NUSTAR Annual Meeting 2019
February 25 - March 01
Helmholtzzentrum für Schwerionenforschung,
Darmstadt, Germany

Status of the Factory of Superheavy Elements
Cyclotron DC280, Separators, Day-01 Experiments

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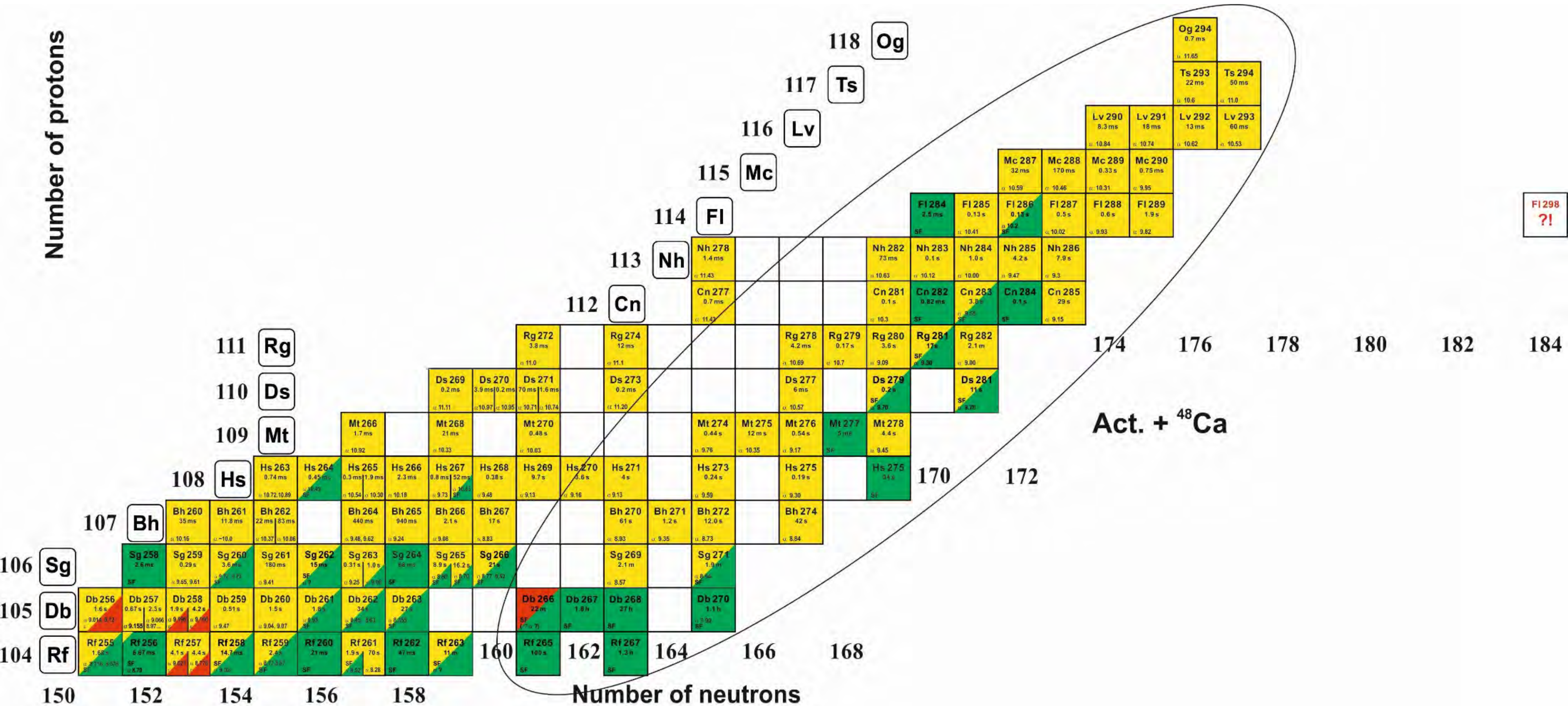
Chart of the heaviest nuclides



That we have learned:

- SHE do exist!
- SHE can be synthesized in fusion reactions;
- Chemistry of SHE can be studied;
- We have only 12,000 hours beam time / year;
- We need new facilities;
- We have not enough experimental space;
- We can not accelerate ions heavier than Xe;
- Radiation safety requirements are stronger.

What is beyond 118 element?

Heaviest target: $^{251}Cf \rightarrow Z_{max} = 118$

$\downarrow$

Heavier projectiles (^{50}Ti, ^{54}Cr, ^{58}Fe, ^{64}Ni)

Sufficient increasing of overall experiment efficiency is needed!

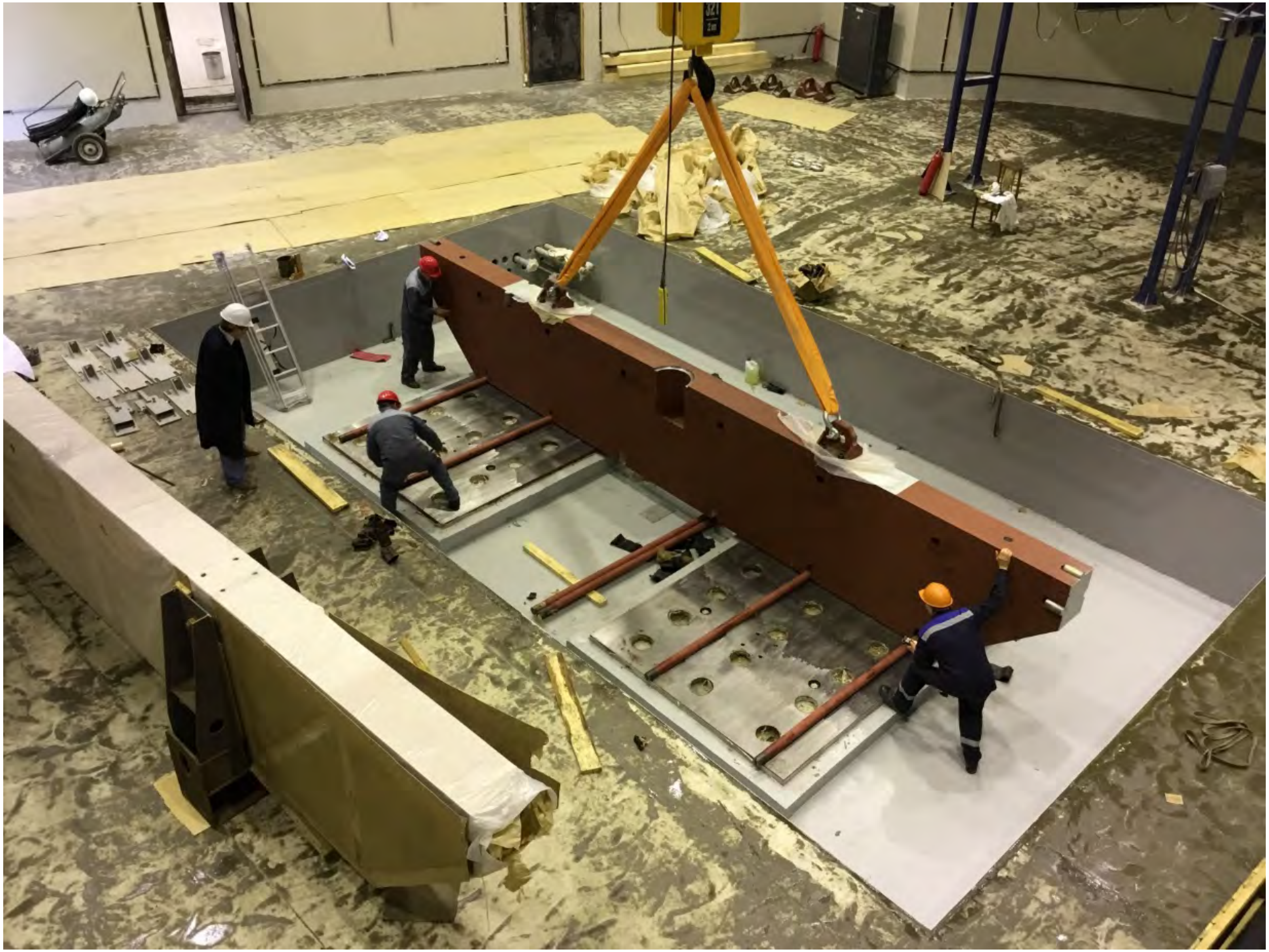
Total optimization!

Superheavy element factory – the goals

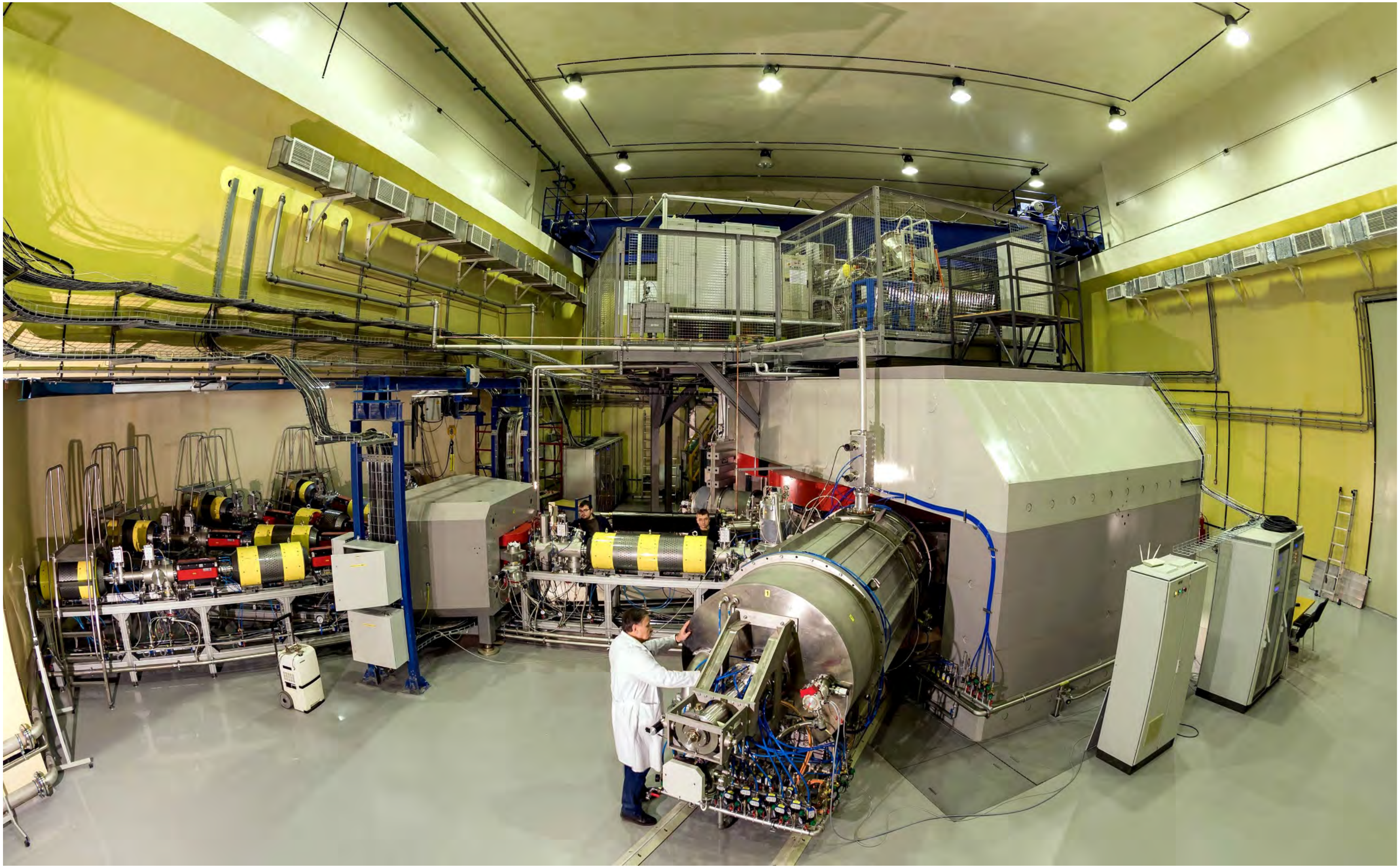
- **Synthesis and study of properties of superheavy isotopes**
- **Chemistry of new elements**
- **Studies of fusion and multi-nucleon transfer reactions**
- **Mass-spectrometry and nuclear spectroscopy of SH nuclei**
- **Laser spectroscopy of heavy atoms.**

2012 -2018 ≈ 60 M$

Start of assembling of the DC280's magnet
15.09.2016, 14:35



Stand-alone SHE factory with DC-280 cyclotron



DC-280
Main Parameters

Ion sources	Permanent magnet ECR DECRIS-PM - 14 GHz
Injection energy	Up to 80 keV/Z
A/Z range	4÷7.5
Energy	4÷8 MeV/n
Magnetic field level	0.6÷1.3 T
K factor	280
Magnet weight	1000 t
Magnet power	300 kW
Dee voltage	2x130 kV
RF power consumption	2x30 kW
Flat-top dee voltage	2x14 kV
Deflector voltage	Up to 90 kV

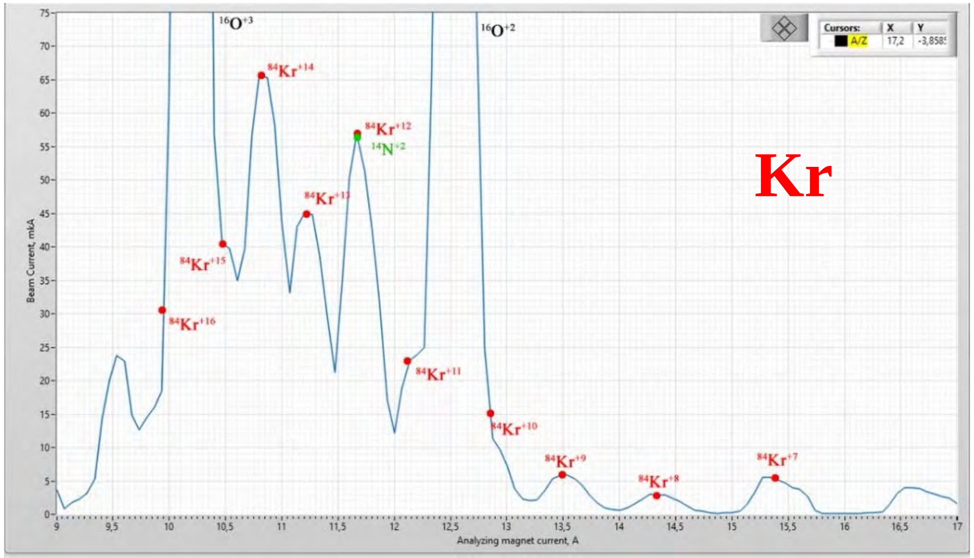
Tests of DECRIS-PM at the HV platform of DC-280

Ions for DC-280 tests

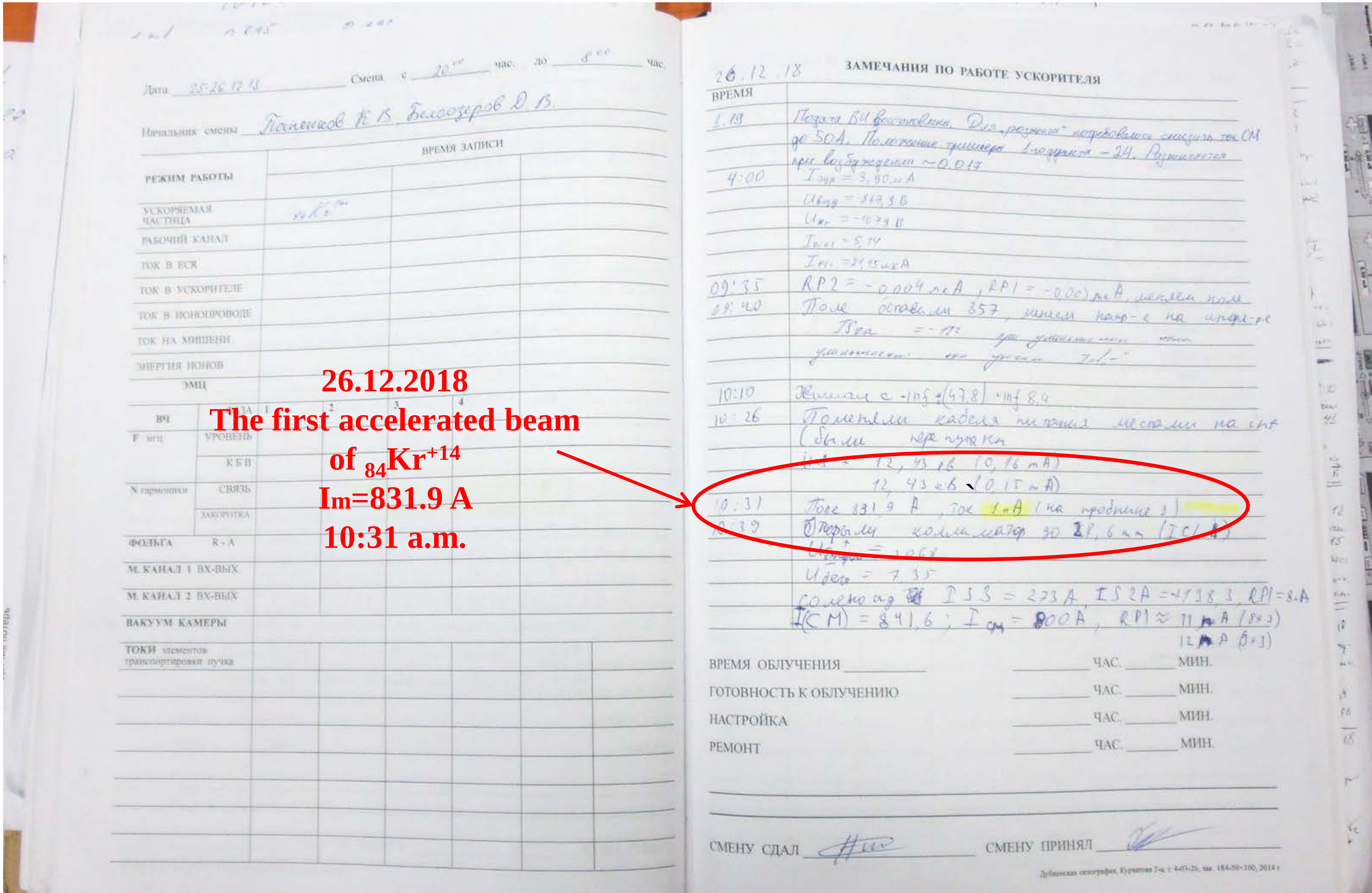
$_{40}Ar^{+7}$, A/Z=5.71
I max=190 μA

$_{40}Ar^{+8}$, A/Z=5
I max=290 μA

$_{84}Kr^{+14}$, A/Z=6
I max=65 μA

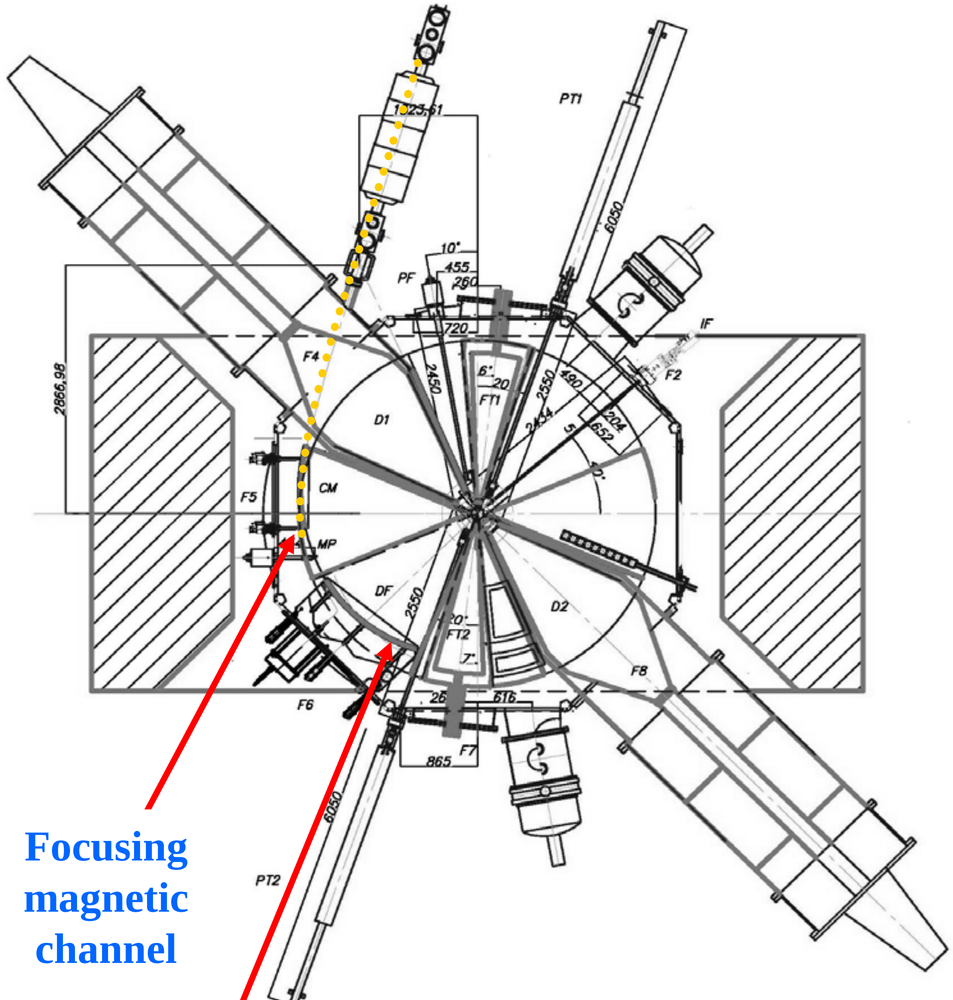


The first ion beam accelerated in DC-280



Current at radius of 1700 mm was up to 4 μA at injection current of 31 μA
Beam was not extracted due to problems with deflector

Beam extraction system



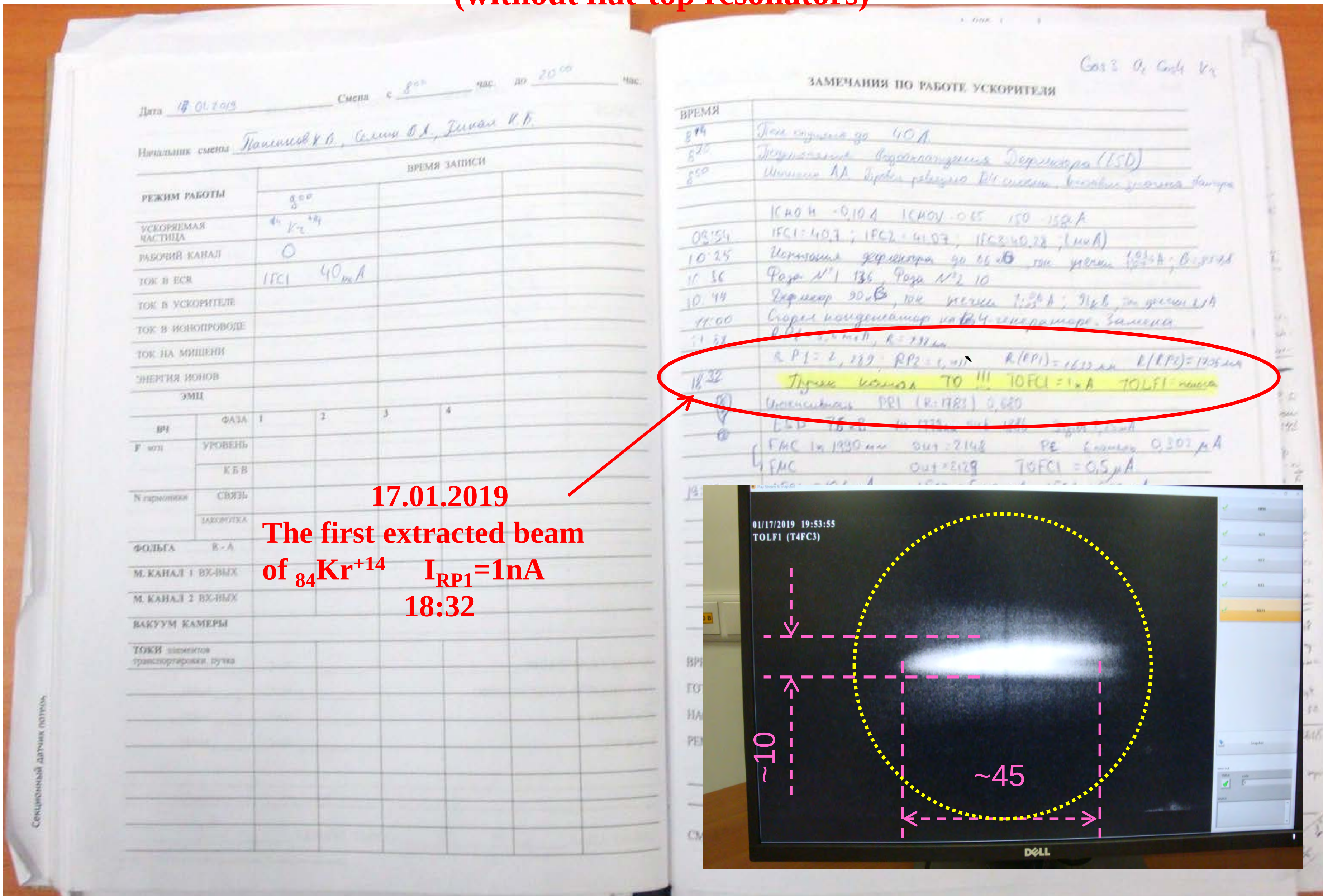
Focusing magnetic channel

Electrostatic deflector

Extraction radius of
R_{ext}=1.79 m
U_d=75.55 kV

The first ion beam extracted from DC-280

(without flat-top resonators)



Future plans

- **Carrying out radiation measurements with participation of FMBA representatives.**
- **Installation of flat-top resonators, installation of regular inflector, improving of vacuum conditions.**
- **Acceleration of $_{48}Ca^{+8,+9}$ $_{50}Ti^{+8,+9}$. Increasing of ion beam intensity, transportation of ion beams to the GFS-2.**

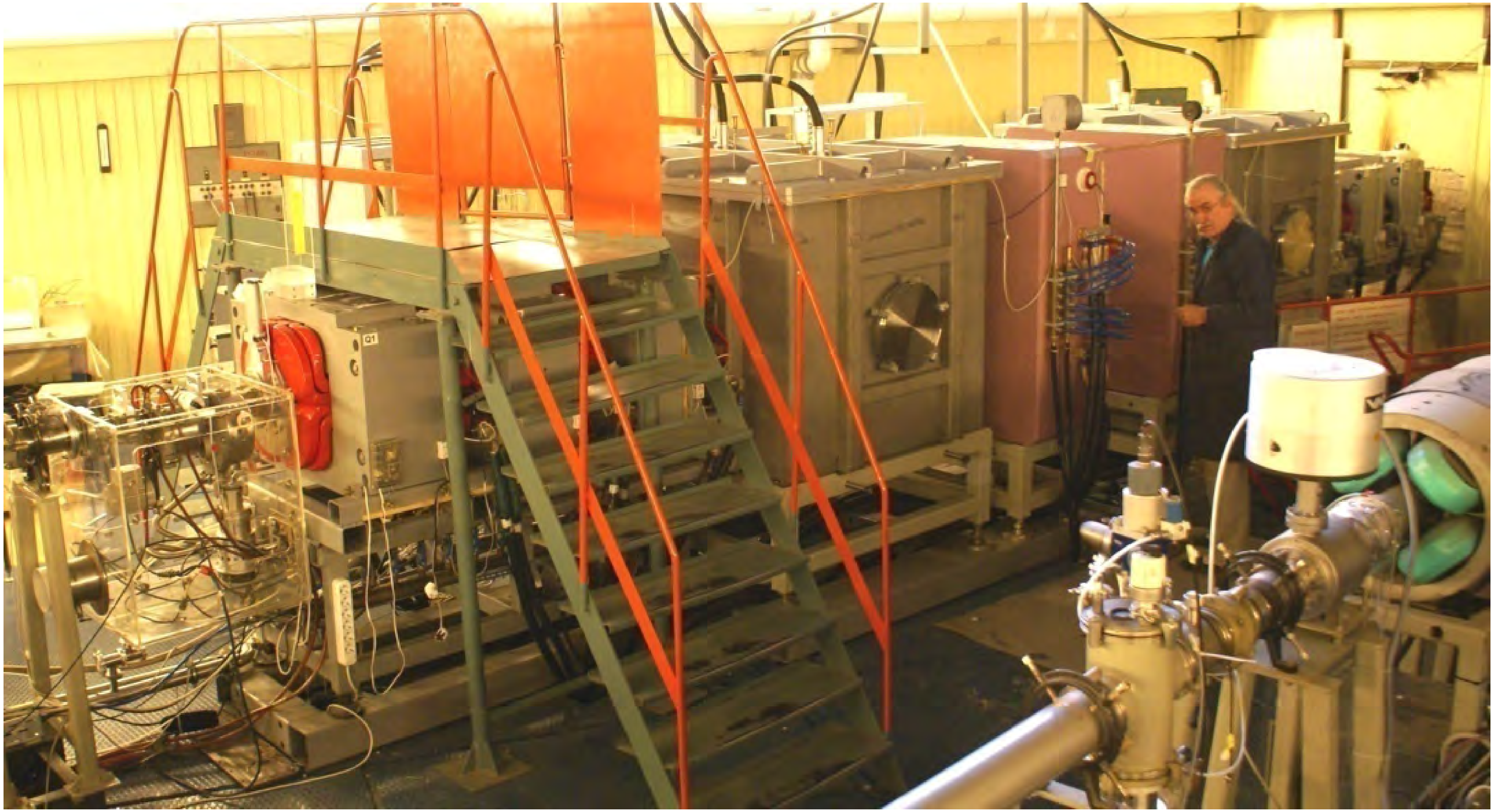
Proposed Separators:

- **Velocity selector,**
- **Gas-filled separator QDQQD,**
- **Gas-filled pre-separator.**

Air-free separator:

- **complete fusion reactions;**
- **multi-nucleon transfer reactions;**
- **nuclear spectroscopy @ target & focal plane.**

SHELS + GABRIELA

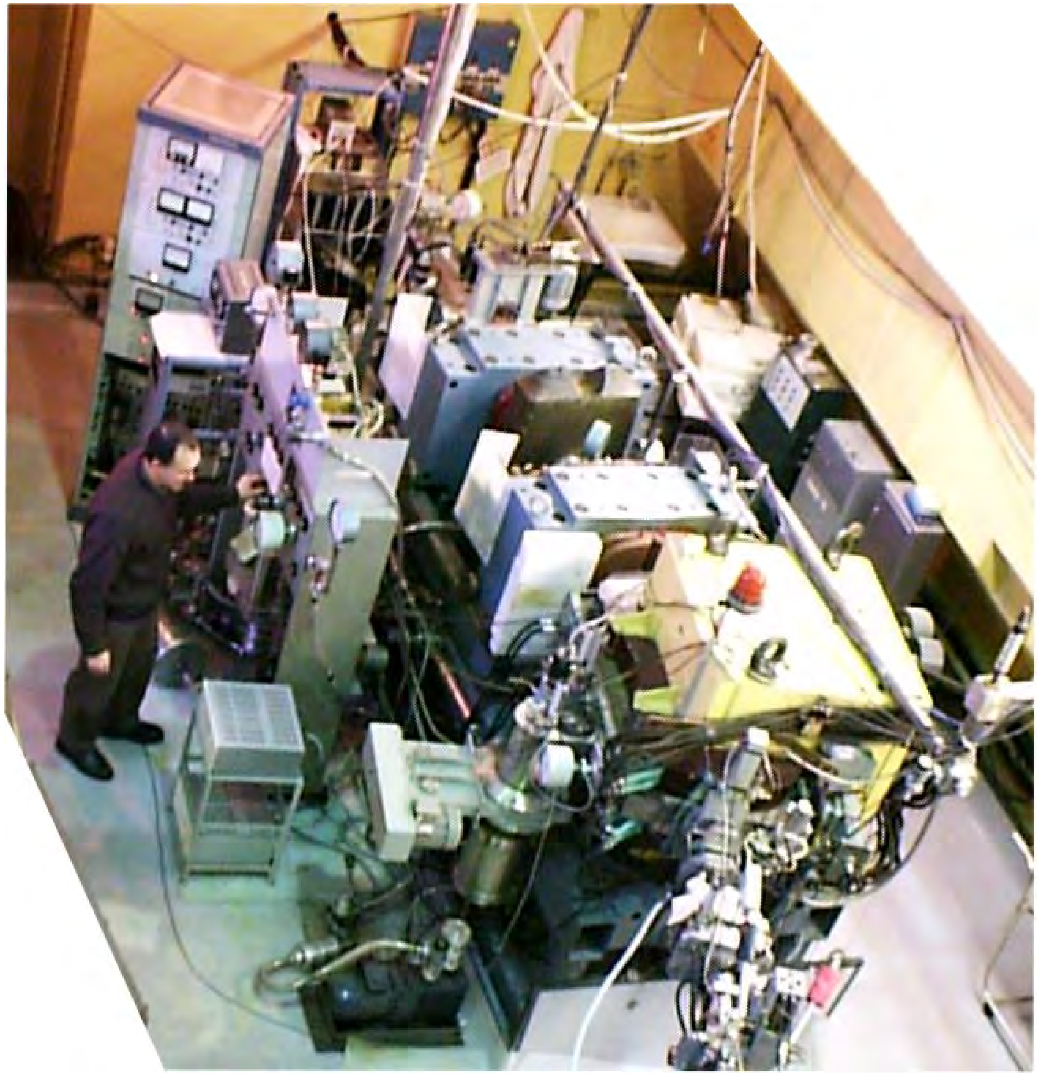


Running @ U400

Gas-filled separator

Synthesis of SHE in complete fusion reactions

Dubna Gas Filled Recoil Separator GFS-1



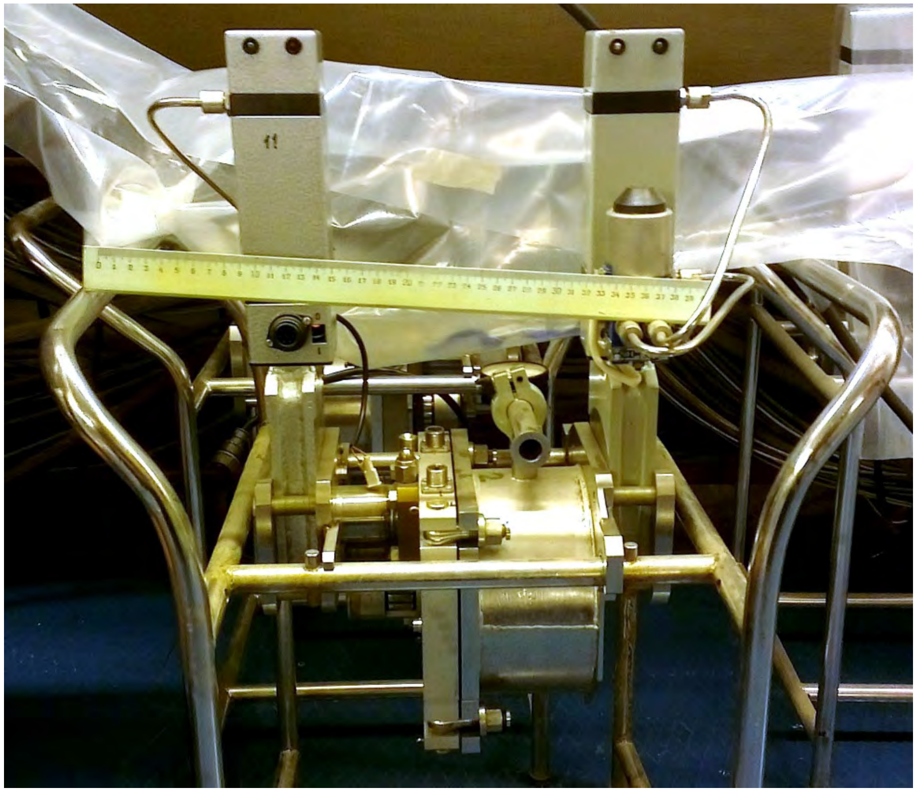
In operation since 1989,
Ist JINR price 1990 in instrumentation

Gas-filled separator GFS-II

Assembled on 12.06.2018

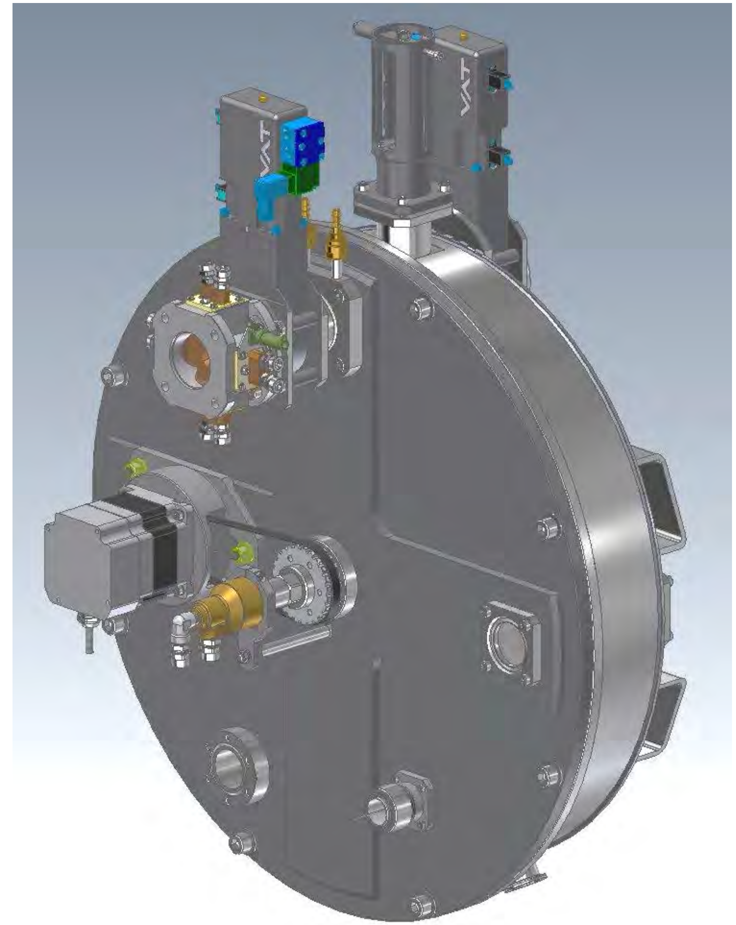
Target block design

Old



- **Ø = 120, 1500 r.p.m. synchronous**
- **Beam wobbler or scanner,**
- **Segmented beam diafragm**
- **Is in use at GFS, SHELS, MASHA**

New!



- **Ø = 480, 1500 r.p.m. synchronous,**
- **e-beam & optical diagnostic,**
- **water cooling**

Focal plane detectors

Detectors & Data Taking Systems
under testing

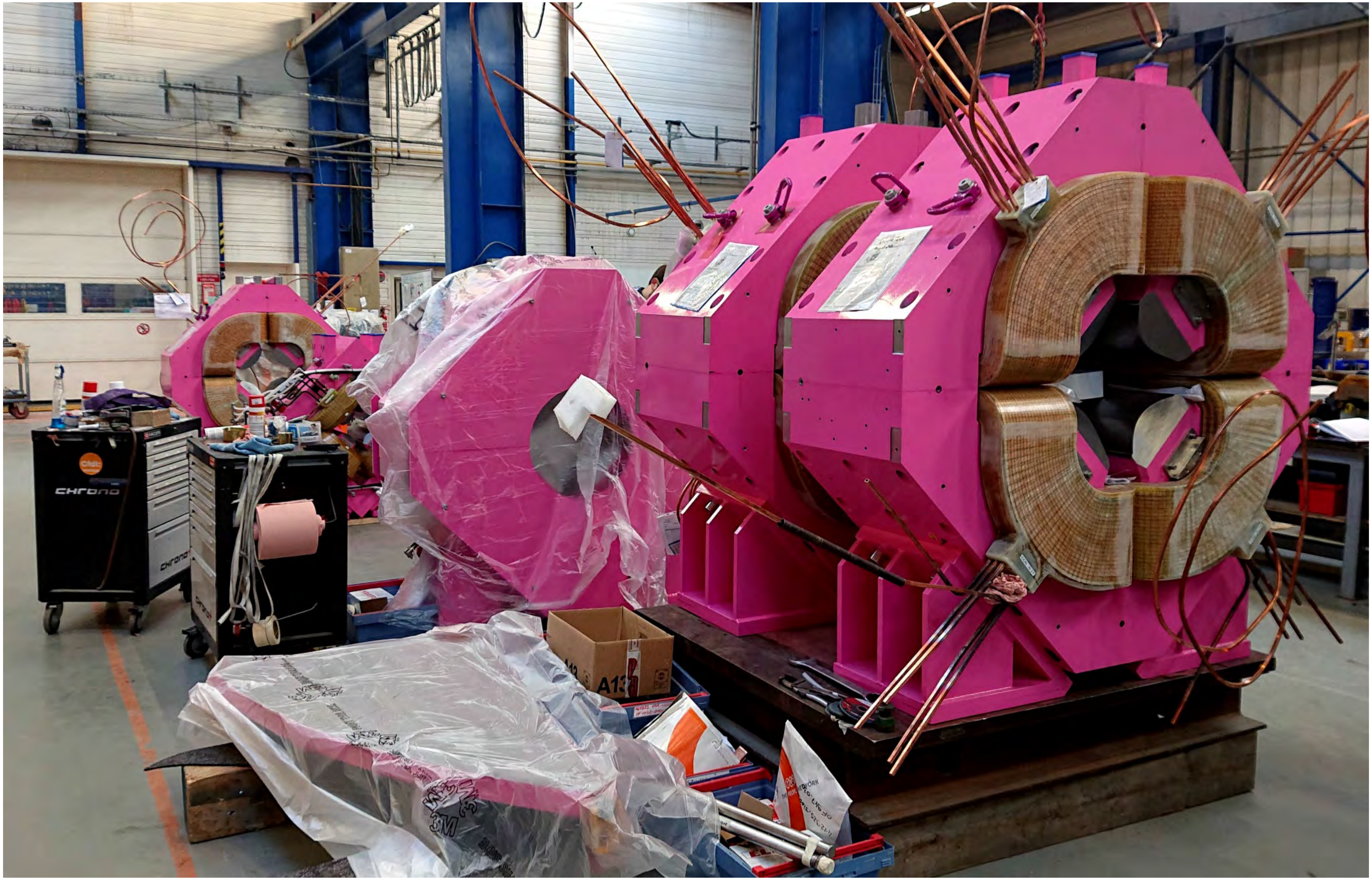
48 × 128 strips
6144 pixels

New, digital
data taking system

Preseparator & gas-catcher, RS-chamber:

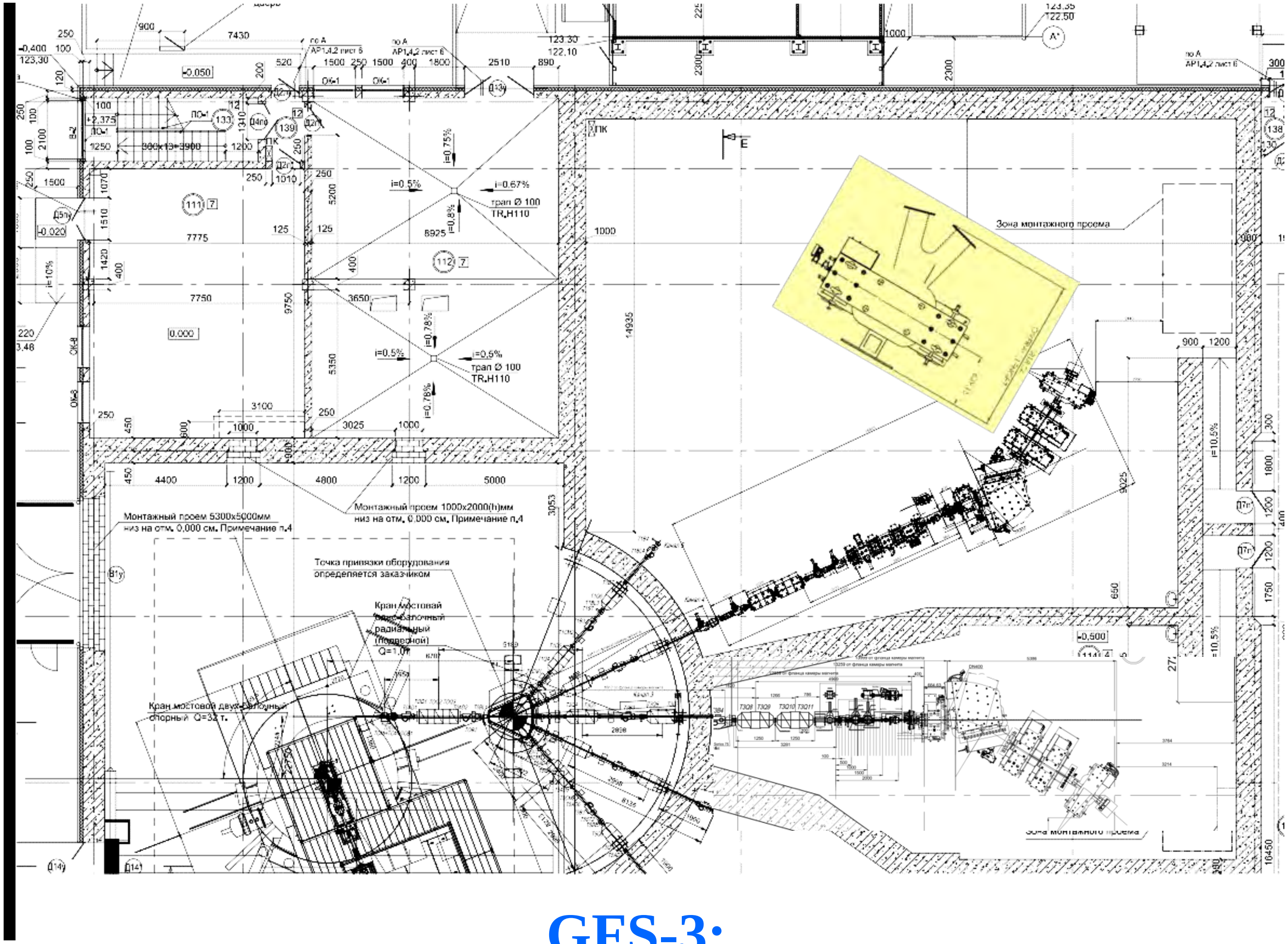
- **chemistry;**
- **fusion and multi-nucleon transfer reactions;**
- **mass-spectrometry and nuclear spectroscopy;**
- **laser spectroscopy of heavy atoms.**

Gas-filled pre-separator GFS-3
(at the ΣΦ's site)



17 December 2018

Gas-filled separators GFS-2 & GFS-3 @ DC280



GFS-3:
installation – Mai 2019
launching - 2020

Tests

Test reactions:

$^{nat}Yb+^{40}Ar \rightarrow Ra$,
$^{nat}Yb+^{48}Ca \rightarrow Th$,
$^{170}Er+^{50}Ti \rightarrow Th$,
$^{206,208}Pb+^{48}Ca \rightarrow No$

- Adjustment of optical elements
- Transmission
- Image size on detector
- Dispersion
- Background
- Optimal gas pressure
- Yield vs. target thickness
- Target stability vs. beam intensity and dose
- Systematics of charge states
- Test of digital and analog data acquisition systems

Targets

- material availability
- radiation safety

Target isotopes

Isotope	Enrichment %	Isotope	Enrichment %
^{232}Th	100	^{244}Pu	98.6
^{233}U	-	^{243}Am	99.9
^{238}U	99.3	^{245}Cm	98.7
^{237}Np	99.3	^{248}Cm	97.4
^{239}Pu	-	^{249}Bk	>95
^{240}Pu	99.8	^{249}Cf	97.3
^{242}Pu	99.98	^{251}Cf	36

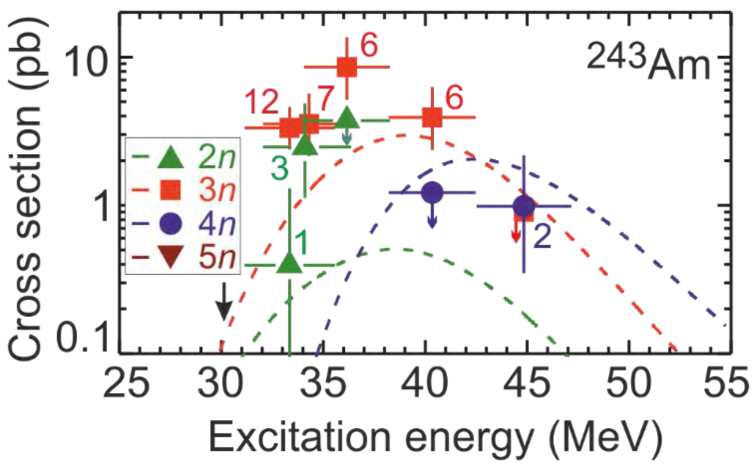
Isotope separators are necessary !

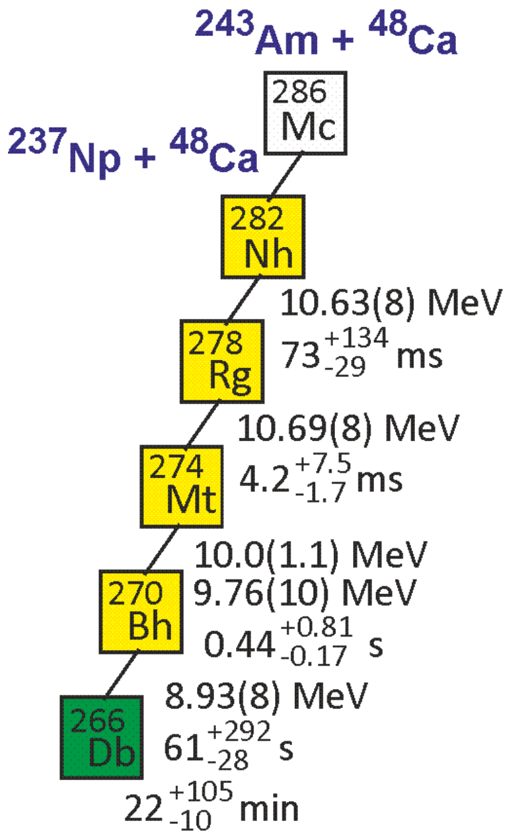
First experiments at SHE Factory
$^{243}Am+^{48}Ca$ test reaction

Excitation function for the 2*n*-evaporation channel
- **Observation of a decay of ^{281}Rg**

Excitation function for the 3*n*-evaporation channel
- **Two decay times of ^{276}Mt**
- **Level of cross section for the p*xn* channel**
- **Level of EC branch for ^{288}Mc and ^{284}Nh**

5*n*-evaporation channel: new isotope ^{286}Mc & descendants

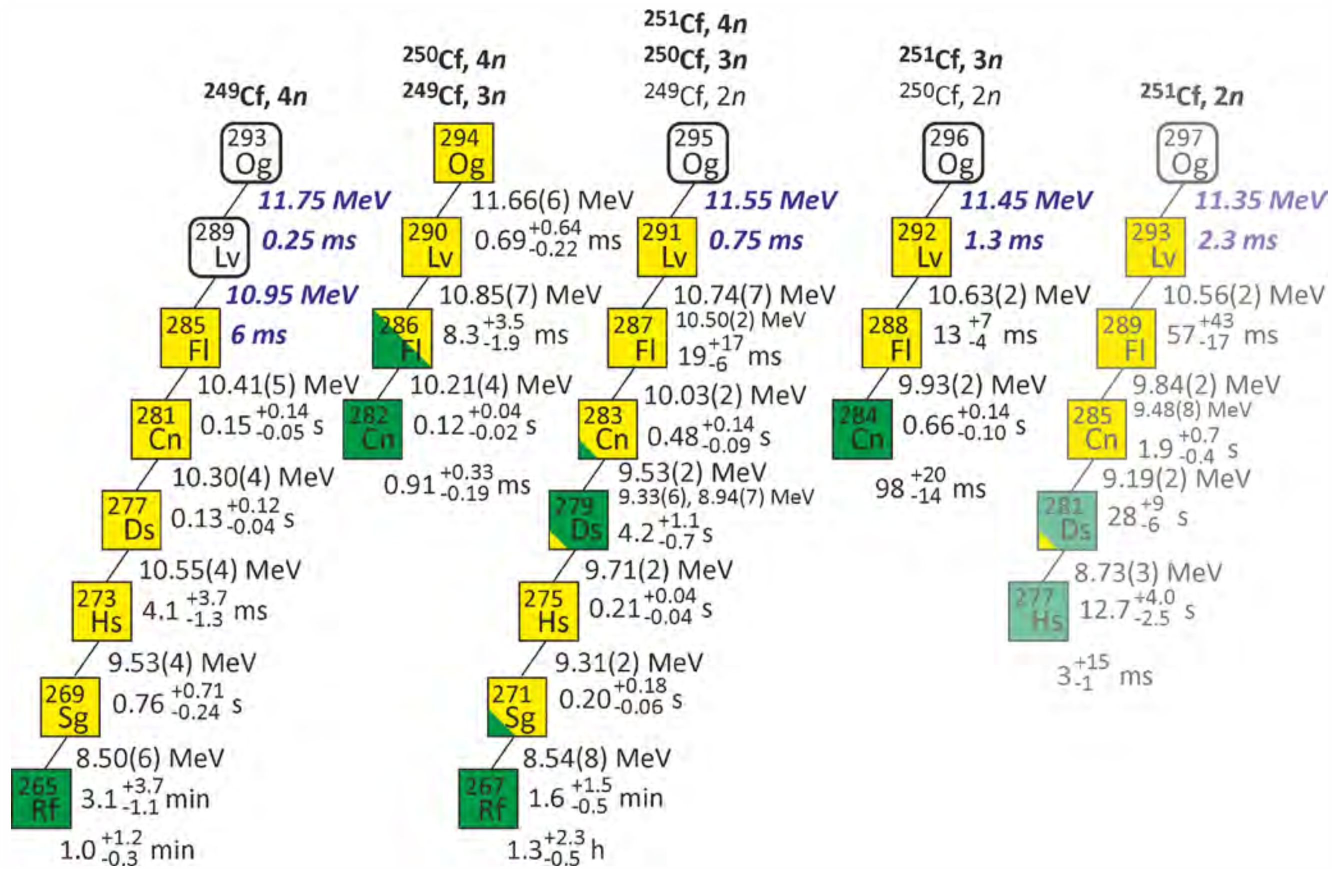




Experiments

First experiments at SHE Factory
$^{249-251}Cf+^{48}Ca$ – synthesis of the heaviest Og isotopes

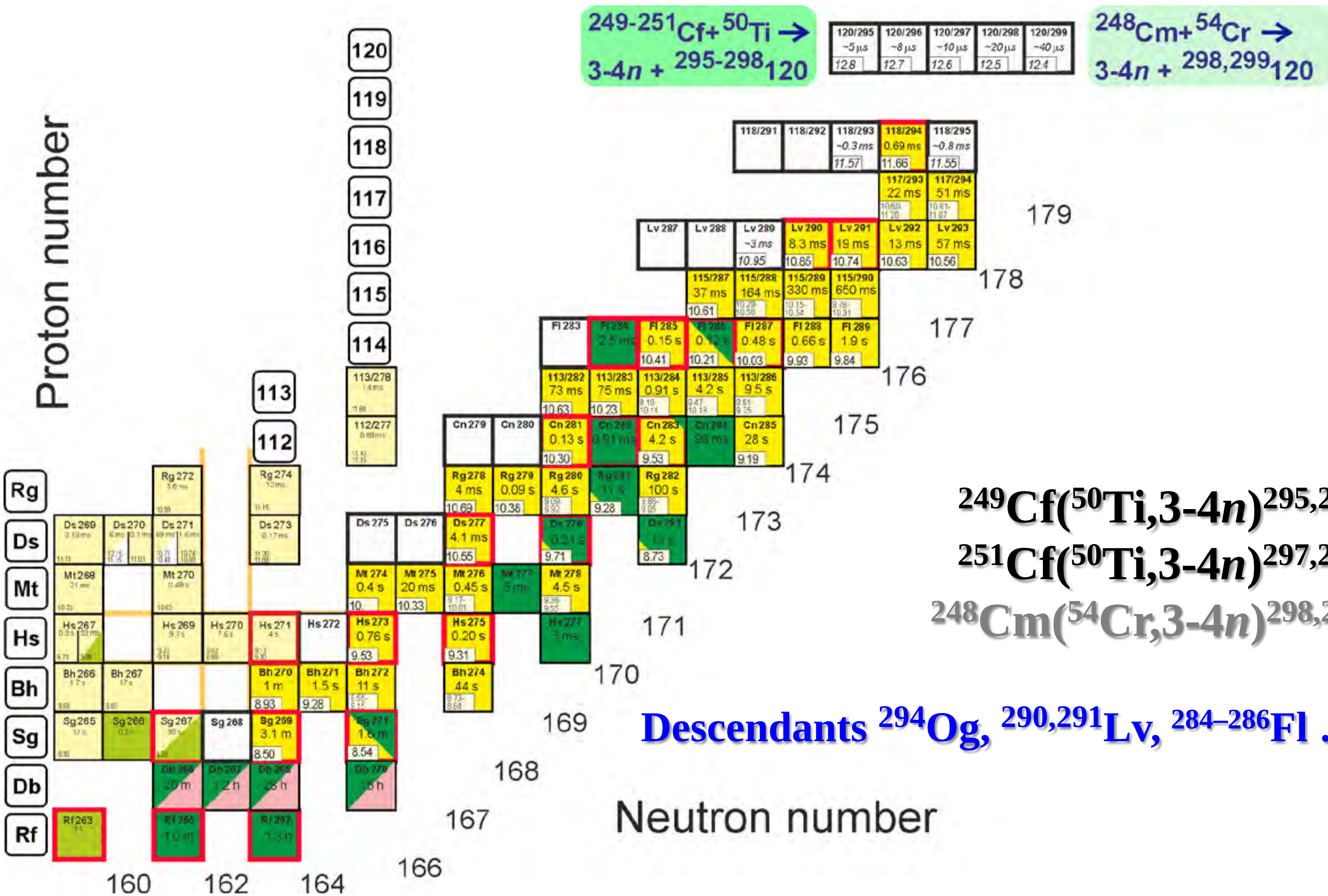
Expected decay properties of Og isotopes



New $^{249-251}$Cf target is under preparation at ORNL

V. Utyonkov

First experiments at SHE Factory
Synthesis of new element 120



$^{249}Cf(^{50}Ti,3\text{-}4n)^{295,296}120$

$^{251}Cf(^{50}Ti,3\text{-}4n)^{297,298}120$

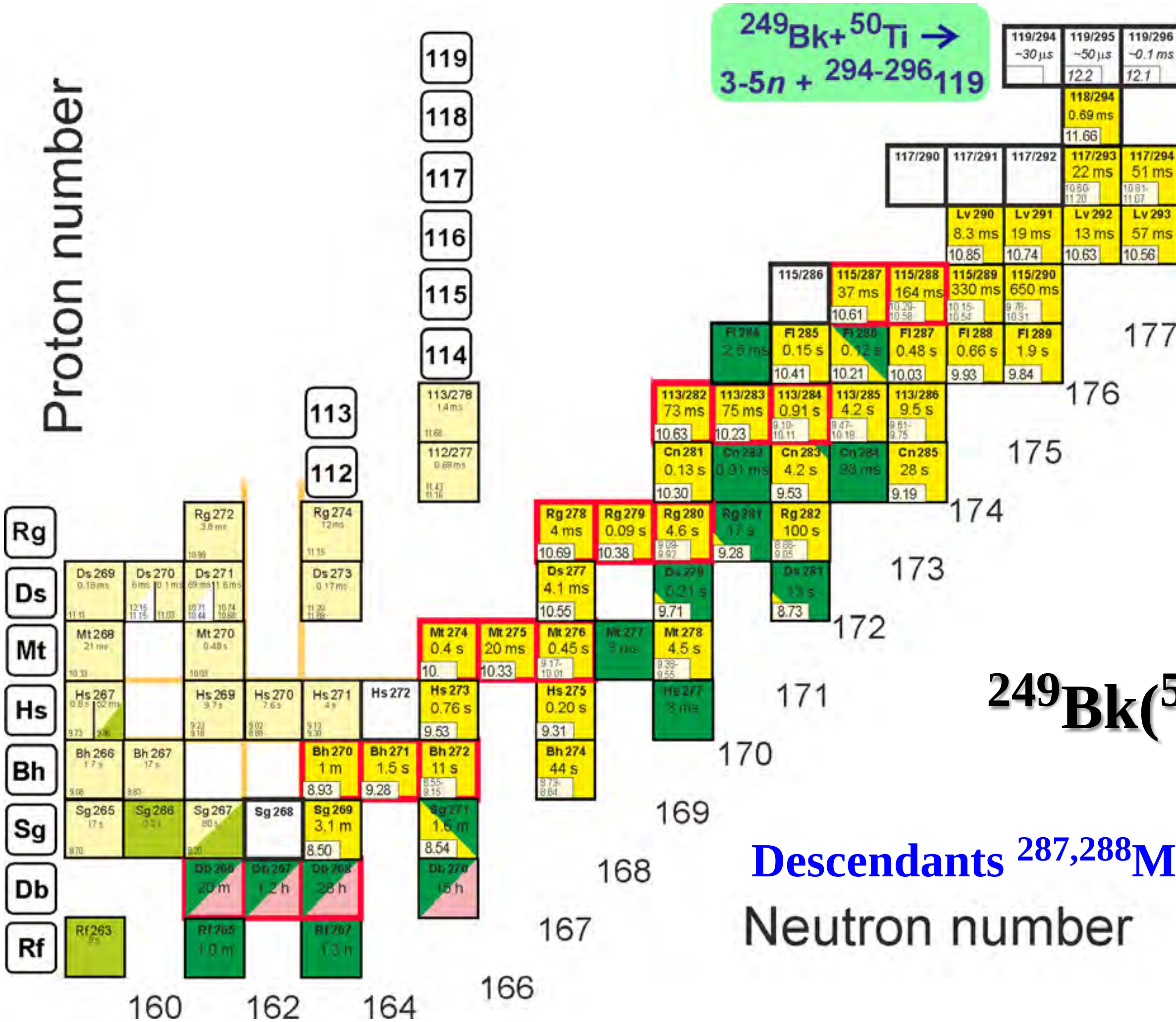
$^{248}Cm(^{54}Cr,3\text{-}4n)^{298,299}120$

Descendants ^{294}Og, $^{290,291}Lv$, $^{284-286}Fl$ … are known

V. Utyonkov

First experiments at SHE Factory

Synthesis of new element 119



$^{249}Bk(^{50}Ti,3\text{-}4n)^{295,296}119$

Descendants $^{287,288}Mc$, $^{282\text{-}294}Nh$… are known

V. Utyonkov

FLEROV LABORATORY of NUCLEAR REACTIONS

Conclusion

- **The realization of the SHE-factory project will provide the quantitative increase of the efficiency of experiments as a whole by at least one order of magnitude.**

SHE factory, DC280 hall, 26.06.2014

SHE-Factory building, January 2019