Identification of isomers in the ^{100}Sn region

Ana Becerril Reyes

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Joint Institute for Nuclear Astrophysics
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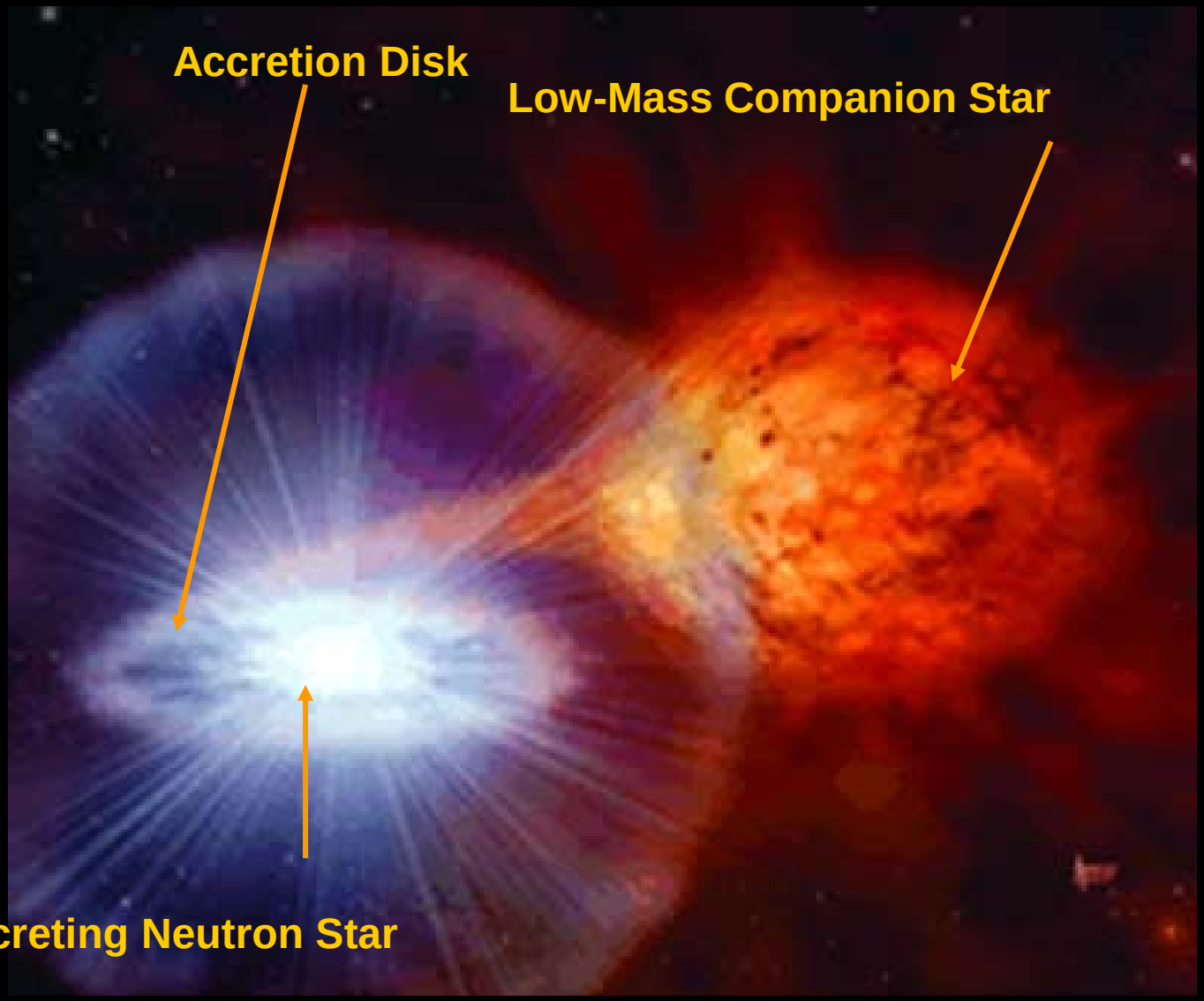
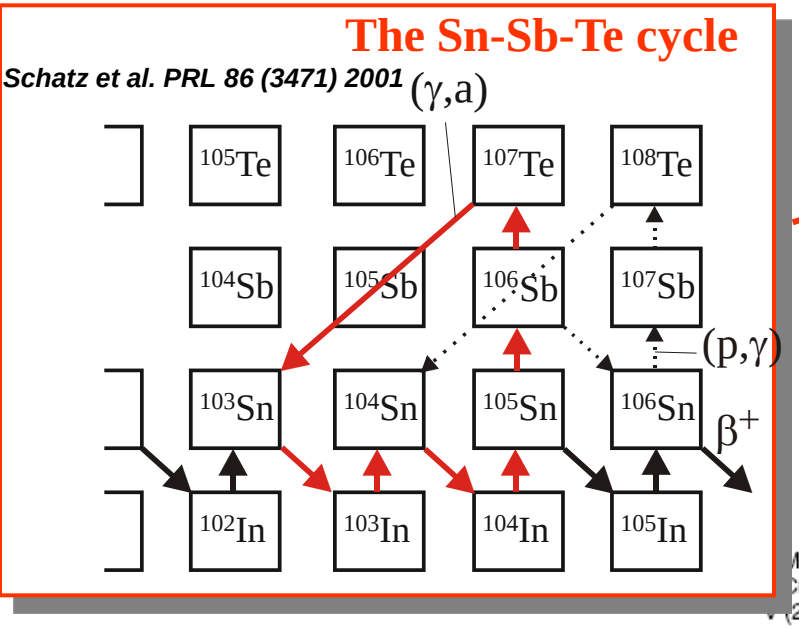
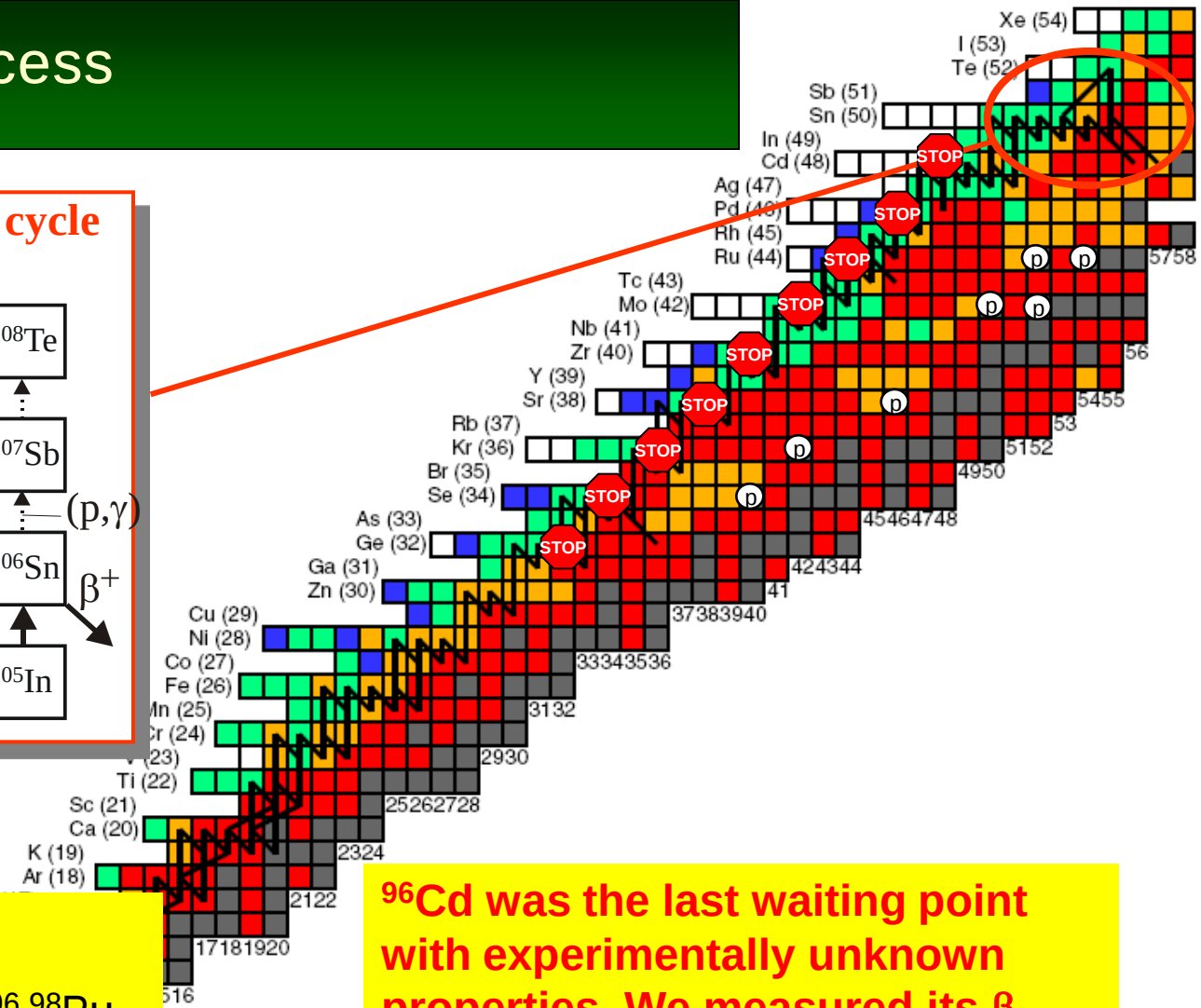
Type I X-ray bursts and the rp-process



The rp-process



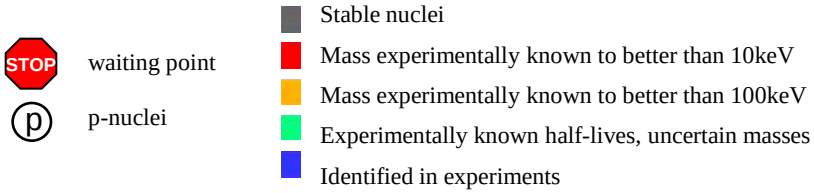


Consequences:

- Origin of ^{92,94}Mo and ^{96,98}Ru.
- Crust composition

(Gupta et al. Ap. J. 2004 arXiv:astro-ph/0609828 v1)

^{96}Cd was the last waiting point with experimentally unknown properties. We measured its β-decay half-life for the first time.

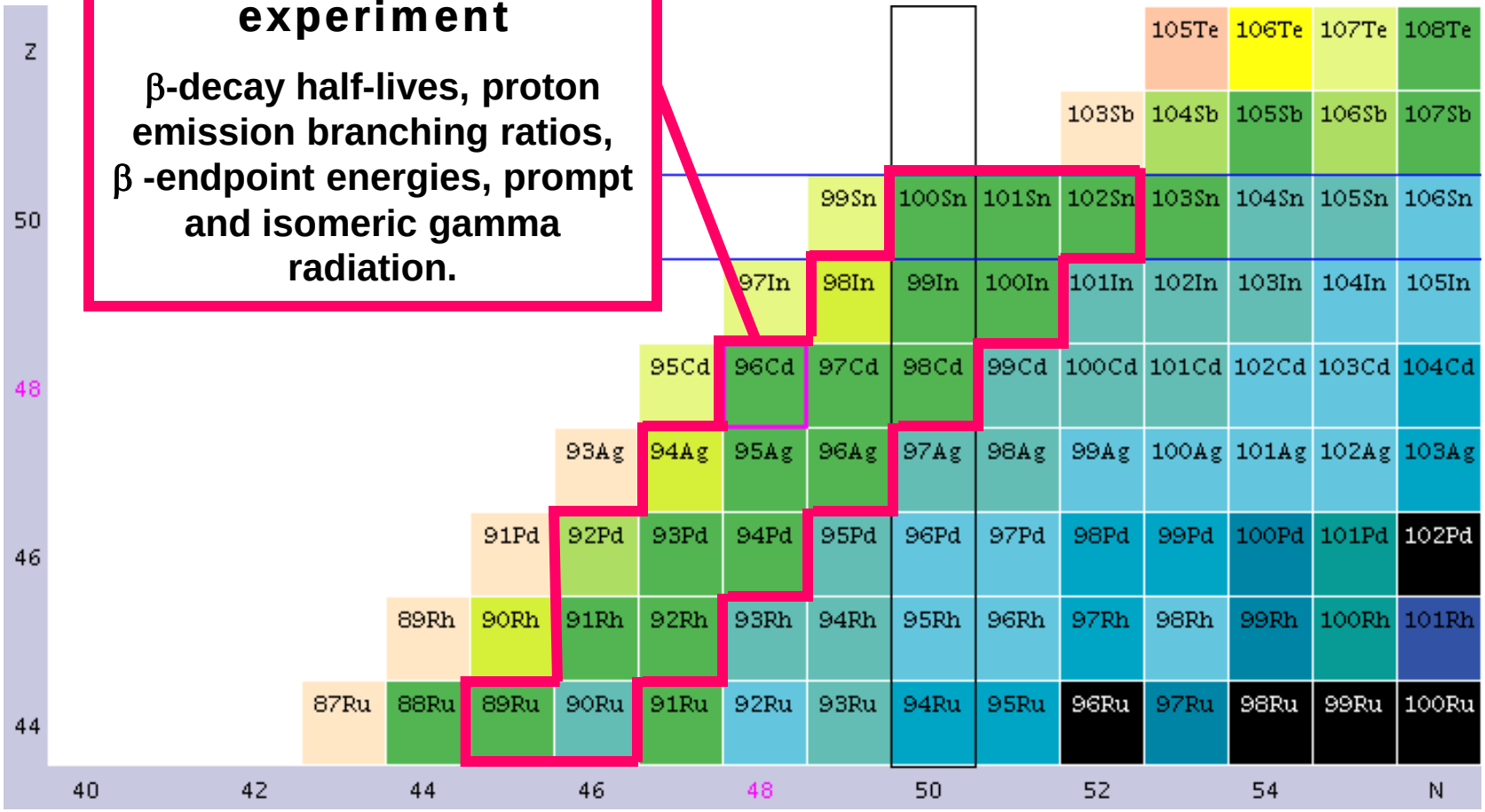


Nuclei of interest

Region studied in our experiment

β-decay half-lives, proton emission branching ratios, β -endpoint energies, prompt and isomeric gamma radiation.

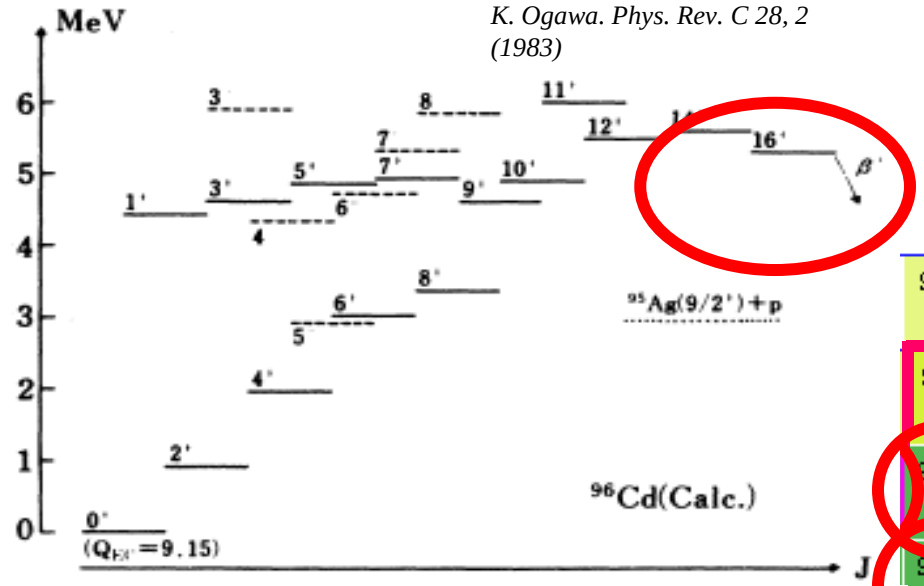
Image: National Nuclear Data Center, Brookhaven National Laboratory: http://www.nndc.bnl.gov/chart/

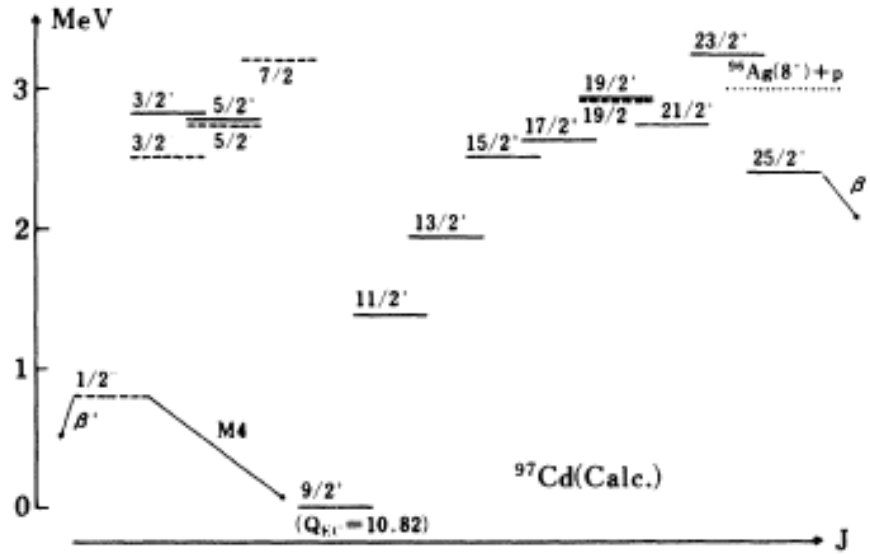


Predicted isomers

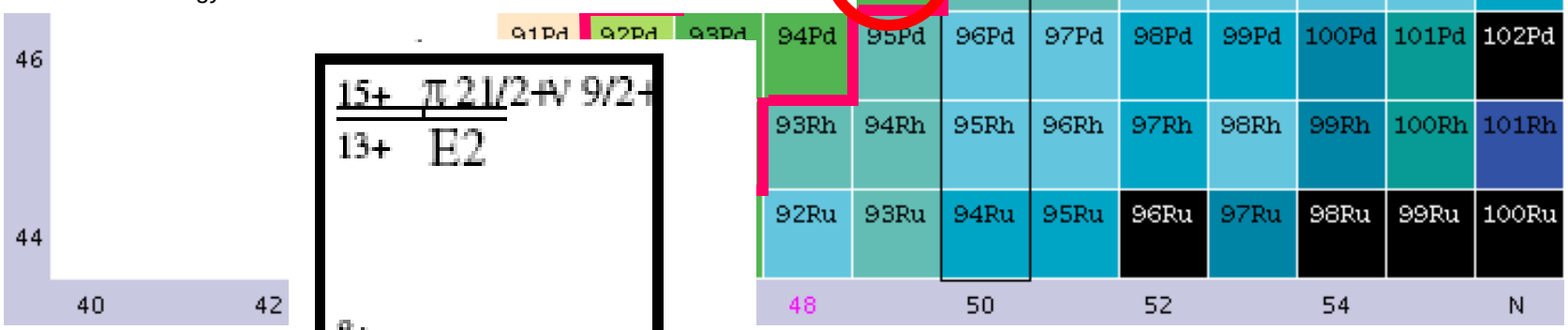
^{96}Cd: A beta-decaying 16^+ spin-gap isomer with $T_{1/2}$ ~ 0.5s has been predicted at an excitation energy of about 5.3 MeV

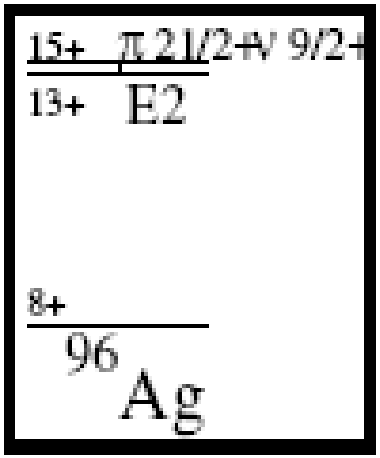
K. Ogawa. Phys. Rev. C 28, 2 (1983)





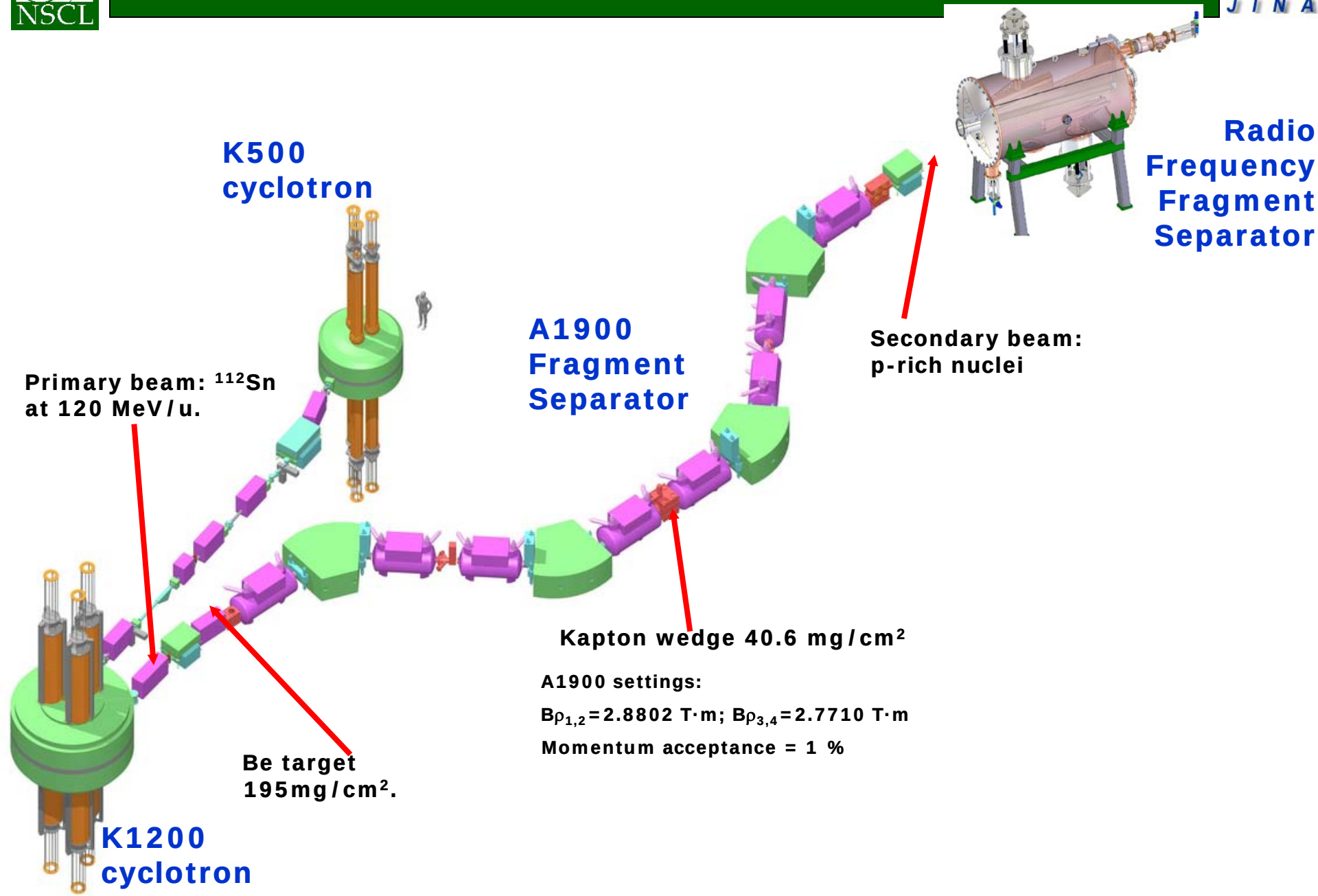
Calculated energy levels of ^{96}Cd.



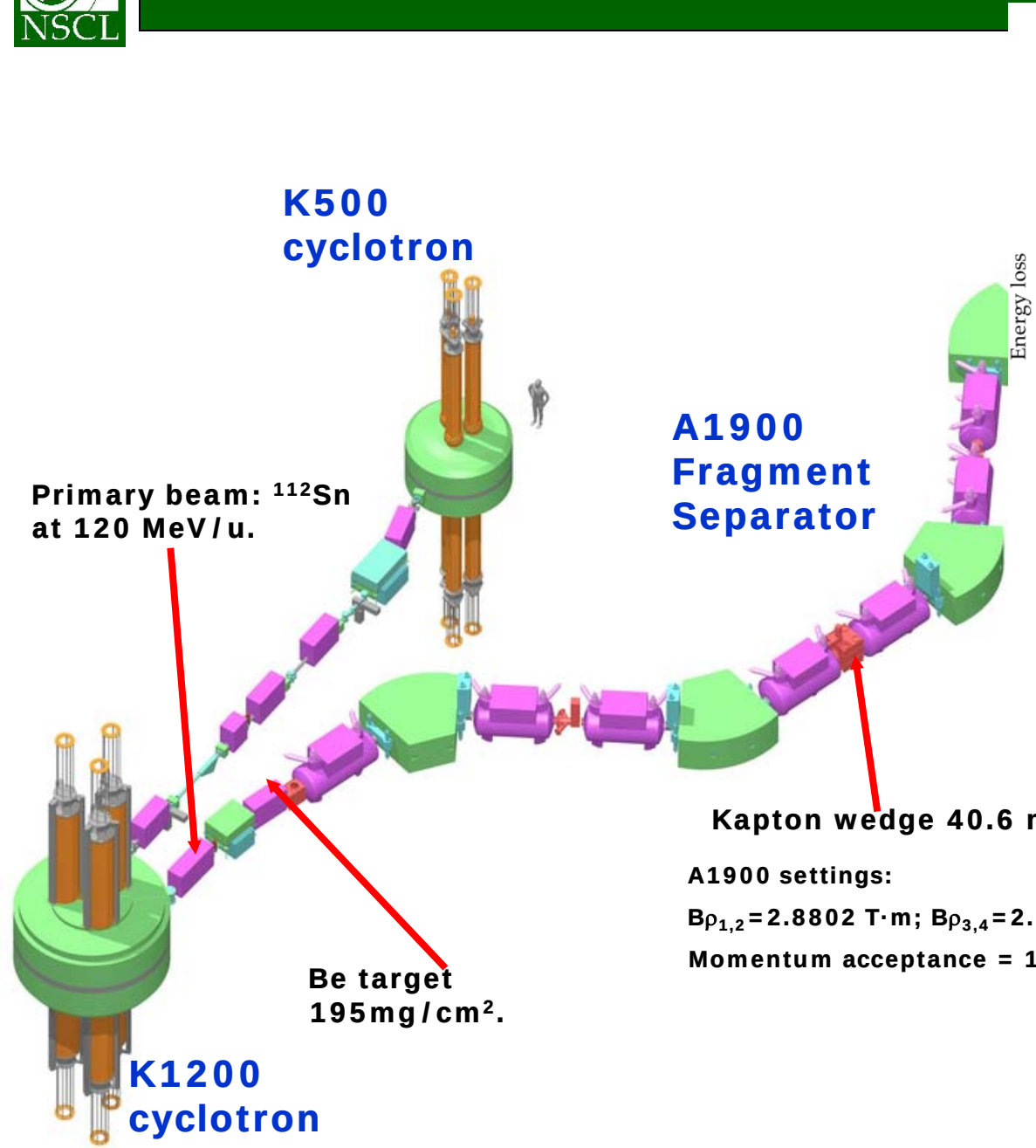


It is essential to ic ng the path, especially in waiting point nuclei, so that ground and isomeric stat to ensure that the half-lives measured in the laboratory are the ones needed tions.

Beam Production at NSCL



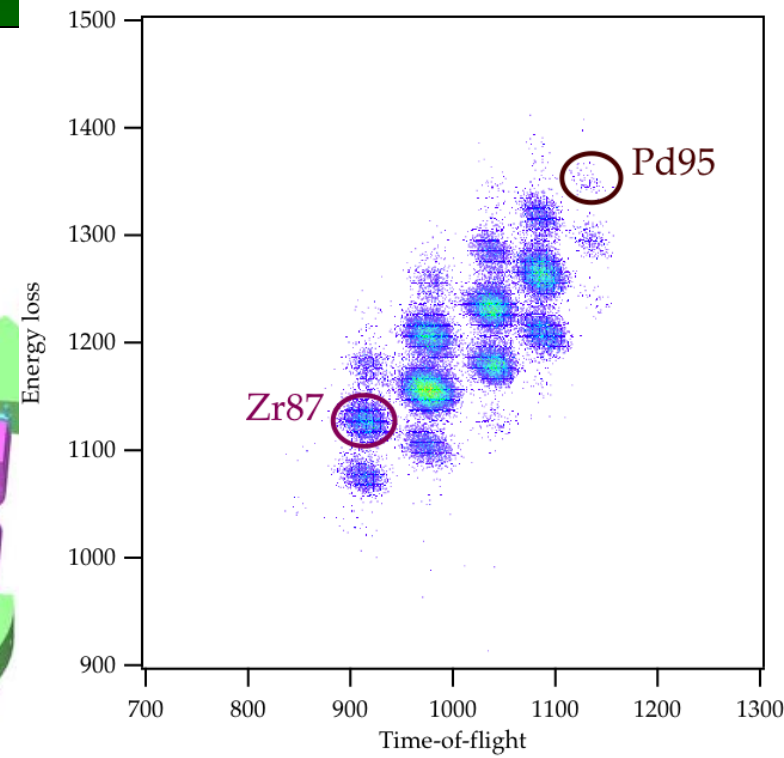
Beam Production at NSCL



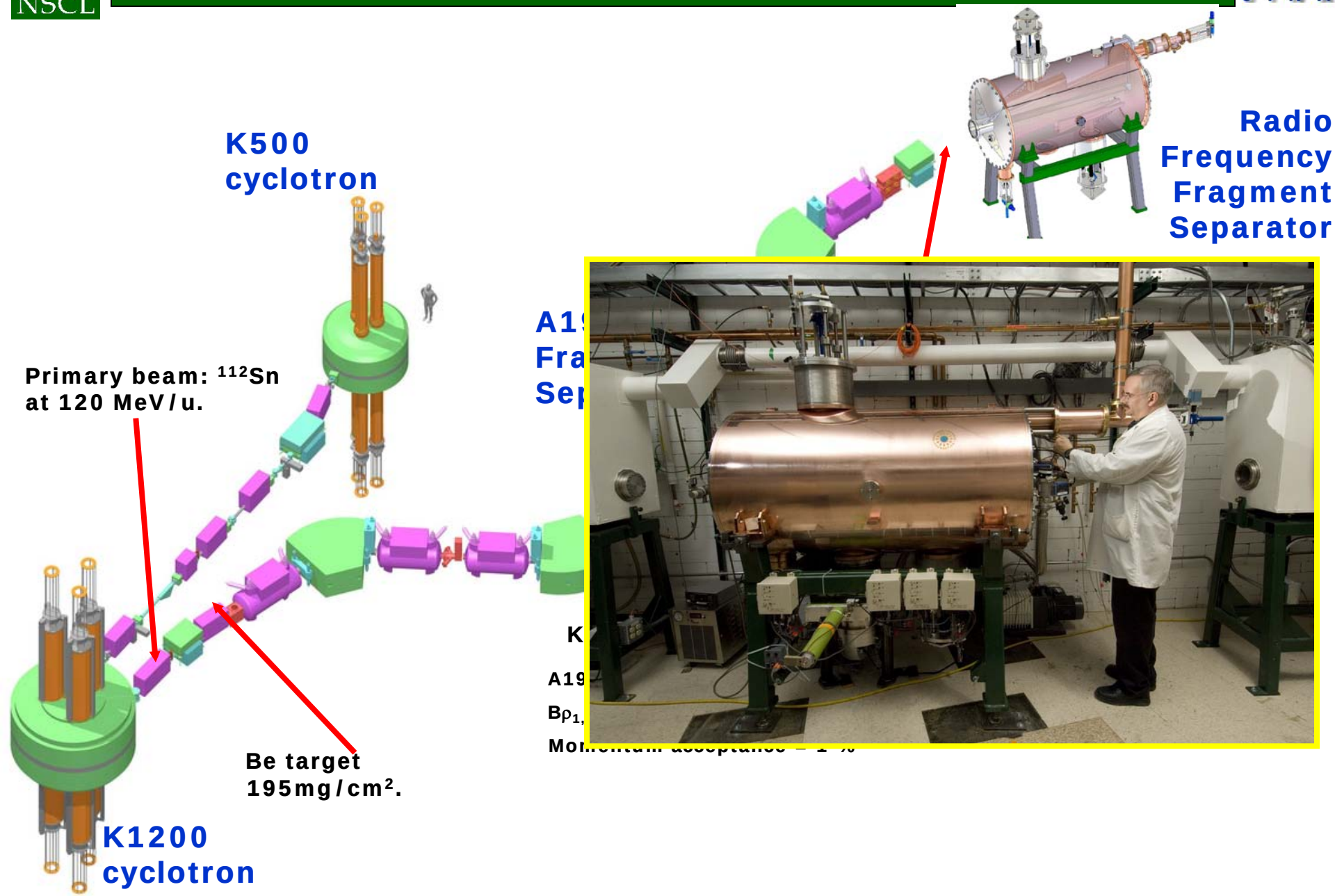
A1900 settings:

$B\rho_{1,2}$=2.8802 T·m; $B\rho_{3,4}$=2.7710 T·m

Momentum acceptance = 1 %



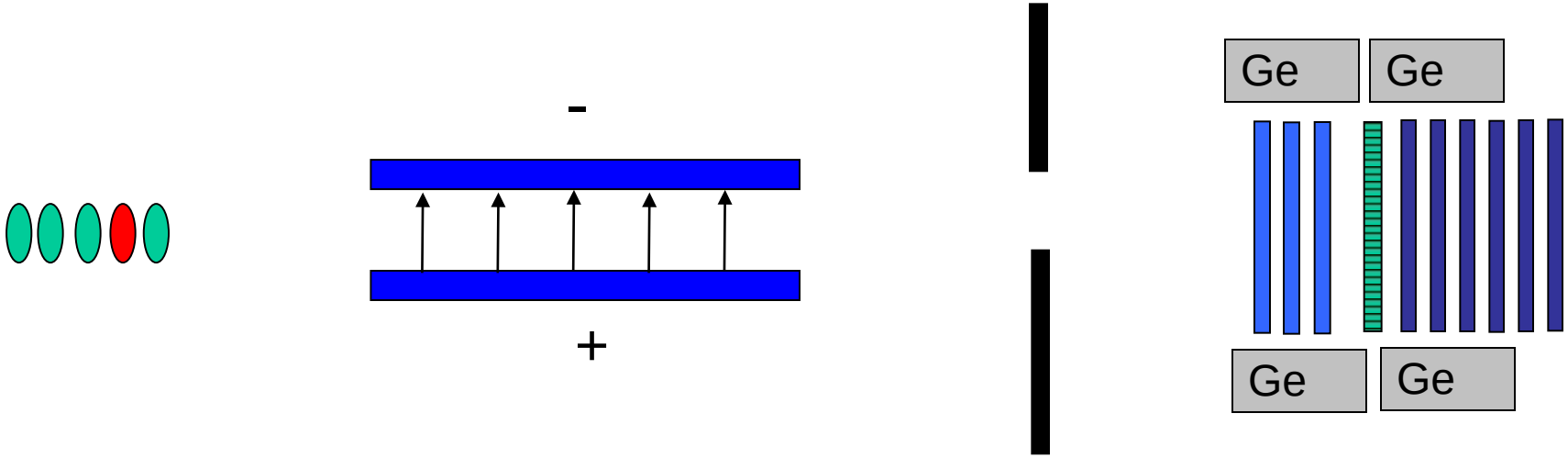
Beam Production at NSCL



Experimental Setup

RF Fragment Separator

NSCL Beta Counting Station
(Mantica et al.)
With SeGA Ge-detectors



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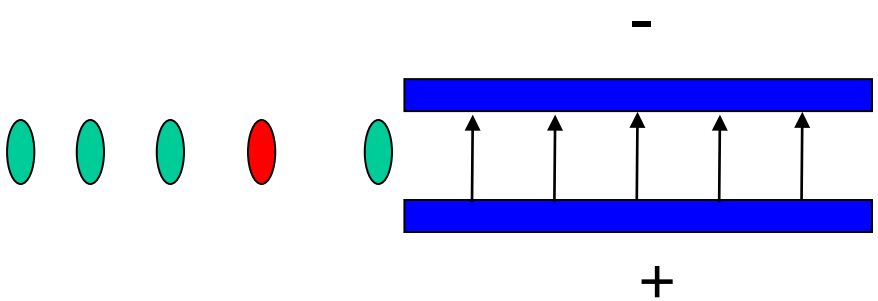

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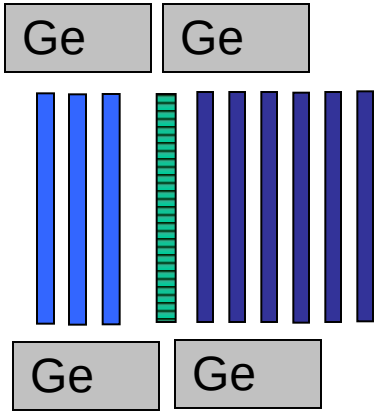

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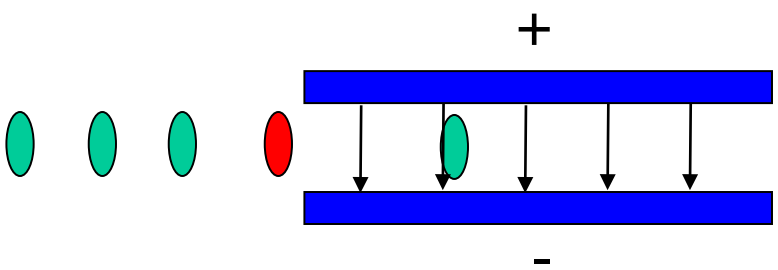

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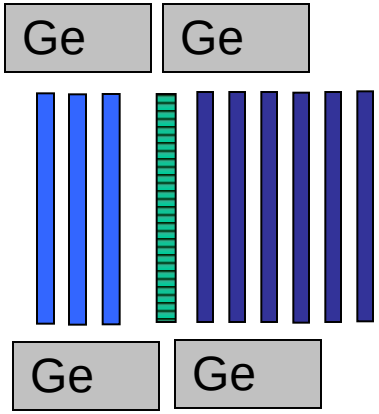

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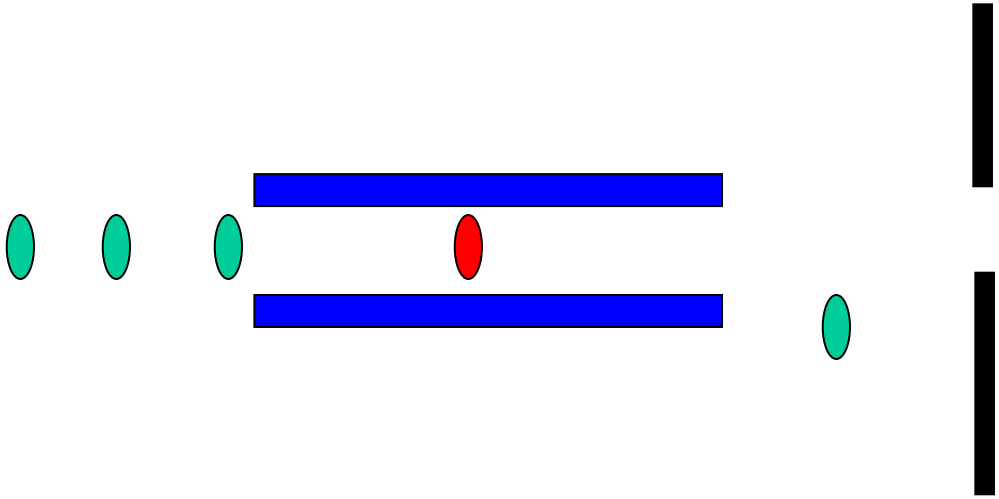

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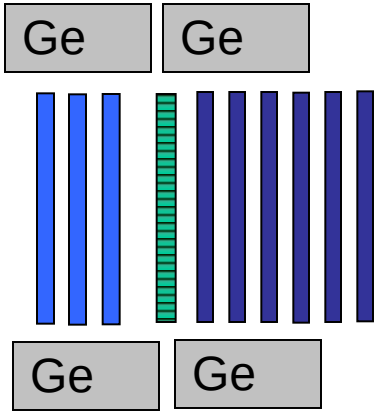

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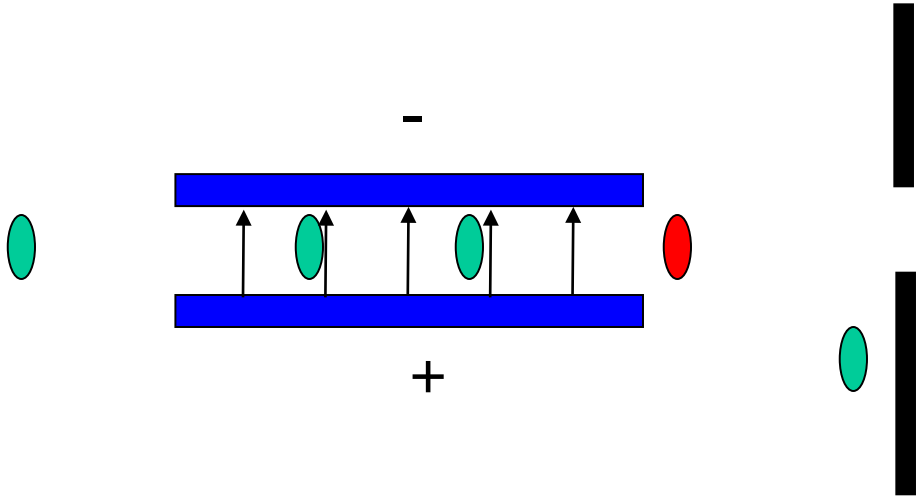

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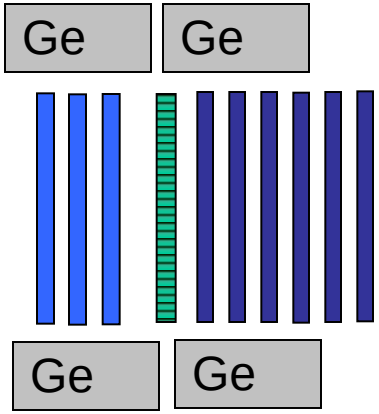

Experimental Setup

RF Fragment Separator

NSCL Beta Counting Station
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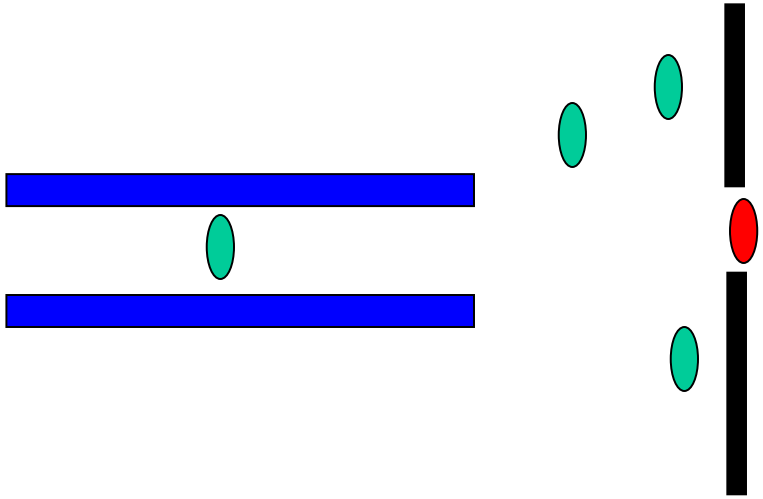

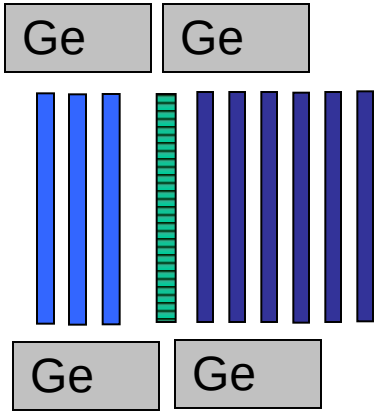

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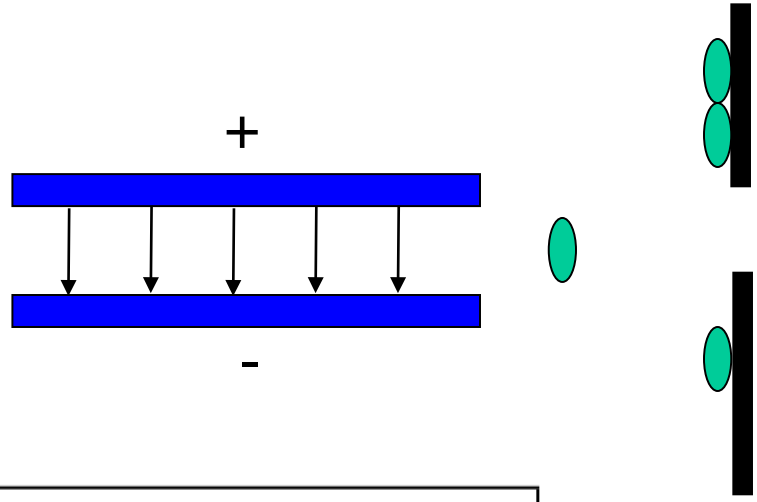

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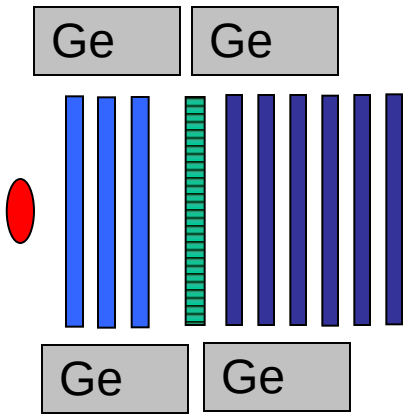
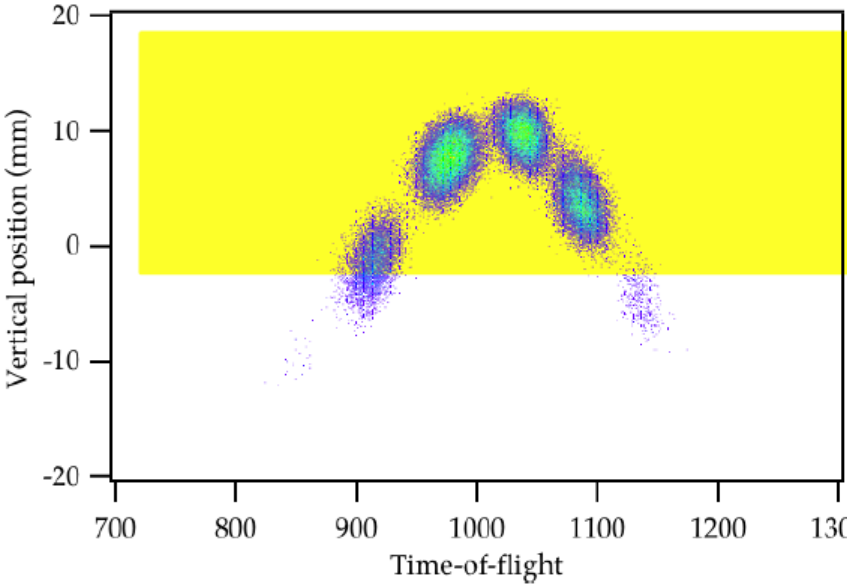
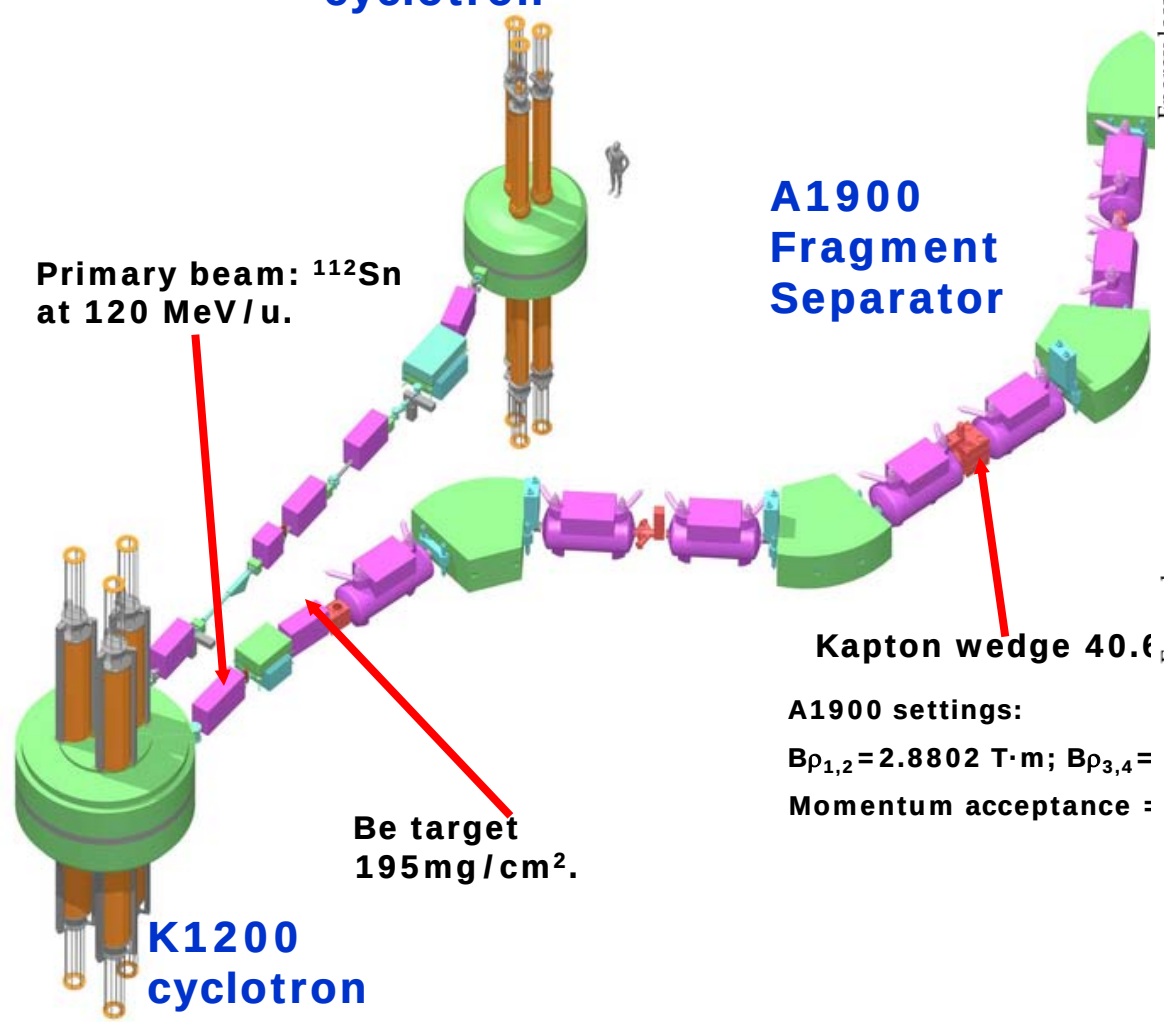
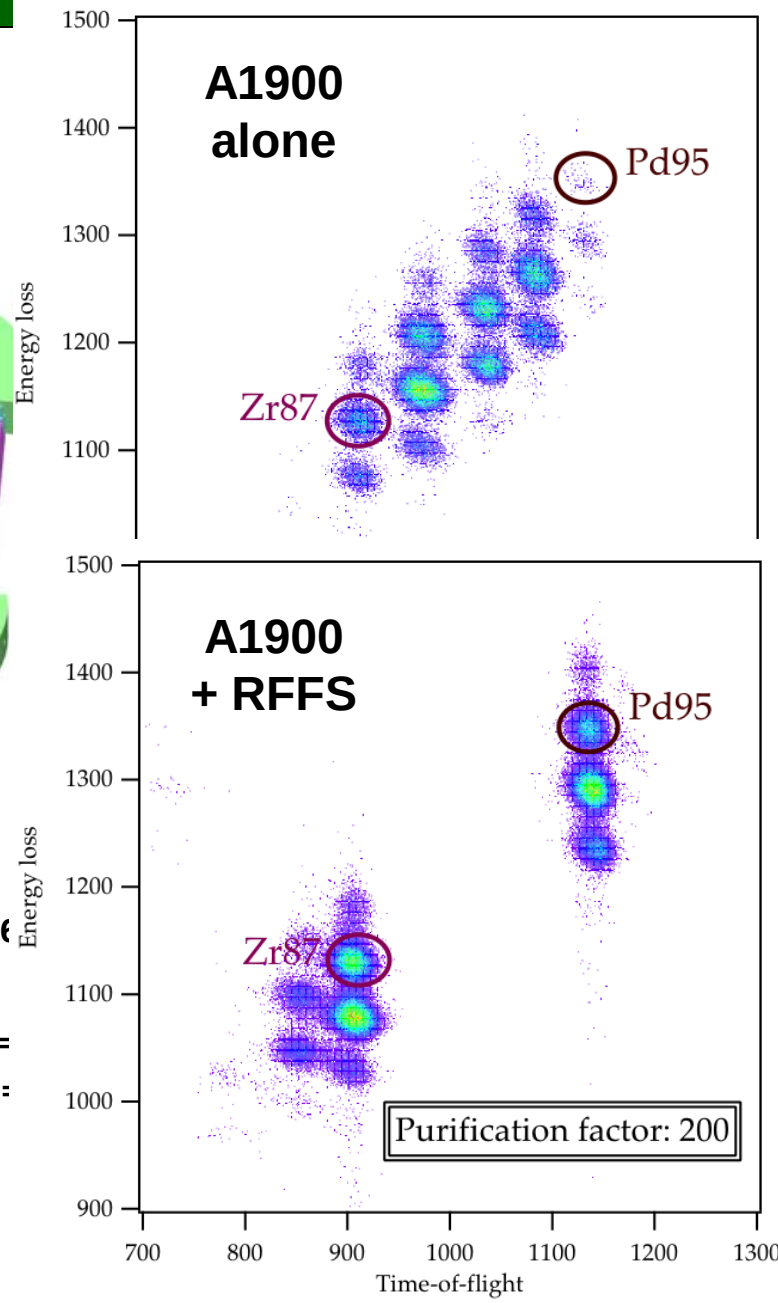




Beam Production at NSCL





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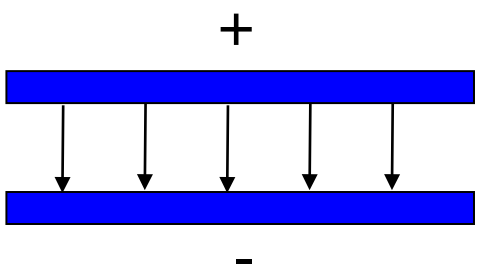

NSCL Beta Counting Station
(Mantica et al.)
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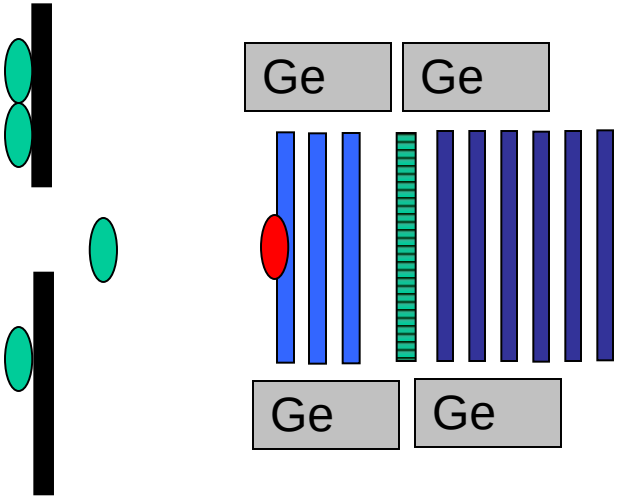
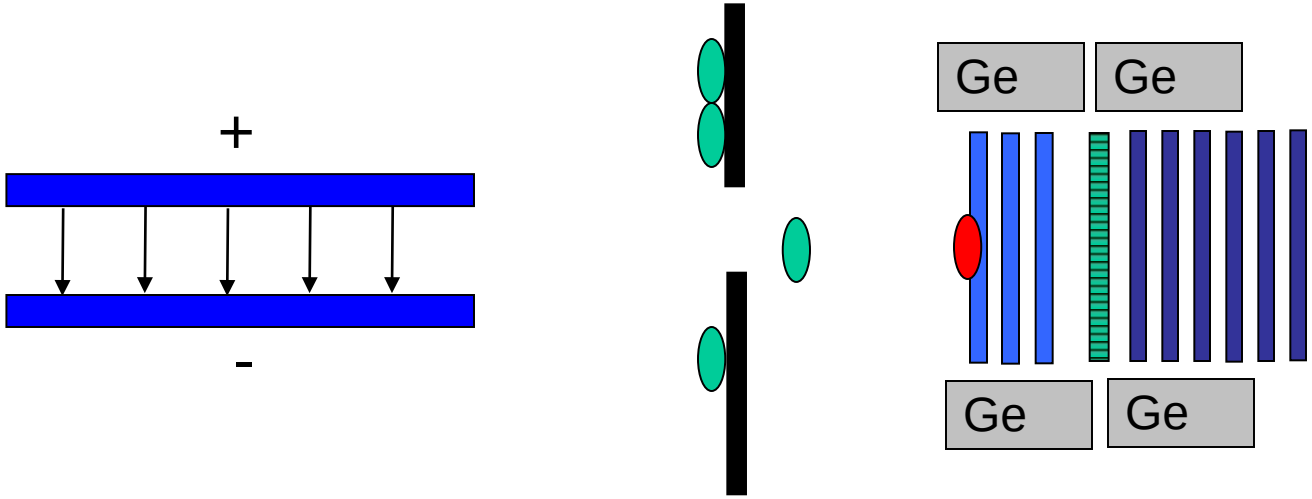


Experimental Setup

RF Fragment Separator

NSCL Beta Counting Station
(Mantica et al.)
With SeGA Ge-detectors

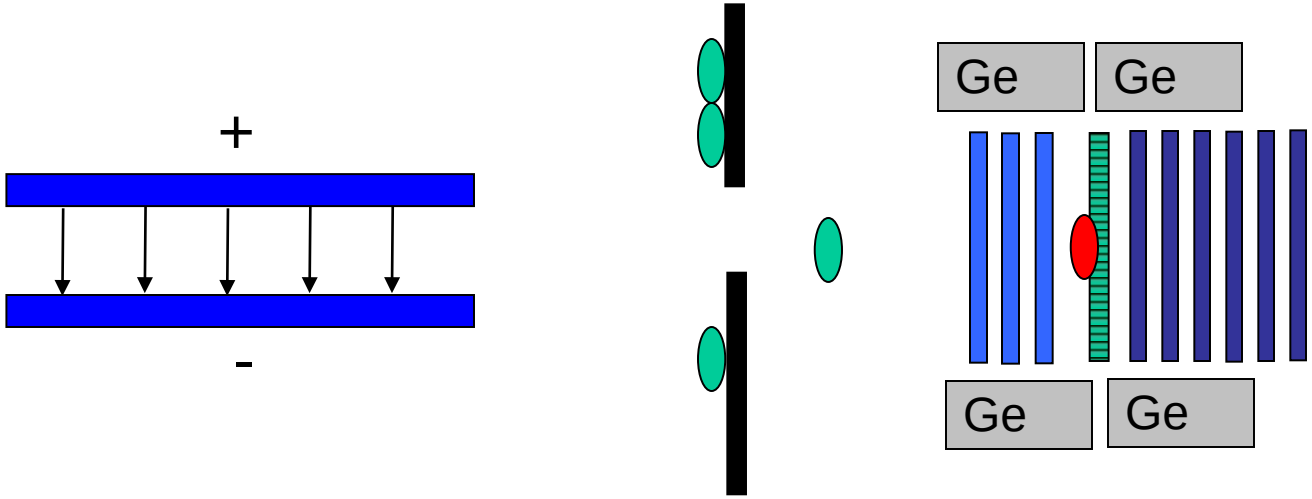


- **measure energy loss and time of flight**

Experimental Setup

RF Fragment Separator

NSCL Beta Counting Station
(Mantica et al.)
With SeGA Ge-detectors

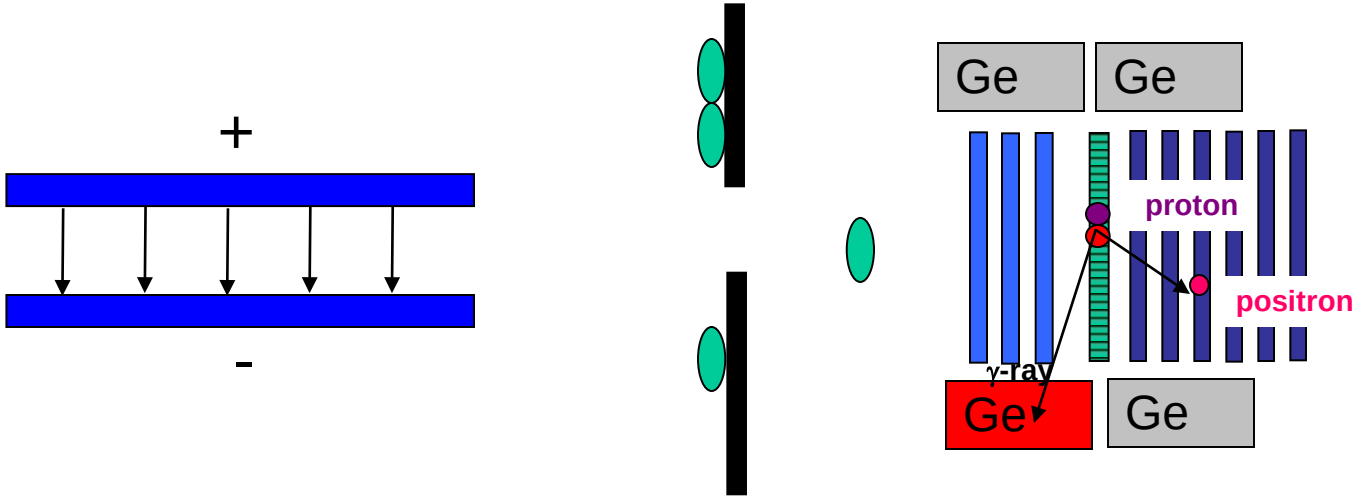


- measure energy loss and time of flight
- **measure arrival time and location**

Experimental Setup

RF Fragment Separator

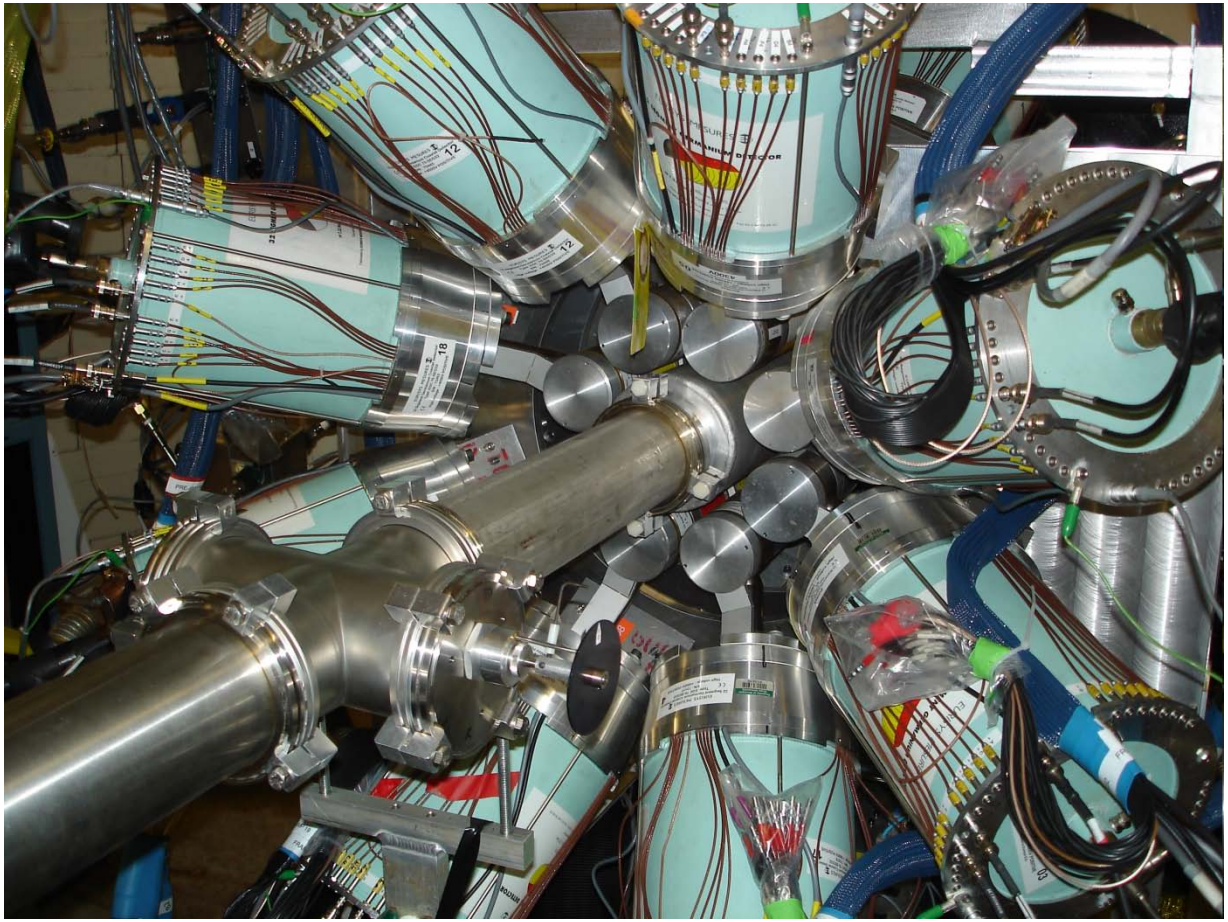
NSCL Beta Counting Station
(Mantica et al.)
With SeGA Ge-detectors



- measure energy loss and time of flight
- measure arrival time and location
- **measure decay time and energy of products**

Experimental Setup

NSCL segmented Ge Array (SeGA)



NSCL Beta Counting Station
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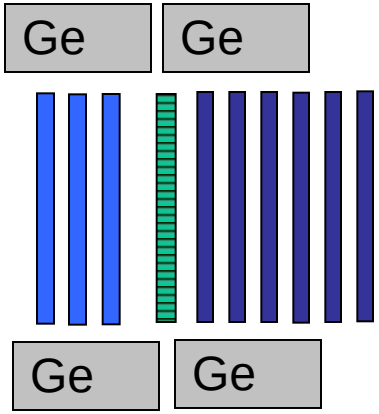
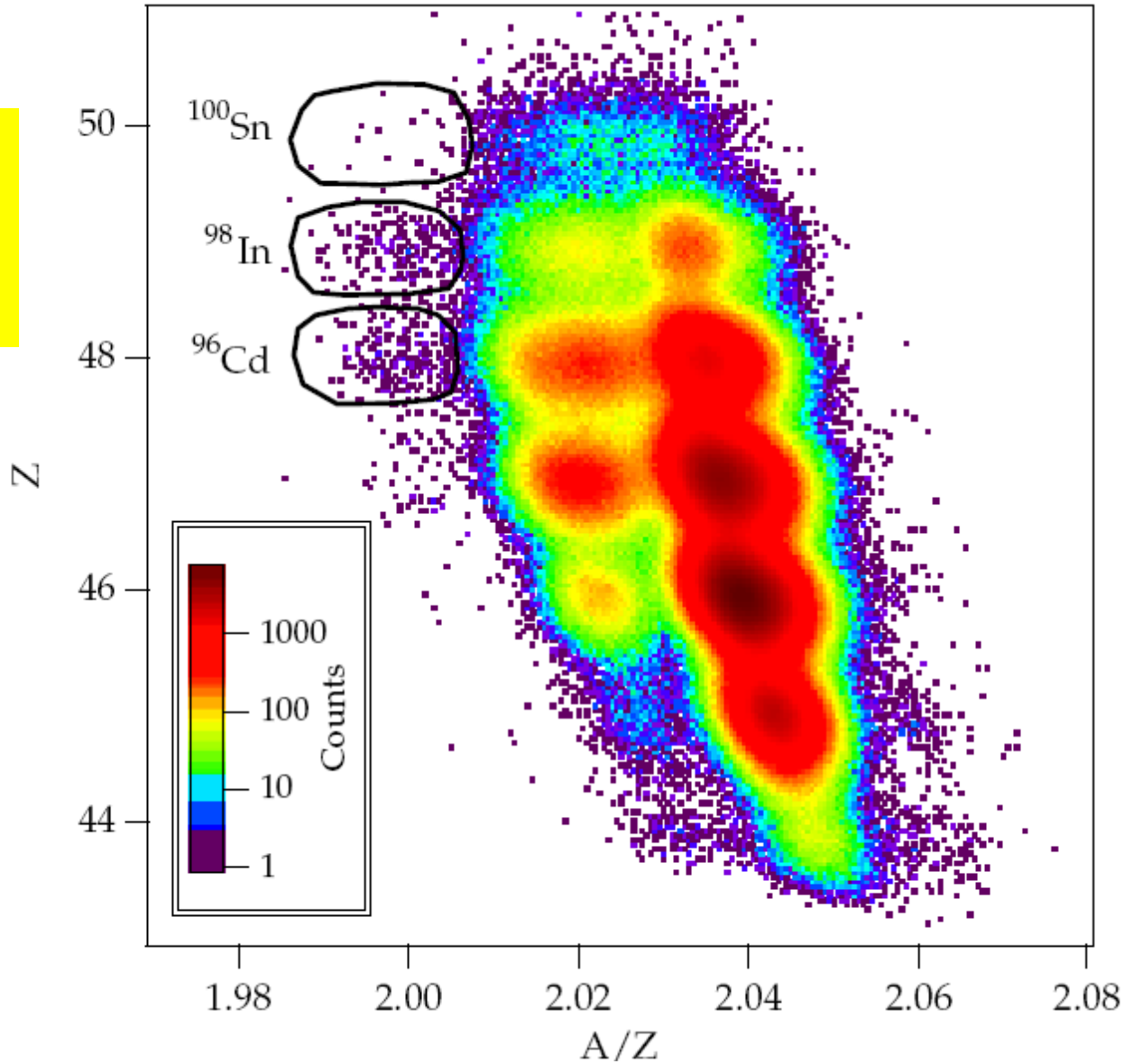


Particle Identification

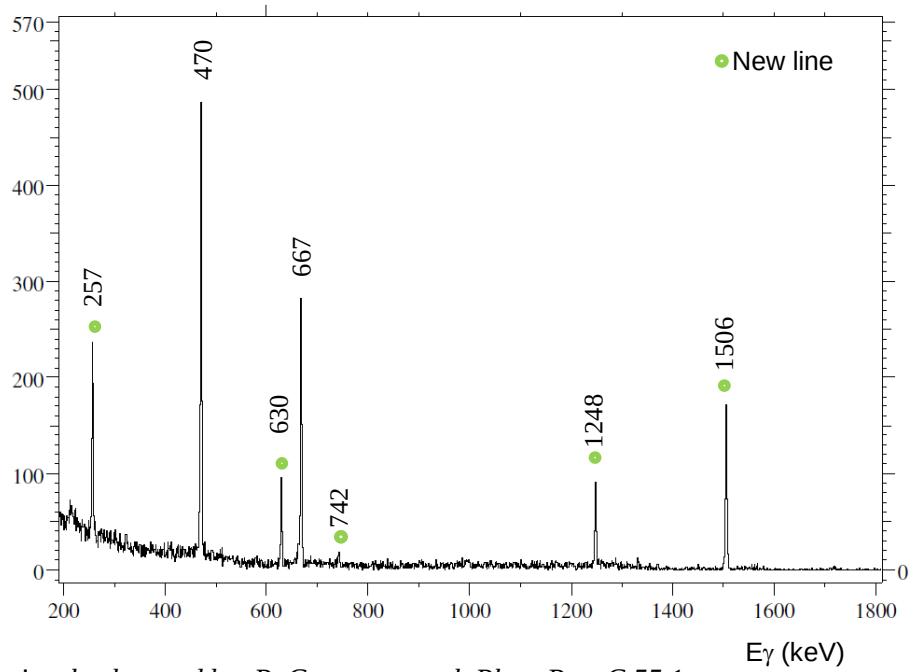
PID verified by observation of γ-rays from known μs isomers (e.g. ^{90}Mo, ^{93}Ru and ^{96}Pd) detected when the RFFS slits were open.

A number of proton-rich fragments were implanted at the experimental station, and their β-decay half-lives were determined taking into account the decay of the parent, growth and decay of the daughter and granddaughter nuclei, as well as β-decay background events. The β-background rate was calculated as a function of time and pixel position.

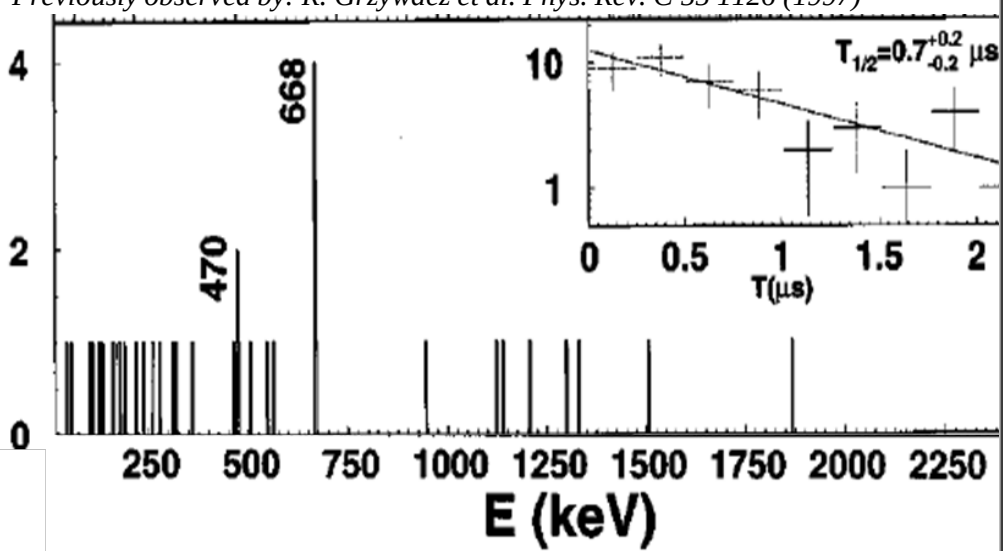
D. Bazin et al PRL 101, 252501 (2008)



^{96}Ag μs – isomer



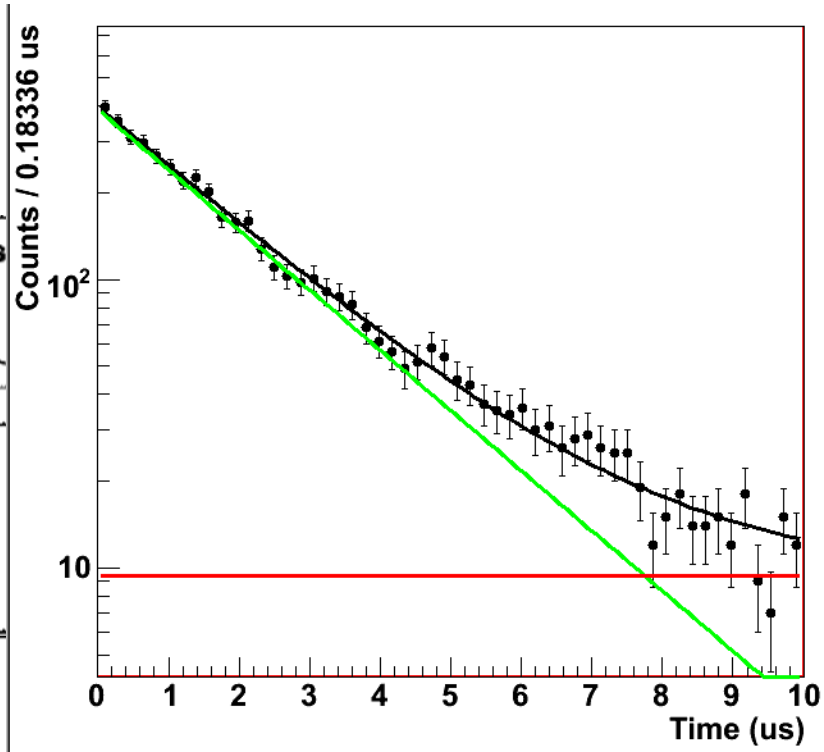
Previously observed by: R. Grzywacz et al. Phys. Rev. C 55 1126 (1997)



$T_{1/2}$ = 1.49±0.05 μs

A factor 2x longer than previously reported

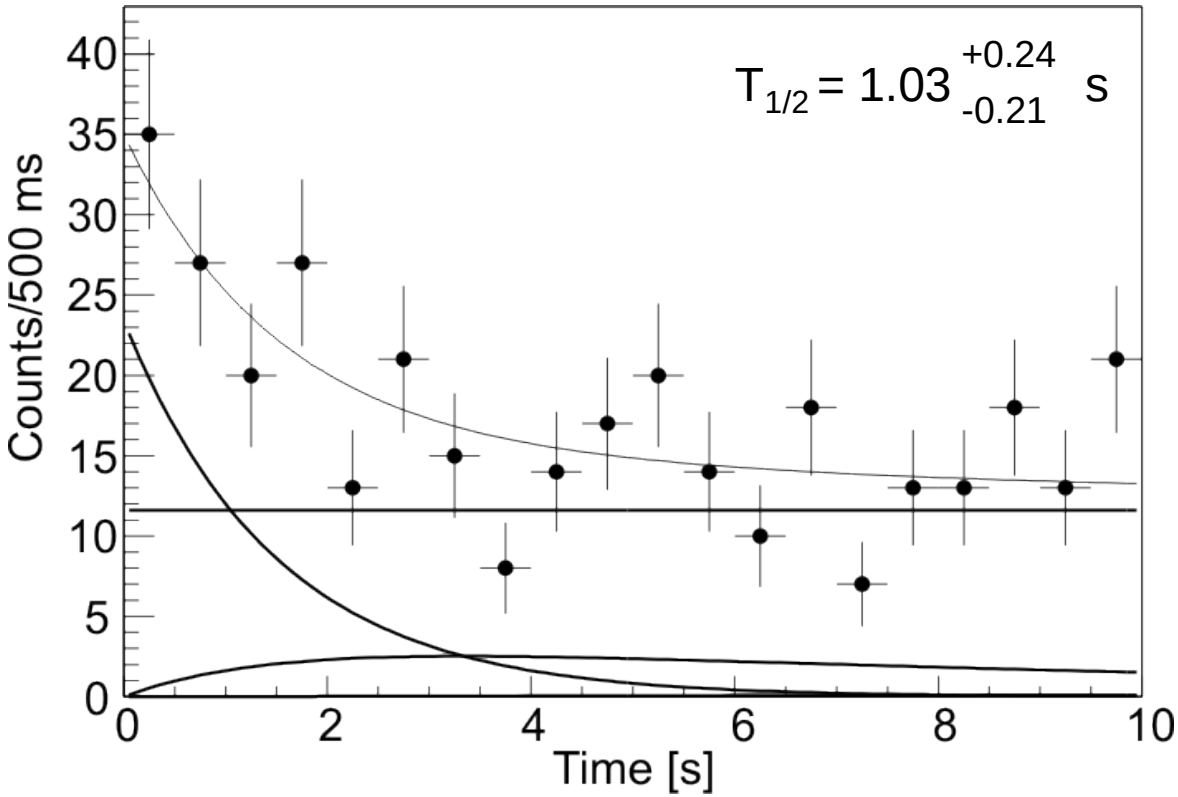
PRELIMINARY!



Results

^{96}Cd

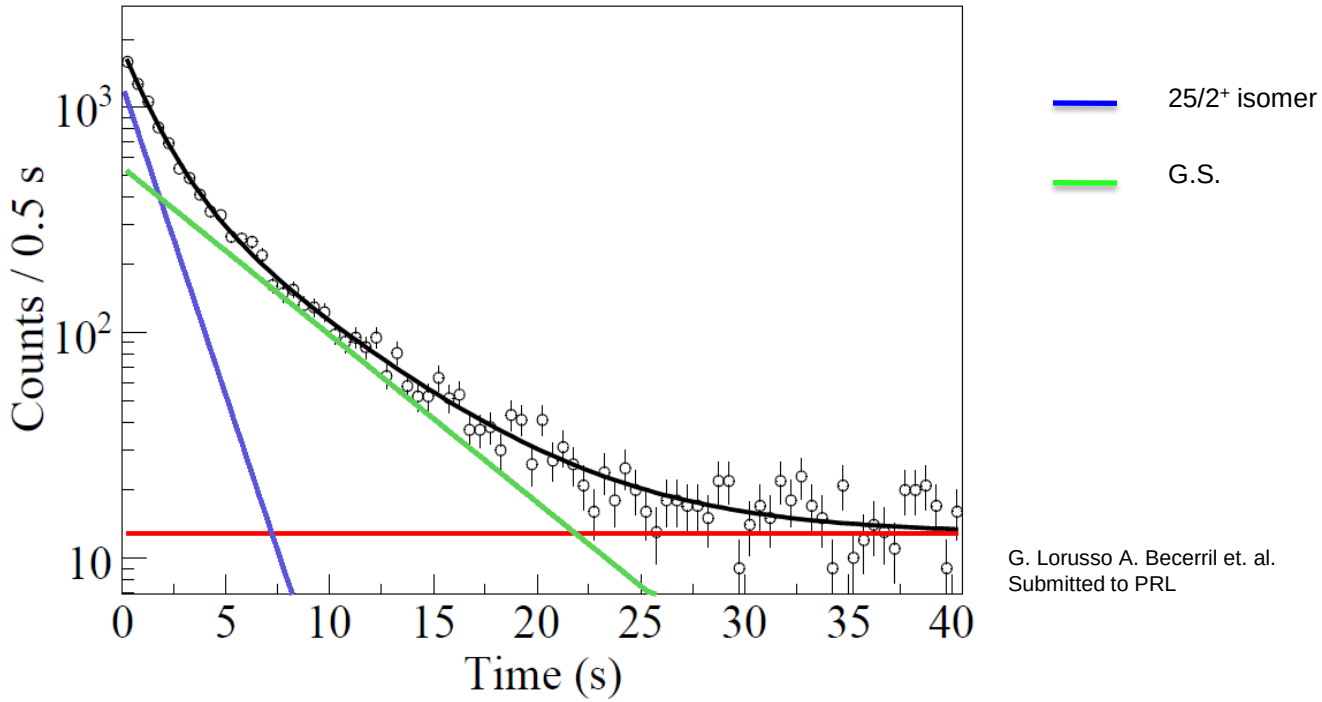
We determined this β-decay half-life for the first time. With it, all rp-process waiting points are now known.



We found no evidence of the existence of a predicted second β-decaying state with a half-life of 0.5 s, but its existence cannot be ruled out.

Results

^{97}Cd



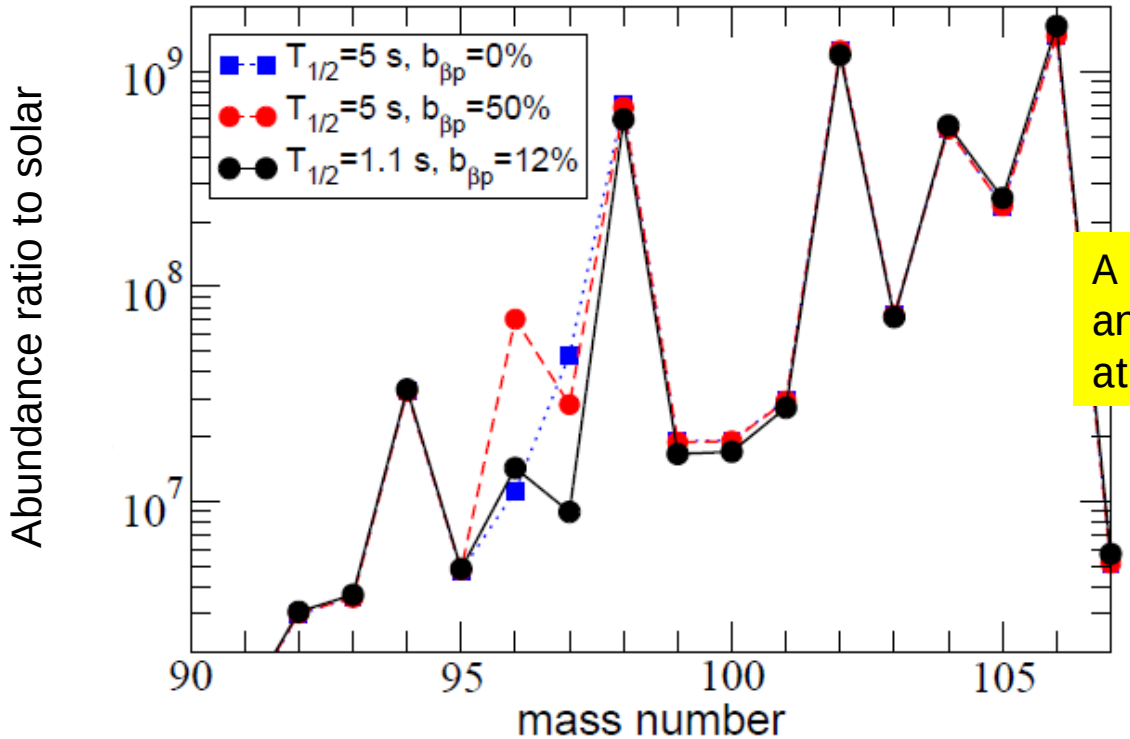
G. Lorusso A. Becerril et. al.
Submitted to PRL

Two components clearly distinguished. The long-lived component corresponds to the decay of the predicted $25/2^+$ β-decaying isomeric state. The short-lived component corresponds to the decay of the ground state. The G.S. half-life is the one that must be used for the ^{97}Cd waiting point in rp-process calculations.

Implications on rp-process

With our half-life measurements, all major waiting points along the reaction path of the rp-process are now known.

The new data indicate that the X-ray bursts are not the main source of the ^{96}Ru observed in the solar system.



A peak as high as those at A=98 and A=102 would be necessary at A=96 to explain origin of ^{96}Ru.

Overproduction factors for X-ray burst ashes obtained with new data from this work. The half-life and βp branching ratio of ^{97}Cd are varied within previous error bars to explore possible impact on final abundances.

Acknowledgments

D. Bazin[1], G. Lorusso[1,2,3], F. Montes[1,2], P. Mantica[1,4] , H. Schatz[1,2,3], A.M. Amthor[1,2,3], T. Baumann[1], J. Berryman[1,4], H. Crawford[1,4], A. Estrade[1,2,3], A. Gade[1,3], T. Ginter[1], C. Guess[1,2,3], M. Hausmann[1], G. W. Hitt[1,2,3], M. Matos[1,2], R. Meharchand[1,2,3], K. Minamisono[1], J. Pereira[1,2], G. Perdikakis[1], M. Portillo[1], K. Smith[1,2,3], J. Stoker[1,4], R. Zegers[1,2,3]

[1]National Superconducting Cyclotron Laboratory
[2]Joint Institute for Nuclear Astrophysics
[3]Department of Physics and Astronomy
[4]Department of Chemistry
Michigan State University, East Lansing, MI 48824.

Painting by H. Bertulani
At NSCL's Atrium

Backup slides

Summary

^{96}Cd:

- β-decay half-life measured: $1.03^{+0.24}_{-0.21}$ s
- No indication of the predicted second β-decaying component, but its existence cannot be ruled out.
- The measured half-life of ^{96}Cd seems to eliminate the possibility that rp-process could be the main responsible for the origin of ^{96}Ru.

^{98}In

- Indication of a long-lived isomeric component and a short half-life attributed to the super-allowed Fermi decay from a 0^+ ground state. Combined with the previous measurements these half-lives are: 44^{+13}_{-12} ms and $0.92^{+0.27}_{-0.17}$ s for the short and long components respectively.

^{100}Sn

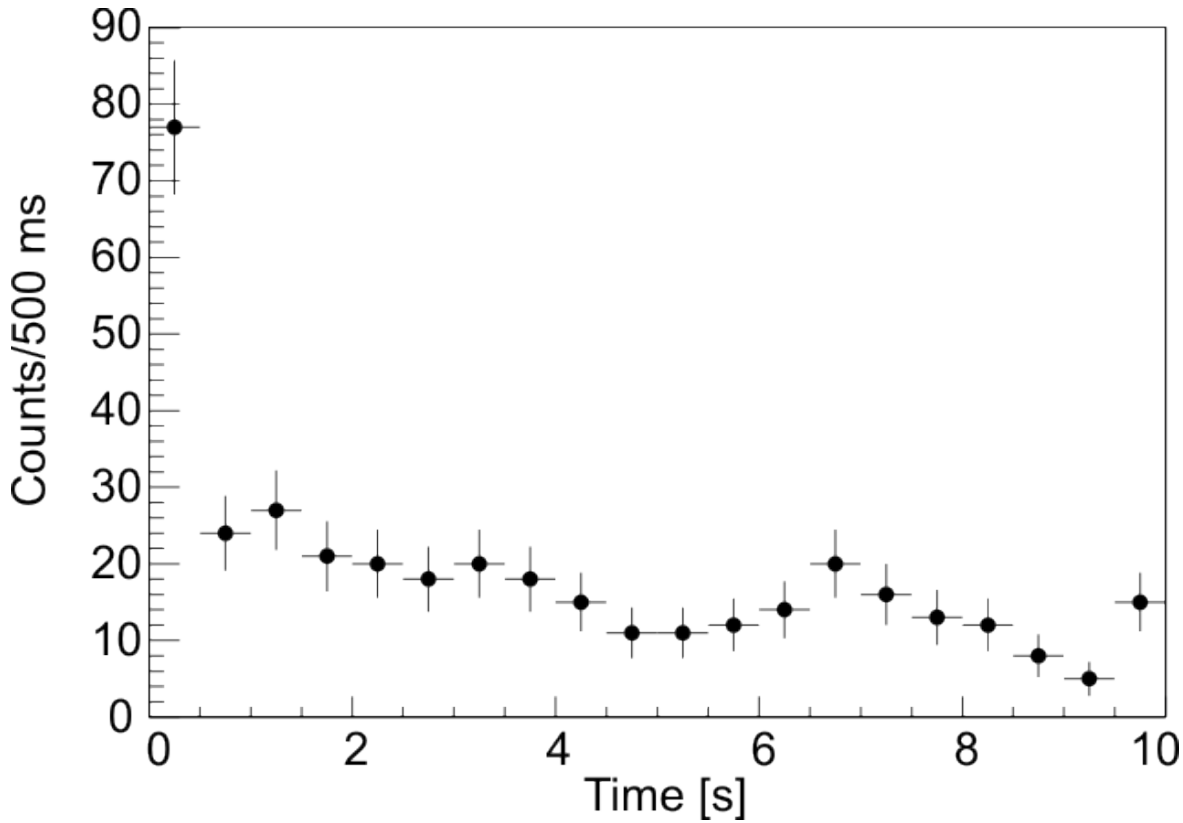
- The precision of our measurement of the ^{100}Sn half-life is compatible with previous measurement. Improved average: $0.86^{+0.37}_{-0.20}$ s

^{96}Ag

- Improved statistics allow for identification of 5 new gamma lines de-exciting the μs isomer previously observed. Isomeric half-life 2x longer than reported in previous work. Level scheme suggested!

Results

^{98}In

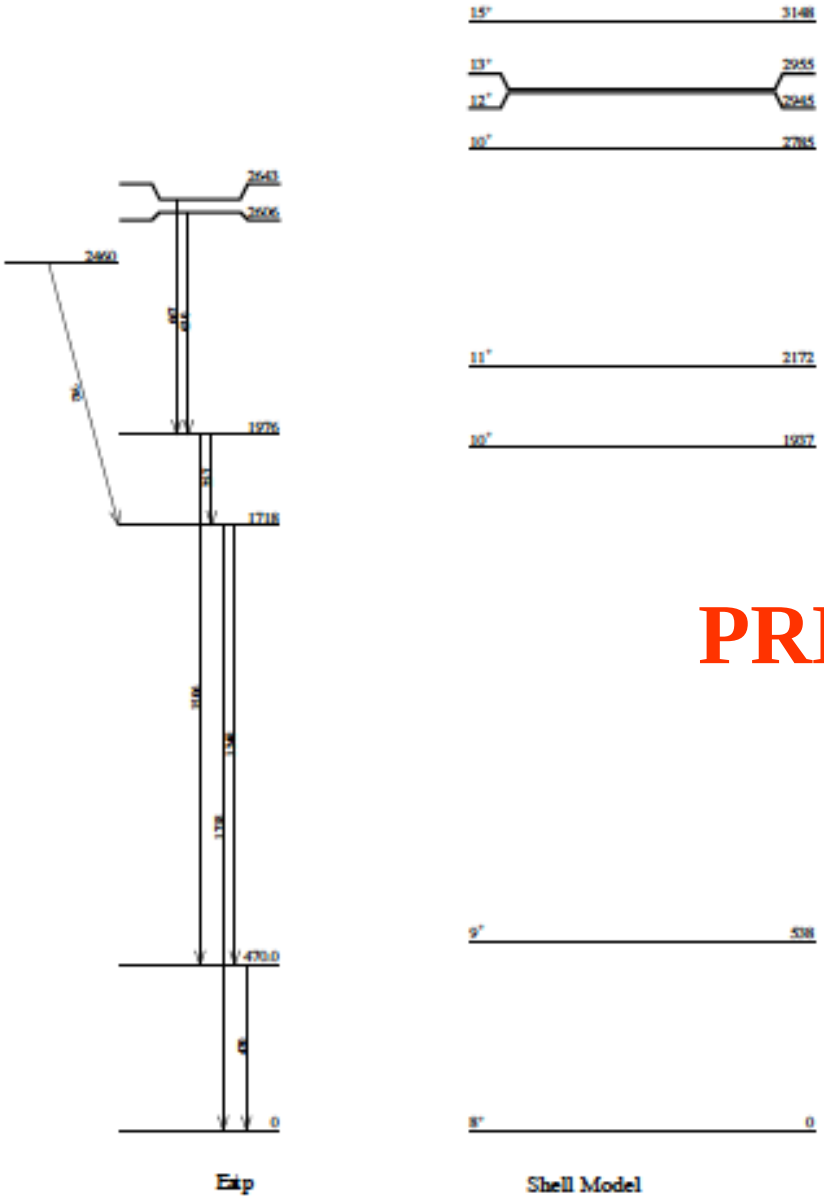


$T_{1/2}$ = 47(13) ms GS

$T_{1/2}$ = 0.66(0.40) s Isomer

Indication of two components in decay spectrum

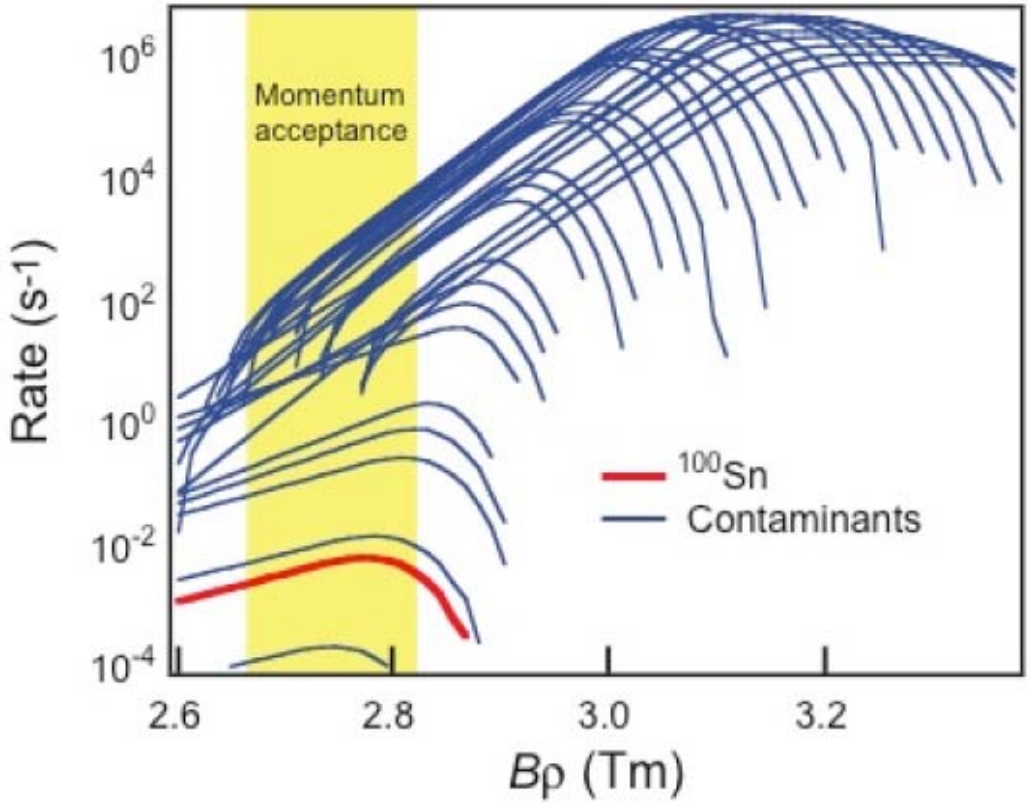
^{96}Ag μs – isomer



96Ag

PRELIMINARY!

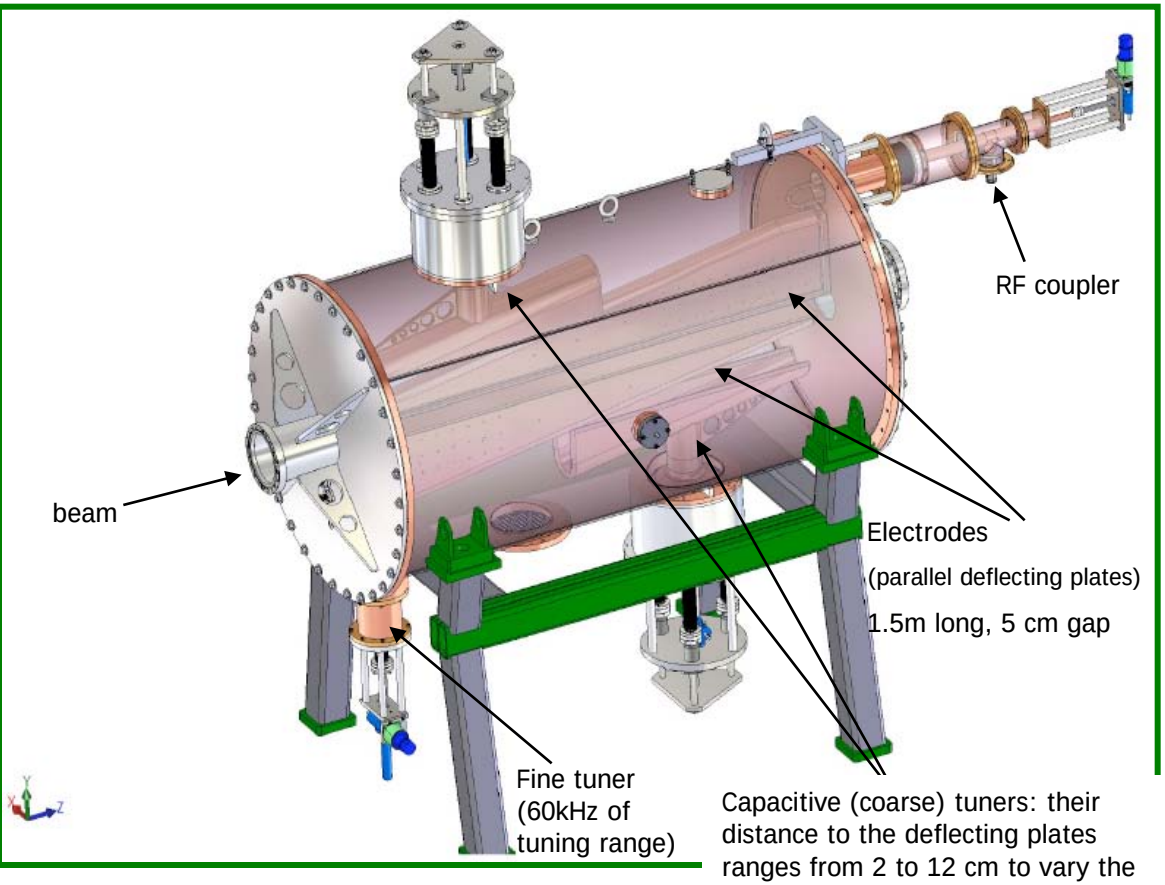
Fragment yields at exit of A1900 Fragment Separator



Huge contamination from low momentum tails of more abundant higher rigidity fragments.

⇒ Need additional purification of secondary beam!

The RF kicker



Capacitive (coarse) tuners: their distance to the deflecting plates ranges from 2 to 12 cm to vary the frequency from the lowest to the highest value.

Vertical deflection given by

$$\delta y = \beta_c \, \delta y'$$

$$\delta y' = c_1 \frac{V}{B\rho \; f} \left| Sin\left(c_2 \frac{f}{\beta} \right) \right| Cos\varphi$$

$\delta y'$ is in mrad
β=v/c reduced velocity
$B\rho$ [T·m] magnetic rigidity
f [MHz] frequency
V [kV] voltage
φ average phase of the beam
c_1=6.37
c_2=0.0157
β_c=3m

RF electric field:
Maximum peak voltage of 100 kV.
Range of frequencies: 17MHz to 27 MHz.