THE ACCULINNA AND ACCULINNA-2 RADIOACTIVE ION BEAM FACILITY AT DUBNA: STATUS AND PERSPECTIVES

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FLNR, JINR, DUBNA

International Nuclear Physics Conference (INPC2016)
Adelaide Convention Centre, Australia
September 11-16, 2016

Short outline

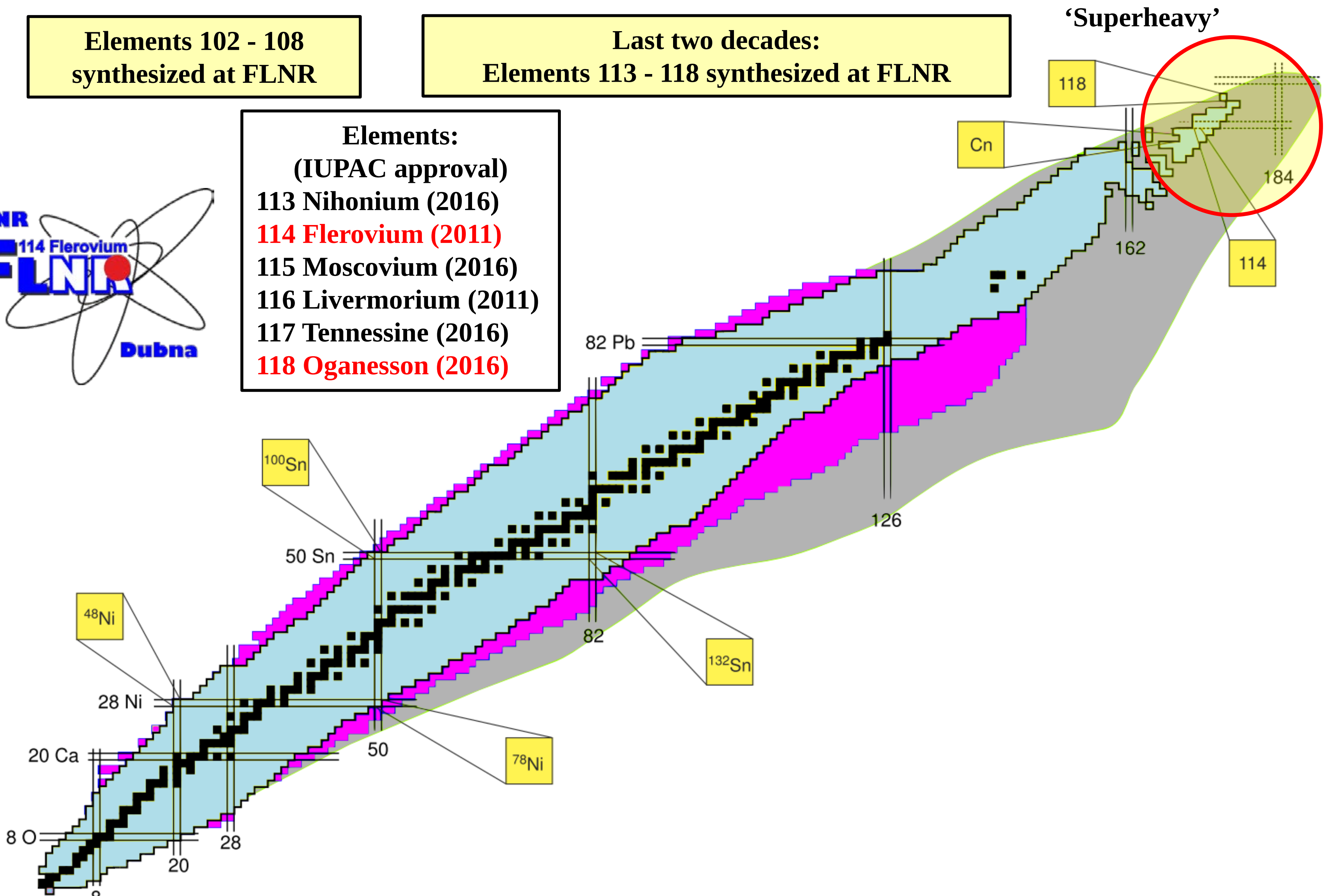
- Introduction: Light RIB facility at FLNR: ACCULINNA
- Status of the ACCULINNA-2 project
- Experiments @ACCULINNA& first day experiments at ACCULINNA-2

Superheavy and "superlight" research at FLNR, JINR

Elements 102 - 108 synthesized at FLNR

Last two decades: Elements 113 - 118 synthesized at FLNR

Elements: (IUPAC approval)
113 Nihonium (2016)
114 Flerovium (2011)
115 Moscovium (2016)
116 Livermorium (2011)
117 Tennessine (2016)
118 Oganesson (2016)



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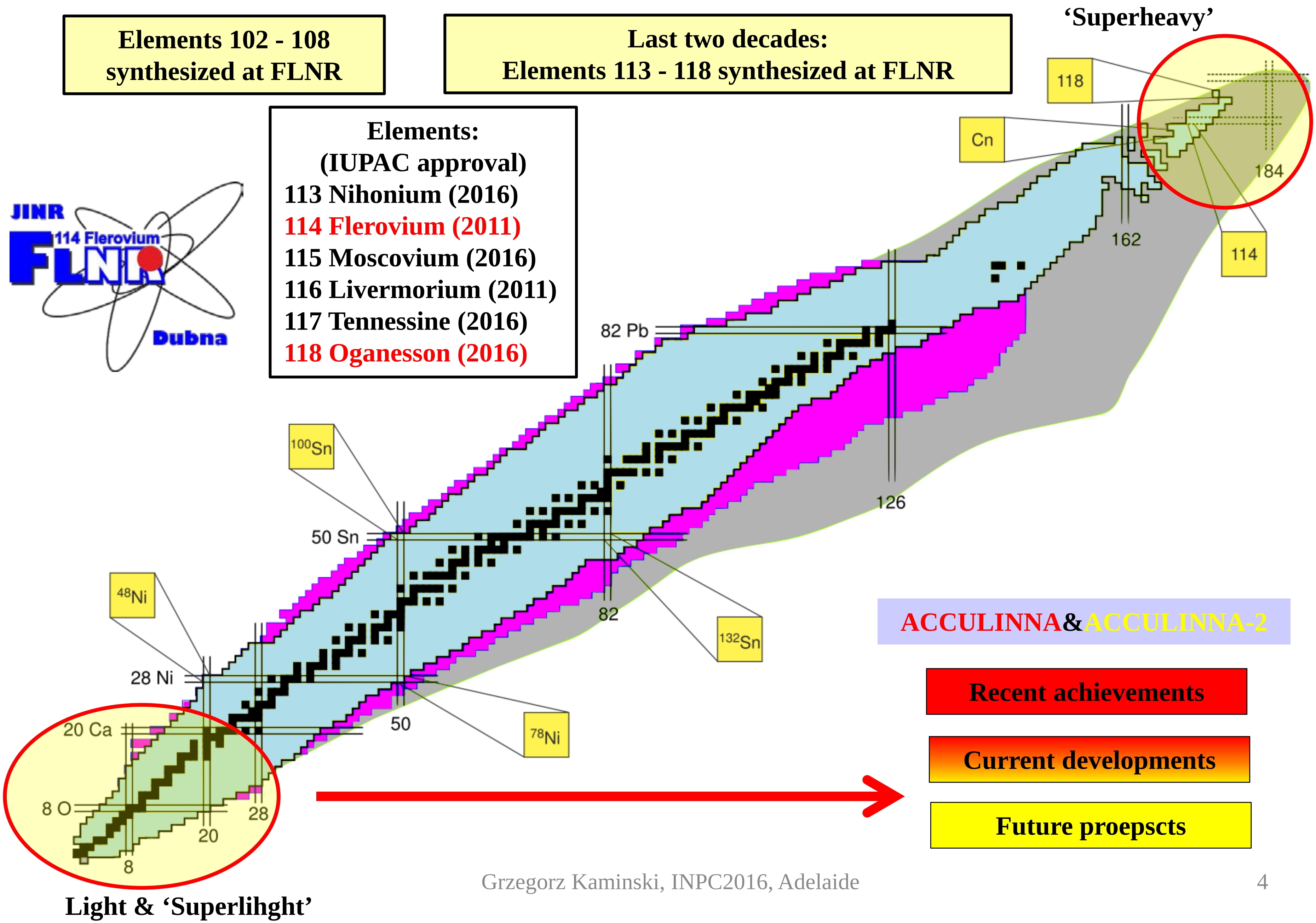


ACCULINNA&ACCULINNA-2

Recent achievements

Current developments

Future proepscts

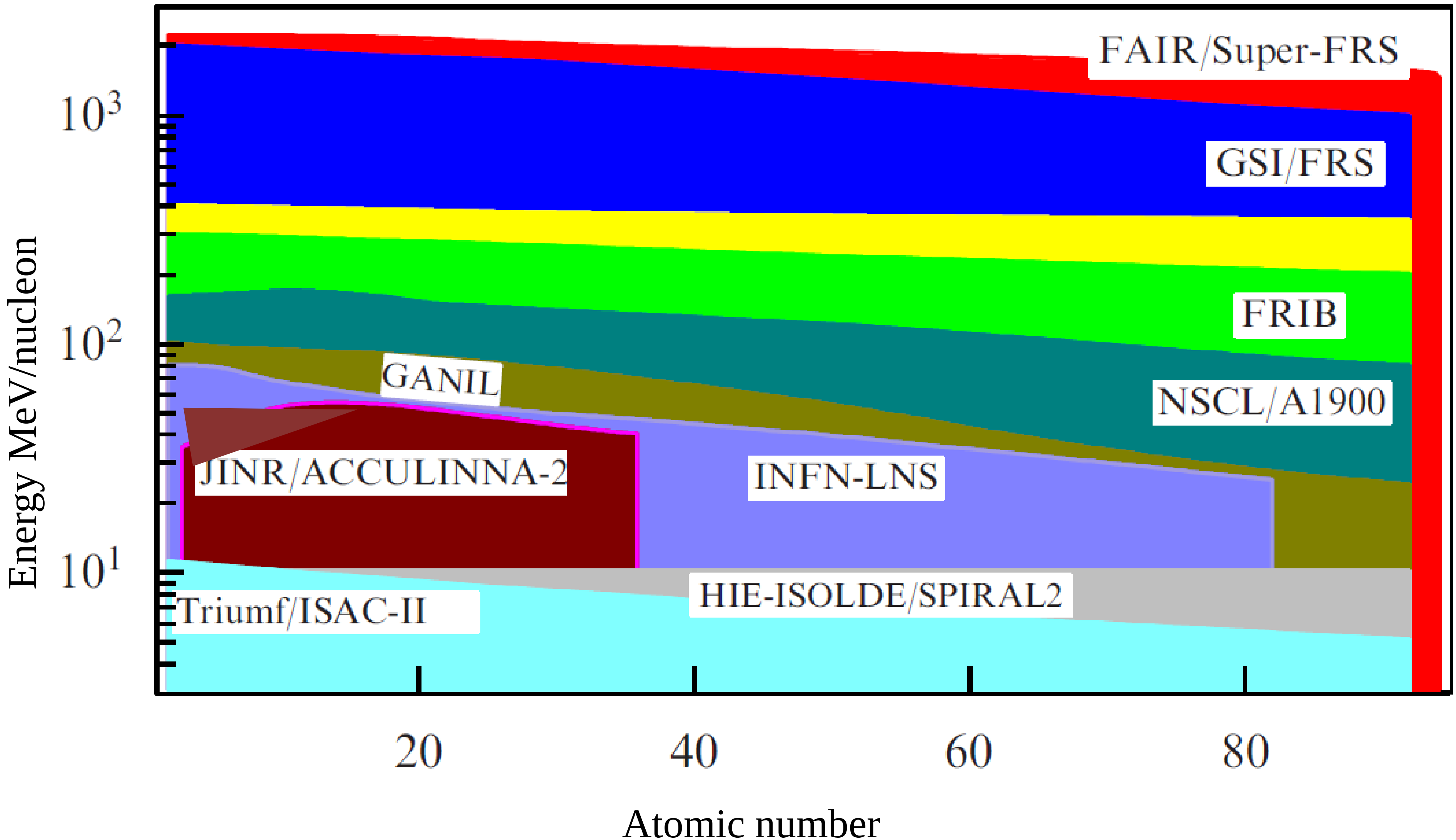
ACCULINNA-2 in perspective

Characteristics of existing and new in–flight RIB separators

($\Delta\Omega$ and $\Delta p/p$ are angular and momentum acceptances, $Rp/\Delta p$ is the first-order momentum resolution when 1 mm object size is assumed)

	ACC / ACC-2 FLNR JINR	RIPS / BigRIBS RIKEN	A1900 MSU	FRS / SuperFRS GSI	LISE3 GANIL
$\Delta\Omega$, msr	0.9 / 5.8	5.0 / 8.0	8.0	0.32 / 5.0	1.0
$\Delta p/p$, %	± 2.5 / ± 3.0	± 3.0 / 6.0	± 5.5	± 2.0 / 5.0	± 5.0
$Rp/\Delta p$	1000 / 2000	1500 / 3300	2915	8600 / 3050	2200
$B\rho$, Tm	3.2 / 3.9	5.76 / 9.0	6.0	18 / 18	3.2 - 4.3
Length, m	21 / 38	27 / 77	35	74 / 140	19(42)
E, AMeV	$\boxed{10\div40 / 6\div60}$	50÷90 / 350	110÷160	220÷1000/1500	40÷80
Additional RIB Filter	No / RF-kicker	RF-kicker / S-form	S-form & RF- kicker	S-form / Preseparator	Wien Filter

… somewhere among other facilities

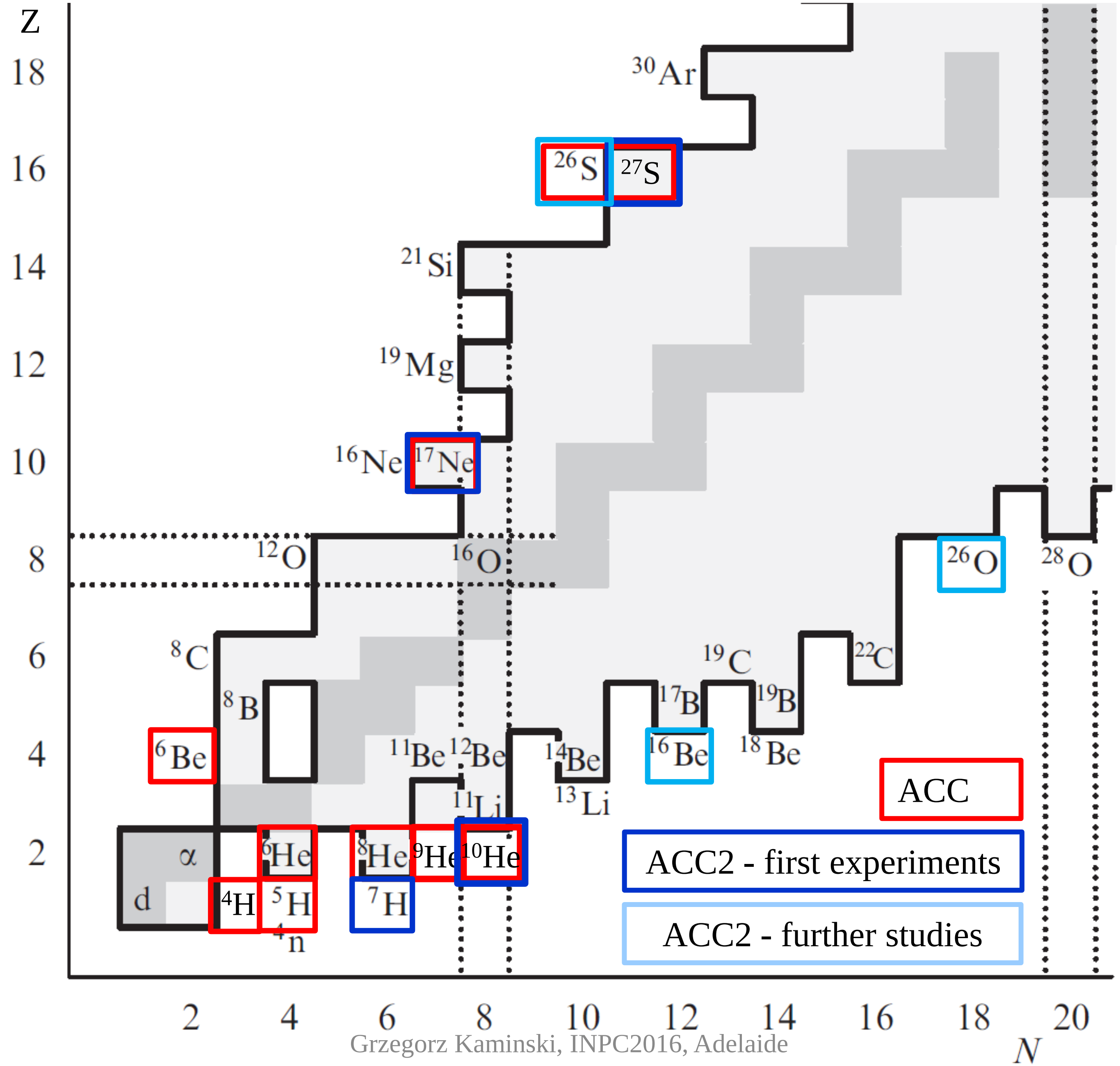


RIBs from ACCULINNA-2

calculations done with LISE++

Primary beam		Radioactive Ion Beam			
Ion	Energy, MeV/u	Ion	Energy, MeV/u	Intensity, s^{-1} (per 1 pμA)	Purity, %
^{11}B	32	**^{8}He**	26	$3*10^5$	90
^{15}N	49	**^{11}Li**	37	$3*10^4$	95
^{11}B	32	**^{10}Be**	26	$1*10^8$	90
^{15}N	49	**^{12}Be**	38.5	$2*10^6$	70
^{18}O	48	**^{14}Be**	35	$2*10^4$	50
^{22}Ne	44	**^{17}C**	33	$3*10^5$	40
		^{18}C	35	$4*10^4$	30
^{36}S	64 (U400M upgrade)	**^{24}O**	40	$2*10^2$	10 (with RF kicker)
^{10}B	39	**^{7}Be**	26	$8*10^7$	90
^{20}Ne	53	**^{18}Ne**	34	$2*10^7$	40
^{32}S	52	**^{28}Be**	31	$2*10^4$	5 (with RF kicker)

Scope of activity for ACCULINNA-2

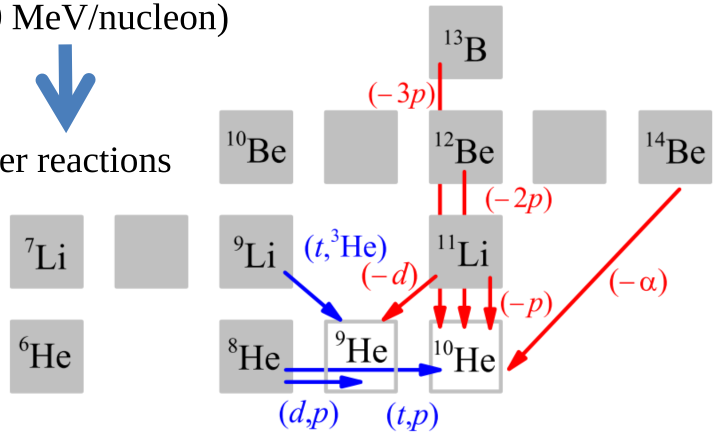


Competitive light nuclei RIB program at ACCULINNA-2

➢ Energy range and reaction selection

Intermediate energy reactions
(20-70 MeV/nucleon)

Transfer reactions



High energy reactions (>70-100 MeV/nucleon)

Knockout reactions

Population of highly aligned states in the intermediate energy transfer reactions

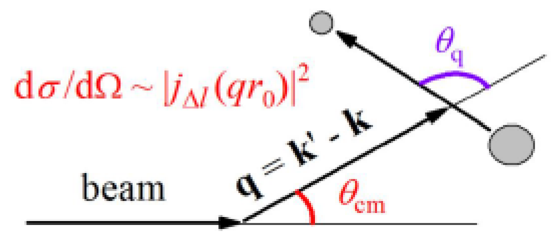
Prospects for specific correlation studies

- **Complementary information from different reaction mechanism**
- **Lower reaction energy - easier to get higher energy resolution**

➢ Correlations and few-body dynamics studies

Correlations for aligned states populated in the direct reactions

- Few-body dynamics near the driplines
- Correlations in the three-body decays: two extra degrees of freedom



ACCULINNA-2 instrumentation development

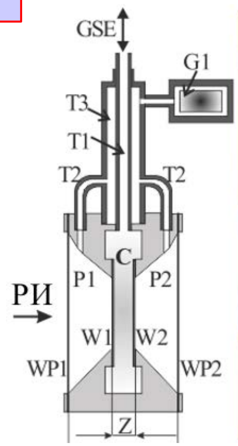
- Instrumentation development

Tritium target system for ACC-2

Zero-angle spectrometer (2016)

Velocity filter (RF-kicker) (2017)

Cryogenic tritium target cell



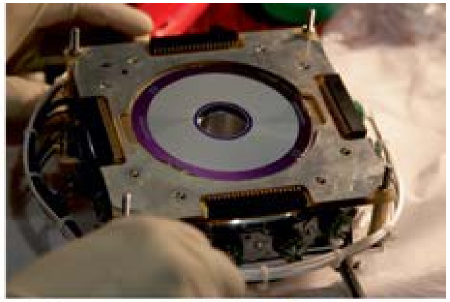
- Detectors development

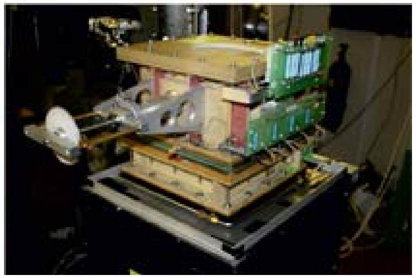
High-resolution telescope array

Neutron detection system (stilbene crystals)

γ-array GADAST

New Optical Time Projection Chamber OTPC (UW, Warsaw)

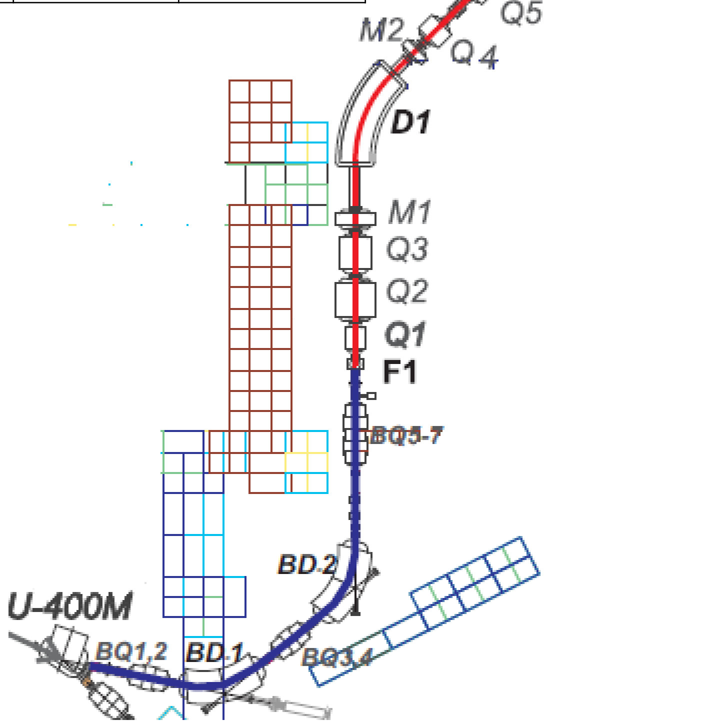
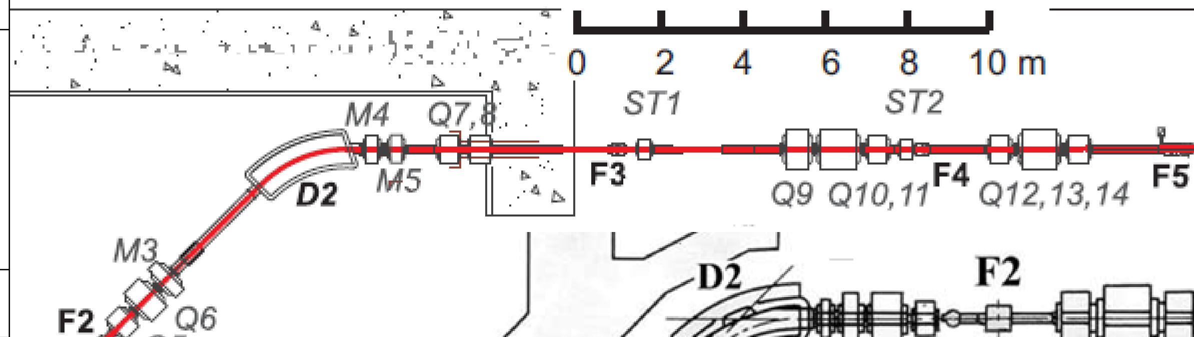


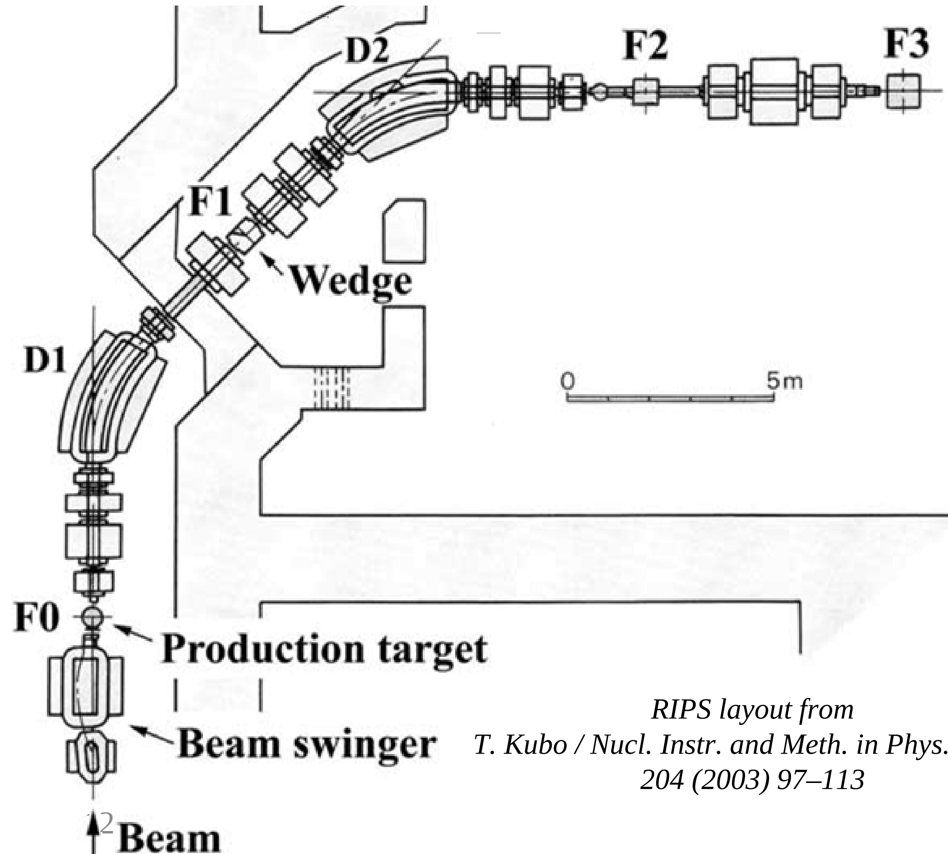


Layout of ACCULINNA-2

Layout of ACCULINNA-2

	ACC-2 FLNR JINR	RIPS RIKEN
ΔΩ [msr]	5.8	5
Δp/p [%]	±3.0	±3.0
Rp/Δp	2000	1500
Bρ [Tm]	3.9	5.76
Length [m]	38	27
E [AMeV]	6÷60	50÷90
Additional RIB Filter	RF-kicker	RF-kicker



RIPS layout from T. Kubo / Nucl. Instr. and Meth. in Phys. Res. B 204 (2003) 97–113

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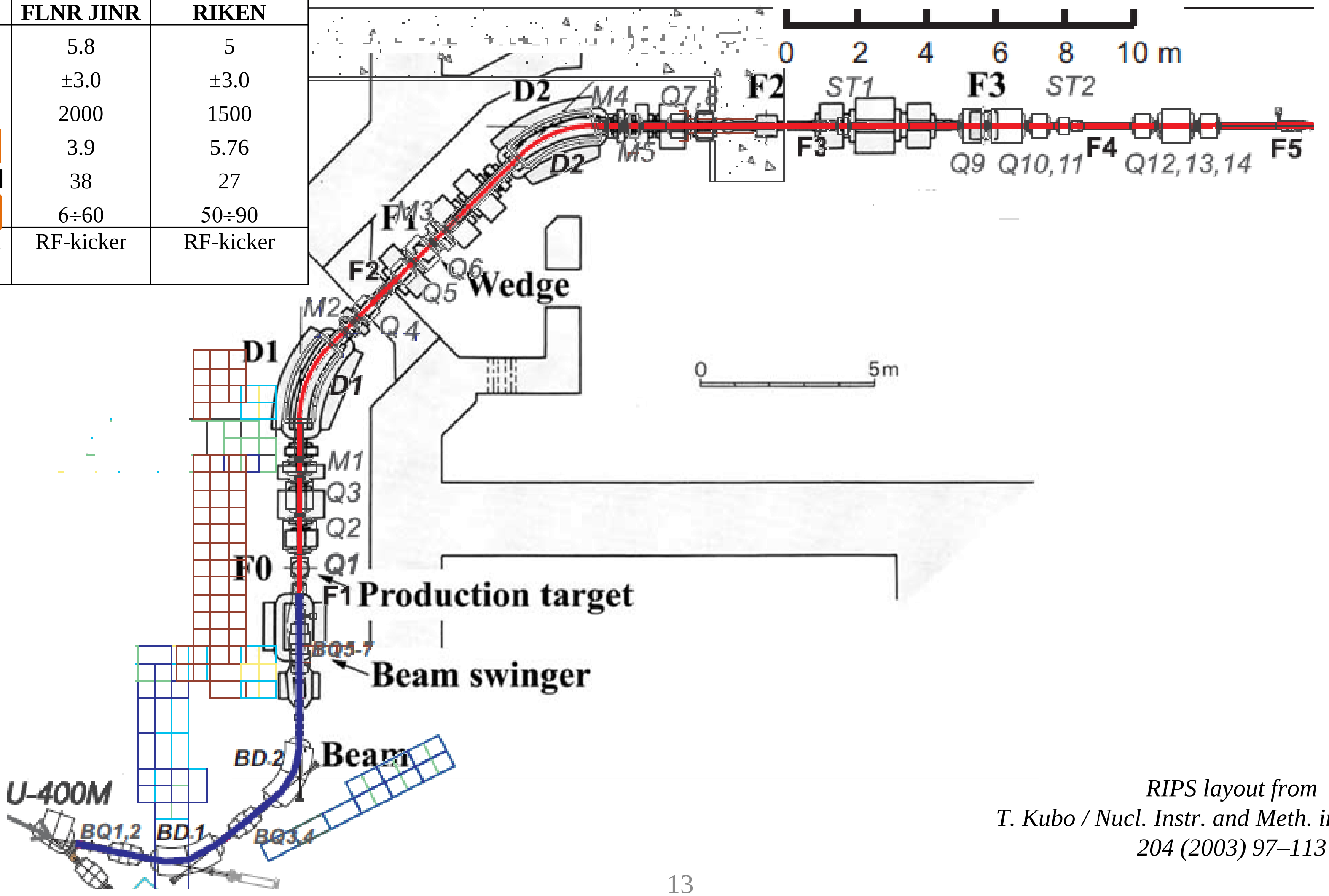

RIPS layout from
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From contract with SIGMA PHI to installation: 2011 - 2015

Layout of ACCULINNA-2

« In the beginning, there was *Chaos* »

Greek Mythology – The Creation

Area & floor preparation 1st delivery

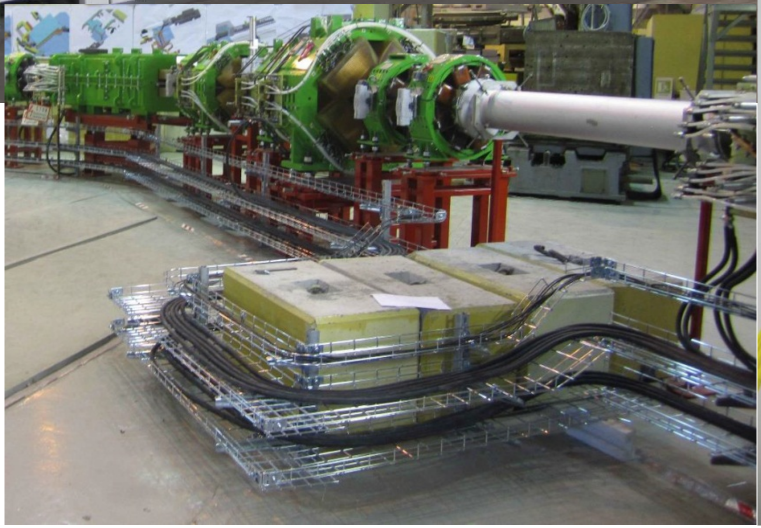
Installation Stands

Installation & Alignment, Available magnets

Installation & Alignment, all magnets and vacuum

Magnets: some big ones

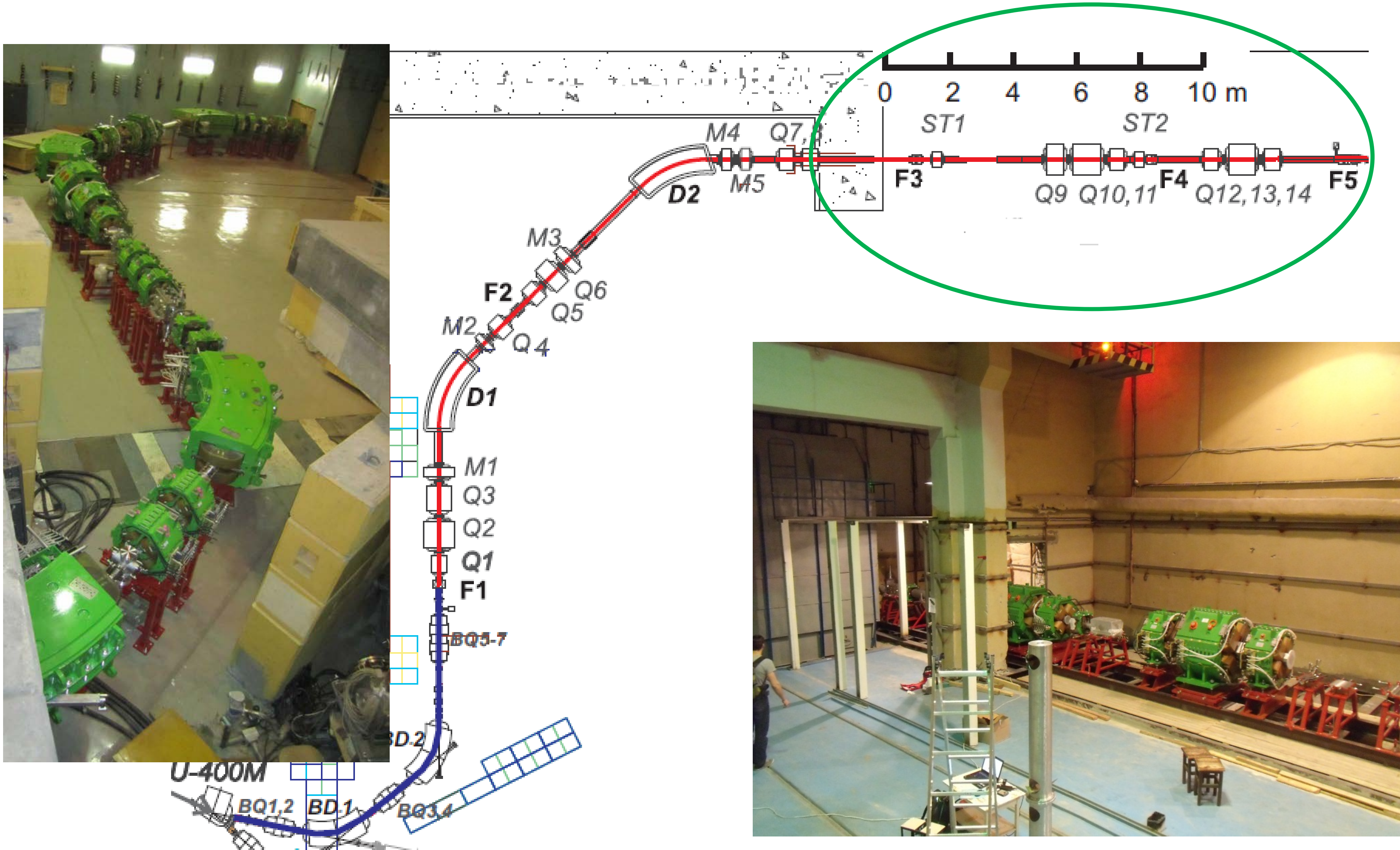
PS installation, full cabling and cooling



Support for shielding walls is prepared

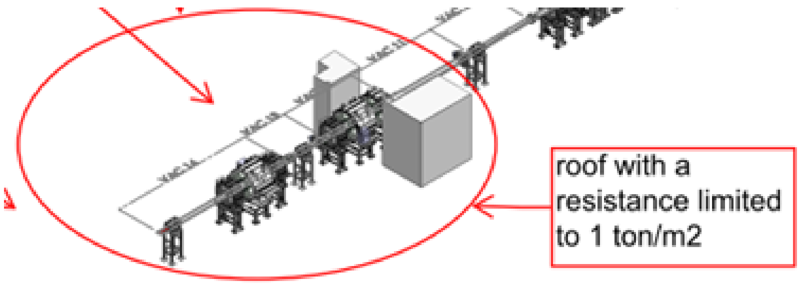
Installation out of reach of the crane

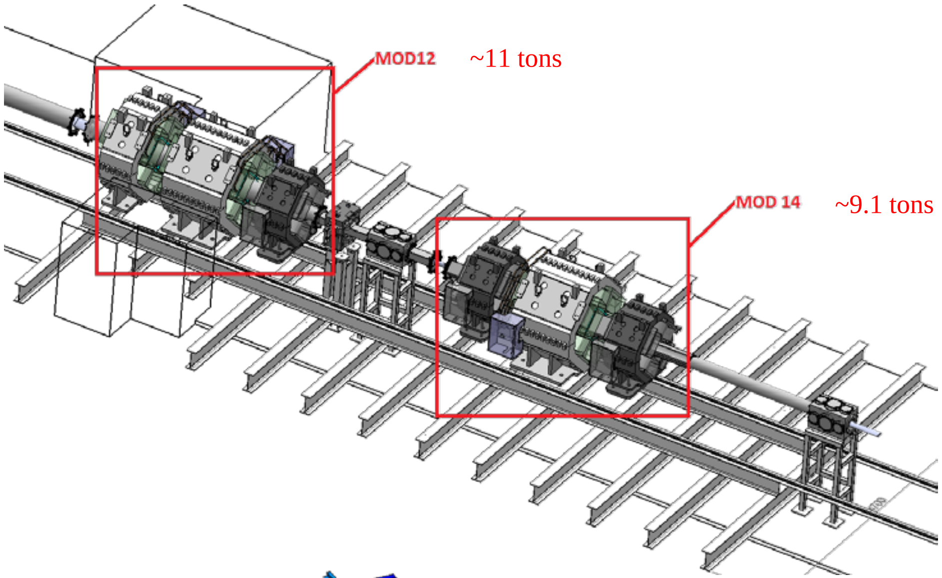
Room 2

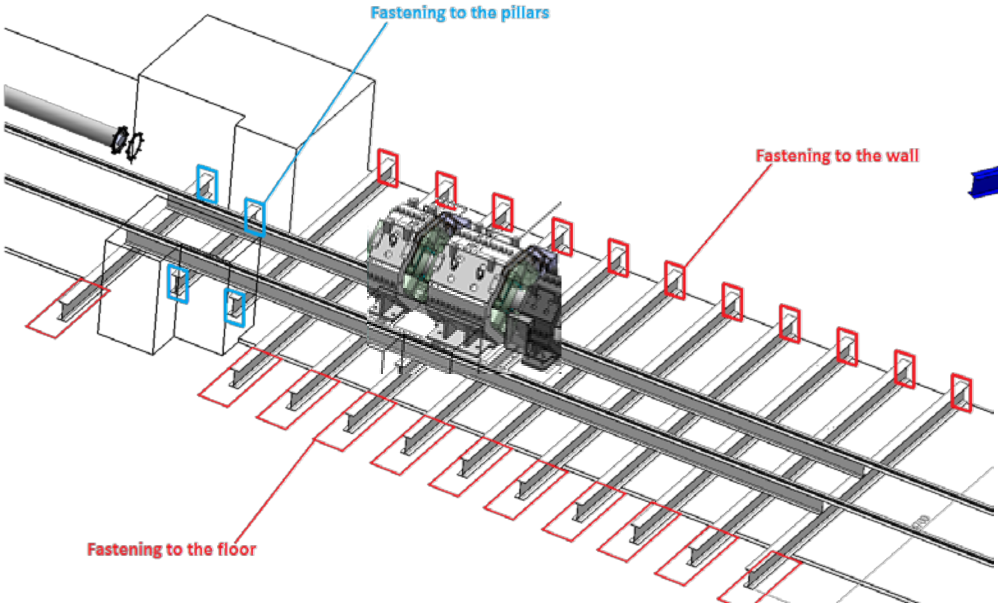


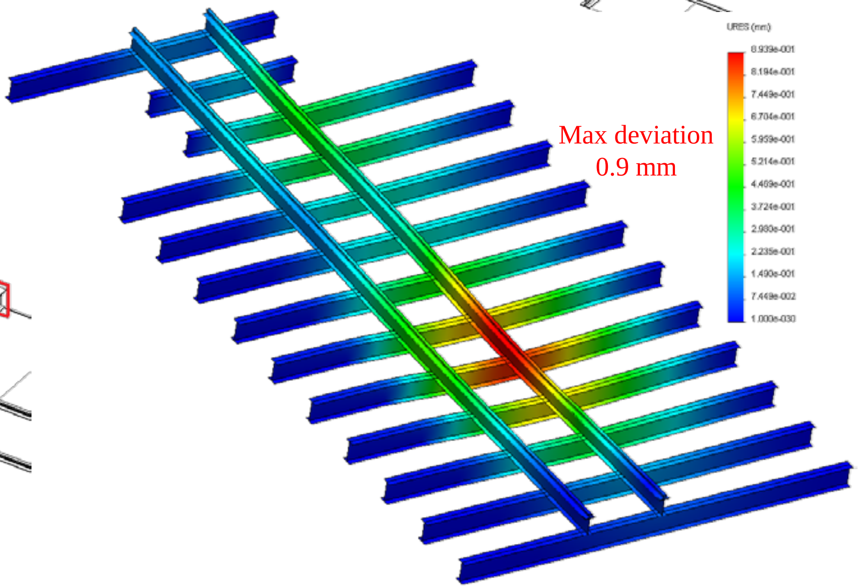
0 2 4 6 8 10 m
ST1
ST2
M4
Q7,8
M5
D2
F3
Q9
Q10,11
F4
Q12,13,14
F5
M3
F2
Q6
Q5
M2
Q4
D1
M1
Q3
Q2
Q1
F1
BQ5-7
BD2
U-400M
BQ1,2
BD1
BQ3,4

Room 2: floor reinforcement









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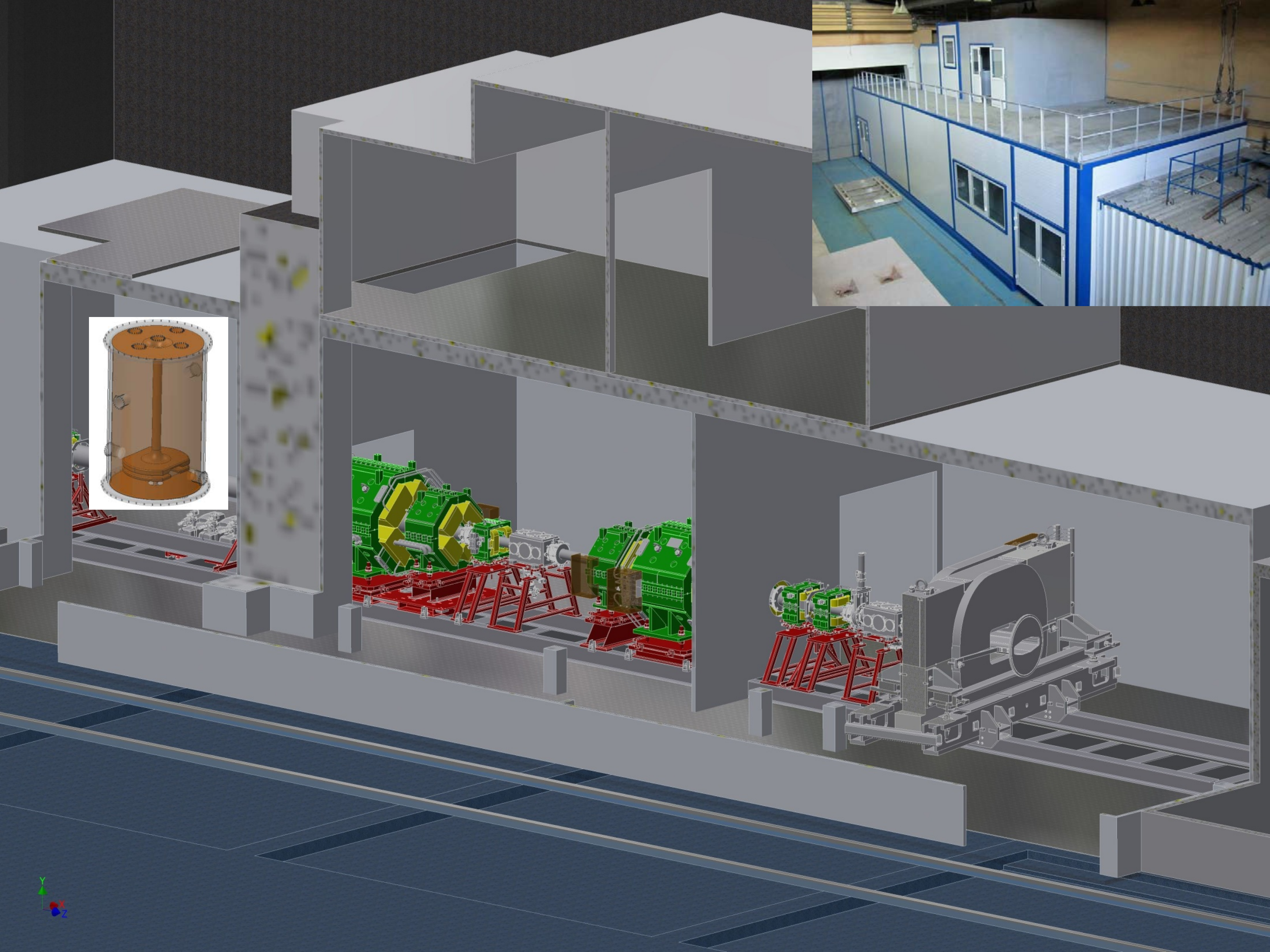
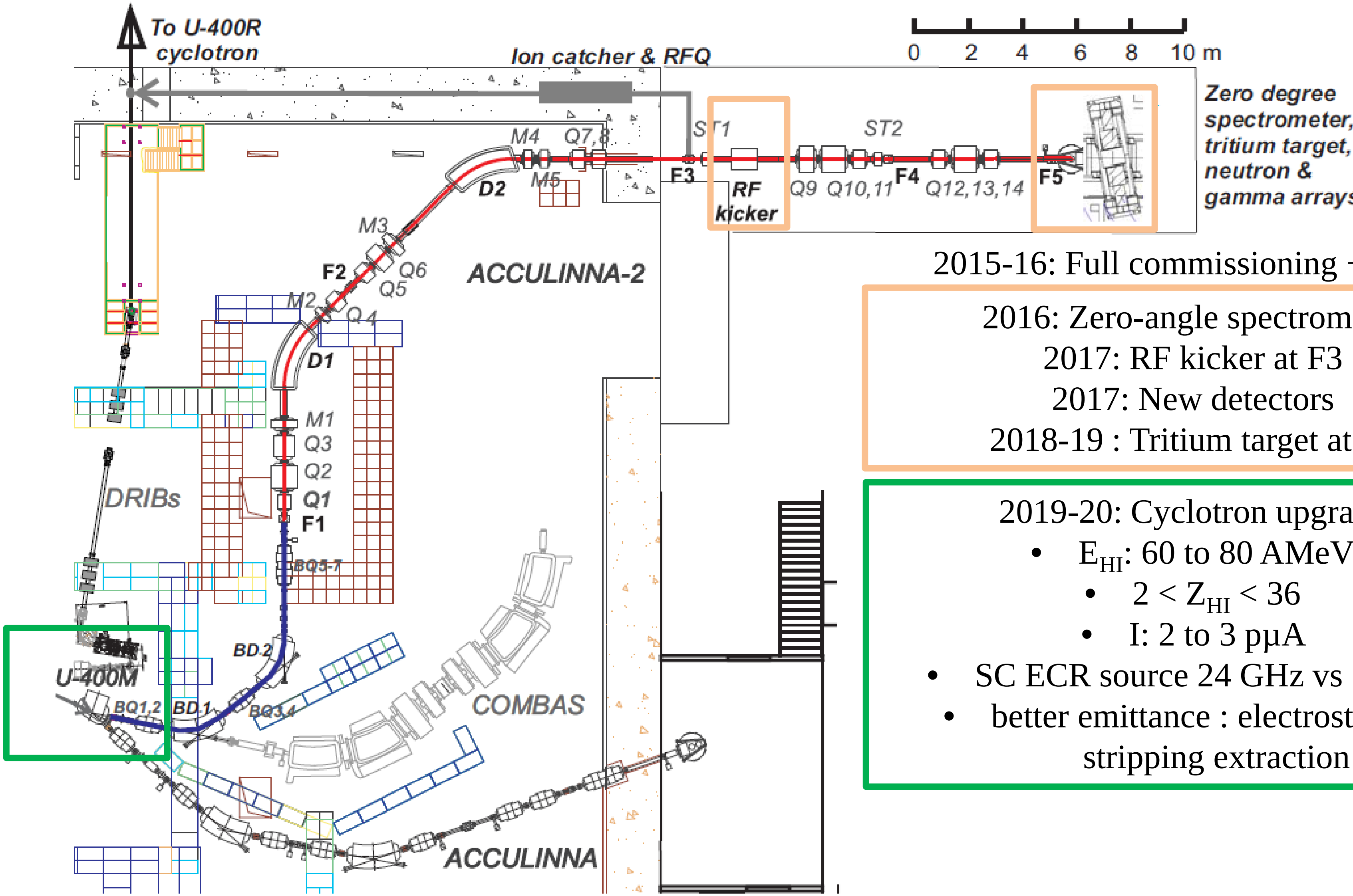


The zero angle spectrometer



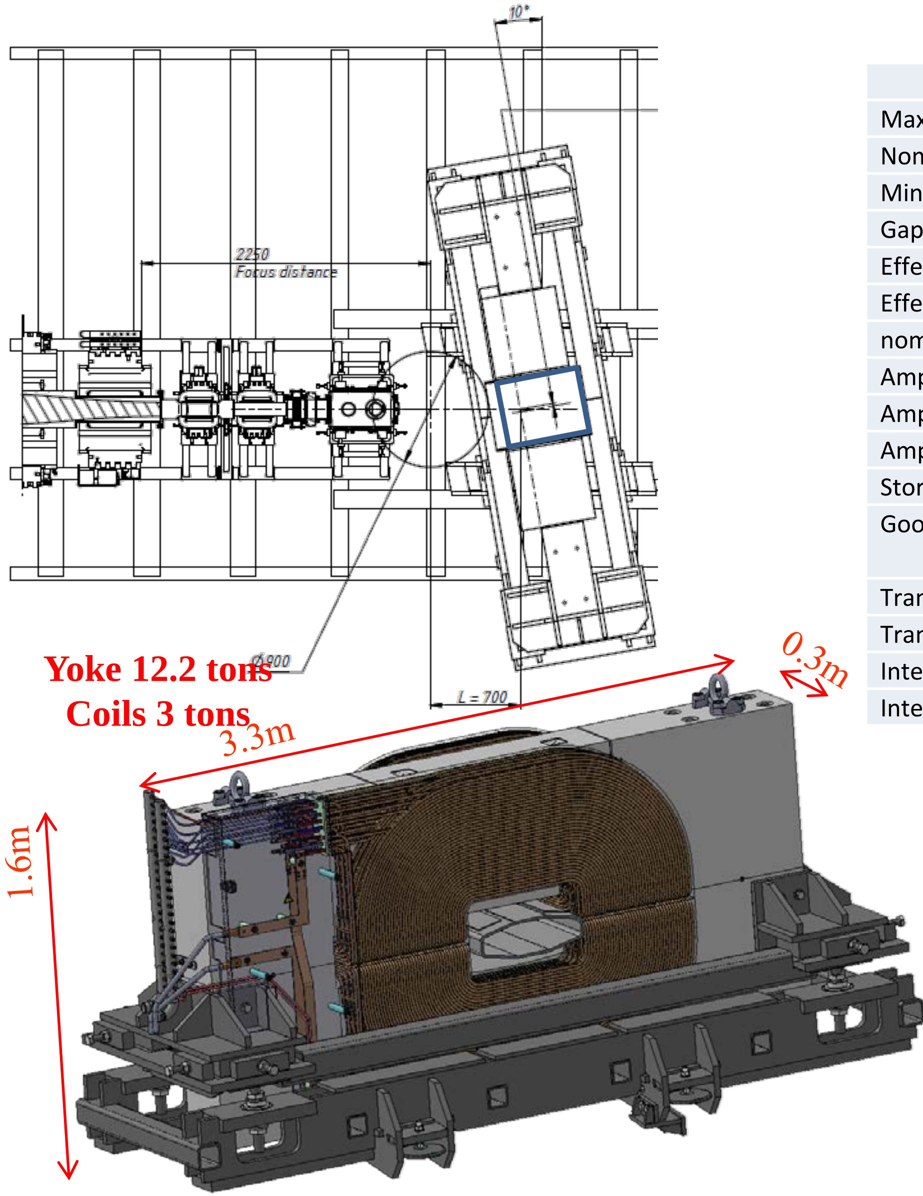
2015-16: Full commissioning + Beam

2016: Zero-angle spectrometer
2017: RF kicker at F3
2017: New detectors
2018-19 : Tritium target at F5

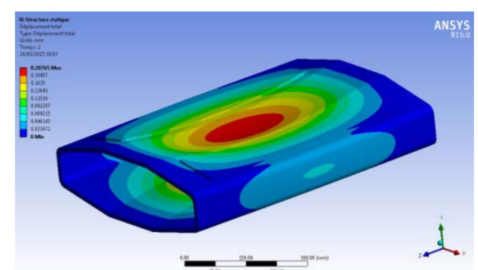
2019-20: Cyclotron upgrade

- E_{HI}: 60 to 80 AMeV
- $2 < Z_{HI} < 36$
- I: 2 to 3 pμA
- SC ECR source 24 GHz vs 18 GHz
- better emittance : electrostatic vs stripping extraction

The near future



PARAMETERS	values
Maximum field - Bmax	1.382T
Nominal field - Bnom	1.207T
Minimum field - Bmin	0.403T
Gap	180 mm
Effective length for Bnom	522.58mm
Effective length variation Bnom - Bmin	5.56mm
nominal integrated field – Blnom	630.65T.mm
Ampere turns per pole for Bnom	93540A.t
Ampere turns per pole for Bmin	29376A.t
Ampere turns per pole for Bmax	115200A.t
Stored Energy for Bmax	99500J
Good field region dimensions	H ±250mm V ±65mm (info)
Transverse Field homogeneity @ Bnom	0/2.7x10^{-3} Midplane
Transverse Field homogeneity @ Bmin	0/2.2x 10^{-3} Midplane
Integrated Field homogeneity @ Bnom	-1.53x10^{-3}/1.22x10^{-3}
Integrated Field homogeneity @ Bmin	-1.39x10^{-3}/1.06x10^{-3}



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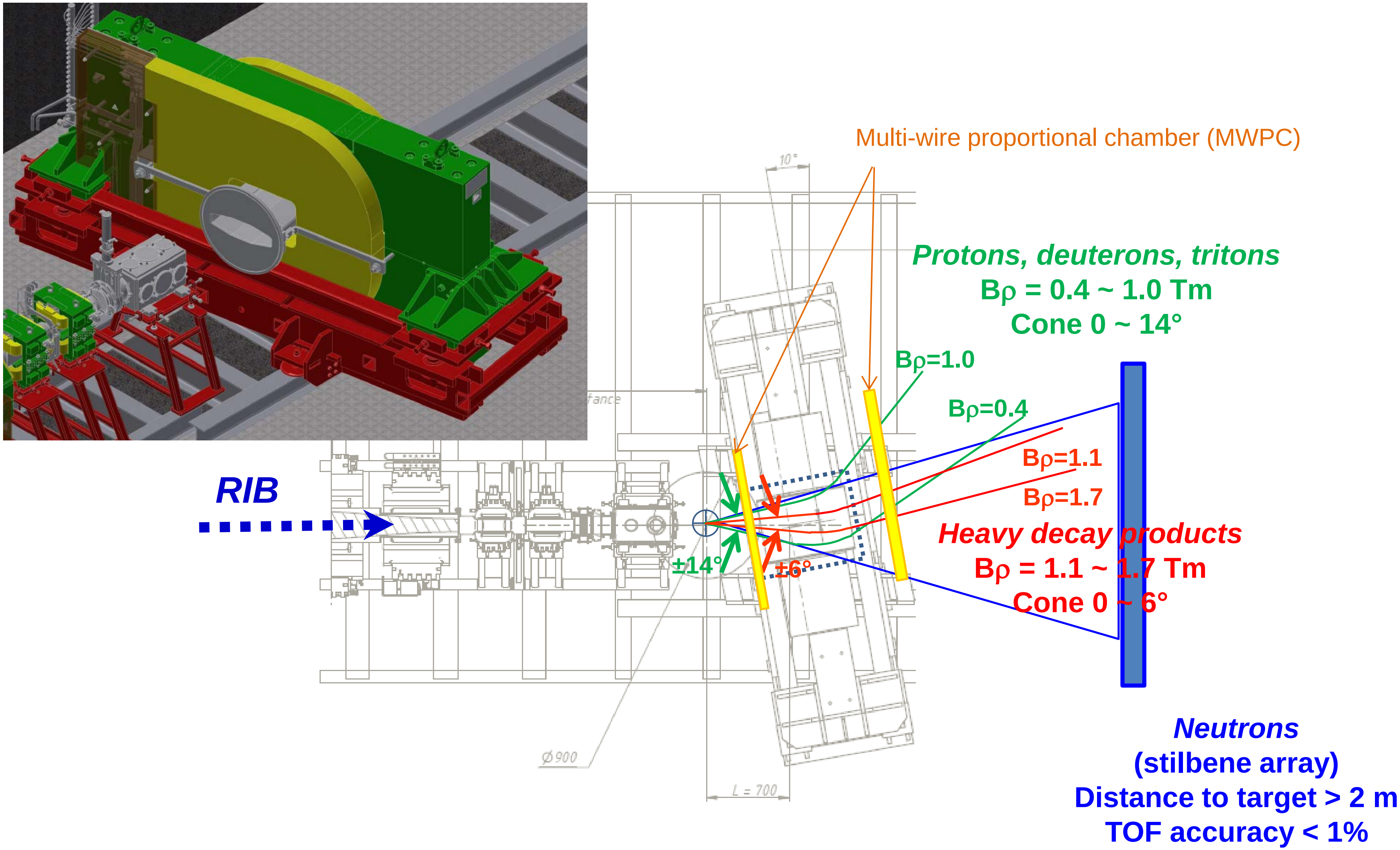
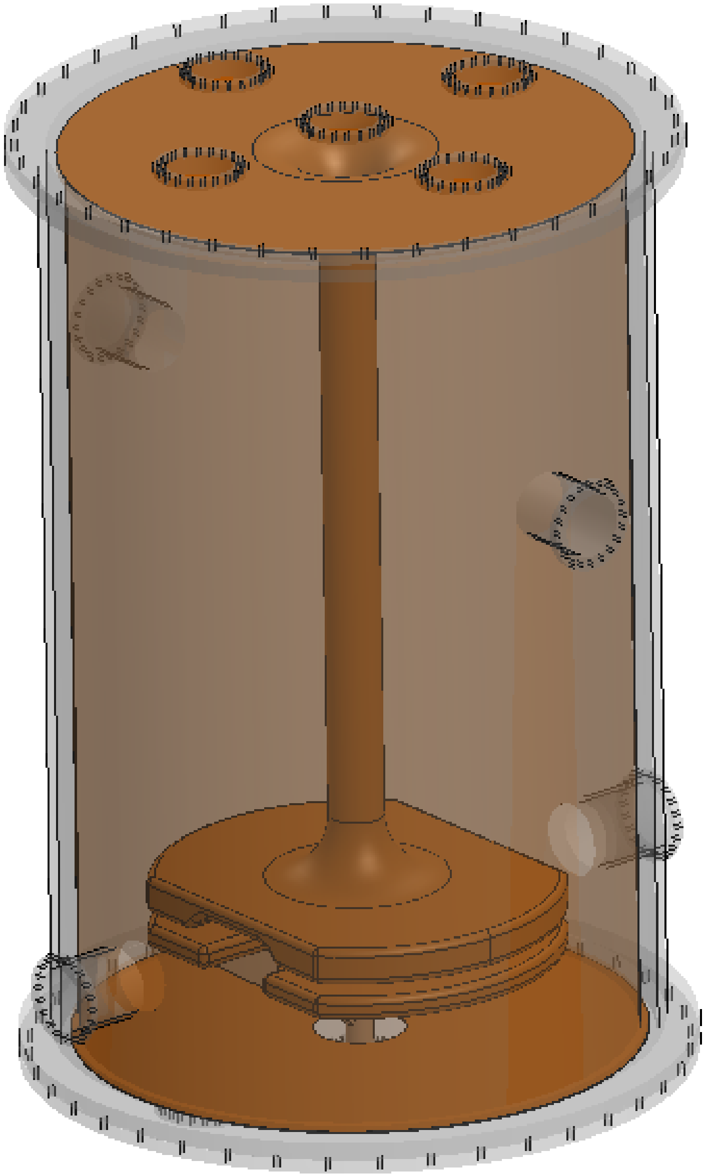


RF-Kicker

Frequency range (MHz)	**14,5 - 20**
Peak voltage (KV)	**120**
GAP (mm)	**70**
Width of electrode (mm)	**120 min**
Length of electrodes (mm)	**700**
Cylinder diameter (mm)	**1200 max**
Stem diameter (mm)	**120 max**
Length of coaxial line from beam axis (mm)	**1830**
RF power (Watts)	**10 000**
Reactance Q	**8 500**



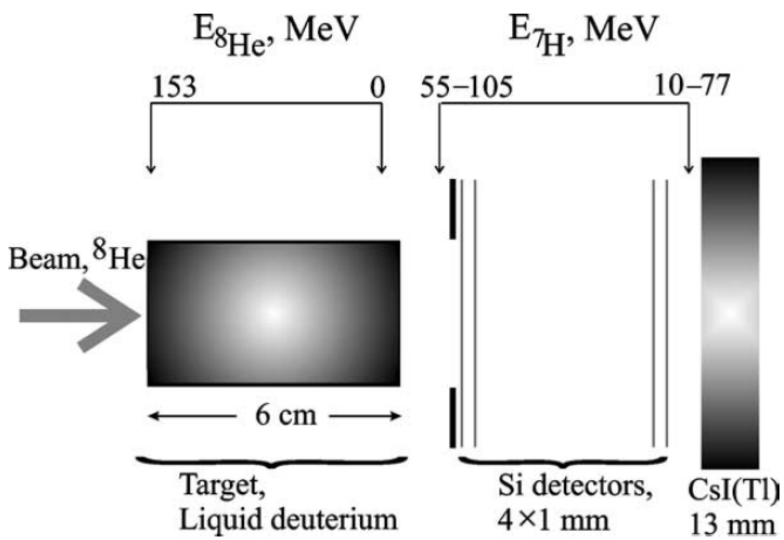
Experiments @ ACCULINNA&ACCULINNA-2

More details about proposed reactions at ACCULINNA-2
G. Kamiński talk, Thursday R3 : 16:05

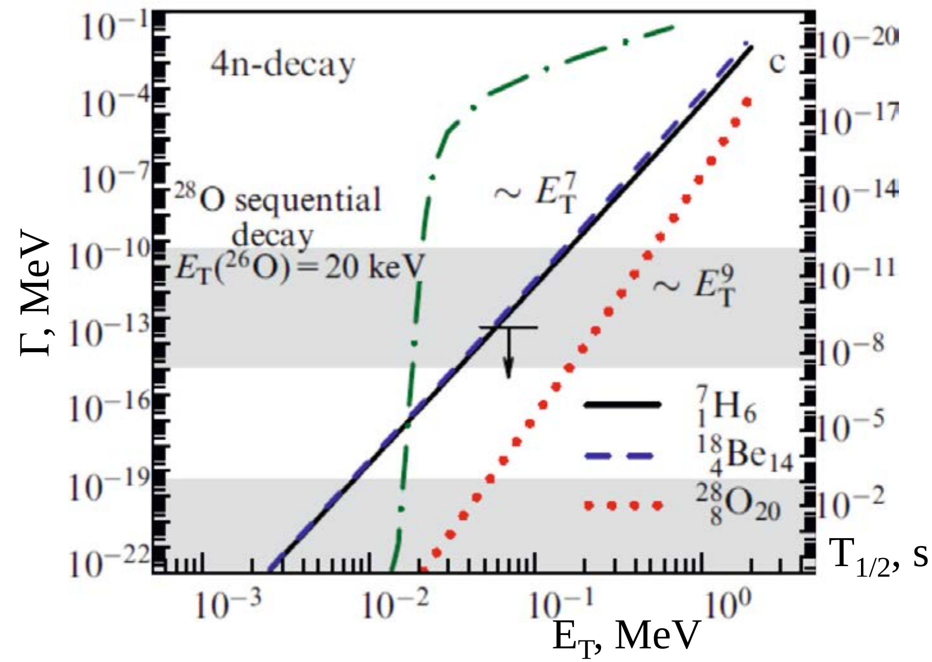
^{7}H: experiments to be done at ACCULINNA-2

M.S. Golovkov et al., Phys. Lett. B **588**, 163 (2004)

Limit $T_{1/2}$ < 1 ns was set for the ^{7}H lifetime, which allowed the authors to estimate a lower limit of 50–100 keV for the ^{7}H energy above the ^{3}H + 4n breakup threshold.



L. V. Grigorenko et al., Phys. Rev. C **84**, 021303(R) (2011).



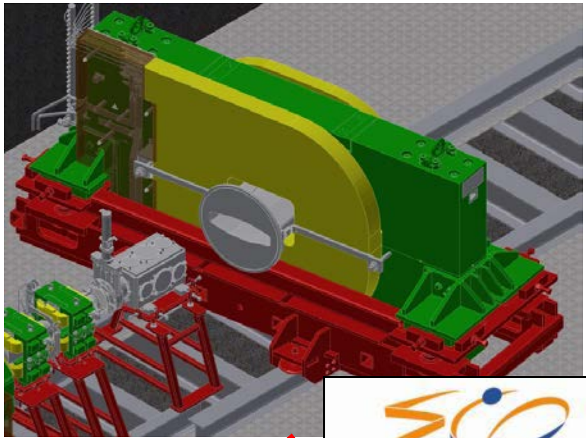
	^{8}He(^{2}H, ^{3}He)^{7}H	^{11}Li(^{2}H, ^{6}Li)^{7}H
	Missing mass spectrum	
Counts in 0^{+} state	2×10^{2} $d\sigma/d\Omega \sim 10$ μb/sr	3×10^{3} $d\sigma/d\Omega \sim 10$ μb/sr
Resolution	400 keV	200 keV

Exciting option is to try the ^{8}He + ^{3}H reaction.
The 4n transfer can be searched for down to a limit of $d\sigma/d\Omega \sim 10$ nb/sr.
The 2n transfer and triton transfer channels, as well as elastic scattering, will be accessible for study.

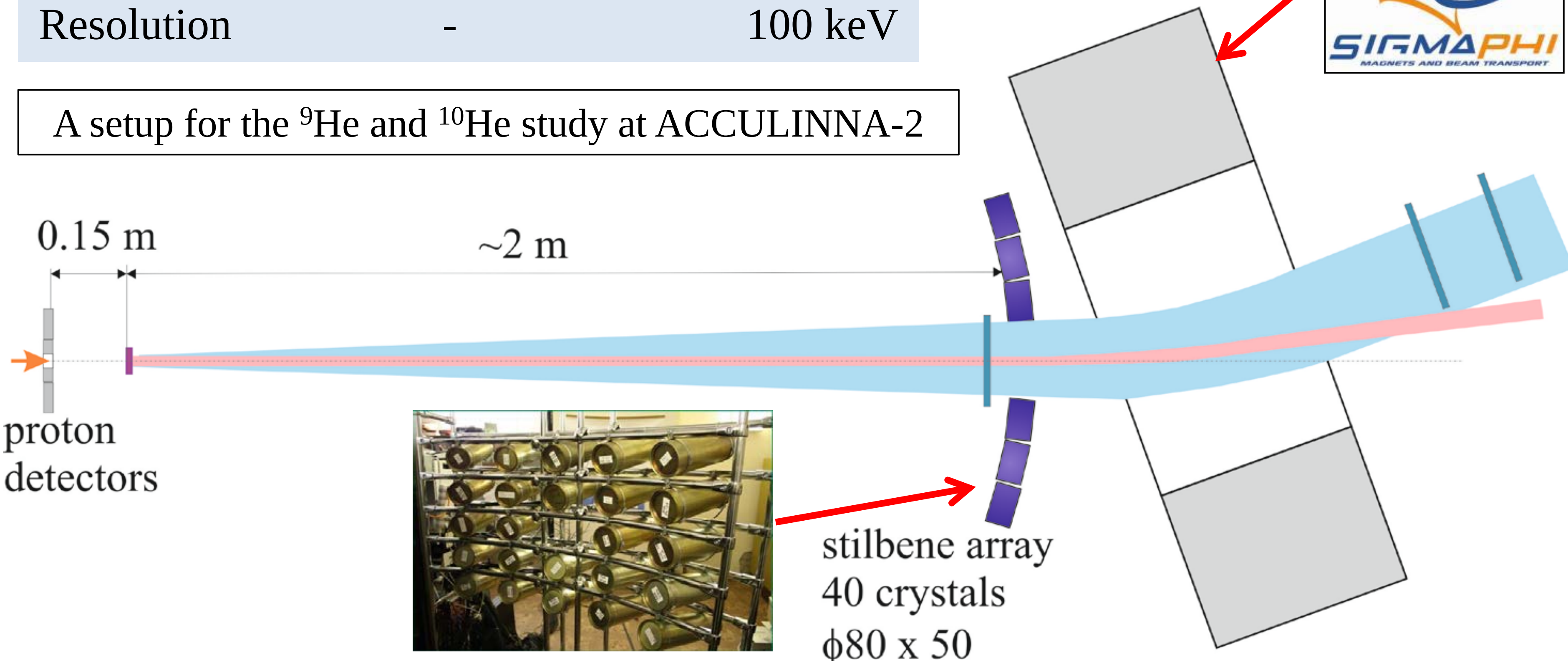
ACCULINNA-2 ^{9}He from the ^{8}He(^{2}H,p)^{9}He reaction

	ACCULINNA	ACCULINNA-2
Missing mass		
Counts	900	10^5
Resolution	800 keV	300 keV
θ_{8He}	12^o	0.3^o
Combined mass		
Counts	–	3×10^4
Resolution	-	100 keV

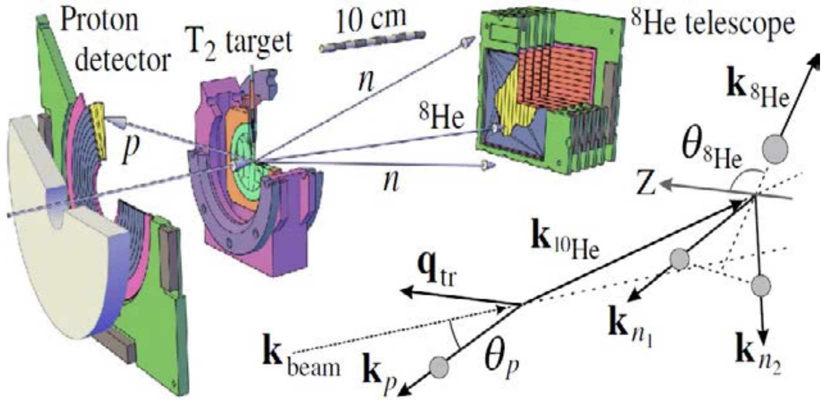
Zero degree spectrometer



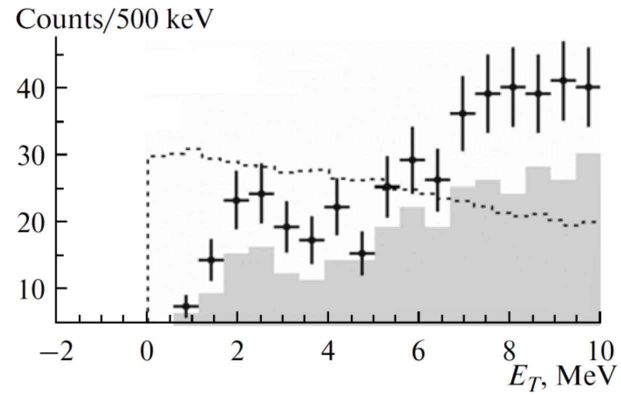
A setup for the ^{9}He and ^{10}He study at ACCULINNA-2



^{10}He: prospects assumed for ACCULINNA-2



S. I. Sidorchuk et al., Phys. Rev. Lett. **108**, 201502 (2012)



^{10}He missing mass spectrum. Points with error bars correspond to the total data array; the grey histogram was obtained for $\varepsilon < 5$. The dashed histogram describes the behavior of the detection efficiency for 8He-p coincidences

^{10}He from ^{8}He(^{3}H,p)^{10}He

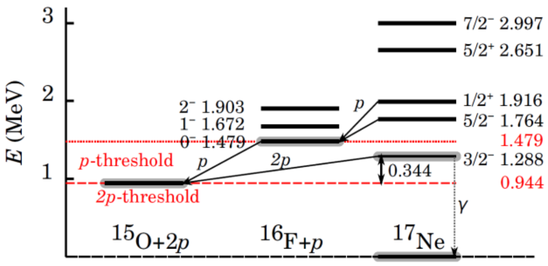
	ACCULINNA	ACCULINNA-2
<u>Missing mass spectrum</u>		
Count number in 0^+ state	~120	2 x 10^4
Resolution	500 keV	200 keV
Resolution in θ_{8He}	12^o	0.3^o
<u>Correlation analysis for the tripple (p-^{8}He-n) events</u>		
Counts (E_T = 0–10 MeV)	–	3 x 10^5

Other reactions

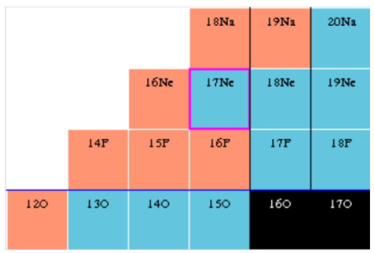
	^{11}Li(^{2}H, ^{3}He)^{10}He	**^{14}Be(^{2}H, ^{6}Li)^{10}He**
<u>Missing mass spectrum</u>		
Counts in 0^+ state	2 x 10^3	3 x 10^3
Resolution	400 keV	200 keV

^{17}Ne

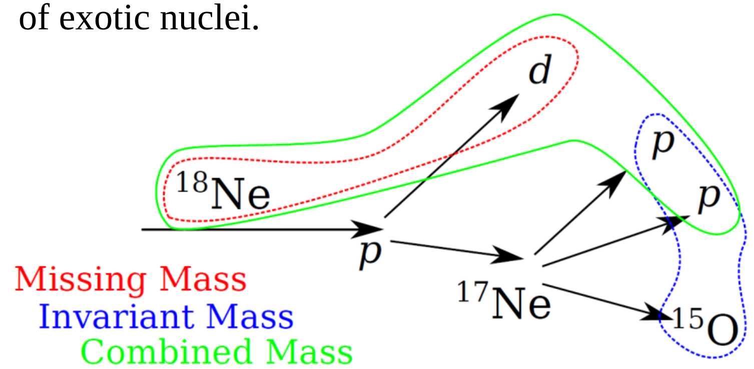
Nuclear structure



Nuclear astrophysics



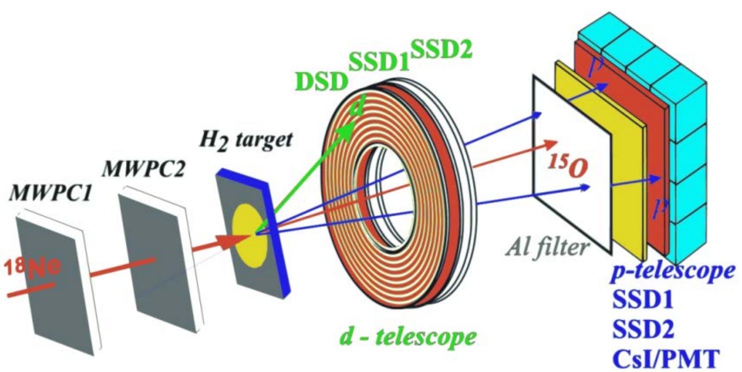
Combined mass approach to the study of decay modes of exotic nuclei.



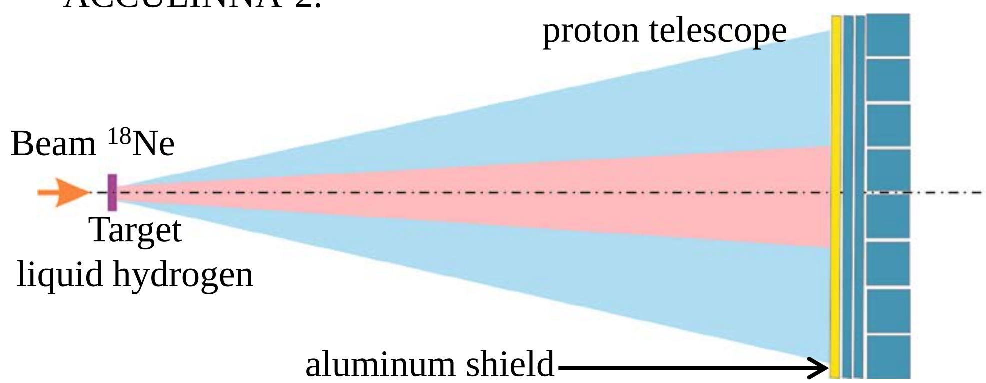
- ^{17}Ne is *2p-halo* candidate
- ^{17}Ne is only one known nuclear system, which excited state can decay through direct 2*p* emission.
- 2*p* radiative capture is a possible by-pass of the ^{15}O waiting point in the astrophysical rp-process

Combined mass spectrum of ^{17}Ne measured by the Acculinna provided a limit $\Gamma_{2p}/\Gamma_{\gamma} < 8 * 10^{-5}$ [**P. Sharov et al., talk given at EXON2016**].

Our task is to come to a level of $\Gamma_{2p}/\Gamma_{\gamma} \sim (2\text{-}3) * 10^{-6}$ in a priority experiment which will be carried out at ACCULINNA-2.



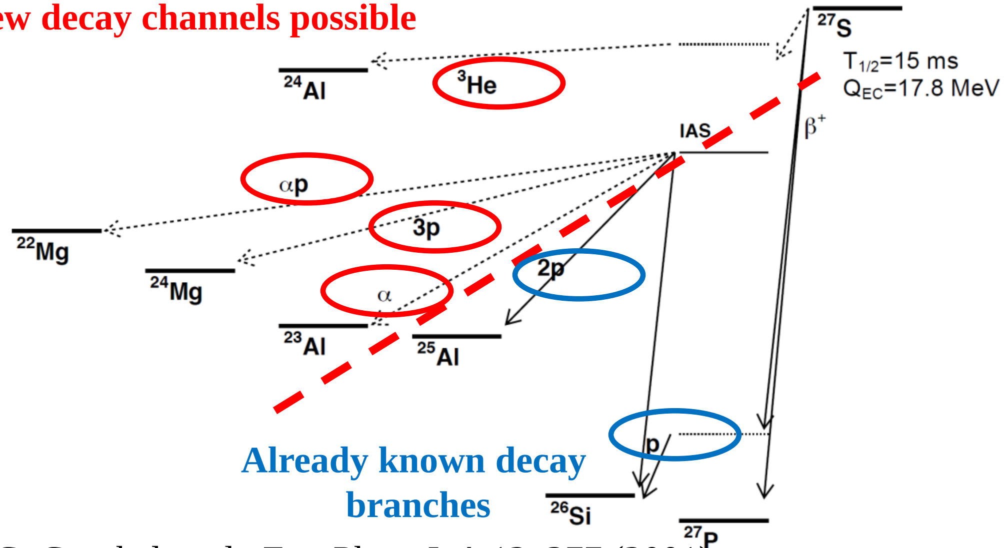
Experimental setup.



$\Gamma_{2p}/\Gamma_{\gamma}$ ratio measurment

β - delayed particle emission (example: ^{27}S)

New decay channels possible



Already known decay branches

G. Canchel et al., Eur. Phys. J. A 12, 377 (2001).

$T_{1/2}(^{27}S)$ = 15.5 ms; P(βp) = 2.3 ± 0.9%; P(β2p) = 1.1 ±0.5%

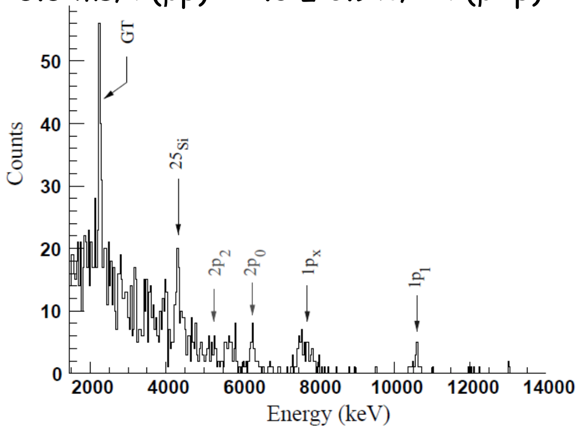
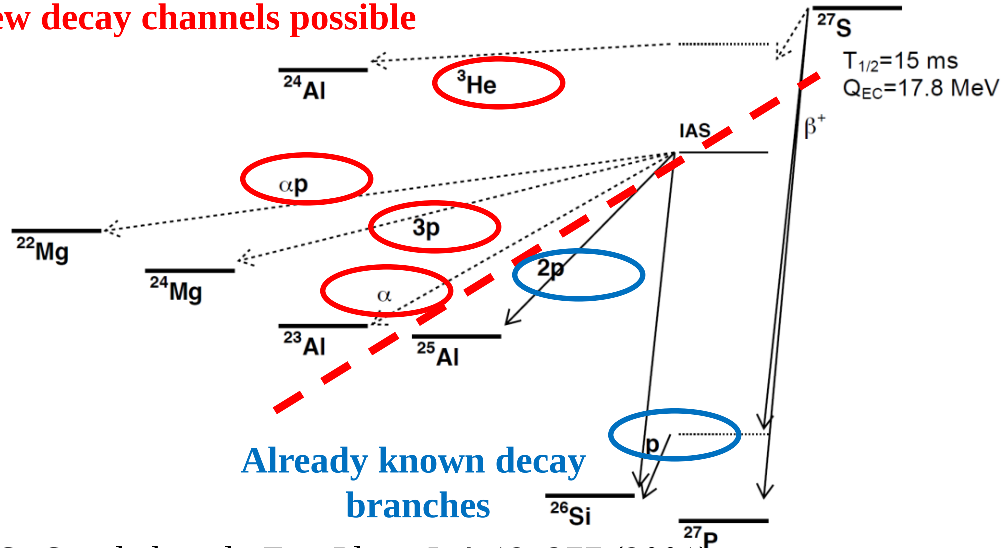


Fig. Charged-particle spectrum of the decay of ^{27}S nuclei implanted in the E3 silicon detector. Proton groups above about 7 MeV have to be reconstructed by summing the energy signals from detectors E3 and E4.

β - delayed particle emission (example: ^{27}S)

New decay channels possible



G. Canchel et al., Eur. Phys. J. A 12, 377 (2001).

$T_{1/2}(^{27}S)$ = 15.5 ms; $P(\beta p) = 2.3 \pm 0.9\%$; $P(\beta 2p) = 1.1 \pm 0.5\%$

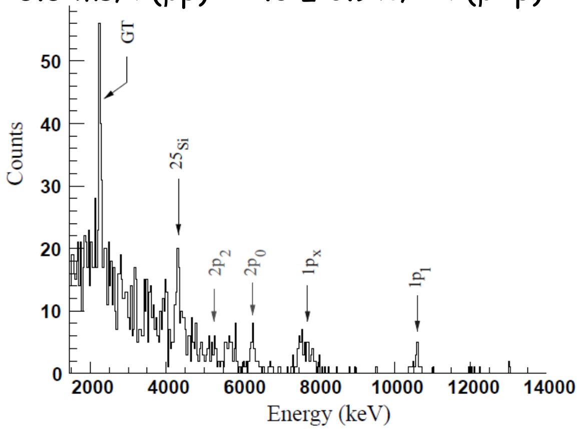
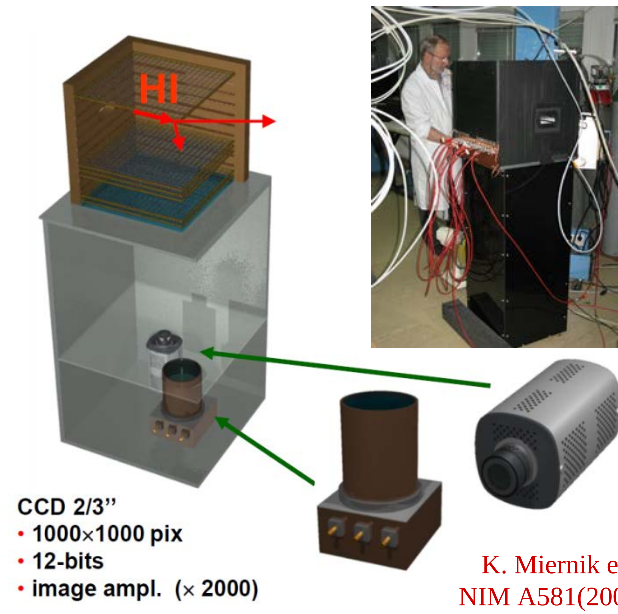


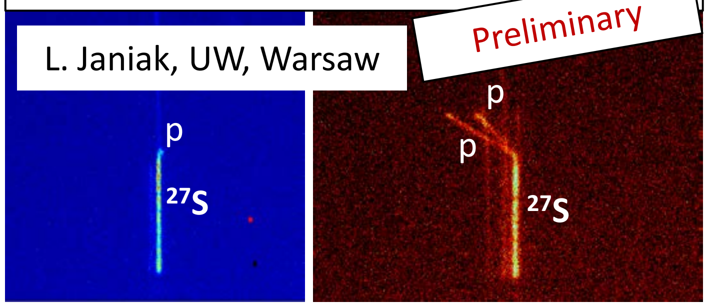
Fig. Charged-particle spectrum of the decay of ^{27}S nuclei implanted in the E3 silicon detector. Proton groups above about 7 MeV have to be reconstructed by summing the energy signals from detectors E3 and E4.

Specific equipment development: Warsaw Optical Time Projection Chamber (OTPC)



K. Miernik et al., NIM A581(2007)194

No events with 3p emission observed (low statistics), but new results (new branching) for low energy (~300 keV) protons are expected.



In 2017 a new measurment of β - delayed particle emission from ^{27}S @ ACCULINNA-2 is planned
→ much better statistic of two order of magnitude expected = **hunting for 3*p* decay**

Conclusions

- Glorious history of light exotic nuclei studies at JINR
- World-class current research program light exotic nuclei
- Specific energy range – intermediate energy direct transfer reactions
- Specific techniques + theory school –(few-body) correlation studies
- Clear plans for the nearest years:
- ACCULINNA-2 – beam test this year
- Instrumentation development + accelerator upgrade = user facility

We plane to extend our studies on more exotic species

THANK YOU FOR ATTENTION!