Phoswich Array for Sub-Fermi Energy Heavy Ion Reaction Dynamics

Summer REU Program 2012

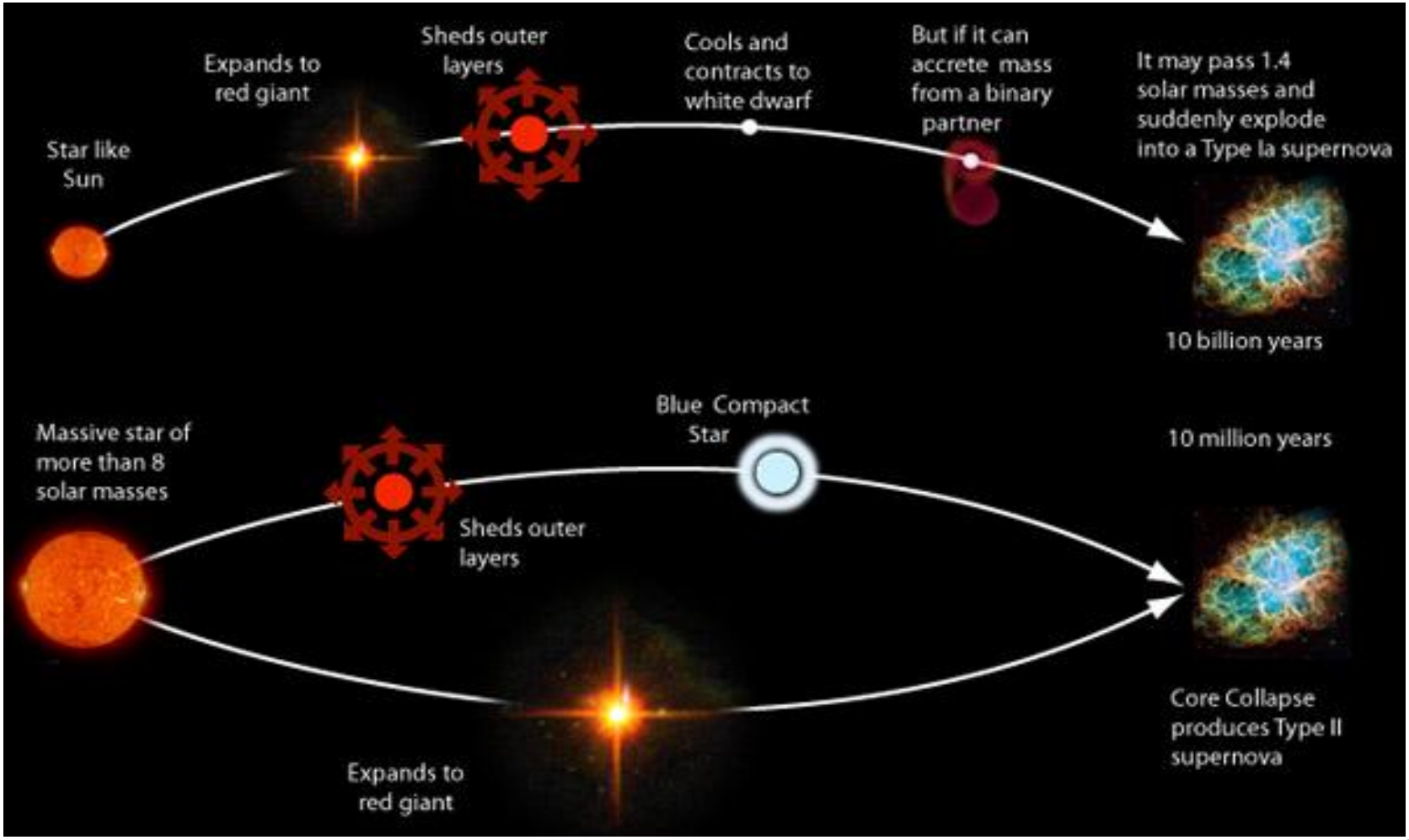
Brittany Abromeit

August 3, 2012

Outline:

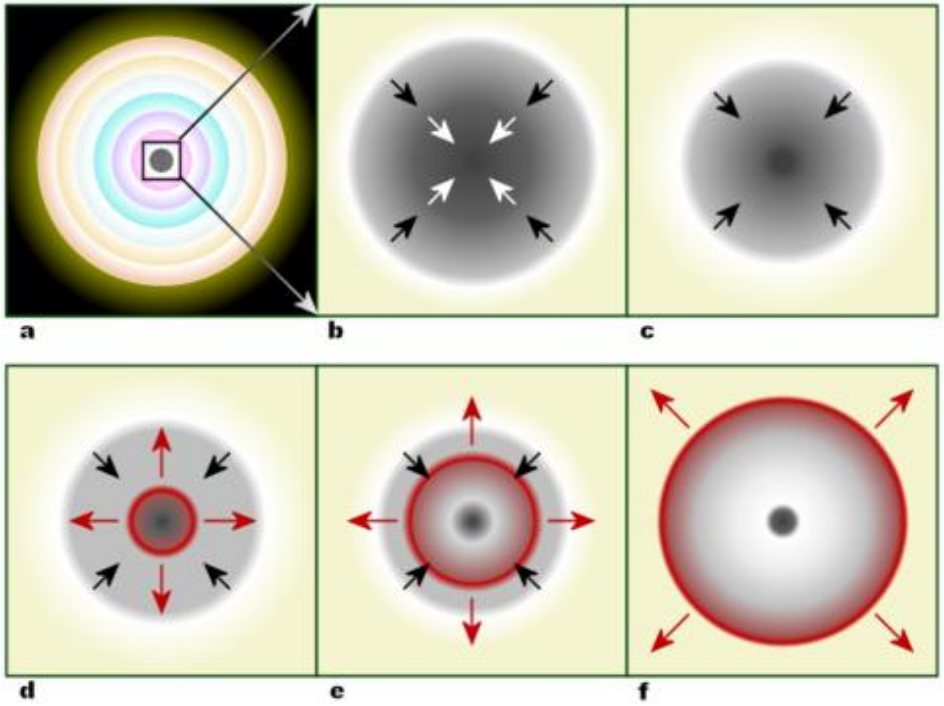
- Supernovae and the resulting neutron stars
- Nuclear Equation of State
- FAUST simulation using Geant4
- Results
- Conclusion

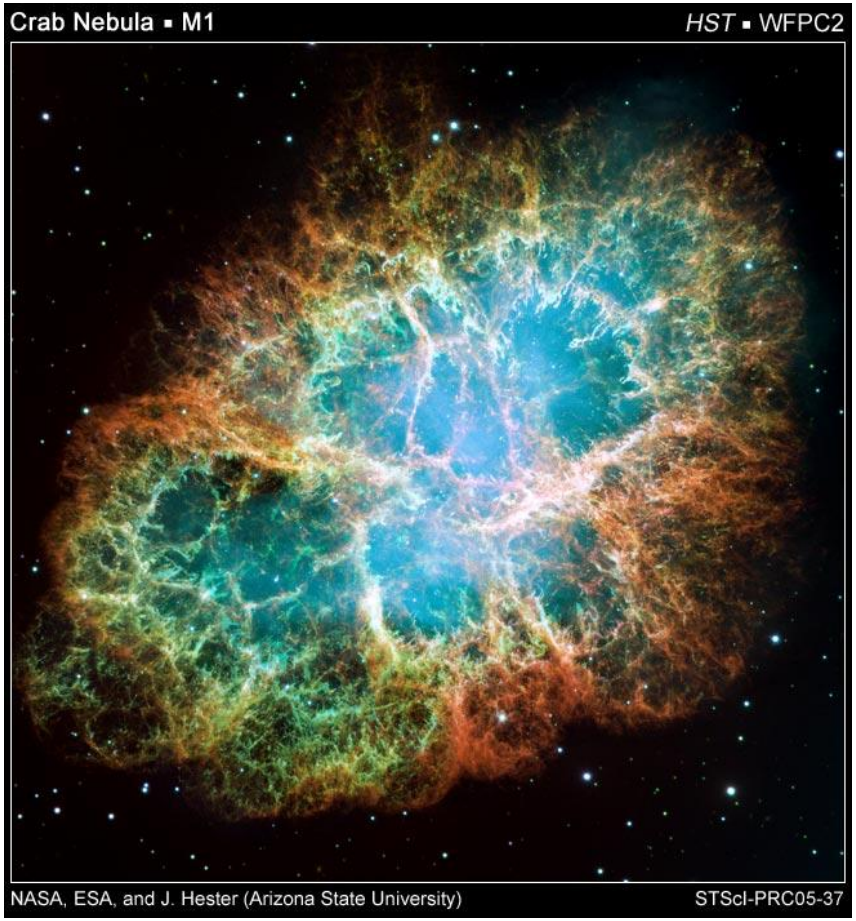
Supernovae Processes



Nave, Carl R. "Supernovae." *Supernovae*. HyperPhysics, n.d. Web

Type II Supernova

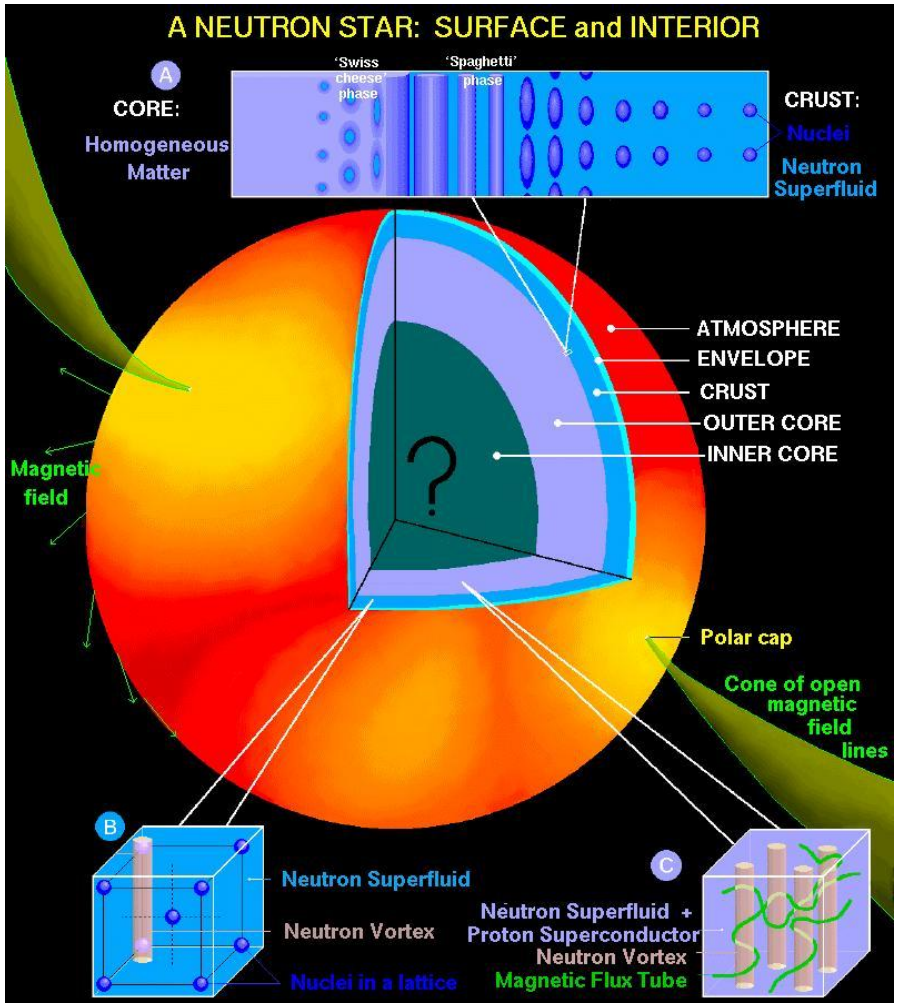




Supernova comes from Neutrino Energy Transport and is governed by Hydrodynamics

NASA, ESA, J. Hester and A. Loll (Arizona State University)
Type II Supernova." *OPT Corp*. Oceanside Photo and Telescope, n.d. Web
S.E. Woosley, Proceeding of the International Astronomical Union, **125**, 255 (1986)

The Resulting Neutron Star

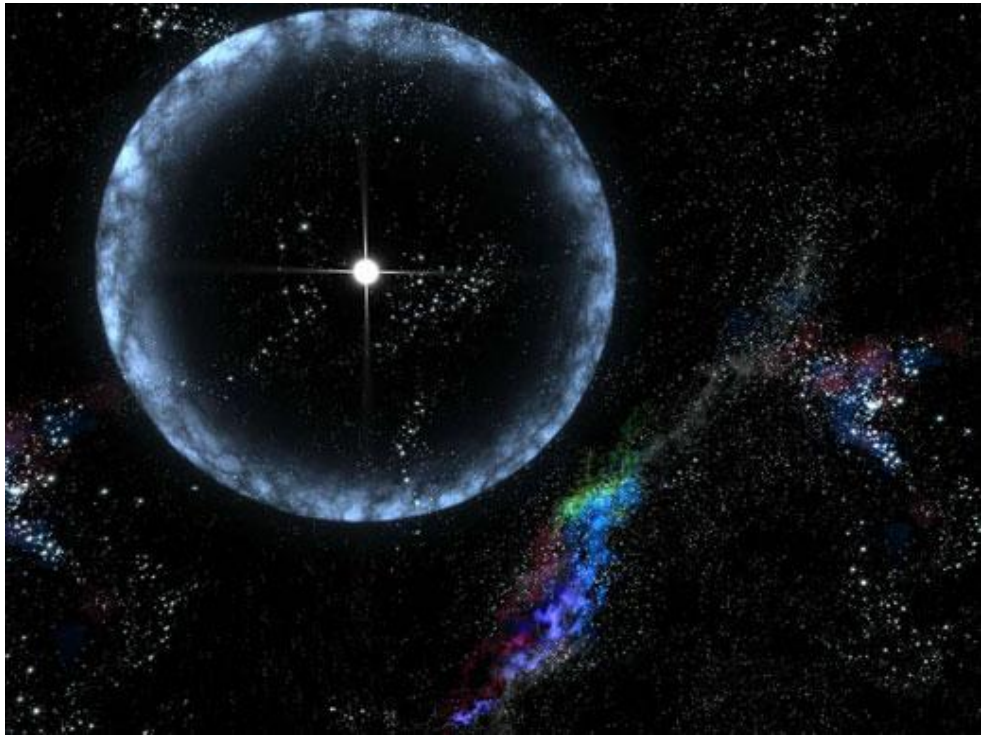


- Structure is relatively unknown
  - Especially inner core
- Inner core especially important.
  - Only observable region of exotic matter and phase transition

Latimer, J.M., et al, Science **304**, 536 (2008)

What Determines Properties of a Neutron Star?

- Nuclear Equation of State
  - Determines:
    - Maximum Mass
    - Radius
    - Surface Temperature
- Properties also determined by supernovae processes



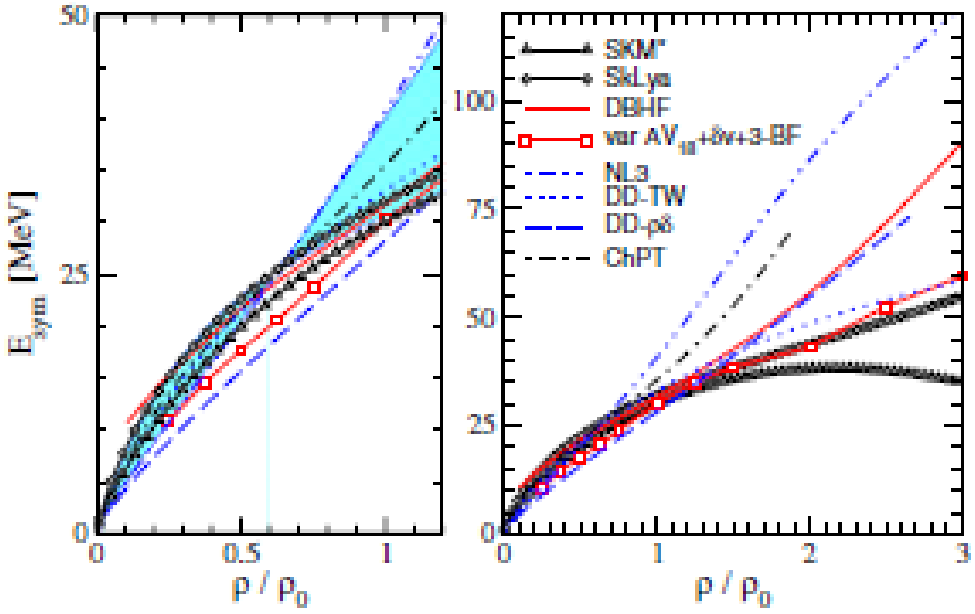
Stellar Quakes." *Stellar Quakes*. NASA, n.d. Web

Nuclear Equation of State

$$E_B = a_v A - a_s A^{2/3} - a_c \frac{Z^2}{A^{1/3}} - a_a \frac{(N-Z)^2}{A} + \delta(A,Z)$$

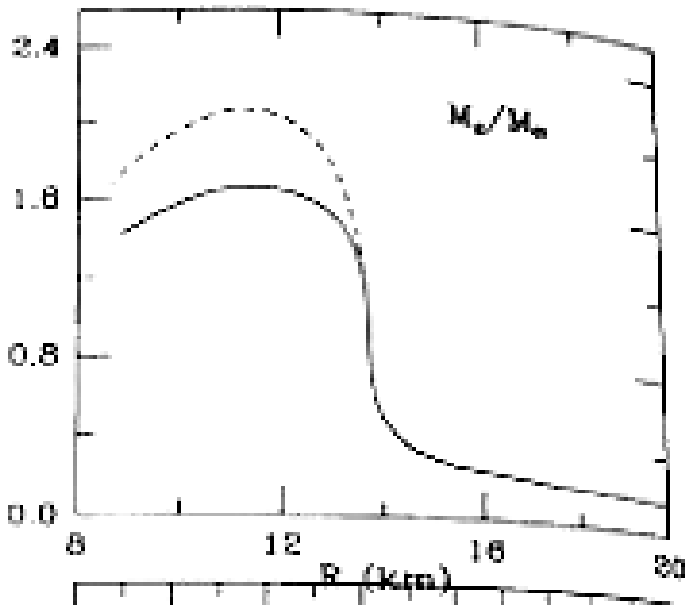
$$E(\rho, I) = E(\rho) + E_{sym}(\rho) I^2$$

- Different Models are used
  - Some Asy-Stiff
  - Some Asy-Soft
  - Which one to use?



H. H. Wolter, *Progress in Particle and Nuclear Physics* 59.1 (2007)

Asy-Stiff vs. Asy-Soft



- Stiff and Soft EoS give different predicted calculations for maximum mass and radius.
- Also allows for different supernova processes to occur.

S.E. Woosley, Proceeding of the International Astronomical Union, **125**, 255 (1986)
M. Prakash, "The equation of state and neutron stars", lecture note at the Winter School on "The Equation of State of Nuclear Matter", held in Puri, India, Jan 4-16, 1994.

Determination:

- Use multiple EoS to model neutron stars at different densities

Goal:

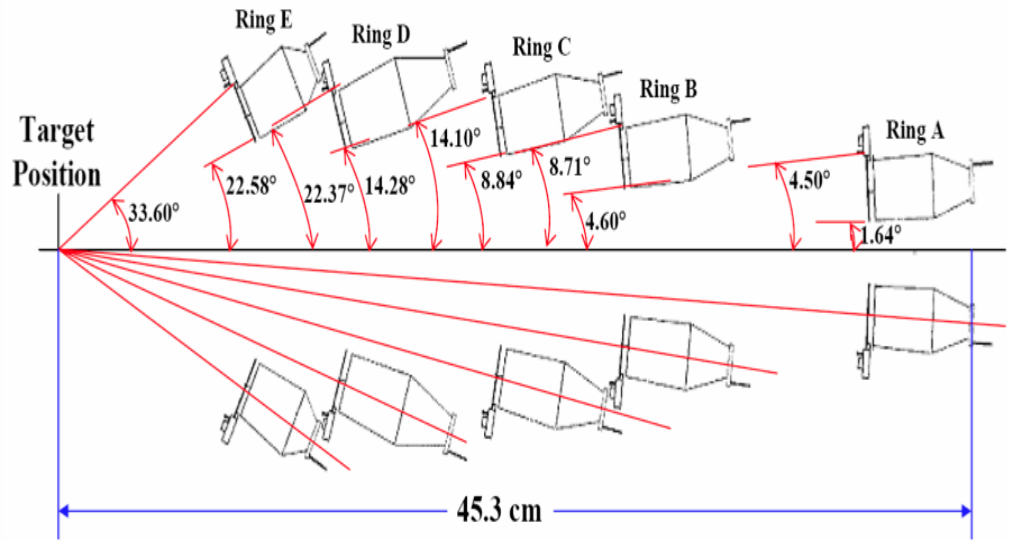
- Have one EoS that can be used at low densities and high densities but will still work at saturation density as well.

Using Simulations

- Simulations allow for experimental setups to planned and “perfected” before the experiment is conducted.
  - Saves money and time.
  - Provides nearly “perfect” data that can be used to compare to experimental data.

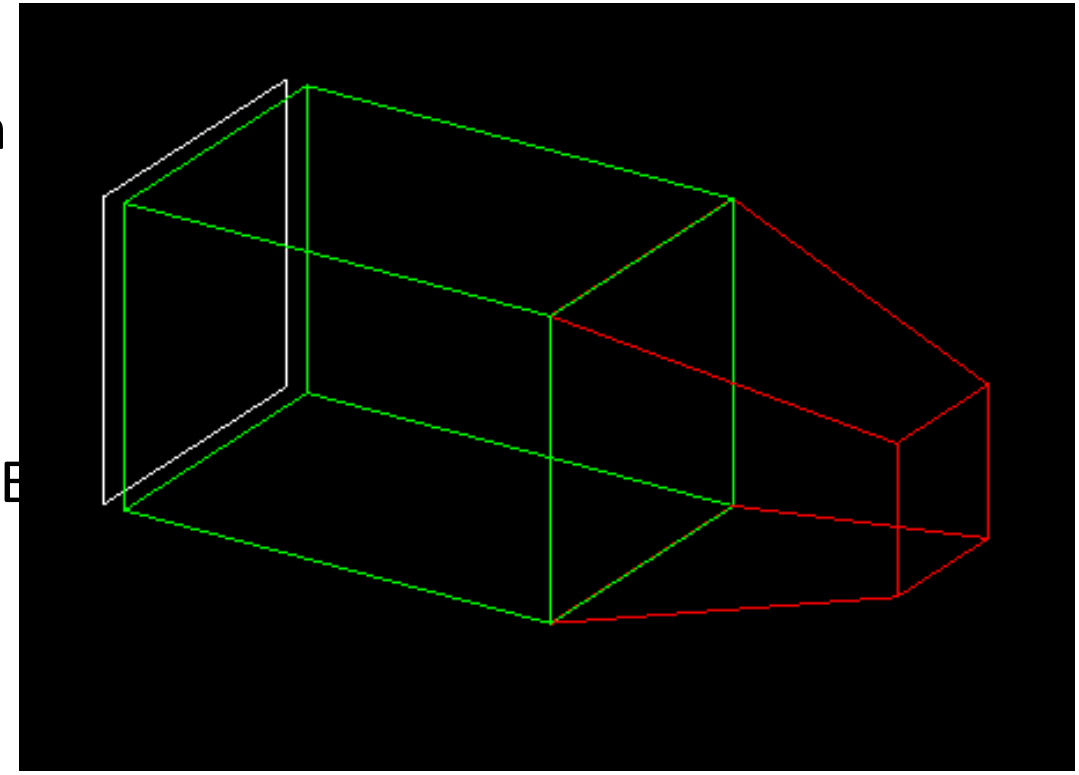
Forward Array Using Silicon Technology (FAUST)

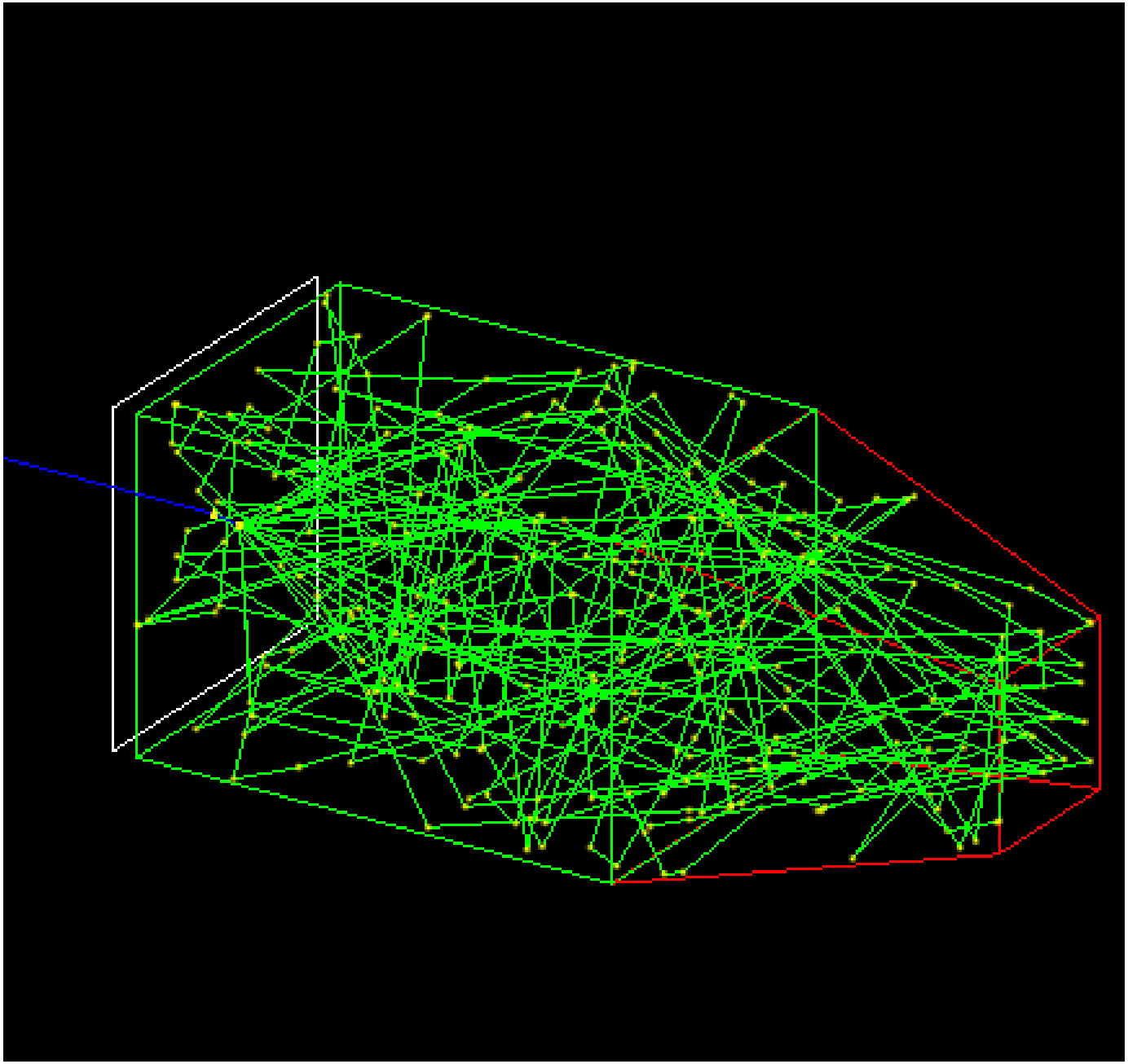
- Array of Silicon and Cesium-Iodide detectors
- Purpose:
  - Charged particle detector for multifragmentation
- Downfall:
  - Si detector too thick for low energy, heavy ions
    - No ΔE/E mass calculations

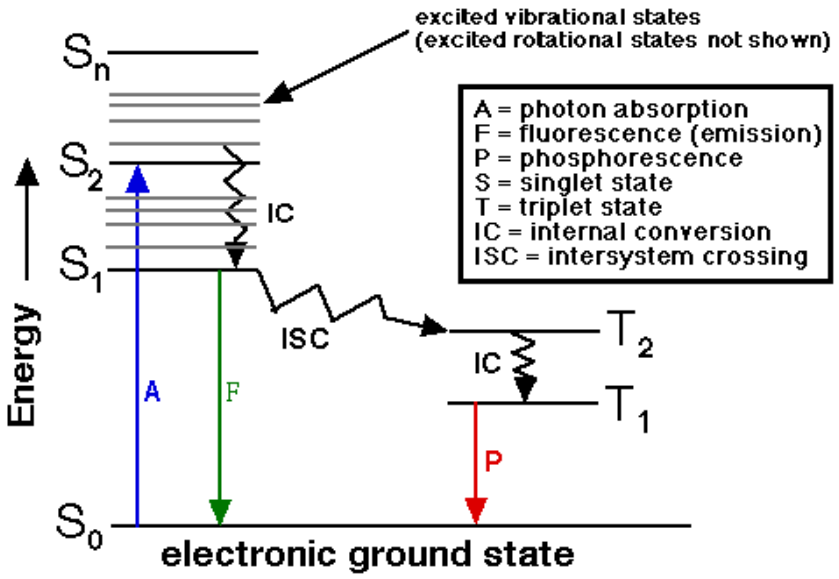


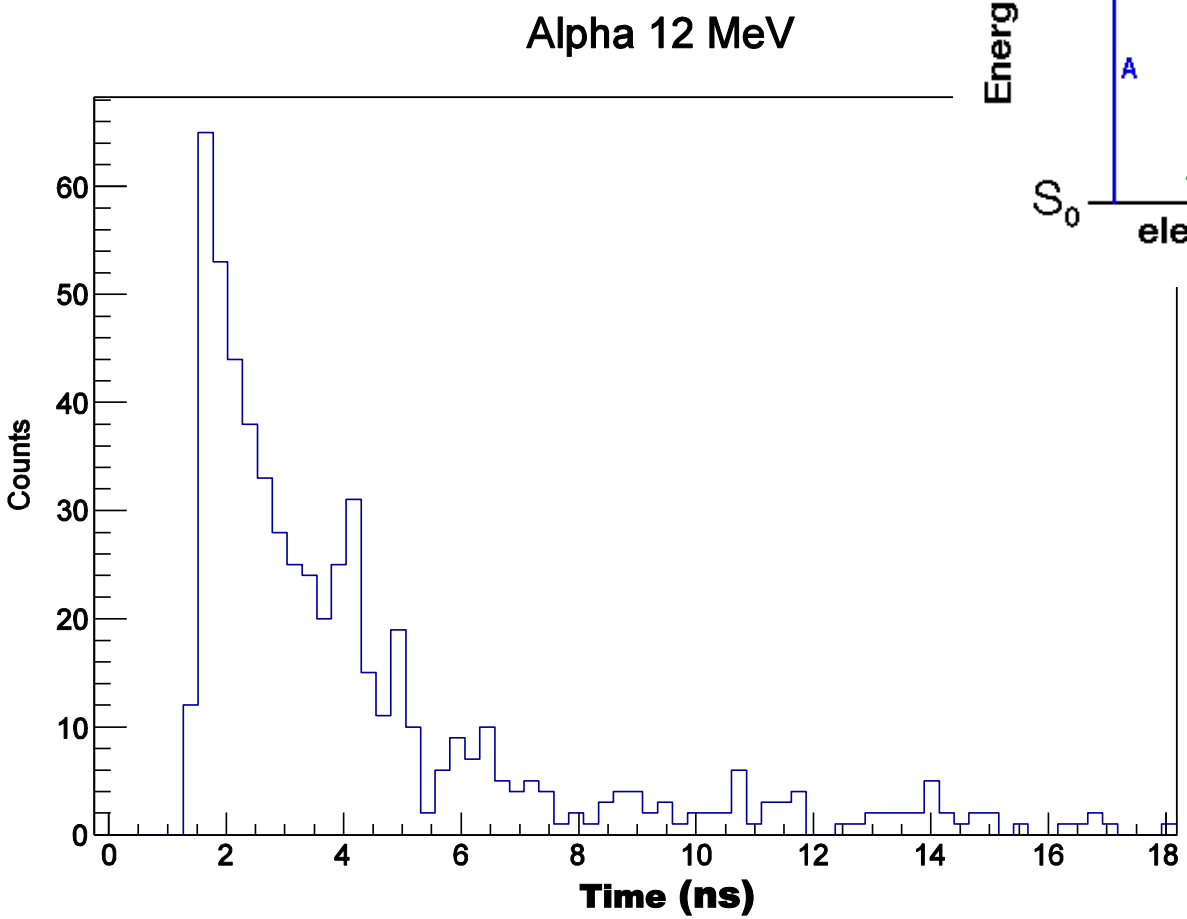
Geant4 Simulation of FAUST

- Purpose:
  - ToF Mass Identification using alpha particles and Zirconium-90 ions
- Benefit:
  - Can be used to get ΔE/E
- Contains:
  - Thin scintillator
  - Thick scintillator
  - Light guide






excited vibrational states
(excited rotational states not shown)
A = photon absorption
F = fluorescence (emission)
P = phosphorescence
S = singlet state
T = triplet state
IC = internal conversion
ISC = intersystem crossing
S_n
S_2
S_1
S_0
IC
ISC
IC
T_2
T_1
A
F
P
Energy
electronic ground state


Alpha 12 MeV
Counts
Time (ns)
0
10
20
30
40
50
60
0
2
4
6
8
10
12
14
16
18

Getting Mass From ToF

$$E = \frac{1}{2}mv^2$$

Kinetic Energy Equation

$$v = \frac{d}{t}$$

Velocity Equation

$$m = \frac{2E}{v^2}$$

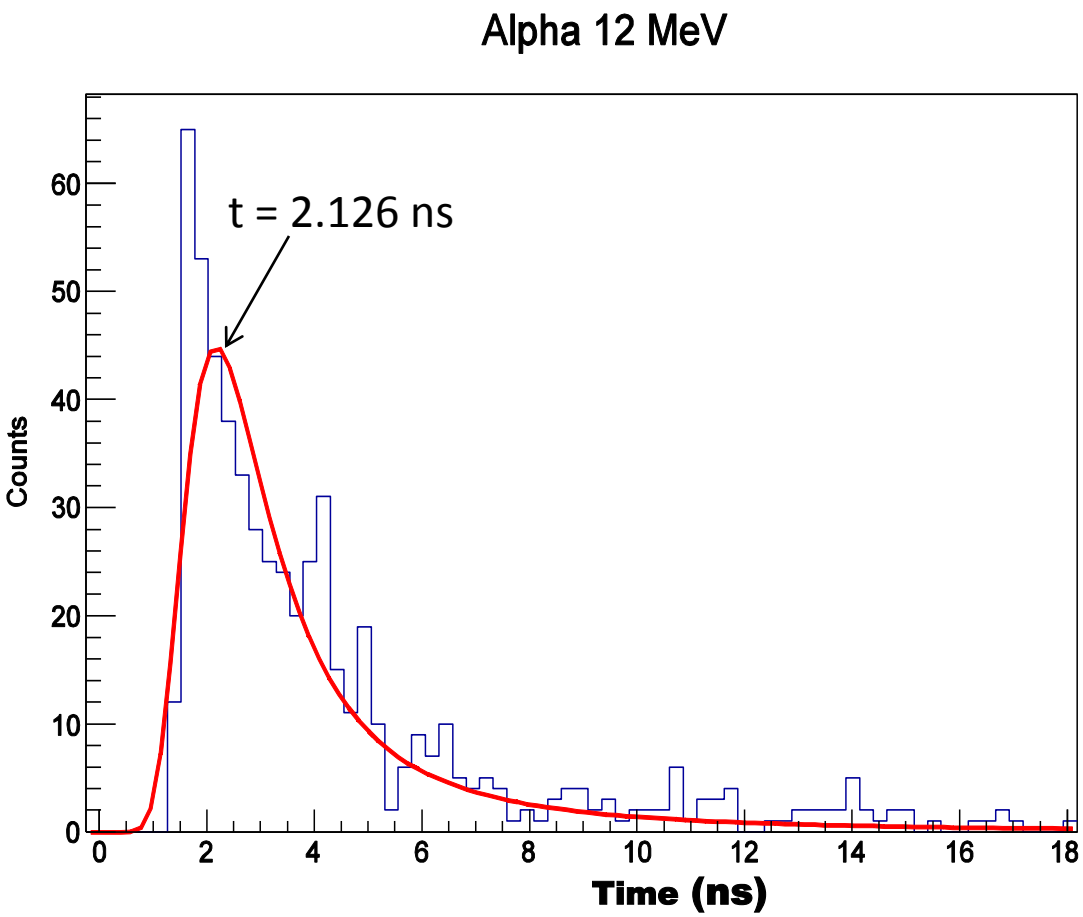
Mass Equation from KE Equation

1. Using a set distance, velocity (v) can be calculated using the measured time.
2. With a calculated velocity and a set energy (E), the mass of the particle can be calculated.

For energies: 10MeV, 12MeV, 14MeV, and 16MeV

ALPHA RESULTS

Alpha Particle 12 MeV



Distance = 0.05 m

v = d/t

v = 0.05 m / (2.126E-9) s

$m = 2E/v^2$

$m = (2*12MeV)/(2.126E\text{-}9s)^2$ Mev/s^2

$m = 4.34E\text{-}14MeV/s^2 * 9E16\ m^2/s^2$

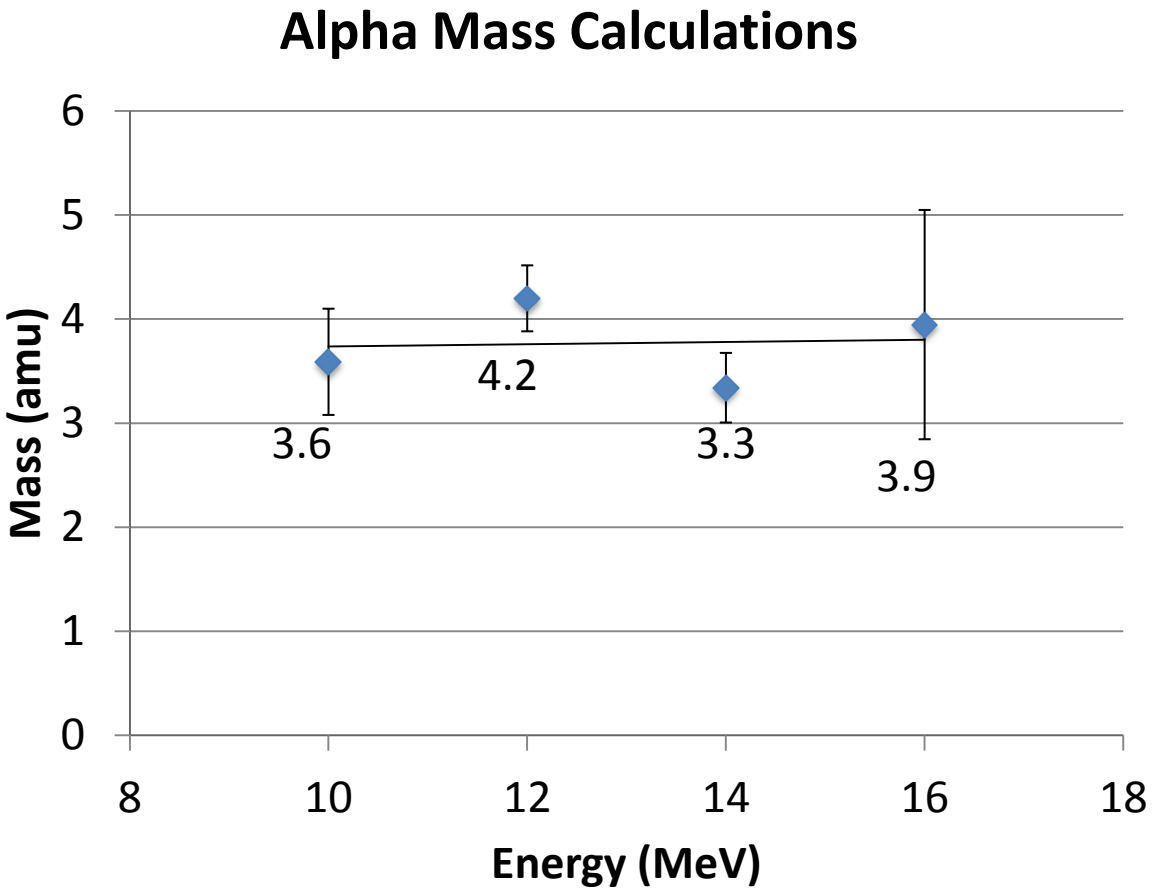
m=3905.173 MeV

---Conversion---
931.494MeV/amu

m = 3905.173 MeV / 931.494 MeV/amu

mass = 4.19 amu

Alphas May Be Too Light

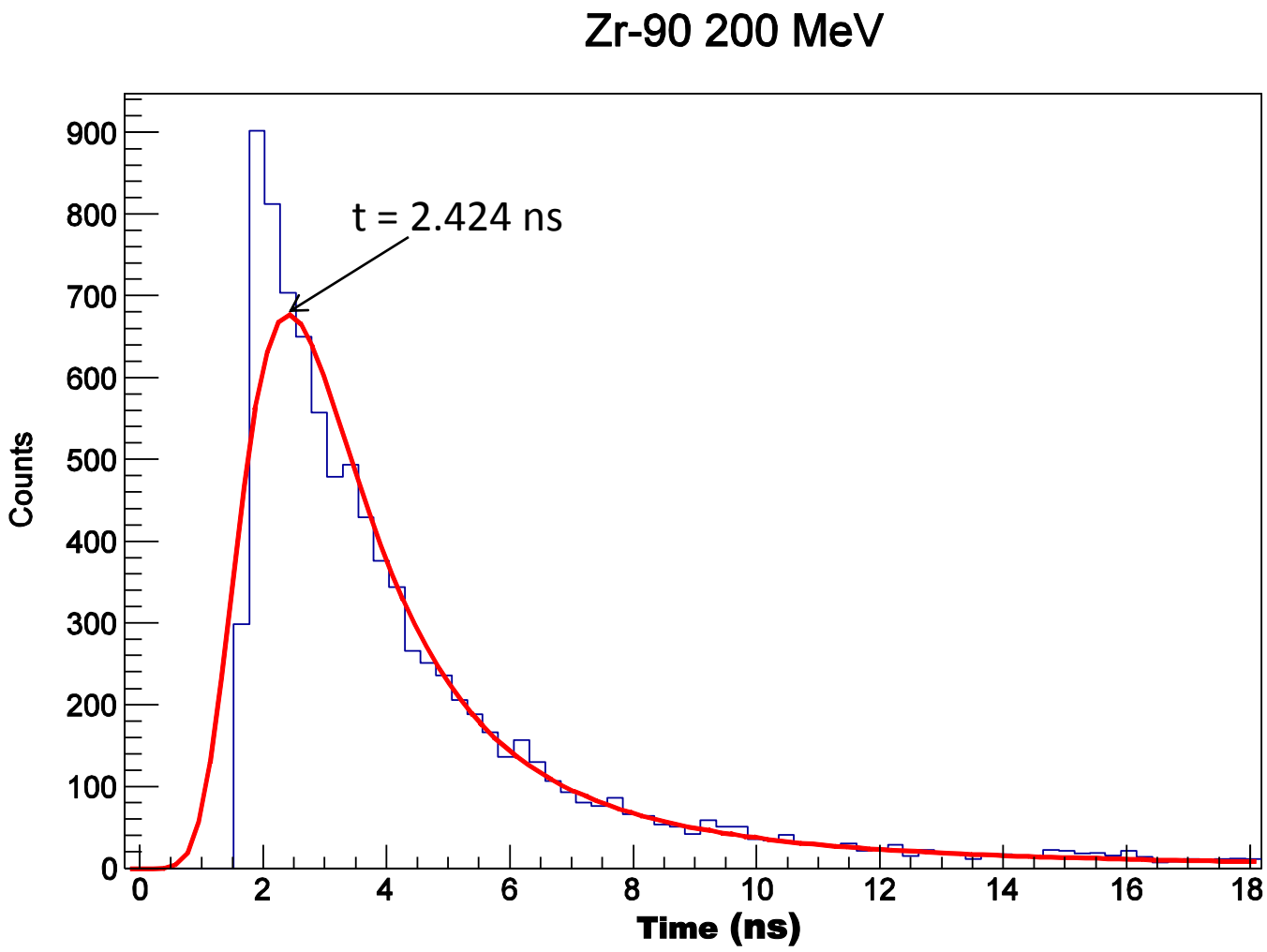


Alpha ToF mass identification calculations close, but inconsistent

With energies: 200MeV, 300MeV, 400MeV, and 500MeV

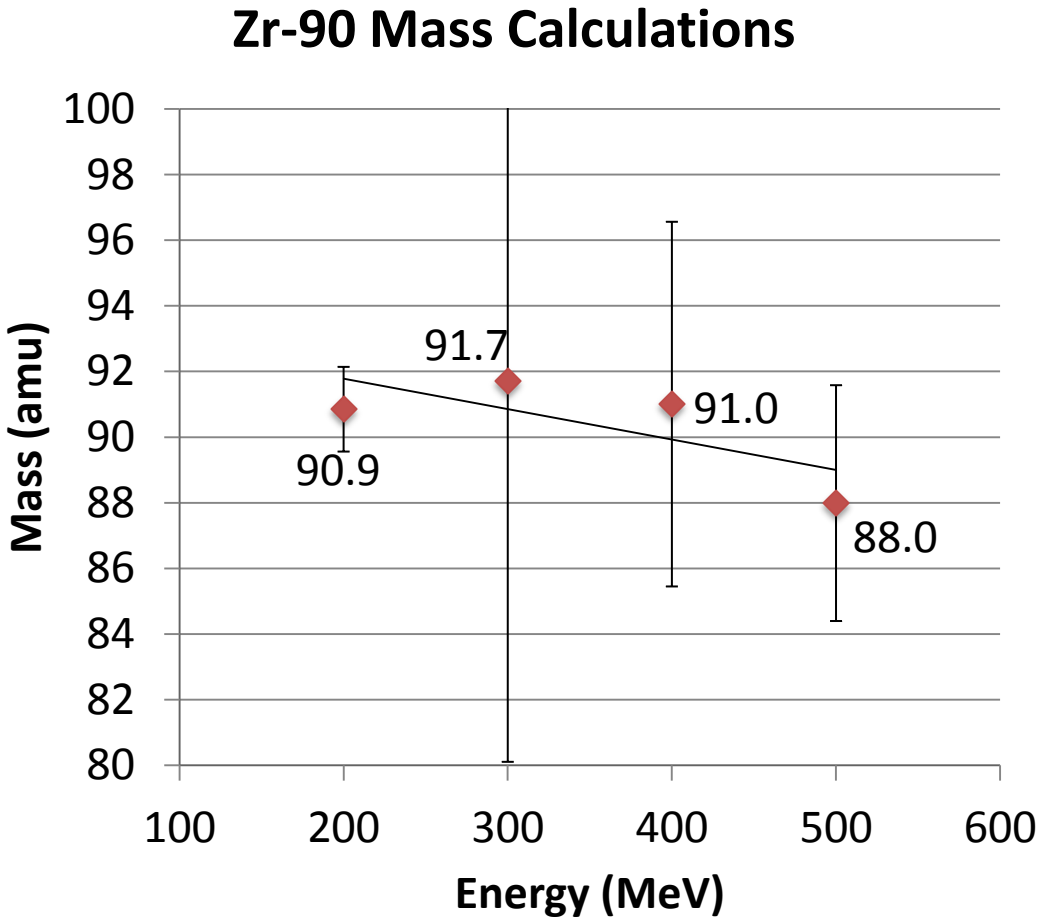
ZIRCONIUM-90 RESULTS:

Zr-90 200 MeV


Zr-90 200 MeV
t = 2.424 ns
Counts
Time (ns)
0
100
200
300
400
500
600
700
800
900
0
2
4
6
8
10
12
14
16
18

Heavy Elements Provide Better Results

Heavy elements see to obtain more accurate and consistent ToF Mass Identification calculations



For the Future:

- The timing resolution and ultimately the mass resolution (from ToF) will be compared to that of the current FAUST detectors.
- Other mass calculations, such as ΔE/E will be compared as well.

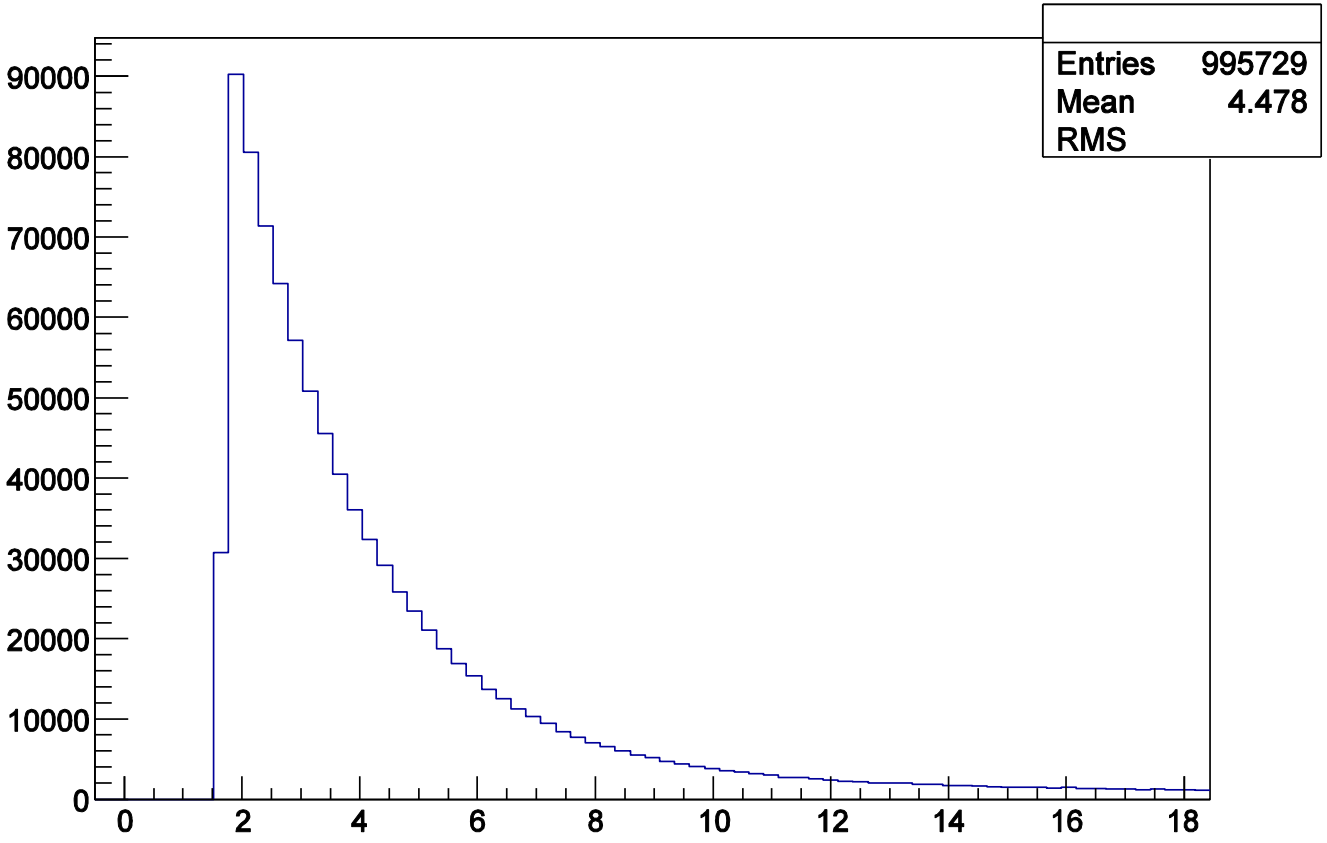
Acknowledgements:

- Special thanks to all the members in the SJY group, especially Paul Cammarata, for all the support and answers to all of my questions.

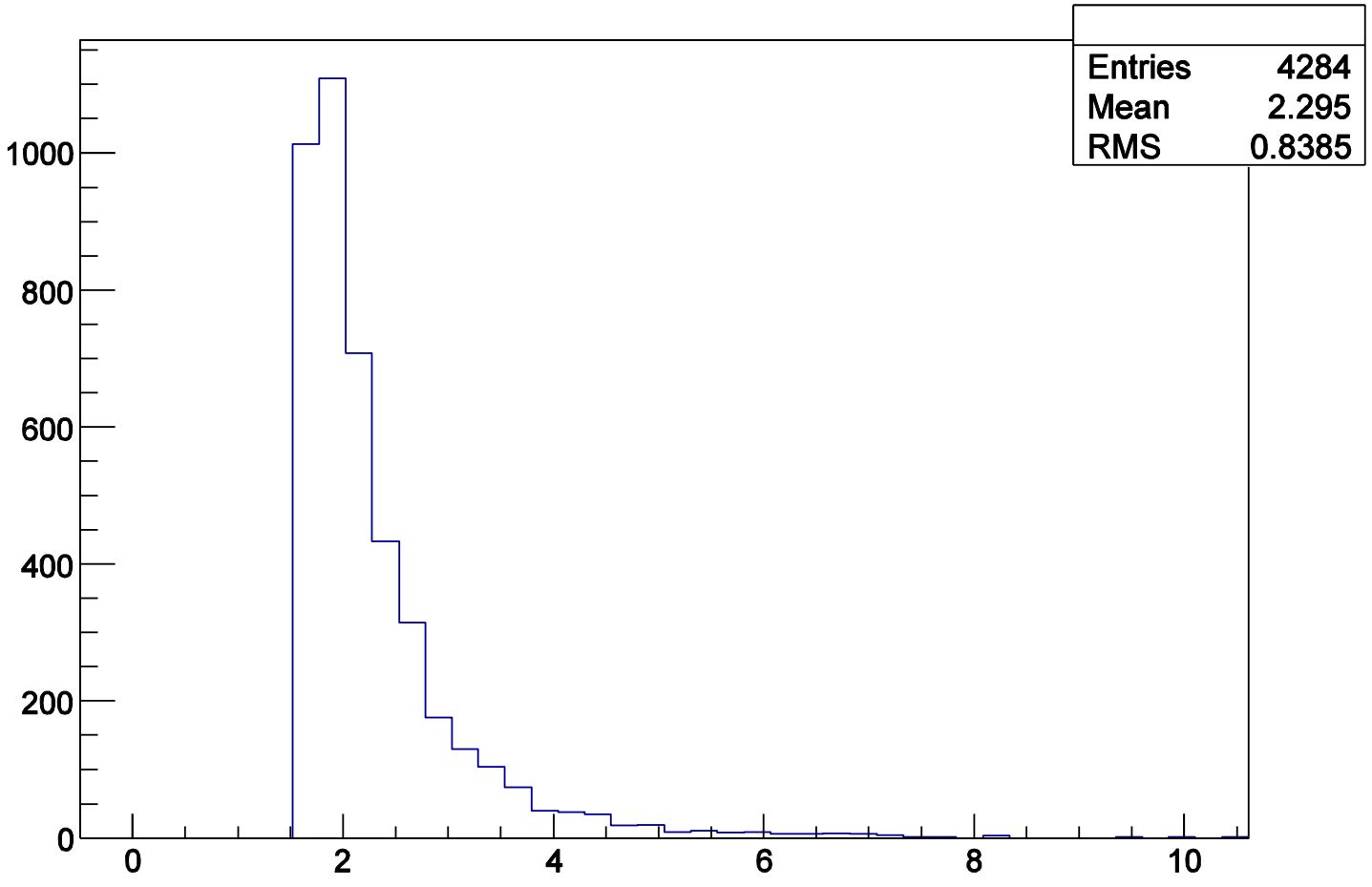
- Another thanks to Brian Roeder for help with the construction of my simulation.

BACKUP SLIDES

Total Thick Scintillator Timing



Total Thin Scintillator Timing



Thin Scintillator