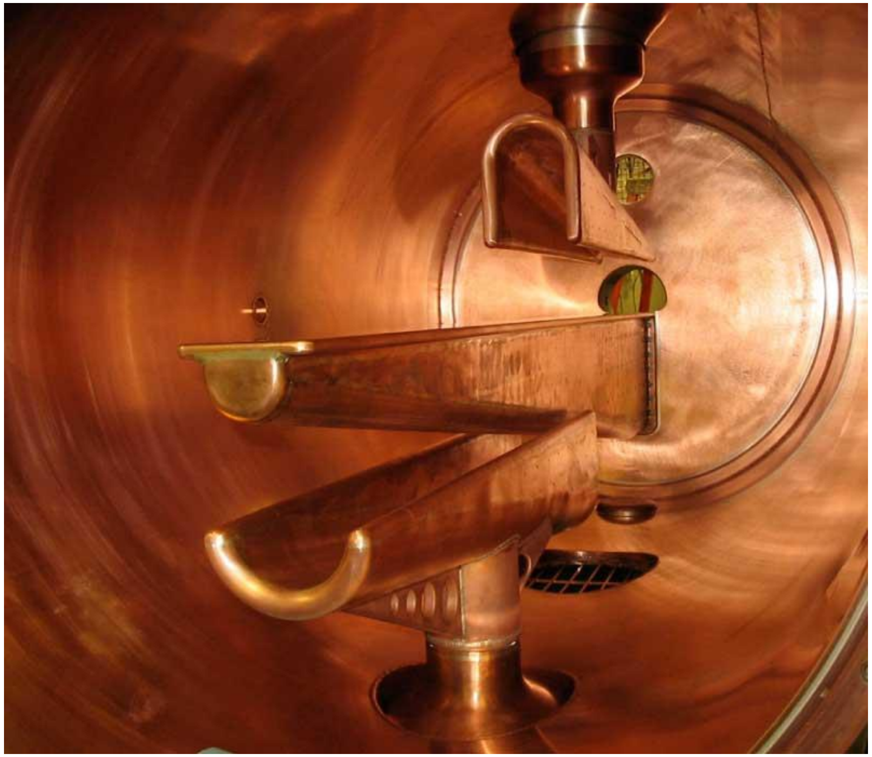
# The Radio Frequency Fragment Separator:

## A Time-of-Flight Filter for Fast Fragmentation Beams



*Thomas Baumann, NSCL*

# Introduction

*Outline of my presentation:*

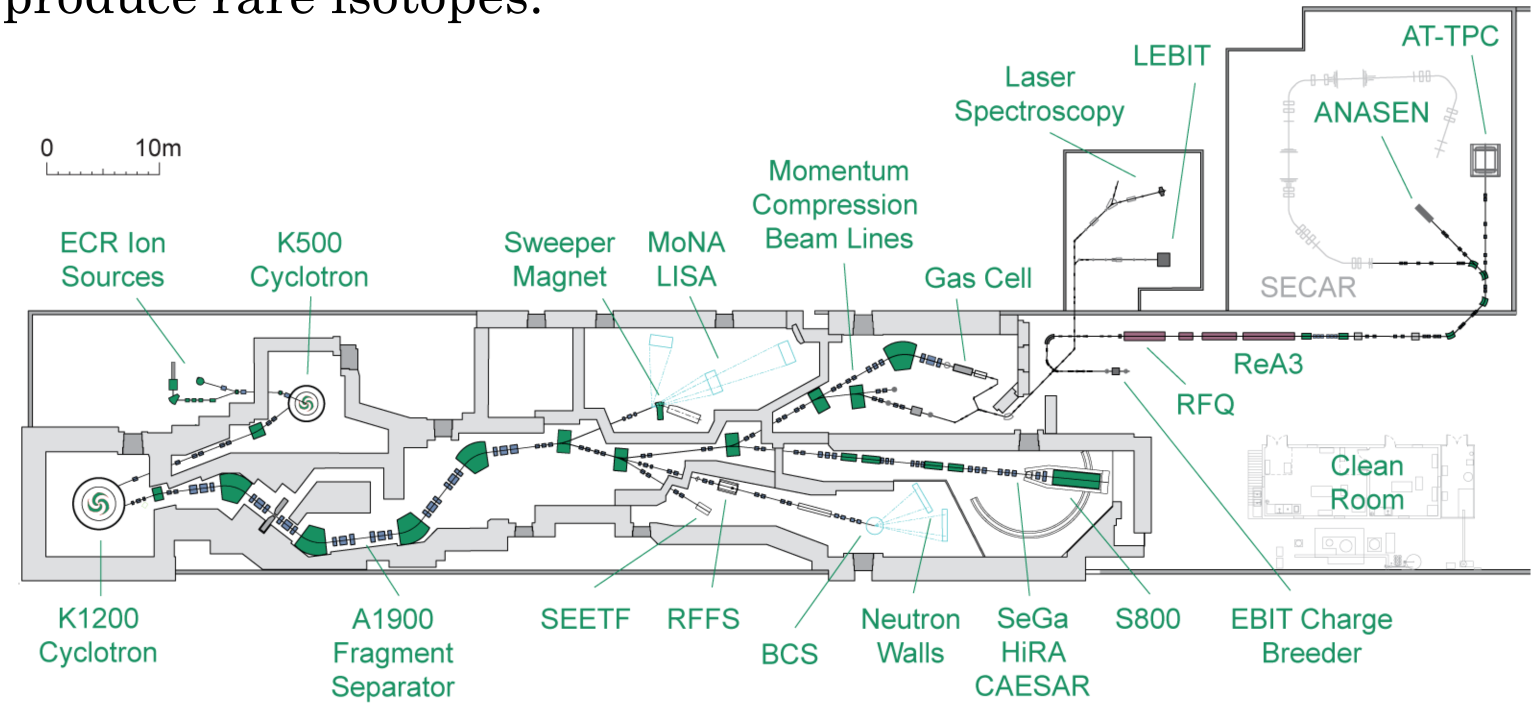
- Brief overview of rare isotope beam production at NSCL.
- Function of the Radio Frequency Fragment Separator (RFFS).
- Separation of neutron-deficient isotopes based on two recent examples.

# The National Superconducting Cyclotron Laboratory

- Fast fragmentation is the method of choice to produce a large range of rare isotope beams.
- Fragment separators can select the isotope of interest by a combination of magnetic rigidity selection and slowing down in matter (i.e. achromatic wedge).
- The National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University is built around this concept.

# NSCL rare isotope beam facility

- The Coupled Cyclotron Facility utilizes two superconducting cyclotrons to accelerate heavy ion beams to typically 100 to 170 MeV/u.
- These primary beams then undergo a fragmentation reaction to produce rare isotopes.



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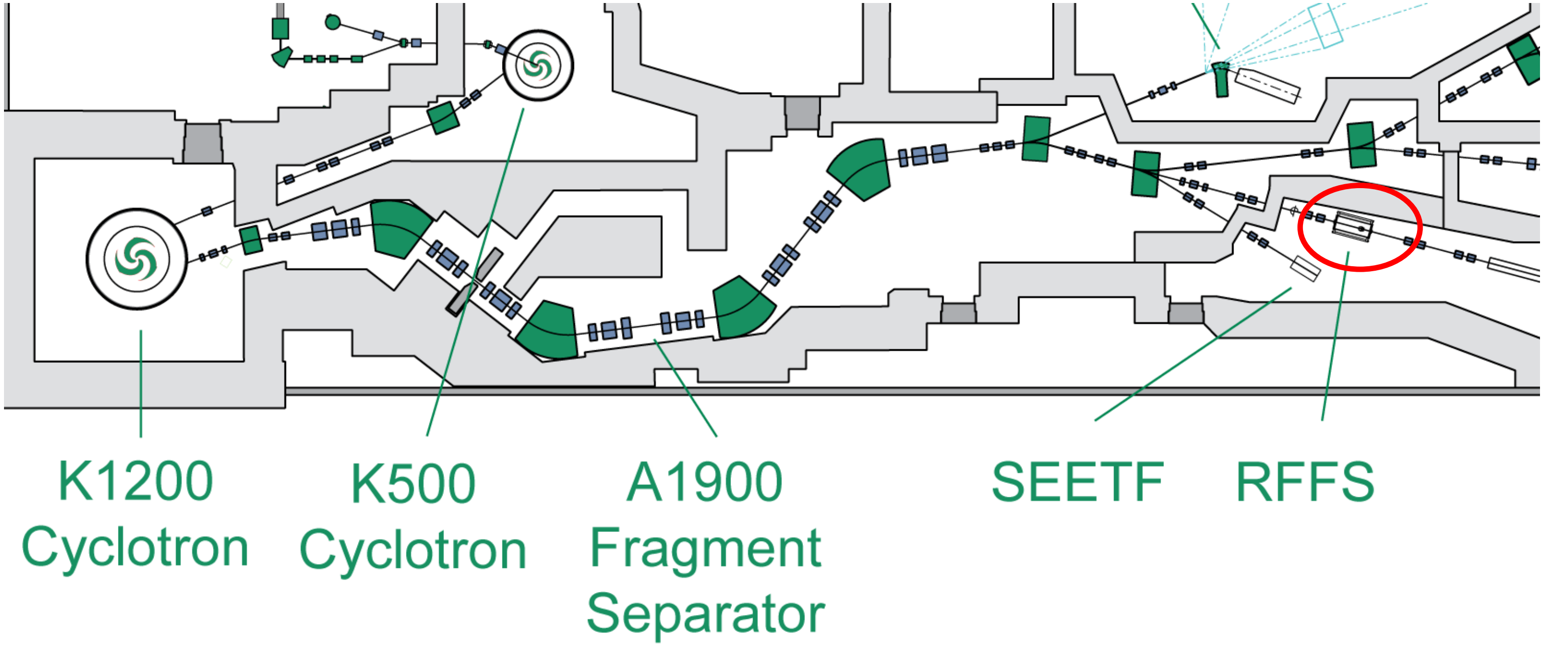
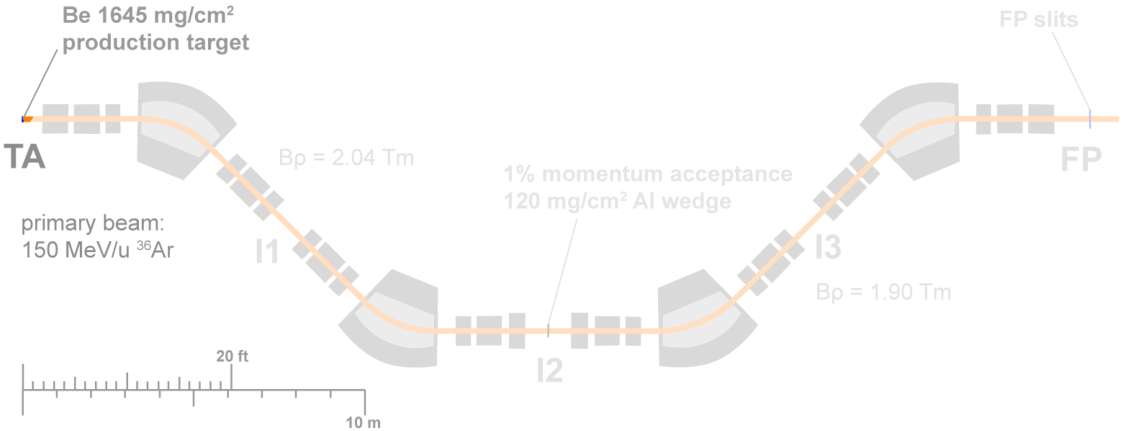
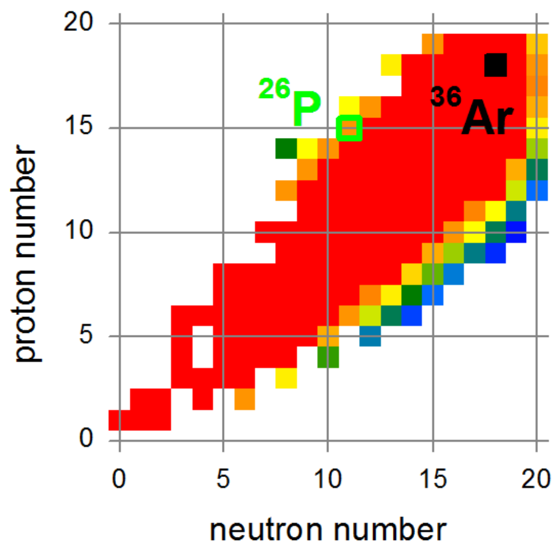


# Production of neutron-deficient $^{26}P$



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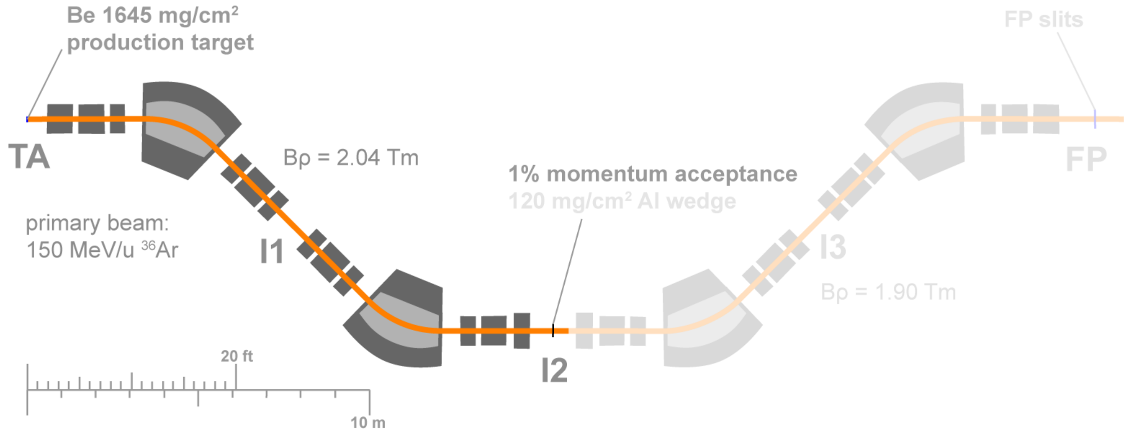


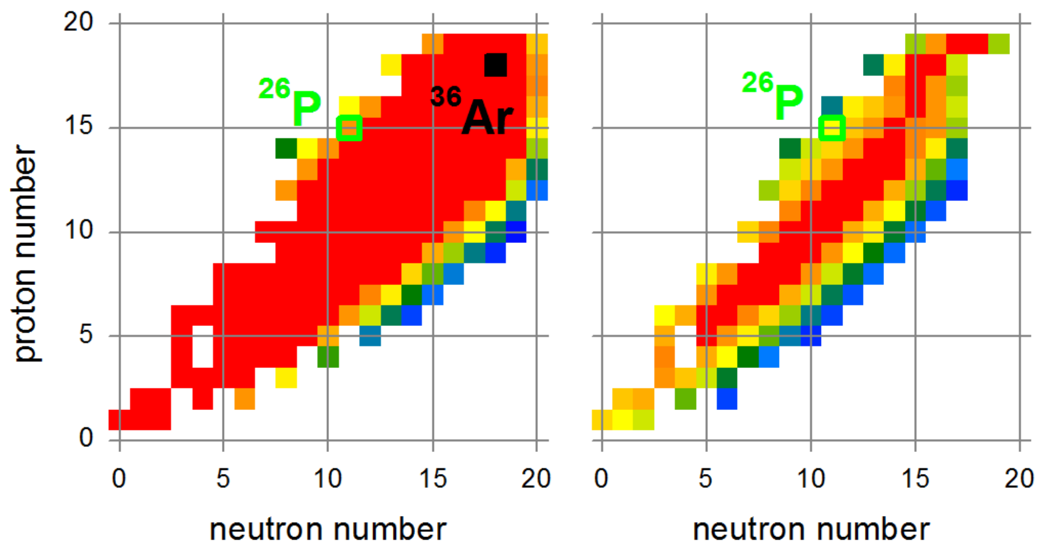

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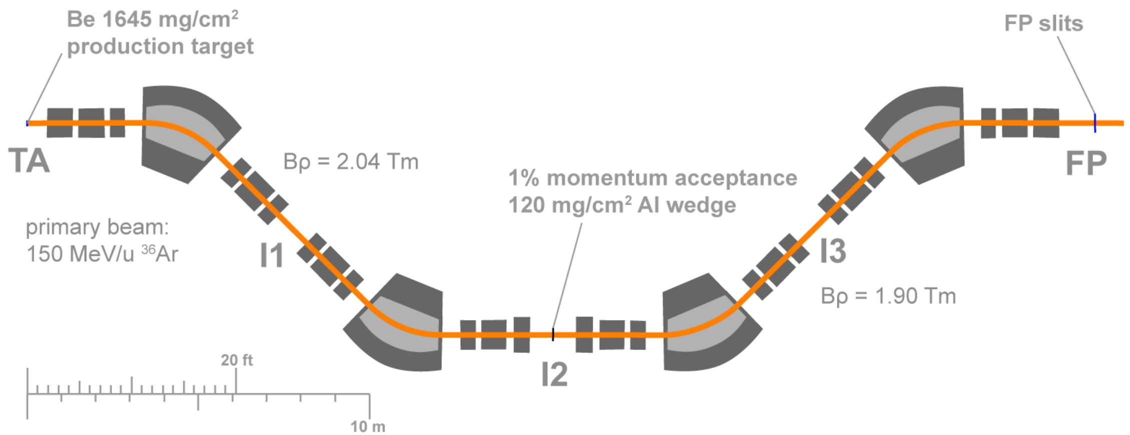
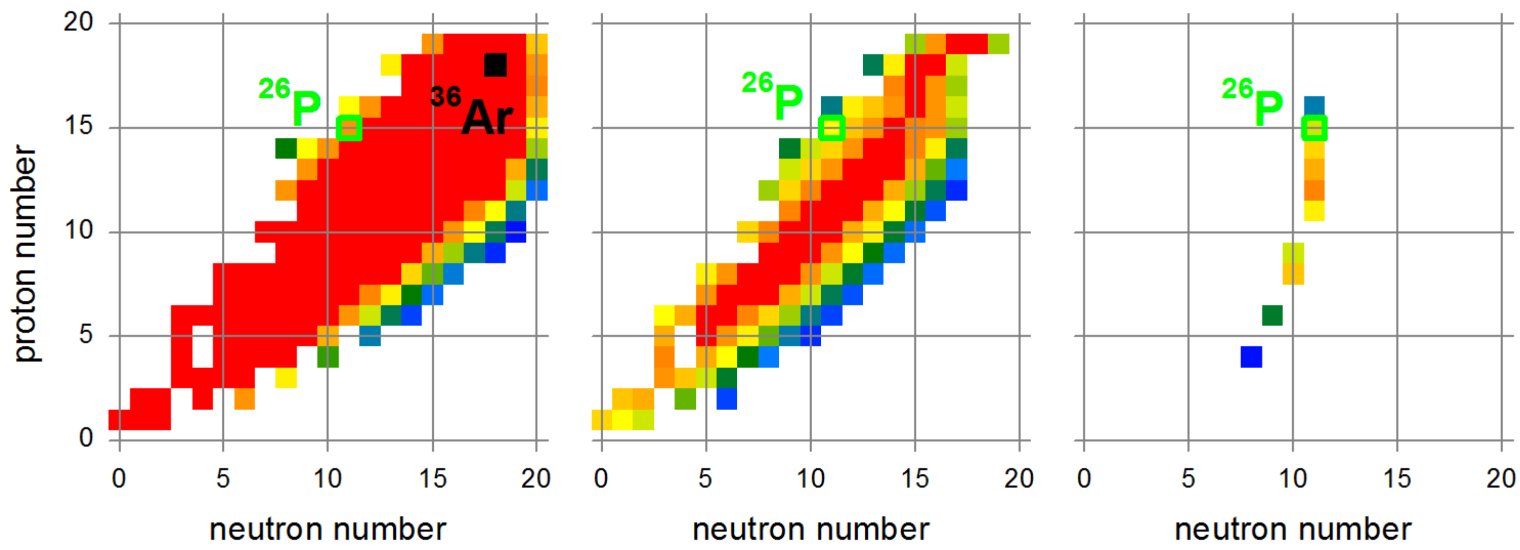
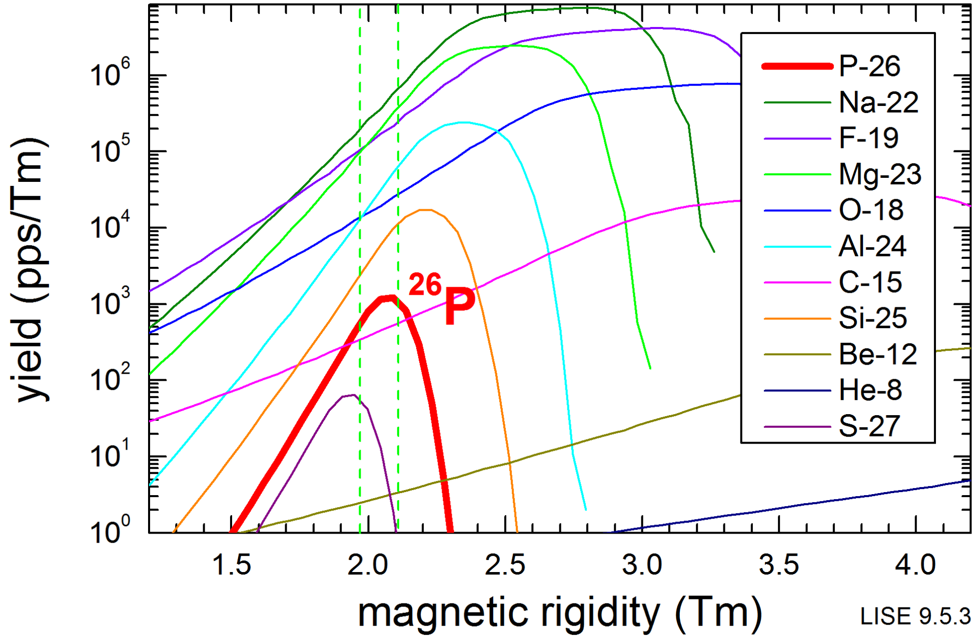


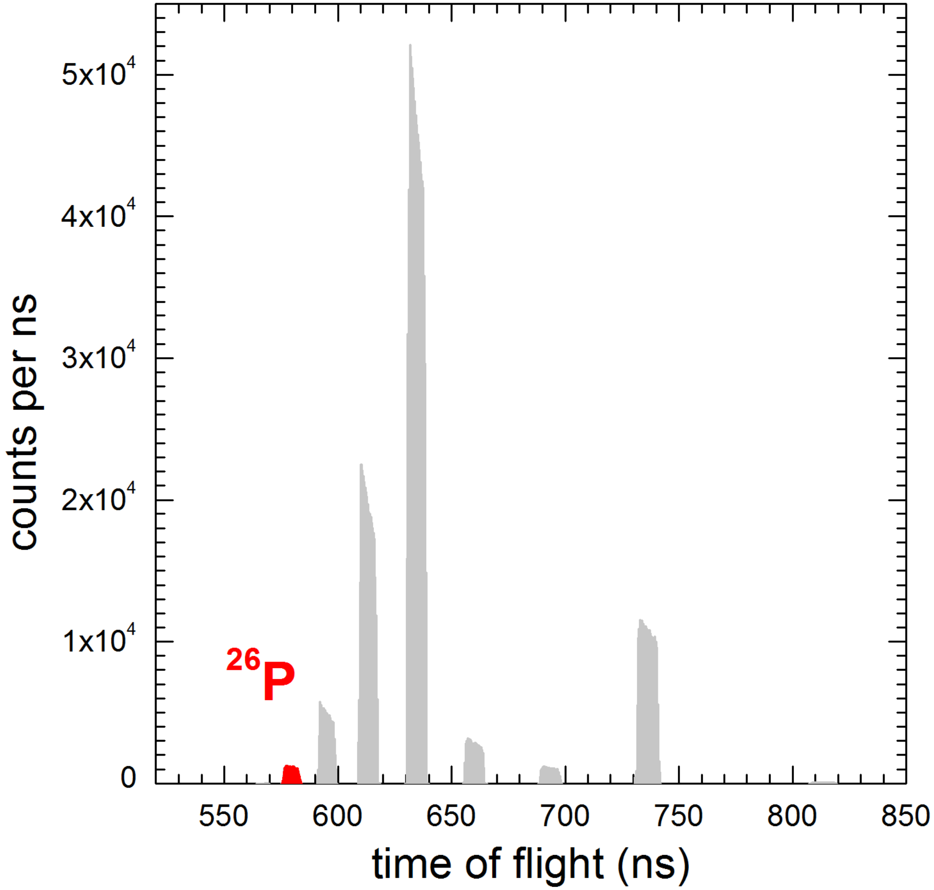
# Challenges of neutron-deficient isotopes

*Separation of neutron-deficient rare isotopes is challenging:*

- At primary beam energies between 50 MeV/u and 200 MeV/u, fragments exhibit a low momentum tail.
- Neutron deficient means lower mass-to-charge ratio or lower rigidity ($B\rho = \frac{mv}{q}$) than isotopes with much higher yields.



# Filtering by time-of-flight

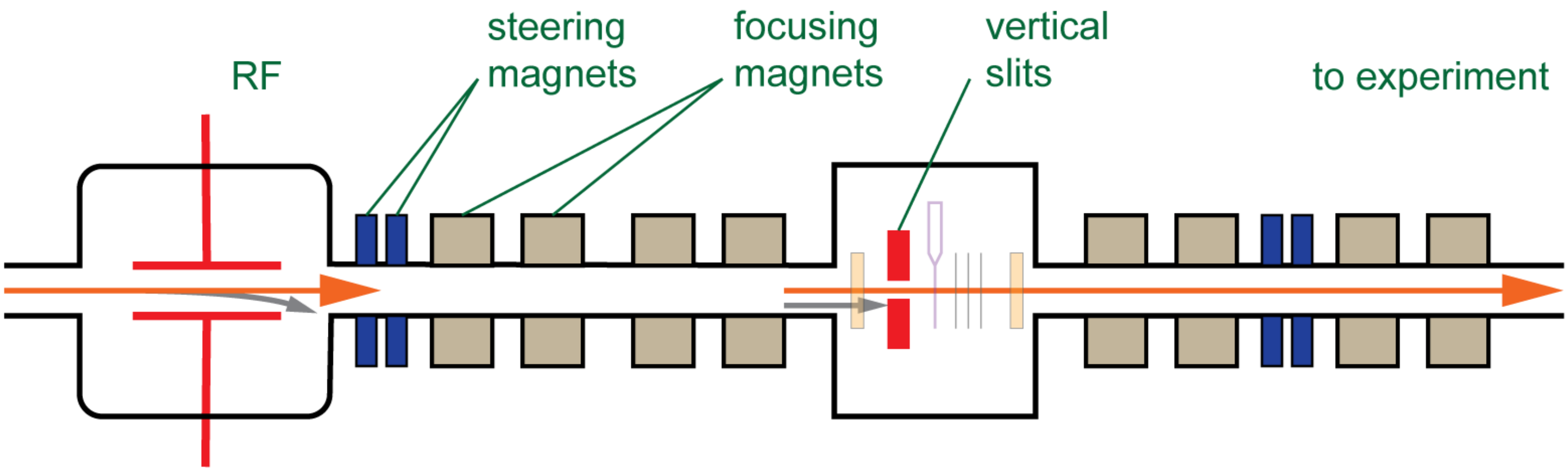



- Isotopes have different velocities and are separated by time of flight.
- A *velocity filter* could separate out the isotope of interest.
- The Radio Frequency Fragment Separator selects fragments based on their phase with respect to the cyclotron RF.

# The RFFS concept

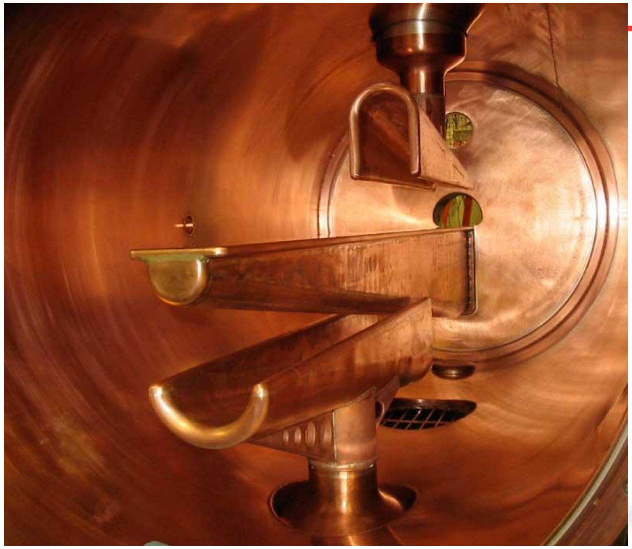
- A radio frequency separator for rare isotope beams was first realized at the RIPS facility in RIKEN (Japan).
  K. Yamada, T. Motobayashi, I. Tanihata, Nucl. Phys. A 746 (2004) 156c

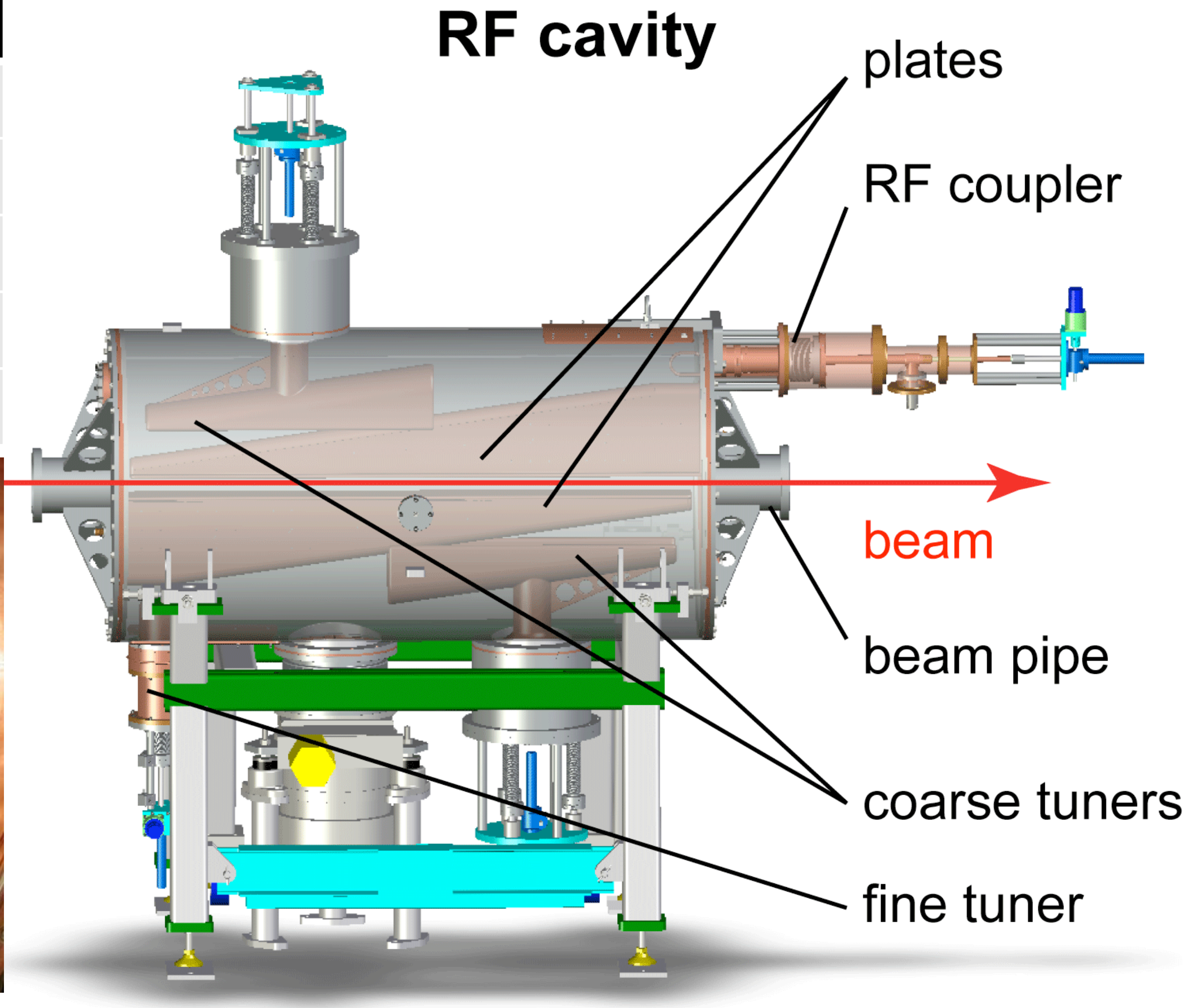
- The RFFS is a combination of an RF driven electric deflector and a set of slits.



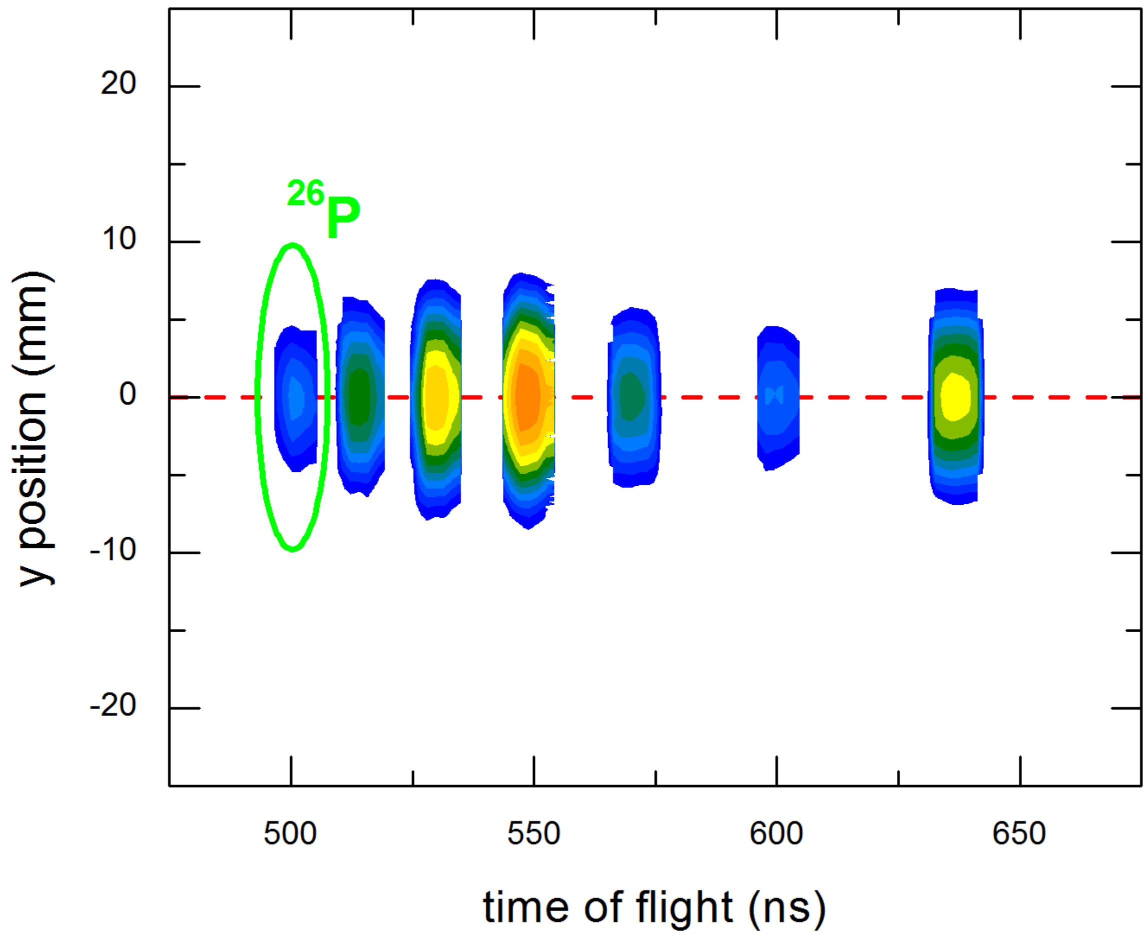
# The RFFS cavity

| RF cavity design parameters | |
|---|---|
| electrode length | 1.5 m |
| electrode gap | 5 cm |
| RF voltage | 100 kV |
| frequency | 21–28 MHz |
| phase length | ~140° |





# How to separate $^{26}P$




- A LISE simulation is used to calculate the optimum RFFS settings.
- $^{26}P$ is a drip-line nucleus (lightest P isotope).
- It was discovered in 1983.
- Produced by fragmentation of $^{36}Ar$ at 150 MeV/u.
- 55 MeV/u beam energy.

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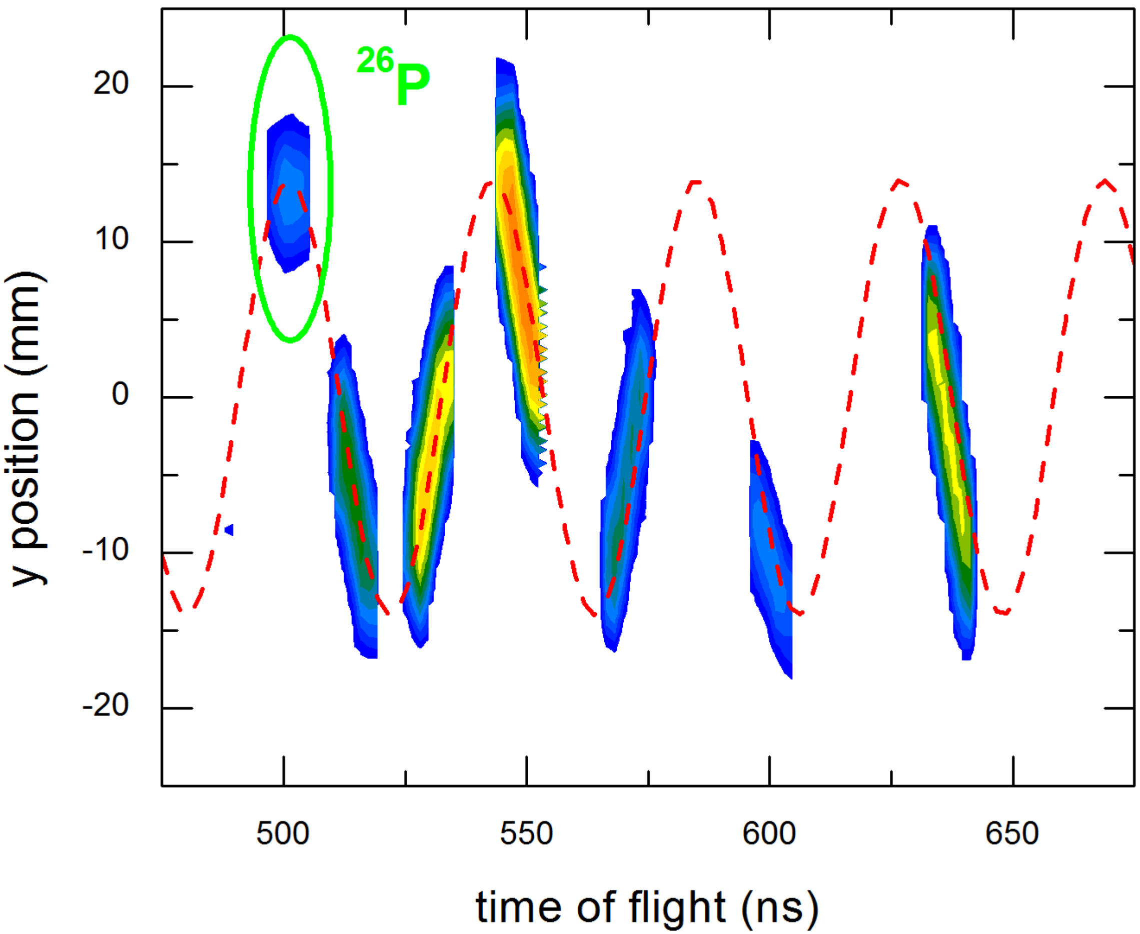


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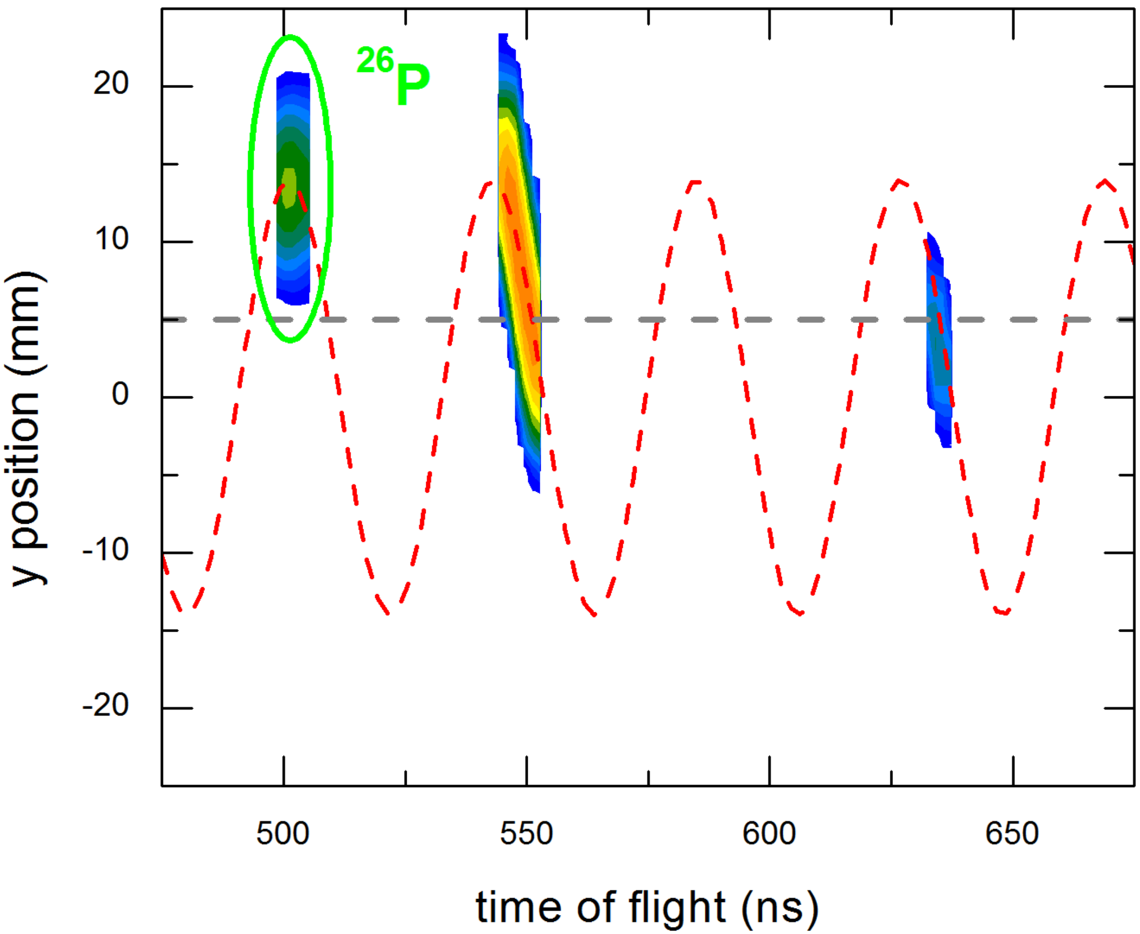


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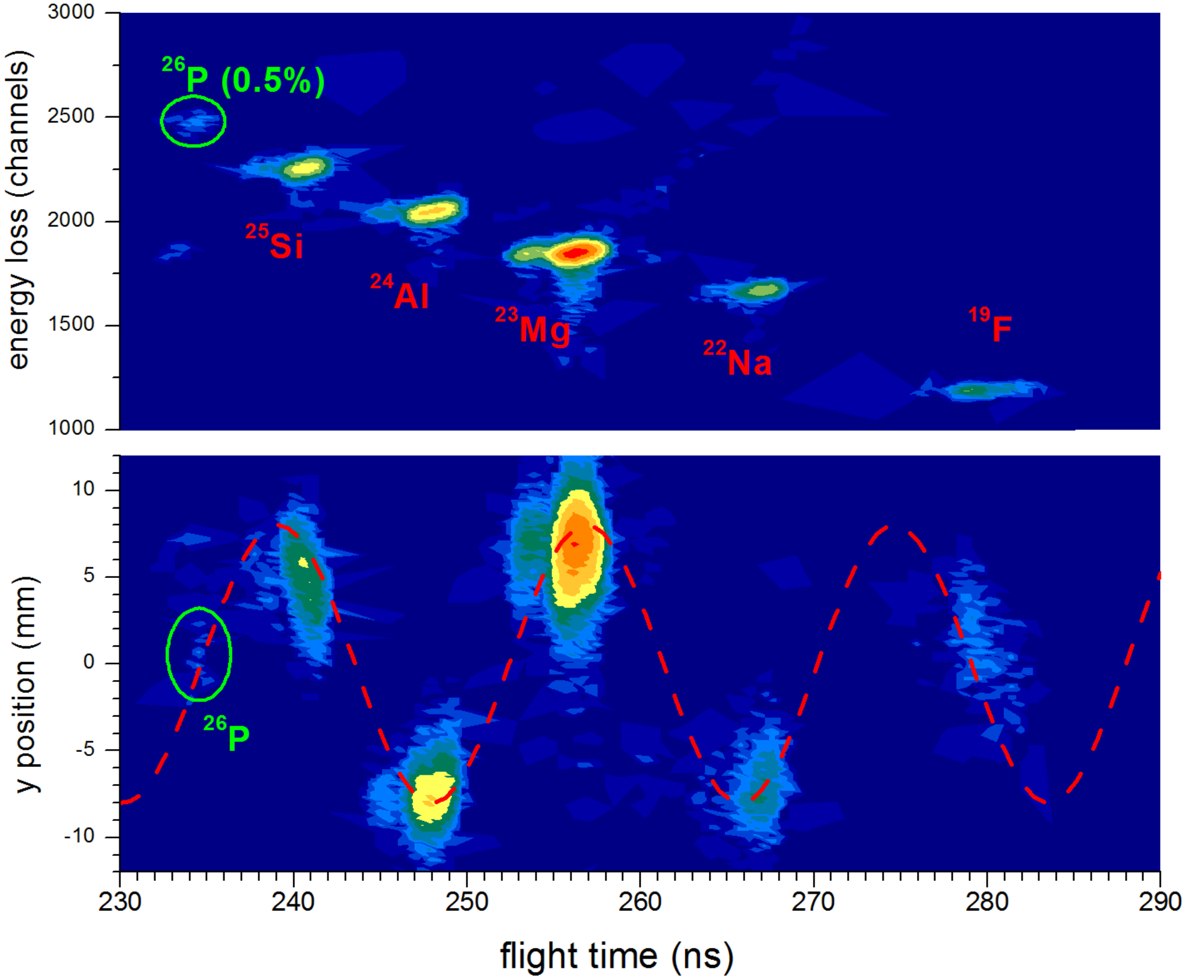
# Measured $^{26}P$ spectra

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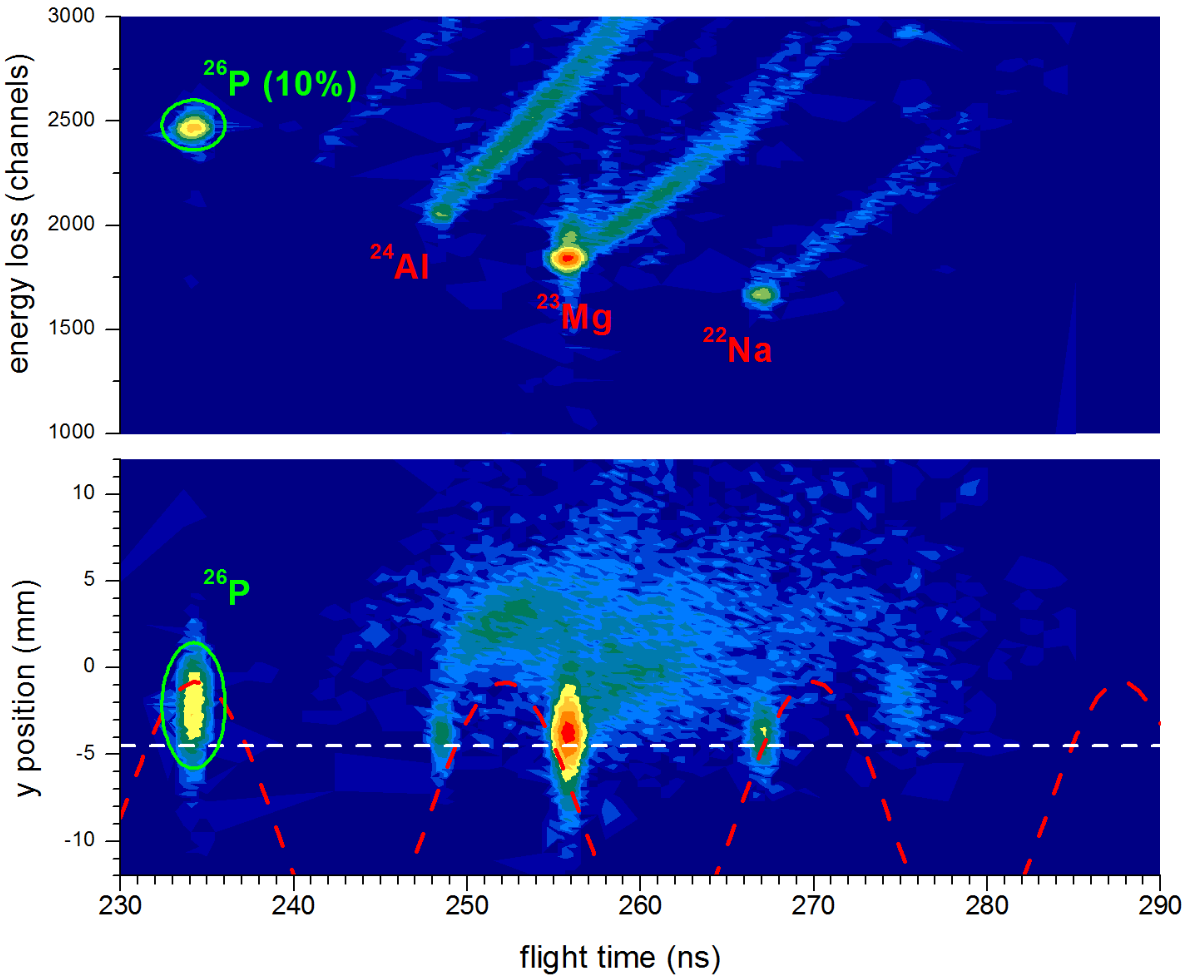
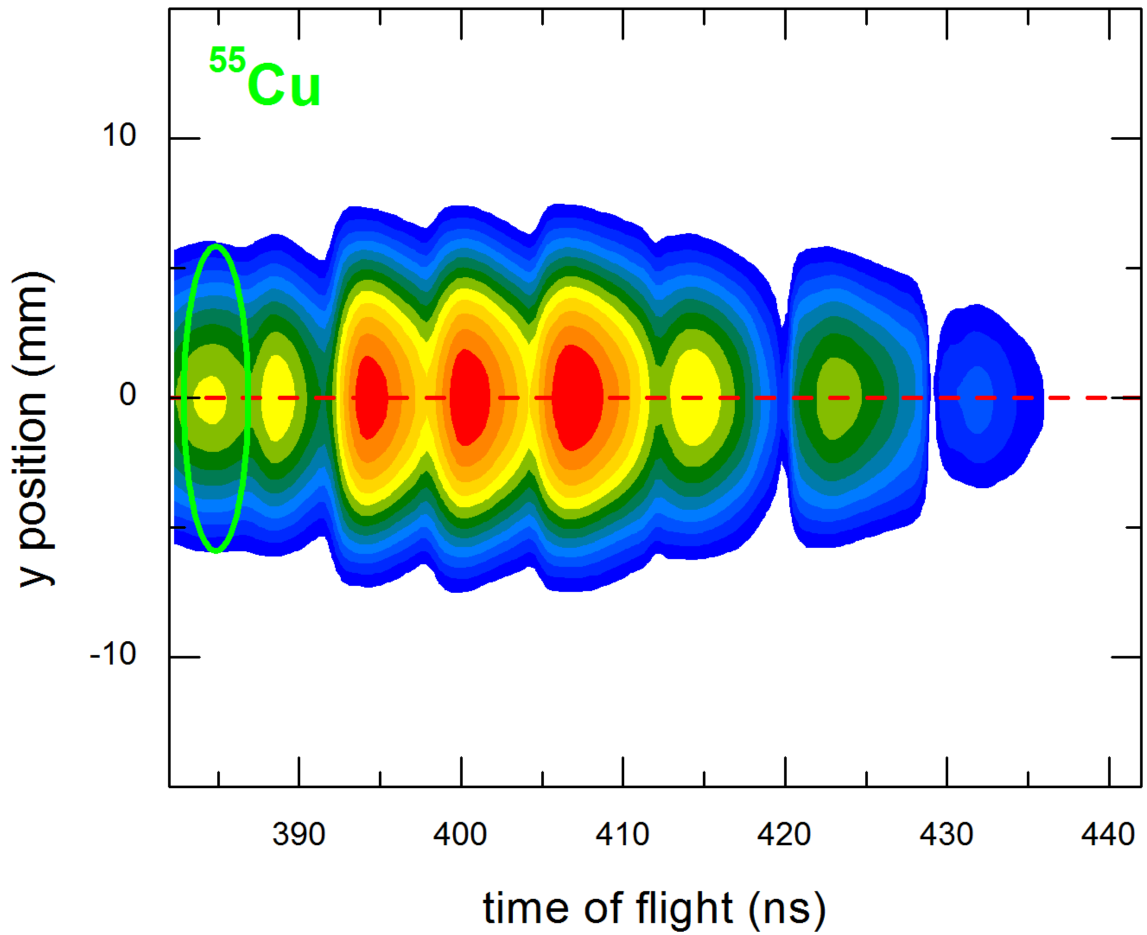



- $^{26}$P beam has only 0.5% purity.
- Using the RFFS this was improved to 10%.
- $^{23}$Mg contaminant can not be removed at this beam energy because it is almost in phase with $^{26}$P.

# Another example: $^{55}$Cu




- Also a drip-line nucleus (lightest Cu isotope).
- Discovered in 1987.
- Produced using a $^{58}$Ni primary beam at 160 MeV/u.
- 100 MeV/u beam energy.

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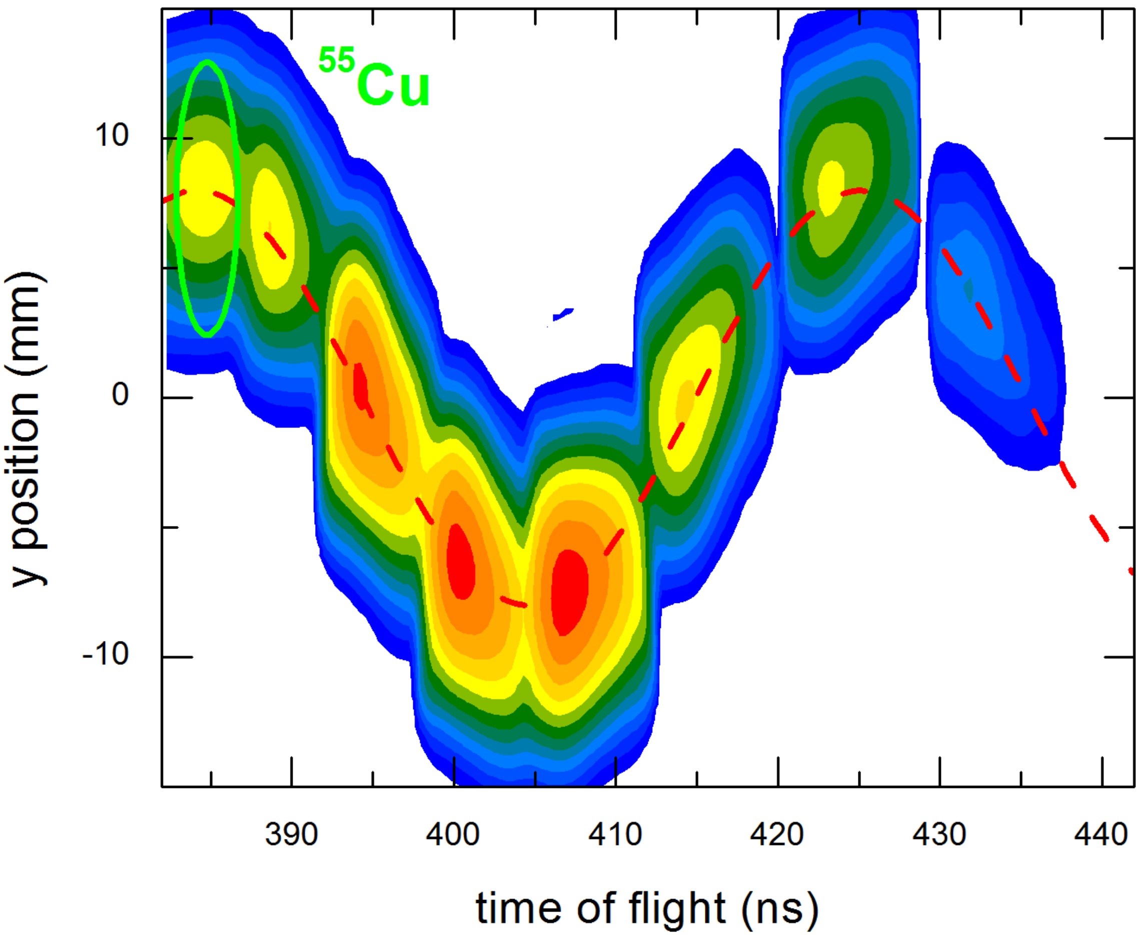


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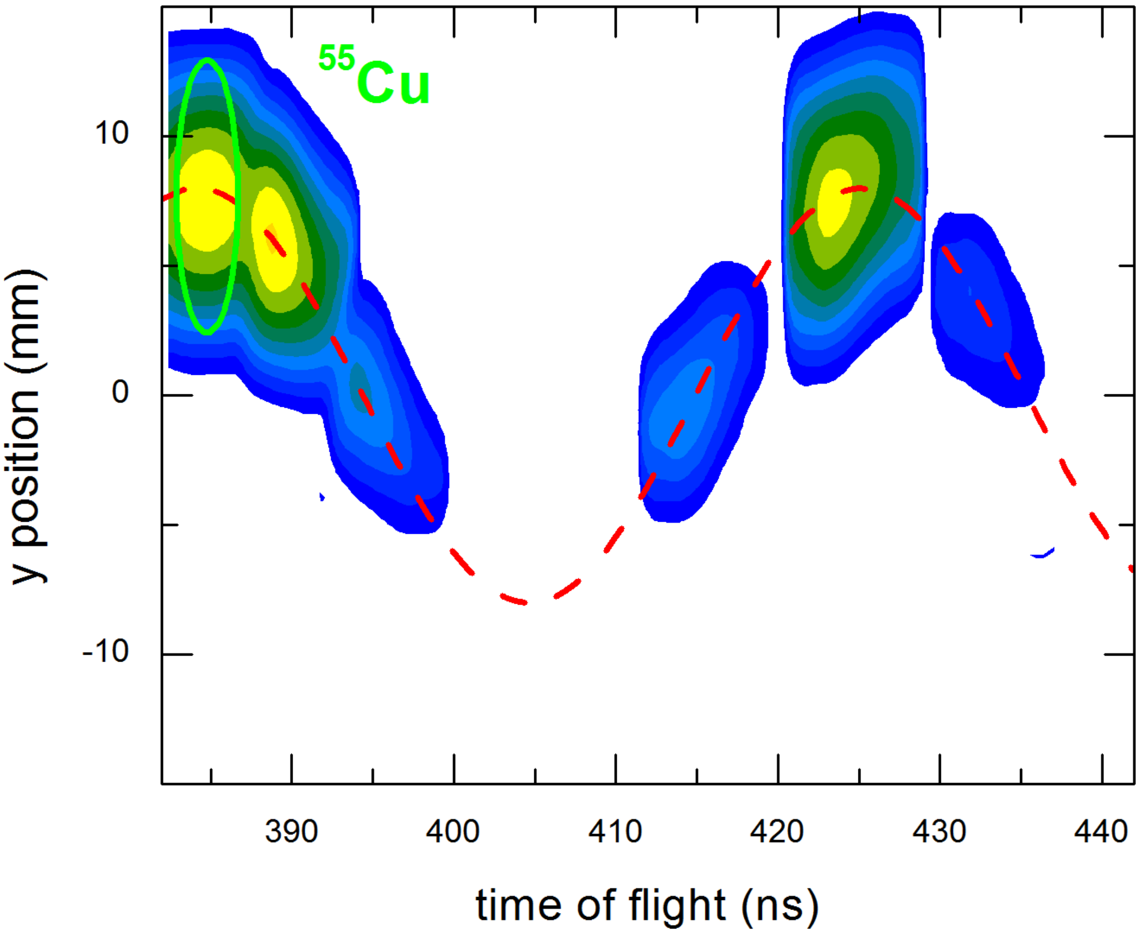


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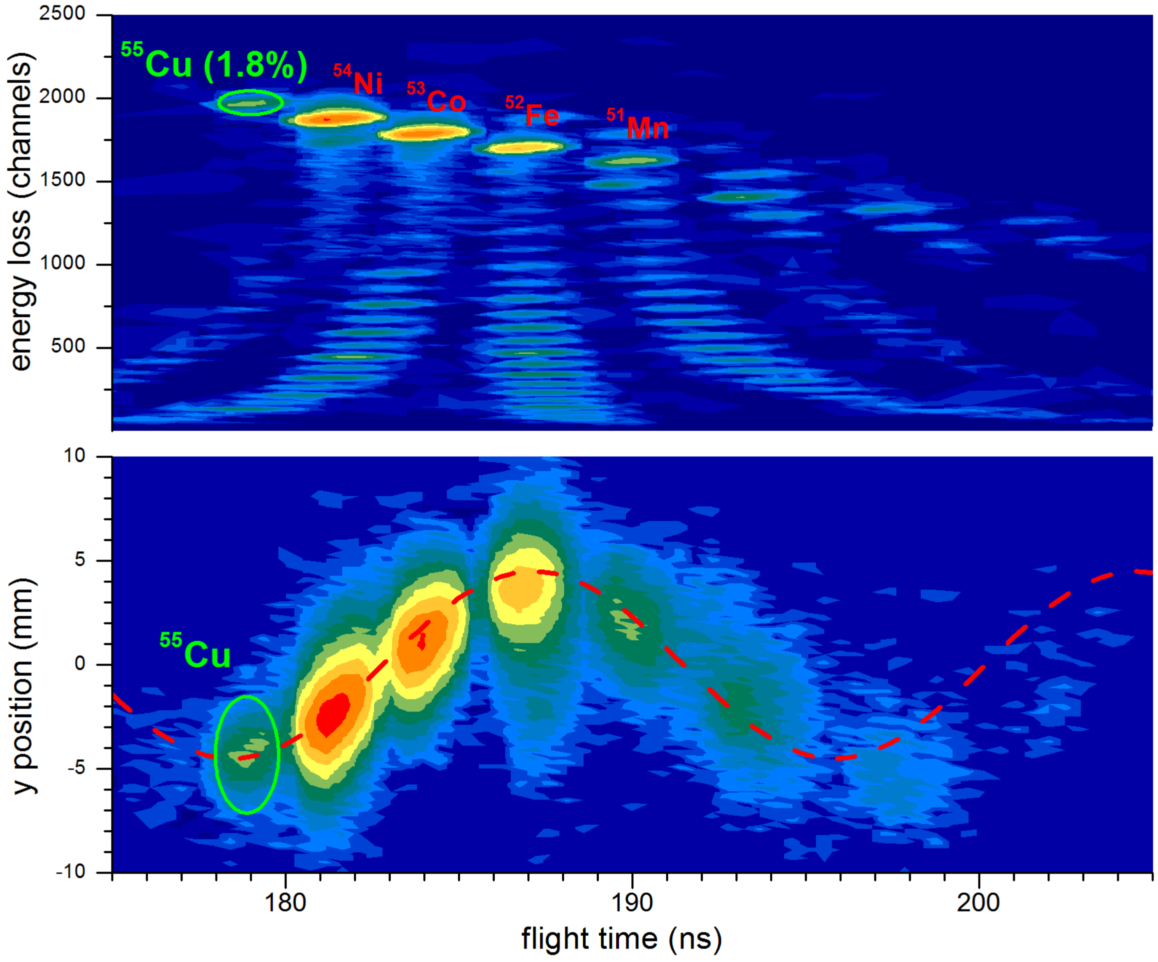


- $^{55}Cu$ beam has not even 2% purity.

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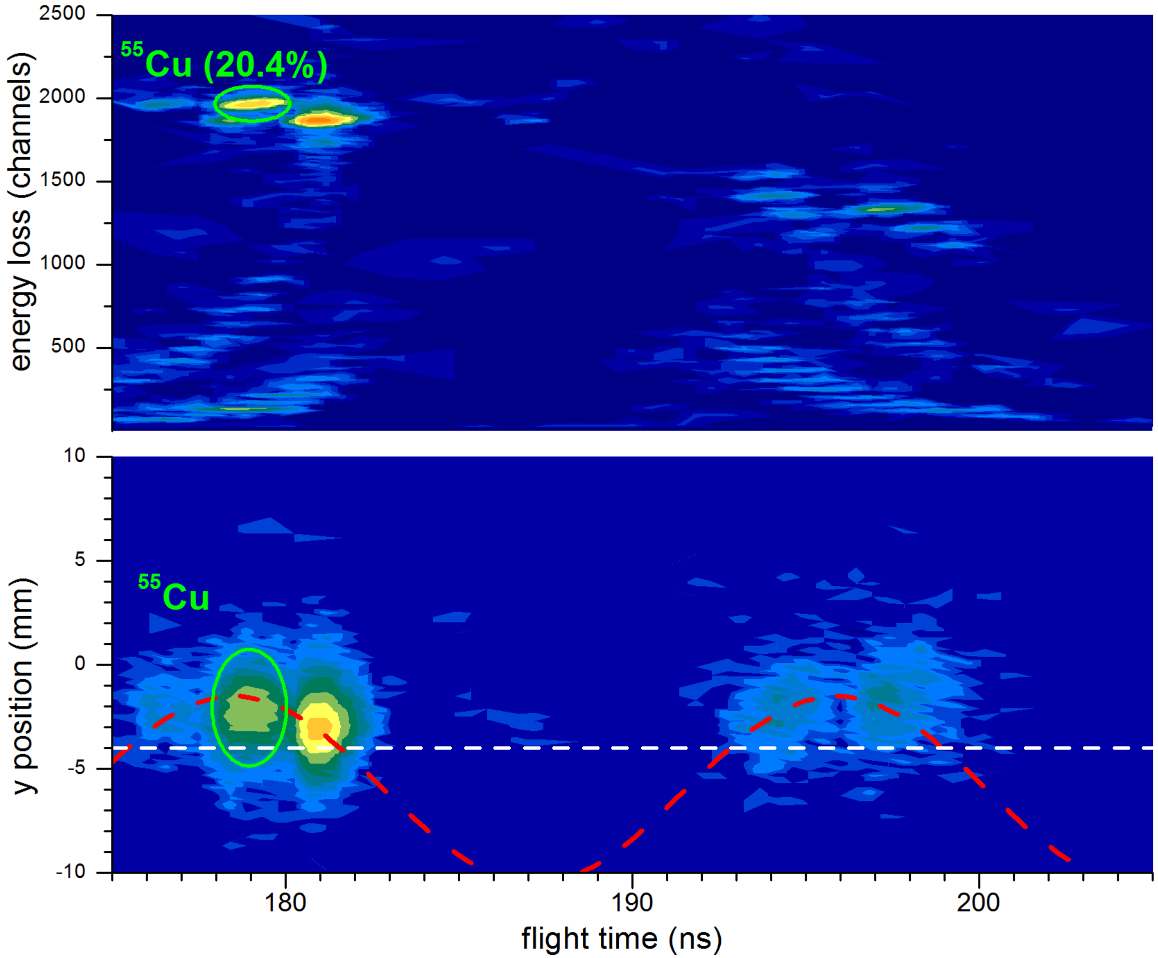
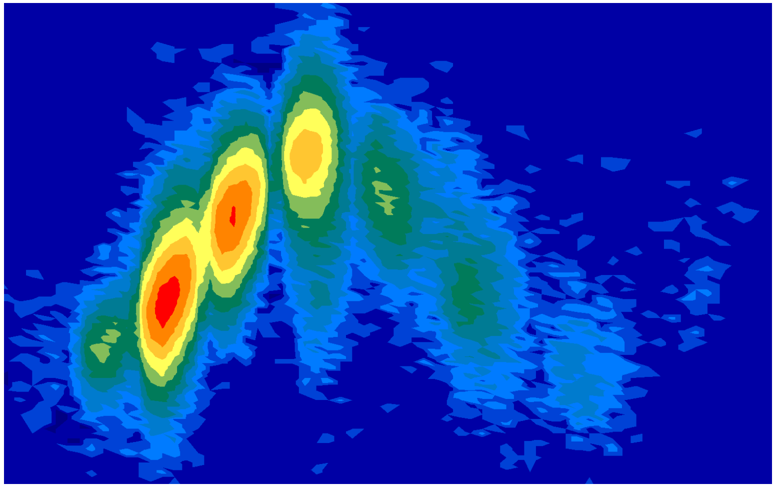



- $^{55}$Cu beam has not even 2% purity.
- Using the RFFS this was improved to over 20%.
- $^{54}$Ni contaminant can not be completely removed because it is too close in phase with $^{55}$Cu.

# Conclusion

- The RFFS is a very useful tool to produce neutron-deficient rare isotopes at improved purity.
- The interplay of beam velocity, RF phase, an slit setting requires careful planning of these beams.
- Even in less than optimal situations the purity can be improved by a factor 10 to 20.



# Acknowledgment

*The beams I showcased were planned and prepared by the NSCL beam physicist group:*

T. N. Ginter, E. Kwan, J. Pereira, C. S. Sumithrarachchi

*The RFFS was developed by:*

D. Bazin, V. Andreev, A. Becerril,
M. Doléans, P. F. Mantica,
J. Ottarson, H. Schatz,
J. B. Stoker, J.Vincent