The new physics possibilities with HIE-ISOLDE

Mark Huyse

Instituut voor Kern- en Stralingsfysica, K.U.Leuven

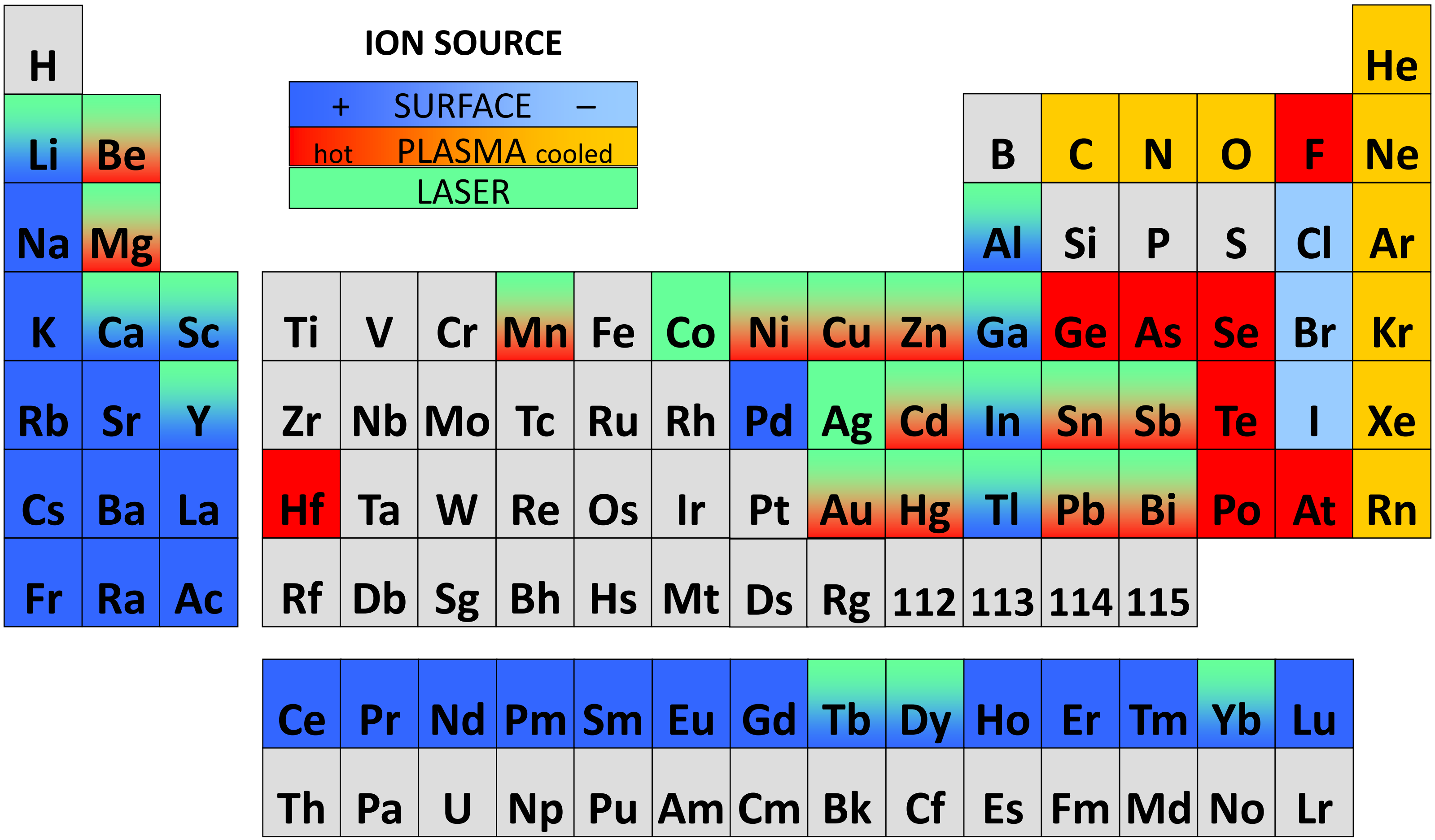
The HIE-ISOLDE Project

ISOLDE today offers the largest range of available isotopes of any ISOL facility worldwide (>600 radioactive isotopes of >60 elements) in an energy range between 60 keV and 3 AMeV.

HIE-ISOLDE aims at increasing the range of elements, the energy of these RIB up to 10 AMeV and their intensity by a factor 10.

HIE-ISOLDE will play an important role in the network of ISOL facilities preparing EURISOL (with SPIRAL2 and SPES).

Increased number of elements, increased selectivity



Increased number of elements, increased selectivity

Continuous target - ion source development (see talks in the ISOLDE technical session)

- New target materials
- n-converter developments
- Ion-source developments
- Transfer line
- Laser ion source (Knut and Alice Wallenberg foundation grant)
  - LARIS off-line test bench
  - Replacement of Copper Vapour Laser by new Syrah Dye lasers
  - Installation of three Ti:sapphire laser units
    - *Isomeric beams are possible*
- In-trap decay

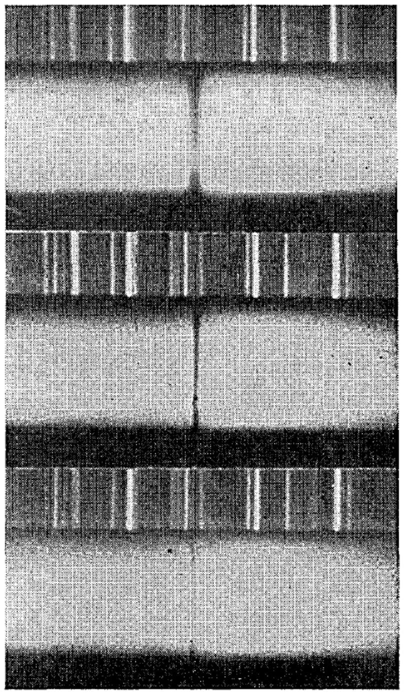
Continuous improvement in ion-optical properties

- ISCOOL : RFQ cooler buncher
- HRS higher mass resolving power

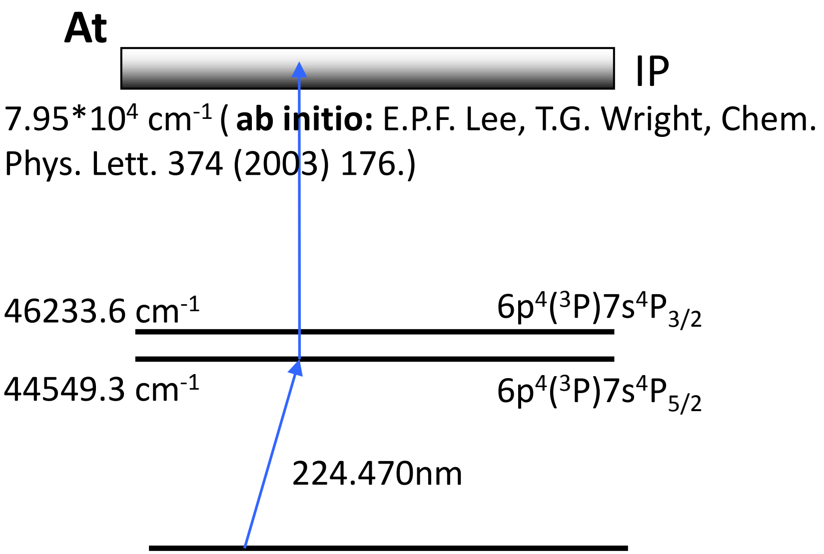
An example: Astatine

Previously produced non-selective in plasma ion source

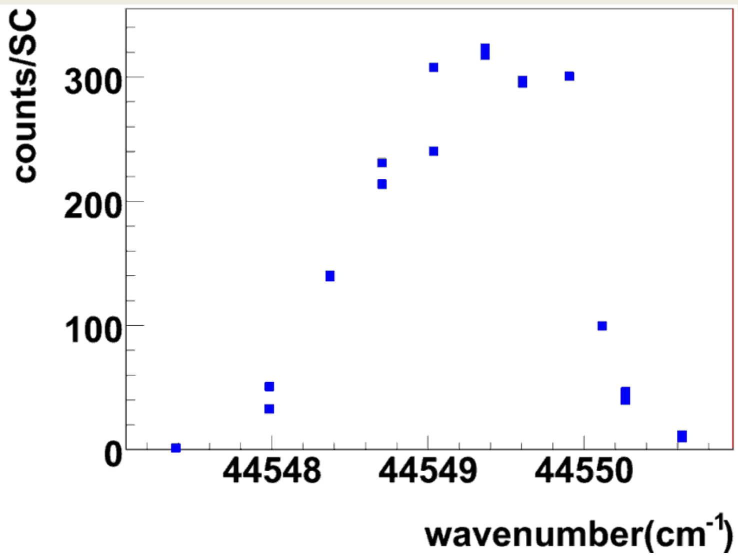
Is laser ionization possible?

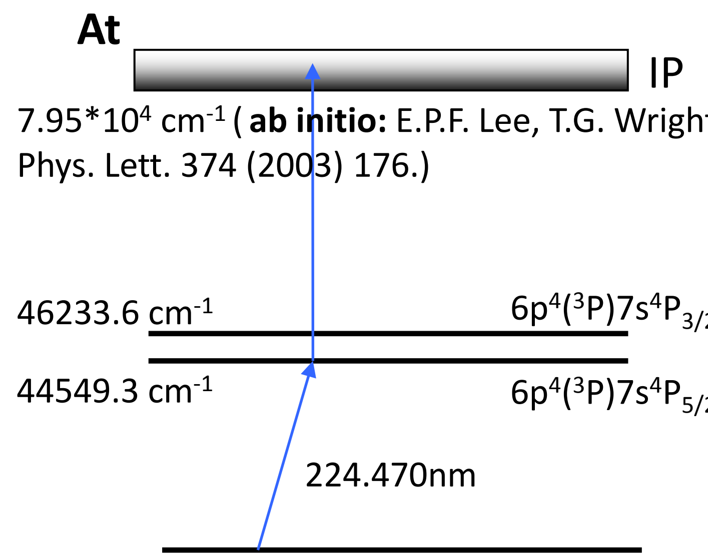


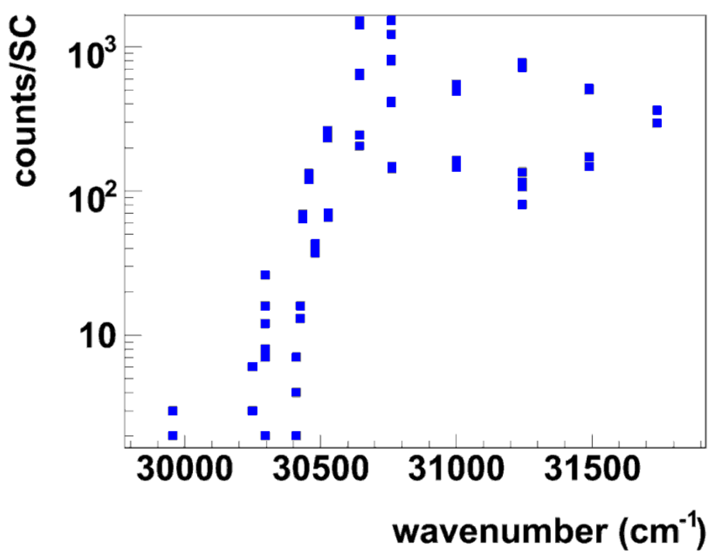
R. McLaughlin. Absorption Spectrum of Astatine. *Optical Society of America*,54 (1964) 965-967.

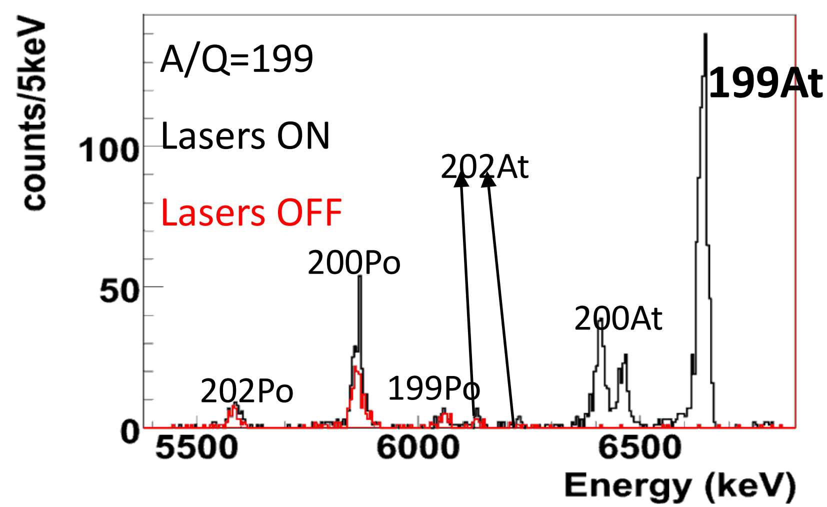


An example: Astatine Letter of intent I86 (UCx target (150 g/cm²))









Increased intensity: design study for 10 kW beams

- Possible scenarios arising from the Linac 4 (4 μA) and the Booster upgrade (1.4 => 2 GeV) and the shorter cycle time.
- Need to upgrade the targets, target stations and infrastructure to accommodate a x4 increase in beam power.

Intensity (p/pulse)	Intensity (μA)	Energy (GeV)	Cycle (s)	Power (kW)
3×10^{13}	2	1.4	1.2	2.8
6×10^{13}	4	1.4	1.2	5.6
6×10^{13}	4	1.4	0.9	7
6×10^{13}	4	2	1.2	8
6×10^{13}	4	2	0.9	10

based on transparancies from R. Catherall

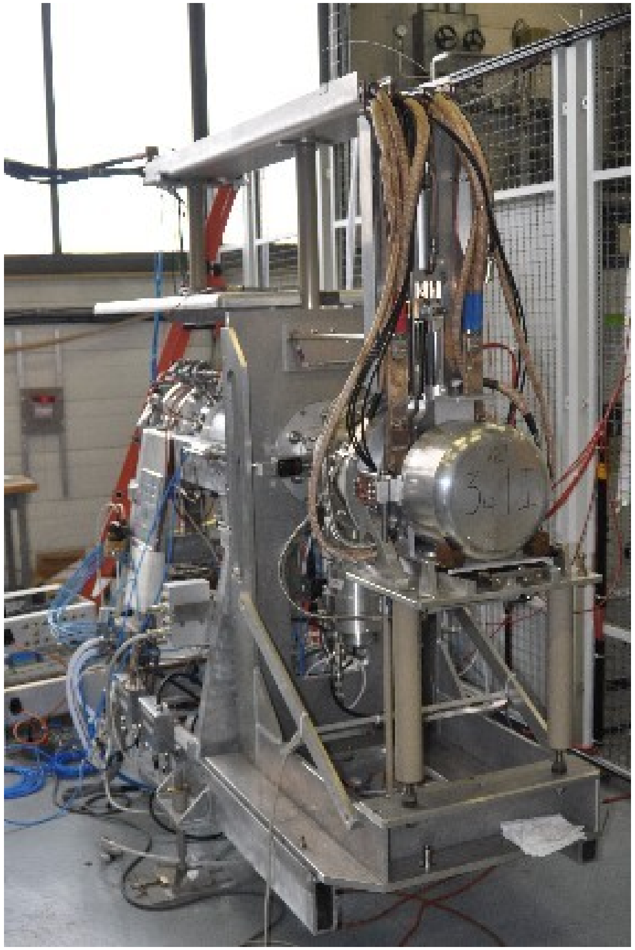
Increased intensity: target and front end design

Issues to be addressed

- Targets
  - Target lifetime, material science, ion source optimization, geometry, energy deposition, handling, elimination pathway.
- Front Ends
  - Material resistance, maintenance, optics, vacuum systems, remote operation…

Starting point

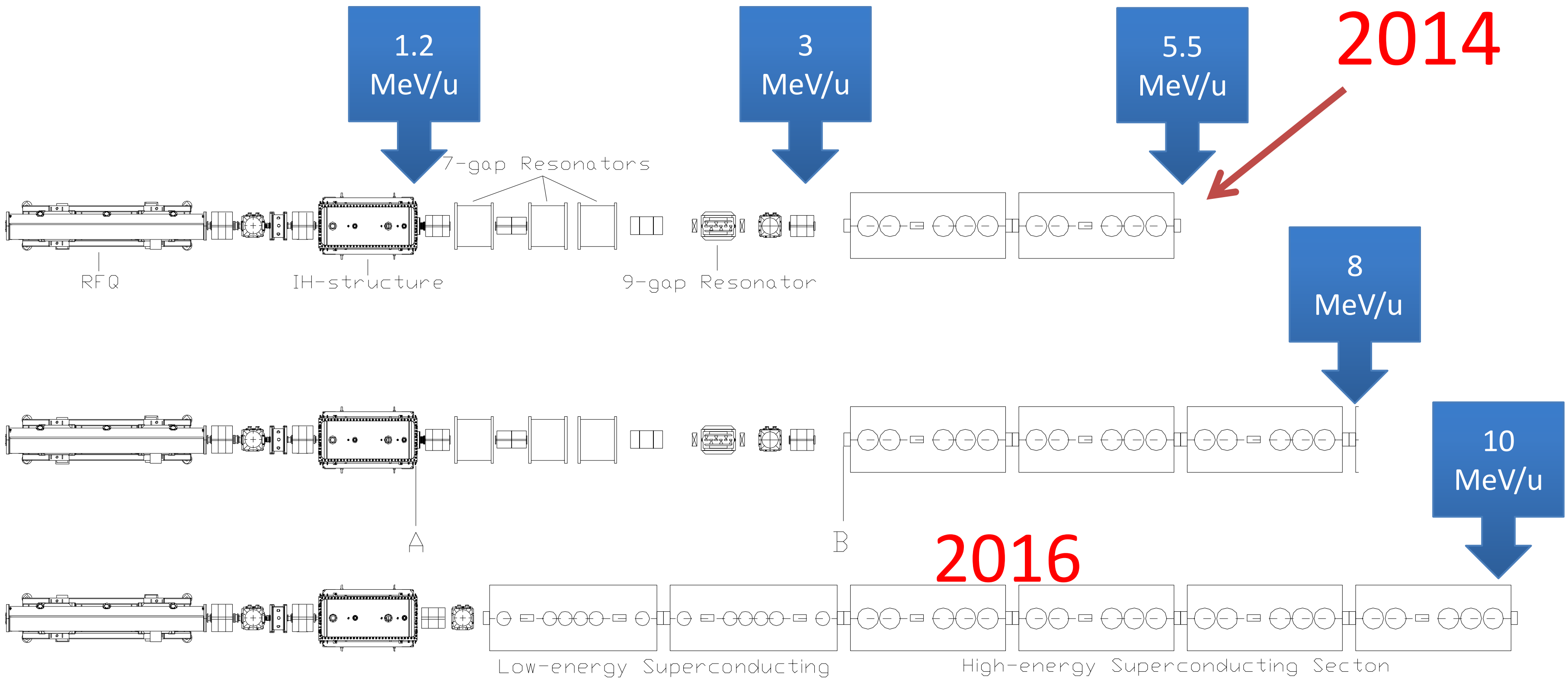
- Simulation of radiation levels



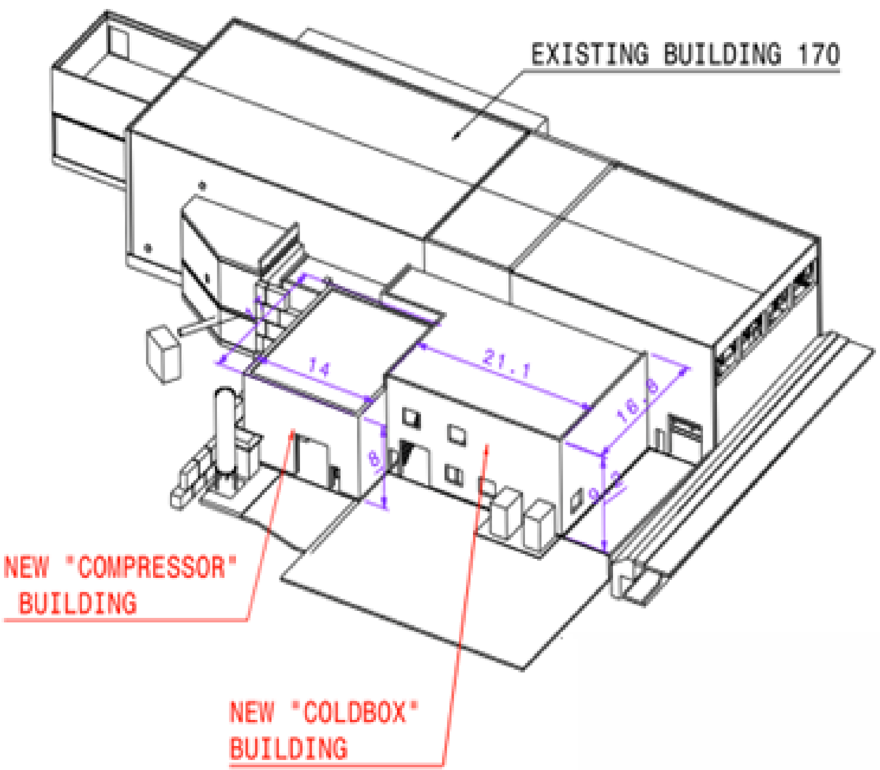
FE#6 – a step towards HIE-ISOLDE

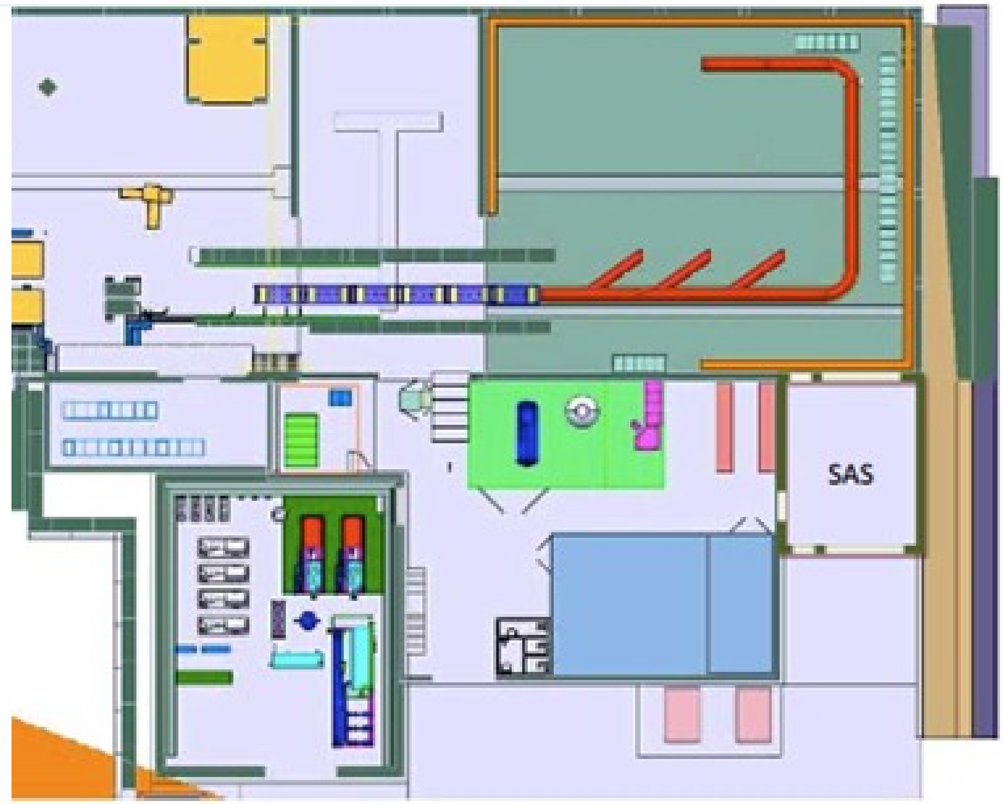
Energy upgrade

see talks in the HIE-ISOLDE Technical Session



Energy upgrade



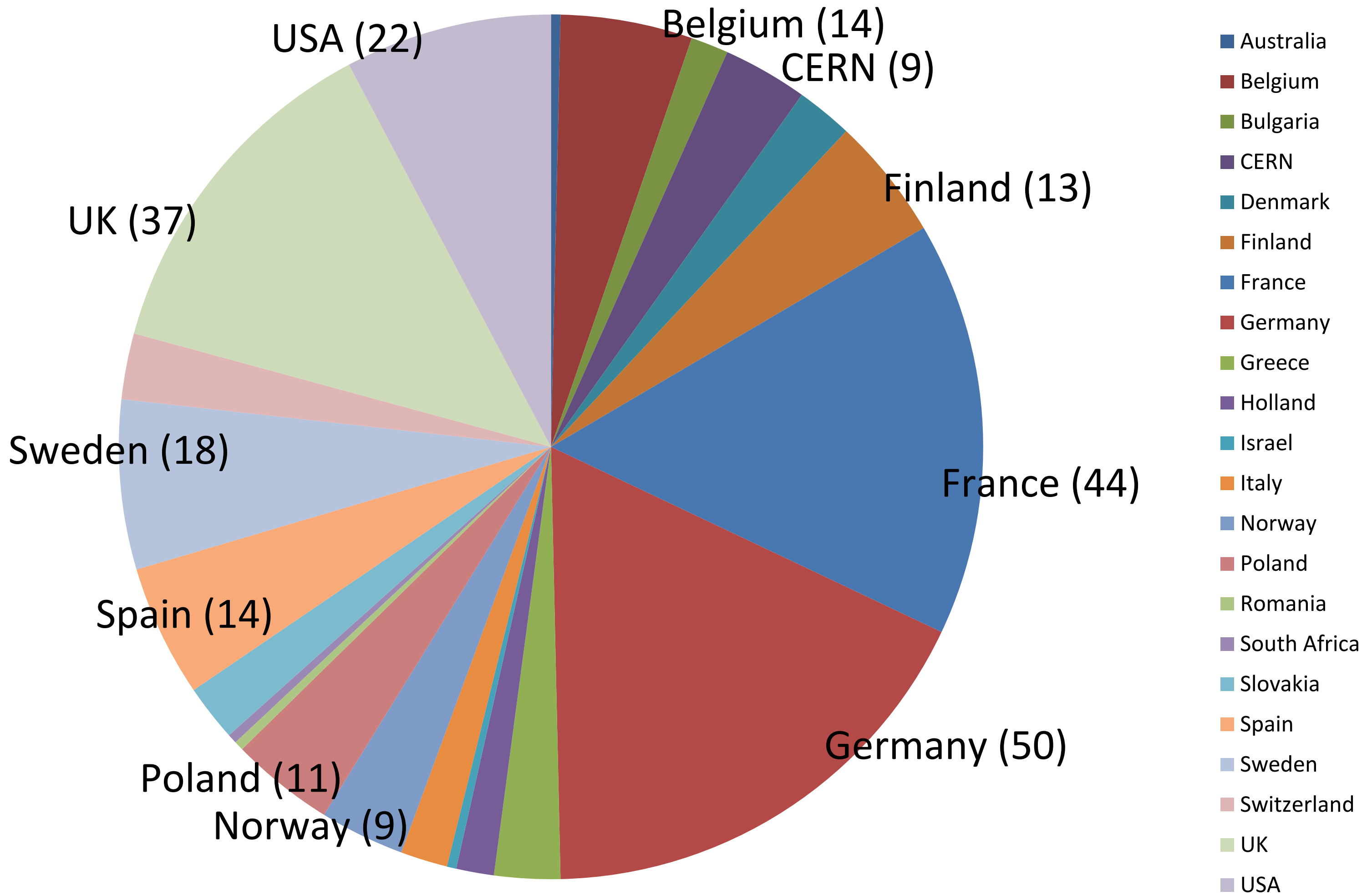


Call for LOI (Deadline May 2010, discussed at INTC June 2010)

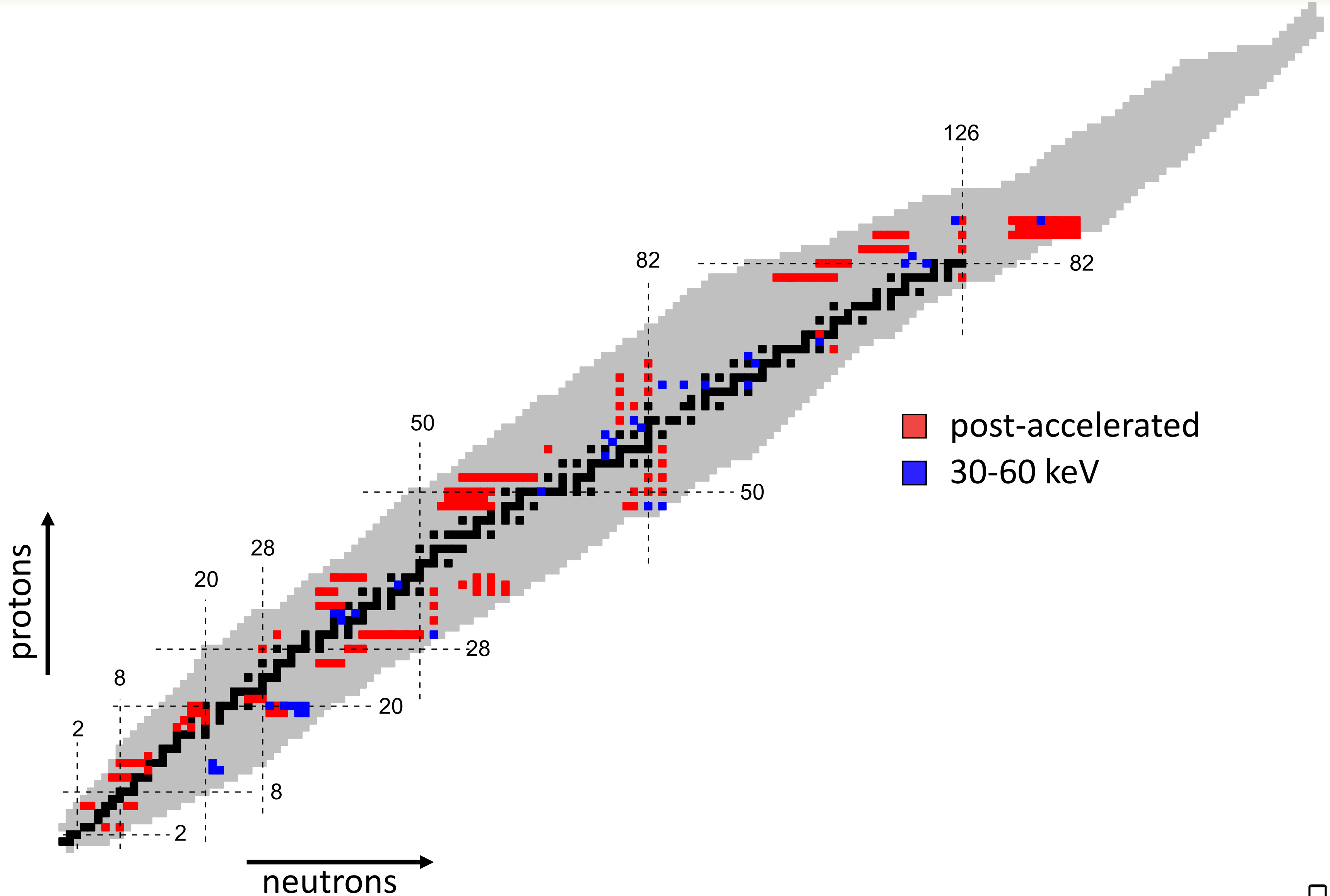
- 34 Letters submitted
- 284 Participants from 76 Laboratories in 22 Countries
- 30 LOIs make use of the Energy and Intensity increases; 4 of the intensity upgrade only
- Major mechanisms are Coulex (13) and transfer (16); elastic scattering (3); fission (2)
- (3) letters concern masses and moments; (4) astrophysics and (5) major new instrumentation
- Major subjects: Nuclear shapes ; Shell evolution; Halo properties; Nuclear astrophysics

based on transparancies from Y. Blumenfeld

LOI participants per country



LOI spread over the whole chart of nuclei, typically ISOLDE



Instrumentation for energetic beams

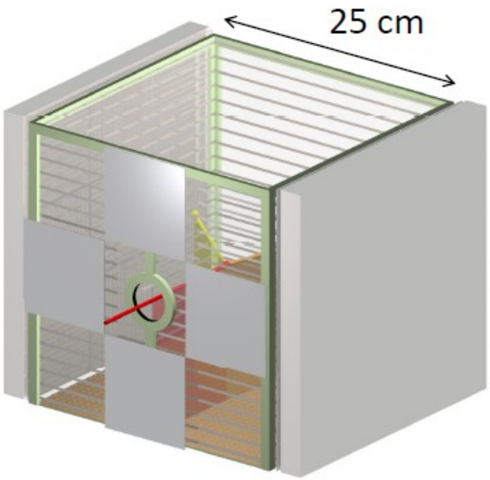
- Main workhorse : MINIBALL + TREX
- New detectors :
  - Active Target MAYA/ACTAR
  - Electron detection SAGE
  - Charged particle detection HELIOS *(talk Benjamin Kay)*
  - PARIS (**P**hoton **A**rray for studies with **R**adioactive **I**on and **S**table beams)
  - GASPARD (**GA**mma **S**pectroscopy and **PA**rticle **D**etection)
  - Neutron detectors
- Magnetic spectrometer *(talk Gry Tveten)*
- Storage Ring *(talk Klaus Blaum)*
- Special requirements
  - Time of Flight detection => buncher + chopper
  - Slow EBIS extraction
  - Beam spot

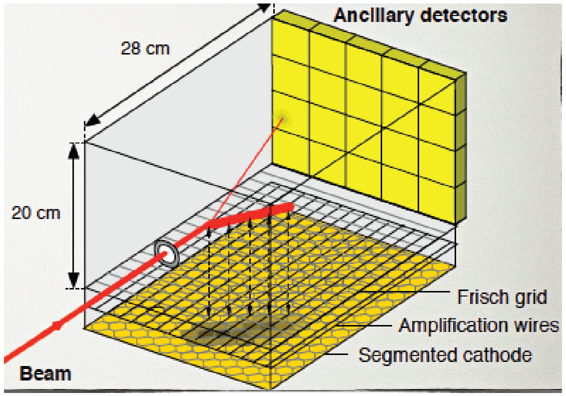
A selection out of the LOI's and past experiments

Reactions with an Active Target

Light nuclei (nuclear structure, nuclear astrophysics)

- Transfer reactions
  to access very exotic states
  Example: $^{9}C(d,p)^{10}C^*$
- Resonant reactions
  Example: $^{12}Be + p$
- Keys:
  Resolution (energy and spatial)
  Efficiency





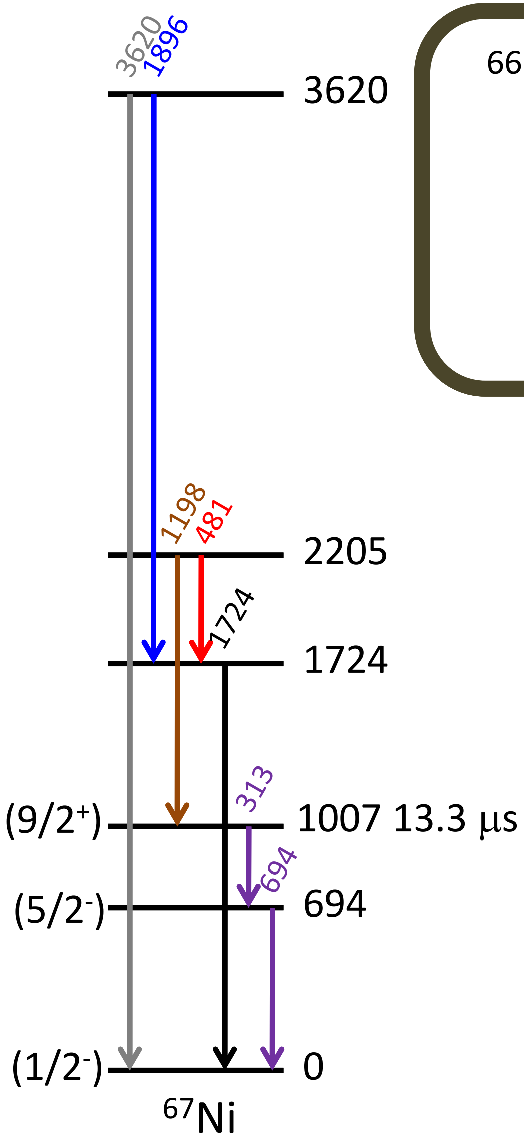
- elastic: $^{12}C(^{A}Z, ^{A}Z)^{12}C$, $^{1}H(^{A}Z, ^{A}Z)^{1}H$, - optical potentials,
  - mass of resonances? (^{73}Rb)
- inelastic: $^{12}C(^{A}Z, ^{A}Z^*)^{12}C^*$, $^{1}H(^{A}Z, ^{A}Z^*)^{1}H$, - beam spectroscopy ($^{76}Sr$)
- neutron transfer: $^{12}C(^{A}Z, ^{A-1}Z)^{13}C$, - mass of ^{A-1}Z system (^{71}Kr)
- proton transfer: $^{12}C(^{A}Z, ^{A+1}Z+1)^{11}B$, - mass of $^{A+1}Z+1$ system (^{73}Rb, ^{77}Y)
  - indirect measurement of p-capture
- fusion: $^{1}H(^{A}Z, ^{A+1}Z+1)\gamma$, - direct proton capture

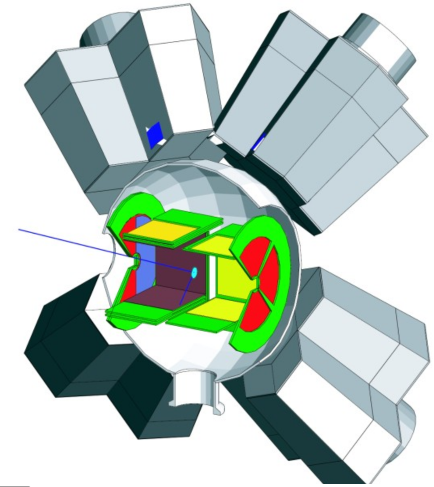
R. Raabe et al.
M. Camaano et al.

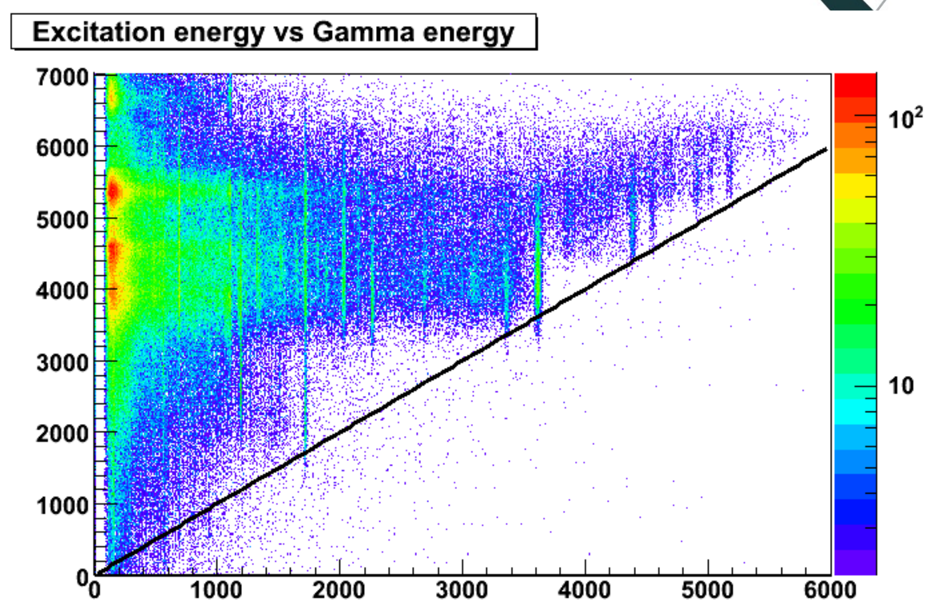
Coulex and transfer in Ni region

Main workhorse : MINIBALL + TREX

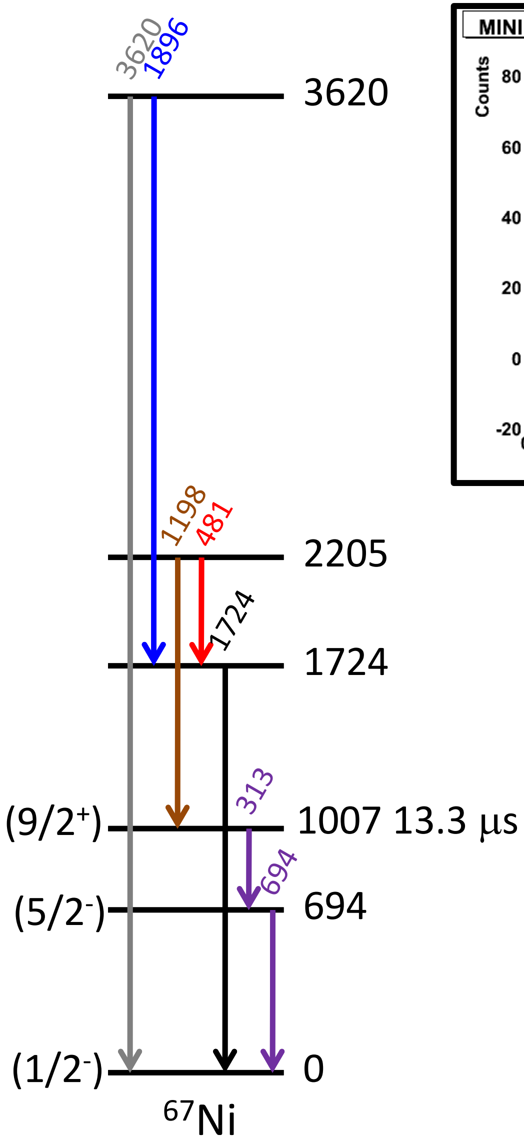
^{66}Ni(d,p)^{67}Ni (thin target 100μg/cm^2)
J. Diriken et al.
More recent results on transfer
see also talks of T. Kroell, R. Orlandi, and K. Riisager

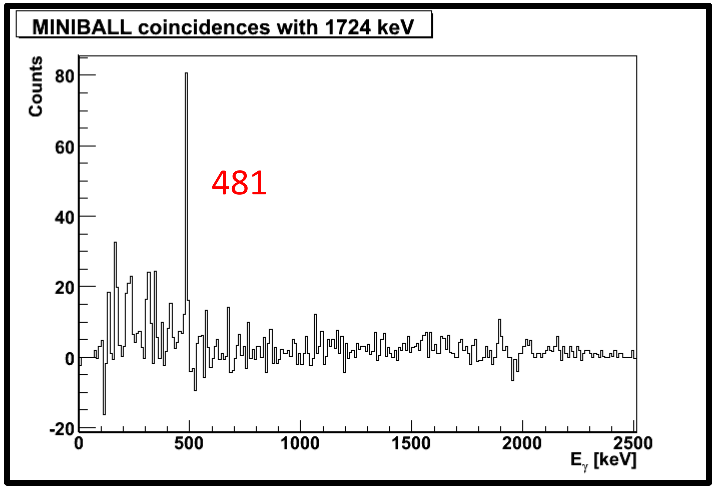


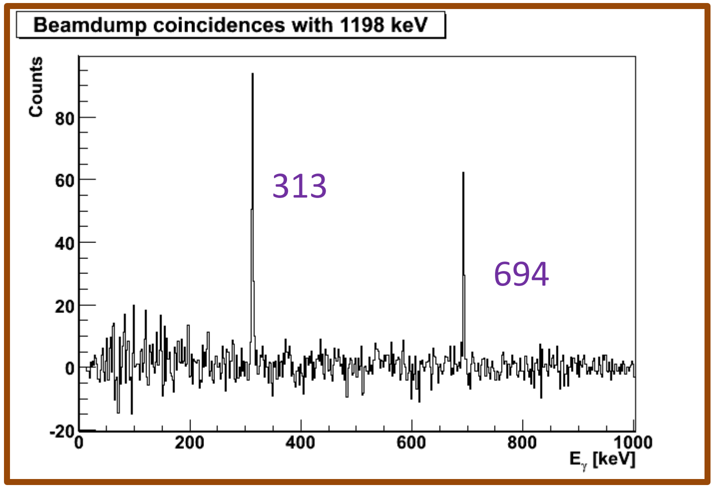


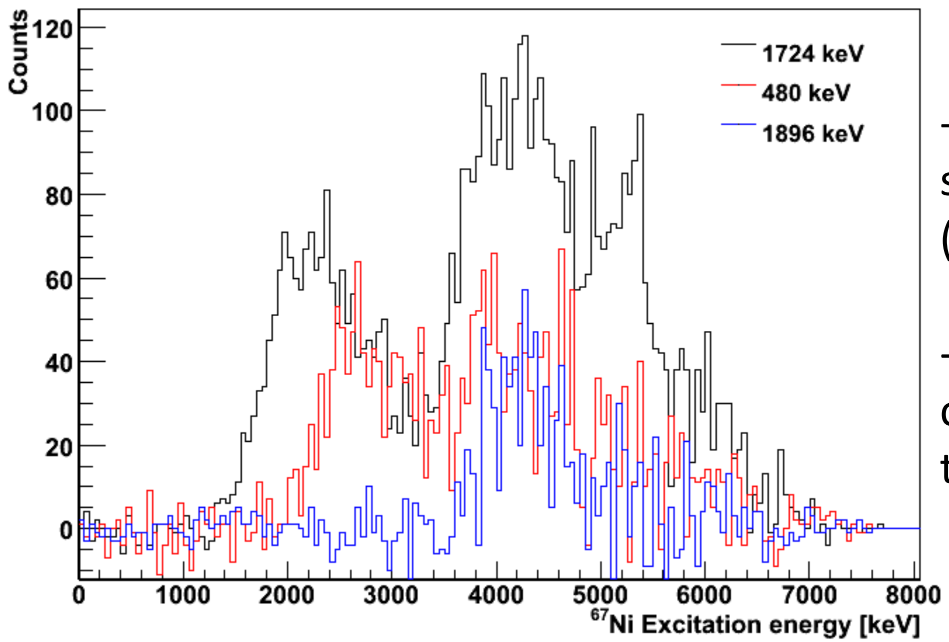


p-γ and γ-γ coincidences: prompt (MB) & delayed (Beam Dump detector)









-Population of ^{67}Ni states up to 6 MeV (γ's up to 5.2 MeV)

-Fits to differential cross-sections and ℓ-transfer assignment

Coulex and transfer in Ni region

LOI (Orlandi et al.)

- ^{68}Ni(d,p) and ^{80}Zn(d,p) N=41 and N=51 single-neutron states ($g_{9/2}$, $d_{5/2}$, $s_{1/2}$, $d_{3/2}$)
- (t,α) reactions on ^{76,78,80}Zn:
- study single-proton states in ^{75,77,79}Cu ($2p_{3/2}$, $1f_{5/2}$, $1f_{7/2}$)
- ^{66}Ni(t,p) to characterize 0^+ states in ^{68}Ni
- ^{80}Zn(^{10}Be,^{12}C): spectroscopy of ^{78}Ni

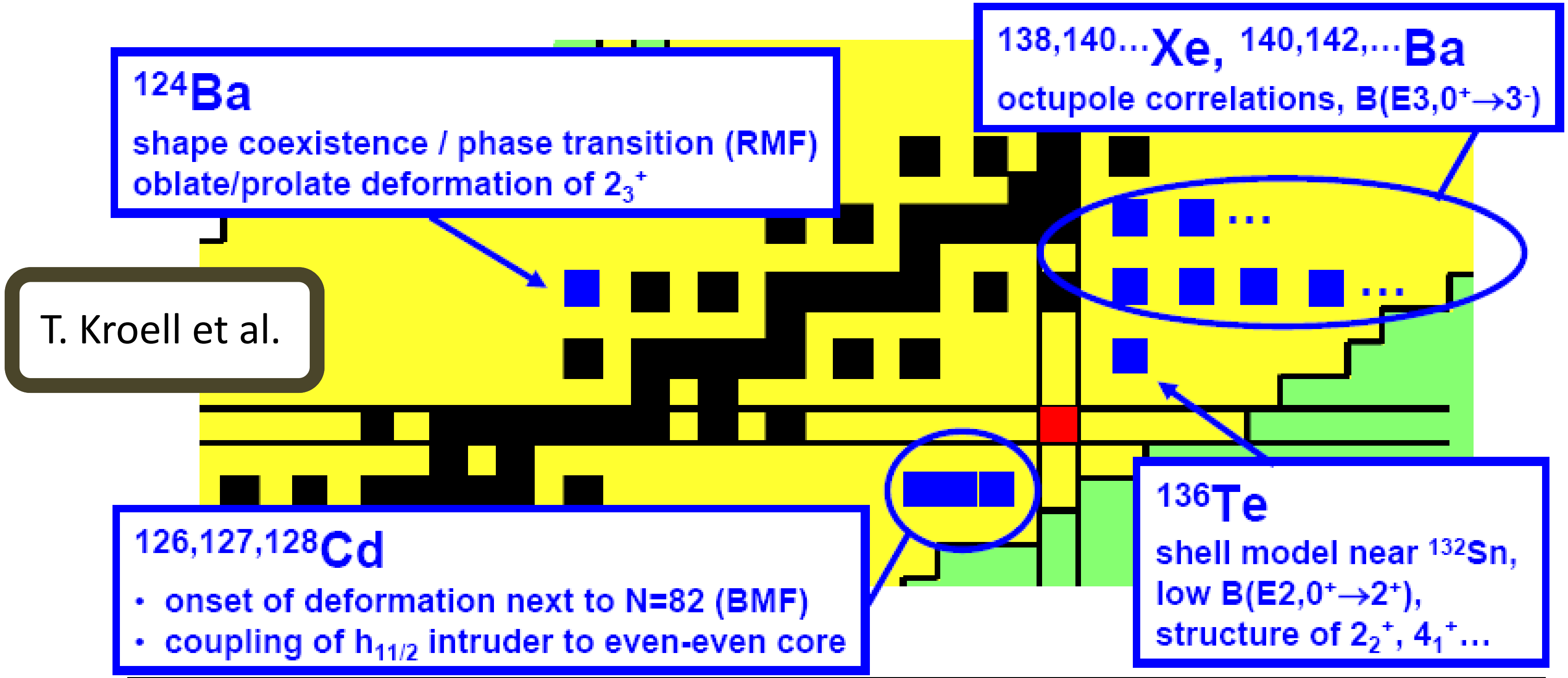
Higher energies at HIE-ISOLDE allow for transfer reactions also with heavy beams!

Coulomb excitation and transfer in the n-rich Sn region

Coulomb excitation

TECHNISCHE UNIVERSITÄT DARMSTADT

Higher energies at HIE-ISOLDE enable
… multiple Coulomb excitation
… population of high lying states, e.g. 3^- states (for ^{140}Xe: 10 x σ @ REX)

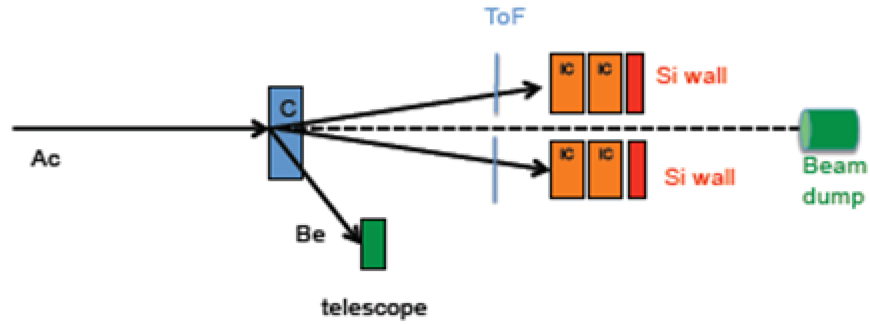


June 23, 2010 | 37th INTC Meeting @ CERN | TU Darmstadt | Thorsten Kröll | 3

Fission

HiE ISOLDE: an unique opportunity for fissionists

- 10 MeV/u actinide beams with >10^6 pps: $^{205-220}$Rn, $^{205-227}$Fr, $^{212-228}$Ra
- Possibility to extend to other actinides (^{232}Th,^{235,238}U,…) T. Stora priv. comm.
- Simple set-up to measure precisely as a function of excitation energy
  - element yields,
  - TKE,
  - fission probability,

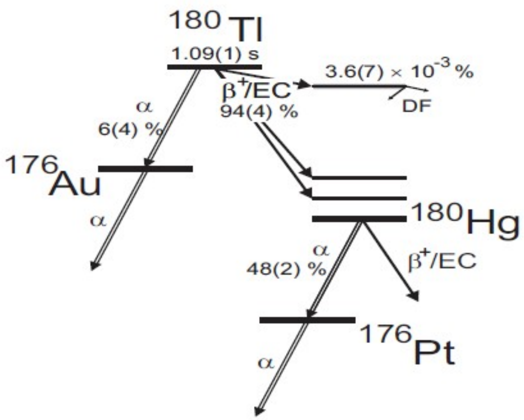


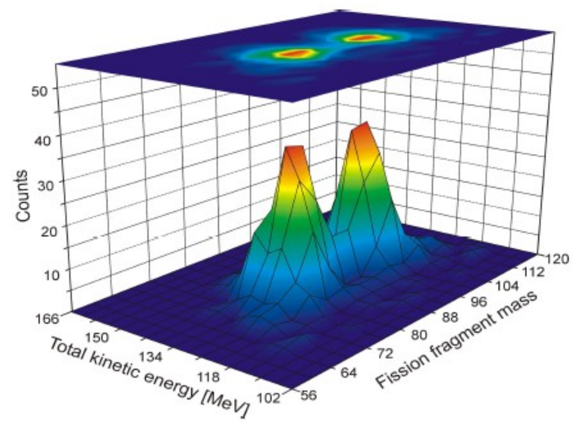
F. Rejmund et al.

- Study shell effects and pairing effects in fission of unstable actinides
- Inverse kinematics gives access to complete fission distributions

Fission

β-delayed fission *see talk V. Liberati*



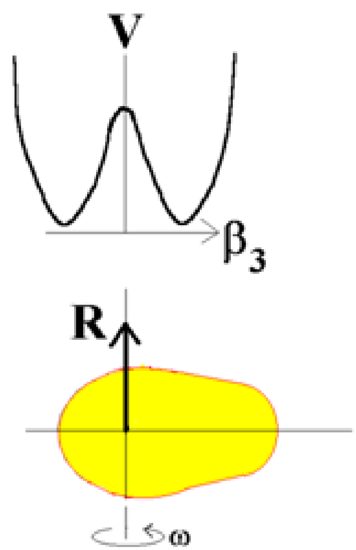


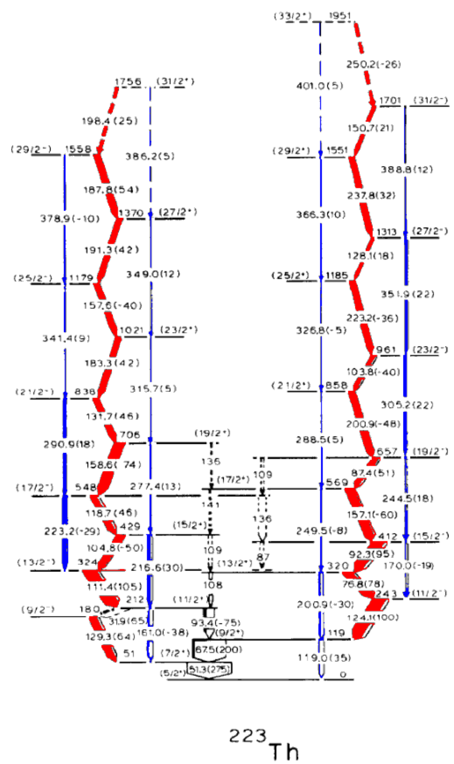
Transfer induced fission of heavy radioactive beams

- Fission barrier heights

M. Veselsky et al.

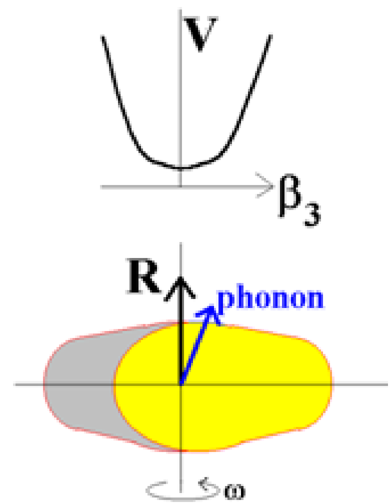
Measurements of octupole collectivity in odd-mass Rn, Fr and Ra isotopes

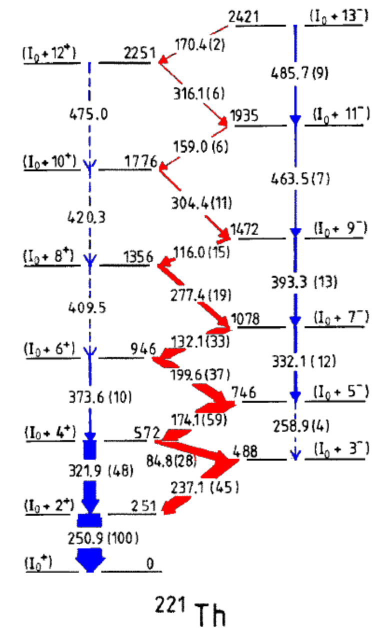




P. Butler et al.

Type (a)
Large octupole correlations
Small parity splitting





Type (b)
Smaller octupole correlations
Large parity splitting

Searches for permanent EDM in Ra isotopes

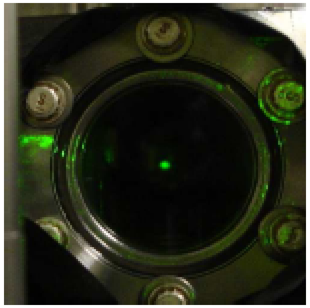
Experimental development →

- KVI, Groningen, frequent access to beam
- Efficient conversion to intense atomic beam
- connection to *"Measurements of octupole collectivity in odd-mass Rn, Fr and Ra isotopes"* (INTC-I-091)

Transfer of experiment to high flux facility (ISOLDE)

- improve statistical limit on EDMs
- utilize several isotopes for systematic studies

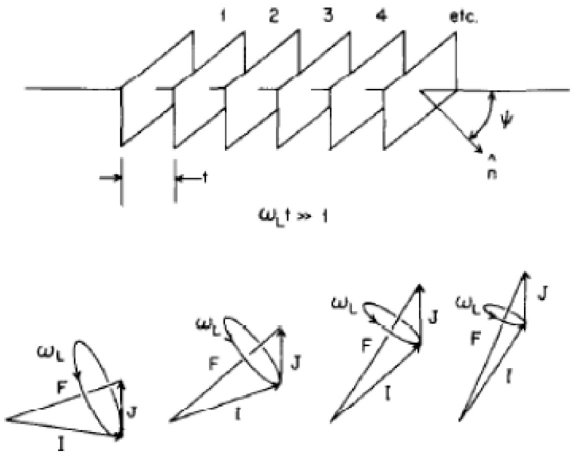
e.g. efficient neutral atom trapping of heavy alkaline earth elements

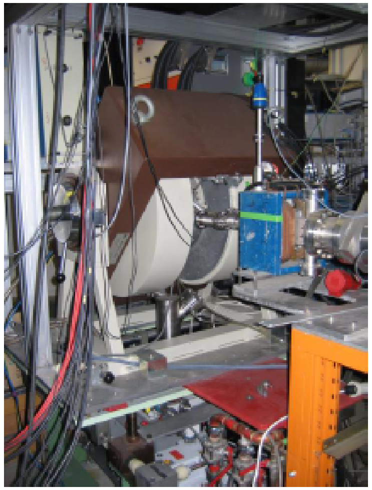


> 1% capture efficiency from thermal atomic beam
(S. De et al. PRA 79, 041402(R) (2009).

L. Willmann et al.

Polarized beams by the tilted-foil technique

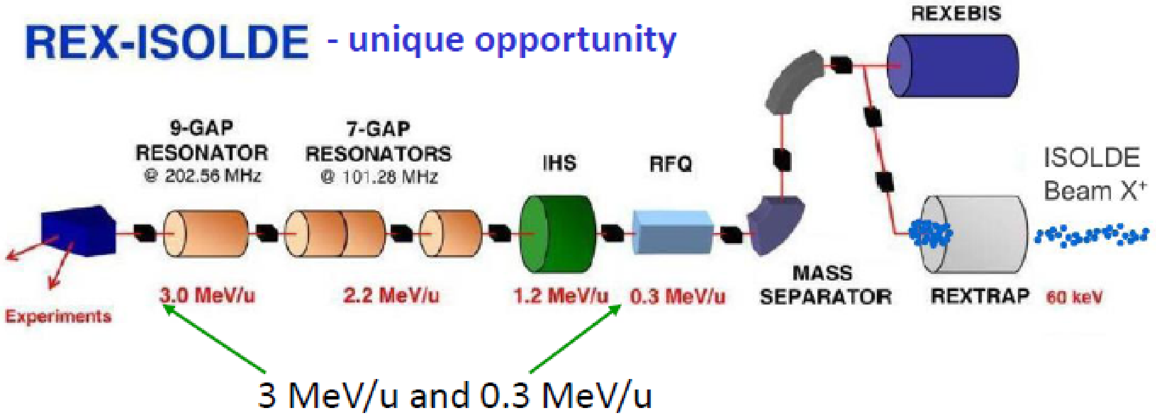




β-NMR setup from HMI Berlin transferred to ISOLDE

- gain of complete control on the TF polarization
- nuclear structure (moments, reactions …), nuclear methods in the solid-state physics, biophysics etc. …
- Flexible set up (depending on application)

G. Georgiev et al.



Conclusions

- In order to coordinate the physics requirements of the ISOLDE users community with the technical developments needed for HIE-ISOLDE a *Physics Coordination Group* has been installed.
- Y. Blumenfeld is chairing this group which has further the following members:

  M. Borge, P. Butler, M. Huyse, D. Jenkins, Y. Kadi, M. Kowalska, T. Kroell, M. Pasini, R. Raabe, E. Siesling and O. Tengblad.
- *Please contact these persons for further information and certainly also input.*

Conclusions from the first meeting of the Physics Coordination Group

- HIE-ISOLDE beam features missing or room for improvement:
  - Time structure
    - bunching and debunching + chopper (100 ns microbunch structure would be beneficial)
    - slower EBIS extraction
  - 1 mm diameter for HELIOS (but 3 mm might also work).
- Agreement of the layout (*which needs to be fixed by June 2011*): In 2014 there will be 2 short beamlines (for Miniball and a second detector) and a third, U-shape beamline will be most probably added when the funds are available.
- A working group on the spectrometer should be set up => **Workshop in Lund, March 10-11, 2011.**
- The community should be stimulated to obtain the remaining funds for the different packages.
- HIE-ISOLDE will require 2 DAQ rooms.

Conclusions

- HIE ISOLDE will offer an unmatched variety of beams at energies ranging from 60 kV to 5.5A MeV (2014) and to 10A MeV (2016).
- A design study is performed to profit from the developments at the PSB and LINAC4 in order to cope with 10 kW beams.
- 34 LOIs have been submitted promising a rich physics program.
  - More LOI's can be submitted to the INTC (first chance: M. Kowalska expect them on January 5, 2011 *at noon*)
- It will be efficient to share detectors between HIE-ISOLDE, SPES and SPIRAL2.
- These 3 facilities will pave the way towards EURISOL if the community coordinates its efforts.