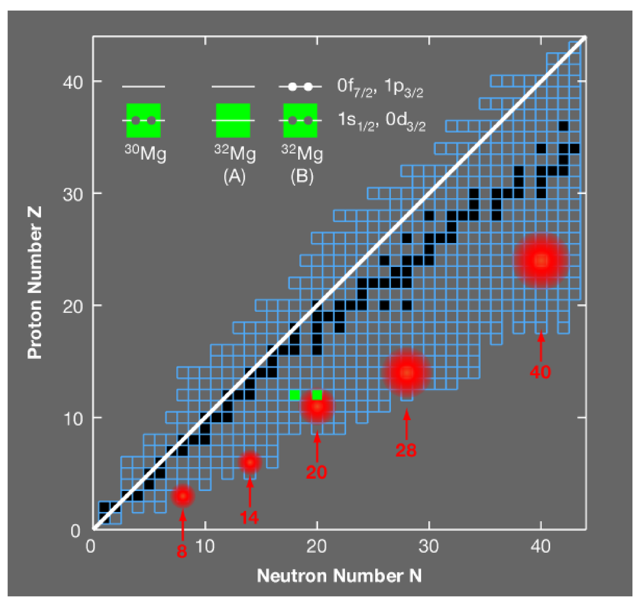
Electromagnetic Transition Rate Studies in ^{28}Mg

M.S. Martin[1], and K. Starosta[2]

[1]Department of Physics, Simon Fraser University, Burnaby, BC, V5A 3S6, Canada

[2]Department of Chemistry, Simon Fraser University, Burnaby, BC, V5A 3S6, Canada

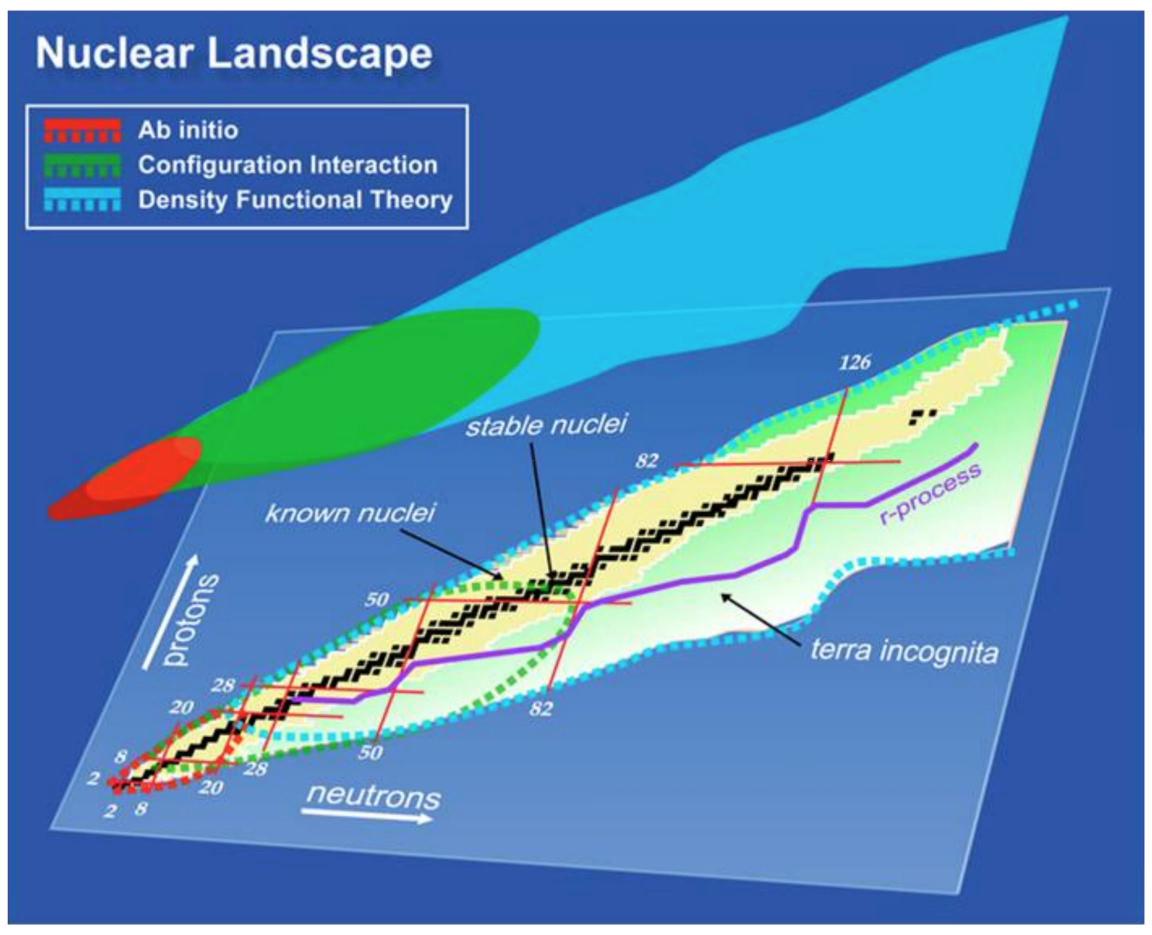
Island of Inversion at N=20 [1]



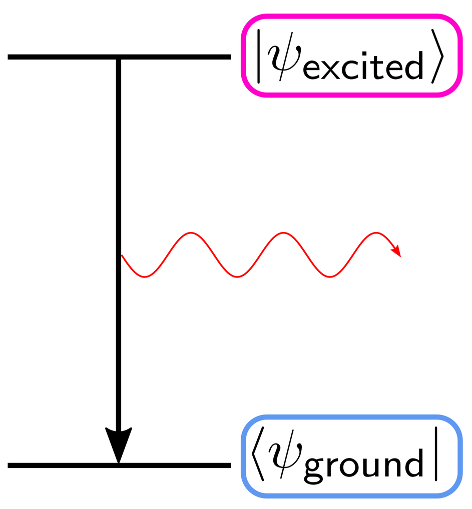
- Nucleons are placed into single particle energy shells analogous to atomic orbitals
- Shell model works very well near stability
- Nuclear models parametrized using data near stability
- Predicts shell gap at N=20 (observed)
- N=20 shell closure broken far from stability
- Structure of Mg isotopes leads to better understanding of shell evolution towards the island of inversion

Nuclear Theory [2]

- No complete theory of nuclei
- Many theoretical approaches reach different nuclei
- Attempt to calculate nuclear wavefunctions and observables from first principles
- Motivates the need for precise experimental measurements
  - Test theoretical predictions
  - Guide future efforts



Electromagnetic Transition Rate Studies



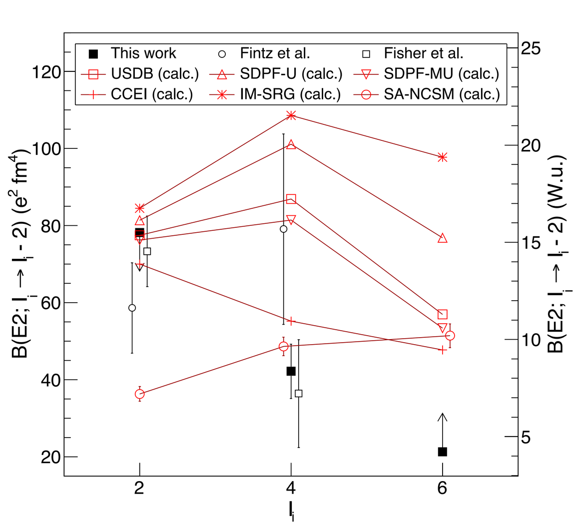
- Excited nuclei decay by emission of gamma rays

$$N(t) = N(0)e^{-t/\tau}$$

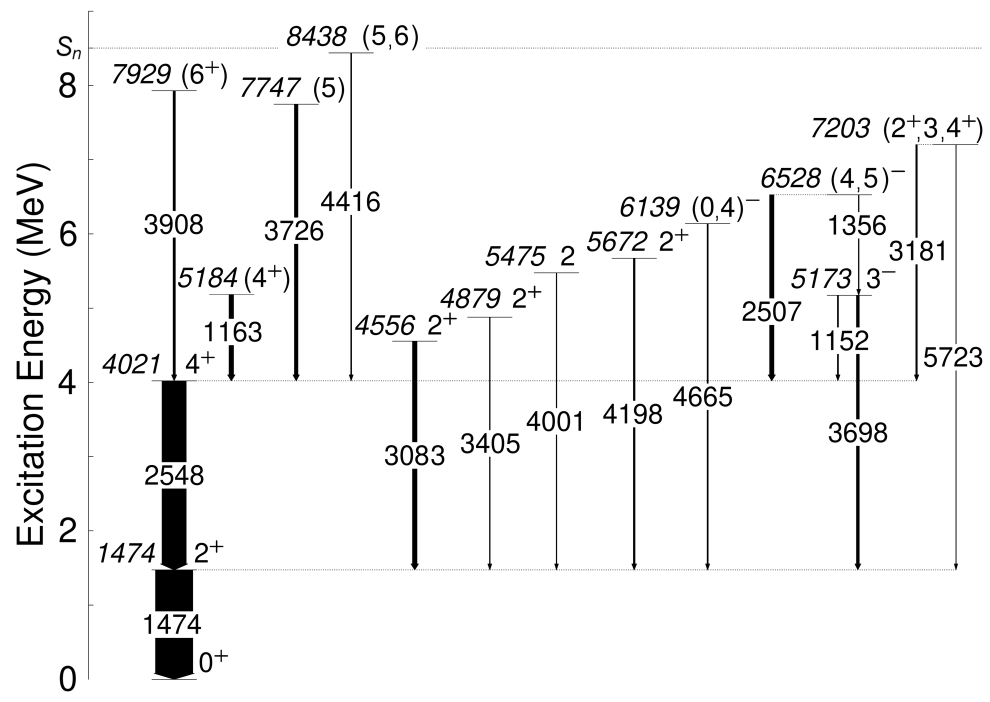
- Can measure lifetime of a given transition
- Electromagnetic interaction well known
  - Well understood E2 operator
- Can calculate B(E2): reduced transition strength
- Provides test of theoretical nuclear wavefunctions

$$\frac{1}{\tau} \propto |\langle\psi_{\text{ground}}|\,\text{E2}\,|\psi_{\text{excited}}\rangle|^2 \propto B(E2)$$

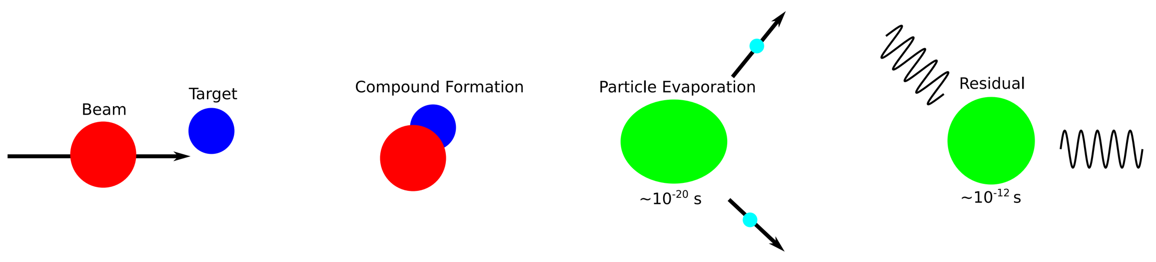
^{28}Mg - Previous Transition Rate Measurements [3-5]



- Theoretical predictions of the B(E2) reduced transition strengths vary widely for both $4^+ \rightarrow 2^+$ and $2^+ \rightarrow 0^+$ transitions
- Previous measurement resolved discrepancy in the $4^+ \rightarrow 2^+$ transition
- Unable to precisely measure the $2^+ \rightarrow 0^+$ transition
- SA-NCSM only calculation in agreement with $4^+ \rightarrow 2^+$ but disagrees with previous $2^+ \rightarrow 0^+$ measurements



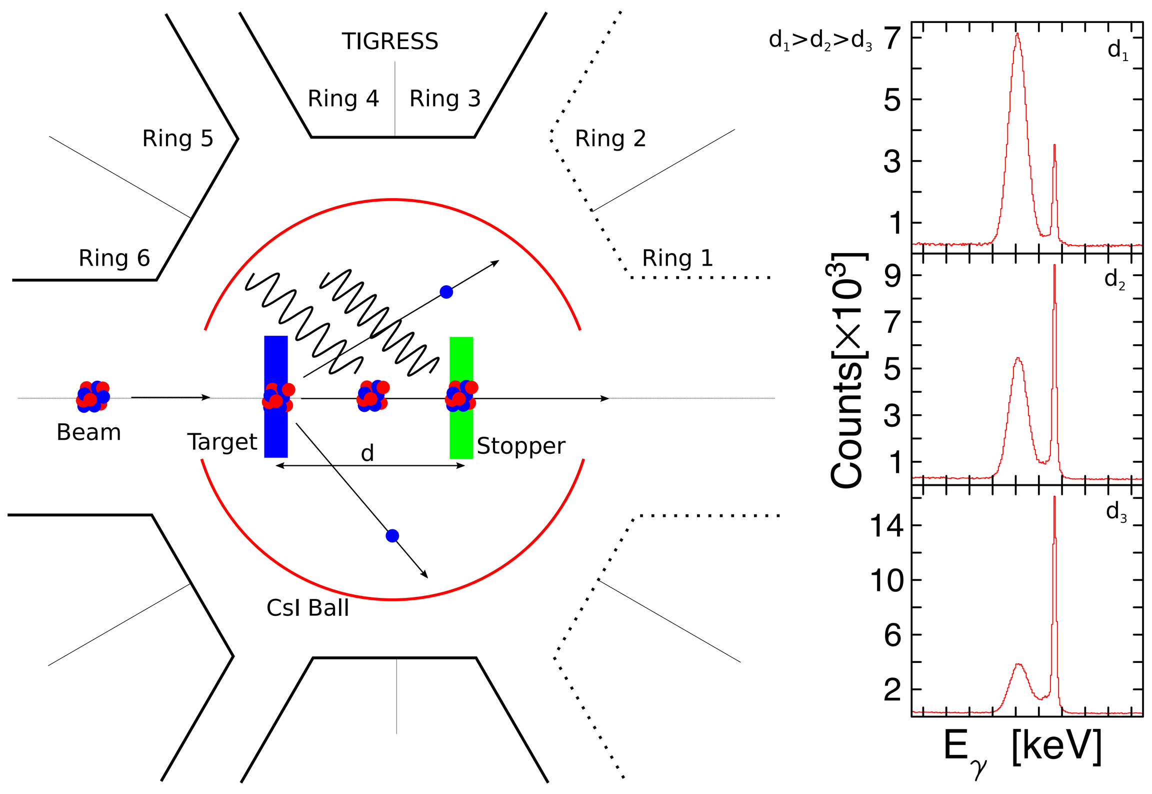
Fusion Evaporation Reactions



$$^{12}\text{C}(^{18}\text{O}, 2p)^{28}\text{Mg}$$

- Beam of ^{18}O impinges on ^{12}C target and fuse together
  - Fusion of ^{18}O and ^{12}C to form ^{30}Si
- Evaporate protons in $\sim 10^{-20}$ s to produce ^{28}Mg
- ^{28}Mg emits gamma rays decaying to the ground state in $\sim 10^{-12}$ s

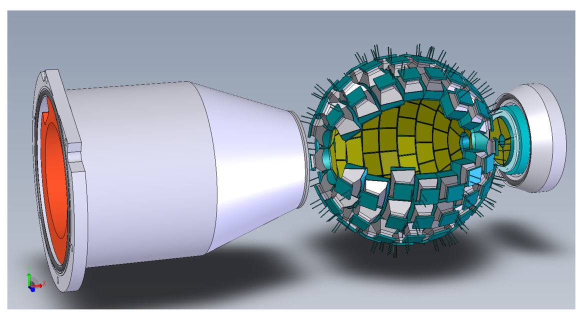
The Recoil Distance Method



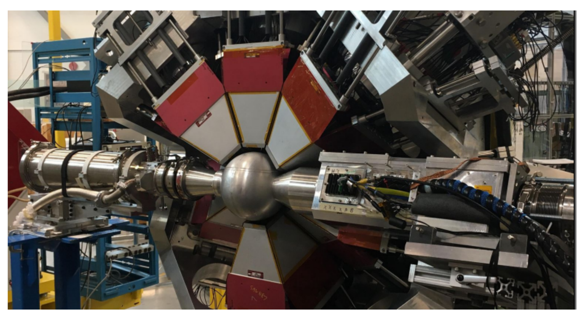
- Beam nucleus impinges on target, undergoing fusion-evaporation
- Charged particles detected in CsI ball of TIP
- Residual nucleus expelled into space between target and stopper
- Either decays in flight or in stopper
- Decays in flight will be Doppler shifted depending on detector
- The comparison of counts in shifted and non-shifted gamma ray peaks provides information on lifetime
  - Sensitive to states with $t_{1/2} \gtrsim 1$ ps

Detector Systems at TRIUMF and SFU

- Coincidence measurement of charged particles with TIP (left) and TIGRESS (right) allow identification of specific reactions

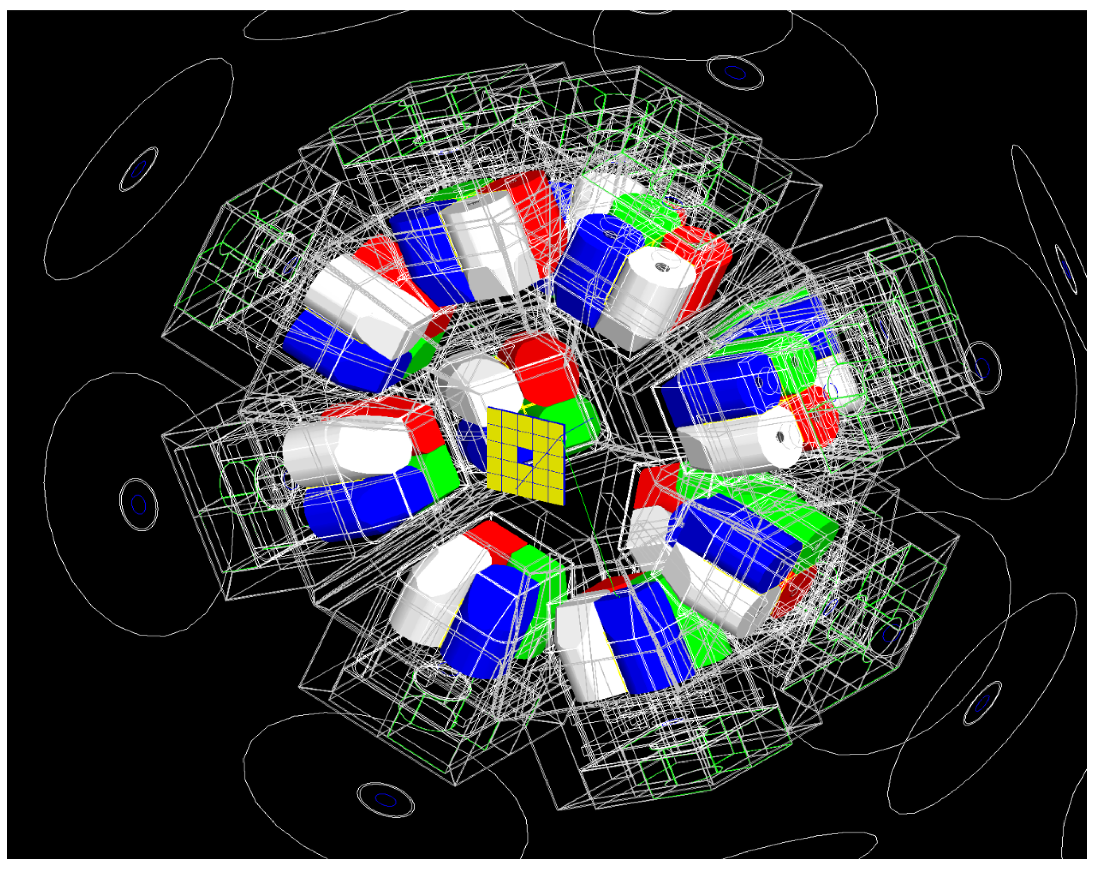


- CsI ball of TIP used for charged particle detection

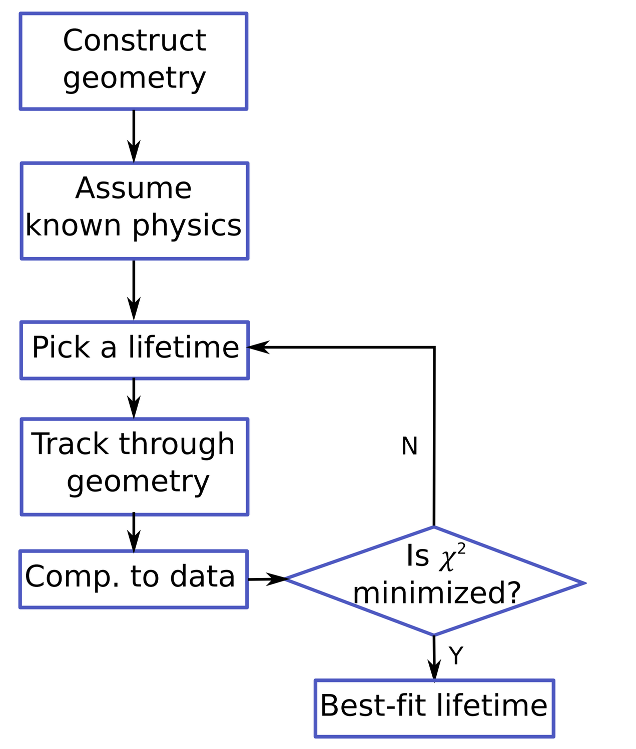


- TIGRESS used for gamma ray detection

GEANT4 Simulation Framework



- Monte Carlo simulation framework for particle interactions
- Simulate nuclear reactions, geometries, and detection
- TIGRESS and CsI ball constructed and tested
- Can simulate and optimize experimental parameters



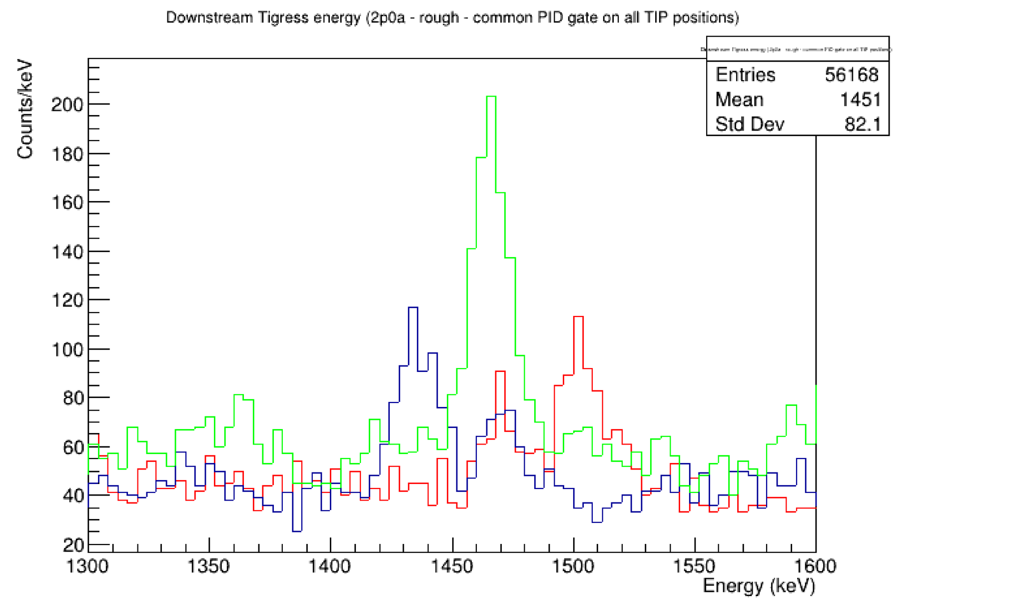
- Data analysis can be done with the aid of GEANT4 simulations
- Simulate experiment with varying lifetimes
  - Match experimental parameters as well as possible
- Use statistical methods to get a best fit lifetime
  - χ^2 minimization
  - Maximum-likelihood

Pre-Experiment Test Runs

- RUN 1: Calibration of CsI ball (May 26 → May 29)
  - Beam of 3(^{1}H) molecules are varying energies
  - No TIGRESS data taken
- RUN 2: DAQ Shakedown (May 31 → June 3)
  - Beam of ^{18}O on ^{197}Au-backed ^{12}C target
  - New firmeware developed for DAQ to store CsI waveforms
  - Tested with both thin-target and with plunger itself

Production Run

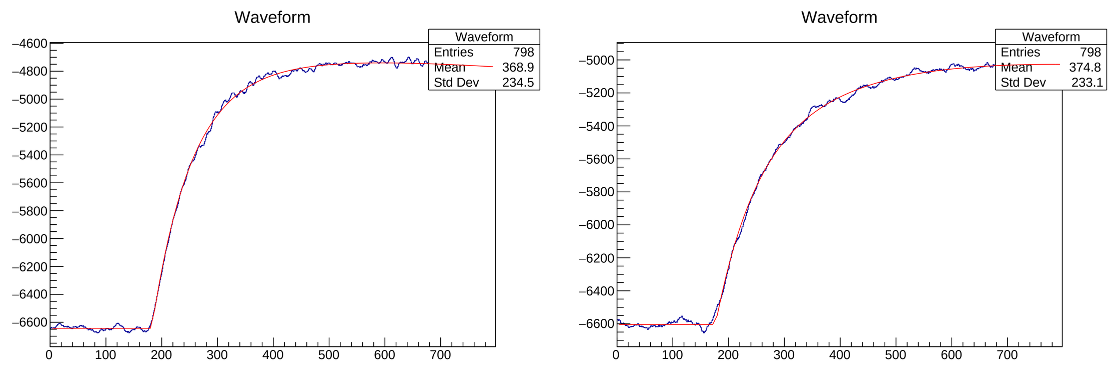
- Took data from June 12 → June 22
- Doppler Shift Attenuation Method run with lead-backed target
  - Method sensitive to short-lived states ($t_{1/2} \lesssim 1$ ps)
  - Represents the "zero-separation" measurement
- 11 plunger distances
  - Ranging from 17 μm through 400 μm
  - ~16 hours per distance to build statistics



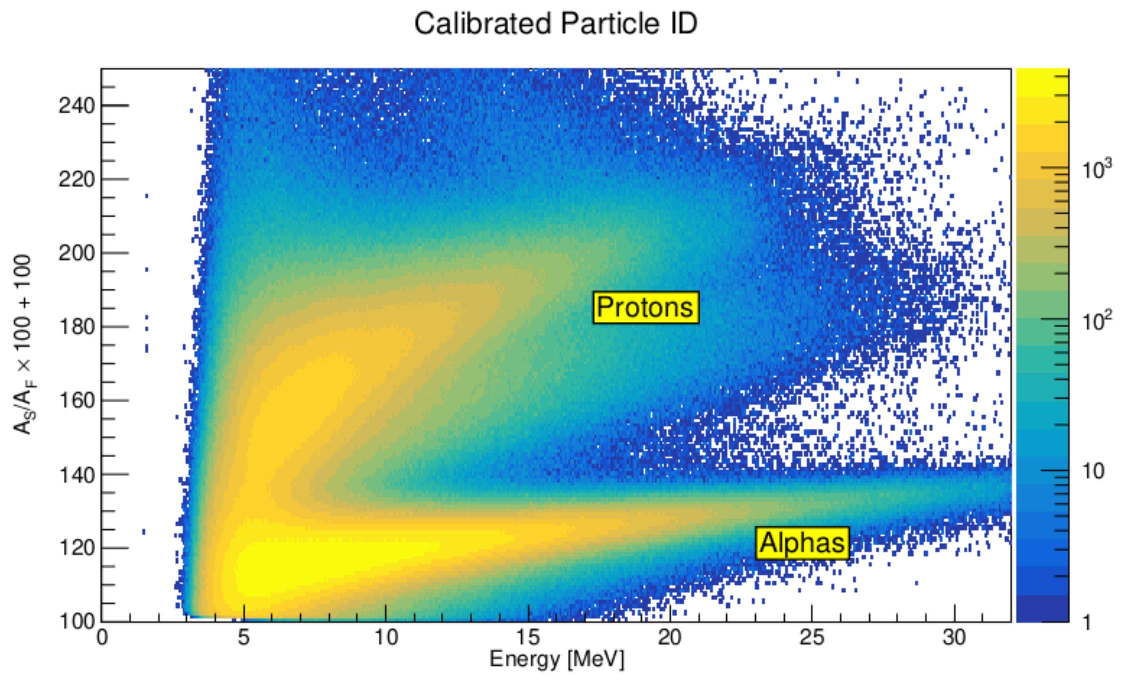
- Able to isolate ^{28}Mg using rough PID gates
- Can see separation of shifted-to-stopped peak
  - Blue: Upstream
  - Green: Corona
  - Red: Downstream

CsI Ball: Particle ID

- First step in analysis is proper PID
  - Requires determination of particle type



- Alphas (left) and protons (right) result in different waveforms
- Ratio of slow-to-fast risetime amplitudes used to determine particle type (below)



Current Work: Reconstructing Events

- Need to isolate ^{28}Mg using $2p$ gate
  - Only ~1 in 1000 events results in ^{28}Mg
  - Requires particle tags for events
  - PID produces particle tags for fragments
- Can reconstruct events using timestamps
  - Events then sorted by particle content

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