DE LA RECHERCHE À L'INDUSTRIE

Technical Specifications for industry studies on the FCC cryogenic system

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INSTITUT NANOSCIENCES ET CRYOGÉNIE

www.cea.fr

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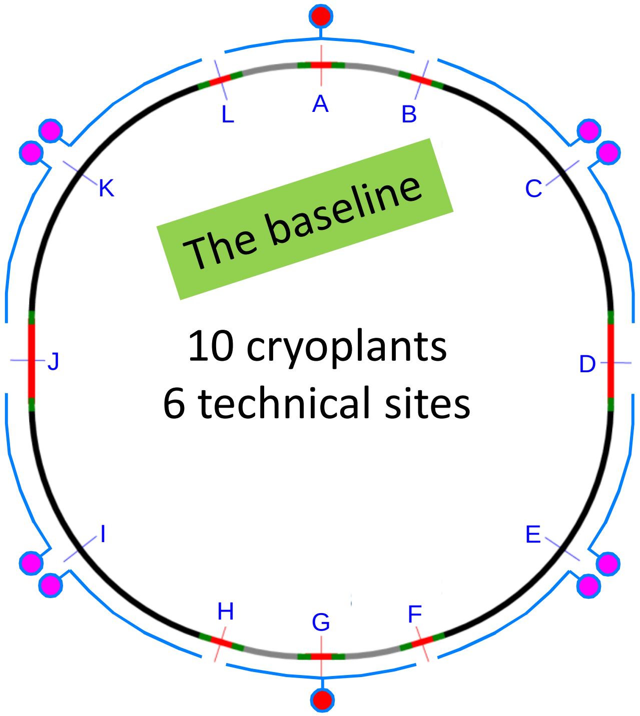
Contents

FCC needs and constraints

See for details, presentation L.Tavian "Towards a conceptual design for FCC cryogenics"

- ❑ **100 TeV hadron collider in a 100 km long tunnel** **=> FCC_hh defining infrastructure requirements**

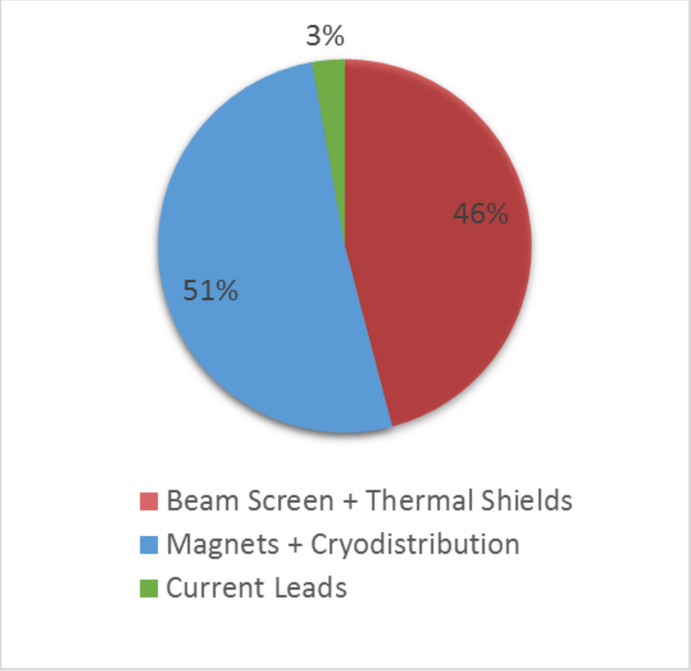
- ❑ Development of **large-scale cryogenic infrastructures** to define a reliable, sustainable and efficient solution
- Cryoplant capacity larger than the state-of-the-art (50 to 100 kW equivalent at 4.5 K)
- Non-conventional thermal load distribution with large thermal loads above 40 K (50% of total heat loads)



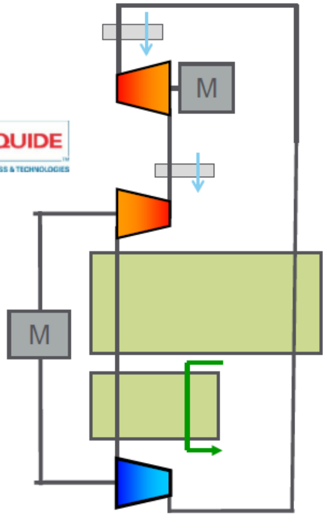
Main FCC_hh cryogenic users :

- Beam Screen and Thermal Shields
  40-60 K cooling
- Magnets and Cryodistribution
  1.9 K cooling
- HTS Current Leads
  40-300 K cooling

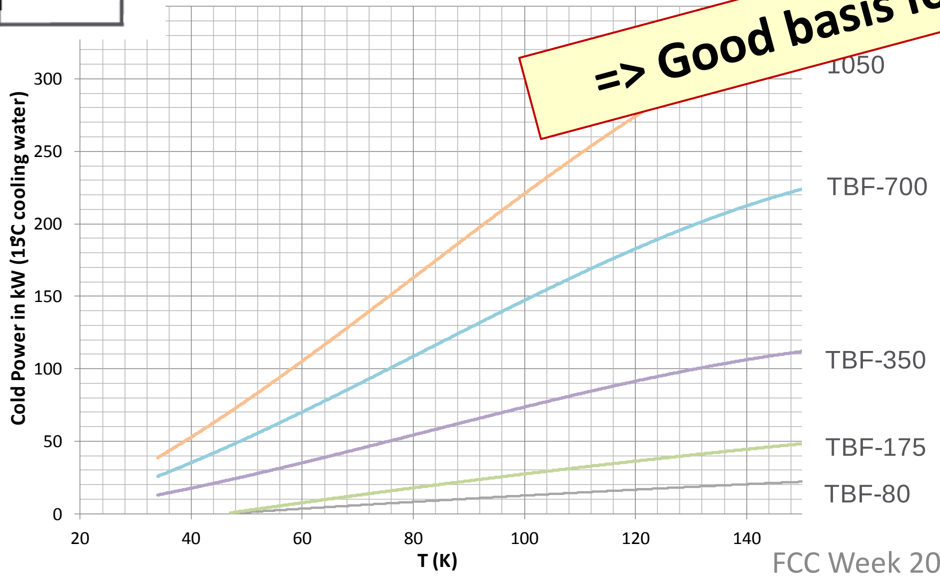
=> Total power consumption ~200 MW with conventional cryoplants



Air Liquide existing products
77 kW@ 50K



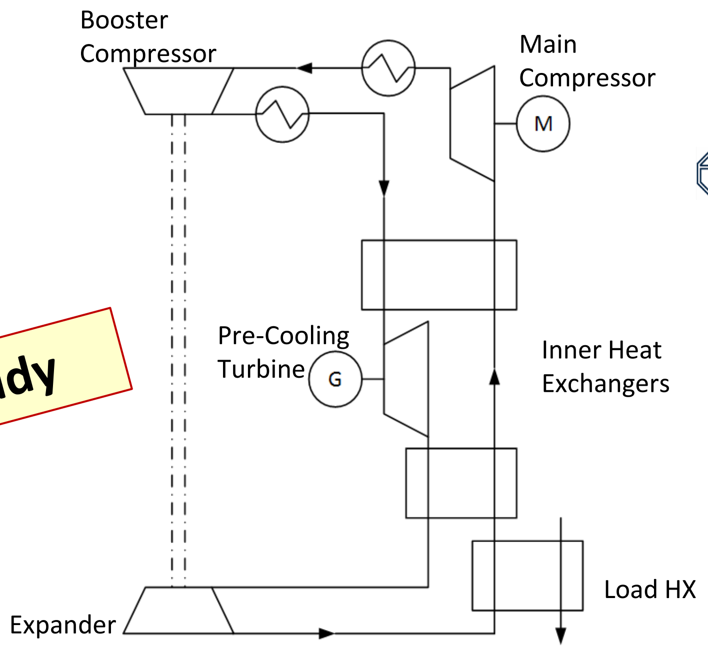
Achieved efficiency
- 40% Carnot



By courtesy C.Gondrand/AL

=> Good basis for industry study

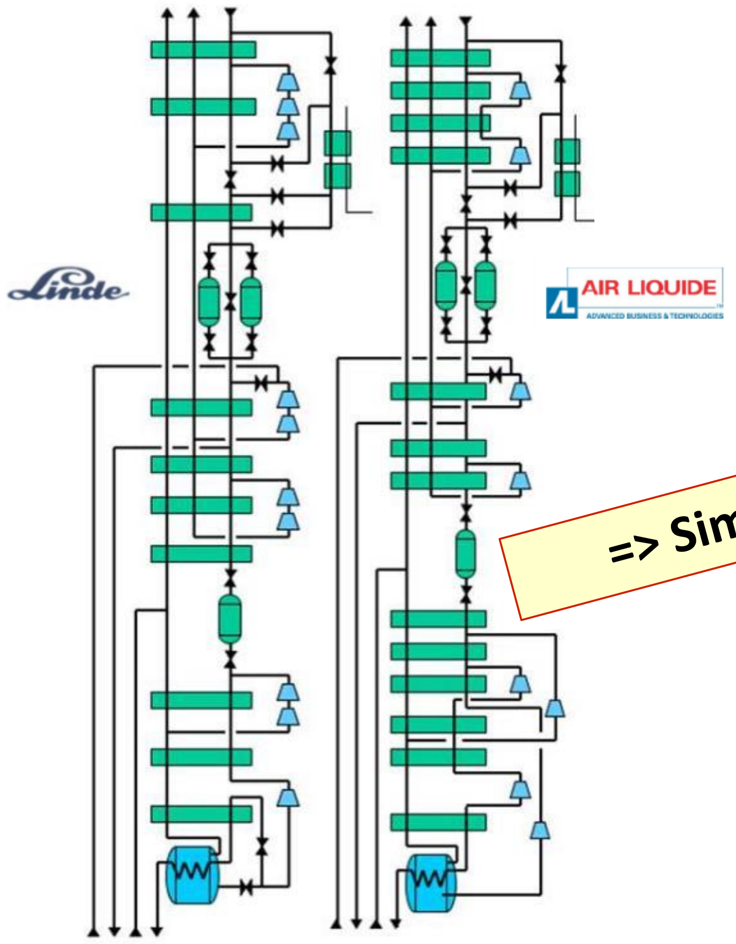
TU Dresden development
750 kW@ 40-60K



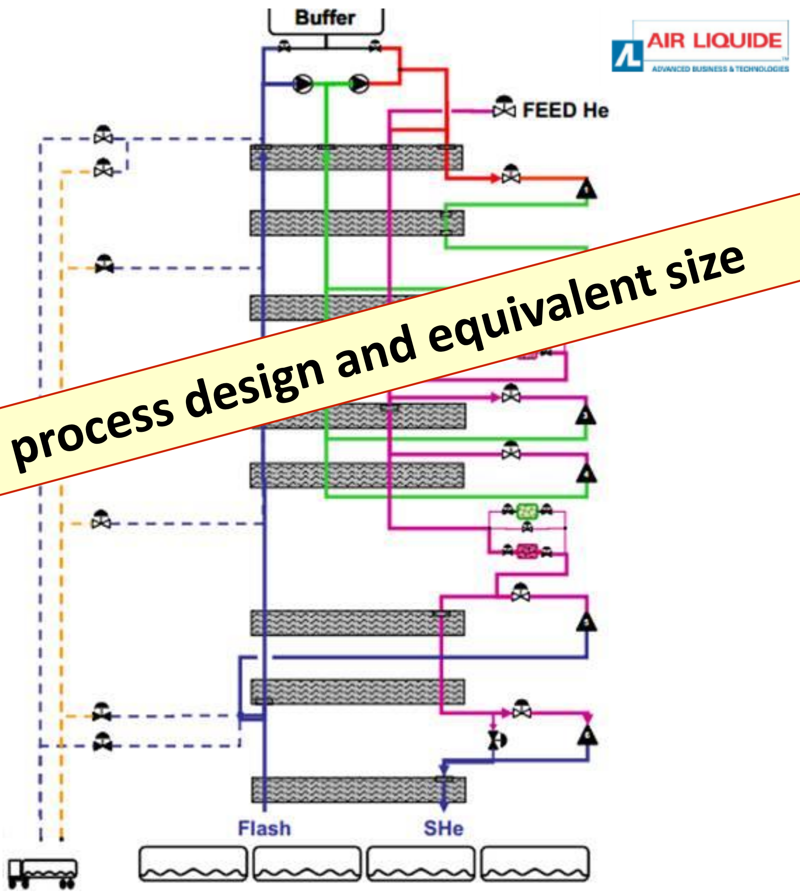
Expected efficiency
- 40% Carnot

See for details : presentation of S.Kloppel "Cryogenic refrigeration with Ne-He mixtures for the FCC_hh"

LHC 4.5 K Refrigerators
8 modules of 18 kWeq @ 4.5K

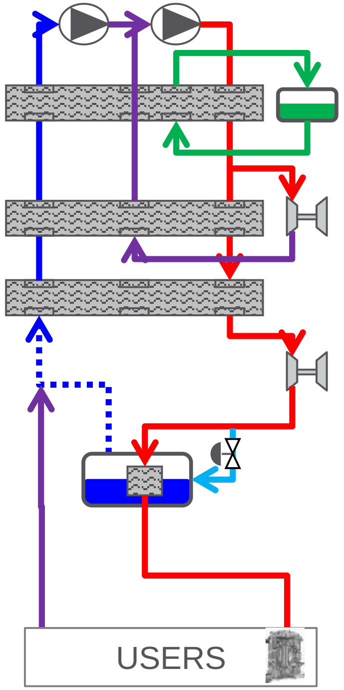


Qatar Helium Recovery Unit
20 tons/day - 24 kWeq @ 4.5K



ITER He Plant
3 x 25 kWeq @ 4.5K

3 modules in //

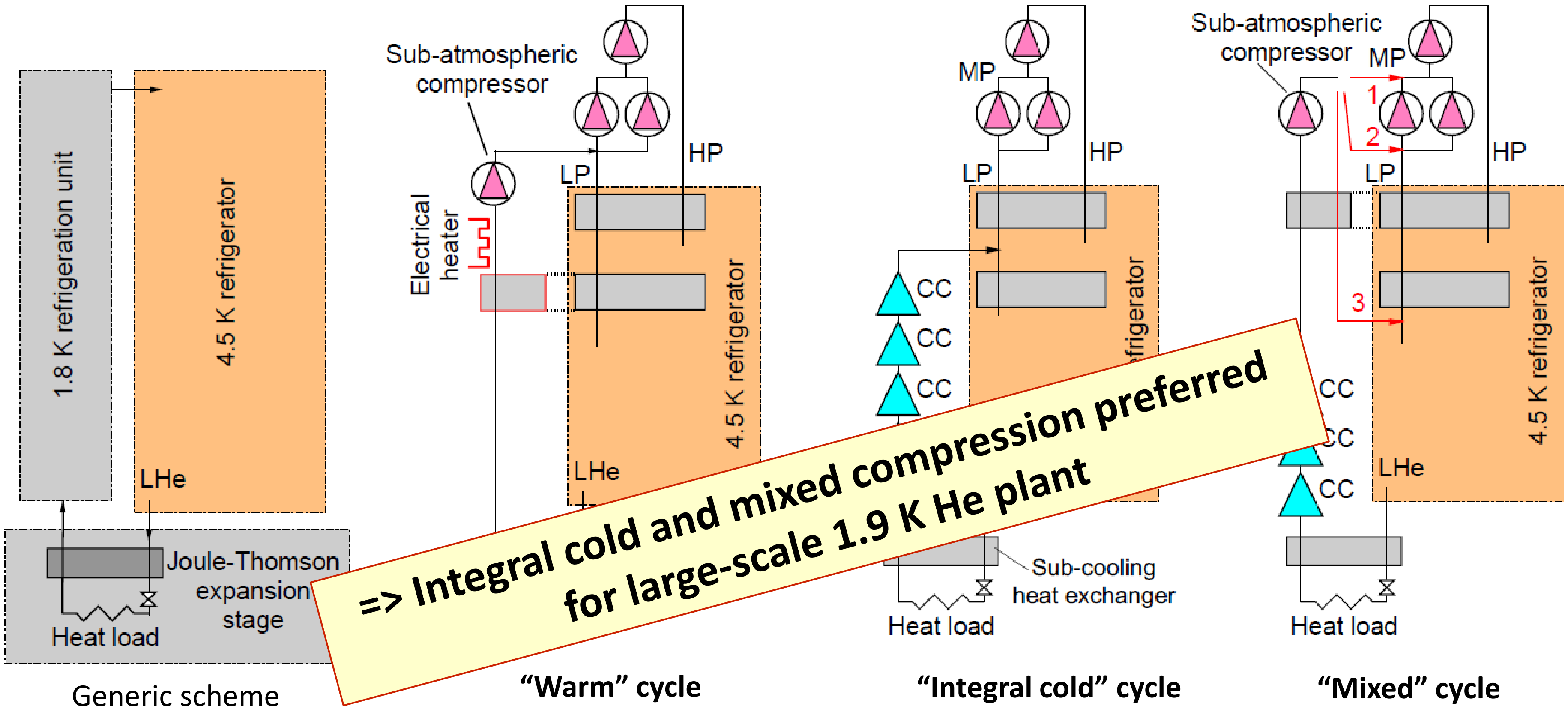


Under construction

=> Similar process design and equivalent size

U.Wagner/ CERN

F.Andrieu / ALAT



Generic scheme

"Warm" cycle

SCA (Stanford)

KIT test facility

CERN test bench

"Integral cold" cycle

CEBAF – SNS

2 x 5.2 kW@2K

"Mixed" cycle

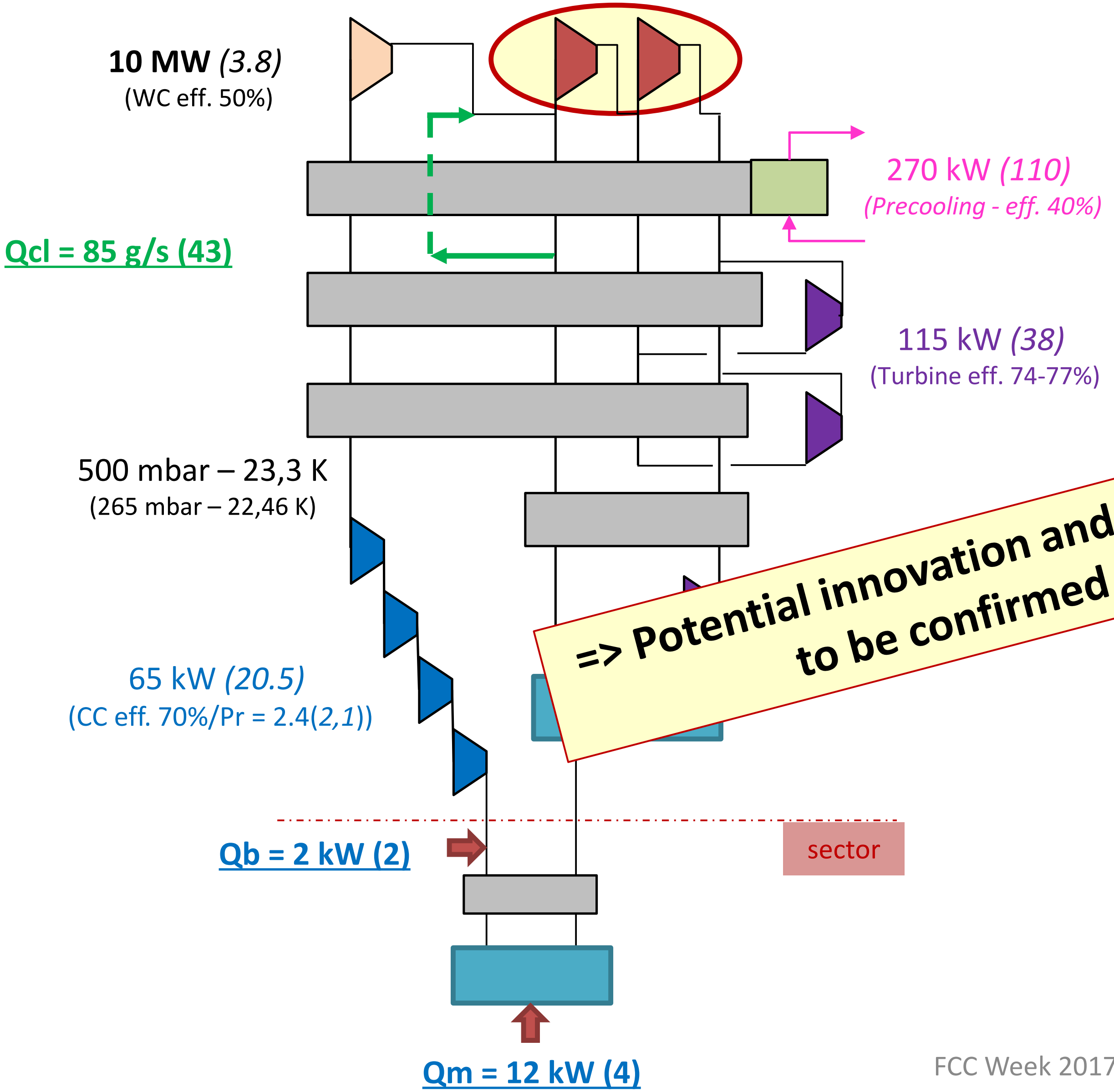
Tore Supra

CEA test facility

LHC

8 x 2.4 kW@1.8K

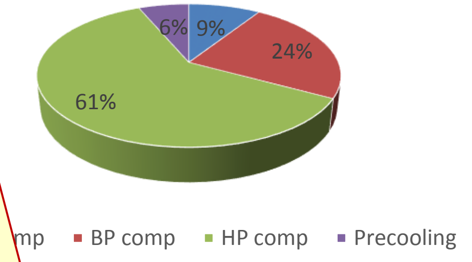
He 1.9K cryoplant – CEA/SBT Pre-study



=> Potential innovation and process optimisation to be confirmed by industry

Simplified process cycle for one FCC He plant in High Mode *(Low Mode)*

Electrical Consumption for High mode (12kW@1.8K + 85g/s@40K)



Electrical consumption reduction ?

- Warm Compressor efficiency from 50% to 70% => -25%
- Turbine efficiency from 75 to 85% => -6%
- Cold Compressor efficiency from 70 to 80% => <-1%
- Heat Exchanger efficiency => < -1%
- High Pressure from 22 to 25 bars => < -1%
- Outlet CC Pressure from 130 to 1050 mbar => +5 to -5 %

Scope of supply - Objectives

It is time to assess industrial solutions for FCC cryoplants

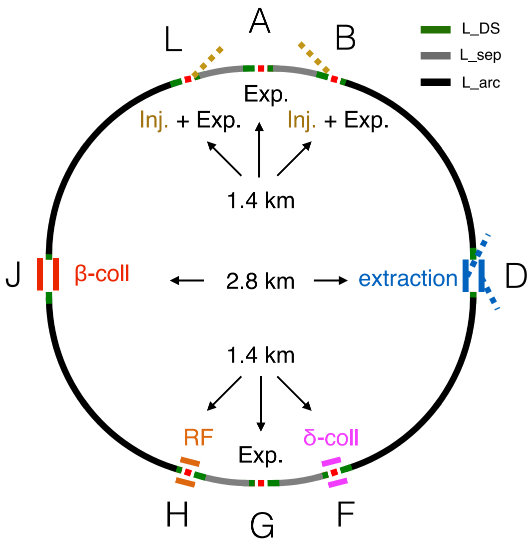
=> An engineering study is started with major European companies with the objectives

- **To define the "Reference Solution - 10 cryoplants"** with magnets operating at 1.9 K.
- *To define an alternative option "Optional Solution - 20 cryoplants" with magnets at 1.9 K*
- **To identify the technical risk items and the innovative technologies for more sustainable and more efficient large-scale cryoplants**
- **To estimate the cryoplant capital and operation costs**

To involve industries at the earliest stage of the FCC project

Contents

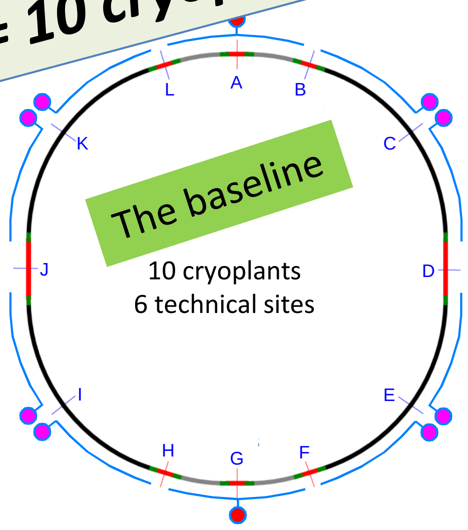
Baseline : 100 TeV - 100 km FCC_hh



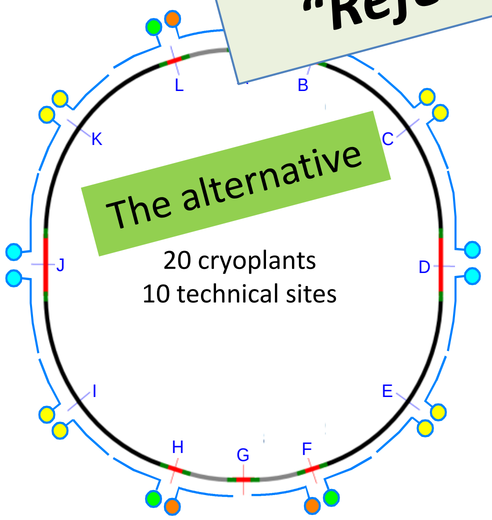
D.Schulte/ CERN

- **12 access points distributed around the tunnel with :**
  - Two high-luminosity experiments (A and G)
  - Two other experiments combined with insertions (B and L)
  - Two collimation insertions (F and J)
  - One extraction insertion (D)
  - One cleaning insertio…

"Reference solution" for industry study = 10 cryoplants

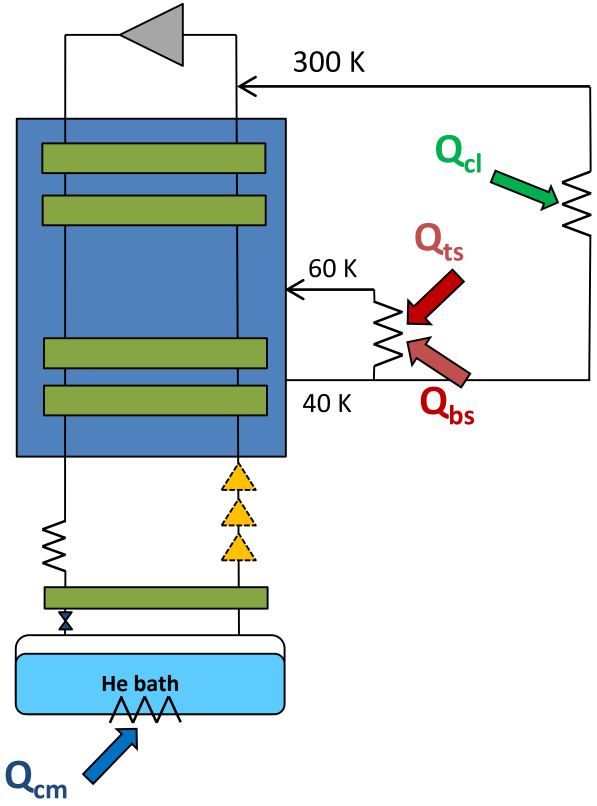


- **Cryogenic Baseline … ts in 6 technical sites**
  - *…o plant redundancy in A and G*
  - *Longer cryolines and larger plants*
  - *No cryogenic system in D,J,F,H,L,B*

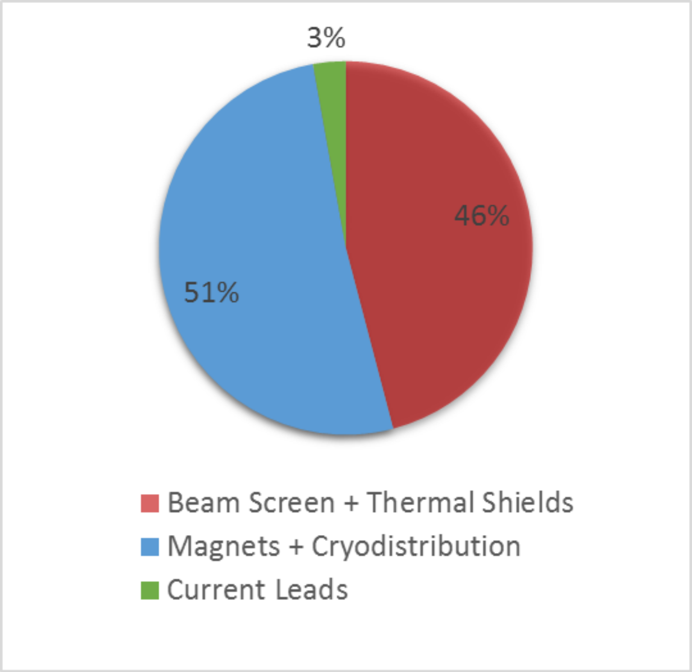


L.Tavian/ CERN

- **Alternative option with 20 cryoplants in 10 sites**
  - *Full redundancy in all sites*
  - *Reduced size for each plant*



- The **cold mass (CM)** of the superconducting magnets operating at 1.9 K,
- The **beam screens (BS)** & **thermal shields (TS)** requiring forced flow cooling between 40 K and 60 K,
- The HTS **current leads (CL)** requiring forced flow cooling between 40 K and 300 K.



Ne-He 300-40 K cryoplant

- Beam screen (40-60 K)
- Thermal shield (40-60 K)
- Current leads (40-300 K)
- Precooling of Magnet cryoplant ?

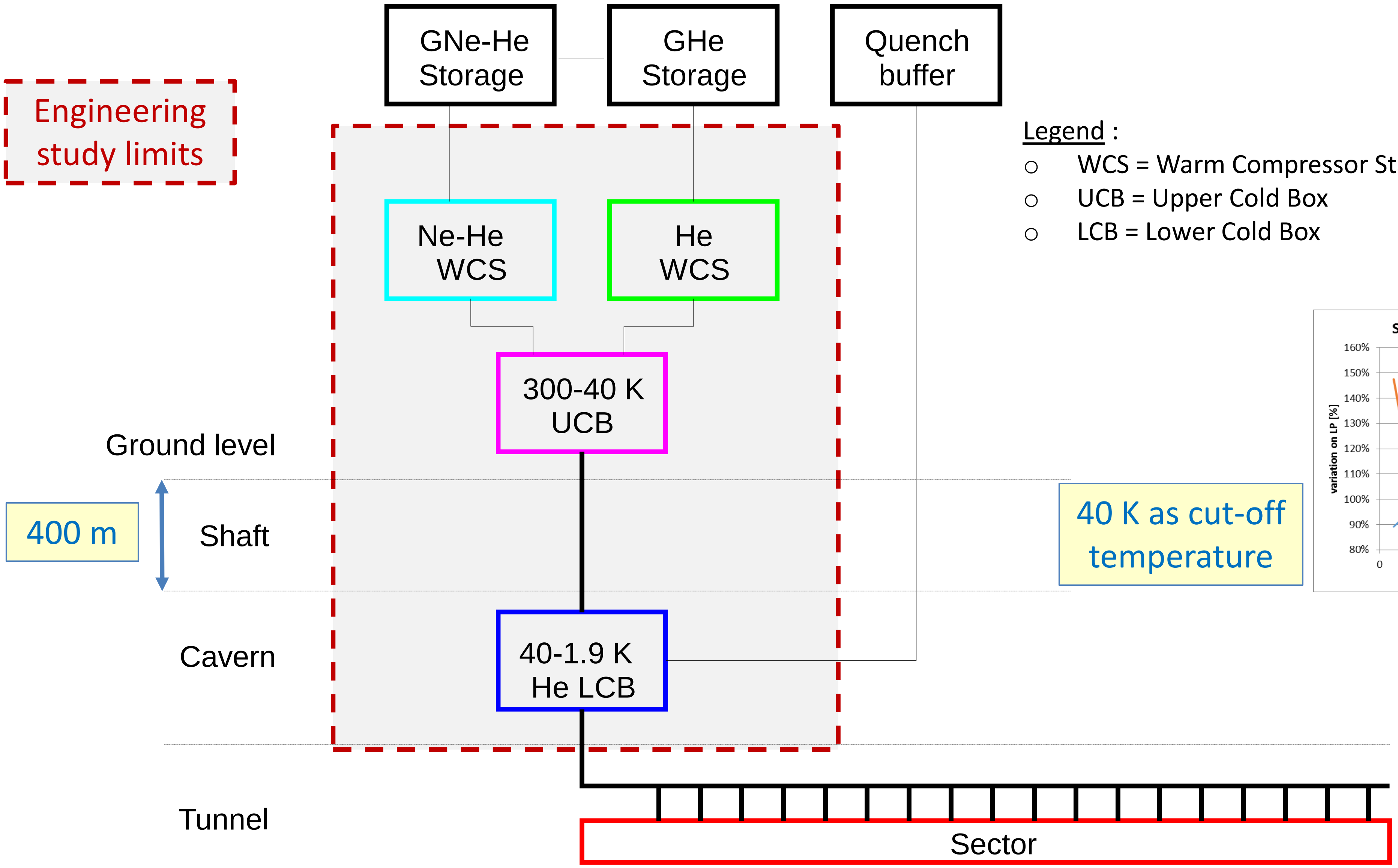
He 1.9 K cryoplant

- SC magnet cold mass (1.9 K)

=> Dedicated cryoplants to optimise overall efficiency

Technical requirements : Cryogenic architecture & study limits

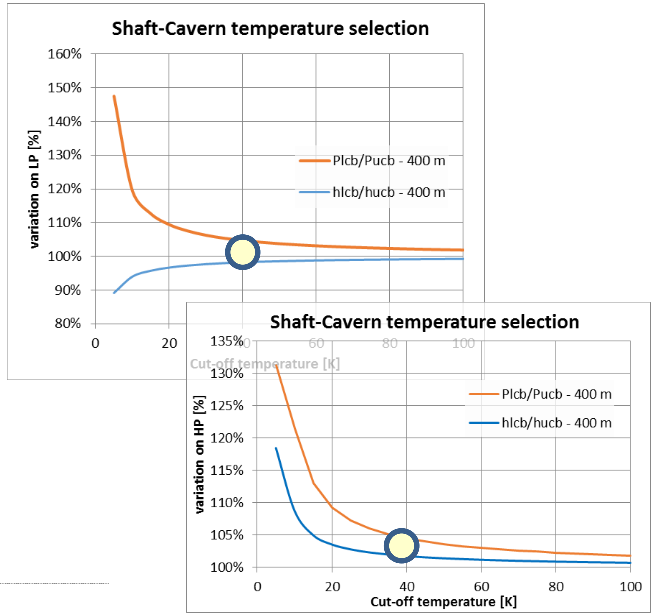
L.Tavian/ CERN



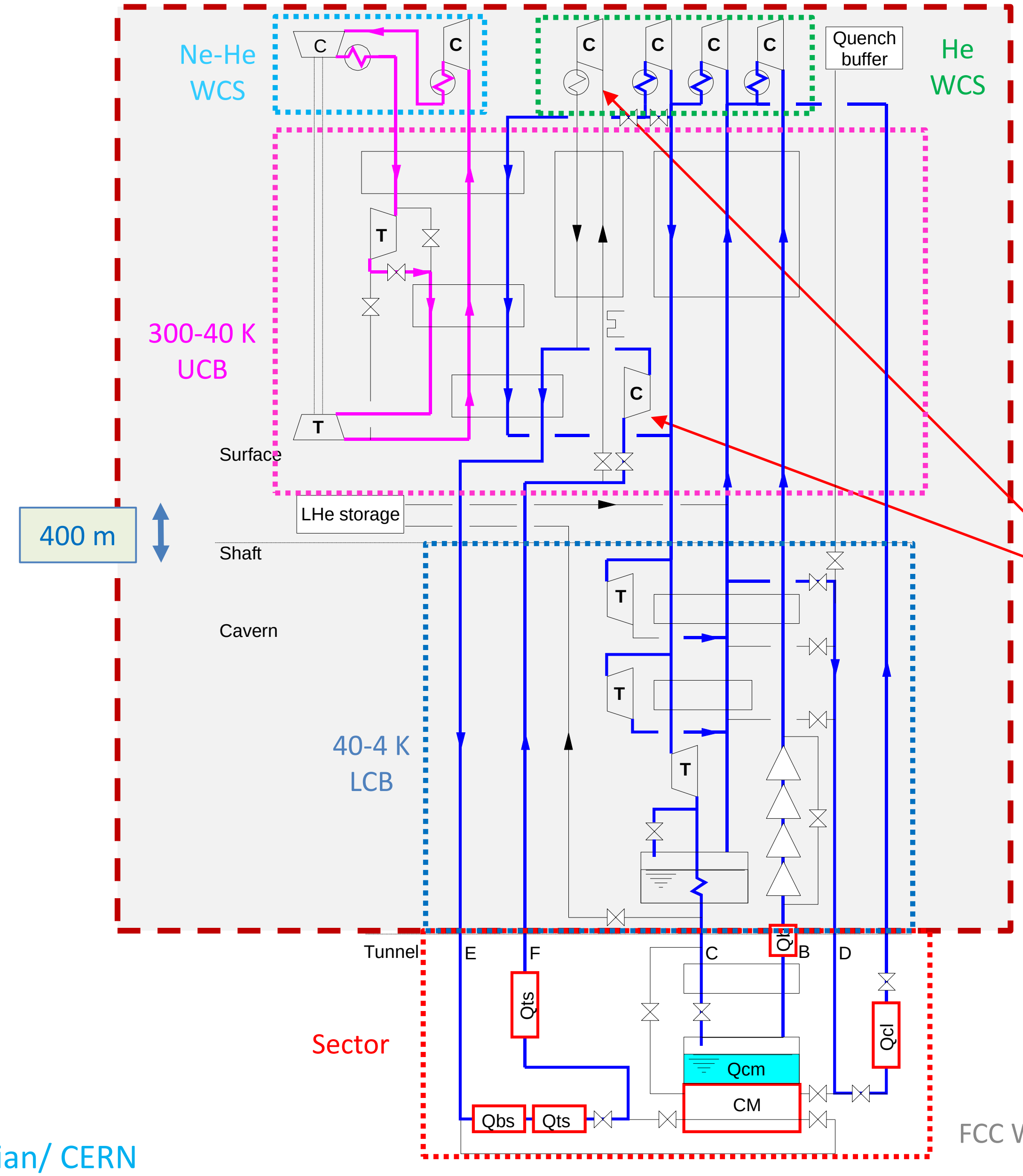
Legend :

- WCS = Warm Compressor Station
- UCB = Upper Cold Box
- LCB = Lower Cold Box

40 K as cut-off temperature



Technical requirements : Process Flow Diagram



Engineering study limits

He plant for magnets & current leads cooling

+

Ne-He plant for beam screen & thermal shield cooling

+

Distribution cooling loops (40-60K) & (4.6-1.8K) & (40-300K)

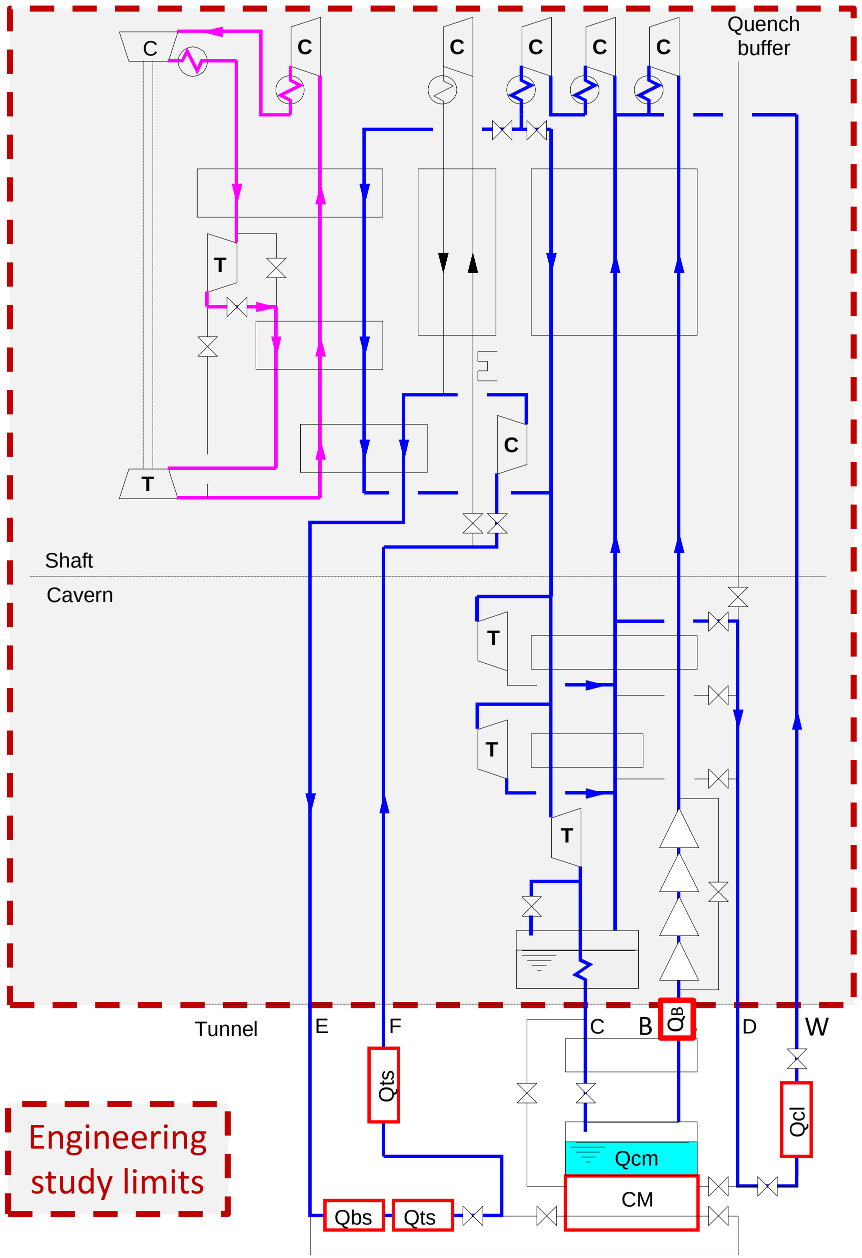
With cold or warm He circulators for 40-60K cooling & cooldown/warm-up

Legend :

- He WCS = Helium Warm Compressor Station
- Ne-He WCS = Neon-Helium WCS
- UCB = Upper Cold Box (single or coupled) for 40-60 K & 40-300 K cooling
- LCB = Lower Cold Box (single or coupled) for 1.9 K cooling
- C = Compressors / Circulators
- T = Turbines

L.Tavian/ CERN

Technical requirements : “High” and “Low” Operation Modes

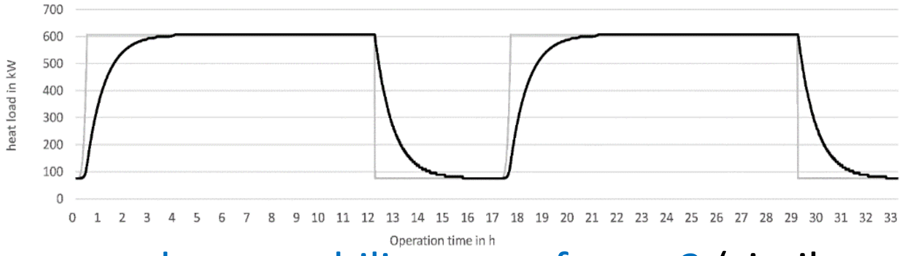


- ❑ Cryogenic power requirements for one FCC hh sector (one cryoplant)

Assumptions : « High » & « Low » modes = maximal & minimal cooling requirements

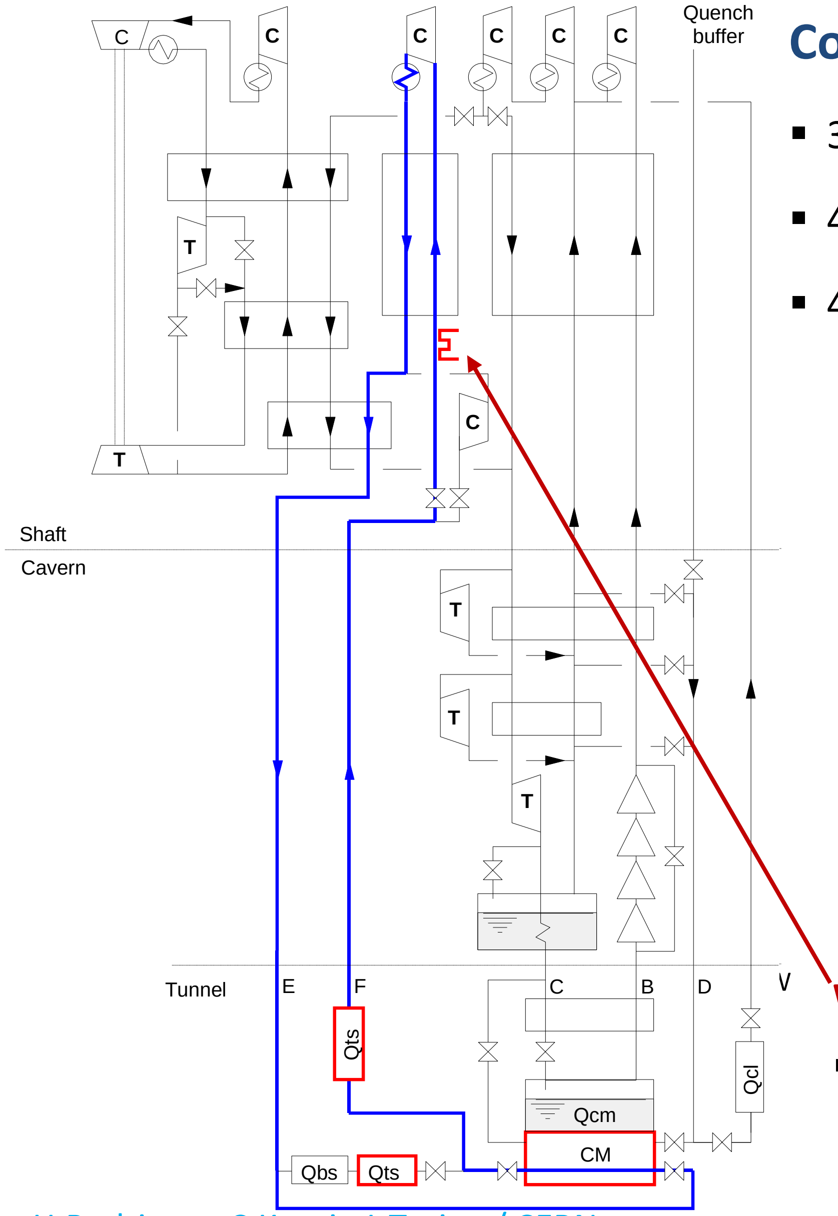
Loads	Cooling circuit	Temp. range	“High” mode 10 cryoplants	“Low” mode 10 cryoplants	“High” mode 20 cryoplants
Qcm [kW]	Magnets	1.9 K	12	4	6.4
QB [kW]	Cryodistribution		2	2	1.1
Qbs [kW]	Beam screens	40-60 K	530	ε	280
Qts [kW]	Thermal shields		90	90	50
Qcl [g/s]	Current leads	40-300 K	85	43	67

- ❑ Beam screen loads : turn-dow capability up to factor 6



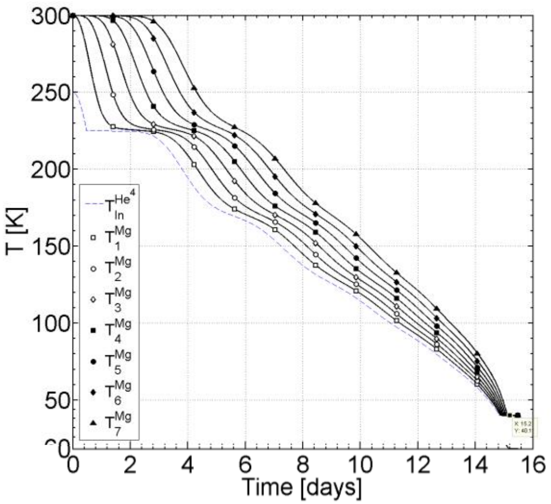
- ❑ Magnet loads : turn-dow capability up to factor 3 (similar to LHC)

Technical requirements : Cooldown & Warm-up



Cooldown : ~ 15 days (comparable to LHC)

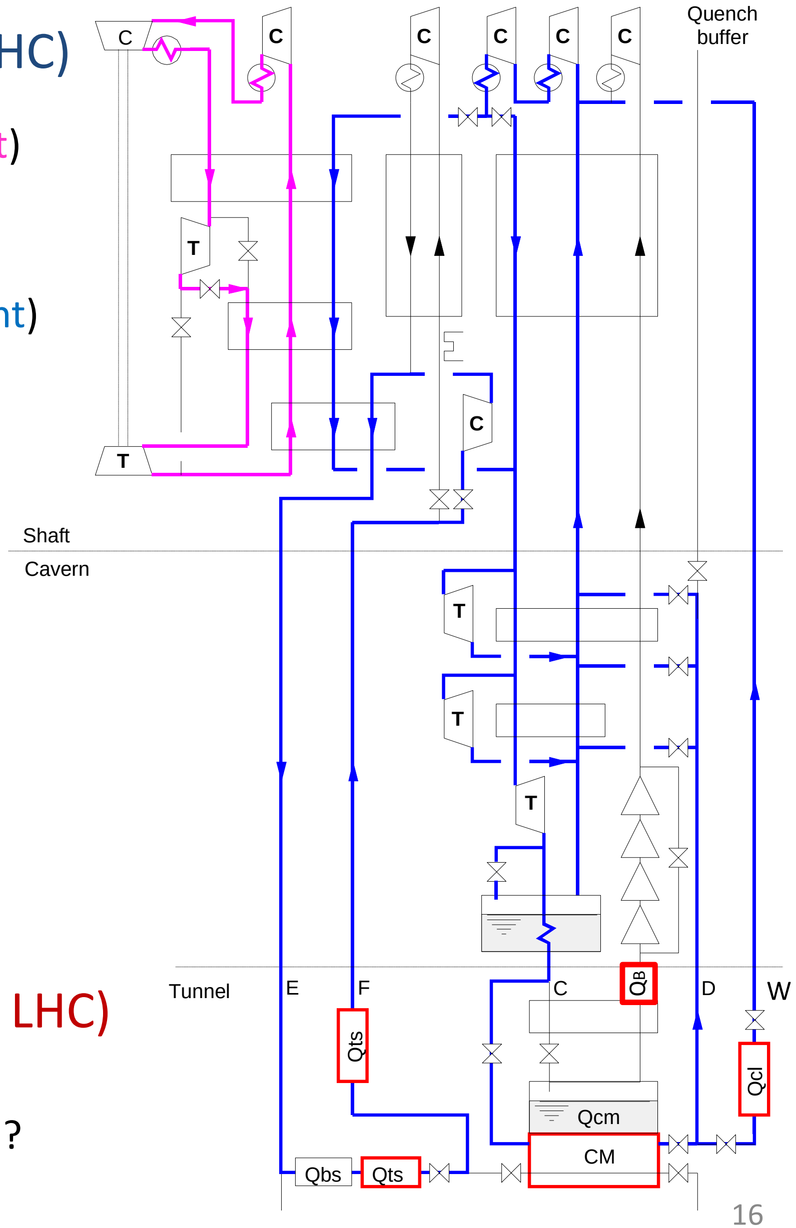
- 300-40 K : 2.5 to 0.65 MW cooling (Ne-He plant)
- 40-4 K : 24 to 12 kW (He plant)
- 4-1.9 K : 0.12 kg/s for filling and 12 kW (He plant)



Warm-up : ~ 15 days (comparable to LHC)

- first stage : 2.5 MW electrical heaters

  or compression power recovery or ?



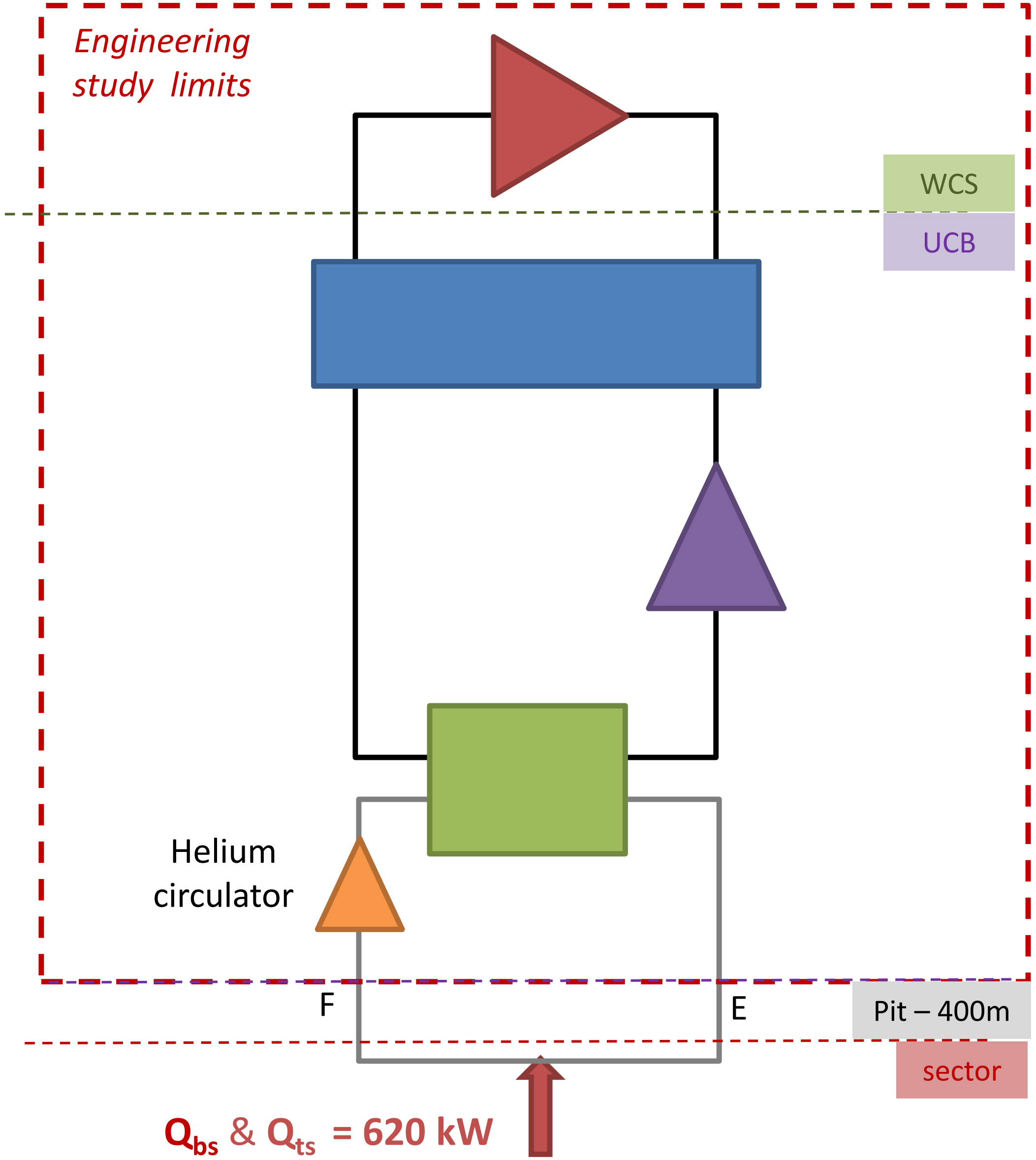
H.Rodrigues-C.Kotnig-L.Tavian / CERN

Technical requirements : Ne-He 40-300K cryoplant & interfaces

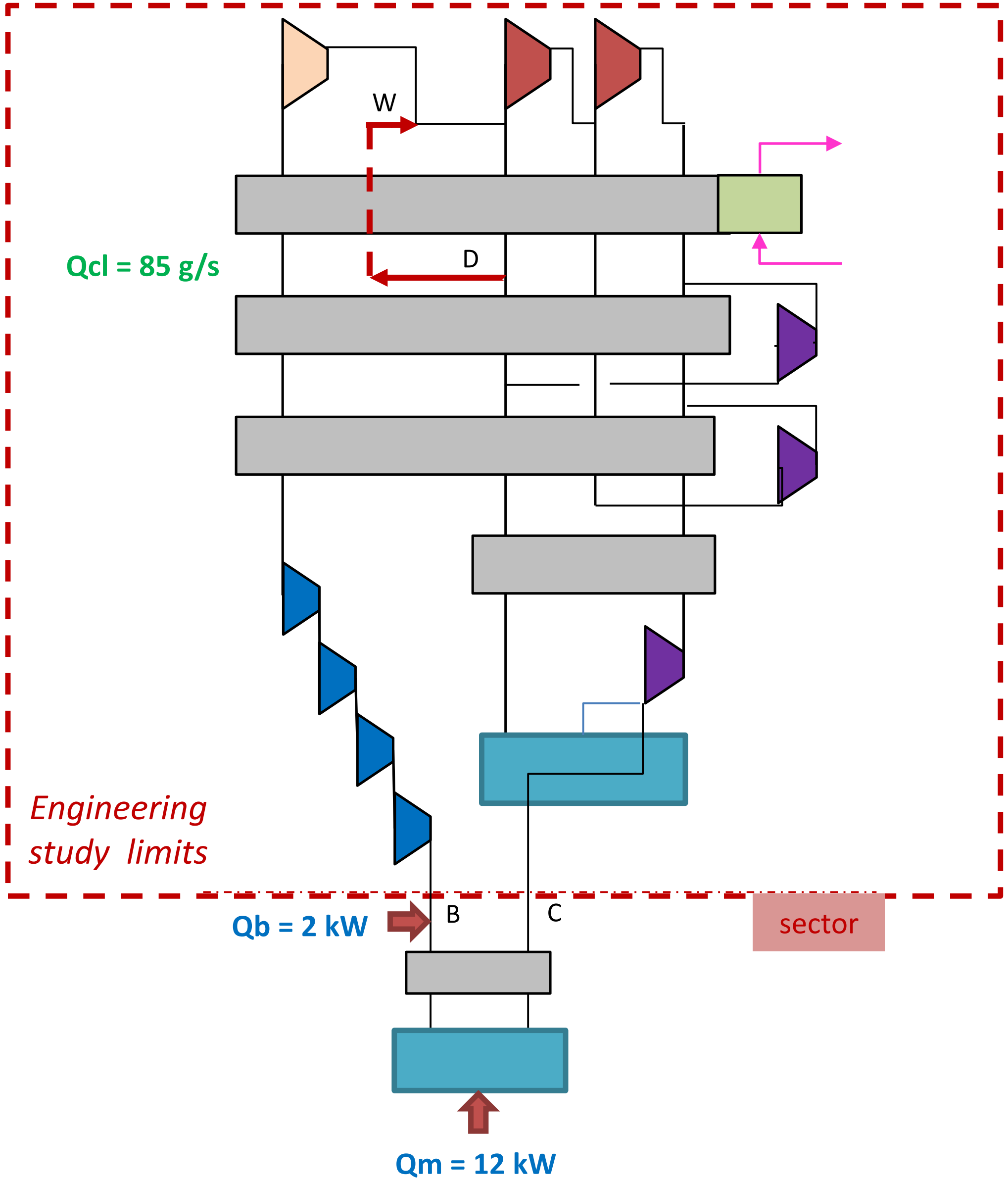
- **Primary loop** with HP He forced flow circulation (cold or warm circulators for nominal and cooldown/warmup modes ?)

- **Secondary loop** based on Turbo-Brayton cycle operating with HP gas mixture (Ne-He) and with cooling capacities from 0.2 to 1 MW at 40 K and cooldown/warmup functions ?

- Two interfaces with cryodistribution :
  - Line E for 40 K HP GHe supply
  - Line F for 60 K HP GHe return



Technical requirements : Magnets and HTS Current Leads cooling



- Modified Claude cycle (similar to LHC)
  - with cooling capacity
    - up to 12 kW at 1.8 K for magnets
    - up to 85 g/s at 40 K for current leads
  - with or without precooling (N2 or Ne-He) ?
- Magnet cooling = integral or mixed cycle for VLP compression

- Two interfaces for magnets cooling:
  - Line B for VLP GHe return
  - Line C for SHe supply at 4.6 K

- Two interfaces for HTS current leads:
  - Line D for 40 K GHe supply
  - Line W for 290 K GHe return

  (D and W not correctly shown on figures)

Contents

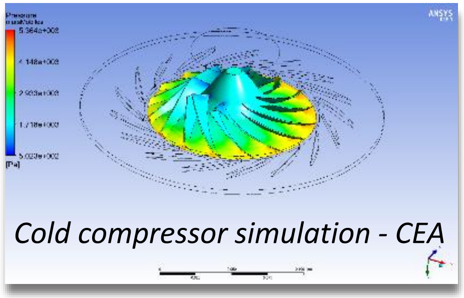
Performance of the contracts : Work breakdown

Phase #	Task #	Title	Objectives *Open issues ?*
Phase 1		**Reference solution selection**	Define and select the appropriate architecture, process cycles and main components with expected efficien… at 30 to 40% and overall availability at 99 6…
	Task 1	He plant and Magnet-CLs loops definition	
	Task 2	Ne-He plant and BS-TS loops definition	
Phase 2		**Reference solution performances**	Assess performan… …elected Reference solution for: • coo… …armup • Tu… …own capability
	Task 3	Cool-down & Warmup	
	Task 4	Turn-down capability evaluation	
Phase 3		***Optional solution design***	*similar objectives as Reference solution*
	Task 5	*Option 20 cryoplants*	
Phase 4		**Identification of innovative technologies**	Identify the technical risk items and i… …ologies Propose a roadmap to ad…
	Task 6	Powerful Turbo-Brayton Fridges	
	Task 7	Large warm and cold centrifugal compressors and circulators studies	
Phase 5	Task 8/9	**Cryoplant comparison and cost estimate**	Compare the technical options Estimate the costs

Ne-He and He schemes & components selection ?

R&D roadmap for optimisation of cost and efficiency, availability, reliability ?

Present status – Towards contract signatures


Cold compressor simulation - CEA

- ❑ First half 2016 : Specification preparation and CERN Price inquiry
  based on studies at CERN, CEA, TU Dresden and TU Wroclaw
- ❑ September 2016 : Industry first offers
- ❑ Second half 2016 : Technical and commercial exchanges for offer review
- ❑ First half 2017 : CERN-Industry exchanges for contract finalisation
  one major issue on Confidentiality and Intellectual Property !

- ❑ 24th of May 2017 : LINDE contract signature
- ❑ June 2017 : Kickoff meeting with LINDE

=> industry engineering studies should be performed in 2017 in time for CDR

Thank you for your attention

Extra slide : Operating conditions in steady-state modes

		Reference solution "High" mode 10 cryoplants			Reference solution "Low" mode 10 cryoplants			Optional solution "High" mode 20 cryoplants		
Line		Temp. [K]	Pres. [kPa]	Flow [kg/s]	Temp. [K]	Pres. [kPa]	Flow [kg/s]	Temp. [K]	Pres. [kPa]	Flow [kg/s]
C	Supercritical helium supply	4.6	300	0.63	4.6	300	0.21	4.6	300	0.32
B	VLP superfluid helium return	3.66	1.5	0.63	4.89	1.5	0.21	3.70	1.5	0.32
E	40 K HP gaseous helium supply	40	5000	5.69	40	5000 (*)	0.8 (*)	40	5000	3.0
F	60 K HP gaseous helium return	60	4400	5.69	60 (*)	4900 (*)	0.8 (*)	60	4400	3.0
D	40 K LP gaseous helium supply	40	130	0.085	40	130	0.043	40	130	0.067
W	Warm LP gaseous helium return	290	110	0.085	290	110	0.043	290	110	0.067

(*) *tbc to fulfill circulator design*

Extra slide : FCC_hh cryoplant and Existing cryoplants