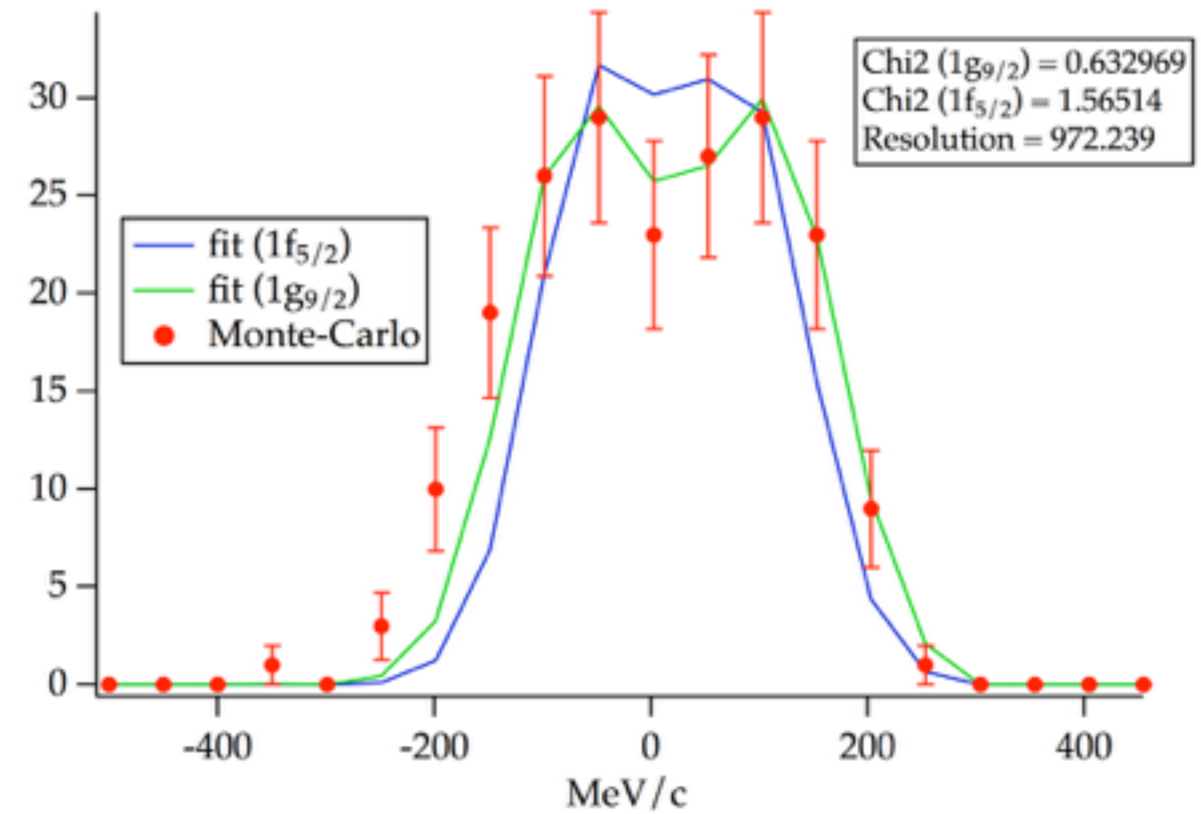
# A spectrometer for knockout reactions @ FRIB

- FRIB will champion production of neutron-rich nuclei
  - Mass > 100 regions at energies ~ 100 - 200 MeV/u
- Neutron-rich beams with Bρ ~ 7 T.m.
  - 1-2 proton knockout leads to residues with similar or higher Bρ
- Knockout reactions remove at most 2 nucleons
  - Bρ 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% ΔP/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: $^{90}Zr$ - 1 neutron
  - Statistics of 200 counts

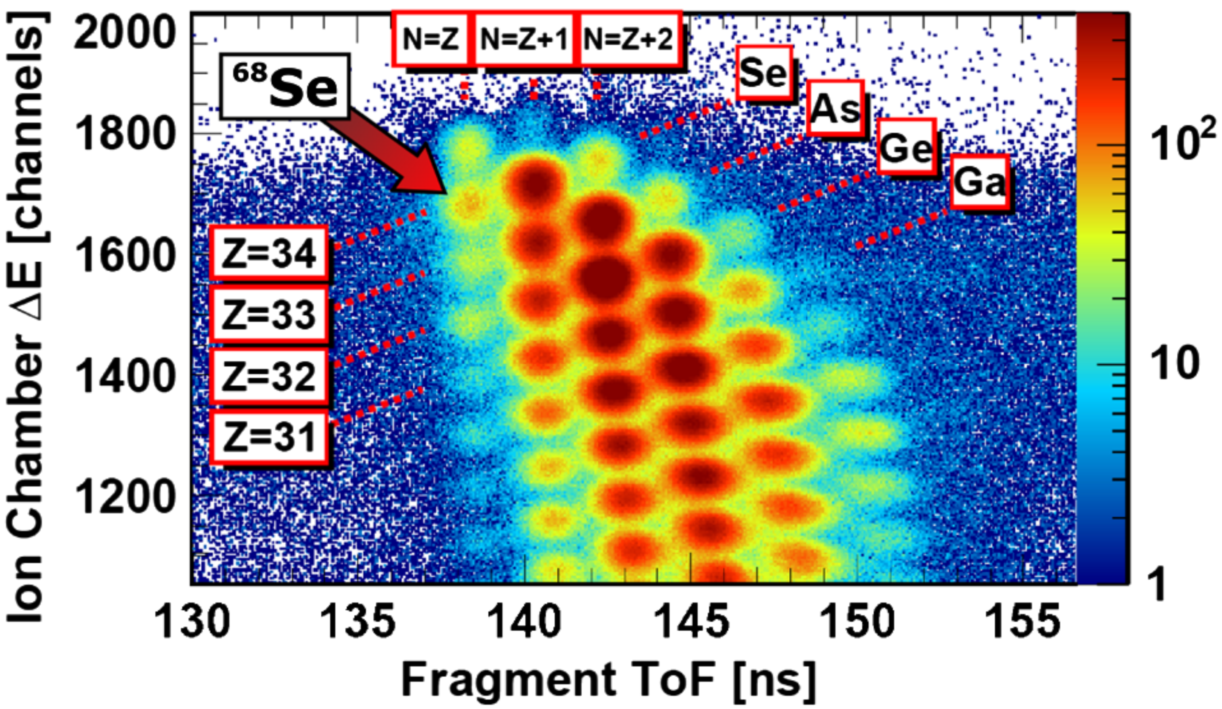



Simulation of the longitudinal momentum distribution of $^{89}Zr$ from the neutron knockout of $^{90}Zr$, assuming the valence neutron is either in the $1f_{5/2}$ or $1g_{9/2}$ orbital. A resolution of 1/1000 in momentum is needed to identify the angular momentum from the shape of the simulated $1g_{9/2}$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

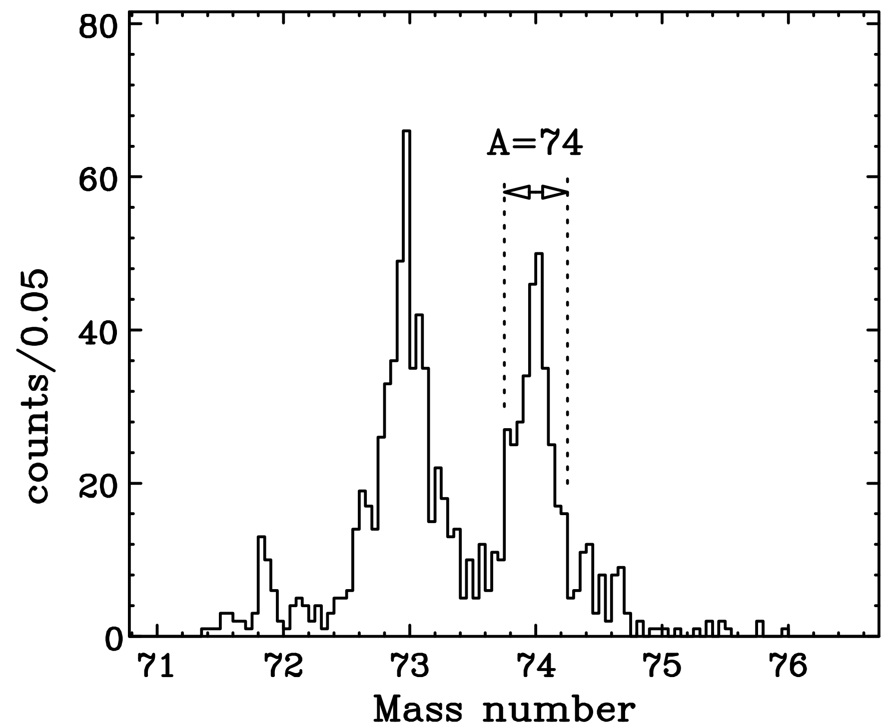
# PID considerations for A > 100

- 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 $^{138}$Sn @ 200 MeV/u
  - $^{137}$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 ~ 1 ns
  - Can resolve up to A ~ 100 after flight path corrections

# Examples from S800

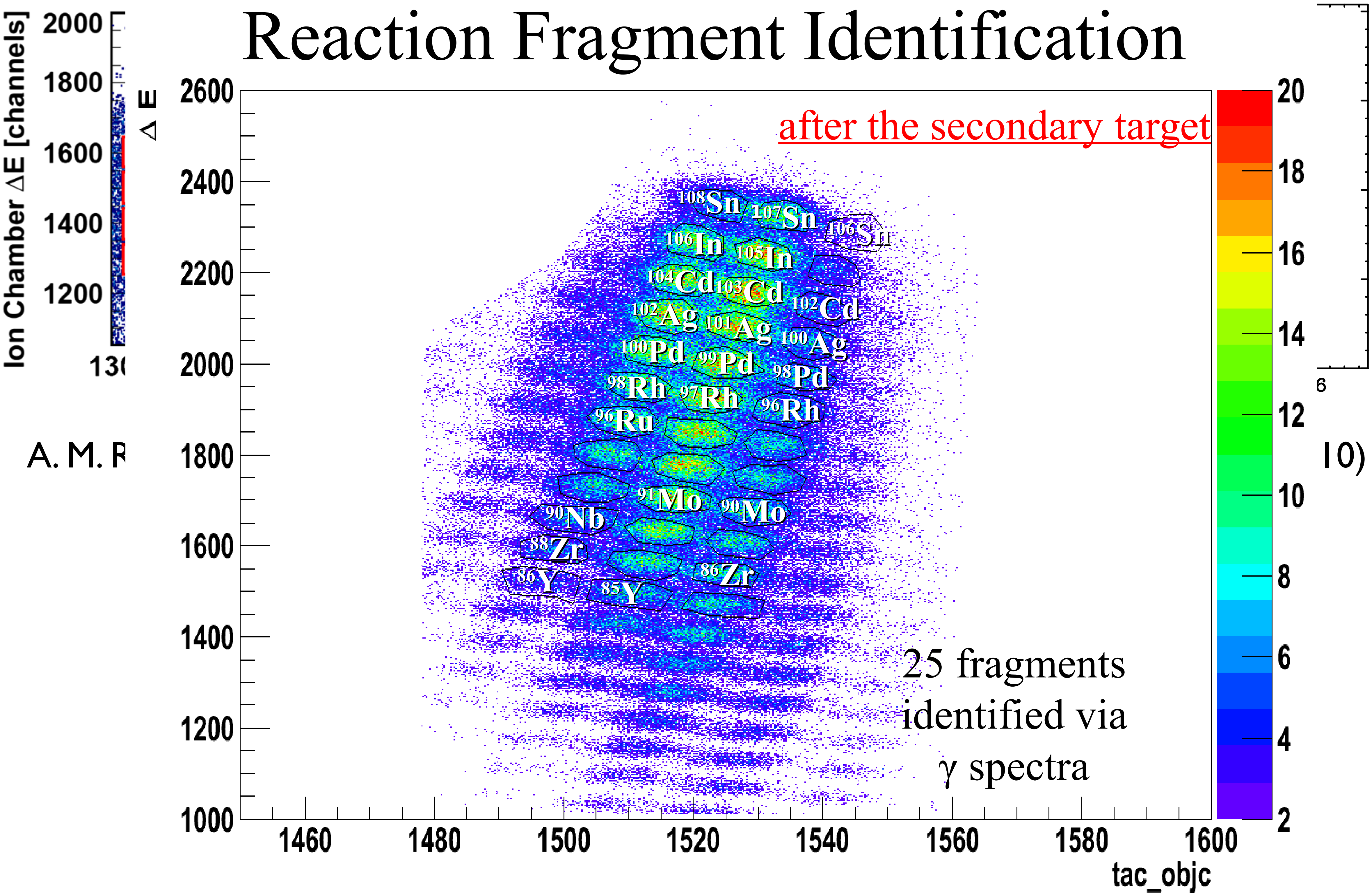



A. M. Rogers et al., PRL 106, 252503 (2011)




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

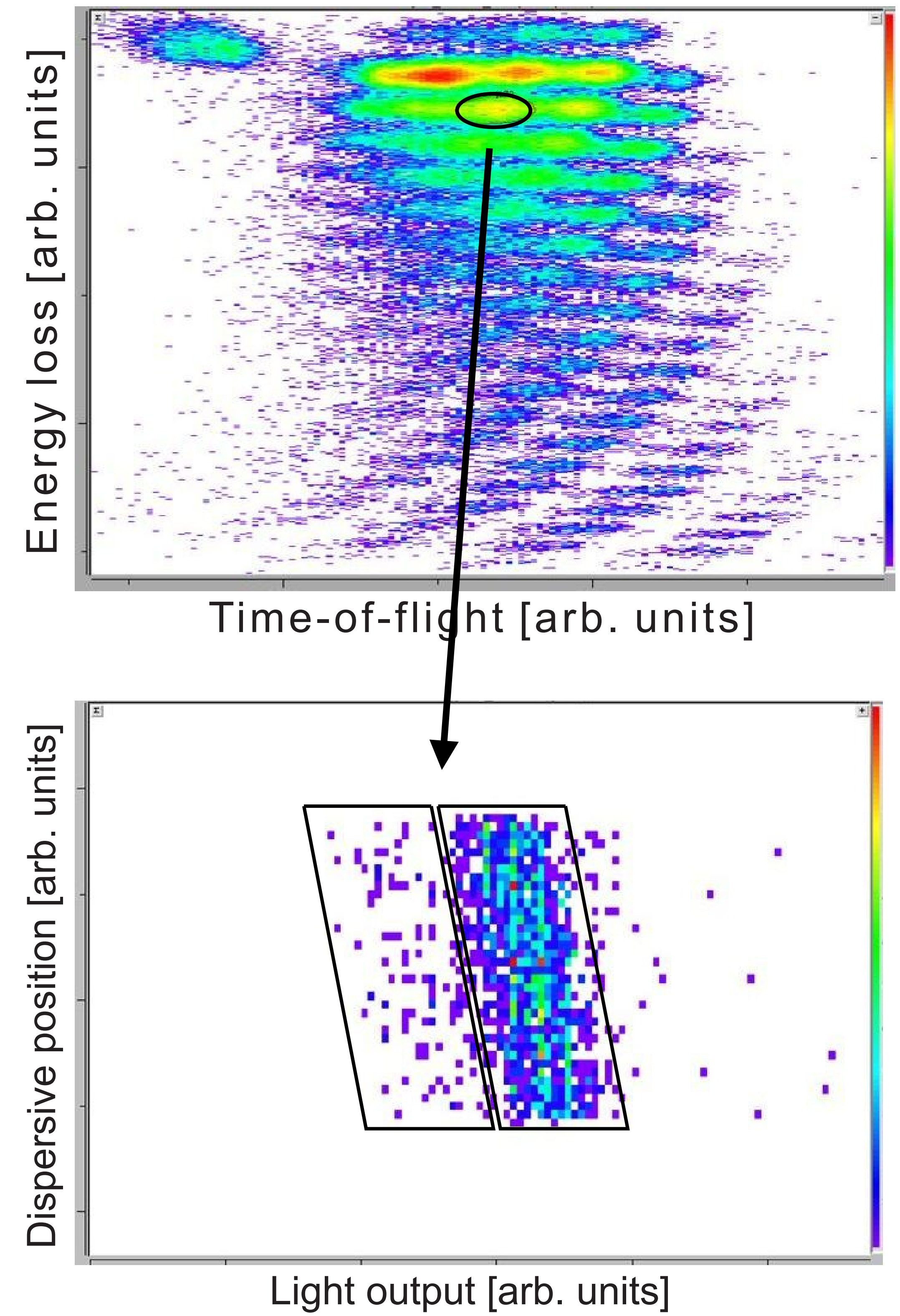
# Examples from S800




A. Ayres, K. Jones, U. of T. (2014)

# 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 $^{197}Au$
  - ΔE-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




K. Meierbachtol, Ph. D. (2012)

# Summary of requirements

- Acceptances similar or smaller than S800
  - 20 msr (± 60 mrad x ± 90 mrad), 5% $\Delta P/P$
- $\Delta P/P$ 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 $\gamma$-ray array (CAESAR, GRETA,…)