A spectrometer for knockout reactions @ FRIB

• FRIB will champion production of neutron-rich nuclei
  • Mass > 100 regions at energies ~ 100 - 200 MeV/u

• Neutron-rich beams with $B_\rho \sim 7$ T.m.
  • 1-2 proton knockout leads to residues with similar or higher $B_\rho$

• Knockout reactions remove at most 2 nucleons
  • $B_\rho$ difference between residue and unreacted beam shrinks with increasing mass (also true for other reactions)

• Good resolution and/or dispersion matching are needed to reject unreacted beam from focal plane
  • For instance, a 1% $\Delta P/P$ incoming beam would overlap with A=99 residue from A=100 projectile
Angular momentum identification

- Angular momentum of the removed nucleon
  - given by the shape of the $p_{//}$ distribution of the residue
- Good resolution needed to identify angular momentum from shape of parallel momentum distributions
  - Compromise between statistics and resolution
- Example: $^{90}\text{Zr} - 1$ neutron
  - Statistics of 200 counts

Simulation of the longitudinal momentum distribution of $^{89}\text{Zr}$ from the neutron knockout of $^{90}\text{Zr}$, assuming the valence neutron is either in the $1f_{5/2}$ or $1g_{9/2}$ orbital. A resolution of 1/1000 in momentum is needed to identify the angular momentum from the shape of the simulated $1g_{9/2}$ momentum distribution.
PID considerations for \( A > 100 \)

- Identification of the mass of the residue
  - Relies on time-of-flight between reaction target and focal plane
  - Trajectory length corrections needed from FP tracking detectors
  - Flight path long enough and time resolution good enough
- Example: 1p knockout from \(^{138}\text{Sn} @ 200\text{ MeV/u}\)
  - \(^{137}\text{In}\) residue TOF in 15m is 93 ns
  - Time resolution needed (combined start-stop): 600 ps
- Present limit in S800
  - TOF is typically 100-150 ns, flight path is 15m, stop scintillator is 60x30 cm\(^2\), combined resolution \( \sim 1\) ns
  - Can resolve up to \( A \sim 100 \) after flight path corrections
Examples from S800

A. M. Rogers et al., PRL 106, 252503 (2011)

N. Aoi et al., PLB 692, 302 (2010)
Examples from S800

Reaction Fragment Identification

![Graph showing reaction fragment identification with labeled elements and color-coded values.]

**After the secondary target**

25 fragments identified via γ spectra

Charge states

• S800 CsI(Na) hodoscope
  • Measure TKE over large area
  • Resolution limited to few % in E
  • Adequate for Q up to ~ 40

• Example from $^{76}$Ge fragmentation on $^{197}$Au
  • $\Delta E$-TOF gate contains both $^{72}$Ga$^{31+}$ and $^{70}$Ga$^{30+}$
  • E difference is 3.7% → 1% in light

• Charge state population at Z>50
  • Need TKE detector with % resolution in E
Summary of requirements

- Acceptances similar or smaller than S800
  - 20 msr (± 60 mrad x ± 90 mrad), 5% ΔP/P
- ΔP/P resolving power ~ 1/1000
  - Like in S800, use “software” spectrometer to achieve resolution
- TOF resolution needed!
  - Compromise between length and time resolution (detectors?)
- Z and TKE measurements
  - Z up to Uranium, TKE to resolve Q, improvements needed compared to s800
- Space around target for γ-ray array (CAESAR, GRETA,...)