Experiments with stored highly-charged ions at ISOLDE: TSR@HIE-ISOLDE proposal

Yuri A. Litvinov
for the TSR@HIE-ISOLDE team

ISOLDE Workshop and Users meeting 2011
05-07 December 2011, CERN

Physics Case For a Low-Energy Storage Ring

Letter of Intent to the ISOLDE and Neutron Time-of-Flight Committee

Storage ring facility at HIE-ISOLDE

evaluated at INTC meeting on 2nd February 2011

CERN-INTC-2011-019, INTC-I-133, *Storage ring facility at HIE-ISOLDE*

The LOI for HIE-ISOLDE was found very interesting and, if successful, it would lead to the first storage ring at an ISOL-type facility. The planned experimental programme is diverse and offers unique opportunities for studies in nuclear structure and nuclear astrophysics. The feasibility of some of the proposed studies needs to be further investigated, as well as the space, cost and manpower required for installing and running the device. The committee **endorsed** the scientific case presented in the LOI and encouraged the proponents to submit a Technical Design Report for the move and installation of the TSR at ISOLDE at their earliest convenience.

we intend to submit the Technical Design Proposal for the evaluation to the coming INTC meeting

First time a storage ring would be connected to an ISOL-based facility!

ISOLDE Workshop and Users meeting 2011
05-07 December 2011, CERN

Physics Case For a Low-Energy Storage Ring

- **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**
- **.....**

Motivation for ISOL facility + Storage ring

1. Higher intensities and cooler beams than in-flight storage rings

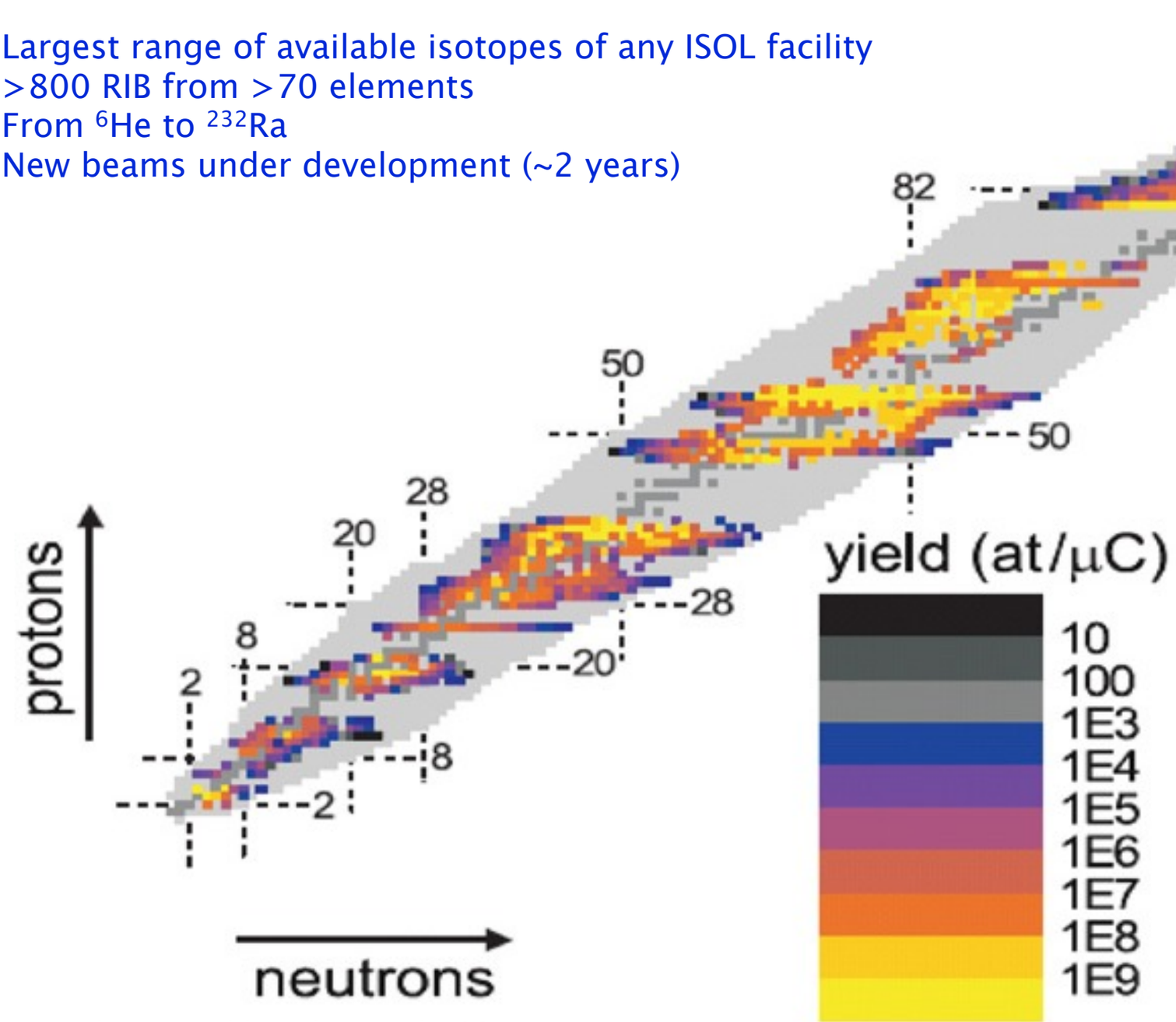
2. Compared to thick experimental target and direct beam from the post-accelerator:
   + no background from a target container or a beam dump
   + reduced energy straggling for projectile and reaction products in thin target
   + smaller beam size -> improved kinematic corrections for reaction products
   + decreased detector dead-time as CW beam (REX and HIE-ISOLDE pulsed)

3. Question marks
   ? Internal target -> beam storage lifetime
   ? Beam injection scheme – exotic ions, limit loss
   ? Loading rate
   ? Luminosities sufficient for nuclear physics

[F. Wenander, STORI'11, Frascati]

Beams @ ISOLDE

* Largest range of available isotopes of any ISOL facility
* >800 RIB from >70 elements
* From ^{6}He to ^{232}Ra
* New beams under development (~2 years)



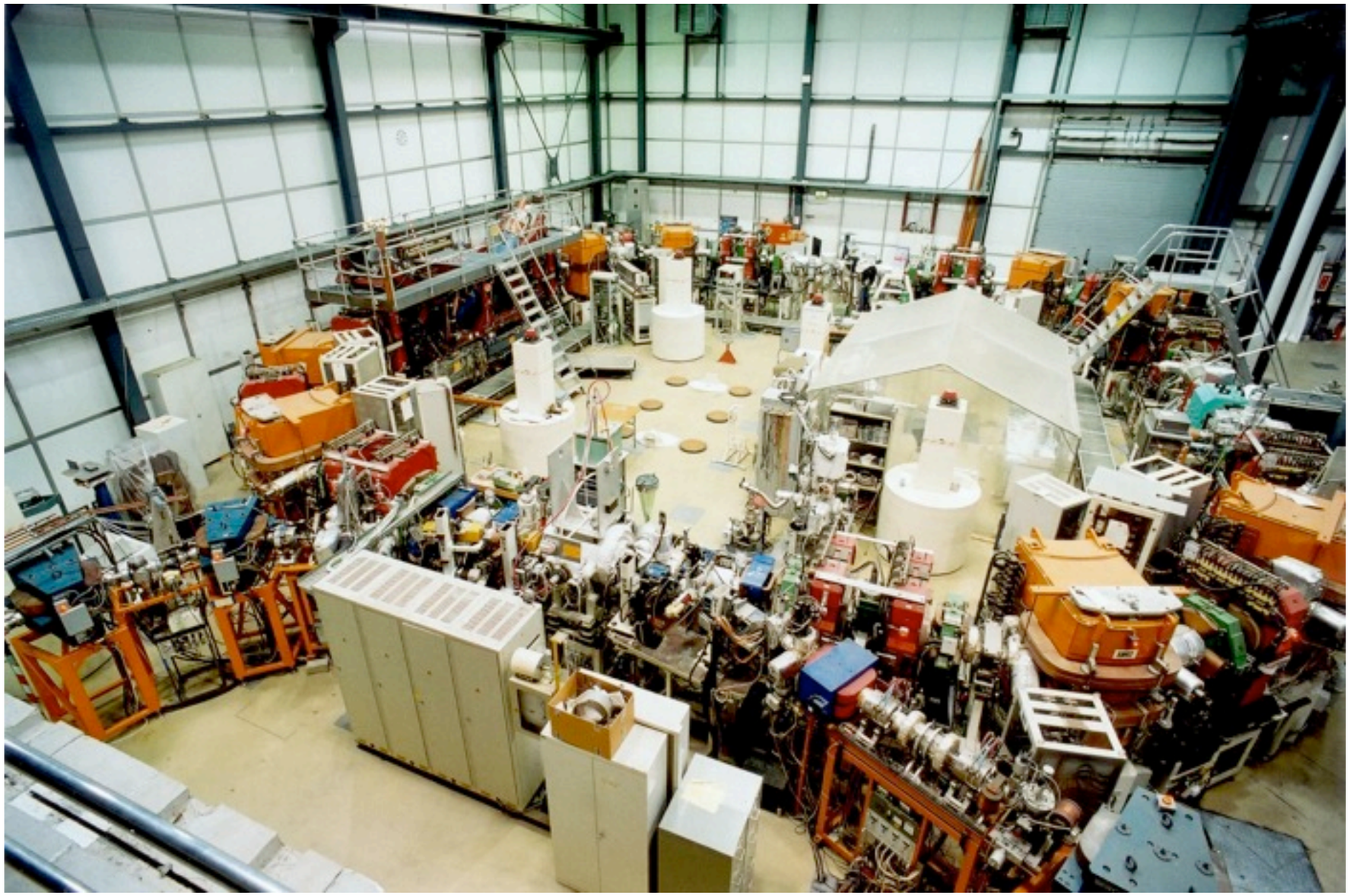
ISOLDE's strength:
heavy isotopes produced with spallation from UCx

The gaps with no beams available correspond to refractory-type elements e.g. the Ti(Z=22)-V(23), Zr(40)-Rh(45) and Ta(73)-Pt(78) regions or extremely short-lived isotopes.

http://isolde.web.cern.ch/ISOLDE/

Old data from 2006

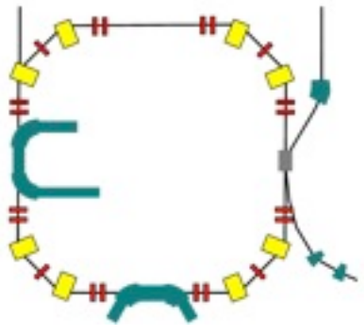
Heavy-Ion Storage Ring TSR at MPIK Heidelberg



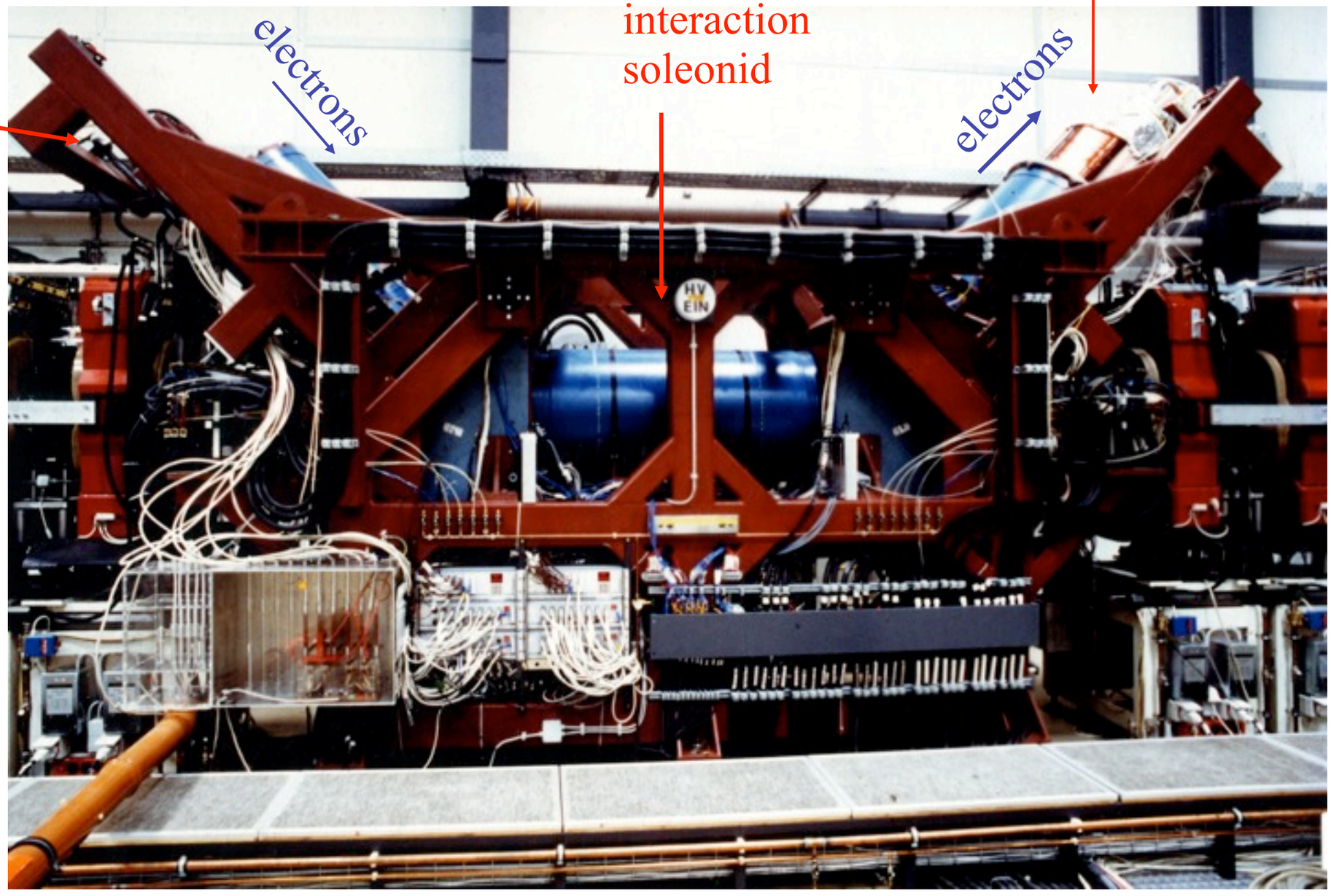
In operation: since 1988
Circumference: 55 m
Vacuum: ~10^{-11} mbar
Acceptance: 120 mm mrad
Multi-turn injection: mA current
Electron cooler
Electron target
RF (de)acceleration

Typical energy $^{12}C^{6+}$: 6 MeV/u
Lifetime: hours

Ion Storage Ring TSR, http://www.mpi-hd.mpg.de/blaum/storage-rings/tsr/index.en.html



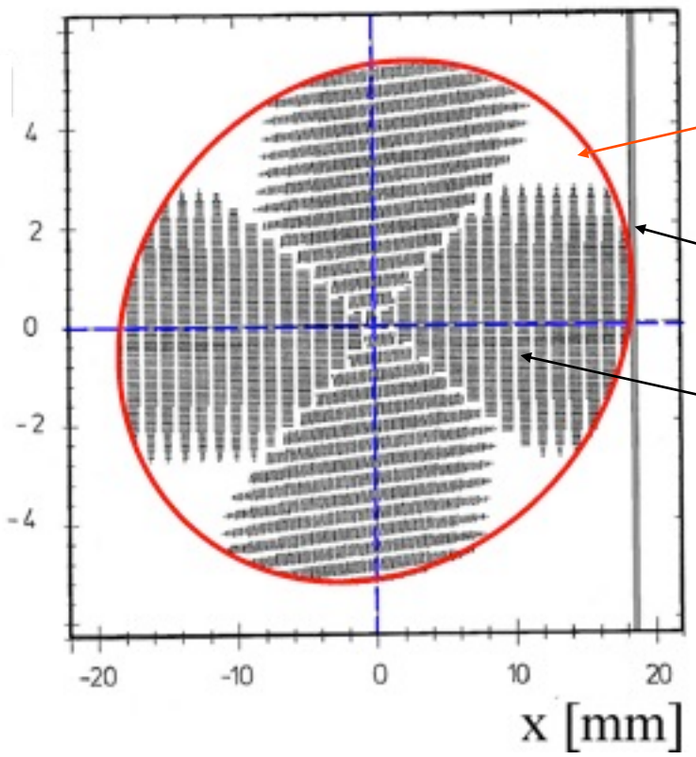
The TSR Electron Cooler



Multi-Turn Injection

With multi-turn Injection filled transverse phase space

Simulation for the heavy ion storage ring TSR



acceptance ellipse
A=120 mm·mrad

septum thickness

phase space
injector beam
(tandem)
ε=1.5 mm·mrad

injection time
≈100 turns

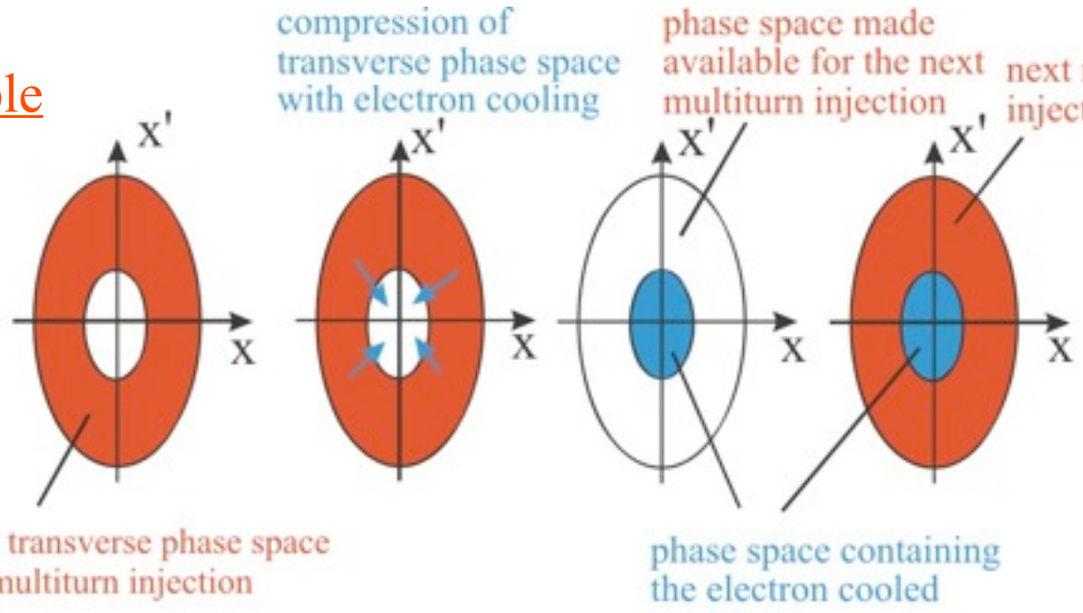
intensity multiplication factor M:

$$M = \frac{I_0}{I_{inj}} = \frac{A}{d \times \varepsilon}$$

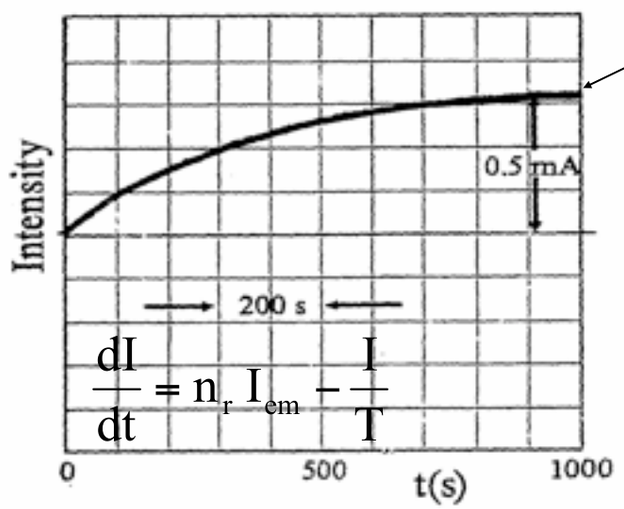
I_0 stored intensity , I_{inj} injector intensity
d- phase space dilution factor,
simulation $d \approx 2 \Rightarrow M \approx 40$

Electron-Cooling Stacking

principle



measured I(t) for $^{35}Cl^{17+}$ ions



$$\frac{dI}{dt} = n_r I_{em} - \frac{I}{T}$$

equilibrium intensity I_0

$$I_0 = n_r \times T \times M_{eff} \times I_{inj}$$

$$n_r = \begin{cases} 1/T_{cool} & T_{cool} > 0.2s \\ 5\ 1/s & T_{cool} \le 0.2s \end{cases}$$

I_{inj}-Injector intensity

M_{eff}- effective intensity multiplication factor :

$$M_{eff} = \frac{I_{em}}{I_{inj}}$$

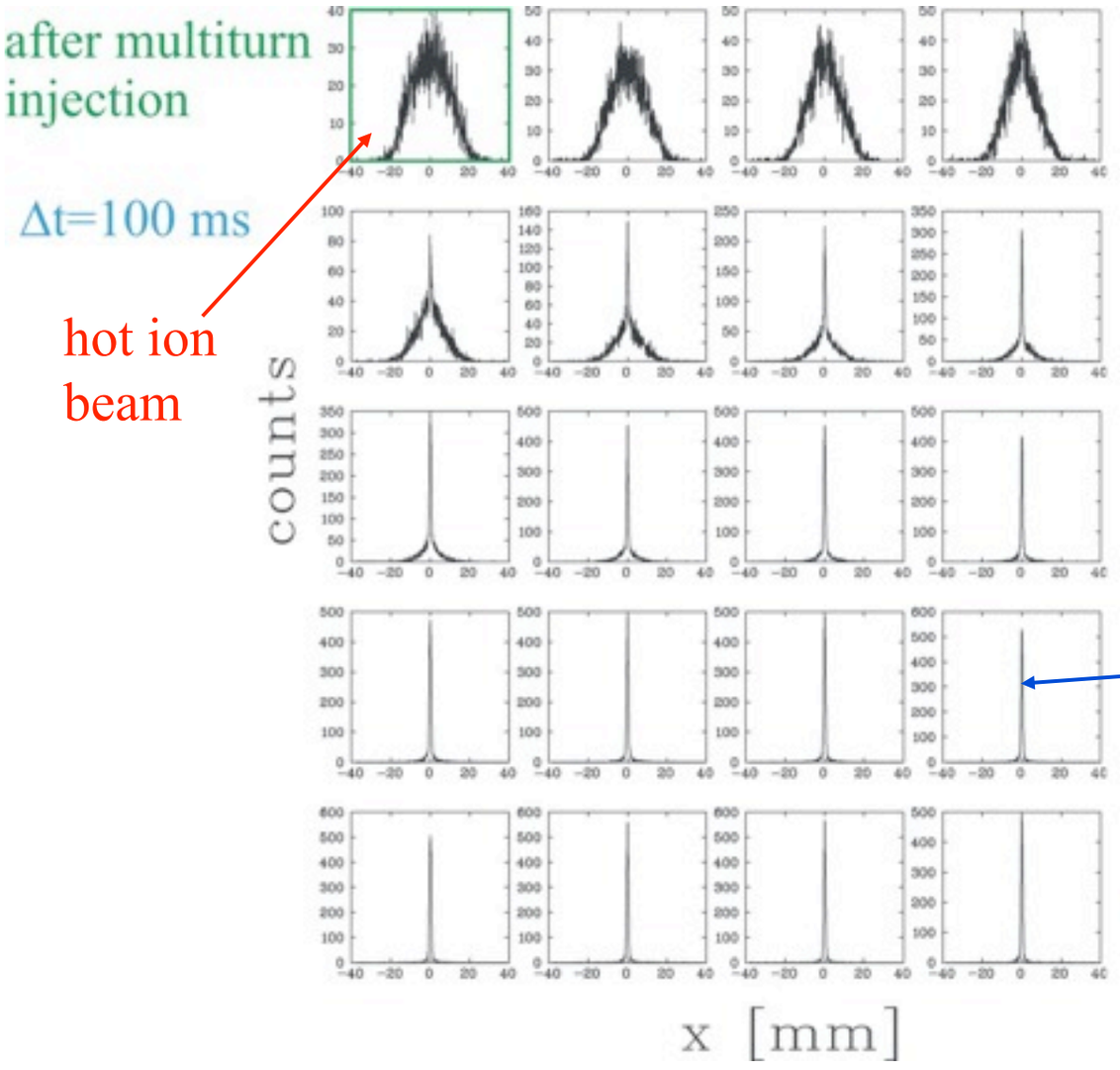
T- beam lifetime

n_r-injection rate

T_{cool}- electron cooling time

I_{em} effective intensity increase with multiturn injection

Transverse Electron Cooling



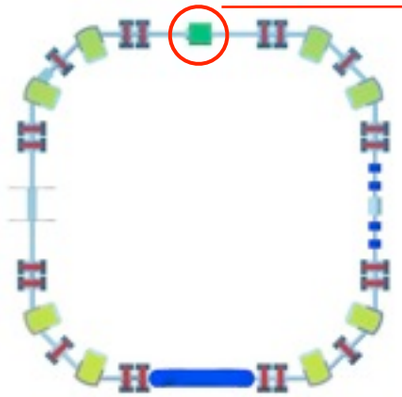
example
horizontal beam profile
$^{12}C^{6+}$ (E=73.3 MeV)

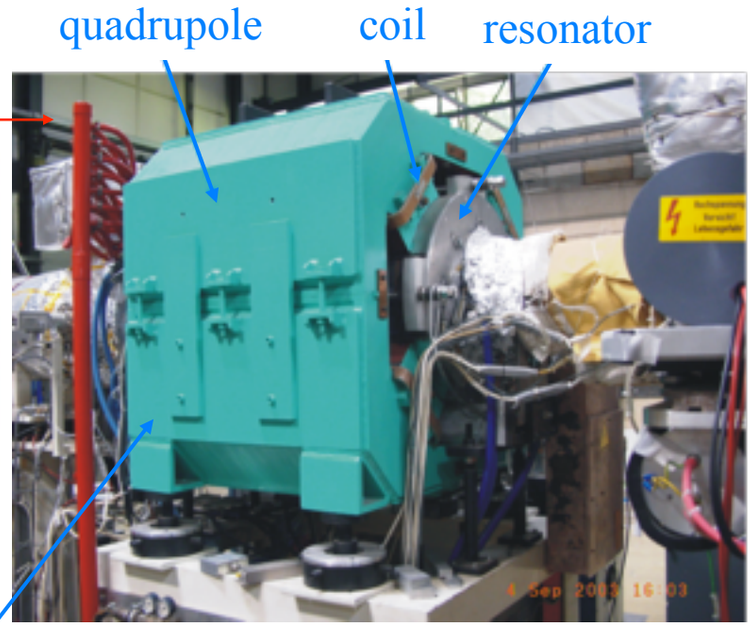
⇒ transverse cooling time:
T ≈ 1s

for α_{ex}= 7.7
and n_e=1.53·10^7 1/cm^3

measuring time: 2s

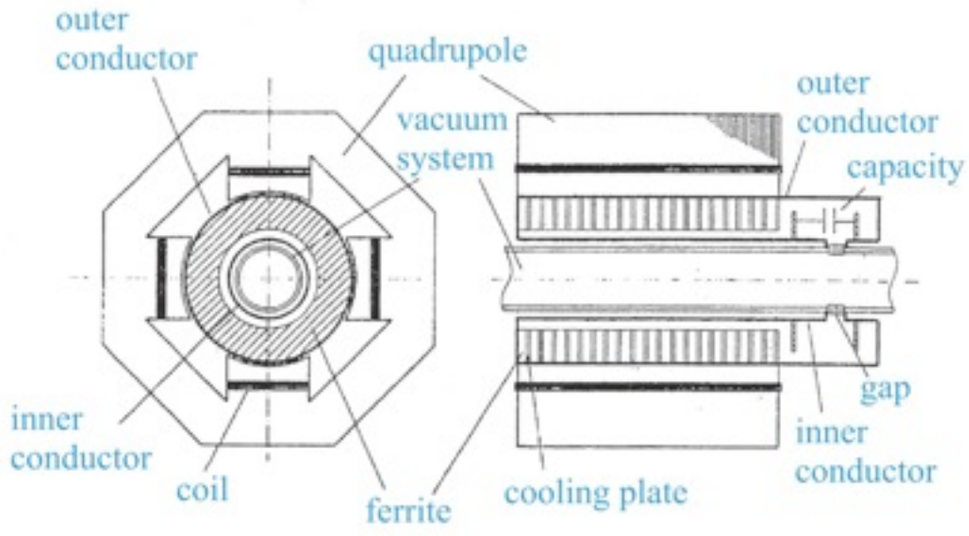
RF Acceleration and Deceleration





frequency range: 0.5-7 MHz
only with magnetization:
factor ≈ 7 I_{mag}=0-150 A
rf voltage: max. 5 kV
rf power: max. 10 kW
ferrite: Philips FXC 8C12
ferrite size: 498x270x25 mm^3
number of ferrites: 20
cooling: 21 water cooled Cu disks

quadrupole
- magnetization of the ferrites
- decoupling of rf field and magnetization field



[F. Wenander, Stori'11
and PoS(STORI11)060]

Maximum beam intensities

Space charge limit in TSR
- Incoherent space-charge tune shift
- Transverse instabilities

intensity limit: $I = \text{const}\,\frac{(A^{19} \times E^{9})^{1/28}}{q}$

E (MeV), I (uA), const=279
calculated from the $^{12}C^{6+}$ data
const valid for e-cooled beams

So far highest REX beam:

3E7 ions/s $^{110}Sn^{27+}$ => $\langle I_{REX} \rangle$= 130 epA

$$I_{0\_TSR} \approx T_{lifetime} \frac{\varepsilon_m}{d_{dilution}} \frac{v_{projectile}}{C_{TSR}} < I_{REX} >$$

for 10 MeV/u, ε_m=0.8,
$d_{dilution}$=2, $T_{lifetime}$=5 s

=>

$I_{0\_TSR}(^{110}Sn^{27+}) \approx$ 200 uA

below the incoherent
tune shift limit of ~1 mA

Exp. Theory

Ion	E [MeV]	Intensit [μA]	Stability limit [μA]
p	21	1000	740
$^{16}O^{8+}$	98	750	1000
$^{12}C^{6+}$	73	1000	1000
$^{32}S^{16+}$	195	1500	999
$^{35}Cl^{17+}$	293	1000	1130
$^{45}Sc^{18+}$	178	380	1087
$^{56}Fe^{22+}$	250	70	1151
$^{56}Fe^{23+}$	260	128	1114
$^{58}Ni^{25+}$	342	600	1147
$^{63}Cu^{25+}$	290	280	1150
$^{63}Cu^{26+}$	510	100	1326
$^{74}Ge^{28+}$	365	110	1234
$^{80}Se^{25+}$	480	100	1590
$^{80}Se^{31+}$	506	<1	1304
$^{197}Au^{50+}$	695	3	1651

close to the limit

stability limit not reached

Intensities obtained in

M. Grieser
presentatio

Beam lifetimes

Internal target

Ion	Energy MeV/u	q	Cooling time (s)	H_2 target thickness atoms/cm^2	Beam lifetime res. gas (s)	Beam lifetime target (s)	Eff. Target thickness µg/cm^2
^{7}Be	10	3^+	2.3		370		
^{18}F	10	9^+	0.7	1E14	280	236	31000
^{70}Ni	10	25^+	0.3	2E13	26	2.1	60
^{132}Sn	4	30^+	0.4	1E12	1.5	1.4	1.2
^{132}Sn	4	45^+	0.2	5E12	1.4	1.6	7
^{132}Sn	10	30^+	0.4	1E12	4	2.2	3
^{132}Sn	10	45^+	0.2	5E13	10	1.3	90
^{182}Pb	10	46^+	0.25	2E12	4	1.5	4
^{182}Pb	10	64^+	0.13	1E13	5	1.7	20

Residual gas 2E-10 mbar; Nicolaev & Dmitriev; summary P. Butler

Conclusions:

avoid too low q

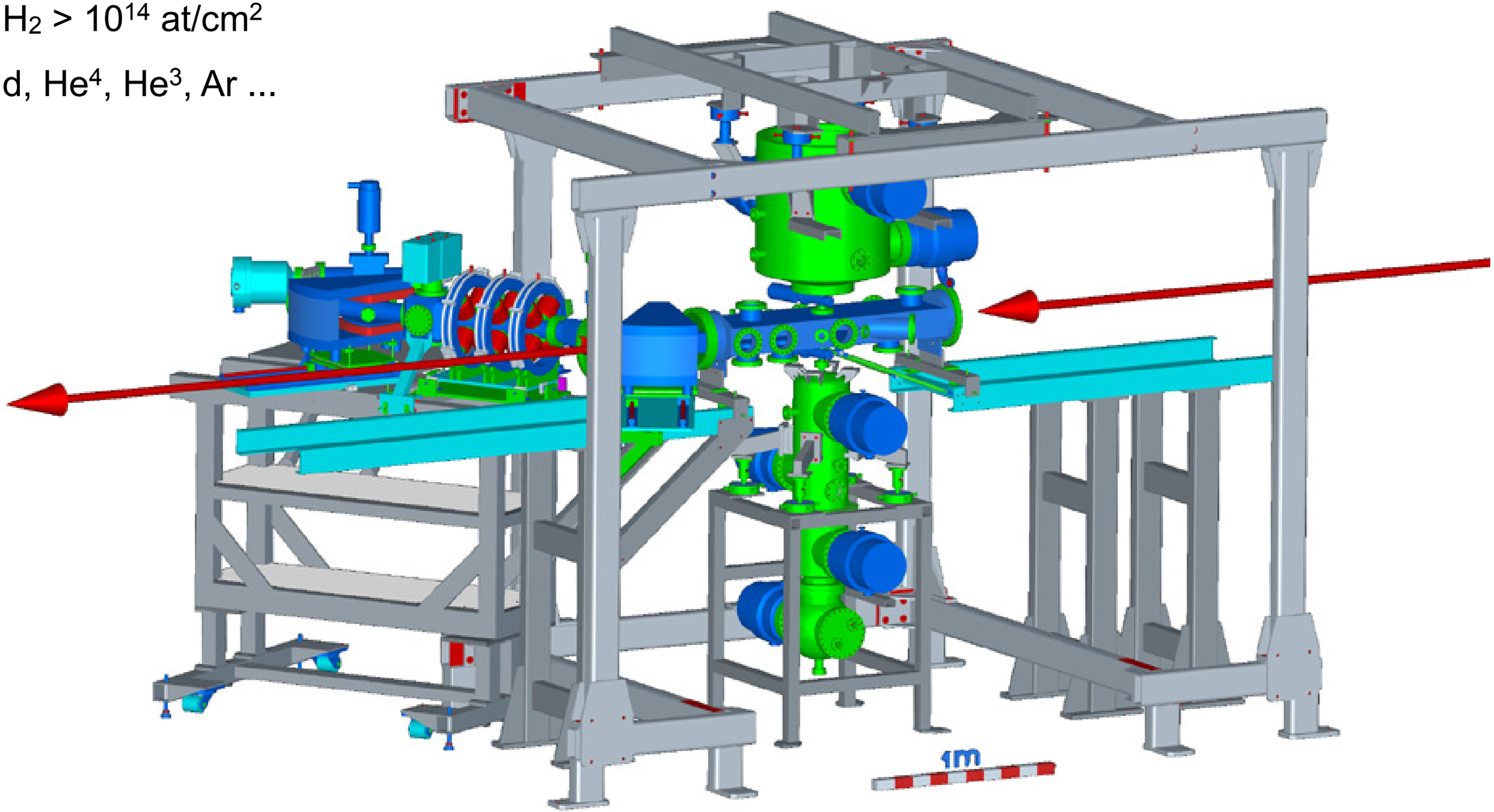
He target -> shorter $T_{storage}$

reduce H_2 target thickness

ESR – Target Environment

$H_2 > 10^{14}$ at/cm^2

d, He^4, He^3, Ar ...



Physics Case For a Low-Energy Storage Ring

- **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**
- **.....**

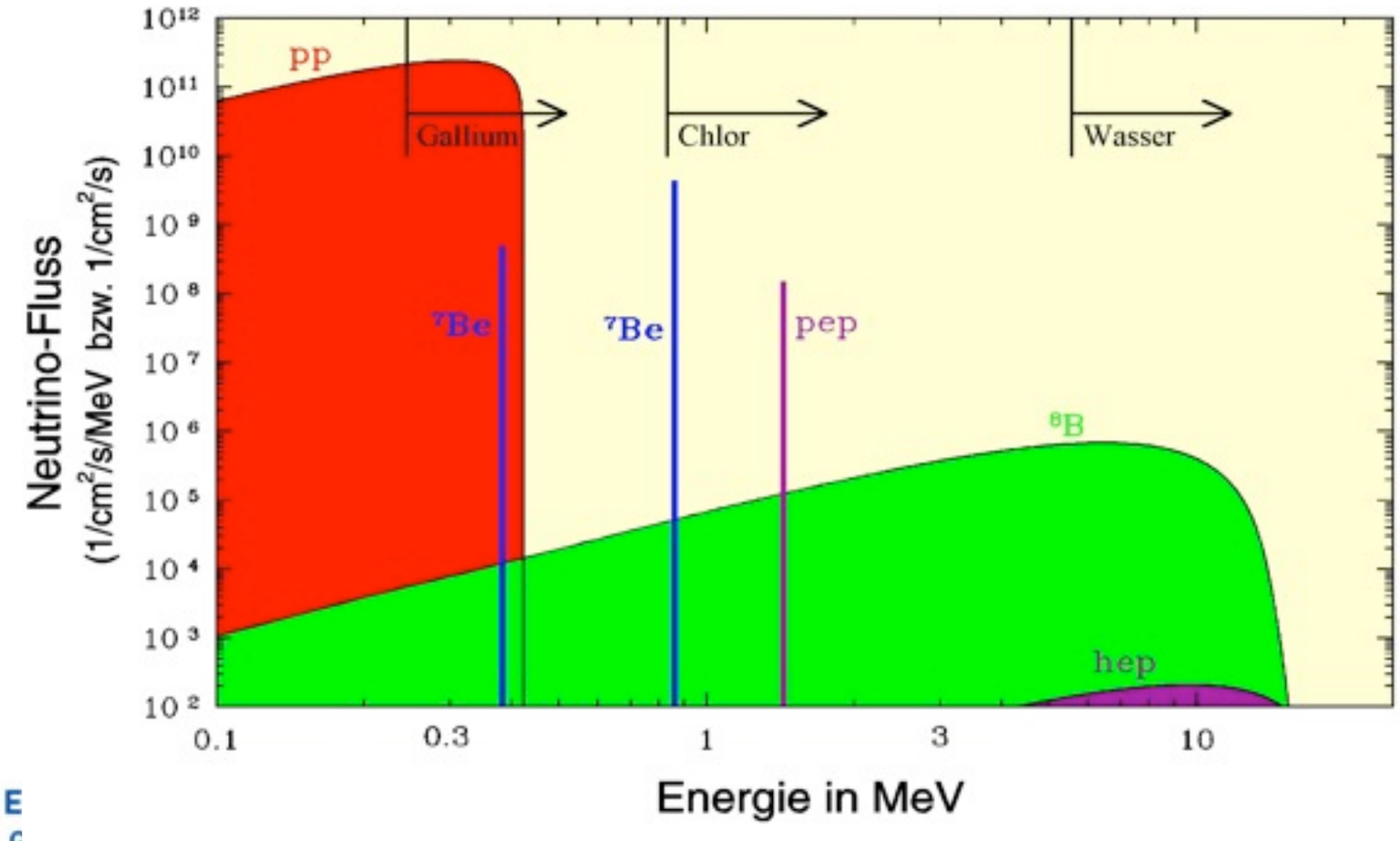
The fate of ^{7}Be in the Sun

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

$$^{7}Be + e^{-} \rightarrow {}^{7}Li + \nu_e$$

$$^{7}Be + p \rightarrow {}^{8}B + \gamma$$



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

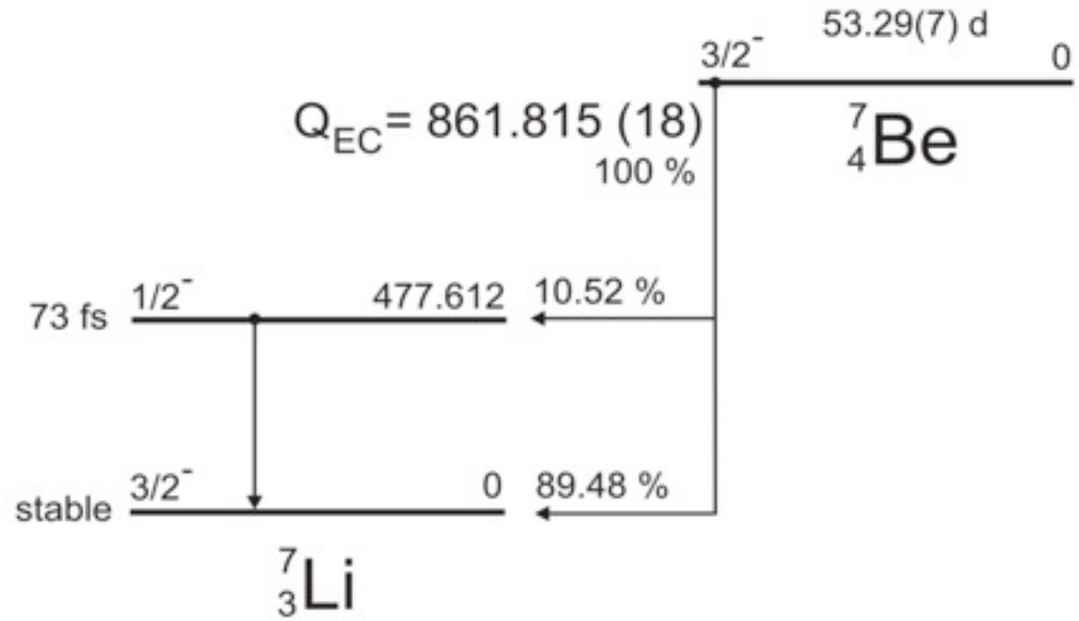
$T_{1/2}$ ($^{7}Be^{0+}$) ~ 53.22 days
NNDC, 2010

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

Measurements with implanted ^{7}Be

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

TSR@ISOLDE would be the best place to perform these experiments!

High-Energy Cosmic Rays

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

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

Adv. Space Res. Vol. 27, No. 4, pp. 727–736, 2001
Published by Elsevier Science Ltd on behalf of COSPAR
Printed in Great Britain
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]

GSI HELMHOLTZ GEMEINSCHAFT

ISOLDE Workshop and Users meeting 2011
05-07 December 2011, CERN

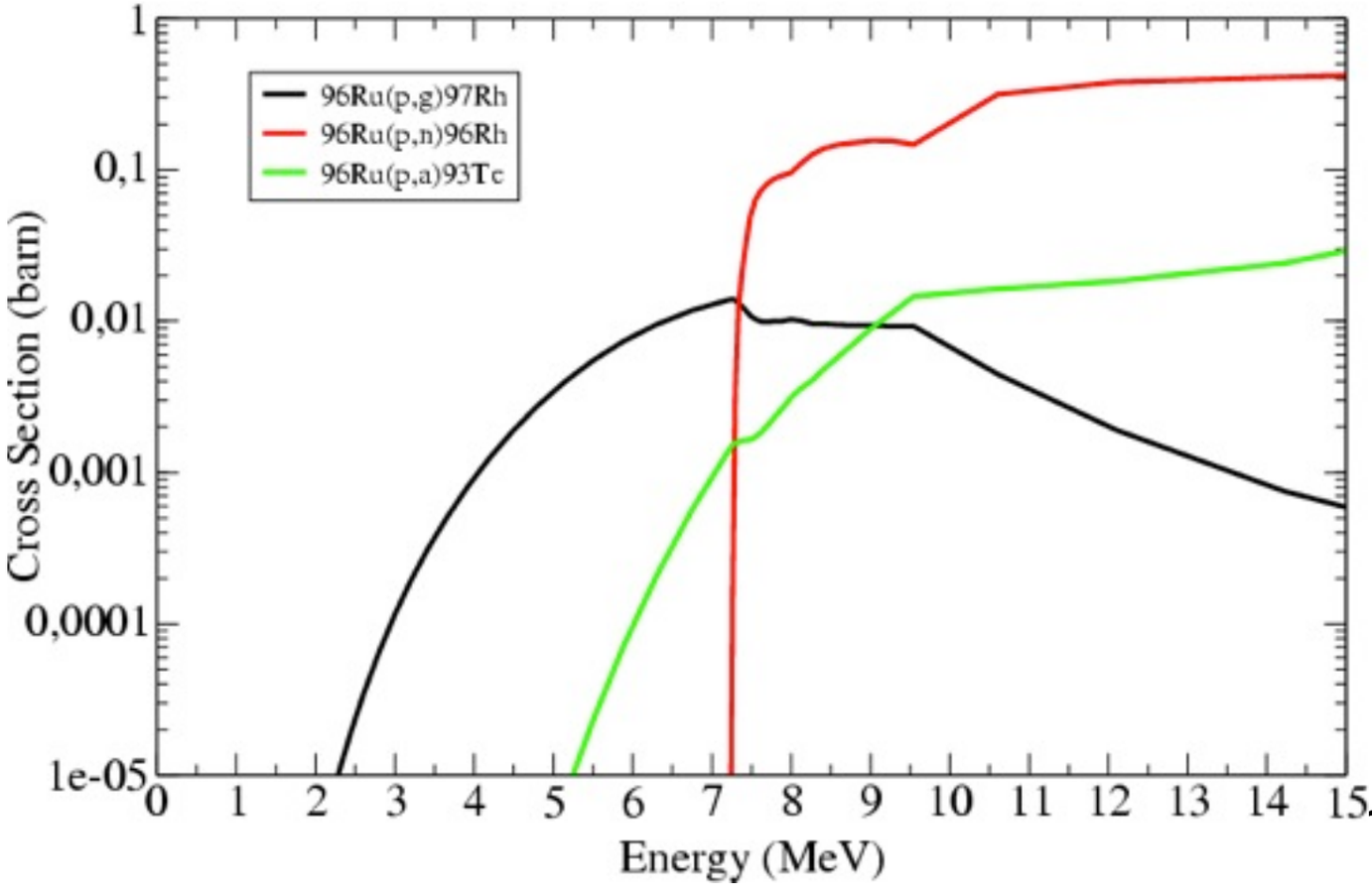
Max-Planck-Institut für Kernphysik

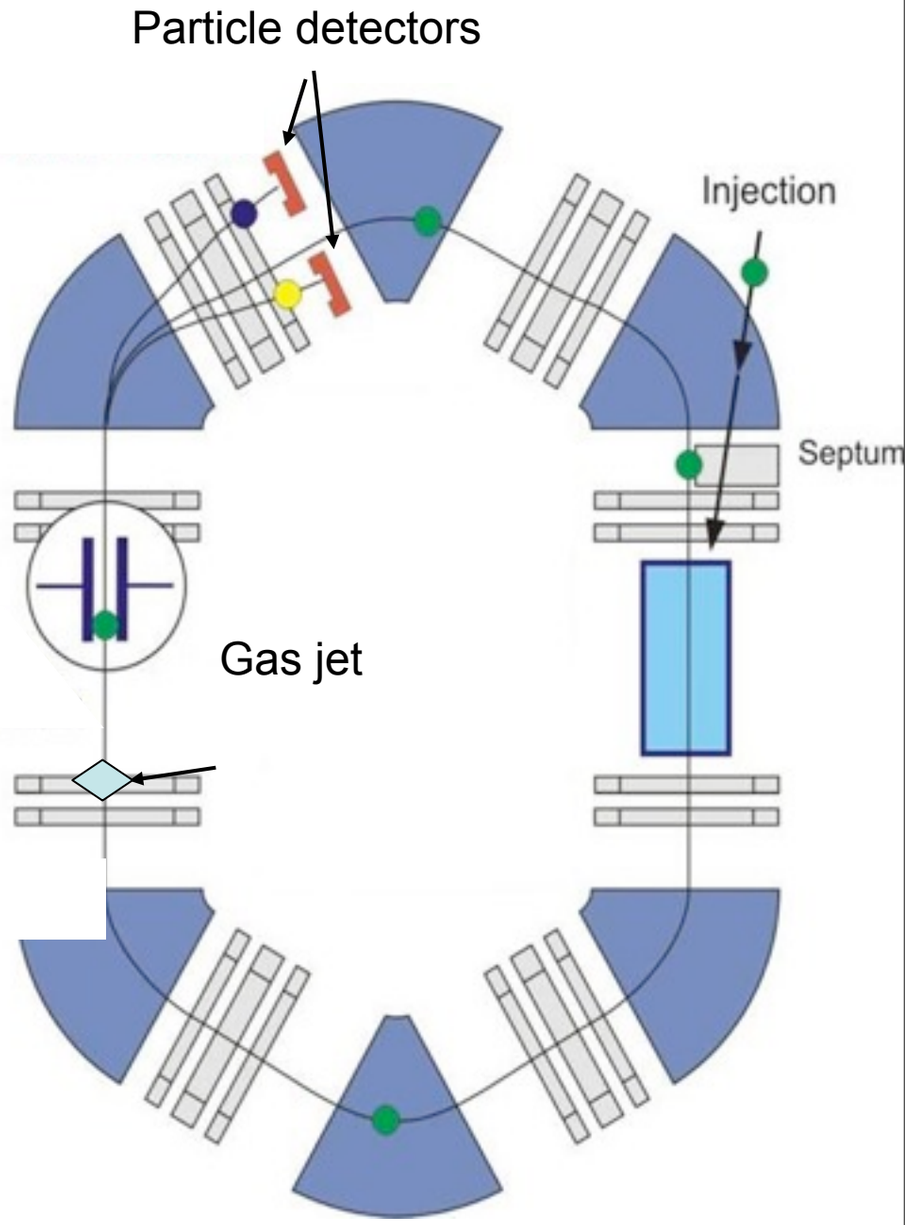
$^{96}Ru(p,\gamma)^{97}Rh$ at the ESR

$^{96}Ru(p,\gamma)^{97}Rh$ measurements at the ESR

- Measurements performed at 9, 10, 11 AMeV
- Gamow window 3-5 AMeV
- 5E6 particles per spill
- 1E13 target density
- Luminosity 2.5E25
- Cross section 2 mbarn -> ~180 counts/h

Text

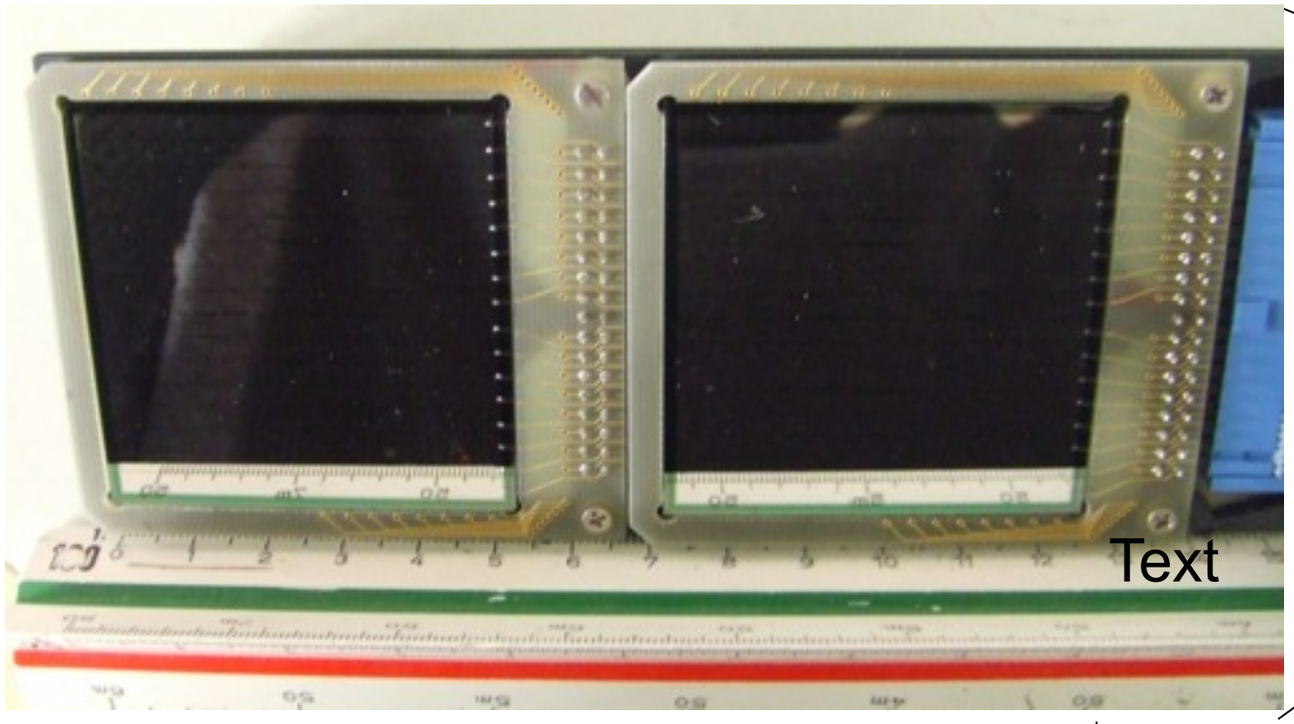


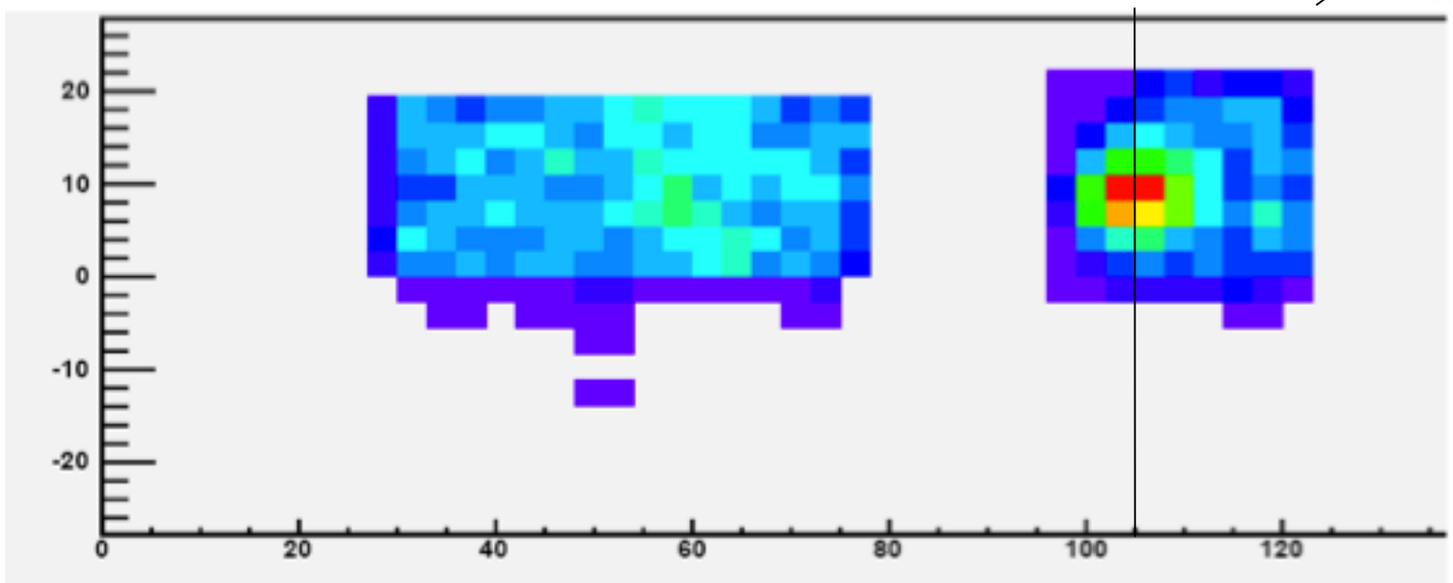


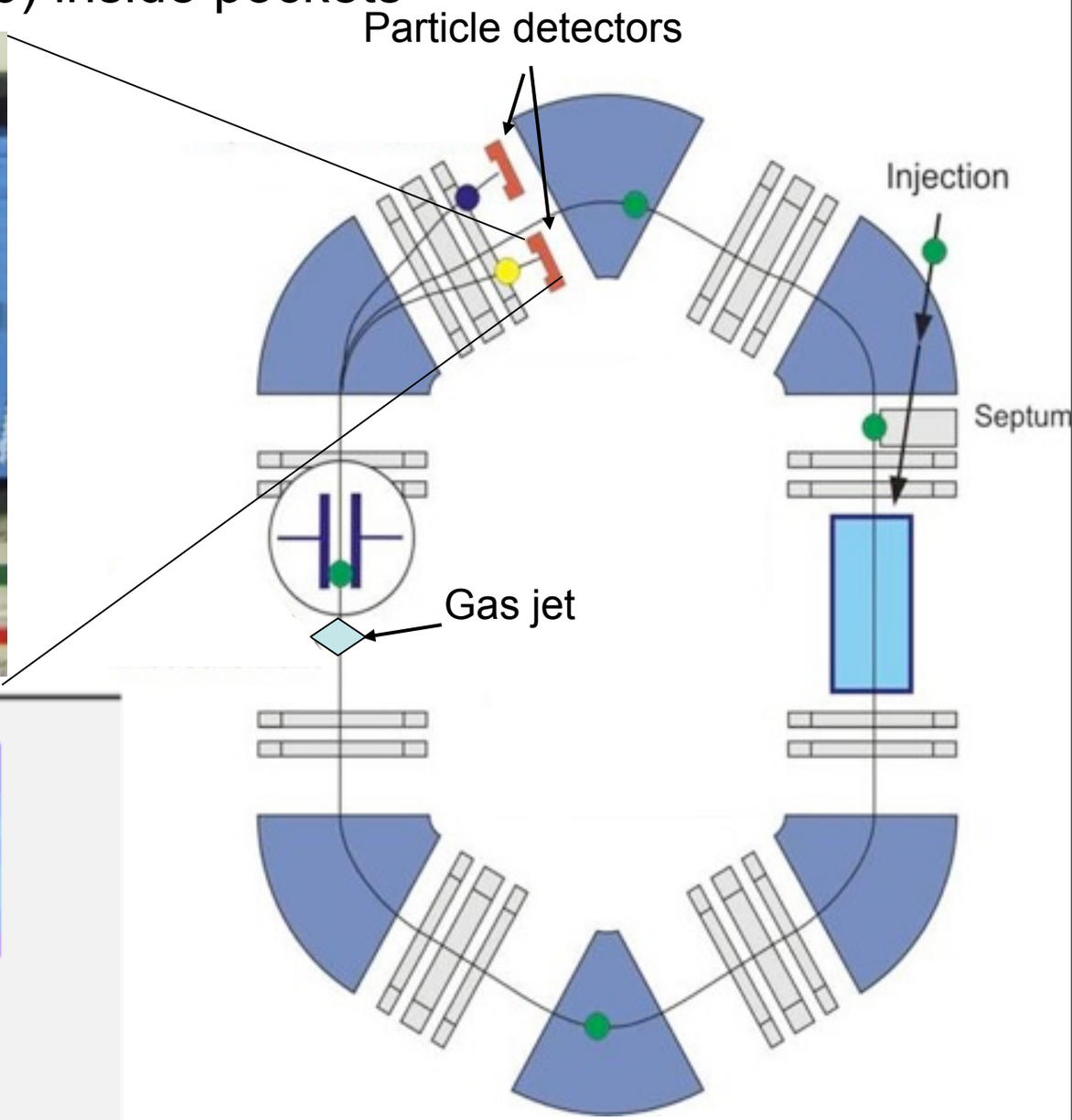
R. Reifarth & M. Heil

Reaction Studies at the ESR

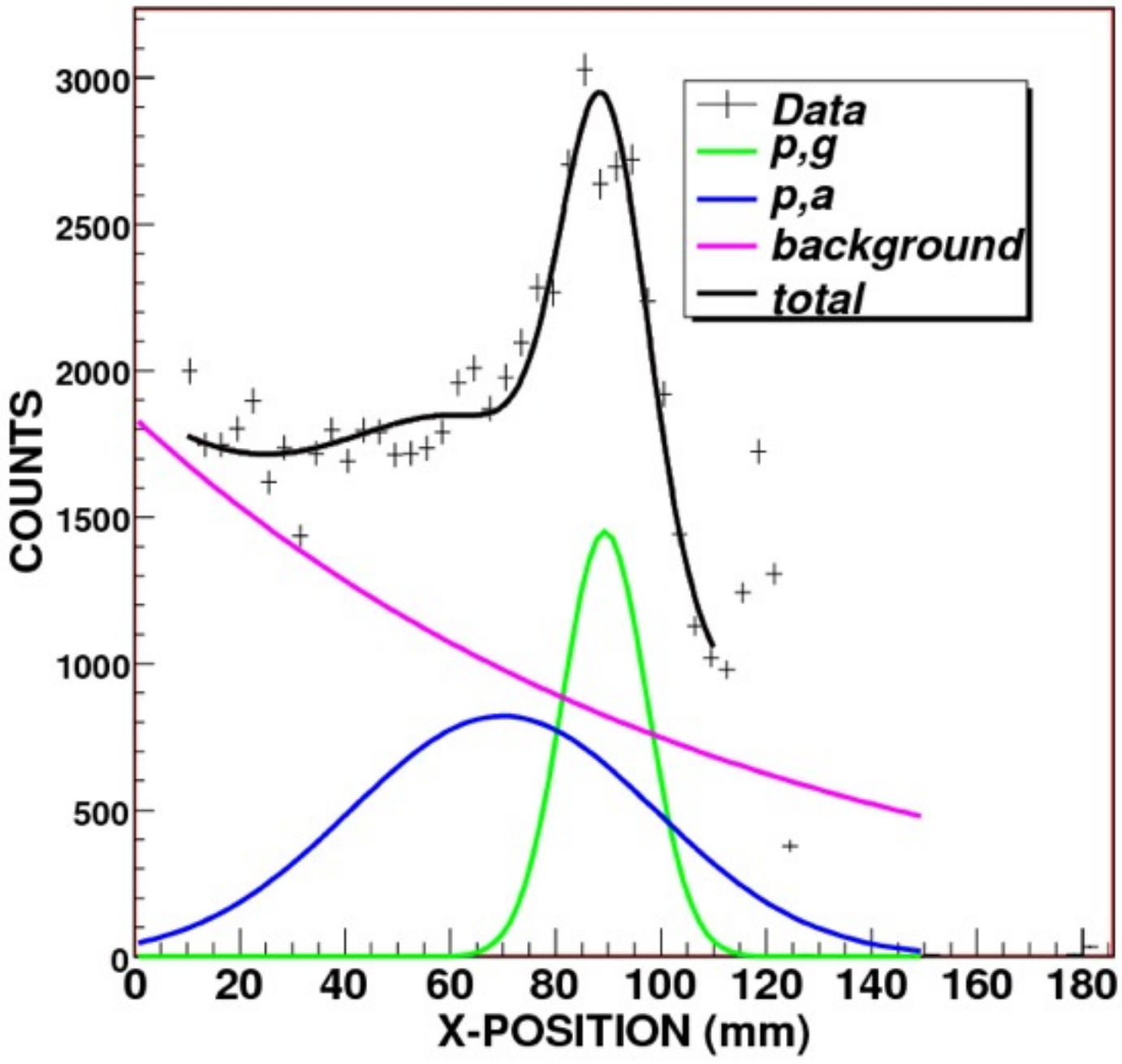
Particle detectors: Double sided silicon strip (16 x 16) inside pockets







Preliminary result @ 11 MeV – upper limit



Ignore (p,n) component – resulting in an upper limit for (p,γ)

$\sigma_{PG} \sim 4.0$ mb

Non-smoker: 3.5 mb

R. Reifarth & M. Heil

ISOLDE Workshop and Users meeting 2011
05-07 December 2011, CERN

Astrophysical reaction in a storage ring

Measurements of (p,γ) or (α,γ) rates in the Gamow window of the p-process in inverse kinematics.

Advantages:

- **Applicable to radioactive nuclei**
- **Detection of ions via in-ring particle detectors (low background, high efficiency)**
- **Knowledge of line intensities of product nucleus not necessary**
- **Applicable to gases**
- **HIE-ISOLDE energy range fits perfectly!**

Proof-of-principle experiment:

^{96}Ru (p,γ)^{97}Rh

Transfer reactions in the TSR

The thickness of gas jet targets is ~10^{14} at/cm^2

Luminosity is about 10^5-10^6 smaller than with foil-targets - compensated by recirculation ~1 MHz

Thus, advantageous for beams with storage times of about a second and longer

- brilliant parameters of e-cooled beams
- good spacial resolution

- EXL-like detector setup (close to 4 pi)

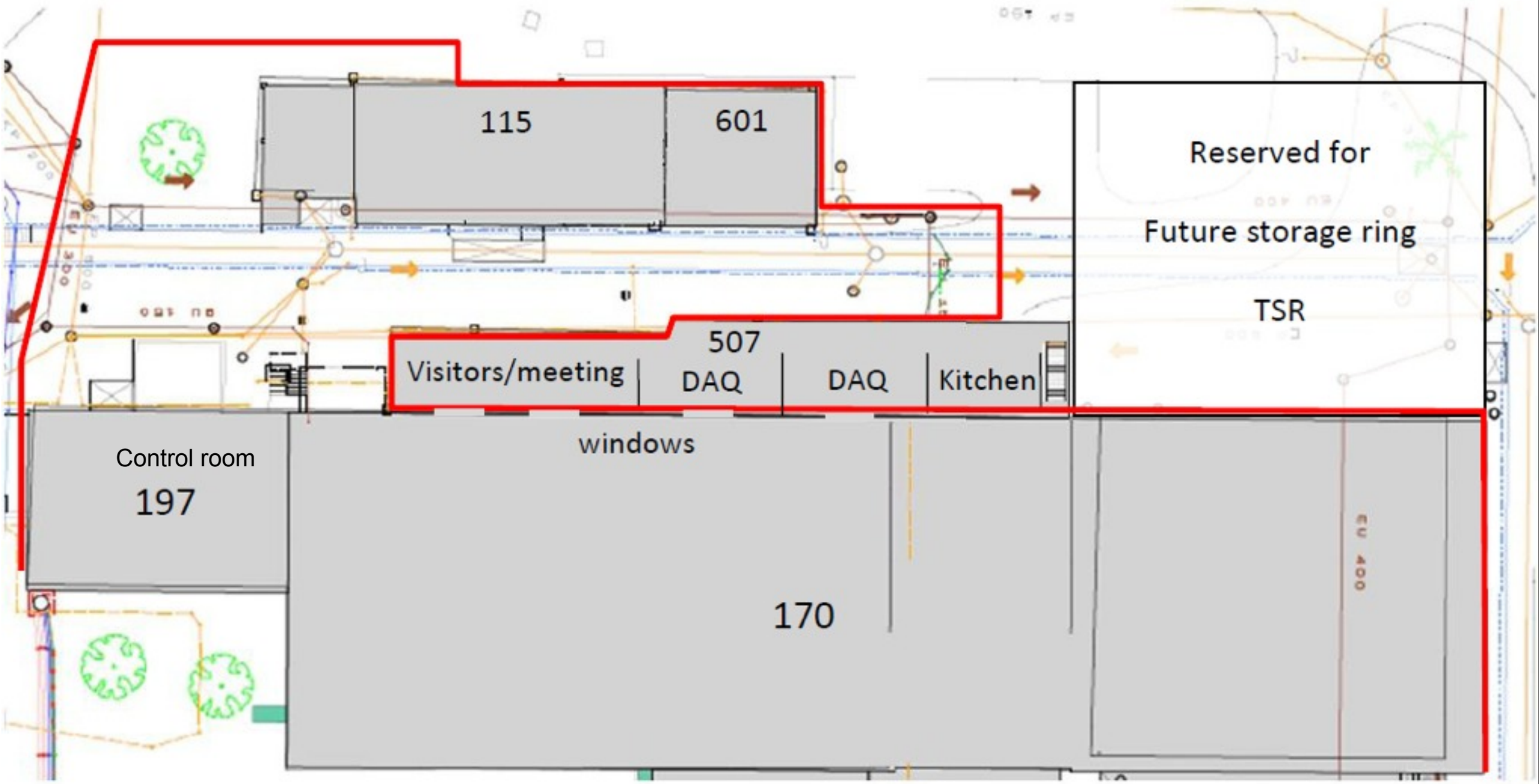
Several meetings & workshops since 02.2011

Slow-extraction of electron-cooled beams from the TSR

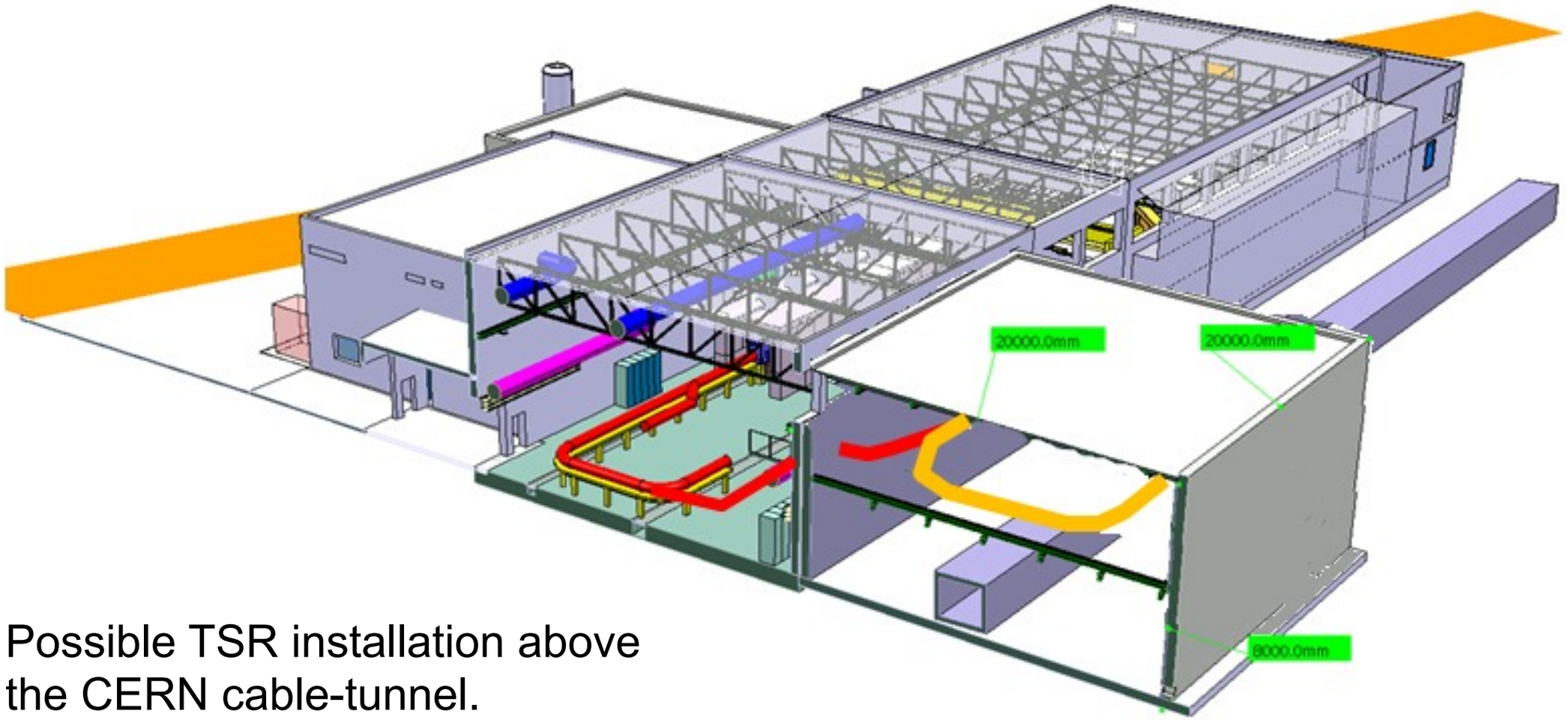
ISOLDE Workshop and Users meeting 2011
05-07 December 2011, CERN

User building 507 & TSR

Replacing the existing building 507 by a new building and possible position for the TSR



TSR @ Hie-Isolde



Possible TSR installation above
the CERN cable-tunnel.
Tilted beamline coming up from the
machine.

Next step:

Finalizing the TDR and its submission to the coming INTC

Present version of the TDR: http://www-linux.gsi.de/~litvinov/TSR_TDR/TSR_TDR.pdf

Your support is warmly welcome!

ISOLDE Workshop and Users meeting 2011

05-07 December 2011, CERN

Time scale

Timeschedule for TSR Disassembly

M :	1				2				3				4			
\ weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Remove Bakeout shields , mark, and pack for future use	■	■														
Remove Bakeout Heaters and Sensors		■														
Disconnect magnets from water and current-leads		■	■													
Vent, open vacuum system, remove bellows, pack them			■	■												
Remove pumps and Gauges (Starcells, Ti-Sub., NEGs)				■	■											
Disconnect Power supplies from cables and hoses					■	■										
Save diagnostics (BPM, Pick ups, CT), pack them						■										
Disassemble Bumper						■	■									
Remove dipole chambers, pack them						■	■	■								
Shipment of Dipoles (2x2 per week)								■	■							
Disassembly of RF + Cavity									■							
Disassembly Induction-Acc.										■						
Shipment of Dipole supports										■						
Shipment of quadrupoles, Sextuipoles, Corr. Magnets											■	■				
Transport chambers, vacuum equipment													■			
Disassembly Electron-Cooler													■	■		
Shipment Electron-Cooler															■	
Shipment of Power Supplies															■	■
E-Target																
Extraction Beamline																
Injection Beamline																
Experimental Beamline																
Reaction Microscope																

* TDR in preparation
* Submit TDR to INTC

Tentative dismantling and installation time schedules

Assembly of TSR@ISOLDE

\week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Grid definition	■																					
Positioning of dipole supports		■																				
Positioning of dipoles		■																				
Alignment of dipoles			■	■																		
Positioning of Quadrupoles+ supports					■	■																
Alignment of quadrupoles						■	■	■														
Coils and chambers of quads								■	■													
all other magnets										■	■	■	■									
bumpers														■	■							
vacuum chambers																■	■	■				
electron cooler																			■	■	■	■

TSR@HIE-ISOLDE Collaboration

more than 120 participants from more than 40 institutions from 17 countries

M. Aliotta, A. Andreyev, A. Artemyev, D. Atanasov, T. Aumann, J. Äystö, D. Balabanski, A. Barzakh, L. Batist, A.-P. Bernardes, D. Bernhardt, J. Billowes, S. Bishop, K. Blaum, Y. Blumenfeld, M. Borge, I. Borzov, F. Bosch, A. Boston, C. Brandau, P. Butler, W. Catford, R. Catherall, J. Cederkäll, D. Cullen, T. Davinson, I. Dillmann, C. Dimopoulou, G. Dracoulis, C. Düllmann, P. Egelhof, A. Estrade, D. Fischer, K. Flanagan, M. Fraser, S. Freeman, H. Geissel, J. Gerl, M. Grieser, R.E. Grisenti, R. von Hahn, M. Hausmann, J. J. He, M. Heil, M. Huyse, D. Jenkins, A. Jokinen, J. Jolie, B. Jonson, D. Joss, Y. Kadi, N. Kalantar-Nayestanaki, B. Kay, H.-J. Kluge, M. Kowalska, C. Kozhuharov, S. Kreim, T. Kröll, R. Krücken, J. Kurcewicz, M. Labiche, R.C. Lemmon, M. Lestinsky, Yu.A. Litvinov, G. Lotay, X.W. Ma, D. Mücher, I. Mukha, A. Müller, A. Murphy, G. Neyens, T. Nilsson, C. Nociforo, W. Nörtershäuser, R. Page, M. Pasini, N. Petridis, N. Pietralla, Zs. Podolyak, R. Raabe, P. Reagan, M.W. Reed, R. Reifarth, P. Reiter, R. Repnow, K. Riisager, B. Rubio, M.S. Sanjari, D.W. Savin, C. Scheidenberger, S. Schippers, D. Schneider, R. Schuch, D. Schwalm, D. Shubina, E. Siesling, H. Simon, J. Simpson, J. Smith, K. Sonnabend, M. Steck, T. Stora, T. Stöhlker, A. Surzhykov, F. Suzaki, O. Tarasov, X.L. Tu, P. VanDuppen, C. Volpe, D. Voulot, P.M. Walker, F. Wenander, E. Wildner, N. Winckler, D.F.A. Winters, A. Wolf, P. Woods, H.S. Xu, A. Yakushev, T. Yamaguchi, Y.J. Yuan, K. Zuber

ISOLDE Workshop and Users meeting 2011

05-07 December 2011, CERN

ISOLDE Workshop and Users meeting 2011

05-07 December 2011, CERN

ISOLDE Workshop and Users meeting 2011

05-07 December 2011, CERN

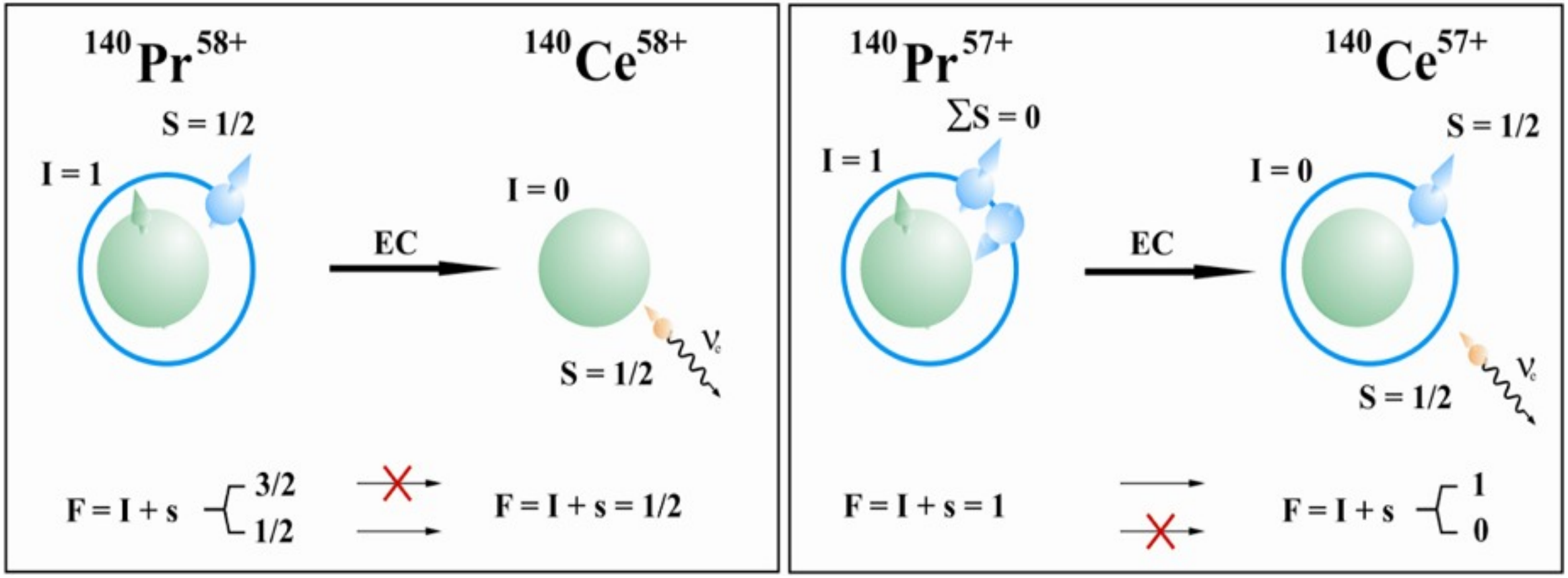
Neutrino physics; Tests for the neutrino beam project

- Production and storage of beta-decaying nuclei which are suitable for beta-beam project (^{6}He, ^{18}Ne, ^{8}Li, ^{8}B)
- Development of the secondary beams, injection, cooling, accumulation, decay losses
- Ideal test facility for the accumulation and storage of ^{6}He
- In-ring production, e.g. ^{6}Li(^{3}He,n)^{8}B (B is not available as ISOL beam) (resonances at low energies -- TSR is an ideal instrument)
- Development of d, ^{3}He targets

T. Stora & C. Volpe

Electron Capture in Hydrogen-like Ions

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



$\mu = +2.7812\mu_N$

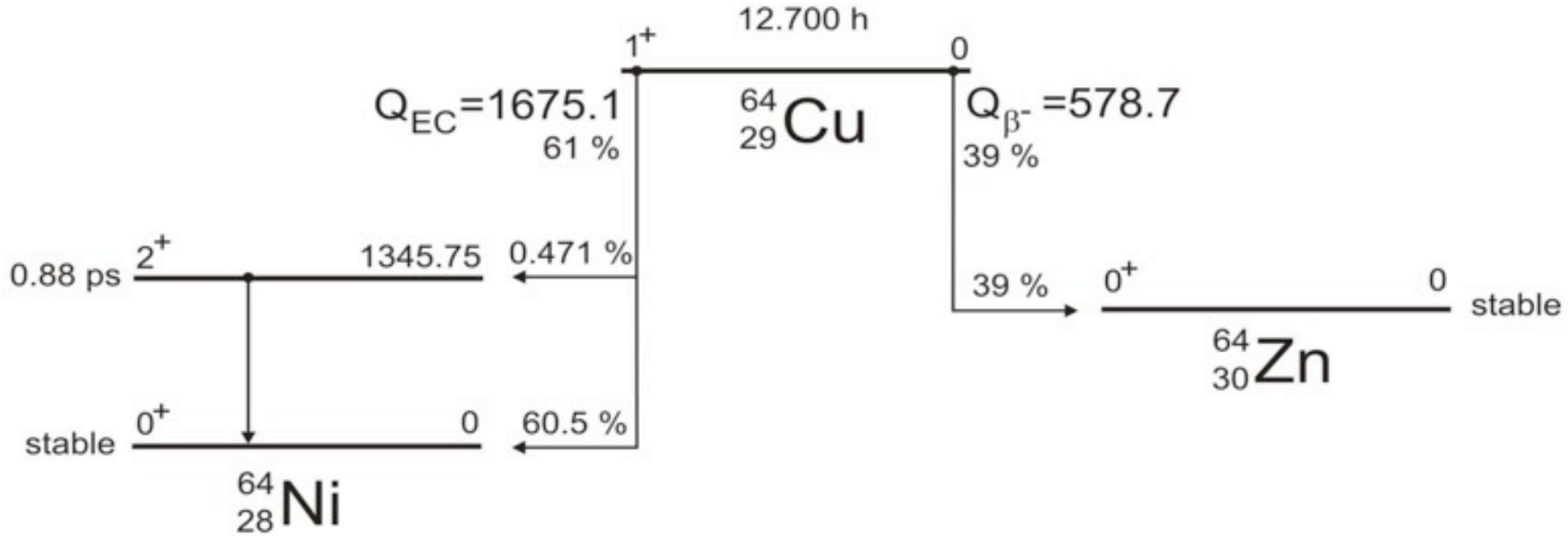
I. N. Borzov et al., Phys. At. Nucl. (2009)

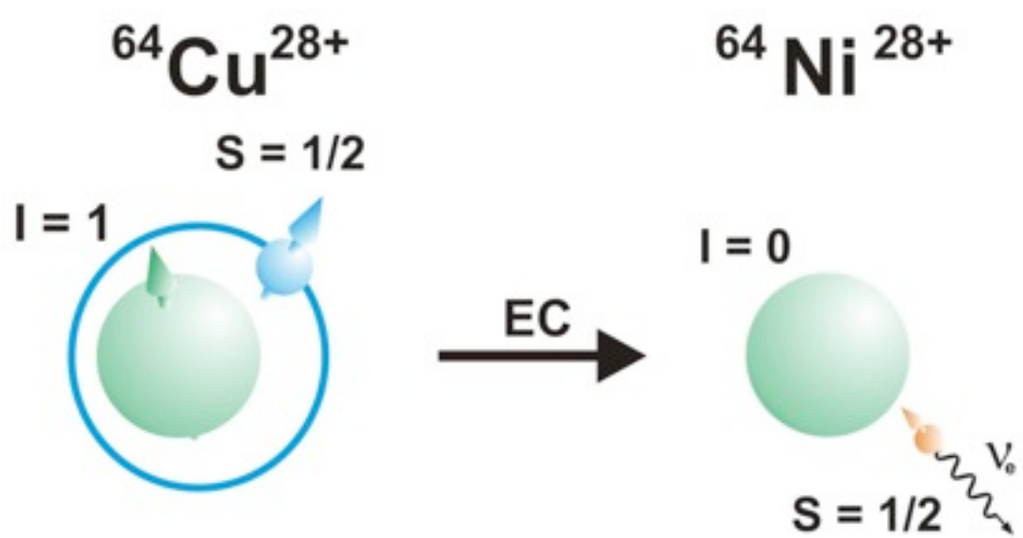
Theory: $\lambda(H)/\lambda(He) = (2I+1)/(2F+1)$

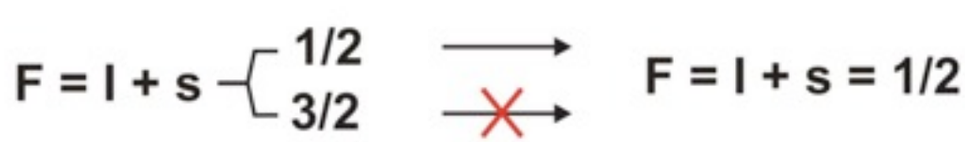
Z. Patyk et al., Phys. Rev. C 77 (2008) 014306

Ratio H/He:		Theory	Measurement
	^{140}Pr	→ 3/2	1.49 (9)
	^{142}Pm	→ 3/2	1.44 (6)

Decay of Hydrogen-like ^{64}Cu







μ (^{64}Cu) = −0.217(2) μ_N

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

High-Energy Cosmic Rays

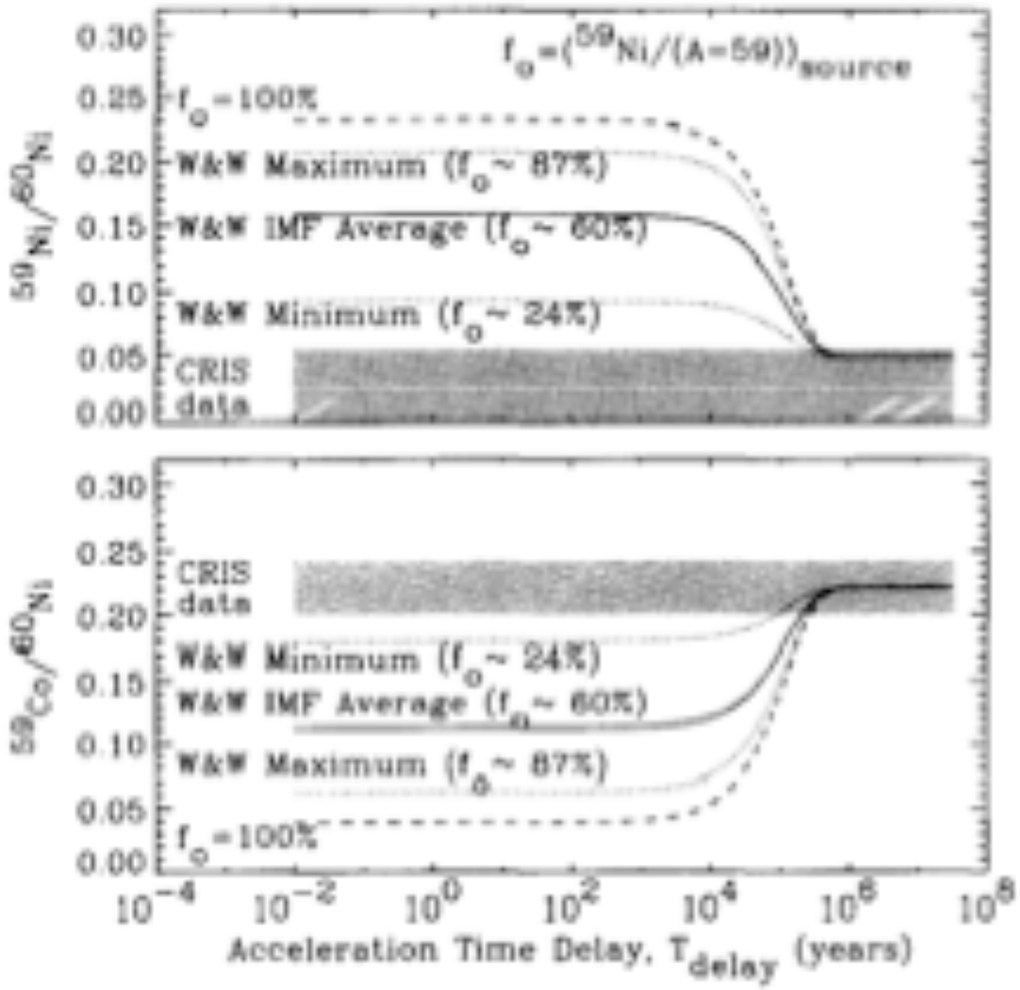


Fig. 3. Dependence of the mass-59 e^--capture GCR relative abundances at Earth on the time delay between nucleosynthesis and acceleration. Different curves assume different fractions f_o of mass-59 nuclei synthesized as ^{59}Ni at the source. The W&W values of f_o come from the SN II yield calculations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

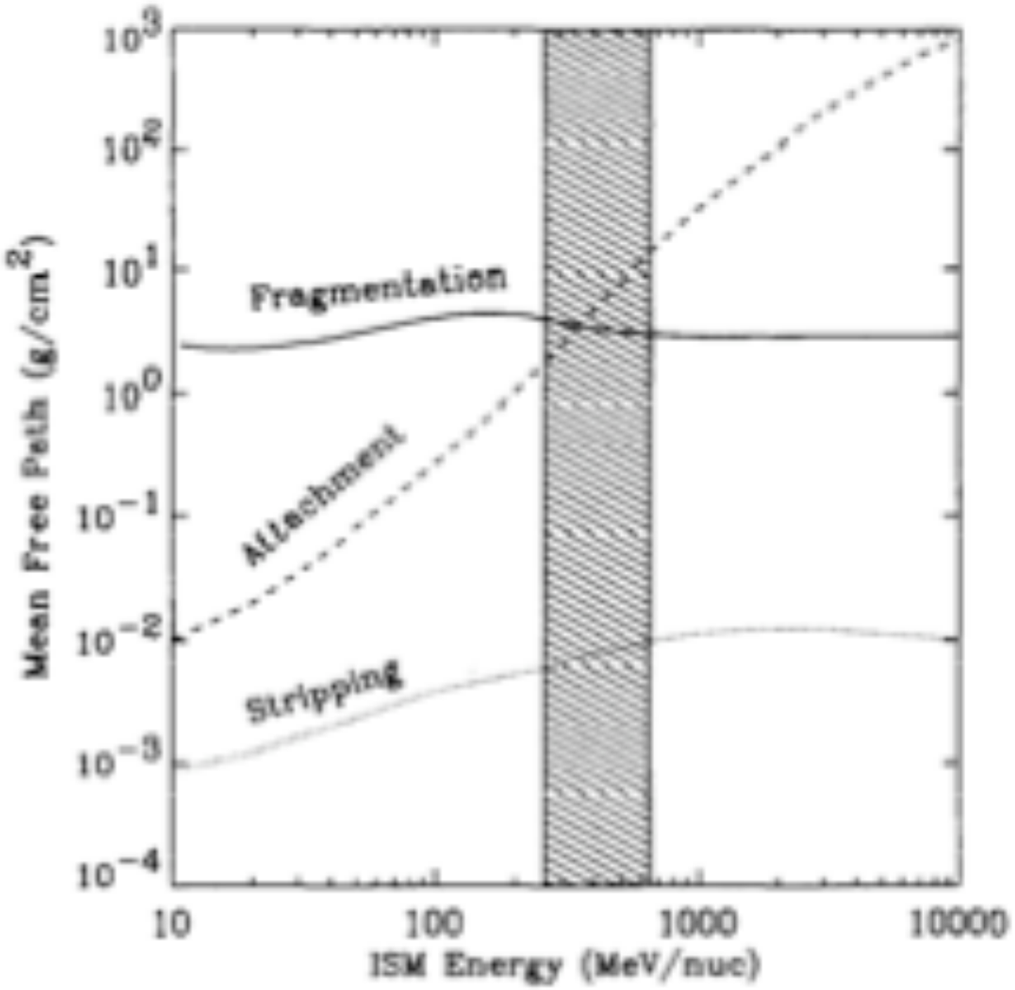
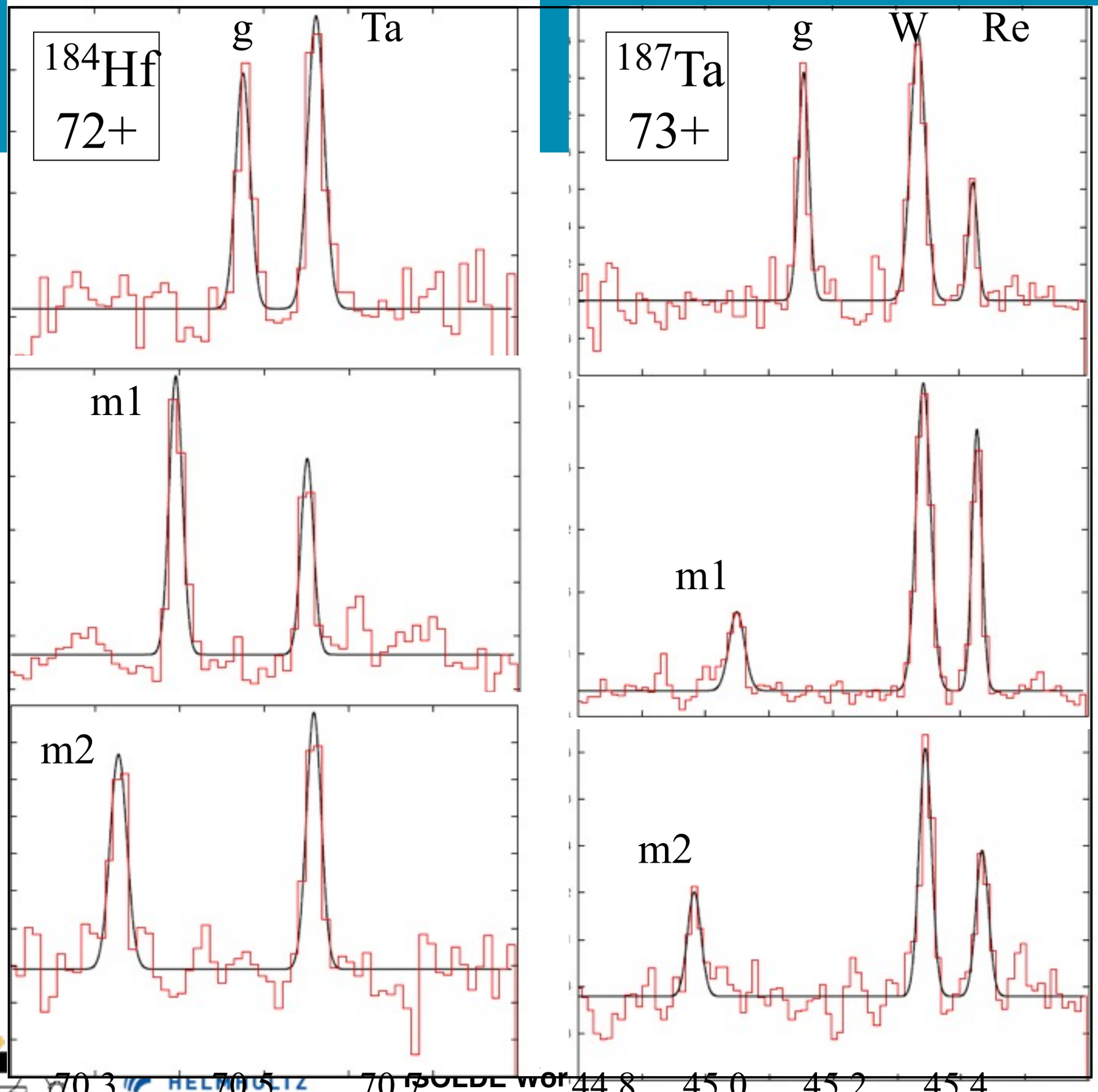
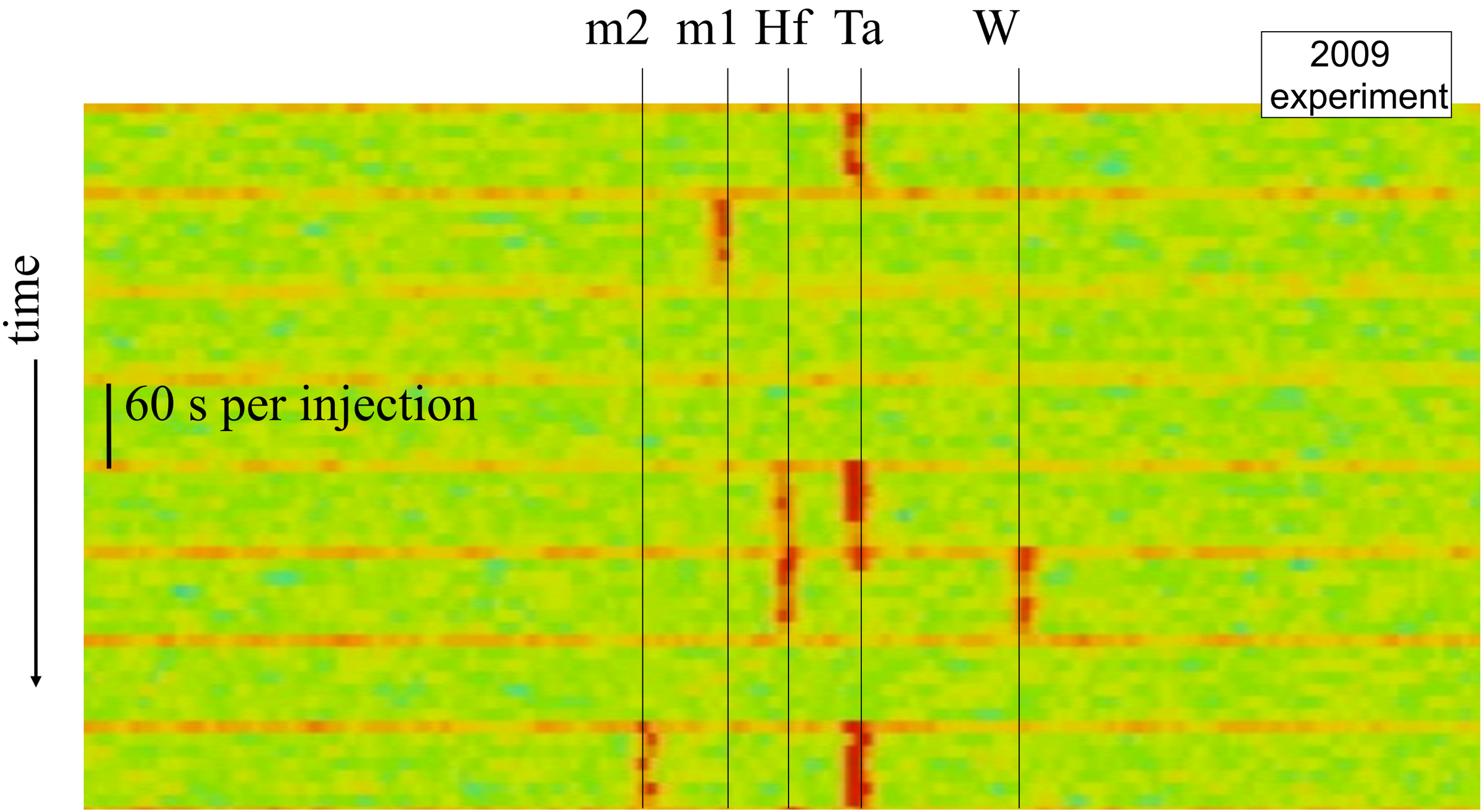


Fig. 4. Mean free paths for electron attachment and stripping (Crawford, 1979) of GCR Co in the ISM as a function of energy, assuming an ISM composition of 90% H, 10% He. Also shown is the mean free path for GCR fragmentation in the ISM (Tripathi et al., 1999). The hatched region indicates the approximate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

Discovery of long-lived isomeric states in the ESR



A=184 (72^{+}) isobars and isomers



Intensities for a few ions achieved with ECOOL stacking

Ion	E [MeV]	life time[s]	Intensity [μA]
p	21	220000	1000
$^{16}O^{8+}$	98		750
$^{12}C^{6+}$	73	1700	1000
$^{32}S^{16+}$	195	450	1500
$^{35}Cl^{17+}$	293	318	1000
$^{45}Sc^{18+}$	178		380
$^{56}Fe^{22+}$	250	77	70
$^{56}Fe^{23+}$	260	74	128
$^{58}Ni^{25+}$	342	60	600
$^{63}Cu^{25+}$	290	49	280
$^{63}Cu^{26+}$	510	122	100
$^{74}Ge^{28+}$	365	45	110
$^{80}Se^{25+}$	480	204	100
$^{80}Se^{31+}$	506	50	<1
$^{197}Au^{50+}$	695	3	3

$N \approx 4000$ $^{32}S^{16+}$

$$N = \frac{I_0}{I_{inj}} = M \times \varepsilon_m \times n_r \times T$$

$$n_r = \begin{cases} 1/T_{cool} & T_{cool} > 0.2s \\ 5\,1/s & T_{cool} \le 0.2s \end{cases}$$

$$\varepsilon_m = \begin{cases} 0.8 & n_r = 1/T_{cool} \\ 1 & n_r < 1/T_{cool} \end{cases}$$

I_0 equilibrium intensity
I_{inj} injected intensity
T- life time
T_{cool} cooling time of a multiturn injected ion beam
M intensity multiplication factor multiturn injection
ECOOL Stacking
$M \le 10$

Internal gas target

Miniball target thickness 0.1 to 4 mg/cm^2 -> cm^2

(^{3}H-loaded Ti, CD_2, Sn, Pd, Ag etc)

N_{MB_target} ~ 1E19 atoms/

To reach the same reaction rate at TSR:

$$N_{TSR\_target} = \frac{N_{MB\_target}}{T_{lifetime}} \frac{C_{TSR}}{v_{projectile}} \frac{d_{dilution}}{\varepsilon_m}$$

Internal gas target

Miniball target thickness 0.1 to 4 mg/cm^2 -> N_{MB_target} ~ 1E19 atoms/cm^2

(^{3}H-loaded Ti, CD_2, Sn, Pd, Ag etc)

To reach the same reaction rate at TSR:

$$N_{TSR\_target} = \frac{N_{MB\_target}}{T_{lifetime}} \frac{C_{TSR}}{v_{projectile}} \frac{d_{dilution}}{\varepsilon_m}$$

Assume:

$T_{lifetime}$=1 s $d_{dilution}\approx 2$ ε_m=0.8 => N_{TSR_target} = 3E13 atoms/cm^2

$v_{projectile}$=0.14·c (10 MeV/u)

Integrated residual gas thickness much smaller
(55.42 m, 5E-11 mbar) => 6.7E9 atoms/cm^2

Internal gas target

Miniball target thickness 0.1 to 4 mg/cm^2 -> N_{MB_target} ~ 1E19 atoms/cm^2

(^{3}H-loaded Ti, CD_2, Sn, Pd, Ag etc)

To reach the same reaction rate at TSR:

$$N_{TSR\_target} = \frac{N_{MB\_target}}{T_{lifetime}} \frac{C_{TSR}}{v_{projectile}} \frac{d_{dilution}}{\varepsilon_m}$$

Assume:

$T_{lifetime}$=1 s $d_{dilution}\approx 2$ ε_m=0.8 => N_{TSR_target} = 3E13 atoms/cm^2

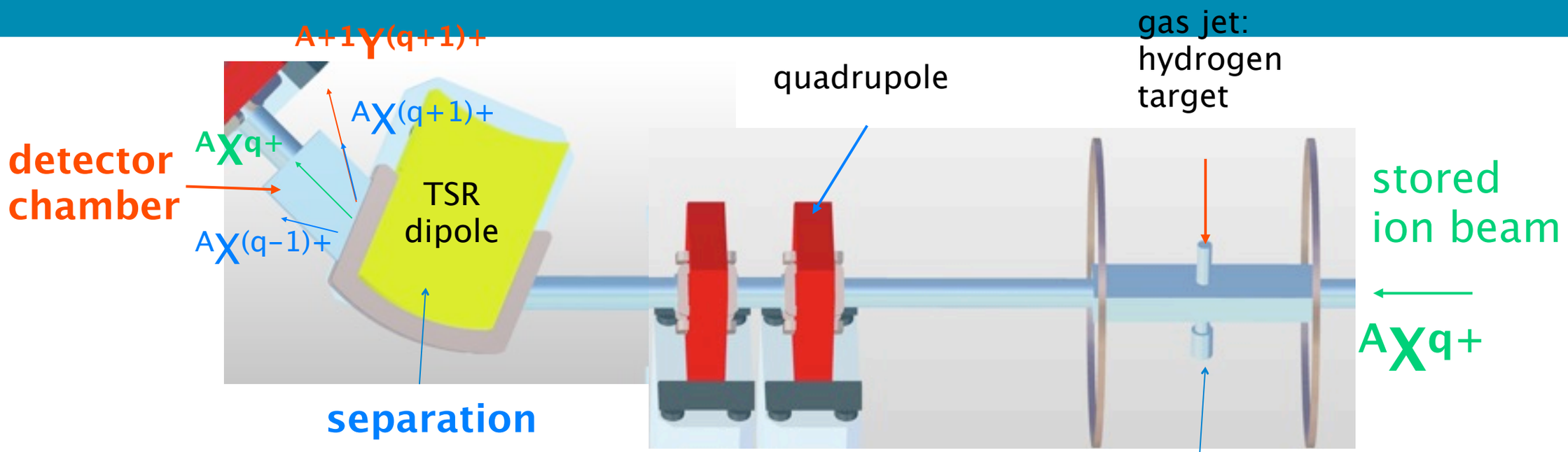
$v_{projectile}$=0.14·c (10 MeV/u)

Integrated residual gas thickness much smaller
(55.42 m, 5E-11 mbar) => 6.7E9 atoms/cm^2

* Target types: H_2 or ^{3,4}He (or even Ar, Xe?)

* To address:
  - Interaction length – ideally 1 mm
  - Pressure around target?

Pick up reaction at TSR



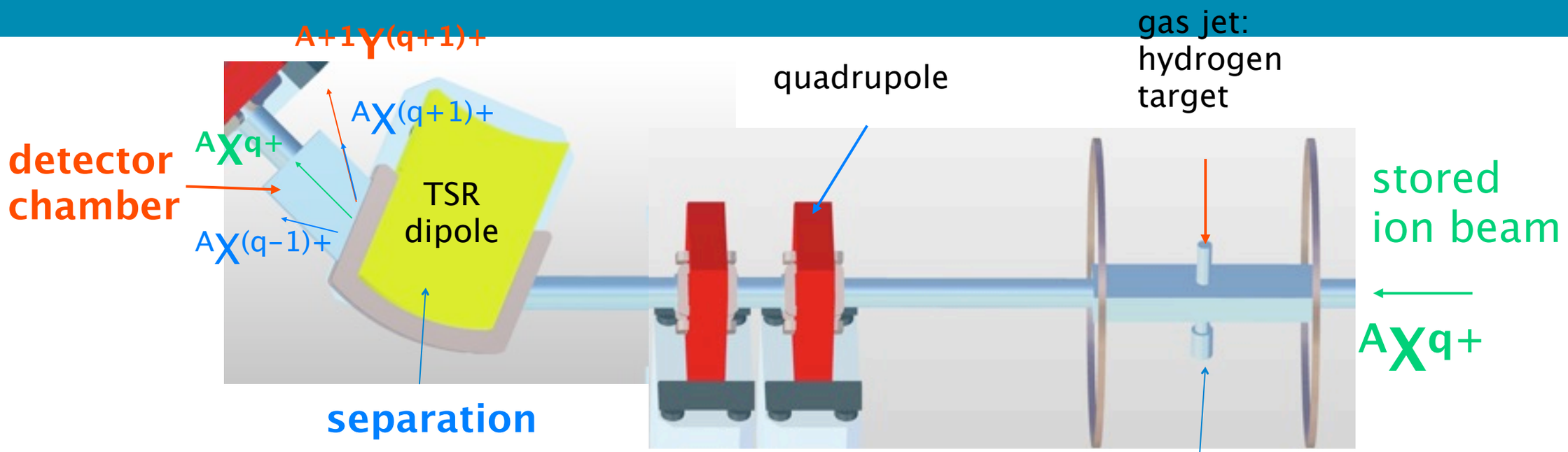
Reactions

nuclear: $^{A}X^{q+} + p \rightarrow {}^{A+1}Y^{(q+1)+}$

ionization: $^{A}X^{q+} \rightarrow {}^{A}X^{(q+1)+} + e$

recombination: $^{A}X^{q+} + e \rightarrow {}^{A}X^{(q-1)+}$

Pick up reaction at TSR



Issue

⇒ rigidities of $^{A}X^{(q+1)+}$ and $^{A+1}Y^{(q+1)+}$ are equal

Energy deviation of $^{A+1}Y^{(q+1)+}$ and $^{A}X^{(q+1)+}$

$$\frac{\delta E}{E} = -\frac{1}{(1+A)}$$

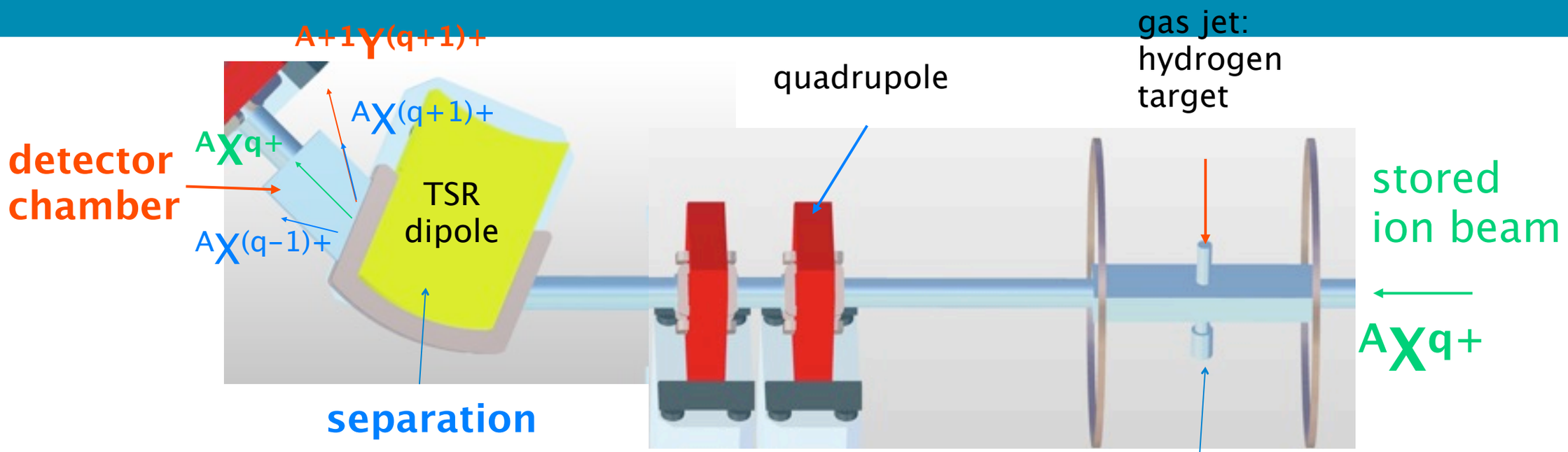
nuclear: $^{A}X^{q+} + p \rightarrow {}^{A+1}Y^{(q+1)+}$

ionization: $^{A}X^{q+} \rightarrow {}^{A}X^{(q+1)+} + e$

recombination: $^{A}X^{q+} + e \rightarrow {}^{A}X^{(q-1)+}$

Dead-time /pile-up due to high flux $^{A}X^{(q+1)+}$

Pick up reaction at TSR



Issue

⇒ rigidities of $^{A}X^{(q+1)+}$ and $^{A+1}Y^{(q+1)+}$ are equal

Energy deviation of $^{A+1}Y^{(q+1)+}$ and $^{A}X^{(q+1)+}$

$$\frac{\delta E}{E} = -\frac{1}{(1+A)}$$

Dead-time /pile-up due to high flux $^{A}X^{(q+1)+}$

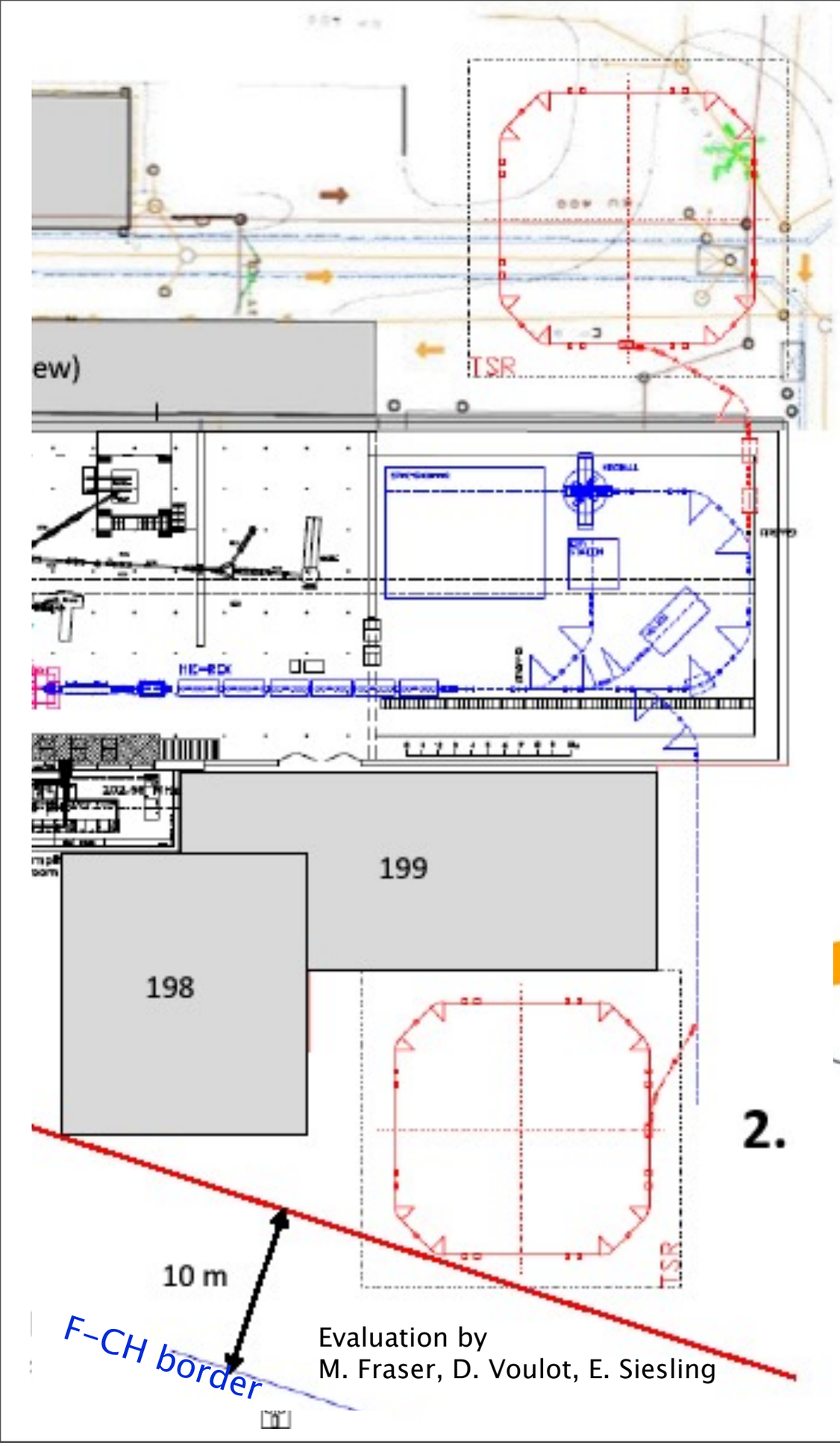
nuclear: $^{A}X^{q+} + p \rightarrow {}^{A+1}Y^{(q+1)+}$

ionization: $^{A}X^{q+} \rightarrow {}^{A}X^{(q+1)+} + e$

recombination: $^{A}X^{q+} + e \rightarrow {}^{A}X^{(q-1)+}$

⇒ experiment has to be carried out with bare $^{A}X^{q+}$ ions

TSR location at ISOLDE

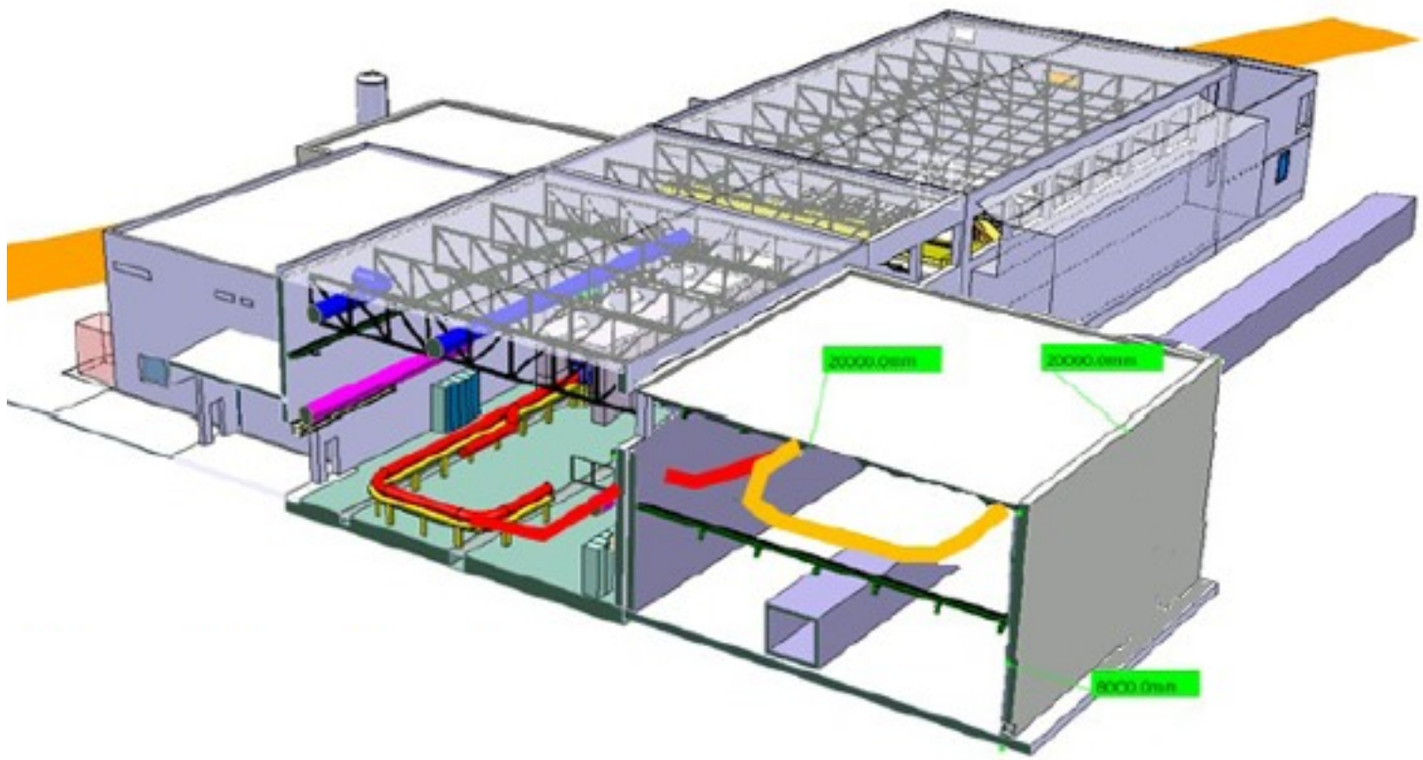


1.

2.

1. – On top of CERN service tunnel
   - Close to road behind
   - Beam level 2.8 m up from HIE-ISOLDE

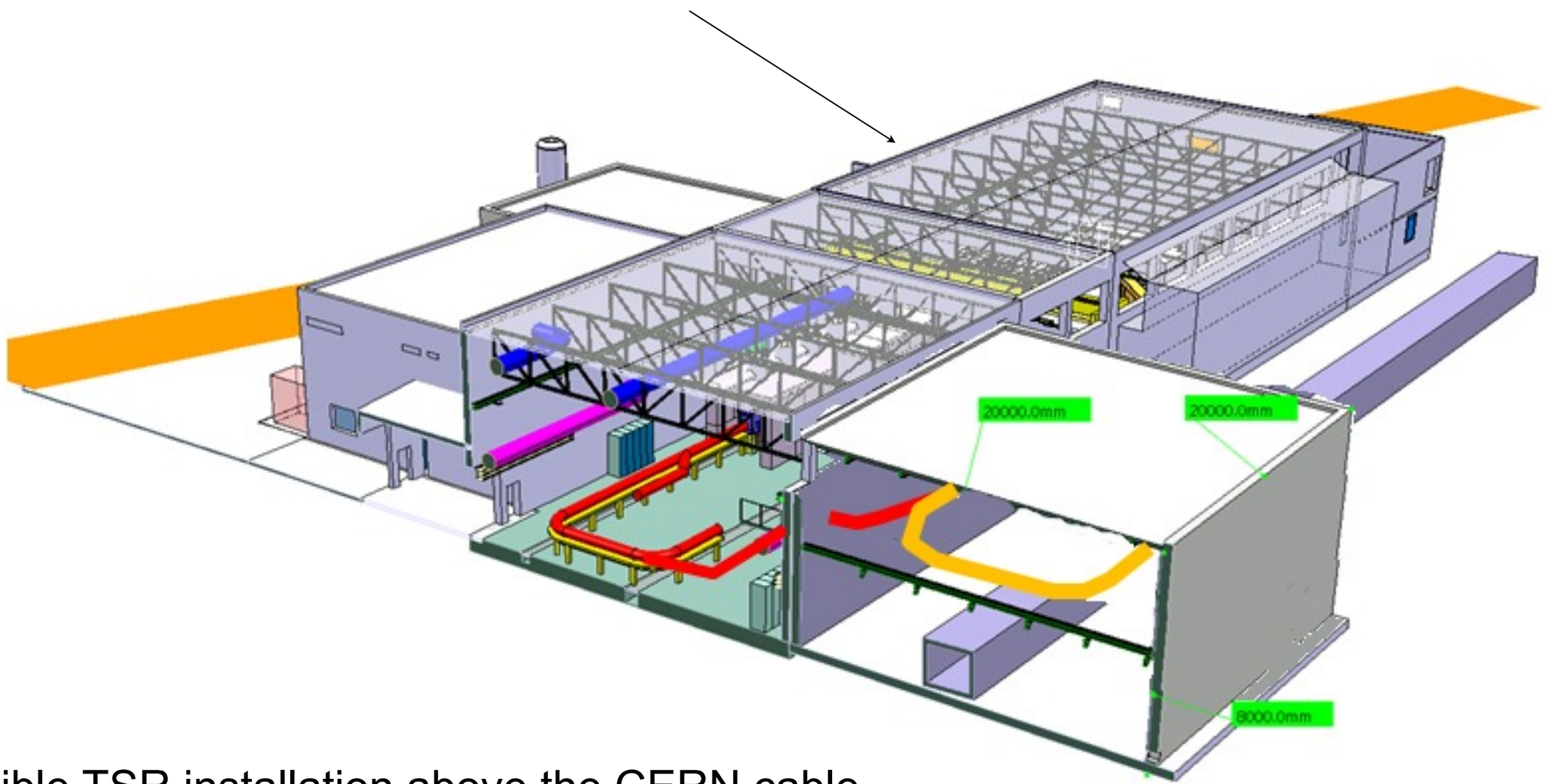
2. – Cryo coldbox and compressor building
   - 10 m distance limit to border
   + Excavate a basement for power supplies



Evaluation by
M. Fraser, D. Voulot, E. Siesling

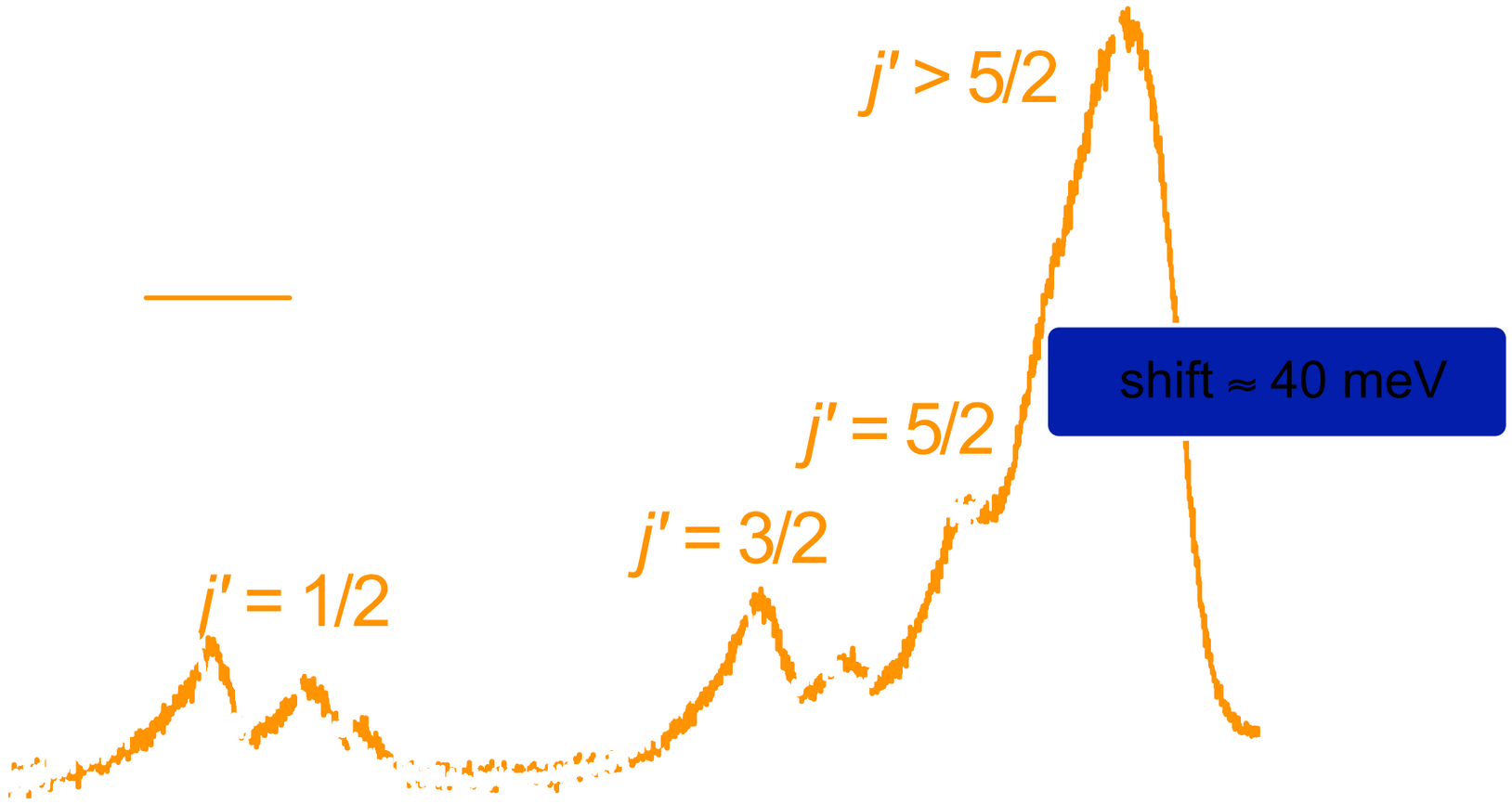
Courtesy E. Siesling

TSR @ Hie-Isolde



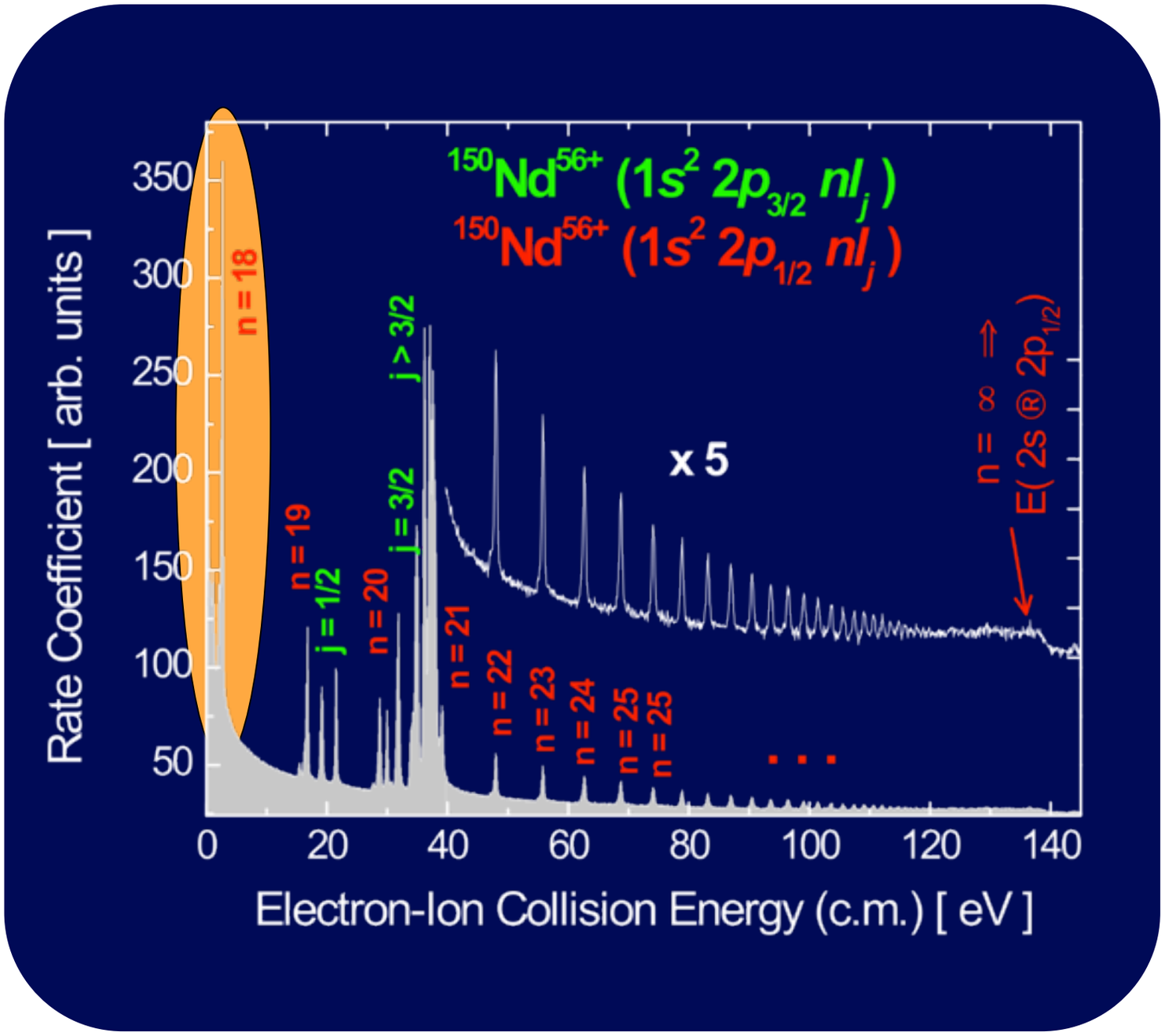
Possible TSR installation above the CERN cable-tunnel.
Tilted beamline coming up from the machine.

Li-like $^{142}Nd^{57+}$ vs. $^{150}Nd^{57+}$



C. Brandau, et al., PRL **100** (2008) 073201

Low-Energy PR Spectrum of Li-like Neodymium ($^{150}Nd^{57+}$)



Li-like ion ($\Delta n = 0$)

2 series of resonances:

E ($2s_{1/2}$ ® $2p_{1/2}$) = 139.2 eV
⇒ $n_{min} = 18$

and to

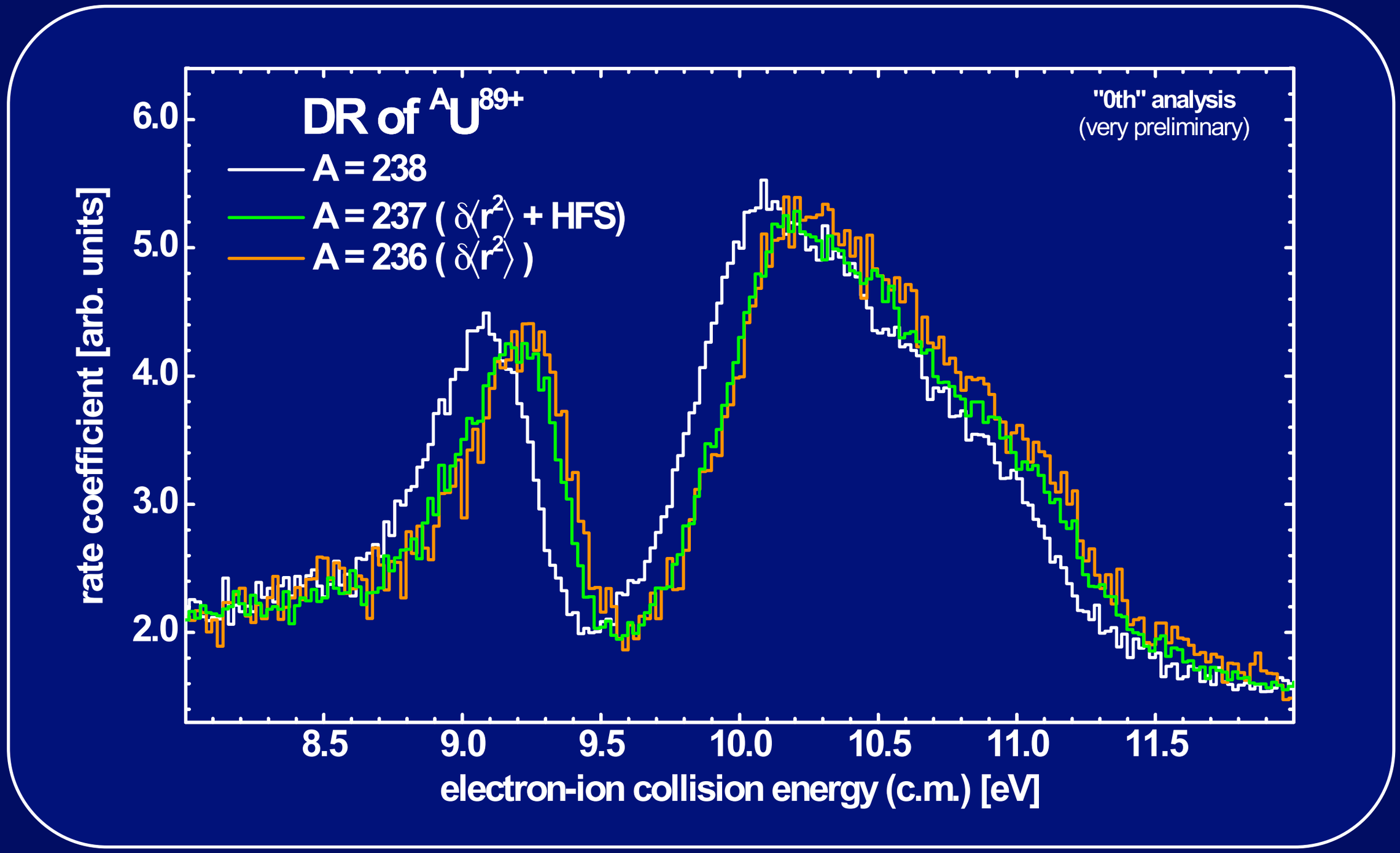
E ($2s_{1/2}$ ® $2p_{3/2}$) = 729.1 eV
⇒ $n_{min} = 8$

HELMHOLTZ GEMEINSCHAFT

ISOLDE Workshop and Users meeting 2011
05-07 December 2011, CERN

Max-Planck-Institut für Kernphysik

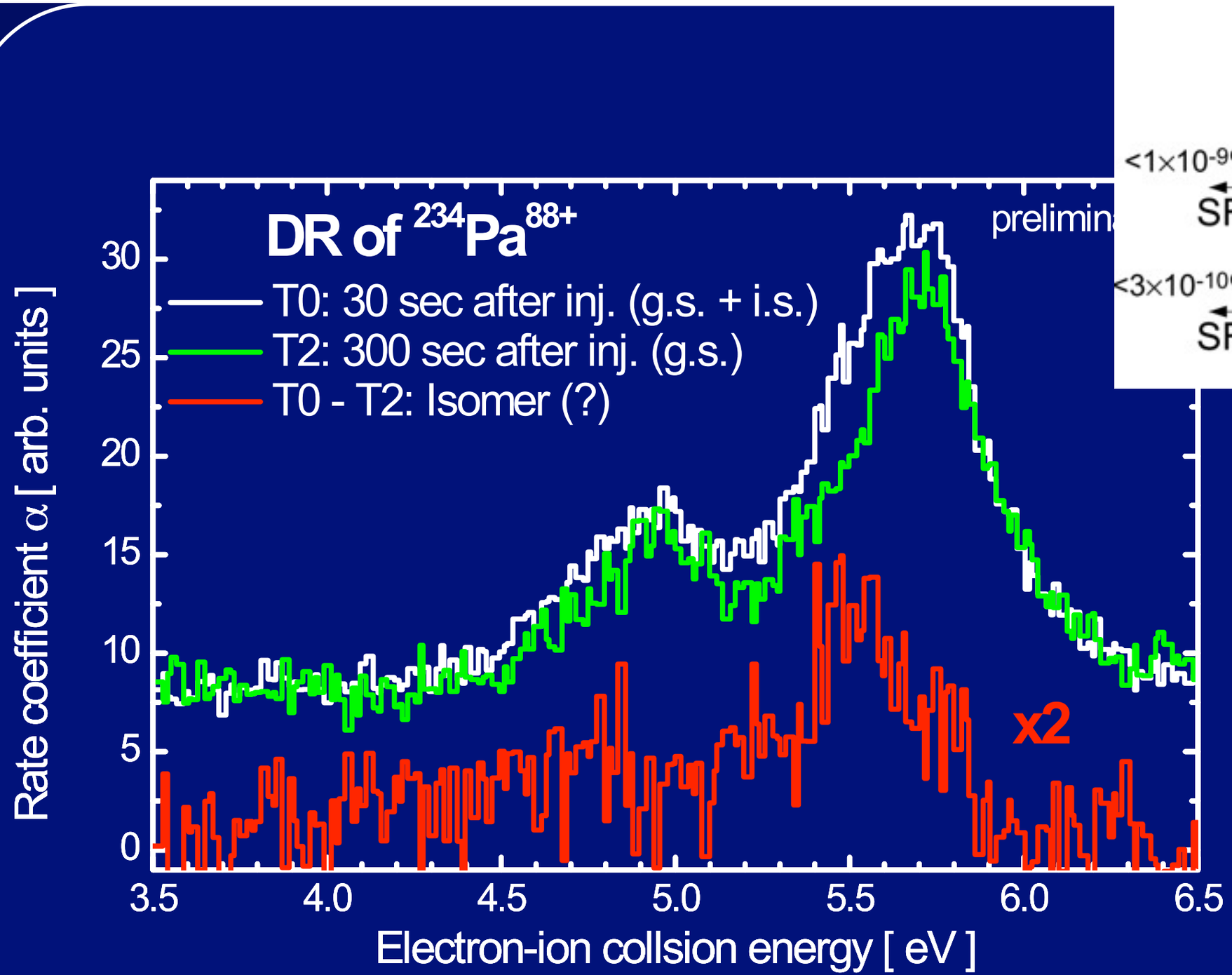
Isotope Shift and Hyperfine Effects in the Dielectronic Recombination of In-Flight Synthesized $^{A}U^{89+}$ (A=236, 237, 238)

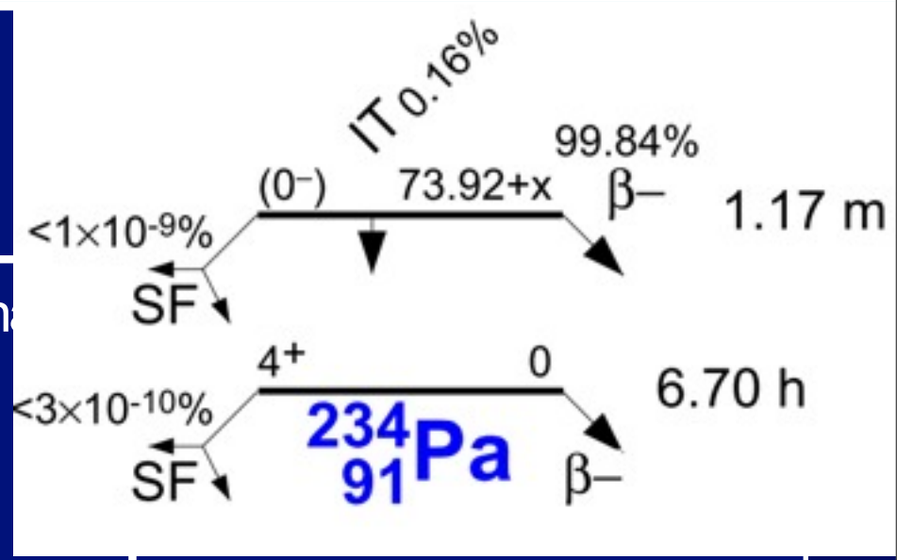


GSI
HELMHOLTZ GEMEINSCHAFT
ISOLDE Workshop and Users meeting 2011
05-07 December 2011, CERN
Max-Planck-Institut für Kernphysik

DR of 0⁻- Isomers in $^{234}Pa^{88+}$

(Preliminary Results from Nov 2010 Test Run)





μ_n (4+ gs) = 0.7

(P. Walker, priv. comm.)

High-Z Long-Lived Nuclear Metastable States (Isomers)

appealing candidates:

^{235m}U: 76.8 eV, E3, τ ~ 26.5 min (for atom),
IC with $\alpha = 10^{10} - 10^{20}$; τ depends on chemical environment

^{234m}Pa: 73.92+x keV, τ = 1.17min fast β-decay of I = 0 isomer;
first isomer discovered: ‘brevium‘ / ‘UX2‘

^{229m}Th: 7.6eV (???), M1 transition, τ = ???)

…and many more (K-isomers, …)

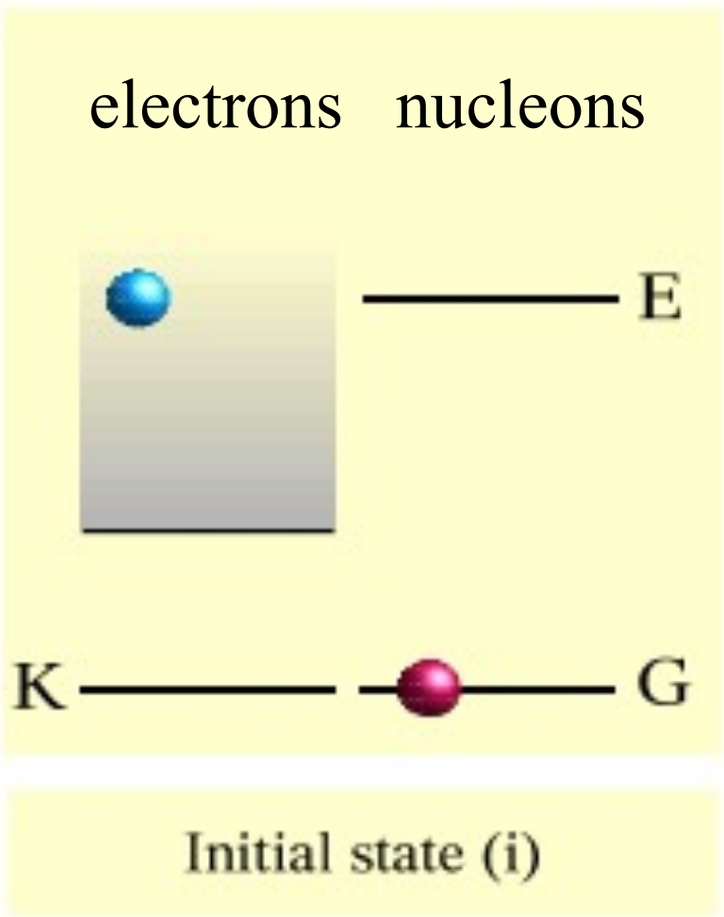
^{229m}Th / ^{235m}U :

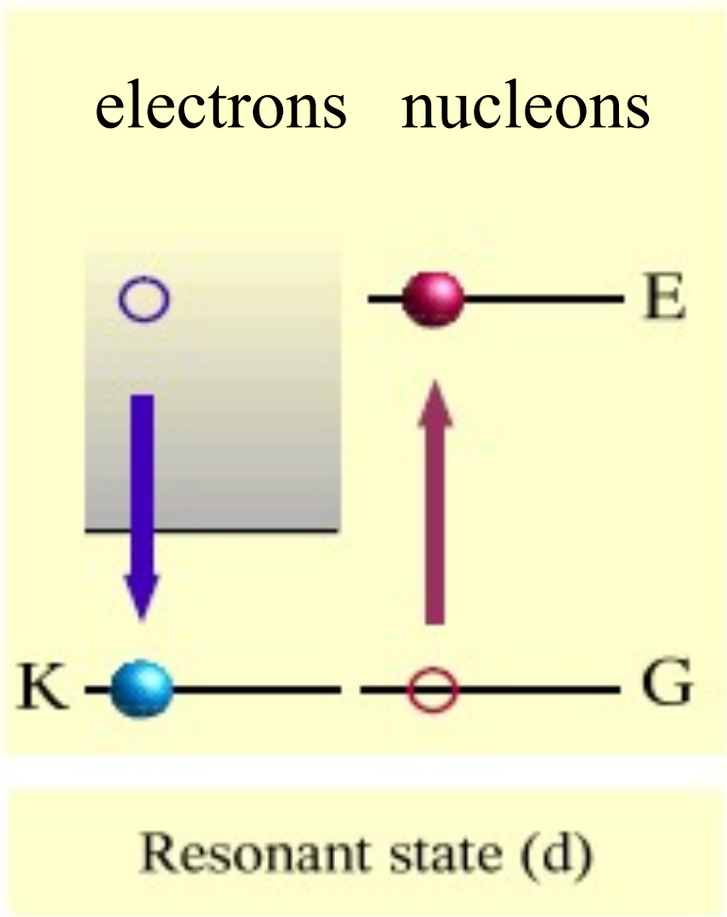
‘eV‘ (‘keV‘) nuclear excitation energies :

nuclear laser spectroscopy (UV or soft x-ray)
lifetime / decay modes of HCI ? (in absence of conversion)
fundamental physics (‘nuclear clock‘)
interface of atomic electrons and the nucleus:
excitation by laser, UV discharge, plasma, electron bridge processes, NEEC, NEET, DR-NEEC etc.

Nuclear Excitation by Electron Capture

an as-yet unobserved process





difficulty: NEEC competes with much stronger, but non-resonant process of radiative capture: X-ray emitted, instead of nuclear excitation.

- nuclear analogue of dielectronic recombination
- inverse of electron conversion

[A. Palffy et al., Phys. Rev. Lett. 99 (2007) 172502]

Proposed candidate ^{93}Mo

Transfer Reaction Studies: Physics cases

31Al 644 MS β-: 100.00%	32Al 33.0 MS β-: 100.00% β-n: 0.70%	33Al 41.7 MS β-: 100.00% β-n: 8.50%	34Al 42 MS β-: 100.00% β-n: 27.00%	35Al 38.6 MS β-: 100.00% β-n: 41.00%
30Mg 335 MS β-: 100.00%	31Mg 232 MS β-: 100.00% β-n: 1.70%	32Mg 86 MS β-: 100.00% β-n: 5.50%	33Mg 90.5 MS β-: 100.00% β-n: 17.00%	34Mg 20 MS β-: 100.00% β-n
29Na 44.9 MS β-: 100.00% β-n: 21.50%	30Na 48 MS β-: 100.00% β-n: 30.00%	31Na 17.0 MS β-: 100.00% β-n: 37.00%	32Na 13.2 MS β-: 100.00% β-n: 24.00%	33Na 8.0 MS β-: 100.00% β-n: 47.00%
28Ne 18.9 MS	29Ne 14.8 MS	30Ne 7.3 MS	31Ne 3.4 MS	32Ne 3.5 MS

69Cu 2.85 M β-: 100.00%	70Cu 44.5 S β-: 100.00%	71Cu 19.5 S β-: 100.00%	72Cu 6.6 S β-: 100.00%	73Cu 4.2 S β-: 100.00%
68Ni 29 S β-: 100.00%	69Ni 11.4 S β-: 100.00%	70Ni 6.0 S β-: 100.00%	71Ni 2.56 S β-: 100.00%	72Ni 1.57 S β-: 100.00% β-n
67Co 0.425 S	68Co 0.199 S	69Co 0.22 S	70Co 119 MS	71Co 79 MS

Transfer Reaction Studies: Physics cases

31Al 644 MS β-: 100.00%	32Al 33.0 MS β-: 100.00% β-n: 0.70%	33Al 41.7 MS β-: 100.00% β-n: 8.50%	34Al 42 MS β-: 100.00% β-n: 27.00%	35Al 38.6 MS β-: 100.00% β-n: 41.00%
30Mg 335 MS β-: 100.00%	31Mg 232 MS β-: 100.00% β-n: 1.70%	32Mg 86 MS β-: 100.00% β-n: 5.50%	33Mg 90.5 MS β-: 100.00% β-n: 17.00%	34Mg 20 MS β-: 100.00% β-n
29Na 44.9 MS β-: 100.00% β-n: 21.50%	30Na 48 MS β-: 100.00% β-n: 30.00%	31Na 17.0 MS β-: 100.00% β-n: 37.00%	32Na 13.2 MS β-: 100.00% β-n: 24.00%	33Na 8.0 MS β-: 100.00% β-n: 47.00%
28Ne 18.9 MS	29Ne 14.8 MS	30Ne 7.3 MS	31Ne 3.4 MS	32Ne 3.5 MS

69Cu 2.85 M β-: 100.00%	70Cu 44.5 S β-: 100.00%	71Cu 19.5 S β-: 100.00%	72Cu 6.6 S β-: 100.00%	73Cu 4.2 S β-: 100.00
68Ni 29 S β-: 100.00%	69Ni 11.4 S β-: 100.00%	70Ni 6.0 S β-: 100.00%	71Ni 2.56 S β-: 100.00%	72Ni 1.57 S β-: 100.00 β-n
67Co 0.425 S	68Co 0.199 S	69Co 0.22 S	70Co 119 MS	71Co 79 MS

Transfer Reaction Studies: Physics cases

Transfer around the island of inversion

- ^{32}Mg(d,p) $T_{1/2}$ = 86 ms, 3×10^3 pps
- TSR current (Pτ) 4×10^8 pps

  ⇒ luminosity $\approx10^{21} - 10^{22}$ cm^{-2}s^{-1}

⇒ not competitive (**half lives**)

Transfer towards ^{78}Ni

- ^{68}Ni(d,p) $T_{1/2}$ = 29 s, 5×10^4 pps
- Limit given by atomic charge exchange

31Al 644 MS β-: 100.00%	32Al 33.0 MS β-: 100.00% β-n: 0.70%	33Al 41.7 MS β-: 100.00% β-n: 8.50%	34Al 42 MS β-: 100.00% β-n: 27.00%	35Al 38.6 MS β-: 100.00% β-n: 41.00%
30Mg 335 MS β-: 100.00%	31Mg 232 MS β-: 100.00% β-n: 1.70%	32Mg 86 MS β-: 100.00% β-n: 5.50%	33Mg 90.5 MS β-: 100.00% β-n: 17.00%	34Mg 20 MS β-: 100.00% β-n
29Na 44.9 MS β-: 100.00% β-n: 21.50%	30Na 48 MS β-: 100.00% β-n: 30.00%	31Na 17.0 MS β-: 100.00% β-n: 37.00%	32Na 13.2 MS β-: 100.00% β-n: 24.00%	33Na 8.0 MS β-: 100.00% β-n: 47.00%
28Ne 18.9 MS	29Ne 14.8 MS	30Ne 7.3 MS	31Ne 3.4 MS	32Ne 3.5 MS

69Cu 2.85 M β-: 100.00%	70Cu 44.5 S β-: 100.00%	71Cu 19.5 S β-: 100.00%	72Cu 6.6 S β-: 100.00%	73Cu 4.2 S β-: 100.00
68Ni 29 S β-: 100.00%	69Ni 11.4 S β-: 100.00%	70Ni 6.0 S β-: 100.00%	71Ni 2.56 S β-: 100.00%	72Ni 1.57 S β-: 100.00 β-n
67Co 0.425 S	68Co 0.199 S	69Co 0.22 S	70Co 119 MS	71Co 79 MS

Transfer Reaction Studies: Physics cases

Transfer around the island of inversion

- ^{32}Mg(d,p) $T_{1/2}$ = 86 ms, 3×10^3 pps
- TSR current (PT) 4×10^8 pps

⇒ luminosity $\approx10^{21} - 10^{22}$ cm^{-2}s^{-1}

⇒ not competitive (**half lives**)

Transfer towards ^{78}Ni

- ^{68}Ni(d,p) $T_{1/2}$ = 29 s, 5×10^4 pps
- Limit given by atomic charge exchange

⇒ Luminosity improvement by a factor >10 (?)

Contaminant?

31Al 644 MS β-: 100.00%	32Al 33.0 MS β-: 100.00% β-n: 0.70%	33Al 41.7 MS β-: 100.00% β-n: 8.50%	34Al 42 MS β-: 100.00% β-n: 27.00%	35Al 38.6 MS β-: 100.00% β-n: 41.00%
30Mg 335 MS β-: 100.00%	31Mg 232 MS β-: 100.00% β-n: 1.70%	32Mg 86 MS β-: 100.00% β-n: 5.50%	33Mg 90.5 MS β-: 100.00% β-n: 17.00%	34Mg 20 MS β-: 100.00% β-n
29Na 44.9 MS β-: 100.00% β-n: 21.50%	30Na 48 MS β-: 100.00% β-n: 30.00%	31Na 17.0 MS β-: 100.00% β-n: 37.00%	32Na 13.2 MS β-: 100.00% β-n: 24.00%	33Na 8.0 MS β-: 100.00% β-n: 47.00%
28Ne 18.9 MS	29Ne 14.8 MS	30Ne 7.3 MS	31Ne 3.4 MS	32Ne 3.5 MS

69Cu 2.85 M β-: 100.00%	70Cu 44.5 S β-: 100.00%	71Cu 19.5 S β-: 100.00%	72Cu 6.6 S β-: 100.00%	73Cu 4.2 S β-: 100.00
68Ni 29 S β-: 100.00%	69Ni 11.4 S β-: 100.00%	70Ni 6.0 S β-: 100.00%	71Ni 2.56 S β-: 100.00%	72Ni 1.57 S β-: 100.00 β-n
67Co 0.425 S	68Co 0.199 S	69Co 0.22 S	70Co 119 MS	71Co 79 MS

Transfer Reaction Studies: Physics cases

Transfer around the island of inversion

- ^{32}Mg(d,p) $T_{1/2}$ = 86 ms, 3×10^3 pps
- TSR current (PT) 4×10^8 pps

  ⇒ luminosity $\approx10^{21} - 10^{22}$ cm^{-2}s^{-1}

⇒ not competitive (**half lives**)

Transfer towards ^{78}Ni

- ^{68}Ni(d,p) $T_{1/2}$ = 29 s, 5×10^4 pps
- Limit given by atomic charge exchange

⇒ Luminosity improvement by a factor >10 (?)

Contaminant?

- Population of states with small spectroscopic factors

Transfer Reaction Studies: Physics cases

Transfer around the island of inversion

- ^{32}Mg(d,p) $T_{1/2}$ = 86 ms, 3×10^3 pps
- TSR current (PT) 4×10^8 pps

  ⇒ luminosity $\approx10^{21} - 10^{22}$ cm^{-2}s^{-1}

⇒ not competitive (**half lives**)

Transfer towards ^{78}Ni

- ^{68}Ni(d,p) $T_{1/2}$ = 29 s, 5×10^4 pps
- Limit given by atomic charge exchange

⇒ Luminosity improvement by a factor >10 (?)

Contaminant?

- Population of states with small spectroscopic factors
- Coincidence with heavy partner detection and identification in 41

31Al 644 MS β-: 100.00%	32Al 33.0 MS β-: 100.00% β-n: 0.70%	33Al 41.7 MS β-: 100.00% β-n: 8.50%	34Al 42 MS β-: 100.00% β-n: 27.00%	35Al 38.6 MS β-: 100.00% β-n: 41.00%
30Mg 335 MS β-: 100.00%	31Mg 232 MS β-: 100.00% β-n: 1.70%	32Mg 86 MS β-: 100.00% β-n: 5.50%	33Mg 90.5 MS β-: 100.00% β-n: 17.00%	34Mg 20 MS β-: 100.00% β-n
29Na 44.9 MS β-: 100.00% β-n: 21.50%	30Na 48 MS β-: 100.00% β-n: 30.00%	31Na 17.0 MS β-: 100.00% β-n: 37.00%	32Na 13.2 MS β-: 100.00% β-n: 24.00%	33Na 8.0 MS β-: 100.00% β-n: 47.00%
28Ne 18.9 MS	29Ne 14.8 MS	30Ne 7.3 MS	31Ne 3.4 MS	32Ne 3.5 MS

69Cu 2.85 M β-: 100.00%	70Cu 44.5 S β-: 100.00%	71Cu 19.5 S β-: 100.00%	72Cu 6.6 S β-: 100.00%	73Cu 4.2 S β-: 100.00
68Ni 29 S β-: 100.00%	69Ni 11.4 S β-: 100.00%	70Ni 6.0 S β-: 100.00%	71Ni 2.56 S β-: 100.00%	72Ni 1.57 S β-: 100.00 β-n
67Co 0.425 S	68Co 0.199 S	69Co 0.22 S	70Co 119 MS	71Co 79 MS

Transfer Reaction Studies: Physics cases

Transfer around the island of inversion

- ^{32}Mg(d,p) $T_{1/2}$ = 86 ms, 3×10^3 pps
- TSR current (PT) 4×10^8 pps

  ⇒ luminosity $\approx10^{21} - 10^{22}$ cm^{-2}s^{-1}

⇒ not competitive (**half lives**)

Transfer towards ^{78}Ni

- ^{68}Ni(d,p) $T_{1/2}$ = 29 s, 5×10^4 pps
- Limit given by atomic charge exchange

⇒ Luminosity improvement by a factor >10 (?)

Contaminant?

- Population of states with small spectroscopic factors
- Coincidence with heavy partner detection and identification in A1
- High resolution + γ-ray coincidence

Transfer Reaction Studies: Physics cases

99Sn 5 MS εp ε	100Sn 1.0 S ε: 100.00% εp < 17.00%	101Sn 1.7 S ε: 100.00% εp: 26.00%	102Sn 4.5 S ε: 100.00%	103Sn 7.0 S ε: 100.00% εp: 1.20%
98In 32 MS ε	99In 3.0 S ε	100In 5.9 S ε: 100.00% εp > 3.90%	101In 15.1 S ε≈ 100.00% εp	102In 23.3 S ε: 100.00% εp: 9.3E-3%
97Cd 2.8 S	98Cd 9.2 S	99Cd 16 S	100Cd 49.1 S	101Cd 1.36 M

Transfer Reaction Studies: Physics cases

99Sn 5 MS εp ε	100Sn 1.0 S ε: 100.00% εp < 17.00%	101Sn 1.7 S ε: 100.00% εp: 26.00%	102Sn 4.5 S ε: 100.00%	103Sn 7.0 S ε: 100.00% εp: 1.20%
98In 32 MS ε	99In 3.0 S ε	100In 5.9 S ε: 100.00% εp > 3.90%	101In 15.1 S ε≈ 100.00% εp	102In 23.3 S ε: 100.00% εp: 9.3E-3%
97Cd 2.8 S	98Cd 9.2 S	99Cd 16 S	100Cd 49.1 S	101Cd 1.36 M

Transfer Reaction Studies: Physics cases

Transfer around ^{100}Sn

99Sn 5 MS εp ε	100Sn 1.0 S ε: 100.00% εp < 17.00%	101Sn 1.7 S ε: 100.00% εp: 26.00%	102Sn 4.5 S ε: 100.00%	103Sn 7.0 S ε: 100.00% εp: 1.20%
98In 32 MS ε	99In 3.0 S ε	100In 5.9 S ε: 100.00% εp > 3.90%	101In 15.1 S ε≈ 100.00% εp	102In 23.3 S ε: 100.00% εp: 9.3E-3%
97Cd 2.8 S	98Cd 9.2 S	99Cd 16 S	100Cd 49.1 S	101Cd 1.36 M

Transfer Reaction Studies: Physics cases

Transfer around ^{100}Sn

- ^{102}Sn(p,d) $T_{1/2}$ = 4.5 s, 10^2 – 10^3 pps ??

99Sn 5 MS εp ε	100Sn 1.0 S ε: 100.00% εp < 17.00%	101Sn 1.7 S ε: 100.00% εp: 26.00%	102Sn 4.5 S ε: 100.00%	103Sn 7.0 S ε: 100.00% εp: 1.20%
98In 32 MS ε	99In 3.0 S ε	100In 5.9 S ε: 100.00% εp > 3.90%	101In 15.1 S ε≈ 100.00% εp	102In 23.3 S ε: 100.00% εp: 9.3E-3%
97Cd 2.8 S	98Cd 9.2 S	99Cd 16 S	100Cd 49.1 S	101Cd 1.36 M

Transfer Reaction Studies: Physics cases

Transfer around ^{100}Sn

- ^{102}Sn(p,d) $T_{1/2}$ = 4.5 s, 10^2 – 10^3 pps ??
- TSR current 6×10^9 pps

99Sn 5 MS εp ε	100Sn 1.0 S ε: 100.00% εp < 17.00%	101Sn 1.7 S ε: 100.00% εp: 26.00%	102Sn 4.5 S ε: 100.00%	103Sn 7.0 S ε: 100.00% εp: 1.20%
98In 32 MS ε	99In 3.0 S ε	100In 5.9 S ε: 100.00% εp > 3.90%	101In 15.1 S ε≈ 100.00% εp	102In 23.3 S ε: 100.00% εp: 9.3E-3%
97Cd 2.8 S	98Cd 9.2 S	99Cd 16 S	100Cd 49.1 S	101Cd 1.36 M

Transfer Reaction Studies: Physics cases

Transfer around ^{100}Sn

- ^{102}Sn(p,d) $T_{1/2}$ = 4.5 s, 10^2 – 10^3 pps ??
- TSR current 6×10^9 pps

⇒ Luminosity improvement factor ≈10 ?
Could be feasible!

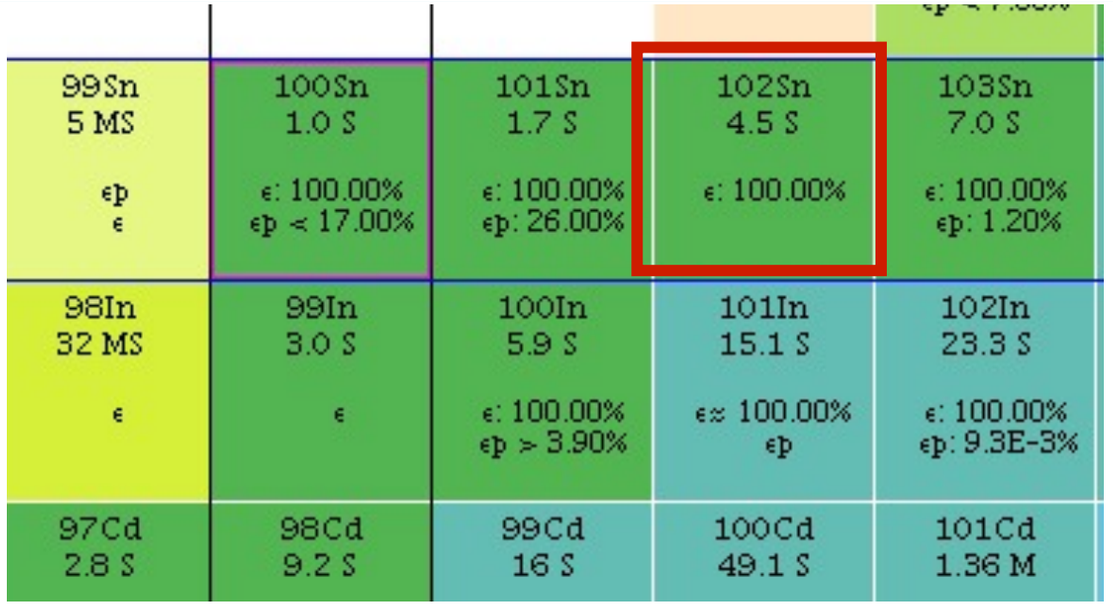
99Sn 5 MS εp ε	100Sn 1.0 S ε: 100.00% εp < 17.00%	101Sn 1.7 S ε: 100.00% εp: 26.00%	102Sn 4.5 S ε: 100.00%	103Sn 7.0 S ε: 100.00% εp: 1.20%
98In 32 MS ε	99In 3.0 S ε	100In 5.9 S ε: 100.00% εp > 3.90%	101In 15.1 S ε≈ 100.00% εp	102In 23.3 S ε: 100.00% εp: 9.3E-3%
97Cd 2.8 S	98Cd 9.2 S	99Cd 16 S	100Cd 49.1 S	101Cd 1.36 M

Transfer Reaction Studies: Physics cases

Transfer around ^{100}Sn

- ^{102}Sn(p,d) $T_{1/2}$ = 4.5 s, 10^2 – 10^3 pps ??
- TSR current 6×10^9 pps

⇒ Luminosity improvement factor ≈10 ?
Could be feasible!



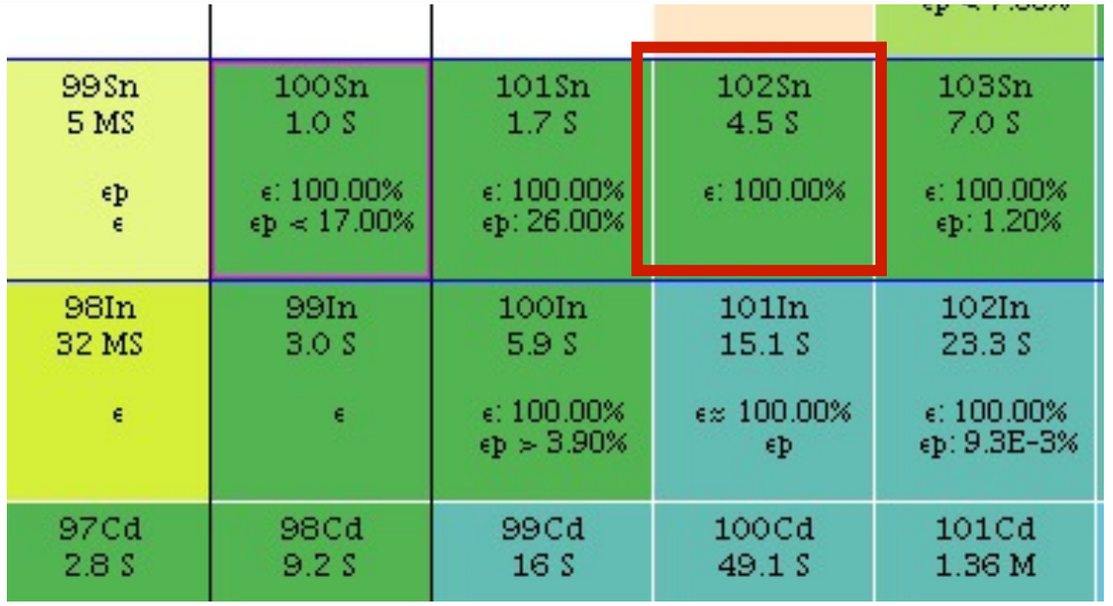
Transfer around ^{132}Sn

Transfer Reaction Studies: Physics cases

Transfer around ^{100}Sn

- ^{102}Sn(p,d) $T_{1/2}$ = 4.5 s, 10^2 – 10^3 pps ??
- TSR current 6×10^9 pps

⇒ Luminosity improvement factor ≈10 ?
Could be feasible!



Transfer around ^{132}Sn

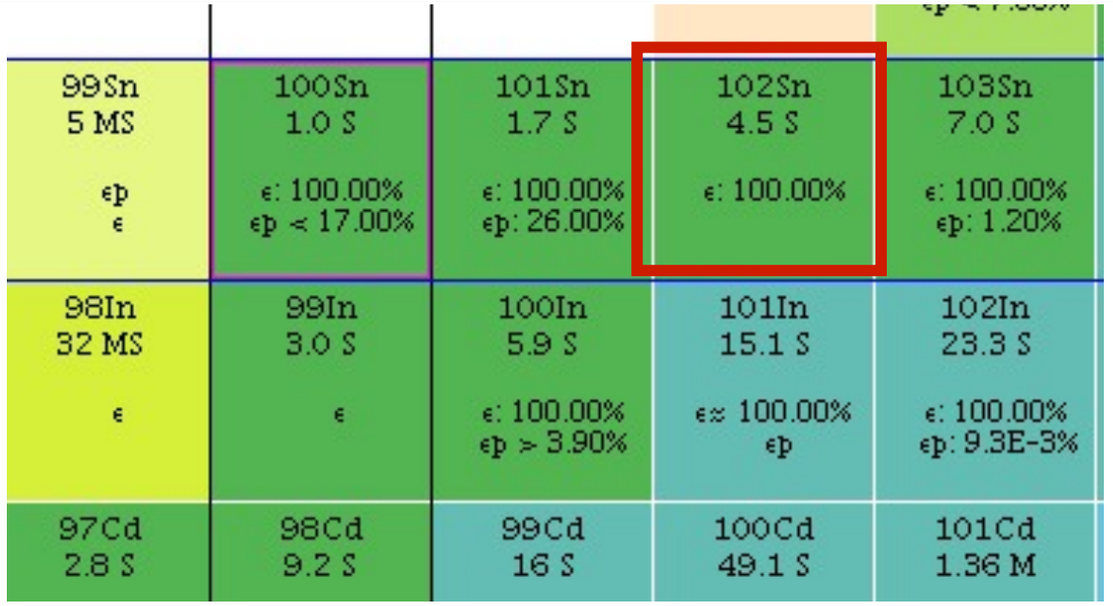
- ^{134}Sn(d,p) $T_{1/2}$ = 1 s, 10^4 pps ?

Transfer Reaction Studies: Physics cases

Transfer around ^{100}Sn

- ^{102}Sn(p,d) $T_{1/2}$ = 4.5 s, 10^2 – 10^3 pps ??
- TSR current 6×10^9 pps

⇒ Luminosity improvement factor ≈10 ?
Could be feasible!



Transfer around ^{132}Sn

- ^{134}Sn(d,p) $T_{1/2}$ = 1 s, 10^4 pps ?

⇒ Luminosity comparable
Better resolution

Transfer Reaction Studies: Physics cases

Shape coexistence in n-poor Pb region

- Still unique @ ISOLDE
  (Bi, Tl never post-accelerated so far)
- Beam losses??

			188Po 0.40 MS ε ≤ 100.00% α > 0.00%	189Po 3.5 MS α≈ 100.00%	190Po 2.46 MS α: 100.00%	191Po 22 MS α: 99.00%	192Po 33.2 MS α≈ 99.50% ε≈ 0.50%
184Bi 13 MS α≈ 100.00% α≈ 100.00%	185Bi 58 μS P: 90.00% α: 10.00%	186Bi 15.0 MS α≈ 100.00%	187Bi 32 MS α: 100.00%	188Bi 265 MS α: 100.00%	189Bi 674 MS ε ≤ 50.00% α > 50.00%	190Bi 6.3 S 1E2	191Bi 12.4 S 1E3
183Pb 535 MS α≈ 90.00%	184Pb 490 MS ε: 77.00% α: 23.00%	185Pb 6.3 S 1E2	186Pb 4.82 S 5E3	187Pb 15.2 S 5E4	188Pb 25.1 S 2E5	189Pb 51 S 1E6	190Pb 71 S 2E6
182Tl 3.1 S 1E3	183Tl 6.9 S 1E4	184Tl 11 S 1E5	185Tl 19.5 S ε	186Tl 27.5 S 1E6	187Tl ≈51 S ε ≤ 100.00% α > 0.00%	188Tl 71 S ε: 100.00%	189Tl 2.3 M ε: 100.00%
181Hg 3.6 S 1E2	182Hg 10.83 S 3E3	183Hg 9.4 S 1E4	184Hg 30.9 S 7E4	185Hg 49.1 S 1E5	186Hg 1.38 M 2E5	187Hg 2.4 M ε: 100.00% α > 1.2E-4%	188Hg 3.25 M ε: 100.00% α: 3.7E-5%

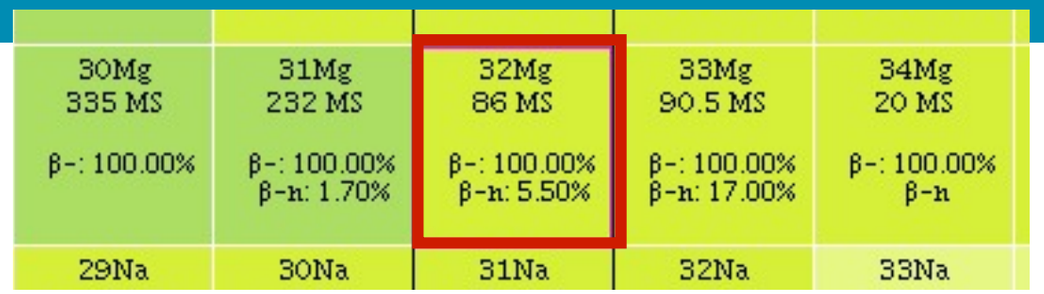
R. Raabe, K.U. Leuven

Transfer Reaction Studies: Physics cases

Transfer around the island of inversion

- ^{32}Mg(d,p) $T_{1/2}$ = 86 ms, 3×10^3 pps

⇒ not possible (**half lives**)



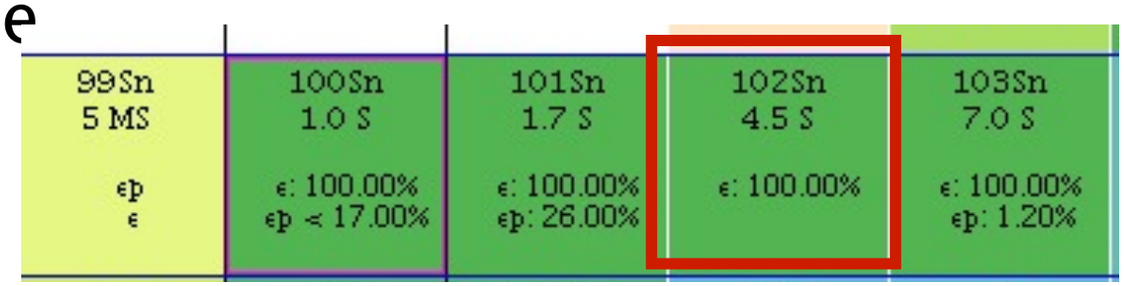
Transfer towards ^{78}Ni

- ^{68}Ni(d,p) $T_{1/2}$ = 29 s, 5×10^4 pps
- Limit given by atomic charge exchange

Transfer around ^{100}Sn

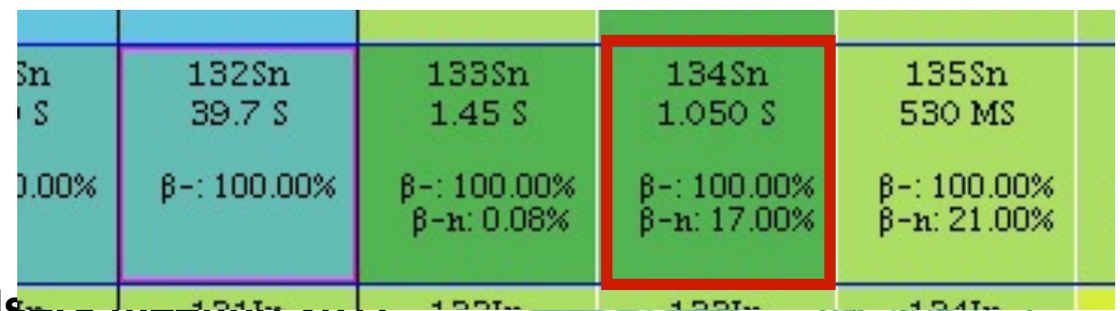
- ^{102}Sn(p,d) $T_{1/2}$ = 4.5 s, 10^2 – 10^3 pps ??

⇒Could be feasible! But probably not at 10 MeV/u



Transfer around ^{132}Sn

- ^{134}Sn(d,p) $T_{1/2}$ = 1 s, 10^4 pps ?



Transfer Reaction Studies: Physics cases

Shape coexistence in n-poor Pb region

- Still unique @ ISOLDE
  (Bi, Tl never post-accelerated so far)
- Beam losses??

			188Po 0.40 MS ε ≤ 100.00% α > 0.00%	189Po 3.5 MS α≈ 100.00%	190Po 2.46 MS α: 100.00%	191Po 22 MS α: 99.00%	192Po 33.2 MS α≈ 99.50% ε≈ 0.50%
184Bi 13 MS α≈ 100.00% α≈ 100.00%	185Bi 58 μS P: 90.00% α: 10.00%	186Bi 15.0 MS α≈ 100.00%	187Bi 32 MS α: 100.00%	188Bi 265 MS α: 100.00%	189Bi 674 MS ε ≤ 50.00% α > 50.00%	190Bi 6.3 S 1E2	191Bi 12.4 S 1E3
183Pb 535 MS α≈ 90.00%	184Pb 490 MS ε: 77.00% α: 23.00%	185Pb 6.3 S 1E2	186Pb 4.82 S 5E3	187Pb 15.2 S 5E4	188Pb 25.1 S 2E5	189Pb 51 S 1E6	190Pb 71 S 2E6
182Tl 3.1 S 1E3	183Tl 6.9 S 1E4	184Tl 11 S 1E5	185Tl 19.5 S ε	186Tl 27.5 S 1E6	187Tl ≈51 S ε ≤ 100.00% α > 0.00%	188Tl 71 S ε: 100.00%	189Tl 2.3 M ε: 100.00%
181Hg 3.6 S 1E2	182Hg 10.83 S 3E3	183Hg 9.4 S 1E4	184Hg 30.9 S 7E4	185Hg 49.1 S 1E5	186Hg 1.38 M 2E5	187Hg 2.4 M ε: 100.00% α > 1.2E-4%	188Hg 3.25 M ε: 100.00% α: 3.7E-5%

R. Raabe, K.U. Leuven