ANPC
African Nuclear Physics Conference

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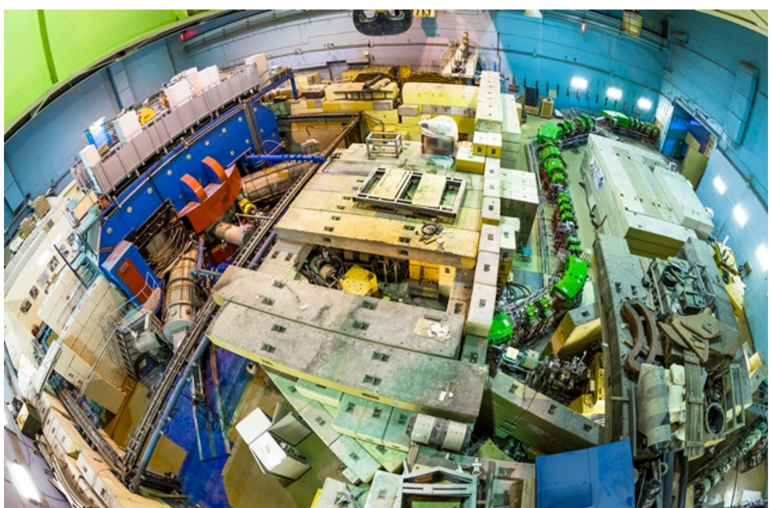
On behalf of the ACCULINNA-2 collaboration

Experimental study with light RIB at ACCULINNA-2 @ FLNR, JINR

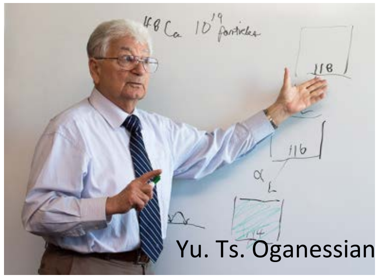


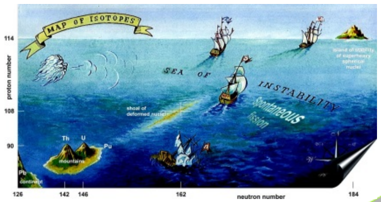
Main areas of interest at FLNR, JINR

Elements 102 - 108 synthesized at FLNR

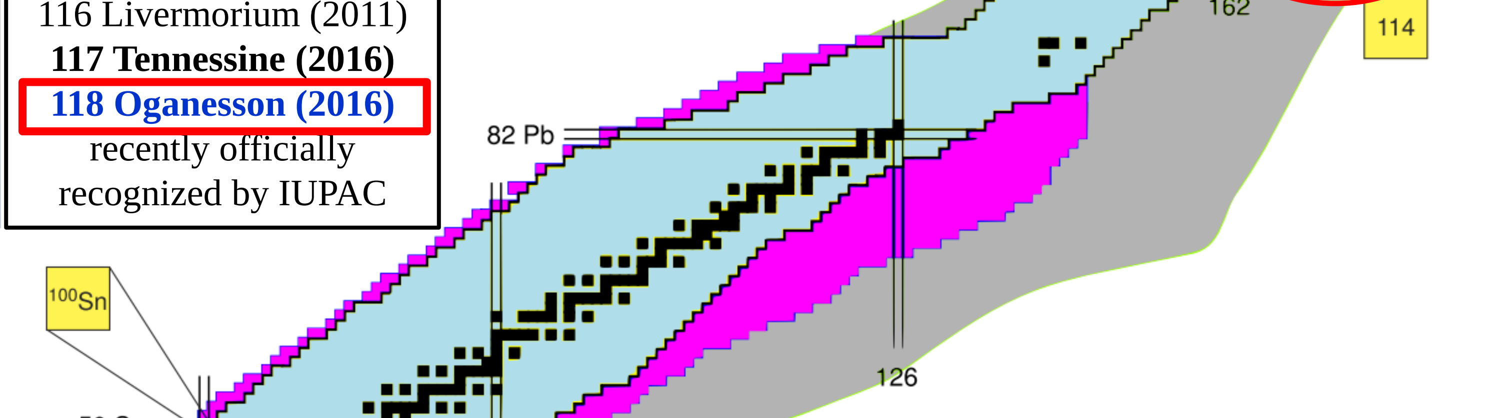
Last two decades:
Elements 113 - 118 synthesized at FLNR

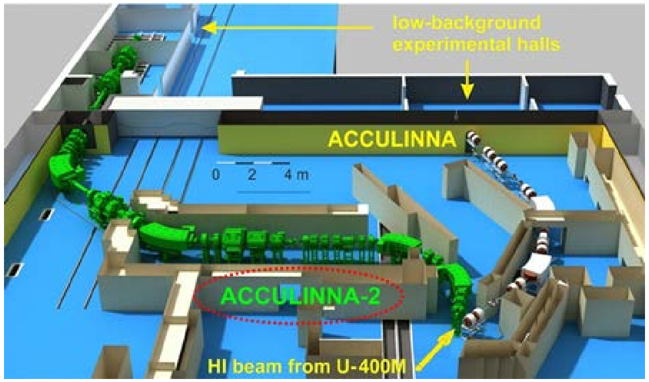
Elements:
113 Nihonium (2016)
114 Flerovium (2011)
115 Moscovium (2016)
116 Livermorium (2011)
117 Tennessine (2016)
118 Oganesson (2016)
recently officially recognized by IUPAC





'Superheavy'

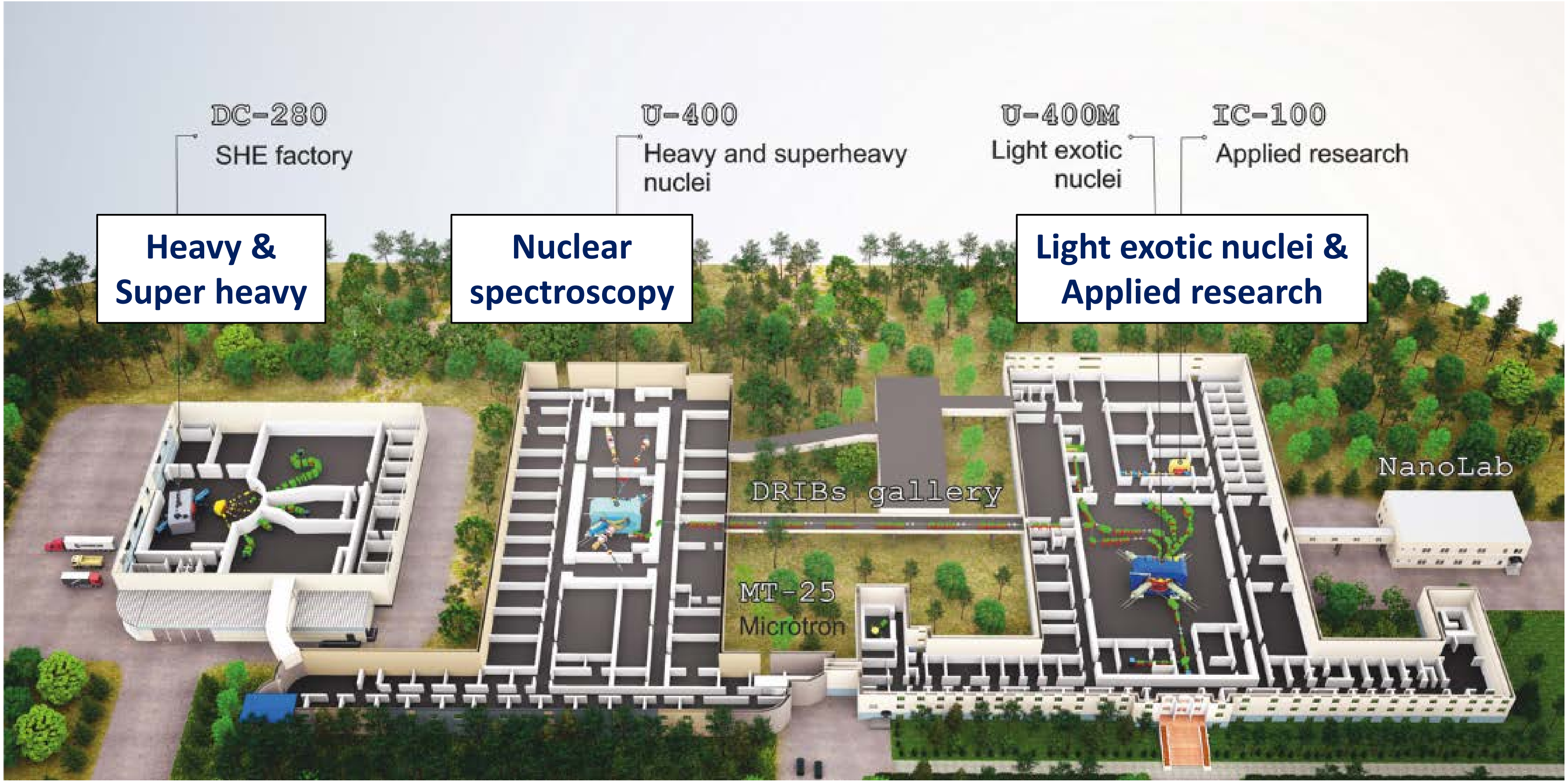




ACCULINNA&ACCULINNA-2

Light & 'Superlihght'

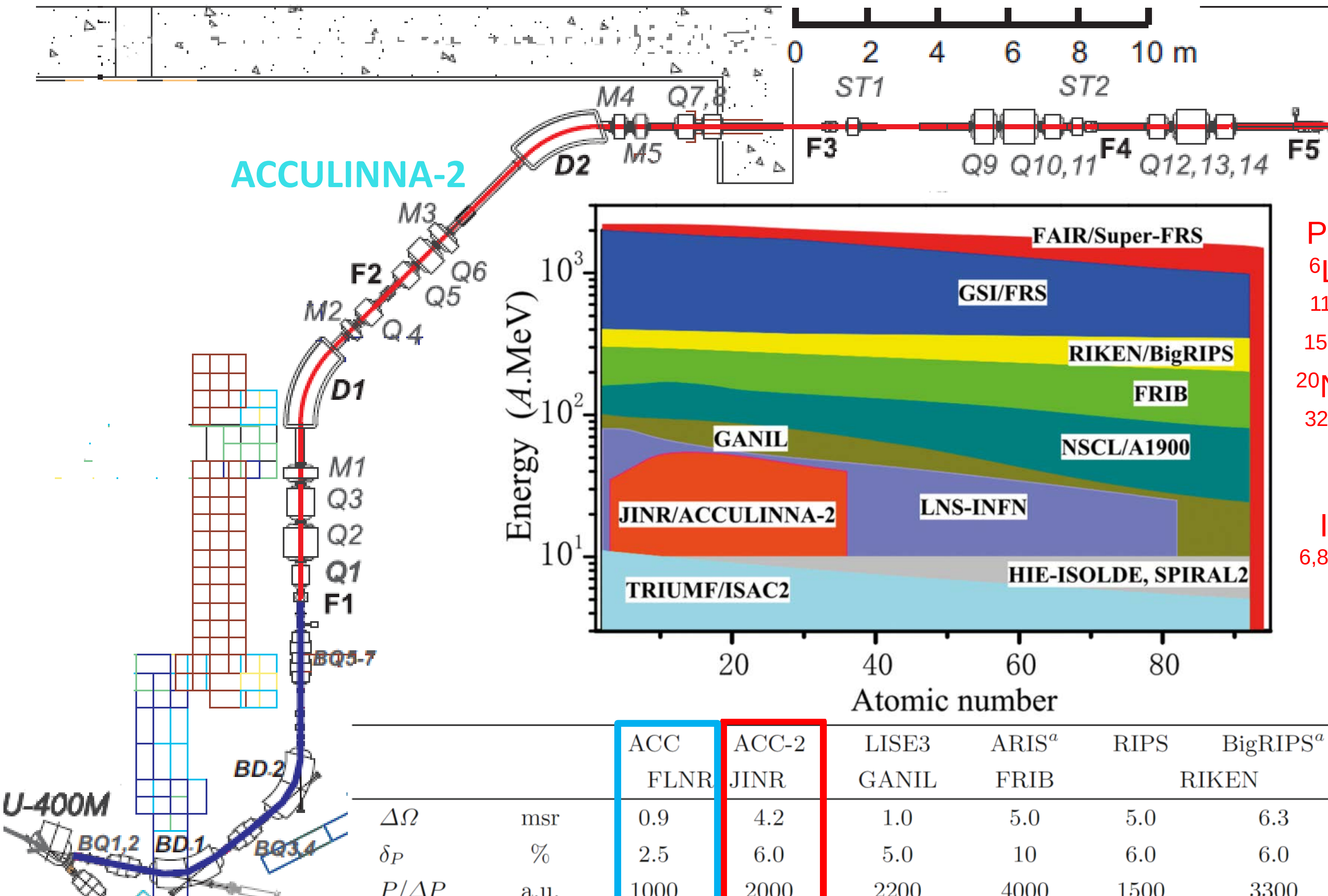
DRIBs-III (Dubna Radioactive Ion Beams) – project & Accelerators @ FLNR



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

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

ACCULINNA-2



Primary beams: I, pμA

^{6}Li @ 46 AMeV 8

^{11}B@ 33 AMeV 5

^{15}N @ 50 AMeV 2

^{20}Ne @ 53 AMeV 1

^{32}S @ 52 AMeV 0.2

$Z_{RIB} \sim 1 - 36$

In-flight separation

^{6,8}He @ 25÷35 AMeV

^{9,11}Li @ 30 AMeV

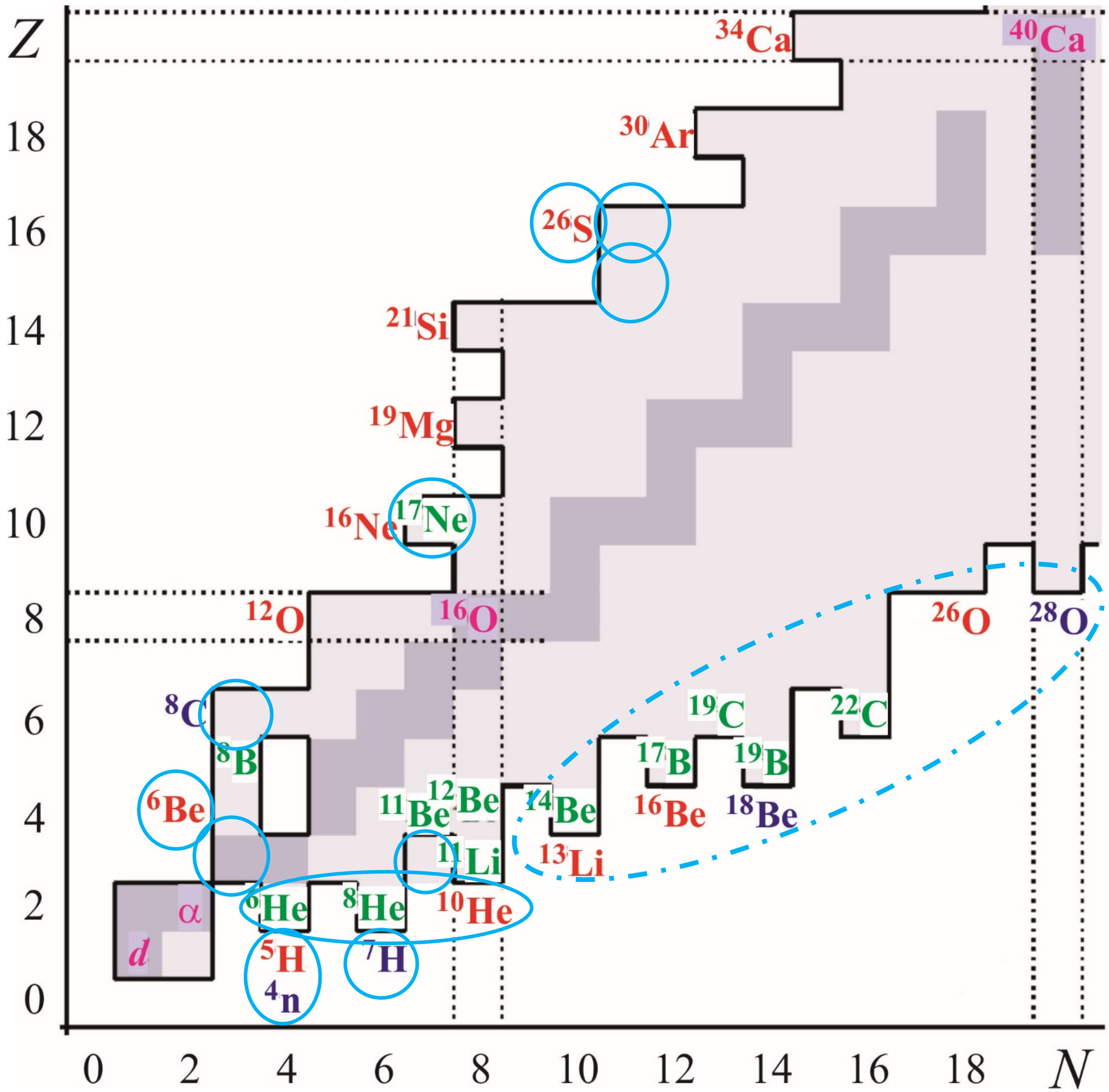
^{18}Ne @ 35 AMeV

^{27}S @ 38 AMeV

		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

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

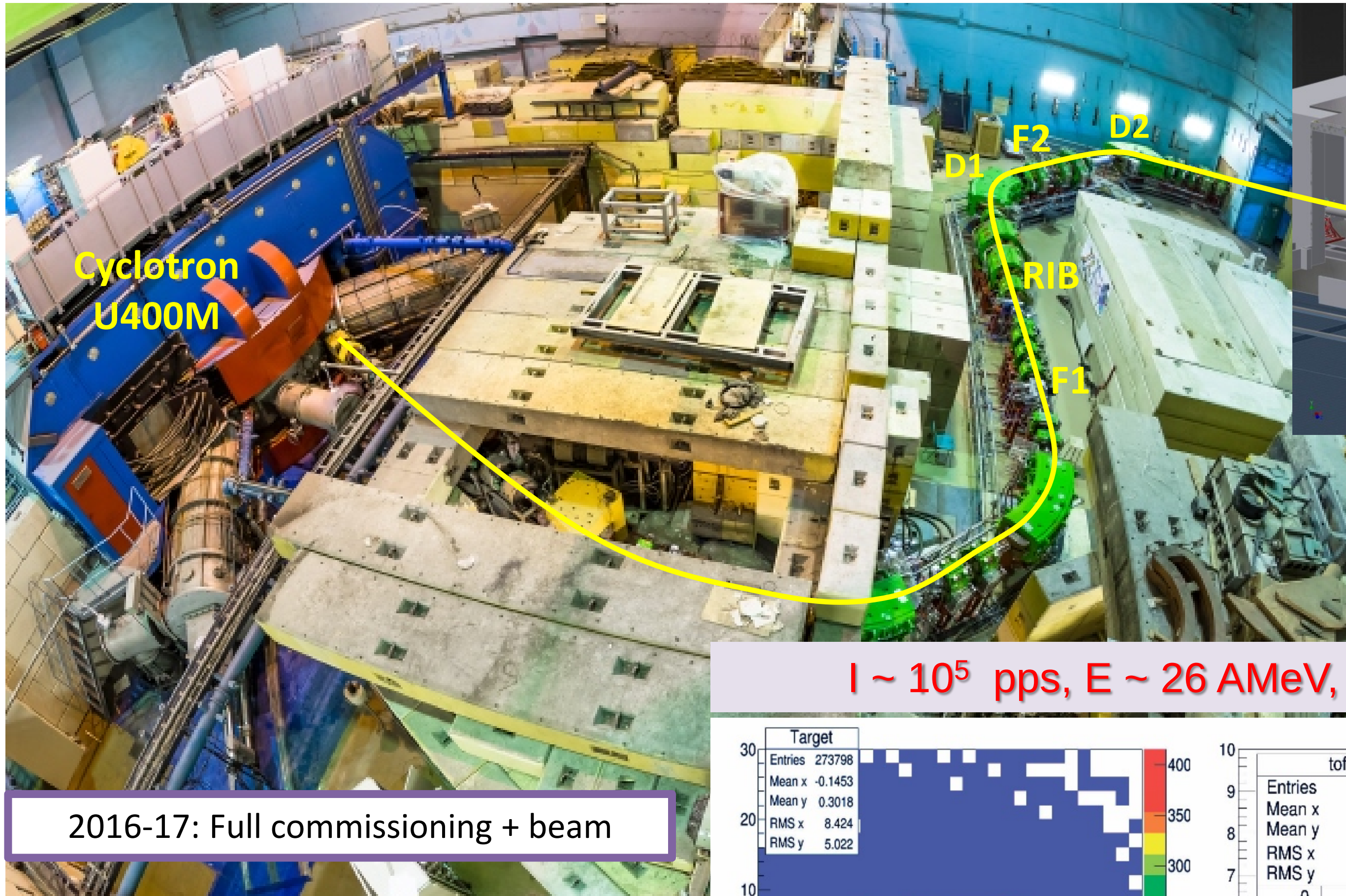
Area of interests for ACCULINNA-2 near drip-lines

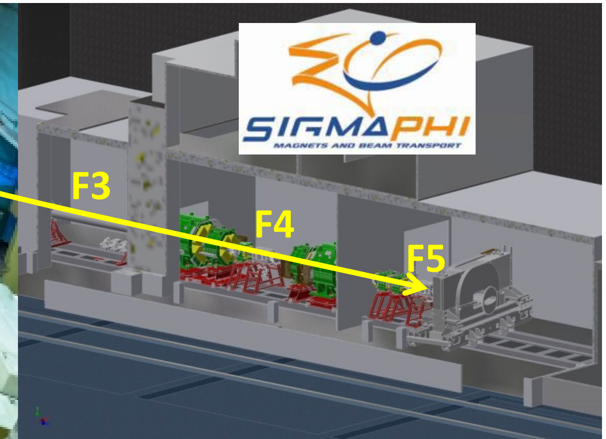


Key instruments and methods:
Exotic and intensive primary beams
(^{11}B, ^{15}N, ^{18}O, ^{32}S, ^{36}S, ^{36}Ar, ^{48}Ca)
Exotic targets with a thickness 0.3÷15.0 mg/cm^2
(^{3}H, ^{10}Be, ^{14}C)
Exotic detectors for charged and neutral particles (optical TPC, neutron wall, scintillator arrays based on CsI, LaBr$_3$, etc., Si-telescopes, active target, HPGe array)

Exotic addition stage for beam purification
(RF-kicker, Zero degree spectrometer)

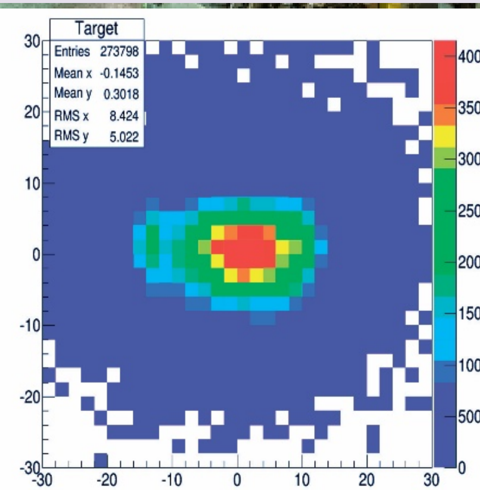
The new in flight facility - ACCULINNA-2

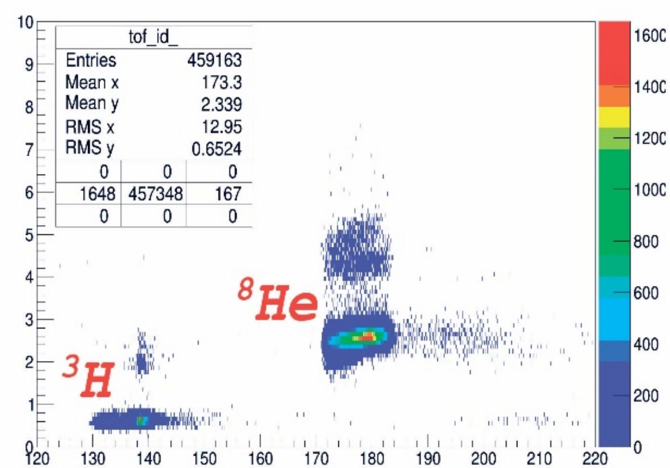




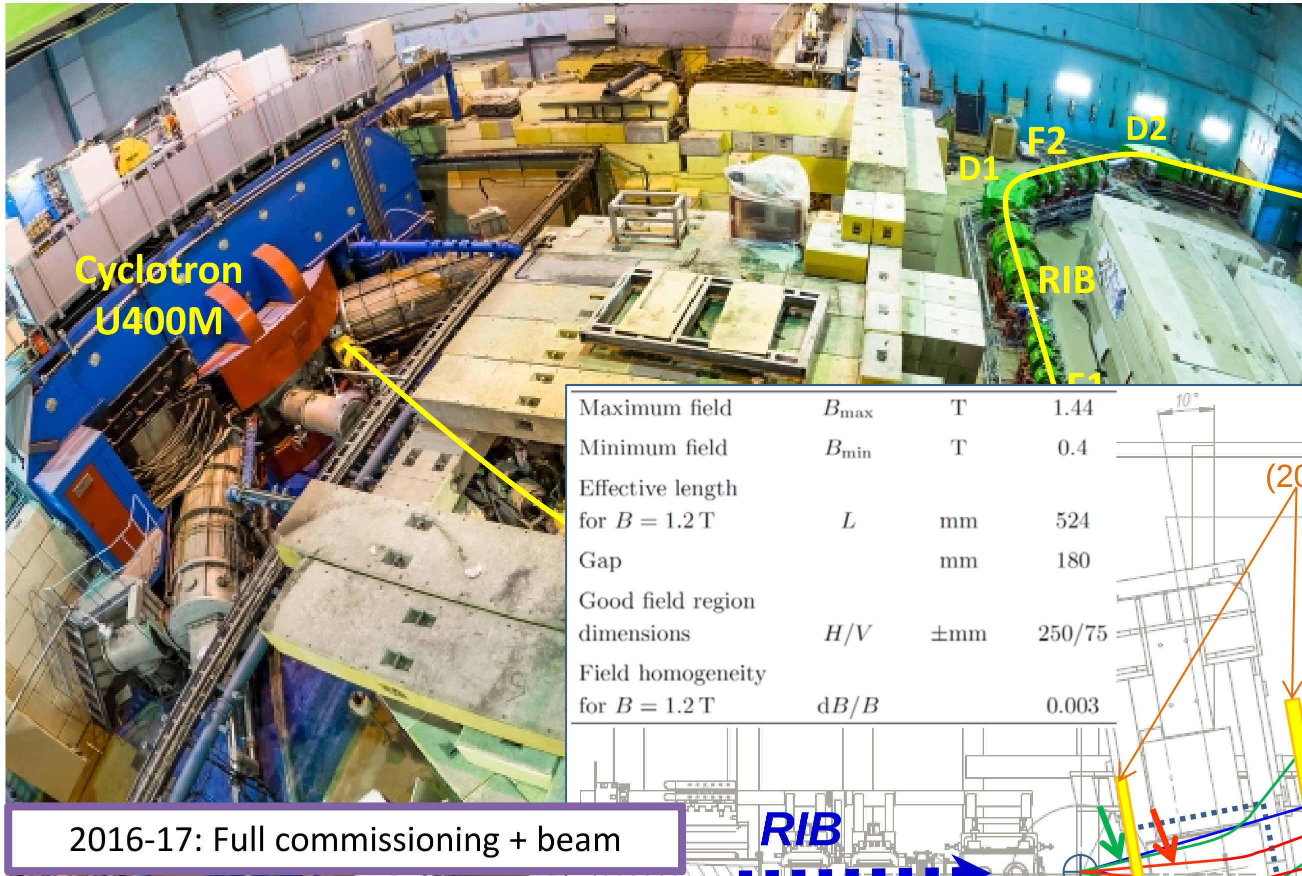
2016-17: Full commissioning + beam

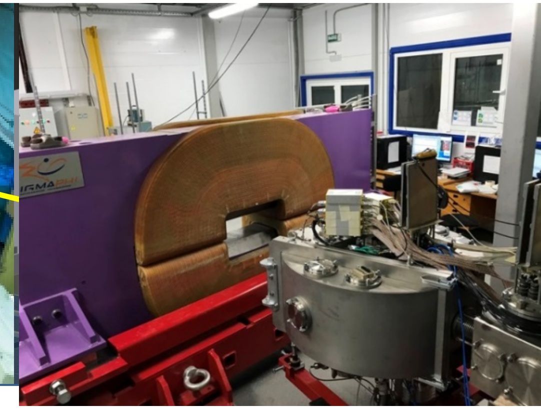
I ~ 10^5 pps, E ~ 26 AMeV, P > 90%, Ø ~17 mm



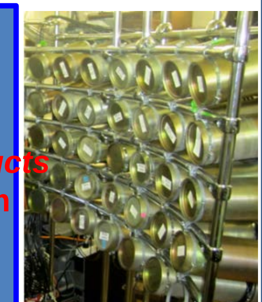


ACCULINNA-2: Zero degree spectrometer





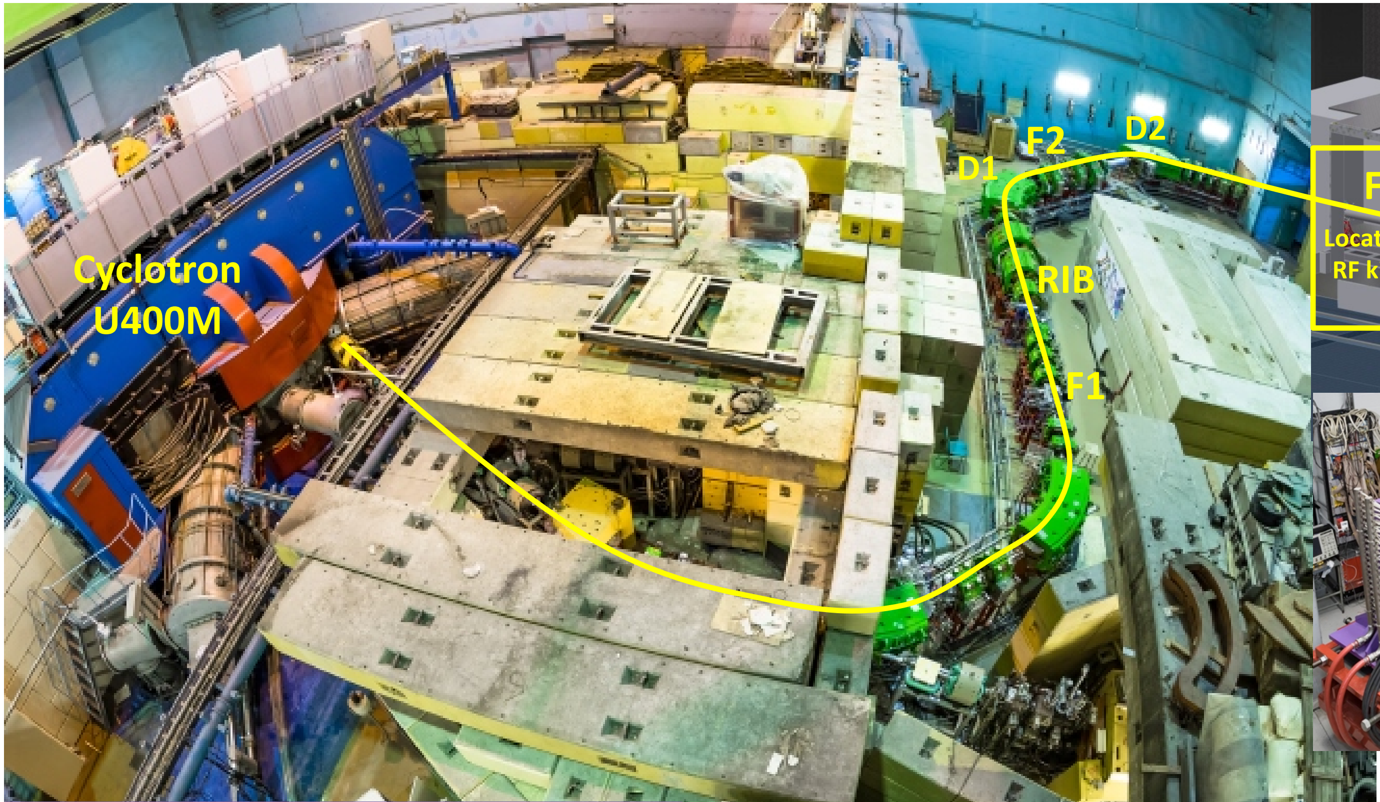
Maximum field	$B_{\max}$	T	1.44
Minimum field	$B_{\min}$	T	0.4
Effective length for $B = 1.2\,\mathrm{T}$	L	mm	524
Gap		mm	180
Good field region dimensions	H/V	±mm	250/75
Field homogeneity for $B = 1.2\,\mathrm{T}$	$\mathrm{d}B/B$		0.003

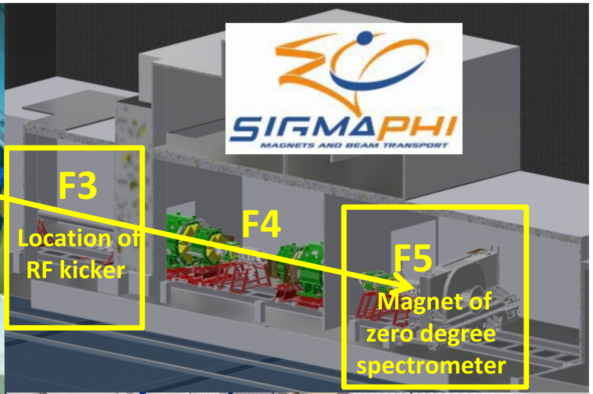


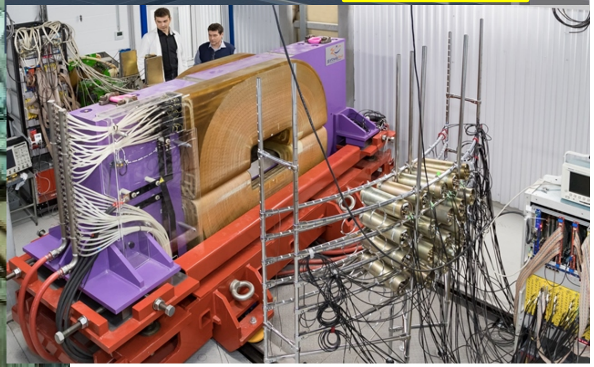
2016-17: Full commissioning + beam

2016-2018: Zero-angle spectrometer

ACCULINNA-2: RF kicker





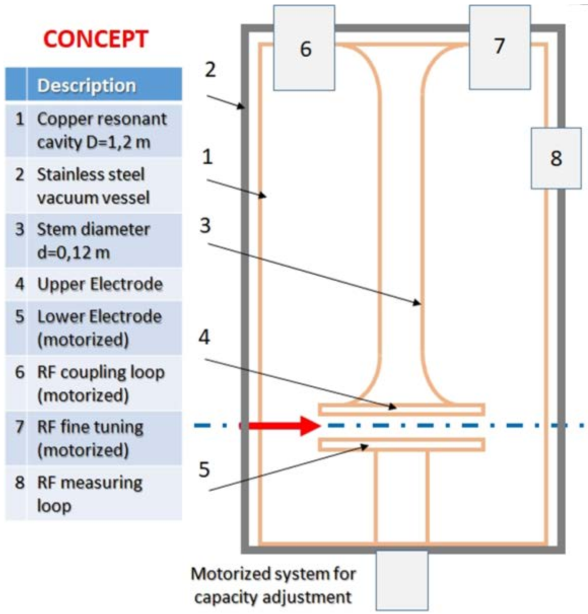


2016-17: Full commissioning + beam

2016-2018: Zero-angle spectrometer

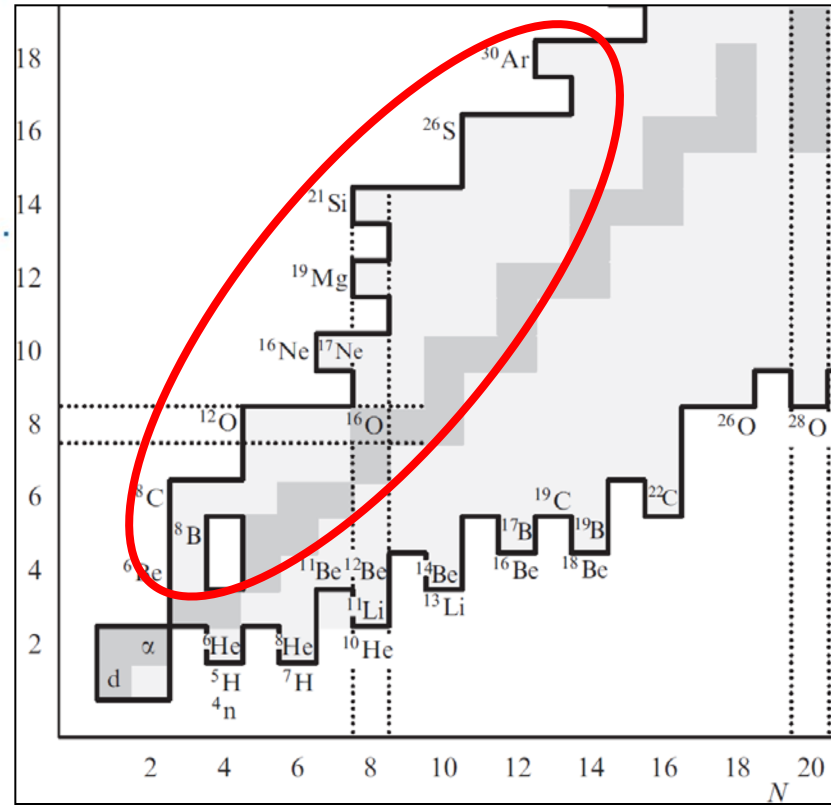
2017-2019: RF kicker at F3

RF kicker installed



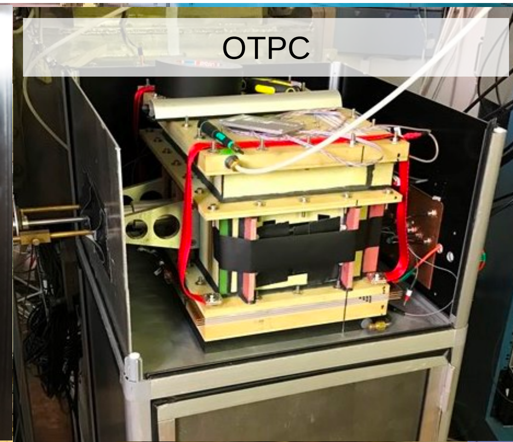
Frequency range (MHz)	15 – 22
Peak voltage (KV)	120
Gap (mm)	70
Width of electrode (mm)	120 min
Length of electrodes (mm)	700
Cylinder diameter (mm)	1200 max
Stem diameter (mm)	120 max
Length of coaxial line (mm)	1830
Distance from A-2 primary target (m)	25

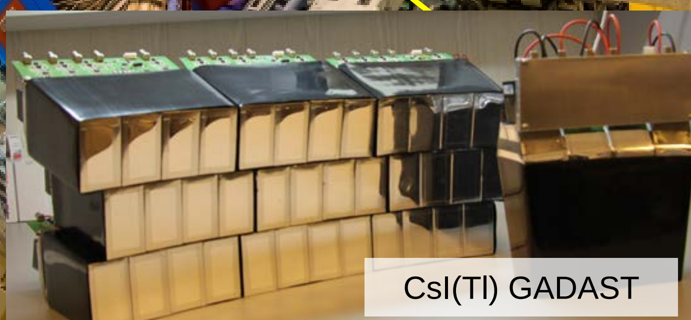
Main application of RF kicker: improvement of neutron-deficient RIB purity

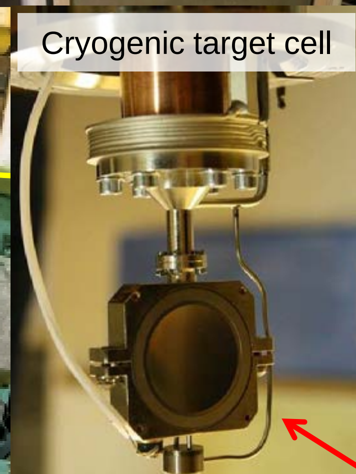


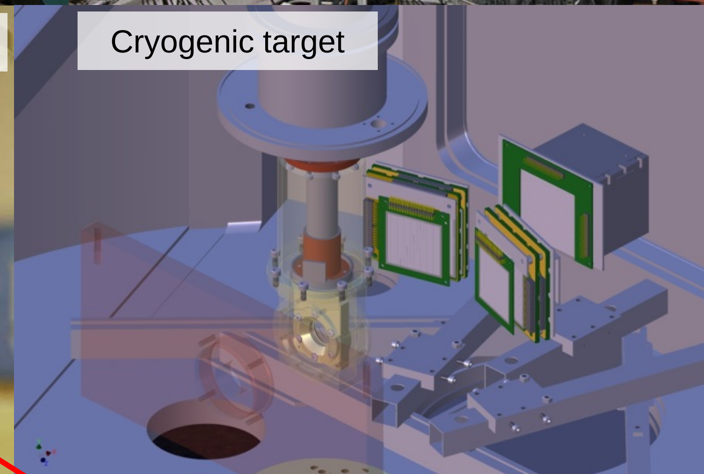
ACCULINNA-2: New detectors & cryogenic target system

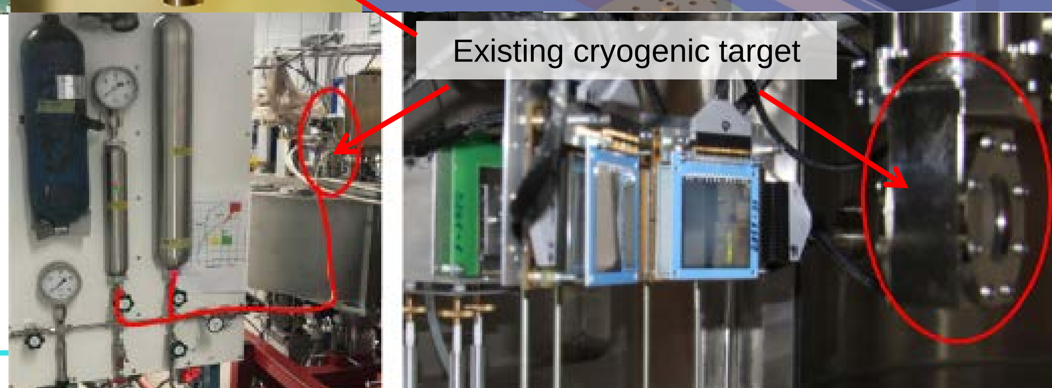
A.A. Bezbakh et al, *Instrum. and Exp. Tech.,* 61(2018) 631











2016-17: Full commissioning + beam

2016-2018: Zero-angle spectrometer

2017-2019: RF kicker at F3

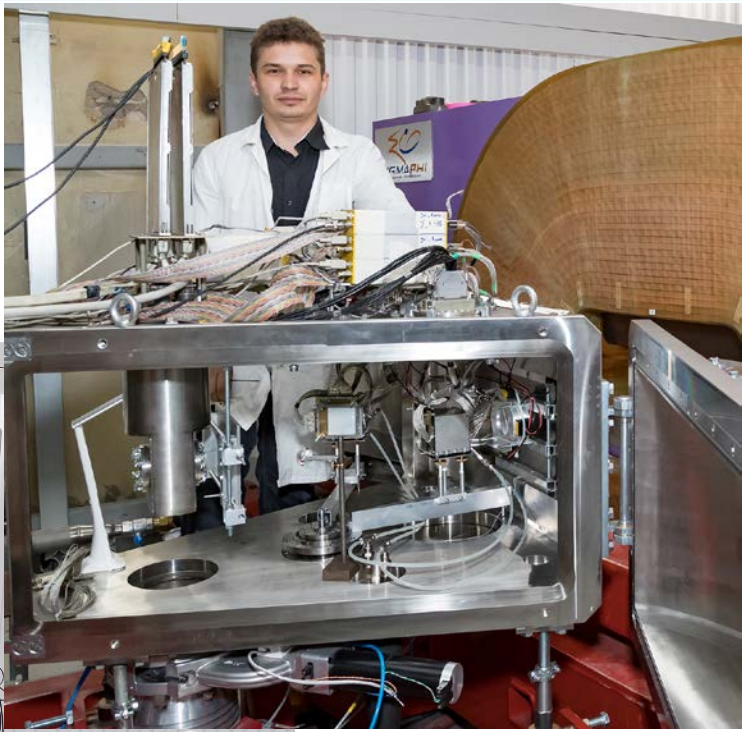
2017-2019: New detectors
2018-2020 : Cryogenic target system & tritium target at F5

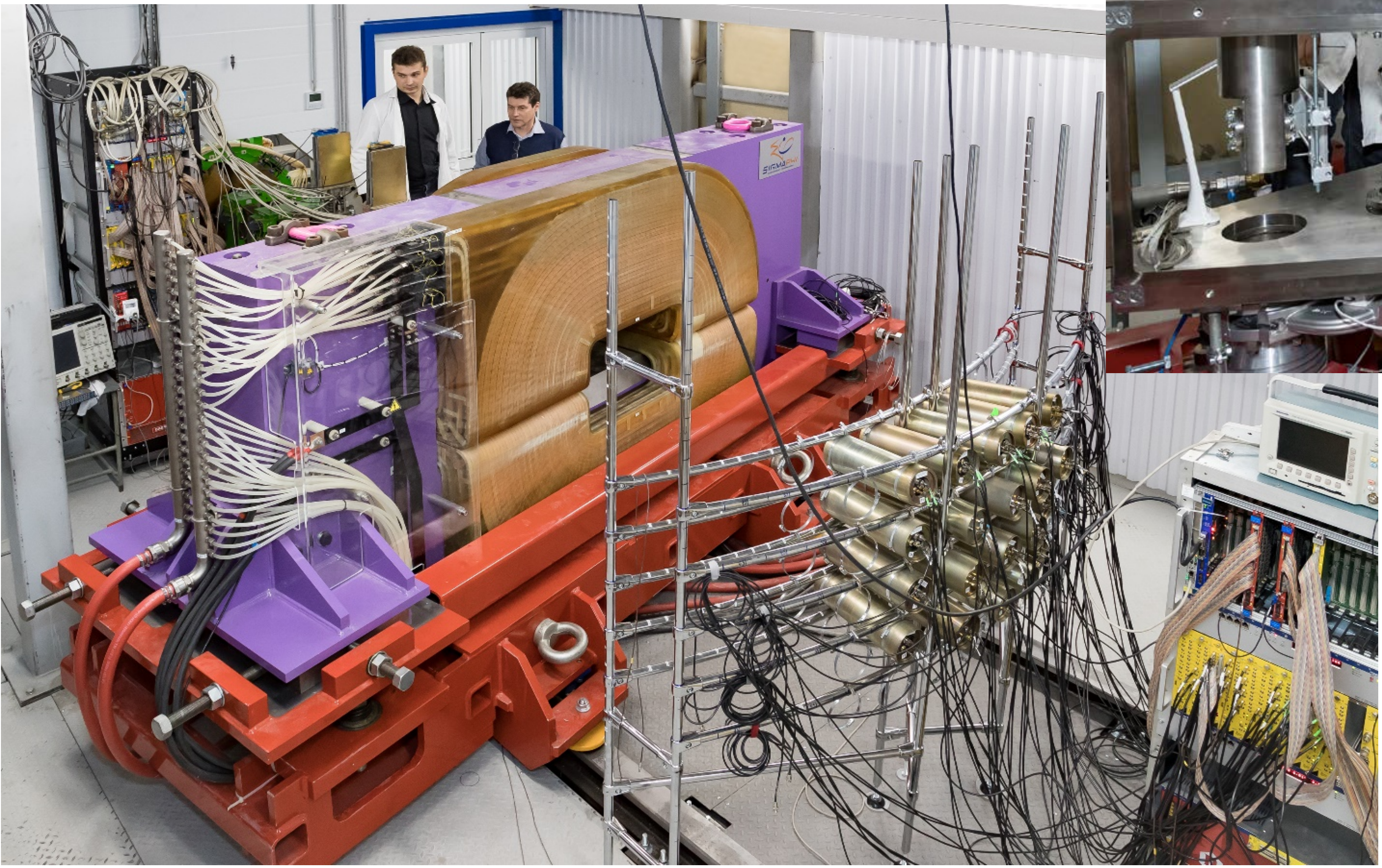
2020-21: Cyclotron upgrade

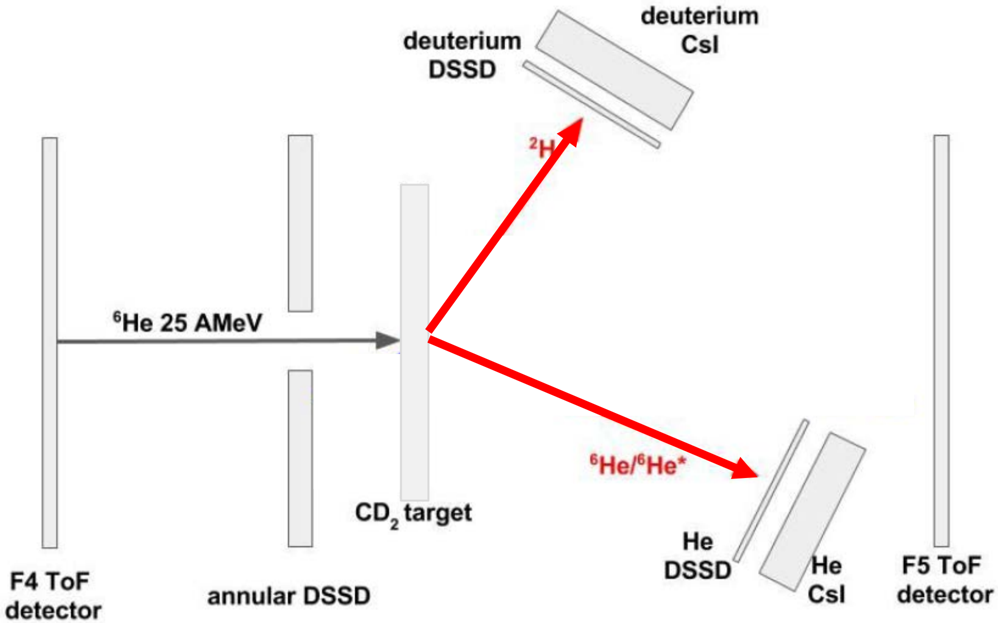
First experiments @ ACCULINNA-2

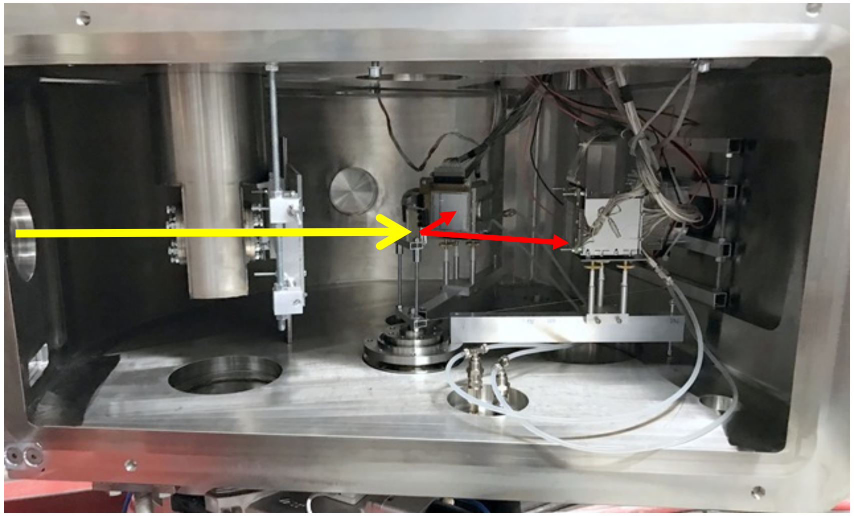
First experiments with ^{6}He and ^{9}Li on CD_2 target were carried out at ACC-2 in spring 2018:

- 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.



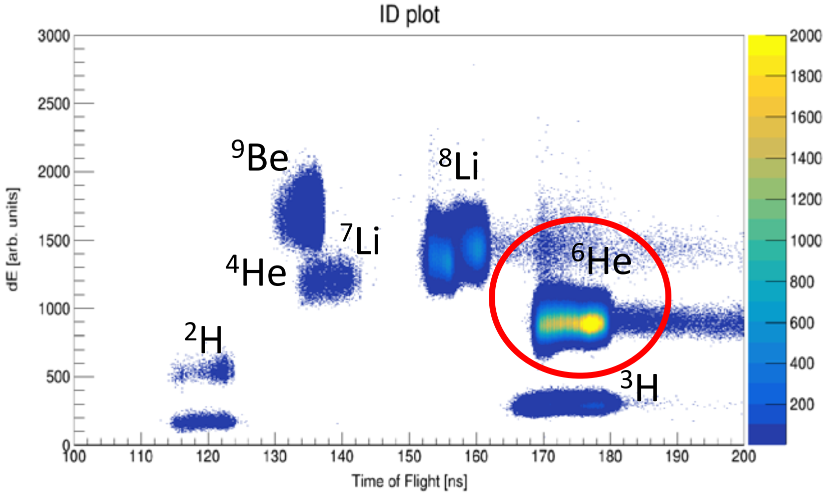






Beam parameters:

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

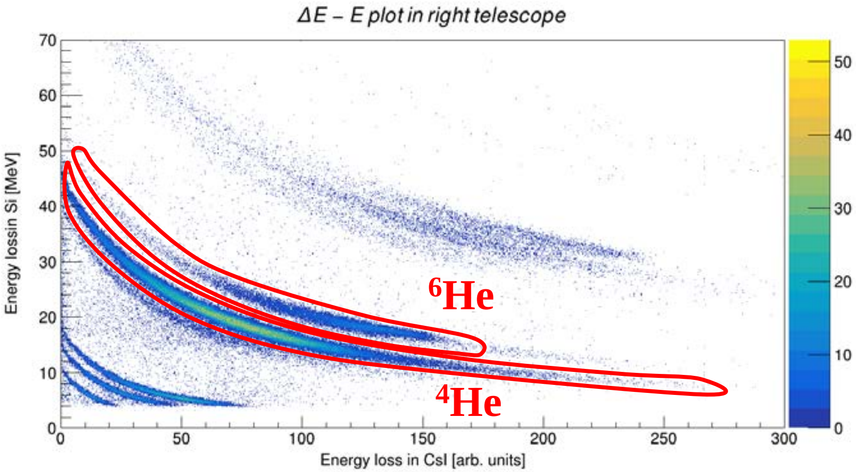


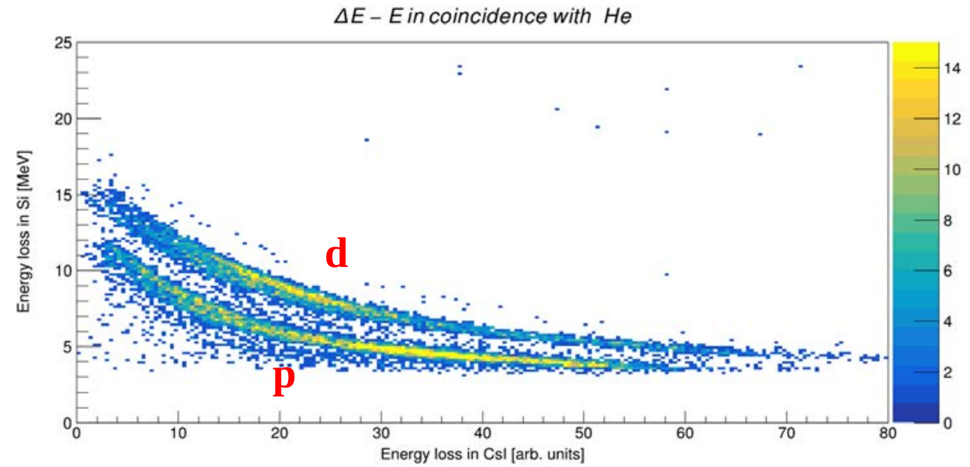
Experimental data for B. Zalewski Ph.D Thesis (HIL, UW, Warsaw)

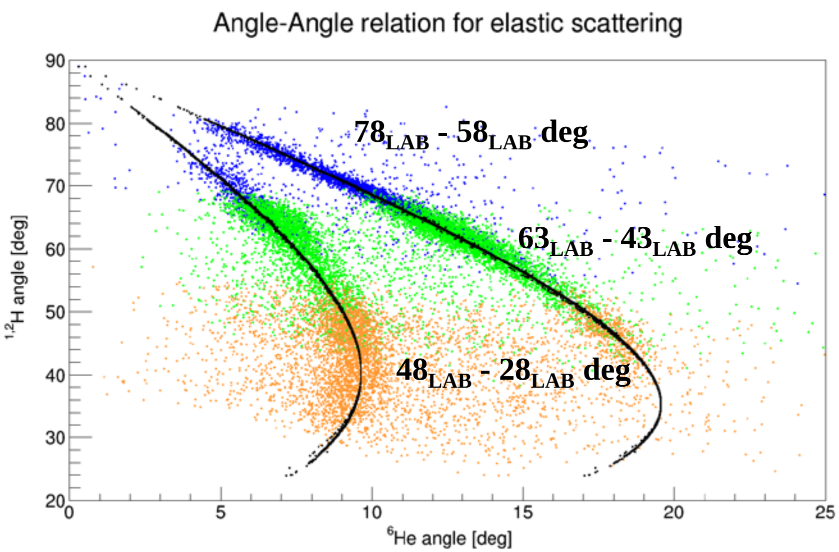
Elastic and inelastic scattering of ^{6}He (25 AMeV) on ^{2}H:

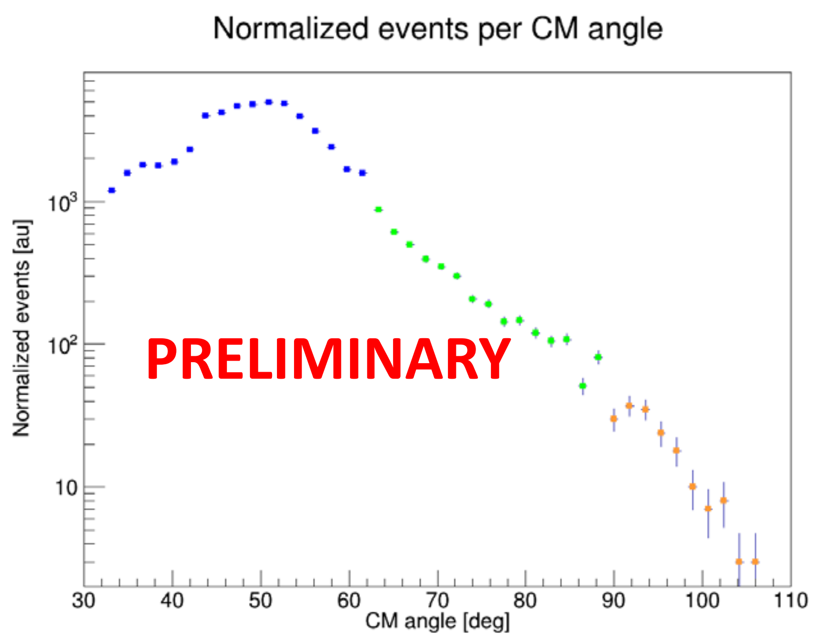
Preliminary results of elastic and inelastic scattering of ^{6}He (25 AMeV) on ^{2}H:

$d\sigma/d\Omega$ in a wide angular range (4 runs, $\theta_{CM} \sim 30 \div 140^o$) with a good statistics



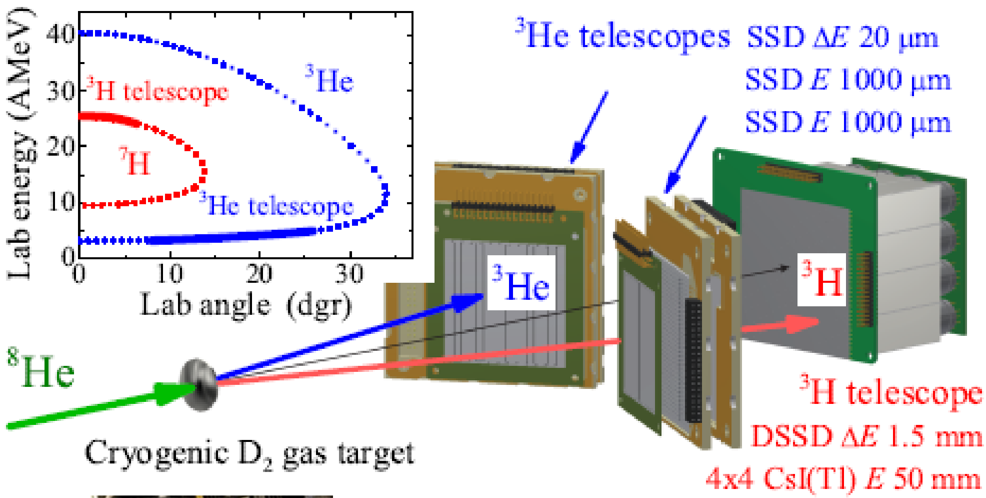




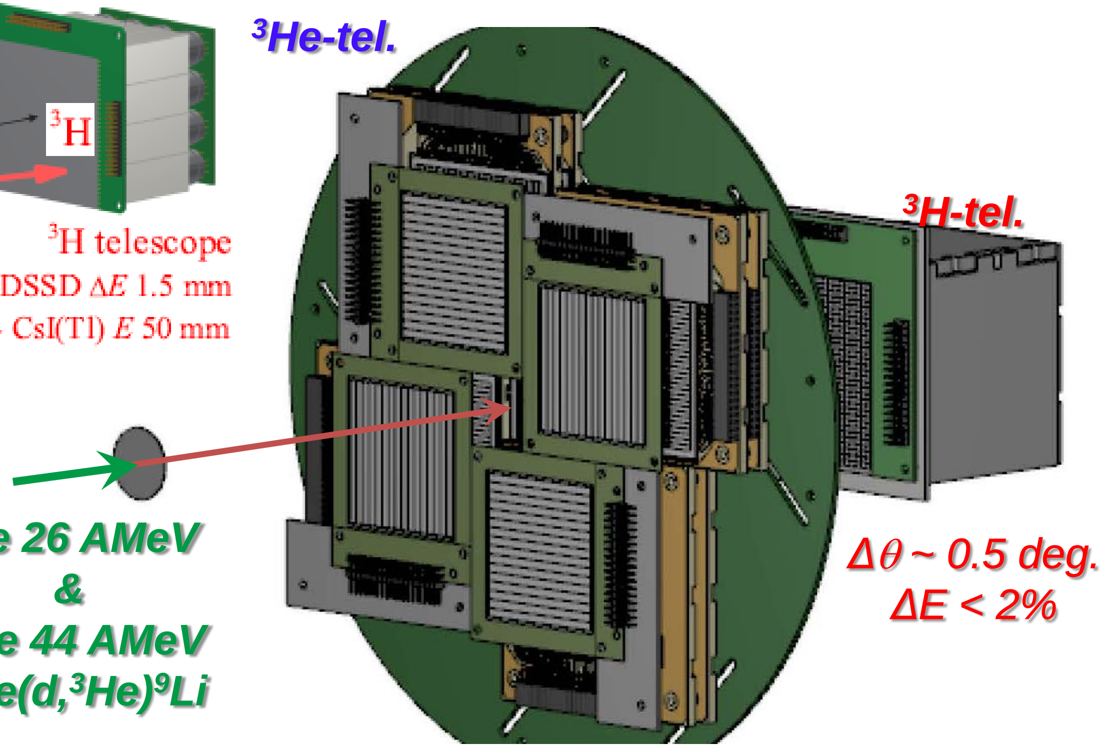


“Hunt for ^{7}H”

^{8}He(d,^{3}He)^{7}H - scheme of the 1-st flagship experiments
November 2018: 10 days, two ^{3}He-telescopes installed at 17 deg.
April 2019: 12 days, four ^{3}He-telescopes installed at 15 deg.

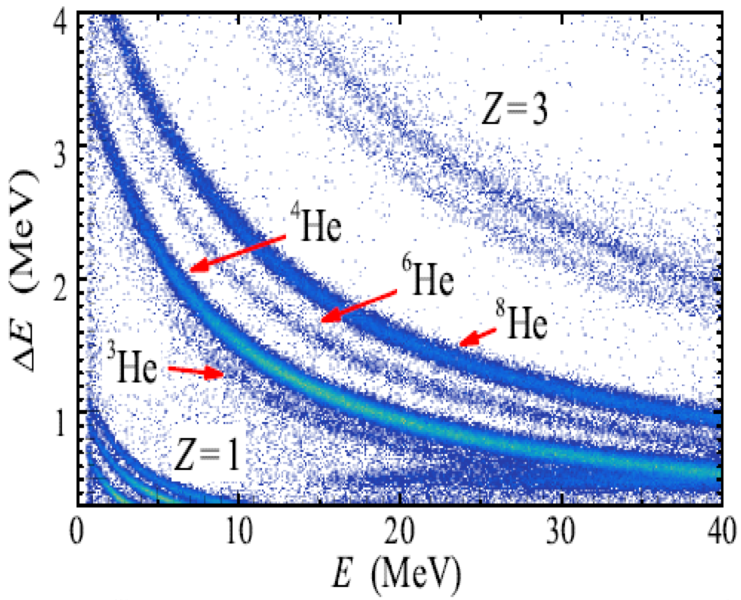


A.A. Bezbakh

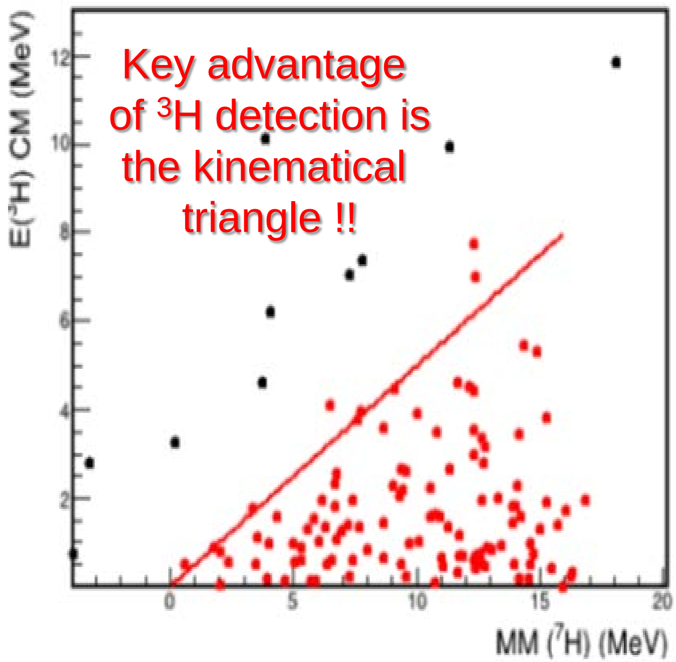


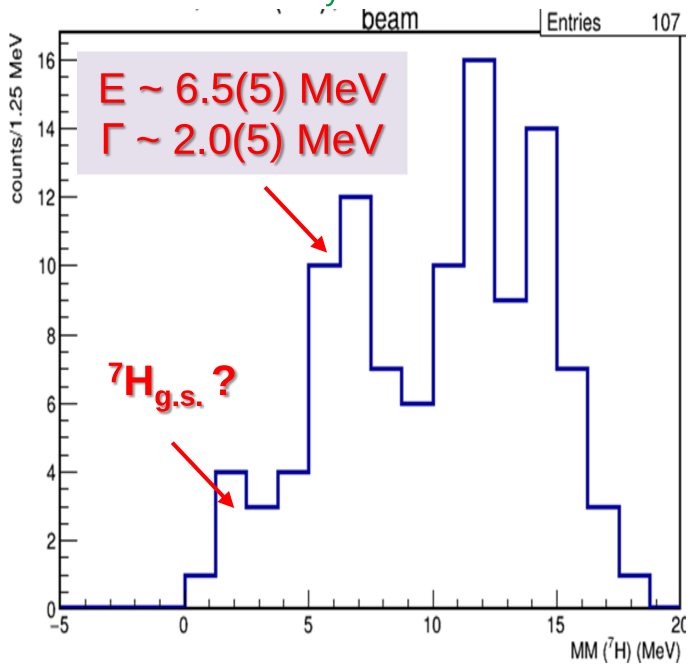
* Expected energy resolution for the ^{7}H missing mass spectra was about 1.1 MeV
** Efficiency of ^{3}He-^{3}H coincidence was about 65% (Nov.2018) and 75% (Apr.2019)

^{8}He(d,^{3}He)^{7}H – preliminary results, energy distributions (Nov. 2018)



1. The indications for the ^{7}H g.s. at 2.0(5) MeV are found in the measured energy and angular distributions.
2. Quite a low population cross section of ~10 μb/sr was obtained for ^{7}H g.s. Attempts to observe ^{7}H g.s. in the same reaction at E < 3 MeV were reported early [M.S. Golovkov et al., AIP Conf. Proc. **912**, 32 (2007); E.Yu. Nikolskii et al., Phys. Rev. C **81**, 064606 (2010)] and the cross-section values dσ/dΩ < 20 μb/sr and ~ 30 μb/sr were obtained respectively.
3. For the first time, the ^{7}H excited state is observed at E_T ~ 6.5(5) MeV with Γ ~ 2.0(5) MeV. It's probably a mix of 3/2+ and 5/2 states, built upon the 2+ excitation of valence neutron, or one of the doublet states.
4. The data with more statistics (April 2019, under analysis now) will clarify the mentioned above statements.





Bezbakh A.A., Chudoba V., Krupko S.A., et al. arXiv: 1906.07818v1 [nucl-ex] 18Jun2019

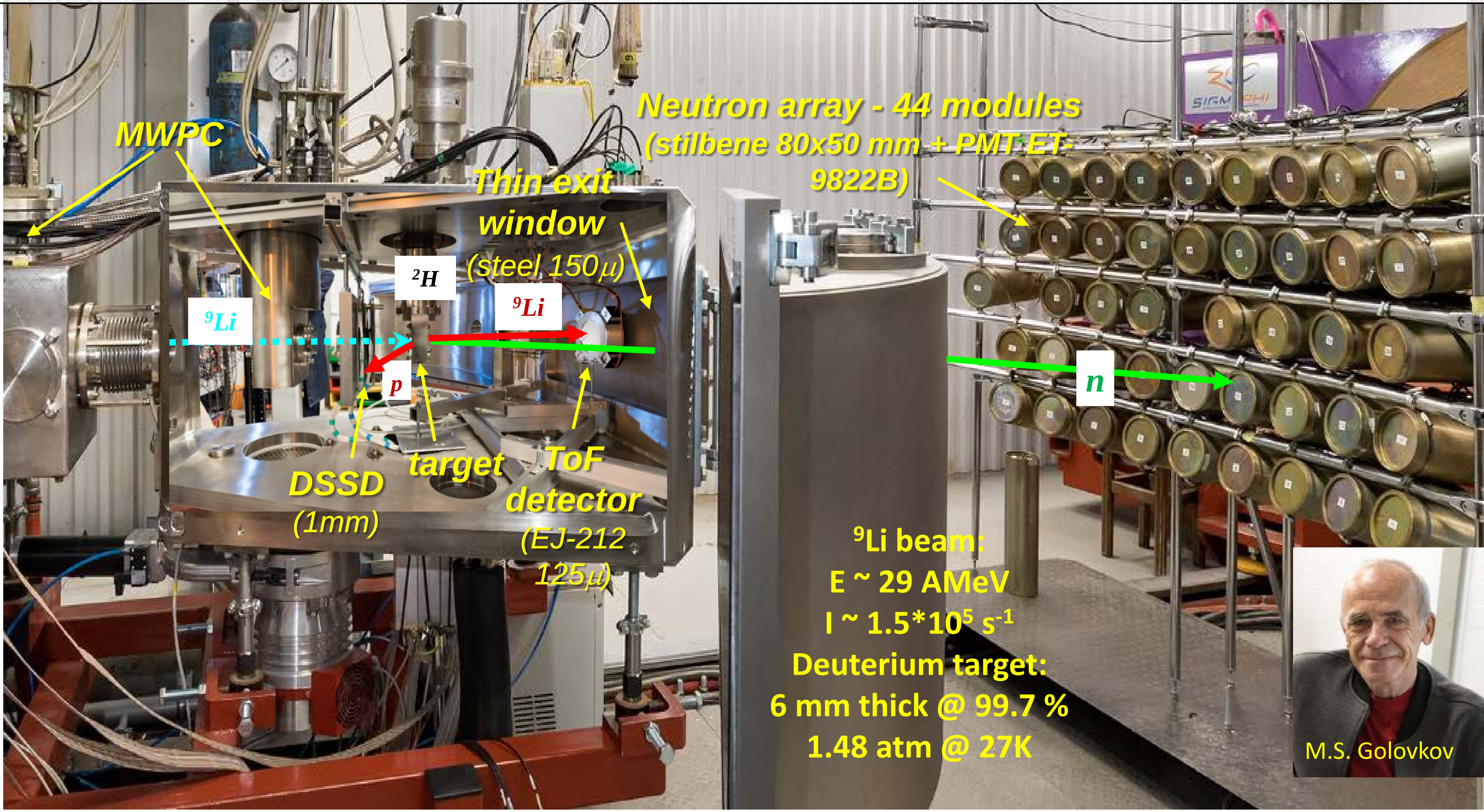
Study of ^{10}Li low energy spectrum in the ^{2}H(^{9}Li,p) reaction

^{10}Li was studied many times using:

a) reactions with pions [Amelin et al., Yad. Fiz. (1990) 52; Chernyshev et al., EPJA (2013) 49]

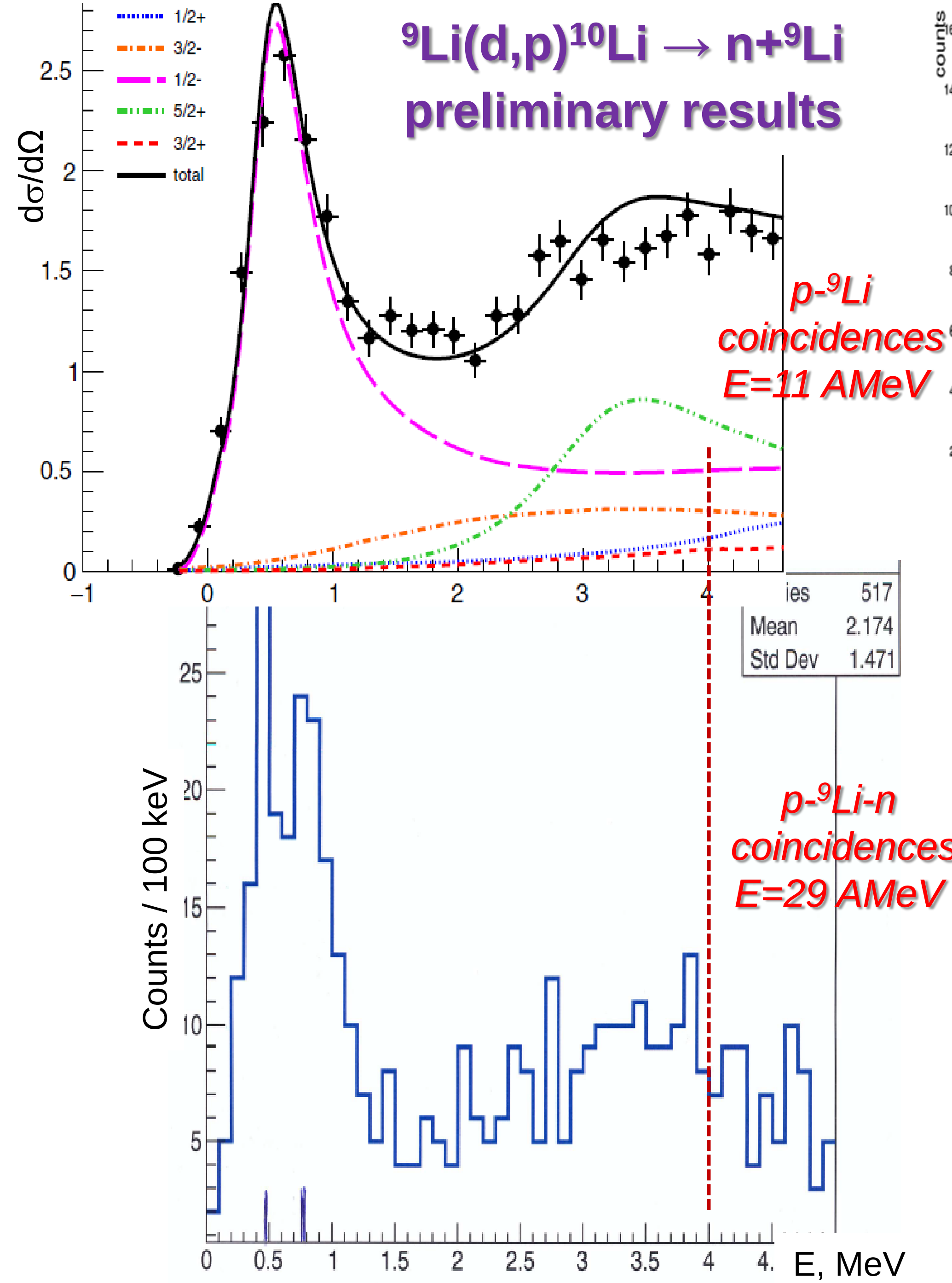
b) knock-out reactions [Thoennessen et. al., PRC 59 (1999); Simon et. al., NPA 791 (2007); Aksyutina et. al., PLB 666 (2008); Smith et.al., NPA 940 (2015) 235]

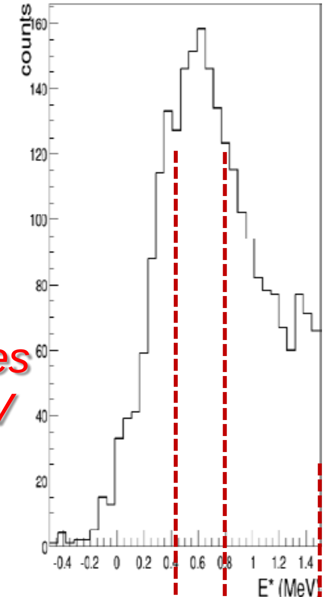
c) transfer reactions [Jeppesen et. al., Physics Letters B 642 (2006); Cavallaro et. al., J. Phys.: Conf. 590 (2015); PRL 118 (2017) 012701]

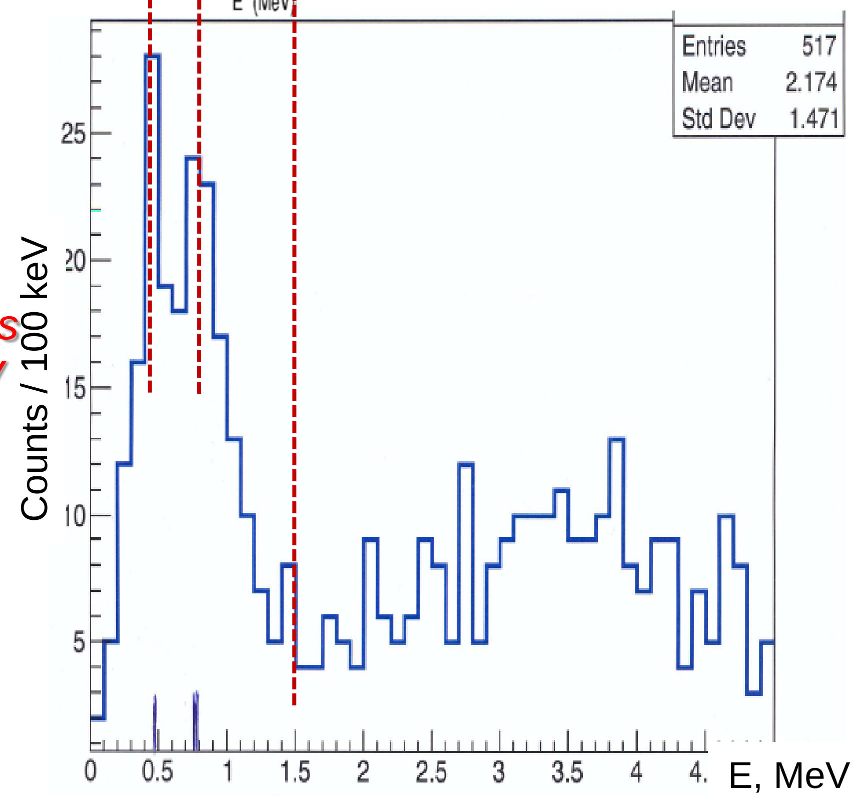


^{9}Li(d,p)^{10}Li → n+^{9}Li /March2019/

$^9Li(d,p)^{10}Li \rightarrow n+^9Li$ preliminary results





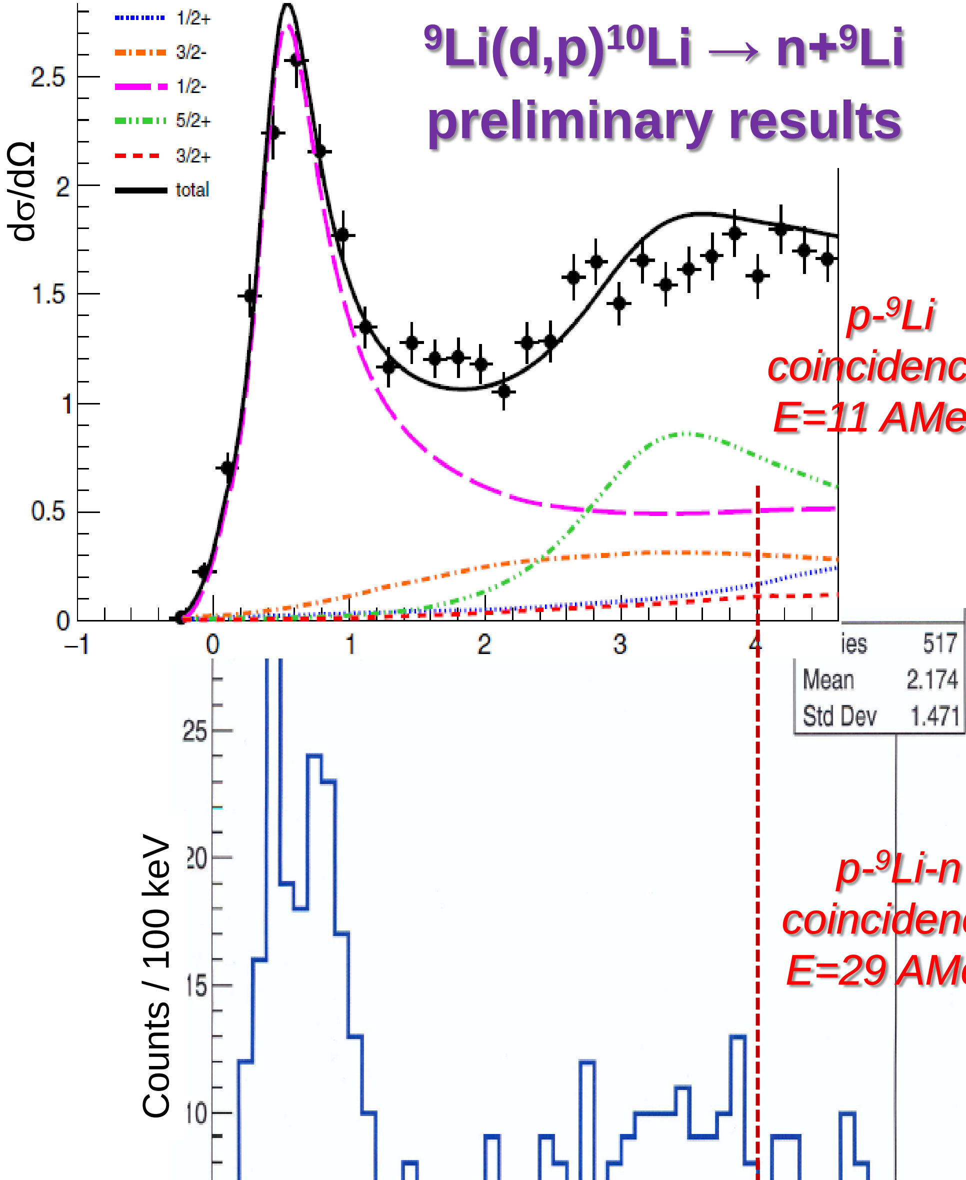


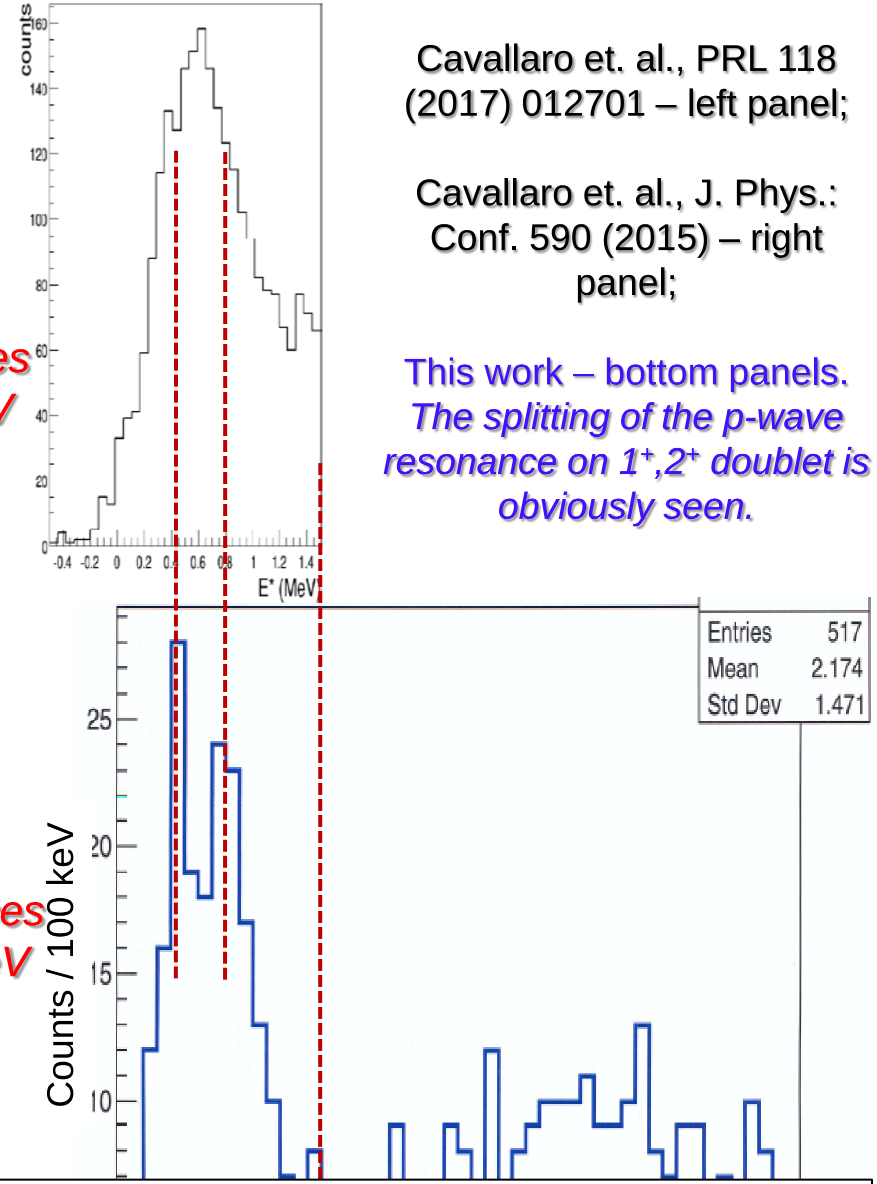
Cavallaro et. al., PRL 118 (2017) 012701 – left panel;

Cavallaro et. al., J. Phys.: Conf. 590 (2015) – right panel;

This work – bottom panels. *The splitting of the p-wave resonance on $1^+,2^+$ doublet is obviously seen.*

$^{9}Li(d,p)^{10}Li \rightarrow n+^{9}Li$ preliminary results





Cavallaro et. al., PRL 118 (2017) 012701 – left panel;

Cavallaro et. al., J. Phys.: Conf. 590 (2015) – right panel;

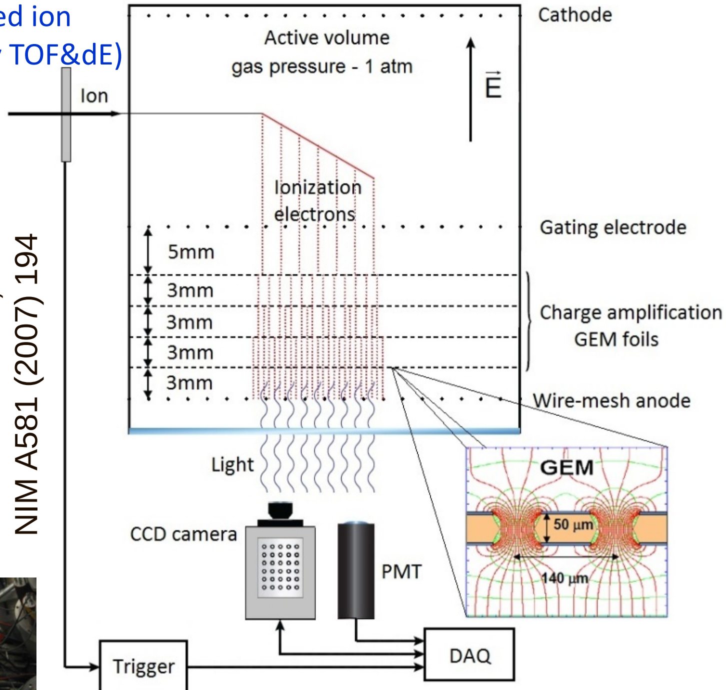
This work – bottom panels. *The splitting of the p-wave resonance on $1^{+},2^{+}$ doublet is obviously seen.*

The combine mass method (p-^{9}Li-n coincidences) is very promising for ^{10}Li study and could be applied for other isotopes (^{7,9}He, ^{10,11,12}Li etc.).
Higher statistics and better quality for neutron detection will help to clarify the ^{10}Li low energy spectrum in more detail. These measurements are scheduled on the fall 2020.

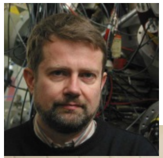
Collaborative experiments with Physics Faculty, UW, Warsaw

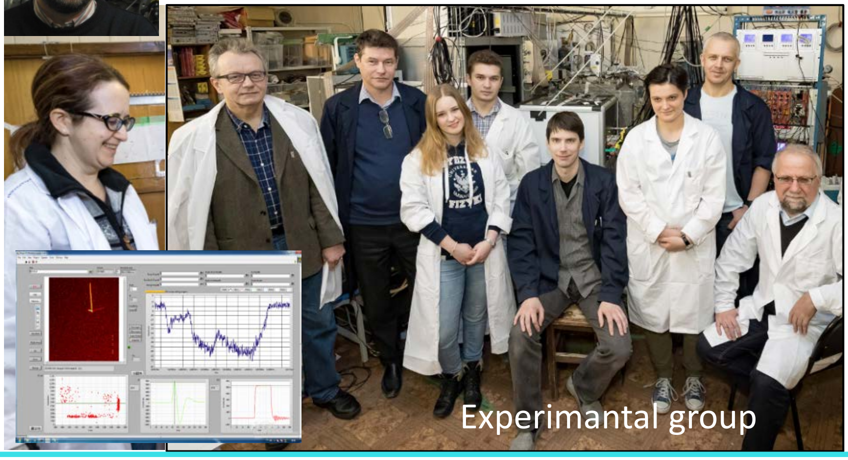
Optical **T**ime **P**rojection **C**hamber (OTPC) - A new type of modern ionization chamber with an optical readout. Invented at the University of Warsaw by W. Dominik

Identified ion
(typically by TOF&dE)

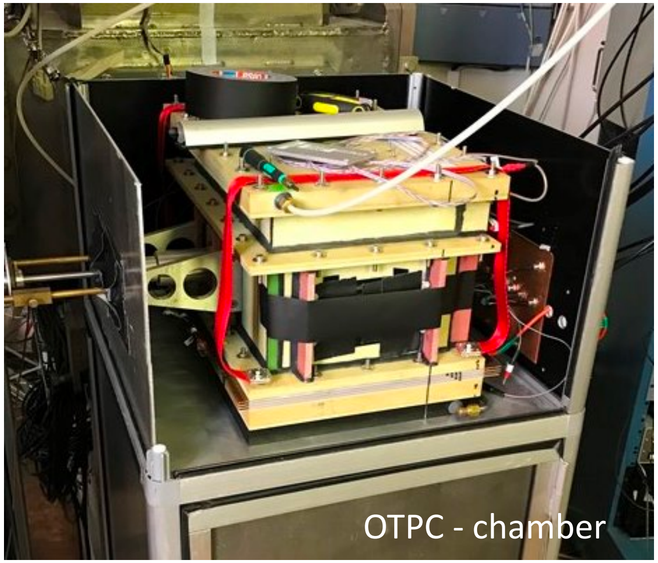


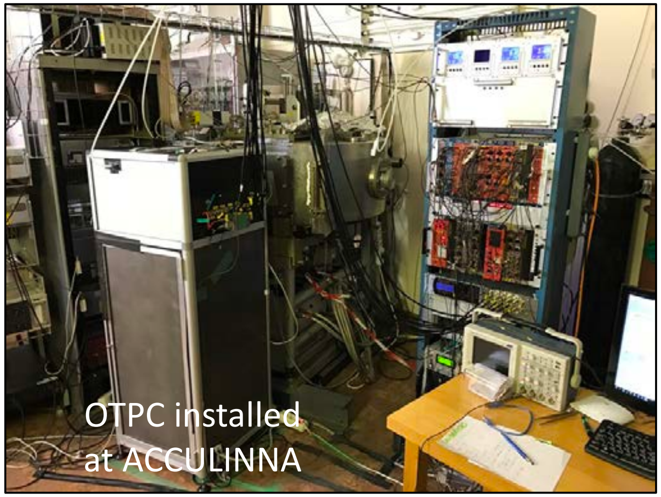
Miernik et al., NIM A581 (2007) 194



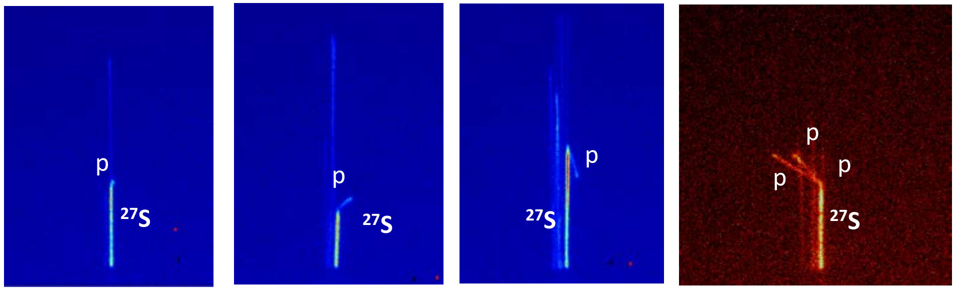


Spectroscopy of β-delayed charged particle emission





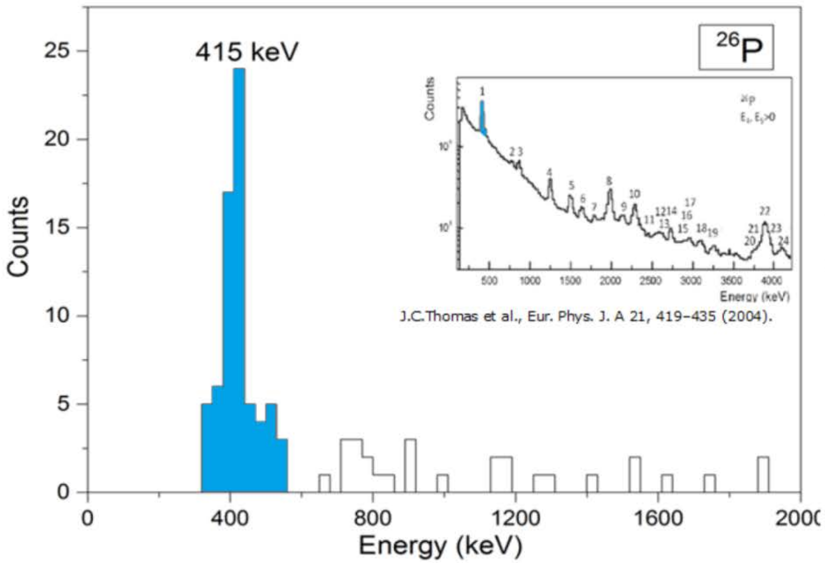
β-delayed charged particle emission from ^{27}S and ^{26}P

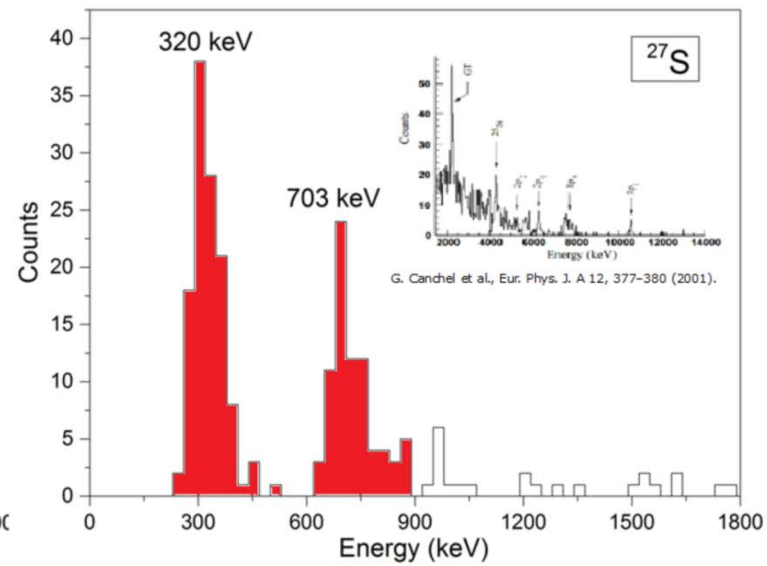


^{32}S @ 50 MeV/u + ^{9}Be $\rightarrow$ ACC $\rightarrow$ ^{27}S,^{26}P

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%

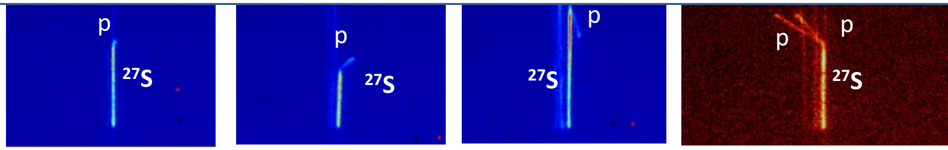
Thomas et al., EPJ A21 (2004) 419

Canchel et al., EPJ A12 (2001) 377

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

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

In 2020 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 $\beta3p$ channel is still an open question.



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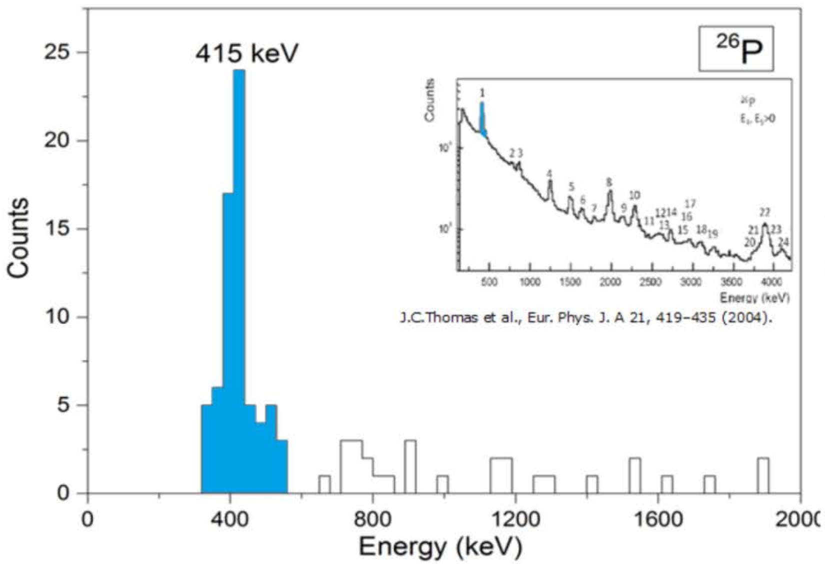

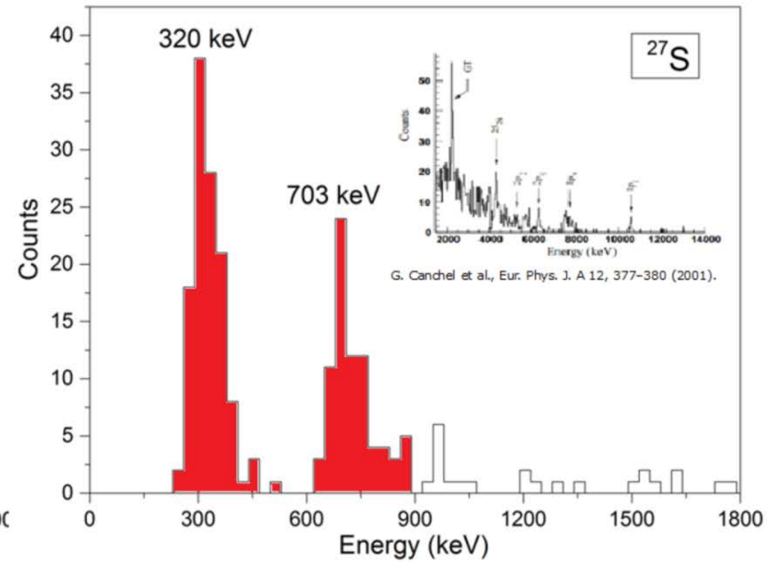

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Thomas et al., EPJ A21 (2004) 419				*Canchel et al.*, EPJ A12 (2001) 377		$P_{\beta 3p}$ < 0.08%	

ACCULINNA-2 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
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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

We are open for new collaborators

Thank you for attention