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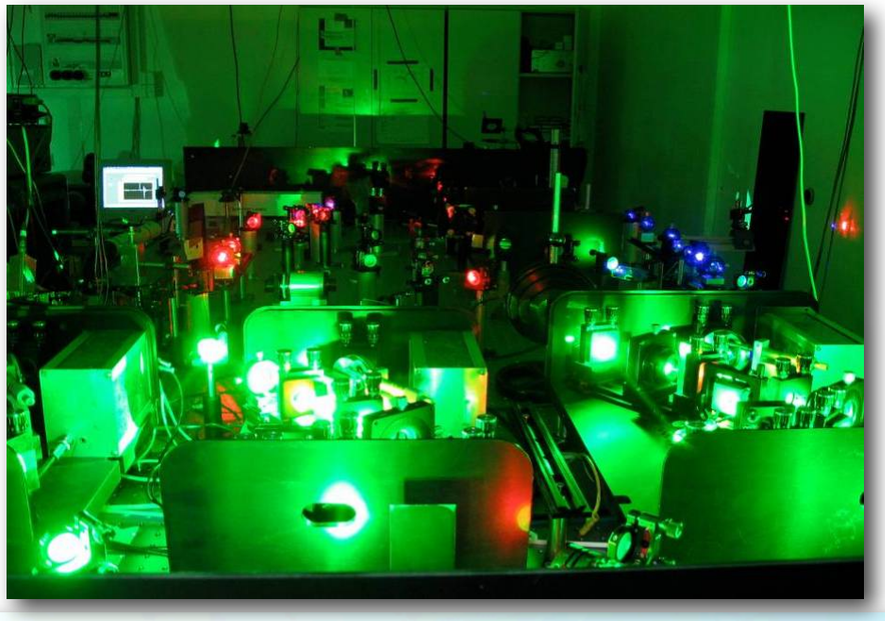
The new IGISOL 4 radioactive ion beam facility: beginning a new era of measurements



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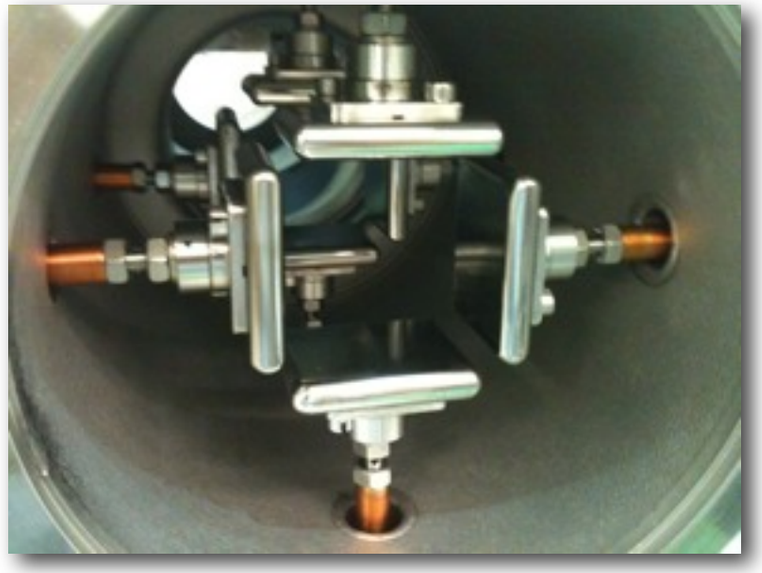
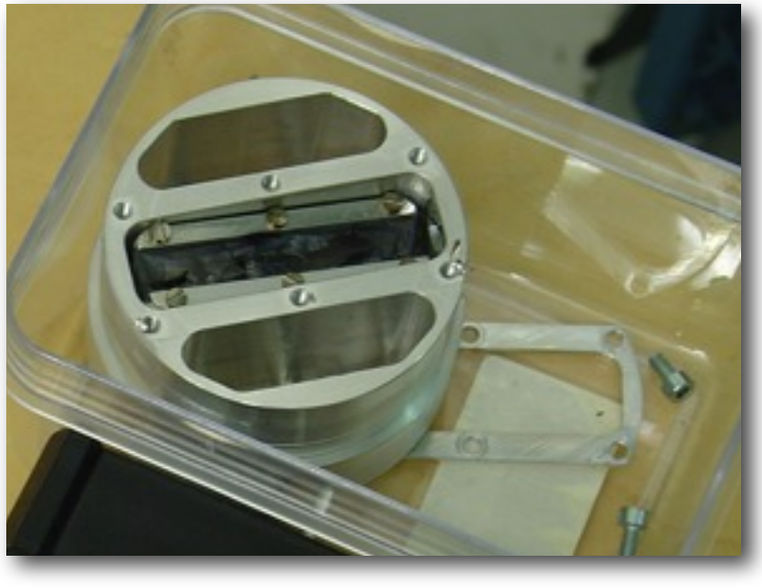
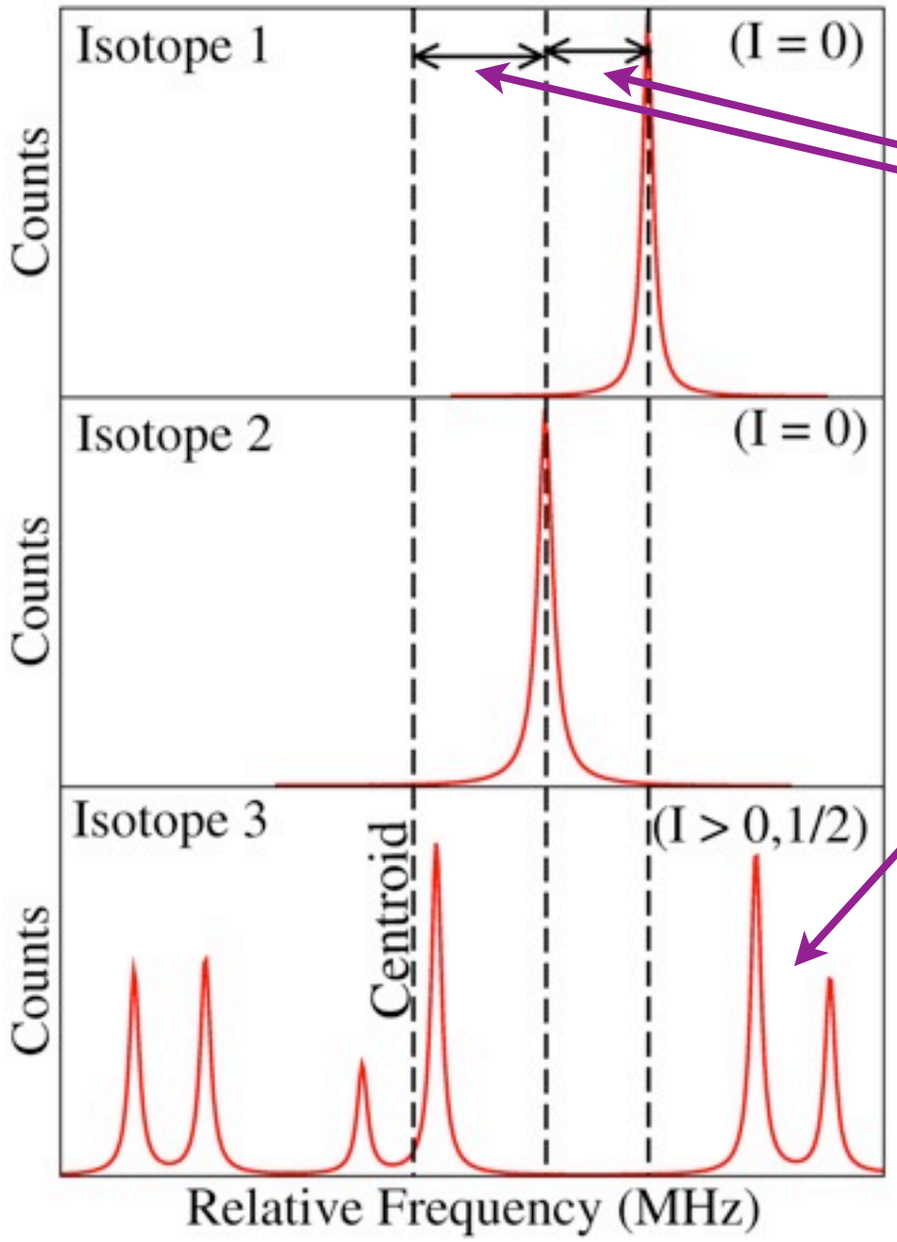
Outline

- Nuclear structure from optical spectra
- Collinear spectroscopy at JYFL
- The IGISOL 4 upgrade
  - Current proposals
  - Status so far





Optical spectra



Isotope Shifts
→ $\delta\langle r^2 \rangle$

Hyperfine Structure
→ μ
→ Q_s (→ $\langle\beta_2\rangle$)
→ Nuclear spin

Model independent

SM comparisons: level occupancy, migration...

$$\langle r^2 \rangle = \langle r^2 \rangle_{\text{sph}} \left(1 + \frac{5}{4\pi} (\langle \beta_2^2 \rangle + ...) + 3\sigma^2 \right)$$

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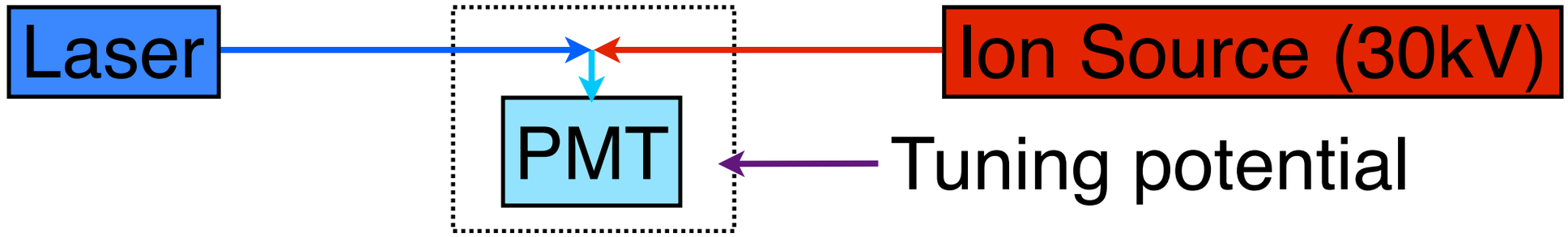
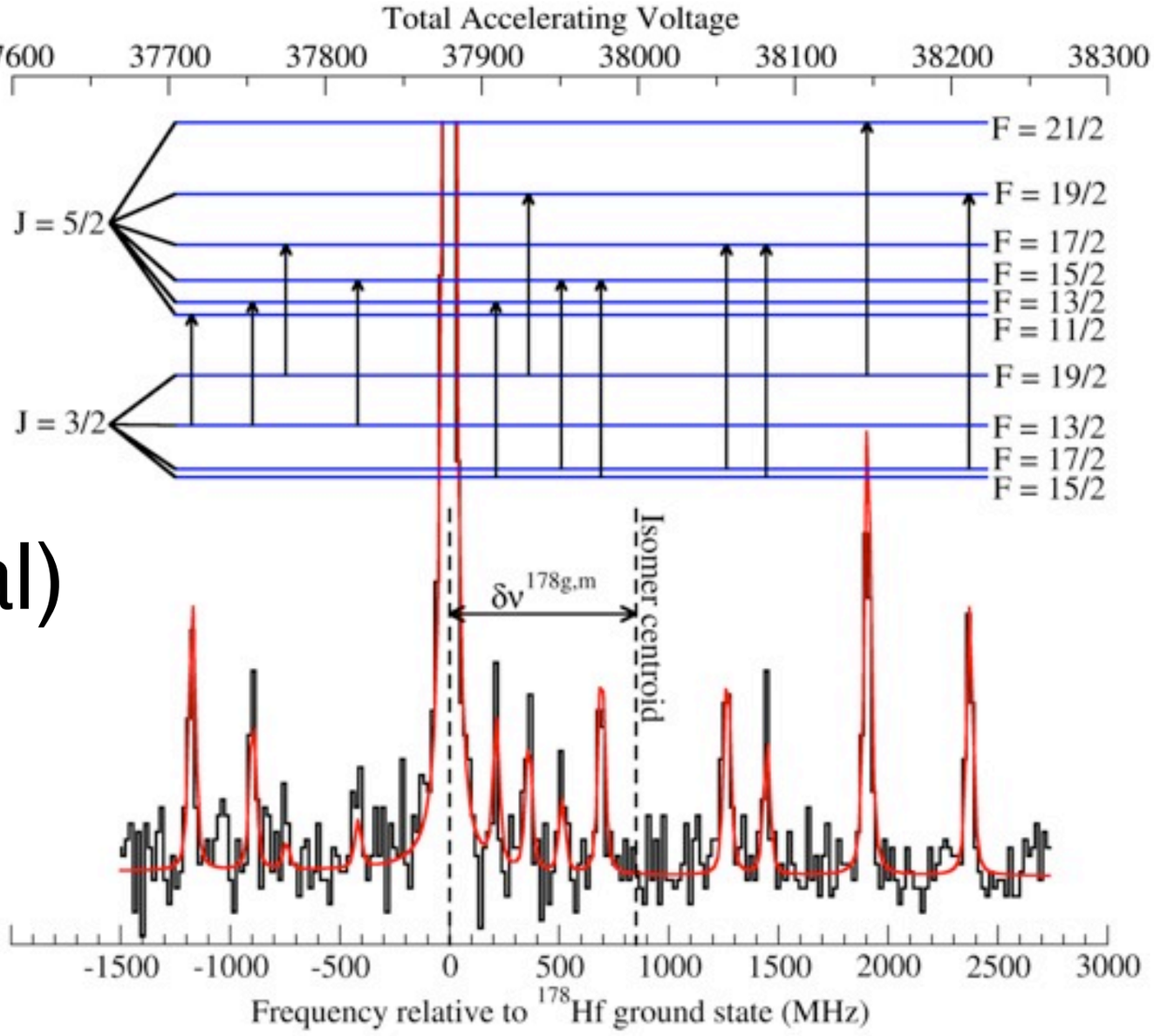
Collinear laser spectroscopy



$$E = \frac{1}{2}mv^2 \rightarrow \Delta v = \frac{\Delta E}{mv}$$

Require:-

- Low ΔE (longitudinal)
- Narrow ion beam
- Small divergence



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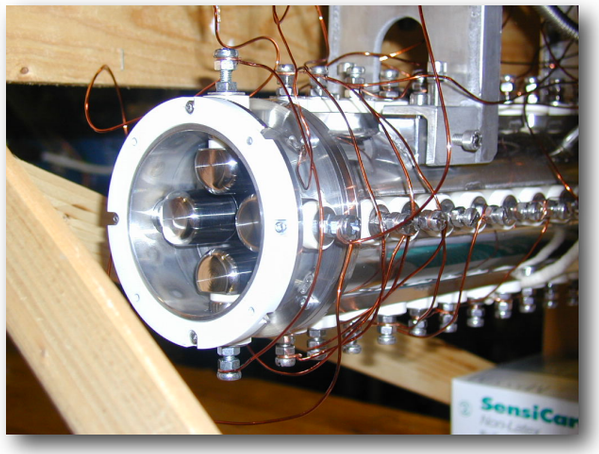
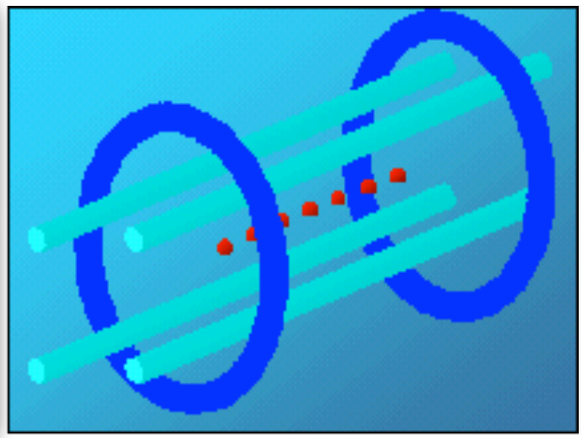
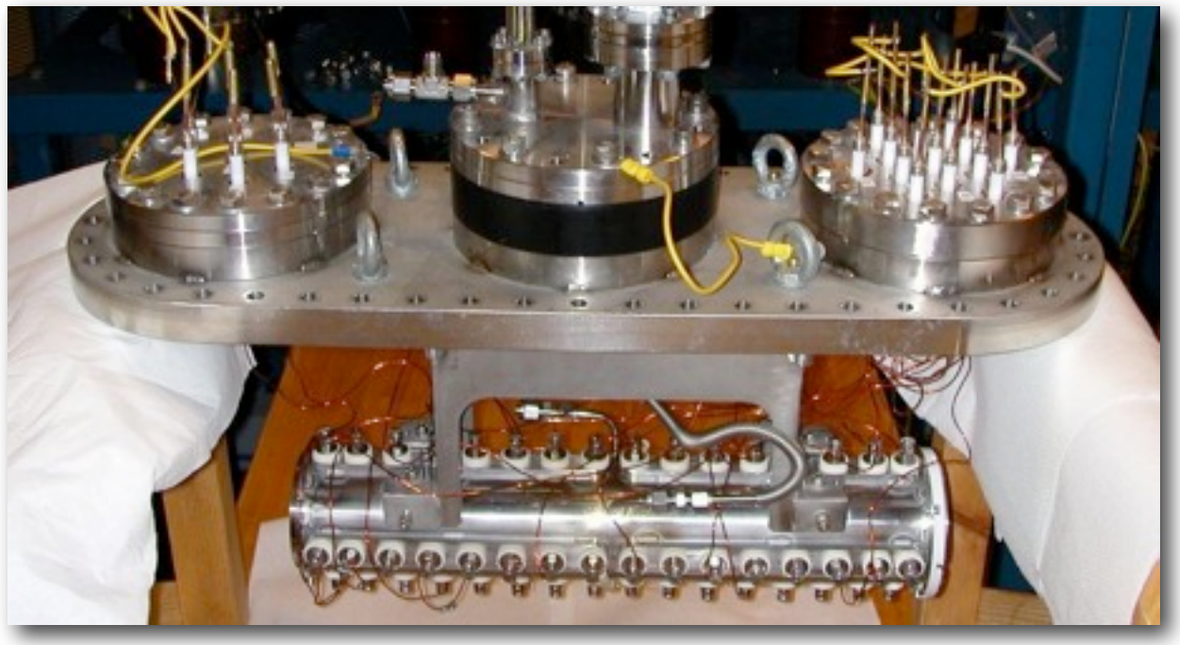
… with cooled, bunched beams



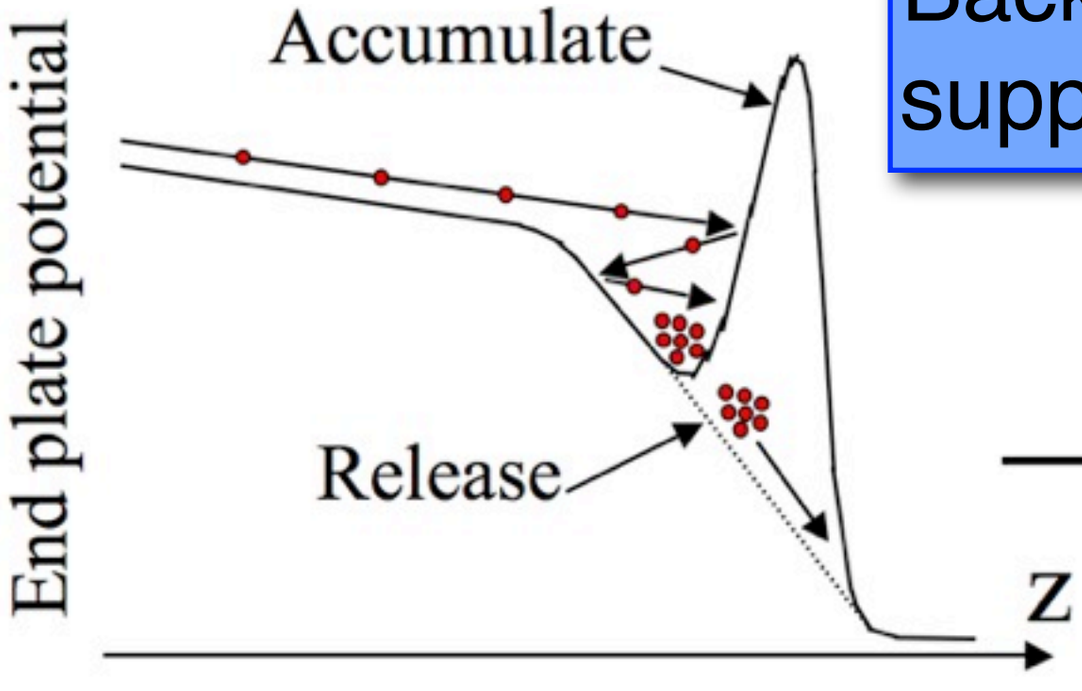


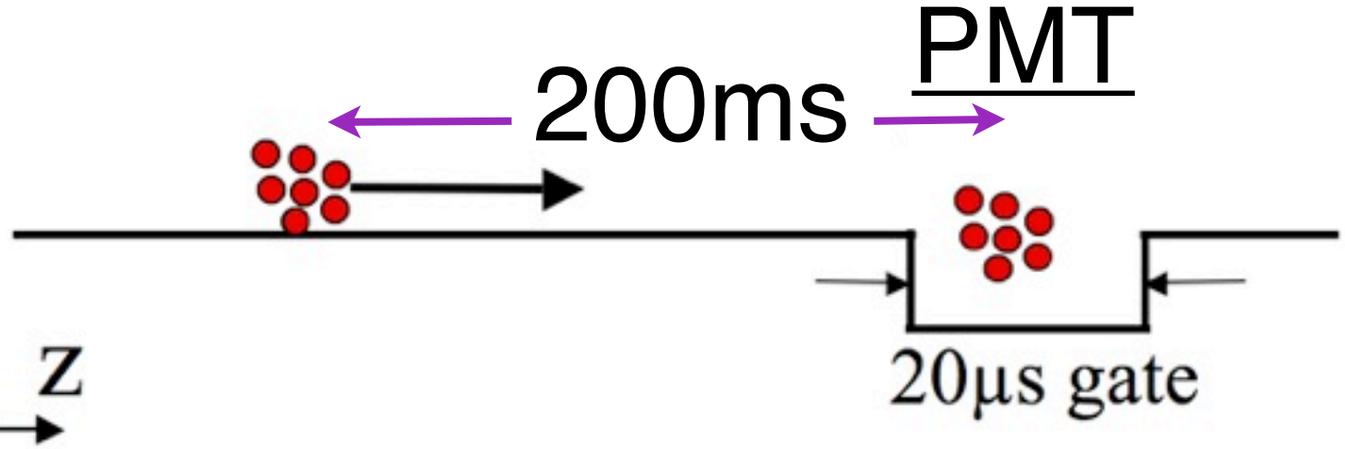


Gas filled RFQ

Photon background dominated by continuous laser scatter

$$\text{Background suppression} = \frac{\text{200ms accumulation}}{\text{20µs gate width}} \sim 10^4$$





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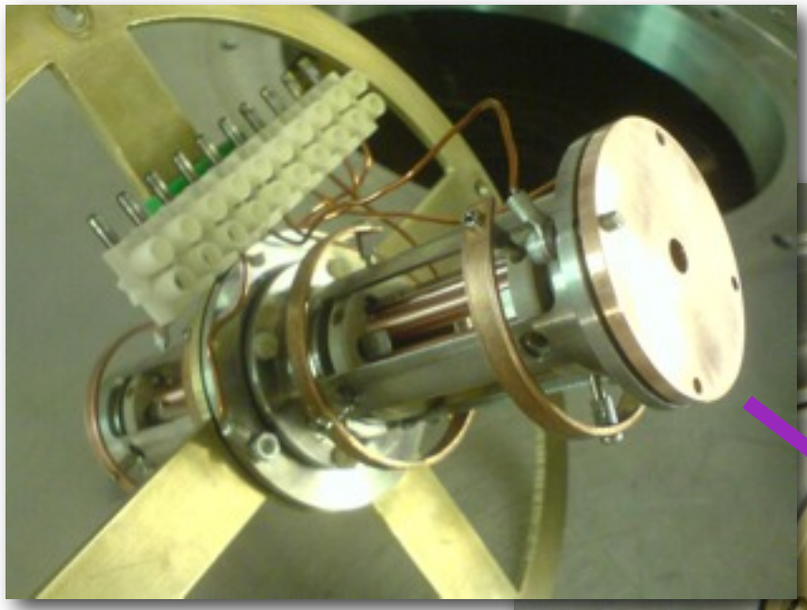
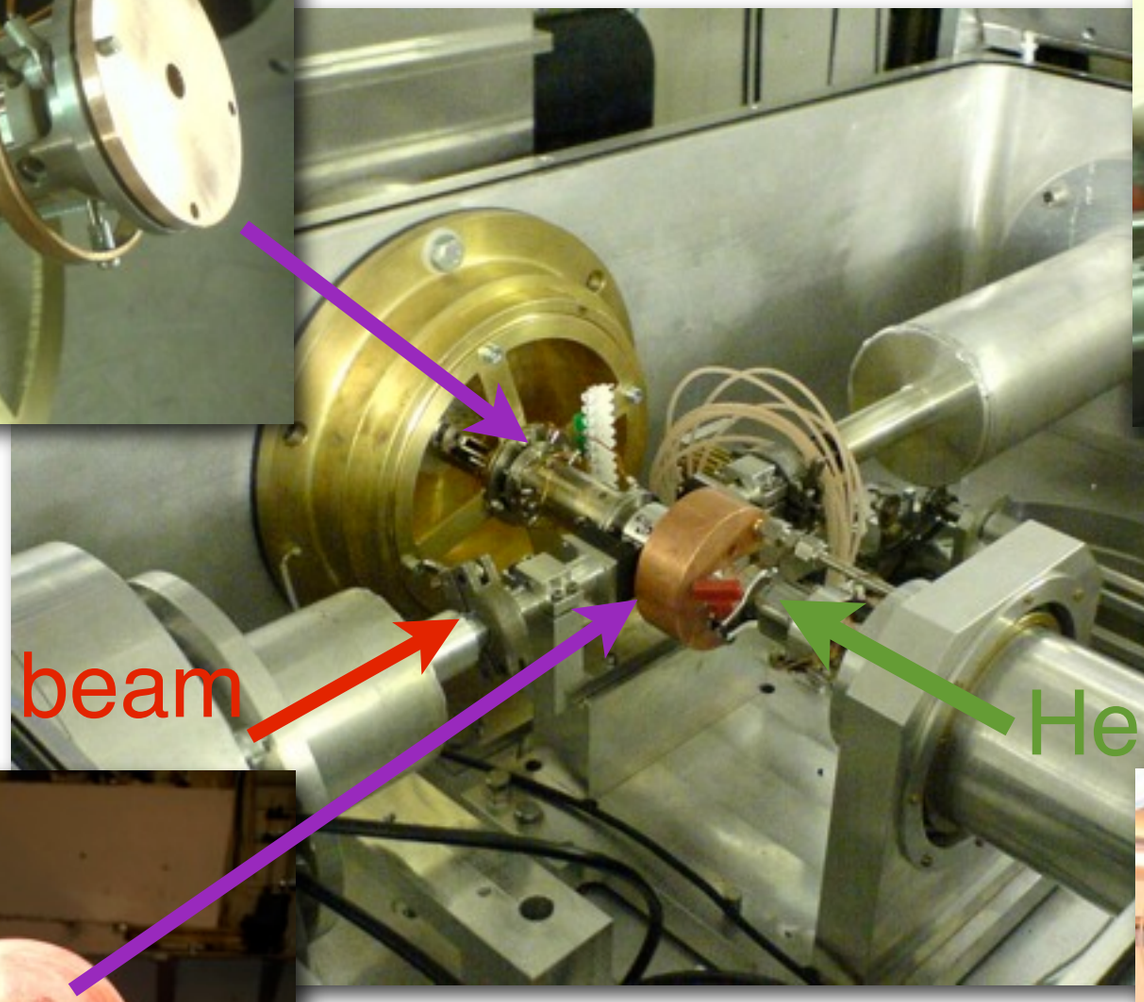
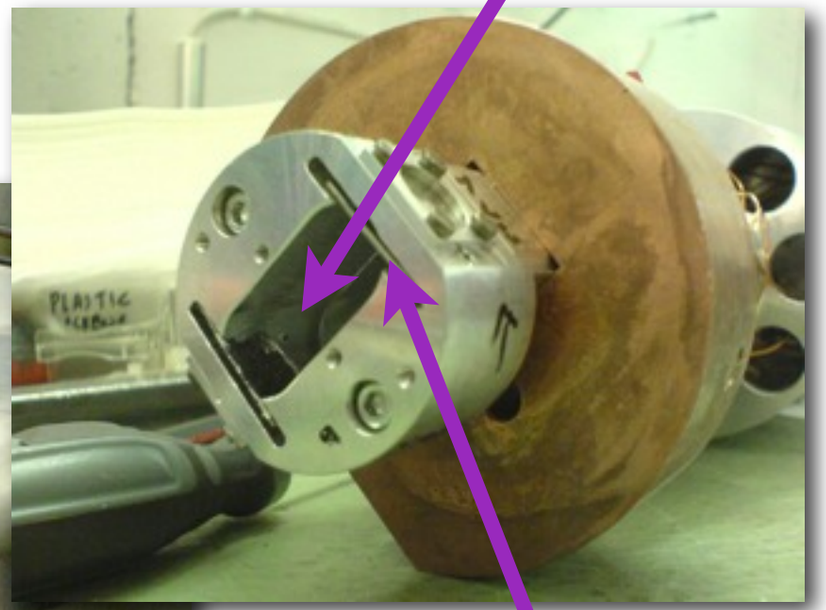
Why use the IGISOL?





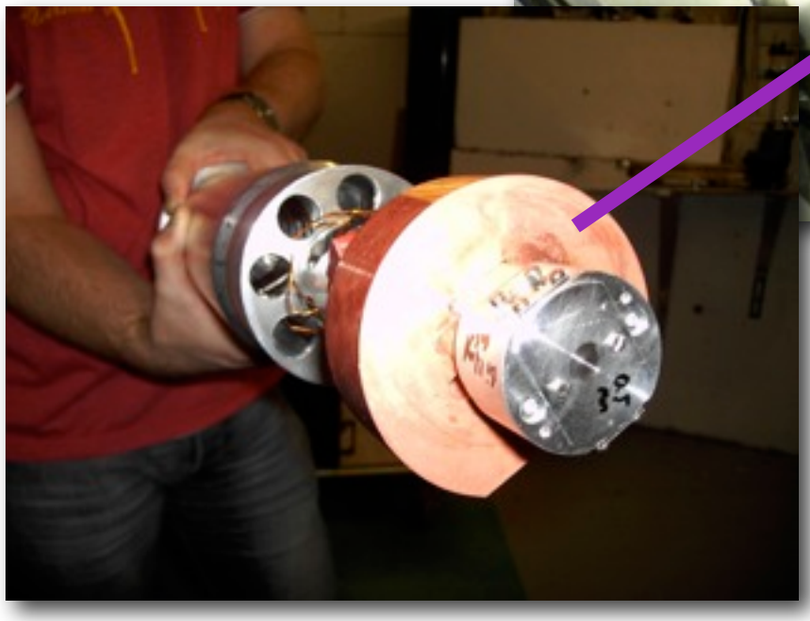


Gas volume

Thin foil targets

Cyclotron beam

He



- Fast (sub-ms)
- Universal

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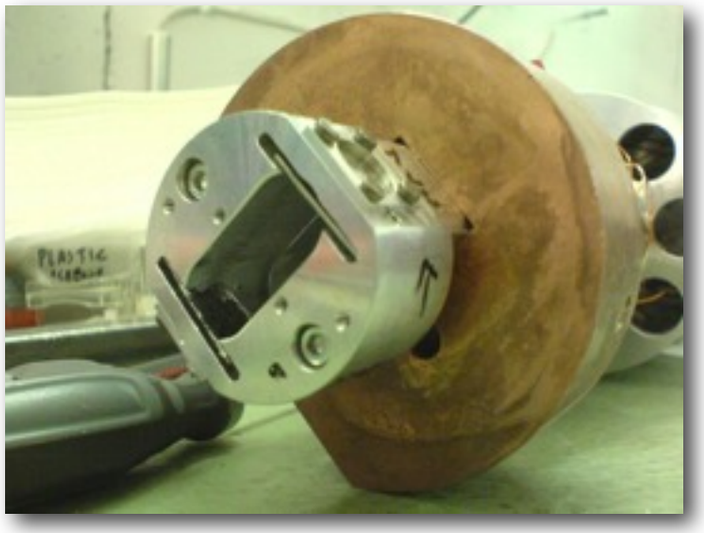
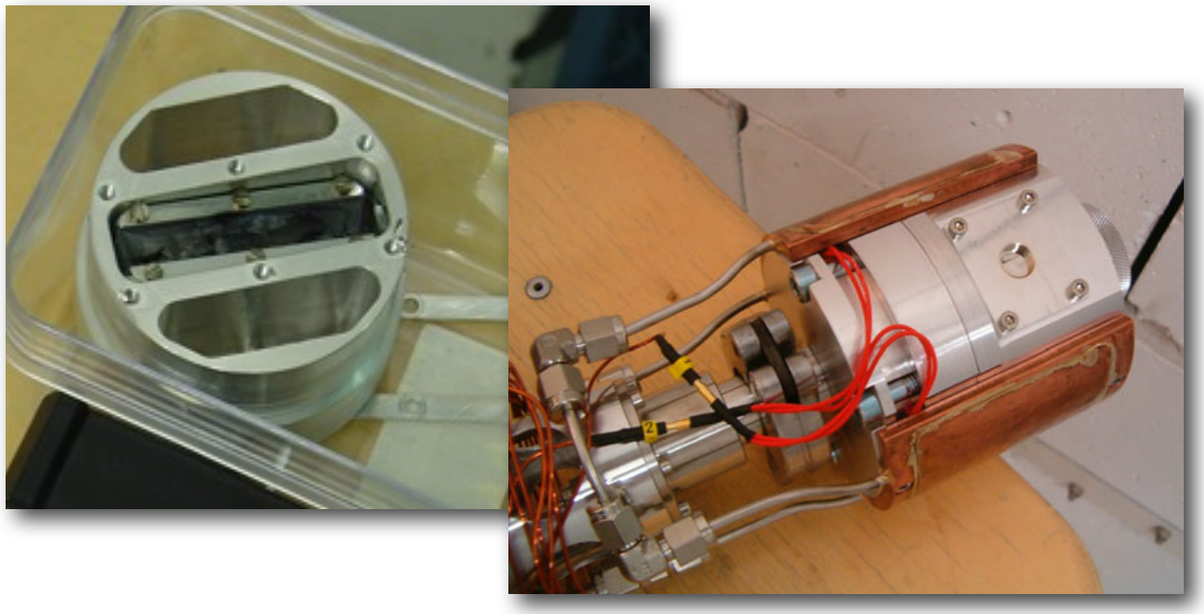
Ion guides

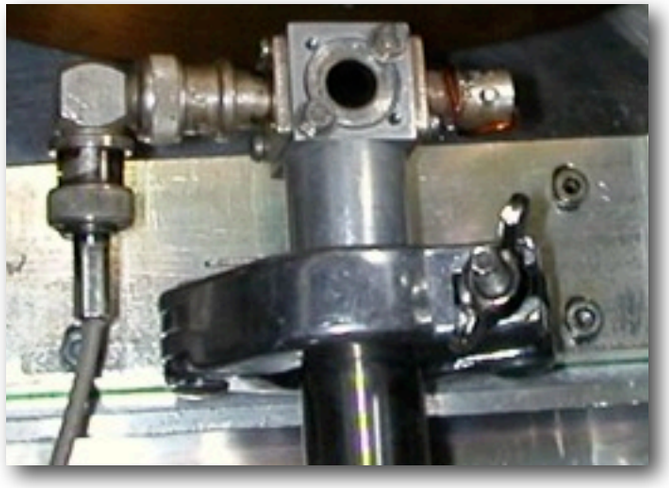
Fusion



Fission



Stable beams



... HIGISOL,

...Laser Ion Source

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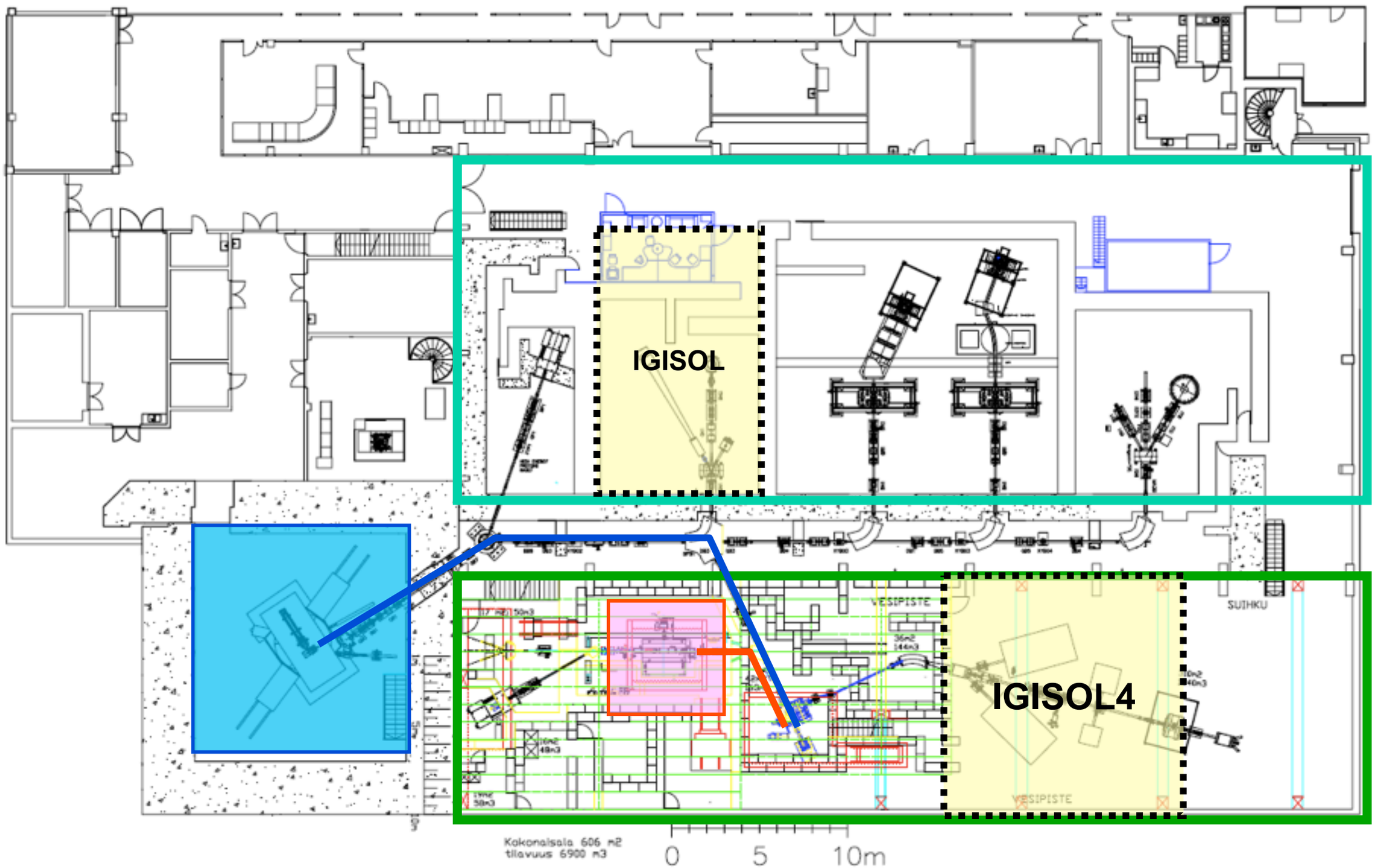
And now: IGISOL 4



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IGISOL 4 facility overview

- Dedicated MCC 30/15
- p (18-30 MeV,100 μA), d, n
- K130 beams

Offline delivery

Decay spec. /yield station

To collinear cabin

JYFLTRAP

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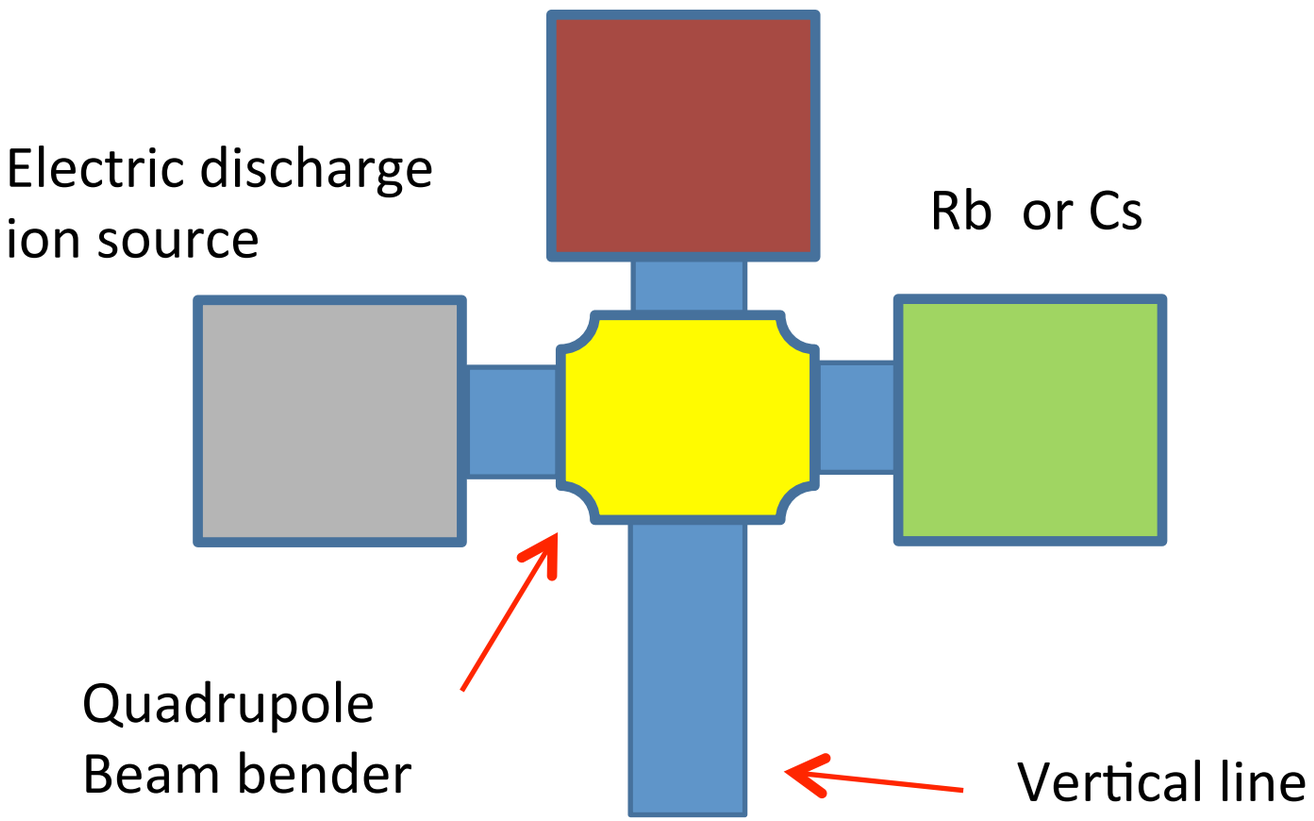
Alternative stable beam access

Intense IGISOL use forseen

➙ Retain access to stable beams during cooling



... and plans underway for a ^{252}Cf source (few mCi)

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Current plans

- Previously, ~continuous offline access
  - Scheme development, preparation
  - Technique development

- IGISOL now has a dedicated cyclotron
  - Maximise use of time with fast target changes and a separate offline source during cooling
  - 32 days of beam time awarded already for:-
    1) Mo
    2) Y
    3) Ta
    4) Th

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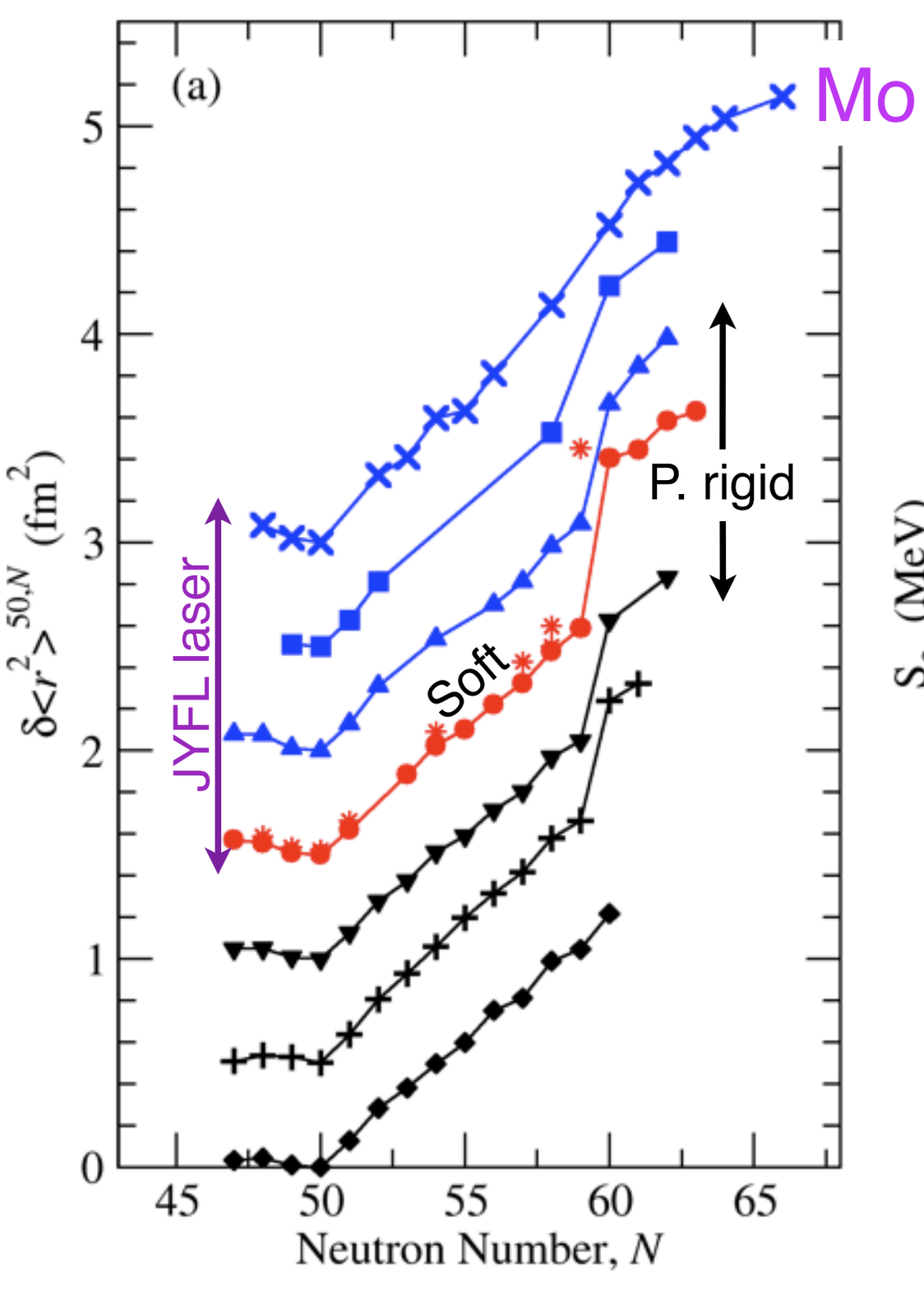
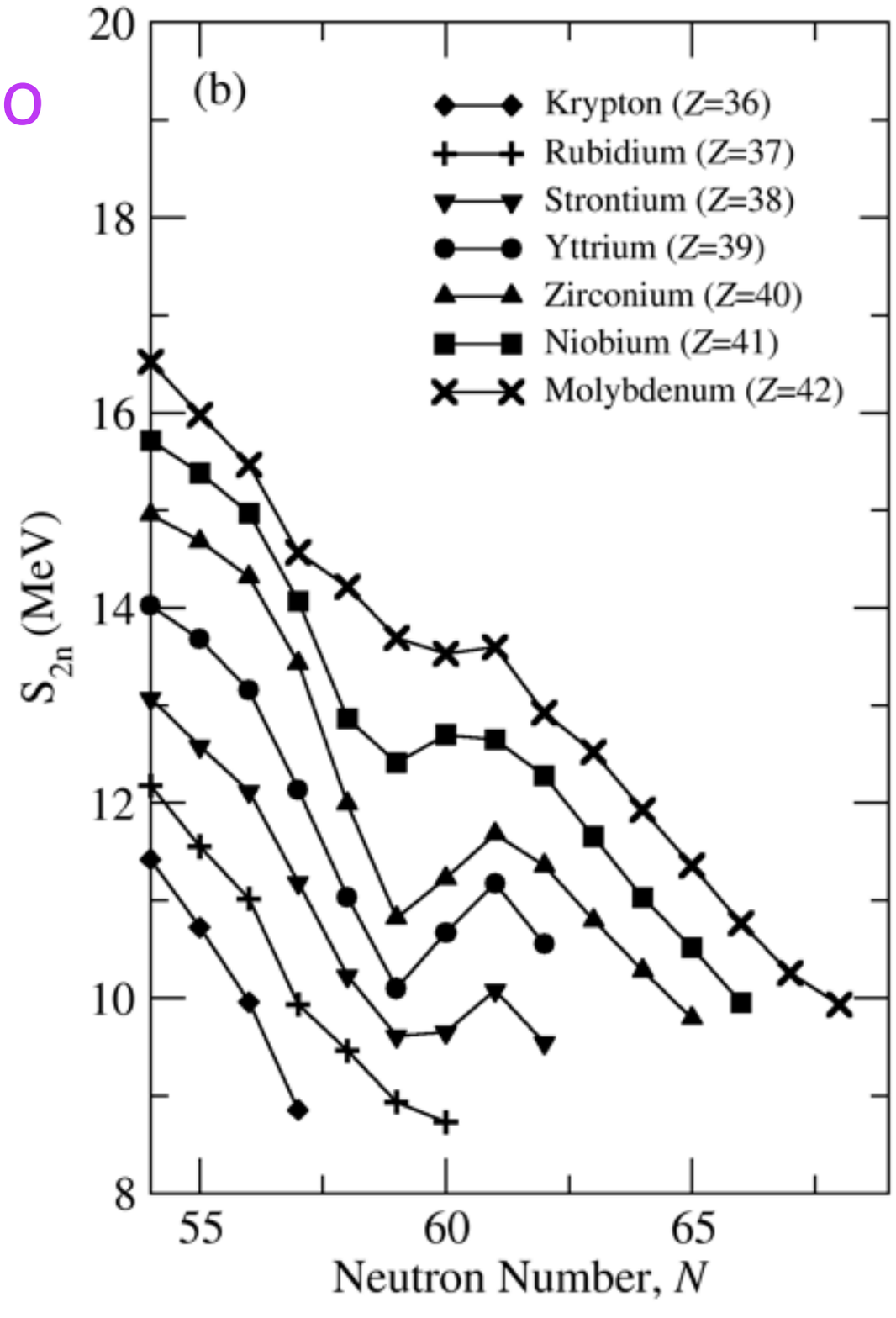
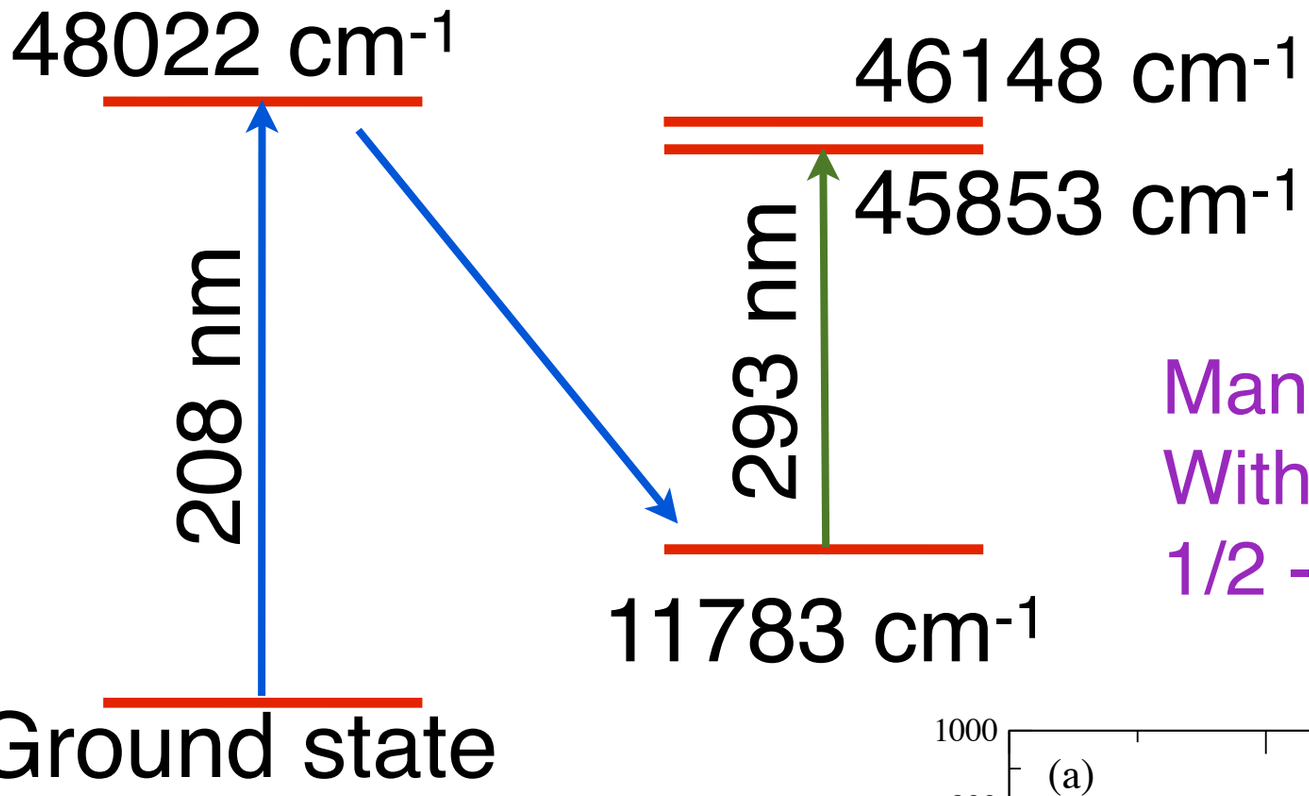
Mapping of the *N*=60 region



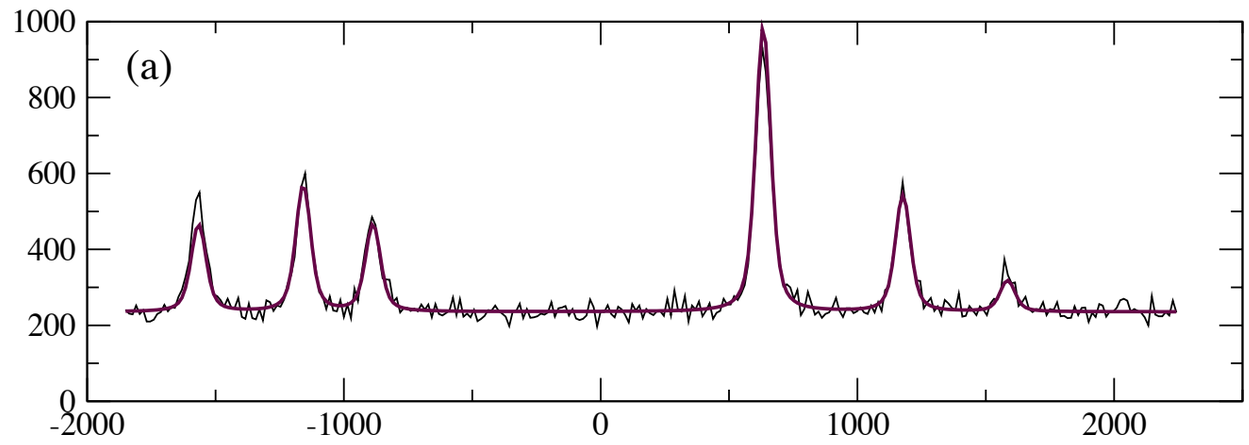


1) Spectroscopy of Mo



Managed 1 photon/3000 ions
Without optical pumping
1/2 -> 1/2 transition

- In-cooler pumping
- HR collinear spectroscopy



Use optical pumping and 1/2->3/2 to get Q_s, and N>66

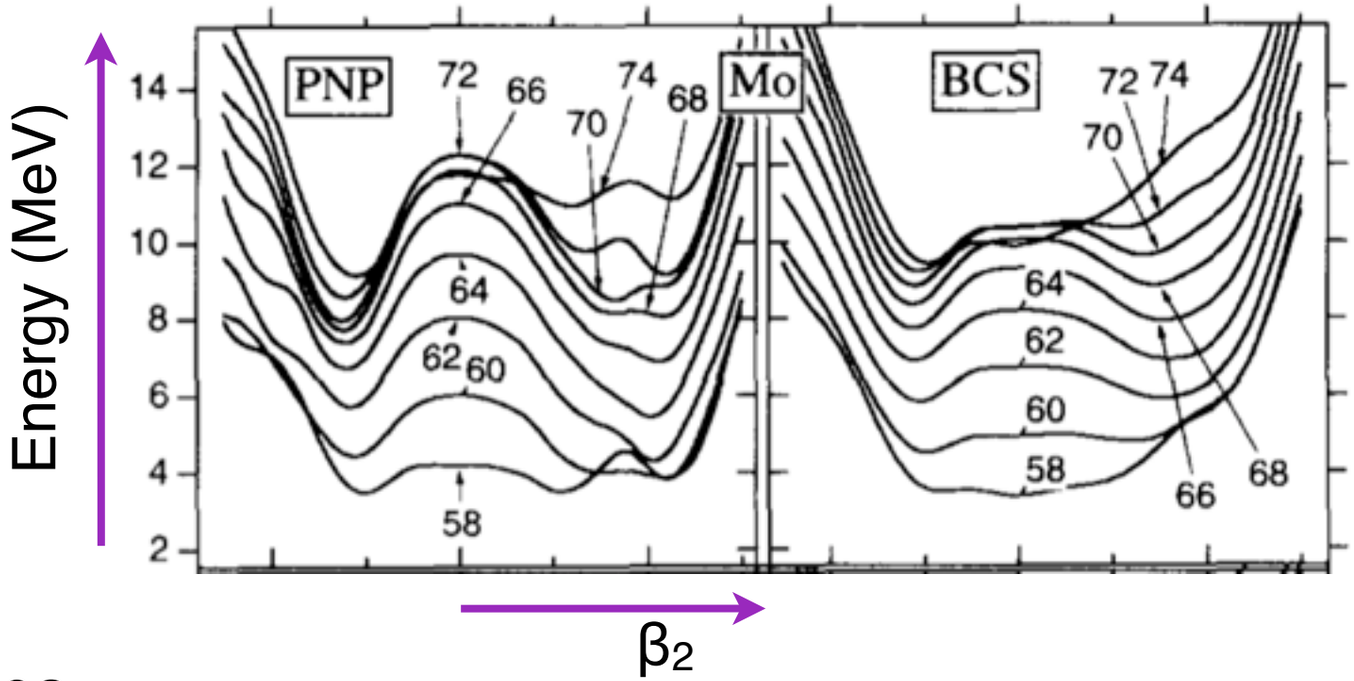
Conflicting predictions (N>66)

- GMM predict oblate shapes A=106-118
  Moller & Nix ADNDT 59 ’95 185

- RMF: prolate until A=113
  Lalazissis & Raman ADNDT 71 ’99 1

- PES: Oblate/Prolate shape coexistence
  Skalski et al. NPA 617 ’97 282

- SCMF: triaxiality
  Rodriguez-Guzman PLB 691 ’10 202



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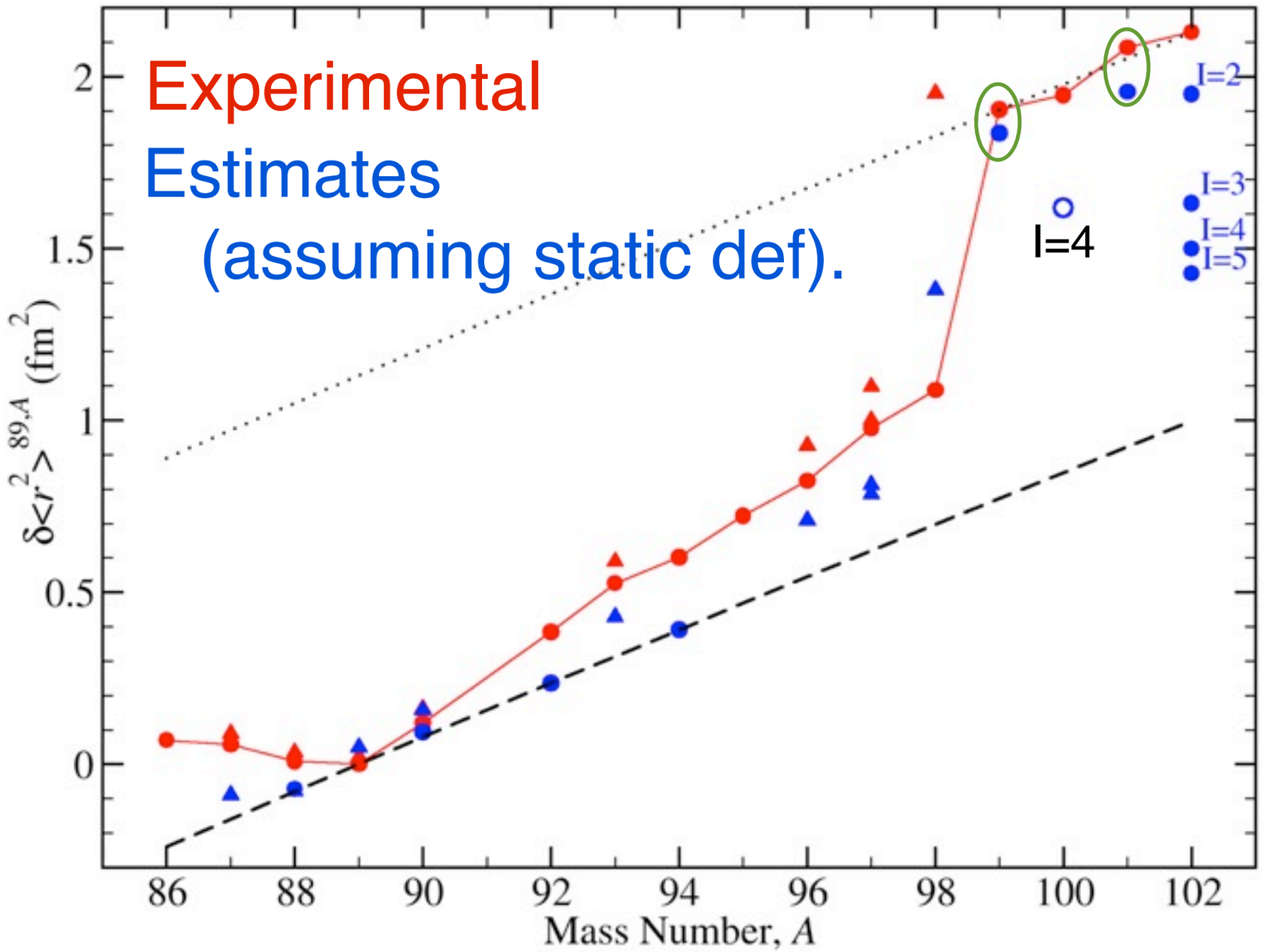
2) Yttrium



- 98m$^{}$Y
- 100g$^{}$Y
- ^{102}Y
- ^{88m2}Y (300μs)

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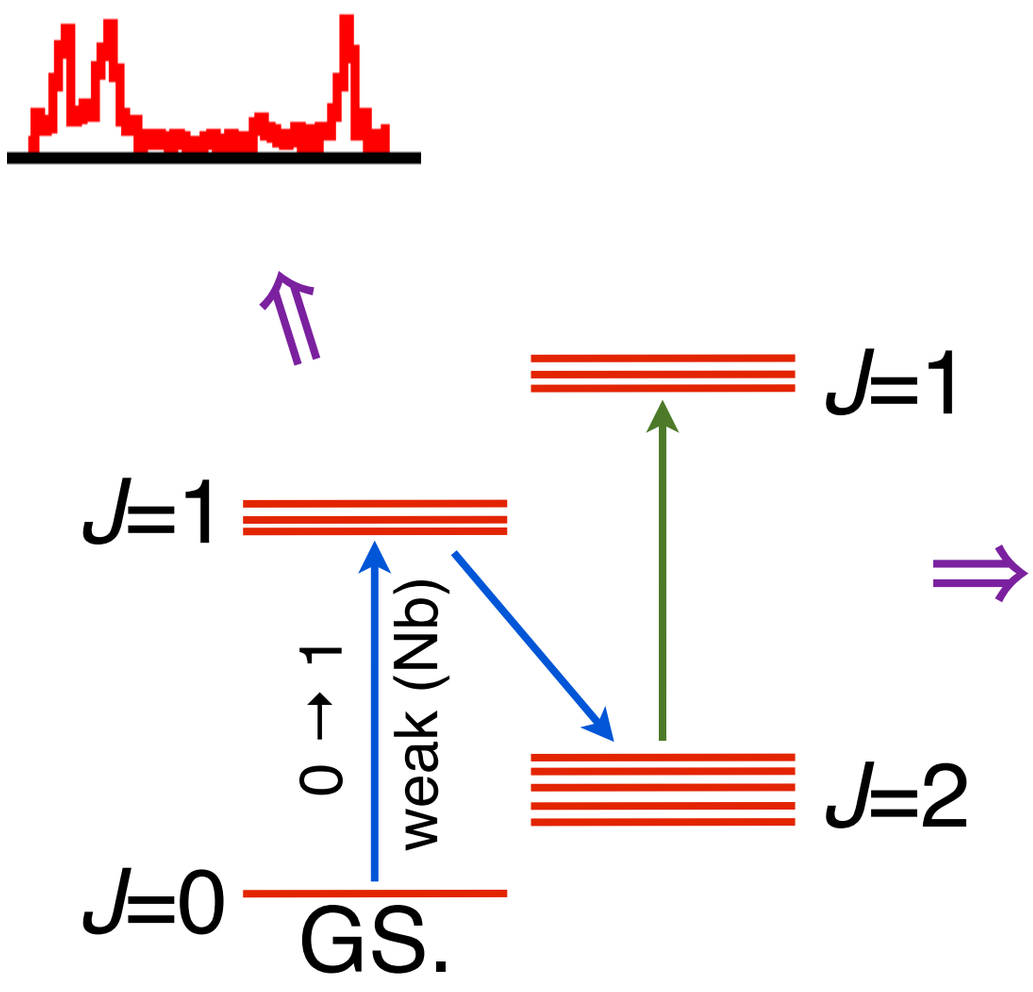
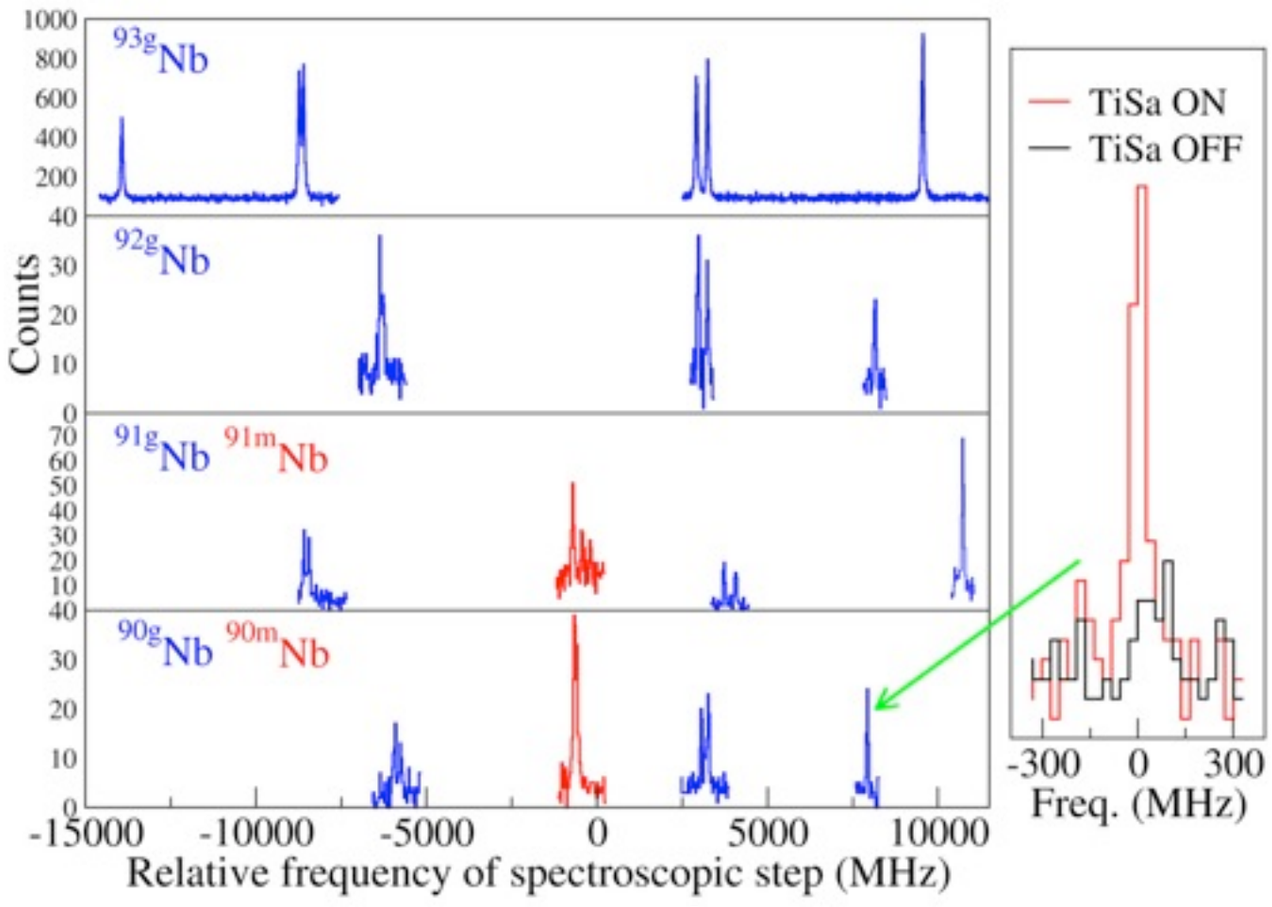
Optical pumping of Y,Nb





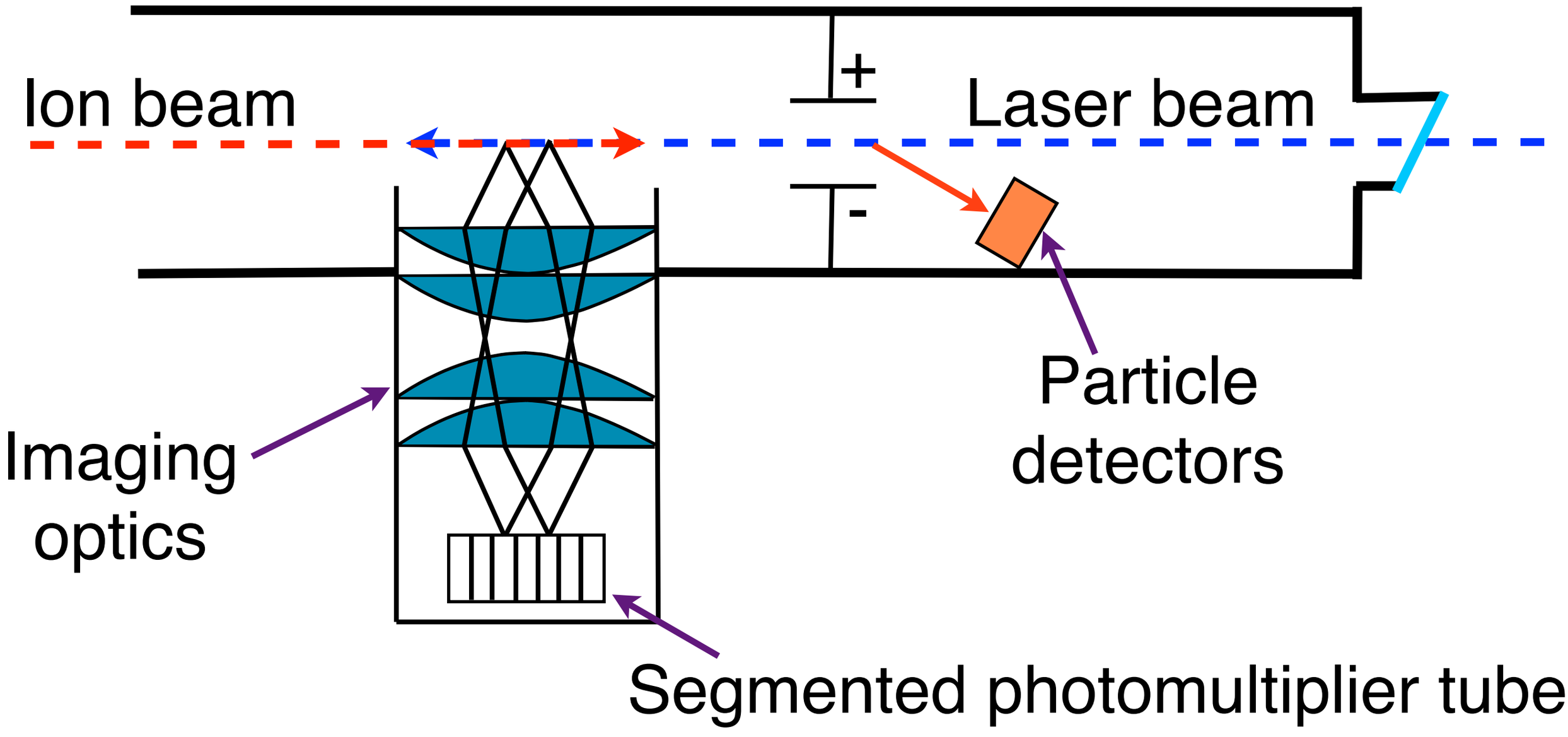
More HF components

↓

Spin determination

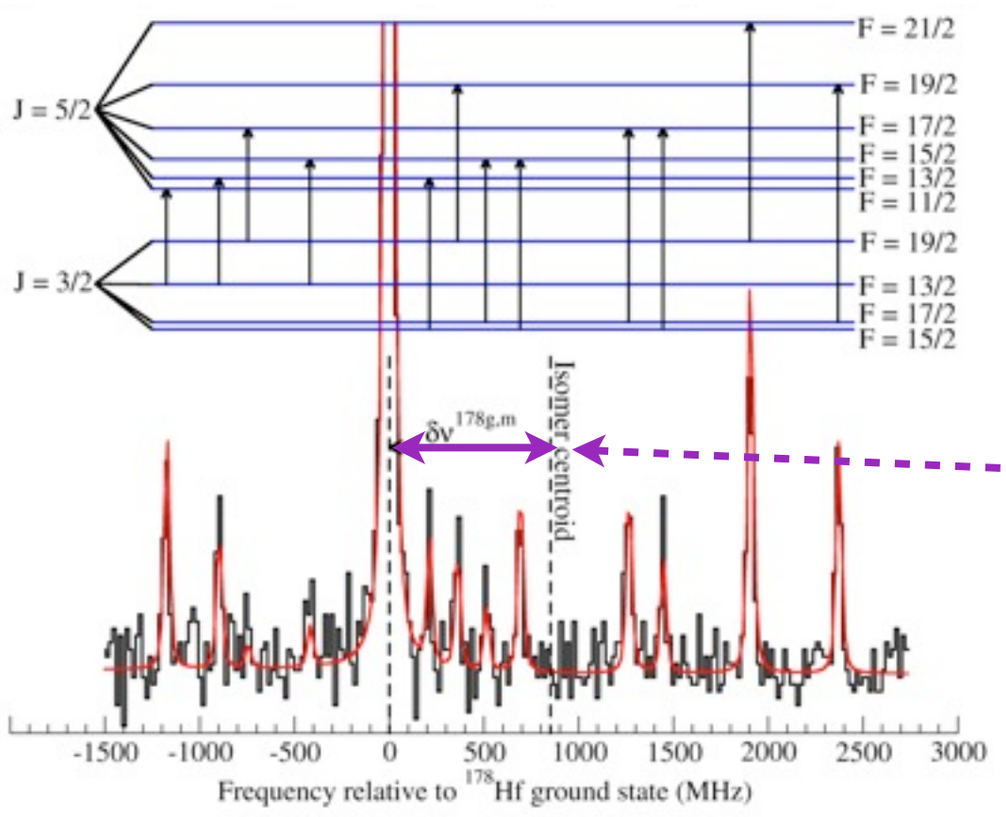
- In-cooler pumping
- HR collinear spectroscopy

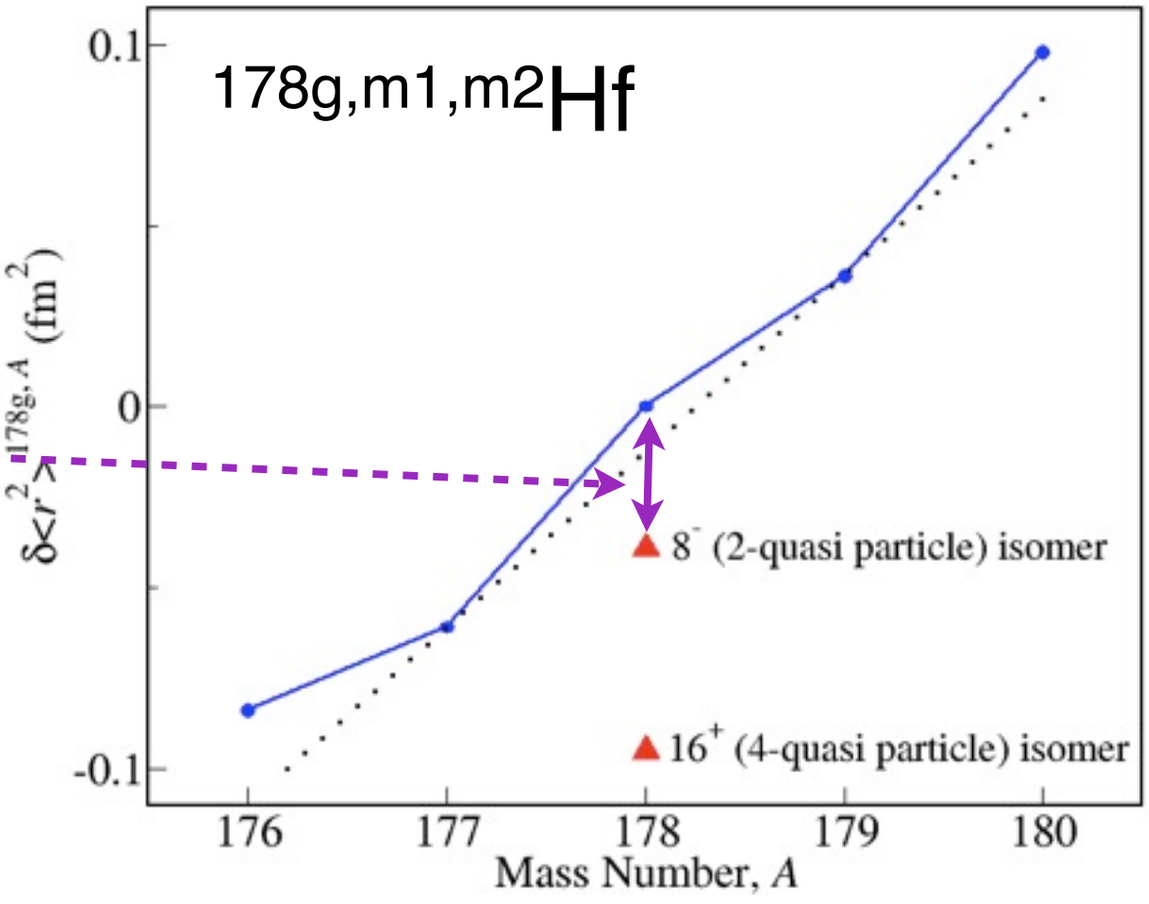
Photon-Ion coincidence



Does not require bunching (clean beams permitting)

3) Tantalum





- Smaller mscr for MQP isomer desp. Q_s (→$<\beta_2>$)↑
- Deformation or diffuseness → pairing
- Decrease is proportional to MQP number
- Nuclear O-E staggering has same origin? 1-QP?

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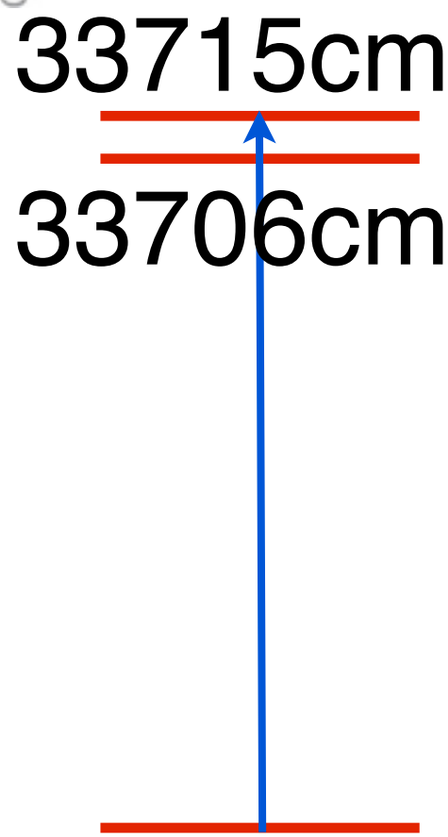
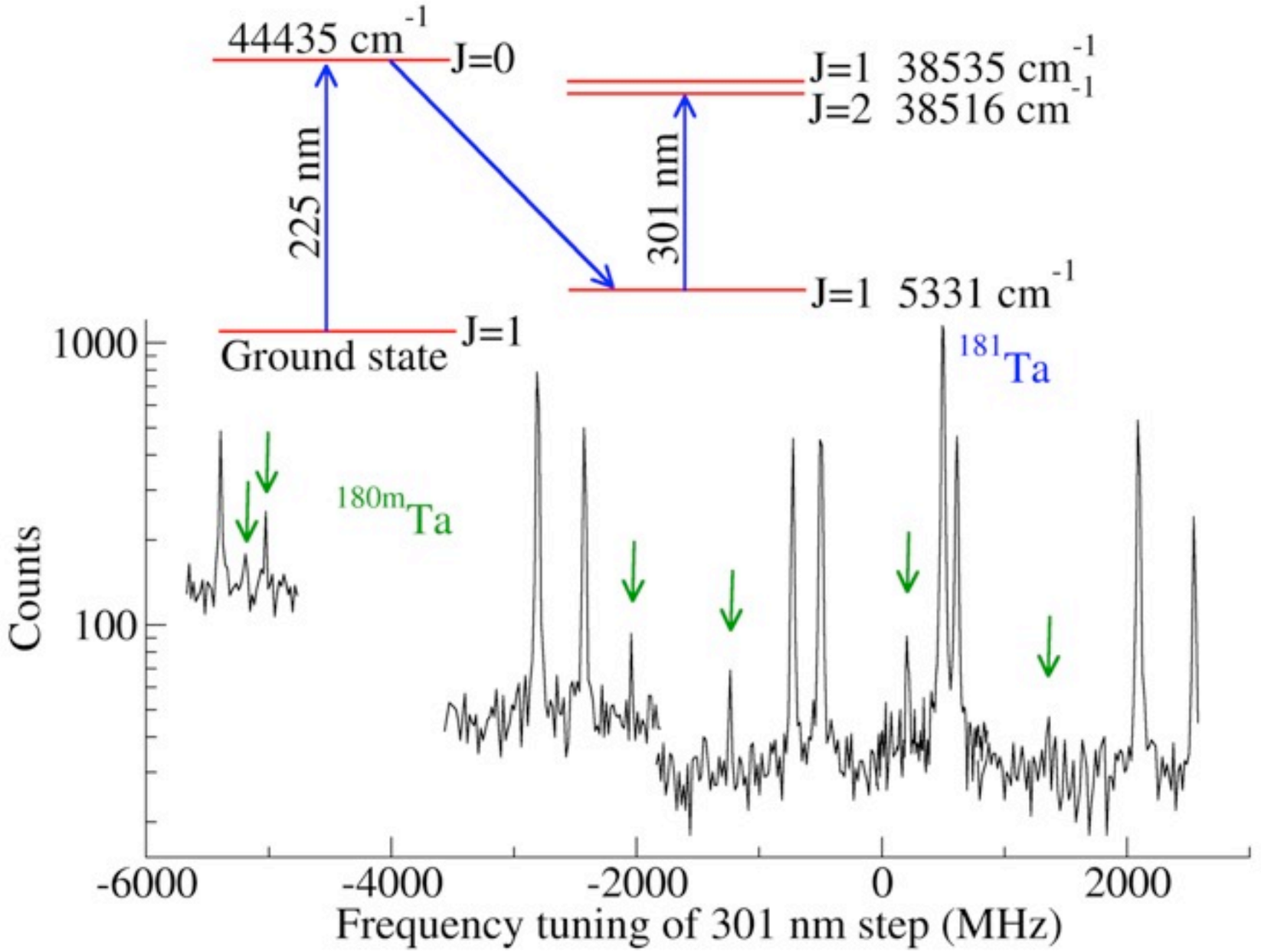
Optical pumping of Ta



Hyperfine Anomaly

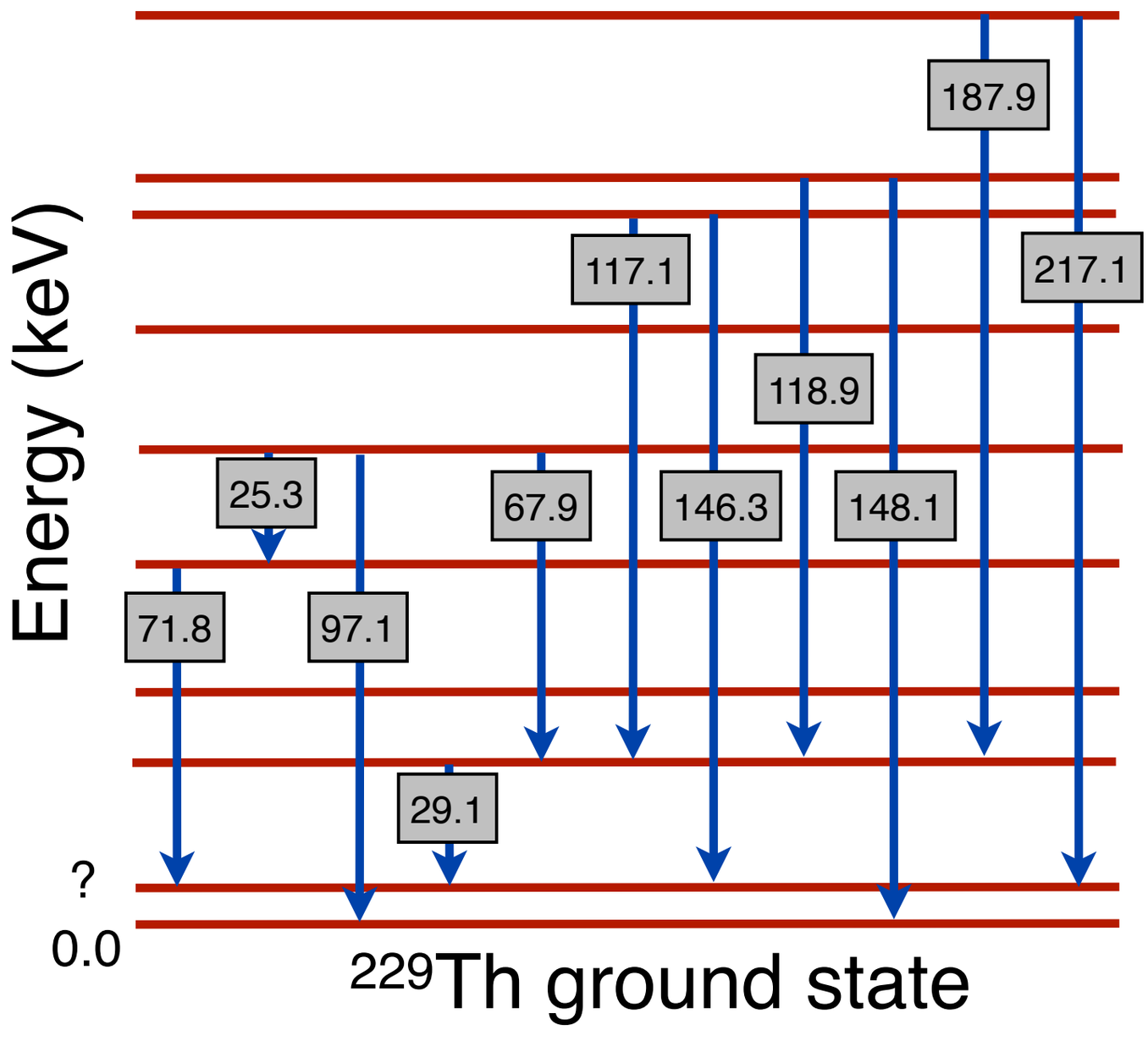


- OP to efficiently double # studied MQP isomers
- Remeasure selected GS transitions for mag. distbn.

4) Thorium - ^{229m}Th

- Indirect evidence of ^{229m}Th
- ~4eV

- Possibility of NEET
- "Nuclear clocks"
  - Test fundamental const. (transition freq vs time)
  - Test General Relativity (f indep. grav. potential)

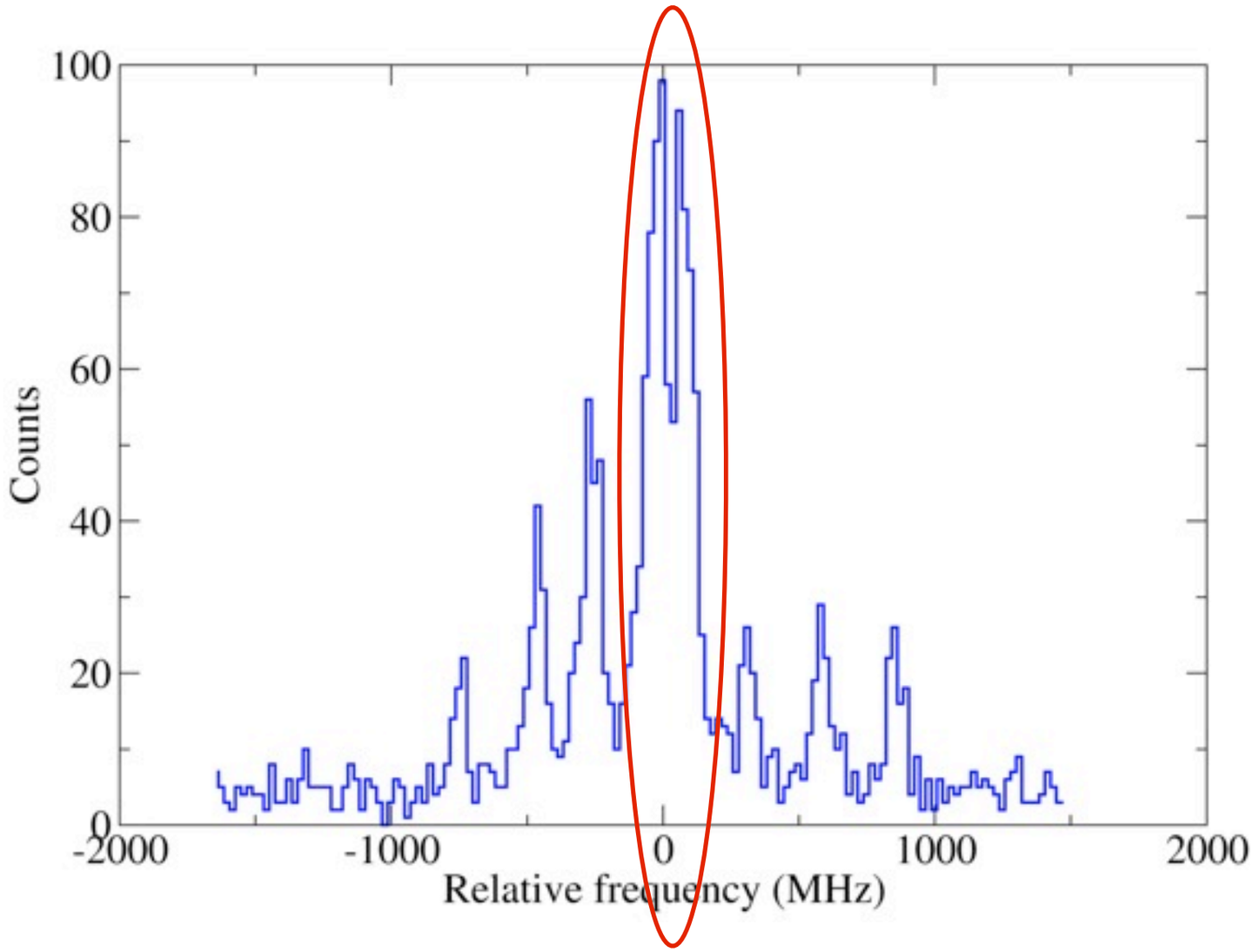


PRL. 97 092502 (2006)
PRL. 98 070802 (2007)
PRL 104 200802 (2010)
PRL 104 213002 (2010)
PRL 105 182501 (2010)

Discovery of new states

A recent example ^{80}Ga:

- Could be too long loved for some decay methods
- Half-life similar to gs
- Too low-lying
  - same mass



Optical spectroscopy is complements these methods

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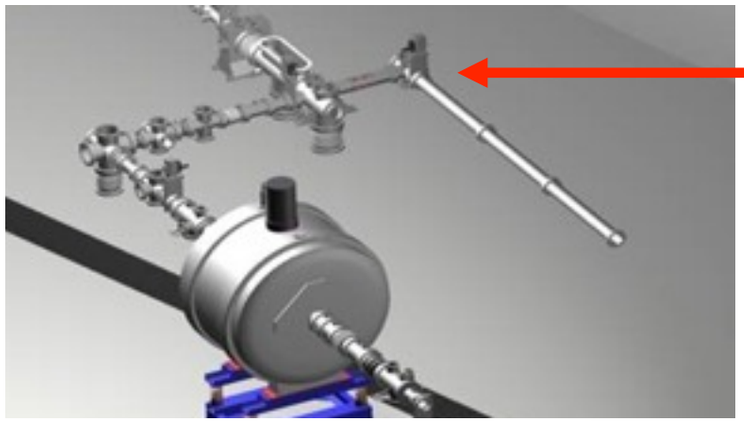
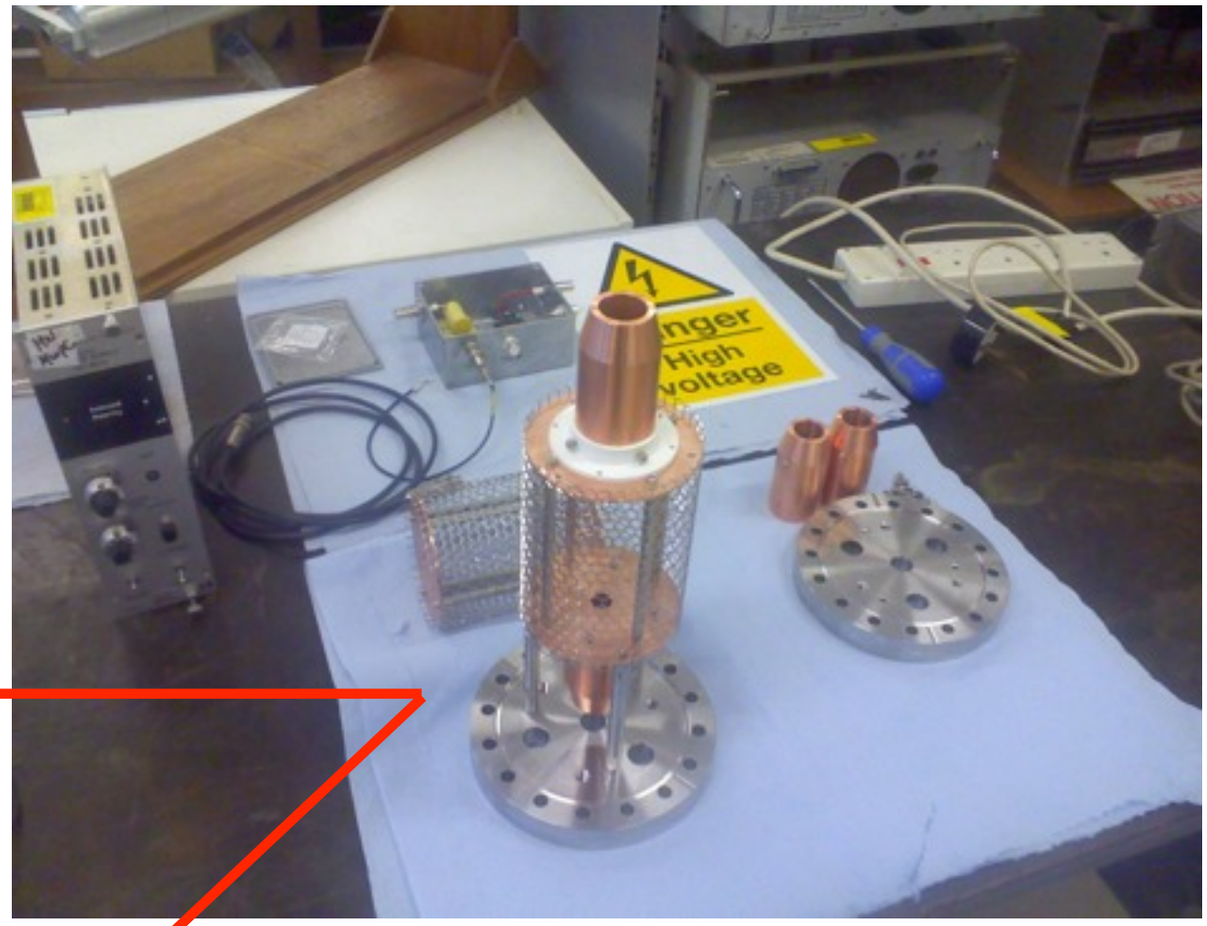
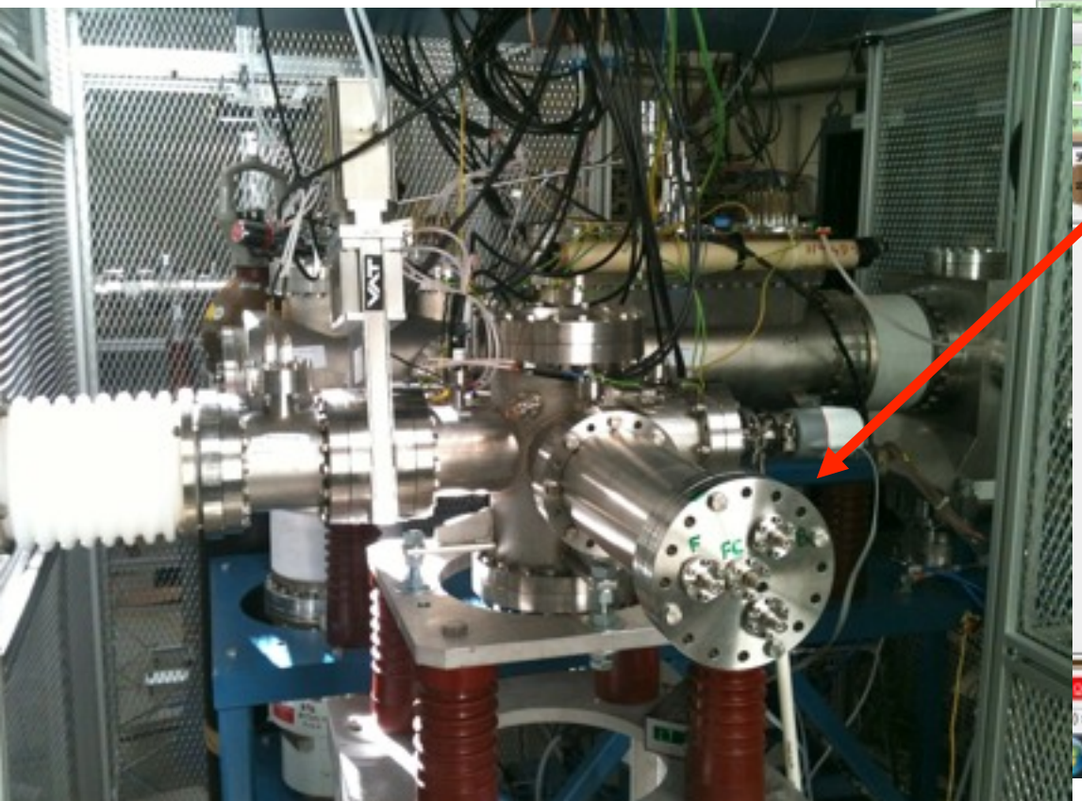
Cone trap

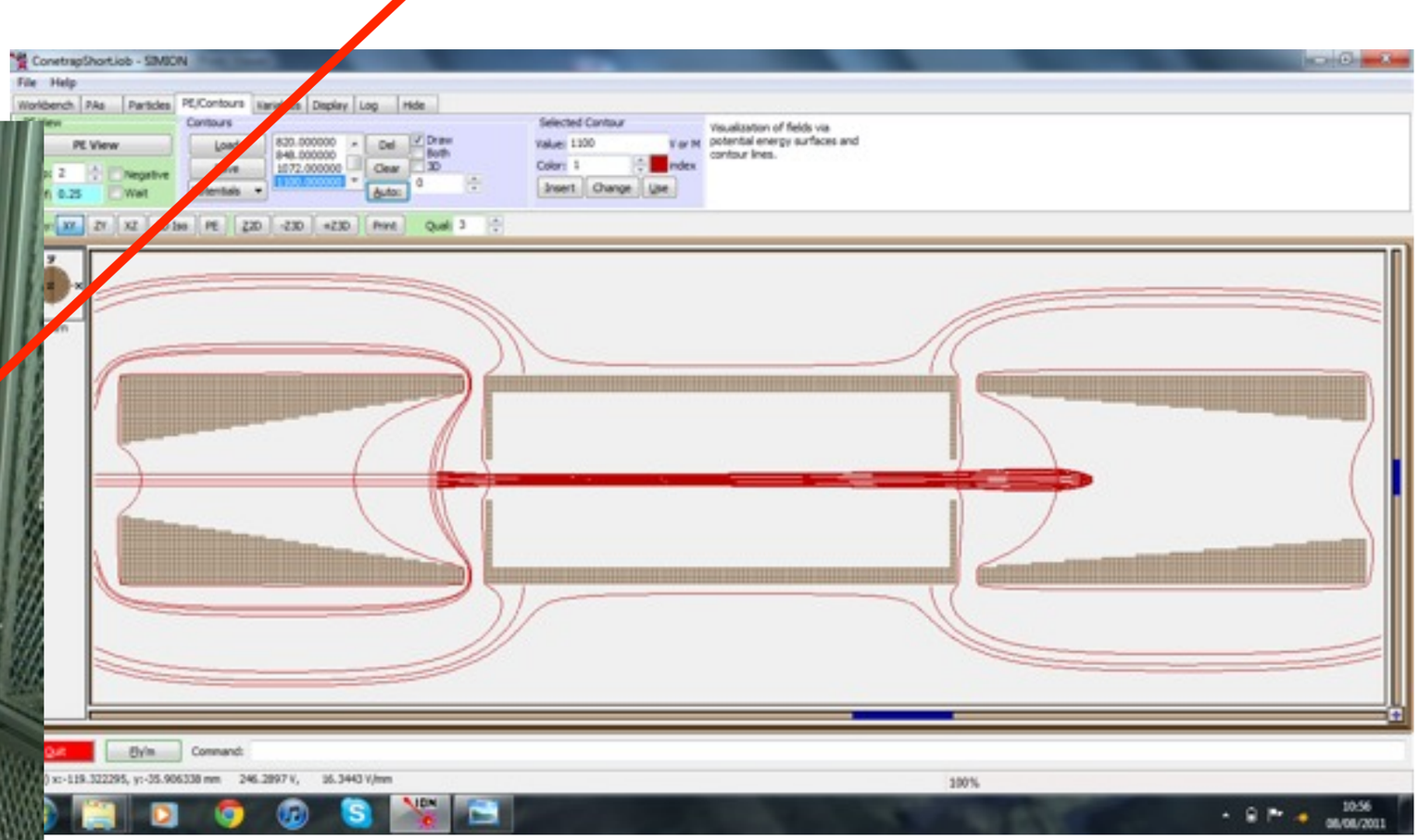
➔ UHV pumping (>1eV)

➔ RIS (purification)









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IGISOL 4 work to date

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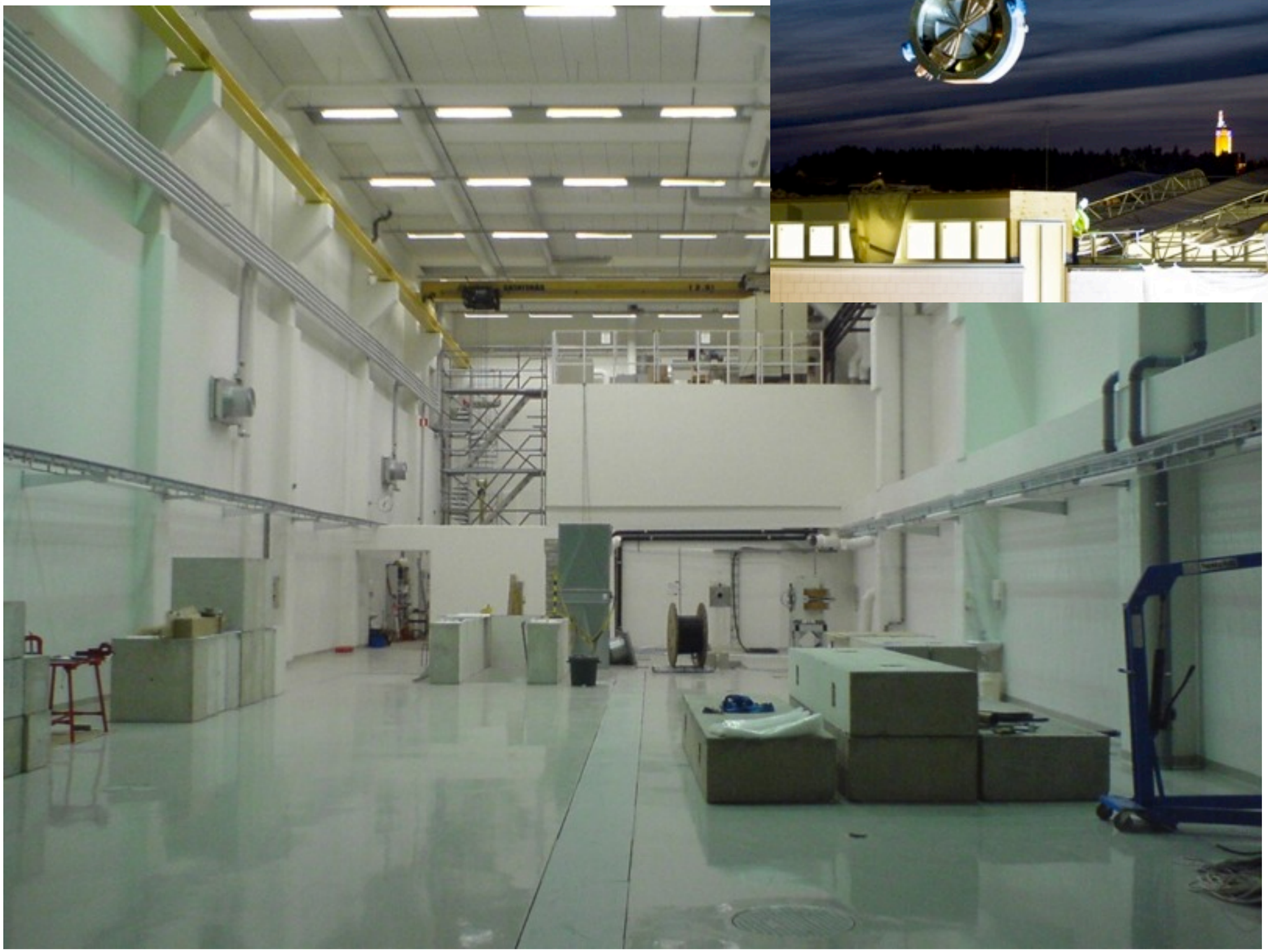
Cyclotron in...



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Summer 2011

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January 2012

(from switchyard)

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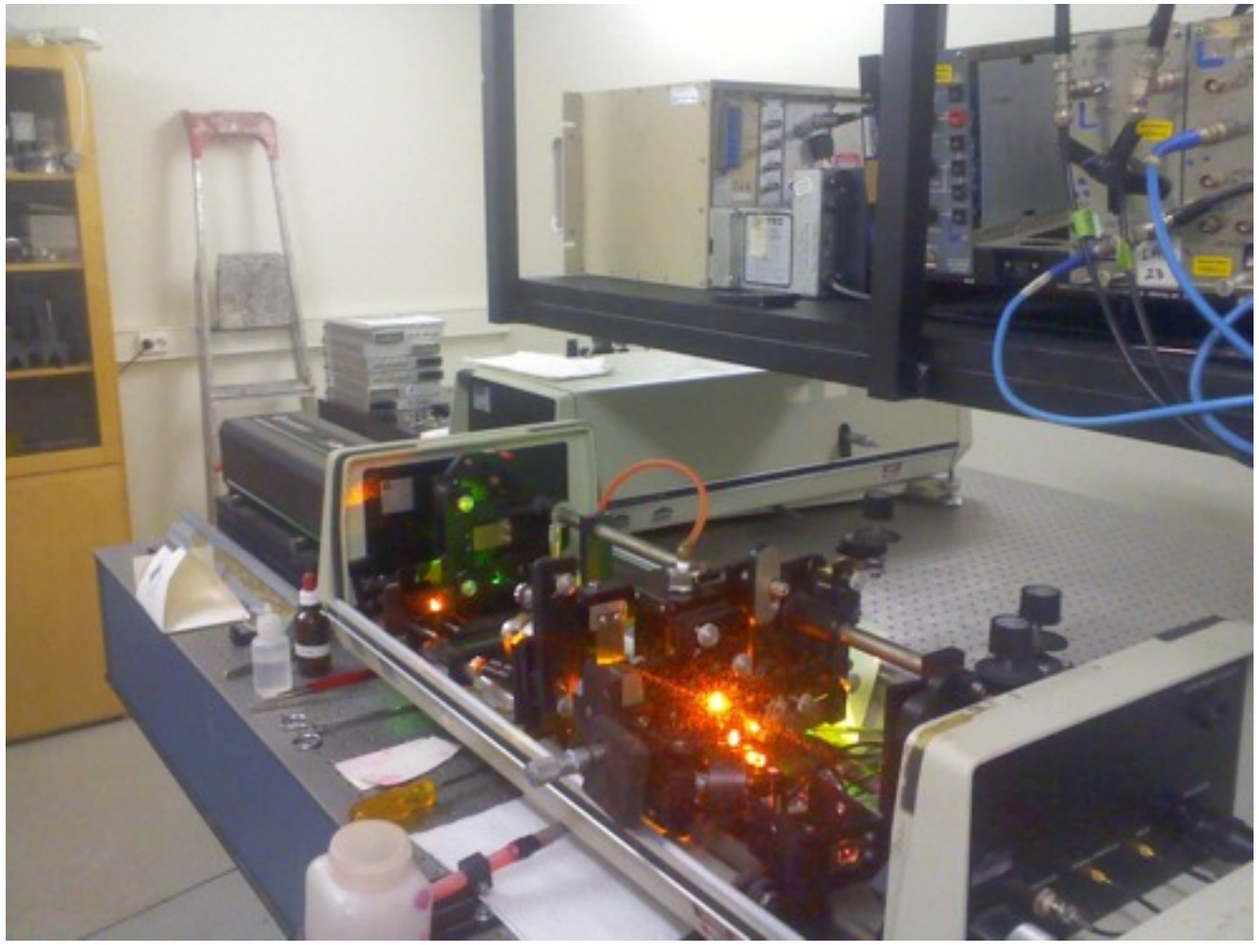
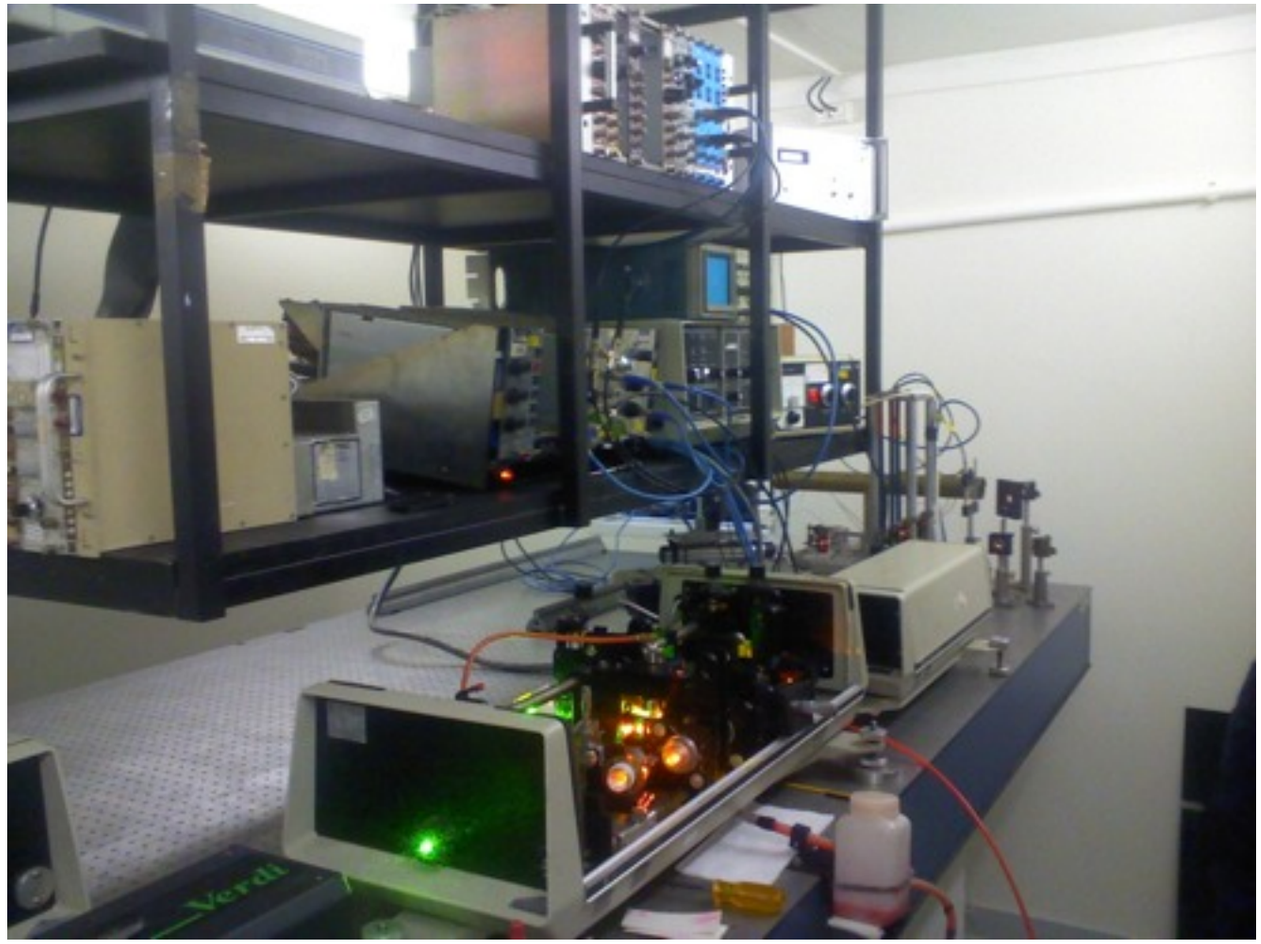
CW(1) Laser cabin





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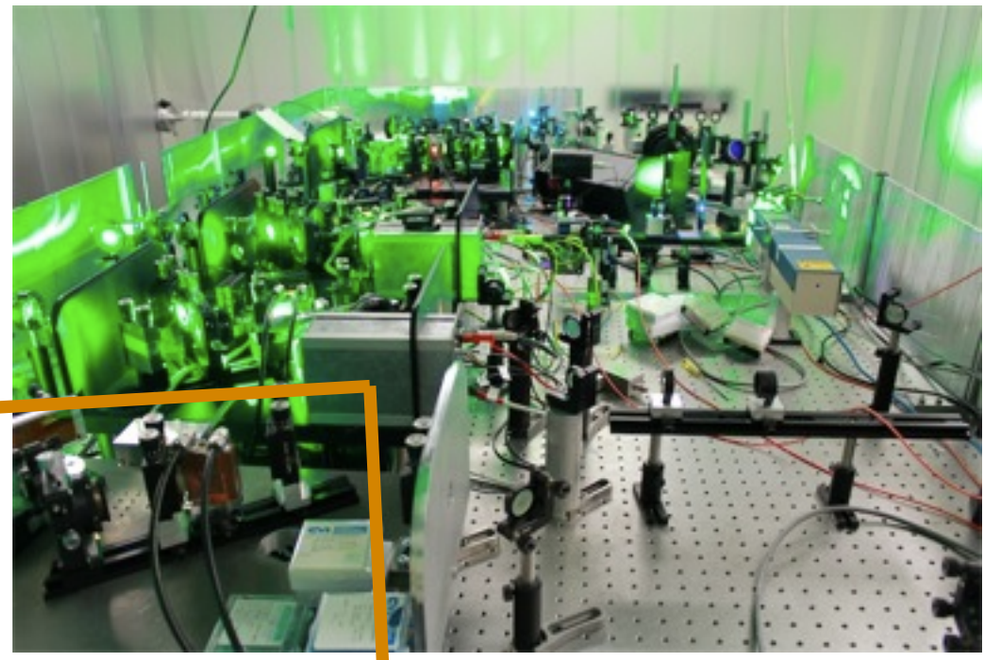
Pulsed laser cabins

Pulsed TiSa



CVL, PDL

& CW TiSa

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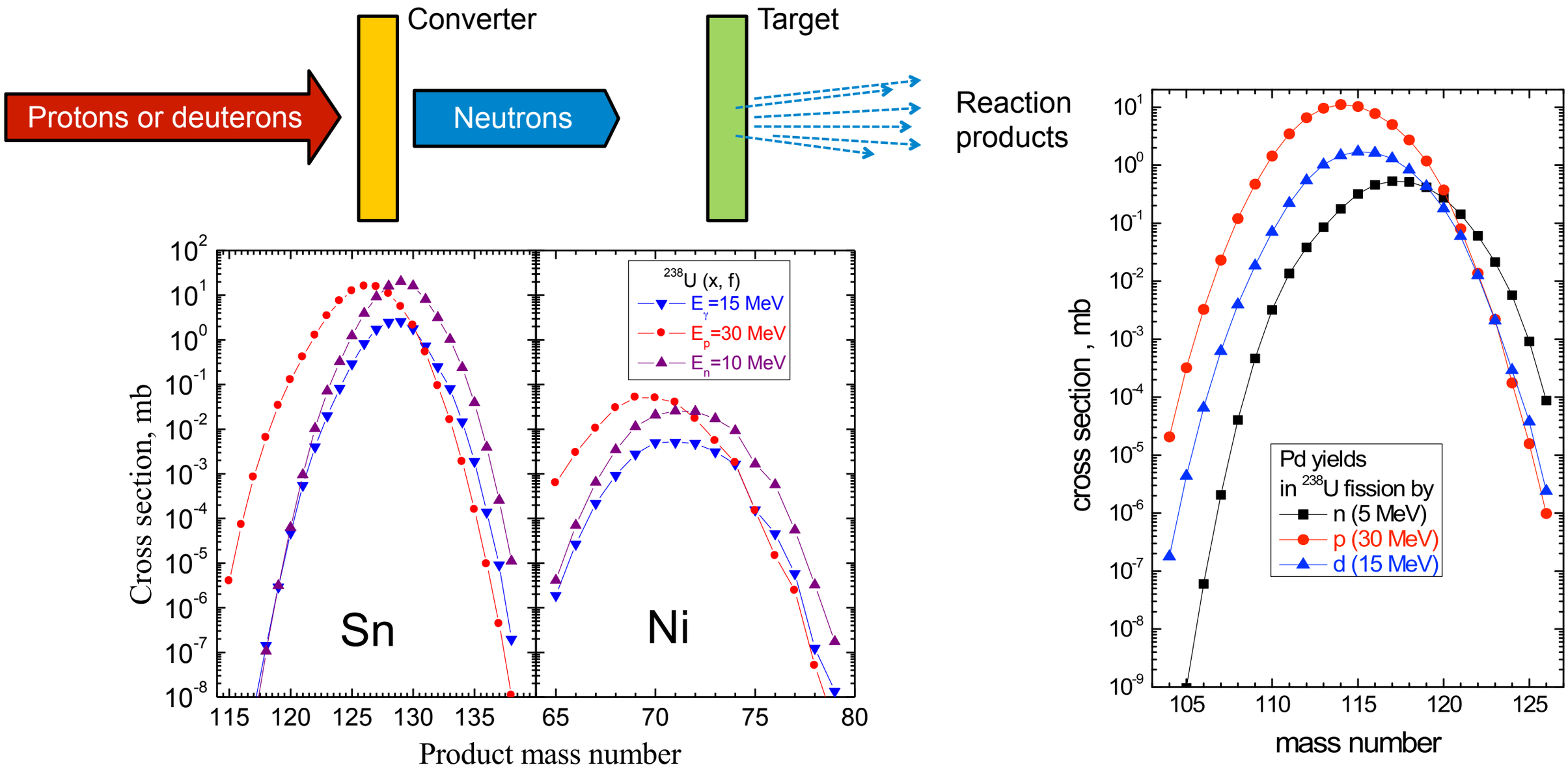
Present status

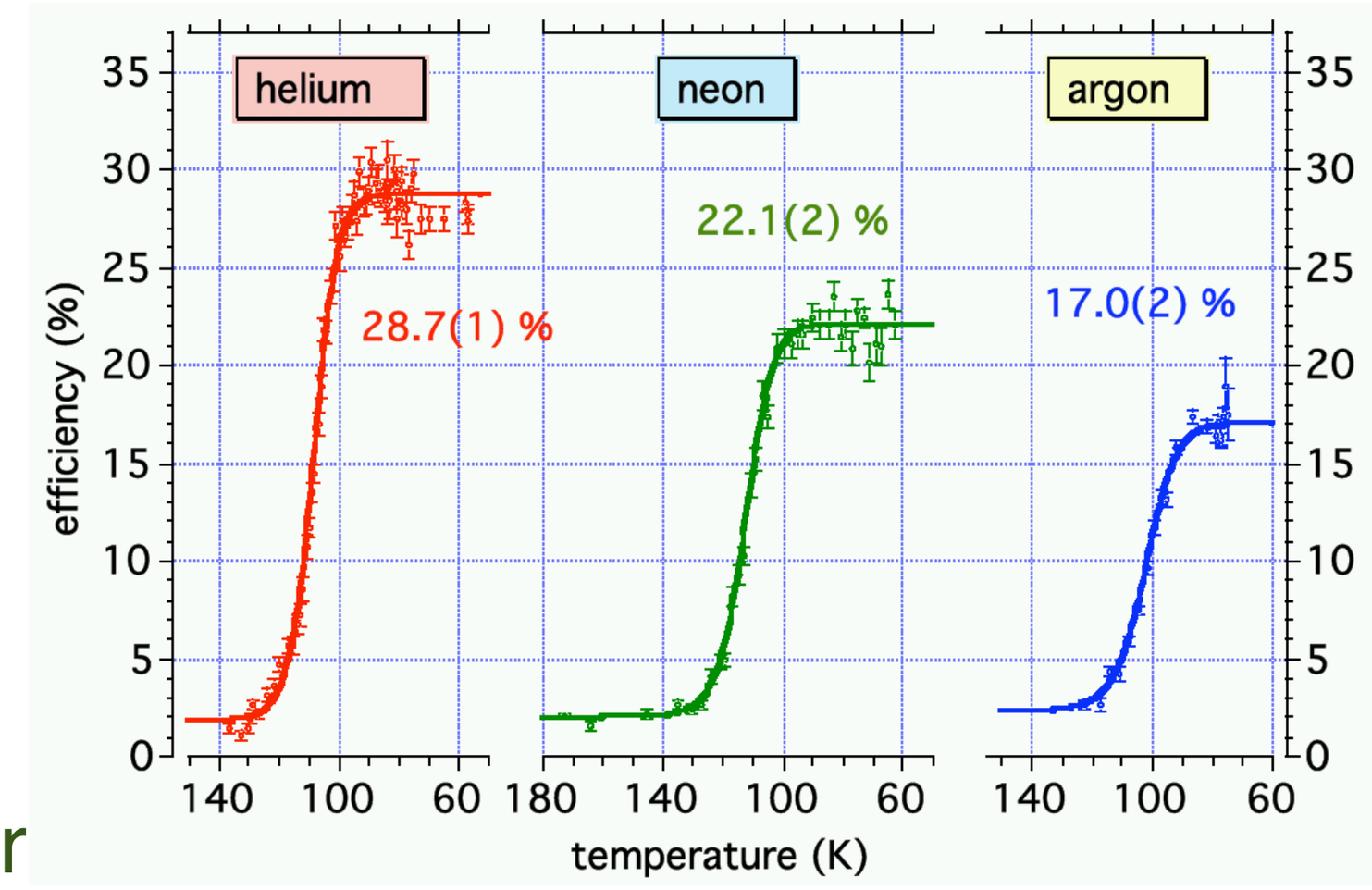
- Laser line in place
- Under vacuum
- Ions from IGISOL
- Online Feb 2012
- Beamtime for
  Y,Mo,Ta,Th,(W)...

Future plans... neutron converter

- 200μA extracted from cyclotron (target cooling?)
- Use of Be converter for n-induced cold fission



Future plans... cryogenic guides



- Use a 30K cryo-cooler
- Ultra-pure helium
  - Ideal for ion survival
    - No formation of molecules/adducts
    - Less neutralisation / charge state spread

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Summary

- Laser spectroscopy provides model independent measurements and a comprehensive picture of ground state and isomeric structure

- The JYFL facility has provided unique access to cases - both short-lived and refractory

- The new laboratory will provide additional opportunities and unparalleled access to beam time for further technique development and exploitation (esp. fission - eg. Ni).

Collaboration

University of Manchester, UK

J. Billowes, P. Campbell, B. Cheal, A. Dicker, D. Johnson, M. Reponen

University of Jyväskylä, Finland

D. Gorelov, A. Jokinen, V. Kolhinen, I.D. Moore, H. Penitllä, I. Pohjalainen, Sami Rinta-Antila

University of Birmingham, UK

D.H. Forest, G. Tungate