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

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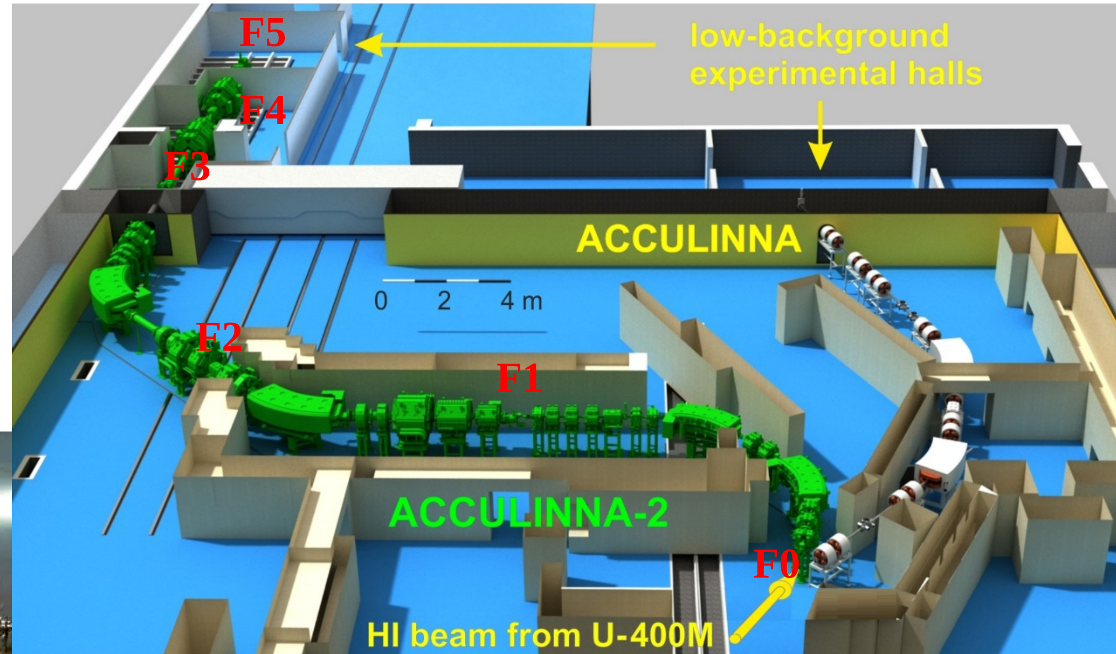
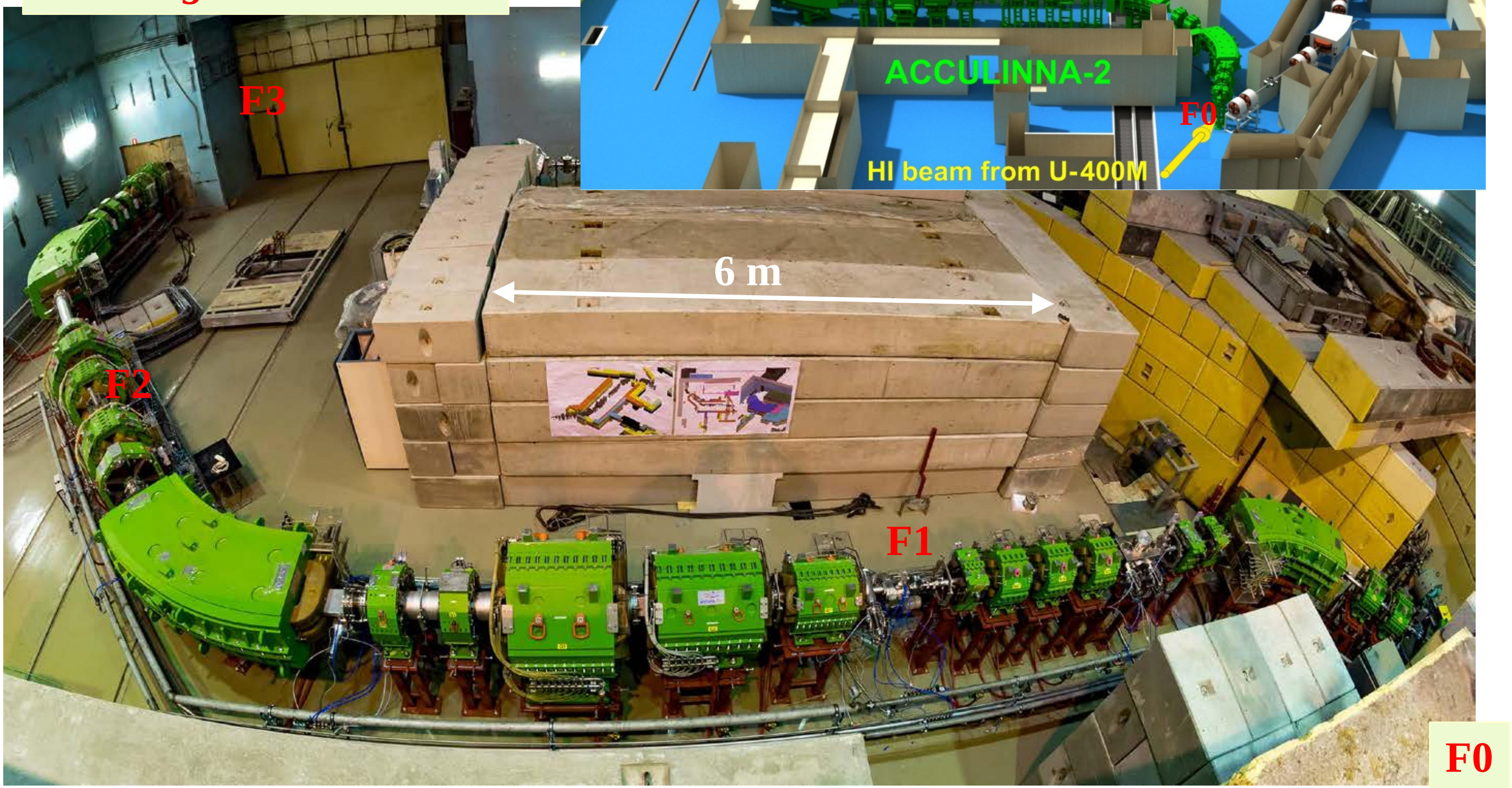
Dubna PAC meeting, June 14-15, 2017

Setup layout
&
Today status

total length F0-F5 ~53m
39 magnetic elements

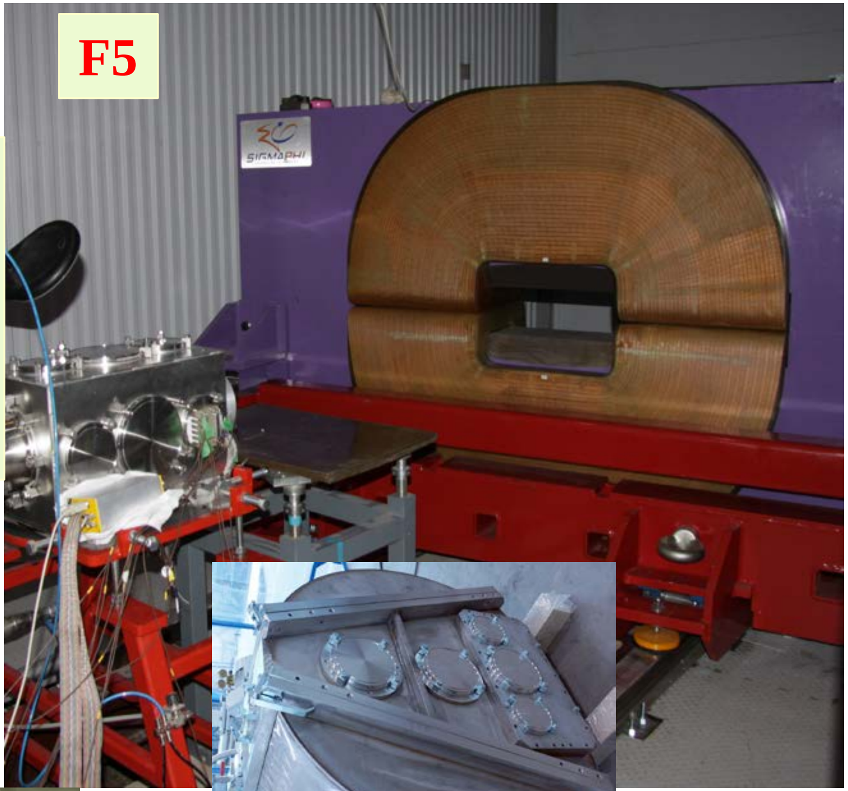




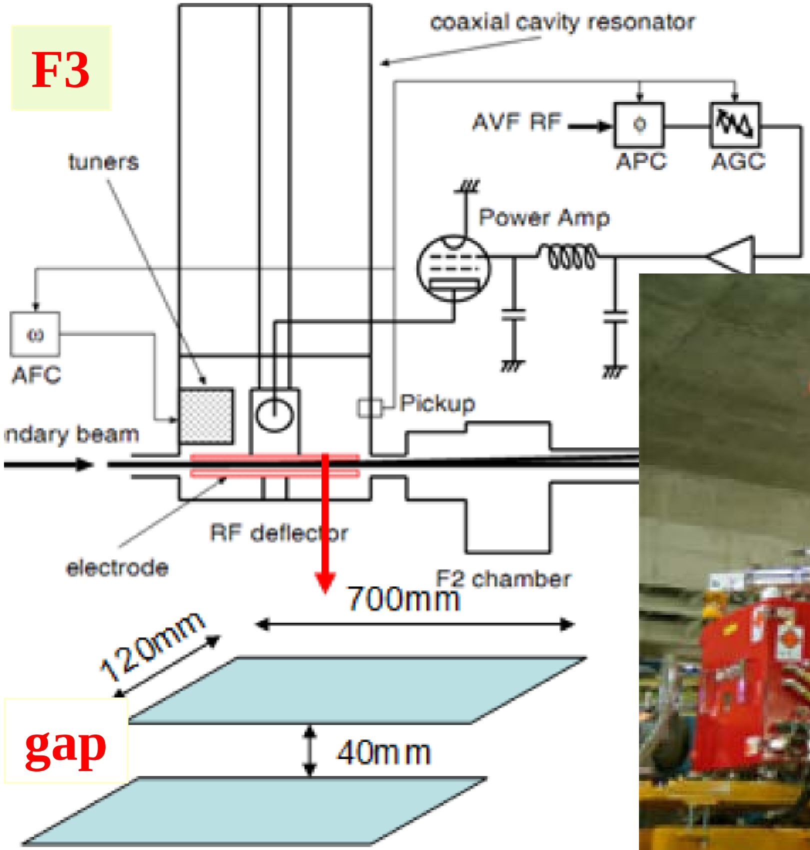
Setup layout in F3-F5

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

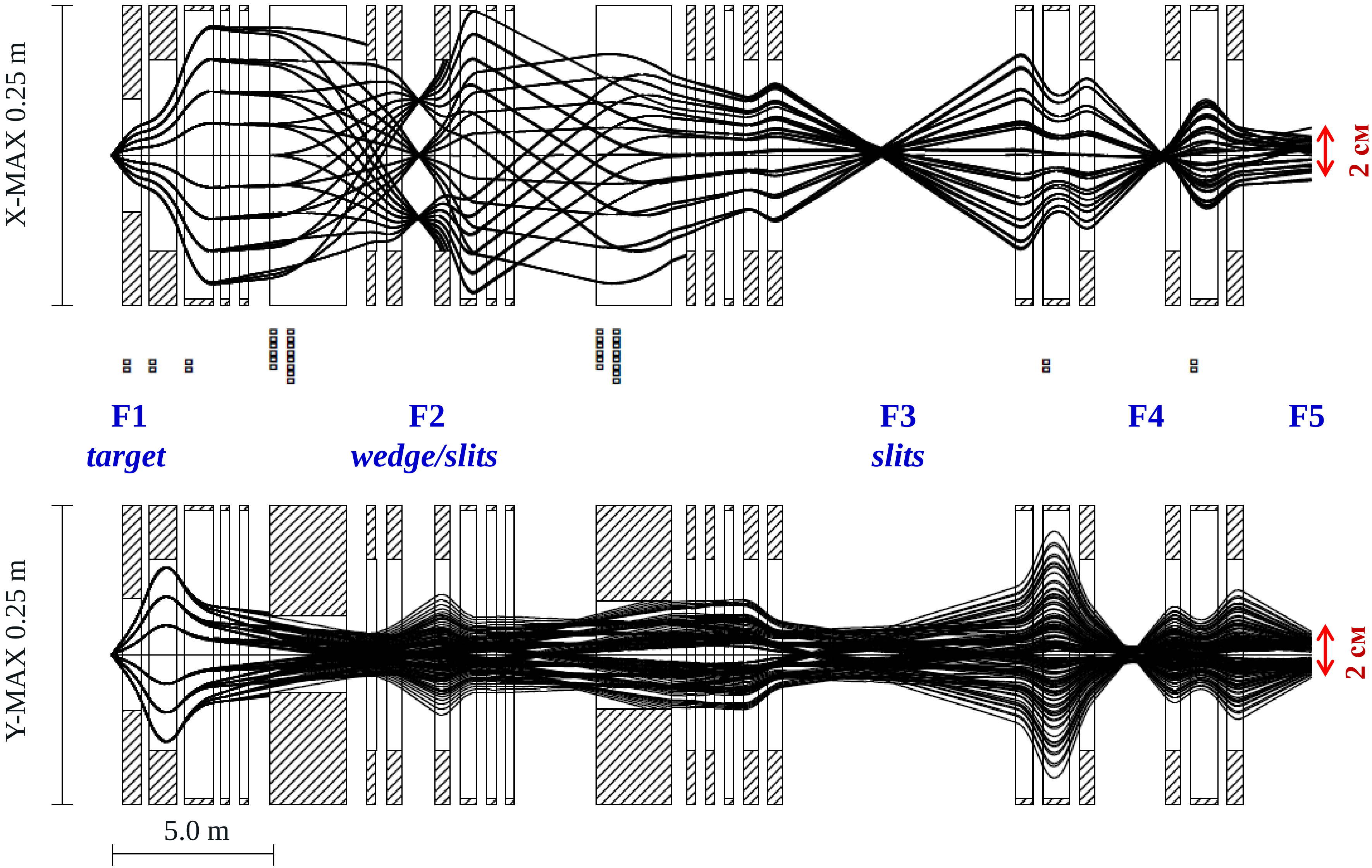


gap

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

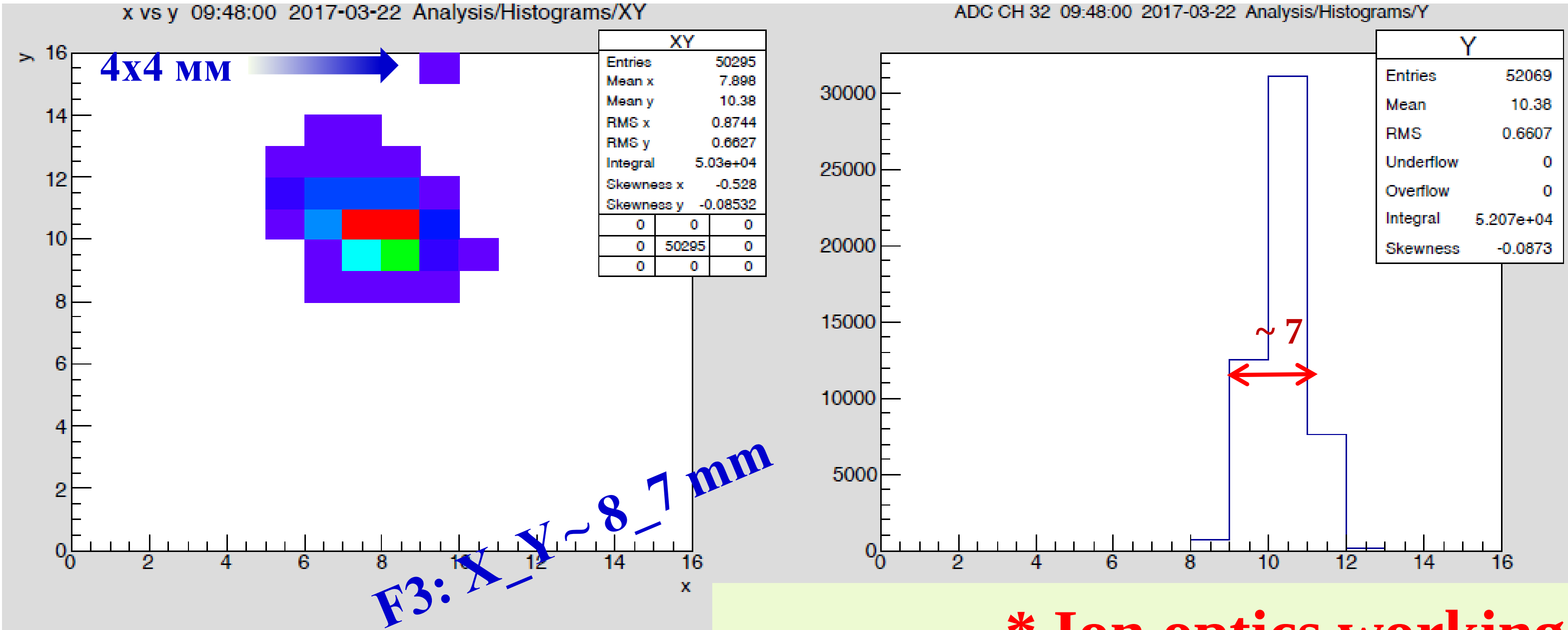
Goals of the test in March 2017:

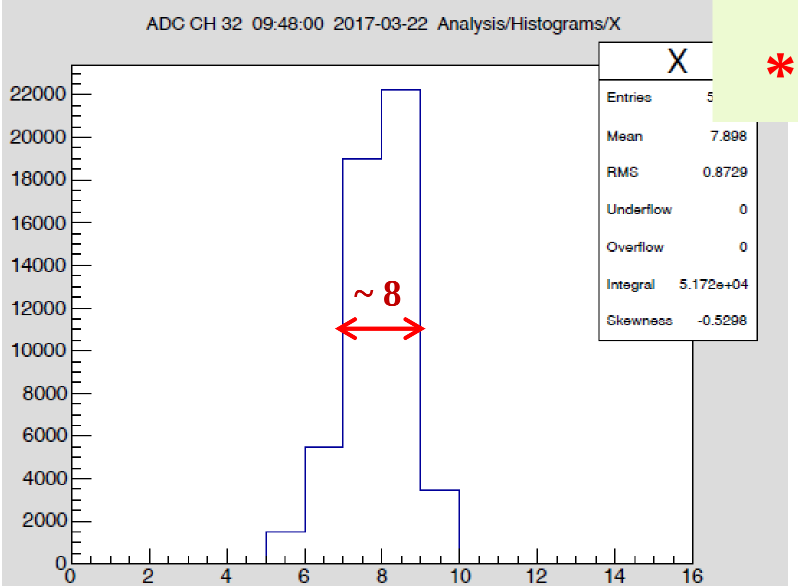
- ^{15}N profile at F3 depending on F1 diaph. (∅ 25, 12, 7 mm)
-- main parameters (I, P, X_Y) of some RIBs at F3, F4, F5



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





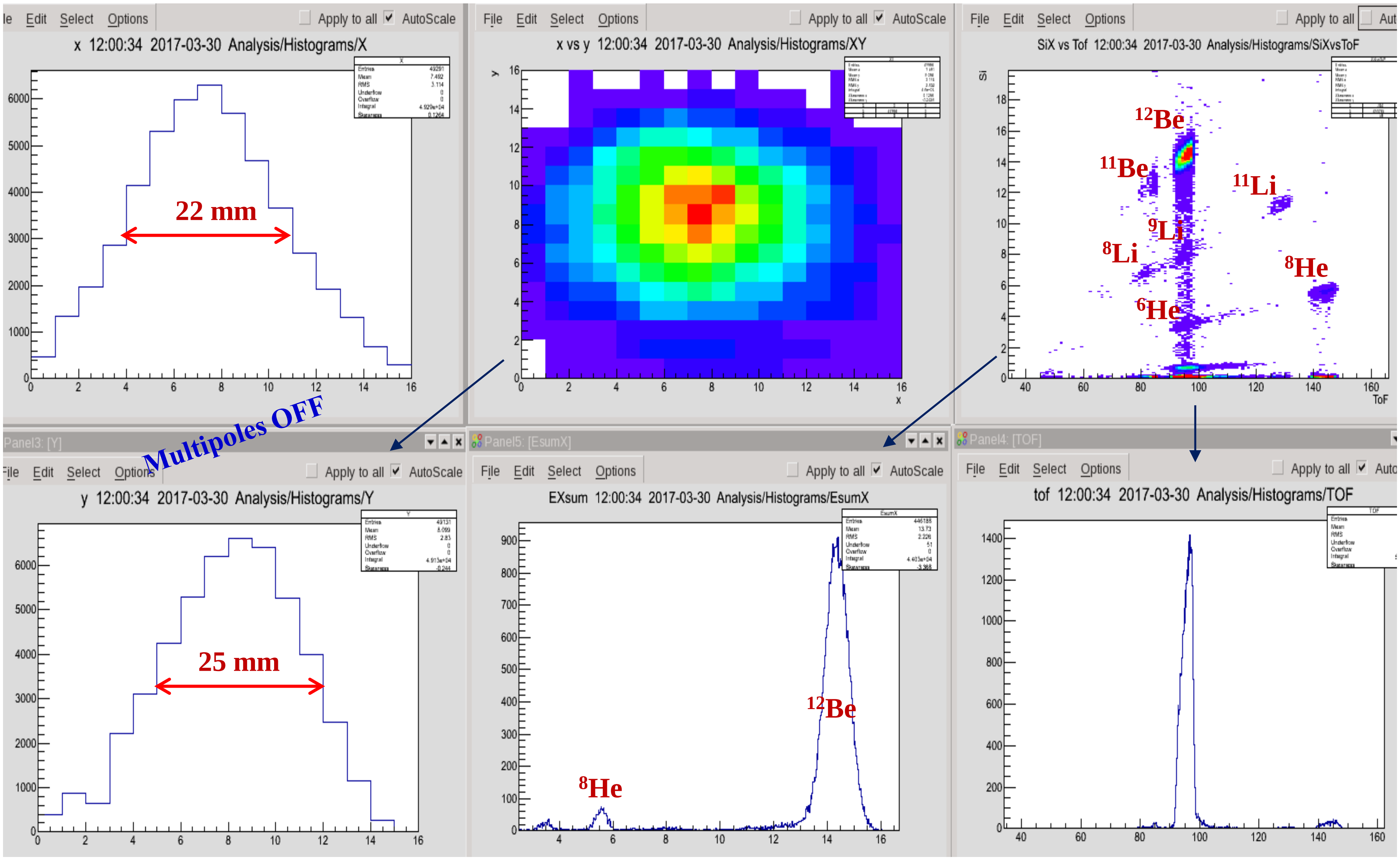
*** Ion optics working well !**

**** RIB production could be started**

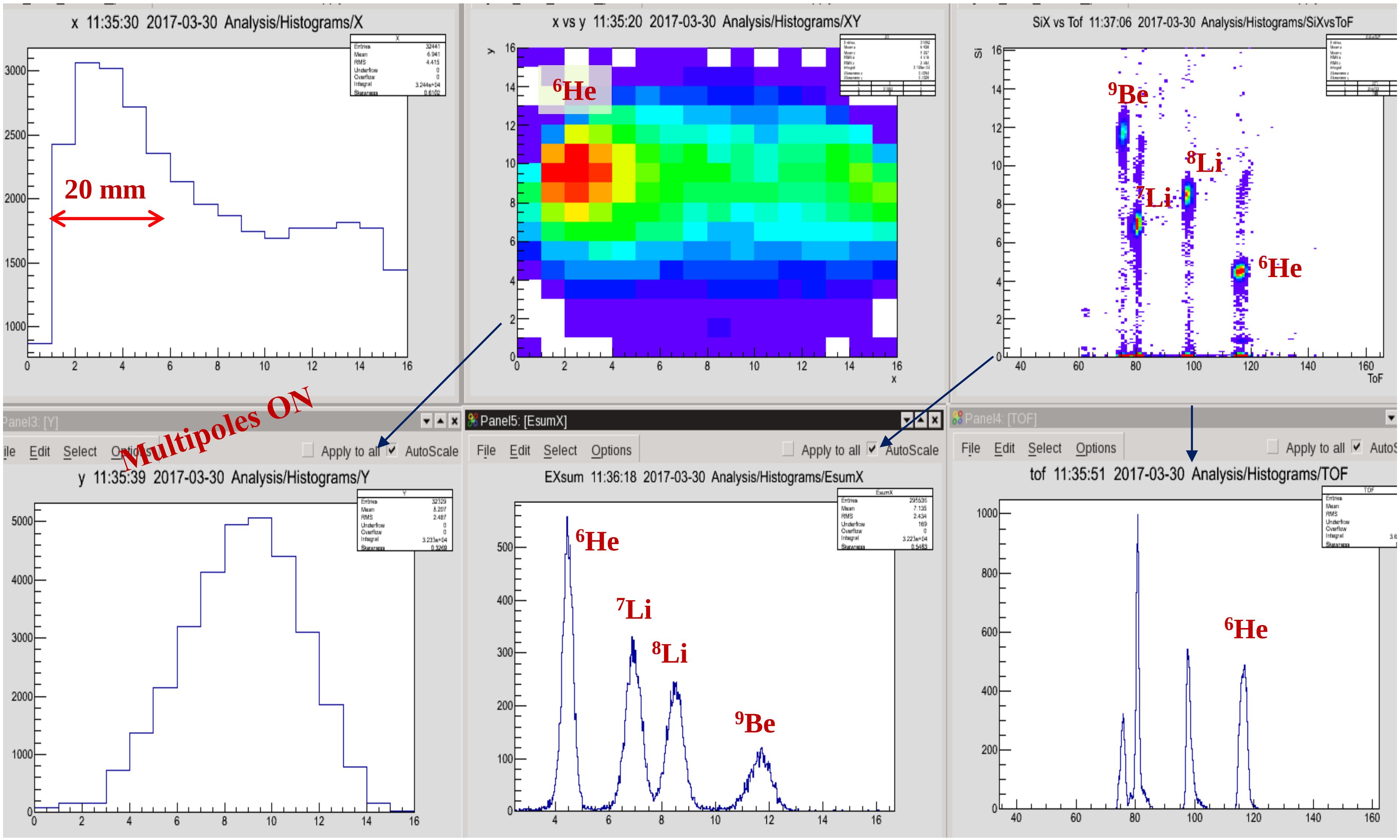
^{12}Be from ^{15}N(49.7 AMeV) + Be(2 mm):

I = 190 1/s @ 1 pnA; $\Delta p/p$ = 4%; P ~ 92%; E = 39.4 AMeV; X_5_Y_5 = 22_25 mm

Good agreement with calculation & Factor ~ 25 (I_Acc2 / I_Acc1)



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



It good agrees with estimations

RIBs production rates in ^{15}N(49.7 AMeV) + Be(2 mm) reaction
F1: I(^{15}N) = 1 pnA @ 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
^{9}Li	33,1	1100
^{8}He	35,8	25
^{6}He	31,5	2700

Experiments in 2017

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

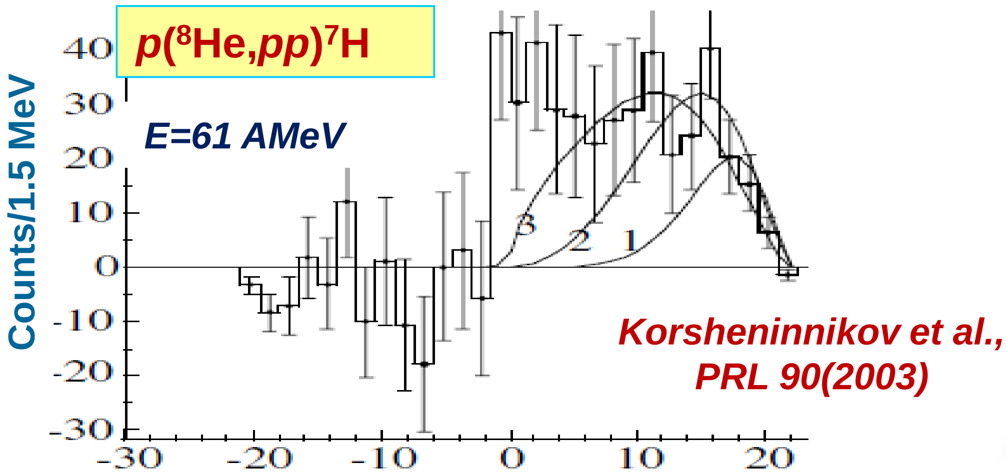
First experiments with RIBs could be started in 2017 (I < 0.1 pμA)

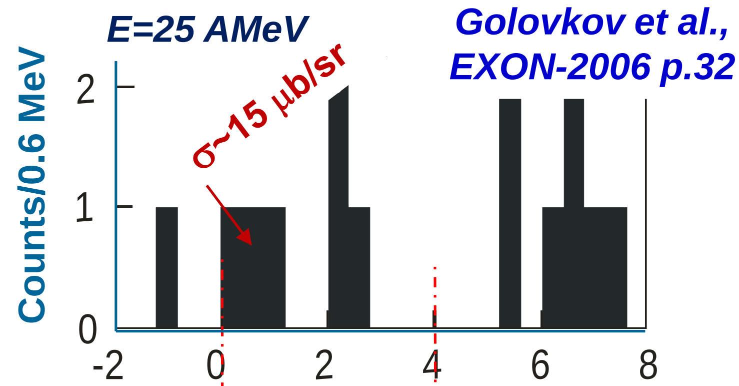
Experiments with intense primary beam (~ 1 pμA) will be able since 2018

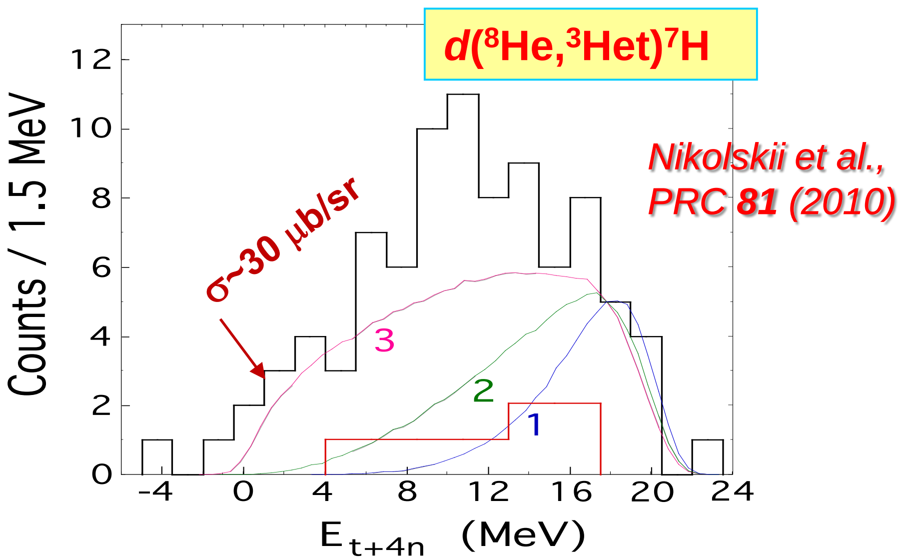
$^{12}Be + d \rightarrow {}^{6}Li + {}^{8}He$ (alpha transfer cross section)
$^{6}He + d \rightarrow {}^{3}He + {}^{5}H$ (proton transfer cross section)
2017

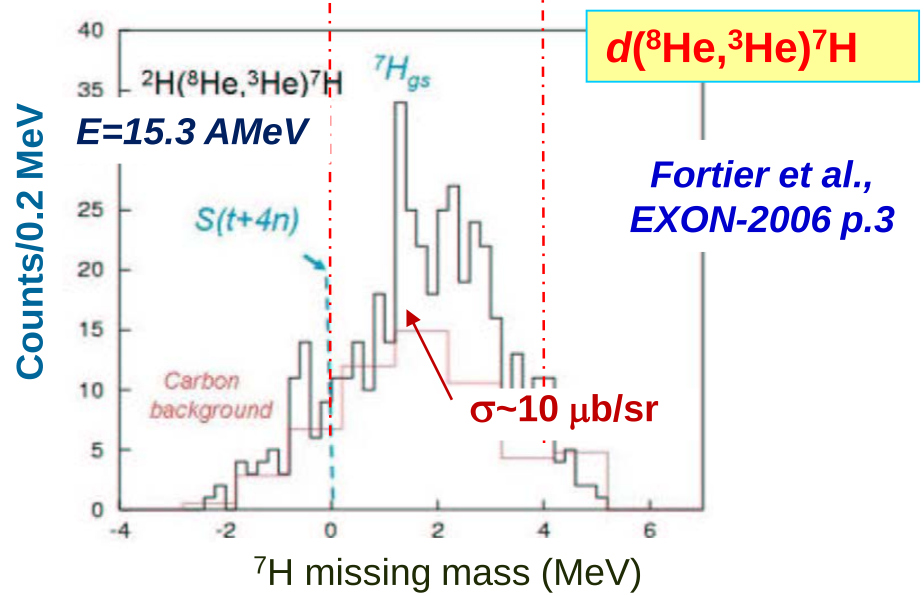
Moving ahead to ^{7}H via ^{11}Li or ^{8}He
2018 - flagship exp.

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







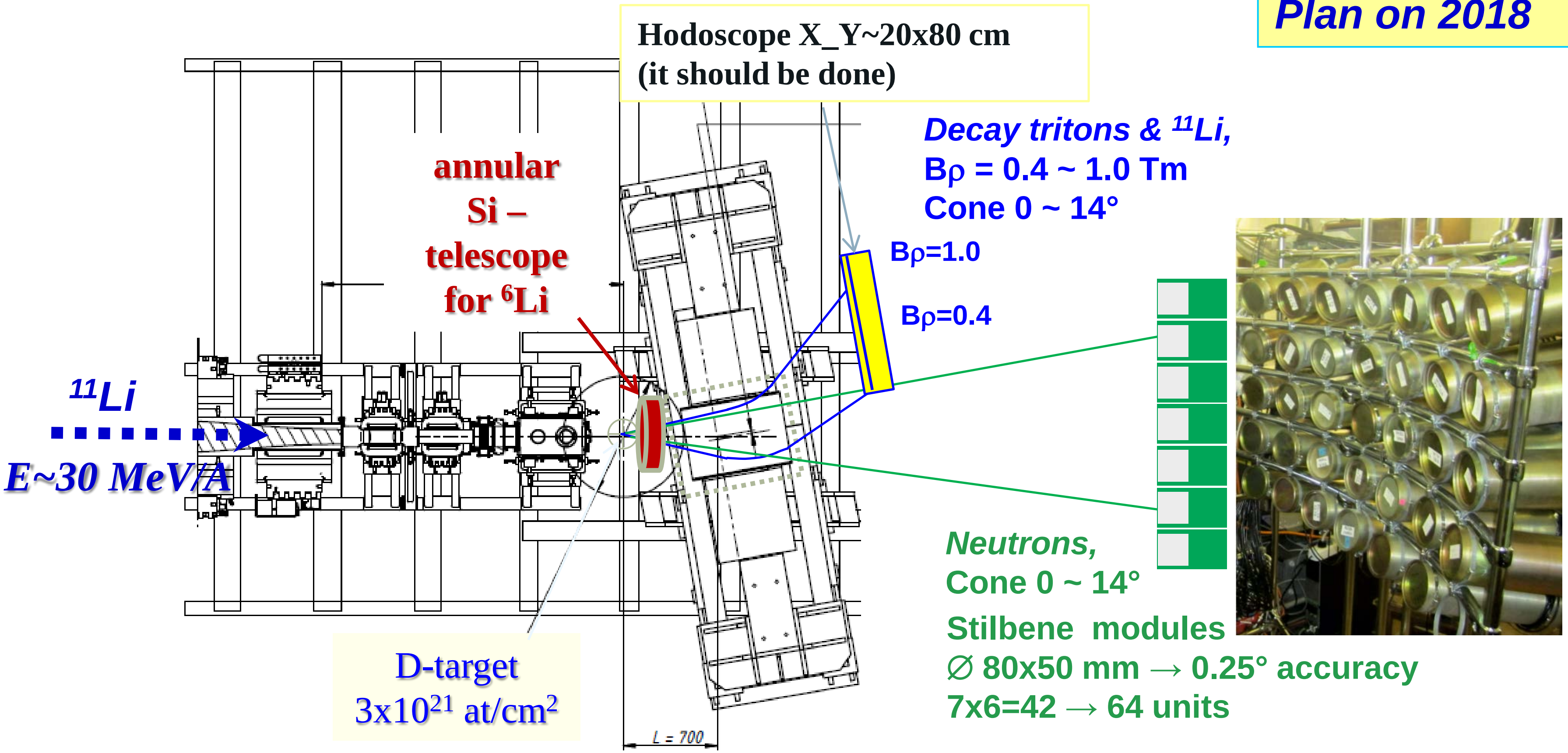


Caamaño et al. PRL 99(2007) ^{12}C(^{8}He,^{13}N)^{7}H ==> $E = 0.57^{+0.42}_{-0.21}$ MeV, $\Gamma = 0.09^{+0.94}_{-0.06}$ MeV

- *Drastically improvement of sensitivity in d*(^{8}He,^{3}He)^{7}H or *p*(^{8}He,*pp*)^{7}H
- ^{11}*Li as a projectile and alpha transfer reaction d*(^{11}Li,^{6}Li)^{7}H

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

Plan on 2018



* *I(^{11}Li @ 30 AMeV) ~ 2x10^{4} pps* **==> ~ 100 ^{7}H events/day (*missing mass*)**

** **Decay energy will be measured with around 100 keV resolution,**

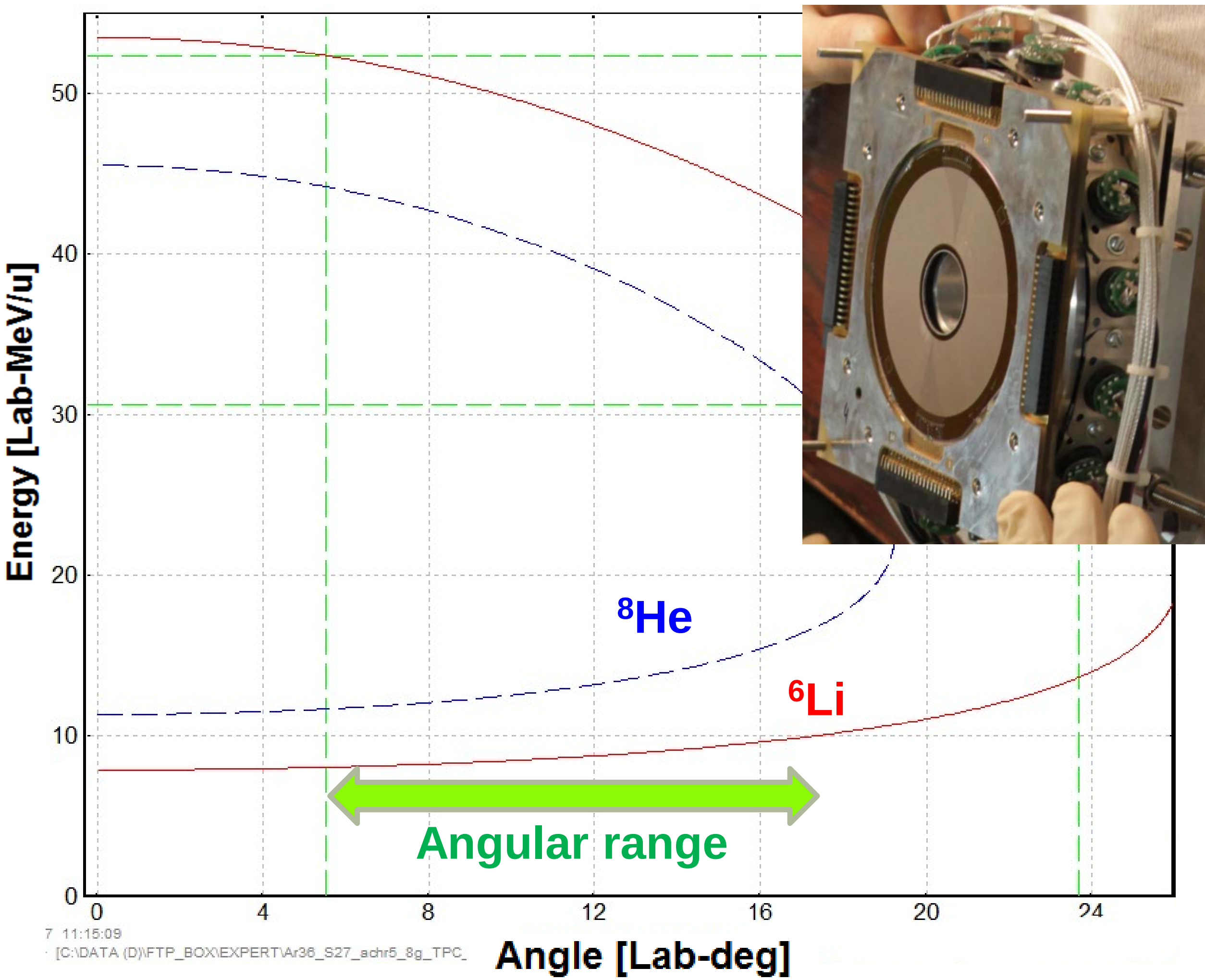
~ 3 events/day (*^{6}Li-t-n coincidences*)

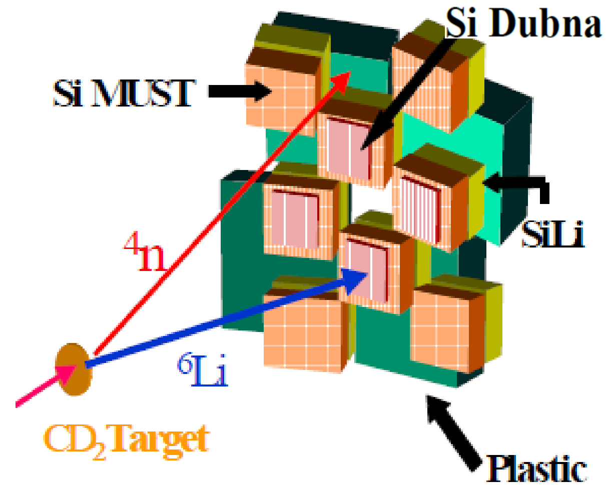
Plan on 2017: ***d*****(^{12}Be,^{6}Li)^{8}He as a tool for the main run *d*(^{11}Li,^{6}Li)^{7}H**

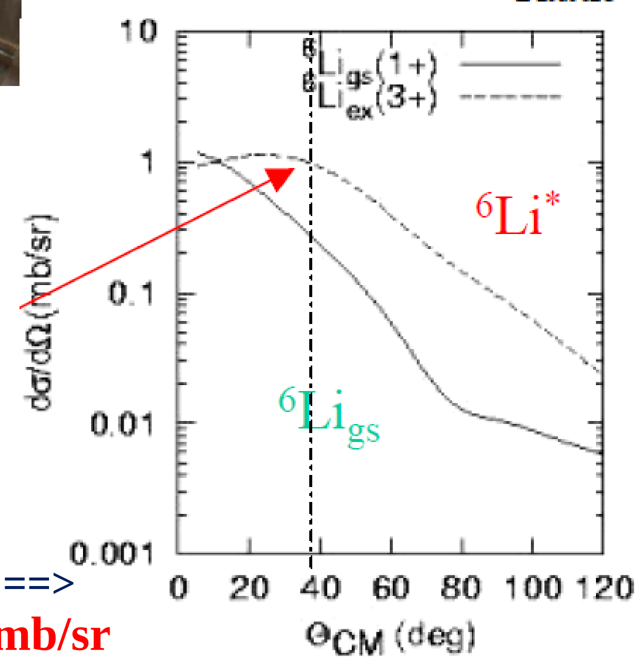
*** alpha transfer cross section at 25 and 35 AMeV;**

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

***** could be done at I(^{15}N) ~ 100 pnA ==> I(^{12}Be) ~ 2*10^{4} pps; *BT ~ 2 weeks***







E.Rich et al.**, 2005 Proc. EXON, Peterhof, Russia ==>**

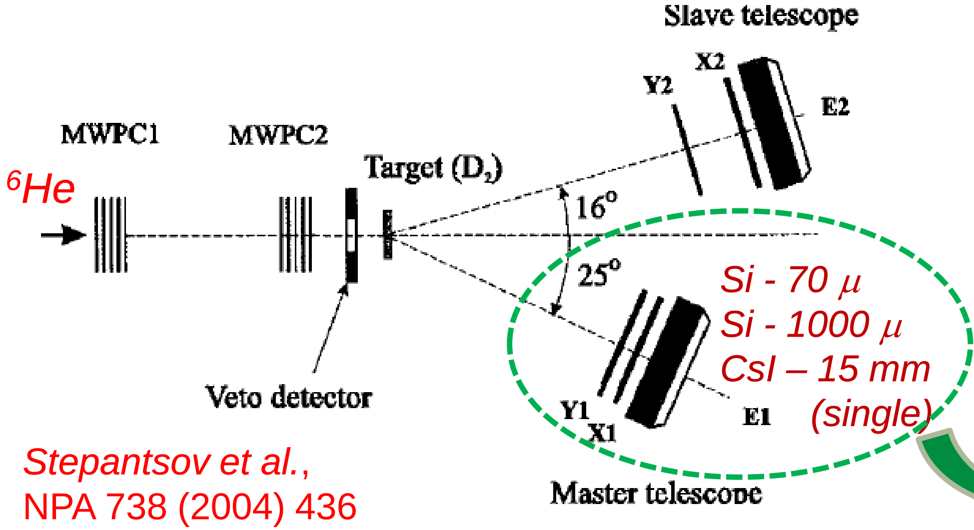
d**(^{8}He,^{6}Li)^{4}n @ 15.4 AMeV $d\sigma/d\Omega$ ~ 0.2÷1.0 mb/sr**

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

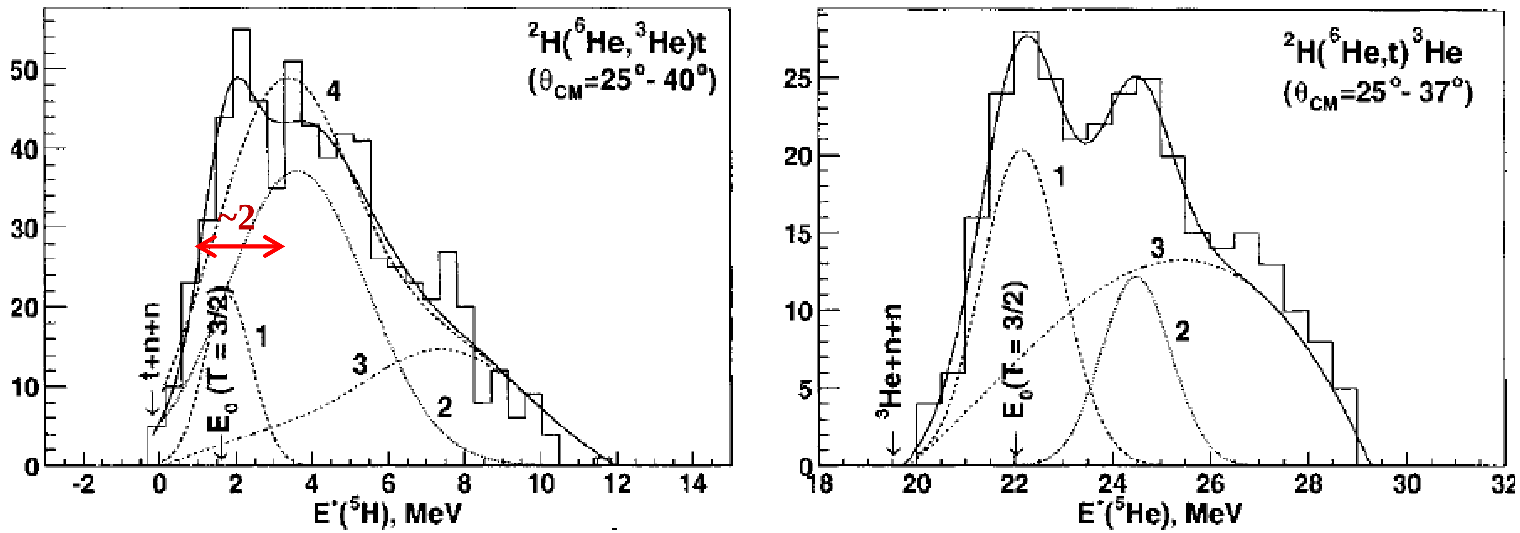
* cross section values for the *1p* and *1n* transfer reactions in a wide θ_{CM}

** improvement in missing mass measurements via novel telescopes

BT ~ 1 week



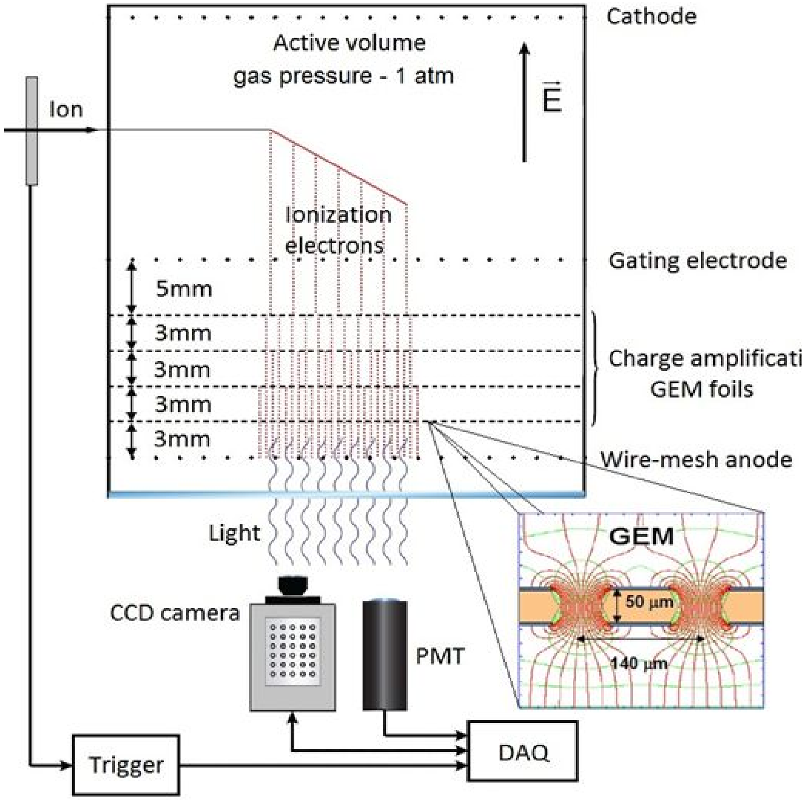
Stepantsov et al., NPA 738 (2004) 436



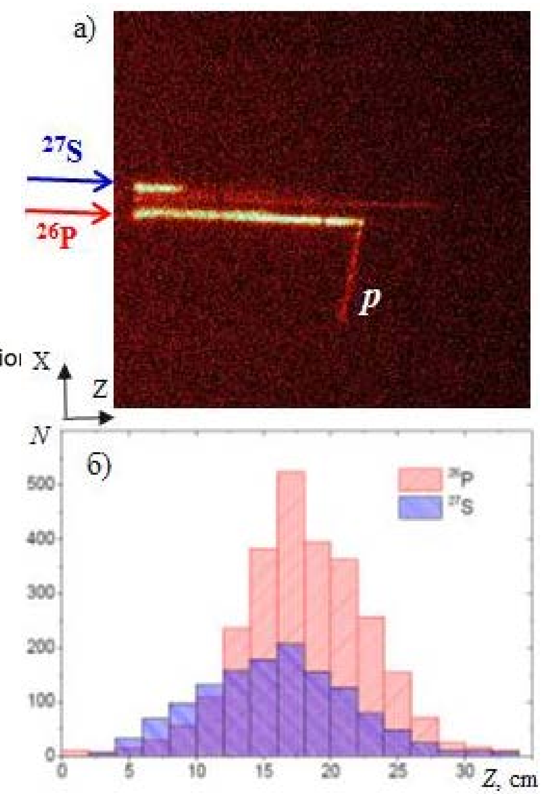
***^5H* (left) and *^5He* (right) energy spectra depending on *^3He-t* coincidences**

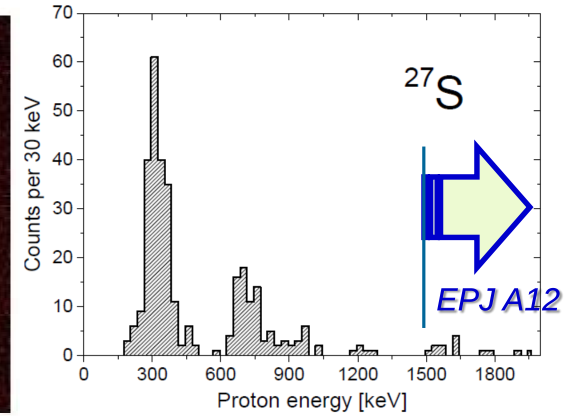
Beta-delayed proton emission from ^{27}S and ^{26}P

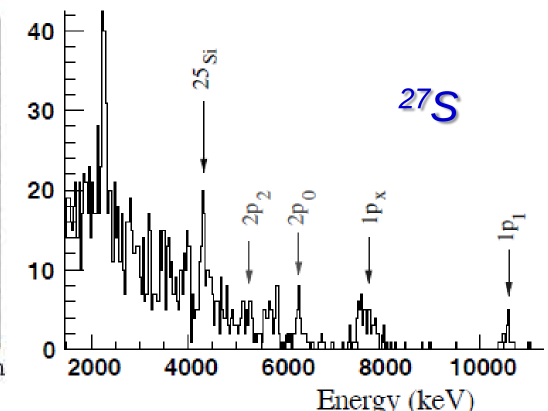
via Optical Time Projection Chamber /*Janiak et al.*, PRC 95 (2017) 034315/



Miernik et al., NIM A581 (2007) 194







Canchel et al., EPJ A12 (2001) 377

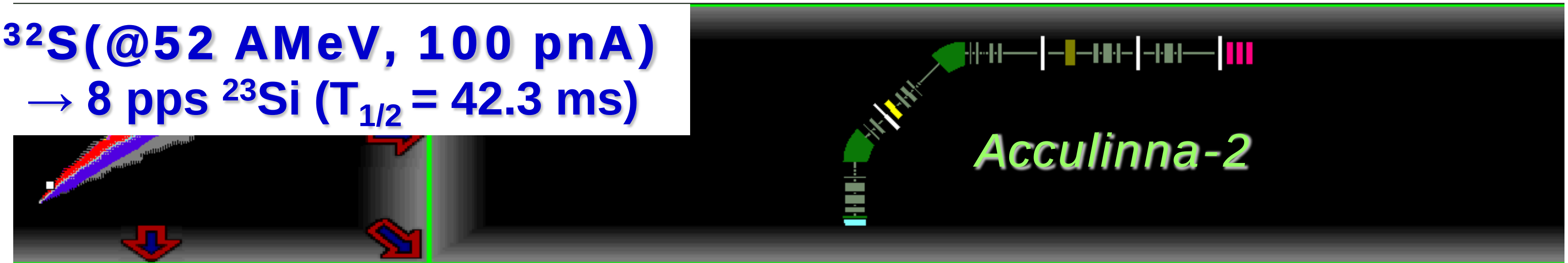
^{26}P				^{27}S			
$P_{\beta p}$	$P_{\beta p}$	$P_{\beta 2p}$	P_{tot}	$P_{\beta p}$	$P_{\beta p}$	$P_{\beta 2p}$	P_{tot}
415 кэВ	~800 кэВ			320 кэВ	710 кэВ		
10.4(9)% ÷ 13.8(10)%	1.1(3)%	1.5(4)%	35(2)%	24(3)% ÷ 28(2)%	> 6.7(8)%	3.0(6)%	64(3)%
17.96(90)%	2.5(3)%	2.2(3)%	39(2)%	2.3±0.9%		1.1±0.5%	~ 4%

Thomas et al., EPJ A21 (2004) 419

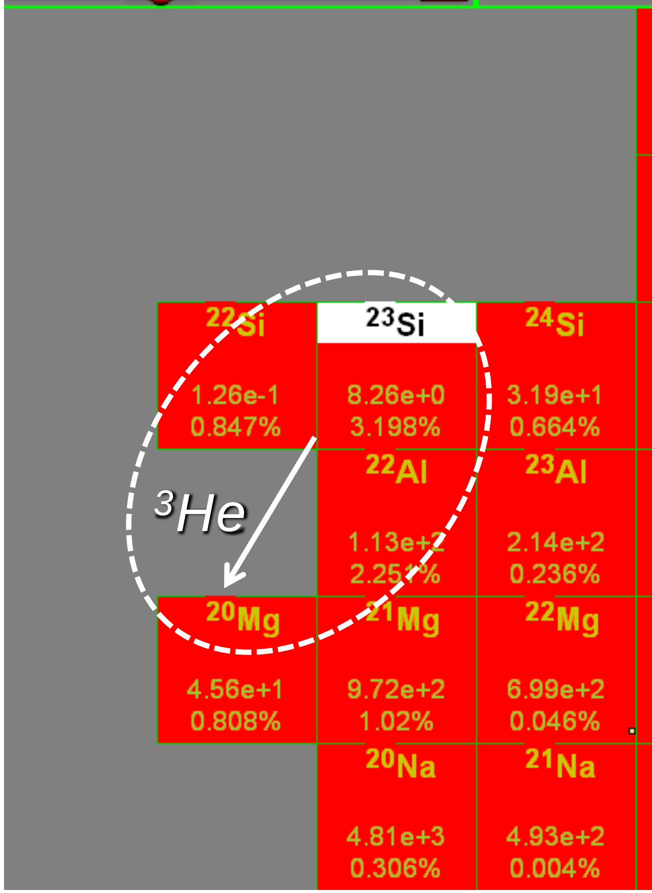
$P_{\beta 3p} < 0.08\%$

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

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



BT ~ 0.5 week



"… ^{23}Si has an open channel for the beta delayed ^{3}He 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 ^{3}He channel is the only one in which a single particle with Z=2 is emitted. The ^{3}He 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, $^{9,11}Li$, $^{6,8}He$ were on average 25 times higher in comparison with the values for old facility.

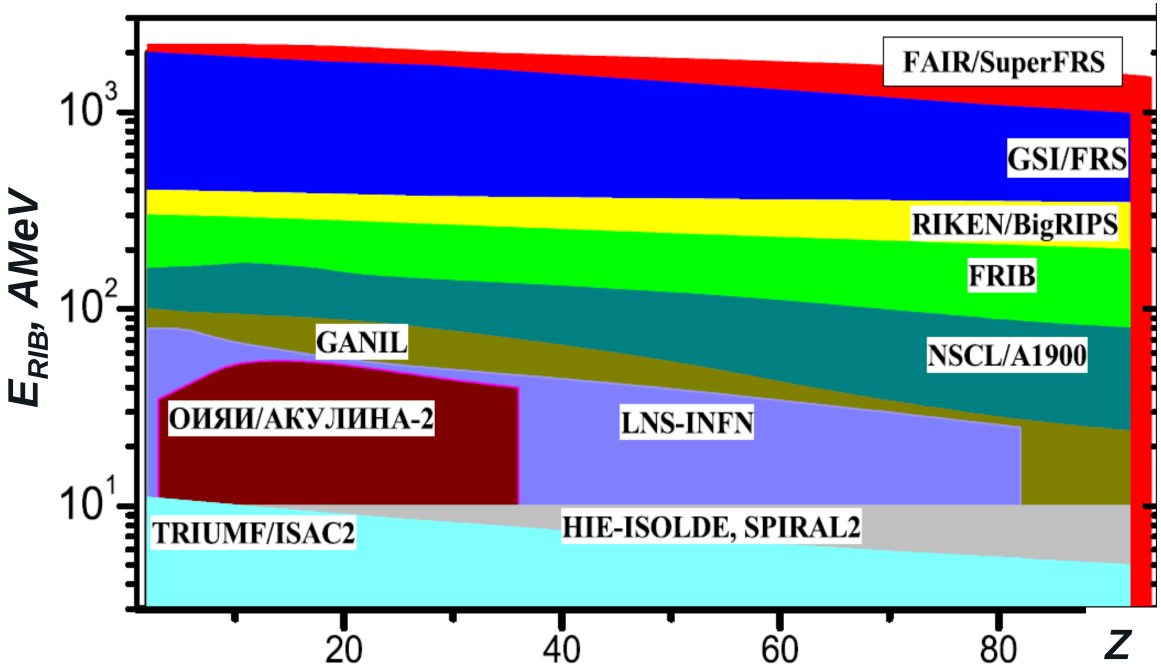
The first-priority experimental program with RIBs is focused on ^{7}H and ^{23}Si nuclides and their possible exotic decays.
It will be started this year.

Thanks for your attention

Acculinna-2 since 2017/18

Request / Cost

Product name	T_{min} U400M	Beam, E, I	Method, equipment
^{27}S : *P(β3p) – value/limit* ^{23}Si : *P(β^{3}He) – yes/no/limit* ^{26}S : *observation, states*	*One week*	^{32}S, 52 AMeV, 0.2 – 0.5 pμA	*OTPC, chopper & RF-kicker* *p(^{28}S,t)^{26}S missing mass & RF-kicker*
^{17}Ne : *2p decay for 3/2$^-$ state $\Gamma_{2p}/\Gamma_\gamma \rightarrow 0.0002\%$* ^{7}H : *observation, states, 4n decay* ^{10}Li : *E and Γ for ground state*	*Two or more weeks*	^{20}Ne, 54 AMeV, 1.0 pμA ^{15}N, 49 AMeV, 1.0 pμA	*p(^{18}Ne,d)^{17}Ne* combined mass, zero angle spec.* d(^{8}He,^{3}He)^{7}H d(^{11}Li,^{6}Li)^{7}H *p(^{11}Li,d)^{10}Li combined mass*
^{10}He : ^{13}Li : ^{16}Be : *E, Γ, J$^\pi$ of excited states, search for exotic decays 2n, 4n*	*Three or more weeks*	^{11}B^{3+}, 34 AMeV, 4.0 pμA ^{22}Ne^{7+}, 44 AMeV, 1.0 pμA	*t(^{8}He,p)^{10}He* *t(^{11}Li,p)^{13}Li* *t(^{14}Be,p)^{16}Be* *tritium target, neutron array*



ACC-2 @ U400M advantages:

Room T operating

Relatively low cost beam time

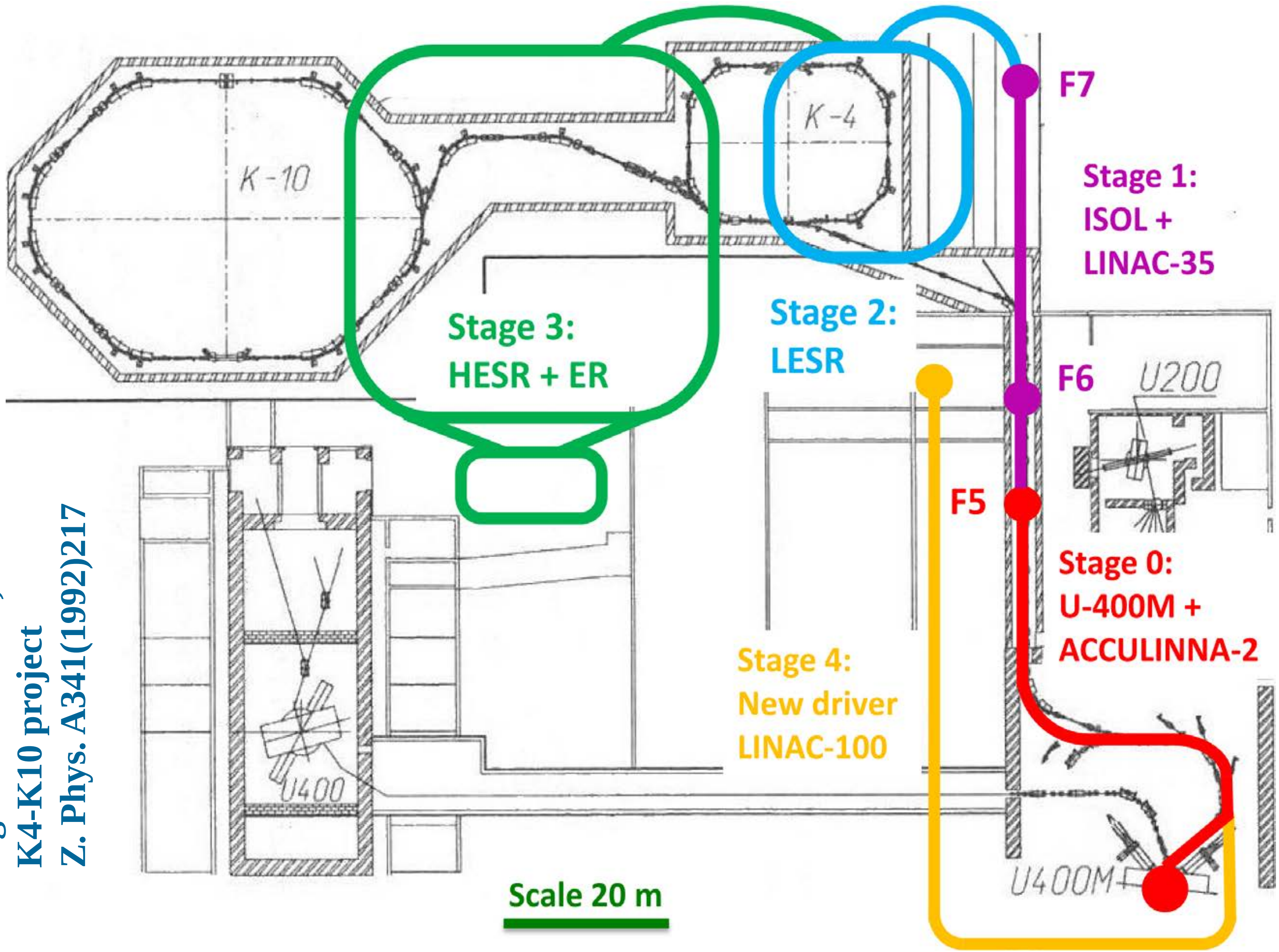
Runs during 2,3 and even more weeks are possible

Cryogenic targets ^3He, ^4He and all hydrogen isotopes

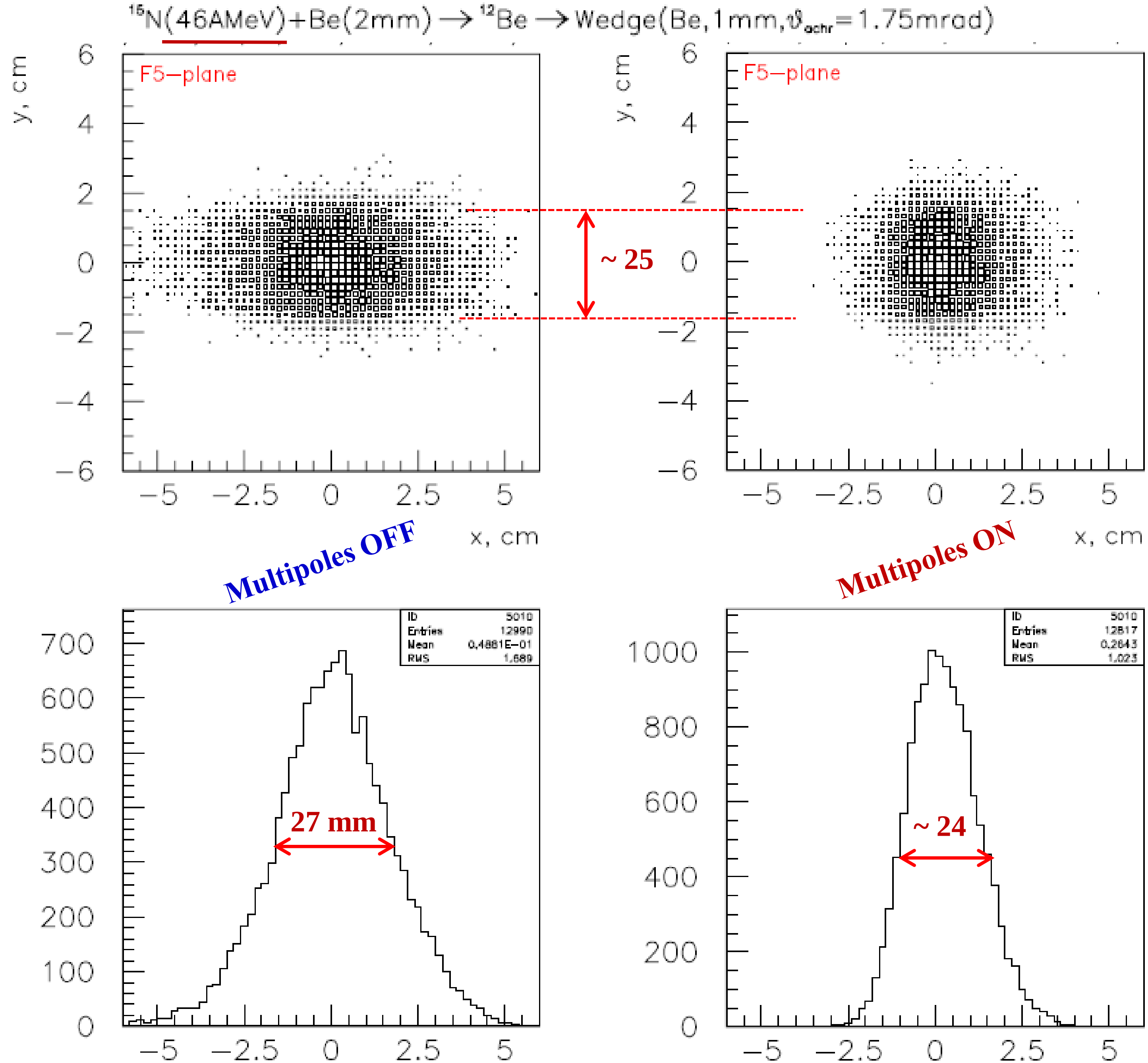
ToF length ~15 m

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
$p/\Delta p$, a.u.	1000	2000	4360	2200	2915	1500	3300	8600	3050
$B\rho_{max}$, 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}, AMeV	10	5	20	40	110	50		220	
E_{max}, AMeV	40	50	80	80	160	90	350	1000	1500

ERICA - Electron-Radioactive Ion Collider @ ACCULINNA-2



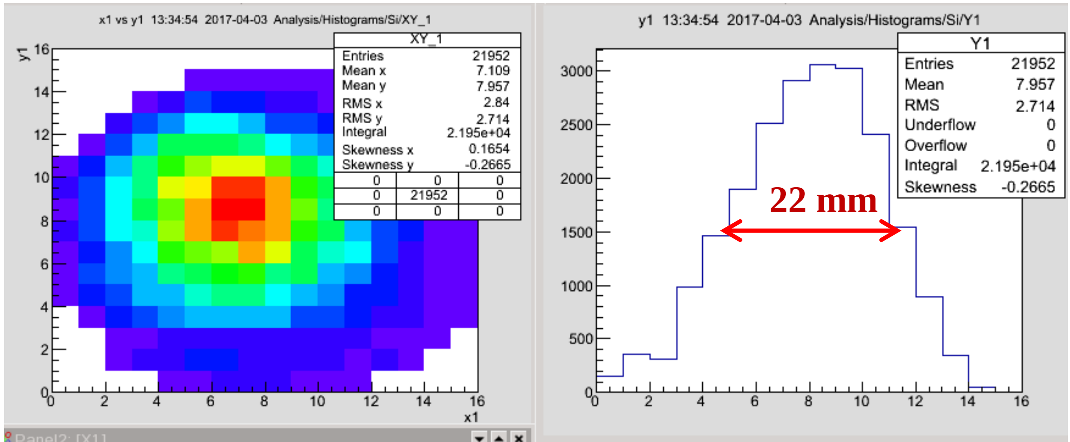
**Oganessian *et. al.*,
K4-K10 project
Z. Phys. A341(1992)217**

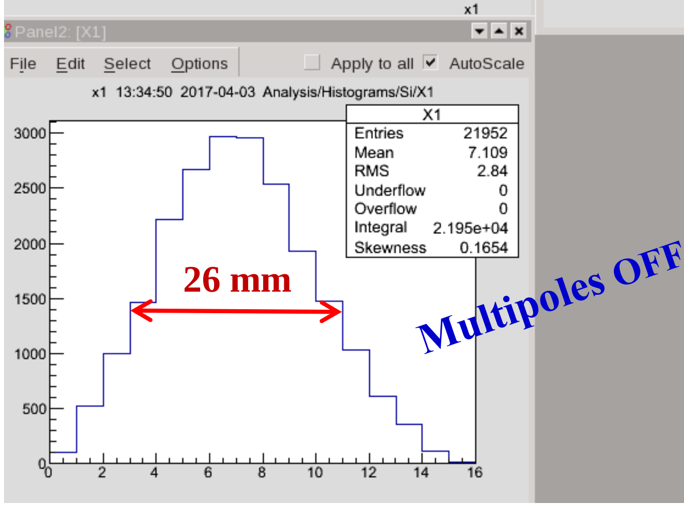


^{12}Be transfers profile at F5 (by S.V. Stepantsov)

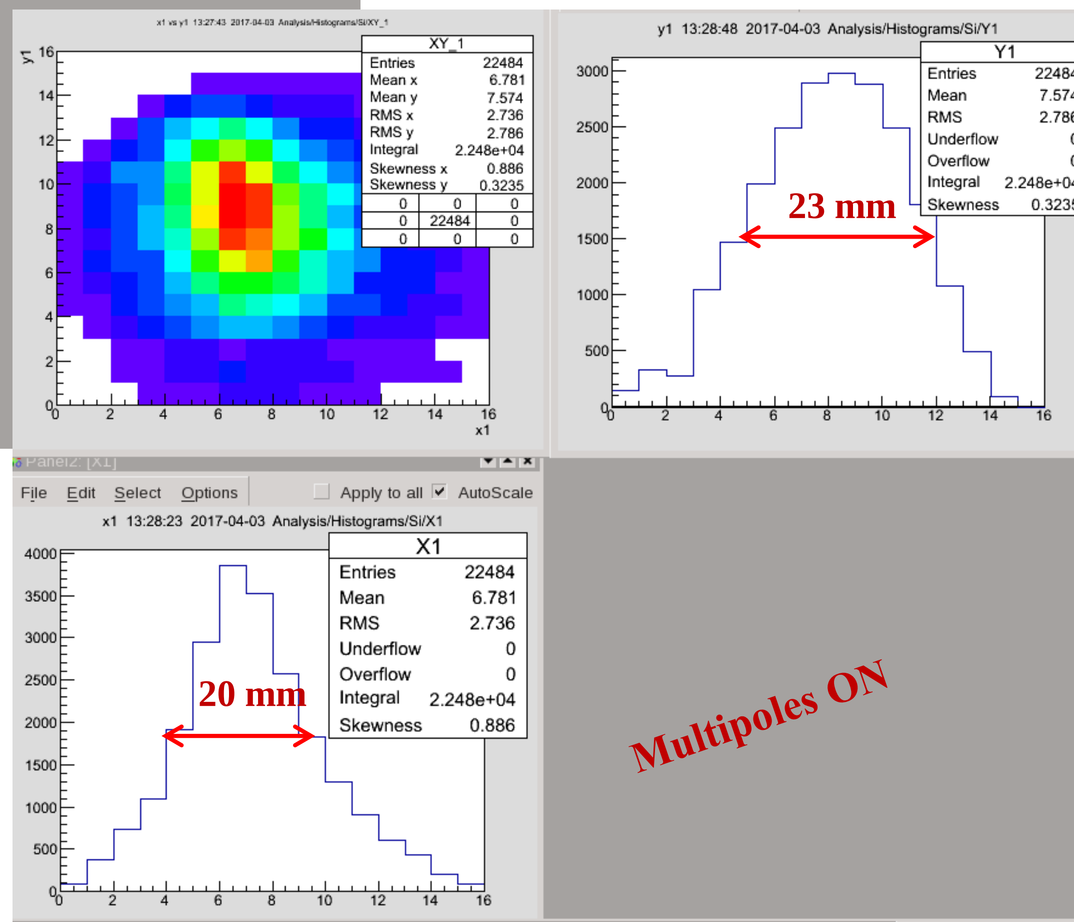
^{12}Be transfers profile at F5

← *Multipoles OFF*





Multipoles ON ↓



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

^{26}S: search via missing mass measurement

NNDC: $T_{1/2}$ ~ 10 ms

Acculinna-1: $ToF_{F1\text{-}F4}$ ~ 0.0003 ms

Experiment (implantation method):

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

Fomichev et al., IJMP E20 (2011) 1491

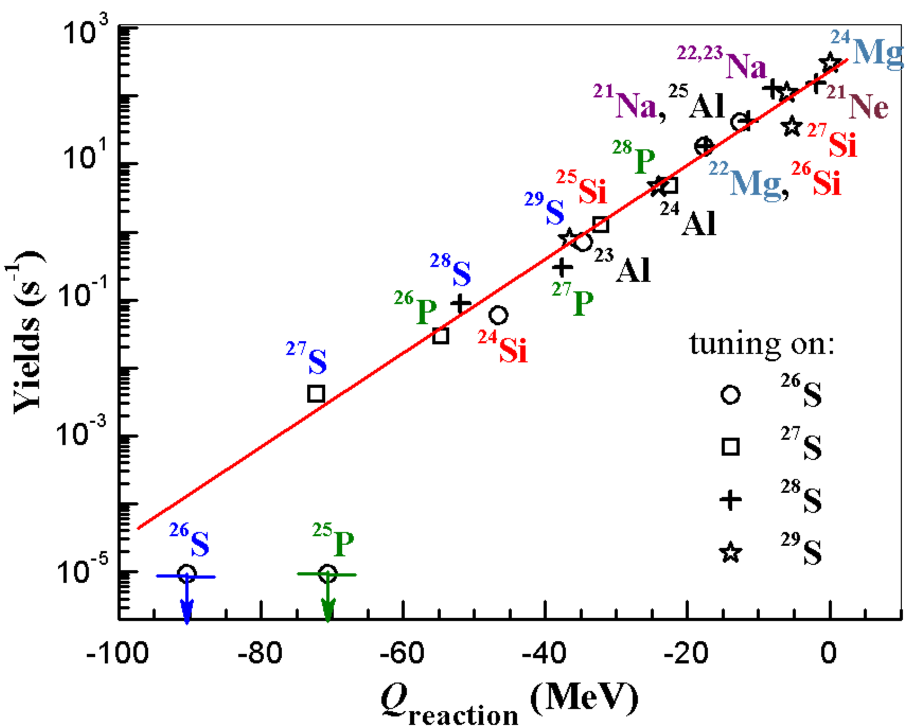
Acculinna-2 with RF-kicker

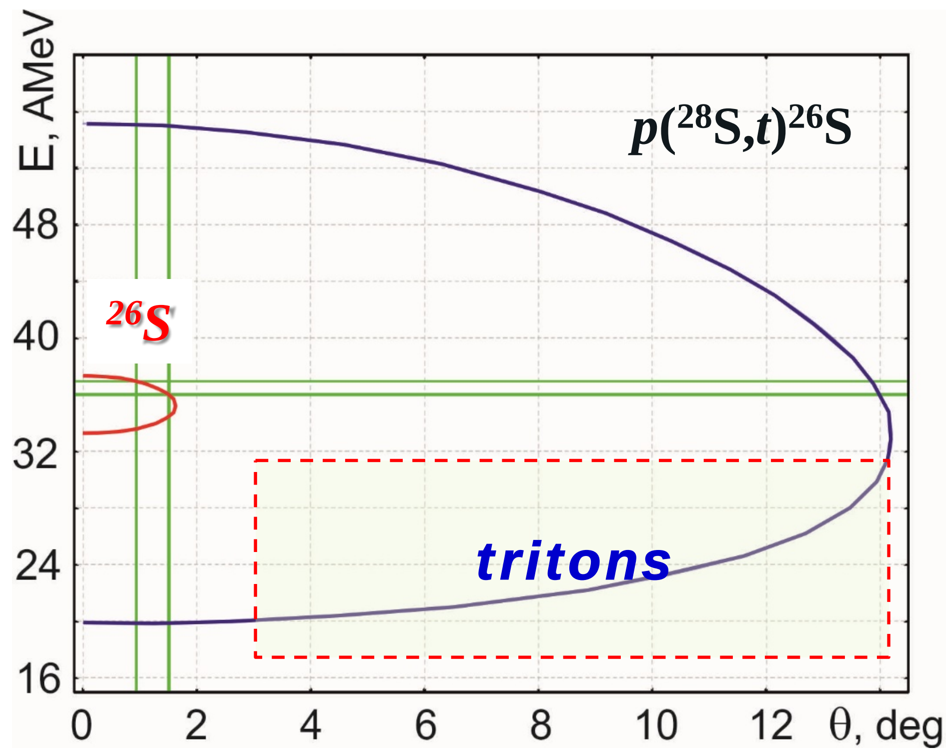
missing mass in $p(^{28}S,t)^{26}S$:

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

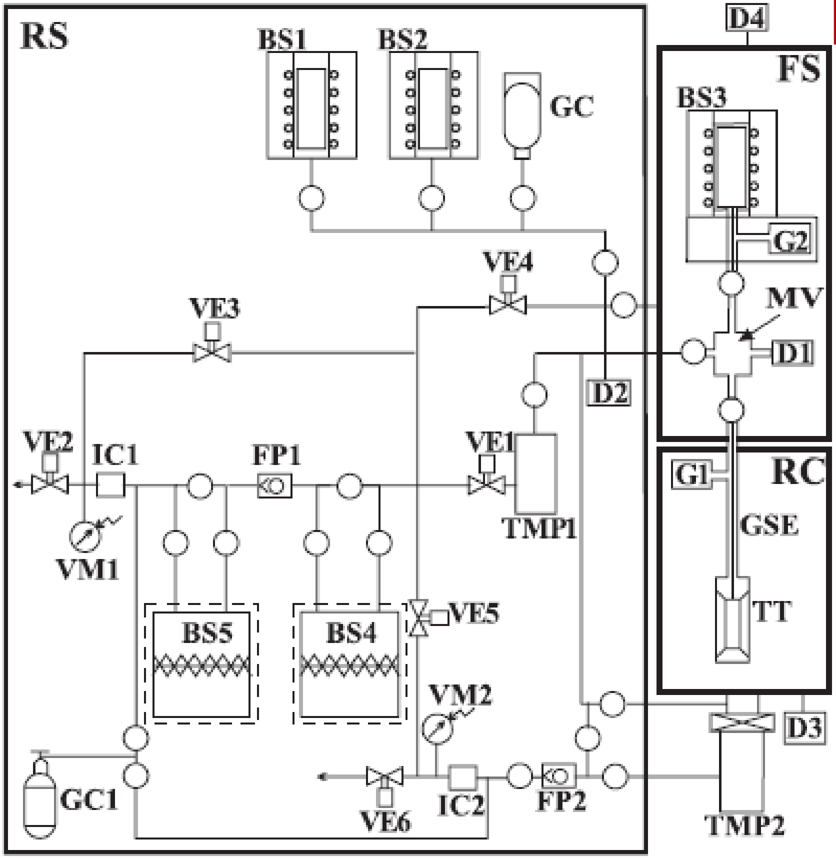
1 mm liquid H_2, σ~200 μb/sr ==>

~ 10 events ^{26}S per week

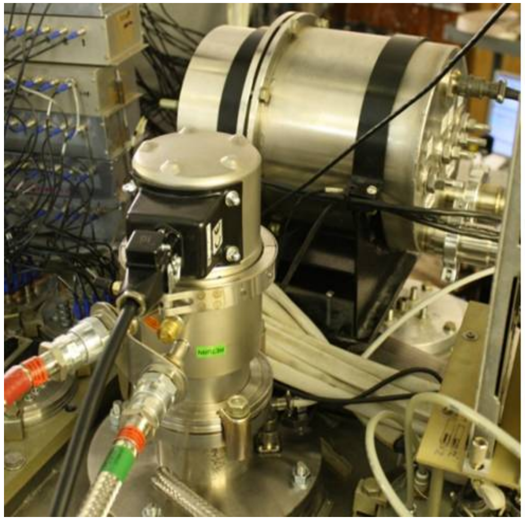


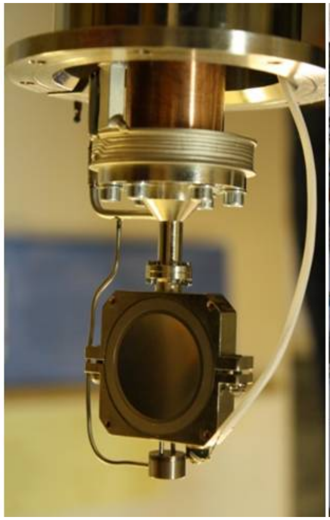


Physical unique targets H, He



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:
ϕ=25 mm, d=3÷6 mm,
T=26 K, P=0.92 Atm,
x=3*10^{20} Atm/cm^2

Liquid:
ϕ=20 mm, d=0.4÷0.8 mm,
w=2x8.4 μ stainless steel,
x=1.1*10^{21} Atm/cm^2
I ≤ 960 Ci (3.54*10^{13} Bq)