# Detection of ultra rare alpha decays of super heavy nuclei



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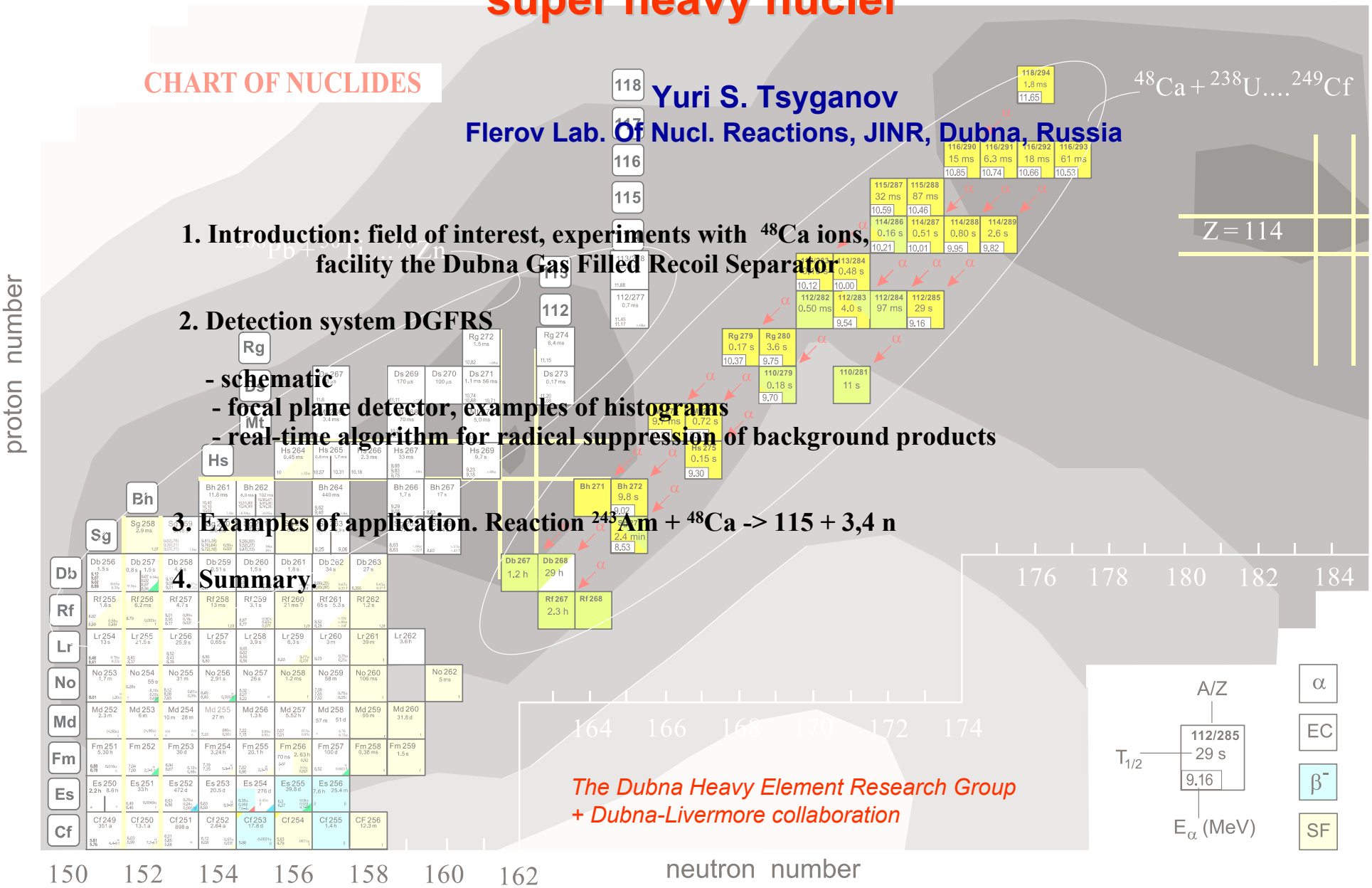
1. Introduction: field of interest, experiments with $^{48}Ca$ ions, facility the Dubna Gas Filled Recoil Separator

2. Detection system DGFRS
   - schematic
   - focal plane detector, examples of histograms
   - real-time algorithm for radical suppression of background products

3. Examples of application. Reaction $^{243}Am + ^{48}Ca$ -> 115 + 3,4 n

4. Summary.

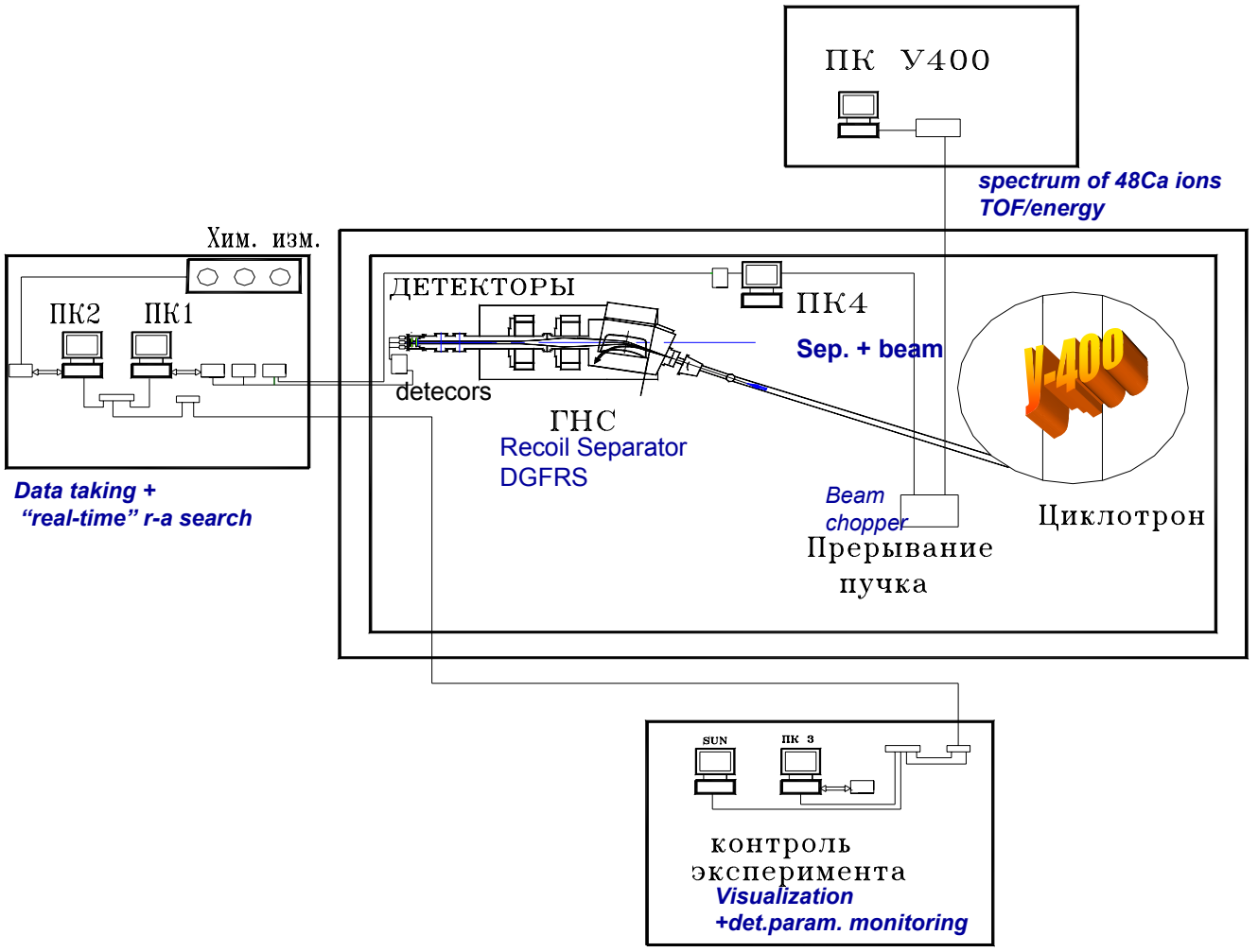


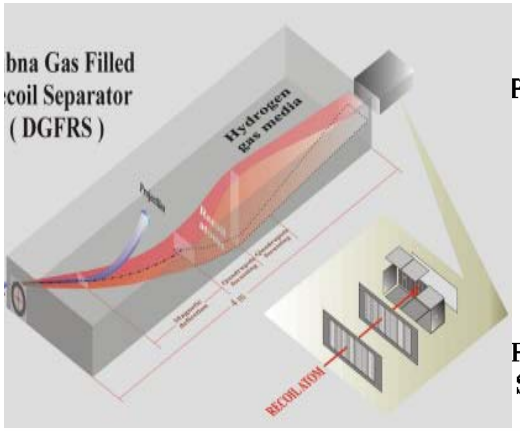
- **Introduction**

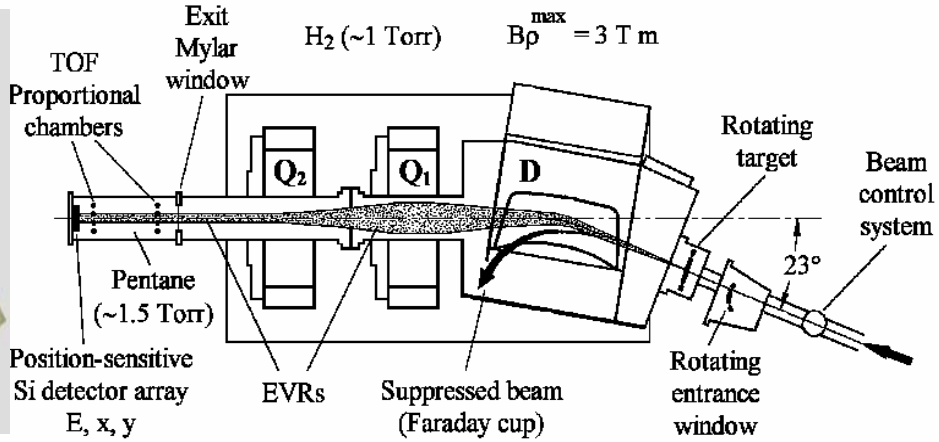
- field of interest: full fusion reactions with heavy ions , synthesis of SHE (Z >110)

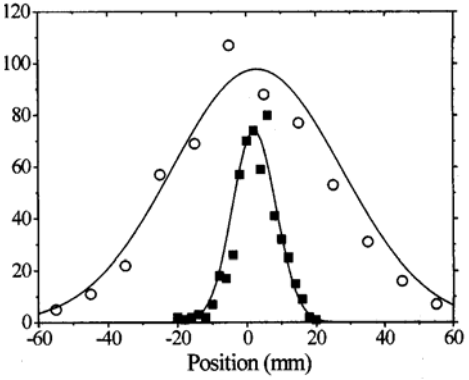
- $^{48}$Ca - chance for relatively higher cross sections of the product under investigation (it follows from ← Pb + Ca )
- Nevertheless, cross section ~units/parts of picobarn -> intense beams, sensitive detection system, good separation
- cyclotron U 400 + gas filled recoil separator (separation by the difference in magnetic rigidity. Gas<- smaller std. of equilibrium charge -> higher efficiency)
- Duration of experiments typically months – ½ year
- special high active materials for targets production ($^{242,244}$Pu, $^{245,248}$Cm, $^{243}$Am, $^{249}$Cf )
- In collaboration with LLNL ( USA, CA)/ Dubna-Livermore

# schematic of the experiments with 48Ca

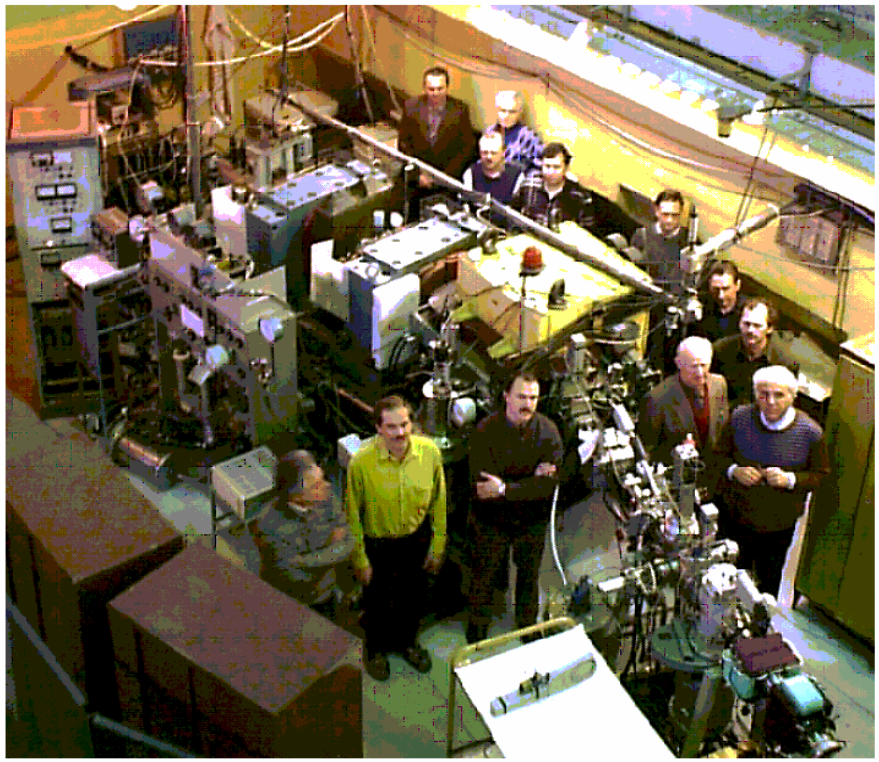





. Comparison of measured horizontal (circles) and al (squares) focal-plane position spectra in the reaction $^{206}Pb \rightarrow {}^{252}No + 2n$ to the calculations of the ANA-I code (lines).



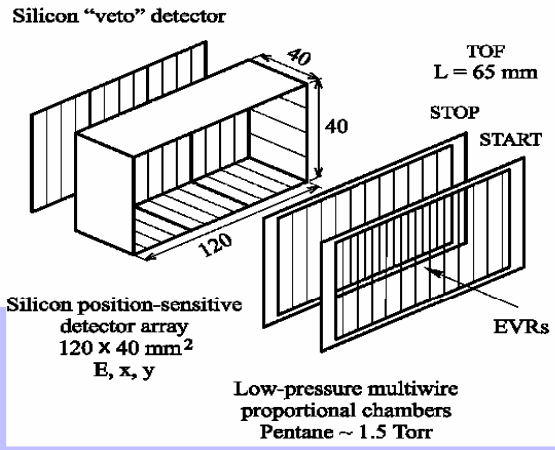
the Dubna Gas Filled Recoil Separator

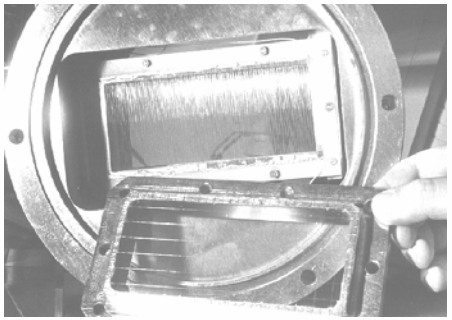
Table 1
Technical parameters of the DGFRS

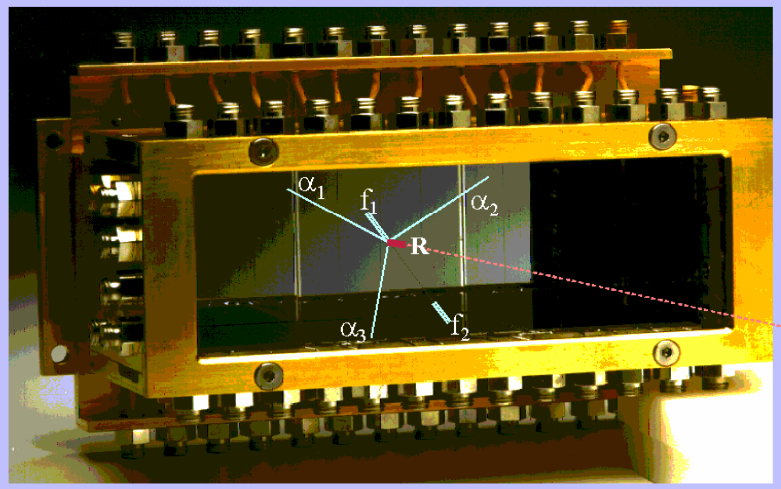
| | |
|---|---|
| **Dipole** | |
| Bending radius $\rho$ | 1.8 m |
| Maximum magnetic flux density $B$ | 1.7 T |
| Bending angle | 23° |
| Inclination of pole edges | 26° |
| Gap | 60 mm |
| Dispersion | 7.5 mm per 1% of $B\rho$ |
| Horizontal acceptance | ±3° |
| Vertical acceptance | ±2° |
| **Quadrupoles** | |
| Yoke length | 31 cm |
| Aperture radius | 10 cm |
| Maximum field gradient | 13 T/m |
| **Distances**[a] | |
| Target–Dipole | 74 cm |
| Dipole–First quadrupole | 88 cm |
| Quadrupole–Quadrupole | 100 cm |
| Quadrupole–TOF system | 122 cm |
| TOF system–PSD array | 18 cm |
| Diameter of target spot | 9 mm |
| **Others** | |
| Pressure of hydrogen | 0.7–1 Torr |
| Pressure of pentane | 1.2–1.7 Torr |
| Typical target thickness | 0.2–0.5 mg/cm$^2$ |
| Mylar window thickness | 0.5–1.0 μm |

[a]The distances correspond to the middles of the dipole.

# Detecting Module of DGFRS






Focal Plane Silicon Position Sensitive Detector Array

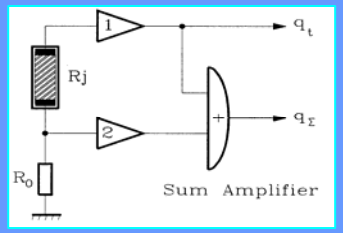
# Subsystems

- 1. data acquisition (CAMAC, PC 85/7/7
  mcS dead time)
- 2. separator parameters monitoring,
  including beam associated
- 3. detecting module parameters
  monitoring
- 4. visualization ( ~ 100 histograms)
- 5. real-time search of recoil-alpha time-energy-position correlated sequences

# real-time algorithm to search recoil-alpha sequences

$$j = \mathrm{int}\{ N_{\max} * [\frac{a_i N_a + b_i}{a_{yi} + b_{yi}} * (\frac{R0_i}{R_i} + 1) - \frac{R0_i}{R_i} + \delta_i^{a,esc,ER} ]\}$$

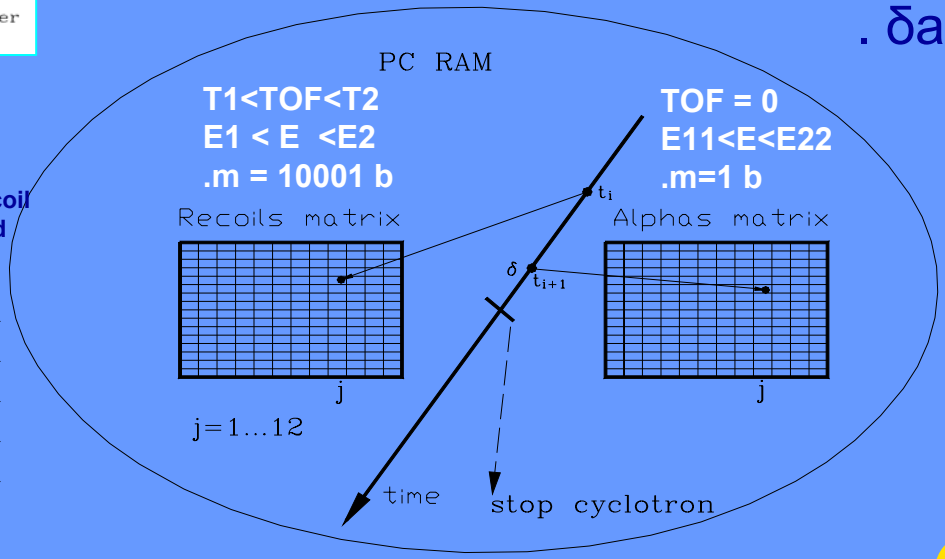
$$t_{i,j}^{a,ER} = t(elapsed\ )$$




One strip input circuit

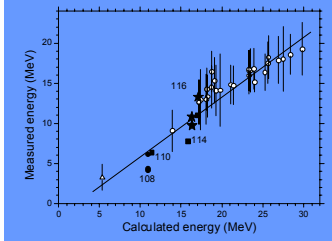
. δa = 0

. i = strip number
1..12




```
dt = (dt1<dt2) ? dt1 : dt2;
dt = (dt<dt3)  ? dt  : dt3;
dt = (dt<dt4)  ? dt  : dt4;
dt = (dt<dt5)  ? dt  : dt5;
dt = (dt<dt6)  ? dt  : dt6;
dt = (dt<dt7)  ? dt  : dt7;
```

Calibration: measured recoil energy against calculated incoming one



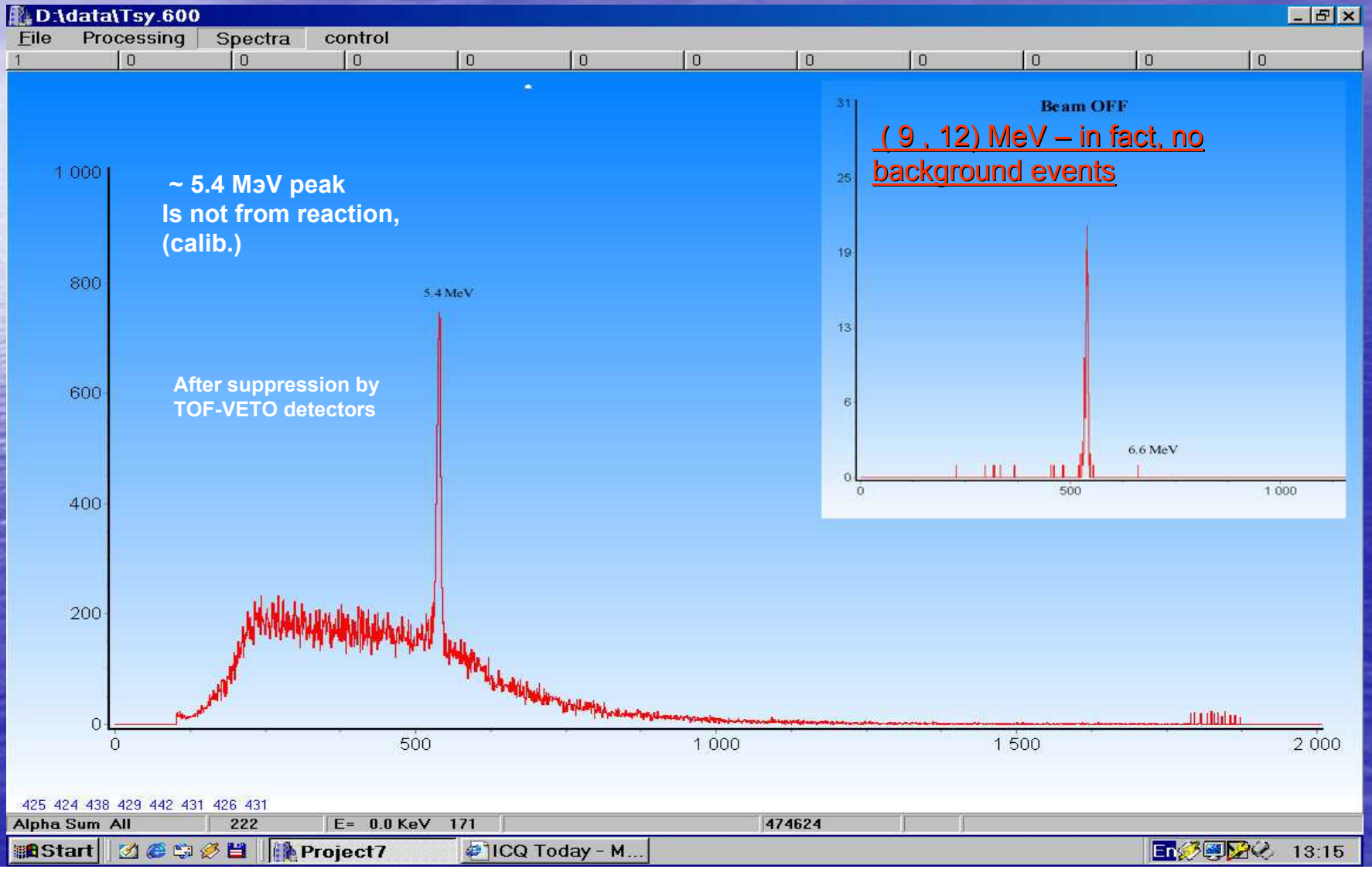

```
if (( dt >= 0  &&  dt < EPSILEN &&
correlation==0
 && e_total>EAMIN)||( corr_f==1) )
                    {
                     correlation = 1;
cnt_cor++;
… code prolongation…
```

(Borland's)

*Dead time ~ 120 мкс*

a, b, ay,by, R0, Ri –calibration coefficients
Detector constants. Nmax = 170

# demonstration of background events suppression ( right upper)



If K ($t_1$, $t_2$) - number of random events, occurred during a time interval ($t_1$,$t_2$)
with probability Qk($t_1$,$t_2$)
(*Zlokazov* formalism Eur. J. A8 81-86 p.82)
t=0 - recoil

$$Qk\ (t) = \frac{(lt)^k}{k!} \bullet \exp(\ -lt)$$

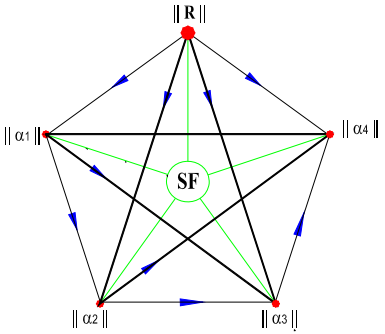
where l = parameter of the Poison distribution, t = time and
$Q_k$ = probability that during a time interval (0,t) k events will be registered.
The probability of k –alphas and one SF as a random sequence is given by
$Ps = Q_k * P_t$, where $P_t$ is one, related with recoil-SF chain
In our case we have not two, but three imitators group : recoil- alpha (in beam), recoil-alpha (out of beam) and recoil-SF

$$\eta = \frac{C_n^m}{K^{n-m}}$$

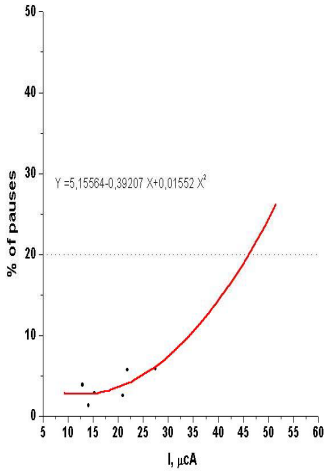
e n – number of alpha particles in chain, m – number of a… switching the beam OFF K – suppression parameter fo… out of beam, usually 1/100 – 1/1000

$$C_n^m = \frac{n!}{m!(n-m)!}$$

11:57 20/ 6 2048
12:25 20/ 6 2048
12:36 20/ 6 2048
12:55 20/ 6 2048
13:38 20/ 6 2048
13:47 20/ 6 2048
13:59 20/ 6 2048
14:30 20/ 6 2048
14:44 20/ 6 2048
15:21 20/ 6 2048
15:33 20/ 6 2048
15:54 20/ 6 2048
16: 6 20/ 6 2048
16:17 20/ 6 2048
16:20 20/ 6 2048
16:24 20/ 6 2048
16:48 20/ 6 2048
16:54 20/ 6 2048
16:59 20/ 6 2048
17:16 20/ 6 2048
17:28 20/ 6 2048
18: 0 20/ 6 2048
18:36 20/ 6 2048
19:45 20/ 6 2048
19:47 20/ 6 2048
19:58 20/ 6 2048
20: 3 20/ 6 2048
20: 5 20/ 6 2048
20:22 20/ 6 2048
20:38 20/ 6 2048
20:53 20/ 6 2048
21: 1 20/ 6 2048
21: 7 20/ 6 2048
21:10 20/ 6 2048
21:12 20/ 6 2048
21:48 20/ 6 2048
21:59 20/ 6 2048
22: 8 20/ 6 2048
22:12 20/ 6 2048
22:15 20/ 6 2048
22:23 20/ 6 2048
22:29 20/ 6 2048
22:43 20/ 6 2048
22:52 20/ 6 2048
23:13 20/ 6 2048
dt ~ 11h
N=45 -→ **6.8%**




*Recoil- α-α-α-α-SF chain*




R –alpha$_{1,2}$

20% → ~ 45 μcA
~ 2.5 pμcA

***Typical losses in the experiment efficiency against incoming beam intensity***

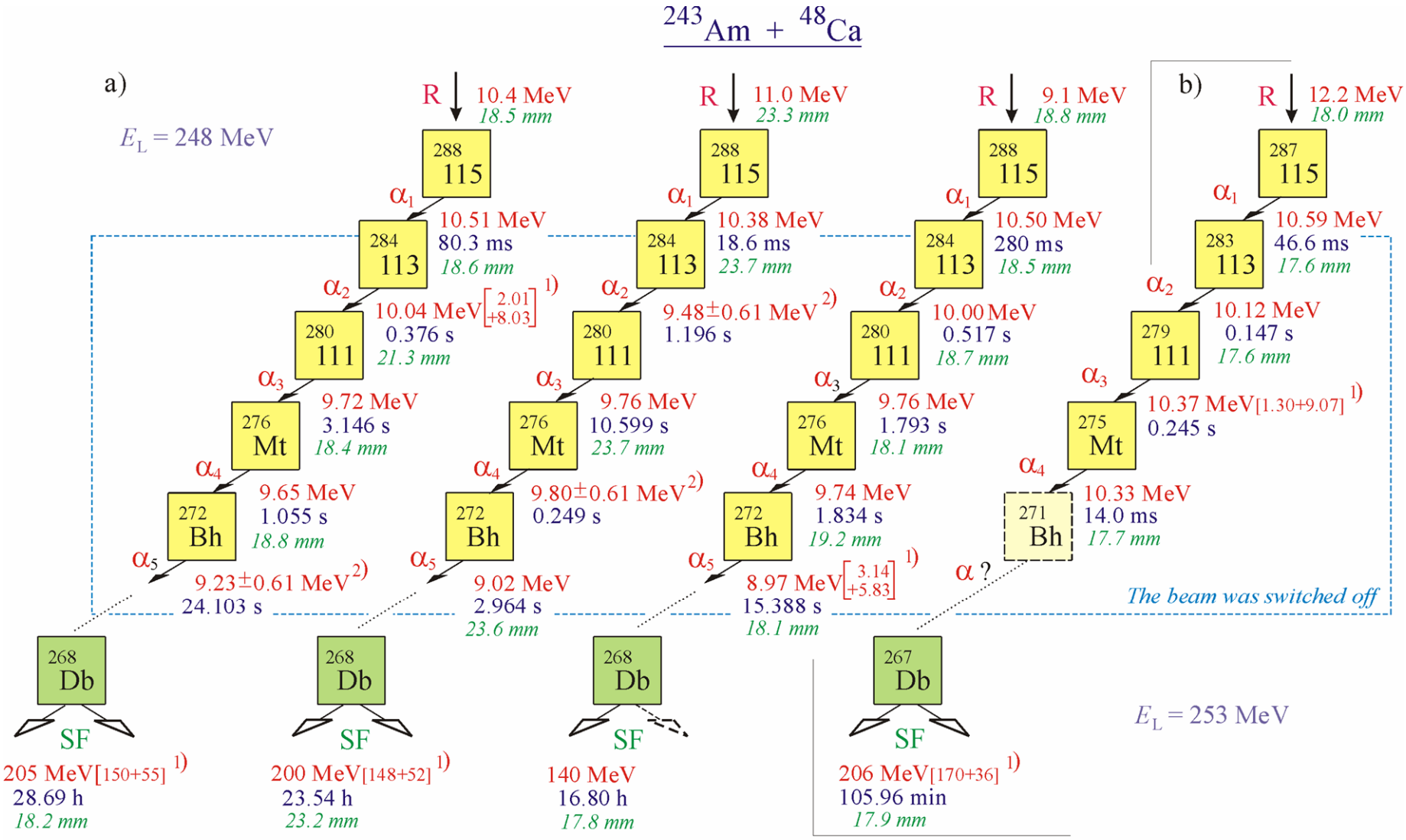
If n =4, m=1 (the first alpha particle stops cyclotron beam) and K~1000,
η= 4/(1000)$^{4-1}$ =4/1.0e+09= 4x10$^{-8}$

# Application in the experiment aimed to the synthesis of element Z=115

- **Reaction $^{243}Am + ^{48}Ca \rightarrow 115 + 3,4n$...**
- **Average intensity of 48Ca ions at the target**
  **~ 1 pmcA ( $18^{+}$)**
- **Energy 248, 253 MeV, beam dose ~ 9.0E+18**
- **« real-time» technique was applied**
- **Four decay chains were obtained**

**( 3 - 3n de - excitation channel + one was attributed to 4n)**

- **Recently, results were confirmed in chemical experiment with long-lived isotope $^{268}Db$ extraction)**




1) Energies of events detected by both the focal-plane and side detectors. 2) Energies of events detected by side detectors only.

**Chemical experiment (** isolation of **Group V** elements **) confirms $^{268}$Db properties:**

**half -life $T_{1/2}$ = $16^{+19}_{-6}$ h - $32^{+11}_{-7}$**

**Formation cross section of 115 = $2.7^{+4.8}_{-1.6}$ pb - $4.2^{+1.6}_{-1.2}$**

**Additionally: average neutron multiplicity per fission act 4.2 was measured**

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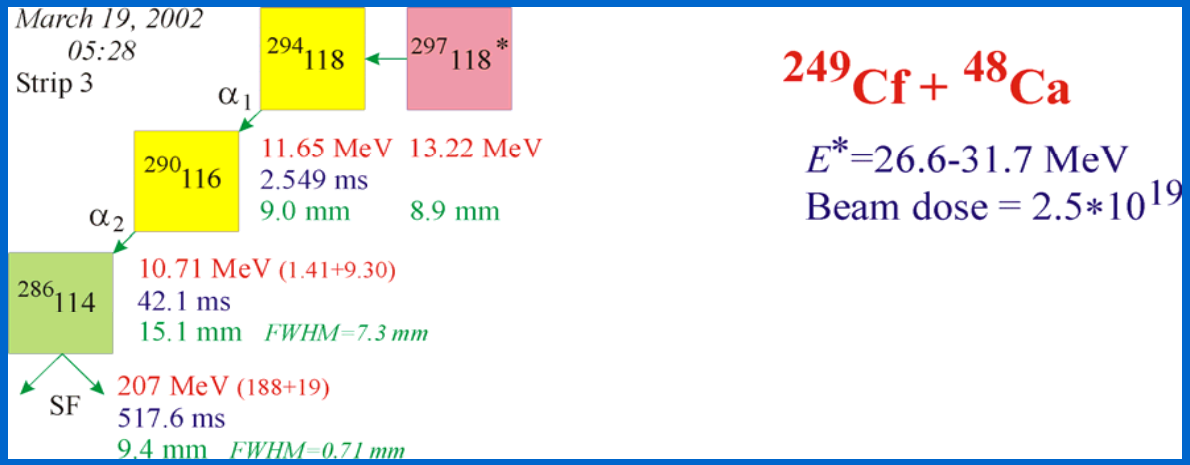


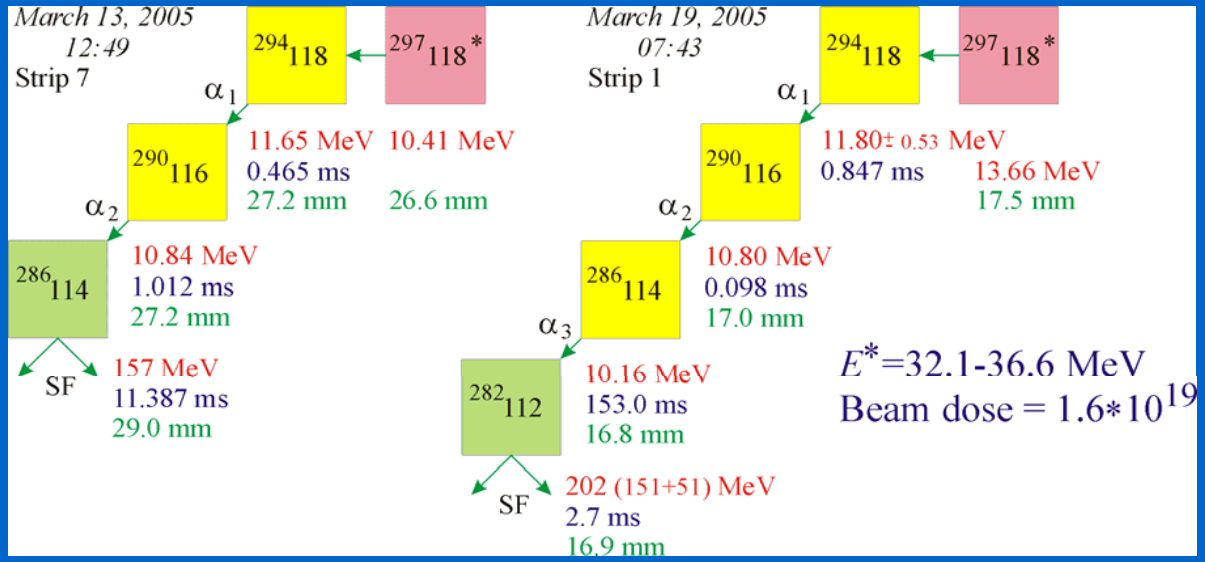


Last experiment (Jan-Jun 2005)

to be published in Phys.Rev.C

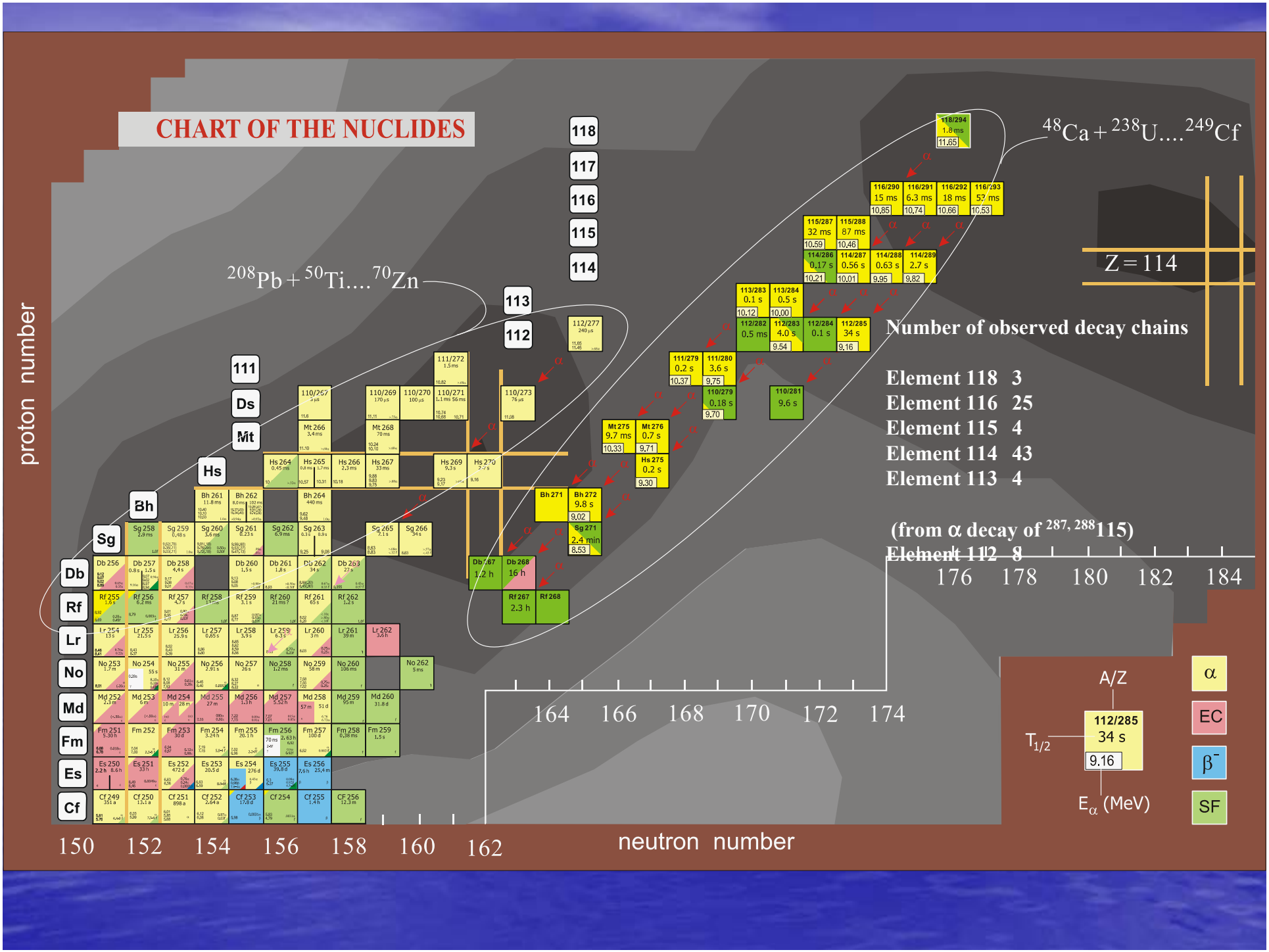
CHART OF THE NUCLIDES
$^{208}Pb + ^{50}Ti \ldots . ^{70}Zn$
$^{48}Ca + ^{238}U \ldots . ^{249}Cf$
Z = 114
Number of observed decay chains
Element 118 3
Element 116 25
Element 115 4
Element 114 43
Element 113 4
(from α decay of $^{287,288}$115)
Element 112 8
proton number
neutron number
118
117
116
115
114
113
112
111
Ds
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
A/Z
$T_{1/2}$
112/285
34 s
9.16
$E_\alpha$ (MeV)
α
EC
$\beta^-$
SF

PSD-7


- Detection a recoil-alpha correlated sequences in a real-time mode provides a radical suppression of background events, when ultra rare alpha decays are detected.

- The detection system of the DGFRS was successfully applied in the reactions aimed to synthesis of 112-118 elements. The mentioned system allows to detect events with cross sections down to units of $10^{-37}$ см2.

- Losses in the total experiment efficiency are in fact units of percents up to incoming beam intensities about 1pμcA ($^{48}$Ca)