

GFS-2 - The New Gas-filled Separator for Super-Heavy Elements in JINR. A Guided Walk through the Genesis of the Project from First Thoughts to Completion

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With special thanks to our co-workers from the « 100 ton » company, for their efficiency and the pleasure to work with them during the installation



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MAGNETS AND BEAM TRANSPORT

Layout inside SHE factory





Super Heavy Elements



WHY ?



Filling in Mendeleev's

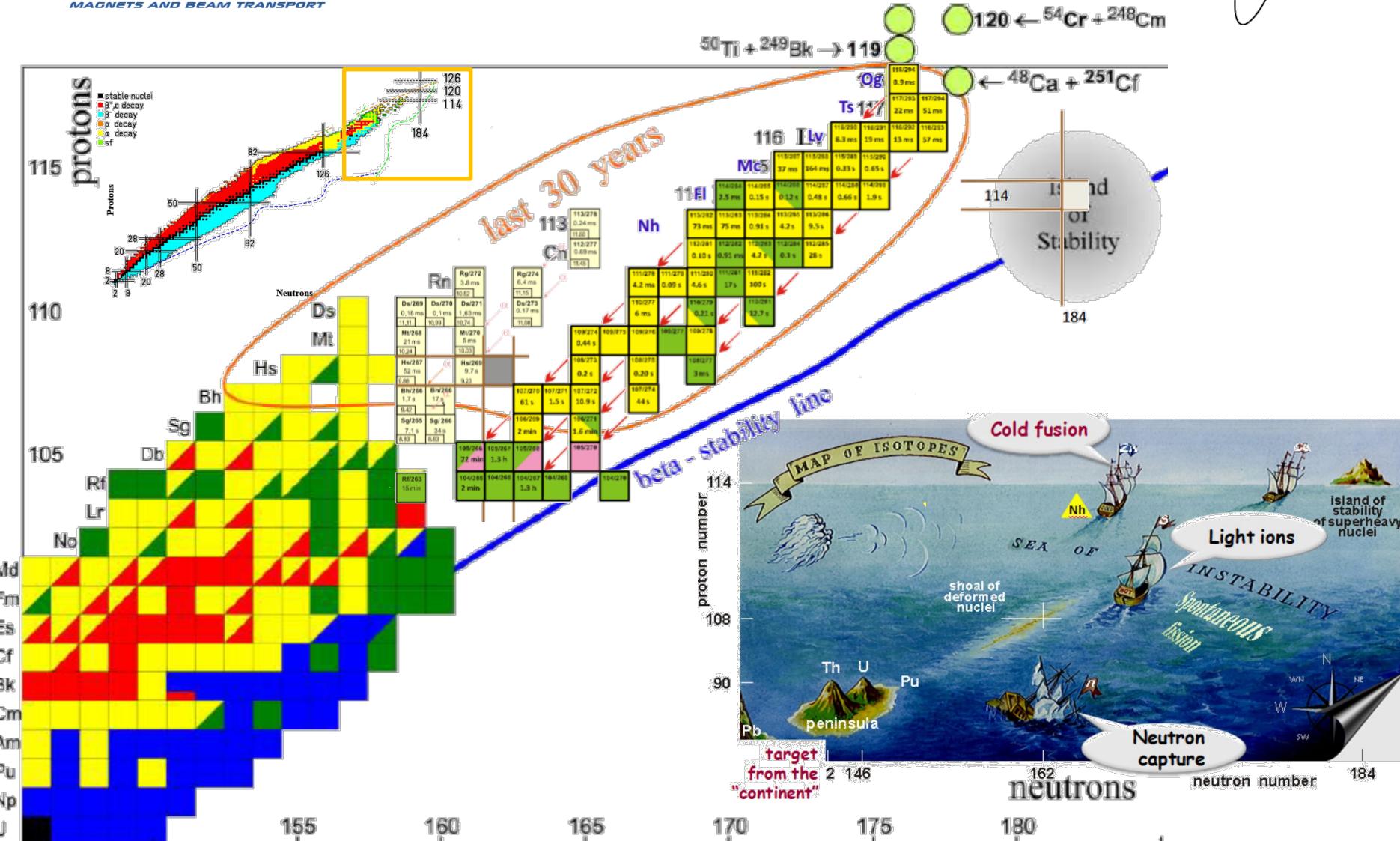
Tableau périodique des éléments

Tableau périodique des éléments																			
1 H Hydrogène 1,008 13,69 1s ¹ -1 +1	  scienceamusante.net wiki • forum chimie physique biologie									2 He Hélium 4,003 24,69 1s ² 0									
3 Li Lithium 6,94 6,391 1,0 1s ² 2s ¹ +1	4 Be Béryllium 8,012 8,322 1,5 1s ² 2s ² +2	<p>Numéro atomique → 80</p> <p>Nom de l'élément → Hg Masse atomique, basée sur $\text{^{120}\text{Zn}}$ [[]] : nombre de masse de l'isotope le plus stable x [] : énergie de première ionisation (eV)</p> <p>Symbole de l'élément (en gris : aucun isotope stable) Électronegativité (échelle de Pauling) Configuration électronique (en rouge : exception à la règle de Koehler)</p> <p>(Principaux noms d'oxydation (le plus fréquent en gras)</p>																	
11 Na Sodium 22,99 22,99 1,0 [Ne] 2s ¹ +1	12 Mg Magnéinium 24,31 27,44 1,2 [Ne] 2s ² +2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
19 K Potassium 38,10 38,10 0,8 [Ar] 4s ¹ +1	20 Ca Calcium 40,08 40,08 1,0 [Ar] 4s ² +2	21 Sc Scandium 44,96 44,96 1,0 [Ar] 3d ¹ 4s ² +3	22 Ti Titane 47,87 47,87 1,5 [Ar] 3d ² 4s ² +2	23 V Vanadium 50,94 50,94 1,6 [Ar] 3d ³ 4s ² +2 +3 +4	24 Cr Chrome 52,00 52,00 1,6 [Ar] 3d ⁵ 4s ¹ +2 +3 +4 +5	25 Mn Manganèse 54,94 54,94 1,8 [Ar] 3d ⁵ 4s ² +2 +3 +4 +5 +7	26 Fe Fer 55,85 55,85 1,8 [Ar] 3d ⁶ 4s ² +2 +3	27 Co Cobalt 58,83 58,83 1,8 [Ar] 3d ⁷ 4s ² +2 +3	28 Ni Nickel 58,99 58,99 1,8 [Ar] 3d ⁸ 4s ² +2 +3	29 Cu Cuivre 63,56 63,56 1,9 [Ar] 3d ¹⁰ 4s ¹ +2 +3	30 Zn Zinc 65,38 65,38 1,8 [Ar] 3d ¹⁰ 4s ² +2	31 Ga Gallium 68,72 68,72 1,8 [Ar] 3d ¹⁰ 4s ² +2 +3	32 Ge Germanium 72,83 72,83 1,8 [Ar] 3d ¹⁰ 4s ² +2 +4	33 As Arsenic 74,82 74,82 1,8 [Ar] 3d ¹⁰ 4s ² +2 +3 +5	34 Se Sélénium 78,98 78,98 2,0 [Ar] 3d ¹⁰ 4s ² +2 +4 +6	35 Br Brome 78,90 78,90 2,0 [Ar] 3d ¹⁰ 4s ² +2 +4 +5 +7	36 Kr Krypton 83,80 83,80 2,0 [Ar] 3d ¹⁰ 4s ² +2		
37 Rb Rubidium 87,47 87,47 0,8 [Kr] 5s ¹ +1	38 Sr Strontium 87,87 87,87 1,0 [Kr] 5s ² +2	39 Y Yttrium 88,91 88,91 1,2 [Kr] 5s ² 4d ¹ +2	40 Zr Zirconium 91,22 91,22 1,4 [Kr] 5s ² 4d ² +4	41 Nb Nioblerium 92,91 92,91 1,8 [Kr] 5s ² 4d ³ +2 +3 +4 +5	42 Mo Molybdène 95,96 95,96 1,8 [Kr] 5s ² 4d ⁵ +2 +3 +4 +5 +6	43 Tc Technétium 98 [98] 98 [98] 1,8 [Kr] 5s ² 4d ⁵ +7	44 Ru Ruthénium 101,07 101,07 2,2 [Kr] 5s ² 4d ⁷ +2 +3 +4 +5 +6	45 Rh Rhodium 102,91 102,91 2,2 [Kr] 5s ² 4d ⁷ +2 +3	46 Pd Palladium 106,42 106,42 2,2 [Kr] 5s ² 4d ⁹ +2 +4	47 Ag Argent 107,87 107,87 1,9 [Kr] 5s ² 4d ¹⁰ +1 +2	48 Cd Cadmium 112,41 112,41 1,7 [Kr] 5s ² 4d ¹⁰ +1 +2 +3	49 In Indium 114,82 114,82 1,7 [Kr] 5s ² 4d ¹⁰ 5p ¹ +1 +2 +3	50 Sn Antimoine 117,81 117,81 1,8 [Kr] 5s ² 4d ¹⁰ 5p ² +1 +2 +3 +5	51 Sb Tellure 121,78 121,78 2,0 [Kr] 5s ² 4d ¹⁰ 5p ³ +1 +2 +4 +6	52 Te Iode 126,80 126,80 2,0 [Kr] 5s ² 4d ¹⁰ 5p ⁴ +1 +2 +4 +6 +7	53 I Xénon 131,29 131,29 2,0 [Kr] 5s ² 4d ¹⁰ 5p ⁵ +1 +2 +4 +6 +7	54 Xe Xénon 131,29 131,29 2,0 [Kr] 5s ² 4d ¹⁰ 5p ⁶ 0		
55 Cs Césium 132,91 132,91 0,7 [Xe] 6s ¹ +1	56 Ba Baryum 137,33 137,33 0,9 [Xe] 6s ² +2	57 à 71 +4 +5 +6 +7	72 Hf Hafnium 178,48 178,48 1,3 [Xe] 6s ² +2	73 Ta Tantale 180,95 180,95 1,5 [Xe] 6s ² +2	74 W Tungstène 183,84 183,84 1,7 [Xe] 6s ² +2	75 Re Rhénium 188,21 188,21 1,9 [Xe] 6s ² +2	76 Os Osmium 190,23 190,23 2,2 [Xe] 6s ² +2	77 Ir Iridium 192,22 192,22 2,2 [Xe] 6s ² +2	78 Pt Platine 195,08 195,08 2,2 [Xe] 6s ² +2	79 Au Or 198,97 198,97 2,4 [Xe] 6s ² +2	80 Hg Mercure 200,69 200,69 1,9 [Xe] 6s ² +2	81 Tl Thallium 204,38 204,38 1,9 [Xe] 6s ² +2	82 Pb Plomb 207,2 207,2 1,9 [Xe] 6s ² +2	83 Bi Bismuth 208,98 208,98 1,9 [Xe] 6s ² +2	84 Po Polonium [208] [208] 2,0 [Xe] 6s ² +2	85 At Astate [210] [210] 2,2 [Xe] 6s ² +2	86 Rn Radon [222] [222] 0 [Xe] 6s ² +2		
87 Fr Francium 4,072 4,072 0,7 [Rb] 7s ¹ +1	88 Ra Radium 8,270 8,270 1,2 [Ra] 7s ² +2	89 à 103 +4 +5 +6 +7	104 Rf Rutherfordium [287] [287] +4	105 Db Dubinium [288] [288] +5	106 Sg Seaborgium [271] [271] +6	107 Bh Bohrium [272] [272] +7	108 Hs Hassium [277] [277] +7	109 Mt Meitnerium [278] [278] +7	110 Ds Darmstadtium [281] [281] +7	111 Rg Roentgenium [280] [280] +7	112 Cn Copernicium [286] [286] +7	113 Nh Nihonium [288] [288] +7	114 Fl Flérovium [288] [288] +7	115 Mc Moscovium [288] [288] +7	116 Lv Livermorium [285] [285] +7	117 Ts Tennessine [284] [284] +7	118 Og Oganesson [284] [284] +7		
119 Actinides 7	120 Actinides 7	57 La Lanthane 138,91 138,91 1,1 [Ce] 6s ² +3	58 Ce Cérium 140,12 140,12 1,1 [Ce] 6s ² +3	59 Pr Praséodyme 140,91 140,91 1,1 [Nd] 6s ² +3	60 Nd Néodyme 144,24 144,24 1,1 [Nd] 6s ² +3	61 Pm Prométhium [145] [145] +3	62 Sm Samarium 150,38 150,38 1,2 [Sm] 6s ² +2	63 Eu Europium 151,98 151,98 1,1 [Eu] 6s ² +2	64 Gd Gadolinium 167,26 167,26 1,2 [Gd] 6s ² +2	65 Tb Terbium 168,93 168,93 1,2 [Tb] 6s ² +2	66 Dy Dysprosium 169,50 169,50 1,2 [Dy] 6s ² +2	67 Ho Holmium 184,83 184,83 1,2 [Ho] 6s ² +2	68 Er Erbium 187,28 187,28 1,2 [Er] 6s ² +2	69 Tm Thulium 188,93 188,93 1,2 [Tm] 6s ² +2	70 Yb Ytterbium 179,06 179,06 1,3 [Yb] 6s ² +2	71 Lu Lutétium 174,97 174,97 1,3 [Lu] 6s ² +2			
Actinides 7		89 Ac Actinium [227] [227] +3	90 Th Thorium 232,04 232,04 1,3 [Th] 7s ² +4	91 Pa Protactinium 231,04 231,04 1,5 [Pa] 7s ² +4	92 U Uranium 238,03 238,03 1,7 [U] 7s ² +4	93 Np Neptunium [237] [237] +5	94 Pu Plutonium [244] [244] +6	95 Am Américium [249] [249] +6	96 Cm Curium [247] [247] +6	97 Bk Berkélium [247] [247] +6	98 Cf Californium [261] [261] +6	99 Es Einsteinium [262] [262] +6	100 Fm Fermium [267] [267] +6	101 Md Mendélévium [268] [268] +6	102 No Nobélium [268] [268] +6	103 Lr Lawrencium [262] [262] +6			



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Heading towards stability





Super Heavy Elements



HOW ?



Schematics of a separator





Schematics of a separator

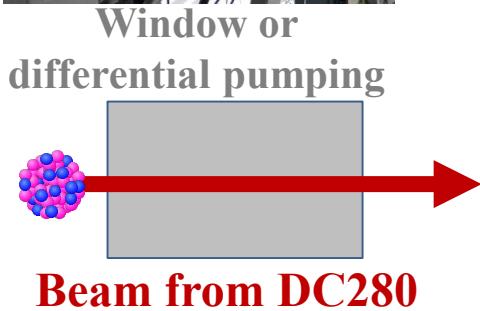


Beam from DC280





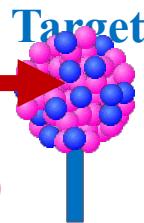
Schematics of a separator



Schematics of a separator



Window or
differential pumping



- Ø 480, 1500 rpm synchronous,
- e-beam & optical diagnostics
- Water & gas cooled



Schematics of a separator



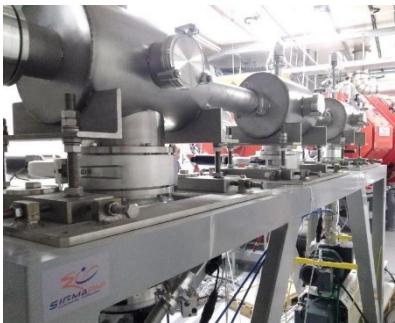
Window or
differential pumping



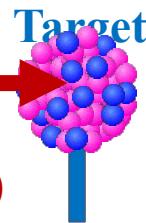
Beam Stop



Schematics of a separator



Window or differential pumping



Beam from DC280

- Ø 480, 1500 rpm synchronous,
- e-beam & optical diagnostics
- Water & gas cooled

Separator



Beam Stop





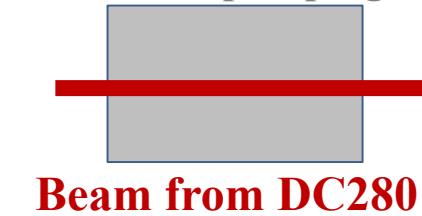
Schematics of a separator



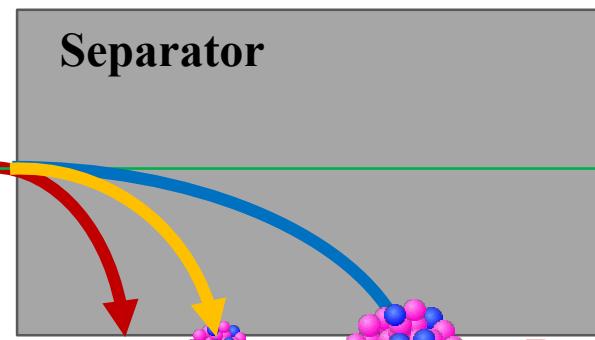
Window or
differential pumping



Target



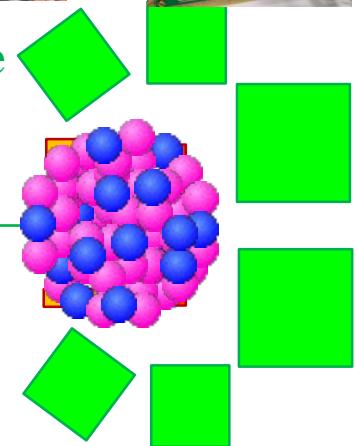
- Ø 480, 1500 rpm synchronous,
- e-beam & optical diagnostics
- Water & gas cooled



48×128 strips 128×128 strips
6144 pixels 16384 pixels



Focal plane
detectors



Detector box



Micron Semiconductors, UK



What are we fighting for?



Reaction products in magnetic separator suffer from

Contamination

Many charge states

Large emission angle



What are we fighting for?



Reaction products in magnetic separator suffer from

Contamination Many charge states Large emission angle

Improve rejection

Bending angle
dispersion



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Separator

What are we fighting for?

Reaction products in magnetic separator suffer from

Contamination

Many charge states

Large emission angle

Improve rejection

Promote

Bending angle
dispersion

mechanisms that
narrow the charge
state distribution

Separator



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MAGNETS AND BEAM TRANSPORT

What are we fighting for?



Reaction products in magnetic separator suffer from

Contamination

Many charge states

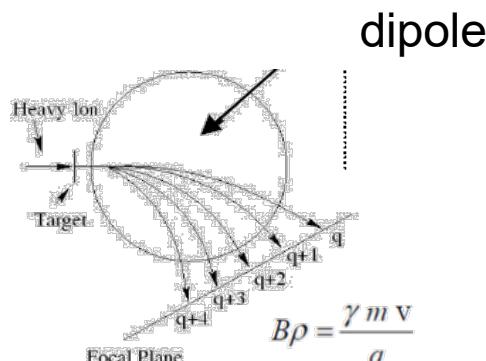
Large emission angle

Improve rejection

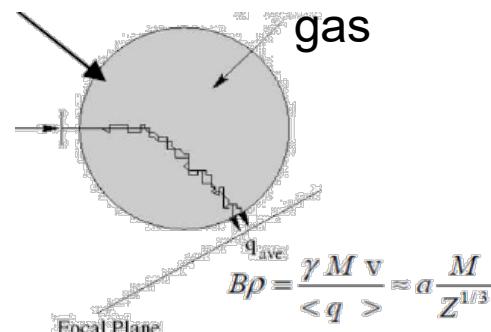
Bending angle
dispersion

Separator

Promote mechanisms that narrow the charge state distribution



**Gas-filled
Separator**



Reaction products in magnetic separator suffer from

Contamination

Many charge states

Large emission angle

Improve rejection

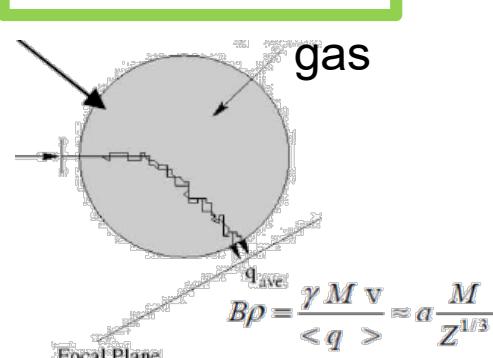
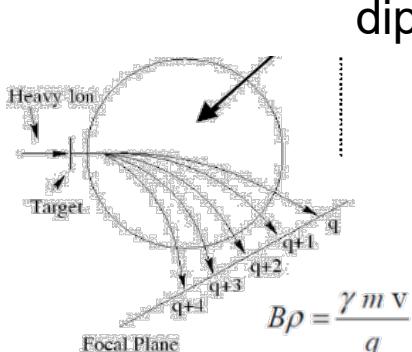
Bending angle
dispersion

Separator

Promote
mechanisms that
narrow the charge
state distribution

**Gas-filled
Separator**

Increase
acceptance/transmission
Optics
Large apertures
Focusing
Optimized chambers



Reaction products in magnetic separator suffer from

Contamination

Many charge states

Large emission angle

Improve rejection

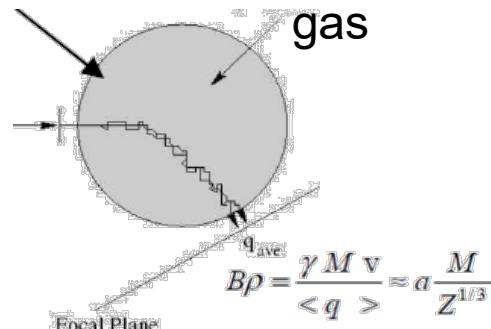
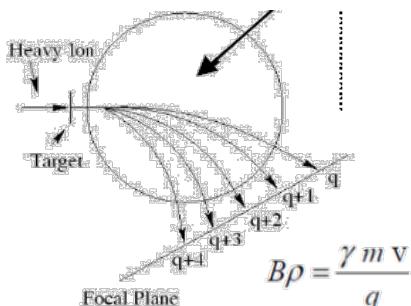
Bending angle
dispersion

Separator

Promote
mechanisms that
narrow the charge
state distribution

**Gas-filled
Separator**

Increase
acceptance/transmission
Optics
Large apertures
Focusing
Optimized chambers



**Large acceptance
Gas-filled
Separator**



... and last but not least
BE PATIENT



Formation of SHE is a very rare event (**pb**)

At 1p μ A of ^{48}Ca

1nb -> 100 events/h

1pb -> 1 event/week

1fb -> 1 event/20 years

“On 9 October 2006, the researchers announced that they had indirectly detected a total of 3 (possibly 4) nuclei of oganesson-294 (1 or 2 in 2002 and 2 more in 2005) produced via collisions of californium-249 atoms and calcium-48 ions”

Excerpt from the Wikipedia webpage on Oganesson
<https://en.wikipedia.org/wiki/Oganesson>



Expectations



Rationale for new layout



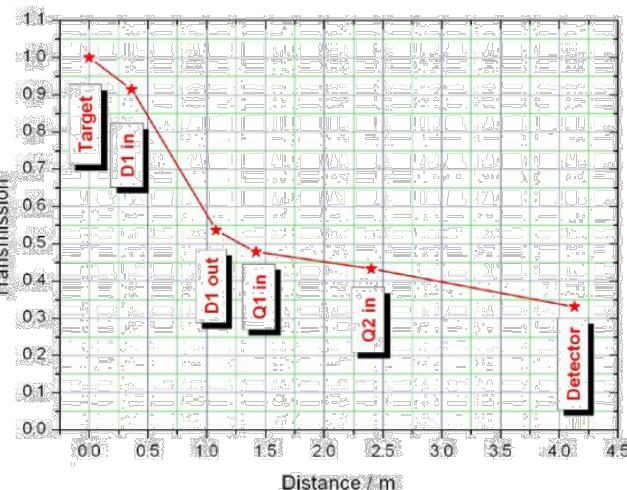


Rationale for new layout

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MAGNETS AND BEAM TRANSPORT



Losses for $^{243}\text{Am}(^{48}\text{Ca},4\text{n})^{286}\text{Mc}$ in existing DGFRS
 DQ_hQ_v layout : dipole gap 58mm, quad diameter 100mm



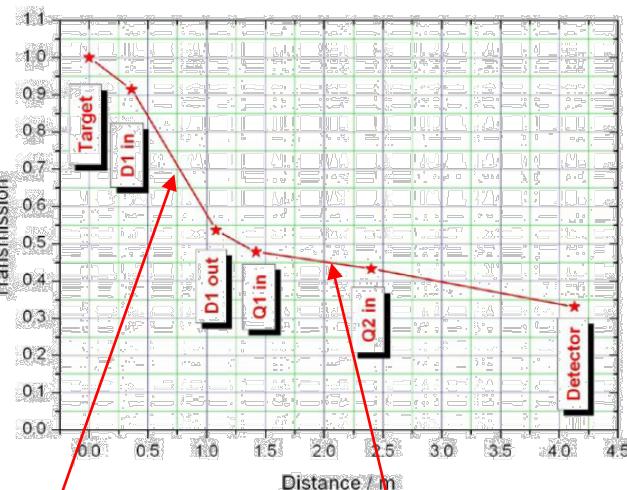


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40% loss
in dipole

15% loss
in quads

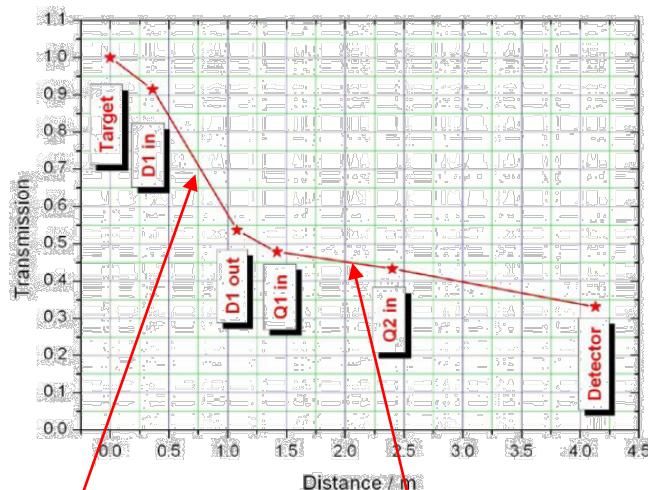


Rationale for new layout

SIGMA PHI
MAGNETS AND BEAM TRANSPORT

JINR
FLNR
114 Flerovium
Dubna

Losses for $^{243}\text{Am}(^{48}\text{Ca},4\text{n})^{286}\text{Mc}$ in existing DGFRS
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40% loss
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MUST IMPROVE
TRANSMISSION

15% loss
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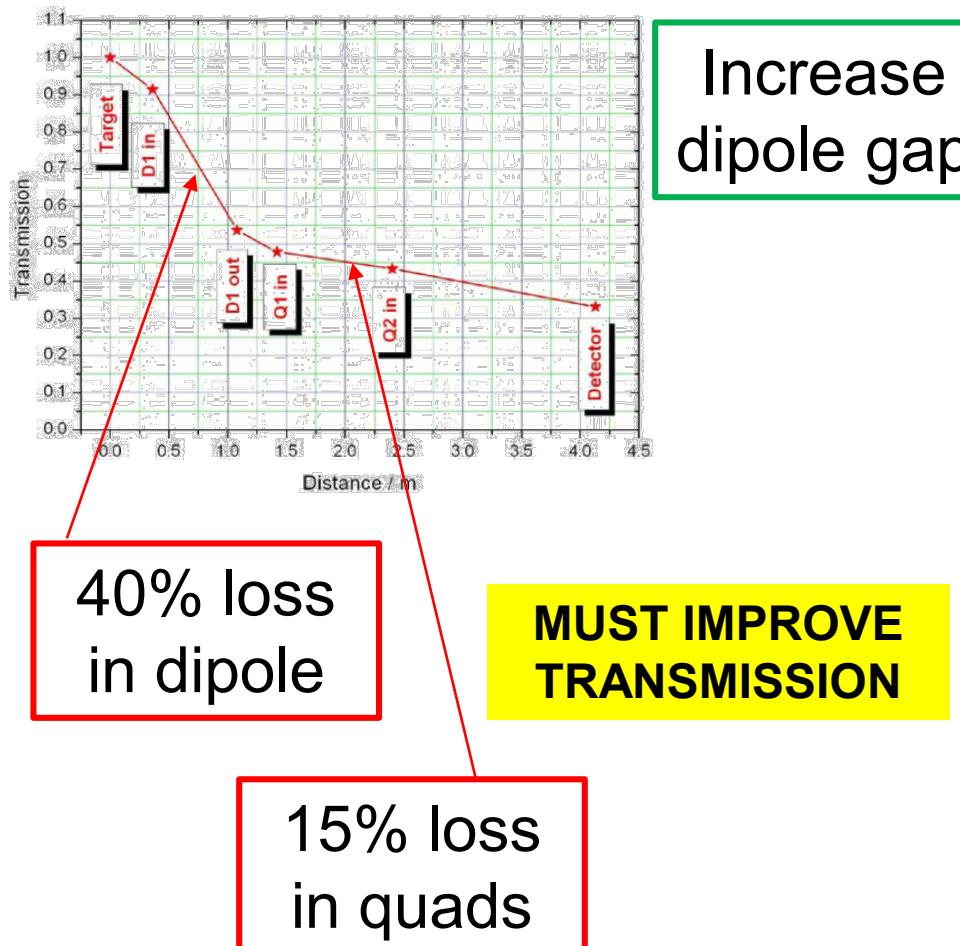


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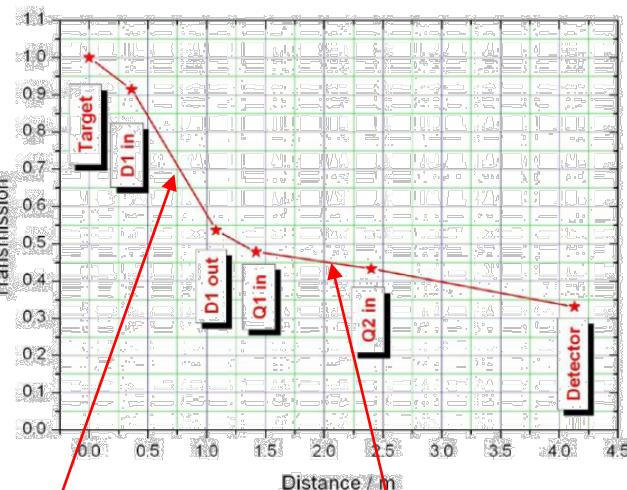


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MUST IMPROVE
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Increase
dipole gap

Q_1 V to
enter dipole

Refocus H
asap

Large exit
pole edge
angle

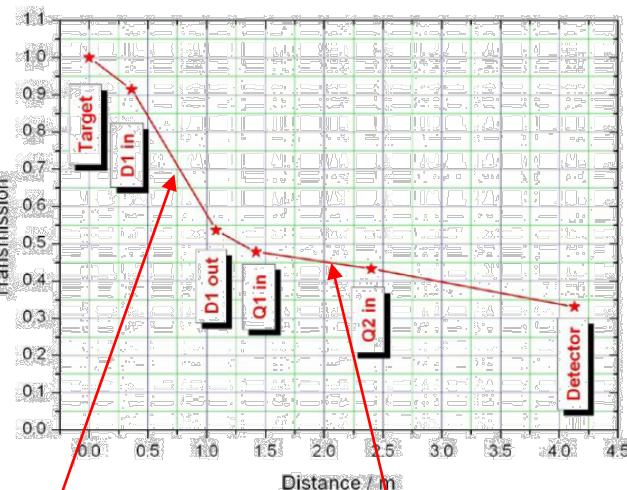


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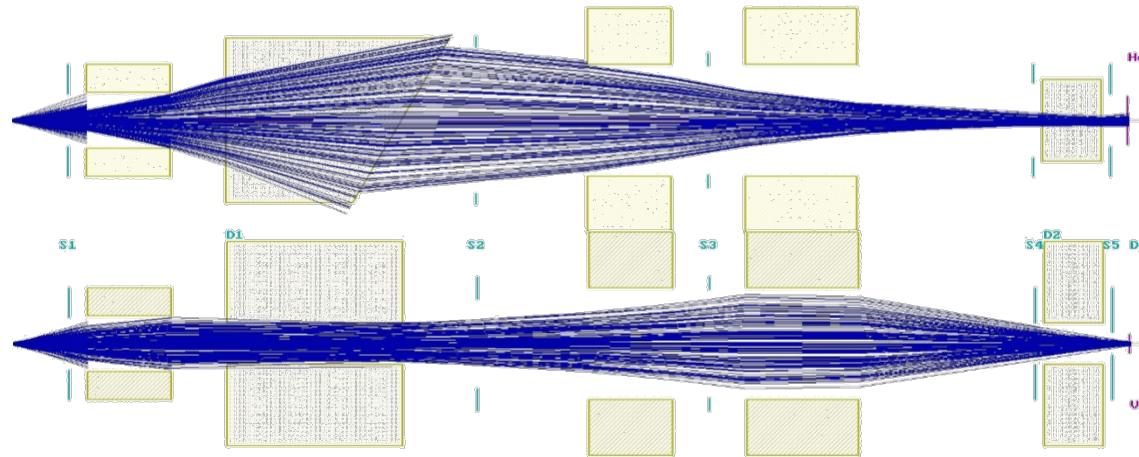
Q_1 V to
enter dipole

Large aperture
quads

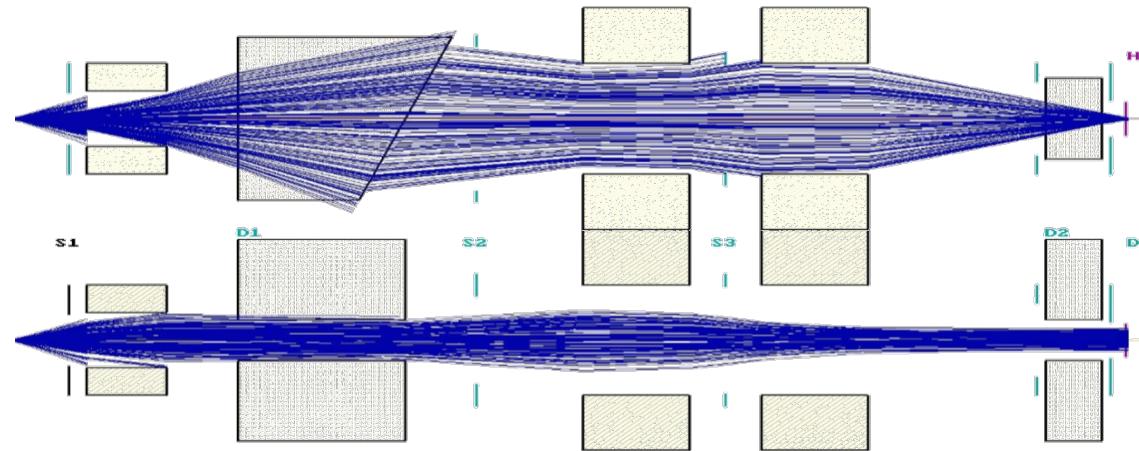
Refocus H
asap

Large exit
pole edge
angle

Transmission or Resolution ?



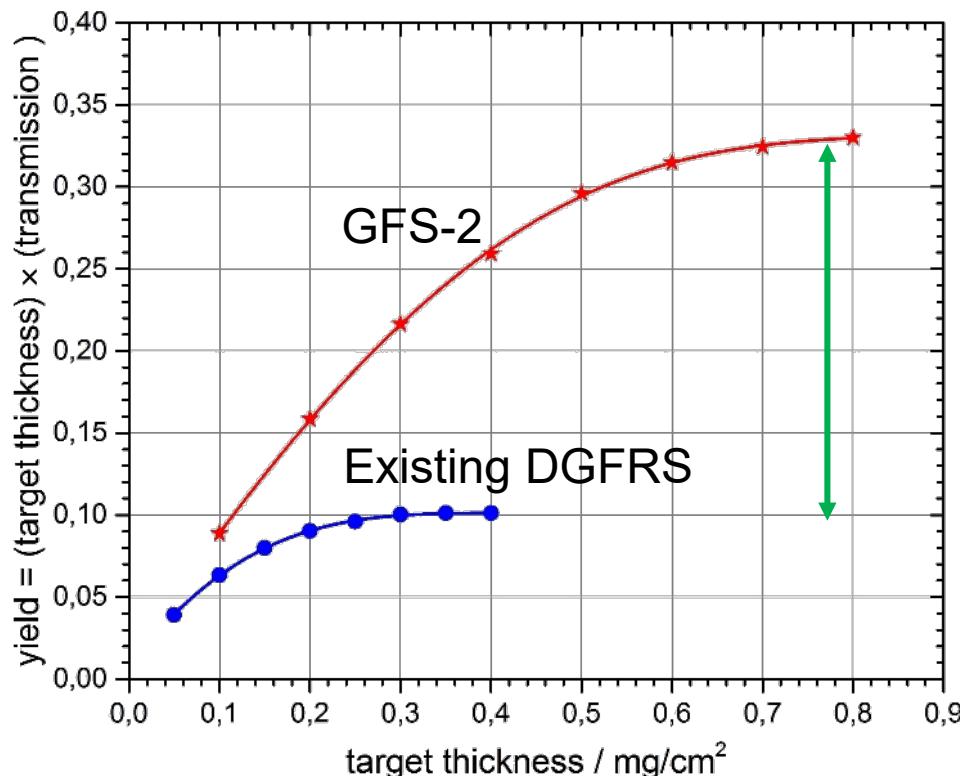
VHHV
Transmission +
Resolution -
Separator



VHVH
Transmission –
Resolution +
Spectrometer

Expected gain

Reaction	Transmission
$^{244}\text{Pu}(^{48}\text{Ca},3\text{n})^{289}\text{Fl}$	60 %
$^{244}\text{Pu}(^{58}\text{Fe},4\text{n})^{298}\text{Fl}$	75 %



$^{244}\text{Pu}(^{48}\text{Ca},4\text{n})^{288}\text{Fl}$
 Over 3 times more !!



GFS2 among some gas-filled separators



Separator	DGFRS	GARIS-II	RITU	BGS	TASCA	SHANS	GFS-II
Location	FLNR Dubna Russia	RIKEN Wakô Japan	JYFL Jyväskylä Finland	LBNL Berkeley USA	GSI Darmstadt Germany	IMP Lanzhou China	FLNR Dubna Russia
Configuration	$DQ_h Q_v$	$Q_v DQ_h Q_v D$	$Q_v DQ_h Q_v$	$Q_v D_h D$	$DQ_h Q_v$	$Q_v DQ_v Q_h$	$Q_v DQ_h Q_v D$
Deflection angle	23°	30°+7°	25°	25°+45°	30°	52°	30°+10°
B_p (max/T·m)	3.1	2.46	2.2	2.5	2.4	2.88	2.25
Length (m)	4	5.06	4.8	4.6	3.5	6.5	6.3
Dispersion (mm/% B_p)	7.5	19.3	10	20	9	7.3	9.7
					High Transmission Mode	High Resolution Mode	

From initial spec to final layout
through various iterations

gives rise to important questions

It is desirable but is it technically feasible ?

Is it economically OK ?

Investment costs AND running costs

Can I trade this for that ?

I can improve. Is it worth ?

...

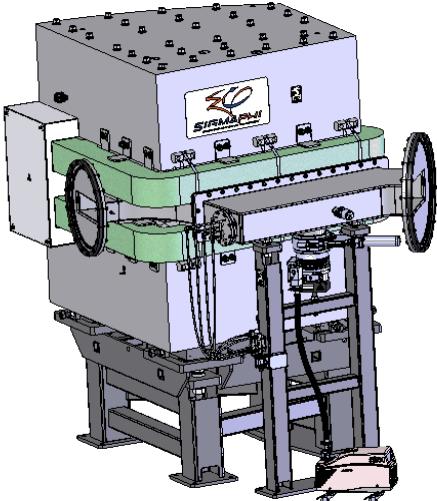


The big guy – 30° D1

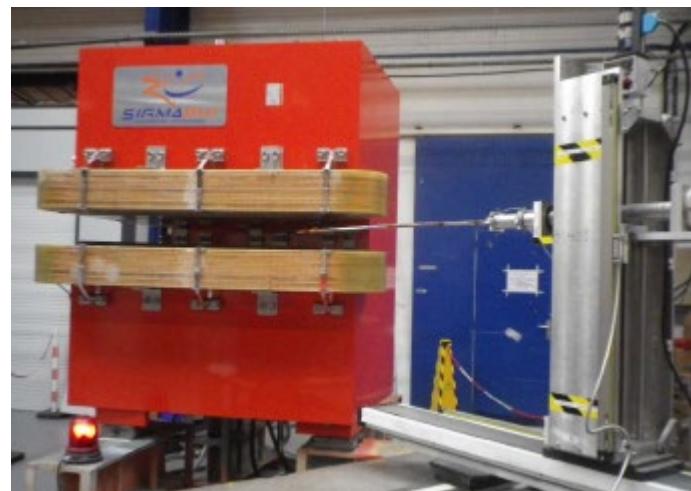


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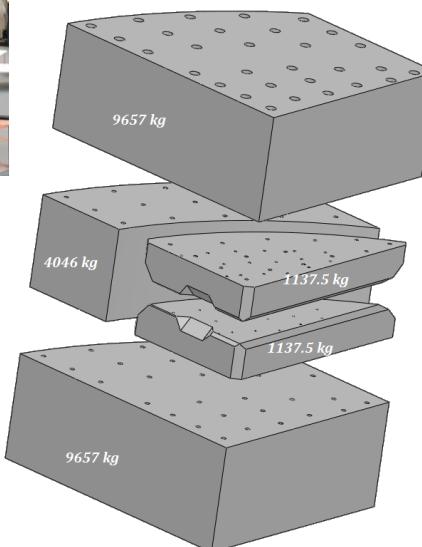
D1 General



Factory
assembly



Each part must
be less than
10 tons



Assembly on site



Hall probe measurement

D1 parameters

Beam free aperture	120	mm
Magnet gap	132	mm
Curvature radius	1800	mm
Entrance face angle	-7 (-2)	°
Exit face angle	-44 (-50)	°
Deviation angle	31.5	°
Effective length	1007	mm
Good Field region	440	mm

Max field	1.8	T
Max current	919	A
# turns (1 coil)	120	
Max current density	7.4	A/mm ²
Magnet power	139	kW
Yoke weight	25.7	ton
Copper weight	1.24	ton



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D1 design (1)

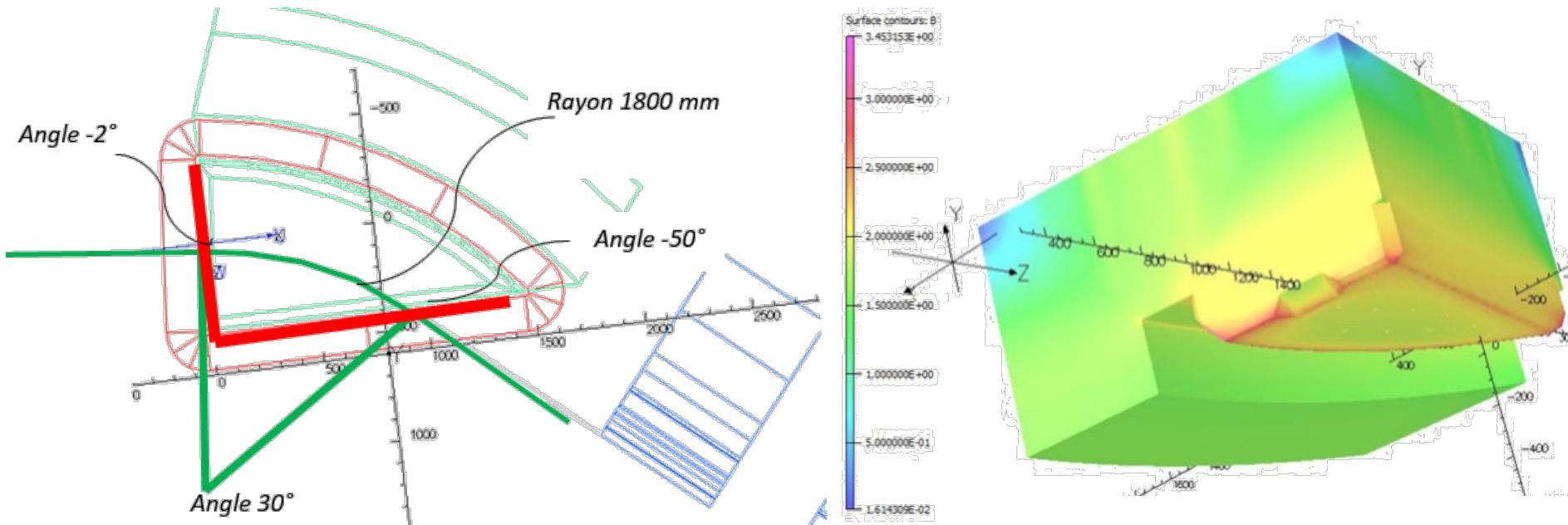


Large exit angle makes a conventional structure very difficult.

Entrance and exit faces side by side

Change on one generate change on the other -> joint optimization

Complex profile on entrance face



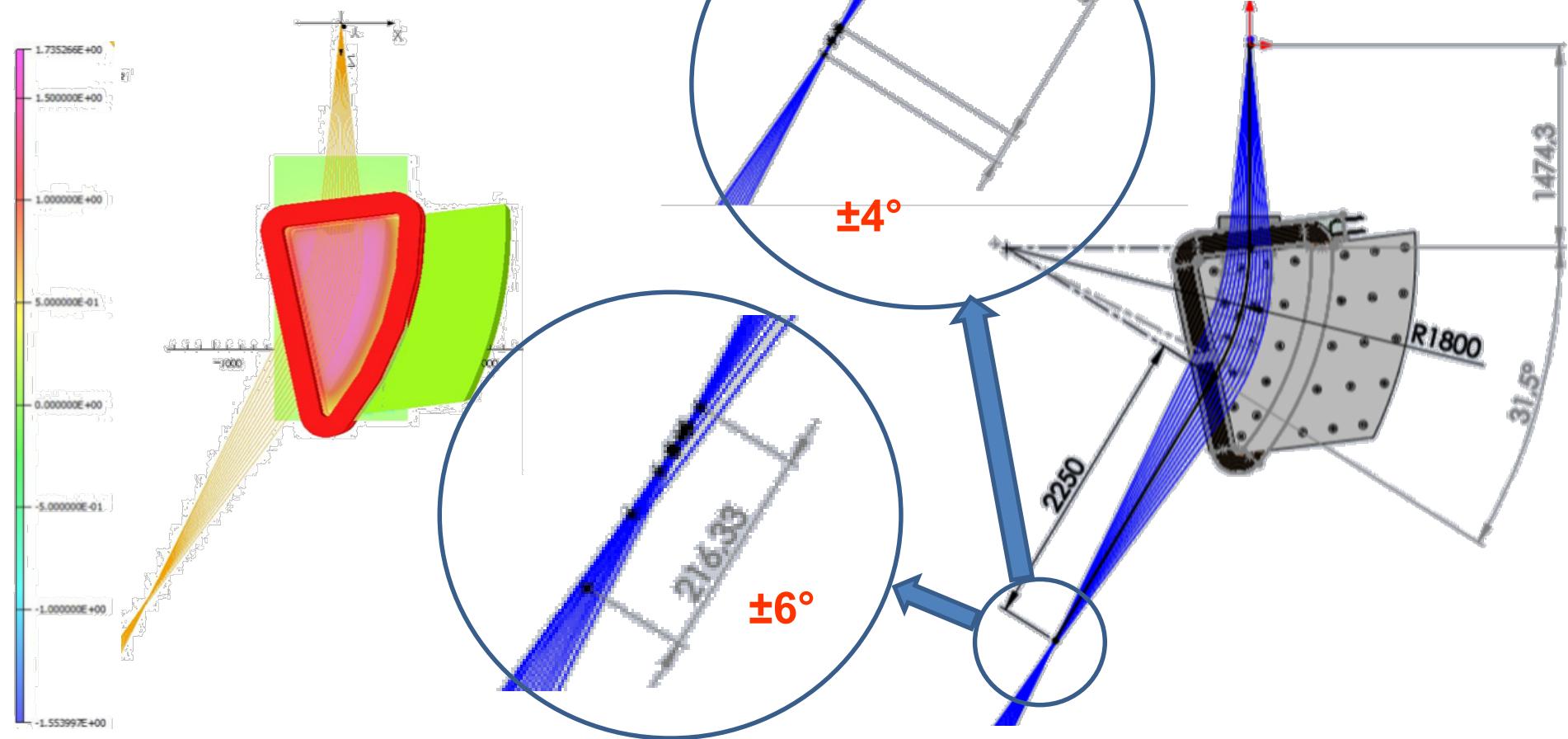


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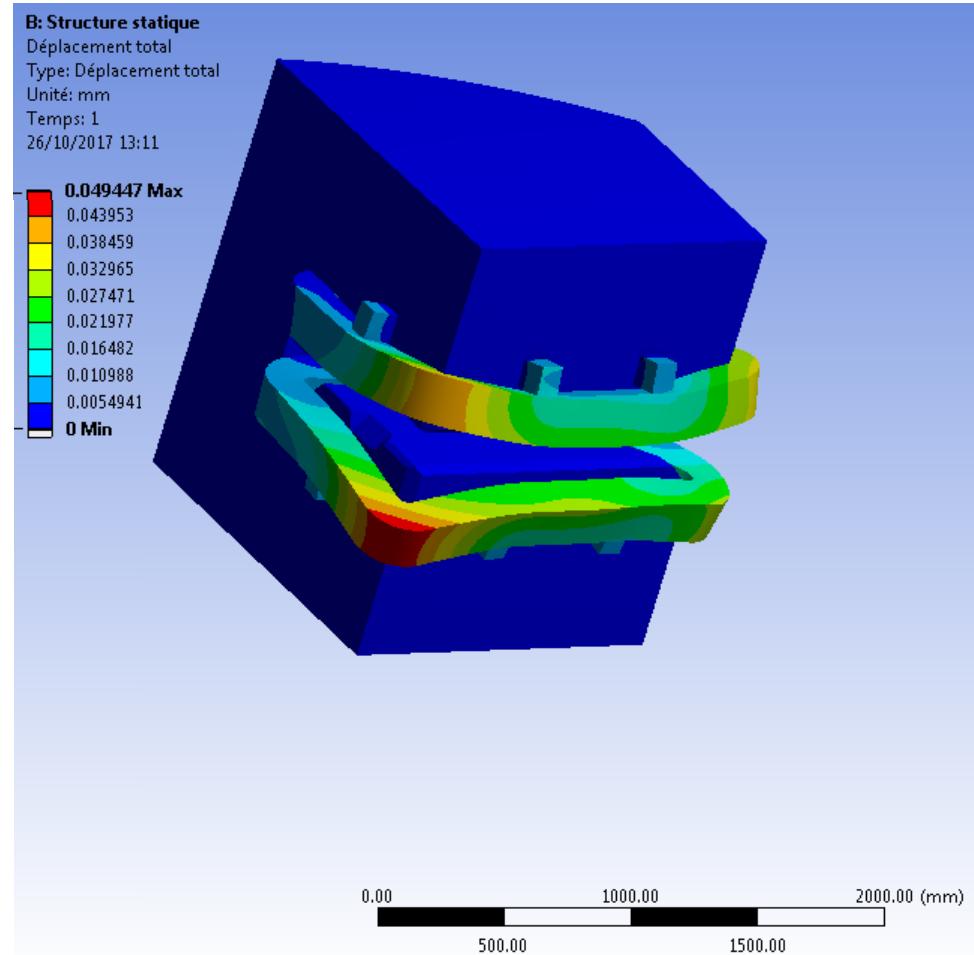
D1 design (2)



Design driven by particle tracking focusing quality



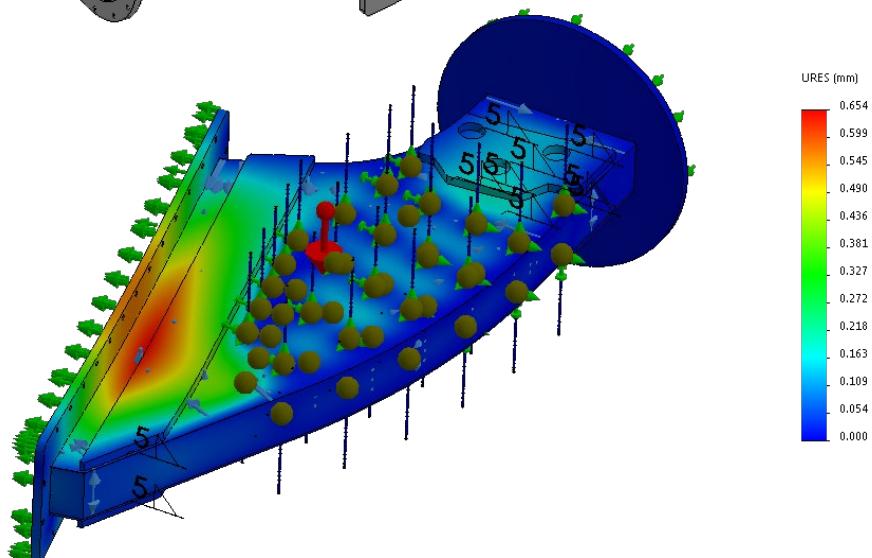
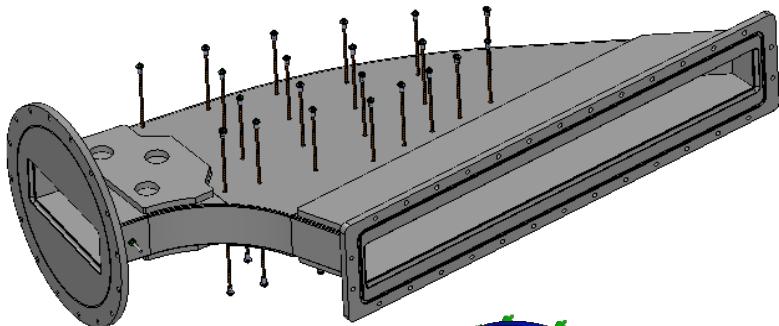
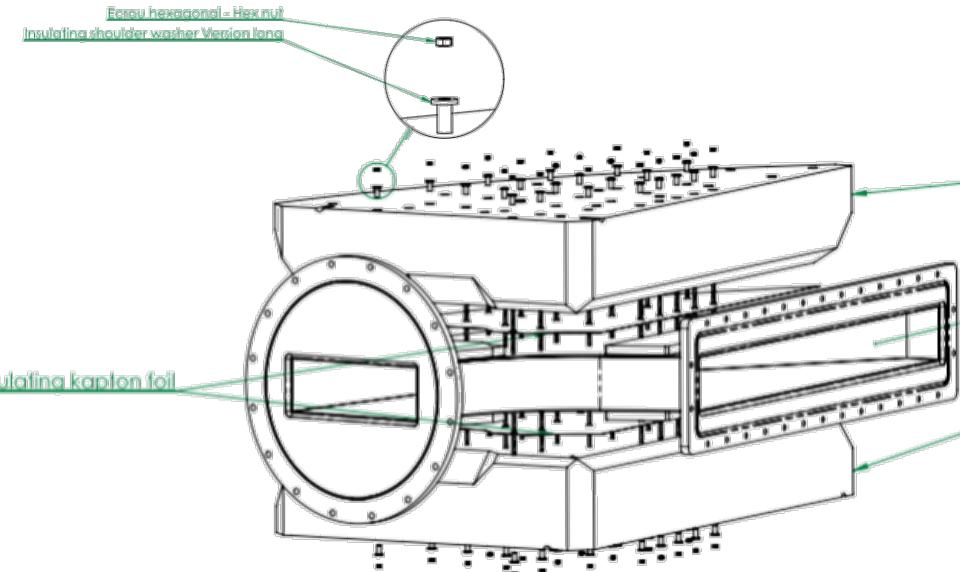
D1 coils





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D1 chamber (1)



Very large surface
Wall must be thick to prevent
deformation
21 struts + edge reinforcement
allow thin walls
0.65 mm max displacement



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D1 chamber (2)



Chamber is
electrically
insulated



Chamber assembly and
testing in factory

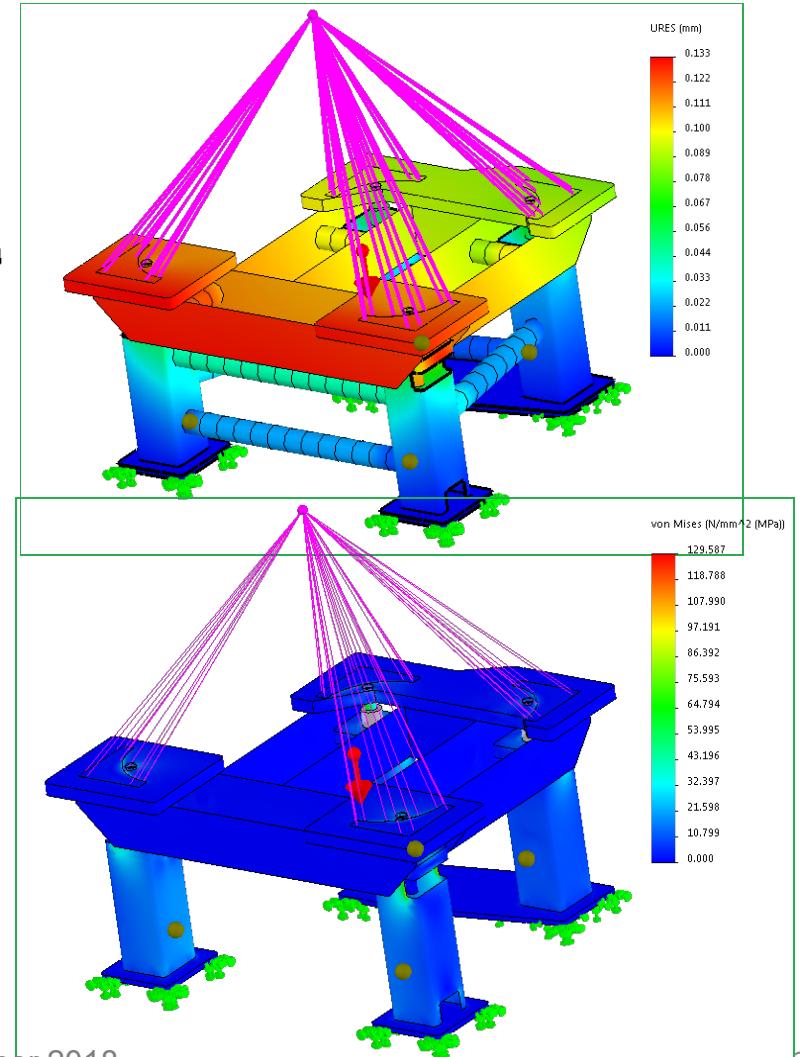
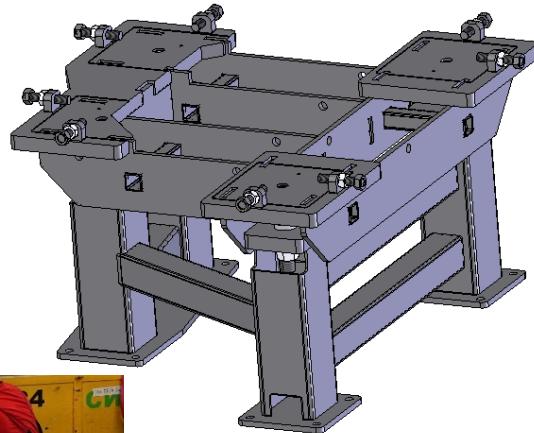


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D1 Stand

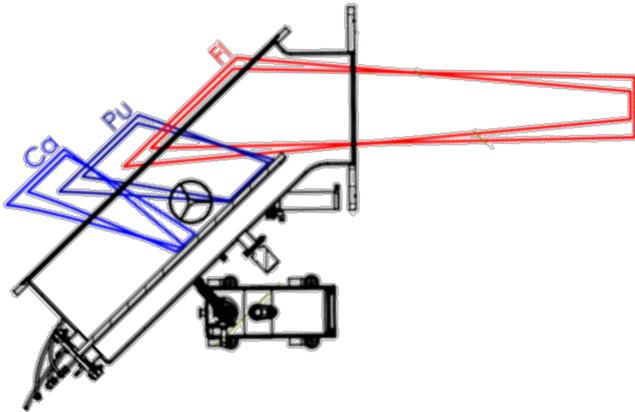


Magnet + chamber : 27.5 tons
Deformation < 0.2 mm
Stress < 130 Mpa (req. <235 Mpa)





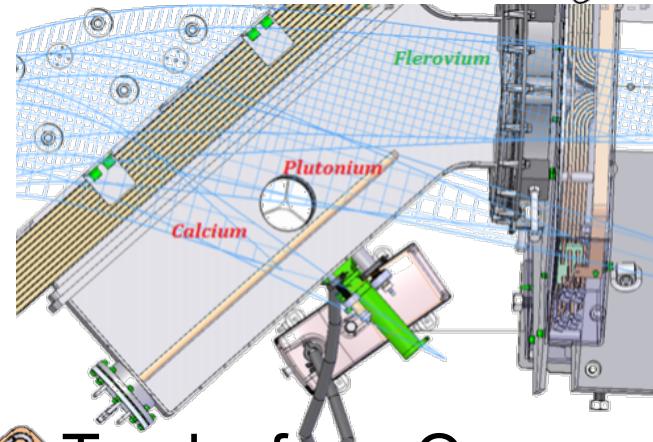
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D1 Beam stop

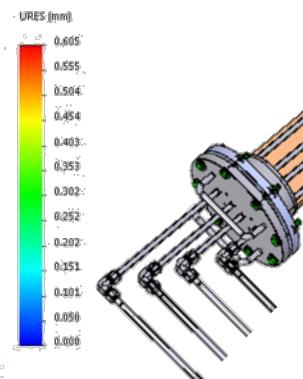
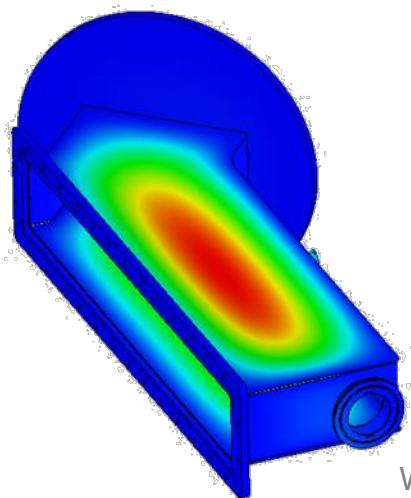


block most
background
species
and let EVR
pass

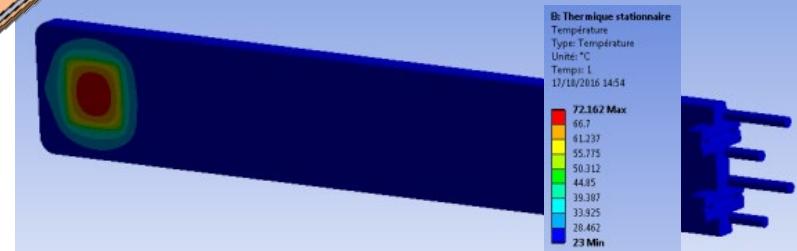


Beam stop housing hooked to
main chamber

Deformation < 0.6 mm



Thick Cu plate
2 cooling circuits
Thermal modelling
crucial





Quadrupoles



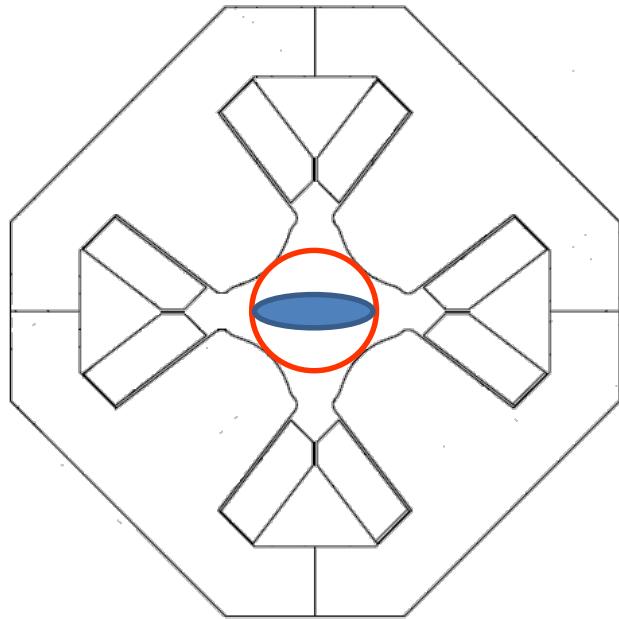
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Quadrupoles parameters

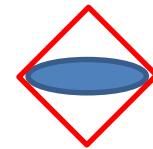
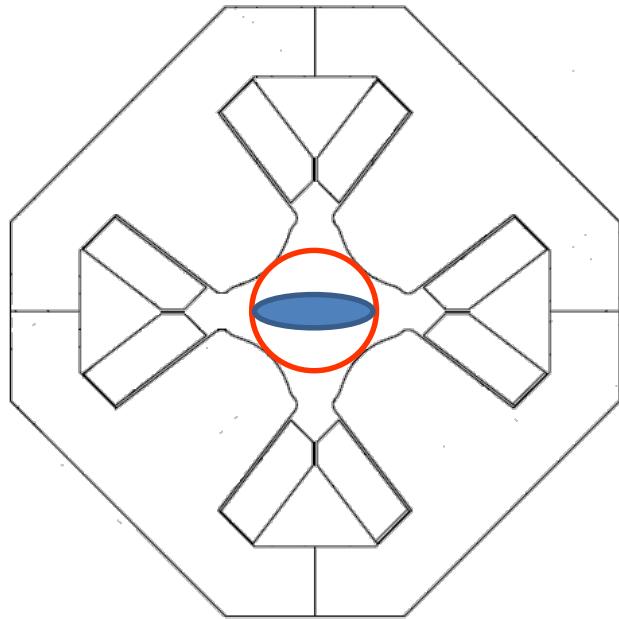


	Q1	Q2/Q3	
Bore diameter	150	300	mm
Iron length	420	520	mm
Effective length	456.6	600	mm
Max gradient	13.2	5.34	T/m
Max current	450	362	A
# turns (1 coil)	88	138	
Max current density	6.35	6.6	A/mm ²
Magnet power	28.2	61.6	kW
Yoke weight	2.07	6.65	ton
Copper weight	0.39	0.68	ton

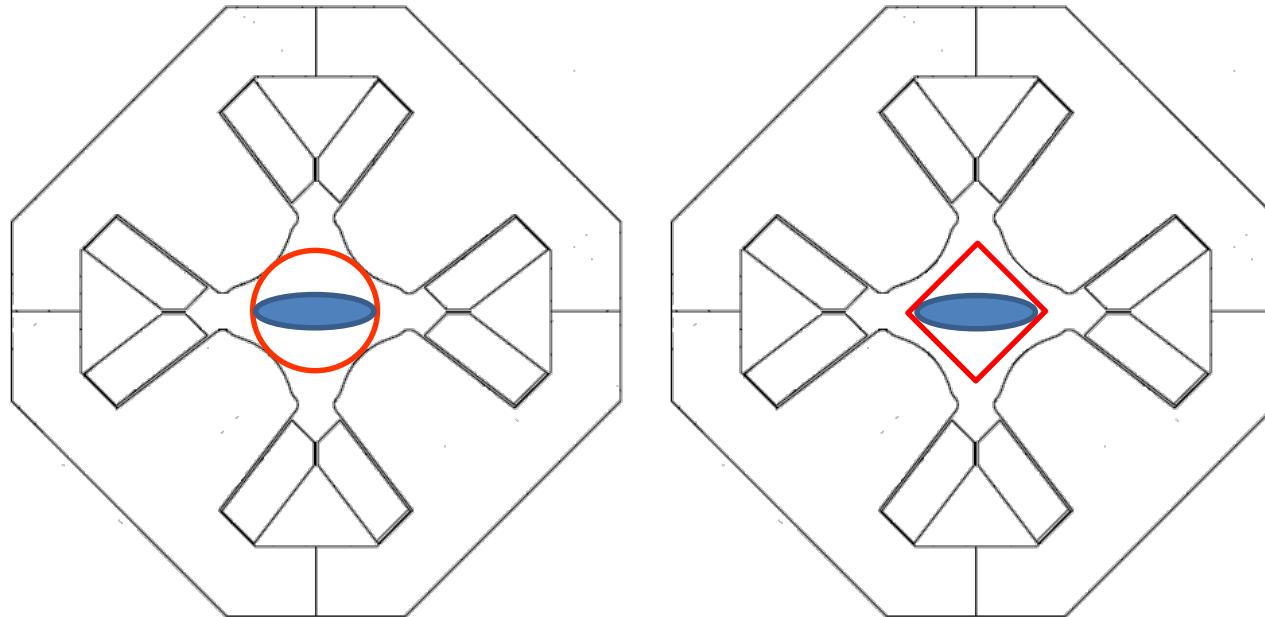
Shaping chambers to reduce bore



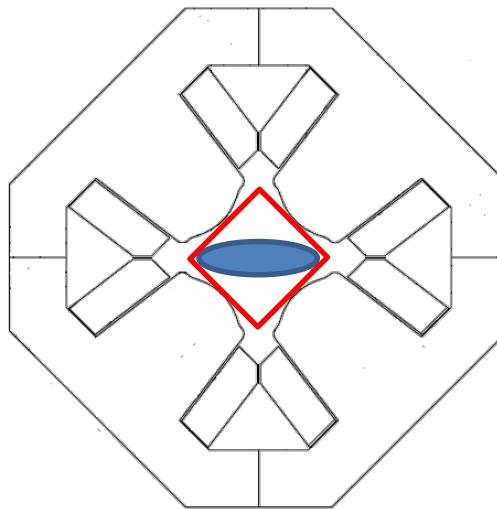
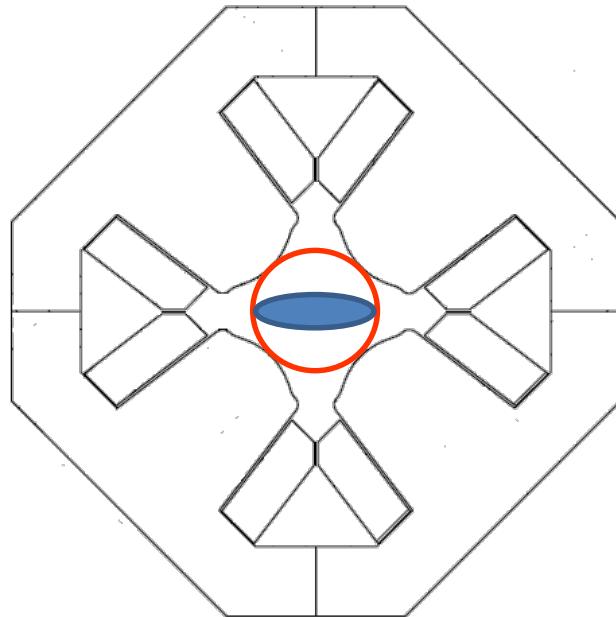
Shaping chambers to reduce bore



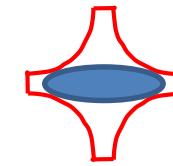
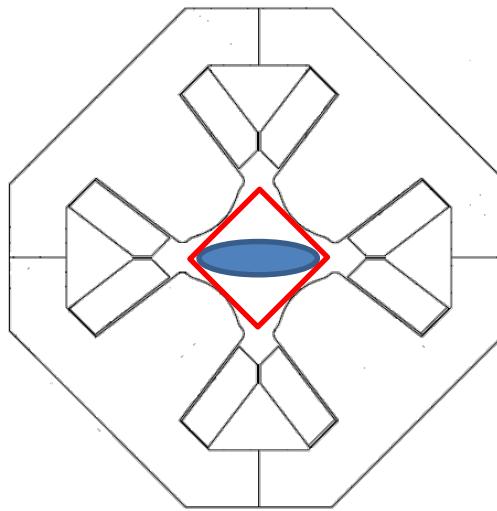
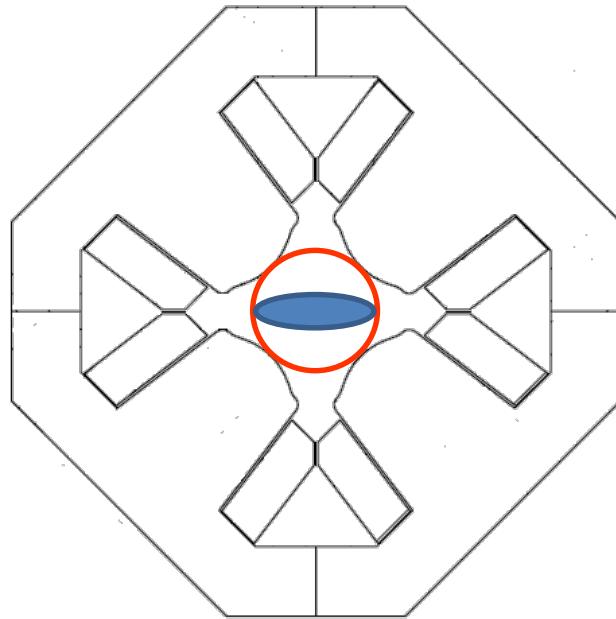
Shaping chambers to reduce bore



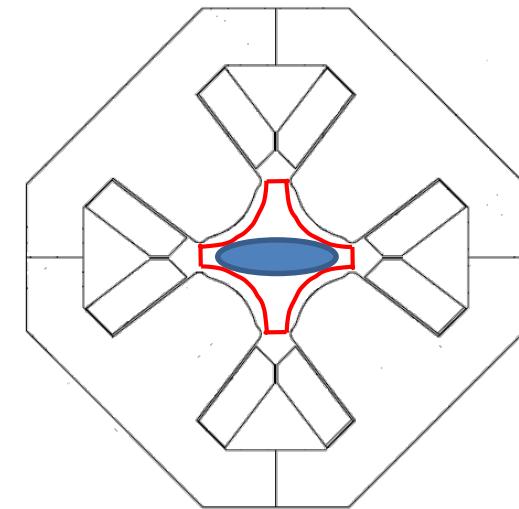
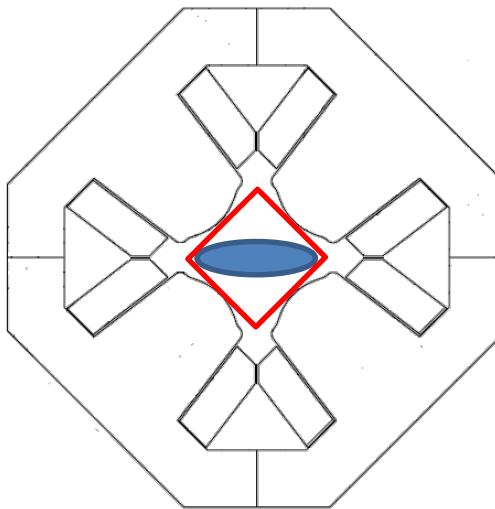
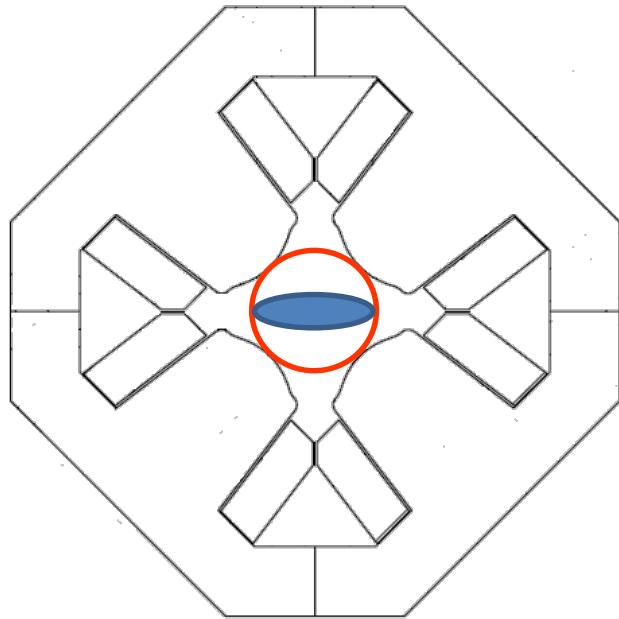
Shaping chambers to reduce bore



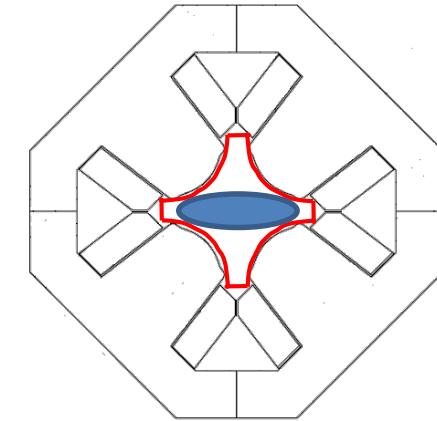
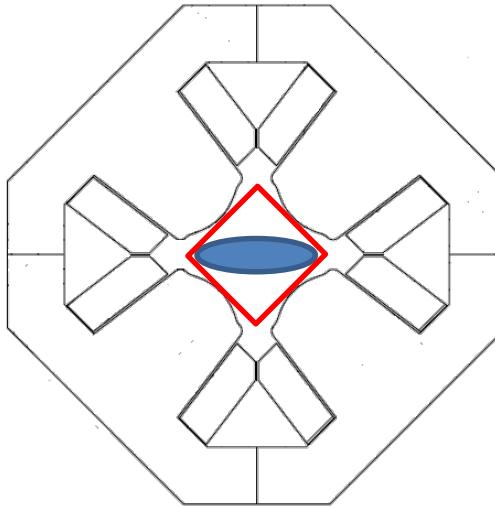
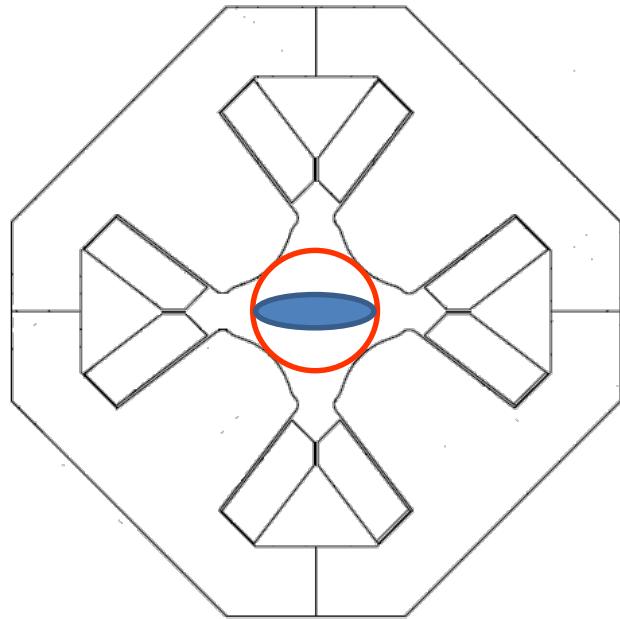
Shaping chambers to reduce bore



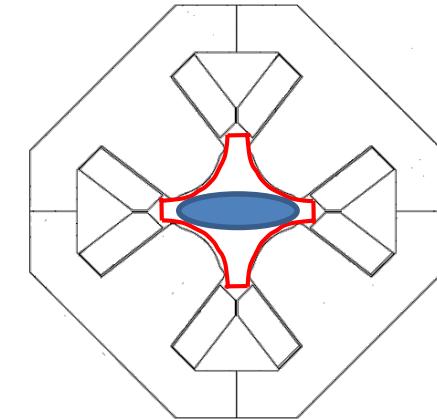
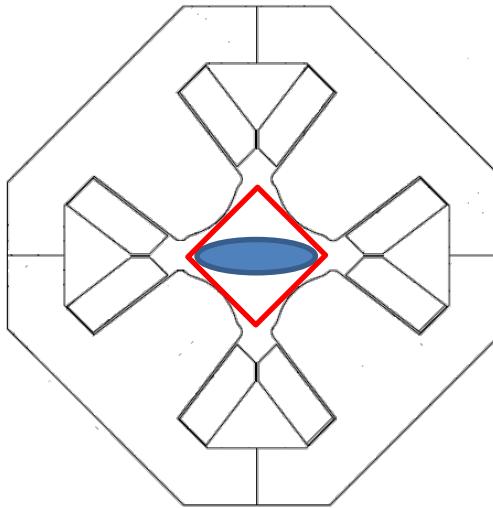
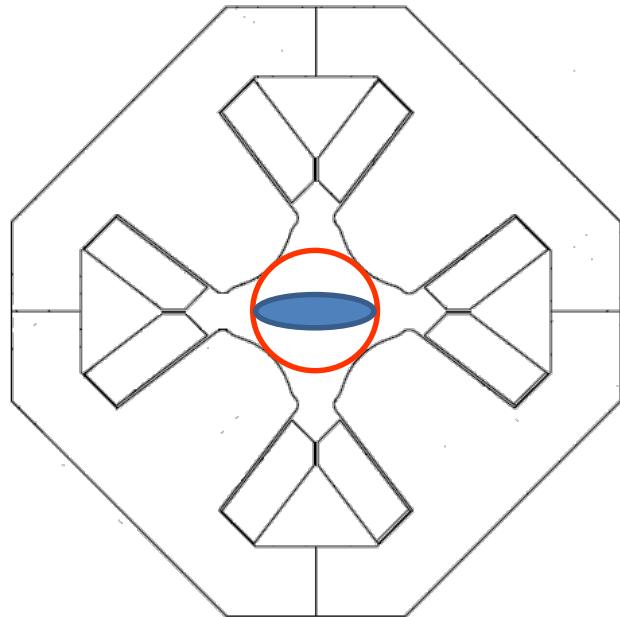
Shaping chambers to reduce bore



Shaping chambers to reduce bore



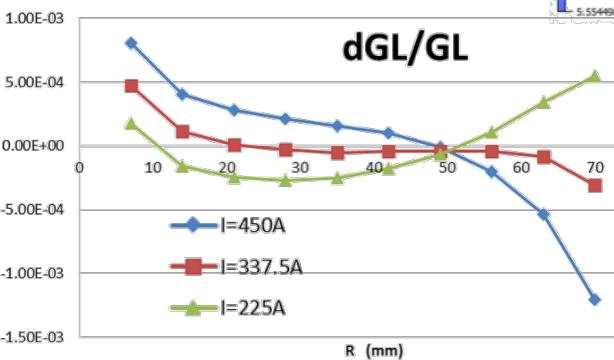
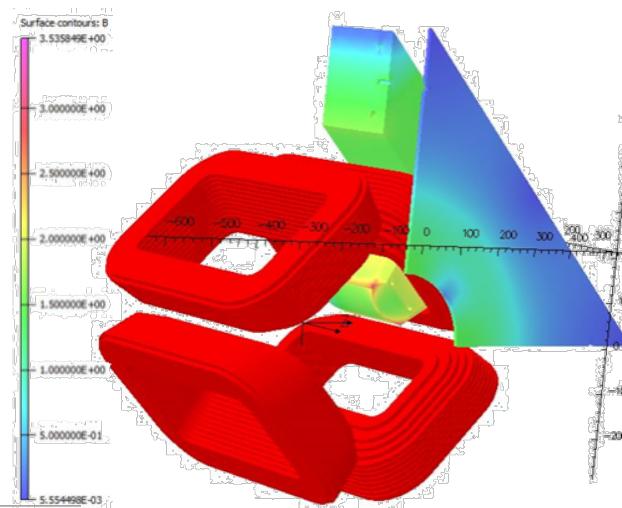
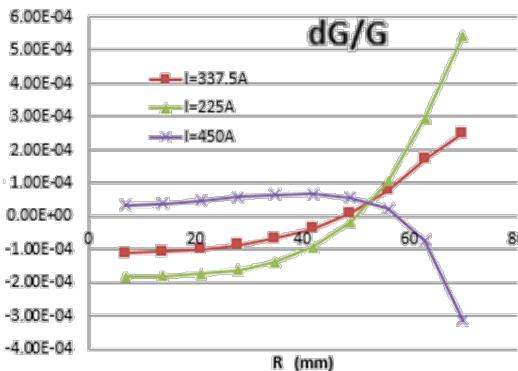
Shaping chambers to reduce bore



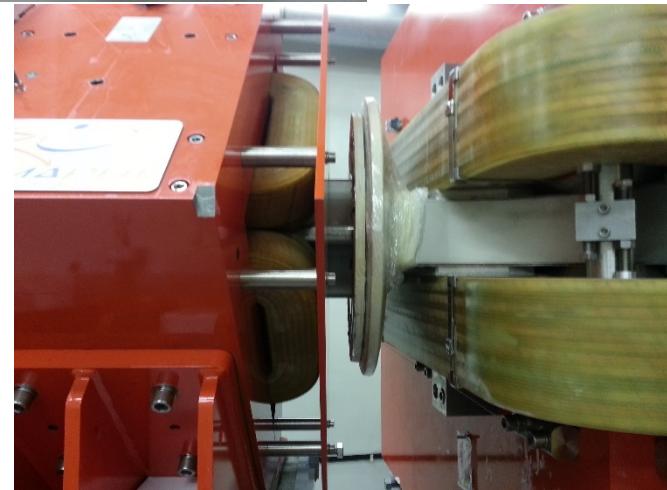
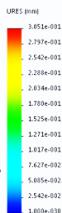
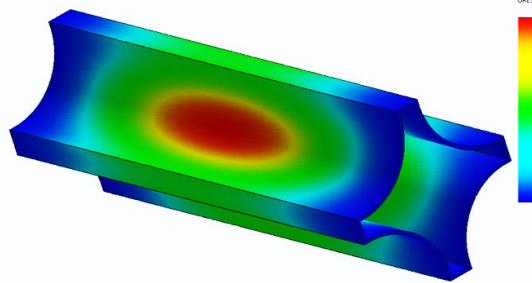


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Q1



$\phi=150\text{mm}$
 $G=13.2 \text{ T/m}$



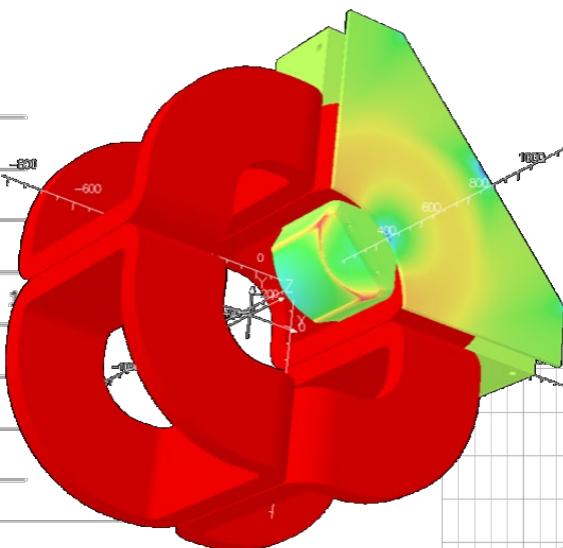
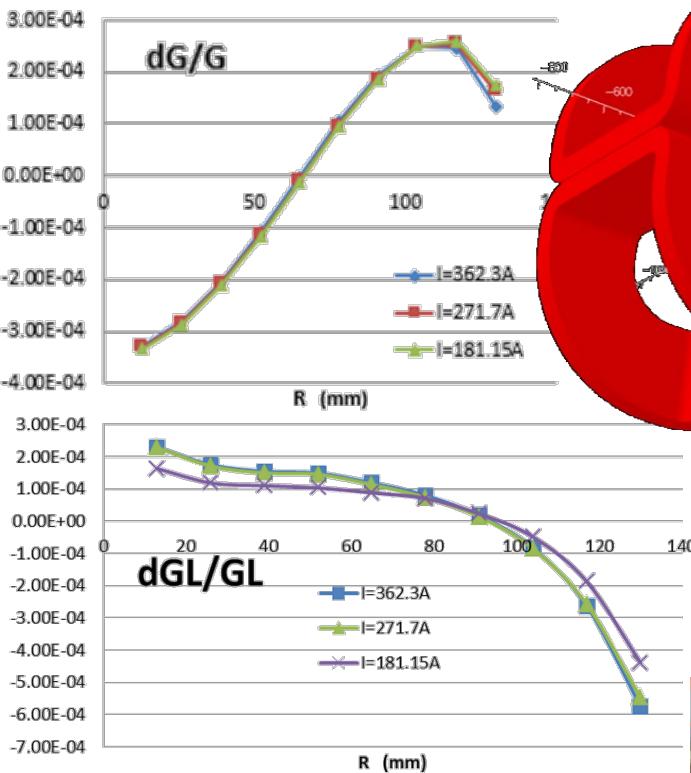
Local & integrated
gradient
homogeneity
along radius



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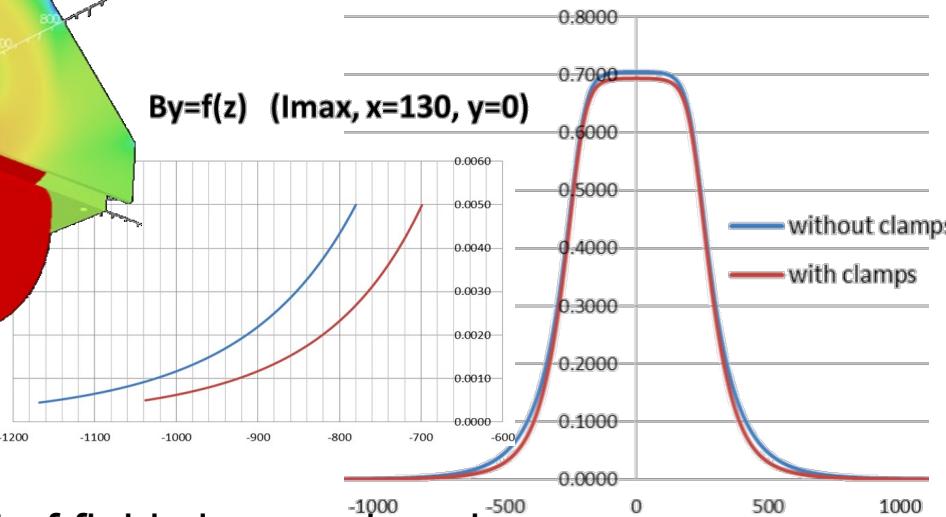
Q2/Q3

JINR
¹¹⁴Flerovium
FLNR
Dubna



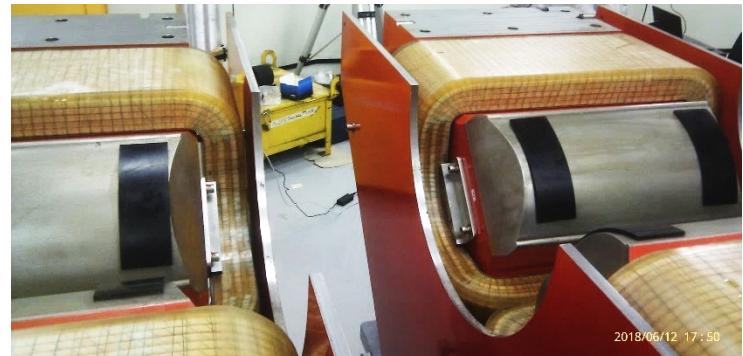
$\phi=300\text{mm}$
 $G=5.34 \text{ T/m}$

$By=f(z) \quad (l_{max}, x=130, y=0)$



Effect of field clamps along beam z (mm)

Local & integrated
gradient
homogeneity
along radius

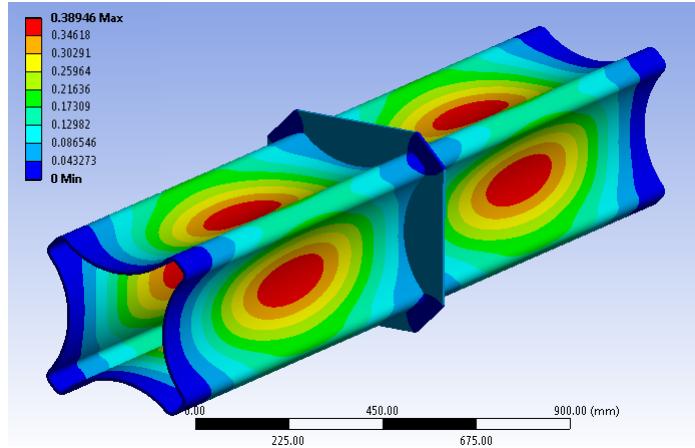


2018/06/12 17:50



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Q2/Q3 Vacuum chamber



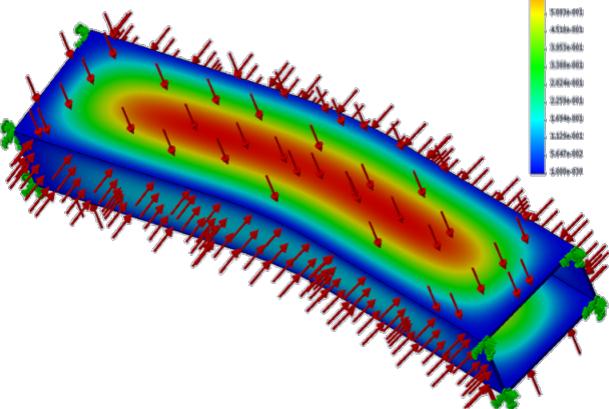
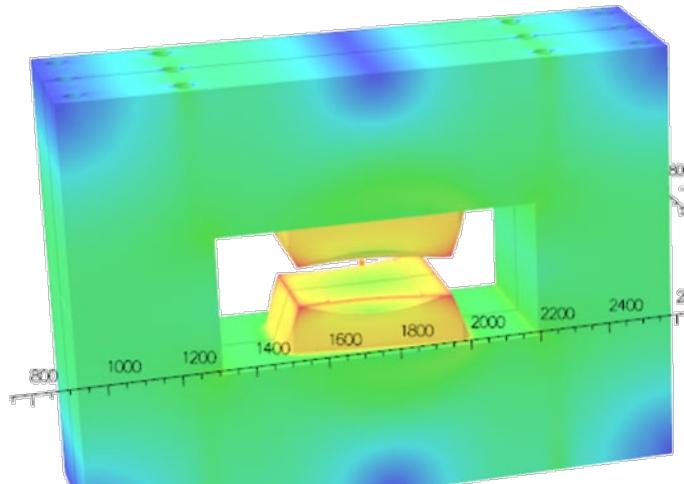


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D2



Gap	132 mm
Deflection angle	10^0
Radius of curvature	1.8 m
Maximum field	1.8 T
Face pole rotation angle	0^0
Rear pole rotation angle	10^0



2018/06/13 20:23



Differential pumping system



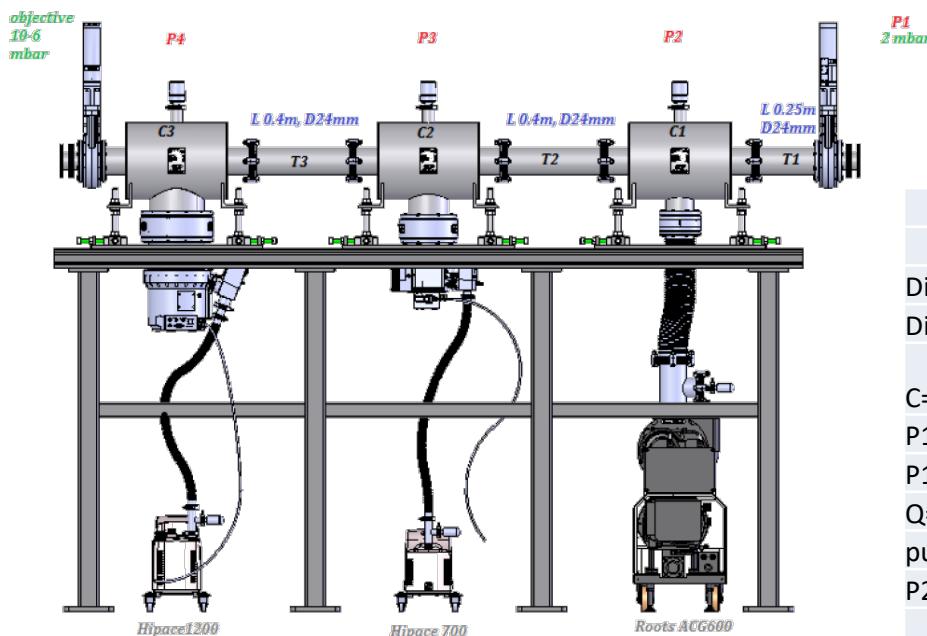
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Magnets and Beam Transport

Differential pumping (1)



2 configurations

- Allows window-less operation
- Tolerate intense heavy ion beams
- Gas contributes to target cooling
- As all recent gas-filled separators
TASCA, GARIS-II, SHANS



Pressure profile (case of He)

	P1	2.00E+00 P2	1.04E-01 P3	6.47E-04 mbar
	P2 goal	1.00E-03 P3 goal	1.00E-03 P4 goal	1.00E-06 mbar
Diaphragm diameter		24	24	24 mm
Diaphragm length		0.25	0.4	0.4 m
$C = 1.22 \cdot 10^{-4} \cdot (D^3/L)$		6.75E+00	0	4.22E+00 l/s
P1-P2		2.00E+00	1.03E-01	6.46E-04 mbar
P1-P2		1.97E-03	1.01E-04	6.37E-07 atm
$Q = C \cdot (P1 - P2)$		1.33E-02	4.27E-04	2.69E-06 l/s
pumping speed He		130	670	1200 l/s
P2=Q/pumping speed		1.02E-04	6.38E-07	2.24E-09 atm
	P2	1.04E-01 P3	6.47E-04 P4	2.27E-06 mbar

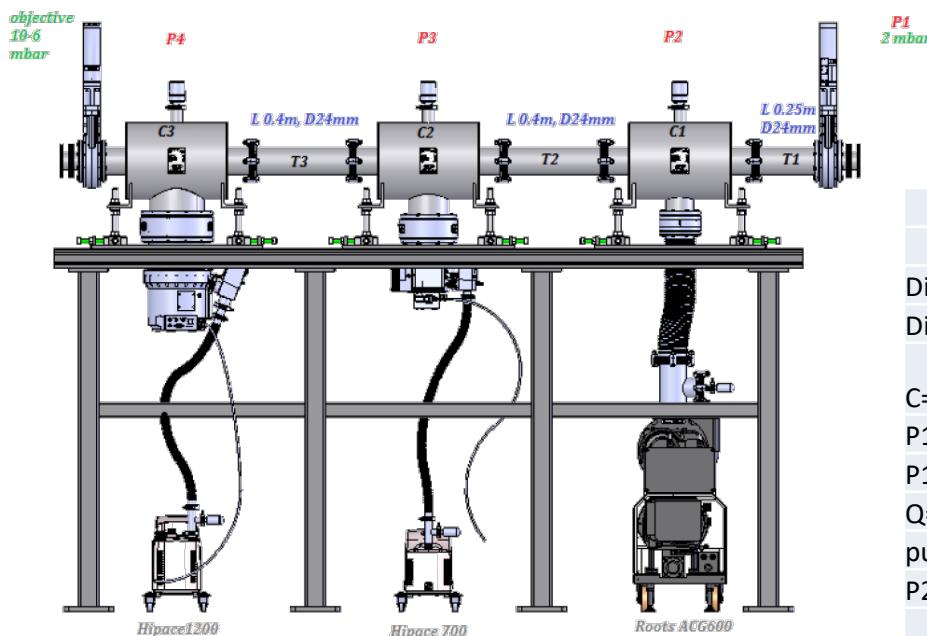


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Magnets And Beam Transport

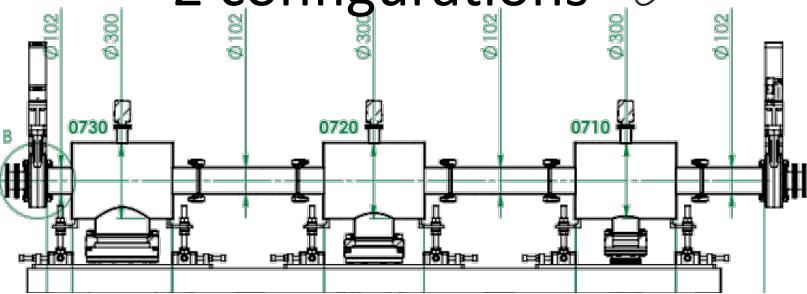
Differential pumping (1)



- Allows window-less operation
- Tolerate intense heavy ion beams
- Gas contributes to target cooling
- As all recent gas-filled separators
TASCA, GARIS-II, SHANS



Large tubes ($\phi 102$): standard pumping



Pressure profile (case of He)

	P1	2.00E+00 P2	1.04E-01 P3	6.47E-04 mbar
	P2 goal	1.00E-03 P3 goal	1.00E-03 P4 goal	1.00E-06 mbar
Diaphragm diameter		24	24	24 mm
Diaphragm length		0.25	0.4	0.4 m
$C = 1.22 \cdot 10^{-4} \cdot (D^3/L)$		6.75E+00	0	4.22E+00 l/s
P1-P2		2.00E+00	1.03E-01	6.46E-04 mbar
P1-P2		1.97E-03	1.01E-04	6.37E-07 atm
$Q = C \cdot (P1 - P2)$		1.33E-02	4.27E-04	2.69E-06 l/s
pumping speed He		130	670	1200 l/s
P2=Q/pumping speed		1.02E-04	6.38E-07	2.24E-09 atm
	P2	1.04E-01 P3	6.47E-04 P4	2.27E-06 mbar

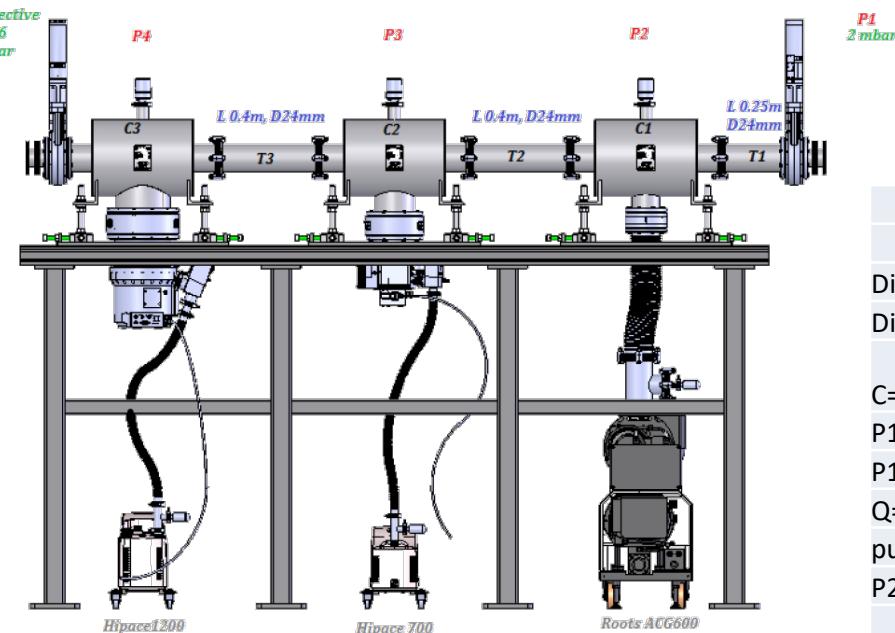


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Magnets And Beam Transport

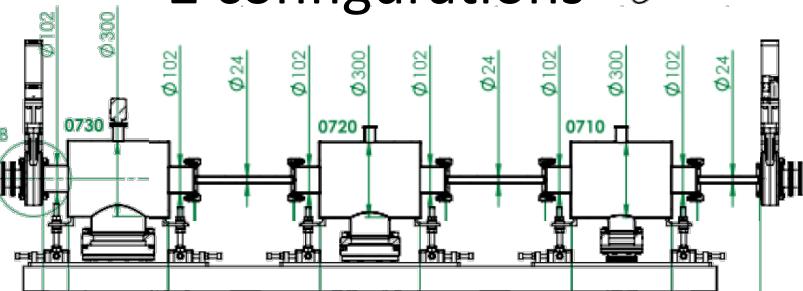
Differential pumping (1)



- Allows window-less operation
- Tolerate intense heavy ion beams
- Gas contributes to target cooling
- As all recent gas-filled separators
TASCA, GARIS-II, SHANS



Diaphragms ($\phi 24$) : differential pumping



2 configurations

Pressure profile (case of He)

	P1	2.00E+00 P2	1.04E-01 P3	6.47E-04 mbar
	P2 goal	1.00E-03 P3 goal	1.00E-03 P4 goal	1.00E-06 mbar
Diaphragm diameter		24	24	24 mm
Diaphragm length		0.25	0.4	0.4 m
$C = 1.22 \cdot 10^{-4} \cdot (D^3 / L)$		6.75E+00	0	4.22E+00
P1-P2		2.00E+00	1.03E-01	6.46E-04 mbar
P1-P2		1.97E-03	1.01E-04	6.37E-07 atm
$Q = C \cdot (P1 - P2)$		1.33E-02	4.27E-04	2.69E-06 l/s
pumping speed He		130	670	1200 l/s
P2=Q/pumping speed		1.02E-04	6.38E-07	2.24E-09 atm
	P2	1.04E-01 P3	6.47E-04 P4	2.27E-06 mbar

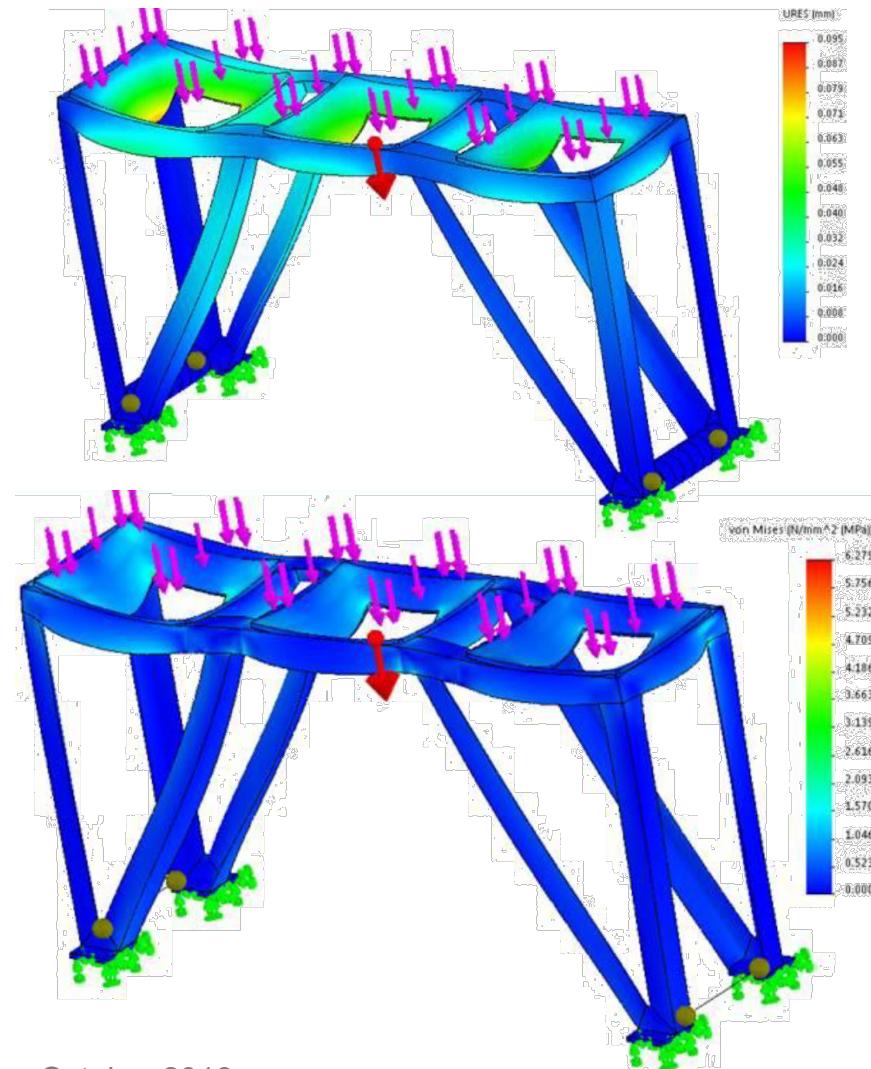
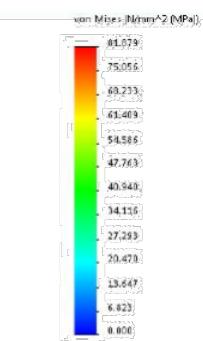
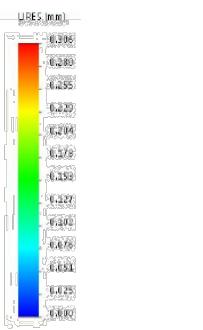
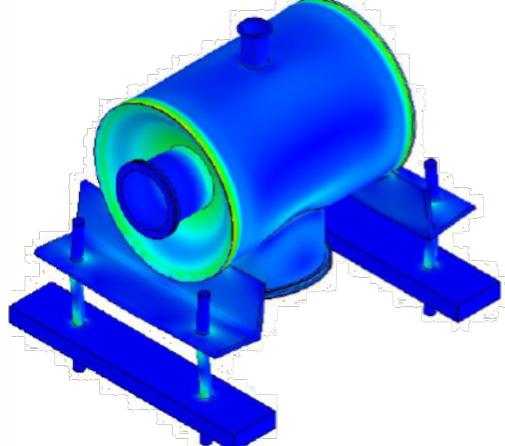
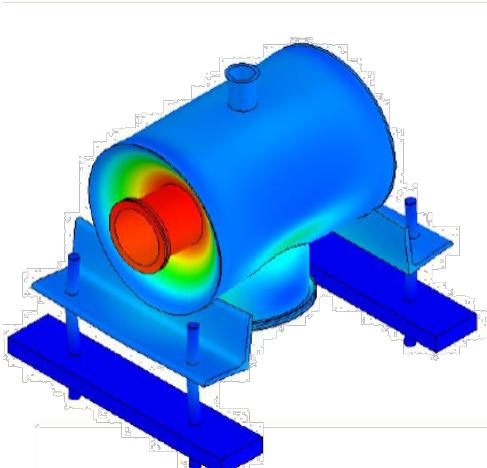


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Differential pumping (2)



Mechanically sound





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MAGNETS AND BEAM TRANSPORT

Differential pumping (3)



Factory testing





Power supplies

Power supplies





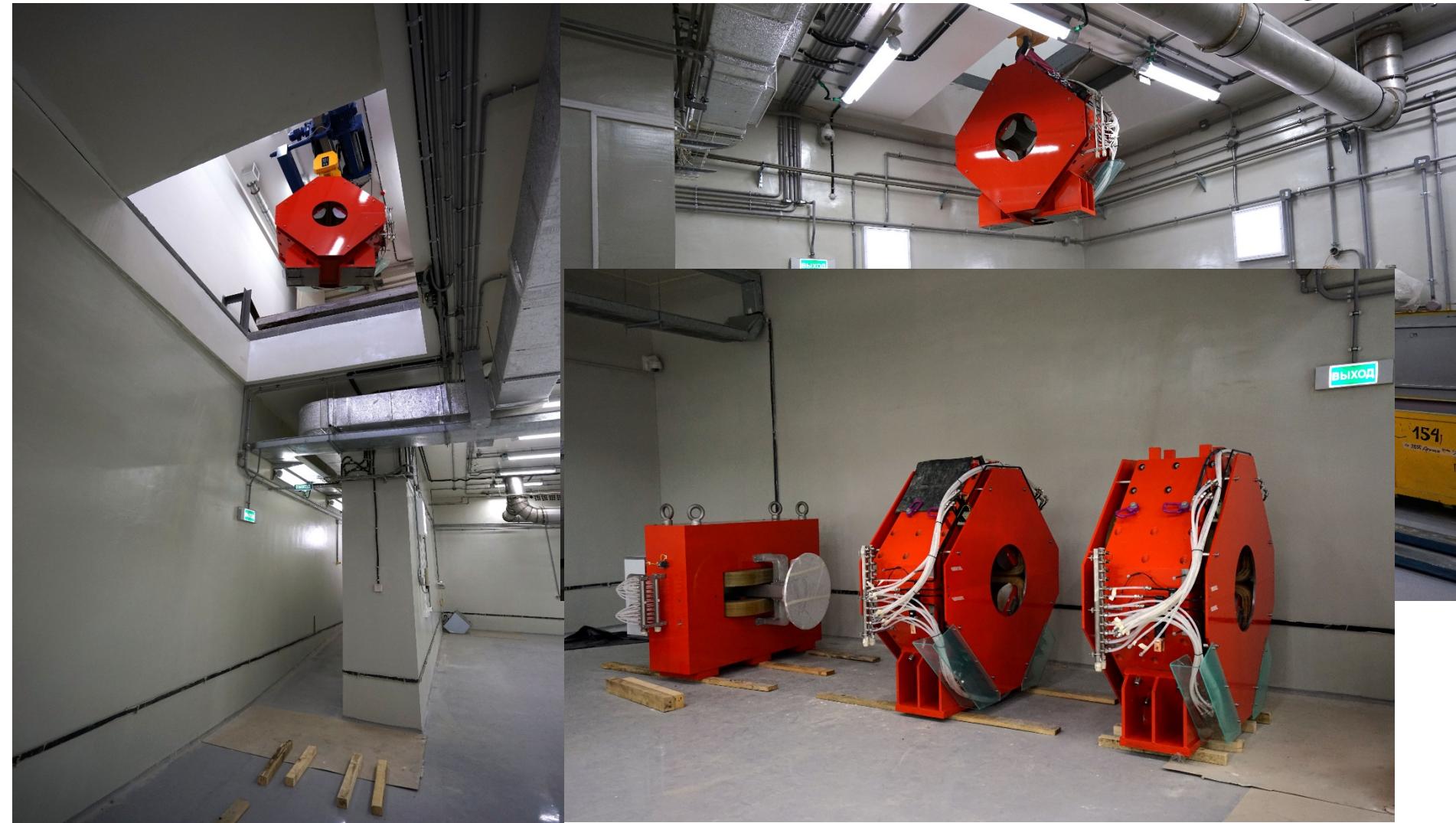
Installation

June 05th-14th 2018



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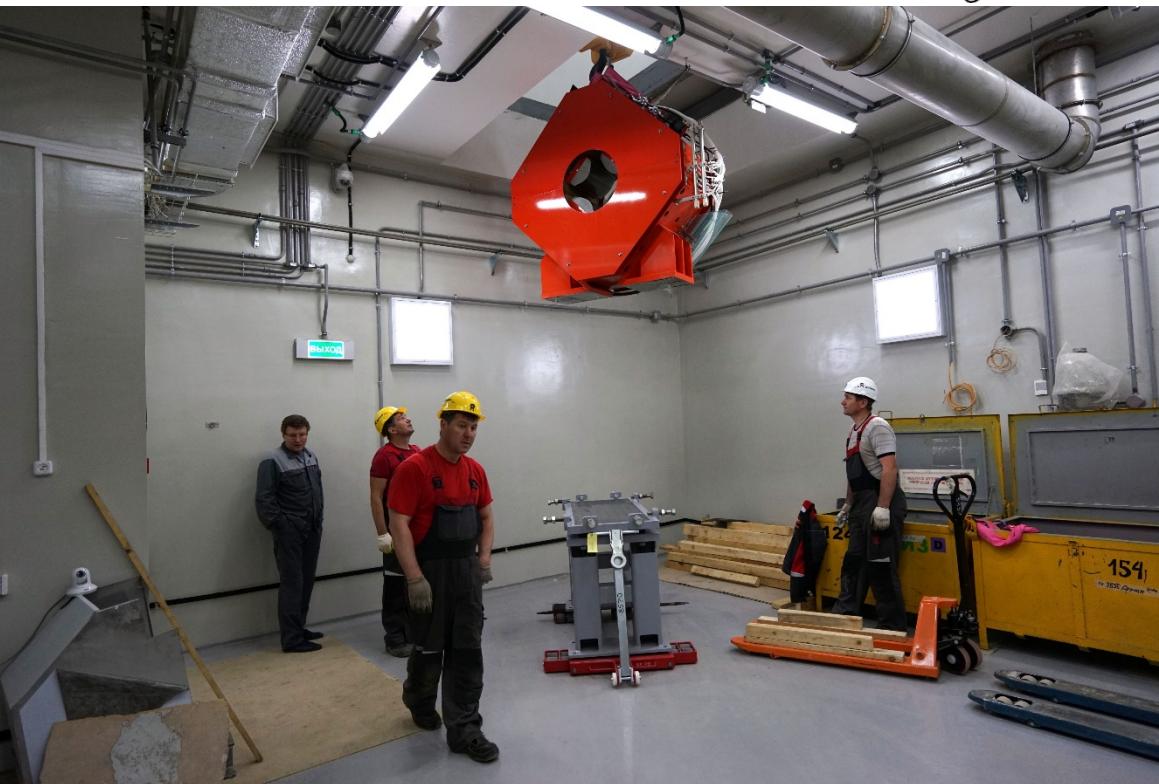
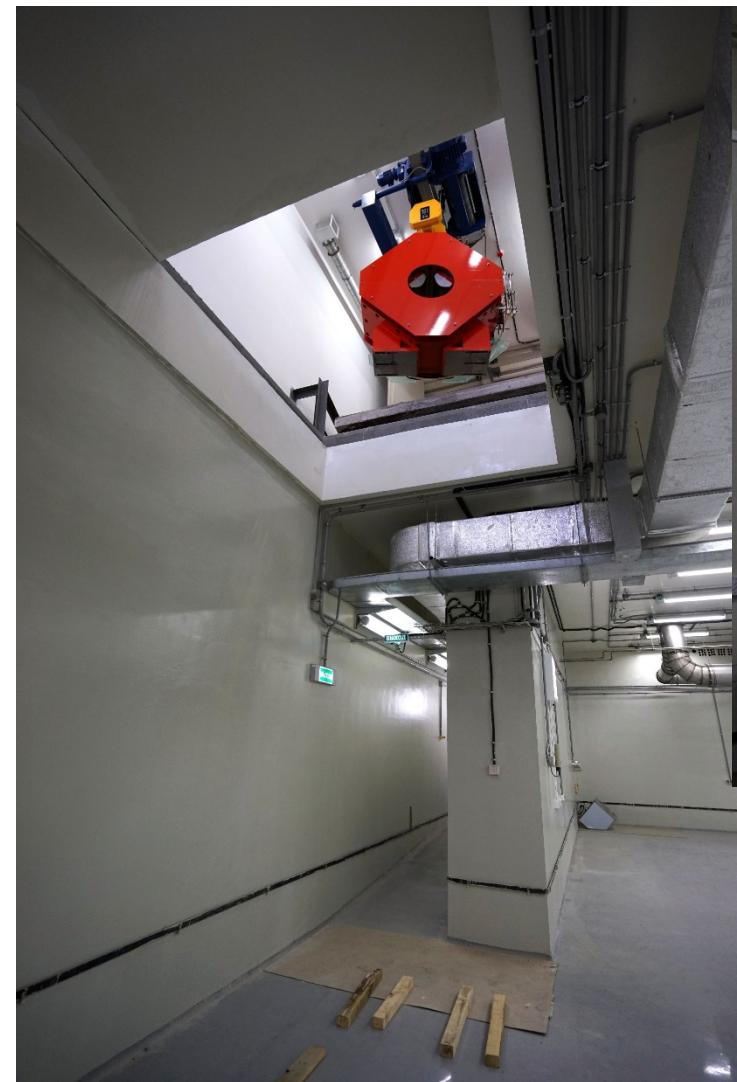
No crane! So what? (1)





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MAGNETS AND BEAM TRANSPORT

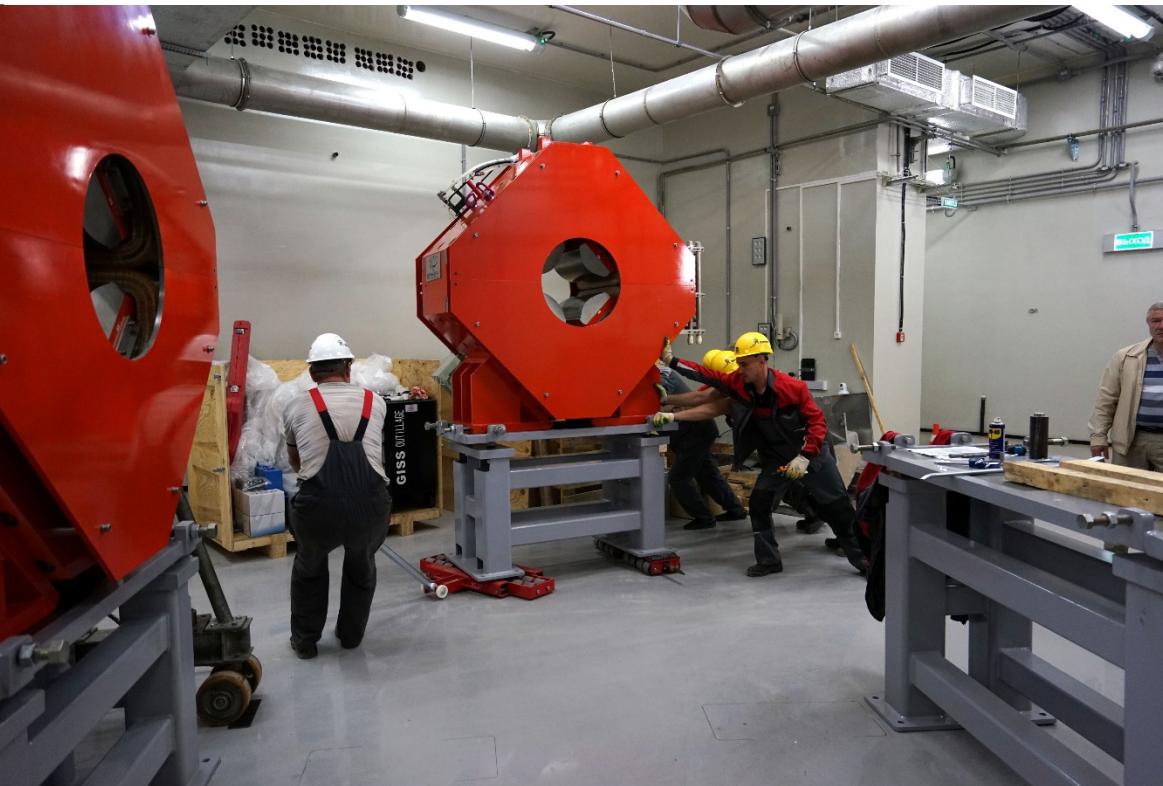
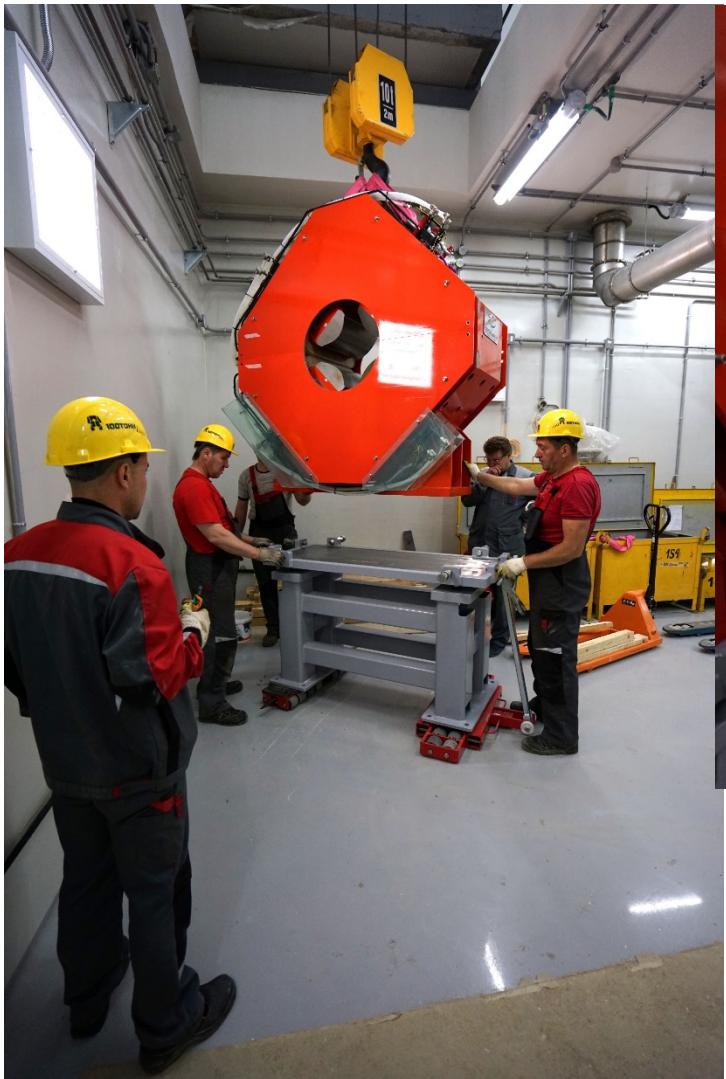
No crane! So what? (1)





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MAGNETS AND BEAM TRANSPORT

No crane! So what? (2)





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MAGNETS AND BEAM TRANSPORT

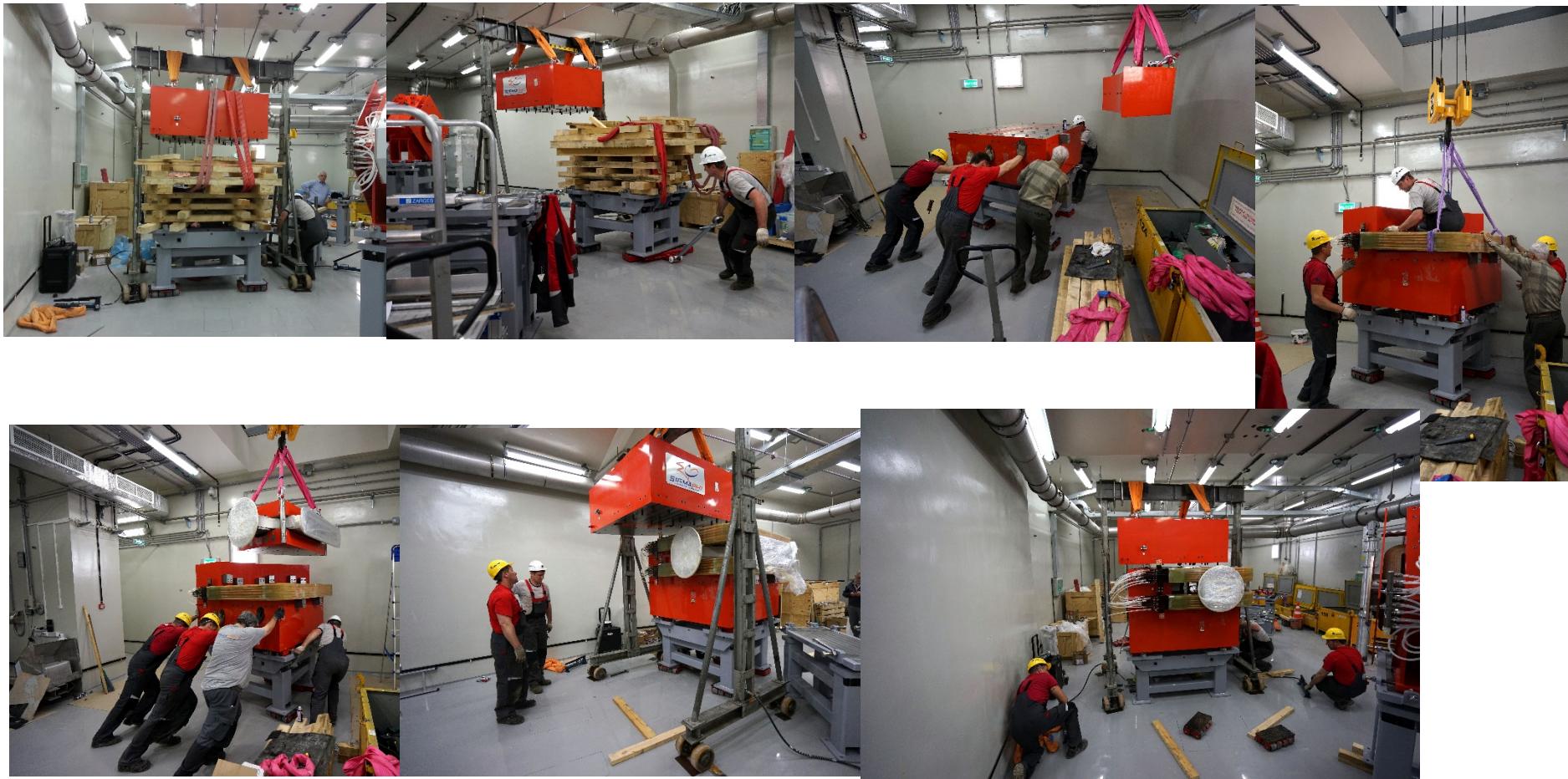
No crane! So what? (3)





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Magnets and Beam Transport

No crane! So what? (4)





Alignment

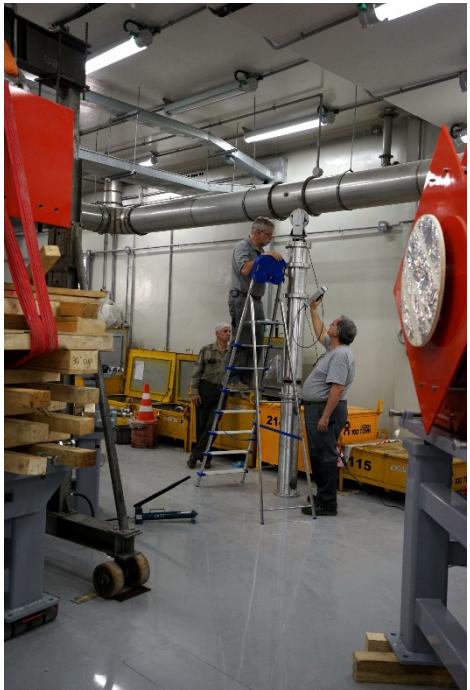


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Alignment



- Leica laser tracker AT401
- Red ring 2.5" targets
- Polyworks software
- Global Alignment accuracy within ± 0.1 mm





The near future

2018 GFS-2 acceptance tests

2018 GFS-2 first beam tests

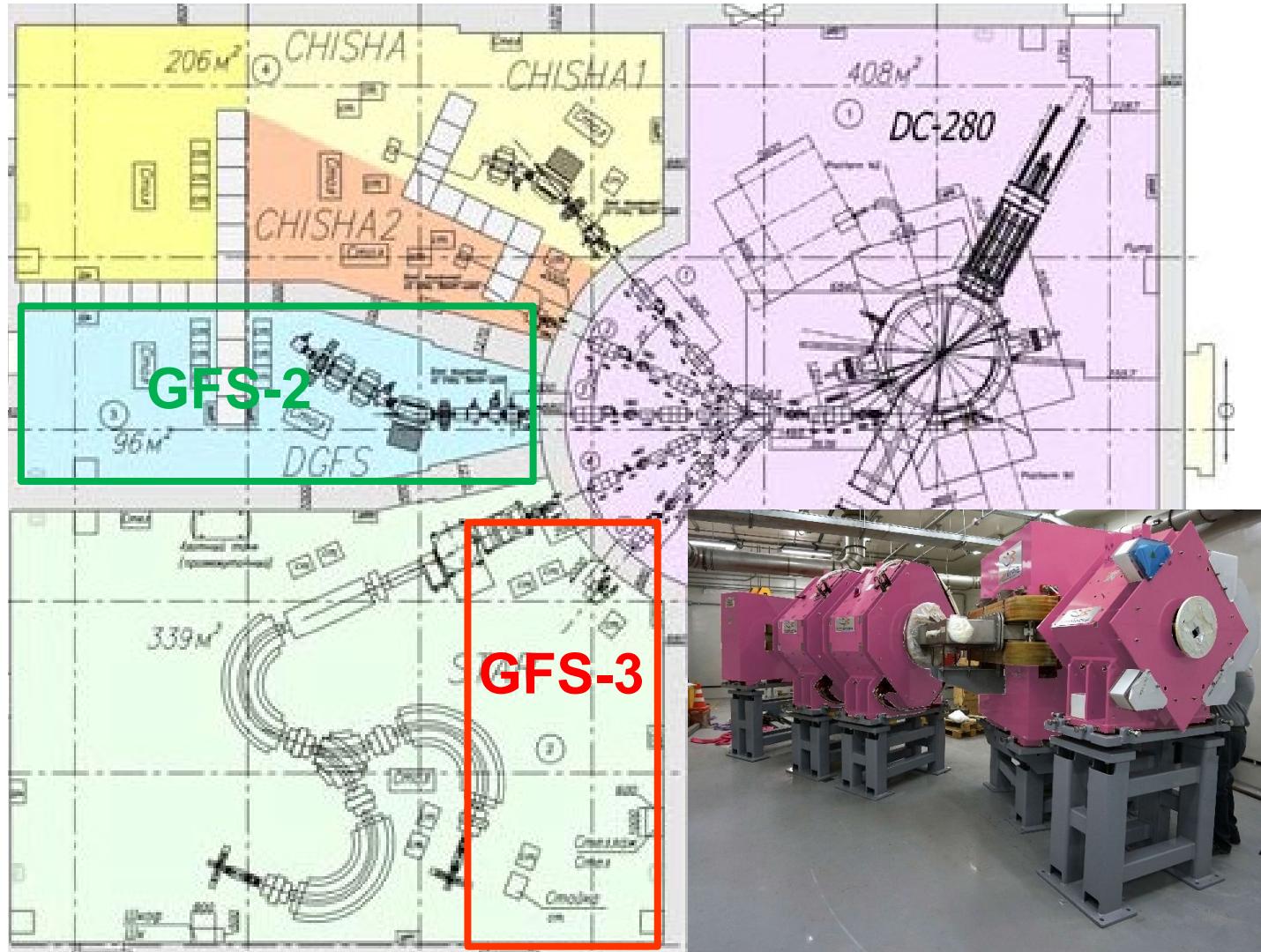
2018 GFS-3 start fabrication

2019 GFS-3 installation



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Magnets and Beam Transport

Future plans





We also built friendship

Human interaction



Team spirit



Conclusions

- GFS-2 is installed and under commissioning. First runs should start by end 2018
- A global contract has opened the possibility for thorough optimization.
- A similar (chiral symmetry) system is produced and will be installed in 2019
- A wonderful human experience!

Thank you for your attention

The essence of the beautiful is unity in variety

W. Somerset Maugham





Questions ?