Recoil Distance Lifetime Measurements at NSCL
Reduced E2 transition probability

- Reduced E2 transition probability $B(E2)$ measures collective effects related to quadrupole deformation of nuclear charge distribution.

- $B(E2)$ is directly related to the E2 transition rate:
  \[
  \lambda(E2, I_i \rightarrow I_f) \sim (E_i - E_f)^5 \times B(E2, I_i \rightarrow I_f)
  \]

- E2 transition rate is inversely related to the lifetime:
  \[
  \lambda(E2, I_i \rightarrow I_f) = \frac{1}{\tau(E2, I_i \rightarrow I_f)}
  \]
Time of flight technique for lifetime measurements

\[ c = 300 \mu \text{m/ps} \]

\[ \beta \sim 0.3c \]

\[ 10 \text{ ps} \sim 1 \text{ mm} \]
At fast beam facilities like the NSCL

- The technique has many advantages:
  - Relies on relative measurements - decay curve measured directly.
  - Impact parameter does not matter (decays are measured instead of excitations)!
  - Relatively simple dependence on reaction kinematics.
  - Not limited by isomer contamination of the beam.
  - Can be easily applied to lifetime measurements in 3 – 500 ps range.
  - Possible extension to sub-picosecond range.

- The technique allows for:
  - Precision lifetime measurement beyond the $2^+_1$ in even-mass nuclei.
  - Lifetimes in odd-mass and odd-odd nuclei.
RDM in the fast-fragmentation scheme

\[ \text{E} \sim 100 \text{ MeV/u} \quad \text{E'} \sim 90 \text{ MeV/u} \quad \text{E''} \sim 60 \text{ MeV/u} \]

- Diamond detector for TOF
  - \( ^{64}\text{Ga} \)
    - \( \beta = 0.42 \)
  - \( ^{12}\text{C} \)
    - 500 \( \mu \text{m} \)
  - \( ^{93}\text{Nb} \) 250 \( \mu \text{m} \)
    - \( \beta' = 0.38 \)
    - \( \beta'' = 0.32 \)
    - to S800 for particle identification

- \( ^{65}\text{Ge}, ^{64}\text{Ga}, ^{63}\text{Zn}, ^{62}\text{Cu} \)

- Incoming cocktail beam:
  - \( \sim 5\% \quad ^{65}\text{Ge}, \sim 35\% \quad ^{64}\text{Ga}, \sim 52\% \quad ^{63}\text{Zn}, \sim 8\% \quad ^{62}\text{Cu} \)
  - produces \( \sim 50 \) different outgoing reaction residues in various reaction channels.

- Each of the outgoing channels can be investigated for lifetime measurements since the method is sensitive to the reaction kinematics only.
RDM in the fast-fragmentation scheme

CCF +

A1900 +

Diamond detector +

Köln/NSCL plunger +

SeGA +

S800
The fragmentation scheme:

- Large number of open channels:
  - many nuclei studied in a single run,
  - good PID necessary.

- Small ~500 µm target-degrader distances:
  - no changes in gamma-ray detection efficiency.

- Excitations at moderate energy/angular momentum:
  - feeding cascade corrections necessary.
Particle Identification: Incoming beam

Time of flight:

from the K500 (RF)

to the S800 object (diamond detector).
Particle Identification: Outgoing beam

TOF Diamond-FP S800 : ΔE S800 FP Ionization chamber
Particle Identification: Outgoing beam

TOF Diamond-FP S800 : $\Delta E$ S800 FP Ionization chamber

- $^{62}\text{Cu}$
- $^{63}\text{Zn}$
- $^{64}\text{Ga}$
- $^{65}\text{Ge}$
Plunger configuration for SeGA

- Detector rings at 30 and 140 deg. for optimal Doppler-shift measurements
Specifics of the NSCL 06502 experiment

• Data taken
  – with the plunger target only,
  – at 0, 200, and 500 µm target/degrader separation.

• Lifetimes from calculated lineshapes of gamma-ray peaks.
  – simulation of heavy ion propagation and gamma-ray detection within a single framework,
  – stopping powers measured and well described at intermediate energies,
  – with the heavy ion part fixed, lifetime of the state defines the gamma-ray lineshape uniquely.
Experimental $\gamma$-ray spectrum for $^{63}$Ga

P. Voss et al.
Color code convention

Target  Degrader

Variable distance
Experimental data for $^{63}\text{Ga}$

$\frac{3}{2}^{-} \rightarrow \frac{3}{2}^{-}$

$\frac{7}{2}^{-} \rightarrow \frac{5}{2}^{-}$

P. Voss et al.
The Coulex scheme:

- Small number of open channels: easy PID.
- Single step excitation process: no feeding corrections necessary.
- Large \( \sim 5 \text{ mm} \) target-degrader distances: efficiency corrections necessary.
Intensity corrections

• No intensity corrections for the decay downstream from the degrader for a stationary degrader.

• For the decay between the target and the degrader:
  – Relativistic beaming,
  – Efficiency,
  – Solid angle change,
  – Angular distribution,
  – Spin deorientation,
  – Attenuation.
Preliminary results for $^{114}$Pd

A. Dewald et al.
Preliminary results for $^{114}$Pd

A. Dewald et al.
Geant4/ROOT simulations for SeGA

- Heavy ions and $\gamma$-rays within a single framework.
- Realistic simulation of the incoming beam properties.
- Stopping powers for various materials verified against LISE.
- Output for spectra corresponding to tracked S800 unreacted and reacted data as well as SeGA data.
- Plunger/regular target experiments implemented.
- Coulex/knock-out reaction kinematics implemented.
- Various SeGA configurations implemented.
- Geant results stored in ROOT trees for flexible analysis.
- Fitting of experimental spectra implemented.
- Gamma-ray tracking simulations for SeGA implemented.
Geant4/RooT simulations for SeGA
Simulations for $^{18}$C plunger experiment 06023

P. Adrich et al., scheduled in the next SeGA campaign
Simulations for $^{18}$C plunger experiment 06023

Au degrader $\tau = 10$ ps

d = 50 µm          d = 500 µm          d = 2000 µm

P. Adrich et al., scheduled in the next SeGA campaign
Conclusions

- The method is well established.

- Plunger measurements to be run in the next SeGA campaign:
  - $^{16}$C by R. Clark et al.
  - $^{18}$C by P. Adrich et al.
  - $^{62-66}$Fe by A. Dewald et al.

- Collaborations are welcomed.