Cryogenics of the 60 GeV LHeC

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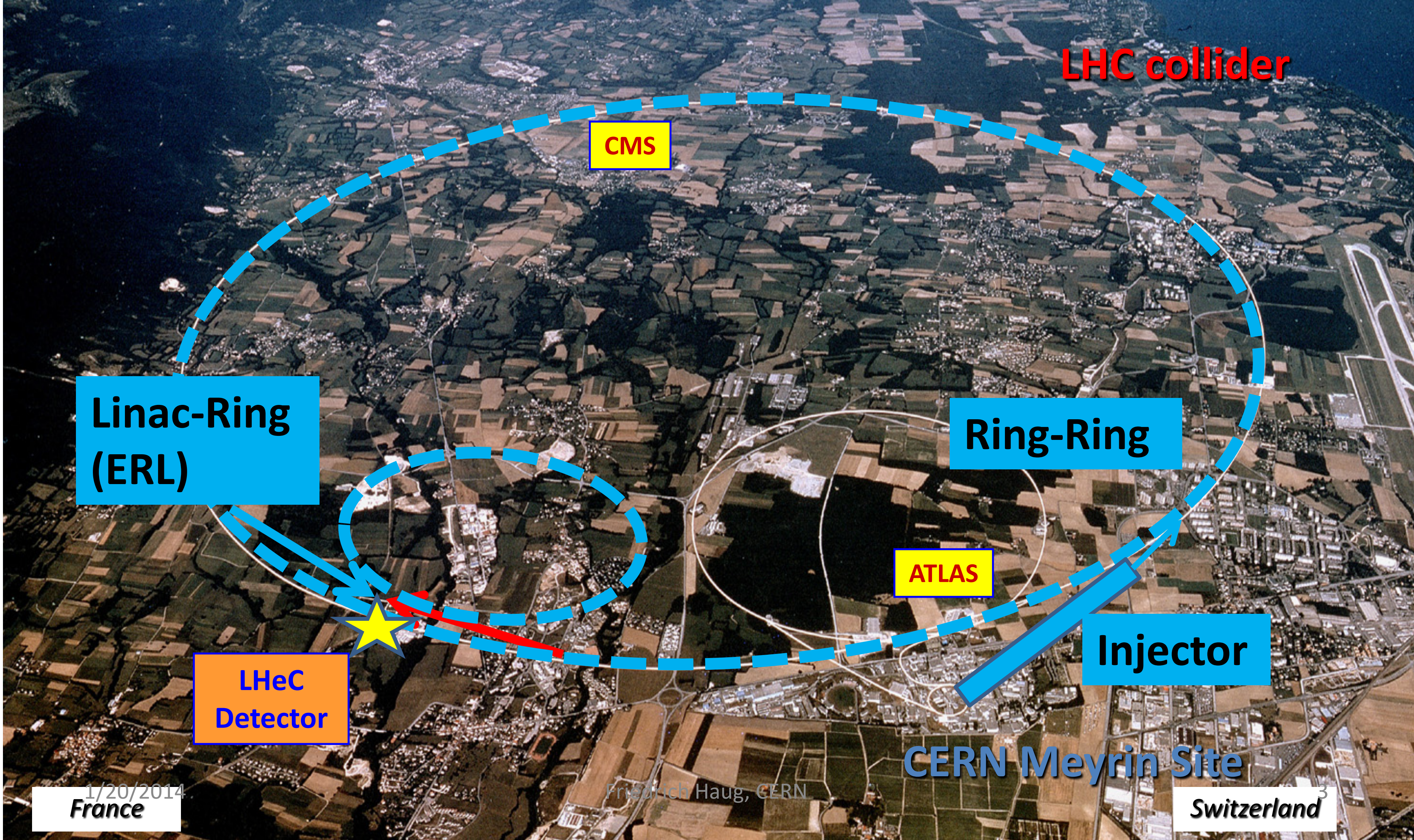
LHeC Workshop, Chavannes-de-Bogis, Jan. 20-21, 2014

Contents....

...largely based on the LHeC Conceptional Design Report

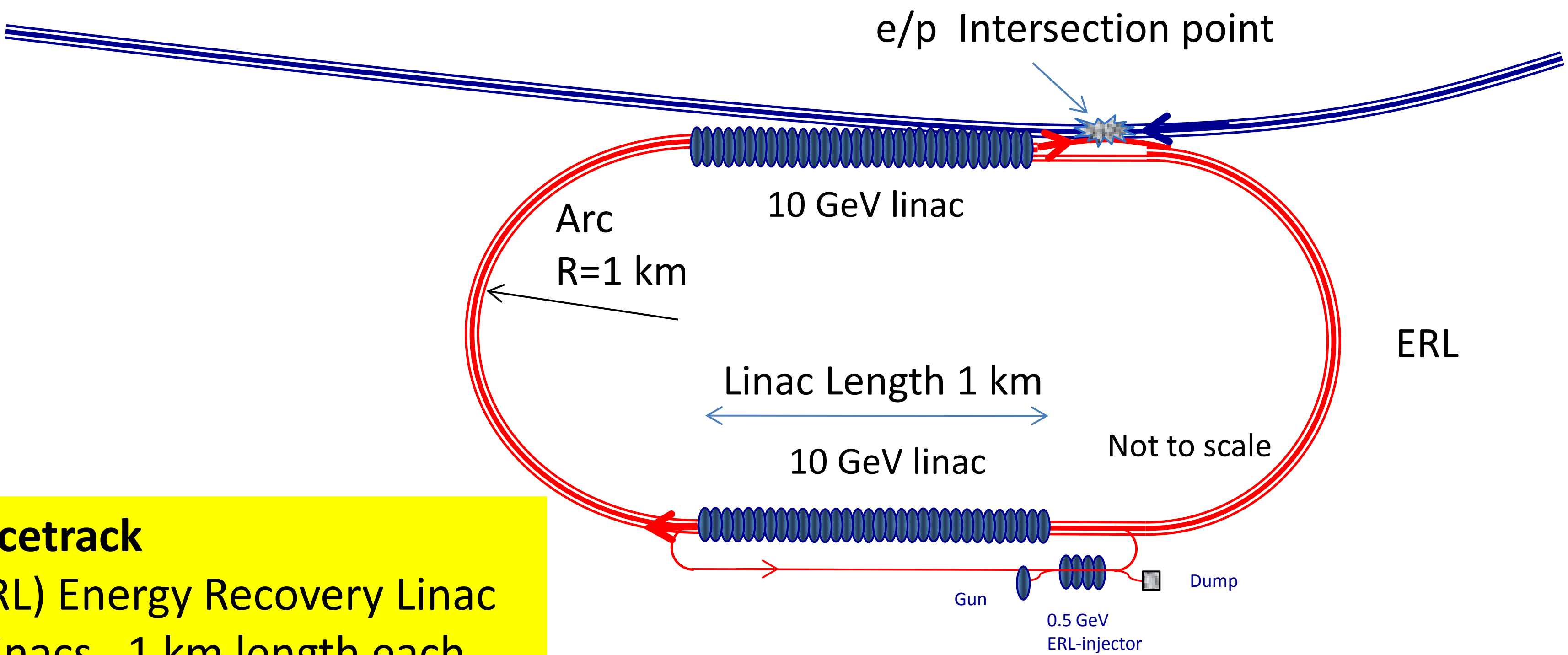
- ERL layout (Linac-Ring)
- Cryomodule principle
- Power consumption of ERL
- Parameters for cryo power
- Ring-Ring version
- Comparison with CERN accelerator plants
- *Detector cryogenics*

Two e-accelerator versions: Linac-Ring, Ring-Ring



Linac-Ring Cryogenics (ERL)

Basic concept



Racetrack
(ERL) Energy Recovery Linac
2 linacs, 1 km length each
3-pass, 60 GeV, 8 mA

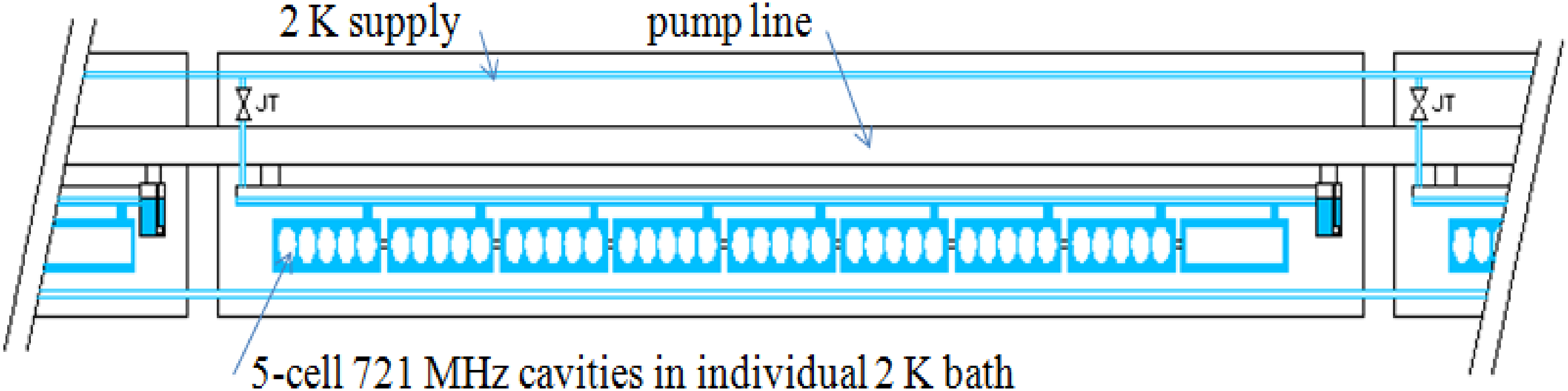
For more details see talk of Frank Zimmermann

Cryomodule configuration

Proposal
based on CDR

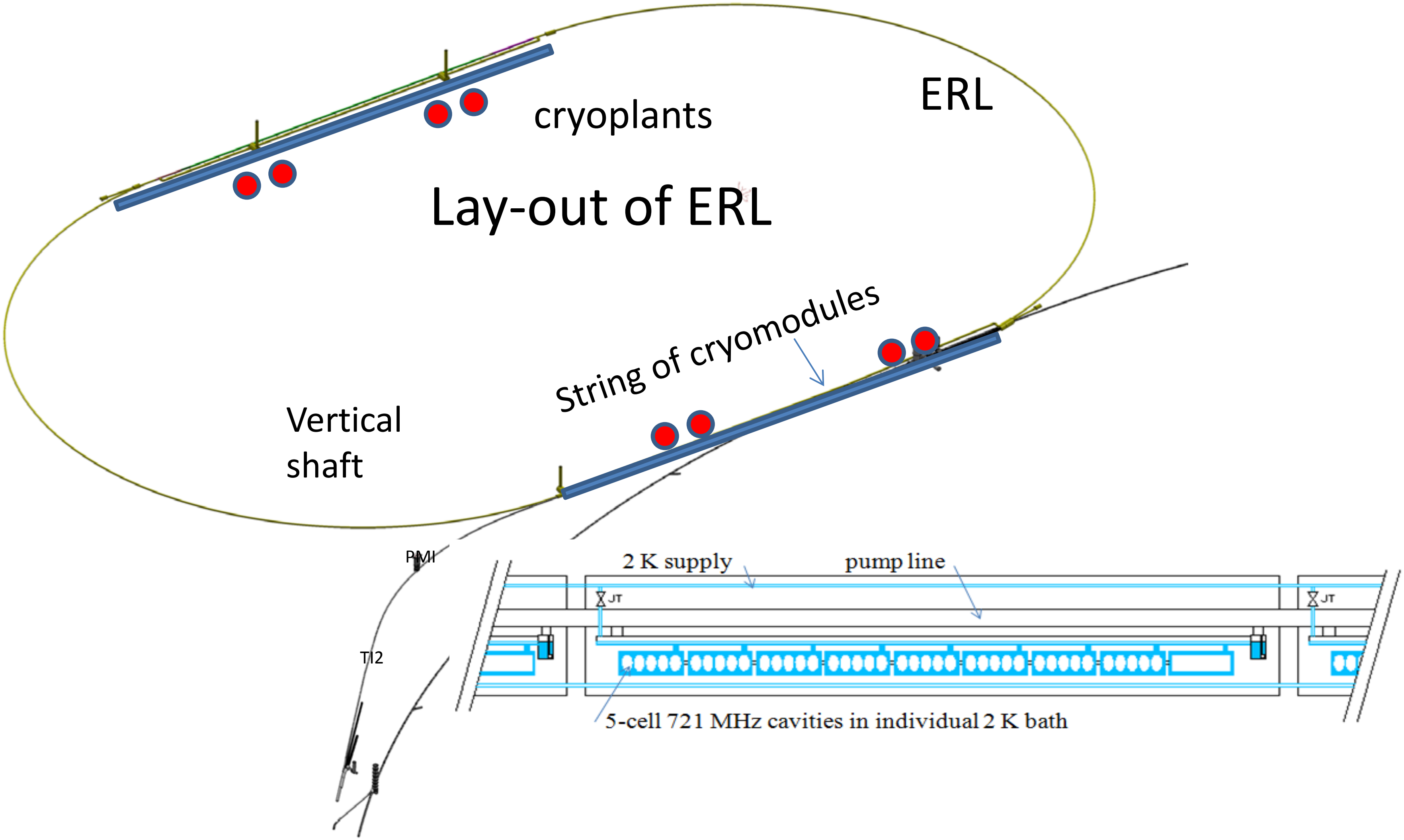
Cryomodule
8 cavities + Quad
~ 15 m length
118 cryomodules

Cavities
5-cell 1.04m length
> 721 MHz, CW operated
Power diss. 32 W @ 2K
for 21.2 MV/m
(based on Qo = 2.5E10)

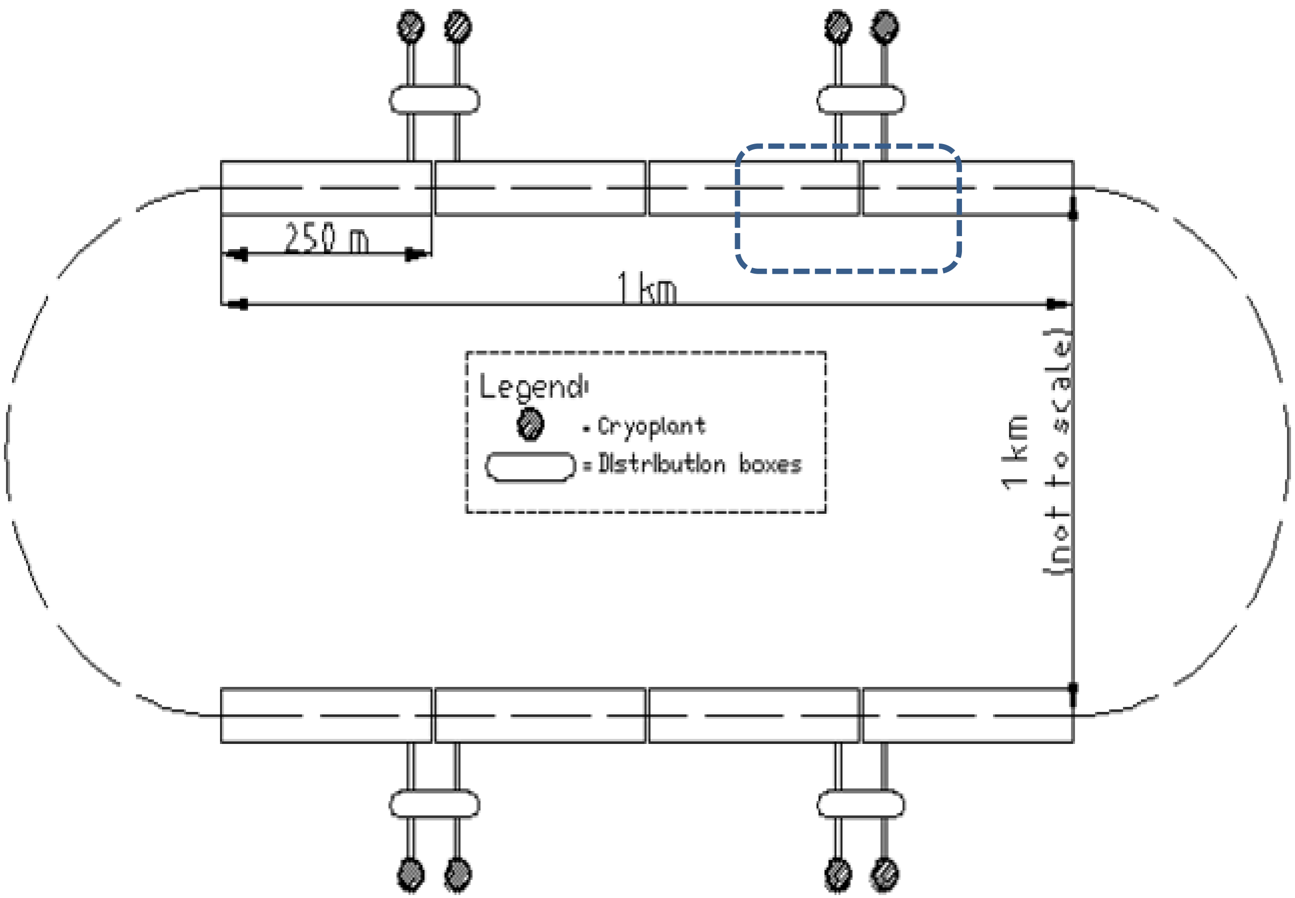


Proposed cryomodule configuration and cryostat similar to XFEL

Basic Lay-out



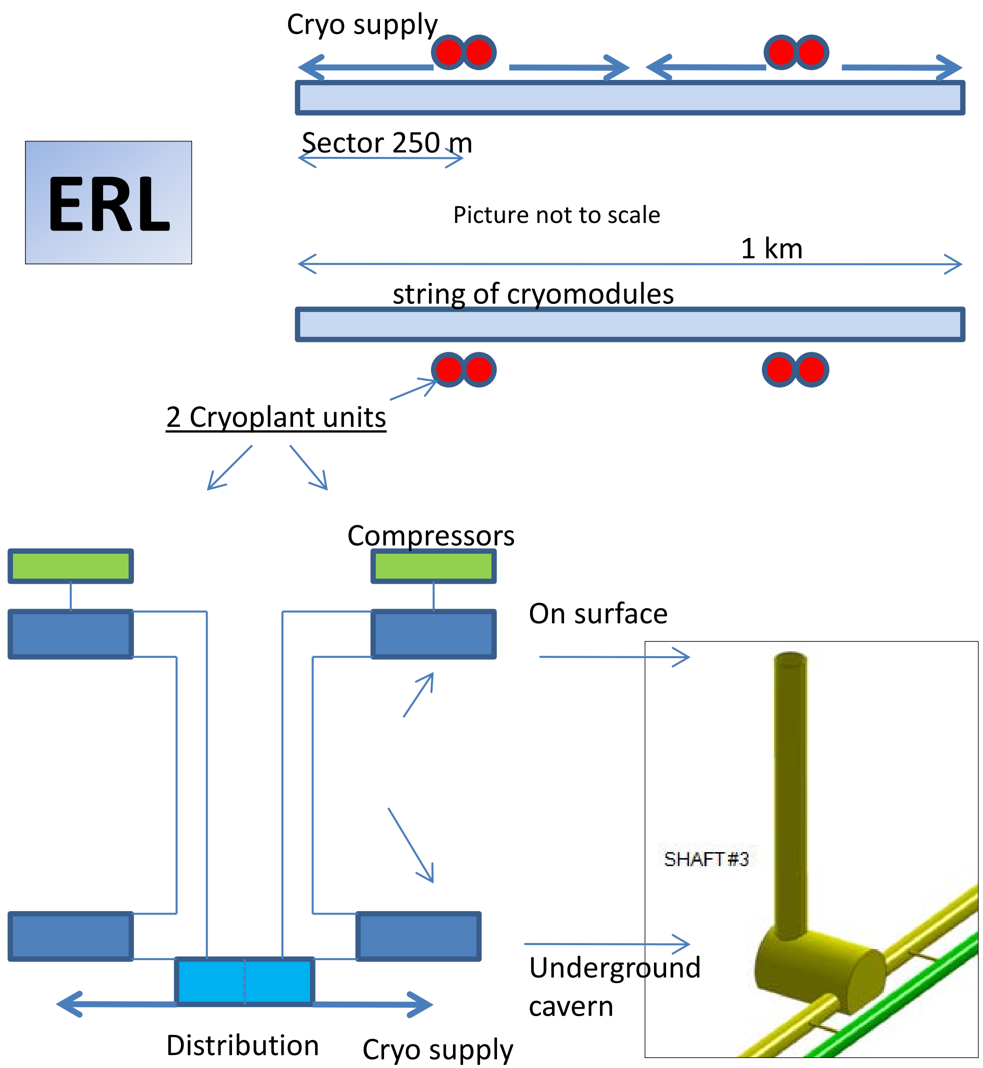
Basic Lay-out

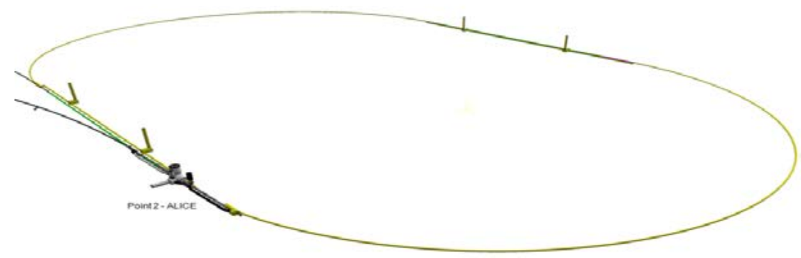


Not to scale

Sectorisation: Eight 250 m long strings. Eight dedicated cryoplants

Lay-out Cryoplants



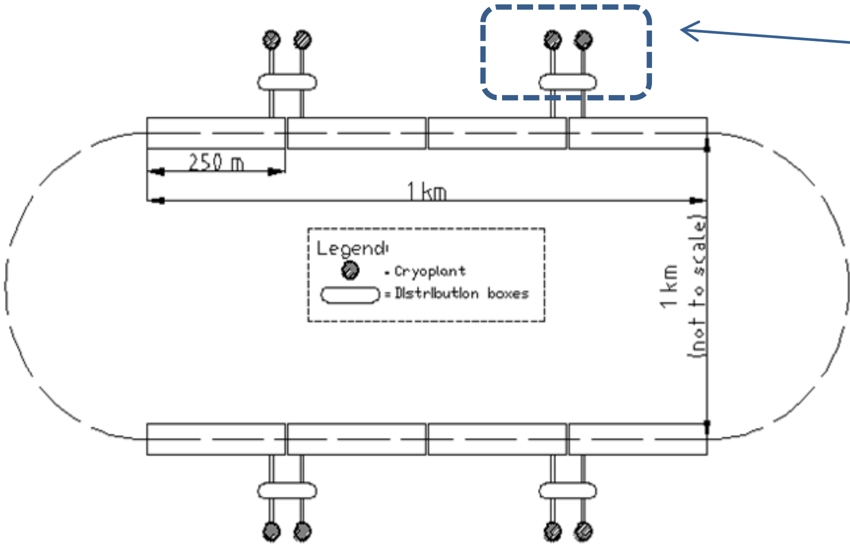


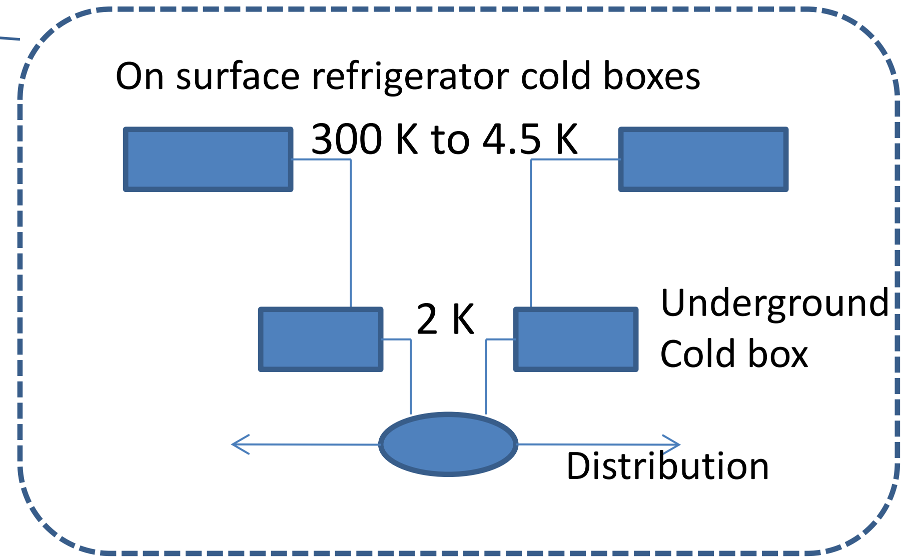
Cooling requirements dominated by dynamic losses at 2 K (other loads neglected here for simplicity)

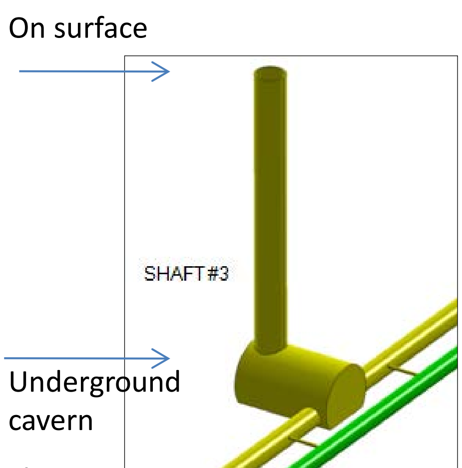
Lay-out is based on LHC cryogenic principles with split cold boxes (surface cold box and underground cold box with cold compressors).

Refrigerator units of approx. 5 kW @ 2 K assumed. To be designed. Technology and experience: LHC, CEBAF (JLAB).

Lay-out Cryoplants







Split cold boxes (see LEP2, LHC (4.2K on surface, 2K in tunnel)

Total (minimum) cooling power;

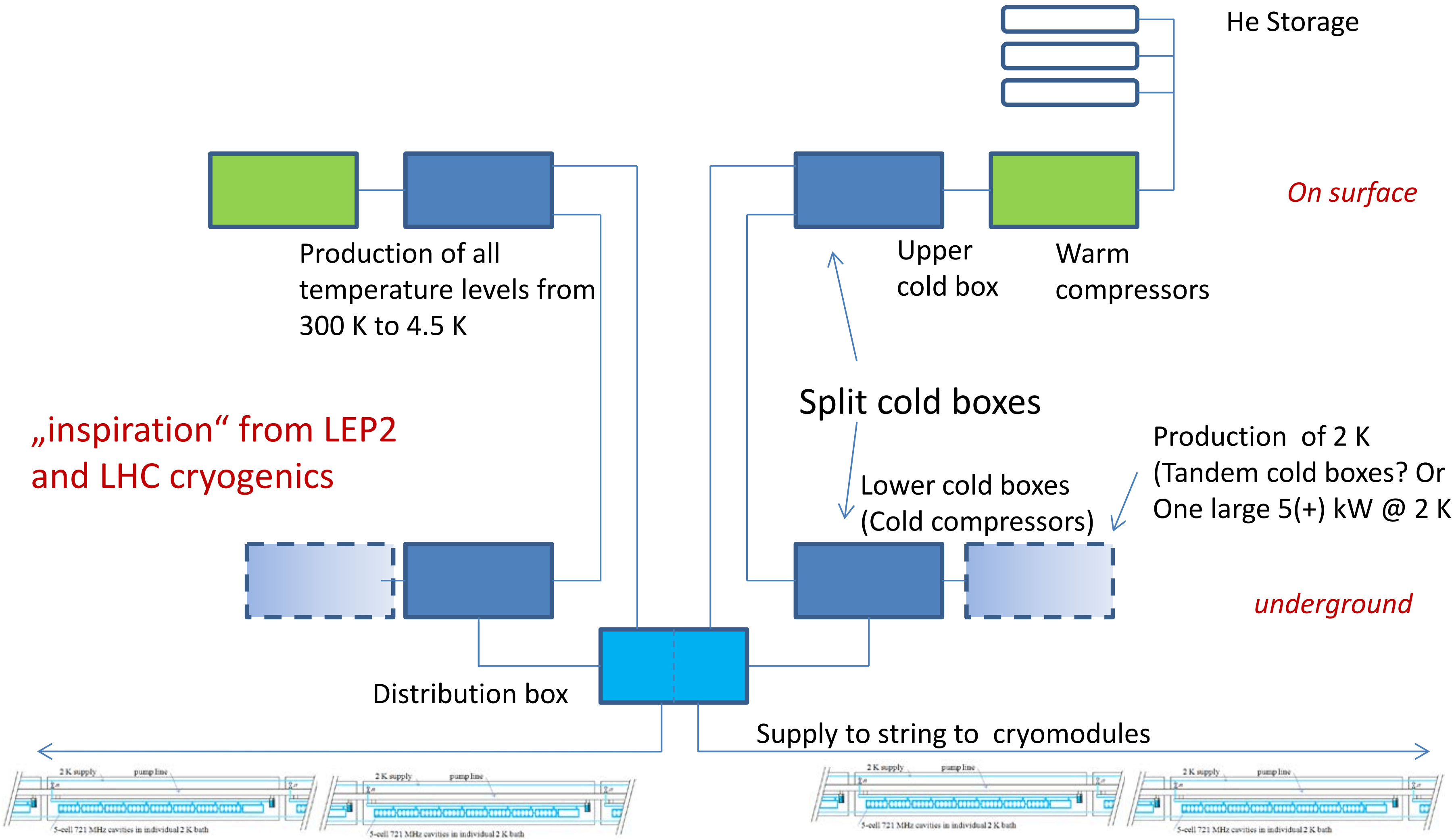
84 kW @ 4.2 K (no contingency)

Cryoplants proposed

8 x 10.5 kW @ 4.2 K

R&D cavities ongoing. Expectance improved Q values.....

Basic refrigerator lay-out



„inspiration“ from LEP2 and LHC cryogenics

Summary Parameters (CDR)

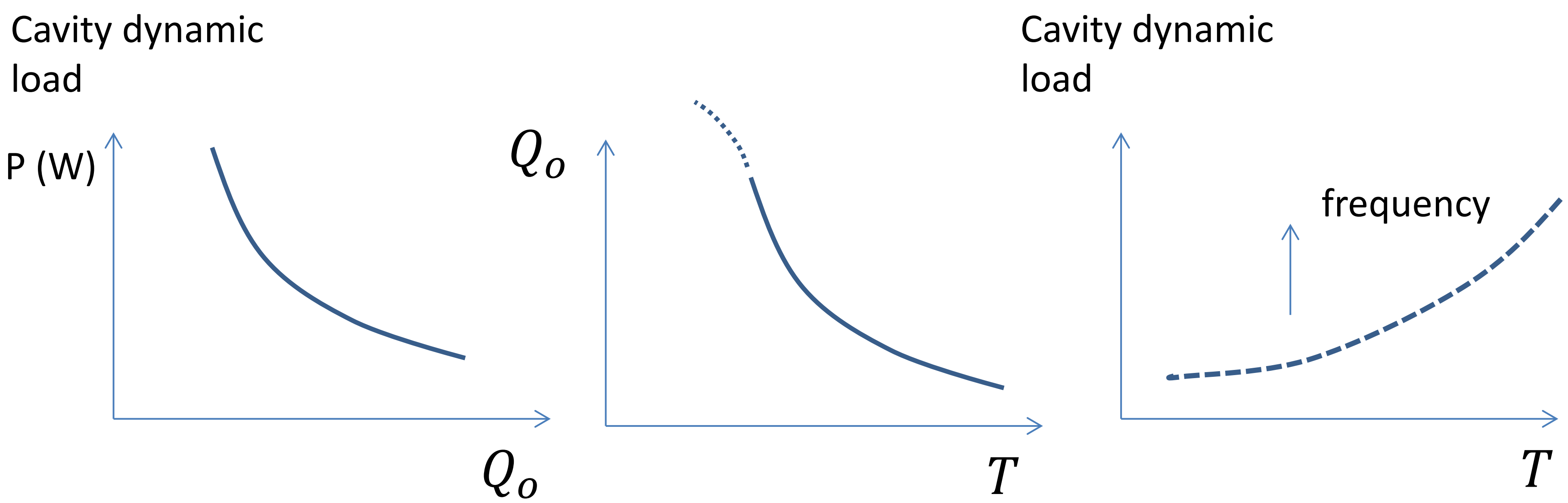
Parameter	Value
Two linacs	length 1 km
5-cell cavities	length 1.04 m
Number	944
Cavities/ cryomodule	8
Number cryomodules	118
Length cryomodule	14 m
Voltage per cavity	21.2 MV
R/Q	285Ω
Cavity Q_0	$2.5 \cdot 10^{10}$
Operation	CW
Bath cooling	2 K
Cooling power/cav.	32 W @ 2 K
Total cooling power (2 linacs)	30 kW @ 2 K

Summary Parameters (CDR)

Parameter	Value
Number of Refrigerators	8
1/COP @ 2 K	700
Minimum cooling capacity/refrigerator	10 kW @ 4.5 K
Contingency	none
Minimum total cooling power	80 kW @ 4.5 K
Grid power consumption	21 MW

Cryo power = f(parameters,

- Power consumption dominated by dynamic load (CW operation)
- Power consumption inverse proportional to Qo
- Lower temperatures: increase in Qo
- Cavity frequency ...etc. (reference is made to SRF experts in this field...)



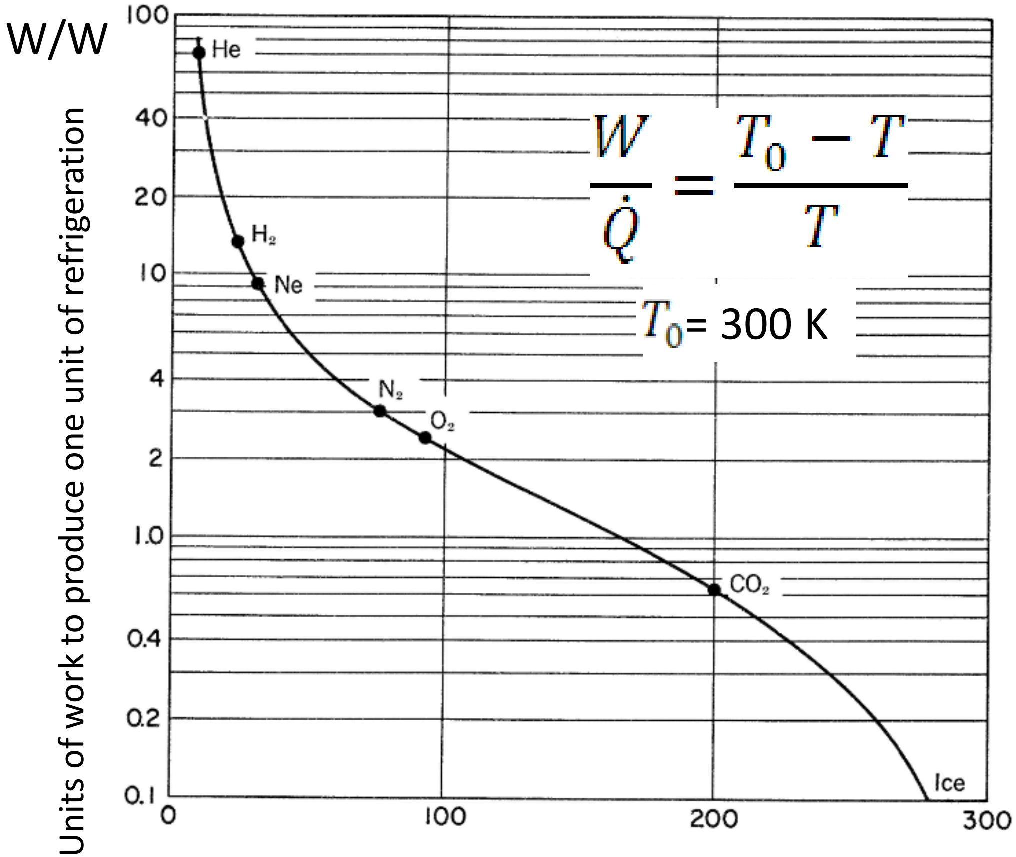
Ideal work for refrigeration

Inverse coefficient of performance

$$COP_{Inv,ideal} = 1/COP_{ideal} = COP_{ideal}^{-1}$$

Units of work required to produce one unit (1 W) of refrigeration of an ideal machine. Equation used

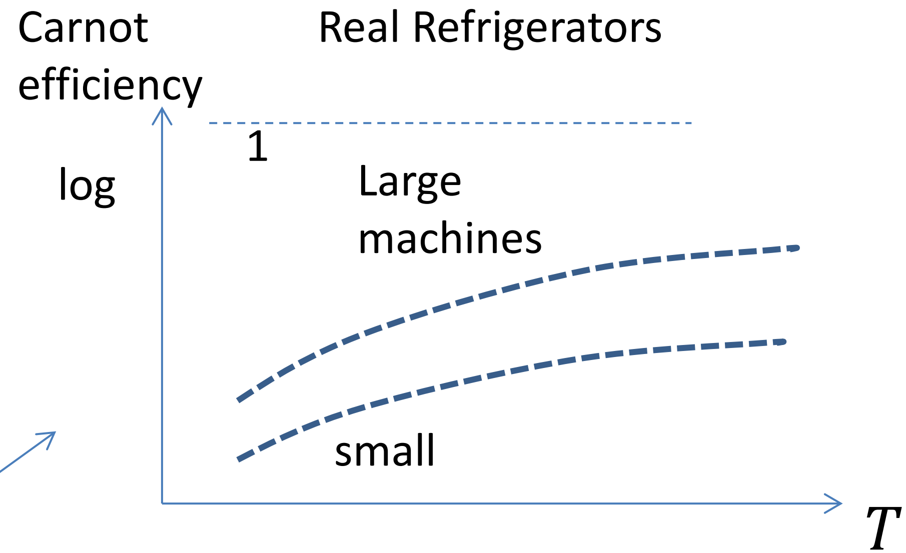
$$\frac{W}{\dot{Q}} = \frac{T_0 - T}{T} \quad \frac{[Watts]}{[Watt]}$$



Gas	Normal boiling point [K]	Ideal work for refrigeraction [W/W]
Oxygen (O2)	90.18	2.3
Argon	87.28	2.4
Air	78.80	2.8
Nitrogen (N2)	77.36	2.9
Neon	27.09	10.1
Hydrogen (H2)	20.27	13.8
Helium-4	4.21	70.3

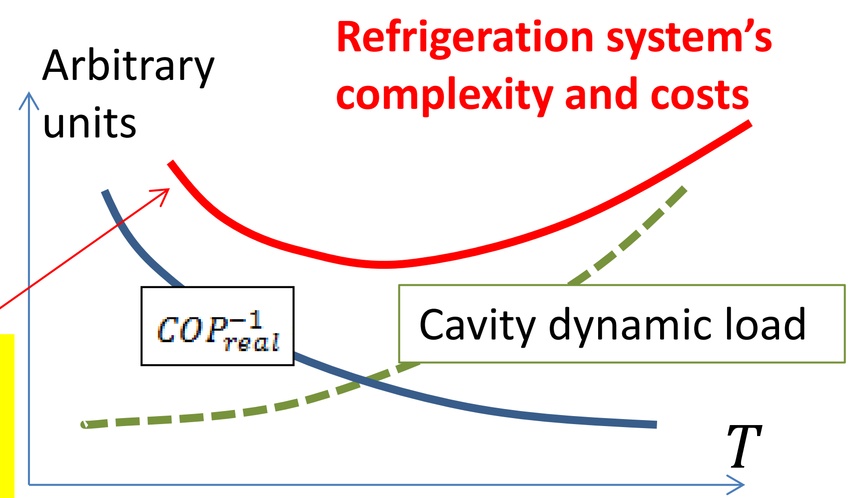
Power = f(parameters)

Gas	Normal boiling point [K]	Ideal work for refrigeraction [W/W]
Helium-I	4.21	70.3
Helium-II	2.0	150
Helium-II	1.8	167
Helium-II	1.6	187



But in addition Carnot efficiency becomes smaller, hence, real inverse COP unproportionally large

$$COP_{real}^{-1} = COP_{ideal}^{-1} / \eta_{Carnot}$$



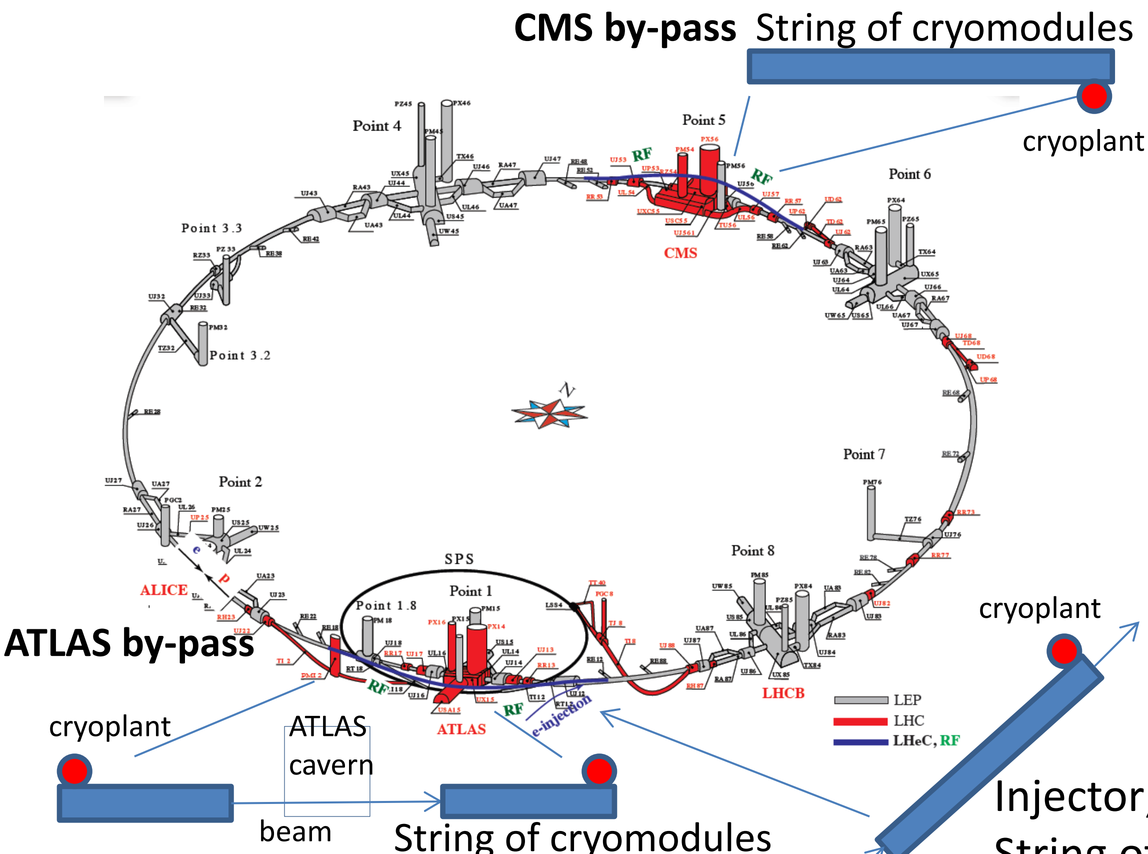
Size, complexity and cost of refrigerators and systems increase unproportianally with decreasing temperatures

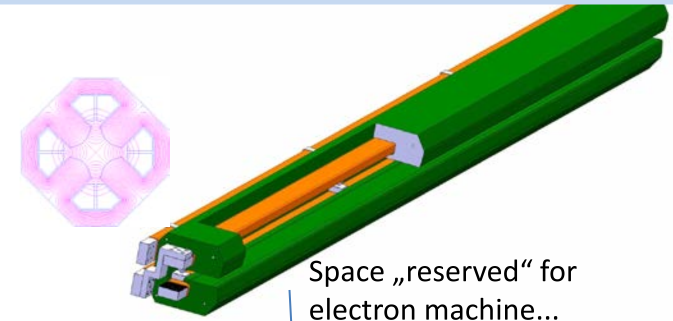
Using the LHC tunnel: Ring-Ring Version

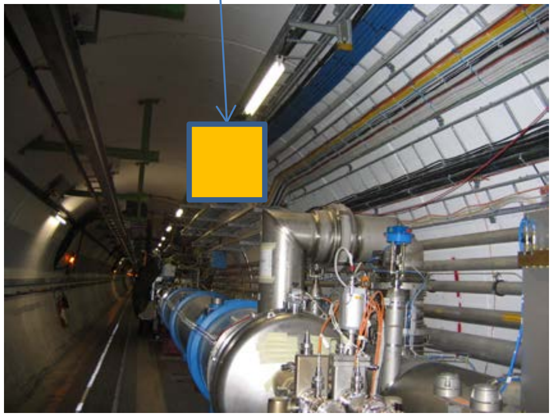
Principle: use LHC tunnel for additonal new electron Ring accelerator

Superconducting cavities for acceleration

Normal conducting low-field magnets to guide electrons of 60 GeV







LHC 27 km tunnel

Ring-Ring Cryogenics

SC Cavities for the bypasses

2-cell	721 MHz
Length	0.42 m
Acc. Field	12 MV/m
Operation	CW mode
Operation temp.	2 K
Dissip.	4 W

Cryomodules

nr. of cavities	8
Length	10 m

Location and number of cryomodules

CMS side	8
ATLAS left	3
ATLAS right	3

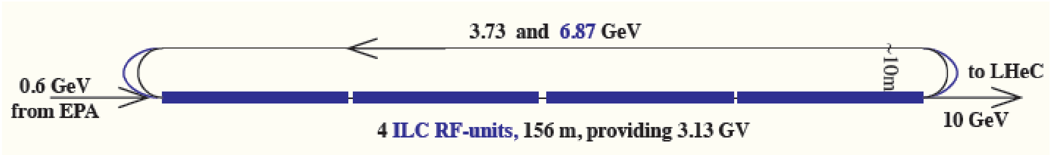
SC Cavities for the Injector

9-cell	1.3 GHz
(ILC/XFEL type)	
Length	1 m
Acc. Field	23 MV/m
Operation	pulsed mode

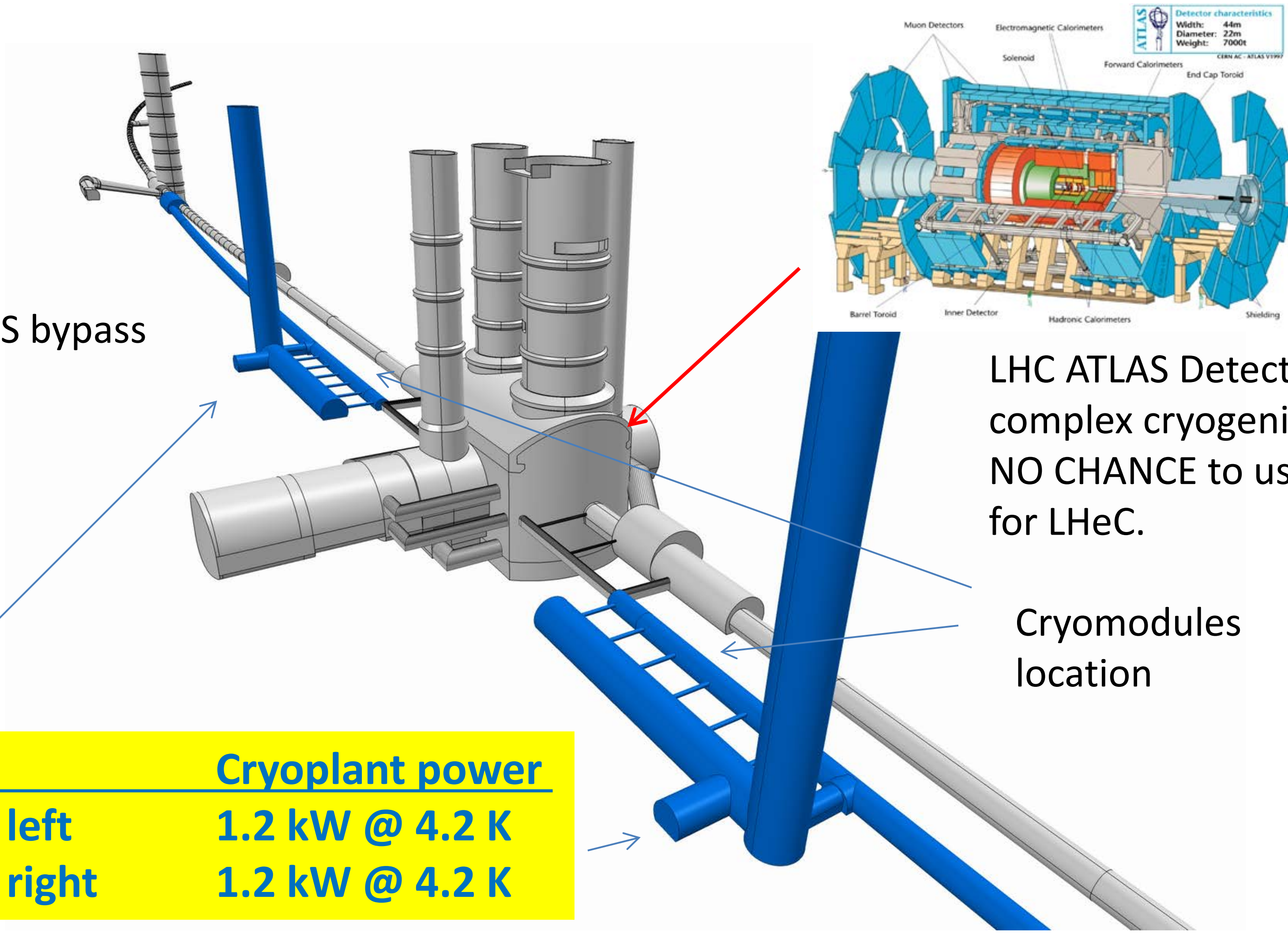
Cryomodules

nr. of cavities	8
Length	12.2 m
Nr. of modules	12

(exact copy of XFEL)



Ring-Ring Cryogenics



ATLAS bypass

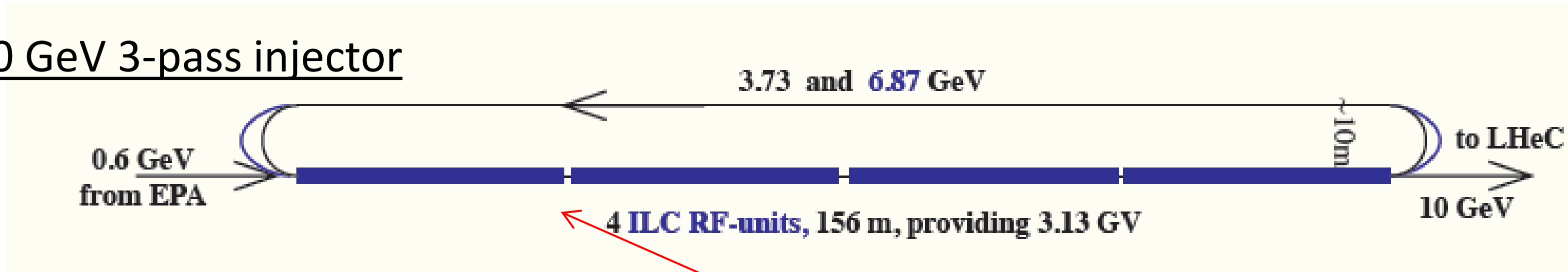
LHC ATLAS Detector with complex cryogenic system. NO CHANCE to use this plant for LHeC.

Cryomodules location

Site	Cryoplant power
ATLAS left	1.2 kW @ 4.2 K
ATLAS right	1.2 kW @ 4.2 K

Ring-Ring Cryogenics

10 GeV 3-pass injector



Site	Cryoplant power
Injector	2.0 kW @ 4.2 K
CMS	3.0 kW @ 4.2 K
ATLAS left	1.2 kW @ 4.2 K
ATLAS right	1.2 kW @ 4.2 K

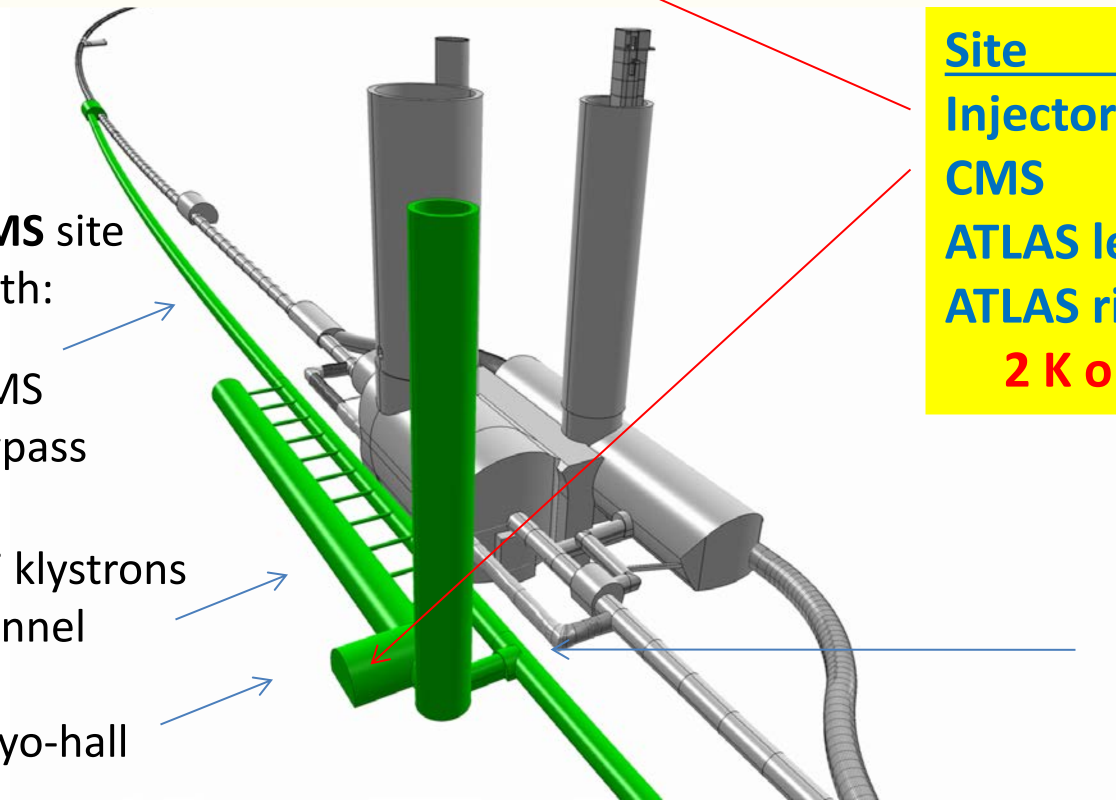
2 K operation of cryomodules

CMS site with:

CMS bypass

RF klystrons Tunnel

Cryo-hall



Acc. String with 8 cryomodules

Comparison (cryogenics only)

LEP2 (cryo for SRF cavities 5 MV/m)

4 Acc points. 4 Cryoplants 12 kW @ 4.5 K.

4.5 K bath cooling (already split principle). Upgraded later for use at LHC...

LHC (cryo for sc bending magnets)

8 Cryoplants 18 kW @ 4.5 K + 8 cold boxes 1.8 K. Largely for LHC sc magnet cooling at 1.9 K. Grid power consumption appr. 40 MW (with ATLAS and CMS detector cryoplants)

LHeC ERL (cryo for SRF cavities > 20 MV/m)

Linac-Ring version: 2 accel. strings 1 km each. 8 cryoplants

2 K bath cooling, 8 x 10 kW @ 4.5 K.

Grid power consumption appr. >21 MW (+ contingency...)

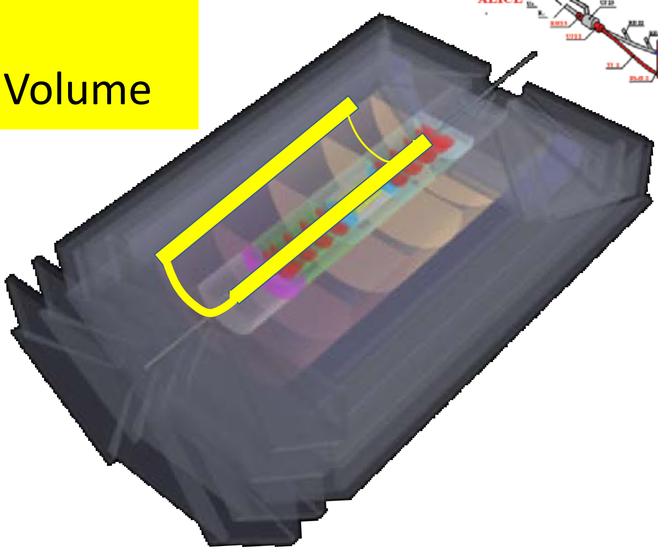
LHeC Ring-Ring version: 2 acceleration points (IP 1, 5), 4 cryoplants,
2 K bath cooling, total < 8 kW @ 4.5 K

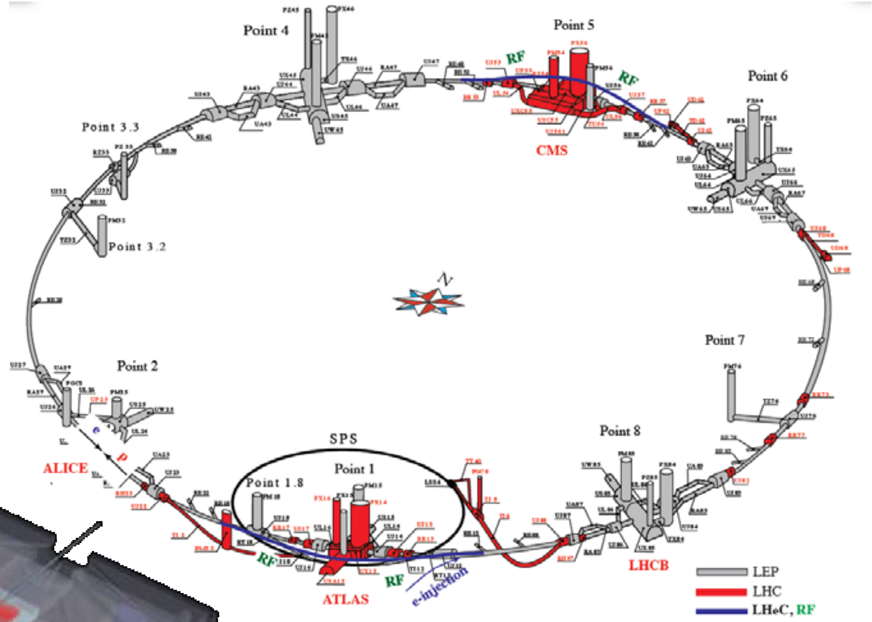
Ring-Ring only appr. 1/10 of ERL power + use of LHC infra (= small LEP2 at 2 K)

Detector Cryogenics

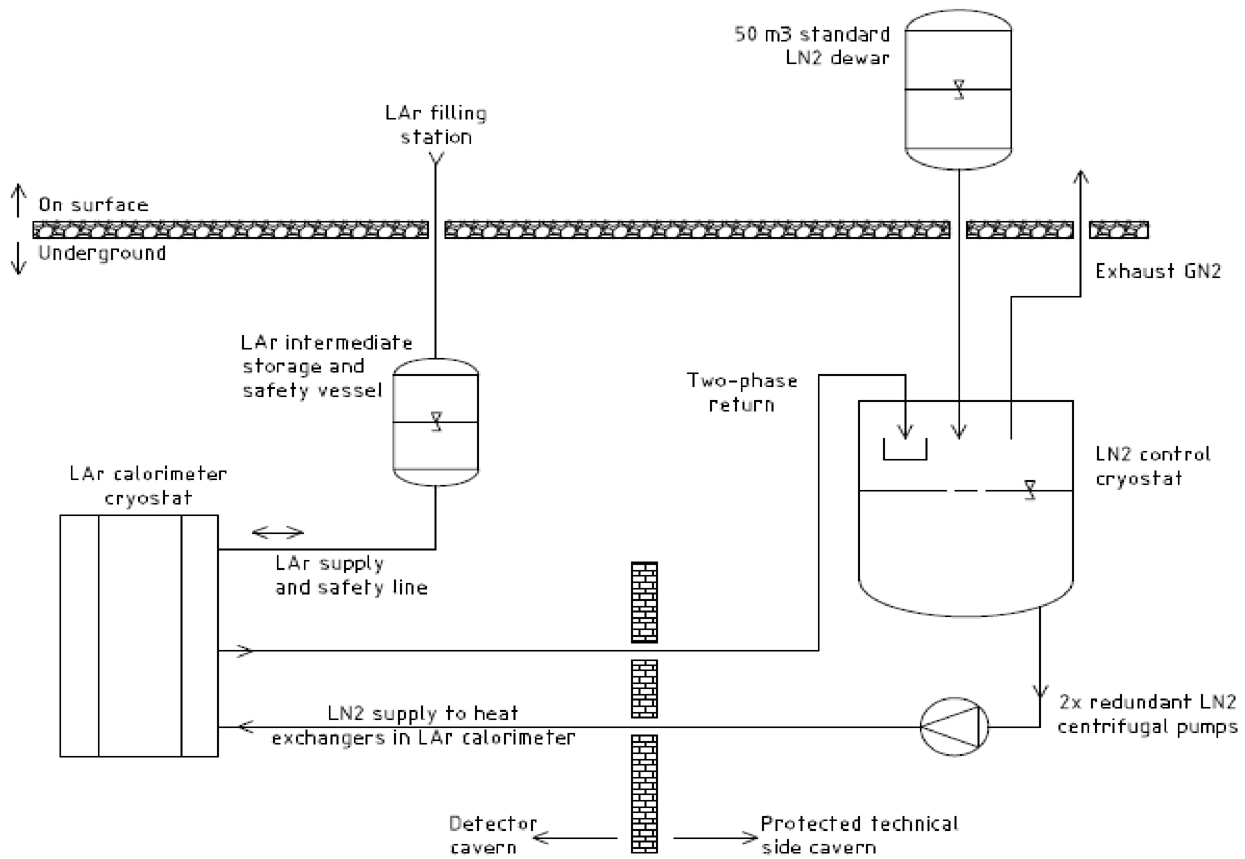
SC solenoid (3.5 T) and two dipoles on one support cylinder
diam. 2 m, 9.5 m length
Cryoplant: 300 W @ 4.5 K

Liquid Argon calorimeter
12 m3
Corresponds to appr.
1/8 of Atlas Calorimeter Volume





Detector Cryogenics



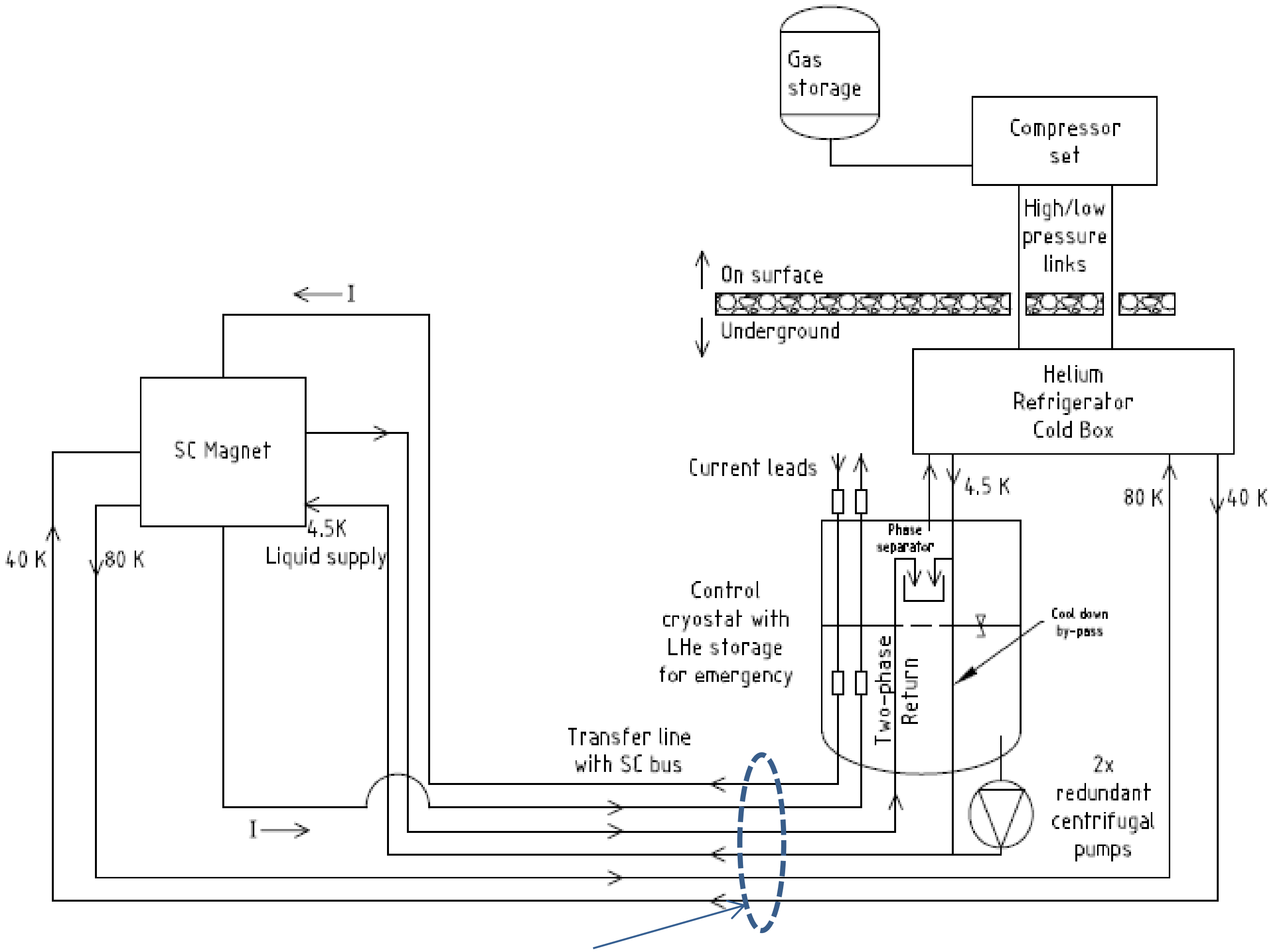
Liquid Argon Calorimeter

Principle flow-scheme of the LN2 (87 K) cooling system

LN2 Cryostat and phase separator

Redundant centrifugal pumps

Detector Cryogenics



SC bus integrated in transfer line

SC Solenoid and dipoles

Principle flow-scheme

He Cryostat and phase separator

Redundant centrifugal pumps

Similar to Atlas Test Facility Hall 180

Thanks for your attention