Status and perspectives of ACCULINNA-2 at U-400M

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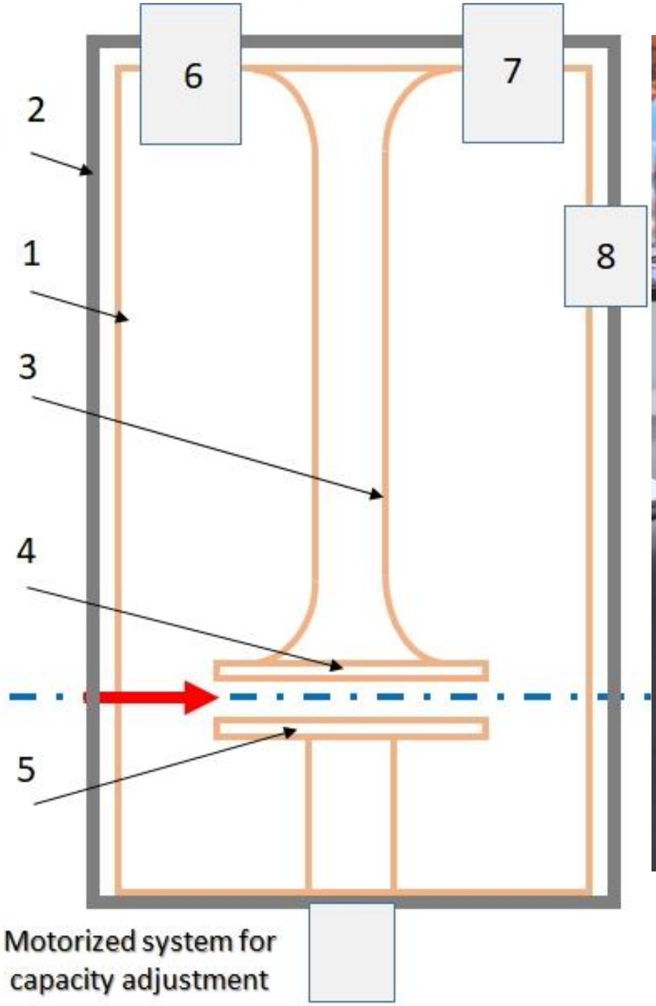
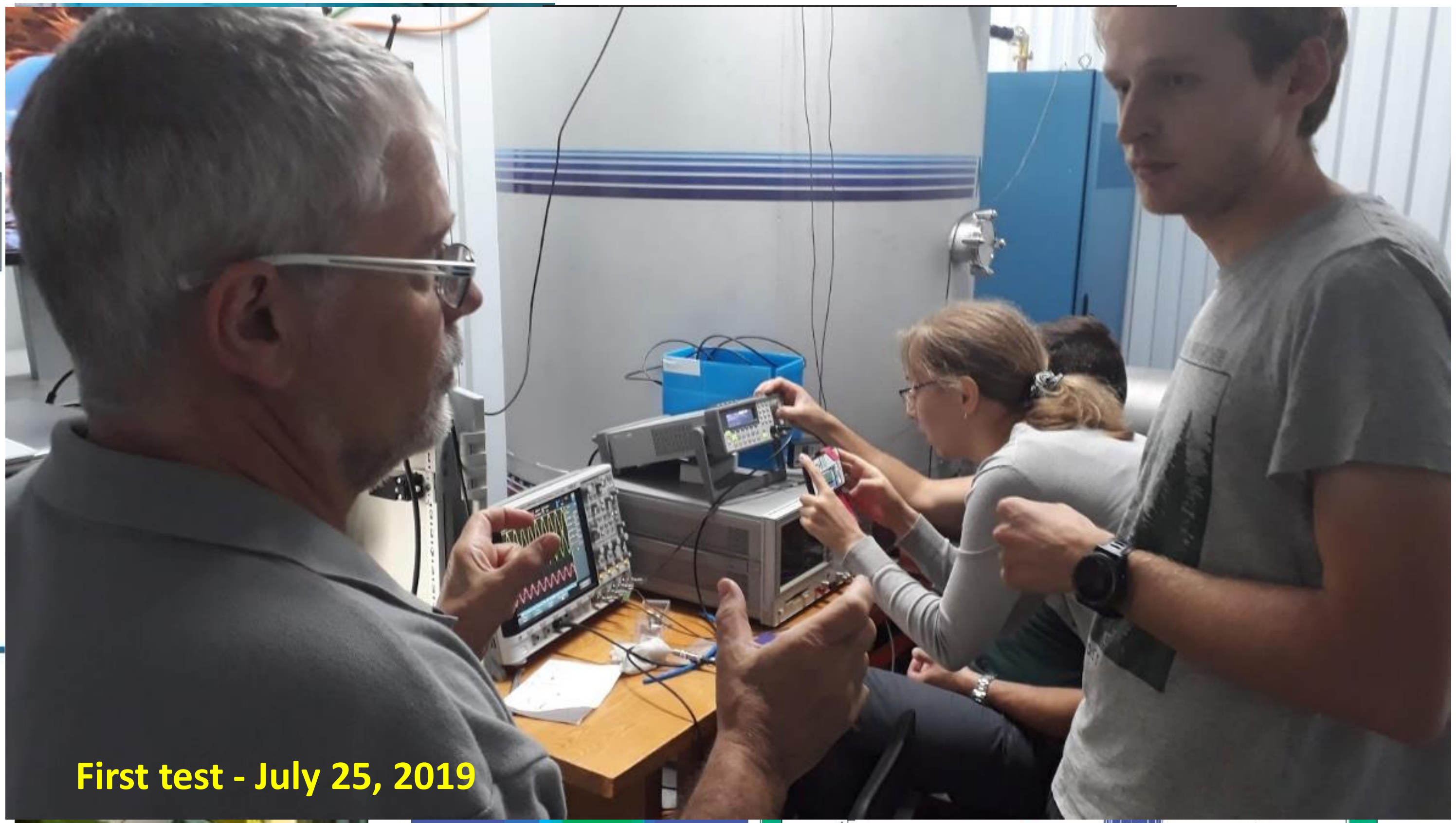
CONCEPT

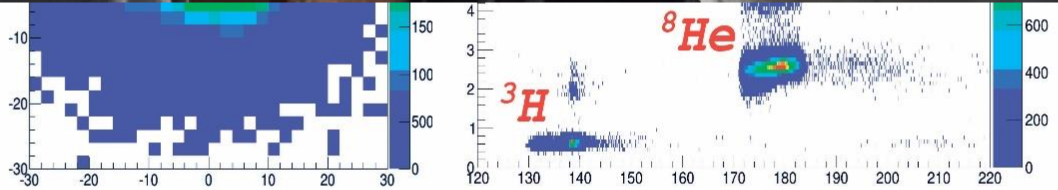
	Description
1	Copper resonant cavity D=1,2 m
2	Stainless steel vacuum vessel
3	Stem diameter d=0,12 m
4	Upper Electrode
5	Lower Electrode (motorized)
6	RF coupling loop (motorized)
7	RF fine tuning (motorized)
8	RF measuring loop



Motorized system for capacity adjustment



First test - July 25, 2019



Workshop on Physics of Exotic Nuclei, Crete, August 22-23 2019

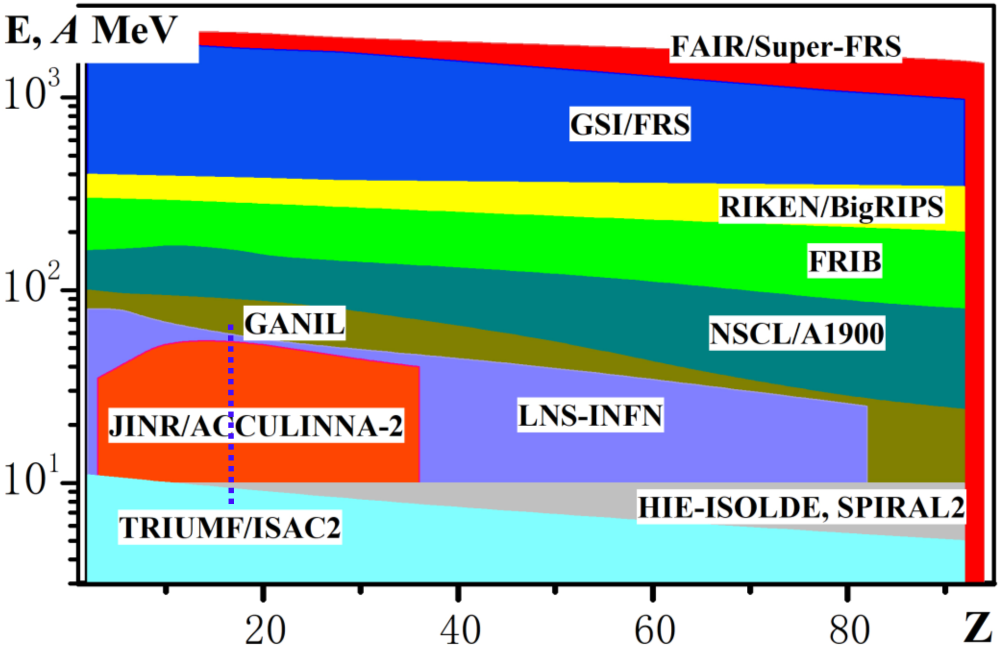
Main parameters of the Dubna RIBs complex

^{6}He @ 10 AMeV
ISOL method

^{7}Li @ 33 AMeV

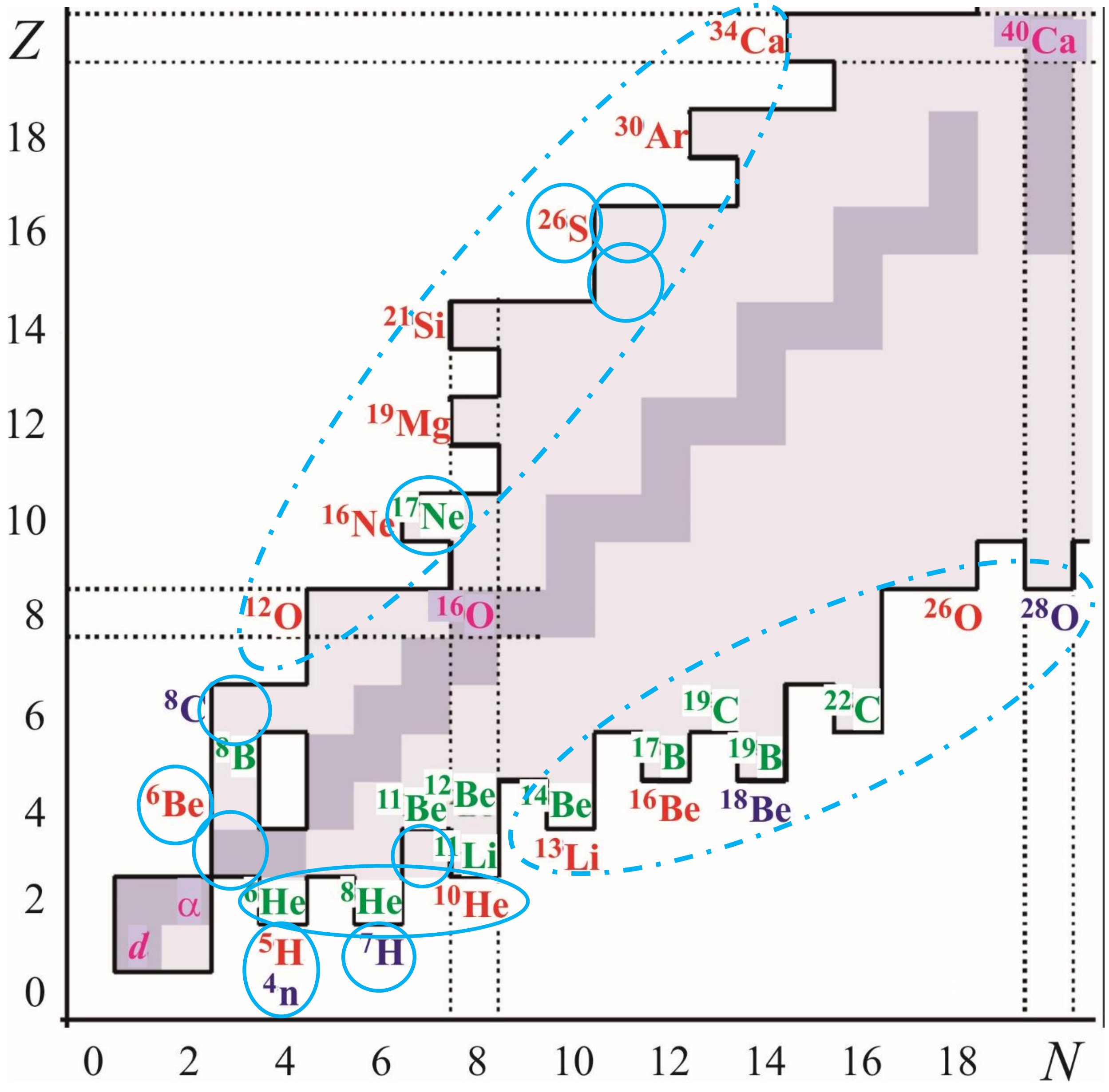
^{6,8}He @ 25÷35 AMeV
^{9,11}Li @ 30 AMeV
^{18}Ne @ 35 AMeV
^{26,27}S @ 38 AMeV
In-flight separation

	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
^{40}Ar @ 34 AMeV	*0.1*
^{84}Kr @ 27 AMeV	*0.05*



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

Sphere of interests for ACCULINNA-2 at U-400M cyclotron



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)

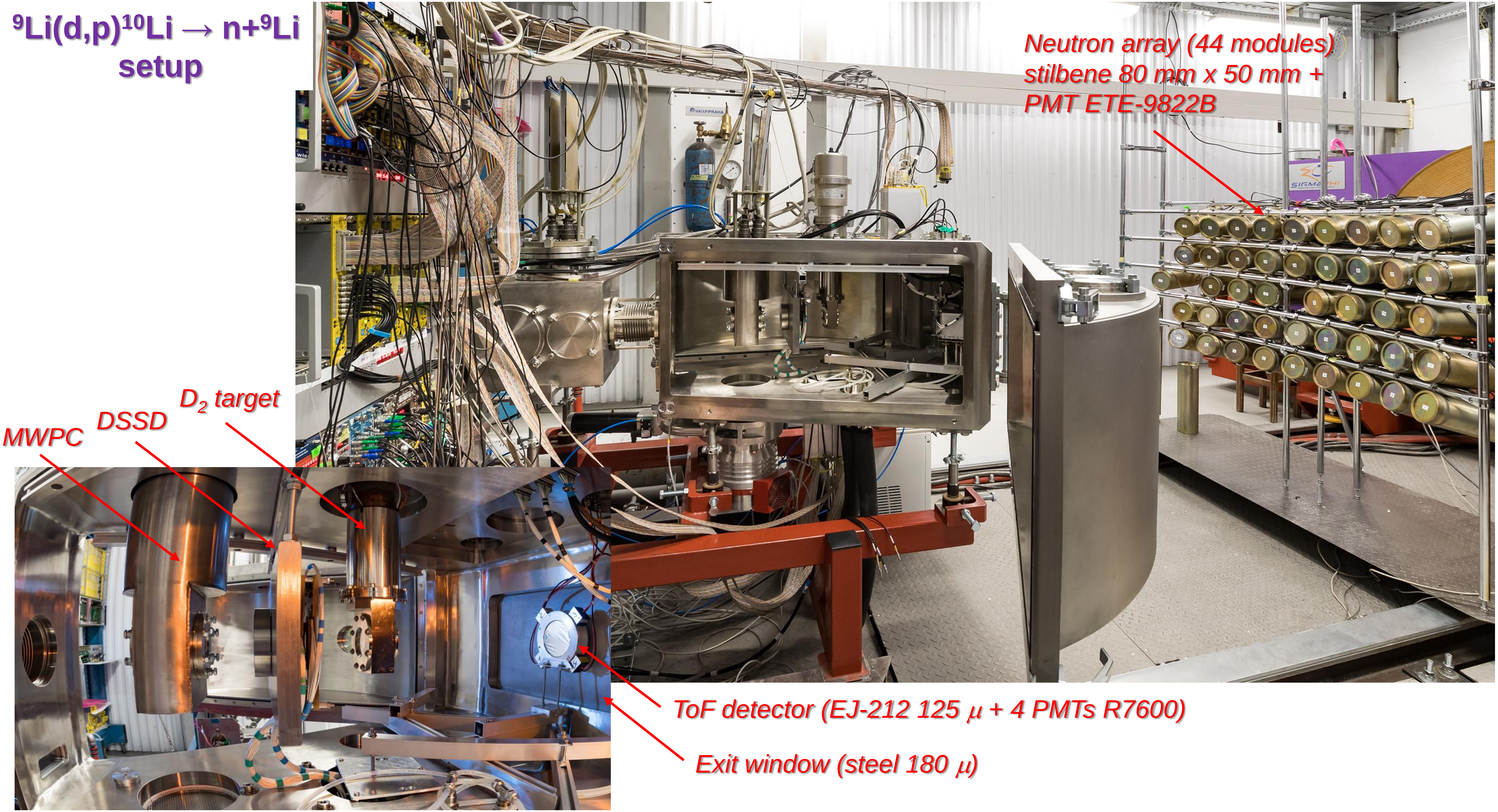
Exotic detectors for charged and neutral particles (optical TPC, neutron wall, scintillator arrays based on CsI, LaBr$_{3}$, etc., Si-telescopes, active target, HPGe array)

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

In perspective: stopping of RIB in gas-cell and post-acceleration by LINAC, implantation to MR-ToF spectrometer, laser spectroscopy

Scientific program strongly depends on U-400M

^{9}Li(d,p)^{10}Li → n+^{9}Li setup



Neutron array (44 modules) stilbene 80 mm x 50 mm + PMT ETE-9822B

MWPC

DSSD

D_2 target

ToF detector (EJ-212 125 μ + 4 PMTs R7600)

Exit window (steel 180 μ)

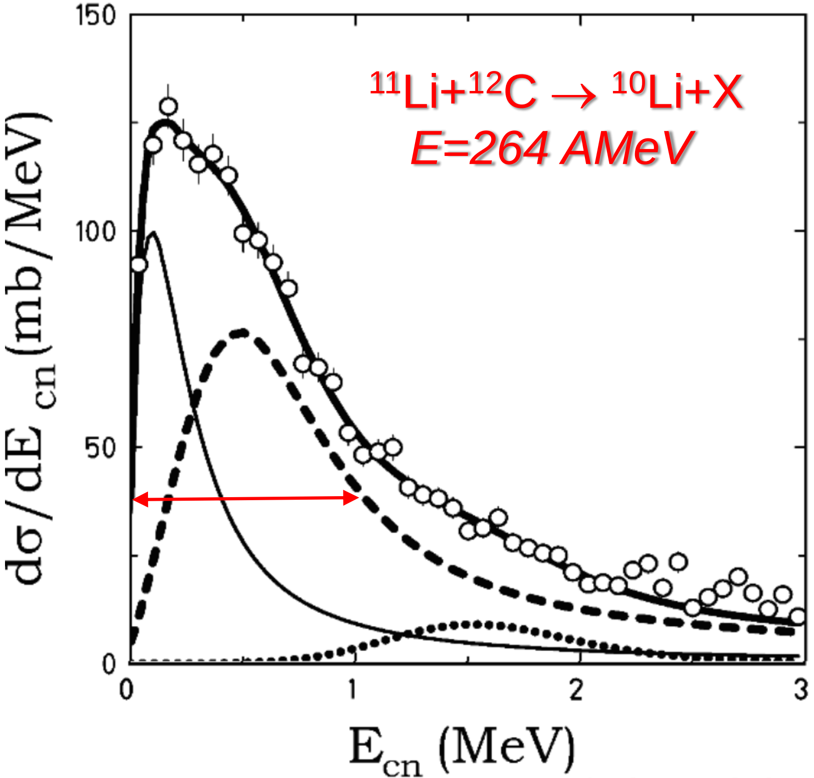
Why ^{10}Li and the reaction ^{9}Li(d,p)^{10}Li → n+^{9}Li ??

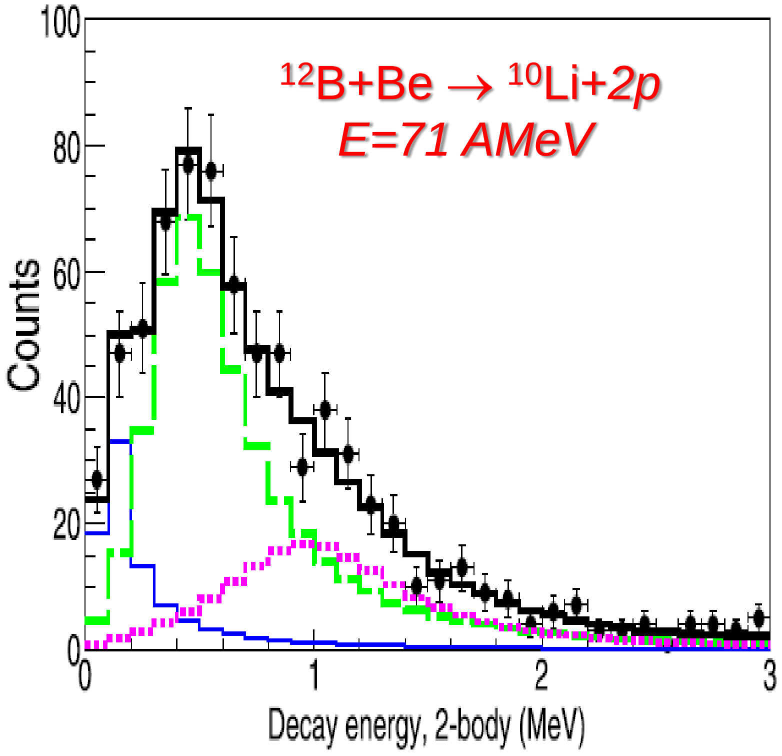
^{10}Li was studied many times using:

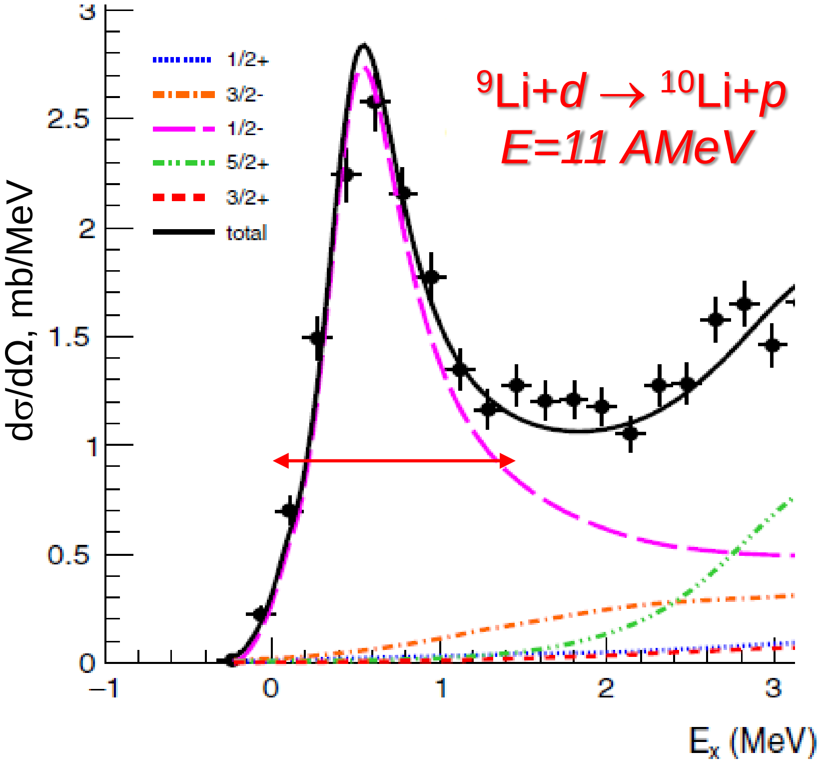
a) reactions with pions [Amelin et al., Yad. Fiz. (1990) 52; Chernyshev et al., EPJA (2013) 49]

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]



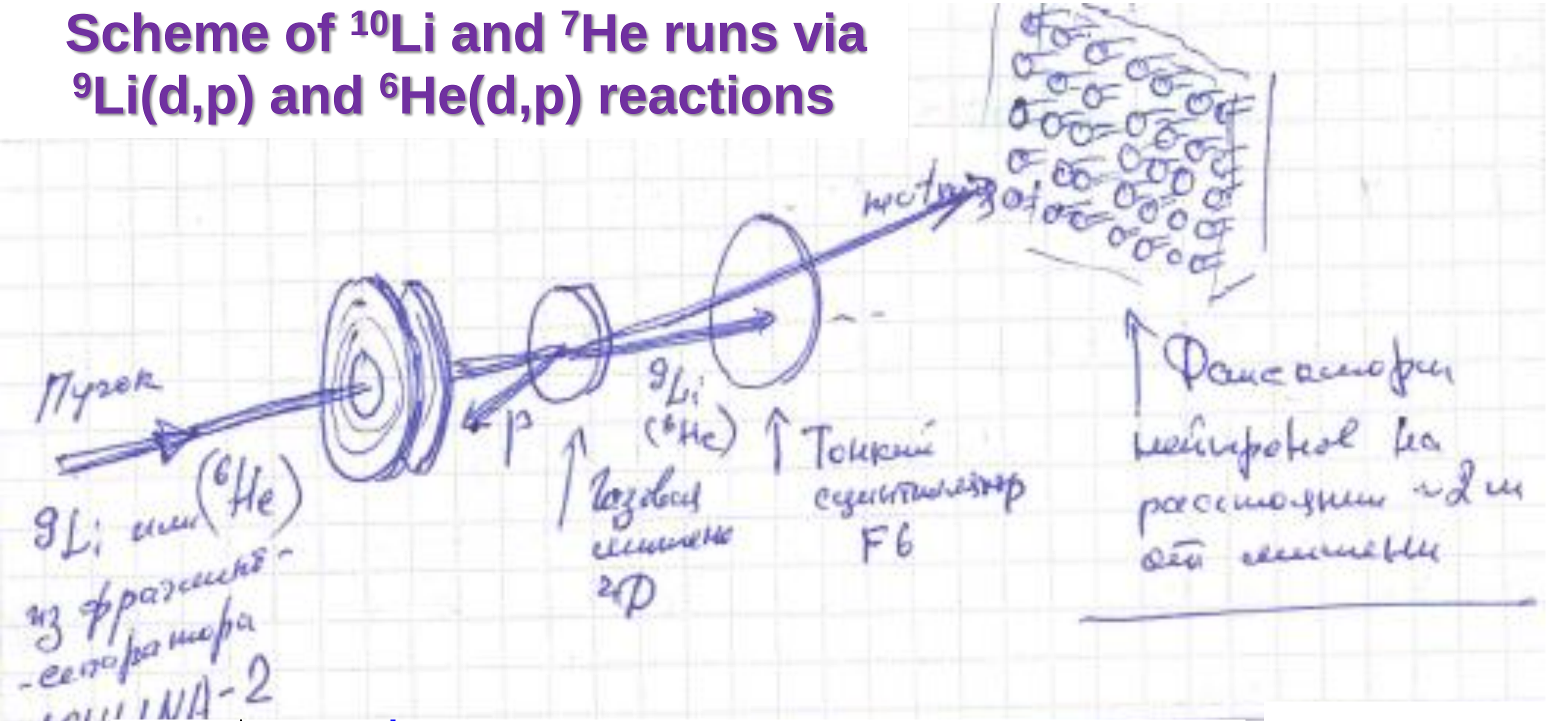


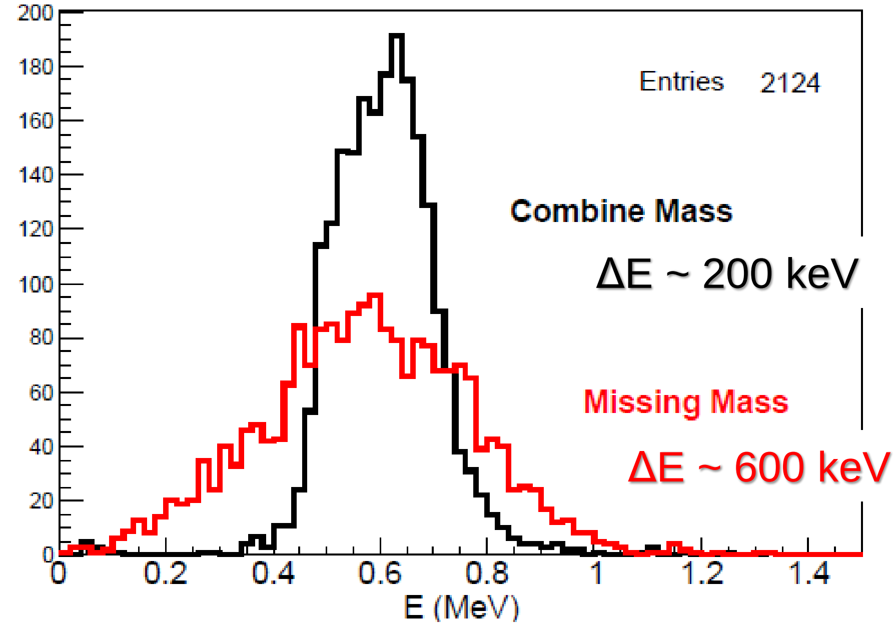


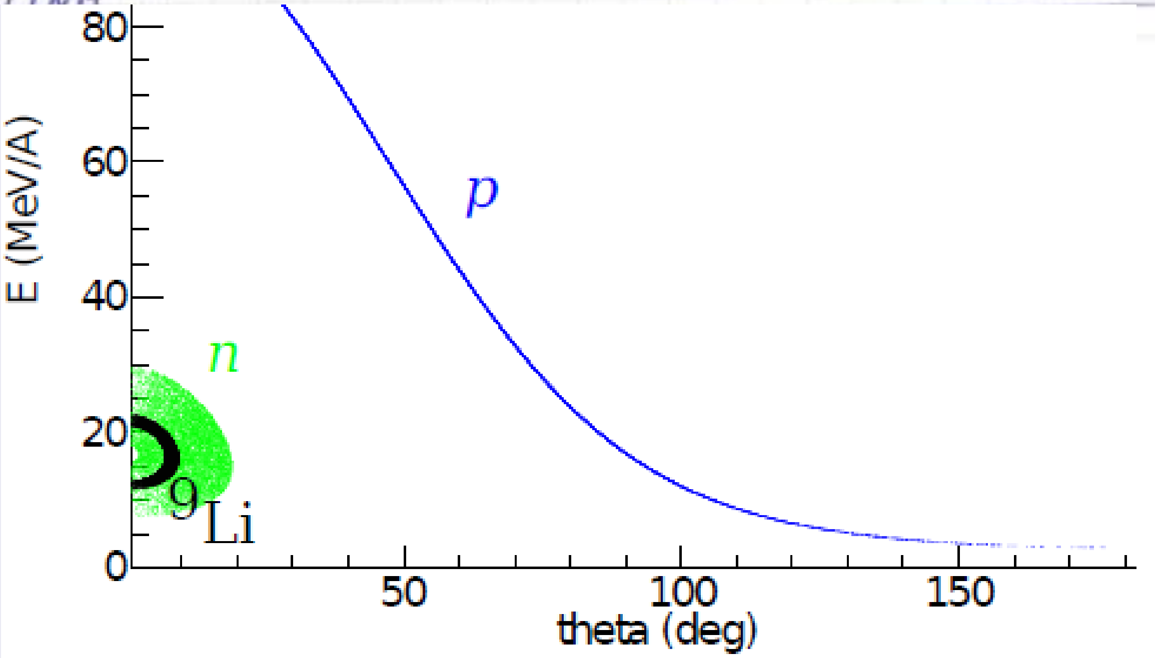
** data & interpretation for the low-energy spectra are still contradicted*

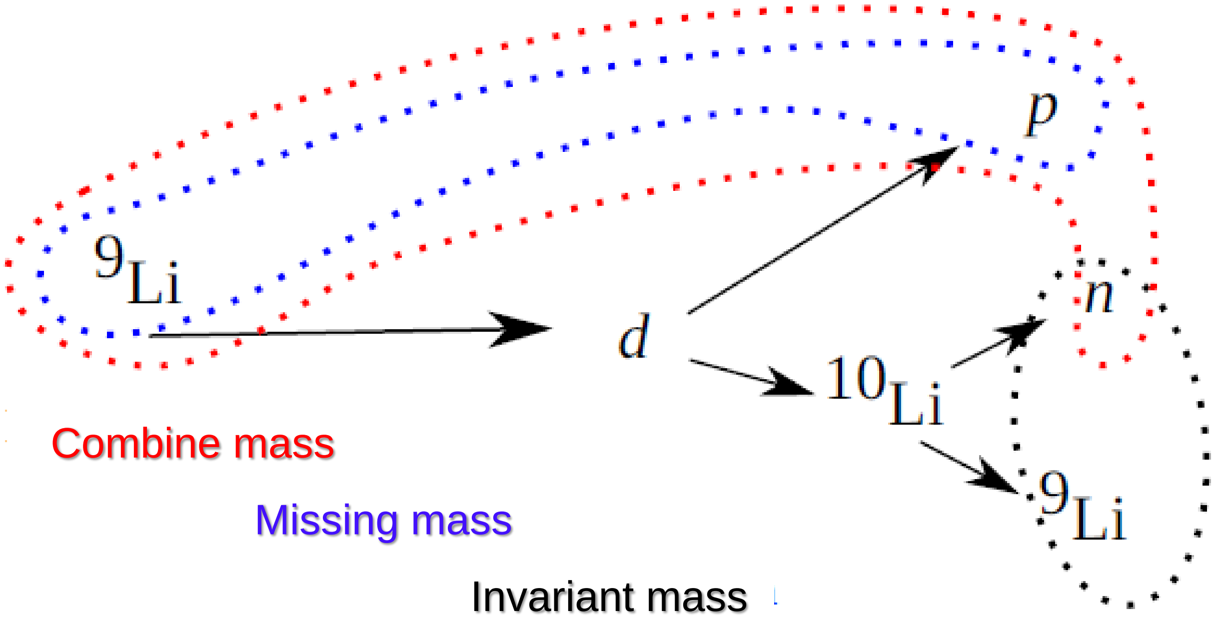
*** p-^{9}Li-n coincidences were proposed for the ^{9}Li(d,p)^{10}Li*

Scheme of ^{10}Li and ^{7}He runs via ^{9}Li(d,p) and ^{6}He(d,p) reactions







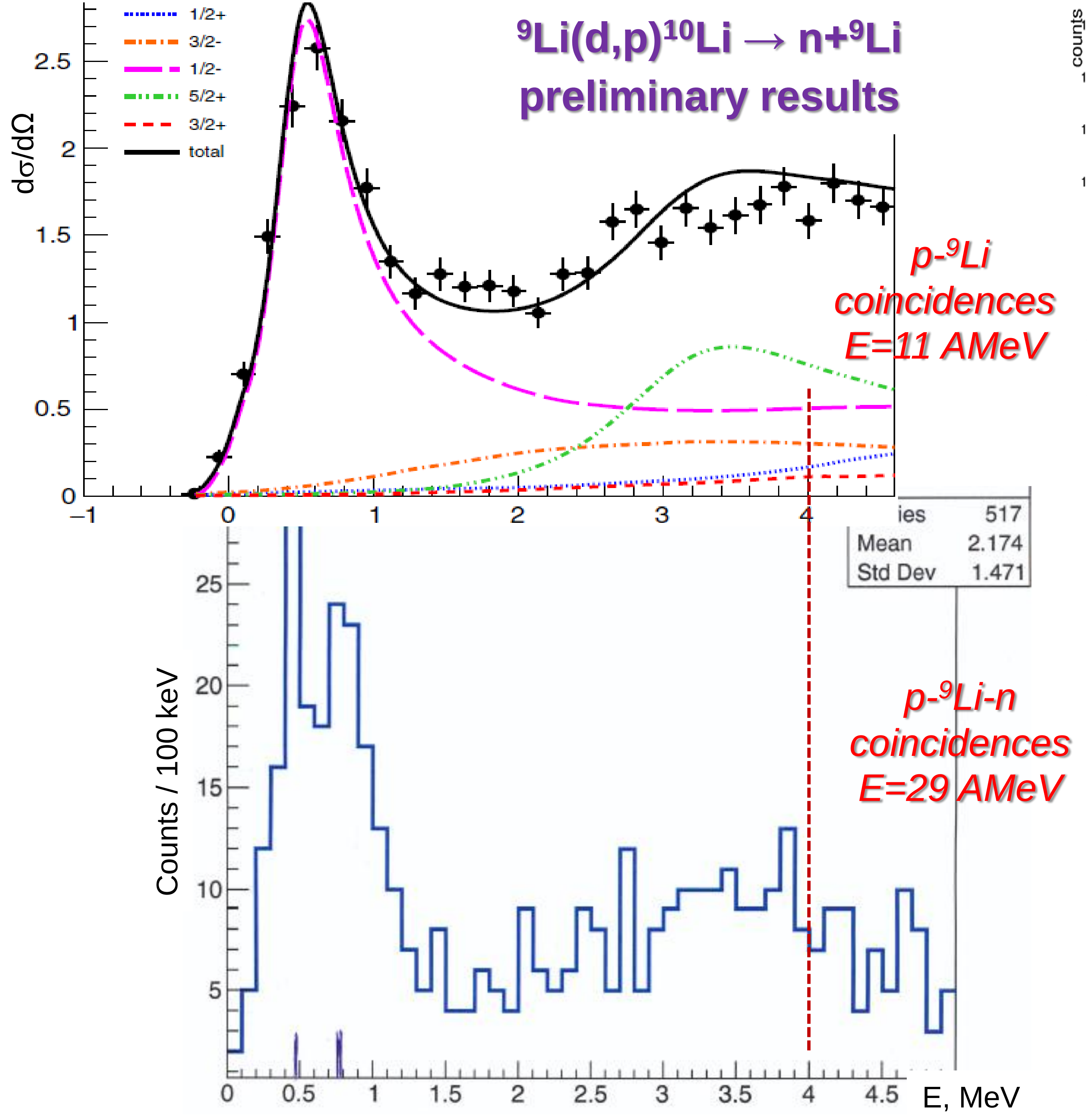


Combine mass

Missing mass

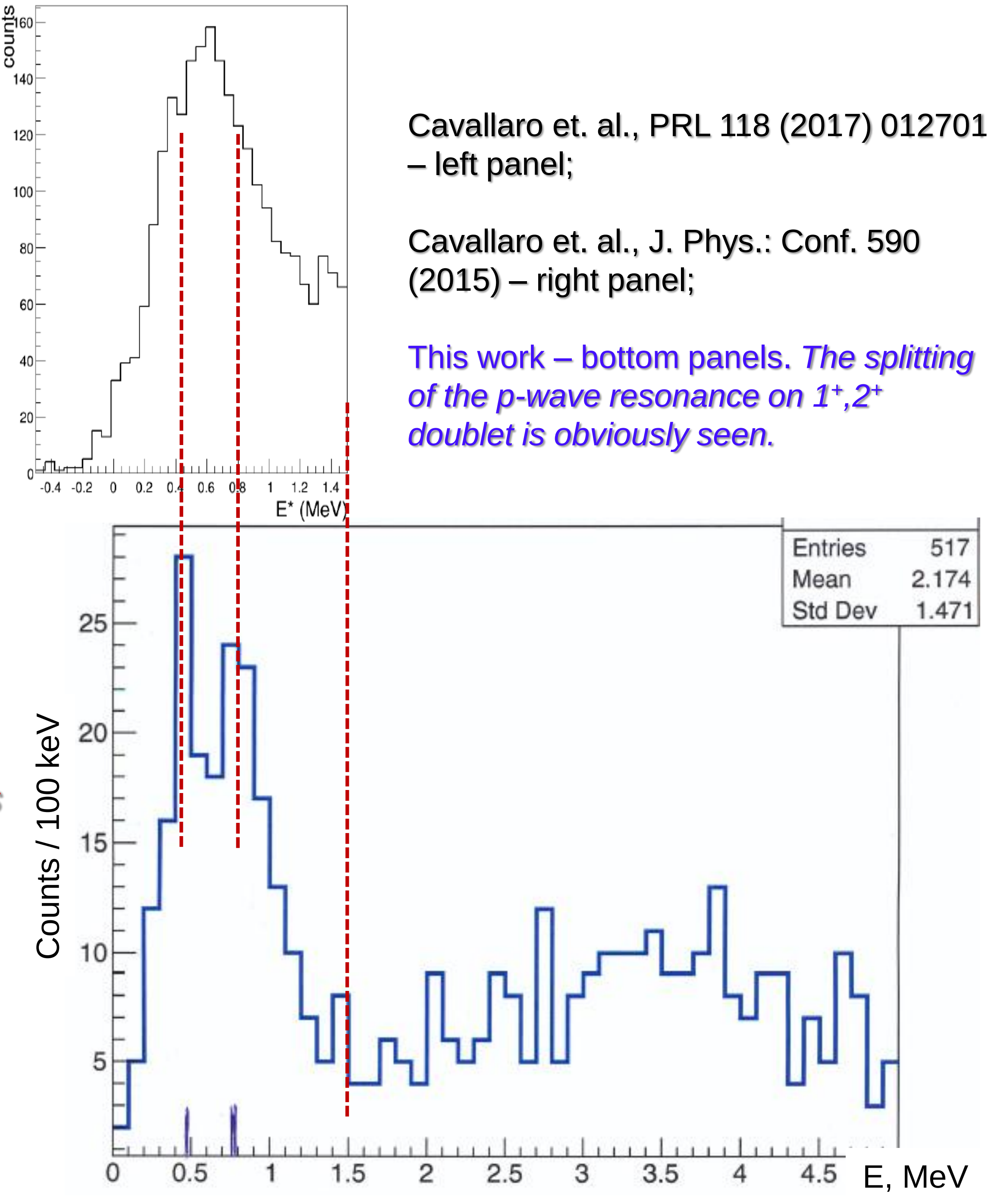
Invariant mass

^{9}Li(d,p)^{10}Li → n+^{9}Li preliminary results



p-^{9}Li coincidences E=11 AMeV

p-^{9}Li-n coincidences E=29 AMeV



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

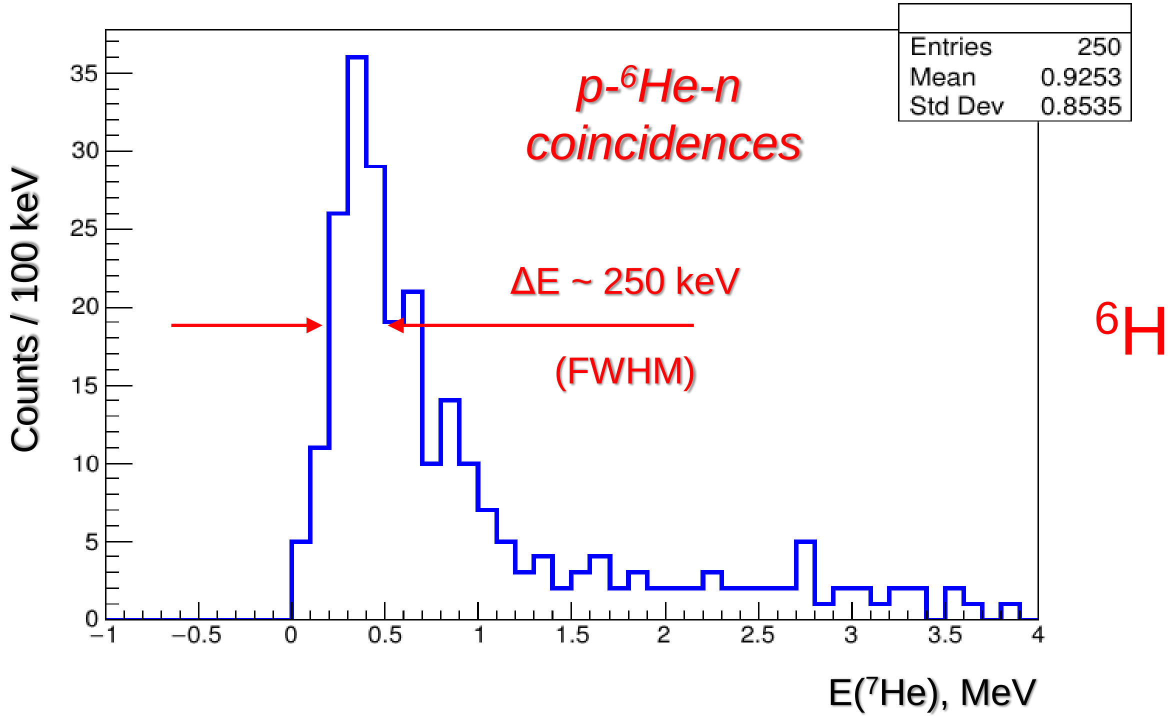
Cavallaro et. al., J. Phys.: Conf. 590 (2015) – right panel;

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

^{9}Li(d,p)^{10}Li → n+^{9}Li – preliminary summary

The combined 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 will be continued in 2019/2020.

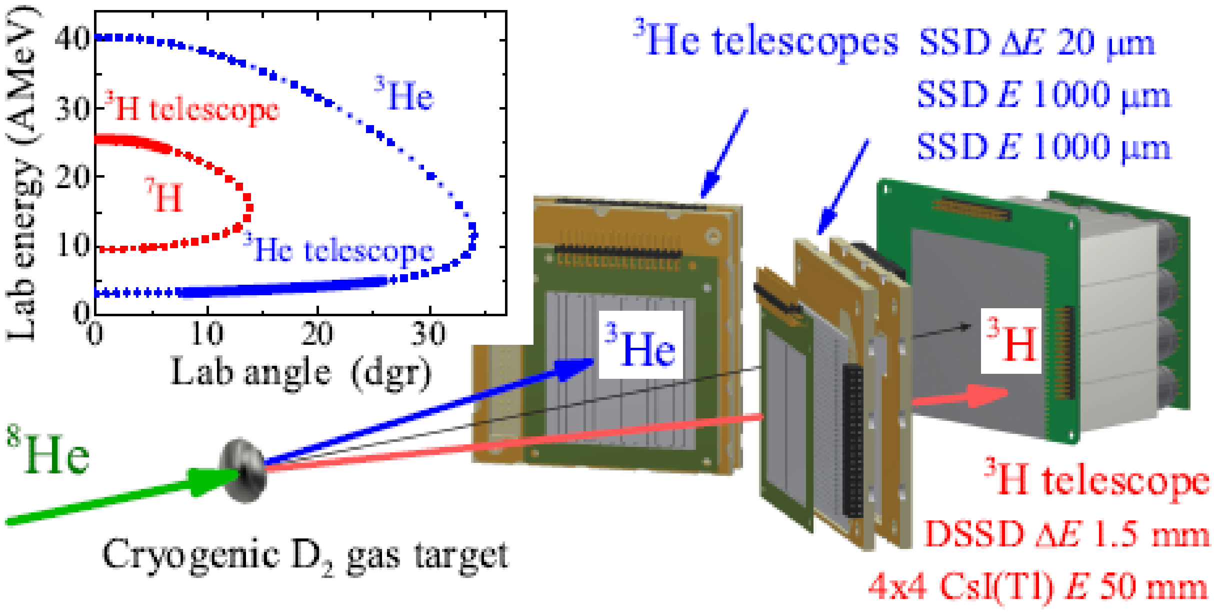


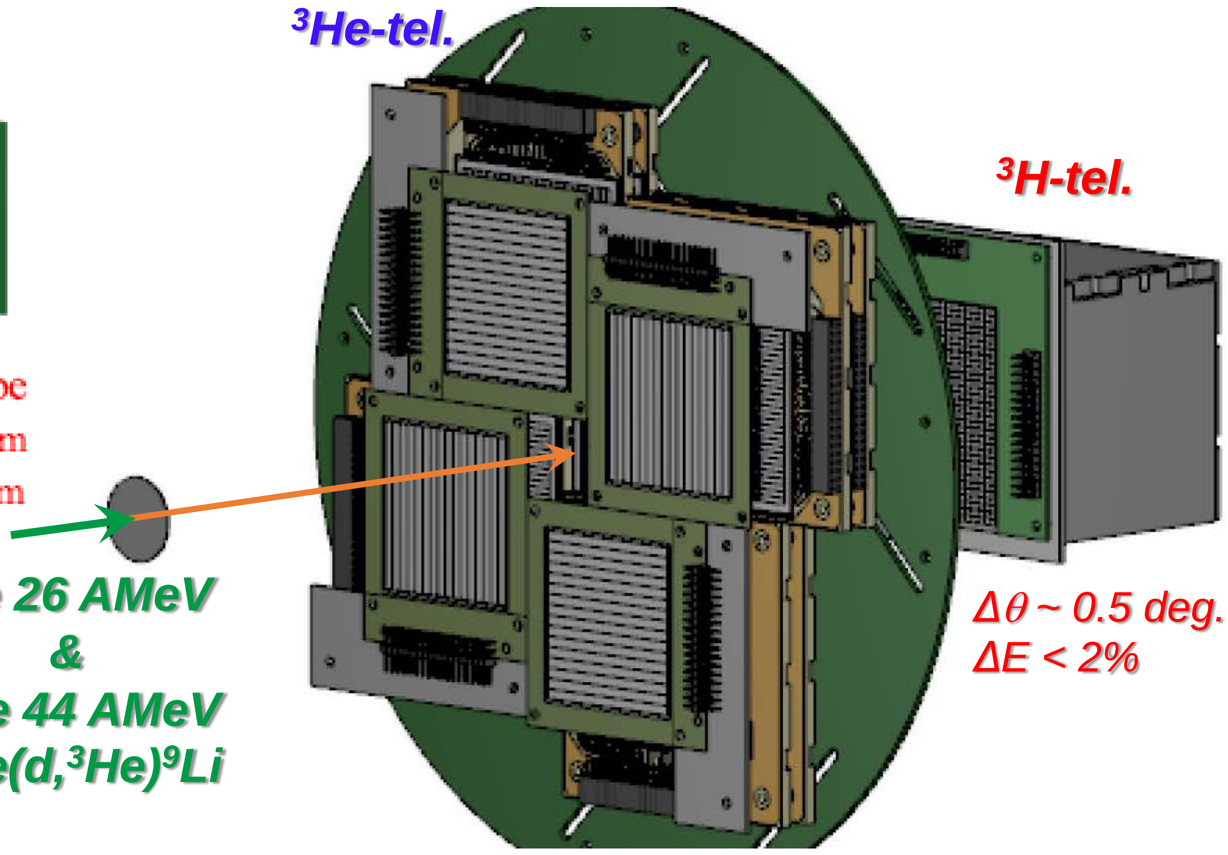
^{6}He+*d* → ^{7}He+*p*

Hunt for ^{7}H in ^{8}He(d,^{3}He)^{7}H reaction

November 2018: 10 days, two ^{3}He-telescopes installed at 17 deg.

April 2019: 12 days, four ^{3}He-telescopes installed at 15 deg.



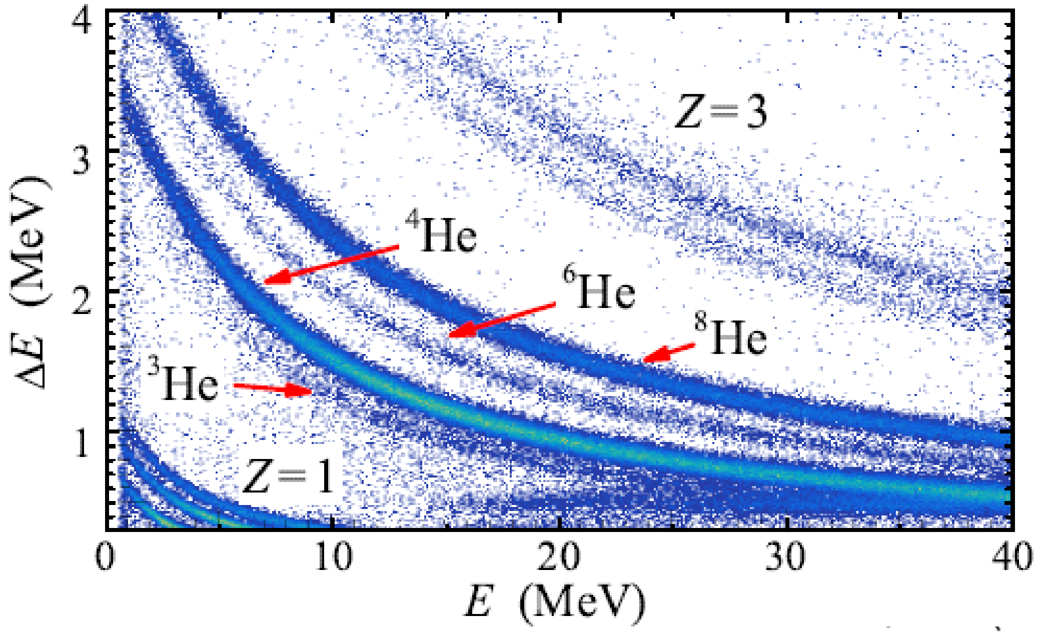


^{8}He 26 AMeV
&
^{10}Be 44 AMeV
^{10}Be(d,^{3}He)^{9}Li

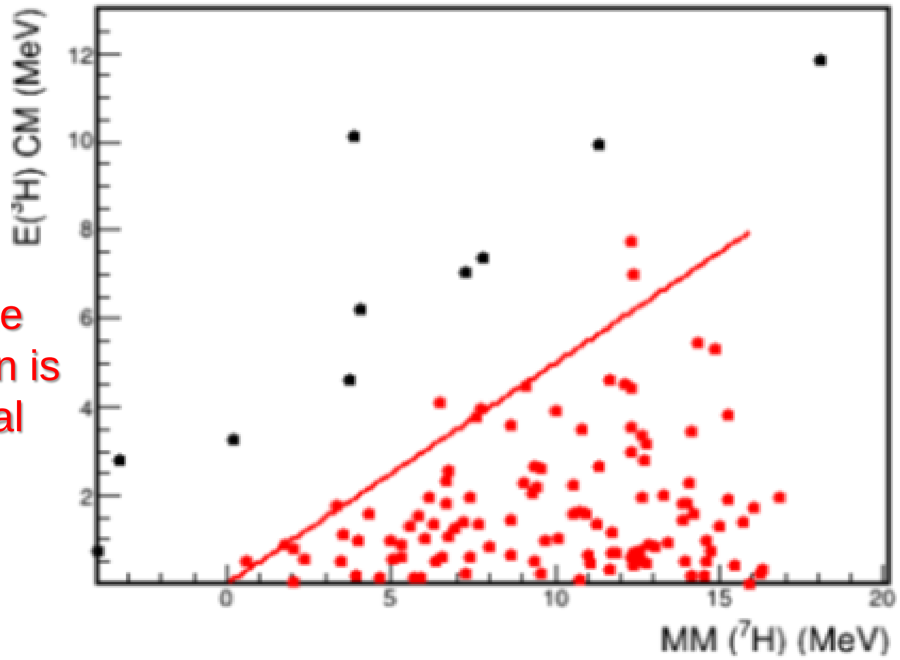
* Expected energy resolution for the ^{7}H missing mass spectra was about 1.1 MeV

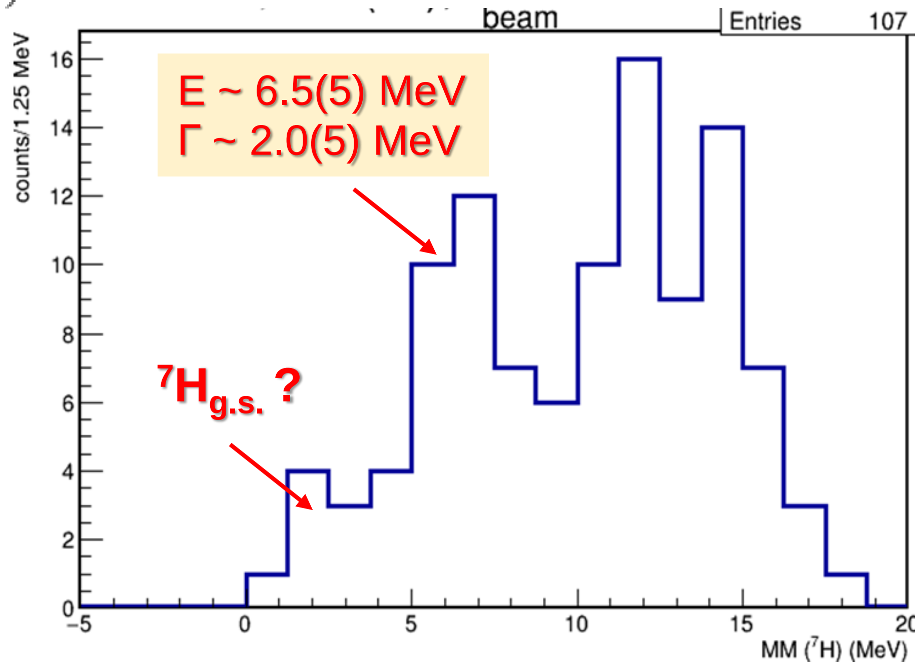
** Efficiency of ^{3}He-^{3}H coincidence was about 65% (Nov.2018) and 75% (Apr.2019)

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



Key advantage of ^{3}H detection is the kinematical triangle !!

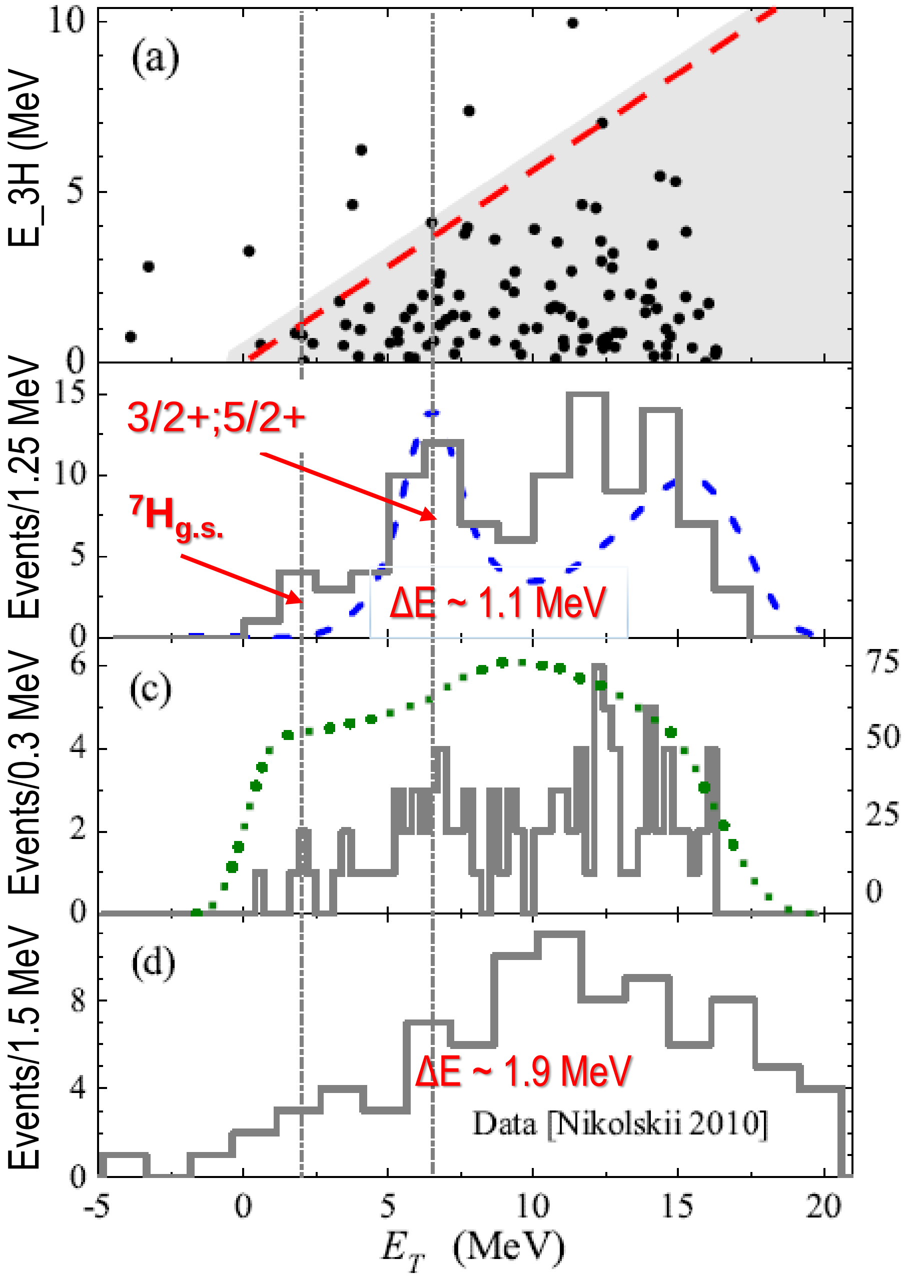




E ~ 6.5(5) MeV
Γ ~ 2.0(5) MeV

^{7}H$_{g.s.}$?

^{8}He(d,^{3}He)^{7}H - effect of coincidence with tritons (Nov. 2018)



Missing mass spectrum of ^{7}H for the **^{8}He(d,^{3}He)^{7}H** reaction at 26 AMeV obtained in coincidence with tritons (E_t > 65 MeV). Blue dashed curve means the *t+4n* five body phase volume and the peak at 6.5 MeV. Green doted curve shows experimental setup efficiency (a.u.).

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

Data for the **^{8}He(d,^{3}He)^{7}H** reaction at 42 AMeV by E.Yu. Nikolskii et al., Phys.Rev. C 81, 064606 (2010). Coincidence with tritons were obtained without energy selection.

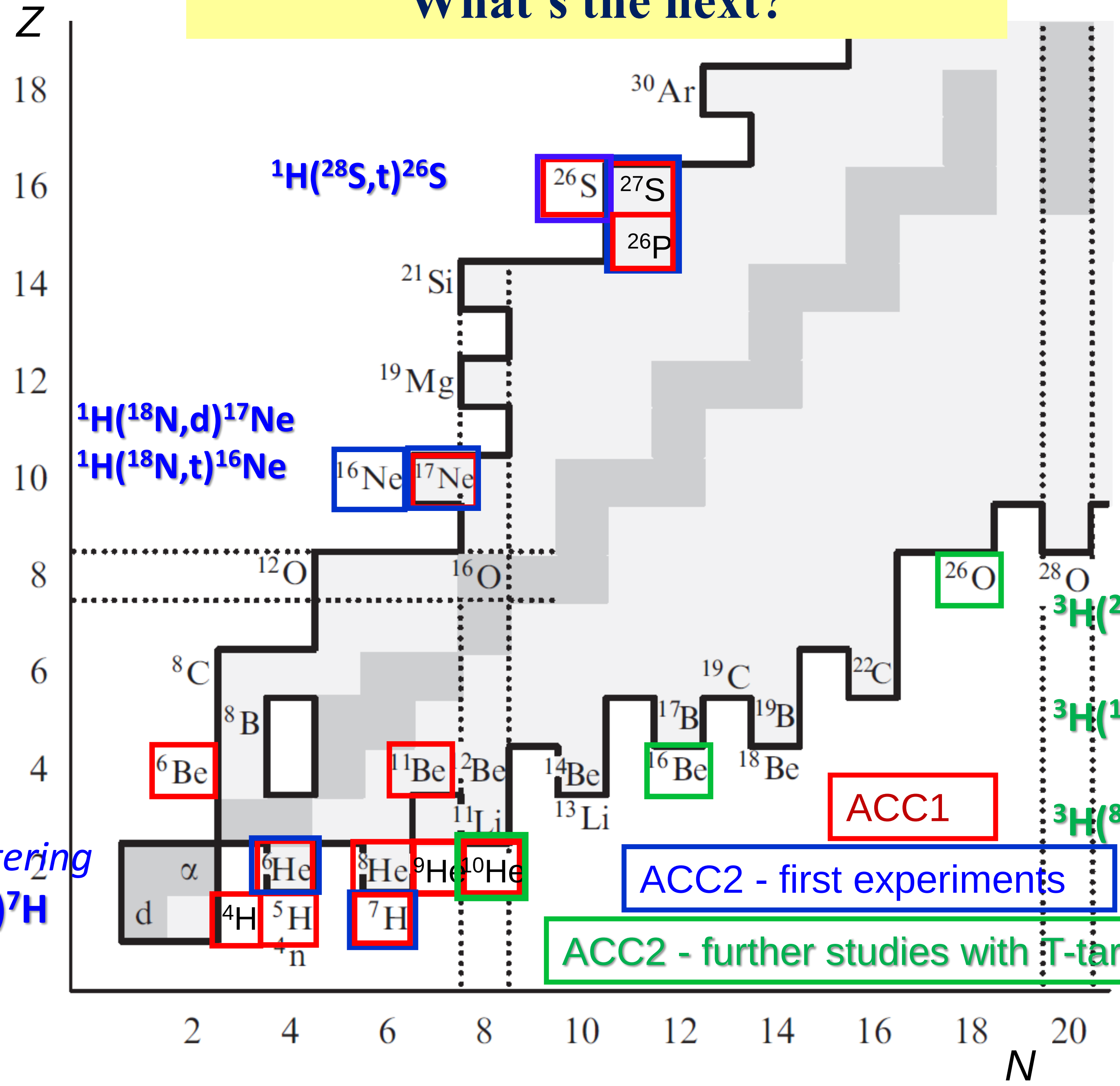
^{8}He(d,^{3}He)^{7}H – preliminary summary (Nov. 2018)

The indications for the ^{7}H g.s. at 1.8(5) MeV are found in the measured energy and angular distributions.

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.

The data with more statistics (April 2019, under analysis now) will clarify the mentioned above statements.

What's the next?



^{1}H(^{28}S,t)^{26}S

^{1}H(^{18}N,d)^{17}Ne
^{1}H(^{18}N,t)^{16}Ne

^{6}He+d *scattering*
^{2}H(^{8}He,^{3}He)^{7}H

^{3}H(^{24}O,p)^{26}O

^{3}H(^{14}Be,p)^{16}Be

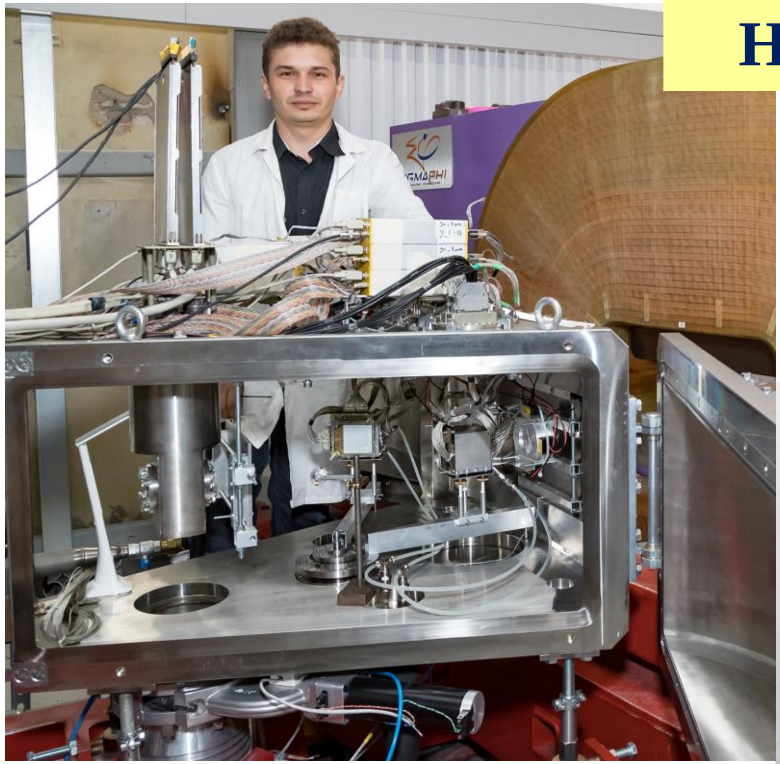
^{3}H(^{8}He,p)^{10}He

ACC1

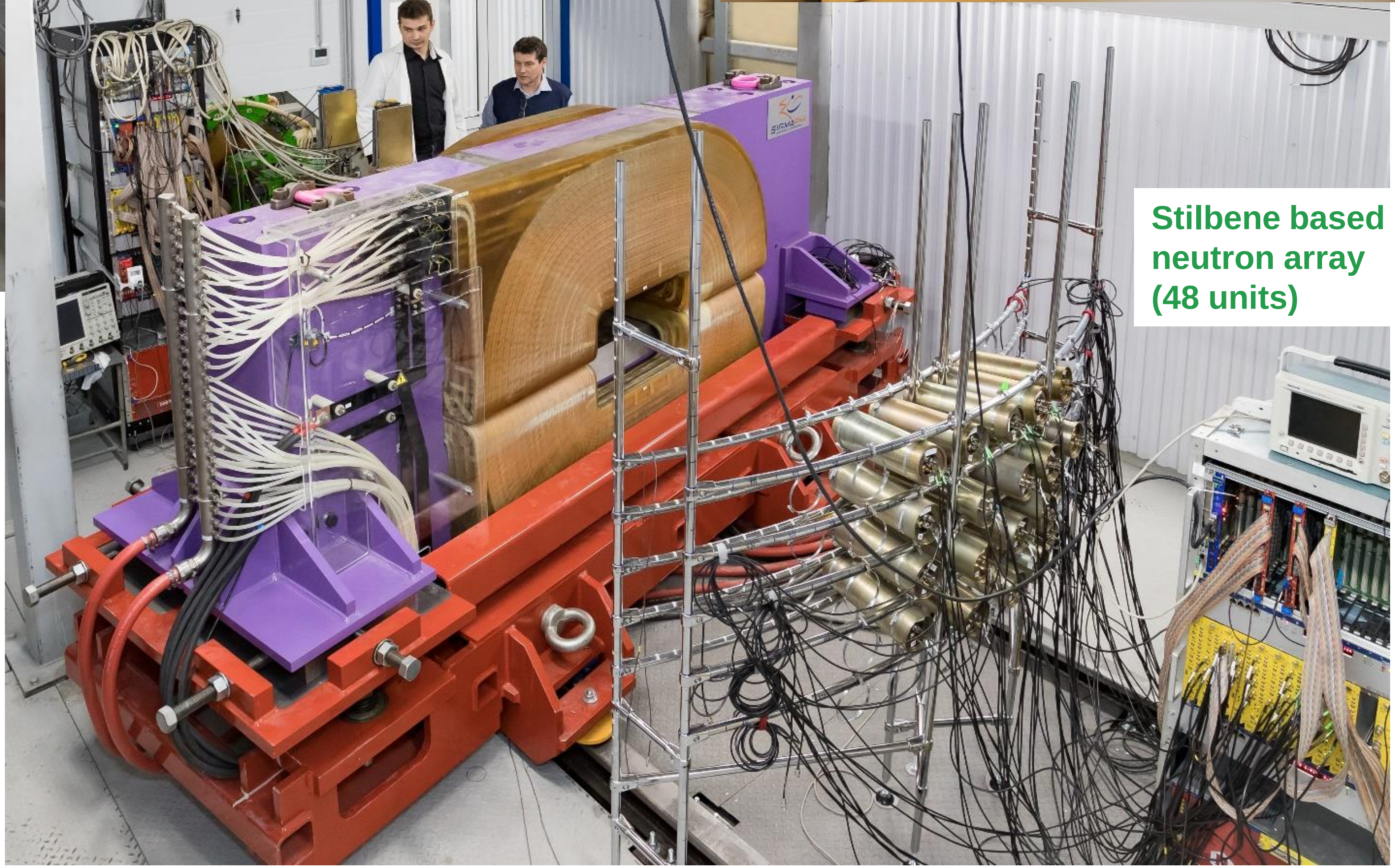
ACC2 - first experiments

ACC2 - further studies with T-target

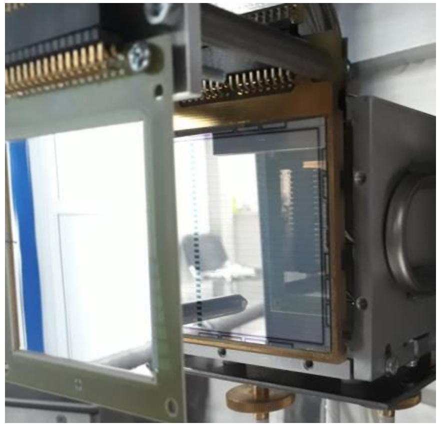
Heavy equipment & detectors



CsI(Tl)/PMT array
GADAST (64 units)
Energy & position



Stilbene based
neutron array
(48 units)

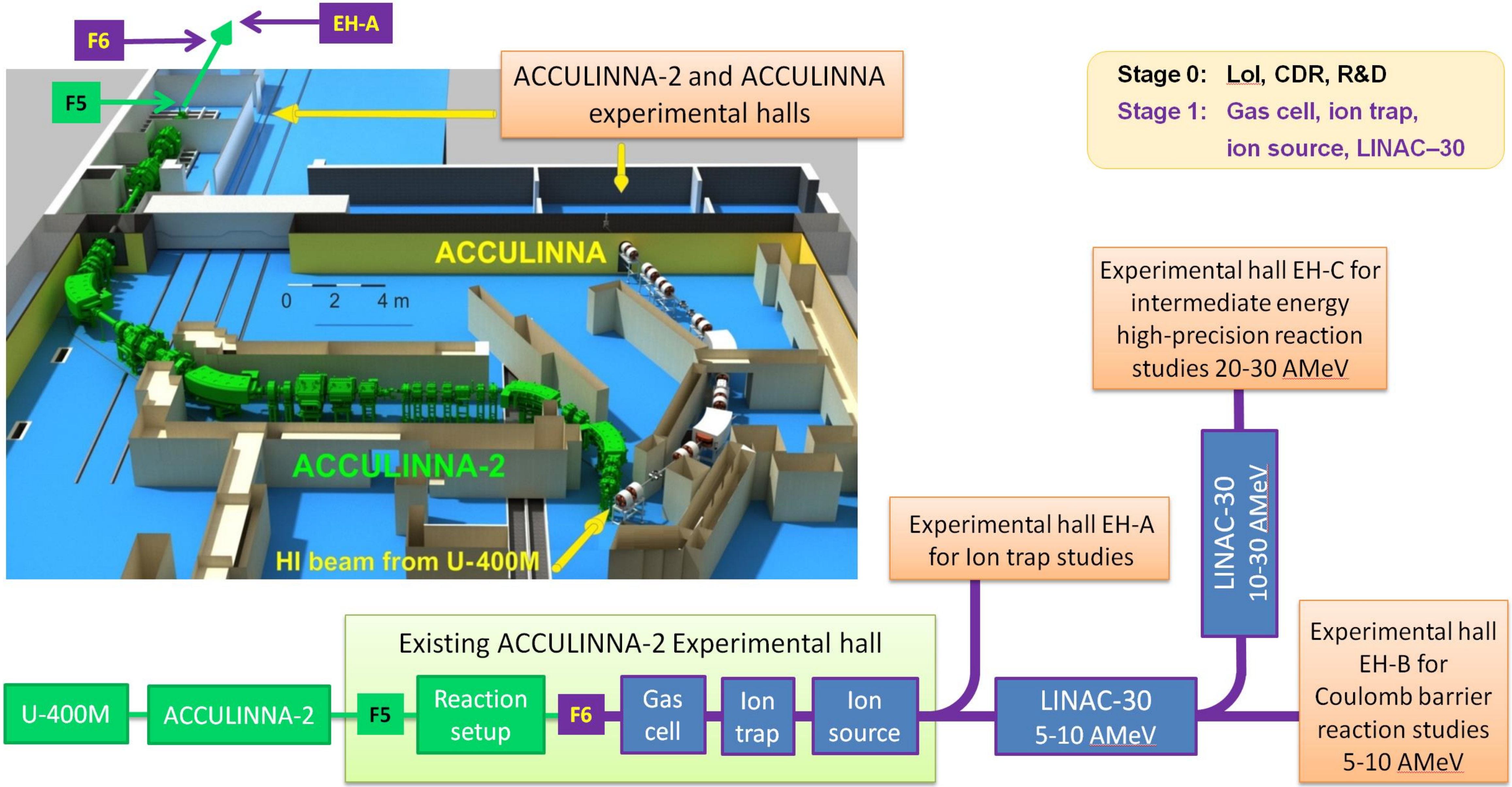


Charged particle telescopes
(Si - 22 μ, 1000 μ ; CsI/PMT)

DERICA concept, stages 0 – 1. Two systems {gas cell - ion trap - ion source/charge breeder} and LINAC-30 could be built and tested at F6 of ACCULINNA-2, then replaced to the new experimental hall.

Stage 0: LoI, CDR, R&D

Stage 1: Gas cell, ion trap, ion source, LINAC–30



ACCULINNA-2 and ACCULINNA experimental halls

Experimental hall EH-C for intermediate energy high-precision reaction studies 20-30 AMeV

LINAC-30 10-30 AMeV

Experimental hall EH-A for Ion trap studies

Experimental hall EH-B for Coulomb barrier reaction studies 5-10 AMeV

Existing ACCULINNA-2 Experimental hall

U-400M → ACCULINNA-2 → F5 → Reaction setup → F6 → Gas cell → Ion trap → Ion source → LINAC-30 5-10 AMeV

Proposal for the opening of a new project

Project: **“Construction of a prototype of the initial section of the high-current heavy-ion linear accelerator for the production of intense radioactive ion beams for basic research”**

Supplement for the physical program of the project **“Development of the FLNR accelerator complex and experimental setups (DRIBs-III)”** on the years 2020/2021.
Theme: 03-0-1129-2017/21

Project leaders:

L.V. Grigorenko (FLNR JINR)
T.V. Kulevoy (NRC “KI” - ITEP)

Deputy project leaders:

A.S. Fomichev (FLNR JINR)
A.A. Efremov (FLNR JINR)
S.M. Polozov (NRNU MEPhI)

50th meeting of the JINR Program Advisory Committee
for Nuclear Physics, June 24-25, 2019

http://aculina.jinr.ru/acc-2.php

Summary and outlook

First experiments at ACCULINNA-2 fragment separator were successfully performed and the scientific program is well defined on 5 or even more years.

The setup is a good point of growing for the new RIB facility DERICA (gas cell, ion trap, post-acceleration technique).

Participation Russian and foreign institutes in the project are foreseen and very welcome.

It’s important to be involved into design and manufacturing of:

i) 28 GHz SC-ECR ion source;
ii) LINAC and components (gas cell, extraction system, etc.)
iii) Fragment separator DFS (ACCULINNA-3);
iv) Production target and beam dump with heating power >400 kW;
v) Ring branch
vi) …

Thanks for your attention

http://aculina.jinr.ru/acc-2.php