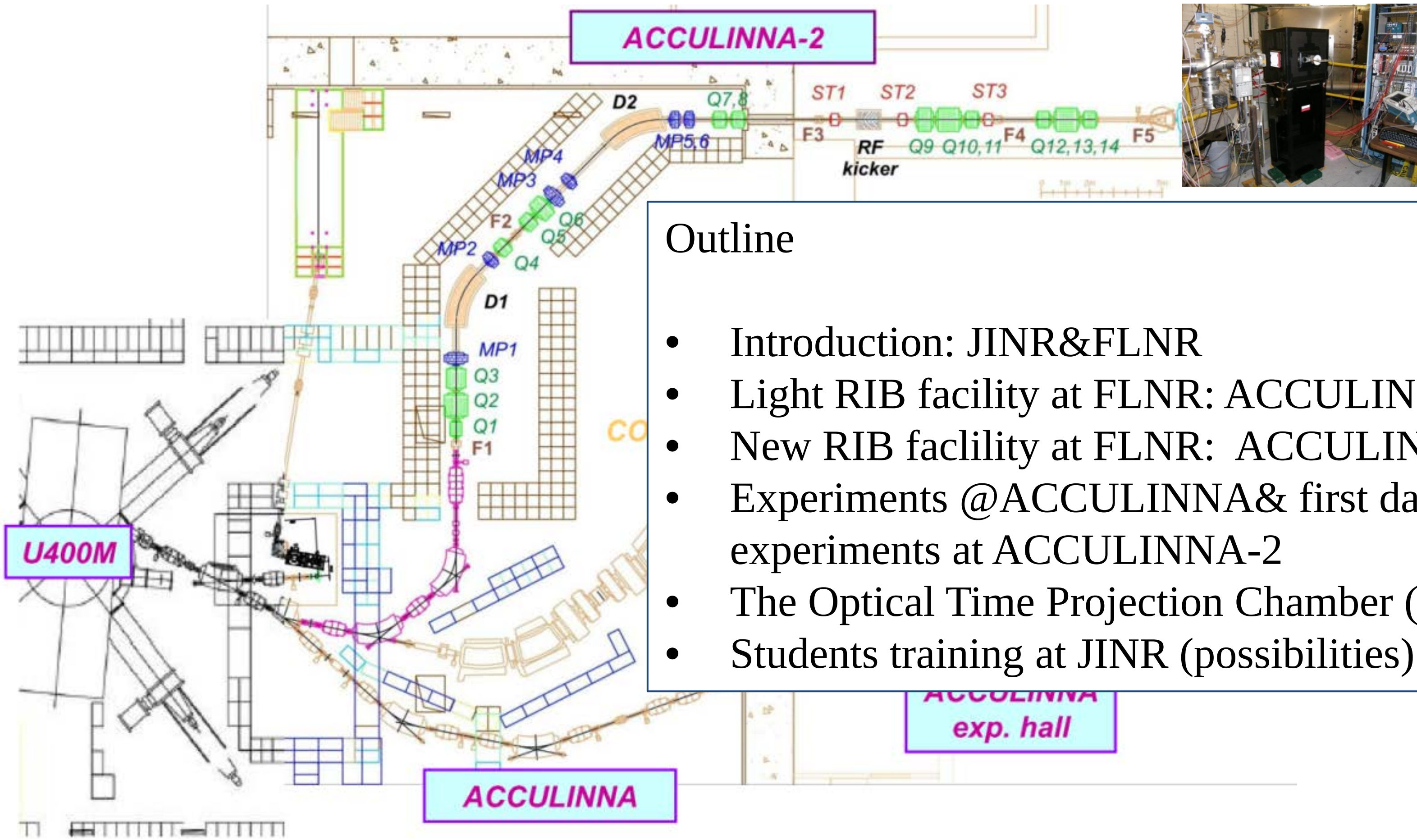
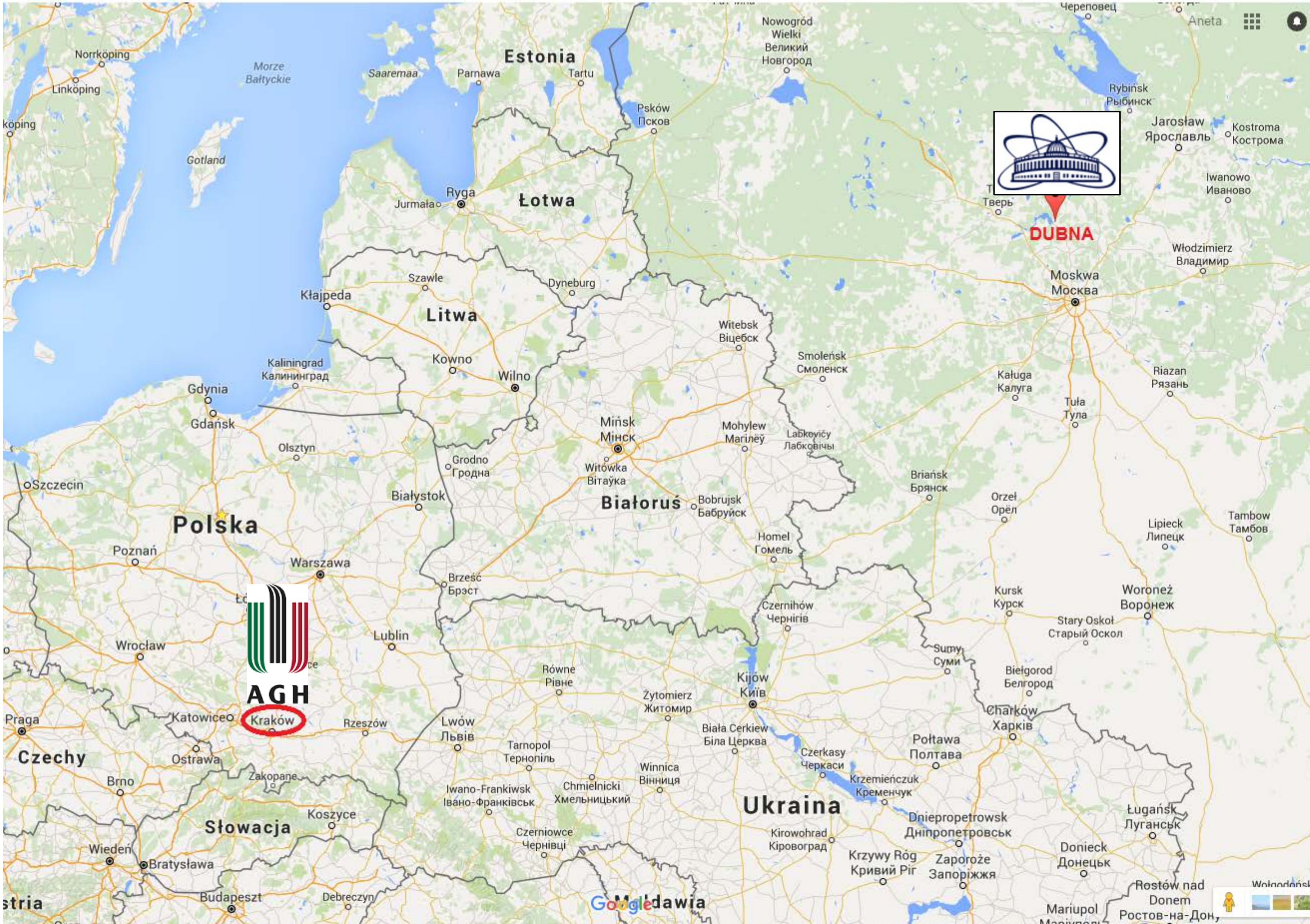
Grzegorz Kaminski
Flerov Laboratory of Nuclear Reactions, JINR
Heavy Ion Laboratory, UW, Warsaw

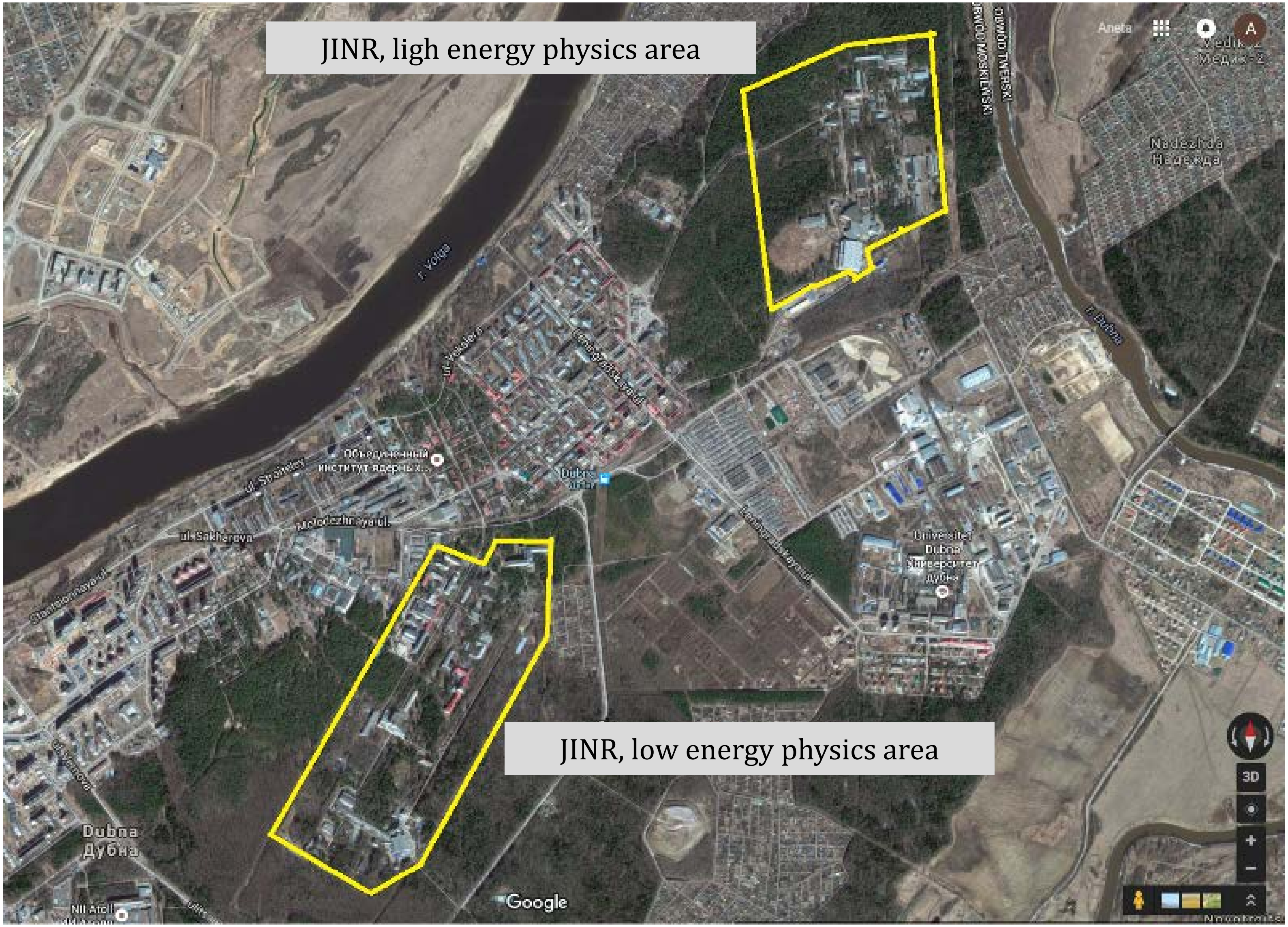



Outline

- Introduction: JINR&FLNR
- Light RIB facility at FLNR: ACCULINNA
- New RIB faclility at FLNR:  ACCULINNA-2
- Experiments @ACCULINNA& first day experiments at ACCULINNA-2
- The Optical Time Projection Chamber (OTPC)
- Students training at JINR (possibilities)


DUBNA
AGH
Kraków
Estonia
Łotwa
Litwa
Białoruś
Polska
Ukraina
Czechy
Słowacja
Morze Bałtyckie
Moskwa
Москва
Warszawa
Ryga
Wilno
Mińsk
Kijów
Київ
Gdańsk
Poznań
Wrocław
Lublin
Rzeszów
Katowice
Praga
Lwów
Львів

# Joint Institute for Nuclear Research @ Dubna map



# JINR Laboratories

Veksler and Baldin Laboratory of High Energy Physics

Bogoliubov Laboratory of Theoretical Physics

Laboratory of Information Technologies

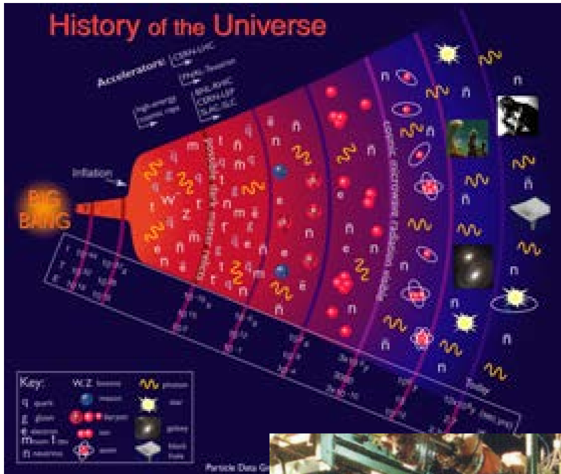
Dzhelepov Laboratory of Nuclear Problems

Laboratory of Radiation Biology

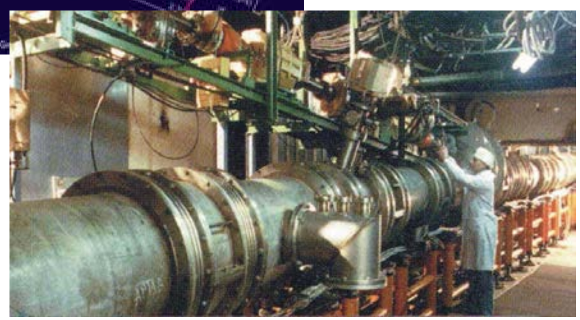
Flerov Laboratory of Nuclear Reactions

Frank Laboratory of Neutron Physics

# Three main areas of activity at JINR




- Fundamental studies
- Particles study at high energies,
- Nuclear physics and condensed phase physics study,

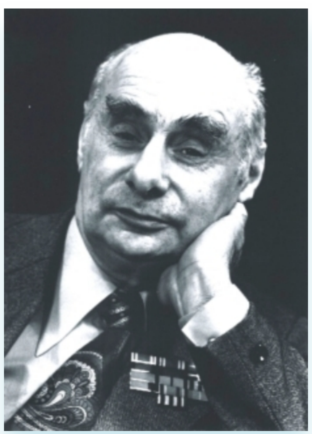


– Innovations,

development and application of advanced technologies,


- University center and education in many different areas of science

# Flerov Laboratory of Nuclear Reactions (FLNR)



**LABORATORY FOUNDER**
*Georgiy Nikolaevich FLEROV, 1913 – 1990*

- **1940** Discovery of spontaneous fission of uranium
- **1942-1950** Participation in Russian atomic project
- **1955** First beams of accelerated heavy ions
- **1957** Foundation of Laboratory of Nuclear Reactions (Dubna)
- **1962-1975** Synthesis of new elements: 102, 103, 104, 105 (Dubnium), 106, 107
- **2012** Element 114 named Flerovium

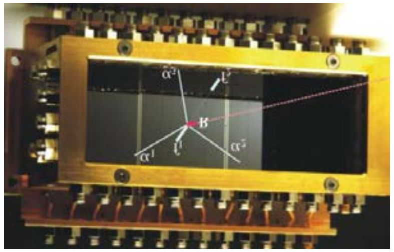
# Accelerators @ FLNR


**DC-280** **U-400** **U-400M** **U-200** **IC-100** **MT-25**

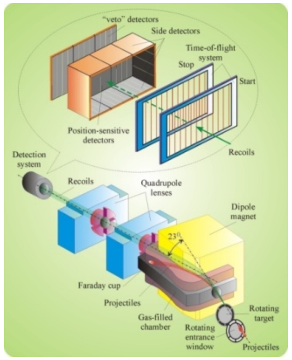
more information @ http://flerovlab.jinr.ru/flnr/accelerators.html

# The main activities at FLNR



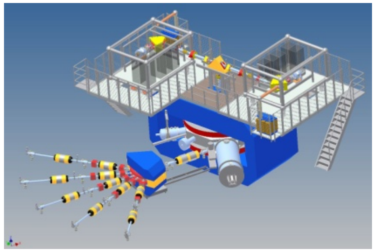
## ❍ Experiments with heavy ion beams of stable and radioactve nuclei:

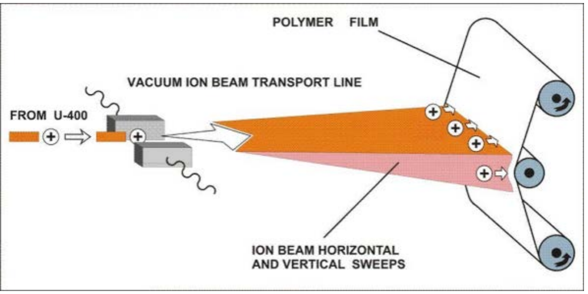
- ✓ Synthesis of superheavy elements
- ✓ Study of fusion and fission of atomic niclei
- ✓ Study of nuclear reaction mechanisms
- ✓ Study of the structure of exotic nuclei




## ❍ Developpment of acceleration techniques

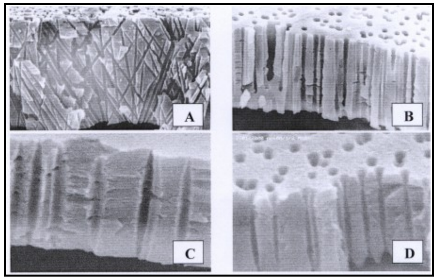
- ✓ cyclotrons
- ✓ ECR ion sources ECR






## ❍ Applied study

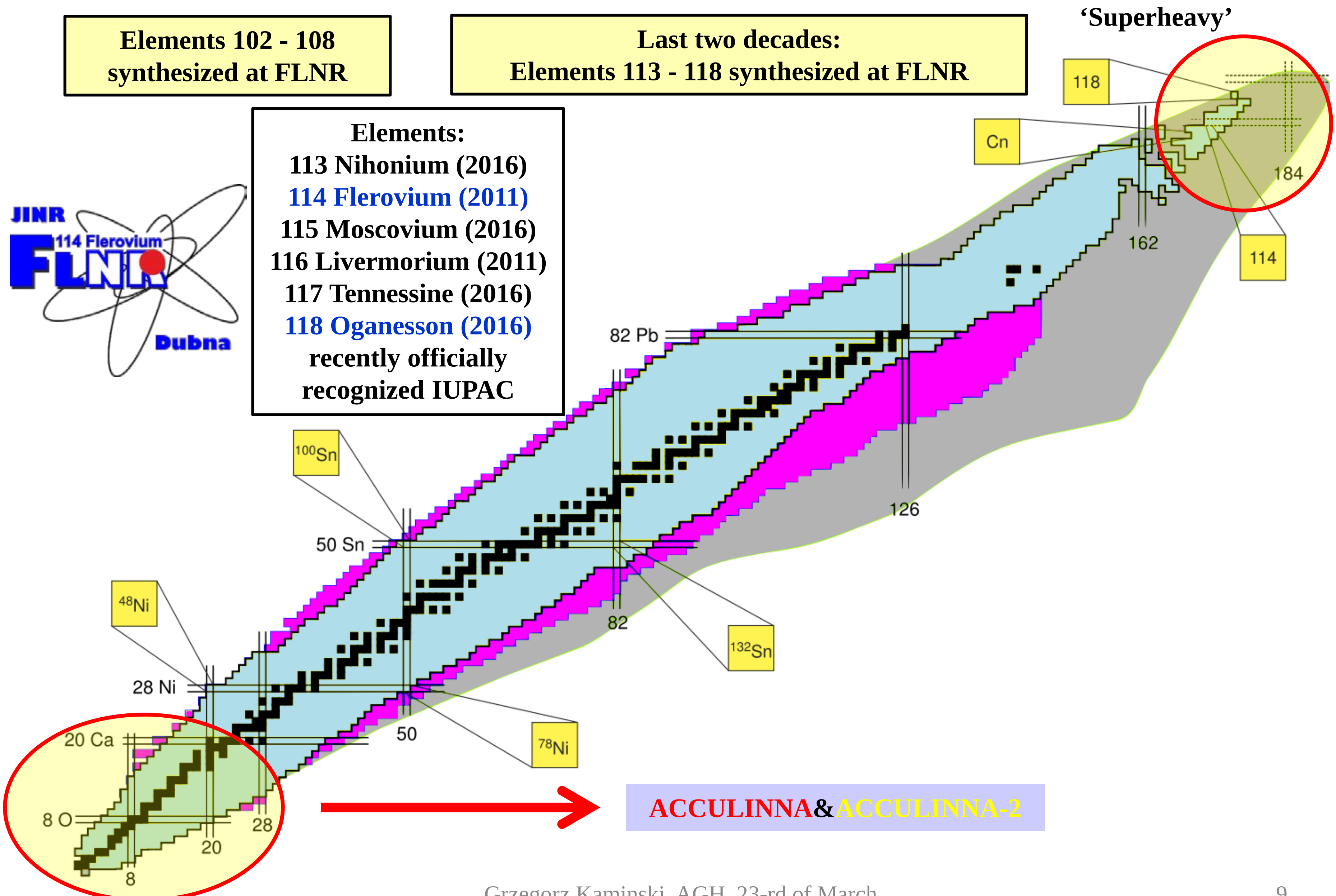
- ✓ Track membrans
- ✓ Nanostructures
- ✓ Study of materials properties
- ✓ Activations analysis



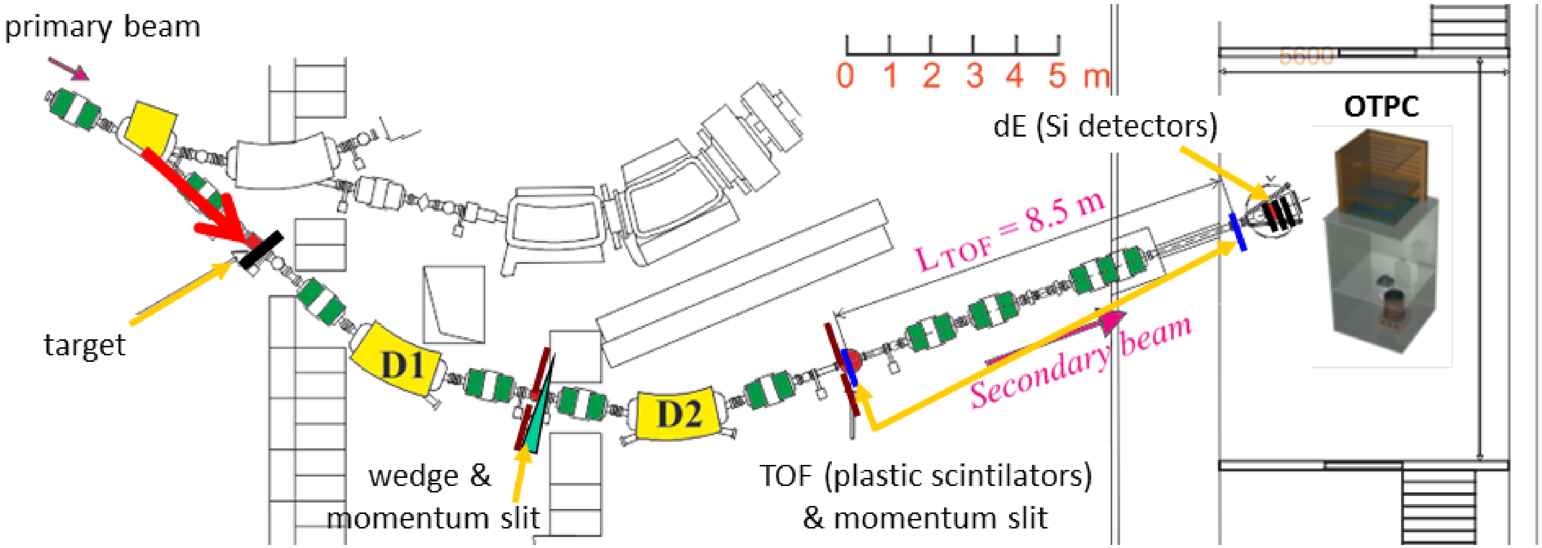
**Elements 102 - 108 synthesized at FLNR**

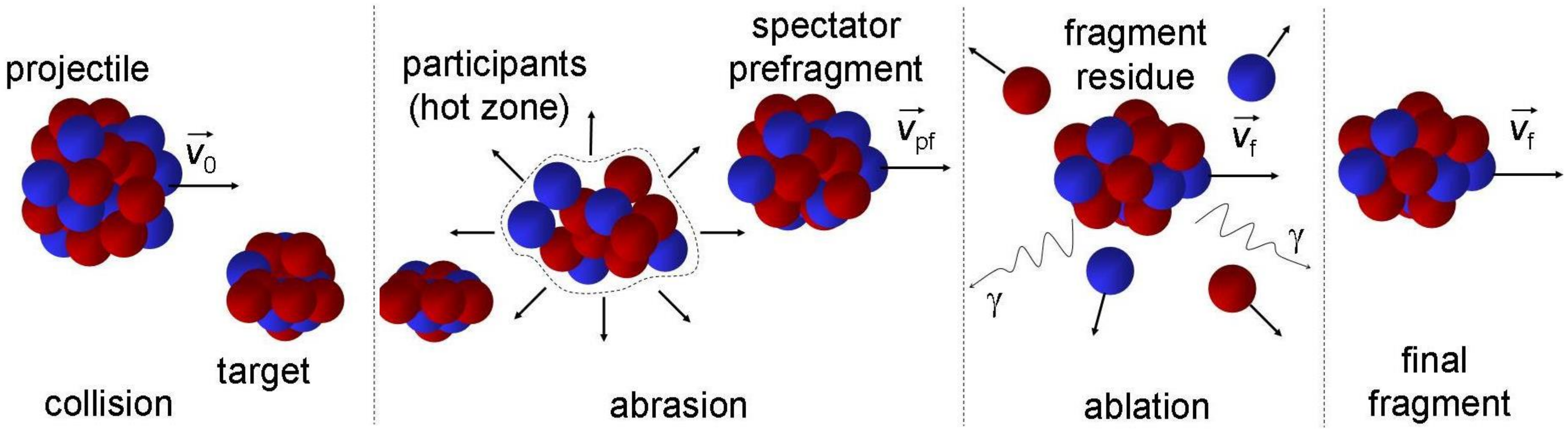
**Last two decades: Elements 113 - 118 synthesized at FLNR**

**Elements:**
**113 Nihonium (2016)**
**114 Flerovium (2011)**
**115 Moscovium (2016)**
**116 Livermorium (2011)**
**117 Tennessine (2016)**
**118 Oganesson (2016)**
**recently officially recognized IUPAC**



# RI beam production at ACCULINNA



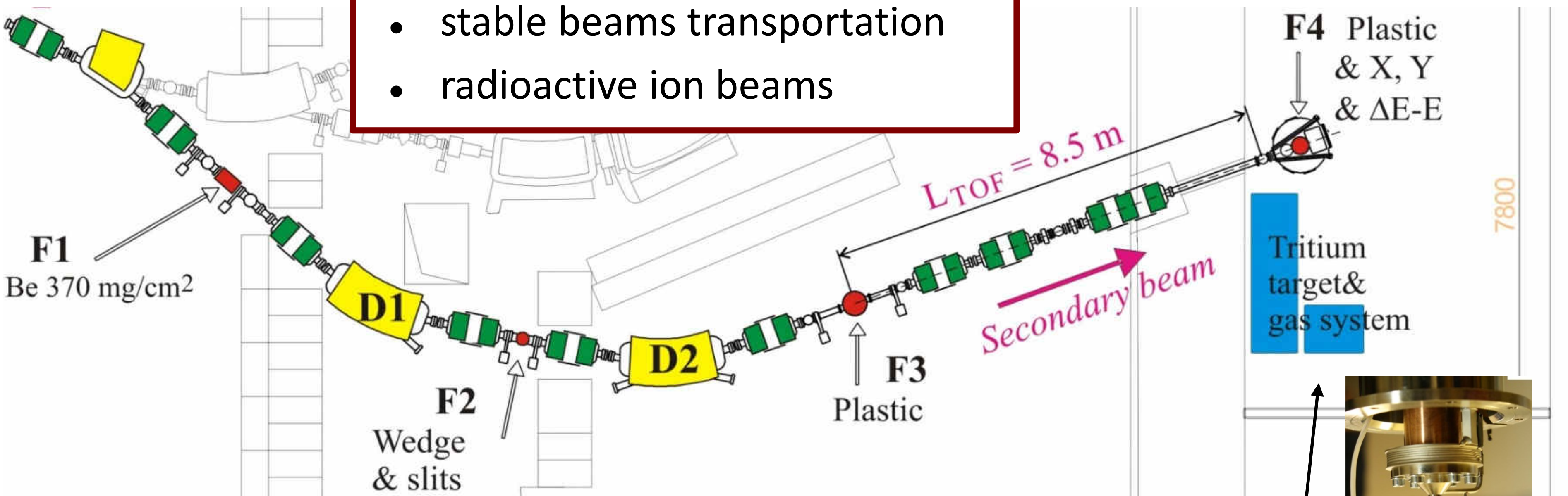

fast Abrasion step
nucleon removal in overlap region of target and projectile

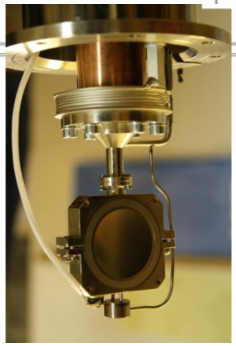
slow Ablation step
equilibration of excited prefragment and evaporation of particles

# RI beam production at ACCULINNA

**U–400M cyclotron:**
**$^{7}Li$, $^{11}B$, $^{18}O$ @ 33 AMeV**
**$^{20}Ne$, $^{32}S$ @ 50 AMeV**

- stable beams transportation
- radioactive ion beams



$$E_{beam} \sim 10 - 45 \text{ MeV/A}, \; I_{beam} \sim 10^{3} - 10^{6} \text{ pps}$$

- the only working RIB facility at JINR
- in-flight technique, TOF, ΔE/E, full kinematic
- beams up to $^{26}S$

unique combination of tritium beam and target

*** 1996 – first experiment**
**** 2000 – last upgrade**
***** 2011 – next step Acc.2**

# Key equipment of the ACCULINNA separator

✓Cryogenic tritium target system & correlation measurements

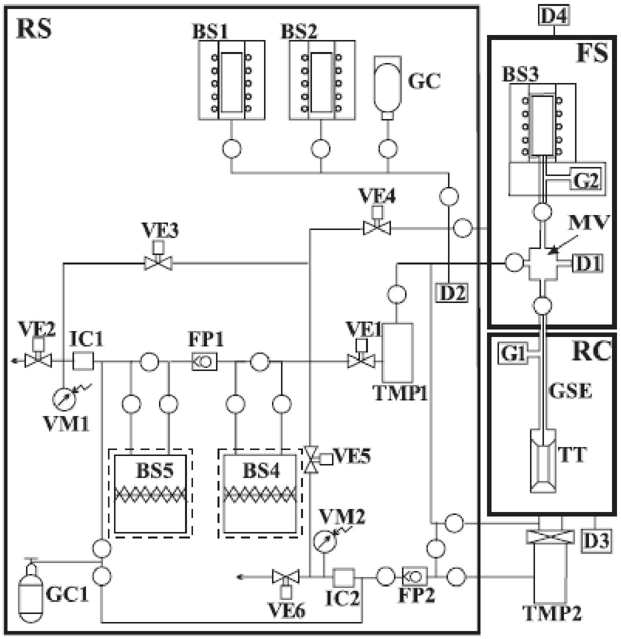
✓Neutron detection system – stilbene crystals

✓Optical Time Projection Chamber (OTPC) at ACCULINNA (developed @ University of Warsaw)

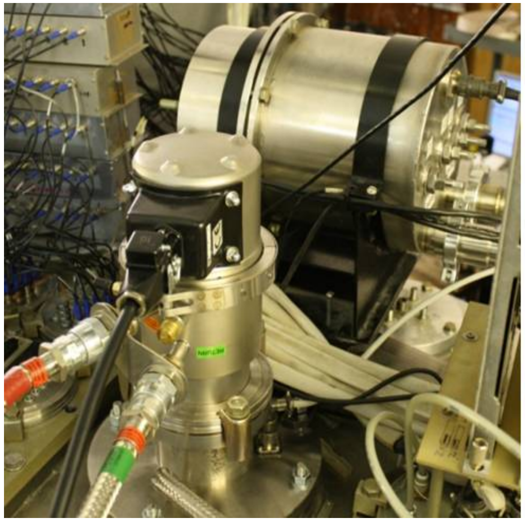
Cryogenic tritium target

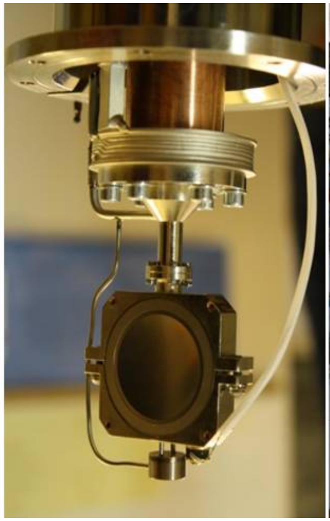
charged particles detectors & neutron detectors, crystal size 80(∅) x 50 $mm^3$

# unique cryogenic target cell: $H_2$, He




Basic scheme of the complex.
FS—filling system; RS—tritium recovery and radiation monitoring system; RC—reaction chamber; TT—tritium target; GSE—gas supply/evacuation line; BS1(2)—hydrogen (deuterium) source; BS3—tritium source; BS4, BS5—traps; GC, GC1—helium gas-cylinders; D1, D2—pressure gauges; D3, D4—vacuum gauges; FP1, FP2—vacuum pumps (BOC EDWARDS GVSP 30); TMP1, TMP2—turbo pumps (STR-300M); MV—measuring vessel (270 cm3); G1, G2—getters; VE1–VE6 valves (open circles show all other valves); IC1, IC2—ionization chambers; VM1, VM2—vacuum gauges blocking the gas release in ventilation in excess of a given level of the gas-specific volumetric activity.



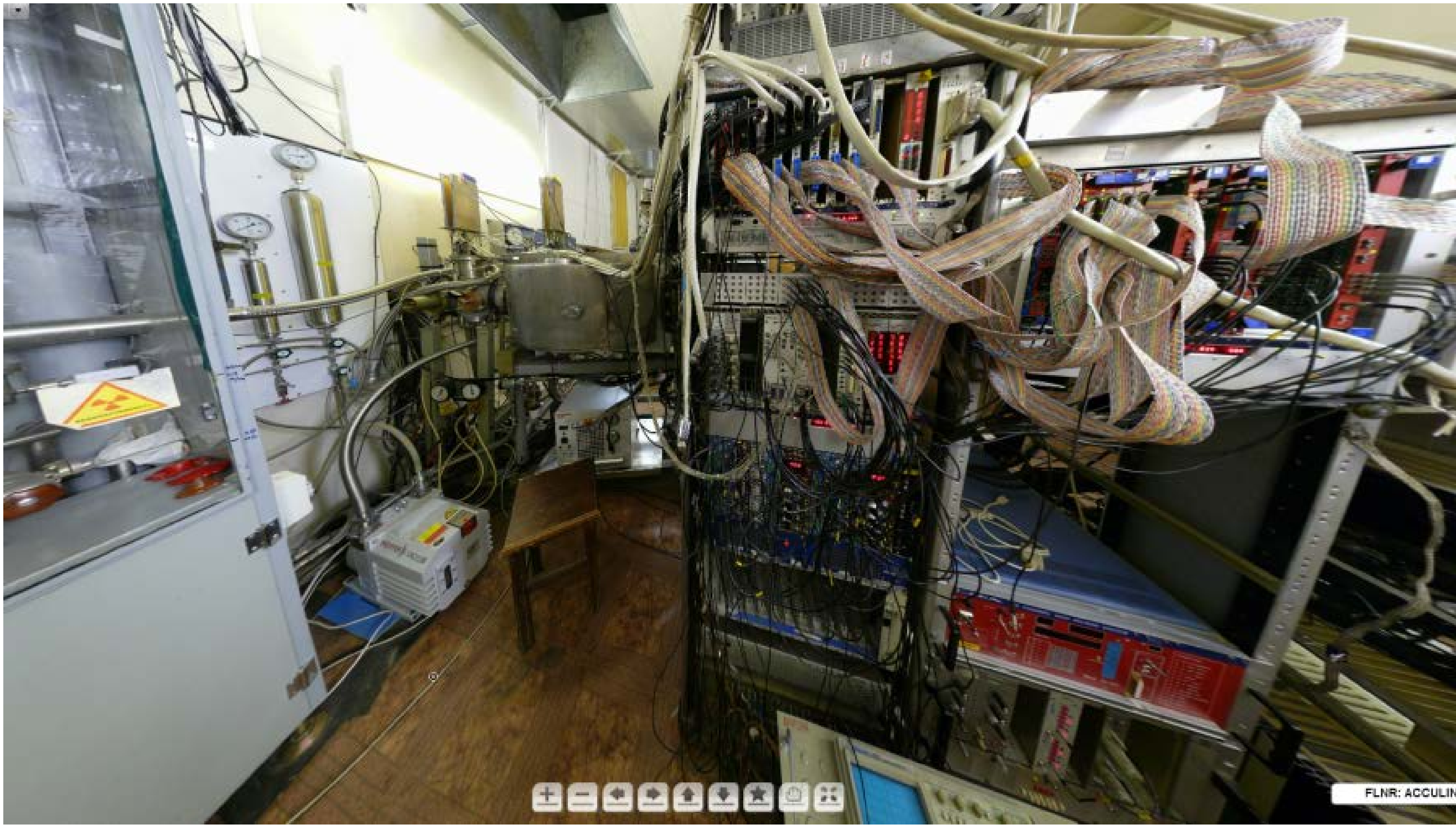


*A.A. Yukhimchuk et al.,*
**NIM A513 (2003) 439.**

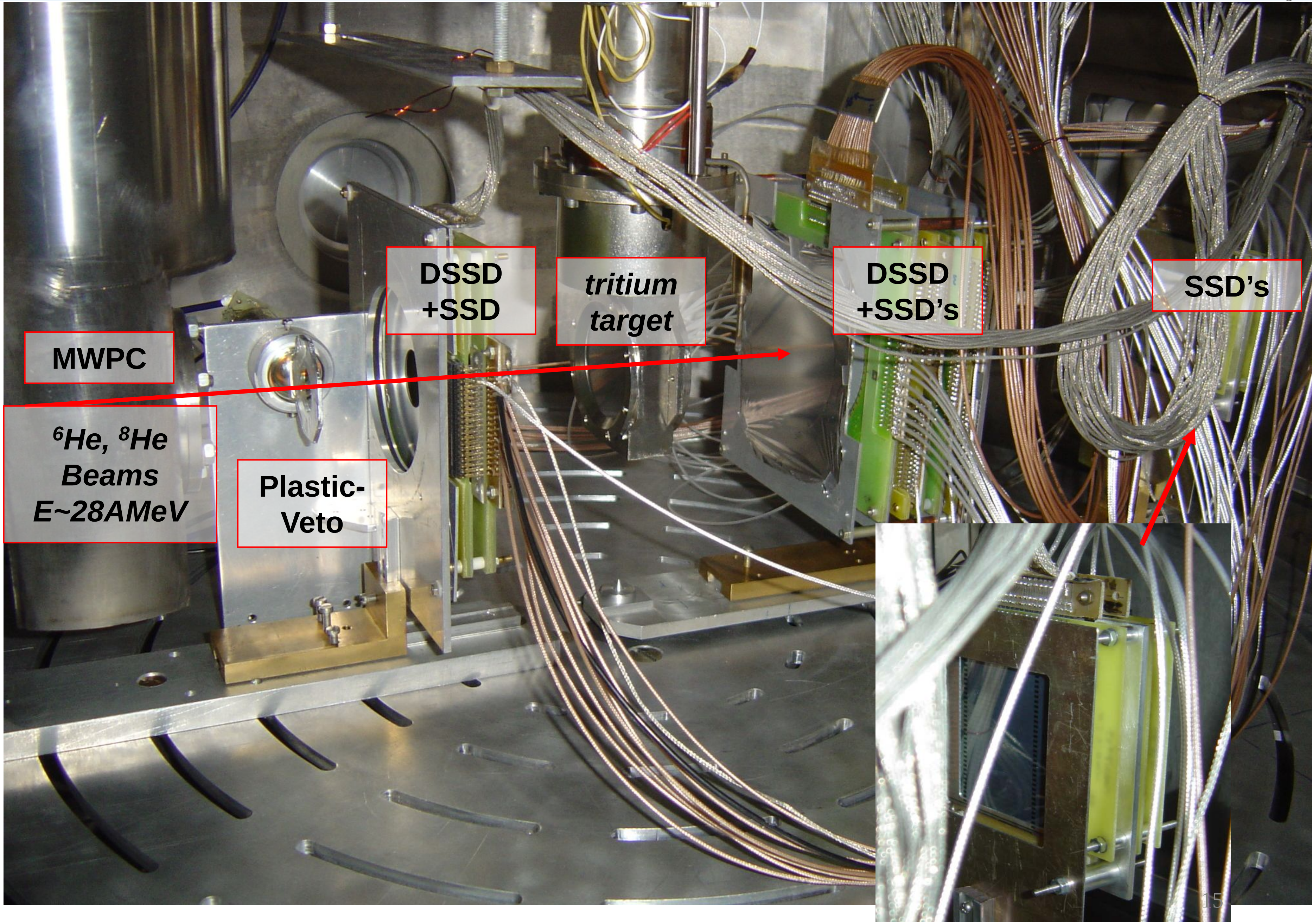
**Gas:**
**$\phi$=25 mm, d=3÷6 mm,**
**T=26 K, P=0.92 Atm,**
**$x=3*10^{20}$ Atm/cm$^2$**

**Liquid:**
**$\phi$=20 mm, d=0.4÷0.8 mm,**
**w=2x8.4 μ stainless steel,**
**$x=1.1*10^{21}$ Atm/cm$^2$**
**I ≤ 960 Ci ($3.54*10^{13}$ Bq)**

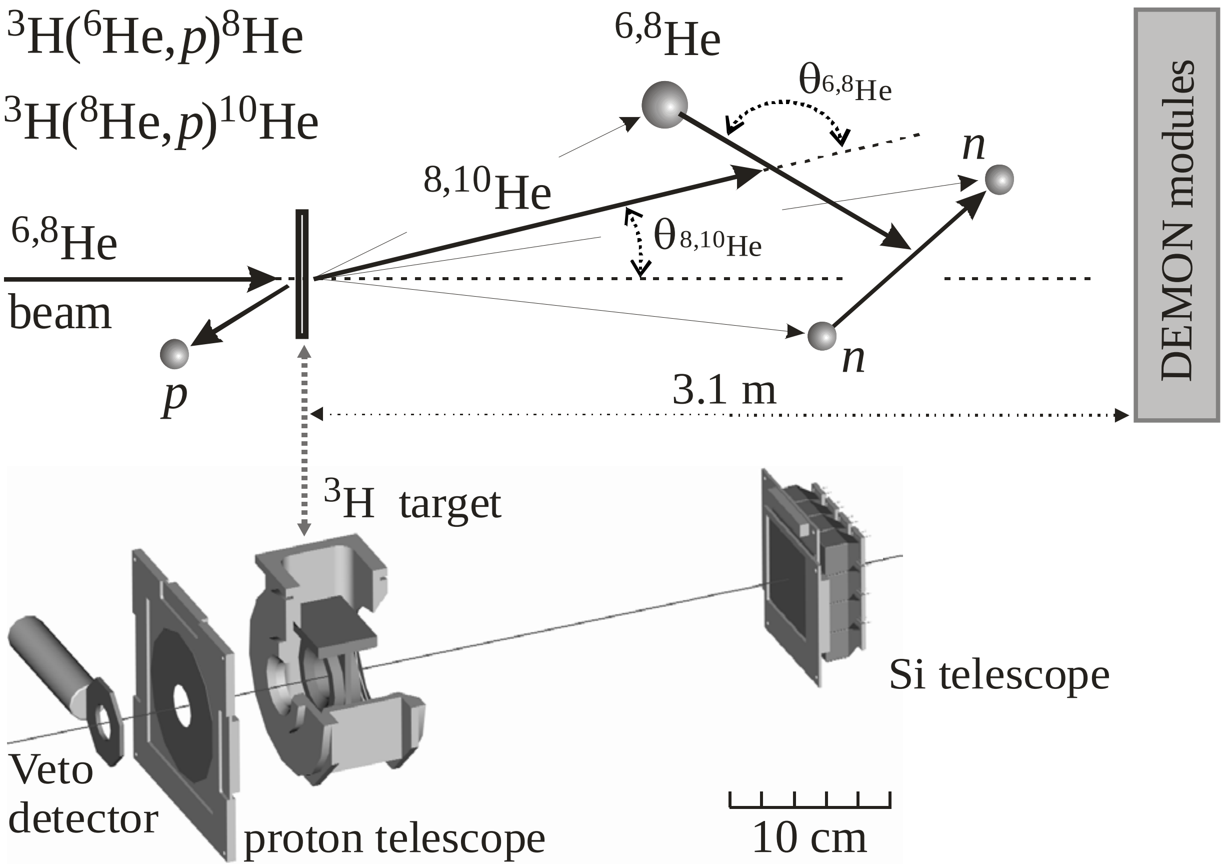
# experimental area: reaction chamber, detectors and DAQ



# $^{8}He$&$^{10}He$: $^{3}H(^{6}He,p)^{8}He$ & $^{3}H(^{8}He,p)^{10}He$ reactions



# $^{8}$He&$^{10}$He: $^{3}$H($^{6}$He,p)$^{8}$He & $^{3}$H($^{8}$He,p)$^{10}$He reactions



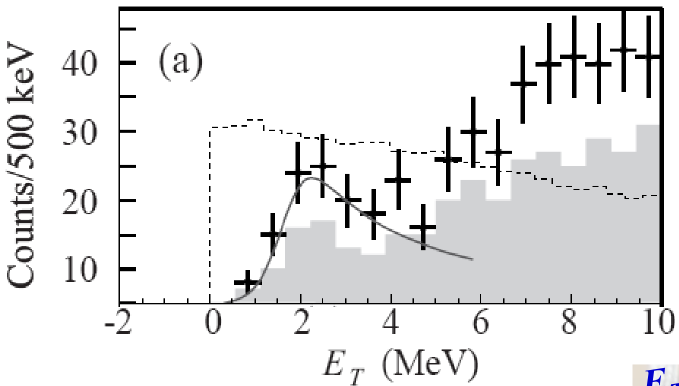

***Features:***

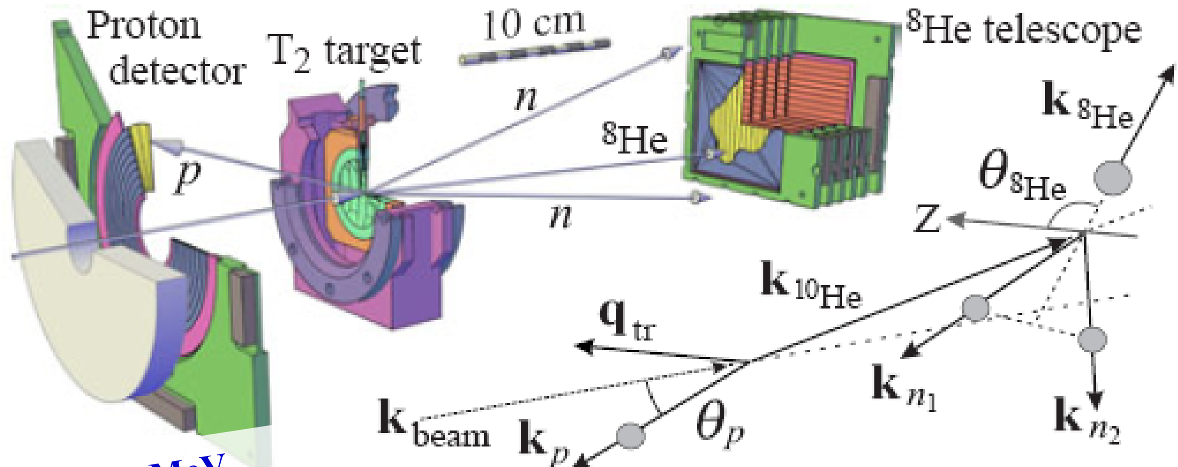
***Reasonable energy resolution ΔE~400 keV (FWHM)***

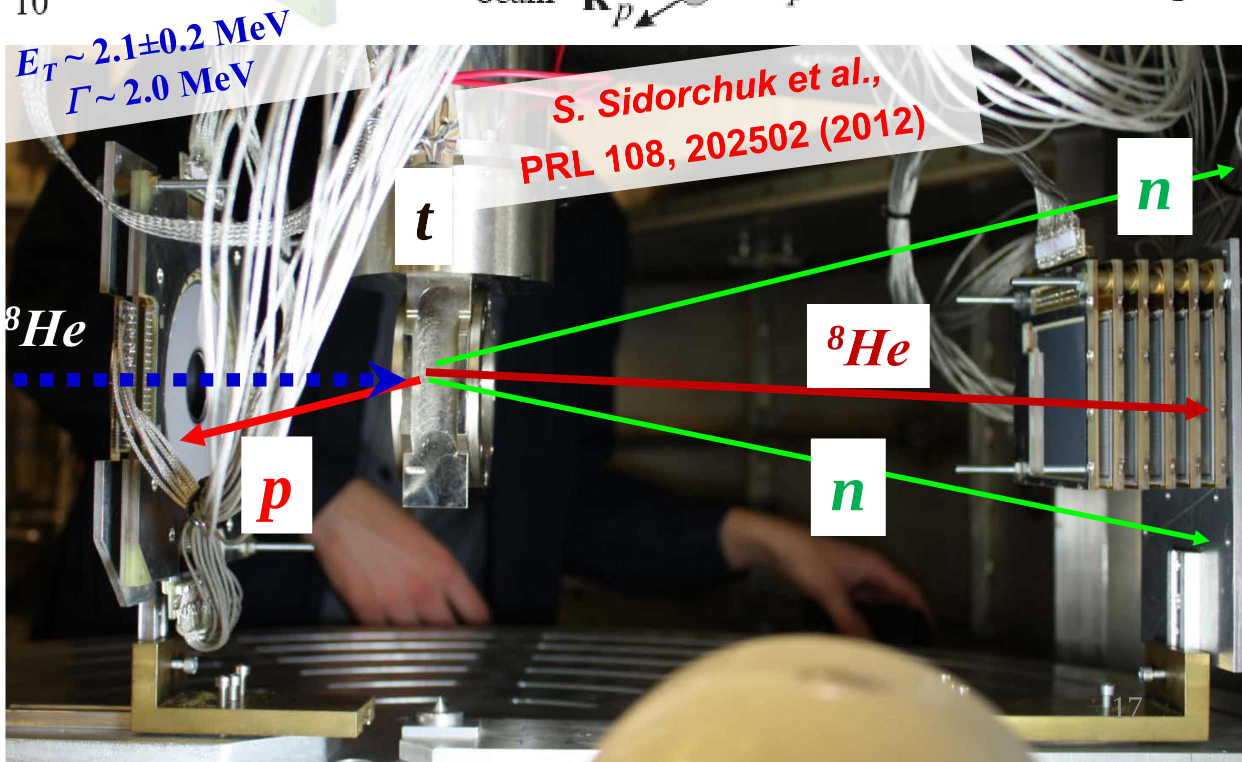
***Practically background free: very few protons go in the backward lab direction***

- Slow protons registered in the backward direction, what limits the maximal $^{8}$He and $^{10}$He excitation energy to about 14 and 17 MeV.
- $^{8,10}$He registered in the forward telescope. Neutrons are registered by 49 DEMON modules.
- It’s complete kinematics reconstruction.

# $^{10}$He: $^{3}$H($^{8}$He,p)$^{10}$He

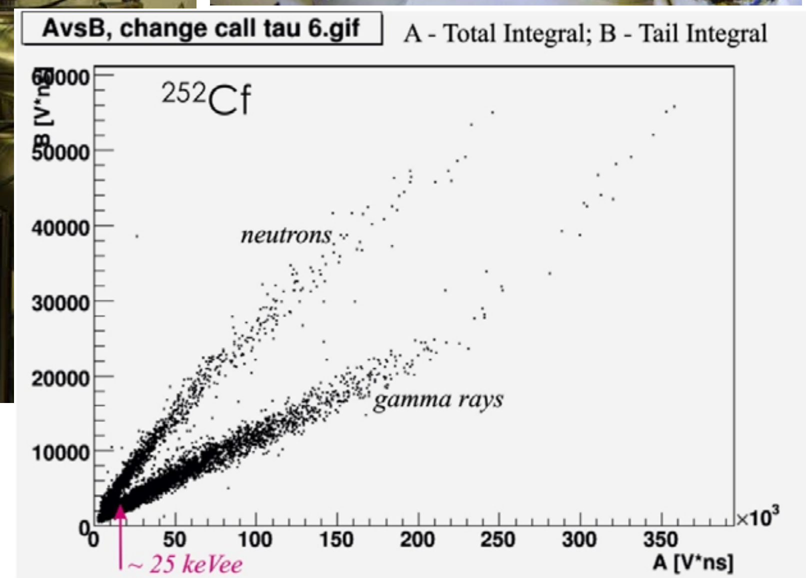


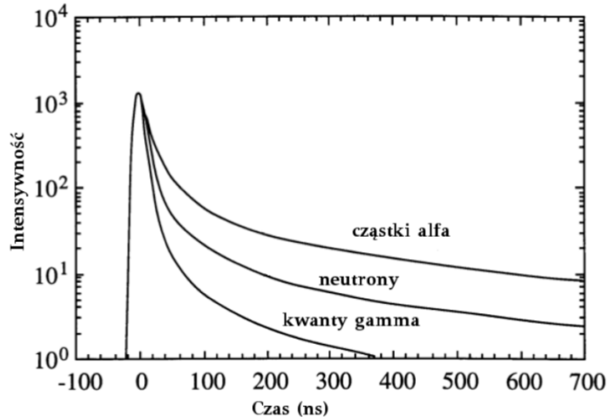

$^8$He beam:
E ~ 23 A·MeV
I ~ 15000 s$^{-1}$
Tritium target:
6 mm thick @ 99.7 %
0.92 atm @ 26 K

# Neutron detection

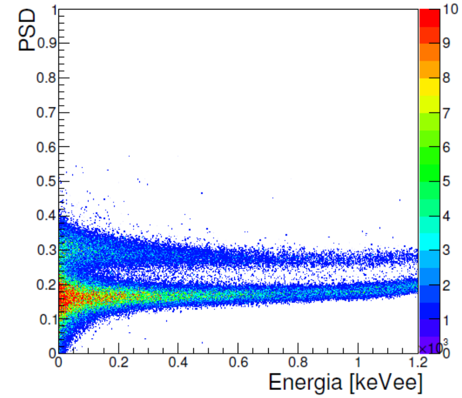



neutron detection array based on stilbene crystals

# Neutron detection & Master Thesis




Differences in shape of the signals
from alphas, neutrons and gamma rays




Pulse shape shape discrimination analysis
of neutrons and gamma signals

AGH
Akademia Górniczo-Hutnicza im. Stanisława Staszica w Krakowie
Wydział Fizyki i Informatyki Stosowanej

**Praca magisterska**

**Marcin Mentel**

kierunek studiów: **fizyka techniczna**
specjalność: **fizyka komputerowa**

**Analiza sygnałów systemu akwizycji danych z neutronowych detektorów na bazie cyfrujących modułów oscyloskopowych CAEN**

Opiekunowie: **dr inż. Krzysztof Malarz**
**dr Grzegorz Kamiński**

**Kraków, lipiec 2013**

AGH
Akademia Górniczo-Hutnicza im. Stanisława Staszica w Krakowie
Wydział Fizyki i Informatyki Stosowanej

**Praca magisterska**

**Piotr Pluciński**

kierunek studiów: **Fizyka Techniczna**
specjalność: **Fizyka Komputerowa**

**Wielomodułowy system detekcji neutronów w standardzie VME**

Opiekunowie: **dr inż. Krzysztof Malarz**
**dr Grzegorz Kamiński**

**Kraków, lipiec 2013**

AGH
Faculty of Physics and Applied Computer Science

**Master thesis**

**Bartłomiej Hnatio**

major: **Applied Computer Science**
specialisation: **Computer Methods in Science and Technology**

**Simulation and data analysis framework for nuclear physics experiment**

Supervisor: **Krzysztof Malarz, Ph.D.**
Co-supervisor: **Vratislav Chudoba, M.Sc.**

**Dubna, June 2013**

# Study of exotic nuclei in FLNR at the low RI energies

Use of the **ACCULINNA** fragment separator **has Advantages:**

• The **record intensity** of the primary cyclotron beams (5 pμA of $^{11}B$);
• Relatively (to in-flight separators) **low beam energies**, that provide a good energy resolution, high reaction cross section partly compensate the low intensities of secondary beams.
• These **beam energies are optimal** for the nuclear structure studies in transfer, charge-exchange reactions;
• **Complete kinematics method** allows for clean, background-free spectra;
• **Correlation studies** provides possibilities for spin-parity identification of the resonance states.

**ACCULINNA** open **possibilities** for wide range of experiments
• correlation experiments
• lifetime measurements
• spectroscopic structure studies
• search for new light exotic nuclei and exotic decays

Use of the **ACCULINNA** fragment separator **has its Disadvantages:**
• It is only efficient with **lightest neutron-rich nuclei**;
• Does not cope with the request of **high intensity clean beams** with Z>8;
• We need **more powerful detector rays**, and a bigger experimental area (for TOF);
• **Small length of the separator** puts limitation on the energy resolution;

# Some results @ ACCULINNA

In the recent years using ACCULINNA separator, new results were obtained for such isotopes as:

**$^{4}$H**[1], **$^{5}$H** [2-4], **$^{7}$H** [5], **$^{6}$He** [10], **$^{8}$He** [6], **$^{9}$He** [7], **$^{26}$S** [8], **$^{6}$Be** [9] and **$^{10}$He** [6, 11]:


[1] S.I. Sidorchuk *et al.*, Phys. Lett. B 594 (2012) 54;

[2] A.A. Korsheninnikov *et al.*, Phys. Rev. Lett. 87, 092501 (2001);

[3] M.S. Golovkov *et al.*, Phys. Lett. B 566, 70 (2003);

[4] M.S. Golovkov *et al.*, Phys. Rev. Lett. 93, 262501 (2004);

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

[6] M.S. Golovkov *et al.*, Phys. Lett. B 672, 22 (2009);

[7] M.S. Golovkov *et al.*, Phys. Rev. C 76, 021605(R) (2007);

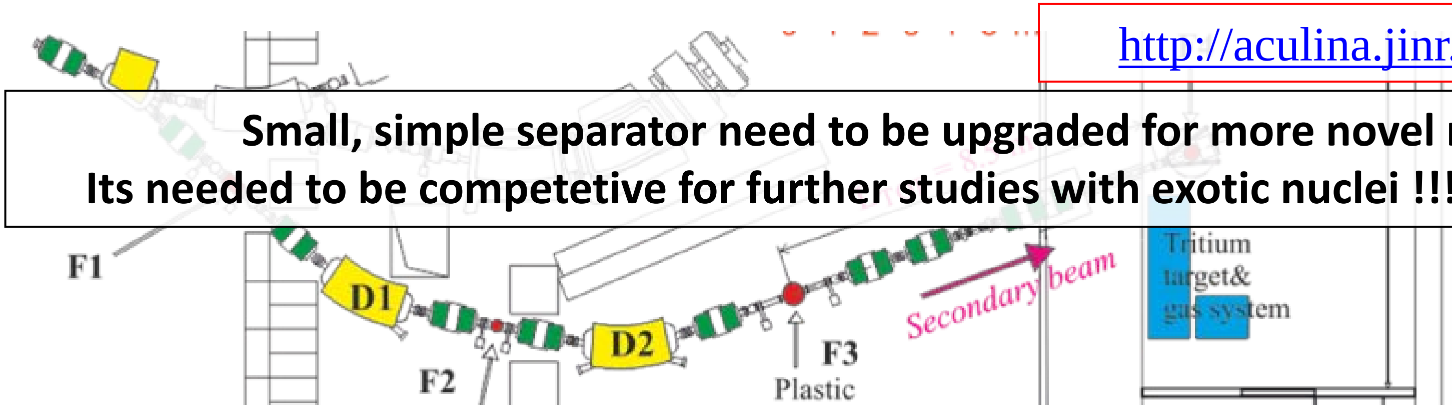
[8] A.S. Fomichev *et al.*, Int. J. Mod. Phys. E 20, 1491 (2011);

[9] A.S. Fomichev *et al.*, Phys. Lett. B 708, 6 (2012);

[10] S.I. Sidorchuk *et al.*, Nucl. Phys. A 840, 1 (2010);

[11] S.I. Sidorchuk *et al.*, Phys. Rev. Lett. 108, 202502 (2012).


http://aculina.jinr.ru -> publications

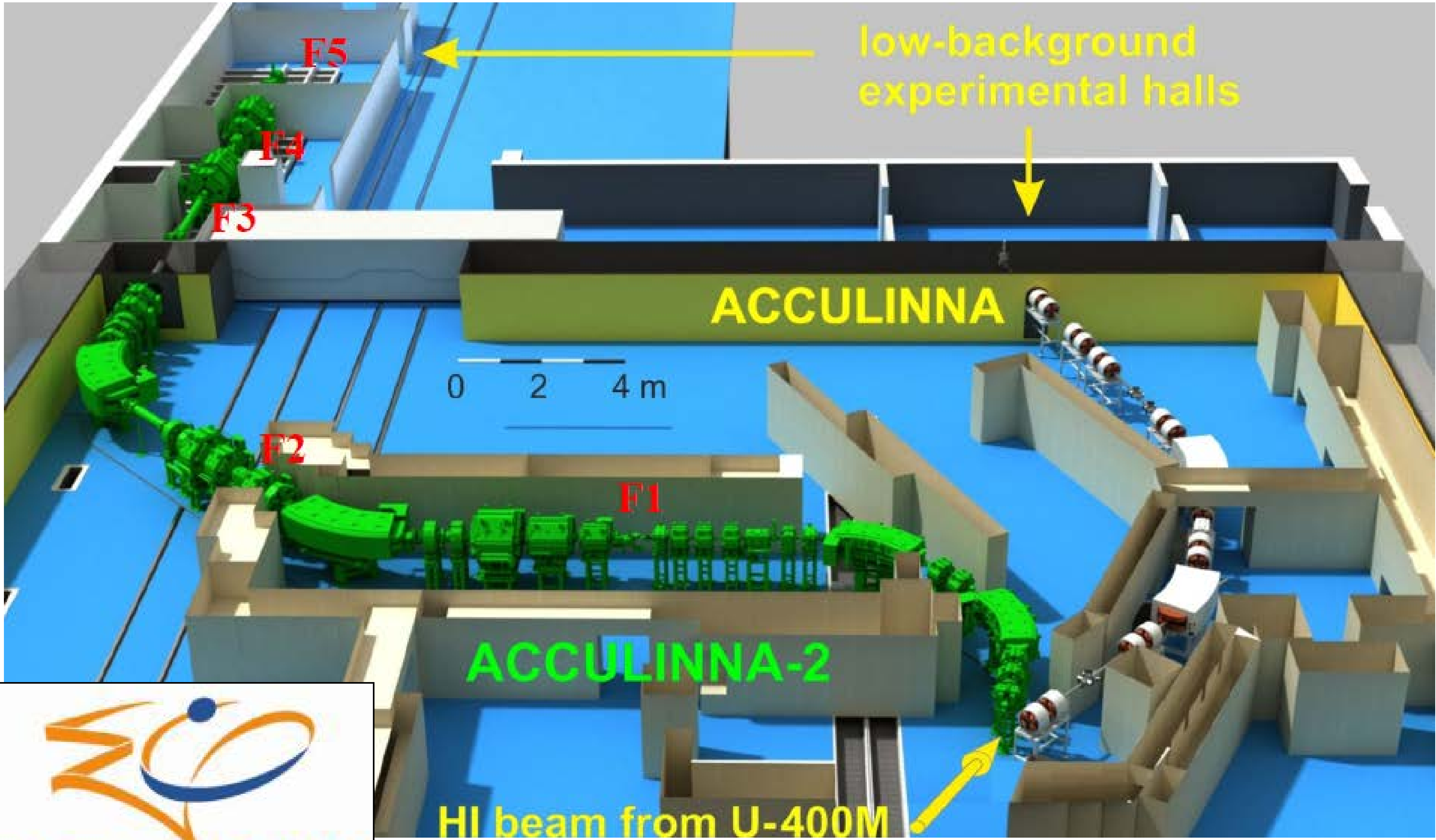



**Small, simple separator need to be upgraded for more novel results !!!**
**Its needed to be competetive for further studies with exotic nuclei !!! -> ACCULINNA-2**

A new separator ACCULINNA-2

Contract with SIGMA PHI to design and instalation of the ACC-2: 2011 - 2015

# Layout of ACCULINNA-2



# ACCULINNA-2 in perspective

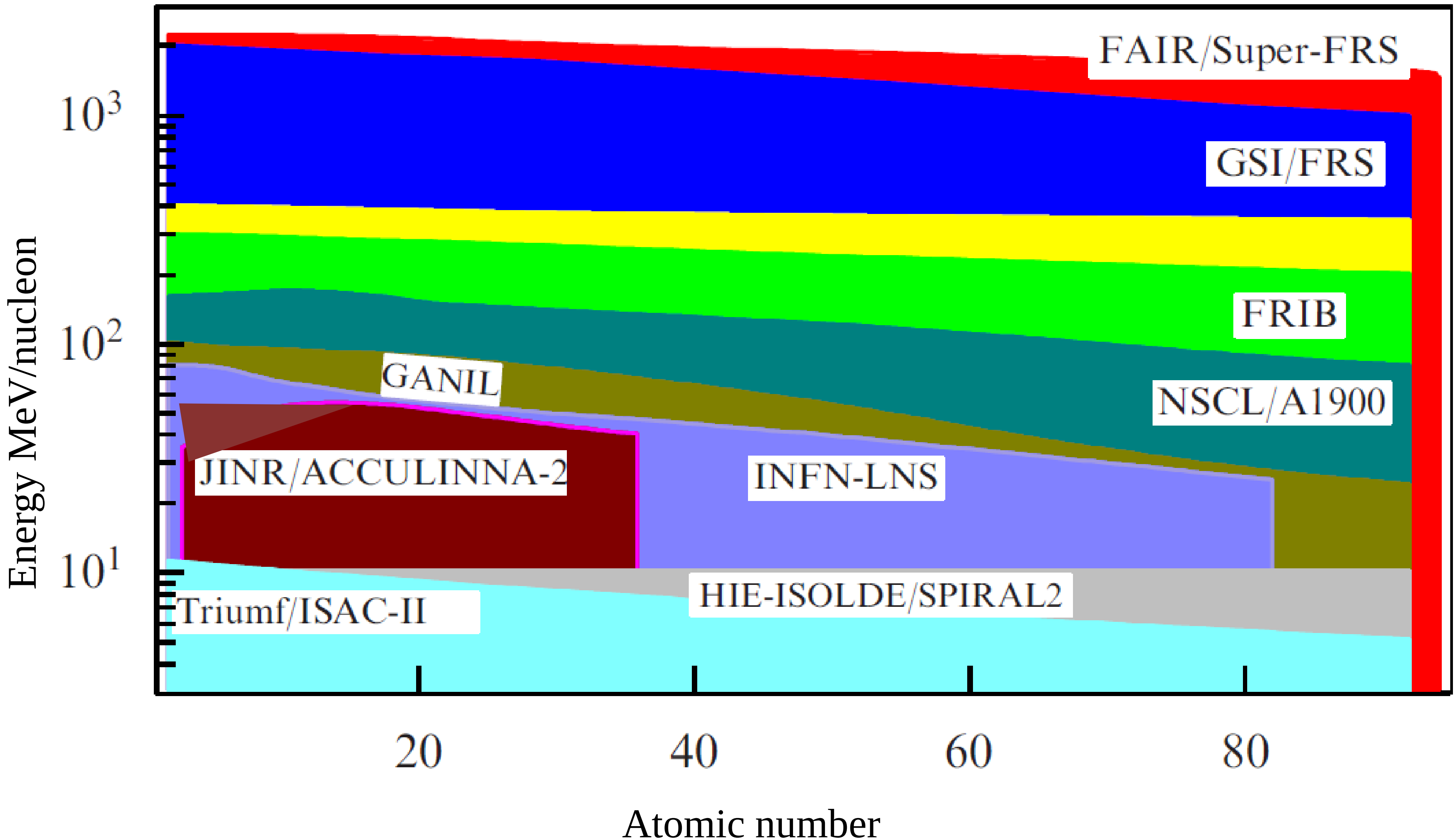
**Characteristics of existing and new in–flight RIB separators**

**(ΔΩ and Δp/p are angular and momentum acceptances, Rp/Δp 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 |
|---|---|---|---|---|---|
| ΔΩ, msr | 0.9 / 5.8 | 5.0 / 8.0 | 8.0 | 0.32 / 5.0 | 1.0 |
| Δp/p, % | ± 2.5 / ± 3.0 | ± 3.0 / 6.0 | ± 5.5 | ± 2.0 / 5.0 | ± 5.0 |
| Rp/Δp | 1000 / 2000 | 1500 / 3300 | 2915 | 8600 / 3050 | 2200 |
| Bρ, 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 | 10÷40 / 6÷60 | 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 |

# Beams and energies @ ACCULINNA-2

***… somewhere among other facilities***



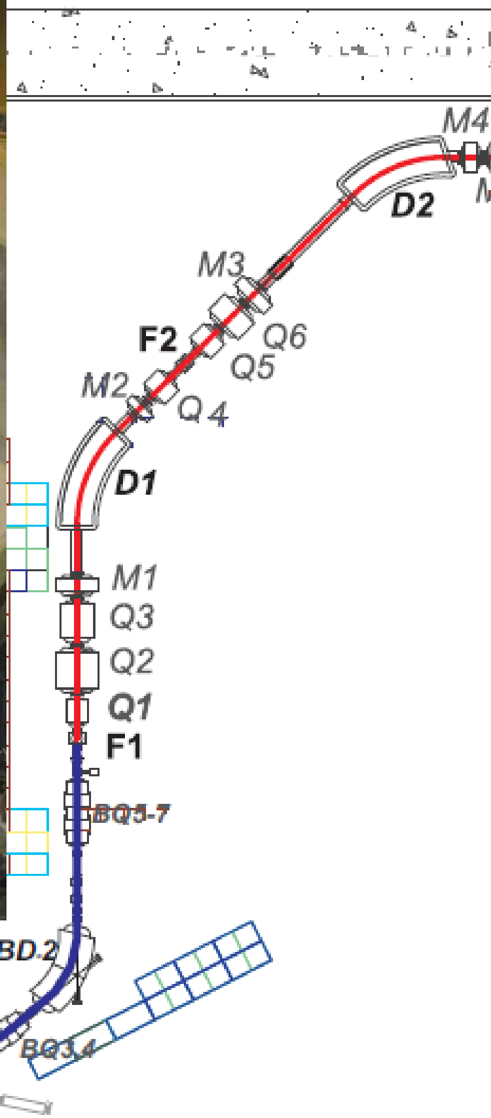
# RIBs from ACCULINNA-2

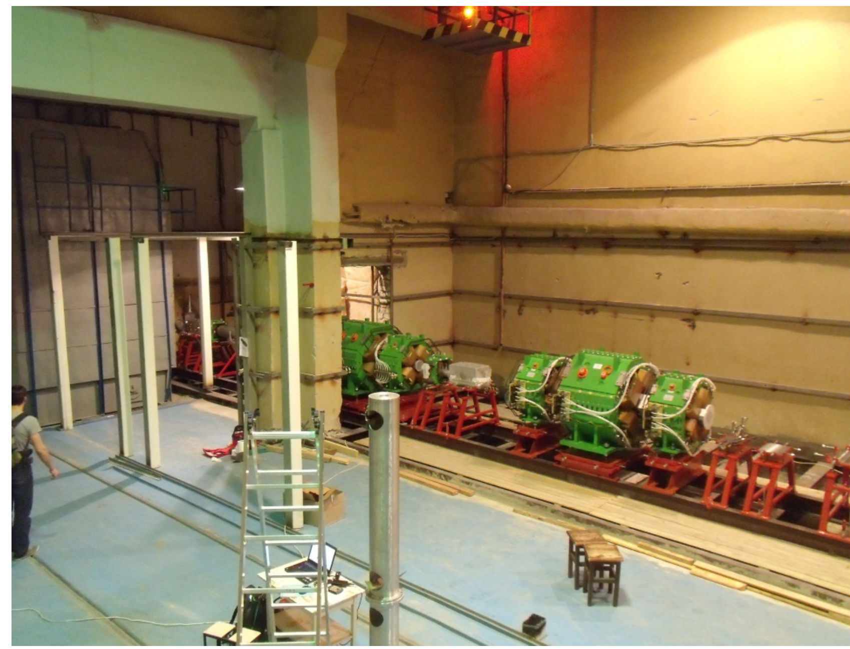
calculations done with LISE++

| 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) |

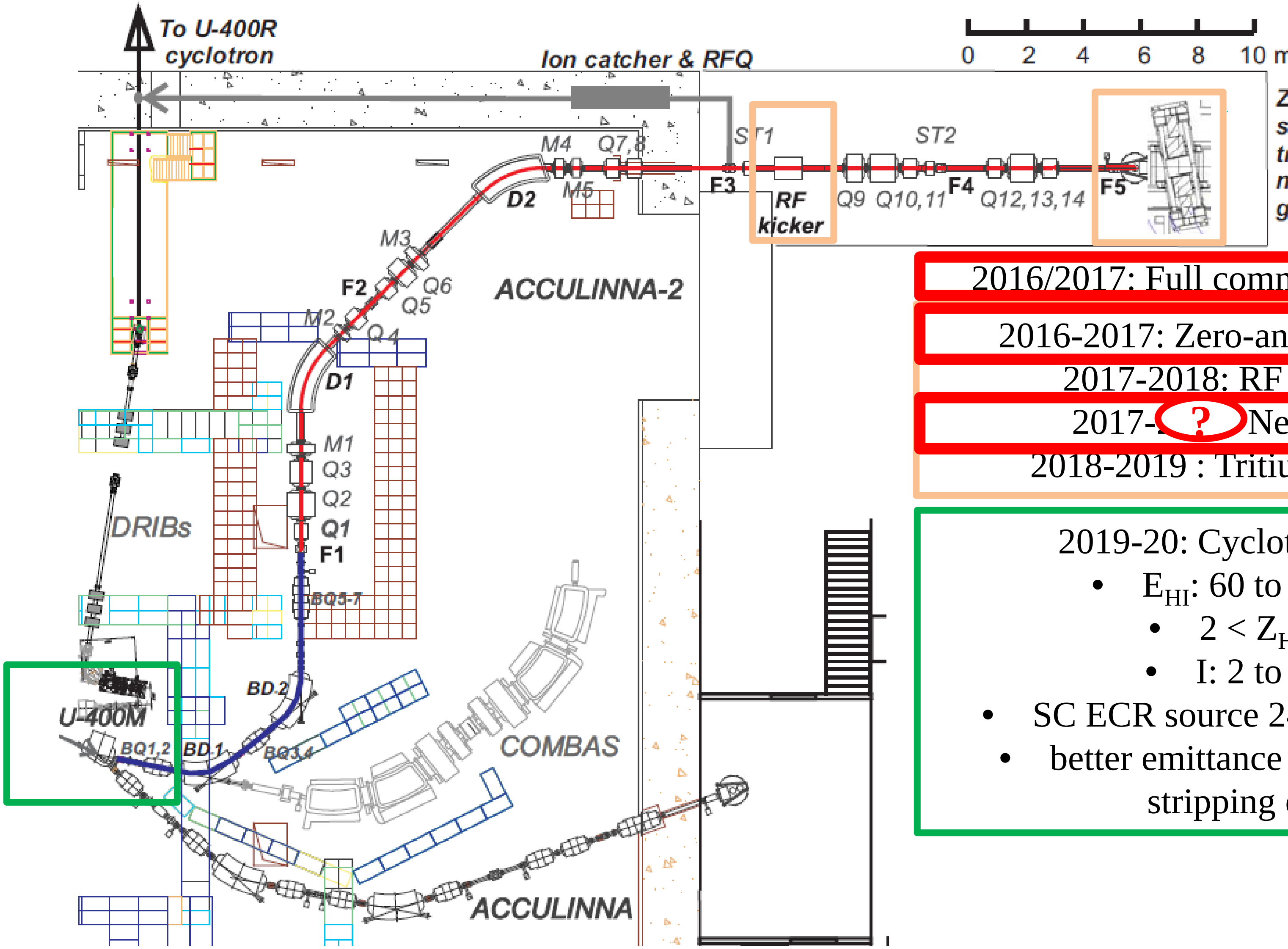
# Layout of ACCULINNA-2

**September 2015**



# ACCULINNA-2 project: timeline




2016/2017: Full commissioning + Beam

2016-2017: Zero-angle spectrometer

2017-2018: RF kicker at F3

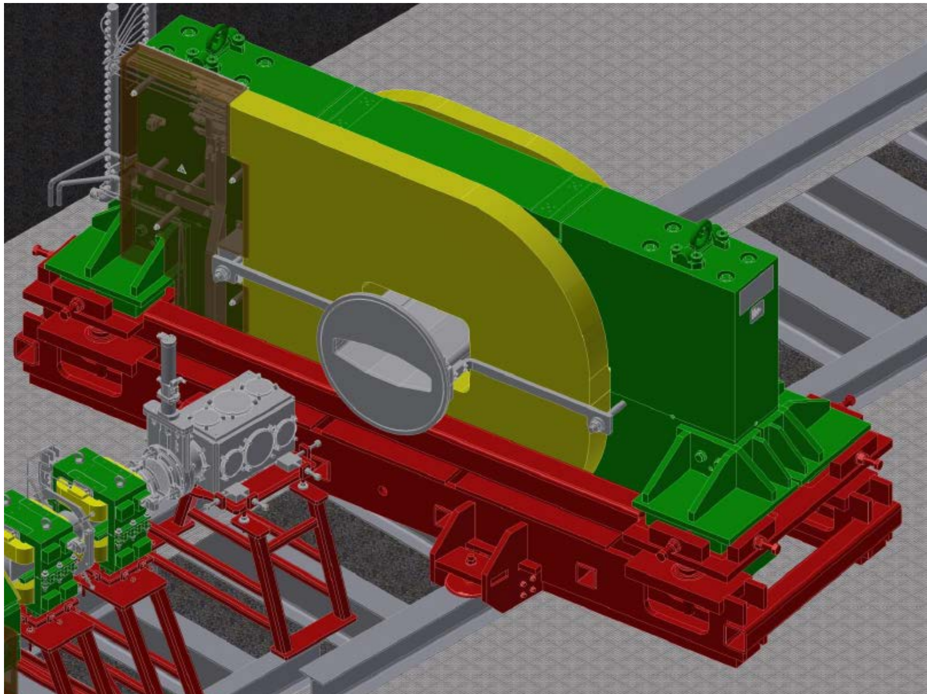
2017-? New detectors

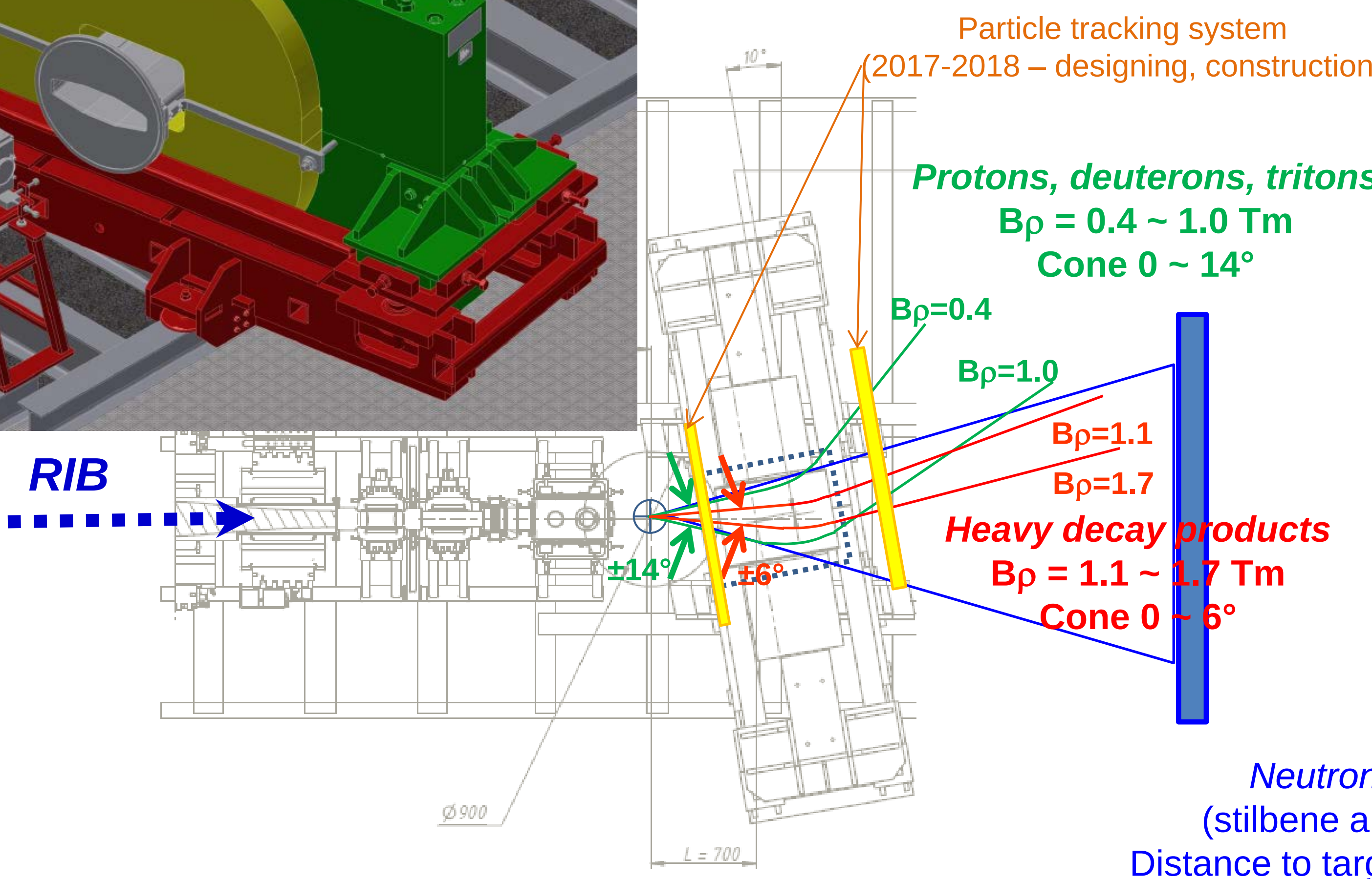
2018-2019 : Tritium target at F5

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 zero angle spectrometer

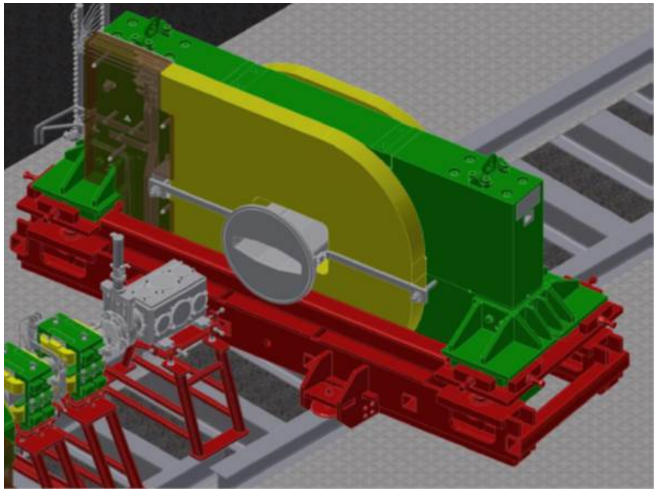





*Neutrons*
(stilbene array)
Distance to target > 2 m
TOF accuracy < 1%

# The zero angle spectrometer

Installation: February 2017, -20 °C outside temperature



*November 2017*

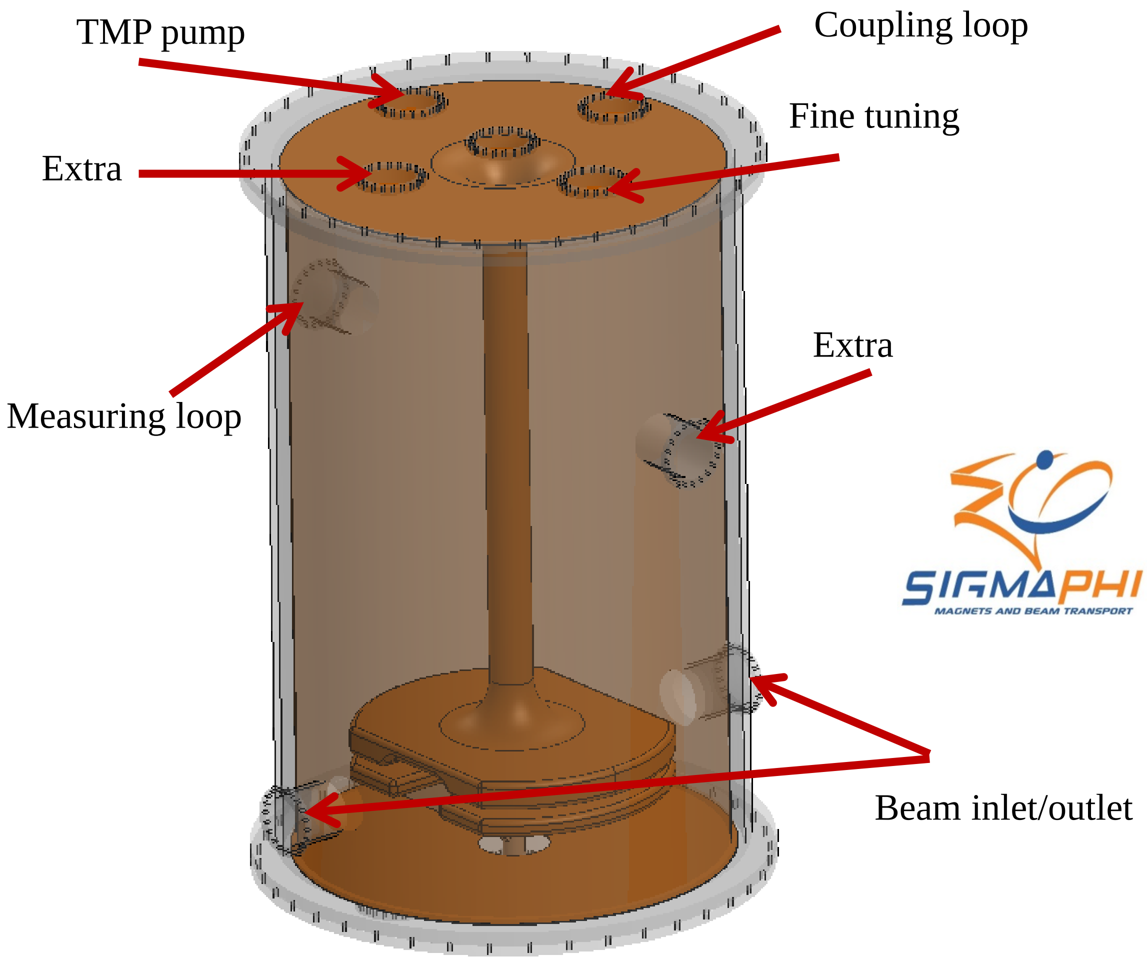
~ Half of the founds for Zero Degree spectrometer was supported by from Polish grants at JINR

# RF kicker: started in 2016, installation in the middle of 2018

- The frequency range 14,5 – 20 MHz is the best compromise in term of dimensions and RF power
- We consider some margin on the RF power and a 15 Kwatts amplifier.
- Reducing the copper cavity diameter to 1000 mm and the coaxial line diameter to 100 mm gives a RF power of 12 Kwatts which is still below 15 Kwatts.

## PARAMETERS AND CALCULATION RESULTS

| | |
|---|---|
| **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** |
| **Current at junction (A)** | **990** |
| **Current in short-cut (A)** | **1200** |
| **RF power (Watts)** | **10 000** |
| **Reactance Q** | **8 500** |
| **Df (RF tuning) (MHz)** | **0,66** |



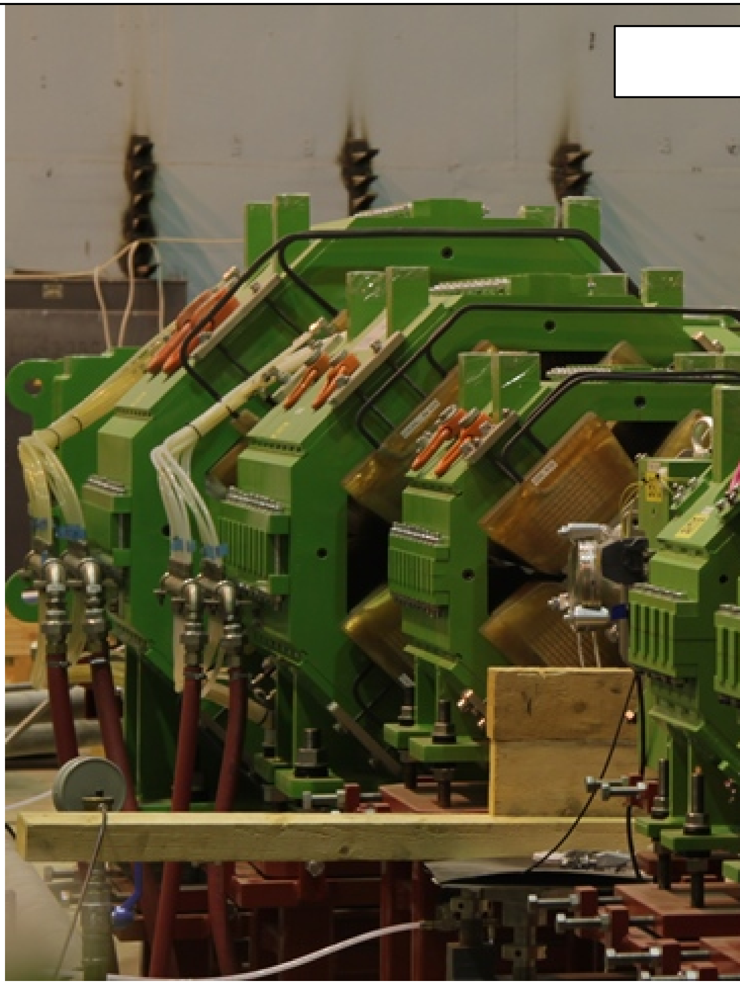
# Setup layout & Today status

*total length F0-F5 ~53m*
*39 magnetic elements*

# ACCULINNA-2 - status

Beam optics test and first radioactive ion beams in March, 2017

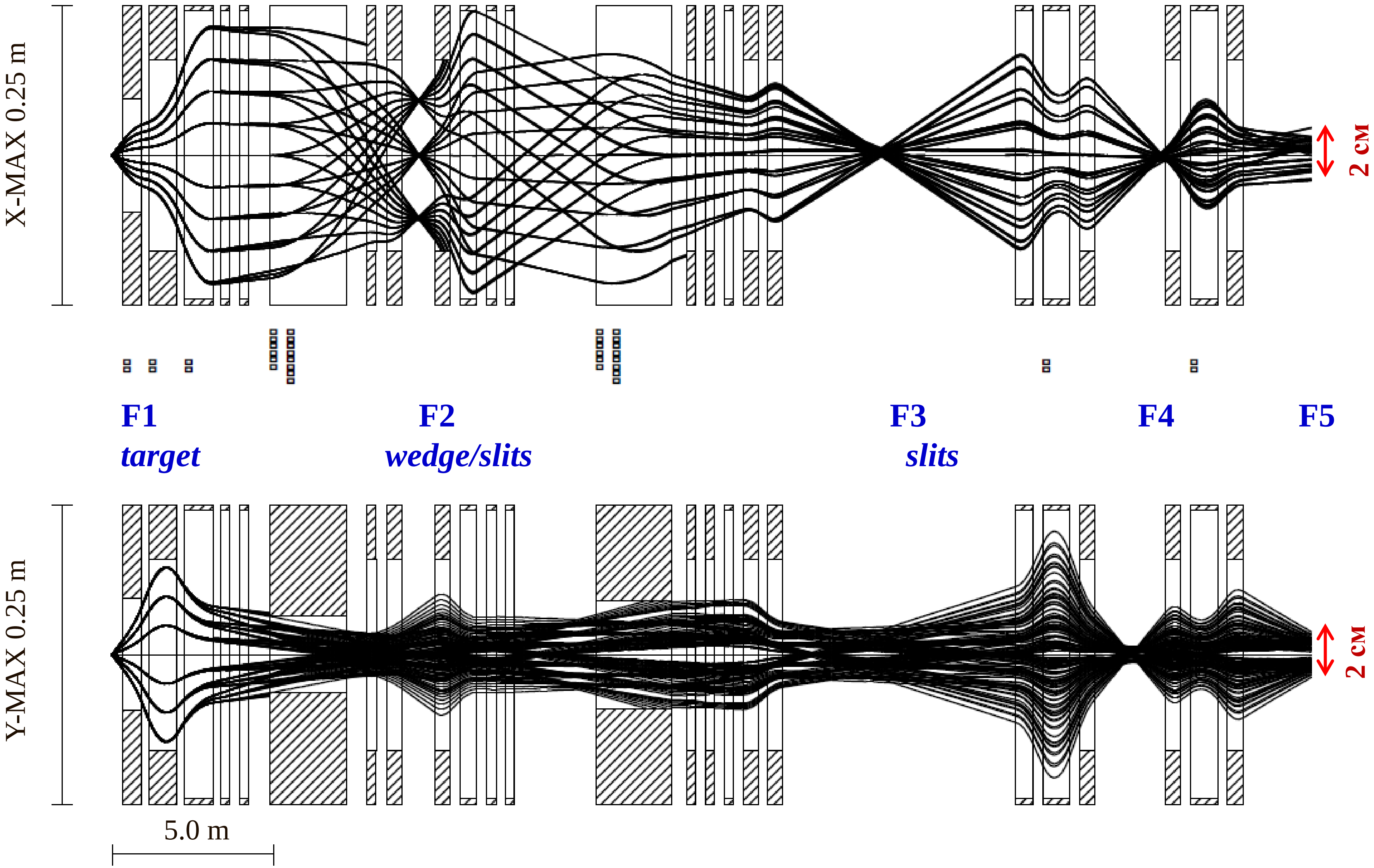
$^{15}N$(49.7 AMeV) +$^{9}Be$(2 mm), @ 1 pnA (7enA)



Polish visitors (**SLCJ UW**, **UW**, **PW**)

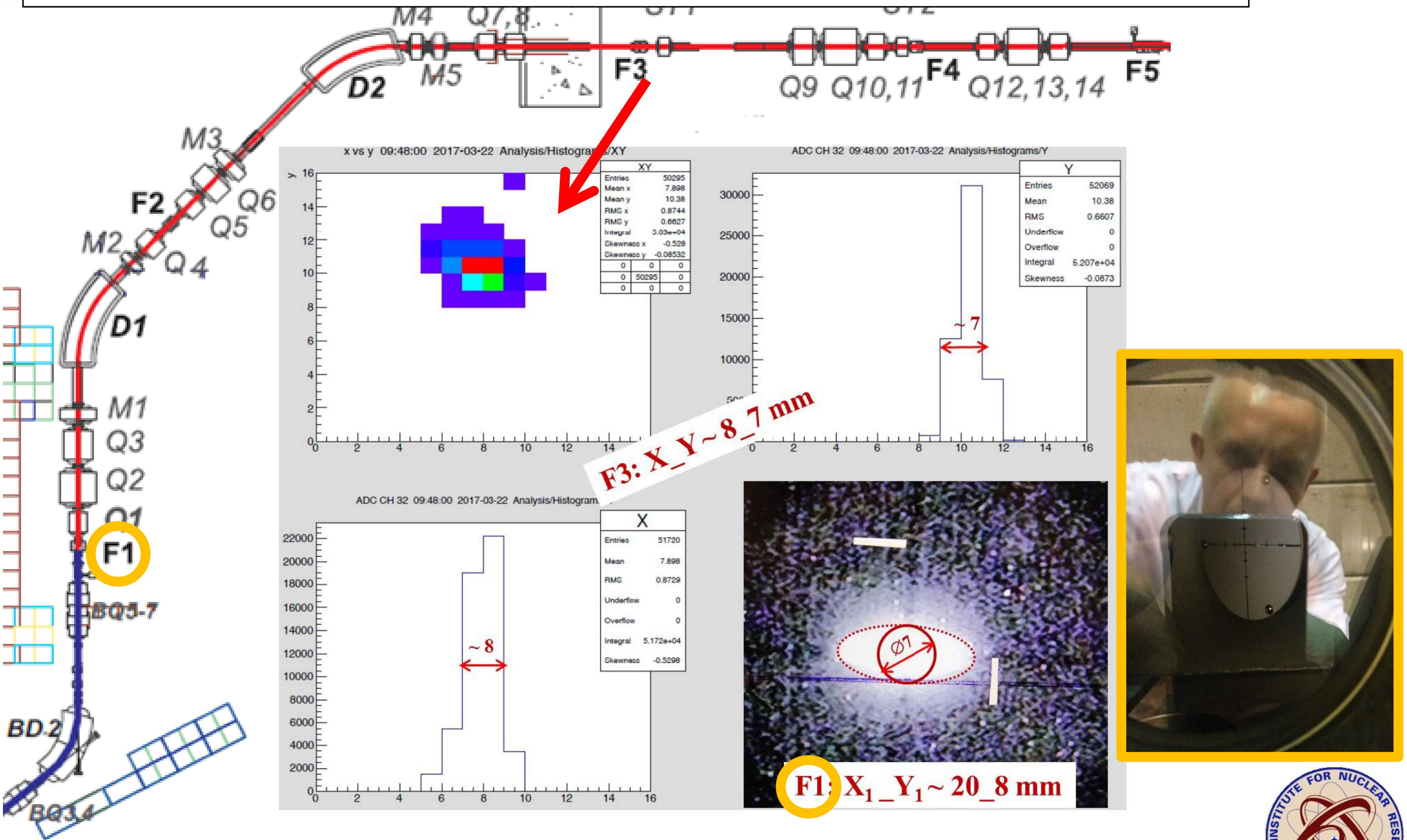
**Goals of the test in March 2017:**

- $^{15}$N profile at F3 depending on F1 diaph. (∅ 25, 12, 7 mm)
-- main parameters (I, P, X_Y) of some RIBs at F3, F4, F5



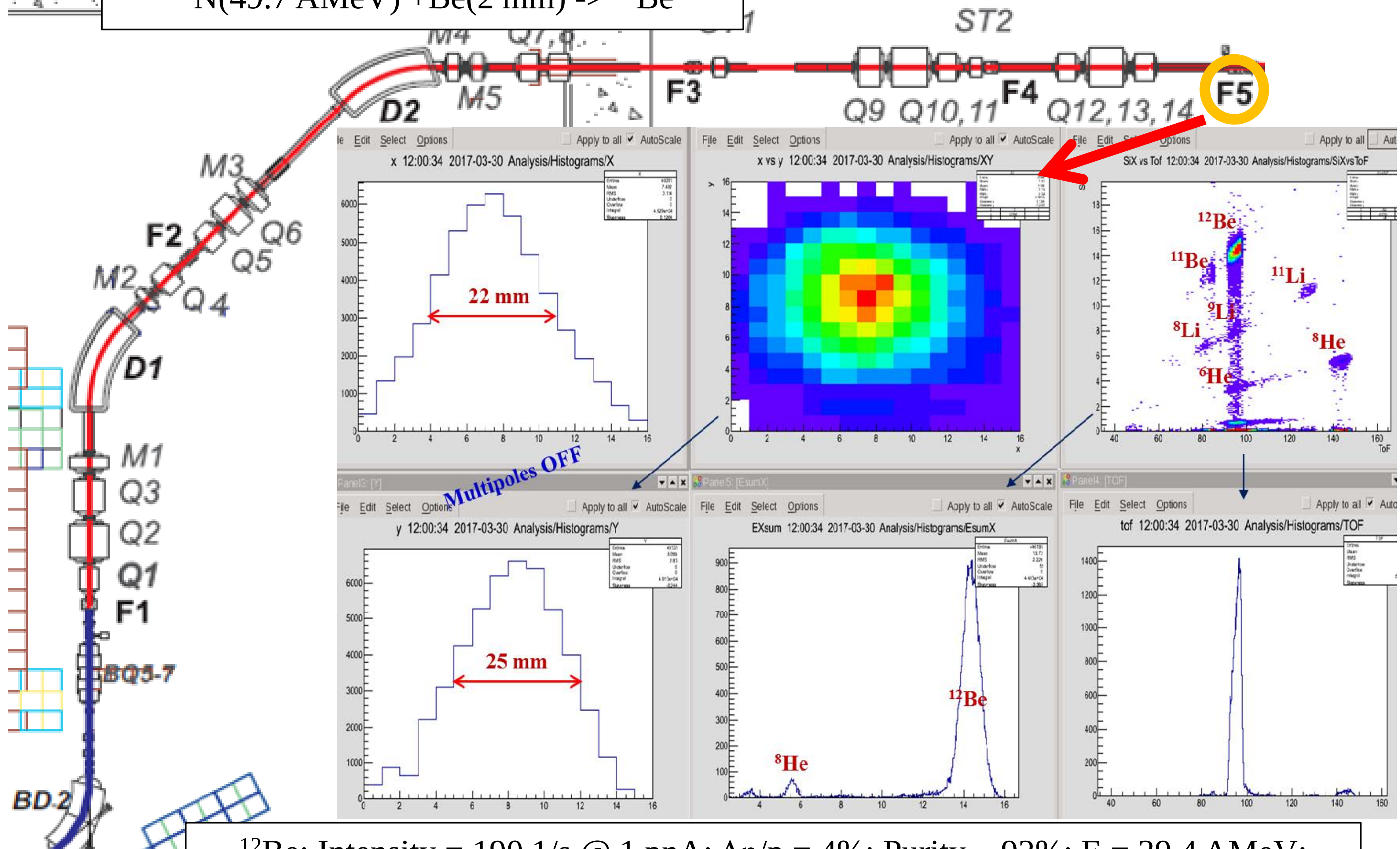

RIB’s profile estimation in $^{15}$N (49.7 AMeV) + Be (2 mm) reaction
($X_1$_$Y_1$ = 2_8 mm, ε = 35 mrad, Δp/p = 2.5%, W = 1 mm)

## Beam profile of $^{15}N$ at F3 with ∅7 mm diaphragm at F1



# ACCULINNA-2 - status

$^{15}$N(49.7 AMeV) +Be(2 mm) -> $^{12}$Be




$^{12}$Be: Intensity = 190 1/s @ 1 pnA; $\Delta p/p$ = 4%; Purity ~ 92%; E = 39.4 AMeV;
size X5 _Y5 = 22_25 mm; ACC2/ACC1 = 25

# ACCULINNA-2 - status

**RIBs production rates in $^{15}N$(49.7 AMeV) + Be(2 mm) reaction**
**F1: I($^{15}N$) = 1 pnA @ 7 mm; F2: Δp/p = 2%, Wedge_Be = 1 mm**

| RIB | Energy, MeV/nucl. | Intensity, 1/s |
|---|---|---|
| $^{14}B$ | 37,7 | 120 |
| $^{12}Be$ | 39,4 | 150 |
| $^{11}Li$ | 37,0 | 4 |
| $^{9}Li$ | 33,1 | 1100 |
| $^{8}He$ | 35,8 | 25 |
| $^{6}He$ | 31,5 | 2700 |

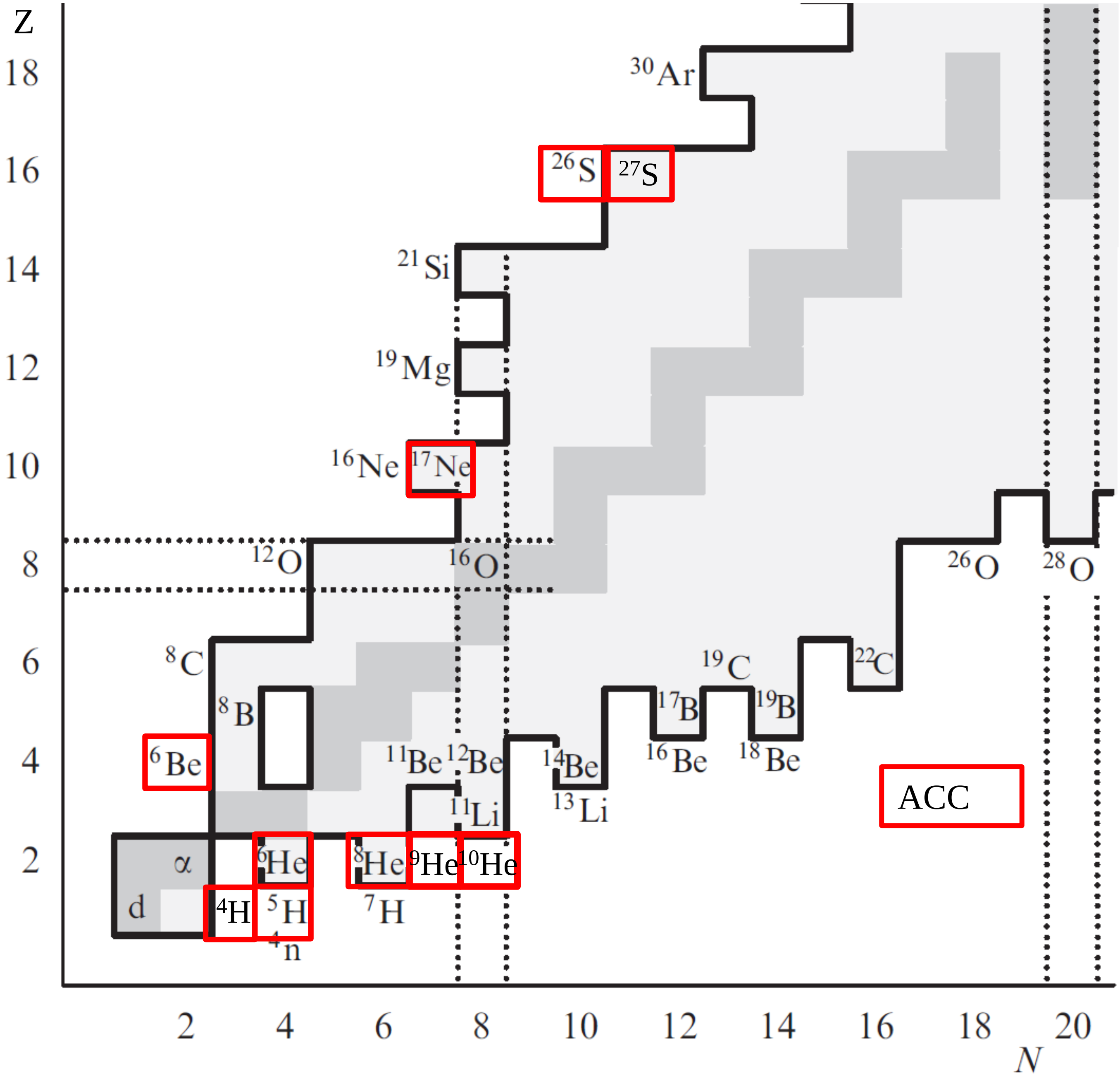
*Experiments in 2018*

**Main parameters (I, P, X_Y) are agree well with estimations**
**First experiments with RIBs could be started in 2017 (I < 0.1 pμA)**
**Experiments with intense primary beam (~ 1 pμA) will be able since 2018**

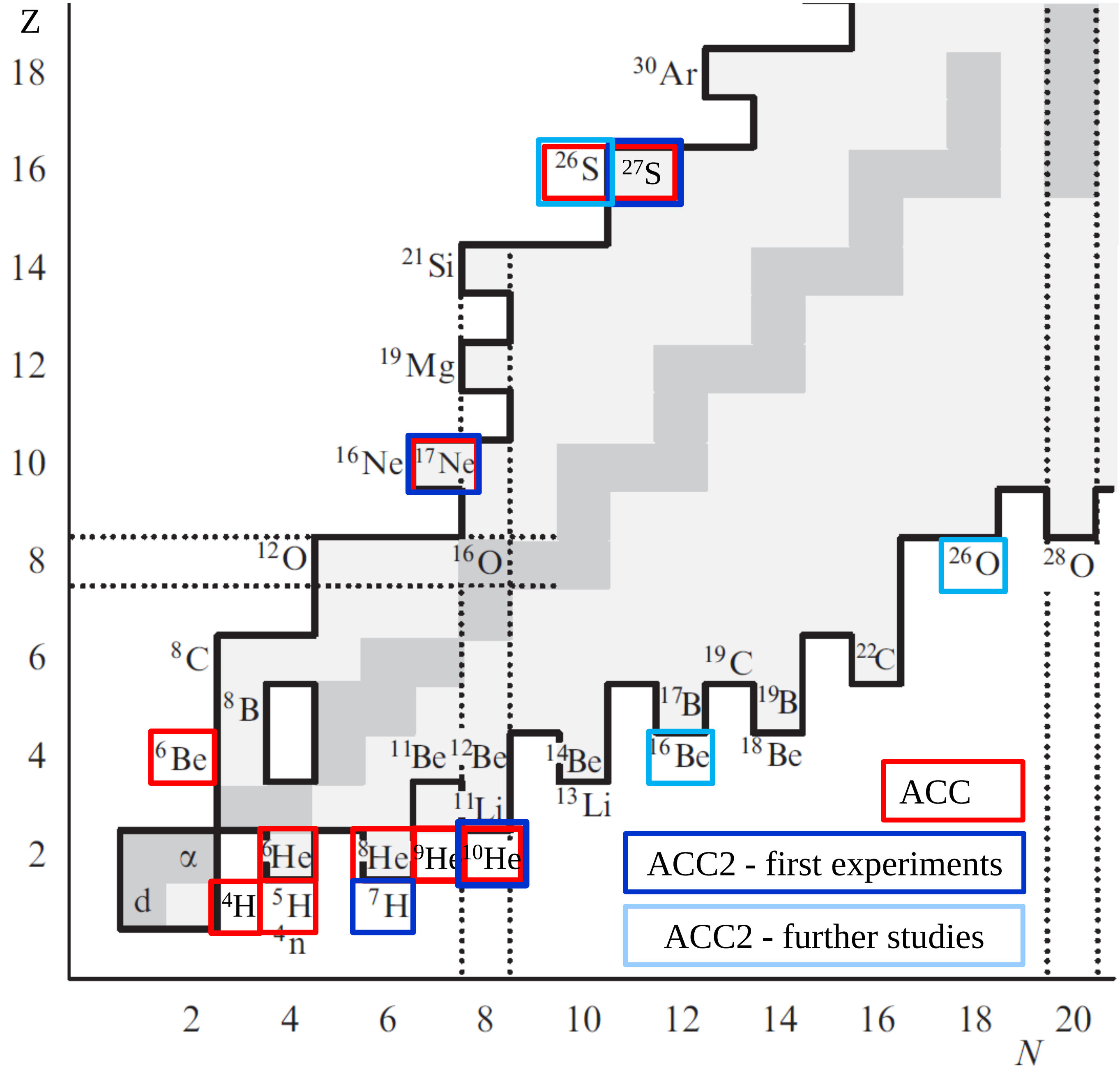
**$^{12}Be + d \rightarrow {}^{6}Li + {}^{8}He$ (alpha transfer cross section)**
**$^{6}He + d \rightarrow {}^{3}He + {}^{5}H$ (proton transfer cross section)**
**December 2017/March 2018**

**Moving ahead to $^{7}H$ via $^{11}Li$ or $^{8}He$**
**2018 - flagship exp.**

# Scope of activity of ACCULINNA



# Scope of activity for ACCULINNA-2



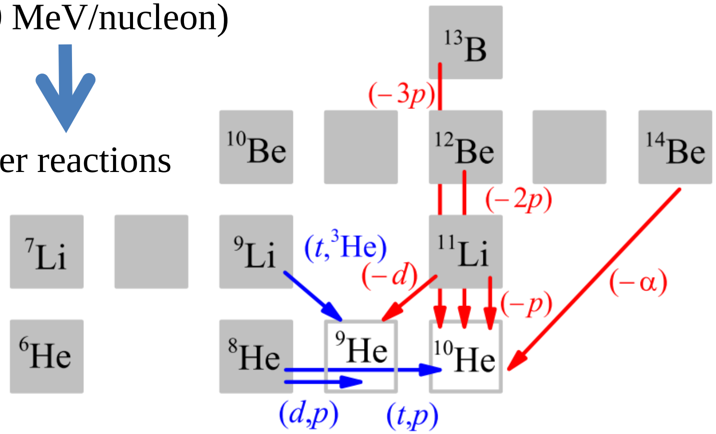
# Competitive light nuclei RIB program at ACC-2

## ➢ 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

↓

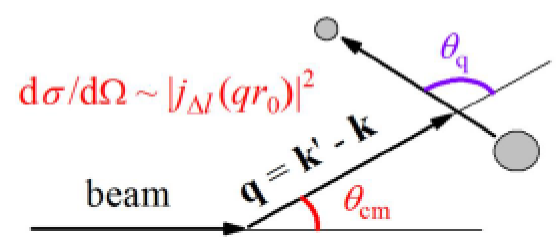
Prospects for specific correlation studies

- **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



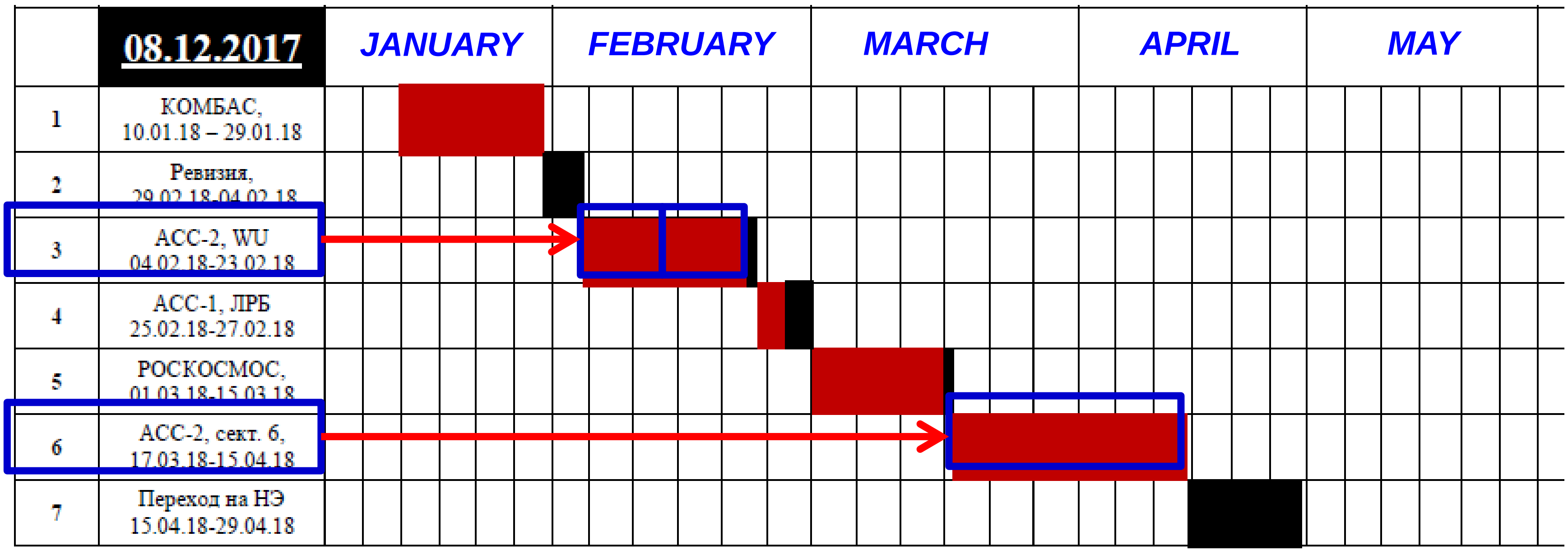
# Plan for the year 2018:

**(February)** ***$^{6}$He+d elastic and inelastic scattering at $\theta_{lab}$ ~*** **5-80 deg (~20-170 CMdeg)**

**(February) Beta-delayed alpha decay of $^{11}$Be:** ***re-investigation with the use optical-TPC***

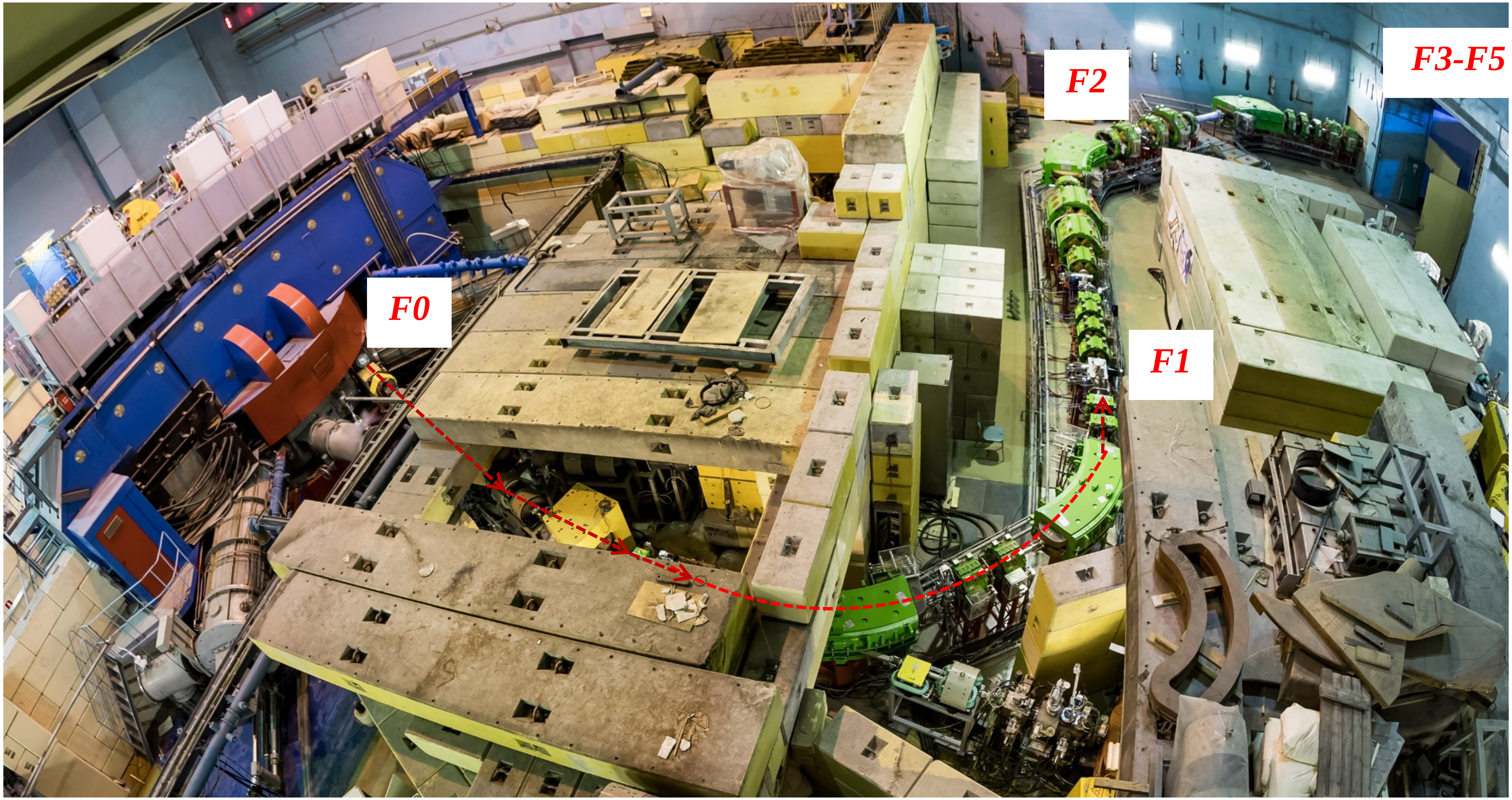
**(March/April)** ***d***($^{6}$He,$^{3}$He)$^{5}$H ***invariant mass measurement*** **and** ***first attempt for d***($^{8}$He,$^{3}$He)$^{7}$H

Beam time schedule for the first half of 2018



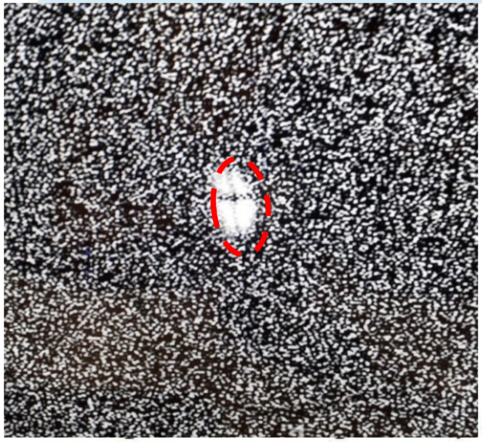

1. КОМБАС, 10 января – 29 января 2018, 11B 36A MeV, 1 eμA.
2. Ревизия каналов. 29 января – 04 февраля 2018.
3. ACCULINNA-1(?), эксперимент (Варшавский ун-т), 4 февраля – 23 февраля 2018, 11B, 32S(?), 36A MeV.
4. ACCULINNA-1, эксперимент (ЛРБ), 25 февраля – 27 февраля 2018, 32S?,11B.
5. РОСКОСМОС, 01 марта – 15 марта 2018.
6. ACCULINNA-2, эксперимент (сектор 6 ЛЯР), 17 марта – 15 апреля 2018, 11B, 36A MeV.
7. Переход на низкие энергии. 15 апреля – 29 апреля 2018.

# Moving ahead to the flagship experiment $^{7}$H



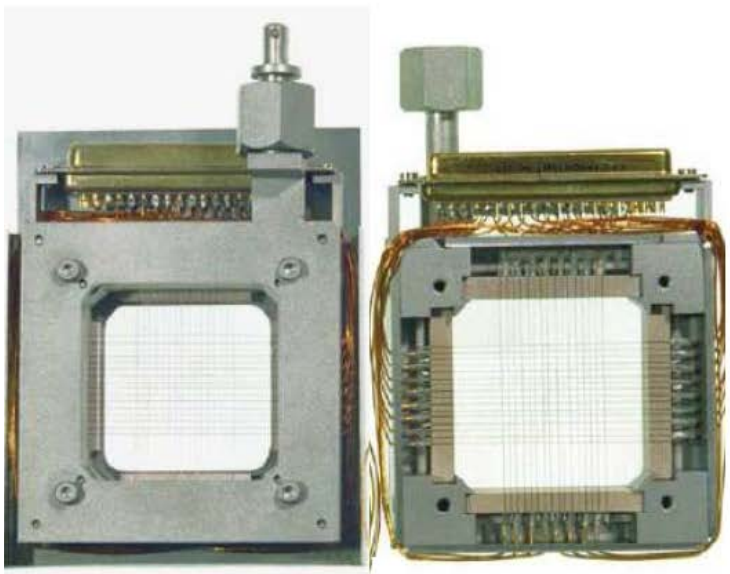

1. *Primary beam diagnostics along the line F0-F1 has been partly completed.*
2. *Radiation shell near movable gate at F3 was done; at F1-F2 area – 2018.*
3. *All communications at F3-F5 (electricity, water, air condition, reaction chamber etc.) were fully completed.*

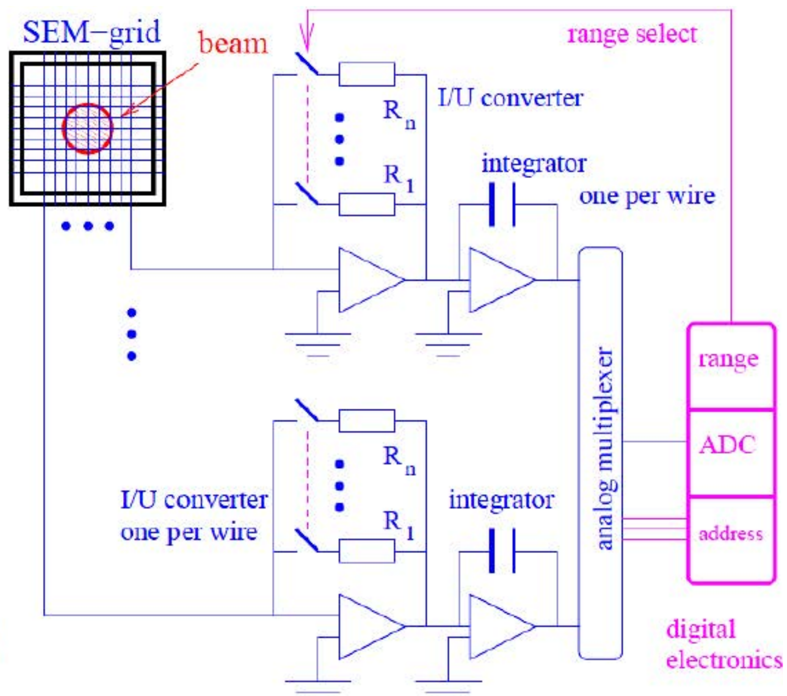
## *Primary beam diagnostics along the line F0-F1: Faraday Cups & $Al_2O_3$*



$^{15}N$ primary beam profile near production target at F1 measured by luminophor (~ 7 mm in diameter).
Simplicity vs. disadvantages (I ~ 1÷50 enA, temporary data).

### *Secondary Electron Emission Crids with POLAND electronics (since 2018)*



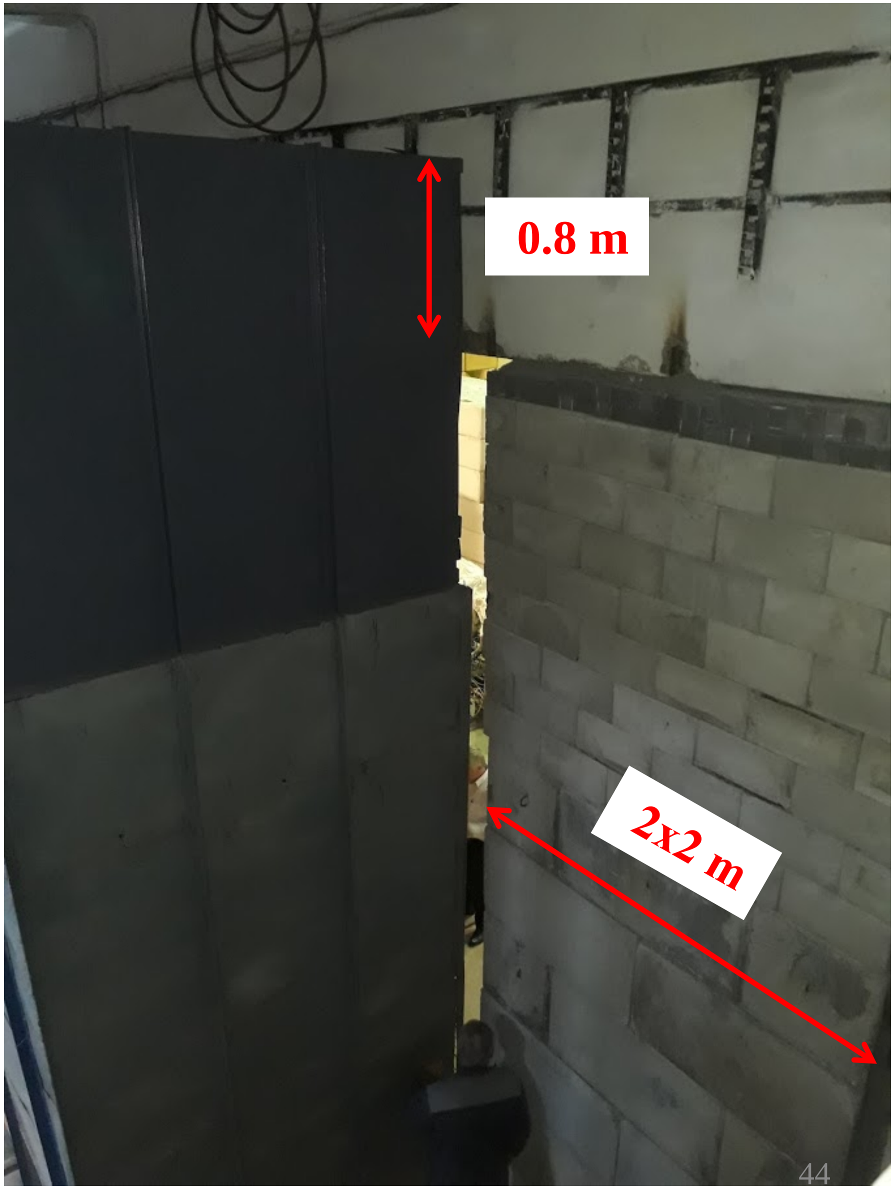



Each wire is equipped with one I/U converter
different ranges settings by $R_i$
⇒ very large dynamic range up to $10^6$.

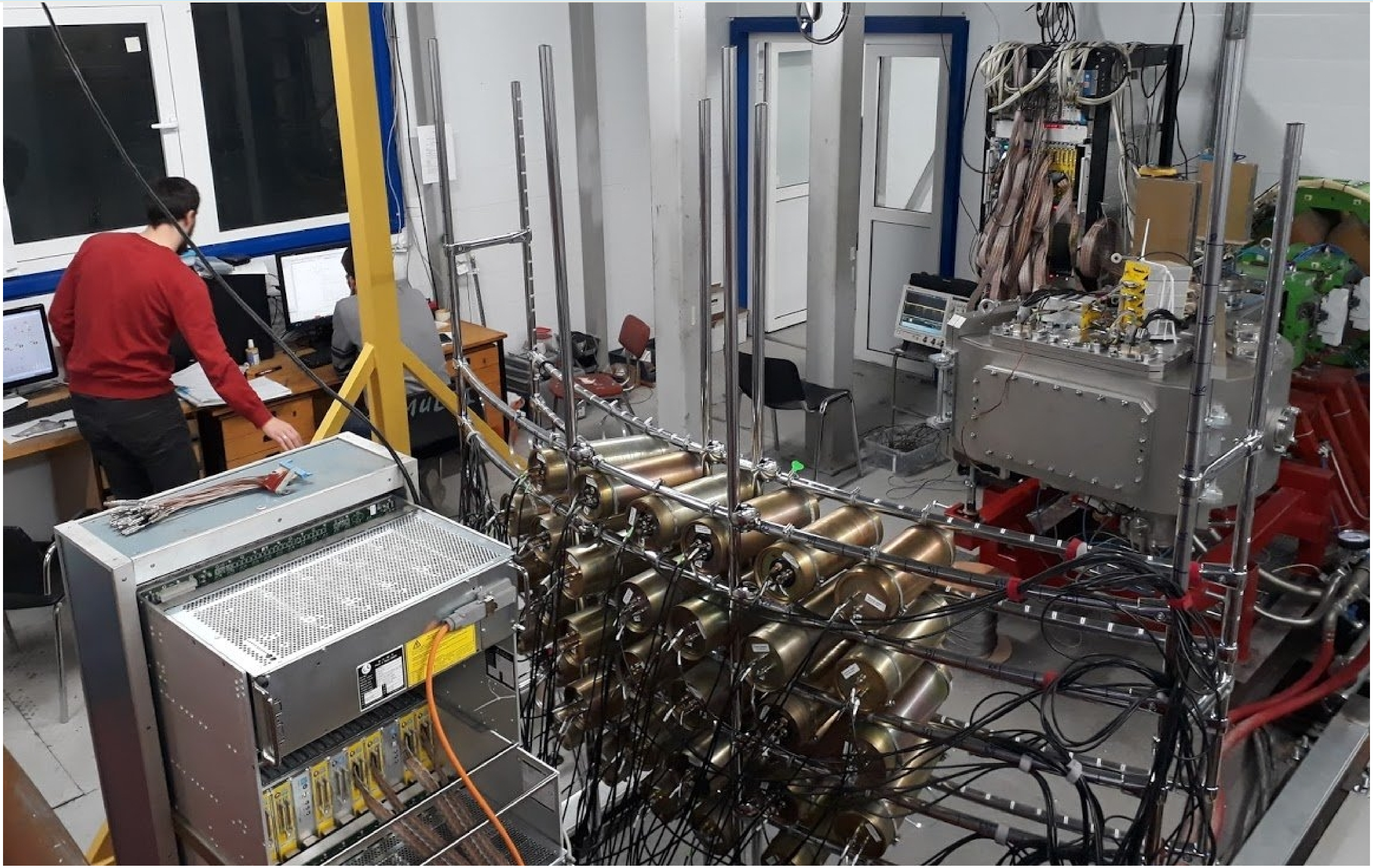
I ~ $10^6$ ÷ $10^{12}$ ions/wire,
permanent data,
~ 0.5 mm accuracy

Peter Forck, JUAS Archamps
GSI
Beam Profile Measurement

***Radiation shell in the area of movable gate was significantly reinforced:***
***a) column 2x2 m; b) top of the gate ++> overlap with a wall (August 2017)***

**F3-F5 area was fully completed by communications, equipment and electronics**

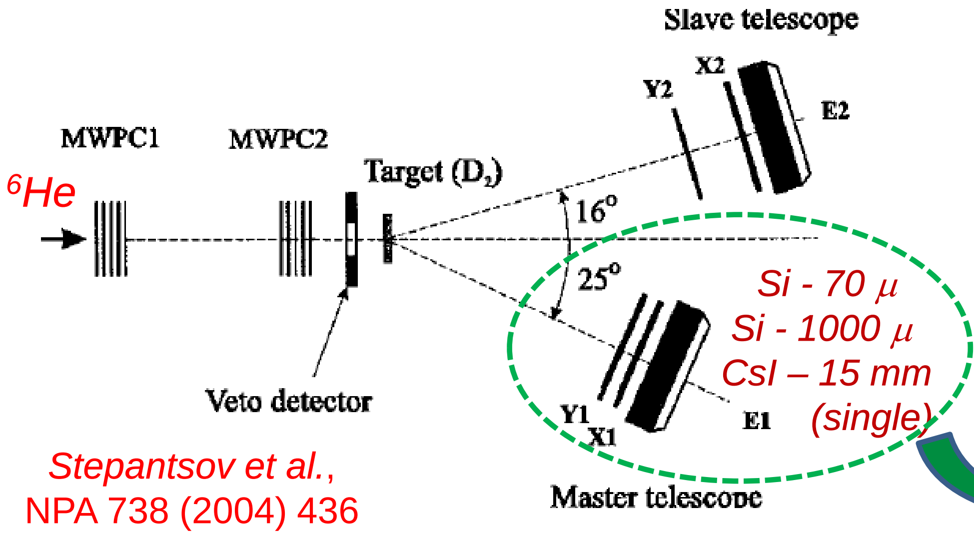


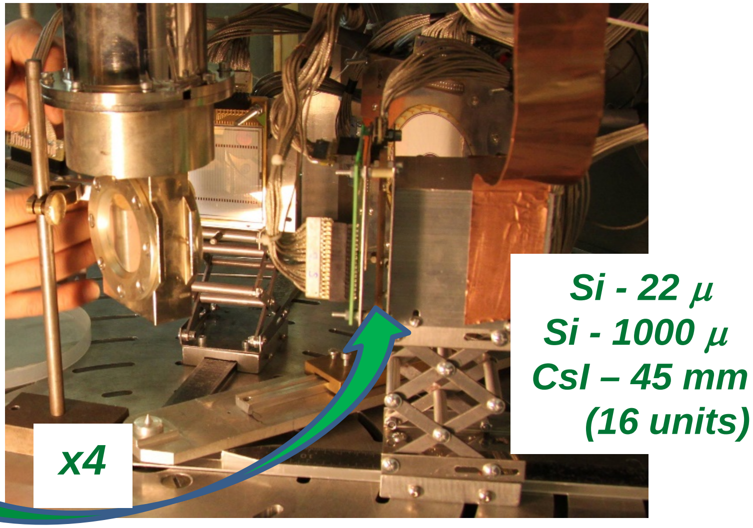
**First experiment at ACCULINNA-2 was performed in December 2017 with $^{15}N$ primary beam (E~49 AMeV & I~0.1 pμA on the production target, Be 2 mm)**

**Plan on 2018:** $d(^6He,^3He)^5H$ as a tool for the main run $d(^8He,^3He)^7H$

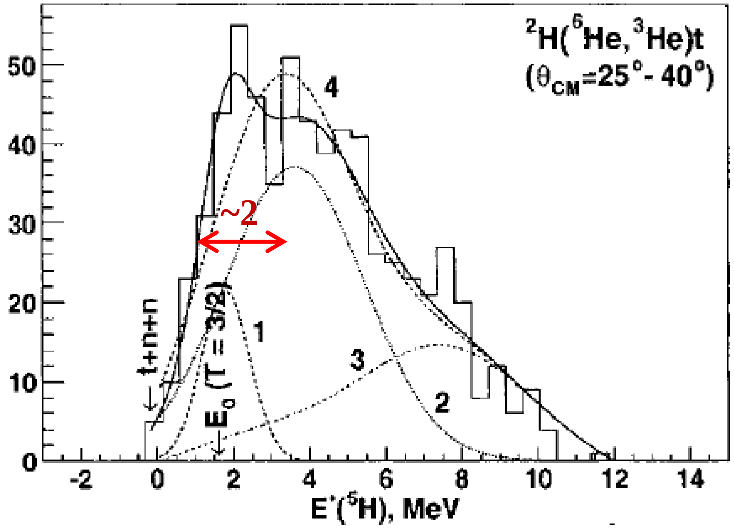
* cross section values for the *1p* and *1n* transfer reactions in a wide $\theta_{CM}$

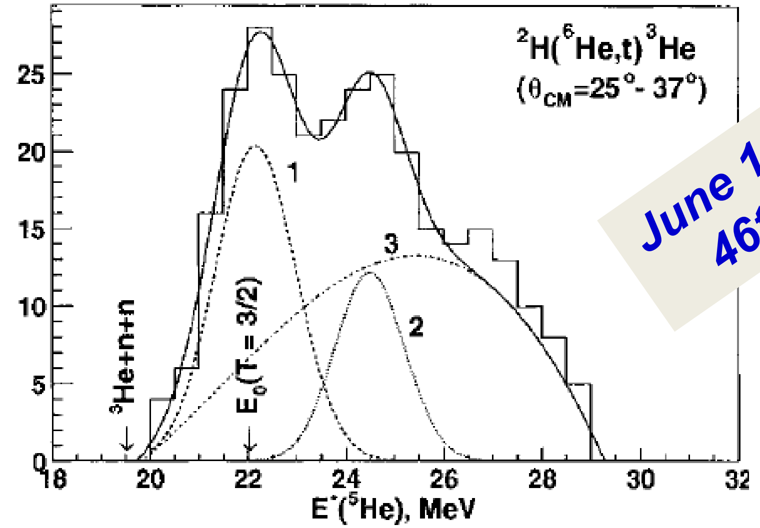
** improvement in missing mass measurements via novel telescopes




*Stepantsov et al.*,
NPA 738 (2004) 436

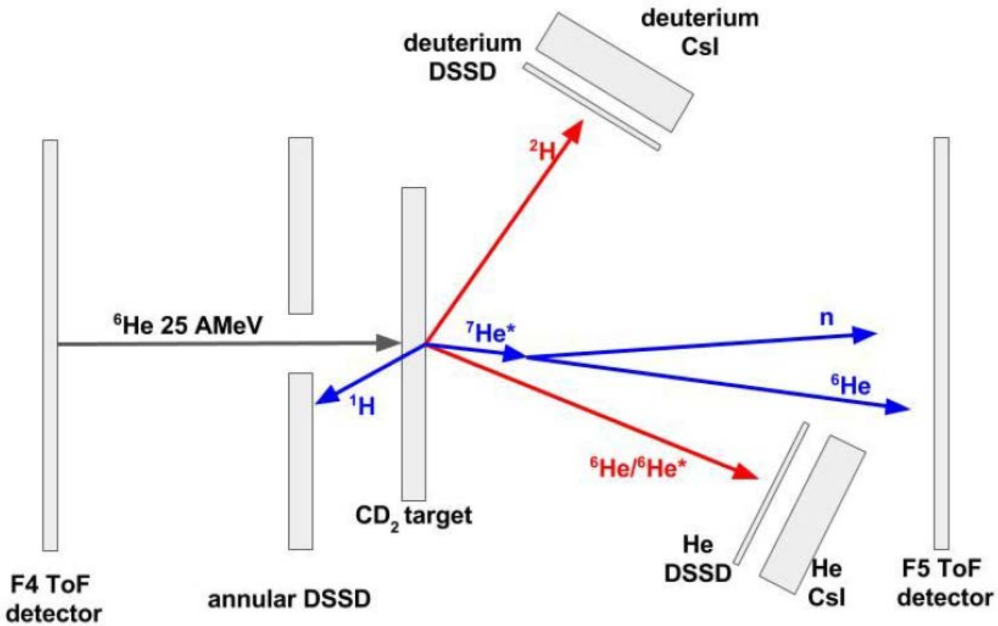


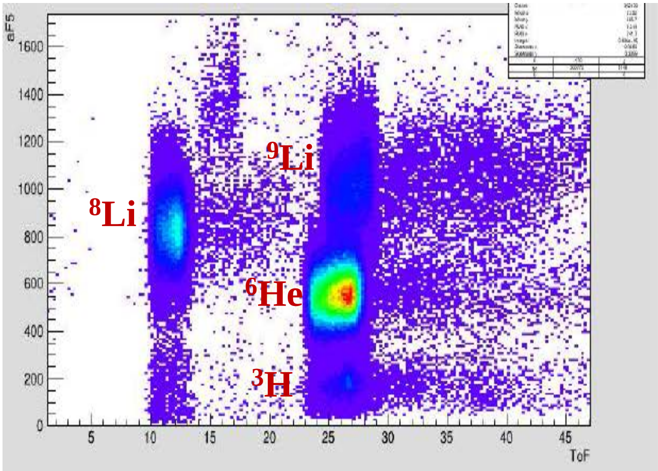



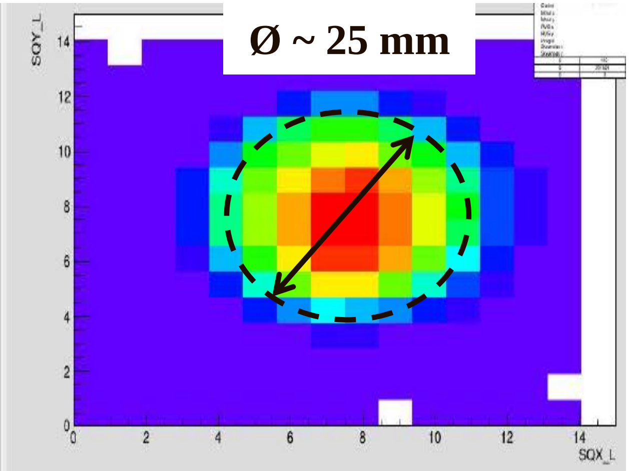

June 14, 2017
46th PAC

**$^5$*H* (left) and $^5$*He* (right) energy spectra depending on $^3$*He-t* coincidences**

**Experimental program in 2017 was a little bit modified:**
**$^{6}$He+*d* (elastic and inelastic scattering in a wide $\theta_{CM}$) instead of *d*($^{6}$He,$^{3}$He)$^{5}$H**
**Motivation: *pure information about OP, more simple run, short expositions***



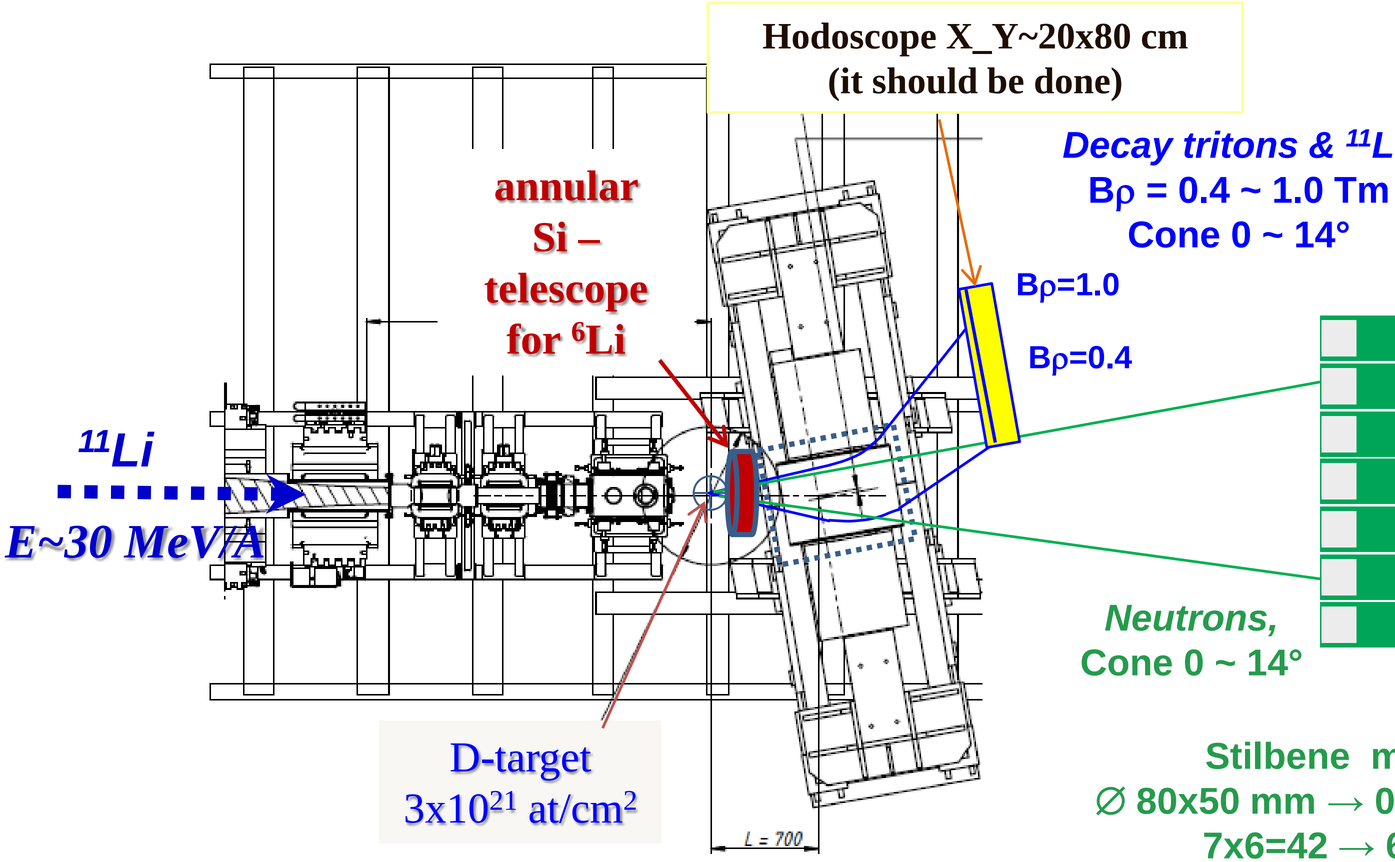



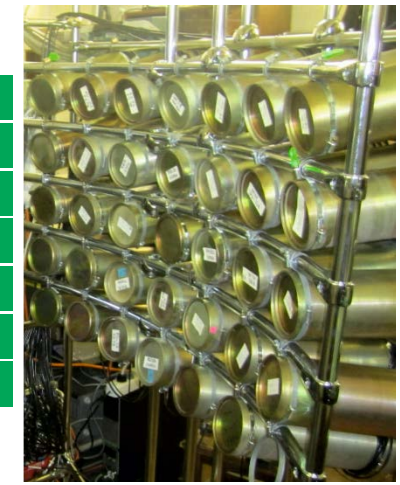




**2x10$^{5}$ $^{6}$He/s @ 0.1 pμA**
**Δp/p = 3%**
**P ~ 75 %**
**E ~ 38 AMeV**

# Hunt for $^{7}$H and search for the *4n* radioactivity in the *d*($^{11}$Li,$^{6}$Li)$^{7}$H reaction

***Plan on 2018***



Stilbene modules
∅ 80x50 mm → 0.25° accuracy
7x6=42 → 64 units

* ***I($^{11}$Li @ 30 AMeV) ~ 2x10$^{4}$ pps ==>*** **~ 100 $^{7}$H events/day (*missing mass*)**

**** Decay energy will be measured with around 100 keV resolution,**

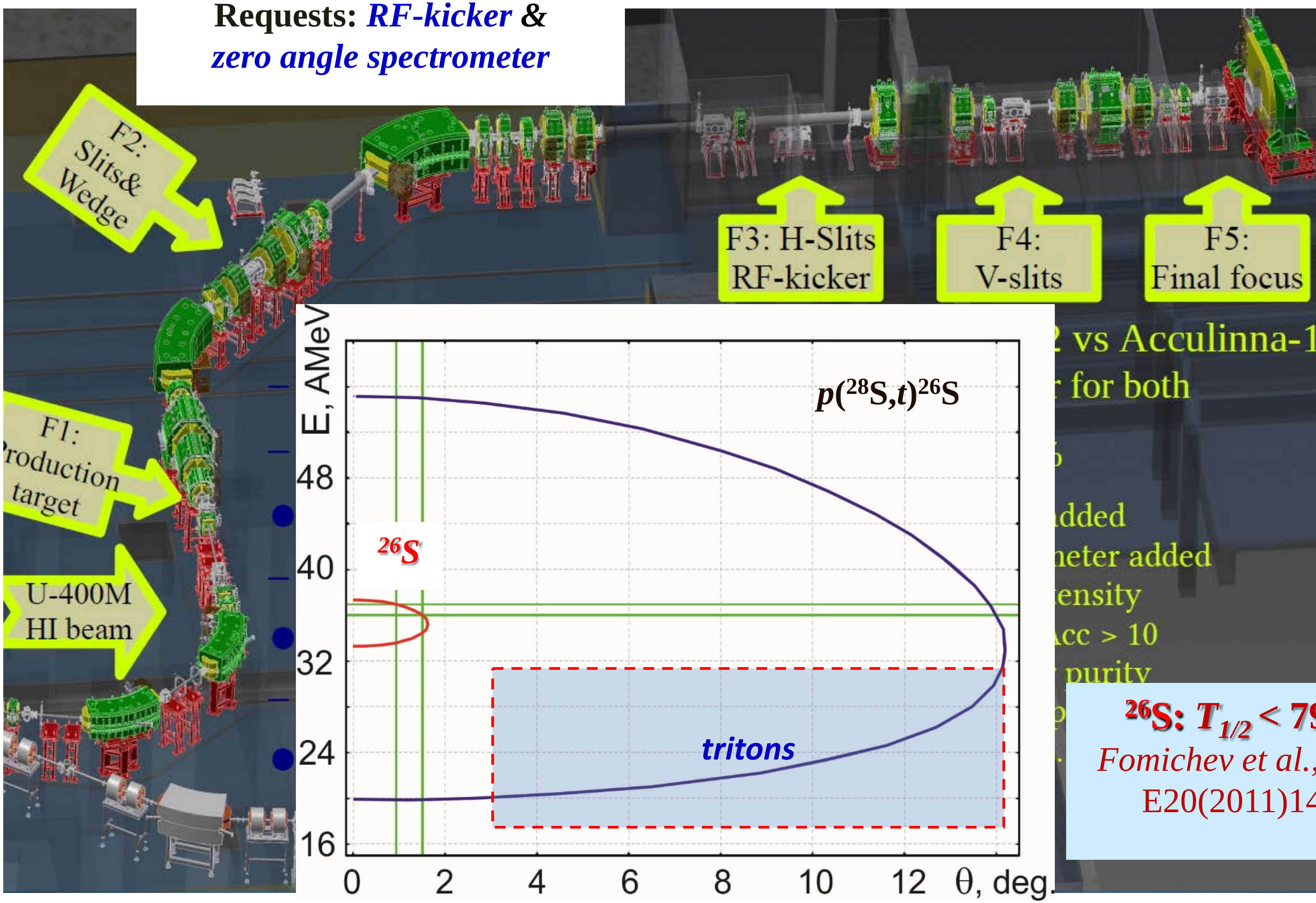
**~ 3 events/day (*$^{6}$Li-t-n coincidences)***

# Plan on 2019:

**$^{26}$S in the reaction *p*($^{28}$S,*t*)$^{26}$S:** ***I*($^{28}$S)~10$^{3}$ pps, *P*~25%, *E*~38 MeV/A,**

***1 mm liquid $H_2$, $\sigma$~200 $\mu$b/sr ==>* ~ 10 events $^{26}$S per week**

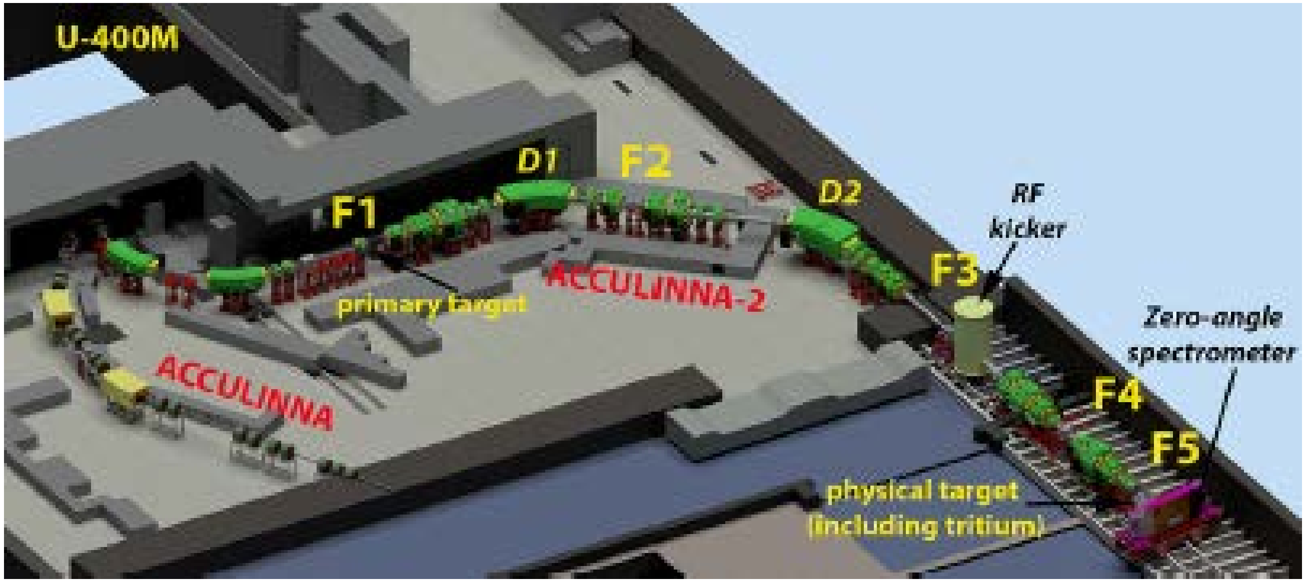
Requests: ***RF-kicker*** **&** ***zero angle spectrometer***




**$^{26}$S: $T_{1/2}$ < 79 ns**
*Fomichev et al.*, IJMP E20(2011)1491

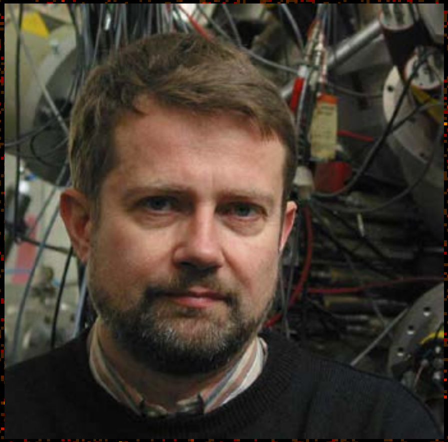
# ACCULINNA-2 Summary and outlook

- ACCULINNA-2 fragment separator commissioned in 2017 is now ready for first-day experiments.
- The intensities obtained in the fragmentation reaction $^{15}N$ (49.7 AMeV) + $^{9}Be$ for the RIBs of $^{14}B$, $^{12}Be$, $^{9,11}Li$, $^{6,8}He$ were on average 20-25 times higher in comparison with the values for old facility.
- The first-priority experimental program with RIBs is focused on $^{6}He$+d scattering, beta-delayed exotic decays of $^{11}Be$ and $^{5,7}H$ study.
- Further experiments (with RF-kicker and zero angle spectrometer) will be aimed on $^{26}S$ observation in (*p*,*t*) reaction with $^{28}S$.



# Optical Time Projection Chamber (OTPC)

Idea of study:
Prof. Marek Pfützner, UW

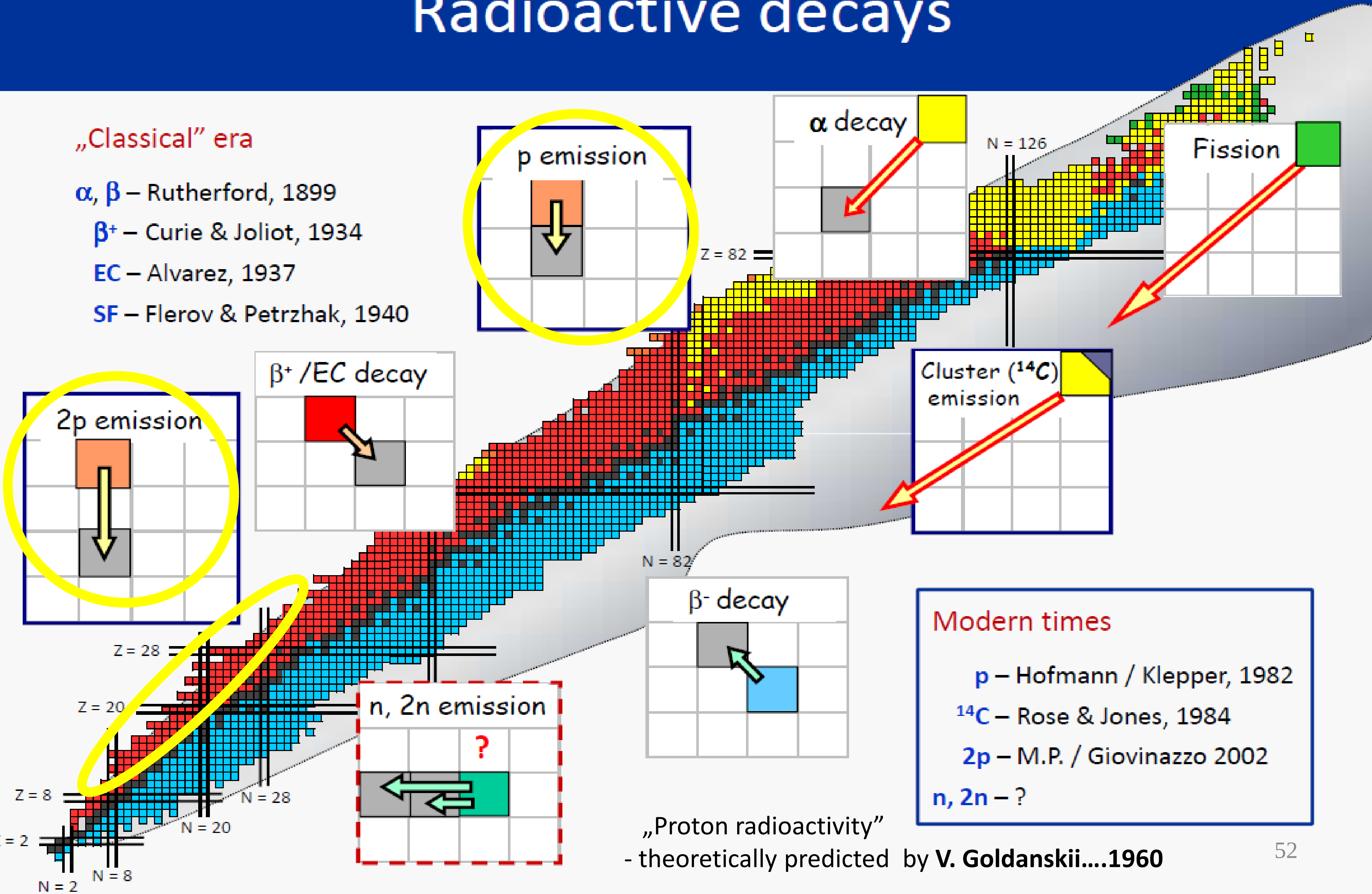


Idea of detector:
Prof. Wojciech Dominik, UW

# Radioactive decays

„Classical" era

- $\alpha$, $\beta$ – Rutherford, 1899
- $\beta^+$ – Curie & Joliot, 1934
- EC – Alvarez, 1937
- SF – Flerov & Petrzhak, 1940

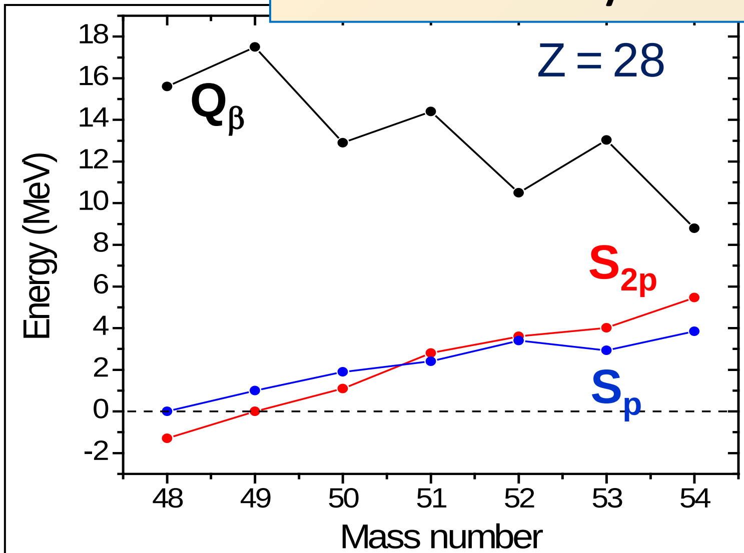



Modern times

- p – Hofmann / Klepper, 1982
- $^{14}C$ – Rose & Jones, 1984
- 2p – M.P. / Giovinazzo 2002
- n, 2n – ?

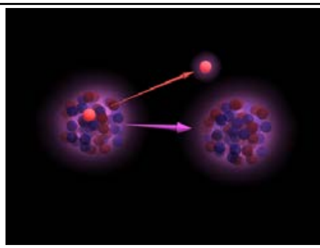
„Proton radioactivity"
- theoretically predicted by **V. Goldanskii….1960**

# Radioactivity at the nuclear drip-lines (proton-rich nuclei)

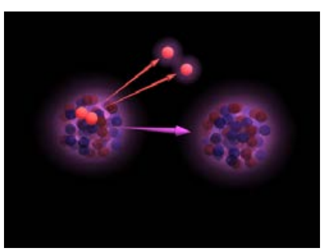



When the $\beta$-decay energy is large, many exotic channels are available:

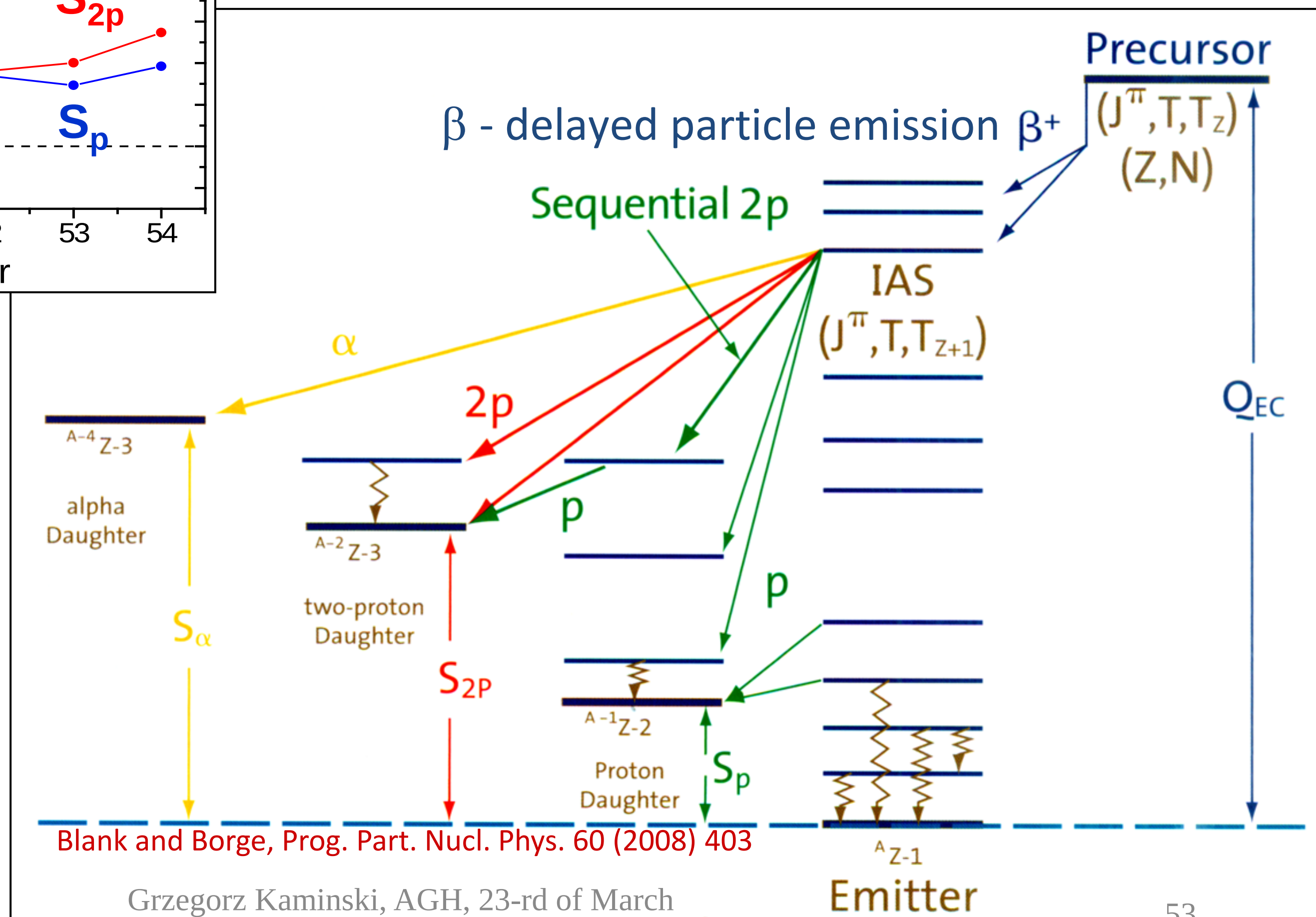
- exotic decay modes ( 1p, 2p radioactivity)
- multiparticle β-delayed particle emission



1 proton emission



2 protons emission

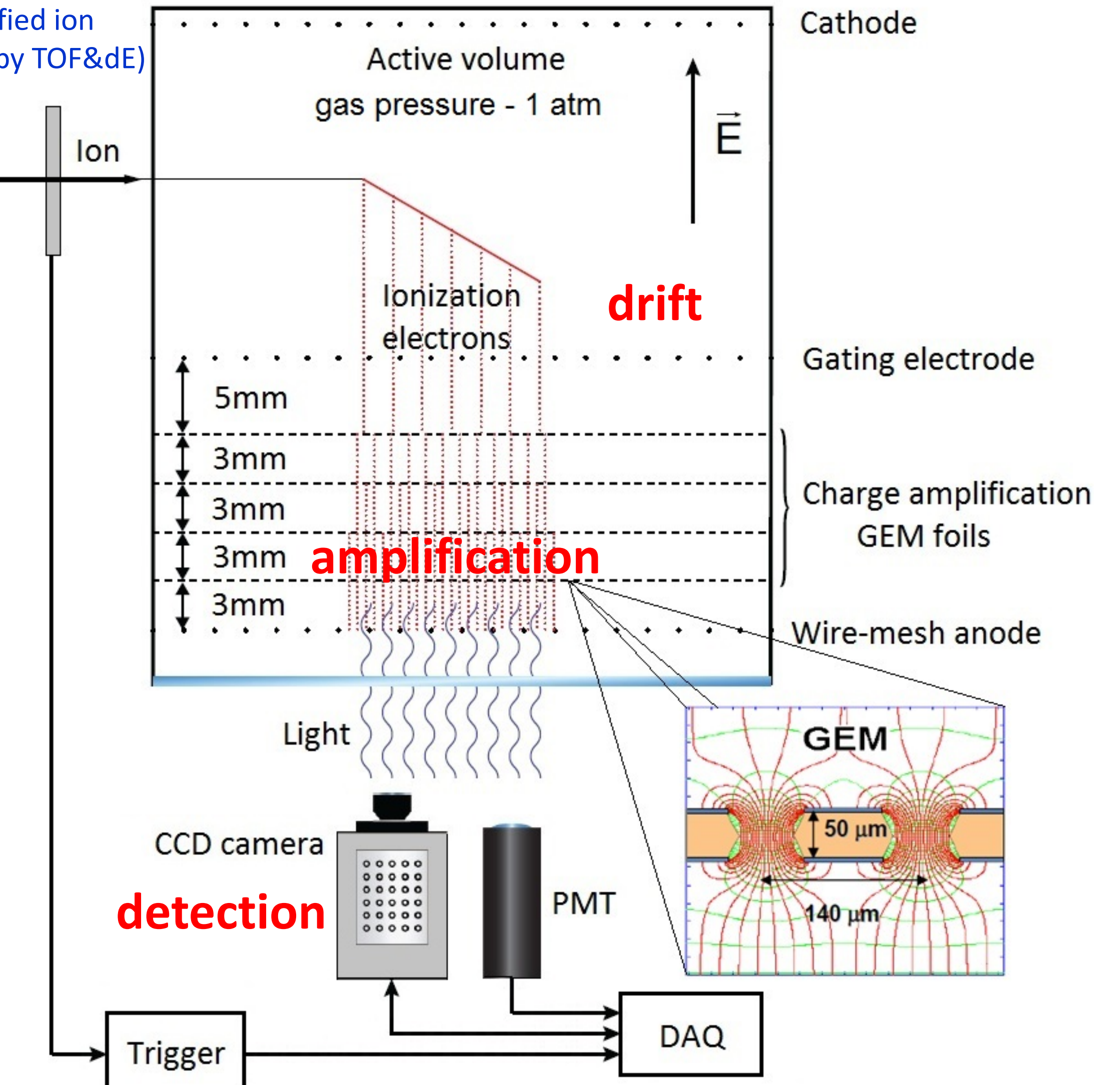



Blank and Borge, Prog. Part. Nucl. Phys. 60 (2008) 403

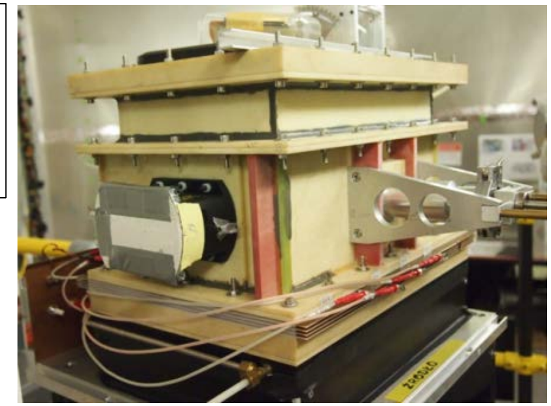
# Experimental tool - Optical Time Projection Chamber

Optical Time Projection Chamber (OTPC) - A new type of modern ionization chamber with an optical readout. Invented at the University of Warsaw by W. Dominik

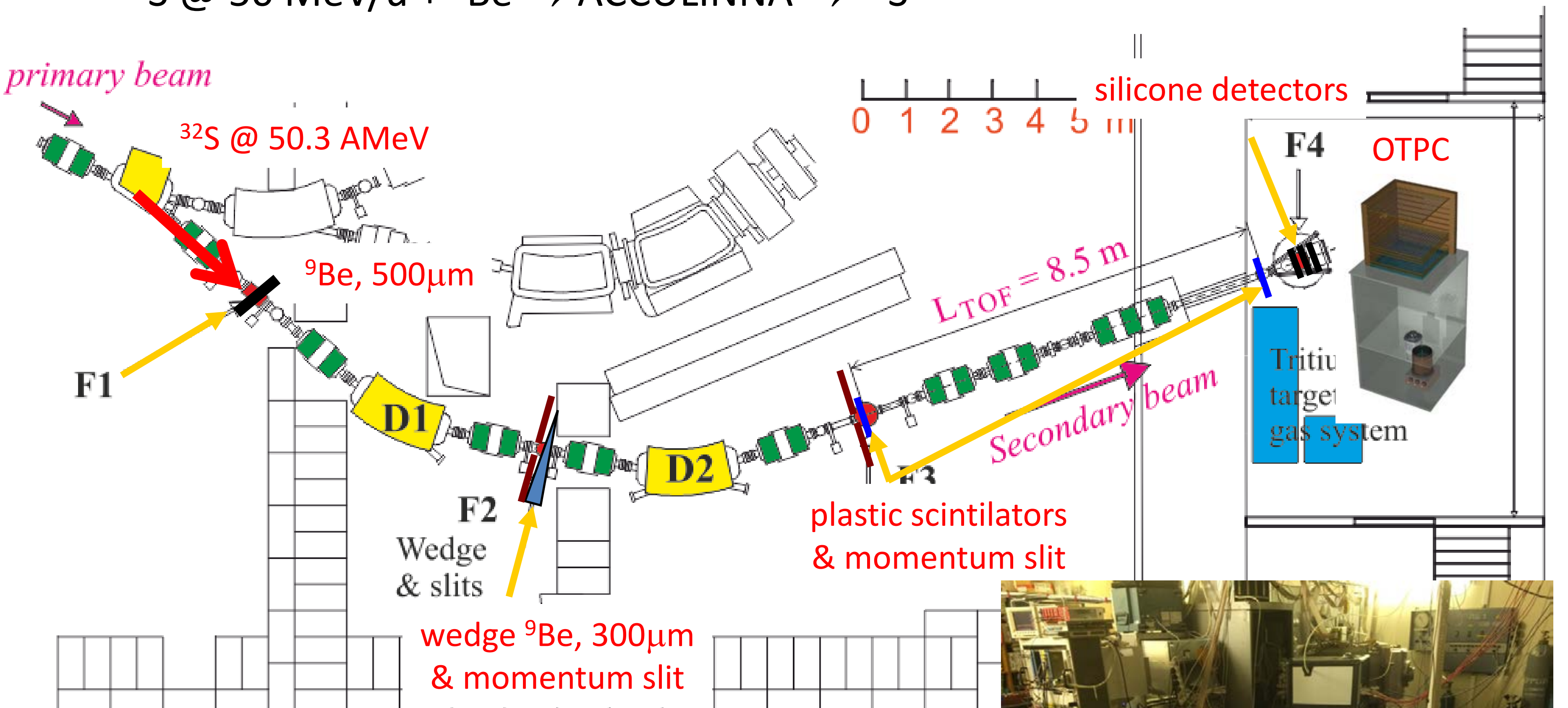
Identified ion
(typically by TOF&dE)

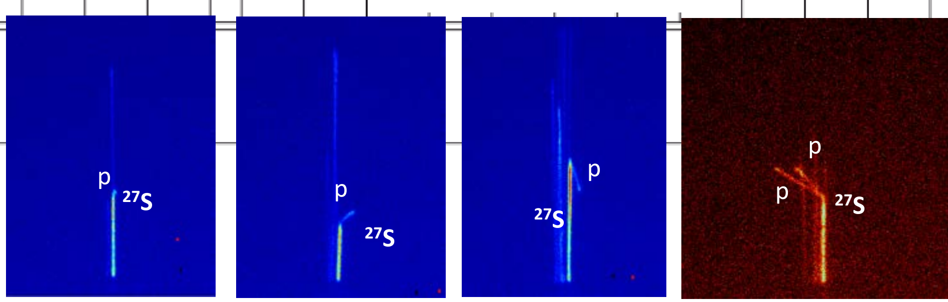


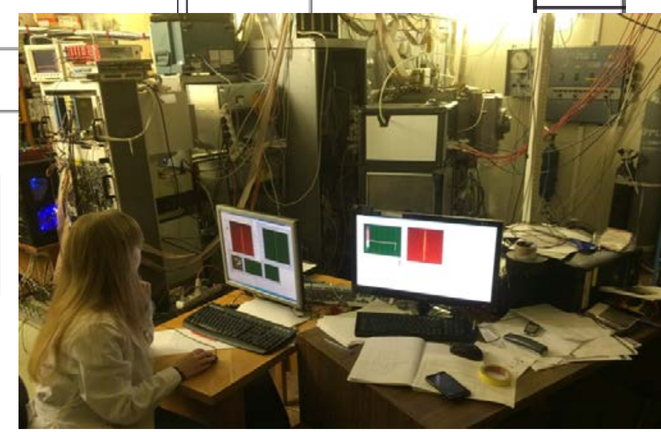

*Miernik et al.*,
NIM A581 (2007) 194



$^{32}S$ @ 50 MeV/u + $^{9}Be$ → ACCULINNA → $^{27}S$



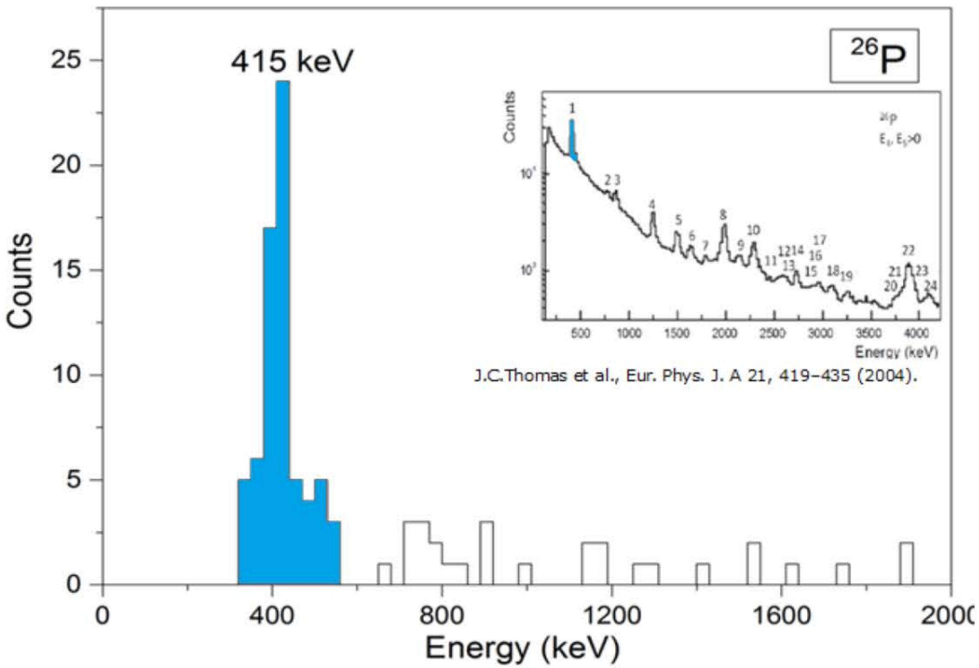



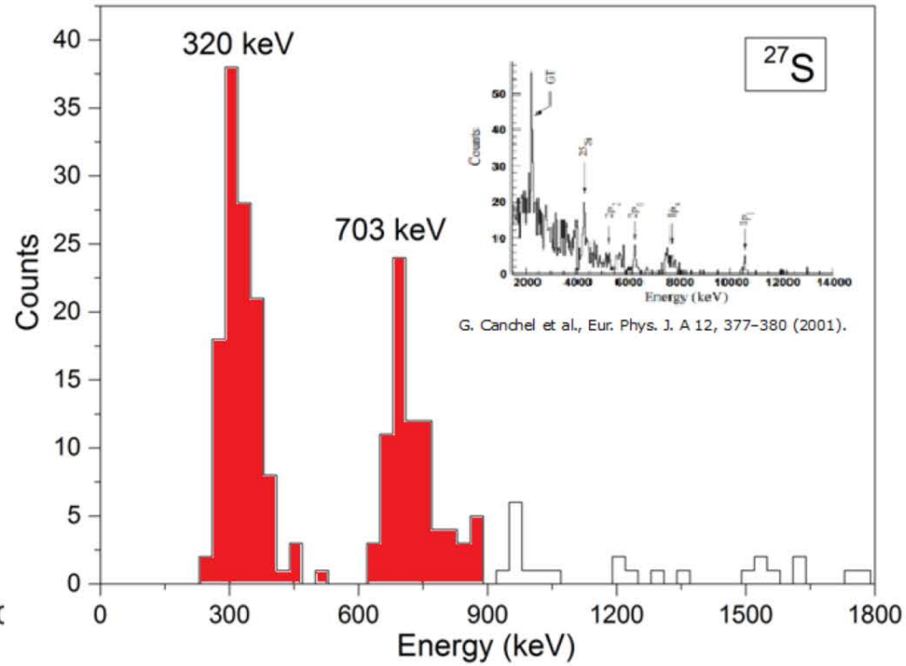



Data acquisition

L. Janiak, N Sokolowska et al., PRC 95 (2017) 034315

# Study of β-delayed charged particle emission from $^{27}S$ and $^{26}P$




| $^{26}P$ | | | | $^{27}S$ | | | |
|---|---|---|---|---|---|---|---|
| $P_{\beta p}$ 415 кэВ | $P_{\beta p}$ ~800 кэВ | $P_{\beta 2p}$ | $P_{tot}$ | $P_{\beta p}$ 320 кэВ | $P_{\beta p}$ 710 кэВ | $P_{\beta 2p}$ | $P_{tot}$ |
| 10.4(9)% ÷ 13.8(10)% | 1.1(3)% | 1.5(4)% | 35(2)% | 24(3)% ÷ 28(2)% | > 6.7(8)% | 3.0(6)% | 64(3)% |
| 17.96(90)% | 2.5(3)% | 2.2(3)% | 39(2)% | 2.3±0.9% | | 1.1±0.5% | ~ 4% |

*Thomas et al.*, EPJ A21 (2004) 419

*Canchel et al.*, EPJ A12 (2001) 377

$P_{\beta 3p} < 0.08\%$

***L. Janiak, N Sokolowska et al.*, PRC 95 (2017) 034315, *N Sokołowska* Master Thesis, AGH, Krakow 2016**

In 2018/2019 new measurments of *β*- delayed particle emission from $^{27}S$ @ **ACCULINNA-2** are planned → much better statistic of two orders of magnitude is expected (we plane tu purify the beam with RF-kicker)

# OTPC collaboration

*University of Warsaw*
- W. Dominik
- A. Korgul
- A. Ciemny
- L. Janiak
- C. Mazzochi
- K. Miernik
- S. Mianowski
- M. Pfutzner
- M. Pomorski
- N. Sokołowska
- A. Kubiela

*JINR Dubna*
- A.Fomichev
- A.Bezbakh
- G.Kamiński
- S.Krupko

*GSI*
- I. Mukha
- H. Geissel
- S. Weick

*NSCL*
- T. Baumann
- T. Ginter
- A. Stolz
- S. Liddick

*Oak Ridge National Lab.*
- K. Rykaczewski

*University of Tennessee*
- R. Grzywacz
- S. Paulauskas

*CERN - ISOLDE*
- M. Kowalska
- M. Borge

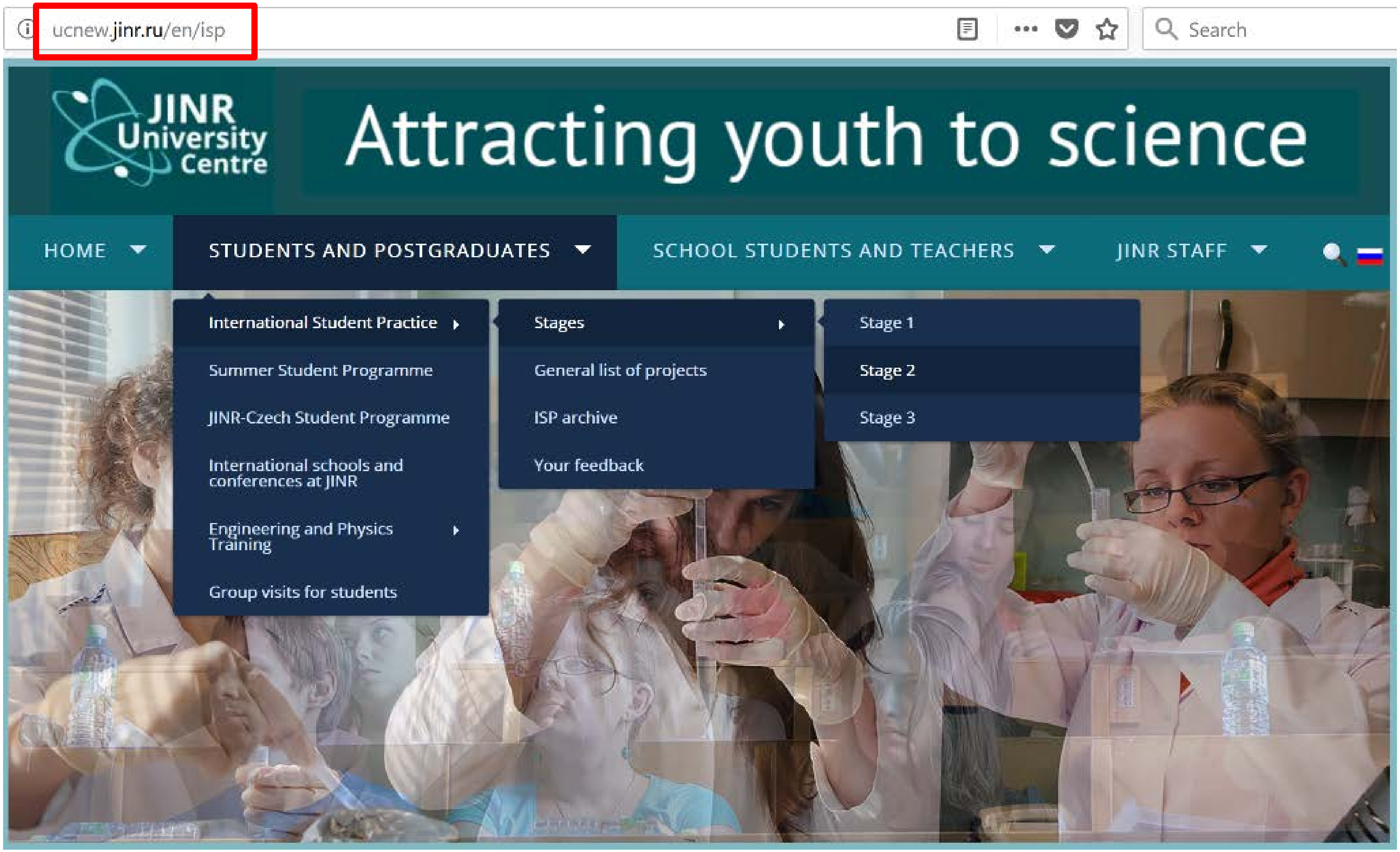
# Possibilities for students at JINR

# Możliwości wyjazdu do ZIBJ

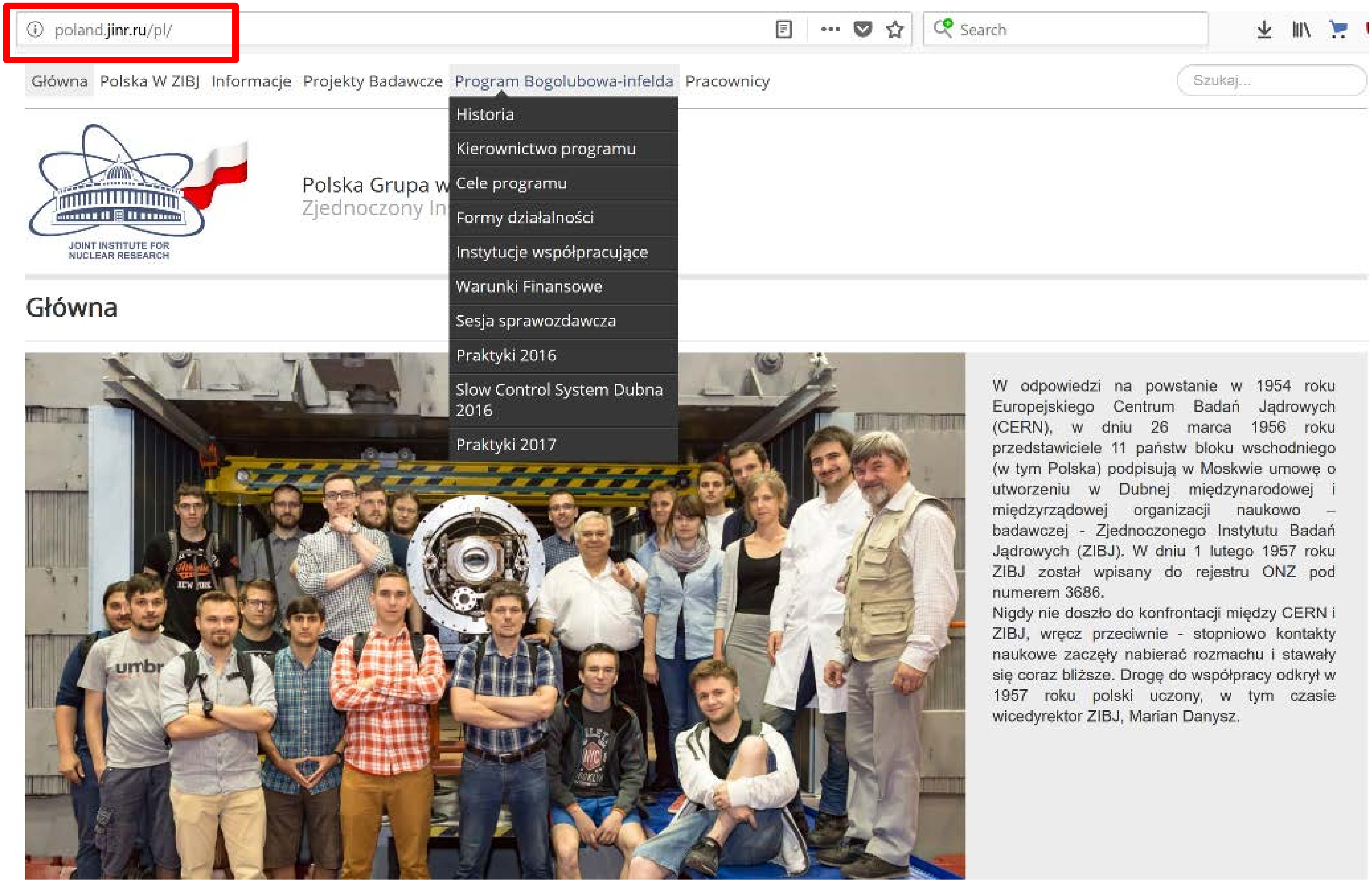
- ✓ Letnie praktyki (3 tyg / 6-8 tyg)
- ✓ Prace dyplomowe
- ✓ Wycieczki naukowe
- ✓ Letnie szkoły/konferencje
- ✓ Zatrudnienie *


Pomocne informacje:
http://poland.jinr.ru
http://ucnew.jinr.ru/en/
http://students.jinr.ru/en

# Letnie praktyki dla studentów w ZIBJ – lipiec 2018



# Letnie praktyki dla studentów w ZIBJ – lipiec 2018




Termin: 8 - 30 lipca, zapisy – kwiecień 2018

# Letnie praktyki dla studentów w ZIBJ – lipiec 2018

http://ucnew.jinr.ru/en/2-stage-2018

**Uczestnik praktyki pokrywa:**

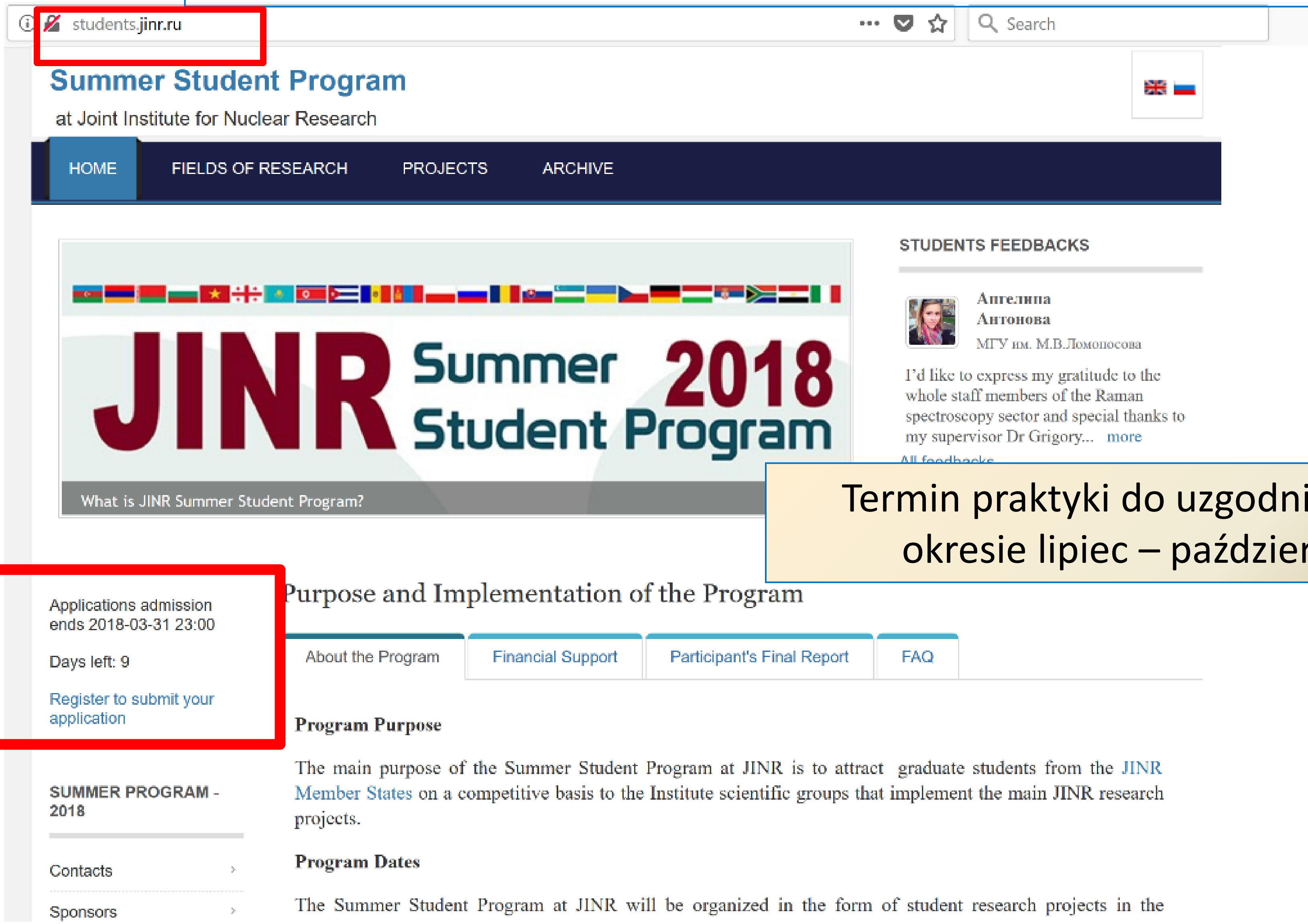
- koszt przejazdu z Moskwy do miejsca zamieszkania w Polsce (około 500 PLN),
- koszt dwukrotnej wizy tranzytowej przez Białoruś ( 15 Euro – opłata za wydanie wizy, plus opłata około 150 PLN za pośrednictwo w załatwieniu wizy) w przypadku podróży pociągiem
- koszt ubezpieczenia KL i NNW na okres podróży i pobytu na praktyce (około 70 PLN).

**Natomiast ZIBJ pokrywa pozostałe koszt**

- zakwaterowania w pokojach 3 lub 4 osobowych w hotelu instytutowym lub w domu studenckim,
- programu turystyczno - rekreacyjnego,
- transportu z Moskwy do Dubnej w dniu przyjazdu i z Dubnej do Moskwy w dniu powrotu do Polski,
- biletu na przelot samolotem lub dojazd pociągiem w wagonie sypialnym II klasy z **Warszawy do Moskwy** (łącznie do ~150 USD)
- dietę w wysokości 22 USD dziennie wypłaconą w rublach,
- bezpłatne śniadania w restauracji hotelowej i 3 USD dziennie stanowiące tzw. fundusz operacyjny z którego będą pokrywane koszty biletów wstępu do muzeów, opłaty za przewodników, opłaty za przejazd metrem w Moskwie itp.. ( w przypadku nie uczestniczenia w wycieczkach nie wydane kwoty nie będą wypłacane uczestnikowi praktyki).

**W celu zgłoszenia chęci uczestnictwa należy przesłać zeskanowane dokumenty na adres zawodny@amu.edu.pl**

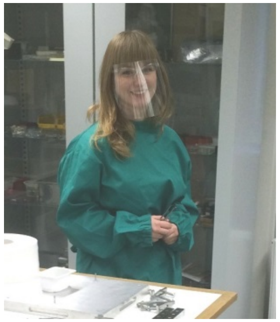
# Letnie praktyki dla studentów w ZIBJ – 6-8 tyg




Termin praktyki do uzgodnienia w okresie lipiec – październik

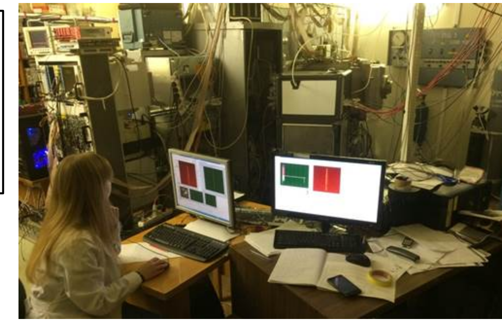
**http://students.jinr.ru/en**

# Współpraca ze studentami 2016-2018

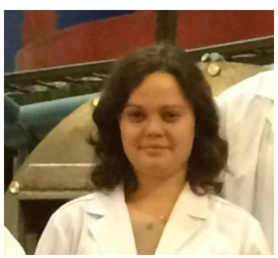


Prace magisterskie:

Natalia Sokołowska, AGH, Kraków, praca magisterska p.t: ***Badanie przemiany $\beta^{+}$ $^{26}$P detektora dryfowego z odczytem optycznym.*** Obrona pracy odbyła się w czerwcu 2016 r.



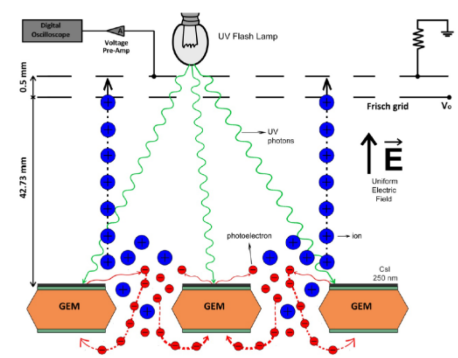
Aleksandra Świercz, AGH, Kraków, praca magisterska p.t.: ***Badanie struktury lekkich egzotycznych jąder na separatorze ACCULINNA-2.*** Temat zatwierdzony do realizacji w roku akademickim 2017/2018.



Magdalena Kaja, Politechnika Warszawska, praca magisterska p.t.: ***Badanie właściwości procesów transportu ładunku w mieszankach gazowych stosowanych w detektorach z projekcją czasową / Study of charge transport properties of gas mixtures for time projection chambers.***

Temat zatwierdzony do realizacji w roku akademickim 2017/2018.

Praca magisterska realizowana we współpracy ZIBJ, Dubna- LIP Coimbra,



## Praktyki indywidualne, staże, eksperymenty

Oprócz letnich praktyk, jest możliwość odbycia praktyk indywidualnych, staży w ramach realizacji prac magisterskich, doktorskich, udział w eksperymentach. Pełne lub częściowe finansowanie na wyjazd uzyskuje się z programu Bogolubowa-Infelda. Warunki ustala się indywidualnie, w zależności od celu wyjazdu i długosci pobytu: głównie są to wyjazdy od tygodnia do dwóch miesięcy

## Wyjazdy na okres od 3 miesięcy i więcej

Informacje o formalnościach zwiazanych z wyjazdami na okres dluższy niż 3miesiące można znaleźć na stronie: http://poland.jinr.ru informacje dla przyjeżdżających
Wyjazd organizowany jest na zasadzie zatrudnienia na czas określony, od 3 miesięcy do 2-3 lat z możliwością przedłużenia kontraktu

Więcej informacji : Władysław Chmielowski, email: wchmiel@jinr.ru
Grzegorz Kaminski: gkaminski@slcj.uw.edu.pl

Dziekuję!