Future Perspectives for Large Cryogenic Systems

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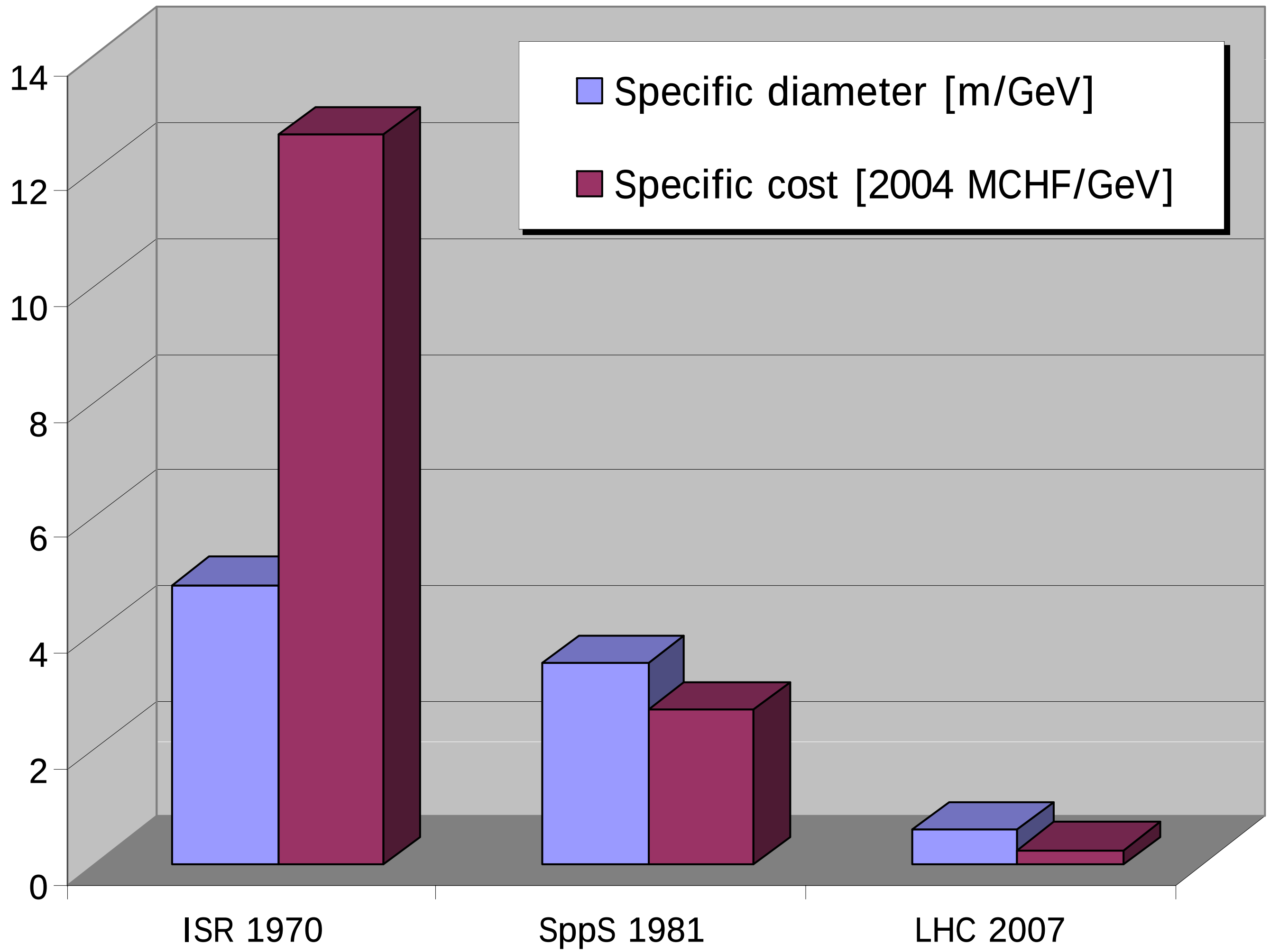
Contents

- The role of cryogenics in future projects
- Thermonuclear fusion research (ITER)
- Particle physics at the energy frontier (ILC, LHC upgrades)
- High-intensity proton linacs (SPL, EURISOL, IFMIF)
- Nuclear physics with protons, antiprotons and ions (FAIR)
- Ultra-fast, intense X-rays to probe condensed matter (the European X-ray FEL and ERLs)
- Cosmic and rare underground signals (ICARUS)
- Conclusions

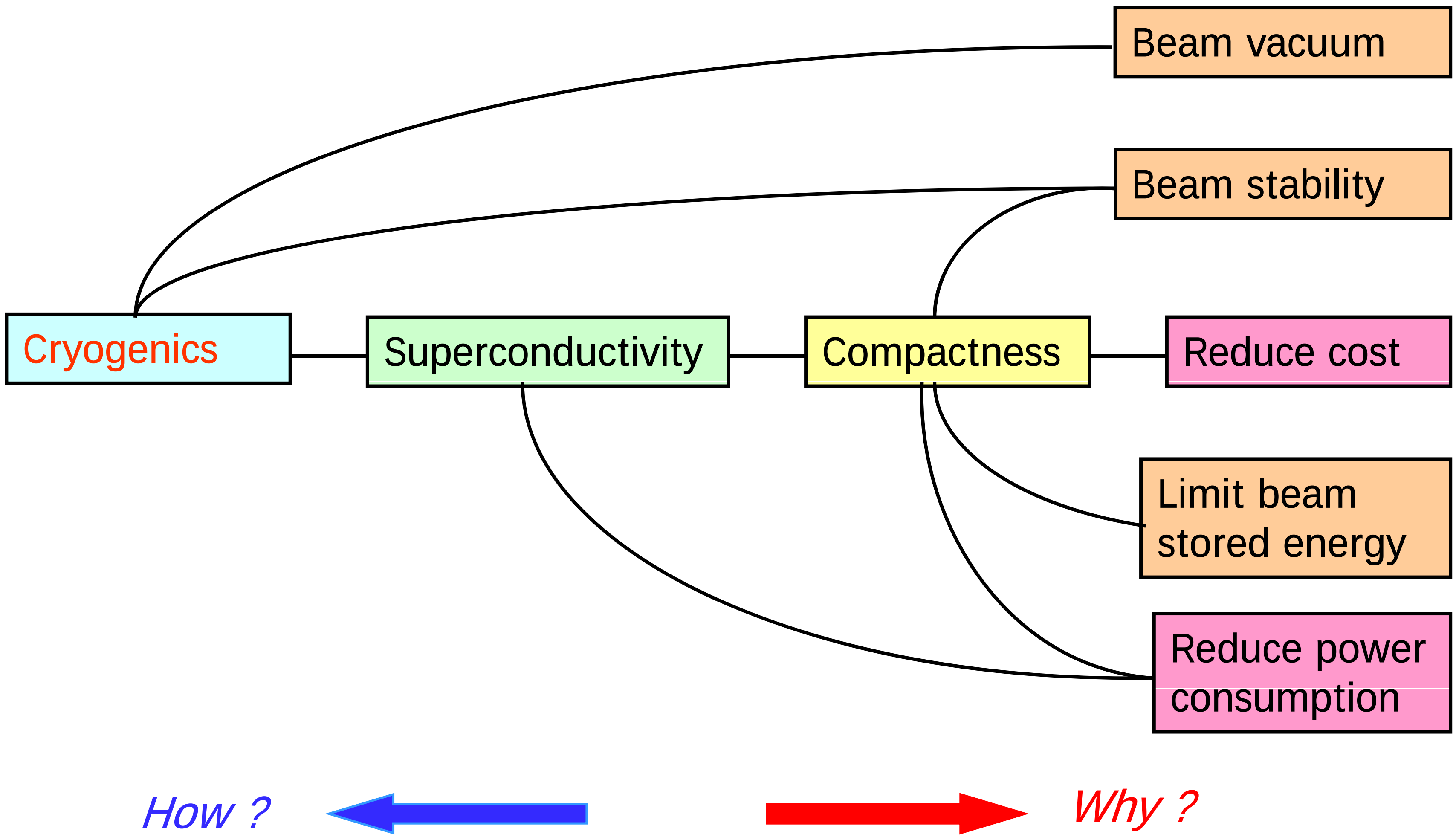
Role of cryogenics

- Compactness through higher fields
  - superconducting bending and focussing magnets for circular accelerators.
  - superconducting acceleration cavities for linear accelerators
- Reducing of specific project cost
- Saving energy
  - in electromagnets
  - In acceleration cavities
- Improvement of environment conditions
  - Cryogenic pumping
  - Low resistive wall in high intensity accelerators
  - Better transparency of particle spectrometers
  - Reduction of background noise in detectors
- Detection through calorimetry or tracking

Size & cost of CERN hadron colliders



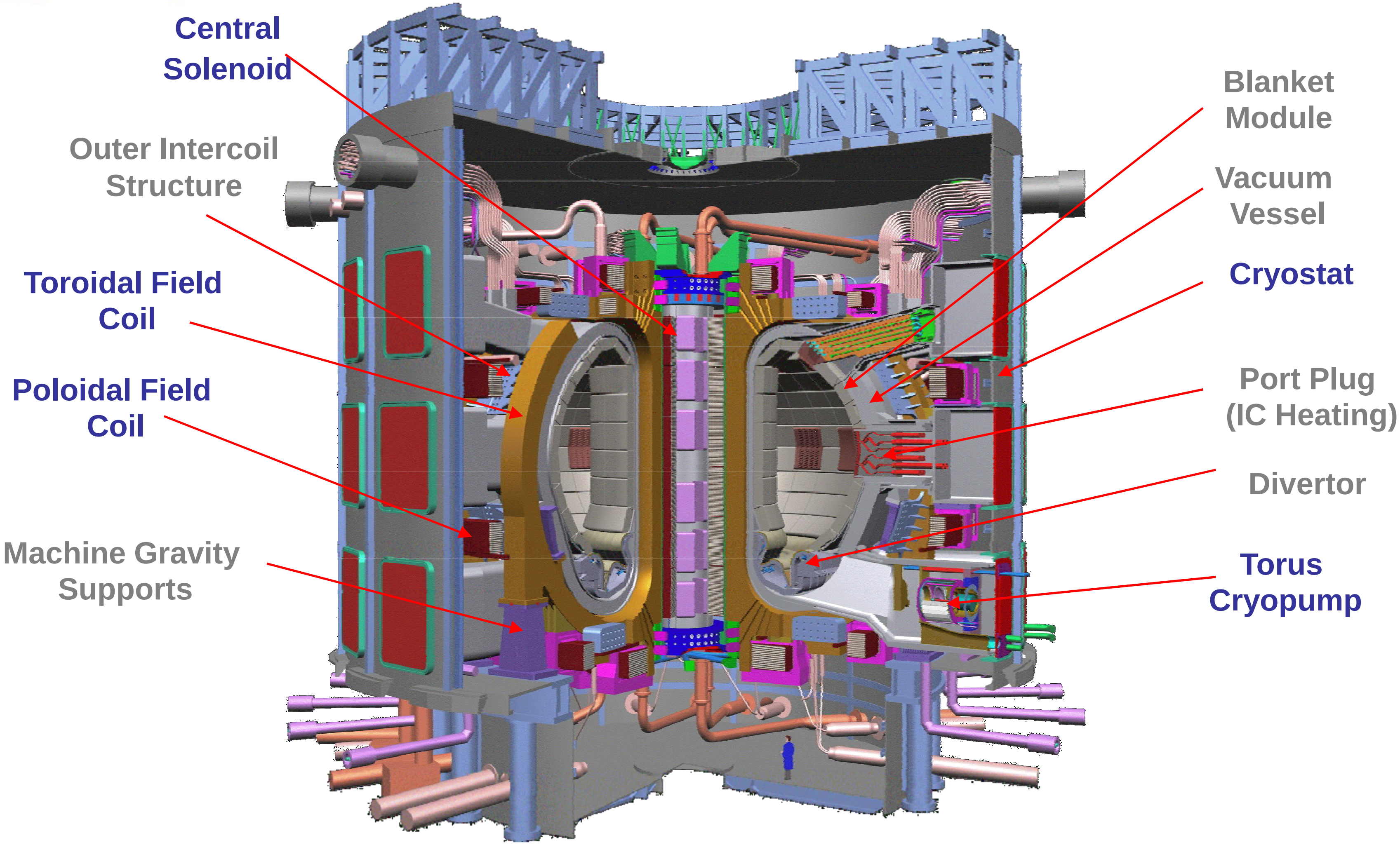
Rationale for superconductivity & cryogenics in particle accelerators



Contents

- The thermonuclear fusion research (ITER)

ITER layout



International Collaboration: Europe – Japan - Russia – Canada - USA – China

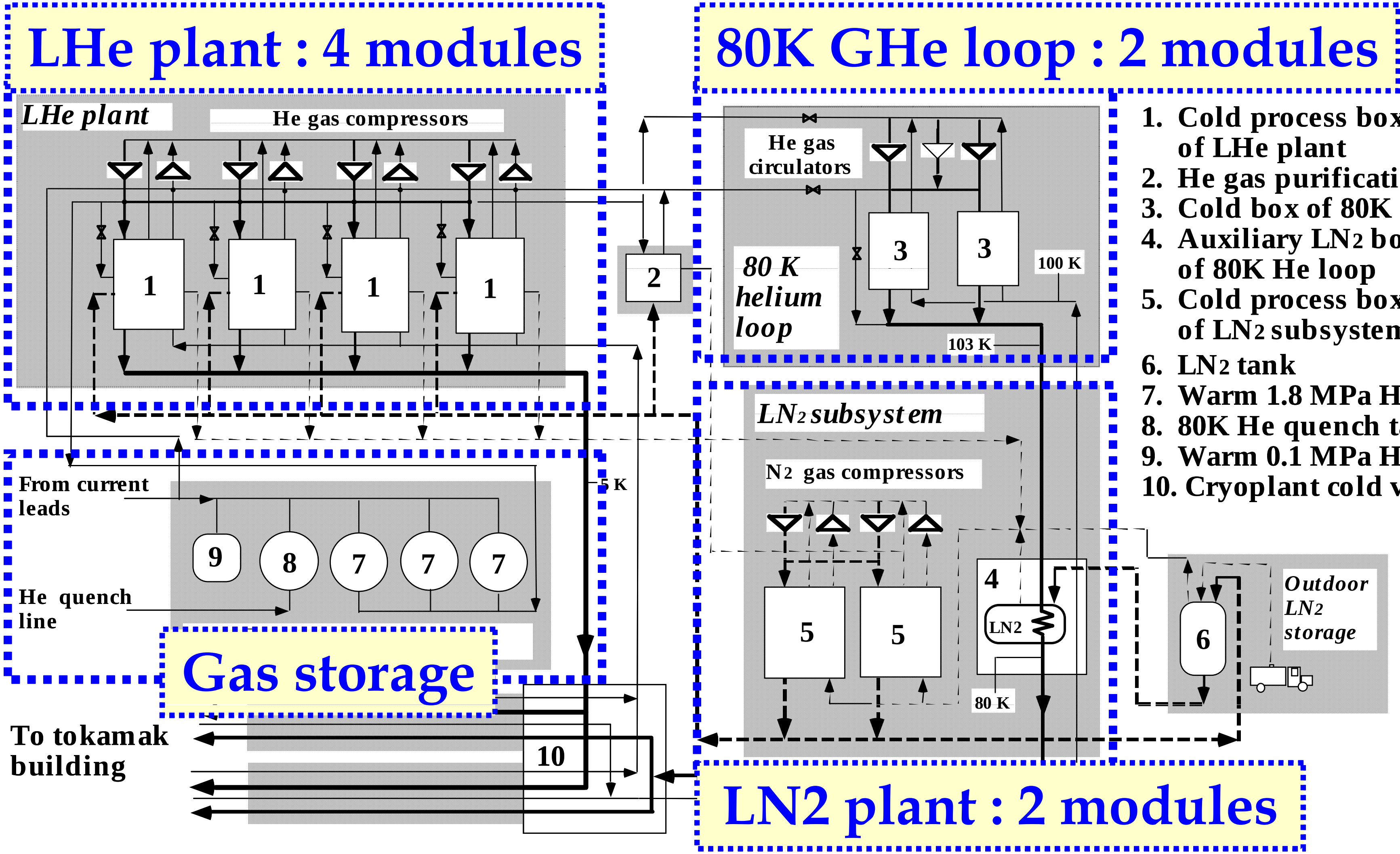
Cryogenic capacity & Thermal loads

- LHe cryoplants: 60 kW equivalent @ 4.5 K
  - Cooling of the superconducting magnet system (Toroidal and poloidal coils):
    - 31 kW @ 4.5 K including 13 kW of pulsed heat loads and 6 kW of cold pump heat loads.
  - Cooling of current leads:
    - 100 g/s of LHe liquefaction
  - Cooling of cryo-pumps with high regeneration frequency:
    - 4 kW @ 4.5 K and 60 g/s of LHe liquefaction

- LN2 cryoplants: 950 kW @ 80 K
  - Thermal shielding:
    - up to 830 kW @ 80 K during chamber baking
  - LHe cryoplant pre-cooling:
    - Up to 280 kW @ 80 K during normal operation

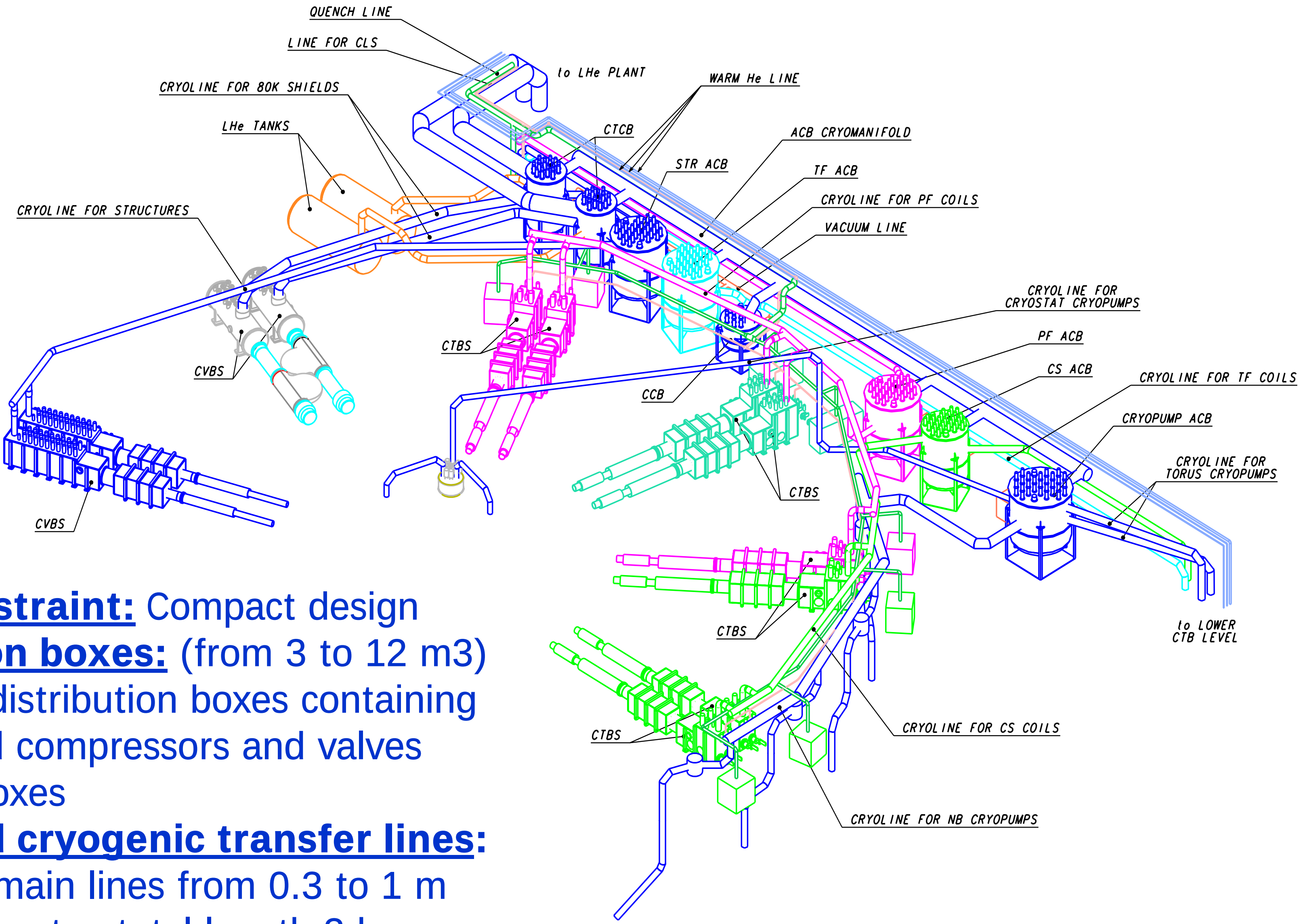
- Helium inventory: 20 t

Cryoplant architecture



1. Cold process box of LHe plant
2. He gas purification unit
3. Cold box of 80K He loop
4. Auxiliary LN_2 box of 80K He loop
5. Cold process box of LN_2 subsystem
6. LN_2 tank
7. Warm 1.8 MPa He vessel
8. 80K He quench tank
9. Warm 0.1 MPa He balloon
10. Cryoplant cold valve box

Cryogenic Distribution

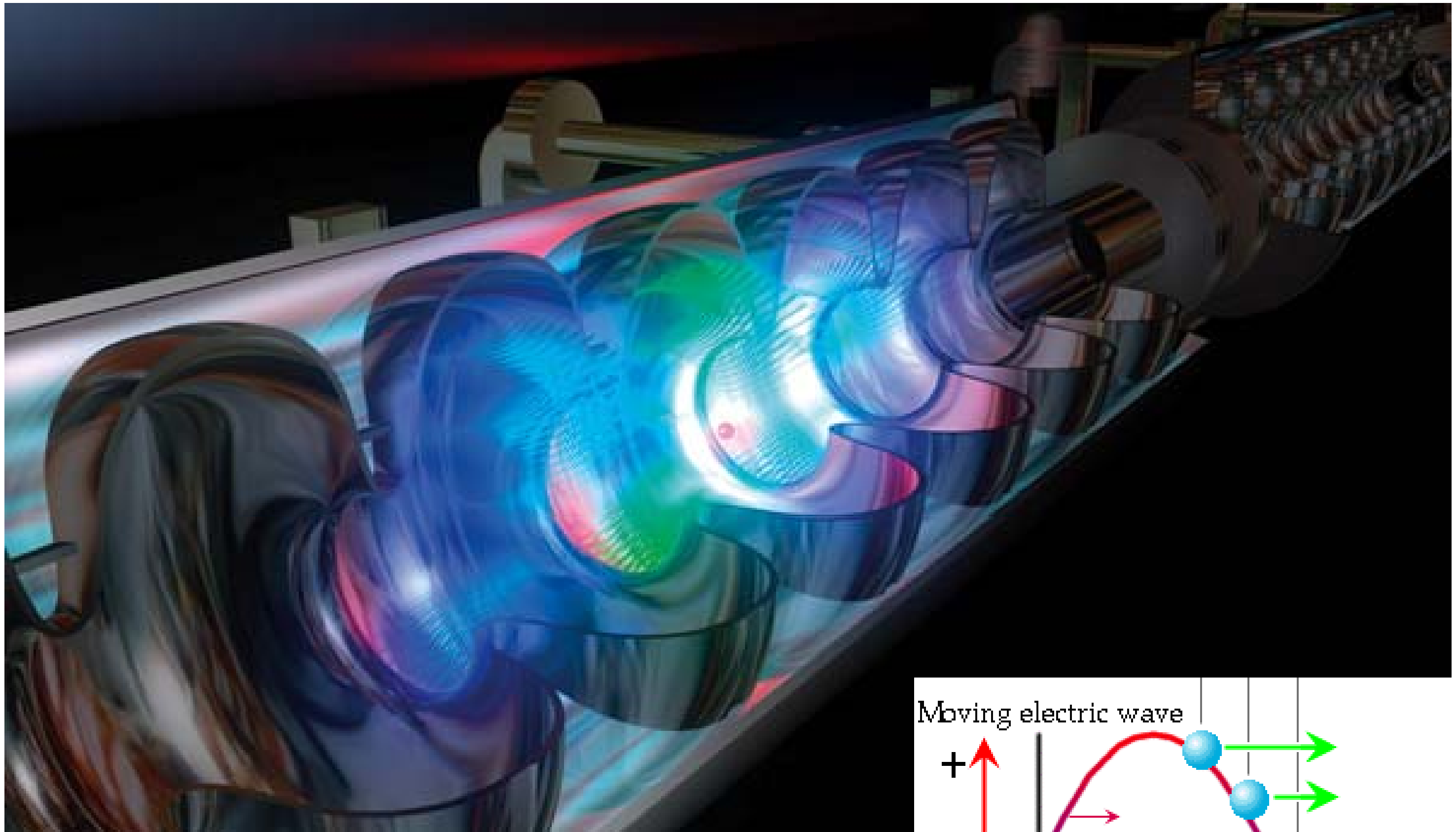


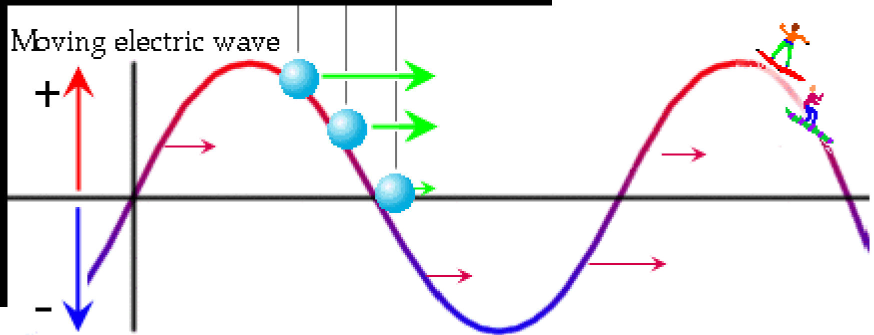
Space constraint: Compact design
Distribution boxes: (from 3 to 12 m3)
~ 10 main distribution boxes containing pumps, cold compressors and valves
~ 45 end boxes
Compound cryogenic transfer lines:
~ 10 to 12 main lines from 0.3 to 1 m external diameter, total length 3 km

Contents

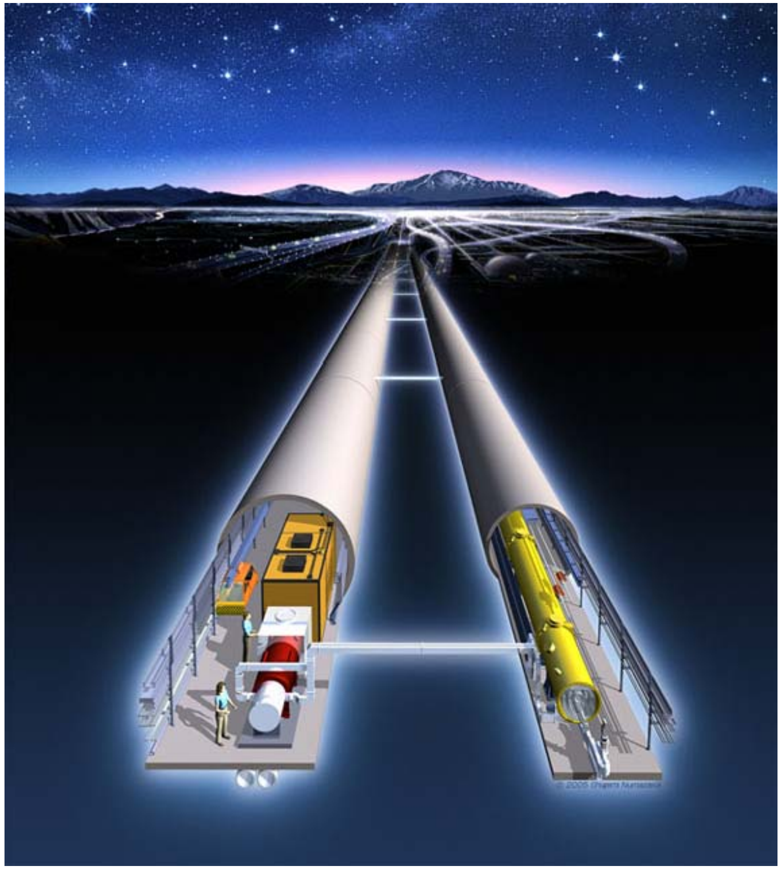
- Particle physics at the energy frontier (ILC, LHC upgrades)

Acceleration by electrical field in RF cavity





Positively charged particles ( ) close to the crest of the E-M wave experience the most force forward; those closer to the center experience less of a force. The result is that the particles tend to move together with the wave.



International Linear Collider study

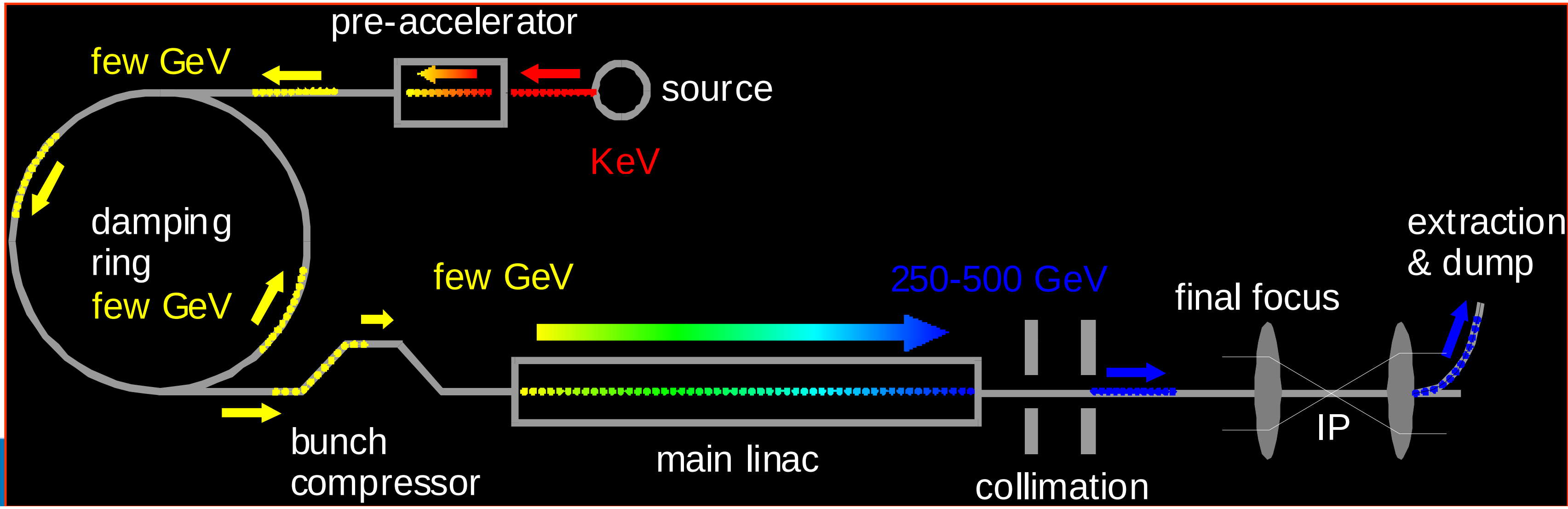
e+ e- linear collider

Collision energy 500 GeV c.m. initially, later upgrade to 1 TeV c.m.

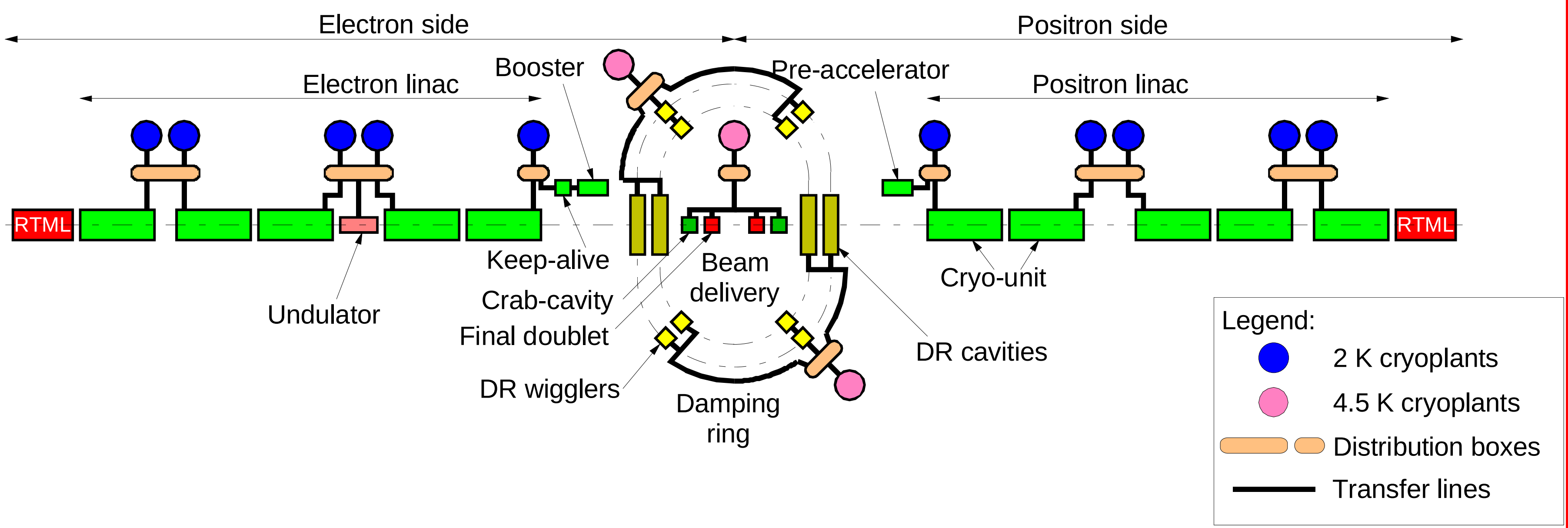
RF frequency 1.3 GHz, Gradient 31.5 – 36 MV/m

Overall length 47 km, of which 22 km linacs

Global Design Effort (GDE)
- No central laboratory
- World-wide collaboration
- Site-specific studies conducted on sample sites

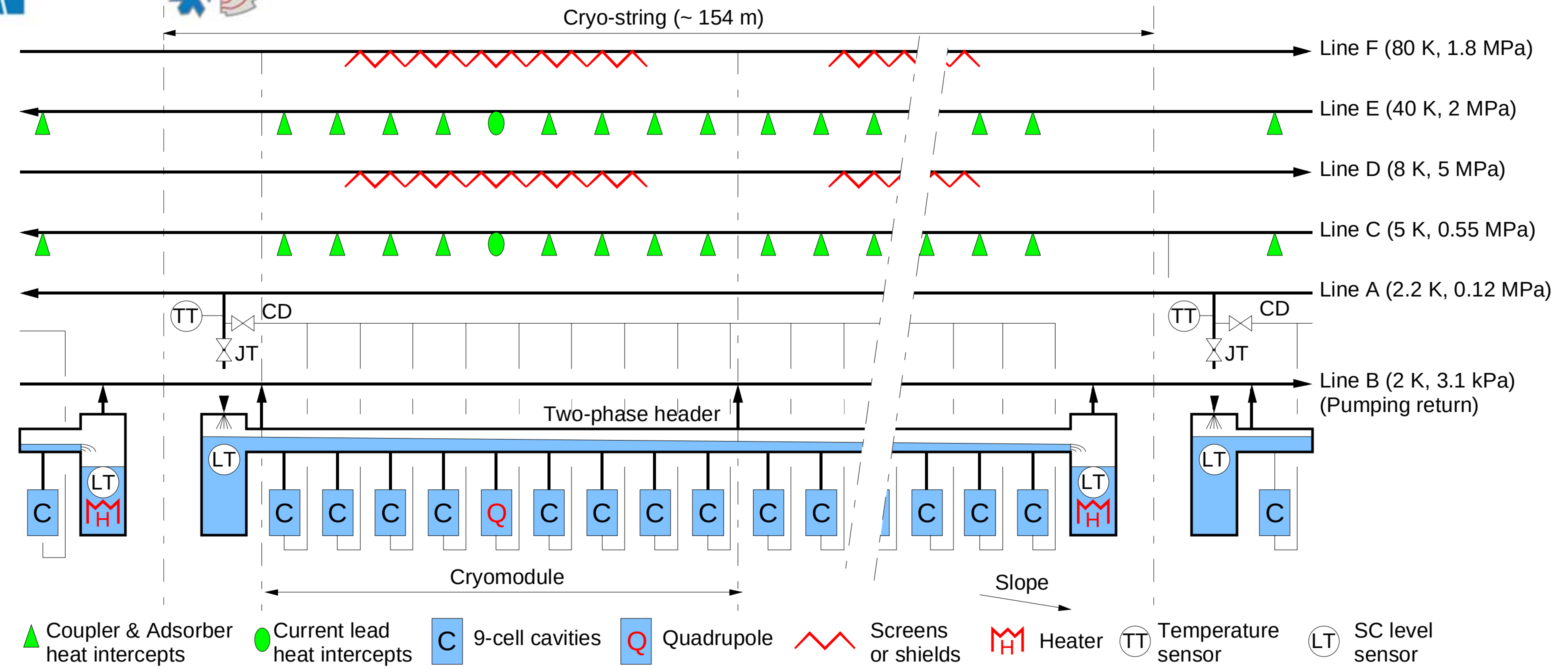


ILC cryogenic layout (Phase 1)



- Cryoplants: Ten 2 K cryoplants and three 4.5 K cryoplants
  - Total installed power: 211 kW @ 4.5 K including 37 kW @ 2 K
  - Size of largest plants: 20 kW @ 4.5 K including 3.7 kW @ 2 K
- Distribution
  - 26 distribution boxes and 132 string feed boxes
  - 10 km of compound transfer lines
- Inventory: ~100 t of helium

ILC cooling scheme and cryomodule



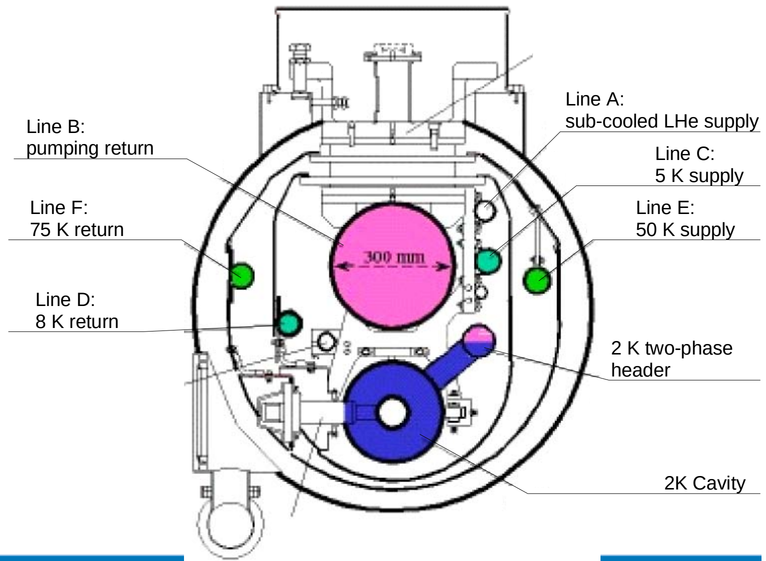
Cavity in saturated bath of superfluid helium at 2 K

192 cryomodules per cryo-unit

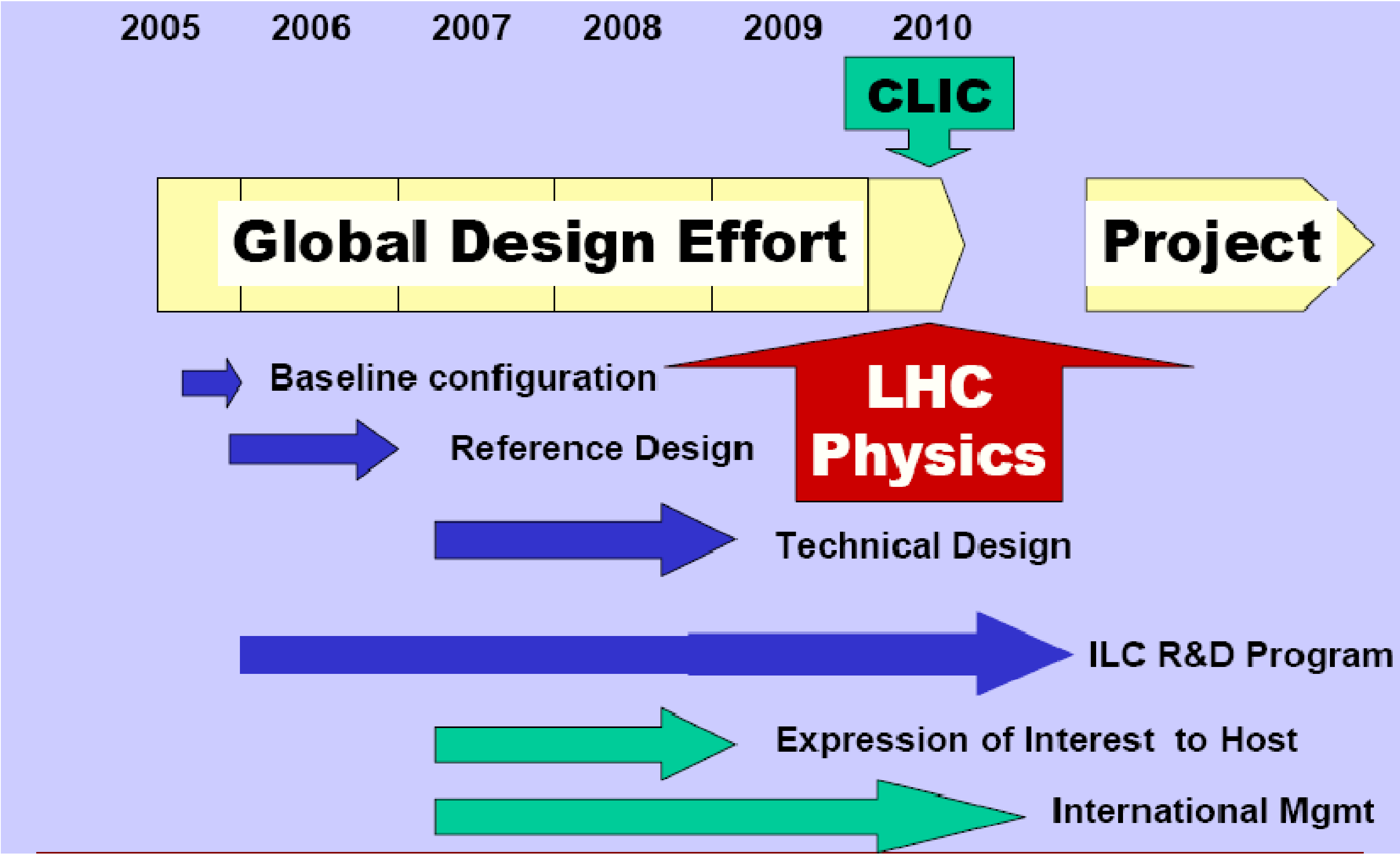
Length of cryo-string 154 m

Length of cryo-unit 2.5 km

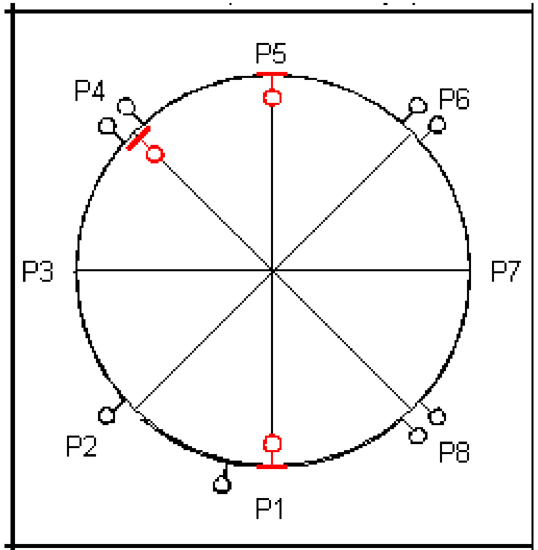
All piping included in cryomodule



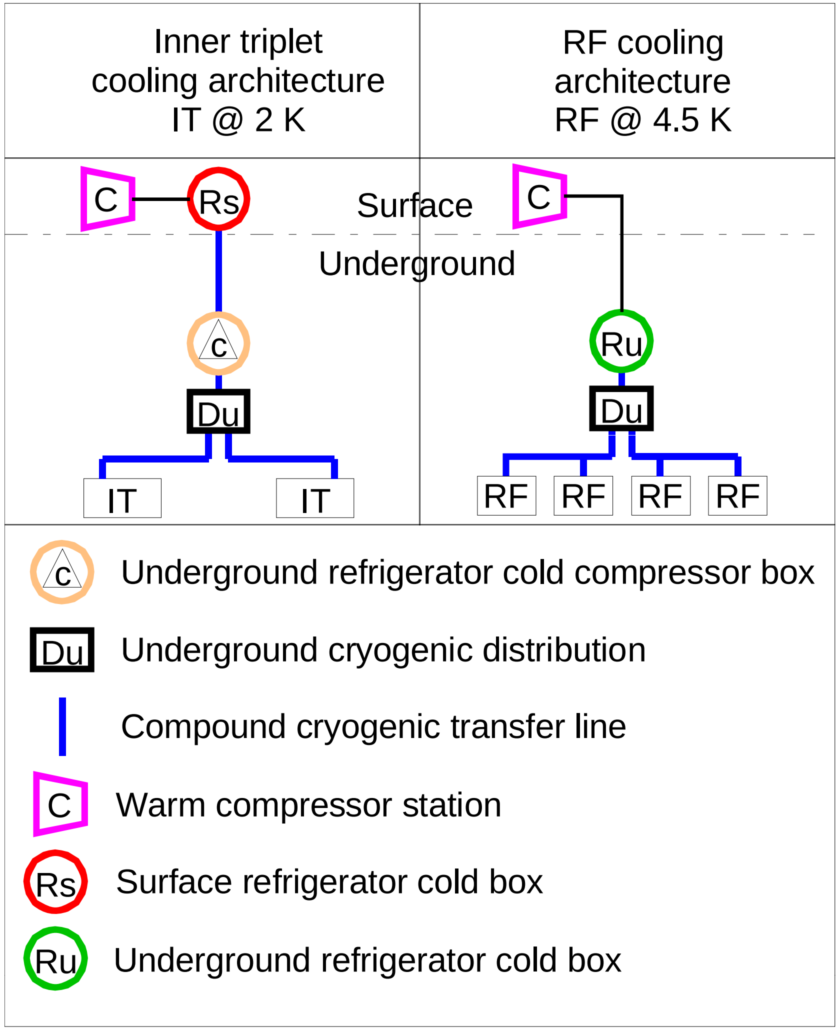
ILC tentative schedule



LHC luminosity upgrade study



Layout 4:
Baseline + separate RF & IT cryoplants

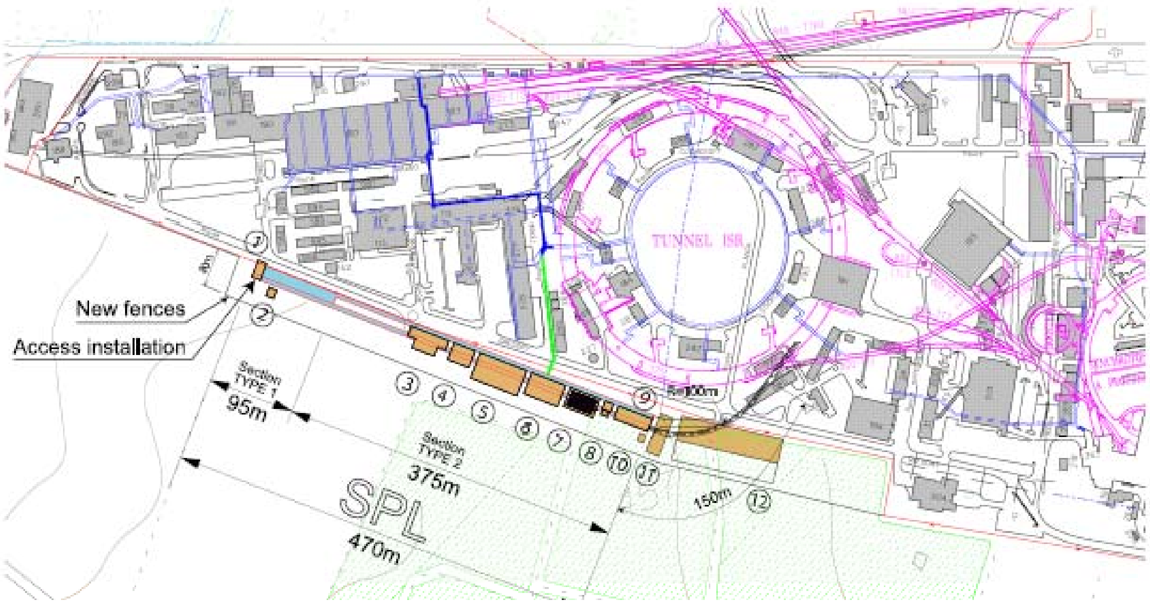


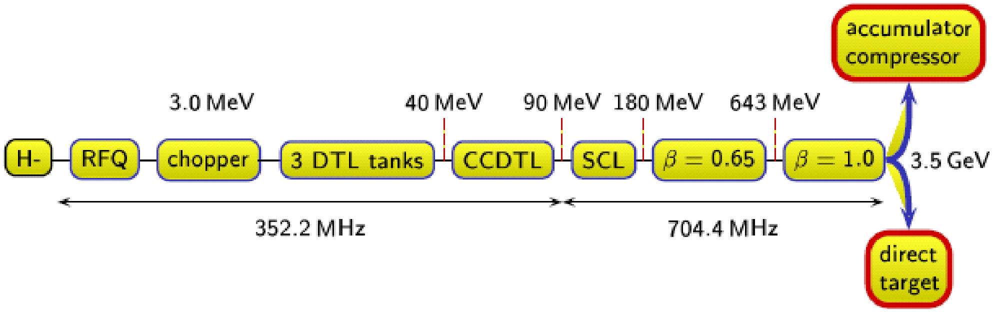
- Cryoplants: Two 2 K cryoplants and one 4.5 K cryoplant
  - Total installed power: 39 kW @ 4.5 K including 10 kW @ 2 K
  - Size of largest plants: 16 kW @ 4.5 K including 5 kW @ 2 K
- Distribution
  - 3 distribution boxes and 500 m of compound transfer lines

Contents

- High-intensity proton linacs (SPL, EURISOL, IFMIF)

SPL planned at CERN





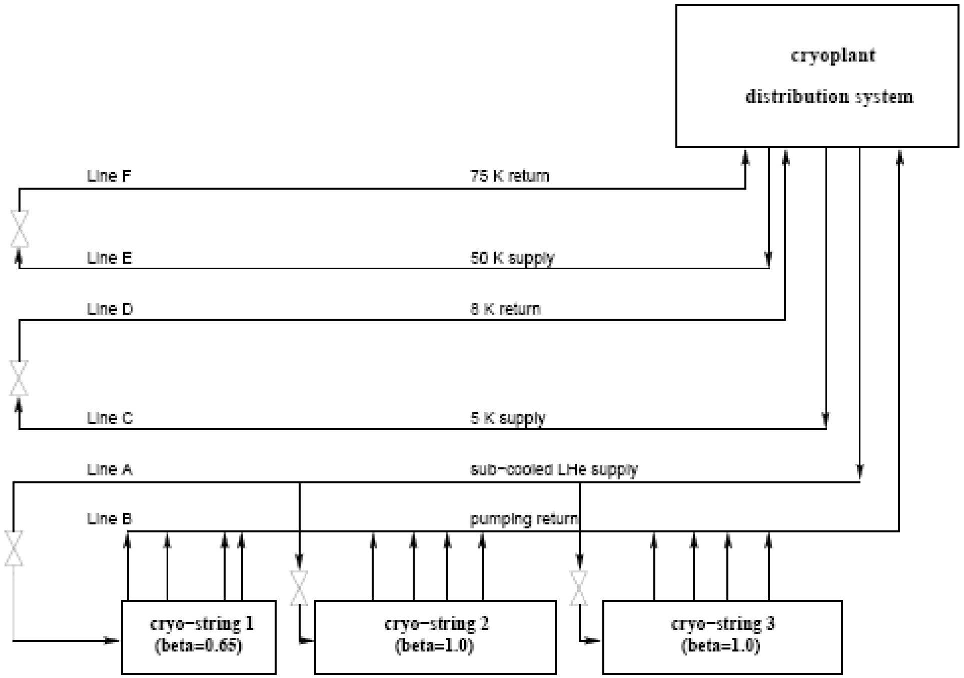
- High-intensity proton linac
- Beam energy 3.5 GeV
- Beam power 5 MW
- Overall length 430 m
- Length of SC linac 340 m
- 178 Nb sc cavities
- RF frequency 704 MHz
- Gradient 19 – 25 MV/m
- Operating temperature 2 K

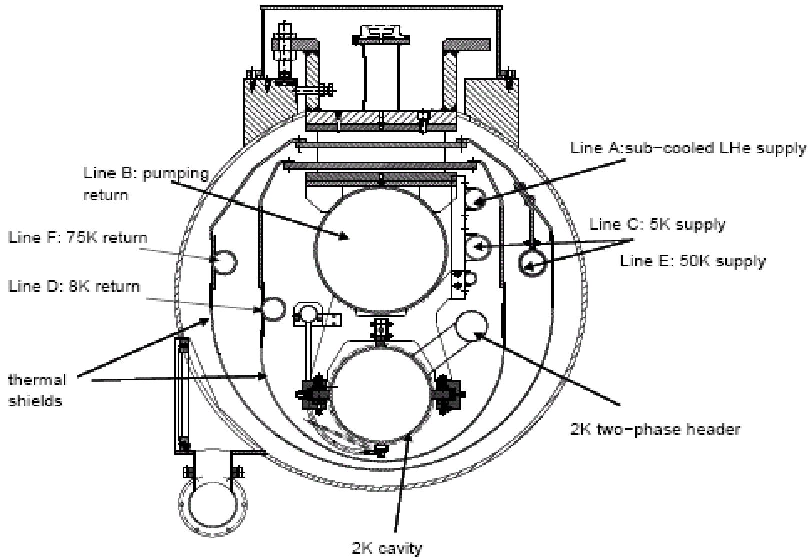
SPL refrigeration and cooling scheme

24 cryomodules housing 6 or 8 cavities each, in 128 m long strings

Operation in static saturated superfluid helium

Refrigeration: 15.8 kW @ 4.5 K including 4.5 kW @ 2 K

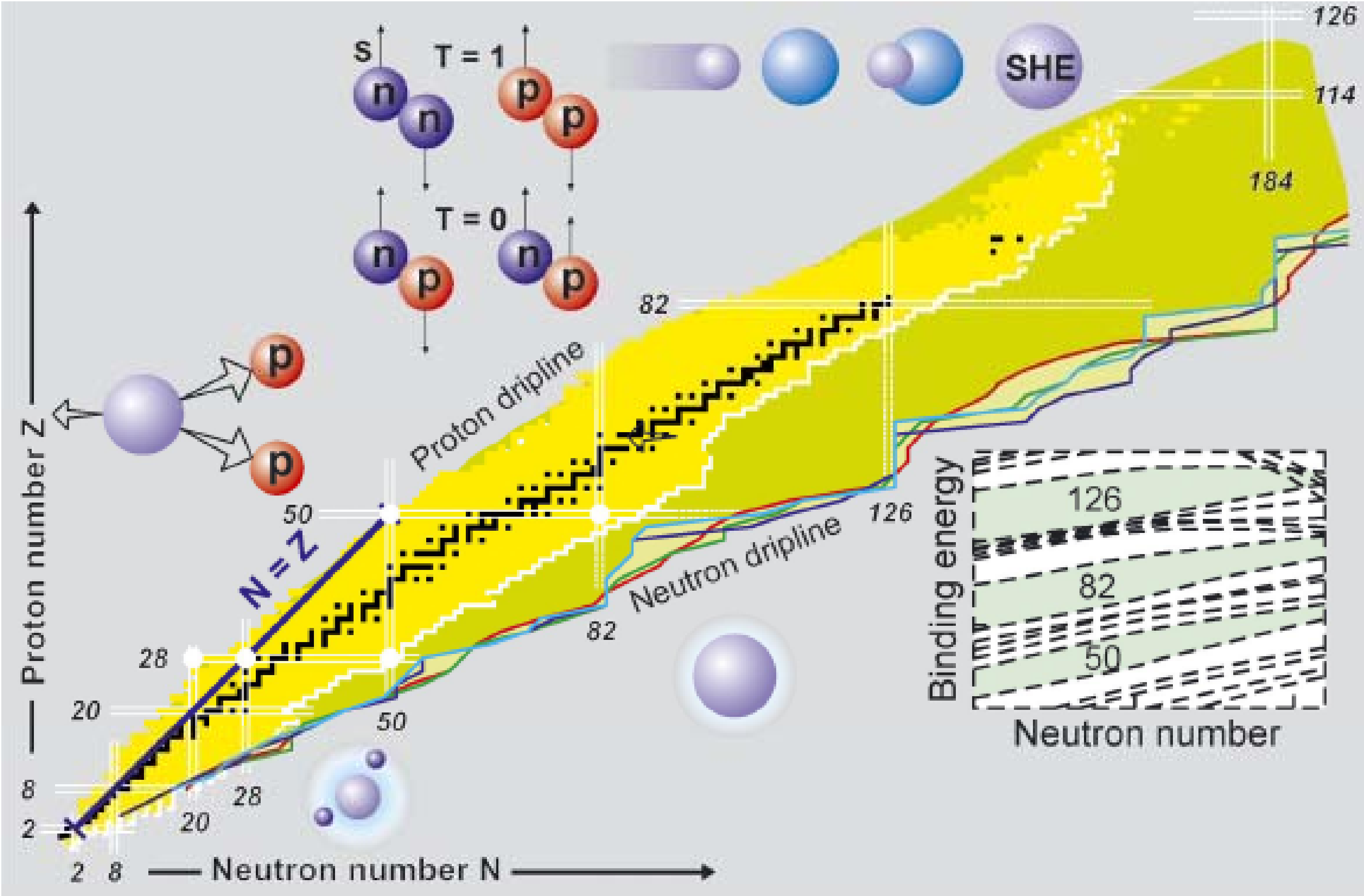




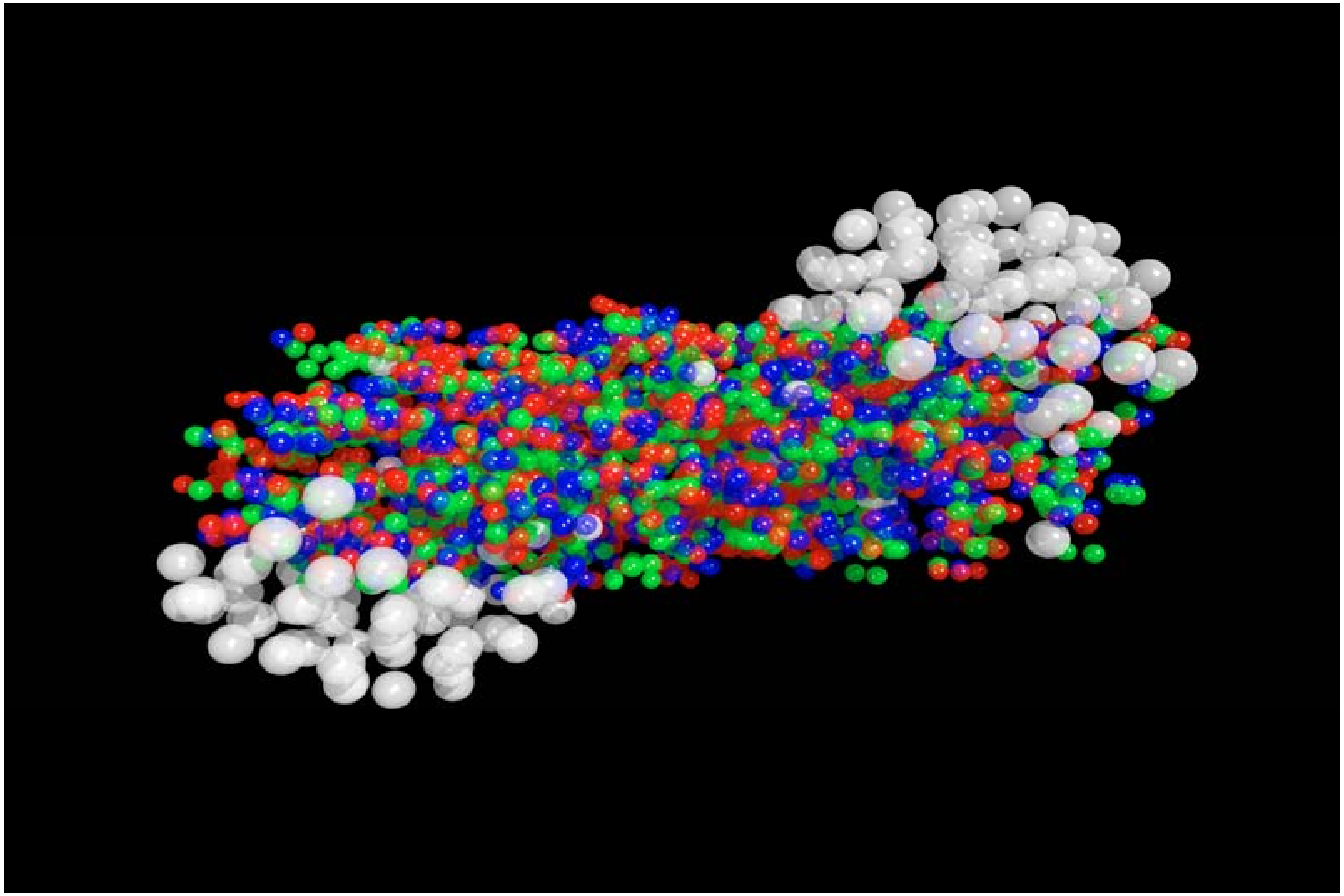
Contents

- Nuclear physics with protons, antiprotons and ions (FAIR)

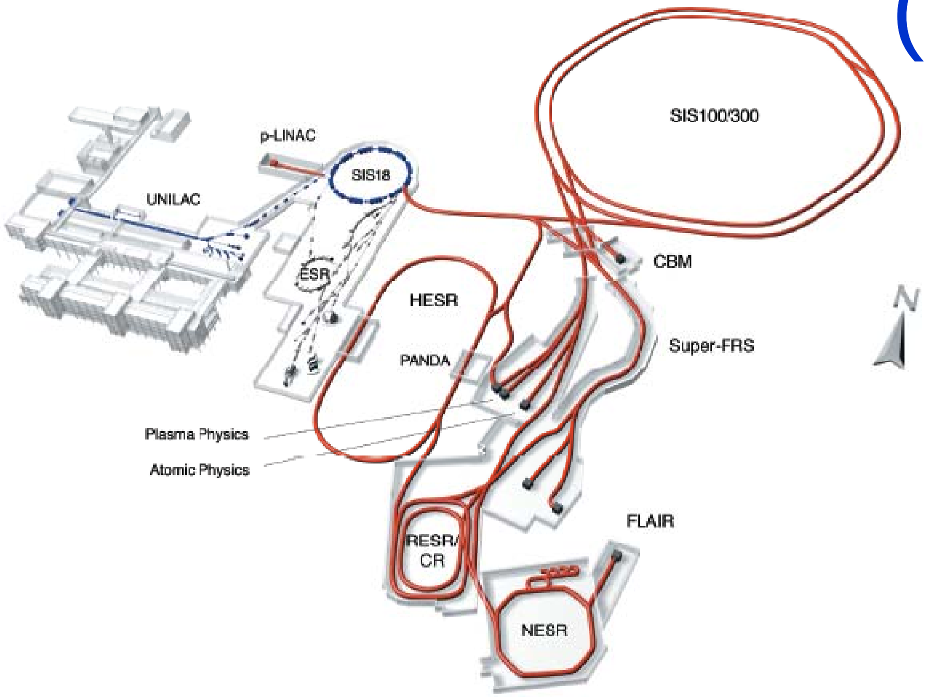
Exploring the confines of the valley of stability

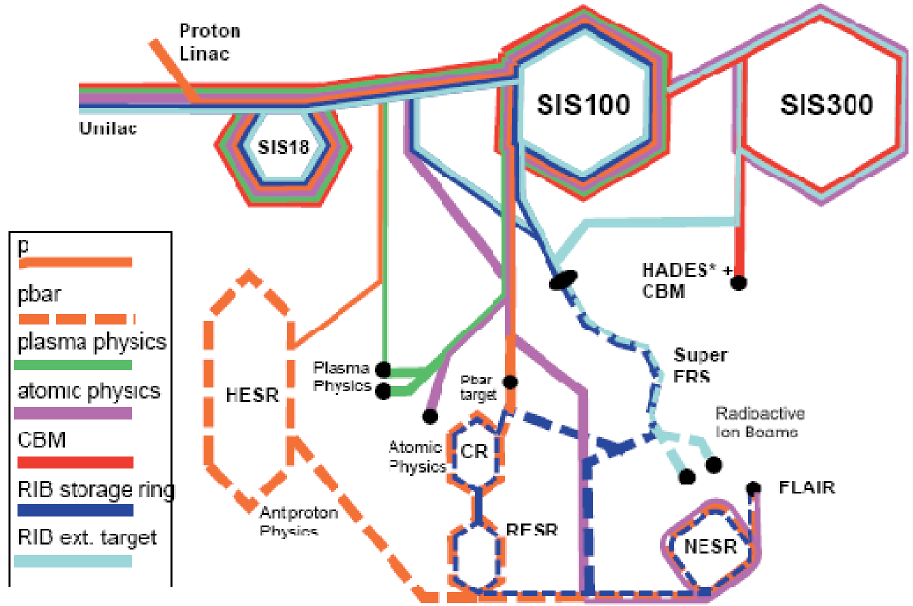


Quark-gluon plasma formation in collision of lead ions



FAIR at GSI, Darmstadt (Germany)





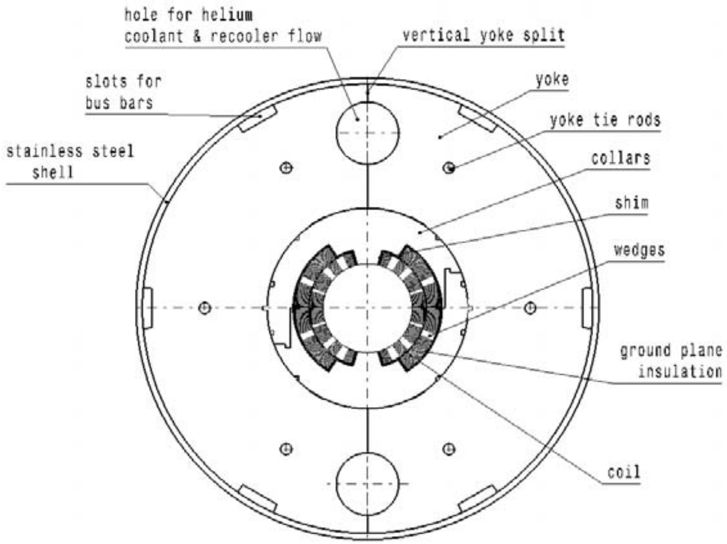
Subproject	Numbers of sc magnets
SIS 100	449
SIS 300	444
HEBT	187
SuperFRS	180
CR	48
HESR	320
MTF	2*

Facility for Antiproton & Ion Research

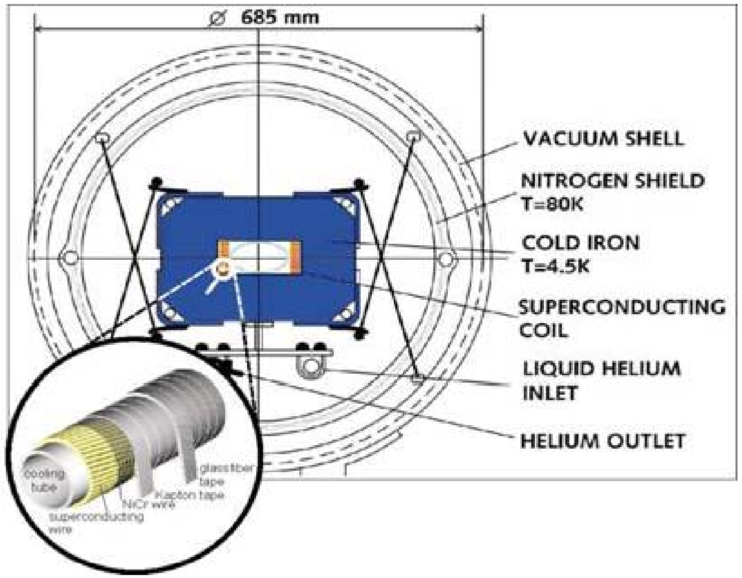
Complex of synchrotrons and storage rings using superconducting magnets

Production: up to 2012
Installation and commissioning: 2011 to 2013
Operation: from 2012

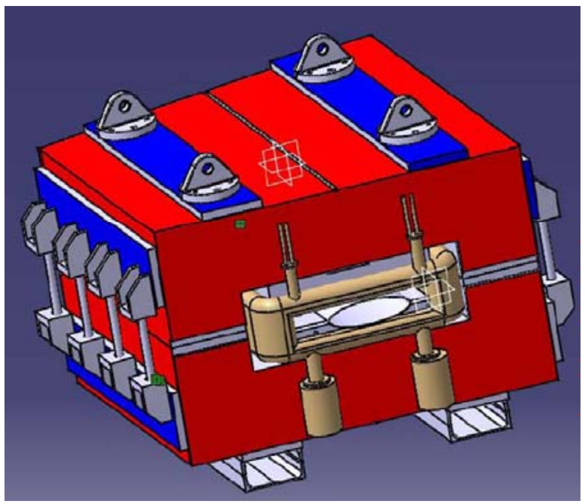
FAIR superconducting magnets



Pulsed SC magnets (444) for SIS300
(Supercritical forced flow cooling)



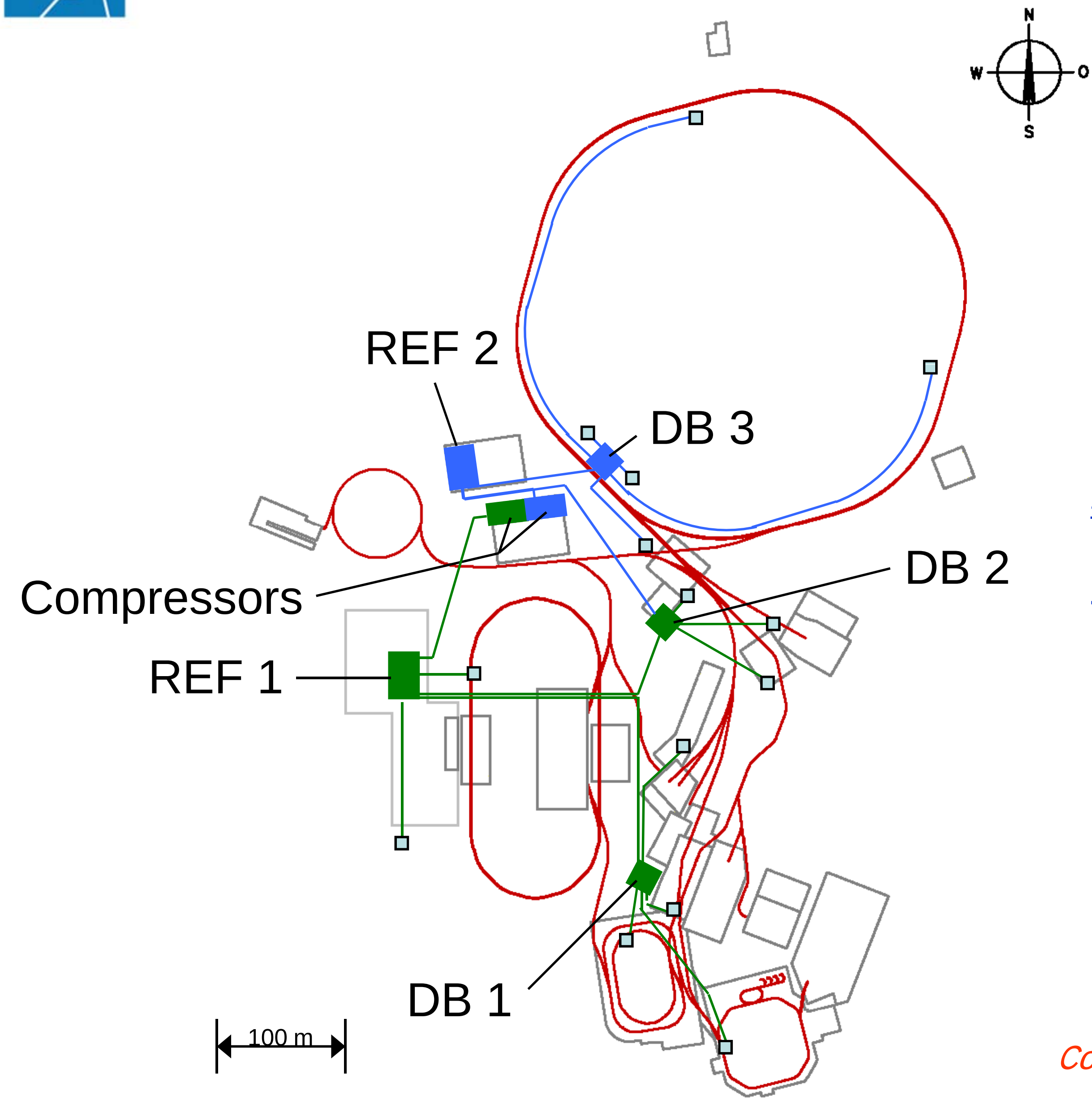
Pulsed SC magnets (449) for SIS100
(two-phase cooling)



SC magnets (228) for
Super-FRS and CR
(bath cooled or supercritical
forced flow cooling)

Courtesy G. Moritz & M. Kauschke

FAIR cryogenic system



Refrigeration @ 4.4 K

Heat load: 27.8 kW
Design capacity: 41.7 kW

Length of transfer lines: 1.7 km
# of distribution boxes: 3

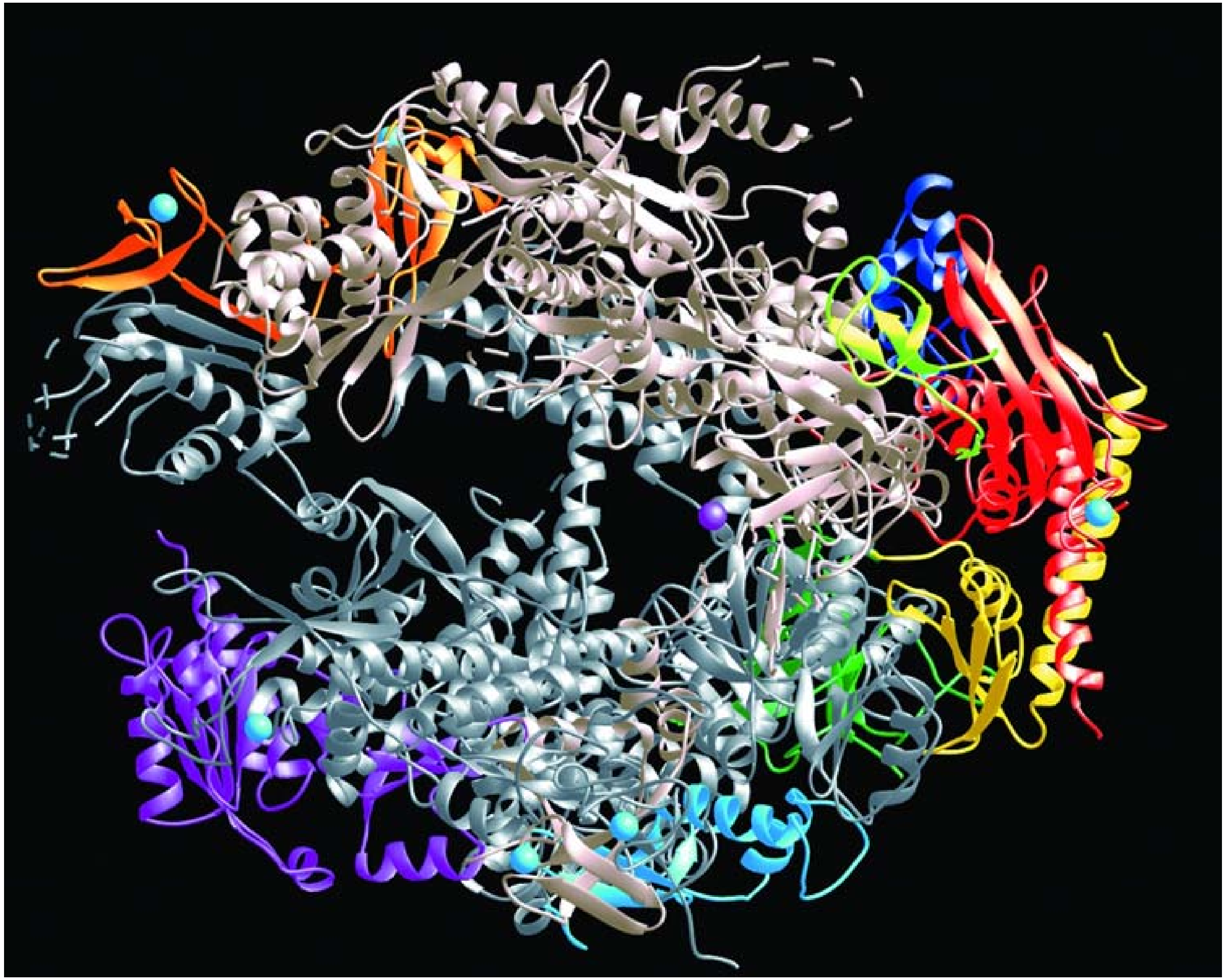
Total helium inventory: 11 t

Courtesy G. Moritz & M. Kauschke

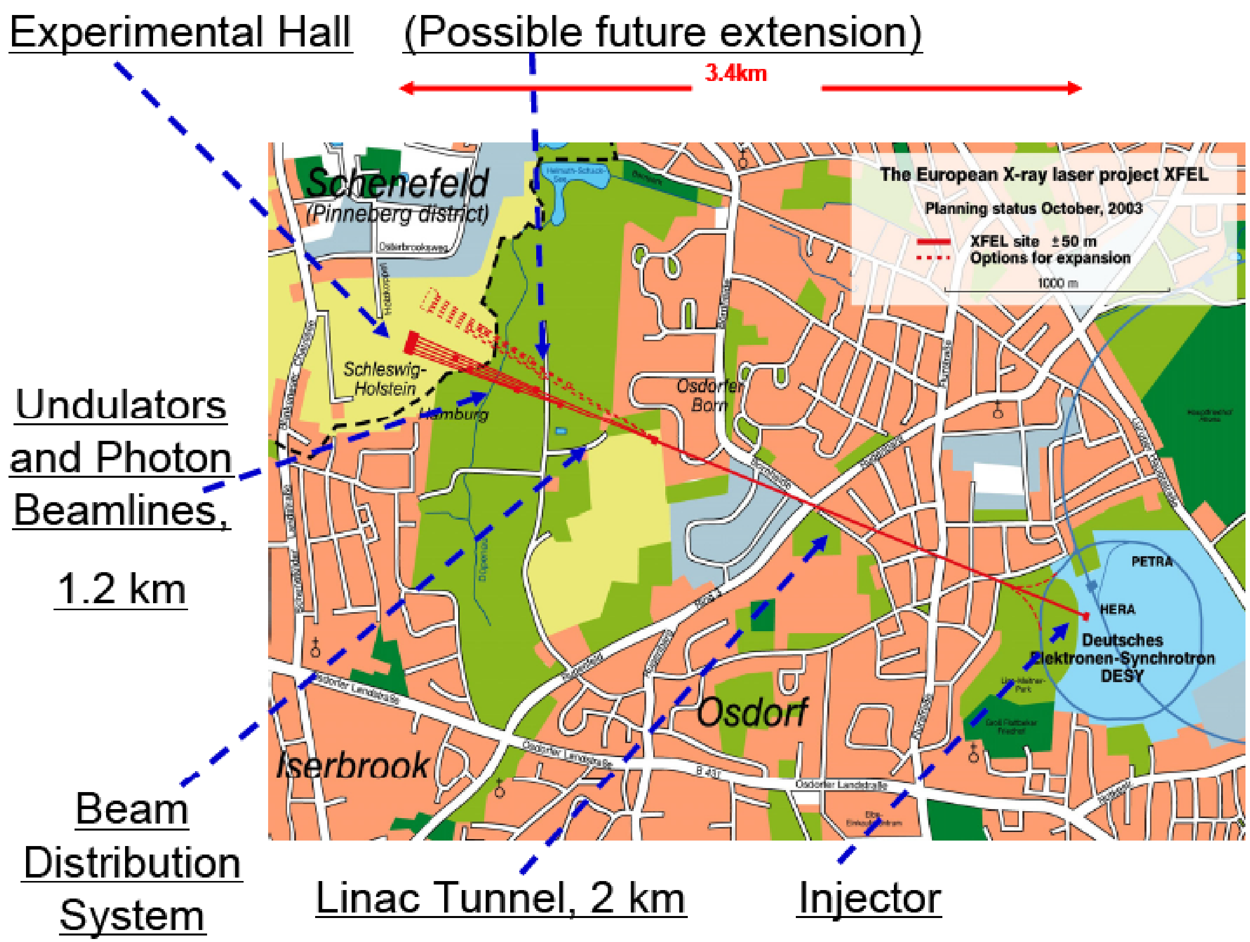
Contents

- Ultra-fast, intense X-rays to probe condensed matter (the European X-ray FEL and ERLs)

Protein structure imaged by X-ray scattering



European X-ray FEL, DESY, Hamburg (Germany)



Very brilliant, ultra-short (100 fs) pulses of X-rays down to 0.1 nm

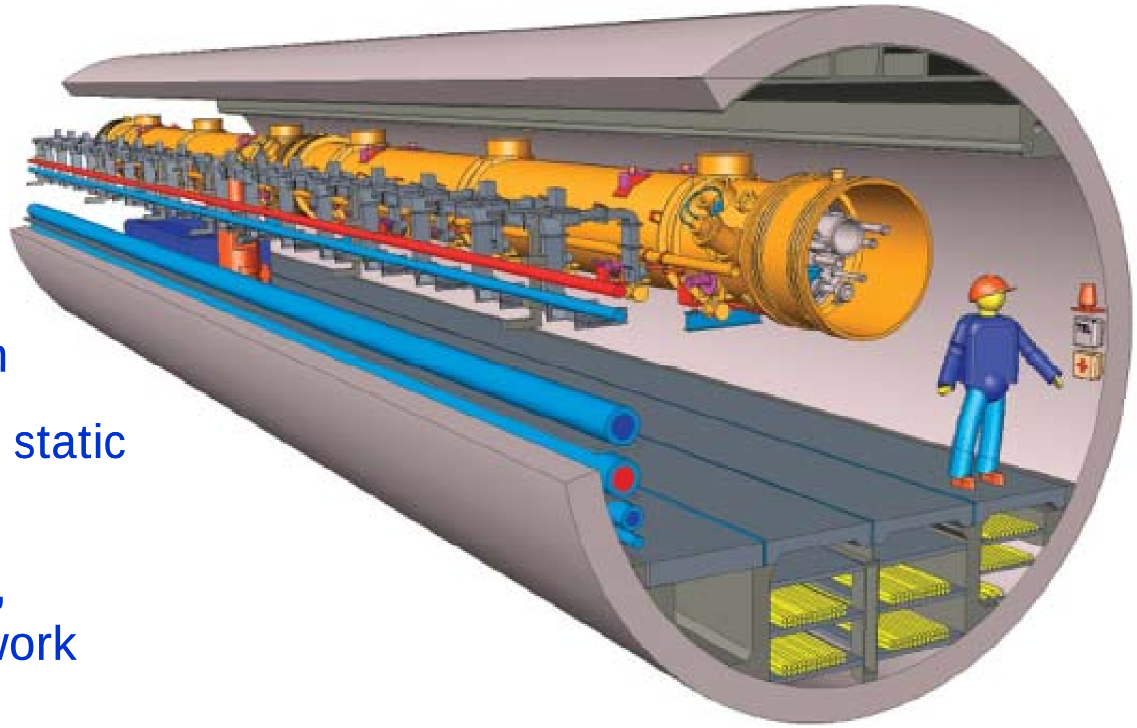
Based on s.c. e linac

Beam energy 17.5 GeV

Beam power 600 kW

Linac length 1.7 km

928 Nb superconducting cavities @ 1.3 GHz



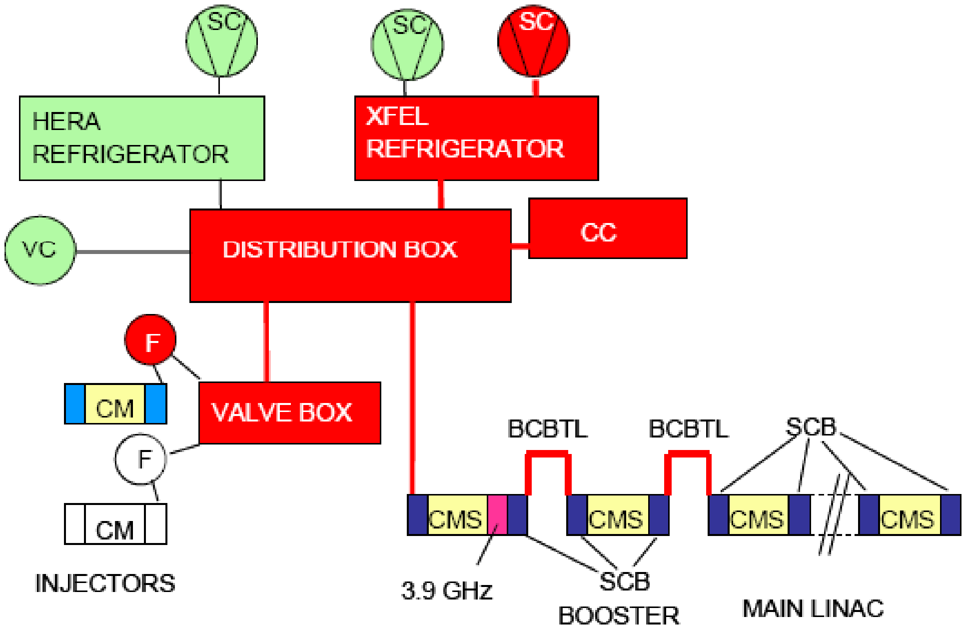
Operating gradient 23.6 MV/m

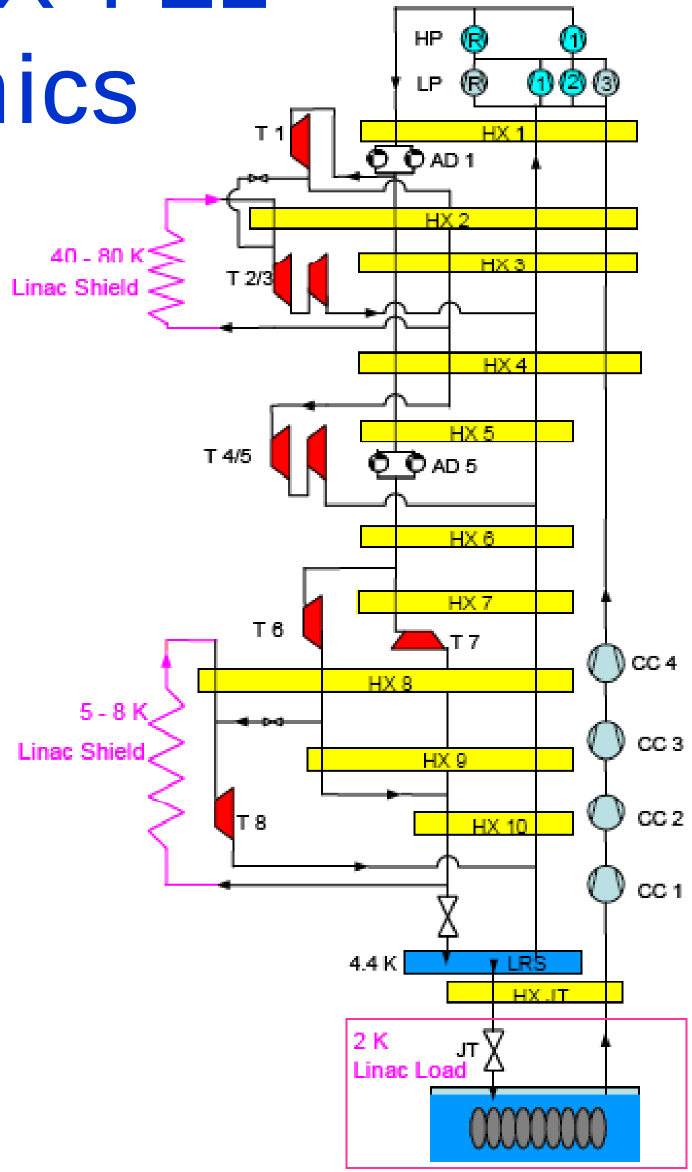
Operating temperature 2 K, in static saturated superfluid helium

116 cryomodules 12.2 m long, integrating all cryogenic pipework

Length of cryo string 146 m

European X-FEL cryogenics



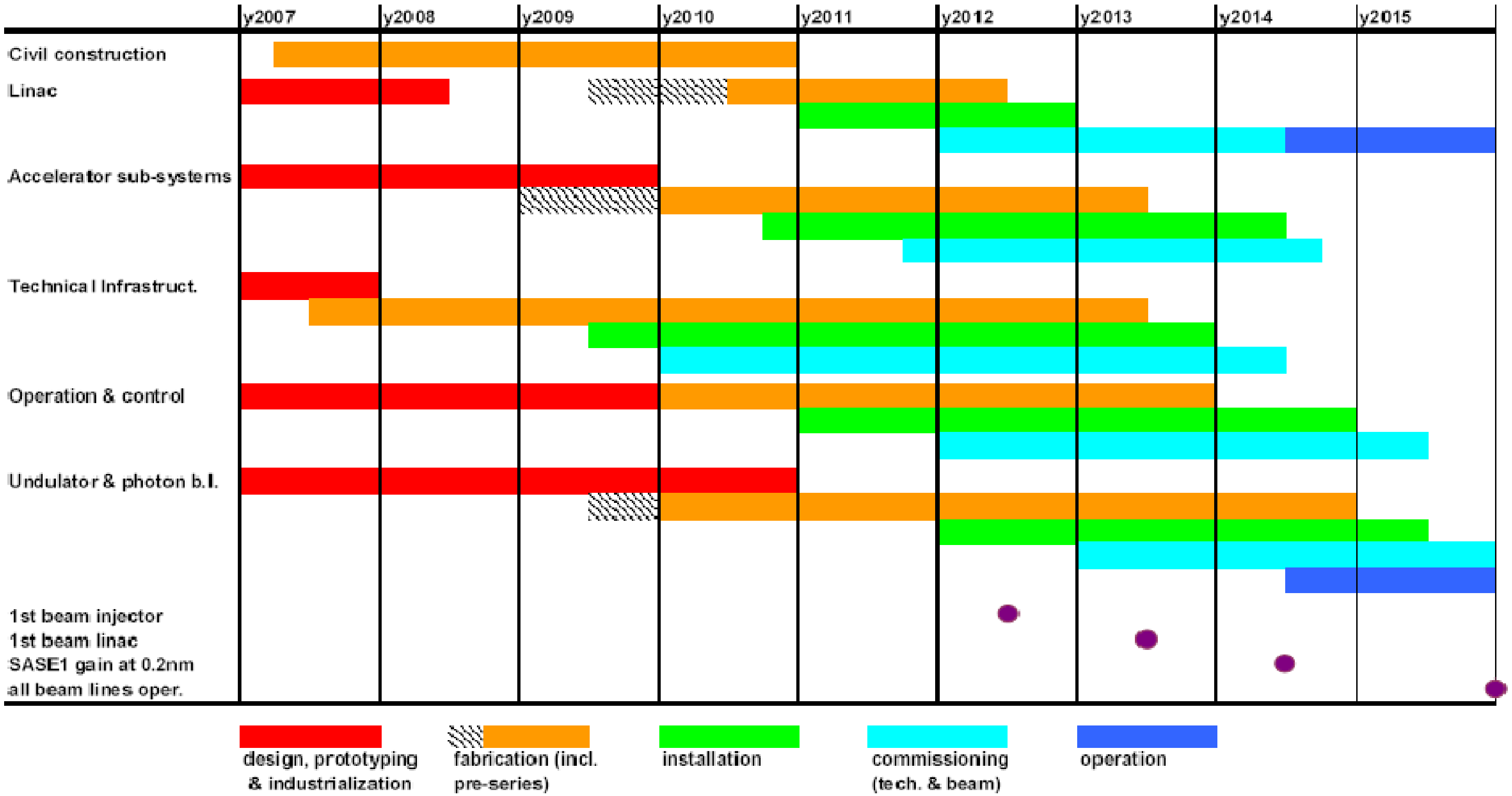


Refrigerator 12 kW @ 4.4 K equivalent power

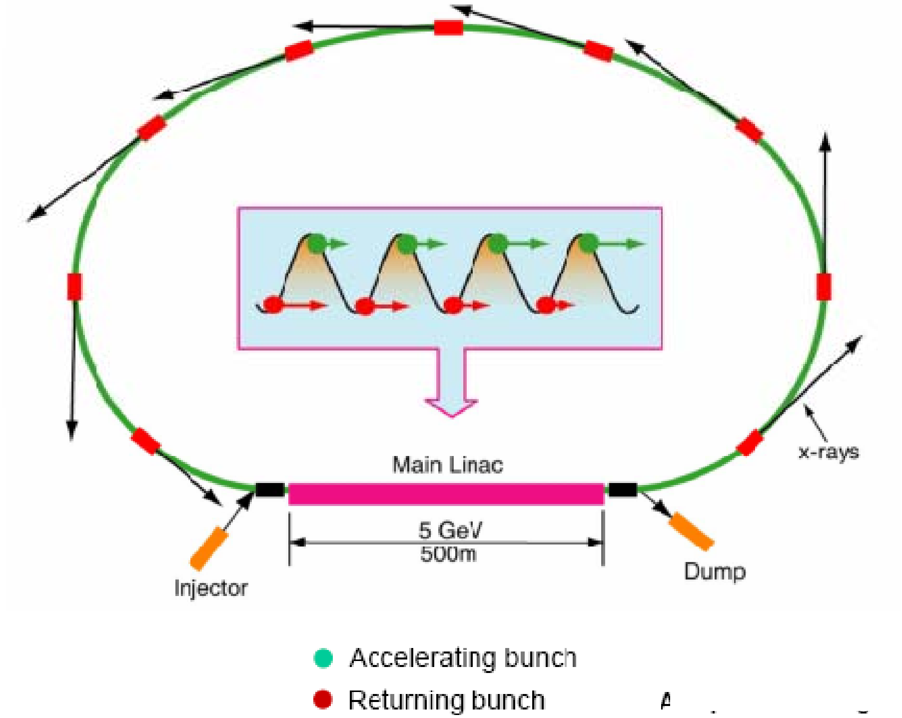
Including 2.45 kW @ 2 K for linac load

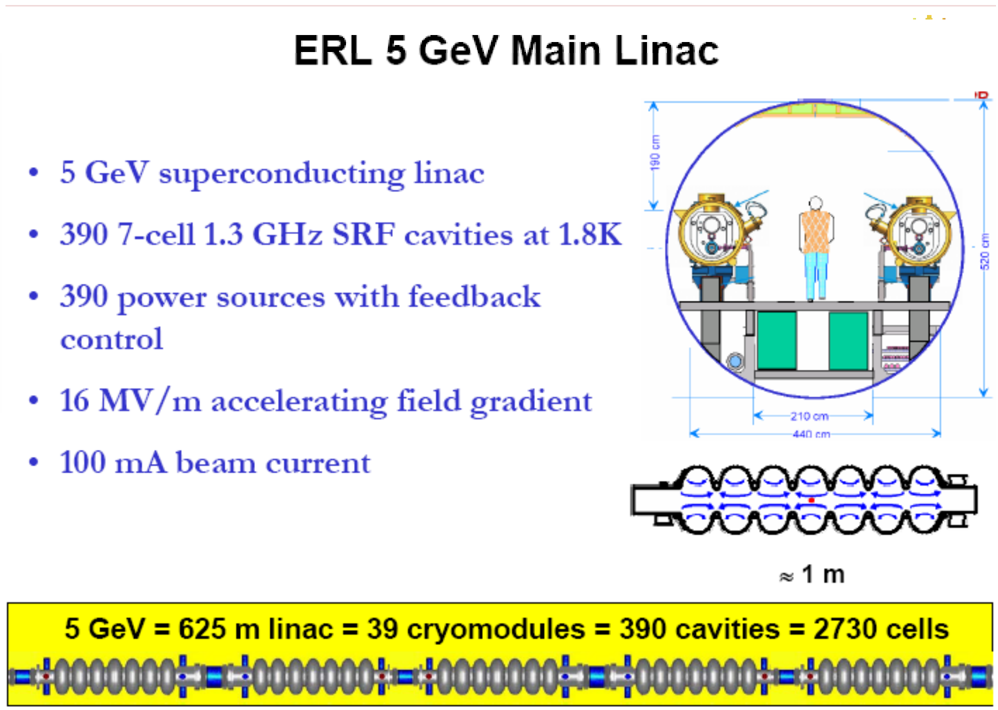
Reuse of HERA refrigerator as backup

European X-FEL schedule



Energy recovery linac (ERL), Cornell (USA)



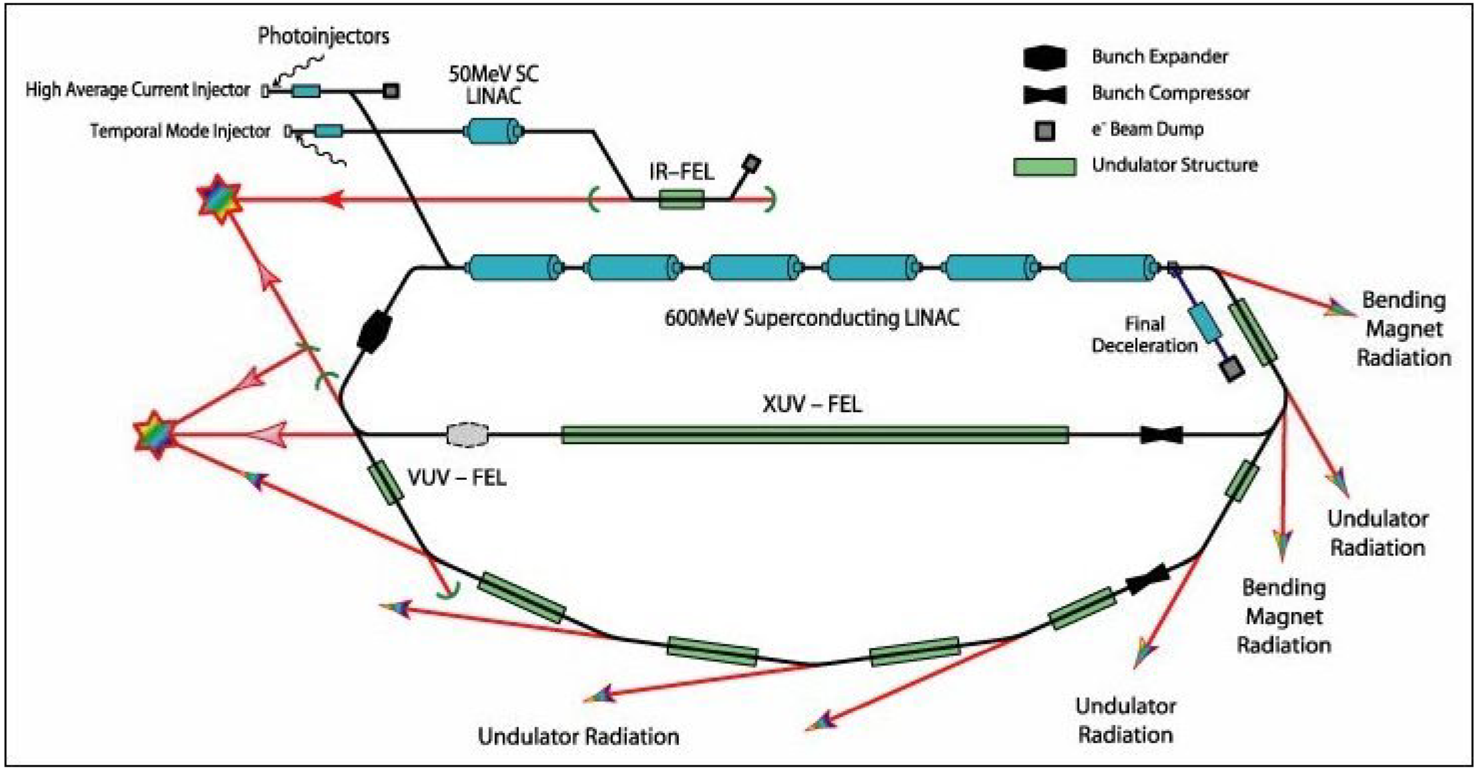


Operated in saturated superfluid helium

Refrigeration power: 40 kW equivalent @ 4.5 K including 10 kW @ 1.8 K

Helium inventory: ~ 5 t of helium

G4LS ERL/FEL at Daresbury (UK)



102 Nb superconducting cavities @ 1.3 GHz with gradients up to 15.5 MV/m

Operated in saturated superfluid helium

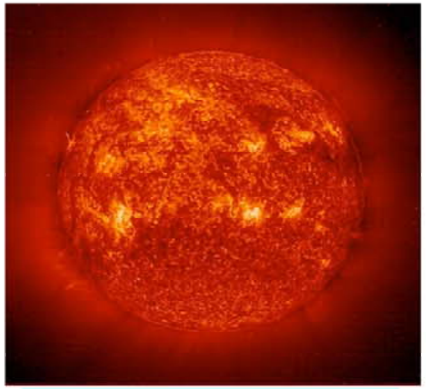
Refrigeration power needed ~ 14 kW equivalent @ 4.5 K including 3.5 kW @ 1.8 K

Contents

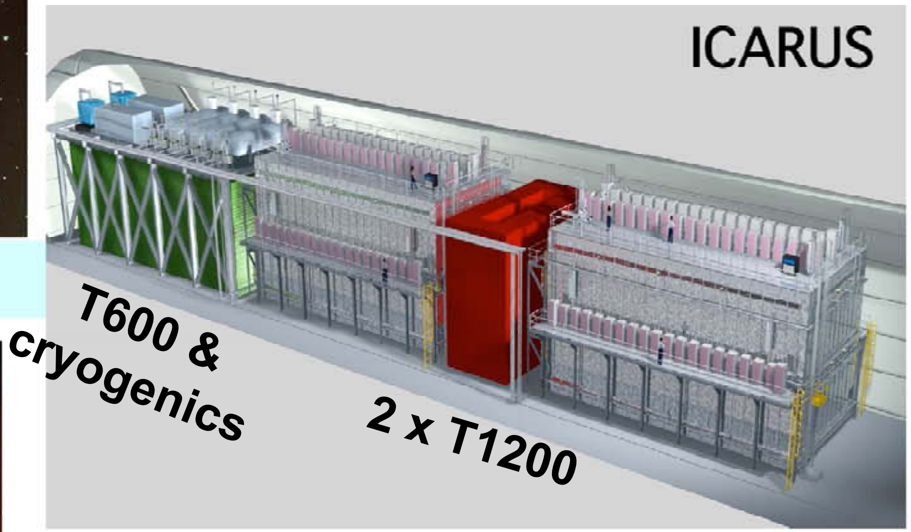
- Cosmic and rare underground signals (ICARUS)

ICARUS physics program

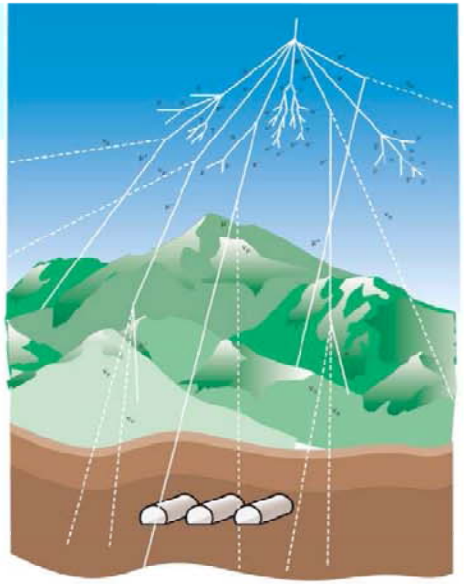
Supernova neutrinos



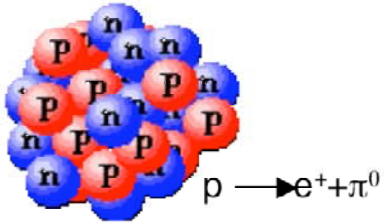
Solar neutrinos



Atmospheric neutrinos

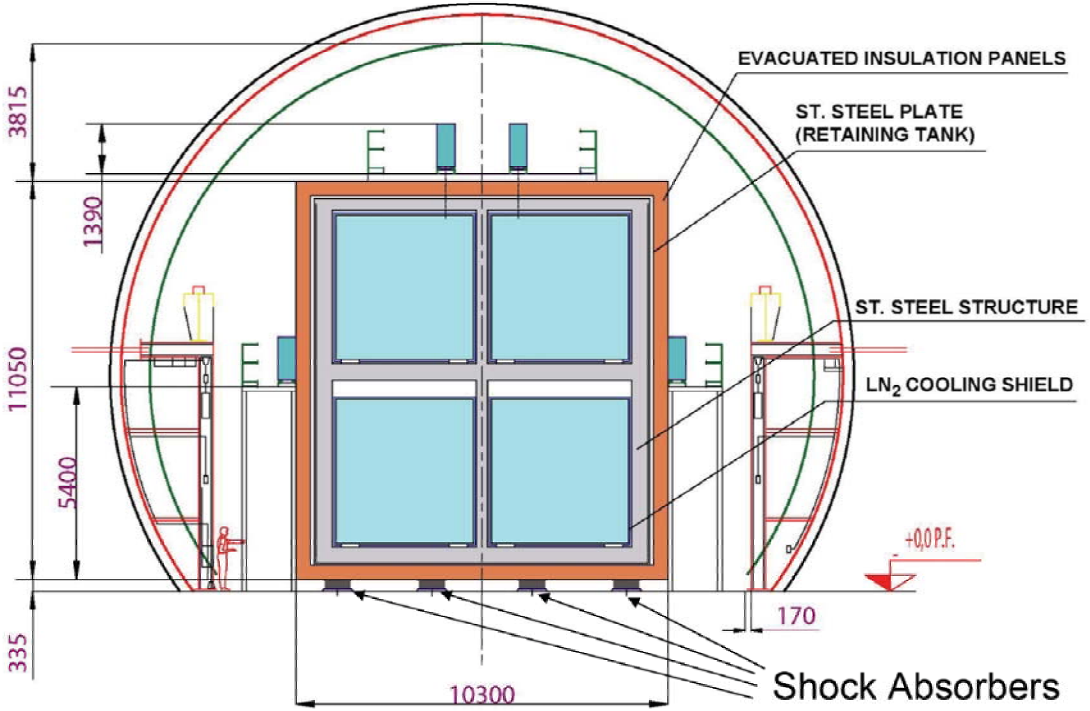


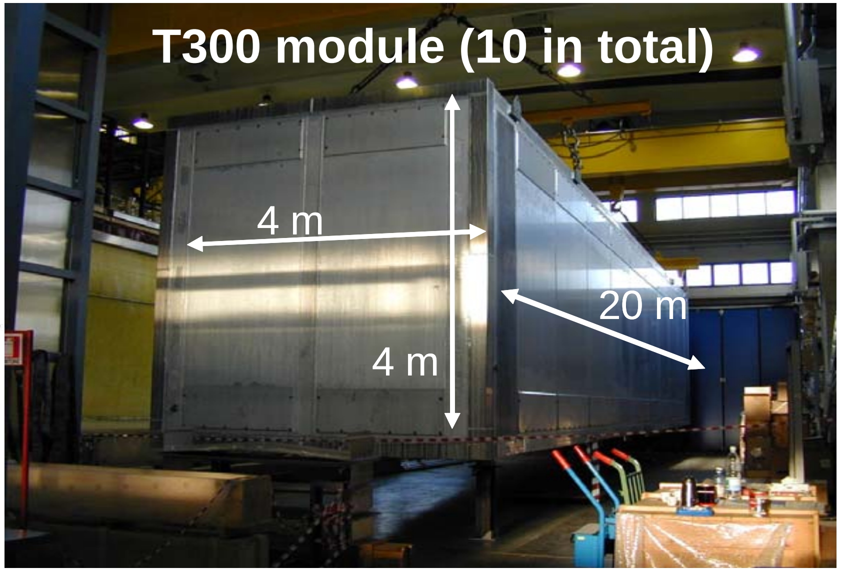
Long Baseline neutrinos



Nucleon stability

ICARUS cryogenic system



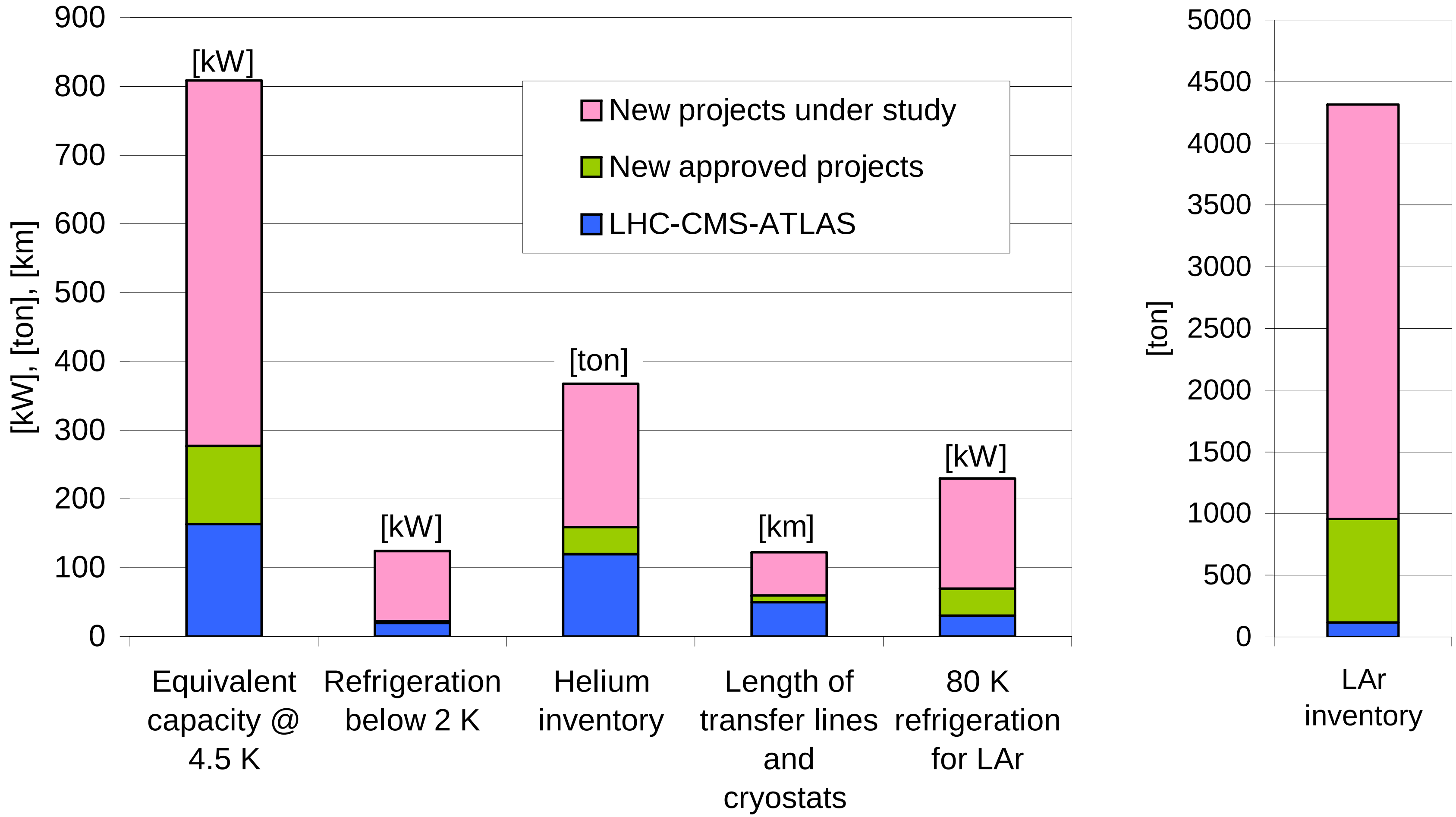


- Refrigeration:
  - T600: 40 kW @ 80 K produced by 10 stirling cryocoolers
  - T3000: 200 kW @ 80 K produced by ?
- Inventory:
  - T600: 600 m3 (840 t) of pure LAr
  - T3000: 3000 m3 (4200 t) of pure LAr

Contents

- Conclusions

New project requirements



Conclusions

- Perspectives for large cryogenic systems are existing and are mainly driven by the use of superconductivity in new projects. In some cases, superfluid helium can be used for boosting superconductor performance and cooling extended systems

- New approved projects (ITER, European X-FEL, FAIR) are already demanding efforts from the cryogenic community.

- Large cryogenic refrigerators with multi-kW capacities down to 2 K as well as complex cryogenic distribution systems will be required for future projects.

- Similarities are existing in between the different projects for devices, cooling method and cryogenic refrigeration. S&D efforts could be mutualized among several projects.