Grzegorz Kaminski[a,f]
for ACCULINNA Collaboration

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*
i – *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 EXPERIMETS

Outline

- Light RIB facility at FLNR (ACC&ACC-2)
- Status of the ACCULINNA-2 project & ACC-2 instrumentation
- First day experiments at ACCULINNA-2
- Experiments with OTPC at ACC
- Summary

INTERNATIONAL CONFERENCE ON ELECTROMAGNETIC ISOTOPE SEPARATORS AND RELATED TOPICS
EMIS XVIII
CERN GENEVA / SWITZERLAND / 16 - 21 SEPTEMBER 2018

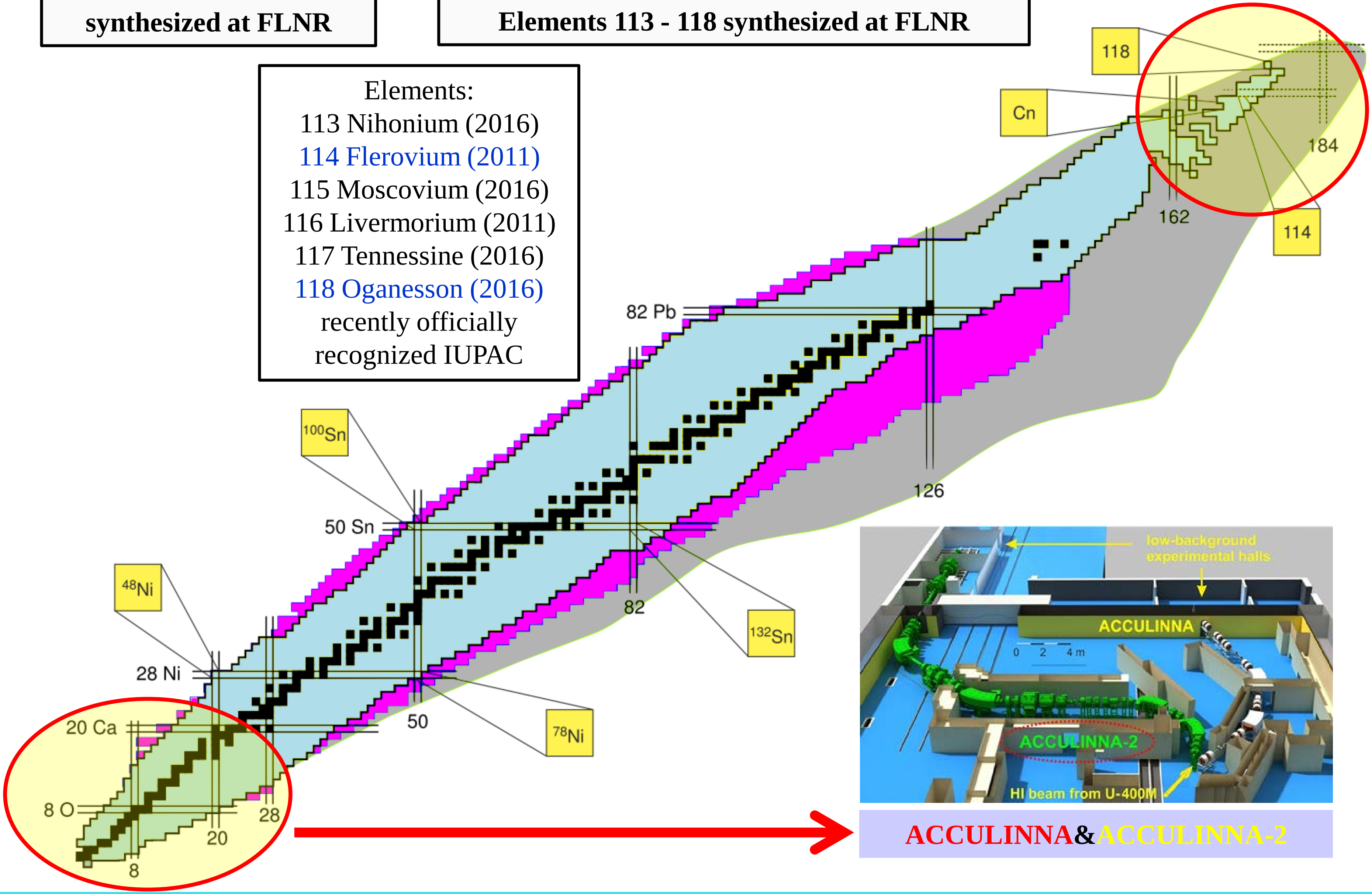
Main areas of interest at FLNR, JINR

Elements 102 - 108 synthesized at FLNR

Last two decades: Elements 113 - 118 synthesized at FLNR

'Superheavy'

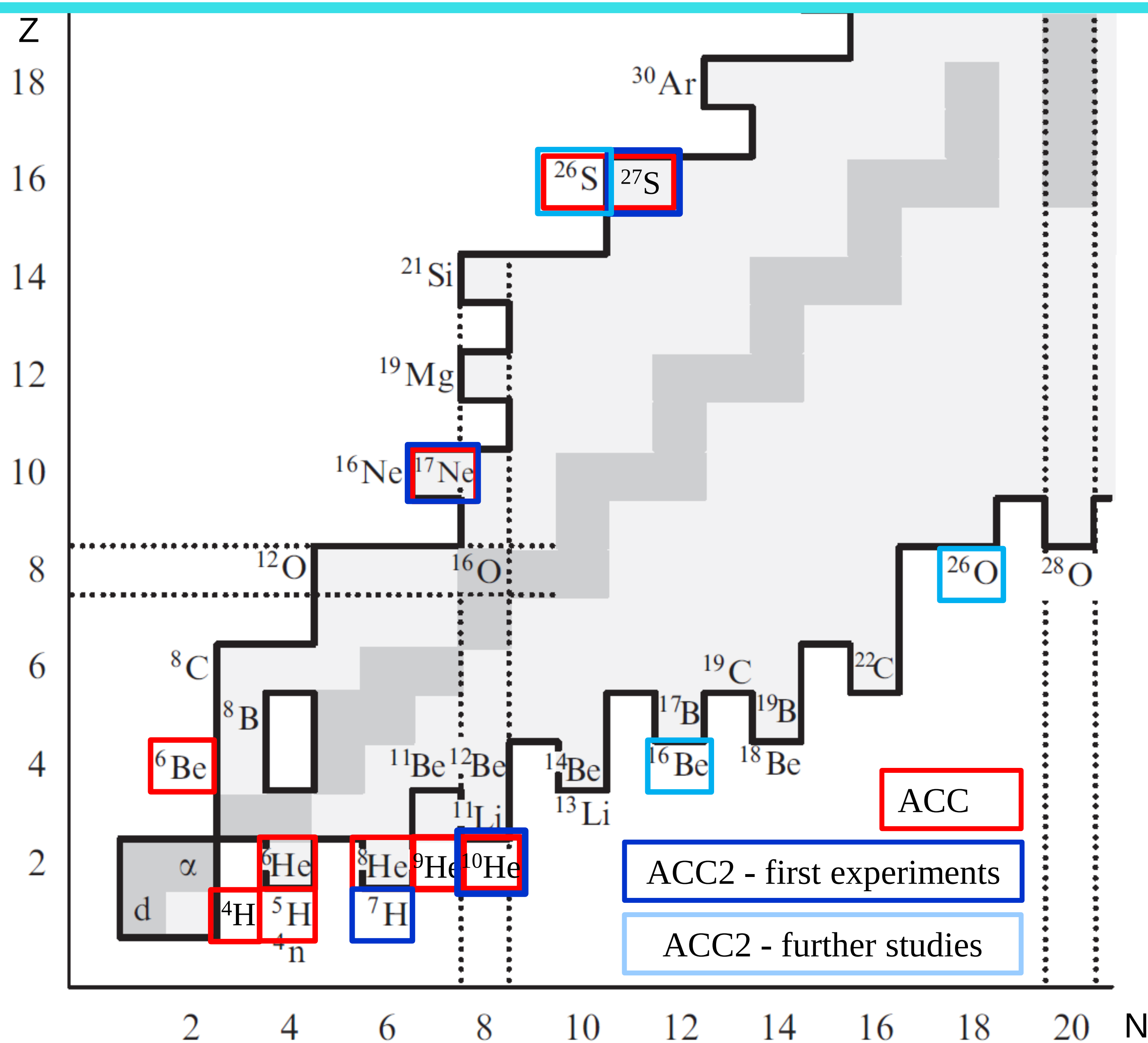
Elements:
113 Nihonium (2016)
114 Flerovium (2011)
115 Moscovium (2016)
116 Livermorium (2011)
117 Tennessine (2016)
118 Oganesson (2016)
recently officially recognized IUPAC



ACCULINNA&ACCULINNA-2

Light & 'Superlihght'

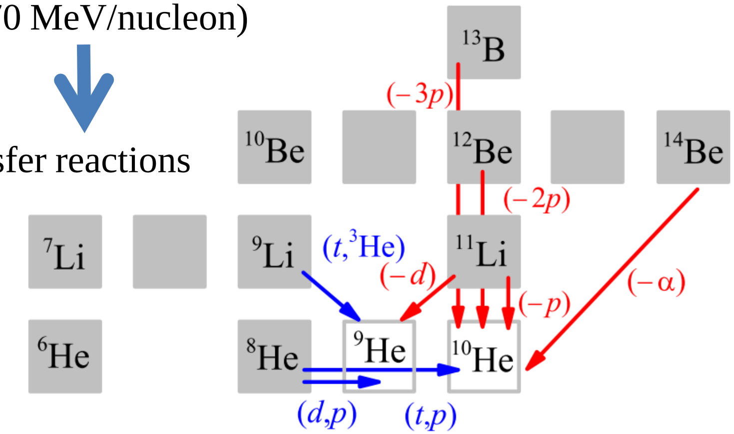
Scope of activity with ACCULINNA-2



➢ 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

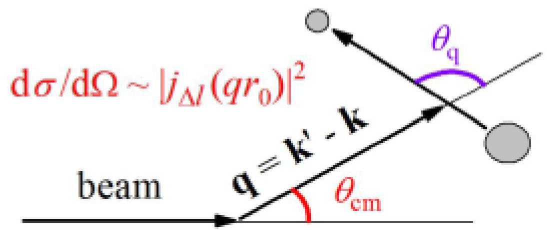
Prospects for specific correlation studies

- **Complementary information from different reaction mechanism**
- **Lower reaction energy - easier to get higher energy resolution**

➢ Correlations and few-body dynamics studies

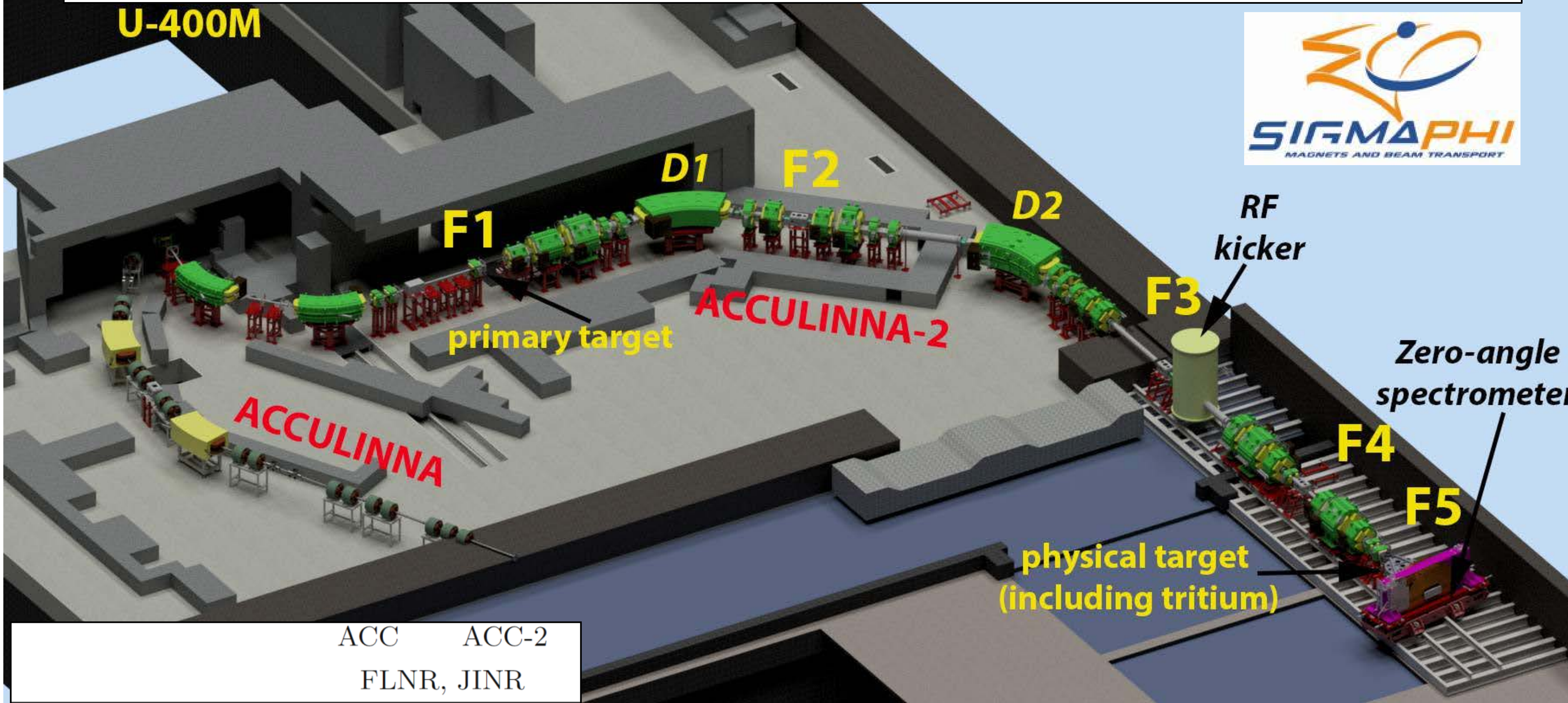
Correlations for aligned states populated in the direct reactions

- Few-body dynamics near the driplines
- Correlations in the three-body decays: two extra degrees of freedom



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)

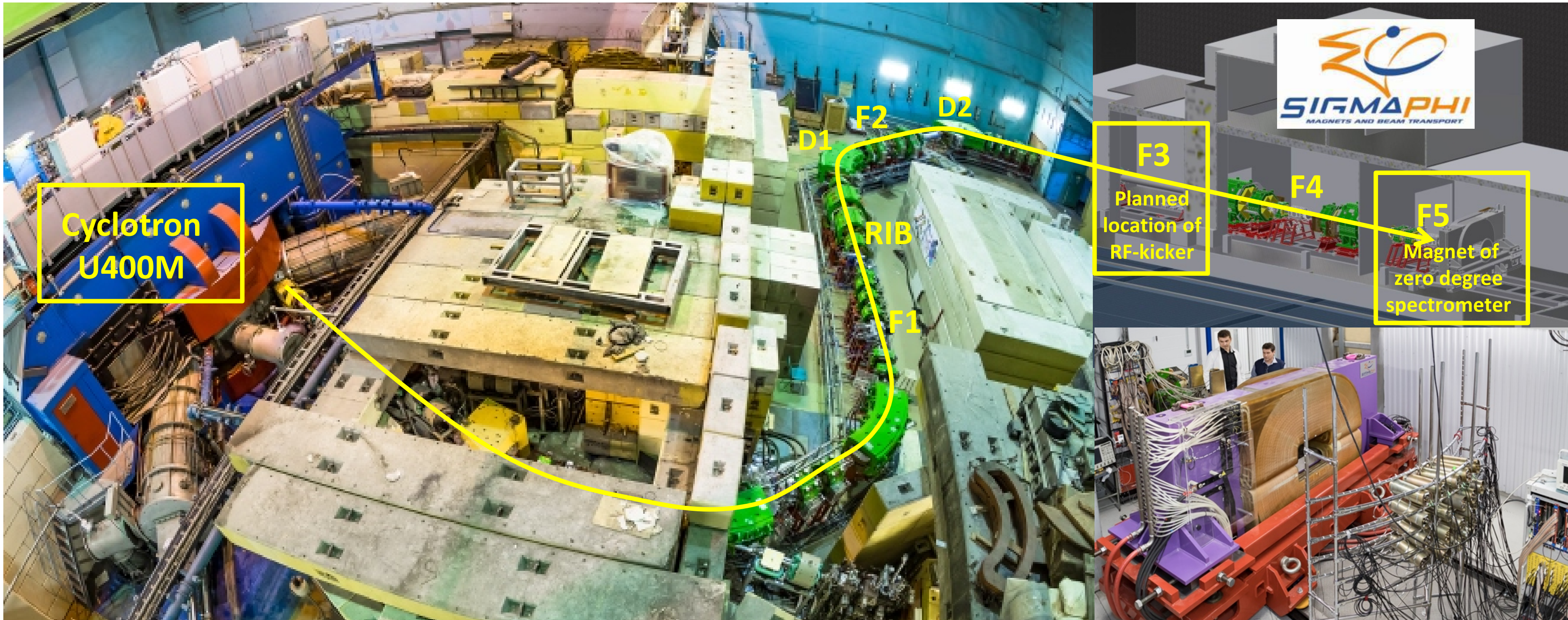


total length F0-F5 ~53m, 39 magnetic elements

		ACC	ACC-2
		FLNR, JINR	
$\Delta\Omega$	msr	0.9	4.2
δ_P	%	2.5	6.0
$P/\Delta P$	a.u.	1000	2000
$B\rho_{max}$	Tm	3.2	3.9
Length	m	21	37
$E_{\min}$	AMeV	10	5
$E_{\max}$	AMeV	40	50

- RIB energy range 5 – 50 MeV/A
- Z_{RIB} ~ 1 – 36

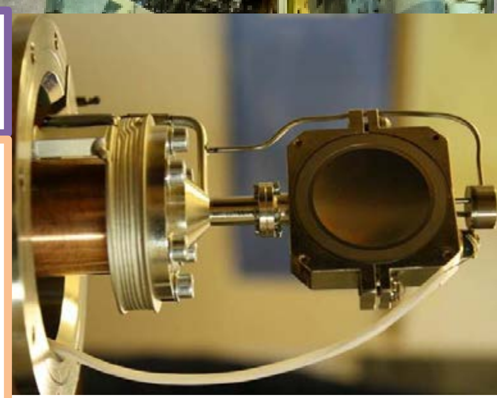
ACCULINNA-2 project: timeline



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

2016-2017: Zero-angle spectrometer
2017-2019: RF kicker at F3
2017-2019: New detectors
2018-2020 : Cryogenic target system & tritium target at F5

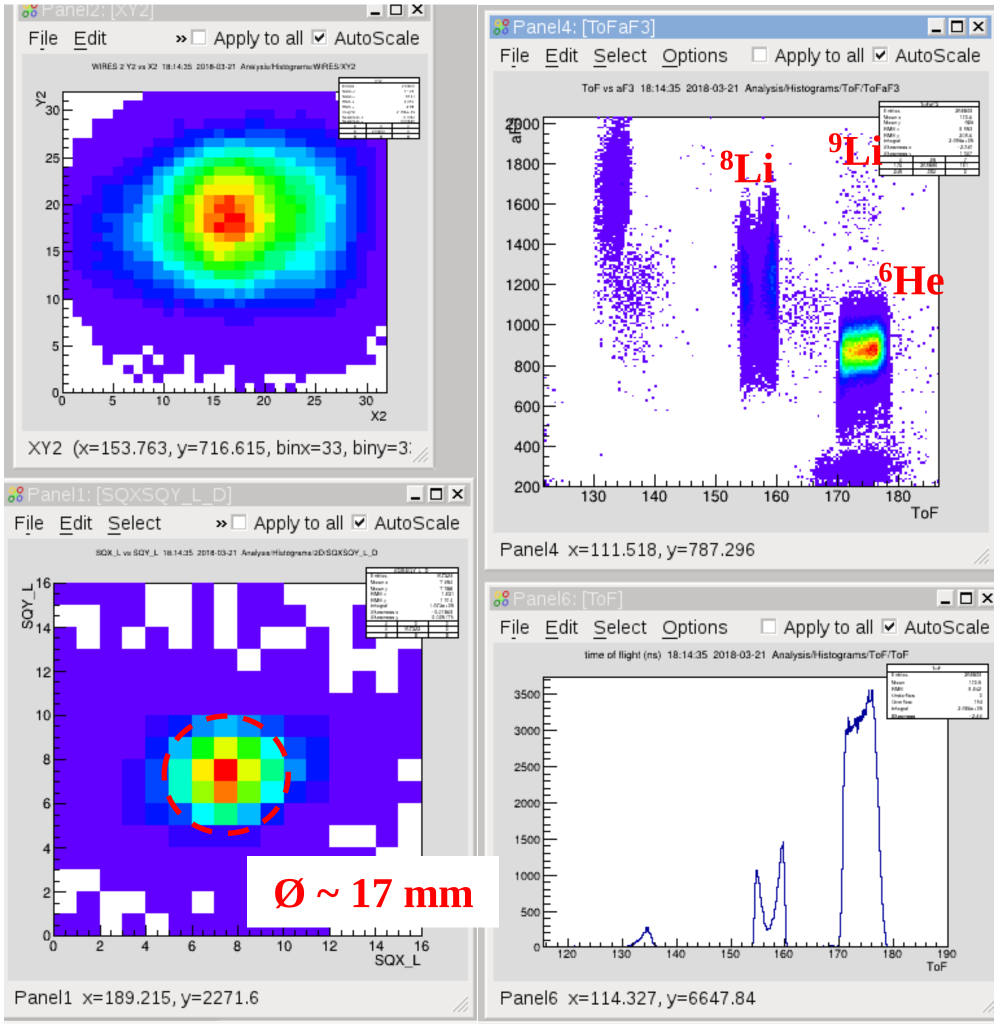
2019-20: Cyclotron upgrade



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)

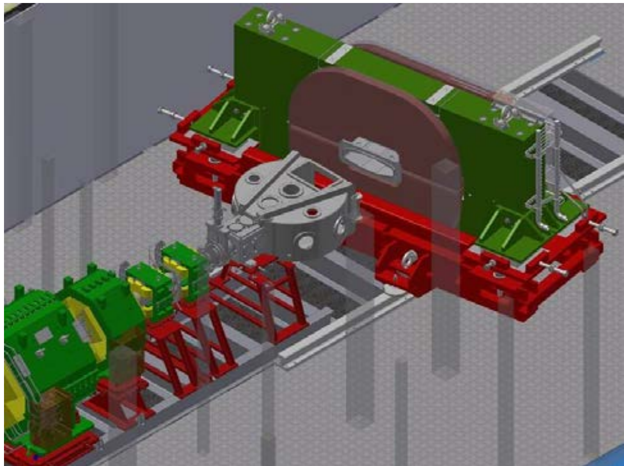


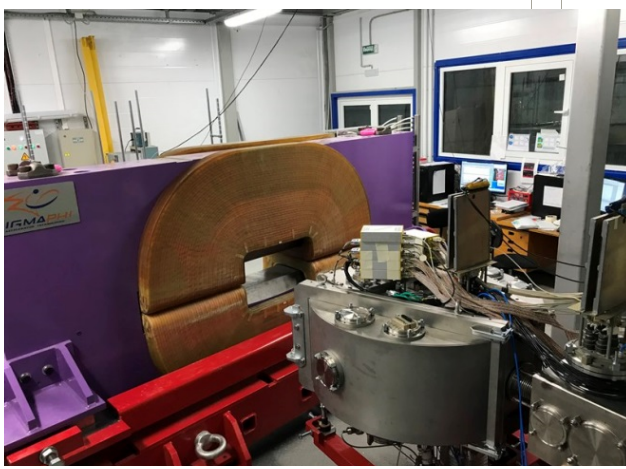
I = 100 pnA , Δp/p = ±2% (Be wedge 1 mm)

RIB	Energy, Amev	Intensity, 1/s	Purity, %
^{14}B	37,7	$1.2\cdot10^4$	65
^{12}Be	39,4	$1.5\cdot10^4$	92
^{11}Li	37	$4\cdot10^2$	67
^{9}Li	33,1	$1.1\cdot10^5$	50
^{8}He	35,8	$2.5\cdot10^3$	89

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

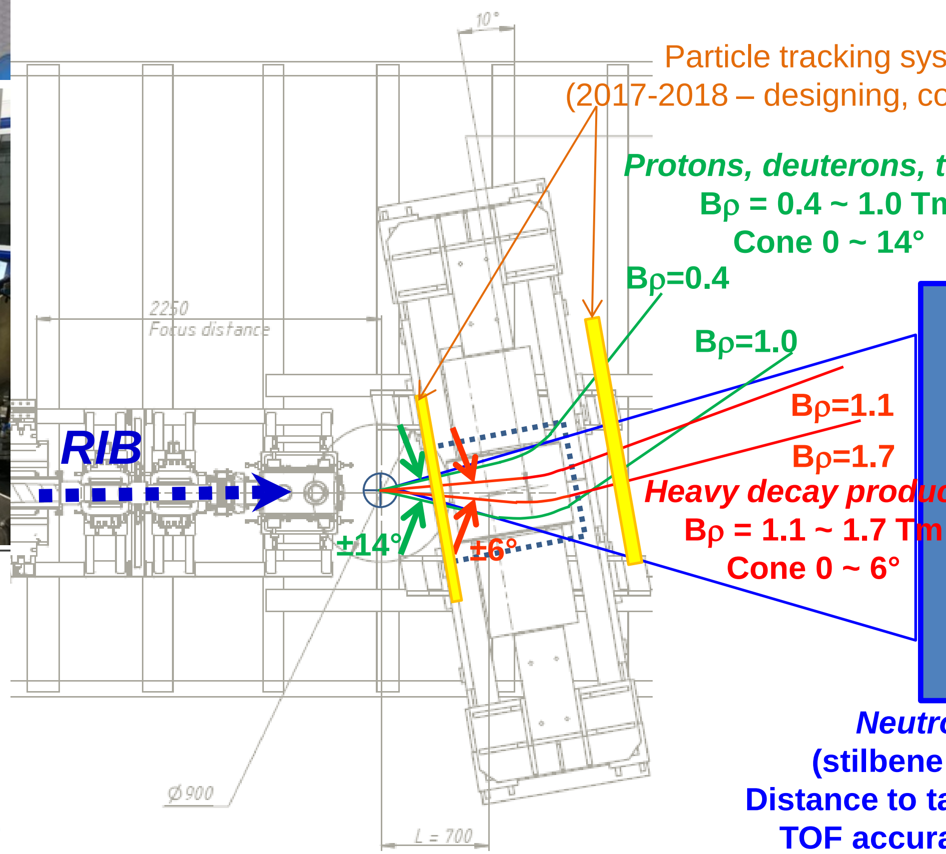
The zero degree spectrometer

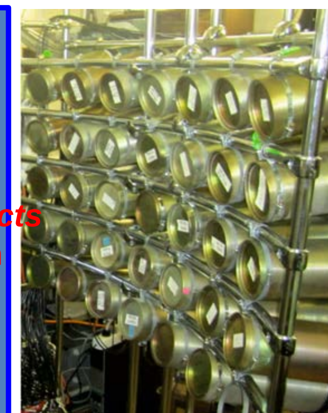




Maximum field	$B_{\max}$	T	1.44
Minimum field	$B_{\min}$	T	0.4
Effective length for $B = 1.2\,\mathrm{T}$	L	mm	524
Gap		mm	180
Good field region dimensions	H/V	±mm	250/75
Field homogeneity for $B = 1.2\,\mathrm{T}$	$\mathrm{d}B/B$		0.003

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

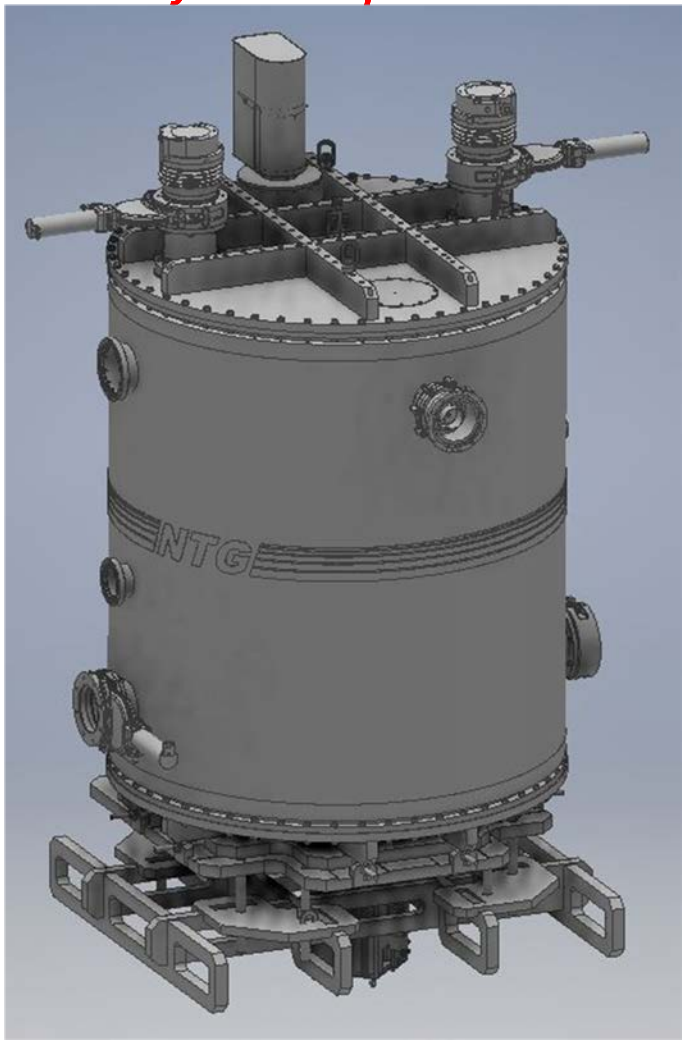


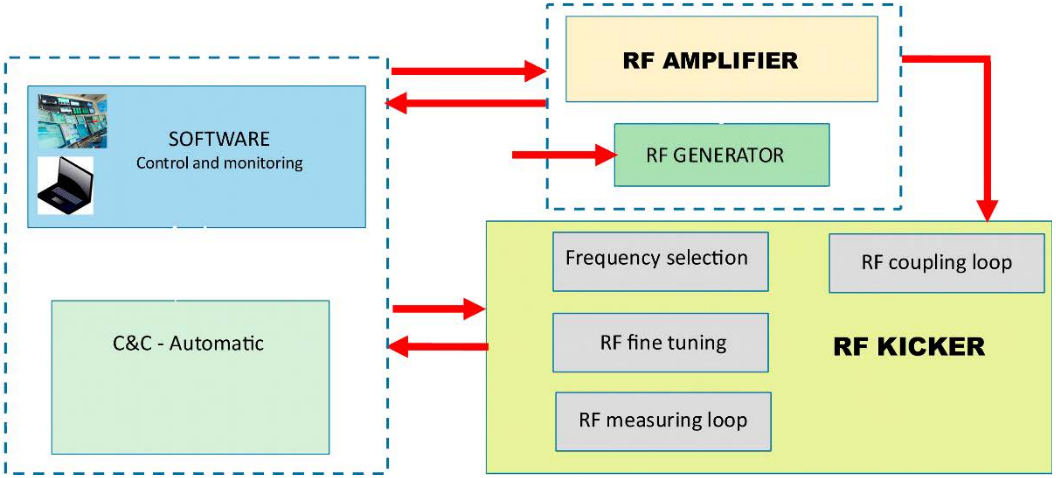


Improvement of RIB purity - RF-kicker

Frequency range (MHz)	15 – 22
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 (mm)	1830
Distance from A-2 primary target (m)	25

Delivery in first quarter of 2019

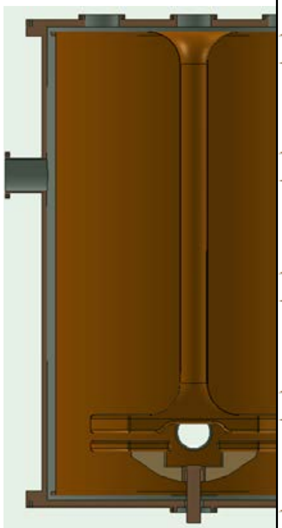


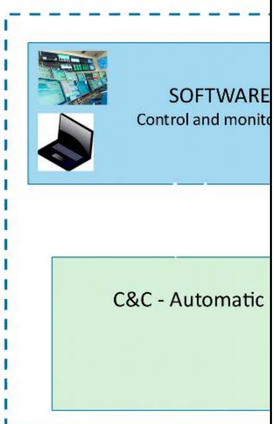


ADJUSTMENT OF RF FREQUENCY – AUTOMATIC REGULATION

RF-kicker phase correction from pickup in primary beam or cyclotron RF signal

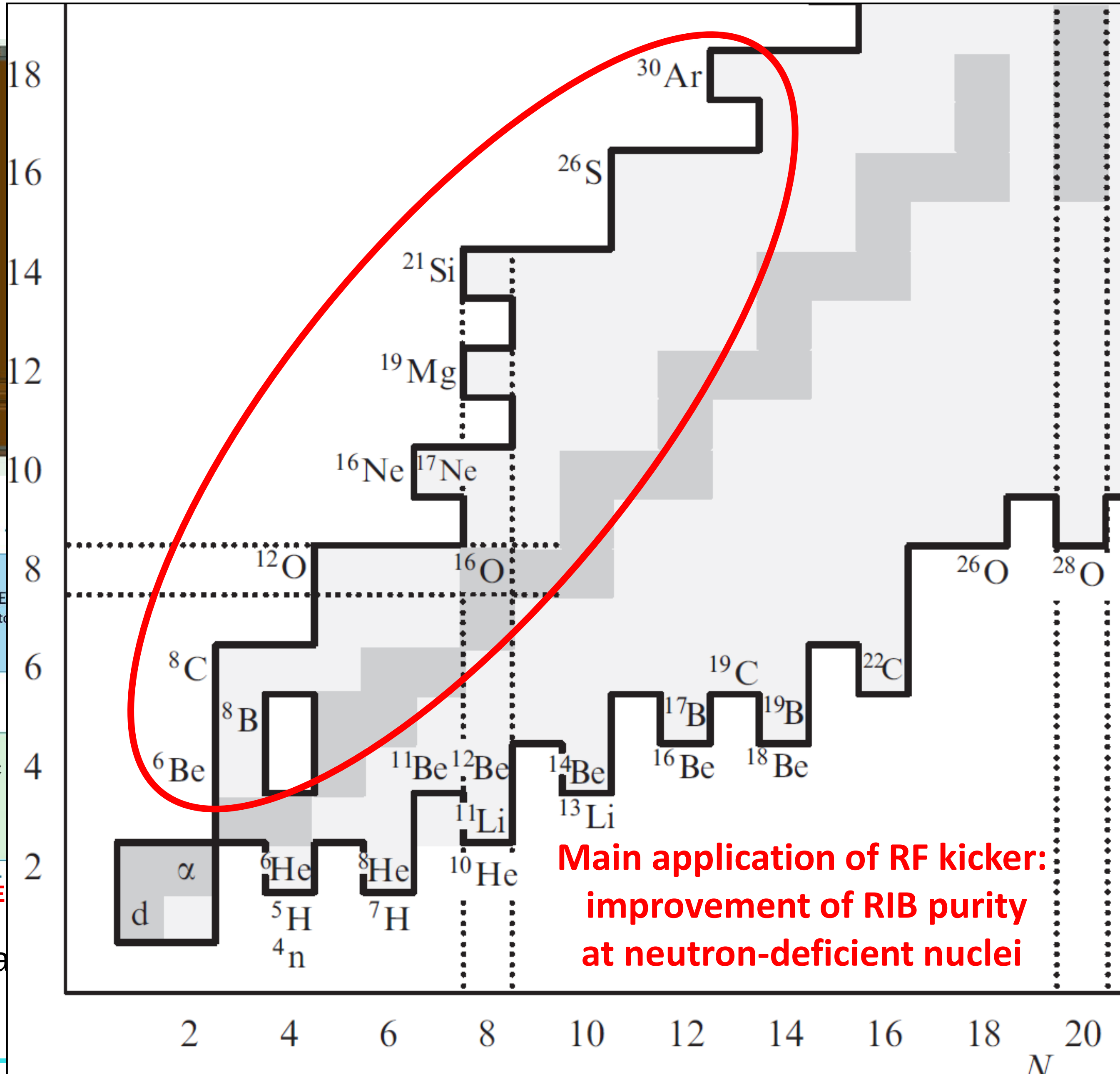
Improvement of RIB purity - RF-kicker





ADJUSTME

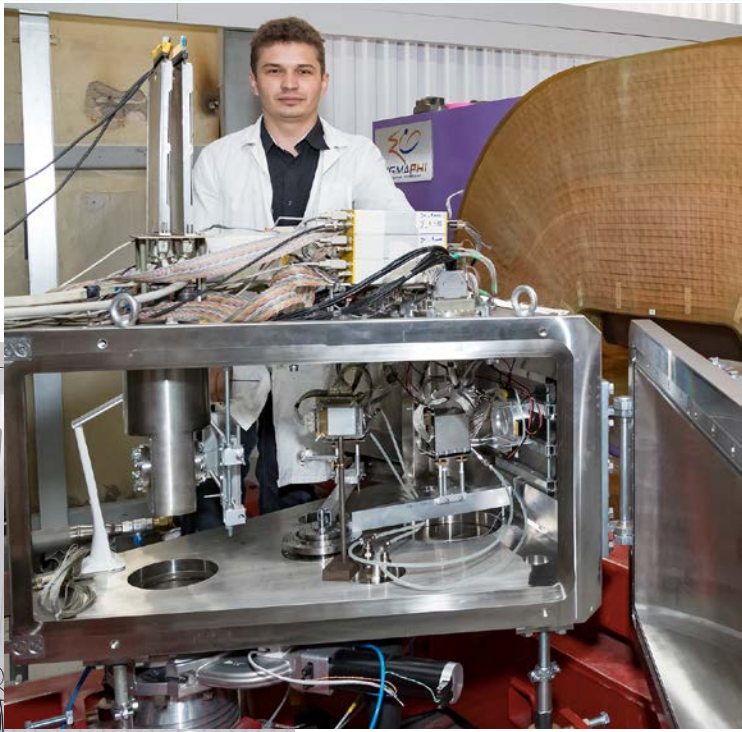
RF-kicker pha

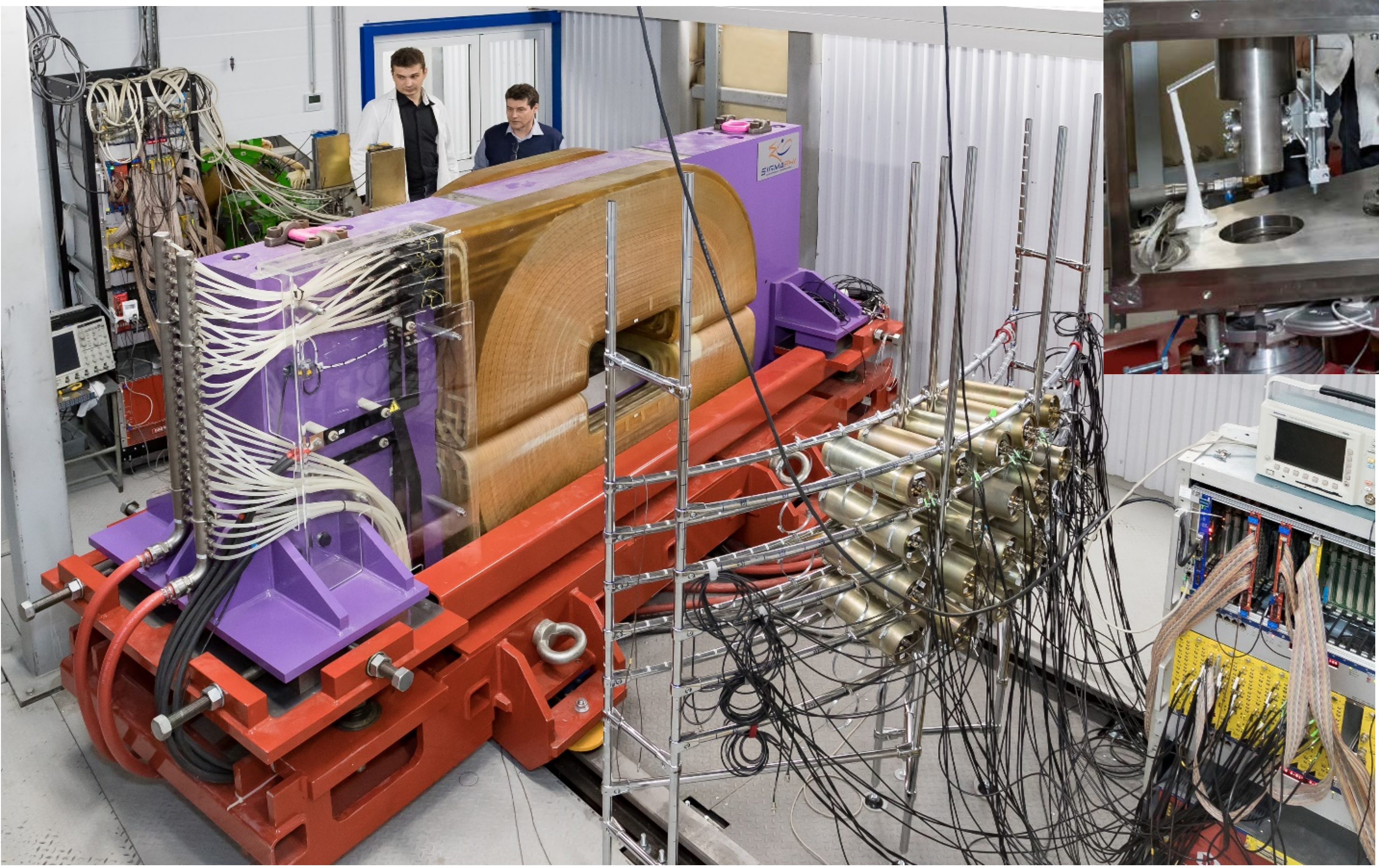


First experiments @ ACCULINNA-2

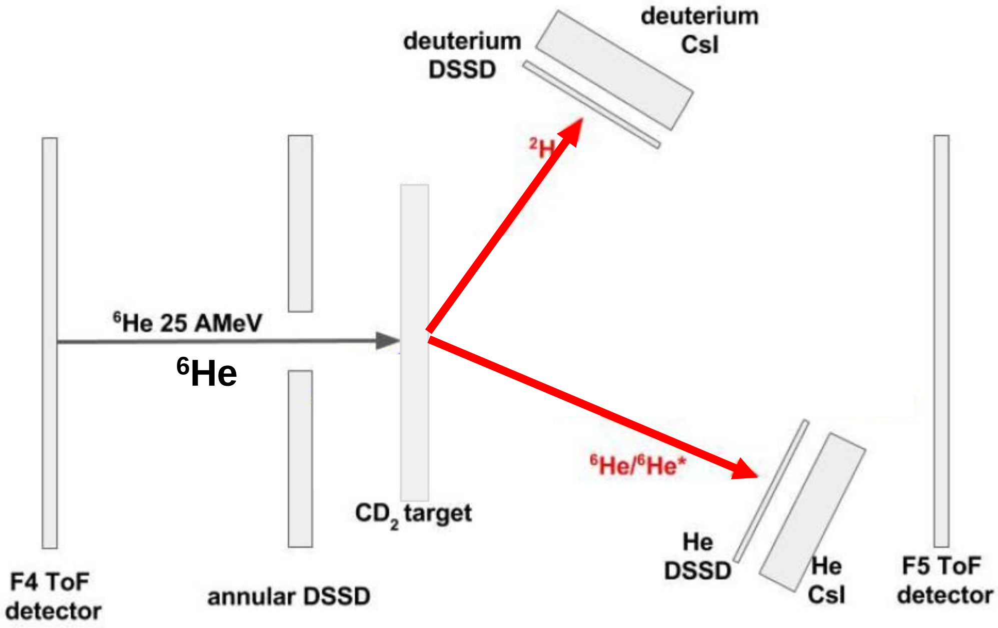
First experiments with ^{6}He and ^{9}Li on CD_2 target were carried out at ACC-2 in spring:

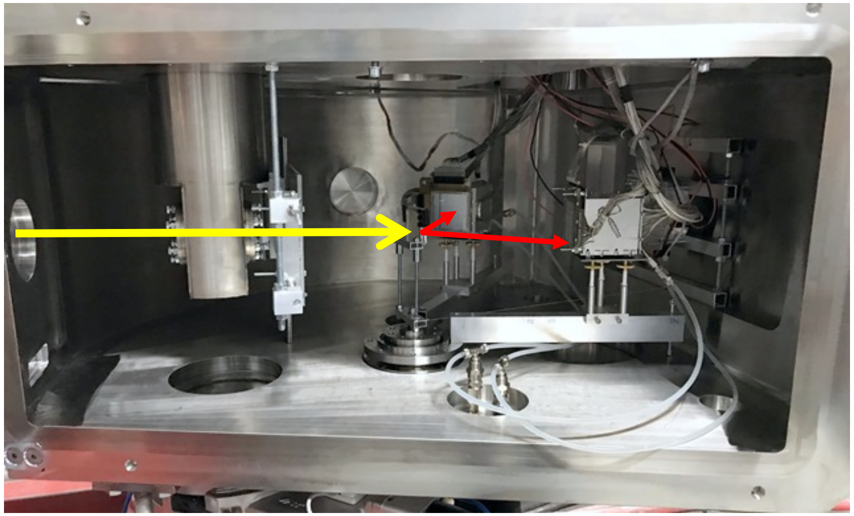
- elastic and inelastic scattering of ^{6}He;
- $d(^{6}\mathrm{He},^{3}\mathrm{He})^{5}\mathrm{H}$ reaction;
- $d(^{9}\mathrm{Li},p)^{10}\mathrm{Li} \rightarrow n+^{9}\mathrm{Li}$ run.





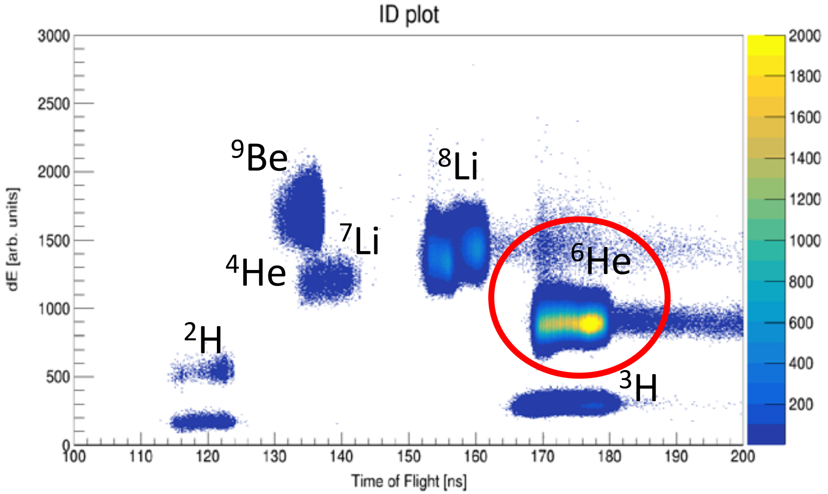
Elastic and inelastic scattering of ^{6}He (26 AMeV) on ^{2}H:





Beam parameters:

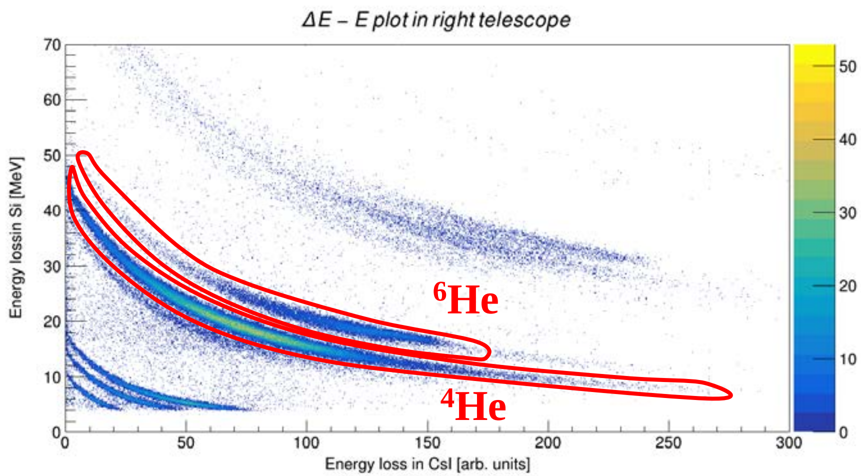
- 78% of ^{6}He
- Energy 26 AMeV
- Intensity 10^5 pps

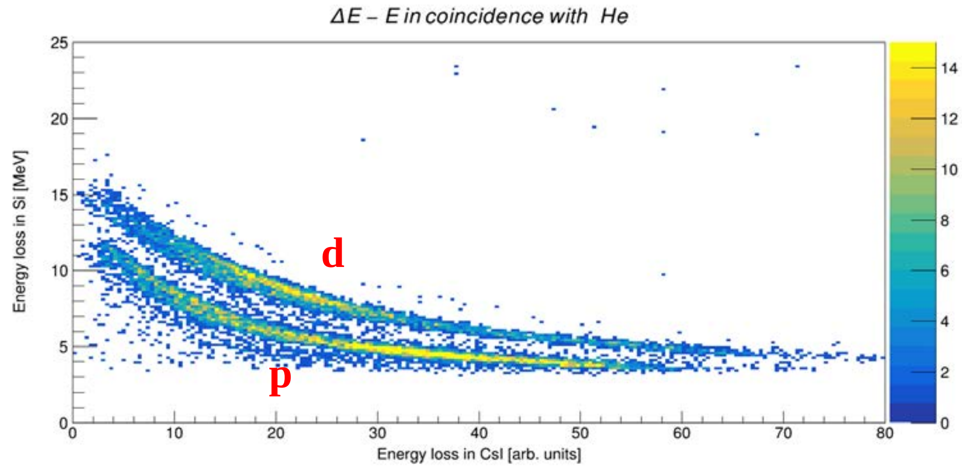


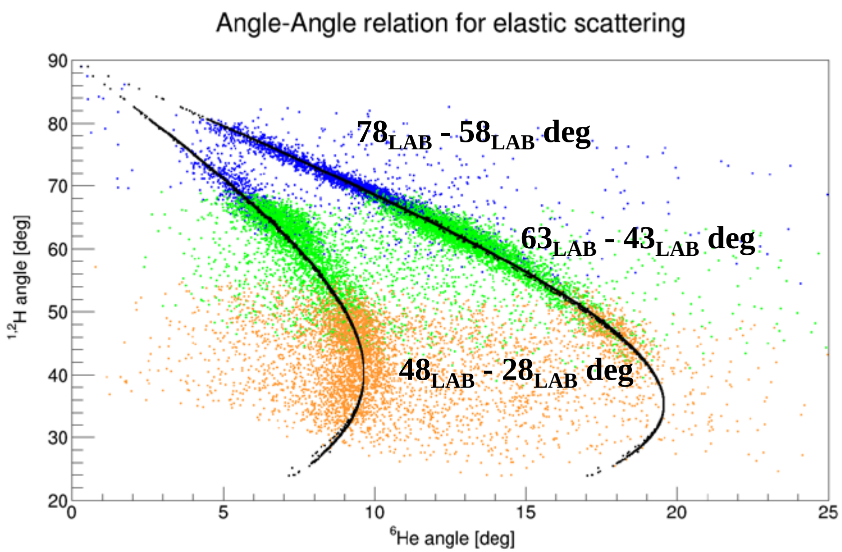
Experimental data for B. Zalewski Ph.D Thesis (HIL, UW, Warsaw)

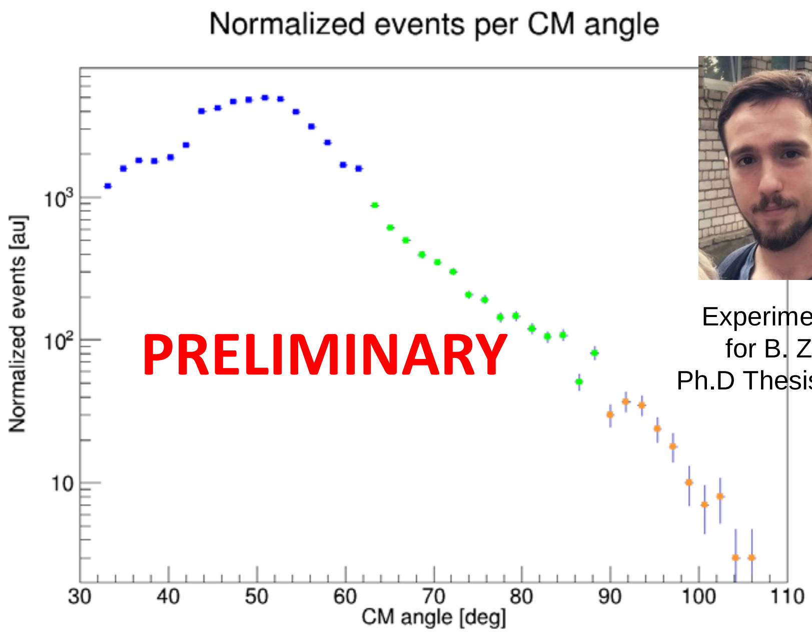
Elastic and inelastic scattering of ^{6}He (26 AMeV) on ^{2}H:

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



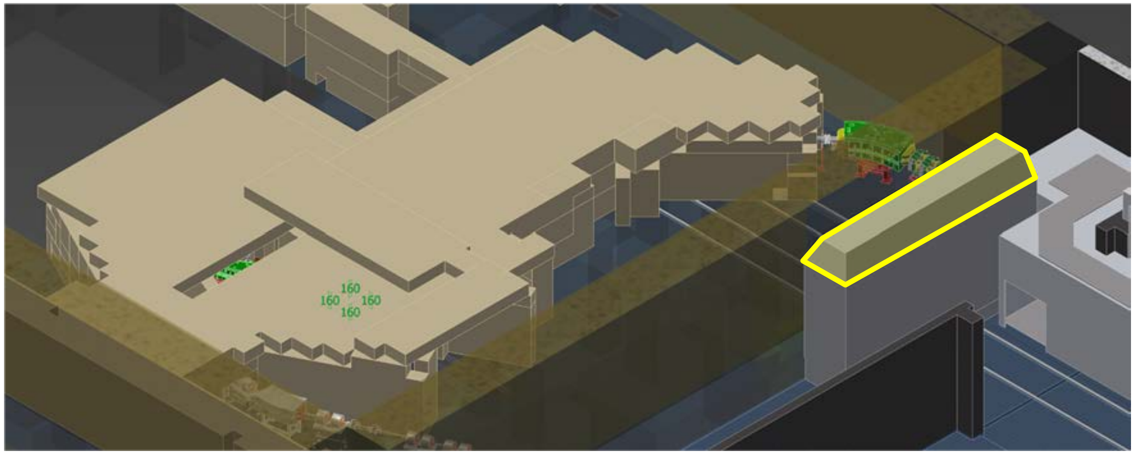


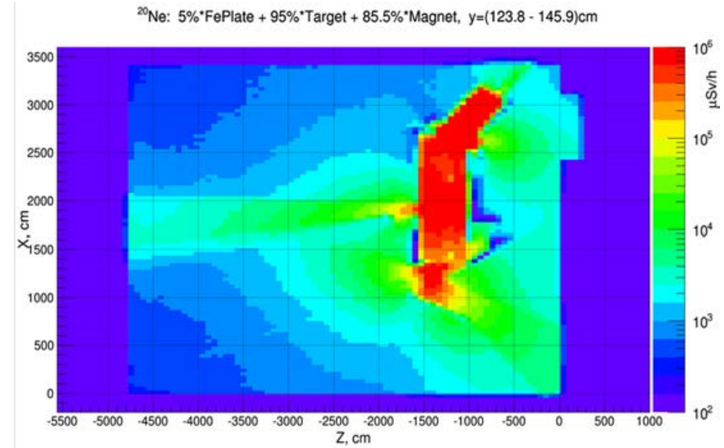




Experimental data
for B. Zalewski
Ph.D Thesis (HIL, UW)

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





Radiation shell around F1-F2 area is completed.

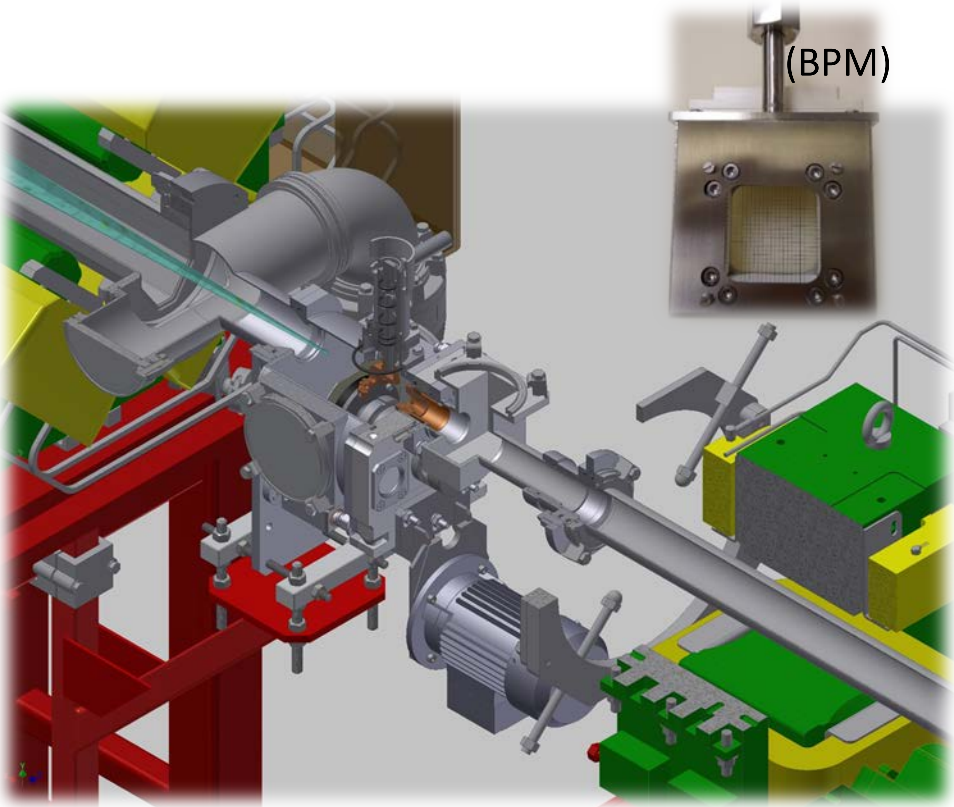
Radiation shell will let to operate at full beam intensity.

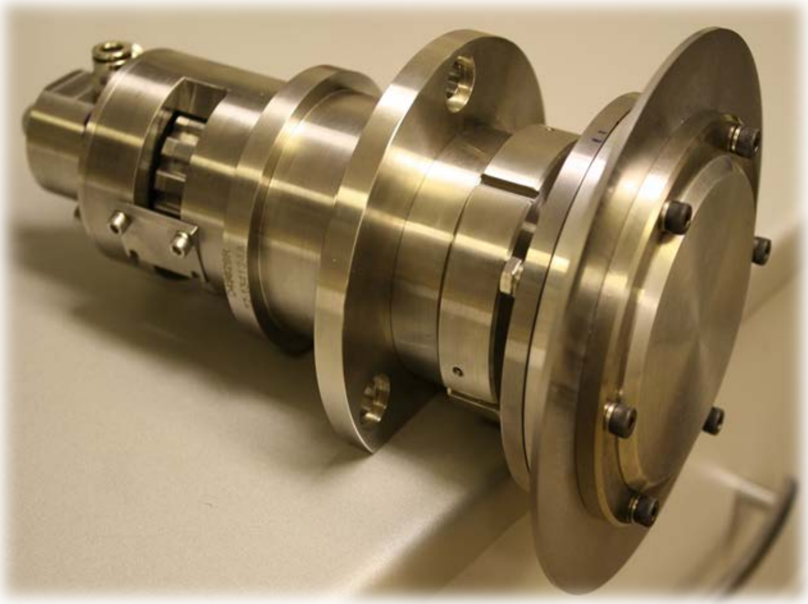
Modernized U-400M cyclotron will provide highly intended beams

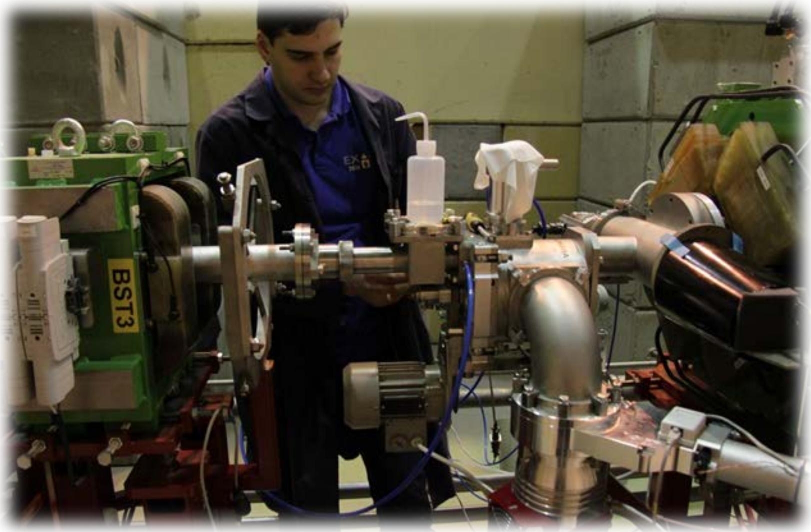
(~ 3 μA on the target in case of ^{15}N)

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

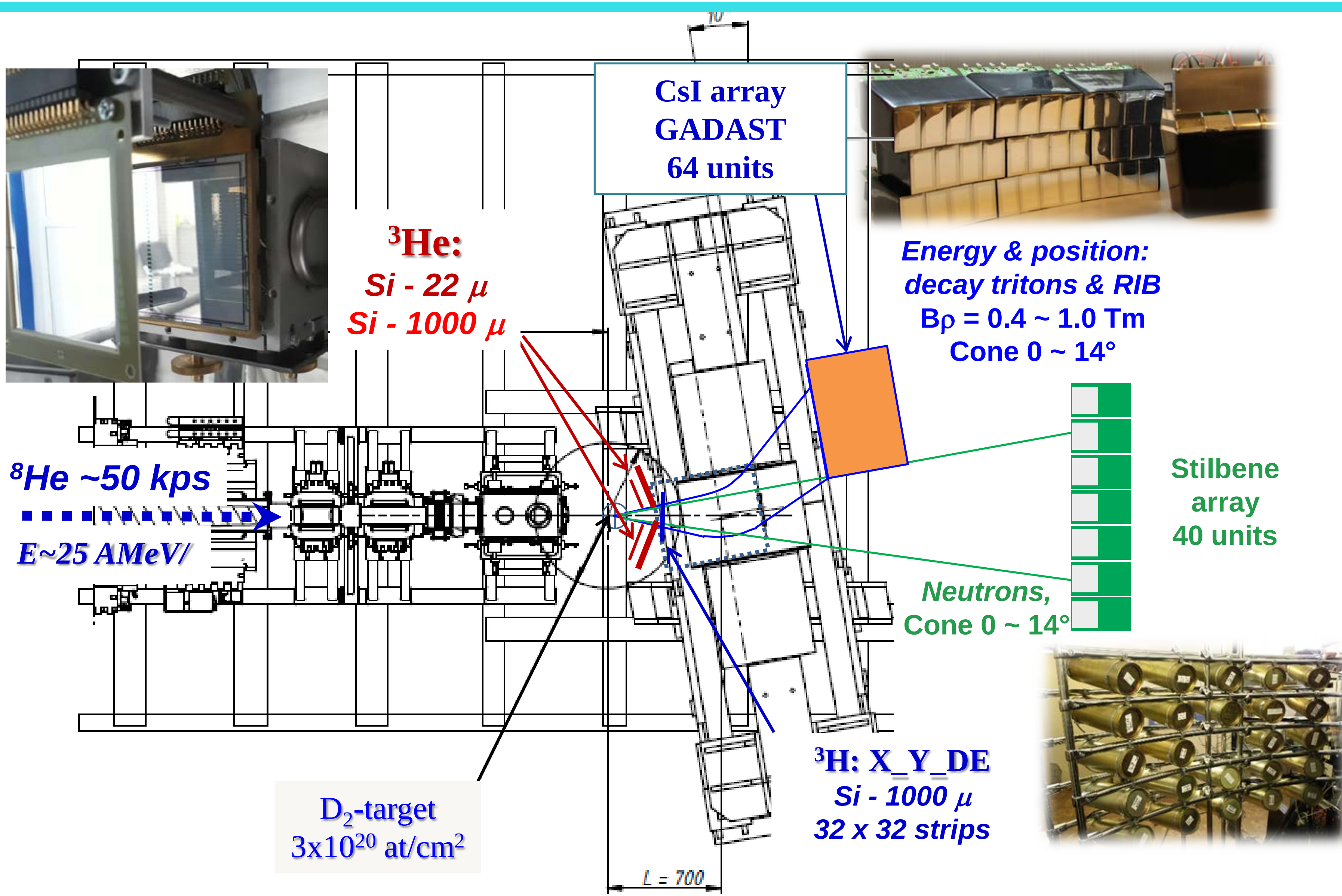
- Water cooled beryllium target mounted on magnetic liquid feedthrough with rotation speed up to 1500 rpm
- Heating power up to 2 kW
- Vacuum chamber for fast opening and service
- Integrated system of water cooled diaphragms
- Special port for beam profile monitor (BPM)







First day flagship experiment $d(^8He,^3He)^7H$

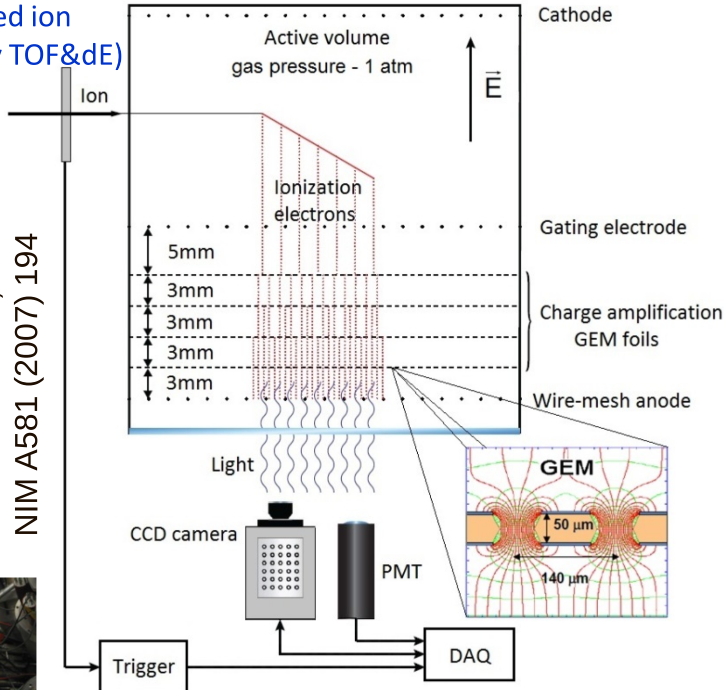


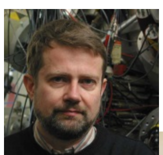
~ 5 ^{7}H per day (two telescopes) @ 5*10^4 ^{8}He/s → ~140 ^{7}H during 4 weeks

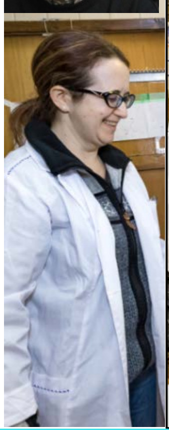
Optical **T**ime **P**rojection **C**hamber (OTPC) - A new type of modern ionization chamber with an optical readout. Invented at the University of Warsaw by W. Dominik

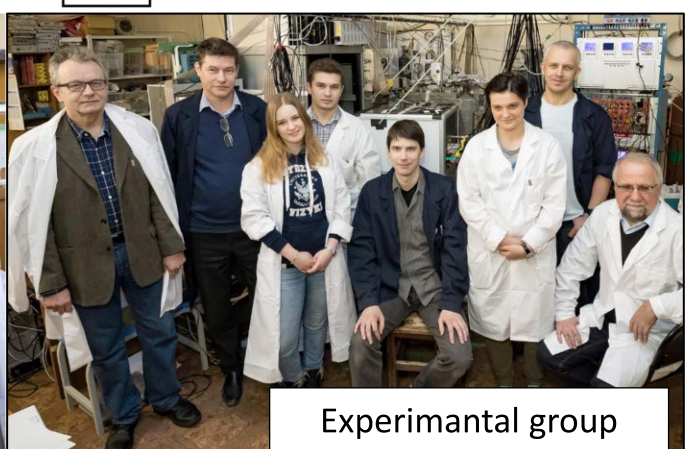
Identified ion
(typically by TOF&dE)

Miernik et al., NIM A581 (2007) 194



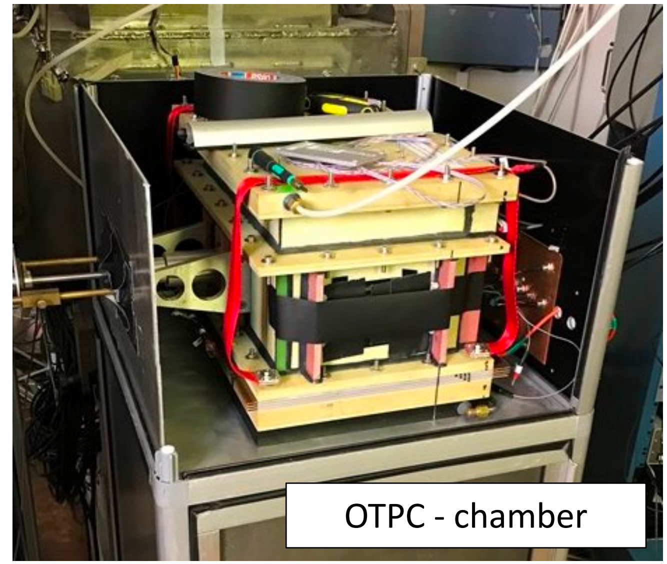






Experimantal group

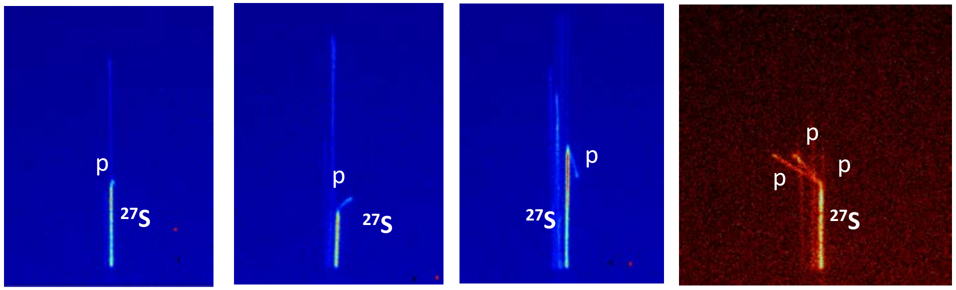
Spectroscopy of β-delayed charged particle emission



OTPC - chamber

OTPC installed at ACCULINNA

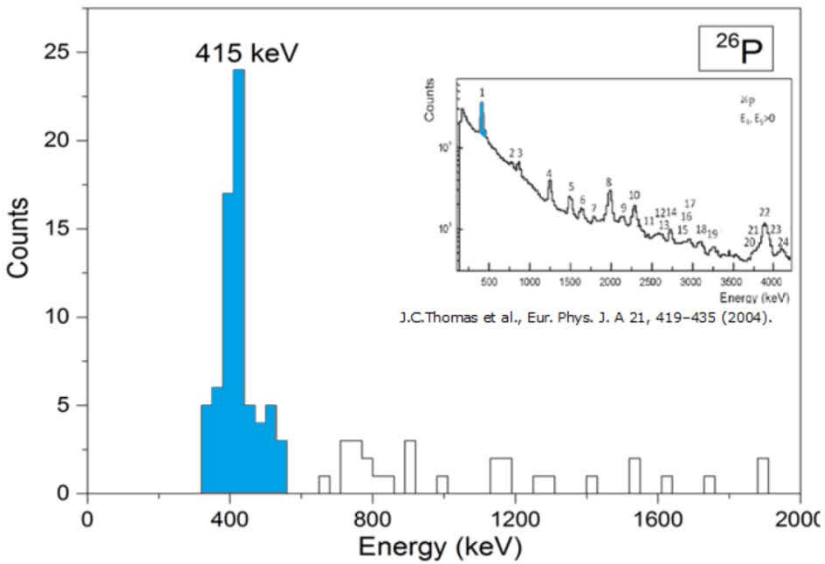
Plans for 2019: β-delayed charged particle emission from ^{27}S and ^{26}P

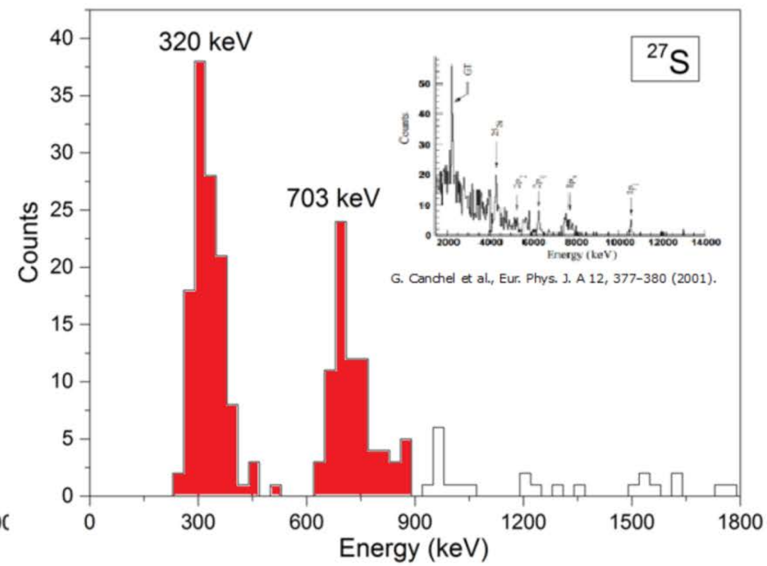


^{32}S @ 50 MeV/u + $^{9}Be \rightarrow$ ACC $\rightarrow$ ^{27}S,^{26}P

We have too low statistic to get the limit for observation of $\beta 3p$

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%

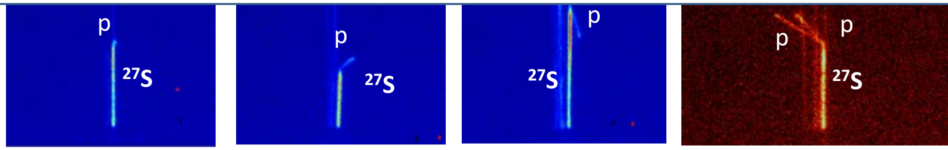
Thomas et al., EPJ A21 (2004) 419

Canchel et al., EPJ A12 (2001) 377

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

Plans for 2019: β-delayed charged particle emission from ^{27}S and ^{26}P

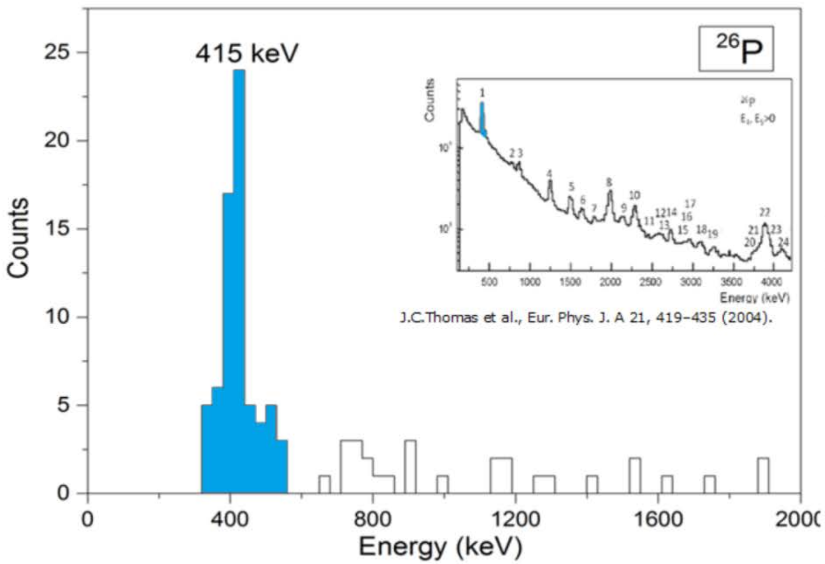
In 2019 new measurments of β-delayed particle emission from ^{27}S @ **ACCULINNA-2** are planned. Much better statistic of two orders of magnitude is expected (we plane to purify the beam with RF-kicker). Observation of $\beta 3p$ channel is still an open question.

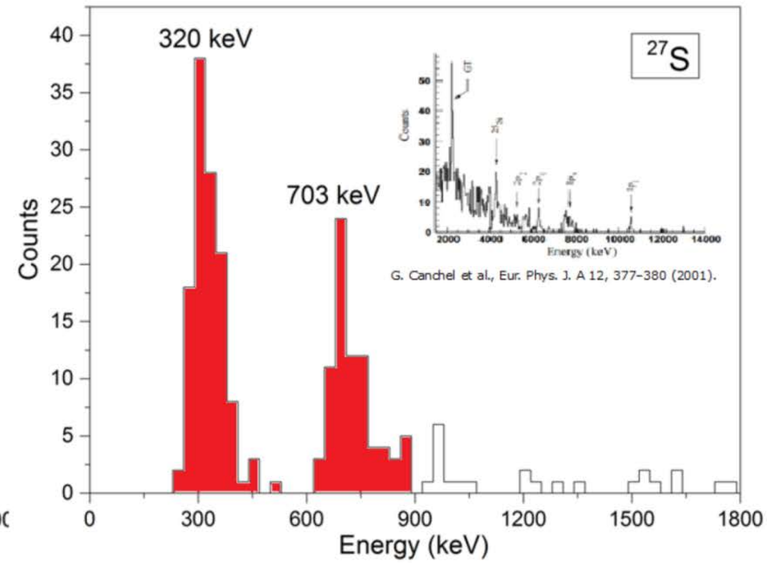


^{32}S @ 50 MeV/u + $^{9}Be \rightarrow$ ACC $\rightarrow$ ^{27}S,^{26}P

We have too low statistic to get the limit for observation of $\beta 3p$

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%

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 15 - 20 times higher in comparison with the values for the old facility.
- In 2018 experimental program with RIBs has been focused on β-delayed exotic decays of ^{11}Be, ^{6}He+d scattering and d(^{6}He,^{3}He)^{5}H reaction study.
- Method to study low-lying states of ^{10}Li populated in the reaction d(^{9}Li,p)^{10}Li $\rightarrow$ n+^{9}Li was tested too (registration of protons, emitted backward in laboratory system, in coincidence with neutrons moving in forward direction).
- The study of the ^{7}H and its 4n-decay in the reaction d(^{8}He,^{3}He)^{7}H is proposed for the fall 2018.
- **Further plans**: search for β-delayed 3p emission from ^{27}S is considered by means of the OTPC (with RF-kicker), experiments (with RF-kicker and zero angle spectrometer) will be aimed on ^{26}S observation in (*p*,*t*) reaction with ^{28}S.
- We are open for collaboration

Thank you for attention