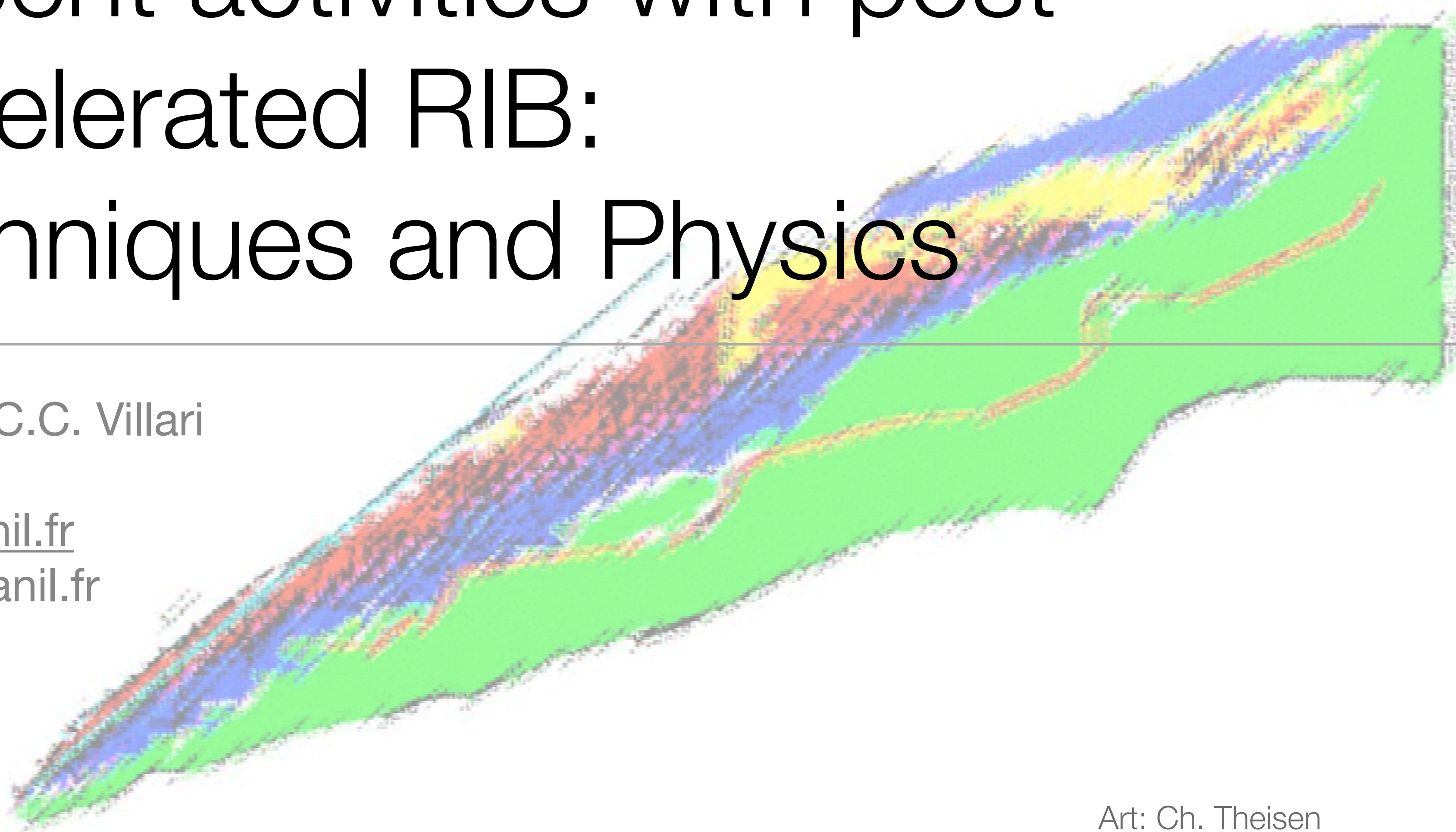
Recent activities with post accelerated RIB: Techniques and Physics



Art: Ch. Theisen

Antonio C.C. Villari
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villari@ganil.fr

INPC 2007 June 3-8 2007

Overview

- Why RIBs
- From principles: ISOL and post acceleration
- Facilities: CRC-LLN, SPIRAL, HRIBF, ISAC
- Selected experiments
- Looking forward

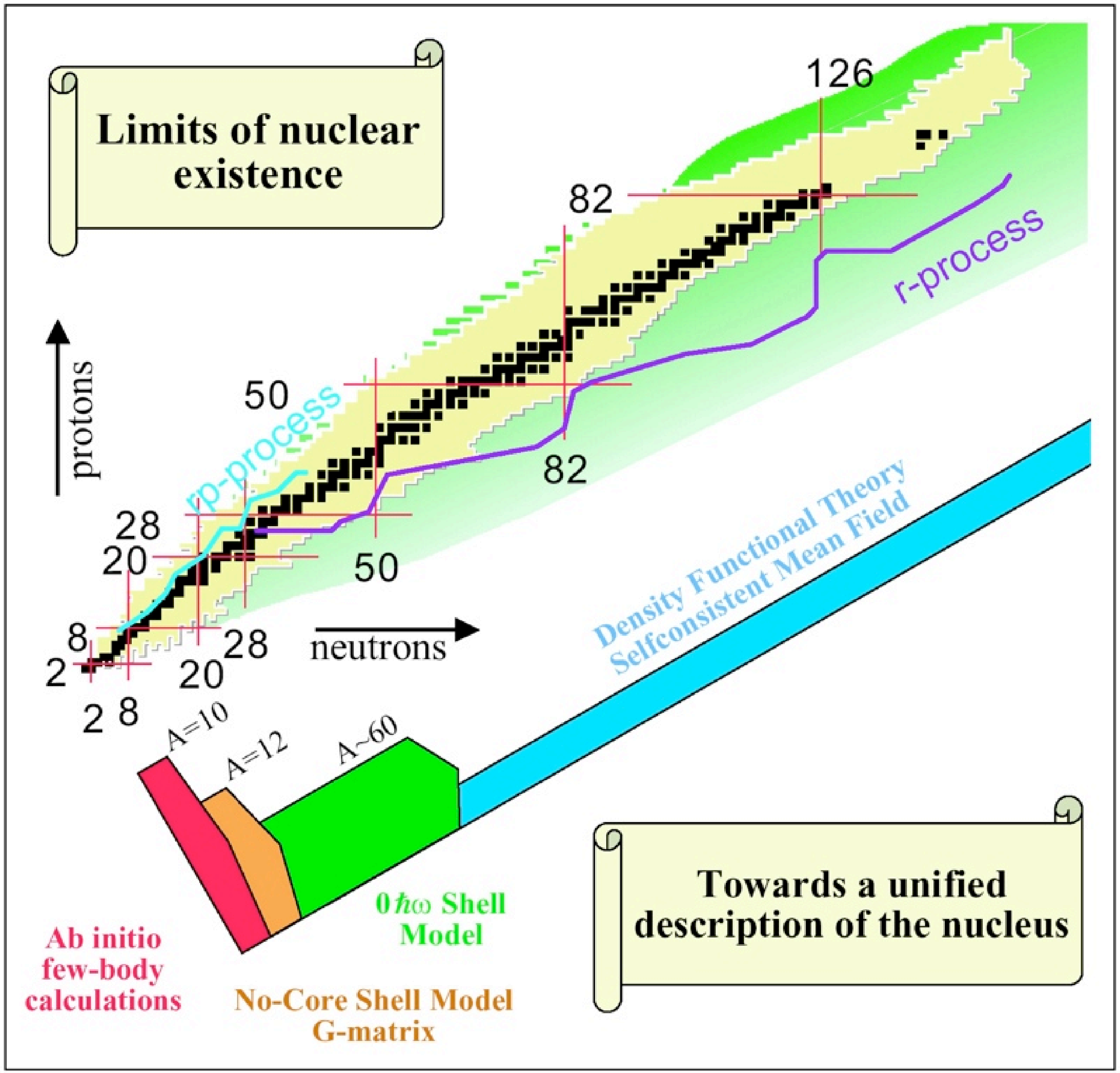
Why

Unknown region is vast
Limits are unknown
Nucleosynthesis path
Magic numbers
Neutron matter

Various descriptions
Relativistic or not
3 body force, 4 body
Unification ?

You have to produce for studying

REACTIONS:
Unstable beams,
where no targets available



from RIA white paper

Why

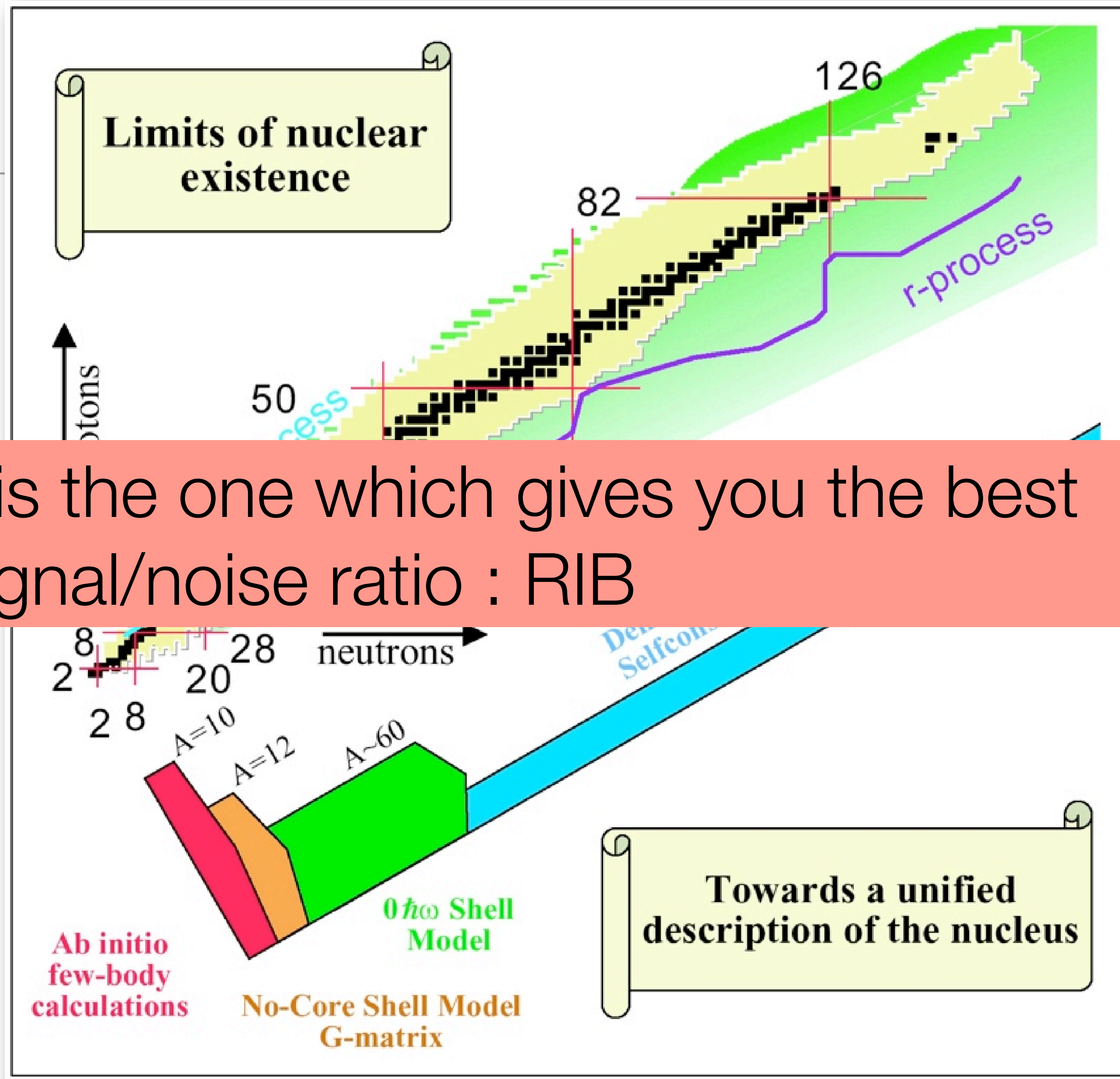
Unknown region is vast
Limits are unknown
Nucleosynthesis path
Magic numbers

The best probe is the one which gives you the best signal/noise ratio : RIB

Relativistic or not
3 body force, 4 body
Unification ?

You have to produce for studying

REACTIONS:
Unstable beams,
where no targets available



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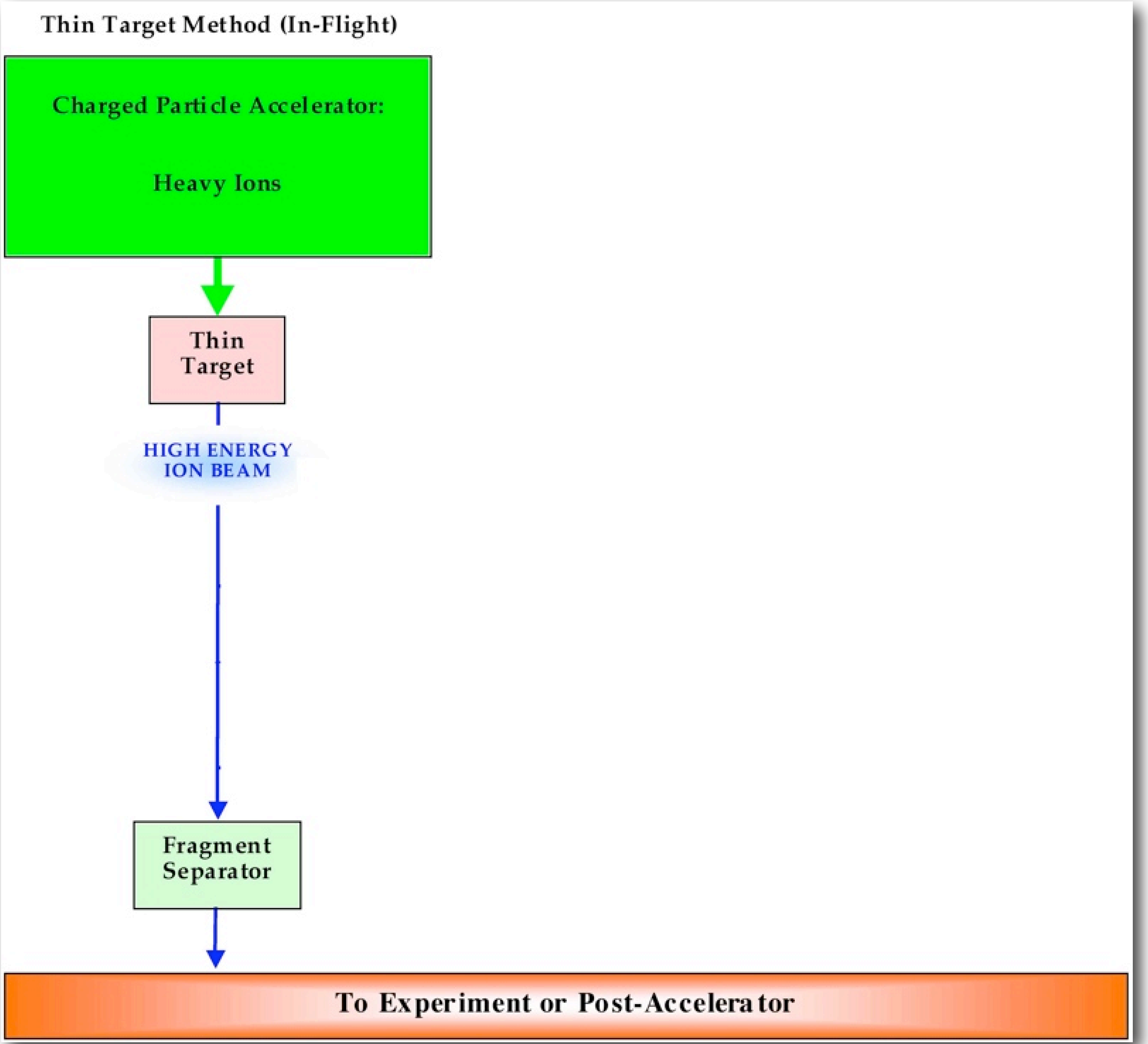
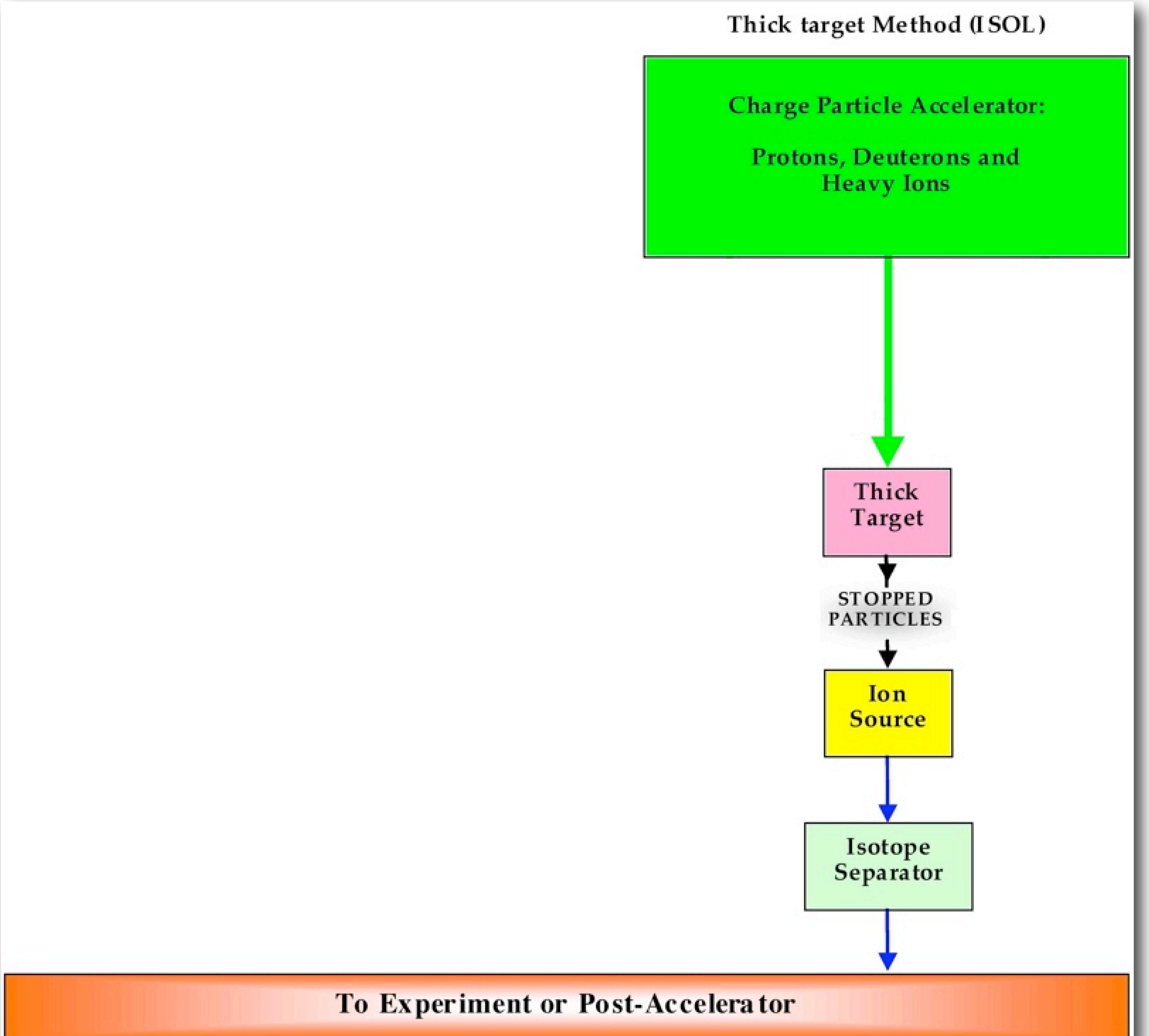
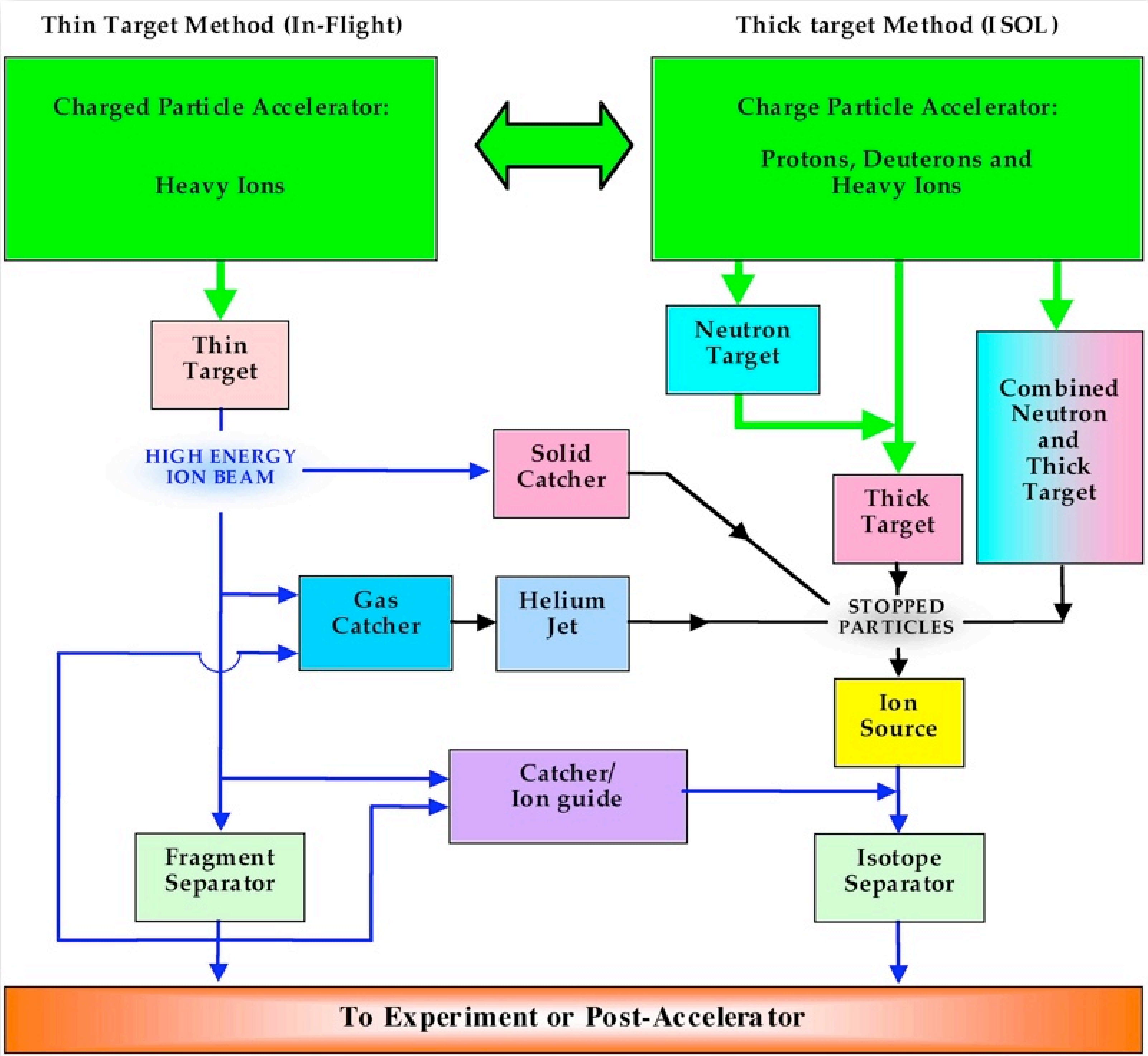
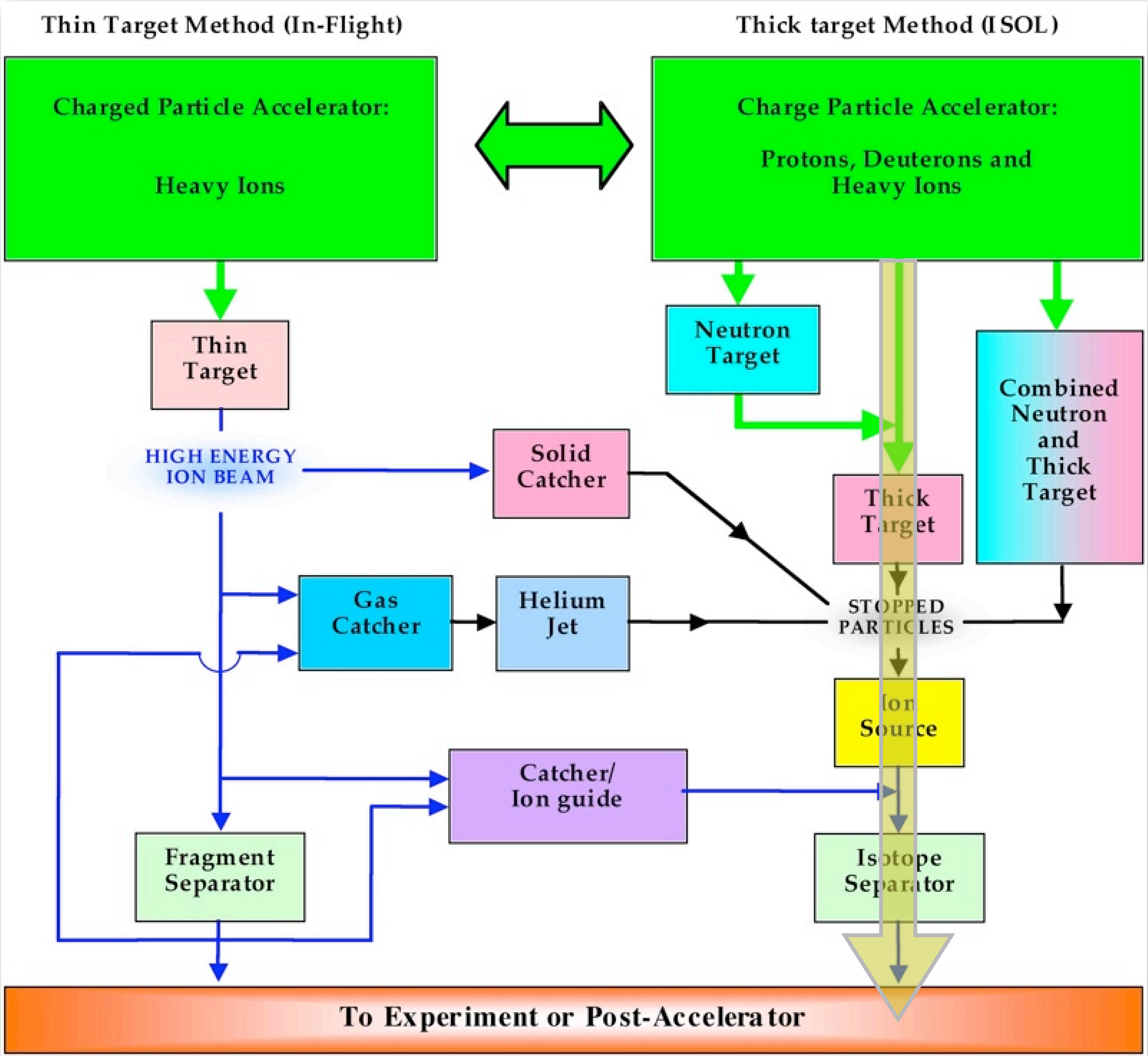

Thin Target Method (In-Flight)
Charged Particle Accelerator:
Heavy Ions
Thin Target
HIGH ENERGY
ION BEAM
Fragment Separator
To Experiment or Post-Accelerator


Thick target Method (ISOL)
Charge Particle Accelerator:
Protons, Deuterons and Heavy Ions
Thick Target
STOPPED PARTICLES
Ion Source
Isotope Separator
To Experiment or Post-Accelerator



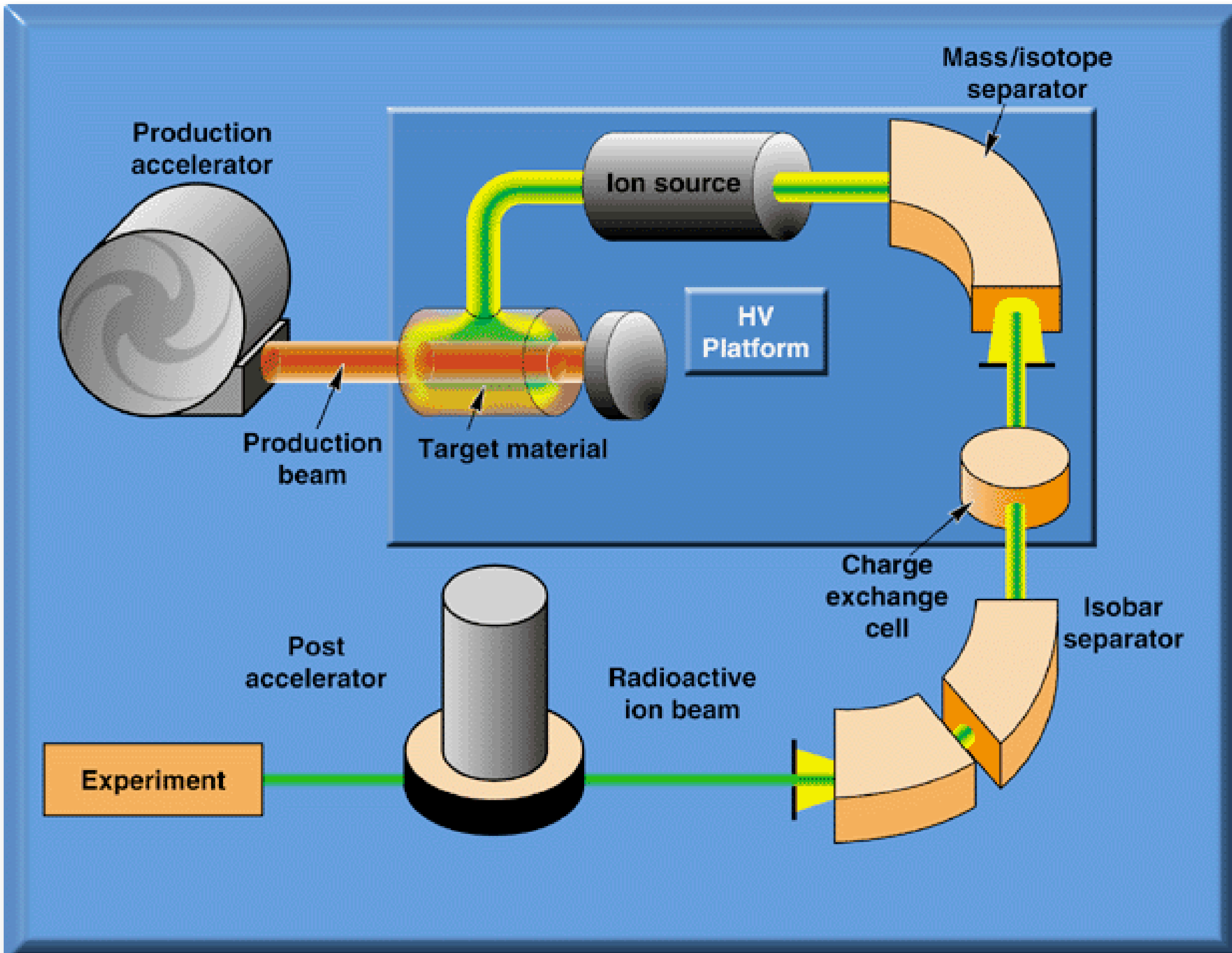
A.C.C. Villari and R. Bennett, Comptes Rendus. Physique (2003) (no.4-5t.4) p. 595



A.C.C. Villari and R. Bennett, Comptes Rendus. Physique (2003) (no.4-5t.4) p. 595

From principles

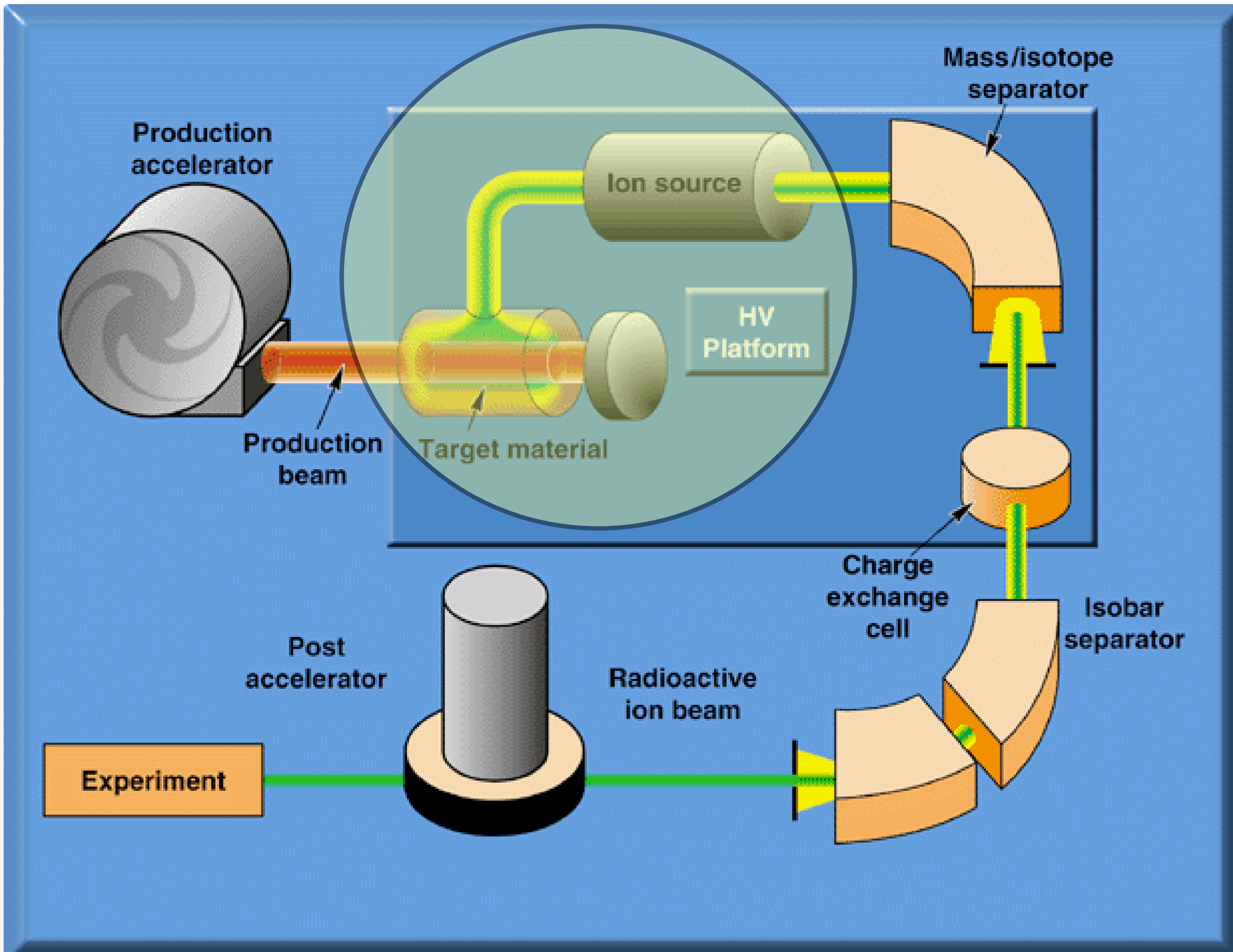
HRIBF



www.phy.ornl.gov

From principles

HRIBF



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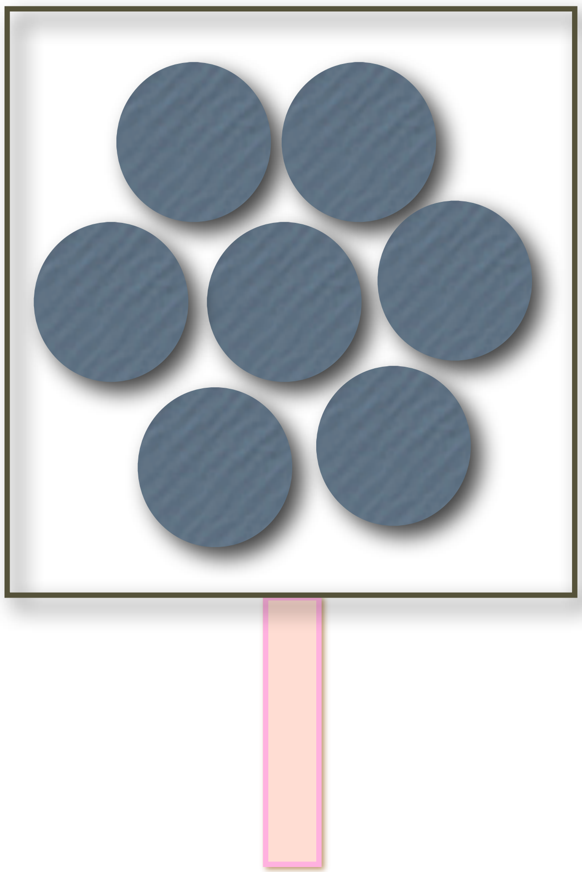
Basics of the production



Diffusion, Effusion, ionization

M. Fujioka and Y. Arai, Nucl. Instr. Meth. 186 (1981) 409
R. Kirchner, Nucl. Instr. Meth. B70 (1992) 186
R. Kirchner, Nucl. Instr. Meth. B203 (2003) 179

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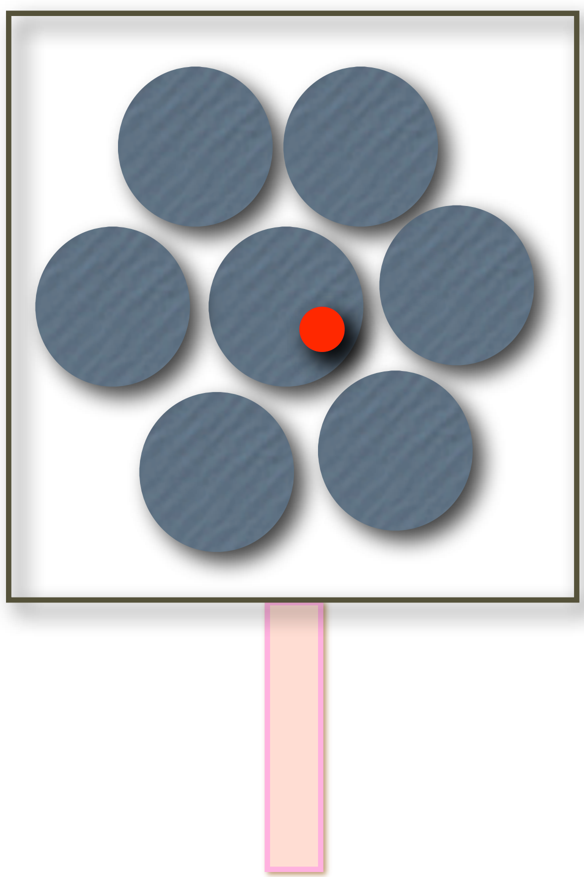

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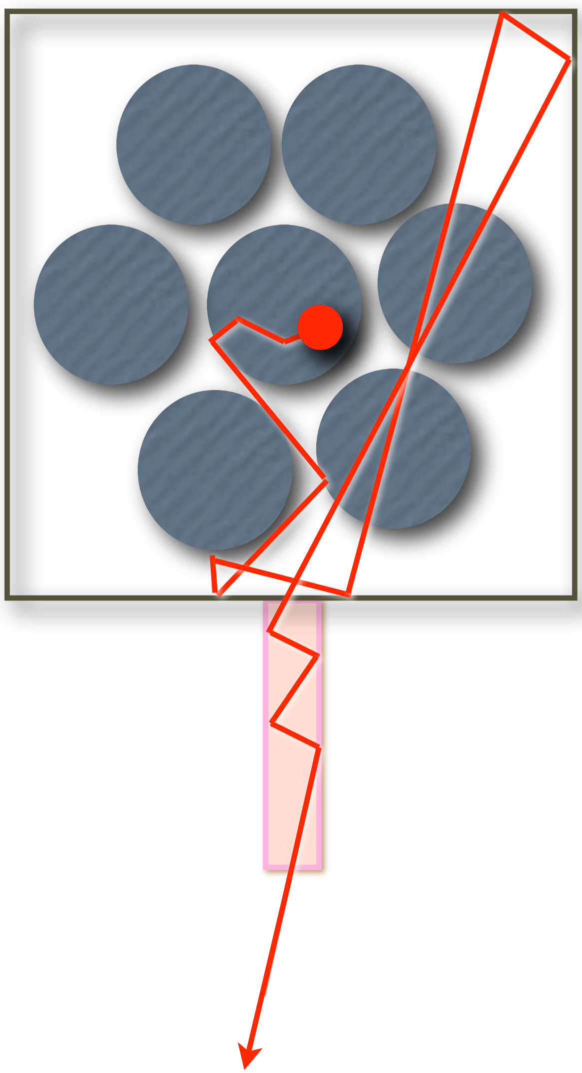

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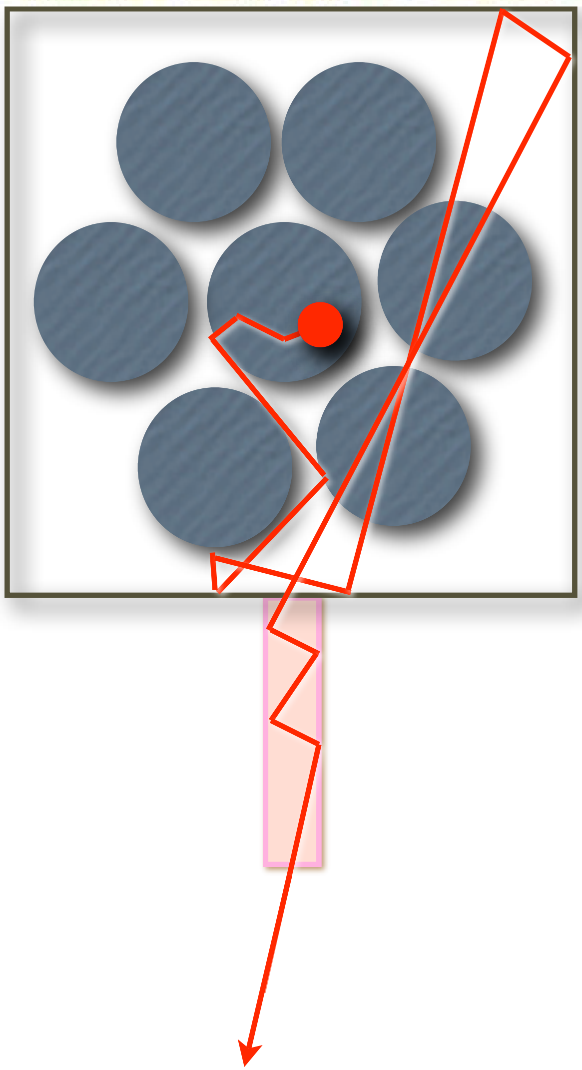
Deauville



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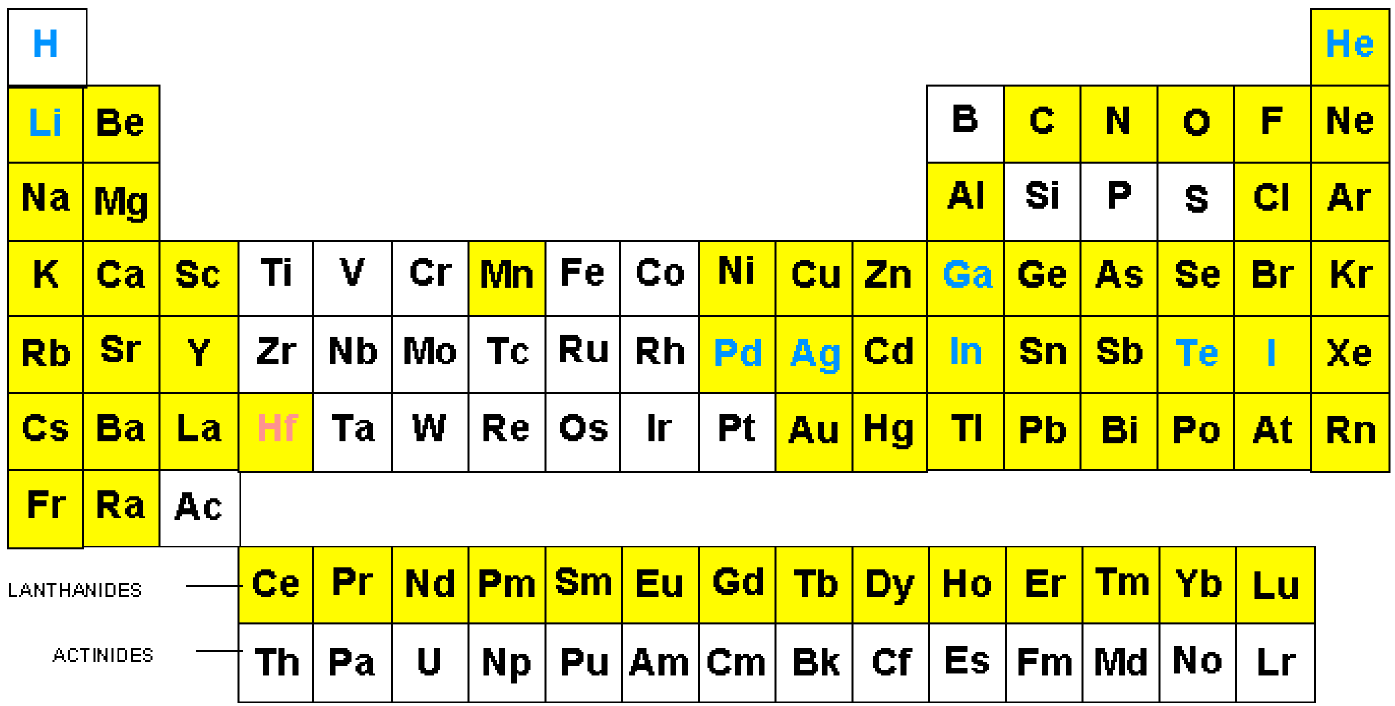
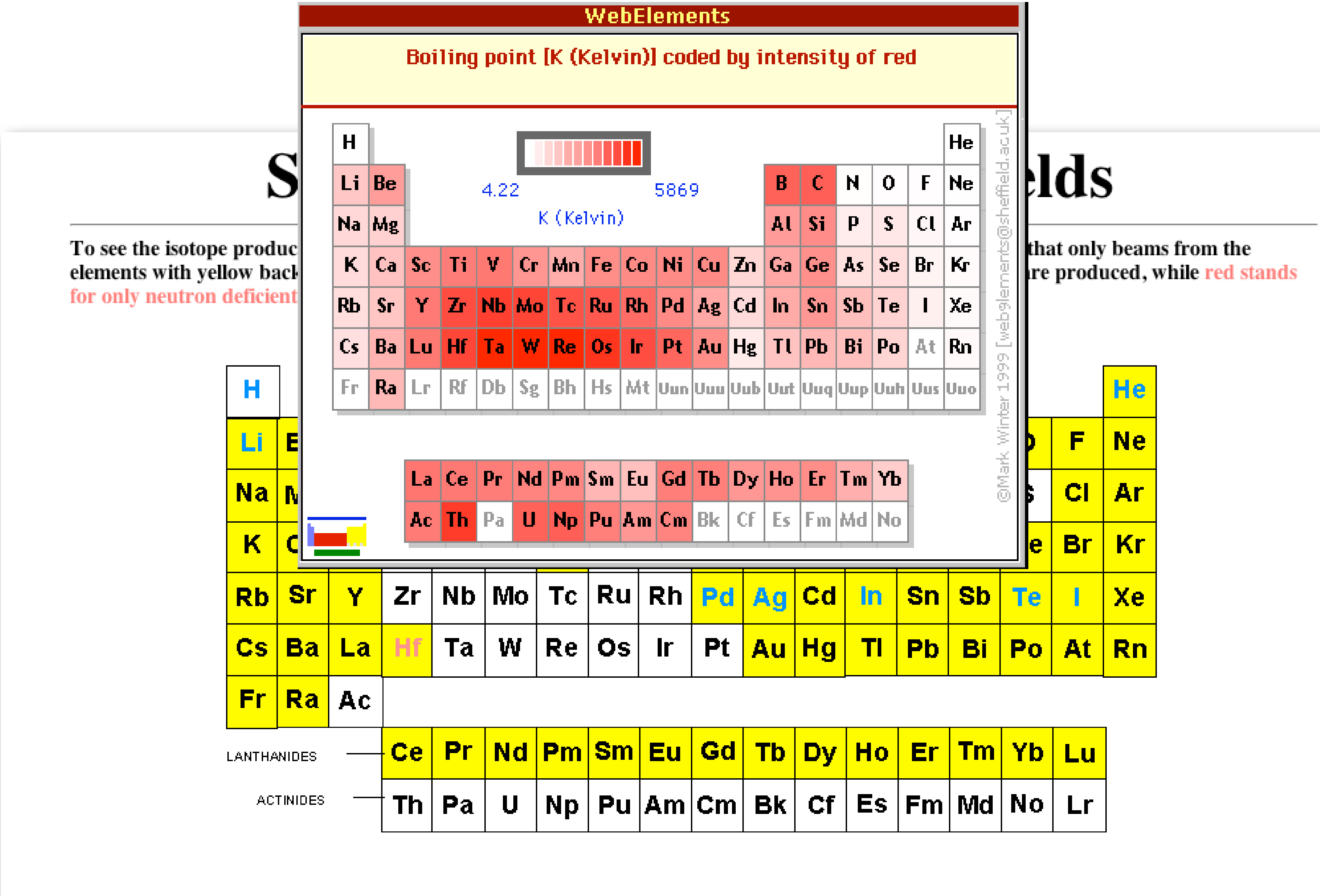
R. Kirchner, Nucl. Instr. Meth. B70 (1992) 186
R. Kirchner, Nucl. Instr. Meth. B203 (2003) 179

SC-ISOLDE Production Yields

To see the isotope production rates of the ISOLDE facility, click on the element you are interested in! Note that only beams from the elements with yellow background are available. If the letters are printed in blue only neutron rich isotopes are produced, while red stands for only neutron deficient ones.

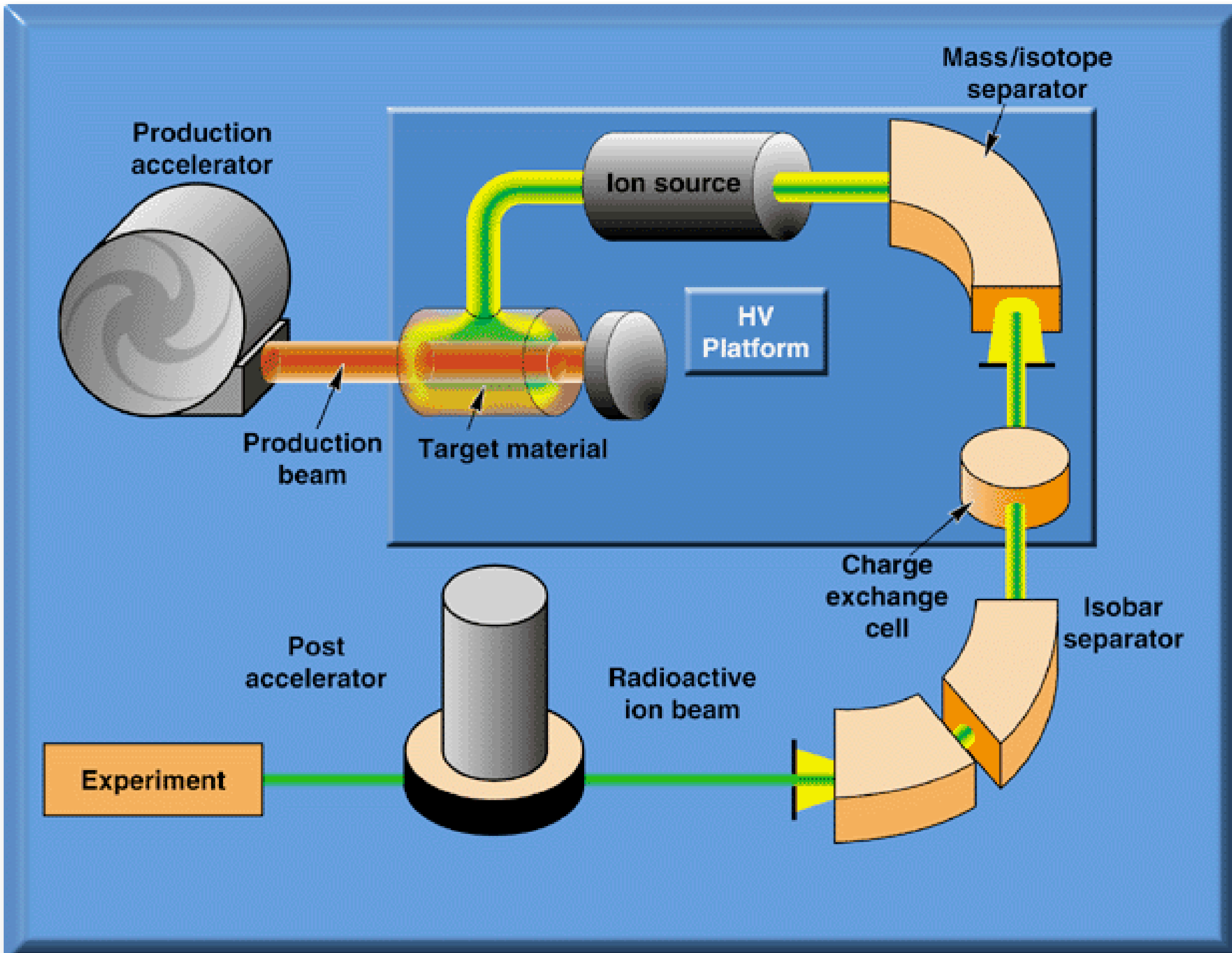


isolde.cern.ch



isolde.cern.ch

From principles



www.phy.ornl.gov

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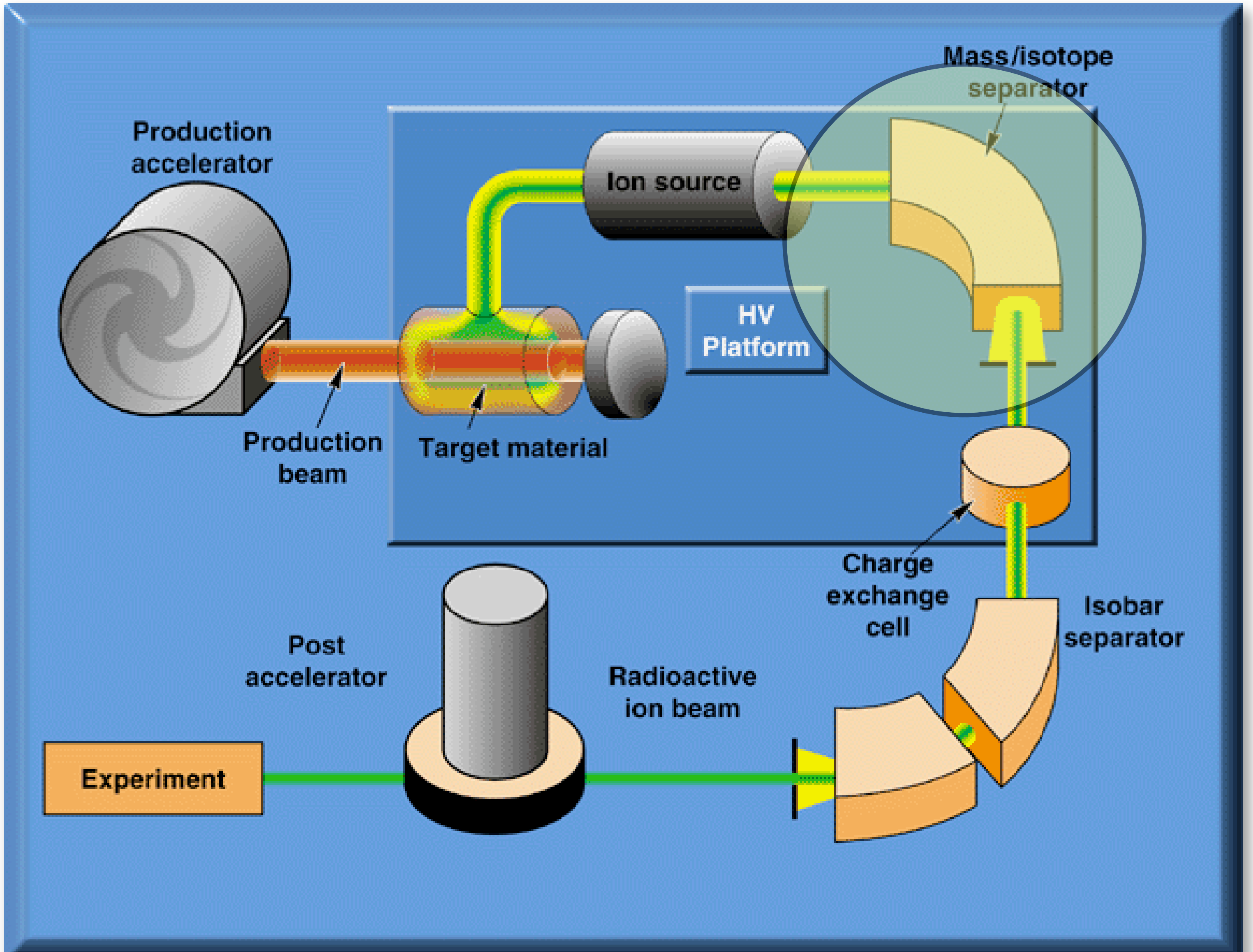

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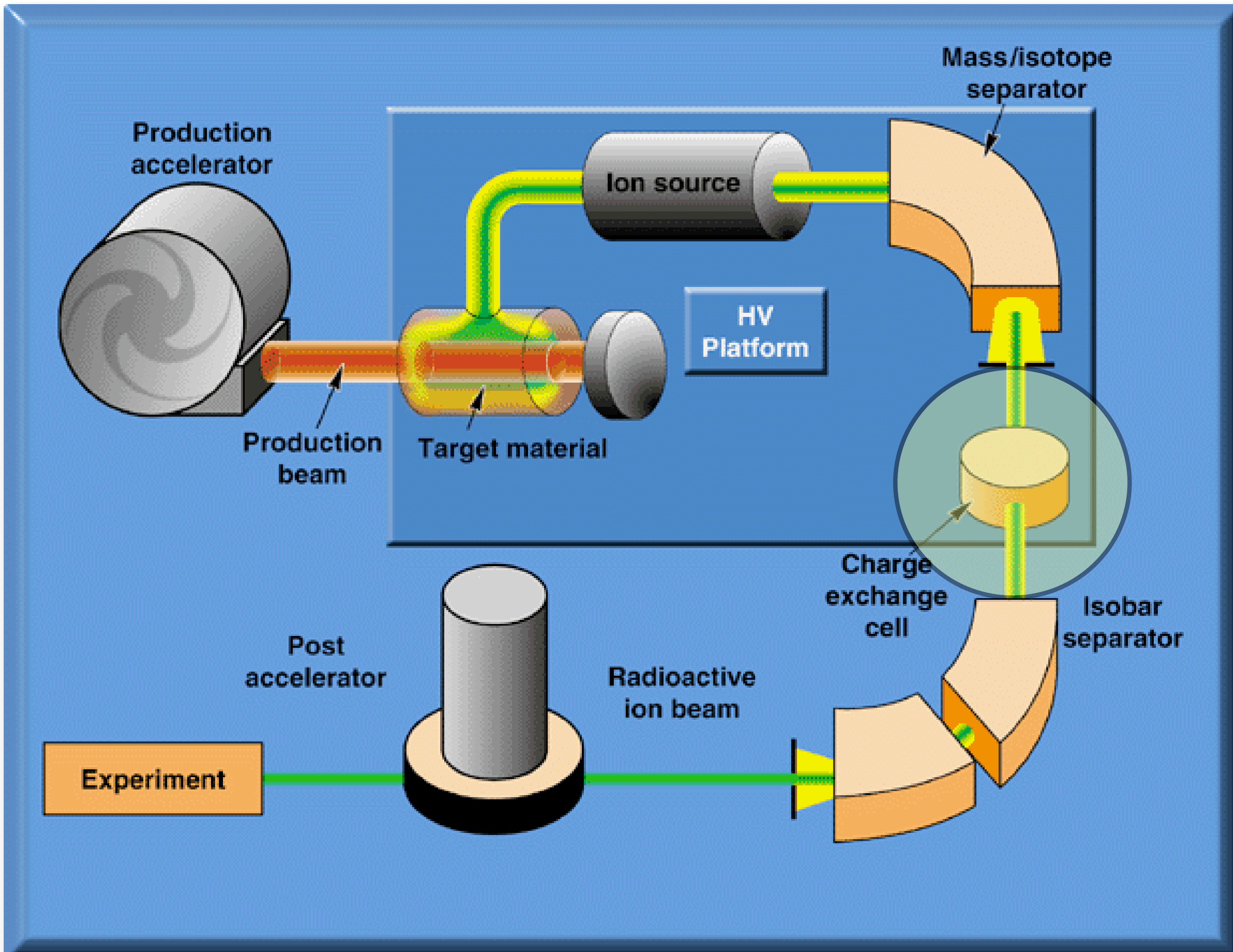

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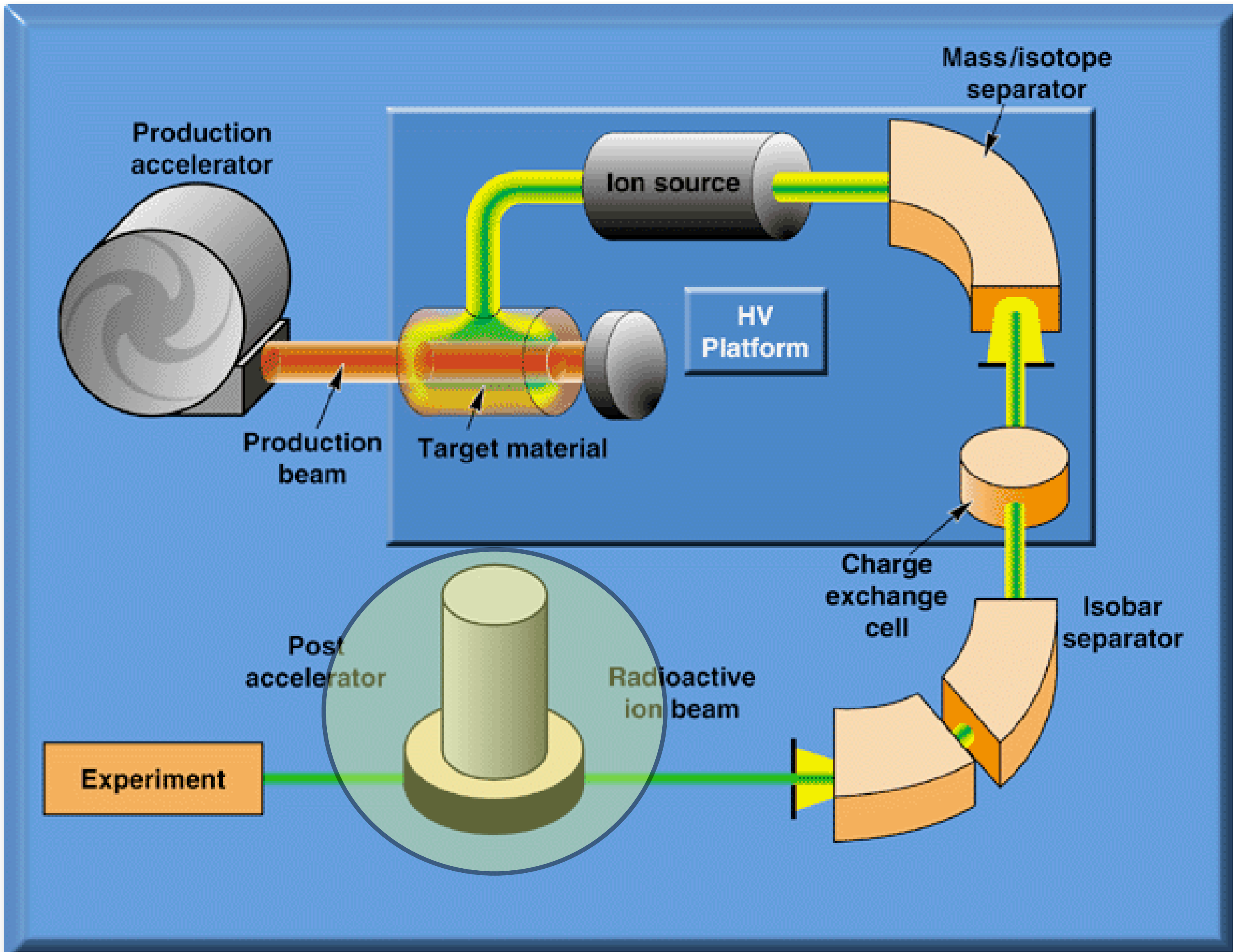

www.phy.ornl.gov

ISOL + post accelerator

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- Provides “high intensity” beams with good optical properties

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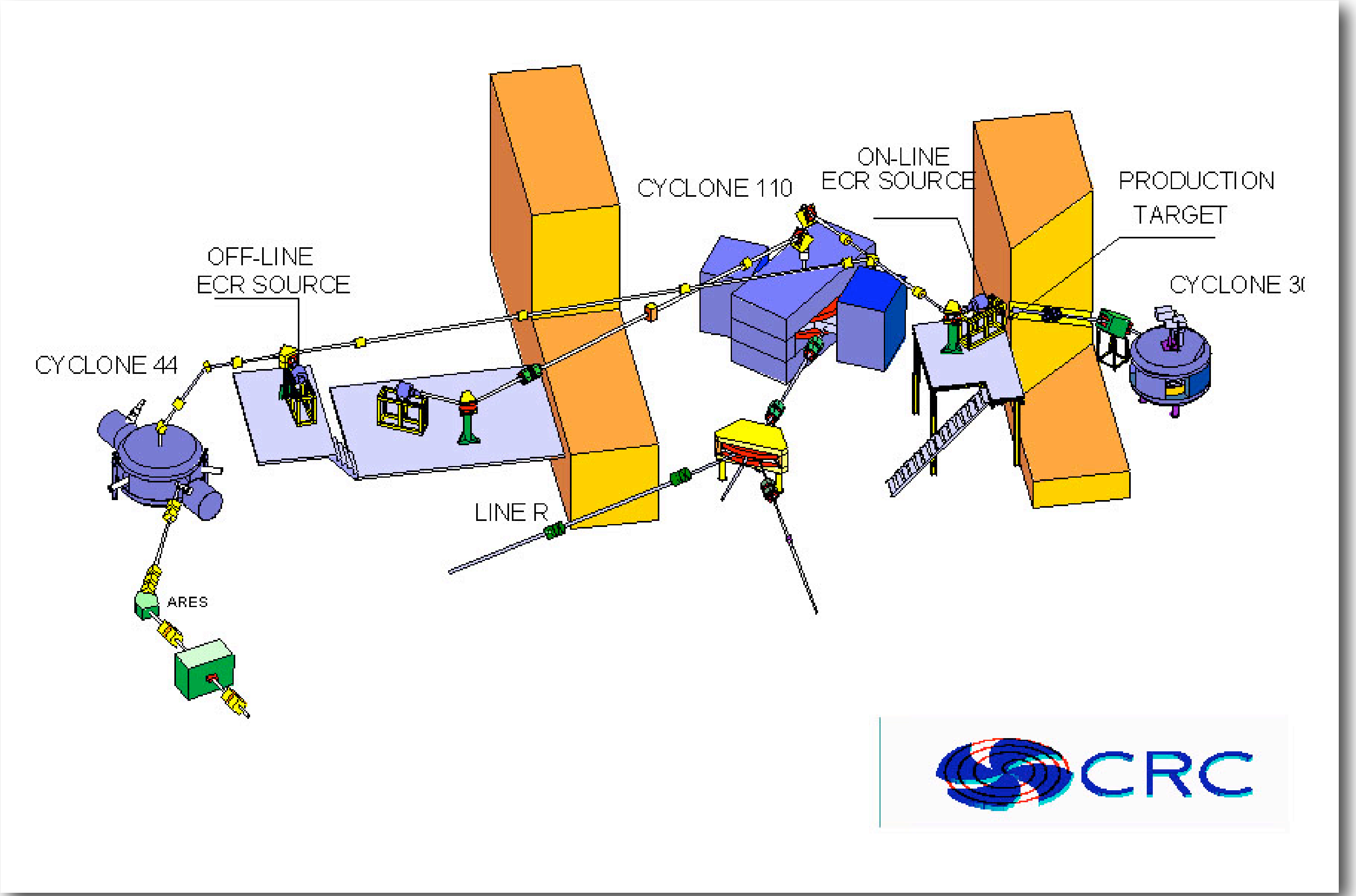
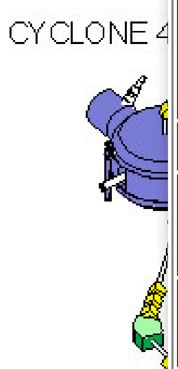
- Can produce “pure” beams
- Poor efficiency for short living nuclei, but progress is being done
- For refractory elements, only possible in “IGISOL” mode
- MANY ways to get lost what you produced... Efficiency is an important issue. Different methods - different facilities - developed complementary techniques, guaranteeing better efficiency and reliability

Selected Facilities : CRC - LLN



www.cyc.ucl.ac.be

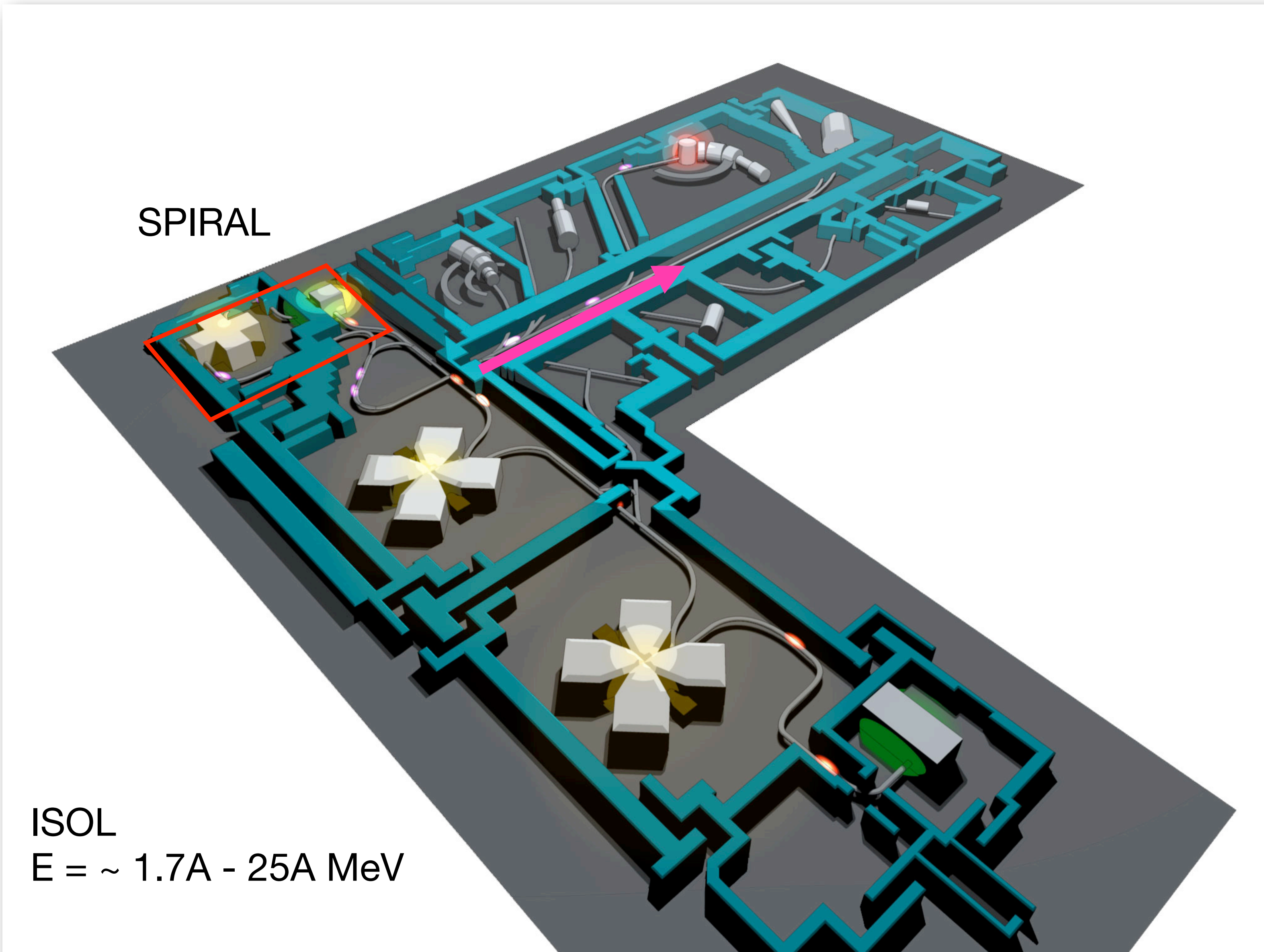
Selected Facilities : CRC - LLN



Element	*Half live, $T_{1/2}$*	*charge state*	*beam intensity [pps on target]*	*energy range [MeV]*
^{6}Helium	0.8 s	1+ 2+	$9 \cdot 10^{6}$ $3 \cdot 10^{5}$	5.3 - 18 30 - 73
^{7}Beryllium	53 days	1+ 2+	$2 \cdot 10^{7}$ $4 \cdot 10^{6}$	5.3 - 12.9 25 - 62
^{10}Carbon	19.3 s	1+ 2+	$2 \cdot 10^{5}$ $1 \cdot 10^{4}$	5.6 - 11 24 - 44
^{11}Carbon	20 min	1+	$1 \cdot 10^{7}$	6.2 - 10
^{13}Nitrogen	10 min	1+ 2+ 3+	$4 \cdot 10^{8}$ $3 \cdot 10^{8}$ $1 \cdot 10^{8}$	7.3 - 8.5 11 - 34 45 - 70
^{15}Oxygen	2 min	2+	$6 \cdot 10^{7}$	10 - 29
^{18}Fluorine NO LONGUER AVAILABLE	110 min	2+	$5 \cdot 10^{6}$	11 - 24
^{18}Neon	1.7 s	2+ 3+	$6 \cdot 10^{6}$ $4 \cdot 10^{6}$	11 - 24 24 - 33,45 - 55
^{19}Neon	17 s	2+ 3+ 4+ 6+	$2 \cdot 10^{9}$ $1.5 \cdot 10^{9}$ $8 \cdot 10^{8}$ $3 \cdot 10^{7}$	11 - 23 23 - 35,45 - 50 60 - 93 171
^{35}Argon	1.8 s	3+ 5+	$2 \cdot 10^{6}$ $1 \cdot 10^{5}$	20 - 28 50 - 79

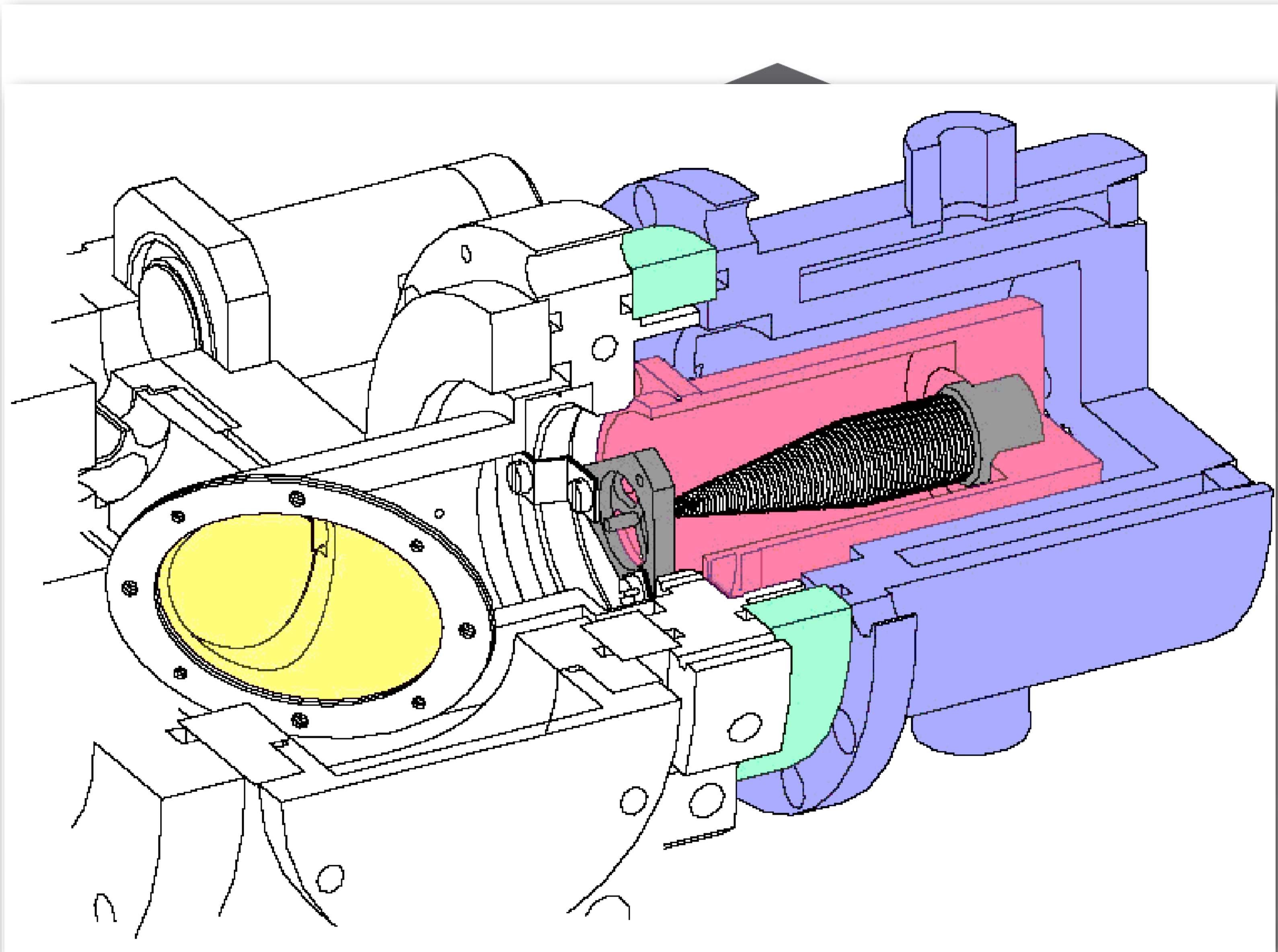
www.cyc.ucl.ac.be

Facilities: SPIRAL - GANIL



ACCV, Nucl.Phys. A693, 465 (2001)

Facilities: SPIRAL - GANIL



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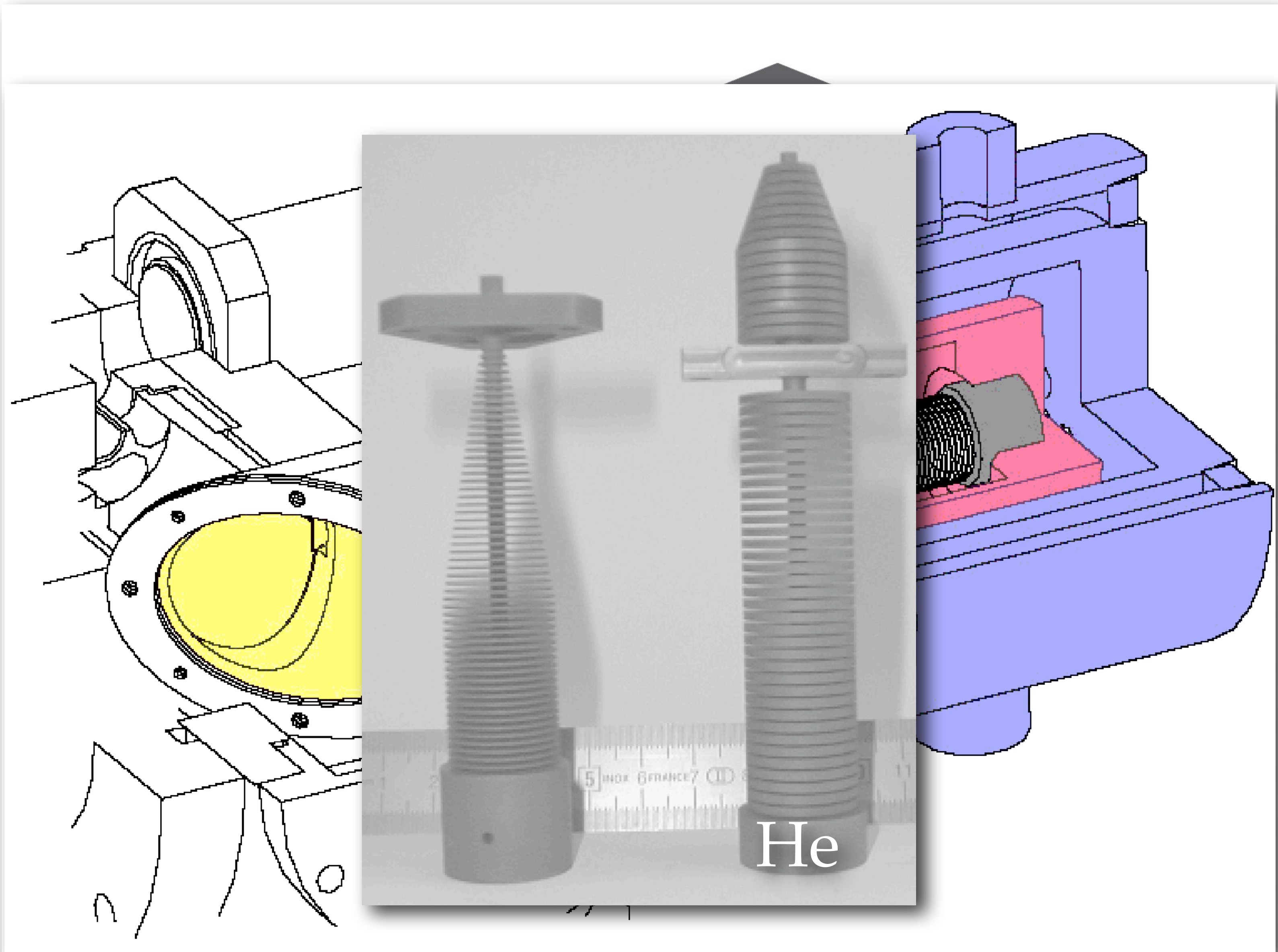

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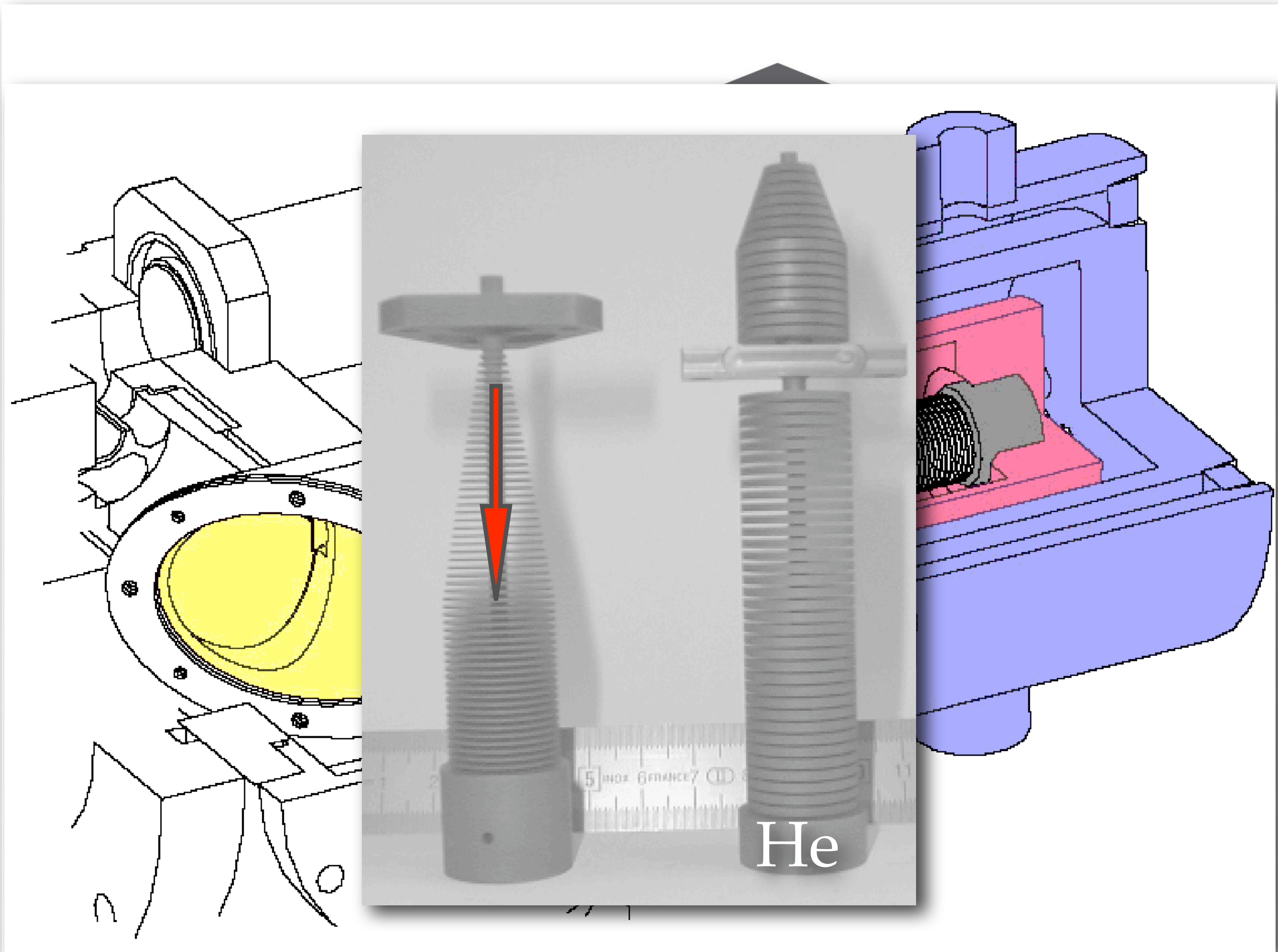

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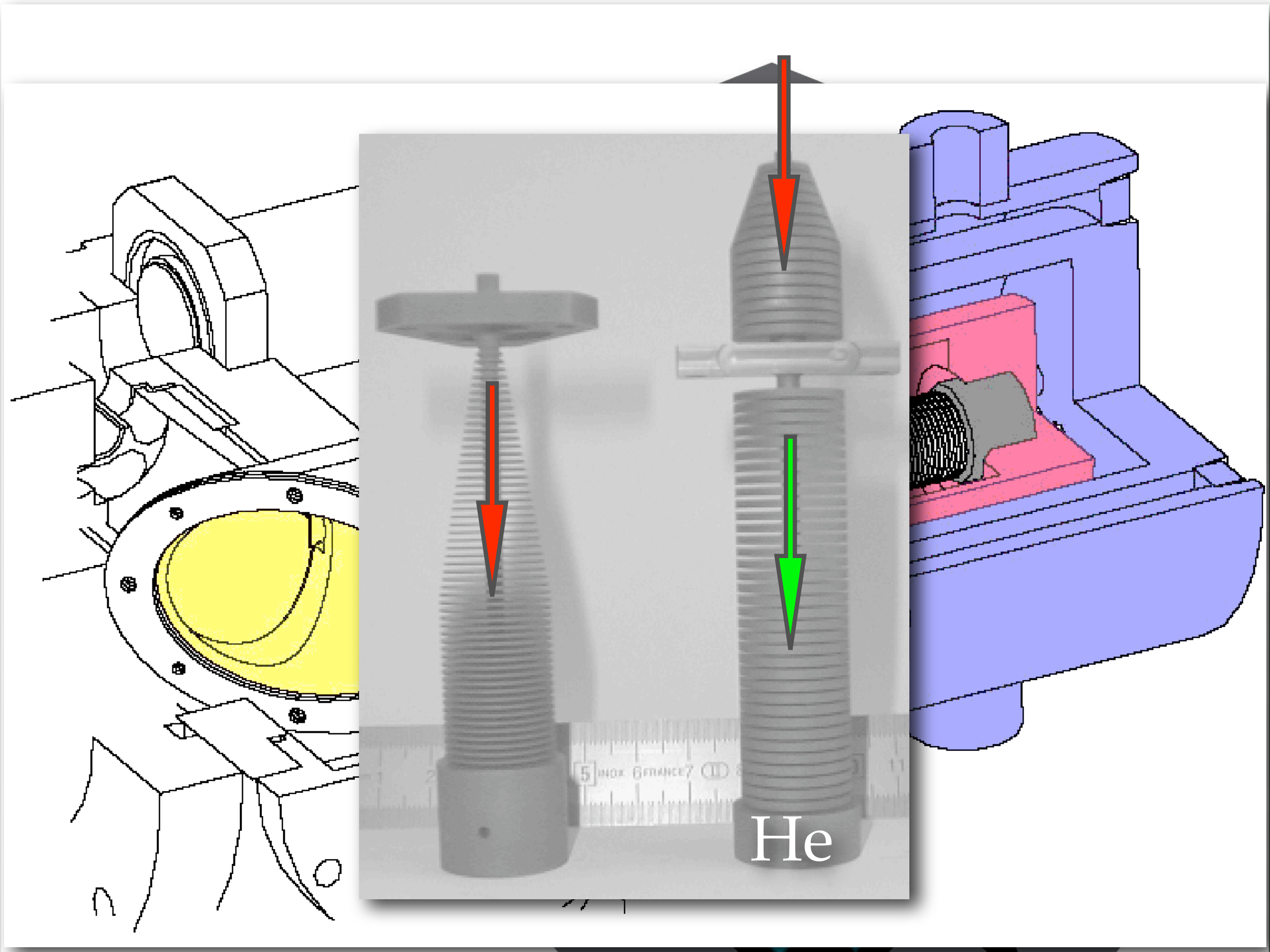

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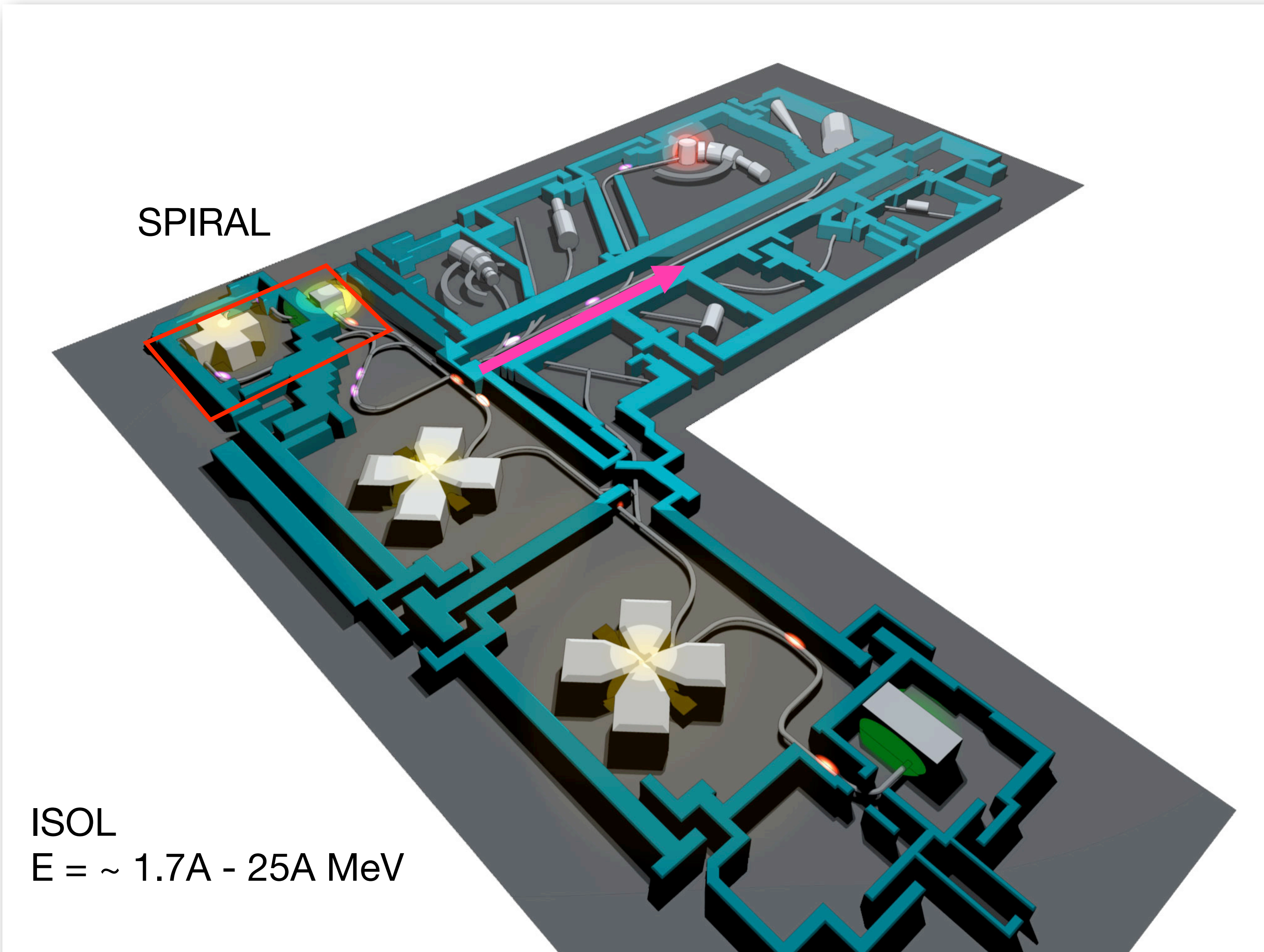
SPIRAL - GANIL



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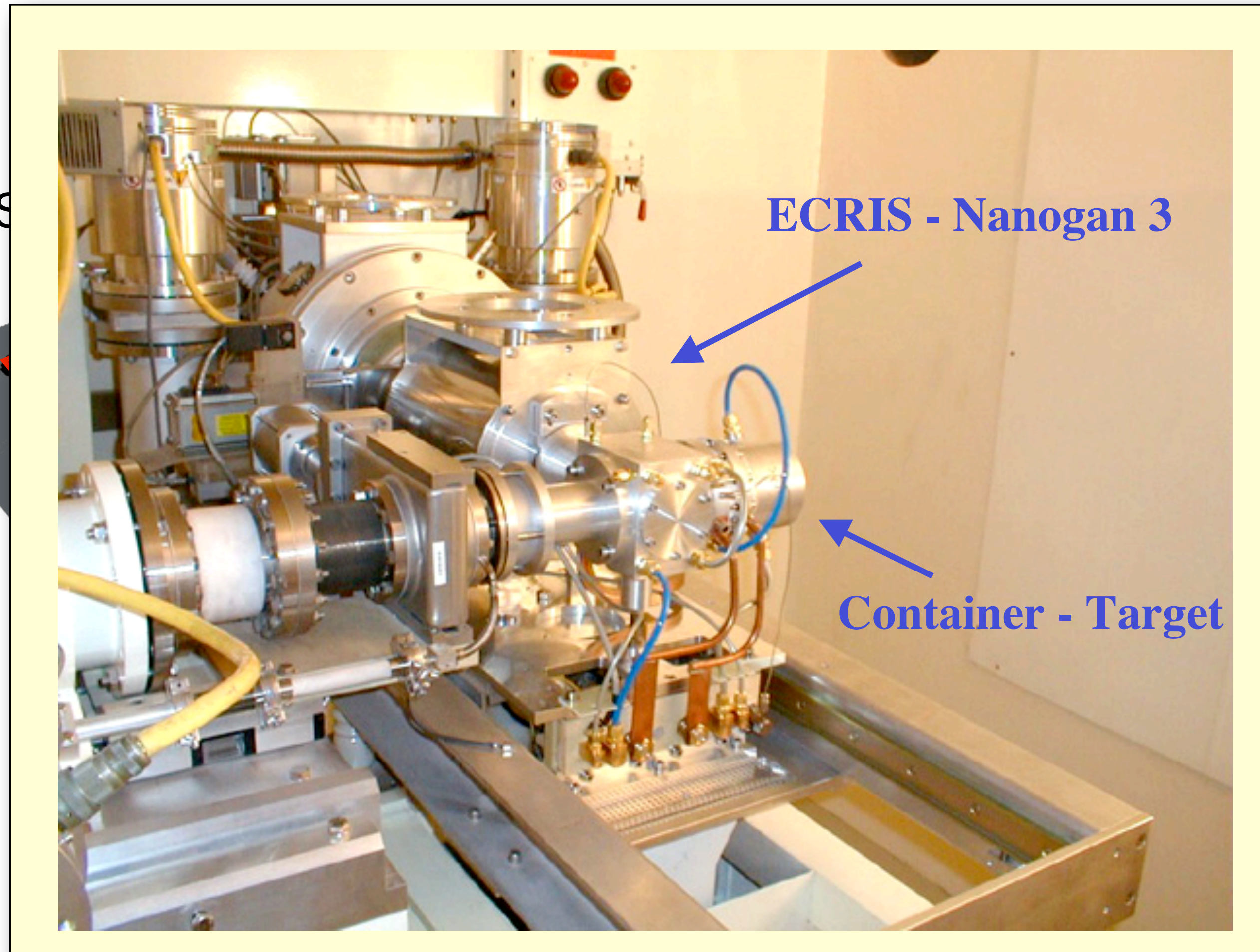
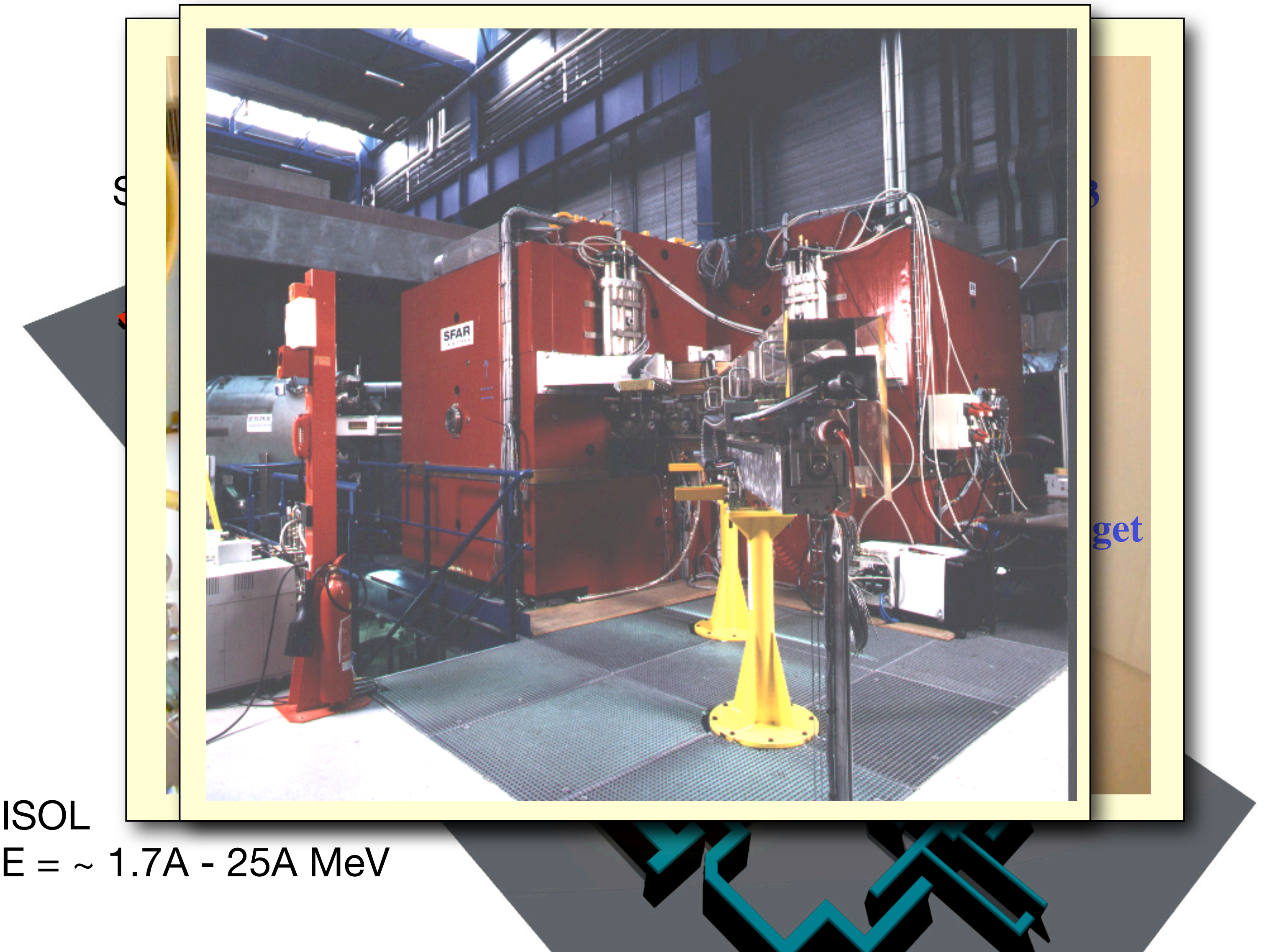


ISOL
E = ~ 1.7A - 25A MeV

ACCV, Nucl.Phys. A693, 465 (2001)

SPIRAL - GANIL



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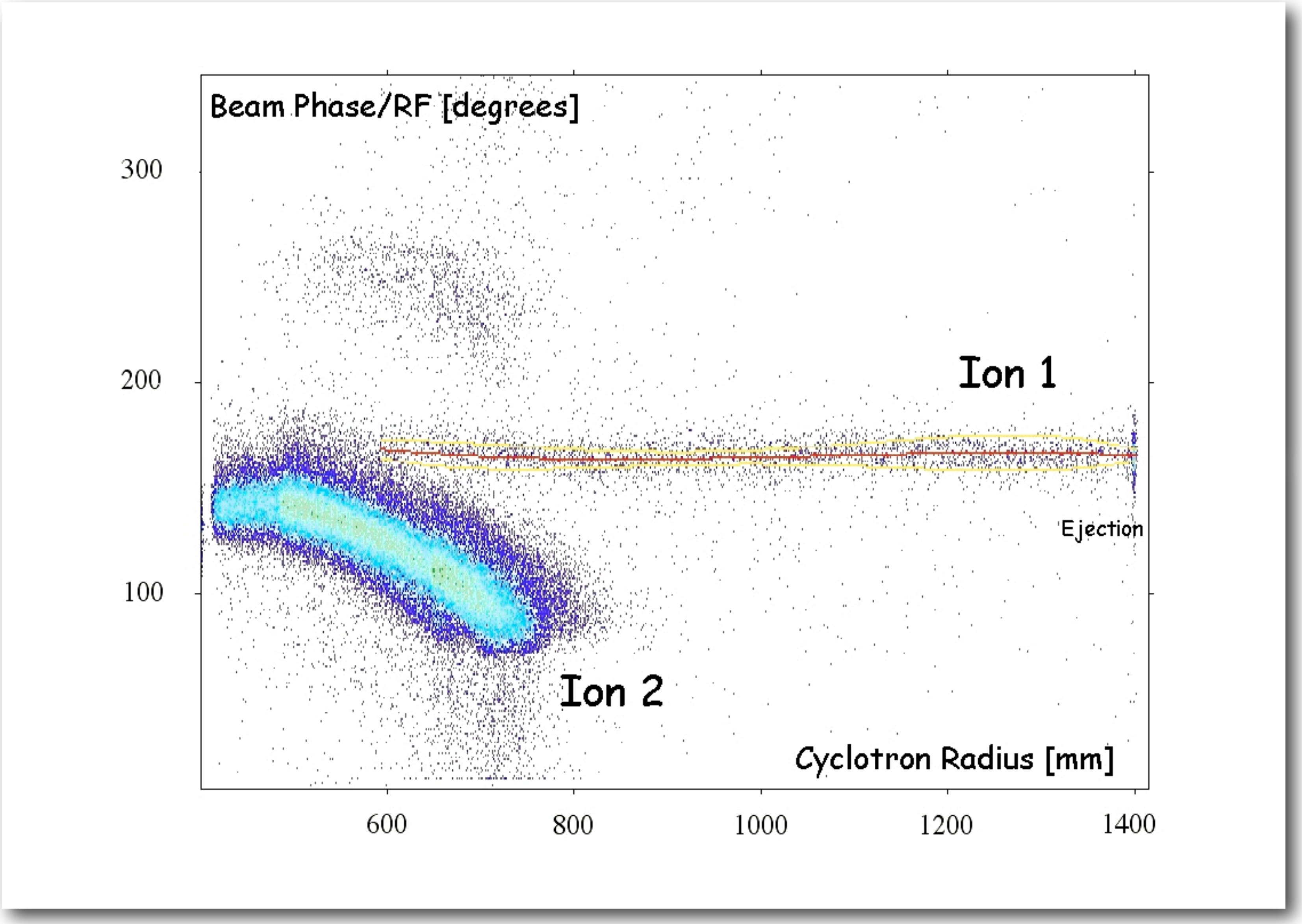
Beam separation



SPIRAL - GANIL

Krypton	69	70	71	72	73	74	75	76	77	**78**	79	**80**	81	**82**	**83**	**84**	85	**86**	…
Argon	30	31	32	33	34	35	**36**	37	38	39	**40**	41	42	43	44	45	46	47	…
Neon	16	17	18	19	**20**	21	**22**	23	24	25	26	27	28	29	30	31	32		
Fluorine	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29			
Oxygen	12	13	14	15	**16**	17	**18**	19	20	21	22	23	24	25	26				
Nitrogen	10	11	12	13	**14**	**15**	16	17	18	19	20	21	22	23	24				
Helium	***3***	***4***	5	6	7	8	9	10											

Stable

Exotic

37 available isotopes and more coming

SPIRAL - GANIL

http://www.ganil.fr/operation/available_beams/radioactive_beams.htm

Helium

update : 24 mars 2006

Radioactive Beam (halflife)	Charge State	Intensity (pps) LEB	Intensity (pps) Target*	Min Energy (MeV/nucleon)	Max Energy (MeV/nucleon)	Primary Beam	Primary Beam Power on ECS Target (kW)	Primary Beam Energy (MeV/nucleon)
^{6}He (0.8s)	+1	$3\ 10^{7}$**				^{13}C	2.4	75
	+1		$1.7\ 10^{7}$	3.2	7.3		1.2	
	+1		$2.8\ 10^{7}$	3.8	7.3		2.5	
	+1		$3.2\ 10^{7}$	5	7.3		1.2	
	+2	$2.8\ 10^{7}$	$5.6\ 10^{6}$	6.8	22.8		1.4	
^{8}He (0.12s)	+1		$1.5\ 10^{5}$	2.5	4.1	^{13}C	2.5	75
	+1	$2.6\ 10^{5}$	$5.2\ 10^{4}$	3.5	4.1		0.9	
	+1		$1.8\ 10^{5}$	3.8	4.1		2.5	
	+2	1.3 to $1.5\ 10^{5}$	2 to $3\ 10^{4}$		15.4		1.4	

* Available intensity for the experiment.
** LIRAT figures

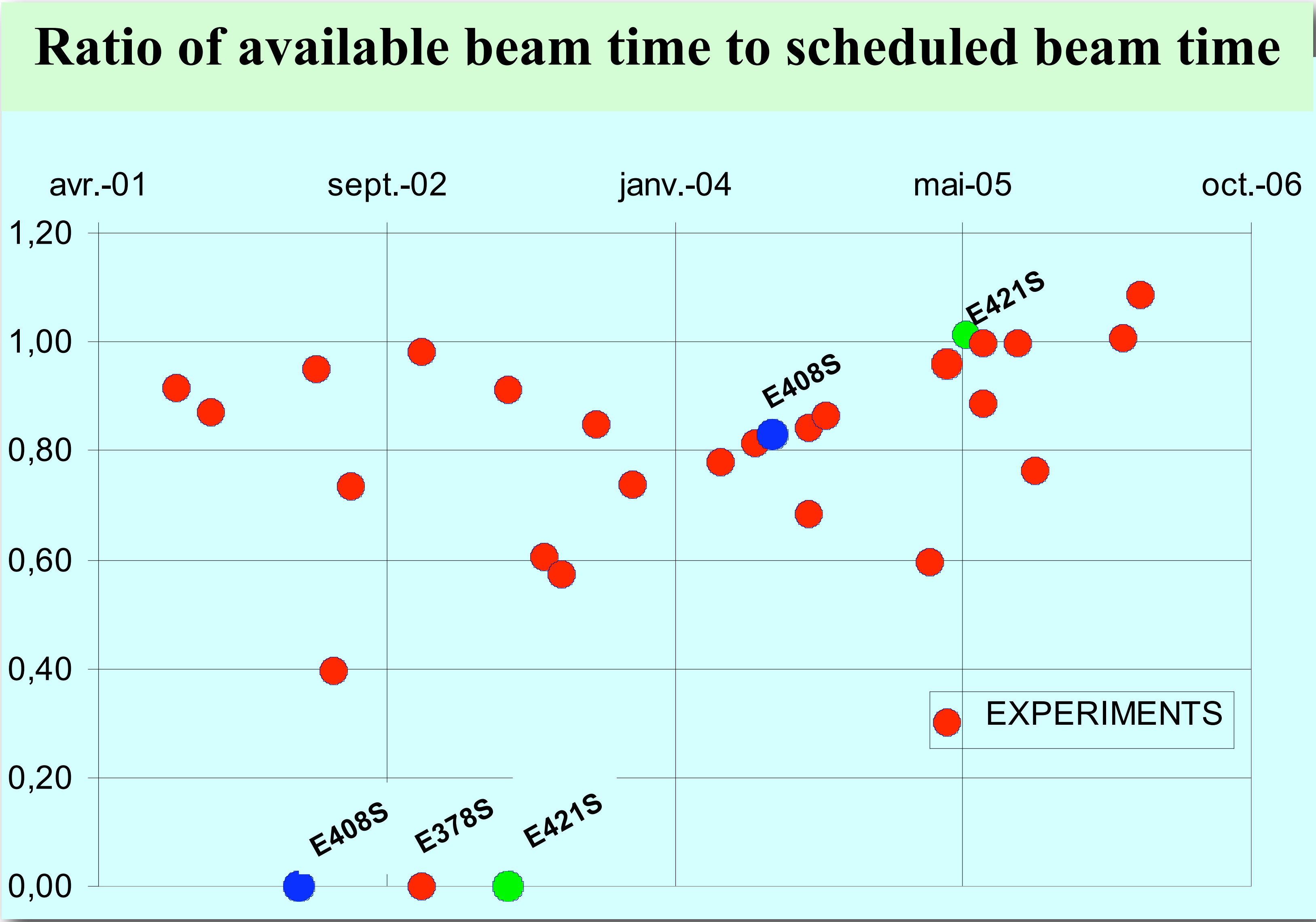
Color code :

$2.8\ 10^{7}$ = extrapolated figures from SIRA experiment from 400 W to 1.4 kW.

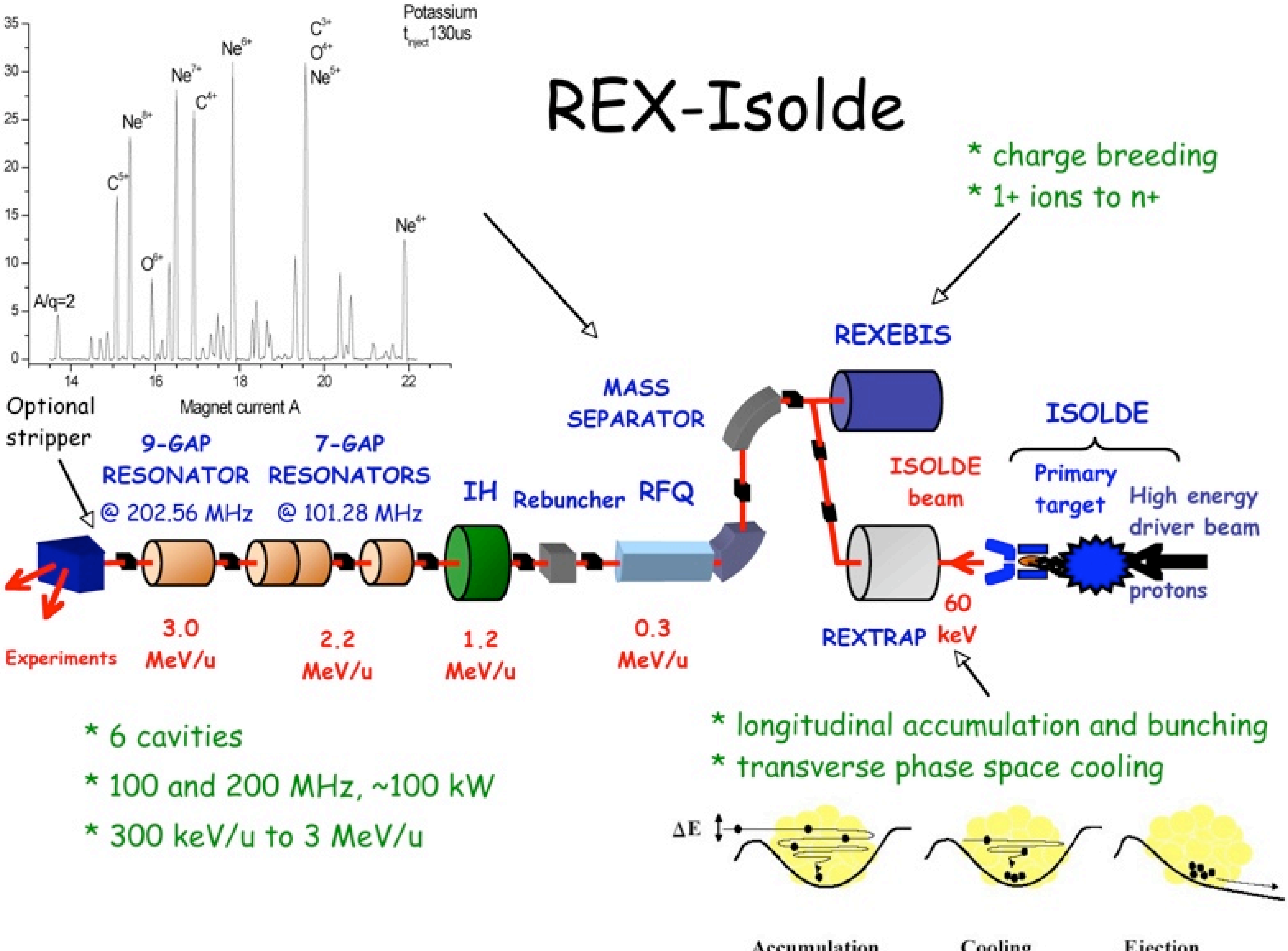
$2.8\ 10^{7}$ = measured figures with SPIRAL.

$2.8\ 10^{7}$ = expected figures after acceleration (not measured) with 20% transport efficiency.

Reliability



REX-Isolde



* 6 cavities
* 100 and 200 MHz, ~100 kW
* 300 keV/u to 3 MeV/u

M. Lindroos courtesy

REX-ISOLDE: Isotopes already accelerated

$^{8}Li^{3+}$, $^{9,11}Li^{2+}$

$^{10,11,12}Be^{3+,4+}$

$^{17}F^{5+}$

$^{24-29}Na^{7+}$

$^{29,31}Mg^{9+}$, $^{28,30,32}Mg^{8+}$

$^{68}Ni^{19+}$

$^{67-71,73}Cu^{19+,20+,20+,19+}$

$^{80}Zn^{21+}$, $^{74,76,78}Zn^{18+}$

$^{70}Se^{19+}$

$^{88,92}Kr^{21+,22+}$

$^{108}In^{30+}$

$^{108,110}Sn^{27+,30+}$

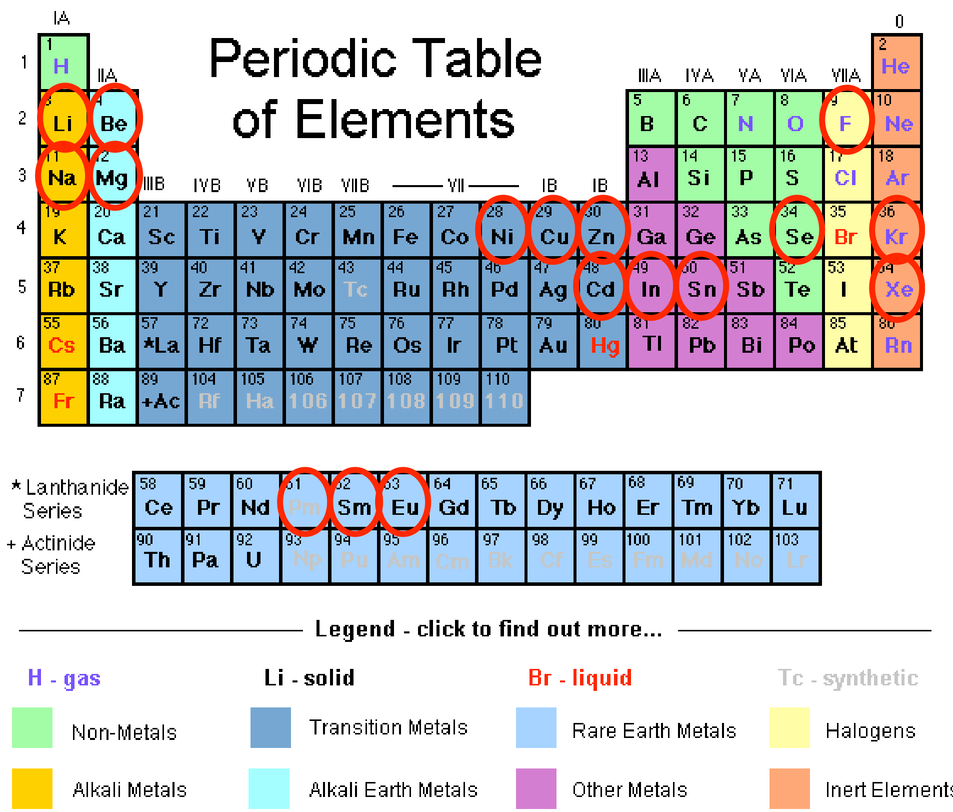
$^{122,124,126}Cd^{30+,31+}$

$^{138,140,142,144}Xe^{34+}$

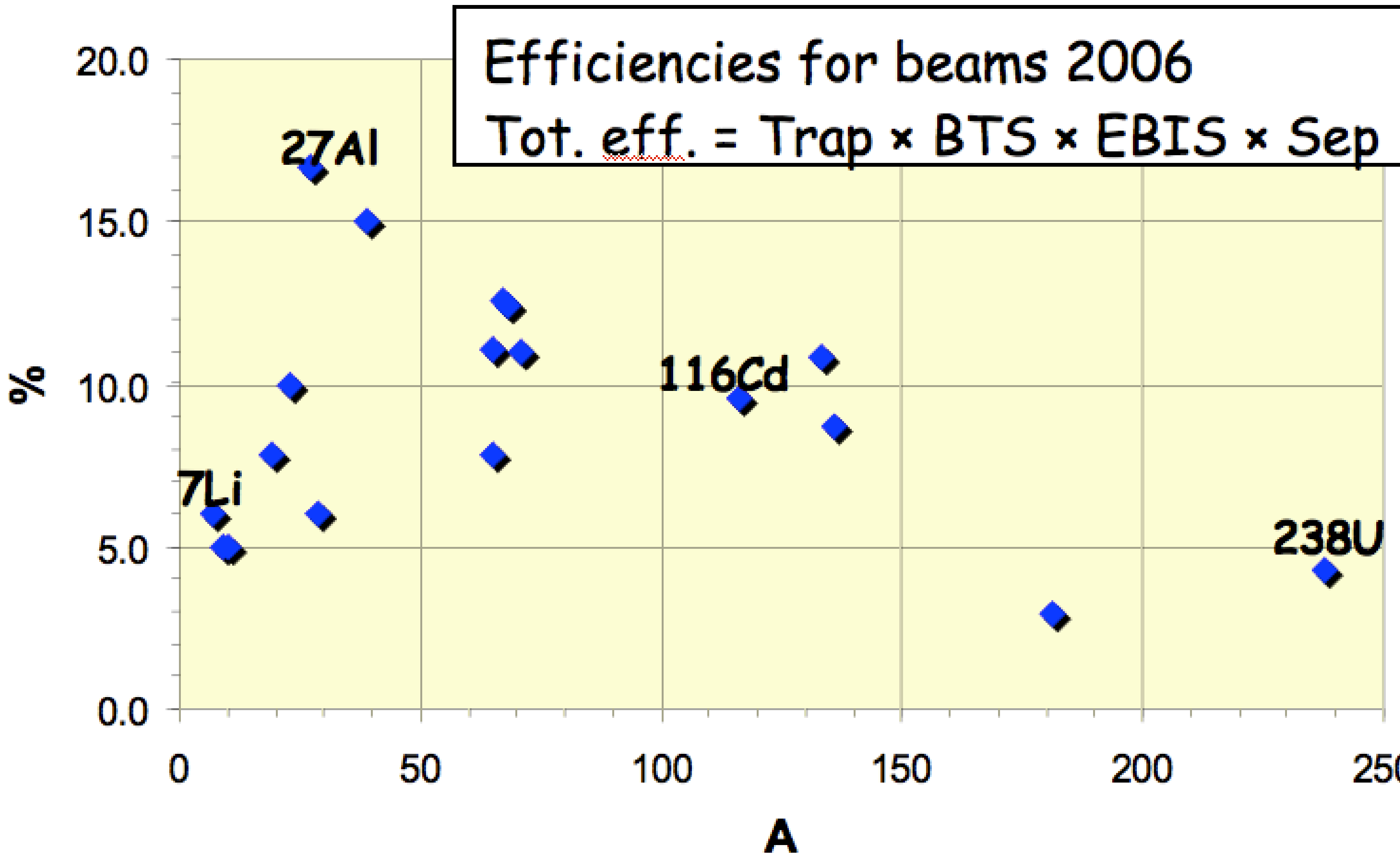
$^{148}Pm^{30+}$

$^{153}Sm^{28+}$

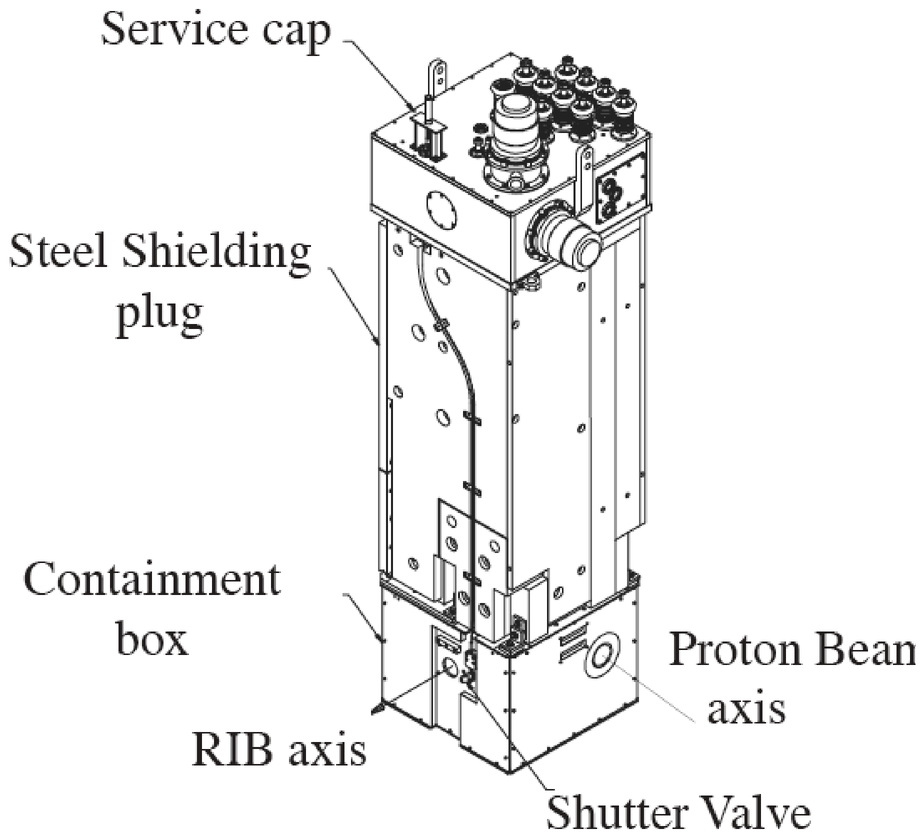
$^{156}Eu^{28+}$

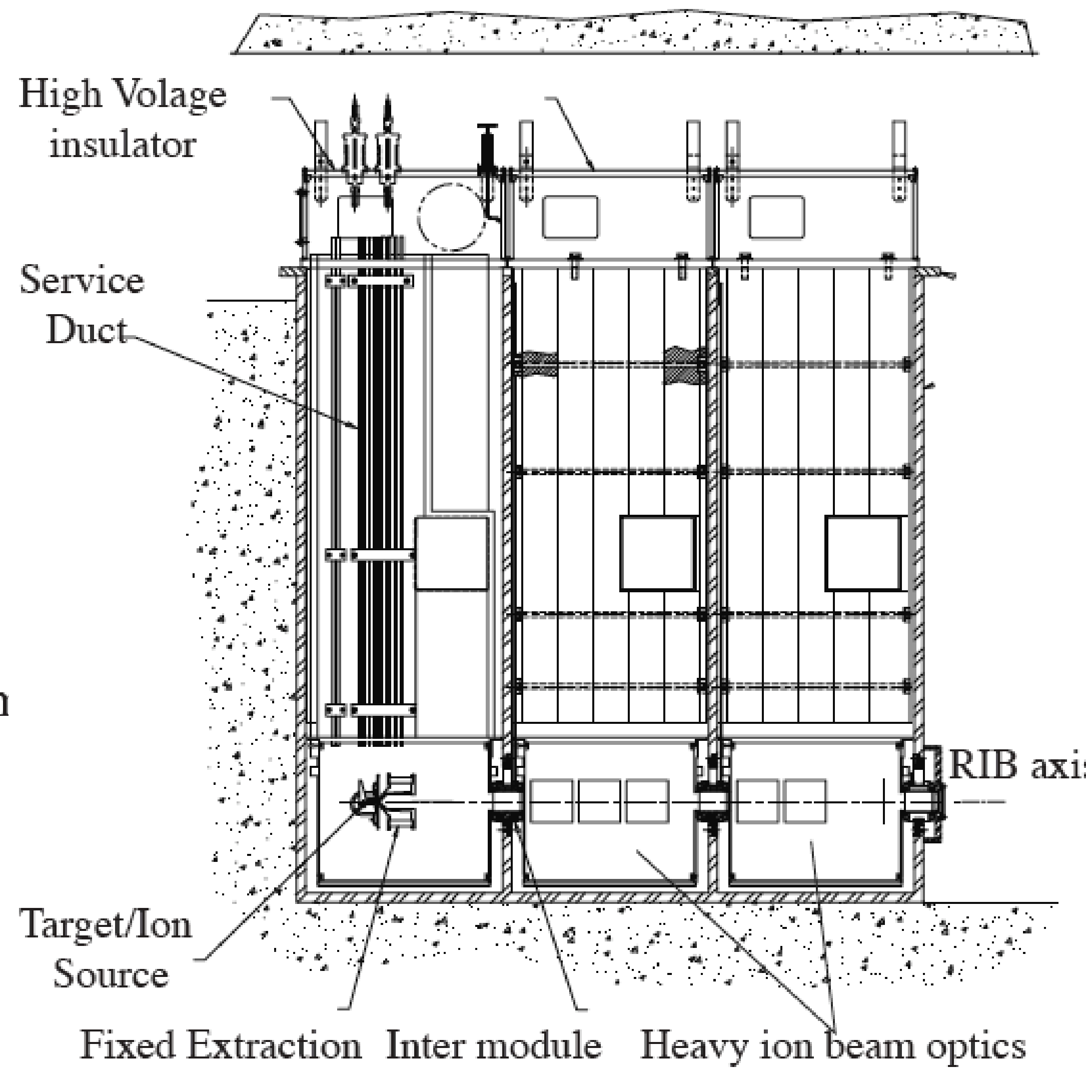


Efficiencies: 2006



ISAC: the best today

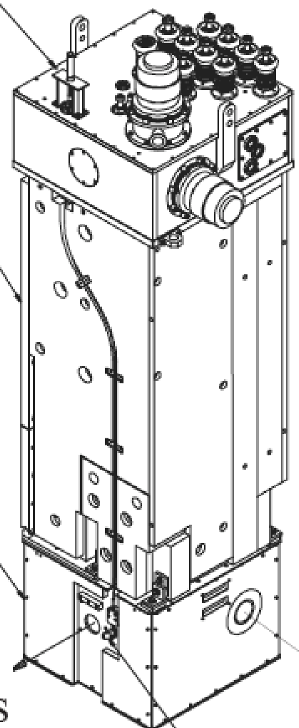


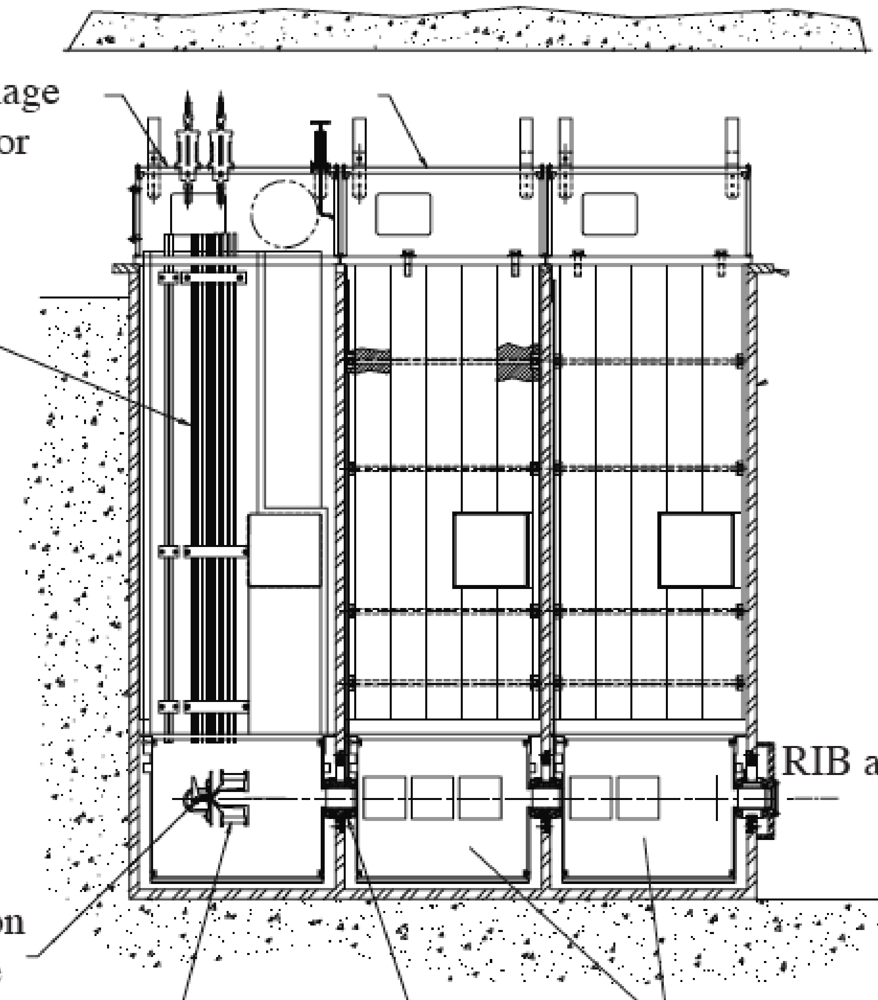


P. Bricault et al., PAC 1999 proceedings

ISAC: the best today

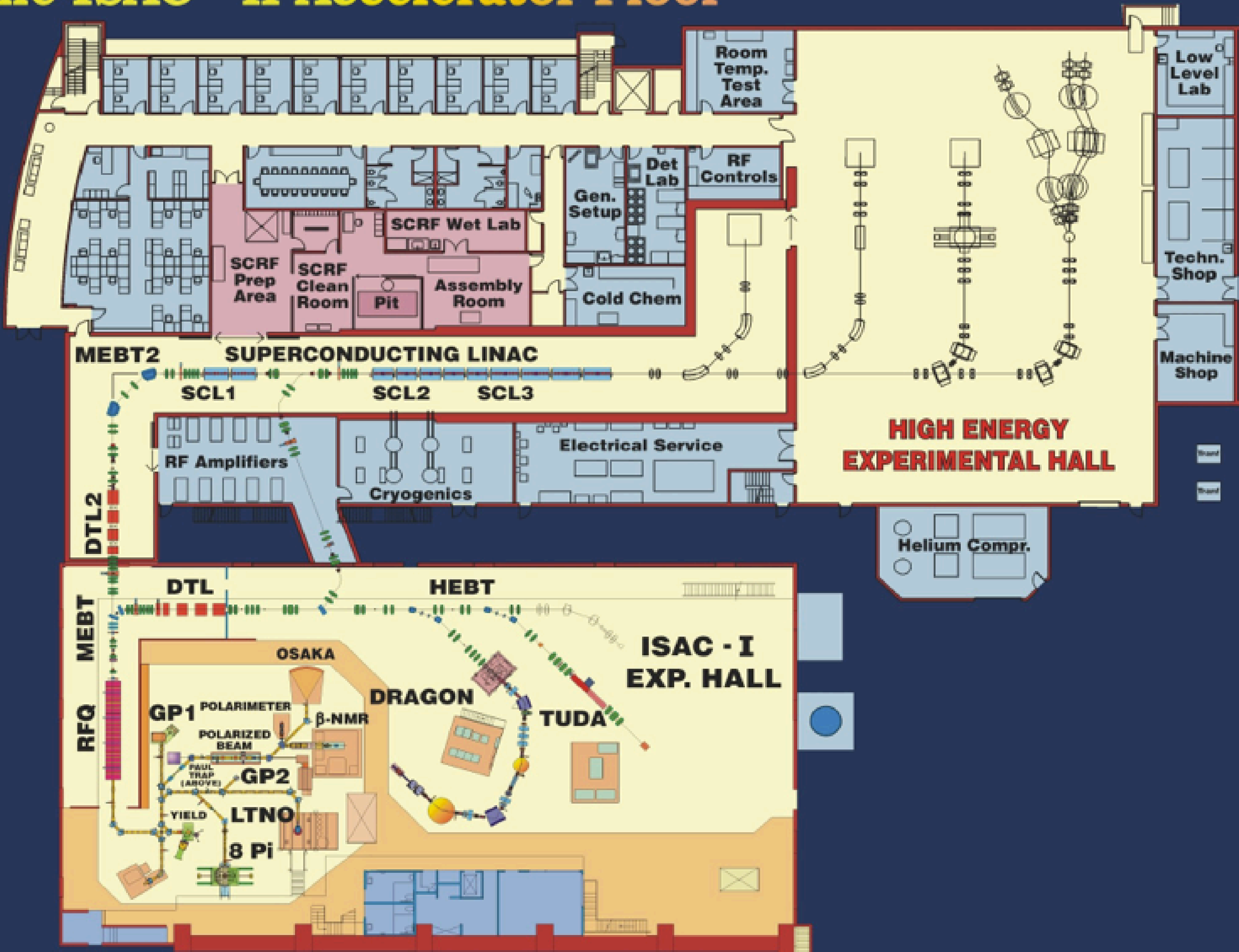
Today: Ep = 500 MeV I = 100µA (50kW)



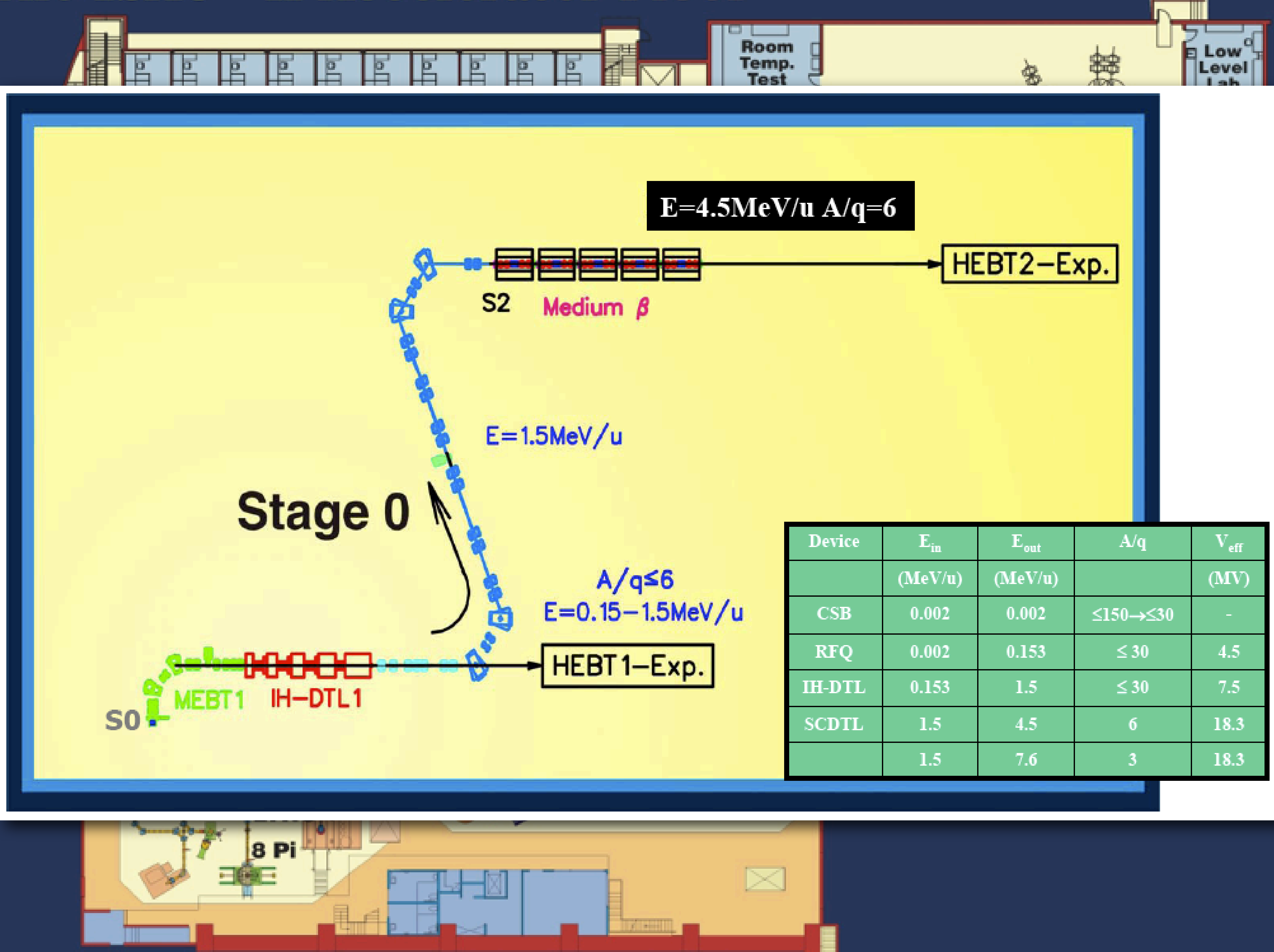


P. Bricault et al., PAC 1999 proceedings

The ISAC - II Accelerator Floor

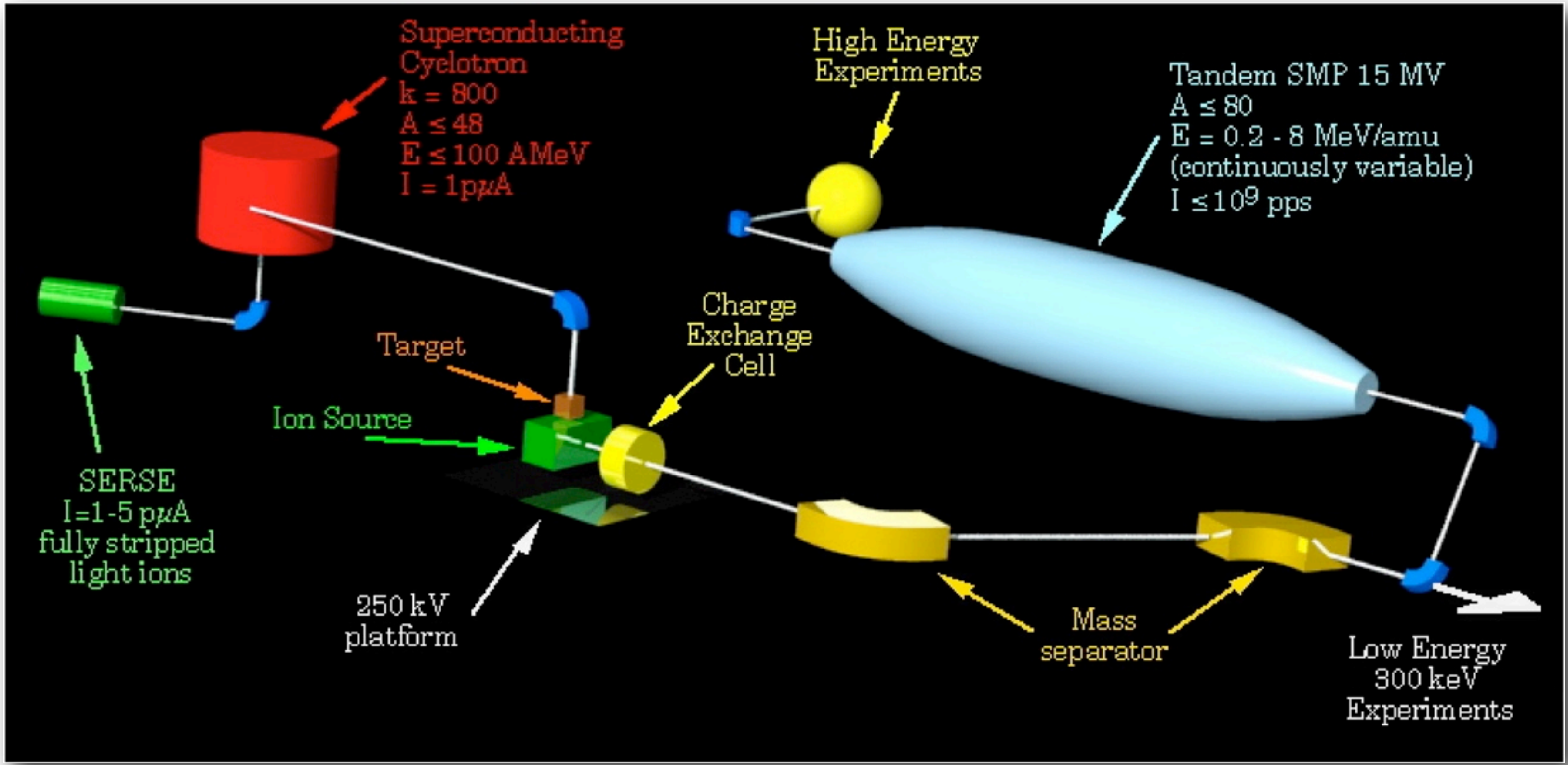


The ISAC - II Accelerator Floor



Device	E_{in}	E_{out}	A/q	V_{eff}
	(MeV/u)	(MeV/u)		(MV)
CSB	0.002	0.002	≤150→≤30	-
RFQ	0.002	0.153	≤ 30	4.5
IH-DTL	0.153	1.5	≤ 30	7.5
SCDTL	1.5	4.5	6	18.3
	1.5	7.6	3	18.3

- EXCYT, Catania - delivered the first ^{8}Li beam



- TRIAC (KEK-JAERI) is also starting (accelerator moved from former INS)

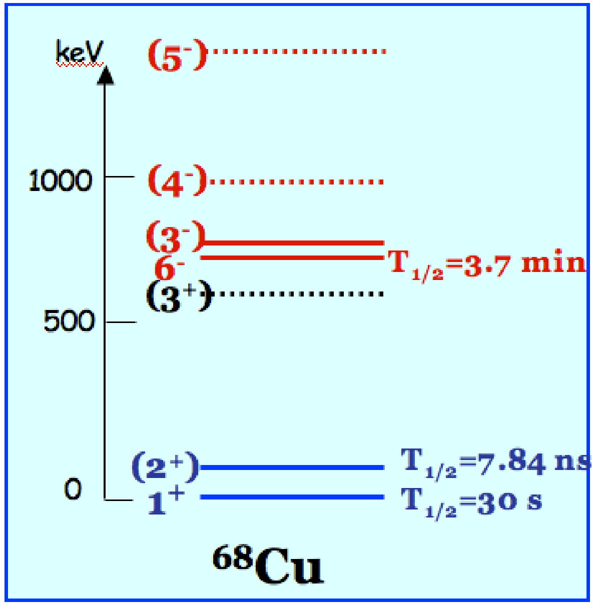
Selected examples (more in the following J. Aysto talk)

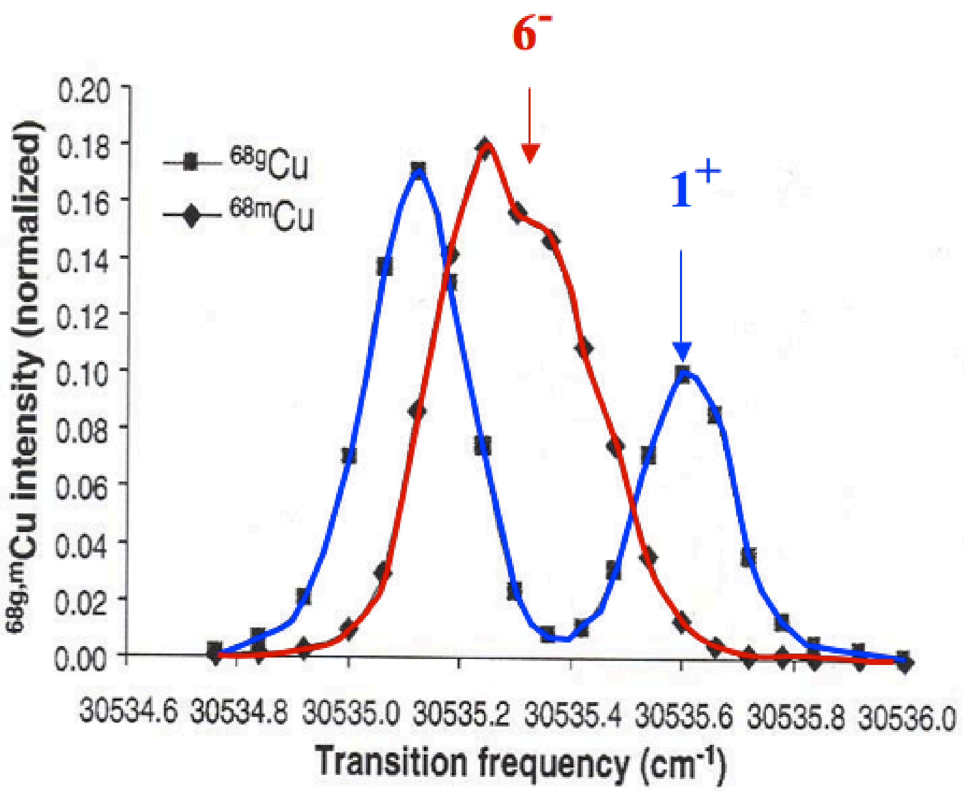
PRL 98, 122701 (2007) PHYSICAL REVIEW LETTERS week ending 23 MARCH 2007

Coulomb Excitation of ^{68,70}Cu: First Use of Postaccelerated Isomeric Beams

I. Stefanescu,[1,2] G. Georgiev,[3,4] F. Ames,[5] J. Äystö,[3,6,22] D. L. Balabanski,[7,8] G. Bollen,[5] P. A. Butler,[9] J. Cederkäll,[3] N. Champault,[3] T. Davinson,[10] A. De Maesschalck,[11] P. Delahaye,[3] J. Eberth,[12] D Fedorov,[13] V. N. Fedosseev,[3] L. M. Fraile,[3] S. Franchoo,[14] K. Gladnishki,[7] D. Habs,[5] K. Heyde,[11] M. Huyse,[1] O. Ivanov,[1] J. Iwanicki,[15] J. Jolie,[12] B. Jonson,[16] Th. Kröll,[17] R. Krücken,[17] O. Kester,[5] U Köster,[3] A. Lagoyannis,[18] L. Liljeby,[19] G. Lo Bianco,[7] B. A. Marsh,[3] O. Niedermaier,[20] T. Nilsson,[16] M. Oinonen,[3,22] G. Pascovici,[12] P. Reiter,[12] A. Saltarelli,[7] H. Scheit,[20] D. Schwalm,[20] T. Sieber,[5] N. Smirnova,[11] J. Van De Walle,[1] P. Van Duppen,[1] S. Zemlyanoi,[21] N. Warr,[12] D. Weisshaar,[12] and F. Wenander[3]

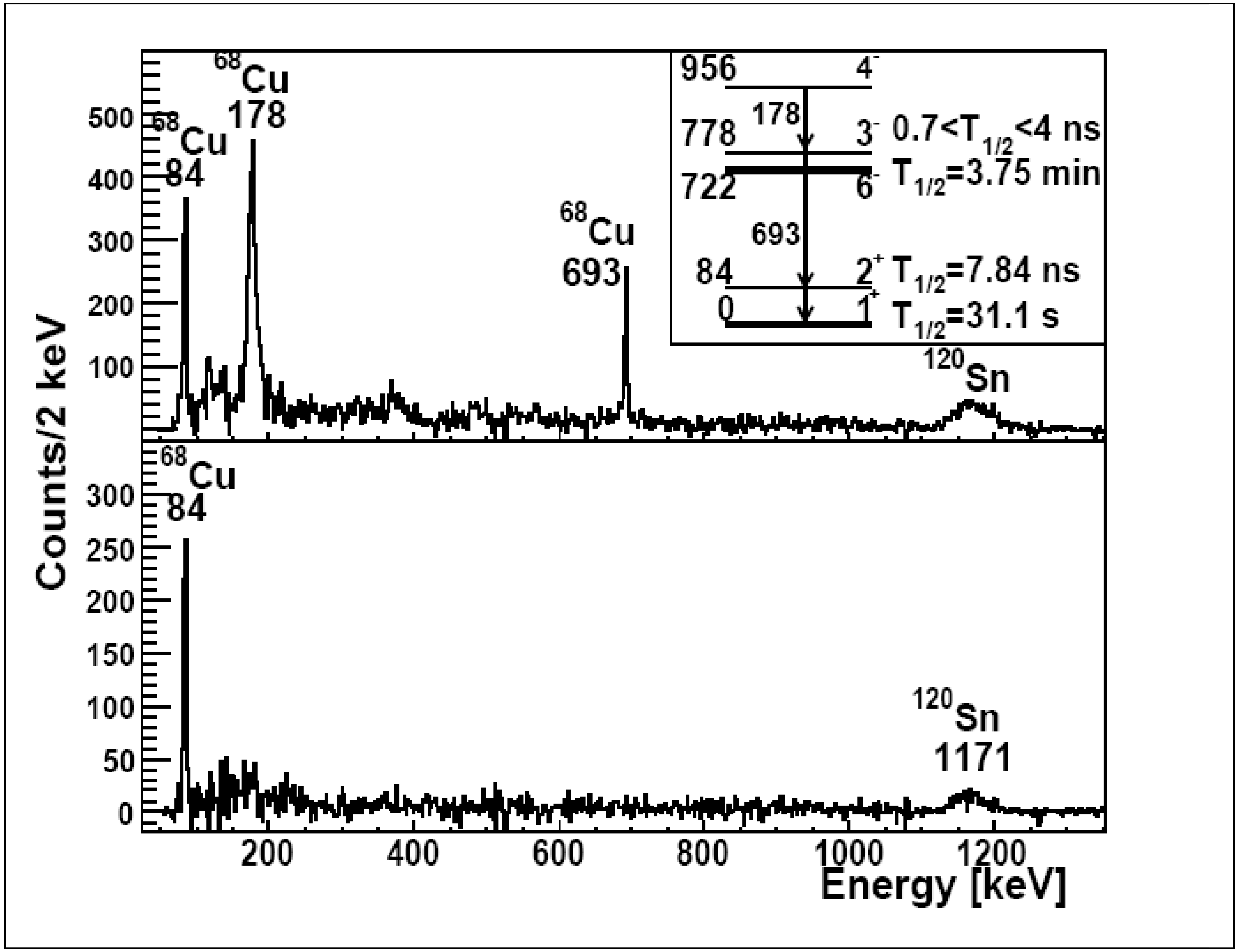
Beam produced at REX-ISOLDE at 2.83A MeV, detection: Miniball





6+ beam

1+ beam

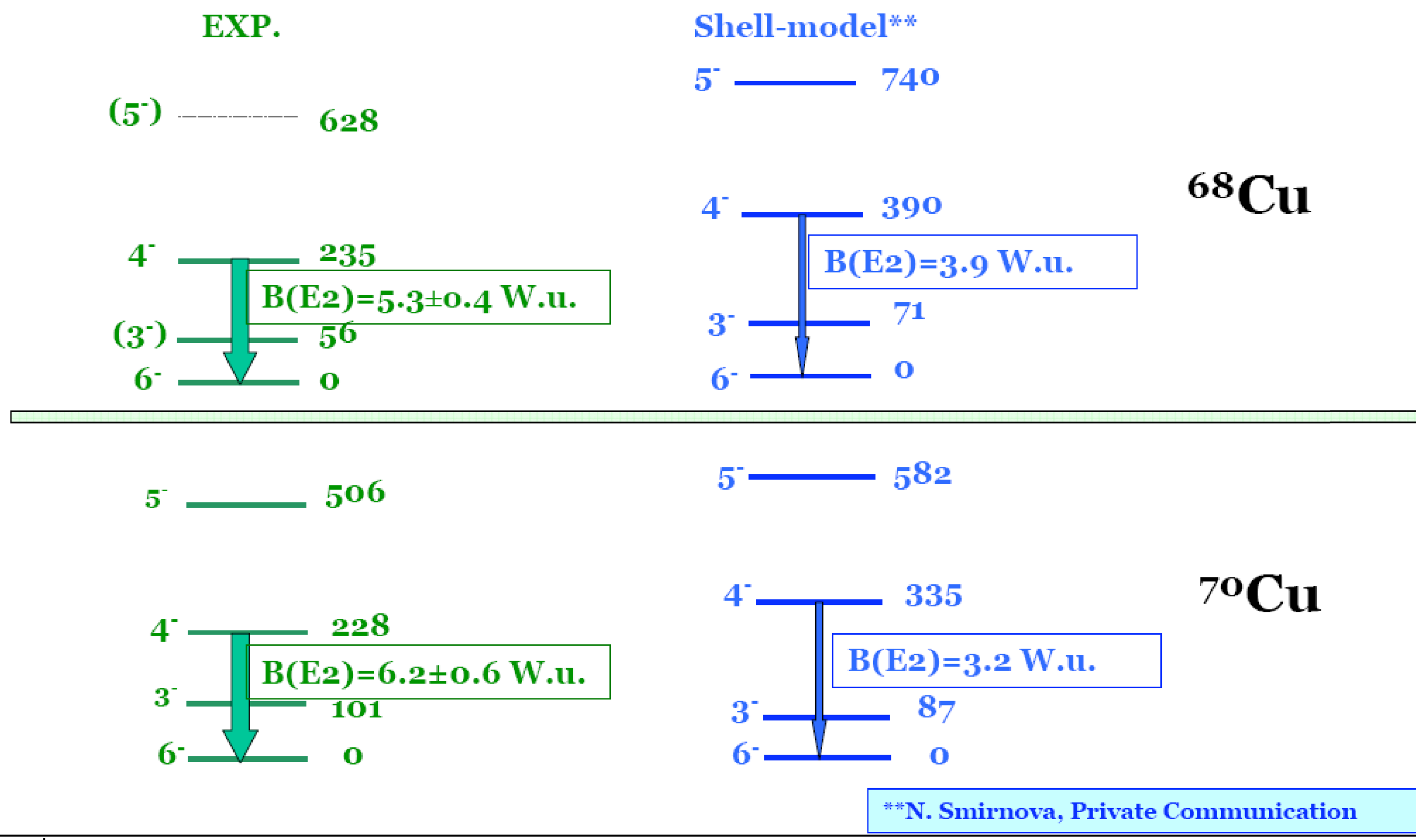


956 4-
178
778 3- 0.7<T1/2<4 ns
722 6- T1/2=3.75 min
693
84 2+ T1/2=7.84 ns
0 1+ T1/2=31.1 s
68Cu 84
68Cu 178
68Cu 693
120Sn
68Cu 84
120Sn 1171
Counts/2 keV
Energy [keV]

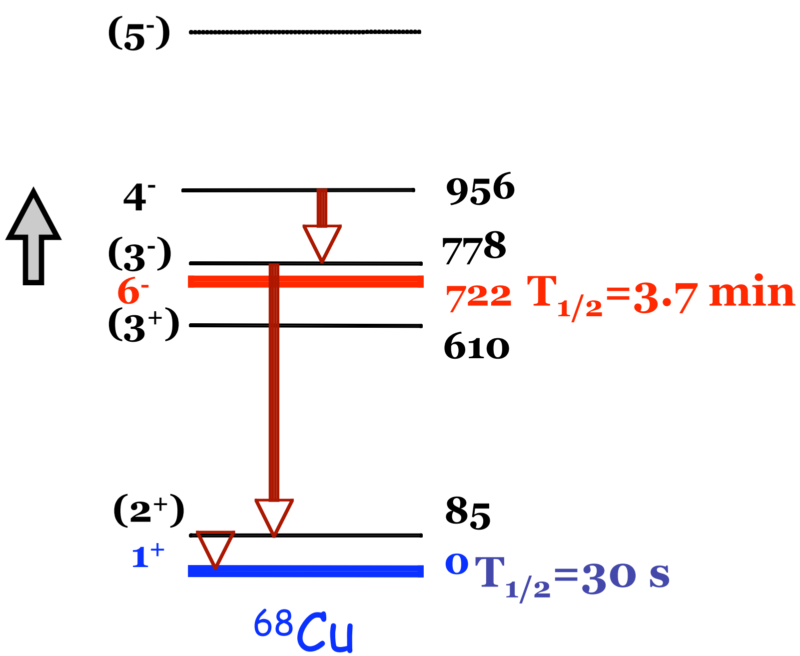
Coulex of $^{68,70,m,g}Cu$

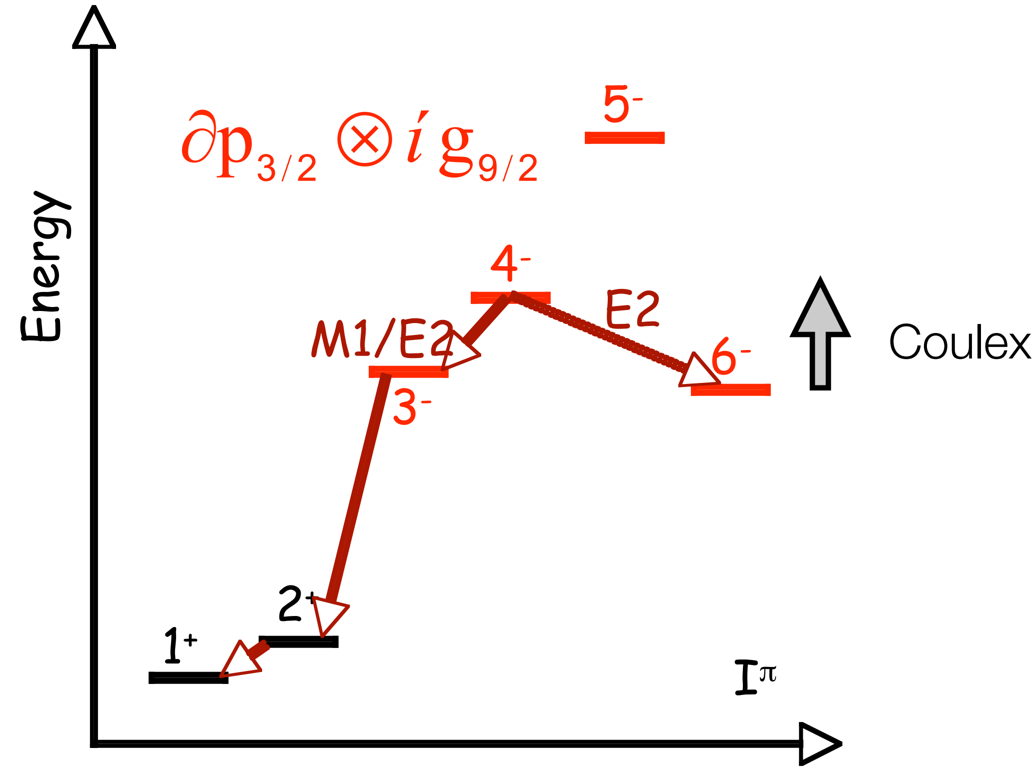
6+ bea

1+ bea



Induced instantaneous depopulation of a nuclear isomer



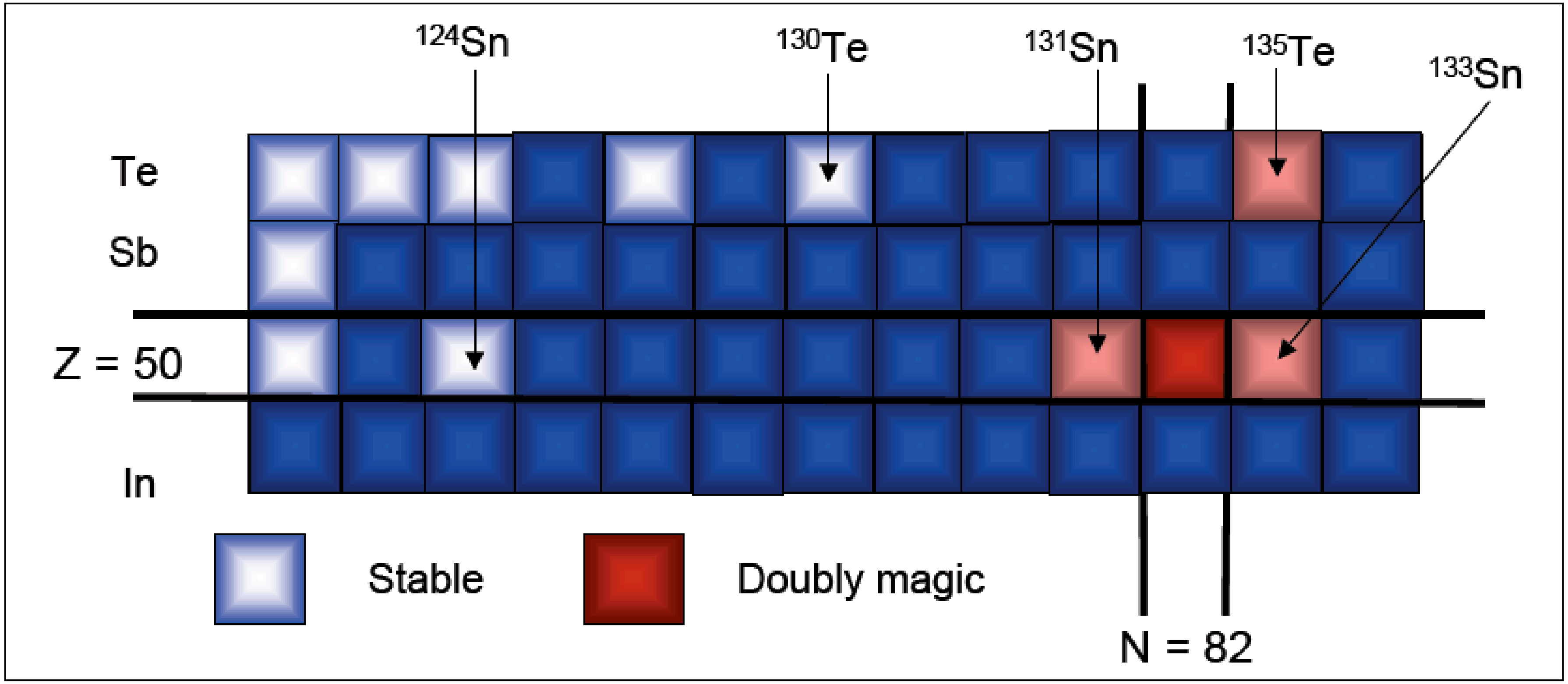


Population via Coulex (E2)

- Decay through faster M1 transition

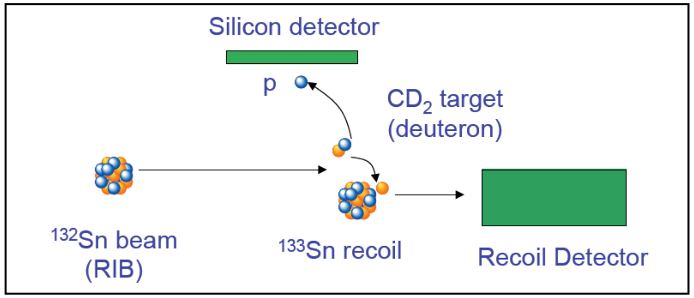
- Energy is "released" and half life of the isotope is changed
- Interest for nucleosynthesis processes?

Courtesy: J. Aysto



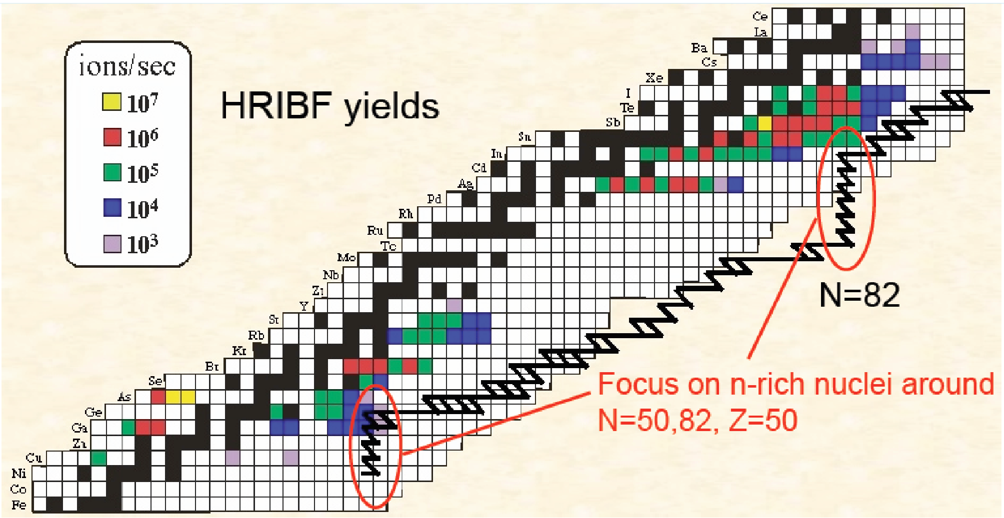
HRIBF very successful in Coulex in the ^{132}Sn region
D. C. Radford *et al.*, Phys. Rev. Lett. **88**, 222501 (2002)

Experiments moving to transfer and fusion.



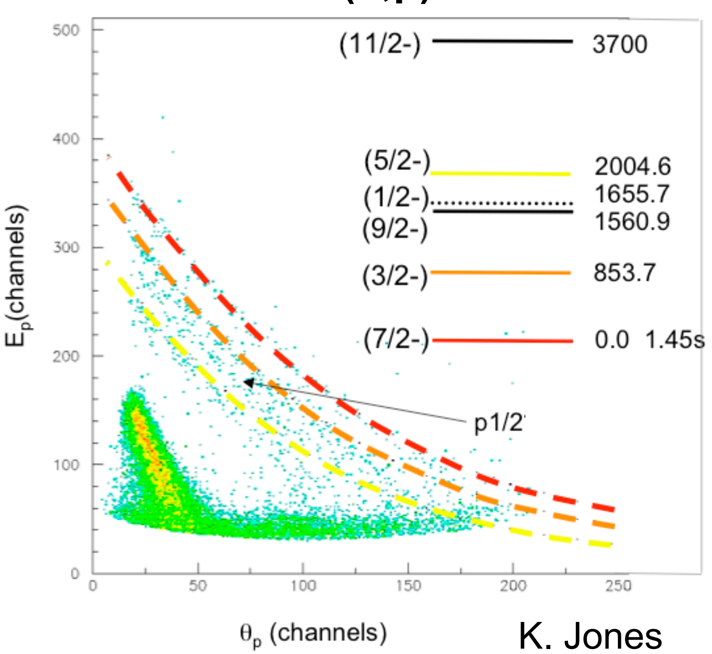
Thanks: W. Nazarewicz

The first transfer measurements on N=82 nuclei on / near r-process path



^{130}Sn(d,p)^{131}Sn - R. Kozub et al.
^{132}Sn(d,p)^{133}Sn - K.L. Jones et al.
^{134}Te(d,p)^{135}Te - S.D. Pain et al.

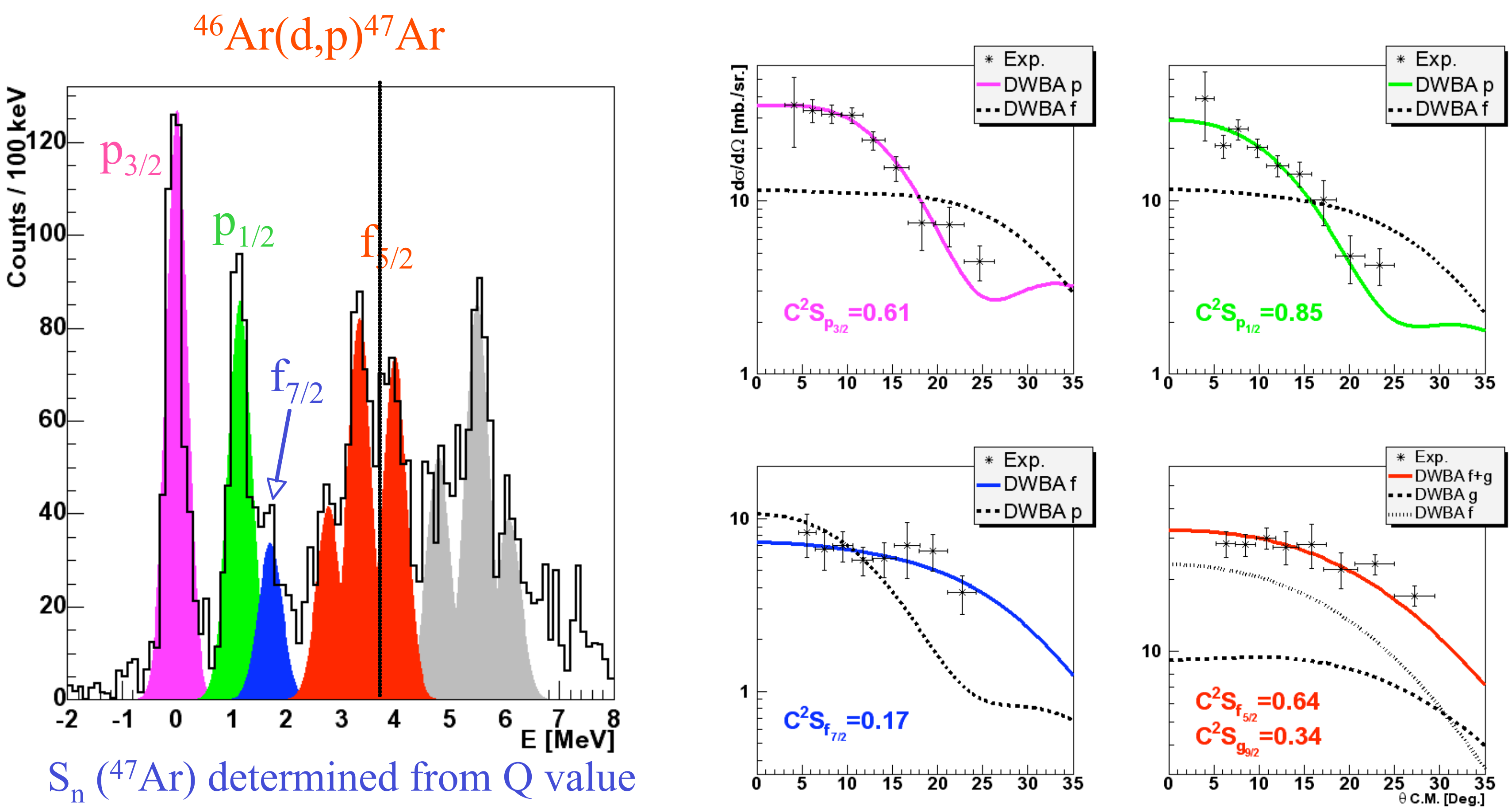
- yields, angular distributions of low-lying states measured
- first observation of $p_{1/2}$ state in ^{133}Sn
- three other states in ^{133}Sn measured, calibrated with ^{130}Te(d,p)
- evidence for numerous states in ^{131}Sn never seen before
- evidence that the $f_{5/2}$ level in ^{135}Te is at a significantly higher energy



PRL 97, 092501 (2006) PHYSICAL REVIEW LETTERS week ending 1 SEPTEMBER 2006

Reduction of the Spin-Orbit Splittings at the $N = 28$ Shell Closure

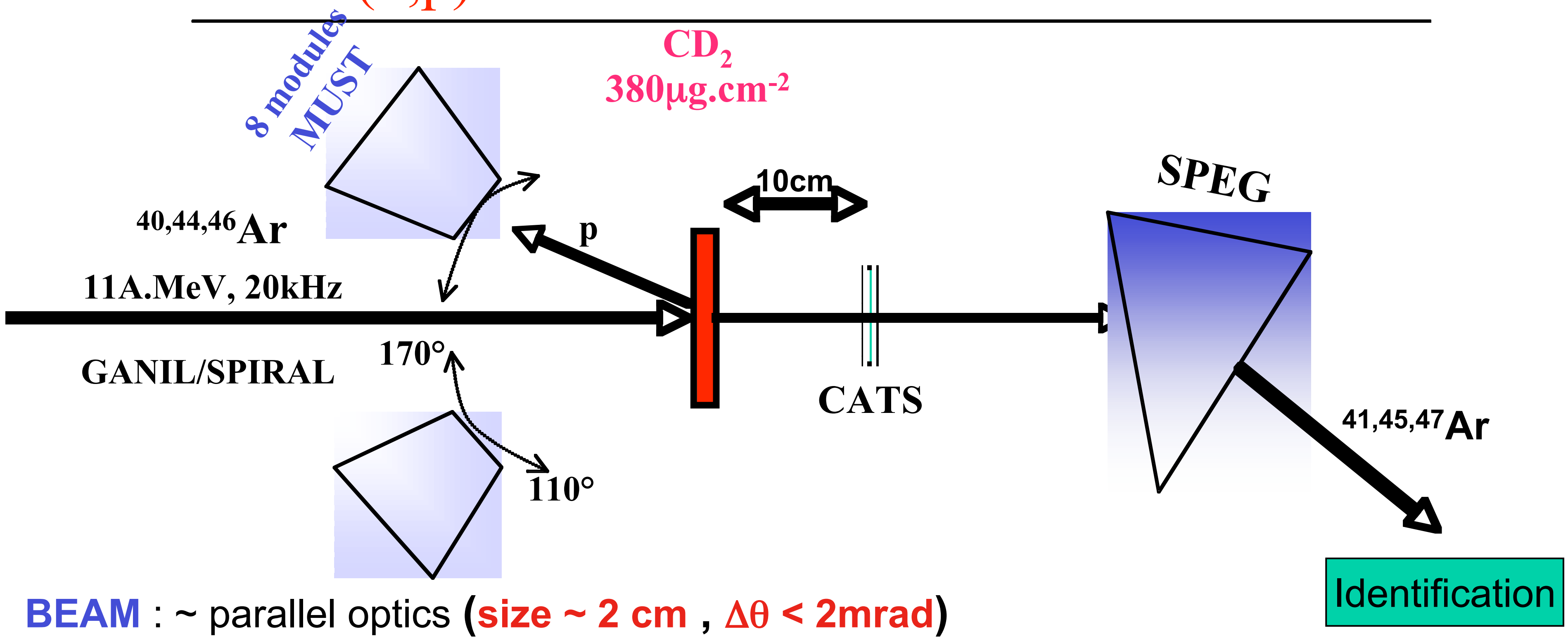
L. Gaudefroy,[1,2] O. Sorlin,[2,1] D. Beaumel,[1] Y. Blumenfeld,[1] Z. Dombrádi,[3] S. Fortier,[1] S. Franchoo,[1] M. Gélin,[2] J. Gibelin,[1] S. Grévy,[2] F. Hammache,[1] F. Ibrahim,[1] K. W. Kemper,[4] K.-L. Kratz,[5,6] S. M. Lukyanov,[7] C. Monrozeau,[1] L. Nalpas,[8] F. Nowacki,[9] A. N. Ostrowski,[5,6] T. Otsuka,[10] Yu.-E. Penionzhkevich,[7] J. Piekarewicz,[4] E. C. Pollacco,[8] P. Roussel-Chomaz,[2] E. Rich,[1] J. A. Scarpaci,[1] M. G. St. Laurent,[2] D. Sohler,[11] M. Stanoiu,[12] T. Suzuki,[13] E. Tryggestad,[1] and D. Verney[1]



S_n (^{47}Ar) determined from Q value

N=28 gap reduced by 330(80)keV

(d,p) reactions with $^{40,44,46}Ar$ beams



BEAM : ~ parallel optics (**size ~ 2 cm , Δθ < 2mrad**)

CATS : -**beam**-tracking detector

- Proton **emission point**.

  resolution : ~0.6 mm

MUST : -**Si Strip** detector

-Proton **impact localisation**

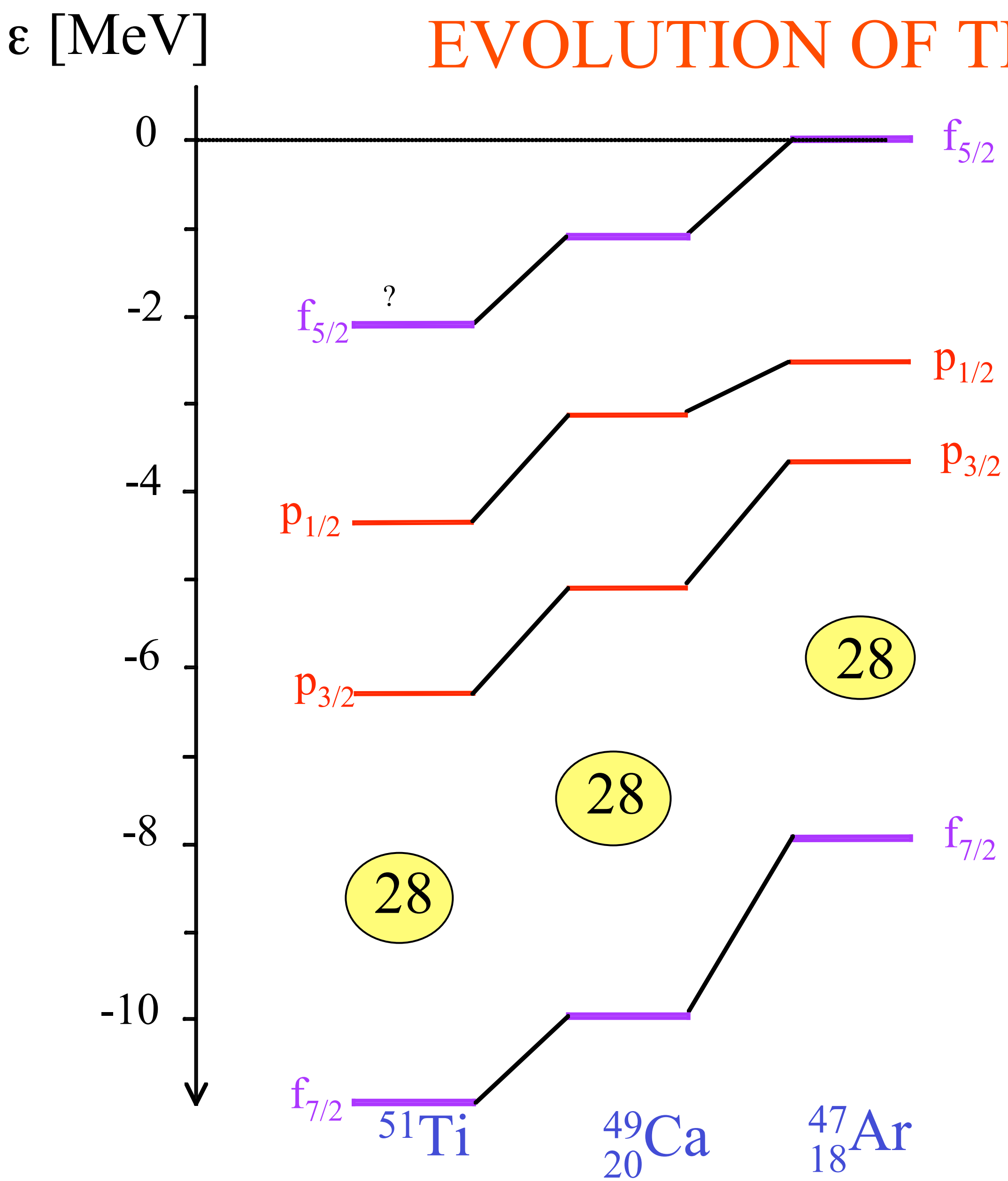
resolution : 1 mm

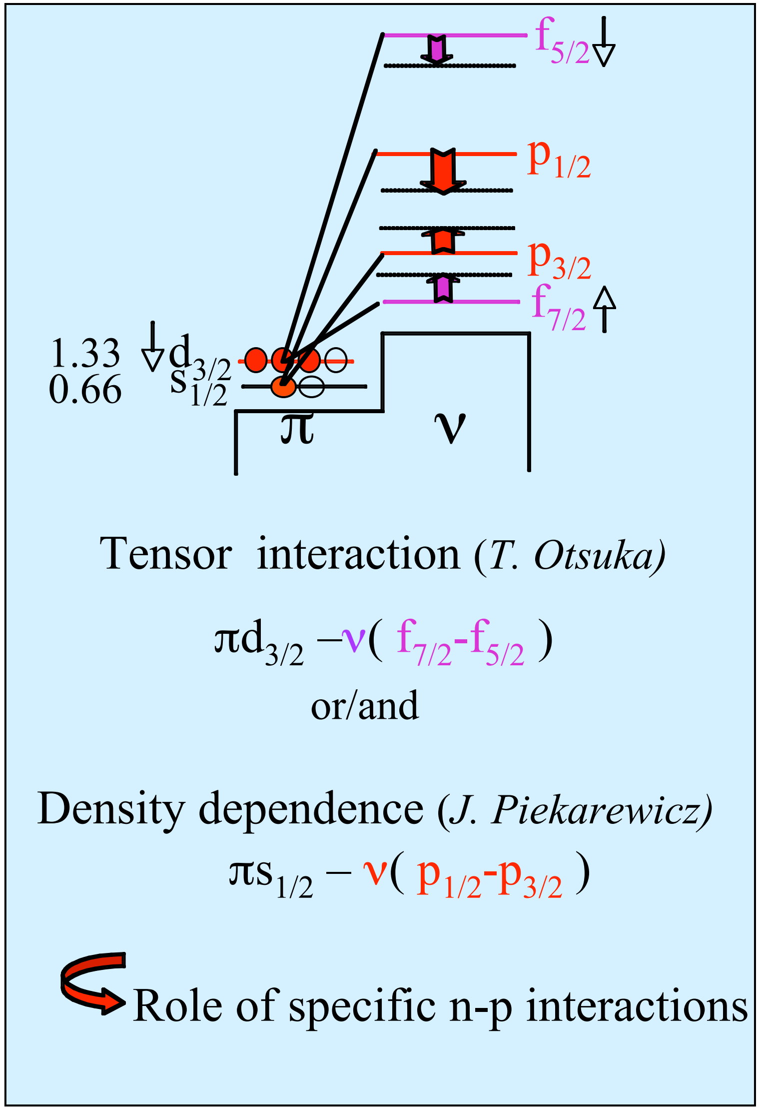
-Proton **energy** measurement.

resolution : 50 KeV

SPEG : Energy loss spectrometer : **recoil ion** identification→transfert-like products

EVOLUTION OF THE LEVELS AT N=29





N=28 gap has decreased by **330(80) keV** between Ca and Ar

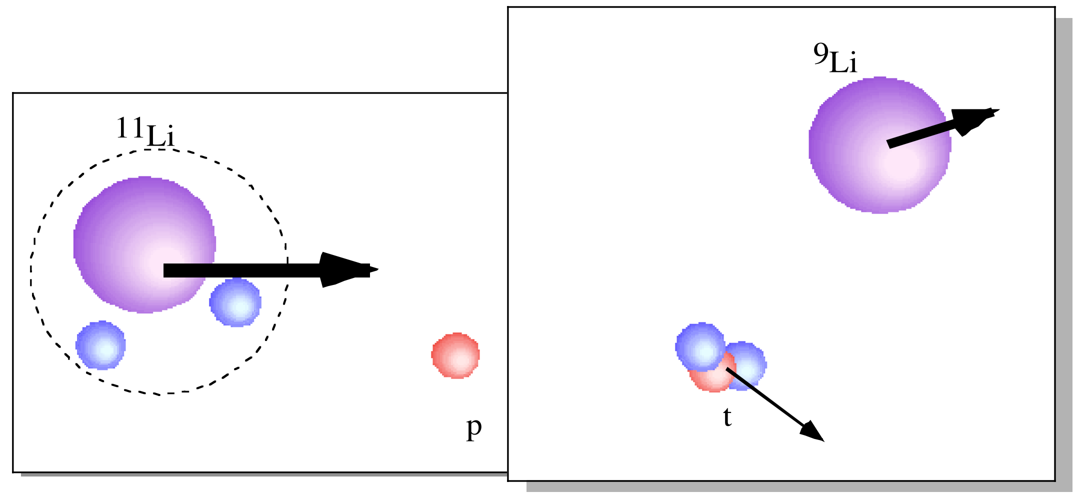
Decrease of the *f* and *p* spin-orbit splittings by **800keV** and **900keV**, respectively

O. Sorlin courtesy

^{11}Li adventure at TRIUMF

E1055

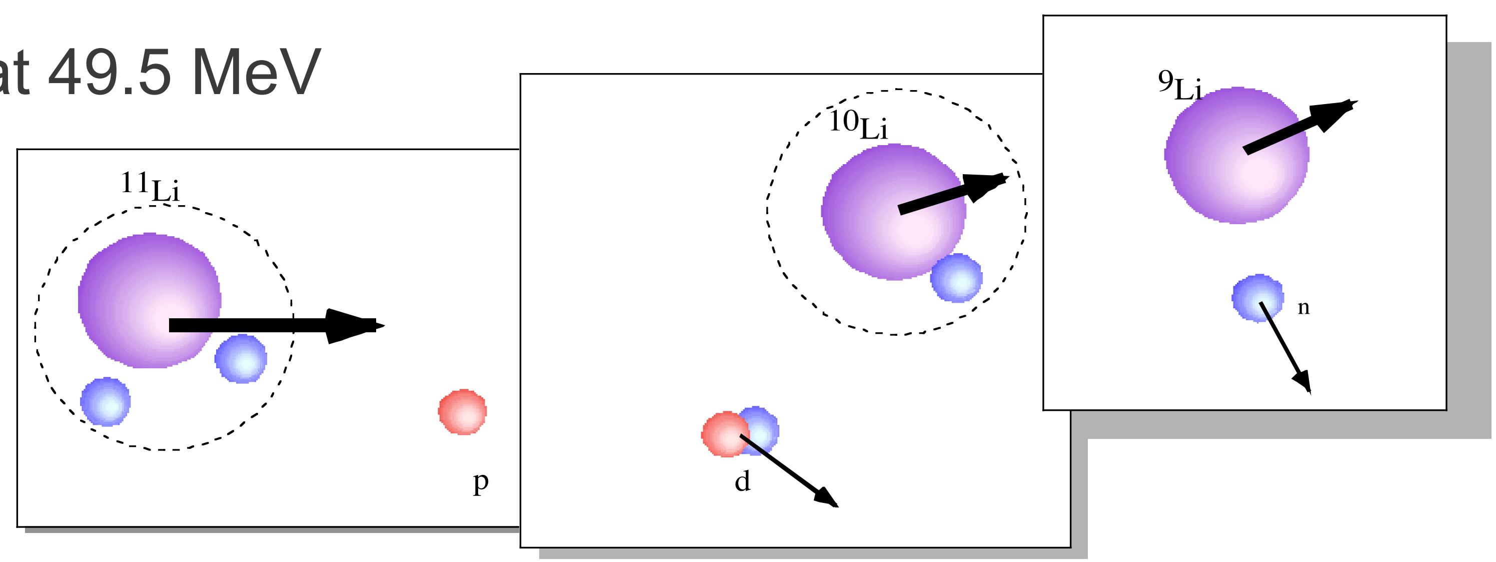
p(^{11}Li, ^{9}Li) t at 39.6 MeV
d(^{9}Li, ^{9}Li) d at 39.6 MeV



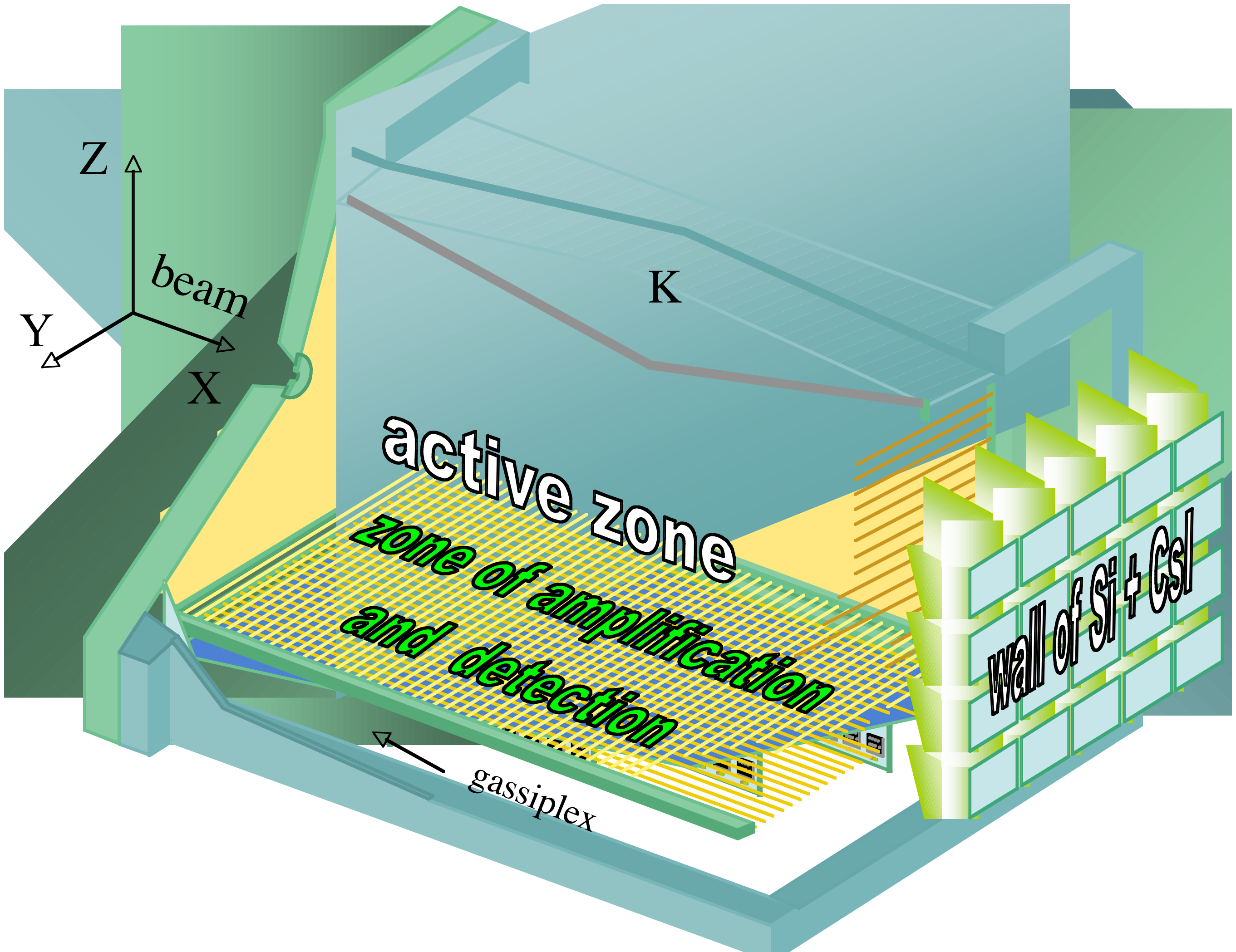
E1078

p(^{11}Li, d)^{10}Li at 49.5 MeV

p(^{11}Li, n)^{11}Be
(^{12}Li IAS)

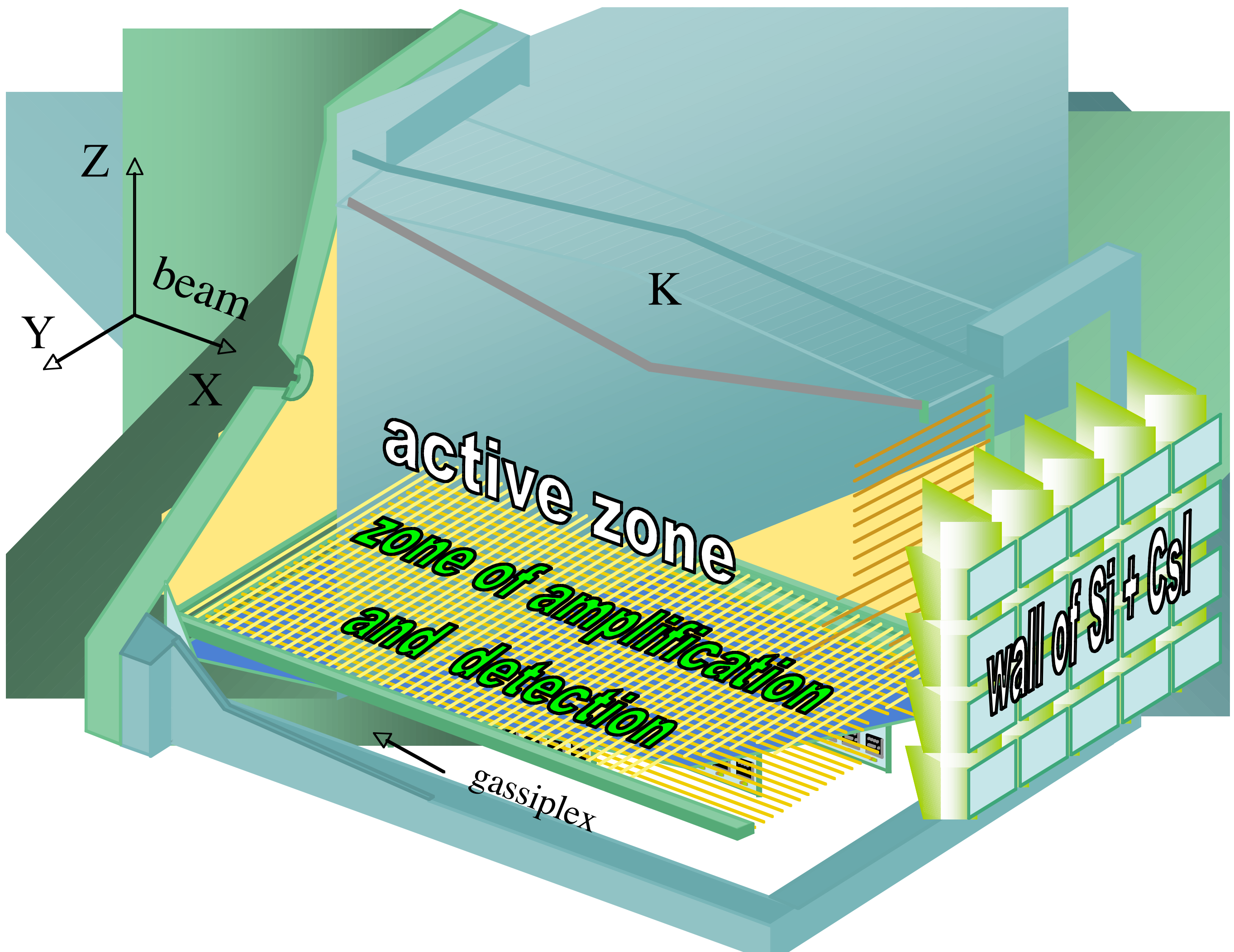


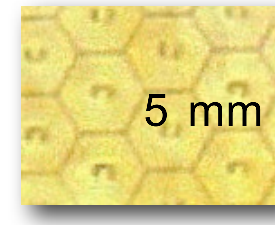
MAYA from GANIL to TRIUMF



W.Mittig et al., Nucl.Phys. A722, 10c (2003)
C.E.Demonchy et al. J.Phys. G31, S1831 (2005)

MAYA from GANIL to TRIUMF





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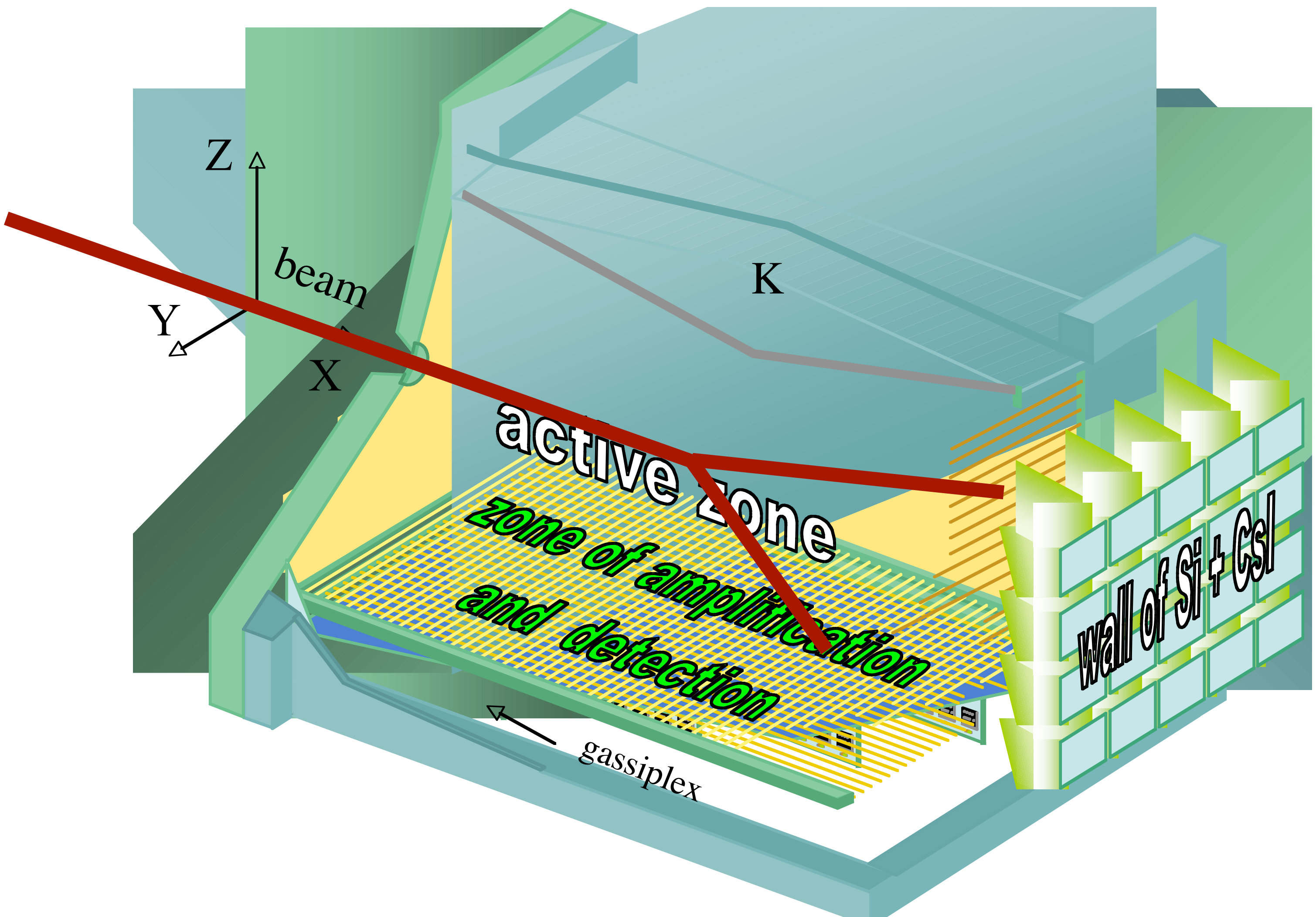
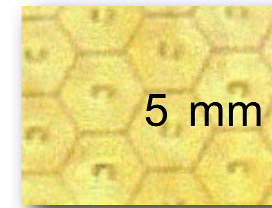
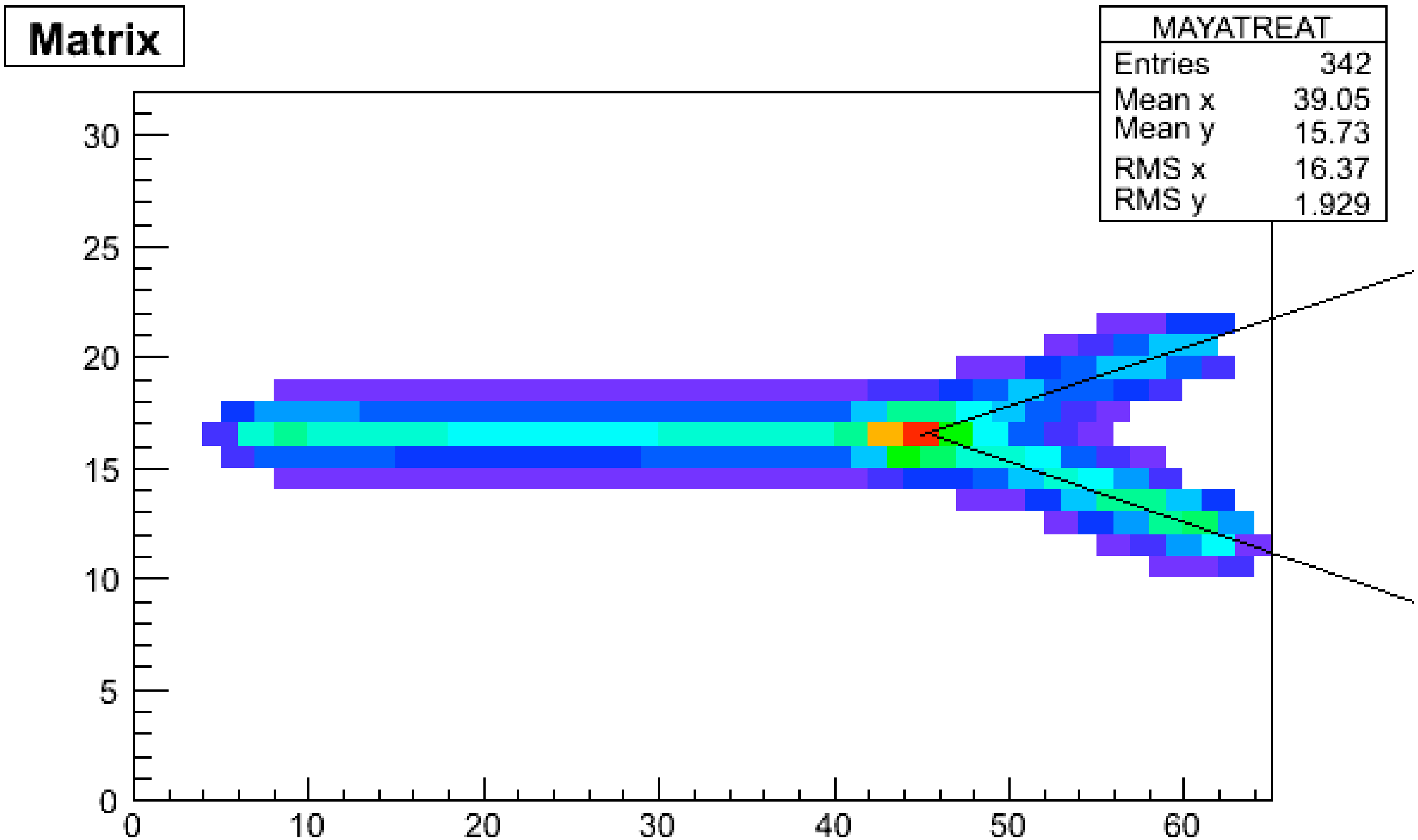




W.Mittig et al., Nucl.Phys. A722, 10c (2003)
C.E.Demonchy et al. J.Phys. G31, S1831 (2005)

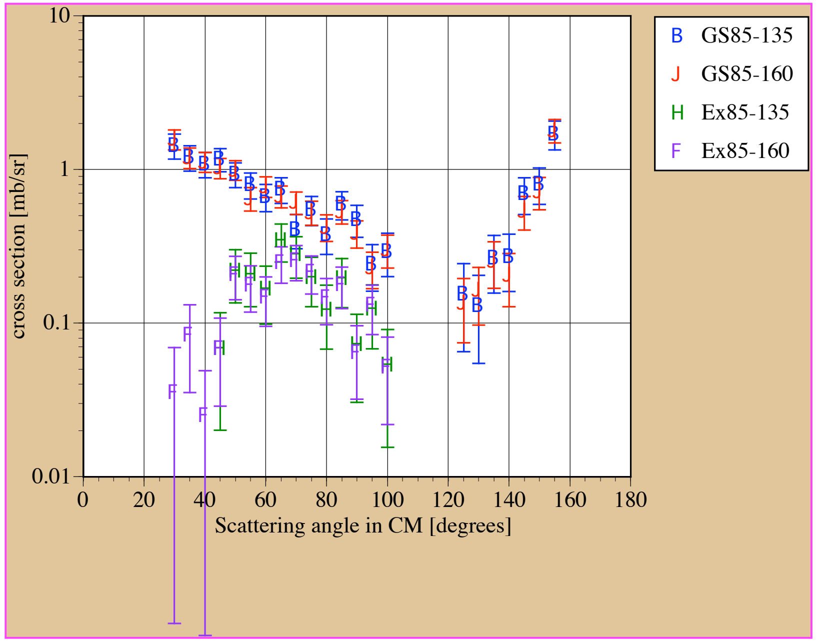
You can actually see the events



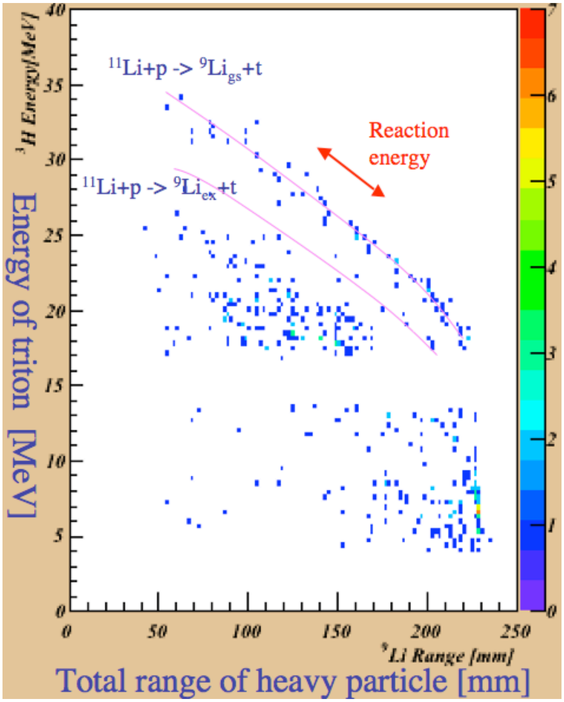
Courtesy: Thomas Roger

PRELIMINARY results

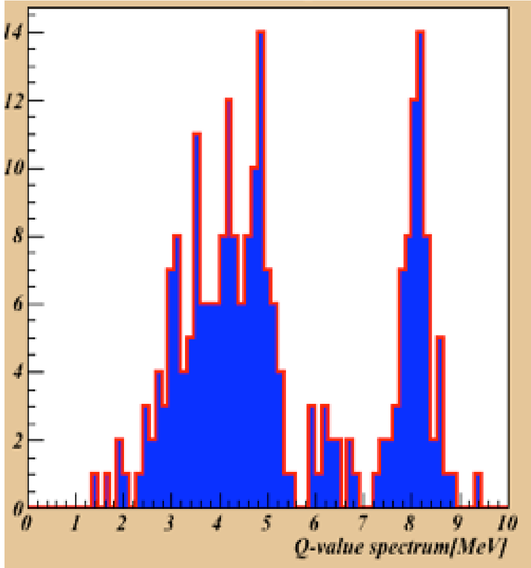
◆ Differential cross section of
$^{11}Li(3/2^-)+p$ -> ^{9}Li (gs:$3/2^-$)+t and
$^{11}Li(3/2^-)+p$ -> ^{9}Li (1st:$1/2^-$)+t
has been extracted from the January run.



Energy dependence of the 180° (p,t) reaction.



Q-value measurement



thanks: H. Savajols and I. Tanihata

Comments

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- Important also: to have high efficiency detectors and to choose the best facility to make your experiment

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- Important also: to have high efficiency detectors and to choose the best facility to make your experiment
- Intensity is not only the issue. Quality and reliability of the probe IS fundamental
- Theory is improving when moving to new areas of the chart
- Safety is “starting” to be an issue. This should not be underestimated

Future

- ISAC-II upgrades - Energy upgrade with charge breeder and new cavities (TIGRESS, EMMA)
- SPIRAL2 - LINAG driver with HI and light beams (14.5A MeV) - 200kW
- HIE-ISOLDE - Energy upgrade of REX up to 10A MeV (step at about 5A MeV)
- New comers with specific added value: EXCYT, TRIAC
- SEE H1,2 (Astrophysics); J3,4 (Coming facilities)
- EURISOL & "RIA lite" are needed to go forward, just because the present facilities are limited by safety.
- NEXT GENERATION SHOULD INTEGRATE CONSTRAINING SAFETY ISSUES UP TO THE EXPERIMENTAL AREA

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EMIS 2007

XV[th] International Conference on Electromagnetic Isotope Separators
and Techniques Related to their Applications

June 24-29, 2007 at Deauville, France.

EMIS 2007 takes place at the "Centre International de Deauville" in Deauville, a wonderful town in the heart of the Pays d'Auge, Normandy, France. The EMIS-2007, is the 15th in the series. The latest of the series, very successful as you certainly remember, was in 2002 at Victoria, Canada.

Following the tradition of EMIS, overview talks and contributions will be offered in morning and afternoon sessions. The scientific program will be composed to attract participants, ranging from established world leading scientists to PhD students, active within theory, experiments and applications. In particular, production and use of radioactive nuclear beams will be focused.

The EMIS2007 conference is hosted and organized by **GANIL**, **IN2P3/CNRS** and **DSM/CEA**.

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Navigation

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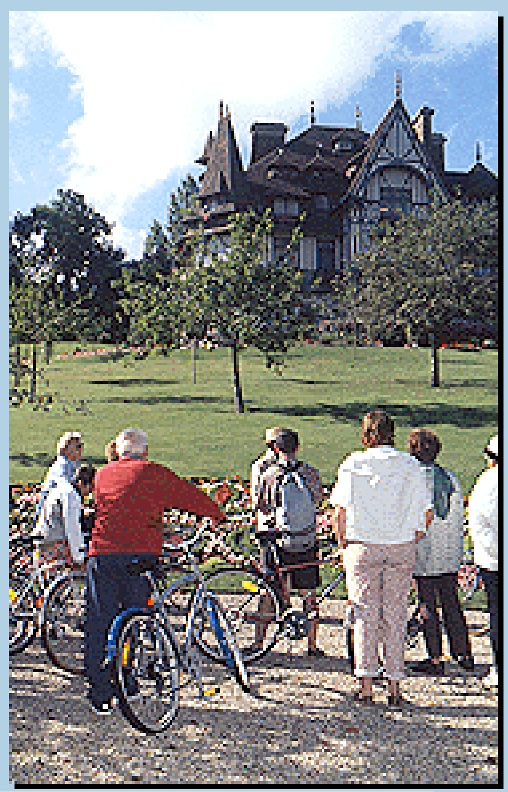
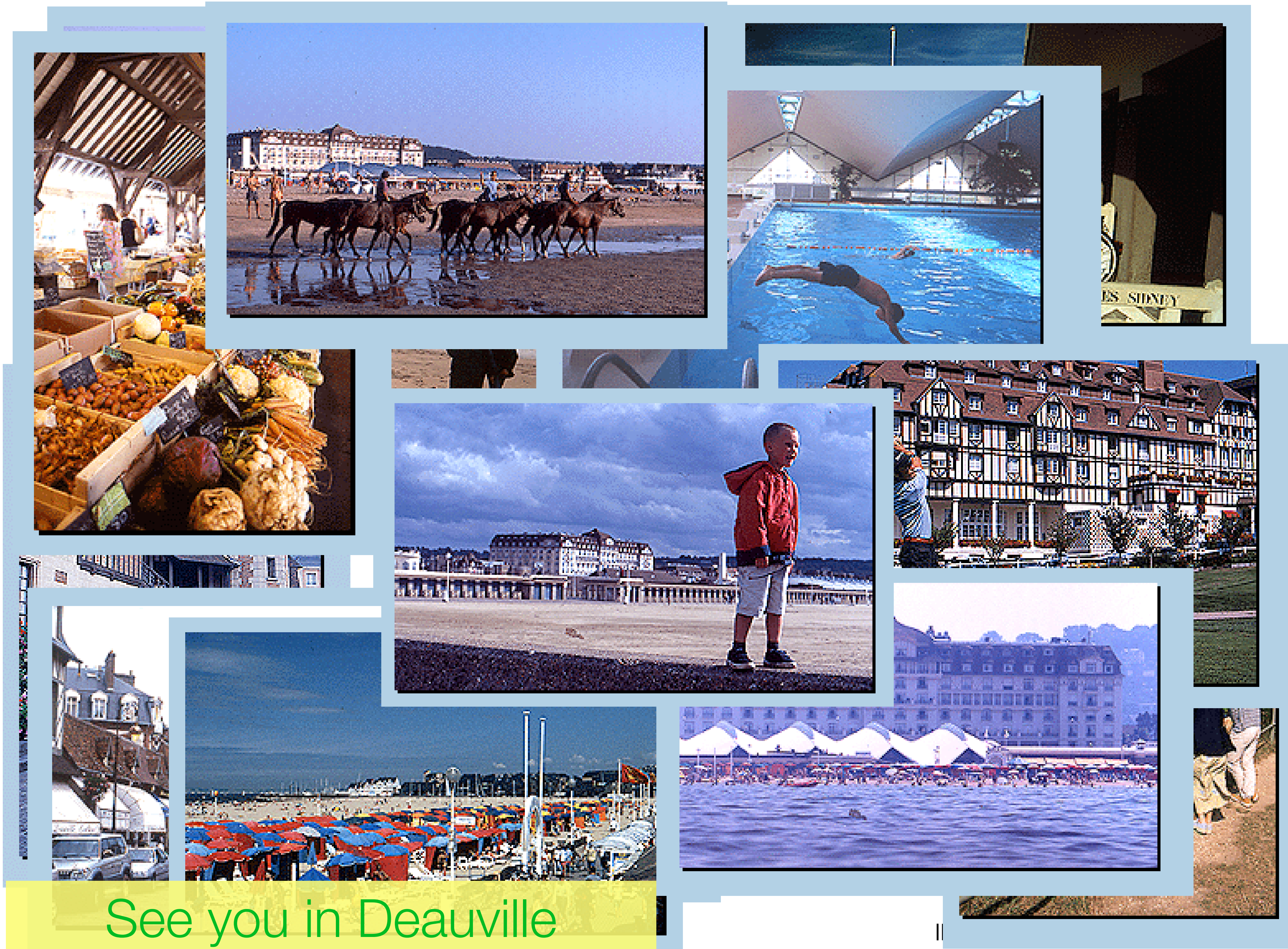


See you in Deauville


See you in Deauville