ECOS 2012 ,Loveno di Menaggio,
18-21 June 2012

Expansion of SHE studies at Flerov Laboratory

S. DMITRIEV

Flerov Laboratory of Nuclear Reactions,
Joint Institute for Nuclear Research

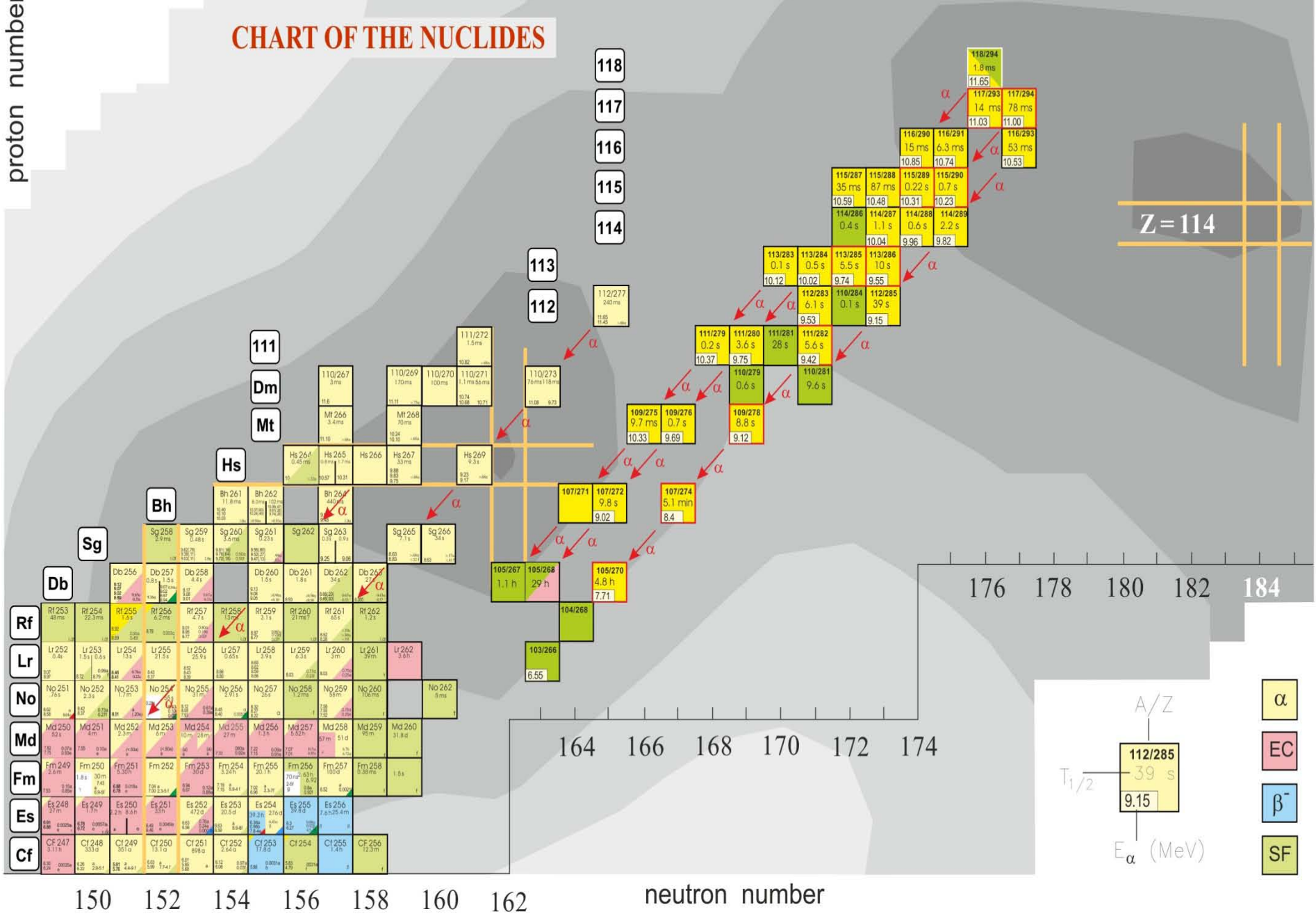
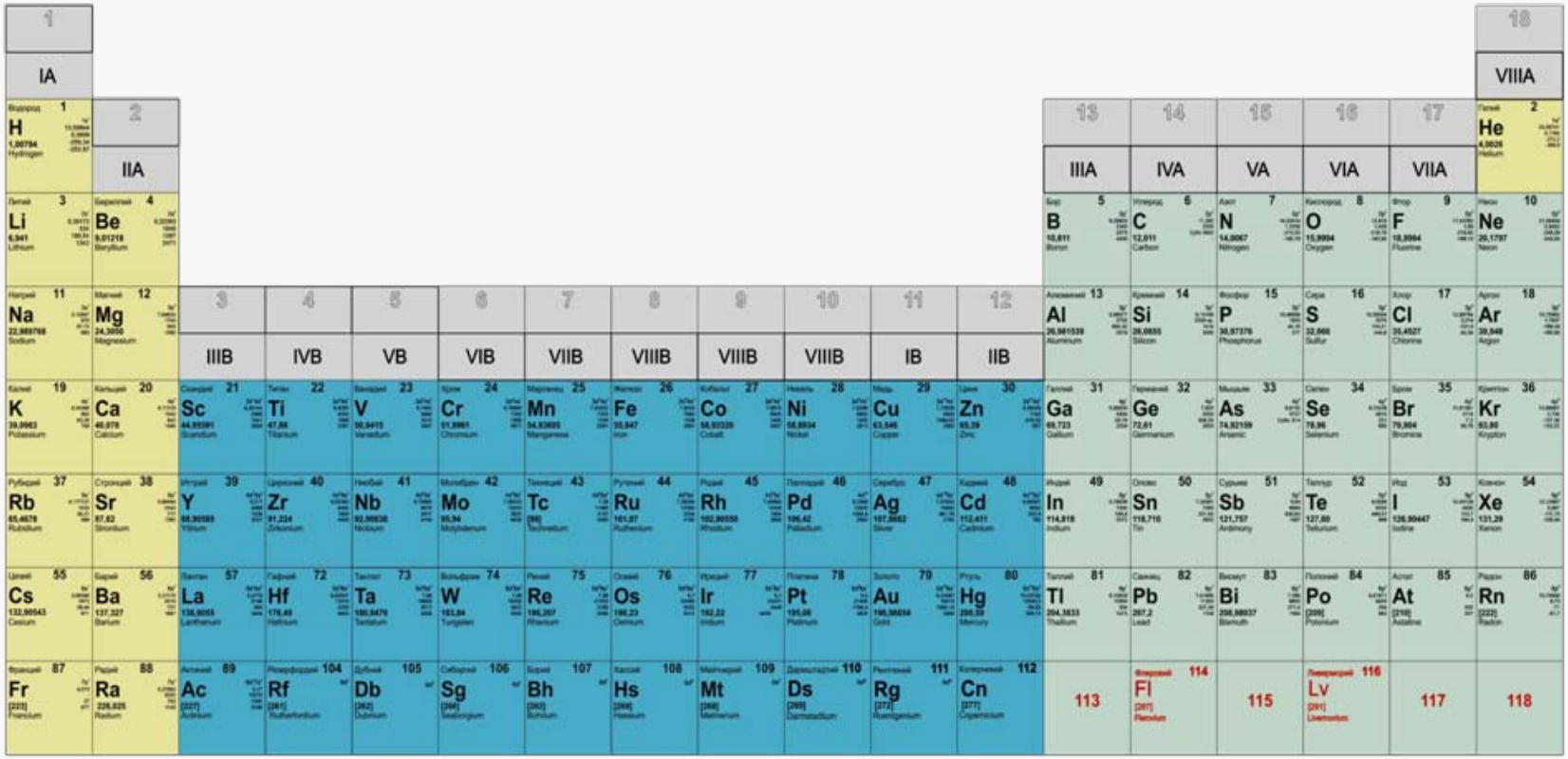
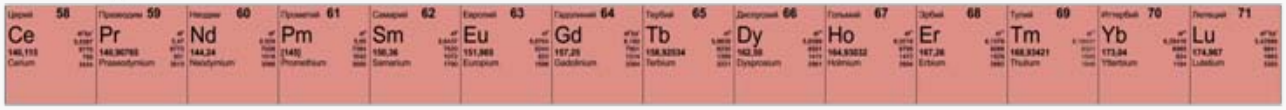


CHART OF THE NUCLIDES
proton number
neutron number
Z = 114
118
117
116
115
114
113
112
111
Dm
Mt
Hs
Bh
Sg
Db
Rf
Lr
No
Md
Fm
Es
Cf
150 152 154 156 158 160 162
164 166 168 170 172 174
176 178 180 182 184
118/294 1.8 ms 11.65
117/293 14 ms 11.03
117/294 78 ms 11.00
116/290 15 ms 10.85
116/291 6.3 ms 10.74
116/293 53 ms 10.53
115/287 35 ms 10.59
115/288 87 ms 10.48
115/289 0.22 s 10.31
115/290 0.7 s 10.23
114/286 0.4 s
114/287 1.1 s 10.04
114/288 0.6 s 9.96
114/289 2.2 s 9.82
113/283 0.1 s 10.12
113/284 0.5 s 10.02
113/285 5.5 s 9.74
113/286 10 s 9.55
112/283 6.1 s 9.53
110/284 0.1 s
112/285 39 s 9.15
112/277 240 ms 11.65 11.46
111/279 0.2 s 10.37
111/280 3.6 s 9.75
111/281 28 s
111/282 5.6 s 9.42
110/281 9.6 s
110/279 0.6 s
109/278 8.8 s 9.12
109/275 9.7 ms 10.33
109/276 0.7 s 9.69
107/271
107/272 9.8 s 9.02
107/274 5.1 min 8.4
105/267 1.1 h
105/268 29 h
105/270 4.8 h 7.71
104/268
103/266 6.55
111/272 1.5 ms
110/267 3 ms
110/269 170 ms
110/270 100 ms
110/271 1.1 ms 56 ms
110/273 76 ms 118 ms
Mt 266 3.4 ms
Mt 268 70 ms
Hs 264 0.45 ms
Hs 265 0.8 ms 1.7 ms
Hs 266
Hs 267 33 ms
Hs 269 9.3 s
Bh 261 11.8 ms
Bh 262 8.0 ms 102 ms
Bh 264 440 ms
Sg 258 2.9 ms
Sg 259 0.48 s
Sg 260 3.6 ms
Sg 261 0.23 s
Sg 262
Sg 263 0.9 s
Sg 265 7.1 s
Sg 266 34 s
Db 256
Db 257 0.8 s 1.5 s
Db 258 4.4 s
Db 260 1.5 s
Db 261 1.8 s
Db 262 34 s
Db 264 27 s
Rf 253 48 ms
Rf 254 22.3 ms
Rf 255 1.6 s
Rf 256 6.2 ms
Rf 257 4.7 s
Rf 258 13 ms
Rf 259 3.1 s
Rf 260 21 ms?
Rf 261 65 s
Rf 262 1.2 s
Lr 252 0.4 s
Lr 253 1.5 s 0.6 s
Lr 254 13 s
Lr 255 21.5 s
Lr 256 25.9 s
Lr 257 0.65 s
Lr 258 3.9 s
Lr 259 6.3 s
Lr 260 3 m
Lr 261 39 m
Lr 262 3.6 h
No 251 .76 s
No 252 2.3 s
No 253 1.7 m
No 254
No 255 31 m
No 256 2.91 s
No 257 25 s
No 258 1.2 ms
No 259 58 m
No 260 106 ms
No 262 5 ms
Md 250 52 s
Md 251 4 m
Md 252 2.3 m
Md 253 6 m
Md 254 10 m 28 m
Md 255 27 m
Md 256 1.3 h
Md 257 5.52 h
Md 258 57 m 51 d
Md 259 95 m
Md 260 31.8 d
Fm 249 2.6 m
Fm 250 1.8 s 30 m 7.43
Fm 251 5.30 h
Fm 252
Fm 253 30 d
Fm 254 3.24 h
Fm 255 20.1 h
Fm 256 70 m 63 h 6.92
Fm 257 100 d
Fm 258 0.38 ms
Es 248 27 m
Es 249 1.7 h
Es 250 2.2 h 8.6 h
Es 251 33 h
Es 252 472 d
Es 253 20.5 d
Es 254 39.3 h 276 d
Es 255 39.8 d
Es 256 7.6 h 25.4 m
CF 247 3.11 h
Cf 248 333 d
Cf 249 351 a
Cf 250 13.1 a
Cf 251 898 a
Cf 252 2.64 a
Cf 253 17.8 d
Cf 254
Cf 255 1.4 h
CF 256 12.3 m
α
A/Z
112/285
39 s
9.15
T1/2
Eα (MeV)
α
EC
β-
SF

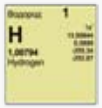
Mendeleev Periodic Table of the Elements



Лантаноиды Lanthanides



Актиноиды Actinides



H - символ
1,00794 -атомный номер
$1s^1$ -электронная конфигурация
13,59844 - 1-й потенциал ионизации, эВ
0,0899 - плотность кг/м^3
-259,34 - температура плавления,°С
-252,87- температура кипения,°С

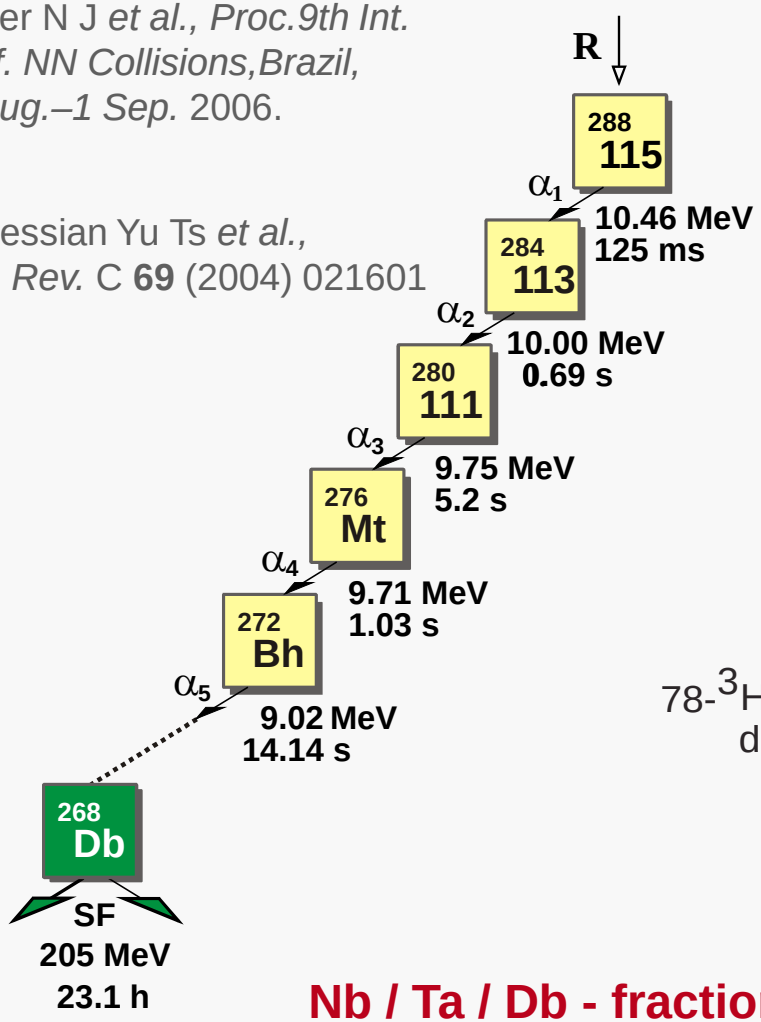
s-элементы
p-элементы
d-элементы
f-элементы

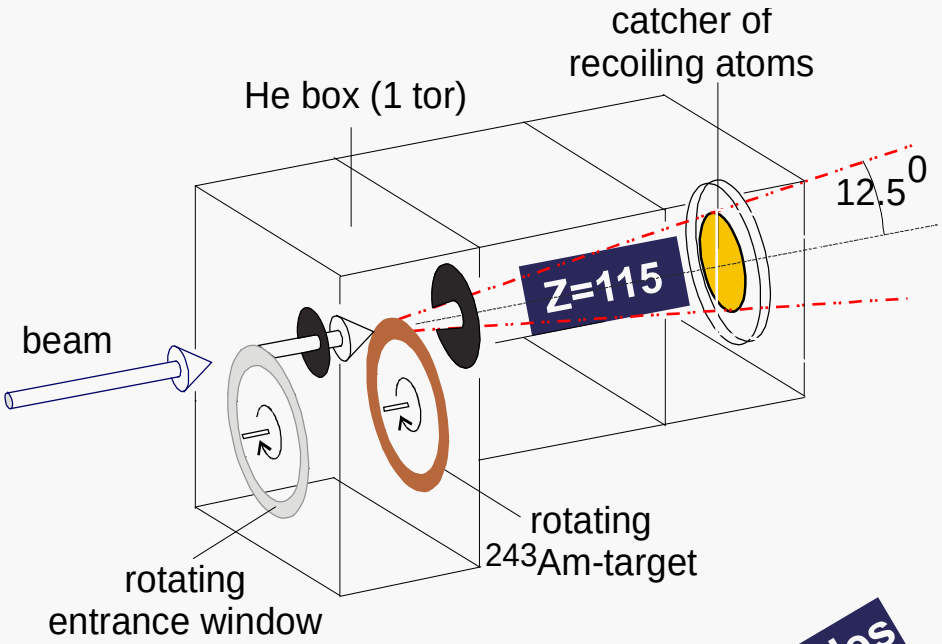
Relatively long half-lives of isotopes of elements 104-116 produced in the reactions with ^{48}Ca and chemical properties of SHE predicted theoretically permit new experiments aimed at:

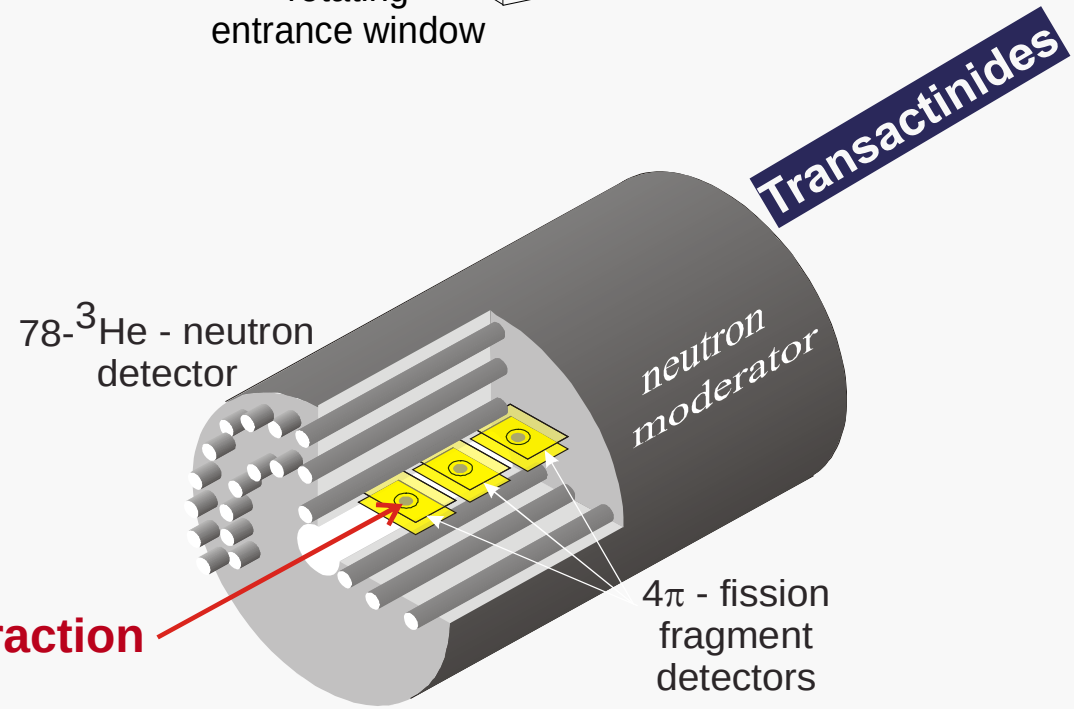
- **the chemical identification of SHE,**
- **study of their chemical properties,**
- **determination of masses of the SHE isotopes**

Dmitriev S N *et al.*, *Mendeleev Commun.* **15** (2005) 1
Schumann D *et al.*, *Radiochim. Acta* **93** (2005) 727
Stoyer N J *et al.*, *Proc.9th Int. Conf. NN Collisions,Brazil, 28 Aug.–1 Sep.* 2006.

Oganessian Yu Ts *et al.*, *Phys. Rev.* C **69** (2004) 021601







Nb / Ta / Db - fraction

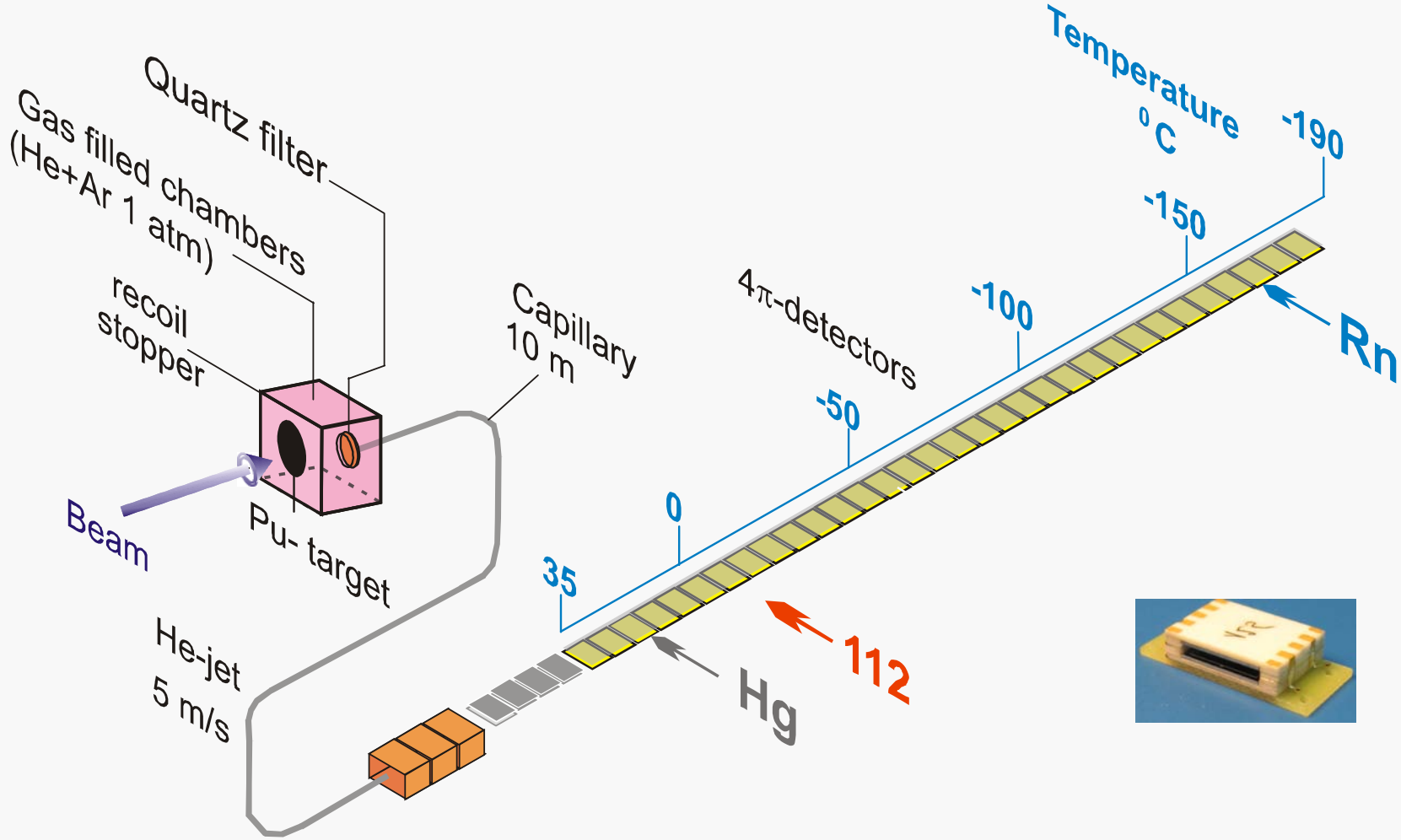
GAS PHASE CHEMISTRY WITH ELEMENTS 112, 113 AND 114

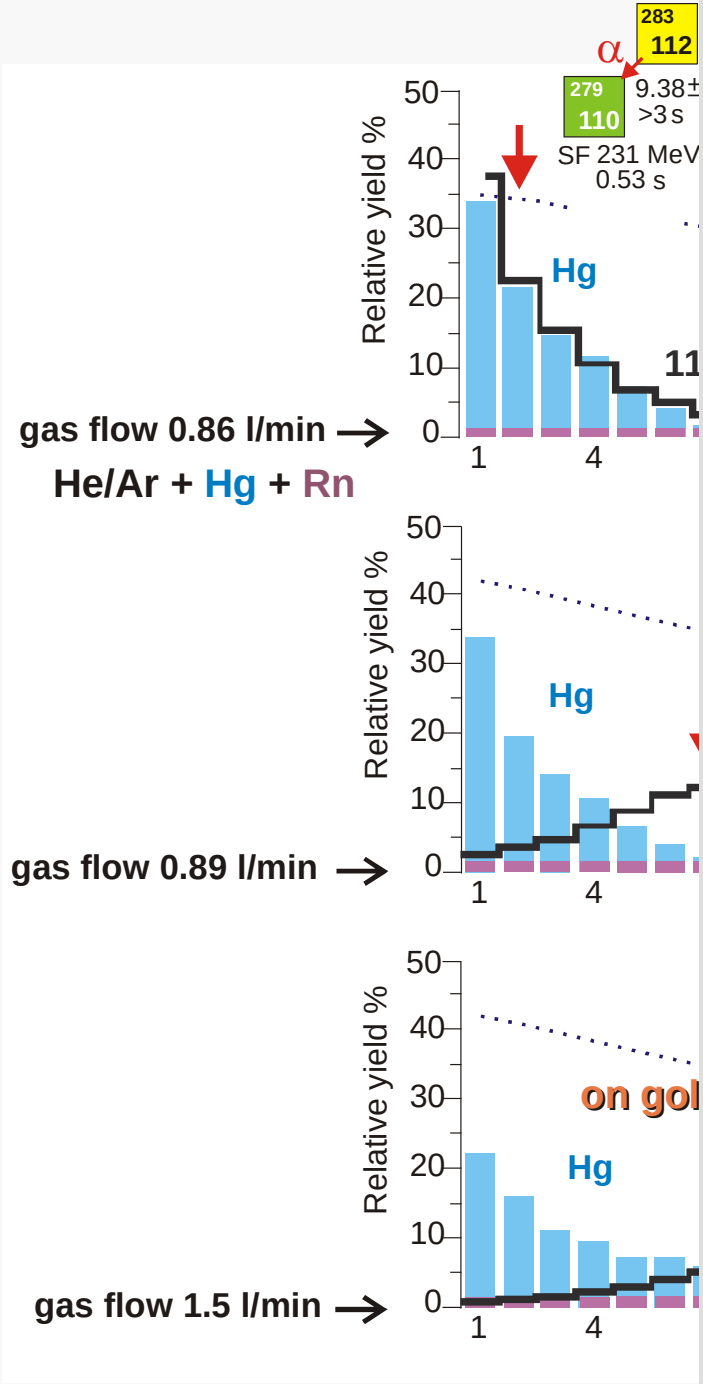
- Are elements 112, 113 and 114 volatile metals?
- How do relativistic effects influence the chemistry of E112, 113 and of E114?

Compound Hg(Au) and 112(Au)

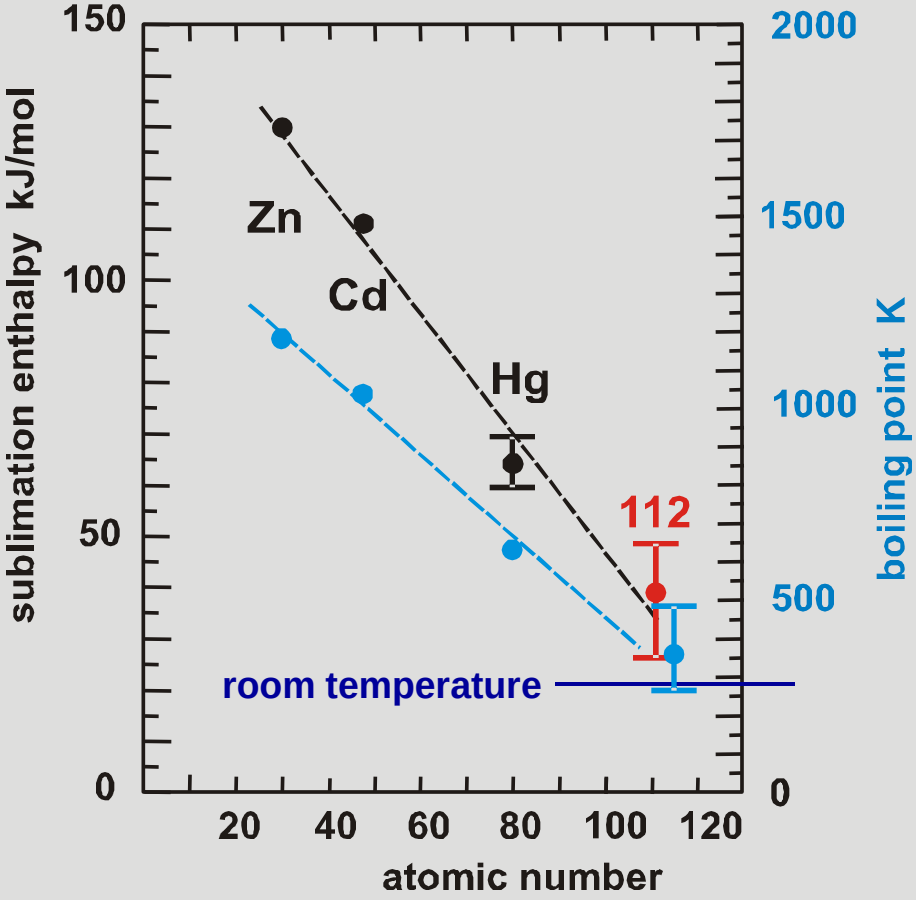
Reaction:

$^{242}Pu(^{48}Ca,3n)^{287}114[0.5s] \rightarrow \alpha \rightarrow ^{283}112[3.6s]$





Element 112 is a noble metal – like Hg



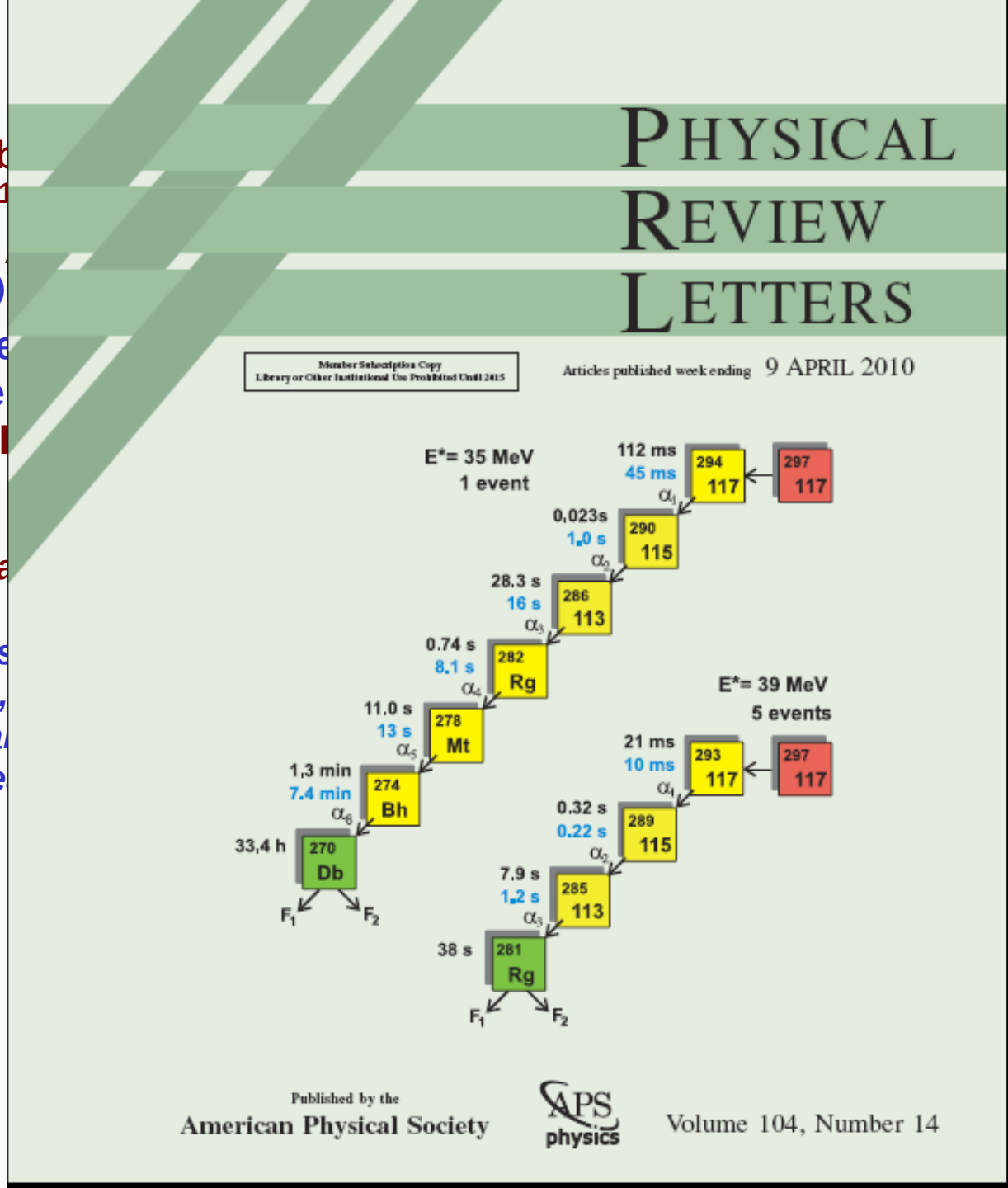
Result from the chemistry experiment with element 114

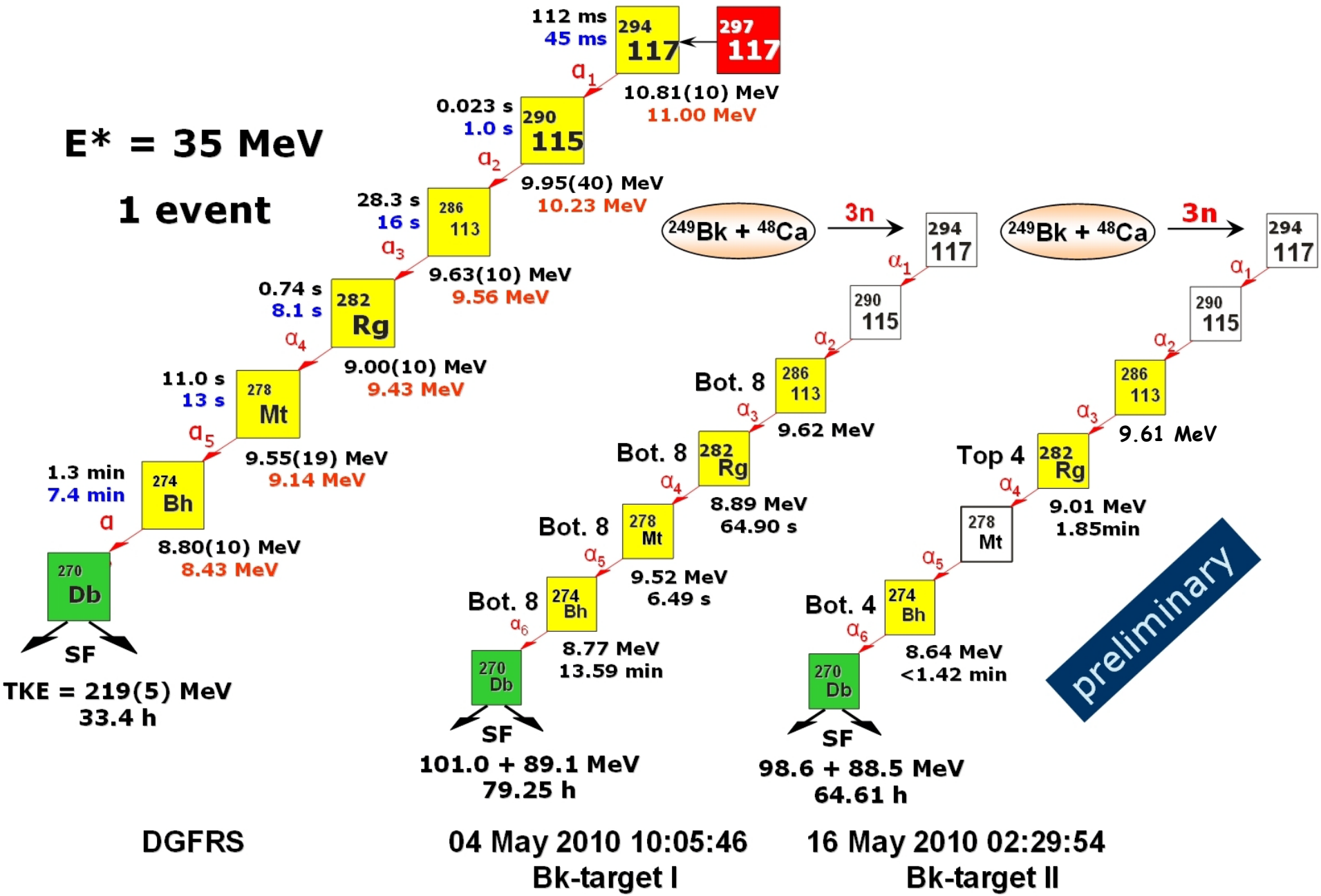
→ Element 114 exhibits a very weak interaction with Au - pointing to a physisorptive interaction (similar to a noble gas).

→ A quantitative description of this behaviour is lacking so far.

Yu. Ts. Oganessian,[1)] F. Sh. Ab
M. E. Bennett,[3)] S N. Dmitriev,[1
M. G. Itkis,[1)] Yu. V. Lobanov,[1)]
A.N. Polyakov,[1)] C. E. Porter,[2)]
M. A. Ryabinin,[6)] K. P. Rykacze
I.V. Shirokovsky,[1)] M. A. Stoye
Yu. S. Tsyganov,[1)] V. K. Utyonl
and P. A. Wilk[5)]

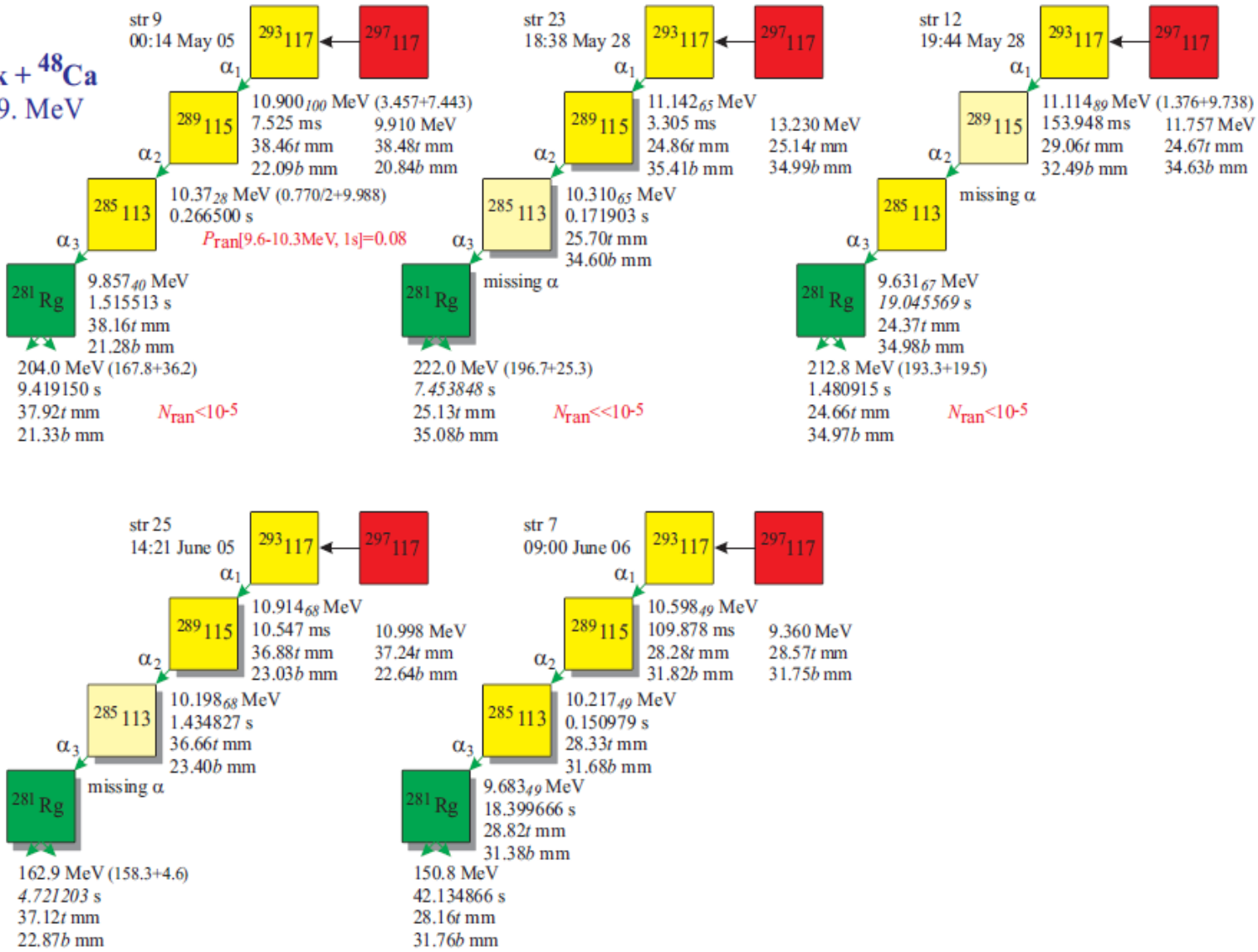
1 Joint Institute for Nuclear Resea
2 Oak Ridge National Laboratory,
3 University of Nevada Las Vegas
4 Vanderbilt University, Nashville,
5 Lawrence Livermore National La
6 Research Institute of Atomic Re




E* = 35 MeV
1 event
112 ms
45 ms
294 117
297 117
α1
10.81(10) MeV
11.00 MeV
0.023 s
1.0 s
290 115
α2
9.95(40) MeV
10.23 MeV
28.3 s
16 s
286 113
α3
9.63(10) MeV
9.56 MeV
0.74 s
8.1 s
282 Rg
α4
9.00(10) MeV
9.43 MeV
11.0 s
13 s
278 Mt
α5
9.55(19) MeV
9.14 MeV
1.3 min
7.4 min
274 Bh
α
8.80(10) MeV
8.43 MeV
270 Db
SF
TKE = 219(5) MeV
33.4 h
249Bk + 48Ca
3n
294 117
α1
290 115
α2
Bot. 8
286 113
α3
9.62 MeV
Bot. 8
282 Rg
α4
8.89 MeV
64.90 s
Bot. 8
278 Mt
α5
9.52 MeV
6.49 s
Bot. 8
274 Bh
α6
8.77 MeV
13.59 min
270 Db
SF
101.0 + 89.1 MeV
79.25 h
249Bk + 48Ca
3n
294 117
α1
290 115
α2
286 113
α3
9.61 MeV
Top 4
282 Rg
α4
9.01 MeV
1.85min
278 Mt
α5
Bot. 4
274 Bh
α6
8.64 MeV
<1.42 min
270 Db
SF
98.6 + 88.5 MeV
64.61 h
preliminary
DGFRS
04 May 2010 10:05:46
Bk-target I
16 May 2010 02:29:54
Bk-target II

$^{249}Bk + ^{48}Ca$

E^*=39. MeV



FLNR BASIC DIRECTIONS of RESEARCH

1. Heavy and superheavy nuclei:

- Synthesis and study of properties of superheavy elements;
- Chemistry of new elements;
- Fusion-fission and multi-nucleon transfer reactions;
- Nuclear- , mass-, & laser-spectrometry of SH nuclei.

Synthesis of SHE

Reaction	E_{beam} (MeV)	Beam dose	Number of events $2n/3n/4n/5n$	Total number of events
$^{238}U+^{48}Ca$	230-240	18.1×10^{18}	-/7/1/-	8
$^{242}Pu+^{48}Ca$	235-250	17.8×10^{18}	1/15/9/-	25
$^{244}Pu+^{48}Ca$	231-257	29.6×10^{18}	-/5/12/1	18
$^{243}Am+^{48}Ca$	240-248	42.1×10^{18}	4/31/2/-	37
$^{245}Cm+^{48}Ca$	243-255	25.7×10^{18}	3/12/-/-	15
$^{248}Cm+^{48}Ca$	237-247	38.3×10^{18}	-/5/6/-	11
$^{249}Bk+^{48}Ca$	247-252	57.0×10^{18}	-/1/10/-	11
$^{249}Cf+^{48}Ca$	245-251	$41.\times10^{18}$	-/3/-/-	3

Beyond ^{48}Ca: ^{50}Ti and ^{54}Cr induced fusion reactions

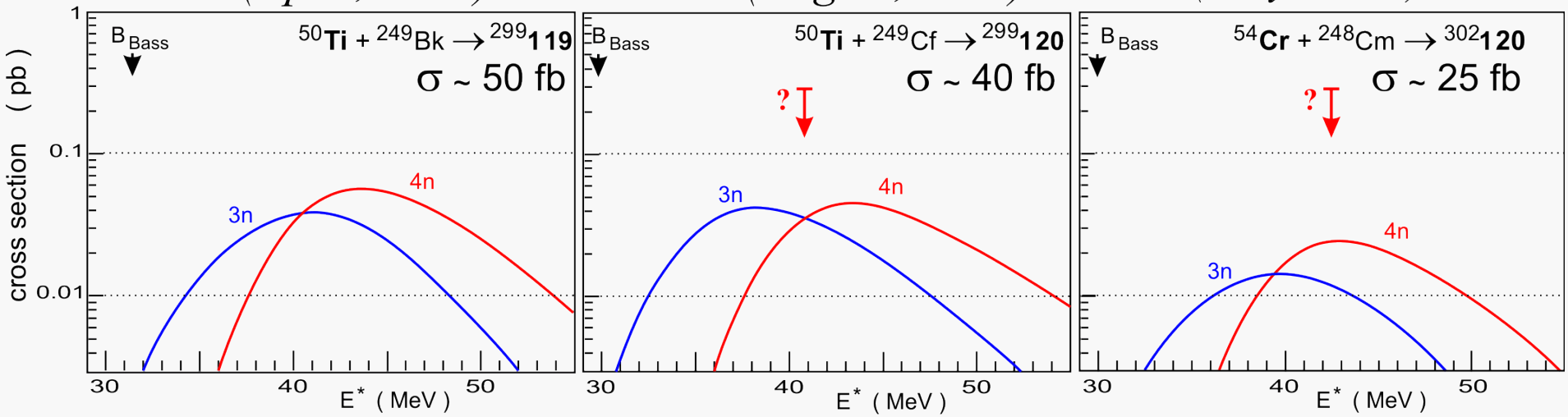
Ti beam:

TASCA (April, 2012)

TASCA (August, 2011)

Cr beam:

SHIP (May, 2011)



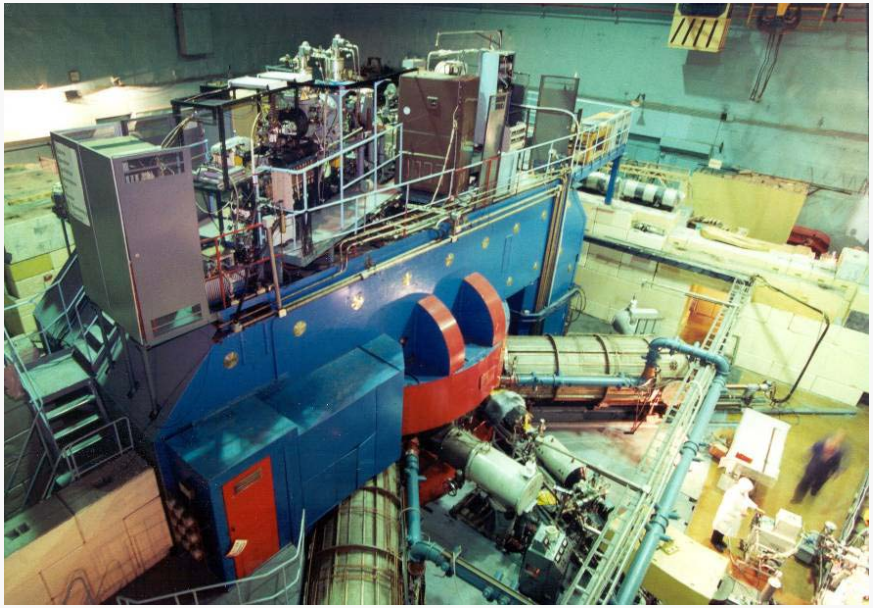
factor $\frac{1}{20}$ as compared to ^{48}Ca

DRIBs-III
2010 -2016

- Modernization of existing accelerators (U400M & U400)
- Creation of the new experimental hall (≈ 2600 м^2)
- Development and creation of next generation set-ups
- Creation of high current heavy ion accelerator

  (A≤ 100, E ≤ 10 MeV ·A , I≥10 pμA)

U400M - stand-alone & driving accelerator



- Properties and structure of light exotic nuclei;
- Astrophysics;
- Reactions with exotic nuclei;
- Light neutron-rich nuclei;
- Deep inelastic scattering;
- Producing of RIBs.

U400M
E=30 50 MeV/A
E=4.5 9 MeV/A

Ion	Ion energy [MeV/A]	Output intensity
^{7}Li	35	$6\ 10^{13}$
^{18}O	33	$1\ 10^{13}$
^{40}Ar	40	$1\ 10^{12}$
^{48}Ca	5	$6\ 10^{12}$
^{54}Cr	5	$3\ 10^{12}$
^{58}Fe	5	$3\ 10^{12}$
^{124}Sn	5	$2\ 10^{11}$
^{136}Xe	5	$4\ 10^{11}$
^{238}U	7	$2\ 10^{10}$

ACCULINNA-I, -II, COMBAS + Gas-Catcher, MASHA, + ...

U400 → U400R GOALS

- Increasing the beam intensity A ≈ 50 ions up to 2.5 pμA;
- Smooth ion energy variation on the target within a factor 5;
- Reducing the ion's energy spread on the target up to 10^{-3};
- Improvement of the beam emittance on the target up to 10 π mm · mrad;
- Reducing the main magnet average field level from 1.8 to 0.8 T.

U400R - stand-alone & post-accelerator

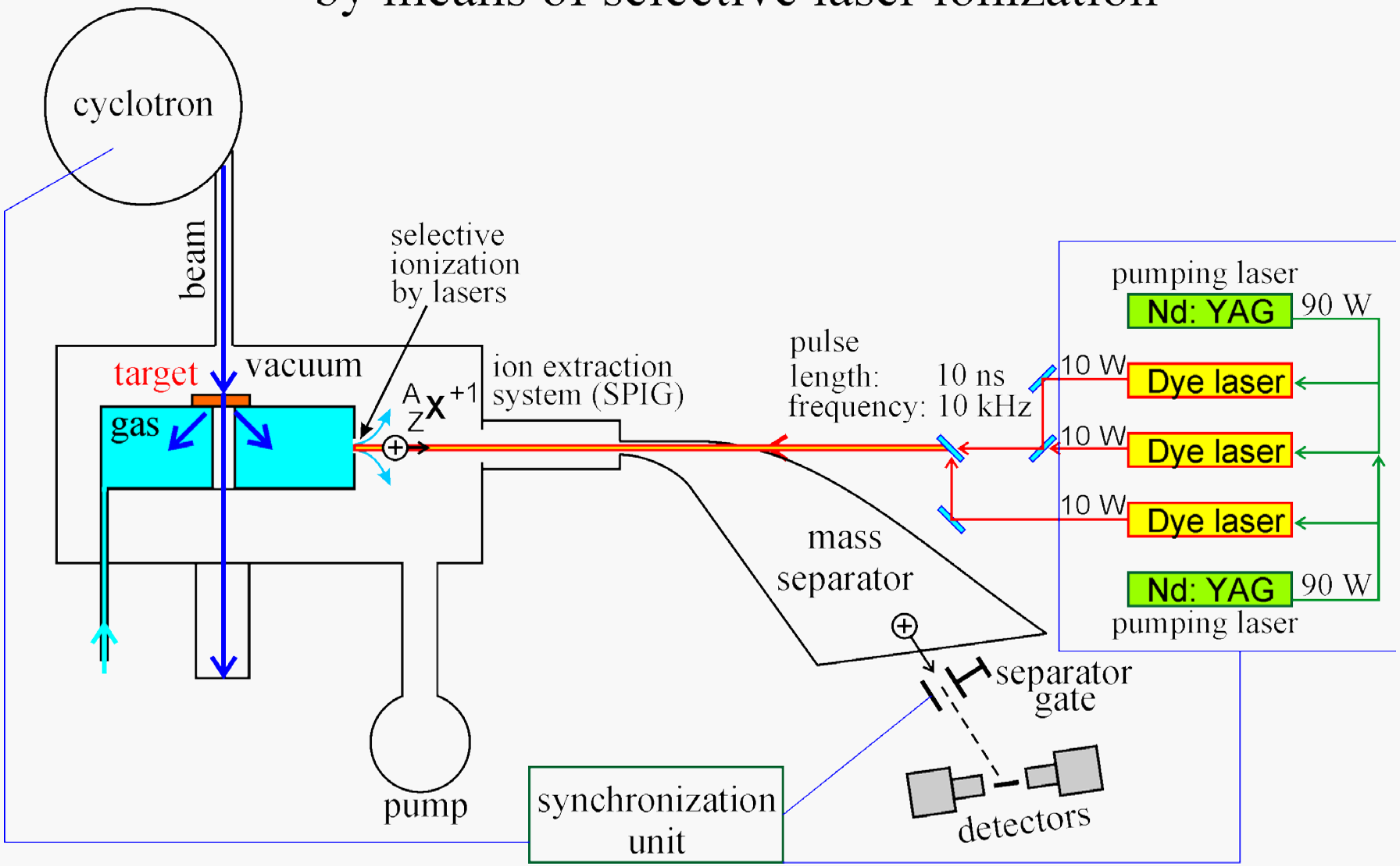
- Fusion-fission;
- Quasi-fission;
- Nuclear spectroscopy;
- New heavy isotopes;
- Multi nucleon transfer reactions;
- Sub-barrier fusion;
- Reactions with exotic nuclei
- Structure of light exotic nuclei;

U400R (expected)

Ion	Ion energy [MeV/A]	Output intensity
^{6}He	2.8 ÷ 14	10^{8}
^{8}He	1.6 ÷ 8	10^{5}
^{7}Li	2-17	1 10^{14}
^{16}O	6,4 -27	1 10^{14}
^{40}Ar	1-5,1	6 10^{13}
^{48}Ca	1,6-11	1.5 10^{13}
^{50}Ti	4,1-21	6 10^{12}
^{58}Fe	1,2-7,5	6 10^{12}
^{84}Kr	0,8-3,5	2 10^{12}
^{132}Xe	0,8-3,5	3 10^{12}
^{238}U	1,5- 8	5 10^{11}

VASSILISSA-II + GABRIELA, DGFRS + Gas-Catcher, CORSET, “LASER” + ···

Scheme of setup for on-line separation of reaction products by means of selective laser ionization



Report of the Experts
on the FLNR project on production and study of heavy neutron rich nuclei formed in multi-nucleon transfer reactions by means of their stopping in gas cell and subsequent resonance laser ionization

The International Workshop on "Resonance Laser Separation of Nuclear Reaction Products" was held on 6-7 December at Flerov Laboratory of Nuclear Reactions JINR. Leading scientists in this field of research from Leuven, Jyvaskyla, GANIL, CERN, GSI, Mainz, iThemba and Troitsk took part in the Workshop and made contributions on the current status of these investigations in their centers. During the Workshop the FLNR project on production and study of heavy neutron rich nuclei formed in multi-nucleon transfer reactions was discussed along with details of the corresponding setup for extraction of reaction products by means of their stopping in gas cell and subsequent resonance laser ionization. The project was undergone an examination by the experts and got their approval. The discussion on the details of the project has been initiated by the decision of the JINR PAC on Nuclear Physics in June 2011.

Experts made a number of recommendations on detailed parts of the project and optimal choosing of setup components: type and initial configuration of laser system, construction of front-end system and gas cell, importance of adequate gas purifying system etc.

It was stressed by experts the following:

1. The proposed physics program is rather ambitious. These studies allow investigating unexplored area of heavy neutron rich nuclei, helping to understand the r-process of astrophysical nucleogenesis near the last "waiting point". The method proposed for production of heavy neutron rich nuclei, namely, the low-energy multi-nucleon transfer reactions, looks promising and adequate; the calculated cross sections of these reactions look quite realistic.

2. The setup proposed, its configuration and components are quite feasible and correspondent the problem. Analogous setups already successfully operated in some facilities for another investigations and reactions type.

   a) The chosen laser system (YAG + DYE) with following extension to (YAG +TiSa) allow performing an efficient ionization of new neutron rich isotopes, giving the possibility of their selection by atomic number and even by isomers.

   b) Gas cell with indicated main parameters (pressure 100-500 mbar of Ar (He), double chambers) will provide efficient stopping and guiding of reaction products to mass separator.

   c) Basic mass separator parameters (with the resolution not less than 1500) fulfill the goal of isotope separation by mass.

   The total efficiency of setup could be of order from few to tens percent.

3. The setup definitely could be build up during the period not exceeding 3 years (depending on financial schedule).

4. Required funding of amount ~2M$ looks absolutely feasible and reasonable.

5. The all experts strongly recommend constructing this setup at FLNR JINR. Many of experts show an interest to participate in realization of this project and forthcoming experiments.

Proponents: V. Zagrebaev, S. Zemlyanoi and E. Kozulin

Experts:

Michael Block (GSI, Darmstadt, Germany)

Valentine Fedosseev (CERN, Switzerland)

Iouri Koudriavtsev (KUL, Leuven, Belgium)

Nathalie Lecesne (GANIL, Caen, France)

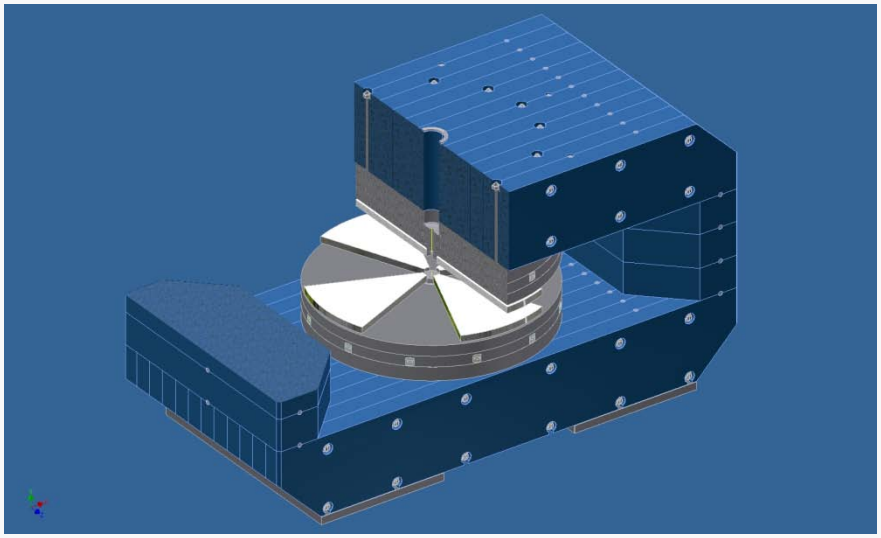
Vyacheslav Mishin (ISAN, Troitsk, Russia)

Iain Moore (JYFL, Jyväskylä, Finland)

Herve Savajols (GANIL, Caen, France)

Klaus Wendt (Institut für Physik Johannes Gutenberg-Universität, Mainz, Germany)

DC280 - stand-alone SHE-factory

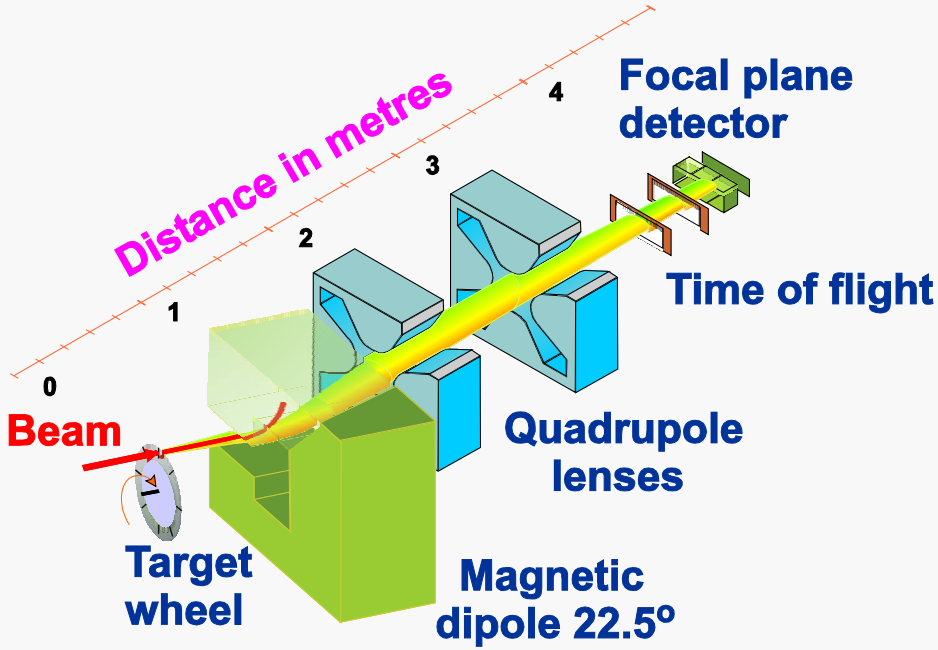


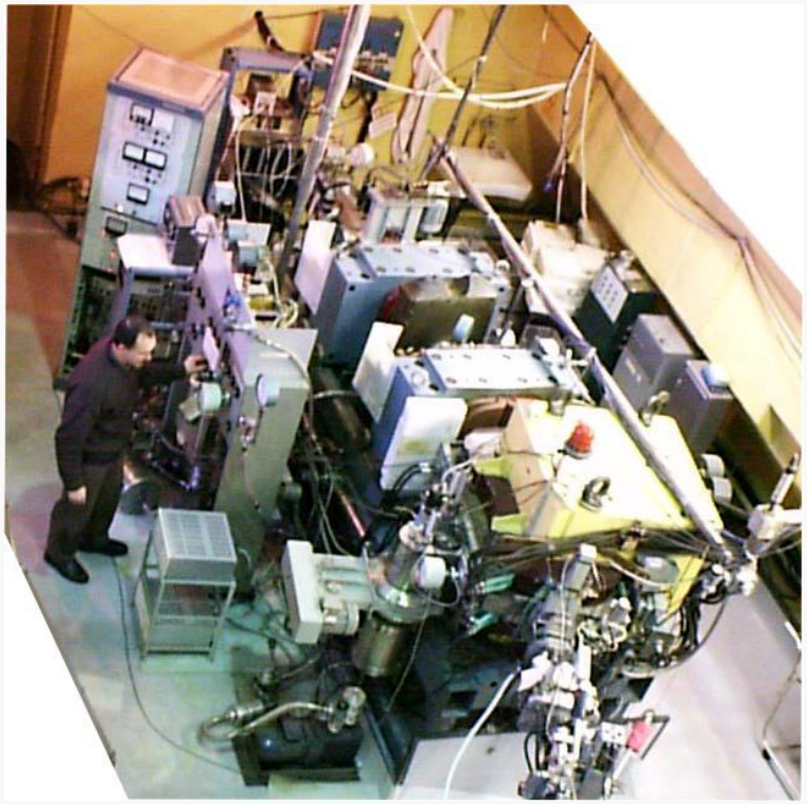
- Synthesis and study of properties of superheavy elements;
- Search for new reactions for SHE-synthesis
- Chemistry of new elements;

DC280 (expected) E=4 8 MeV/A		
Ion	Ion energy [MeV/A]	Output intensity
^{7}Li	4	1 10^{14}
^{18}O	8	1 10^{14}
^{40}Ar	5	6 10^{13}
^{48}Ca	5	0,6-1,2 10^{14}
^{54}Cr	5	2 10^{13}
^{58}Fe	5	1 10^{13}
^{124}Sn	5	2 10^{12}
^{136}Xe	5	1 10^{14}
^{238}U	7	5 10^{10}

DGFRS-II, Chemistry, Preseparator + Cryo-Detector, + ···

Dubna Gas Filled Recoil Separator

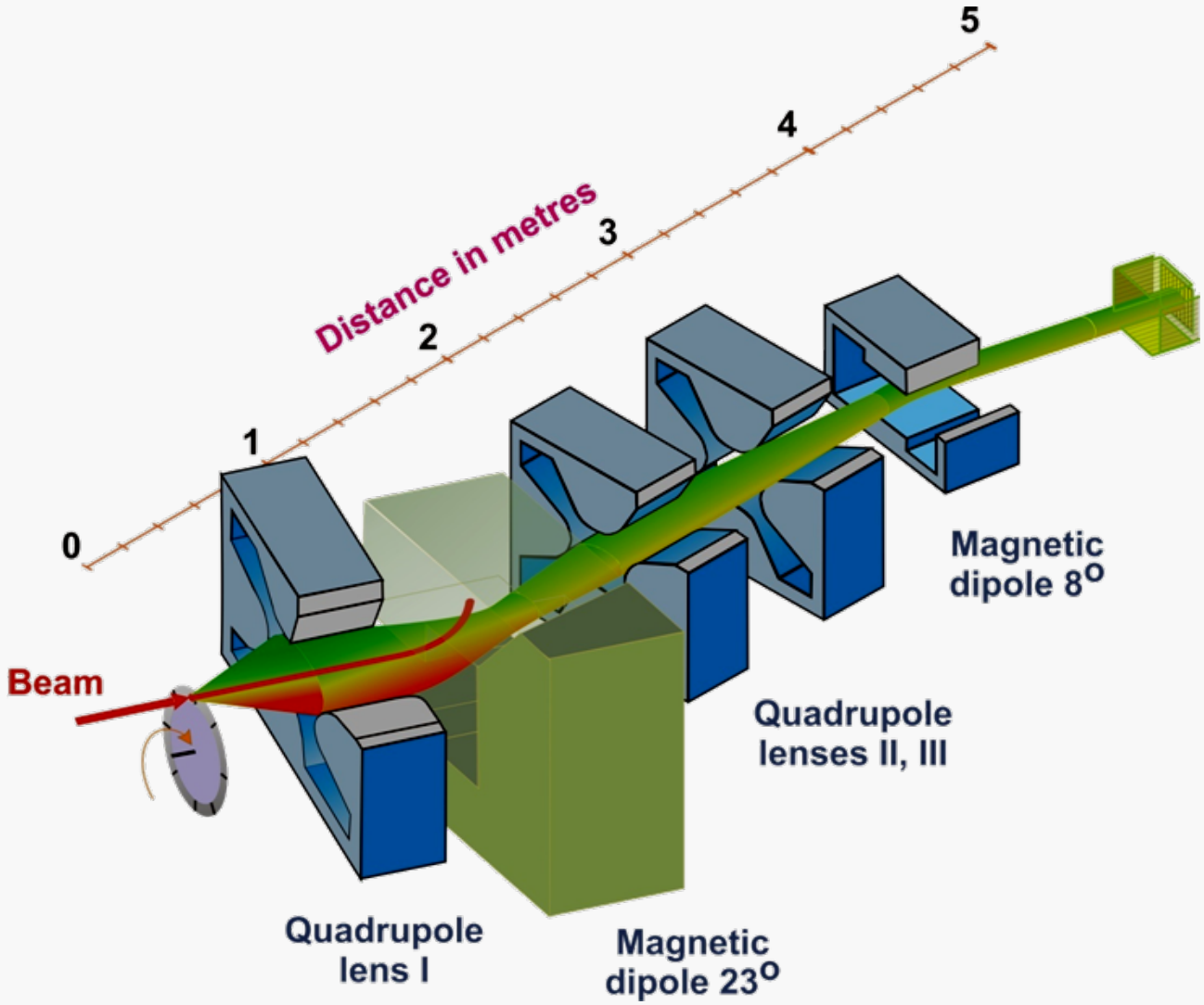




Known GF-separators

Separator	DGFRS	GARIS	RITU	BGS	TASCA
Configuration	DQ_hQ_v	DQ_hQ_vD	$Q_vDQ_hQ_v$	Q_vD_hD	DQ_hQ_v
Deflection angle (°)	23	45+10	25	70	30
Bρ (max/T·m)	3.1	2.15	2.2	2.5	2.4
Length (m)	4.0	5.75	4.7	4.6	3.5
Dispersion (mm/% Bρ)	7.5	9.7	10.0	20.0	9.0

We propose to use the QDQQD-scheme



Main optical elements of the new GFS

Magnetic quadrupole 1

Effective length	370
Bore diameter	150 mm
Maximum field gradient	14.7 T/m

Magnetic quadrupole 2 & 3

Effective length	520
Bore diameter	220 mm
Maximum field gradient	10 T/m

Magnetic dipole 1

Gap	120 mm
Deflection angle	30^0
Radius of curvature	1.8 m
Maximum field	1.7 T
Face pole rotation angle	10^0
Rear pole rotation angle	55^0

Magnetic dipole 2

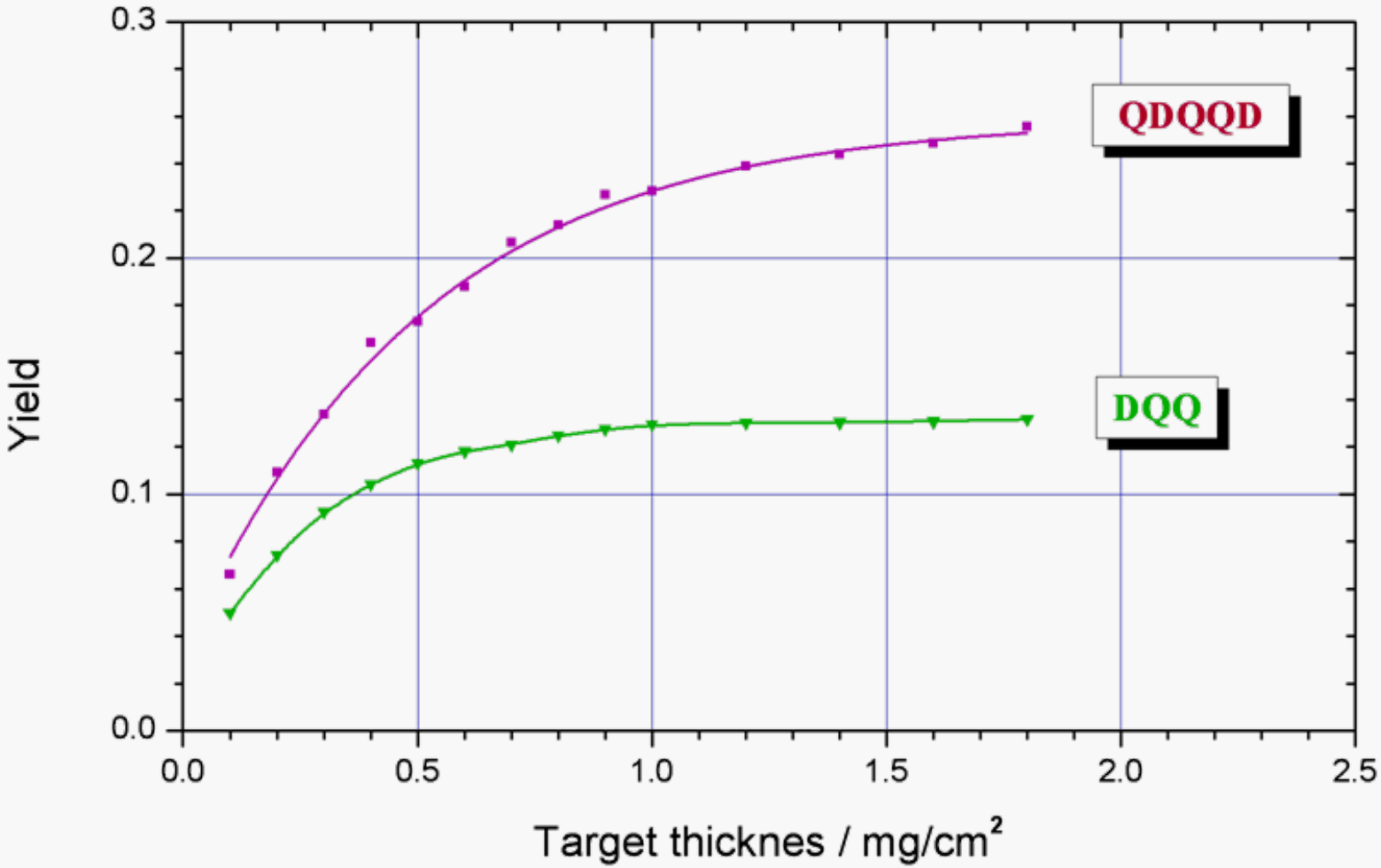
Gap	120 mm
Deflection angle	10^0
Radius of curvature	1.8 m
Maximum field	1.7 T
Face pole rotation angle	0^0
Rear pole rotation angle	10^0

Transmissions of the QDQQD

Reaction	Asymmetry $A_p/(A_p+A_t)$	Transmission %
$^{244}Pu(^{22}Ne,3n)^{263}Rf$	0.083	7.5
$^{244}Pu(^{48}Ca,3n)^{289}114$	0.164	35
$^{244}Pu(^{58}Fe,4n)^{298}120$	0.192	50
$^{70}Zn(^{208}Pb,1n)^{277}Cn$	0.252	60
$^{93}Kr(^{226}Ra,1n)^{318}124$	0.291	70

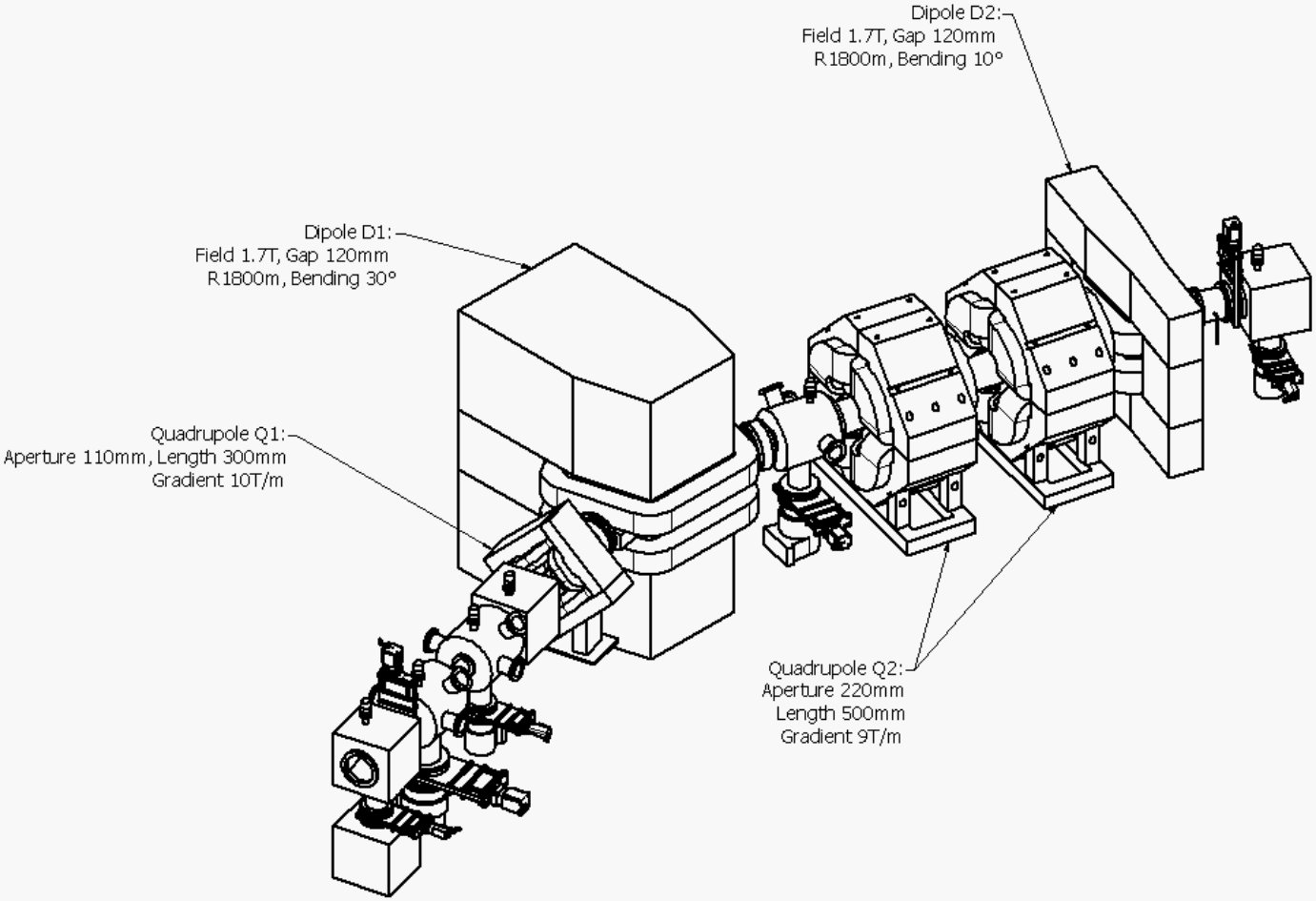
Yields of ^{276}Cn for DQQ & QDQQD – separators

^{238}U(^{48}Ca,4n)^{276}112 (FWHM=10.0 MeV→1.37 mg/cm^2, σ =0.583 mg/cm^2)



New Gas-Filled Separator

(DANFYSIKs technical drawing, 1.5 years, 1.5 M€)



Ready time must be synchronized with the construction of the new experimental hall & accelerator

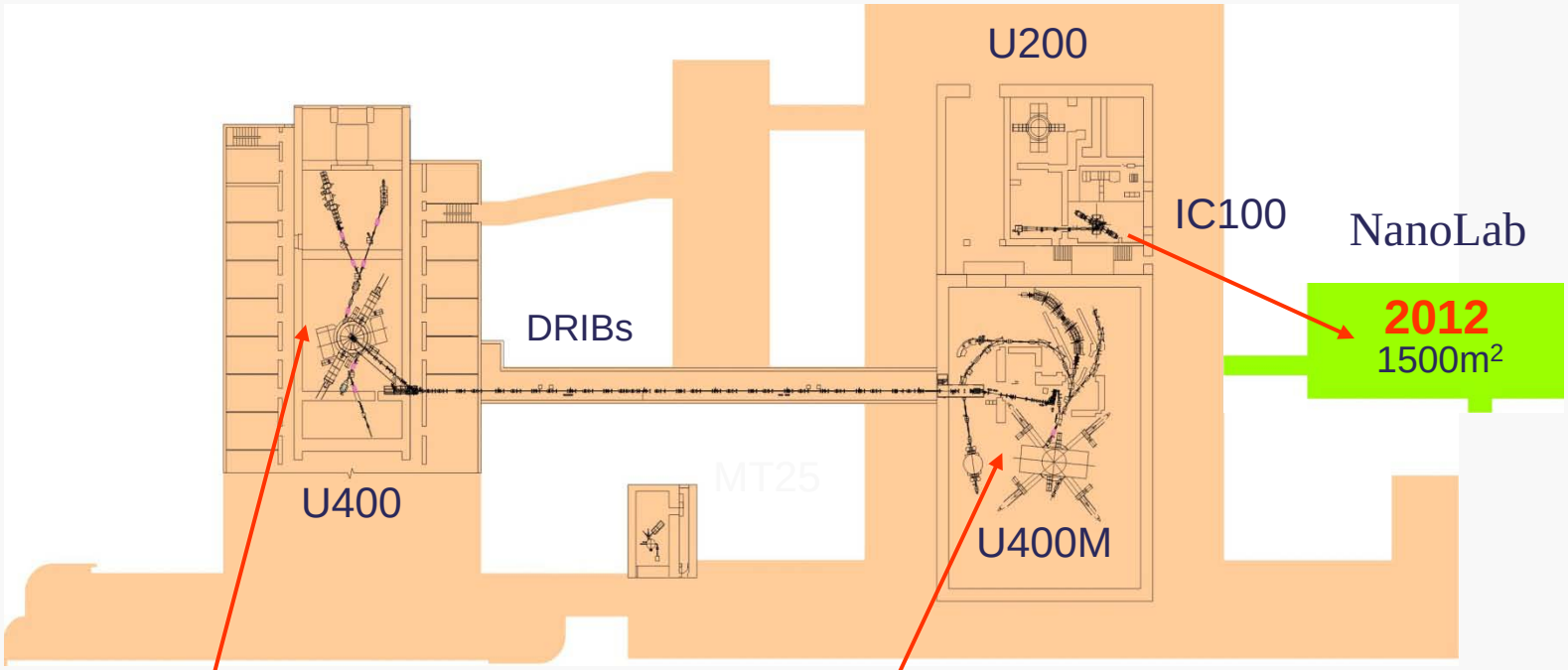

Flerovlab
Building 101
Flerovlab
Building 131
Place for New Experimental Building
with DC280 accelerator complex

SHE factory

Building computer model

2012

FLNR - 2012



SHE

$^{243}Am+^{48}Ca$

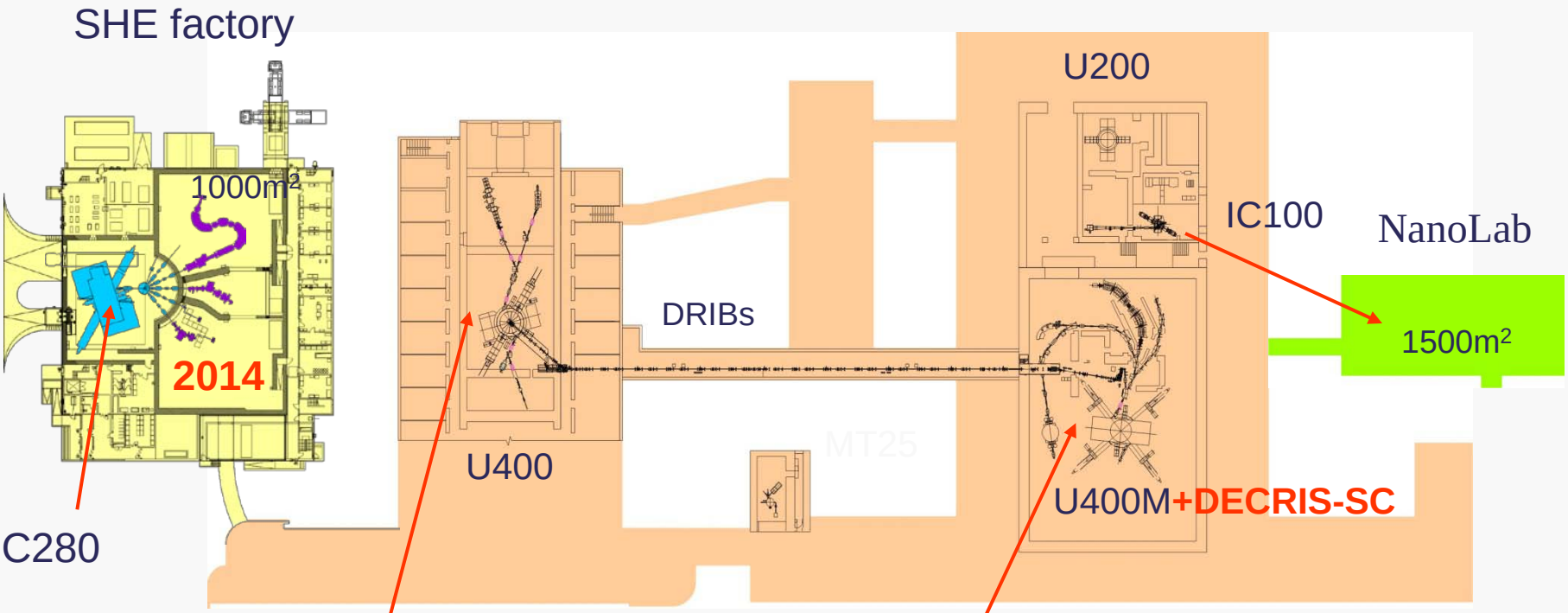
$^{249}Bk+^{48}Ca$

Exotic Nuclei

E = 30 50 MeV/n

A < 20

FLNR - 2014



Start

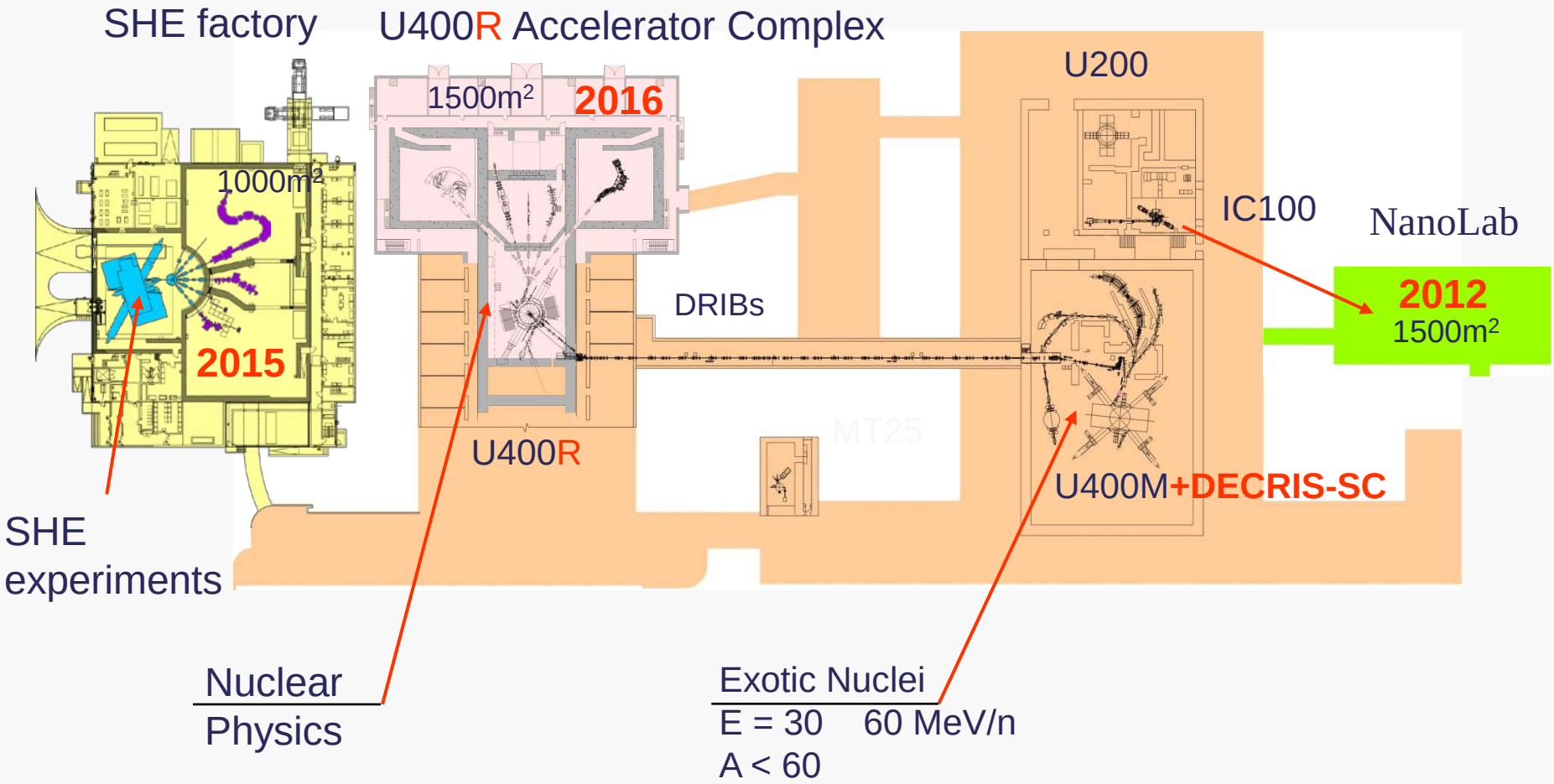
of the Reconstruction

Exotic Nuclei

E = 30 60 MeV/n

A < 60

FLNR – 2016


SHE factory
U400R Accelerator Complex
1500m²
2016
1000m²
2015
U200
IC100
NanoLab
2012
1500m²
DRIBs
U400R
U400M+DECRIS-SC
SHE experiments
Nuclear Physics
Exotic Nuclei
E = 30 60 MeV/n
A < 60

THANKS FOR YOUR ATTENTION!