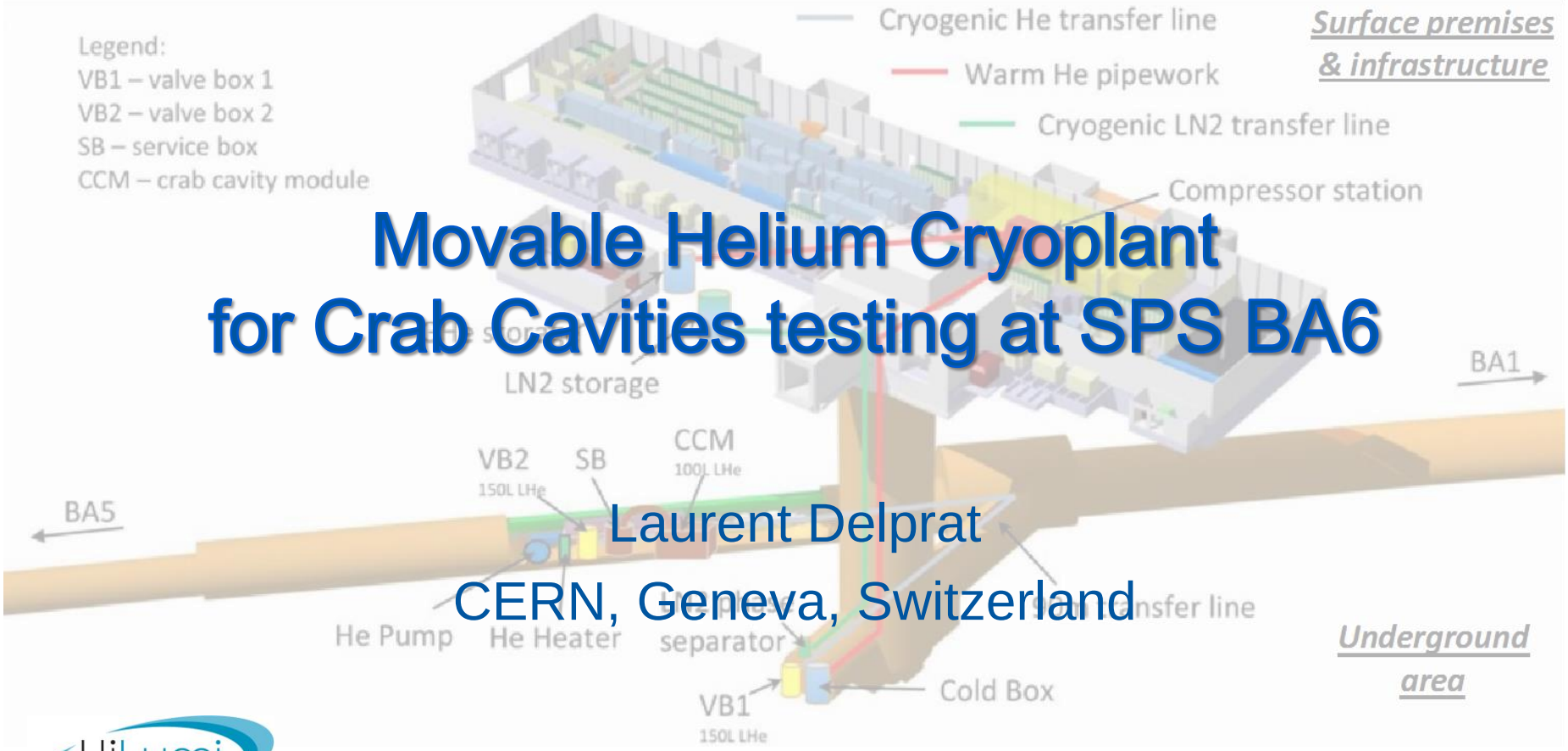


Movable Helium Cryoplant for Crab Cavities testing at SPS BA6

Laurent Delprat

CERN, Geneva, Switzerland

With contribution from K. Brodzinski, S. Claudet, H. Derking

Research supported by the High Luminosity LHC project

laurent.delprat@cern.ch

OUTLOOK

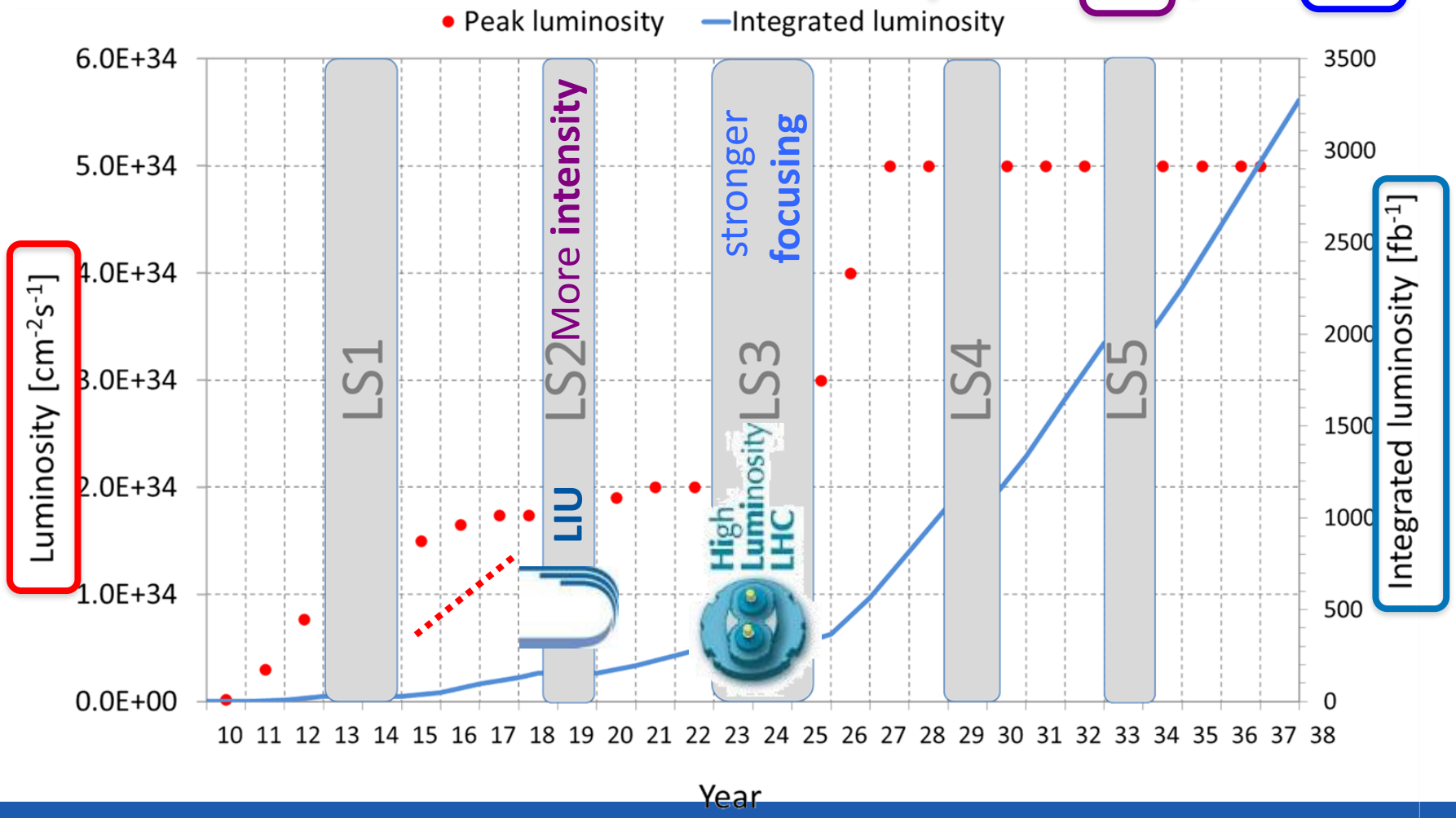
- Introduction to High-Luminosity LHC project – HL-LHC
- Design principles and key features
- Timeline of procurement and installation
- Commissioning and operation
- Conclusions and perspectives

Introduction to the High-Luminosity LHC Project

Towards higher collision rates

New discoveries or precision measurements need integrated luminosity !!!

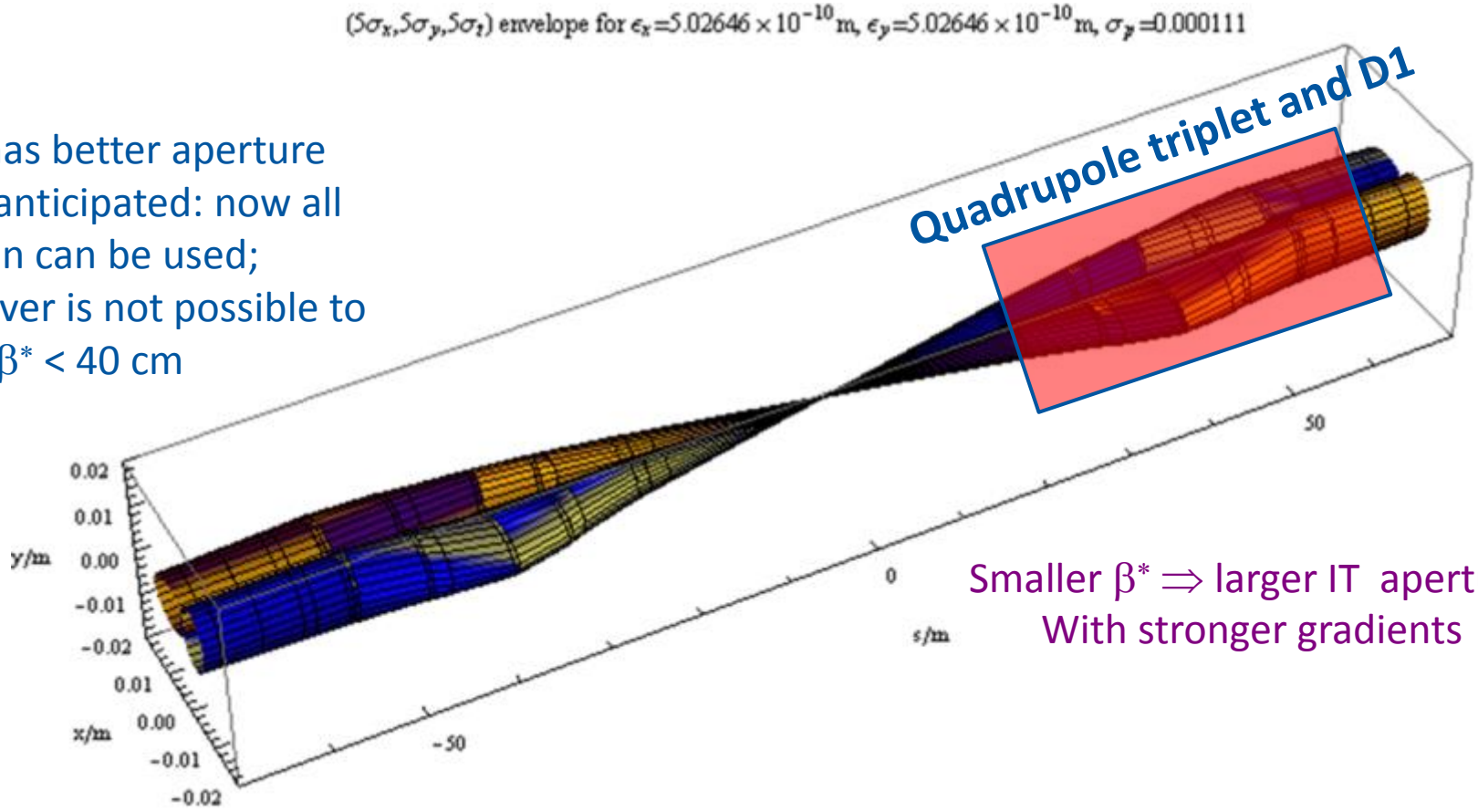
$$\text{Luminosity} = f * N^2 / 4\pi\sigma^2$$



The most straight forward action: reducing beam size with a “local action”

To increase Luminosity

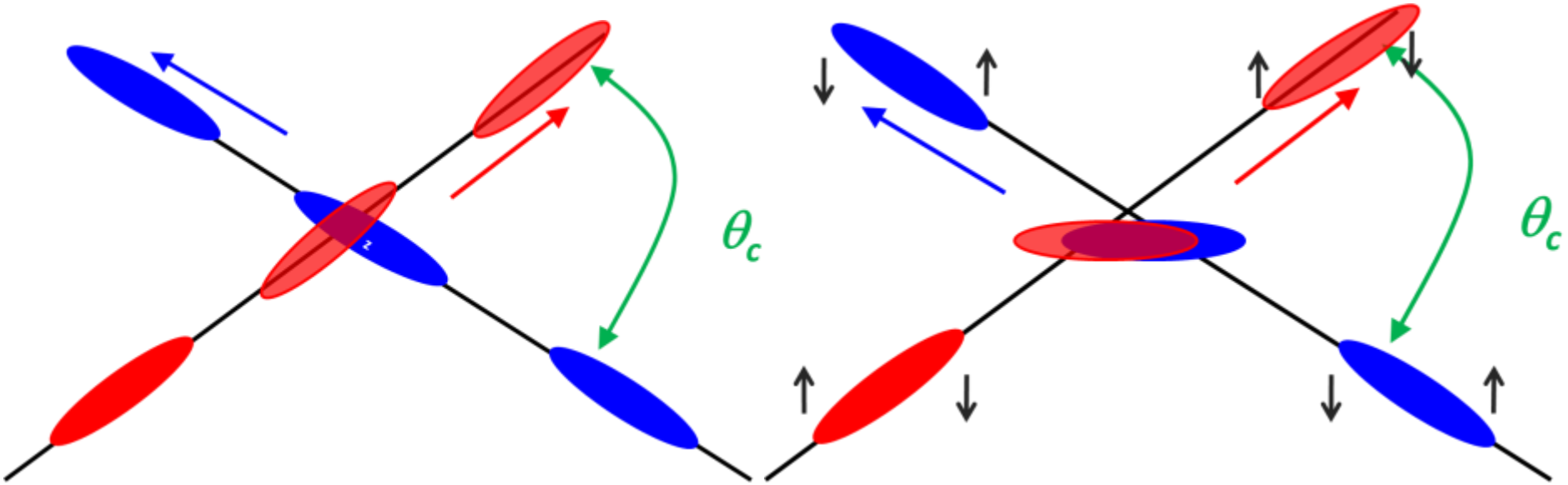
LHC has better aperture than anticipated: now all margin can be used; however is not possible to have $\beta^* < 40$ cm



Smaller $\beta^* \Rightarrow$ larger IT aperture
With stronger gradients

Effect of the crab cavities

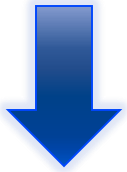
To compensate for the larger crossing angle



- RF crab cavity deflects head and tail in opposite direction so that collision is effectively "head on" and then luminosity is maximized
- *Crab cavity maximizes the lumi and can be used also for luminosity levelling: if the lumi is too high, initially you don't use it, so lumi is reduced by the geometrical factor. Then they are slowly turned on to compensate the proton burning*

Our need for cryogenics

- Use of superconducting crab cavities
- Operating in superfluid helium

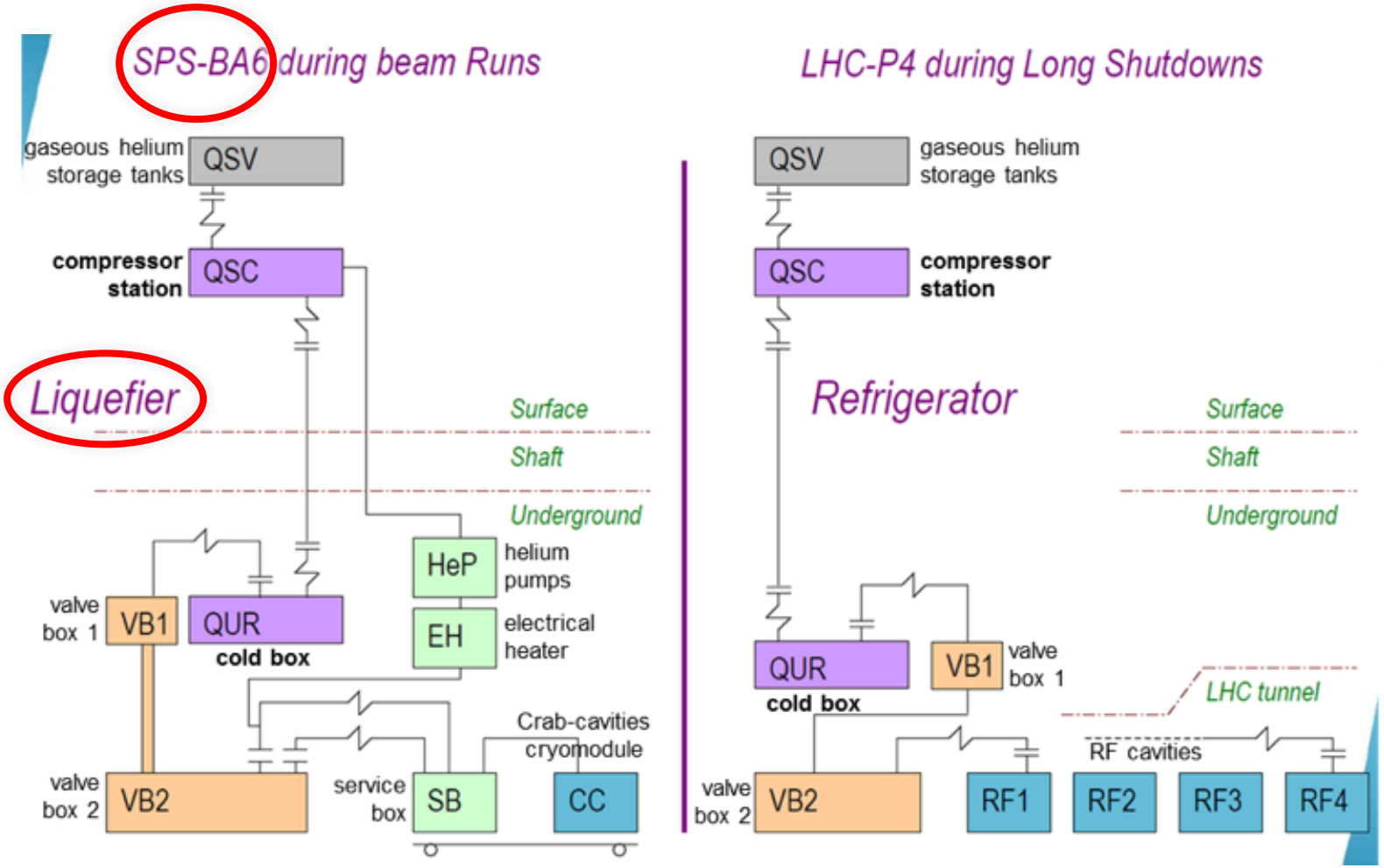


Need for a new cryogenic infrastructure

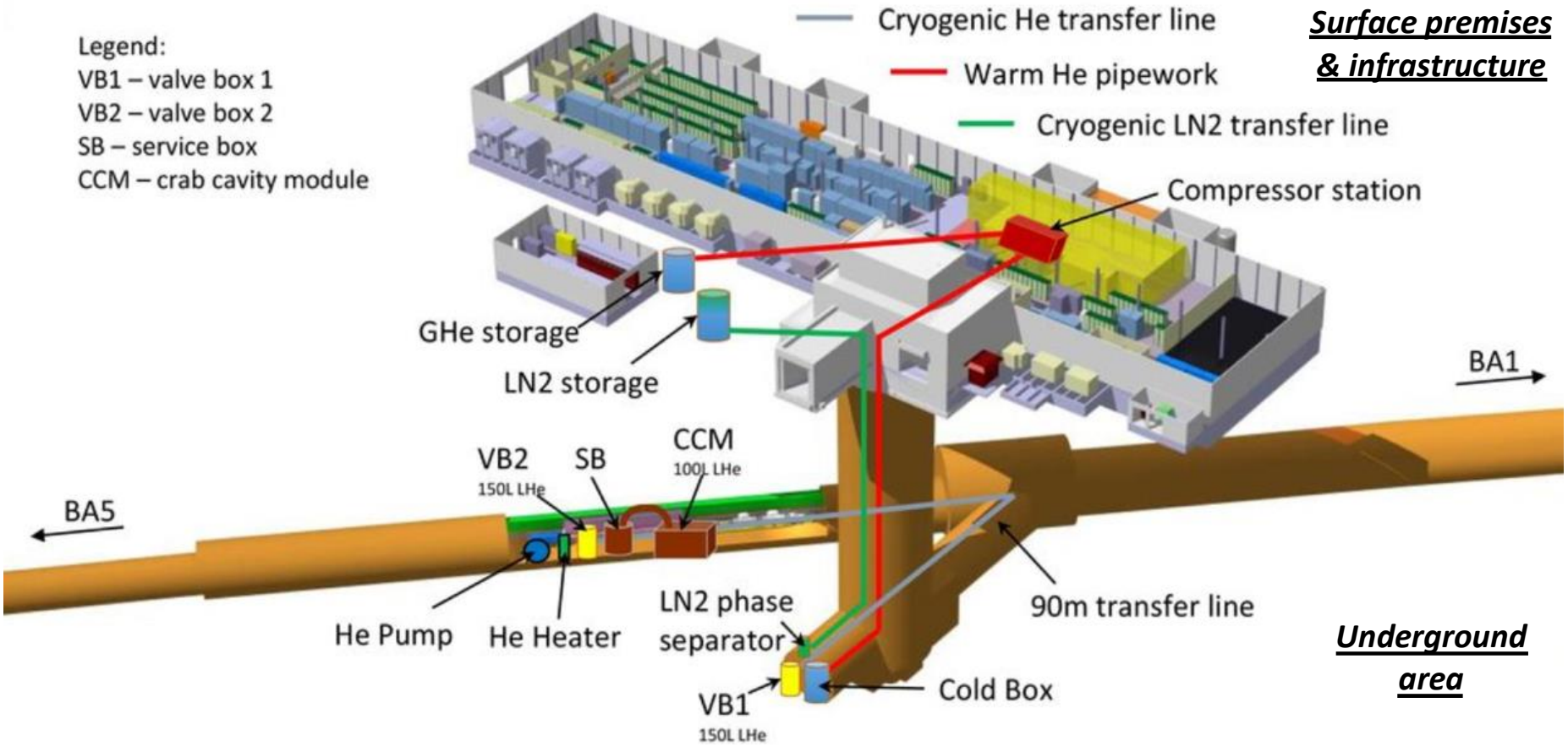
for a superconducting RF test facility with proton beams

at CERN SPS accelerator

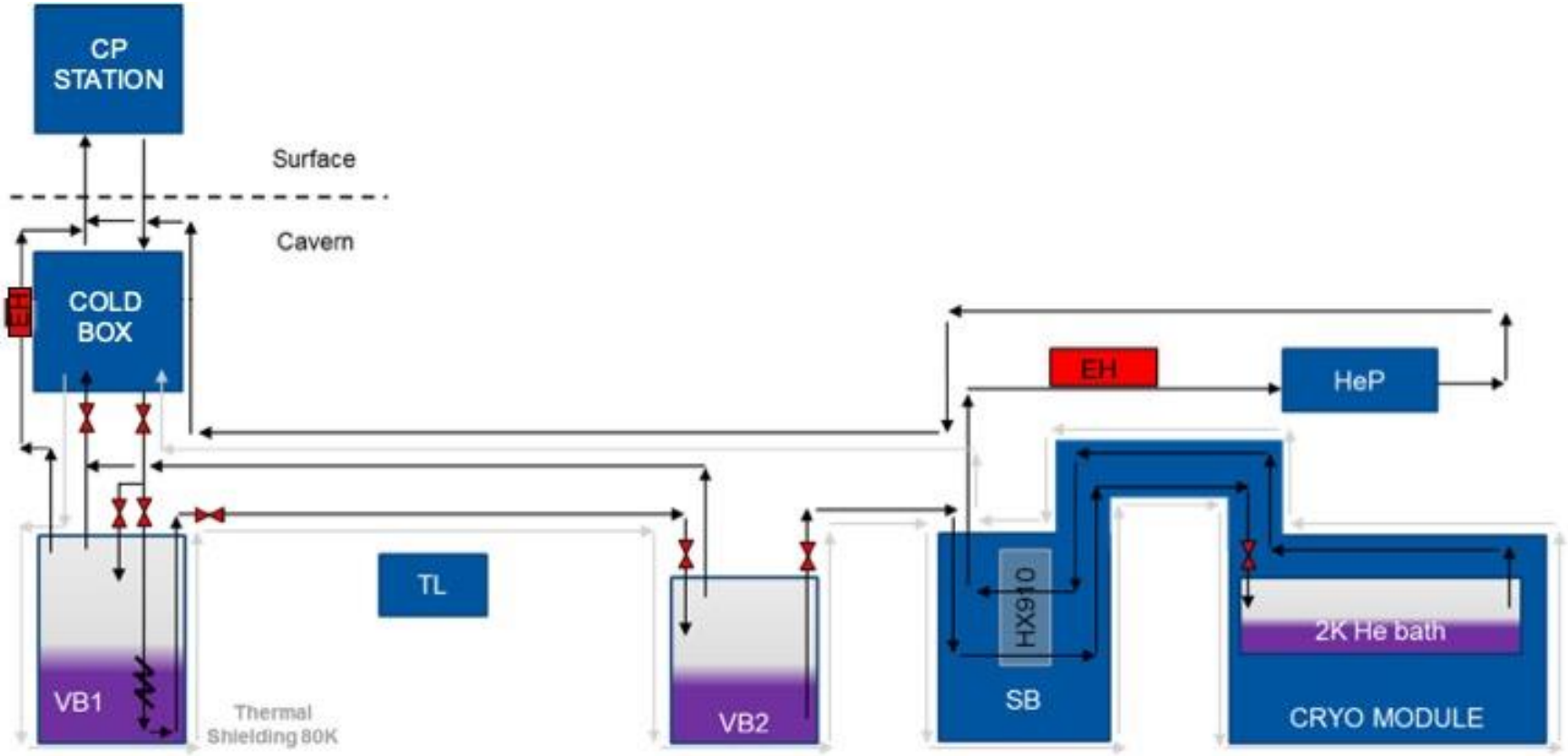
Design principles and key features



Layout


Legend:
VB1 – valve box 1
VB2 – valve box 2
SB – service box
CCM – crab cavity module
Cryogenic He transfer line
Warm He pipework
Cryogenic LN2 transfer line
Surface premises & infrastructure
Compressor station
GHe storage
LN2 storage
BA1
BA5
VB2
150L LHe
SB
CCM
100L LHe
He Pump
He Heater
LN2 phase separator
90m transfer line
VB1
150L LHe
Cold Box
Underground area

Simplified flow diagram



Design principles and key features

Movable helium cryoplant @ 4.5 K

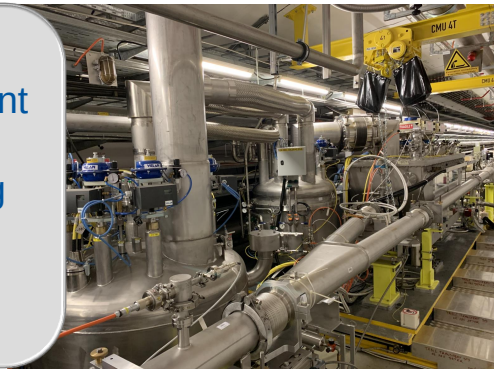
- 4 major **constraints**: timeframe of the supply, guarantee of the required performances, accessibility of installation location, **movability** requirement
- **Liquefaction** mode: **7 g/s of LHe @ 4.5 K + 750 W shielding @ 50 – 80 K**
- **Refrigeration** mode: **700 W @ 4.5 K + 300 W shielding @ 50 – 80 K**
- **LN_2 precooling** in both modes
- **LR280** from Linde Kryotechnik AG® with liquefaction and refrigeration turbines

Cryogenic distribution system

- **2 valve boxes** – VB1 as interface to the cold box, VB2 to the Service Box
- **Sub-cooler in VB1 phase separator** to recondition supercritical helium supply stream
- **80 m long distribution line** (TL): supercritical He for the supply and thermal shielding to minimize the losses
- Liquid helium produced at VB2 then sent to the Service Box

Service Box

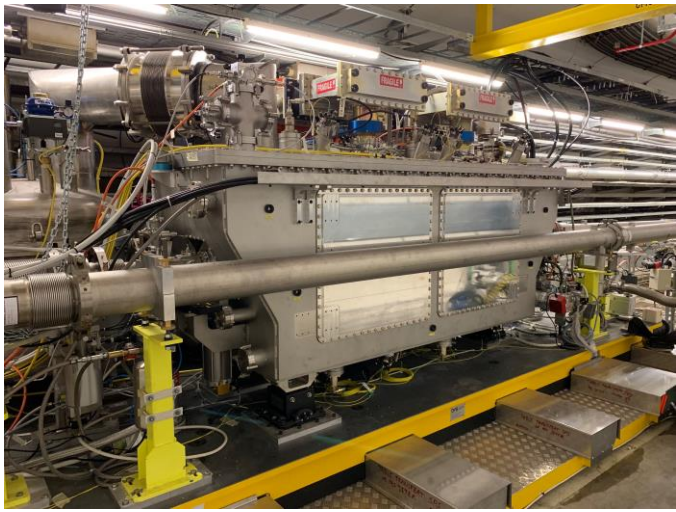
- Main function: provide **adapted interfaces** between 4.5 K distribution, client cryostat and helium pumping system
- **Integrated subcooling heat exchanger** for supply helium stream precooling



Design principles and key features

Crab cavities cryomodule

- 4.5 K LHe sat and 2 K – 30 mbar abs operation
- 18 W (static) and expected 13 W (dynamic) @ 2 K
- **Integration in SPS** (same proton beams as in LHC)
- **Mobile platform to bypass it** when SPS serves as LHC injector



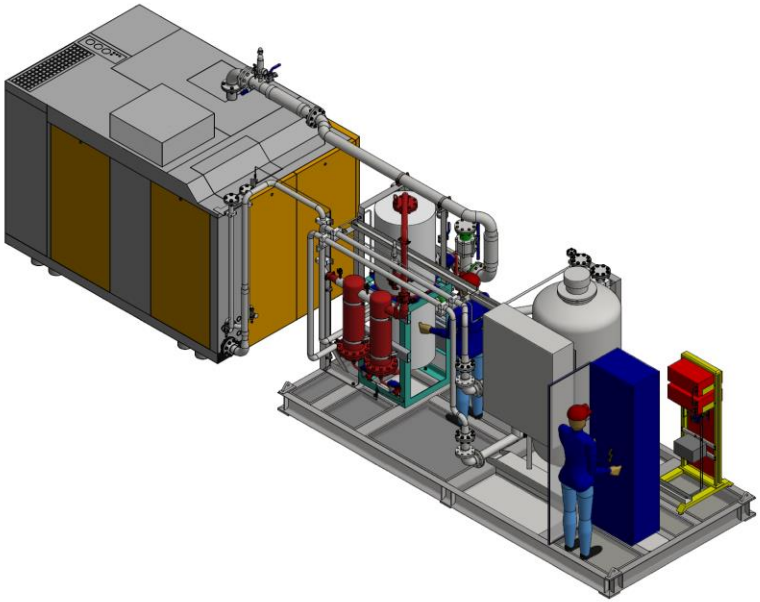
Helium pumping system

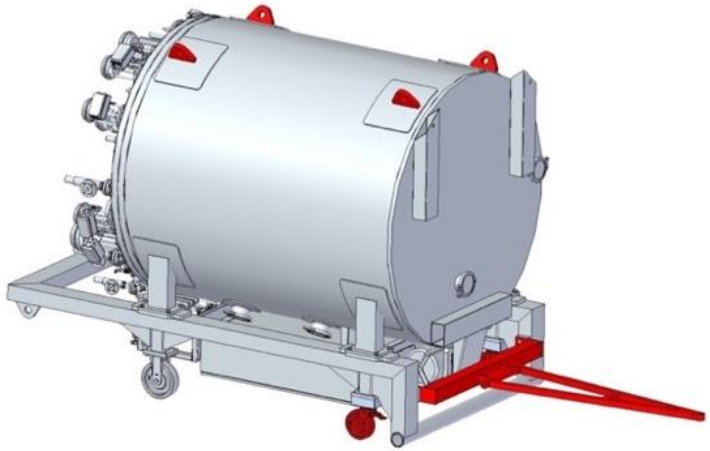
- Water bath heater, installed power 10 kW
- 2 Roots pumping units, total 2.3 g/s at 20 mbar abs

First operational results of the cryoplant

- **Timeframe of the supply**:
  - 2-year-project started from scratch – deadline met for delivery, installation and commissioning in time with the final user need (the crab cavities cryomodule)
- **Guarantee of the required performances**:
  - Liquefaction capacity already assessed up to 60% of the design, in line with water cooling restriction at the time of the performance test done in December 2018 – to be completed in 2020 after restart but already good hope to match the specified values
  - Refrigeration capacity will be evaluated as well in 2020 after restart of the whole facility
- **Accessibility of installation location**:
  - 90° tilting capability of the cold box, specific handling of the heat exchangers inside the vacuum vessel
- **Movability requirement**:
  - 2 iso-frame skids design for the compressor station
  - Special transportation frame for the cold box with wheels and drawbar
  - Interfaces regrouped in one single location per skid
  - Installed the two CP skids + the cold box in less than a week

Design of the 4.5 K cryoplant





GHe and LN2

GHe storage

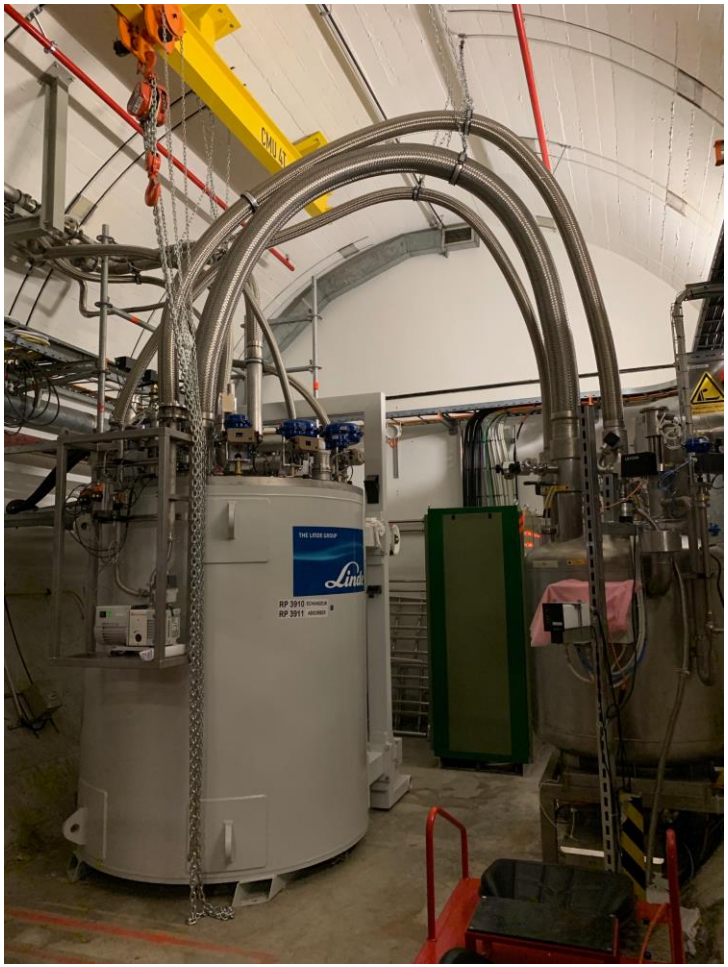
Handled by CERN – not in the scope of supply of the compressor station
2 * 35 m^3, up to 15 bar abs

LN_2 facility

Handled by CERN – not in the scope of supply of the cold box
1*20 kL Dewar LN_2 for cold box precooling

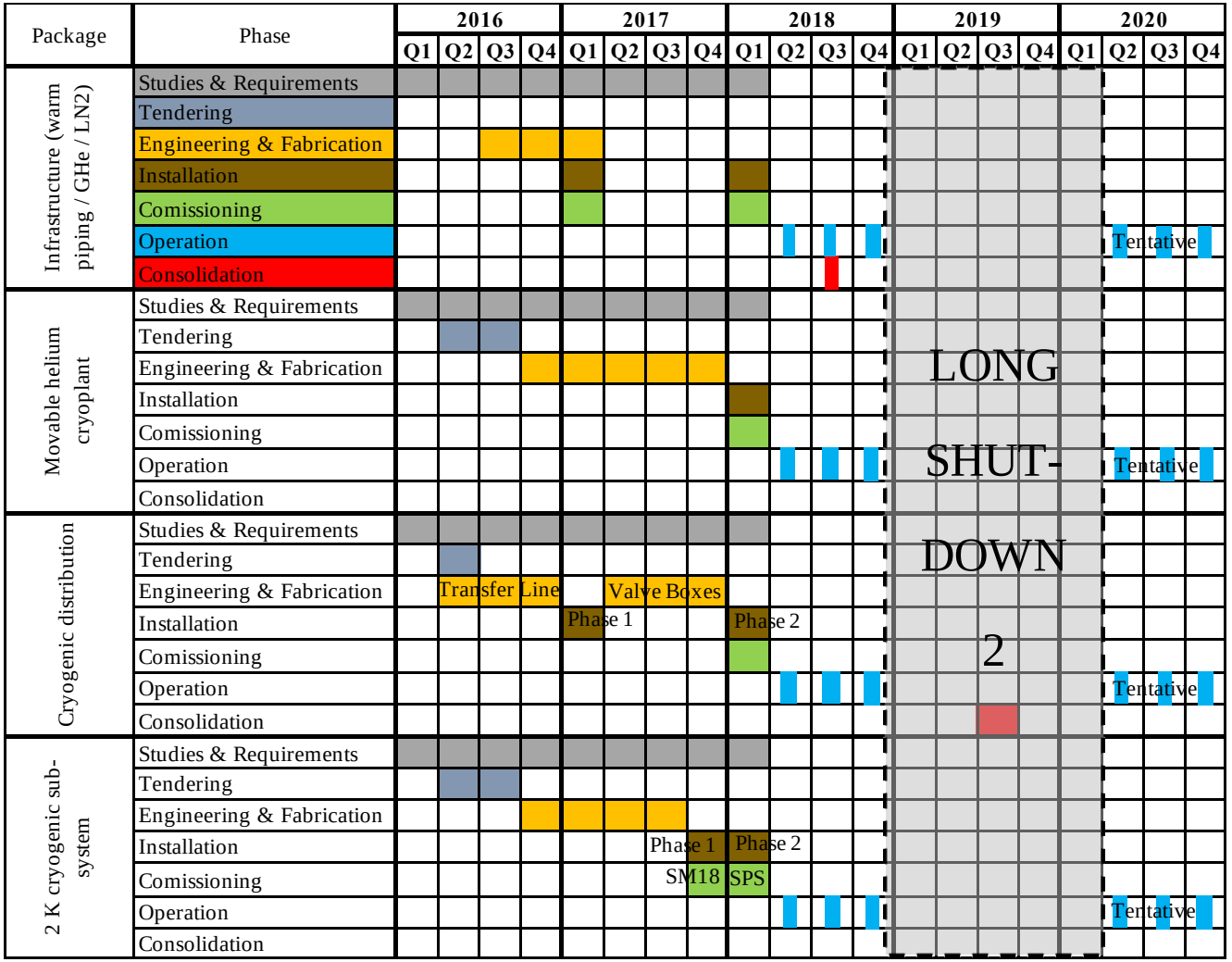
Compressor station

Cold Box and LN_2 phase separator



CB, LN_2 φ-sep, VB1

Timeline of procurement

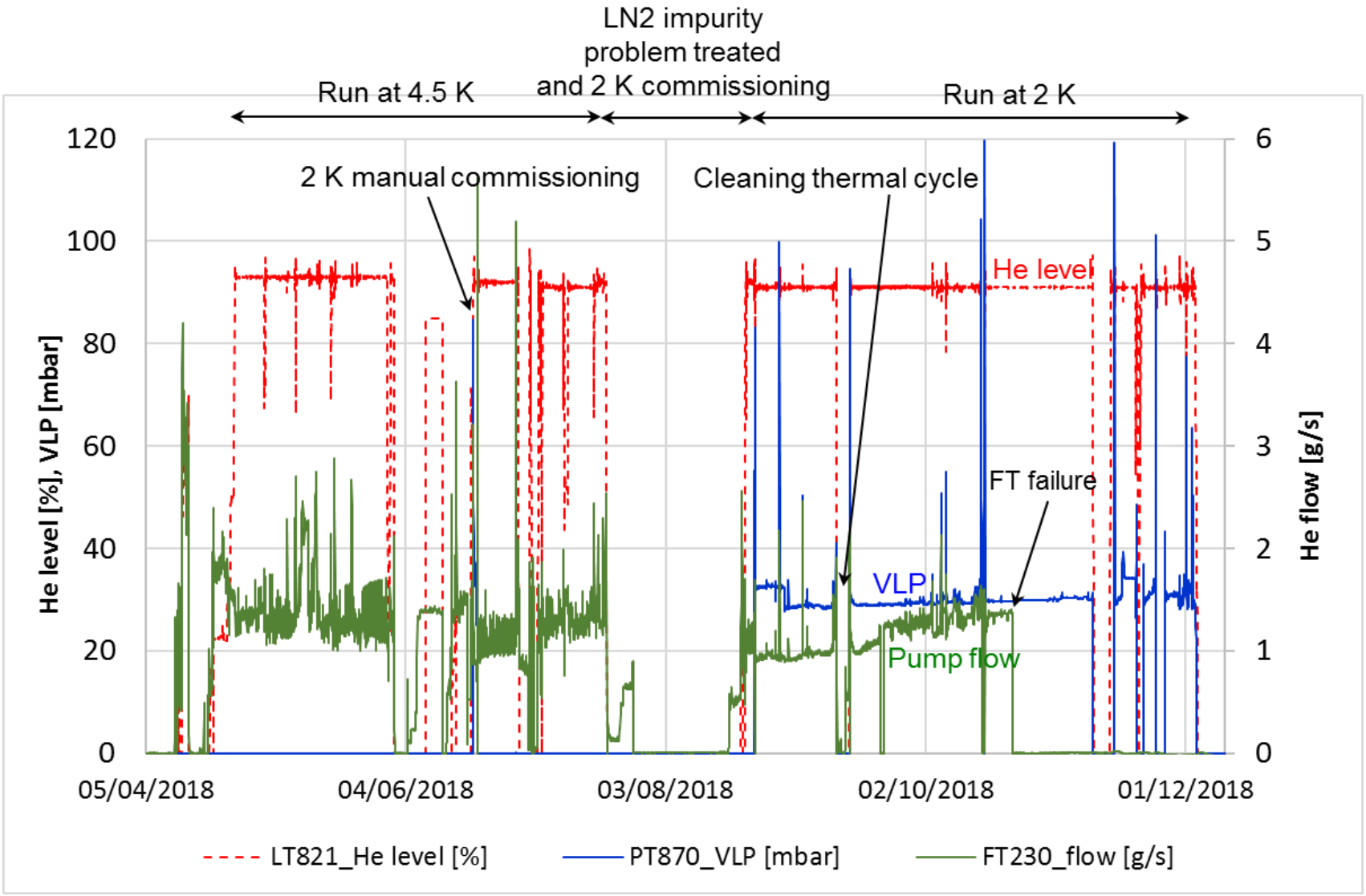


2016: studies and procurements launched

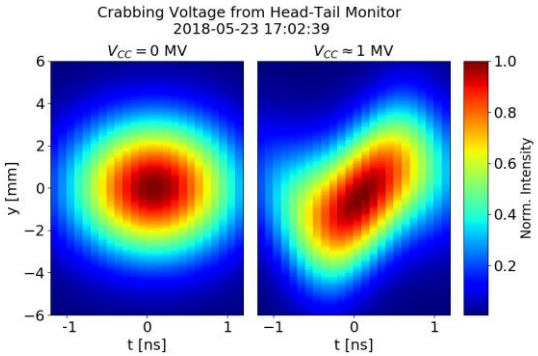
2017: detailed engineering & fabrication

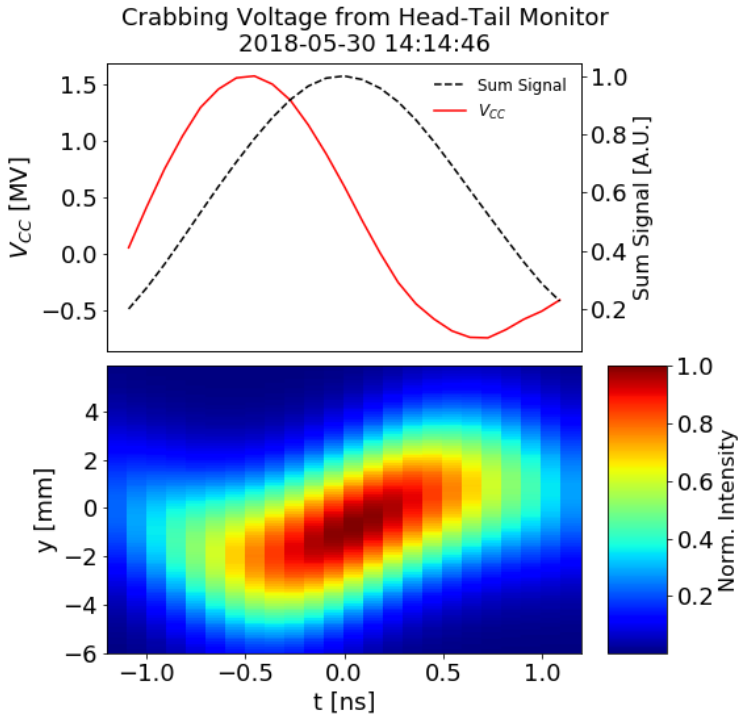
2018: commissioning and operation

Commissioning / Operation at 4.5 K then 2 K

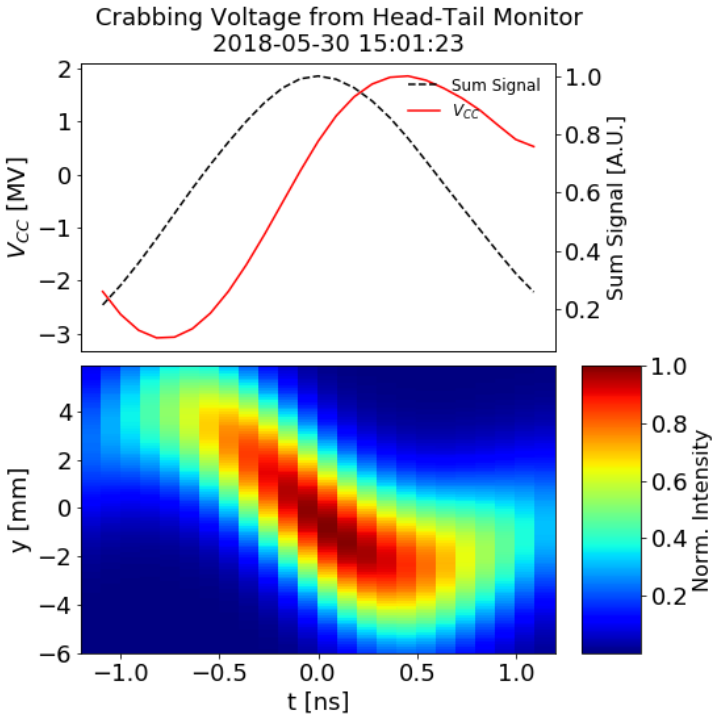


First tilting of the proton beam by a Crab Cavity! SPS 23 May 2018 at 1 MV (3.4 MV nominal)





10 slots of SPS Machine Development foreseen in 2018



Conclusions and perspectives

- The complete 2 K cryogenic infrastructure was **designed and built from scratch between 2016 and beginning of 2018**,
- The **reception test** was conducted **during Q1 of 2018** with direct operation afterwards,
- **First stable operation** of crab cavities in LHe successful in **spring 2018**, in superfluid helium from September 2018,
- **Long Shutdown #2** started with the stop of the cryogenic test facility, allowing for the required maintenance and consolidation,
- **Restart** of the whole facility **in 2020** to allow for completing performance assessment and further testing of the cavities with proton beams in SPS

Thank you for your attention !

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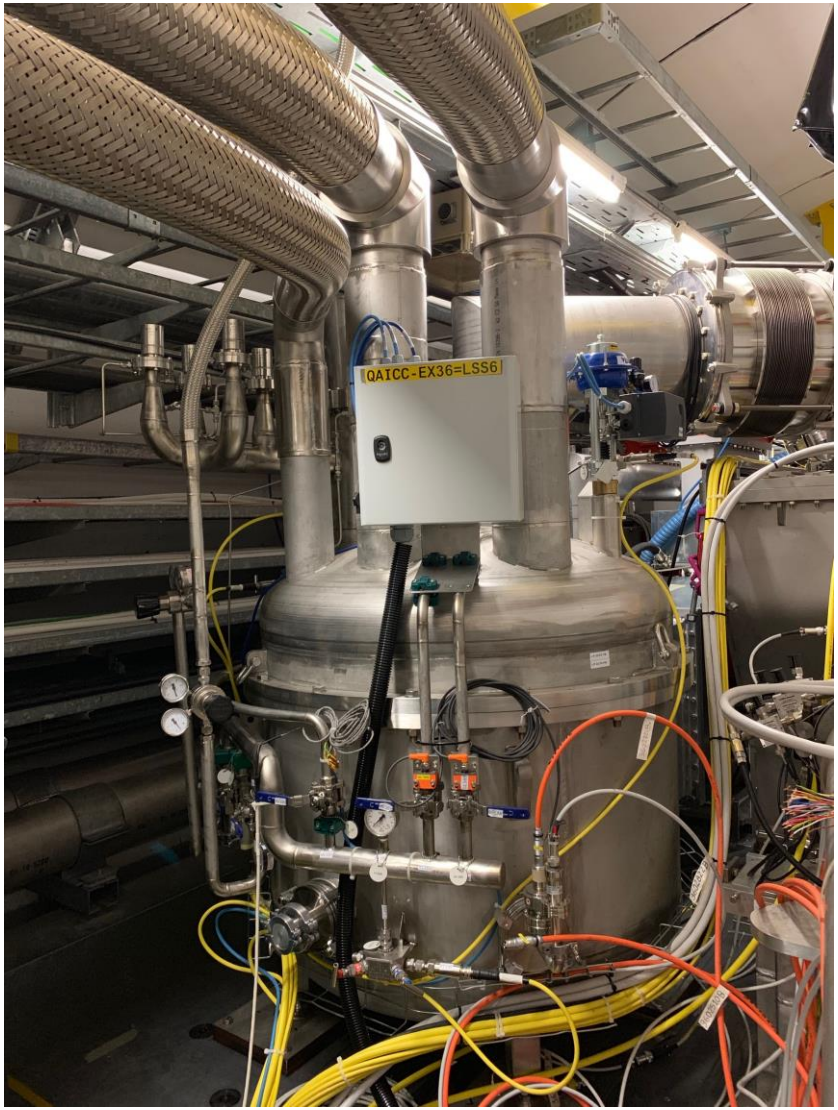
Spare Slides

VB1

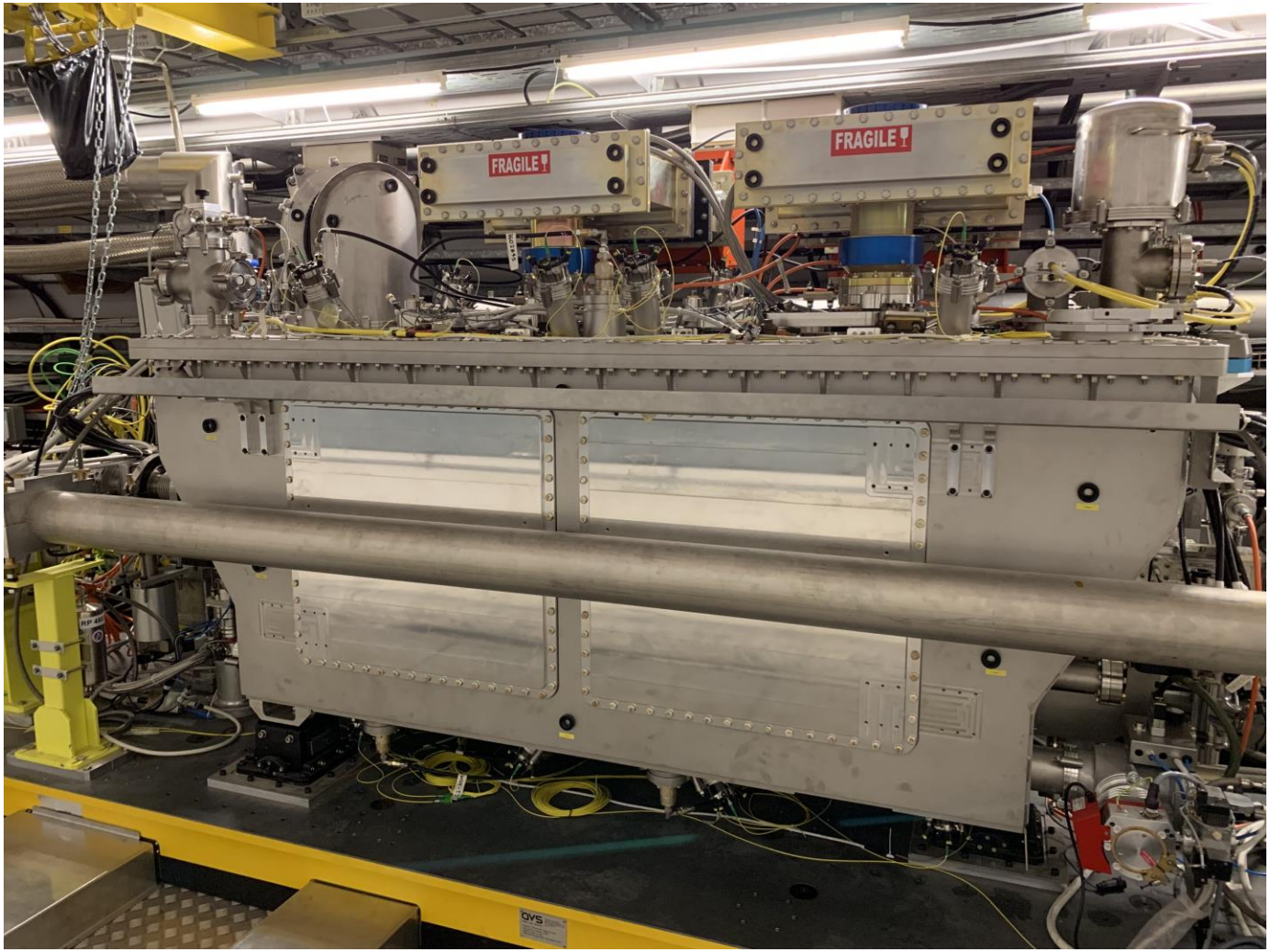
Transfer line

VB2

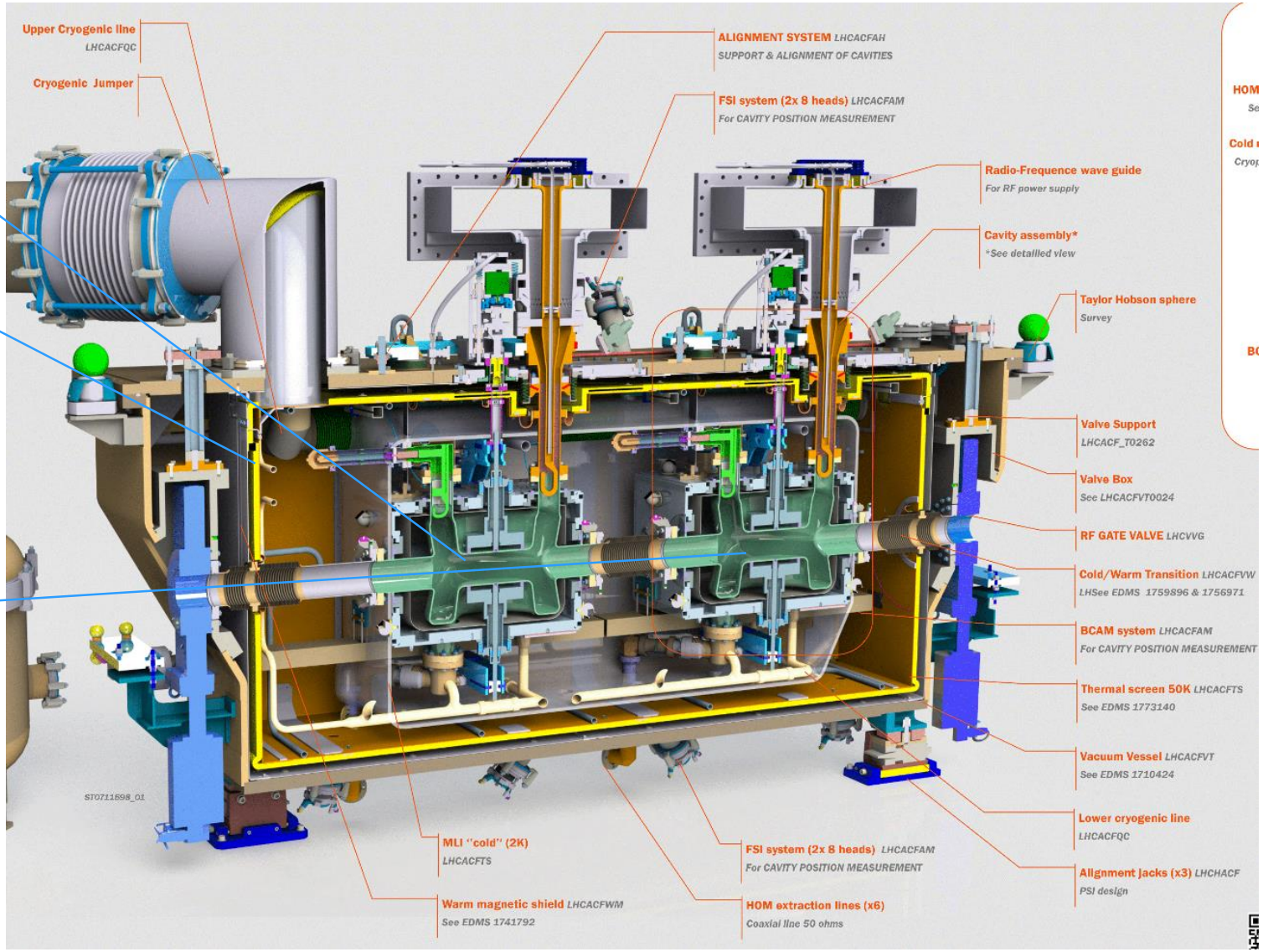
Service Box



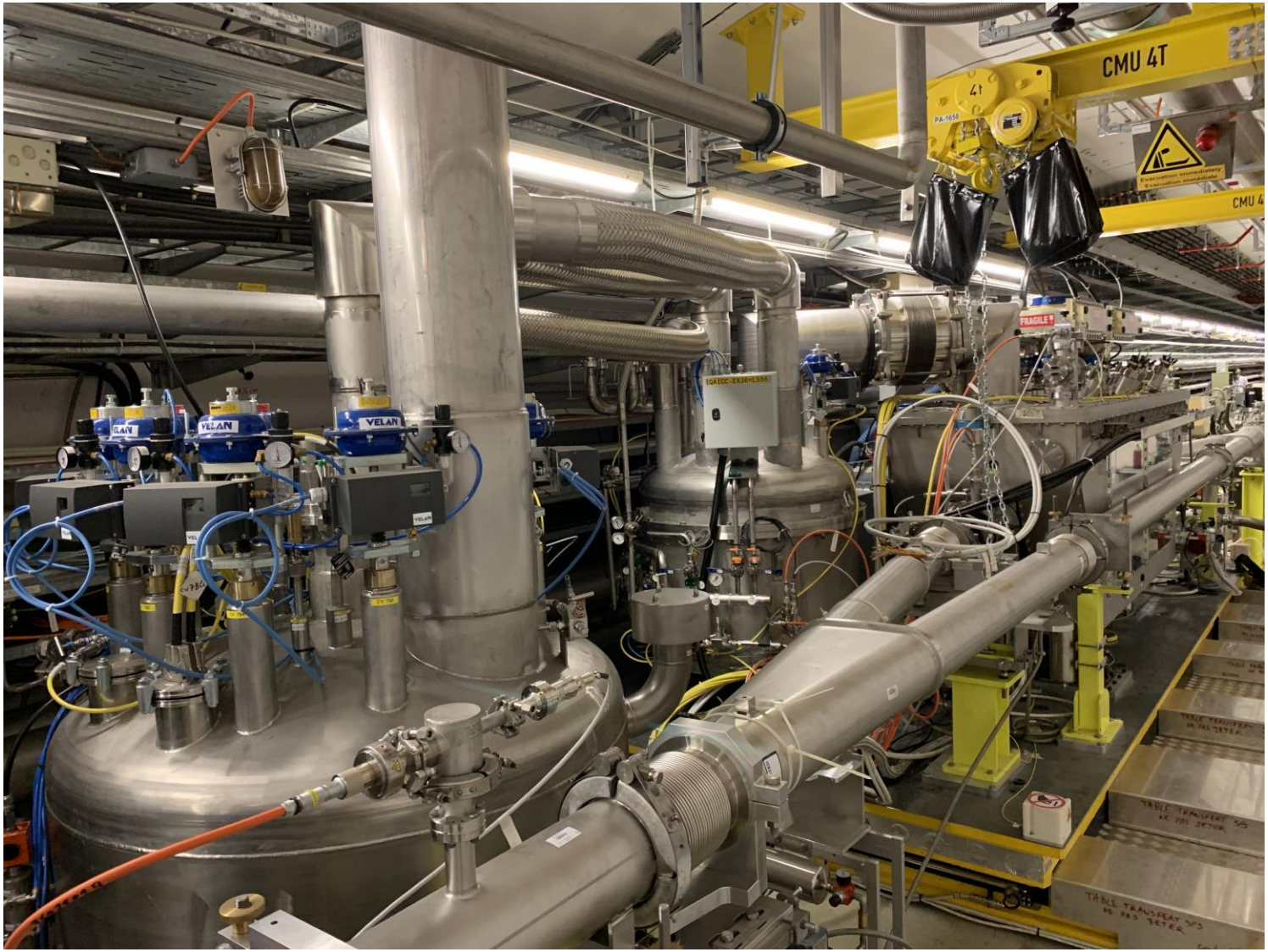
Crab cavities cryomodule



Cryomodule internal 3D preview



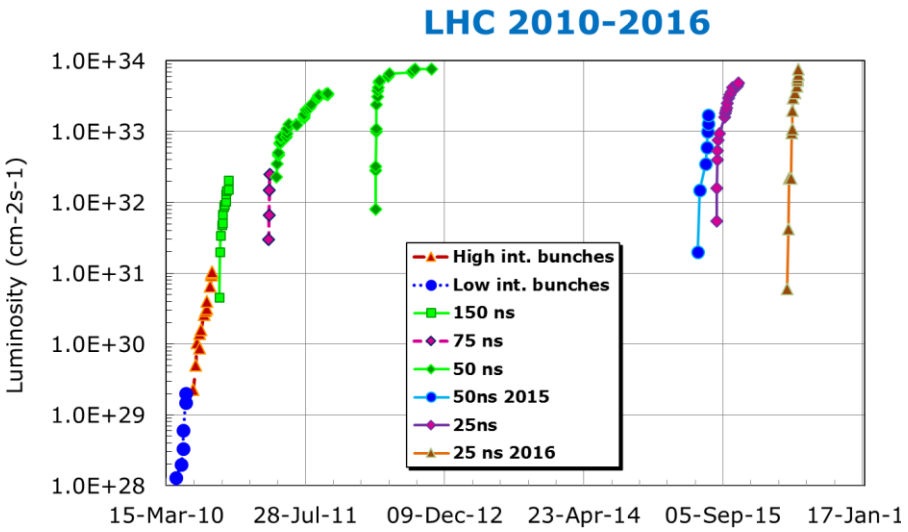
VB2, SB, CM



LHC performance so far

Peak Luminosity

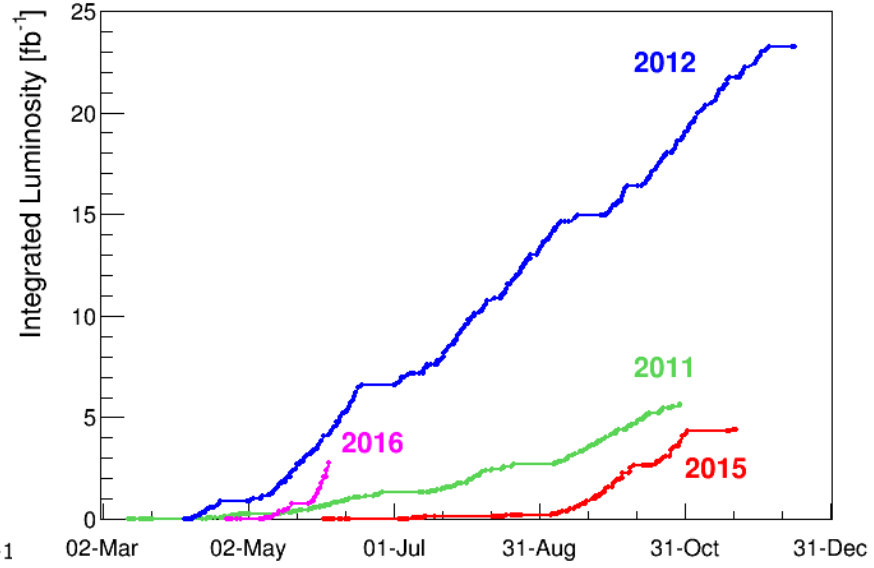
"The potential of the facility"



Performance

Integrated Luminosity

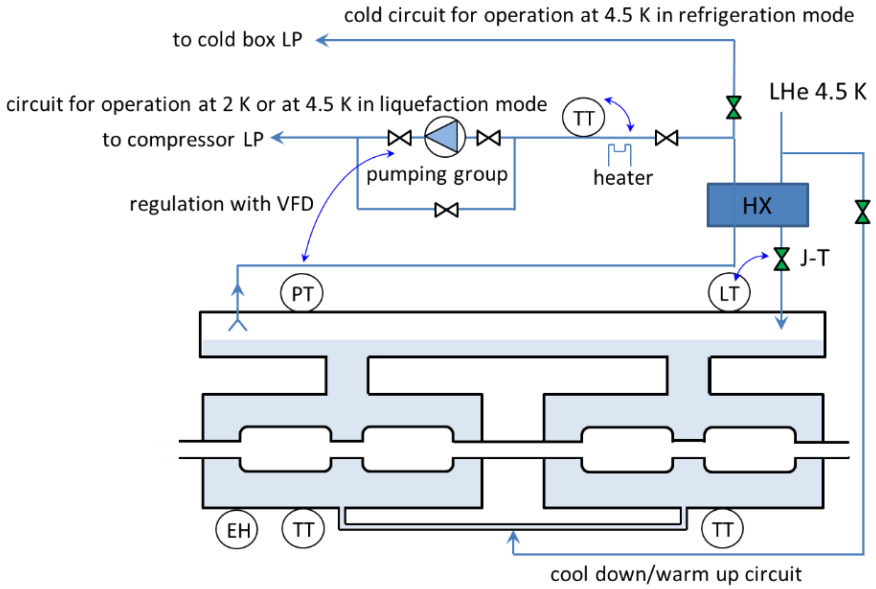
"What allows science" (statistics)



Time - Qualification

Global availability

Principle of 2 K cooling system of the cavity



2 K operation:

- Saturated superfluid helium bath
- Integrated subcooling heat exchanger
- Water bath heater – installed power of 10 kW
- Helium pumping system – 2.3 g/s at 20 mbar abs

Integration requirement:

- Possibility to bypass the test cryostat when SPS serves as the LHC injector => installation on a mobile platform

  => use of specially designed beam vacuum « Y » chamber connected to the cryomodule and its bypass