2 K System Exergetic Optimisation and Helium Recovery System for FCC-ee

FUTURE CIRCULAR COLLIDER

CERN

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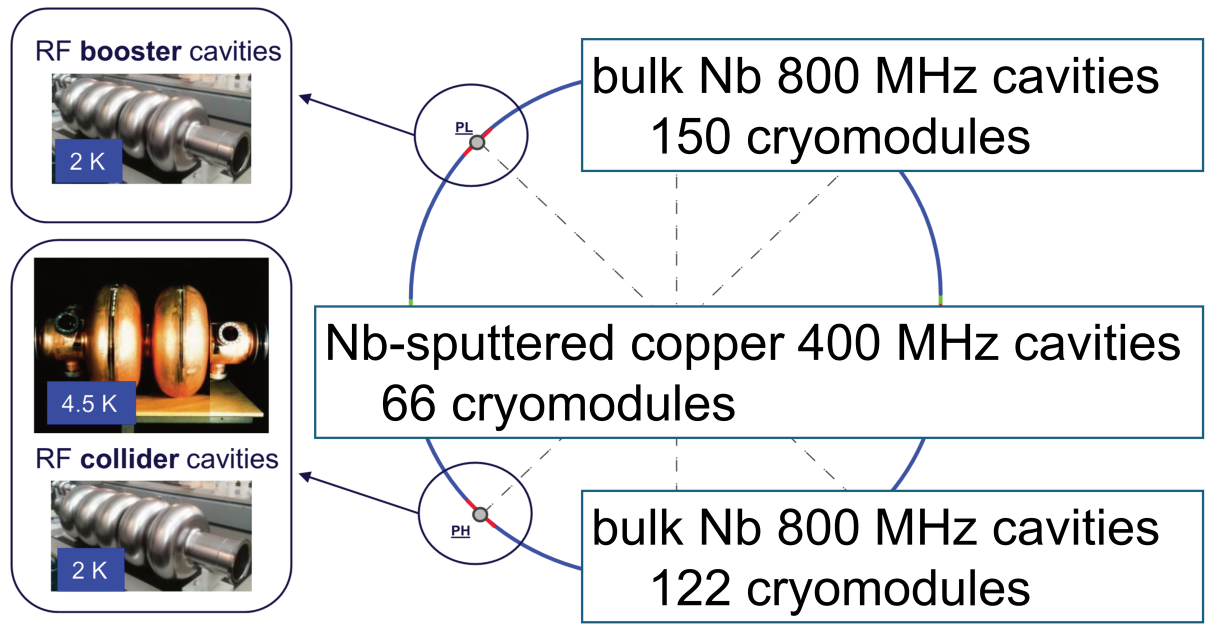
Introduction

FCC-ee @ ttbar



Addressed design challenges

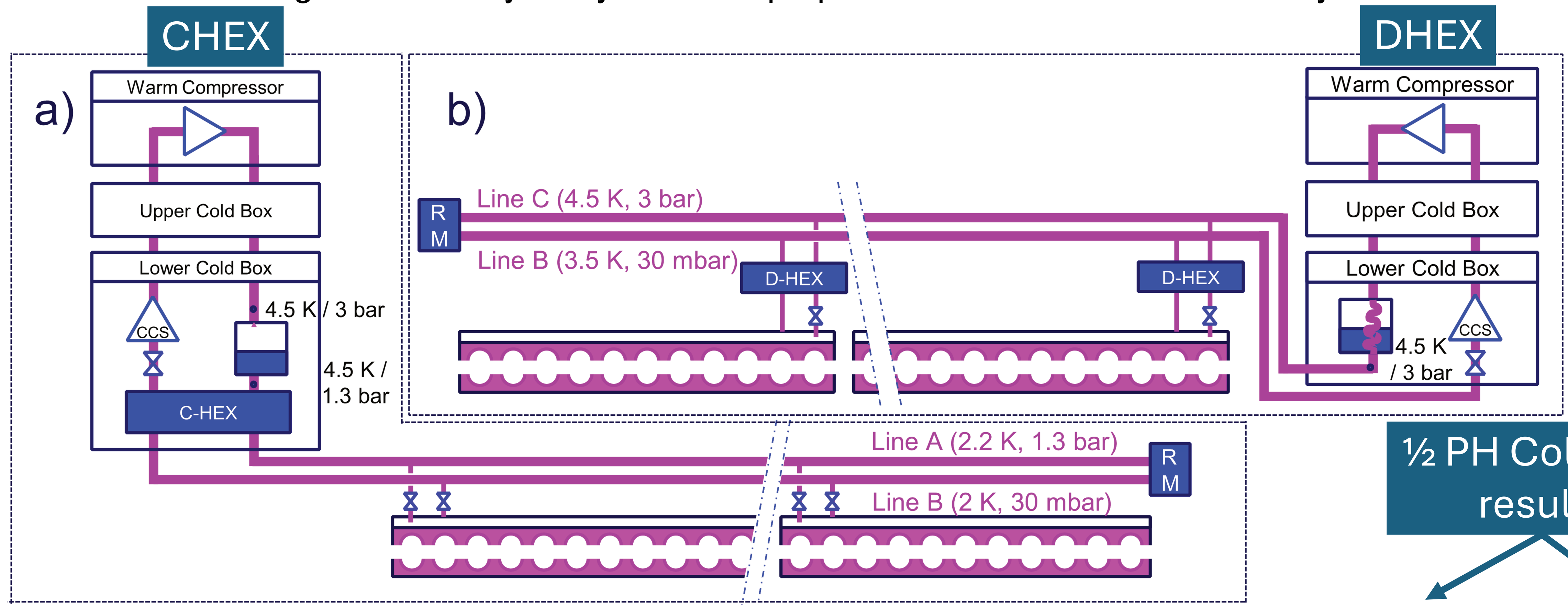
- Sustainability and energy consumption
- Resilience against market volatility and electrical grid perturbations
- Integration of booster and collider in a Φ5.5m tunnel

Studies

- Energy consumption: exergetic investigation around two architectures for a 2 K system – DHEX vs CHEX
- Helium inventory preservation: proposal of a Helium Recovery System (HRS)

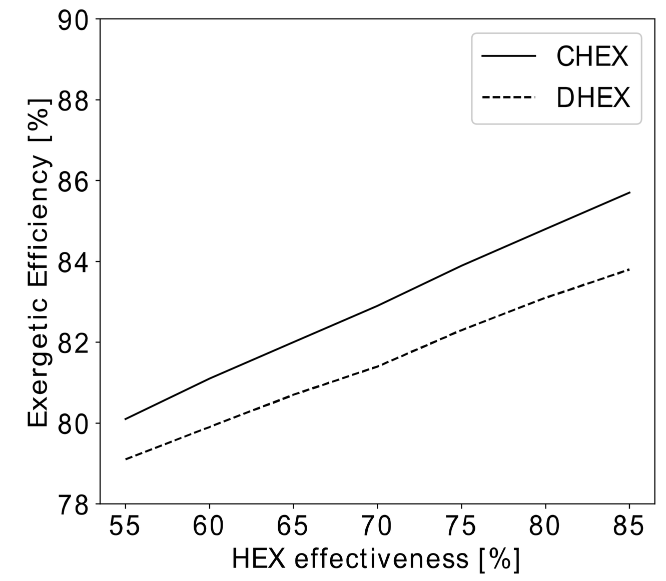
2 K system exergetic efficiency optimization

Exergetic efficiency analysis of two proposed architectures for the 2 K system tasked with cooling the 272 cryomodules of FCC-ee at ttbar



Sensitivity Analysis

Reachable effectiveness of the CHEX will drive the most energy efficient solution.

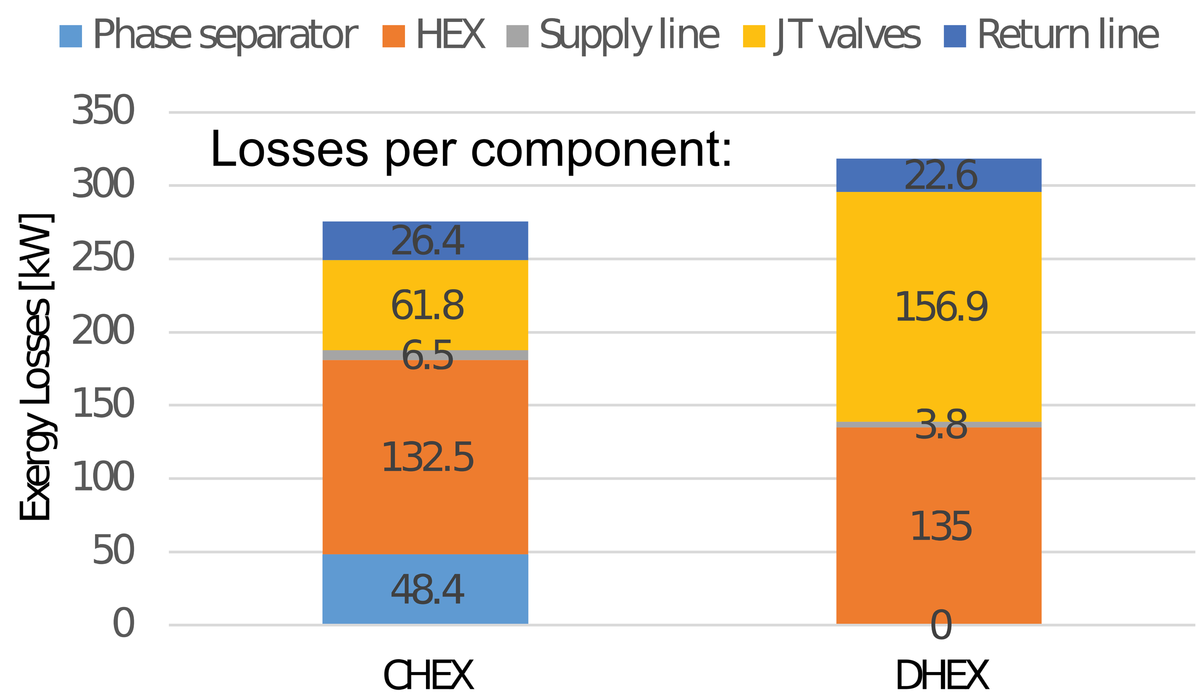


- **Useful exergy** ΔE_u : needed to keep the system at 2 K with He II without considering any losses (Carnot)
- **Real exergy** ΔE_r : actual increase of exergy experienced by the fluid through a given system, including its losses. Values obtained from a process simulation: $\Delta E_r = \dot{m} \times (\Delta h - To \times \Delta s)$
- **Exergetic efficiency [1]**: $\xi = \frac{\Delta E_u}{\Delta E_r} \times 100$ To = 290 K

½ PH Collider - results

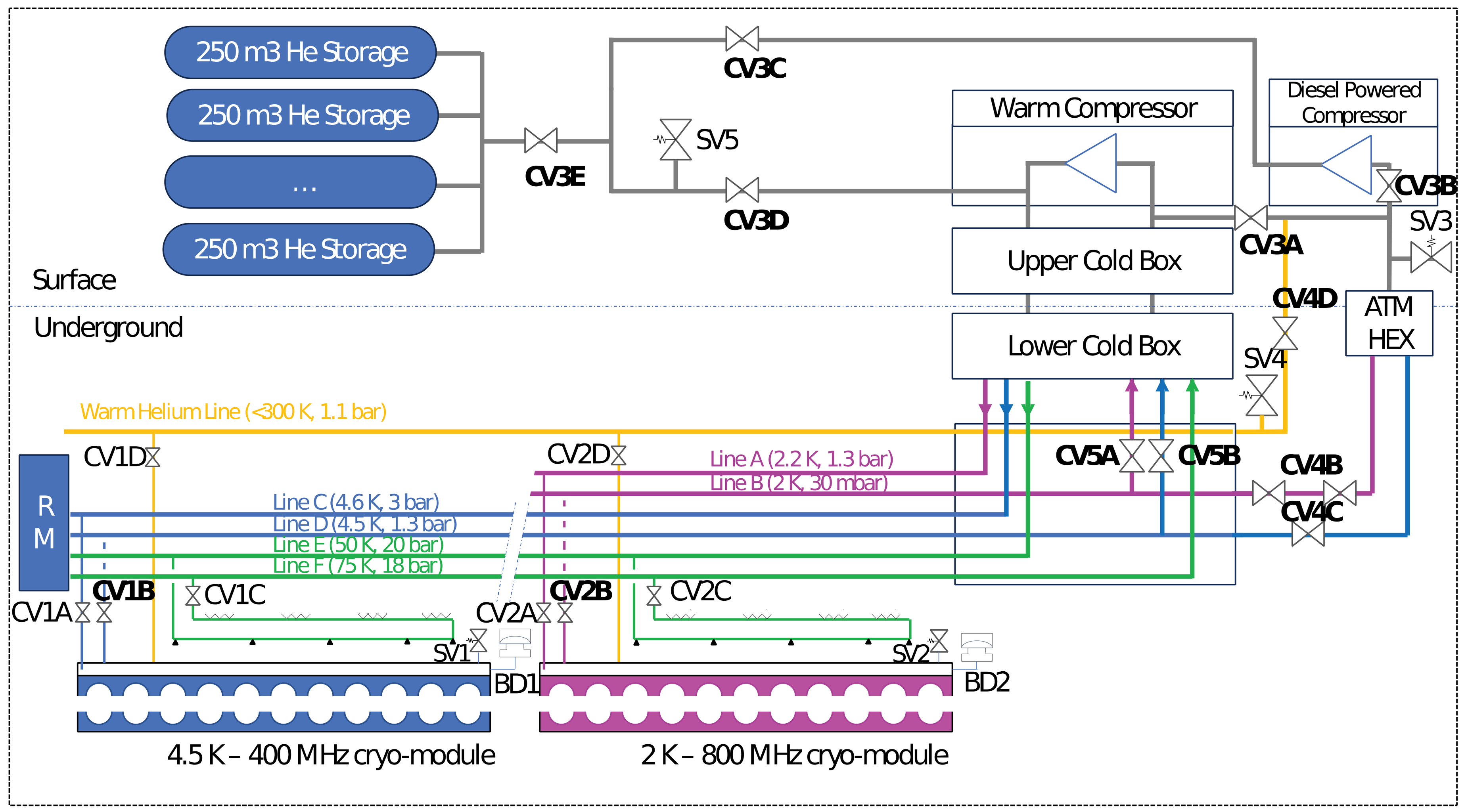
At max HEX effectiveness

	C-HEX	D-HEX
ξ_{max} [%]	85.7%	83.8%
VLP Diam. [mm]	330	375
$\dot{m}$ per HEX [g/s]	544	10



[1] S Claudet et al. "Exergy Analysis of the Cryogenic Helium Distribution System for the Large Hadron Collider (LHC)" In: AIP Conference Proceedings 1218 (Apr. 2010). doi: 10.1063/1.3422294.

Helium Recovery System (HRS) proposal



Cryomodules = low-pressure rated devices ⇔ high risk of inventory loss in case of a non-nominal scenario:

- **S1** – Isolated cryomodule(s) from the cryoplant due to a malfunctioning valve
- **S2** – Loss of full sector cooling (e.g., due to power outage)
- S3 – Beam vacuum break
- S4 – Insulation vacuum break

CM + Distribution LHe inv. @ttbar: 18t in PH, 10t in PL

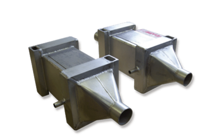
HRS shall address S1 & S2

- S1: return valve should not block closed – mitigation is achieved by a **fail-open valve** and purification systems.
- S2: **UPS powered valves** (in bold) start releasing the He into the return line (D or B) once the CM reaches 1.5 bar. The **cold box is then bypassed** (with CV5x and CV4x), through an atmospheric heat exchanger and a diesel-powered compressor. **No additional cold line required.**

	Point H	Point L
Mass flow rate	530 g/s	315 g/s
Isothermal compression power	1 MW	600 kW
Autonomy	24 h	13 h
Cooling water needs	~100 m3/h	~60-100 m3/h
Atmospheric heat exchanger	810 kW	500 kW
Cavern volume needs	16 m2 x 8 m	10 m2 x 8 m

Conclusions

- **Energy consumption**: exergetic investigation around two architectures for a 2 K system – **DHEX vs CHEX.**



  - *CHEX = preferred option*
    - Easier integration (smaller distribution line and a lower amount of components)
    - Drawback: more complex / less proven HEX design (further R&D needed)
  - *DHEX*
    - Fallback industry-ready option if high-effectiveness CHEX incompatible with expected mass flow rates.
    - Could outweigh integration benefits of CHEX option

$^{4}_{2}He$

- **Helium inventory preservation**: a Helium Recovery System (HRS) was proposed.
  - Four scenarios identified, two of them addressed by the HRS
  - Preservation of the full helium inventory during an incident
  - Market volatility exposure reduction
  - Constraints:
    - Large space occupation of the atmospheric evaporator
    - Necessity of a diesel-powered supply for the compressor used to recover the helium