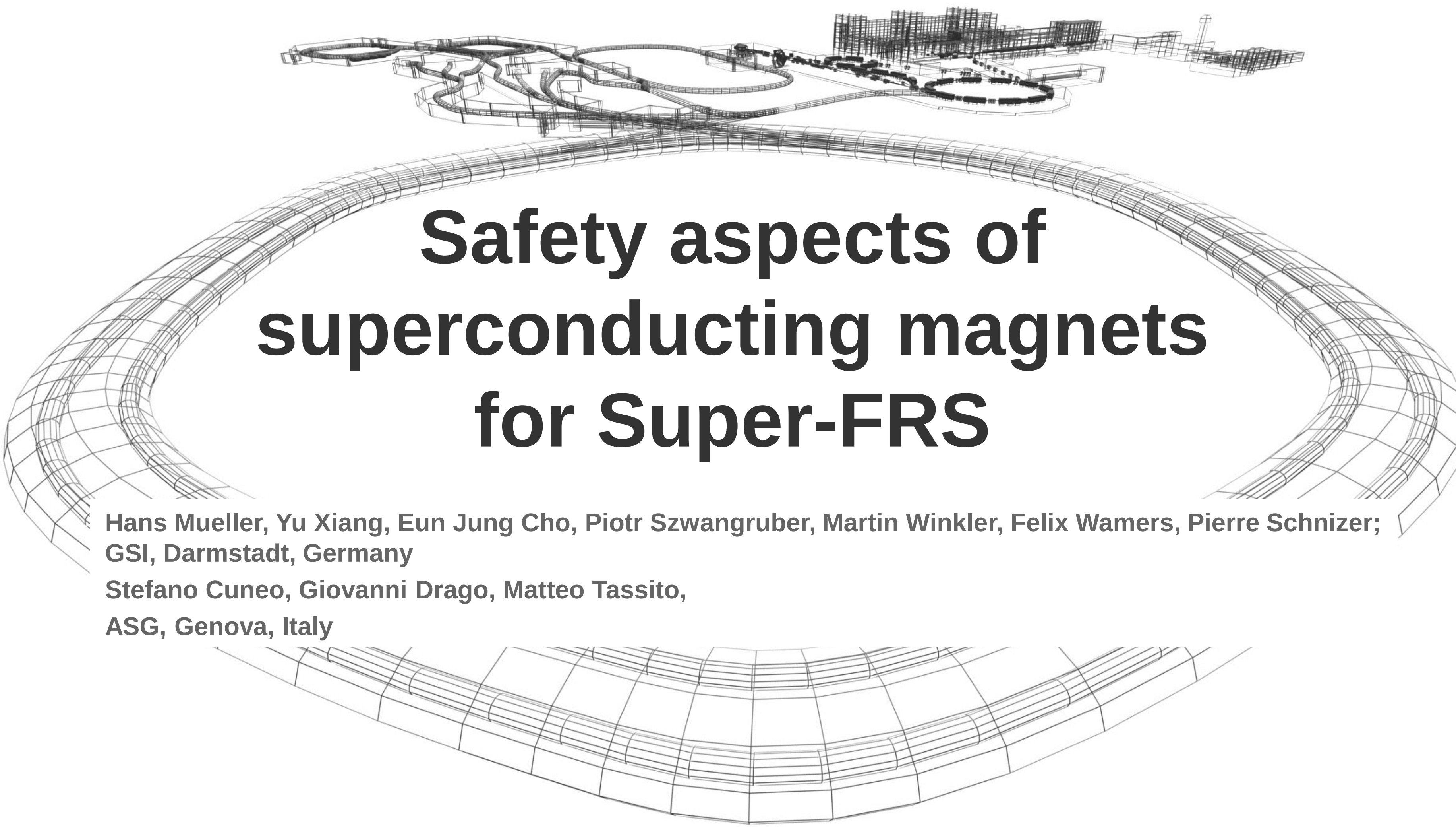


Safety aspects of superconducting magnets for Super-FRS

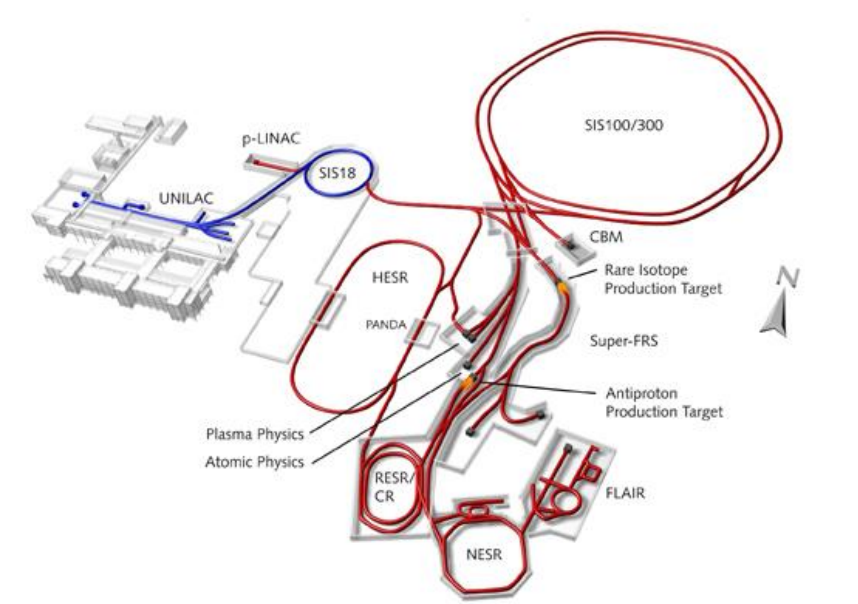
Hans Mueller, Yu Xiang, Eun Jung Cho, Piotr Szwangruber, Martin Winkler, Felix Wamers, Pierre Schnizer; GSI, Darmstadt, Germany

Stefano Cuneo, Giovanni Drago, Matteo Tassito,

ASG, Genova, Italy

- What is Super-FRS
- SC- Magnets of Super-FRS
  - Dipoles
  - Multiplets
- Safety aspects
  - Pressure
  - Electrical
  - Other

What is Super-FRS



- Facility for Antiproton and Ion Research (FAIR)
- to be built at GSI Darmstadt
- Experimental pillars
  - CBM
  - PANDA
  - APPA
  - NUSTAR

What is Super-FRS

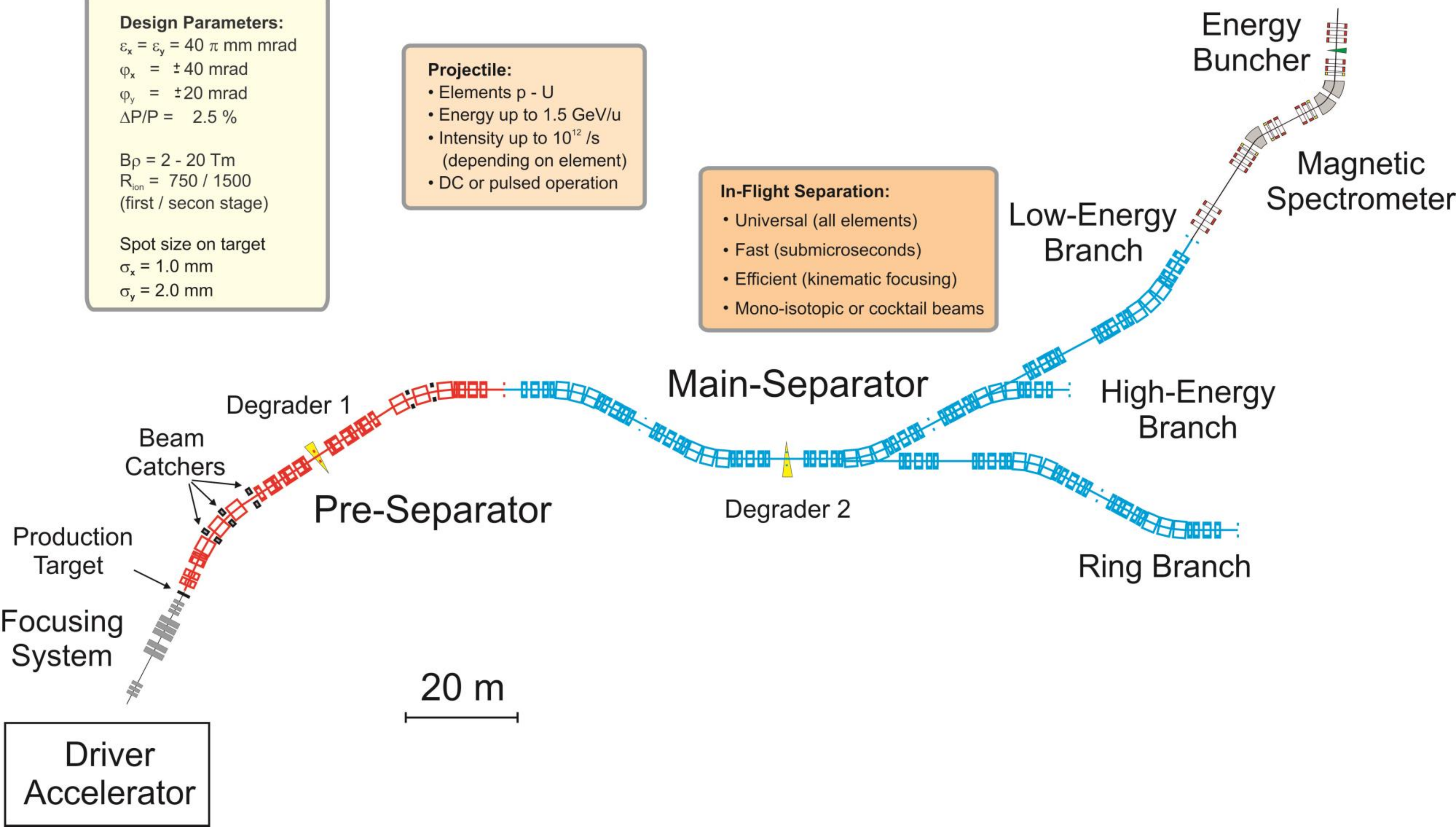
Design Parameters:
$\varepsilon_x = \varepsilon_y = 40\ \pi$ mm mrad
$\varphi_x = \pm 40$ mrad
$\varphi_y = \pm 20$ mrad
$\Delta P/P = 2.5$ %

$B\rho = 2 - 20$ Tm
$R_{ion} = 750 / 1500$
(first / secon stage)

Spot size on target
$\sigma_x = 1.0$ mm
$\sigma_y = 2.0$ mm

Projectile:
- Elements p - U
- Energy up to 1.5 GeV/u
- Intensity up to 10^{12} /s (depending on element)
- DC or pulsed operation

In-Flight Separation:
- Universal (all elements)
- Fast (submicroseconds)
- Efficient (kinematic focusing)
- Mono-isotopic or cocktail beams



SC-Magnets: Design principles

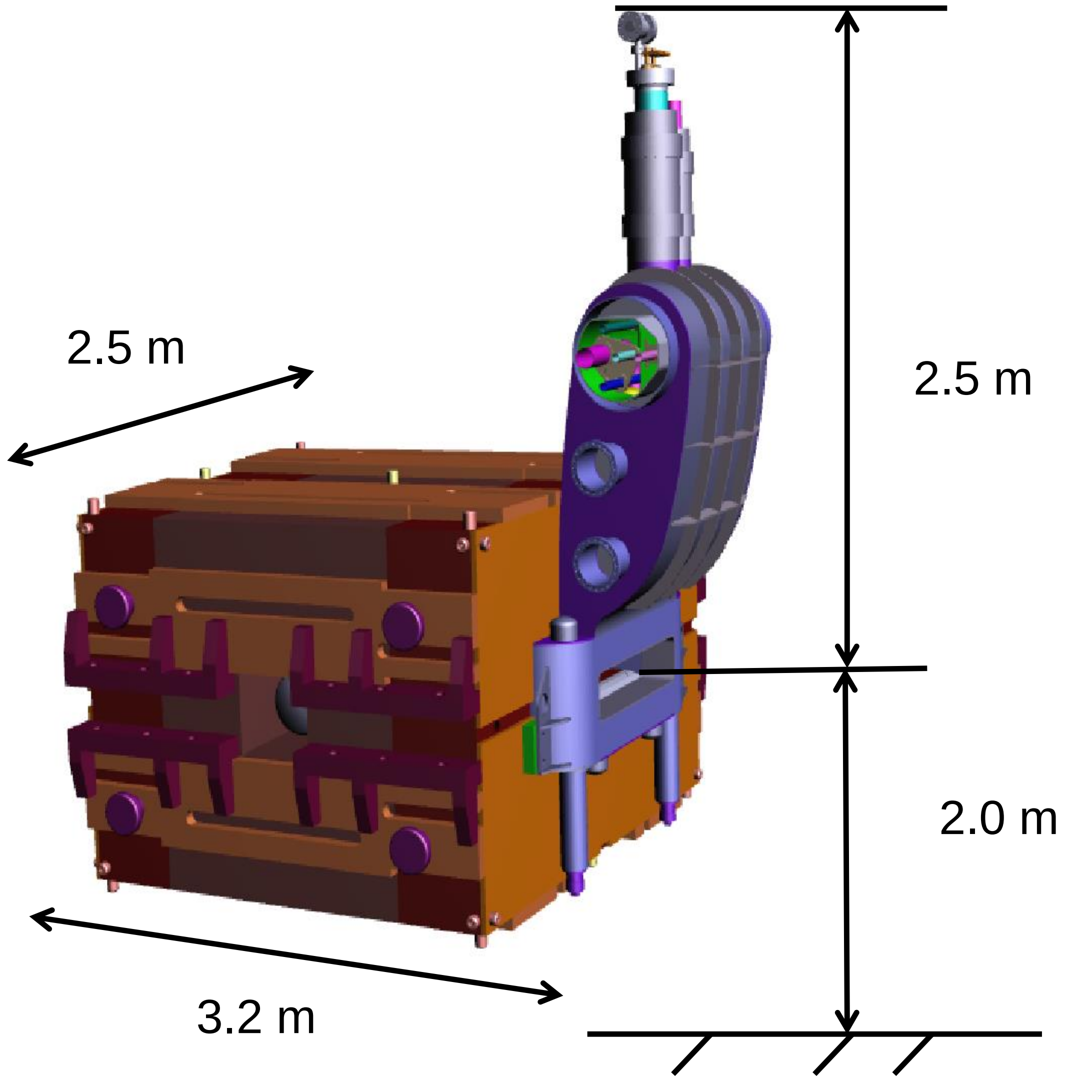
- Large acceptance → large aperture
- Superferric (magnetic field shaped by iron yoke)
- Cooling by LHe bath (dipoles 45 l; Multiplets 1200 l)
- Individually powered magnets → max.operation current < 300 A
  → high inductivity
- Different setting should be adjustable in reasonable time
  → ability for 3 consecutive triangular cycles with t_r=120 sec.
- Common cryo-system with SIS100 and avoiding loss of Helium
  → 20 bar design pressure
- Quench Protection Scheme:
  - main dipoles and quads: energy extraction resistor
  - steering dipoles, sextupoles & octupoles: self-protecting
- Warm beam pipe

Super-FRS Dipoles

	Arranged in groups of 3	
	Dipole Type 2	Dipole Type3
Number of Magnets	3	21
Effective length	2.40 m	2.13 m
Gradient/ Field Range	0.15-1.6 T	0.15-1.6 T
Field Quality	$\pm 3 \times 10^{-4}$	$\pm 3 \times 10^{-4}$
Usable aperture	380x140 mm	380x140 mm

Remark: 3 of the dipoles of type 3 are branching dipoles with an additional straight exit.
No design exists up to now for these 3 magnets

Super-FRS Dipole (conceptual design by CEA)



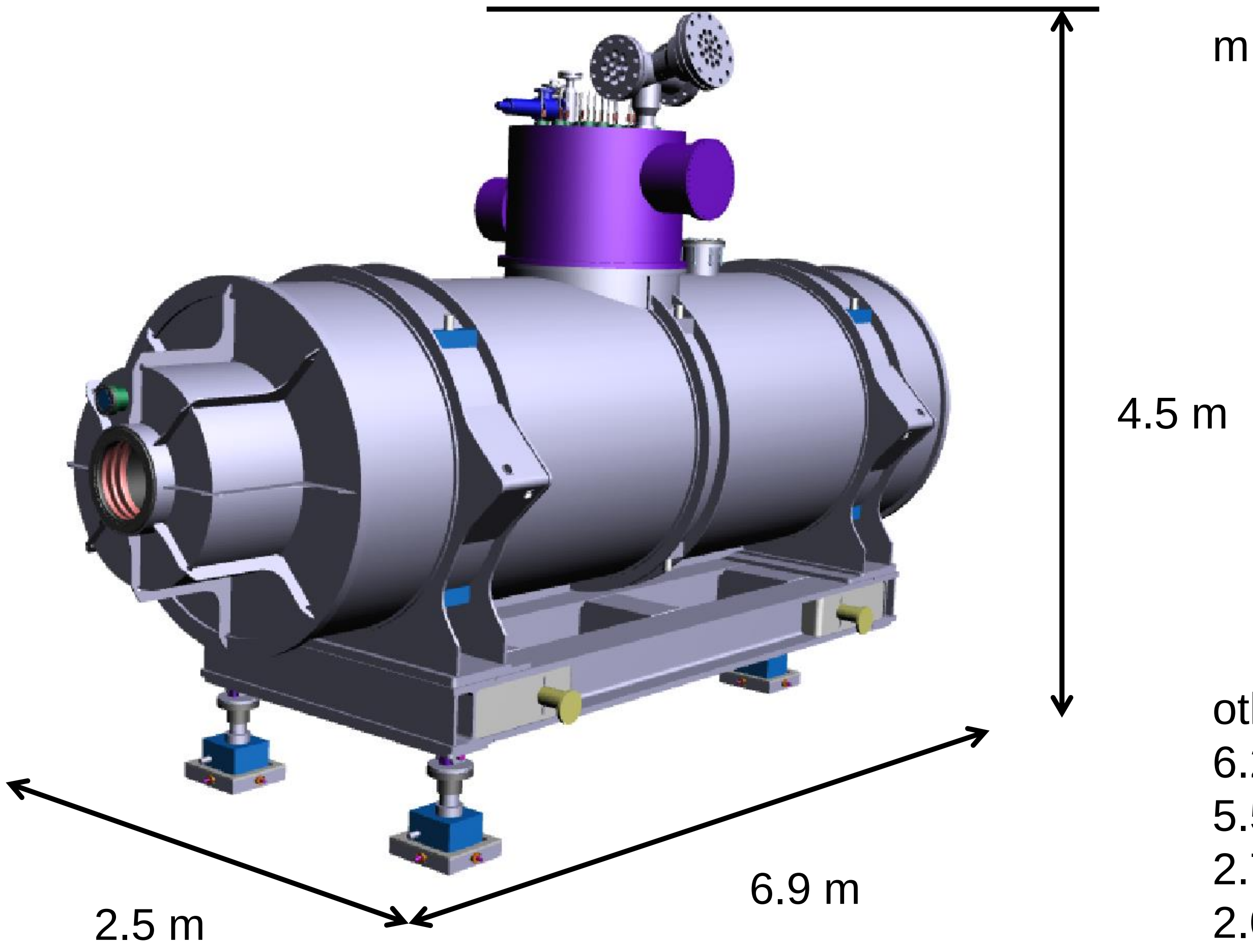
Dipole (9.75°)
E=450 kJ
L=15.4 H
I = 245 A
m= 50 t
warm iron

Super-FRS Multiplets

	Arranged in 33 Multiplets (2-9 magnets)			
	Quadrupole Type 3	Quadrupole Type 4	Sextupole	Steerer
Number of Magnets	46	34	41	14 (13v/1h)
Effective length	0.8 m	1.2 m	0.5 m	0.5 m
Gradient/ Field Range	1.0-10 T/m	1.0-10 T/m	4-40 T/m2	0-0.2 T
Field Quality	$\pm 1 \cdot 10^{-3}$	$\pm 1 \cdot 10^{-3}$	$\pm 5 \cdot 10^{-3}$	
Usable aperture	Ø 380 mm	Ø 380 mm	Ø 380 mm	Ø 380 mm
Inductance	30 H	43 H	1.04 H	0.067 H
Nominal max, current	300 A	300 A	291 A	280 A
Stored Energy	670 kJ	950 kJ	37 kJ	2.6 kJ

In quadrupoles type 3 an octupole magnet with gradient 105 T/m^3 is embedded

Super-FRS long multiplet (ASG)

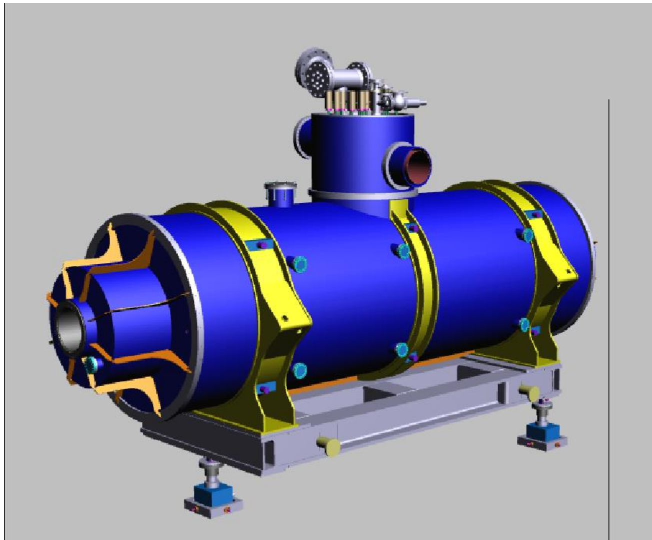


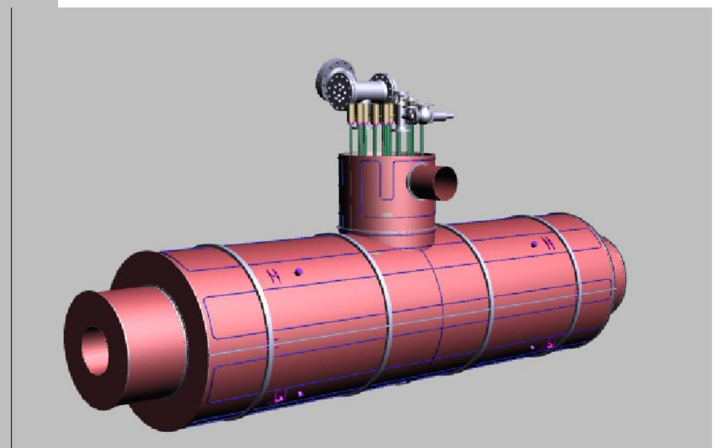
m = 70 t

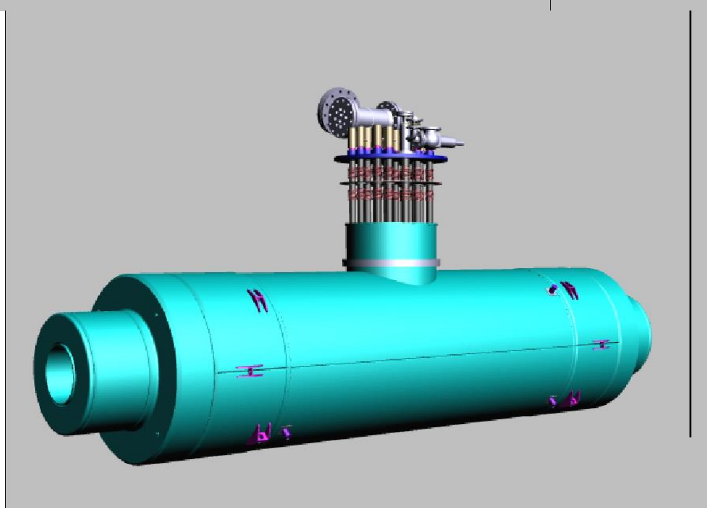
other lengths:
6.2 m
5.5 m
2.7 m
2.0 m

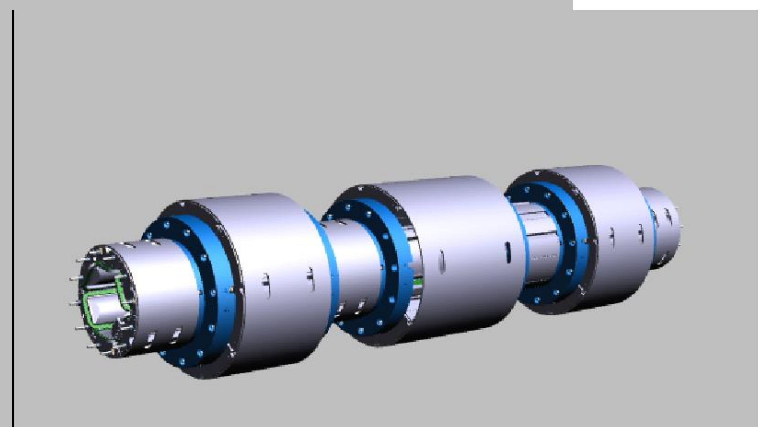
Super-FRS long multiplet

Design and manufacturing of multiplet according to AD2000









Risk Analysis Multiplets

RISK ID	DESCRIPTION	MITIGATION	PROBA BILITY	IMPACT	RATING
1 Injury of Personnel					
1.0	Electric short	none	2	4	8
		insulation, design by code, quality control, operating and safety instructions, personal safety equipment (insulating gloves and shoes), warning panels, access restrictions,	1	3	3
1.1	LHe vessel overpressure	none	2	3	6
		redundant safety valves, design by code, operating instructions	2	2	4
1.2	Vacuum vessel overpressure	none	2	4	8
		safety valves, design by code	2	2	4
1.3	Cryogen release	none	2	4	8
		Cryogen release Safety instructions, warning panels, protections shields, personal safety equipment (life support systems), personnel training, access restrictions	2	3	6
1.4	Static stability	none	2	4	8
		structural design with safety factors, seismic stability analysis, alignment limits, installation instructions, access restrictions	1	4	4
1.5	Fall while lifting	none	2	4	8
		design by code, CE labelling, operation manual, safety rules, personal protection devices, warning panels, access restrictions	1	4	4
1.6	Fall	none	3	4	12
		access ladders with protections balustrades, operation manual, personal protection devices	2	2	4
1.7	Heavy item fall	none	3	3	9
		lifting points, operation manual, personnel training, personal protection devices, appropriate tooling recommendation	2	2	4

EUROPÄISCHE KOMMISSION

Pressure Equipment Directive 97/23/EG - European Union

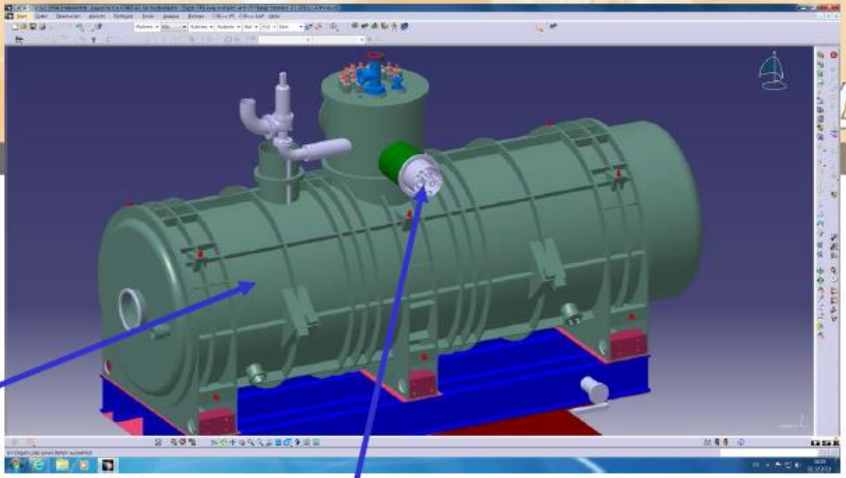
Brüssel, den 28.6.2013
COM(2013) 471 final

2013/0221 (COD)

Vorschlag für eine

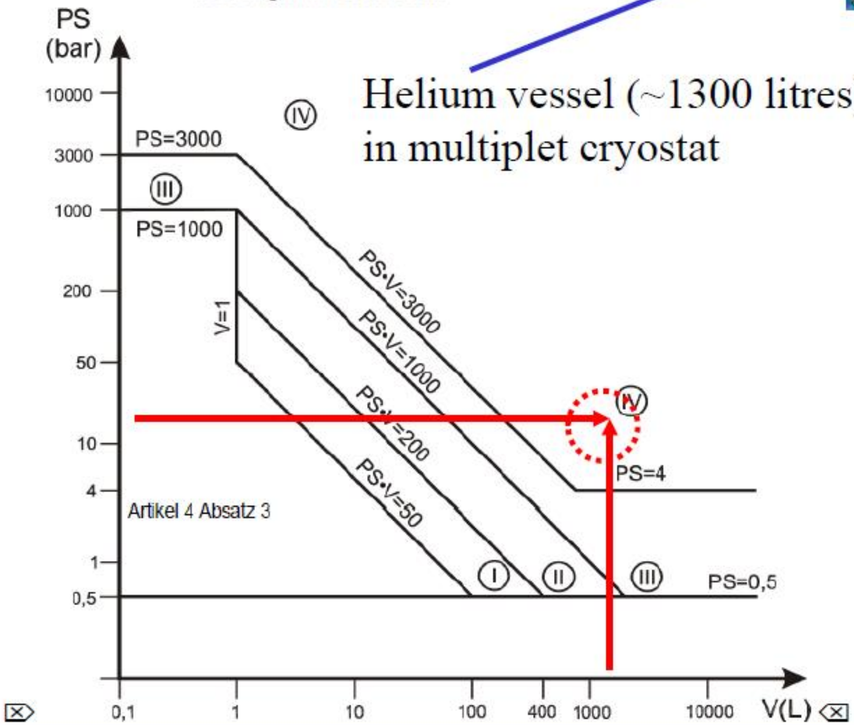
RICHTLINIE DES EUROPÄISCHEN PARLAMENTS UND DES RATES

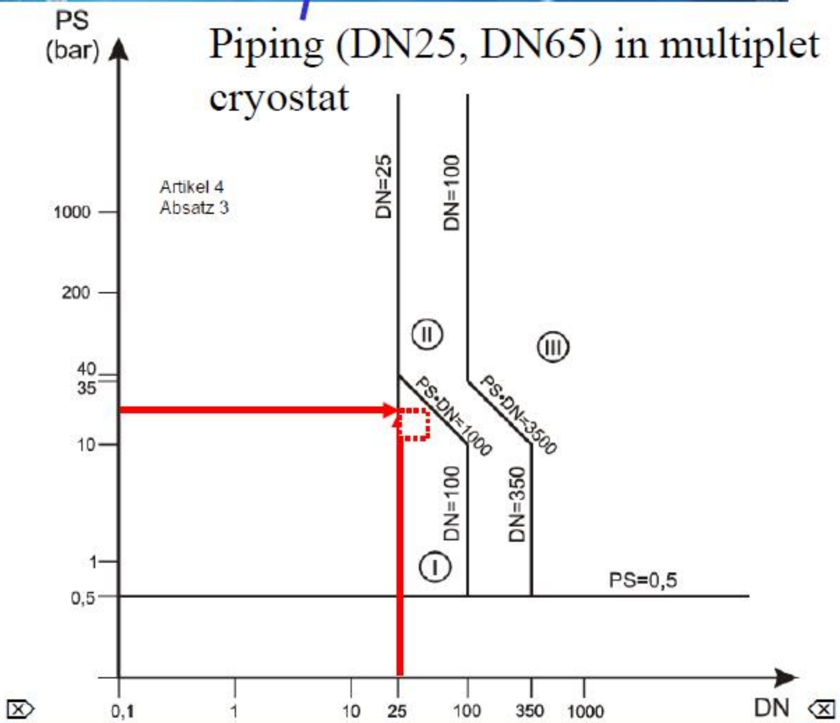
zur Harmonisierung der Rechtsvorschriften der Mitgliedstaaten über die Bereitstellung von Druckgeräten auf dem Markt



Helium vessel (~1300 litres) in multiplet cryostat

Piping (DN25, DN65) in multiplet cryostat





Vessel and pipings for liquid and its vapor whose pressure is 0.5 bar more than atmosphere (1.013 bar) at its maximum allowed temperature.

EUROPÄISCHE KOMMISSION

Pressure Equipment Directive 97/23/EG - European Union

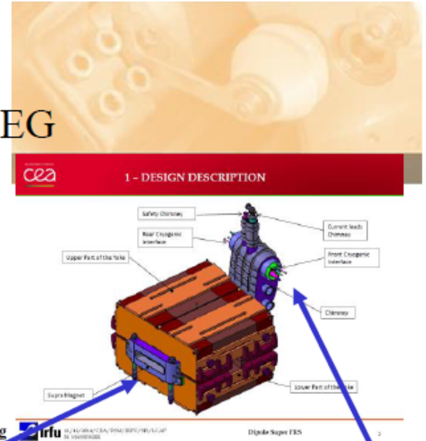
Brüssel, den 28.6.2013
COM(2013) 471 final

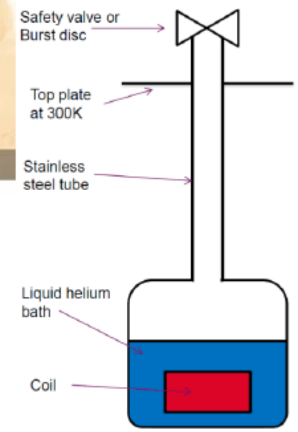
2013/0221 (COD)

Vorschlag für eine

RICHTLINIE DES EUROPÄISCHEN PARLAMENTS UND DES RATES

zur Harmonisierung der Rechtsvorschriften der Mitgliedstaaten über die Bereitstellung von Druckgeräten auf dem Markt





Bath equations :
- Assumption : 1 mixed phase model
- Assumption : All the energy dissipated in the coils goes to the helium bath
- Mass balance :

$$V_b \frac{\partial \rho}{\partial t} = -\dot{m}$$

- Enthalpy balance :

$$\rho V_b \frac{\partial h}{\partial t} = Q - \dot{m}h - V_b \frac{\partial p}{\partial t}$$

Bath parameters :
- Total volume : 44.1 liters
- Liquid volume : 21.5 liters
- Initial conditions : 1 bar, 4.2 K

Helium vessel (~45 litres) in dipole cryostat

Category II:
PS x V = 20 bar (design pressure) x 45 litres = 900 < 1000

Piping (8 mm, DN25, DN65) in CEA dipole cryostat

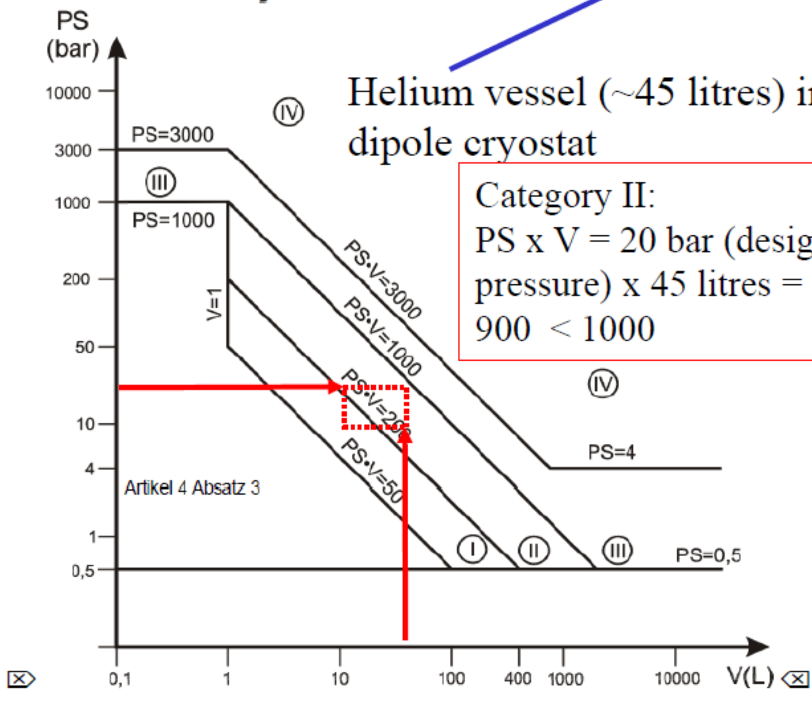


Diagramm 2

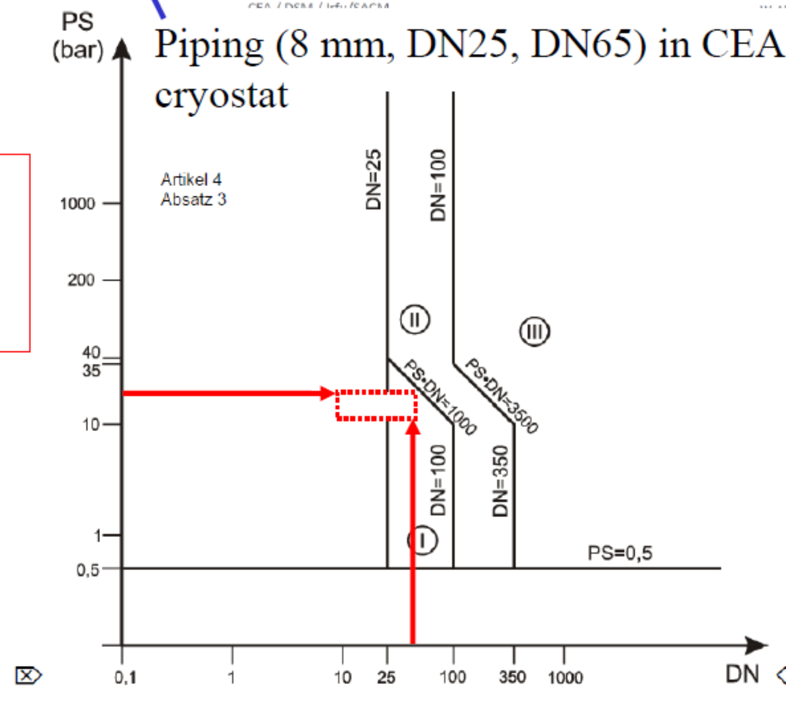


Diagramm 6

Dipole will be treated in any case as category III vessel (notified body involvement)

Safety device calculations multiplet

L-He vessel: 20 bar

- Most catastrophic event for sizing:

  → loss of insulation vacuum

  → magnet(s) quench

  + dump resistor(s) fails

- Safety devices:
  - Safety valve (opening pressure 20 bar; min. orifice diameter 25 mm)
  - Rupture disc (additional device at 23.5 bar)

Safety device calculations multiplet

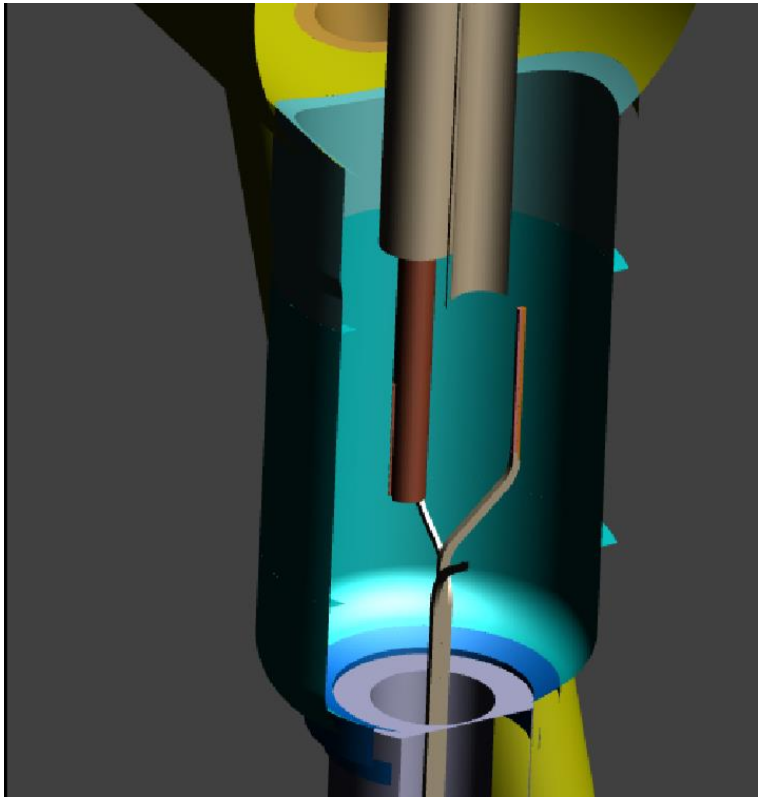
Vacuum vessel: 1.3 bar

- Most catastrophic event for sizing:
  after quench pressure rise in LHe circuit to 20 bar
  → rupture of He line and leakage of He-gas into the vacuum vessel
  → further rise of He temperature (and pressure)

- Safety device:
  - Drop-off plate (212 mm diameter)

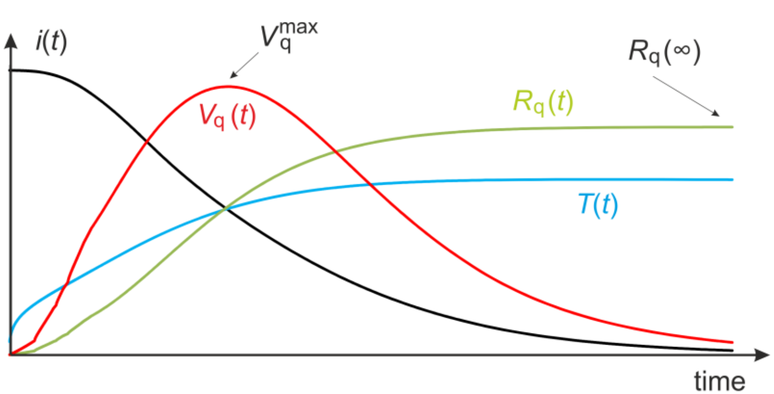
Safety device calculations dipole

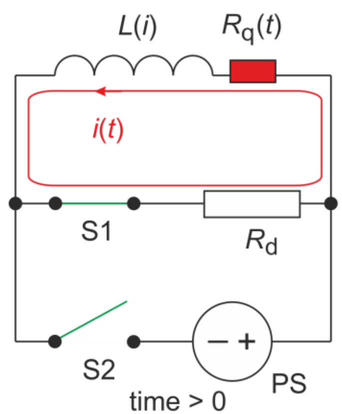
- Similar to multiplet
- Additionally:
- Possibility of arc formation due to opening of a joint
  - (Not an issue for multiplets because joints are far away from He-vessel wall)
  - About 1.47 cm^3 stainless steel could be melted
  - Mitigation actions necessary (increasing tube thicknesses re-inforce wire insulation; G10 supporting parts)

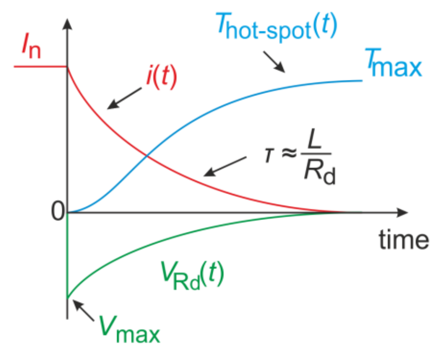


Voltages and temperatures during quench

Magnet	Rd [Ω]	Rqmax [Ω]	Vqmax [V]	Tmax [T]	Vmax-coil to ground (ground in the middle) [V]
Dipole	0	5.2	441	105	220
	2.8	1.1	90	53	± 360
Long quadrupole	0	17.8	2130	180	1600
	2.8	11.3	1110	137	± 950







current leads

- Vapour cooled
- Instrumentation:
  - Temperature sensors on 90% of length (for valve regulation)
  - Temperature sensors on warm terminal
  - Heaters on warm terminal (to prevent icing)
  - Voltage taps
    - Middle of magnet
    - End of the magnets
    - Top of current leads
- All instrumentation has to survive voltages during quench
  - Proper insulation of temperature sensors and heaters required
  - Voltage tap spacing has to consider Paschen effect
  - HV-tests at 2.5 kV are required.

Electrical safety: Paschen curve

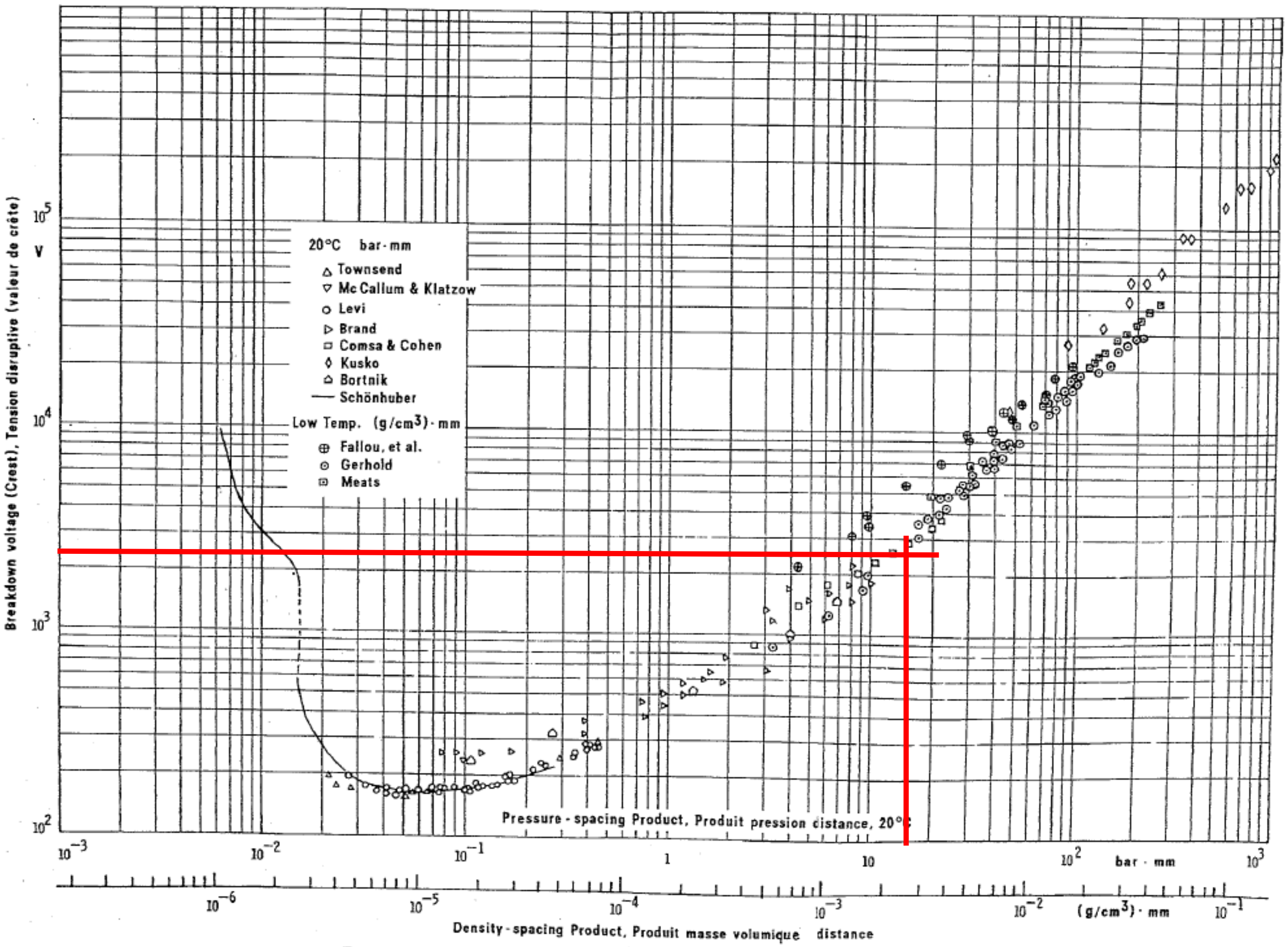


Figure G1 — Courbe de Paschen pour l'hélium en échelles logarithmiques. Température 20°C.
Paschen curve for helium in log log scale. Temperature 20°C.

Spacing between pins for adjacent voltage taps > 20 mm

Other electrical tests

- Electrical continuity test
    - For large inductance magnets check the presence and order of V-taps at max 100 mA and protect the current source with a resistor equivalent to the dc resistance of the coil at warm
    - Control the current source via software at 0.1 A/s
  - → **very dangerous due to the high inductance (up to 40 H)**
- Inductance measurement with V-I method
    - A standard RLC might be damaged and therefore is not recommended
- Capacitor discharge to investigate the turn-to-turn insulation
    - Is the meter used at CERN suitable for 40 H magnet?

Other safety issues

- Weight of magnets (up to 70 t)

→support frame and lifting devices have to be CE- certified

- Cryogenic connection instrumentation flange at >3 m height

→ instructions/measures for workers protection necessary

Conclusions

- Magnet design driven by requirements of machine
- Risk analysis of magnets
- Find mitigation actions
  - Designing/manufacturing according to standards
  - Instructions for operating testing

- Risk analysis for test station / machine operation

  .. but that´s another topic

Thank you