

# 25th Symposium of the Hellenic Nuclear Physics Society

## Investigating the role of vp-process by measuring the p( $^{56}\text{Co}$ ,n) $^{56}\text{Ni}$ reaction

Athens, Greece  
June 2016

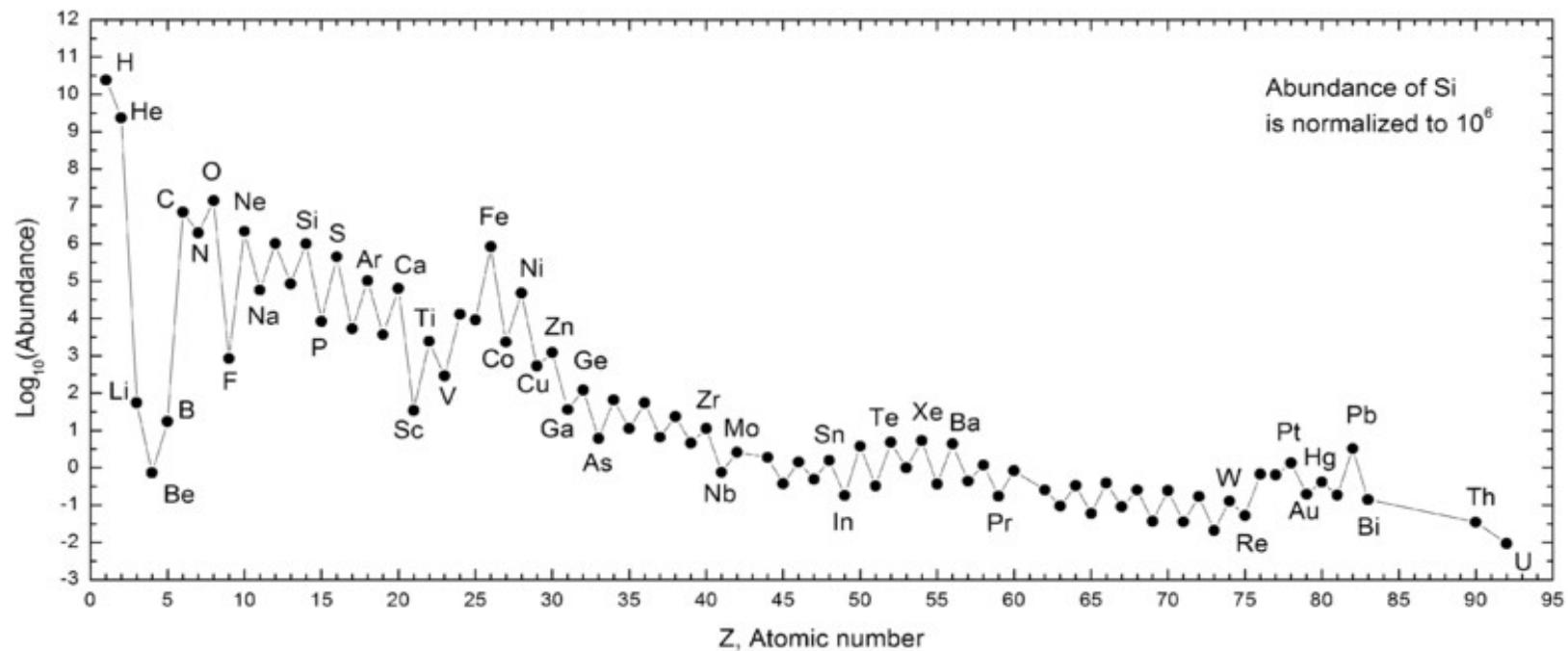
PANAGIOTIS GASTIS

GRADUATE STUDENT  
CENTRAL MICHIGAN UNIVERSITY  
DEPARTMENT OF PHYSICS

Background image: <http://people.sc.fsu.edu/~tplewa/SNII/>



# Introduction

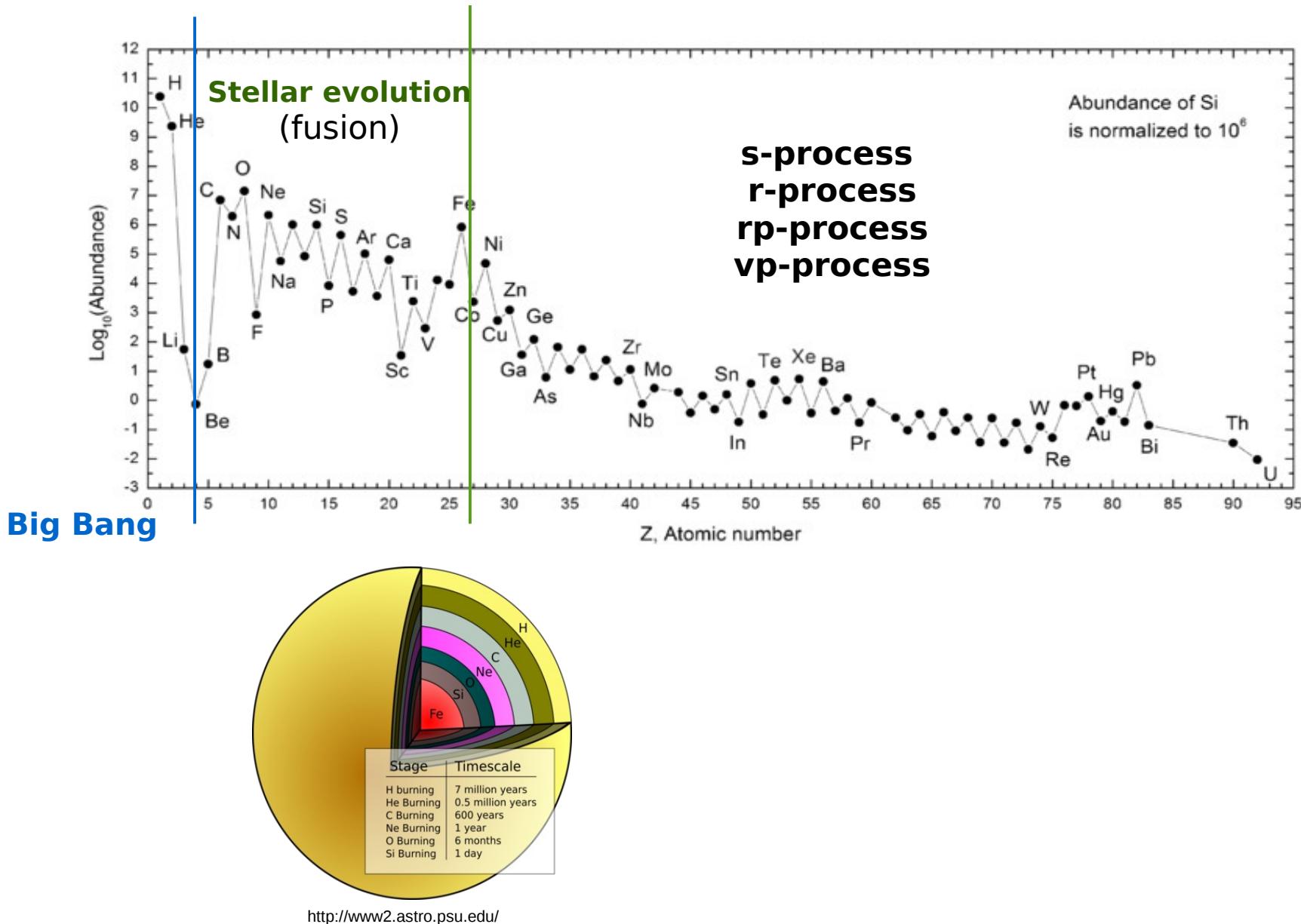


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# Introduction

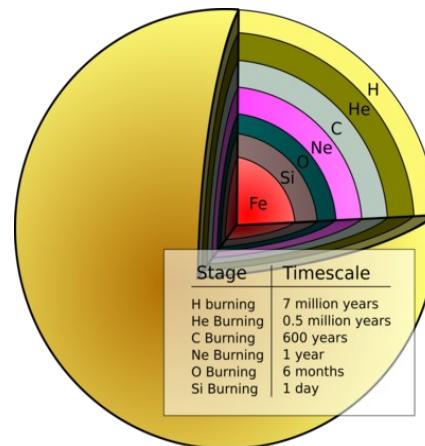
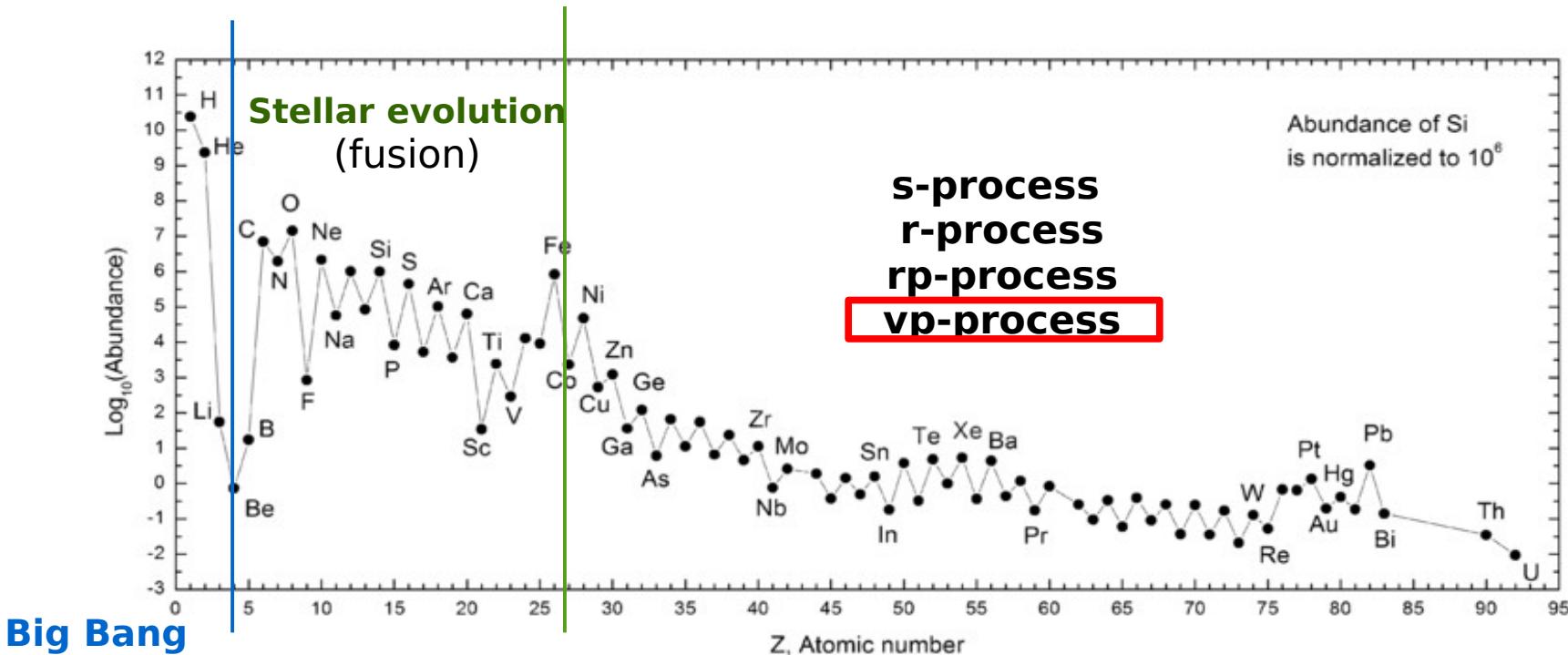


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# Introduction



<http://www2.astro.psu.edu/>



<http://www.whillyard.com/>



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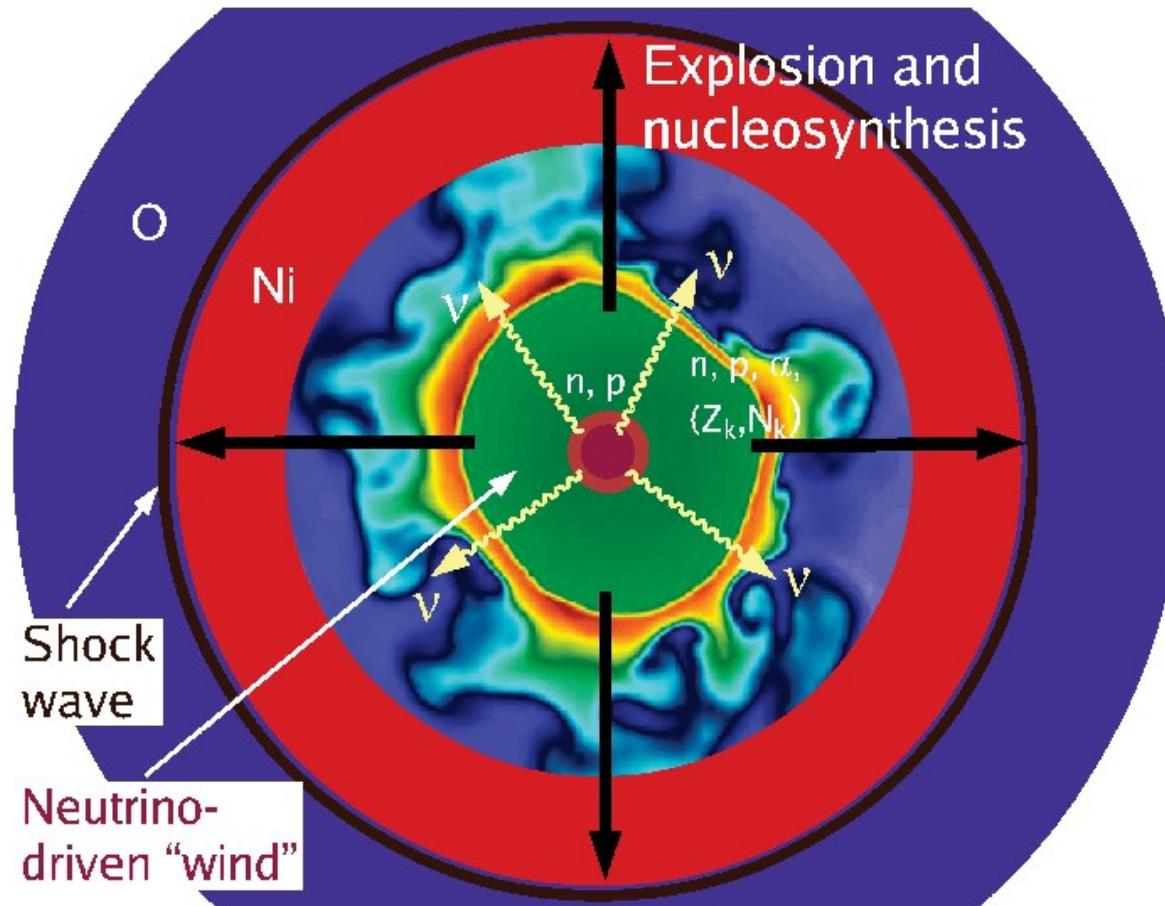


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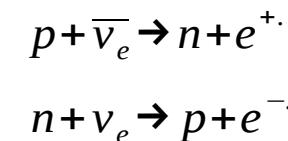
# Neutrino Driven Winds

## Type II Core Collapse Supernovae

~0.5 second after the bounce



<http://inspirehep.net/record/1198936/plots>



### From the most recent simulations:

- NDW possibly slightly proton rich
- Not high enough entropy for robust r-process



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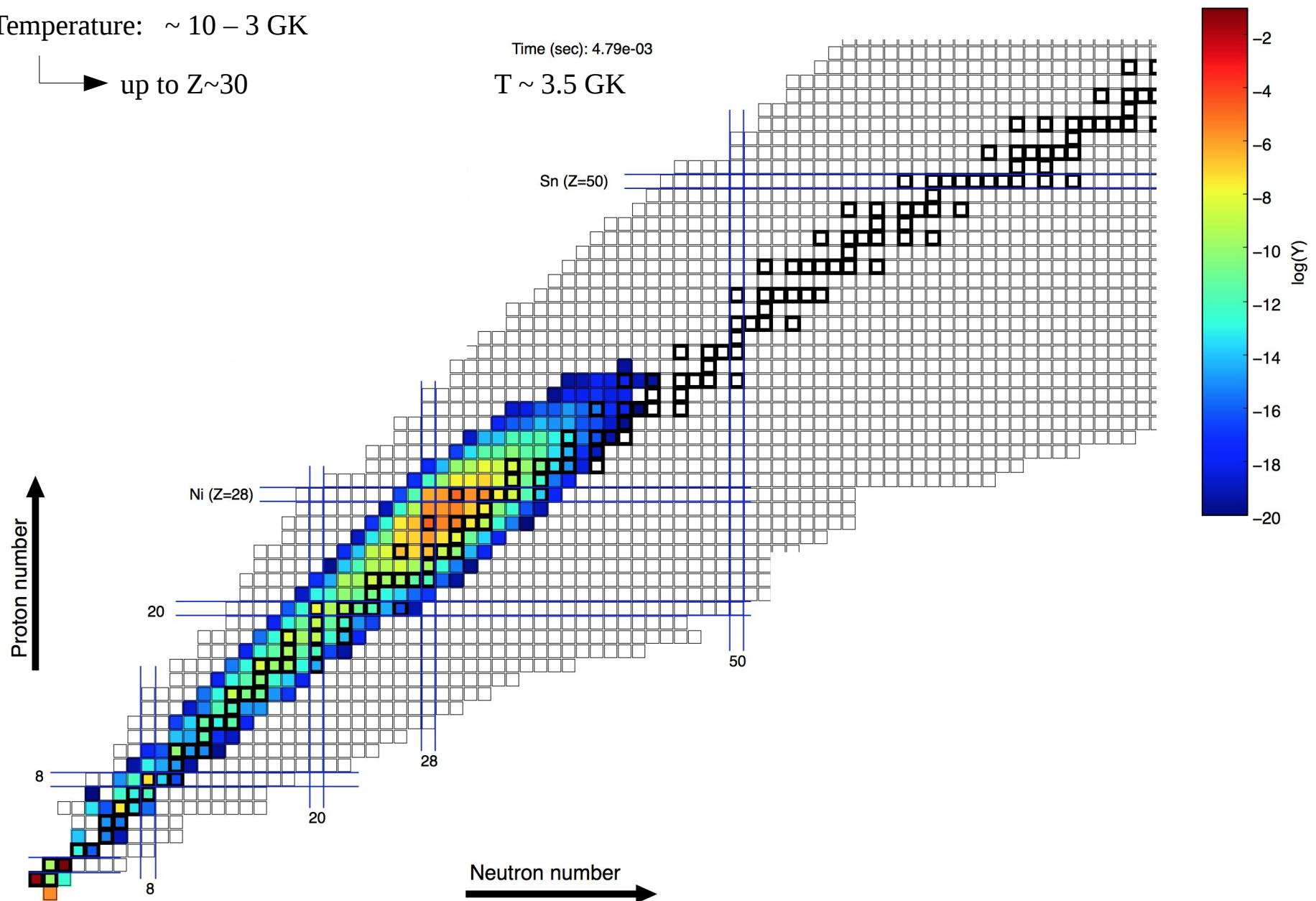


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# The vp-process

➤ Temperature:  $\sim 10 - 3$  GK

→ up to  $Z \sim 30$



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# The vp-process

- Temperature:  $\sim 10 - 3$  GK

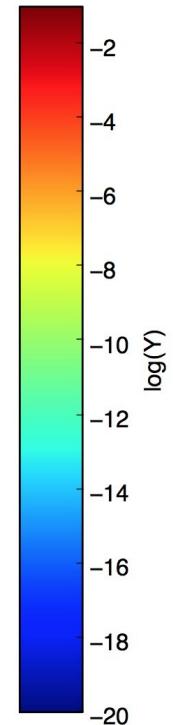
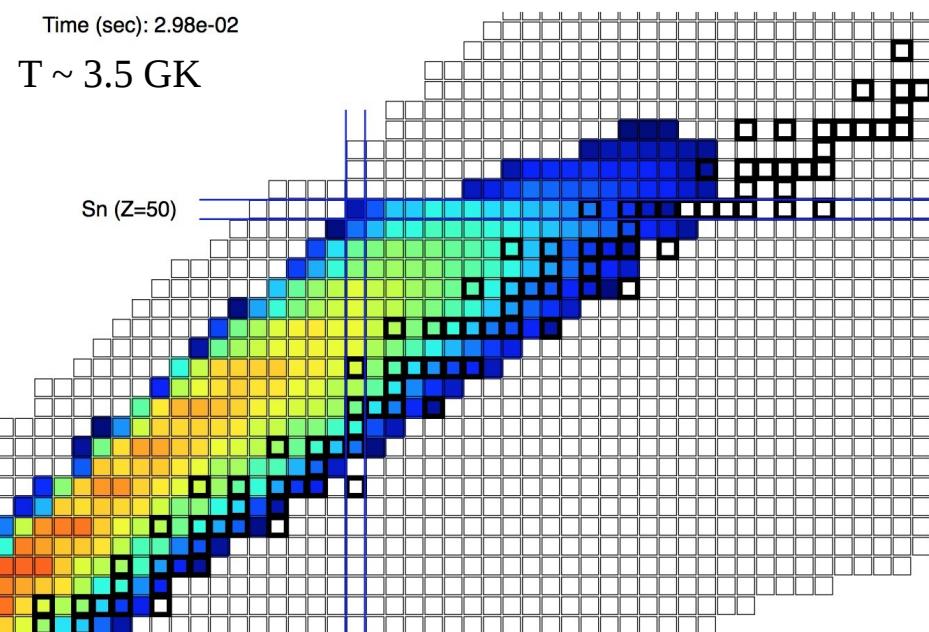
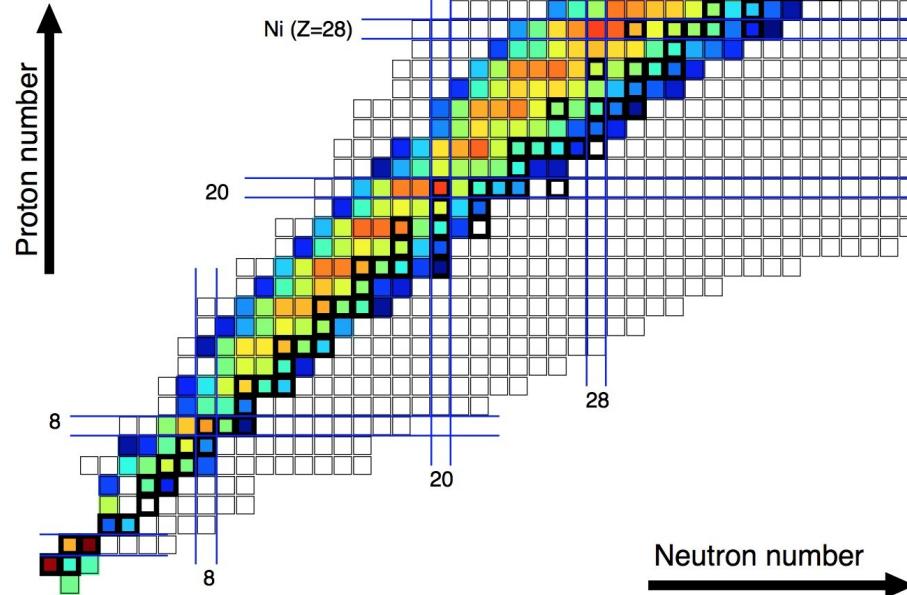
↳ up to  $Z \sim 30$

## vp-process:

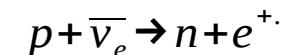
- Temperature:  $\sim 3 - 1$  GK

$p$ -capture  $\rightarrow (n, p)$

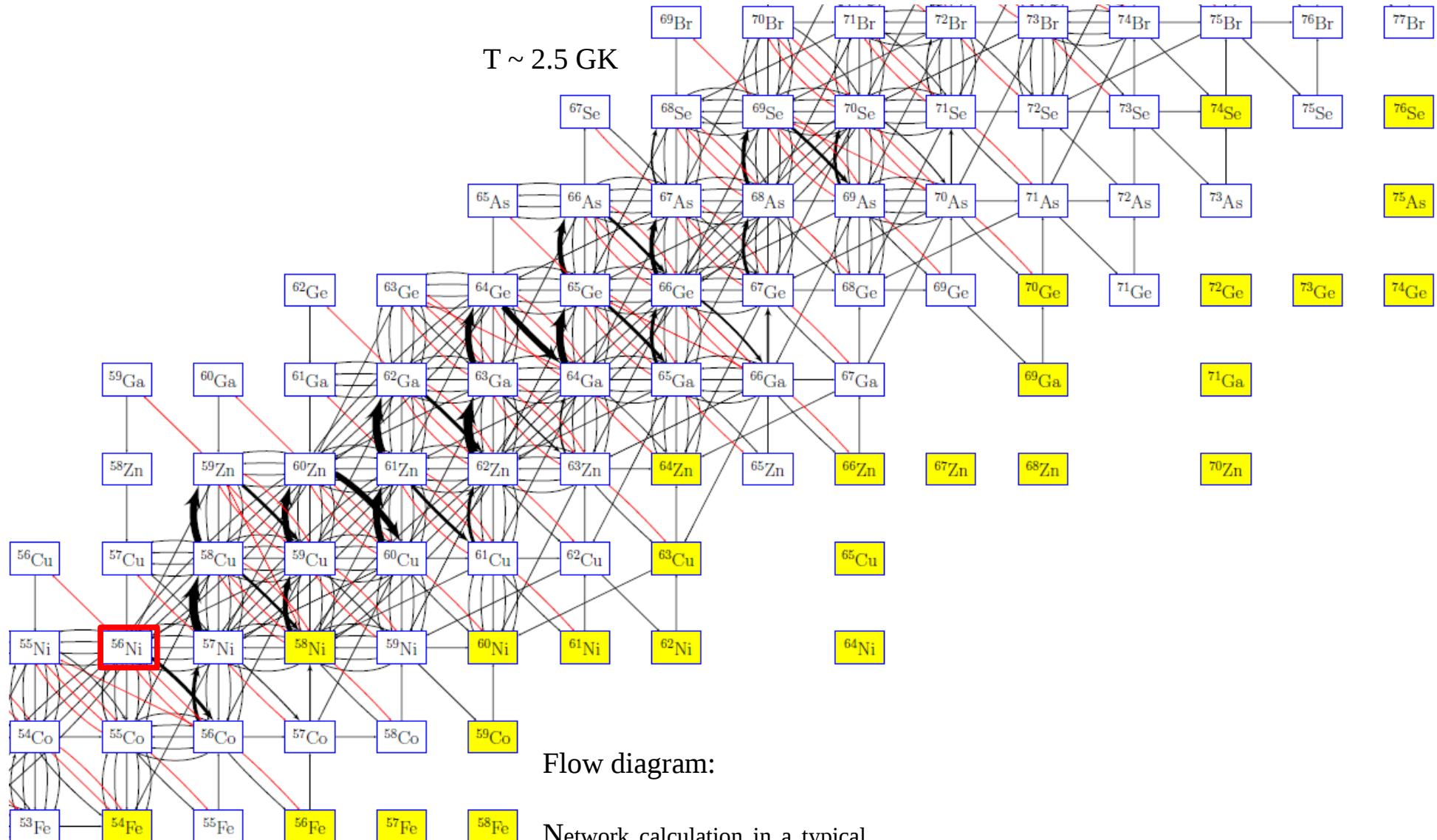
↳ up to  $Z \sim 50$



- Additional neutrons from:



# vp-process



Network calculation in a typical  
neutrino driven wind environment  
( $Y_e = 0.52$ ,  $S = 100 \text{ k}_b/\text{u}$ ,  $\tau = 2 \text{ ms}$ )

Code: **nucnet tools**

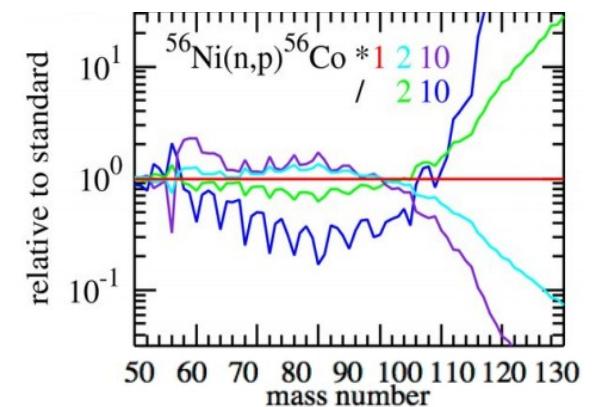
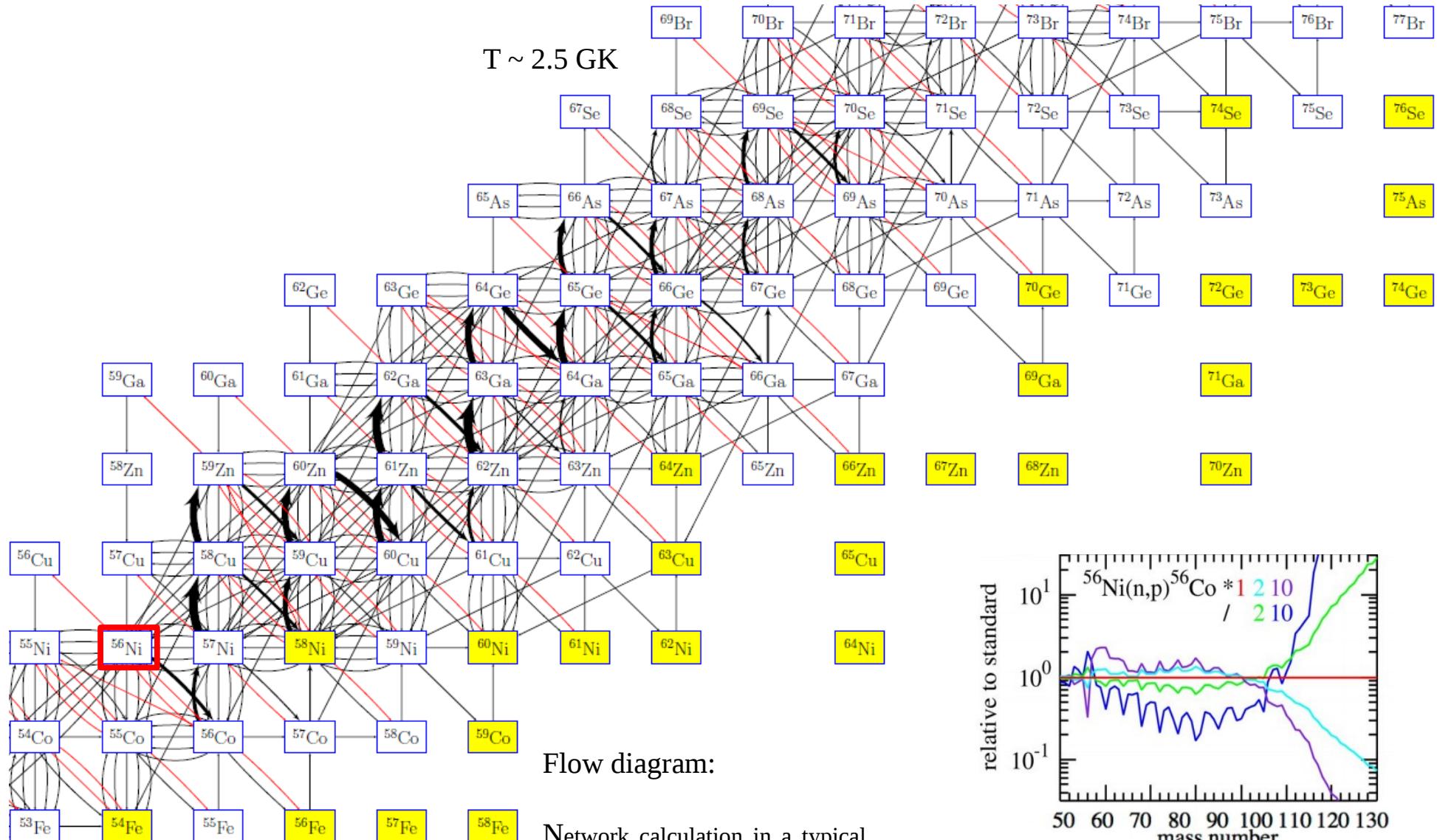


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# vp-process



S. Wanajo, et. al, The Astrophysical Journal, 729(1):46, (2011)

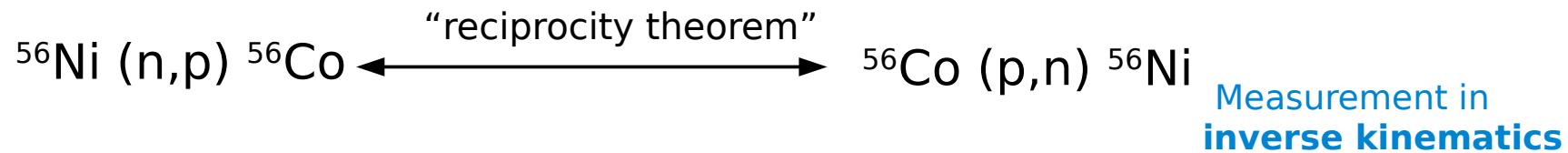


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# Constraining the reaction rates

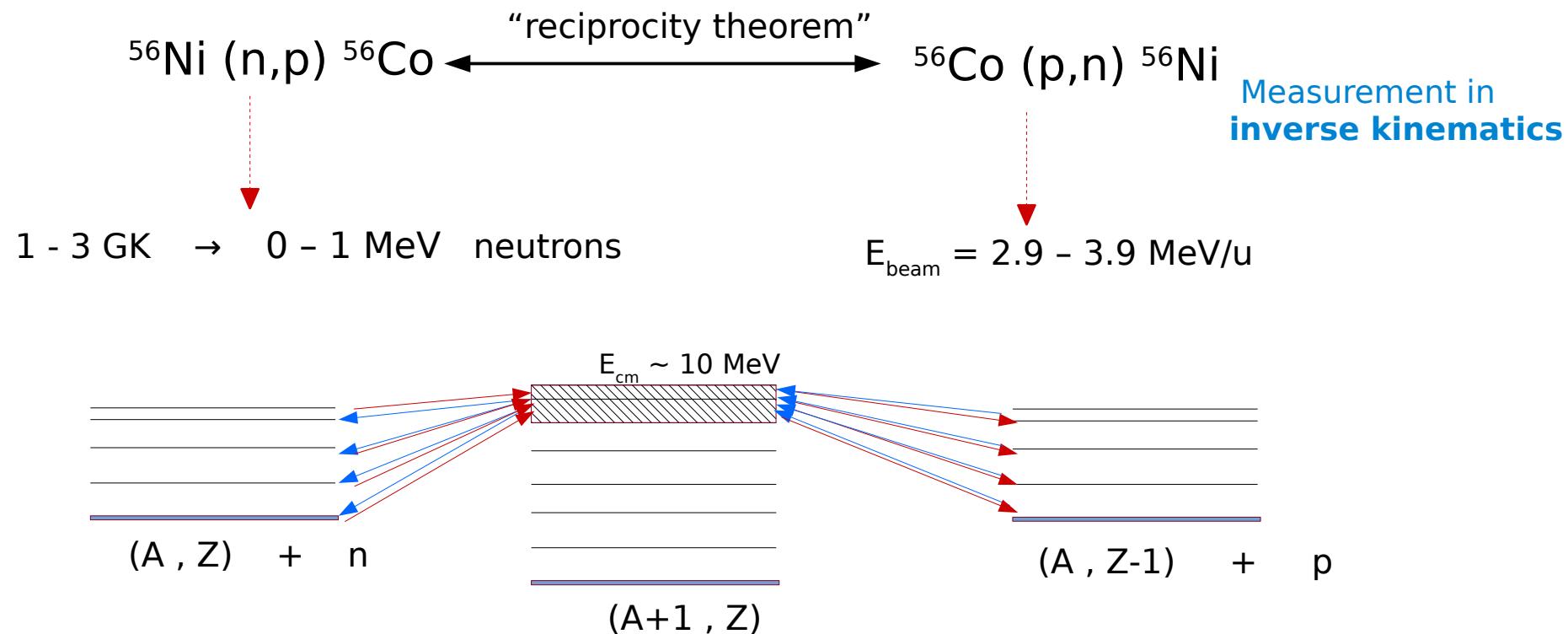


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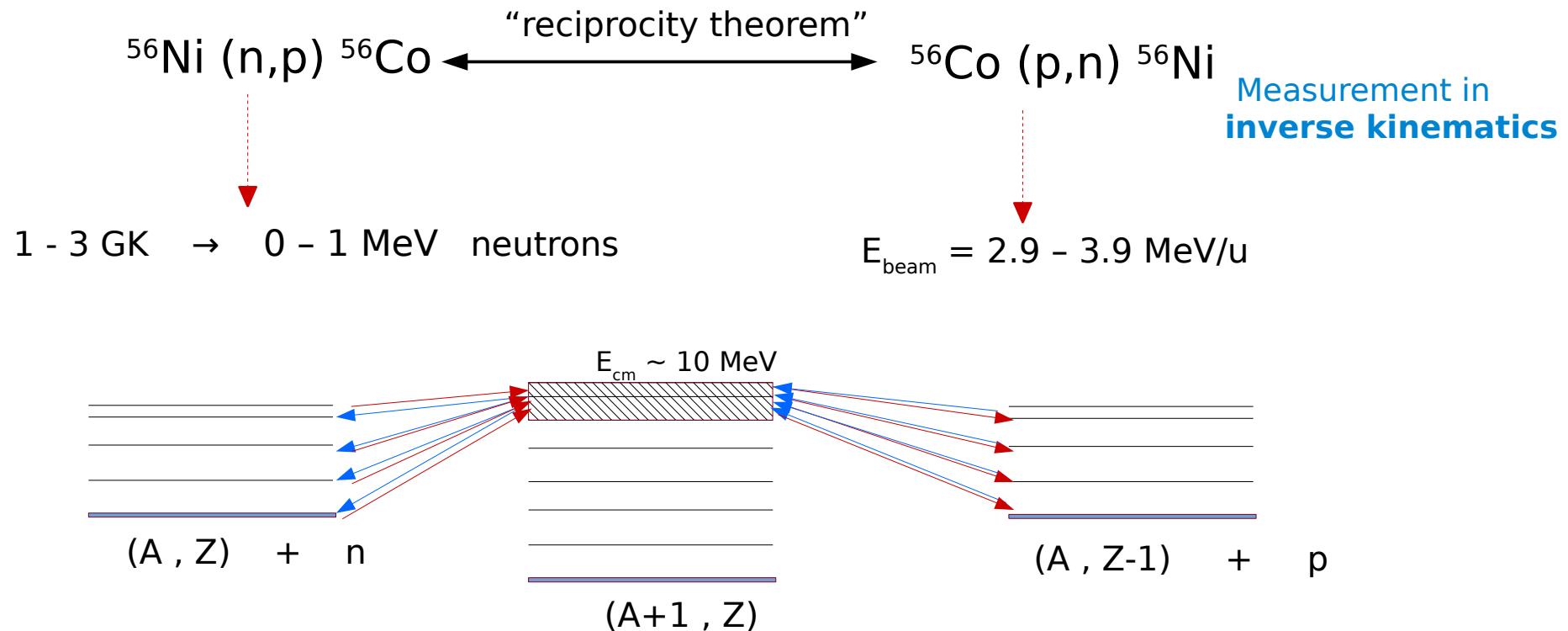


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# Constraining the reaction rates



## Limitations:

$$\sigma^{lab} = \sum_f \sigma^{0 \rightarrow f} \longrightarrow 18\% \text{ contribution from the g.s in our case}$$

From:

T. Rauscher and F-K Thielemann, Atomic Data and Nuclear Data Tables, 79(1):47-64, 2001

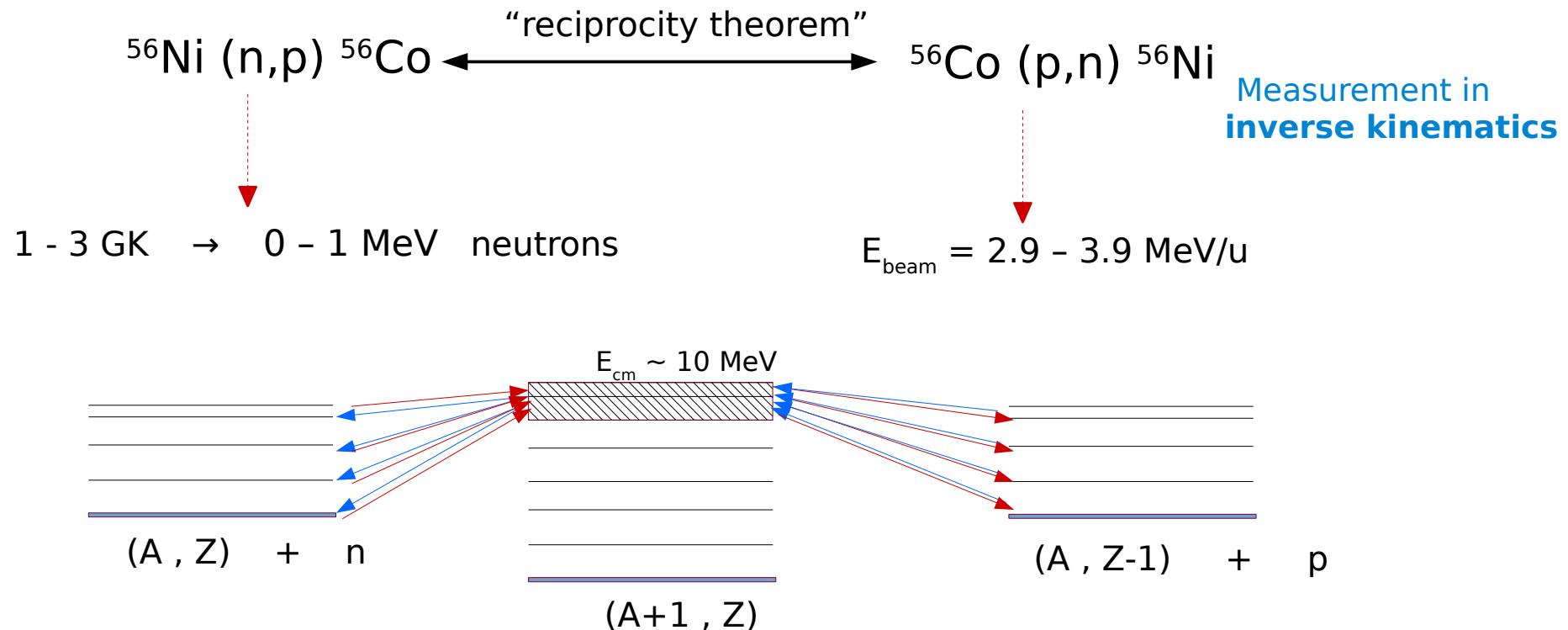


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# Constraining the reaction rates



## Limitations:

$$\sigma^{lab} = \sum_f \sigma^{0 \rightarrow f} \longrightarrow 18\% \text{ contribution from the g.s in our case}$$

We will find proper parameters  
to constrain the theoretical calculations

From:

T. Rauscher and F-K Thielemann, Atomic Data and Nuclear Data Tables, 79(1):47-64, 2001

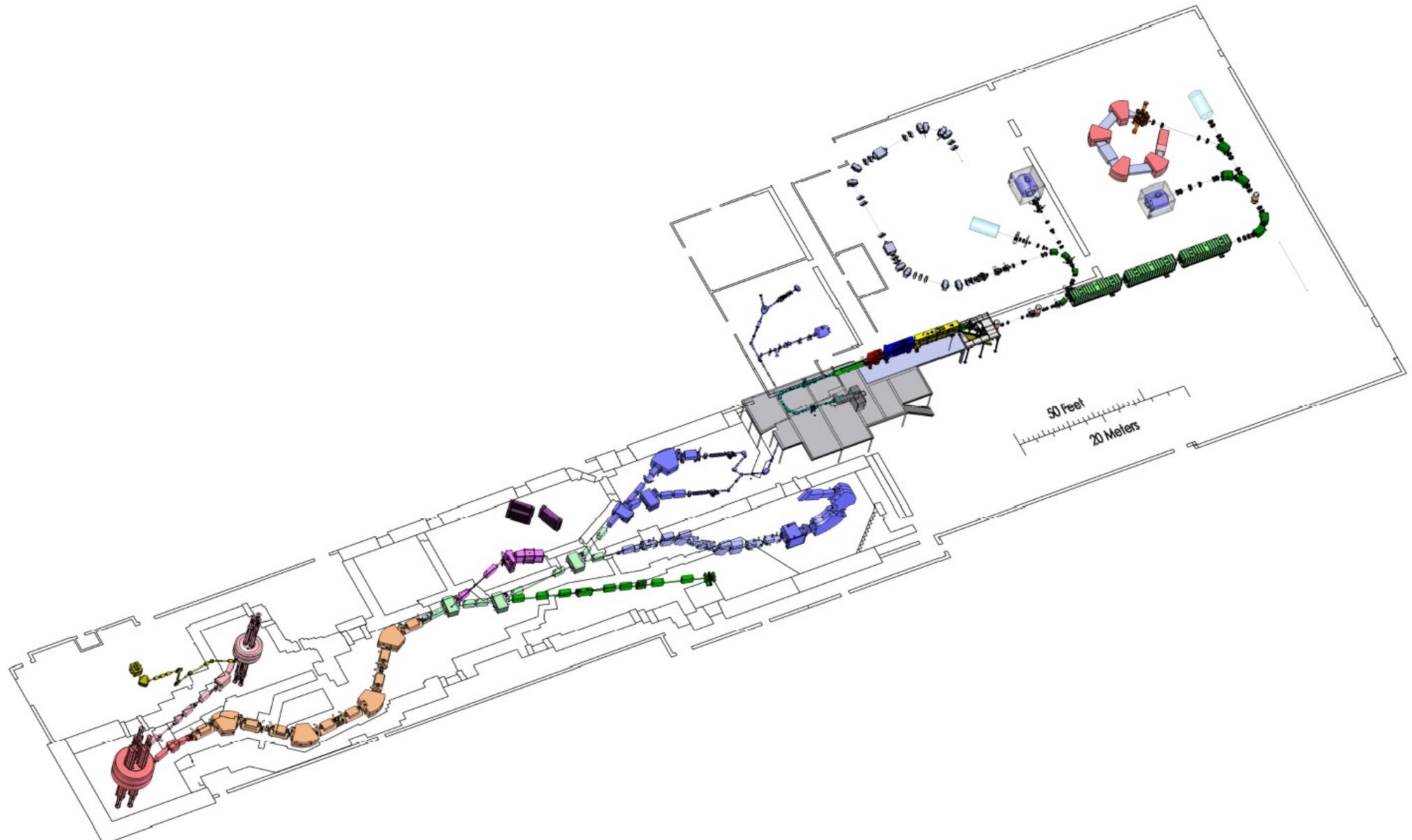


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# Layout of NSCL / ReA3



[https://people.nscl.msu.edu/~iwasaki/reas\\_layout.html](https://people.nscl.msu.edu/~iwasaki/reas_layout.html)

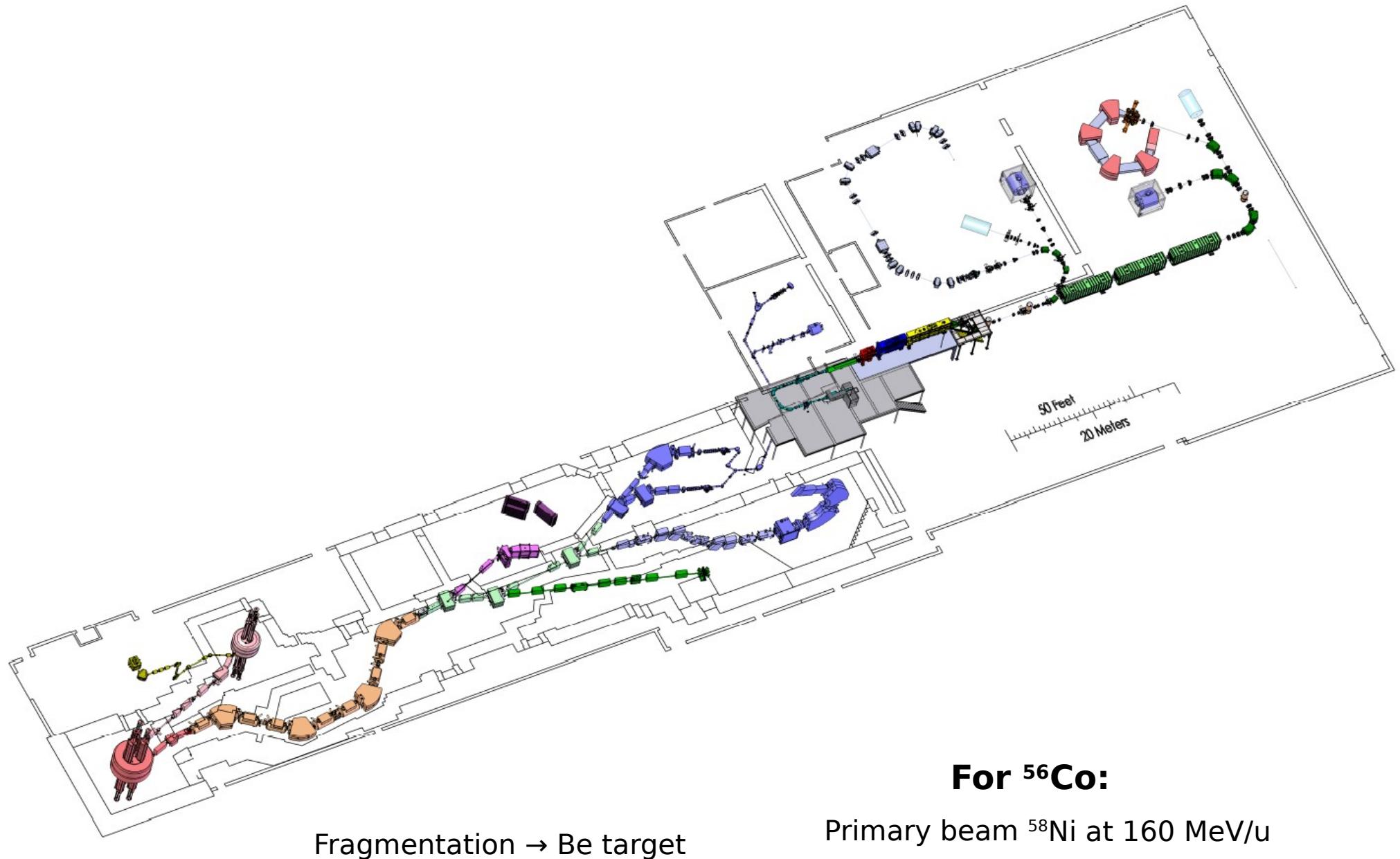


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# Layout of NSCL / ReA3



Fragmentation → Be target

For  $^{56}\text{Co}$ :

Primary beam  $^{58}\text{Ni}$  at 160 MeV/u

[https://people.nscl.msu.edu/~iwasaki/reas\\_layout.html](https://people.nscl.msu.edu/~iwasaki/reas_layout.html)

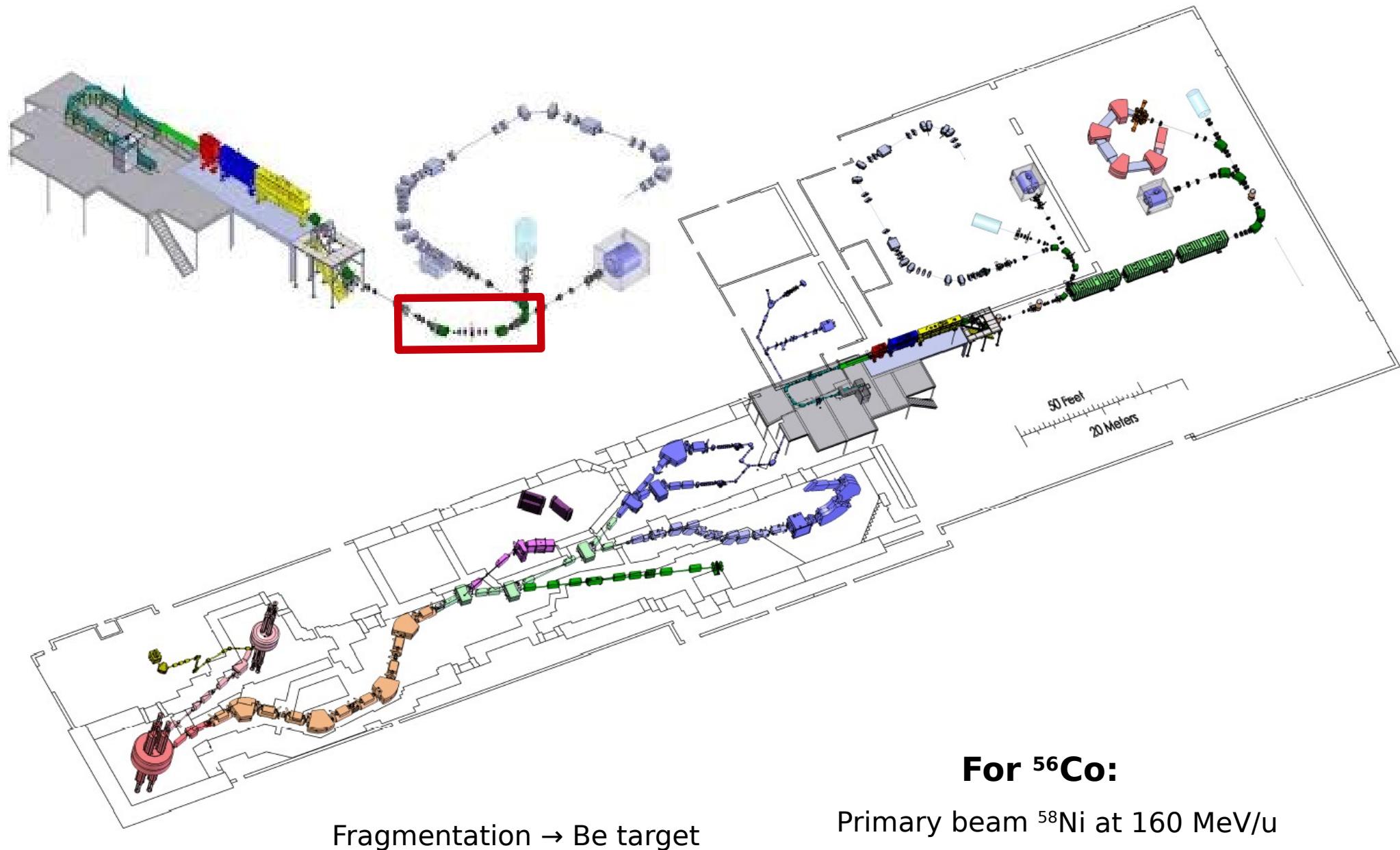


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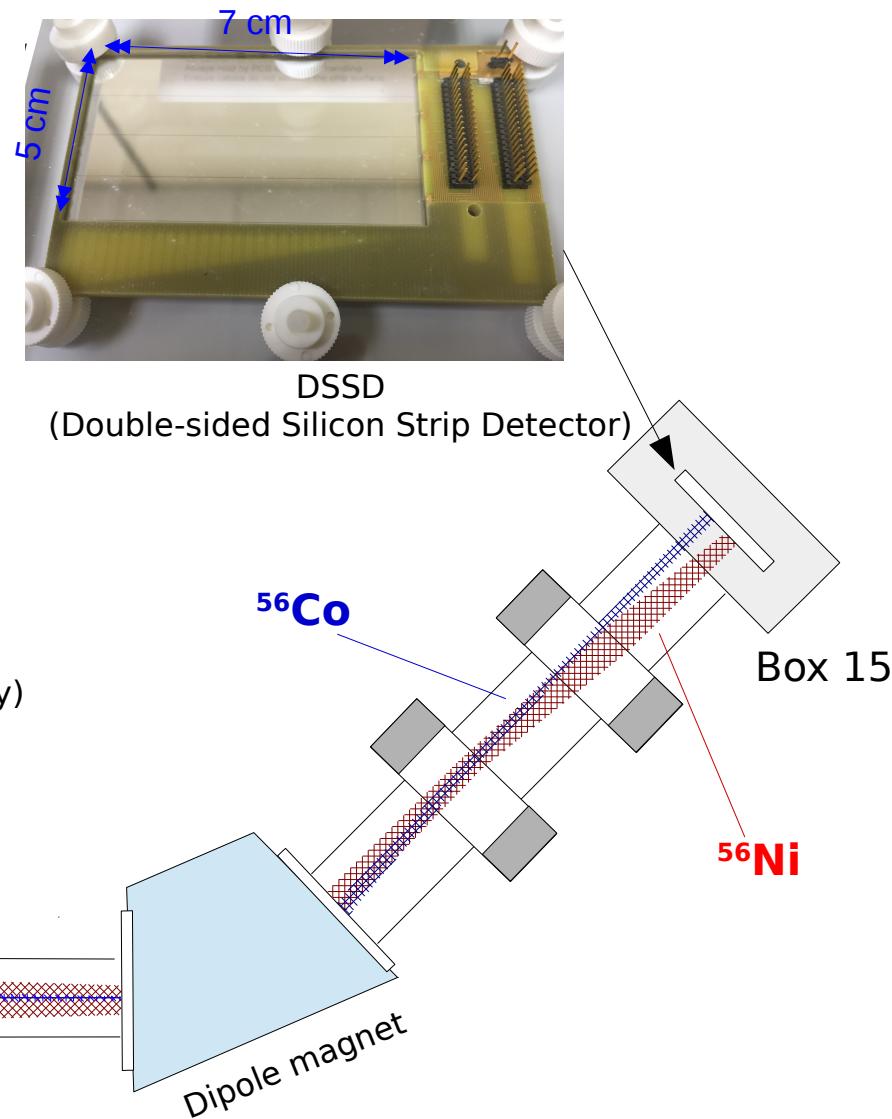
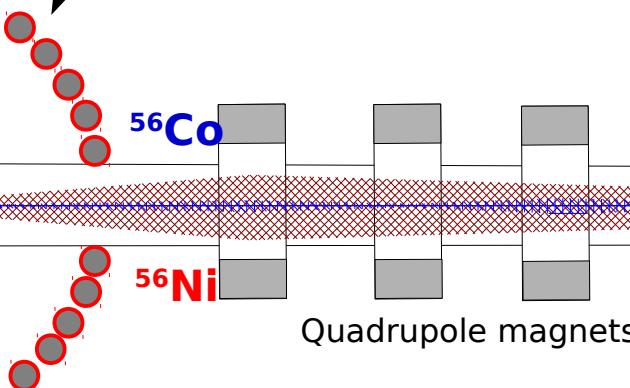
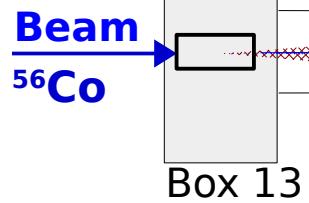
# Measurement of the p( $^{56}\text{Co}$ ,n) $^{56}\text{Ni}$ reaction at ReA3



Hydrogen gas-cell



LEND  
(Low Energy Neutron Detector Array)

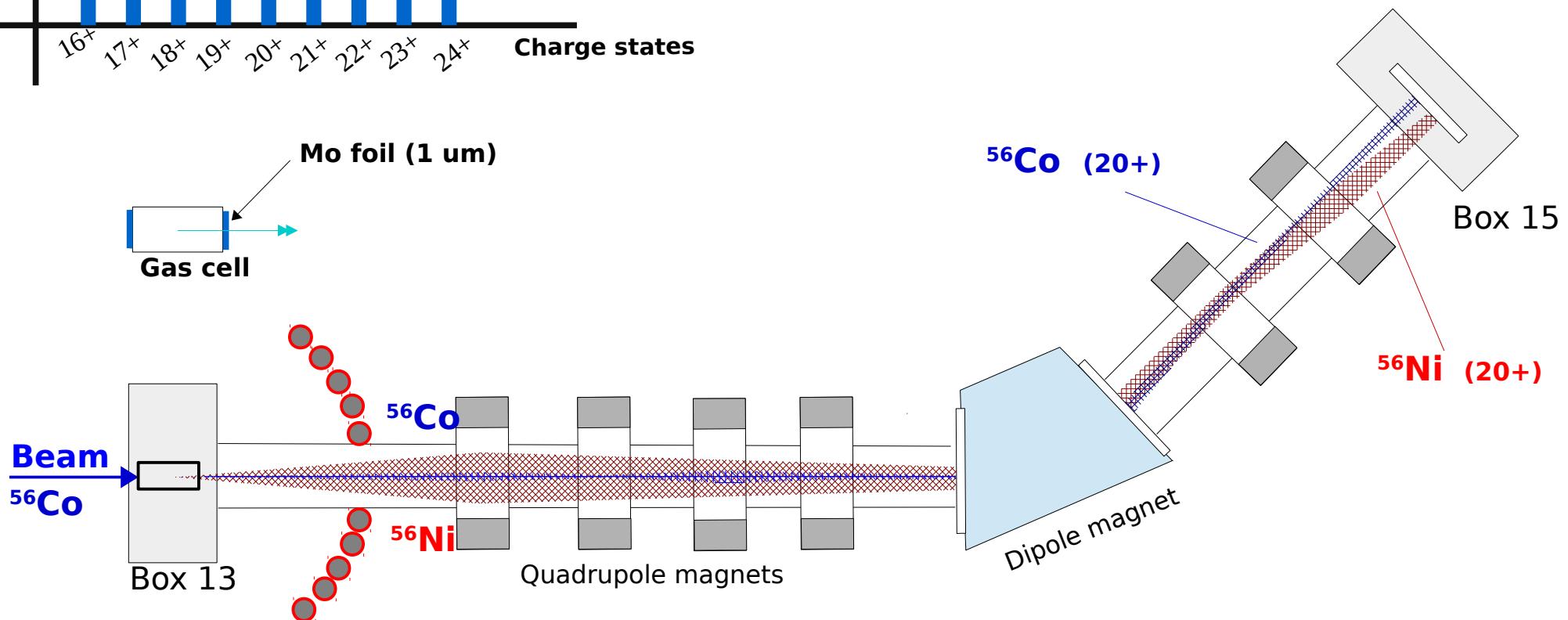
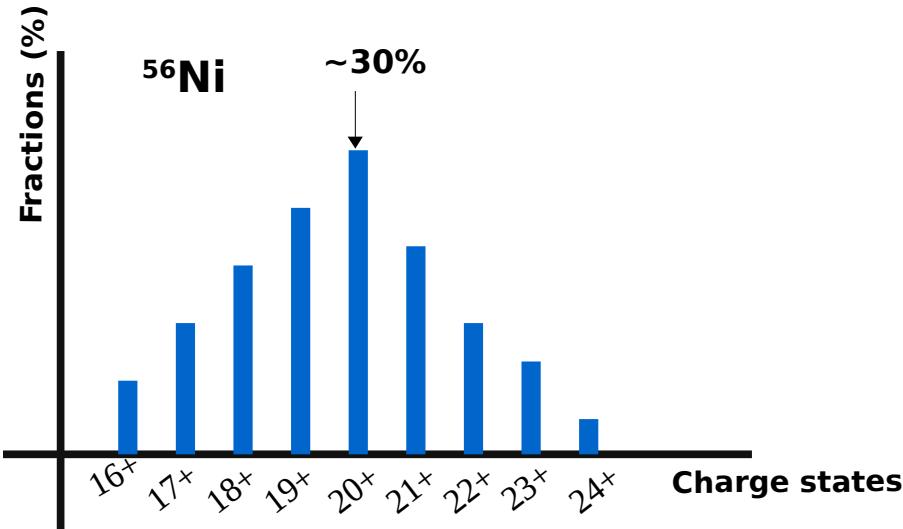


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# Measurement of the p( $^{56}\text{Co}$ ,n) $^{56}\text{Ni}$ reaction at ReA3



Review and evaluation of the models:  
P. Gastis, G. Perdikakis, et. al, NIMB 373, 117-125 (2016)

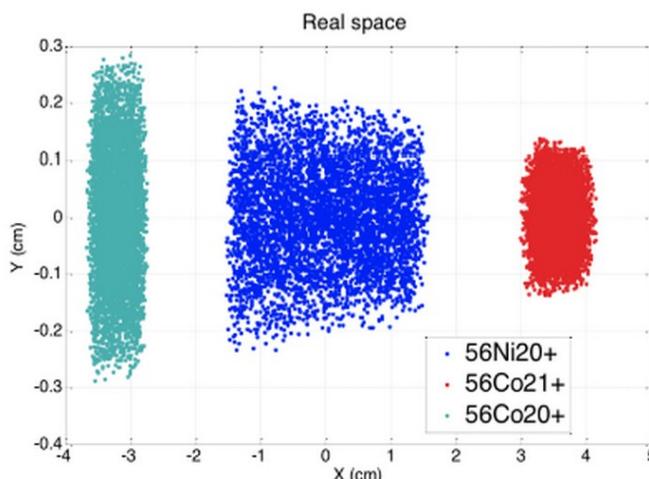
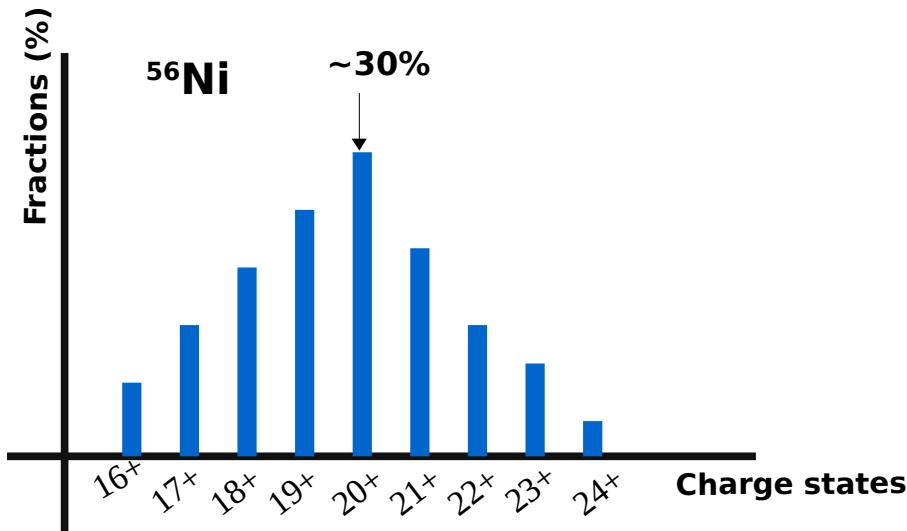


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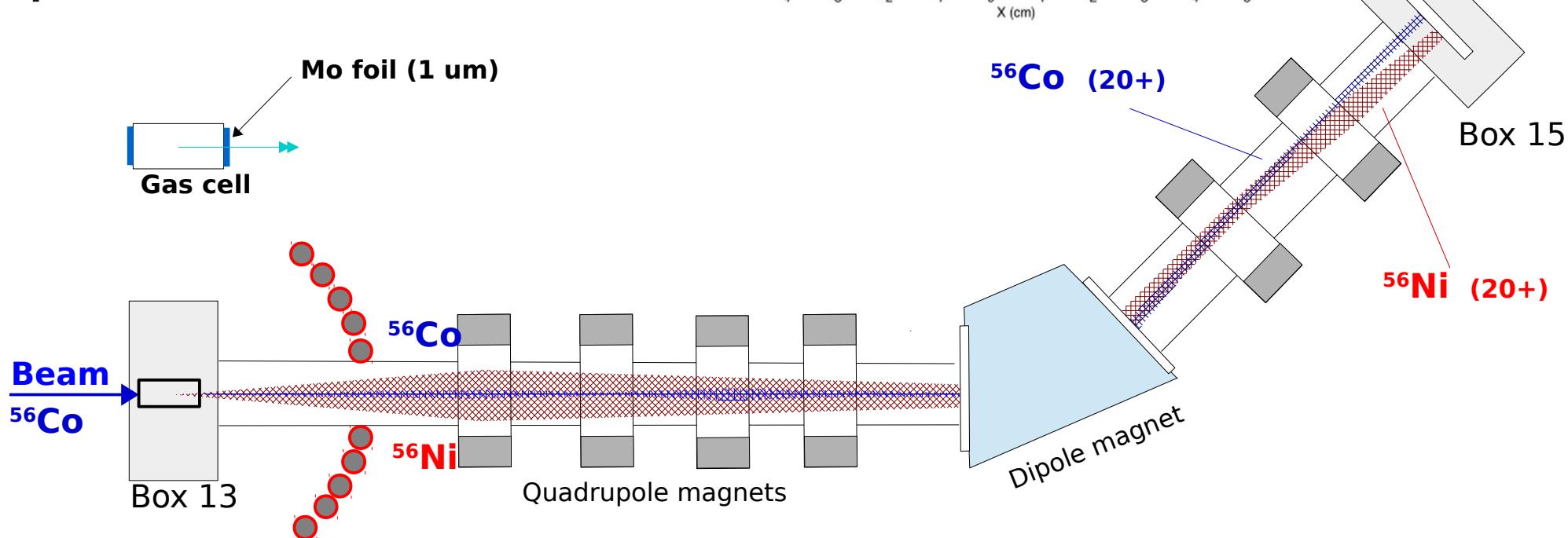


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# Measurement of the p( $^{56}\text{Co}$ ,n) $^{56}\text{Ni}$ reaction at ReA3



Calculation with  
DYNAC  
(by Ling-Ying Lin)



Review and evaluation of the models:  
P. Gastis, G. Perdikakis, et. al, NIMB 373, 117-125 (2016)

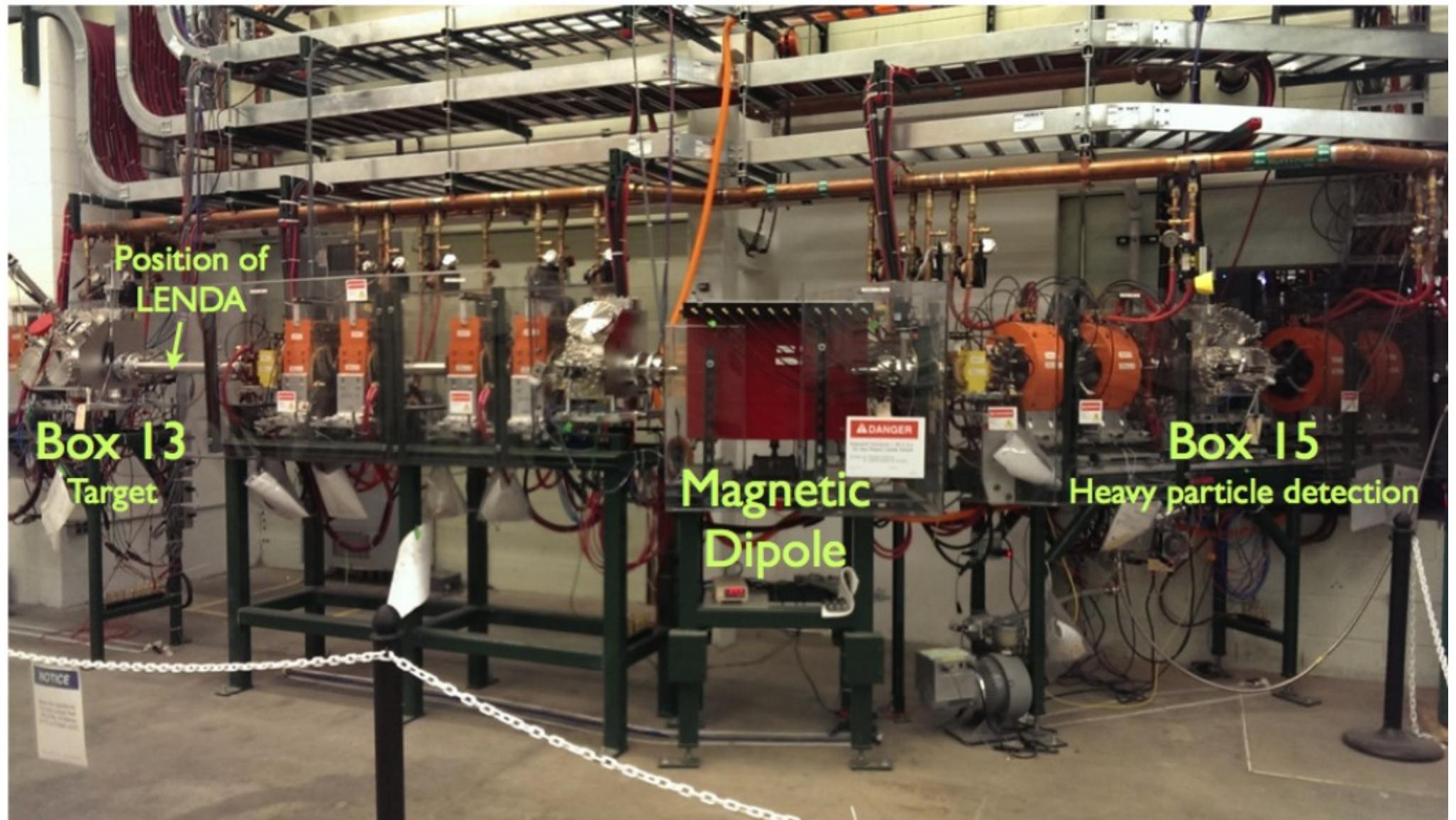


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# Measurement of the p( $^{56}\text{Co}$ ,n) $^{56}\text{Ni}$ reaction at ReA3



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## Summary

- **For the first time we attempt to measure (p,n) reactions relevant to the vp-process**
- **From the results on the (p,n) reaction**
- **More measurements needed on key reactions along the vp-process path [e.g.  $^{64}\text{Ge}(\text{n},\text{p})^{64}\text{Ga}$ ]**
  - **Reducing the uncertainties in the nuclear physics input is crucial**



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## Summary

- For the first time we attempt to measure (p,n) reactions relevant to the vp-process
- From the measurements key parameters for the theoretical calculations will be extracted
- More measurements needed on key reactions along the vp-process path [e.g  $^{64}\text{Ge}(\text{n},\text{p})^{64}\text{Ga}$ ]
  - Reducing the uncertainties in the nuclear physics input is crucial

## Next steps

- Run test experiment with Ar beam at 4 MeV/u. Measure the  $^{40}\text{Ar}(\text{p},\text{n})^{40}\text{K}$  (November 2016)  
(Test the experimental technique)
- Run the final experiment [  $^{56}\text{Co}(\text{p},\text{n})^{56}\text{Ni}$  ] (2017)

# Collaborators

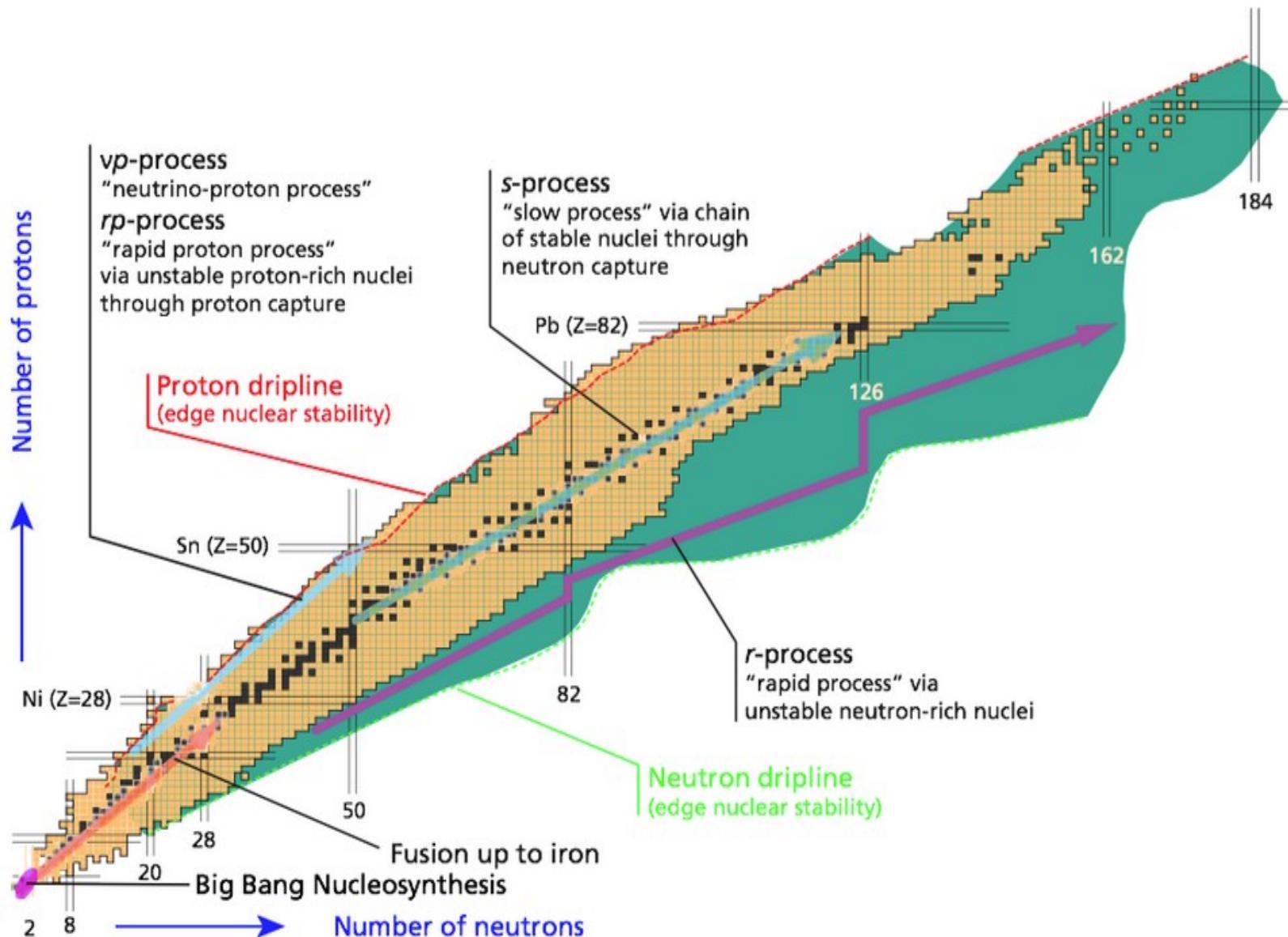
**G. Perdikakis, C. Frohlich,**  
D. Alt, K. M, Ahmed, J. A. Davison, M. Horoi, A. Kontos, Ling-Ying Lin,  
A. K. Mamnum, F. Montes, S. Nikas, T. Redpath, M. Redshaw, R. Senkov,  
A. Spyrou, A. Villari, K. Wimmer, R. Zegers





**Thank you for your attention!**

# Introduction



<https://inspirehep.net/record/860811/plots>

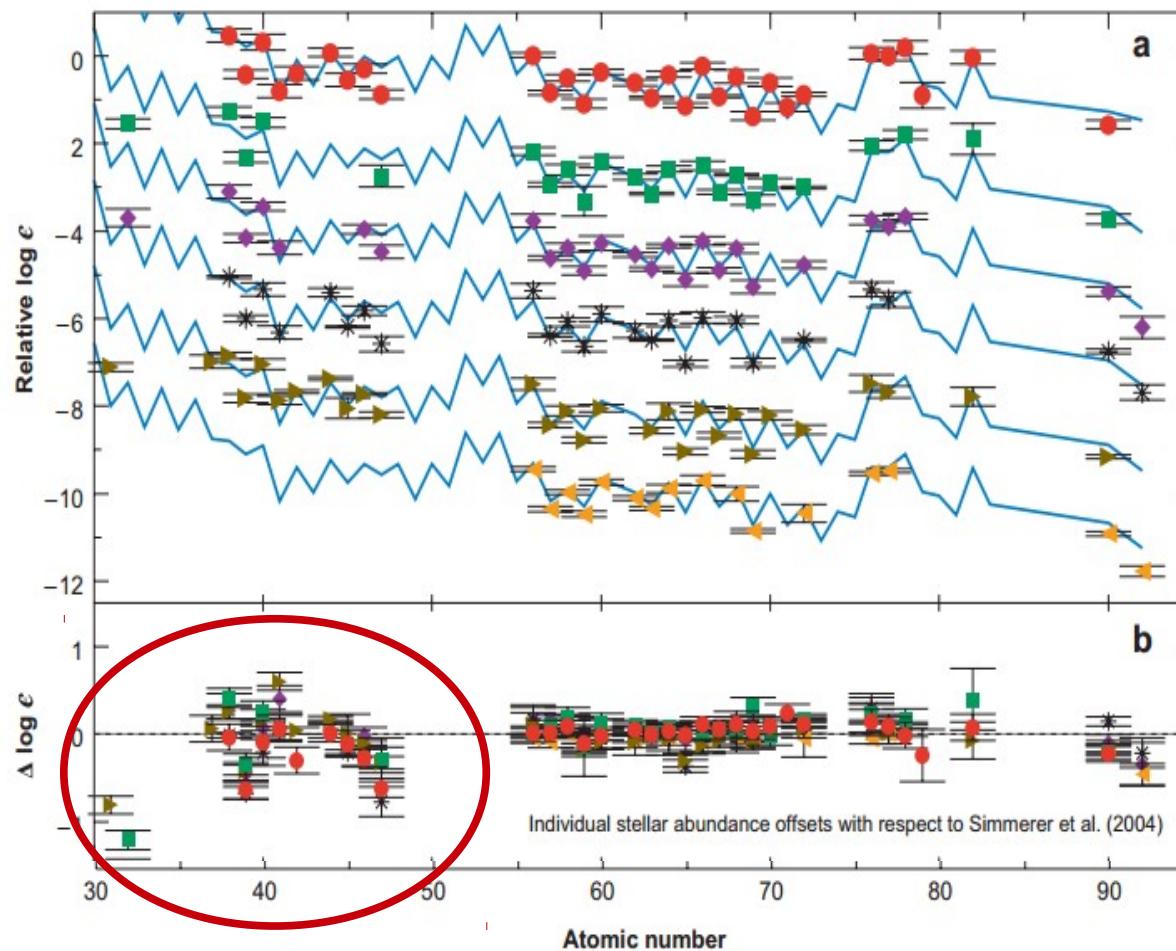


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# Abundances of light elements ( $Z>26$ ) in metal poor stars



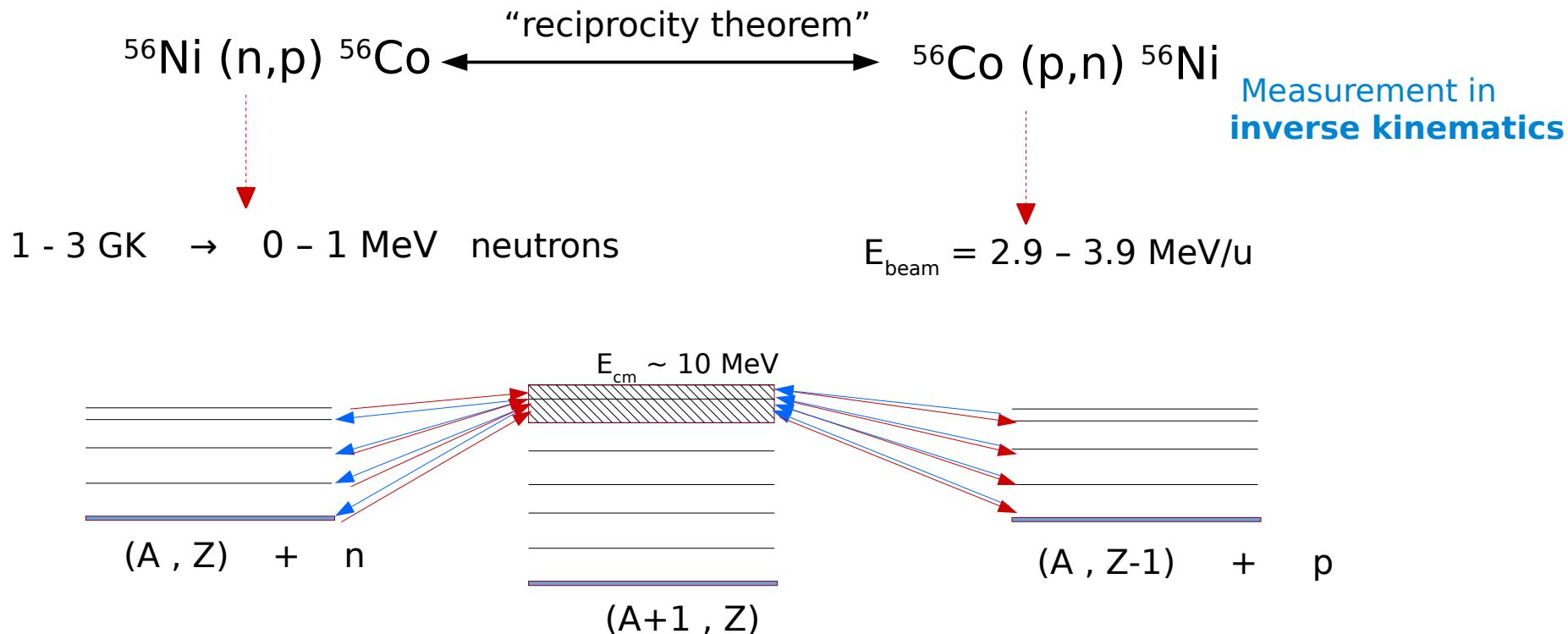
- CS 22892-052: Sneden et al. (2003)
- HD 115444: Westin et al. (2000)
- ▲ BD+17°324817: Cowan et al. (2002)
- \* CS 31082-001: Hill et al. (2002)
- ▶ HD 221170: Ivans et al. (2006)
- ◀ HE 1523-0901: Frebel et al. (2007)

**LEPP**  
(Light Element  
Primary Process)

→ Sr, Y, Zr  
peaks

From: C. Sneden, J. J. Cowan, and R. Gallino, Annu. Rev. Astrophys. 2008, 46:241-288

# Constraining the reaction rates



Reaction rate:  $R \propto \int_0^{\infty} \sigma^{\text{eff}}(E) \Phi_{MB}(E, T) dE$

$$\sigma^{\text{eff}}(E) = \sum_i \sum_f \frac{2J_i + 1}{2J_o + 1} \frac{E - E_i}{E} \sigma^{i \rightarrow f}(E - E_i)$$

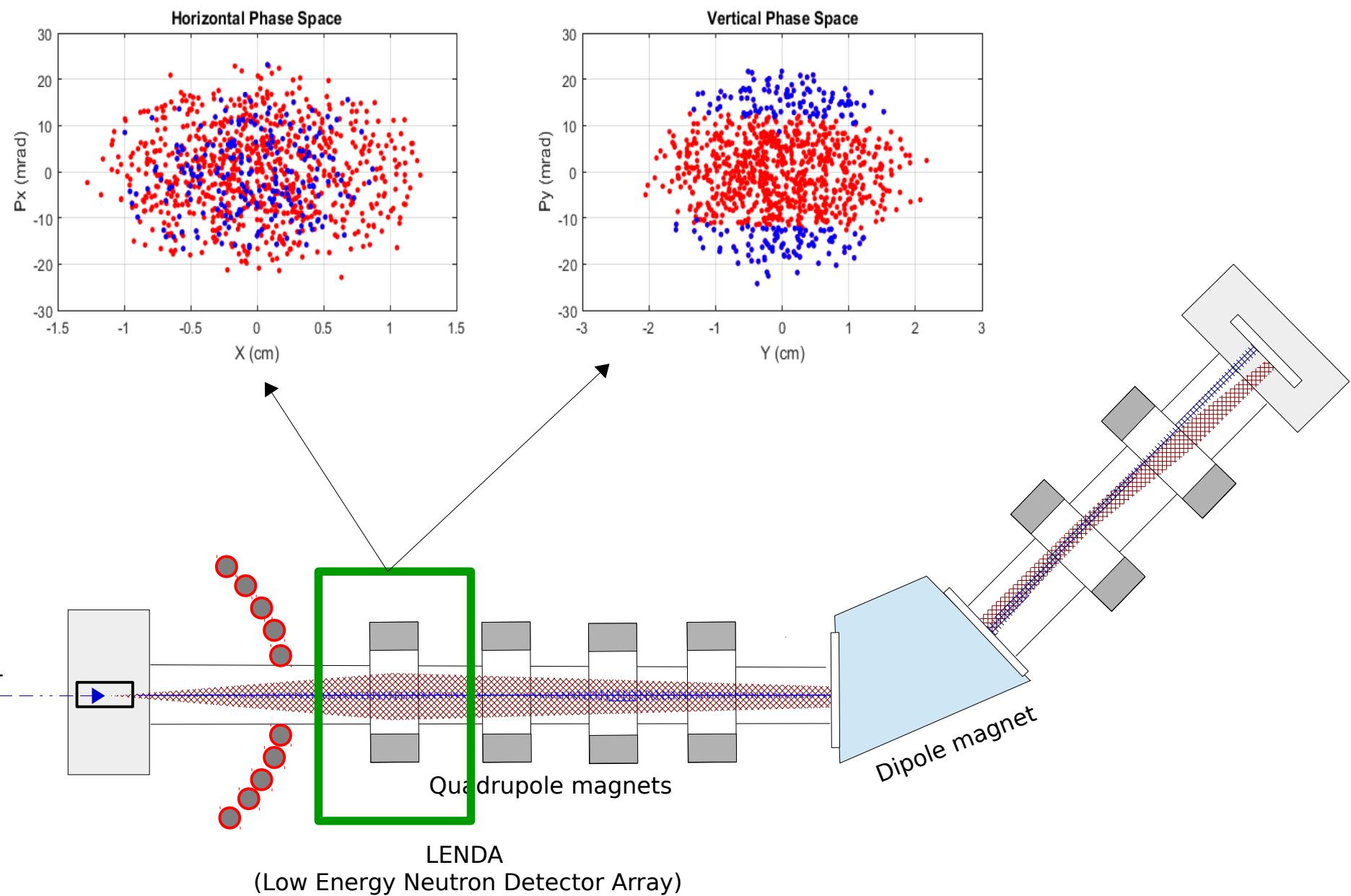
## Limitations:

$[\sigma^{\text{lab}} \neq \sigma^{\text{eff}}]$        $\sigma^{\text{lab}} = \sum_f \sigma^{0 \rightarrow f}$        $\rightarrow$  18% contribution from the g.s in our case

From:

T. Rauscher and F-K Thielemann, Atomic Data and Nuclear Data Tables, 79(1):47-64, 2001

# EXTRA

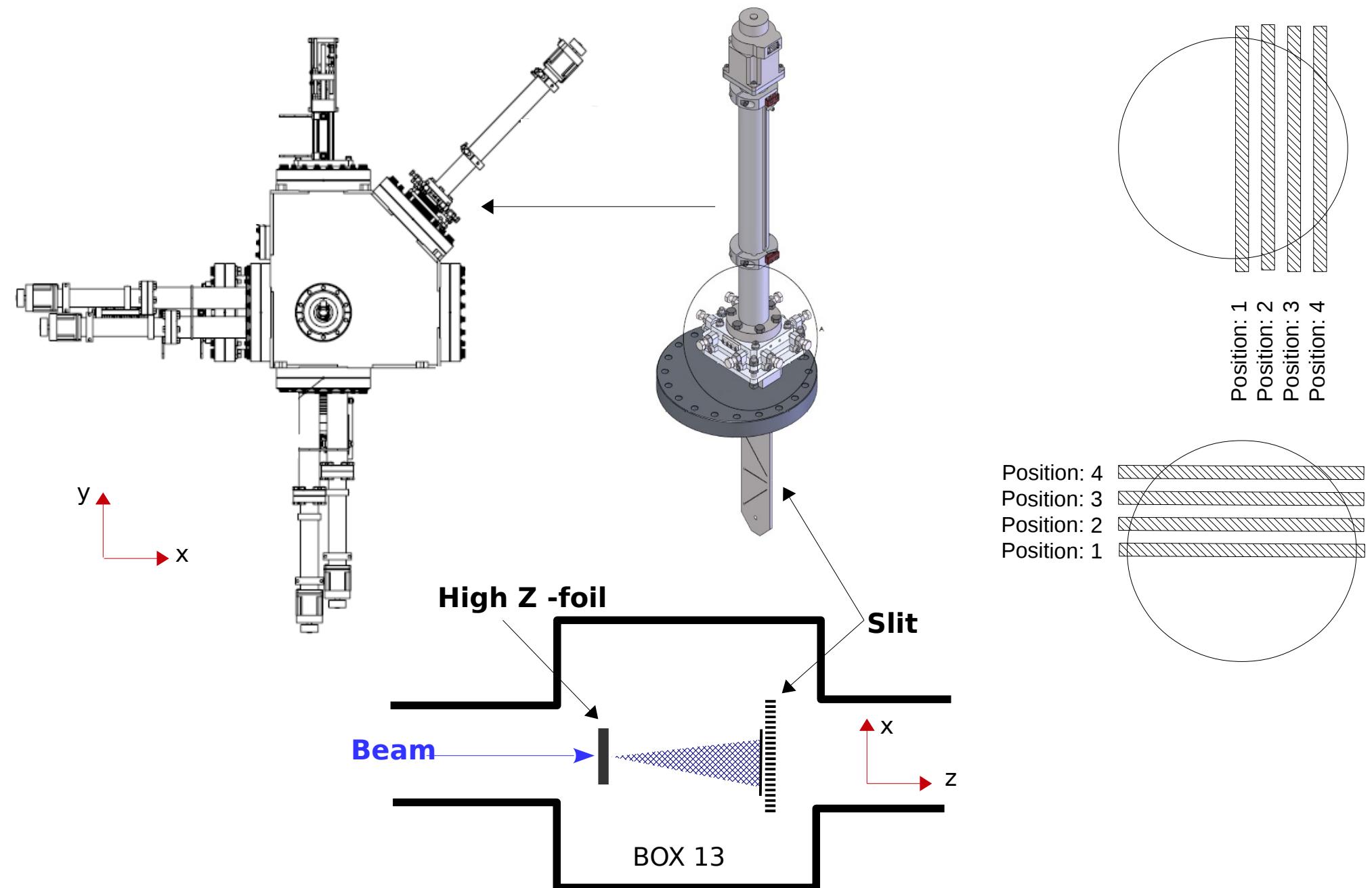


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# Acceptance measurements – EXTRA

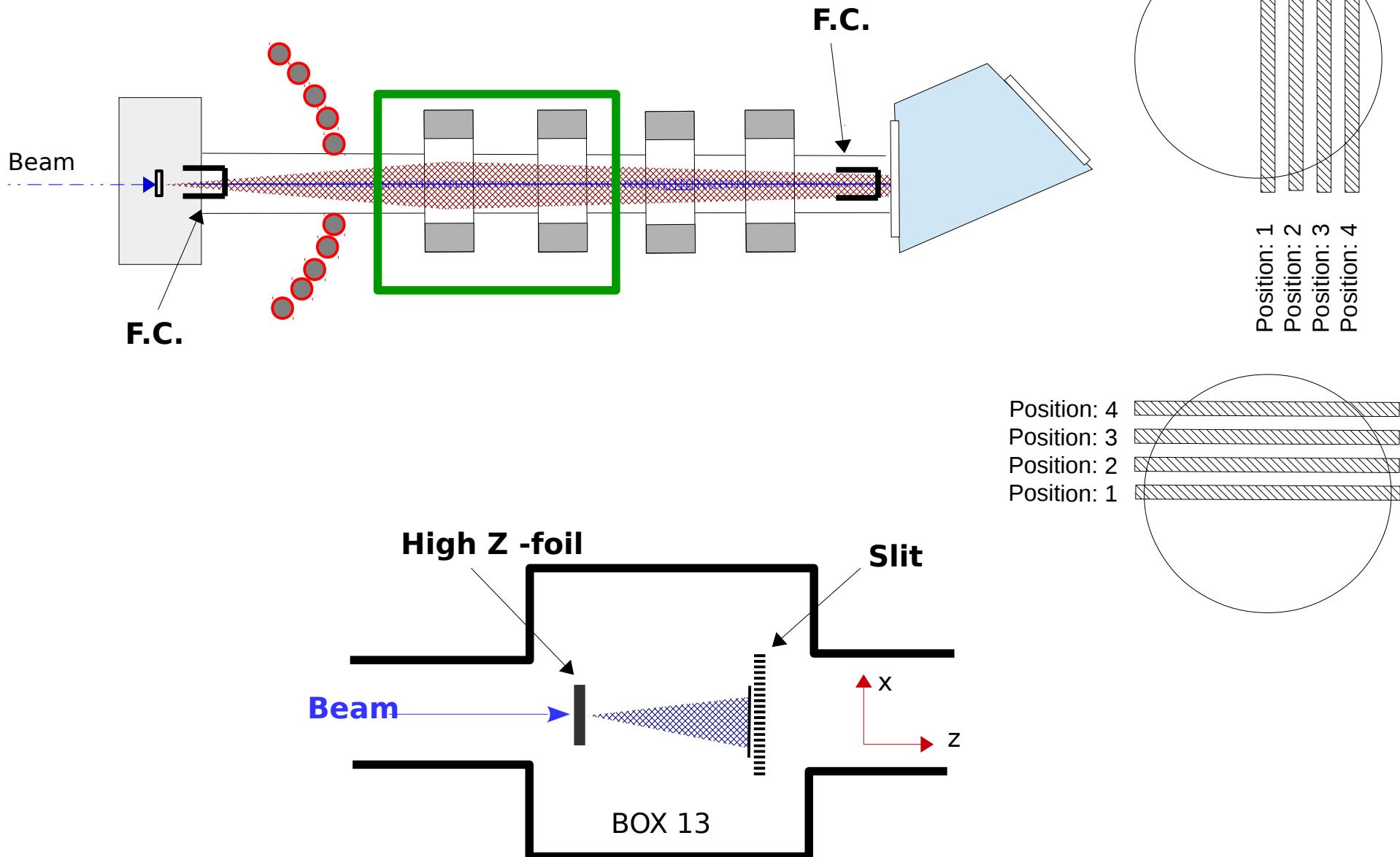


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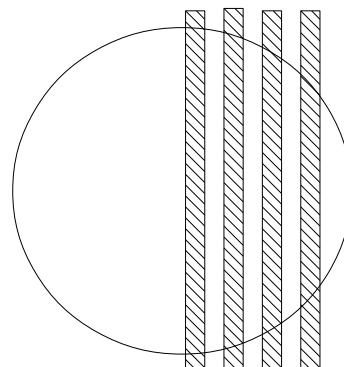
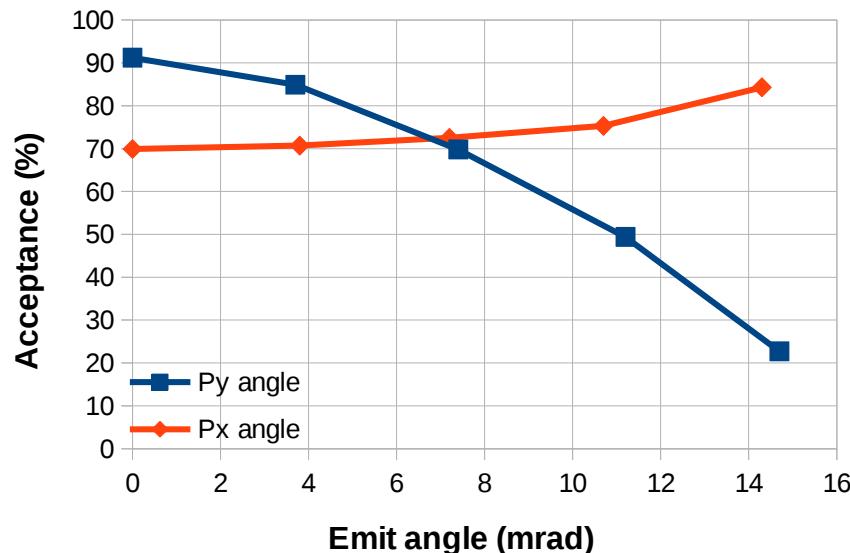
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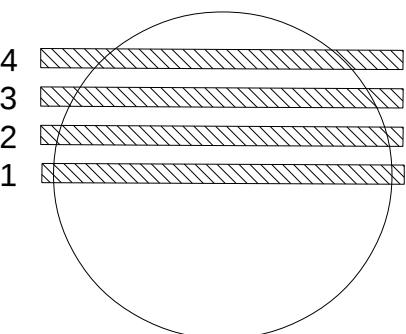
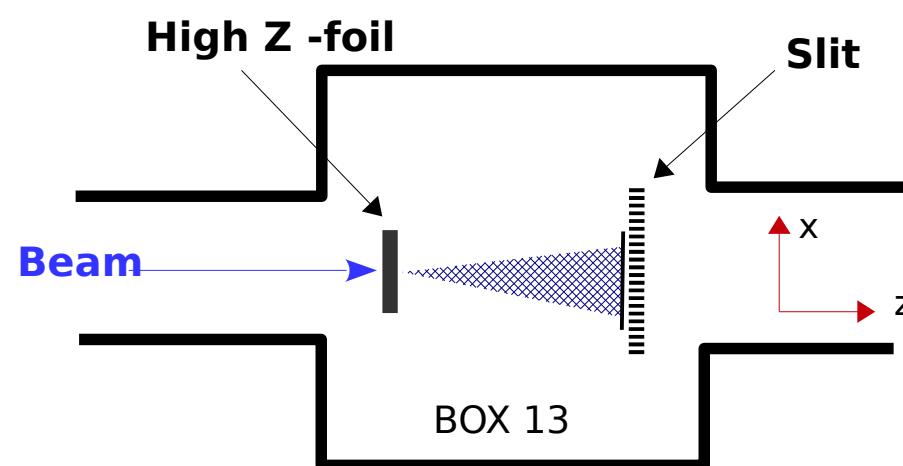
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# Acceptance measurements – EXTRA

## Simulation with DYNAC

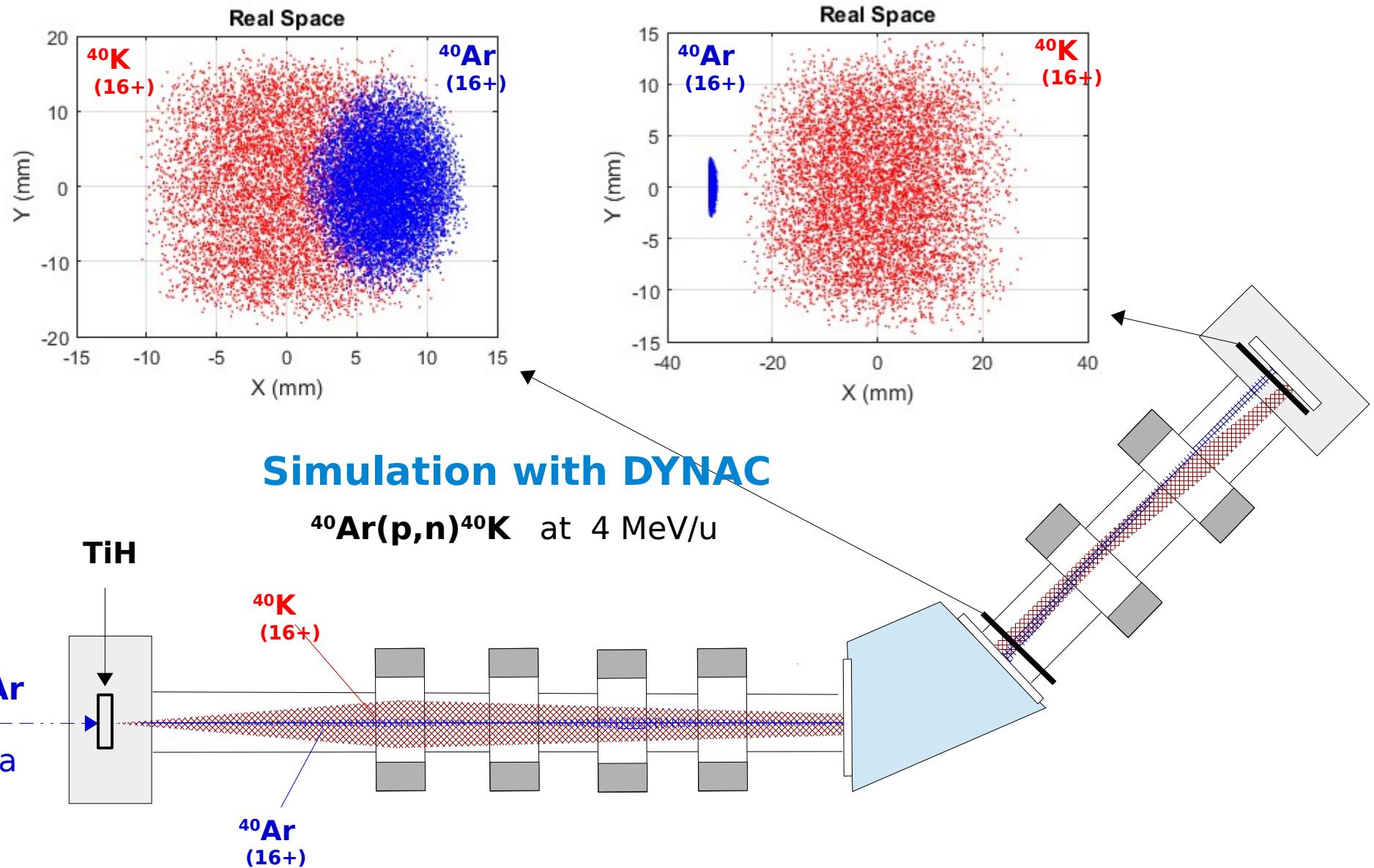


Position: 1  
Position: 2  
Position: 3  
Position: 4



Position: 4  
Position: 3  
Position: 2  
Position: 1

# EXTRA

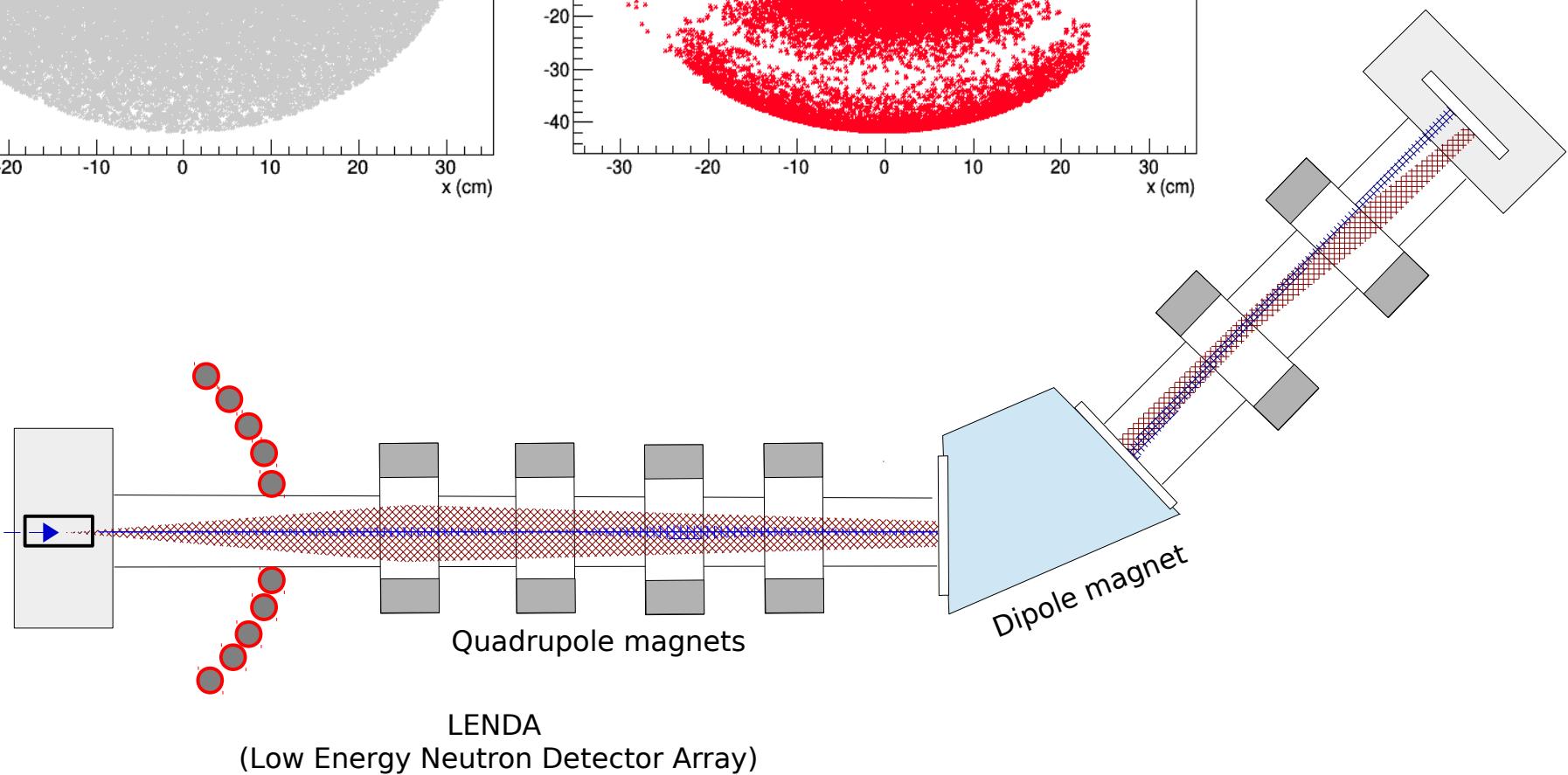
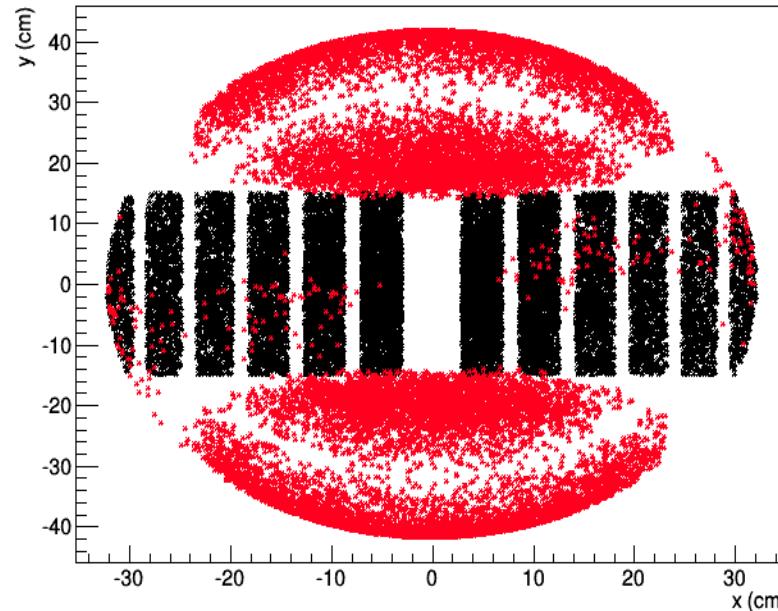
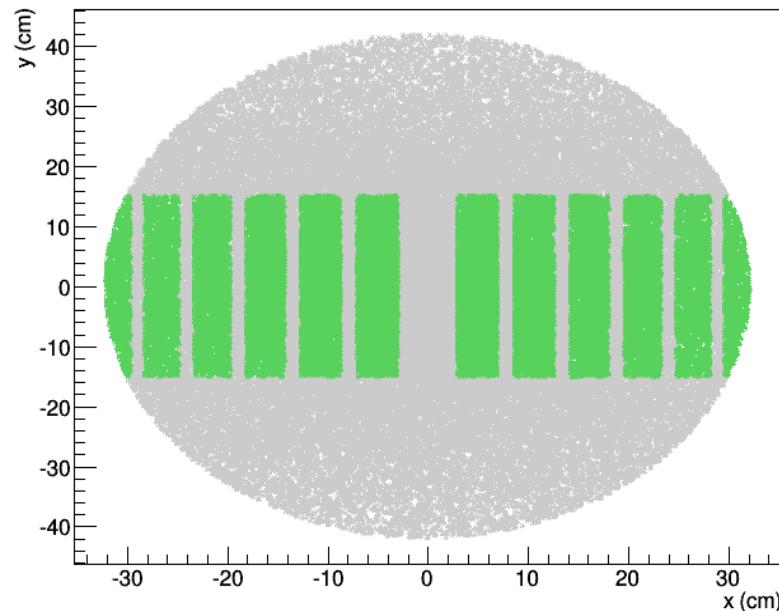


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# EXTRA



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