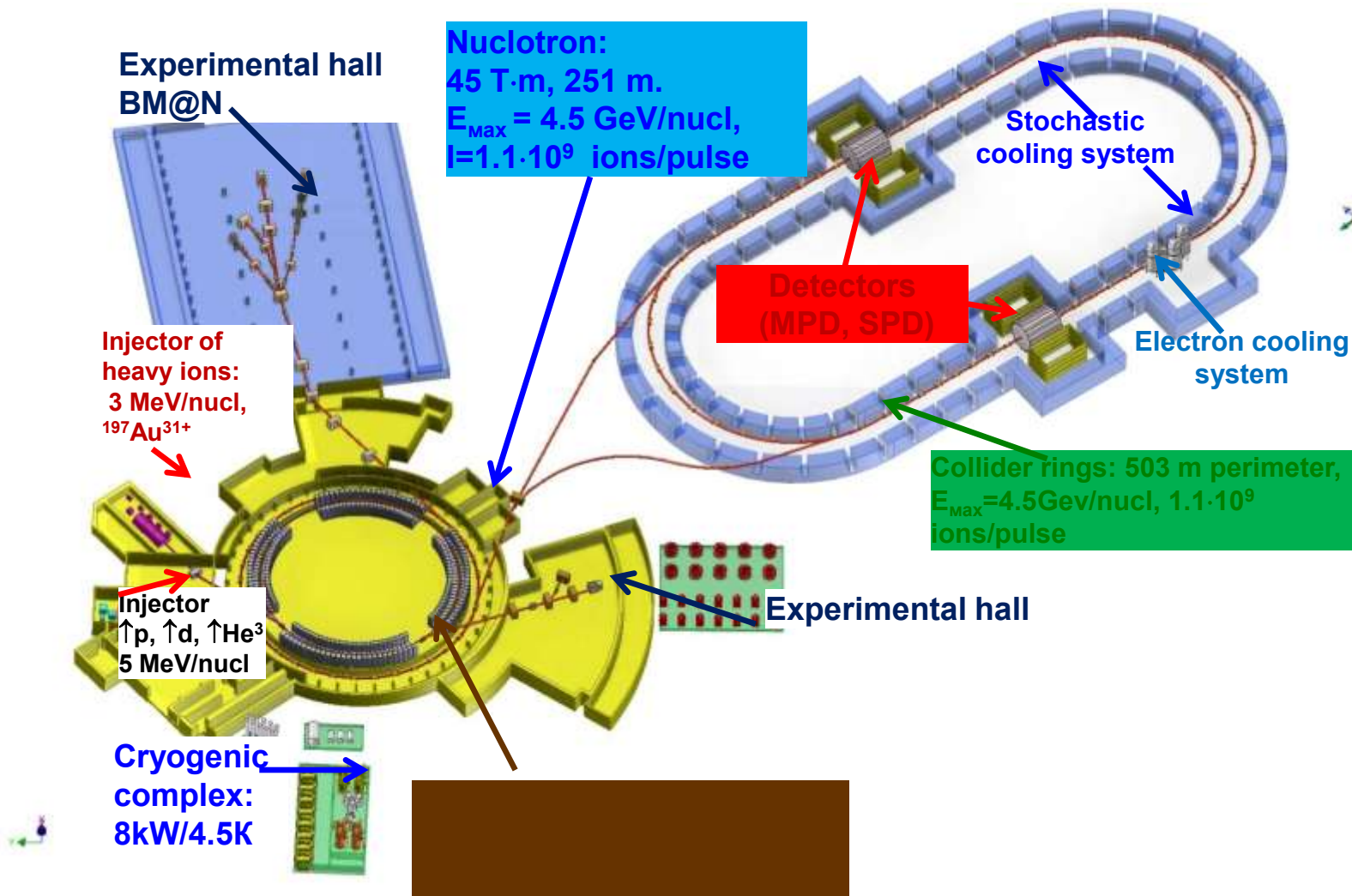




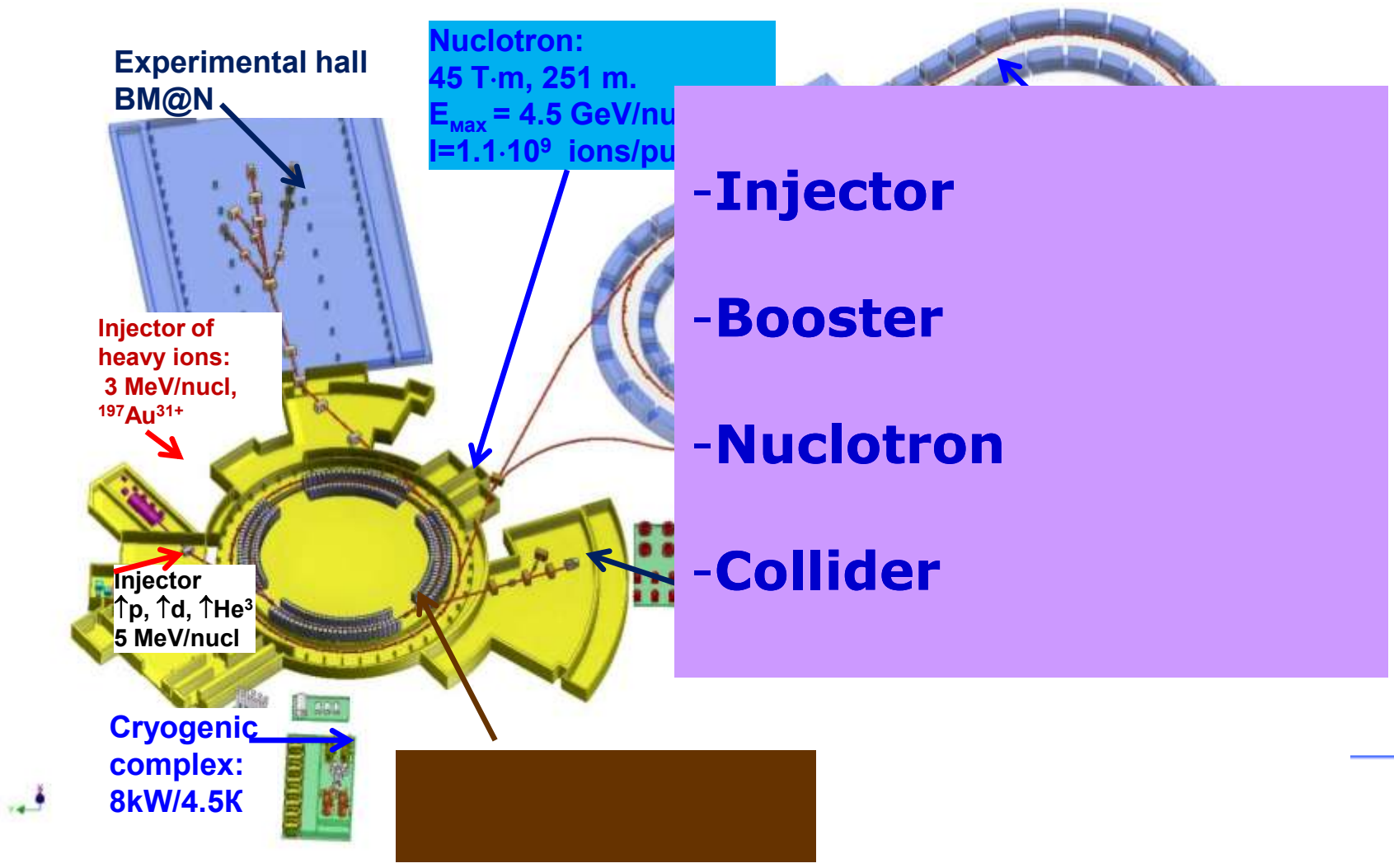
Facility for Assembling and Testing of SC Magnets for NICA and FAIR projects



NICA facility

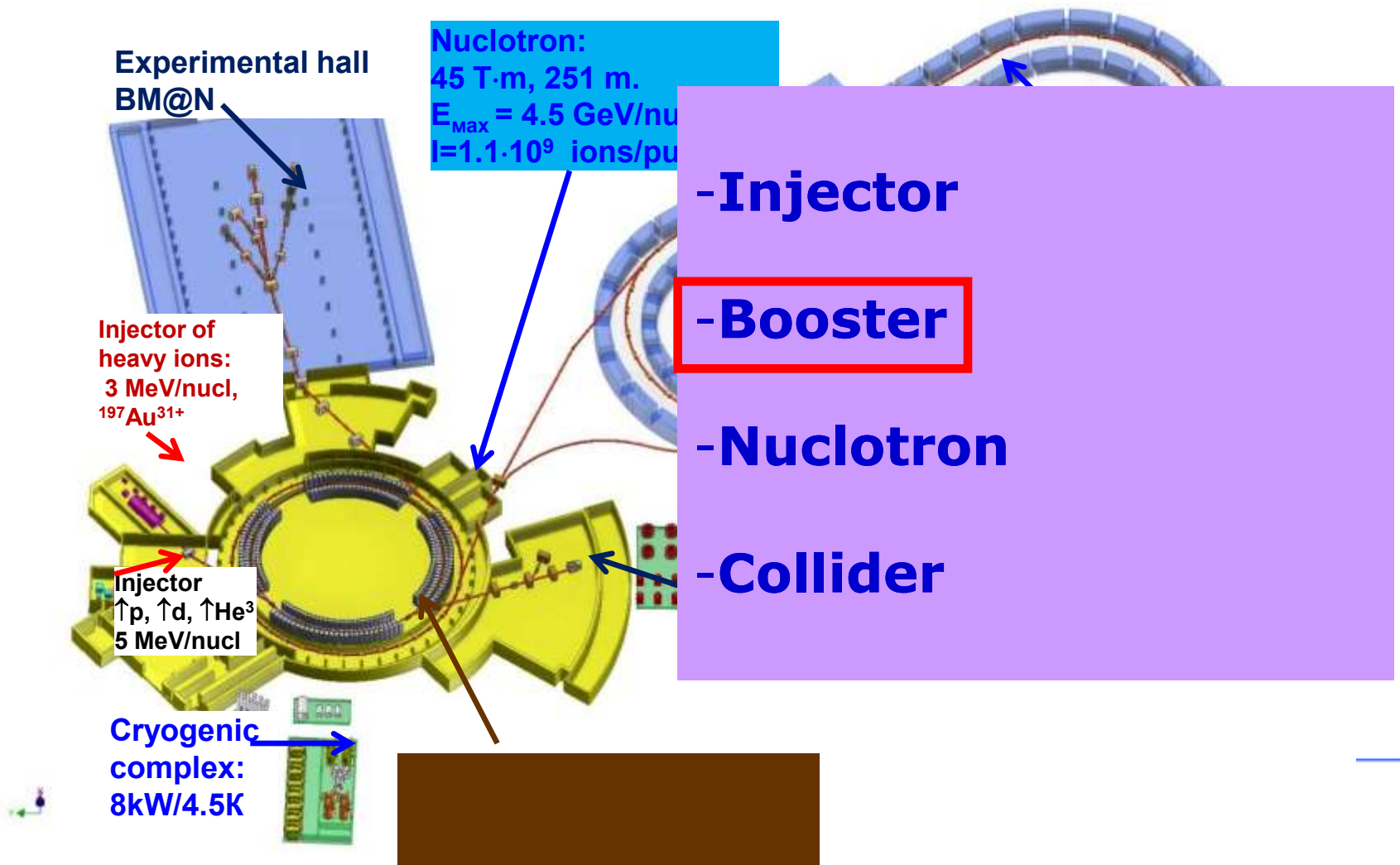


NICA facility





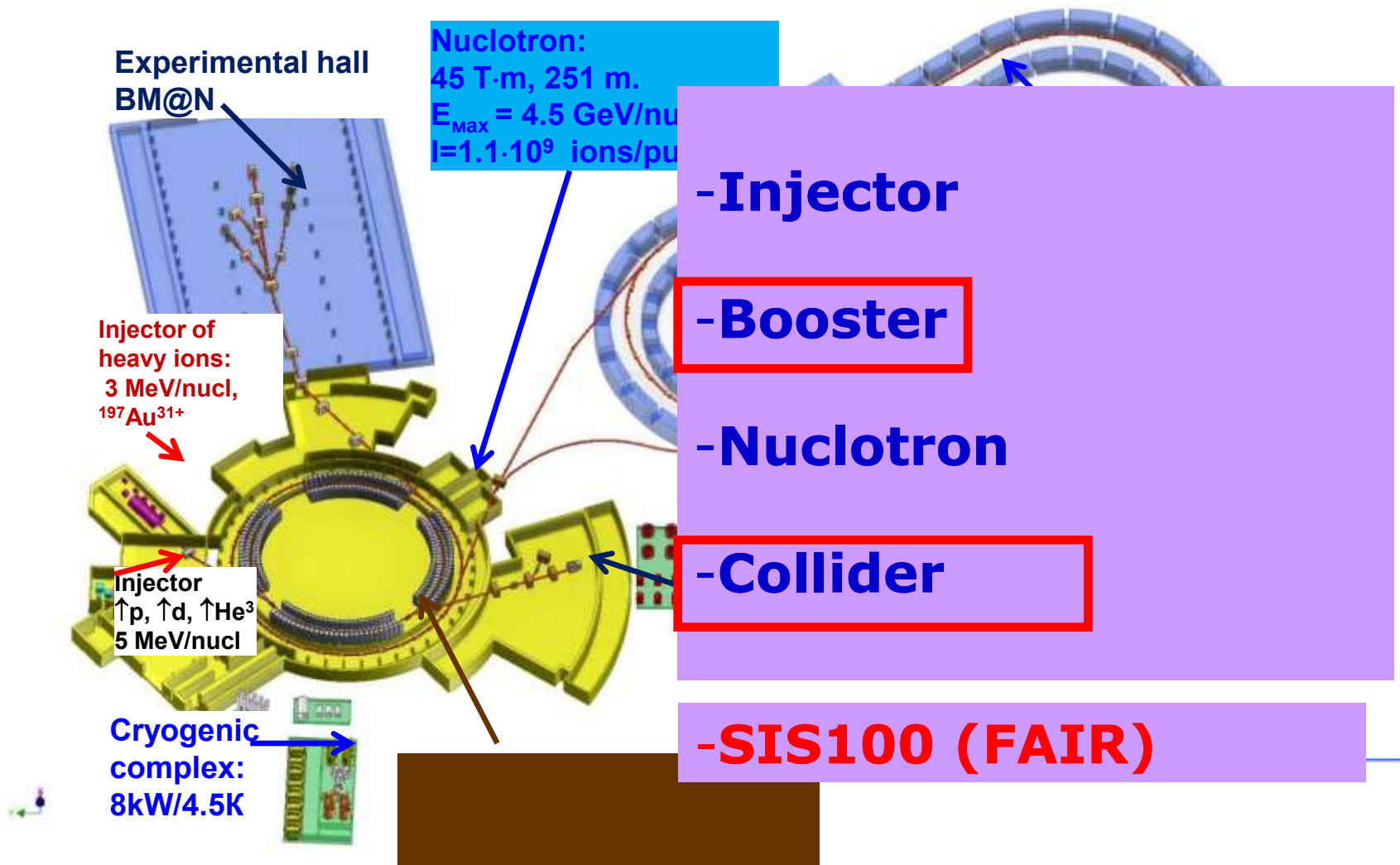
NICA facility



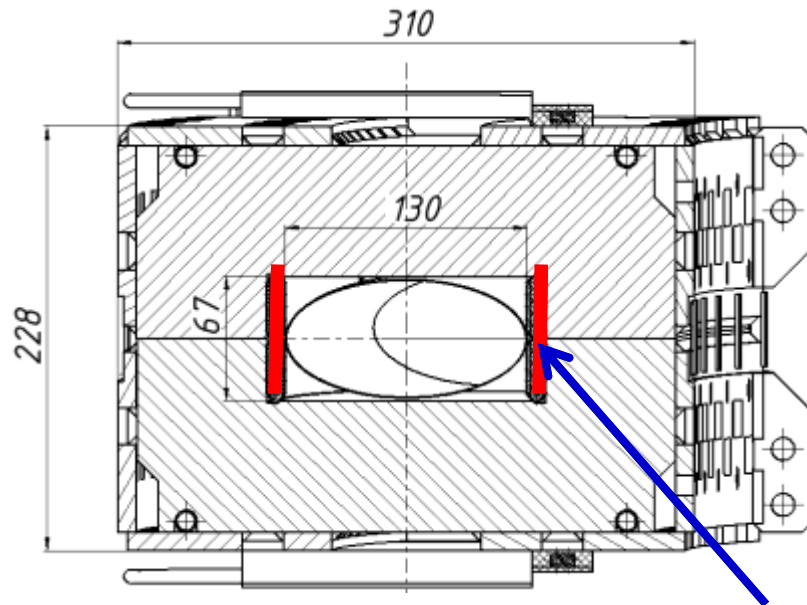




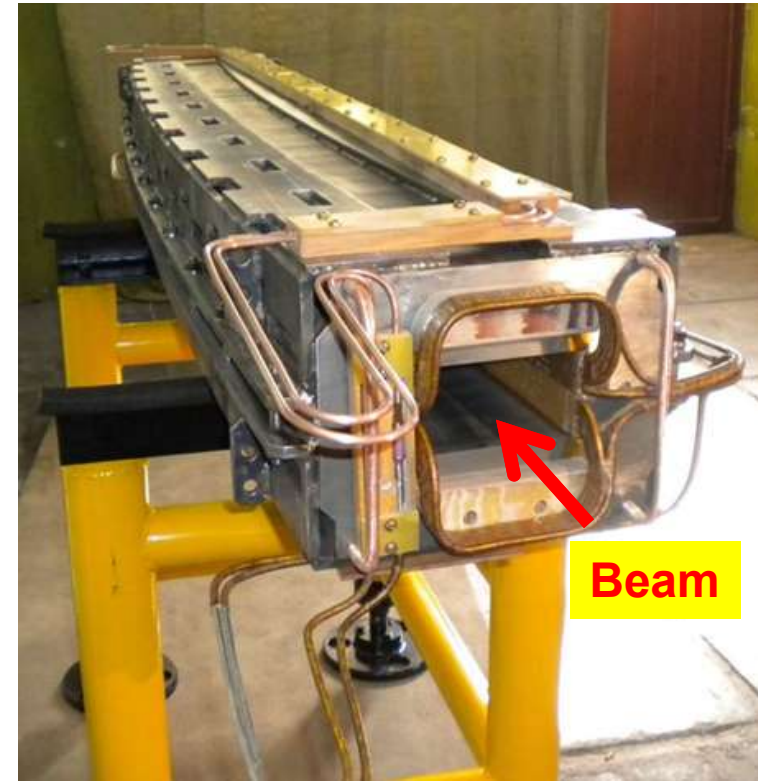
NICA facility



SC dipole magnet for NICA Booster



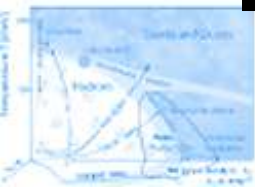
Coil with electrical current



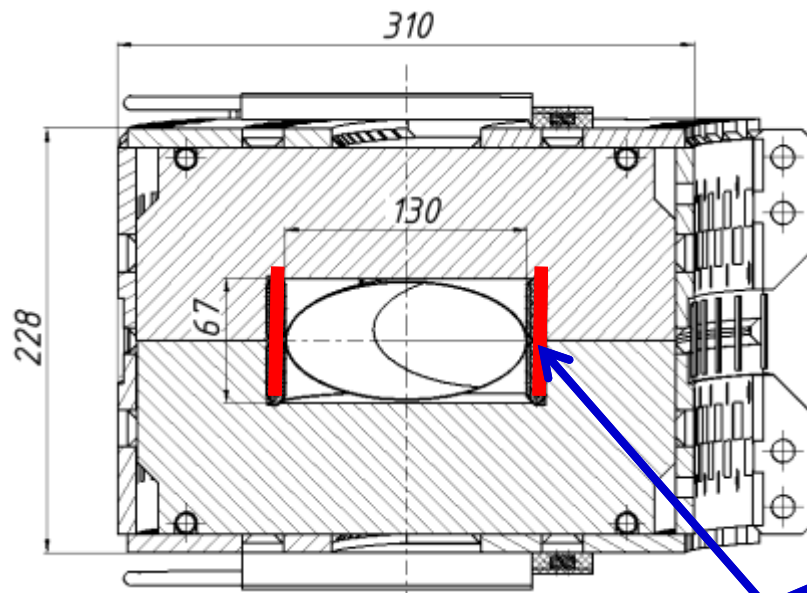
Beam



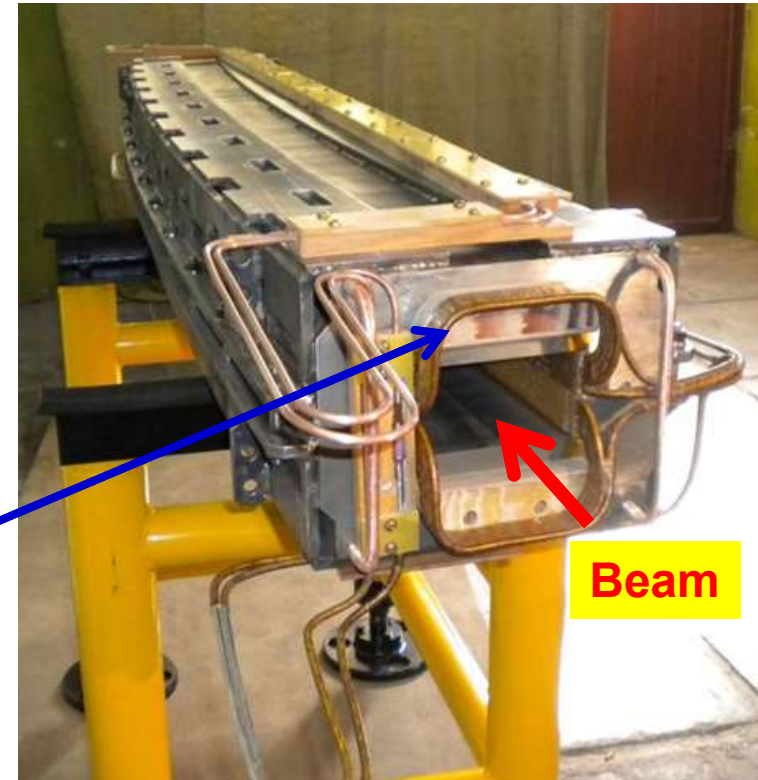
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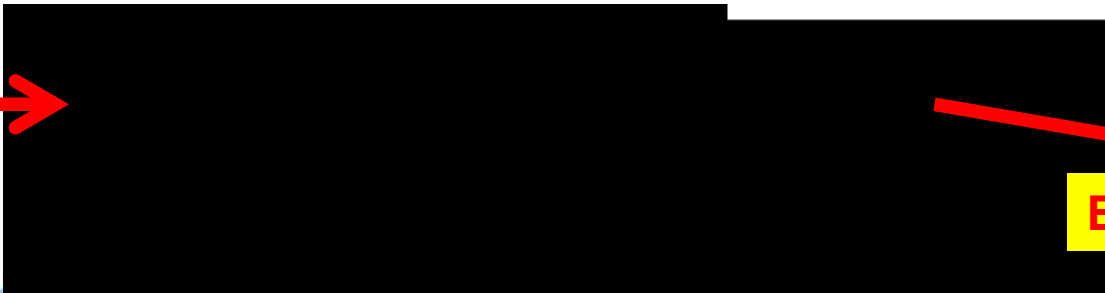
SC dipole magnet for NICA Booster



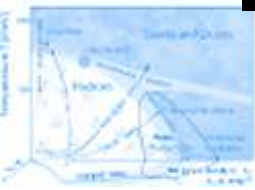
Coil with electrical current



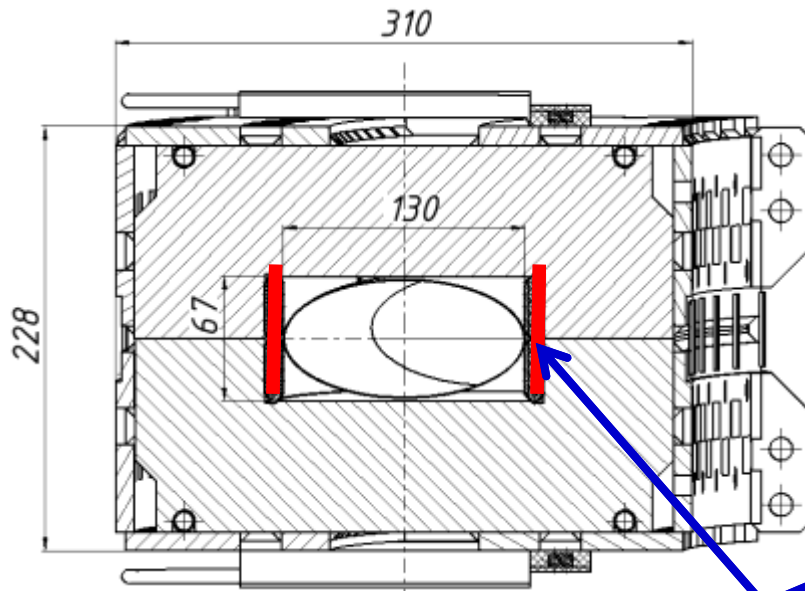
Beam



Beam

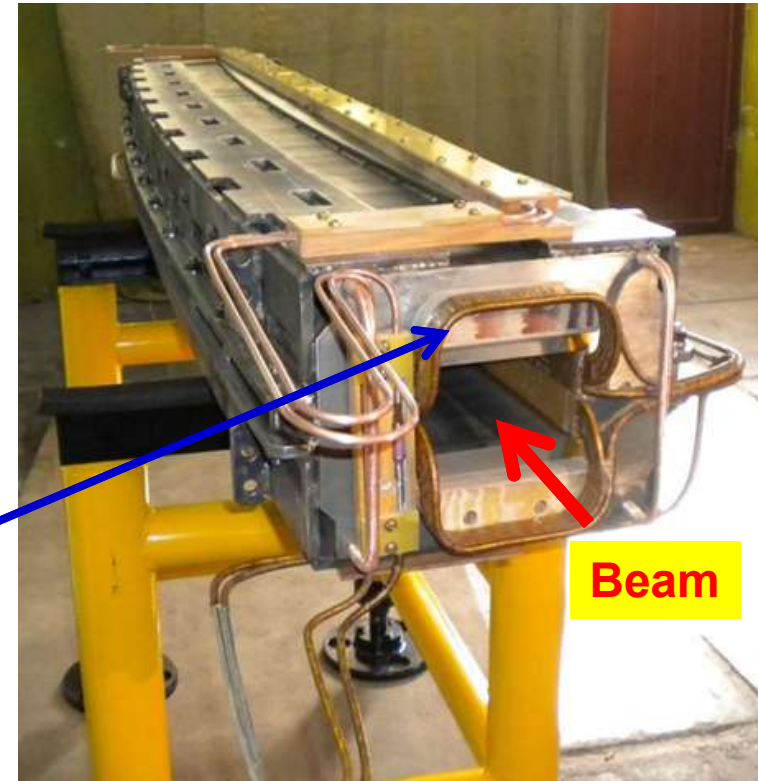


SC dipole magnet for NICA Booster



Magnetic field **B**

Coil with electrical current



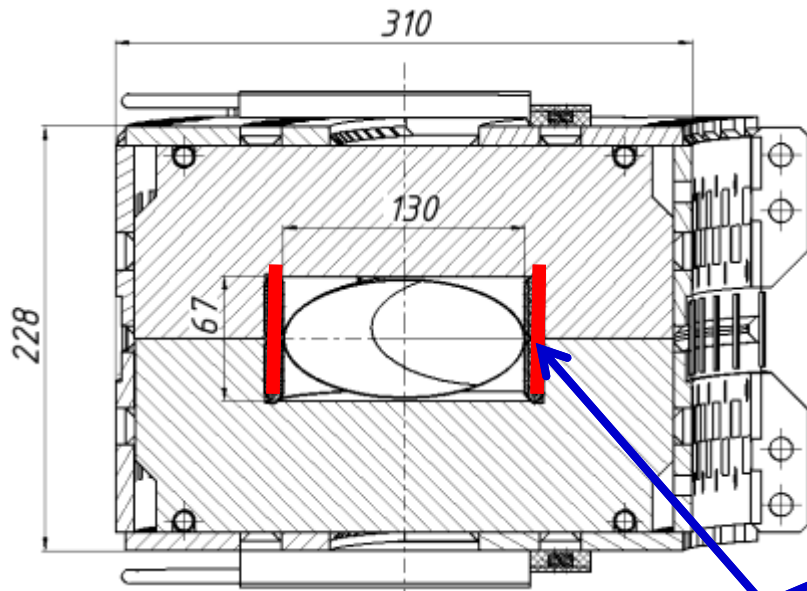
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Beam



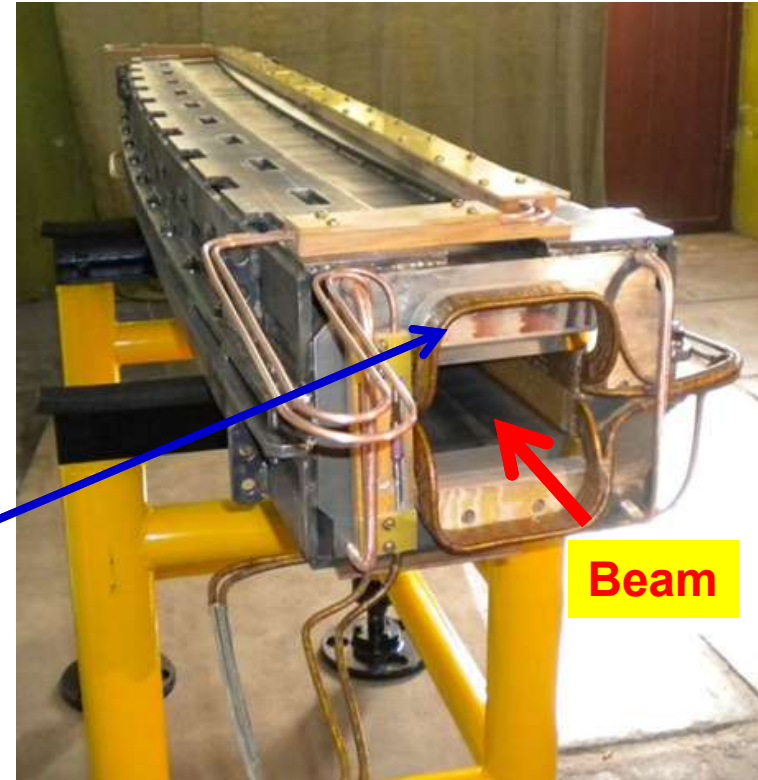
SC dipole magnet for NICA Booster



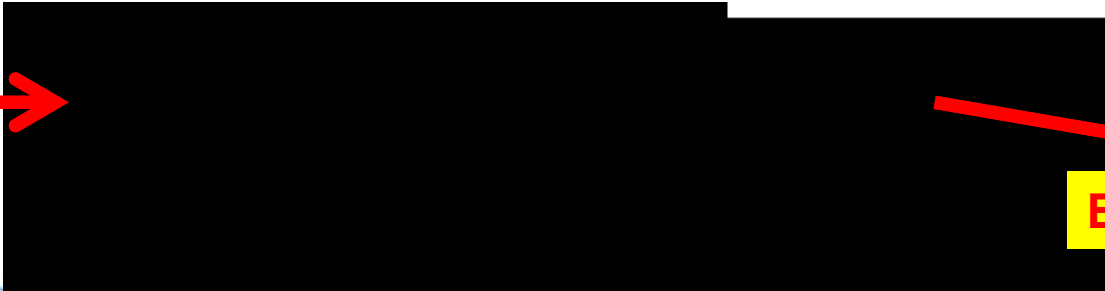
Magnetic field **B**

Coil with electrical current

B



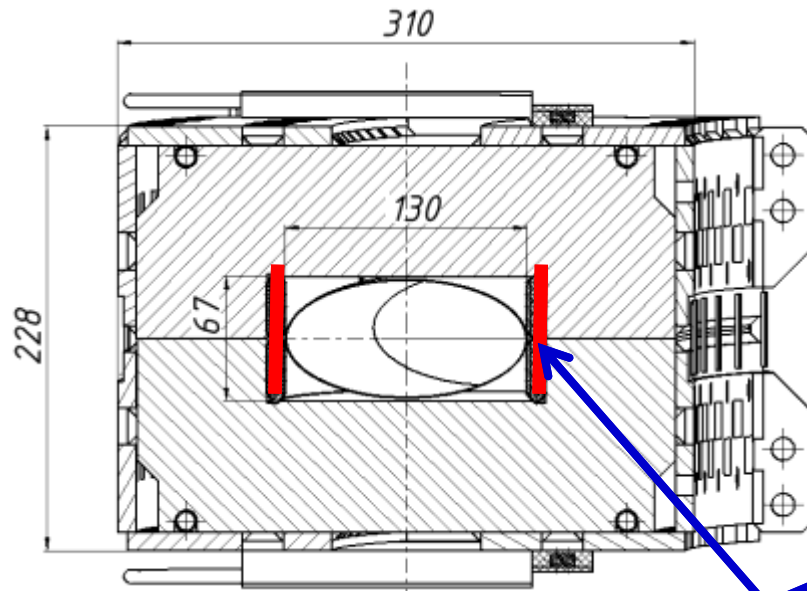
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Beam



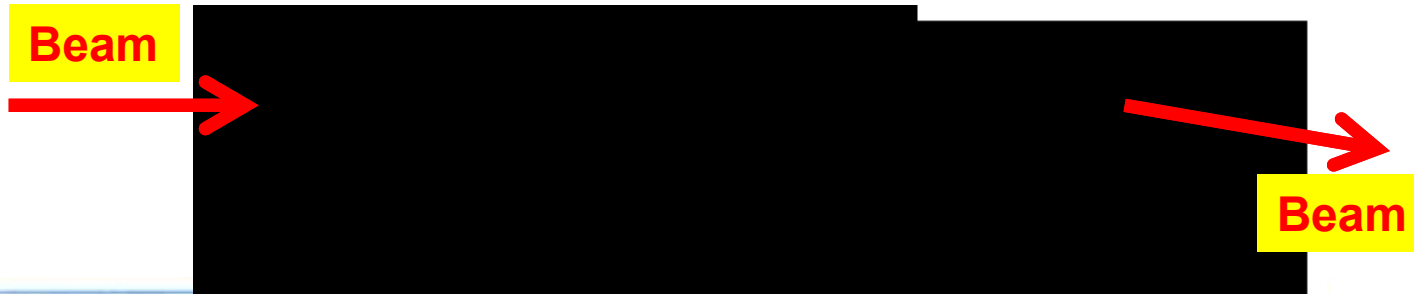
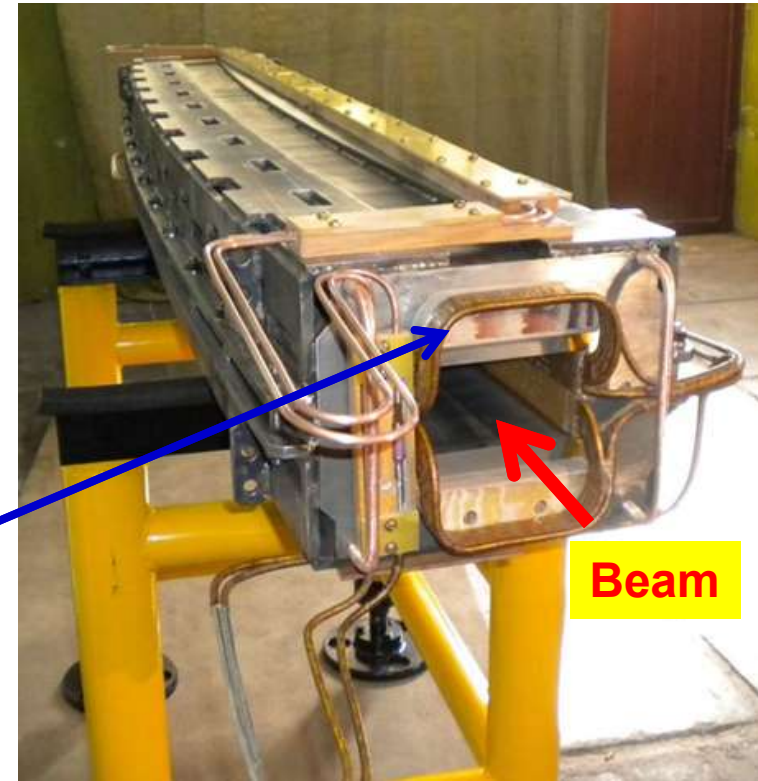
SC dipole magnet for NICA Booster



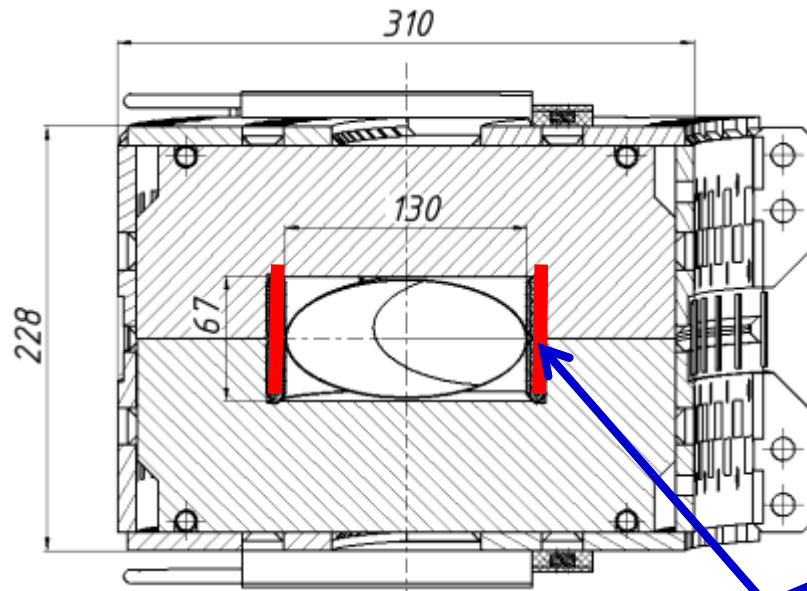
Magnetic field **B**

Coil with electrical current

B ↘



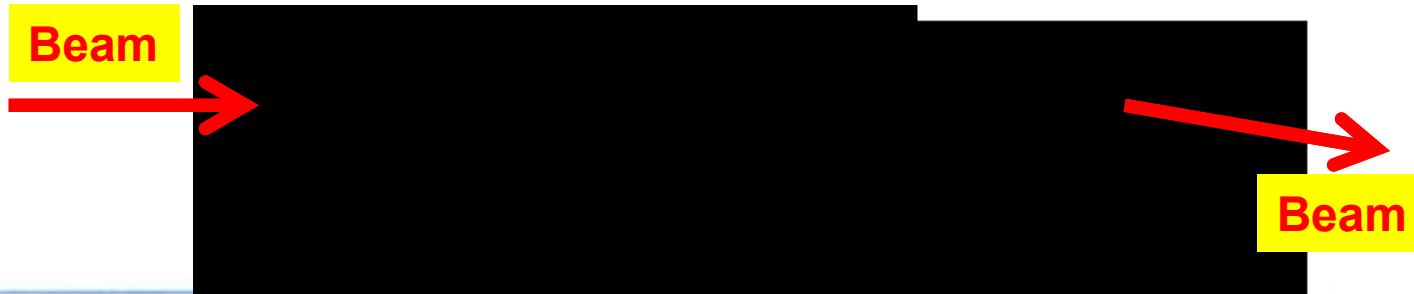
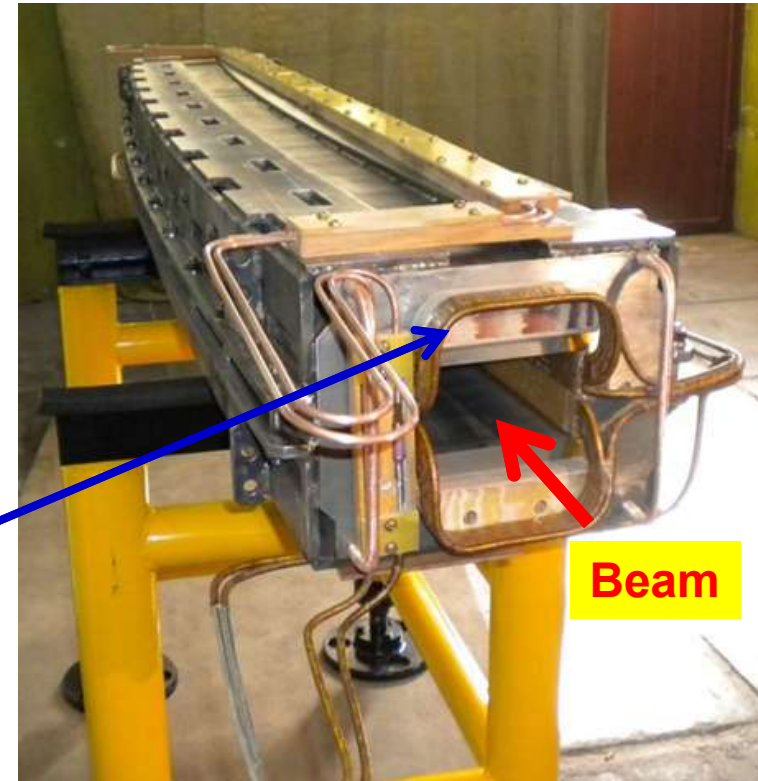
SC dipole magnet for NICA Booster



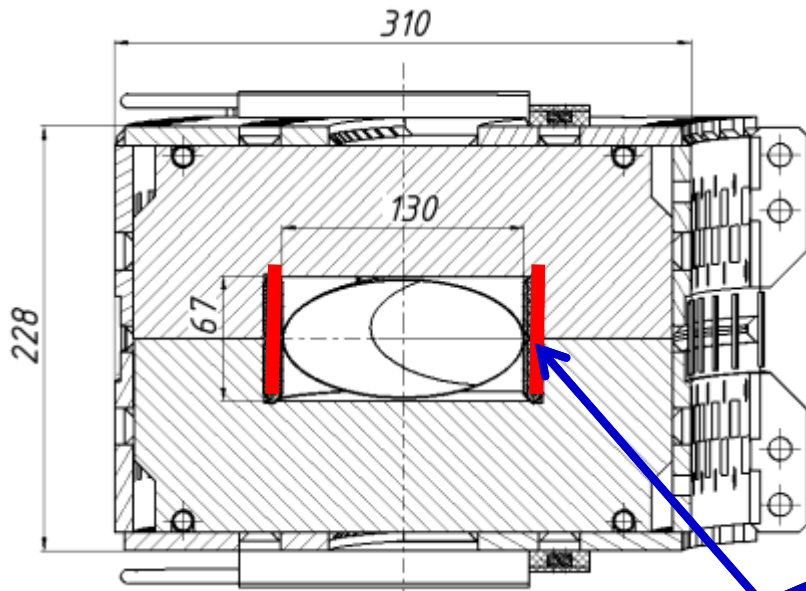
Magnetic field **B**

Coil with electrical current

B ×

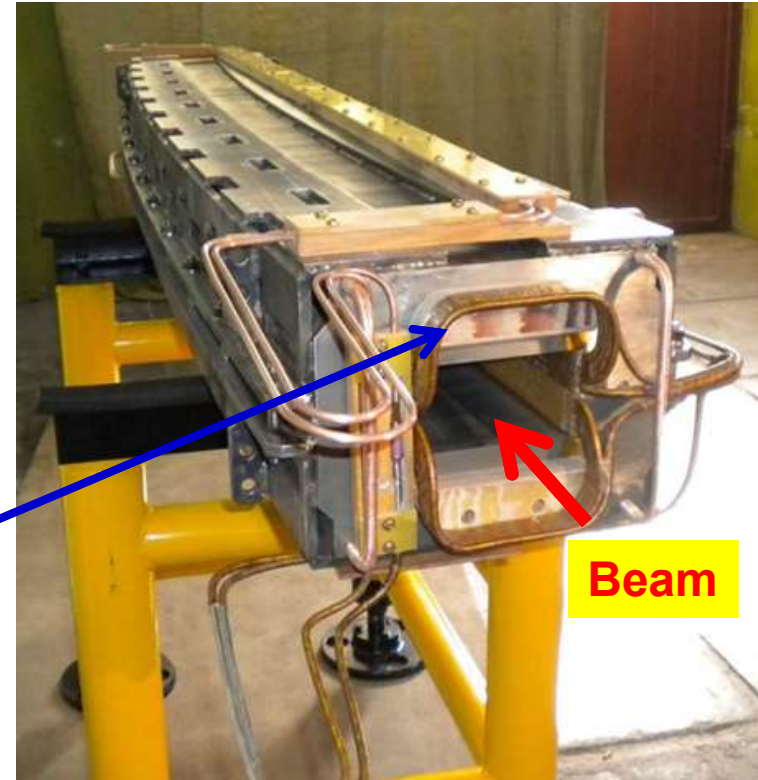


SC dipole magnet for NICA Booster



Magnetic field **B**

Coil with electrical current



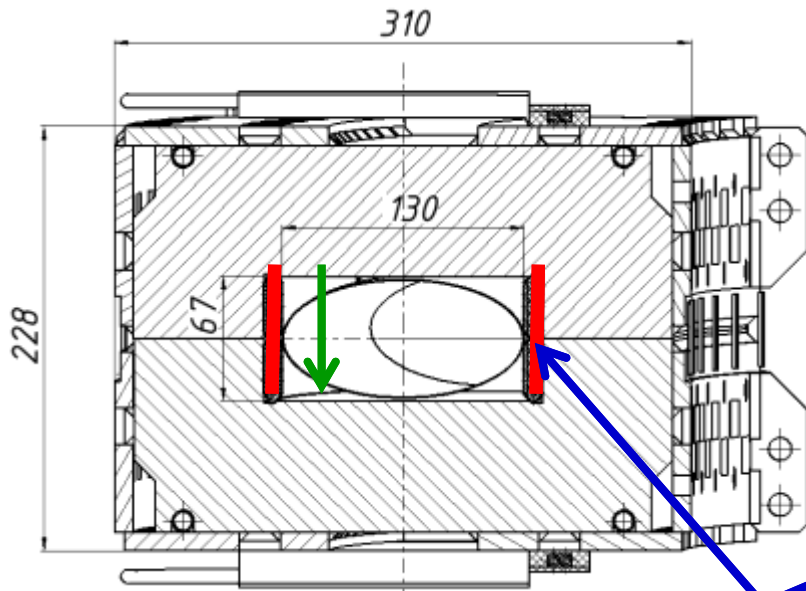
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Beam

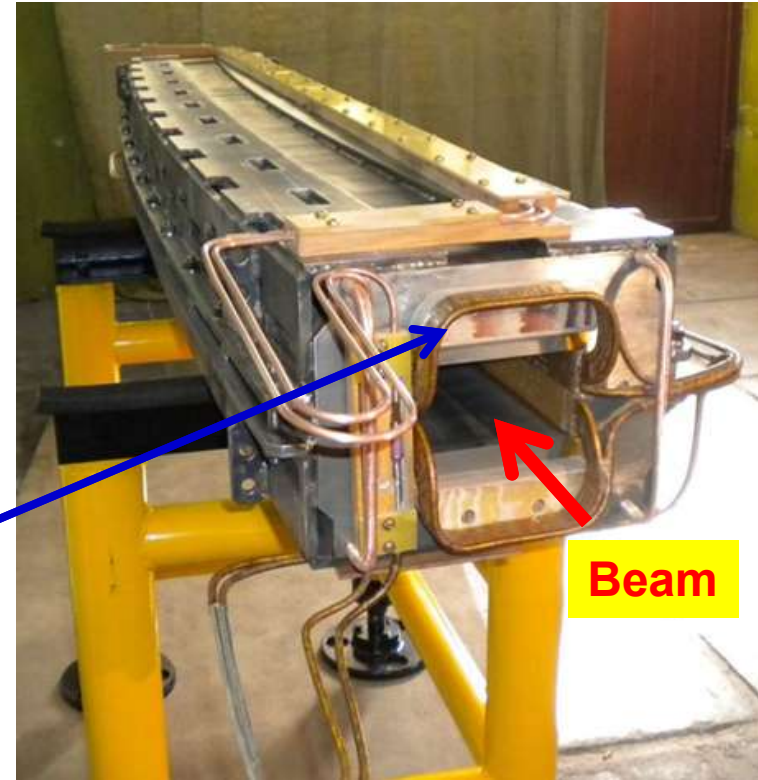


SC dipole magnet for NICA Booster



Magnetic field **B**

Coil with electrical current



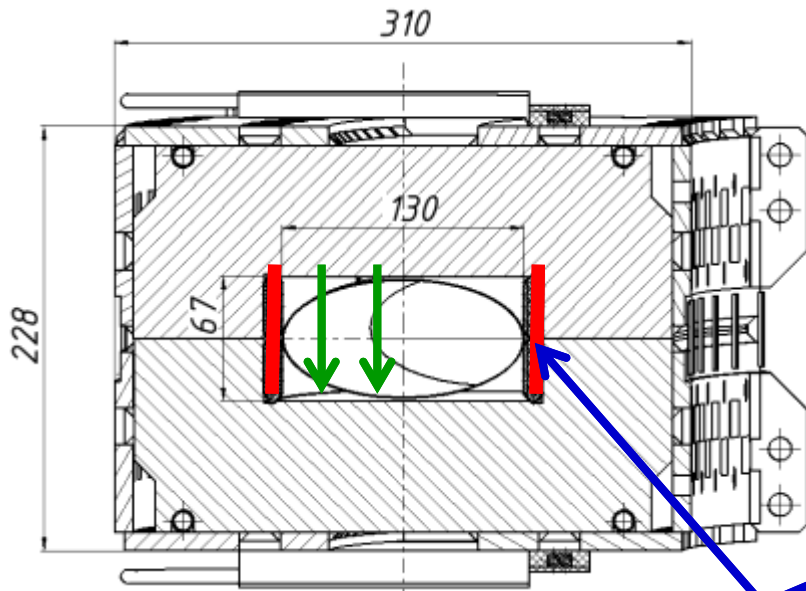
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Beam

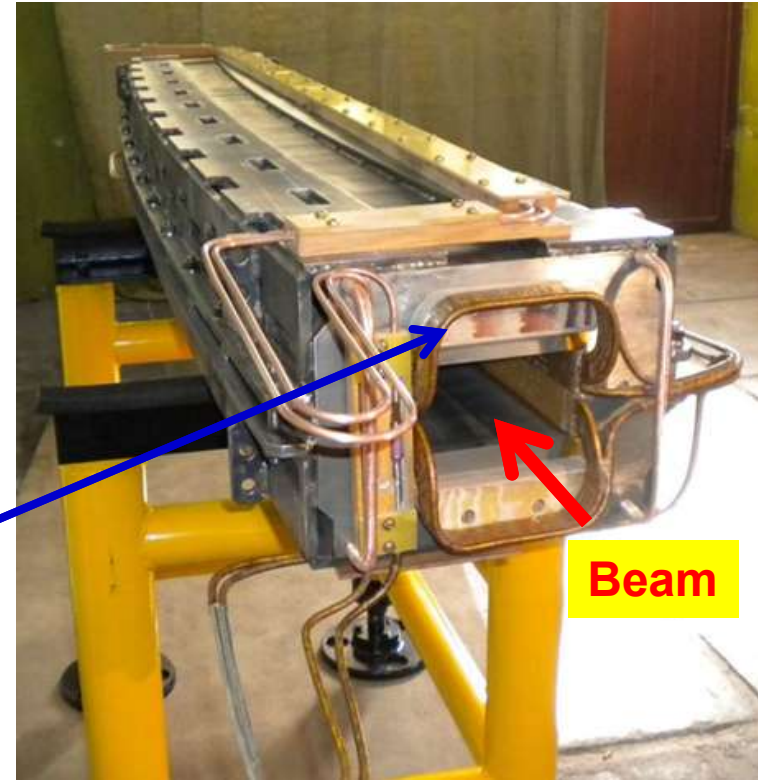


SC dipole magnet for NICA Booster



Magnetic field B

Coil with electrical current

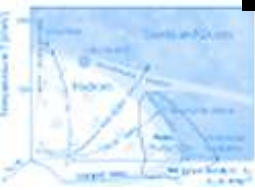


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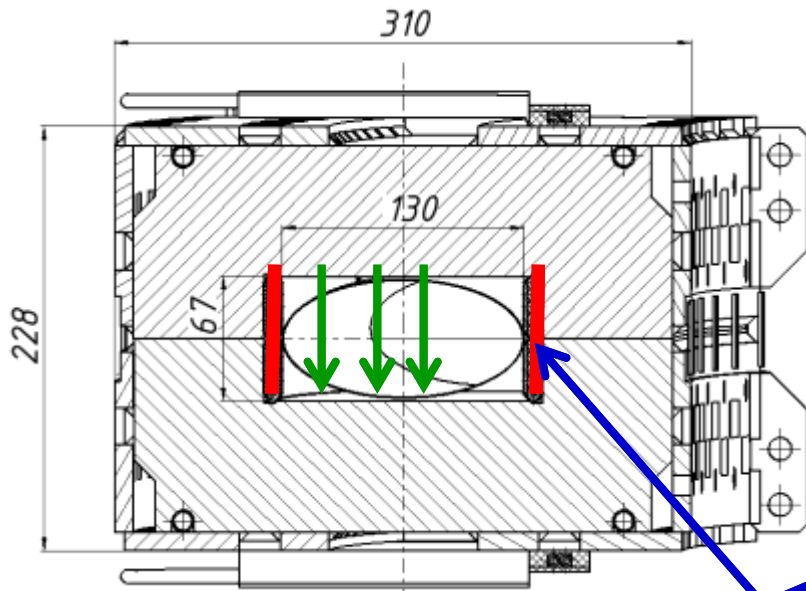
Beam



Beam

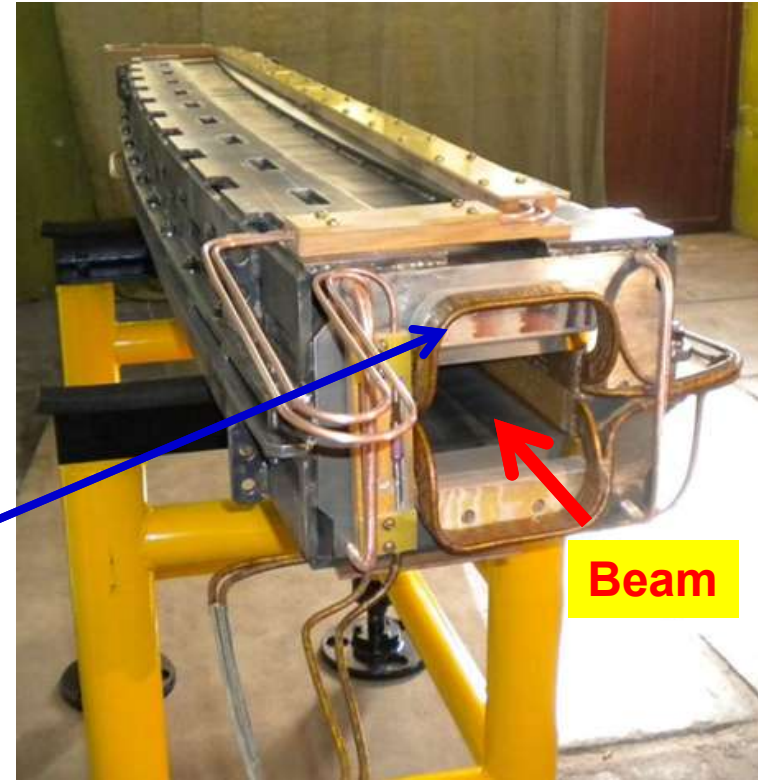


SC dipole magnet for NICA Booster



Magnetic field **B**

Coil with electrical current



Beam

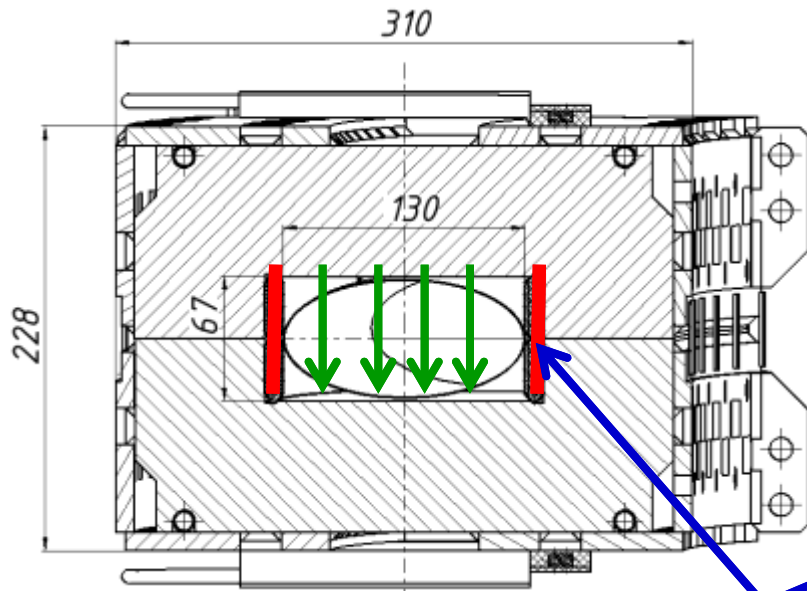
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Beam

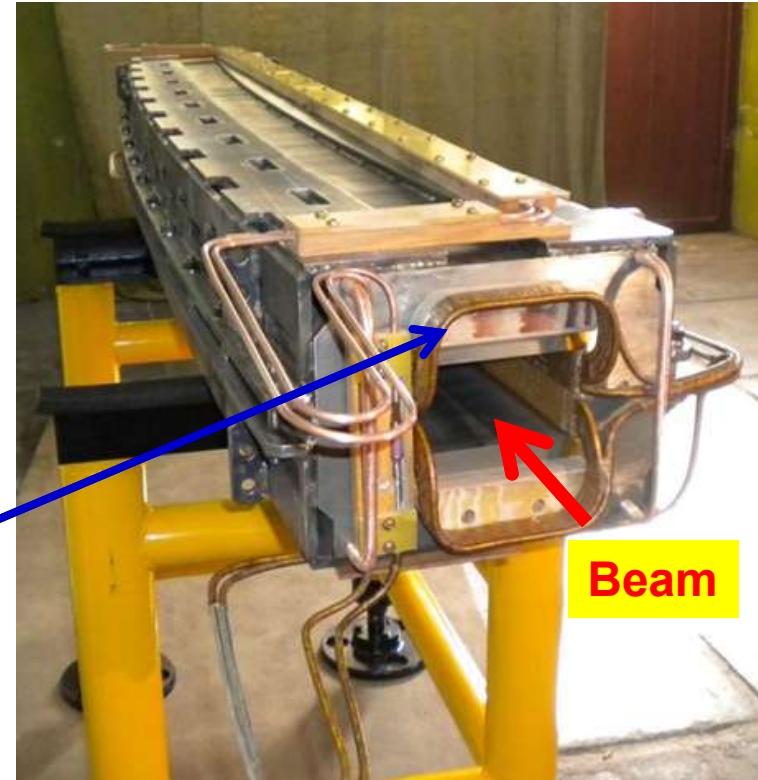


SC dipole magnet for NICA Booster



Magnetic field **B**

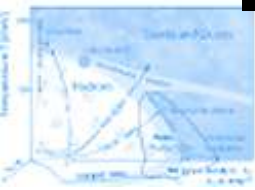
Coil with electrical current



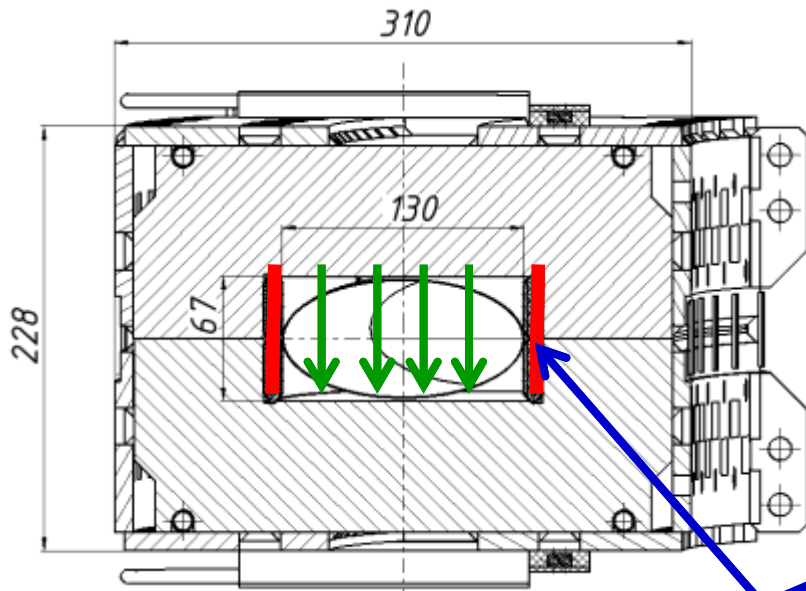
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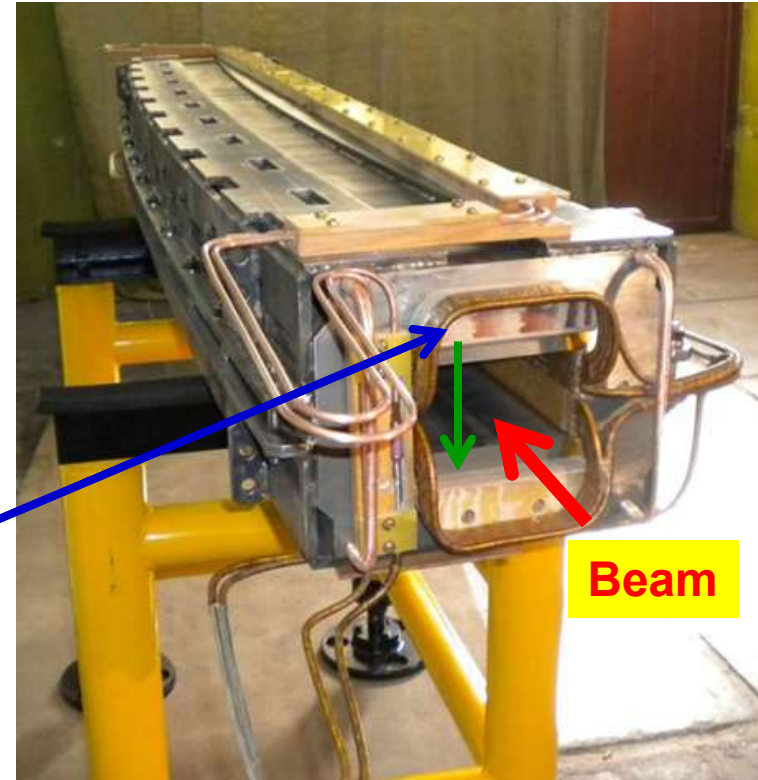


SC dipole magnet for NICA Booster



Magnetic field **B**

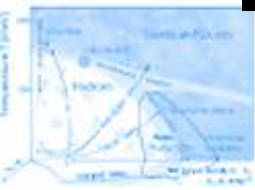
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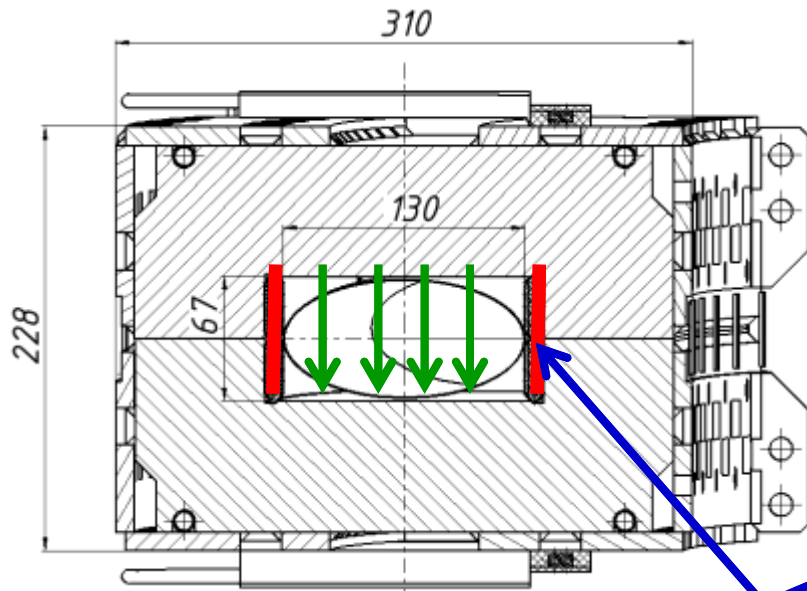
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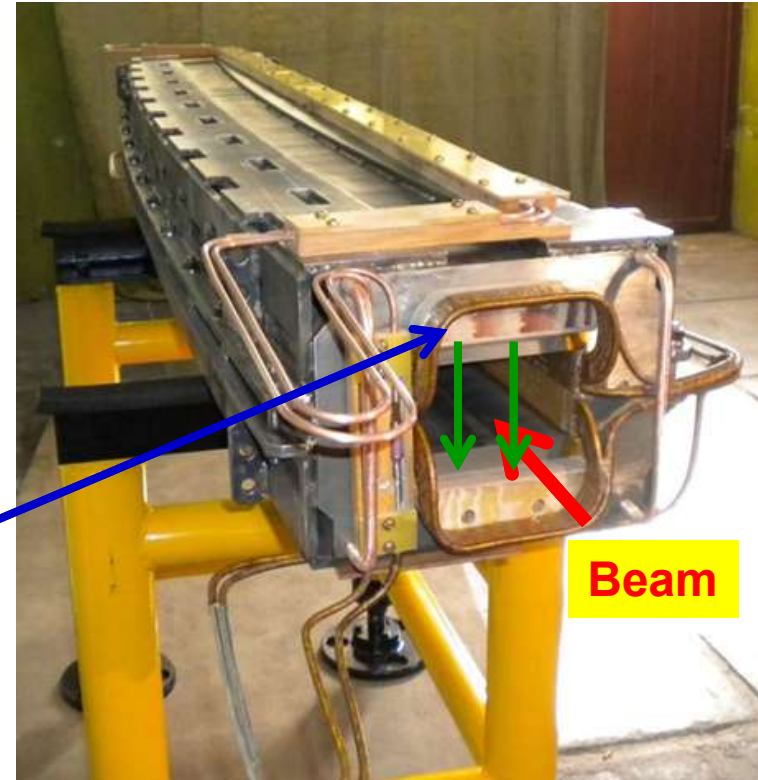


SC dipole magnet for NICA Booster



Magnetic field B

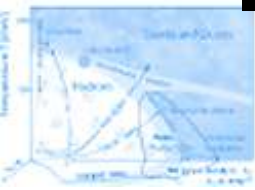
Coil with electrical current



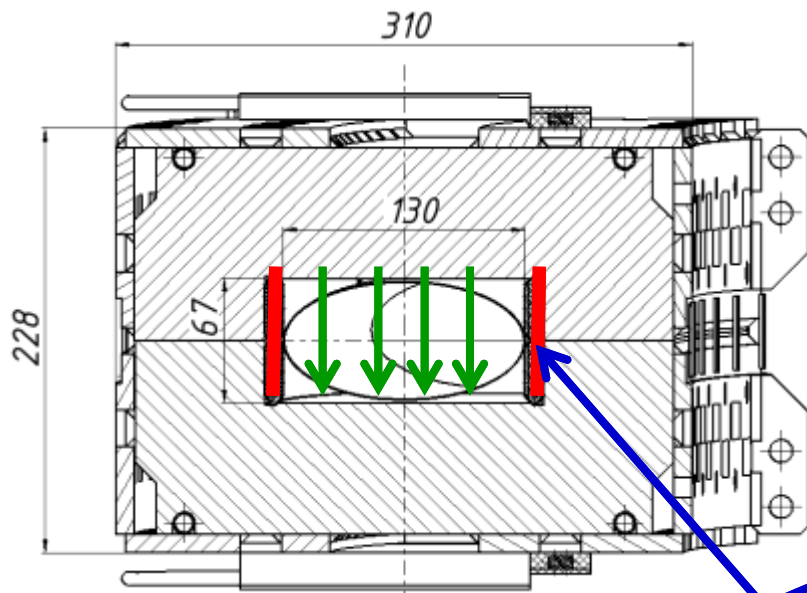
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Beam

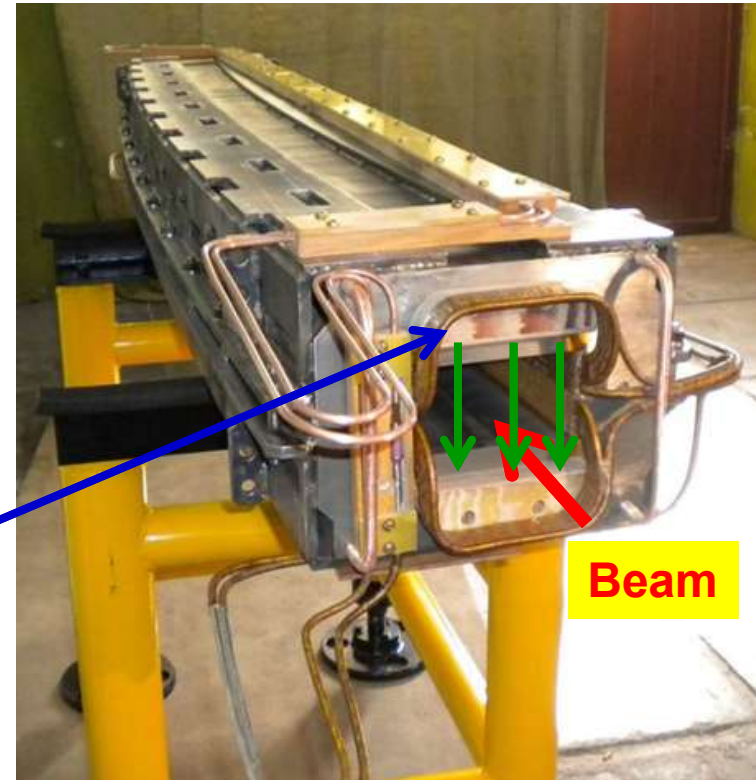


SC dipole magnet for NICA Booster



Magnetic field B

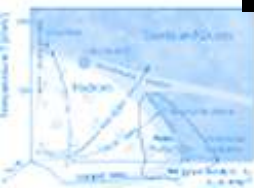
Coil with electrical current



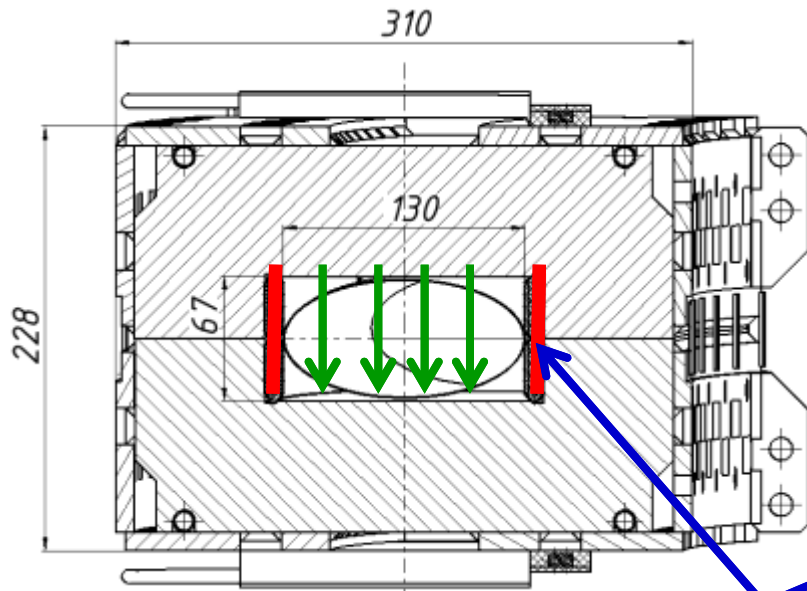
Beam



Beam

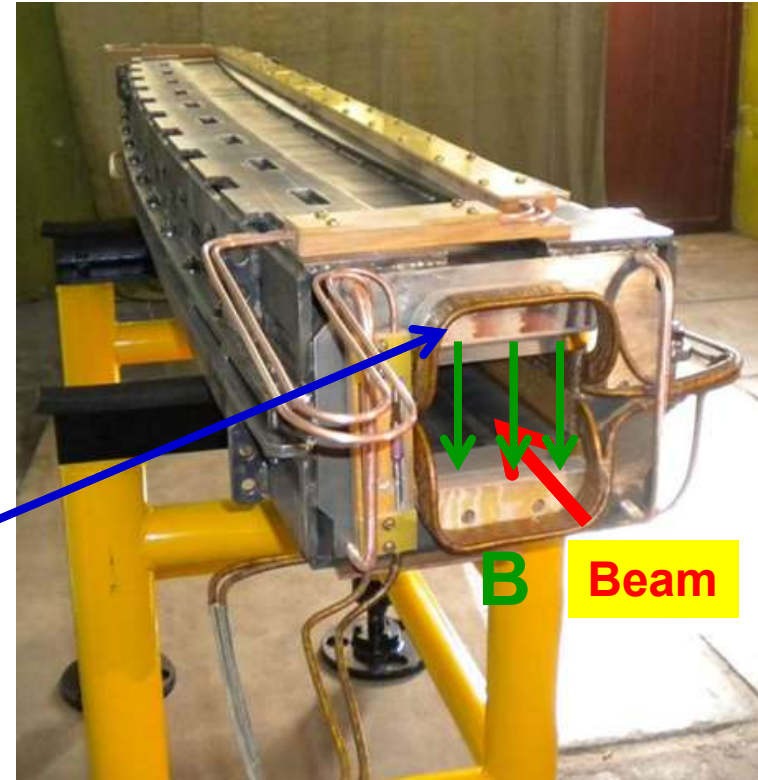


SC dipole magnet for NICA Booster



Magnetic field B

Coil with electrical current

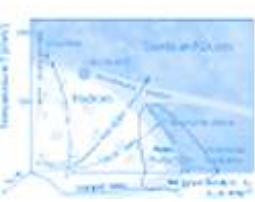
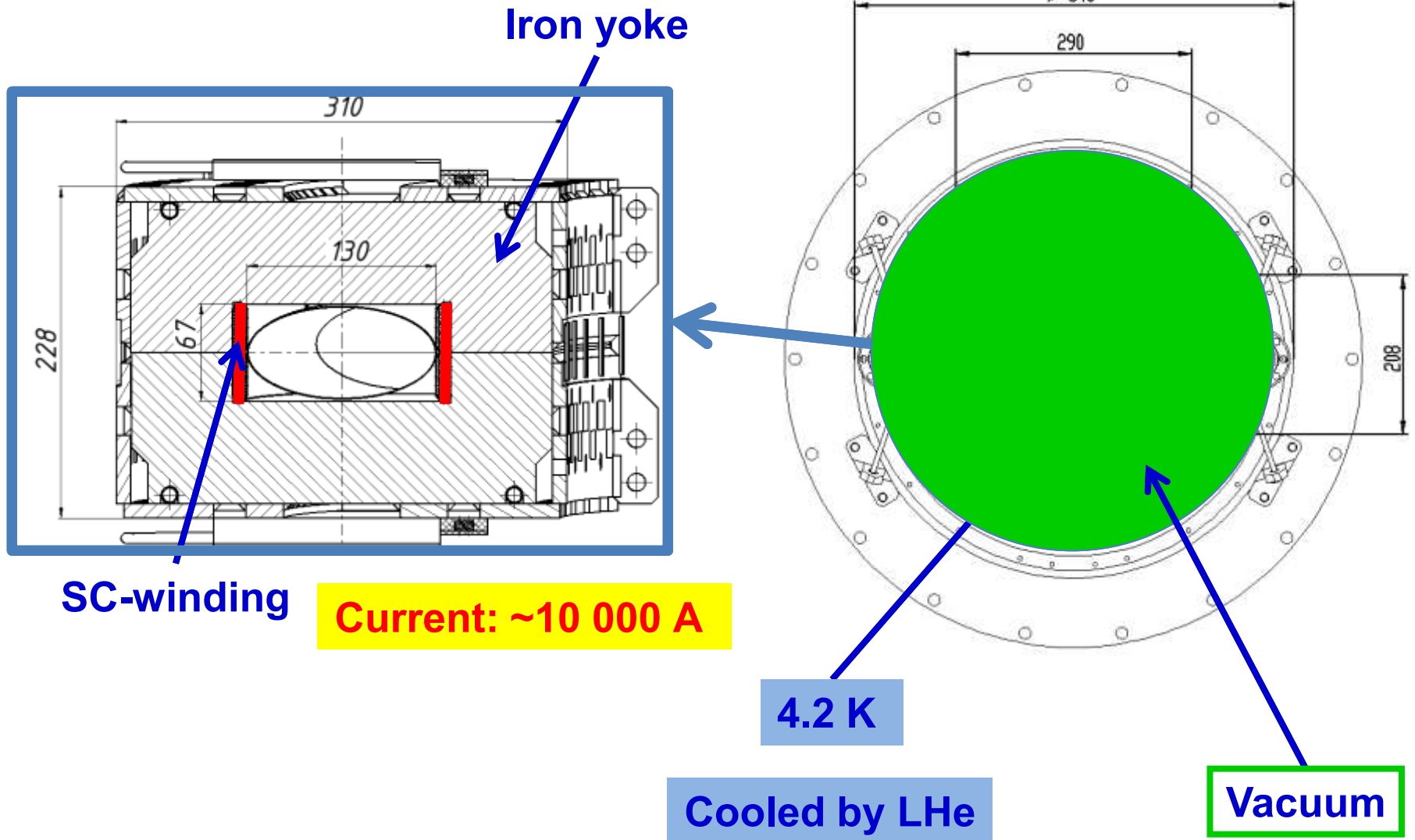


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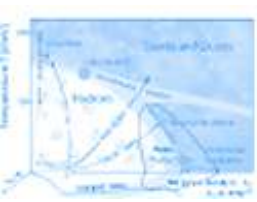
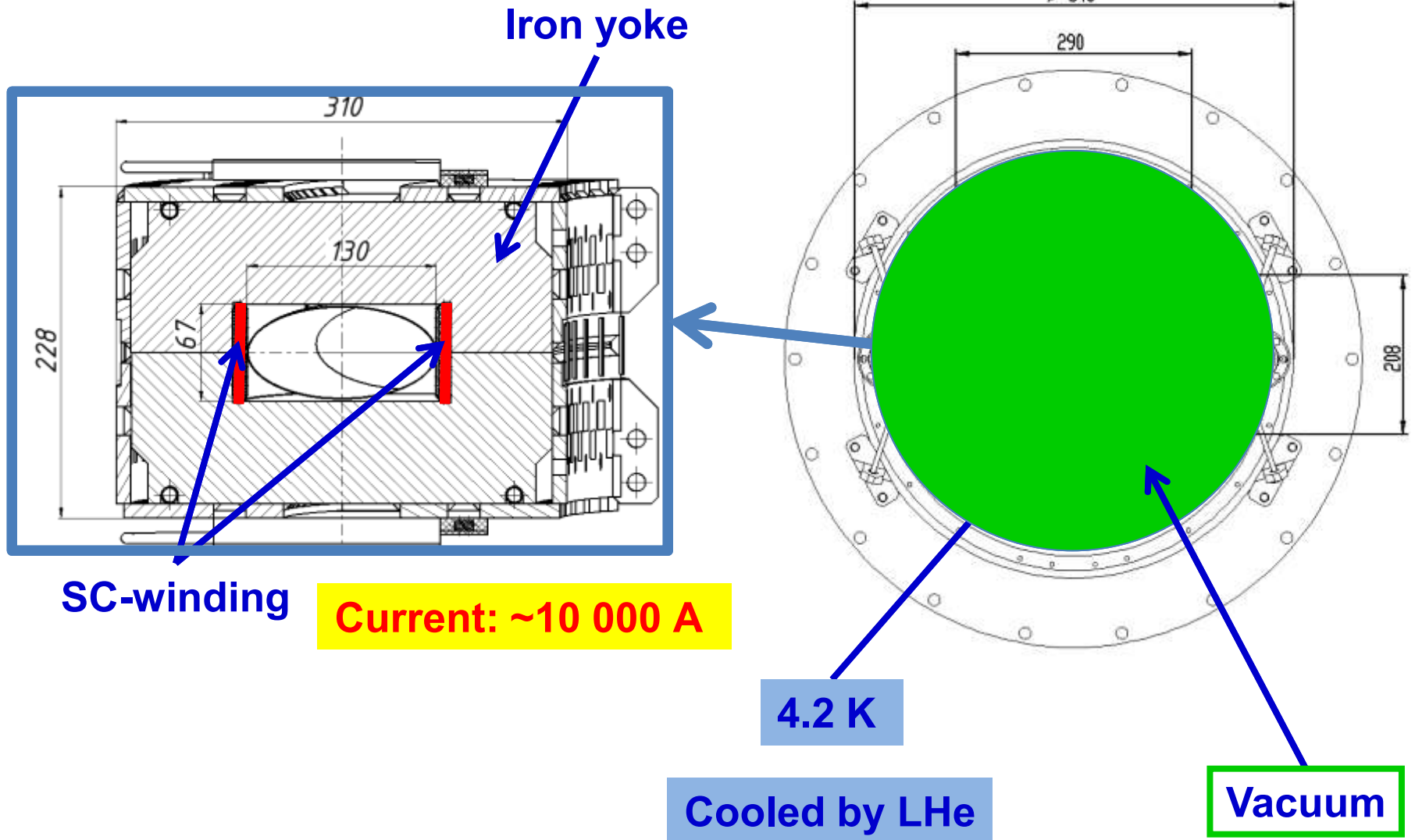
Beam



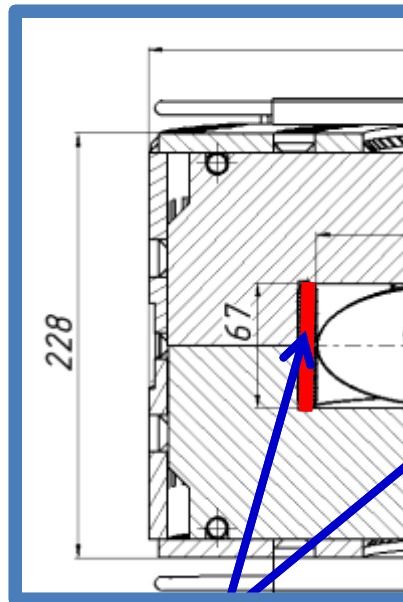
SC dipole magnet for NICA Booster



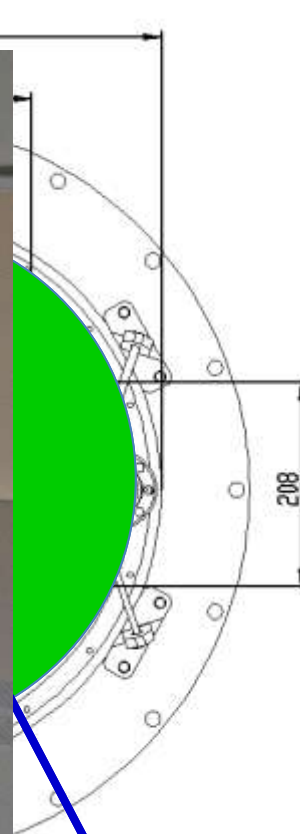
SC dipole magnet for NICA Booster



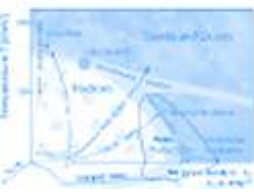
SC dipole magnet for NICA Booster



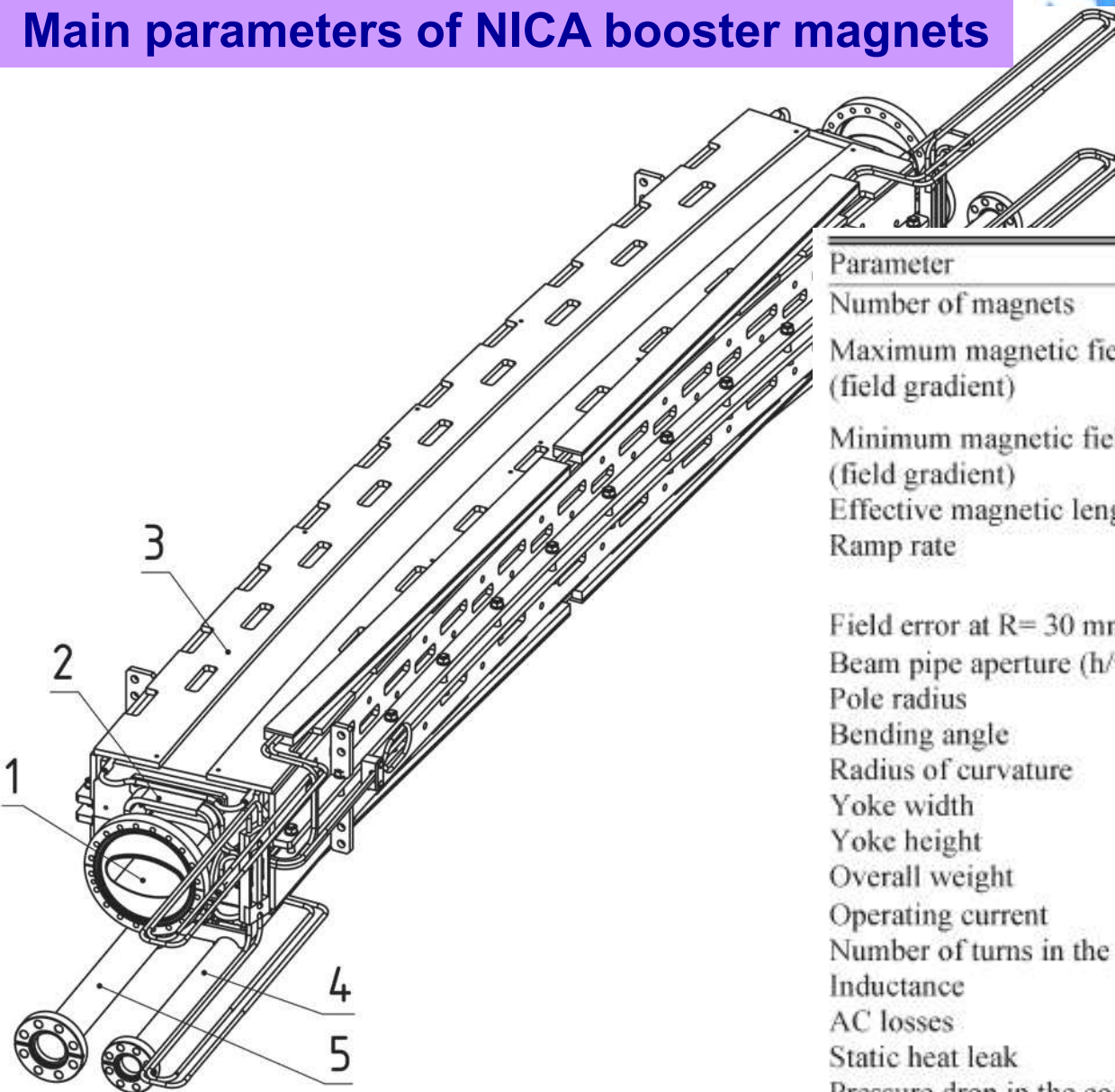
SC-winding



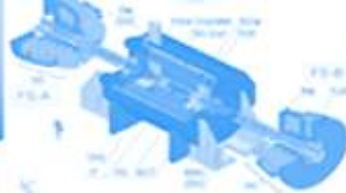
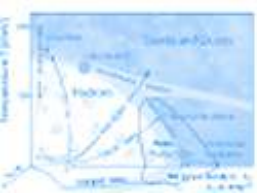
Vacuum



Main parameters of NICA booster magnets

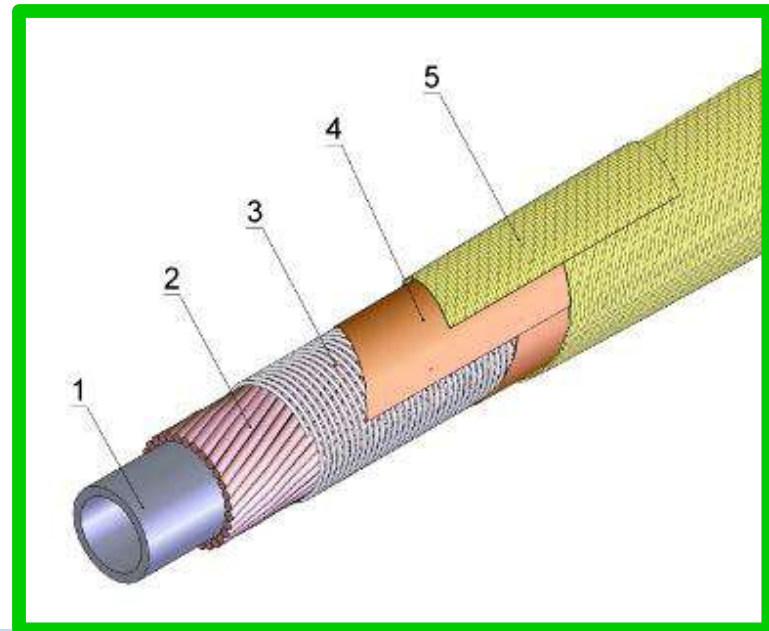


Parameter	Unit	Dipole	Lens
Number of magnets		40	48
Maximum magnetic field	T	1.8	
(field gradient)	T/m		21.5
Minimum magnetic field	T	0.11	
(field gradient)	T/m		1.3
Effective magnetic length	m	2.2	0.47
Ramp rate	T/s	1.2	
	T/(m·s)		14.3
Field error at R= 30 mm			$\leq 6 \cdot 10^{-4}$
Beam pipe aperture (h/v)	mm		128 / 65
Pole radius	mm	-	47.5
Bending angle	deg	9	-
Radius of curvature	m	14.01	-
Yoke width	m	0.31	0.226
Yoke height	m	0.228	0.226
Overall weight	kg	1030	110
Operating current	kA		9.68
Number of turns in the coil		10	8
Inductance	μH	630	96
AC losses	W	8.4	0.8
Static heat leak	W	4.4	3.0
Pressure drop in the cooling channel	kPa		≤ 27
Maximal temperature of He in the coil	K		4.65



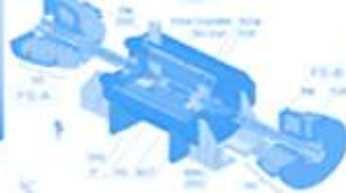
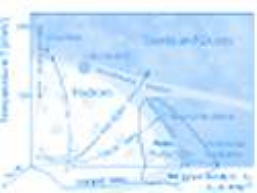
SC-cable

Developed in LHEP JINR



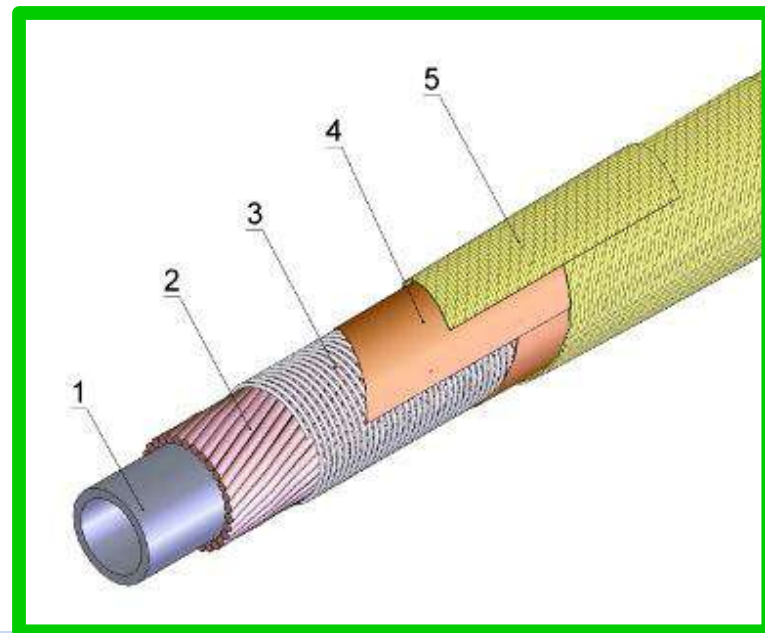
- 1 – CuNi-tube
- 2 – Superconducting strand
- 3 – NiCr-wire for fixation
- 4 – Capton tape
- 5- Fiberglass tape

Nuclotron-cable



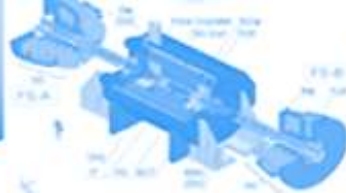
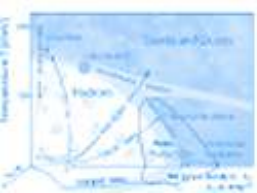
SC-cable

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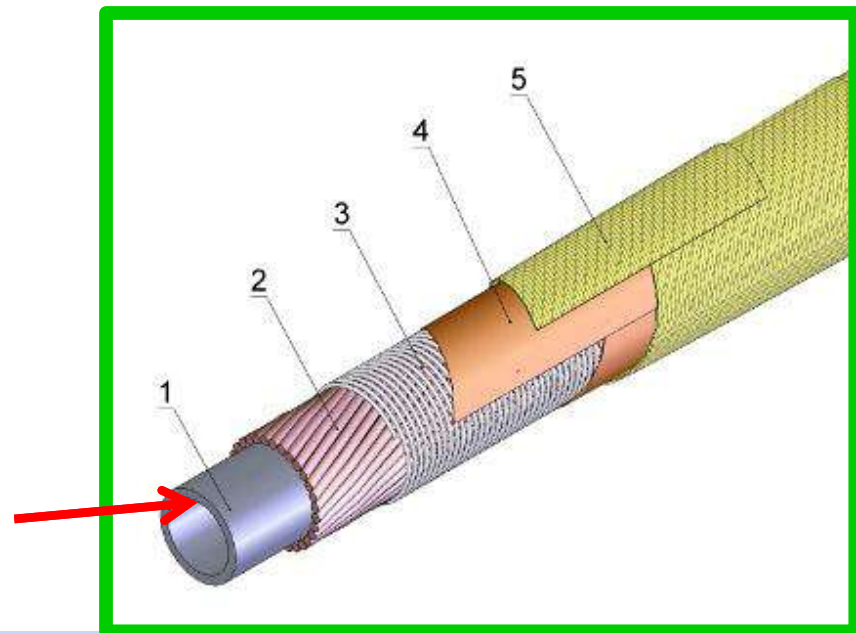
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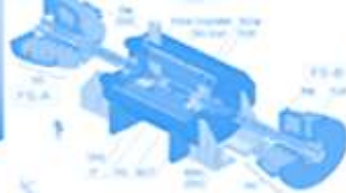
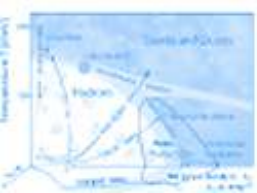
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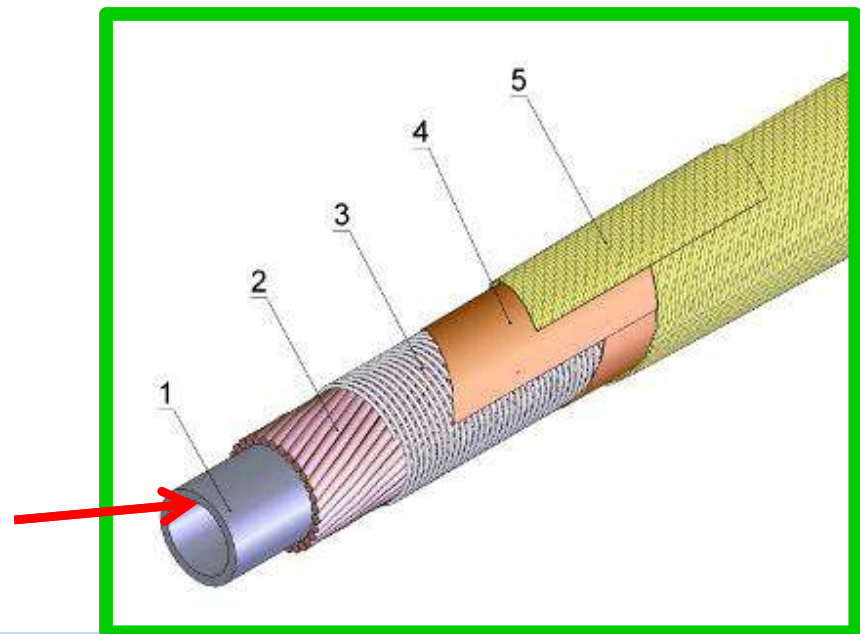
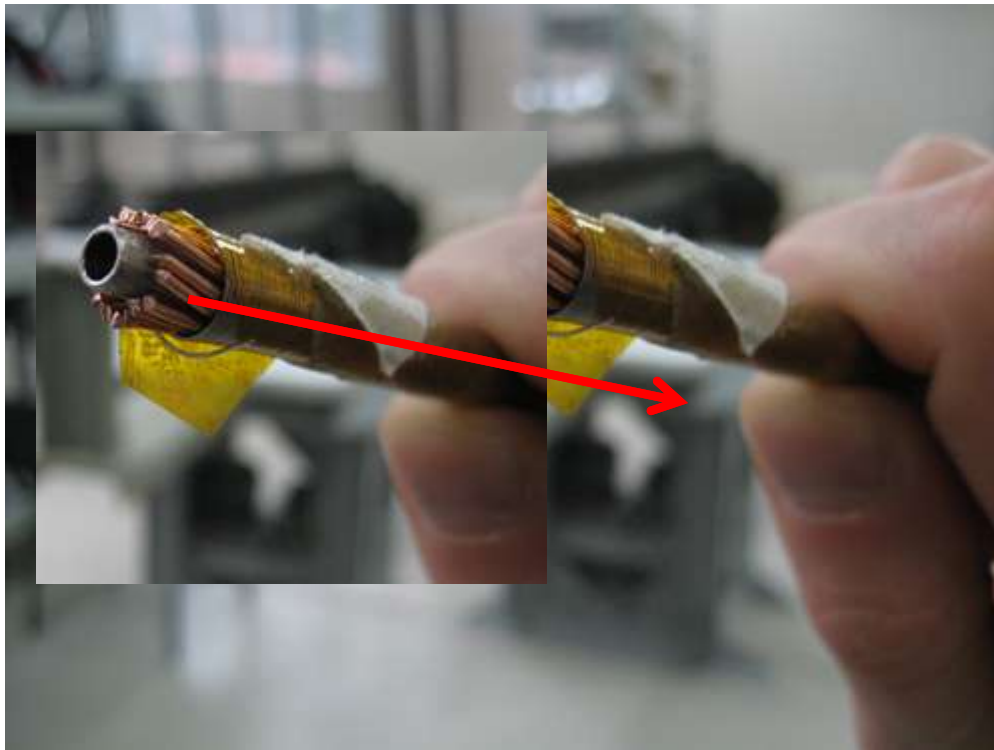
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Nuclotron-cable



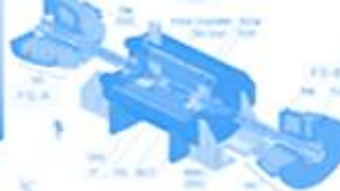
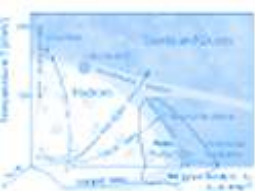
SC-cable

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Nuclotron-cable



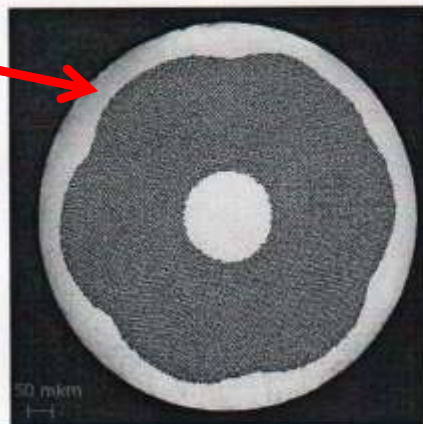
SC-cable

СЕРТИФИКАТ

Ниобий-титановый сверхпроводящий стренд усовершенствованной конструкции для модельного магнита Бустера ускорительного комплекса NICA

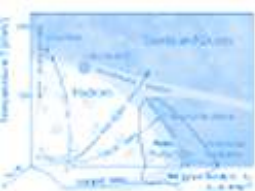
СКНТ 0,78-8214-1,38

Партия 1-C2-18-1-12/2-1-2



Диаметр, мм	0,781
Количество волокон, шт	8214
Материал волокон	Сплав НТ 47 (ТУ 001. 405 - 2008)
Диаметр волокон, мкм	5,8
Матрица	Бескислородная медь

Nuclotron-cable



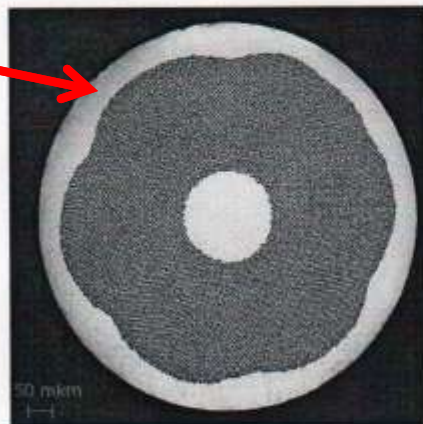
SC-cable

СЕРТИФИКАТ

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Nuclotron-cable



Main stages in the production of SC magnet Nuclotron type

- ☐ SC cable production
- ☐ SC coils production
- ☐ Iron yoke production
- ☐ Assembling of the yoke and coil
- ☐ Magnetic measurements at the room temperature
- ☐ Electrical and vacuum tests of the magnet
- ☐ Assembly of the magnet into cryostat
- ☐ Cryogenic tests and “training” of the magnet
- ☐ Magnetic measurements of the cooled magnet

2010-2013

Bld. 217 LHEP JINR (workshops)
30 x 75 m



2010-2013

Bld. 217 LHEP JINR (workshops)
30 x 75 m



2010-2013

Bld. 217 LHEP JINR (workshops)
30 x 75 m



2010-2013

Bld. 217 LHEP JINR (workshops)
30 x 75 m



~1.5 M\$



2010-2013

Bld. 217 LHEP JINR (workshops)





❑ Nuclotron cable production



Cable machine – production of the cable via “one pass”

Cable for SIS100
sextupole magnet
production



Production of SC coil



SIS100 sextupole



NICA dipole



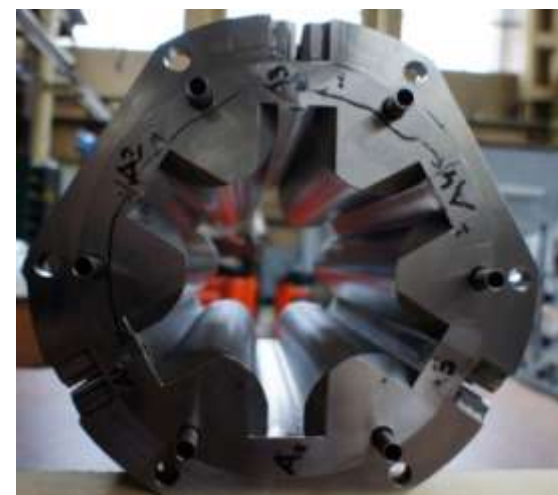


❑ Production of SC coil





NICA booster quadrupole magnet yoke



SIS100 sextupole magnet yoke

Production of iron yoke

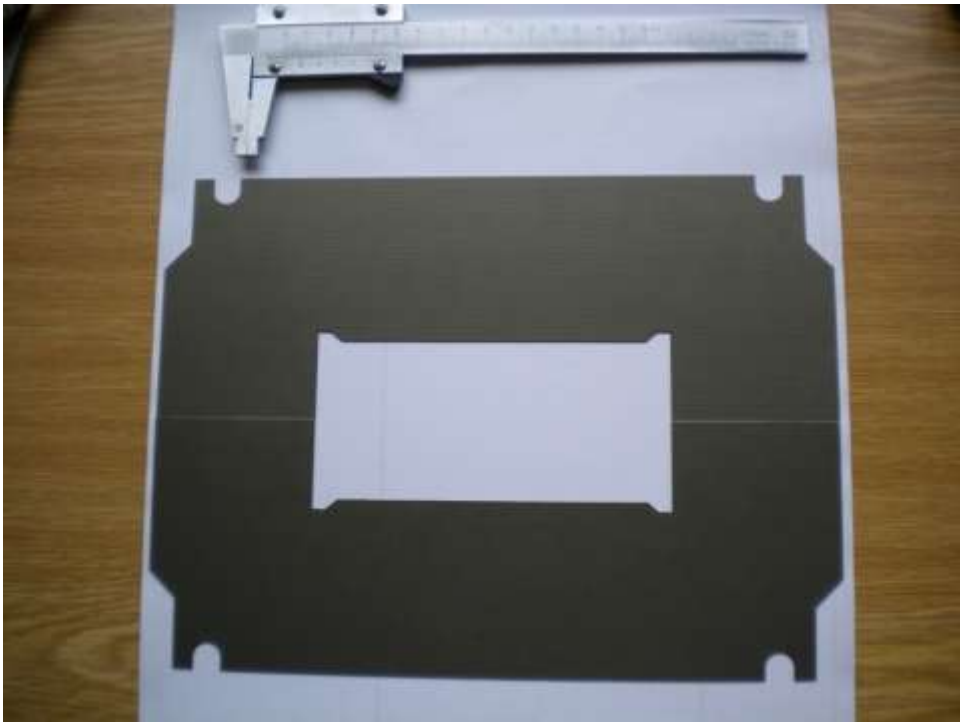
Савеловский машиностроительный завод
Дубненский машиностроительный завод
НПО Атом



Half-yokes of the NICA Booster dipole



❑ Production of iron yoke



Parts of NICA booster dipole



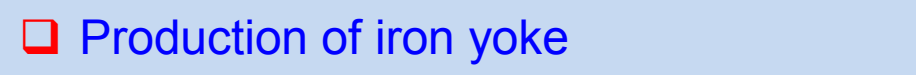
☐ Production of iron yoke



Assembly of iron plates, compression in axial direction with 50kN

Welding of iron plates



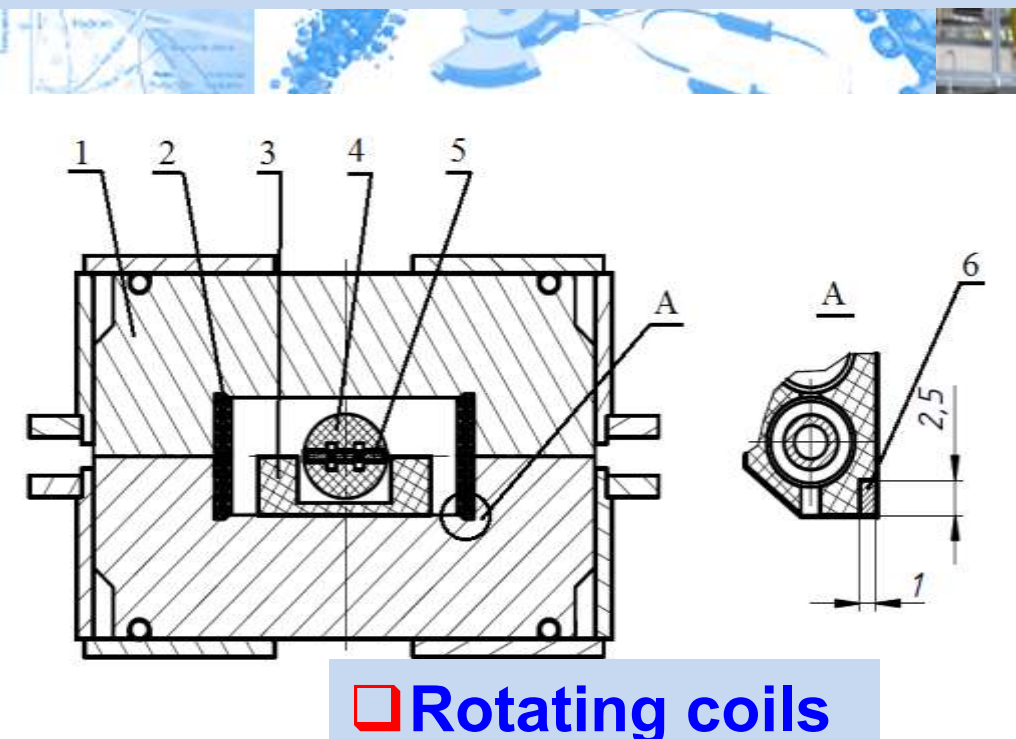


Final machining of half of the yoke

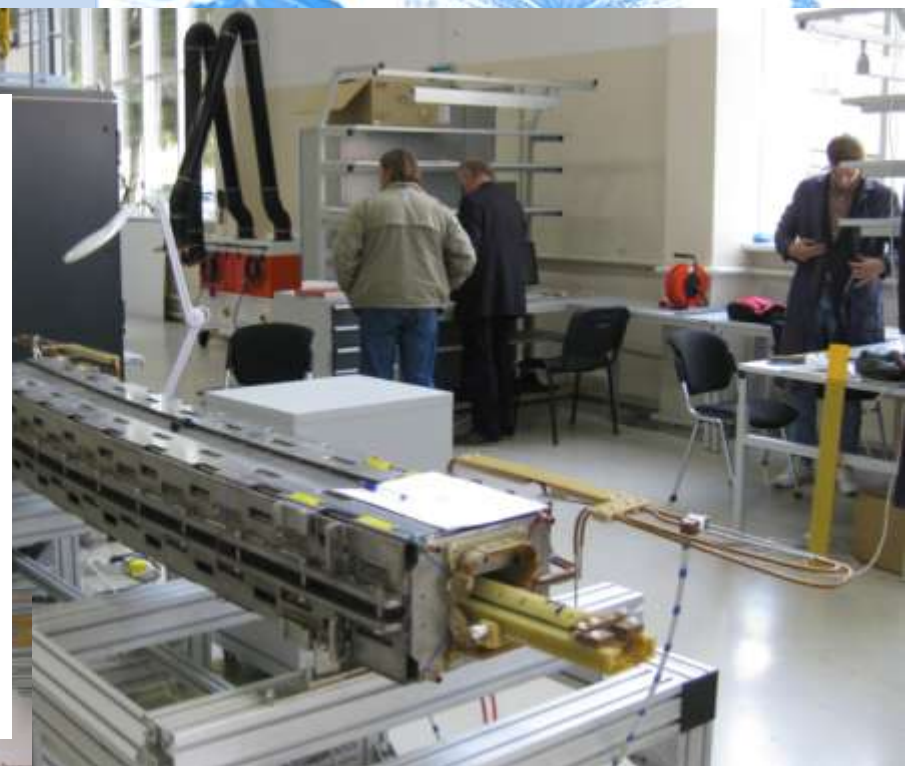


❑ Assembling of yoke and coil





❑ Rotating coils



Cross-section of NICA booster dipole with magnetic measurement system installed.

1. Magnet yoke
2. SC coil
3. Magnetometer support
4. Rotating part with coils
5. Measurement coils
6. Coils for reference field





Parameters to measure:

- Effective length

$$L_{eff} = \frac{1}{B_0} \int_{-\infty}^{+\infty} B_y(s) ds \quad \frac{\delta L}{L} < 10^{-4}$$

- Angle between mechanical and magnetic planes

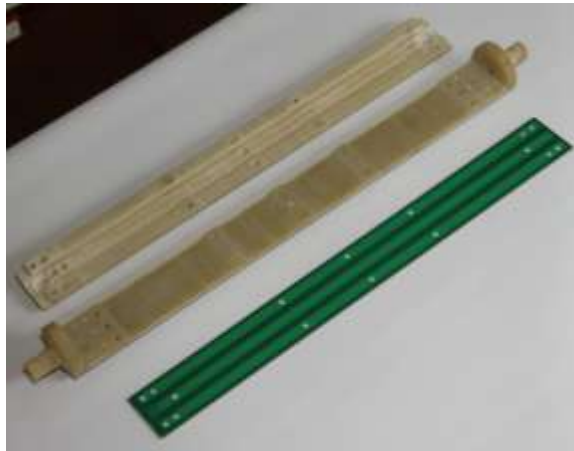
$$\alpha = \frac{\int_{-\infty}^{+\infty} B_x(s) ds}{\int_{-\infty}^{+\infty} B_y(s) ds} \quad \frac{\delta \alpha}{\alpha} < 10^{-4}$$

- Integral harmonics of magnetic field

$$\mathbf{b}^*_n = \int_{-\infty}^{+\infty} \mathbf{b}_n \mathbf{ds} , \mathbf{a}^*_n = \int_{-\infty}^{+\infty} \mathbf{a}_n \mathbf{ds}, \mathbf{n}=1..10$$

☐ Magnetic measurements at room temperature

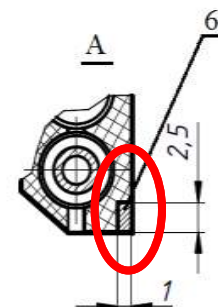
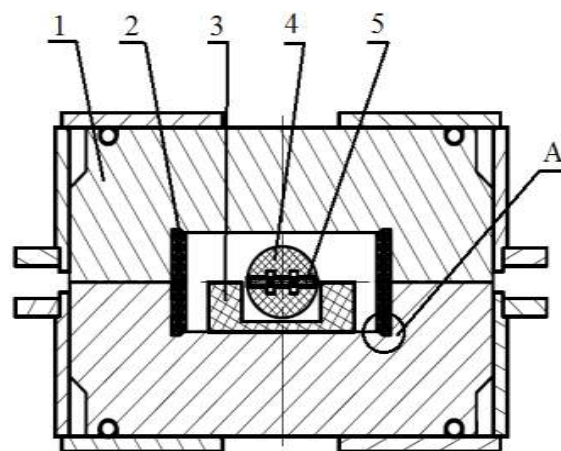
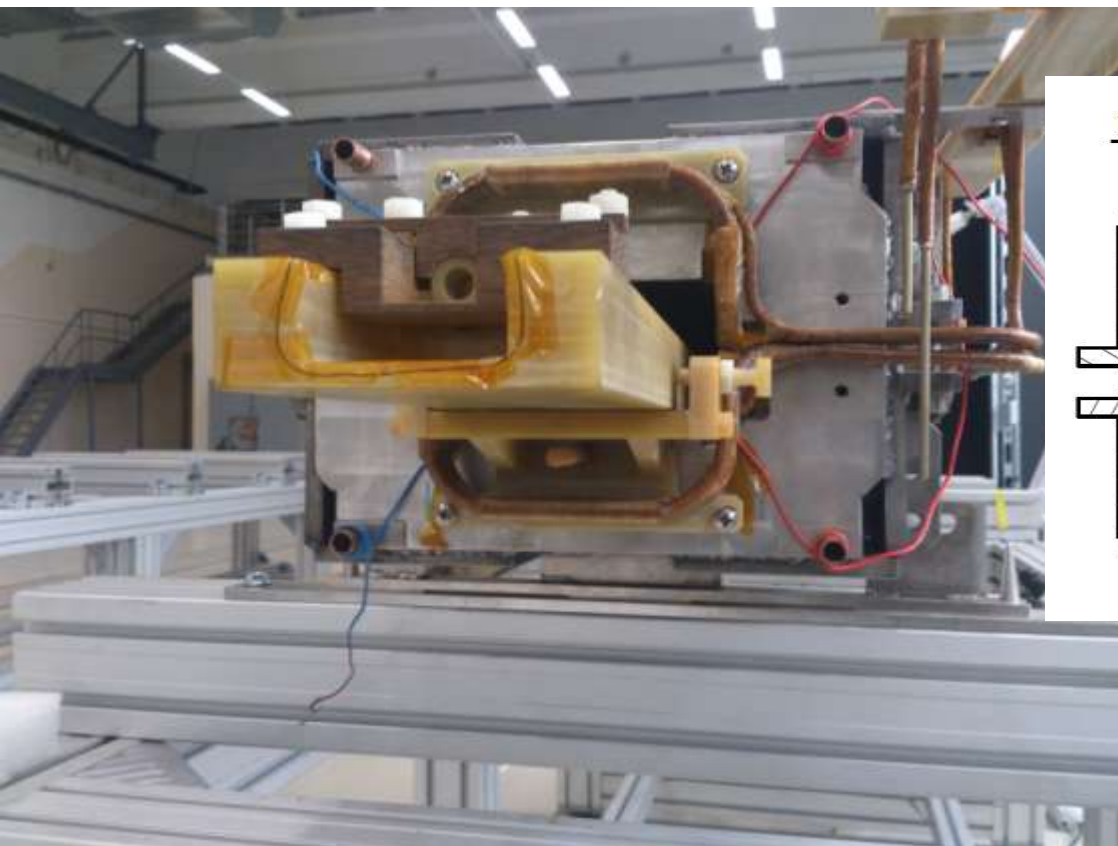
- 5 sections (430mm length) with harmonic coils
- Additional not-rotating coil in the median plane of magnet around all rotating coils
- Measurements without anti-cryostat inside cooled magnet



☐ Magnetic measurements at room temperature

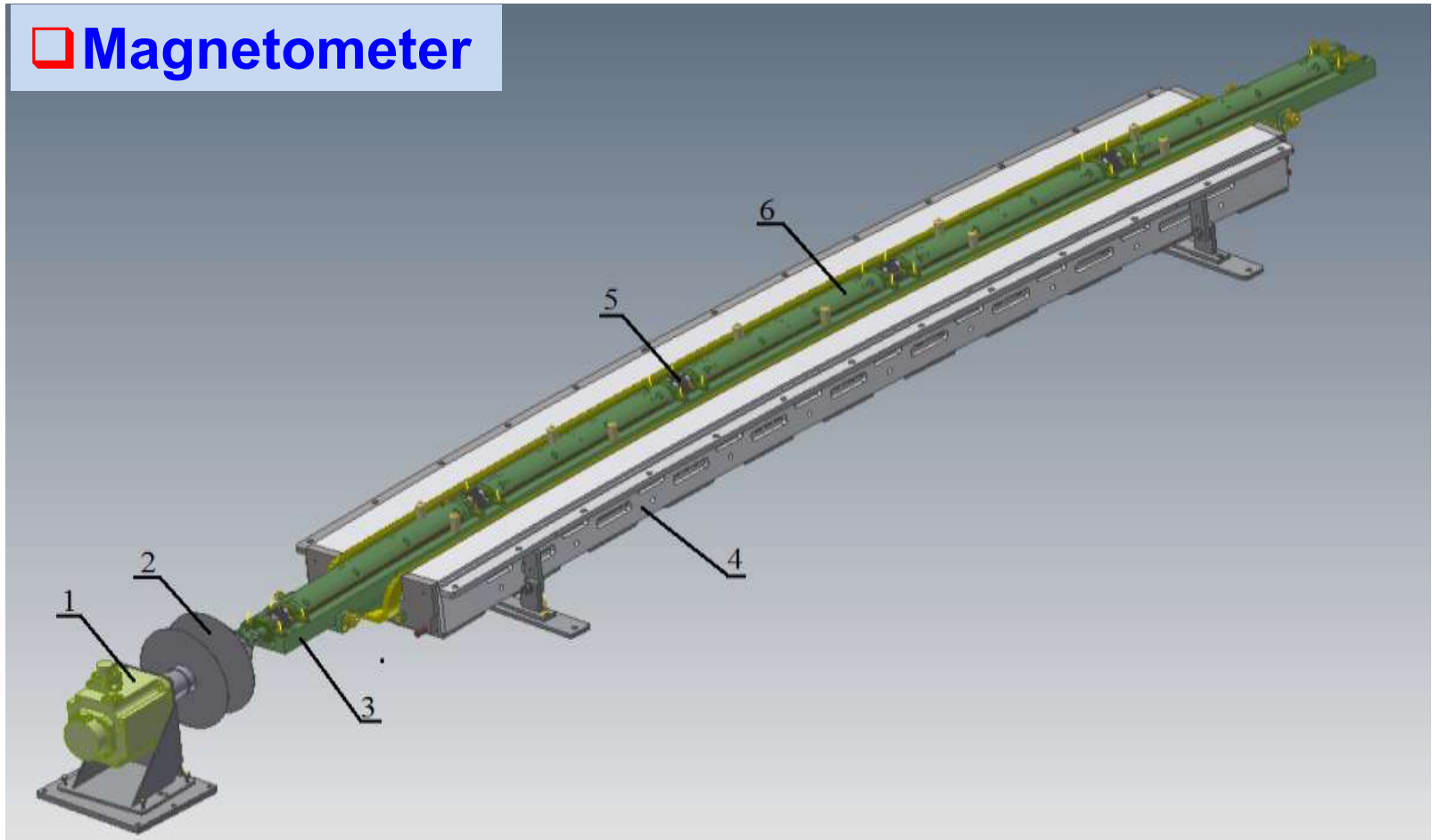


☐ Reference magnetic field





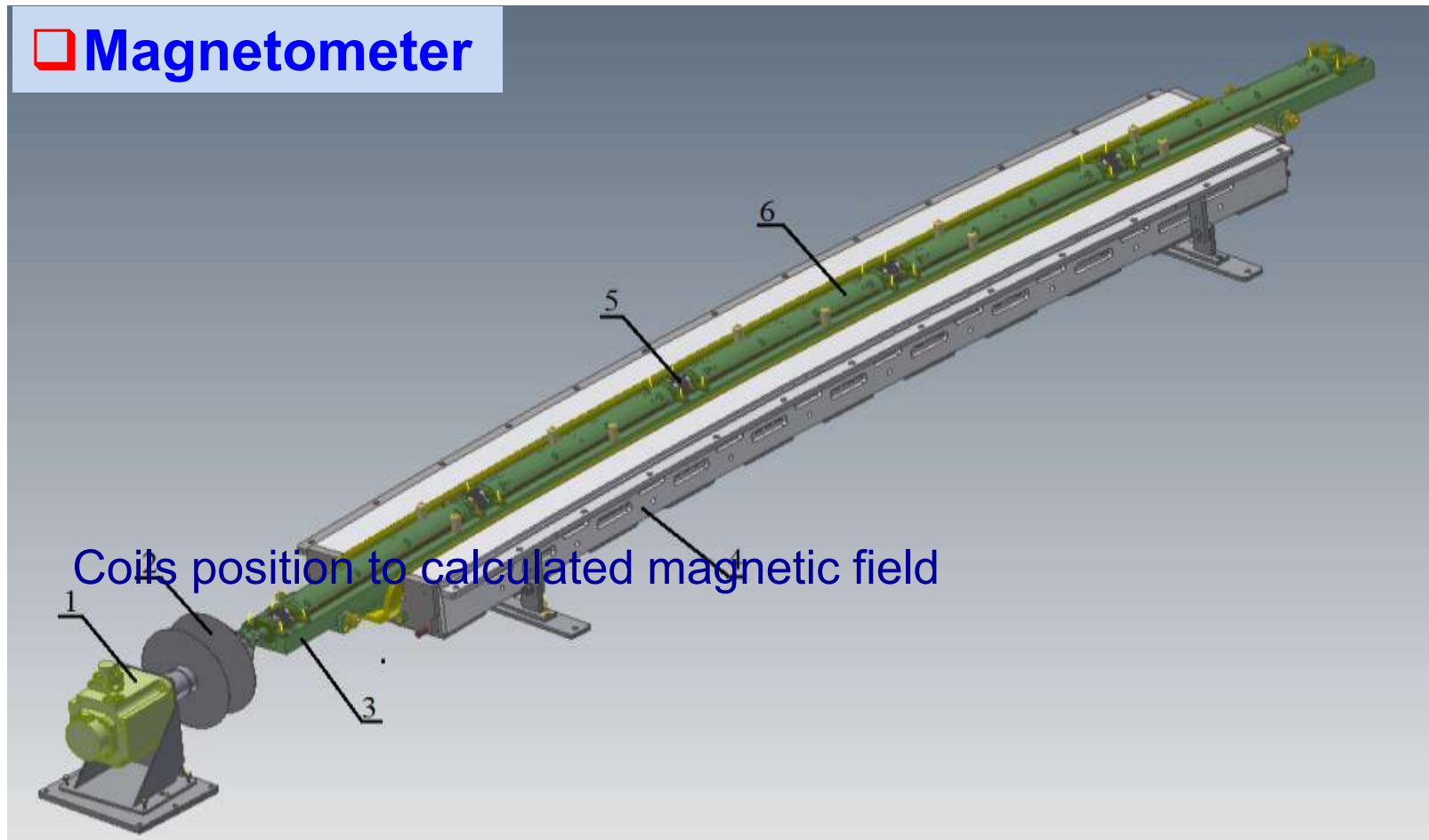
❑ Magnetometer



1. Servo-Motor, 2. Cable-coil, 3. Support, 4. Lower yoke, 5. Connections, 6. Measurement sections with coils.



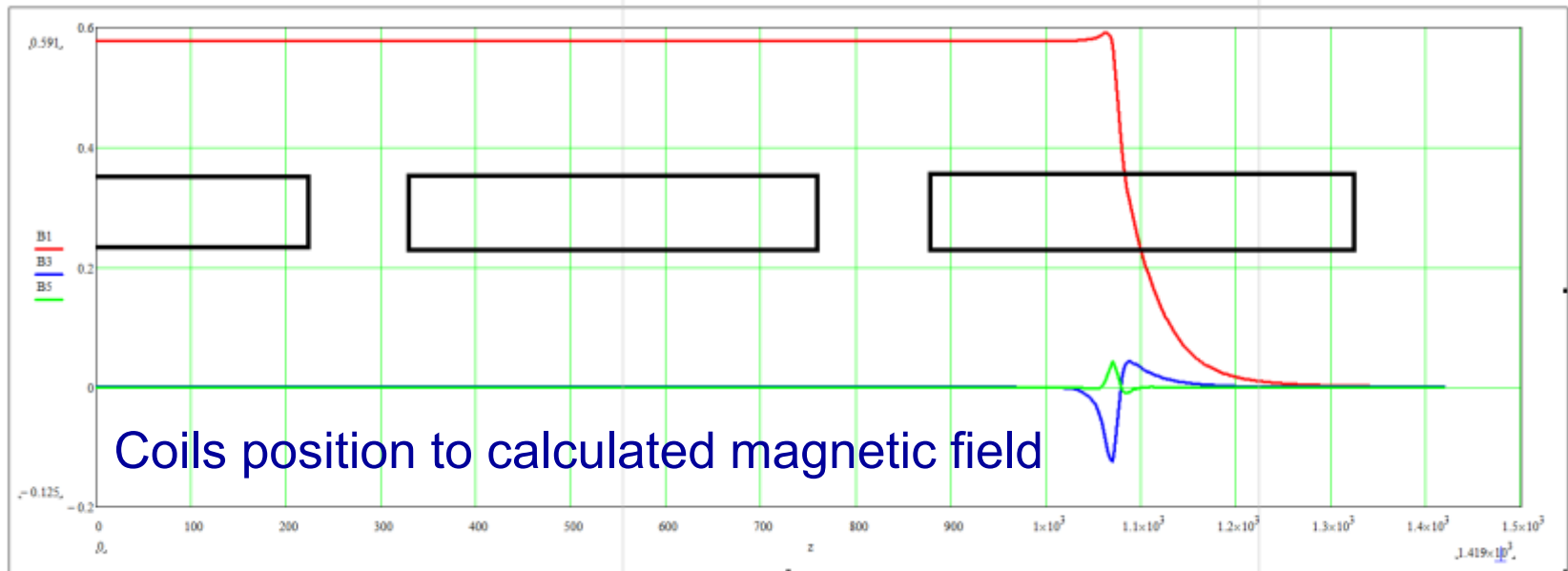
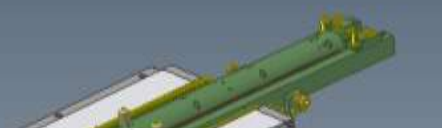
❑ Magnetometer



1. Servo-Motor, 2. Cable-coil, 3. Support, 4. Lower yoke, 5. Connections, 6. Measurement sections with coils.



❑ Magnetometer



1. Servo-Motor, 2. Cable-coil, 3. Support, 4. Lower yoke, 5. Connections, 6. Measurement sections with coils.

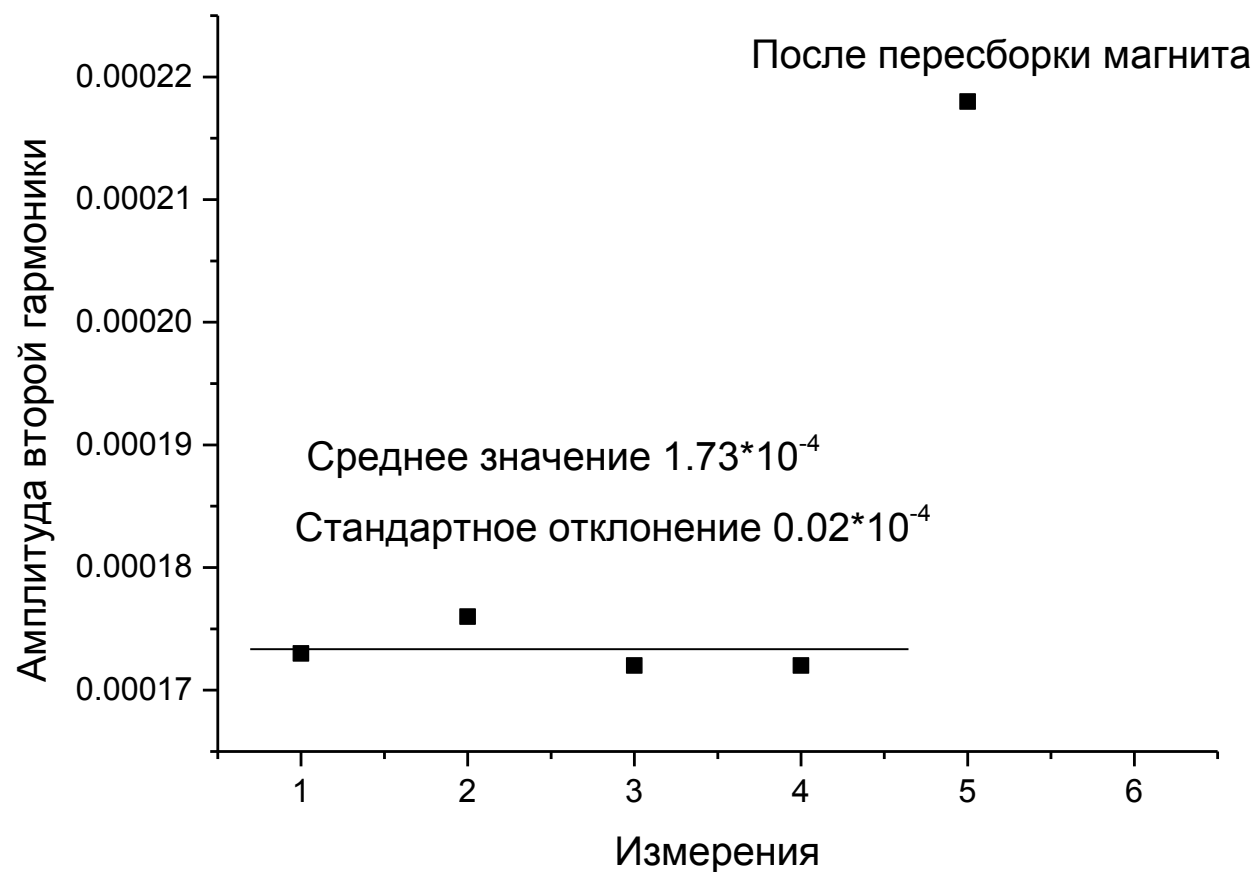


Измеренные и расчетные интегральные относительные гармоники, 10^{-4}

	b_2	a_2	b_3	a_3	b_4	a_4	b_5	a_5	b_6	a_6
Измеренные прототип	-1.30	4.34	-1.80	1.76	0.27	0.82	0.27	0.18	0.17	0.05
Измеренные предсерийный	-2.93	0.88	4.79	0.71	0.33	0.88	0.58	0.08	0.05	-0.08
Вычисленные	-1.13	0	-7.71	0	0.04	0	3.15	0	0.14	0

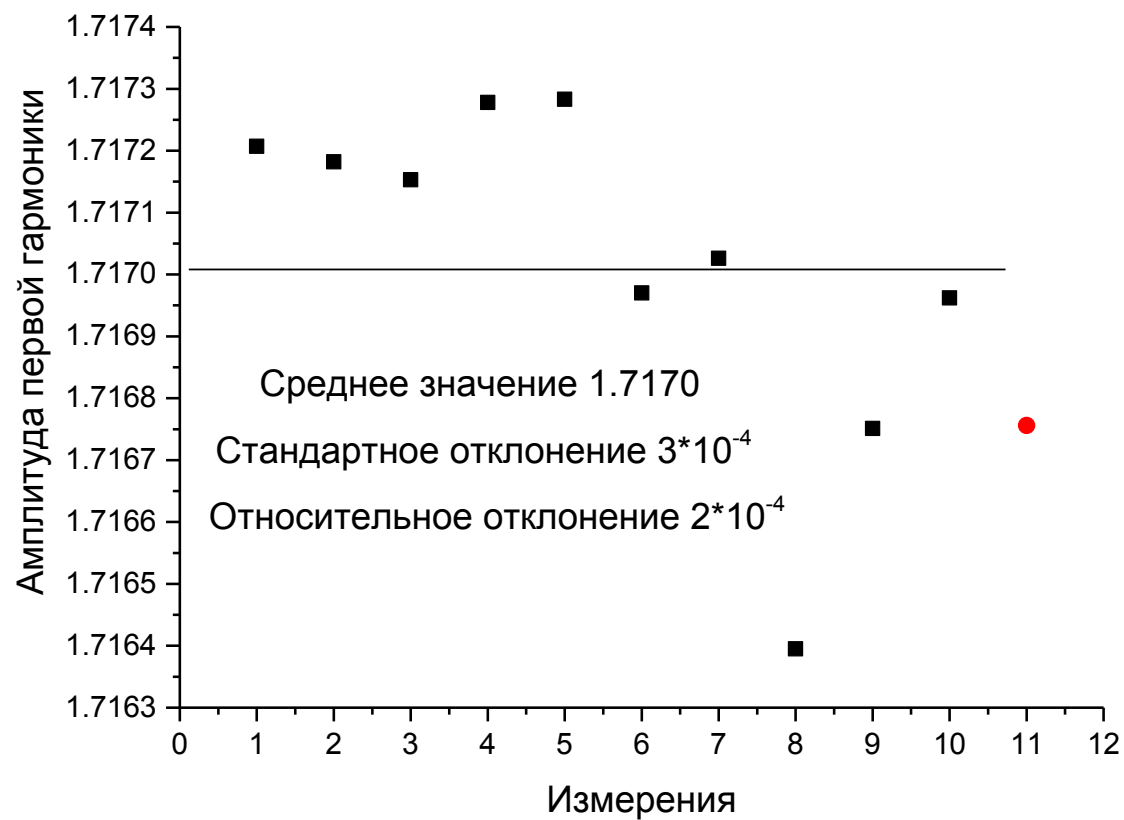


Разброс амплитуды второй гармоники





Разброс амплитуды первой гармоники





- 1 – SC cable production hall**
- 2 – SC coils production hall**
- 3 – Yoke and coil assembly**
- 4- Room temp. magnetic measurements**
- 5 - Vacuum test bench**
- 6 – Mounting magnet into cryostat**
- 7 – Cryogenic tests hall**
- 8- Power supply**

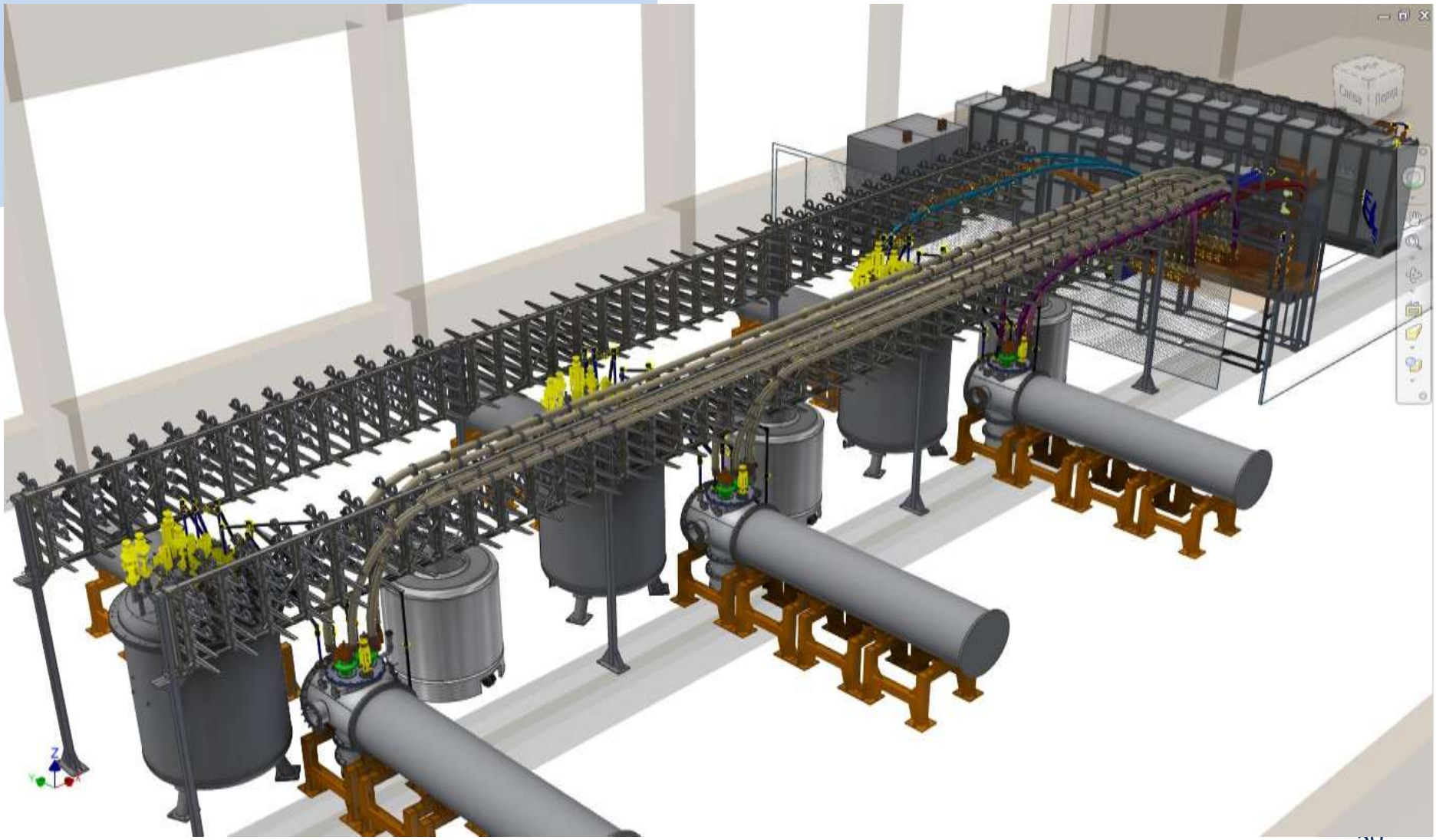


☐ Cryogenic tests hall:

- ☐ Cryogenic tests of SC magnets
- ☐ Magnetic measurements in cooled magnets



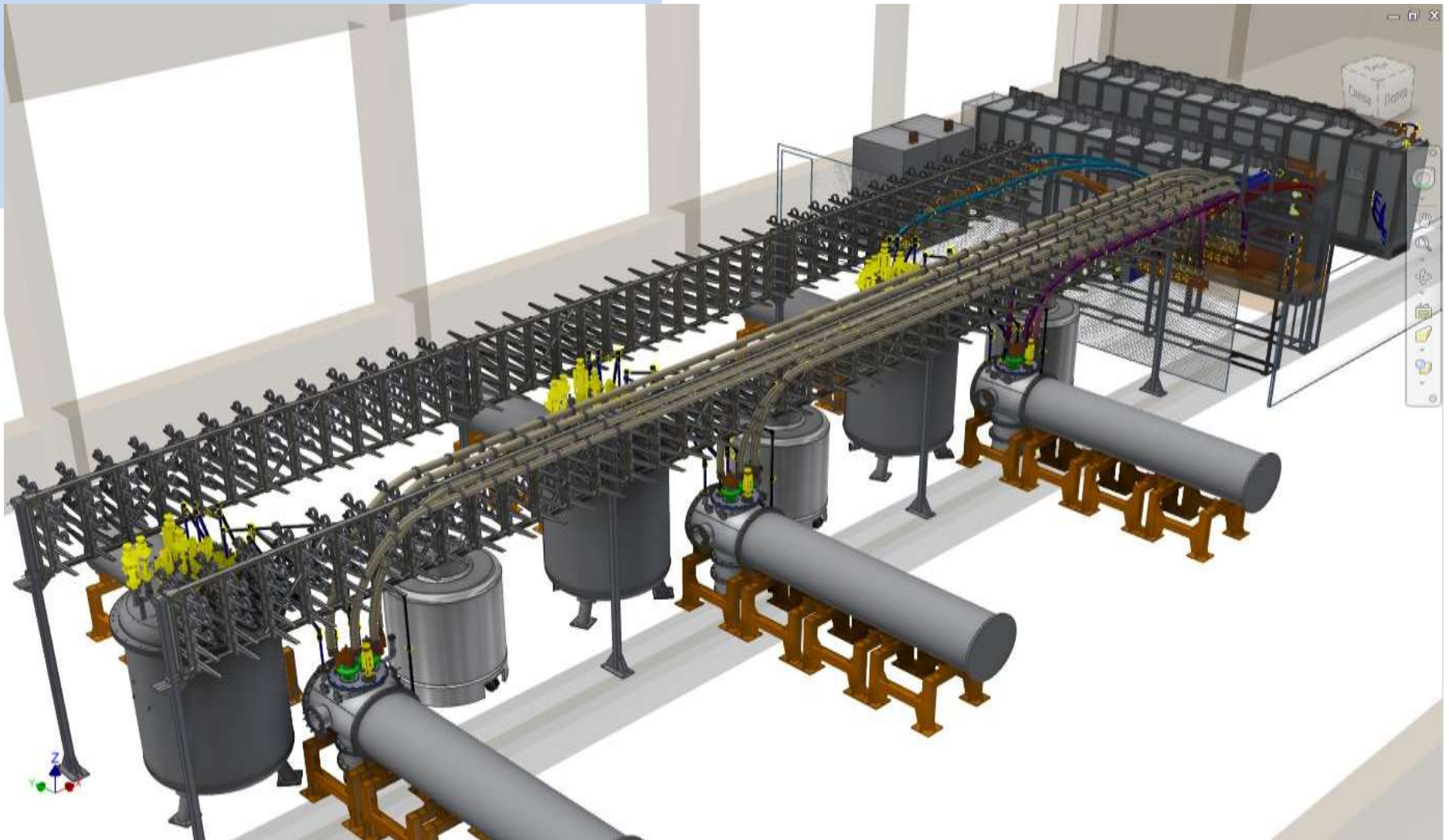
☐Cryogenic tests hall:





☐ Cryogenic tests hall:

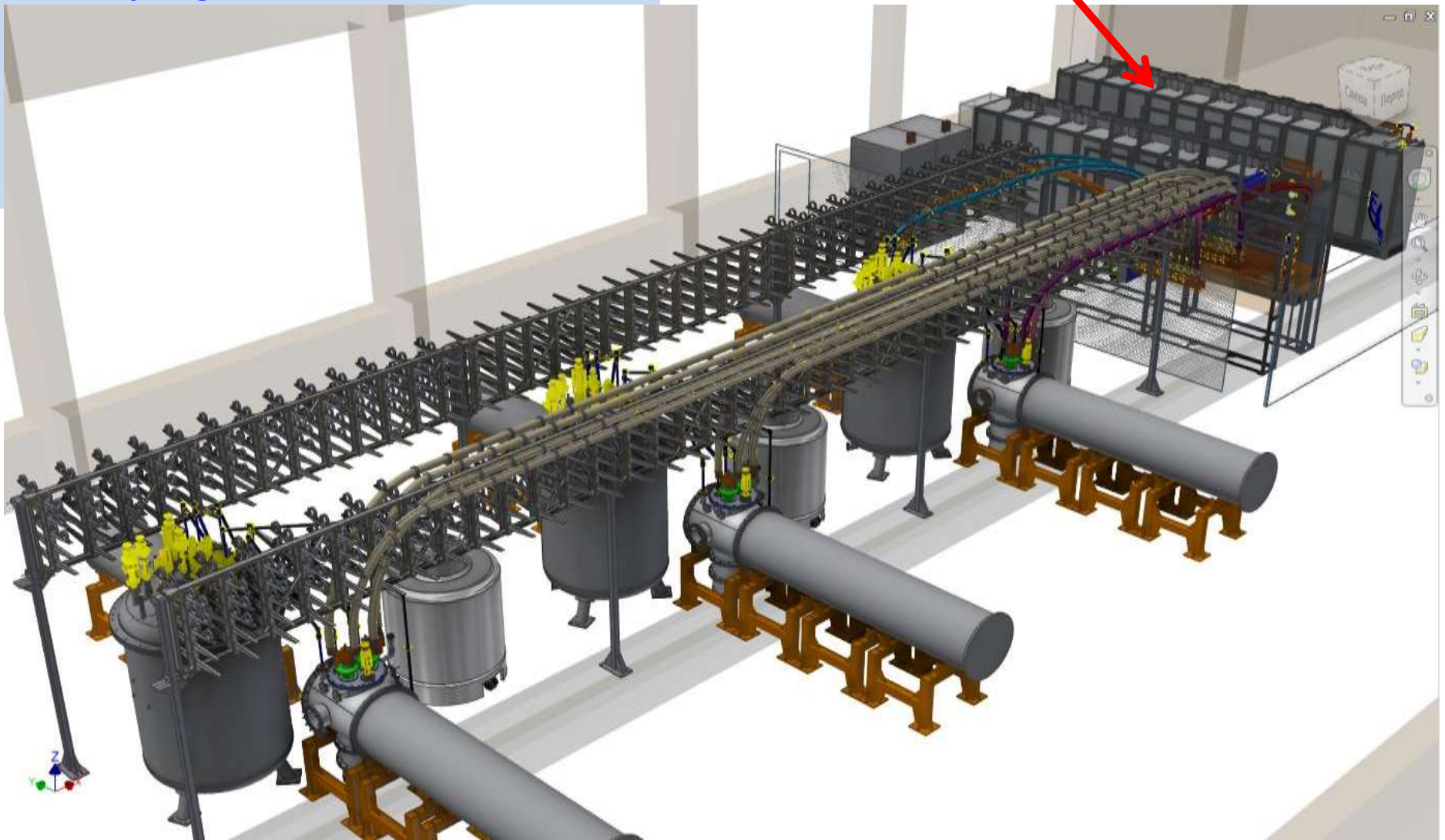
Power supply





☐ Cryogenic tests hall:

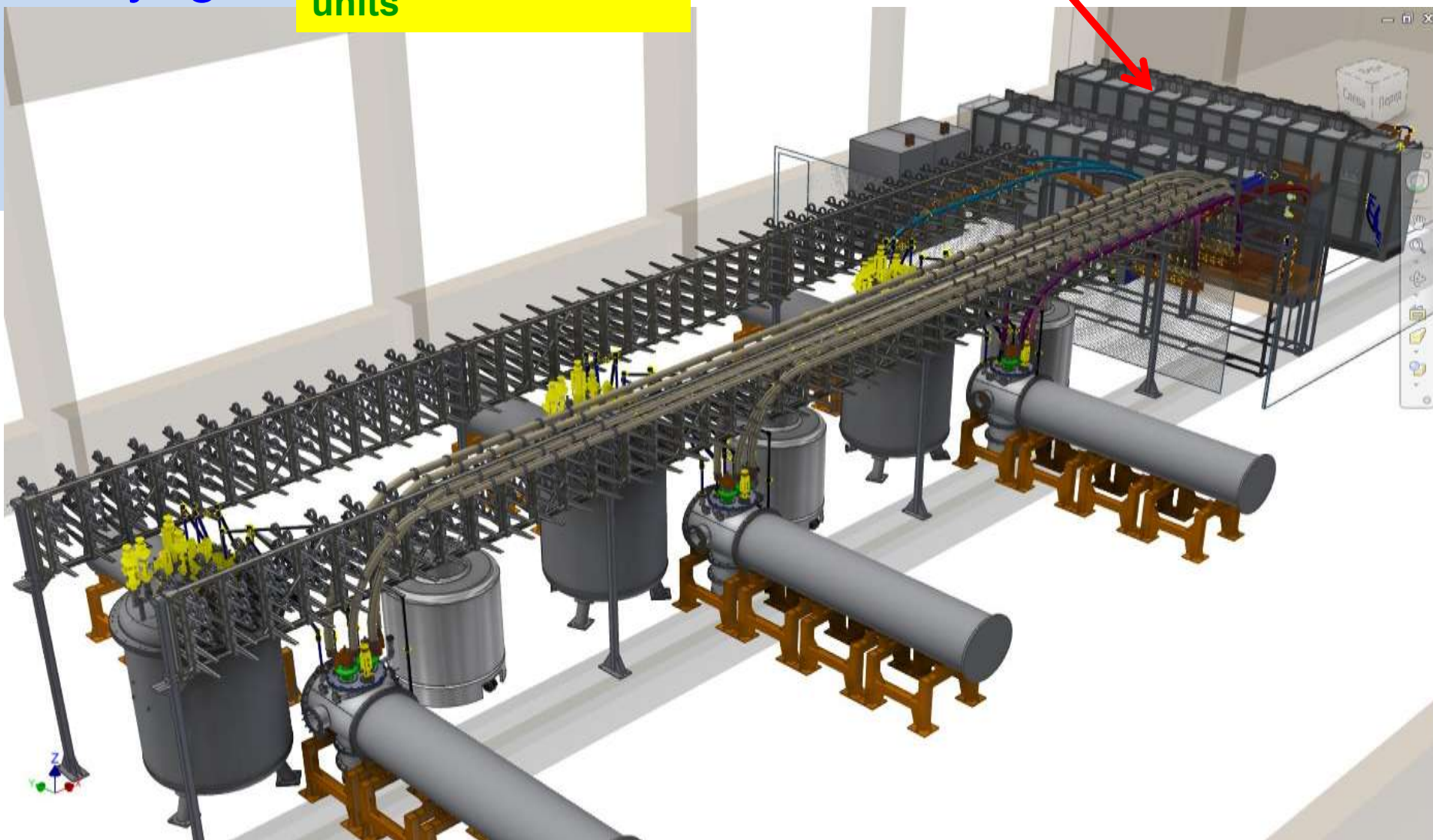
Power supply





☐ Cryogenic Satellite refrigerator units

Power supply

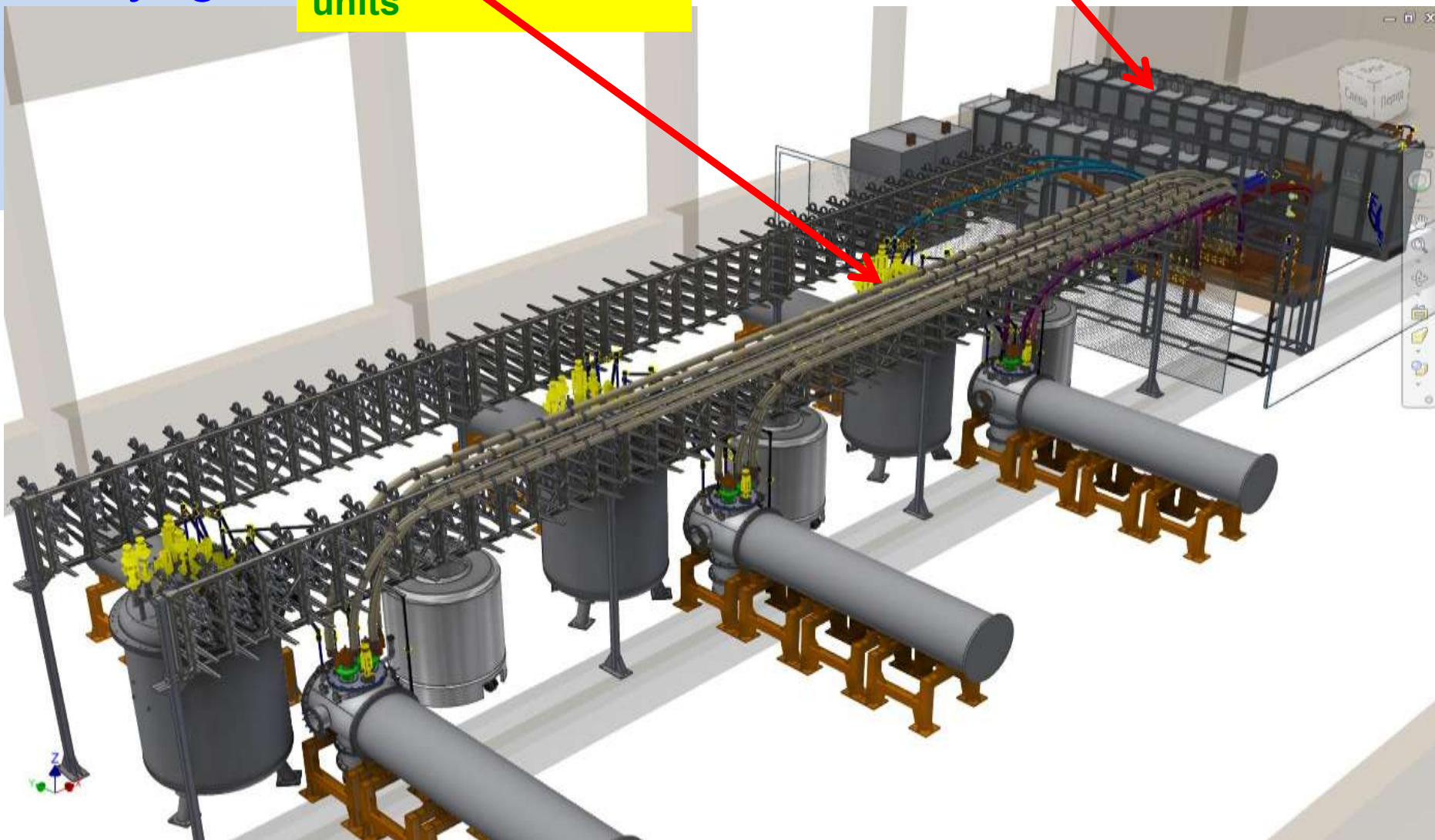




☐ Cryogeni

Satellite refrigerator units

Power supply

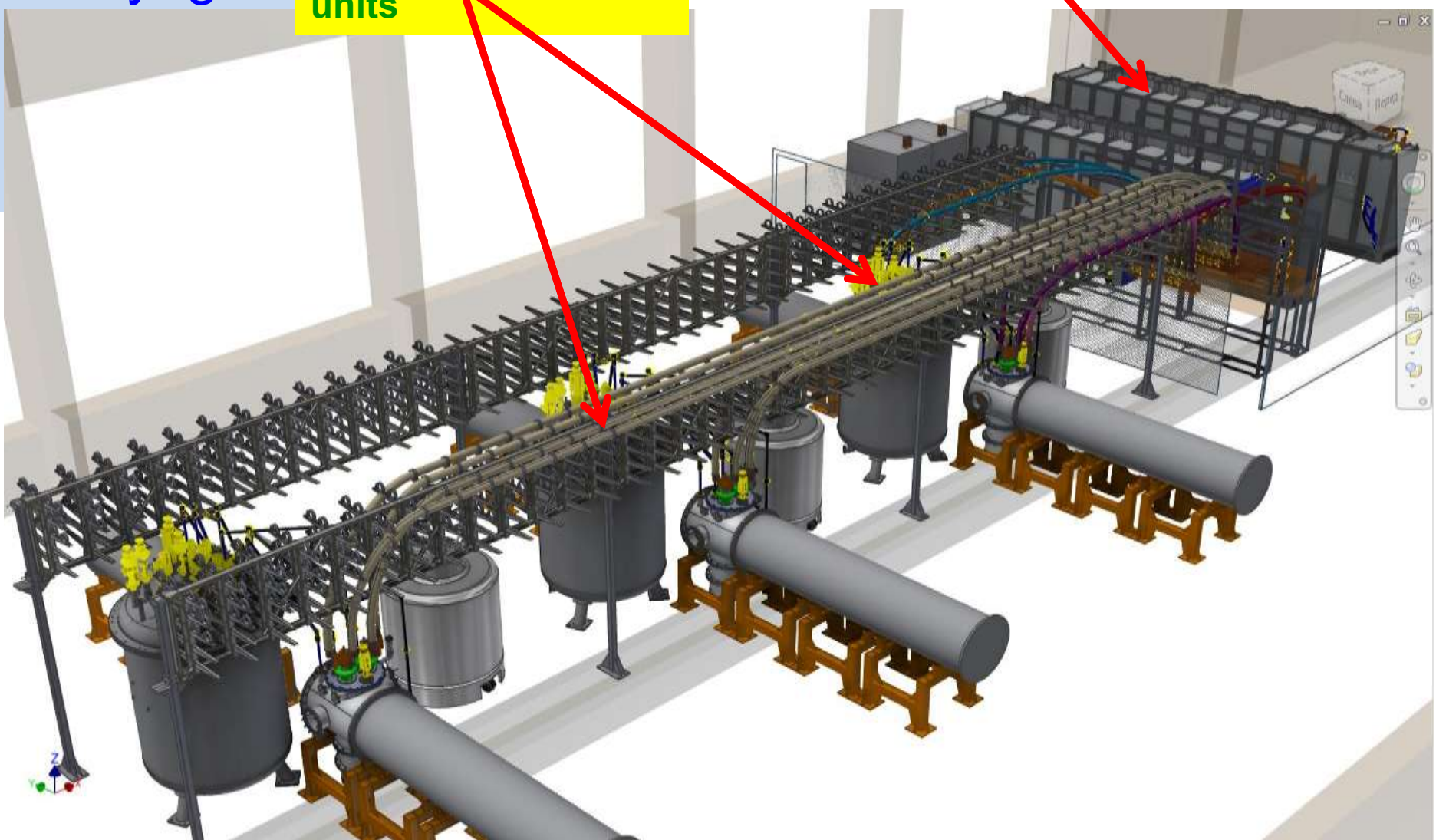




☐ Cryogeni

Satellite refrigerator units

Power supply

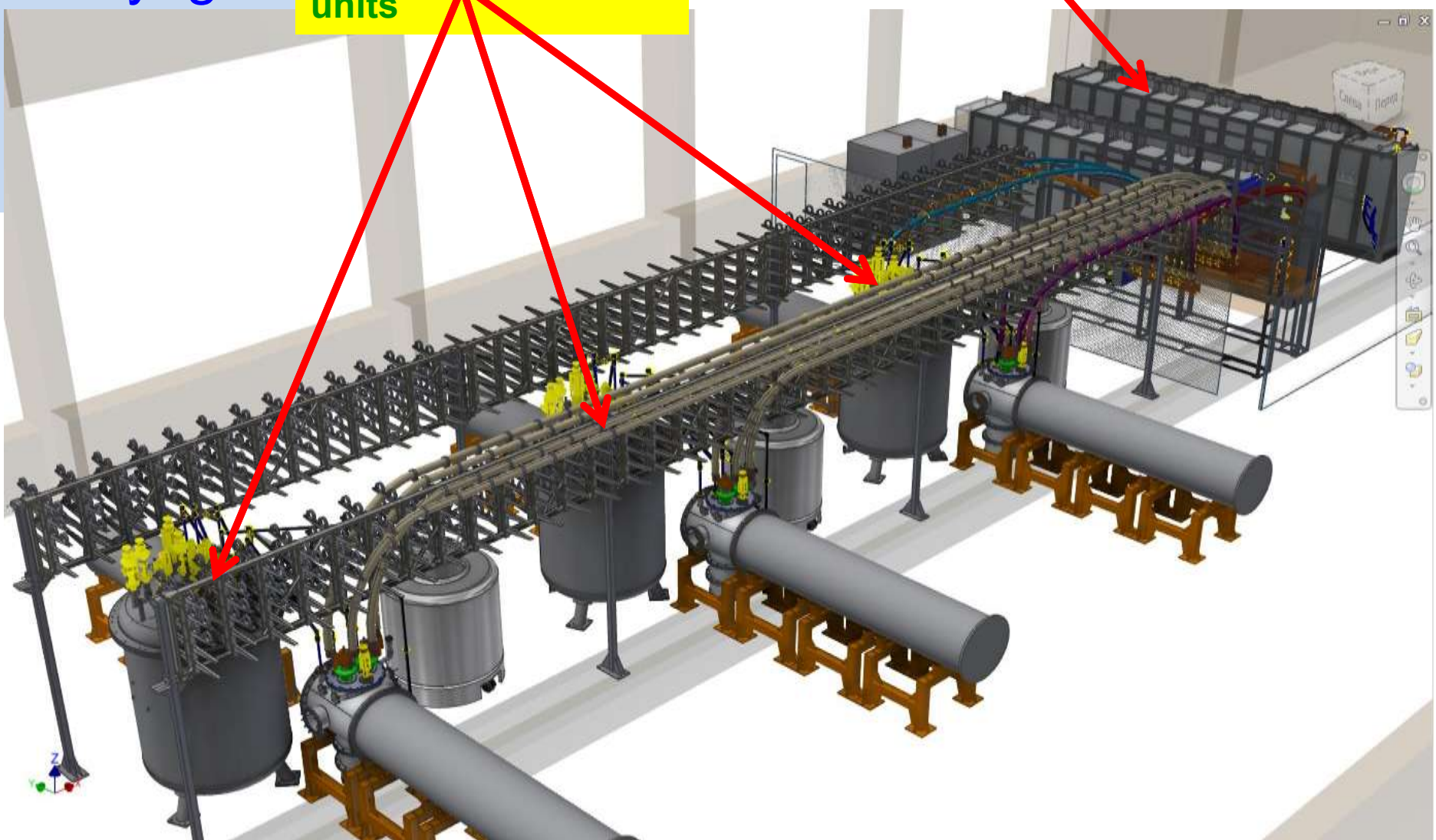




☐ Cryogeni

Satellite refrigerator units

Power supply

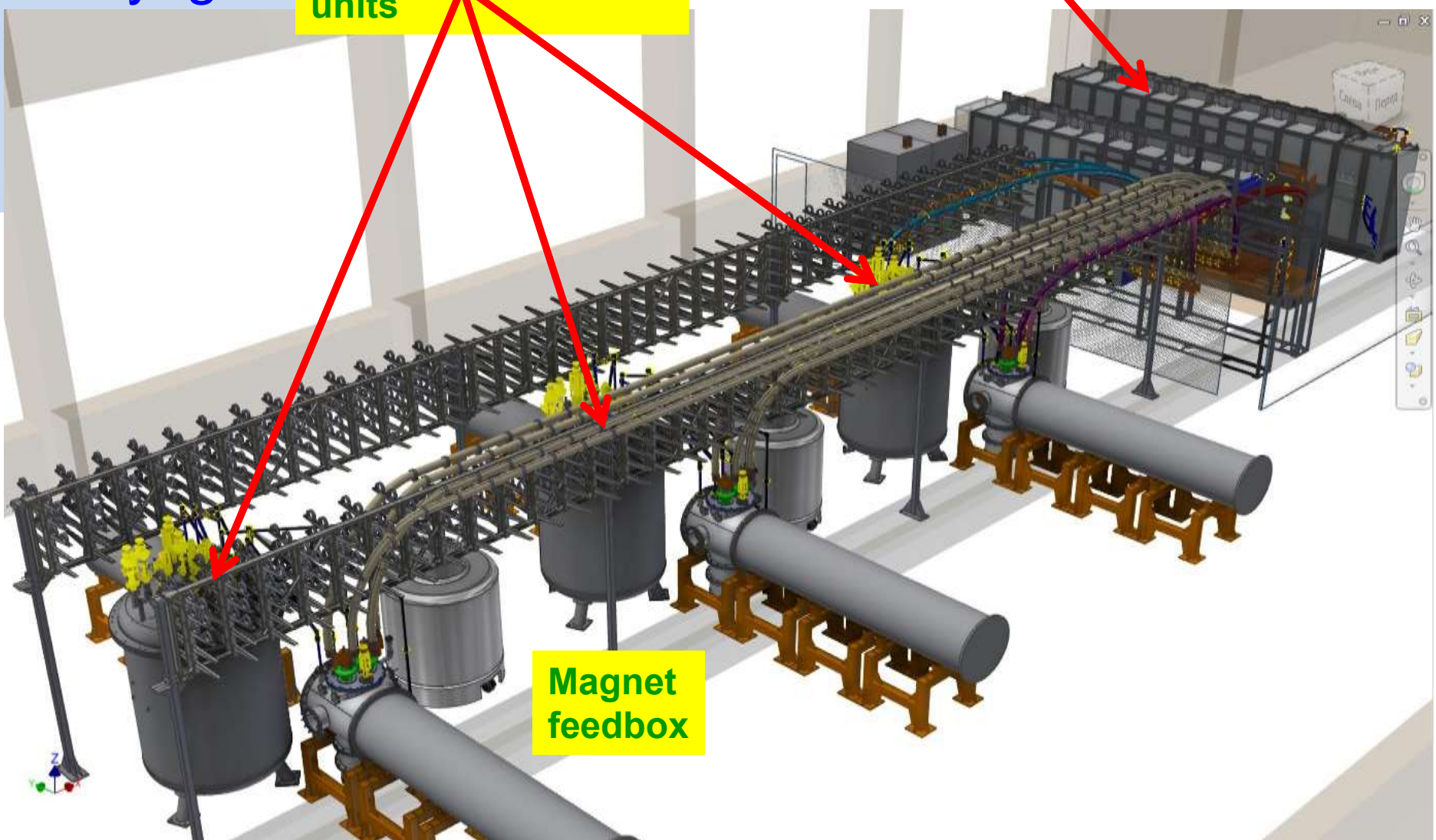




☐ Cryogeni

Satellite refrigerator units

Power supply



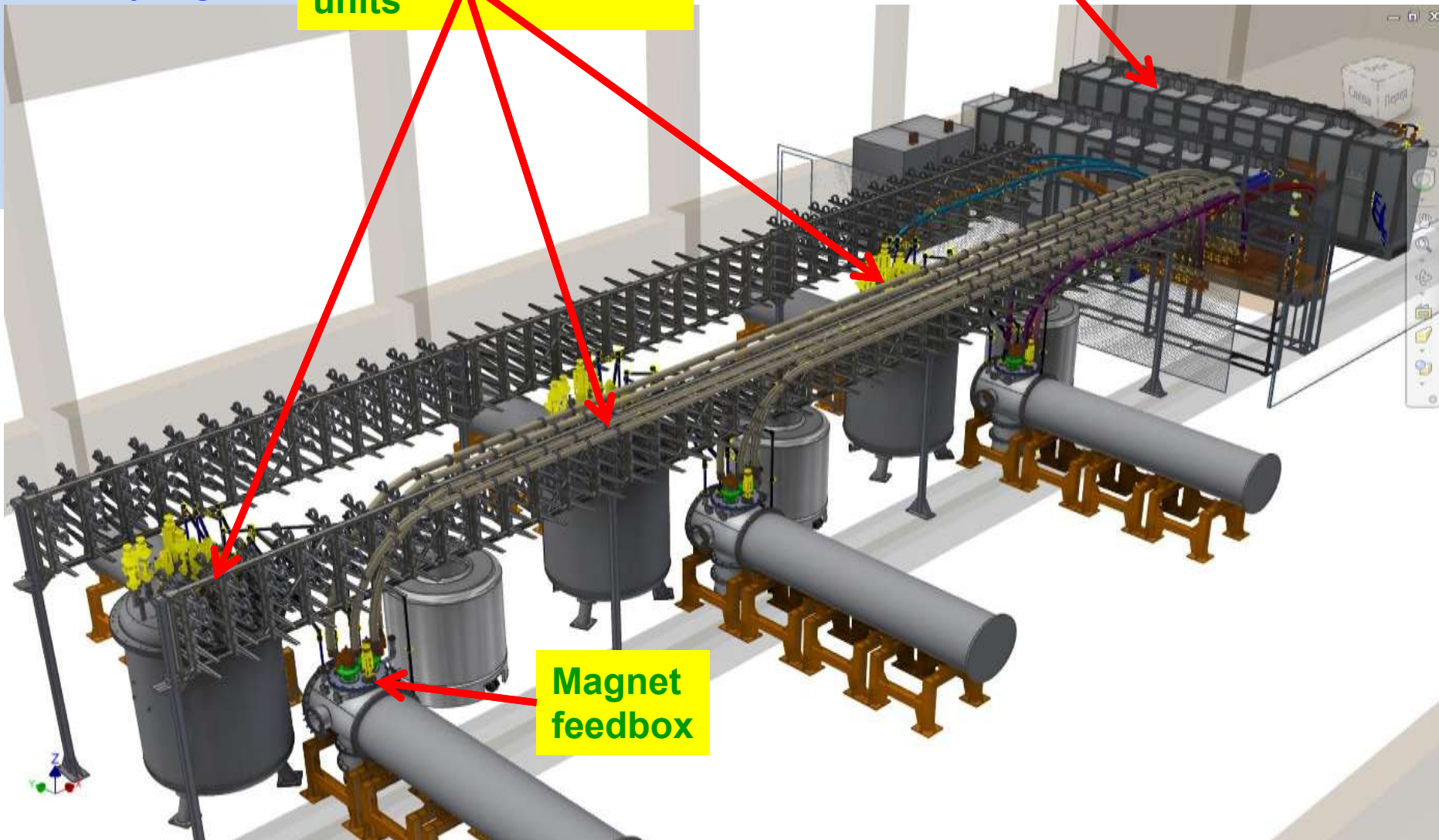
Magnet feedbox



☐ Cryogeni

Satellite refrigerator units

Power supply



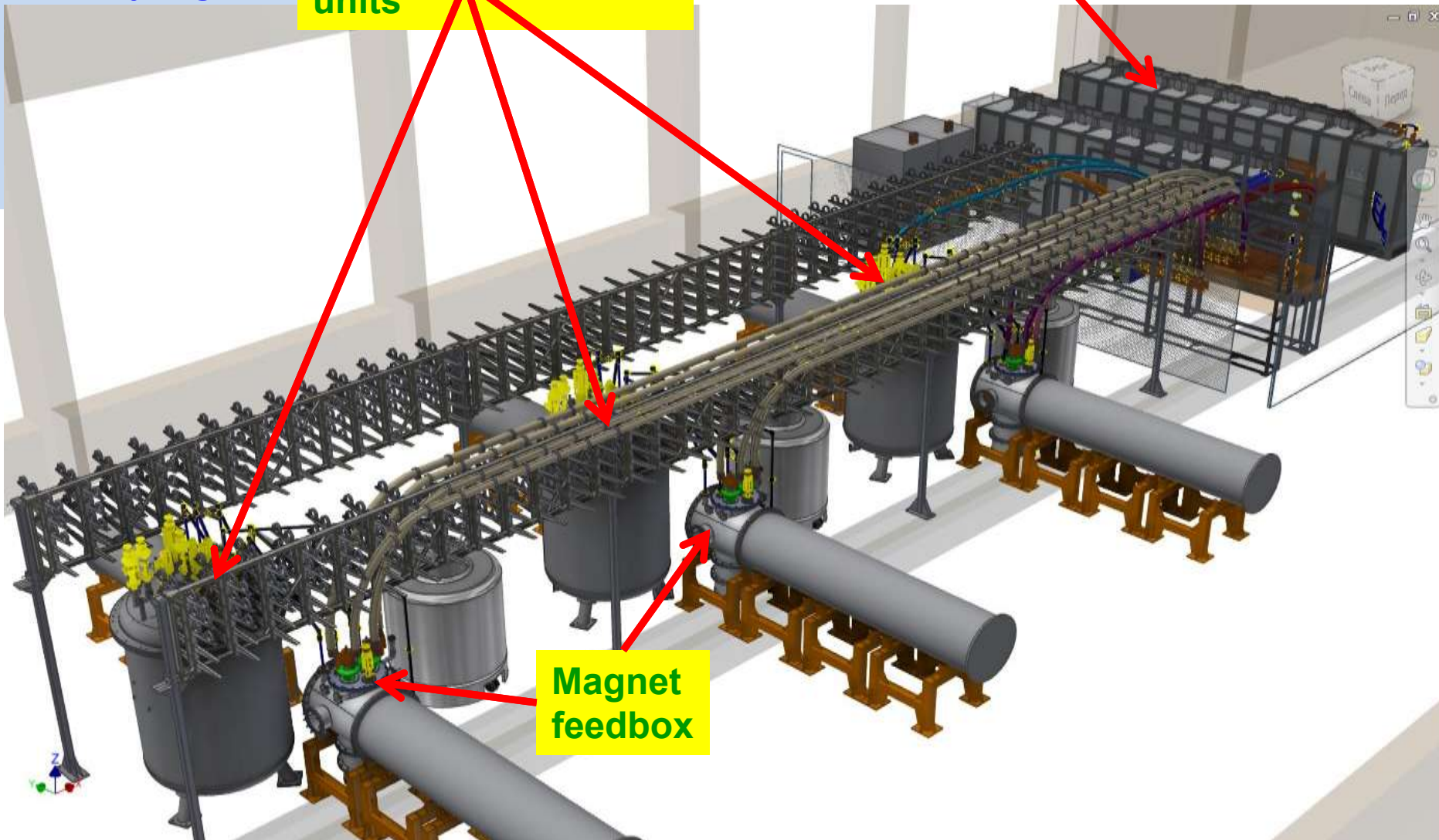
Magnet feedbox



☐ Cryogeni

Satellite refrigerator units

Power supply



Magnet feedbox



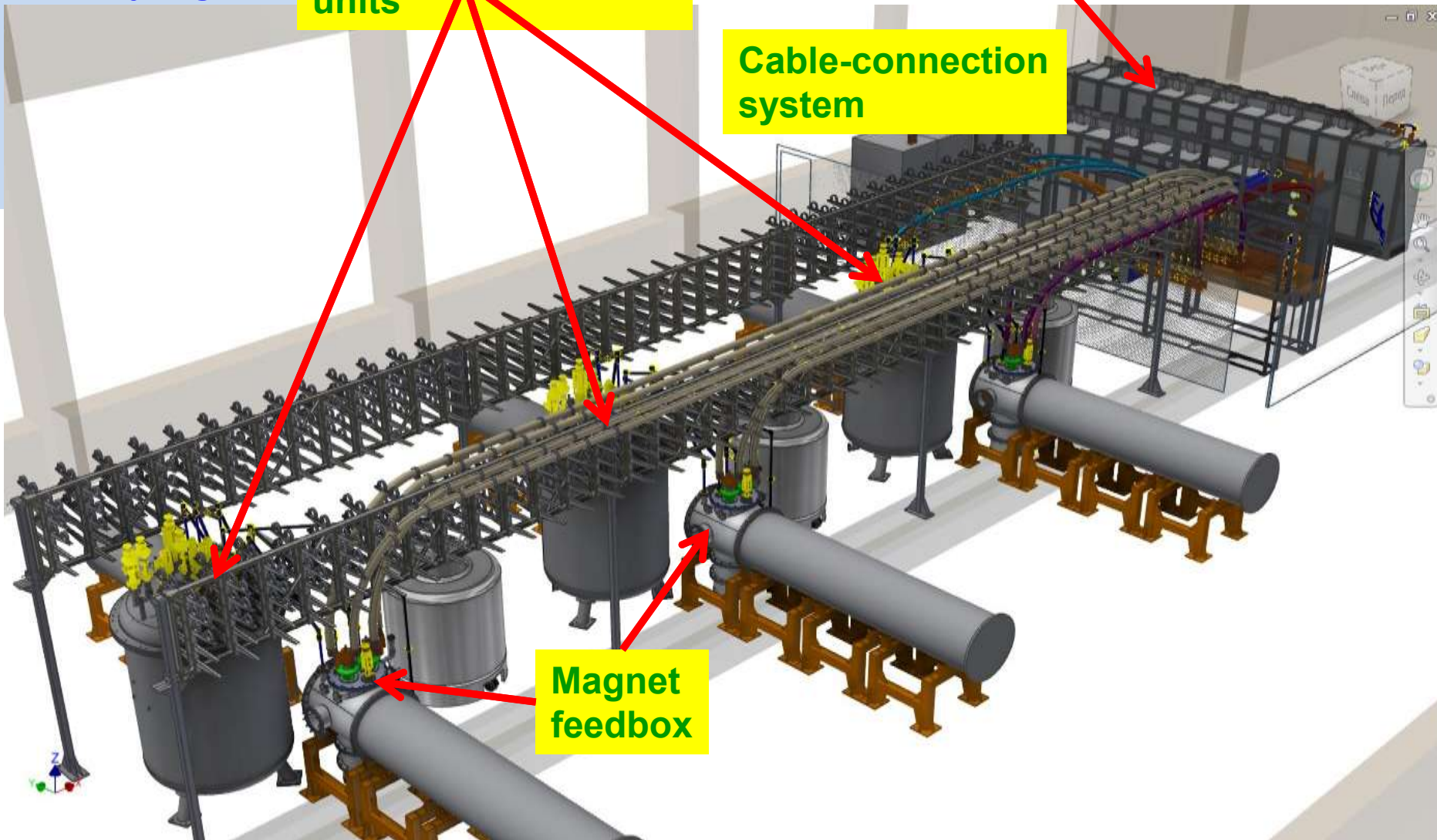
☐ Cryogeni

Satellite refrigerator units

Power supply

Cable-connection system

Magnet feedbox





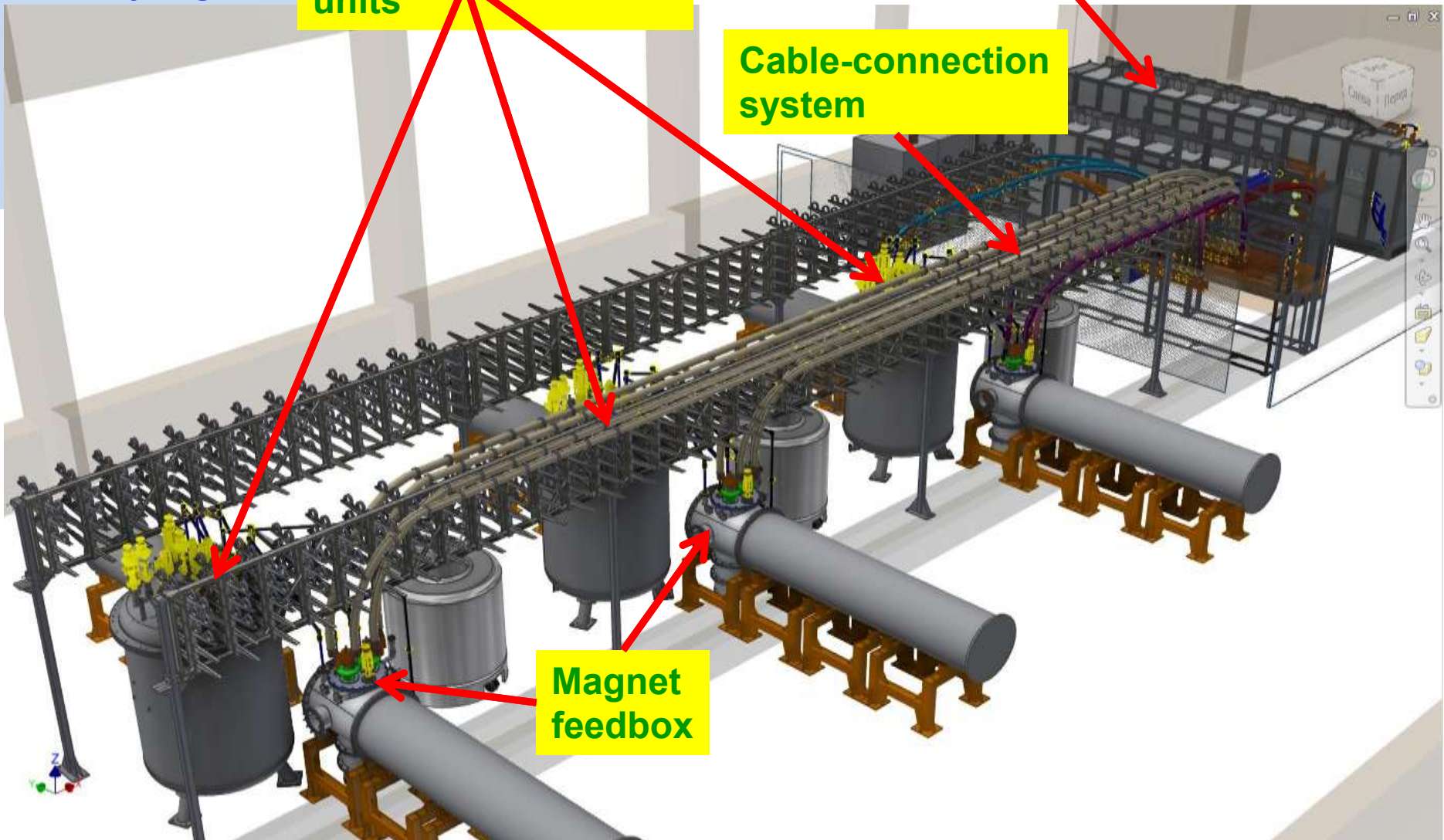
☐ Cryogeni

Satellite refrigerator units

Power supply

Cable-connection system

Magnet feedbox





☐ Cryogeni

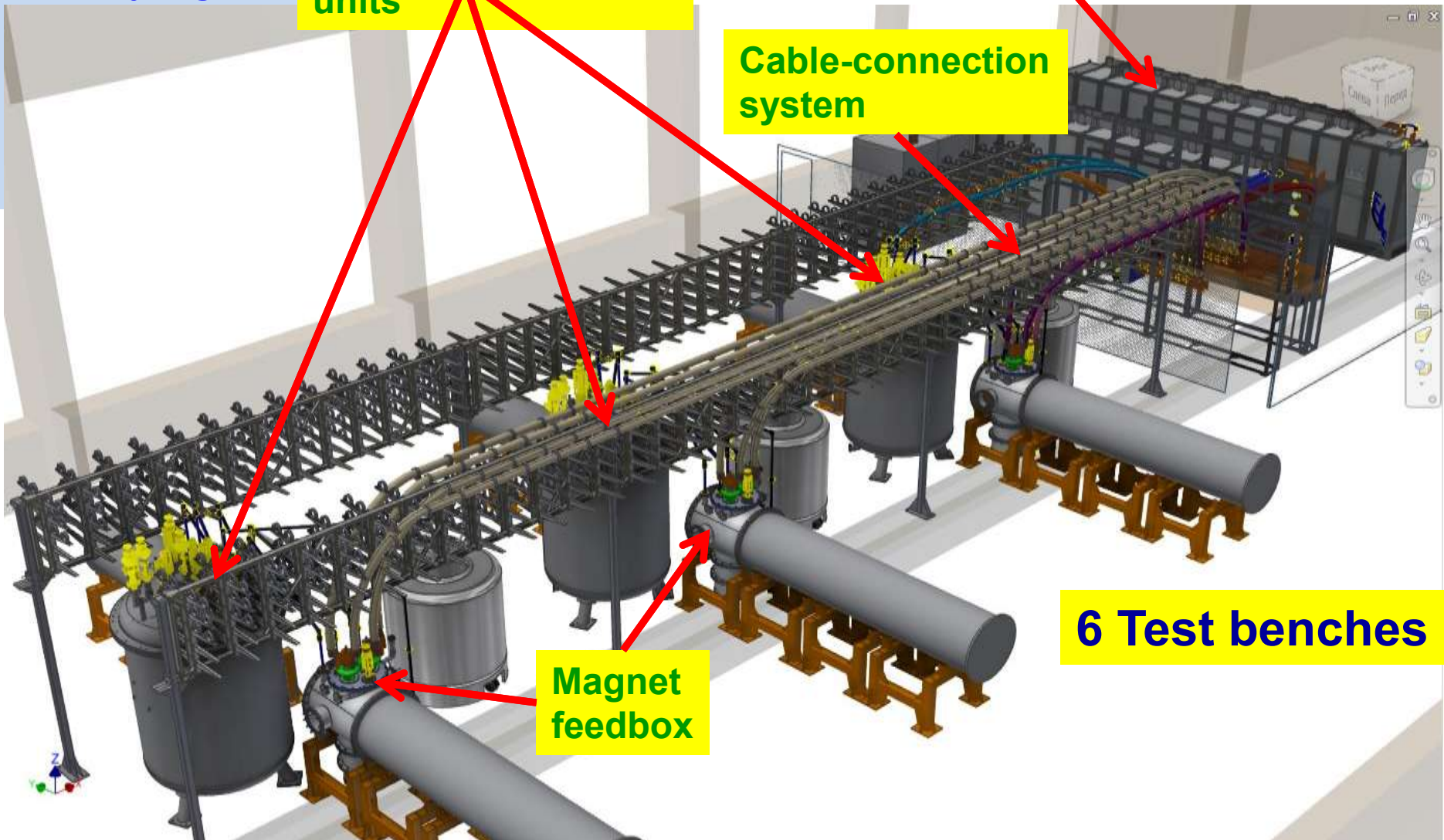
Satellite refrigerator units

Power supply

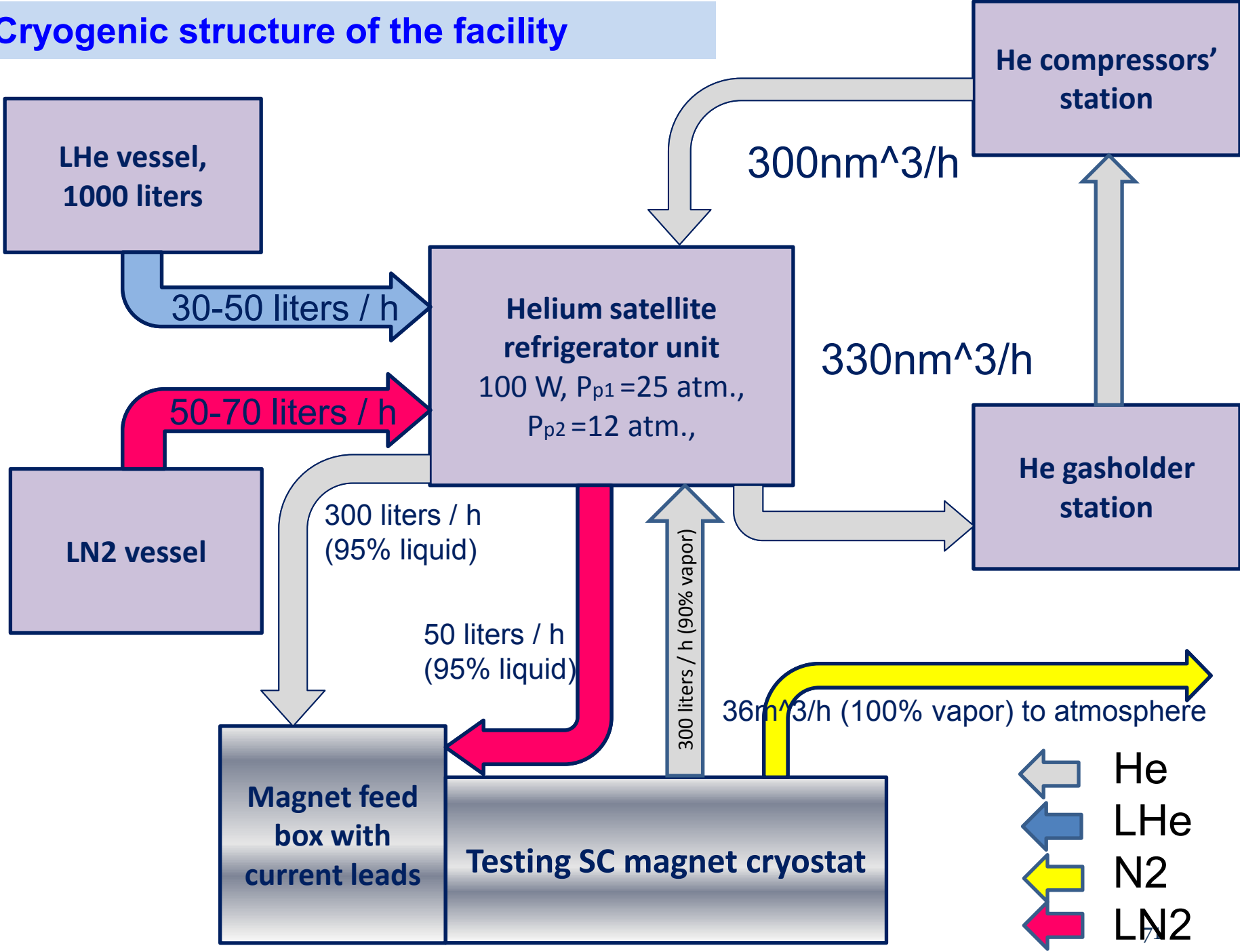
Cable-connection system

Magnet feedbox

6 Test benches



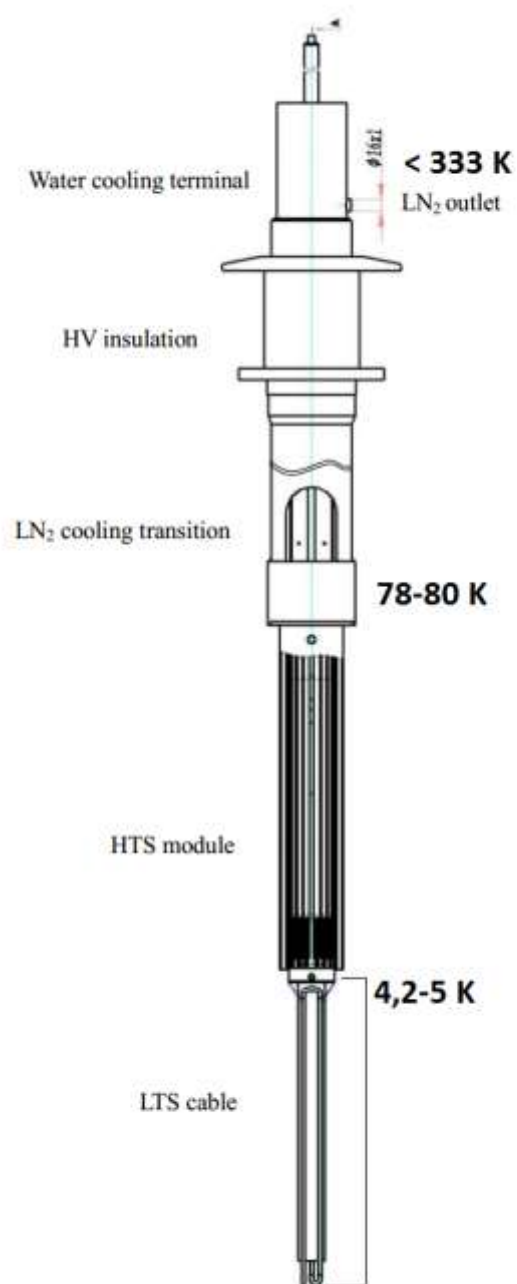
Cryogenic structure of the facility



❑ Cryogenic structure of the facility

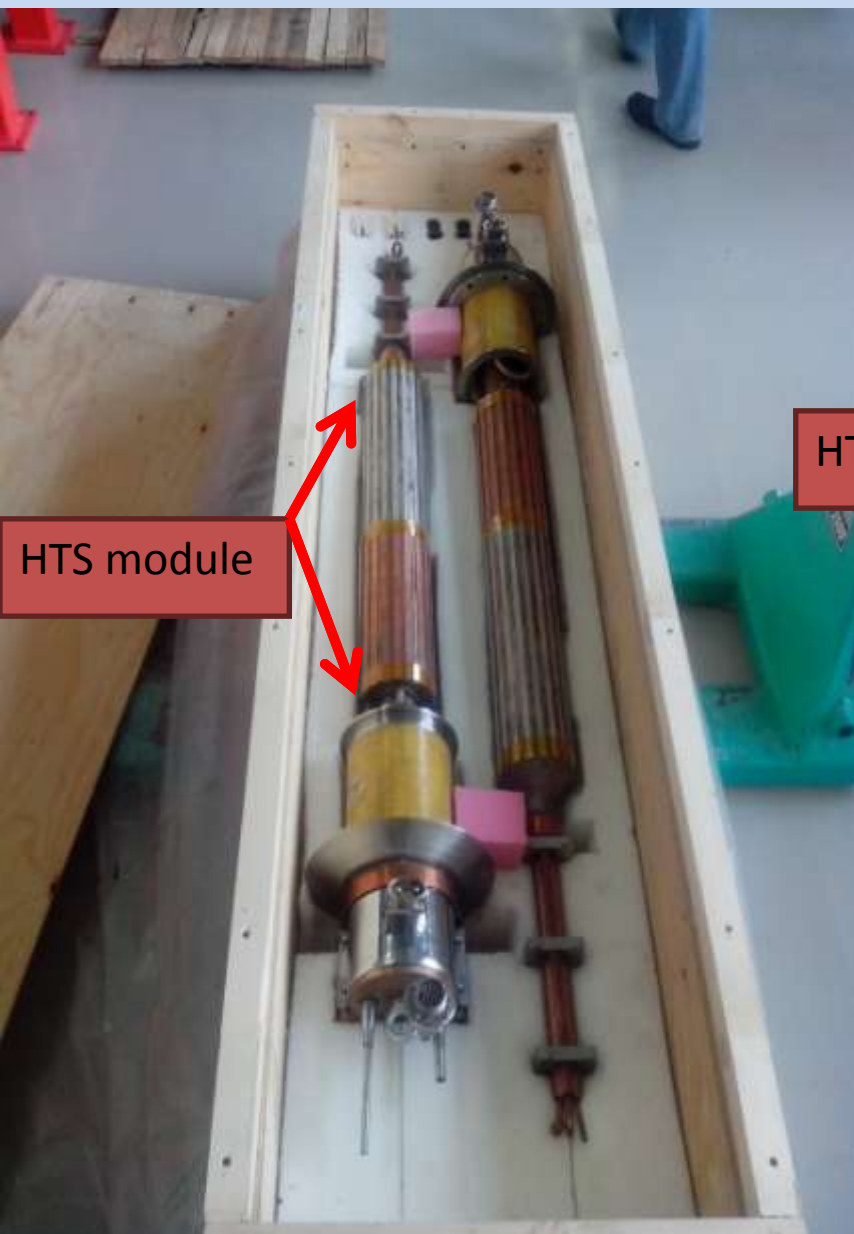


❑ Magnet feed box with HTS current leads



HTS current lead – more effective due to reduced by 25-30% LHe flow

☐ HTS current leads



HTS module



“Everfit” Co., China

☐ Current leads
dynamic power
supply
with recuperation
of energy
to supply network

☐ 15 000 kA
☐ 25 V



- Static mode

- Dynamic mode with ramp rate
up to 40kA/sec

☐ Energy evacuation

☐ Energy:
 $2 \cdot 10^6 \text{ J}$

☐ Time
0.5 sec



Cryogenic tests hall



Cryogenic tests hall

1 – SC cable production hall

2 – SC coils production hall

3 – Yoke and coil assembly

4- Room temp. magnetic measurements

5 - Vacuum test bench

6 – Mounting magnet into cryostat

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8- Power supply





❑ **40** дипольных магнитов Бустера NICA





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❑ **48** квадрупольных магнитов с
мультипольными корректорами Бустера NICA





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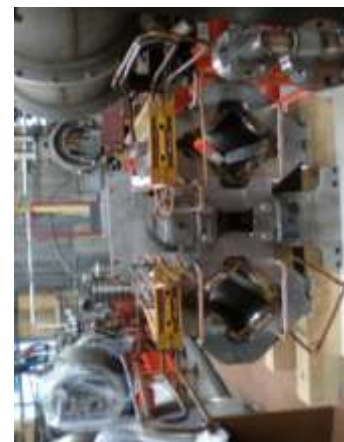
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Всего: 429 магнитов





Спасибо за внимание

Источник PS15000-25D представляет собой цепочку преобразователей

сеть - AC/DC преобразователь - DC/DC преобразователь - "С"
накопитель энергии (суперконденсаторы) - DC/DC преобразователь -
фильтр

Такая схемотехника позволяет PS15000-25D работать:

- в режиме постоянного тока,
- в динамическом режиме со скоростью изменения тока до 40кА/с, при этом накопленная магнитная энергии рекуперируется (возвращается в накопитель "С" источника, а не рассеивается) при выводе тока из нагрузки.

PS15000-25D можно называть - динамический источник тока (буква "D" в названии означает именно это) с рекуперацией энергии.



Испытания

одного магнита (SIS-100) ~ 2 недели

**Жидкий
Азот**

**Жидкий,
газообр.
Гелий**

~10.5 тонн

~4000 литров



Трудозатраты

~17 чел x мес

~117 000 кВт*ч

Электроэнергия

Overview of the power supplies for the NICA project

For the NICA project are required power supplies with defined leading edge, region of stable operation and controlled falling edge. Due to the control of the converter output current falling edge, the regeneration of the energy from the inductive load occurs. This energy is necessary to accumulate in the converter DC-link (capacitor) or return it to the feeding network. There are two main concepts for the current source dynamic power supplies which can recuperate the energy from the load. The first one is regenerating energy from the load to the DC-link and it is more suitable for power supplies with lower output voltages and with lower energy stored in the load (Fig. 1).

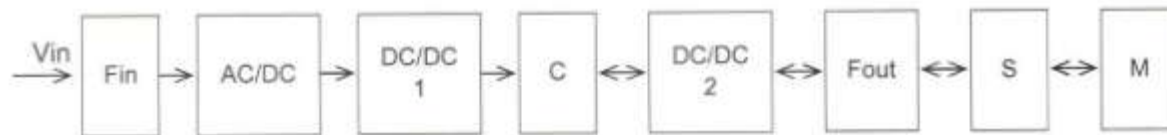


Figure 1 Block diagram of the supply with recuperation to the DC-link

The second concept is regenerating energy from the load to the feeding network and it is more suitable for power supplies with higher output voltages and with higher energy stored in the load (Fig. 2).



Figure 2 Block diagram of the supply with recuperation to the supply network

Методика измерений

метод гармонических катушек

Мультипольное описание магнитного поля

$$B(z) = B_y + iB_x = \sum_{n=1}^{\infty} C_n \left(\frac{z}{R_{ref}} \right)^{n-1} \quad C_n = B_n + iA_n \quad z = x + i y$$

$$b_n = \frac{10^4 B_n}{B_{ref}} \quad a_n = \frac{10^4 A_n}{B_{ref}}$$

Магнитный поток через катушку

$$\Phi = \int \vec{B} d\vec{S}$$

При изменении магнитного потока в катушке возникает ЭДС индукции

$$\mathcal{E} = -\frac{d\Phi}{dt}$$

Интегрирование ЭДС индукции дает:

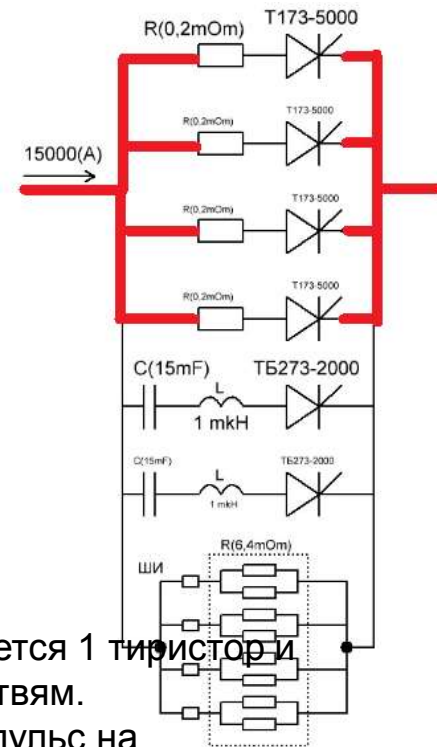
$$\int_{t_0}^t \mathcal{E} dt = \Phi(t_0) - \Phi(t)$$

Energy evacuation



Energy:
 $2 \cdot 10^6 \text{ J}$

Time
0.5 sec



В рабочем режиме ток идёт по выделенной «жирным» ветке. Изначально открывается 1 тиристор и достигая тока 850 А, включаются все 4 тиристора. Ток идёт по 4 параллельным веткам. При срабатывании защит о срыве сверхпроводимости, электроникой подаётся импульс на коммутационные тиристоры ТБ273-2000 и за 65 мкс ток выводится из цепи силовых тиристоров в коммутационную цепь. Быстрый вывод тока осуществляется с помощью заряженных до 260 Вольт ёмкостей 15 мФ. Для надёжности используется 2 параллельные коммутационные ветки, каждая из которых способна вывести ток из силовой цепи. После разряда ёмкостей, ток через эту ветвь прекращается. Обесточенные тиристоры силовой ветви уже закрылись и току некуда идти кроме как через ящики сопротивлений ШИ. Сопротивления рассчитаны погасить на себе энергию в течении 0.5 секунды