Study of exotic nuclei

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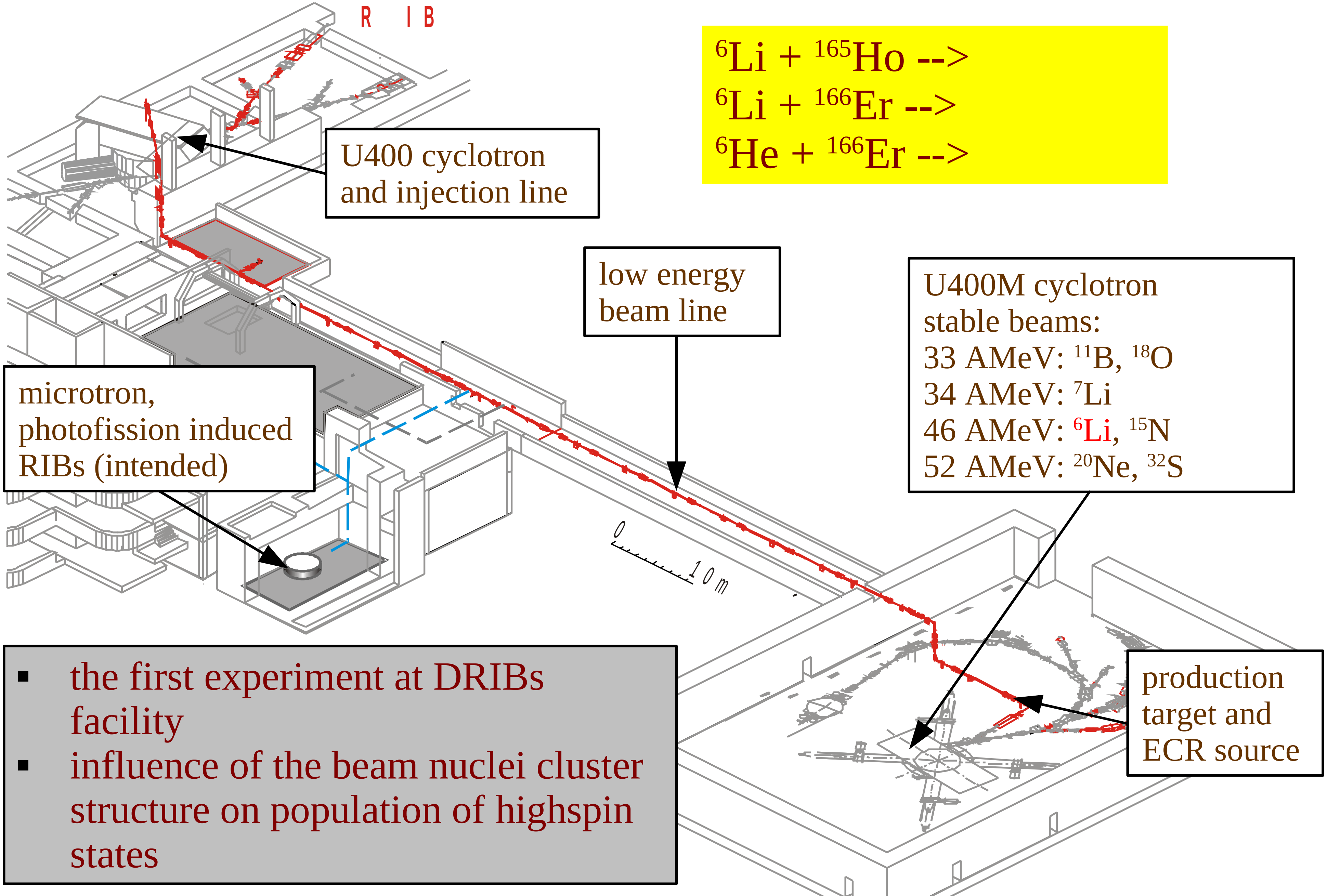
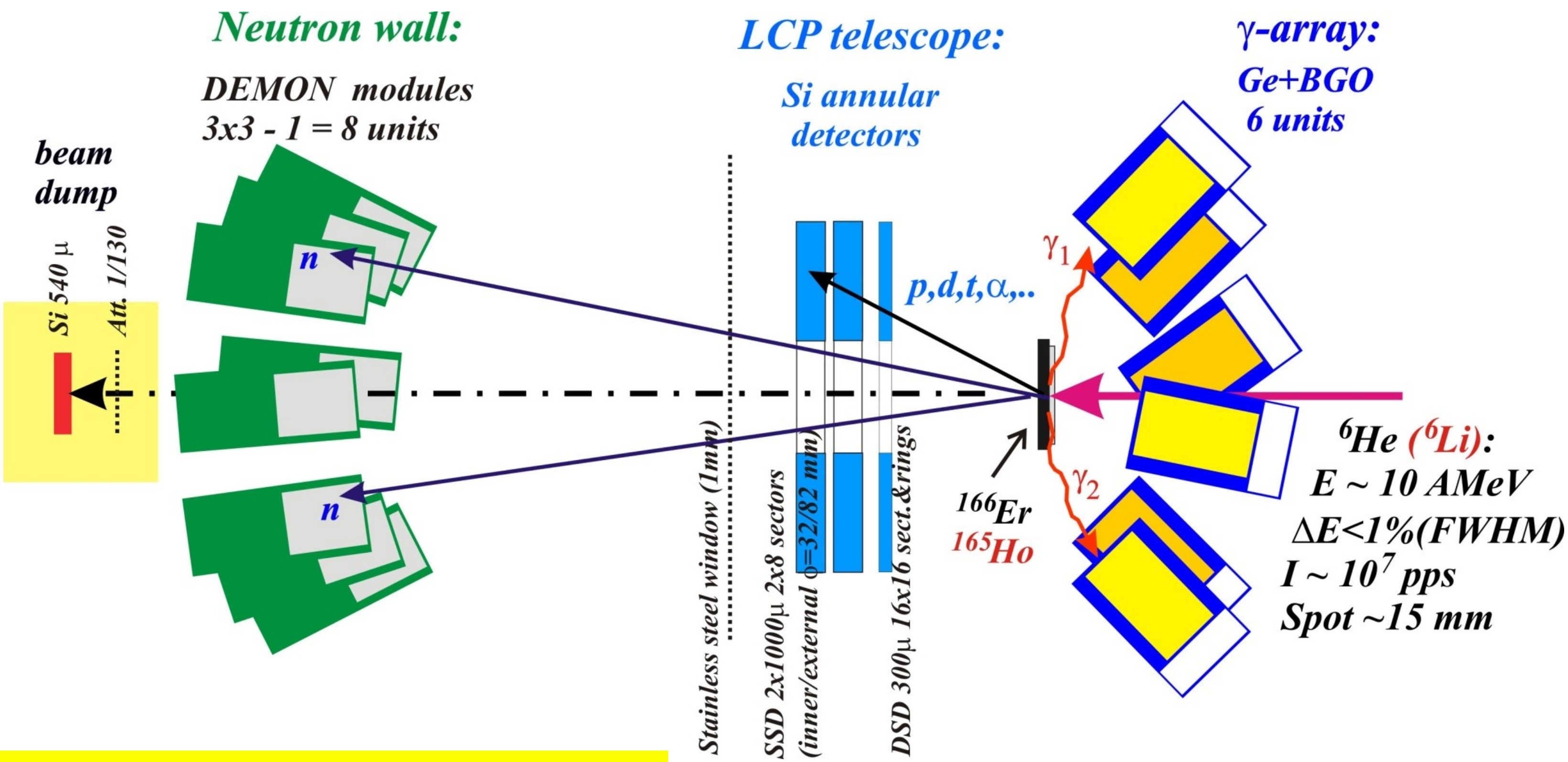
2007-2008: Complete and incomplete fusion of ^{6}He and ^{6}Li with ^{165}Ho and ^{166}Er

$^{6}Li + ^{165}Ho$ -->
$^{6}Li + ^{166}Er$ -->
$^{6}He + ^{166}Er$ -->



- the first experiment at DRIBs facility
- influence of the beam nuclei cluster structure on population of highspin states

2007-2008: Complete and incomplete fusion of ^{6}He and ^{6}Li with ^{165}Ho and ^{166}Er



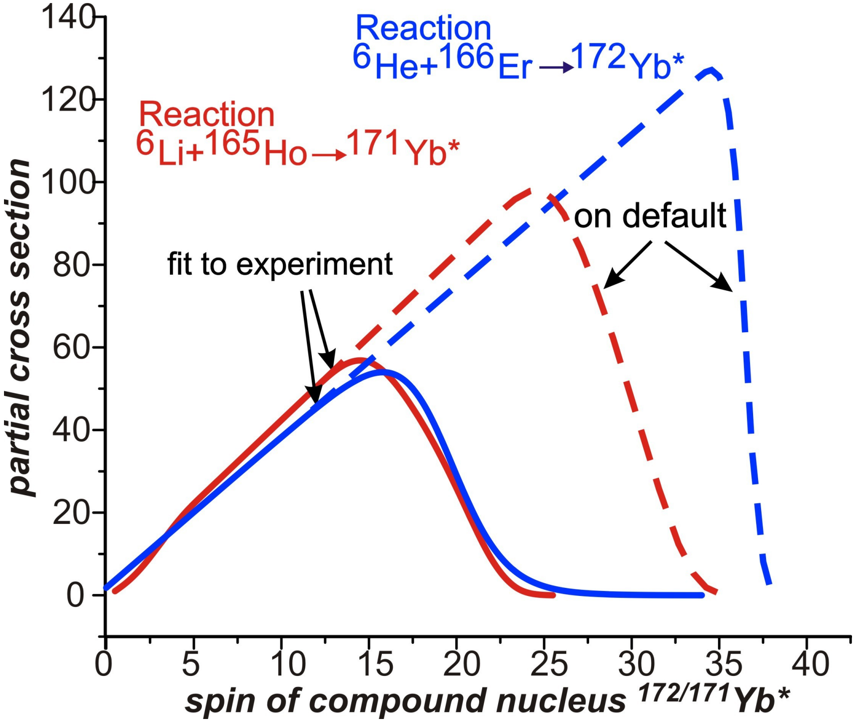
^{6}Li + ^{165}Ho --> ^{171}Yb* --> ^{166}Yb + 5n
--> ^{169}Tm* + d
--> ^{167}Er* + α

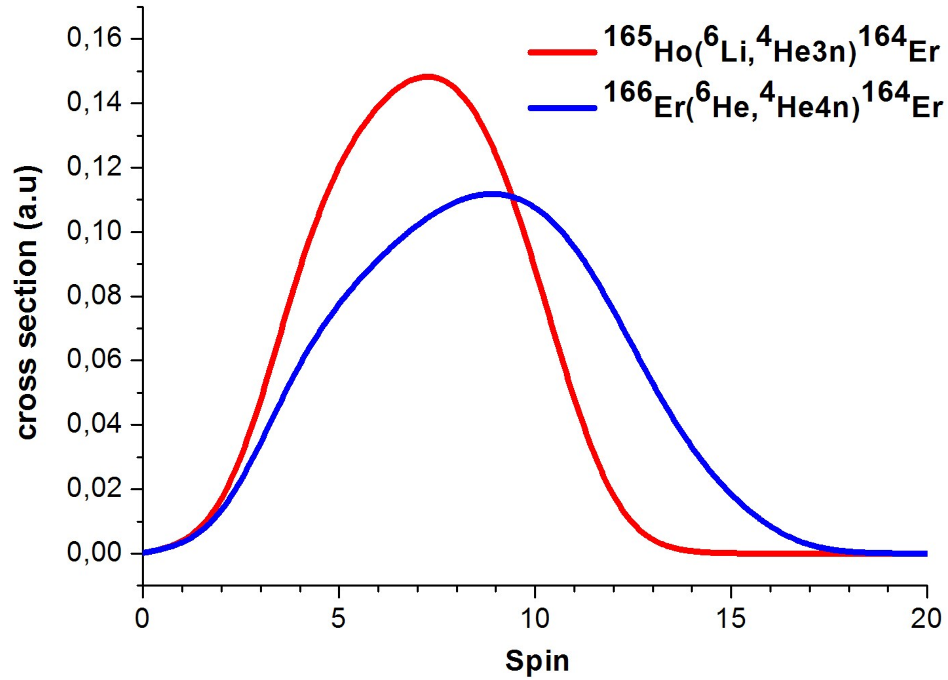
^{6}He + ^{166}Er --> ^{172}Yb* --> ^{166}Yb + 6n
--> ^{170}Yb* + 2n --> ^{166}Yb + 4n
--> ^{168}Er* + alpha

^{6}Li + ^{166}Er --> ^{170}Yb* + d --> ^{166}Yb + d + 4n
--> ^{168}Tm* + alpha
--> ^{172}Lu* --> ^{166}Yb + p + 5n

^{166}Er(^{4}He,4n)^{166}Yb
J.D. Bierman et al., PRC 48 (1993) 319

2007-2008: Complete and incomplete fusion of ^{6}He and ^{6}Li with ^{165}Ho and ^{166}Er





Complete Fusion

^{6}He:		
theory:	σ_{cf} ~ 2490 mb;	$l_{crit.}$ ~ 39
experiment:	σ_{cf} ~ 731 mb;	$l_{crit.}$ ~ 19.3
^{6}Li:		
theory:	σ_{cf} ~ 1770 mb;	$l_{crit.}$ ~ 32.5
experiment:	σ_{cf} ~ 737 mb;	$l_{crit.}$ ~ 18.6

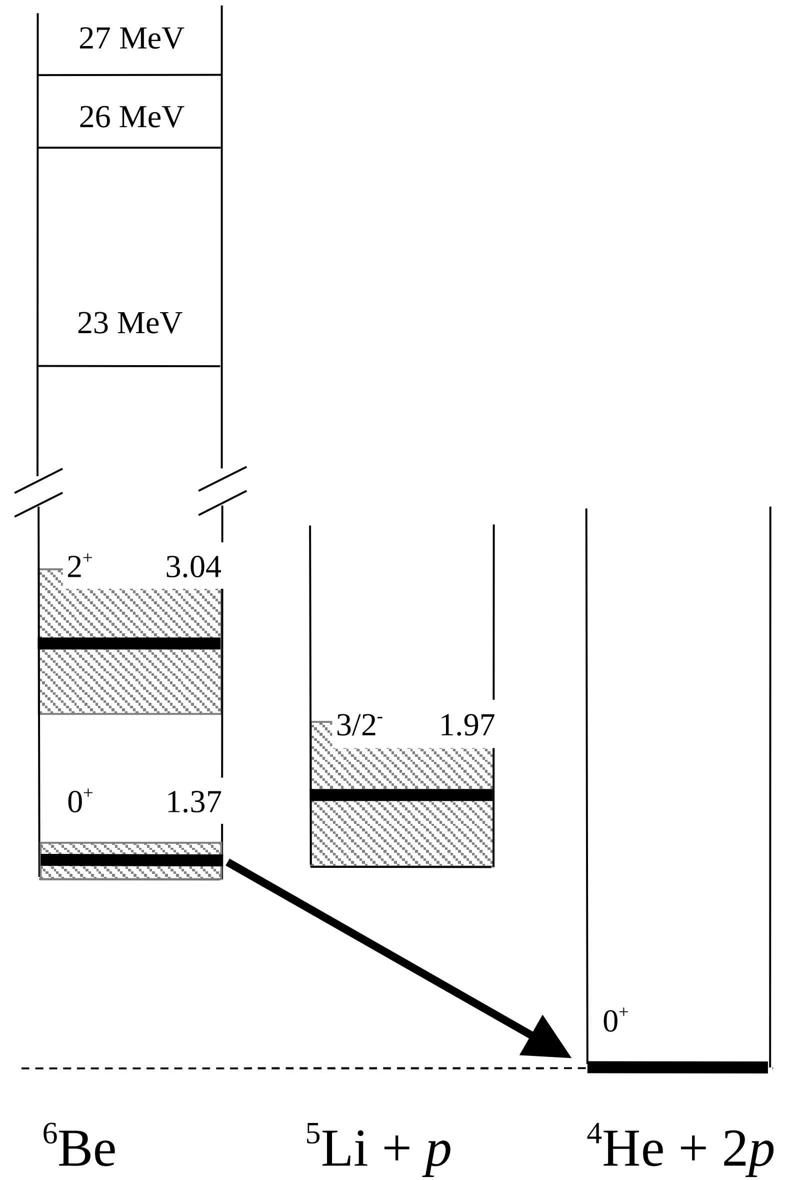
Incomplete Fusion

^{6}He:		
theory:	σ_{xn} ~ 881 mb;	D_l ~ 1.56
experiment:	σ_{xn} ~ 254 mb;	D_l ~ 1.52
^{6}Li:		
theory:	σ_{xn} ~ 656 mb;	D_l ~ 0.2
experiment:	σ_{xn} ~ 244 mb;	D_l ~ 0.4

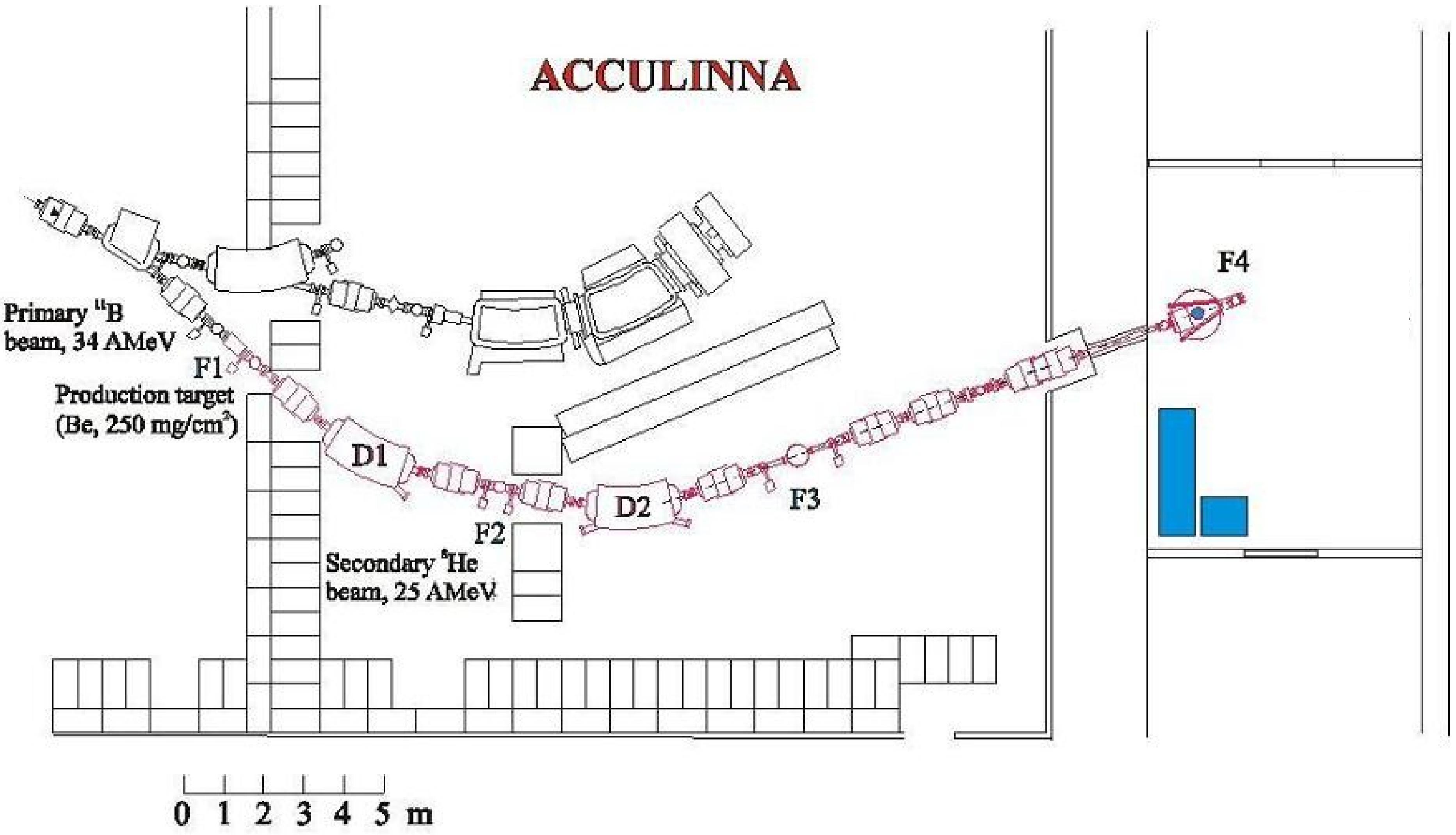
2009-2010: 6Be structure

- isotopes at A = 6 are very important
- lightest 2p emitter
- just a few experimental works, absence of correlation studies
- offers better acces to ^{6}He properties (3 charged particle structure)

E [MeV]	$E_{αpp}$ [MeV]	Γ [MeV]	$J^π$	Decay
g.s.	1.37	0.092	0^+	p, α
1.67	3.04	1.16	$(2)^+$	p, α
23		broad	4^-	γ, ^{3}He
26		broad	2^-	^{3}He
27		broad	3^-	^{3}He



2009-2010: 6Be structure – Experimental set-up



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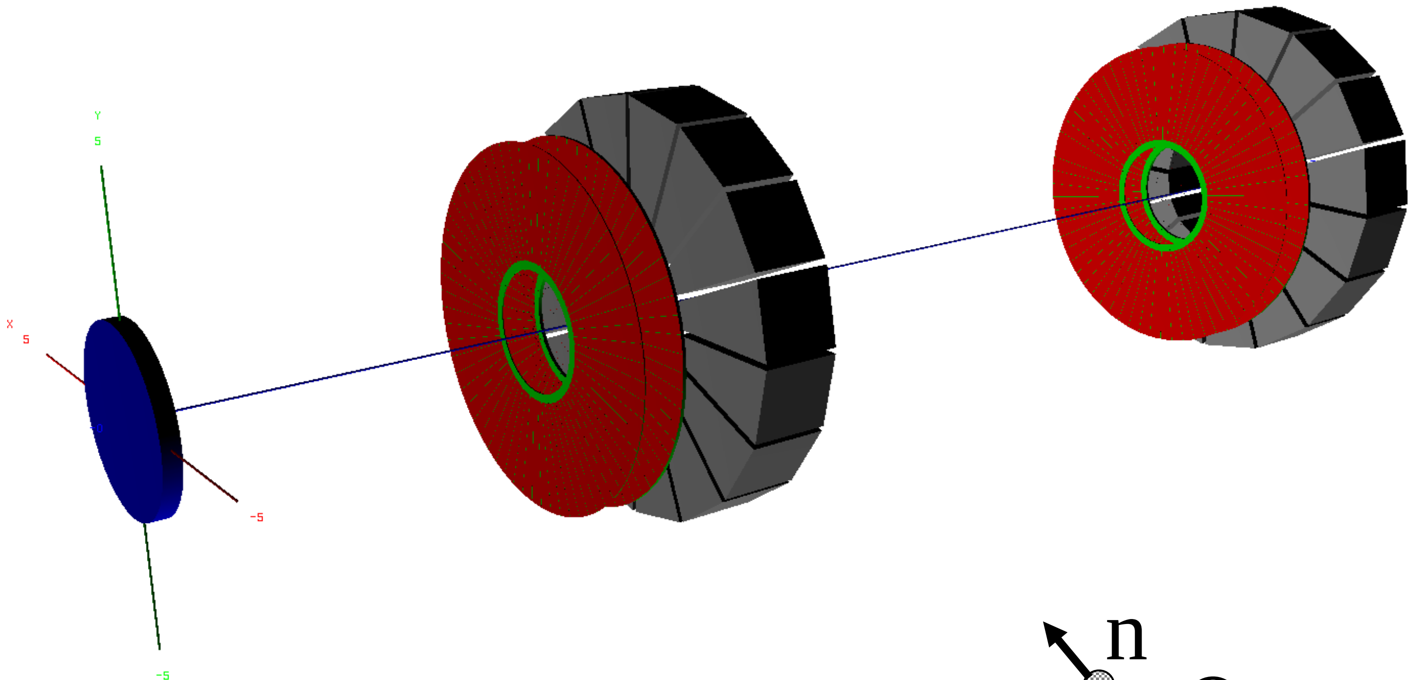
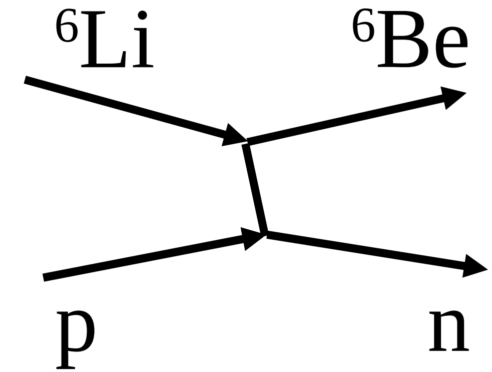
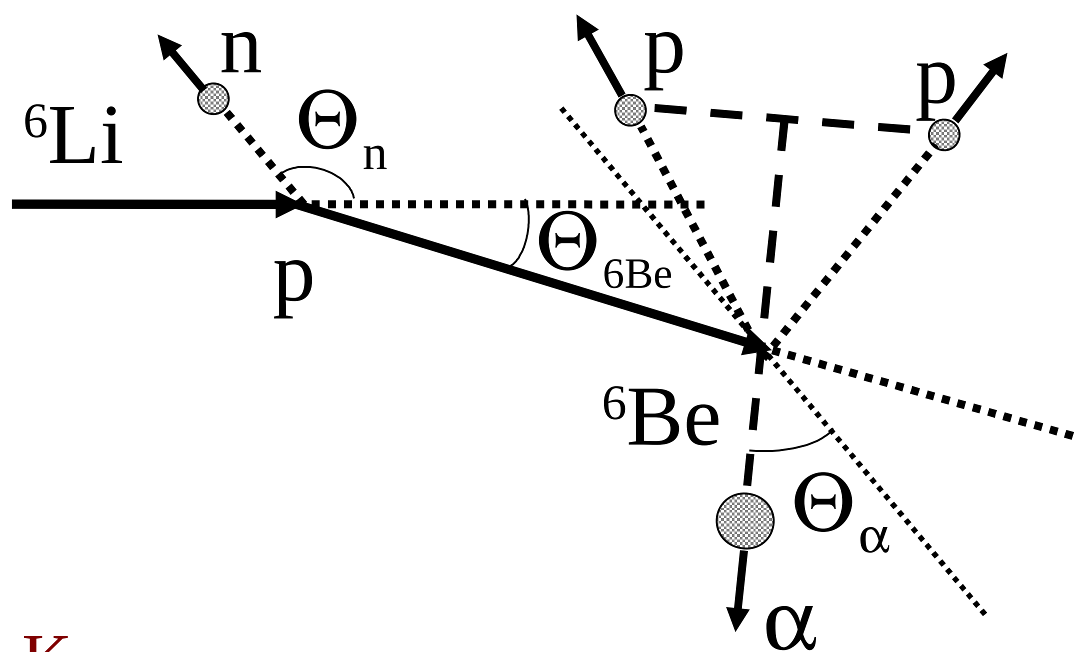
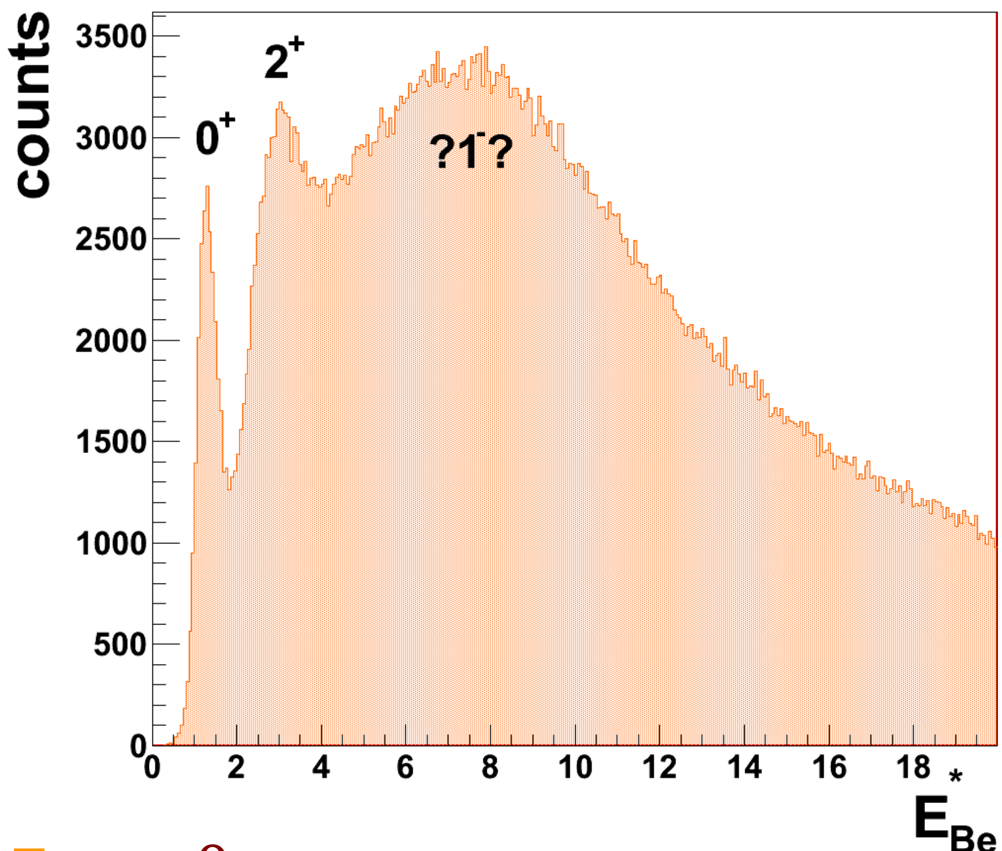


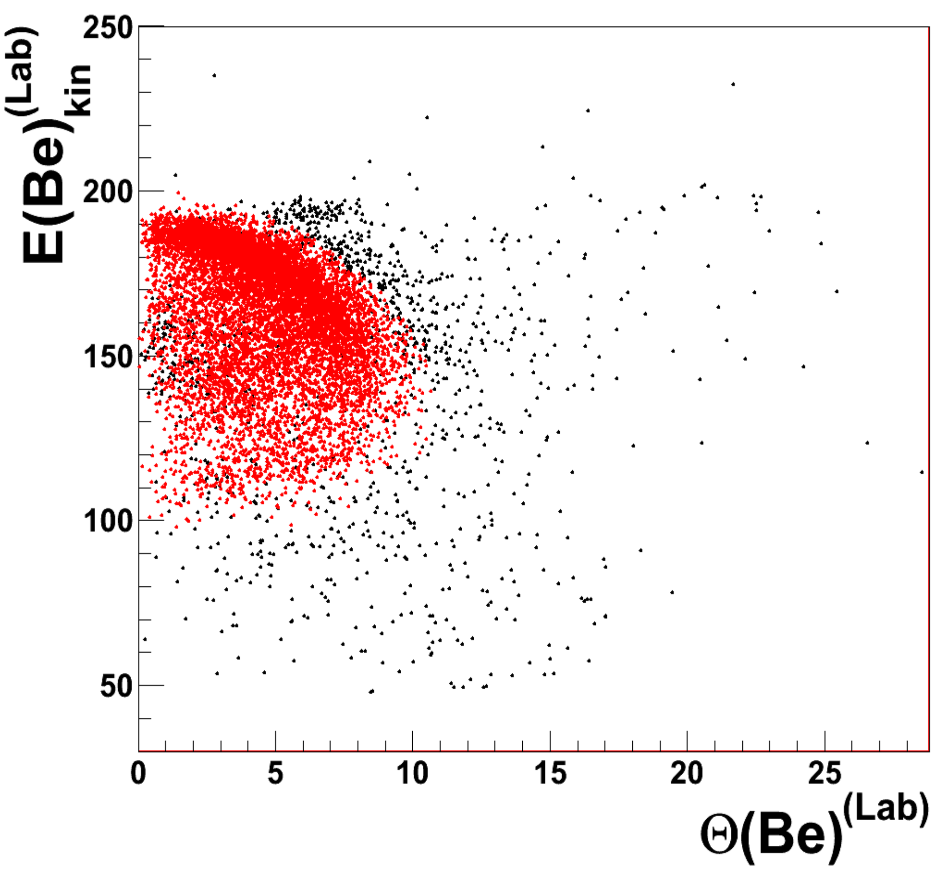


- reaction:
  $^6Li + p \rightarrow n + {}^6Be$
  $^6Be \rightarrow {}^4He + p + p$
- beam:
  25 and 33 MeV/A
- target:
  d = 4 mm; p ~ 300 kPa; T ~ 35 K



2009-2010: 6Be structure – Invariant mass spectrum

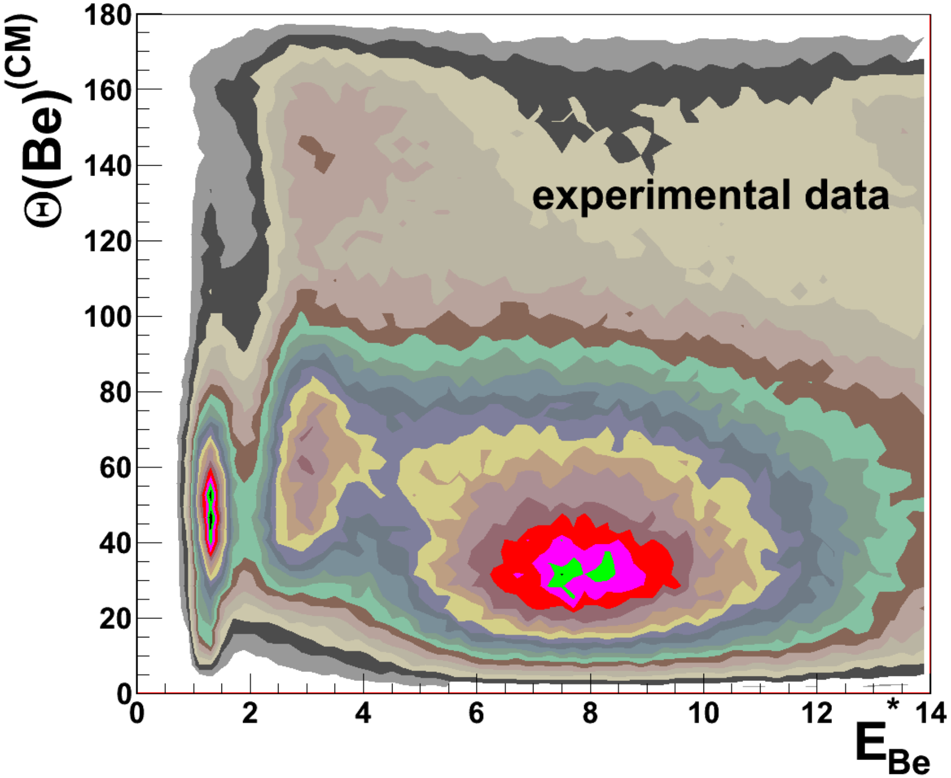


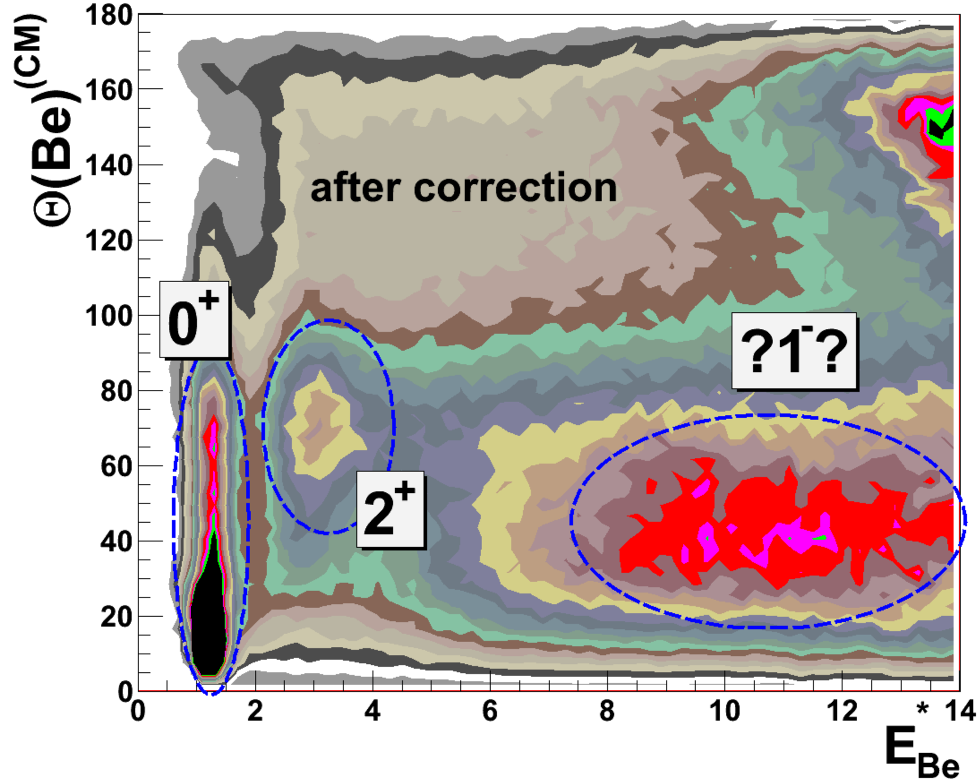


- g.s. 0+
  - $E_{\alpha pp}$ ~ 1.3 MeV; G ~ 0.25 MeV
- e.s. 2+
  - $E_{\alpha pp}$ ~ 3.0 MeV; G ~ 1.2 MeV
- bump in region E > E(2^+)

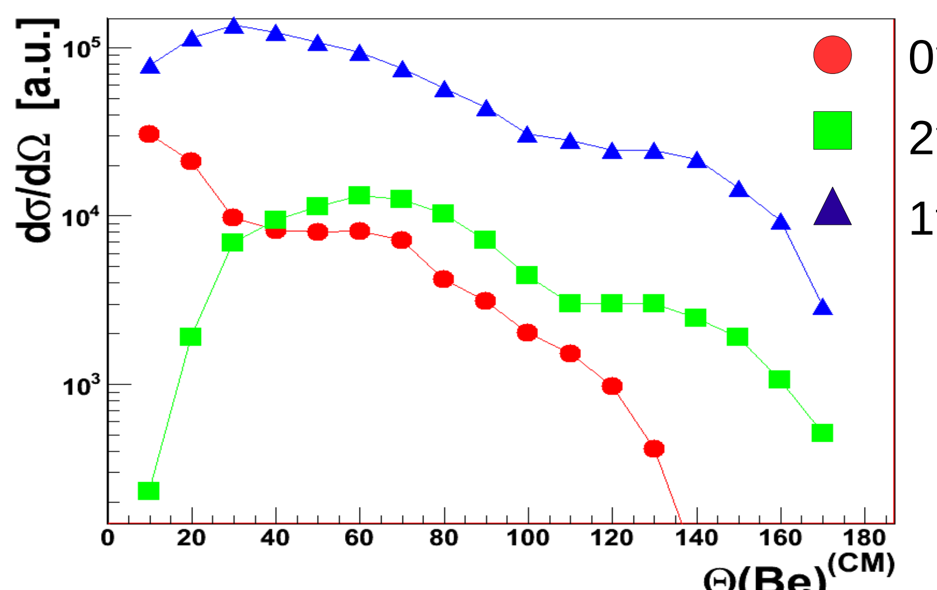
- E^*_{Be} populated up to ~23 MeV above the α + 2p threshold
- spectrum was measured in range (0; π) of Θ_{cm}
- low background

2009-2010: 6Be structure – Angular distribution



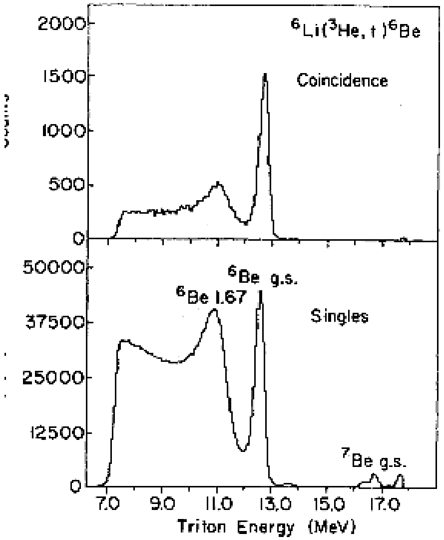


- broad bump above the first e.s.
  - maximum at 9 – 12 MeV
  - uniform shape at different angles
- such a rise above the 2^+ state was observed also in other experiments

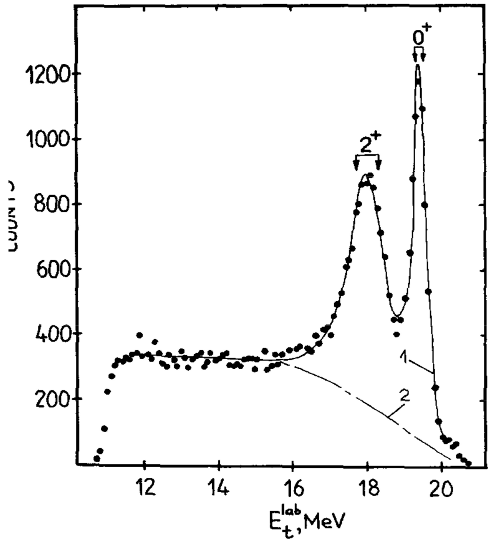


2009-2010: 6Be structure – Measured data

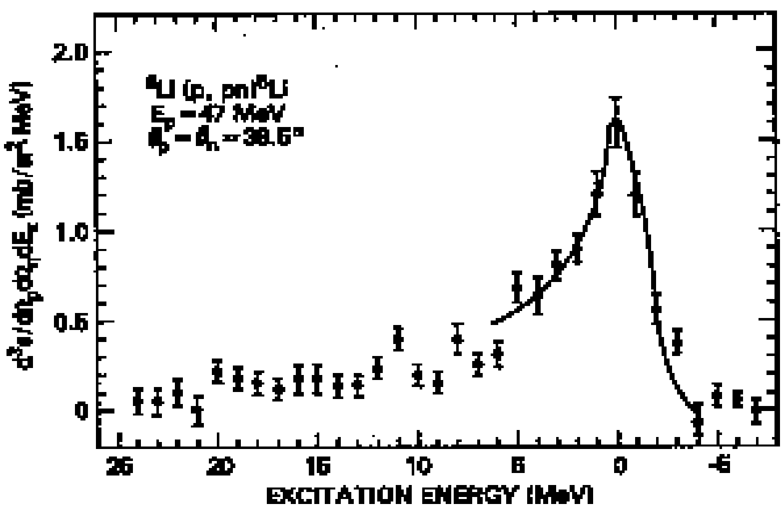
previous works



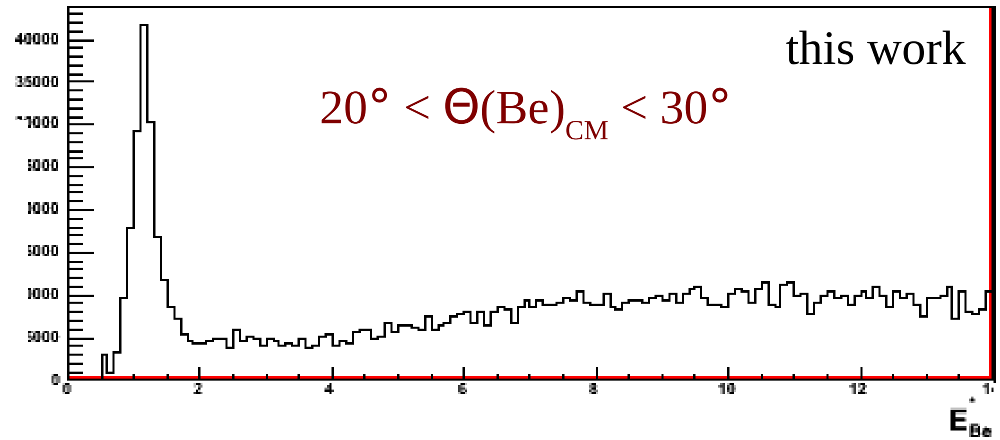
D.F. Geesaman et al.,
Phys.Rev.C vol. 15, 5 (1977)

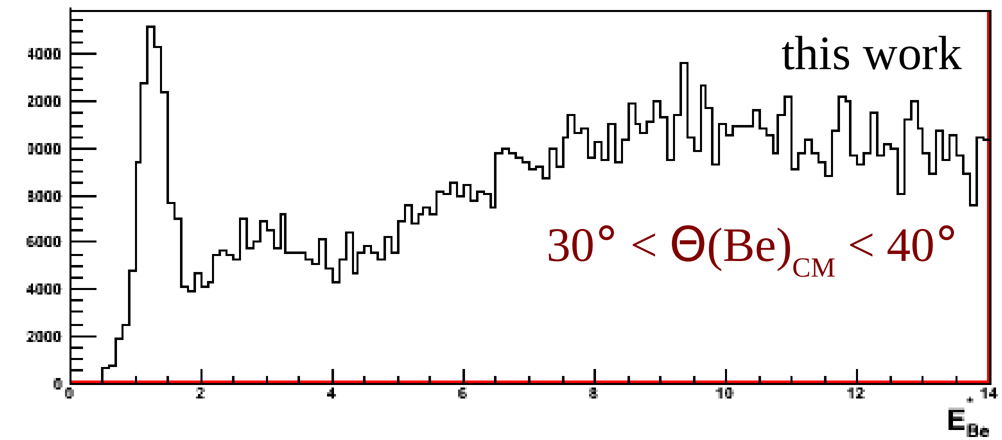


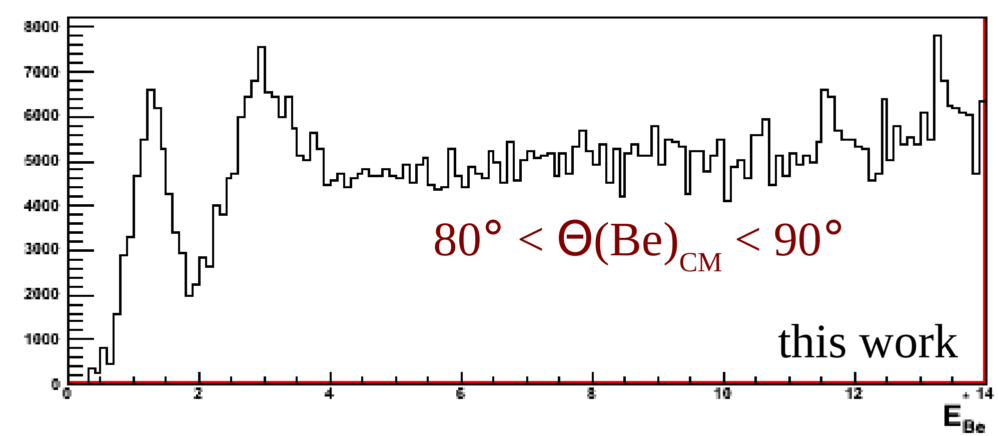
O.V. Bochkarev et al.,
Nucl.Phys.A505 (1989)



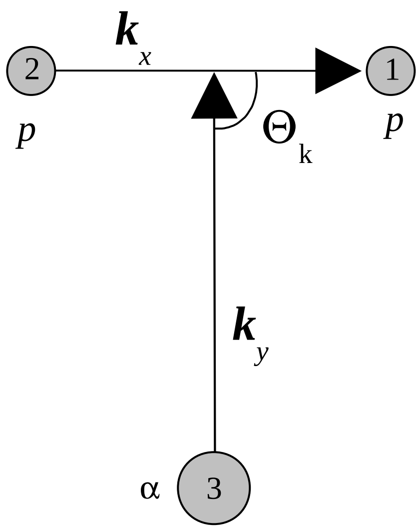
C.N. Waddel et al., Nucl.Phys.A281 (1977)

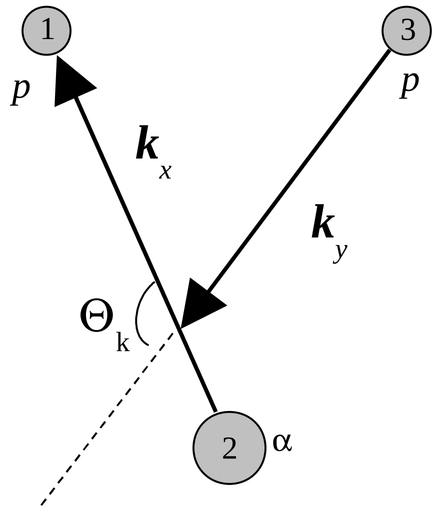






2009-2010: 6Be structure –Jacobi coordinates





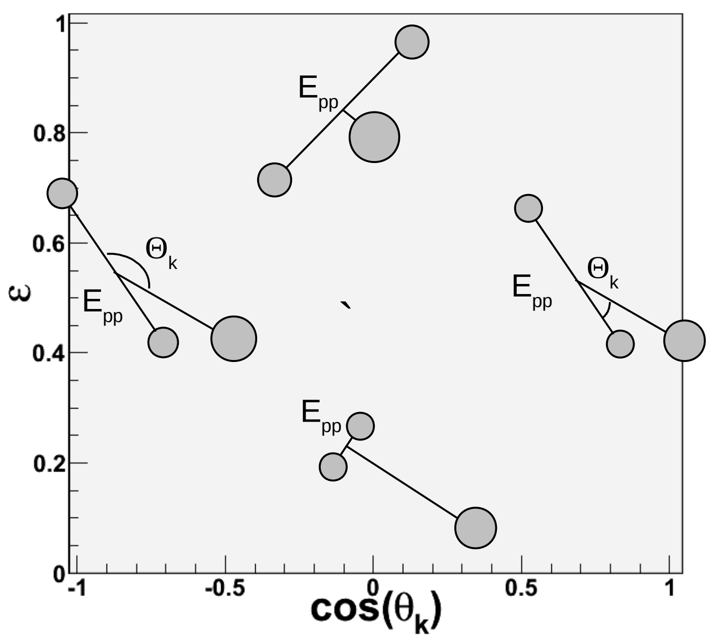
- Full description of the inner structure
- α core with valence protons

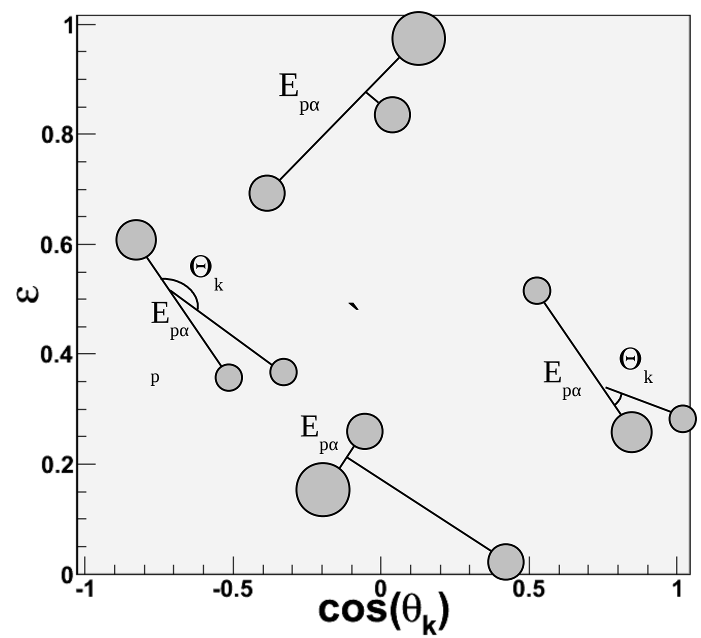
$$\varepsilon = \frac{E_x}{E_x + E_y}$$

$$\cos(\Theta_k) = \frac{\mathbf{k}_x \cdot \mathbf{k}_y}{k_x k_y}$$

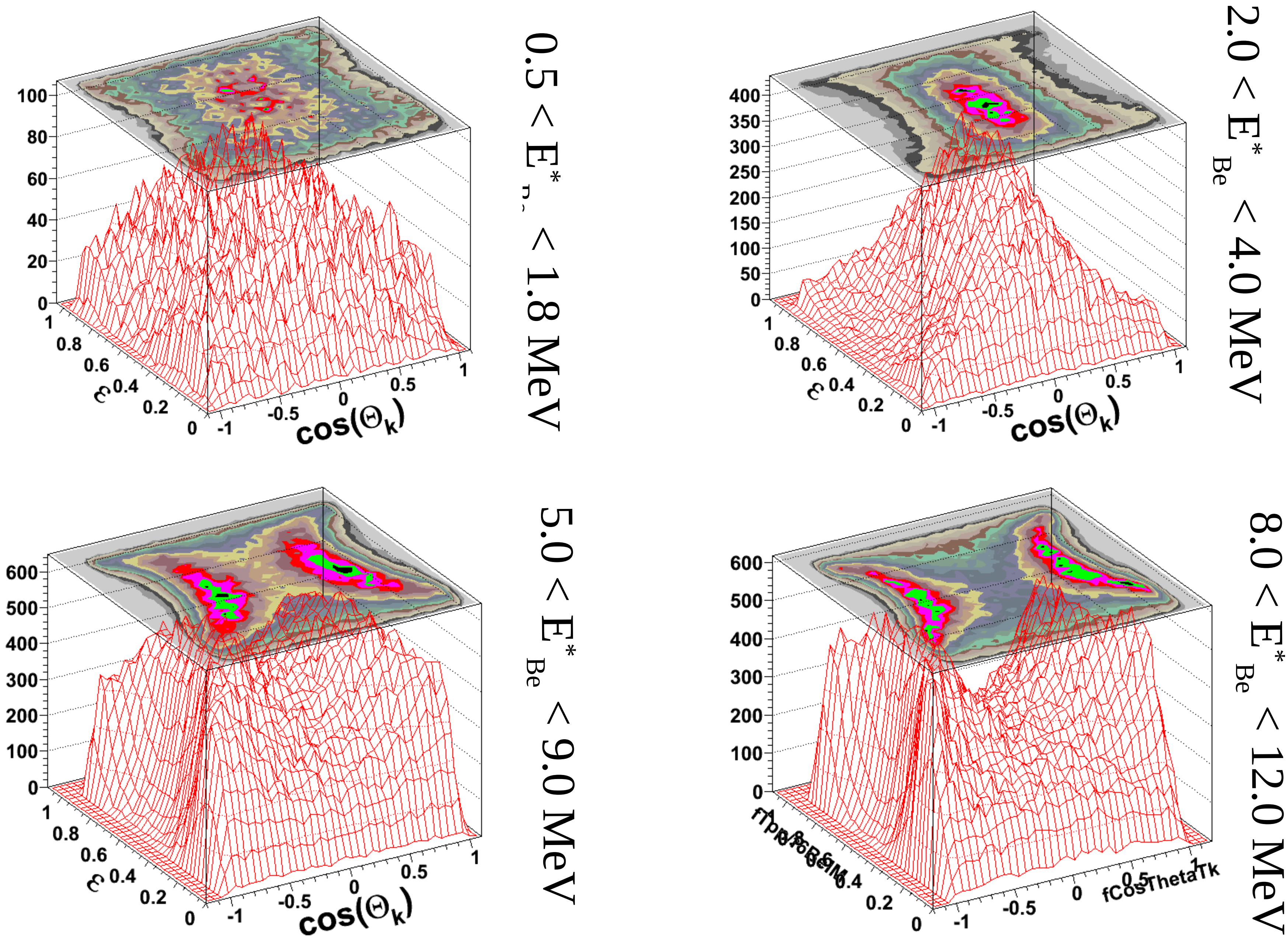
$$E_x = \frac{\mathbf{k}_x^2}{2M_x}$$

$$E_y = \frac{\mathbf{k}_y^2}{2M_y}$$





2009-2010: 6Be structure – Structure

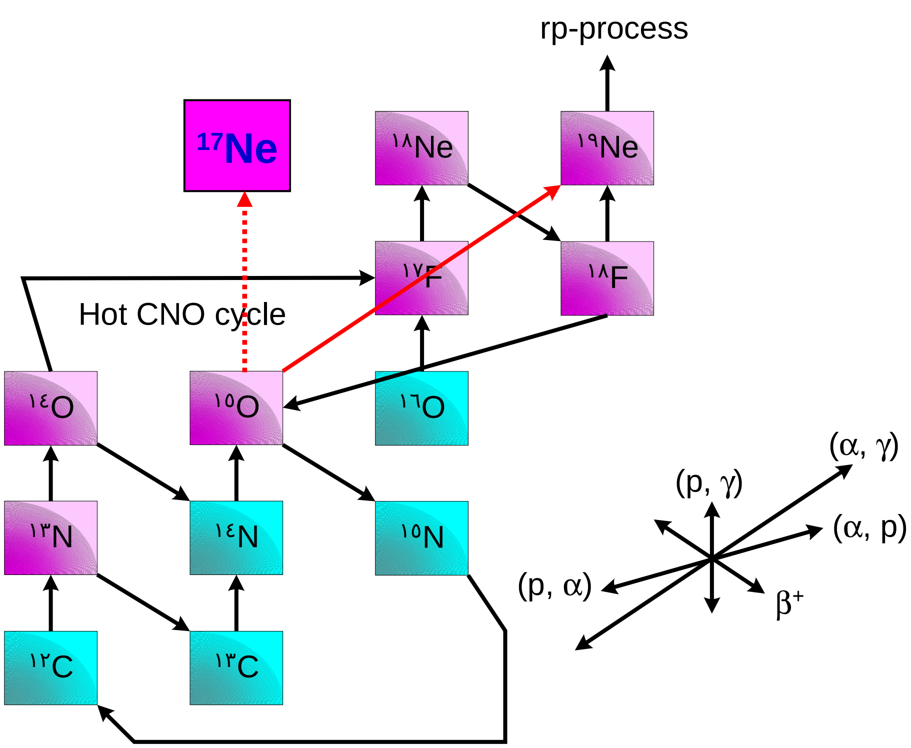


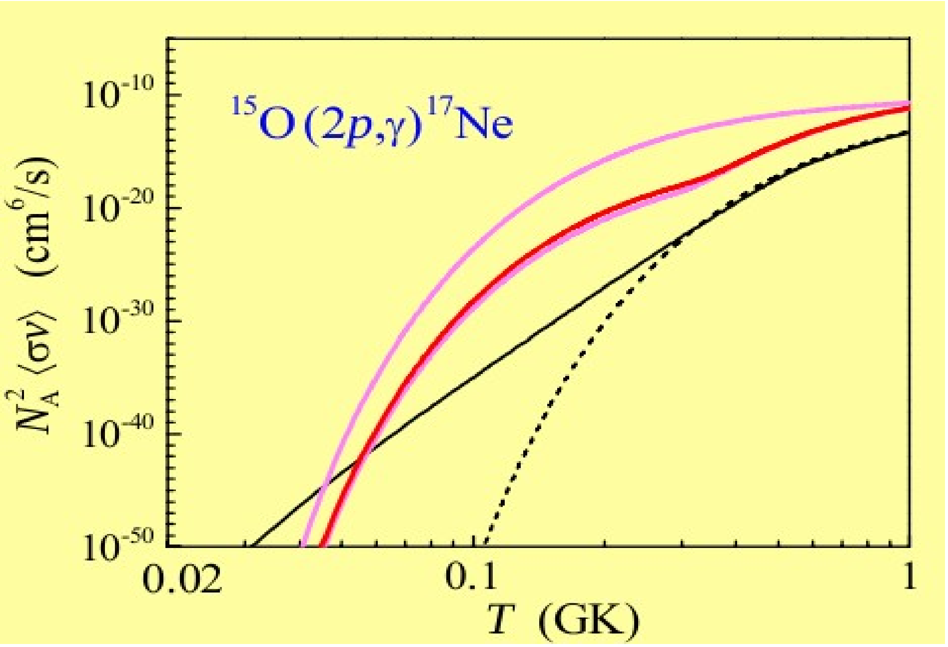
2009-2010: 6Be structure – Preliminary results

- invariant mass (IM) spectrum of ^{6}Be was investigated in reaction $^{1}H(^{6}Li, p)^{6}Be$ in full CMS angular range
- in IM spectrum of ^{6}Be in addition to well known g.s. (0^{+}) and first e.s. (2^{+}) the broad bump with the maximum at the energy 8 – 12 MeV was observed
- analysis of the angular distributions allowed us to assigne $L_{trans.} = 1$ to this structure
- further analysis of inner correlations should elucidate both the structure of this nucleus and reaction mechanism

2011: Study of the ^{17}Ne two-proton decay

- waiting points of r-p process: ^{15}O, ^{18}Ne, ^{38}Ca
  $\tau_{1/2}$ for β^+ decay: 122 s, 1.67 s, 0.44 s
- pessimistic prediction about possibility to bridge the waiting points by 2p capture (*J. Gorres et al*, Phys. Rev. C 51 (1995) 392)
- only sequential processes taken into account:
  - ^{15}O(2p, γ)^{17}Ne omitted 3/2$^-$ at 1288 keV (Q_{2p} = 344 keV)
  - ^{18}Ne(2p, γ)^{20}Mg
  - ^{38}Ca(2p, γ)^{40}Ti omitted 0$^+$ at 2100 keV (Q_{2p} = 550÷740 keV)





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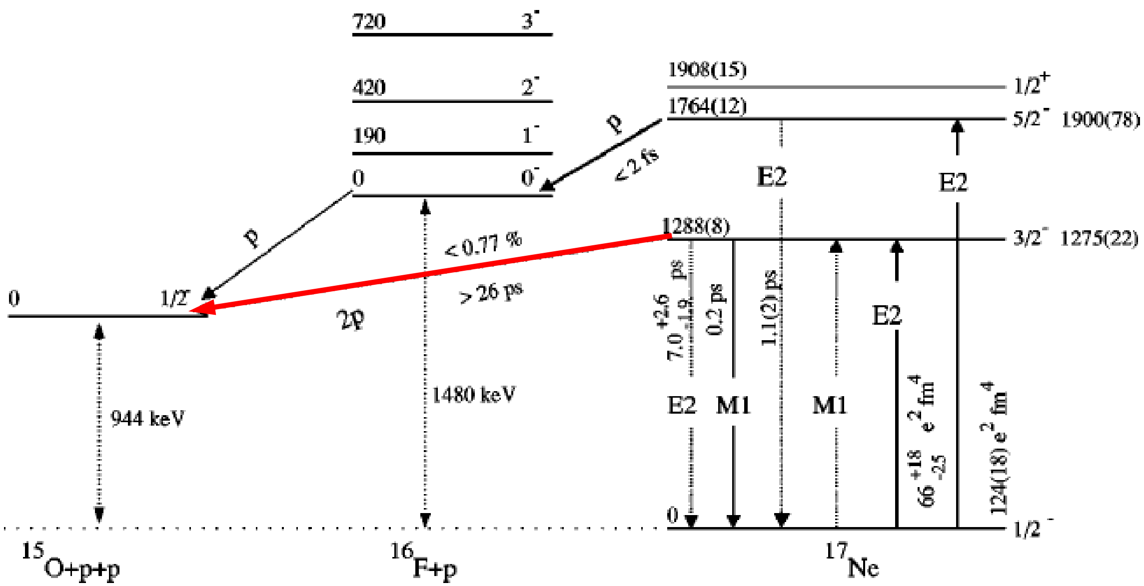


M.J. Chromik et al.

PRC66, 024313 (2002)

^{17}Ne+^{197}Au, Coulomb excitation

$\sigma_{3/2-} = 12.0^{+5.3}_{-3.9}$ mb

$\tau_{2p} > 26$ ps

^{18}Ne(p,d)^{17}Ne / ^{17}Ne+p QFS

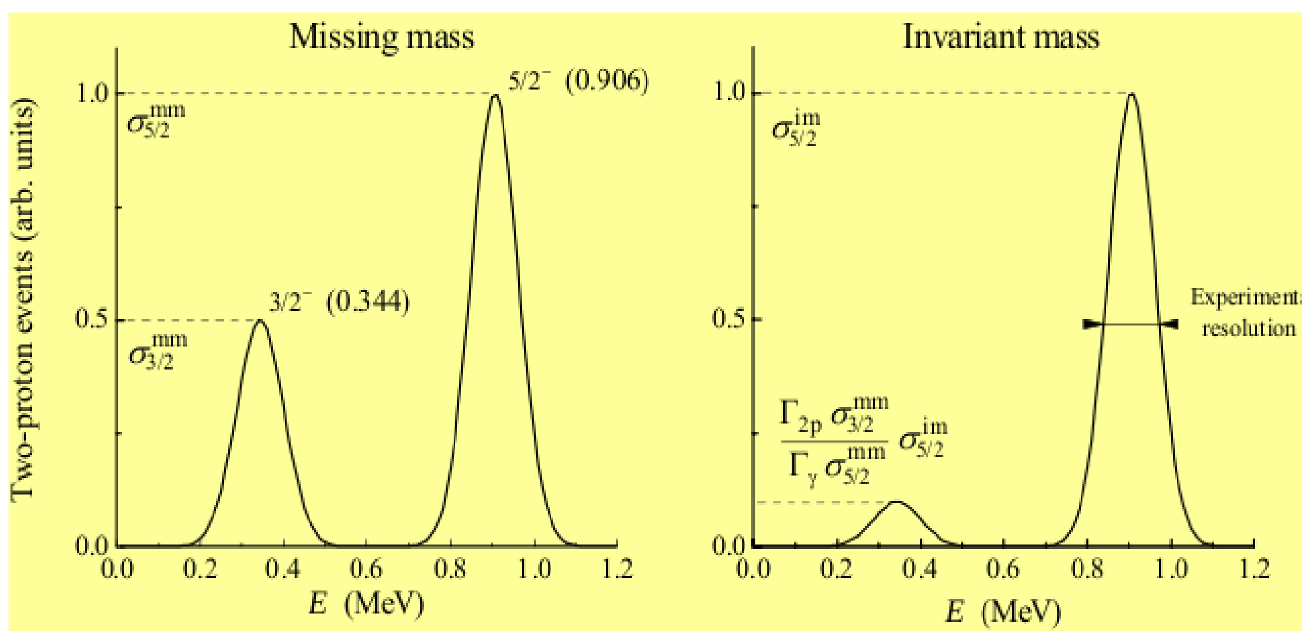
+ Theory and complex simulation of the experiment;

+ High energy resolution ΔE~250 keV (FWHM);

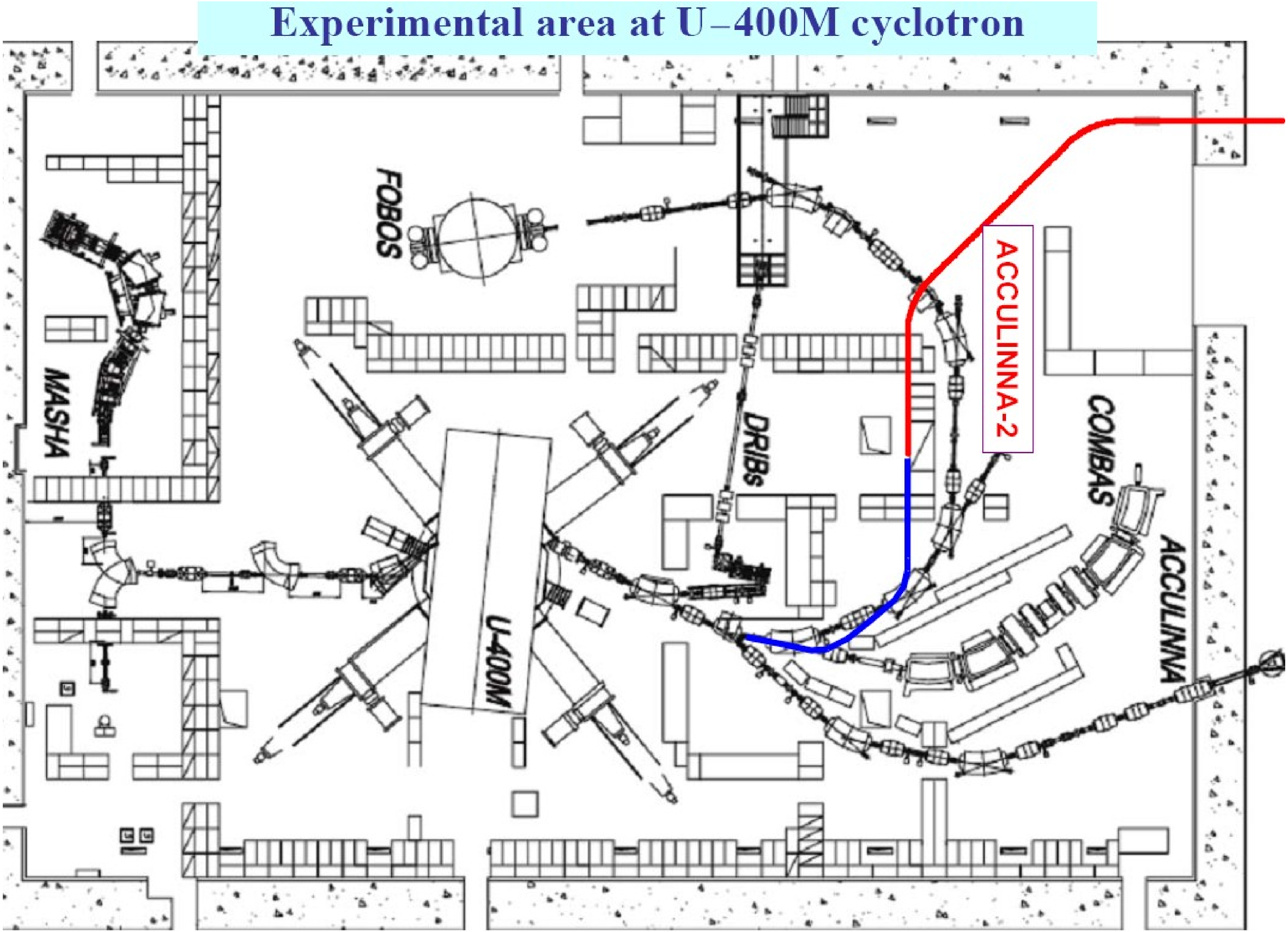
± Problem with a statistics: probability of *2p* branch is ~10^{-5} for the 3/2− state

⇩ ⇩

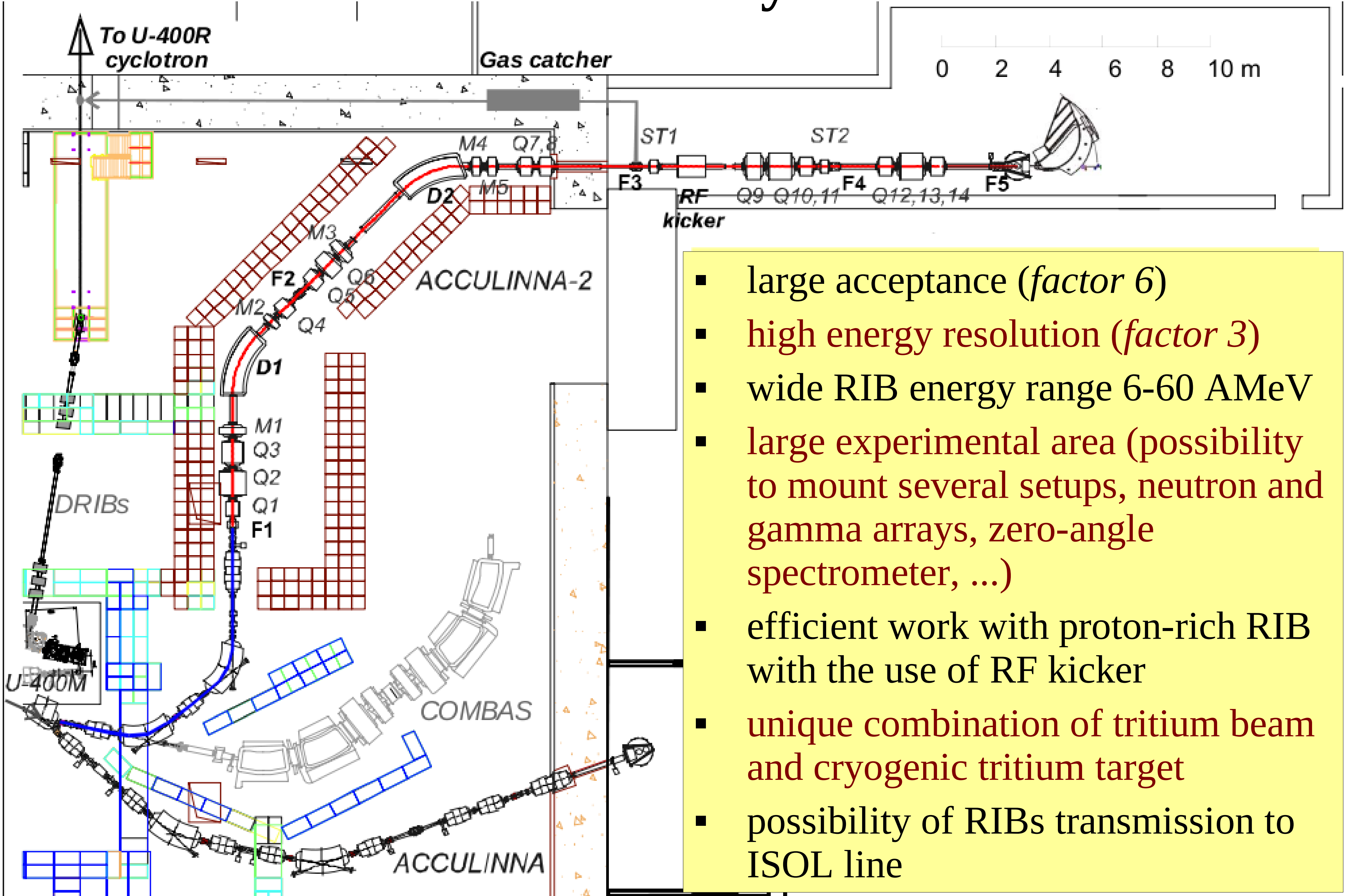
I(^{18}Ne)~5× 10^4 / I(^{17}Ne)~10^3 s^{-1}



2011 – 2016: New RIB facility ACCULINNA2

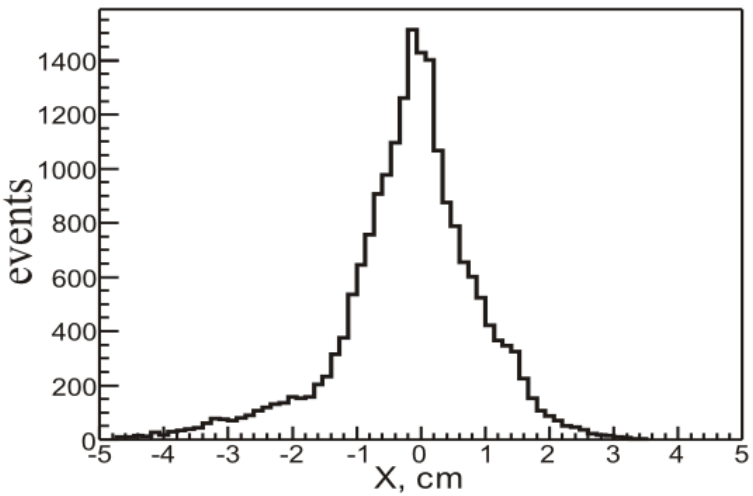


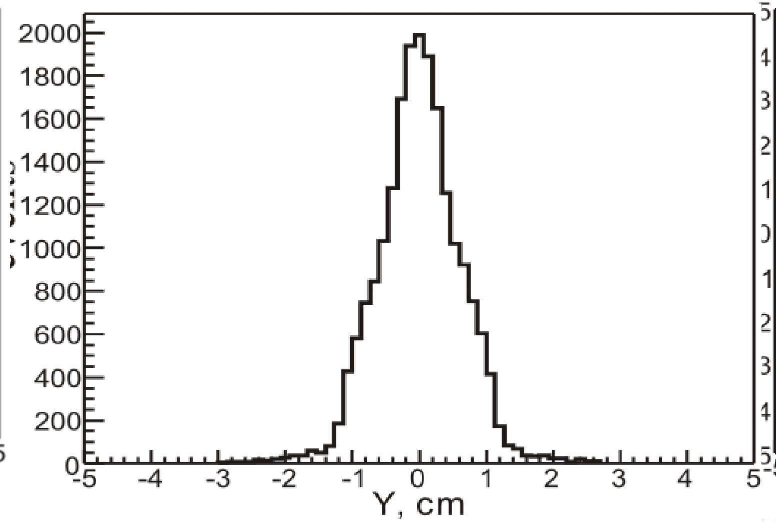
2011 – 2016: New RIB facility ACCULINNA2



- large acceptance (*factor 6*)
- high energy resolution (*factor 3*)
- wide RIB energy range 6-60 AMeV
- large experimental area (possibility to mount several setups, neutron and gamma arrays, zero-angle spectrometer, ...)
- efficient work with proton-rich RIB with the use of RF kicker
- unique combination of tritium beam and cryogenic tritium target
- possibility of RIBs transmission to ISOL line

2011 – 2016: New RIB facility ACCULINNA2





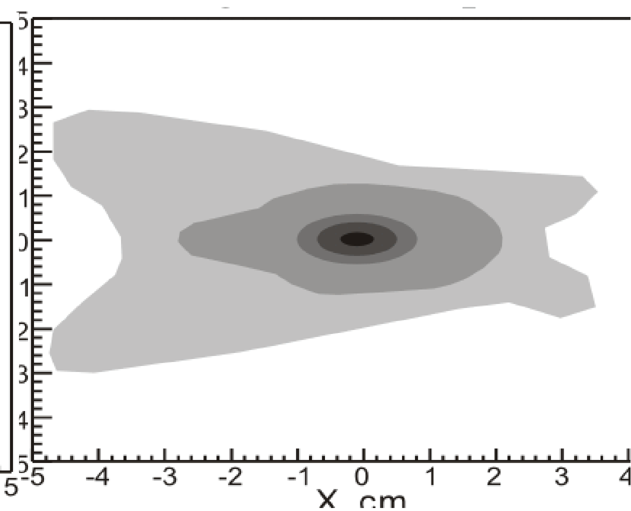


Table 1: Characteristics of in-flight RIB separators; $\delta_P = \Delta P/P$ is the momentum acceptance and $P/\Delta P$ is the first-order momentum resolution, obtained at a 1 mm object size.

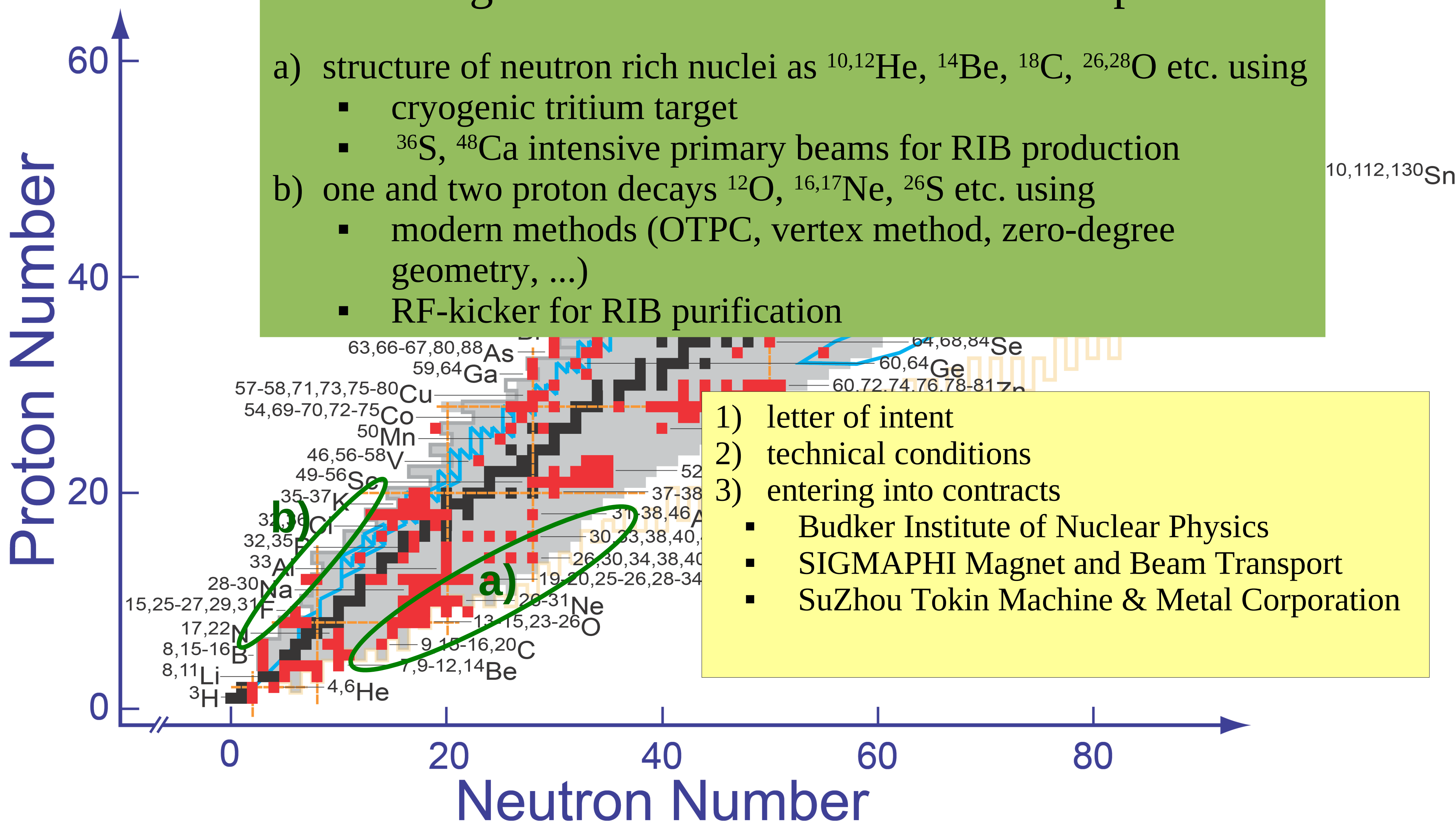
		ACC	ACC-2	LISE	A1900	RIPS	BigRIPS	FRS	SuperFRS
		FLNR, JINR		GANIL	MSU	RIKEN		GSI	
$\Delta\Omega$,	msr	0.9	5.8	1.0	8.0	5.0	8.0	0.32	5.0
δ_P ,	%	2.5	6.0	5.0	5.5	6.0	6.0	2.0	5.0
$P/\Delta P$,	a.u.	1000	2000	2200	2915	1500	3300	8600	3050
$B\rho_{max}$,	Tm	3.2	3.9	3.2(4.3)	6.0	5.76	9.0	18	18
Length ,	m	21	38	19(42)	35	21	77	74	140
E_{min} ,	A·MeV	10	5	40	110	50		220	
E_{max} ,	A·MeV	40	50	80	160	90	350	1000	1500

2011 – 2016: New RIB facility ACCULINNA2

ecological niche for ACCULINNA2 separator

a) structure of neutron rich nuclei as ^{10,12}He, ^{14}Be, ^{18}C, ^{26,28}O etc. using
- cryogenic tritium target
- ^{36}S, ^{48}Ca intensive primary beams for RIB production

b) one and two proton decays ^{12}O, ^{16,17}Ne, ^{26}S etc. using
- modern methods (OTPC, vertex method, zero-degree geometry, ...)
- RF-kicker for RIB purification



1) letter of intent
2) technical conditions
3) entering into contracts
   - Budker Institute of Nuclear Physics
   - SIGMAPHI Magnet and Beam Transport
   - SuZhou Tokin Machine & Metal Corporation

Conclusion and outlooks

- the RIB research at FLNR JINR is running
- unique experimental opportunities and theoretical background
- ACCULINNA group have an ambition to make FLNR famous in the world not only for ***Super Heavy Elements*** studies
- collaboration with *iTEMBA Lab* and *Stellenbosch University* is obviously seen and will continue

Thank you for your attention