Structural effects in nuclide distributions from fission and fragmentation

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- Structural effects in low-energy fission.
  - Even-odd structure.
  - Fission channels.

- Structural effects in fragmentation products.
  - Enhancement of specific classes of nuclei.

- Recent experimental results.
- Theoretical interpretation.
- Speculative ideas.

Invited talk given at the

284. WE-Heraeus-Seminar
"Symposium on Nuclear Clusters: from Light Exotic to Superheavy Nuclei"

at Rauischholzhausen Castle (near Marburg, Hessen, Germany)
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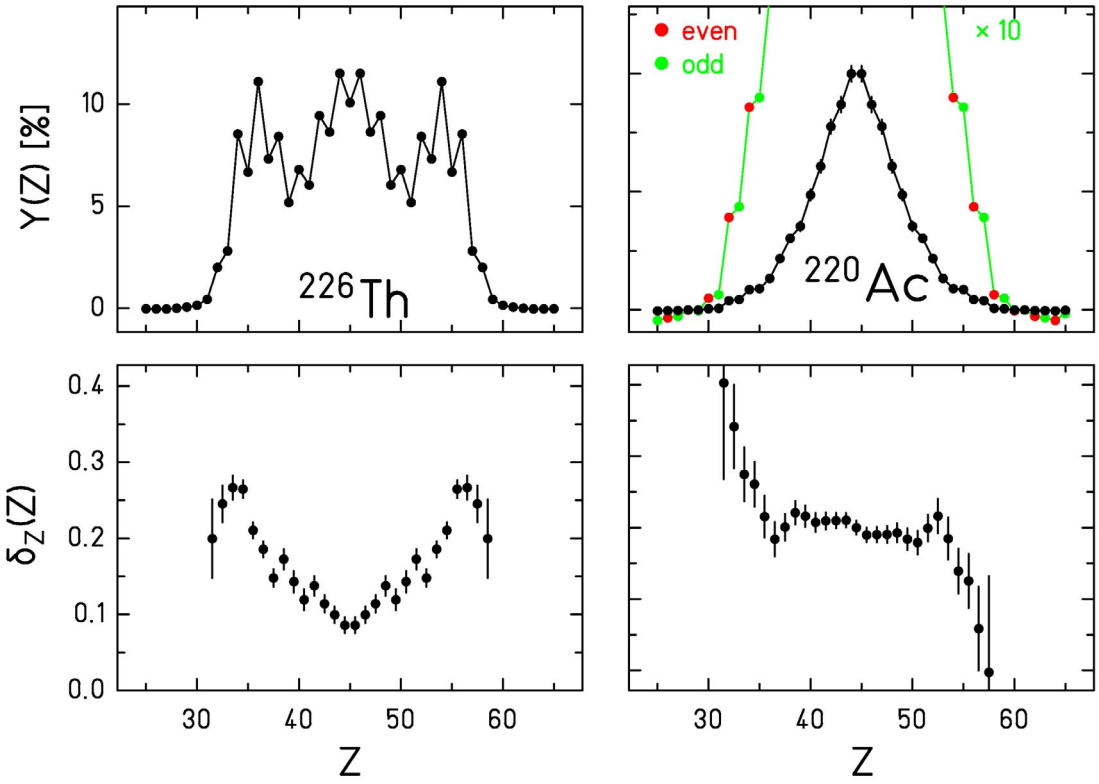
Even-odd structure in low-energy fission



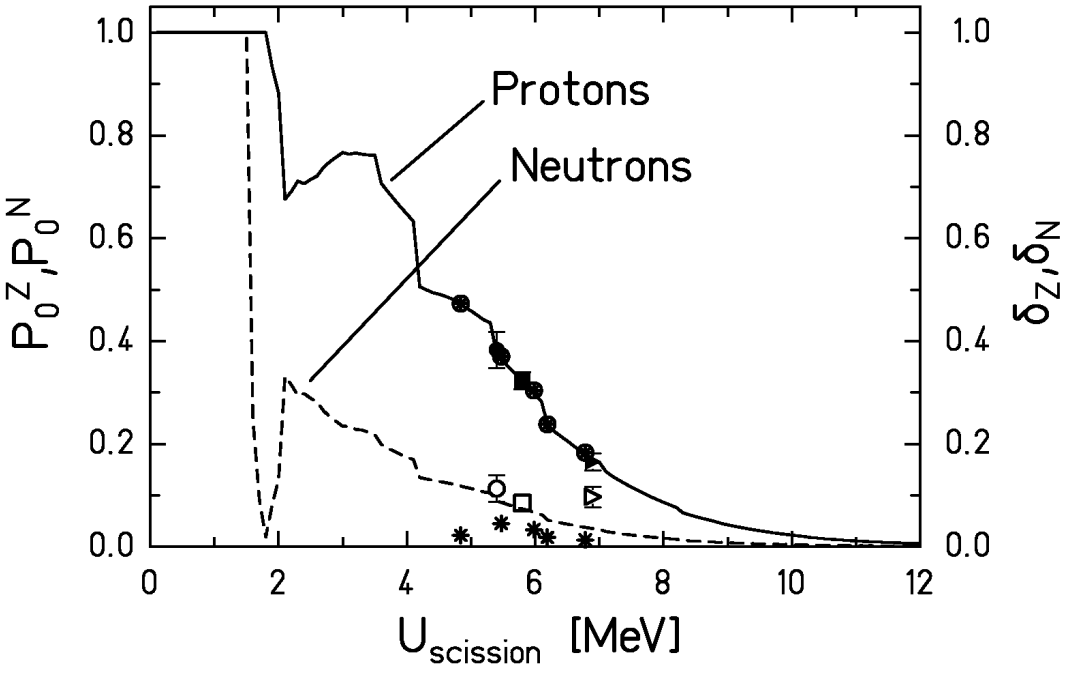
Results from e.m.-induced fission of 70 different secondary projectiles (Steinhäuser et al., NPA634 89, 1998)

[δ_Z is a measure of the deviation of 4 yields from a Gaussian curve (Tracy et al., PRC5 222, 1972)]

Strong even-odd effect at asymmetry:
Odd protons prefer heavy fragment

Even-odd effect for even-Z systems at symmetry:
Measure of pairing correlations

Survival of cold proton (neutron) subsystem



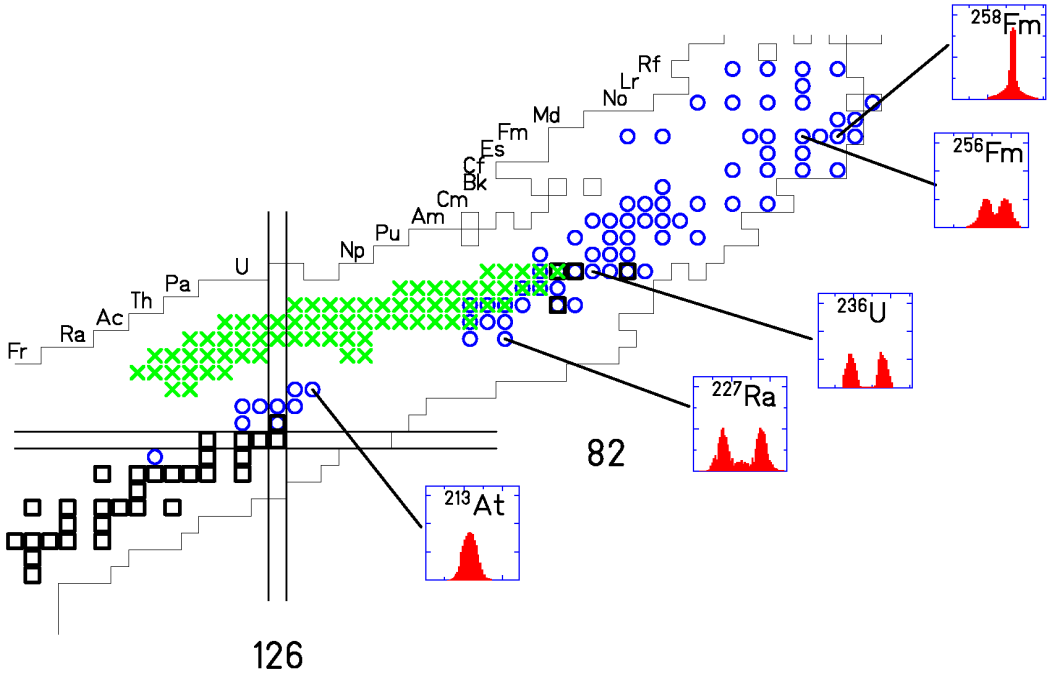
New idea (F. Rejmund et al., NPA678, 215, 2000)
Even-odd structure due to survival of completely paired configuration.

P_0^Z = Probability for completely paired proton configuration:

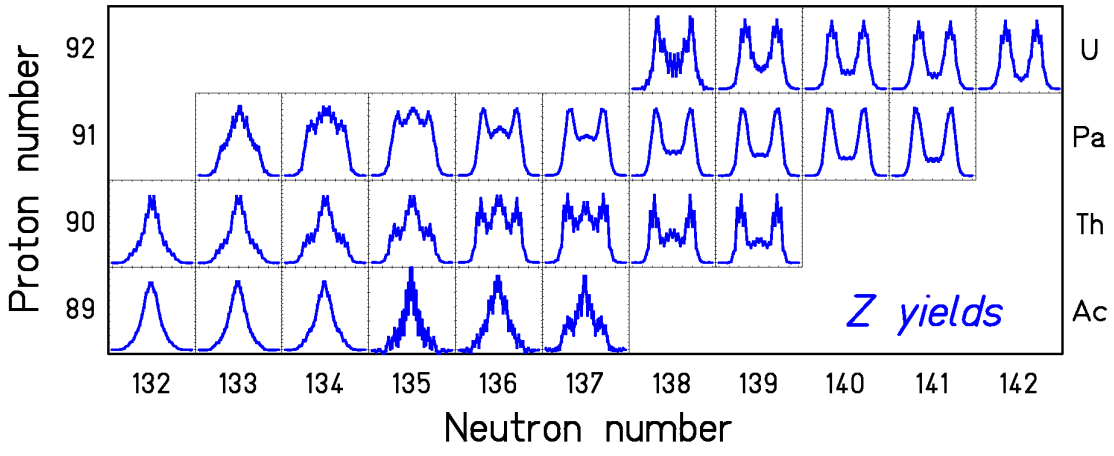
$$P_0^Z = \frac{\sum_{n_N} \rho_{n_z=0,n_N}}{\sum_{n_Z,n_N} \rho_{n_Z,n_N}}$$

δ_Z = Local proton even-odd effect

Fission channels in low-energy fission



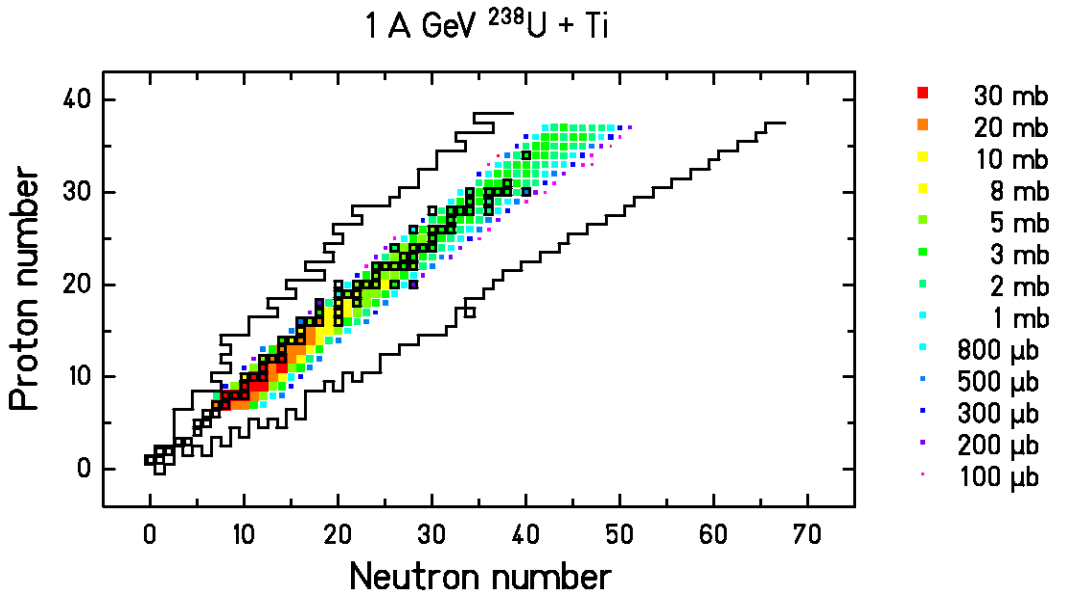
Mass distributions (conventional experiments)



Z distributions (secondary beams)
(K.-H. Schmidt et al., NPA655, 221, 2000)

Survival of shell structure at saddle → scission

Structural effects in fragmentation, overview

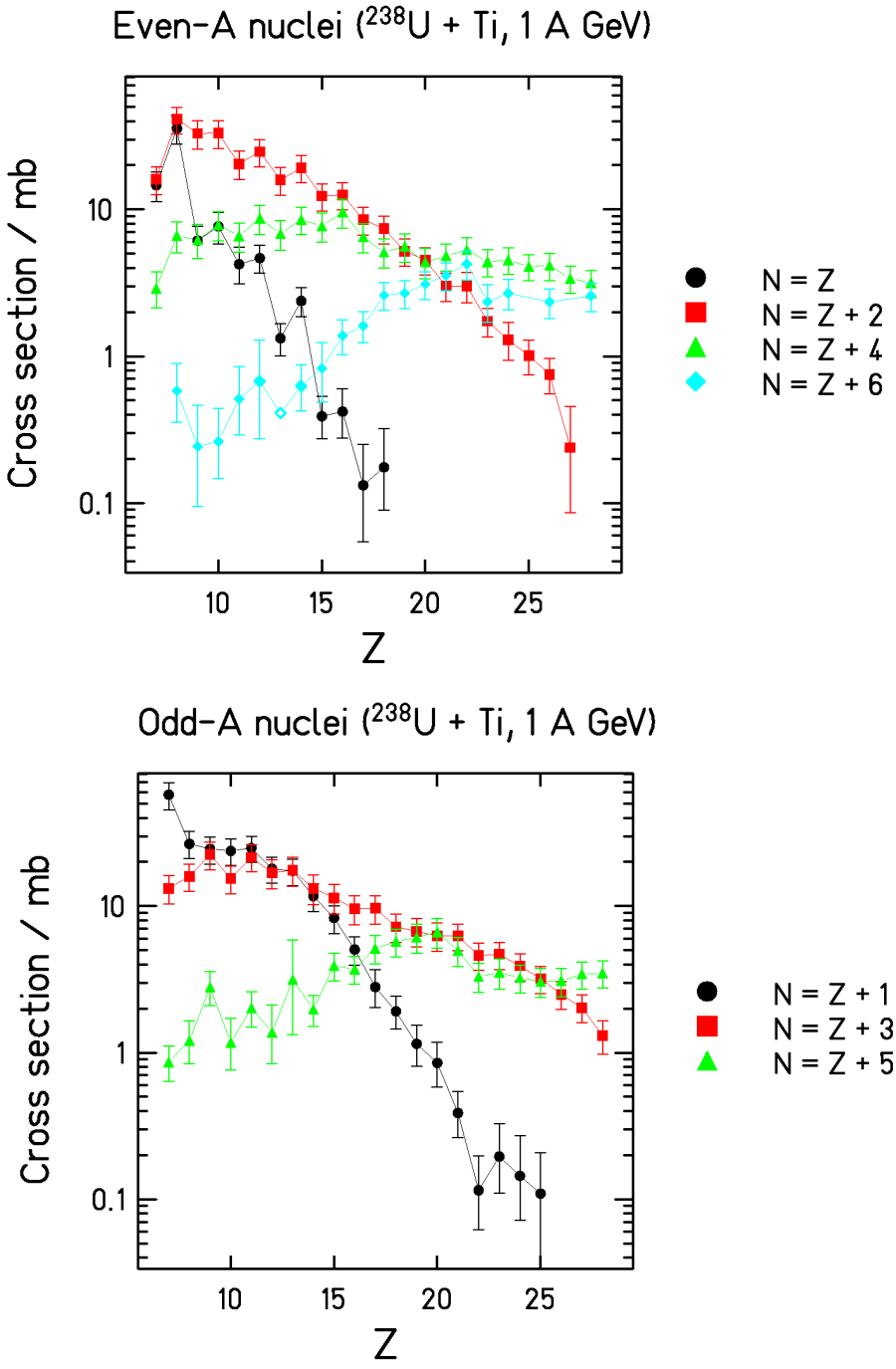


Light fragments of ^{238}U (1 A GeV) produced in collisions in a Ti target

M. V. Ricciardi, PhD in preparation

First analysis of fine structure in fragmentation with individual production yields of fully identified nuclides.

Cuts with fixed N-Z

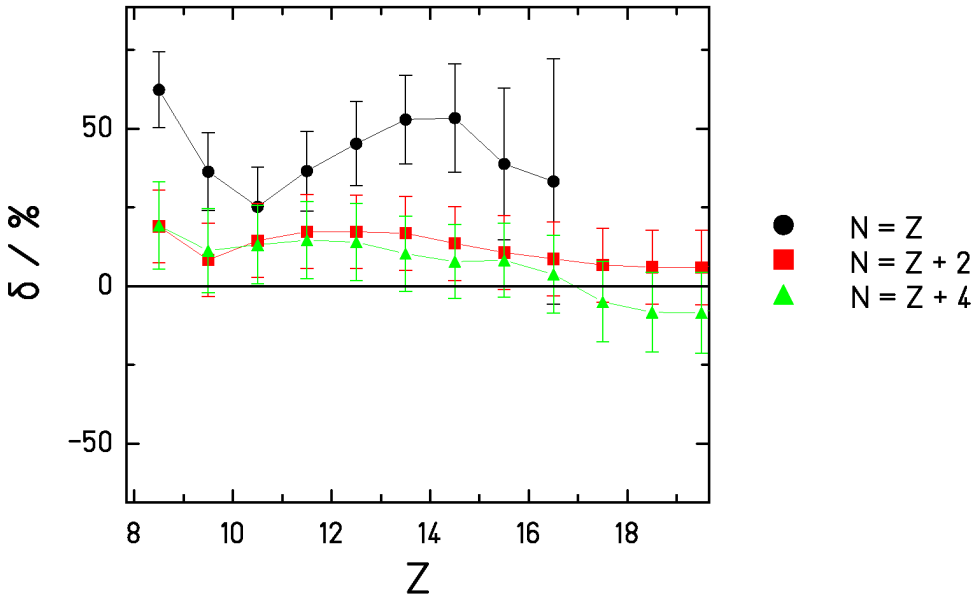


Complex fine structure:

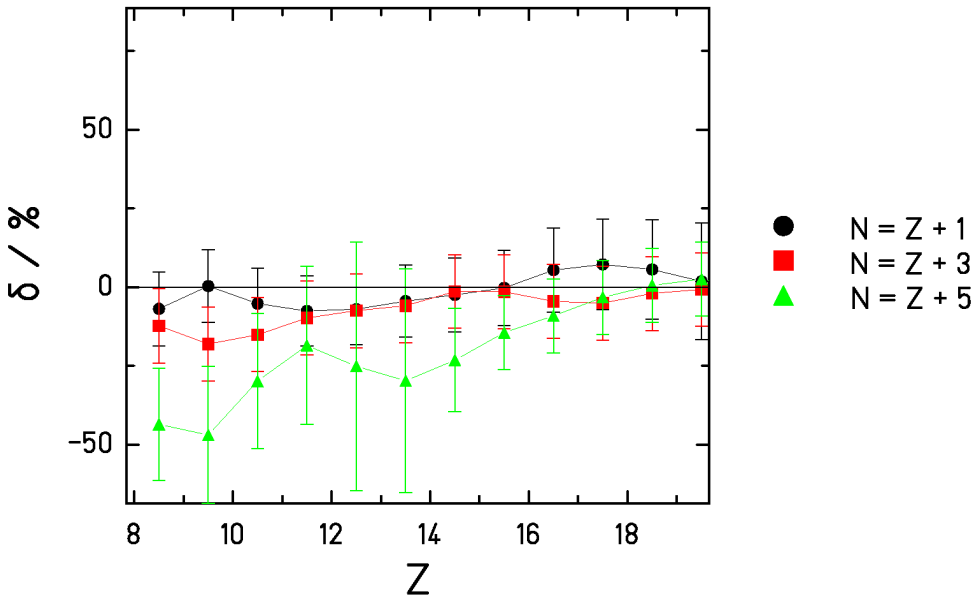
- Even-even enhanced
- Multiples of alpha particles strongly enhanced
- Very neutron-rich odd-Z (even-N) enhanced

Local even-odd effect (Tracy)

Even-odd structure in even-A nuclei (^{238}U + Ti, 1 A GeV)



Even-odd structure in odd-A nuclei (^{238}U + Ti, 1 A GeV)



Quantitative measure of even-odd effect.

Observations of fine structure in fragmentation

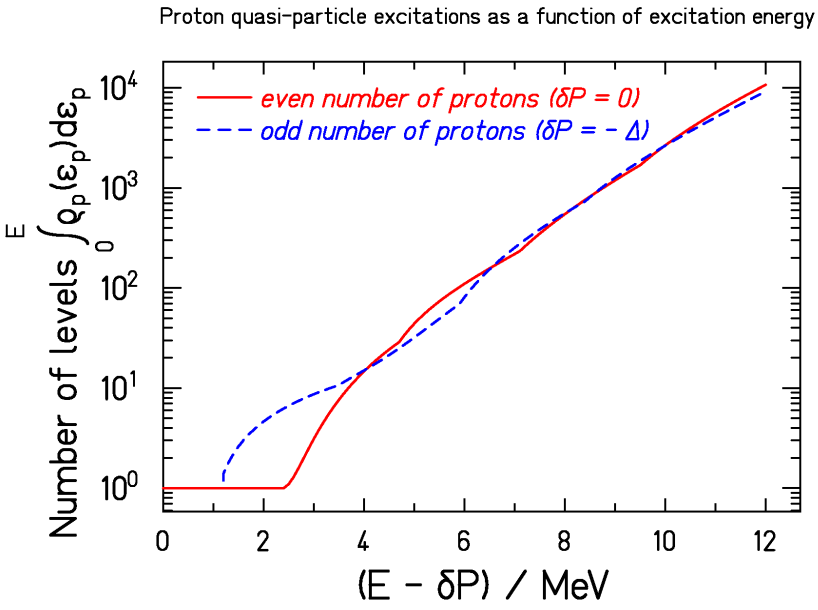
Authors	Publication	Reaction	Beam energy
B. Blank et al.	NIM A 286 (1990) 160	40Ar + 12C	403 A MeV
W. R: Webber et al.	PRC 41 (1990) 547	56Fe + 12C	600 A MeV
C. N. Knott et al.	PRC 53 (1996) 347	e.g. 32Si + 1H	e.g. 571 A MeV
C. Zeitlin et al.	PRC 56 (1997) 388	56Fe + div.	1.05 A GeV
Sl. Cavallaro et al.	PRC 57 (1998) 731	35Cl + 24Mg	8 A MeV
L. B. Yang et al.	PRC 60 (1999) 041602(R)	58Fe + 58Fe 58Ni + 58Ni	45 to 105 A MeV
E. M Winchester et al.	PRC 63 (2000) 014601	40Ca + 58Ni 40Ar + 58Fe	25 A MeV
M. V. Ricciardi	PhD	238U + Ti	1 A GeV

Fine structure appears over wide range of

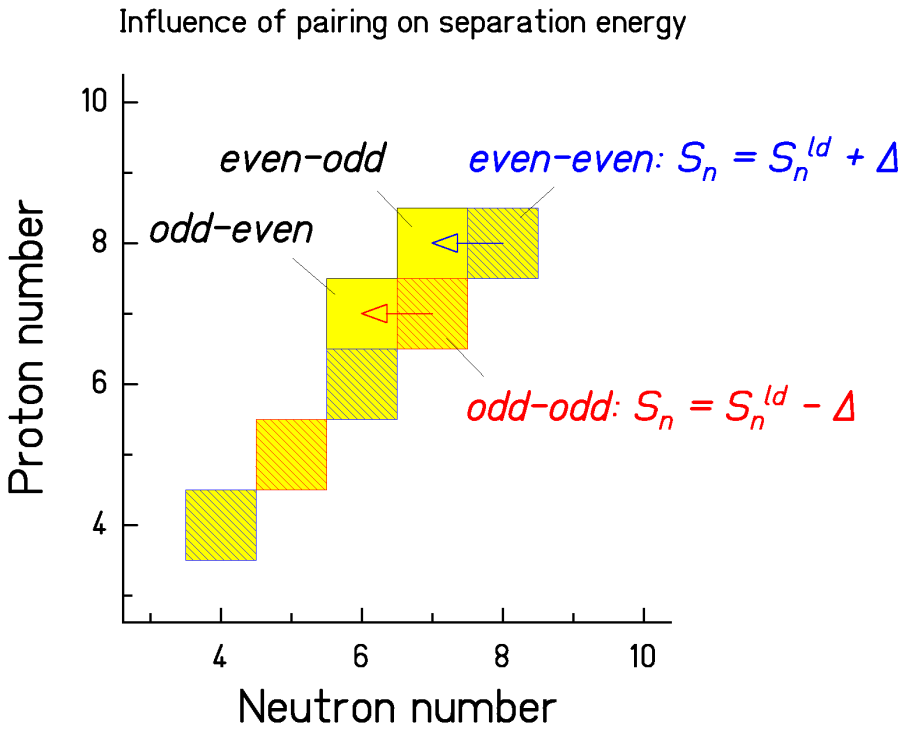
- projectile,
- target,
- energy!

Hypothesis: Fine structure measures the phase space of bound levels at the end of the evaporation process.

Expectation from conventional models



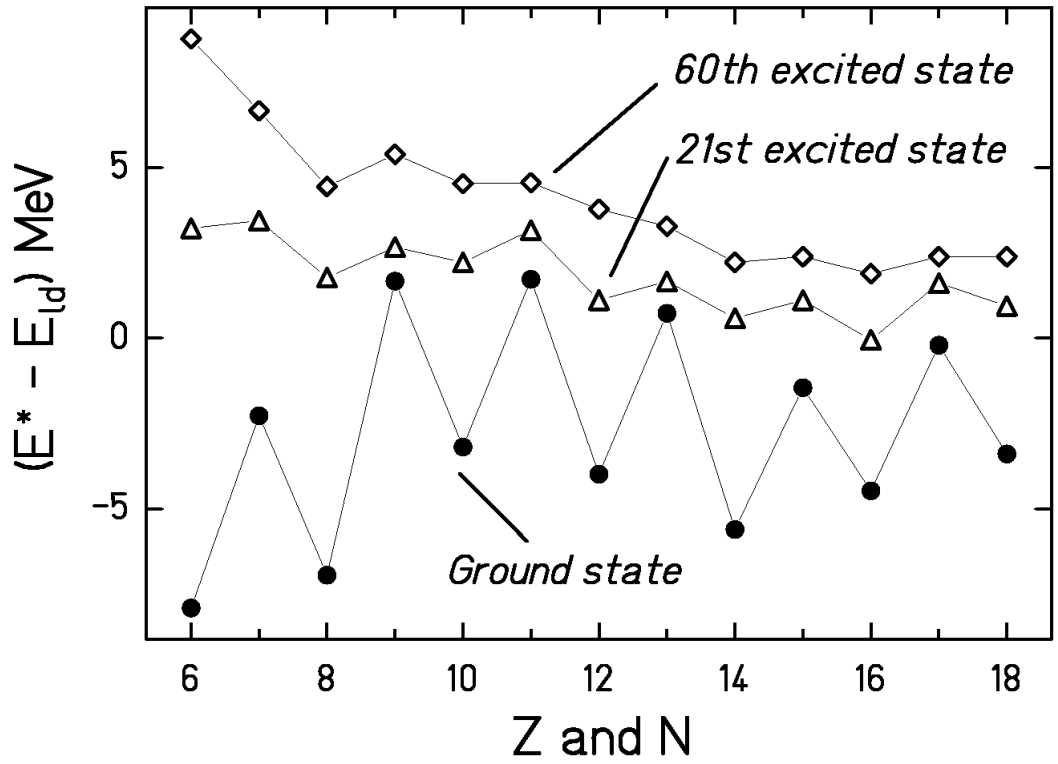
Proton quasiparticle excitations in the Boltzmann-gas model (Strutinski, 1958)



Fluctuation of S_n = backshift in ρ
[Ericson, AP9 425 (1960)]

Number of bound levels below S_n is "smooth".

Experimental information on excited levels

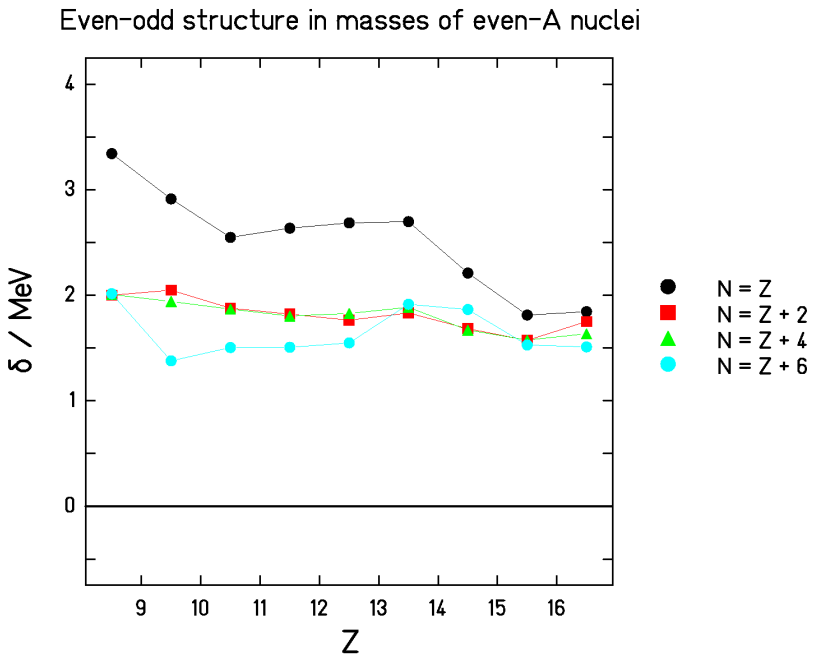


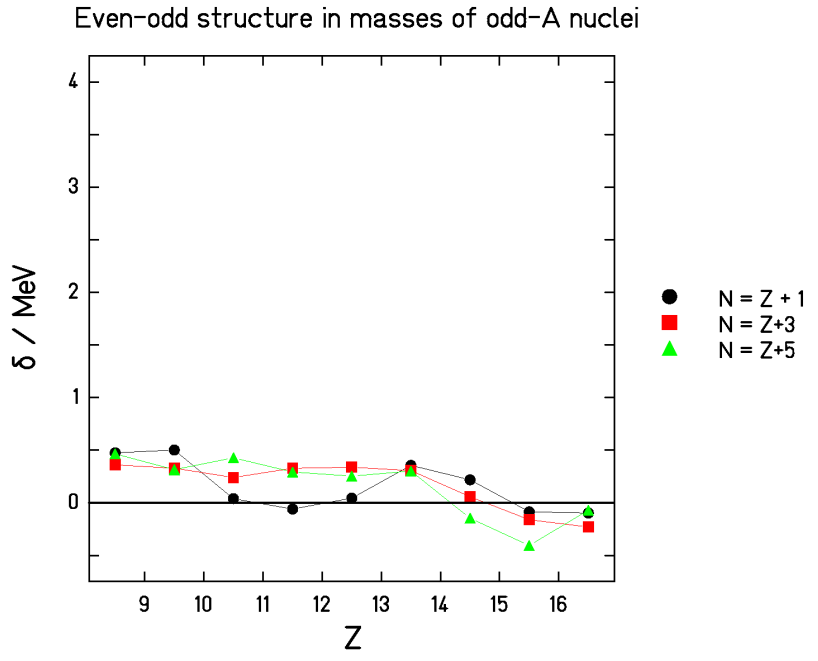
Excitation energy – energy of liquid drop for N = Z nuclei.

Small part of even-odd structure is preserved in excited levels!

Complex nuclear-structure phenomena which go beyond the conventional understanding.

Even-odd structure in binding energies



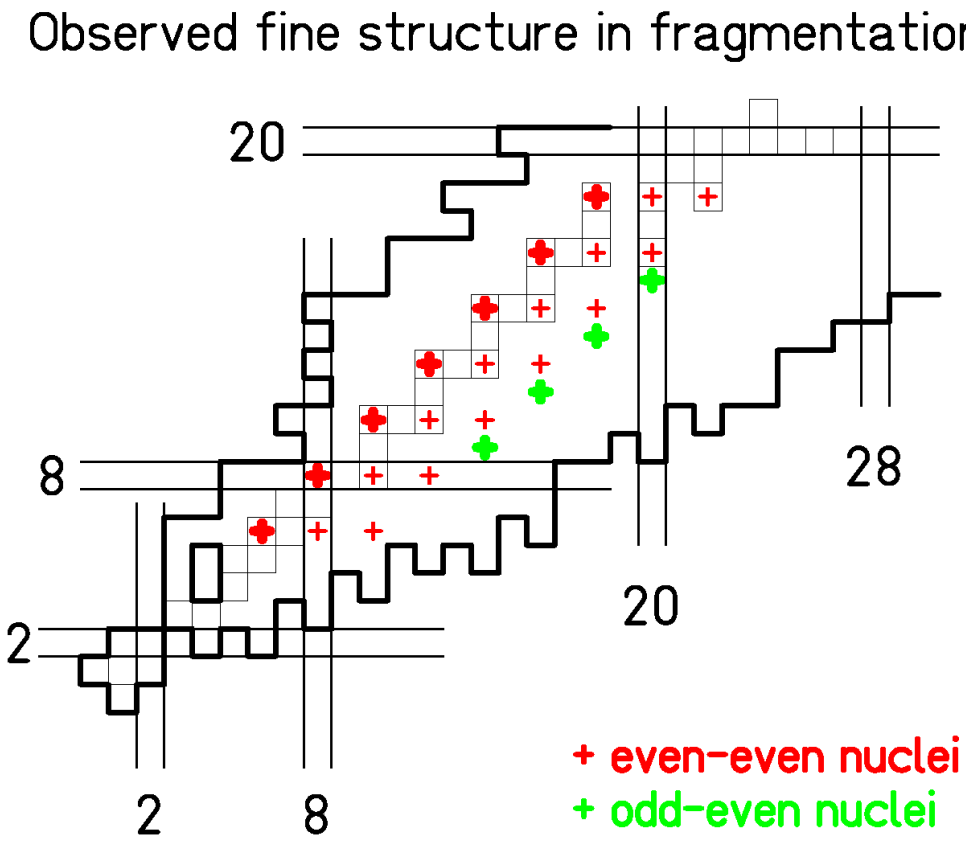


δ is a measure of the deviation of 4 masses from a parabola.

Exceptionally strong even-odd structure along N=Z.

- Alpha clustering?
- Neutron-proton pairing?

Speculative list of phenomena



- All even-even nuclei enhanced:
  - Mean-field contributions to pairing effects?
- Even-even N=Z nuclei strongly enhanced:
  - Alpha clustering?
  - Neutron-proton pairing?
  - Congruence energy, Wigner term?
- Neutron-rich odd-Z even-N nuclei enhanced:
  - Continuum effects on neutron pairing?

Conclusion

Structural effects in low-energy fission:

- Survival of pairing and shells in cold nuclei.
- Qualitatively explained by conventional models.
- Quantitative prediction needs more advanced dynamical models.

Structural effects in fragmentation etc.:

- Appearance of complex structures after the deexcitation of highly excited systems:
  Even-even nuclei
  N = Z nuclei
  Neutron-rich odd-Z, even-Z nuclei
- Not explained by conventional models.
- New experimental information on complex nuclear-structure phenomena.