Large-capacity Helium refrigeration :

from state-of-the-art towards FCC reference solutions

Francois Millet – March 2015

INAC — Institut Nanosciences et Cryogénie — la recherche, ressource fondamentale / research - a fundamental resource

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Université Grenoble Alpes

Université Joseph Fourier Grenoble

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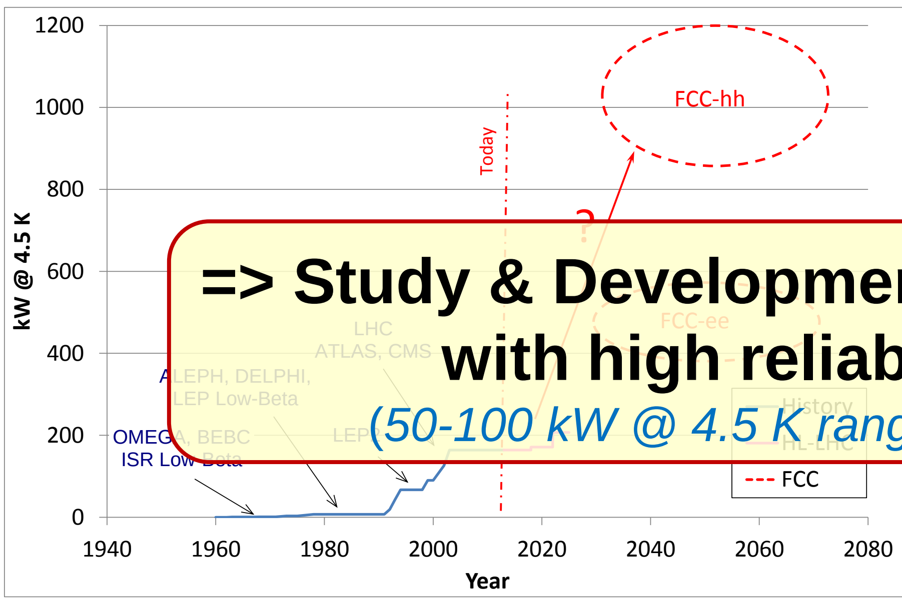
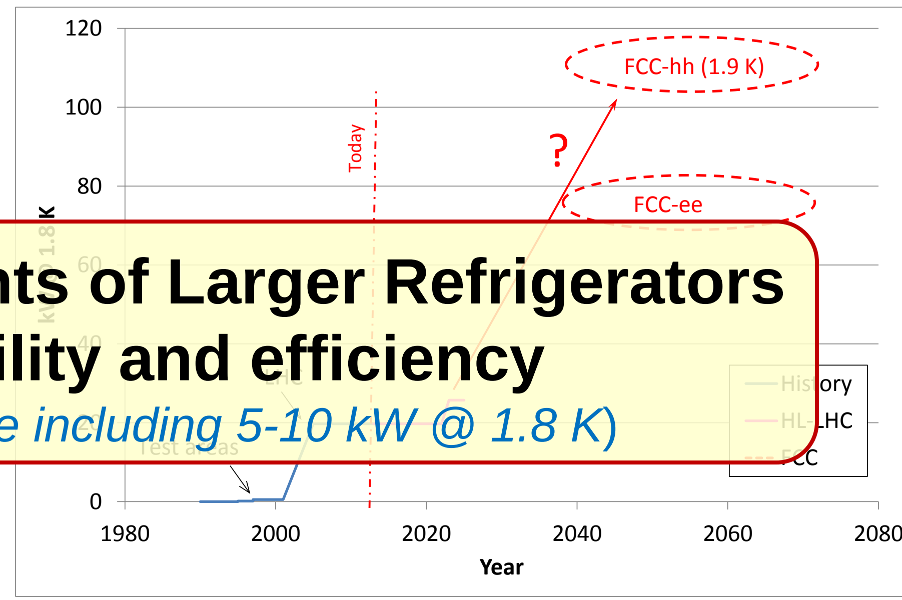
- ✓ **FCC requirements & constraints**
- ✓ **From the state-of-the-art towards FCC**
  - Refrigeration scheme & components
  - Cooling capacity
  - Cooling architecture
- ✓ **Conclusion**

Main FCC cryogenic challenges :

- towards 1 MW @ 4.5 K *(> 200 MW of electrical power consumption)*
- mainly dynamic heat loads at 40-60 K *(Synchrotron radiation)*
- Large-scale superfluid helium refrigeration down to 1,6 K *(*)*

(*) see presentation "Study of a magnetic refrigeration stage"





=> Study & Developments of Larger Refrigerators with high reliability and efficiency

(50-100 kW @ 4.5 K range including 5-10 kW @ 1.8 K)

CEA study roadmap

Study & Developments of Larger Refrigerators

(40-100 kW @ 4.5 K range including 5-10 kW @ 1.8 K)

- ❑ Analysis of **FCC requirements & constraints**
- ❑ Review of the **State-Of-the-Art**
- ❑ Identification of present **process and component limits**
- ❑ Development of **new technologies or architectures**

in collaboration with CERN & major cryoplant industries

=> Definition of <u>FCC reference solutions</u>

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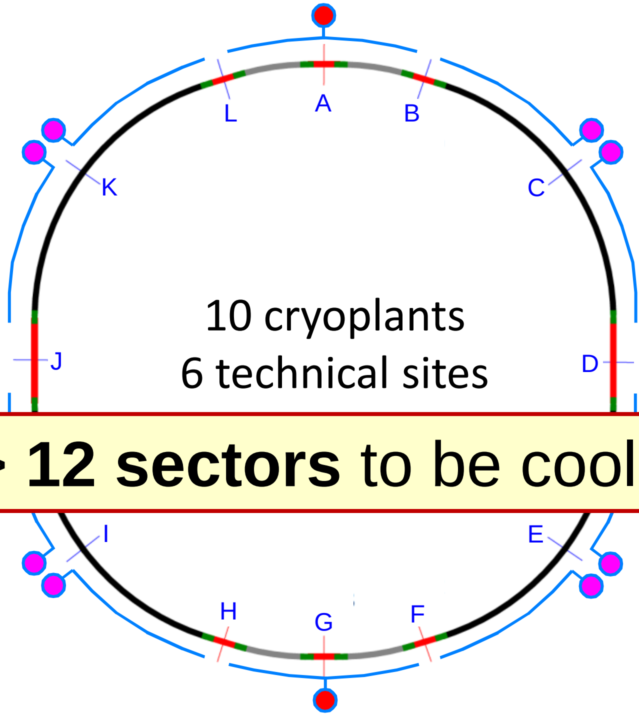
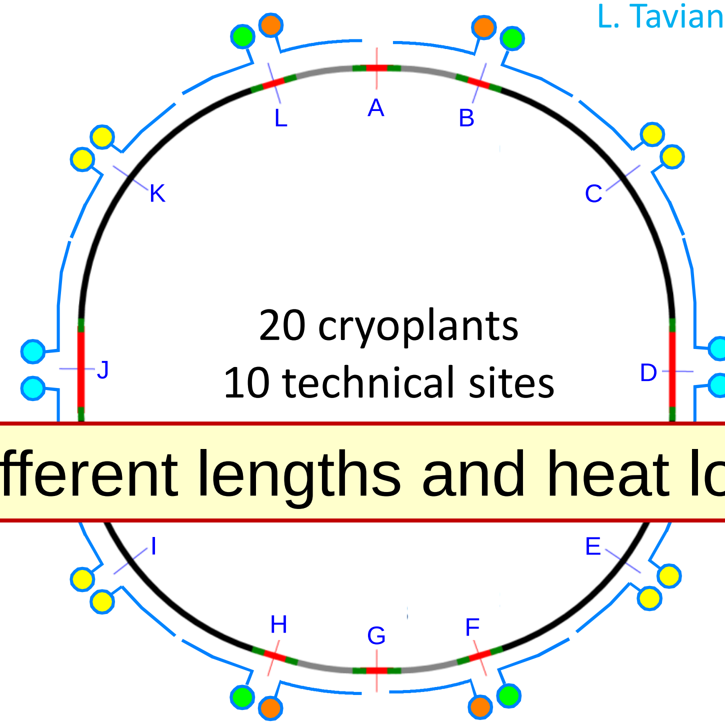
FCC-hh cryogenic layout

L. Tavian / CERN





=> **12 sectors** to be cooled with different lengths and heat loads

Cryoplant	L Arc+DS [km]	L distribution [km]
	2 x 4 = 8	2 x 4.7 = 9.4
	8.4	8.4

No cryoplant redundancy at Point A and G

No distribution in ESS

Cryoplant	L Arc+DS [km]	L distribution [km]
	4	4.7
	4.4	5.1
	4	4
	4.4	6.5

Rough FCC-hh heat loads estimate

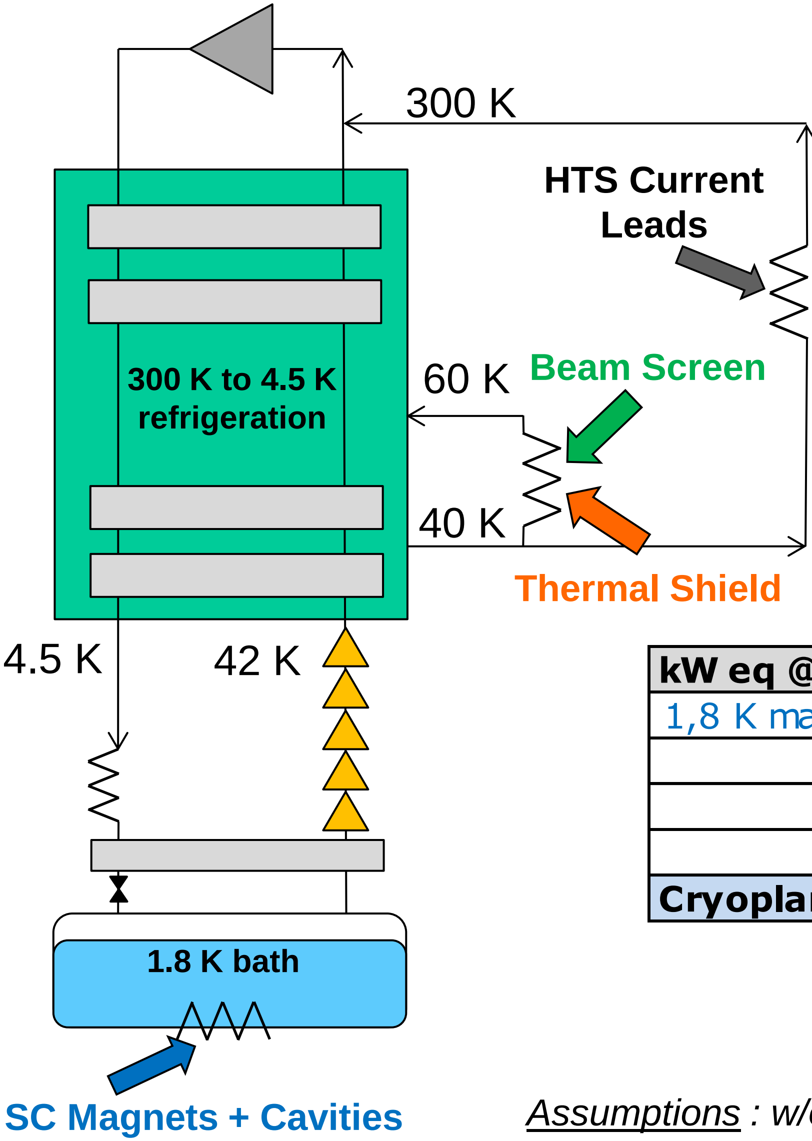
L. Tavian / CERN

	Temperature level	LHC [W/m] 50-75 K	LHC [W/m] 4.5-20 K	LHC [W/m] 1.9 K	FCC-hh [W/m] 40-60 K	FCC-hh [W/m] 1.9 K
Static heat inleaks	CM supporting system	1.5		0.10	2.0	0.13
	Radiative insulation			0.11		0.13
	Thermal shield	2.7			3.1	
	Feedthrough & vac. barrier	0.2		0.1	0.2	0.1
	Distribution	3.2	0.1	0.02	4	0.1
	Total static	7.6	**0.1**	0.3	9.3	0.46
Dynamic heat loads	Synchrotron radiation		0.33	ε	57 (88)	0.2
	Image current		0.36		2.7 (2.9)	
	Resistive heating			0.1		0.3 (0.4)
	Beam-gas scattering			0.05		0.45
	Total dynamic		0.7	0.15	64 (95)	0.95 (1.05)
Total		7.6	0.8	0.45	73 (104)	1.4 (1.5)

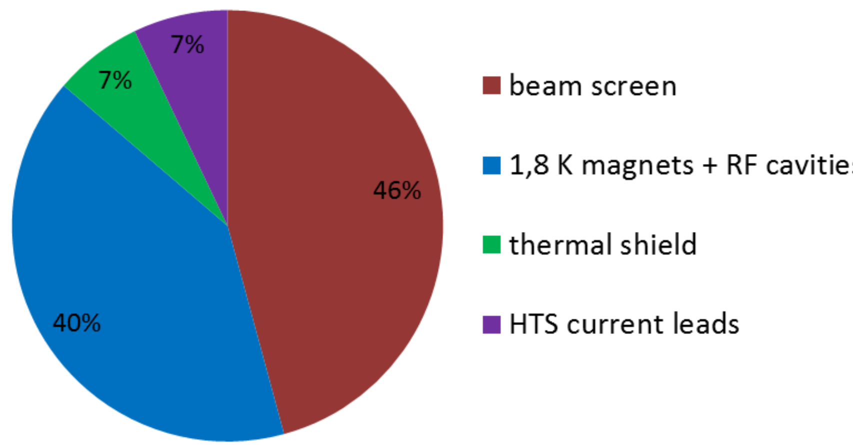
+ cooling for HTS current leads from 40 K to 300 K

(): Value in brackets for 80-km FCC-hh

FCC–hh cooling requirements



FCC-hh 100 km heat loads



kW eq @ 4.5K	10 cryoplants	20 cryoplants
1,8 K magnets + RF cavities	40	21
beam screen	46	24
thermal shield	7	3
HTS current leads	6	4
Cryoplant kW eq @ 4.5 K	**99**	**51**

1 MW eq @ 4.5 K
(> 200 MW of Elec. Power)

Assumptions : w/o over-capacity margin / integral CC & CC efficiency = 70%

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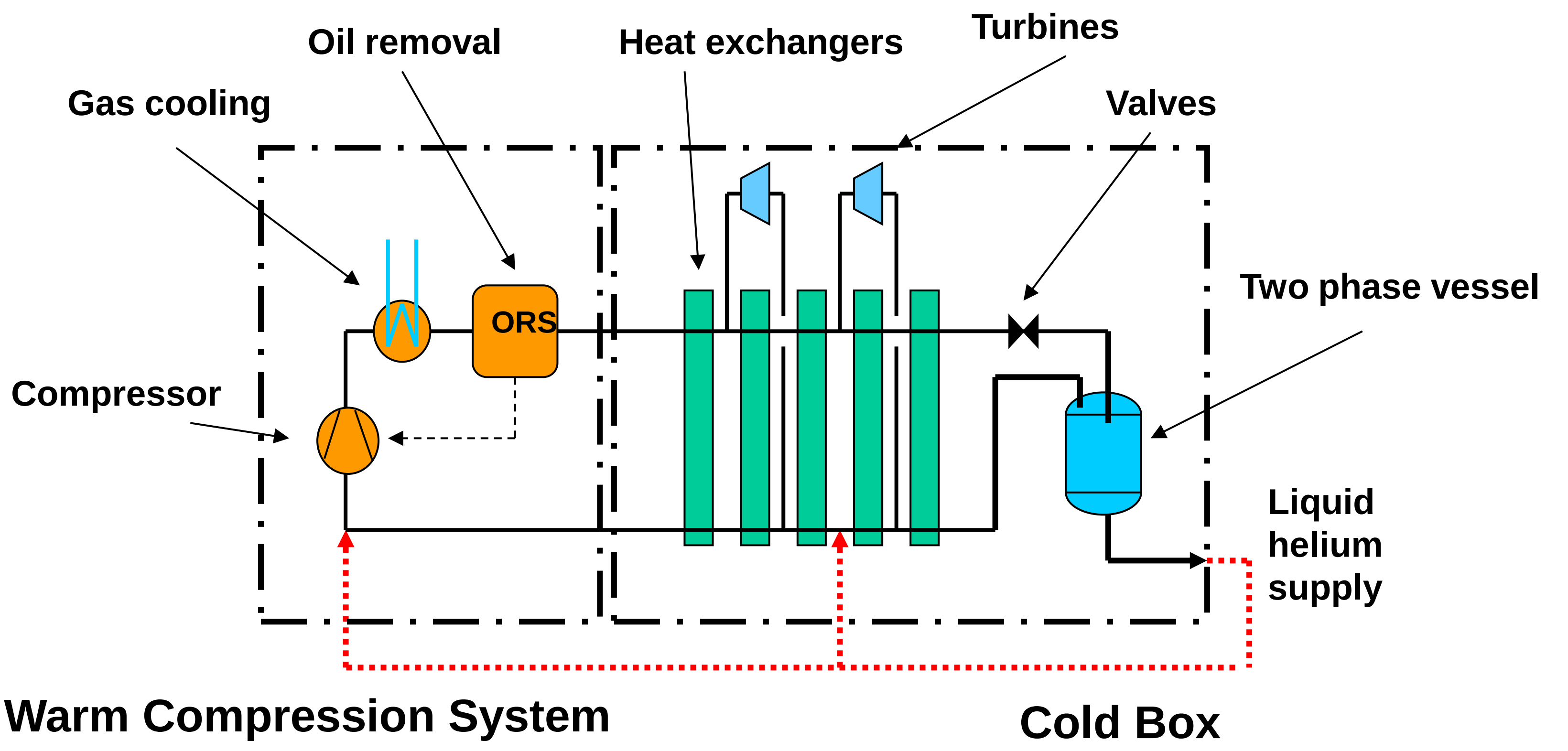
Conventional refrigeration scheme

Principle scheme of a simple refrigerator

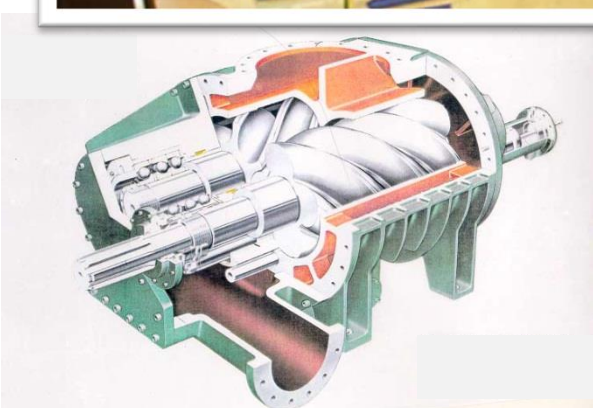


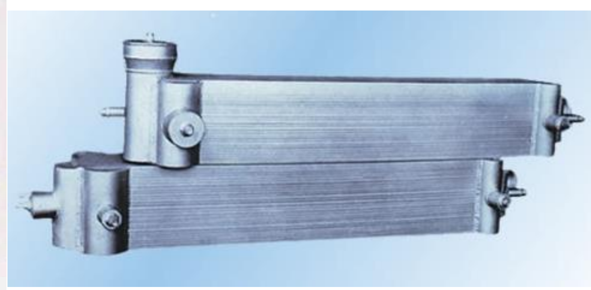
U.Wagner/ CERN

Refrigeration technology – Main components

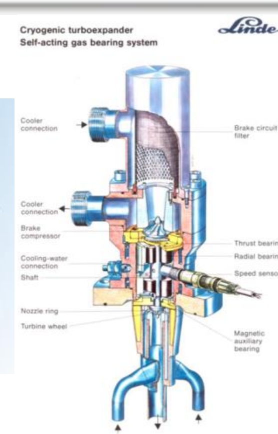
Warm Compressor System

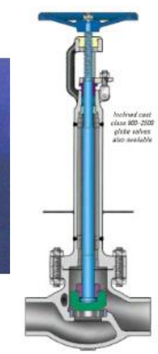
Cold Box





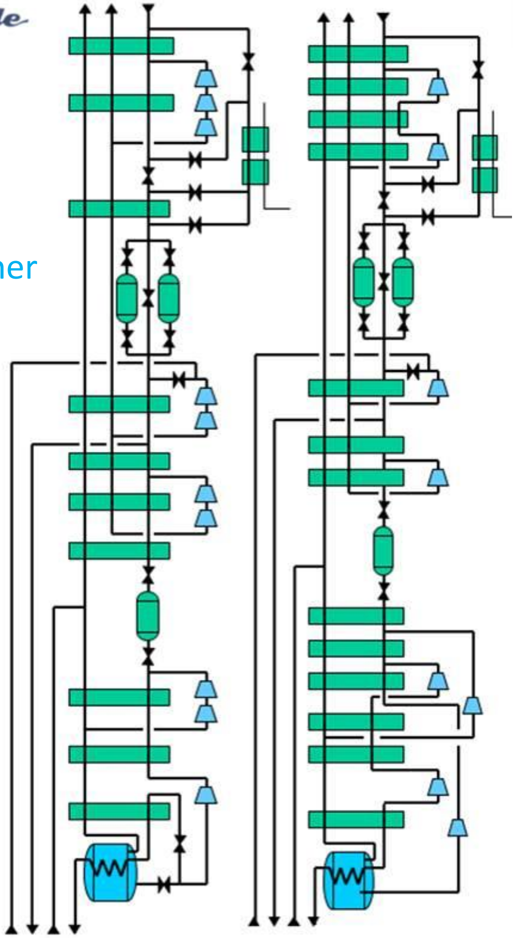
Linde / Air Liquide





Present large-scale He refrigerators & Liquefiers

LHC 4.5 K Refrigerators
18 kWeq @4.5K

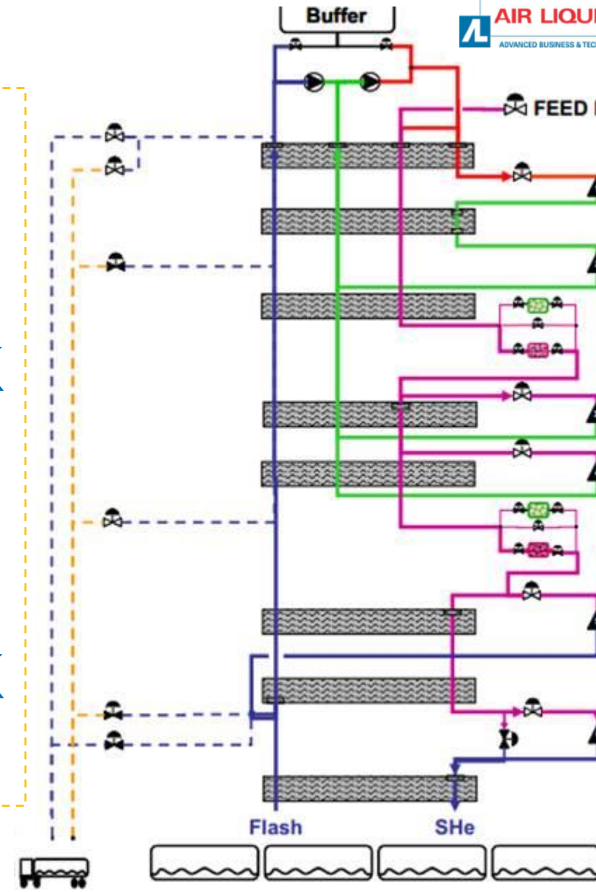


U.Wagner / CERN

Under construction

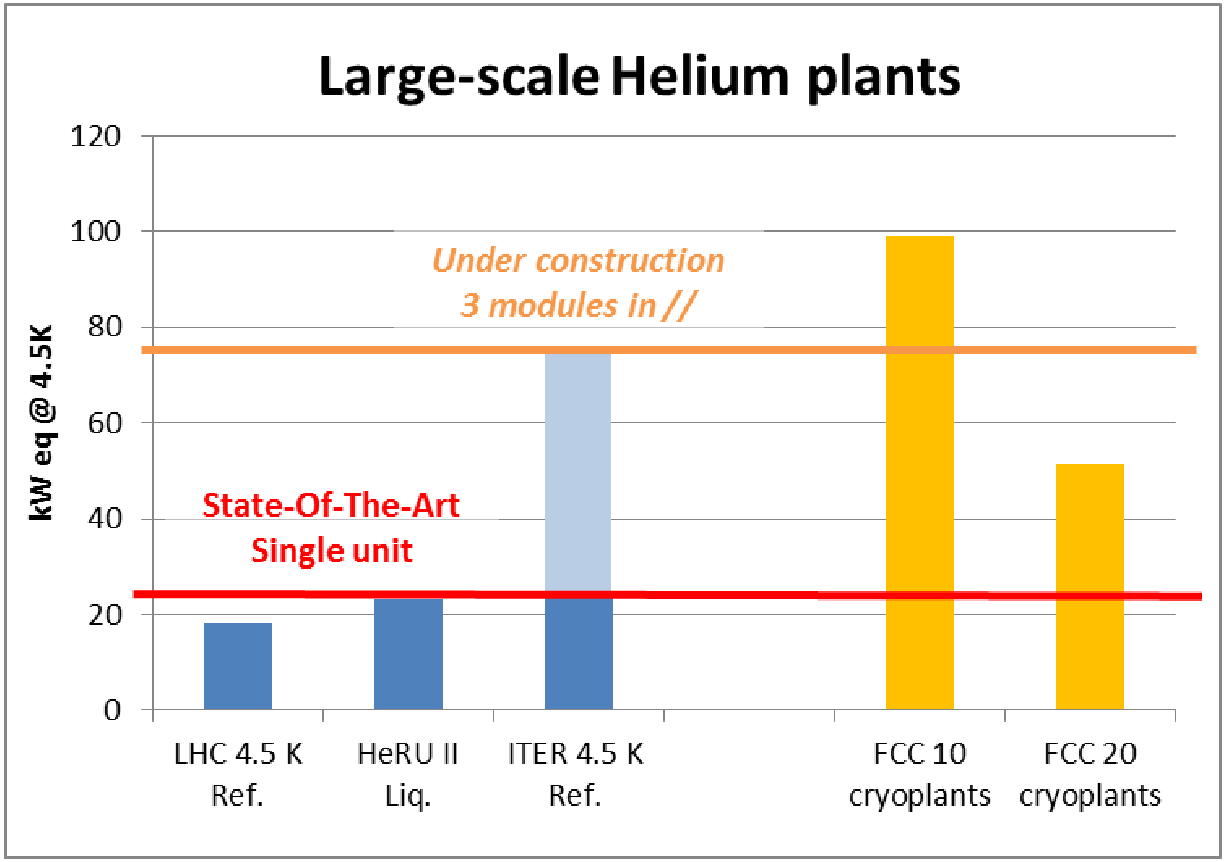
ITER He Plant
3x25 kWeq @4.5K
3 modules in //
+
ITER 80 K Loop
2x20 kWeq @4.5K
2 modules in //

Qatar Helium Recovery Unit
20 tons/day - 24 kWeq @4.5K



F.Andrieux / ALAT

FCC cryoplant cooling capacity



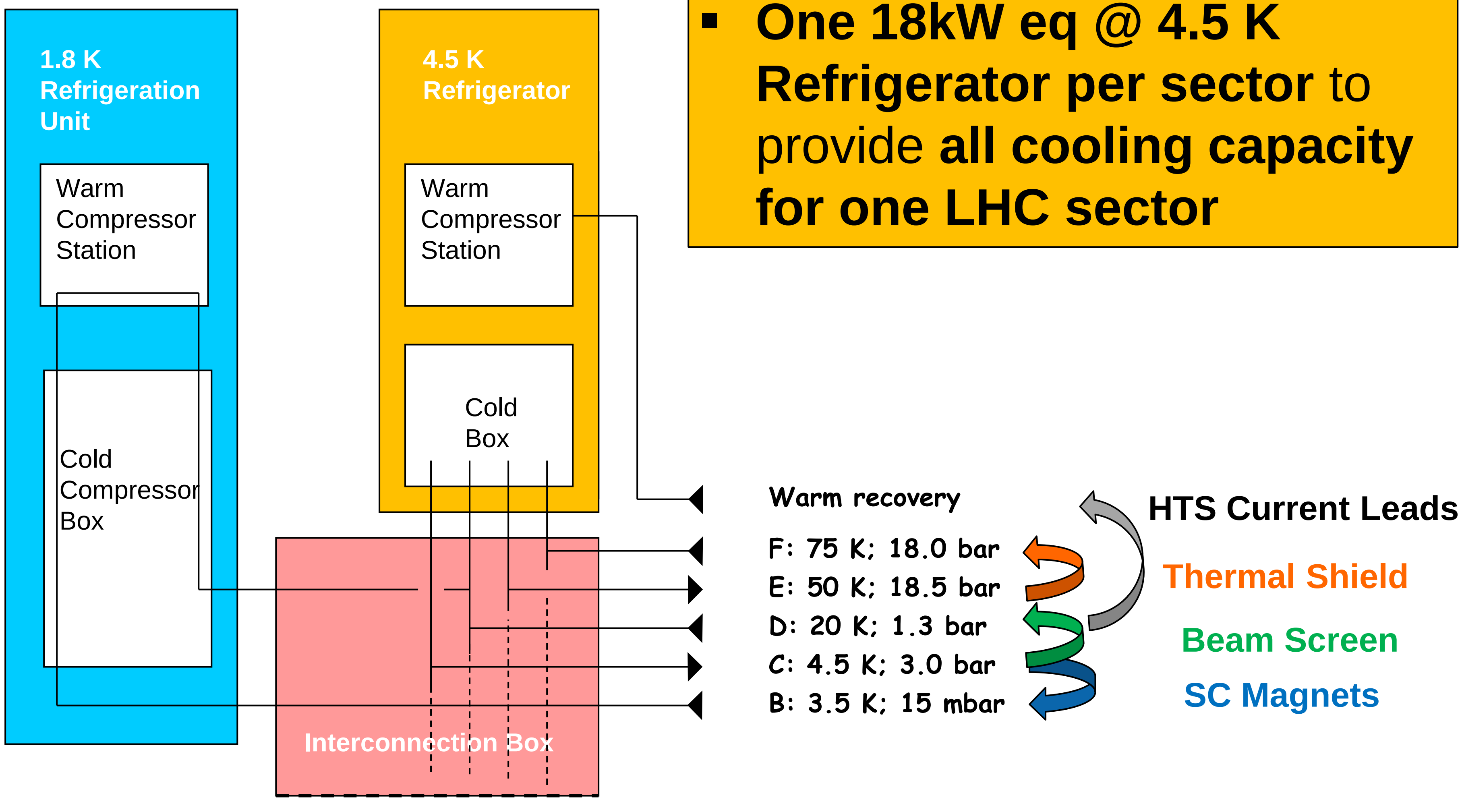
He plant cooling capacity for FCC ?

Larger cryoplants *(up to factor 4)*

or modules in // *(2 to 4 modules)*

LHC architecture

- **One 18kW eq @ 4.5 K Refrigerator per sector** to provide **all cooling capacity for one LHC sector**



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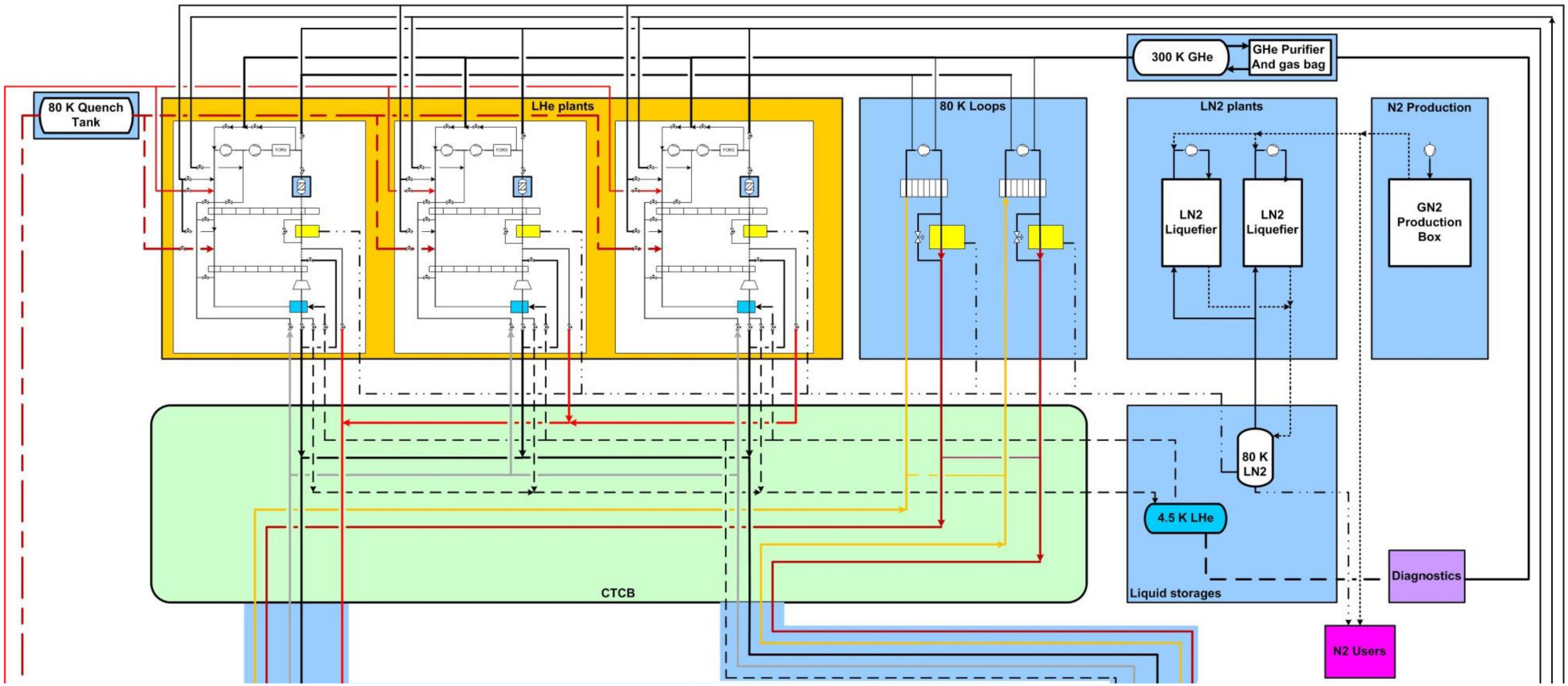
ITER architecture



- **One He plant for ITER heat loads < 80 K**

SC magnets, HTS current leads, *cryopumps*

- **One 80 K loop for ITER heat loads > 80 K**

Thermal shields, precooling of He plant

E.Monneret/ITER

Cryoplant architecture for FCC ?

- **LHC-like design = One cryoplant** per sector for all cooling needs of the FCC machine
  - SC magnets & RF cavities, HTS current leads, beam screens, thermal shields

Low number of plants & interfaces

Limited efficiency optimisation

- **ITER-like design = Two cryoplants (4.5K & 40K)** per sector for separated cooling needs of the FCC machine
  - 4.5K plant for SC magnets & RF cavities
  - 40K plant for beam screens, thermal shields , HTS current leads, He plant precooling *(see TU-Dresden presentation)*

Possible efficiency optimisation

Large number of plants & interfaces

Contents

Conclusion

- **Large helium refrigeration capacity required for FCC**
  - *Towards 1 MW eq.@ 4.5K for FCC-hh / 100 km @ 1.8 K*
- **Mainly dynamic heat loads around 50 K**
  - *~50% of total kW eq @ 4.5 K heat loads*
- **On-going works to define reference solutions for FCC based on :**
  - *FCC cryogenic requirements and constraints,*
  - *Review of the State-Of-The-Art and present limitations,*
  - *Study of new architectures and technologies with industries and partners (*).*

(*) CEA study with strong interaction with CERN and TU-Dresden as well as major cryoplant industries

Thanks you for your attention

Any question ?