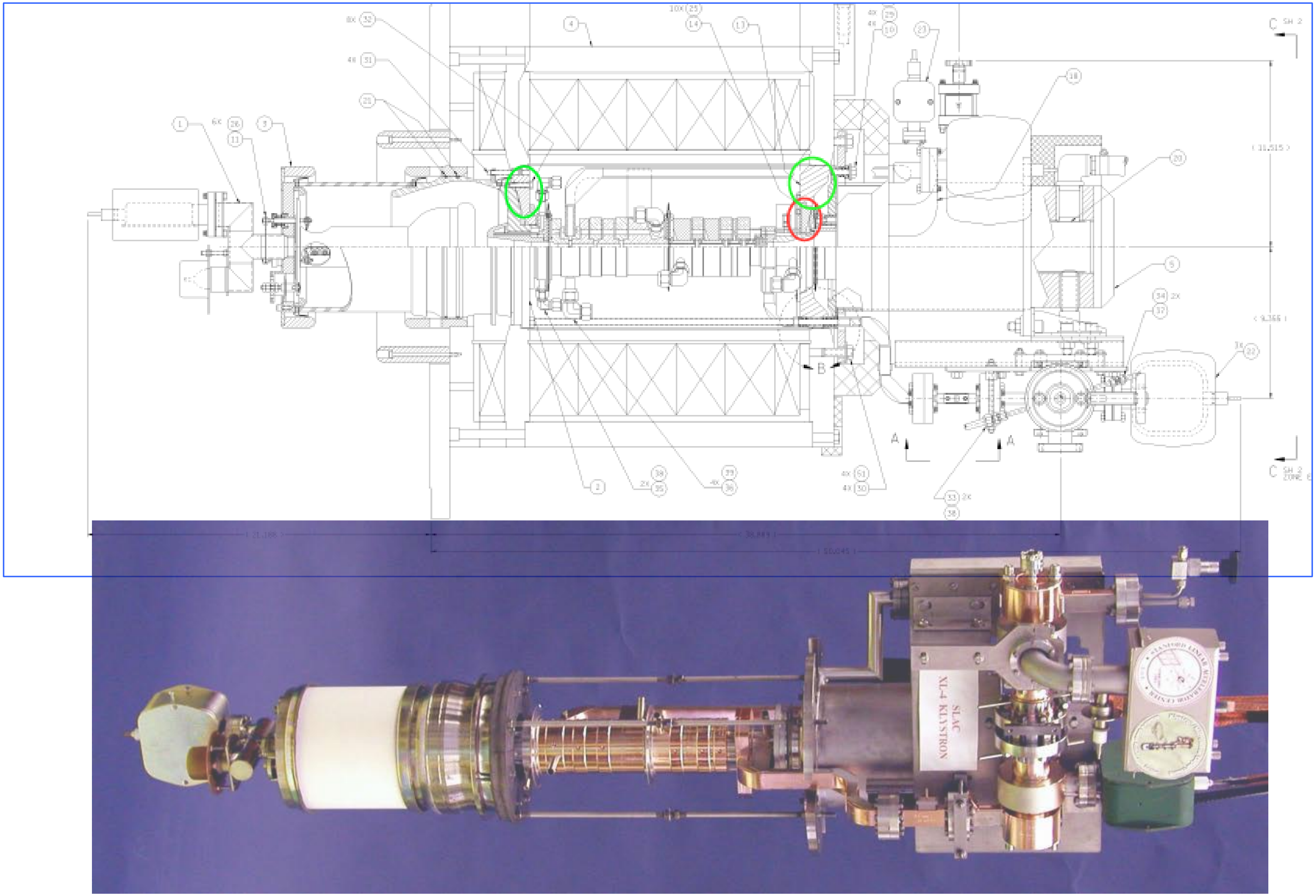
A SC Solenoid Magnet proposed

Design Parameters	
Superconductor (T-operation)	MgB_2 (@ 20 K)
Current	50 A
Central field	0.7 T
Stored energy	~ 10 kJ
Cryo-cooler applied (SHI: CH-204S 10K/Zephyr)	6.7 W @ 20 K 13.5 W @ 80 K
AC Power Consumption	~ 3 kW (1,5 kW/Klystron in case of a pair)

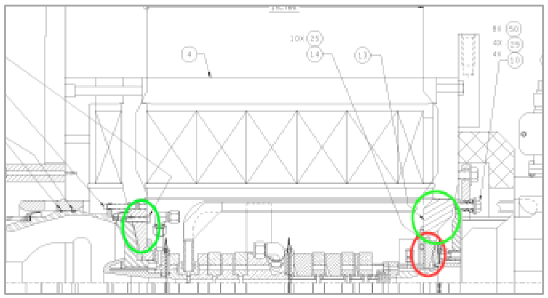




Courtesy: jeff Neilson

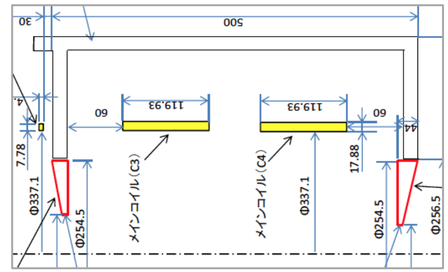


Axial Magnetic Field Profile
Comparison of Cu and SC Solenoids

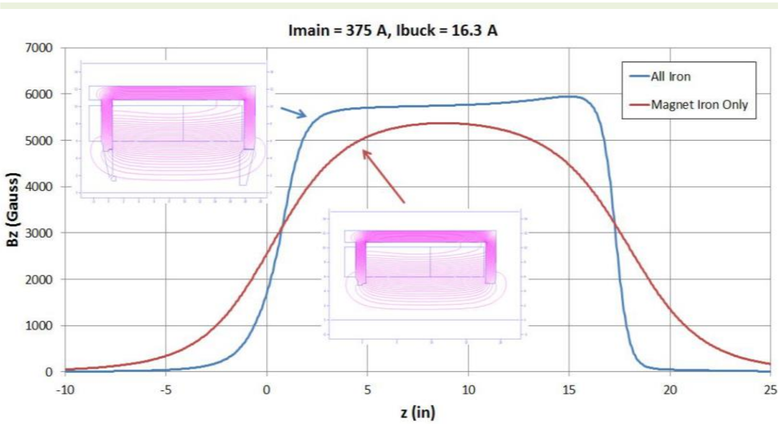


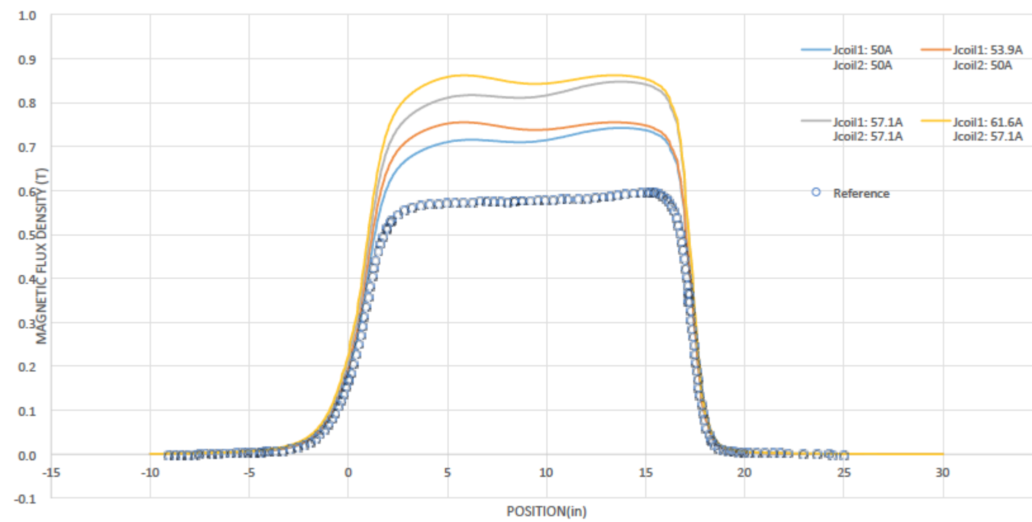
←Cu Solenoid

SC Solenoid →



Courtesy: j. Neilson



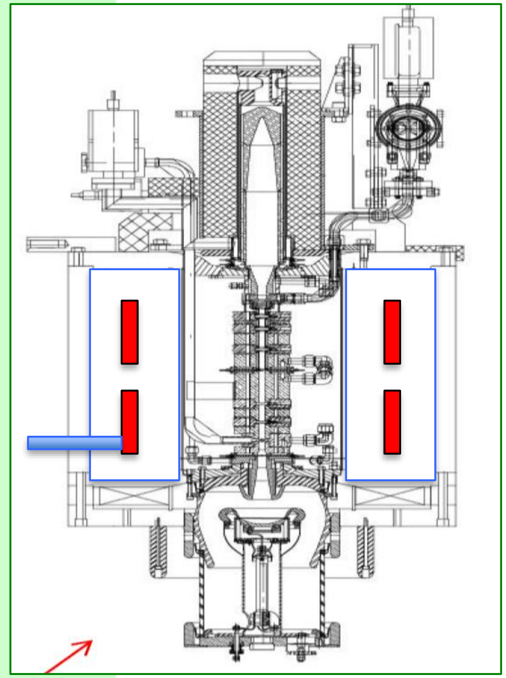


A Prototype to be Developed

Objective

- Demonstrate SC-mag technology to be applicable for X-band Klystron

Prototype Magnet:



- A prototype solenoid using **MgB_2**
  - B = > **0.7 T** (central field), Coil size: ~ 0.35 m (dia.)
  - Iron Yoke size: interface compatible
  - Operational **Temp**. **20 K**, cooled by using a cryo-cooler
  - AC-plug power saving to be demonstrated:
    - → < 3 kW / Klystron (corresponding < 1.5 KW/ a pair)
- A goal with operation of the magnet with an existing Klystron

Future:

- Pairing the solenoid, for reducing # CLs
- HTS solenoid (when it will become cost-effective),
- Cooling by using a dedicated cryogenics for a series of Klystron Solenoids to reach < 1 kW AC-plug power /Klystron (< 1/10 of AC power)
- → Saving expected : ~ (20-1) kW x 4,500 = > ~ 80 MW in CLIC-staging-380 .

Tasks of KEK

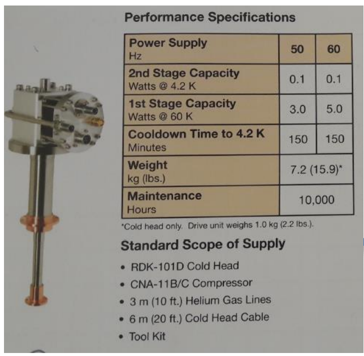
- Design and construct a prototype superconducting magnet compatible with the 50 MW klystrons used in the CERN high-gradient test facilities and providing a significant energy saving compared to the existing normal-conducting solenoid;

- Provide experimental evaluation of the magnet performance and characteristics prior to the system test with the klystron;

- Deliver the prototype klystron to CERN; and

- Undertake further design study for the advanced superconducting magnet design for applications in future accelerator and other programmes.

Configuration of the Prototype Klystron SC Solenoid



Performance Specifications

	50	60
Power Supply Hz	50	60
2nd Stage Capacity Watts @ 4.2 K	0.1	0.1
1st Stage Capacity Watts @ 60 K	3.0	5.0
Cooldown Time to 4.2 K Minutes	150	150
Weight kg (lbs.)	7.2 (15.9)*	
Maintenance Hours	10,000	

*Cold head only. Drive unit weighs 1.0 kg (2.2 lbs.).

Standard Scope of Supply

- RDK-101D Cold Head
- CNA-11B/C Compressor
- 3 m (10 ft.) Helium Gas Lines
- 6 m (20 ft.) Cold Head Cable
- Tool Kit

SHI:
CH-204s 10K
Zephyr

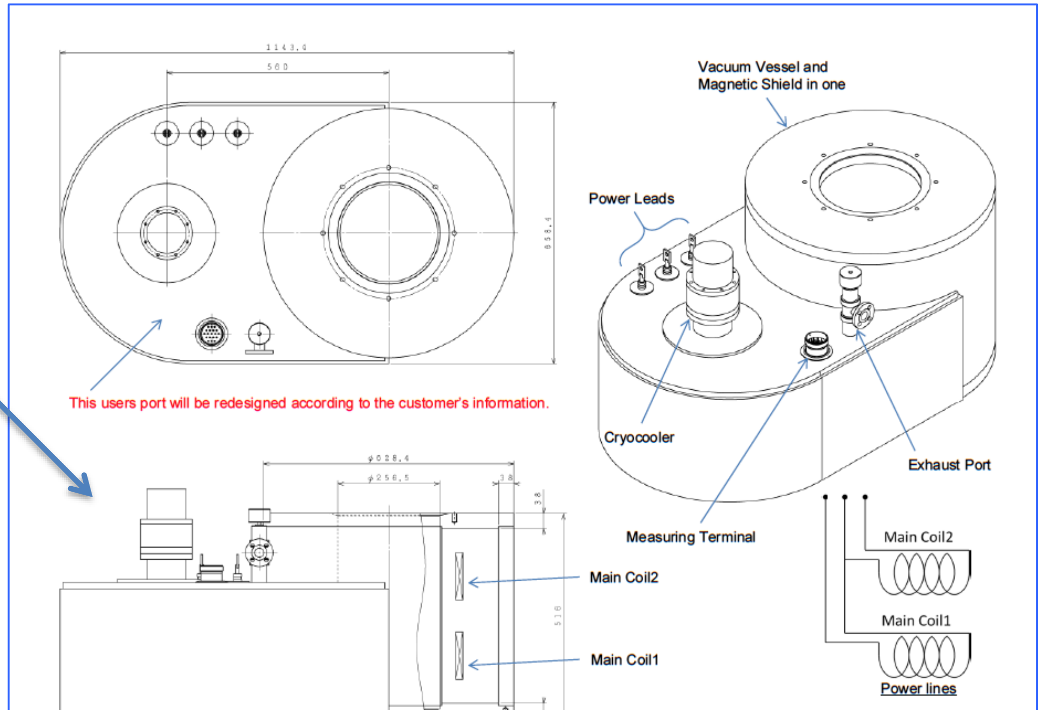
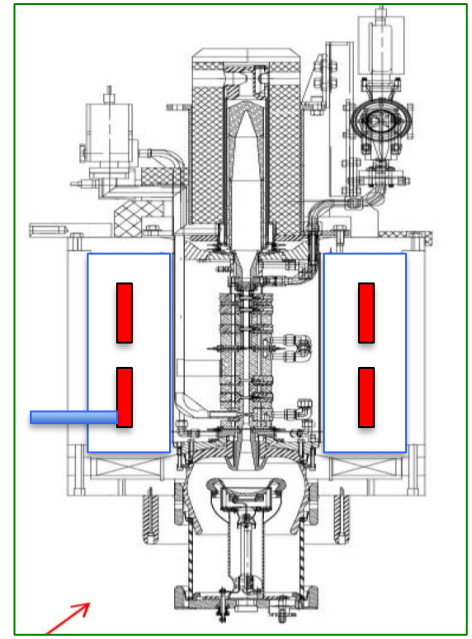


Figure 2-1 External View (Plan)



Tasks of CERN

- Provide the necessary technical information, requirements and specifications for the focusing solenoid of the 50 MW X-band klystron currently in use at CERN in the CLIC high-gradient test facility;
- Support the research activities at KEK;
- Install the superconducting magnet prototype coupled with klystron in one of the CLIC high-gradient test stands and provide an operational evaluation; and
- Provide measurements of crucial parameters such as klystron stability and system energy consumption.

A Possible Setup w/ the Klystron at the CERN RF experimental hall