PS/OP/Info 92-13
9.03.1992

ISOLDE

Copie des transparents
du cours donné aux techniciens d'opération LI/BR
le 19.2.1992
par K. Elsener et P. Lievens

Distribution

Section OP/LI/BR
BS

ISOLDE

Isotope Separator On-Line

⇒ production of clean beams of radioactive nuclei (ions), which are so short-lived that they have to be used immediately (for expts.)

$\tau \gtrsim 10\,ms$ (hopefully less!)

SC ⟶ Booster

(Note: ISOL technique is complementary to recoil sep. (GANIL, GSI ...)

Selective production of isotopes

principle: nuclear reactions

10^{13} protons/burst + anything
$\rightarrow$ "almost anything"

choice of target material !

for high intensity radioactive beams:

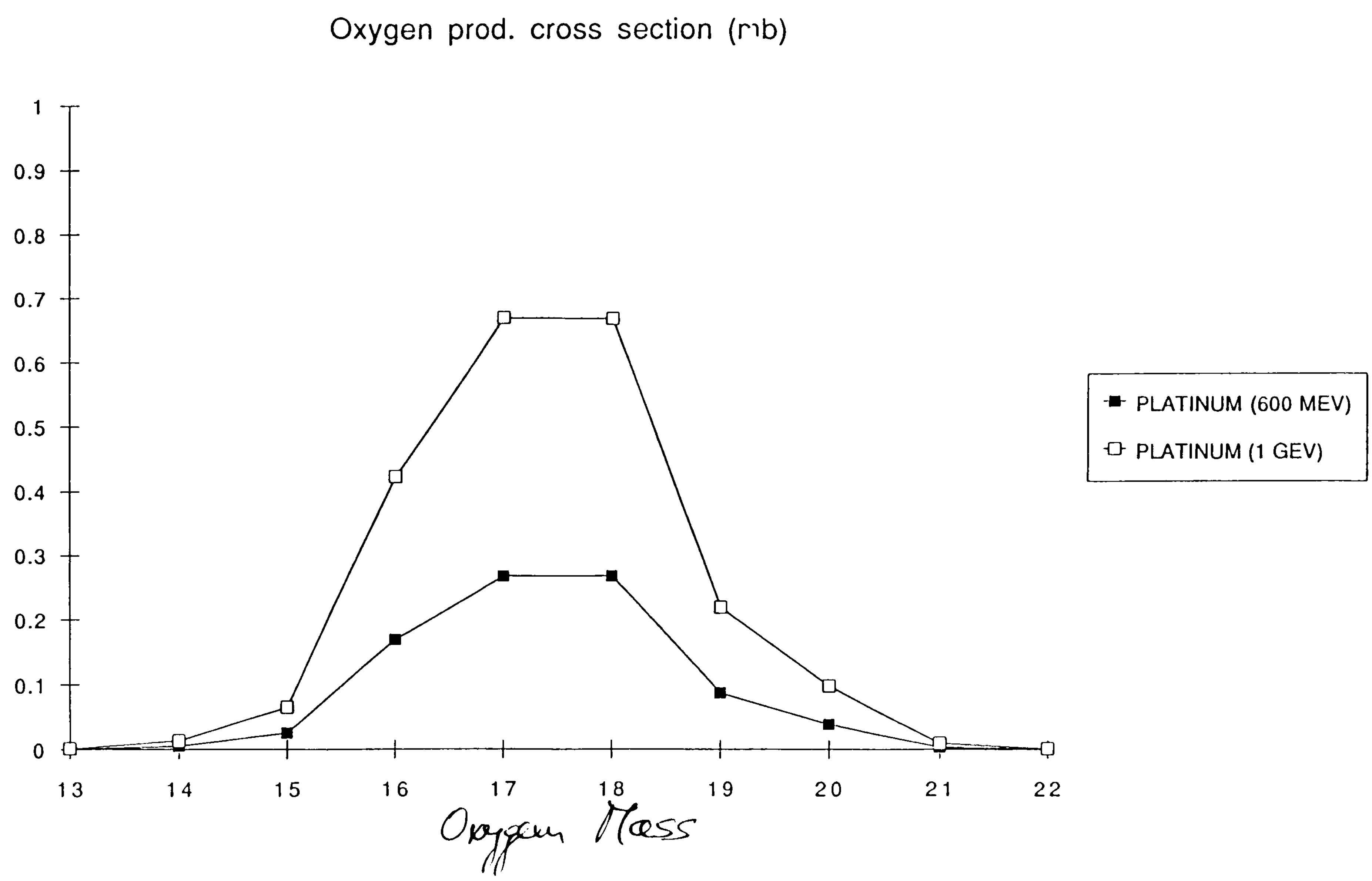
thick targets ! (diffusion and desorption of neutrals with radioactive nuclei)

there is a drawback:

needs **ionizer** ! (+60 kV acceleration before mass separation)

(therefore a transfer of atoms from the target to the ionizer)

ALL THIS HAS TO HAPPEN **FAST!** (lifetimes of <10 ms)


Oxygen prod. cross section (mb)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
13
14
15
16
17
18
19
20
21
22
Oxygen Mass
PLATINUM (600 MEV)
PLATINUM (1 GEV)

TARGET

→→ should be THICK: high yields (20 cm long) (4 cm long)
→→ should be CLEAN: unwanted products, dirt load
→→ should be HOT: fast diffusion to the surface
(but not too hot: e.g. evaporize the target material!)

→→ should have large surface/volume ratio:
same reason

→→ should have "good" surfaces for desorption !

examples: Niobium foils, Uranium carbide, Magnesium oxide, Iridium powder, etc.

NOTE: the target container (and transfer line) has to be made of a material which can be vacuum tight and can withstand high temperatures and radioactivity: Tantalum (in most cases), Tungsten, Graphite,... are used.

TRANSFER LINE

→→ should be SHORT: lifetimes
→→ should be TIGHT: losses
→→ can be COLD or HOT: selectivity of noble gases / others (affinity!)

ION SOURCE

→→ wanted: high EFFICIENCY (for desired element!)

→→ should be "SMALL": lifetimes
→→ should have a large exit hole: "
(but not too large: efficiency, beam optics)
→→ should be COLD or HOT: element sel.

surface ionizer

atoms leave a hot surface after collision with one electron less (positive ion) or more (negative ion), if the ionization potential is below 7 eV or the electron affinity above 1.5 eV, respectively (efficiencies between 0.1% and 100%, about 40 to 50 elements).

→→ element **selectivity** !

examples: hot tungsten surface, VERY GOOD for alkalines (Li, Na, ...)
LaB_6, efficient for Cl, Br, etc.

advantage: "EASY TO OPERATE"

"plasma" ionizer

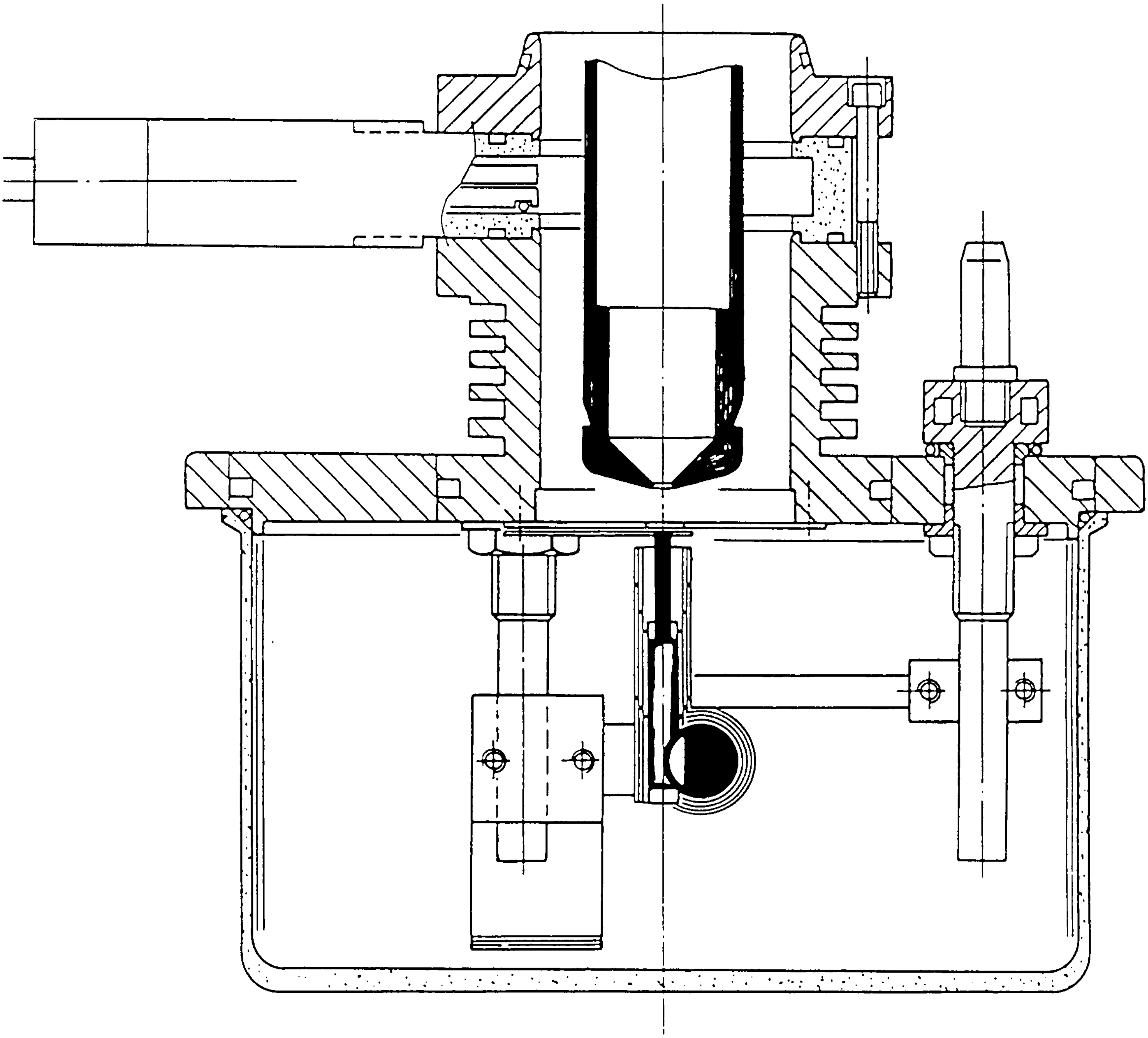
atoms are ionized by electron bombardement and/or collisions with other ions in a low density plasma; electrons injected into the source from a hot cathode (metal plate, filament), and "contained" in a magnetic field (for a short while only...)

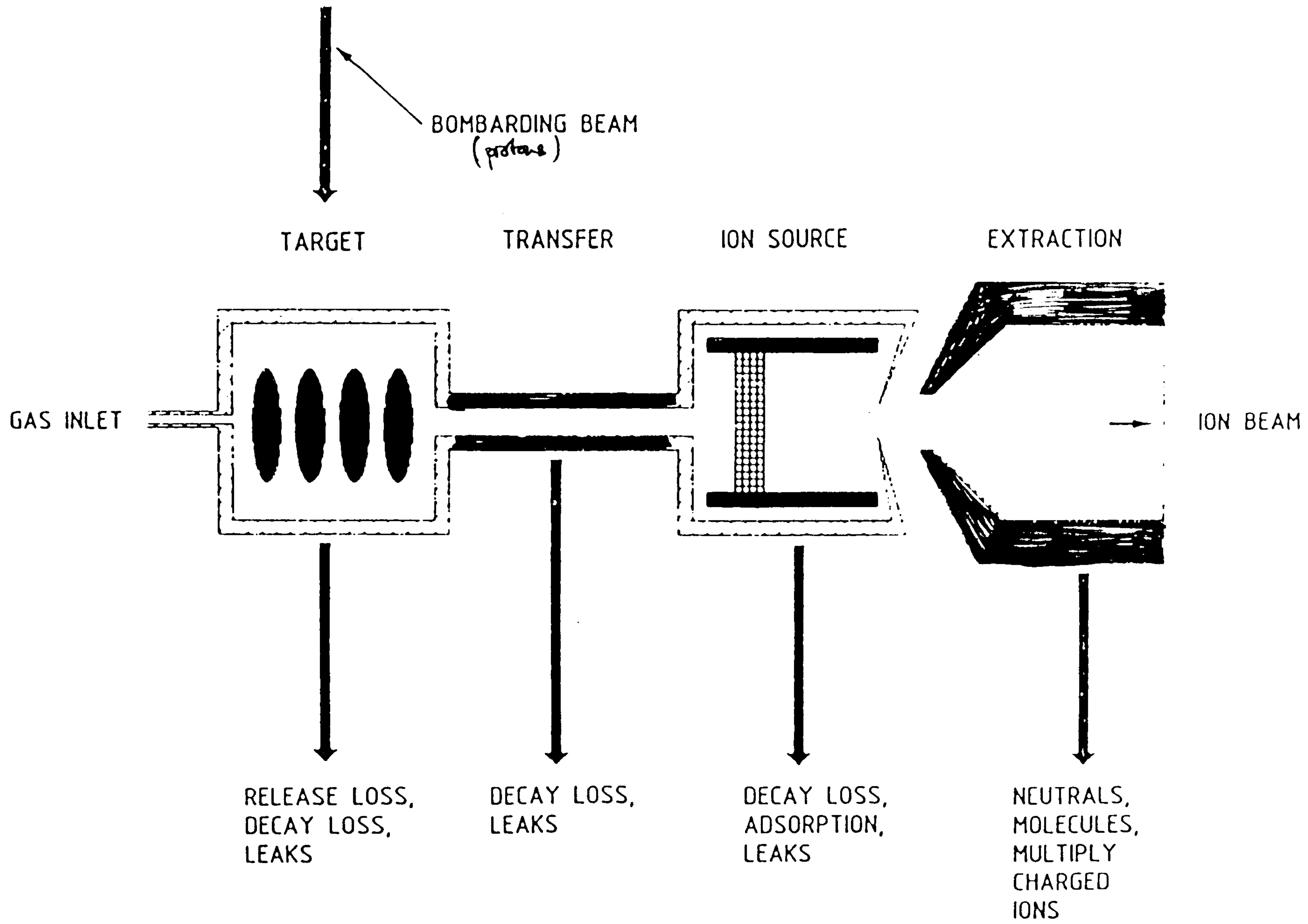
→→	HOT:	for elements with high affinity
→→	COLD:	for noble gases
→→	+ GASES:	to form molecular sidebands

all together: element **selectivity** !!

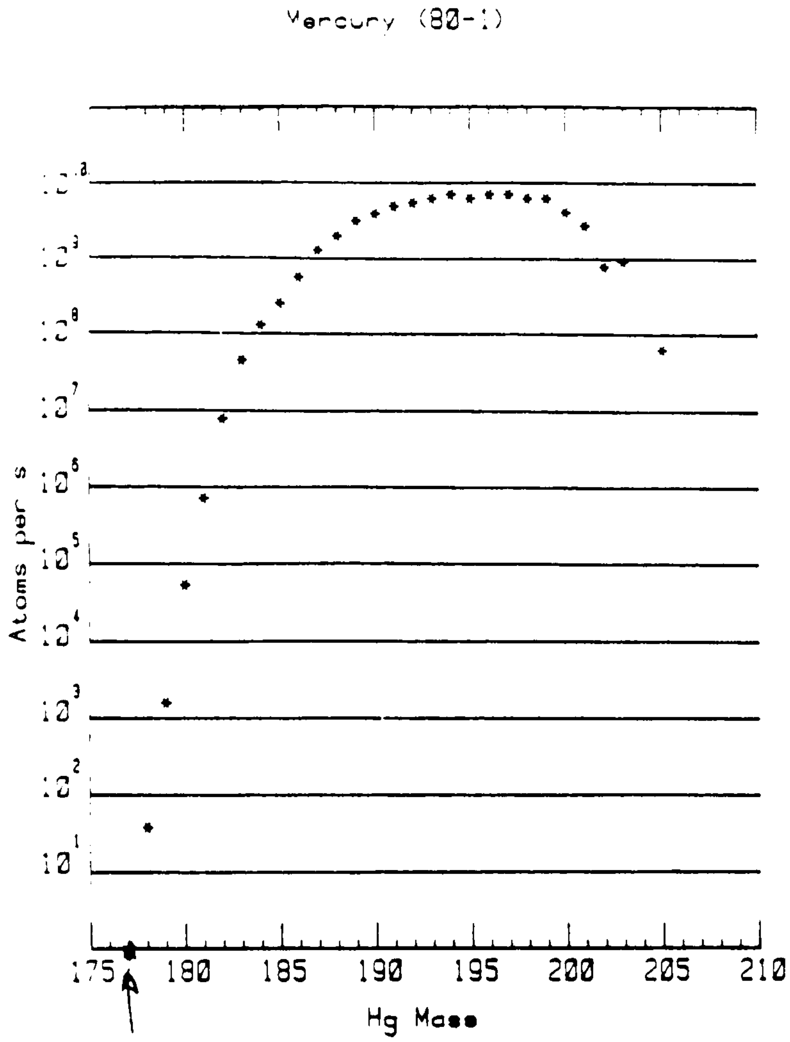
examples:	Ne isotopes:	cooled transfer line + "cold" plasma source
	Cu isotopes:	hot plasma source
	F isotopes:	hot plasma source, addition of CF_4, found as AlF^+ sideband (SiC target !!!)

(operation involves several parameters: cathode heating, anode voltage, magnet current...)



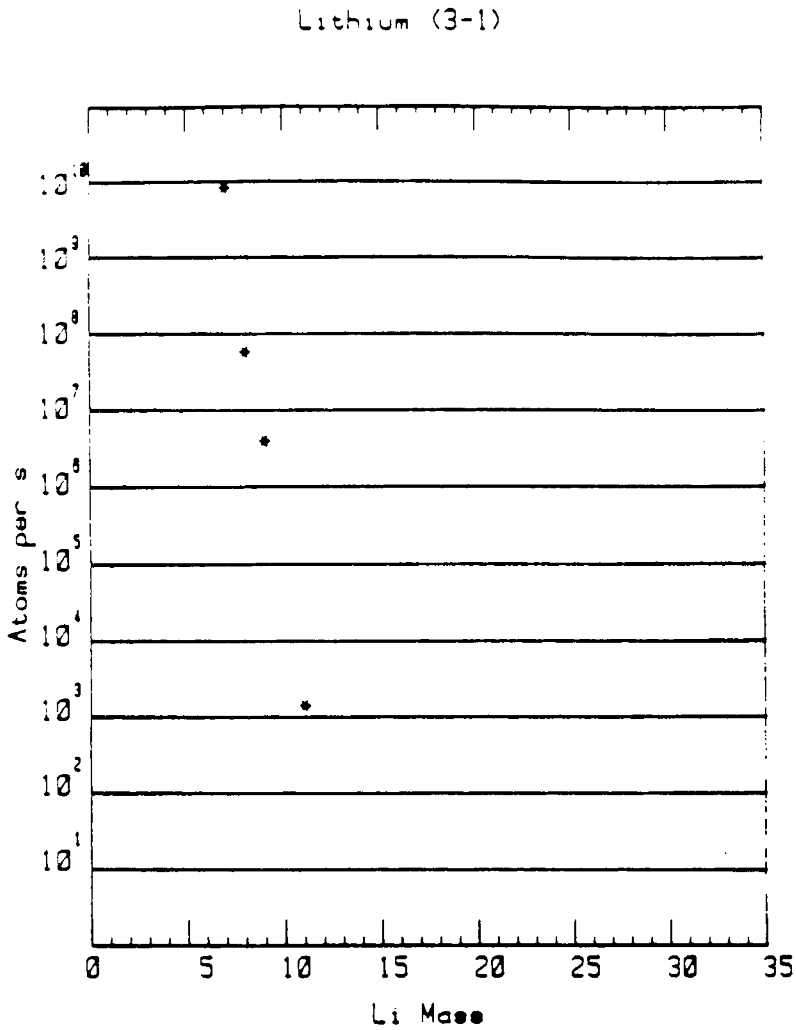


BOMBARDING BEAM
(protons)
TARGET
TRANSFER
ION SOURCE
EXTRACTION
GAS INLET
ION BEAM
RELEASE LOSS, DECAY LOSS, LEAKS
DECAY LOSS, LEAKS
DECAY LOSS, ADSORPTION, LEAKS
NEUTRALS, MOLECULES, MULTIPLY CHARGED IONS



Date : 29.8.77
Target material : Molten lead
Ion source : Plasma discharge with heated line
Target thickness : 170 g/cm^2
Projectile : 600 MeV protons

Mass No.	Half-life	Yield (atoms/s)	Remarks
177	0.17 s	8.90×10^{-1}	Ref. 1
178	0.26 s	3.80×10^{1}	Ref. 3
179	1.1 s	1.60×10^{3}	Chemically selective
180	2.9 s	5.30×10^{4}	
181	3.6 s	7.10×10^{5}	
182	11.2 s	7.90×10^{6}	
183	8.8 s	4.50×10^{7}	
184	30.6 s	1.30×10^{8}	
185	50 s	2.50×10^{8}	
186	1.4 min	5.60×10^{8}	
187	2.2 min	1.30×10^{9}	
188	3.3 min	2.00×10^{9}	
189	7.7 min	3.20×10^{9}	
190	20.0 min	4.00×10^{9}	
191	50 min	5.00×10^{9}	
192	4.9 h	5.60×10^{9}	
193	3.5 h	6.30×10^{9}	
194	367 y	7.10×10^{9}	
195	9.5 h	6.30×10^{9}	
196	Stable	7.10×10^{9}	
197	64.1 h	7.10×10^{9}	
198	Stable	6.30×10^{9}	
199	Stable	6.30×10^{9}	
200	Stable	4.20×10^{9}	
201	Stable	2.80×10^{9}	
202	Stable	7.90×10^{8}	
203	46.6 d	9.30×10^{8}	
205	5.2 min	6.30×10^{7}	



Date : 7.5.80
Target material : Uranium carbide
Ion source : W-surface ionization
Target thickness : 13 g/cm^2
Projectile : 600 MeV protons

Mass No.	Half-life	Yield (atoms/s)	Remarks
7	Stable	8.20×10^9	Ref. 7
8	842 ms	5.80×10^7	Ref. 8
9	173 ms	3.90×10^6	Chemically selective
11	8.70 ms	1.40×10^3	

e.g. ... (τ = 8.7 ms)

$\Rightarrow$ HV (60 kV) has to come back to its nominal value **fast** after beam impact

(1) for GPS (R ≈ 2500 (?)) ;

(2) for HRS (R ≳ 15000 (?))
inside 0.6 Volts

cf. laser exp. (P. Lievens)

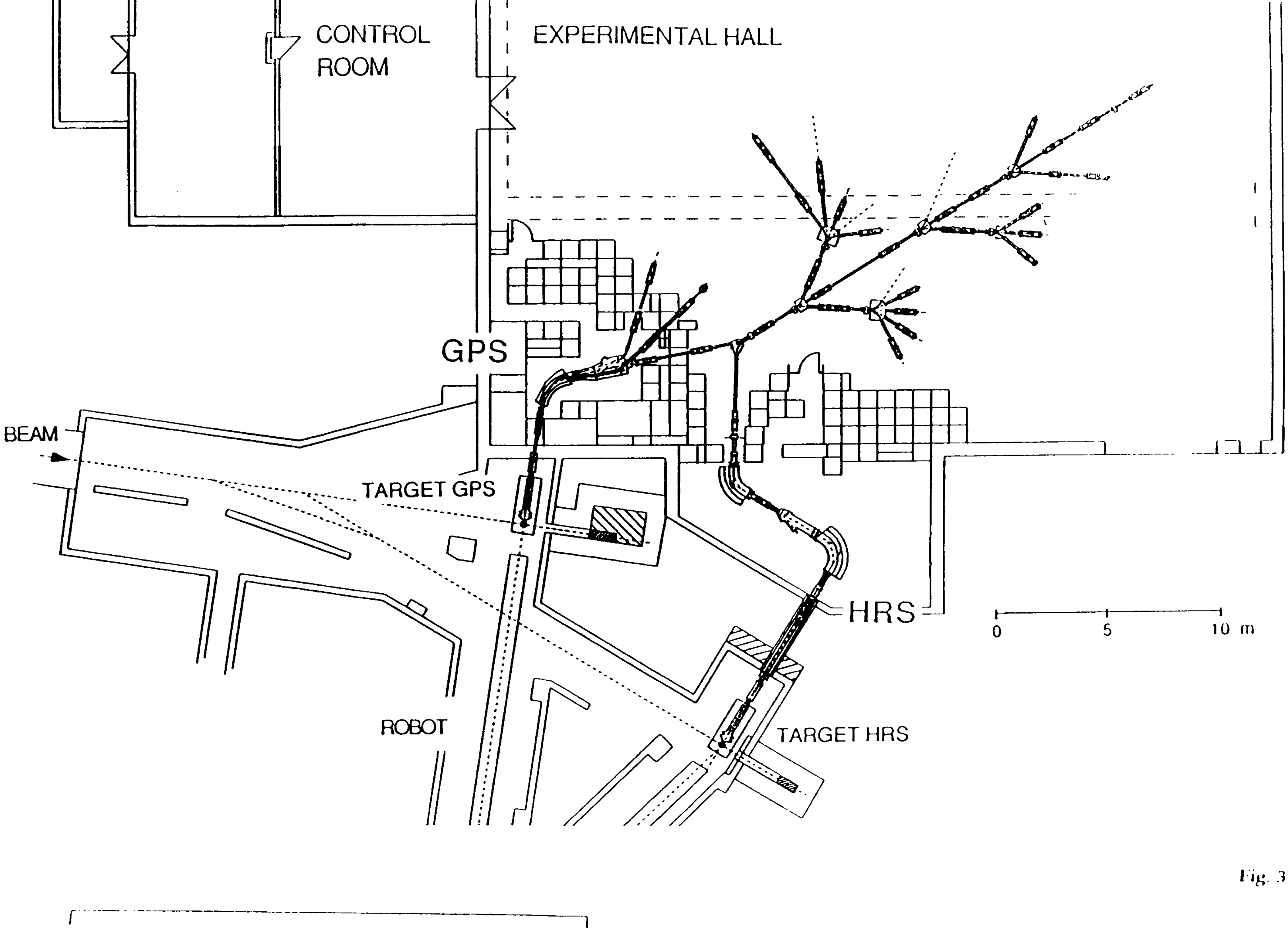
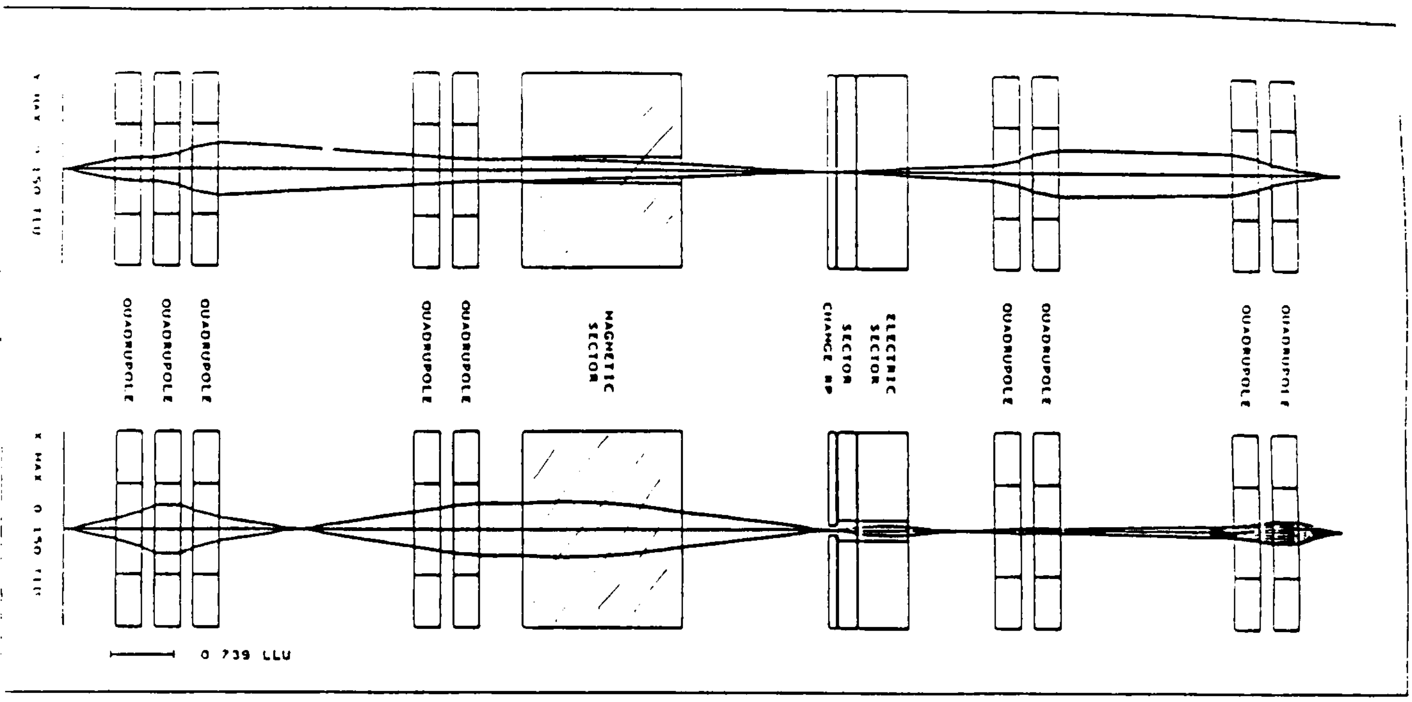

CONTROL
ROOM
EXPERIMENTAL HALL
GPS
BEAM
TARGET GPS
HRS
0
5
10 m
ROBOT
TARGET HRS

Fig. 3

GPS

Switch yard - light mass side

Andreas Przewloka
II. Physikalisches Institut
D-6300 GIESSEN



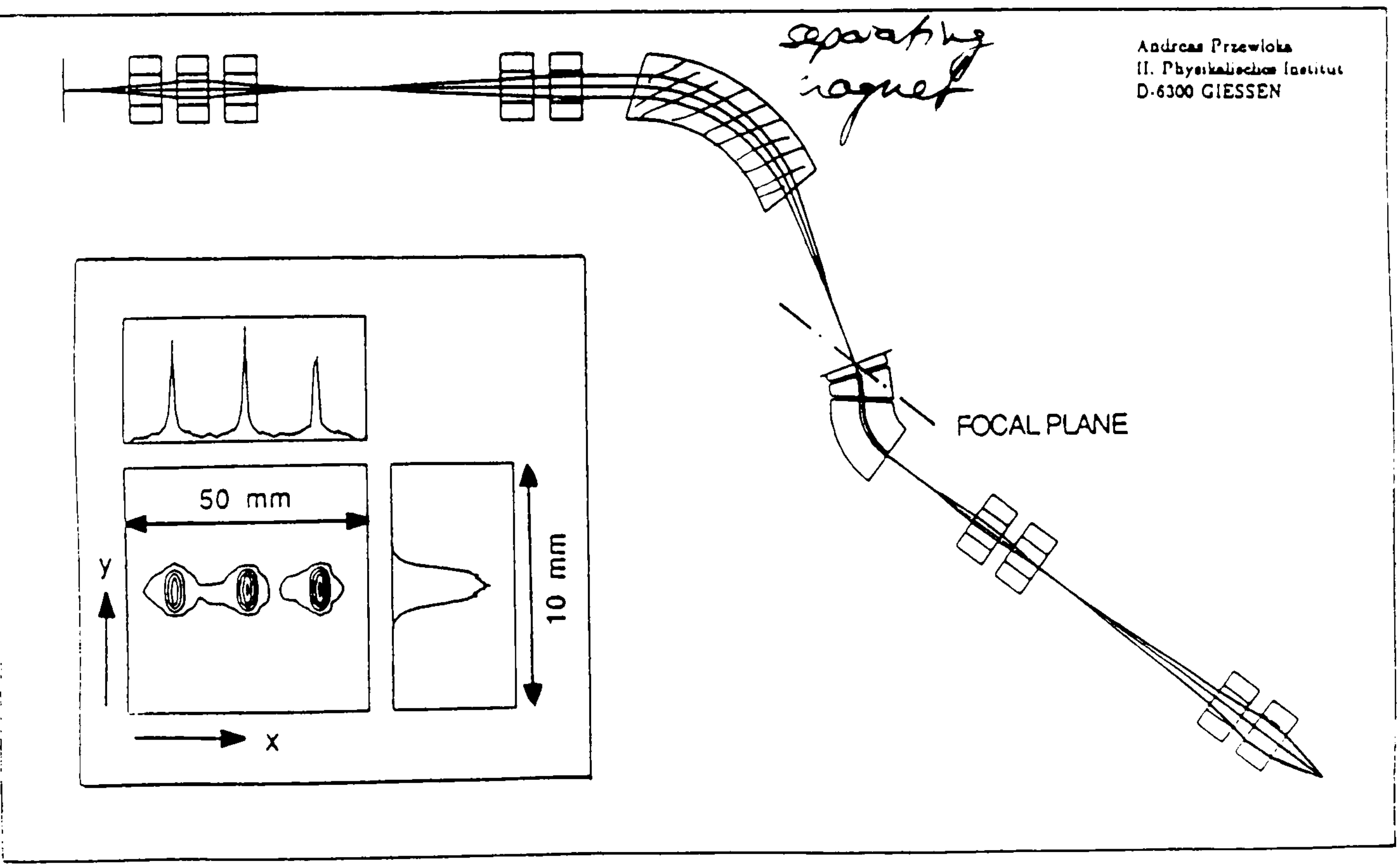


Fig. 4

"special feature":

rule: <u>one</u> magnet in a mass-
separator, i.e. separating magnet

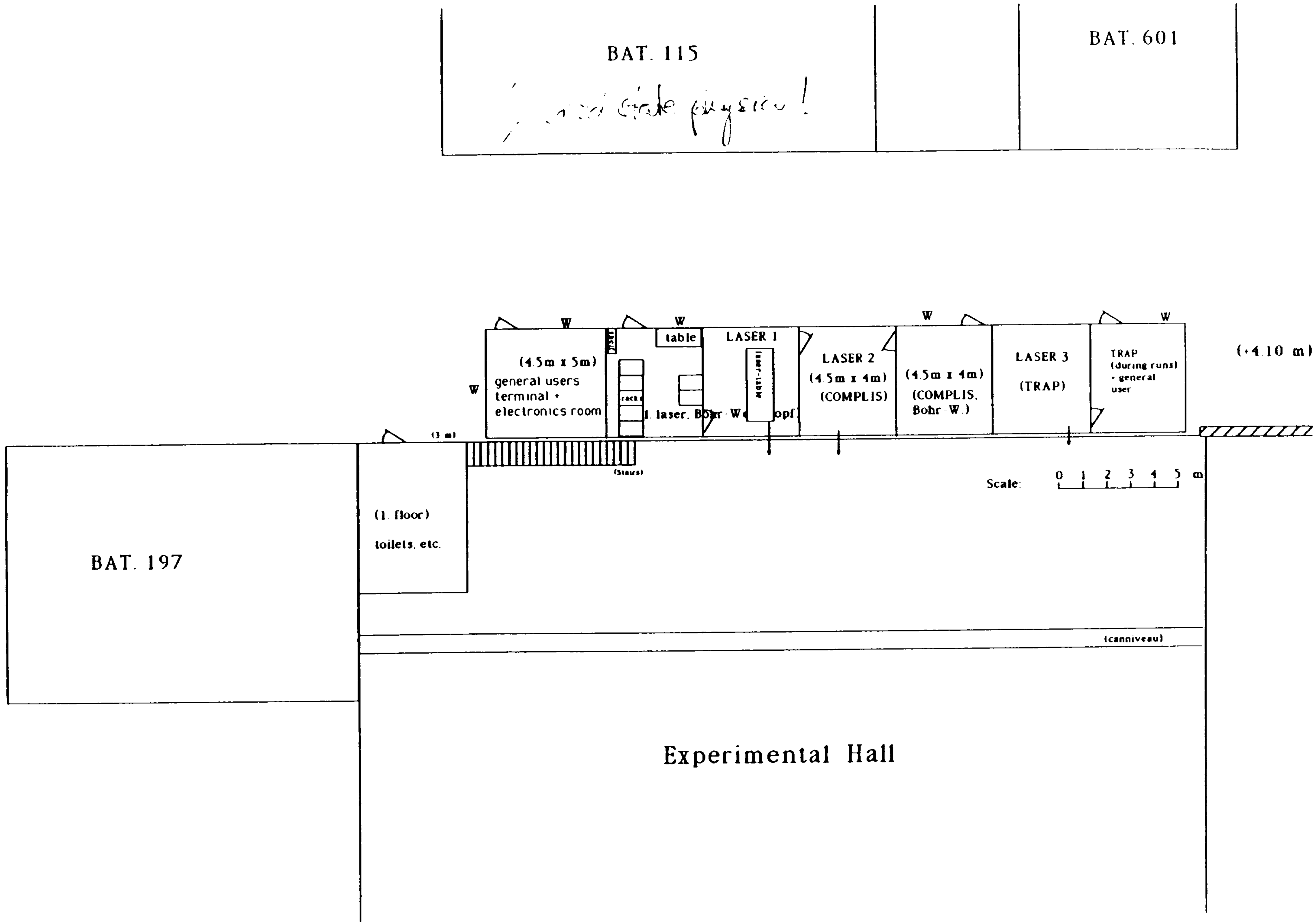
all other beamline elements
(focussing, steering) are
<u>el. stat.</u> elements

reason: steering is the same
for all beams
⟹ use stable beams
(i.e. non-radioactive)
for tuning !!

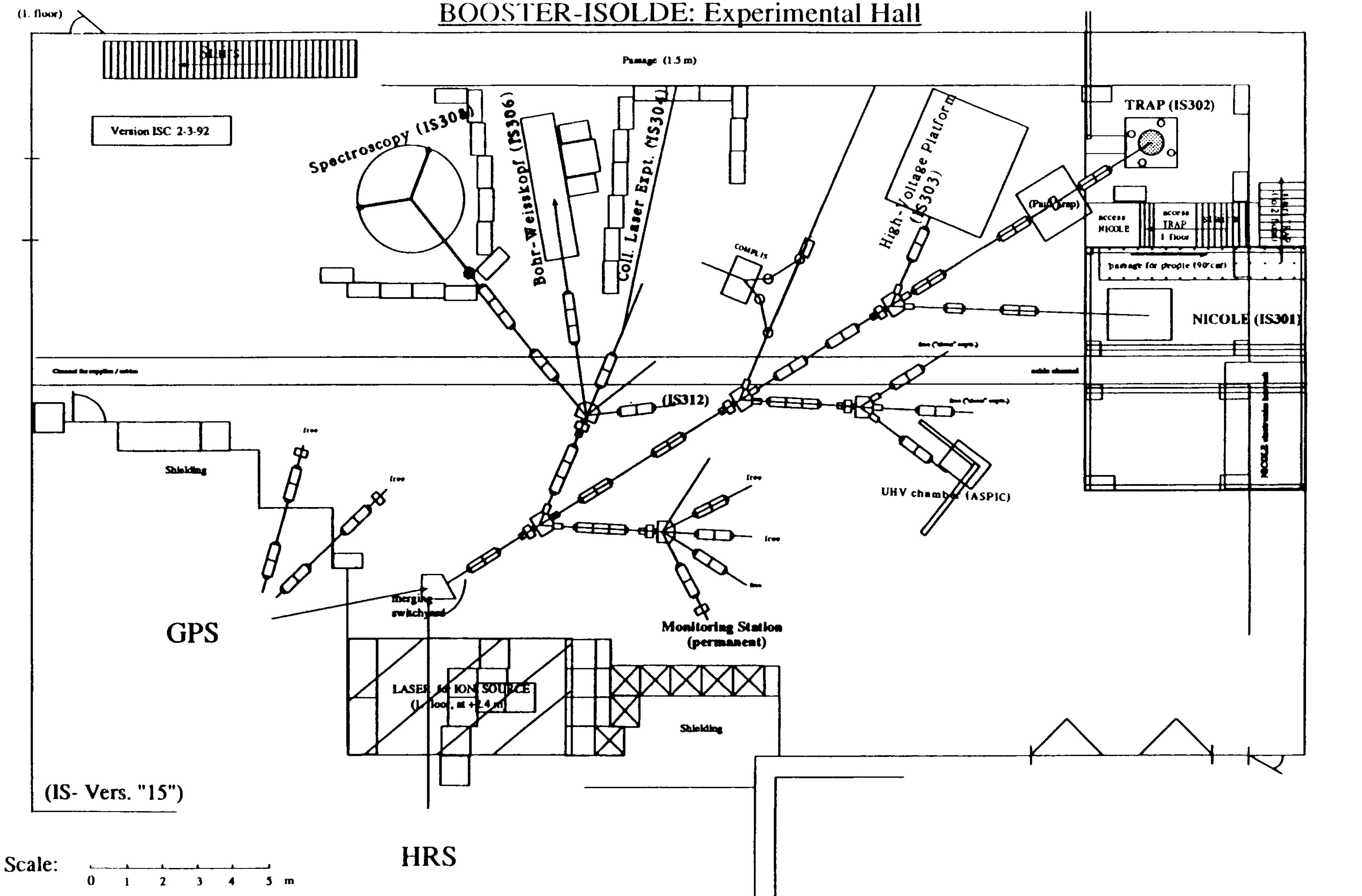
IS experiments

('real' numbers: IS 300 ff.)

- a few (~ 12) big installations
- a lot of small experiments, moving quickly in / out.


BAT. 115
BAT. 601
(4.5m x 5m)
general users
terminal +
electronics room
table
rack
shelf
1. laser, Bohr-W
LASER 1
laser-table
LASER 2
(4.5m x 4m)
(COMPLIS)
(4.5m x 4m)
(COMPLIS,
Bohr-W.)
LASER 3
(TRAP)
TRAP
(during runs)
+ general
user
(+4.10 m)
W
(3 m)
(Stairs)
Scale:
0 1 2 3 4 5 m
(1. floor)
toilets, etc.
BAT. 197
(canniveau)
Experimental Hall

BOOSTER-ISOLDE: Experimental Hall



(Konrad Elsener, PPE)

3 March 1992 (K. Elsener)

Prop.-No.	Exp.-No.	keyword	total req.	total appr.	1992	1993	1994
ISC / P2	IS300	axions (G. Weyer)	40	40	40 (*)		
ISC / P4	IS301	NICOLE-Sb (N. Stone)	14	14	8	6 (?)	
ISC / P6	IS302	TRAP (G. Bollen)	50 (+20 stable)	30 (incl. stable)	10	20	
ISC / P8	IS303	TFP (polarization) (M. Hass)	36	36	9	27 (?)	
ISC / P9	IS304	collinear laser (R. Neugart)	60 (+20 stable)	60 (+20 stable)	20	40	20
ISC / P10	IS305	Na-targets (C. Rolfs)	(2 weeks off-line)	(2 weeks off-line)	(*)		
ISC / P1	IS306	Bohr-Weisskopf (H.T. Duong)	40	20		20	
ISC / P12	IS307	diffusion a-Si (W. Ulfert)		5	2 (*)	2	
ISC / P15	IS308	French-ISOLDE (G. Walter)	27	27	15	12 (pr. rep.)	
ISC / P16	IS309	lattice relaxations (H.Hofsaess)	24	8	8 (*)		
ISC / P17	IS310	channeling (H.Hofsaess)	15	10	0	10	
ISC / P18	IS311	el. struct. impur. (J.W. Petersen)	50	12	12 (*)		
ISC / P19	IS312	passivation (D. Forkel)	45	15	15 (*)		
ISC / P20	IS313	Blue Oxidases (T. Butz)	32	16	8 (*)	8	
ISC / P22	IS314	NICOLE-Au (E. Hagn)	23	23	11	12	
ISC / P5		COMPLIS (G. Huber)	25	16 (+ 3 stable)	8 (?) (+ 3 stable)	8	
ISC / P29		ASPIC (H.H. Bertschat)	30	15		15	
ISC / P24		proton halo (K. Riisager)	10	10	5 (*)	5	
ISC / P28		monopole trans. (P. Sona)	9	9	3 (*)	6	

* can run already earlier in 1992				
total (all physics, incl. stable beams)	389 (+2 weeks offl.)	177 (+2 weeks offl.)	191	

for comparison: total (radioactive beams) in 1990 was 366 shifts for all experiments
227 shifts for "large" experiments (IS.....)

ISOLDE startup

(1) ~ 4 weeks of tests with "stable beams" (MD w/o protons)

(2) ? weeks with protons
→ LOW INTENSITY at first (target heating with I_{Target})
→ more bursts
→ more proton per burst

PLEASE FORGIVE US:
there will be frequent changes demanded for quite some time ....

what do we want to measure first?

→ some radioactivity

→ short-lived isotopes

[illegible]

⇒ test HV, diffusion speed, etc.!

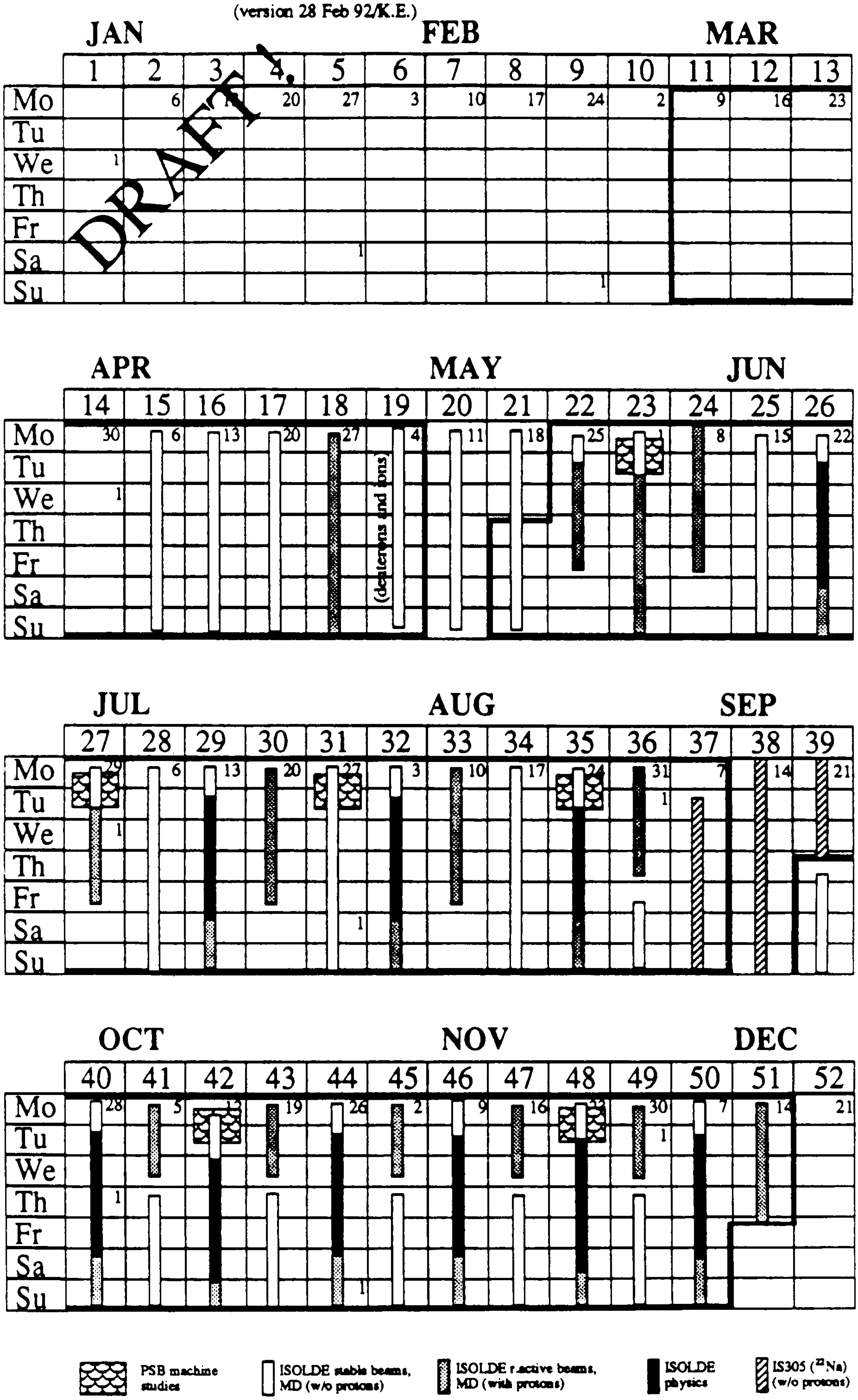
⇒ get reference data for PSB - ISOLDE production rates!

"Tape-Station"

monitor radioactivity of a given (unknown) halflife τ

1992 PSB-ISOLDE SCHEDULE

(version 28 Feb 92/K.E.)



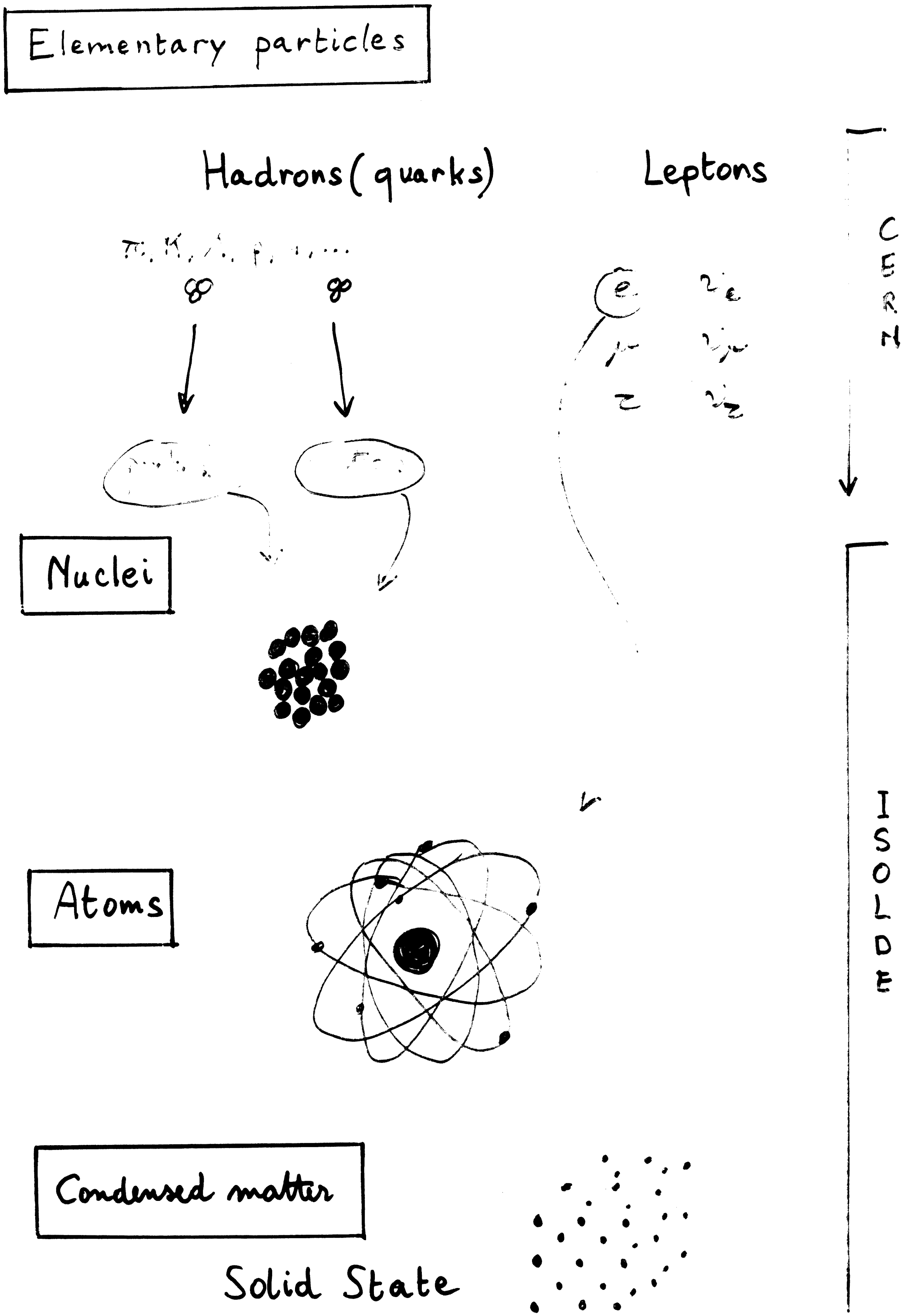
COLLINEAR

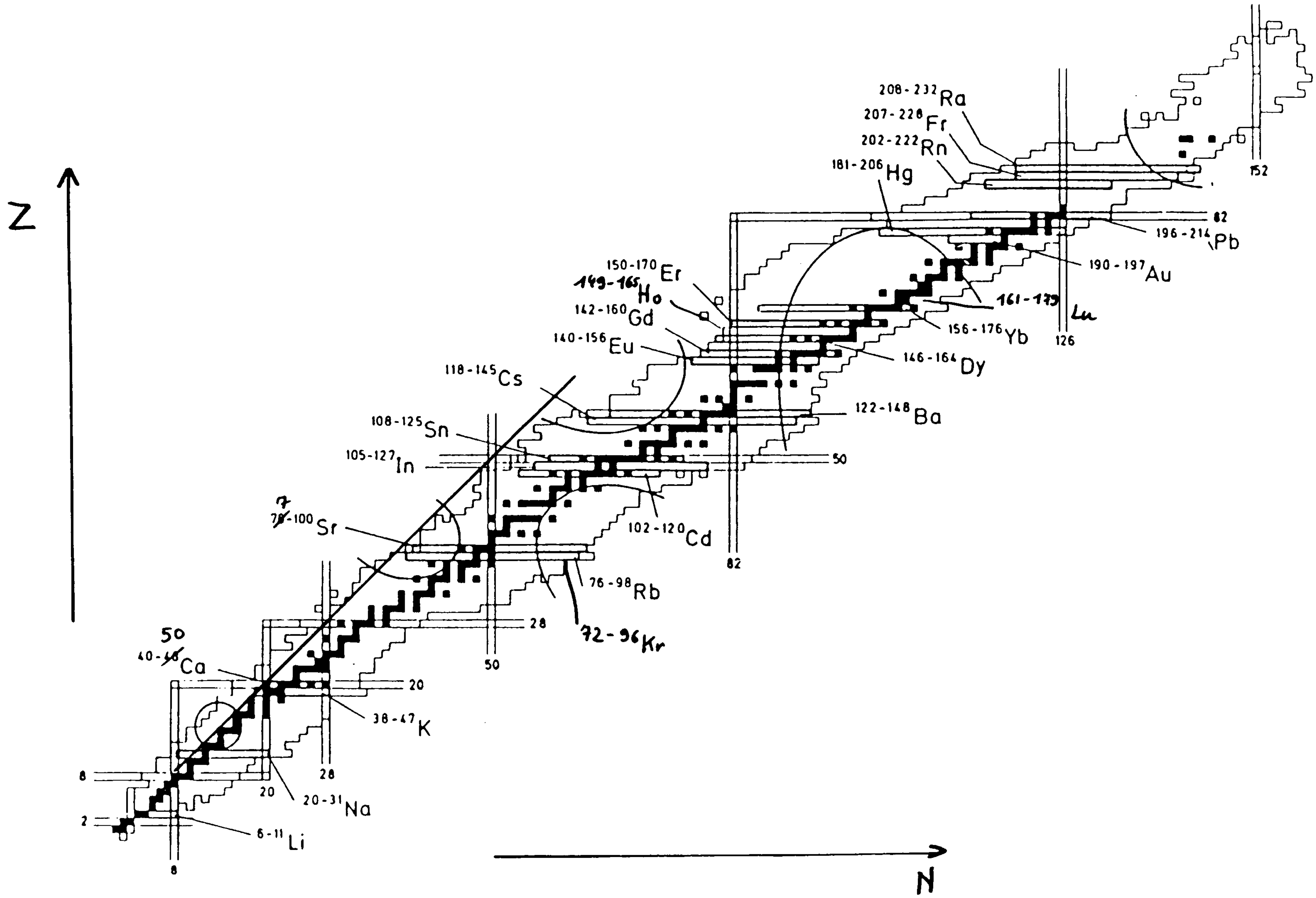
LASER SPECTROSCOPY

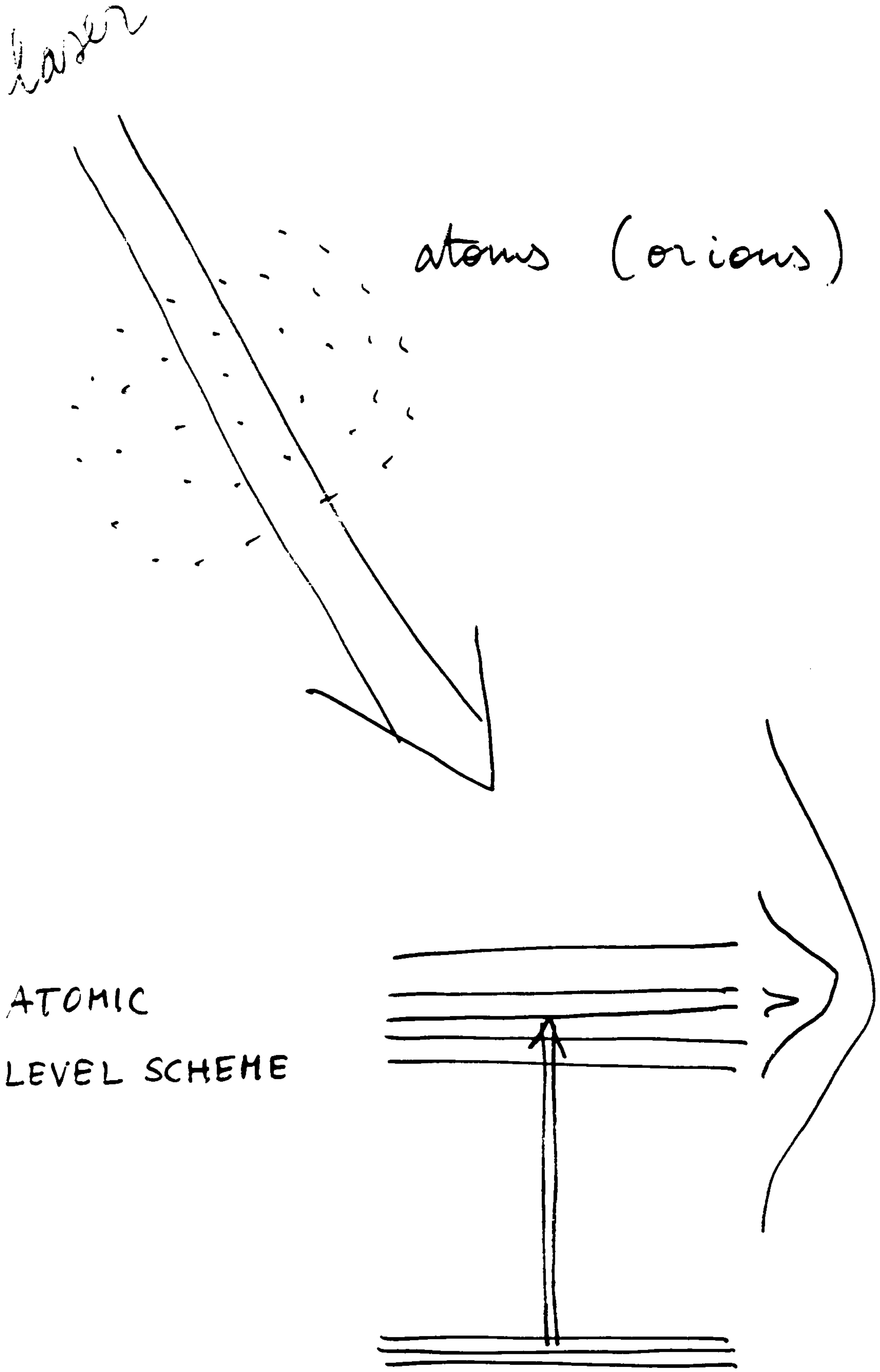
LASERSPECTROSCOPY :

Study of atomic level scheme
using laser - induced excitations

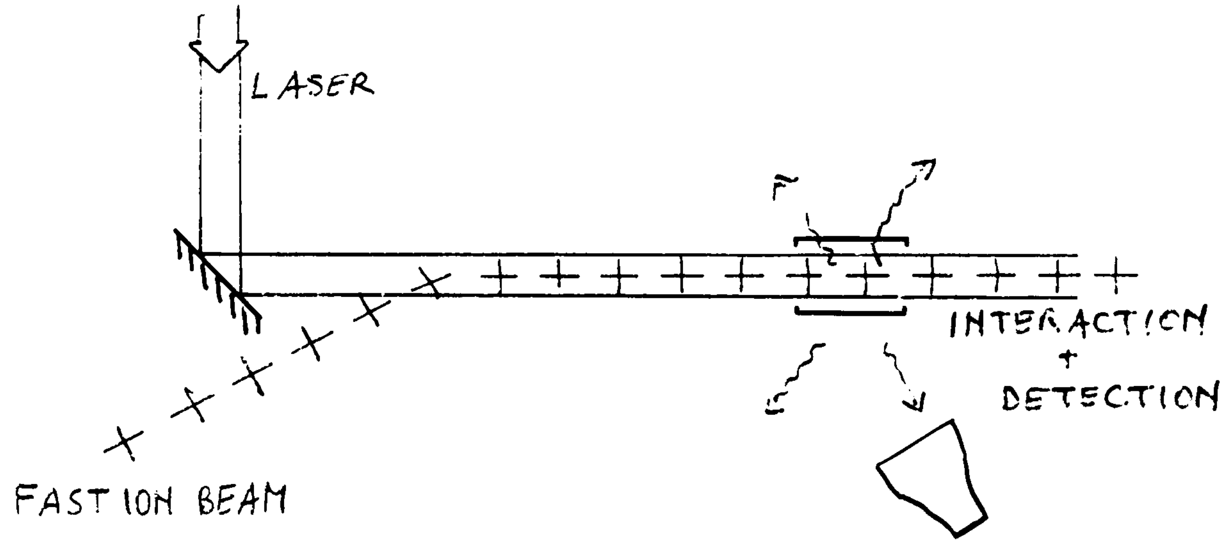
AIM: study of <u>nuclear</u> ground-state
properties

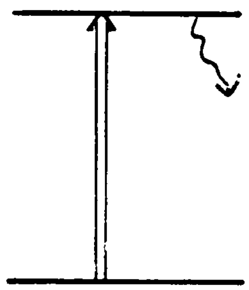

Elementary particles
Hadrons (quarks)
Leptons
e
ν_e
μ
ν_μ
τ
ν_τ
CERN
Nuclei
Atoms
ISOLDE
Condensed matter
Solid State

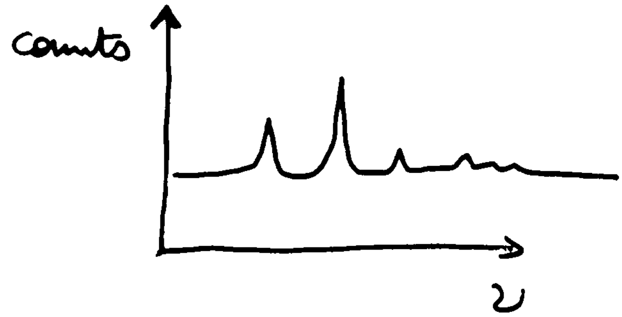

Z
N
208-232 Ra
207-228 Fr
202-222 Rn
181-206 Hg
196-214 Pb
190-197 Au
161-179 Lu
156-176 Yb
146-164 Dy
150-170 Er
149-165 Ho
142-160 Gd
140-156 Eu
118-145 Cs
122-148 Ba
108-125 Sn
105-127 In
102-120 Cd
78-100 Sr
76-98 Rb
72-96 Kr
40-50 Ca
38-47 K
20-31 Na
6-11 Li
152
126
82
50
28
20
8
2


laser
atoms (or ions)
ATOMIC
LEVEL SCHEME

FAST (ION) BEAM COLLINEAR LASERSPECTROSCOPY







* ISOTOPE SHIFT

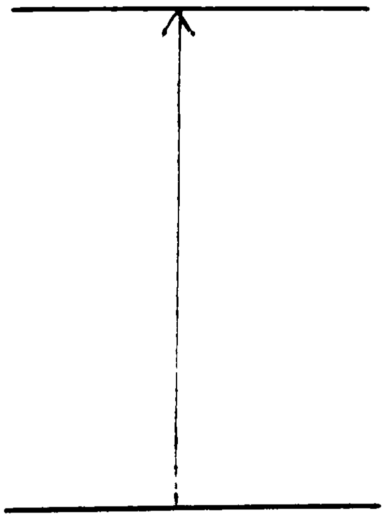
→ DIFFERENT CHARGE DISTRIBUTION

* HYPERFINE SPLITTING

→ INTERACTION BETWEEN NUCLEUS AND SURROUNDING ELECTRONS

RADIUS, SPIN, MOMENTS

DETECTION OF RESONANCE



PRECISION: $\pm 1\,\mathrm{MHz}$

$\nu_0 \simeq 5 \times 10^{14}\,\mathrm{Hz}$

$$\Rightarrow \boxed{\frac{\delta\nu}{\nu} = 2 \times 10^{-9}}$$

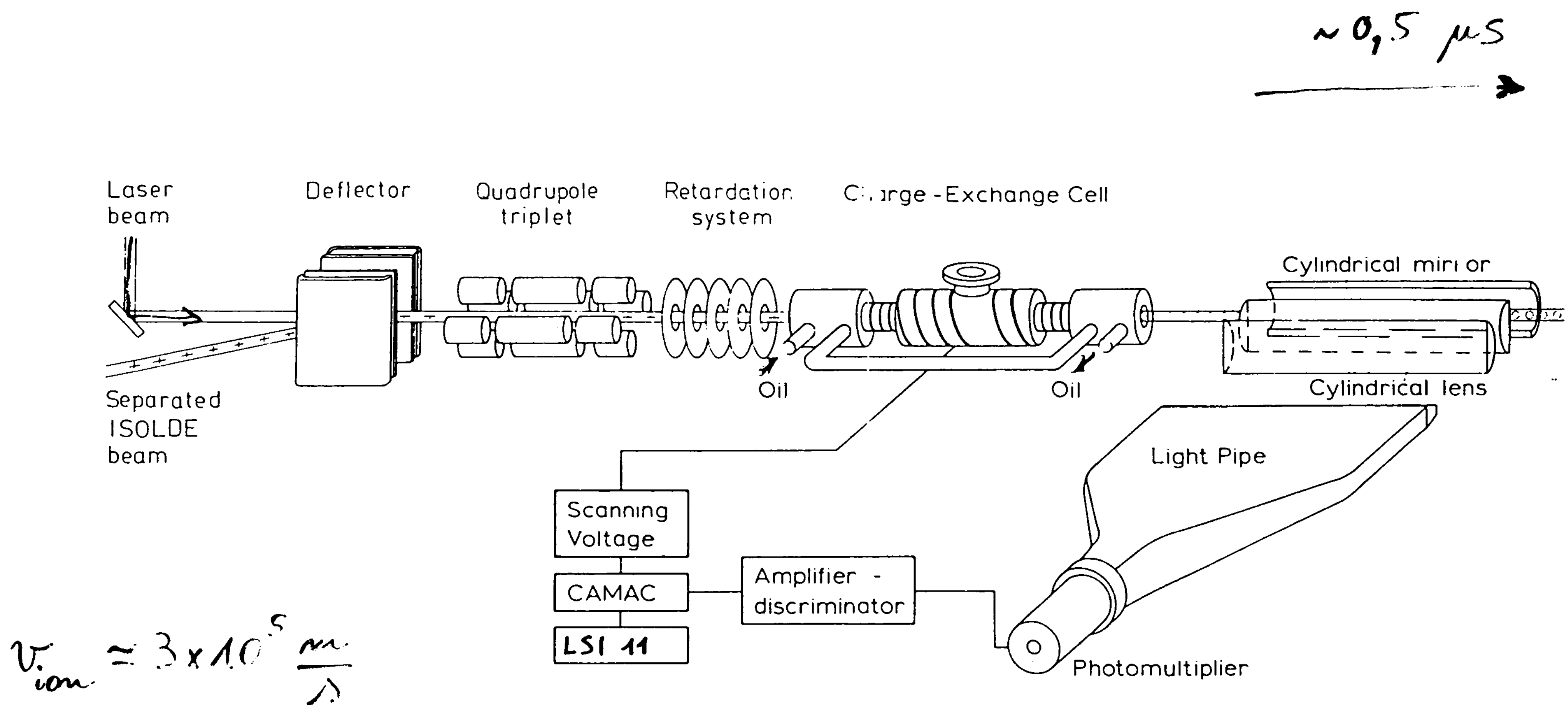
- CHANGE LASER FREQUENCY
- CHANGE ION (ATOM) VELOCITY

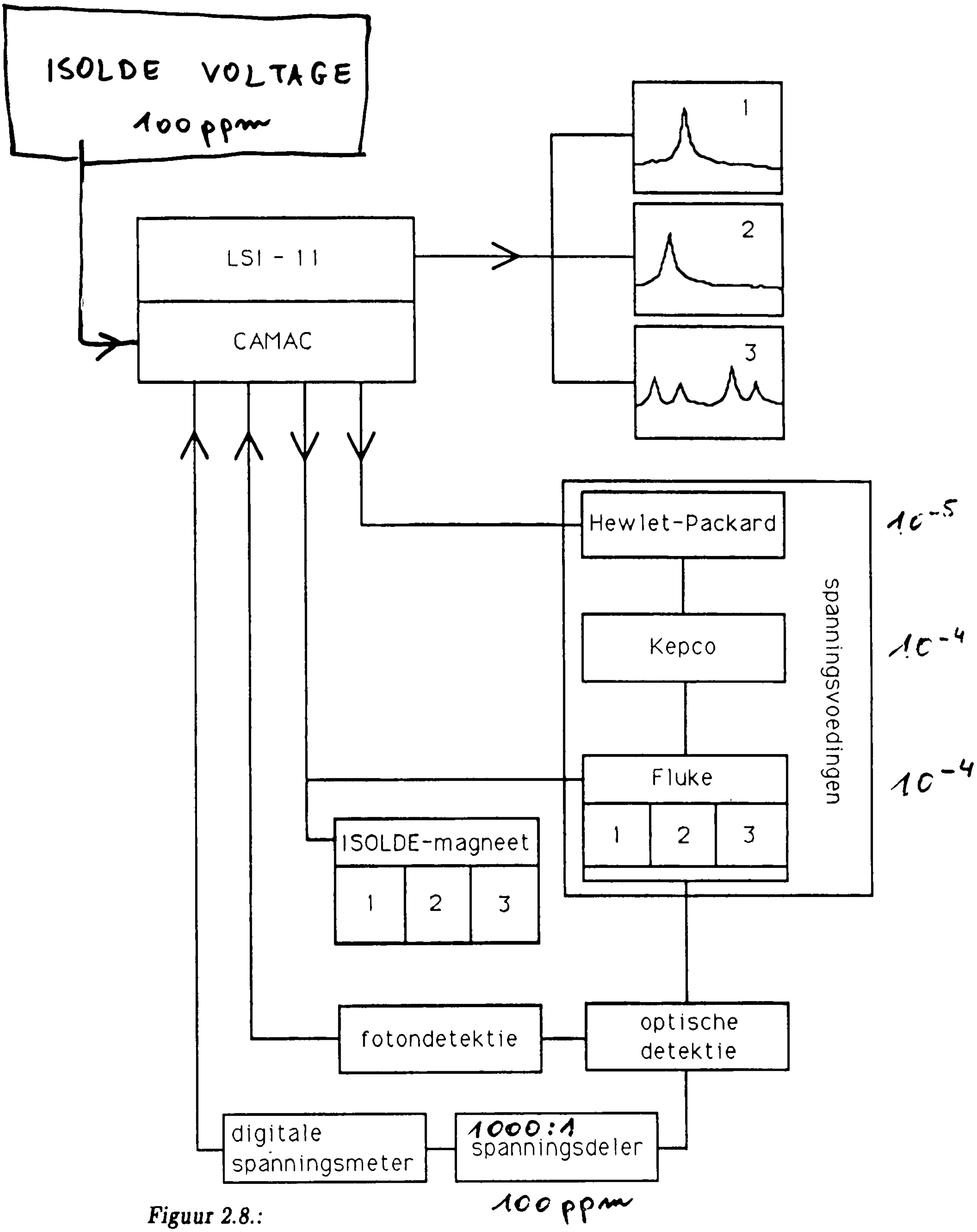
→ DOPPLER EFFECT

$U = 60\,\mathrm{kV}$ $\qquad \beta = \frac{v}{c} = \sqrt{\frac{2e\boxed{U}}{mc^2}}$

Dopplershift: $\Delta\nu_D = -\nu_0\left(\beta - \frac{1}{2}\beta^2\right)$

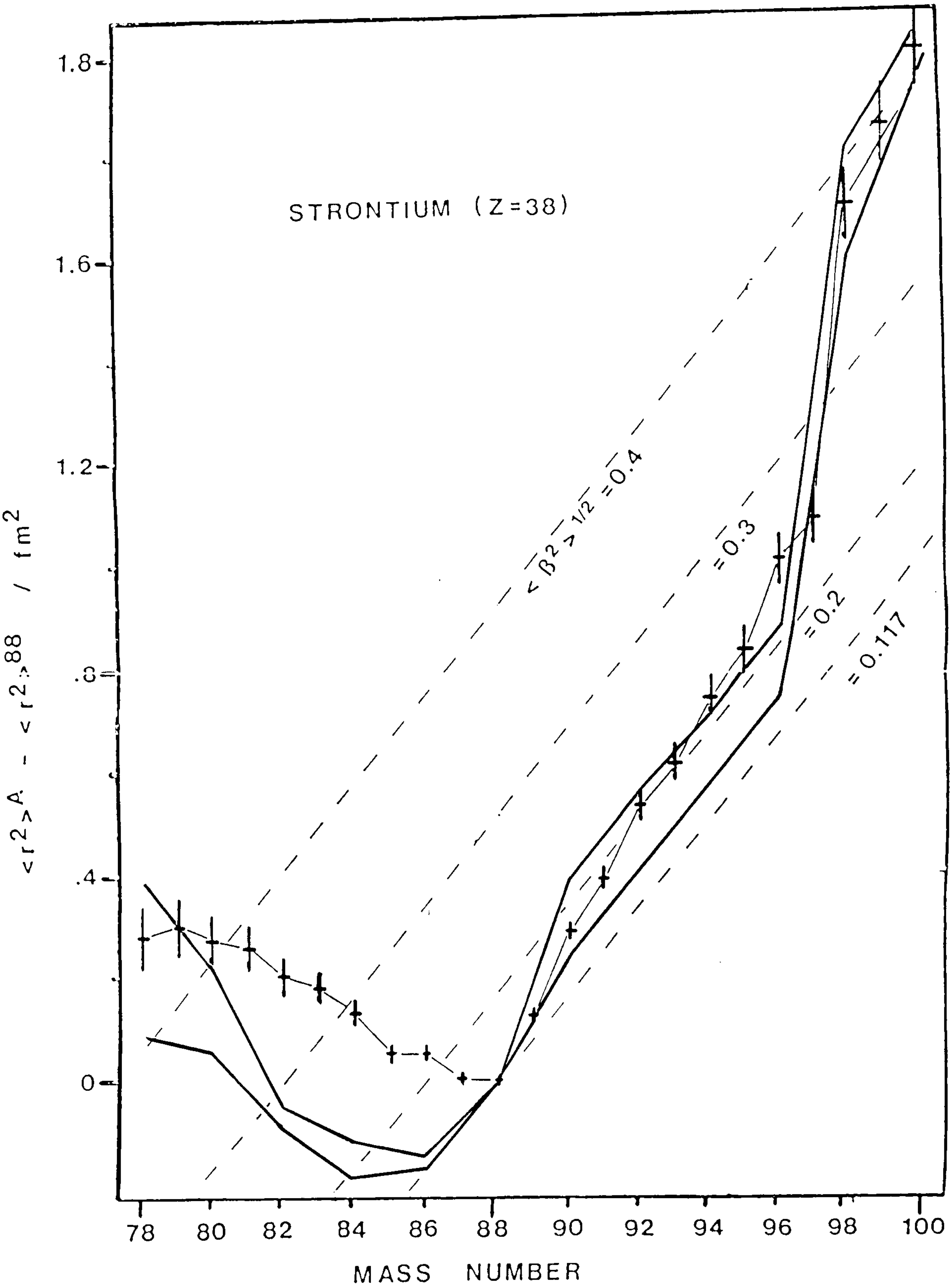
$$\left[\begin{array}{l} \nu_0 \simeq 5 \times 10^{14}\,\mathrm{Hz} \\ \Delta\nu_D \simeq 500\,\mathrm{GHz} \end{array}\right.$$


~0,5 μs
Laser beam
Deflector
Quadrupole triplet
Retardation system
Charge-Exchange Cell
Cylindrical mirror
Cylindrical lens
Oil
Oil
Separated ISOLDE beam
Light Pipe
Scanning Voltage
CAMAC
LSI 11
Amplifier - discriminator
Photomultiplier
$v_{ion} \simeq 3 \times 10^5 \frac{m}{s}$



Figuur 2.8.:

Blokdiagram voor experimenten met optische resonantiedetektie.

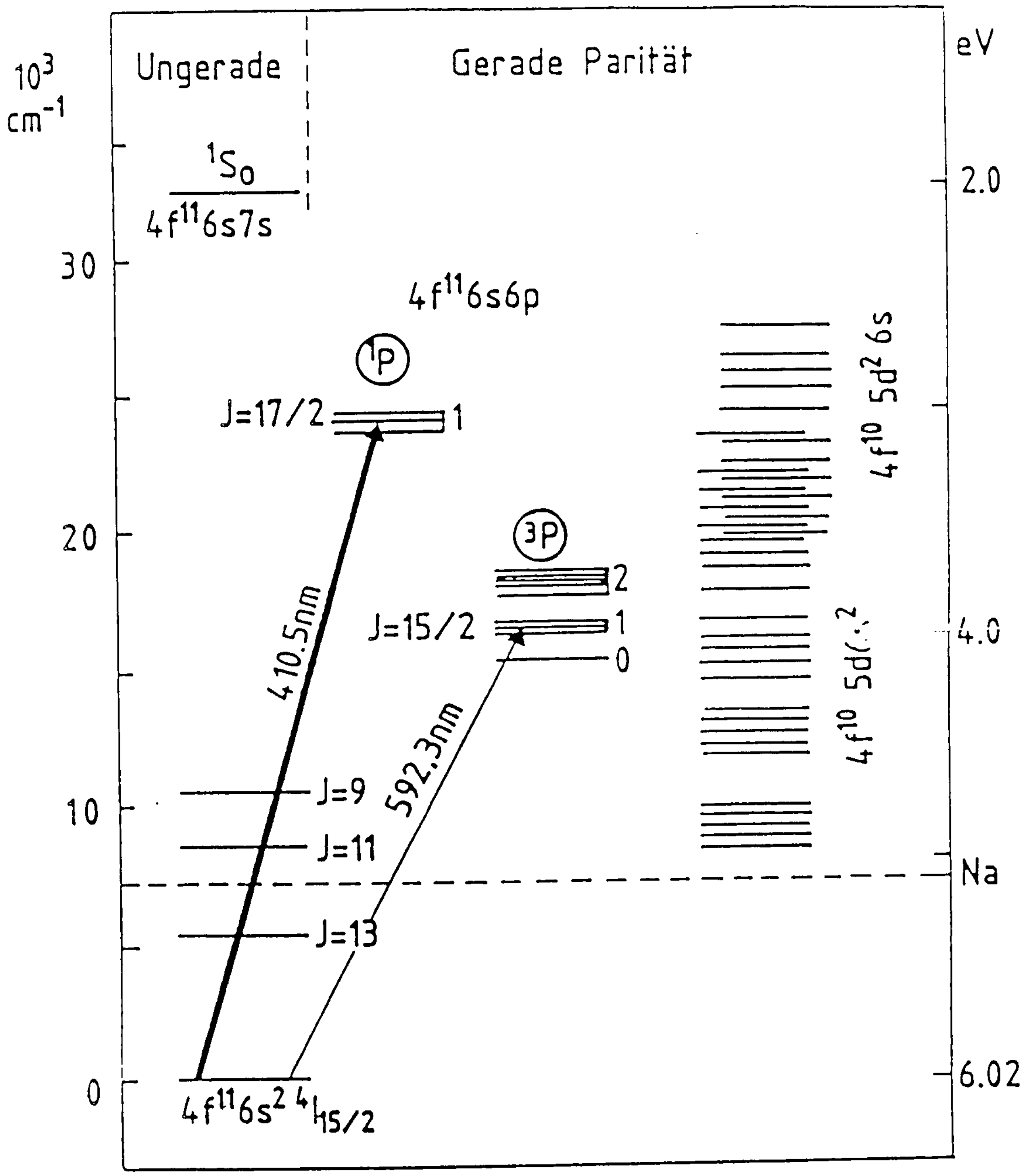


χ DROPLET ISODEFORMATION CURVES

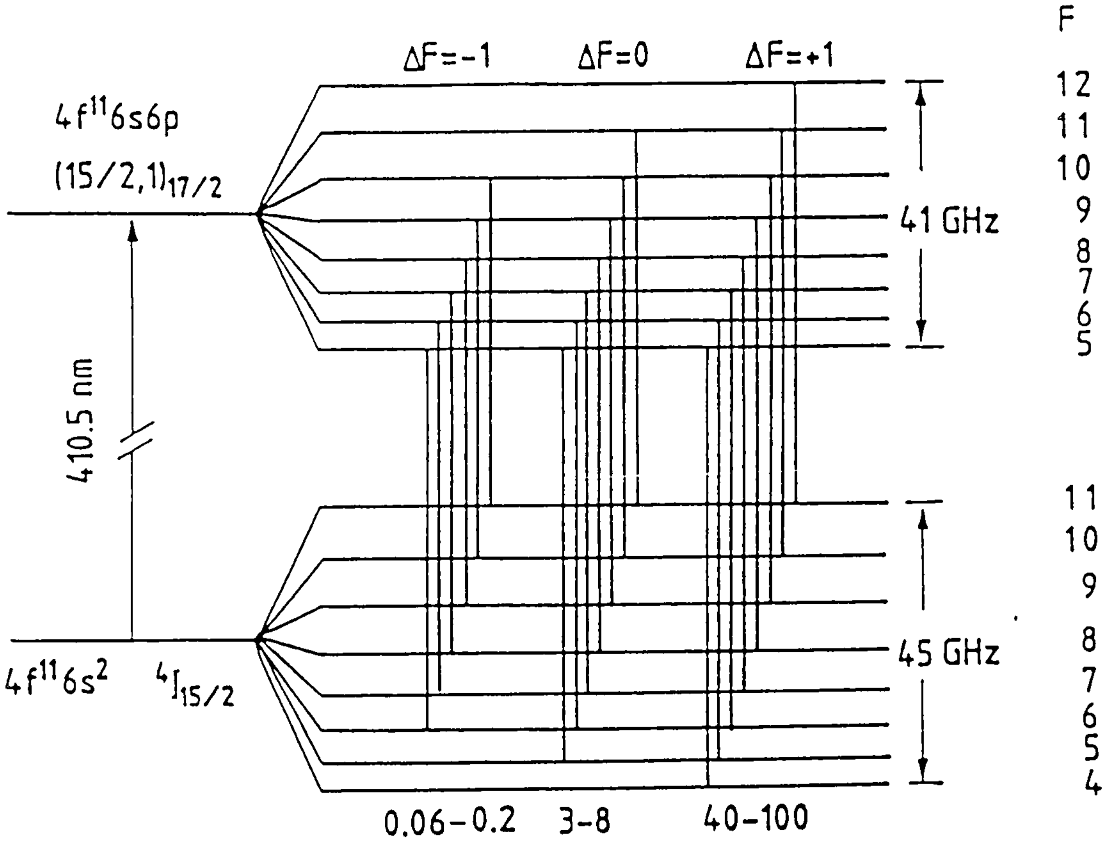
χ EXPERIMENTAL VALUES; (The error bars indicate the systematic errors from the specific mass shift and the calibration factor F)

χ DROPLET MODEL + DEFORMATION PARAMETERS FROM BE2 VALUES

Ho I (atoms)

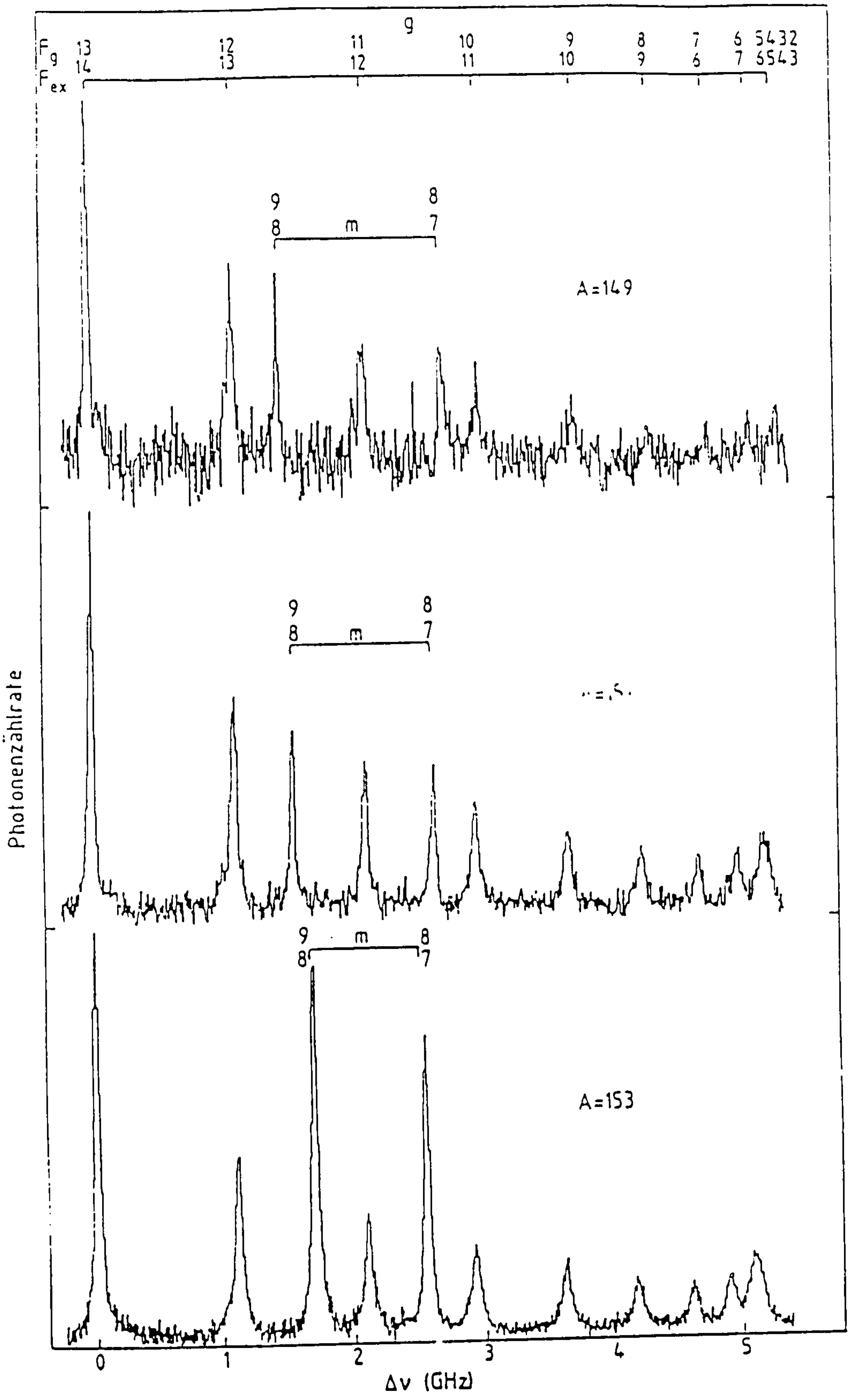


10^3 cm^{-1}
Ungerade
Gerade Parität
eV
$^1S_0$
$4f^{11}6s7s$
2.0
30
$4f^{11}6s6p$
^1P
J=17/2
1
$4f^{10}\ 5d^2\ 6s$
20
^3P
2
J=15/2
1
0
4.0
410.5nm
592.3nm
J=9
10
J=11
Na
J=13
0
$4f^{11}6s^2\ ^4I_{15/2}$
6.02


F
ΔF=-1
ΔF=0
ΔF=+1
12
11
10
9
8
7
6
5
4f¹¹6s6p
(15/2,1)17/2
41 GHz
410.5 nm
11
10
9
8
7
6
5
4
45 GHz
4f¹¹6s²
⁴I15/2
0.06–0.2
3–8
40–100

$I = 7/2$ (^{165}Ho)

149, 151, 153 Ho (I = 11/2, J = 1/2)



^{11}Li

- VERY SENSITIVE TECHNIQUE
- PHYSICS
  - spherical shell model
  - neutron halo

METHOD: (β-RADOP)

β-Radiation Detected Optical Pumping

= KOMBINATION OF

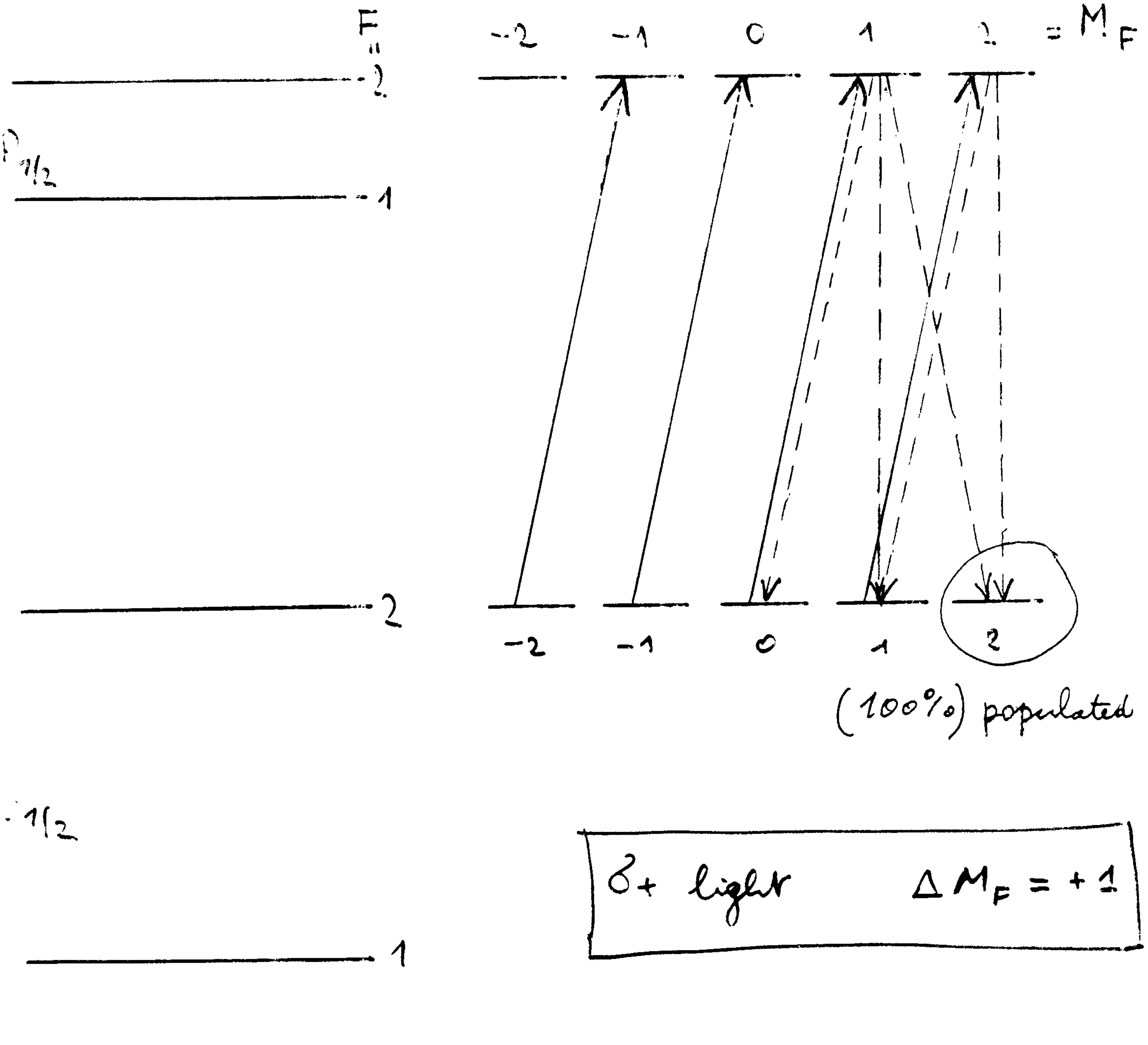
LASER - TECHNIQUES

&

NUCLEAR ORIENTATION

OPTICAL PUMPING WITH CIRCULARLY POLARIZED LASER LIGHT

→ NUCLEAR POLARIZATION



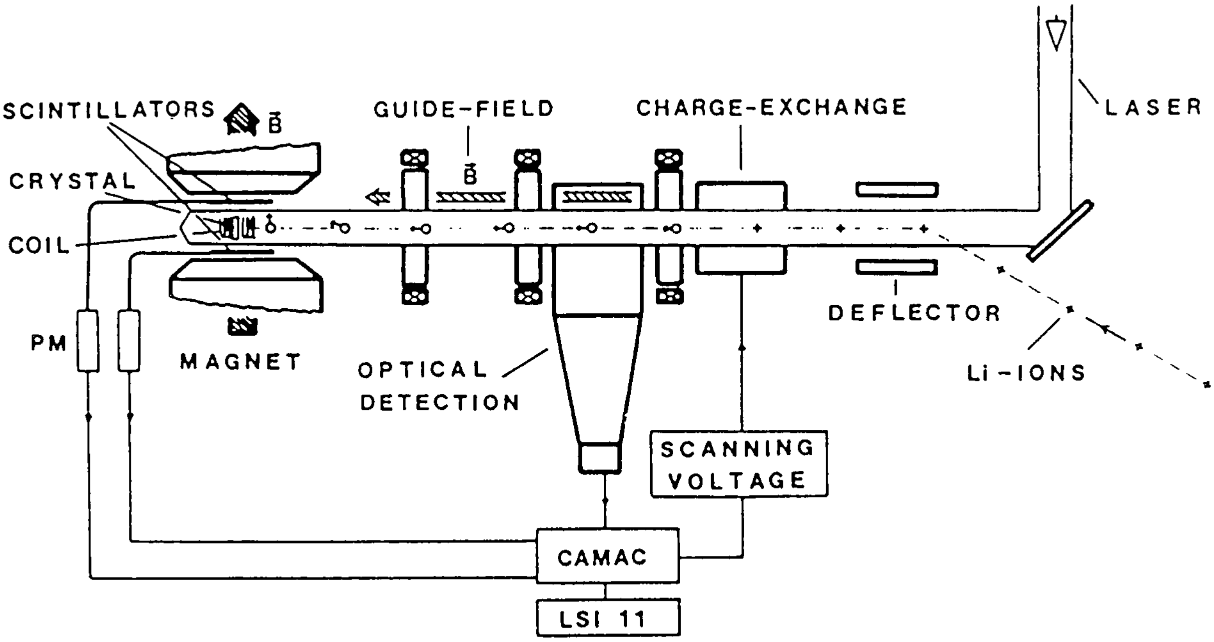
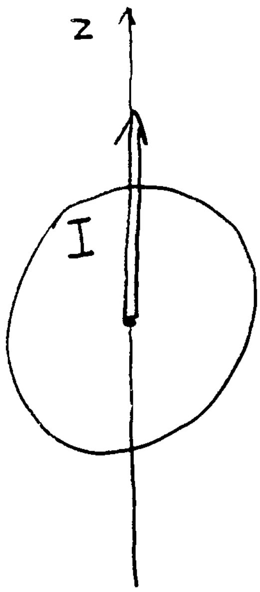


Fig. 1. Schematic view of the experimental setup. The arrows indicate the nuclear spin direction.

HYPERFINE INTERACTION

↓

NUCLEAR SPIN IS POLARIZED



$$W(\theta) = 1 + \frac{v}{c} A P \cos\theta$$

P: polarization

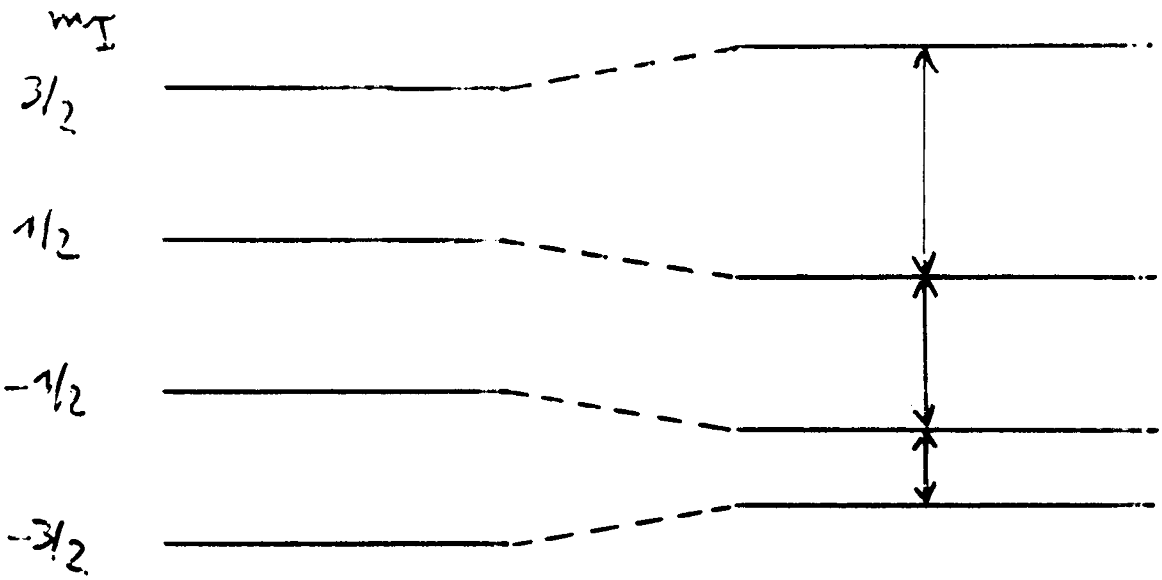
A: asymetry parameter

→ asymetric emission of β-radiation

This is detected

NMR in $LiNbO_3$

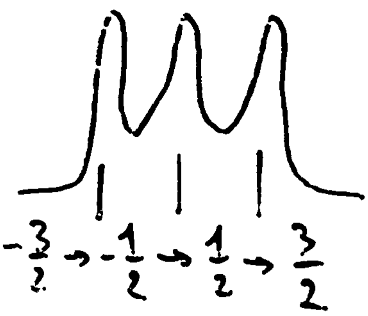
$I = 3/2 \rightarrow M_I = 3/2, \; 1/2, \; -1/2, \; -3/2$



in magnetic field H_0 | in electric field gradient

$-m_I \, g \, \mu_N H_0$ | $\dfrac{e^2 q Q}{8I(2I-1)} \left(3 m_I^2 - I(I+1)\right)$

RF - interaction



At RF-resonance :

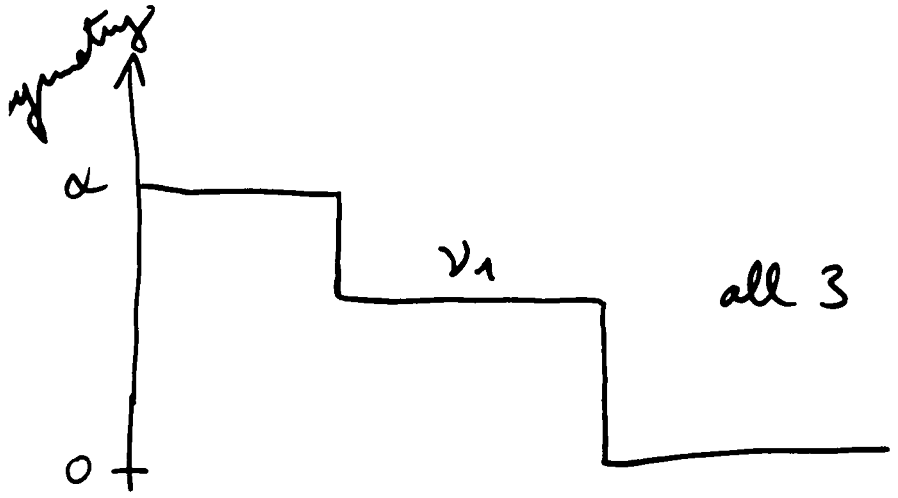
initial polarization is distroyed
→ no β-asymmetry visible

3 resonances

Complication :

- 1 frequency fixed at magnetic resonance fequency (ν_1)
- 2 others scanning up and down starting from ν_1

→ at the same time in resonance all 3 transitions



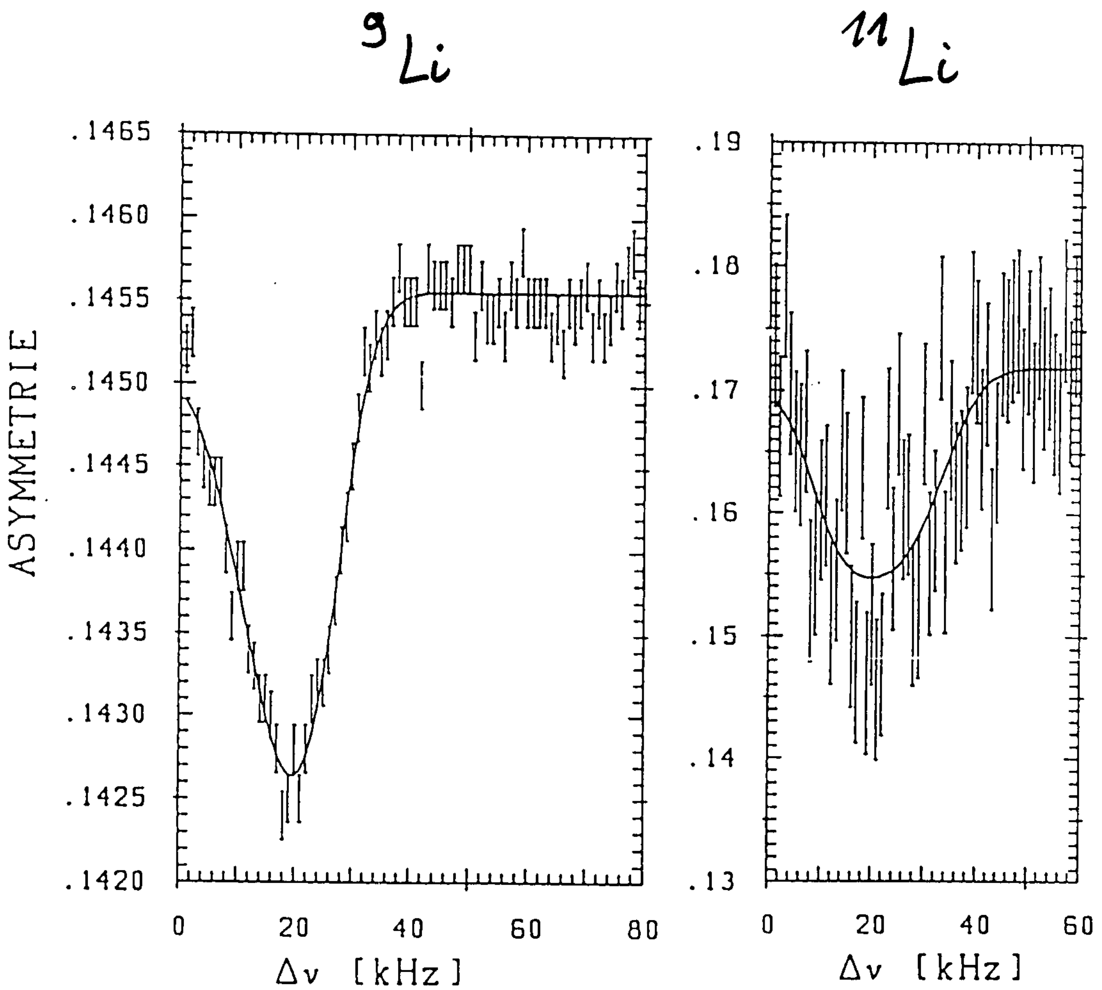


Figure. Quadrupole splitting of NMR signals of ^{9}Li and ^{11}Li in $LiNbO_3$, measured by simultaneous irradiation of three equidistant frequencies.