Production and Separation of Exotic Beams via Fragmentation Reactions using MARS

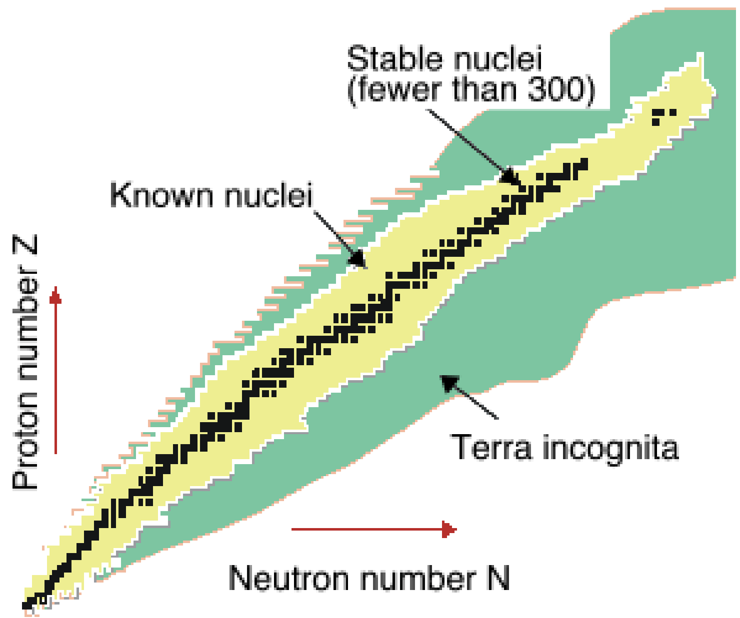
Kenneth Whitmore, William Jewell College
Advisor: Dr. Robert Tribble,
Texas A&M Cyclotron Institute

Overview

- Motivation
- Physics behind MARS
- My research
  - Fragmentation
  - Using LISE++
  - Particle identification
  - Production rate calculations
- Conclusions

Motivation

- We want to study radioactive nuclei
- Important for nuclear astrophysics
- Exotic nuclei not found in nature, they must be produced in the lab



What is MARS?

- Momentum Achromat Recoil Spectrometer
- Can isolate specific beams of products from other beam products
- Separates based on magnetic rigidity and velocity selection
- Inverse kinematics – heavy ion beam on light target
  - Products are forward focused due to momentum conservation

R. E. Tribble, R. H. Burch, and C. A. Gagliardi, Nucl. Instrum. Meth. A **285**, 441 (1989).

Magnetic Rigidity

- Used to disperse secondary beams after target
- Moving charge curves in magnetic field
- Given by Lorentz force
- This is a centripetal force
- Bρ is chosen
  - Determined by magnetic field
  - Allows for p/q selection

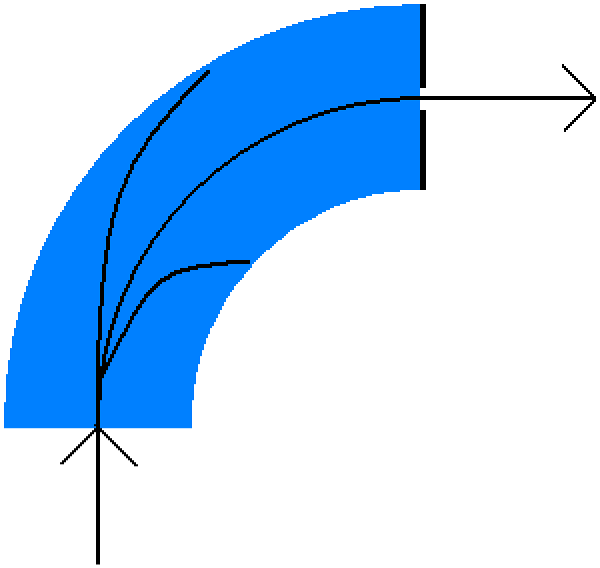
$$F_{magnetic} = F_{centripetal}$$

$$qvB = \frac{Mv^2}{\rho}$$

$$B\rho = \frac{Mv}{q}$$

Magnetic Rigidity

- Only specific p/q will pass through, others are blocked
- Higher p/q = more rigid
- Lower p/q = less rigid
- Slits block off unwanted beam
  - Width of slits determines acceptance



Velocity Selection

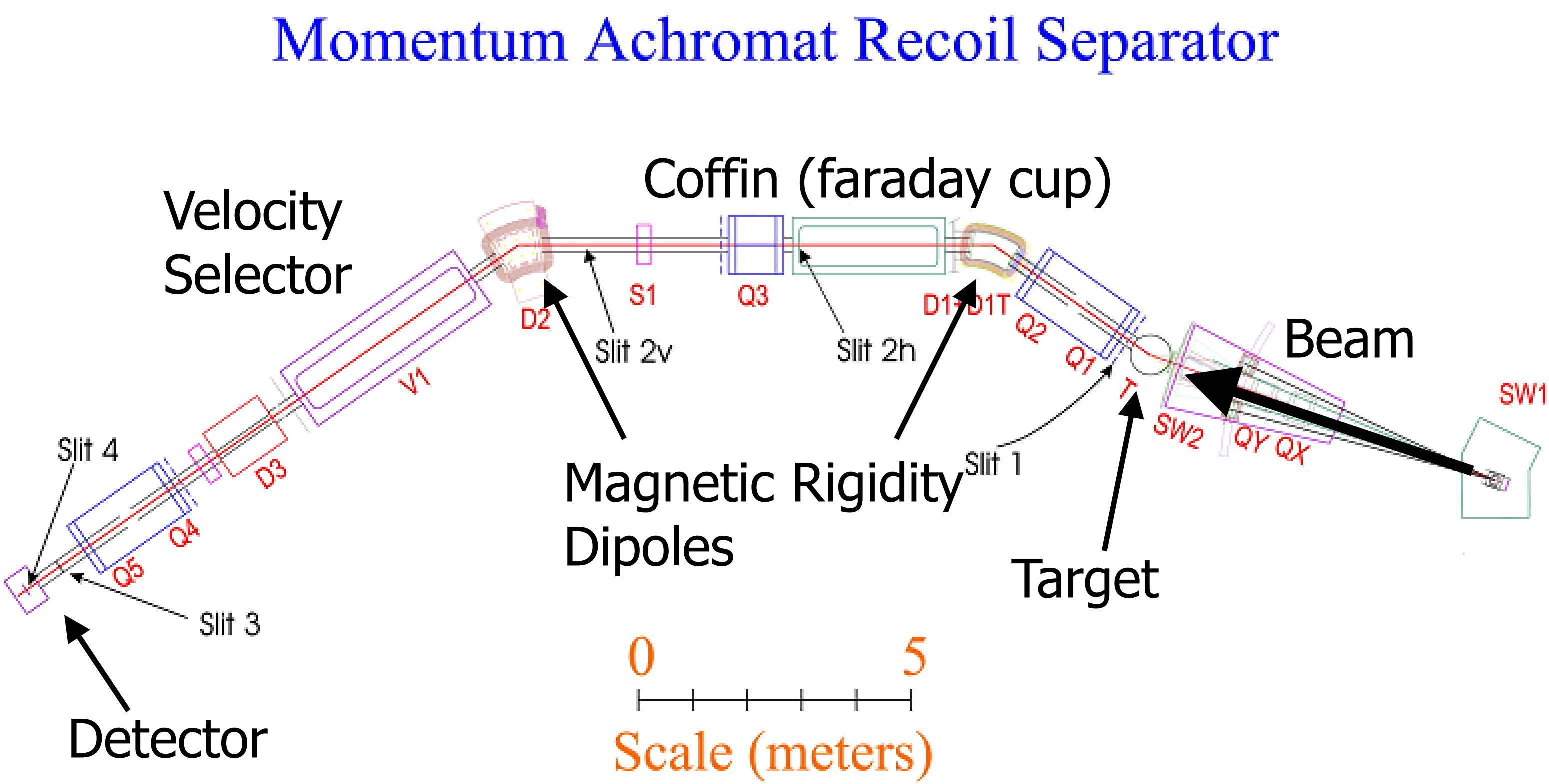
- Perpendicular electric and magnetic fields
- Create forces in opposite directions
- Forces balance for specific velocity
  - Centered on detector
- Because nuclei have the same mv/q, selection in v is also selection in q/m

$$F_{magnetic} = F_{electric}$$

$$qvB = qE$$

$$v = \frac{E}{B}$$

MARS Design



Momentum Achromat Recoil Separator
Coffin (faraday cup)
Velocity Selector
Beam
SW1
D2
S1
Q3
D1
D1T
Q2
Q1
T
SW2
QY
QX
Slit 2v
Slit 2h
Slit 1
V1
D3
Slit 4
Q4
Q5
Slit 3
Magnetic Rigidity Dipoles
Target
Detector
0
5
Scale (meters)

My Research

- Study reaction products for three different fragmentation reactions
- Calculate production rates, then compare to computer predictions
- Important for computer predictions to be accurate
- Different methods of beam production are being investigated
  - Want to know which reactions are best for maximizing production rates

Nuclear Fragmentation

- Primary beam nucleus has nucleons shaved off as it passes target
  - Keeps its velocity
- Produces wider range of exotic nuclei at higher energies than other mechanisms
  - Fusion-evaporation, transfer
- First fragmentation reactions used with MARS

Reactions

- Three reactions studied:
  - ^{36}Ar at 45 MeV/u
  - ^{40}Ar at 40 MeV/u
  - ^{24}Mg at 48 MeV/u
- 306 μm ^{9}Be target
- 1000 μm Silicon detector
  - Position-sensitive
- Reactions done with MARS here at the Cyclotron Institute

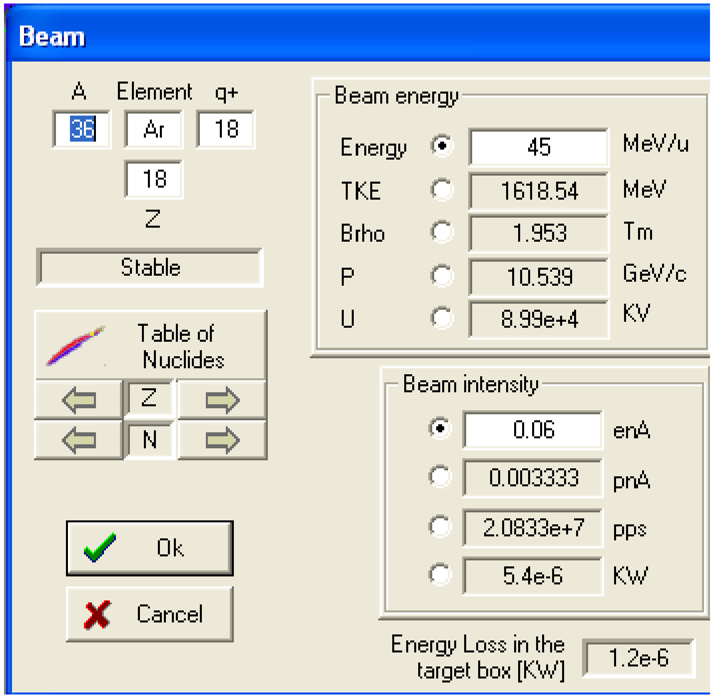
LISE++

- Mass spectrometer simulation tool
- Developed for French spectrometer
- Calculates cross sections for nuclear reactions
- Uses cross section to determine momentum distributions of products
- Uses momentum distributions and magnetic settings to determine final production rates

O. Tarasov and D. Bazin, Nucl. Instrum. Meth. B **266**, 4657 (2008).
K. Sümmerer *et al.*, Phys. Rev. C **42**, 2546 (1990).

Using LISE++

- LISE++ has entire MARS setup installed
- Just select beam, target, and magnet settings
- Calculates production rates for different magnetic settings

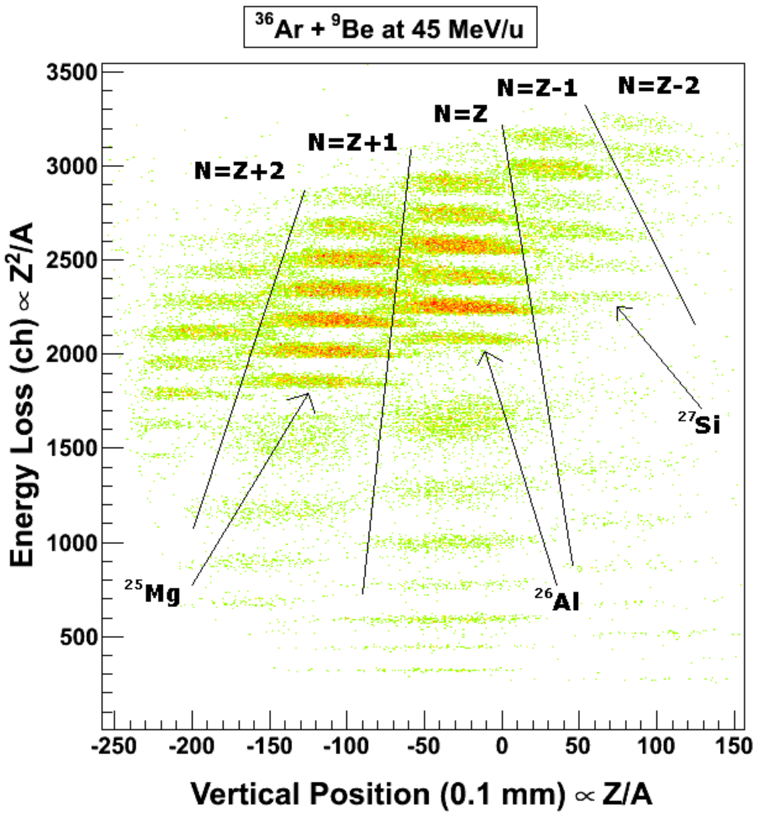


Particle Identification

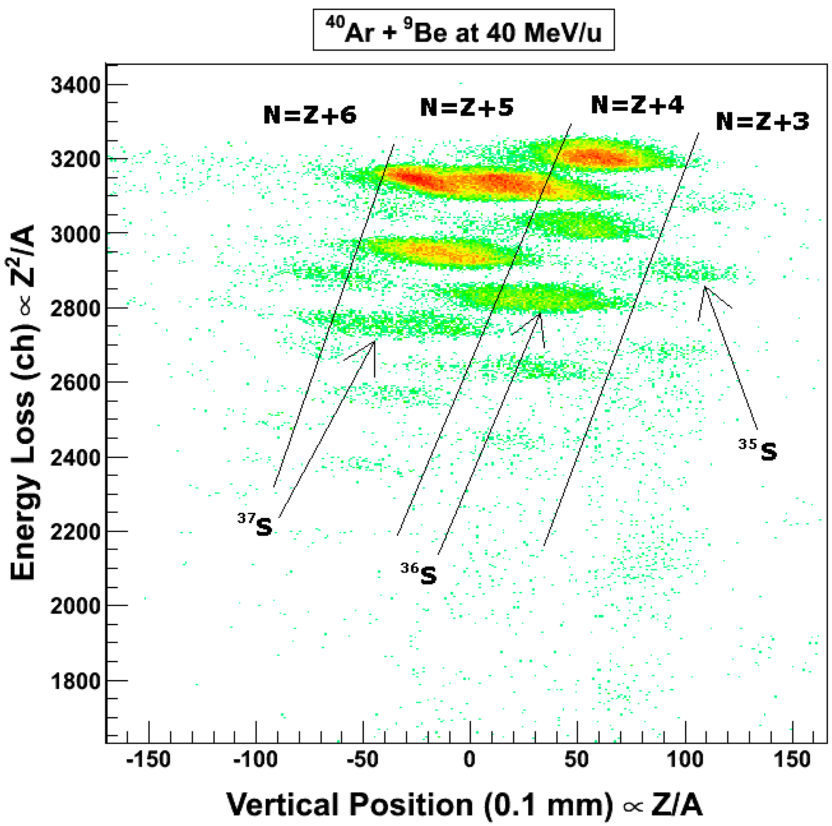
- Use plots of energy loss versus vertical position
  - Energy loss of particles $\propto q^2/m$
  - Vertical position $\propto q/m$
- Can identify regions for N=Z, N=Z+1, etc.
- LISE++ gives energy loss in detector
  - Some particles lose all their energy
  - Some make it through detector
- Different shapes are different energy loss

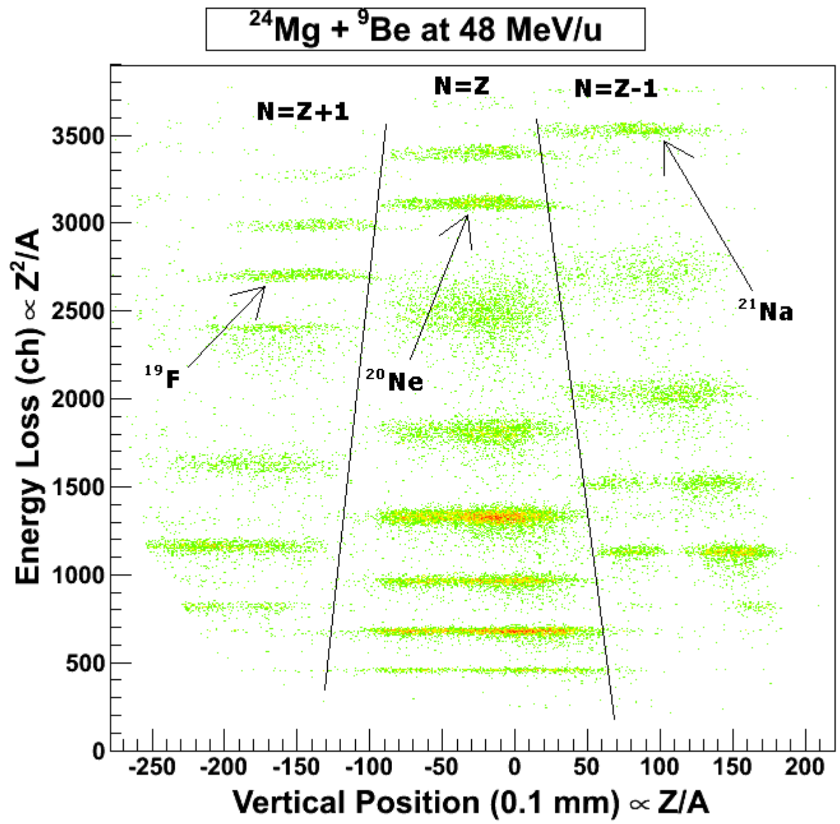
Particle Identification

- Vertical axis is energy loss
  - Units are channel number, but proportional to energy
- Horizontal axis is vertical position!
- Each cluster is different isotope
- Decreasing number of neutrons left to right
- Increasing mass going up



Particle Identification





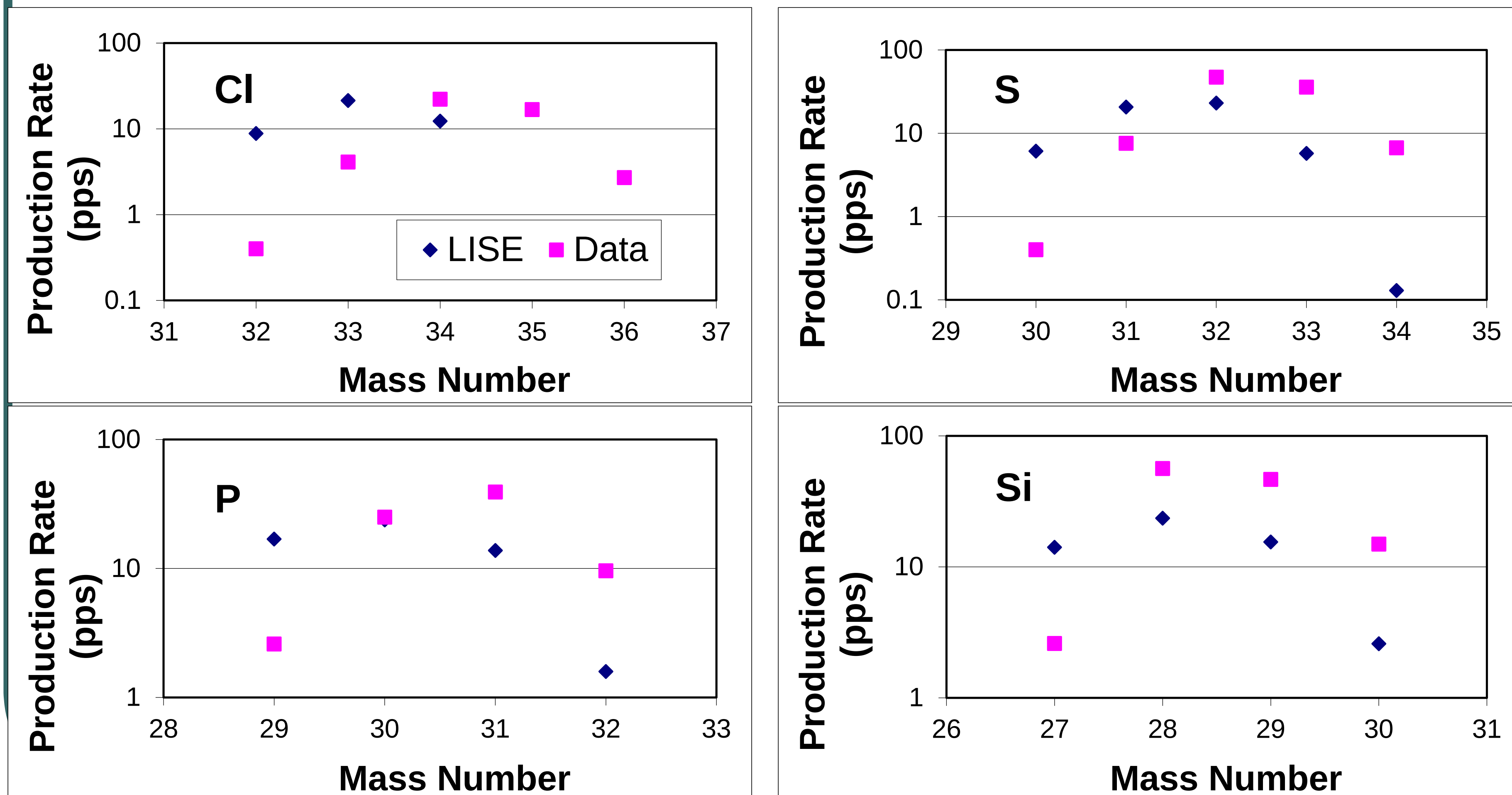
Calculation of Production Rates

- Integrate around each isotope to find total counts
- Normalize counts to total beam current
  - Measured in Faraday cup
- Use calculations from spectra and compare to LISE++ predictions

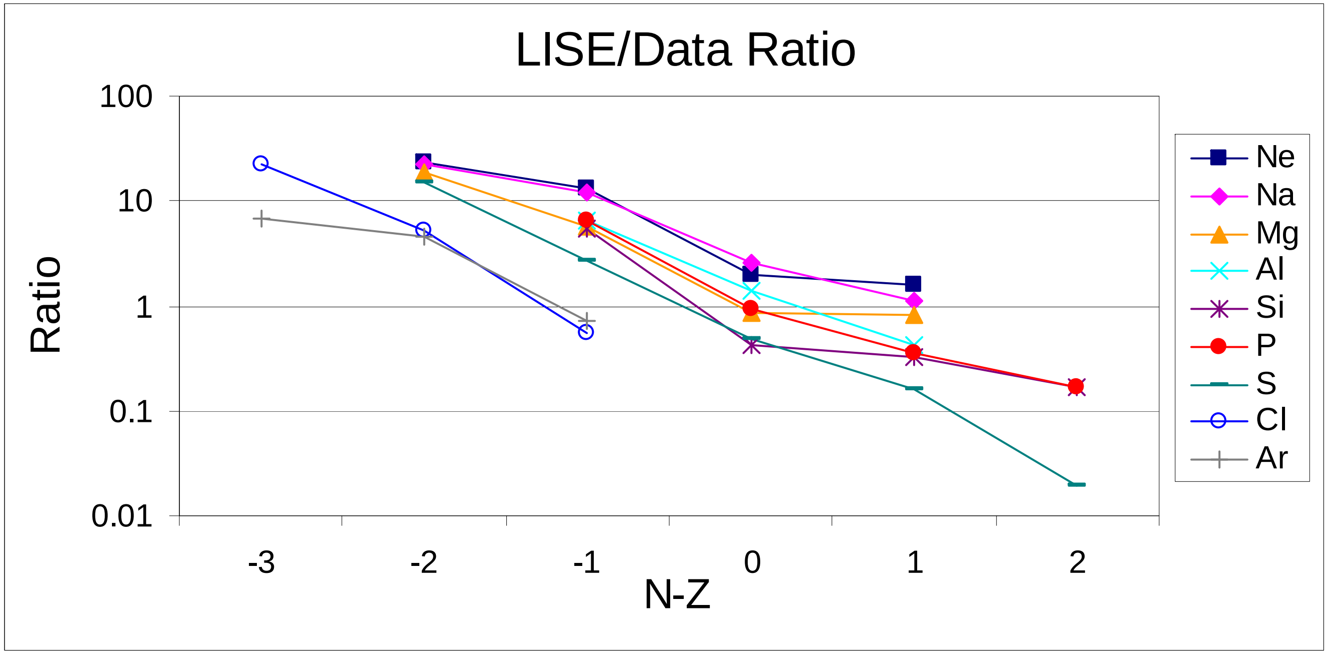
Example: ^{25}Al

(1670 counts) * (60 pA) / (60 nC) = 1.67 particles per second

$^{36}\mathrm{Ar} + {}^{9}\mathrm{Be}$

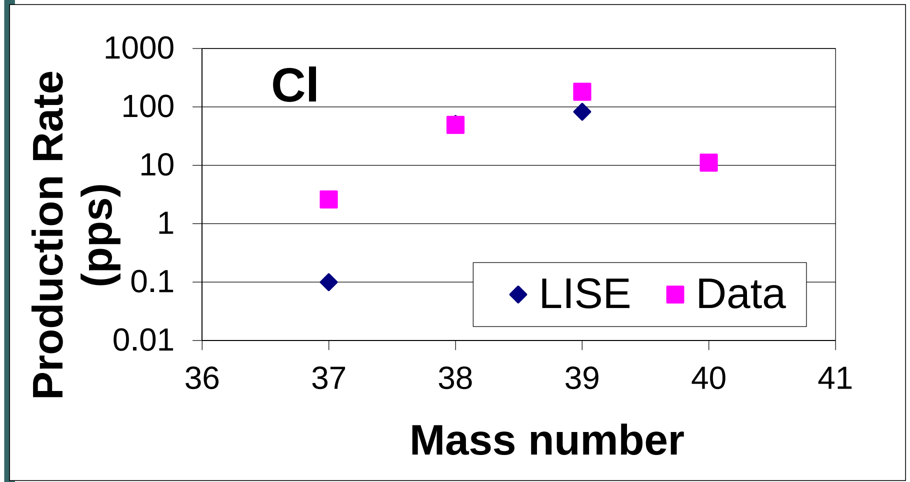


$^{36}Ar + {}^{9}Be$

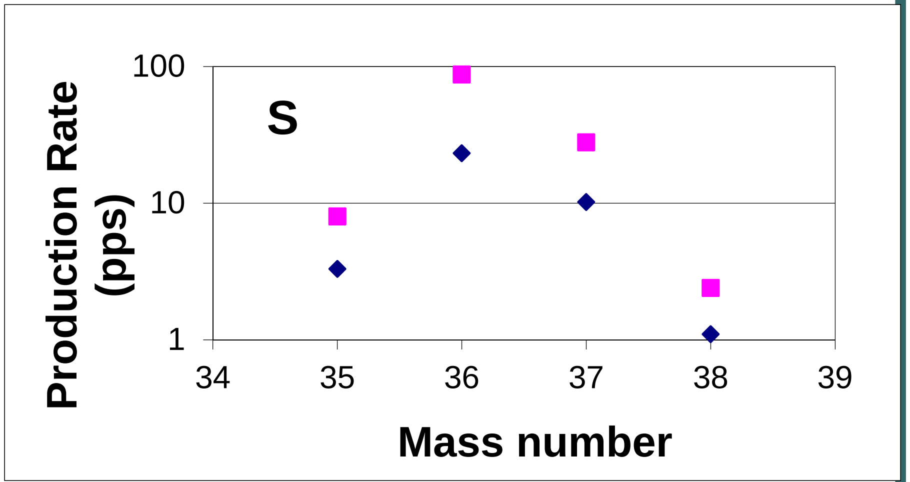


LISE/Data Ratio
100
10
1
0.1
0.01
Ratio
-3
-2
-1
0
1
2
N-Z
Ne
Na
Mg
Al
Si
P
S
Cl
Ar

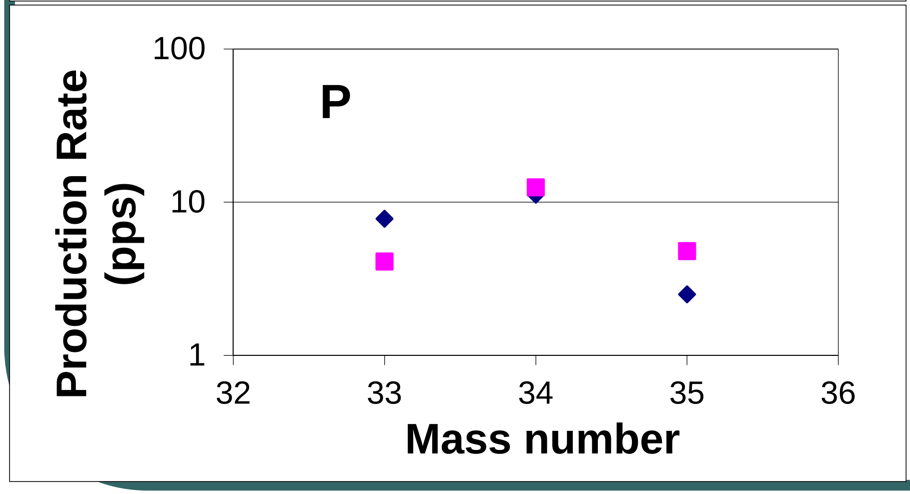
$^{40}Ar + {}^{9}Be$



Cl
Production Rate (pps)
1000
100
10
1
0.1
0.01
36
37
38
39
40
41
Mass number
LISE
Data

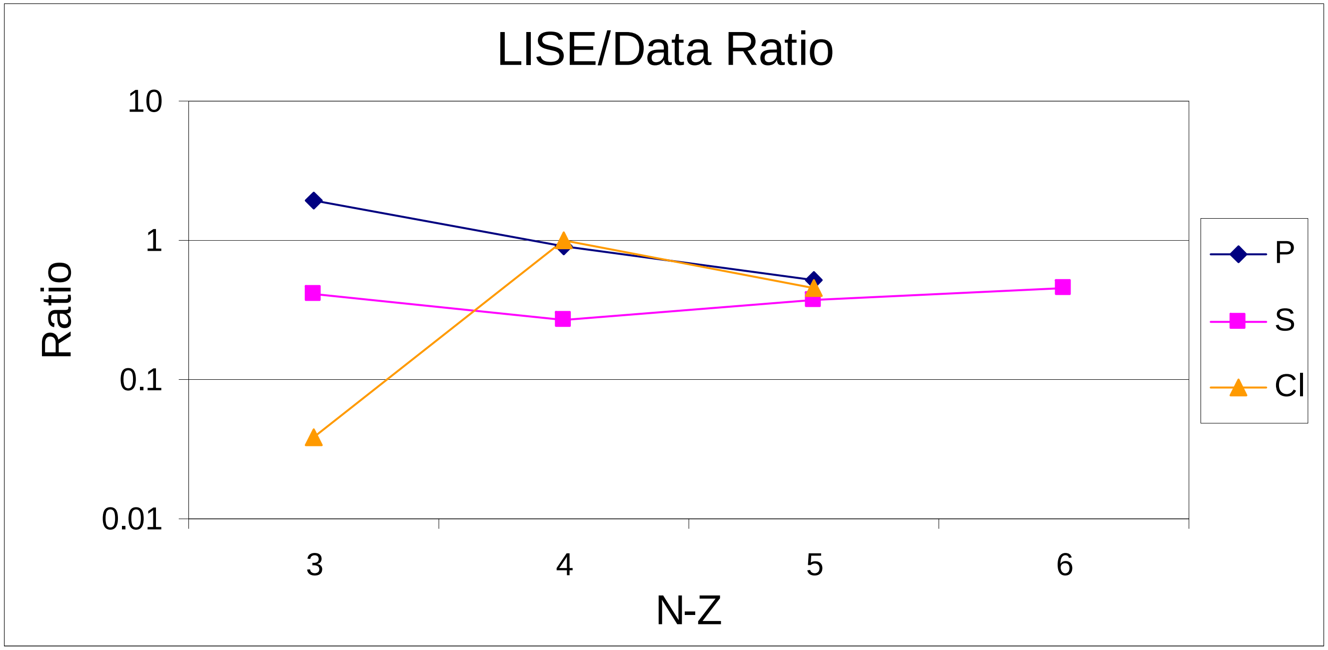


S
Production Rate (pps)
100
10
1
34
35
36
37
38
39
Mass number

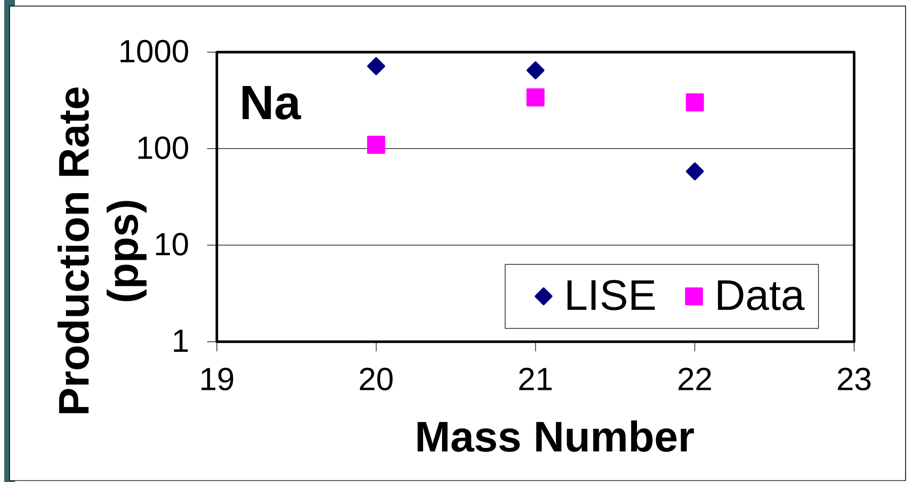


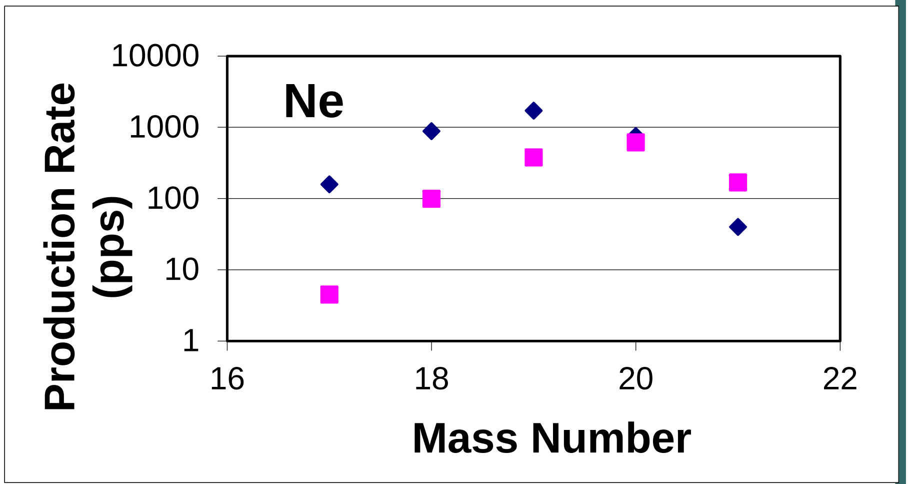
P
Production Rate (pps)
100
10
1
32
33
34
35
36
Mass number

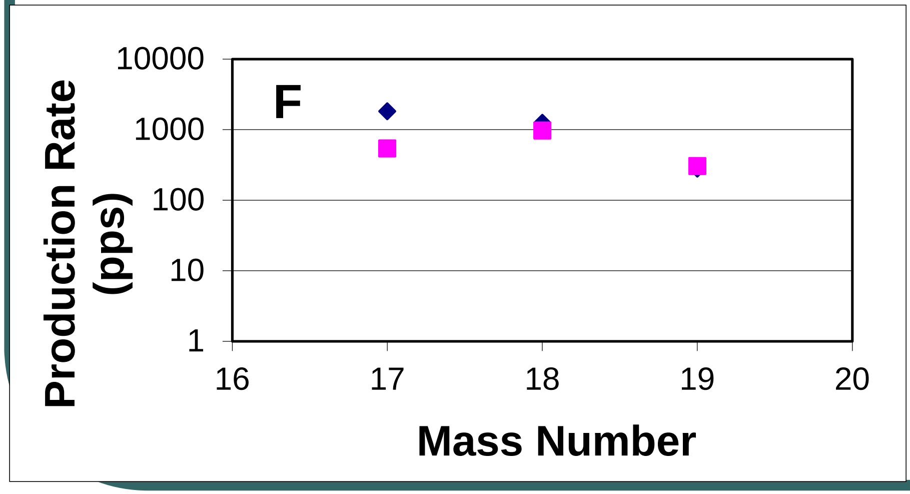
$^{40}Ar + ^{9}Be$

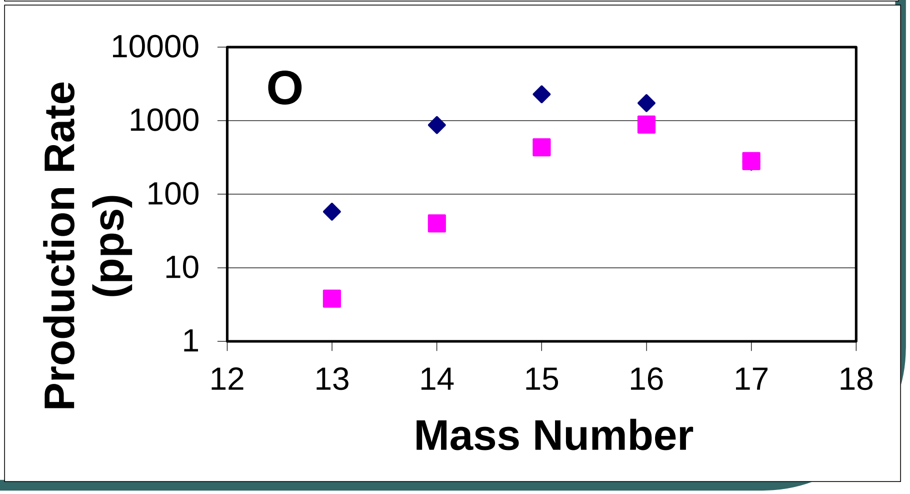


$^{24}Mg + ^{9}Be$

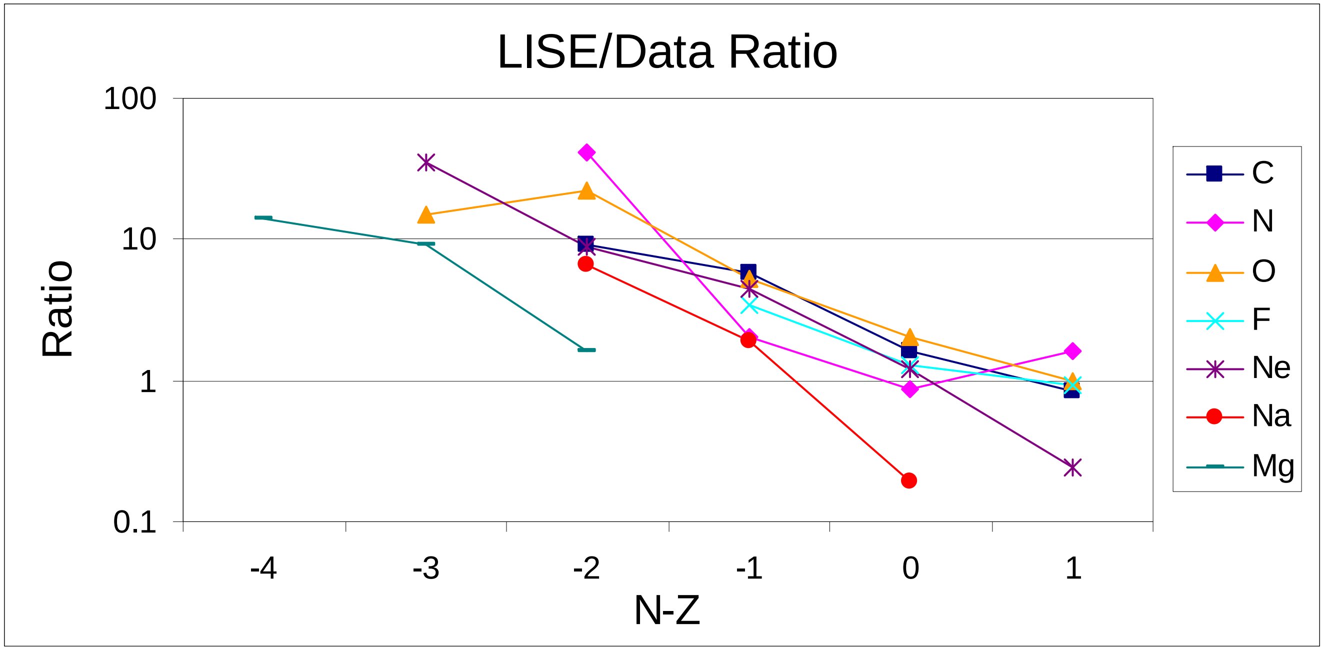

Na
Production Rate (pps)
1000
100
10
1
19
20
21
22
23
Mass Number
LISE
Data


Ne
Production Rate (pps)
10000
1000
100
10
1
16
18
20
22
Mass Number


F
Production Rate (pps)
10000
1000
100
10
1
16
17
18
19
20
Mass Number


O
Production Rate (pps)
10000
1000
100
10
1
12
13
14
15
16
17
18
Mass Number

$^{24}Mg + ^{9}Be$



Conclusions

- LISE++ predictions are most accurate for stable (N=Z) isotopes
- Higher predictions for proton-rich (N<Z)
  - A few off by more than factor of 10
- Lower predictions for neutron-rich (N>Z)
- Most predictions are reasonable, but model could be improved

Acknowledgements

- Dr. Tribble, Dr. Brian Roeder, Dr. Livius Trache and the rest of the Tribble group
- Dr. Sherry Yennello
- US DOE and NSF

Cyclotron Institute
Texas A&M University

Questions?