a – Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia

b – *Institute of Physics, Silesian University in Opava, Czech Republic*

c – *Bogolyubov Laboratory of Theoretical Physics, JINR, Dubna, Russia*

d – *GSI Helmholtzzentrum fur Schwerionenforschung, Darmstadt, Germany*

e – *National Research Center "Kurchatov Institute", Moscow, Russia*

f – Heavy Ion Laboratory, University of Warsaw, Warsaw, Poland

g – *Skobel'tsyn Institute of Nuclear Physics, Moscow State University, Russia*

h – *Faculty of Physics, University of Warsaw, Warsaw, Poland*

– *Fundamental Physics, Chalmers University of Technology, Goteborg, Sweden*

j– *All-Russian Research Institute of Experimental Physics, Sarov, Russia*

k – *Ioffe Physical Technical Institute, St. Petersburg, Russia*

l – *NSCL, Michigan State University, East Lansing, Michigan, USA*

STATUS OF THE NEW FRAGMENT SEPARATOR ACCULINNA-2 AND FIRST EXPERIMENTS

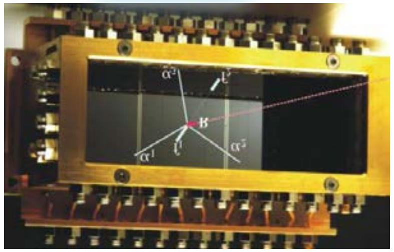
Grzegorz Kaminski[a,f]
for ACCULINNA Collaboration

Outline

- Introduction: FLNR research area
- Light RIB facility at FLNR: ACCULINNA
- New RIB faclility at FLNR: ACCULINNA-2
- ACCULINNA-2 instrumentation
- Experiments @ACCULINNA& first day experiments at ACCULINNA-2
- The Optical Time Projection Chamber (OTPC) at ACCULINNA
- Future plans & collaborations

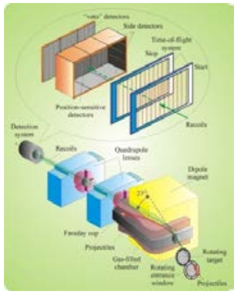
LABORATORY FOUNDER - Georgiy Nikolaevich FLEROV, 1913 – 1990

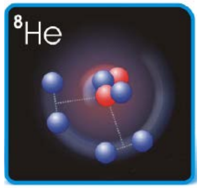
Basic directions of research at FLNR



1. Heavy and superheavy nuclei

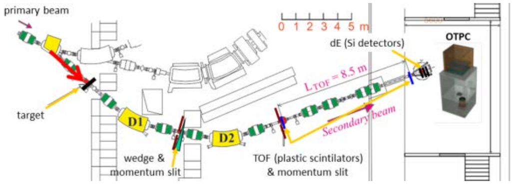
- Synthesis and study of properties of superheavy elements
- Chemistry of new elements
- Fusion-fission and multi-nucleon transfer reactions
- Mass-spectrometry and nuclear spectroscopy of SH nuclei



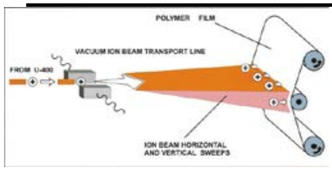


2. Light exotic nuclei

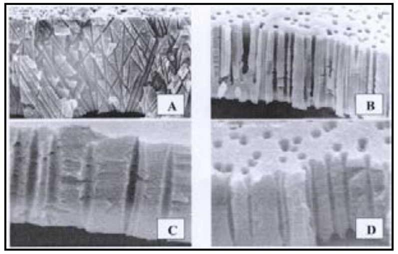
- Properties and structure of light exotic nuclei
- Reactions with exotic nuclei



3. Radiation effects and physical bases of nanotechnology

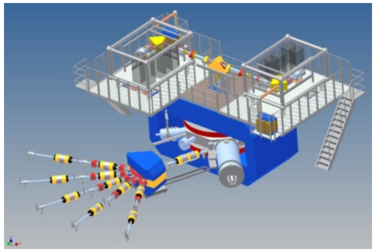


- Track membrans
- Nanostructures
- Study of materials properties



4. Accelerator technology

- cyclotrons
- ECR ion sources

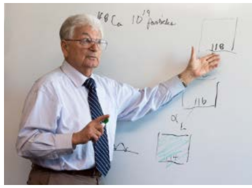


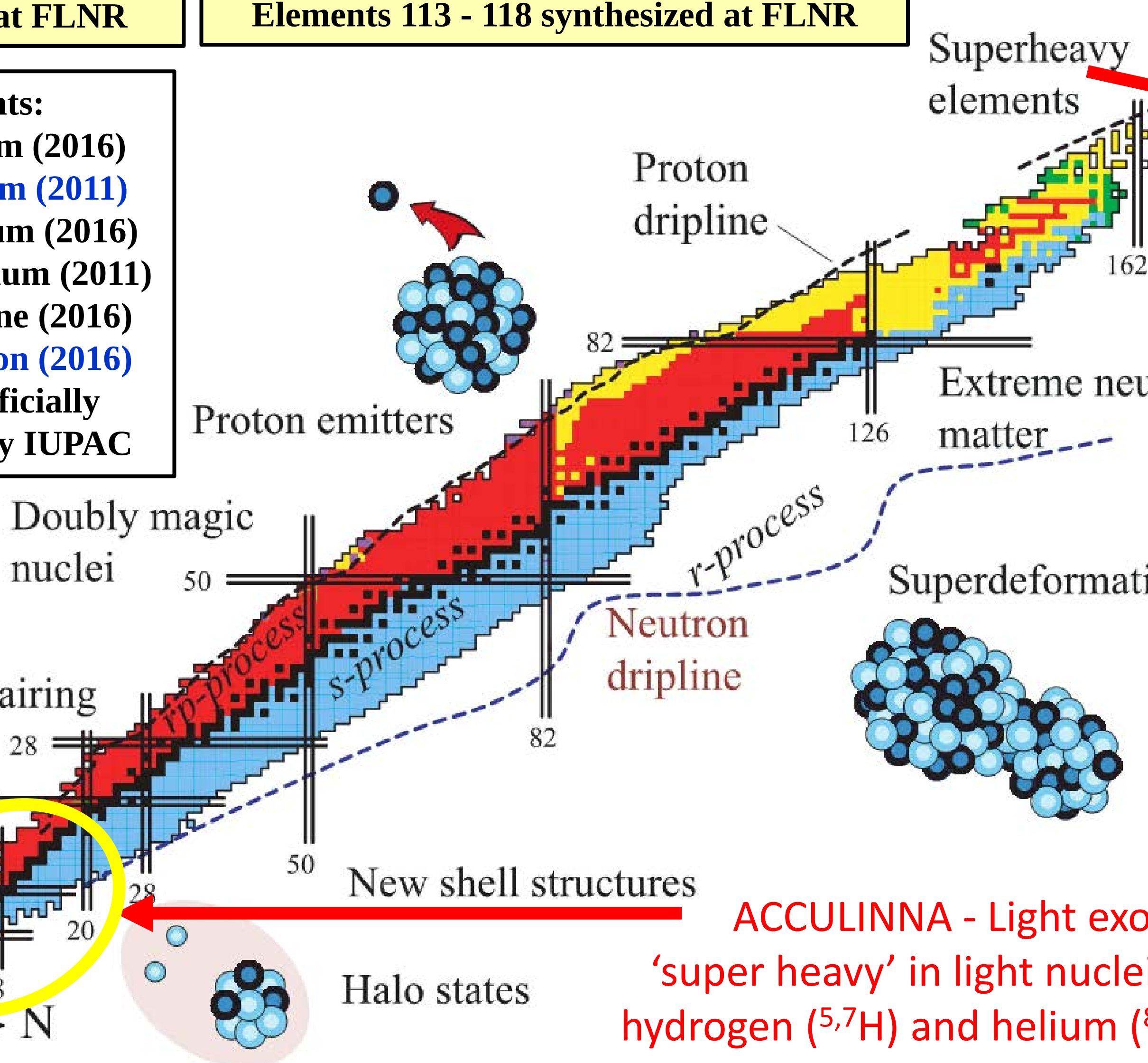
Main areas of interest at FLNR at nuclide chart

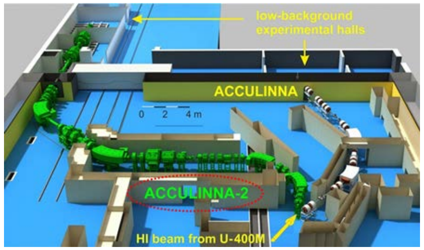
Elements 102 - 108 synthesized at FLNR

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 by IUPAC

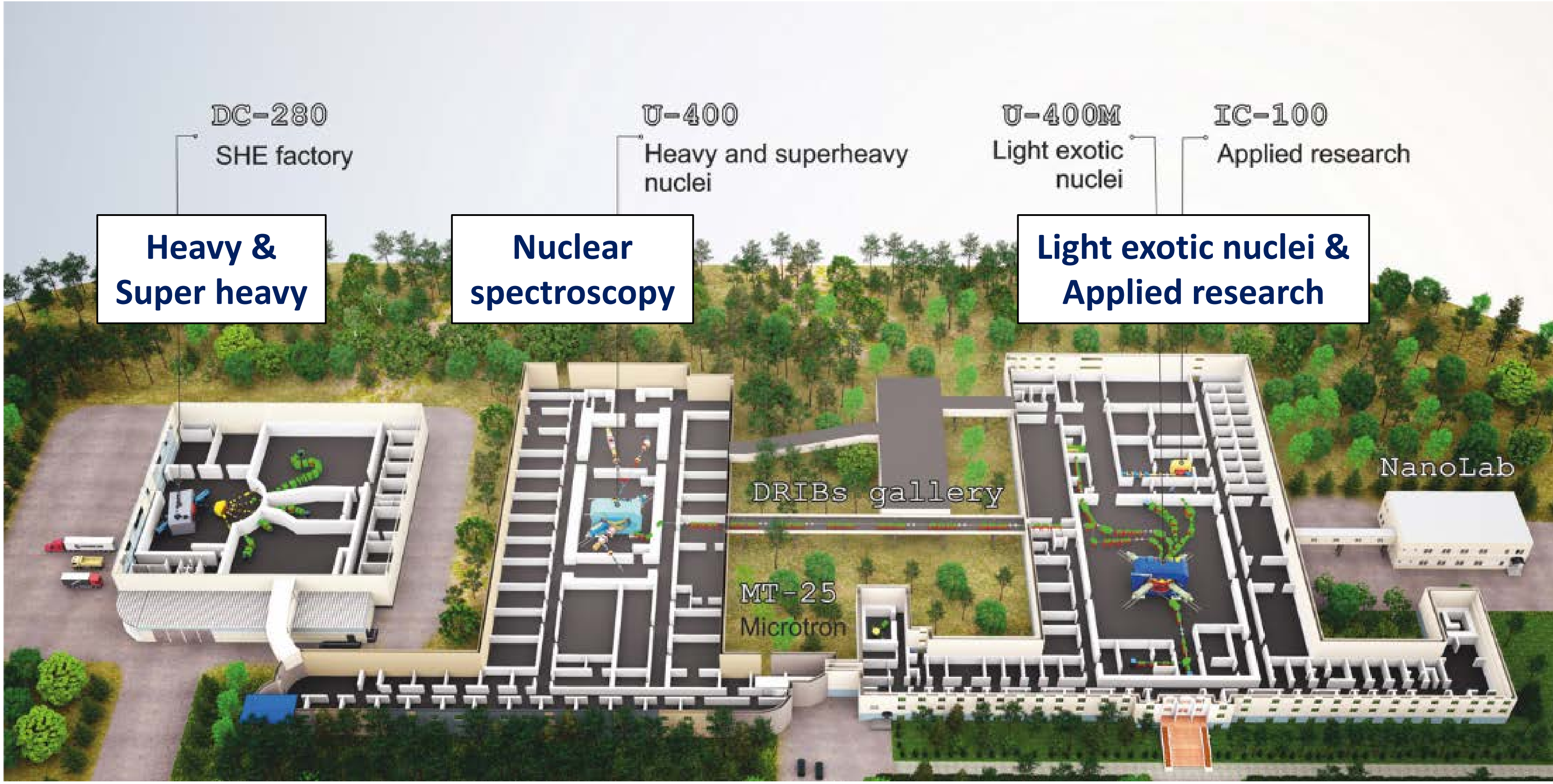






ACCULINNA - Light exotic nuclei, 'super heavy' in light nuclei (neutron-rich hydrogen ($^{5,7}H$) and helium ($^{8,10}He$) isotopes)

Full-scale realization of the DRIBs-III –project & Accelerators @ FLNR



DC-280

U-400

U-400M

U-200

IC-100

MT-25

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

ACCULINNA separator

АКУЛИНА (ACULINA) – russian name

ACCULINNA – High resolution RIB line for K4 storage ring

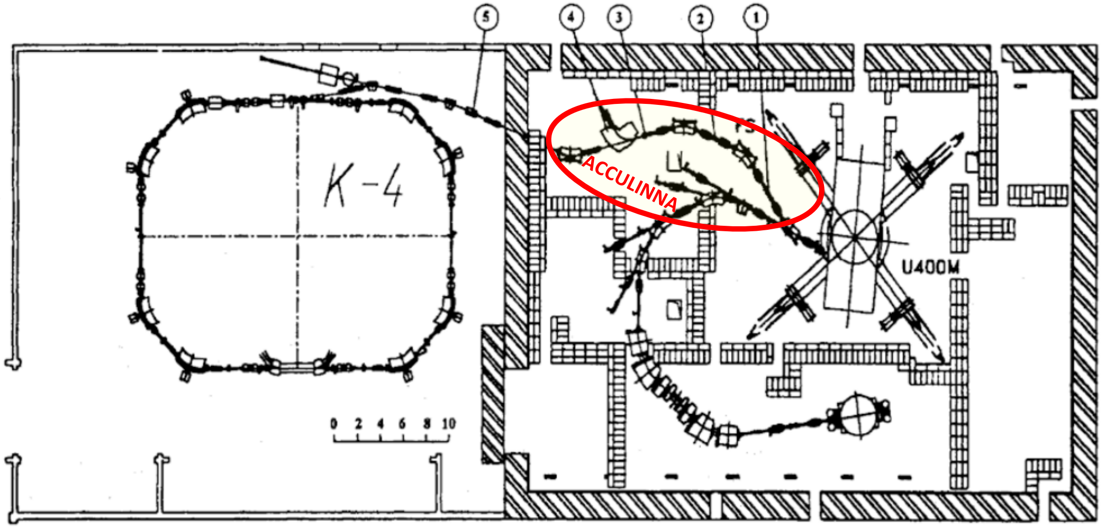
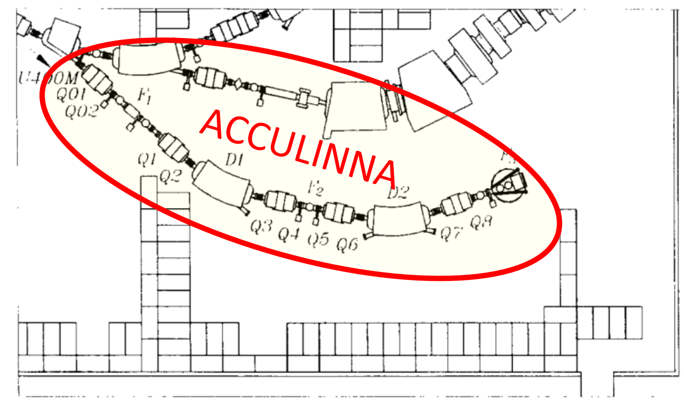


Fig. 1. The general view of the latest upgrad of the storage complex K4-K10.
1 - RIB production target; 2 - intermediate focal plane;
3 - secondary experemental target; 4 - analysing magnet; 5 - debuncher.



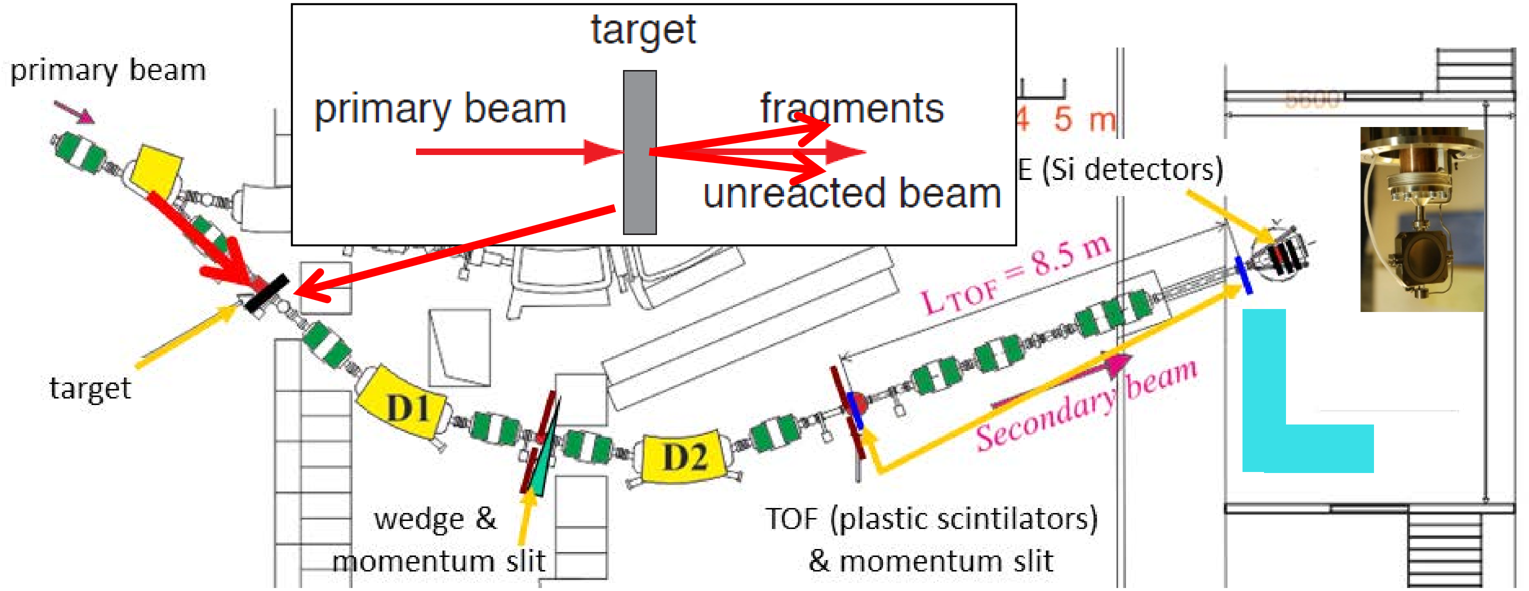
Exotic Beams in K4.

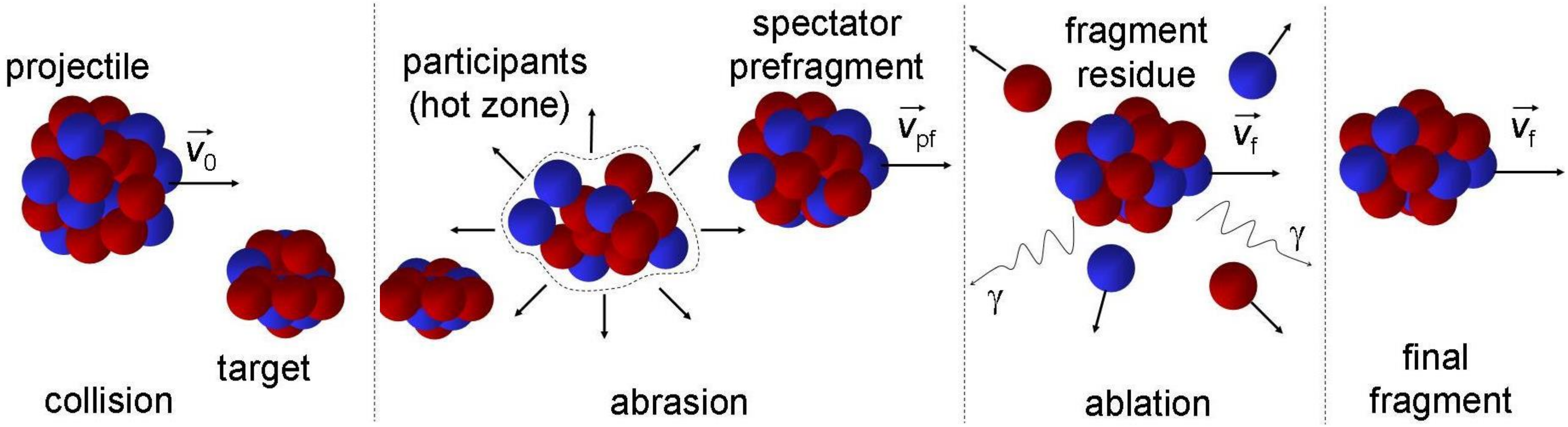
BEAMS	$T_{1/2}$ (sec)	$\lvert N - N_{drip} \rvert$	E_{inj} (Mev/amu)	E_{max} (Mev/amu)	NUMBER OF IONS ON ORBIT	L $(s^{-1} cm^{-2})$
^{6}He	0.808	2	42	80	10^4	10^{24}
^{8}He	0.122	0	43	50	10^2	10^{22}
^{8}Li	0.84	3	41	105	10^4	10^{24}
^{9}Li	0.178	2	44	80	10^3	10^{23}
^{11}Be	13.8	3	44	100	10^5	10^{25}
^{12}B	0.02	5	40	125	10^5	10^{25}
^{16}C	0.75	6	42	105	10^3	10^{23}
^{14}O	70.6	2	36	225	10^5	10^{25}
^{24}Ne	225	8	20	125	10^6	10^{26}
^{28}Mg	7×10^4	12	20	130	10^7	10^{27}
^{38}S	1×10^4	14	17	130	10^7	10^{27}
^{44m}Sc $(J^p = 6^+)$	2×10^5	9	22	160	10^8	10^{28}

K4 storage ring: production of high precision Exotic Ion Beams (EIB's) with $A < 100$.

G. M. Ter-Akopian et al., Heavy Ion Storage Ring Complex K4-K10. A technical proposal JINR E9-92-15, Dubna 1992

RIB production at ACCULINNA – projectile fragmentation





fast Abrasion step

nucleon removal in overlap region of target and projectile

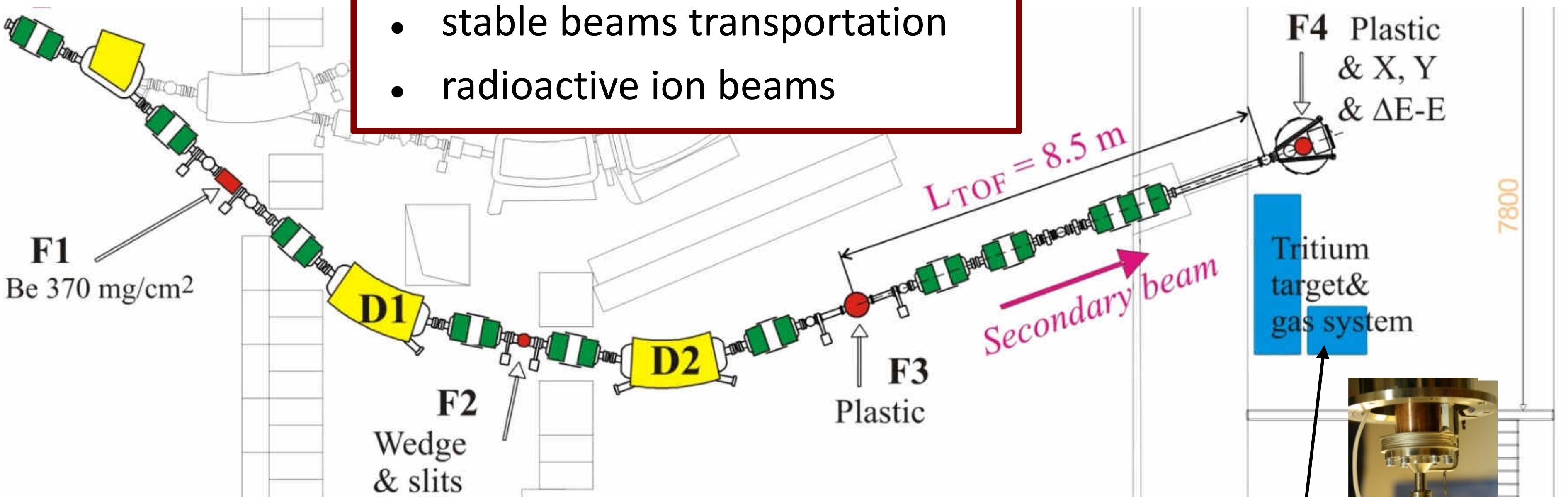
slow Ablation step

equilibration of excited prefragment and evaporation of particles

RIB production at ACCULINNA – projectile fragmentation

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

- stable beams transportation
- radioactive ion beams



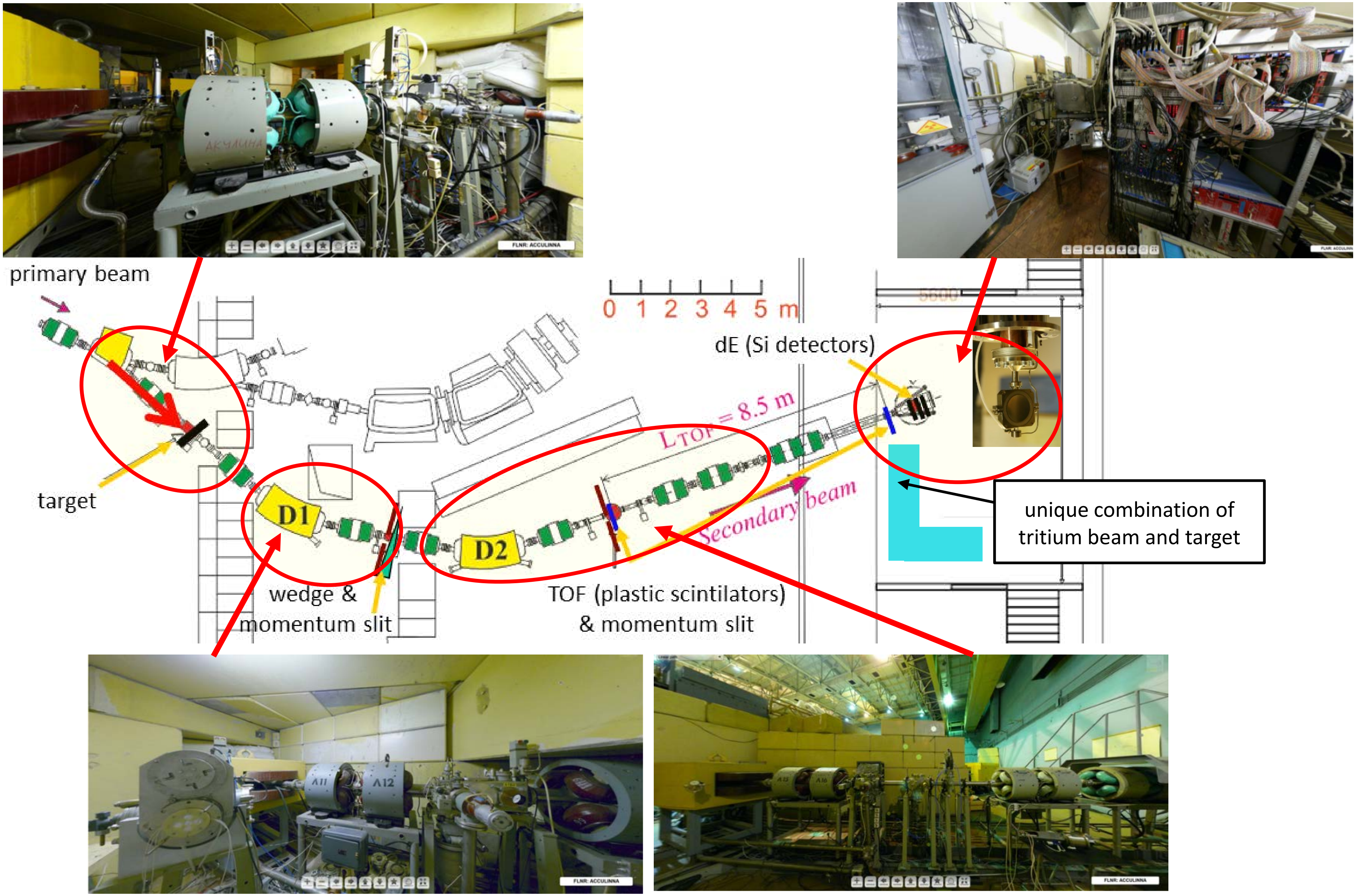
$E_{beam} \sim 10 – 45$ MeV/A, $I_{beam} \sim 10^{3} – 10^{6}$ pps

unique combination of tritium beam and target

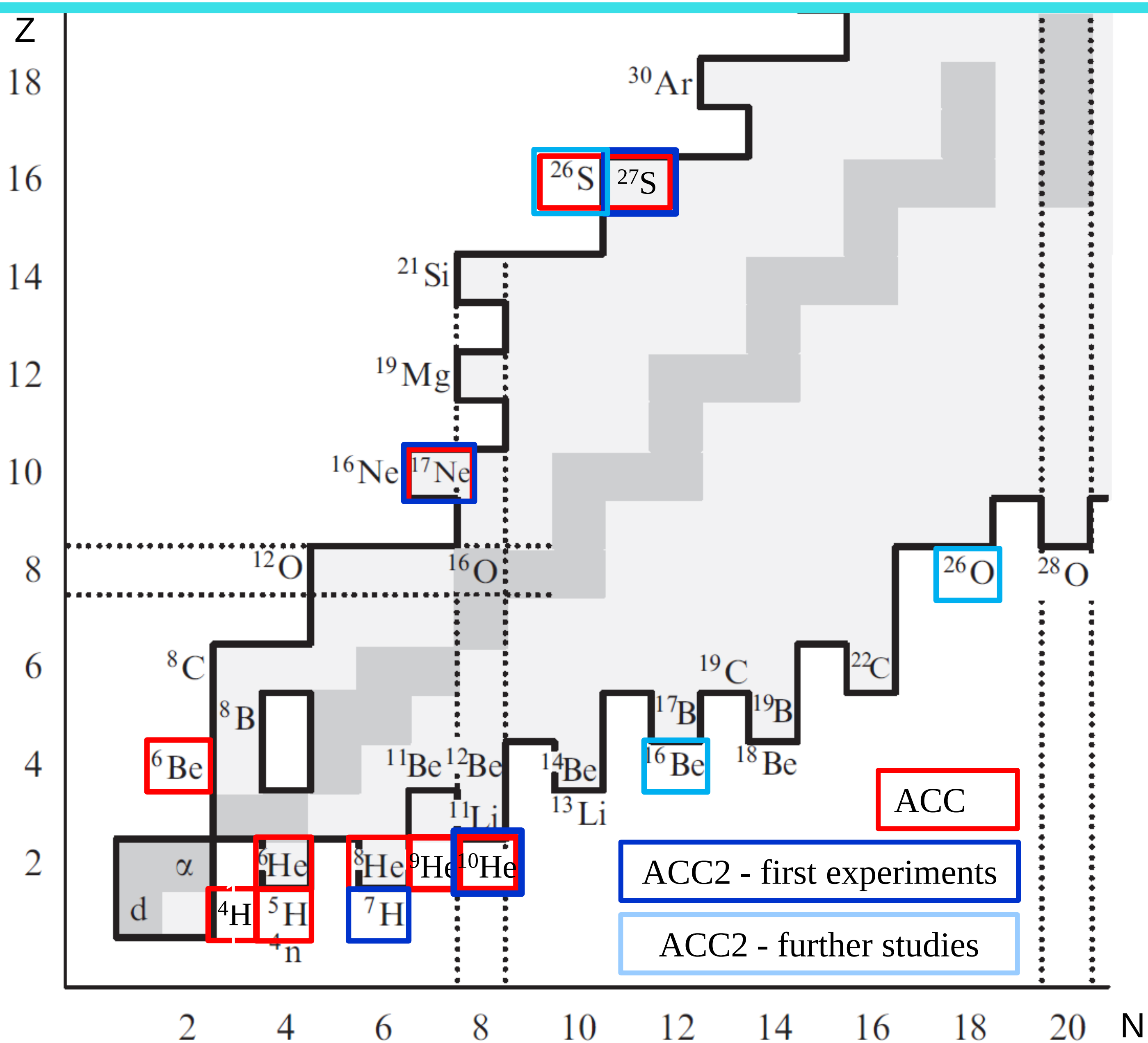
- the only working RIB facility at JINR
- in-flight technique, TOF, ΔE/E, full kinematic
- beams up to ^{26}S

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

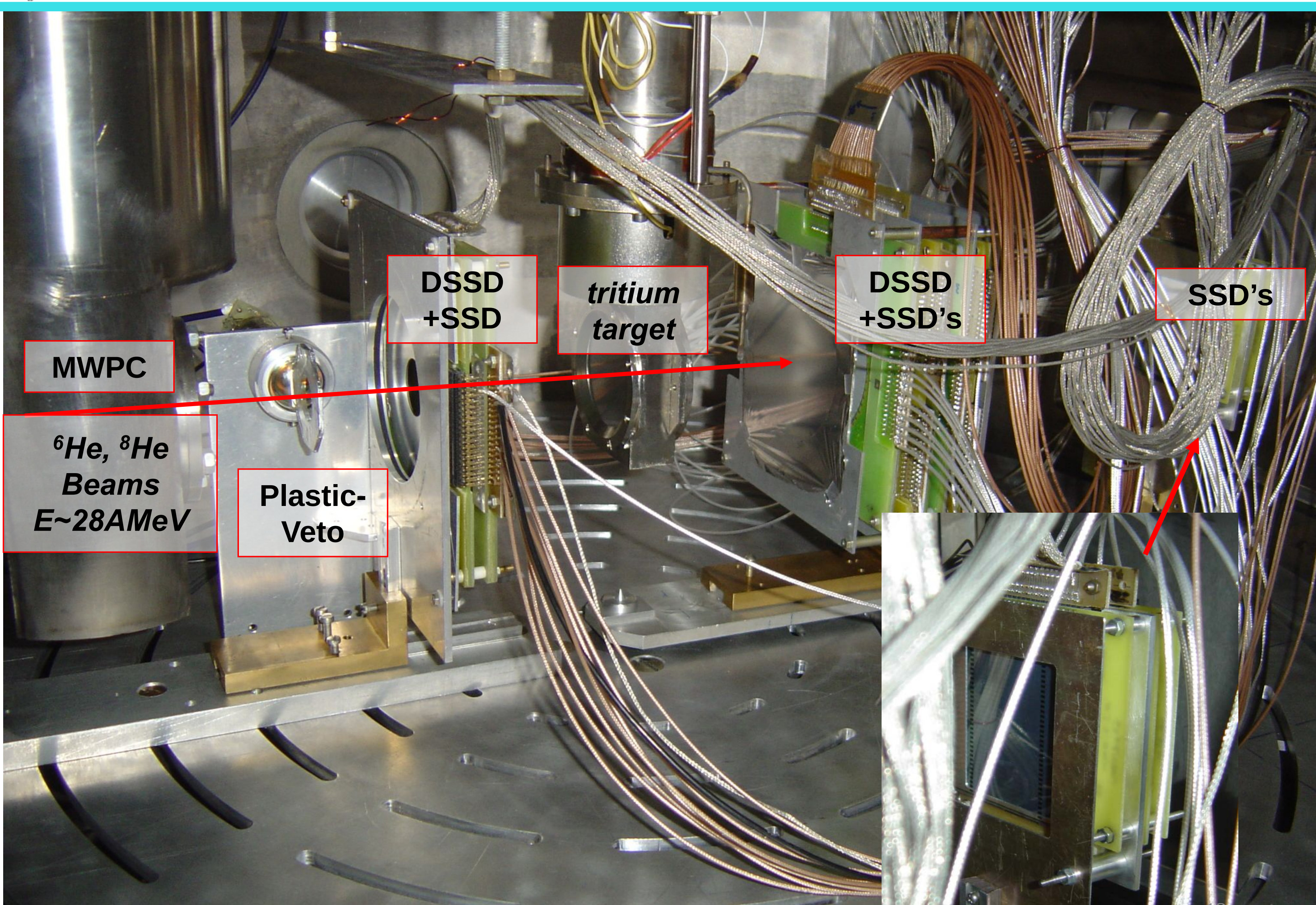
ACCULINNA at the U400M cyclotron hall



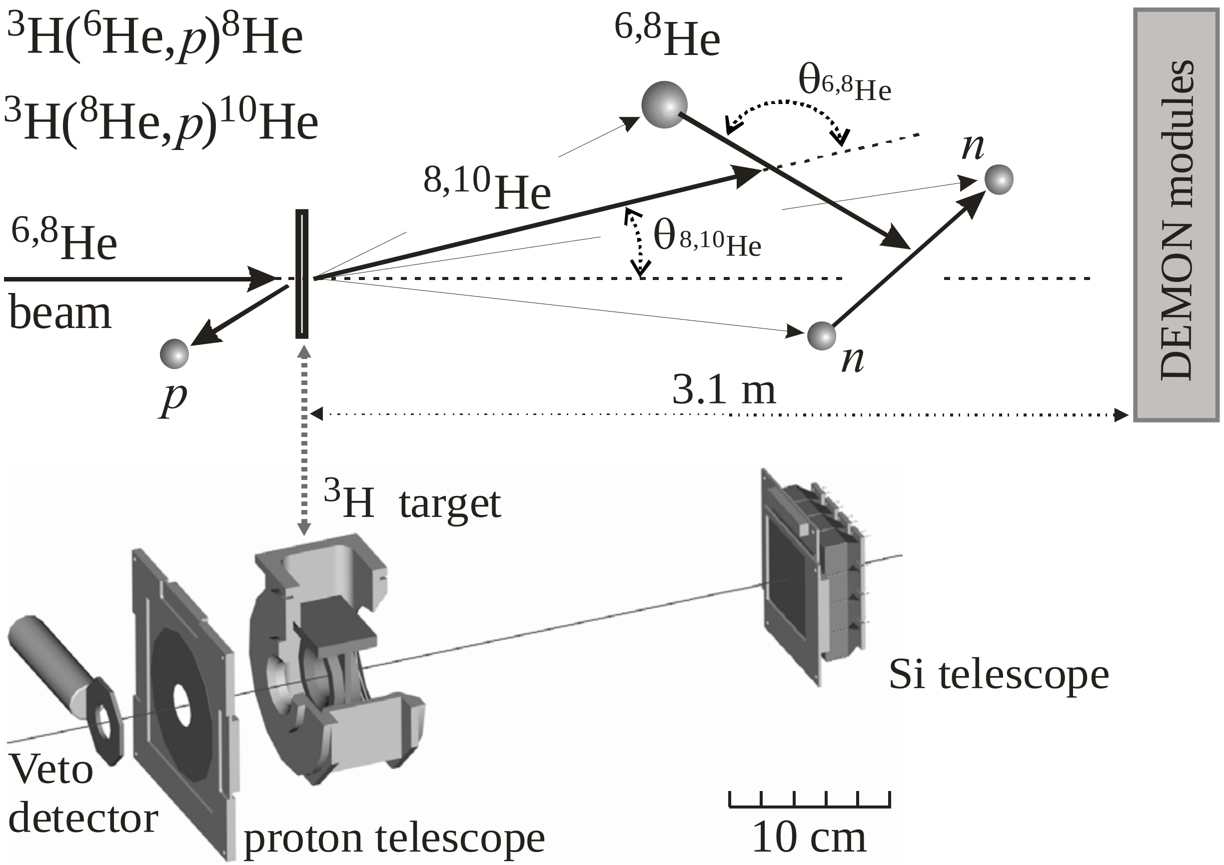
The main area of activity at ACCULINNA, FLNR



^{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



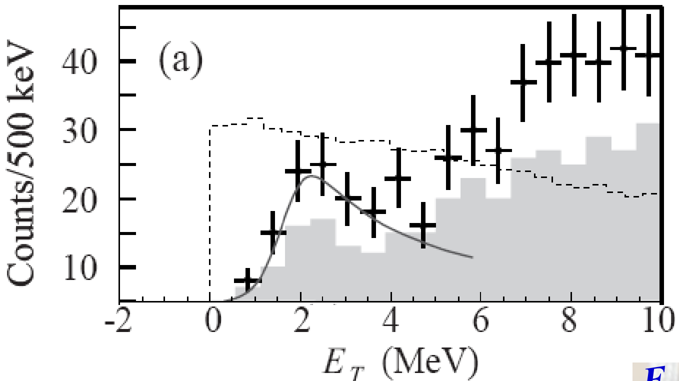
Features:

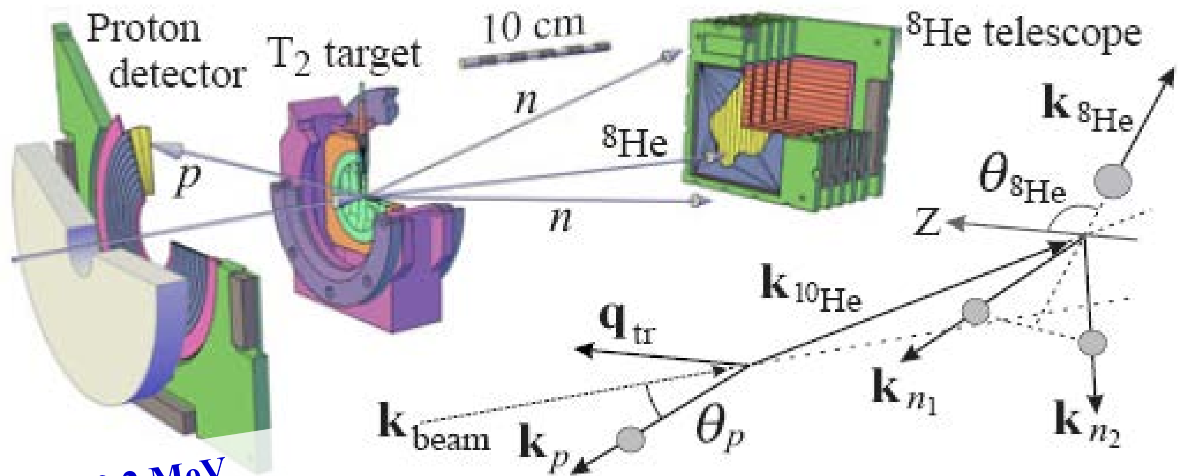
Reasonable energy resolution ΔE~400 keV (FWHM)

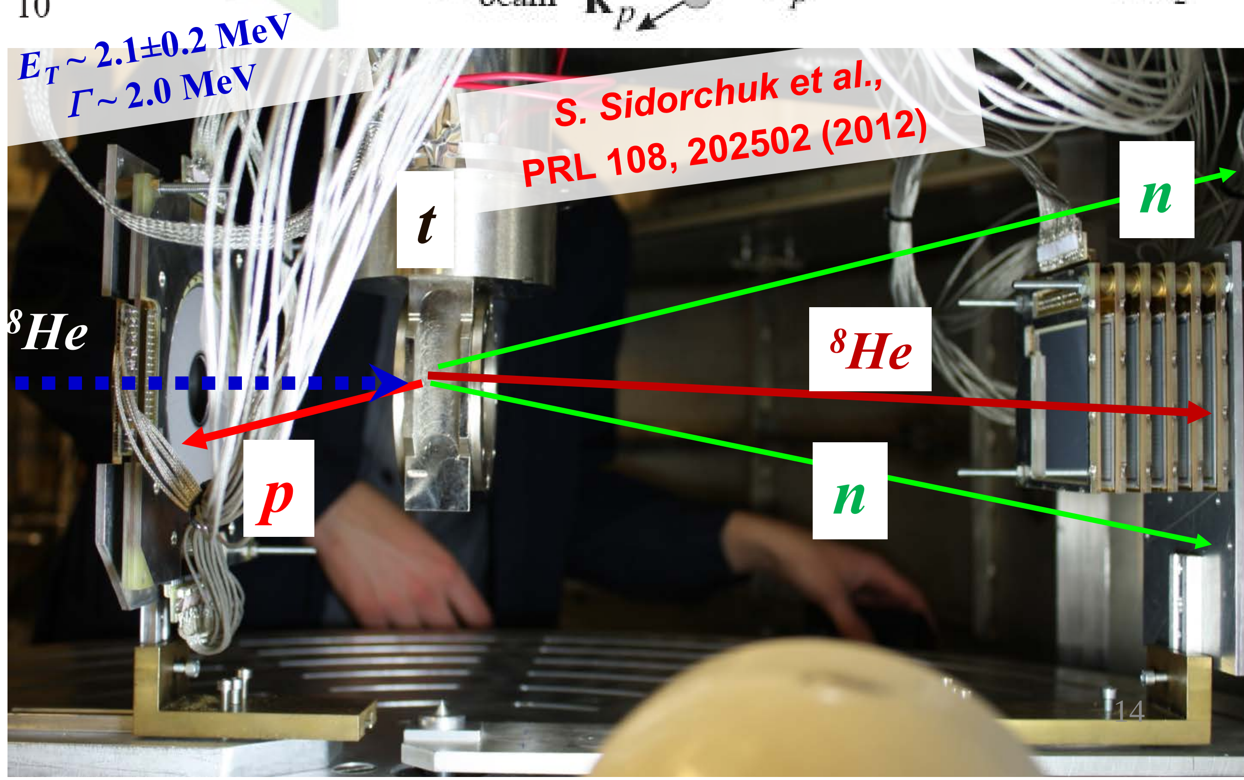
Practically background free: very few protons go in the backward lab direction

- 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





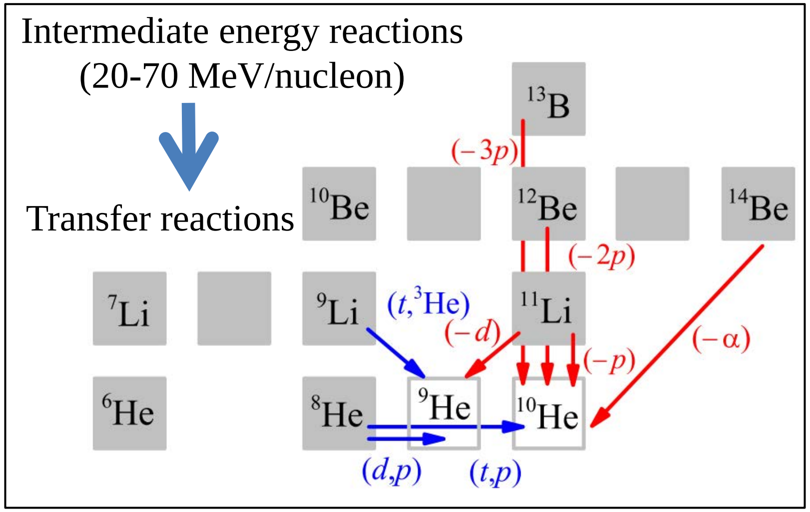


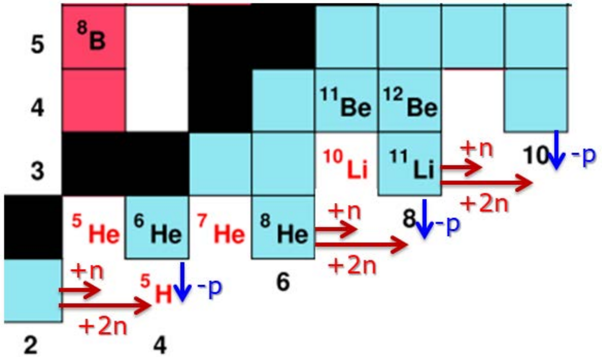
^{8}He beam:
E ~ 23 A·MeV
I ~ 15000 s^{-1}
Tritium target:
6 mm thick @ 99.7 %
0.92 atm @ 26 K

Study of exotic nuclei in FLNR at the low RI energies

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

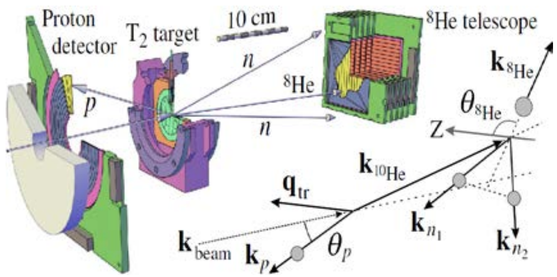
- The **record intensity** of the primary cyclotron beams (5 pμA of ^{11}B);
- Relatively (for in-flight separators) **low beam energies**, that provide a good energy resolution, high reaction cross section partly compensate the low intensities of secondary beams.
- These **beam energies are optimal** 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

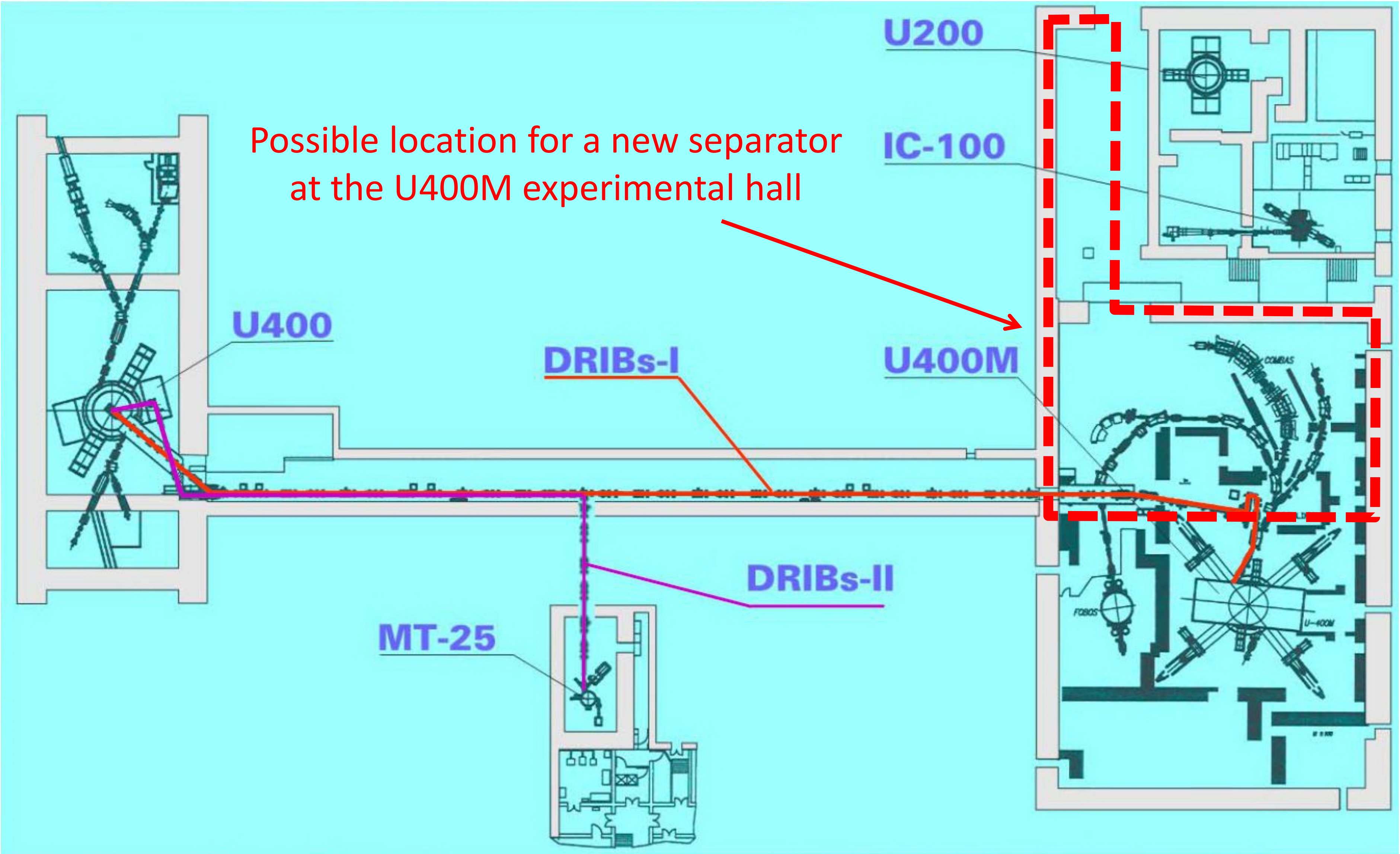
- correlation experiments
- lifetime measurements
- spectroscopic structure studies
- search for new light exotic nuclei and exotic decays



Use of the **ACCULINNA** fragment separator **has its Disadvantages:**

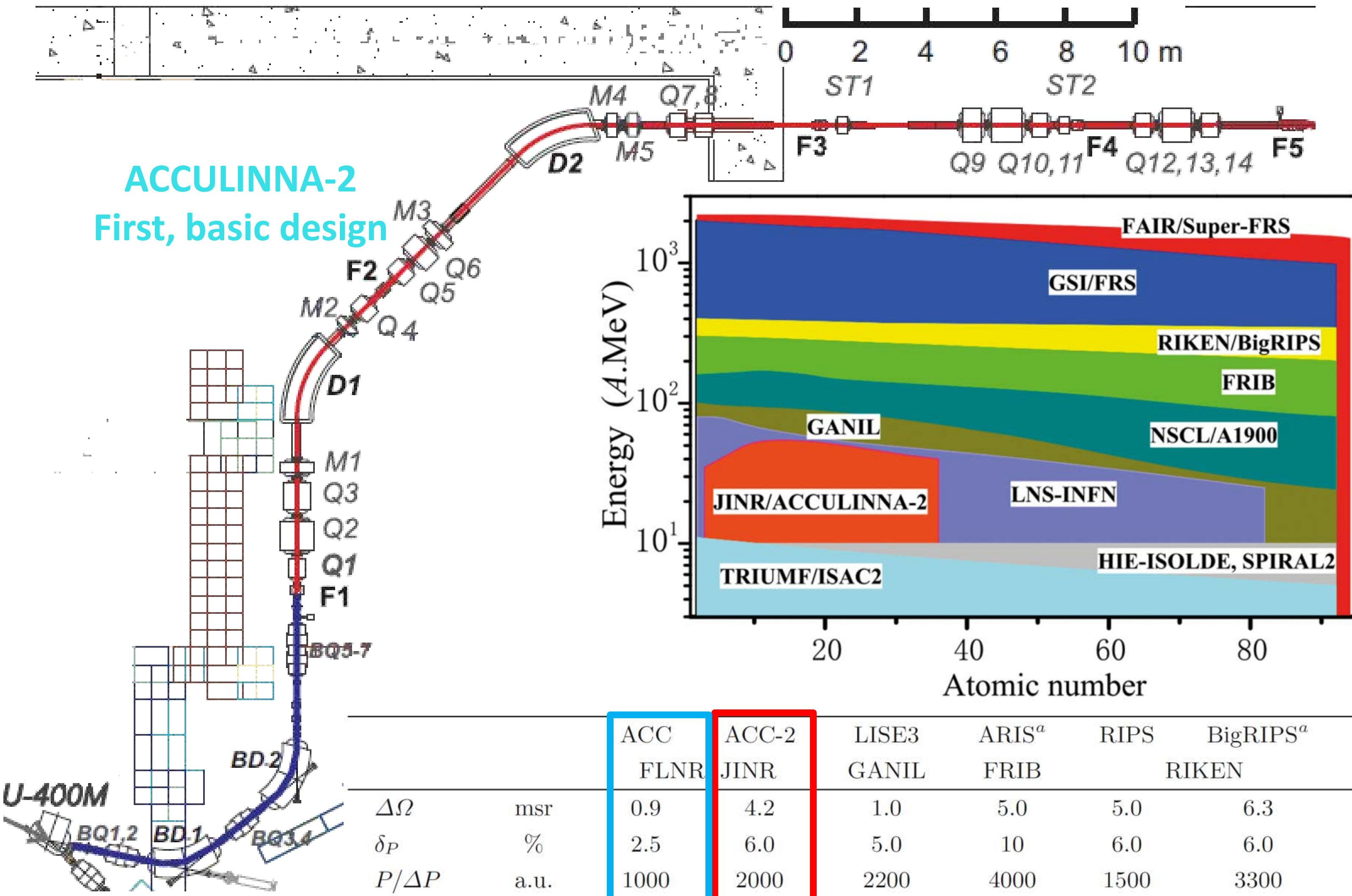
- It is only efficient with **lightest neutron-rich nuclei**;
- Does not cope with the request of **high intensity clean beams** with Z>8;
- We need **more powerful detector array**, and a bigger experimental area (for TOF);
- **Small length of the separator** puts limitation on the energy resolution;

ACCULINNA-2 separator – beginning of the project
2010 - 2011


U200
IC-100
Possible location for a new separator
at the U400M experimental hall
U400
DRIBs-I
U400M
DRIBs-II
MT-25
COMBAS
FOBOS
U-400M

ACCULINNA-2 – project assumptions

ACCULINNA-2
First, basic design



		ACC FLNR	ACC-2 JINR	LISE3 GANIL	ARIS[a] FRIB	RIPS RIKEN	BigRIPS[a] RIKEN	FRS GSI/FAIR	SuperFRS[a] GSI/FAIR
$\Delta\Omega$	msr	0.9	4.2	1.0	5.0	5.0	6.3	0.32	5.0
δ_P	%	2.5	6.0	5.0	10	6.0	6.0	2.0	5.0
$P/\Delta P$	a.u.	1000	2000	2200	4000	1500	3300	8600	3050
$B\rho_{max}$	Tm	3.2	3.9	3.2-4.3	8.0	5.76	9.0	18	18
Length	m	21	37	19(42)	87	21	77	74	140
$E_{\min}$	AMeV	10	5	30	30[b]	30	5[c]	220	
$E_{\max}$	AMeV	40	50	80	300	90	350	1000	1500

Grzegorz Kaminski, FUW, 29.11.2018

ACCULINNA-2 – project assumptions

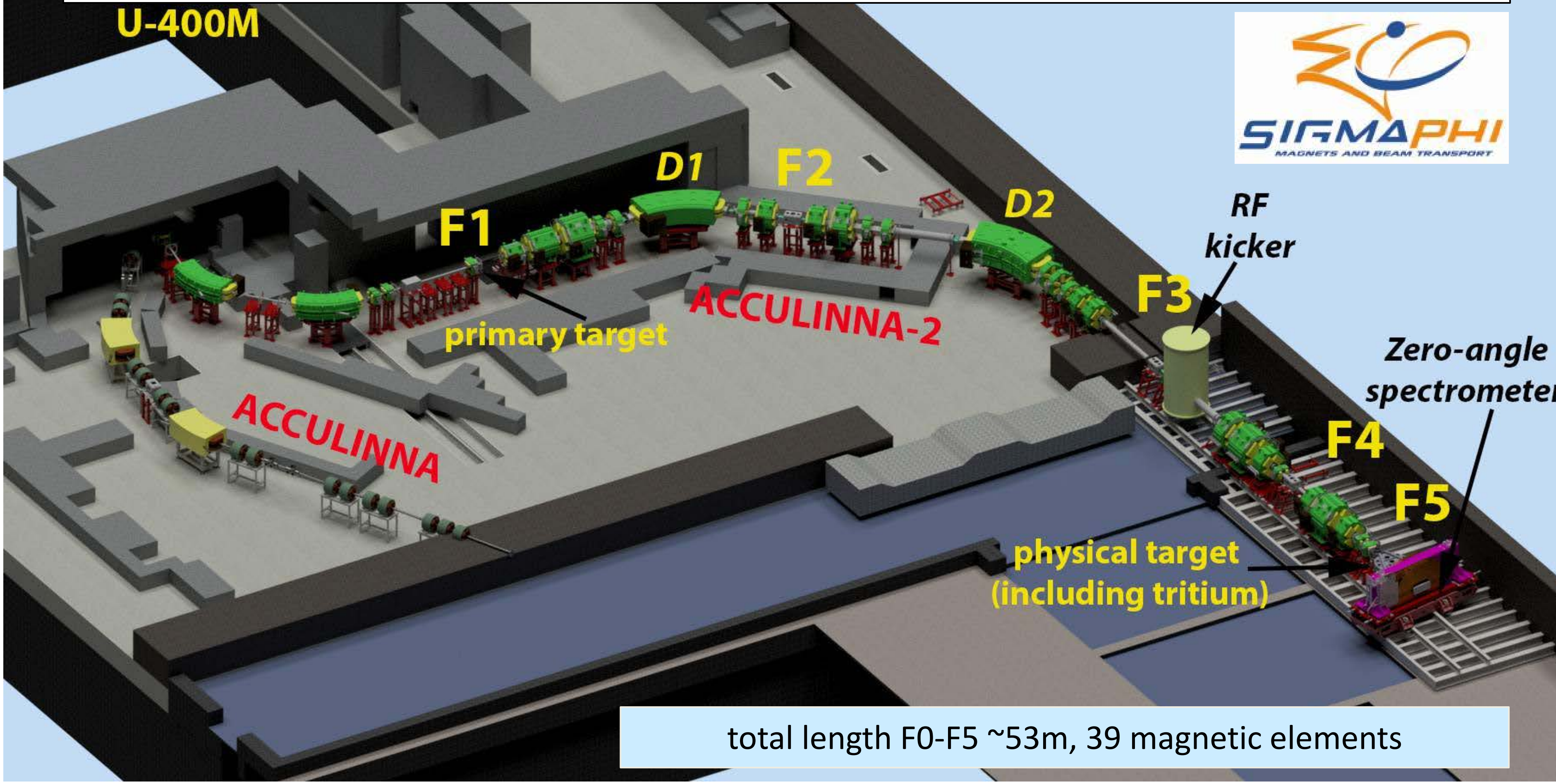
calculations done with LISE++

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)

From contract signing to installation
October 2011 to December 2015

Layout of the ACCULINNA-2 separator

A.S. Fomichev et al. *The ACCULINNA-2 project: The physics case and technical challenges*, Eur. Phys. J. A 54, 97 (2018)



- RIB energy range 6 – 50 MeV/A
- Z_{RIB} ~ 1 – 36

« In the beginning, there was *Chaos* »

Greek Mythology – The Creation

Area & floor preparation 1st delivery

Installing stands

Installation & Alignment, magnets

Installation & Alignment, magnets and vacuum

Magnets: some big ones

Installation out of reach of the crane

Standardization - Grouping

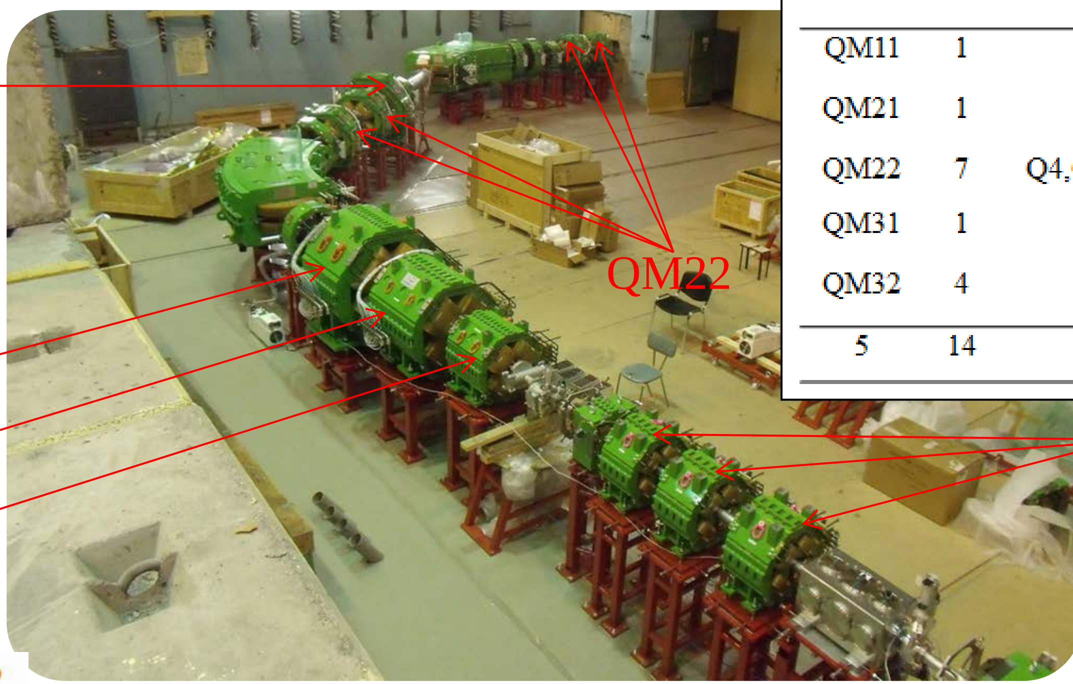
Standardization groups objects with “similar” properties

Advantages
- Huge reduction in cost for design, tooling and fabrication
- Exchangeability and servicing

Drawbacks
- Slightly sub-optimal design
- Higher material costs

PARTIAL standardization keeps most of the advantages while taming drawbacks
COMPLETE standardization is NOT the best solution

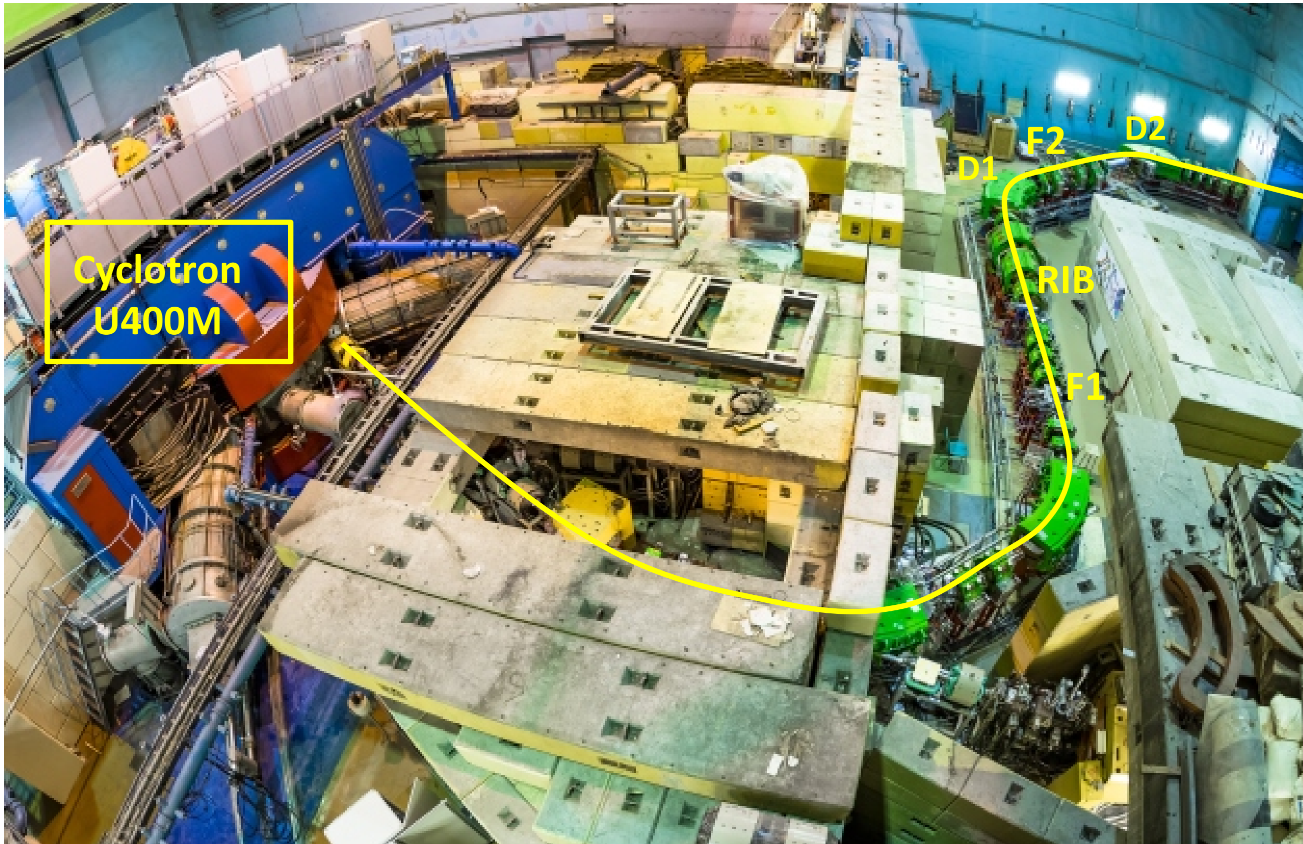
Type	Qty	Quad name	Core	Coil	Design
QM11	1	Q1	A	1	1
QM21	1	Q2	B	1	1
QM22	7	Q4,Q5,Q7,Q8,Q11,Q12,Q14	B	1	1
QM31	1	Q3	C	1	1
QM32	4	Q6,Q9,Q10,Q13	C	1	1
5	14		3	5	5

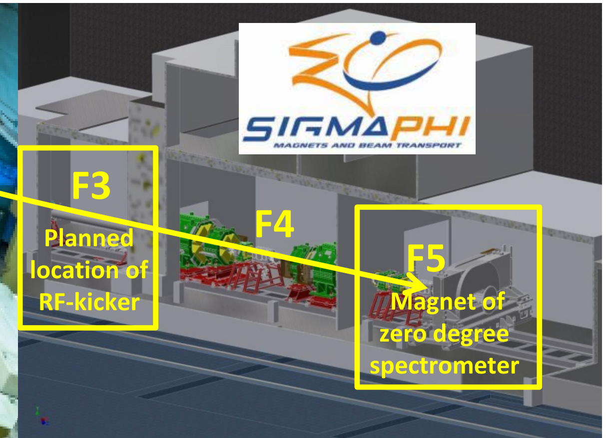


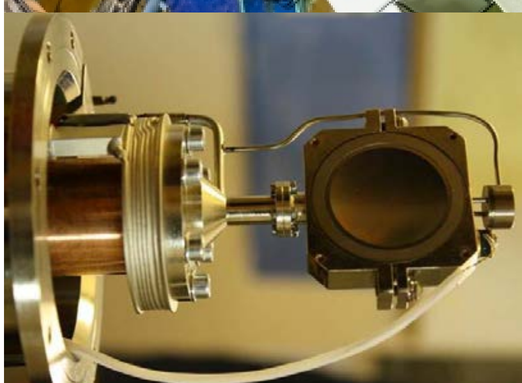
PS installation, full cabling and cooling

Support for shielding walls is prepared

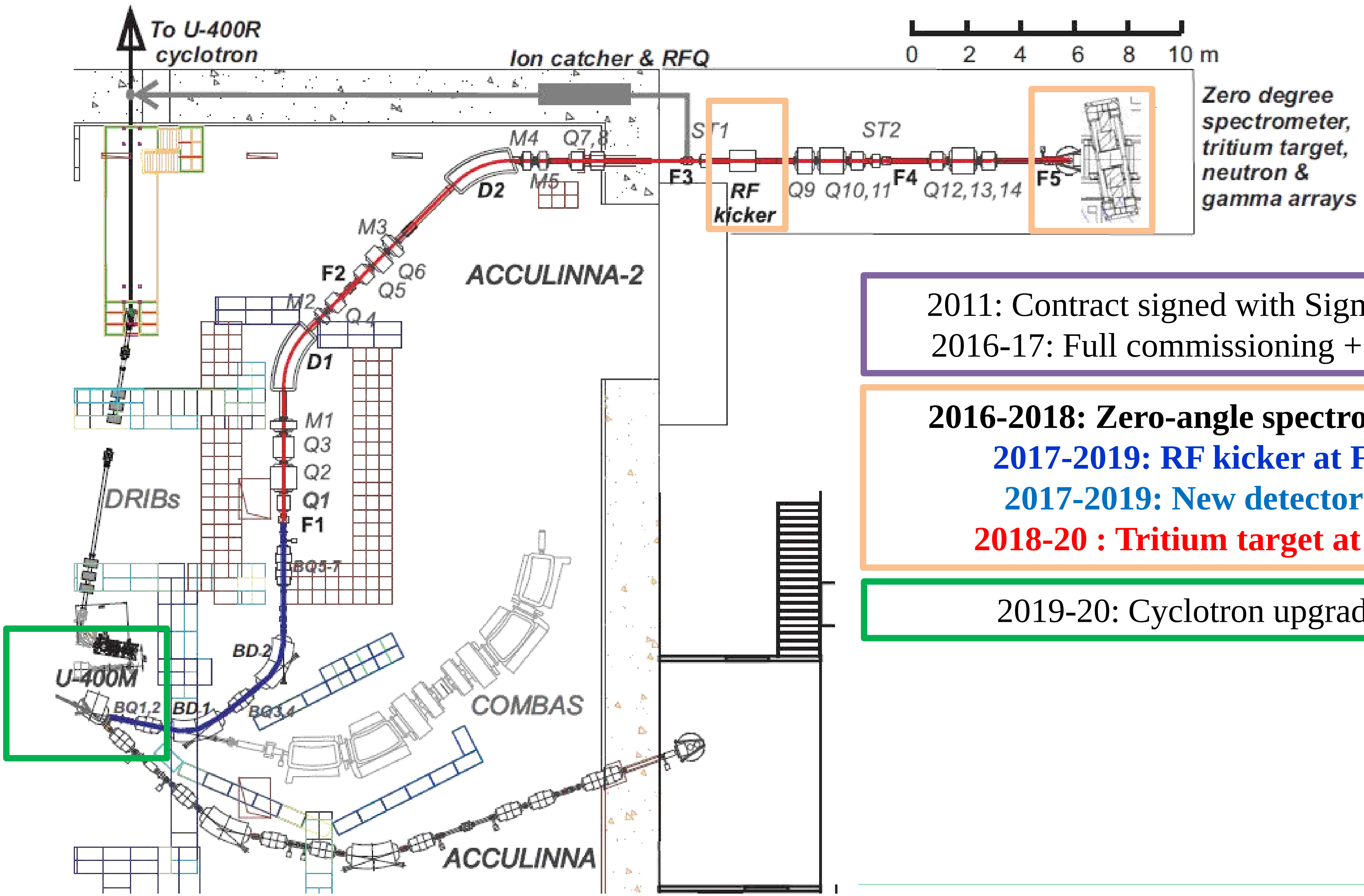
ACCULINNA-2 at experimental area







Instrumentation at ACCULINNA-2



2011: Contract signed with Sigma PHI
2016-17: Full commissioning + Beam

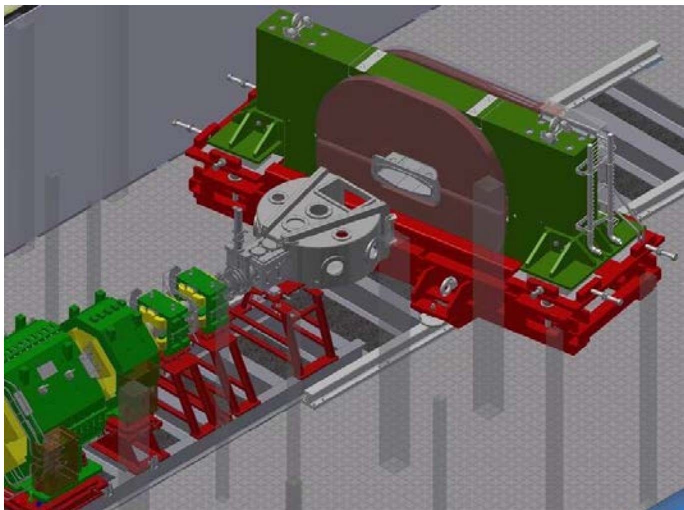
2016-2018: Zero-angle spectrometer
2017-2019: RF kicker at F3
2017-2019: New detectors
2018-20 : Tritium target at F5

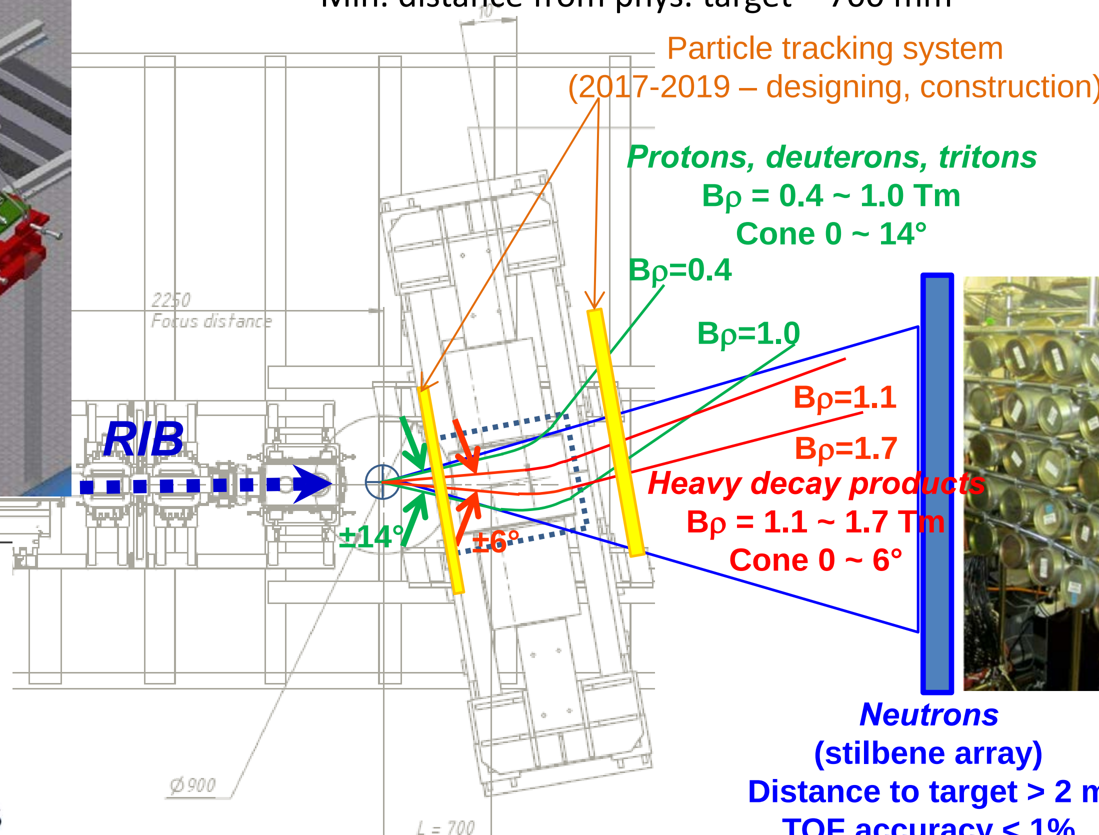
2019-20: Cyclotron upgrade

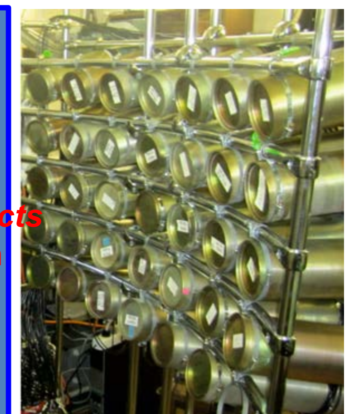
The zero degree spectrometer

Zero degree spectrometer - experiments with light RIB : separation of light and heavy charged fragments and neutrons

- Weight ~ 20 t
- Max. 1,38 Tm
- Thin (330 mm) open-frame design
- Mounted on guiding rails. Precision in different positions ±0,2 mm. Repeatability ~ 0,1 mm
- Min. distance from phys. target ~ 700 mm



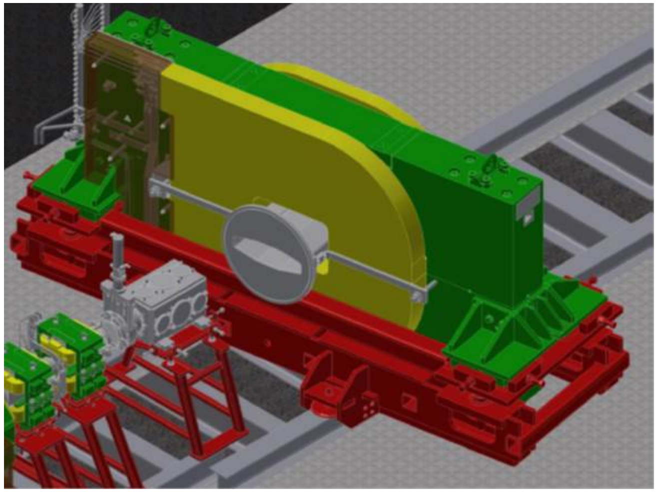




Maximum field	$B_{\max}$	T	1.44
Minimum field	$B_{\min}$	T	0.4
Effective length for $B = 1.2\,\mathrm{T}$	L	mm	524
Gap		mm	180
Good field region dimensions	H/V	±mm	250/75
Field homogeneity for $B = 1.2\,\mathrm{T}$	$\mathrm{d}B/B$		0.003

The zero degree spectrometer

Installation: February 2017, -20 °C outside temperature



November 2017

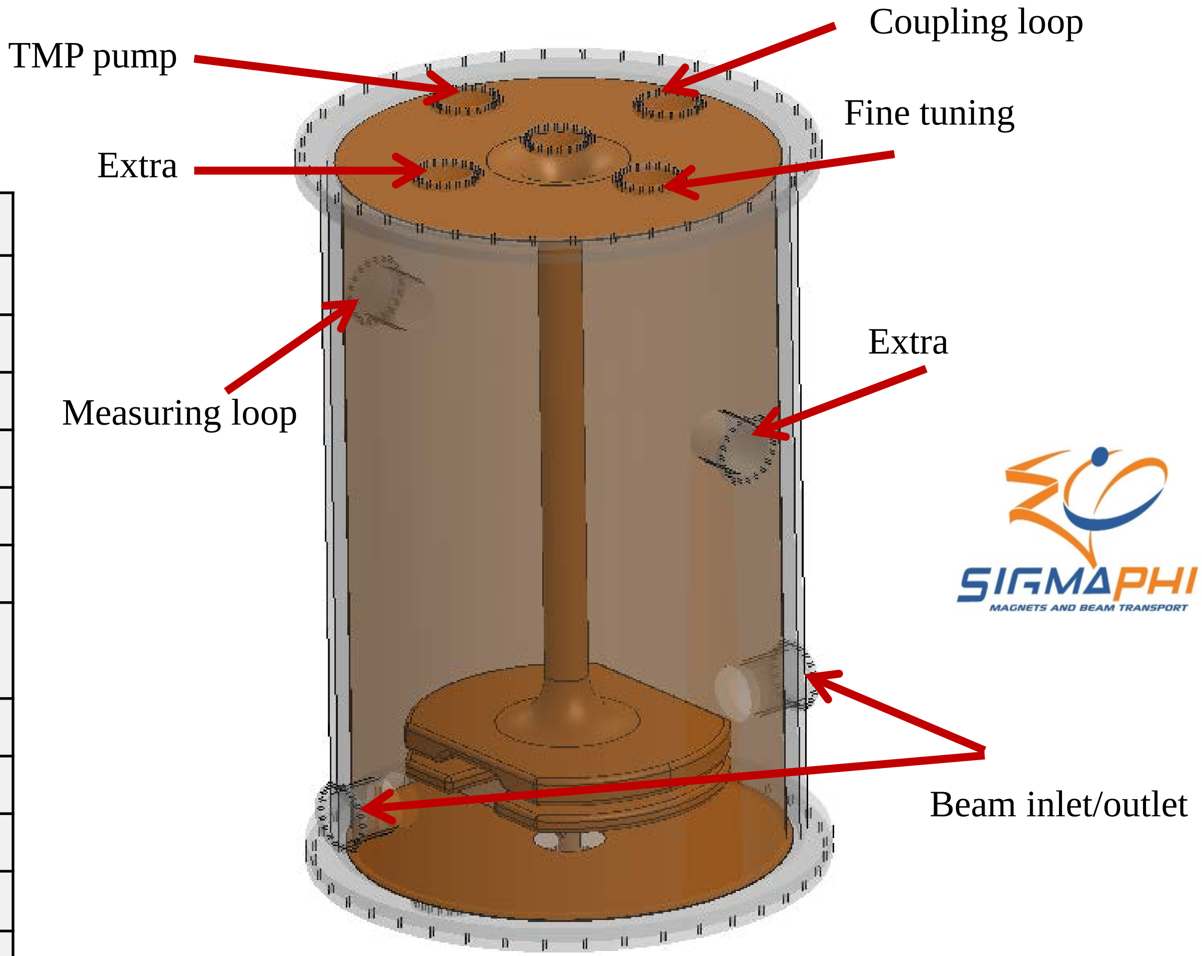
~ Half of the founds for Zero degree spectrometer was supported from Polish grants at JINR

RF kicker: started in 2016, installation planned in 2019

- The frequency range 14,5 – 20 MHz is the best compromise in terms 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



RF kicker: started in 2016, installation planned in 2019

- The frequency
- We consider s
- Reducing the of 12 Kwatts v

er

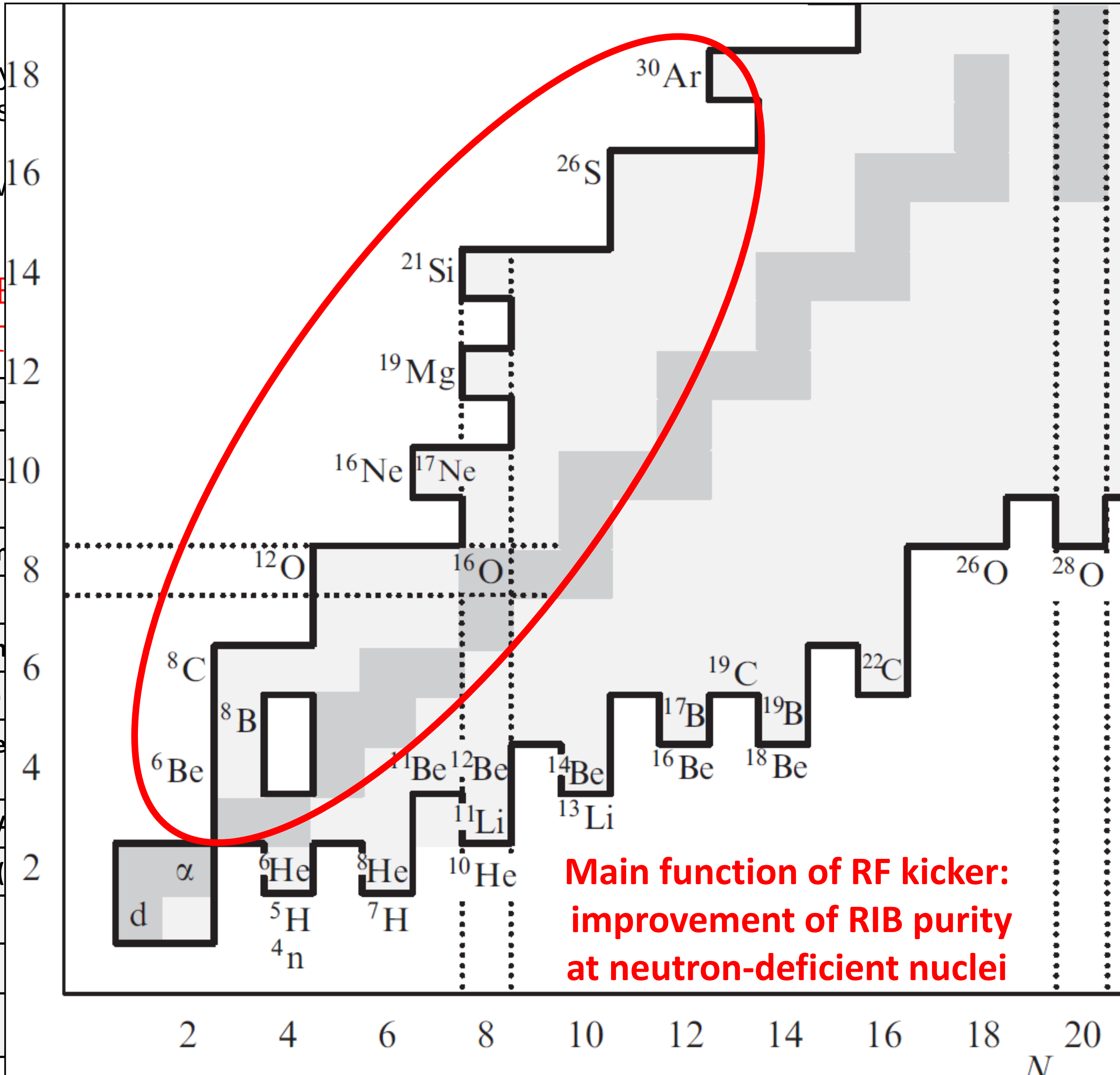
es a RF power

ng loop

ng

PARAME
CALCULAT

Frequency range (MH
Peak voltage (KV)
GAP (mm)
Width of electrode (r
Length of electrodes
Cylinder diameter (m
Stem diameter (mm)
Length of coaxial line beam axis (mm)
Current at junction (A
Current in short-cut (
RF power (Watts)
Reactance Q
Df (RF tuning) (MHz)

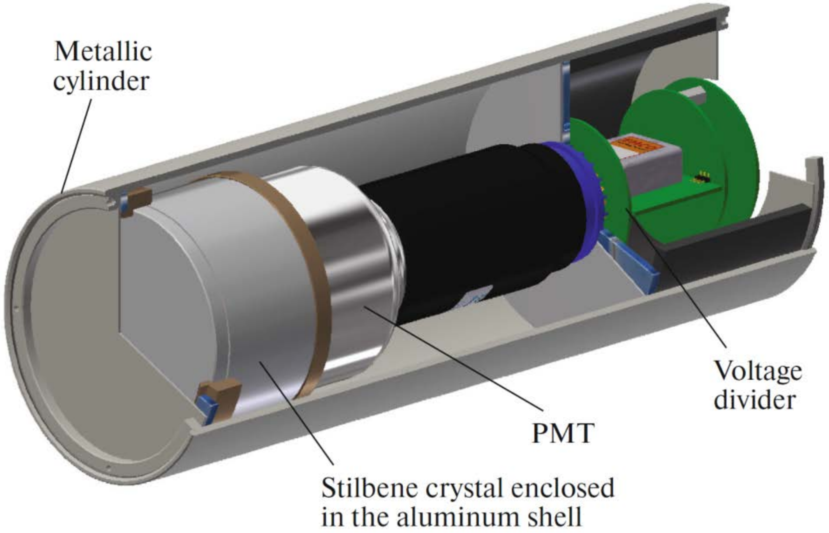


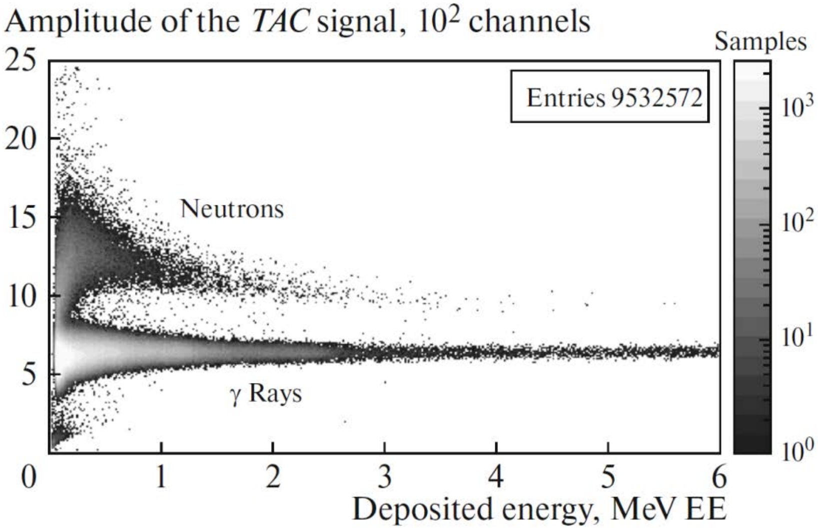
am inlet/outlet

Neutron detector array

Study light exotic nuclei such as ^{5}H, ^{7}H, ^{9}He, ^{10}He, and ^{10}Li, etc. – neutron detection

Stilbene crystal: ∅ 80 mm, thickness 50 mm





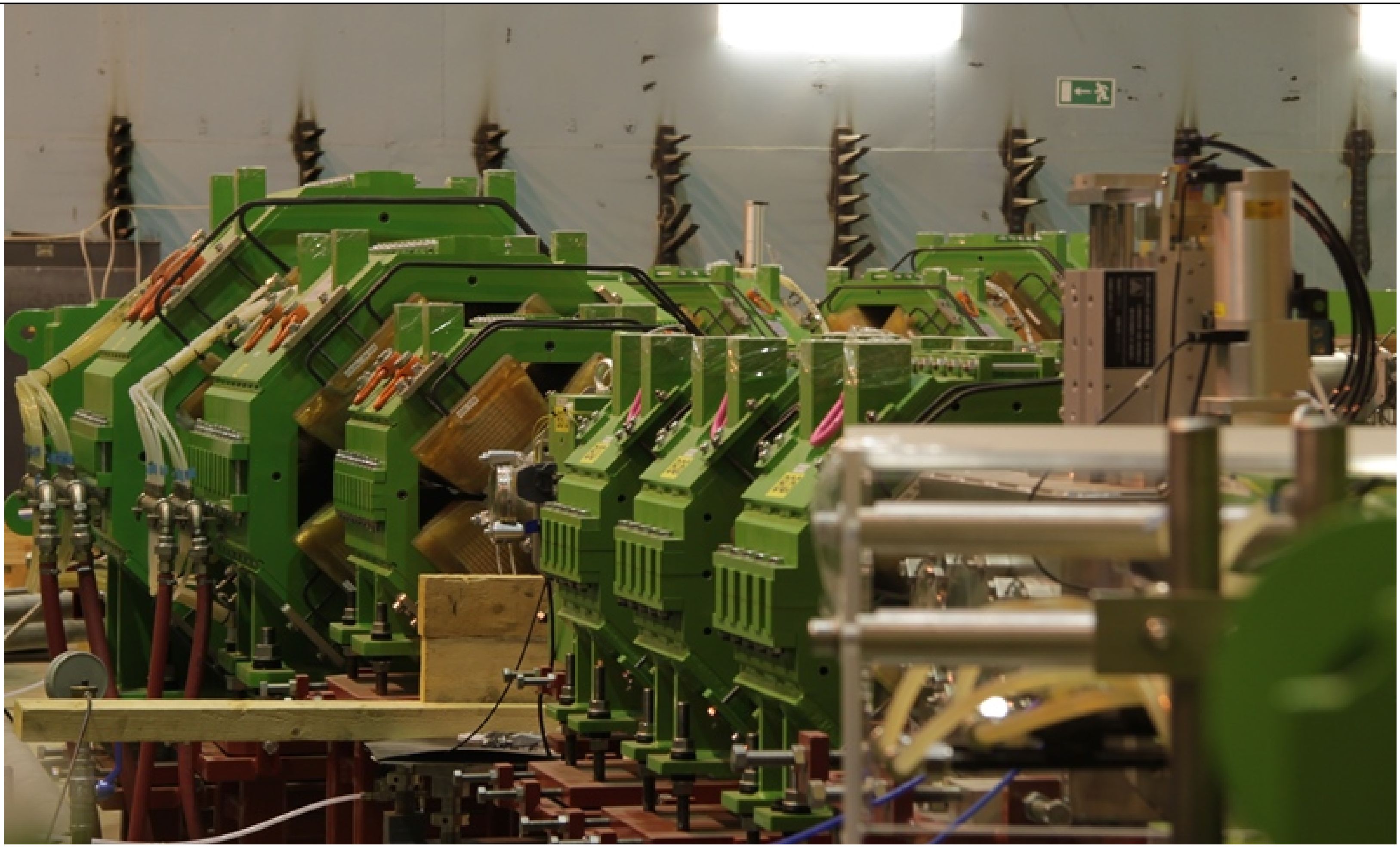
A. Bezbakh et al.,, Instr. and Exp. Tech. 2018, Vol. 61, No. 5, pp. 631–638.

neutron array at ACCULINNA-2

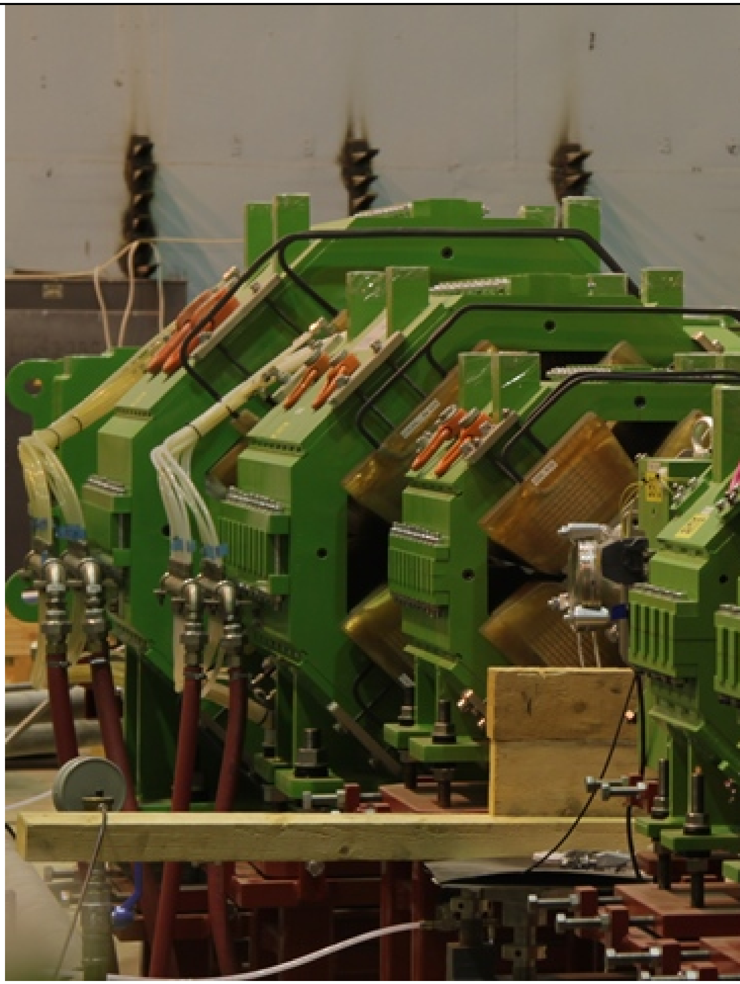
ACCULINNA-2 separator – First RIBs

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

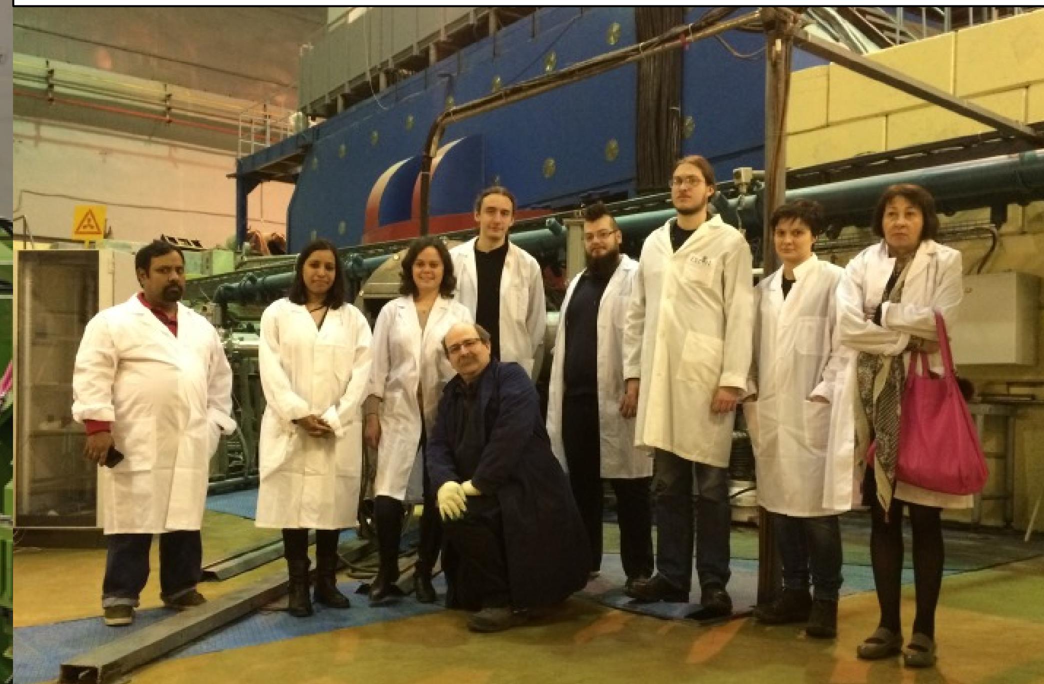
^{15}N(49.7 AMeV) +^{9}Be(2 mm), @ 1 pnA (7enA)



Beam optics test and first radioactive ion beams in March, 2017
^{15}N(49.7 AMeV) +^{9}Be(2 mm), @ 1 pnA (7enA)



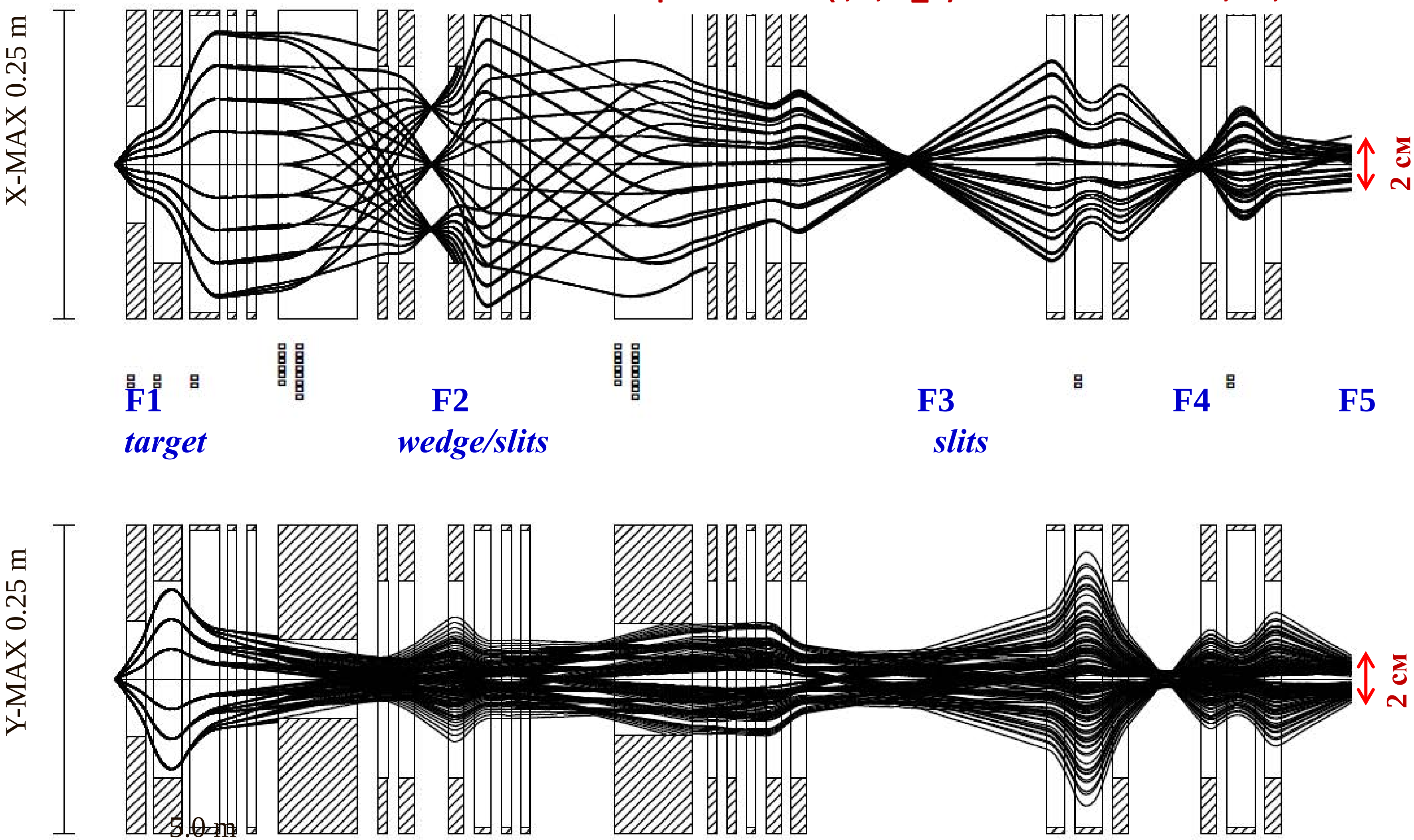
Polish visitors (**HIL UW**, **FUW**, **WUT**)



First beam optics tests & First RIB at ACCULINNA-2

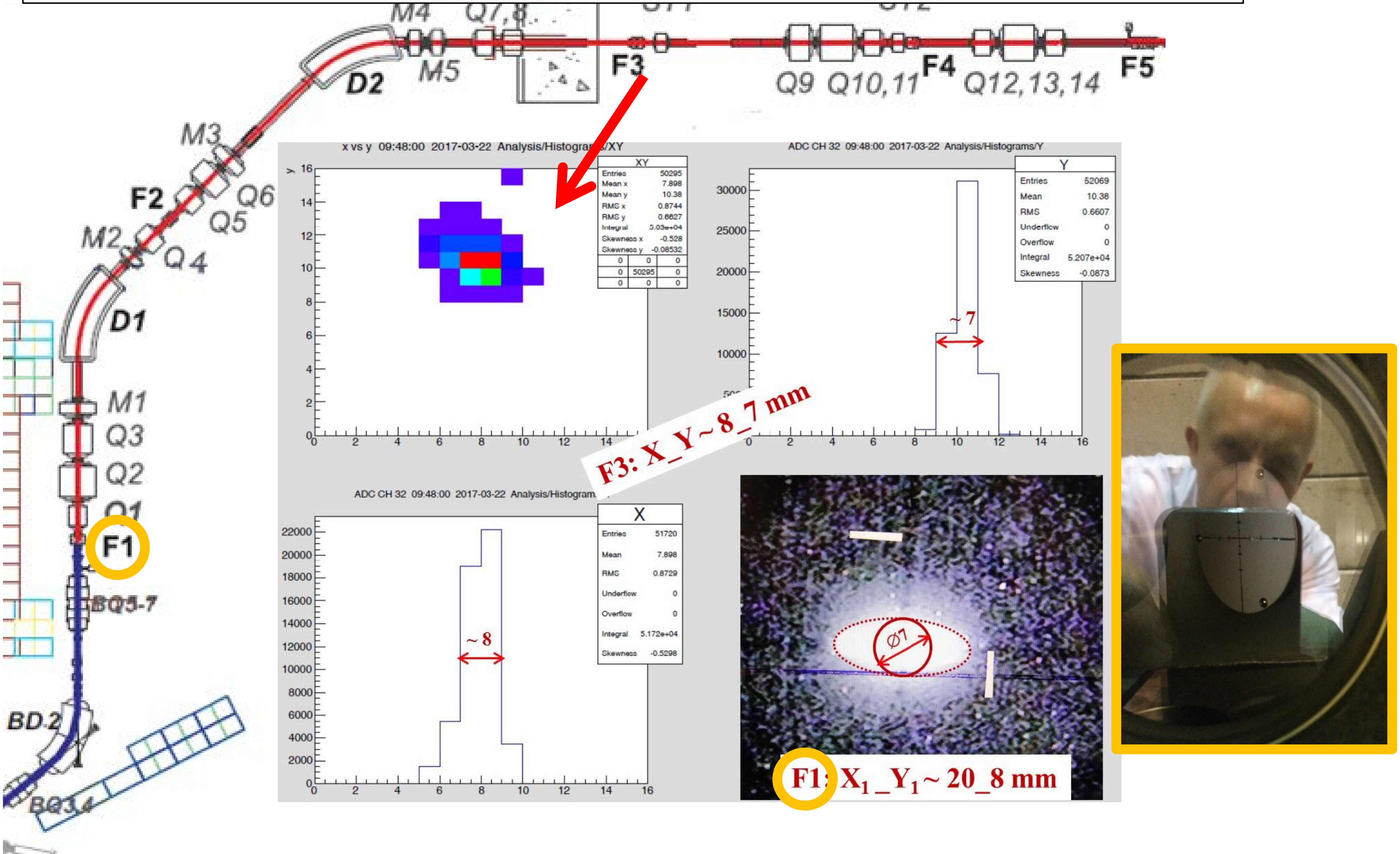
Goals of the test in March 2017:

- ^{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



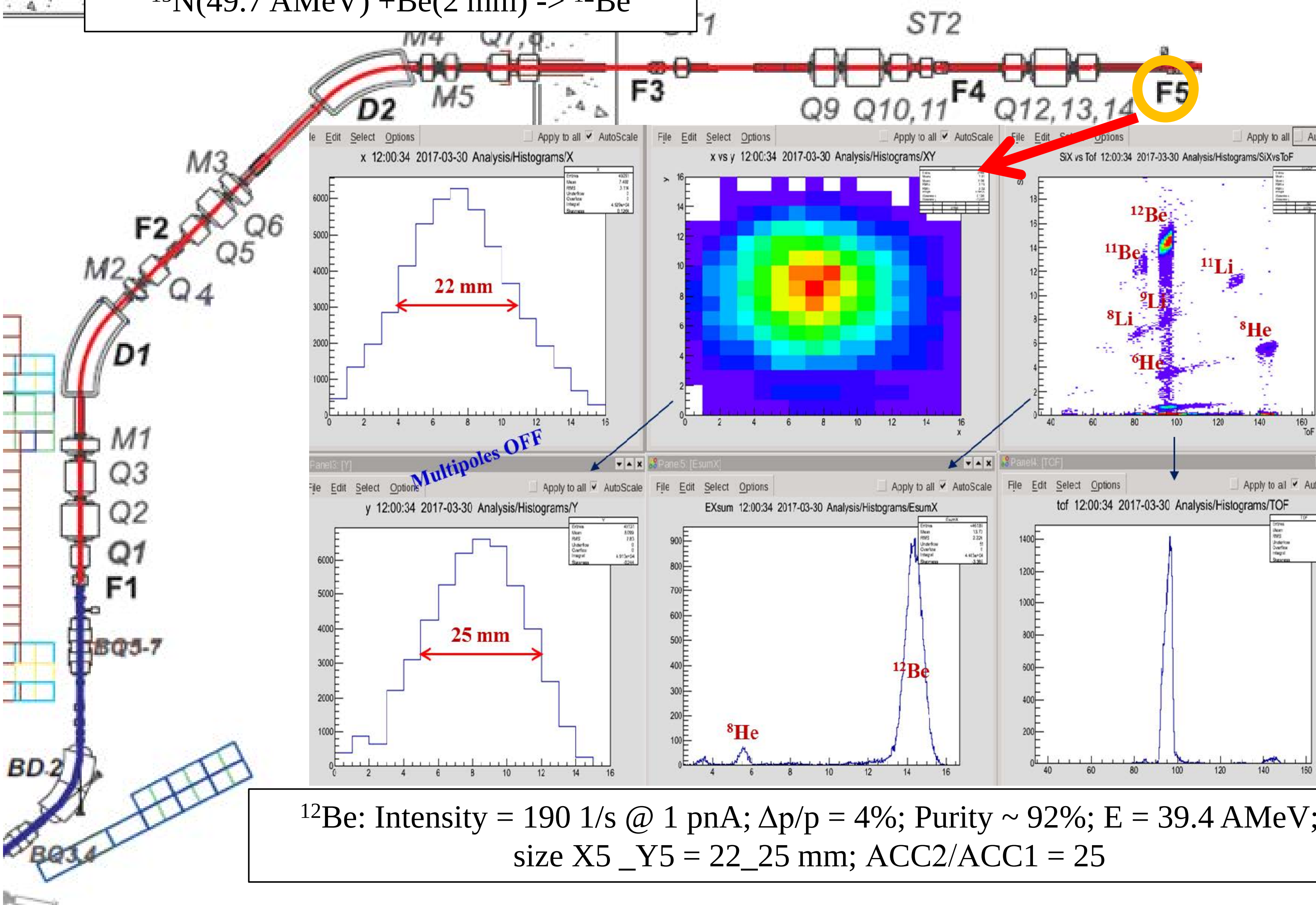
RIB's profile estimation in ^{15}N (49.7 AMeV) + Be (2 mm) reaction
(X_1_Y_1 = 2_8 mm, ε = 35 mrad, Δp/p = 2.5%, W = 1 mm)

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

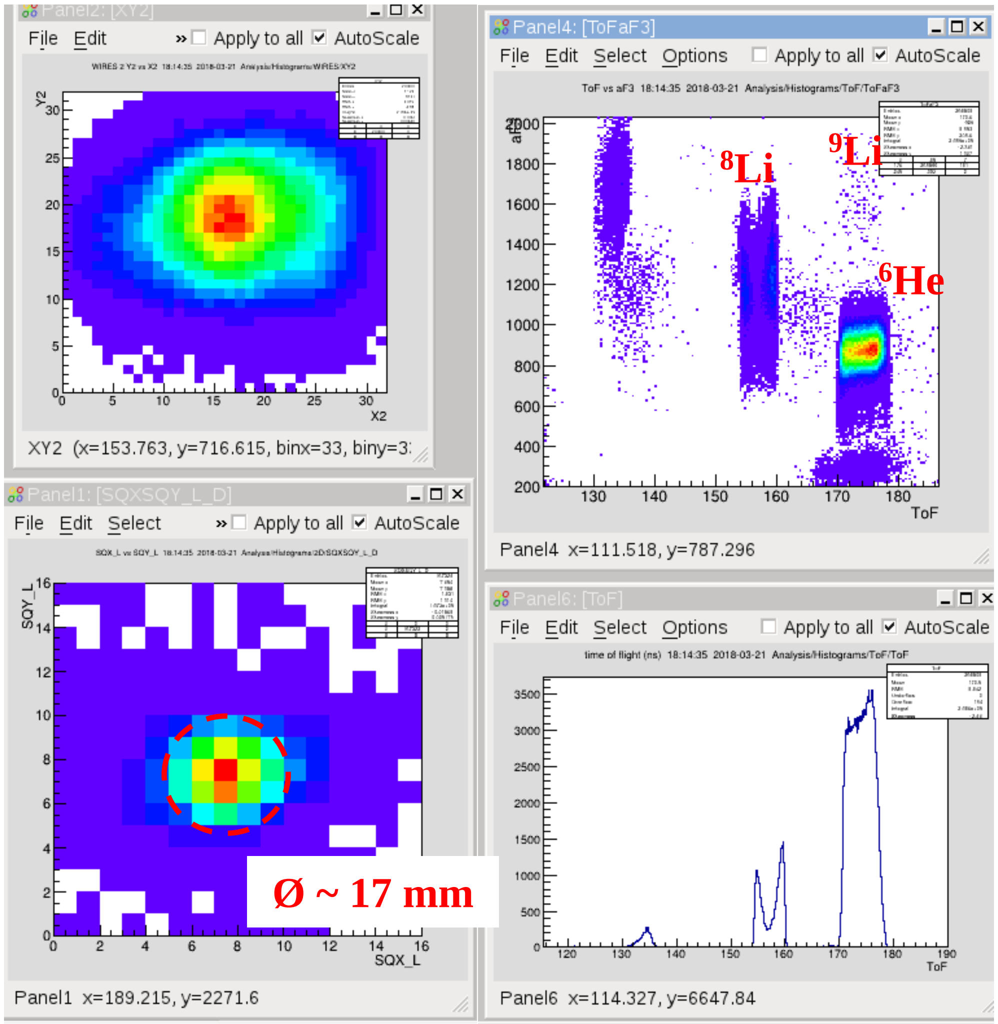


^{12}Be: Intensity = 190 1/s @ 1 pnA; Δp/p = 4%; Purity ~ 92%; E = 39.4 AMeV; size X5 _Y5 = 22_25 mm; ACC2/ACC1 = 25

First radioactive ion beams at ACCULINA-2

^{15}N (49.7 AMeV) + Be (2 mm)

I ~ 10^5 pps @ 100 pnA, Δp/p = 6% (Be wedge 3 mm)



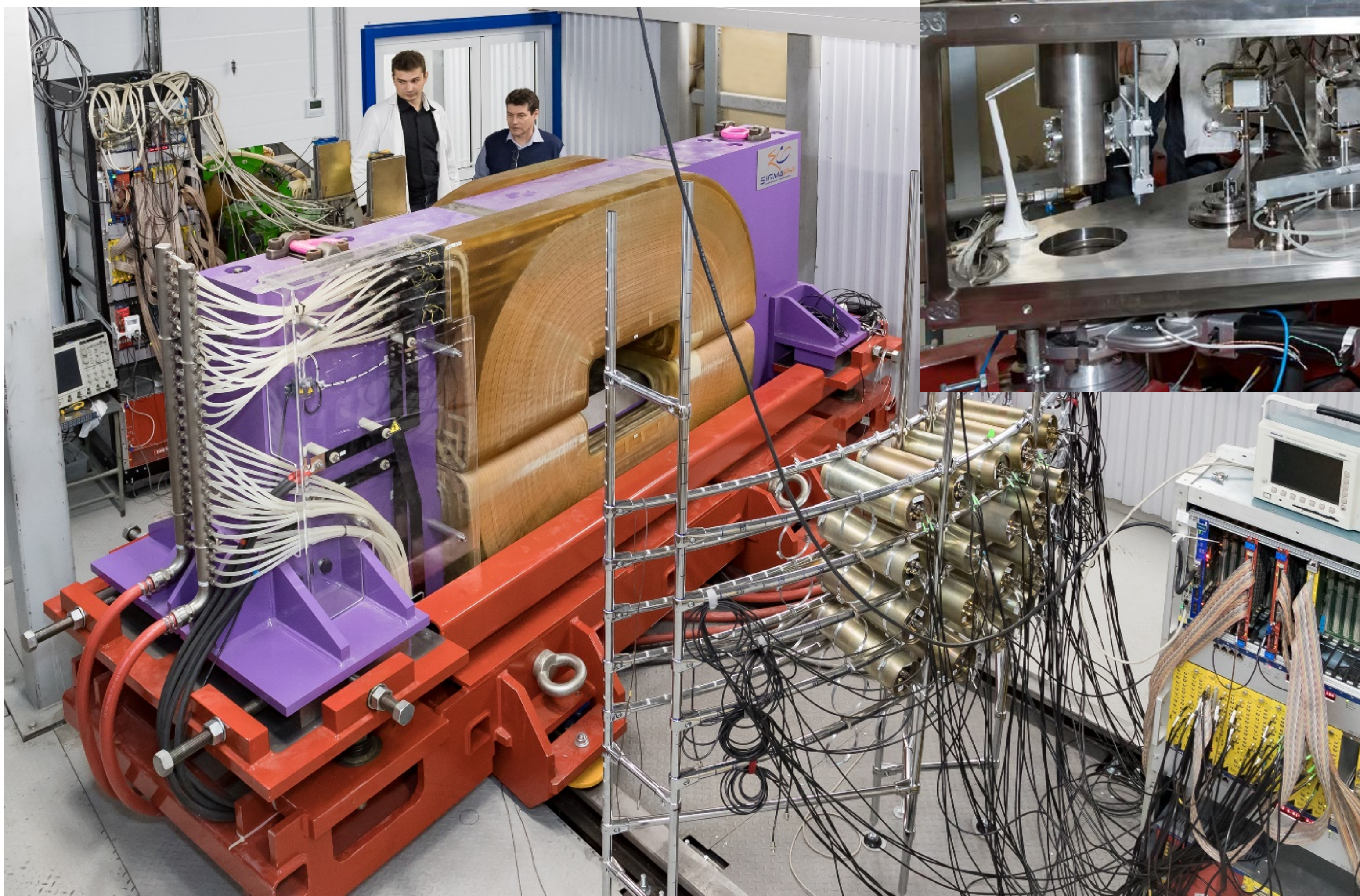
I = 100 pnA , Δp/p = ±2% (Be wedge 1 mm)

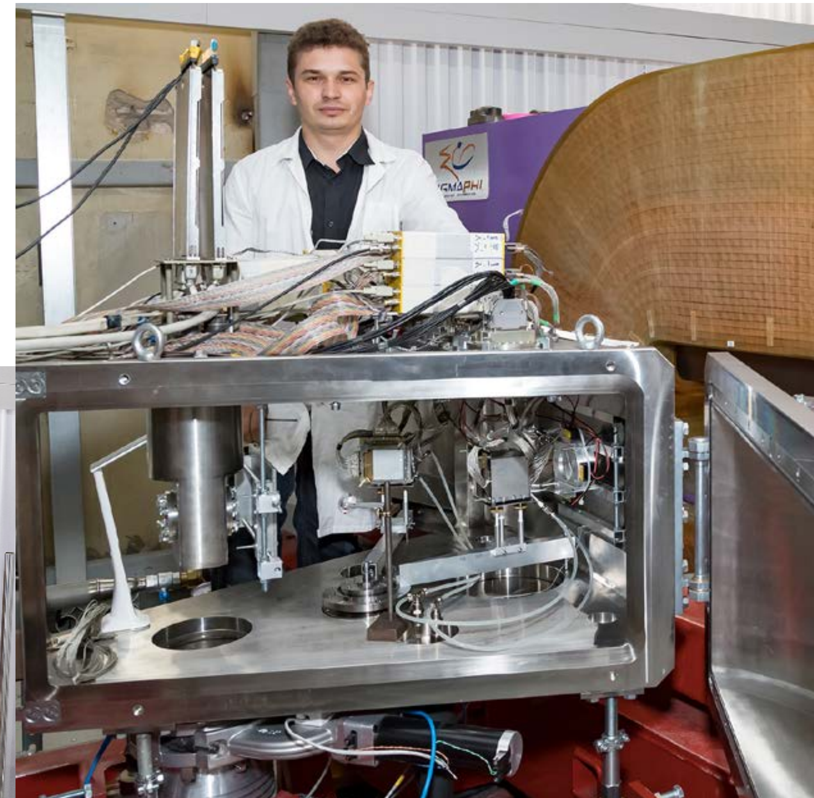
RIB	Energy, Amev	Intensity, 1/s	Purity, %
^{14}B	37,7	$1.2 \cdot 10^4$	65
^{12}Be	39,4	$1.5 \cdot 10^4$	92
^{11}Li	37	$4 \cdot 10^2$	67
^{9}Li	33,1	$1.1 \cdot 10^5$	50
^{8}He	35,8	$2.5 \cdot 10^3$	89

- Good agreement with calculations Intensity, Lise++
- Higher intensity compared to ACCULINNA in 15 times!

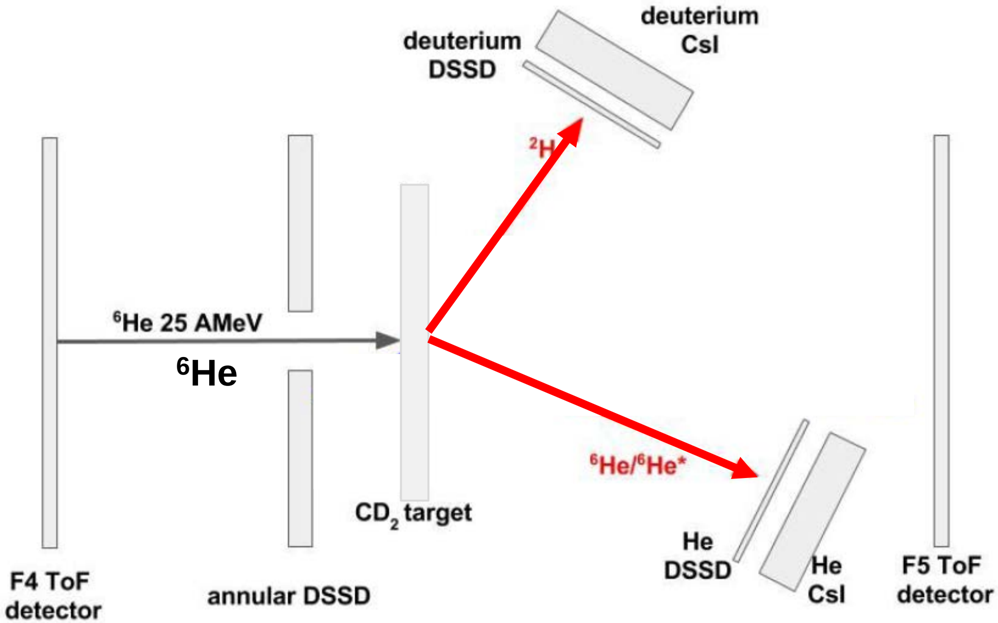
First experiments with ^{6}He and ^{9}Li on CD_2 target were carried out at ACC-2 in spring:

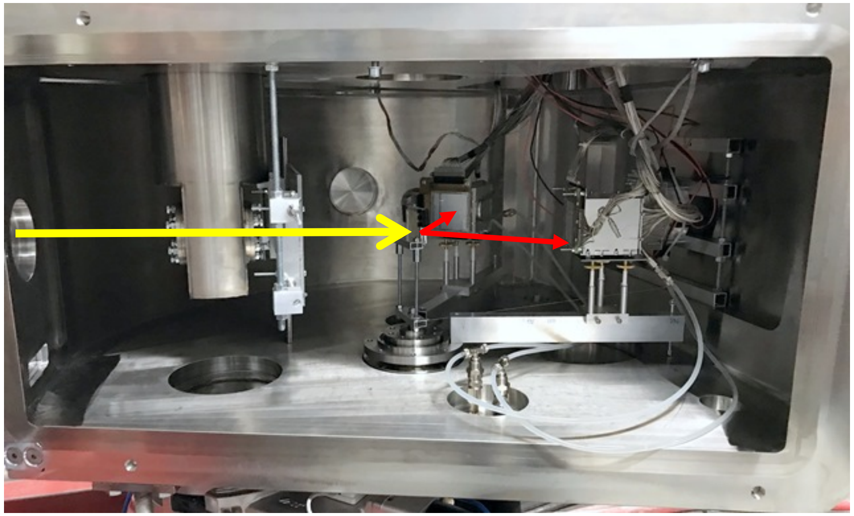
- elastic and inelastic scattering of ^{6}He;
- $d(^{6}\text{He},^{3}\text{He})^{5}\text{H}$ reaction;
- $d(^{9}\text{Li},p)^{10}\text{Li} \rightarrow n+^{9}\text{Li}$ run.





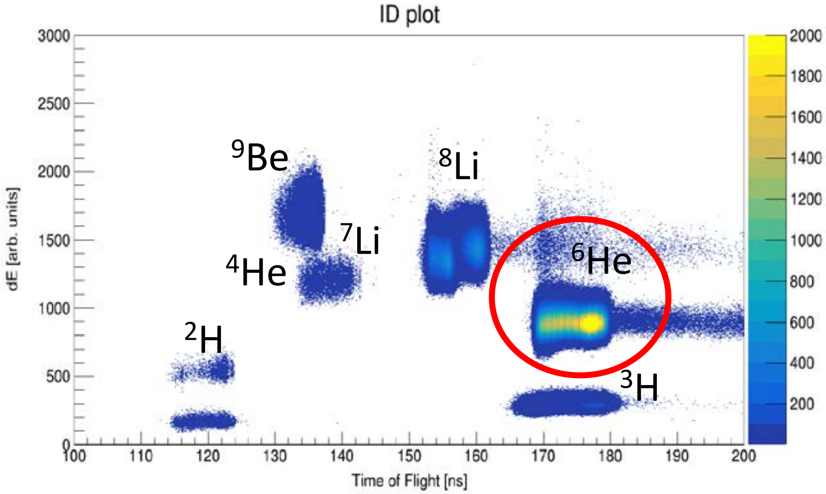
Elastic and inelastic scattering of ^{6}He (26 AMeV) on ^{2}H:





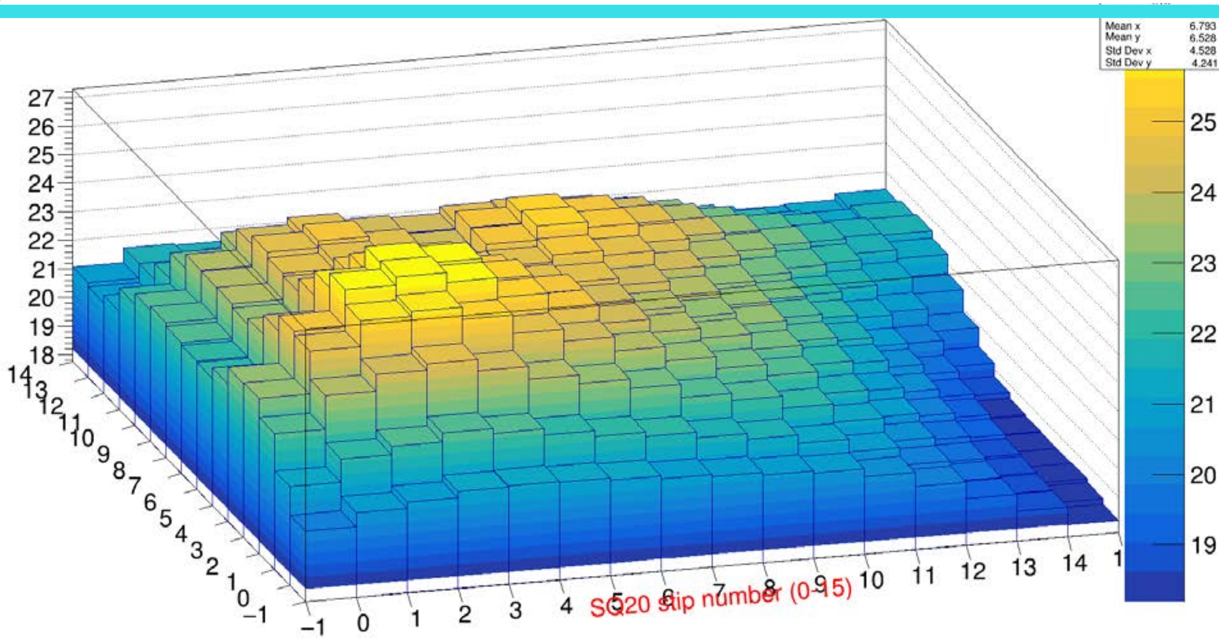
Beam parameters:

- 78% of ^{6}He
- Energy 26 AMeV
- Intensity 10^{5} pps



Experimental data for B. Zalewski Ph.D Thesis (HIL, UW, Warsaw)

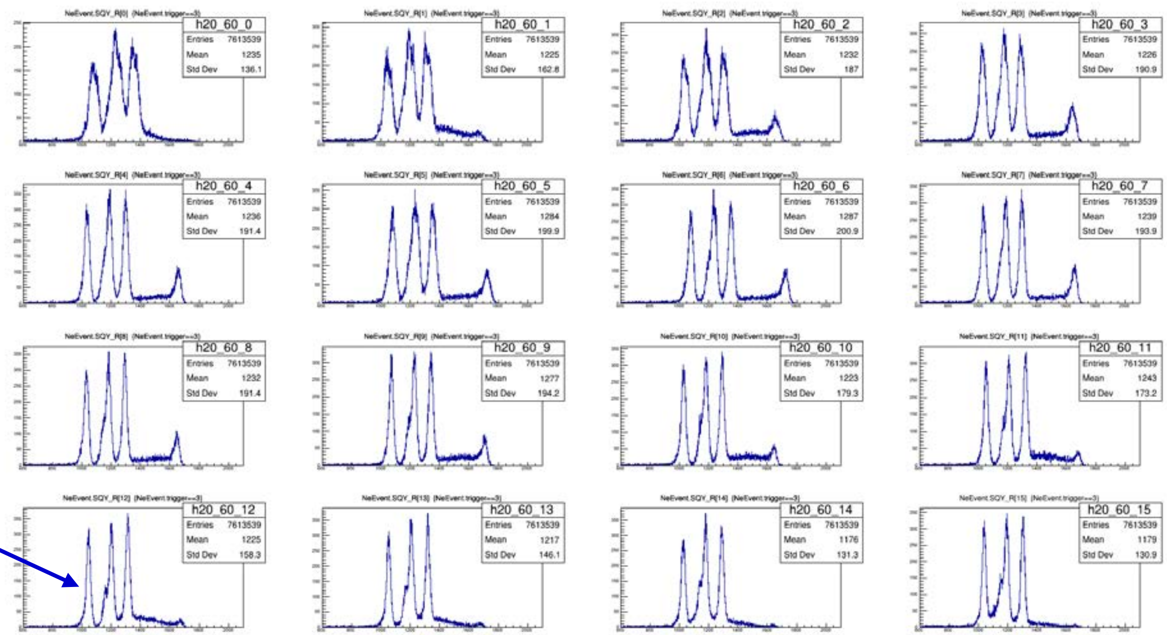
Key points for 22 μm Si : thickness uniformity and energy resolution



Thickness distr.:
from 19 μ
up to 26 μ
(instead of ±1.5 μ)

^{226}Ra source

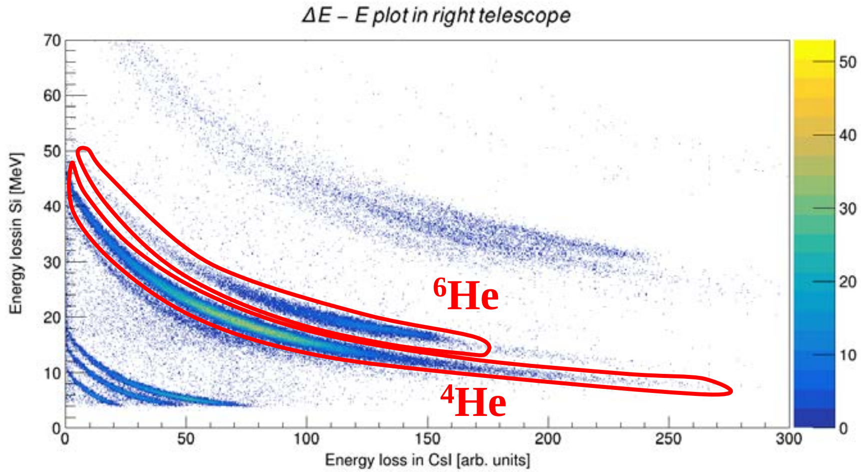
Energy resolution:
~ 270 keV (~ 4%)
for E_α = 6.0 MeV

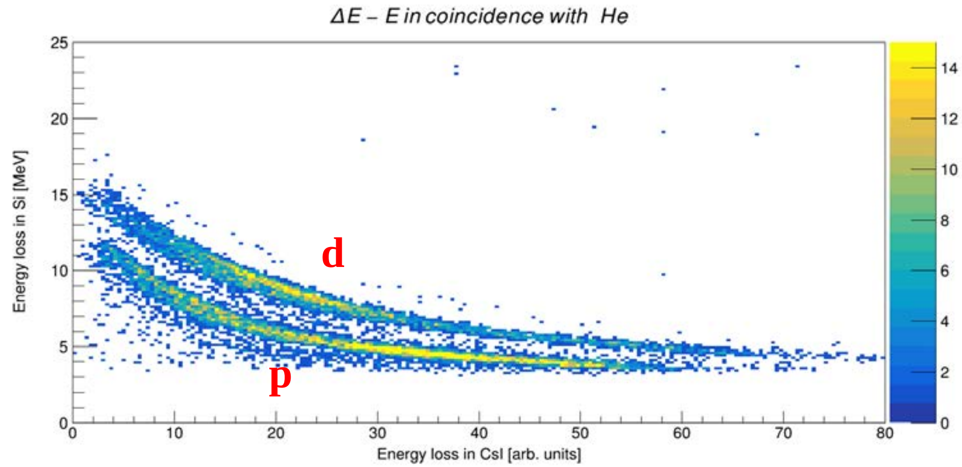


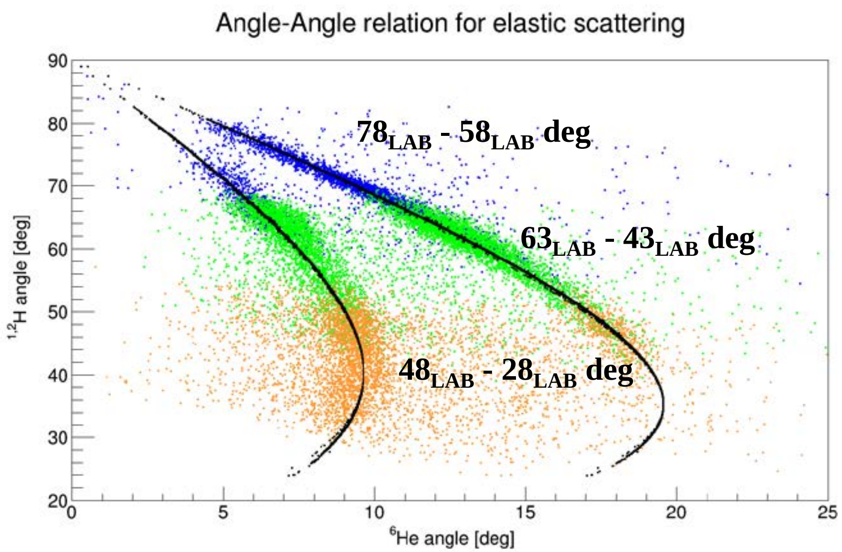
Elastic and inelastic scattering of ^{6}He (26 AMeV) on ^{2}H:

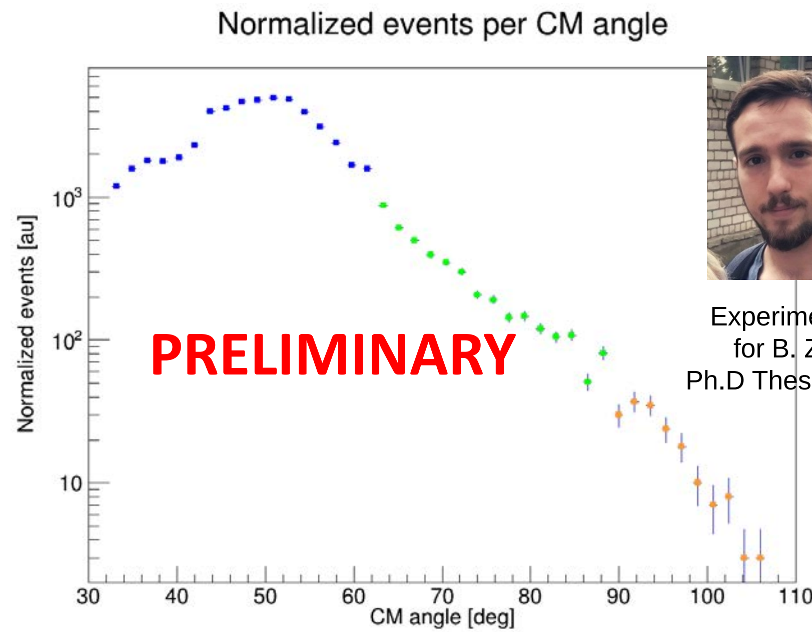
Preliminary results of elastic and inelastic scattering of ^{6}He (26 AMeV) on ^{2}H:

$d\sigma/d\Omega$ in a wide angular range (3 runs, $\theta_{CM} \sim 30 \div 110^o$) with a good statistics



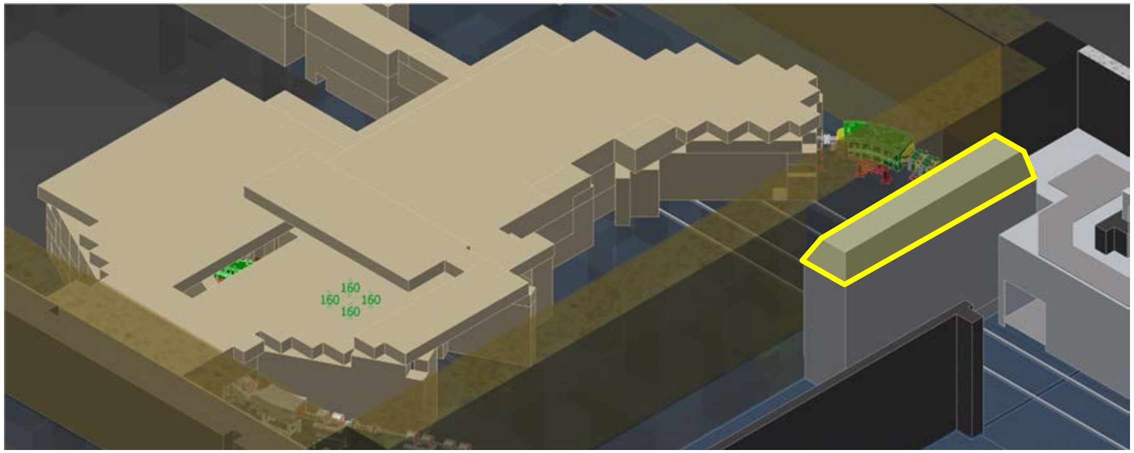


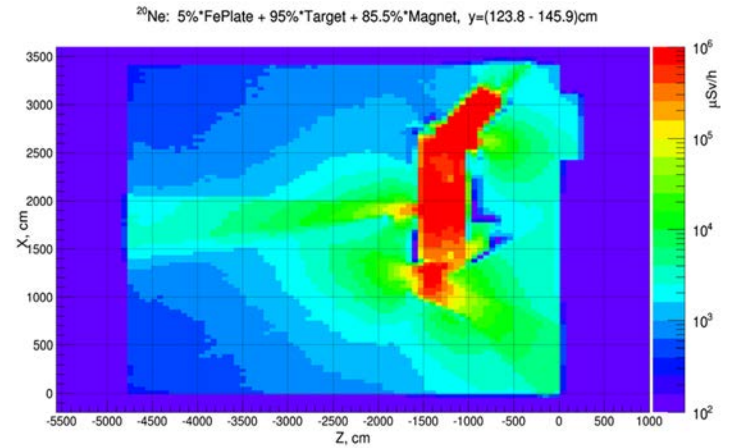




Experimental data for B. Zalewski Ph.D Thesis (HIL, UW)

Moving ahead to the flagship experiment ^{7}H - Radiation shield





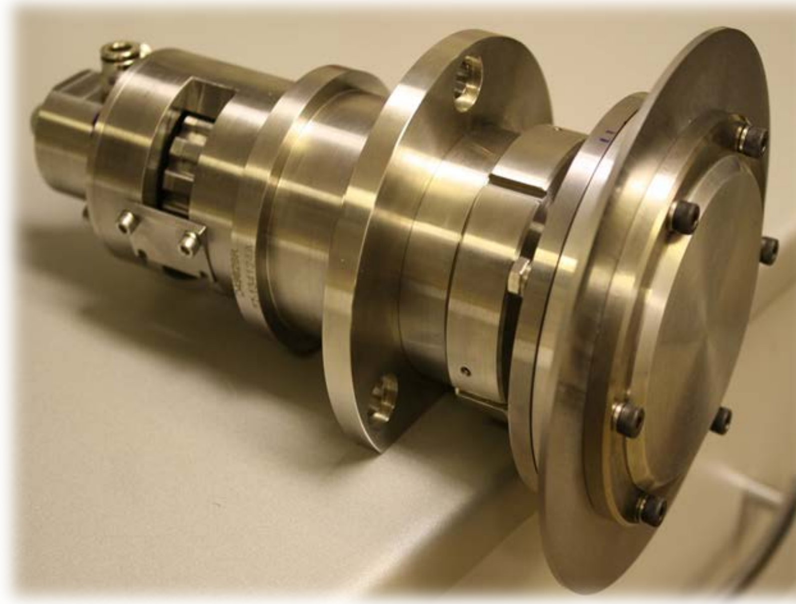
Radiation shell around F1-F2 area is completed.

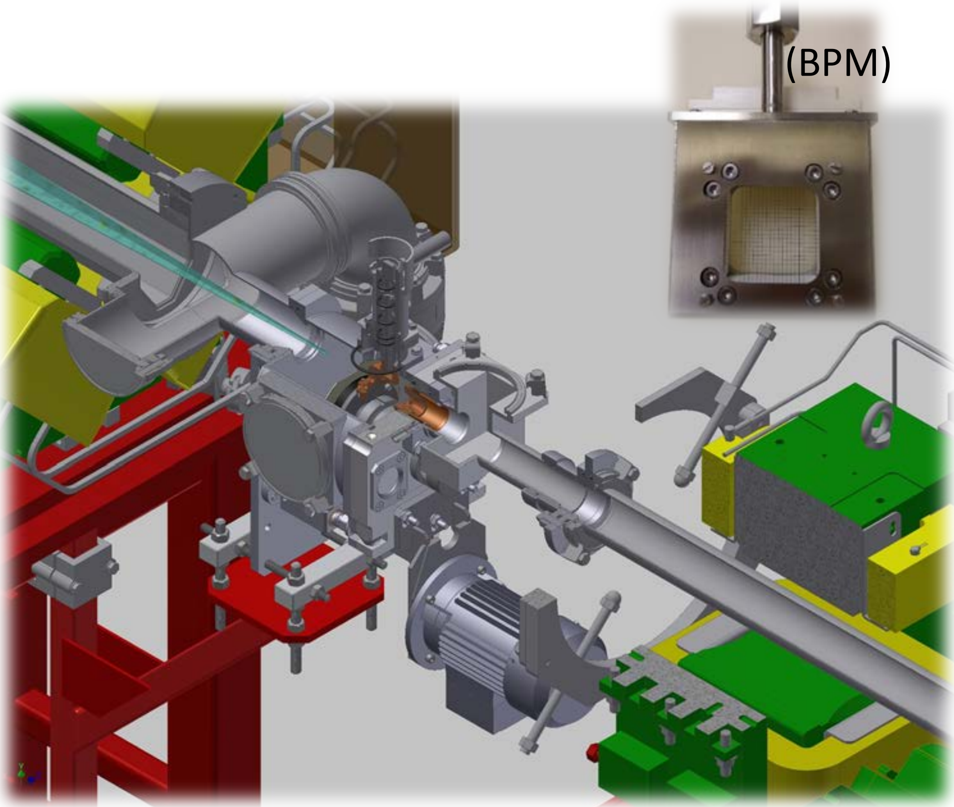
Radiation shell will let to operate at full beam intensity.

Modernized U-400M cyclotron will provide higher intensity beams (~ 3 µA on the target in case of ^{15}N)

Moving ahead to the flagship experiment ^{7}H - primary target

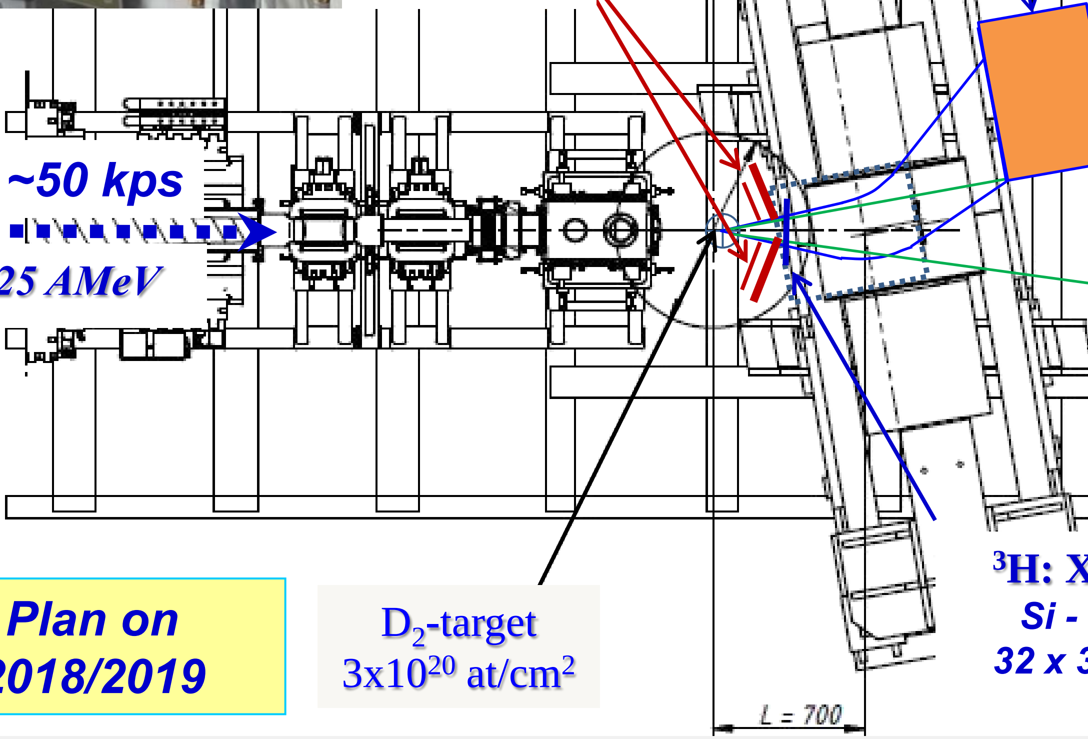
- Water cooled beryllium target mounted on magnetic liquid feedthrough with rotation speed up to 1500 rpm
- Heating power up to 2 kW
- Vacuum chamber for fast opening and service
- Integrated system of water cooled diaphragms
- Special port for beam profile monitor (BPM)

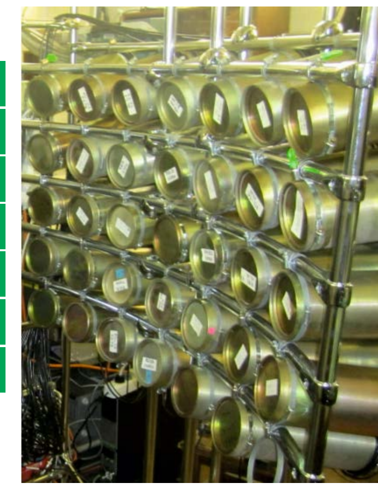




Nov. 2018: $d(^8He,^3He)^7H$: 7 weeks (effect + background)

Running experiment





CsI array GADAST 64 units

Energy & position: decay tritons & RIB
Bρ = 0.4 ~ 1.0 Tm
Cone 0 ~ 14°

^{3}He:
Si - 22 μ
Si - 1000 μ

^{8}He ~50 kps
E~25 AMeV

Neutrons,
Cone 0 ~ 14°

Plan on 2018/2019

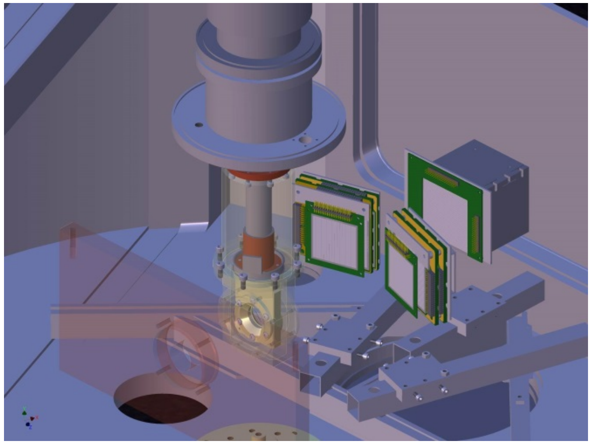
D_2-target
3×10^{20} at/cm^2

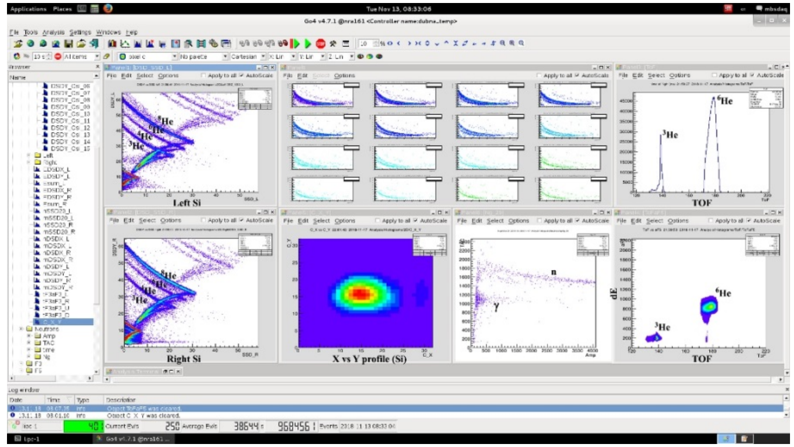
^{3}H: X_Y_DE
Si - 1000 μ
32 x 32 strips

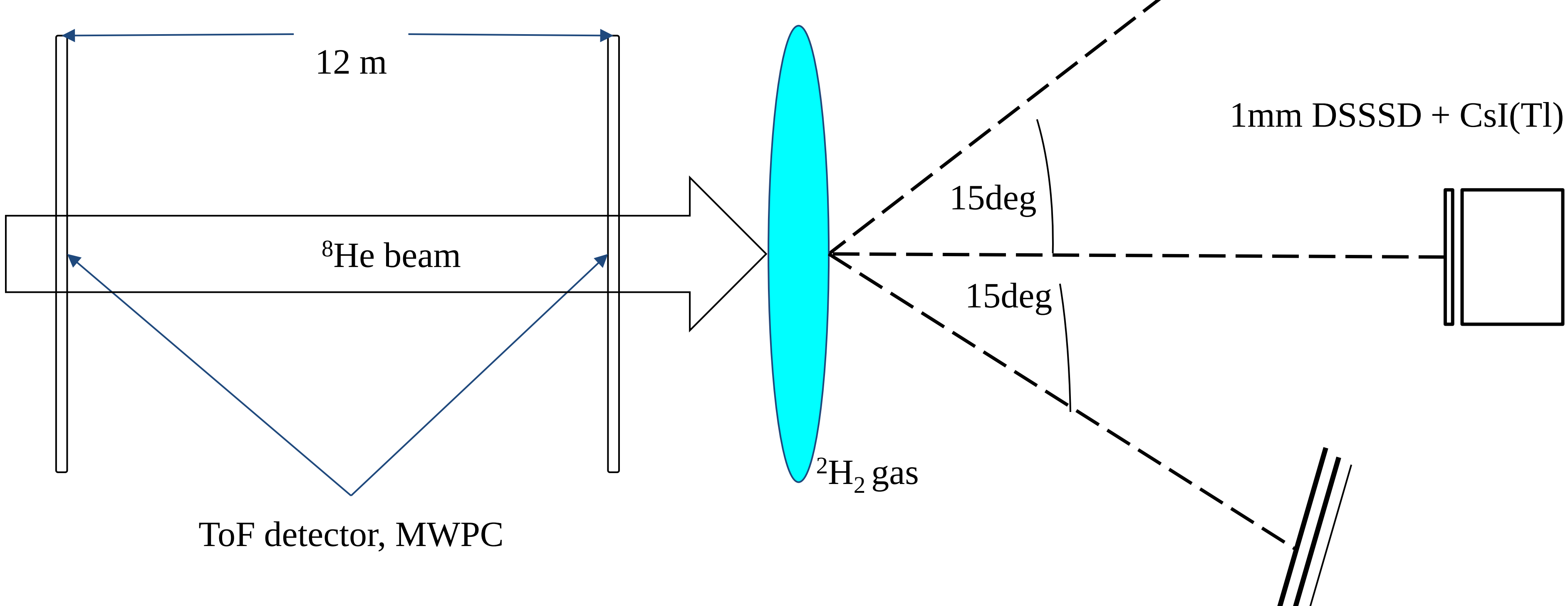
Stilbene modules
∅ 80x50 mm →
∅ 0.25° accuracy
7x6=42 → 64 units

Advantages: good energy resolutions (~1.2 MeV) & ^{3}He-t-n coincidencdes

Nov. 2018: *d*(^{8}He,^{3}He)^{7}H: 7 weeks (effect + background)



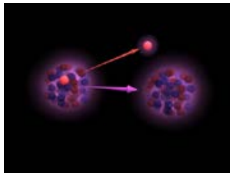




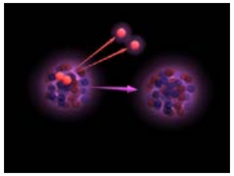
Running experiment: ^{3}He-t-n coincidencdes

Study with OTPC at ACCULINNA

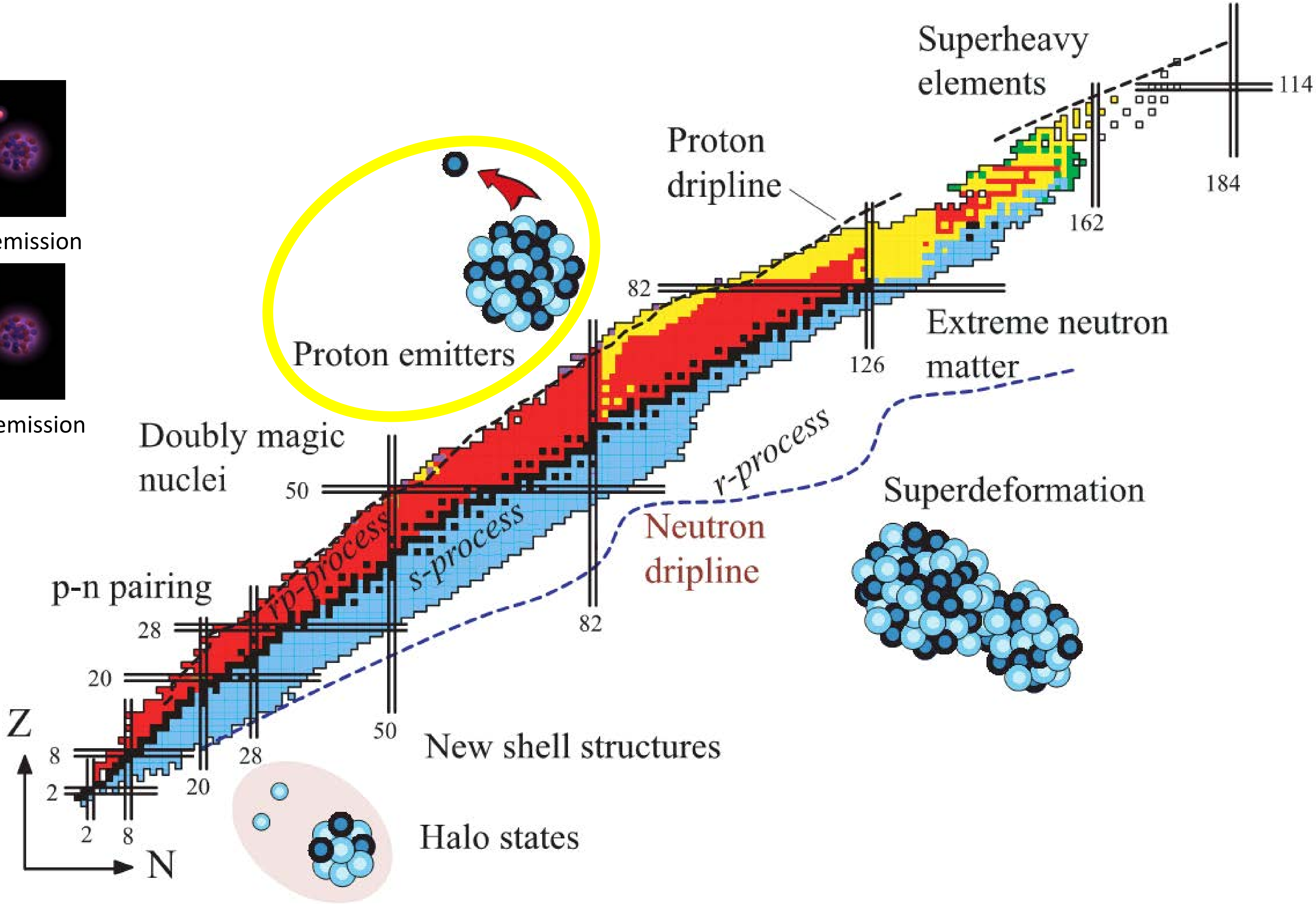
More than 10 years of collaboration with FUW



1 proton emission



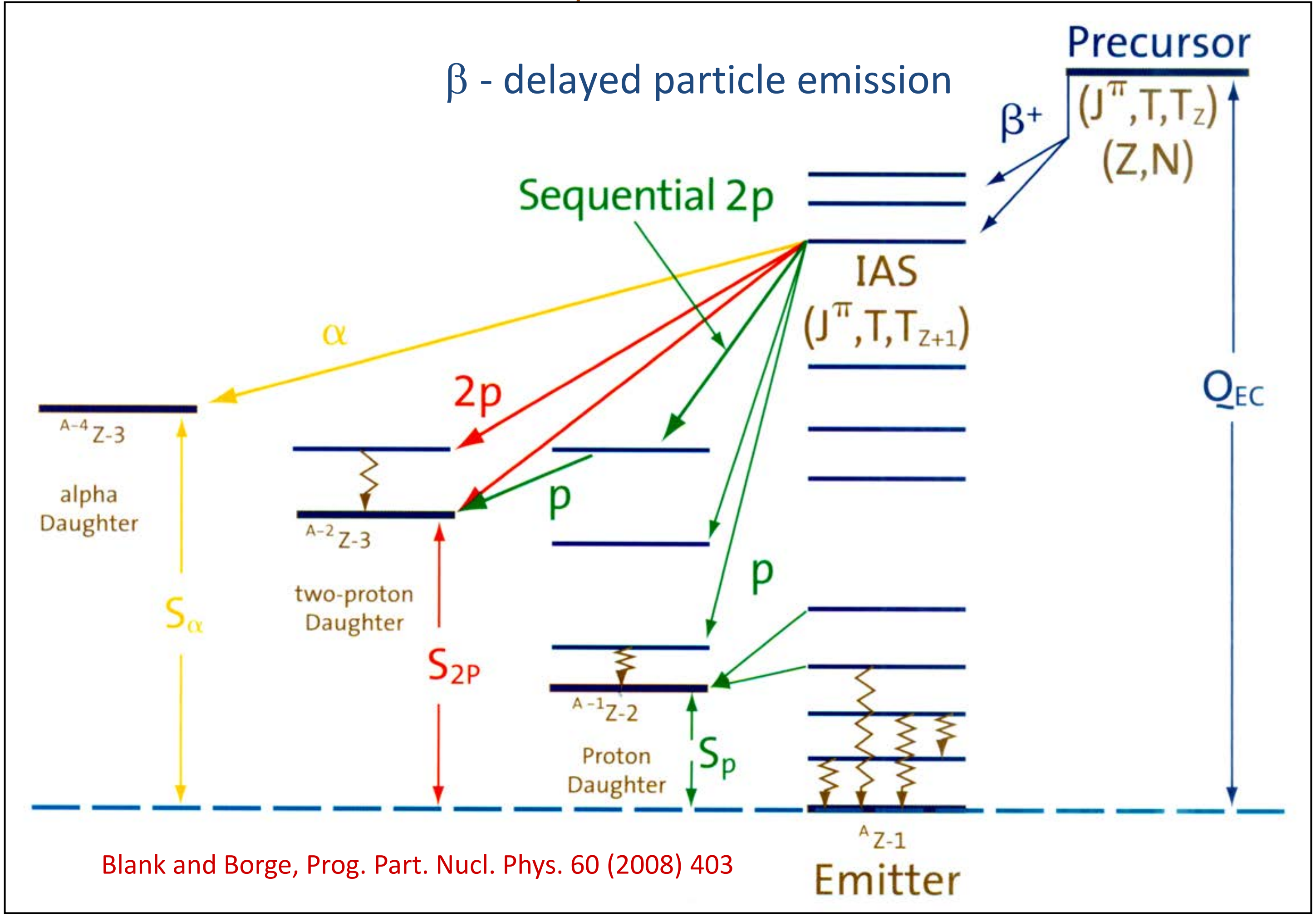
2 protons emission



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

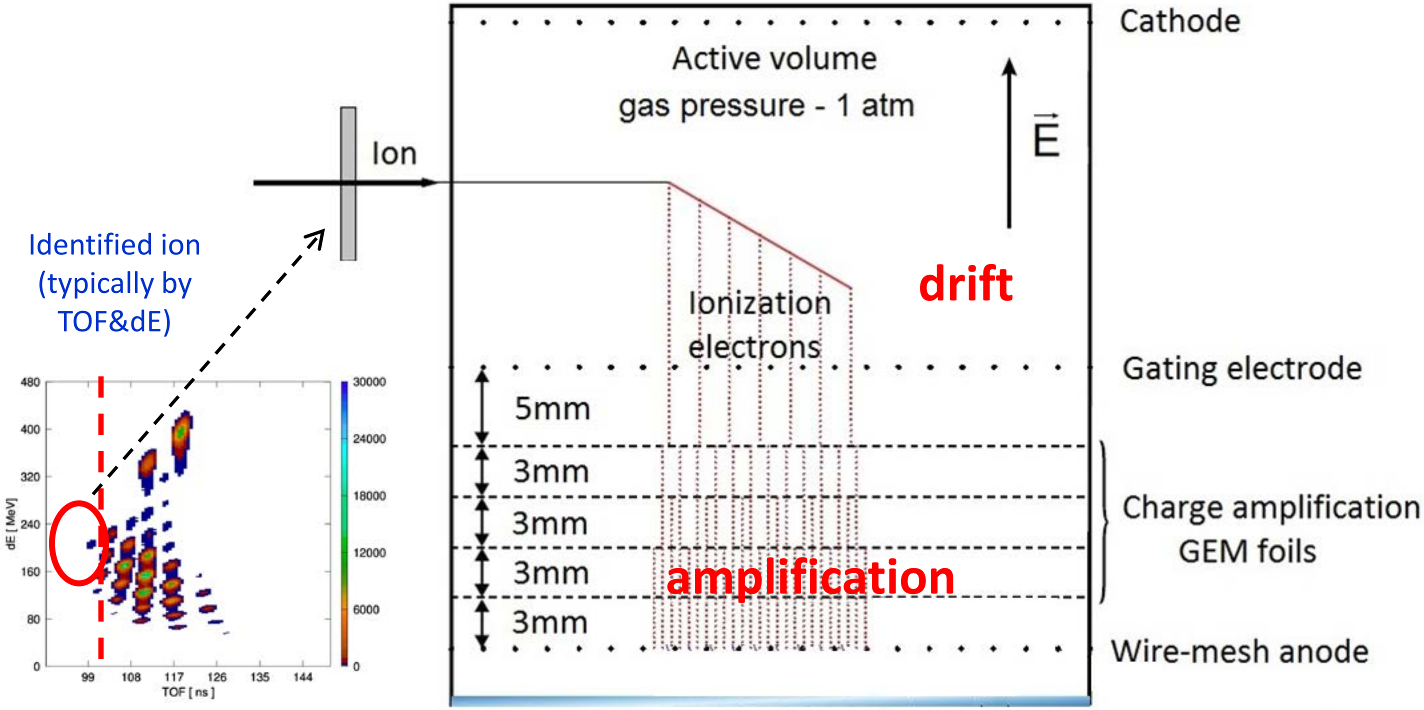
When the β-decay energy is large, many exotic channels are available:

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

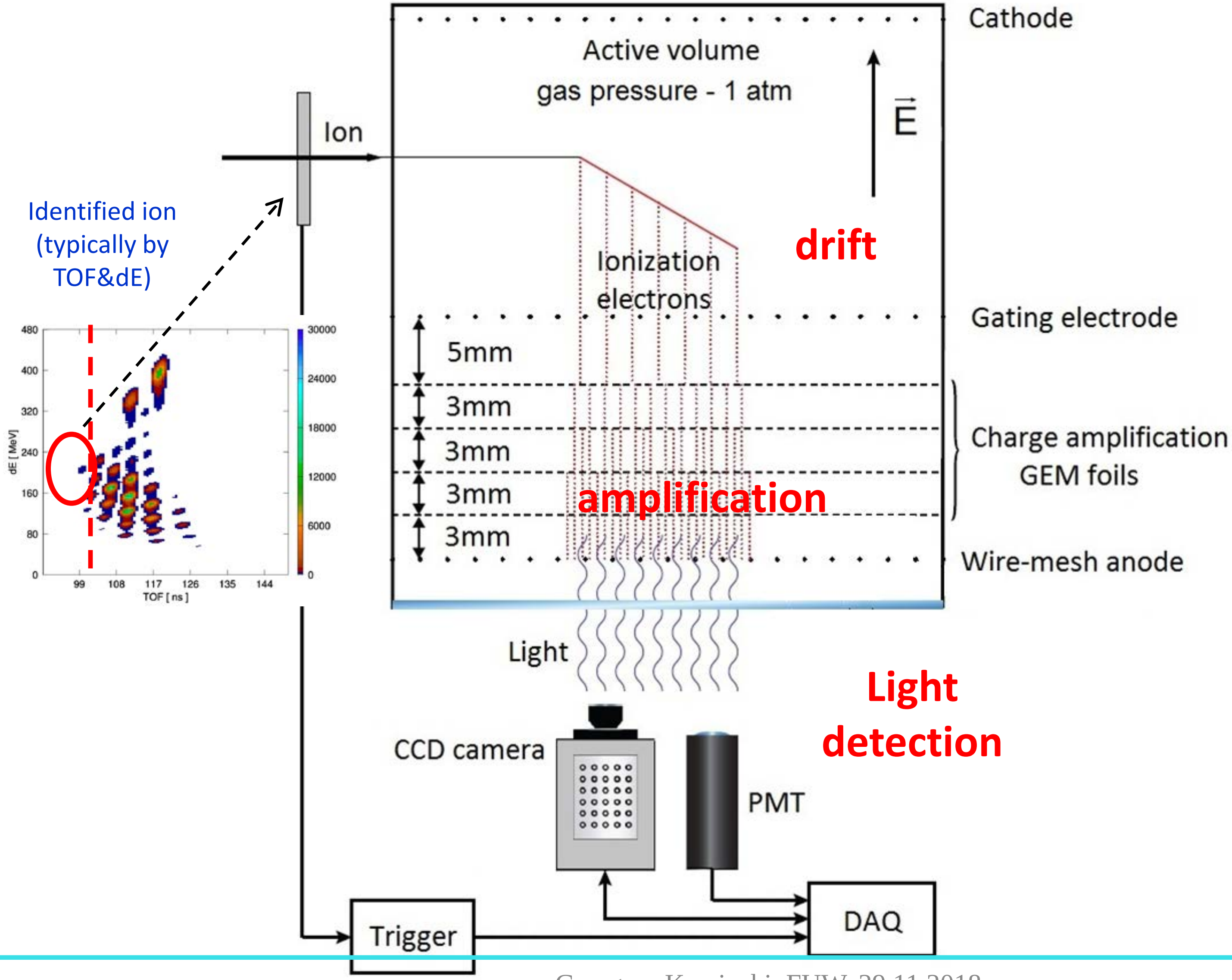


Blank and Borge, Prog. Part. Nucl. Phys. 60 (2008) 403

Optical **T**ime **P**rojection **C**hamber (OTPC) - A new type of modern ionization chamber with an optical readout. Invented at the University of Warsaw by prof. W. Dominik

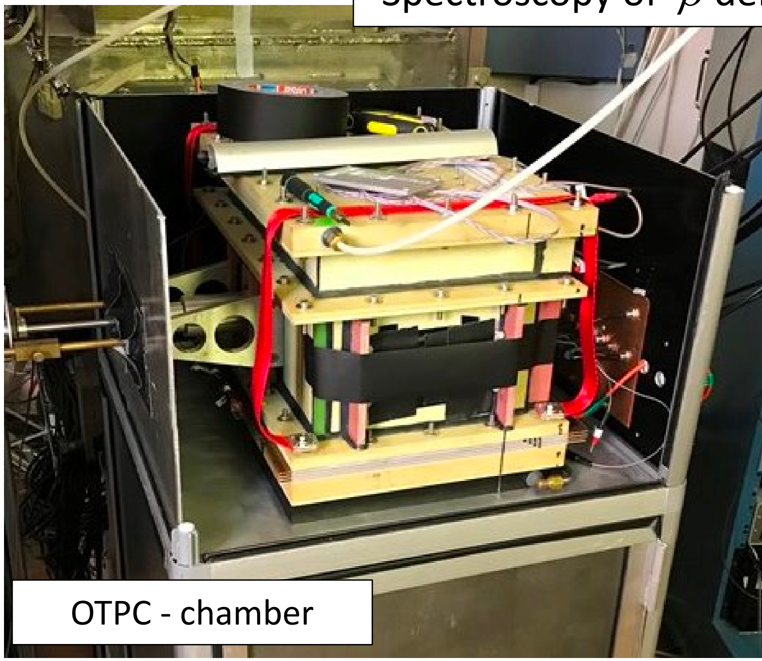


Experimental tool - Optical Time Projection Chamber

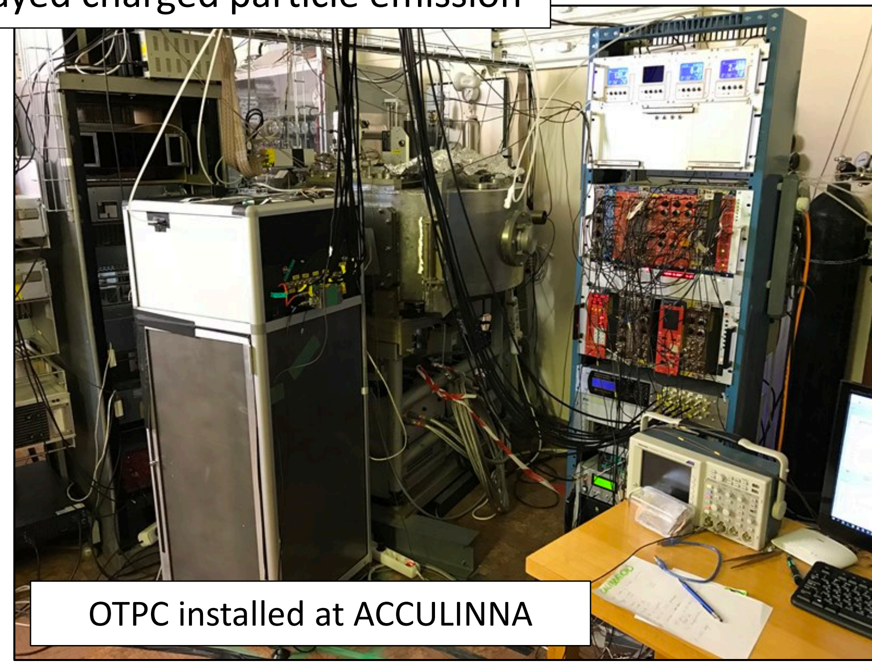


Collaborative experiments with Physics Faculty, UW, Warsaw

Spectroscopy of β-delayed charged particle emission

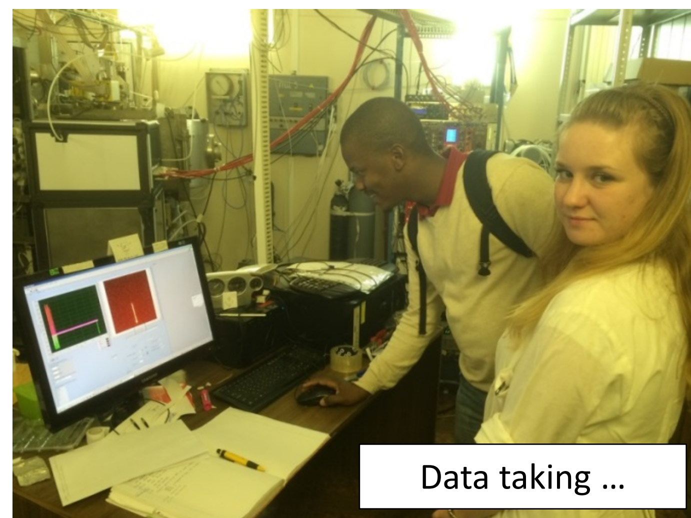


OTPC - chamber



OTPC installed at ACCULINNA

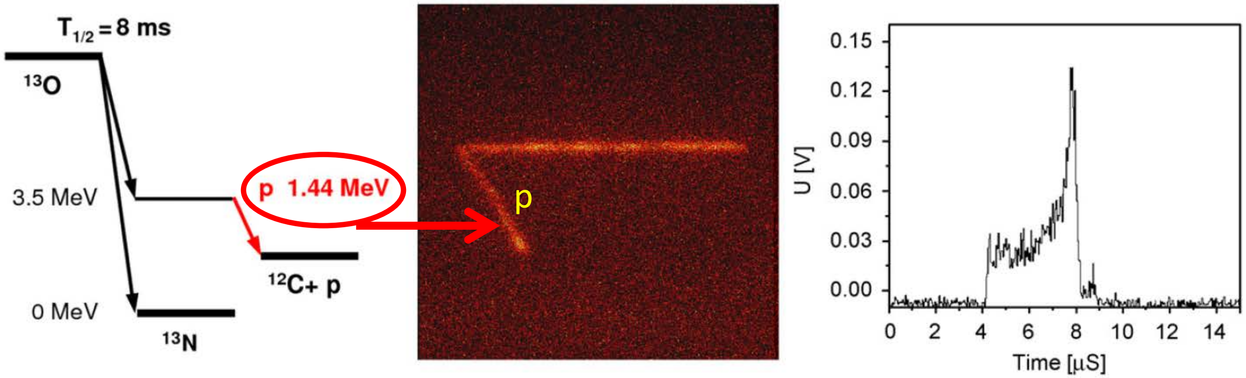
Experimantal team

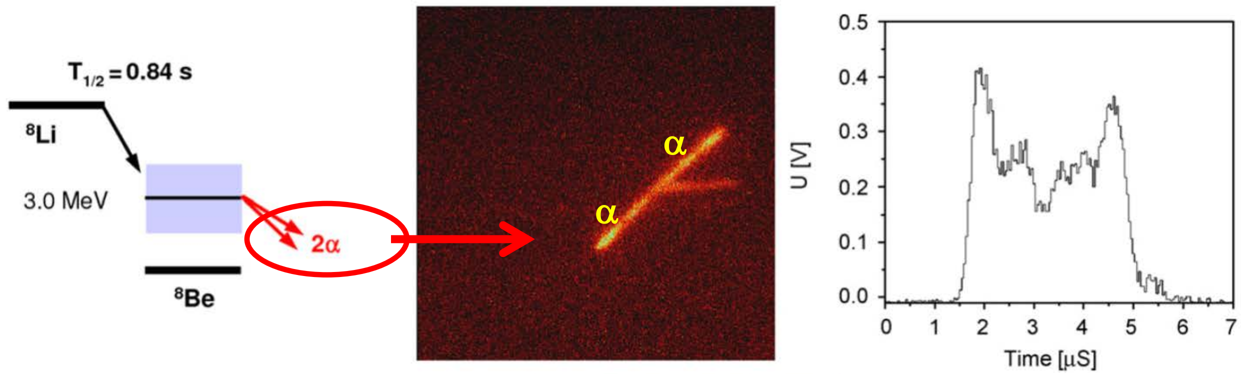


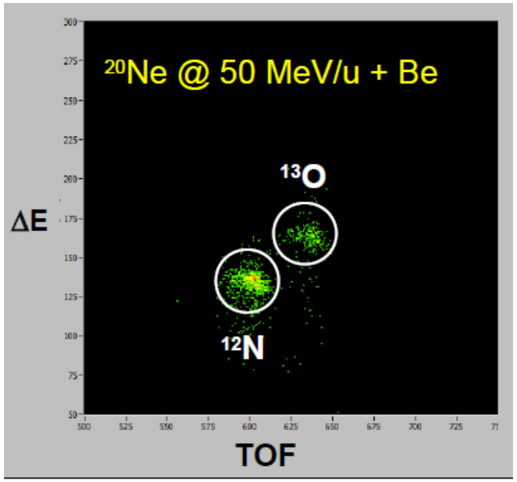
Data taking …

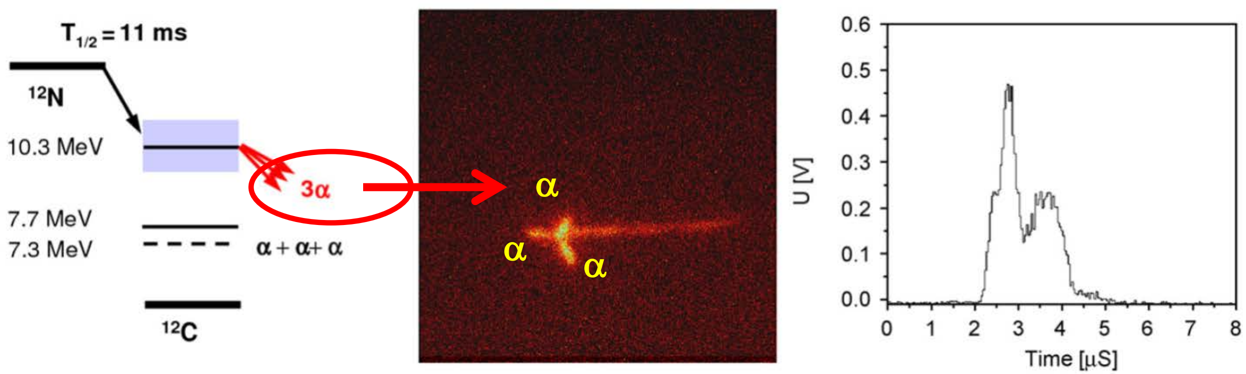
Historical: first tests of the OTPC at ACCULINNA by FUW team

^{20}Ne @ 50 MeV/u + ^{9}Be → ACCULINNA → tests beams : ^{13}O, ^{12}N, ^{8}Li



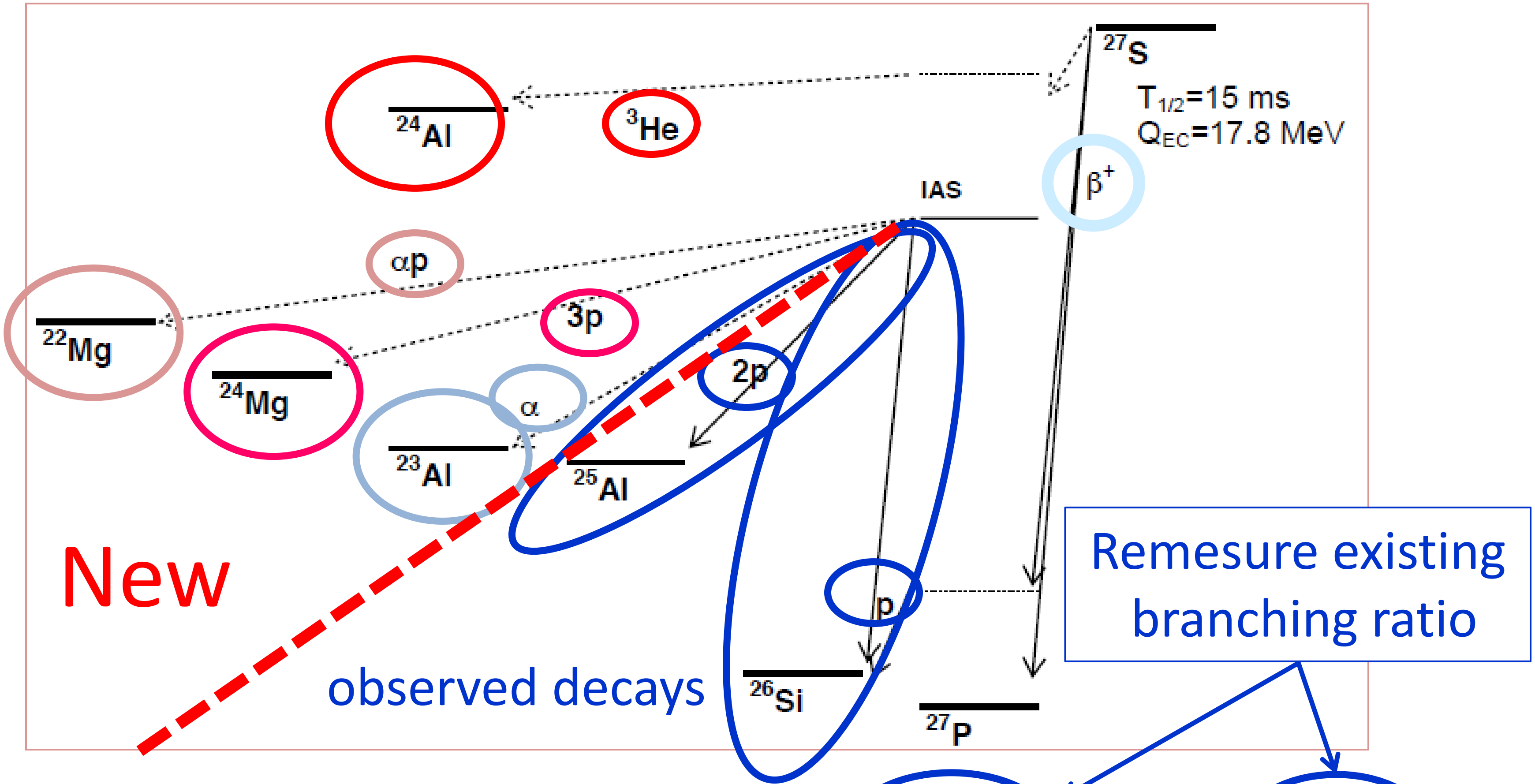






K. Miernik et al.,
NIM A 581 (2007) 194

Study of β-delayed charged particle emission from ^{27}S @ACCULINNA, FLNR, JINR



EPJ A12 (2001) 377: $T_{1/2}(^{27}S)$ = 15.5 ms; P(βp) = 2.3 ± 0.9%; P(β2p) = 1.1 ±0.5%

New possible decay channels:
β3p, βα, βαp, β^{3}He

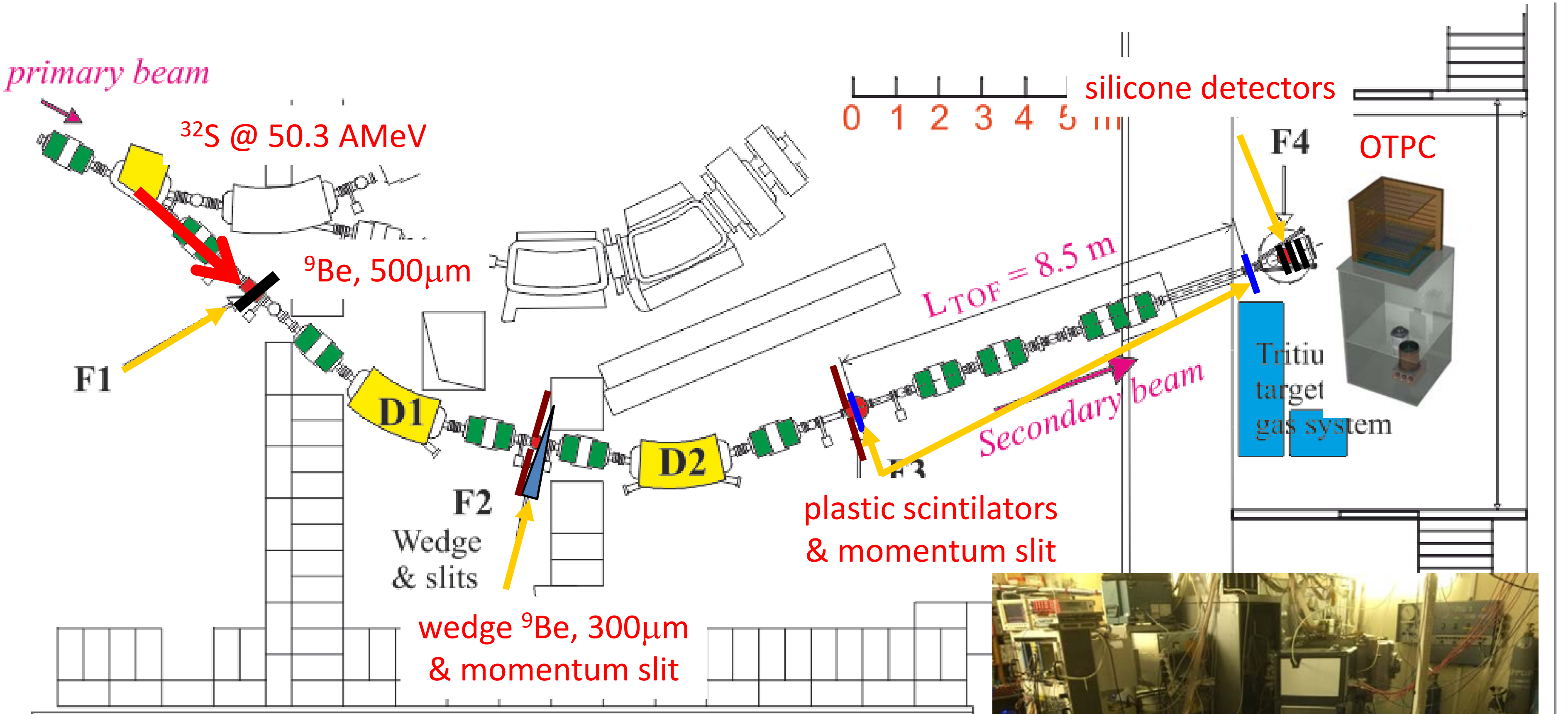
Direct observation of 2p emmision
angular correlations between protons

Study of β-delayed charged particle emission from ^{27}S @ACCULINNA, FLNR, JINR

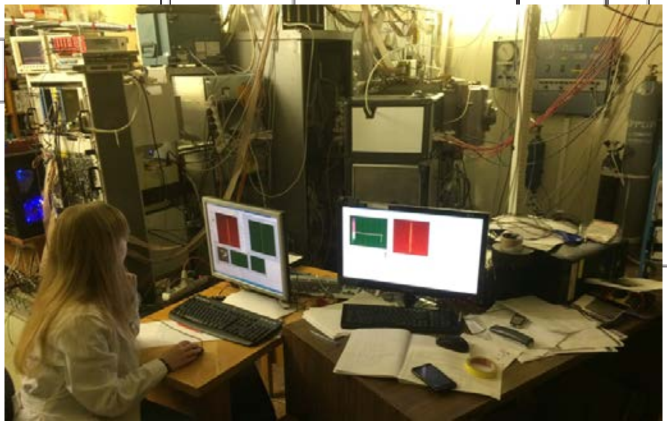
Polish colleagues coming to FLNR (September 2015)

ACCULINNA during ^{27}S beam preparation

Study of β-delayed charged particle emission from ^{27}S

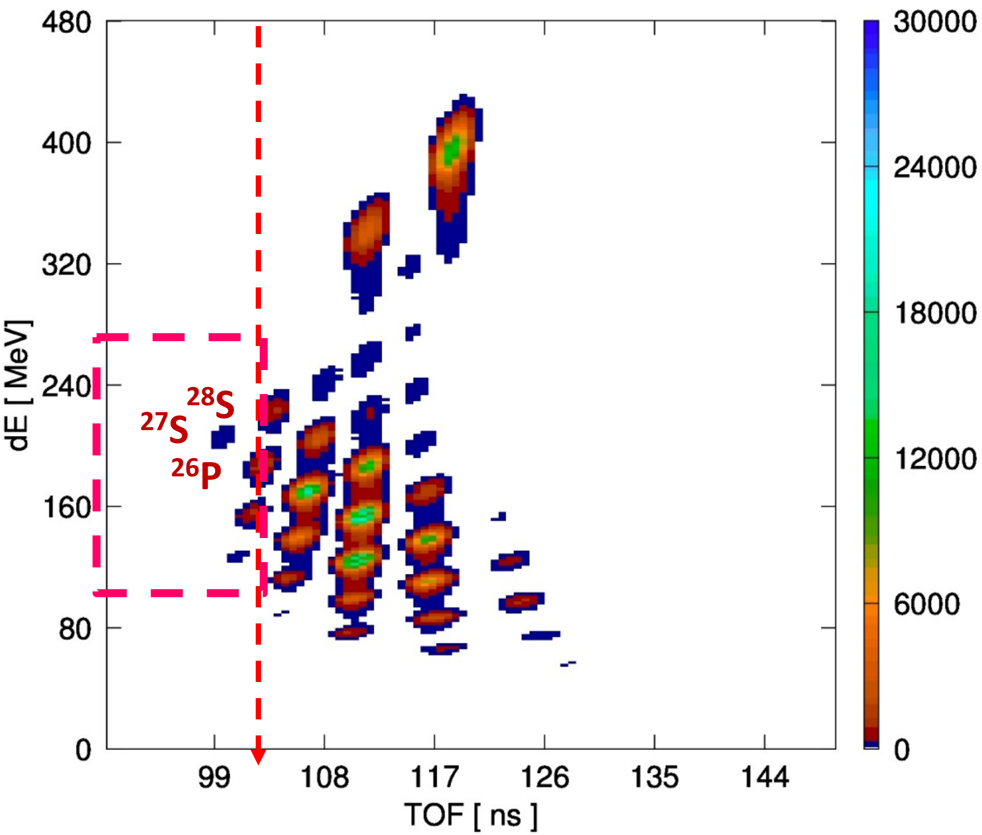


^{32}S @ 50 MeV/u + ^{9}Be → ACCULINNA → ^{27}S

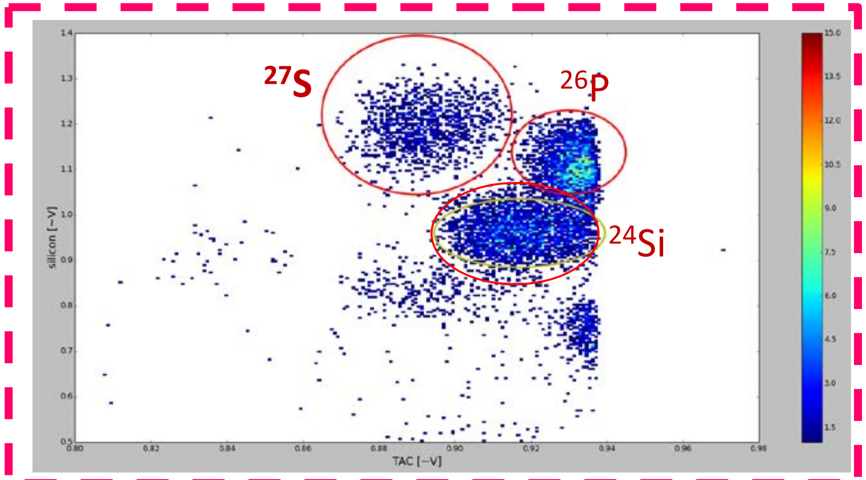


Data acquisition

Study of β-delayed charged particle emission from ^{27}S



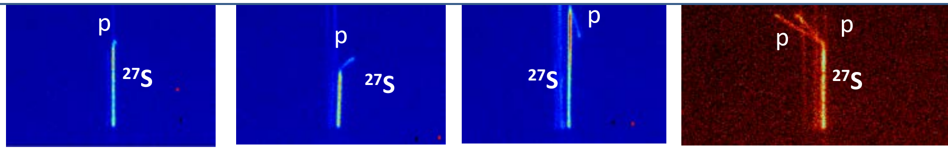
ID plot: dE-TOF



OTPC ID plot: dE-TOF (TOF gate)

β-delayed charged particle emission from ^{27}S and ^{26}P

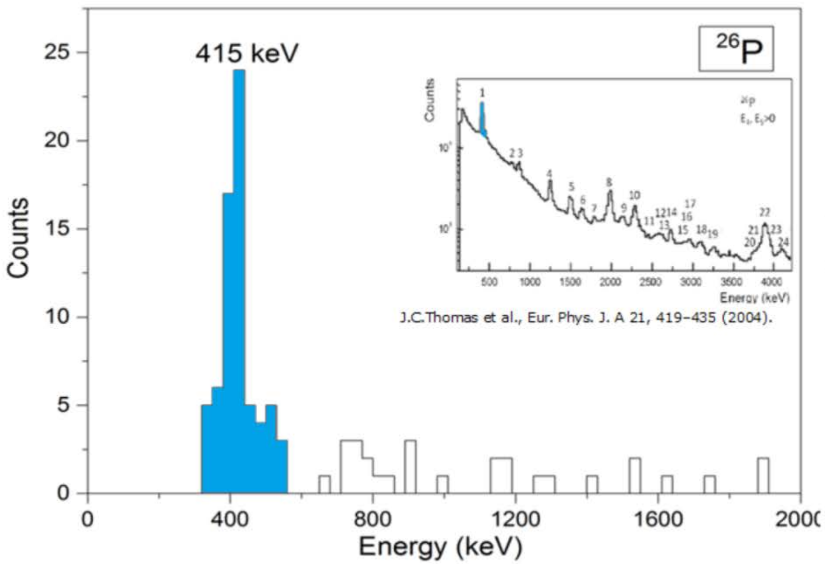
In 2019 new measurments of *β*-delayed particle emission from ^{27}S @ **ACCULINNA-2** are considered. Much better statistic of two orders of magnitude is expected (we plan to purify the beam with RF-kicker). Observation of *β3p* channel is still an open question.

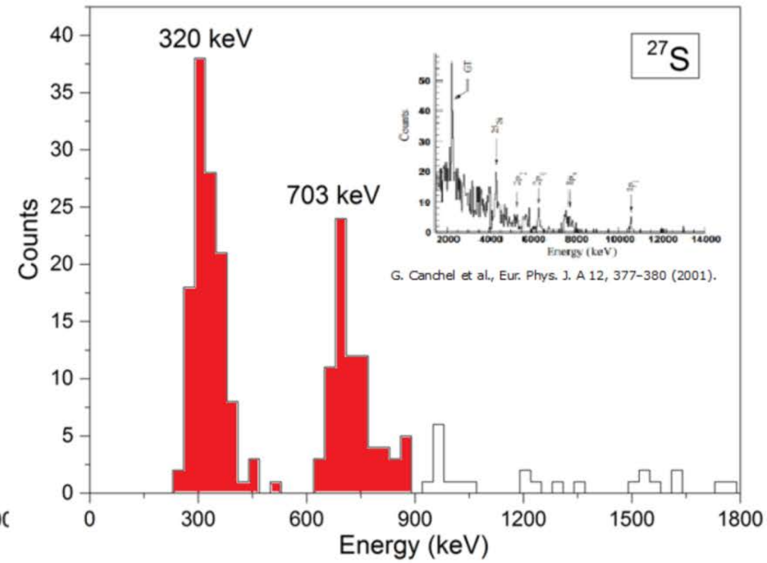


^{32}S @ 50 MeV/u + ^{9}Be → ACC → ^{27}S,^{26}P

We have too low statistic to get the limit for observation of *β3p*

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





^{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

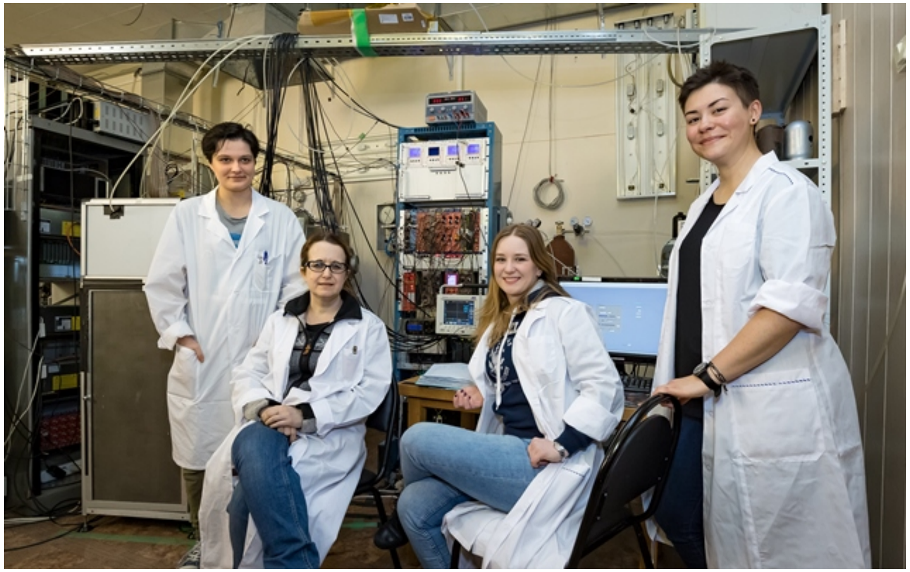
Canchel et al., EPJ A12 (2001) 377

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

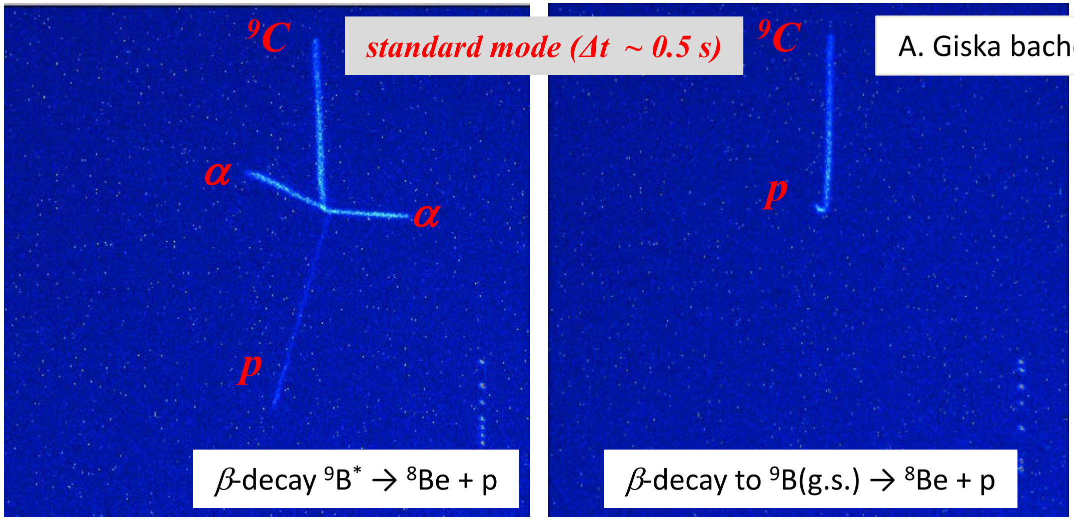
Feb. 2018, ACC-1. β-delayed particle emission of **^{11}Be** ($T_{1/2}$ = 13.76 s) was studied. The other isotopes, **^{8}Li** ($T_{1/2}$ = 0.84 s), **^{8}B** ($T_{1/2}$ = 0.77 s) and **^{9}C** ($T_{1/2}$ = 0.126 s), were used for the crosscheck measurements.

→ The method OTPC works well even in the case of long-lived nuclei.

→ New data with a good statistics were obtained for **^{11}Be** and **^{9}C**.

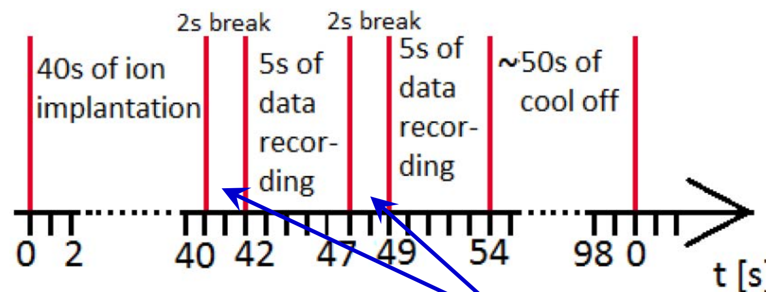


Preliminary results: examples of ^{9}C ($T_{1/2}$ = 0.126 s) and ^{11}Be ($T_{1/2}$ = 13.76 s) decay

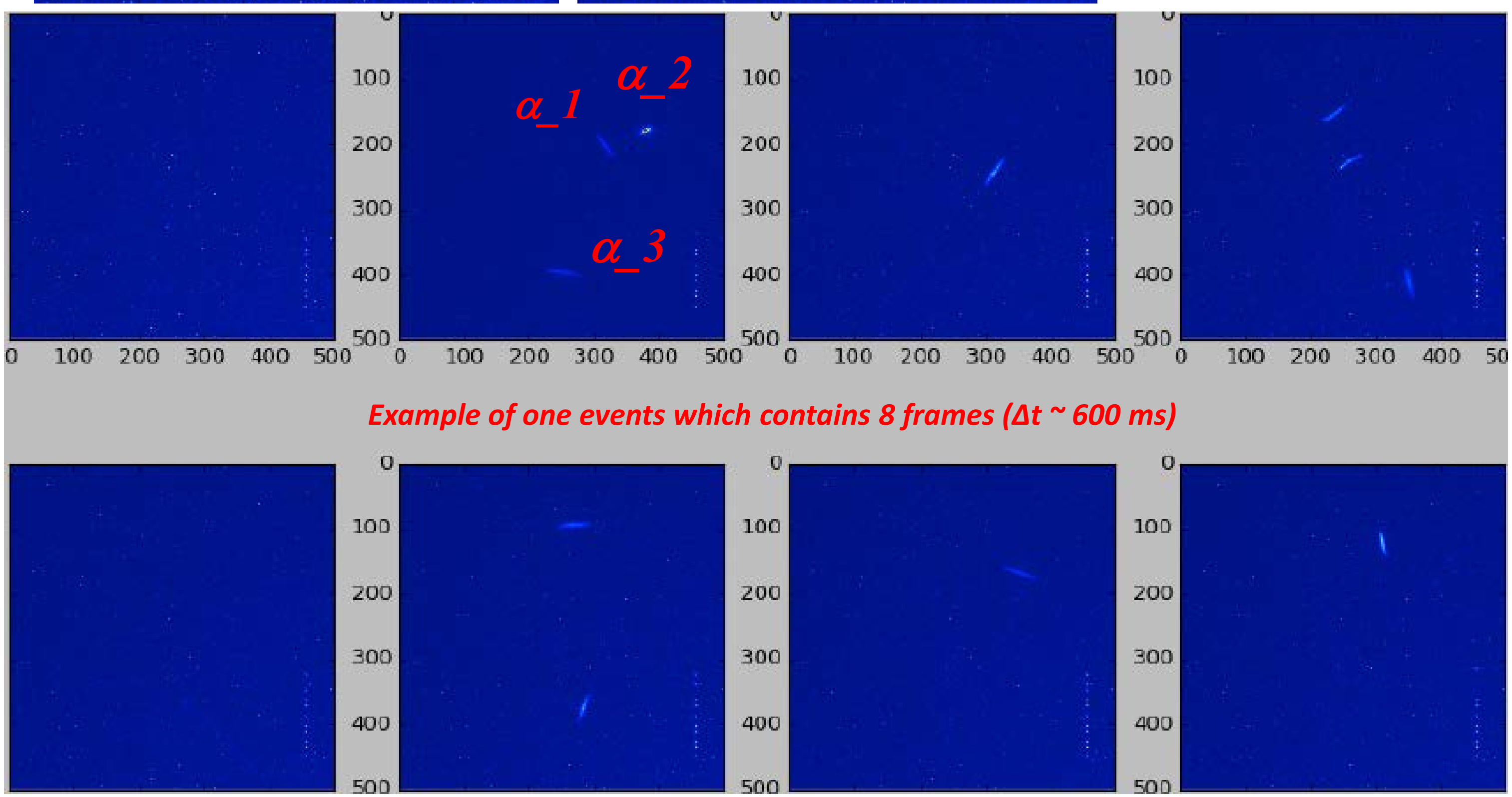


A. Giska bachelor thesis, UW 2018

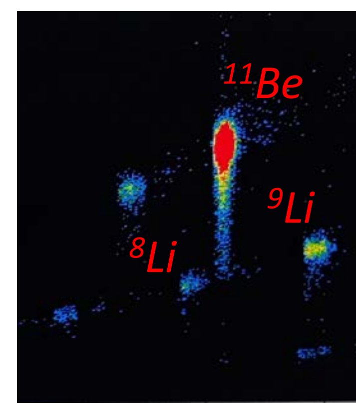
^{11}Be case (~10^3 1/s):
so-called "saturation mode"



2s break needs to get rid from ^{8}Li



Example of one events which contains 8 frames (Δt ~ 600 ms)



β-delayed alpha emission: P ~ 3%

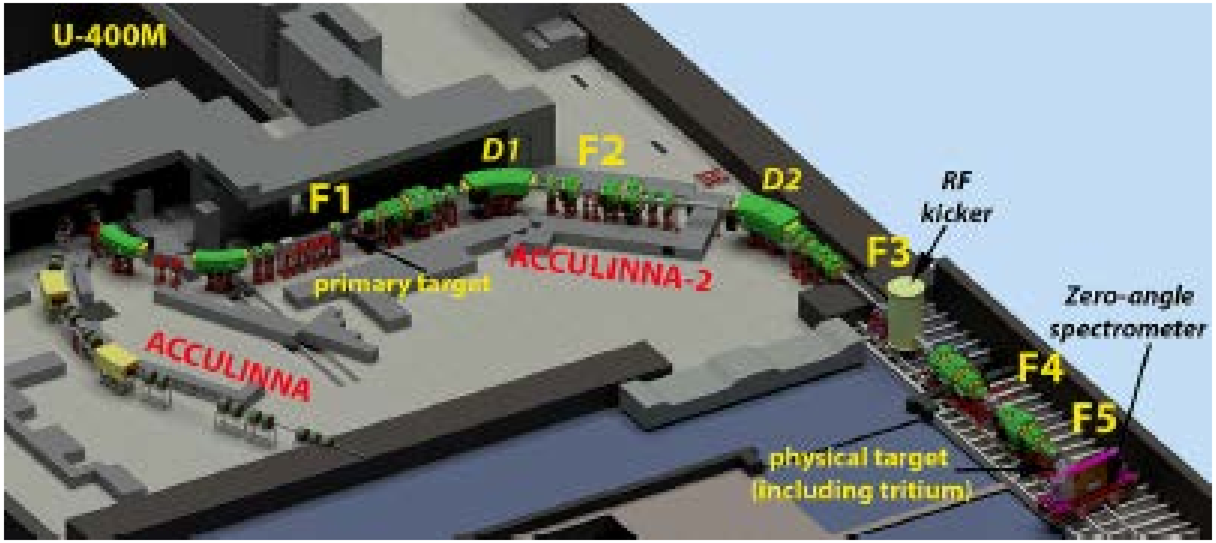
University of Warsaw

- E. Adamska
- A. Ciemny
- W. Dominik
- L. Janiak
- A. Giska
- Z. Janas
- A. Kubiela
- C. Mazzochi
- K. Miernik
- M. Pfutzner
- M. Pomorski
- N. Sokołowska

JINR Dubna

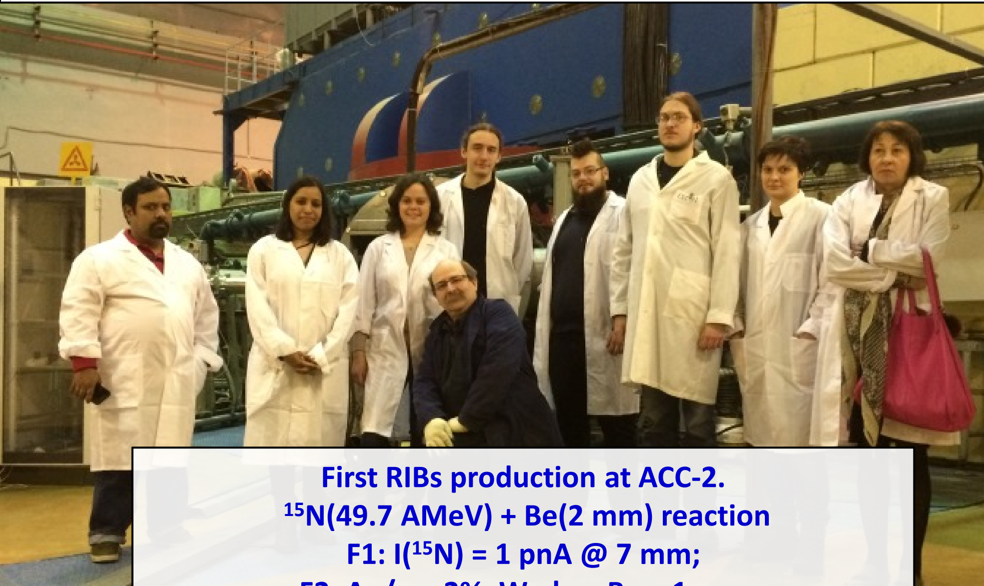
- A. Bezbakh
- A. Fomichev
- M. Golovkov
- A. Gorshkov
- G. Kamiński (HIL, UW)
- S. Krupko
- R. Slepnev
- B. Zalewski (HIL, UW)

- 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 15-20 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 and ^{27}S with the OTPC spectrometer.
- Study of RIB at driplines stimulates of a new novel instrumentation and engineering inventions
- We are open for collaboration



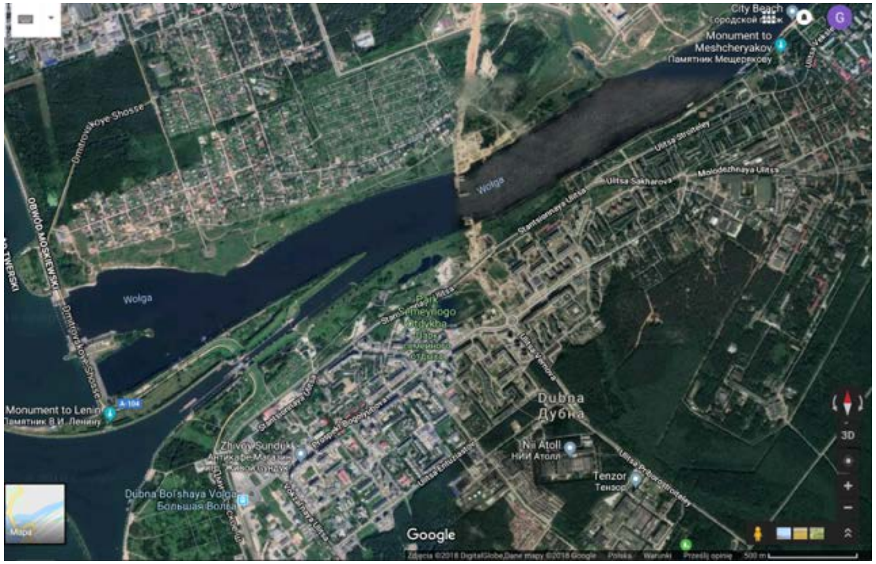
Some of Polish collaborators at FLNR at the beam time

Polish collaborators (**HIL UW**, **FUW**, **WUT**)



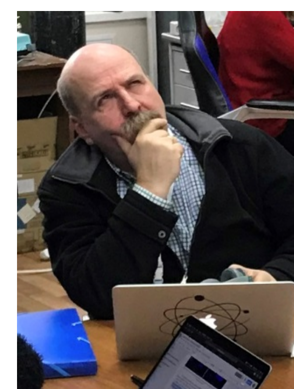
First RIBs production at ACC-2.
^{15}N(49.7 AMeV) + Be(2 mm) reaction
F1: I(^{15}N) = 1 pnA @ 7 mm;
F2: Δp/p = 2%, Wedge_Be = 1 mm

Visit at FLNR in Novemver 2018



Today (29.11.2018) in Dubna there is an official "opening" of a new bridge

The first collaborator who could cross the bridge is dr Paweł Napiorkowski – who is now in Dubna



Thank you for attention