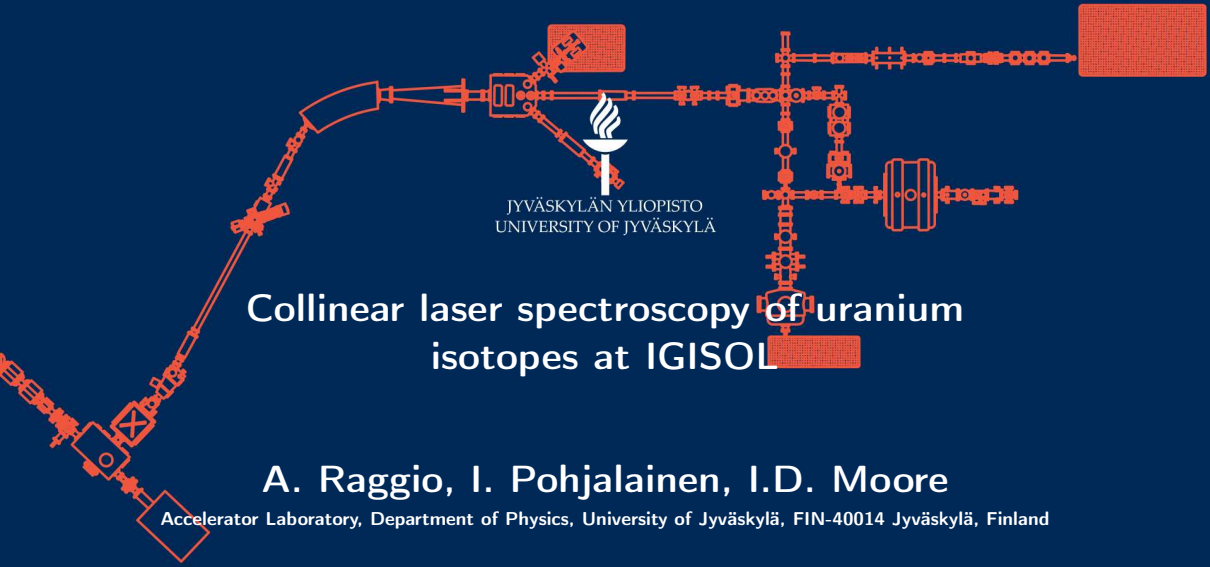


Collinear laser spectroscopy of uranium isotopes at IGISOL

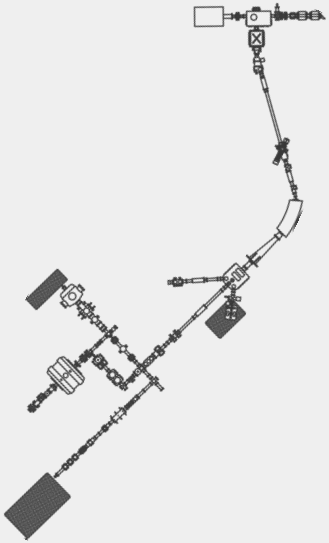
A. Raggio, I. Pohjalainen, I.D. Moore

Accelerator Laboratory, Department of Physics, University of Jyväskylä, FIN-40014 Jyväskylä, Finland

Content

Physics motivations and context

- Optical spectroscopy for nuclear physics
- The ^{235m}U isomer case



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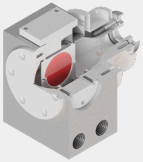

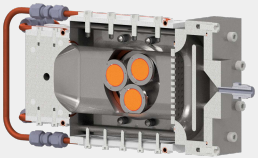

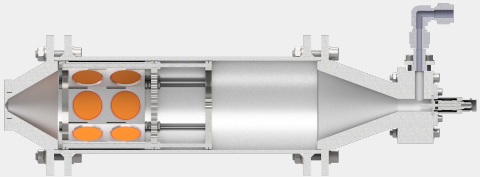

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Isomeric beam production

- Alpha-recoil sources
- Gas-cell development

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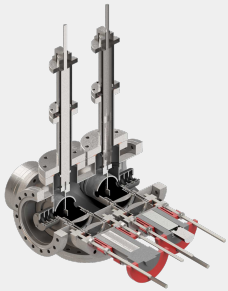
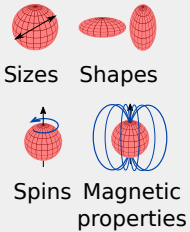
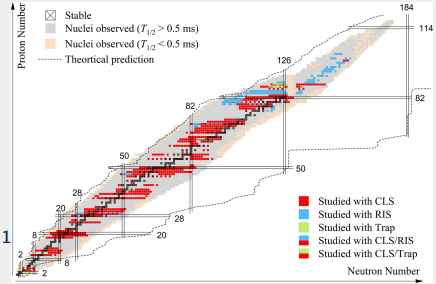
- CLS @IGISOL
- Natural Uranium measurement
- LCR upgrades



Optical Spectroscopy for nuclear physics

A useful tool to extract fundamental nuclear ground-state properties





Nuclear model-independent measurement

[1]X. F. Yang, et al. PPNP (2022): 104005.

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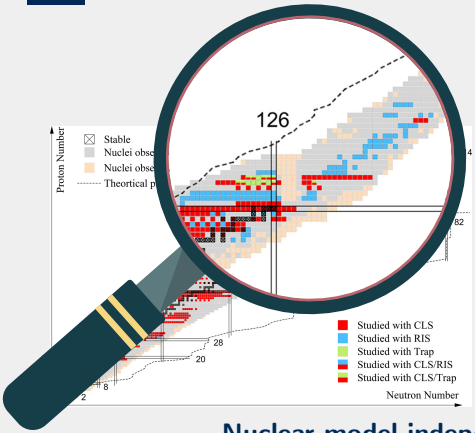

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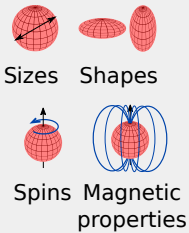
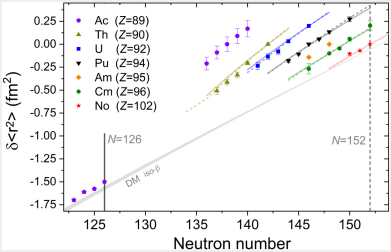


General lack of optical data

- Lack of Stable isotopes
- Challenging Production

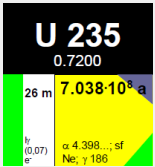


Nuclear model-independent measurement

[2]

[1]X. F. Yang, et al. PPNP (2022): 104005.
[2]M. Block et al., PPNP, 116 (2021), 103834

^{235m}U isomeric state

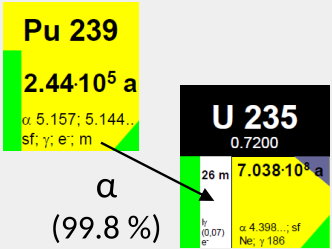


Second lowest isomeric state in the nuclide landscape

- 76 eV [3]
- ∼26 minutes half life

[3] F. Ponce, et. al. PRC, 97.5 (2018): 054310.

^{235m}U isomeric state



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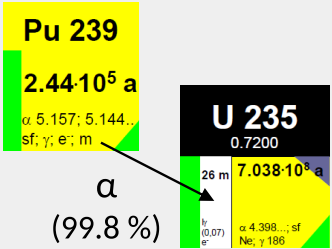

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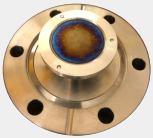
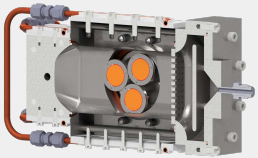
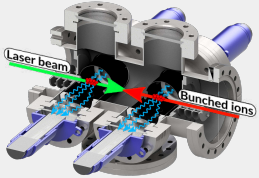
Source



Extraction



Measurement



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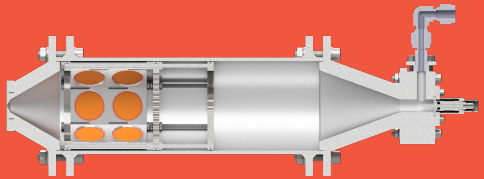
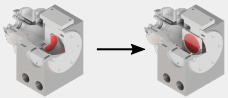
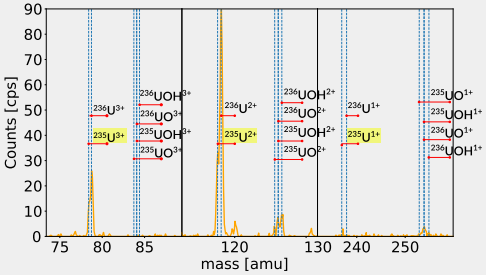
Isomeric beam production



Gas-cell development

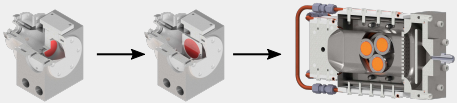


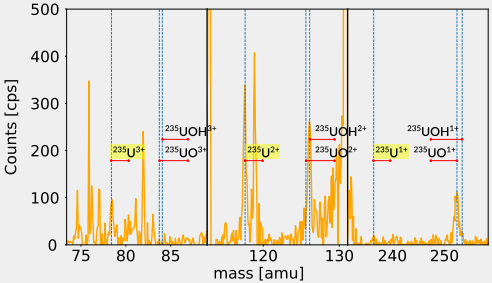


Mk. I - Actinide gas-cell

- up to 2 sources (with axial mount)
- tested with ^{239}Pu and ^{240}Pu
- Recoils in the 3+ and 2+ charge states
- Presence of molecular compound
- ~50 cps of $^{235}U^{2+}$at switchyard MCP detector (1 source)

Gas-cell development

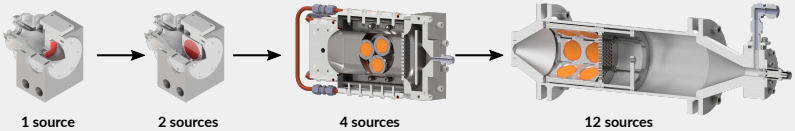


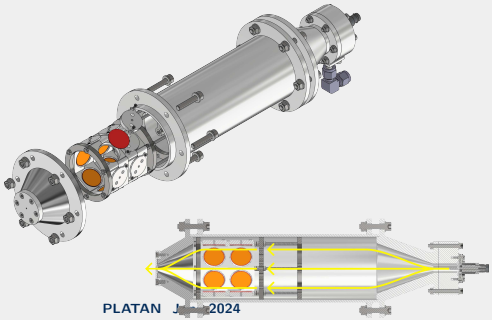


Mk. II - Mara LEB gas-cell

- up to 4 sources
- tested with ^{239}Pu
- Small bias voltage applied at the source mount
- Recoils in the 3+ and 2+ charge states
- Molecular compunds and impurities dominates
- ∼800 cps of $^{235}U^{2+}$at switchyard MCP detector

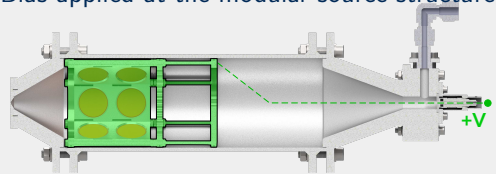
Gas-cell development





Mk. III - Large recoil gas-cell

- tested with 12 ^{239}Pu sources
- 2.5 mm nozzle and 55 mbar He
- Bias applied at the modular source structure



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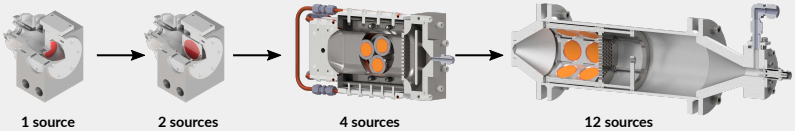

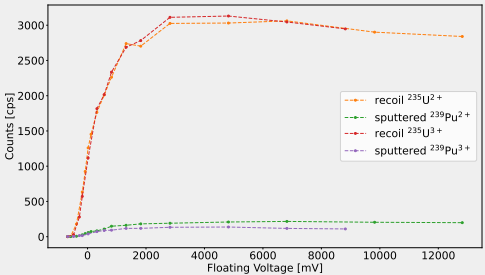

Mk. III - Large recoil gas-cell

- tested with 12 ^{239}Pu sources
- 2.5 mm nozzle and 55 mbar He
- Bias applied at the modular source structure
- ∼3000 cps for both 3+ and 2+ charge states

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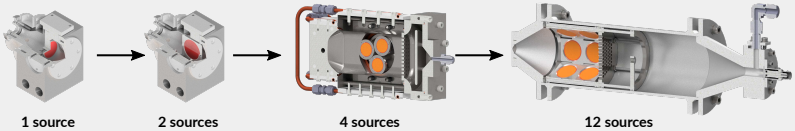

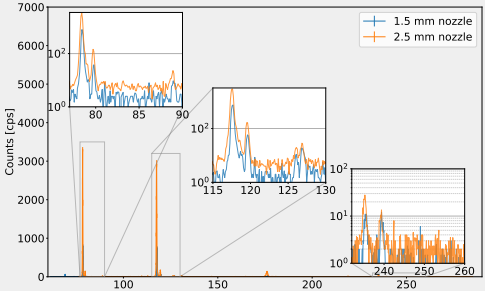

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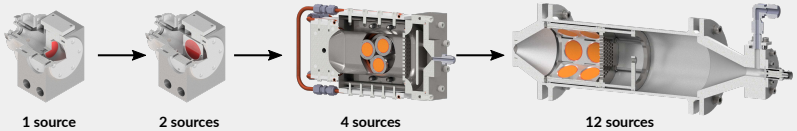

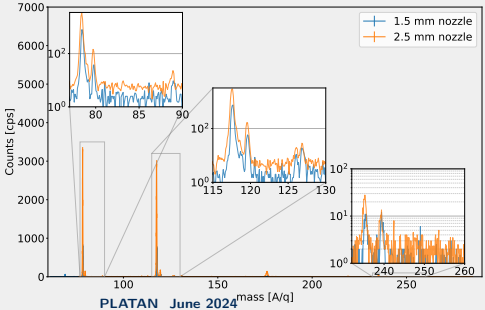

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- tested with 12 ^{239}Pu sources
- 2.5 mm nozzle and 55 mbar He
- Bias applied at the modular source structure
- ∼3000 cps for both 3+ and 2+ charge states
- Minimized molecular formation
- 1+ too little for laser spectroscopy

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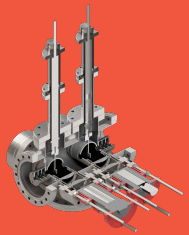
Collinear Laser Spectroscopy



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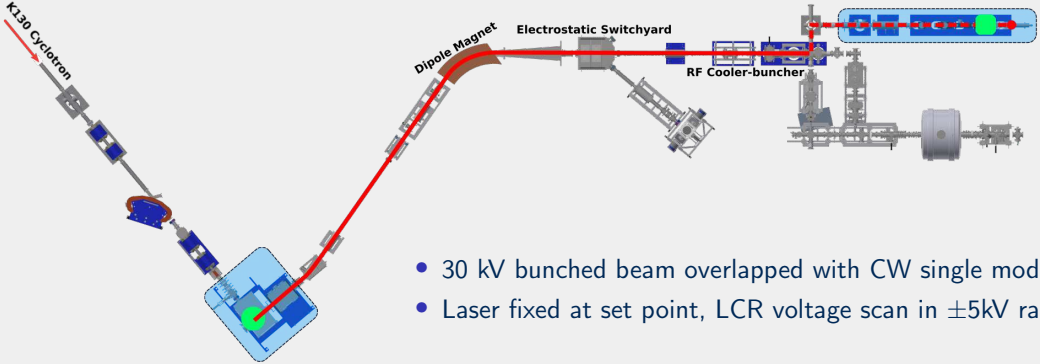

- 30 kV bunched beam overlapped with CW single mode laser light
- Laser fixed at set point, LCR voltage scan in $\pm$5kV range

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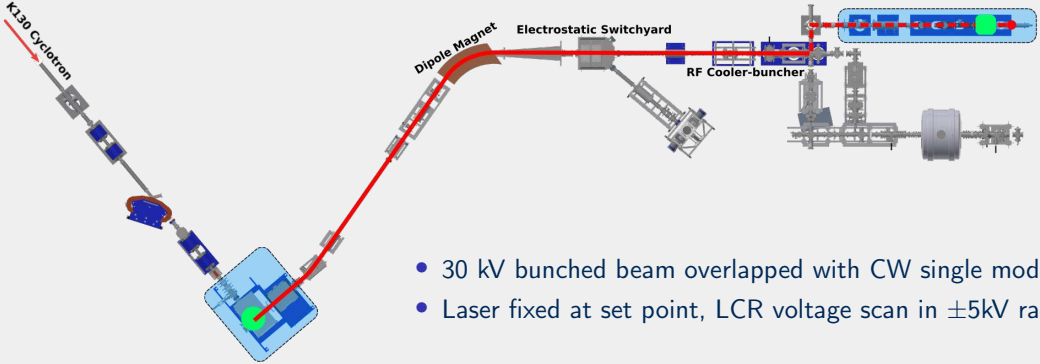

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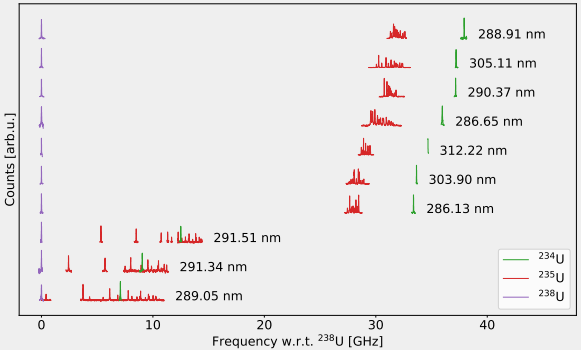
Preparatory experiment needed to find the optimal transition

Groundwork: CLS of ^{nat}U



- ^{234}U 0.0054%, ^{235}U 0.7204%,^{238}U 99.2742%
- Offline study of ionic transition in the UV range 288-314 nm

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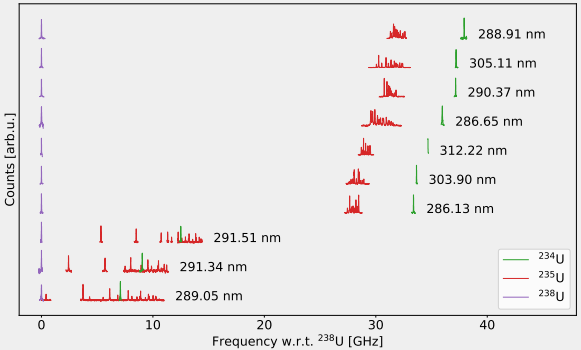
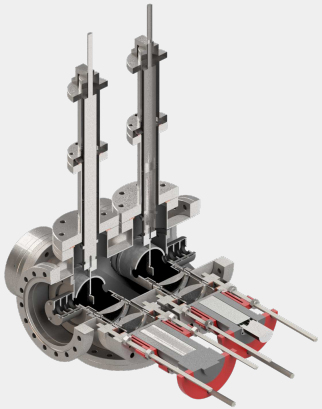


- ^{234}U 0.0054%, ^{235}U 0.7204%,^{238}U 99.2742%
- Offline study of ionic transition in the UV range 288-314 nm
- HFS parameters for ^{235}U and isotopic shift for each studied level
- Optimum transition had a spectroscopy efficiency of $\sim$ 1/3000 photons/ion
- Performed with the original LCR (single segmented PMT)

LCR upgrades

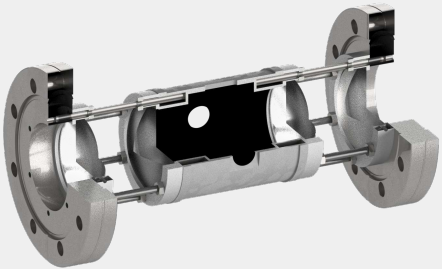


- 4 PMT tubes arranged in a two rows configuration

4

[4] Á. Koszorús et al.,SR, 13.1 (2023), p.4783.

LCR upgrades



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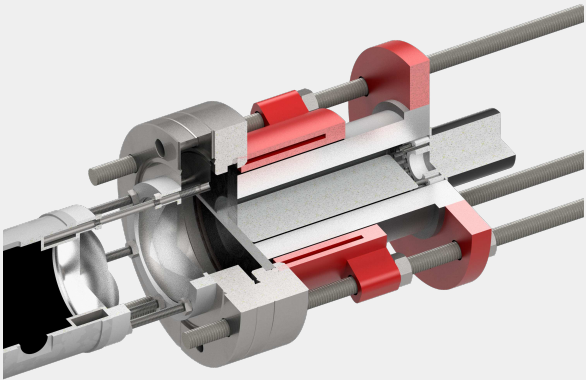

- 4 PMT tubes arranged in a two rows configuration
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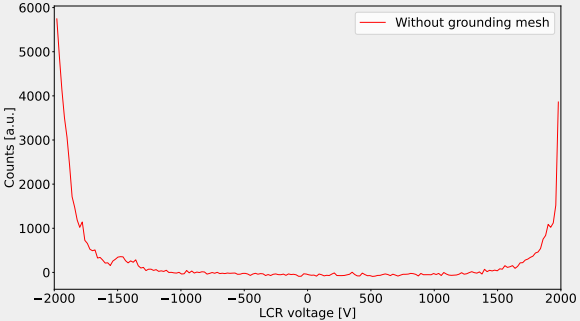
- custom 3D printed PMT support to ensure light tightness and focal point tunability

LCR upgrades



- 4 PMT tubes arranged in a two rows configuration
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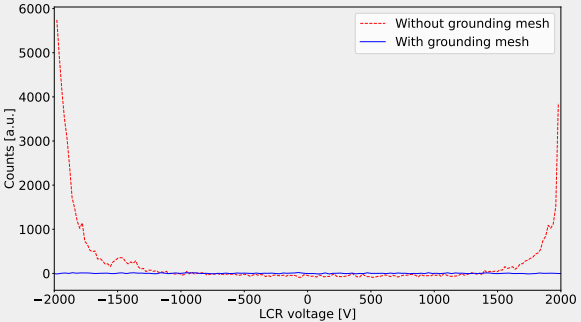
- Grounding mesh with >90% transparency in front of the PMT tube to reduce electric field induced dark counts

LCR upgrades



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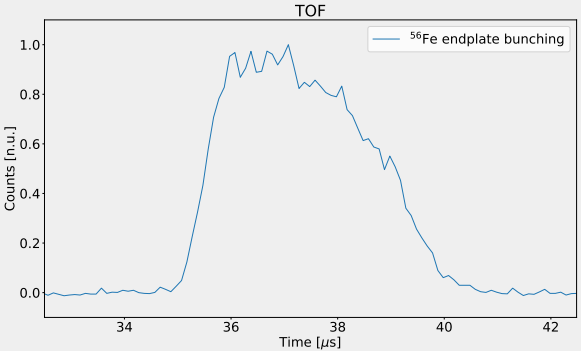
New RFQ mini buncher section

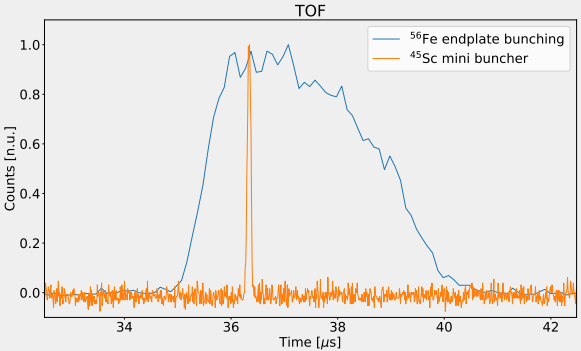


- Typical bunch width with endplate bunching $\sim 5\mu$s
- $\sim 10^4$ background reduction with respect to continous beam (for typical 100 ms cycle) [4]

[4] A. Nieminen, et al. PRL 88.9 (2002): 094801.

***Ville Talk**

New RFQ mini buncher section



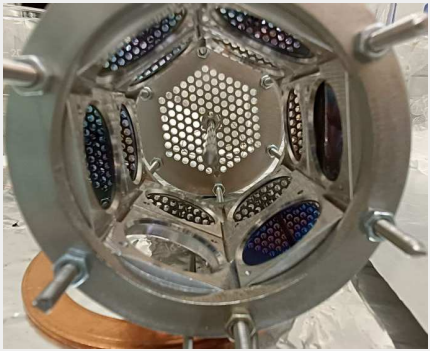
- Typical bunch width with endplate bunching $\sim 5\mu$s
- $\sim 10^4$ background reduction with respect to continous beam (for typical 100 ms cycle) [4]
- New cooler 3-stage bunching section produce ~ 80 ns bunches [5]
- $\sim 10^6$ background reduction with respect to continous beam

[4] A. Nieminen, et al. PRL 88.9 (2002): 094801.
[5] V. Virtanen PhD thesis

***Ville Talk**

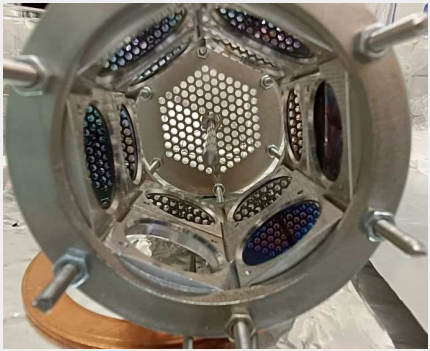
Summary and Outlook

- Mark III version has produced sufficient yields for a laser spectroscopy run but...



Summary and Outlook

- Mark III version has produced sufficient yields for a laser spectroscopy run but...
- Charge state still remains a problem, possibilities are under investigation



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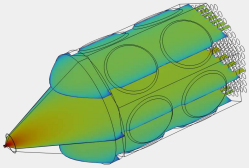
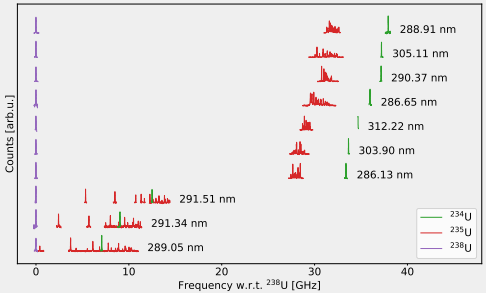
- Gas flow and ion transport simulations are underway to further characterize the effect of source bias



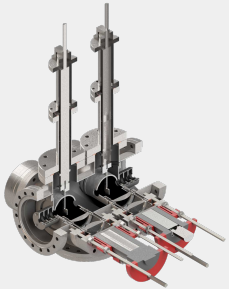
Summary and Outlook

- Mark III version has produced sufficient yields for a laser spectroscopy run but...
- Charge state still remains a problem, possibilities are under investigation
- Gas flow and ion transport simulations are underway to further characterize the effect of source bias
- New HFS parameters and isotopes shifts measured for 10 transition in the UV range for natural U



Summary and Outlook

- Mark III version has produced sufficient yields for a laser spectroscopy run but...
- Charge state still remains a problem, possibilities are under investigation
- Gas flow and ion transport simulations are underway to further characterize the effect of source bias
- New HFS parameters and isotopes shifts measured for 10 transition in the UV range for natural U
- General upgrade for the CLS light collection region with improvements on background reduction and sensitivity



LISA

LASER IONISATION AND SPECTROSCOPY OF ACTINIDES

Thank you

D. Bettaney, M. Block, P. Campbell, B. Cheal, C. Düllmann, T. Eronen, R. de Groote, A. Koszorus, I. Moore, I. Pohjalainen, L. Reed, D. Renisch, M. Reponen, Z. Shen, J. Warbinek and IGISOL group

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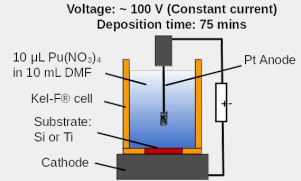
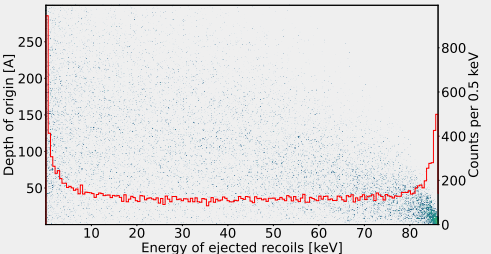
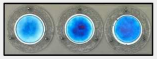
Alpha-recoil sources



[6]

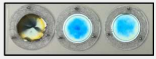


[6] A. Vascon et al., NIMA 721 (2013): 35



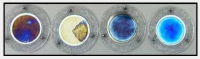
^{239}Pu
Substrate: Si
Thickness: 16 ug/cm^2
Activity: ~135 kBq

^{239}Pu
Substrate: 2x Si, 1x Ti
Thickness: 7 ug/cm^2
Activity: ~57 kBq



^{239}Pu
Substrate: 2x Si, 1x Ti
Thickness: 23 ug/cm^2
Activity: ~200 kBq

^{239}Pu
Substrate: Si
Thickness: 16-26 ug/cm^2
Activity: 3x ~75 kBq, 2x ~12 kBq



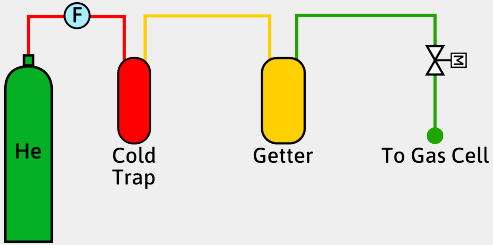
^{239}Pu
Substrate: 3x Si, 1x Ti
Thickness: 9-23 ug/cm^2
Activity: 75-200 kBq
Oven dried at 200C 1.5h

^{240}Pu
Substrate: 2x Si, 1x Ti
Thickness: 6-12 ug/cm^2
Activity: 200-400 kBq

15 molecular plated ^{239}Pu sources created in collaboration with Mainz radiochemistry department
Characterization tests:

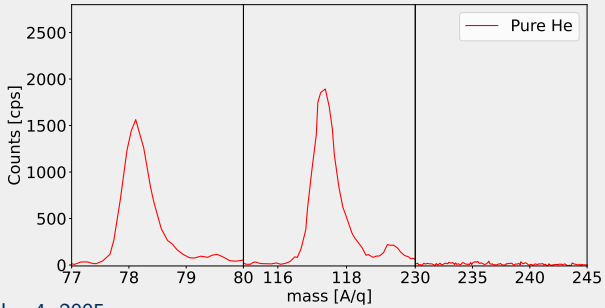
- SEM and radiographic imaging
- Alpha/gamma spectrometry
- Rutherford back-scattering

Charge state manipulation



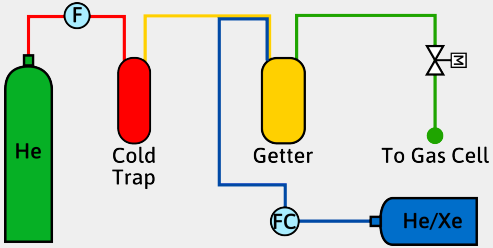
Use of trace gasses

- He gas is purified through a two step system



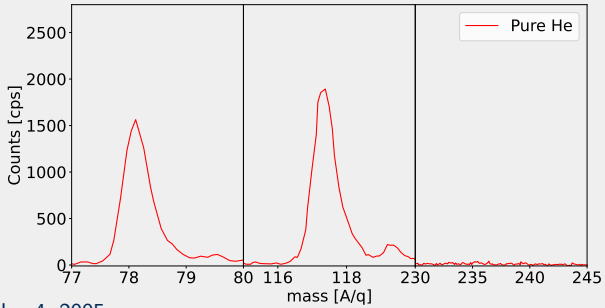
[7] J. Sansonetti et. al. J. PCR Data, Vol. 34, No. 4, 2005

Charge state manipulation



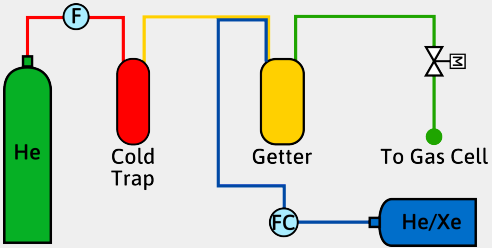
Use of trace gasses

- He gas is purified through a two step system
- Use of a 0.1% He/Xe mixture
- Release of ppm level of trace gasses



[7] J. Sansonetti et. al. J. PCR Data, Vol. 34, No. 4, 2005

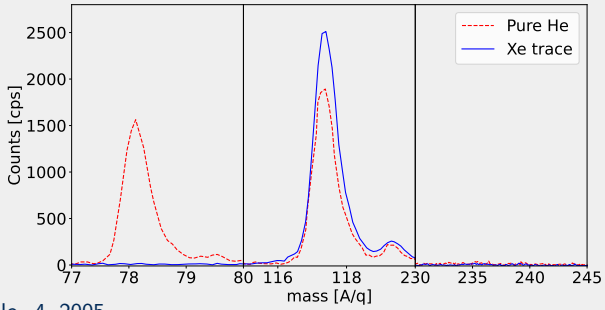
Charge state manipulation



- ∼30% conversion of 3+ to 2+
- no 1+ production
- U^{1+} IP 10.6 eV [7]
- Xe IP 12.13 eV

Use of trace gasses

- He gas is purified through a two step system
- Use of a 0.1% He/Xe mixture
- Release of ppm level of trace gasses



[7] J. Sansonetti et. al. J. PCR Data, Vol. 34, No. 4, 2005