Measurement of isospin diffusion using residue

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Washington
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Louisiana
Florida
Alaska
Hawaii
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New Jersey
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Virginia
North Carolina
South Carolina

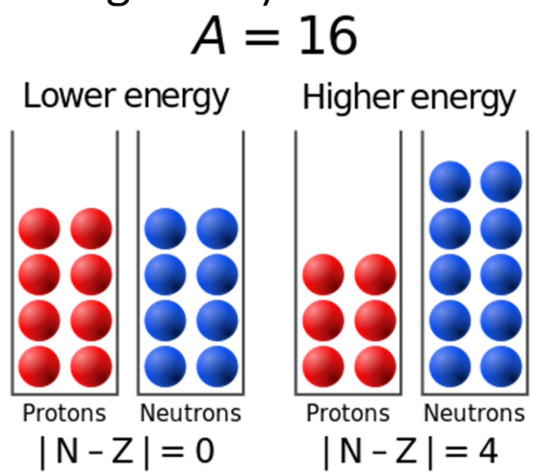
NSCL (National Superconducting Cyclotron Laboratory)

My “office”

Motivation

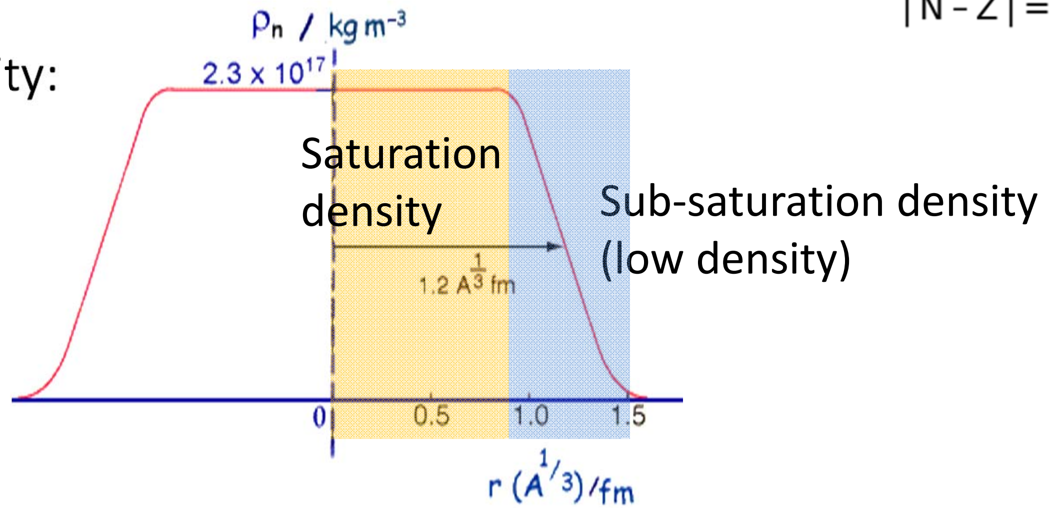
- Nucleus want to have equal number of proton and neutron due to Pauli exclusion principle (if other effects like coulomb force are ignored)
- Liquid drop model:

$$E_B = a_V A - a_S A^{2/3} - a_C \frac{Z^2}{A^{1/3}} - \boxed{a_A \frac{(A-2Z)^2}{A}} - \delta(A,Z)$$



(A)symmetric term: Reduction in binding energy as number of neutrons and protons are different, i.e. asymmetric

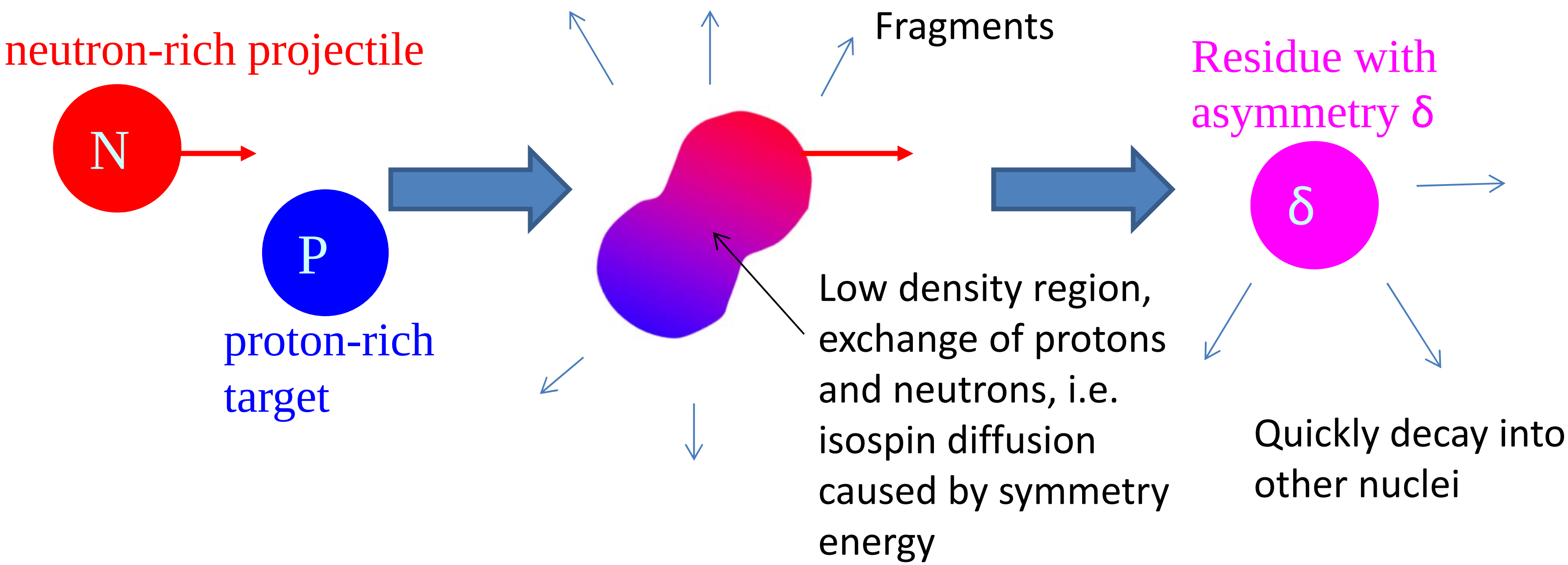
- Nuclear density:



- GOAL: Study the ***density dependent*** of ***(a)symmetric term*** in nuclear EOS.

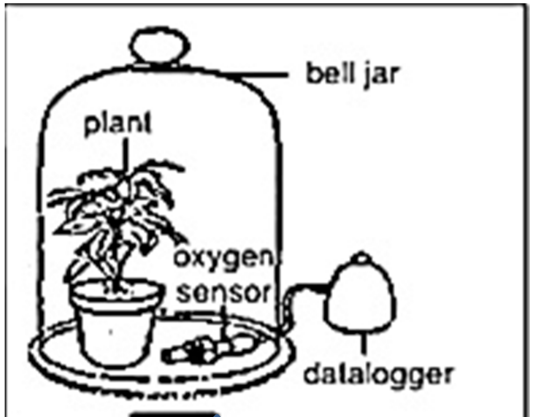
Motivation

- Nuclei of different neutron excess (N-Z) are collided. Protons and neutrons are exchanged during the collision
- Asymmetry term says that number of neutron of reside of projectile and target should be the same for lowest energy (**equilibrium**)
- We study the term in low density (i.e. skin of nuclei). They barely touch each other and don't have much interaction, so number of neutron of residue of projectile is closer to the projectile than equilibrium

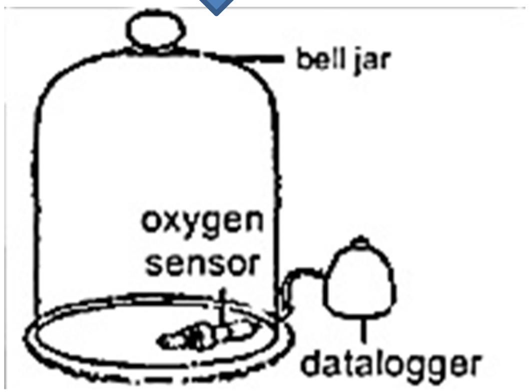


Study asymmetric term

- Lots of terms in nuclear EOS → Effects other than asymmetric term is present, cannot understand the sole effect of the desire term.
- Solution: Control experiment



Compare → Effect of the presence of plant can be studied



Symmetric system:

$^{112}Sn + ^{112}Sn$

$^{118}Sn + ^{118}Sn$

$^{124}Sn + ^{124}Sn$

Compare → Effect of the change in asymmetry can be studied

Mixed system:

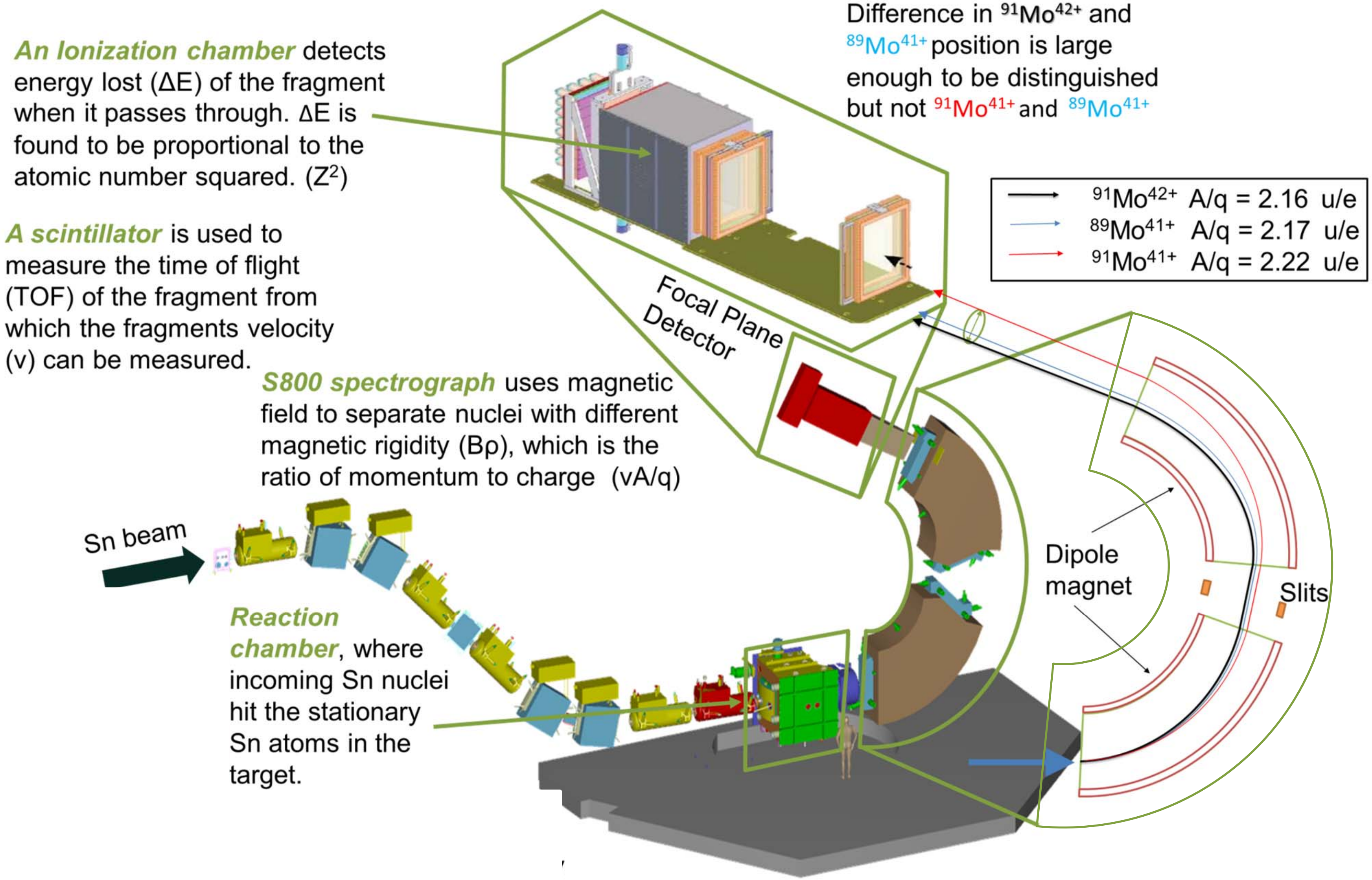
$^{112}Sn + ^{124}Sn$

$^{124}Sn + ^{112}Sn$

$^{124}Sn + ^{112}Sn$

$^{124}Sn + ^{118}Sn$

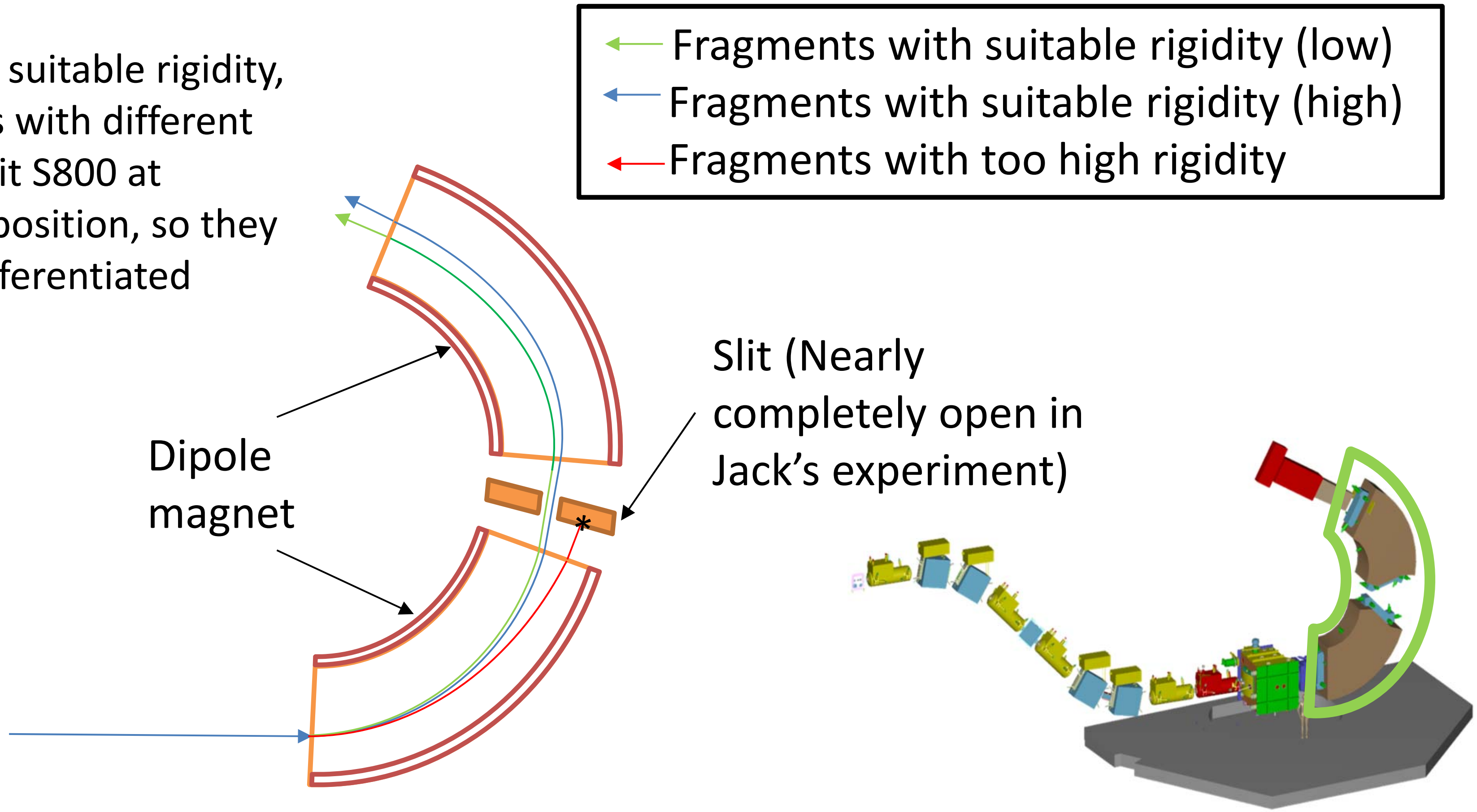
Experimental Set-up



S800 spectrograph

- Use magnetic field to separate fragments according to its magnetic rigidity (momentum over charge)

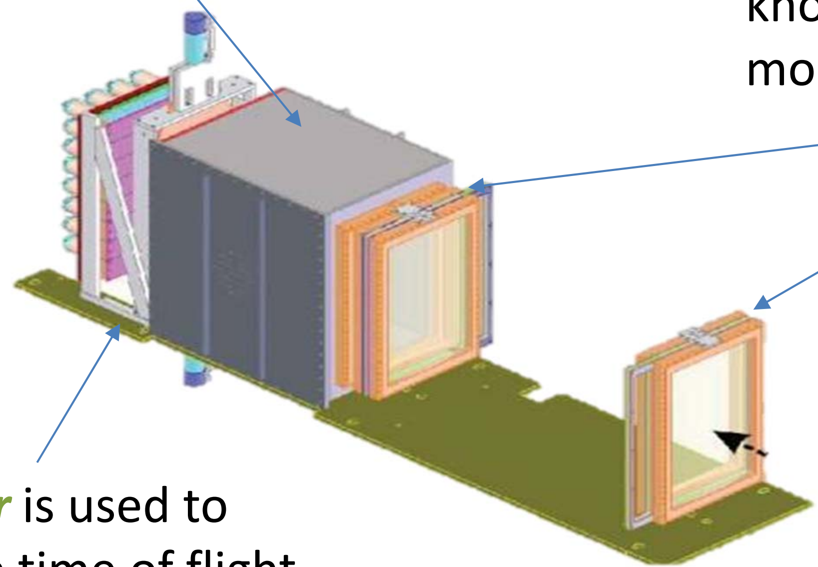
Even with suitable rigidity, fragments with different rigidity exit S800 at different position, so they can be differentiated



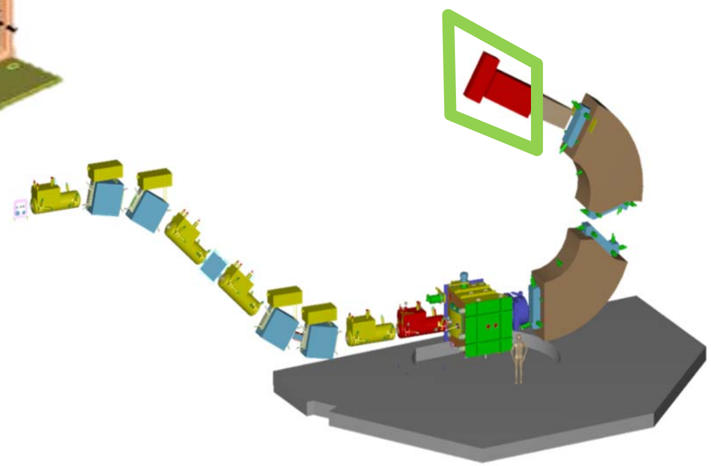
Focal Plane detector

An Ionization chamber detects energy lost (ΔE) of the fragment when it passes through. ΔE is found to be proportional to the atomic number squared. (Z^2)

CRDCs detects where the fragment exit S800, thus knowing the fragment's momentum to charge ratio.



A scintillator is used to measure the time of flight (TOF) of the fragment from which the fragments velocity (v) can be measured.



Charge state contamination

- What do we know about the fragment: ***Atomic number Z*** from ionization chamber, ***time of flight*** from scintillator, ***momentum over charge*** ratio from S800 and CRDCs.

Measured Quantity	Correspoinding detector(s)
Atomic number (Z)	Ionization chamber
Time of flight (TOF)	Scintillator
Momentum over charge (Bρ)	S800 and CRDCs
Calculated Quantity	**Way to calculate**
Velocity (v)	From TOF
Mass to charge ratio (m/q)	From Bρ and v
Charge (q)	q=Z
Mass (m)	From m/q once q is found

Fragments could gain electrons after passing through materials, but are not detected.

They will be misidentified as other nuclei.

May not be true!! (Charge (q) and Mass (m))

Charge state contamination

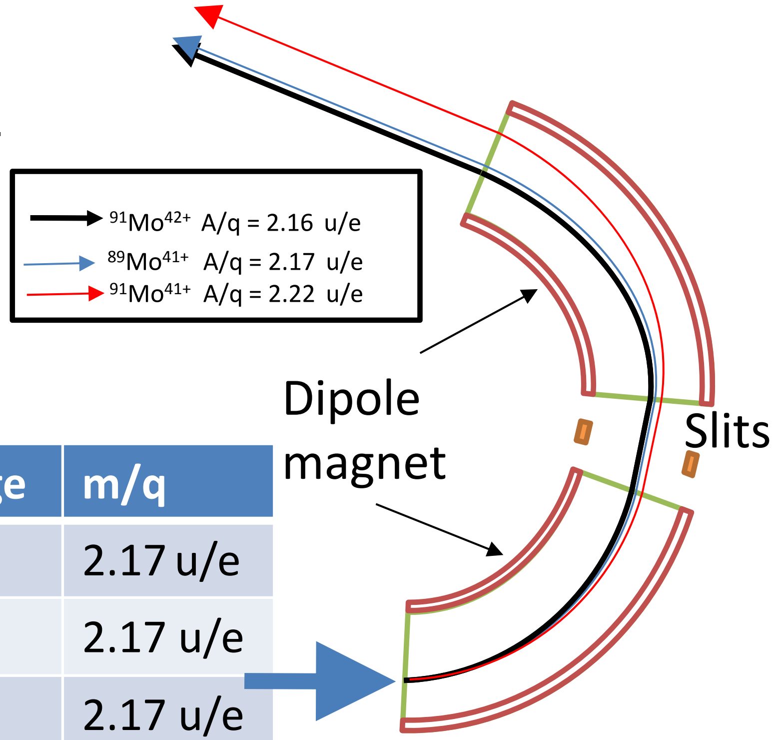
- What we know for certain is m/q, but the following calculation shows that mass to charge ratio of fragments (A-2,Z) that gain one electron (***hydrogen-like charge state***) have very similar m/q to fully stripped (A,Z), so close that they will be misidentified as each other.

- $$\frac{A-2}{Z-1} = \left(\frac{A}{Z} - \frac{2}{Z}\right)\left(1 - \frac{1}{Z}\right)^{-1} \approx \frac{A}{Z} - \frac{2}{Z} + \frac{2}{Z} - \frac{2}{Z^2}$$

  Assume $\frac{A}{Z}$ ~2 and Z^2>>2, $\frac{A-2}{q=(Z-1)} \sim \frac{A}{q=Z}$

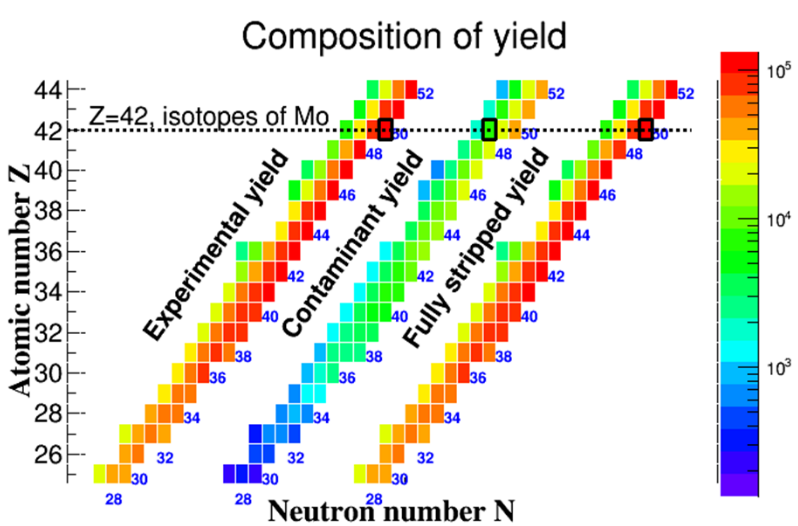
- Examples:

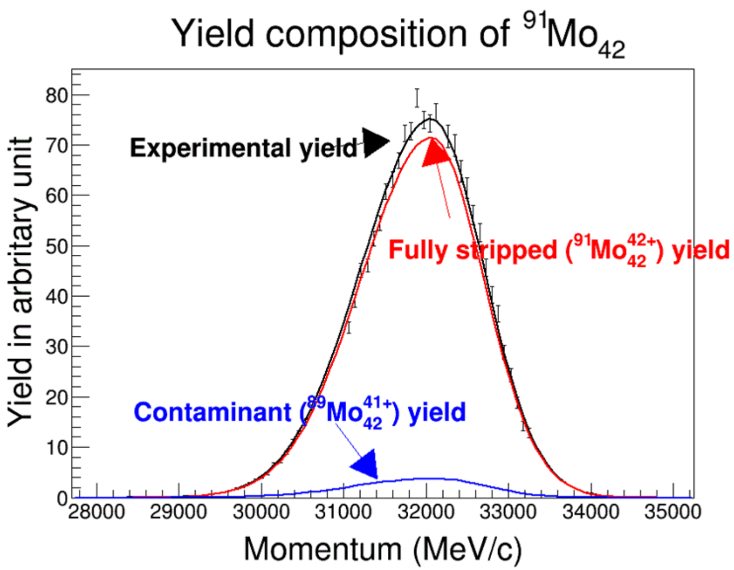
Fully stripped	m/q	hydrogen-like charge	m/q
$^{91}Mo^{42+}$	2.16 u/e	$^{89}Mo^{41+}$	2.17 u/e
$^{78}Kr^{36+}$	2.17 u/e	$^{76}Kr^{35+}$	2.17 u/e
$^{67}Zn^{31+}$	2.16 u/e	$^{65}Zn^{30+}$	2.17 u/e



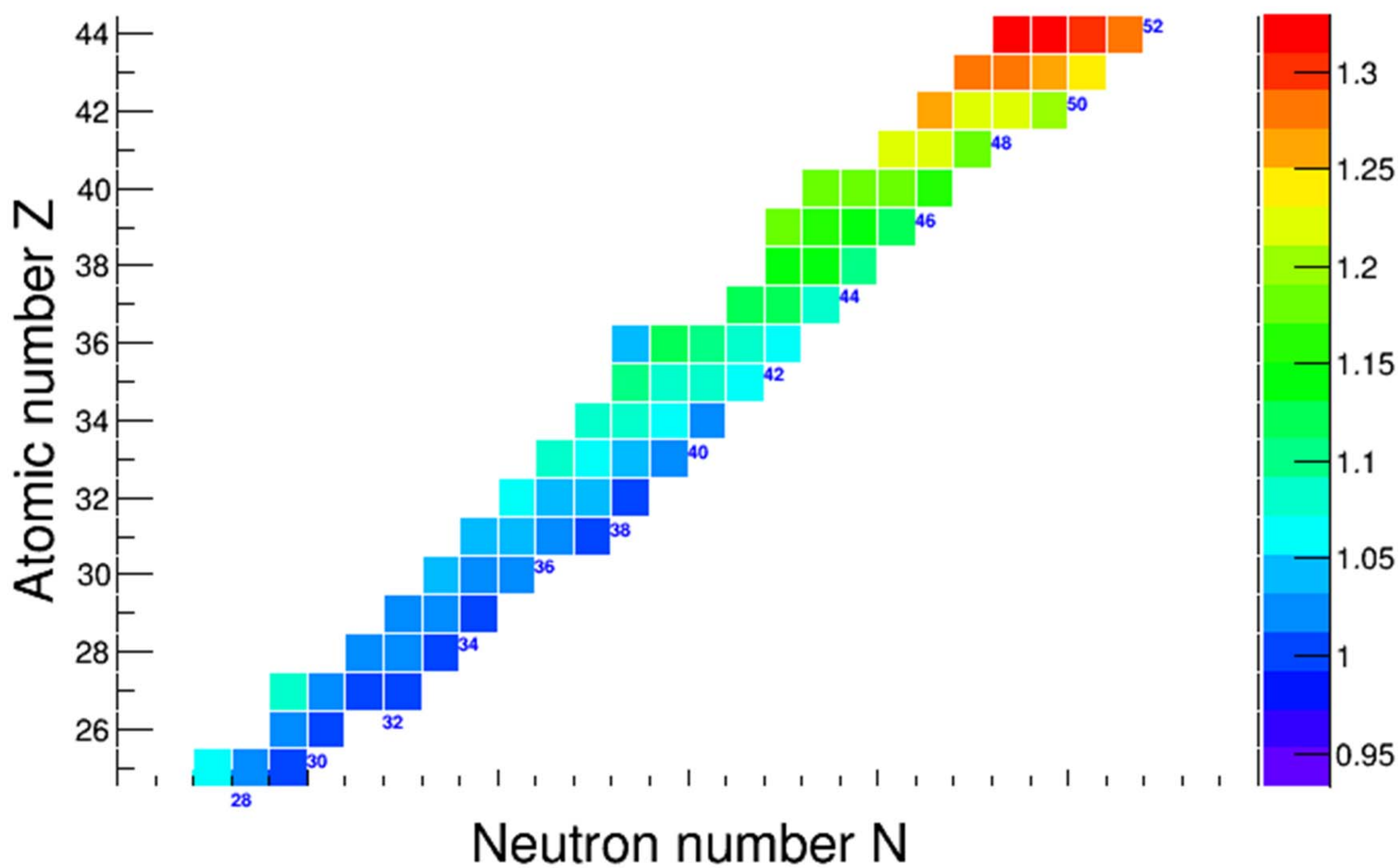
Charge state correction

- We estimate the contributions from hydrogen like fragments with an algorithm called GLOBAL and correct the experimental yields.
- For constant Z, yield goes down with N, so yield of neutron deficient fragments is negligible
- It's shown that charge state fragments of neutron deficient nuclei is misidentified as neutron reach one, so we can assume that nuclei from upper-left edge have negligible contamination and correct for those on the lower-right edge





Correction factor



Isolate the effect

- Need to know the asymmetry of the residue, but it decays quickly and is not detected.

- Reconstruct asymmetry with decay products with statistical theory:

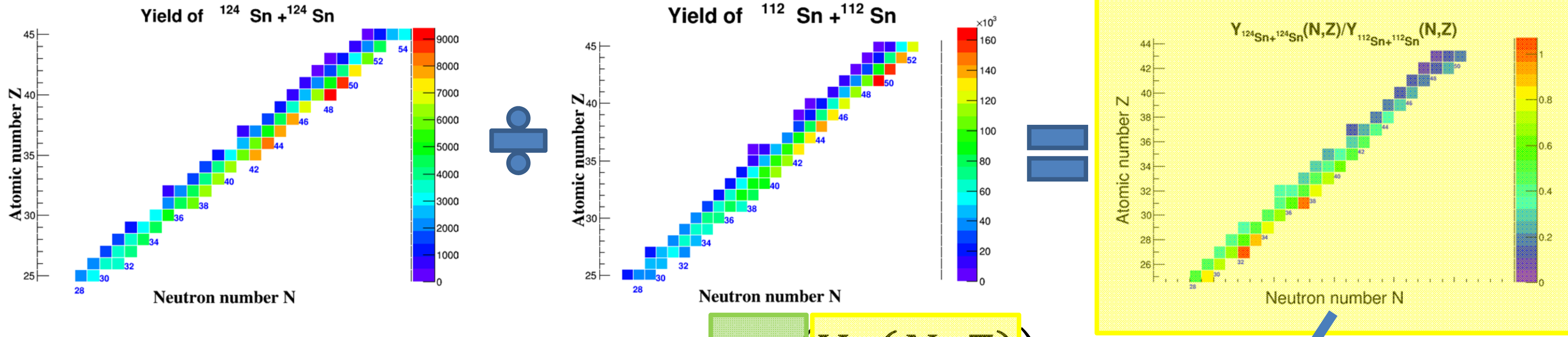
$$\ln\left(\frac{Y_2(N,Z)}{Y_1(N,Z)}\right) = \alpha N + \beta Z + c \; and \quad \alpha = a\delta + b$$

- ***α is the neutron isoscaling parameter and β is the proton isoscaling parameter.*** $Y_1(N,Z)$ is yield of fragments of symmetric system of the proton rich nuclei and $Y_2(N,Z)$ is the corresponding yield of mixed system. (e.g. If ^{124}Sn + ^{112}Sn is system 2, ^{112}Sn + ^{112}Sn is system 1)

- System 1 is used as a reference, so asymmetry of all other system are compared with system 1, i.e. α of system 1 is always 0

- ***Can treat α as δ in arbitrary unit***

Construction of isoscaling constant α



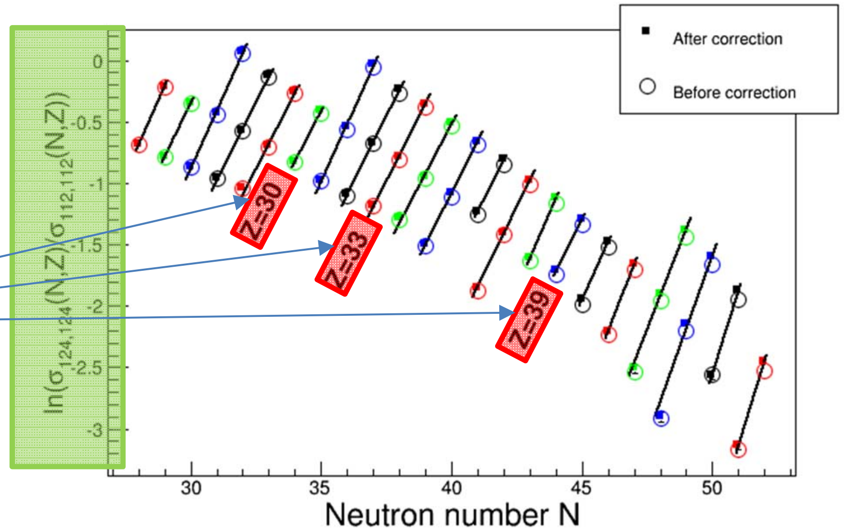
$$\alpha N + \beta Z + c = \ln\left(\frac{Y_2(N,Z)}{Y_1(N,Z)}\right)$$

Projection onto N

Log Scale

By connecting lines of isotope, red part can be regarded as constant.
With N as x-axis, slope = α

β Can be constructed the same way, although no used here.



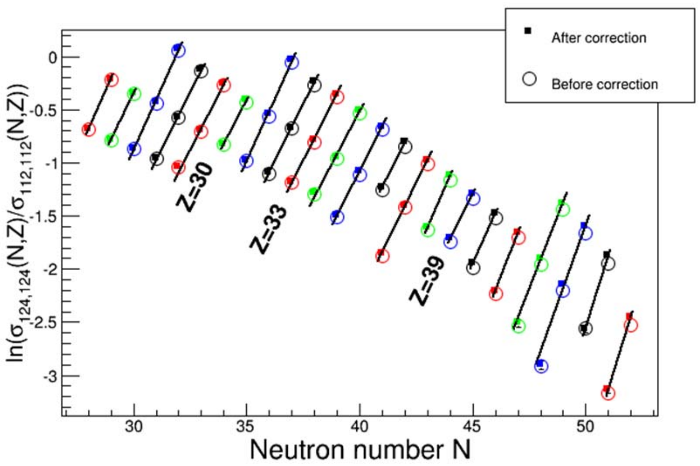
Systematics of isoscaling parameter α

Isoscaling equation

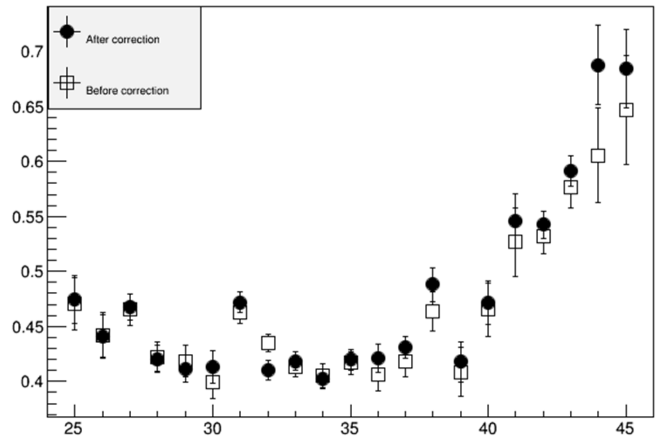
$$\frac{Y_2(N,Z)}{Y_1(N,Z)} = Ce^{\alpha N + \beta Z}$$

- Slope of each line on the upper graph is plotted.
- Slope increases with Z in all systems after Z > 40.
- In all systems studied here , value of alpha at roughly Z > 40
- Only fragments with atomic number 24<Z<41 are used to calculates alpha.

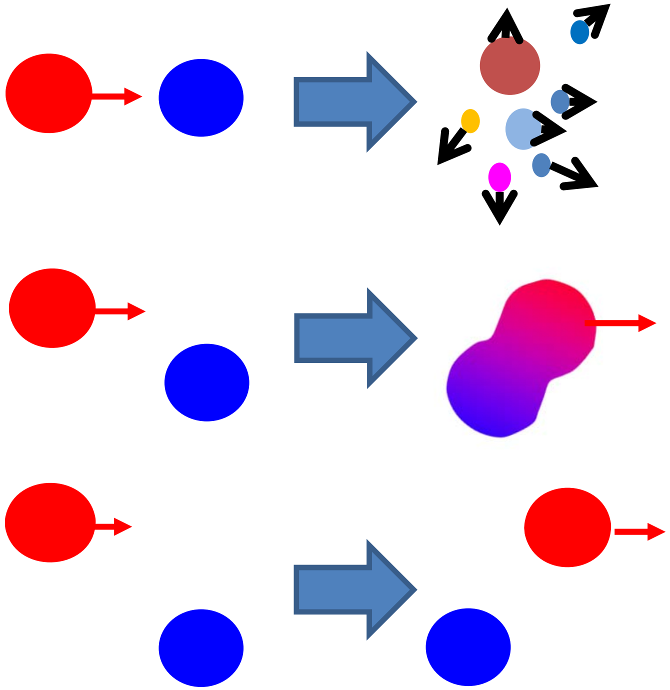
Y(^{124}Sn+^{124}Sn)/Y(^{112}Sn+^{112}Sn)



Values of alpha



Reason for change in alpha



Central collision: Lots of fragments and most of them are small. System reach equilibrium since it has too much interaction

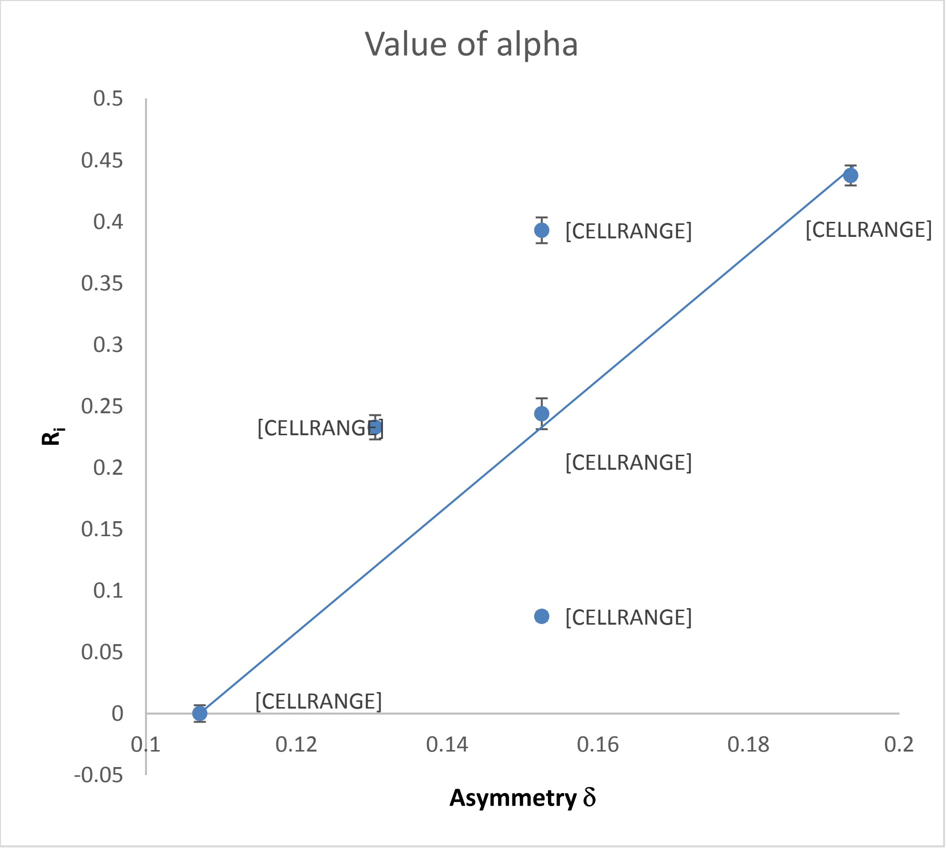
Peripheral collision: moderate fragment yield with moderate mass. Not yet in equilibrium

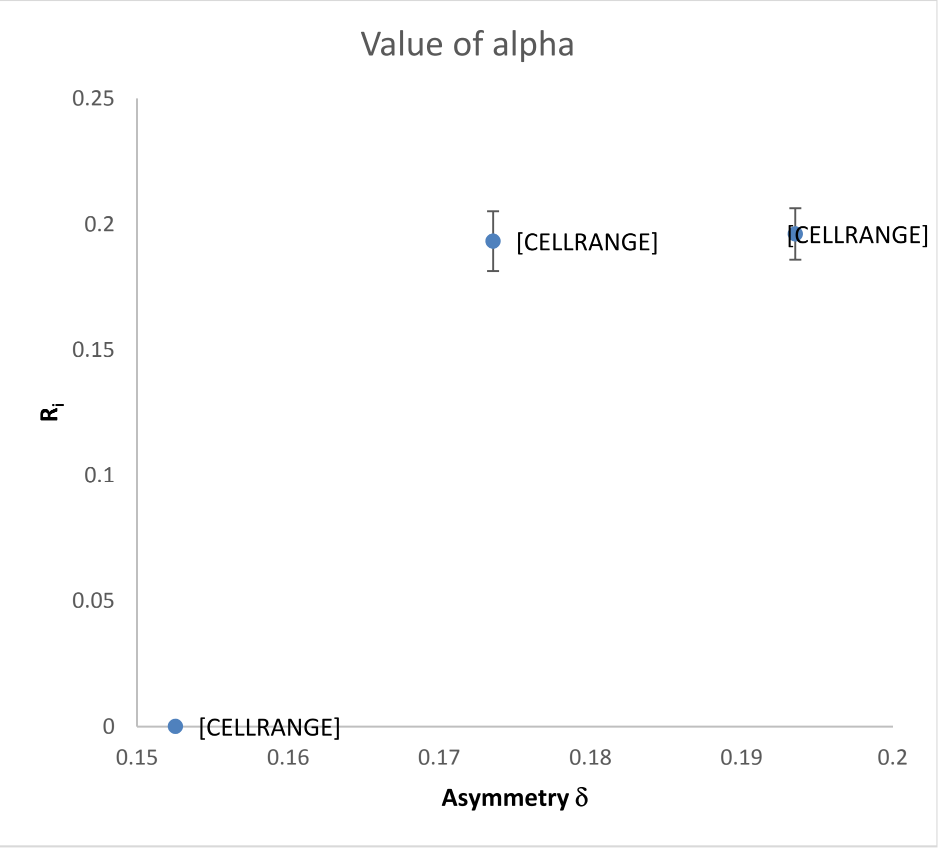
Too Peripheral collision: not enough interaction, low fragment yield and are massive

- Fragments with large Z usually correspond to high impact parameter, and there is not enough diffusion to be interesting
- By limiting the range of fragment's atomic number, we can be sure that we are studying collisions that are desirable

Value of alphas

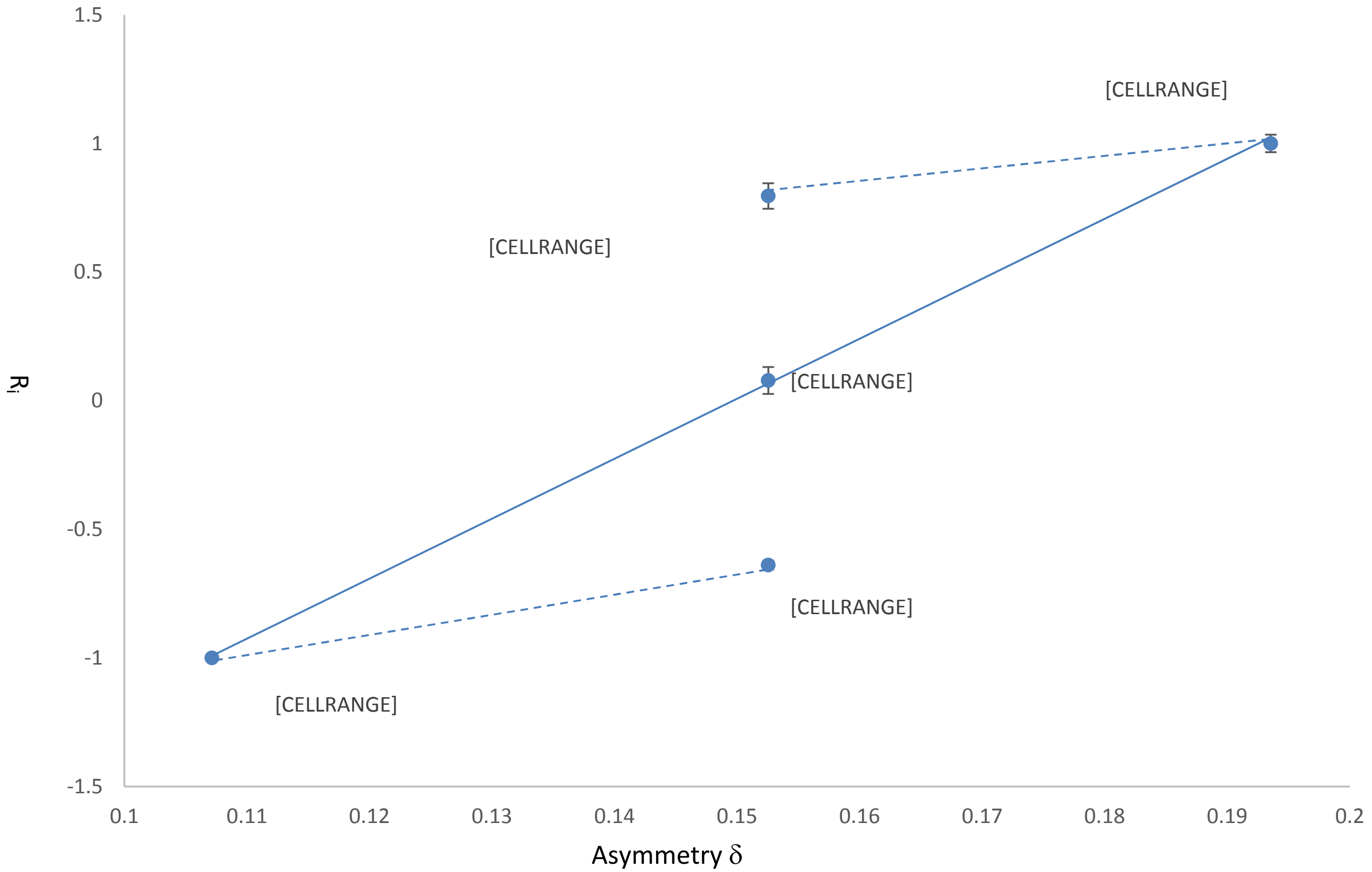
- Only fragments with 24<Z<41 is used to calculate α.
- Here is 2 plots of alphas vs. asymmetry δ_{tot} = (N-Z)/(N+Z) of the system (sum of target and projectile).

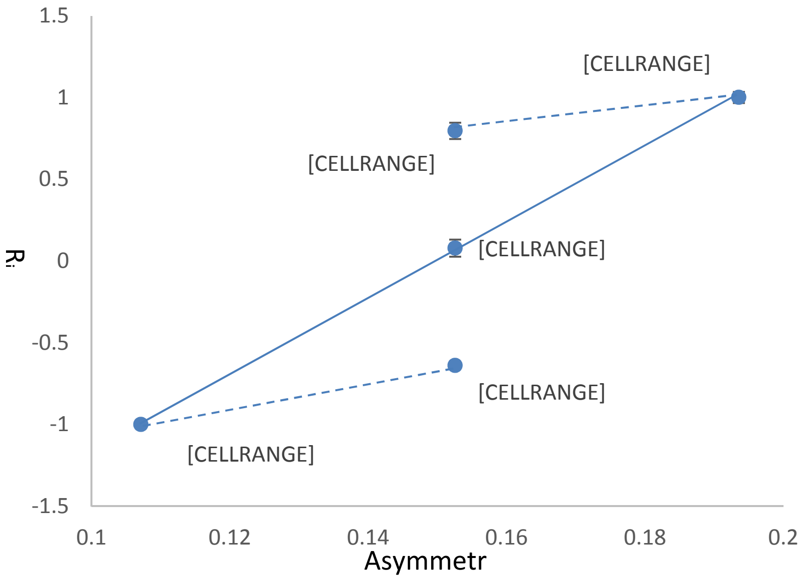




Values of R_i

$$R_i(X) = 2 \cdot \frac{X - (X_{Neutron-rich} + X_{Proton-rich})/2}{X_{Neutron-rich} - X_{Proton-rich}}$$ where X is α





[CELLRANGE]
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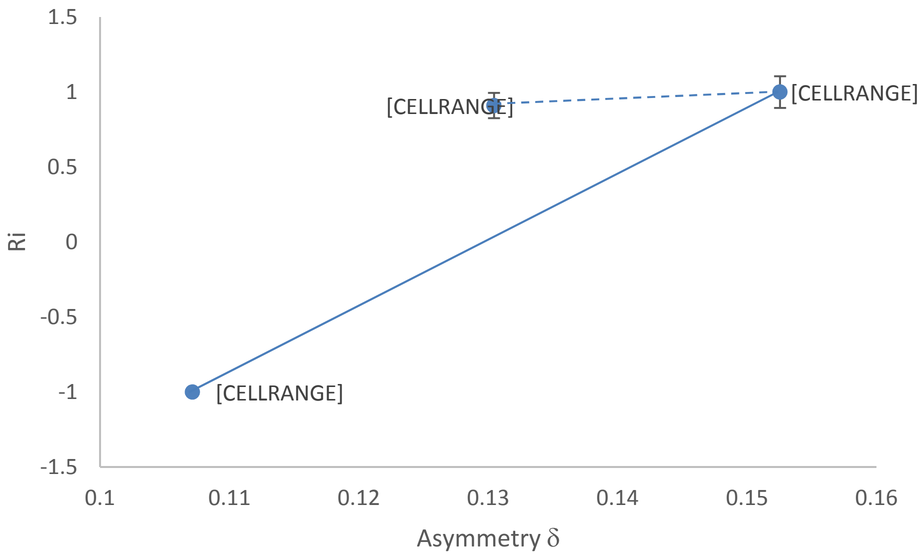
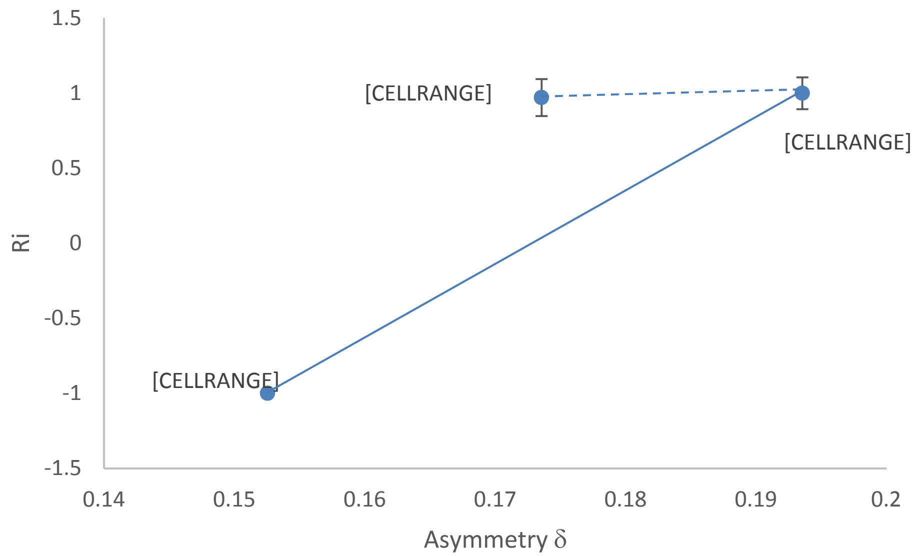
[CELLRANGE]
Ri
1.5
1
0.5
0
-0.5
-1
-1.5
0.1
0.12
0.14
0.16
0.18
0.2
Asymmetr

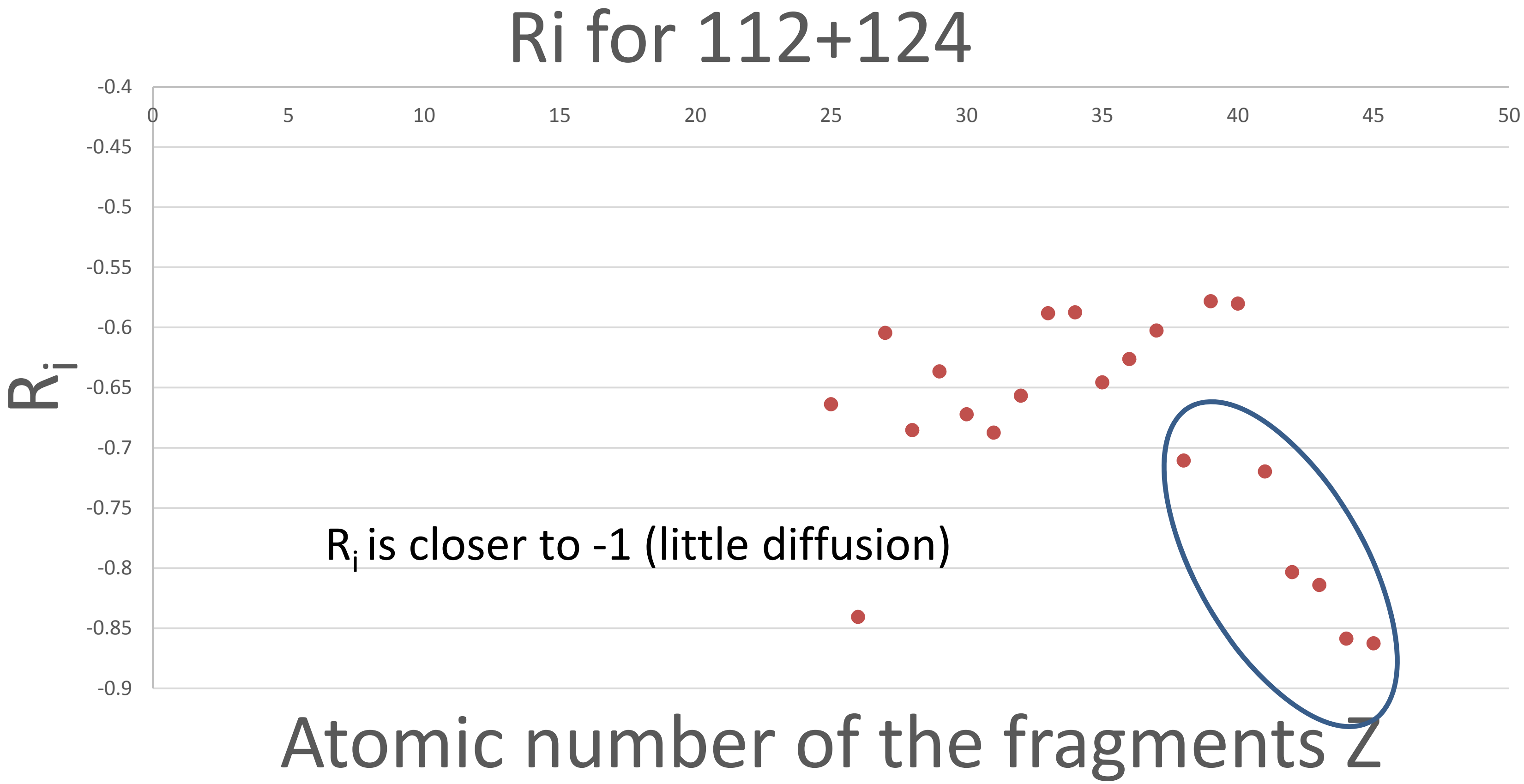


[CELLRANGE]
[CELLRANGE]
[CELLRANGE]
Ri
1.5
1
0.5
0
-0.5
-1
-1.5
0.1
0.11
0.12
0.13
0.14
0.15
0.16
Asymmetry δ



[CELLRANGE]
[CELLRANGE]
[CELLRANGE]
Ri
1.5
1
0.5
0
-0.5
-1
-1.5
0.14
0.15
0.16
0.17
0.18
0.19
0.2
Asymmetry δ

R_i calculated with α in different Z



Conclusion

- The method can be used to correct for charge state contamination.
- The values of R_i for different systems are extracted.
- Diffusion for mixed systems involving ^{118}Sn may be too low, but error bar is too large to conclude

Acknowledgement

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