

Commissioning of the ACCULINNA-2 fragment separator and its first day experiments



Andrey Fomichev^a
for ACCULINNA Collaboration

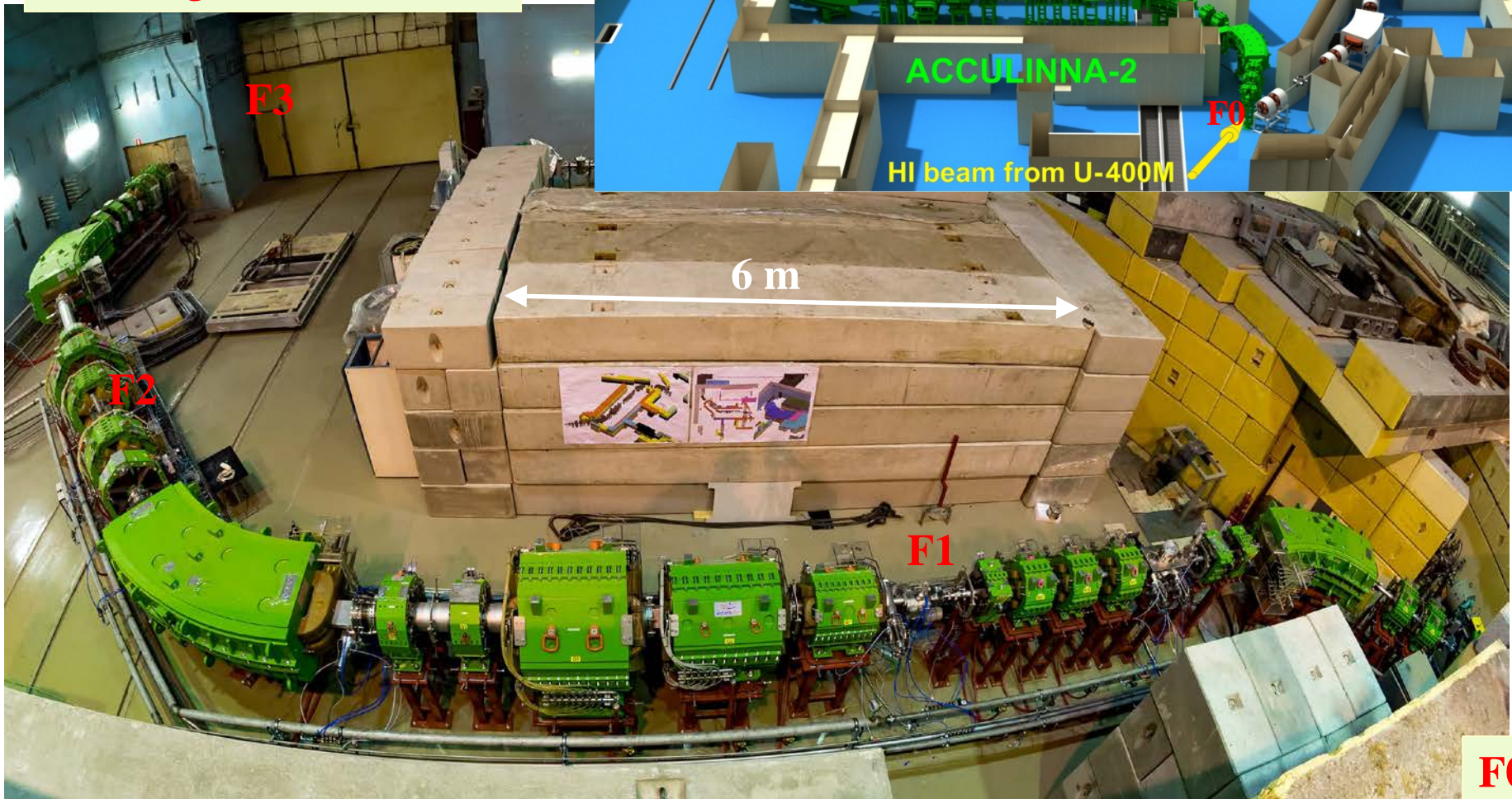


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- h – *Faculty of Physics, University of Warsaw, Warsaw, Poland*
- i – *Fundamental Physics, Chalmers University of Technology, Goteborg, Sweden*
- j – *All-Russian Research Institute of Experimental Physics, Sarov, Russia*
- k – *Ioffe Physical Technical Institute, St. Petersburg, Russia*
- l – *NSCL, Michigan State University, East Lansing, Michigan, USA*

**Dubna PAC meeting,
June 14-15, 2017**

Setup layout & Today status

total length F0-F5 ~53m
39 magnetic elements



Setup layout in F3-F5

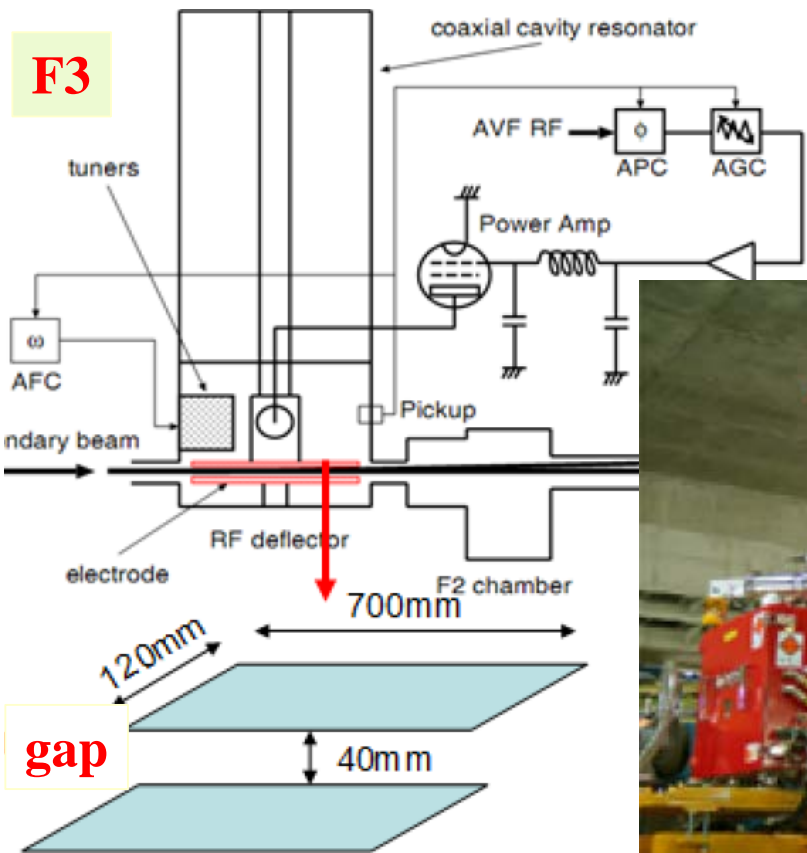
F5: Dipole magnet – installed, detector system & electronics in a progress; new reaction chamber is recently delivered;

F3: RF-kicker – contracted in 2016, will be ready in the middle 2018

F5



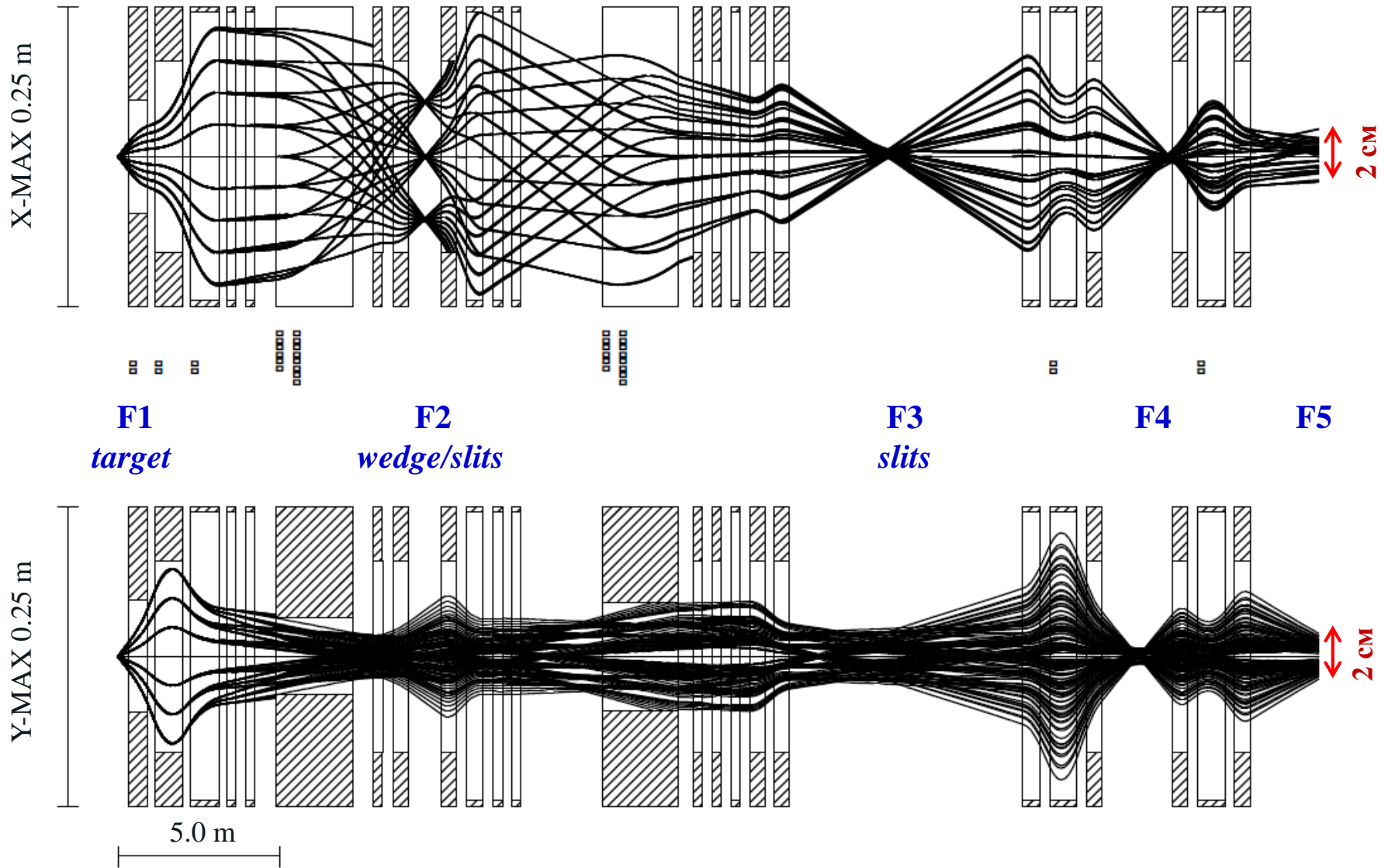
F3



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

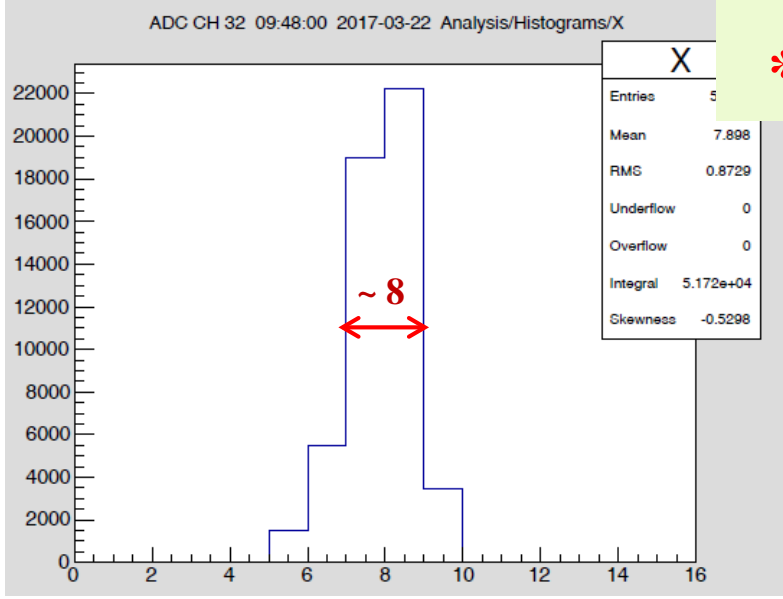
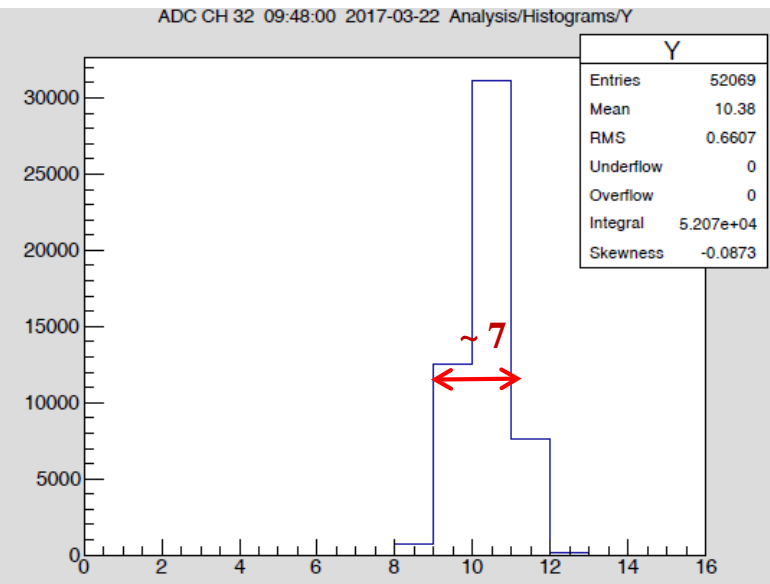
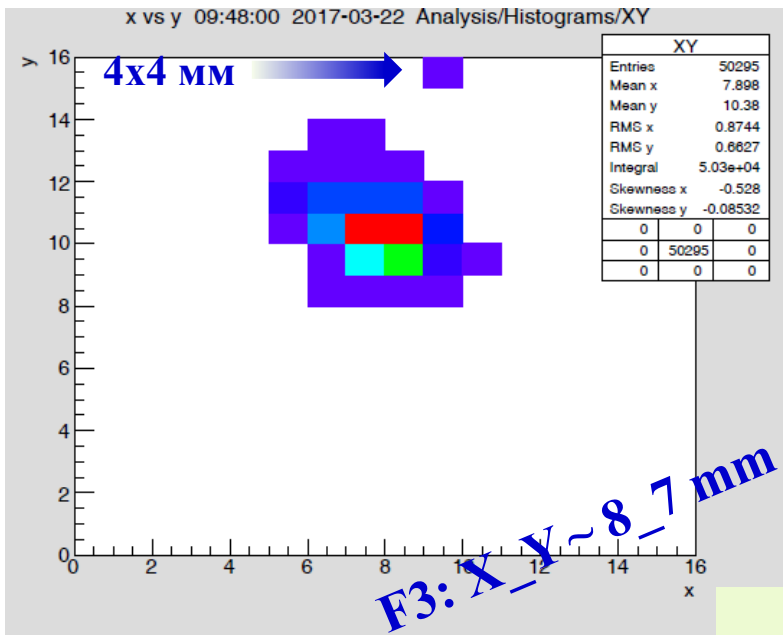
**Goals of the test
in March 2017:**

- ^{15}N profile at F3 depending on F1 diaph. (\varnothing 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, $\varepsilon = 35$ mrad, $\Delta p/p = 2.5\%$, $W = 1$ mm)**

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



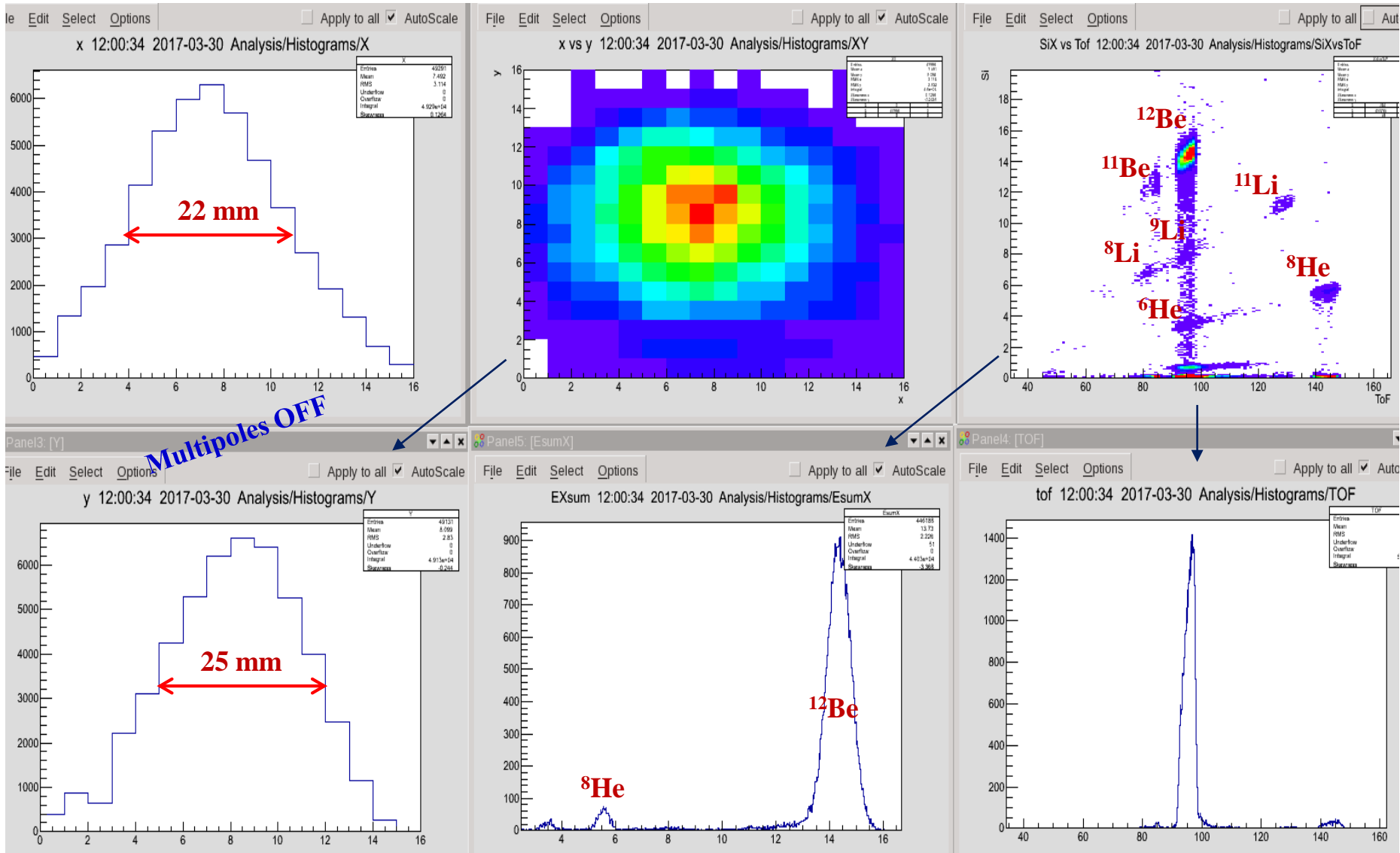
*** Ion optics working well !**
**** RIB production could be started**



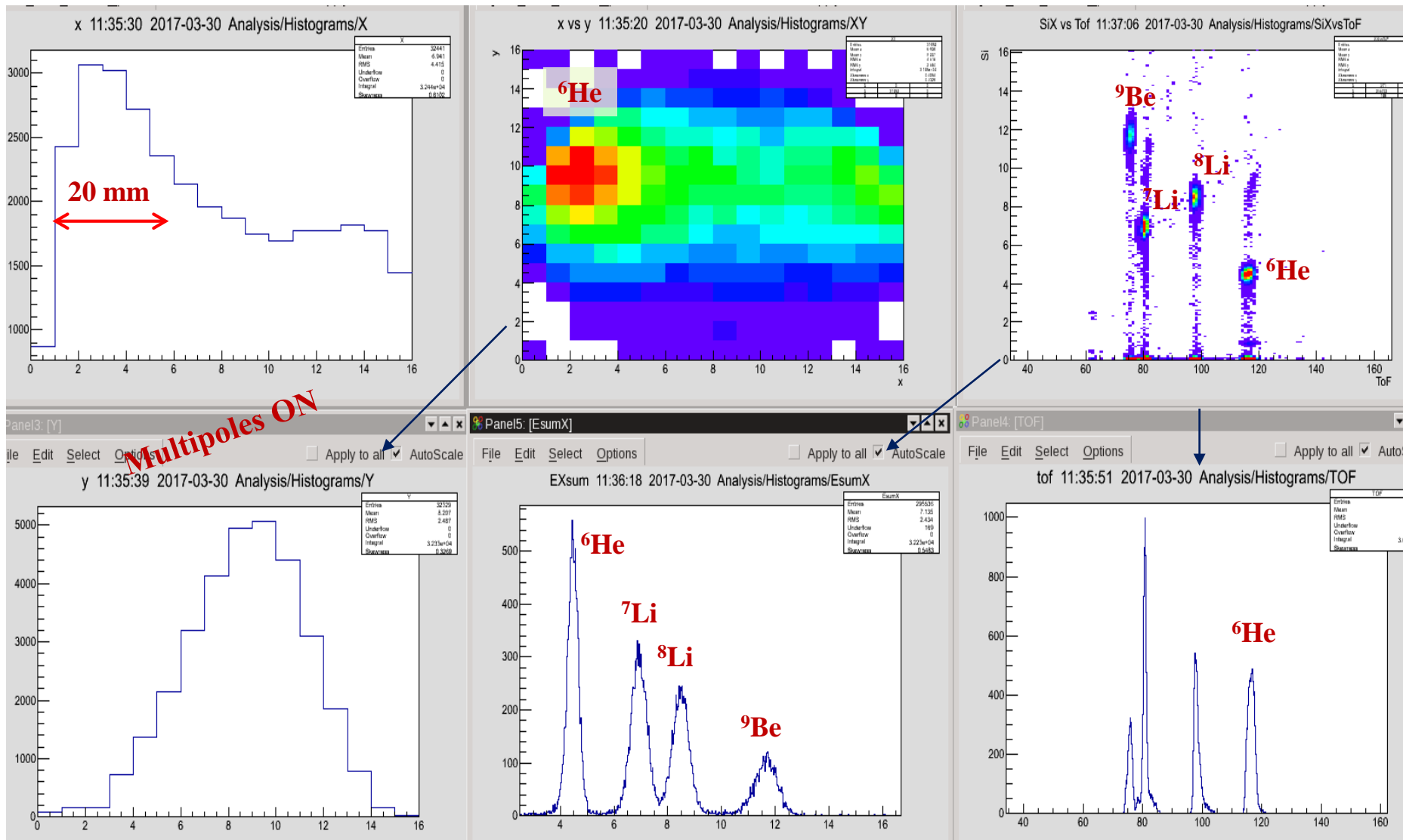
^{12}Be from $^{15}\text{N}(49.7 \text{ AMeV}) + \text{Be}(2 \text{ mm})$:

$I = 190 \text{ 1/s @ } 1 \text{ p nA}; \Delta p/p = 4\%; P \sim 92\%; E = 39.4 \text{ AMeV}; X_5_Y_5 = 22_25 \text{ mm}$

Good agreement with calculation & Factor $\sim 25 (I_{\text{Acc2}} / I_{\text{Acc1}})$



${}^6\text{He}$ from ${}^{15}\text{N}(49.7 \text{ AMeV}) + \text{Be}(2 \text{ mm})$:
 $I = 2700 \text{ 1/s @ } 1 \text{ pnA}; \Delta p/p = 2\%; E = 31.5 \text{ AMeV};$
 $X_5_Y_5 = 20_20 \text{ mm}; P \sim 53\% \text{ @ F3: } \pm 11 \text{ mm}$



It good agrees with estimations

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

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

Experiments in 2017

Main parameters (I, P, X_Y) are agree well with estimations

First experiments with RIBs could be started in 2017 ($I < 0.1 \mu\text{A}$)

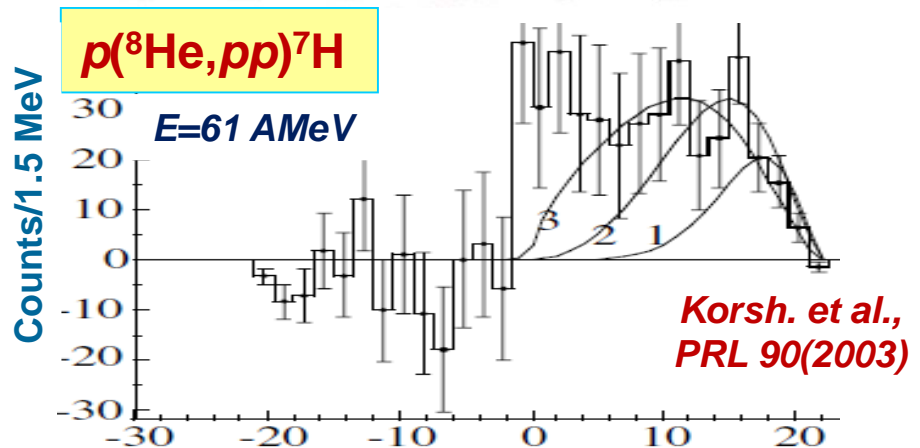
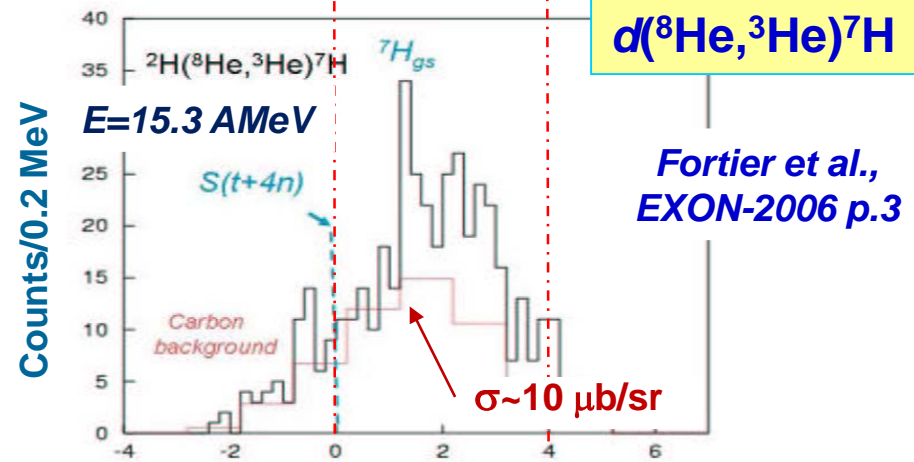
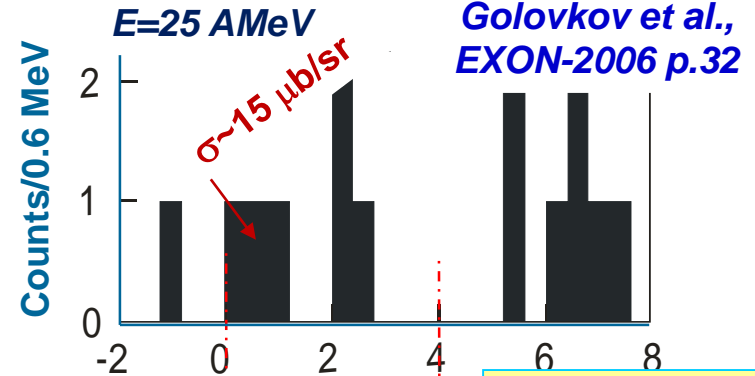
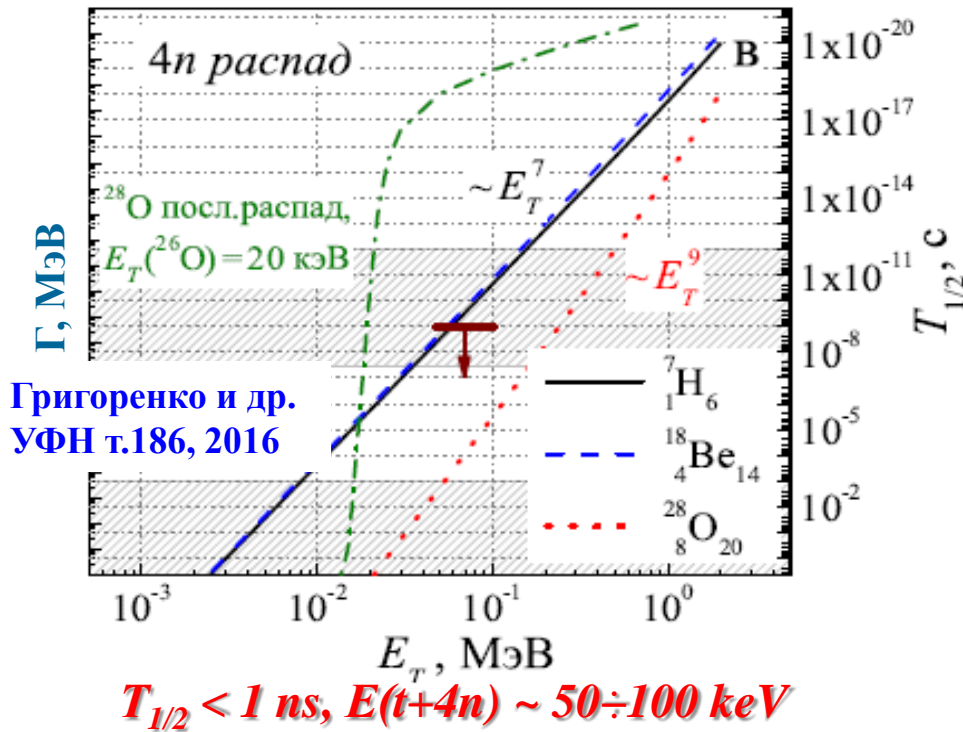
Experiments with intense primary beam ($\sim 1 \mu\text{A}$) will be able since 2018



2017

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

^7H puzzle: each time only limits of σ were observed

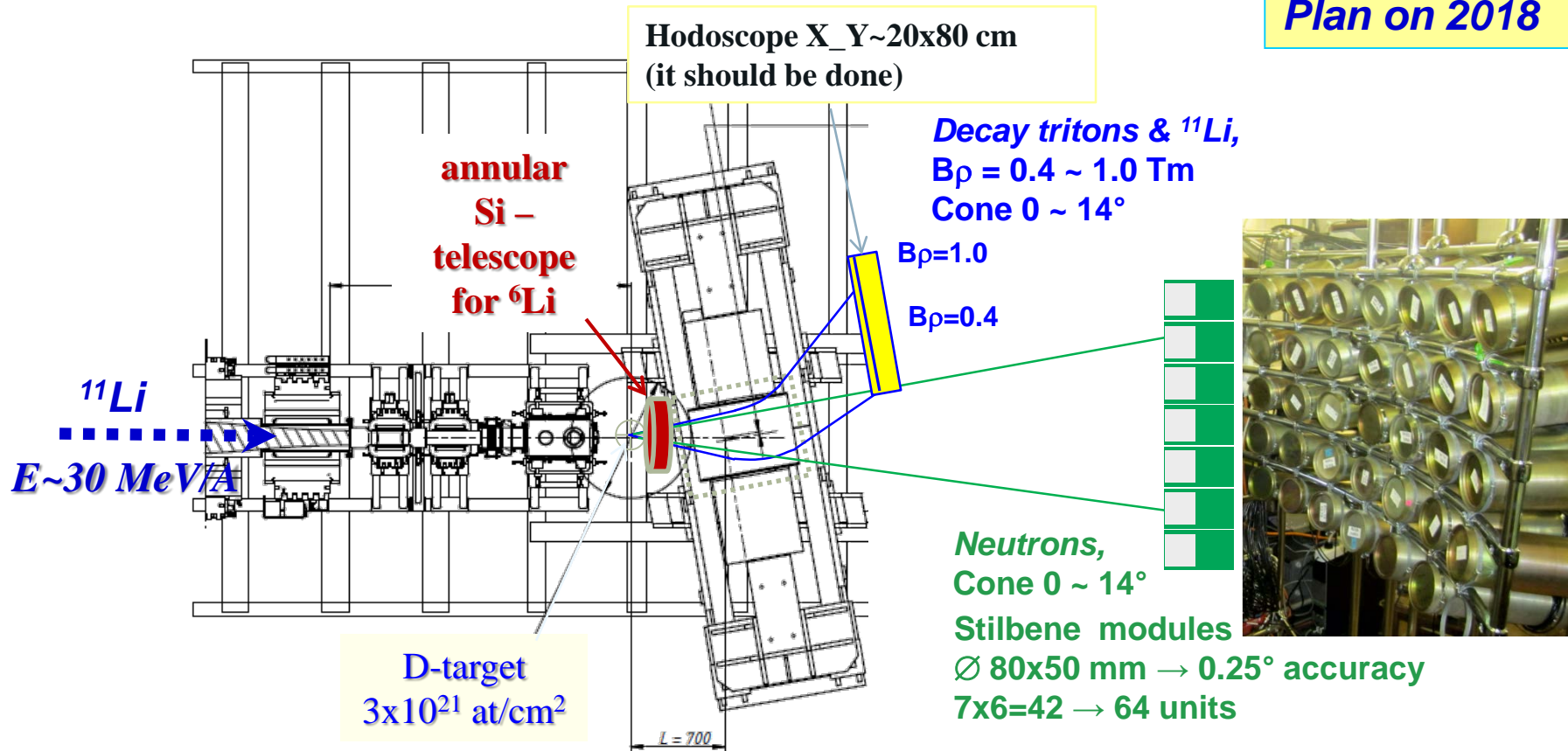


One could propose:

- 1) Drastically improvement of sensitivity in the reactions $d(^8\text{He}, ^3\text{He})^7\text{H}$ and $p(^8\text{He}, pp)^7\text{H}$ or
- 2) ^{11}Li as a projectile and alpha transfer reaction $d(^{11}\text{Li}, ^6\text{Li})^7\text{H}$

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

Plan on 2018



* $I({}^{11}\text{Li} @ 30 \text{ A MeV}) \sim 2 \times 10^4 \text{ pps} \implies \sim 100 \text{ } {}^7\text{H} \text{ events/day (missing mass)}$

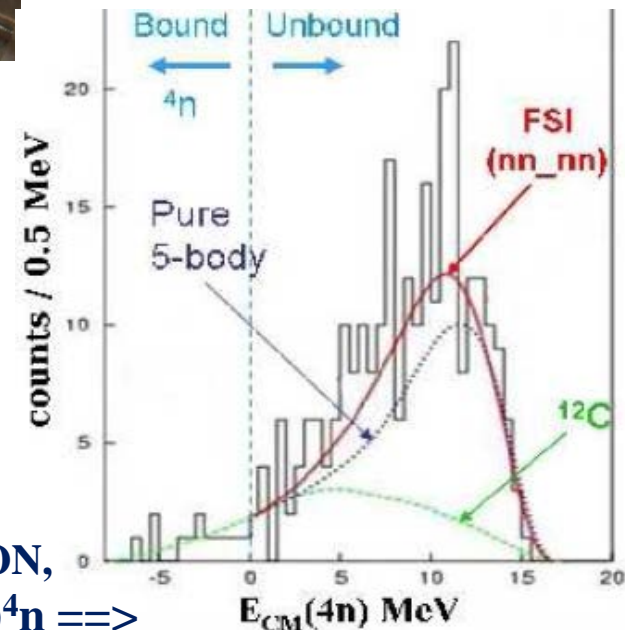
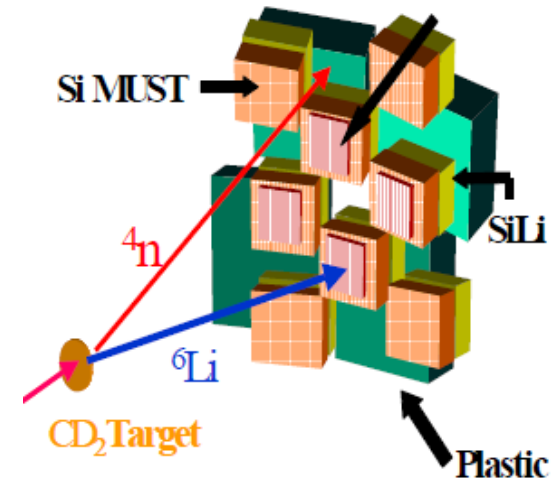
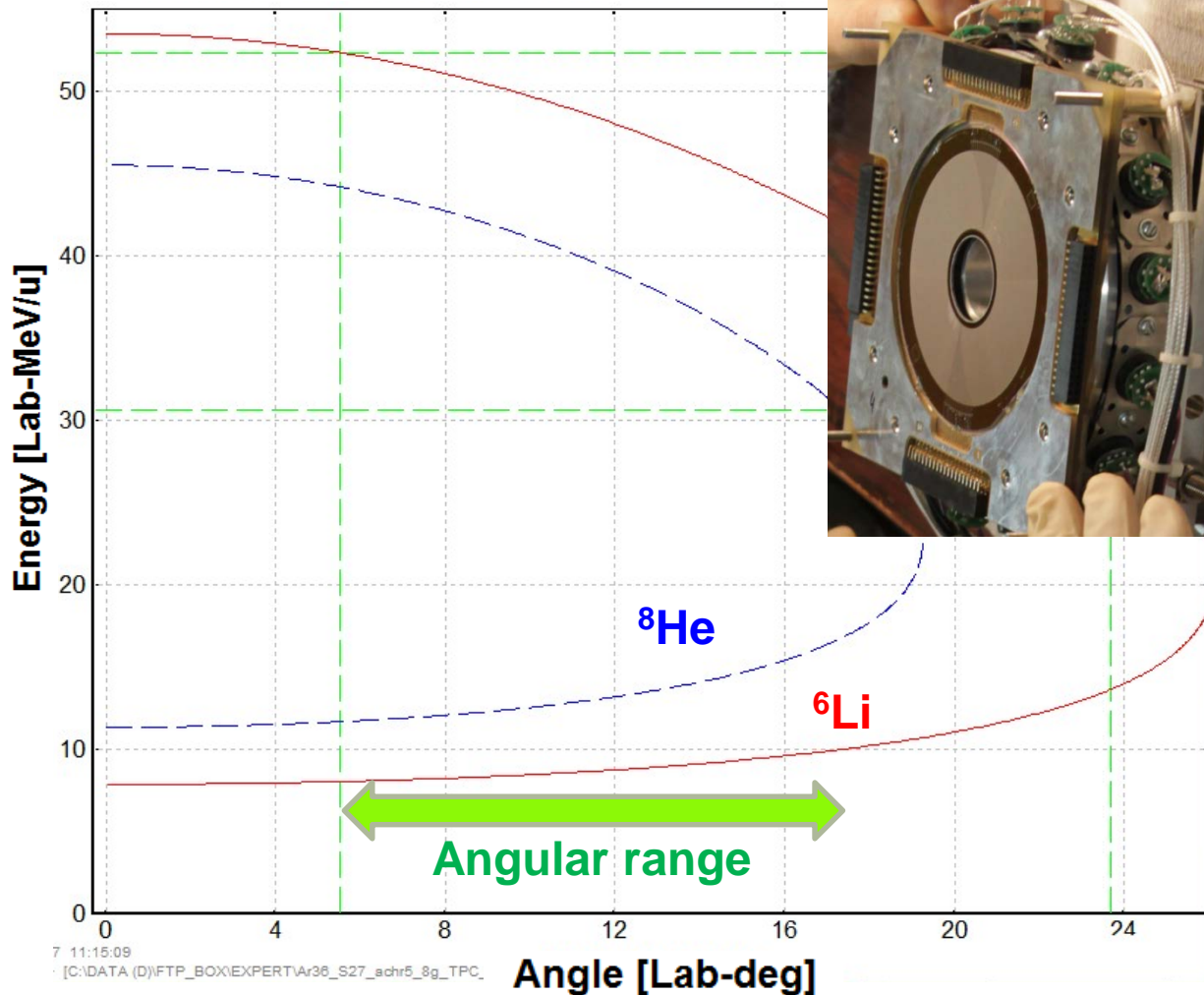
** Decay energy will be measured with around 100 keV resolution,
 $\sim 3 \text{ events/day (} {}^6\text{Li-t-n coincidences)}$

Plan on 2017: $d(^{12}\text{Be}, ^6\text{Li})^8\text{He}$ as a tool for the main run $d(^{11}\text{Li}, ^6\text{Li})^7\text{H}$

* alpha transfer cross section at 25 and 35 AMeV;

** useful kinematics to detect two stable particles via annular telescope;

*** could be done at $I(^{15}\text{N}) \sim 100 \text{ pA} \implies I(^{12}\text{Be}) \sim 2 \cdot 10^4 \text{ pps}$



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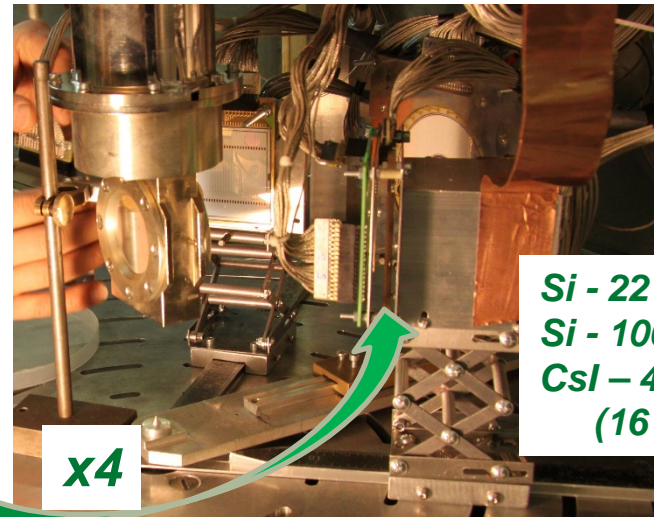
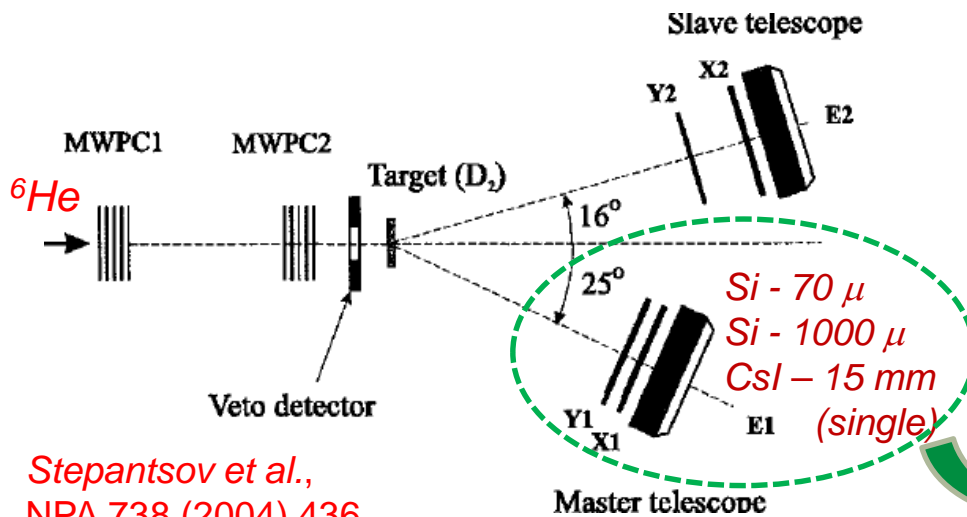
Angle [Lab-deg]

E. Rich et al., 2005 Proc. EXON, Peterhof, Russia $d(^8\text{He}, ^6\text{Li})^4n \implies$

Plan on 2017: $d(^6\text{He}, ^3\text{He})^5\text{H}$ as a tool for the main run $d(^8\text{He}, ^3\text{He})^7\text{H}$

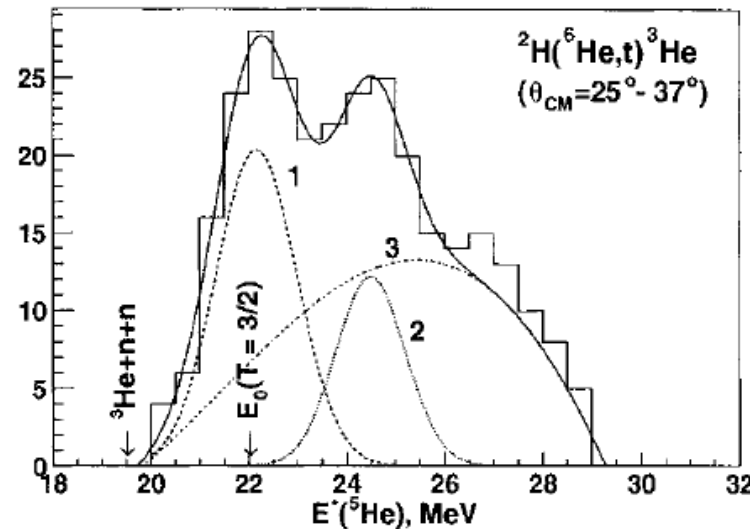
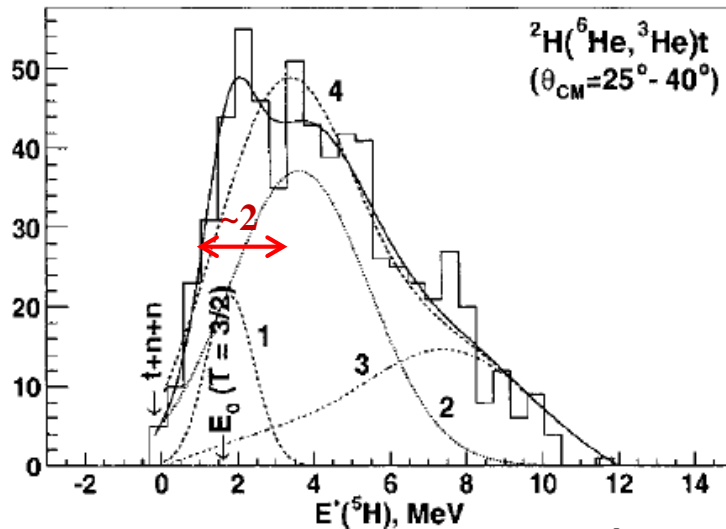
* cross section values for the $1p$ and $1n$ transfer reactions in a wide θ_{CM}

** improvement in missing mass measurements via novel telescopes



Si - 22 μ
Si - 1000 μ
CsI - 45 mm
(16 units)

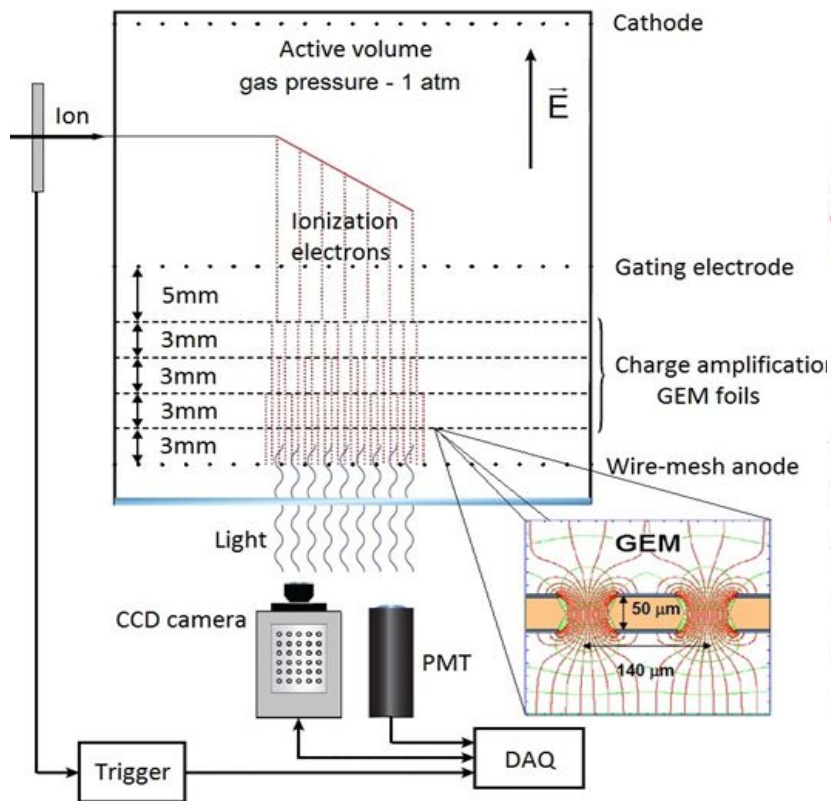
Stepantsov et al.,
NPA 738 (2004) 436



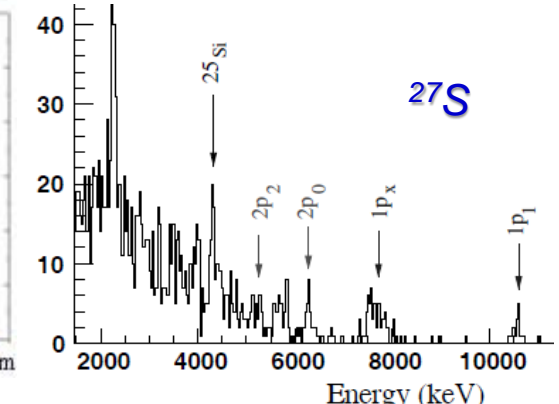
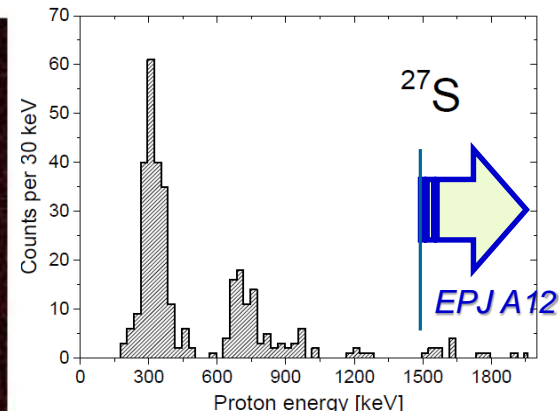
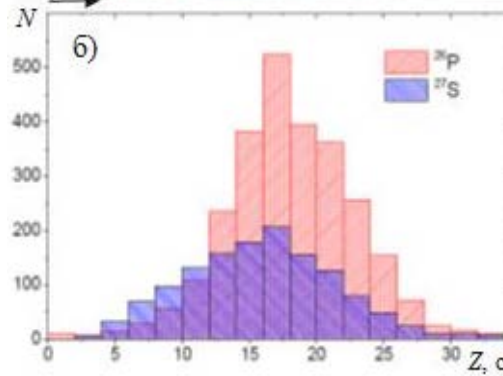
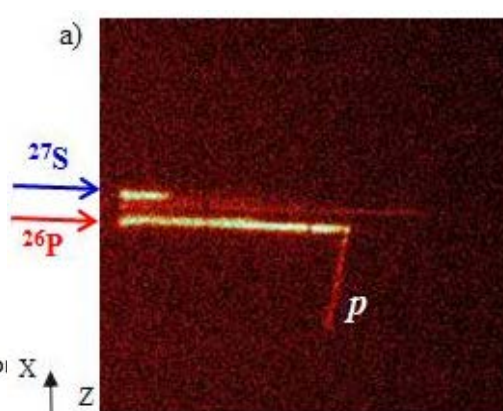
^5H (left) and ^5He (right) energy spectra depending on $^3\text{He}-t$ coincidences

Beta-delayed proton emission from ^{27}S and ^{26}P

via Optical Time Projection Chamber / *Janiak et al., PRC 95 (2017) 034315/*



Miernik et al., NIM A581 (2007) 194



Canchel et al., EPJ A12 (2001) 377

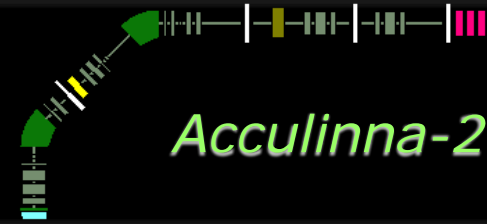
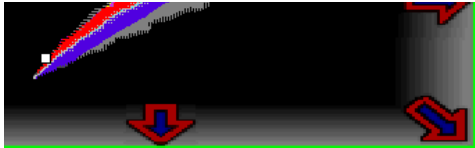
^{26}P				^{27}S			
$P_{\beta p}$	$P_{\beta p}$	$P_{\beta 2p}$	P_{tot}	$P_{\beta p}$	$P_{\beta p}$	$P_{\beta 2p}$	P_{tot}
415 κεB	~800 κεB			320 κεB	710 κεB		
10.4(9)% ÷ 13.8(10)%	1.1(3)%	1.5(4)%	35(2)%	24(3)% ÷ 28(2)%	> 6.7(8)%	3.0(6)%	64(3)%
17.96(90)%	2.5(3)%	2.2(3)%	39(2)%	2.3±0.9%		1.1±0.5%	~ 4%

Thomas et al., EPJ A21 (2004) 419

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

^{23}Si : β delayed ^3He radioactivity search via OTPC

^{32}S (@52 AMeV, 100 pA)
 \rightarrow 8 pps ^{23}Si ($T_{1/2} = 42.3$ ms)



Acculina-2

	^{27}S	^{28}S	^{29}S	^{30}S	^{31}S	^{32}S	^{33}S
	3.45e-3 0.001%						
	^{26}p	^{27}p	^{28}p	^{29}p	^{30}p	^{31}p	^{32}p

^{22}Si	^{23}Si	^{24}Si
1.26e-1 0.847%	8.26e+0 3.198%	3.19e+1 0.664%
	^{22}Al	^{23}Al
	1.13e+2 2.257%	2.14e+2 0.236%
	^{21}Mg	^{22}Mg
	9.72e+2 1.02%	6.99e+2 0.046%
	^{20}Na	^{21}Na
	4.81e+3 0.306%	4.93e+2 0.004%

^3He (indicated by a dashed circle and arrow pointing to the ^{23}Si cell)

“... ^{23}Si has an open channel for the **beta delayed ^3He** emission - *never seen before*. Moreover, this channel should be relatively easy to see, because the beta-alpha decay leads to the unbound ^{19}Na . Thus, the **^3He channel is the only one in which a single particle with $Z=2$** is emitted. The ^3He emission is a sort of a mirror of tritium emission - this may contain some physics. **This point was born in discussion with Karsten Riisager and Hans Fynbo in Aarhus.** It would be great if we could make the ^{23}Si experiment at Dubna.”

Proposal by M. Pfützner et al.

Summary and outlook

ACCULINNA-2 fragment separator is commissioned in 2017, the design parameters of this facility were experimentally confirmed.

The intensities obtained in the fragmentation reaction ^{15}N (49.7 AMeV) + Be (2 mm) for the RIBs of ^{14}B , ^{12}Be , $^{9,11}\text{Li}$, $^{6,8}\text{He}$ were on average 25 times higher in comparison with the values for old facility.

The first-priority experimental program with RIBs is focused on ^7H and ^{23}Si nuclides and their possible exotic decays. It will be started this year.

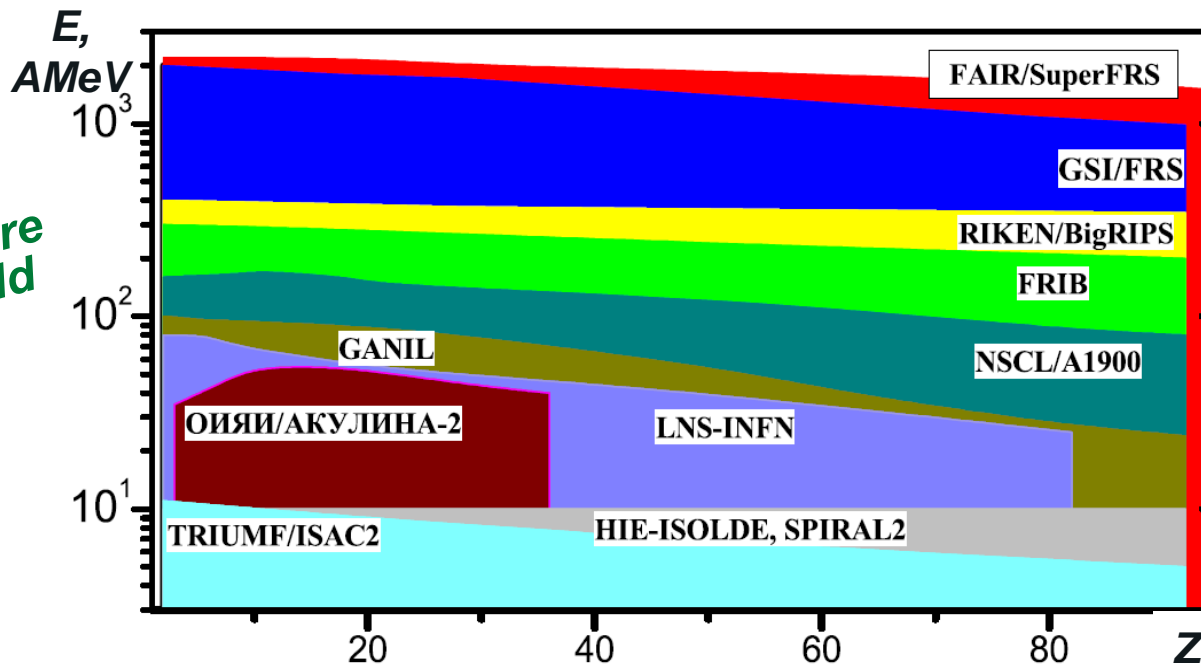
Thanks for your attention

Acculina-2 since 2017/18

Request / Cost

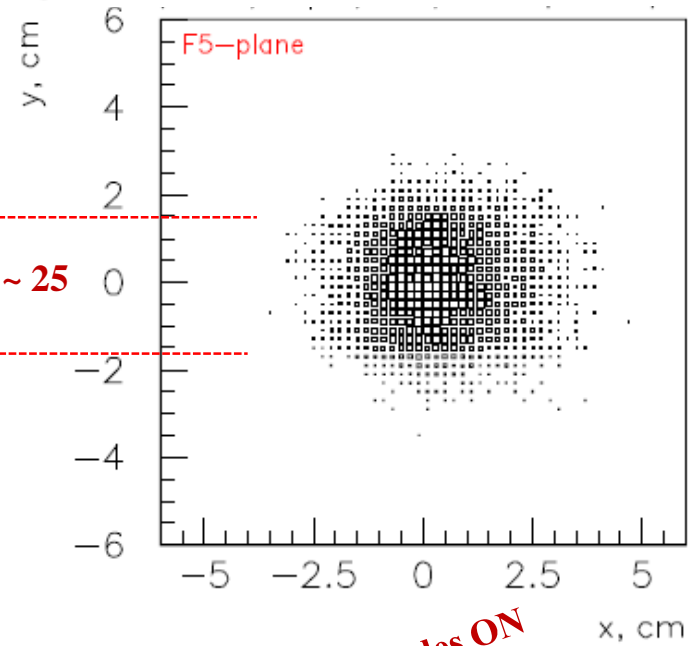
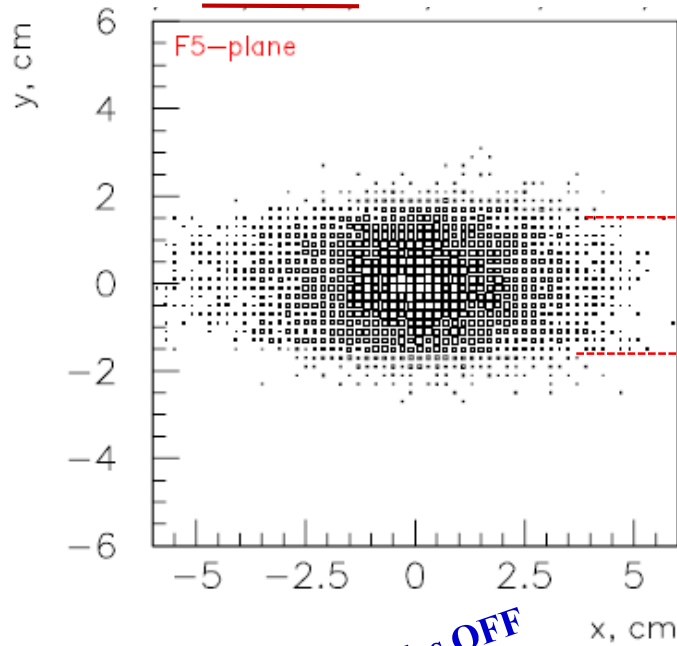
Product name	T_{\min} U400M	Beam, E, I	Method, equipment
<p>^{27}S : $P(\beta 3p)$ – value/limit</p> <p>^{23}Si : $P(\beta^3\text{He})$ – yes/no/limit</p> <p>^{26}S : observation, states</p>	One week	^{32}S , 52 AMeV, 0.2 – 0.5 pμA	<p>OTPC, chopper & RF-kicker</p> <p>$p(^{28}\text{S},t)^{26}\text{S}$ missing mass & RF-kicker</p>
<p>^{17}Ne : 2p decay for $3/2^-$ state $\Gamma_{2p}/\Gamma_{\gamma} \rightarrow 0.0002\%$</p> <p>$^7\text{H}$: observation, states, 4n decay</p> <p>^{10}Li : E and Γ for ground state</p>	Two or more weeks	^{20}Ne , 54 AMeV, 1.0 pμA ^{15}N , 49 AMeV, 1.0 pμA	<p>$p(^{18}\text{Ne},d)^{17}\text{Ne}^*$ combined mass, zero angle spec.</p> <p>$d(^8\text{He},^3\text{He})^7\text{H}$ $d(^{11}\text{Li},^6\text{Li})^7\text{H}$</p> <p>$p(^{11}\text{Li},d)^{10}\text{Li}$ combined mass</p>
<p>^{10}He :</p> <p>^{13}Li :</p> <p>^{16}Be :</p> <p>E, Γ, J^π of excited states, search for exotic decays 2n, 4n</p>	Three or more weeks	$^{11}\text{B}^{3+}$, 34 AMeV, 4.0 pμA $^{22}\text{Ne}^{7+}$, 44 AMeV, 1.0 pμA	<p>$t(^8\text{He},p)^{10}\text{He}$</p> <p>$t(^{11}\text{Li},p)^{13}\text{Li}$</p> <p>$t(^{14}\text{Be},p)^{16}\text{Be}$</p> <p>tritium target, neutron array</p>

Where we are
in the world



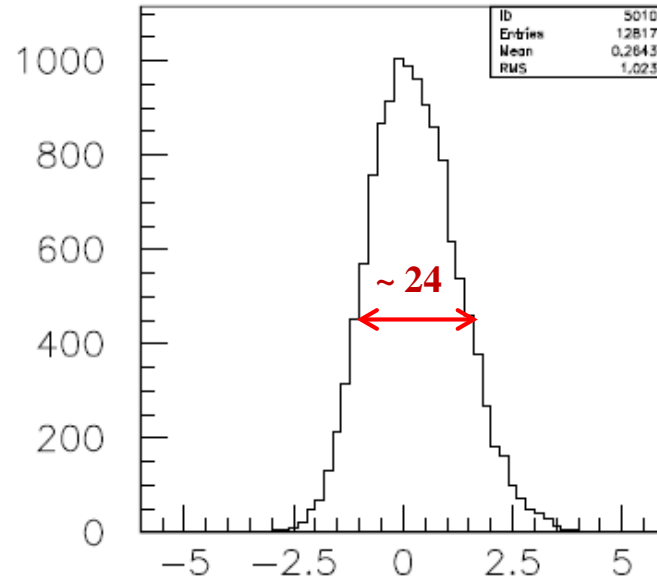
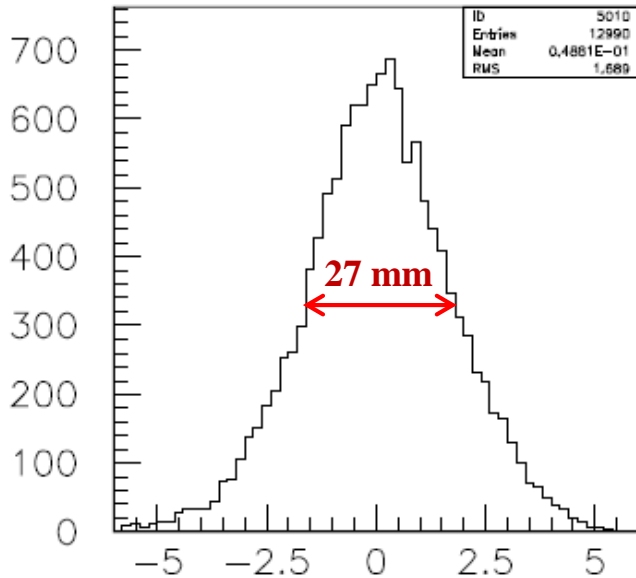
Установка	ACC	ACC-2	COMBAS	LISE	A1900	RIPS	BigRIPS	FRS	SFRS
Институт		FLNR, JINR		GANIL	MSU	RIKEN		GSI	
$\Delta\Omega$, msr	0.9	5.8	6.4	1.0	8.0	5.0	8.0	0.32	5.0
δ_p , %	2.5	6.0	20	5.0	5.5	6.0	6.0	2.0	5.0
$\rho/\Delta\rho$, a.u.	1000	2000	4360	2200	2915	1500	3300	8600	3050
$B\rho_{\text{max}}$, Tm	3.2	3.9	4.5	4.3	6.0	5.76	9.0	18	18
Length, m	21	38	14.5	42	35	21	77	74	140
E_{min} , A MeV	10	5	20	40	110	50		220	
E_{max} , A MeV	40	50	80	80	160	90	350	1000	1500

$^{16}\text{N}(46\text{MeV}) + \text{Be}(2\text{mm}) \rightarrow ^{12}\text{Be} \rightarrow \text{Wedge}(\text{Be}, 1\text{mm}, \theta_{\text{achr}} = 1.75\text{mrad})$



Multipoles OFF

Multipoles ON

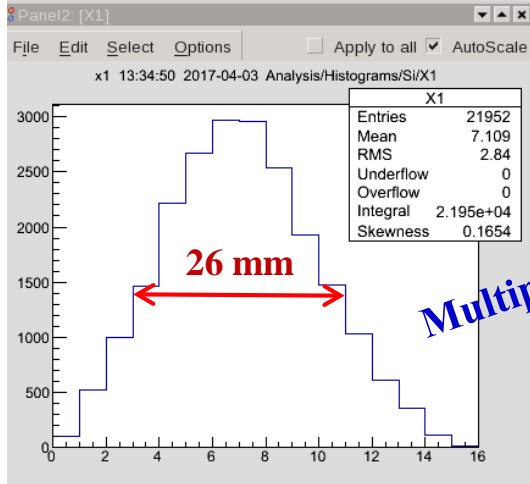
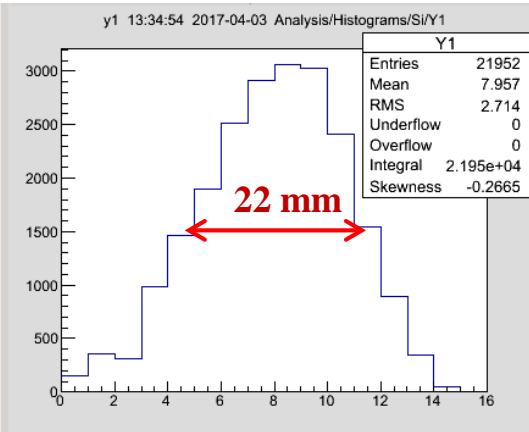
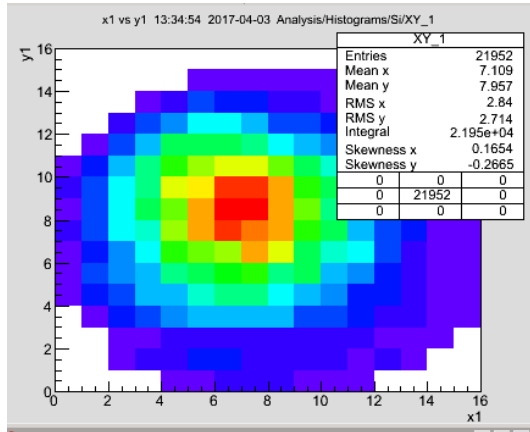


^{12}Be transfers profile at F5 (by S.V. Stepanov)

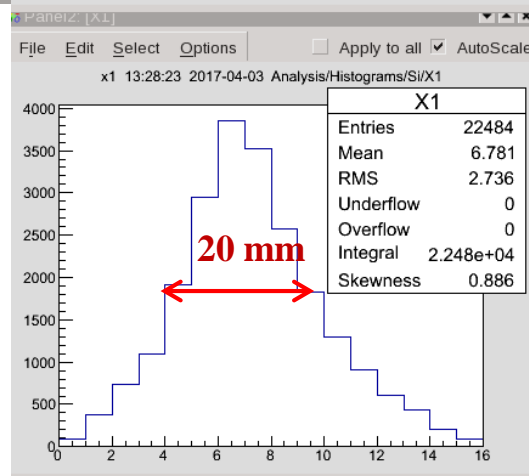
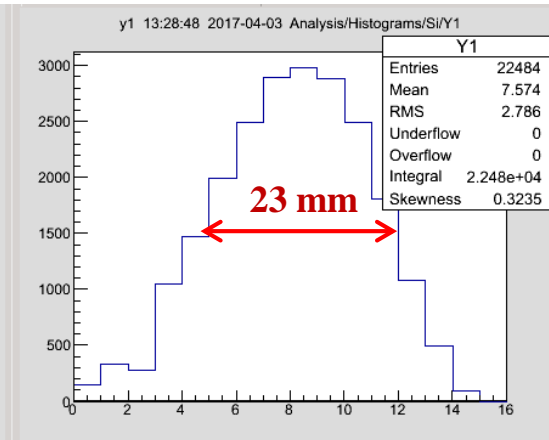
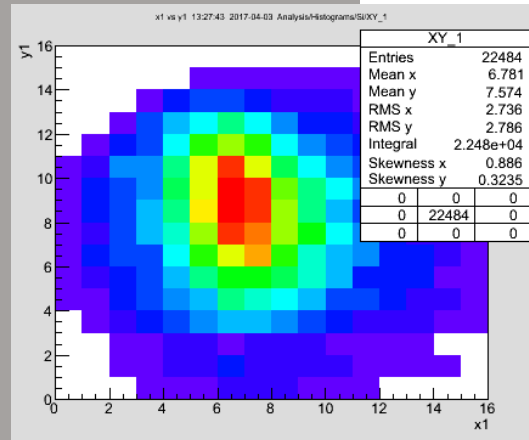
^{12}Be transfers profile at F5

← *Multipoles OFF*

Multipoles ON



Multipoles OFF



Multipoles ON

$^{15}\text{N}(49.7 \text{ AMeV}) + \text{Be}(2 \text{ mm}) \rightarrow$
 $^{12}\text{Be} @ 39.4 \text{ AMeV};$
 Wedge(Be, 1 mm), $\Delta p/p = 4\%$

^{26}S : search via missing mass measurement

NNDC: $T_{1/2} \sim 10$ ms

Acculina-1: $\text{ToF}_{\text{F1-F4}} \sim 0.0003$ ms

Experiment (implantation method):

$T_{1/2} < 79$ ns, $Q_{2p} > 640$ keV

Fomichev et al., IJMP E20 (2011) 1491

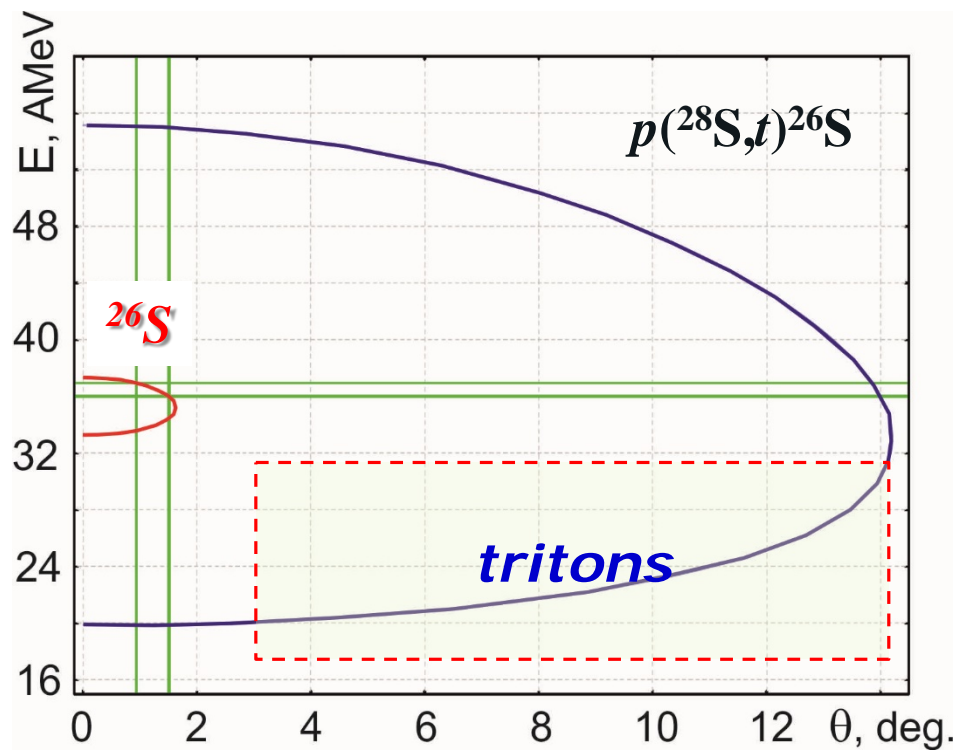
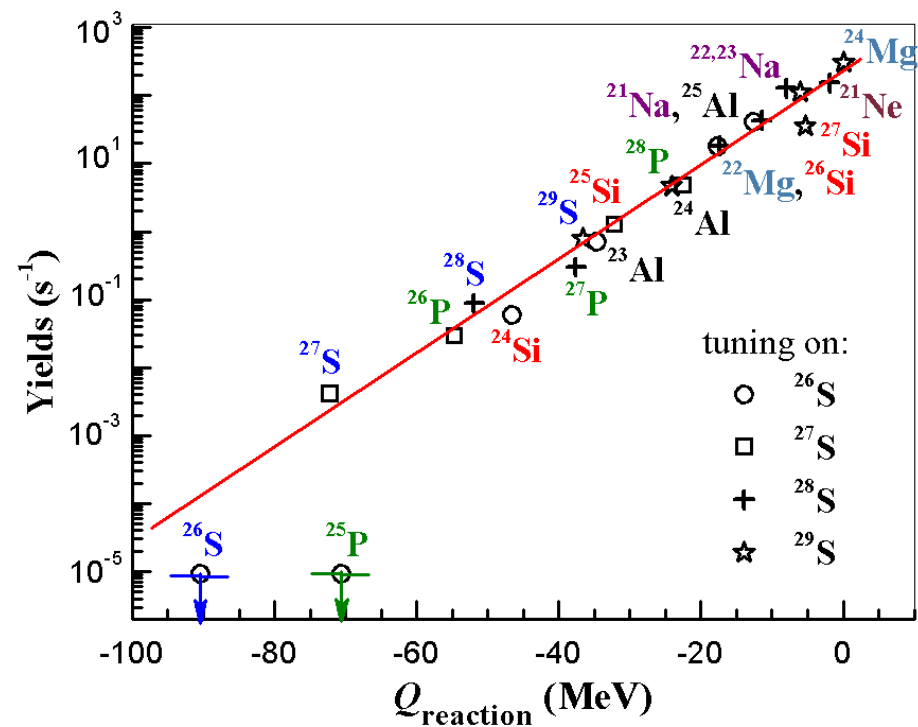
Acculina-2 with RF-kicker

missing mass in $p(^{28}\text{S}, t)^{26}\text{S}$:

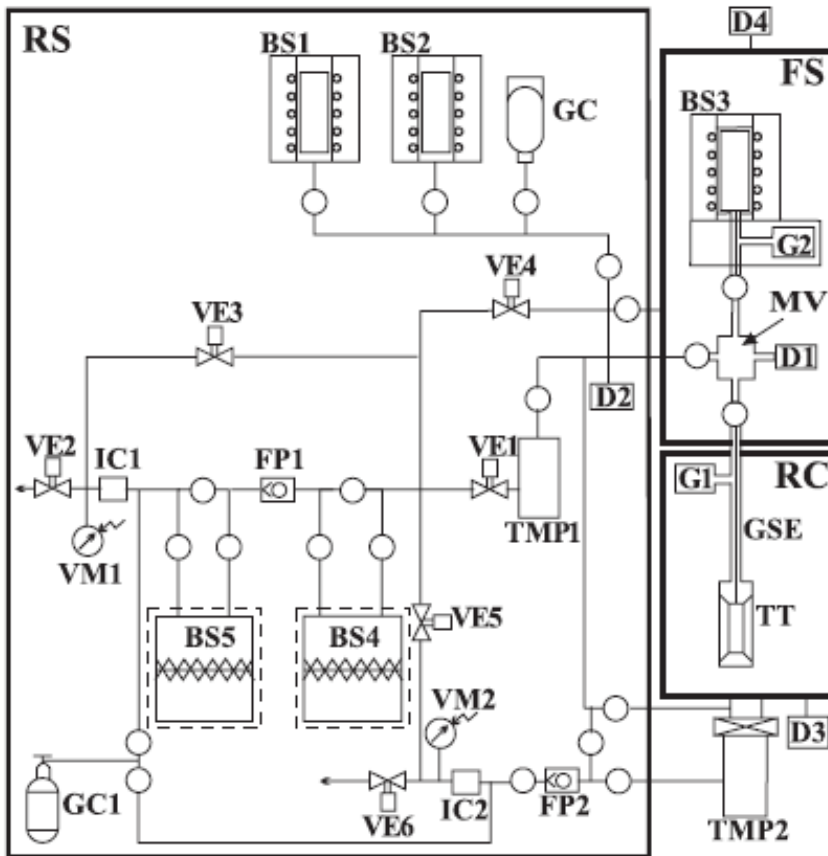
$I(^{28}\text{S}) \sim 10^3$ pps, $P \sim 12\%$, $E \sim 38$ MeV/A,

1 mm liquid H_2 , $\sigma \sim 200$ $\mu\text{b}/\text{sr} \implies$

~ 10 events ^{26}S per week



Physical unique targets H, He



Basic scheme of the complex.

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

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

Gas:

$\phi=25$ mm, $d=3\div 6$ mm,
 $T=26$ K, $P=0.92$ Atm,
 $x=3\cdot 10^{20}$ Atm/cm²

Liquid:

$\phi=20$ mm, $d=0.4\div 0.8$ mm,
 $w=2\times 8.4$ μ stainless steel,
 $x=1.1\cdot 10^{21}$ Atm/cm²
 $I \leq 960$ Ci ($3.54\cdot 10^{13}$ Bq)

