Summary of the Review of FAIR Cryogenics 27-28 February 2012

Philippe Lebrun
CERN

7th Machine Advisory Committee meeting
Forschungszentrum Jülich, 2-3 April 2012

General aspects

- Review requested by the FAIR project management and Machine Advisory Committee
- Held at GSI Darmstadt on 27-28 February 2012
- Review panel members
  - L. Evans (CERN), Chairman
  - J. Fydrych (WUT)
  - Ph. Lebrun (CERN)
  - B. Petersen (DESY)
  - T. Peterson (FNAL)
  - L. Tavian (CERN)
  - U. Wagner (CERN)

Program – Day 1

Monday 27 February 2012

10:00 - 10:15	Welcome and FAIR Update *15'* (Universe (KBW Hörsaal/Lecture Hall)) Speaker: Dieter Krämer (FAIR GmbH)
10:15 - 10:35	Super-FRS: Machine and magnets *20'* (KBW Hörsaal/Lecture Hall) Speaker: Hanno Leibrock (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI))
10:35 - 11:05	Super-FRS Multiplets cooling (inner piping optimization and ANSYS simulation for cool-down) *30'* Speaker: Yu XIANG
11:05 - 11:20	C o f f e e B r e a k
11:20 - 12:05	Local cryogenics for Super-FRS (flow scheme, feedbox, cryogenic transfer lines, Branch box) *45'* Speaker: Yu XIANG
12:05 - 12:35	Layout (digital mock-up) of cryogenic facility in Super-FRS tunnel and buildings *30'* Speaker: A. BREIDERT
12:35 - 14:00	L u n c h _ B r e a k (GSI Canteen)
14:00 - 14:30	SIS100: Machine, magnets and operation cycles *30'* Speaker: Jens Stadlmann (GSI Ges. für Schwerionenforschung mbH)
14:30 - 15:00	Analyses of the SIS100 SC magnets cooling *30'* Speaker: Alexander BLEILE
15:00 - 15:30	Experiences at Dubna/Nuclotron *30'* Speaker: Hamlet KHODZHIBAGIYAN
15:30 - 15:45	C o f f e e _ B r e a k
15:45 - 16:15	Hydraulic analysys, operation scenarios and special installations *30'* Speaker: Marion Kauschke (Gesellschaft für Schwerionenforschung mbH)
16:15 - 16:55	Cryogenics hardware (Polish In-kind) *40'* Speaker: Jaroslaw Fydrych
16:55 - 18:00	Open Discussion *1h05'*

Program – Day 2

Tuesday 28 February 2012

09:00 - 10:30	Cryo 1, Cryo 2 *1h30'* Speaker: Marion Kauschke (Gesellschaft für Schwerionenforschung mbH)
10:30 - 10:50	Control system *20'* Speaker: Ralph Bär (GSI Helmholtzzentrum für Schwerionenforschung GmbH)
10:50 - 11:00	C o f f e e _ B r e a k
11:00 - 11:30	Prototype Test Facility Operation, Series Test Facility Planning *30'* Speaker: Claus SCHROEDER
11:30 - 11:45	Reliability at Super FRS *15'* Speaker: Eugen MOMPER
11:45 - 12:00	Test of radiation hardness *15'* Speaker: Edil Mustafin (GSI Helmholtzzentrum für Schwerionenforschung GmbH)
12:00 - 13:00	Lunch_Break (GSI Canteen)
13:00 - 15:00	Final Discussion *2h00'*

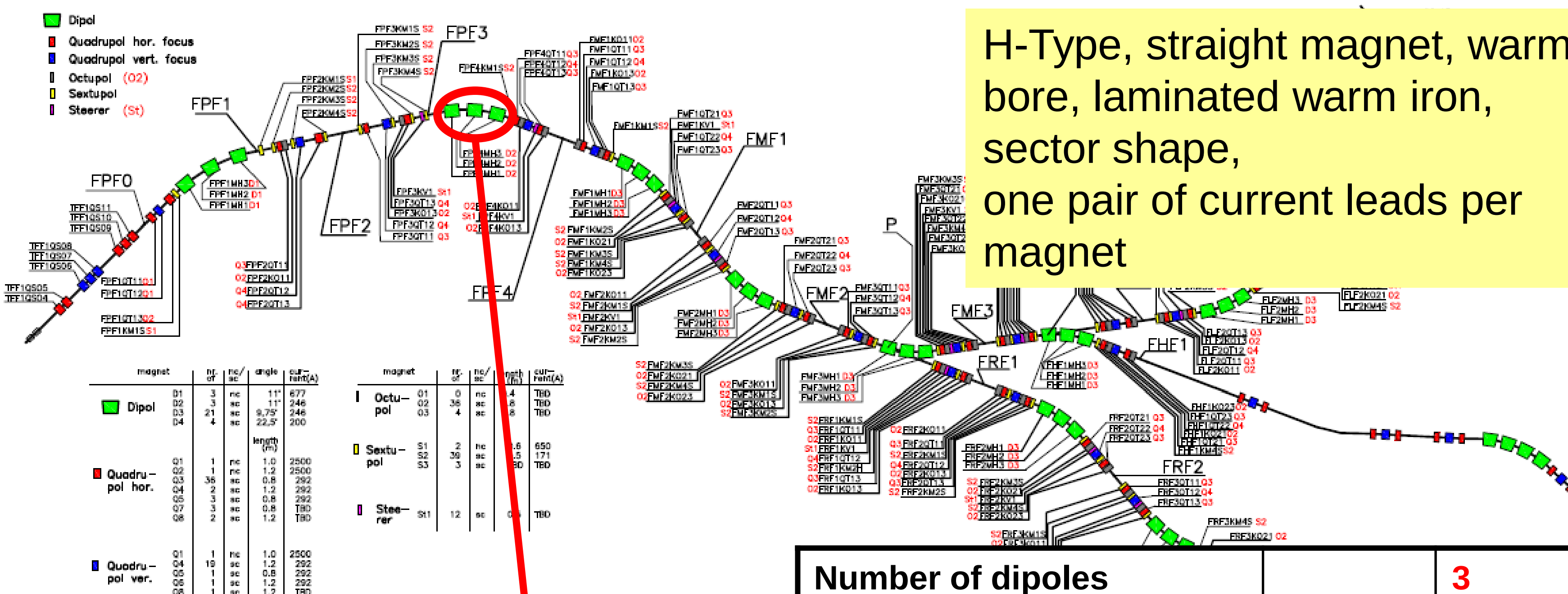
General findings [1/2]

- Design of FAIR cryogenics proceeds in « concurrent engineering » mode
  - Addressing technical details in parallel with identification or revision of major requirements and boundary conditions
  - Effect amplified by the collaborative structure of the project (in-kind WPs)
  - Requires tight technical and organizational management
  - Iterative process needs technical reviews and interface management between the contributing teams
- Urgent need to implement configuration management and change control procedures
  - In particular for documenting cost implications and allowing cost tracking
  - Applies to whole project and not only cryogenics
- Need to establish basic requirements at project level
  - Stages of installation & commissioning
  - Operational flexibility, accessibility, reliability, repairability
  - Acceptable dead-time for cryogenic transients (CD, WU, quench recovery)
  - Redundancy/overcapacity in refrigeration
  - High-level technical parameters (e.g. design pressure)

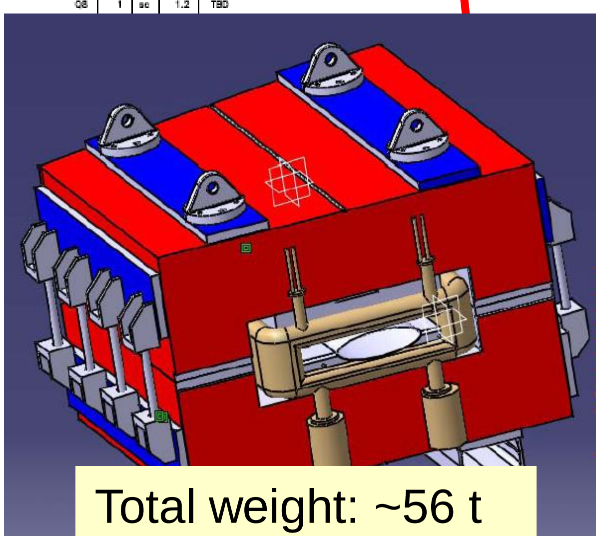
General findings [2/2]

- The review panel
  - Appreciates that the FAIR cryogenics team feels responsible not only for the production and distribution of cooling, but also for proper operation of cryomagnets
  - Is of the opinion that the size of the present team is insufficient to carry out all the tasks attributed to it
- The Review was efficiently organized and the presentations of good quality

Superferric Dipoles for the FRS Pre-Separator



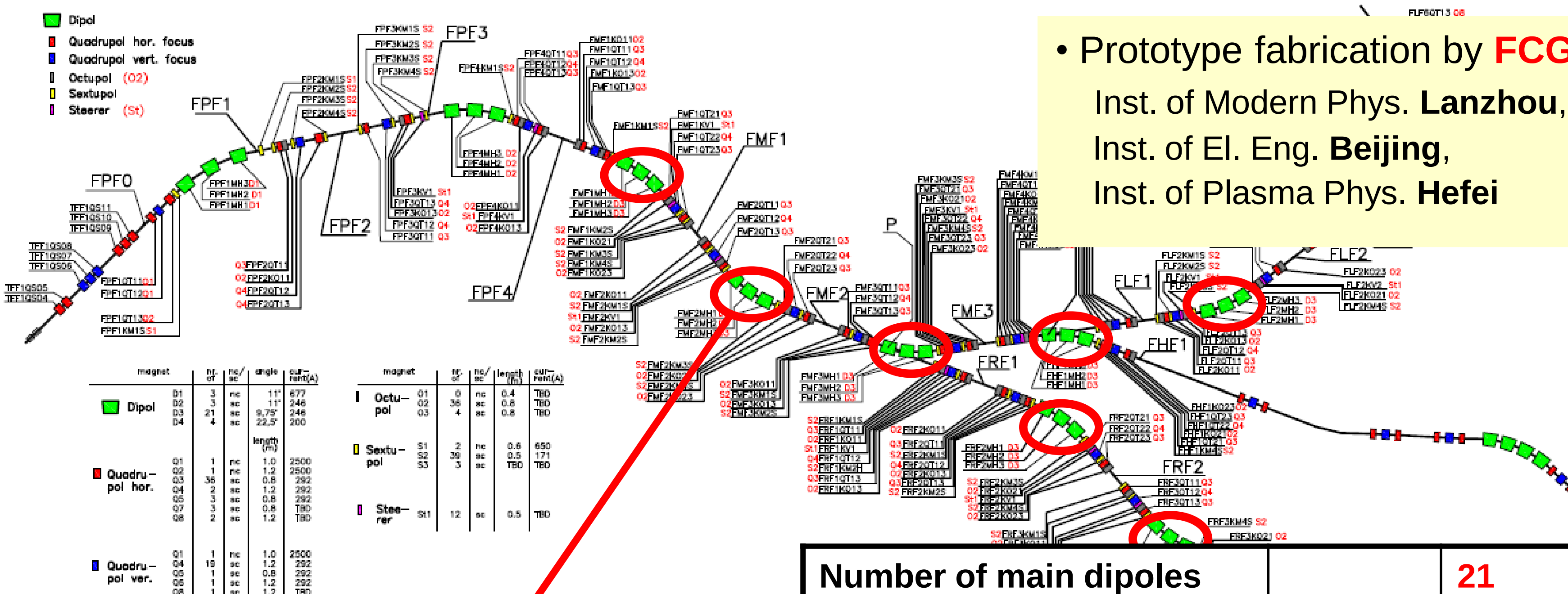
H-Type, straight magnet, warm bore, laminated warm iron, sector shape,
one pair of current leads per magnet



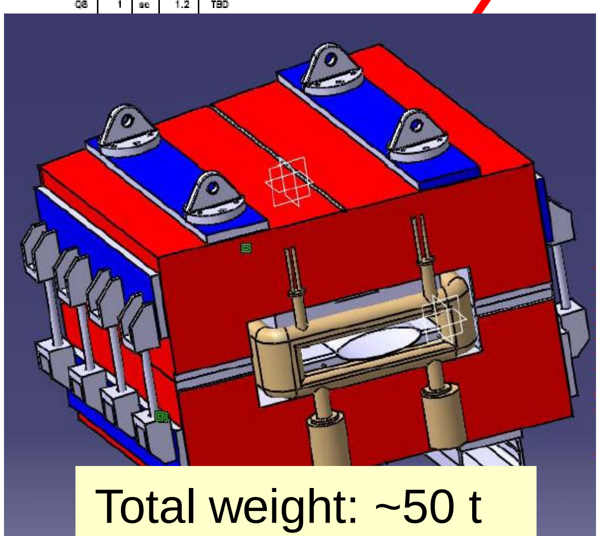
Number of dipoles		**3**
Dipole field	**T**	**0.15-1.6**
Bending angle	**Degree**	**11.0**
Curvature radius, R	**m**	**12.5**
Effective length, $L_{effe.}$	**mm**	**2400**
Good field region	**mm**	**±190**
Pole gap height	**mm**	**170**
Integral field quality (rel.)		**$\pm 3\times10^{-4}$**

H. Leibrock

Superferric Dipoles for the FRS Main Separator



- Prototype fabrication by **FCG**
  - Inst. of Modern Phys. **Lanzhou**,
  - Inst. of El. Eng. **Beijing**,
  - Inst. of Plasma Phys. **Hefei**

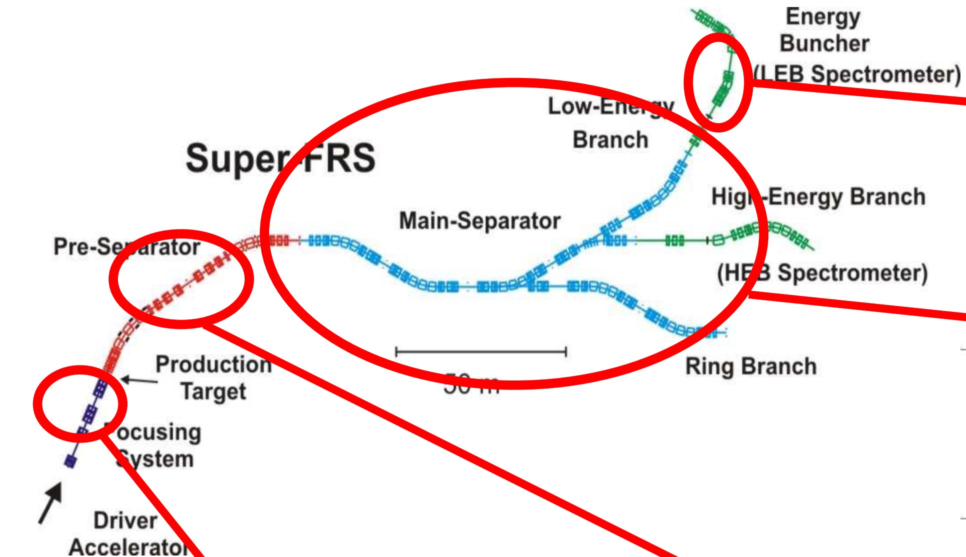


Total weight: ~50 t

Number of main dipoles		**21**
Dipole field	**T**	**0.15-1.6**
Bending angle	**Degree**	**9.75**
Curvature radius, R	**m**	**12.5**
Effective length, $L_{effe.}$	**mm**	**2127**
Good field region	**mm**	**±190**
Pole gap height	**mm**	**170**
Integral field quality (rel.)		**$\pm 3\times 10^{-4}$**

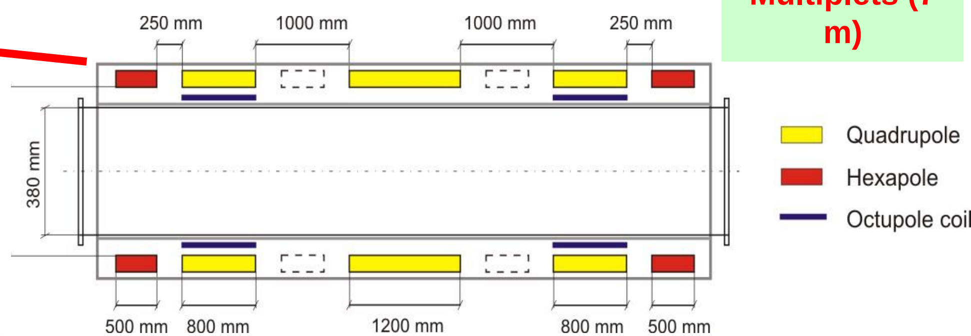
H. Leibrock

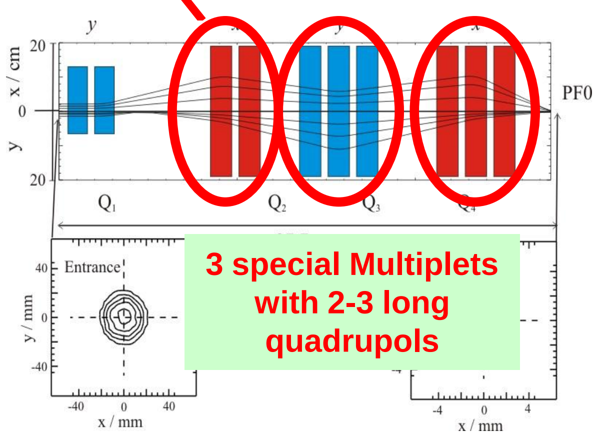
Multiplets for the Super-FRS



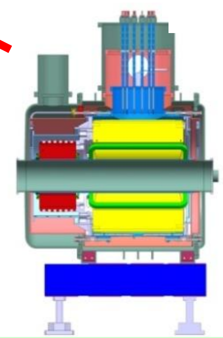
one special Multiplet with two quadrupoles

20 standard Multiplets (7 m)





3 special Multiplets with 2-3 long quadrupols



7 short Multiplets with 2 magnets (2.6 m)

- Quadrupol triplet + up to 3 sextupoles
- Octupole coils in short quadrupoles
- warm beam pipe (38 cm inner diameter)
- iron dominated, cold iron (up to 37 tons)
- common helium bath (~1500 liter helium)
- per magnet 1 pair of current leads
- max. current <300A for all magnets

H. Leibrock

Superconducting magnets in Super-FRS

Multiplets:

- 31 Multiplets (+ 2 spare Multiplets).
- Magnet departments of GSI are preparing specification of superferric Multiplets based on principles of Toshiba's conceptual design study.
- Documents for procurement will be ready 2012.
- First Multiplet: 2015 (estimation)
- Last Multiplet: 2019 (estimation)

Dipoles:

- 24 dipoles
- Prototype built and tested
- Only very small modifications are required for the series
- France (CEA, Saclay) and Spain (CIEMAT, Madrid) are interested in superferric dipoles as contribution in kind.
- First dipole: 2014

H. Leibrock

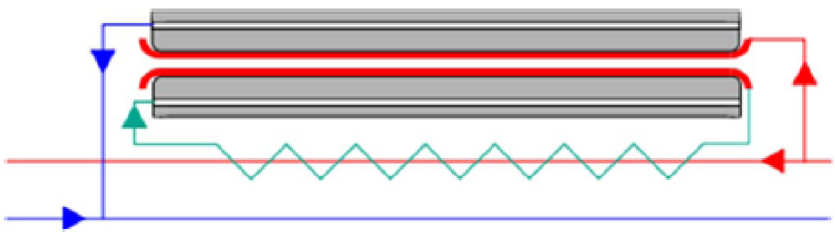
Super-FRS cryogenics [1/2]

- Superconducting magnets
  - The review panel strongly recommends that the final design of the multiplet be reviewed when completed
- Magnet cooling scheme
  - Lack of clear understanding and late changes (not documented) in the cooling method of S-FRS magnets, from forced-flow of saturated He to bath cooling
  - Bath cooling requires precise level control and thus top-feed with decanting in the cryostat: avoid bottom-feed of two-phase He, particularly with high vapor quality
  - Conversely, decanting in final cryostat relaxes need for subcooler in feed box and requirement for low transfer losses
  - The review panel recommends documenting the choice of cooling method and adapting the design of the dipole coil and multiplet cryostats accordingly
- Design pressures
  - Rather low and different for the two types of magnets
  - May result in large losses of He or very tight operational constraints
  - The review panel recommends reviewing and substantiating the choice of design pressures

Super-FRS cryogenics [2/2]

- Temperature gradients for CD/WU
  - Very tight constraints presented, without firm design basis
  - The review panel recommends defining these constraints on the basis of actual design requirements
- Operational flexibility
  - Multiplets cooled in small clusters
  - The review panel recommends clarifying the need for full independent cryogenic mode within each cluster
- Cryogenic distribution
  - Very complex cryolines and distribution boxes, with very constrained routing, resulting in large number of singularities and large intrinsic consumption of LHe (60% lost in distribution)
  - Very long transfer line for feeding the first elements of S-FRS
  - The review panel recommends re-examining the justification for this very long line and studying simpler routing

SIS100 parallel magnet cooling scheme



Inlet – sub-cooled helium

P_{in} = 1.5 bar, T_{in} = 4.5 K

Coil out:
P = 1.1 bar, two-pase (4.3 K)

Joke out:
P = 1.1 bar, two-phase, x = 0.9 – 1.0

Heat load:
static: 7 W
dynamic: up to 60 W (triangular cycle)

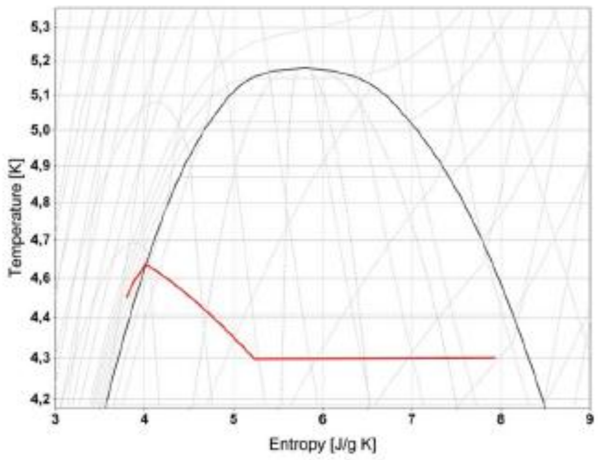
Mass flow: defined by the total heat load

Pressure dprop: defined by the mass flow rate and hydraulic resistance of cooling channels:

cable inner diameter: d = 4.7 mm iron yoke: d = 10 mm
dipole: L = 54 m + 54 m
quadrupole: L = 34 m + 27 m

A. Bleile

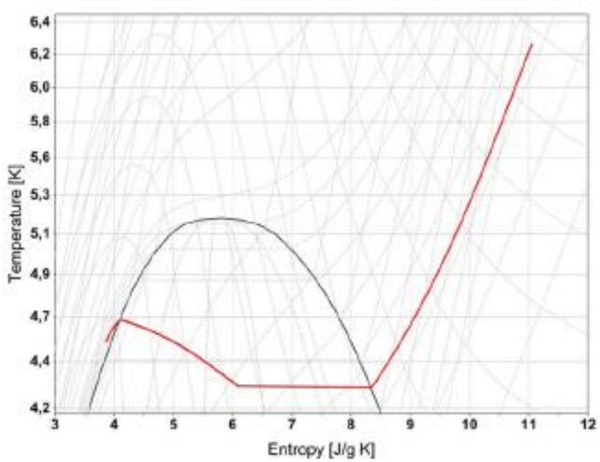
SIS100 dipole cooling for different magnet cycles



Busbar + Coil: 54 m + 54 m
Minor losses: $\xi = 26.0$

$P_1 = 1.6$ bar, $T_1 = 4.51$ K (subcooled)
$P_3 = 1.1$ bar, $T_3 = 4.31$ K

$P_{total} = 40$ W: m = 2.4 g/s
$x_2 = 0.30$
$x_3 = 0.88$



$P_{total} = 70$ W: m = 2.1 g/s
$x_2 = 0.56$
$T_3 = 6.52$ K

A. Bleile

Risks in two-phase cooling of SIS100 magnets

Potential problems:

- departure from nucleate boiling:
  not expected because of very small heat flux
- stratifyed flow patterns:
  dangerous only when occures in the coil
- instabilities of two-phase flow in vertical channels:
  should be small ($\rho_L/\rho_V \approx 7$)
- instabilities due to parallel channels
  Arrangements needed for parallel cooling:
  subcooled helium in the supply header
  bypass valve in the end box
  adjustments of hydraulic resistance for each channel

A. Bleile

Compared cooling schemes of SIS100 & Nuclotron

Nuclotron:
- 2 sectors
- 100 parallel chanels / sector
- 4.0 mm cable inner diameter
- beam vacuum chamber cooled by yoke

SIS100:
- 6 sectors
- 47 parallel chanels / sector
- 4.7 mm cable inner diameter
- beam vacuum chamber cooled by helium flow

Conclusions on SIS100 magnet cooling scheme

- SIS100 cooling systems is based on Nuclotron design
- the number of parallel channels is reduced by factor of two
- the phase separation in the coil is not expected
- adjustment of hydraulic resistance has to be performed for each type of cooling channel
- additional valve can be installed on each channel for fine adjustement

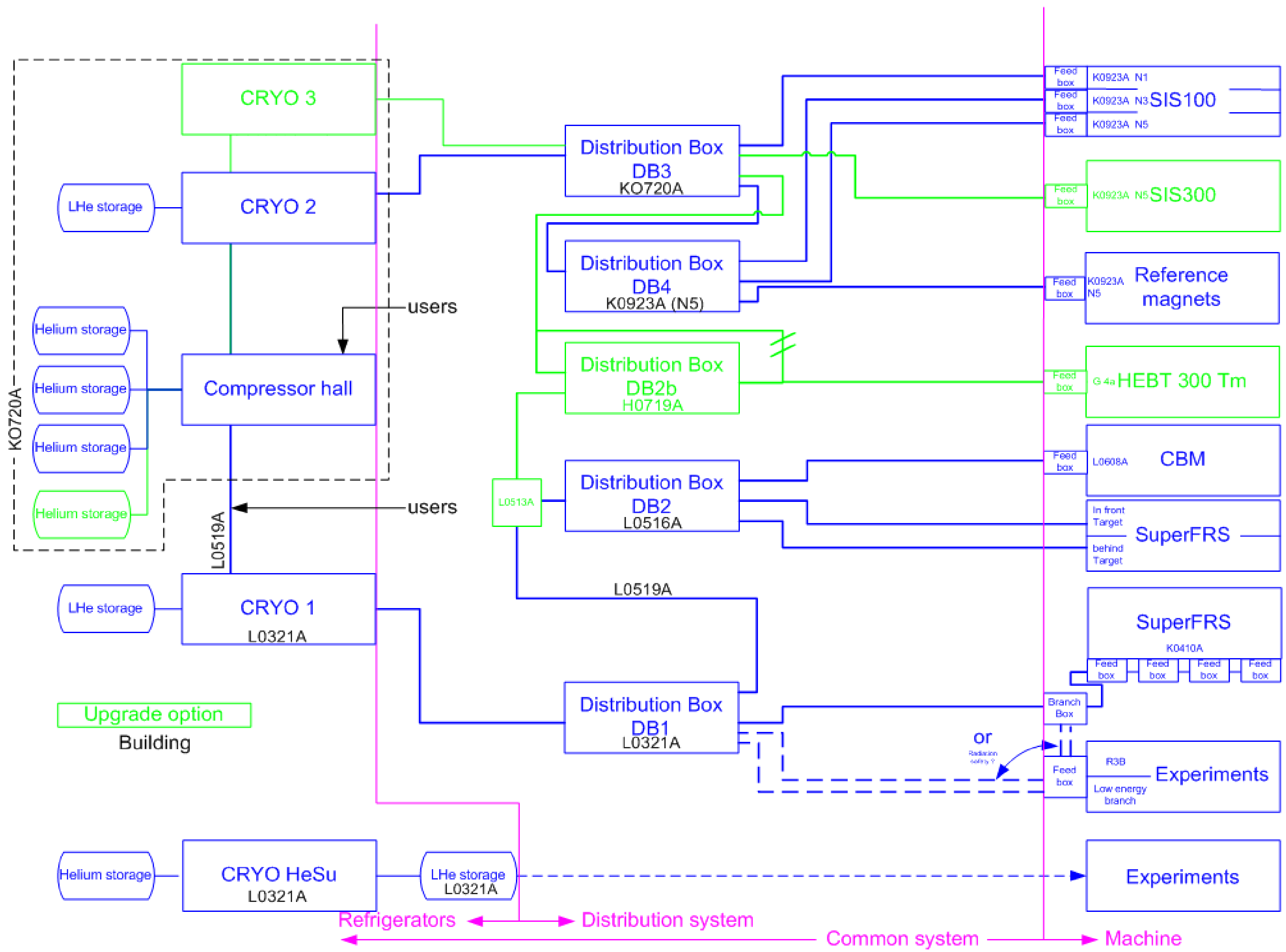
SIS100 cryogenics [1/2]

- SIS100 cryogenics govered by dynamic loads due to accelerator cycles
  - Variety of operating modes studied and corresponding heat loads defined
  - Together with static heat loads from cryostat design, this is a sound basis for specification of SIS100 cryogenic requirements
- Magnet cooling scheme based on parallel flows of two-phase helium across full liquid-to-vapor range, with no active balancing
  - Appears to violate good design practice; however works in Nuclotron!
  - Compliance provided by large cooling load and allowed temperature excursions of yoke (in series with coils), as well as excess He flow (resulting in thermodynamic inefficiency)
  - Still, precise balancing of parallel circuits required by construction and to be maintained (risk of clogging by contaminants)
  - The review panel welcomes the construction of a thermo-hydraulic model in a first stage, and the testing of magnets and a magnet string in a later stage, for full validation of the cooling scheme

SIS100 cryogenics [2/2]

- Design pressure of 1.8 MPa
  - Should help contain He inventory in case of quench or unforeseen stop of refrigerator
- Sectorization
  - The review panel appreciates the proposed vacuum & cryogenic sectorization in 150-m long sectors, to ease leak detection and allow localized interventions on the machine
- Electrical feed-boxes with HTS leads
  - Two possible cooling schemes were presented
  - The review panel firmly favors that with LHe phase separator providing fixed-temperature heat sink for electrical connexions

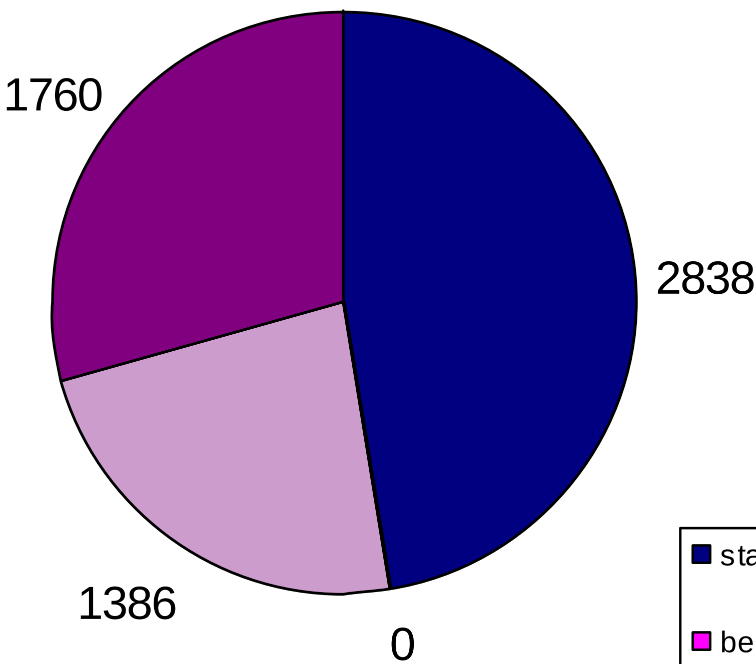
Cryogenic system architecture



M. Kauschke

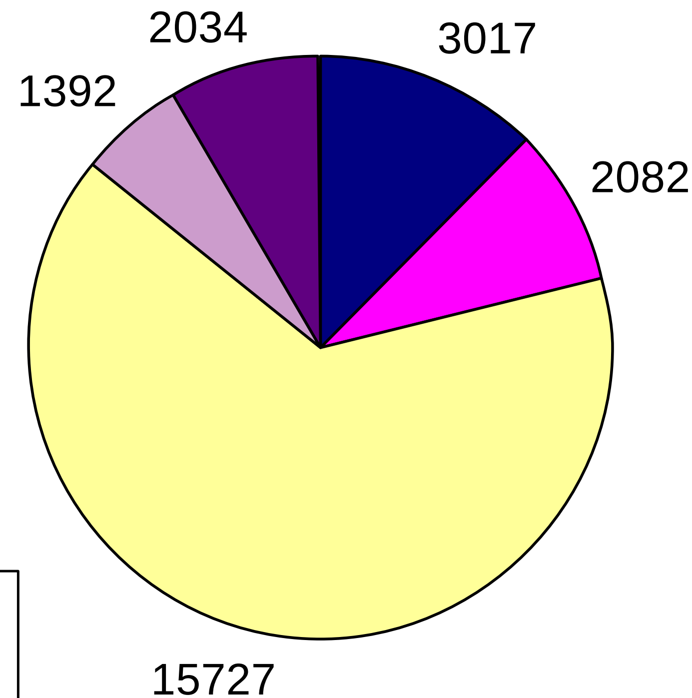
Refrigerator cooling duties

CRYO 1



Σ ~ 6 kW

CRYO 2



- static load @ 4K
- beam induced losses
- dynamic load @ 4K
- liquefaction
- static load @ 50-80K (4K equivalent)

Σ~ 24 kW

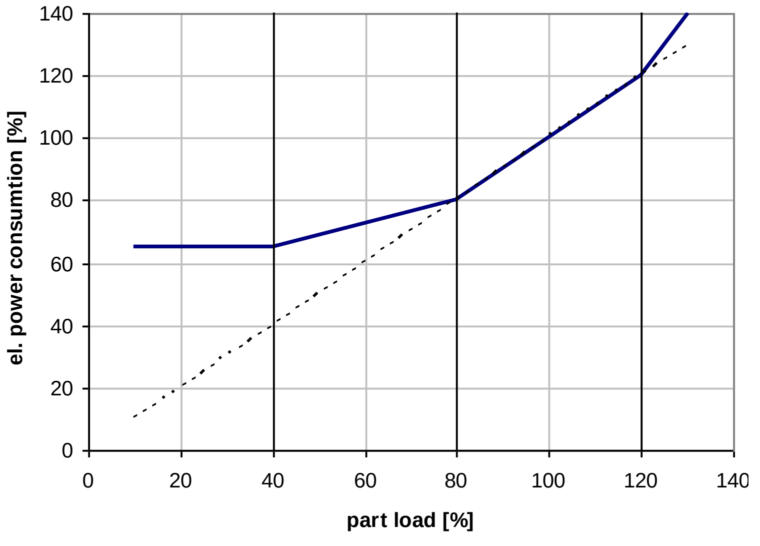
=> 2 design points for operation @ 230W/ W

Including the safety factor 1.5 (TAC 2007)

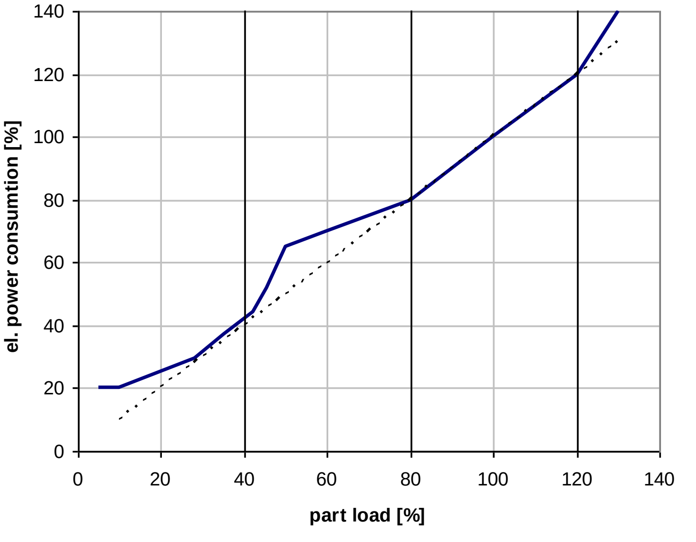
M. Kauschke

Requested part-load efficiency of refrigerators

CRYO 1

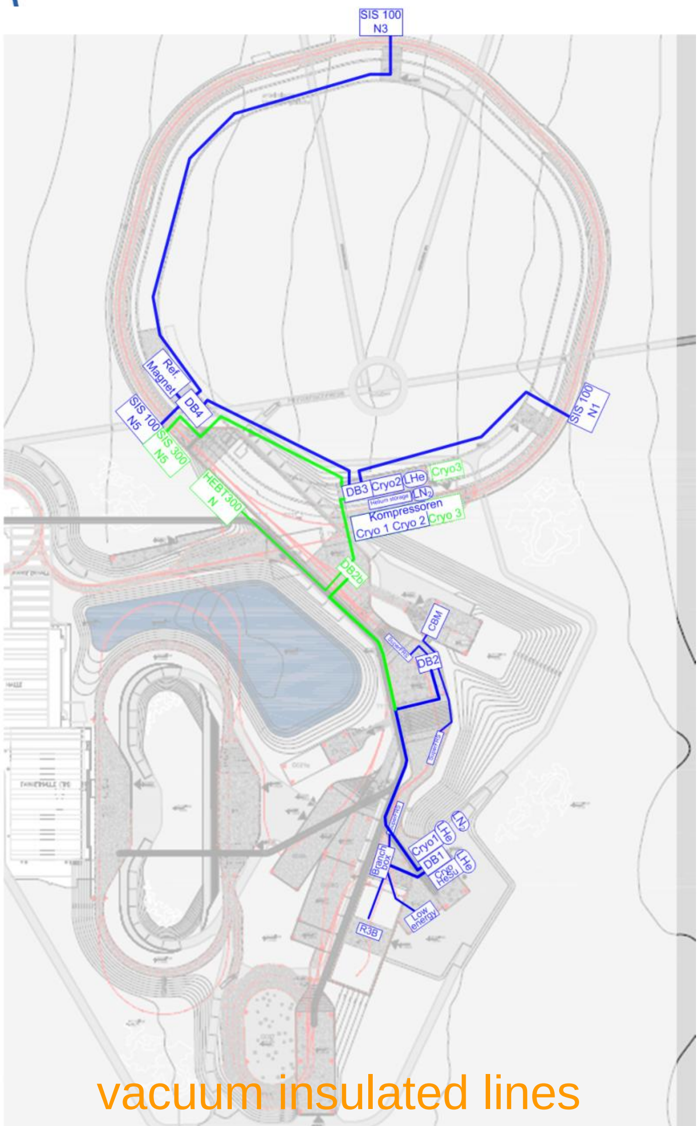


CRYO 2

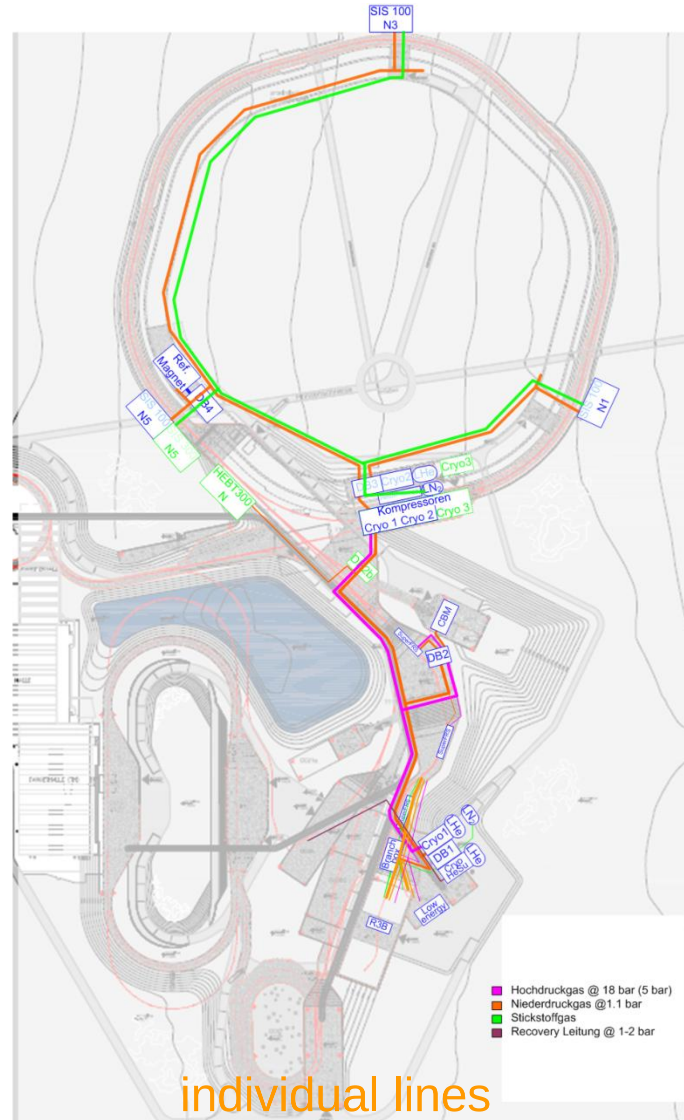


M. Kauschke

Cryogenic distribution layout



vacuum insulated lines



individual lines

M. Kauschke

Cryogenic refrigeration and controls

- General architecture
  - Common compressor station for CRYO1 and CRYO2 provides some redundancy
  - However, strict allocation of CRYO1 and CRYO2 plants to their respective users precludes mutualization of overcapacity and redundancy
- Heat loads and refrigerator cooling duties
  - Sizing method presented, including 50% overcapacity factor
  - Correspondence between calculated heat loads and plant sizing not given explicitly
- Part-load efficiency
  - The review panel appreciates the quest for preserving plant efficiency at part load
  - However, the review panel recommends reconsidering the requirement of maintaining full efficiency at 25% load for CRYO2, which will likely result in 2-in-1 coldbox construction with high investment cost
- Additional 1.5 kW @ 4.5 K cryoplant for magnet test station
  - Resources for procuring and commisioning this plant do not seem to exist
- Control system
  - The review panel supports the approach of implementing a control system based on CERN UNICOS
  - The review panel points out that resources will be needed in the cryogenics group to provide input to the controls team