Report on Accelerator Plenary Session
"Power Consumption"

Chris Adolphsen & Philippe Lebrun

LCWS 12
University of Texas at Arlington, USA
22 – 26 October 2012

Session Program

Accelerator Plenary: - Common Topics (Power Consumption)

Convener: Philippe Lebrun (CERN), Chris Adolphsen (SLAC)

Location: Rosebud Theater

11:00 **ILC Linac Power Losses and Possible Efficiency Improvements** *20'*

Speaker: Dr. Shigeki Fukuda (KEK)

11:20 **CLIC Power and Energy** *30'*

Speaker: Philippe Lebrun (CERN)

Material: **Slides**

11:50 **ILC Power Load and States of Operation** *20'*

Speaker: Randal Wielgos (Fermilab)

Material: **Slides**

12:10 **Asian ILC Site Power Load and States of Operation** *20'*

Speaker: Dr. atsushi Enomoto (KEK)

12:30 **ILC Cryogenic Power Load and States of Operation** *20'*

Speaker: Prof. Akira Yamamoto (KEK)

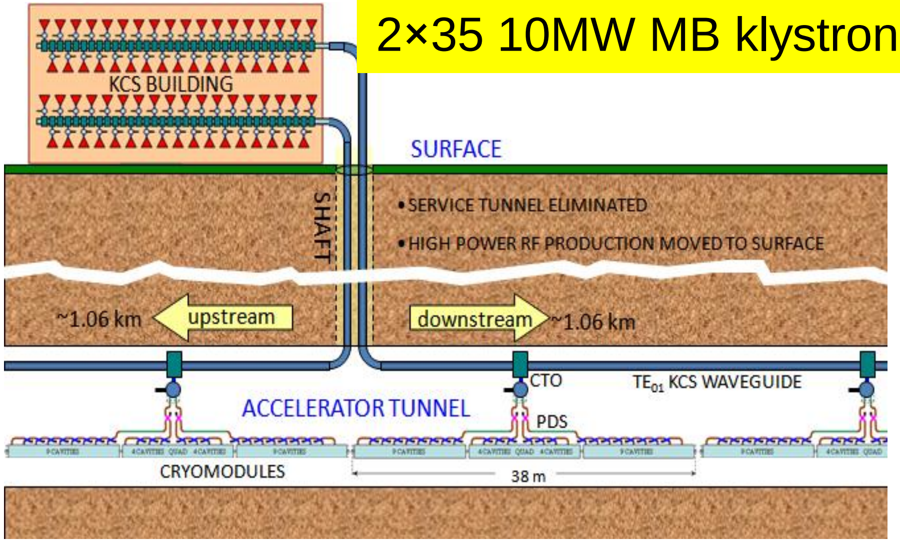
Material: **Slides**

Power Consumption of HLRF in SC Linear Collider

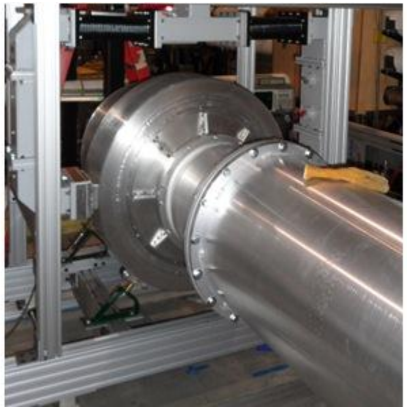
KEK
S. Fukuda

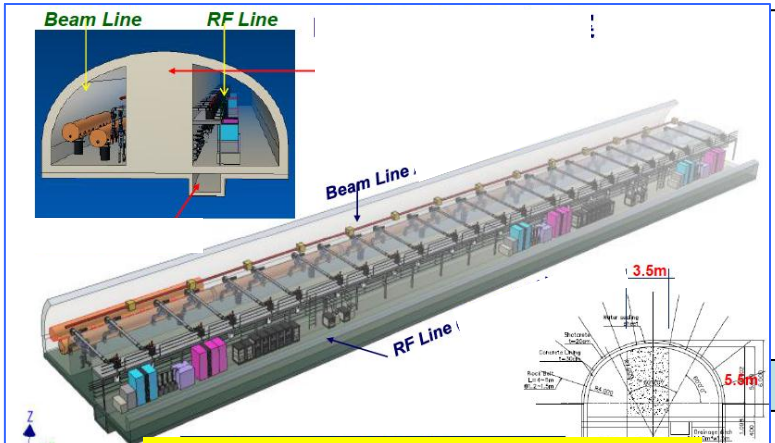
High-Level RF Solutions in single tunnel plan

2×35 10MW MB klystrons



Klystron Cluster Scheme, KCS (SLAC)



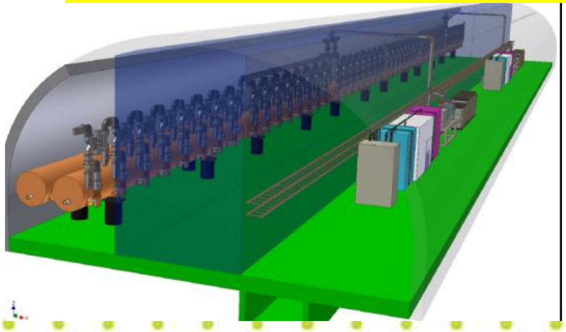


~4000×800kW klystrons

Distributed RF Sources, DRFS (KEK)

DKS

~378×10MW klystrons



RF Power Budgets for KCS and DKS

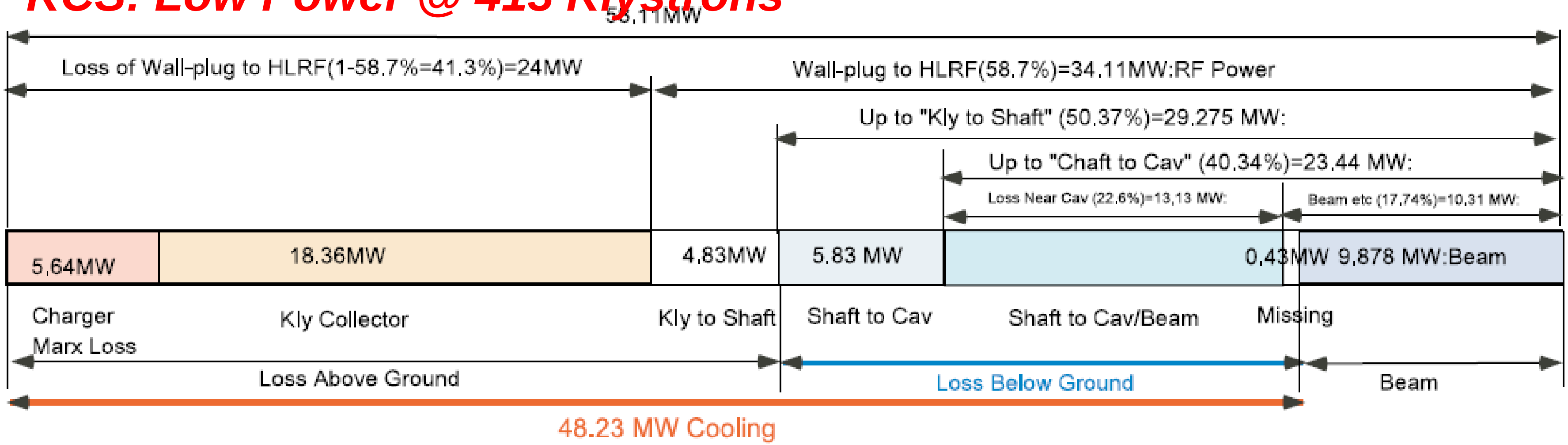
Cavity and Local Power Distribution		KCS (kW)		DKS (kW)
Mean beam power per cavity		*189.18*		*189.18*
Extra beam power for ±20% gradient spread	2.90%	194.67	5.30%	199.21
s.s. reflection for ±20% gradient spread	6.00%	206.35	6.00%	211.16
Required LLRF overhead	7.00%	220.8	7.00%	225.95
Local PDS average losses	8.00%	240	8.00%	245.59
Multiply by number of cavities fed as a unit	26	6239.9	39	9578.1
Required local PDS RF input power		*6239.9*		*9578.1*

Power Combining & Transport (DKS)		(MW)
RF power to local PDS		*9.578*
Combining/splitting and shielding penetrations	1.10%	9.6847
WR770 run loss/3	1.40%	9.8222
Required power from klystron (DKS)		*9.822*

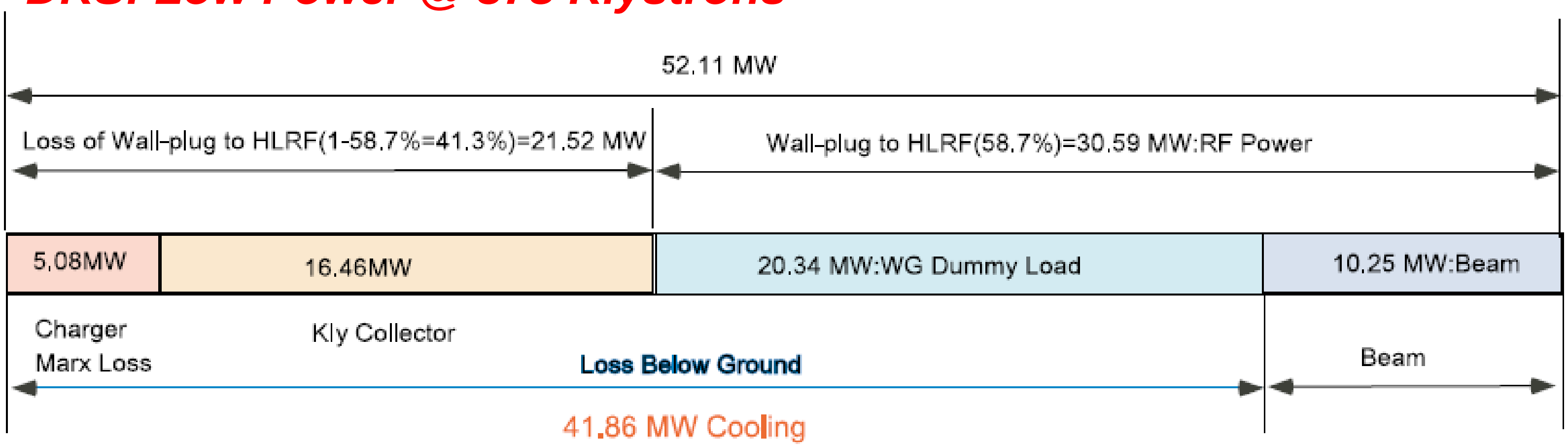
Power Combining & Transport (KCS)		(MW)
RF power to ML Unit		*6.2399*
Multiply by number of ML Units per KCS	26 (25)	162.24 (156)
KCS main waveguide loss	5.0% (4.7)	170.78 (163.69)
Shaft and bends loss	1.80%	173.91 (166.69)
CTO string and upgrade WC1375 run loss	1.50%	176.55 (169.23)
Klystron waveguide into CTO	5.60%	187.03 (186.74)
Divide by number of klystrons	19 (18)	9.8436 (9.9594)
Required power from each klystron (KCS)		*9.844 (9.959)*

Heat Loss Comparison for Baseline

KCS: Low Power @ 413 Klystrons

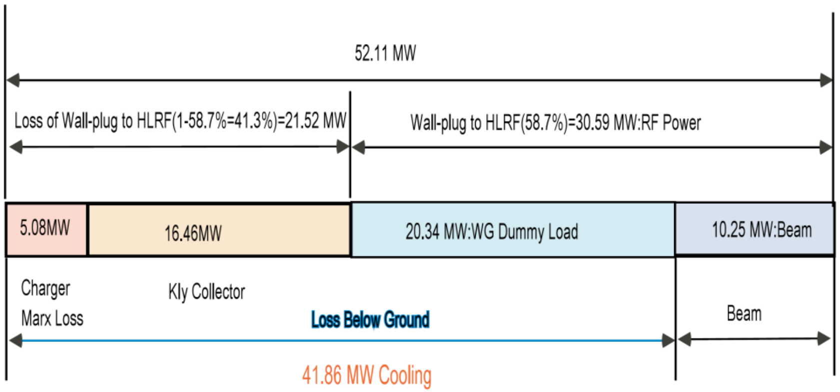


DKS: Low Power @ 378 Klystrons

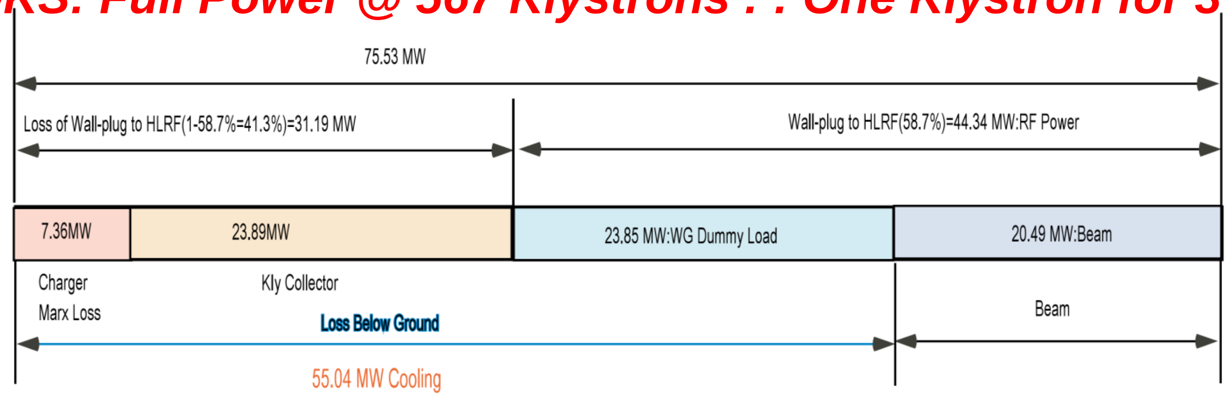


DKS Heat Loss Comparison Low Power & Full Power Baseline

DKS: Low Power @ 378 Klystrons : One Klystron for 4.5 Cryomodules



DKS: Full Power @ 567 Klystrons : : One Klystron for 3 Cryomodules



Ratio of FPB/LPB

Total Power=75.53/52.11
=1.45
Cooling Power=55.04/41.86
=1.31
Power from W.P. to HLRF
=44.34/30.59=1.45
Beam Power=20.49/10.25=2.0

CLIC CDR
Power & Energy

Philippe Lebrun & Bernard Jeanneret

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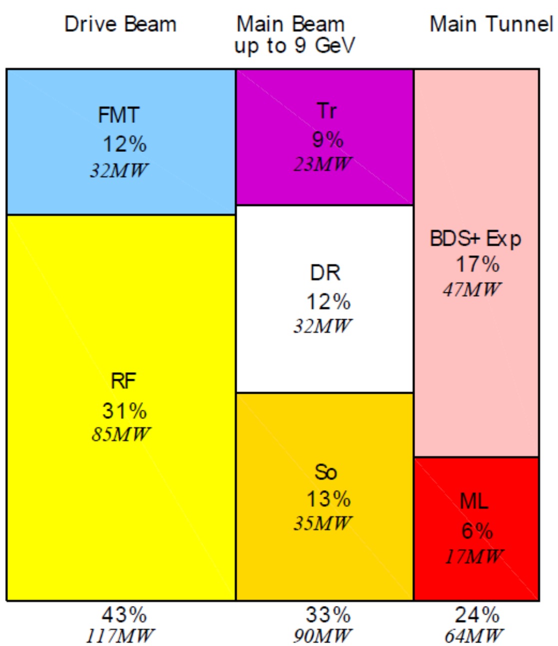
Assumptions & boundary conditions for CLIC power estimates

- Power & energy consumption are consistent with the technical definition of the CLIC accelerator project as per the CDR
  - Minor adjustments have been made to the numbers between CDR Volume 1 and Volume 3
  - In addition, Volume 3 includes numbers for scenario 500 GeV B
- Assumptions for RF-to-beam efficiencies
  - Modulators 0.89 (0.95 flat-top, 3 μs rise time, 5 μs setting time)
  - Klystrons 0.7 (R&D goal, best achieved today 0.68)
  - Drive beam acceleration 0.89 (low-gradient structures)
  - PETS (fully loaded) 0.98
  - Residual drive beam power after deceleration 17 % ⇒ effective power extraction from drive beam 0.81
  - Main beam acceleration 0.25 (compromise between gradient, efficiency and minimization of wake fields)
- A number of technical alternatives aiming at mitigation of power and energy consumption have been identified, and will be studied in the post-CDR phase

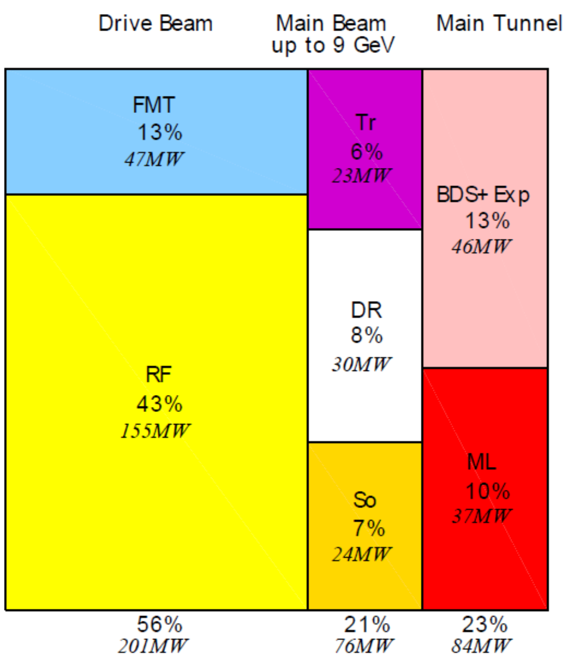
Power consumption by WBS domain

Minor changes between CDR Volume 1 and Volume 3
Numbers in parentheses refer to CDR Volume 1
Power consumption of ancillary systems ventilated pro rata and included in numbers by WBS domain

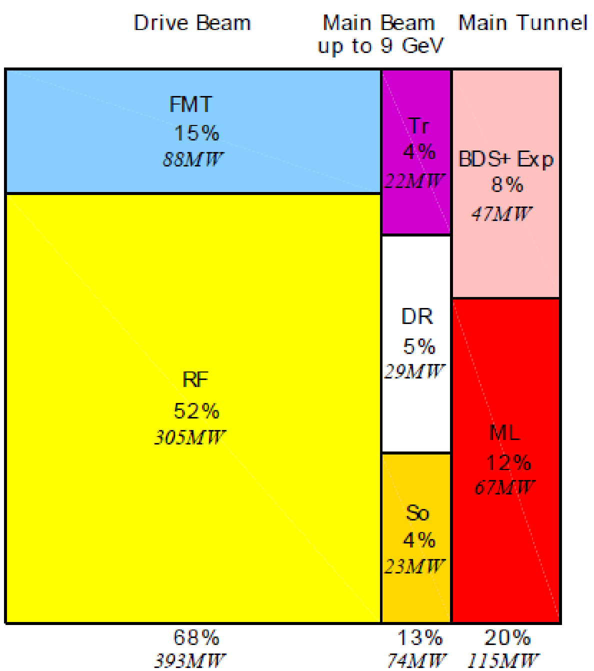
500 GeV A
Total 272 (271) MW



1.5 TeV
Total 364 (361) MW



3 TeV
Total 589 (582) MW

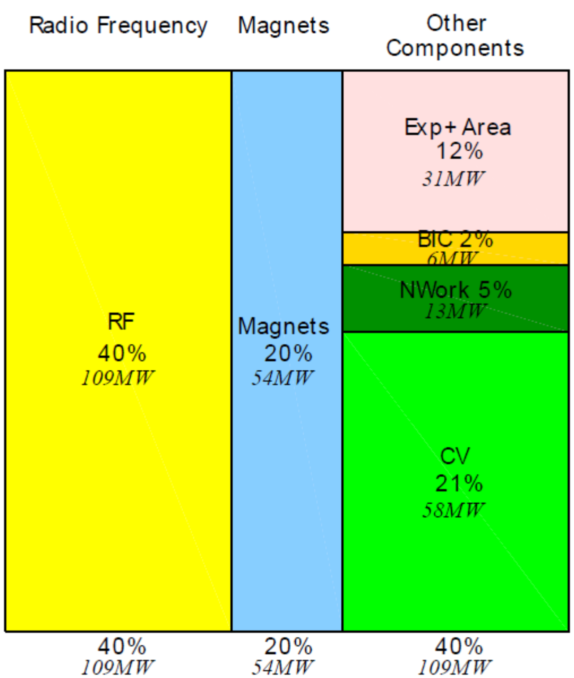


RF: drive beam linac, FMT: frequency multiplication & transport, So: sources & acceleration up to 2.5 GeV, DR: damping rings, Tr: booster linac up to 9 GeV & transport, ML: main linacs, BDS: beam delivery system, main dump & experimental area

Power consumption by technical system

Minor changes between CDR Volume 1 and Volume 3
Numbers in parentheses refer to CDR Volume 1

500 GeV A
Total 272 (271) MW



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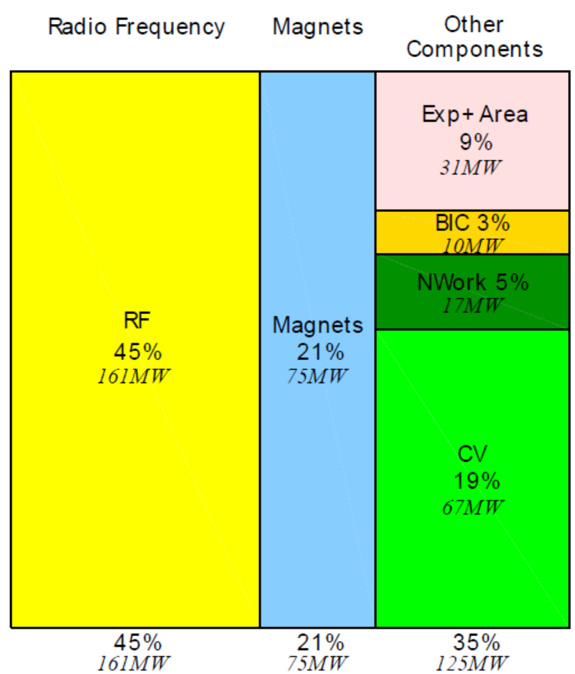

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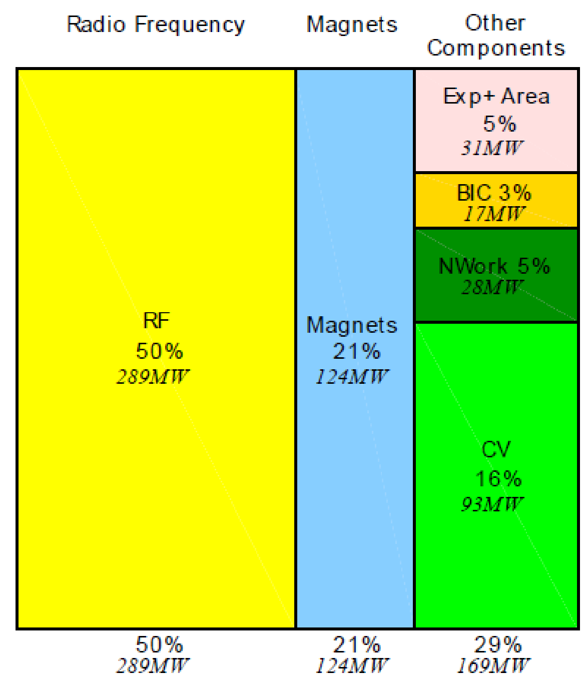

CV: cooling & ventilation, NW: electrical network losses, BIC: beam instrumentation & control

Paths to power & energy savings [1/2]

- Sobriety
  - Reduced current density in normal-conducting magnets
  - Reduction of HVAC duty
- Efficiency
  - Grid-to-RF power conversion
  - RF-to-beam power conversion
  - Permanent or super-ferric superconducting magnets

$\Rightarrow$ Potential for power savings at 3 TeV
- magnets ~ 86 MW
- cooling & ventilation ~24 MW

Paths to power & energy savings [2/2]

- Energy management
  - Low-power configurations in case of beam interruptions
  - Modulation of scheduled operation to match electricity demand

Staging Scenario	E_{CM} [TeV]	$P_{nominal}$ [MW]	$P_{waiting\ for\ beam}$ [MW]	$P_{shutdown}$ [MW]
	0.5	272	168	37
A	1.4	364	190	42
	3.0	589	268	58
	0.5	235	167	35
B	1.5	364	190	42
	3.0	589	268	58

- Waste heat recovery
  - For concomitant uses, e.g. adsorption chillers

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Conventional **Electrical** System
Americas Region
Power Requirements

October 23, 2012

Randy Wielgos
FNAL

LOAD TABLE

TDR Baseline

Peak Operating Loads MW

Developed by CF&S from Loads Provided by the Area System Groups

Area System	RF Power	RF Racks	NC Magnets & Power Supplies	Cryo	Conventional		Total
					Normal Load	Emergency Load	
e-sources	1.28	0.09	0.73	0.80	1.02	0.16	4.08
e+sources	1.39	0.09	4.94	0.59	2.19	0.35	9.56
DR	8.67		2.97	1.45	1.84	0.14	15.08
RTML	4.76	0.32	1.26	part of ML cryo	0.12	0.14	6.59
Main Linac	58.1	4.9	0.914	32	8.10	5.18	109.16
BDS			10.43	0.41	0.24	0.28	11.36
Dumps					1		1.00
IR			1.16	2.65	0.09	0.17	4.07
TOTALS	74.2	5.4	22.4	37.9	14.6	6.4	161

General Criteria

Peak Operating Power Loads – Loads During Steady State Operations at Baseline Design

Conventional Power – Power Required to Support the Facilities and Tech. Loads

***Normal* –** Loads that Do Not Require Alt. Source Backup Power

***Emergency* –** Critical Loads that Require Alt. Source Backup Power

Conventional Load Development (Peak During Operations)

Surface

- Lights
- Receptacles
- Crane
- Elevator
- Chillers
- Cooling Towers
- Chilled Water Pumps
- Cooling Water Pumps
- LCW Pumps
- CRAC units
- HVAC Units
- Cryo Liquid StorageSystem
- Ventilation Units

Tunnel

- Lights
- Welding Receptacles
- Receptacles
- Process Water Pumps
- LCW Pumps
- LCW Booster Pumps
- Fan Coil Units
- Sump Pumps
- Groundwater Lift Pump

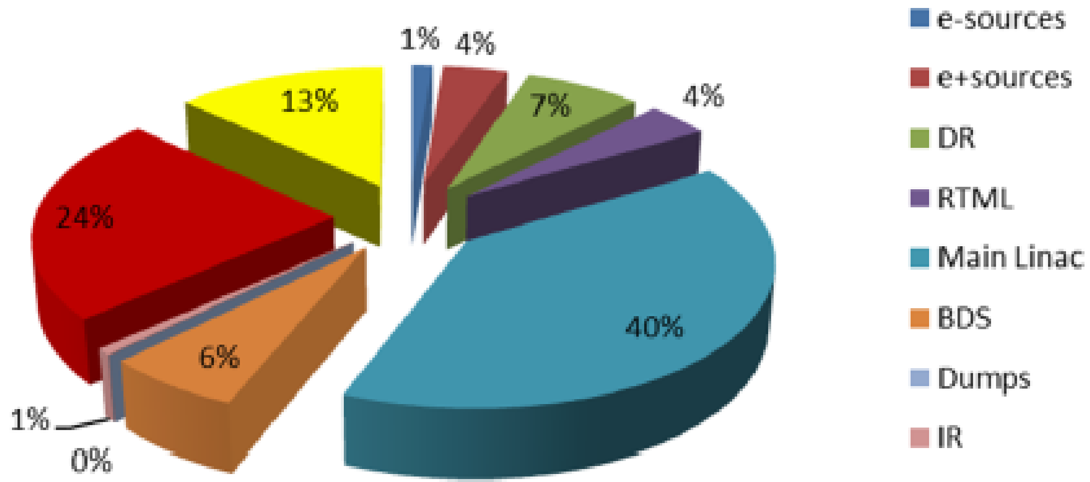
Emergency Power Required Loads Included in Peak

Loads Included in Peak

Loads NOT Included in Peak

Load Distribution

Conventional - 21MW (13% of the total)
Conventional related to heat rejection equipment - 14 MW (8% of total)
Fractional improvements to the heat rejection system can provide small improvements to the overall power load



Percent Loads by Area System

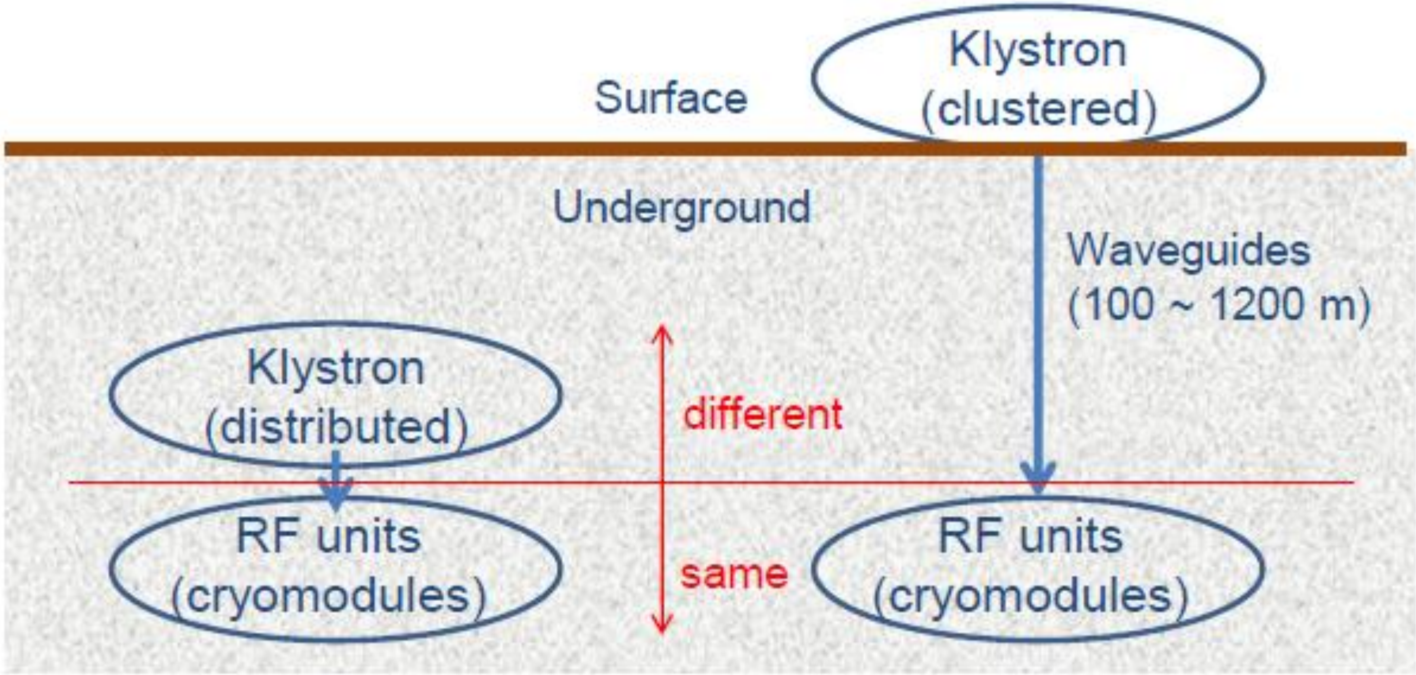
Area System MW

e-sources	2.1	1%
e+sources	6.4	4%
DR	11.6	7%
RTML	6.3	4%
Main Linac	63.9	40%
BDS	10.4	6%
Dumps	0.0	0%
IR	1.2	1%
Cryo	37.9	24%
Conv	21.0	13%

Asian Region Conventional Power Loads

A. Enomoto (KEK)

Regional specific part
- DKS and KCS -



	DKS	KCS
Klystron	**378**	**403**
RF units (3 cryomodules)	**567**	**567**

~6%

ML Technical Equipment Power Loads

- Asian specific loads -

DKS Power Load in MW (TDR baseline - Low Power)

Area System	RF Power	Racks	NC magnets	Cryo	Conventional		Total
					Normal	Emerg	
e- sources	1.28	0.09	0.73	0.80			
e+ sources	1.39	0.09	4.94	0.59			
DR	8.67		2.97	1.45			
RTML	4.76	0.32	1.26	part of ML cryo			
Main Linac	52.13	3.78	2.28	32.00			
BDS			10.43	0.41			
Dumps							
IR			1.16	2.65			
TOTALS	68.2	4.3	23.8	37.9	0.0	0.0	0

Common loads

Asian specific

ILC Technical Equipment Heat Loads

- Asian specific loads -

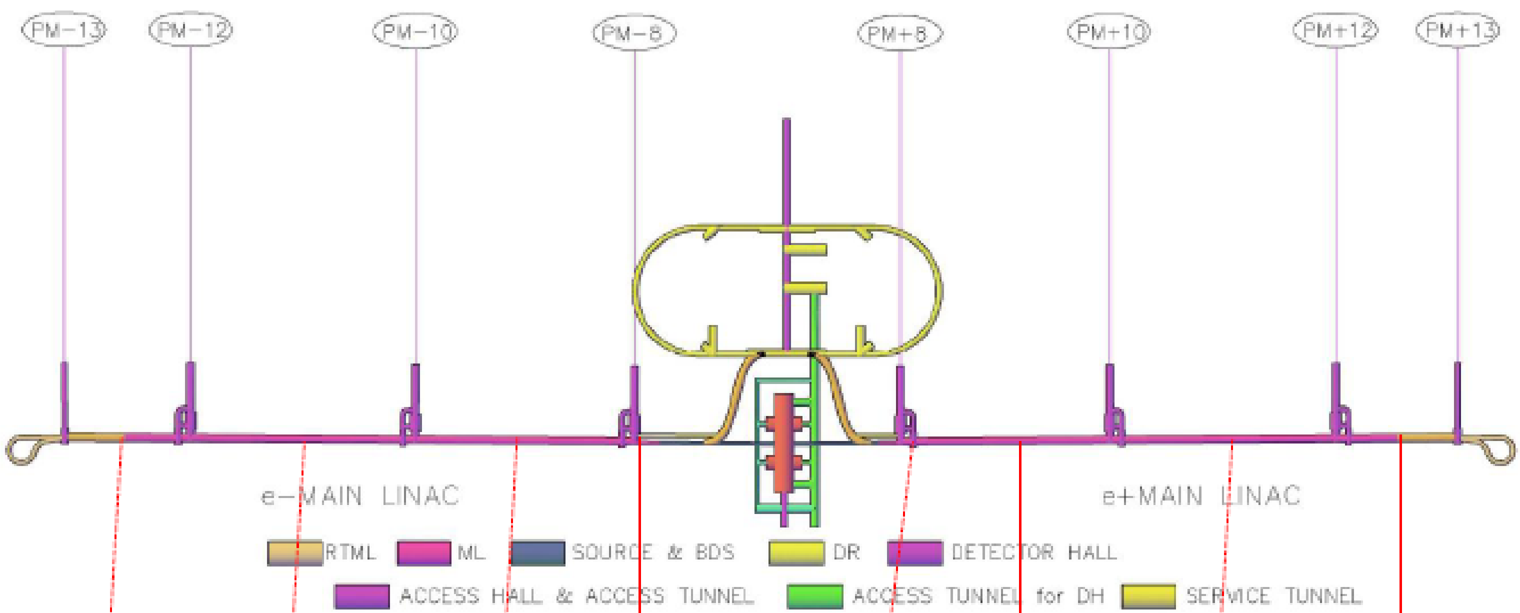
DKS Thermal Loads in MW (TDR baseline - Low Power)

Area System	load to LCW	load to Air	Cryo (Water load)	Conven tional	Total
e- sources	1.40	0.70	0.80		2.9
e+ sources	5.82	0.64	0.59		7.1
DR	10.92	0.73	1.45		13.1
RTML	4.16	0.76	part of ML cryo		4.9
Main Linac	42.17	5.77	32.00		79.9
BDS	9.20	1.23	0.41		10.8
Dumps	14.00				14.0
IR	0.40	0.76	2.65		3.8
TOTALS	88.1	10.6	37.9	0.0	137

Common loads

Asian specific

Distribution of ML Power 58 MW



	PM-12	PM-10	PM-8		PM+8	PM+10	PM+12	Total
RTML + ML RF units	113	126	63		60	126	113	601
%	18.8%	21.0%	10.5%		10.0%	21.0%	18.8%	100%
ML RF units	96	126	63		60	126	113	567
%	16.9%	22.2%	11.1%		10.6%	22.2%	16.9%	100%

Summary: CF Power Loads by Areas

DKS Power Load in MW (TDR baseline - Low Power)

Area System	RF Power	Racks	NC magnets	Cryo	Conventional		Total
					Normal	Emerg	
e- sources	1.28	0.09	0.73	0.80	1.47	0.50	4.9
e+ sources	1.39	0.09	4.94	0.59	1.83	0.48	9.3
DR	8.67		2.97	1.45	1.93	0.70	15.7
RTML	4.76	0.32	1.26	part of ML cryo	1.19	0.87	8.4
Main Linac	52.13	3.78	2.28	32.00	12.10	4.30	106.6
BDS	58.1	4.9	10.93 0.9	0.41	8.1 1.34	5.18 0.20	109.2 12.4
Dumps					0.00	1.21	1.2
IR			1.16	2.65	0.90	0.96	5.7
TOTALS	68.2	4.3	23.8	37.9	20.8	9.2	164
					14.6	6.4	161

Red numbers are for KCS

2 K cryogenic plant turn-down

Two slides from a talk by Laurent Tavian (CERN)
Presented at Fermilab (27 Sep 2012)

With introduction from Tom Peterson (Fermilab)

To be presented at LCWS-12, Oct. 23, 2012, by Akira Yamaoto (KEK)
(with some additional slides)

Comments from Tom Peterson about cryogenic capacity and efficiency

- Cryogenic plant efficiency is optimal when the plant capacity is matched to the load.

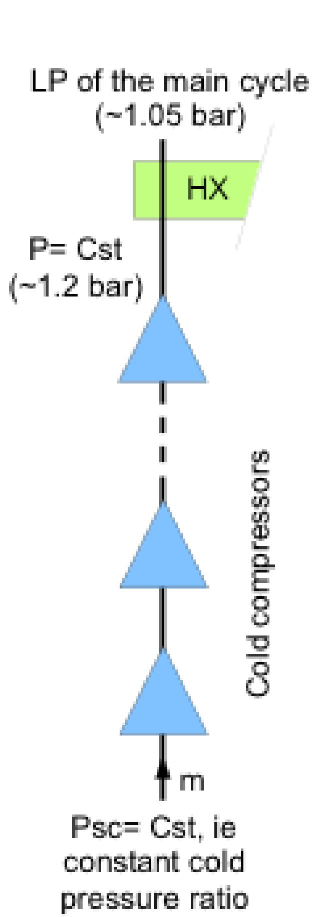
- Due to various factors such as uncertainties in final as-installed heat loads, overcapacity required for control, and variability or absence of large dynamic heating, ILC may experience varying levels of mismatch between cryogenic plant capacity and loads.

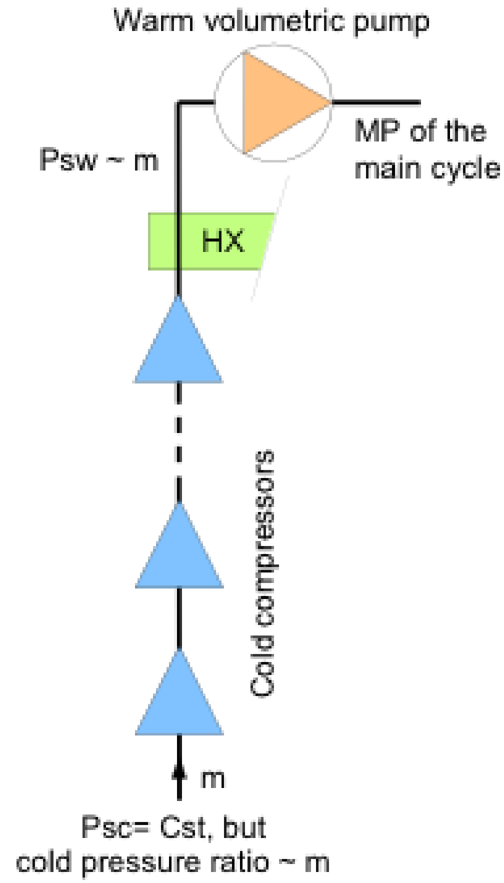
- This mismatch results not only in inefficiency but control difficulties for the 2 Kelvin system due to the dynamic nature of the cold compressors.

Matching load to capacity

- Two mechanisms (among other features in the cryogenic plant) would provide matching of cryogenic capacity to the load in an ILC
- 1. Electric heaters in cryomodules will be required to compensate dynamic loads from variations in RF power.
  - These will also operate continuously at some low level for control
- 2. Slow changes in required capacity can be accommodated by the cryogenic plant at the 2 Kelvin level using a mixed compression cycle as described by Laurent Tavian in the following slides.

Integral-cold vs mixed compression cycle



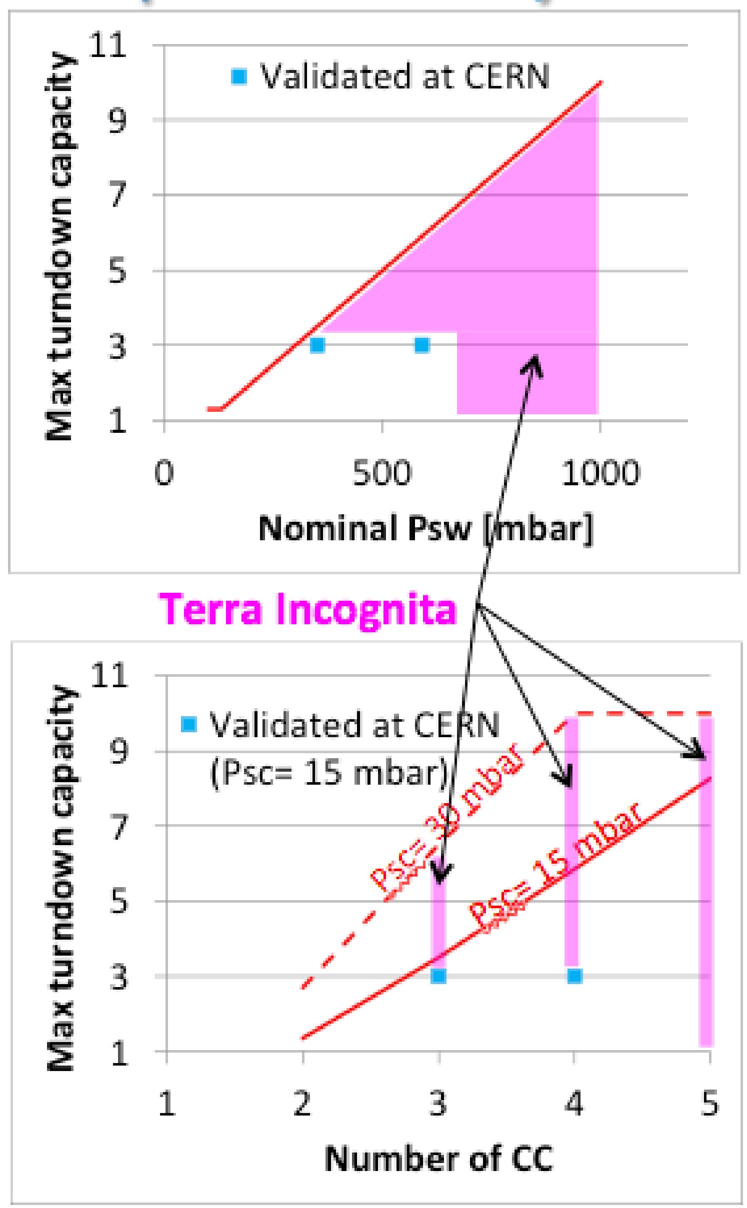


Integral-cold

Limited turndown capacity : ~1.3 (electrical heating required)

Mixed

Turndown capacity: theoretically up to 10 depending on CC number and the nominal warm suction pressure Psw



Summary

- Linear colliders are single-pass machines and thus unavoidably show low energy efficiency, resulting in high power consumption. The nominal power consumption at 500 GeV CM is 161 (164) MW for ILC, and 235 MW for CLIC
- Optimization of the RF chain is therefore an essential issue, from power grid to RF and from RF to beam. This has driven design choices and triggered specific R&D in both projects, e.g. MBK and modulators
- In both cases, the RF system however uses only about half of the total power consumed. Other high-power items are cryogenics (for ILC), NC magnets and conventional systems
- The distribution of power loads among domains/systems is different between ILC KCS and ILC DKS. The total numbers are however very similar
- Substantial differences have been found between CLIC and ILC concerning power consumption of conventional systems and interaction region. Further analysis is required for their understanding
- Significant and swift decrease of power consumption in standby modes opens the way for CLIC load shedding in periods of peak demand
- Efficient turn-down of a large cryogenic system requires adequate design and operation strategies