In-Ring Decay Experiments and Plans for TSR & FAIR

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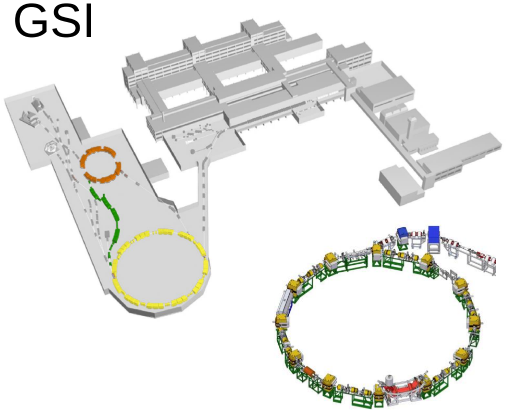
HELMHOLTZ GEMEINSCHAFT

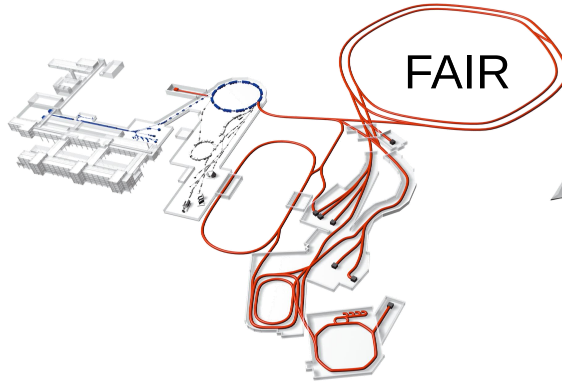
TSR@ISOLDE Workshop
CERN, Geneva, Switzerland, 14 February 2014

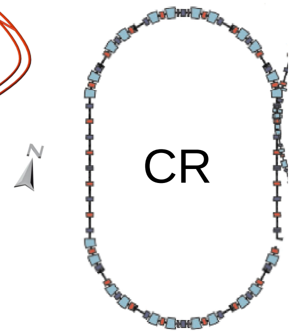
Physics at Storage Rings

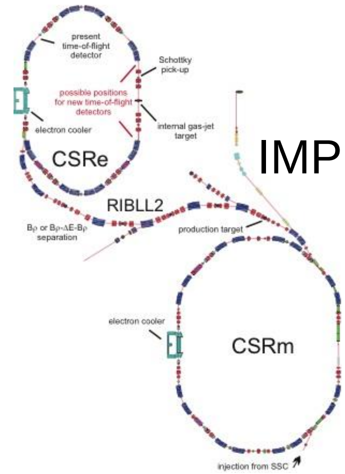
GSI

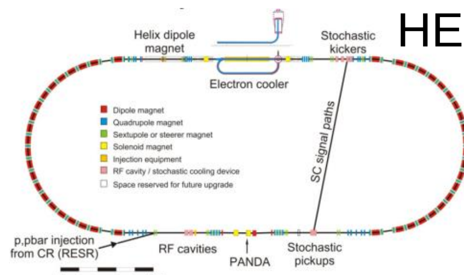


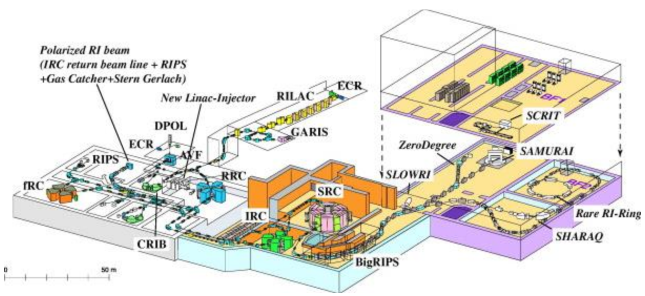
CRYRING





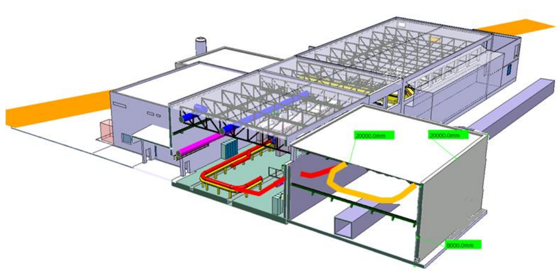


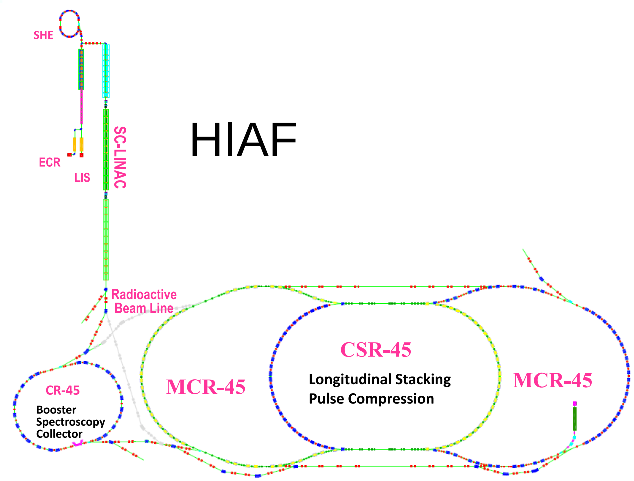




RI-RING

TSR@ISOLDE





High-energy and low-energy storage rings

Storage Rings for Physics with Exotic Nuclei

Easy access to highest charge states

High-energy

- ESR @ GSI
- CSRe @ IMP

- RI-RING @ RIKEN
- CR @ FAIR
- HESR @ FAIR

- NESR @ FAIR
- RESR @ FAIR
- HIAF

Low-energy

- TSR @ ISOLDE
- CRYRING @ ESR

Highly-charged ions at low-energies

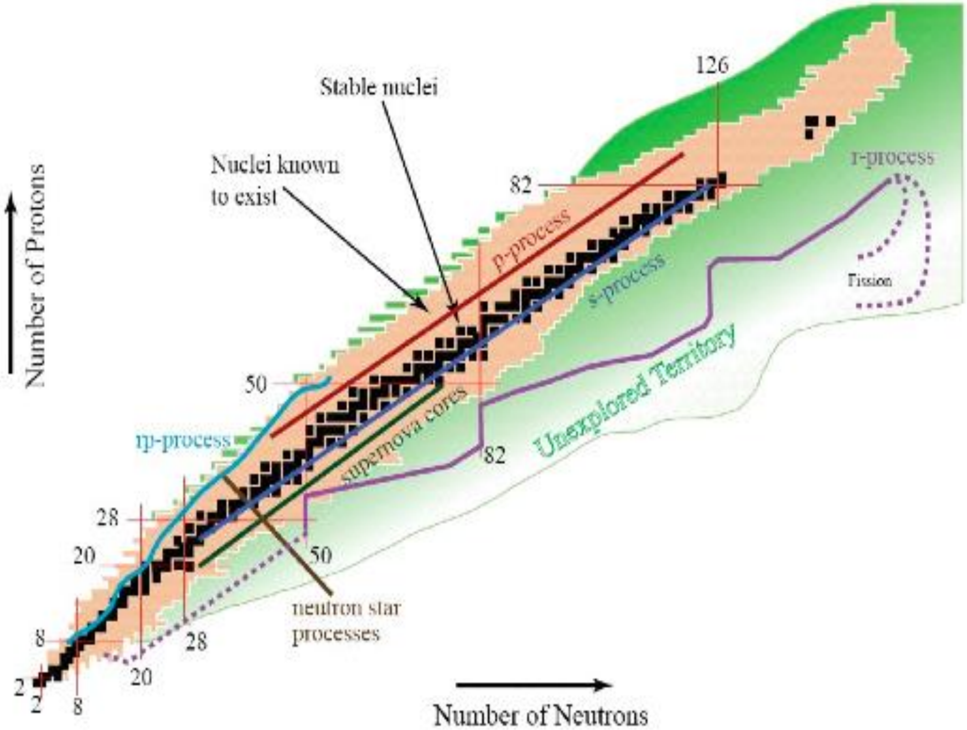
Radioactive Decay of Highly-Charged Ions

Few-electron ions
well-defined quantum-mechanical systems

New decay modes
(bound-pair-creation, bound-state beta decay, etc.)

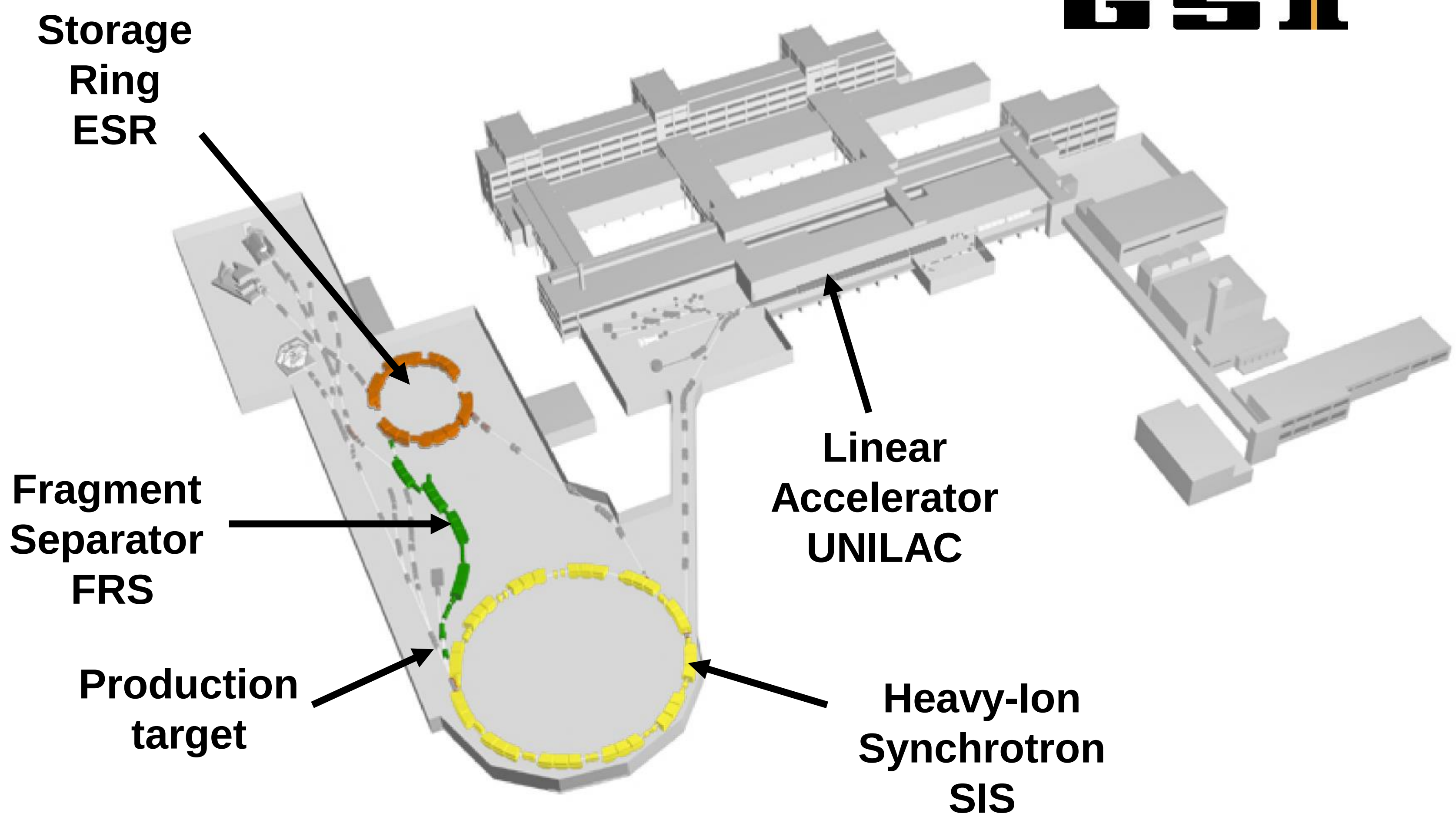
Influence of electrons on radioactive decay

Astrophysical scenarios:
high temperature = high degree of ionization



Yu.A. Litvinov & F. Bosch, Rep. Prog. Phys. 74 (2011) 016301

Secondary Beams of Short-Lived Nuclei



Experimental Storage Ring ESR

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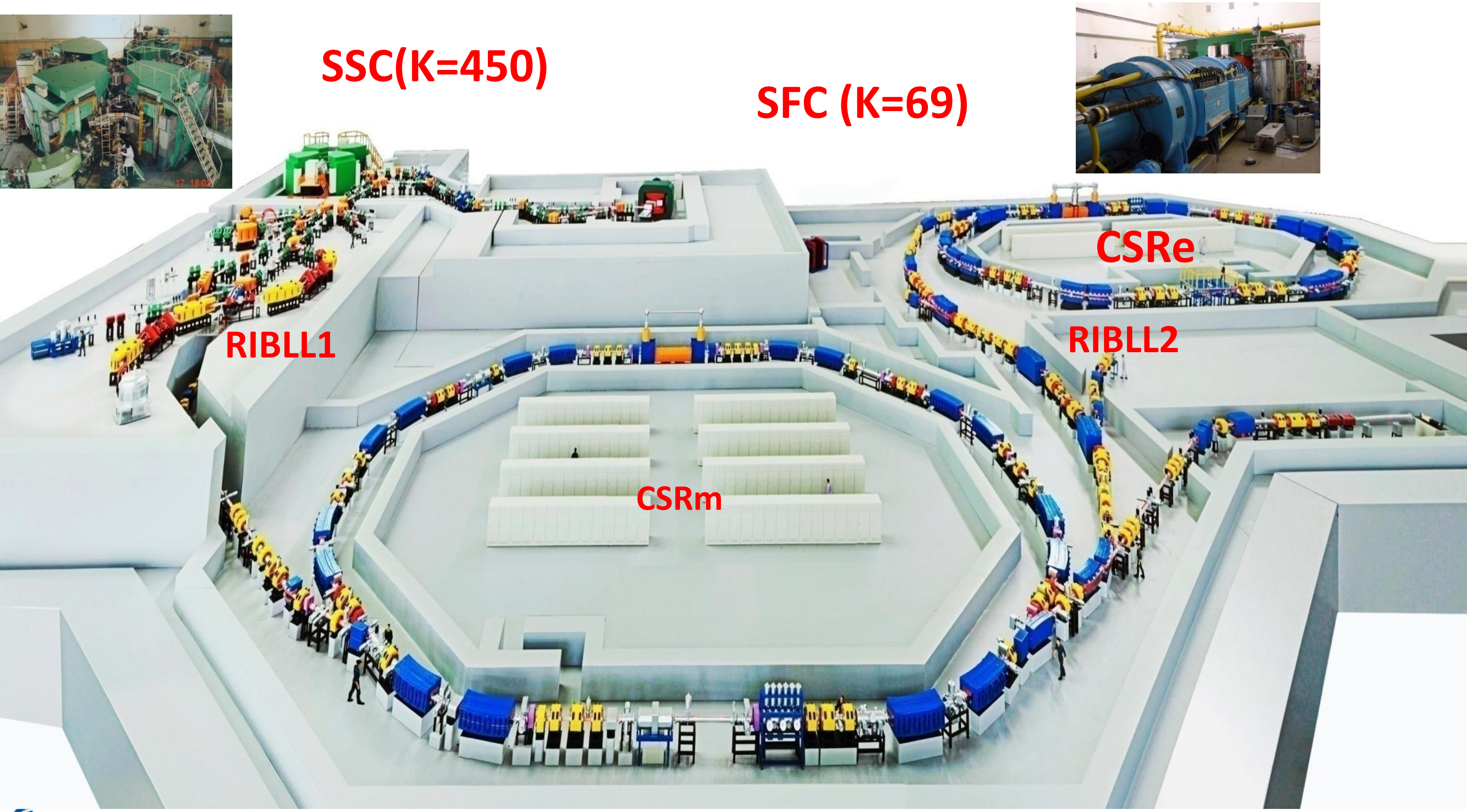
B. Franzke, NIM B 24/25 (1987) 18

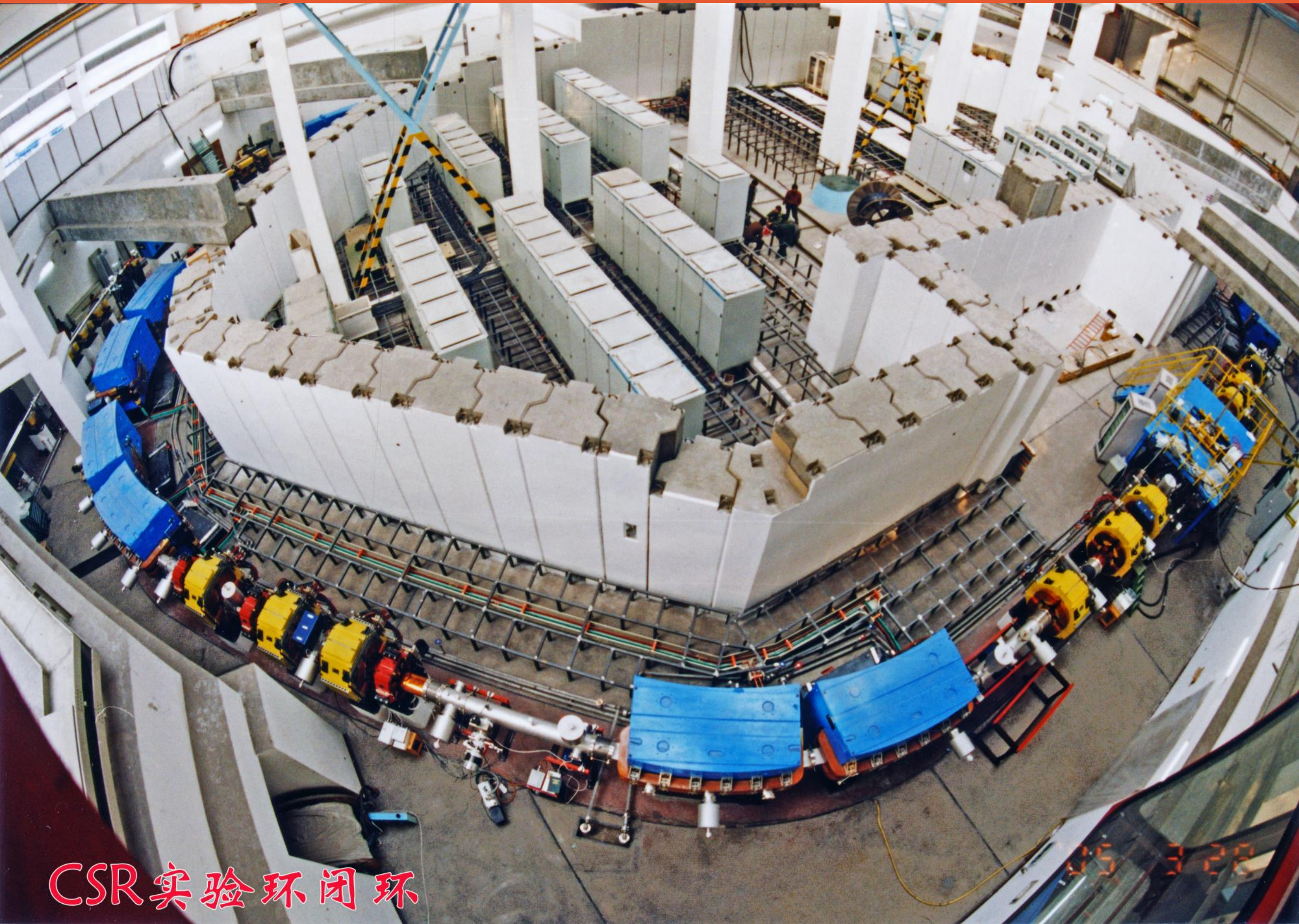
F. Nolden et al., NIM B 532 (2004) 329
M. Steck et al., NIM B 532 (2004) 357

GSI

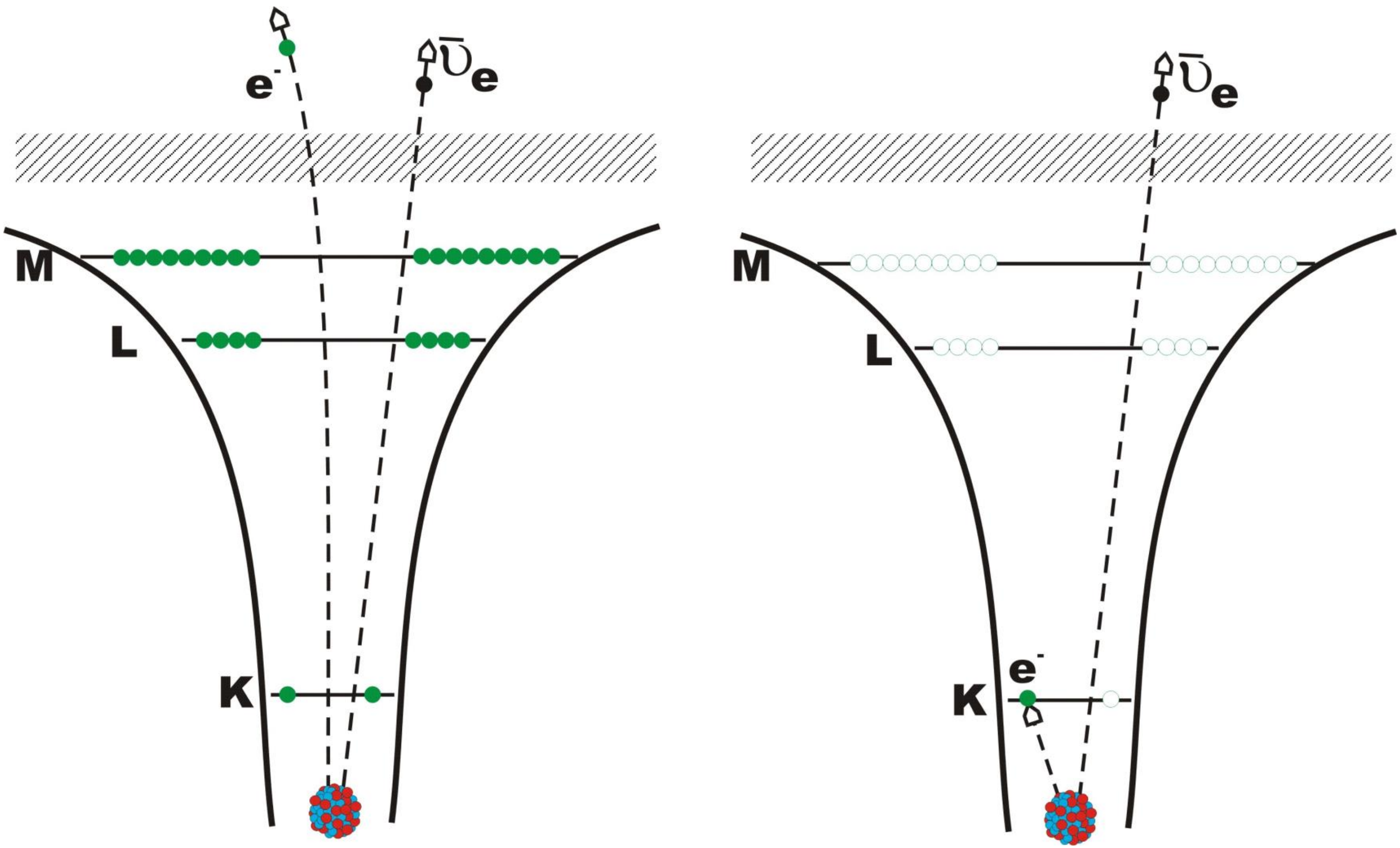
Heavy Ion Research Facility in Lanzhou (HIRFL)



Experimental Cooler Storage Ring CSRe

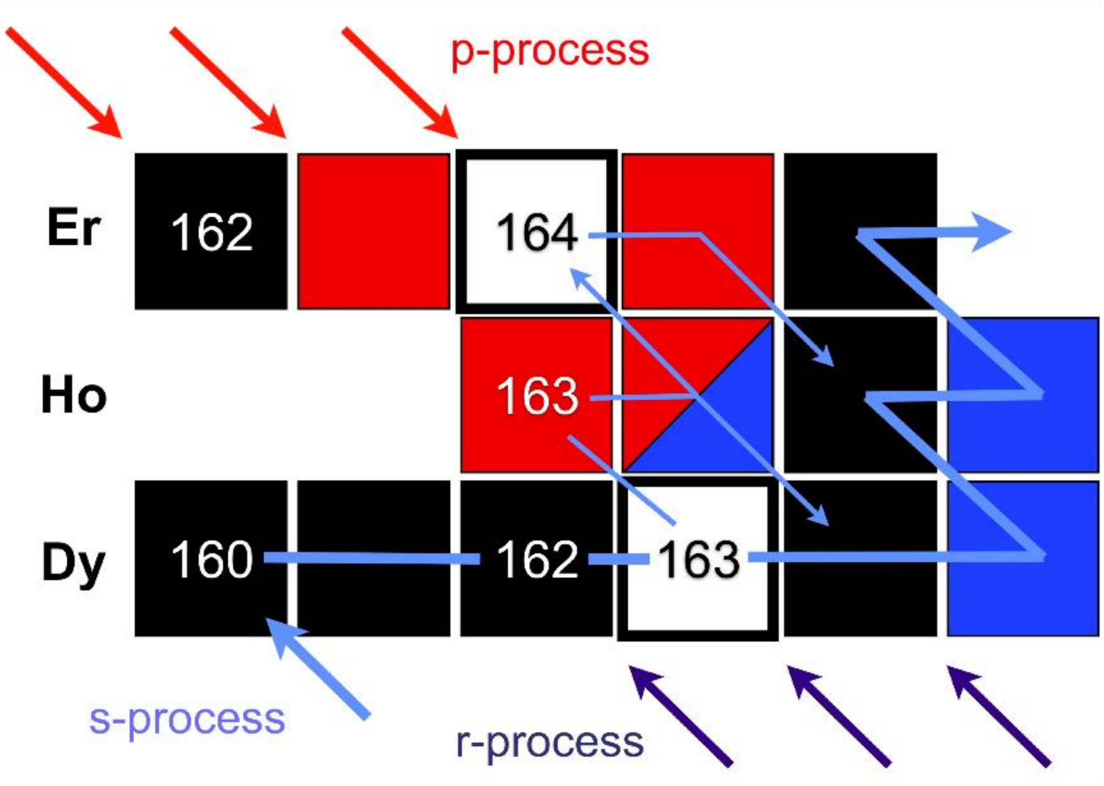


Bound-State β-decay



Bound-State ®-decay of ^{163}Dy

s process: slow neutron capture and β- decay near valley of β stability at kT = 30 keV; → high atomic charge state → bound-state β decay

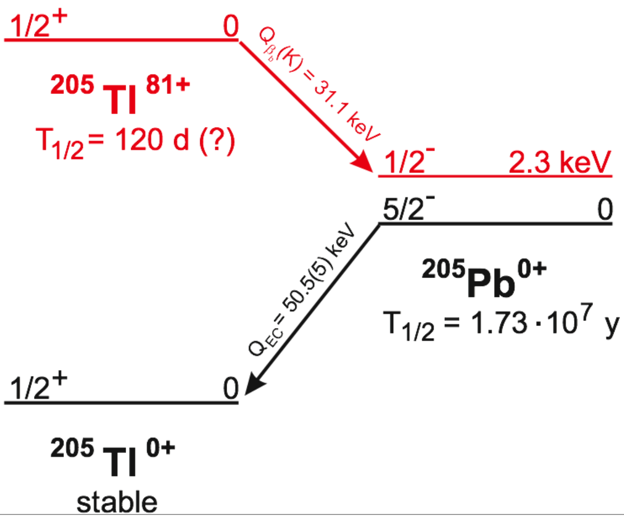


$T_{1/2}$ = 48 days

branchings caused by bound-state β decay

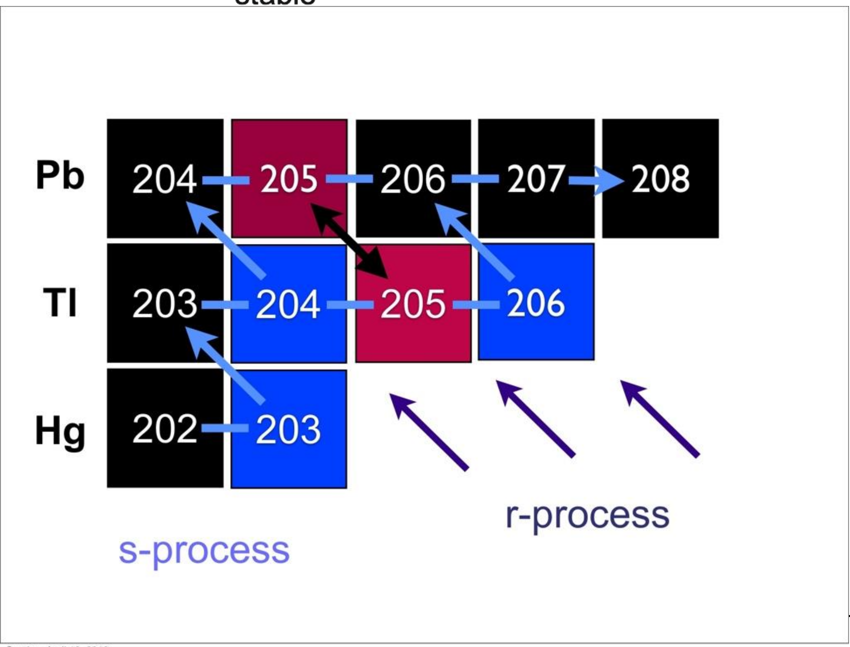
M. Jung et al., Phys. Rev. Lett. 69 (1992) 2164

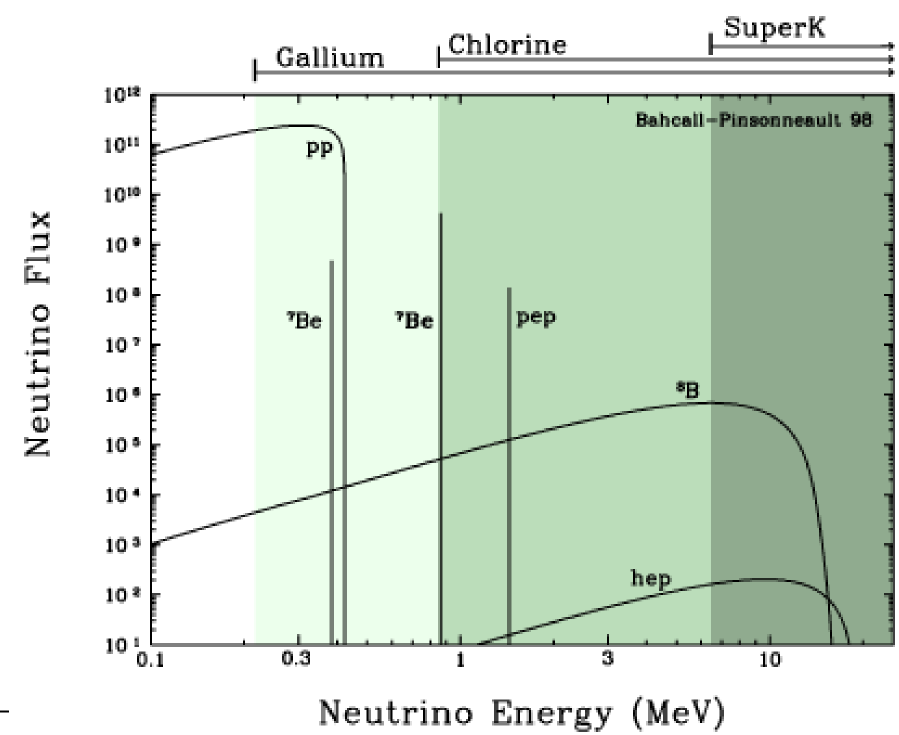
Bound-State Beta Decay of ^{205}Tl Nuclei



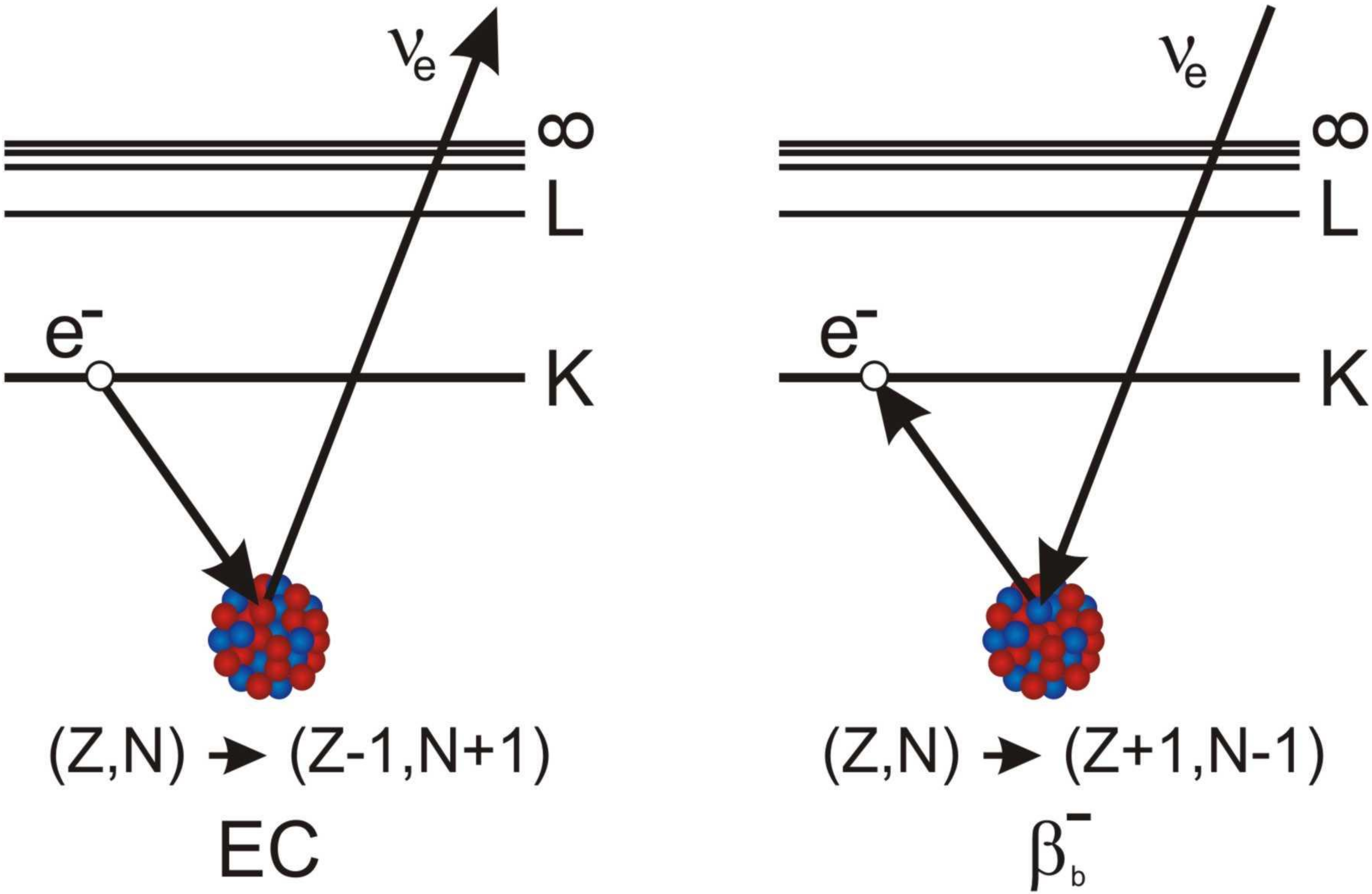
New ESR proposal to study $^{205}Tl^{81+}$

F. Bosch, Yu.A. Litvinov et al., GSI Proposal E100 (2010)

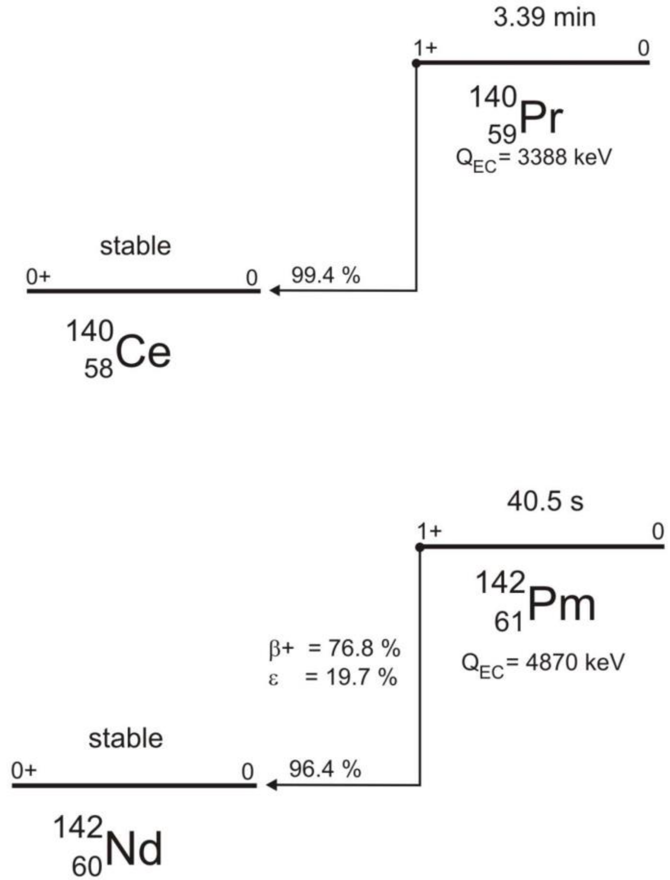


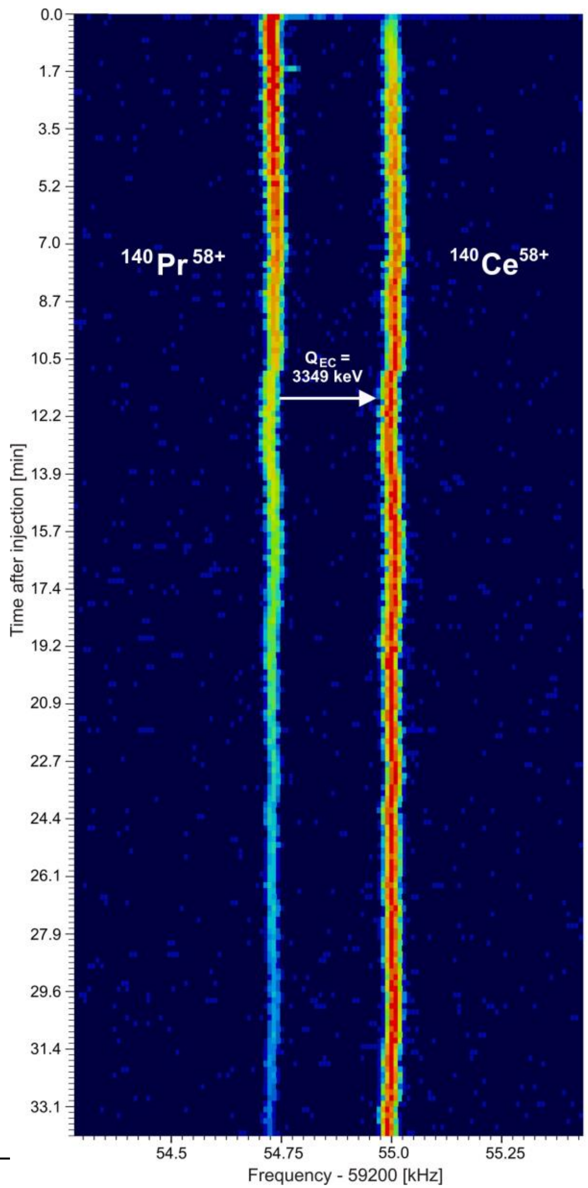


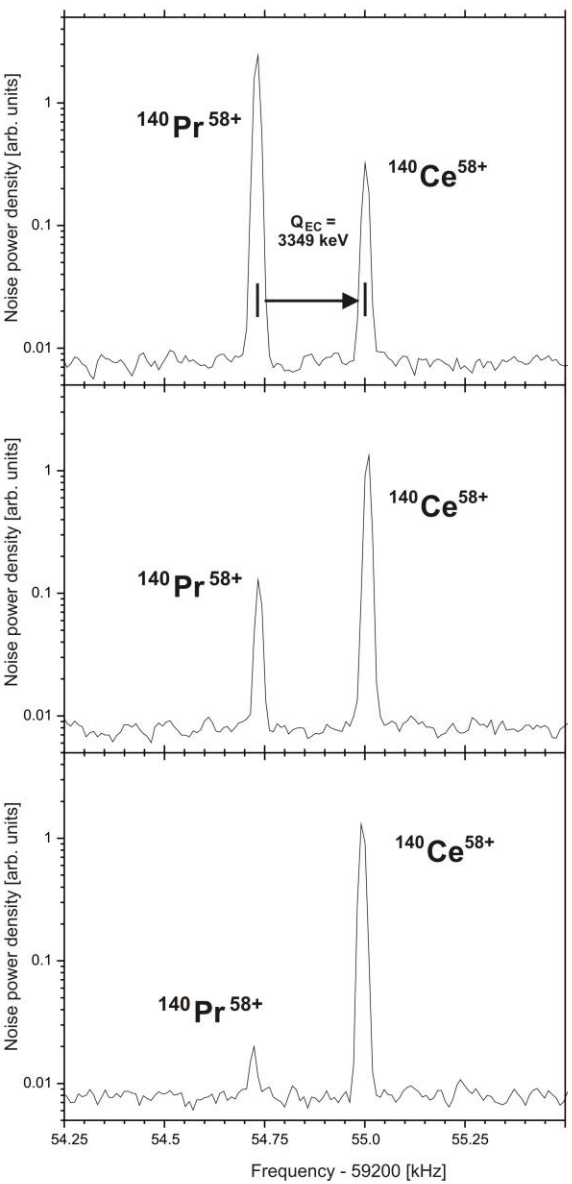
Two-Body Beta Decay



Orbital Electron Capture Decay of Few-Electron Ions



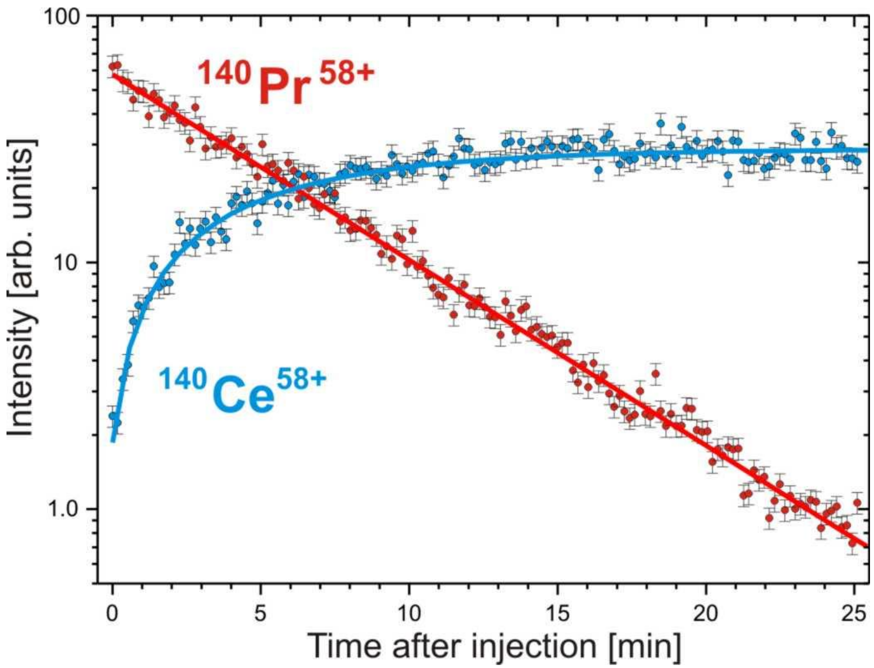




Orbital Electron Capture Decay of Few-Electron Ions

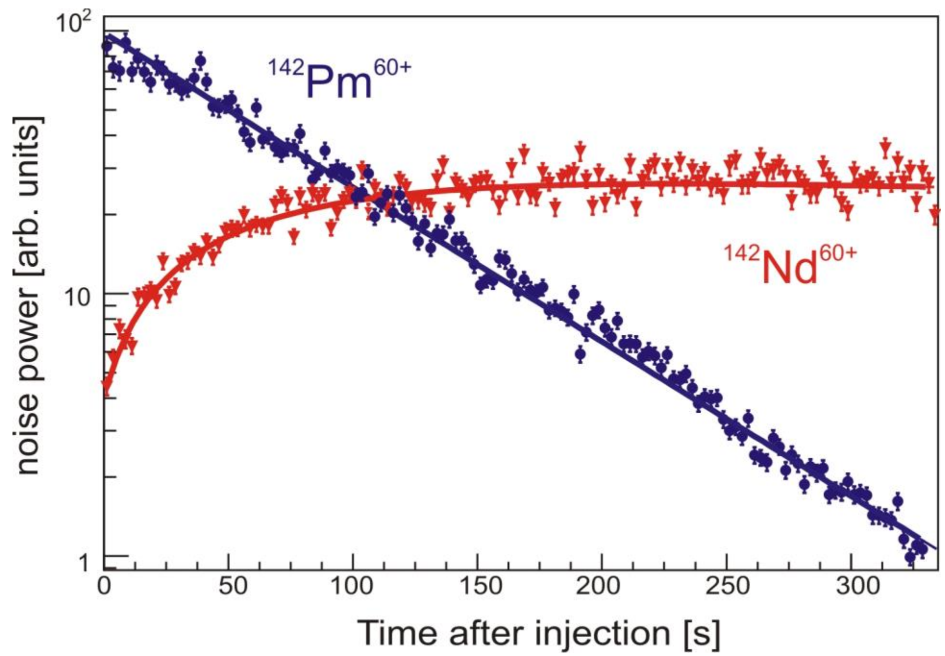
Expectations: ⎿ $_{EC}$(H-like)/⎿ $_{EC}$(He-like) ≈ 0.5

⎿ $_{EC}$(H-like)/⎿ $_{EC}$(He-like) = 1.49(8)



Yu.A. Litvinov et al., Phys. Rev. Lett. 99 (2007) 262501

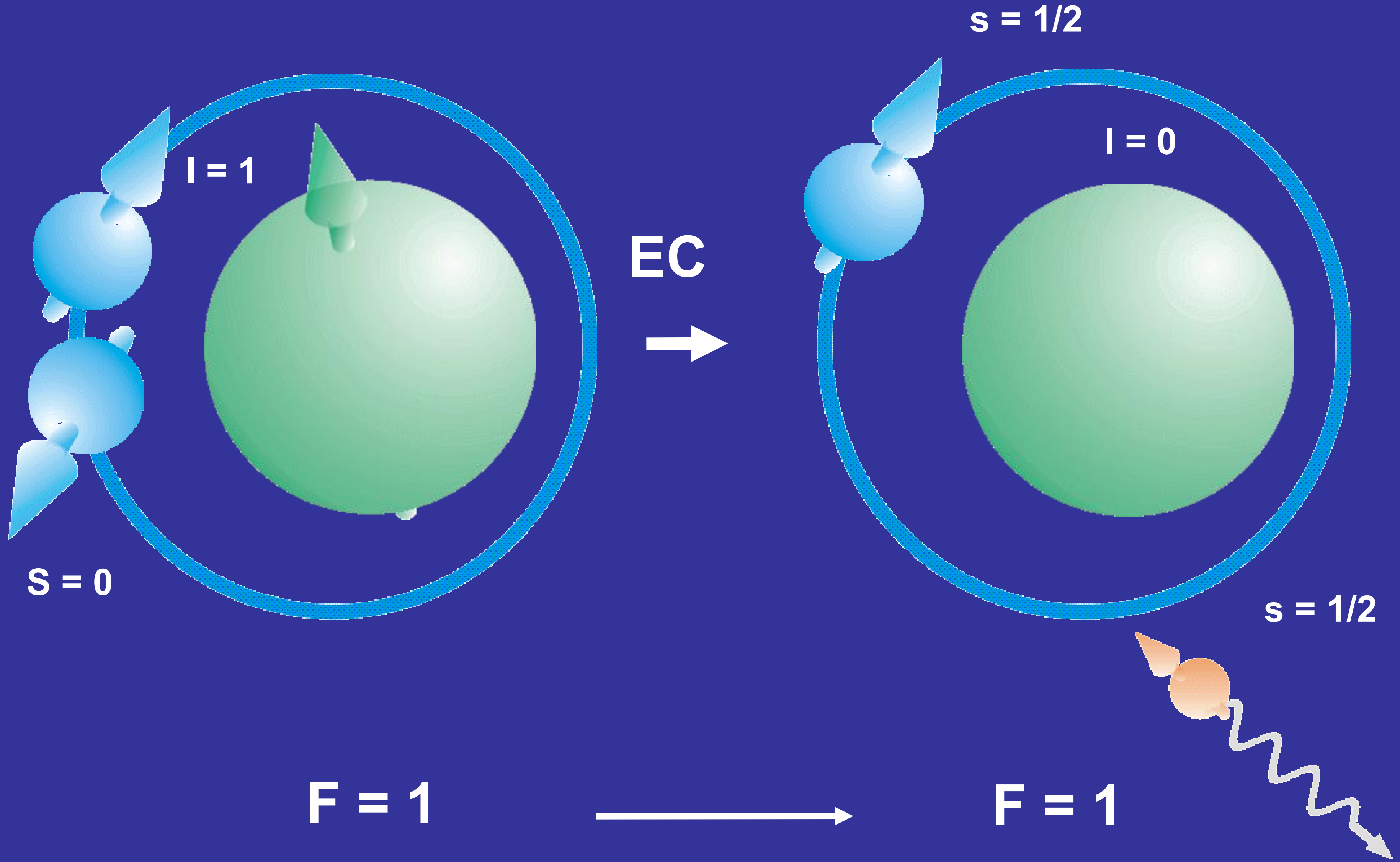
⎿ $_{EC}$(H-like)/⎿ $_{EC}$(He-like) = 1.44(6)



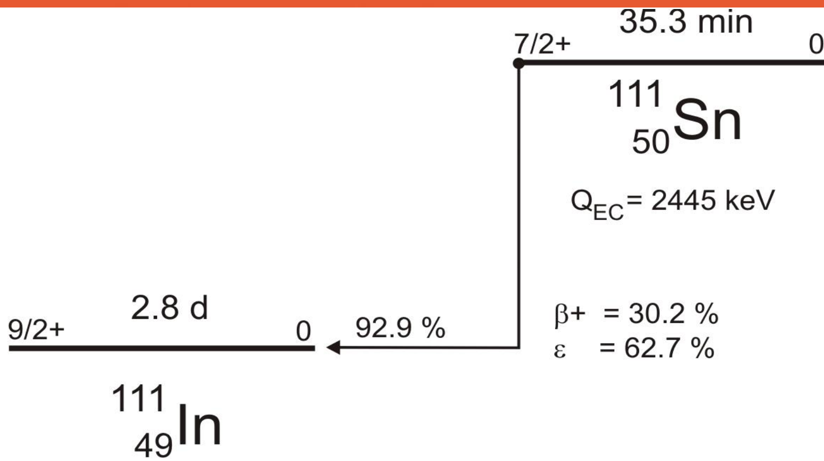
N. Winckler et al., Phys. Lett. B579 (2009) 36

Electron Capture in Helium-like Ions

Gamow-Teller transition $1^+ \rightarrow 0^+$

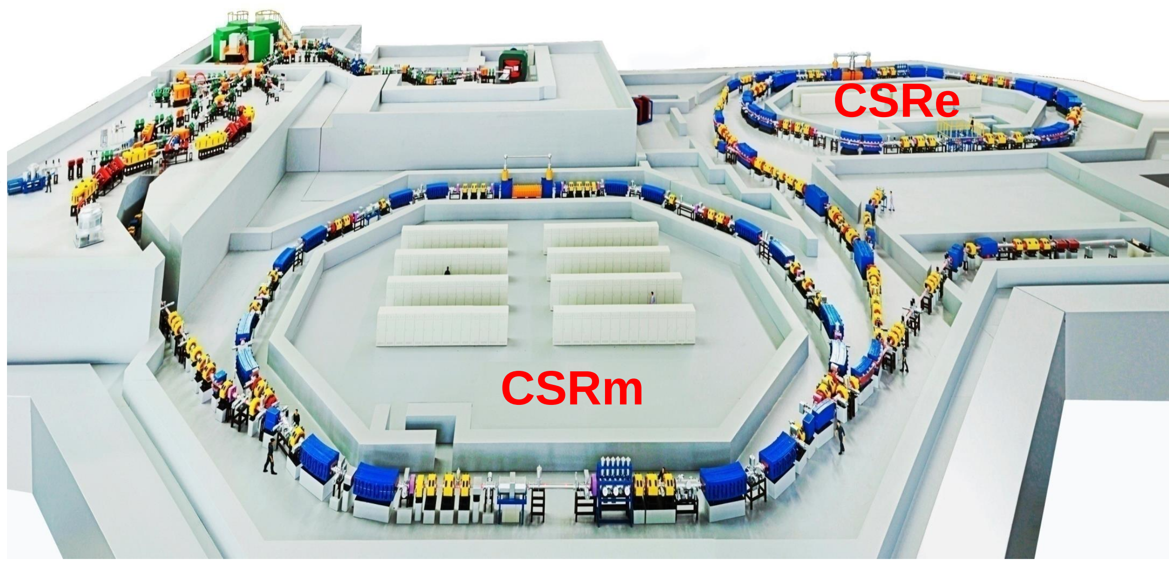


Electron Capture in Hydrogen-like Ions

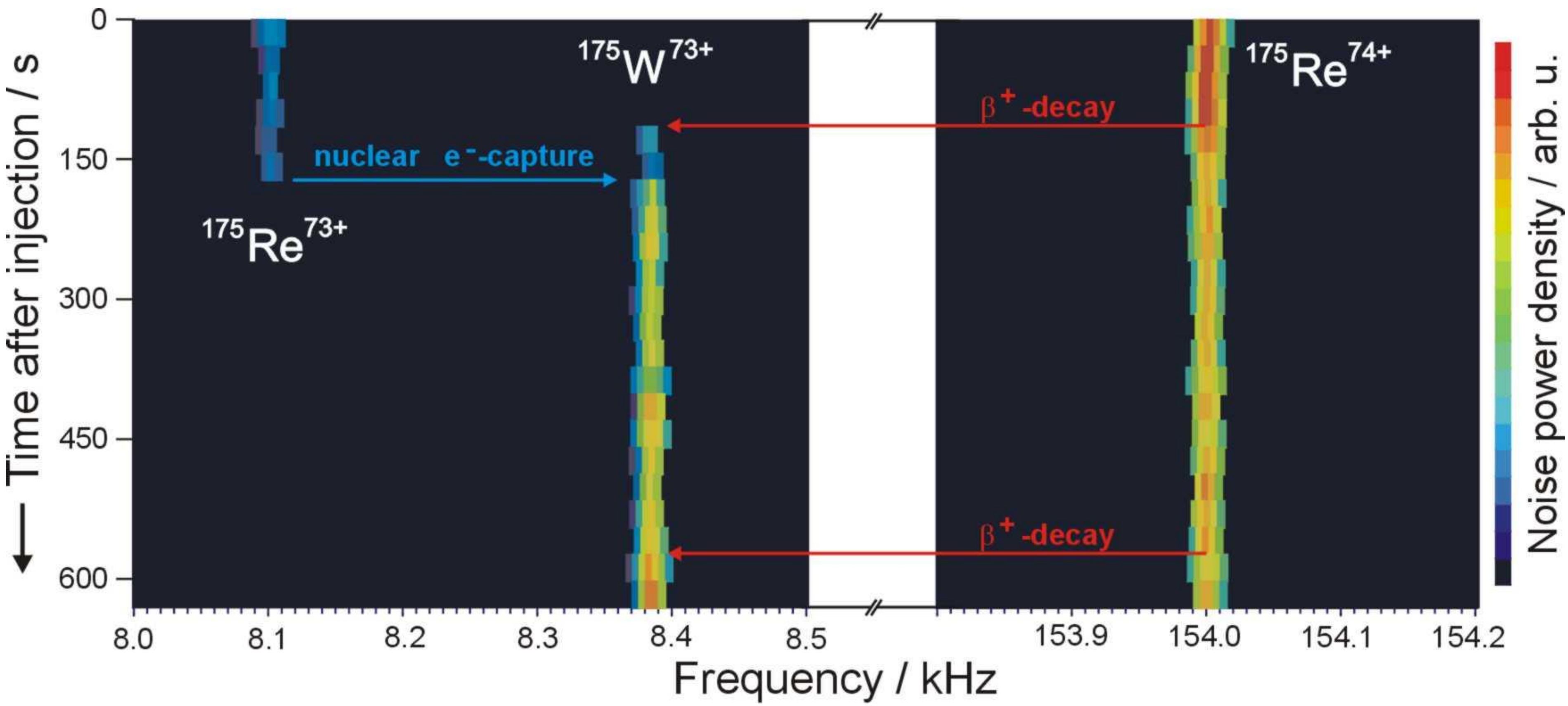


Addressing electron screening in beta decay under very clean conditions !

$$F = I + s \; \begin{cases} 4 \\ 3 \end{cases} \longrightarrow F = I + s \; \begin{cases} 5 \\ 4 \end{cases}$$



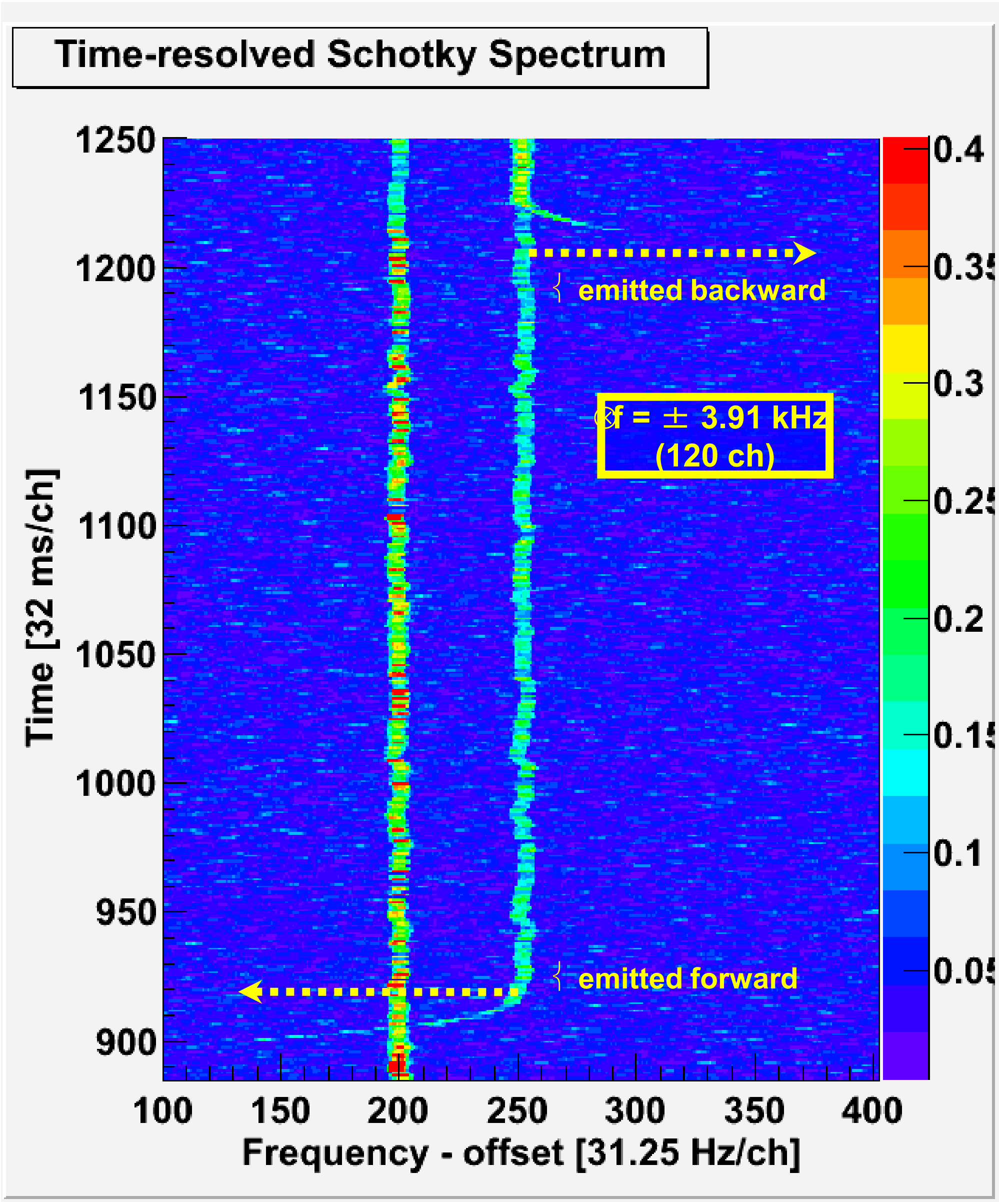
Nuclear Decays of Stored Single Atoms

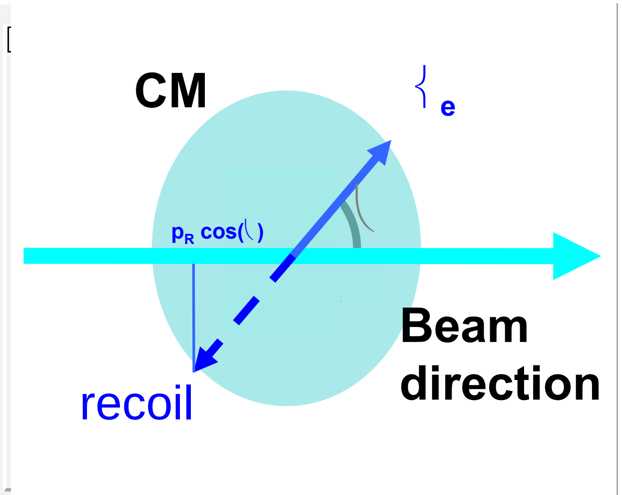


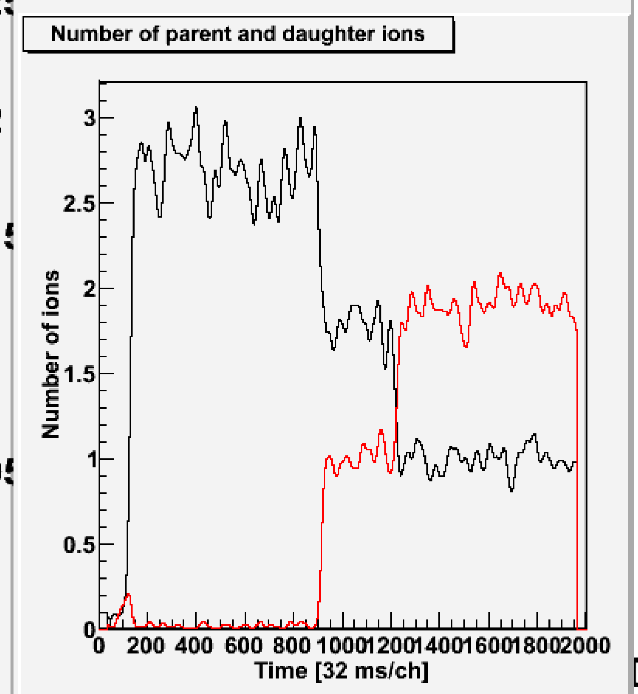
Nuclear electron capture, β+,β- and bound-β decays were observed

F. Nolden et a., Nucl. Instr. Meth. A659 (2011) 69--77

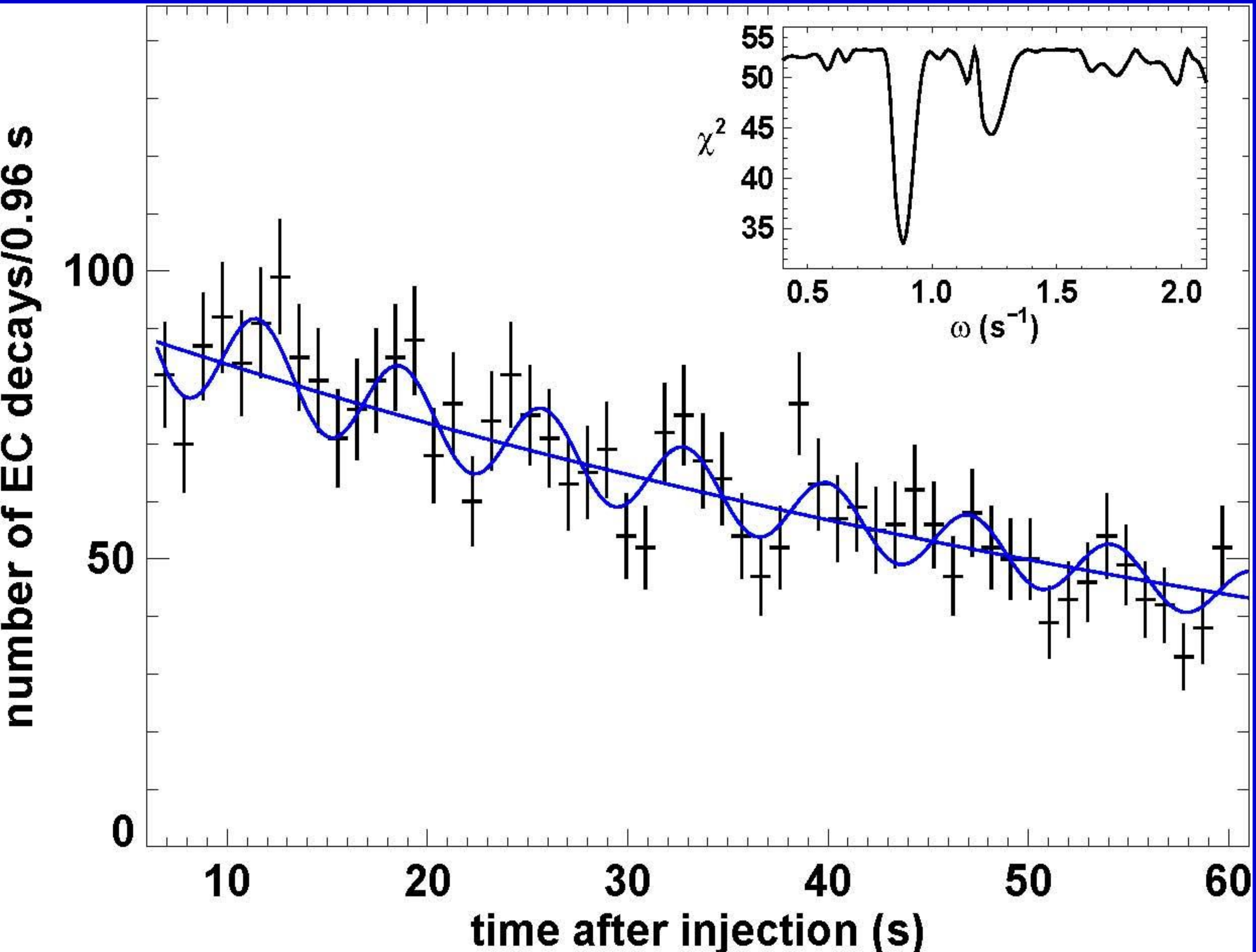
Three Parent He-Like ^{142}Pm Ions



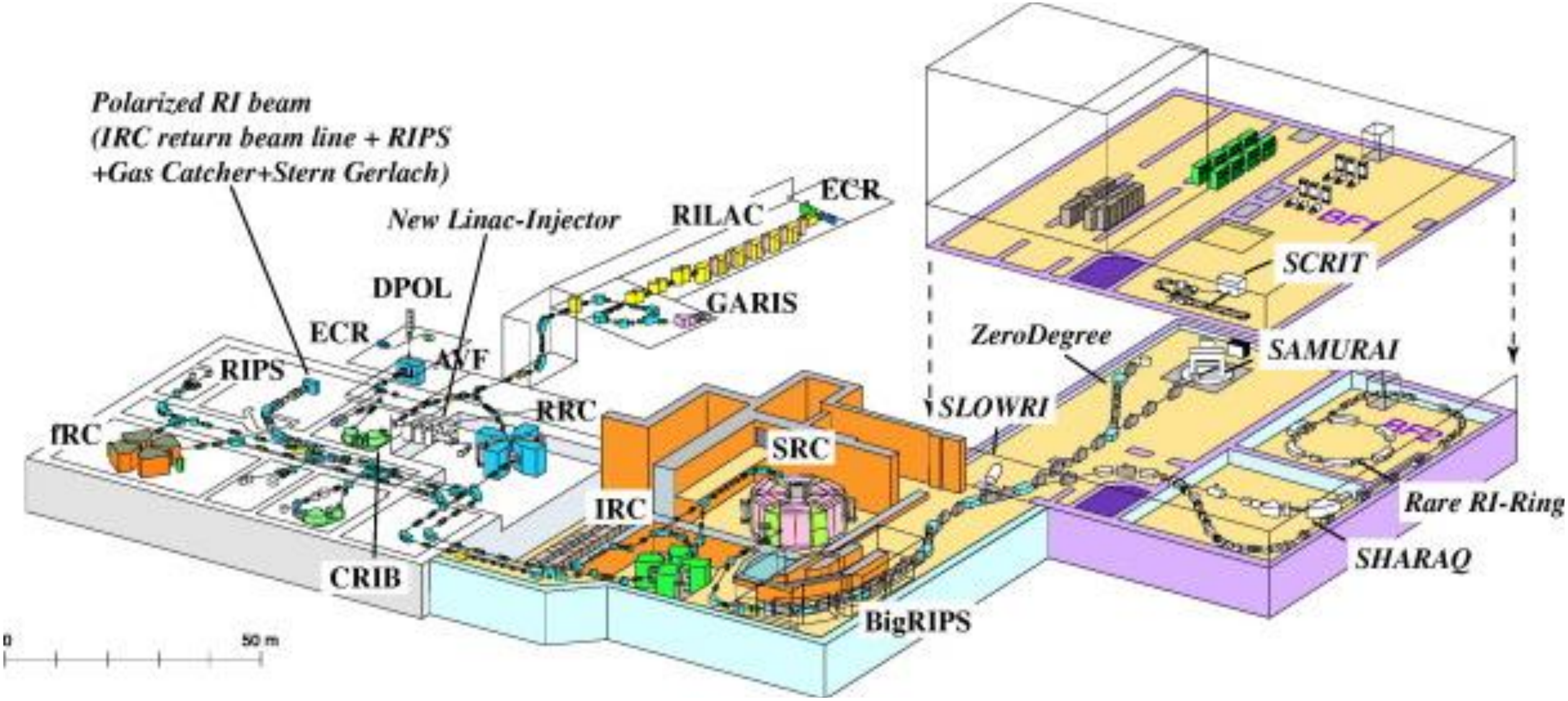




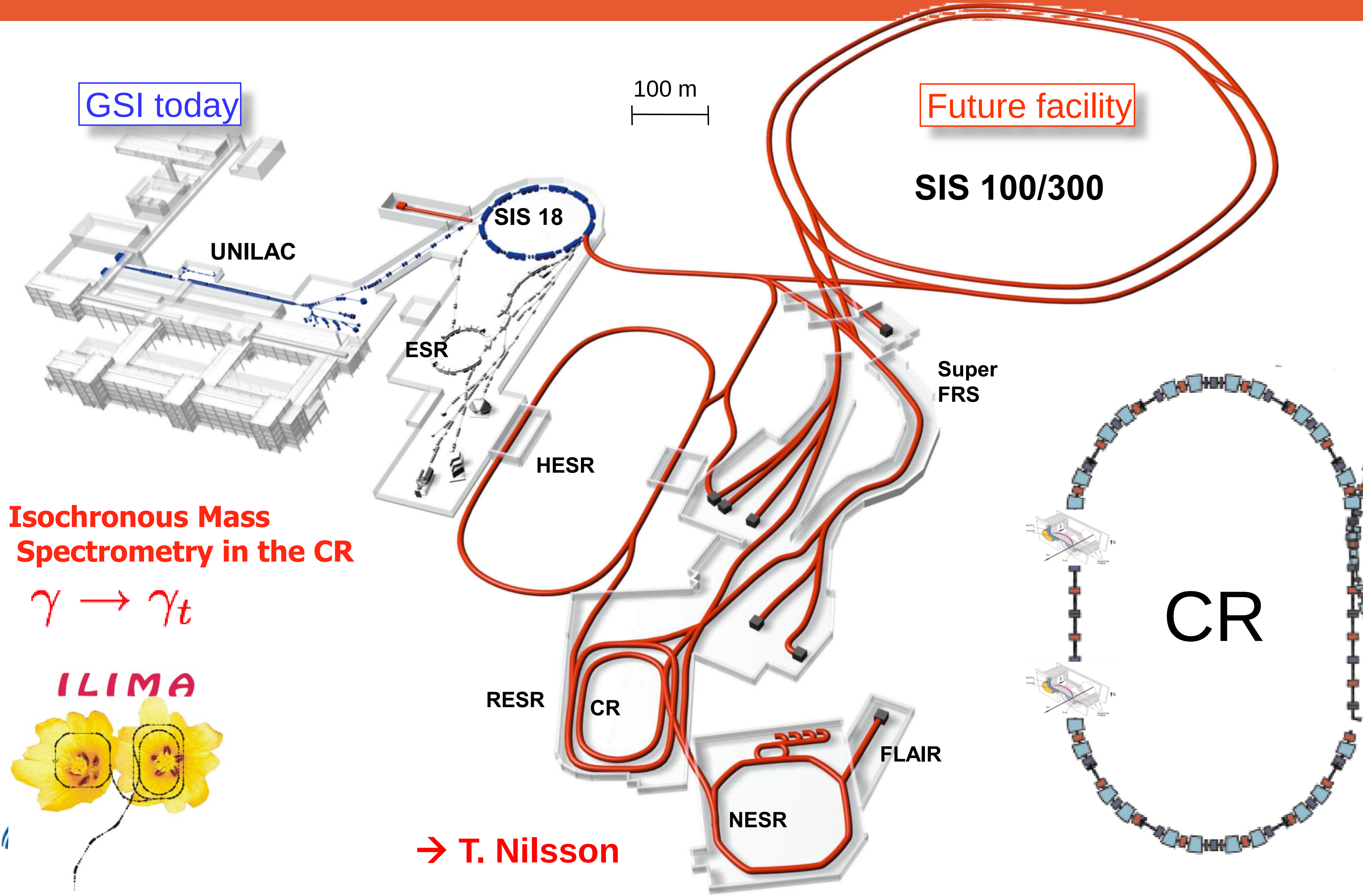
245 MHz Resonator: ω = 2π/T = 0.884(14)/s, **T = 7.11(11) s**, a = 0.107(24)



RI-RING at RIBF



FAIR - Facility for Antiproton and Ion Research

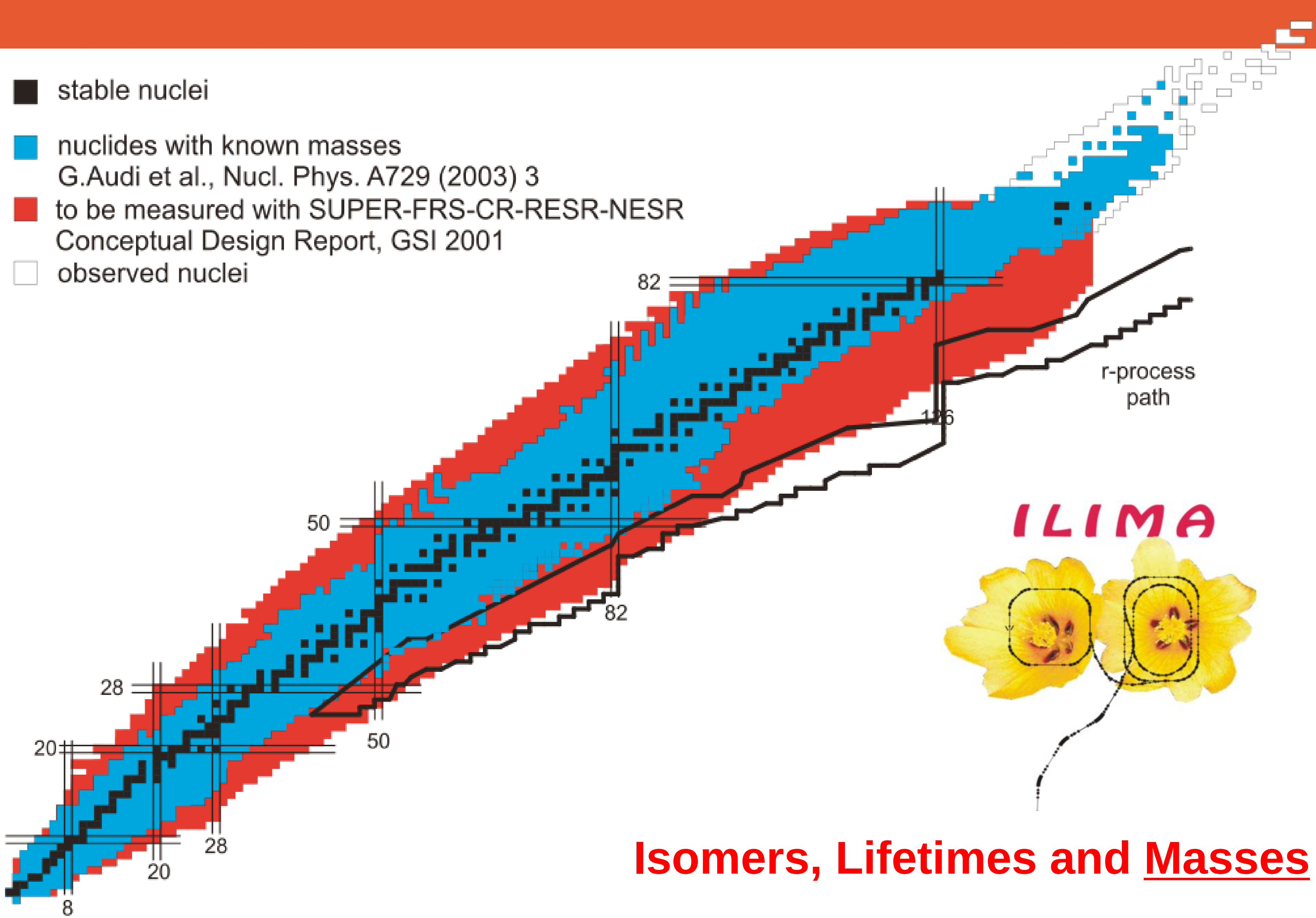


Isochronous Mass Spectrometry in the CR

$$\gamma \rightarrow \gamma_t$$

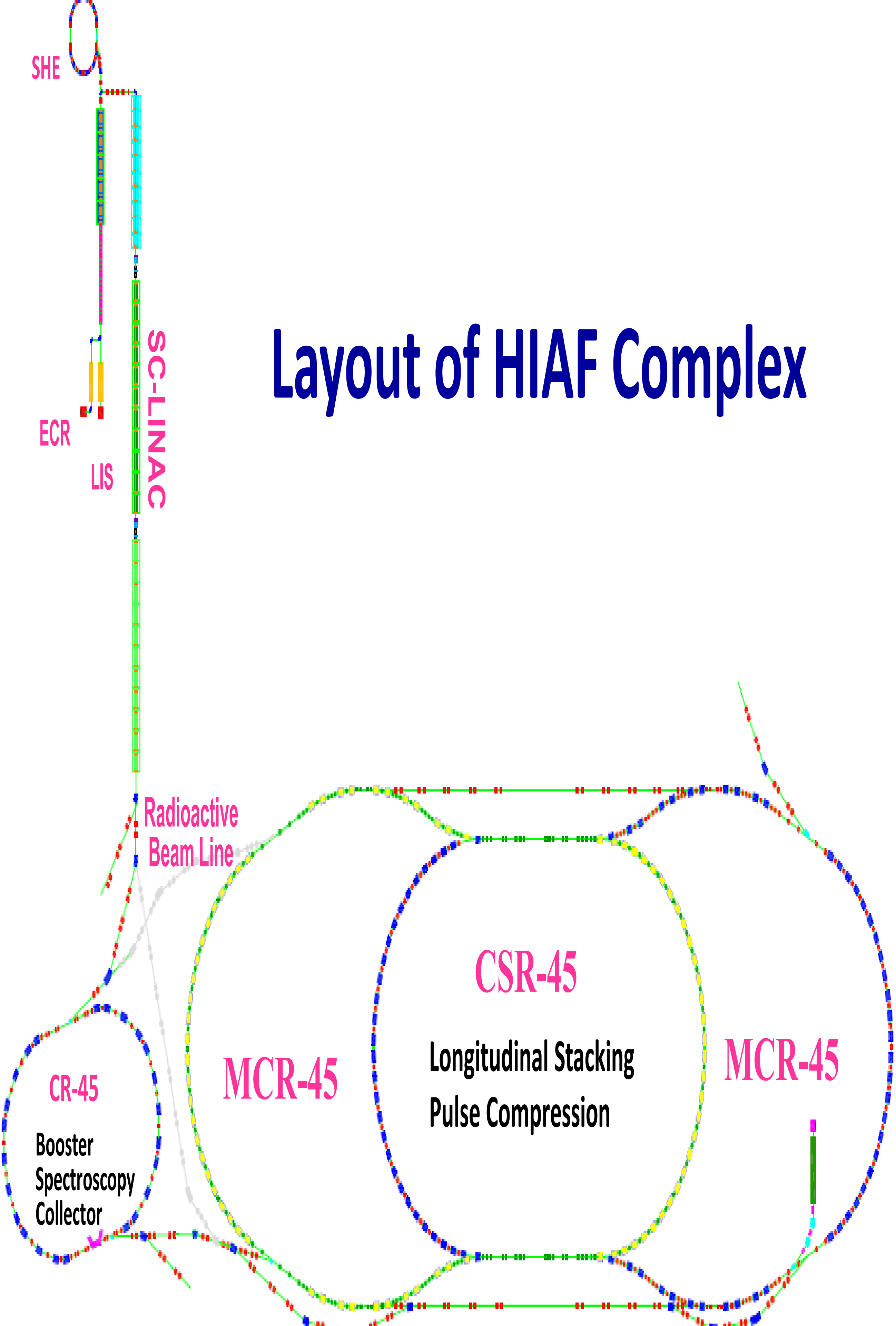
→ T. Nilsson

ILIMA: Masses and Halflives



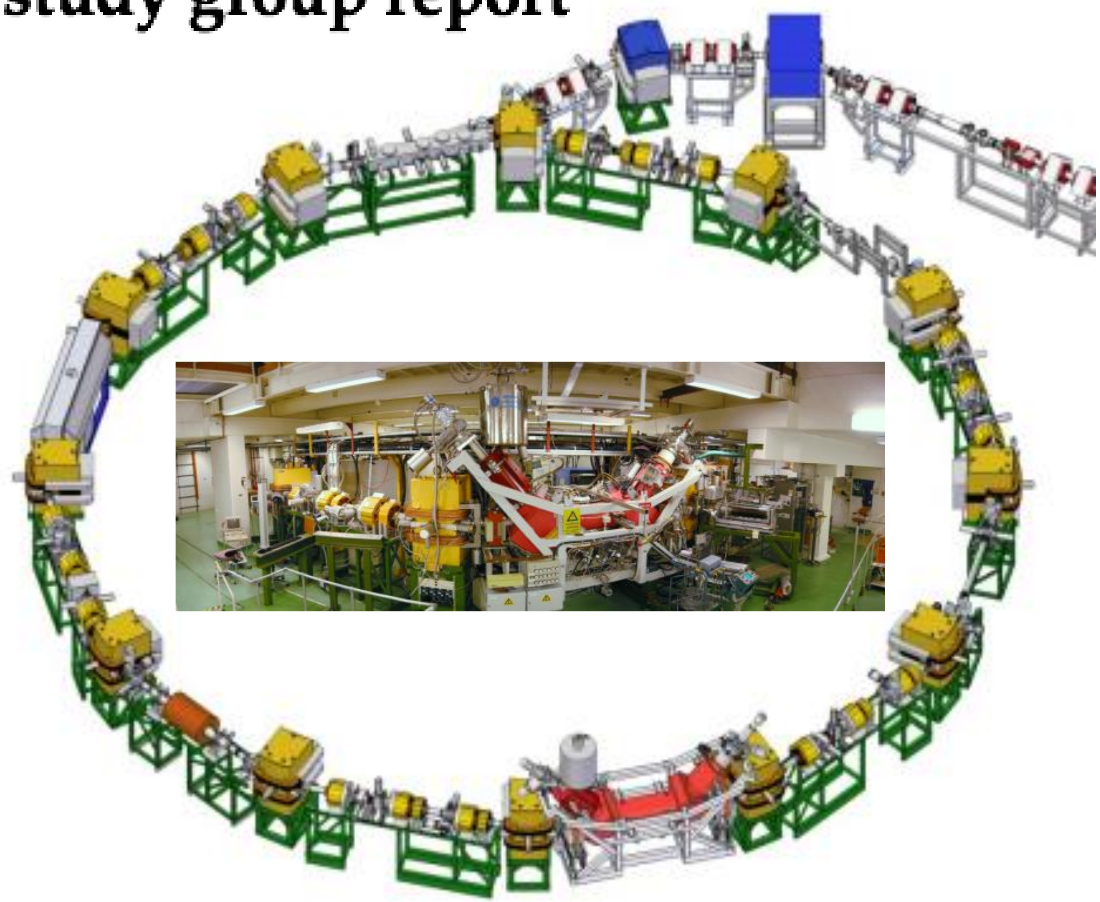
Isomers, Lifetimes and <u>Masses</u>

Layout of HIAF Complex



CRYRING@ESR

CRYRING@ESR:
A study group report



<u>Study Group</u>

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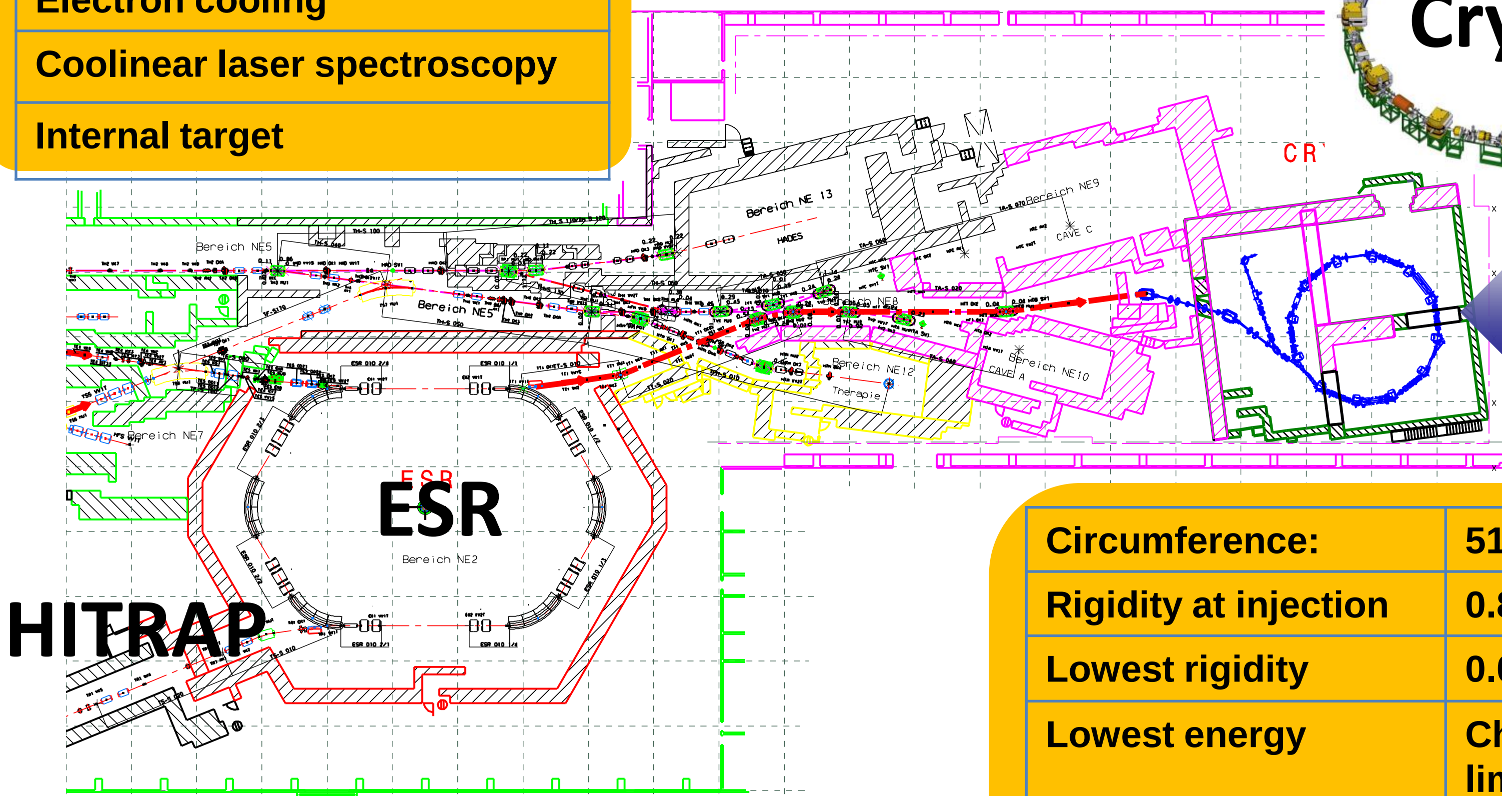
Wolfgang Enders
Mats Engström
Bernhard Franzke
Anders Källberg
Oliver Kester
Michael Lestinsky
Yuri Litvinov
Markus Steck
Thomas Stöhlker

CRYRING@ESR

Project coordination:
F. Herfurth & M. Lestinsky

Electron cooling
Coolinear laser spectroscopy
Internal target



Circumference:	**51.63 m**
Rigidity at injection	**0.88 Tm (1.44 Tm)**
Lowest rigidity	**0.054 Tm**
Lowest energy	**Charge exchange limited**
Magnet ramping	**7 T/s; 1 T/s**
Vacuum system	**10^{-11} -10^{-12} bar**
Slow extraction	

Working group report: http://www.gsi.de/en/start/fair/fair_experimente_und_kollaborationen/sparc/news.htm

CRYRING Physics Book

Physics book:
CRYRING@ESR

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T. Nilsson,[e] G. Paulus,[i,j] R. Reifarth,[1,h] R. Reuschl,[b,c] S. Schippers,[g] H. Schmidt,[n] R. Schuch,[n]
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H. Y. Zhao,[?] *et al.*

This text is an an early editing stage and is not authorized by the respective coauthors!

Editors:

M. Lestinsky et al.

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October 23, 2012

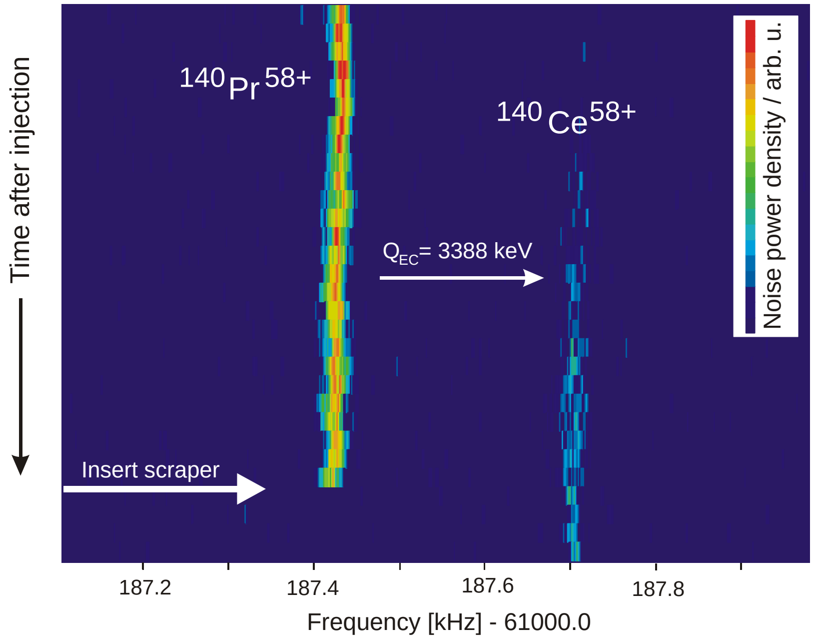
$Revision: 1.9 $ $Date: 2012-08-09 12:52:22 $

Presently:
63 Scientists from
24 Institutions in
10 Countries

More contributions are expected

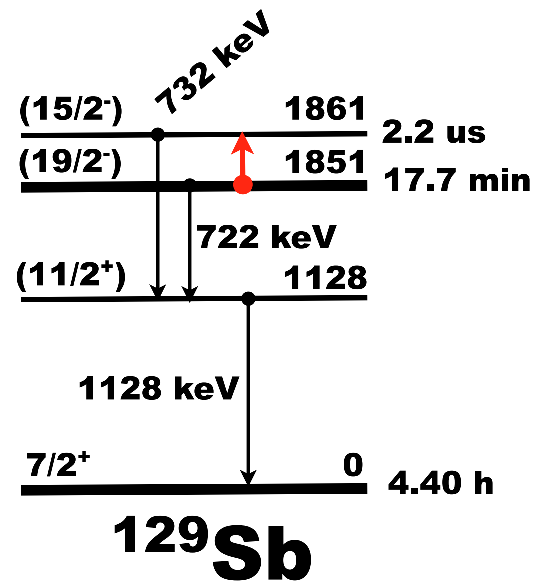
New contributions are welcome

Search for Nuclear Excitation in Electron Capture process



ESR:
Ability to prepare pure isomeric beams

Slowing down to 4 MeV/u



CRYRING:
Slowing down to a few 10 keV/u

Fast extraction towards an external Detection system

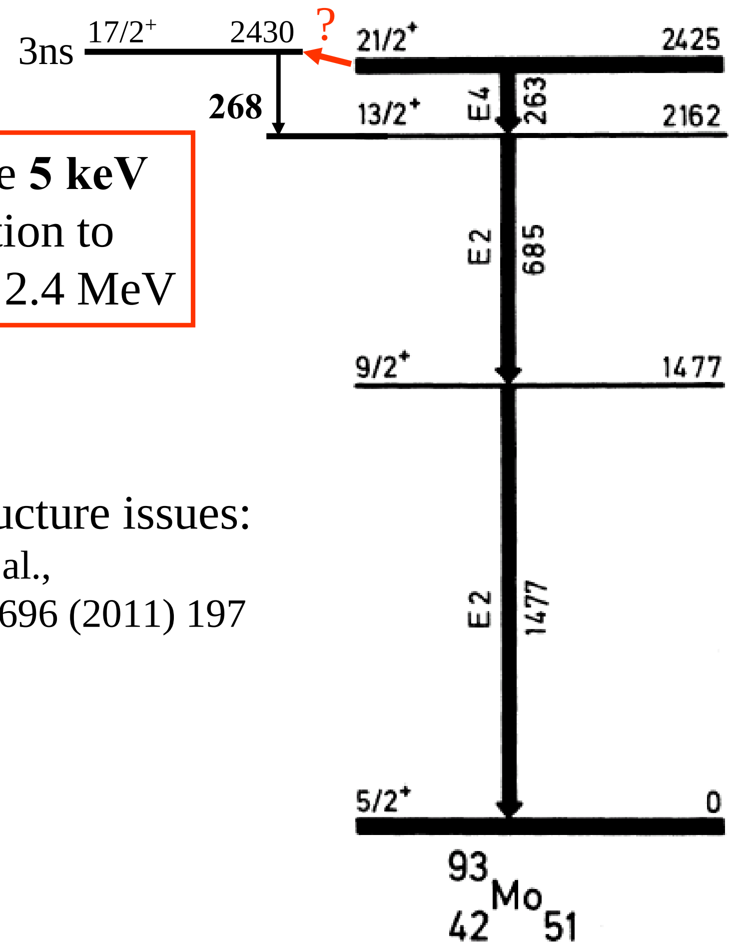
Search for NEEC Process

^{128m}Sn

po
tr
rel

^{204m}Pb

possible **5 keV** transition to release 2.4 MeV



$(\pi g_{9/2})^2, \nu d_{5/2}$

^{93}Mo
N=51
Z=42

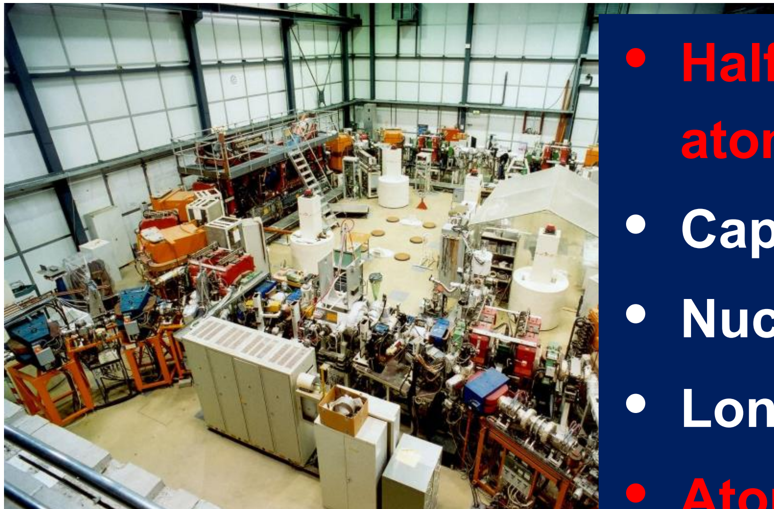
nuclear structure issues:
Hasegawa et al.,
Phys. Lett. B696 (2011) 197

Hagn et al., Phys. Rev. C23 (1981) 2252

$^{204}_{82}Pb_{122}$

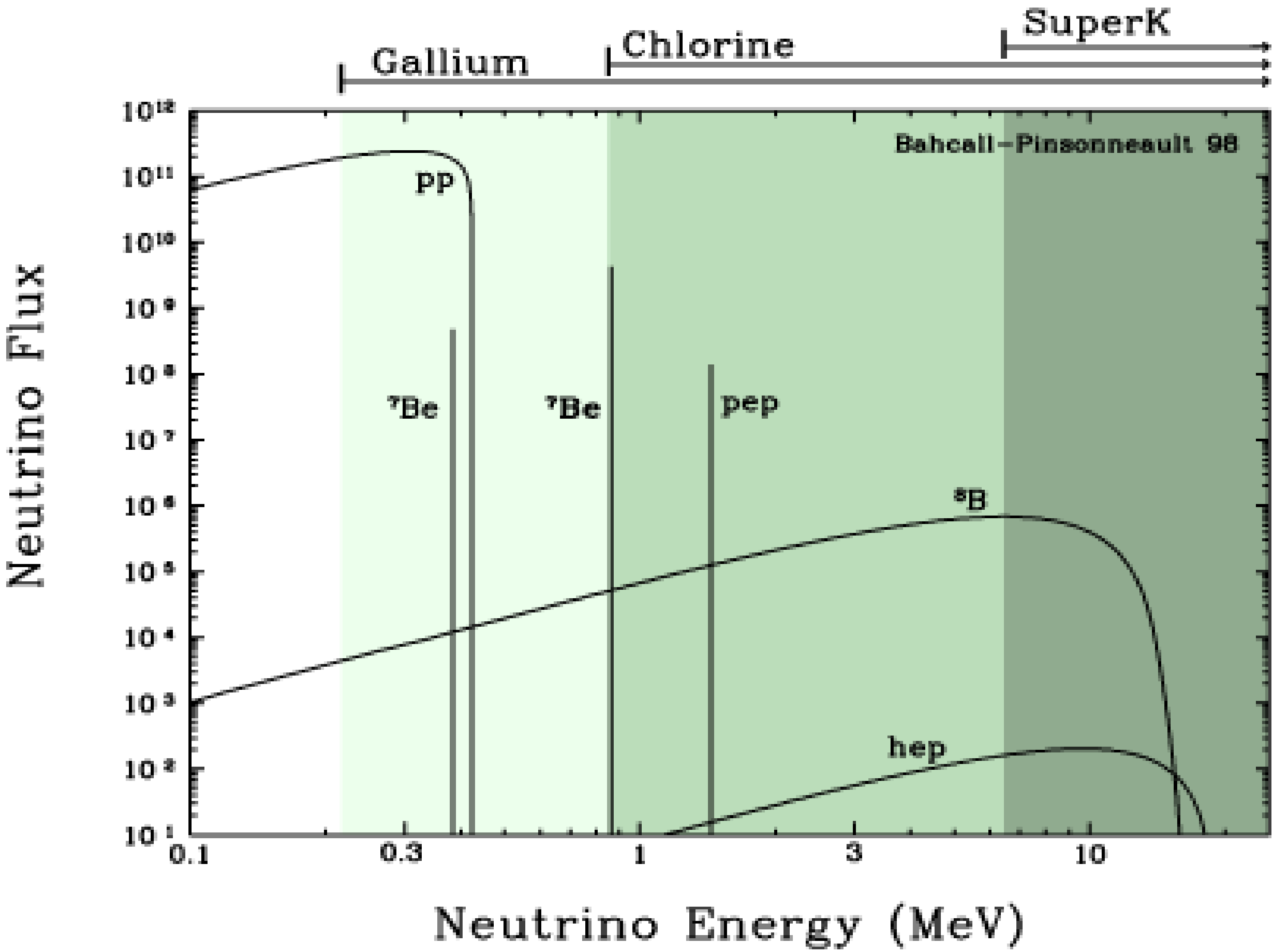
GSI

TSR @ ISOLDE



- Half-life measurements of ^{7}Be in different atomic charge states
- Capture reactions for astrophysical p-process
- Nuclear structure through transfer reactions
- Long-lived isomeric states
- Atomic effects on nuclear half-lives
- Nuclear effects on atomic decay rates
- Di-electronic recombination on exotic nuclei
- Neutrino physics; Tests for the neutrino beam project
- Purification of secondary beams from contaminants
- .....

The fate of ^{7}Be in the Sun



K. Langanke and G. Martinez-Pinedo, Rev. Mod. Phys. 75 (2003) 819

The fate of ^{7}Be in the Sun

J.N. Bahcall, Phys. Rev. C 128 (1962) 1297
I. Iben, K. kalata, J. Schwartz, ApJ 150 (1967) 1001
J.N. bahcall, C.P. Moeller, ApJ 155 (1969) 511
C.W. Johnson, E. Kolbe, S.E. Koonin, K. Langanke, ApJ 392 (1992) 320
A.V. Gruzinov, J.N. Bahcall, ApJ 490 (1997) 437
A.V. Gruzinov, J.N. Bahcall, ApJ 504 (1998) 996
and many others

About 20% of ^{7}Be EC decay rate in the Sun are due to bound electrons

$$\frac{\delta R(^7\mathrm{Be}+e^-)}{R(^7\mathrm{Be}+e^-)} \leqslant 0.02.$$

E.G. Adelberger et al., Rev. Mod. Phys. 70 (1998) 1265

Half-life of H-like ^{7}Be

$T_{1/2}$ ($^{7}Be^{0+}$) ~ 53.22 days

NNDC, 2010

$T_{1/2}$ ($^{7}Be^{4+}$) ~ infinity

$T_{1/2}$ ($^{7}Be^{3+}$) ~ 106 days

$T_{1/2}$ ($^{7}Be^{2+}$) ~ 53 days

$T_{1/2}$ ($^{7}Be^{1+}$) ~ 53 days

C. Rolfs et al., suggestion for an ESR proposal, ~2003
C. Rolfs, W. Rodney, Cauldrons in the Cosmos, 1988

A. Ray et al., Phys. Lett. B 455 (1999) 69
B. Wang et al., Eur. Phys. J. A 28 (2006) 375
T. Ohtsuki et al., Phys. Rev. Lett. 98 (2007) 252501
A. Ray et al., Phys. Lett. B 679 (2009) 106
and many, many others

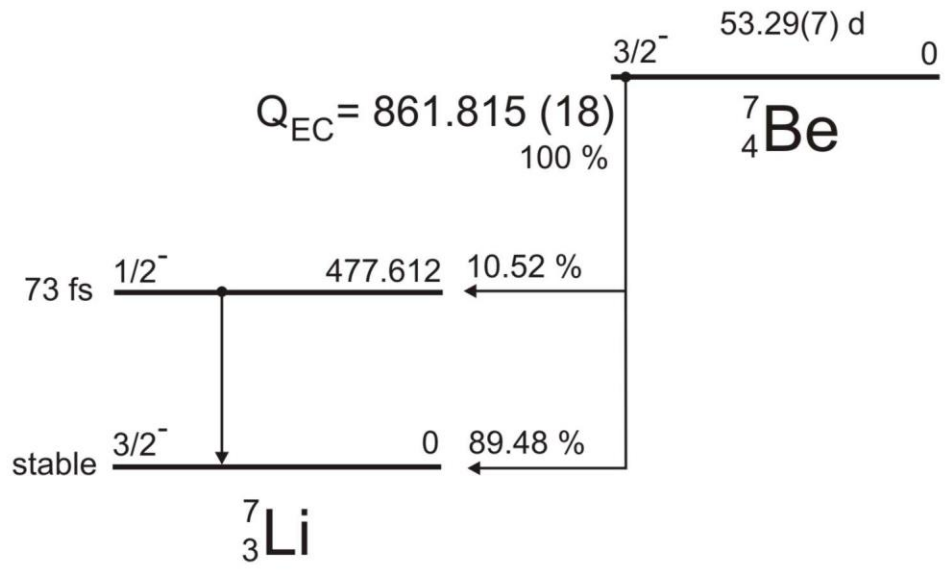
Some speculations on the EC-decay of ^{7}Be

A.V. Gruzinov, J.N. Bahcall, ApJ 490 (1997) 437

Ionization of ^{7}Be in the Sun can be ~ 20-30 %

S. Kappertz et al., AIP Conf. Proc. Vol. 455 (1998) 110

Negative magnetic moment of ^{7}Be

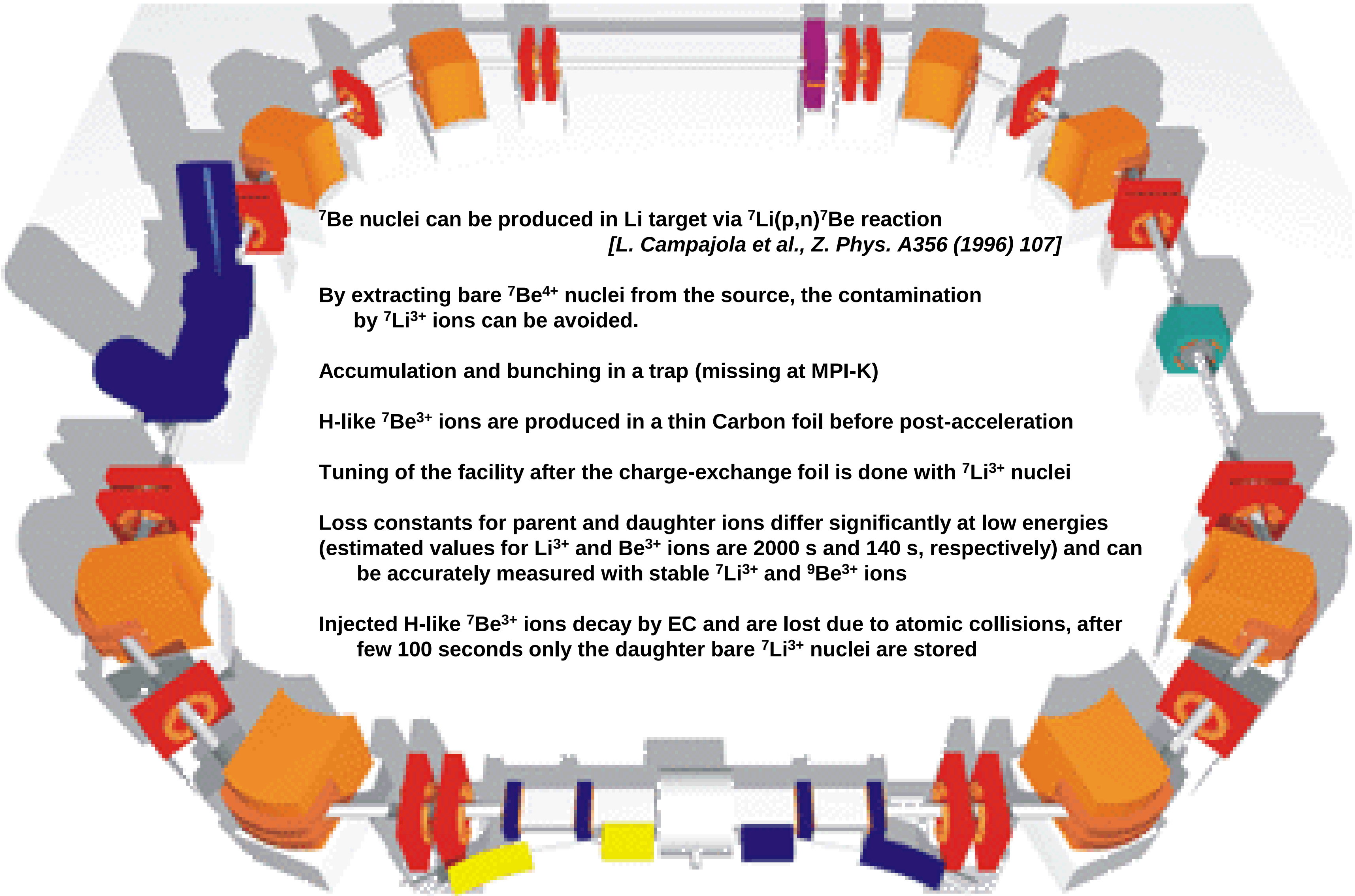


Transition (F=1→F=1) is accelerated by **$(2I+1)/(2F_1+1)$** i.e. by 8/3

However, there are only $(2F_1+1)/((2F_1+1)+(2F_2+1)) = 3/8$ of ^{7}Be in this state

MAX PLANCK INSTITUTE FOR NUCLEAR PHYSICS

A possible scenario for an experiment at the TSR



^{7}Be nuclei can be produced in Li target via $^{7}Li(p,n)^{7}Be$ reaction
[L. Campajola et al., Z. Phys. A356 (1996) 107]

By extracting bare $^{7}Be^{4+}$ nuclei from the source, the contamination by $^{7}Li^{3+}$ ions can be avoided.

Accumulation and bunching in a trap (missing at MPI-K)

H-like $^{7}Be^{3+}$ ions are produced in a thin Carbon foil before post-acceleration

Tuning of the facility after the charge-exchange foil is done with $^{7}Li^{3+}$ nuclei

Loss constants for parent and daughter ions differ significantly at low energies (estimated values for Li^{3+} and Be^{3+} ions are 2000 s and 140 s, respectively) and can be accurately measured with stable $^{7}Li^{3+}$ and $^{9}Be^{3+}$ ions

Injected H-like $^{7}Be^{3+}$ ions decay by EC and are lost due to atomic collisions, after few 100 seconds only the daughter bare $^{7}Li^{3+}$ nuclei are stored

Max Planck Institute for Nuclear Physics

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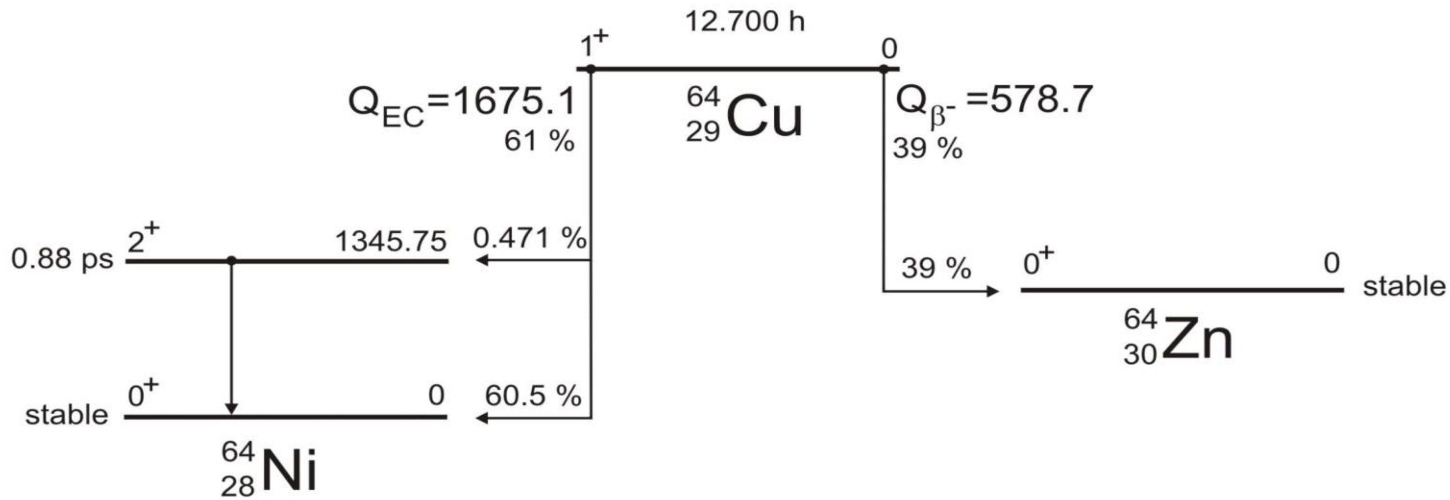
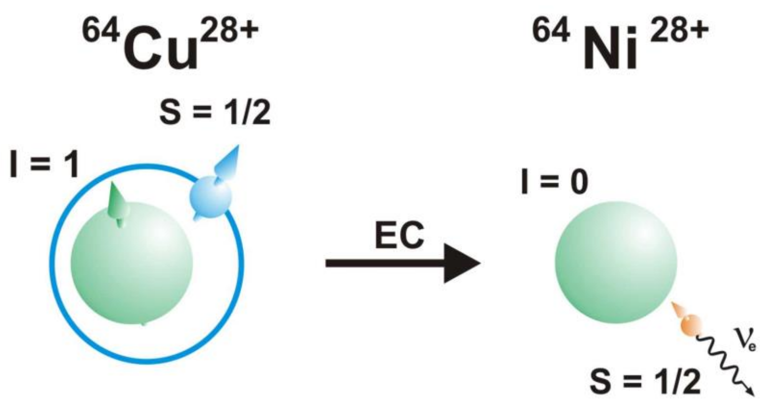
Decay of Hydrogen-like ^{64}Cu



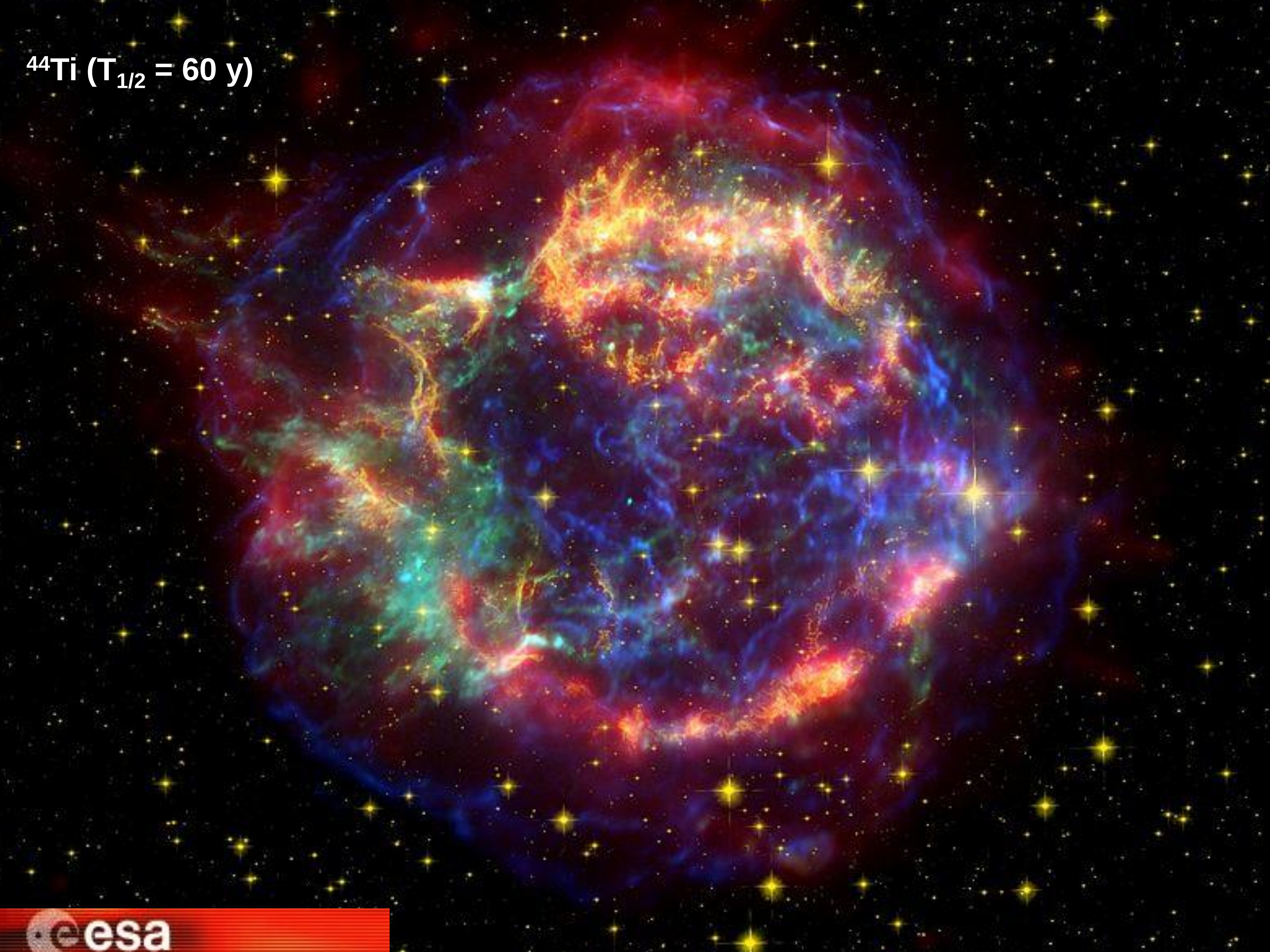


$F = I + s$ — 1/2 → $F = I + s = 1/2$; 3/2 ✗→

$\mu\,(^{64}Cu) = -0.217(2)\ \mu_N$

B.M. Dodsworth et al., Phys. Rev. 142 (1966) 638.

^{44}Ti ($T_{1/2}$ = 60 y)



High-Energy Cosmic Rays

A&A 381, 539–559 (2002)
DOI: 10.1051/0004-6361:20011447

Astronomy & Astrophysics

β–radioactive cosmic rays in a diffusion model: Test for a local bubble?

F. Donato[1], D. Maurin[1,2], and R. Taillet[1,2]

Pergamon
www.elsevier.com/locate/asr

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0273-1177/01 $20.00 + 0.00

PII: S0273-1177(01)00114-4

COSMIC-RAY TIME SCALES USING RADIOACTIVE CLOCKS

N.E. Yanasak[1], M.E. Wiedenbeck[1], W.R. Binns,[2], E.R. Christian[3], A.C. Cummings[4], A.J. Davis[4], J.S. George[4], P.L. Hink[2], M.H. Israel[2], R.A. Leske[4], M. Lijowski[2], R.A. Mewaldt[4], E.C. Stone[4], T.T. von Rosenvinge[3]

Cosmic-Ray Propagation and Interactions in the Galaxy

Andrew W. Strong,[1] Igor V. Moskalenko,[2] and Vladimir S. Ptuskin[3]

MAX PLANCK INSTITUTE FOR NUCLEAR PHYSICS

MAX-PLANCK-GESELLSCHAFT

High-Energy Cosmic Rays

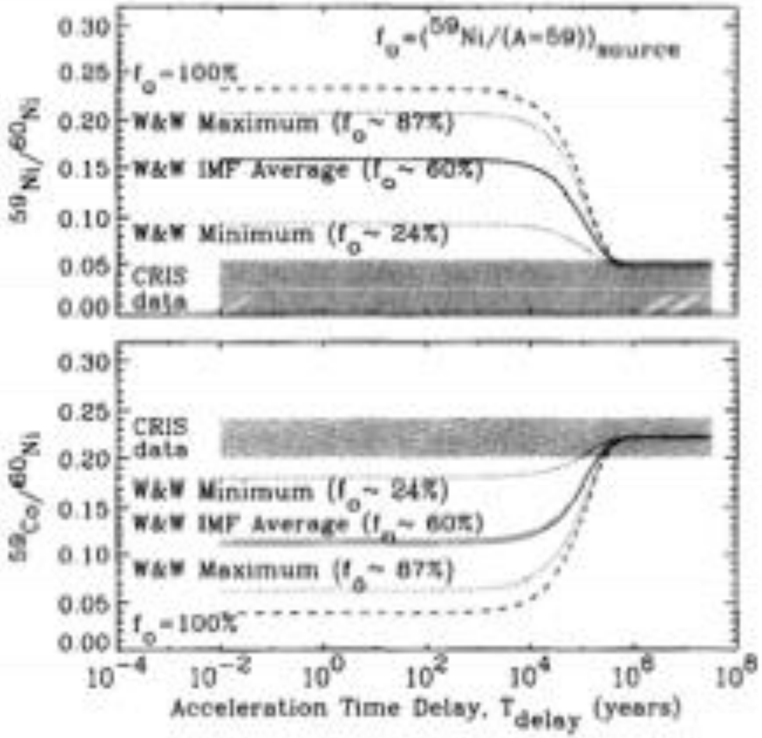


Fig. 3. Dependence of the mass-59 e^--capture GCR relative abundances at Earth on the time delay between nucleosynthesis and acceleration. Different curves assume different fractions f_o of mass-59 nuclei synthesized as ^{59}Ni at the source. The W&W values of f_o come from the SN II yield calculations of Woosley and Weaver (1995). CRIS abundances are shown as a hatched region.

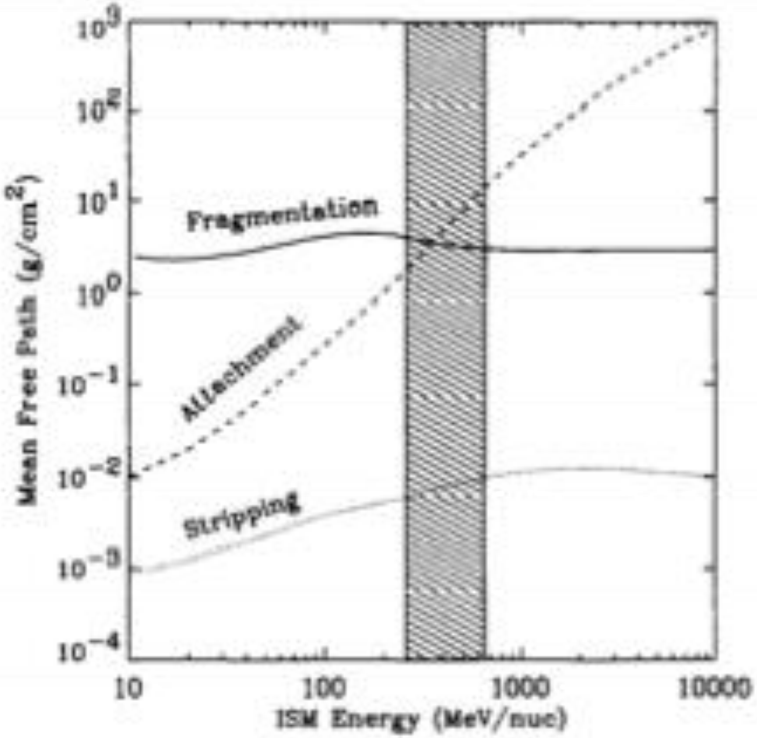
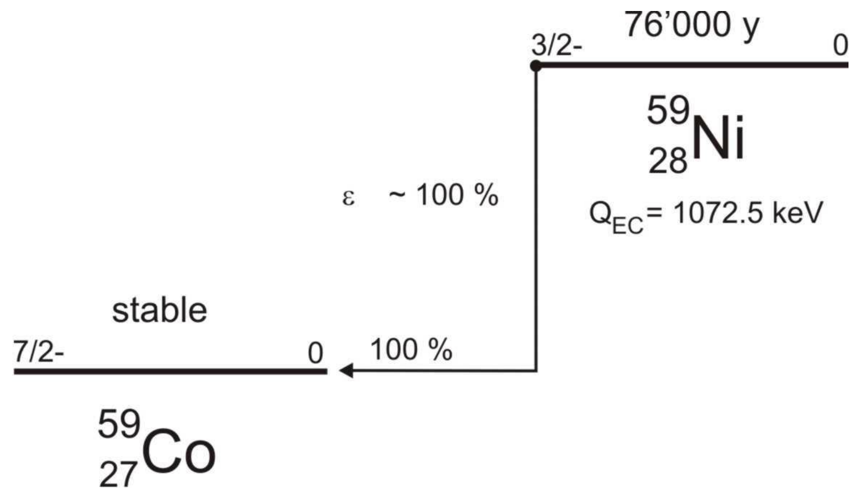
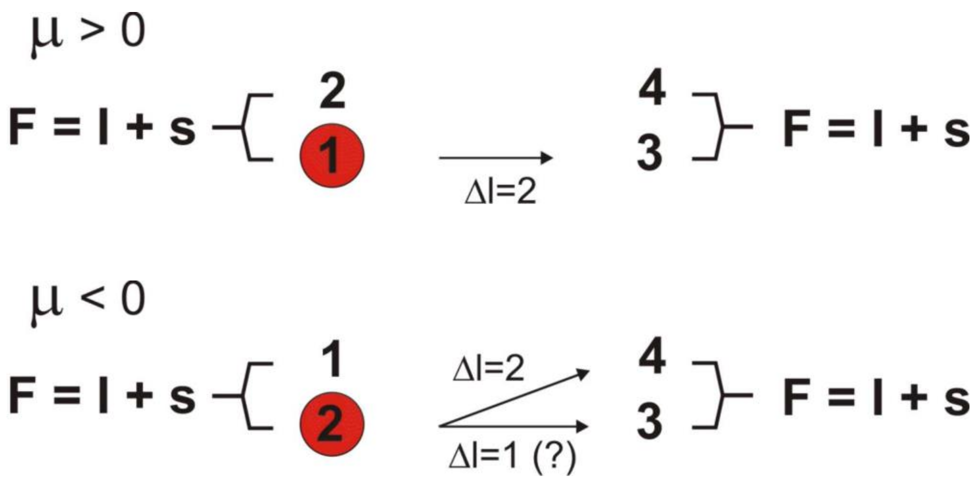


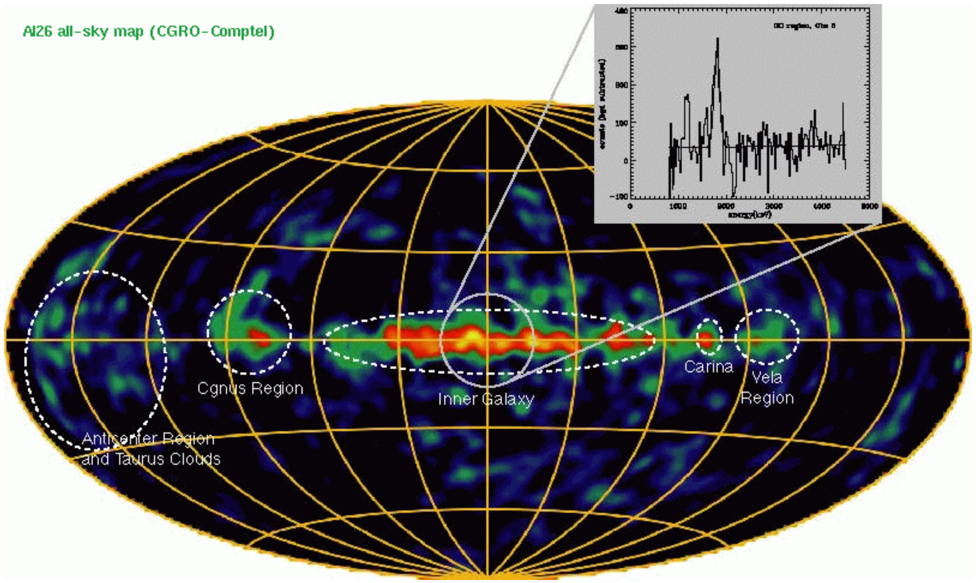
Fig. 4. Mean free paths for electron attachment and stripping (Crawford, 1979) of GCR Co in the ISM as a function of energy, assuming an ISM composition of 90% H, 10% He. Also shown is the mean free path for GCR fragmentation in the ISM (Tripathi et al., 1999). The hatched region indicates the approximate energy range for the GCR Co observed by CRIS, with a mean ISM energy of ~500 MeV/nuc.

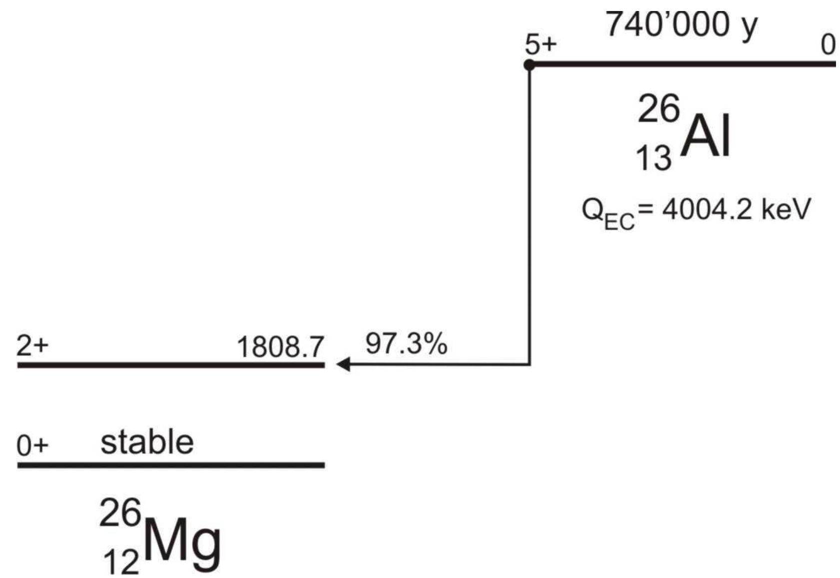
What happens in hydrogen-like ^{59}Ni



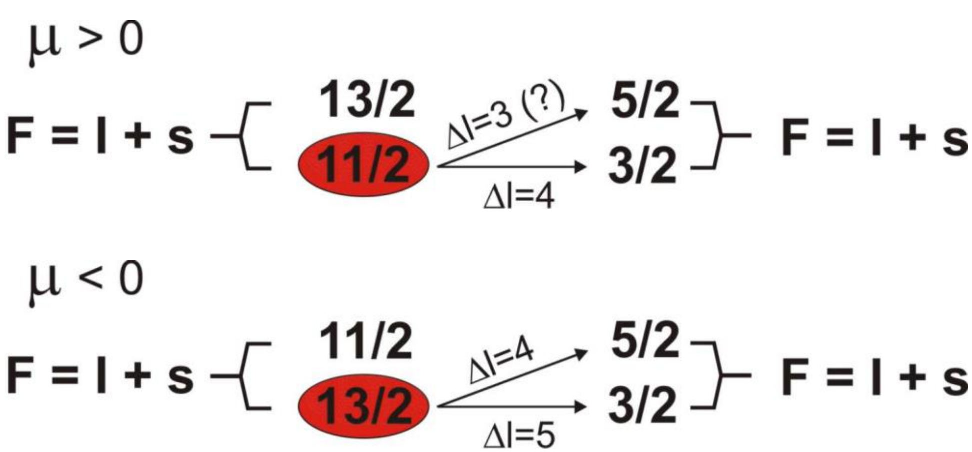


Stellar Gamma-Ray Emitters

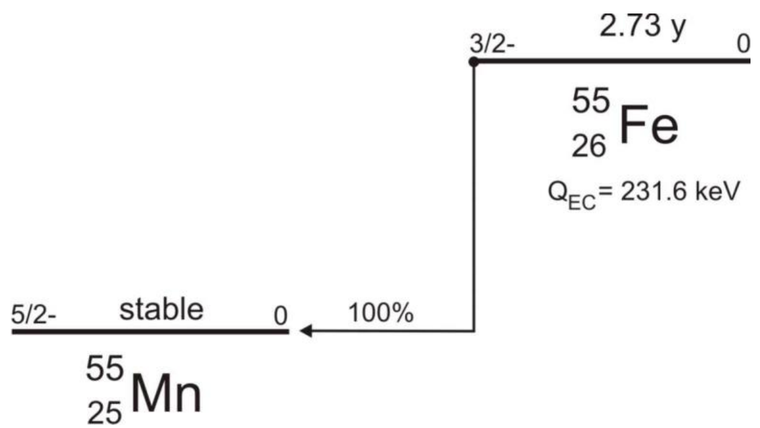


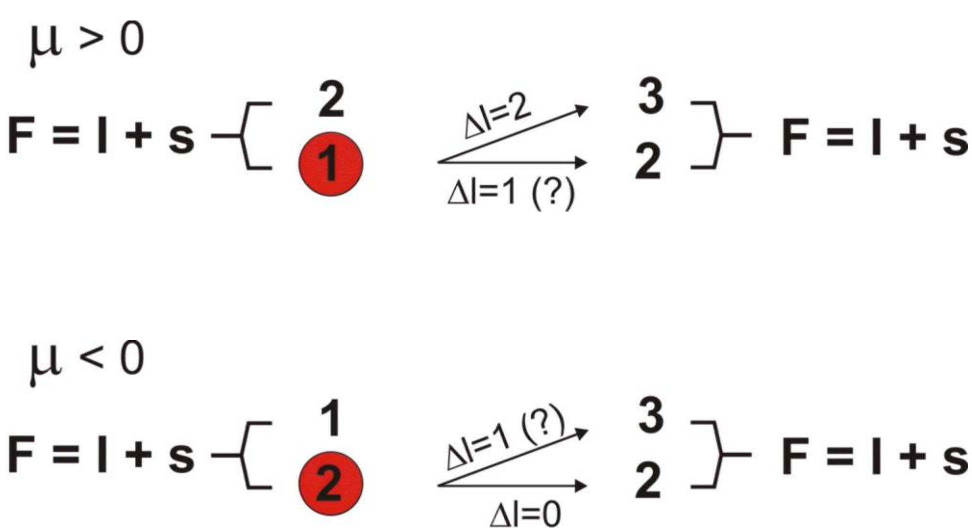


Hydrogen-like ^{26}Al

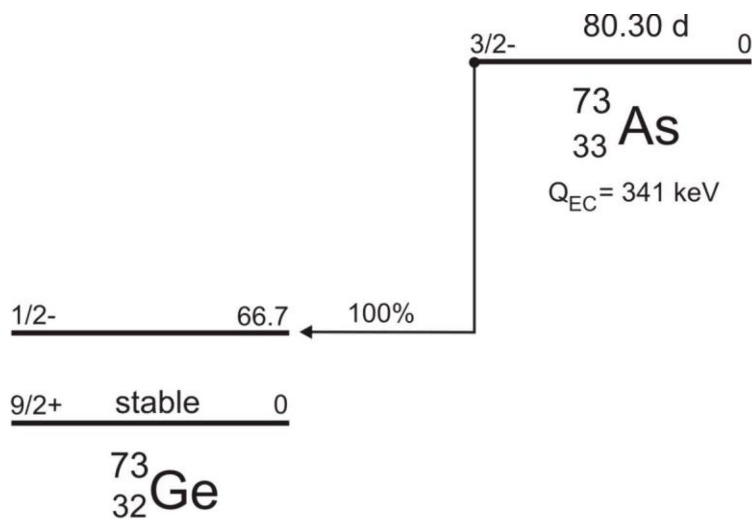


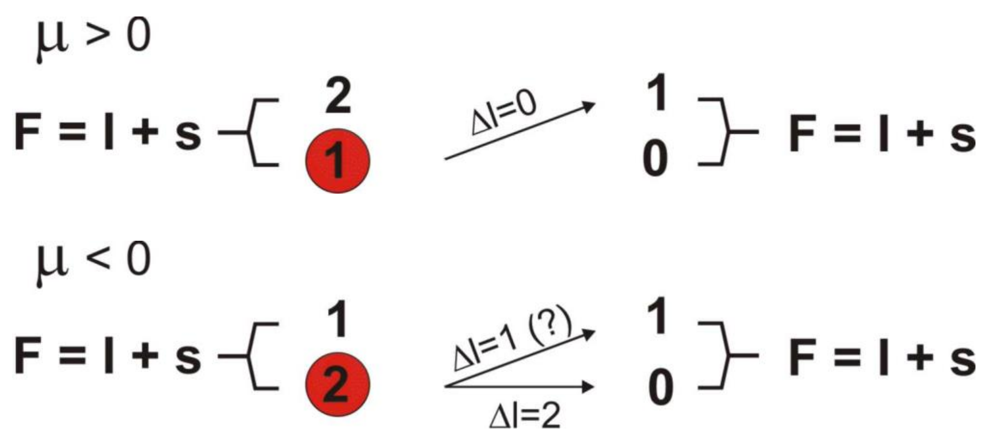
What happens in hydrogen-like ^{55}Fe





What happens in hydrogen-like ^{73}As





Physics cases

⇨ "Stellar lifetimes of SN isotopes" (Wed, 17:45) *Sorry for the house advertising...*

Mixed decay isotopes

Al 26 — 6,35 s | 7,16 · 10^5 a; β^+ 3,2 | β^+ 1,2; γ 1809; 1130...

Cl 36 — 3,0 · 10^5 a; β^- 0,7; ϵ; β^+...; no γ; σ < 10

Mn 54 — 312,2 d; ϵ; γ 835

CR clocks

Co 56 — 77,26 d; ϵ; β^+ 1,5...; γ 847; 1238; 2598; 1771; 1038...

Ni 56 — 6,075 d; ϵ; no β^+; γ 158; 812; 750; 480; 270...

Ni 59 — 7,5 · 10^4 a; ϵ; β^+ ...; no γ; σ 77,7; $\sigma_{n,\alpha}$ 12,3; $\sigma_{n,p}$ 1,34

SN isotopes

Secondary CR spallation products

Primary SN isotopes

Pure EC decay isotopes

Ar 37 — 35,0 d; ϵ; no γ; $\sigma_{n,p}$ 69; $\sigma_{n,\alpha}$ 1970

V 49 — 330 d; ϵ; no γ

Cr 51 — 27,70 d; ϵ; γ 320

Mn 53 — 3,7 · 10^6 a; ϵ; no γ; σ 70

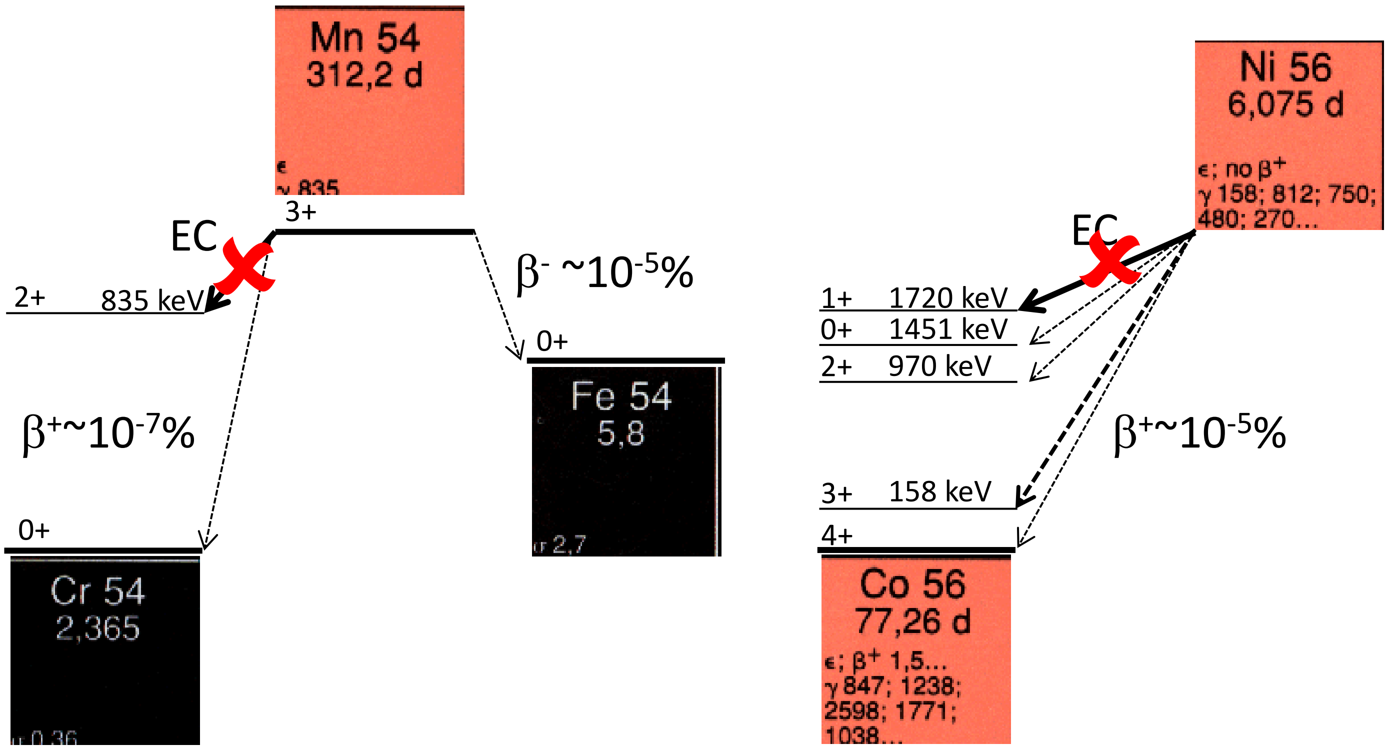
Ti 44 — 47,3 a; ϵ; γ 78; 68...

Fe 55 — 2,73 a; ϵ; no γ; σ 13

Co 57 — 271,79 d; ϵ; γ 122; 136; 14

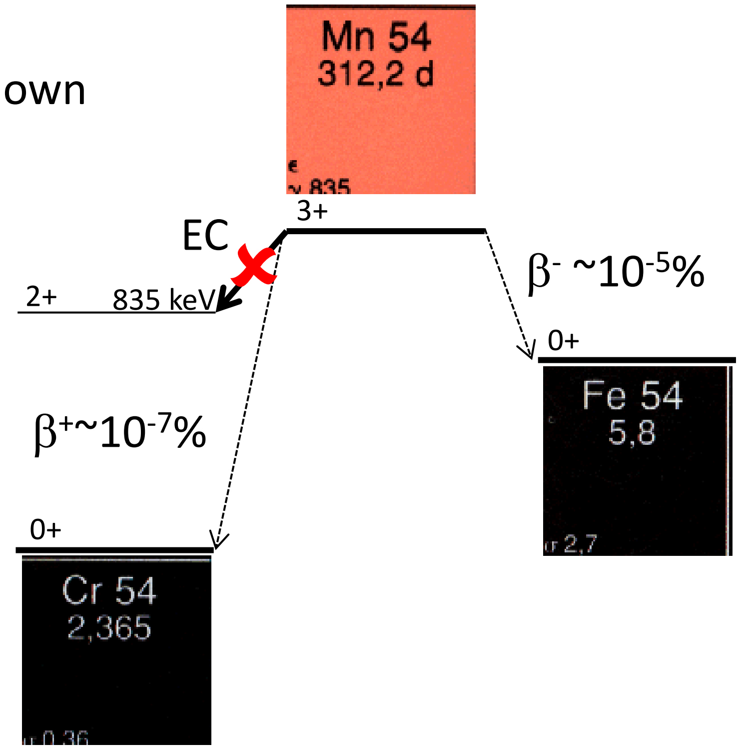
Mixed EC/β-decay isotopes

- Stellar conditions: EC hindered, weak β^+/β^- decay channel determines $t_{1/2}$
- 10^7 pps injected, 30min measured ⇨ ~1 event/d if partial $t_{1/2}$= 25000 y



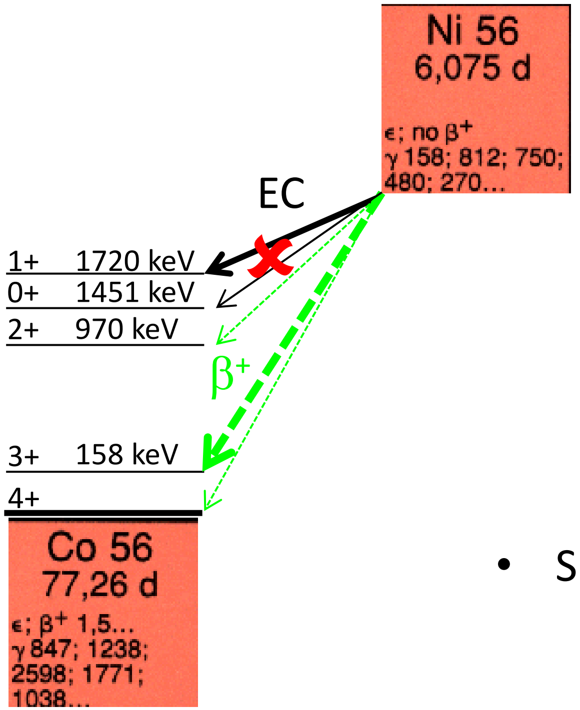
^{54}Mn

- CR chronometer if partial $t_{1/2}$ of β^- branch known
- β^+ branch measured
- **Assuming same log ft for β^- branch** (factor 2-3 uncertainty)
- Direct: $\beta^- < 3.9*10^{-5}$ ⇨ $t_{1/2}(\beta^-) > 22000$ y
- Shell model prediction: $t_{1/2}(\beta^-) \sim 500\,000$ y
  Martinez-Pinedo et al., PRL 81, 281 (1998)
- Form factor for β^- larger than for β^+ decay
  ⇨ Quenching of GT necessary, not necessary for forbidden transitions



	β+ branch		partial half-life (β+) (years)		est. β- branch	est. part. half-life (β-) (years)
Sur (1989)	<4.4E-08		>2.0E+07			>40000
da Cruz (1993)	<5.7E-09		>1.5E+08		<2.9E-06	>295000
Wuosmaa (1997)	1.2E-09	+/-0.3E-09	7.10E+08	+/- 1.5E+08	~6.0E-07	~630000
Zaerpoor (1999)	1.8E-09	+/-0.8E-09	4.70E+08	+/- 2.1E+08	~9.0E-07	~930000

^{56}Ni decay



- Most abundant isotope from SN explosions: early SN lightcurve
- Measure for acceleration time scale if $t_{1/2}$> 10 My

- Measurement (0.1 MBq source, $8*10^{10}$ at.): β^+(158 keV) <$6.3*10^{-5}$ % ⇨ $t_{1/2}(\beta^+)$> 27000 y

Zaerpoor et al., PRC 59, 3393 (1999)

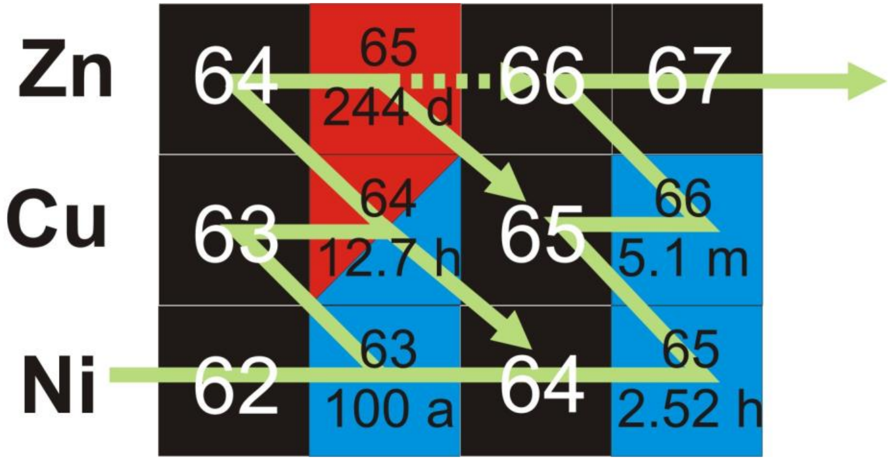
- Shell model predictions   Lund Fisker et al., EPJA 5, 229 (1999)

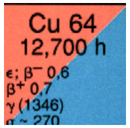
  Partial $t_{1/2}(\beta^+)$
  2+: $(0.6\text{-}3.3)*10^8$ y
  3+: $(3.7\text{-}4.2)*10^4$ y ⇨ **No CR chronometer**
  4+: $(2.6\text{-}5.0)*10^{12}$ y

- Quenching of GT, not for forbidden transition
- If quenched: $t_{1/2}(\beta^+)$= 73000 y

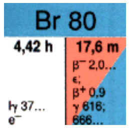
Mixed EC/β-decay isotopes: s process

- s-process "branchings"
- Determines how much material is transferred to next isotope
- Interior of stars: high recombination rates but also high temperatures
- T≈30-1000 MK

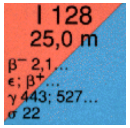




43.9% EC/17.6% β^+

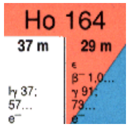


6.1% EC/ 2.2% β^+

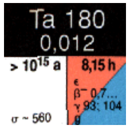


6.9% EC

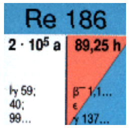
28 (4)% EC
72.1% EC



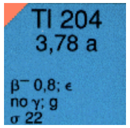
60 (5)% EC



86 (3)% EC

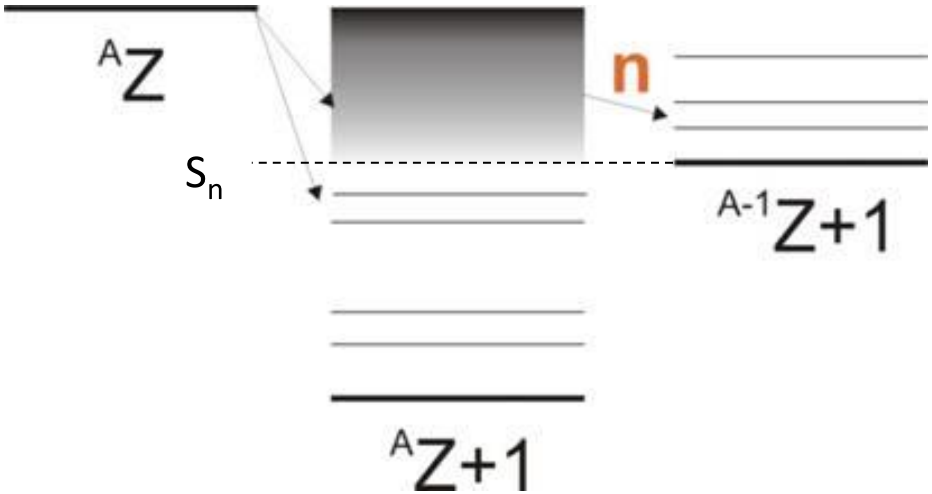


7.47% EC



2.92% EC

β-delayed neutron emission probability



$S_n < Q_\beta$

Important nuclear structure information
P_n : β-strength above S_n
$t_{1/2}(^{A}Z+1)$: sensitive to low-lying β-strength

- Important for nuclear structure, astrophysics (r-process), and reactor physics
- ^{8}He- ^{150}La: ~200 datasets available, ~75 in non-fission region (A<70)

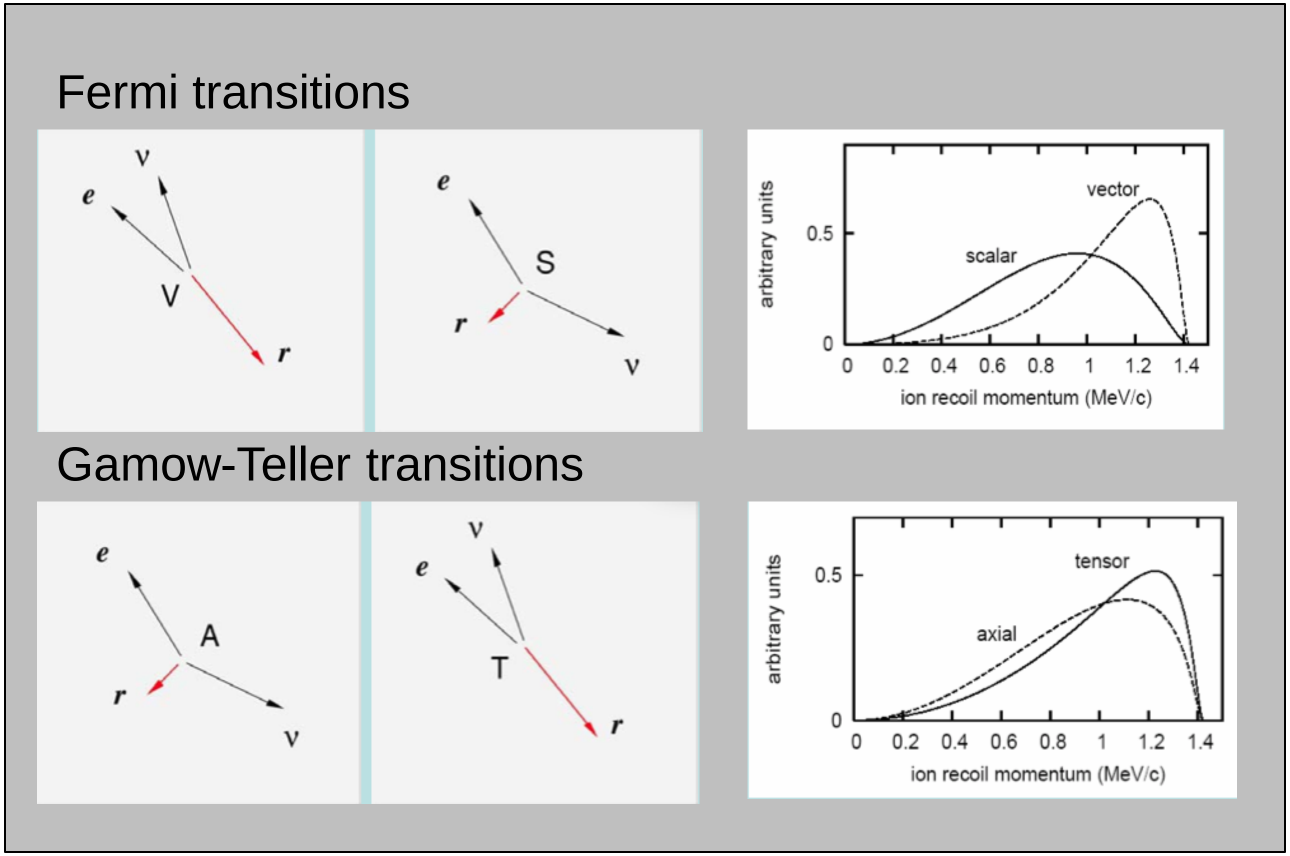
"Biased" Conclusion

Physics Case:	Comments:
New long-lived isomeric states	Single-particle sensitivity → high energy
Lifetimes of exotic nuclei	Single-particle sensitivity → high energy
Beta-decay of heavy-Z HCI	Highest atomic charge states → high energy, Super-EBIT
Beta-decay of low-, medium-Z HCI	High intensities of stored beams → TSR
Beta-decay n-emission	If T1/2 allows → TSR since no long cooling is needed
"GSI Oscillations"	Single-particle sensitivity → high energy, but TSR is possible
7Be and other light-Z isotopes	Few-electron systems → TSR is unique
Isomeric beams, NEEC	Fast slowing down → CRYRING is better

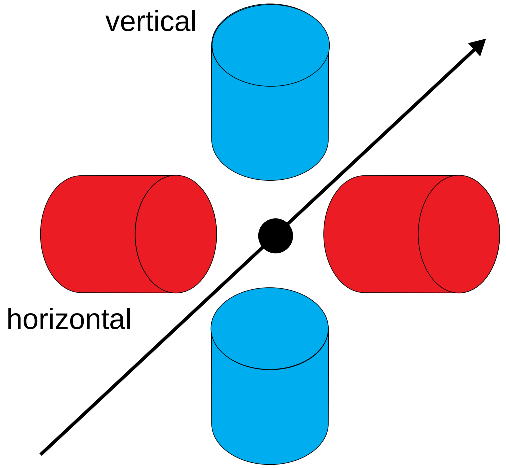
<u>All lifetime studies can run already at 3.8 MeV/u</u>

Paul Kienle
1931-2013

Transverse Schottky pick-up - Test of the V-A nature of weak interaction



Transverse Schottky



accurate determination of transversal component (vertical and horizontal) of the momentum transfer to a recoiling ion in a decay or reaction

Both Schottky detectors together will enable fully-kinematical studies of decays and/or reactions (e.g. to test the fundamental nature of weak interaction via an accurate measurement of the the shape of a beta-decay spectrum)

Physics at Storage Rings

Single-particle sensitivity

Broad-band measurements

High atomic charge states

High resolving power

Long storage times

Very short lifetimes

Direct mass measurements of exotic nuclei

Radioactive decay of highly-charged ions

Charge radii measurements [DR, scattering]

Experiments with polarized beams

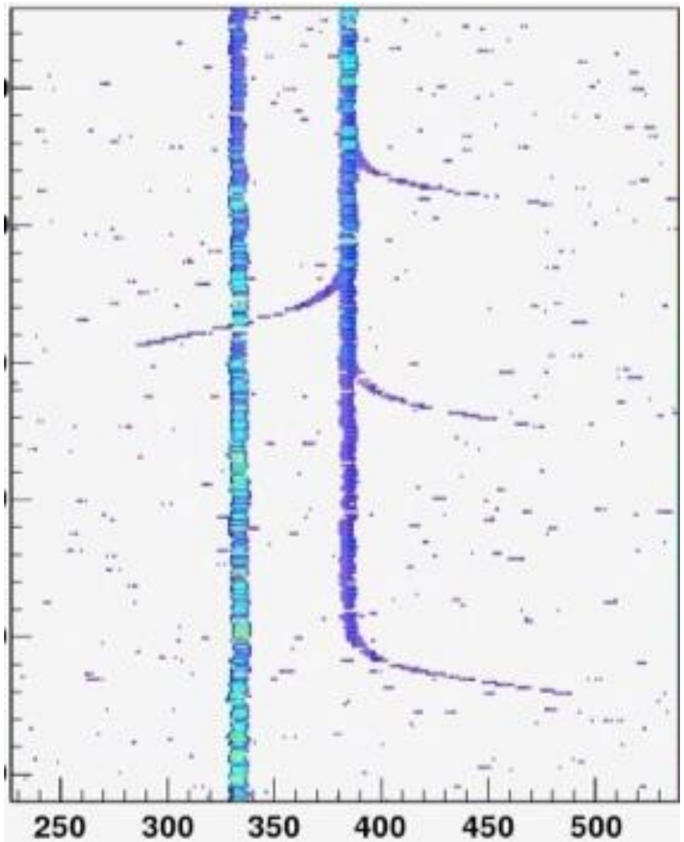
Experiments with isomeric beams [DR, reactions]

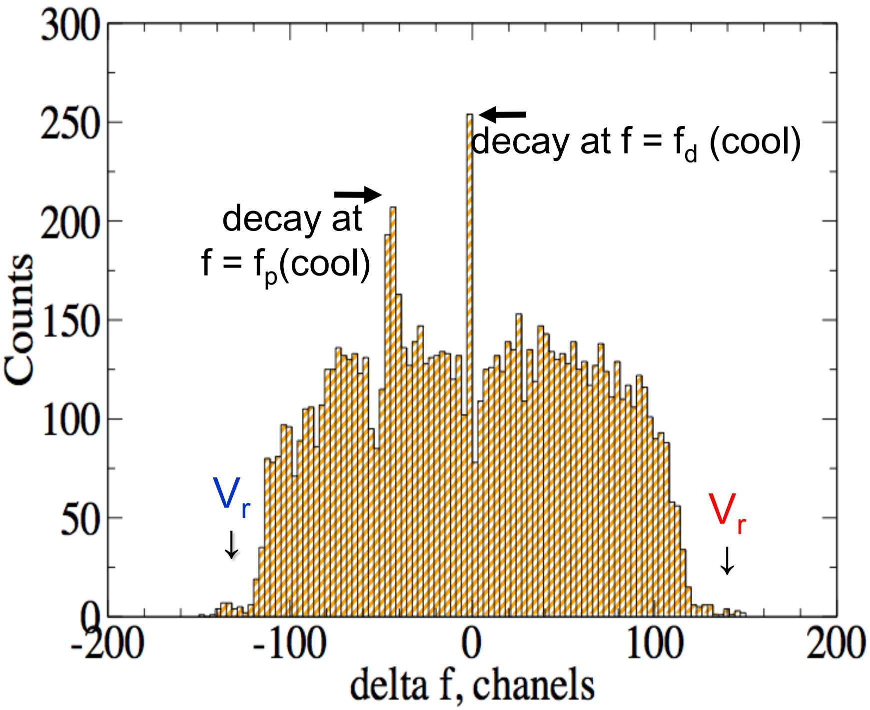
Nuclear magnetic moments [DR]

Astrophysical reactions [(p,g), (a,g) ...]

In-ring nuclear reactions

Revolution-frequency difference δf of the recoils just after decay: $\delta f = f_{dec} - f_{cool}$





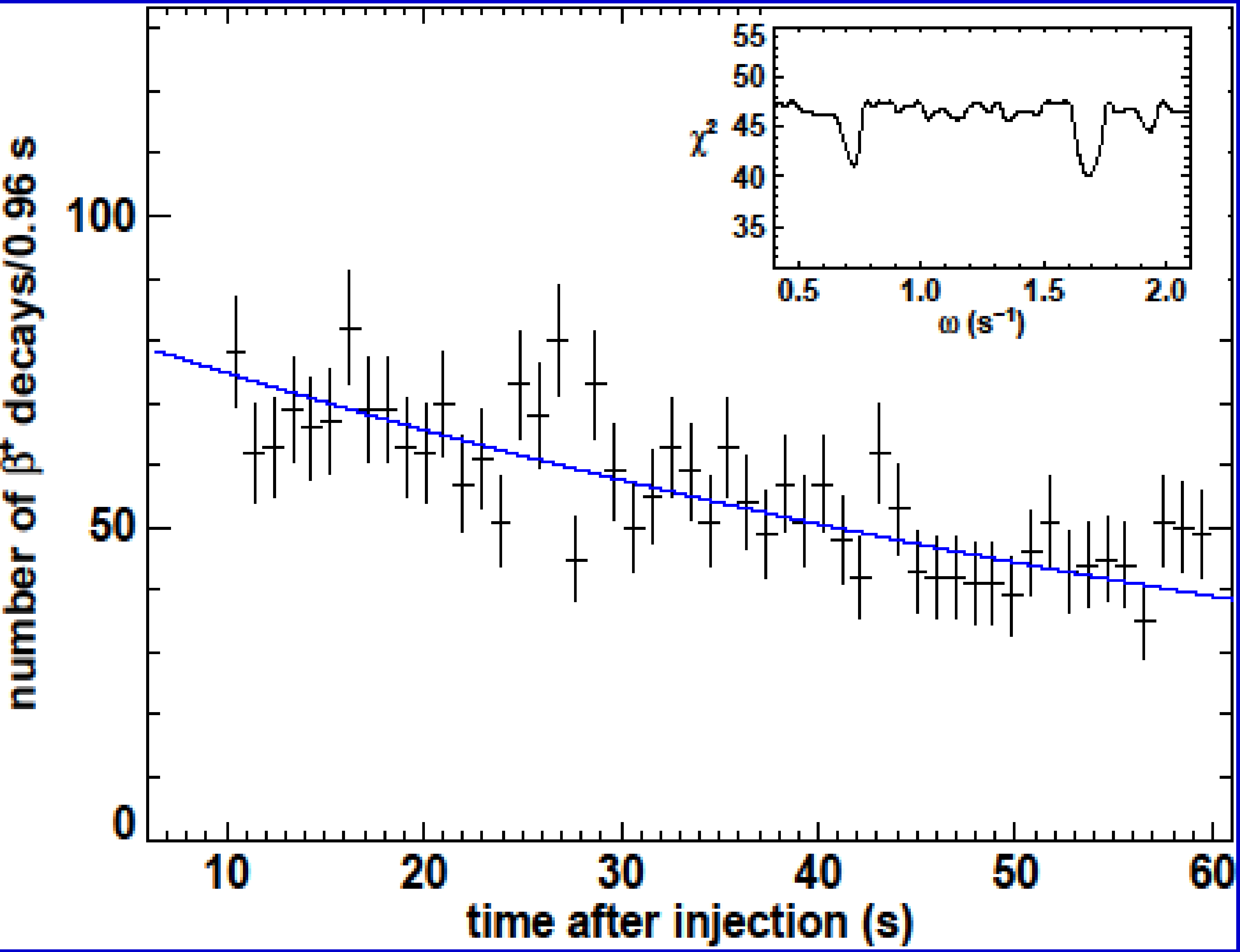
For a (longitudinally) unpolarized beam the distribution should have a rectangular shape

For a (steadily controlled) polarized beam the distribution would provide the helicity of the neutrino

From v_r and m_r one gets the momentum of the (monochromatic) neutrino: $(pc)_d = m_d\, cv_d = (pc)_\nu$

From m_p and m_d one gets its energy: $E_\nu = (m_p - m_d)\, c^2$ and then $\beta_\nu = E_\nu /(pc)_\nu$

245 MHz Resonator: bei ω = 0,907/s a = 0,03(3), **no** significant modulations



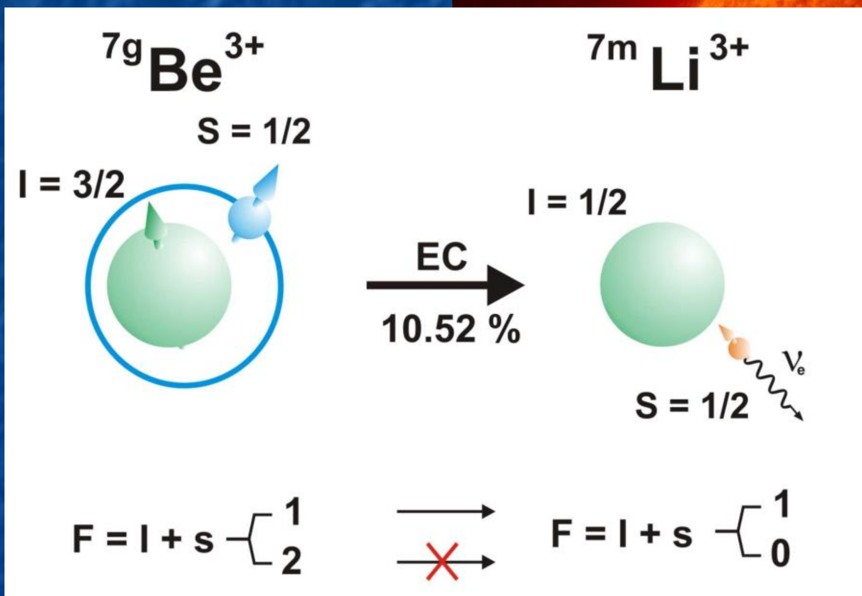
Experimental Collaboration

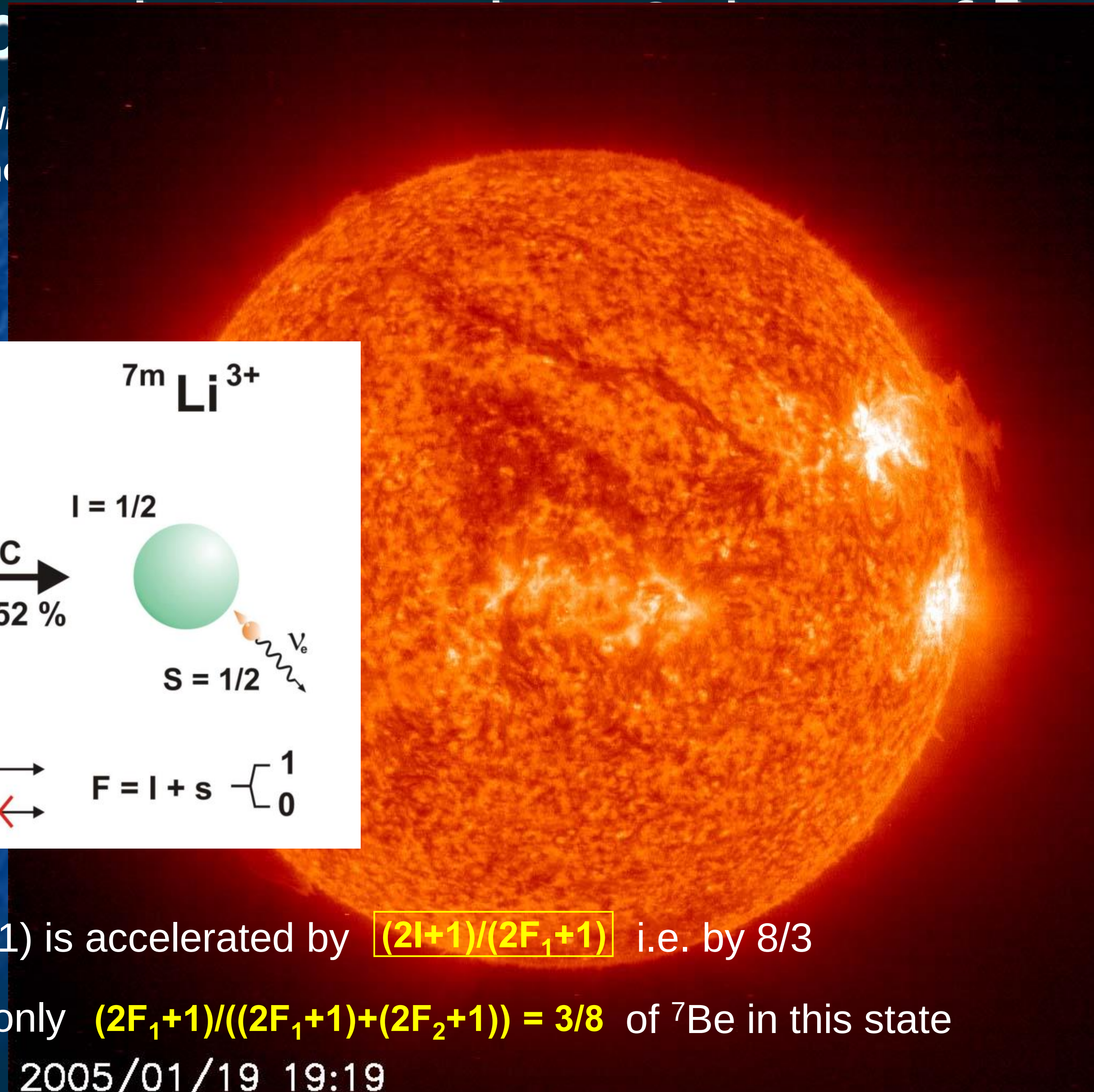
K. Blaum, F. Bosch, M. Grieser, R. von Hahn, B. Jordon-Thaden, Ch. Kozhuharov, Yu.A. Litvinov, R. Repnow, S. Sanjari, D. Shubina, Th. Stöhlker, N. Winckler, A. Wolf

Some sp

A.V. Gruzinov, J.N. Bahcal

Ionization of ^{7}Be in th

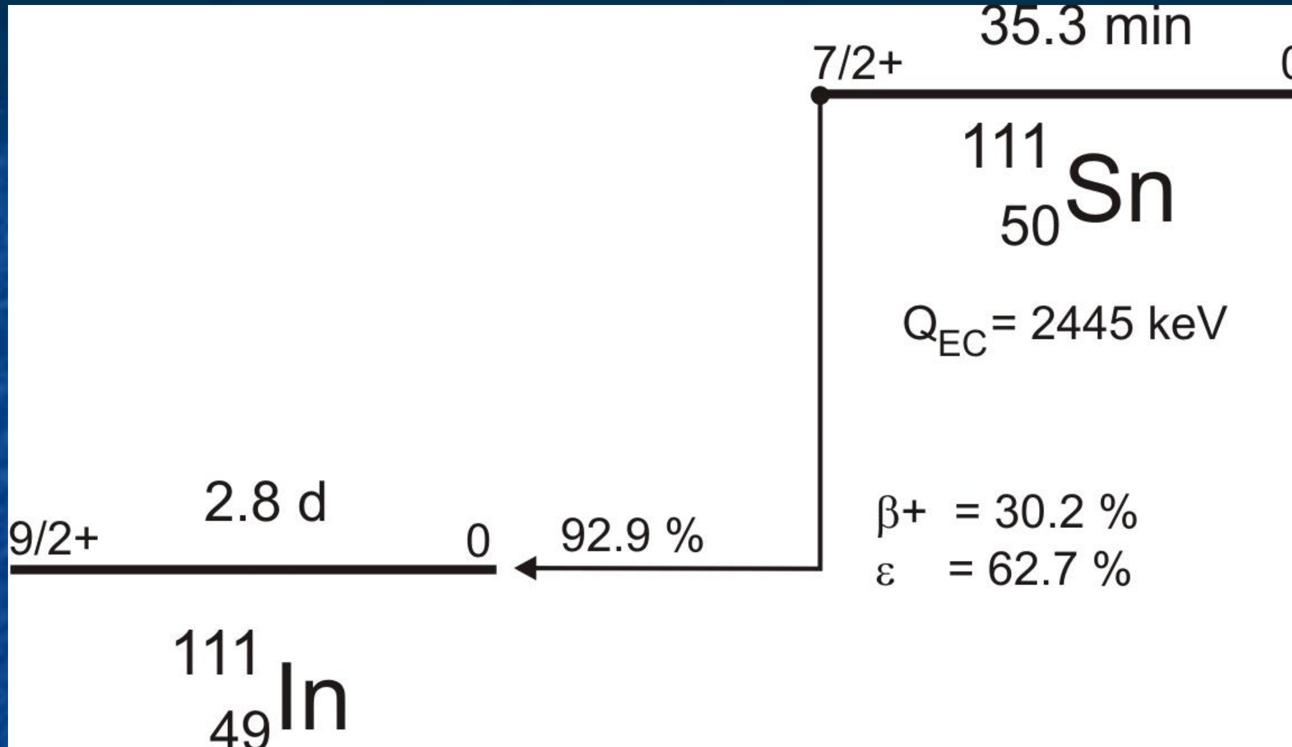




Transition (F=1→F=1) is accelerated by **$(2I+1)/(2F_1+1)$** i.e. by 8/3

However, there are only **$(2F_1+1)/((2F_1+1)+(2F_2+1)) = 3/8$** of ^{7}Be in this state

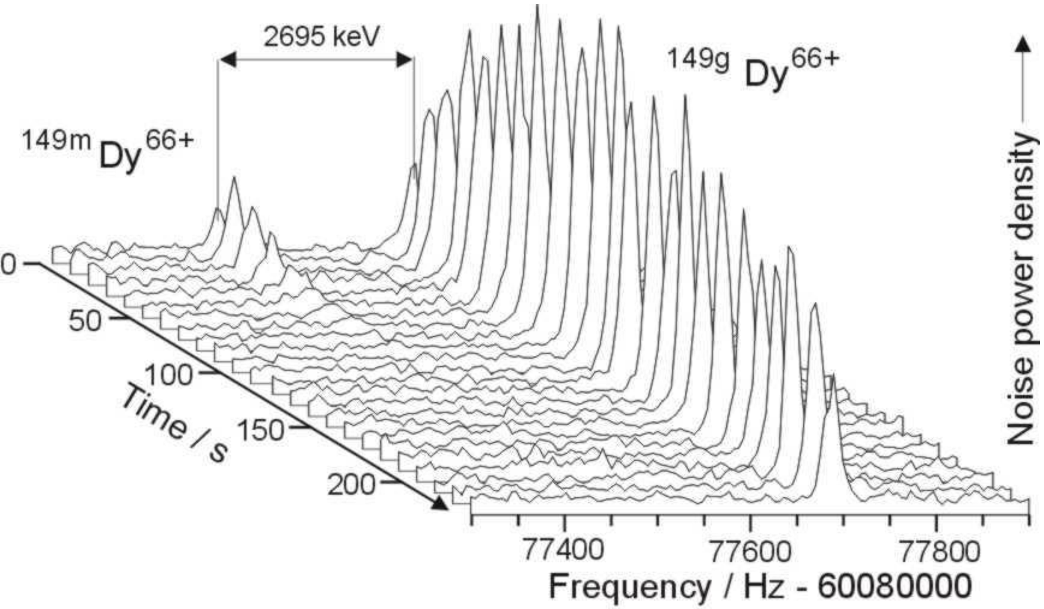
Electron Capture in Hydrogen-like Ions

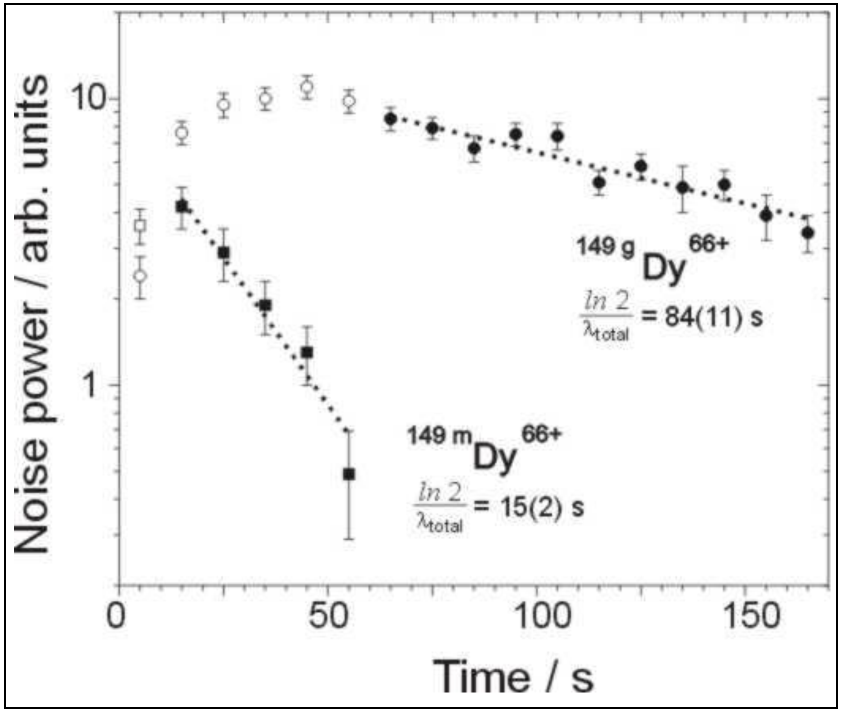


F = I + s → 4, 3 ⟶ F = I + s → 5, 4

Possibility to address the electron screening in beta decay under very clean conditions !

Half-Lives of Nuclear Isomers





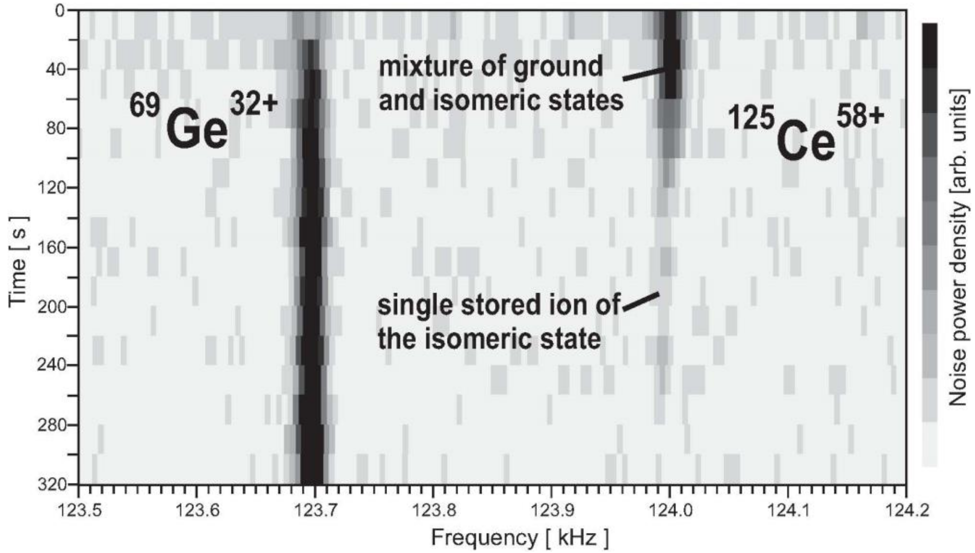
Neutral atom is 0.49(2) s

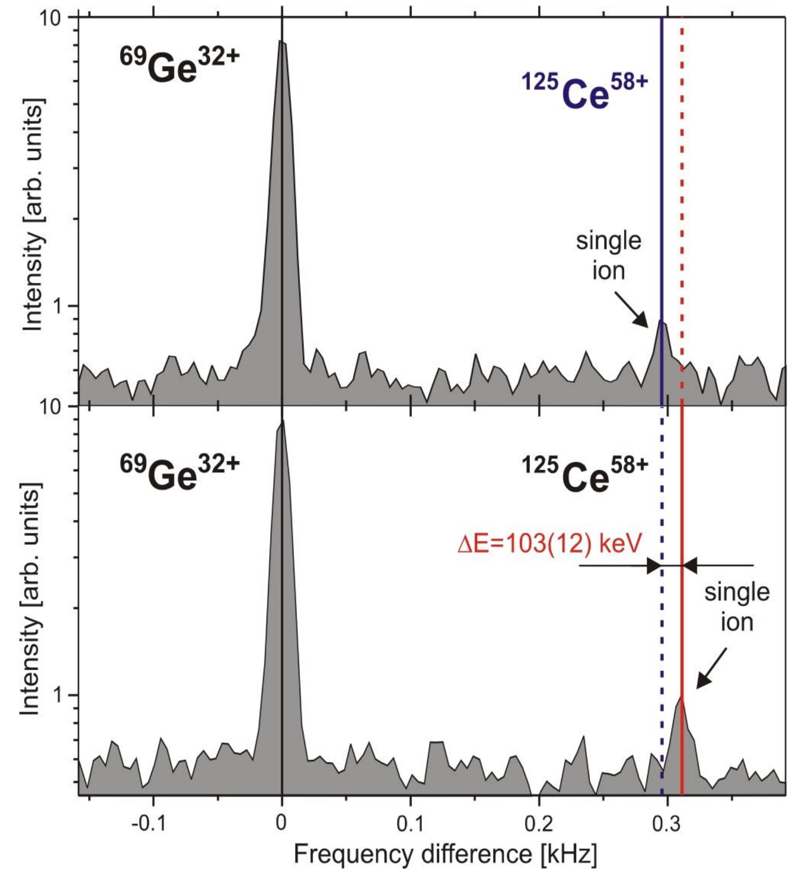
Fully ionized atom is 11(1) s

$$\frac{T_{1/2}\text{ (fully ionized)}}{T_{1/2}\text{ (neutral)}} = 22(2)$$

Isomer	$T_{1/2}$ bare, s	$T_{1/2}$ neutral, s	Hindrance factor
^{151m}Er	19(3)	0.58(2)	33(5)
^{149m}Dy	11(1)	0.49(2)	22(2)
^{144m}Tb	12(2)	4.25(15)	2.8(5)

New isomeric states

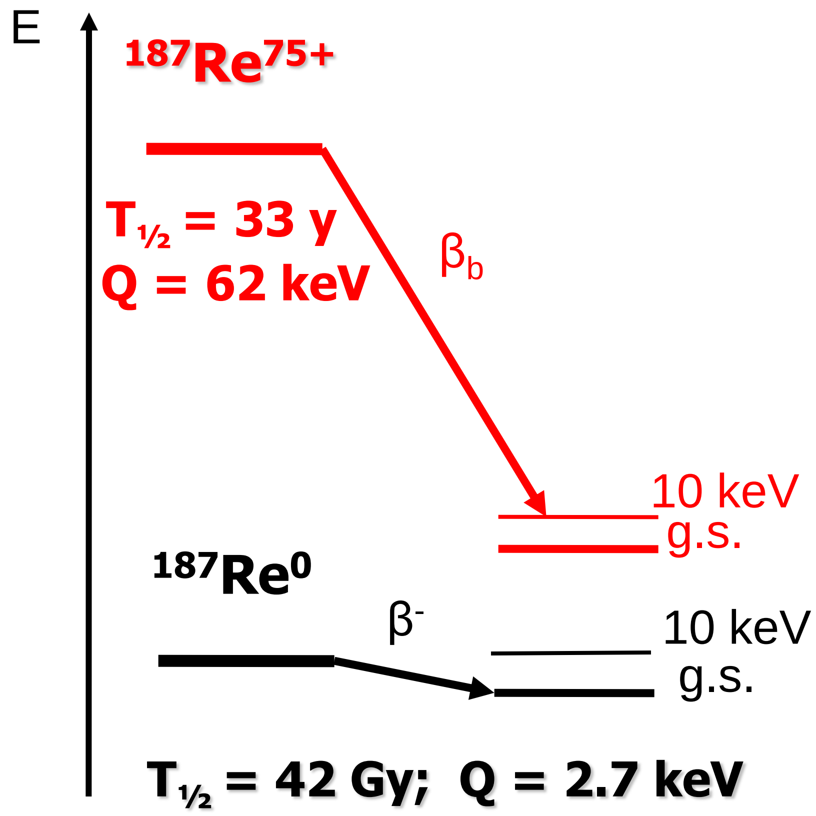




Lifetime = 193 s

B. Sun et al., EPJA 31 (2007) 393

Bound-State β-decay of ^{187}Re



F. Bosch et al., Phys. Rev. Lett. 77 (1996) 5190

The 7 Nuclear Clocks

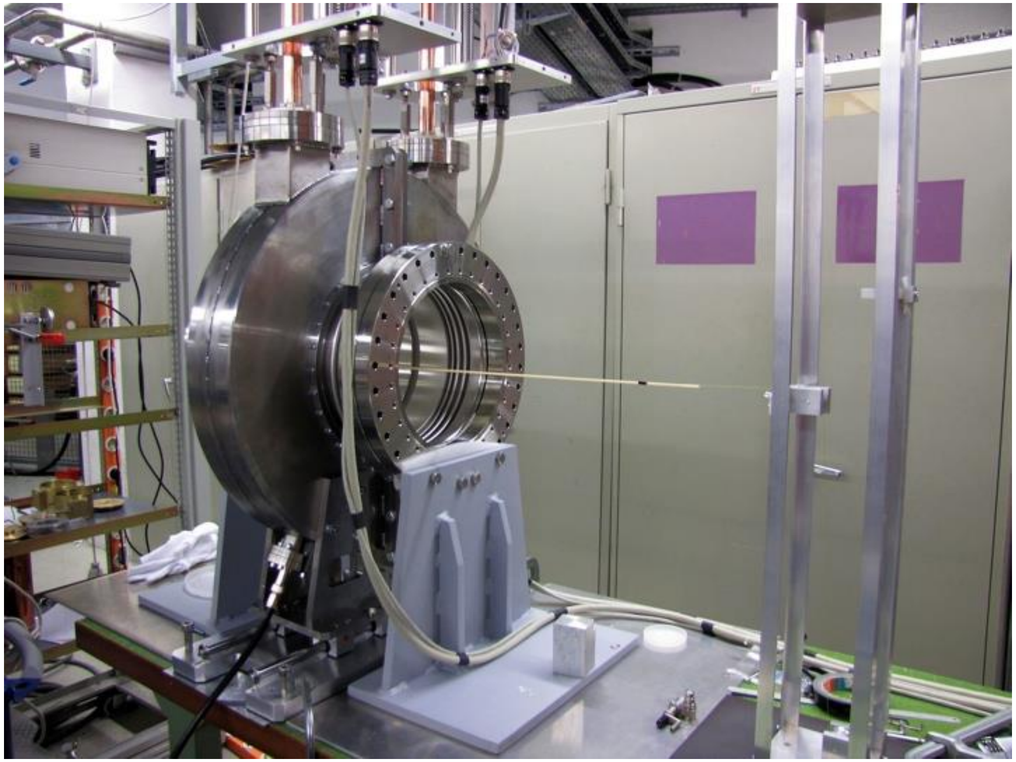
the Earth, the Solar System, the Galaxy, and the Universe

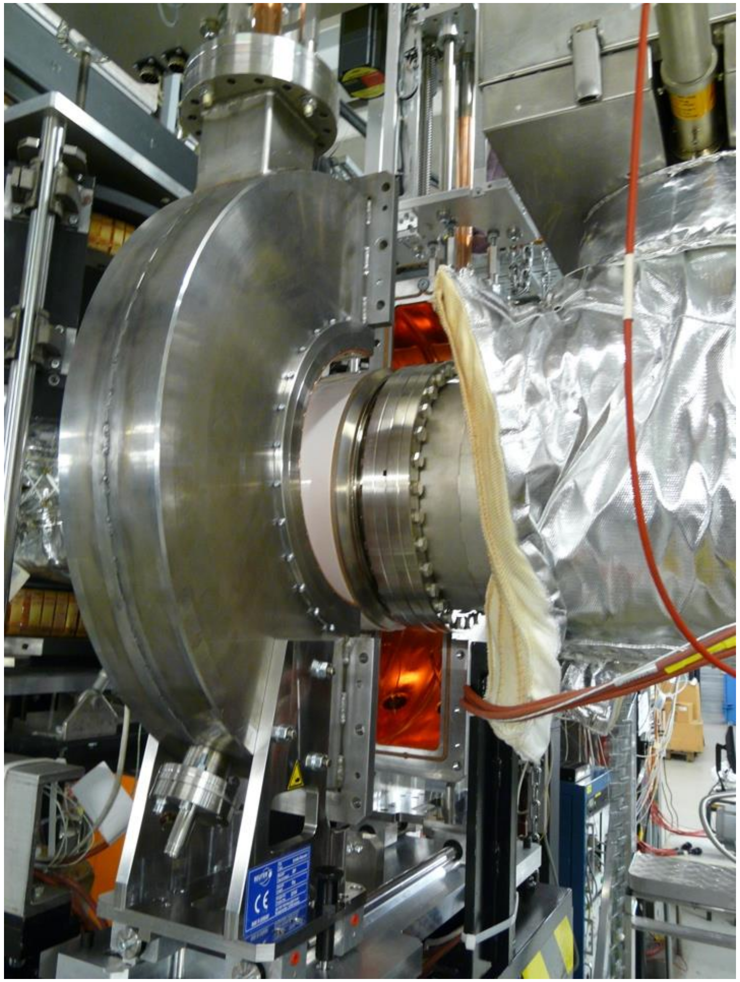
clock	$T_{1/2}$ [10^9 y]
$^{40}K/^{40}Ar$ (®)	1.3
^{238}U...Th...^{206}Pb (《,®)	4.5
^{232}Th...Ra...^{208}Pb (《,®)	14
$^{176}Lu/^{176}Hf$ (®)	30
$^{187}Re/^{187}Os$ (®)	42
$^{87}Rb/^{87}Sr$ (®)	50
$^{147}Sm/^{143}Nd$ (《)	100

Hubble Ultra Deep Field
Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, S. Beckwith (STScI) and the HUDF Team STScI-PRC04-07a

New Resonant Schottky Cavity

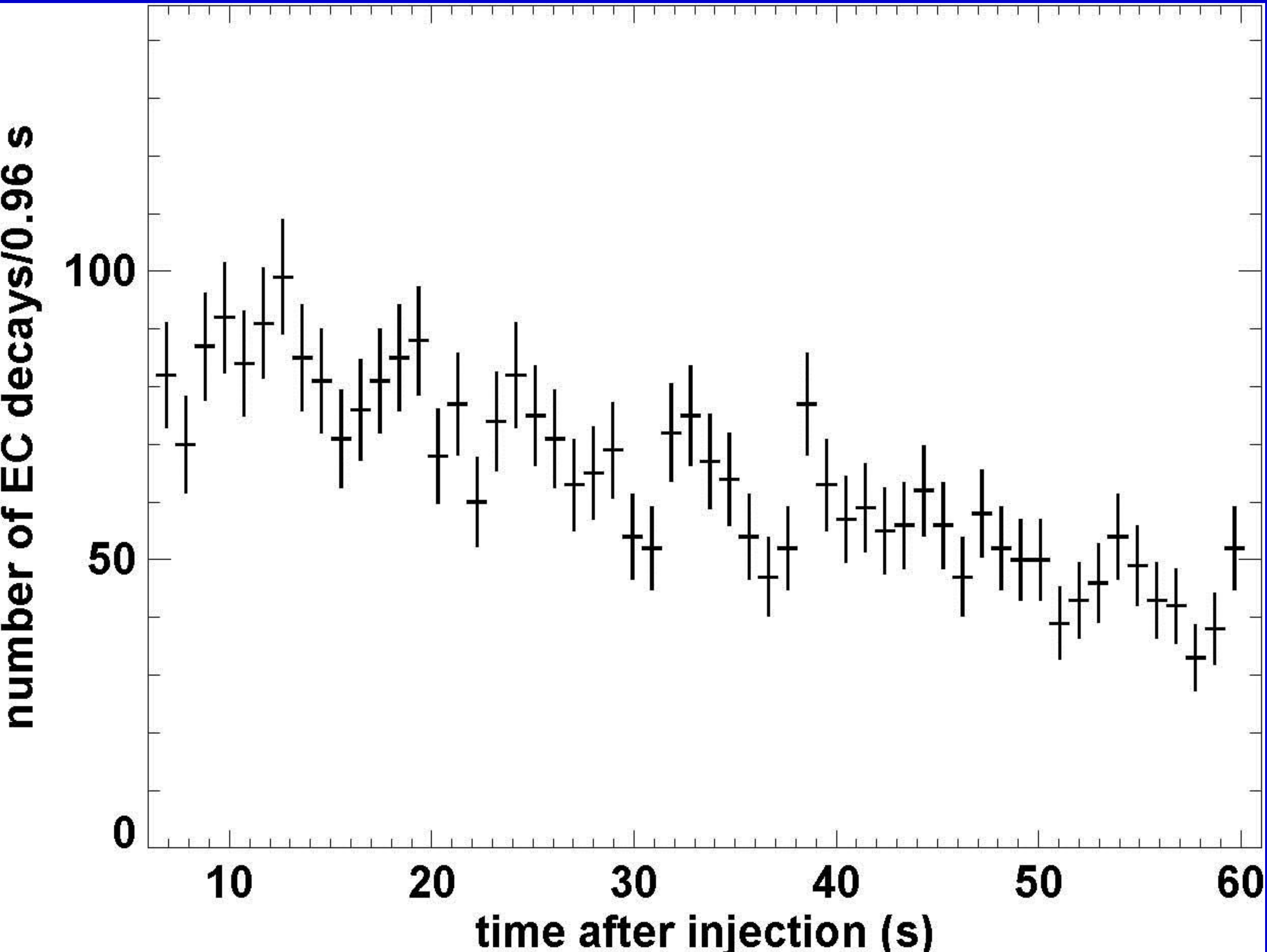




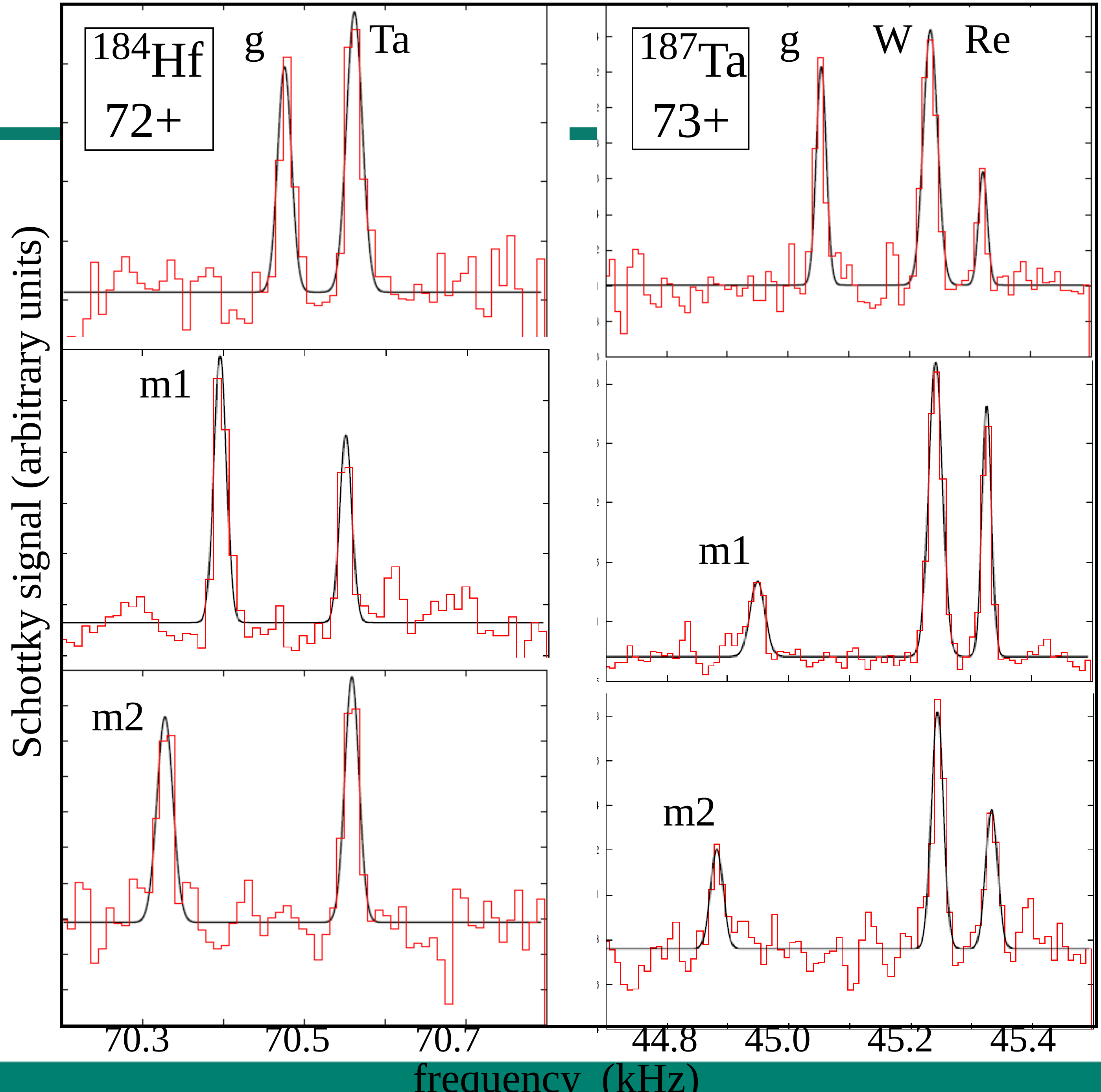
The signal-to-noise ratio is improved by a factor of about 100

F. Nolden et al., Nucl. Instr. Meth. A (2011) in press

245 MHz Resonator: 3660 **EC-Decays** of H-like $^{142}Pm^{60+}$

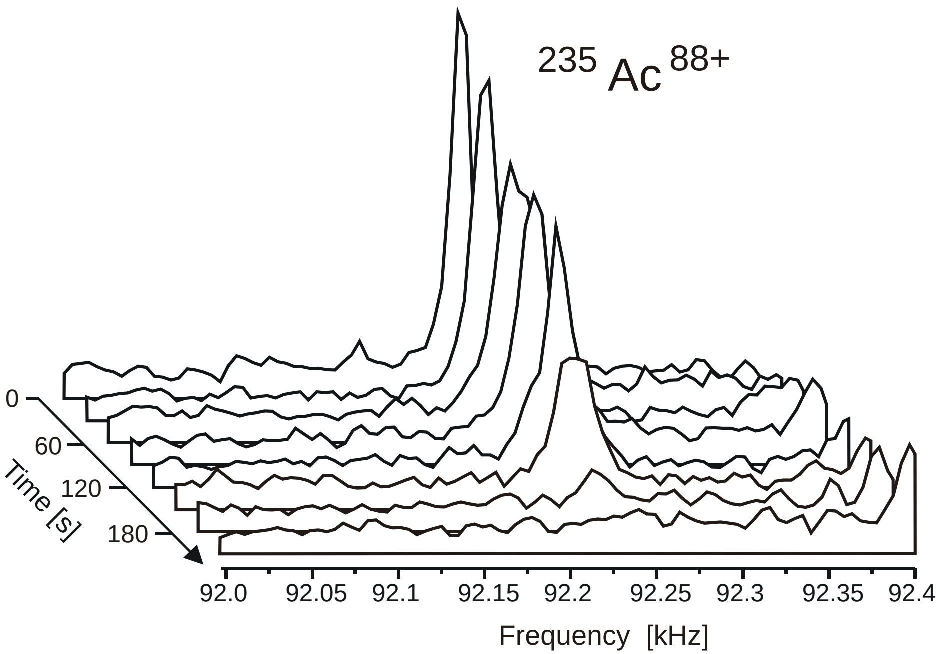


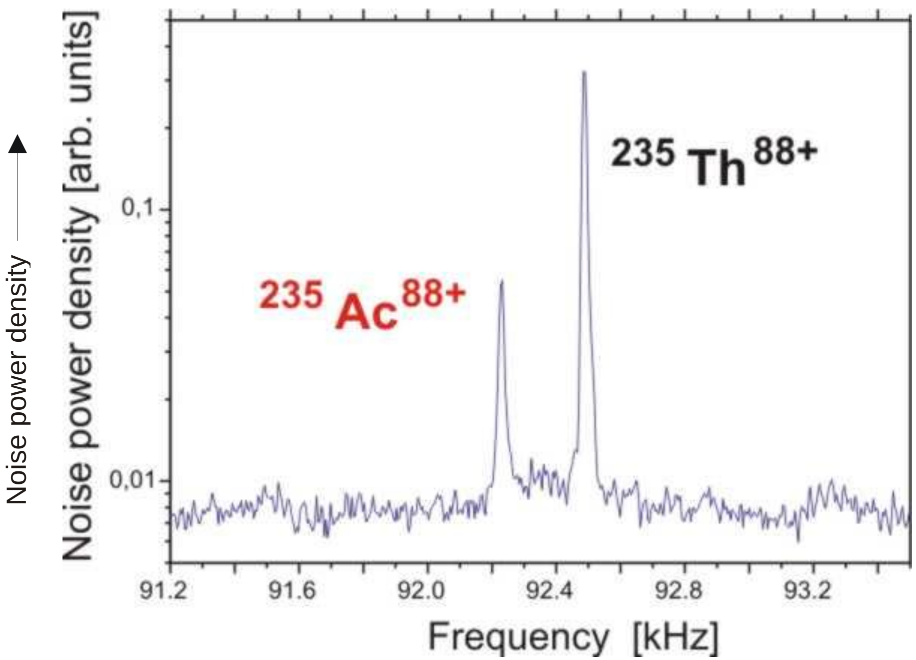
Max Planck Institute for Nuclear Physics



2009 experiment

New Isotope ^{235}Ac





Mass and half-life values
in one experiment

MAX PLANCK INSTITUTE FOR NUCLEAR PHYSICS

Fragmentation of ^{197}Au

2009 experiment

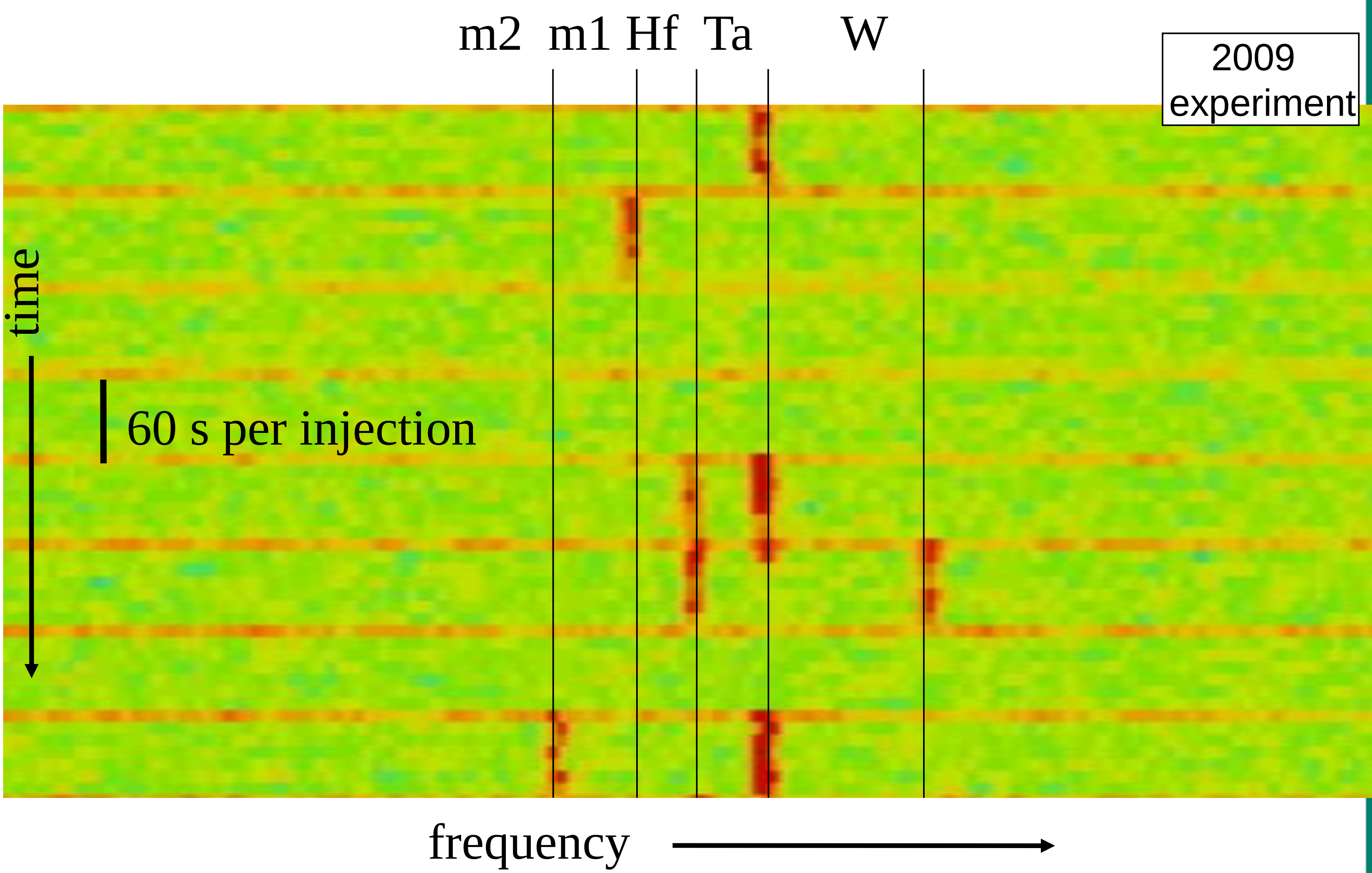
187Au 8.4 M ε: 100.00% α: 3.0E-3%	188Au 8.84 M ε: 100.00%	189Au 28.7 M ε: 100.00% α < 3.0E-5%	190Au 42.8 M ε: 100.00% α < 1.0E-6%	191Au 3.18 H ε: 100.00%	192Au 4.94 H ε: 100.00%	193Au 17.65 H ε: 100.00%	194Au 38.02 H ε: 100.00%	195Au 186.098 D ε: 100.00%	196Au 6.1669 D ε: 93.00% β-: 7.00%	197Au STABLE 100%
186Pt 2.08 H ε: 100.00% α≈ 1.4E-4%	187Pt 2.35 H ε: 100.00%	188Pt 10.2 D ε: 100.00% α: 2.6E-5%	189Pt 10.87 H ε: 100.00%	190Pt 6.5E+11 Y 0.014% α: 100.00%	191Pt 2.83 D ε: 100.00%	192Pt STABLE 0.782%	193Pt 50 Y ε: 100.00%	194Pt STABLE 32.967%	195Pt STABLE 33.832%	196Pt STABLE 25.242%
185Ir 14.4 H ε: 100.00%	186Ir 16.64 H ε: 100.00%	187Ir 10.5 H ε: 100.00%	188Ir 41.5 H ε: 100.00%	189Ir 13.2 D ε: 100.00%	190Ir 11.78 D ε: 100.00%	191Ir STABLE 37.3%	192Ir 73.827 D β-: 95.13% ε: 4.87%	193Ir STABLE 62.7%	194Ir 19.28 H β-: 100.00%	195Ir 2.5 H β-: 100.00%
184Os >5.6E+13 Y 0.02% α	185Os 93.6 D ε: 100.00%	186Os 2.0E+15 Y 1.59% α: 100.00%	187Os STABLE 1.6%	188Os STABLE 13.29%	189Os STABLE 16.21%	190Os STABLE 26.36%	191Os 15.4 D β-: 100.00%	192Os STABLE 40.93%	193Os 30.11 H β-: 100.00%	194Os 6.0 Y β-: 100.00%
183Re 70.0 D ε: 100.00%	184Re 38.0 D ε: 100.00%	185Re STABLE 37.40%	186Re 3.7186 D β-: 92.53% ε: 7.47%	187Re 4.12E+10 Y 62.60% β-: 100.00% α < 1.0E-4%	188Re 17.003 H β-: 100.00%	189Re 24.3 H β-: 100.00%	190Re 3.1 M β-: 100.00%	191Re 9.8 M β-: 100.00%	192Re 16 S β-: 100.00%	193Re
182W >8.3E+18 Y 26.50% α	183W >1.3E+19 Y 14.31% α	184W >2.9E+19 Y 30.64% α	185W 75.1 D β-: 100.00%	186W >2.7E+19 Y 28.43% α	187W 23.72 H β-: 100.00%	188W 69.78 D β-: 100.00%	189W 10.7 M β-: 100.00%	190W 30.0 M β-: 100.00%	191W >300 NS β-	192W >300 NS β-
181Ta STABLE 99.988%	182Ta 114.43 D β-: 100.00%	183Ta 5.1 D β-: 100.00%	184Ta 8.7 H β-: 100.00%	185Ta 49.4 M β-: 100.00%	186Ta 10.5 M β-: 100.00%	187Ta ≈2 M β-	188Ta ≈20 S β-	189Ta 3 S β-	190Ta 0.3 S β-	
180Hf STABLE 35.08%	181Hf 42.39 D β-: 100.00%	182Hf 8.90E+6 Y β-: 100.00%	183Hf 1.067 H β-: 100.00%	184Hf 4.12 H β-: 100.00%	185Hf 3.5 M β-: 100.00%	186Hf 2.6 M β-: 100.00%	187Hf 30 S β-	188Hf 20 S β-		

beam

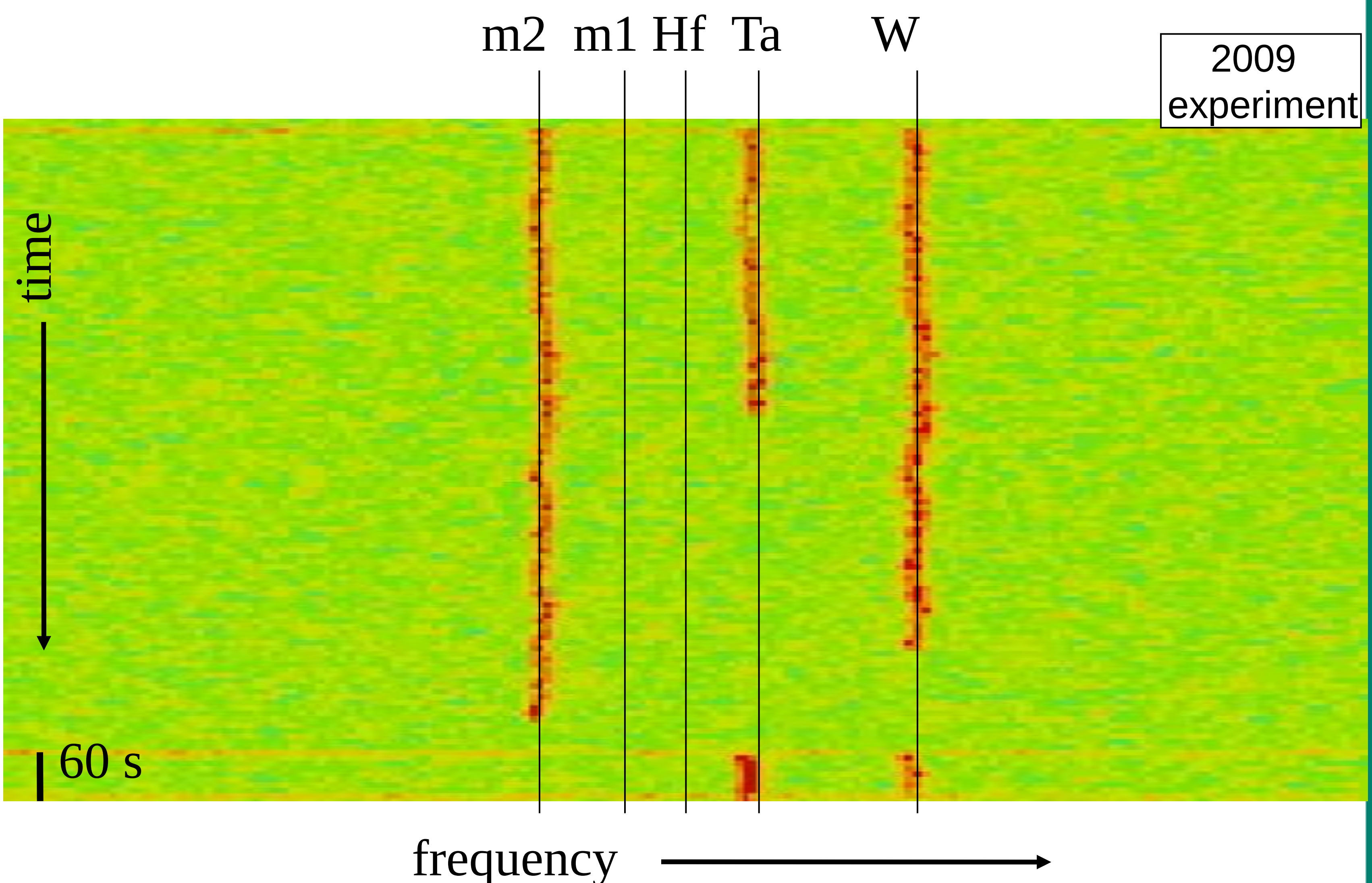
new isomers $T_{1/2}$ >10 s

MAX-PLANCK-GESELLSCHAFT

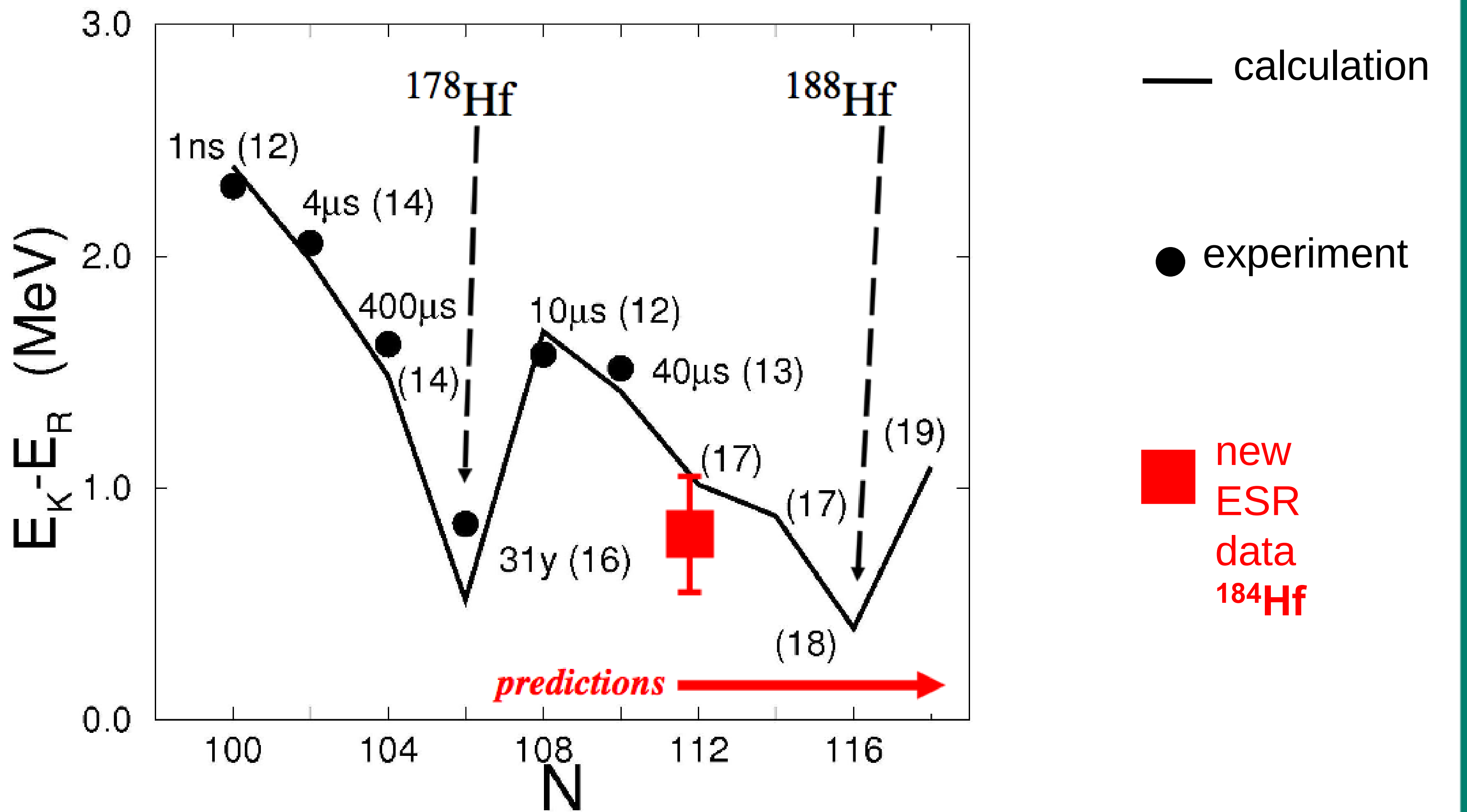
A=184 (72^+) Isobars and Isomers



A=184 (72^+) Isobars and Isomers

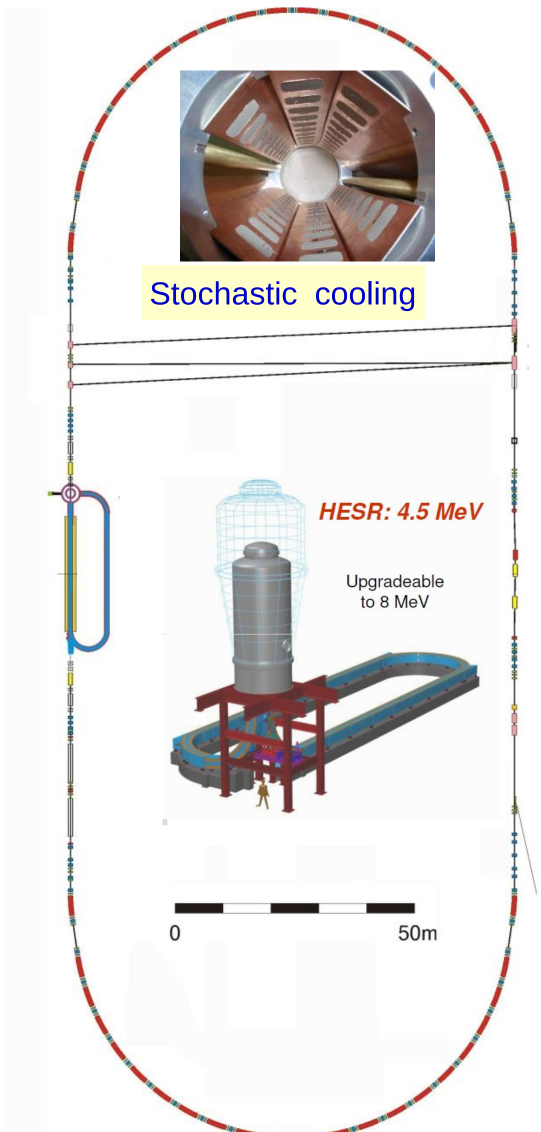


Hafnium 4-Quasiparticle Isomers



Walker and Dracoulis, Nature 399 (1999) 35; Hyp. Int. 135 (2001) 83

The High Energy Storage Ring HESR



SPARC Experiments at the HESR:

A Feasibility Study

Thomas Stöhlker[1,2,3], Reinhold Schuch[4], Siegbert Hagmann[1,5], Yuri A. Litvinov[1,2]
for the SPARC Collaboration[*]
Christina Dimopoulou[1], Alexei Dolinskii[1], & Markus Steck[1]

Advantages & Drawbacks

+ Independent on worldwide ^{3}He shortage

+ Decay detector: cheaper than neutron detector array

+ Only few atoms/ injection needed

+ Independent on neutron energy (detection efficiency problem)

- No cooling possible (isotopes too short-lived)

- Low efficiency (could be increased by 2nd detector)

- Produced ions have to be transferred from FRS into ESR (losses)

Possible cases: βn standards

Possible standards selected by IAEA consultants' meeting (2011)

^{9}Li: P_n= 50.8 (2) %

^{17}N: P_n= 95.1 (7) %

^{87}Br: P_n= 2.43 (14) %

^{88}Br: P_n= 6.67 (17) %

^{94}Rb: P_n= 10.19 (30) %

^{95}Rb: P_n= 8.89 (33) %

^{137}I: P_n= 7.33 (38) %

- Should be measured with independent methods and agree
- Standard for every mass region
- Missing: A>150 and A~60

β-delayed neutron emitters

- Measuring P_n values without neutron detectors
- Complementary to standard methods

Available methods (up to now):

•**"n/β":** Neutron-beta coincidences

•**"n-β":** Neutrons and betas counted separately (no coincidences) but simultaneously

•**"γ ^{A}Z+n":** Abundance of precursor determined via gamma-counting of any β-decay daughter

•**"P_n ^{A}Z":** Normalization of the ratio $\varepsilon_b/\varepsilon_n$ with known P_n value from precursor ^{A}Z

•**"γ–γ":** Number of neutron decays determined only via γ-counting

•**"ion":** Ion counting

•**"fiss":** Fission yields