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GEMINI: Dexcitation of excited compound nuclei through a series of binary decays

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GEMINI code

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Monte Carlo statistical-model code to follow the decay of a compound nucleus by a series sequential binary-decays.

Angular-momentum consistent formalism.

Washington University in St. Louis

GEMINI

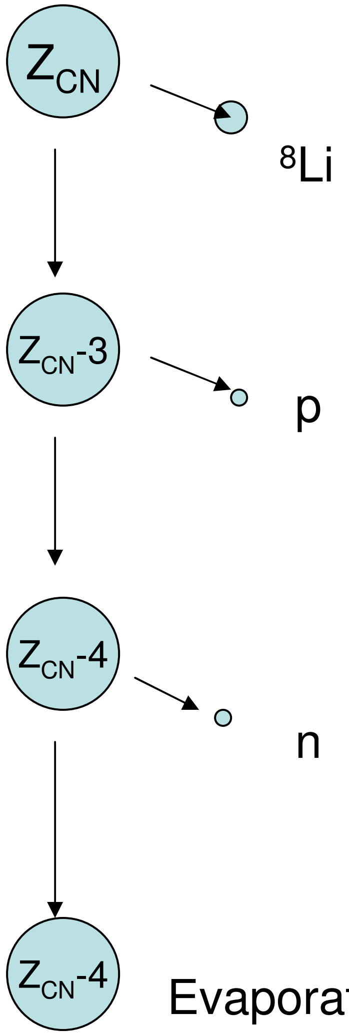
- Born 1986 (Berkeley, Darmstadt, St. Louis)
- Not written to predict, but to interpret data and test sensitivity to different physics.
- Fortran95 (on web) and C++ versions
- Lot of options, user chooses.
- Written for heavy-ion fusion reactions

  a) only equilibrium decay.

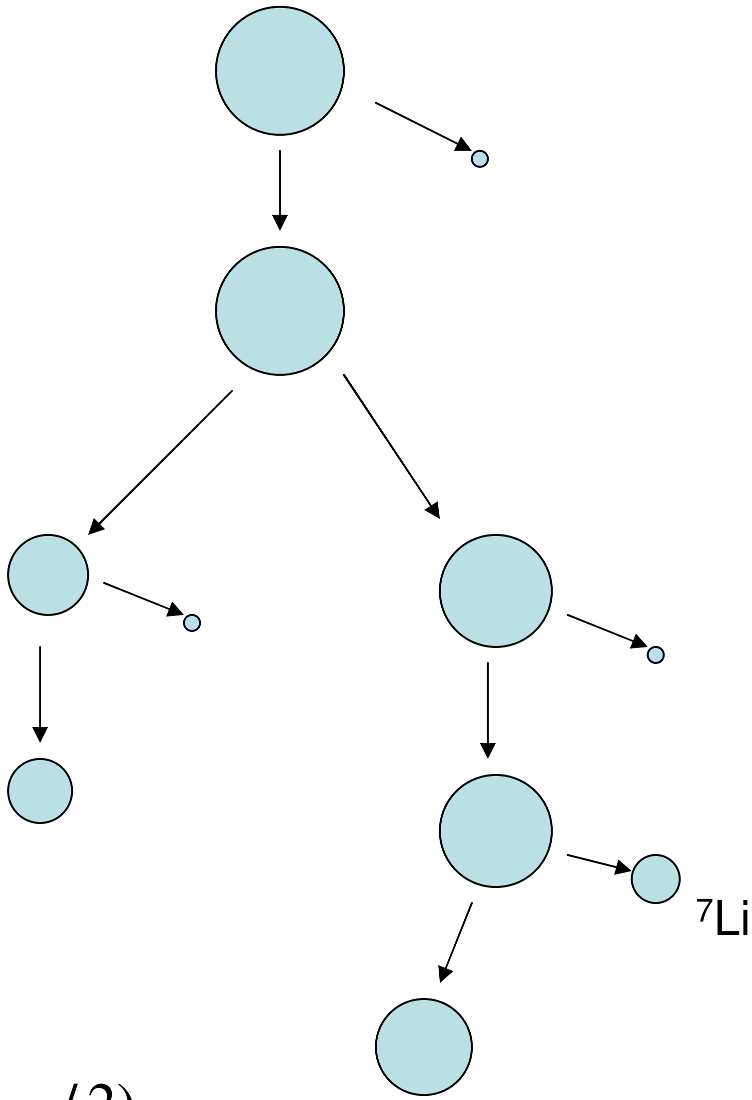
  b) must handle large angular momentum

  c) $E^*/A<3$MeV.

Typical decay trees



Evaporation residue



$$P_i = \frac{\Gamma_i}{\sum_j \Gamma_j}, \; i = n, p, \alpha, d, t, {}^7Li, {}^8Li, ...(Z_{CN}/2, A_{CN}/2)$$

Fission

General binary decay mode of a compound nucleus

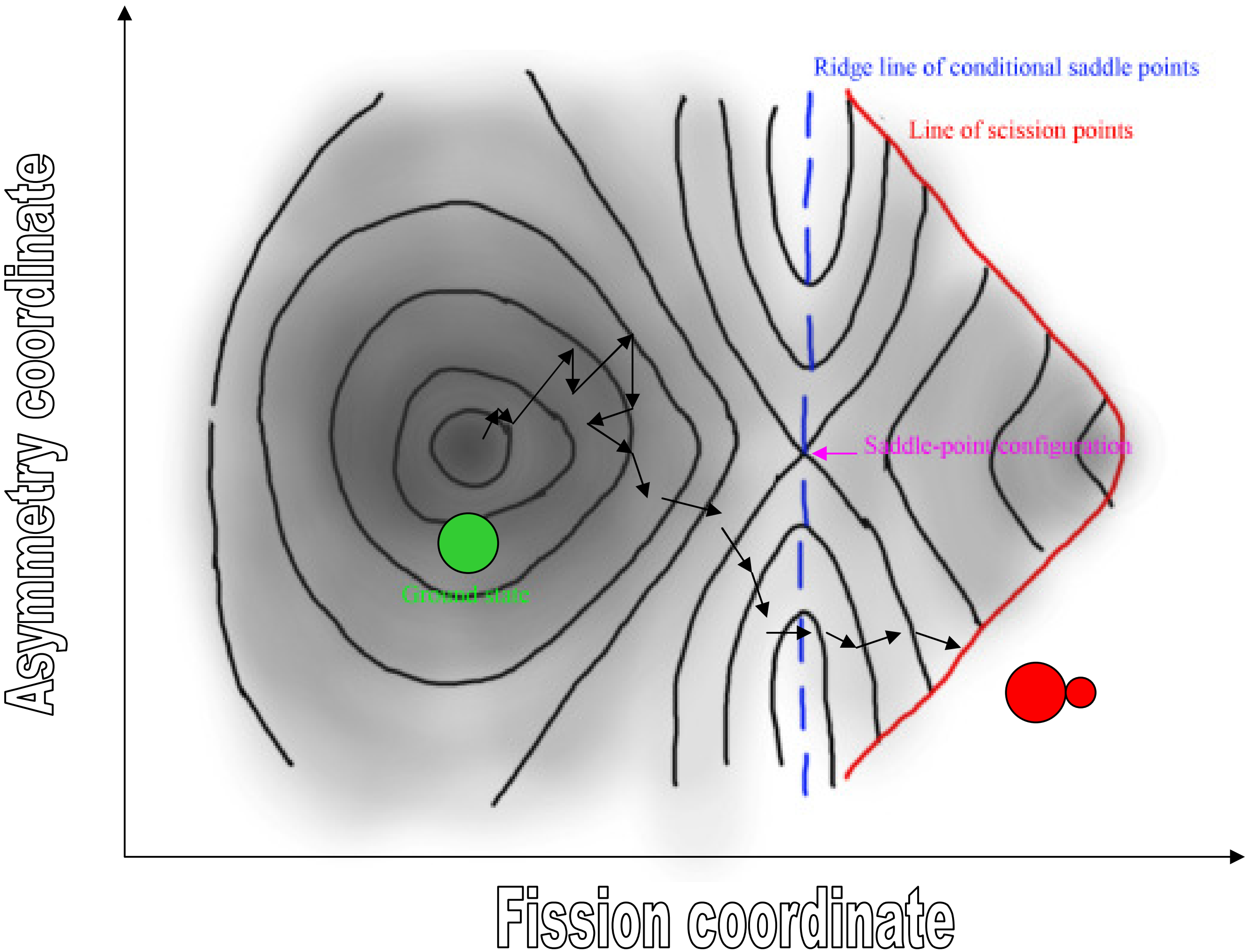
- Very-asymmetric split– light-particle evaporation (n,p,α,Li,…)
  Weisshopf-Ewing or Hauser-Feshbach formulism
- Symmetric split – fission
  Bohr-Wheeler (Transition-state) formalism (1Dim)– needs fission barrier
- Morreto (Nucl. Phys. A247 (1975) 211) considered a generalized binary-decay mode where all asymmetric mass slits were allowed (2Dim)

  Includes evaporation and fission as its extremes.

  modified transition-state formulism

  Requires conditional fission barriers for each asymmetry.

Random walk in the Potential energy surface



1-d model (Bohr Wheeler) fission rate controlled by the saddle-point energy

2-d model (Moretto) asymmetry determined by conditional saddle point.

asymmetry not changed in transition from saddle to scission?

GEMINI Details

- Z_imf_min =3,4,5 – user parameter
- If (Z < Z_imf_min) Γ(Z,A) from Hauser-Feshbach formalism (n,p,d,t,^{3}He,α,^{6}He,^{8}He,^{6}Li,^{6}Li*'s,^{7}Li,…^{10}Be,^{10}Be*'s)

  excited states of evaporated particle up to E*=5 MeV
- If (Z>= Z_imf) Γ(Z,A) from Moretto's transition-state formalism
- Gamma-decay decay also included.
- Spin and spin orientation of all particles determined – needed for angular distributions at large angular momenta. Requires initial orientation.
- Velocities and emission angles of all particle are determined, not always isotropic, but symmetry about 90^0.
- Decay cascade followed until a binary decay is not possible.

Light-particle evaporation, n,p,d,t,^{3}He,α,^{6,7,8,9}Li*,^{7,8,9,10,11}Be*

Hauser-Feshbach formulism – most appropriate for large angular momenta

$$\Gamma_i = \frac{1}{2\pi\rho_{CN}\left(E^*, S_0\right)} \int d\varepsilon \sum_{s_2=0}^{\infty} \sum_{J=|S_0-S_2|}^{S_0+S_2} \sum_{l=|J-S_1|}^{J+S_1} T_l(\varepsilon)\rho\left(E^* - B_i - \varepsilon, S_2\right)$$

$T_l(\varepsilon) = \text{transmission coef. (related to } \sigma_{\text{inv}})$

$\varepsilon, S_1 = \text{kinetic energy ans spin of evaporated particle}$

$\mathrm{S}_2 = \text{spin of daughter}$

$\mathrm{B}_\mathrm{i} = \text{separation energy}$

$\overrightarrow{S_0} = \overrightarrow{S_2} + \overrightarrow{S_1} + \vec{l}, \qquad \vec{J} = \overrightarrow{S_1} + \vec{l}$

Need level densities, transmission coefficients, and separation energies

Separation energies from experimental mass or if unknown from Moller-Nix

Transmission coefficients

- From global optical-model fits to elastic-scattering data (detailed balance => evaporation Coulomb barrier is same as absorption barrier)
- For faster calculation, there is an option

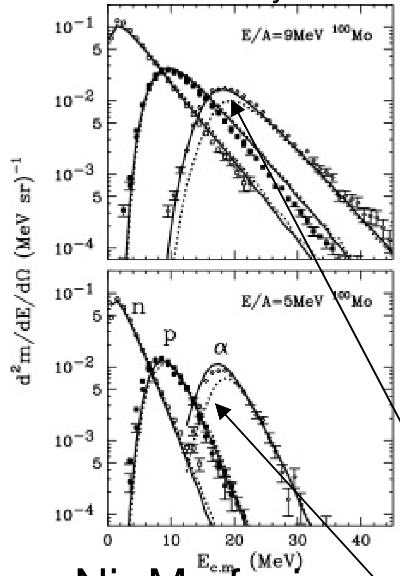
$T_l(\varepsilon) = 0, \varepsilon < V_C(l)$

$T_l(\varepsilon) = 1, \varepsilon > V_C(l)$

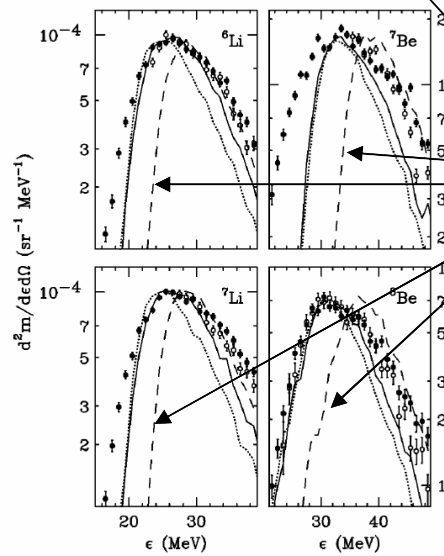
Problem with transmission coefficients for α and heavier particles

- Weiskopf formalism derived from principle of detailed balance – evaporation is the time-reversed equivalent of absorption – this implies that we should be able to can use transmission coefficients obtained from global optical-model fits to elastic scattering data. WRONG
- These Coulomb barriers are too large
- They will underpredict the yield of alpha and heavier fragments
- Increase radius of nuclear potential by 10% for A=170 , more for heavier systems (Fineman 1994)–
- will systematize in future.
- With also be important for σ_{inv}

Charity et al. PRC 67 (2003)04461



Ni+Mo fusions reactions



Transmission coefficients from elastic scattering

Charity et al PRC 63 (2001)024611

Level Densities

$$\rho(E^*, S) \propto (2S+1)\exp\left[2\sqrt{a(E^* - E_{rot}(S))}\right]$$

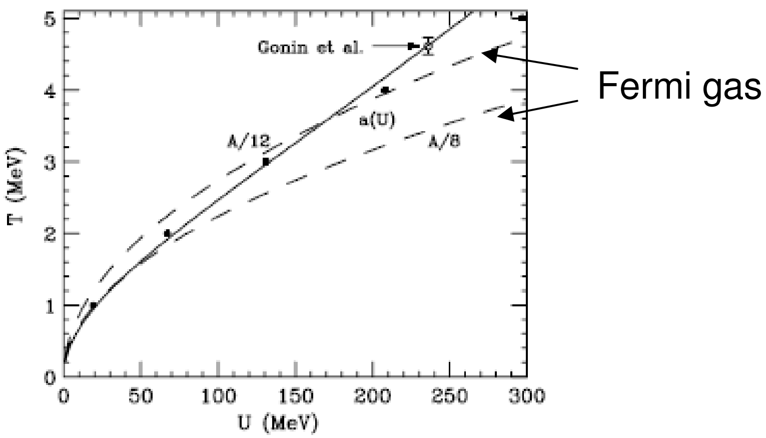
- Spin dependent Fermi-gas formula
- Backshifted for pairing
- Shell effects fade out according to Ignatyuk
- Many options for level-density parameter “a”
  (deformation dependent – excitation energy dependent)
- Rotational energies E_{rot} from Finite-Range Liquid-Drop of Sierk
- Collective enhancement and fadeout – according to Hansen and Jensen doesn’t work.

Level densities

Excitation-energy dependence of level-density parameter.

$$a(U) = \frac{A}{7 + 1.3\frac{U}{A}}$$

For A~170



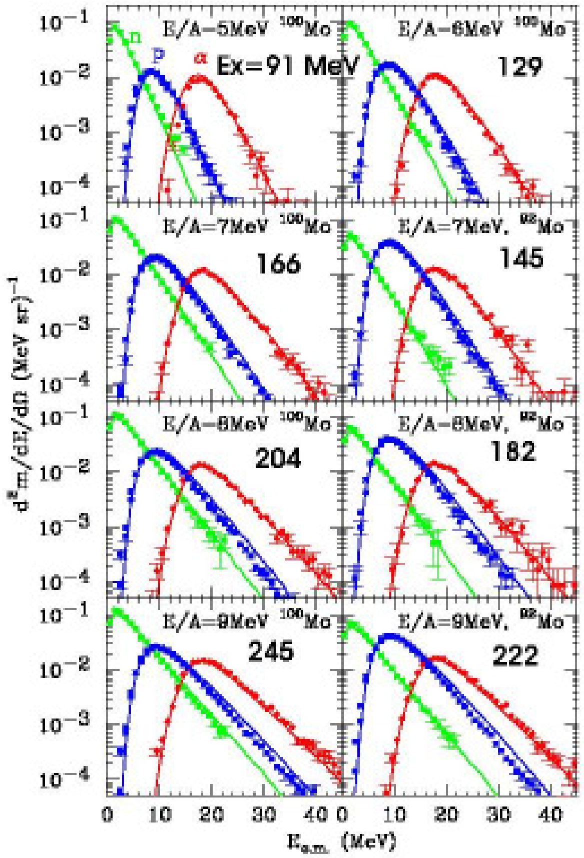
Energy-dependent effective mass -> 1.00

Loss of coupling of single-particle degrees of freedom to surface vibrations

Increases multiplicity of low-yield particles,

Fission mass distributions

Fits to shapes and absolute magnitudes of evaporation spectra



Charity et al. PRC 67 (2003)044611

Deviations from Fermi gas behavior seem to increase with increasing mass [Fineman PRC50, 1991 (1994)]

Predictions by Shlomo and Natowitz

d, t, ^{3}He yields in fusion reactions are always a factor of two lower than statistical model estimates.

In next version of GEMINI this scaling will be incorporated.

Other Binary decays (symmetric and asymmetric fission)

First consider Bohr-Wheeler (transition state) for symmetric fission

$$\Gamma_{BW}^{f}\ d\varepsilon = \frac{1}{2\pi\rho_{CN}(E^*,S)}\int \rho[E^* - B(S) - \varepsilon, S]d\varepsilon$$

Moretto's original formalism Nucl. Phys. A247 (1975) 211
Thermal distribution along the ridge-line of conditional saddle points

$$\Gamma(y)d\varepsilon\, dy\, dp_y = \frac{1}{2\pi\rho_{CN}(E^*)}\int \rho\left[E^* - B(y) - \varepsilon - \frac{p_y^2}{2m_y}\right]d\varepsilon \frac{dy dp_y}{h}$$

$\varepsilon =$ kinetic energy in fission coordinate

$y =$ asymmetry coordinate

$p_y =$ conjugate momenta

$B(y) =$ conditional barrier

$m_y =$ inertia for motion in y coordinate

$\rho(E^*) =$ level density as function of excitation energy

Integrate over p_y

$$\Gamma d\varepsilon\, dy = \frac{1}{2\pi\rho_{CN}(E^*)}\frac{\sqrt{2\pi T m_y}}{h}\rho[E^* - B(y) - \varepsilon]d\varepsilon\, dy$$

Most important ingredient is the level densities at the conditional saddle points

Conditional barriers

Angular-momentum dependent conditional barriers from Finite-Range Liquid-Drop model (Sierk)– interpolated from full calculations for ^{111}In,^{149}Tb,^{194}Hg and from a two-spheroid approximation for lighter nuclei. No shell corrections – no double-humped mass distributions.

B(Z,A,S,y)

Uncertainties with the Metric

Moretto Nucl. Phys. **A247** (1975) 211

$$\Gamma(y)\,dy = \frac{1}{2\pi\rho_{CN}(E^*)}\frac{\sqrt{2\pi T m_y}}{h}\int \rho[E^* - B(y) - \varepsilon]\,d\varepsilon\,dy$$

Moretto + Wozniak Prog. In Part. And Nucl. Phys. **21** (1988)

$$\Gamma(Z) = \frac{1}{2\pi\rho_{CN}(E^*)}\int \rho[E^* - B_Z - \varepsilon]\,d\varepsilon\,,\ \mathrm{Z} = 3,4,\ldots..\mathrm{Z}_{\mathrm{CN}}/2$$

but why not

$$\Gamma(A) = \frac{1}{2\pi\rho_{CN}(E^*)}\int \rho[E^* - B_A - \varepsilon]\,d\varepsilon\,,\ \mathrm{A} = 6,7,\ldots..\mathrm{A}_{\mathrm{CN}}/2$$

or

$$\Gamma(Z,A) = \frac{1}{2\pi\rho_{CN}(E^*)}\int \rho[E^* - B_{Z,A} - \varepsilon]\,d\varepsilon\,,\ \mathrm{A} = 6,7,\ldots..\mathrm{A}_{\mathrm{CN}}/2,\ \mathrm{Z} = 3,4,..\mathrm{Z}_{\mathrm{CN}}/2$$

Now 3 dimenional. The latter is used in GEMINI and was also used in EDCATH [Mittig PRC **35** (1987)190]

Why does metric matter – effects the total fission width
Sum over all asymmetries associated with the fission peak.

$$\text{parabolic expansion } B(y) = B_f + \frac{1}{2}k\ y^2,\ \ y = \frac{A_1 - A_2}{A_1 + A_2}$$

$$\Gamma_y^f = \int_{y\min}^{y\max} \Gamma(y)dy \approx \frac{1}{2\pi\rho_{CN}} \frac{\sqrt{2\pi T m_y}}{h} \int_{-\infty}^{\infty}\int \rho\left(E^* - B_f - \frac{1}{2}ky^2 - \varepsilon\right)d\varepsilon dy$$

$$\text{use } \rho\left(E^* - \frac{1}{2}ky^2\right) \approx \rho(E^*)\exp\left(\frac{ky^2}{T}\right), \frac{1}{T} = \frac{d\rho}{dE^*}$$

$$\Gamma_y^f \approx \frac{1}{2\pi\rho_{CN}} \frac{T}{\omega_b^y} \int \rho(E^* - B_f - \varepsilon)d\varepsilon = \frac{T}{\omega_b^y}\Gamma_{BW},\ \omega = \sqrt{\frac{k}{m_y}}$$

$$\Gamma_Z^f = \sum_{Z\min}^{Z\max}\Gamma(Z) \approx \frac{T}{\omega_b^y}\frac{Z_{CN}}{2}\frac{h}{\sqrt{2\pi T m_y}}\Gamma_{BW}$$

$$\Gamma_A^f = \sum_{Z\min}^{Z\max}\Gamma(A) \approx \frac{T}{\omega_b^y}\frac{A_{CN}}{2}\frac{h}{\sqrt{2\pi T m_y}}\Gamma_{BW}$$

$$\Gamma_{ZA}^f = \sum\sum\Gamma(Z,A) = \ldots$$

$$A = 200,\ m_y = 636\ \text{MeV zs}^2,\ \omega_b^y = .2\ \text{MeV},\ \text{T} = 1\ \text{MeV}$$

$$\Gamma_y^f = 5\,\Gamma_{BW}^f,\ \Gamma_Z^f = 13\,\Gamma_{BW}^f,\ \Gamma_A^f = 33\,\Gamma_{BW}^f,\ \Gamma_{ZA}^f = 65\,\Gamma_{BW}^f$$

Moretto's Solution
Level densities dependent on the metric

$$\Gamma_Z^f == \Gamma_A^f == \Gamma_y^f == \Gamma_{BW}^f$$

$$\Gamma_{BW} = \frac{1}{2\pi\rho_{CN}} \int \rho^{BW} \left(E^* - B_f - \varepsilon\right) d\varepsilon$$

$$\Gamma(Z) = \frac{1}{2\pi\rho_{CN}} \int \rho^{Z} \left(E^* - B_Z - \varepsilon\right) d\varepsilon$$

$$\rho^Z = \frac{\rho^{BW}}{\frac{\omega_b}{T} \frac{Z_{CN}}{2} \sqrt{\frac{h}{2\pi T m_y}}}$$

Which of ρ^z , ρ^A, ρ^y, ρ^{ZA}, or ρ^{BW} are Fermi-gas level densities
What do you do for light nuclei where there is no fission peak?

The transition-state formalism is an ansatz borrowed from chemistry where it is used to describe chemical reaction rates…

$$\text{as } \rho(E^* - x) \approx \rho(E^*)\exp\left(\frac{x}{T}\right)$$

$$\Gamma_{BW} \approx \frac{1}{2\pi\rho(E^*)}\int \rho(E^*)\exp\left(\frac{B_f - \varepsilon}{T}\right)d\varepsilon \approx \frac{T}{2\pi}\exp\left(\frac{-B_f}{T}\right)$$

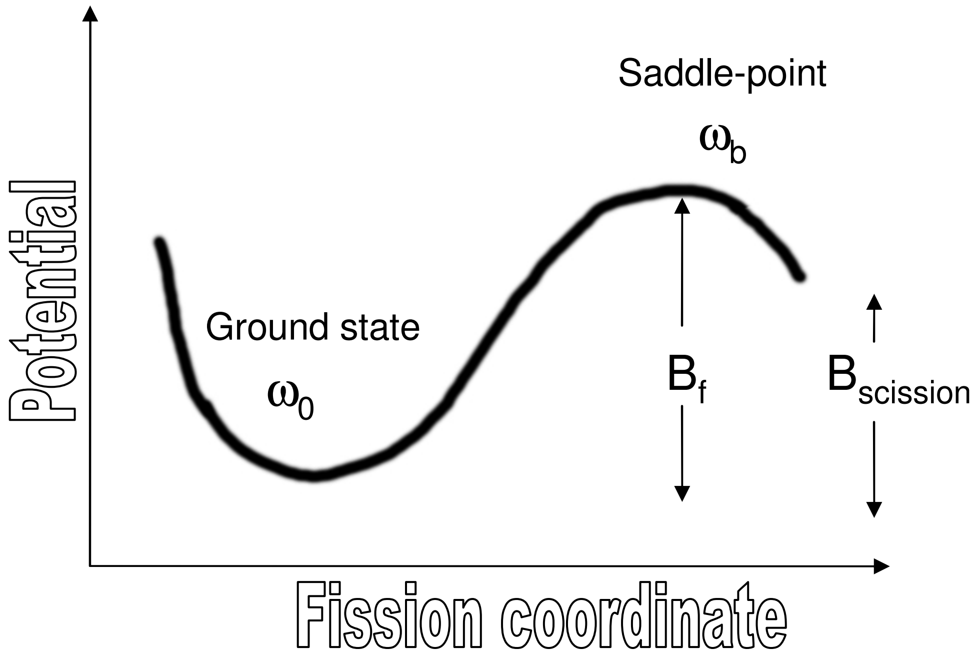
In a one dimensional model, Kramers solved the problem for barrier crossing due to a random walk. Physica **7** , 284 (1940)

$$\Gamma_K = P_K \frac{\omega_0}{2\pi}\exp\left(\frac{-B_f}{T}\right)$$

Extra factors

$$\Gamma_K / \Gamma_{BW} = P_K P_C, \quad P_C = \frac{\omega_0}{T}$$

$$P_K < 1$$



Collective enhancement factor (P_C >1)[Strutinsky Phys. Lett. 47B, 121 (1960)]
vibrations in ground state well

$$\rho *_{CN}(E*) \approx \iint \rho\left(E* - \frac{1}{2}kx^2 - \frac{p_x^2}{2m_x}\right)\frac{dx\,dp_x}{h}$$

$$= \frac{\mathrm{T}}{\omega_0}\rho(E*) = C\left(\frac{\mathrm{T}}{\omega_0}\right)\rho(E*) \qquad \omega_0 = \sqrt{\frac{k}{m_x}}$$

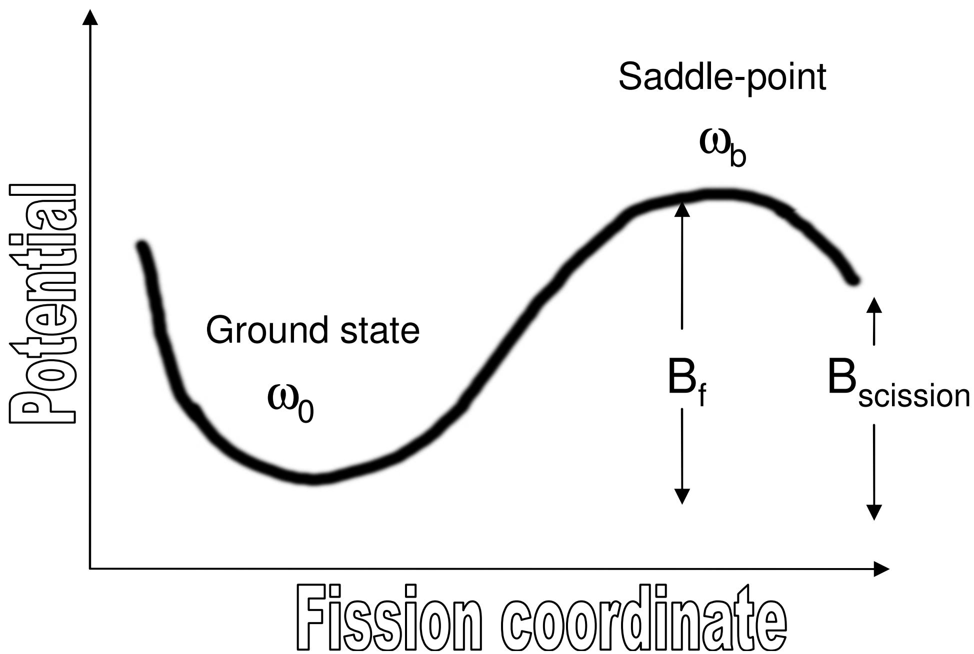
Classical result $C=T/\omega_0$, $T > \omega_0$

Quantum

$$C\left(\frac{T}{\omega}\right) = \frac{\exp\left(\frac{\omega}{T}\right)}{\exp\left(\frac{\omega}{T}\right)-1}$$

If $T<\omega$, $C=1$, mode is turned off

$$P_C = \frac{1}{C\left(\frac{T}{\omega}\right)} \leq 1$$



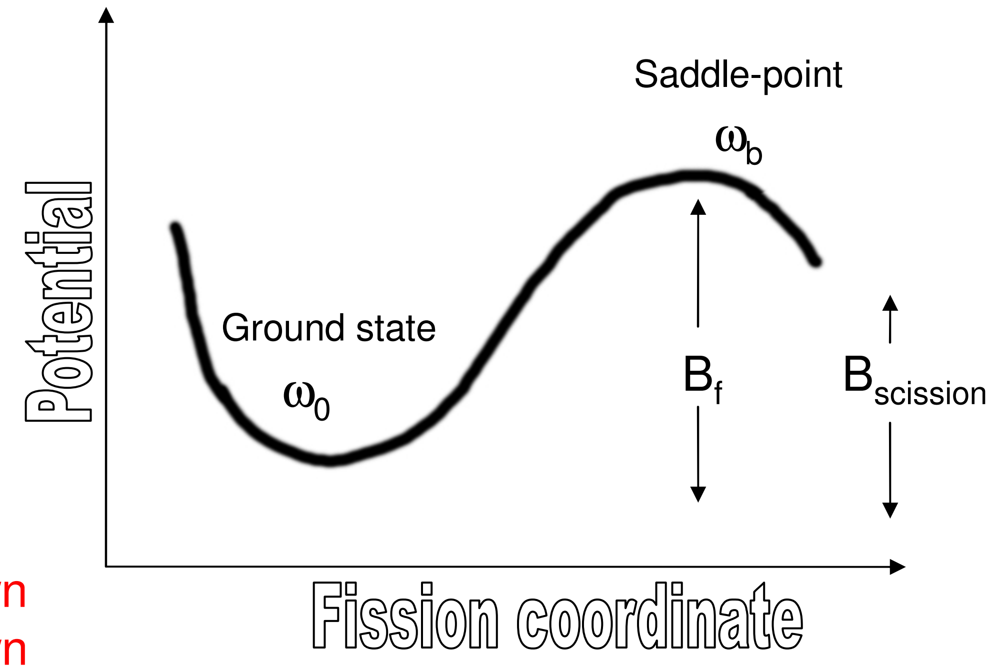
Kramers' factor

(Large friction result)

$$P_K = \sqrt{\frac{\gamma^2}{4} + \omega_b^2} - \frac{\gamma}{2}, \gamma = \text{friction}, \mathrm{P_K} < 1$$

$$\text{Gavron}\,1987, \gamma \approx 3,\ \ P_K \approx .16$$

$$\text{Hinde}\,1989, \gamma \approx 7.2,\ \ P_K \approx .07$$



Friction poorly known, thus P_K unknown
Asymmetry dependence of P_K unknown

No P_K or P_C in GEMINI
$P_K<1$, $P_C<1$ (1-DIM)

Two dimension Kramers model (Jing-Shang+Weidenmuller)

$$\Gamma_K^{2d} = P_K^{2d} \frac{1}{2\pi\rho_{CN}^{**}(E^*)} \int \rho^*(E^* - B_f - \varepsilon) d\varepsilon$$

$$\rho_{CN}^{**}(E^*) = \rho_{CN} C\left(\frac{T}{\omega_0^x}\right) C\left(\frac{T}{\omega_0^y}\right)$$

$$\rho^*(E^*) = \rho(E^*) C\left(\frac{T}{\omega_b^y}\right)$$

P_K^{2d} is a complicated function of the friction tensor, inertia tensor, Hessian of the potential energy surface at the barrier

$A = 200$

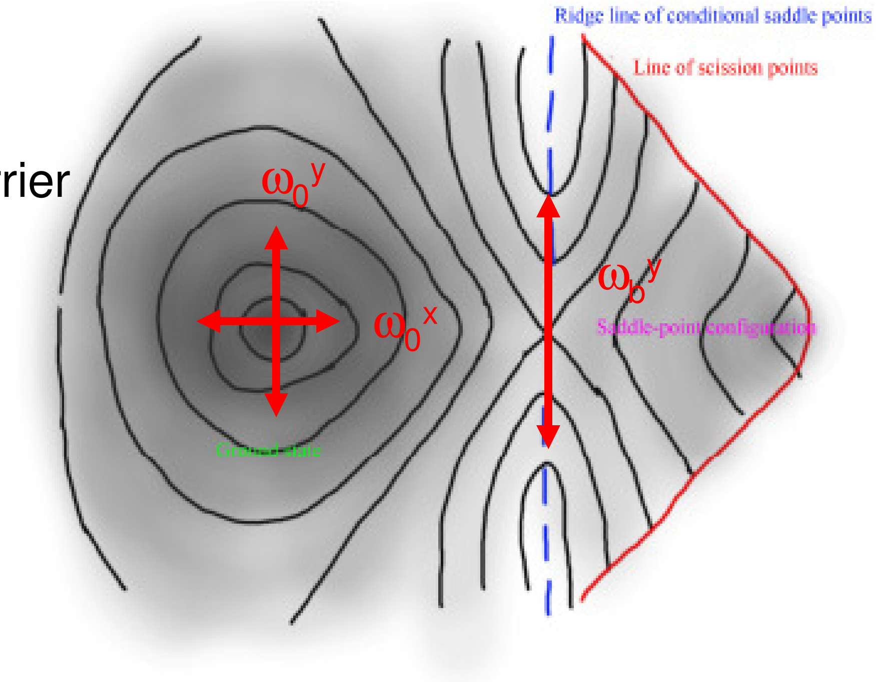
ω_0^x (quadrupole vib) $= 1.4$ MeV

ω_0^y (octapole vib) $= 3.7$ MeV (Turned off)

ω_b^y (fission asy) $= 0.2$ MeV

at $T = 1$

$$P_C = \frac{C\left(\frac{T}{\omega_b^y}\right)}{C\left(\frac{T}{\omega_0^x}\right) C\left(\frac{T}{\omega_0^y}\right)} = 4.07 \geq 1, P_K < 1 \text{ (2-dim)}$$



Multi dimensional model

$$P_C = \frac{\prod_{i=1}^{N-1} C_i^{\text{saddepoint}}}{\prod_{i=1}^{N} C_i^{gs}}$$

ground state : A = 200, $\omega_{hexadecapole} = 6.76$ MeV, other higher order modes have larger frequencies.

The ground state collective vibrations are turned off, except for the quadrupole mode, $C_{i>1}^{gs} = 1$

Saddle - point has many more (turned on) collective modes,

P_C increases if we go to higher dimensions

There are angular momentum baring modes at the saddle point (wriggling, bending, tilting, twisting) which should further enhance level density and P_C

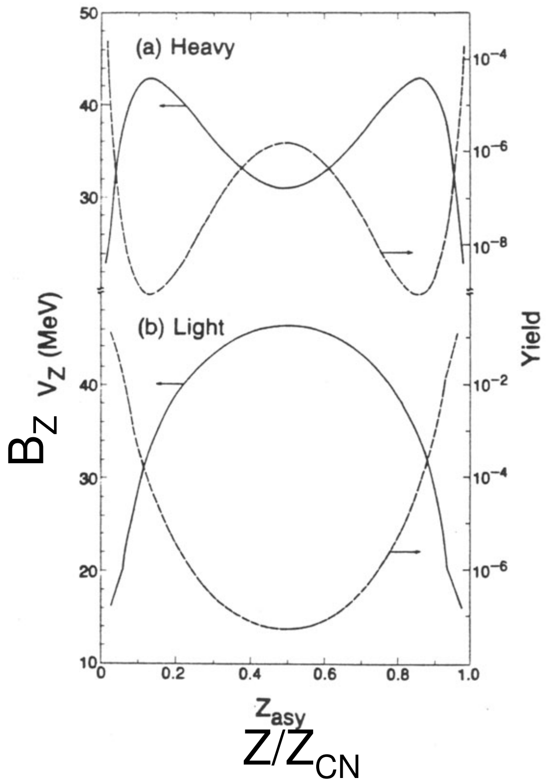
$P_K<1$, $P_C>1$ – maybe they cancel?

- Results for symmetric and asymmetric fission dependent on the dimensionality of the calculation.
- How many dimensions to work in ?

  A free parameter of the model.
- The dimensionality will change with mass number
- One approach will not work for all masses
- The extent that the Bohr-Wheeler formulism works is probability due to cancellation of the P_K and P_C factors

Charge or mass distribution is a refection of the potential energy surface

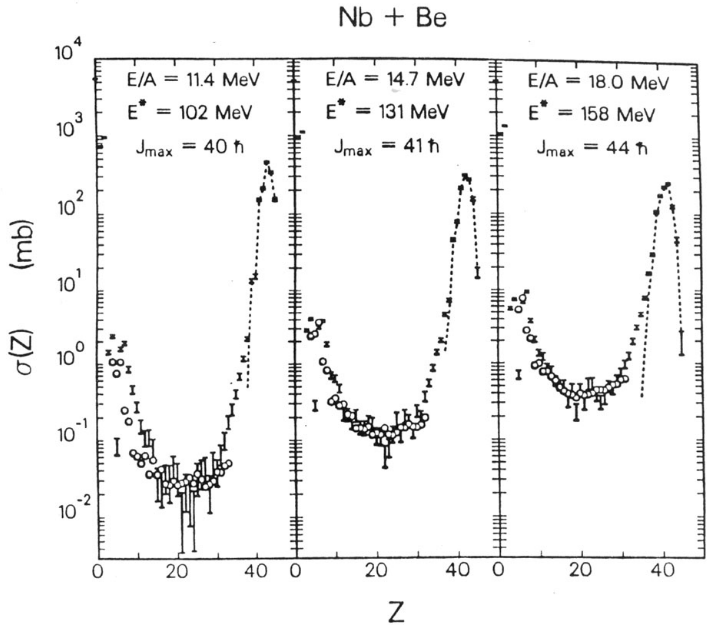
$$\Gamma(Z) \propto \rho(E^* - B_Z) \approx \rho(E^*)\exp\left(\frac{-B_Z}{T}\right), T = \text{temperature}$$



Above Businaro-Gallone point

Below Businaro-Gallone point

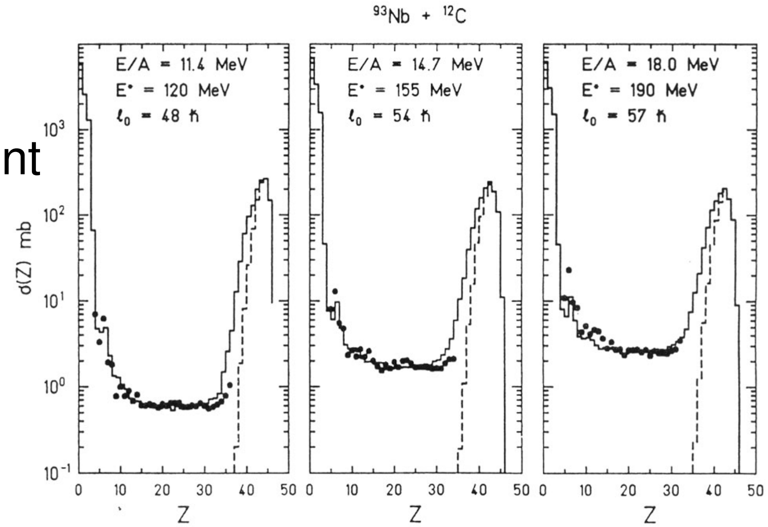
Comparison of GEMINI to heavy-ion fusion data
E* known well, angular momentum distribution poorly known



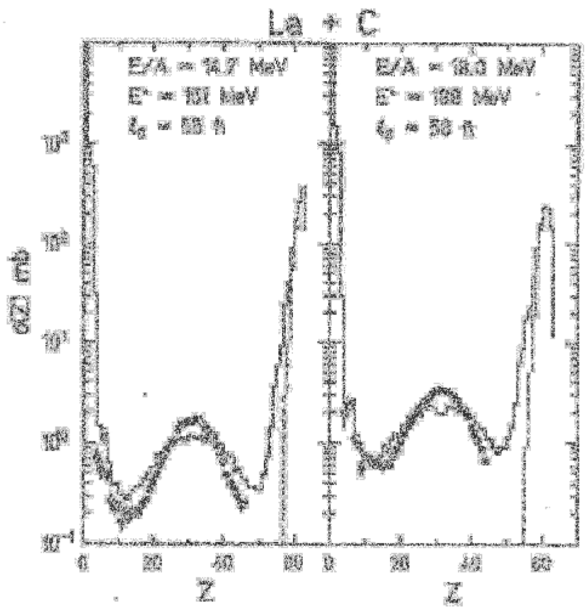
Below BG point

Γ(Z,A) formulism

At BG point



Above BG point



Shapes well reproduced

J_{max} or l_0 – (maximum CN spin) was adjusted to fit data. Fitted values are close to expectation, but could have got an equally good fit with the Γ(Z) formulation. Measured fusion cross sections would determine J_{max} and better calibrate the statistical model in this mass region

Increasing angular momentum has the same effect as increasing the mass

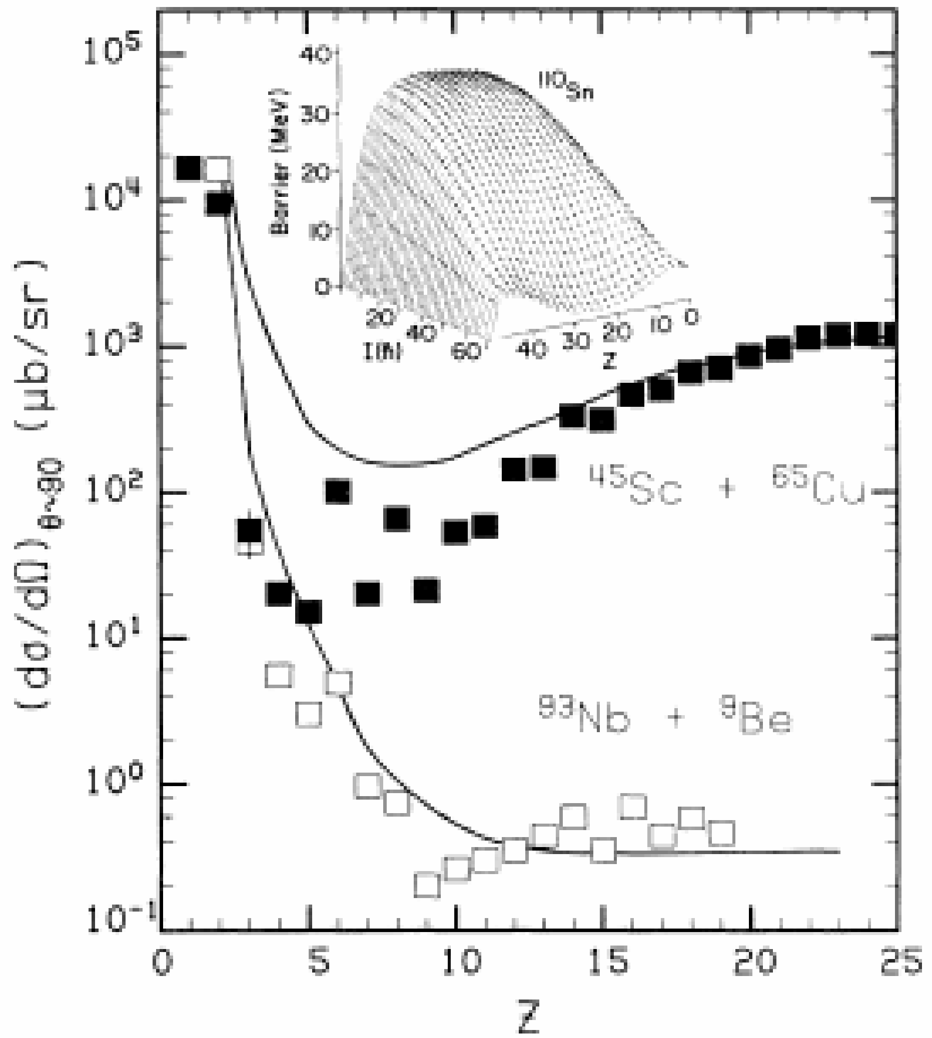
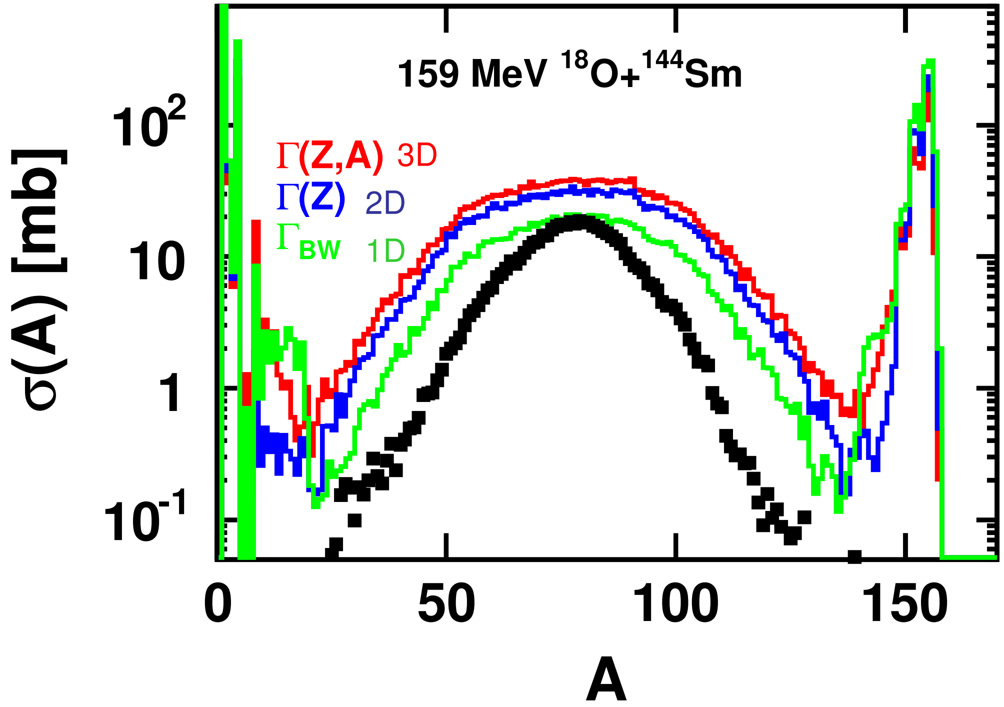


TABLE I. Quantities characterizing the reactions of interest.

System	E_{lab} (MeV)	CN	E^* (MeV)	l_{crit} [a] (ħ)	l_m [b]	x [c]	y [d]
^{93}Nb + ^{9}Be	782	^{102}Rh	78	34	43	0.40	0.05
^{45}Sc + ^{65}Cu	200	^{110}Sn	94	70	80	0.45	0.17

Sobotka et al PRC **36**, 2713 (1987)

More fissile system – Fusion cross section measured, J_{max}=72.5 hbar



Standard GEMINI [Γ(Z,A)] over predicts the fission yield –
The Γ_{BW} formulism does much better – but still too big
Need recalibration for this mass region

For fissile compound nuclei GEMINI overpredicts the width of the fission mass distributions

a) temperature at saddle point is colder than GEMINI predicts?
c) problem with the asymmetry dependence of barriers?
b) saddle-scission transition modifies distribution?

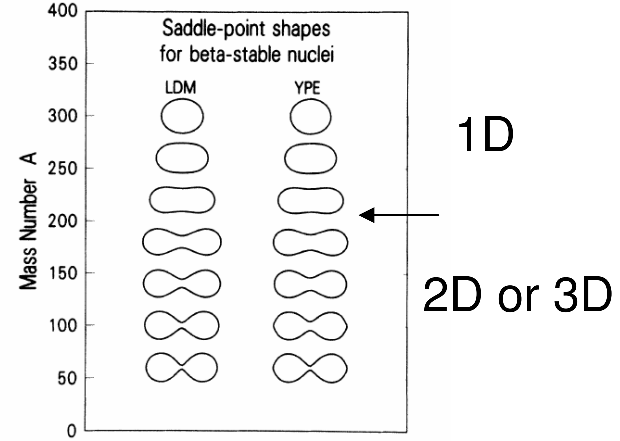
$$\Gamma_Z \propto \exp\left(-\frac{B_Z}{T}\right)$$

GEMINI assumes the saddle and scission point are degenerate.

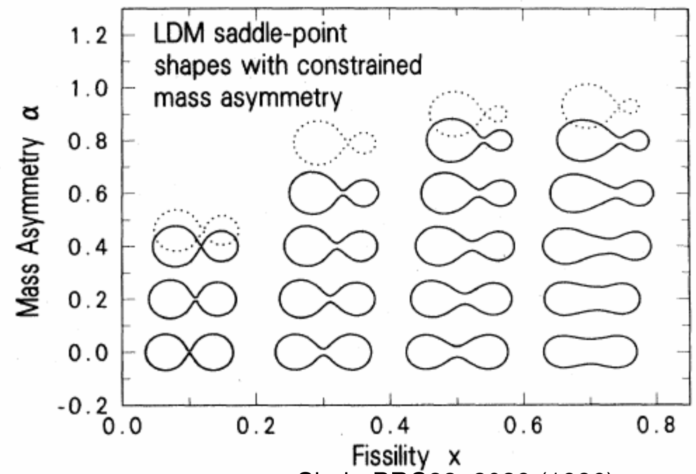
a) excitation at scission is divided between the two fragments.
No dissipation of energy between the saddle and scission

b) mass asymmetry at saddle and scission are identical.
No fluctuations in asymmetry between saddle and scission

This is reasonable when the saddle-point has a well defined neck – short saddle-to scission distance
Bad Assumption for symmetric division of heavy systems.
For very heavy systems, there is not neck and the asymmetry parameter is not defined at all.

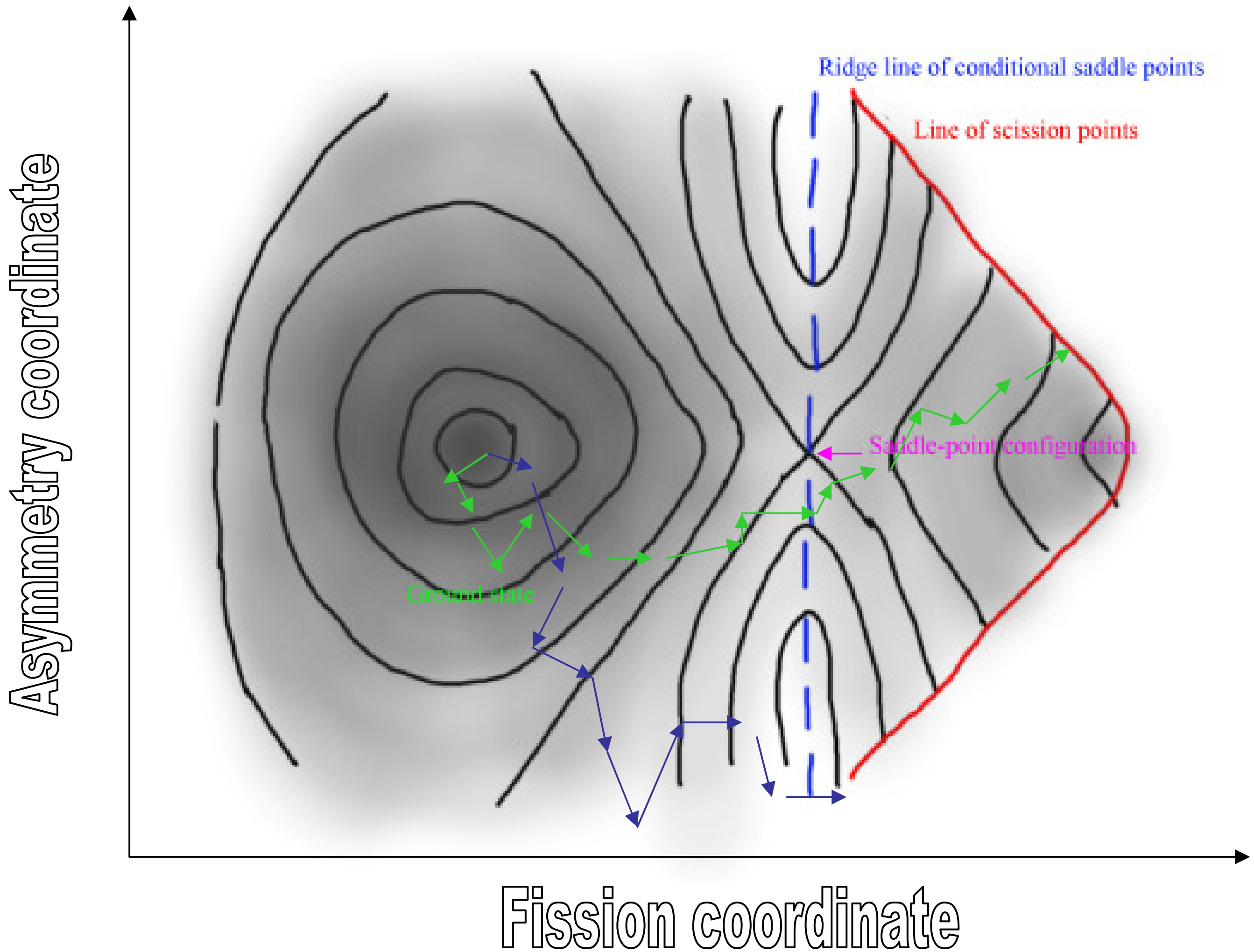


Thomas, Davies, + Sierk, Phys. Rev. C31, 915 (1985)



Sierk, PRC33, 2039 (1986)

Potential energy surface

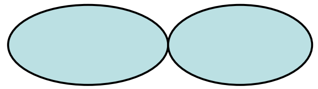


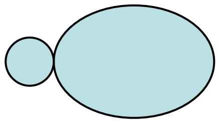
For large saddle-to-scission distance asymmetry at saddle may not be preserved at scission

Another formulism – Scission-point logic instead of saddle-point

Scission-point model of nuclear fission based on deformed-shell effects
Wilkins, Steinberg and Chasman, PRC 14, 1832 (1976)

Fission mass distribution determined from a thermal model at scission
Scission-point energy determined from touching spheroids with shell corrections





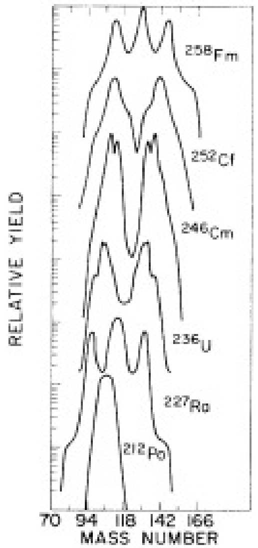


FIG. 8. Calculated mass-yield distributions for various fissioning systems using a single set of parameters (T_{coll} = 1.0 MeV, τ_{int} = 0.75 MeV and d = 1.4 fm) for all systems.

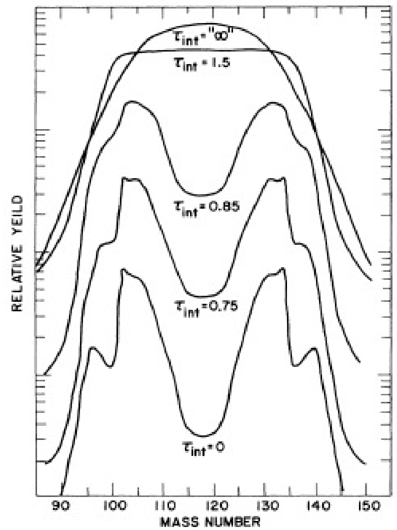
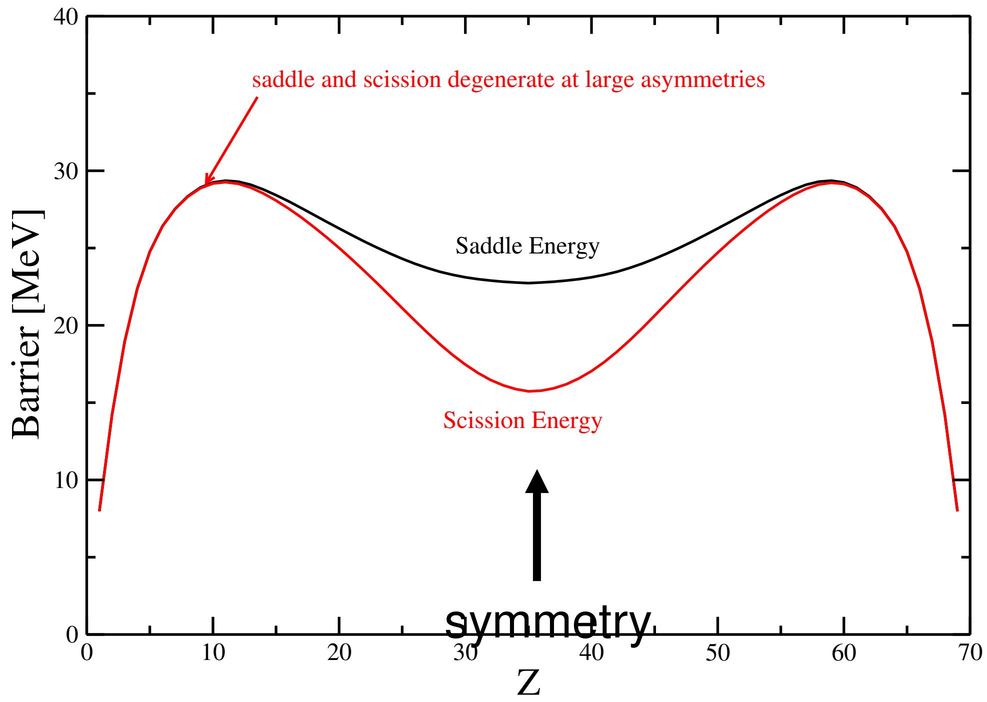


FIG. 11. The mass distribution for ^{236}U calculated at several different temperatures τ_{int}. The calculation at τ_{int} = "∞" has the shell and pairing corrections set to zero.

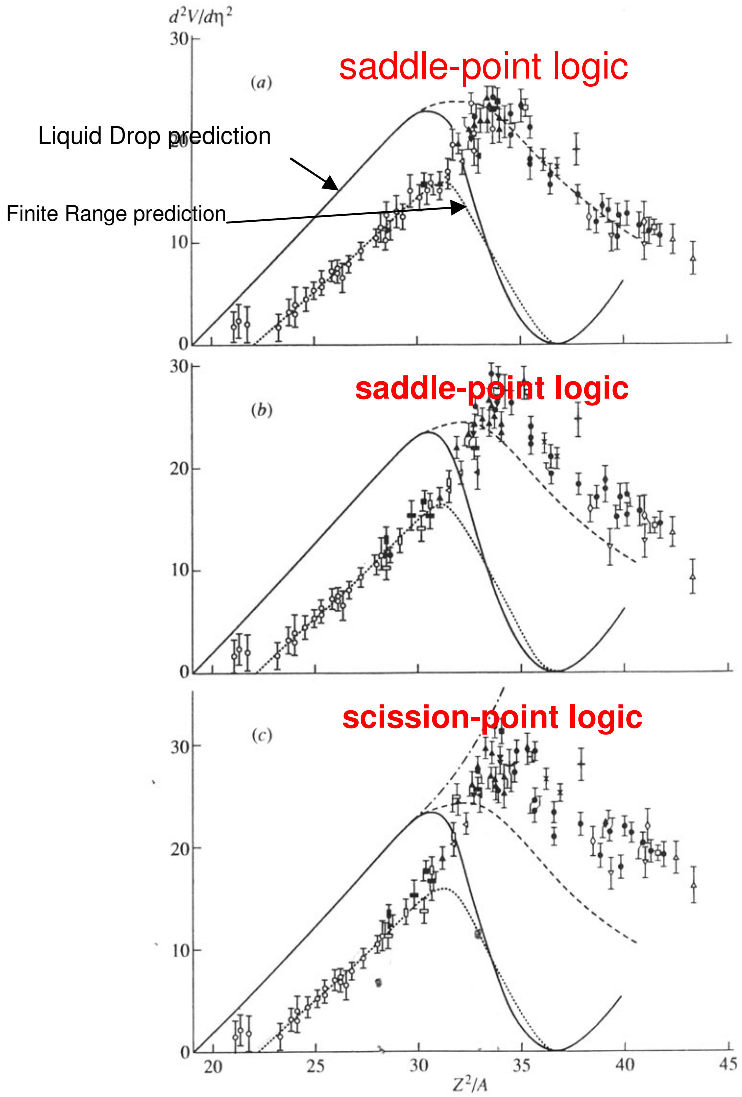
Light systems saddle-point and scission point model are degererate

Stiffness $(d^2V/dZ^2)_{sym}$ at scission point should be larger than that at saddle for a heavy system–
so a scission-point logic would predict
narrower barrier distributions than a saddle-point logic



Systematic of fission mass distributions (no double-humped distributions)

Rusanov, Itkis, Okolovich, Phys. Atomic. Nucl. 60,683 (1997)



$$\text{asymmetry stiffness} = \frac{d^2V}{d\eta^2} = A_{CN}\frac{T}{16\sigma_M}$$

$$\sigma_M = \text{standard deviation of fission mass distribution}$$

The stiffness in the stiffness at the saddle or scission points, depending on which logic one used.

T (temperature) determined after accounting for presaddle and or saddle-to-scission neutrons emitted.

From measured $\sigma_{M,}$ (corrected for angular momentum), deduce stiffness.

As a practical matter, could use these stiffnesses and statistical model values of T to predict the mass distributions – interpolation from the systematics.

Is the asymmetry dependence of conditional saddle-point energies correct in GEMINI?

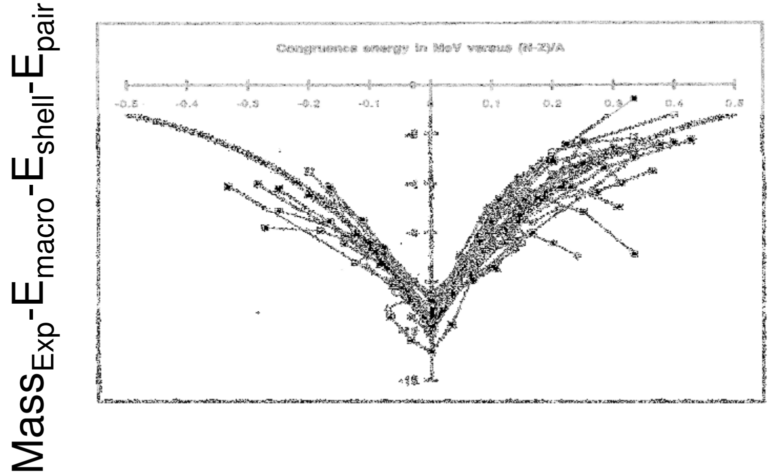
Saddle-point energies are often calculated as $\Delta E_{Coulomb} + \Delta E_{Surface}$
For example the Sierk's calculations used by GEMINI

What about the Wigner Energy in the mass formula?

$$E_{Wigner} = \left|\frac{N-Z}{A}\right| 36\,\text{MeV}\text{ , from proton - neutron pairing? washes out?}$$

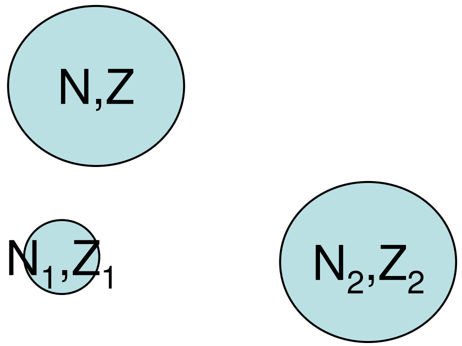
$$= 7.61\,\text{MeV for } {}^{208}\text{Pb}$$

There is also a constant term is some mass formula



initial state

final state



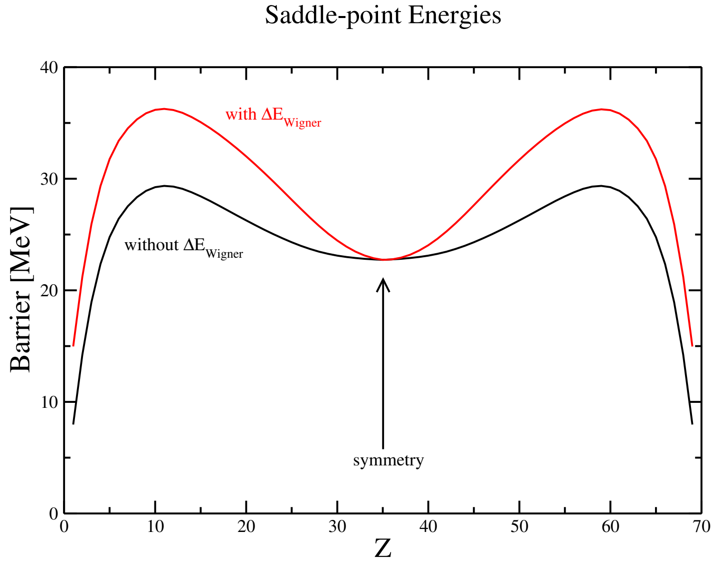
$N=N_1+N_2$, $Z=Z_1+Z_2$

$$\frac{N-Z}{A} \approx \frac{N_1-Z_1}{A_1} \approx \frac{N_2-Z_2}{A_2}$$

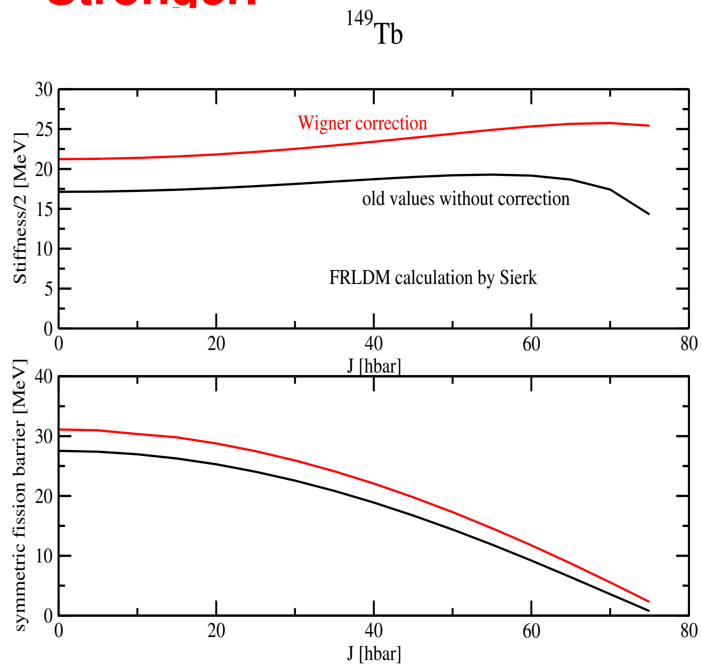
$$\Delta E_{Wigner} = 36\,\text{MeV}\left|\frac{N-Z}{A}\right|$$

How does the Wigner energy change with deformation?
What is the Wigner energy at the conditional saddle-points?

schematic



Wigner correction make asymmetry dependence Stronger.



Effect not large enough to fully explain the ^{162}Yb results

Asymmetric saddle-point has prominent neck E_{Wigner}=2xE_{Wigner}(gs)

Symmetric saddle-point heavy nucleus – no neck E_{Wigner} = E_{Wigner}(gs)

Inclusion of Wigner Energy will give narrower mass distributions?

Fission dynamics

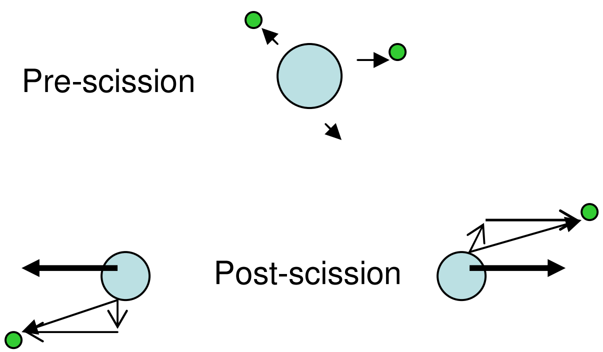
Pre and post-scission multiplicities of light particles are sensitive probes to the fission dynamics.

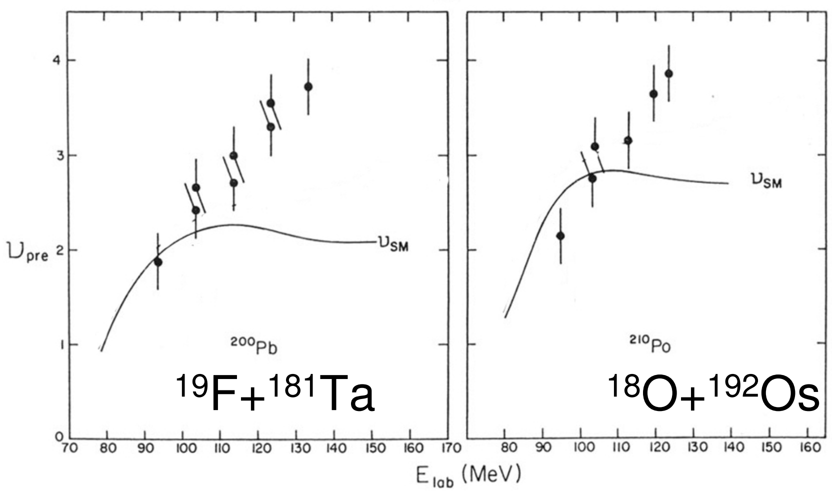
Motion along the fission coordinate is slow and highly dissipative (over damped) for symmetric fission.

Large friction – large fluctuations (fluctuation dissipation theorem)

Post-scission multiplicities->The excitation energy at the scission point is 0.2 to 0.4 MeV/A independent of the initial compound-nucleus excitation energy. 40-80 MeV for A=200 [Hilscher and Rossner Ann. Phys. Fr. **17** (1992) 471]

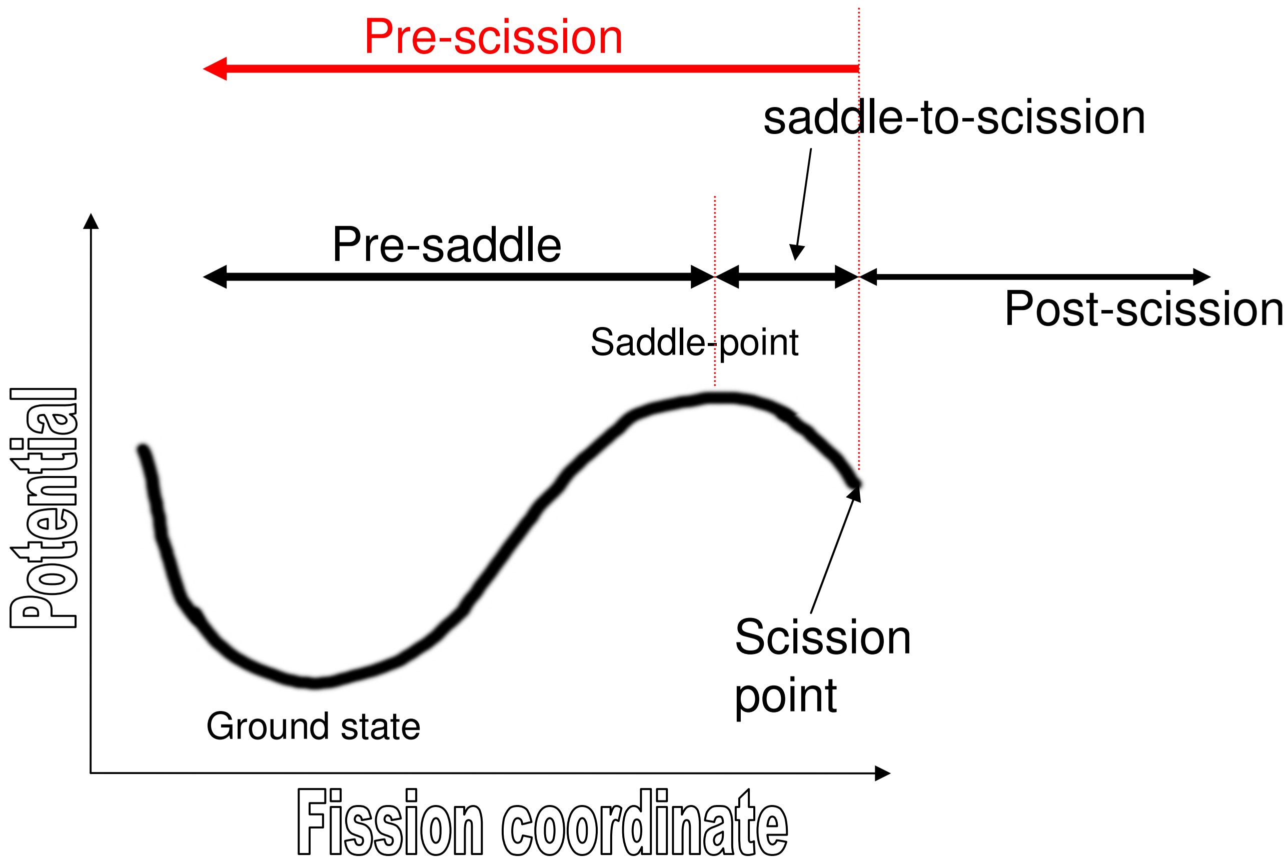
Pre-scission neutron multiplicities cannot be explained with the standard statistical model (GEMINI) without dynamics





To explain experimental pre-scission multiplicities need

a) More pre-saddle emission – fission transients
   and/or
b) saddle-to-scission emissions



Fission transients

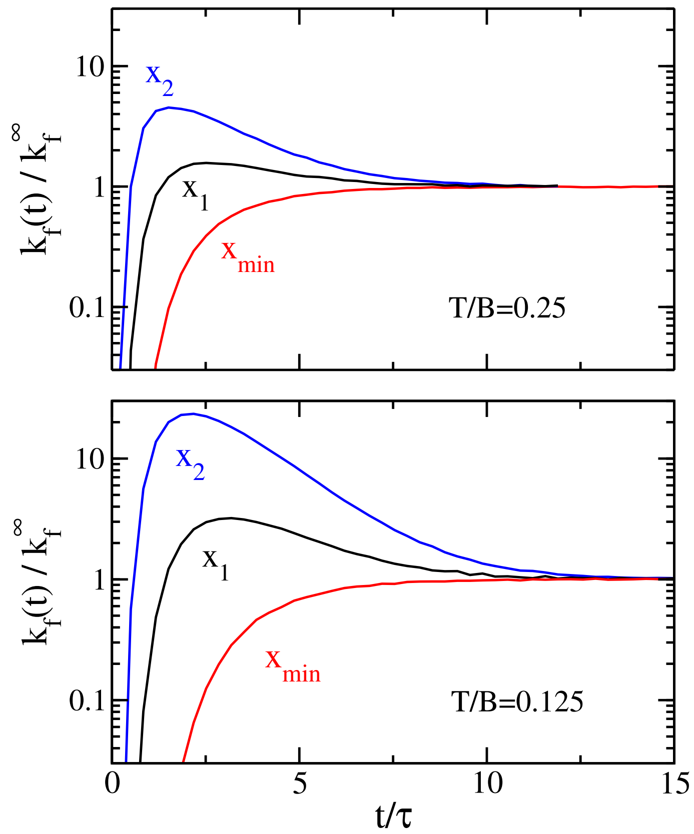
Compound-nucleus decay widths are appropriate for a system equilibrated in all of its degrees of freedom. The Kramers' fission rate assumes the collective or shape degrees of freedom are in equilibrium.

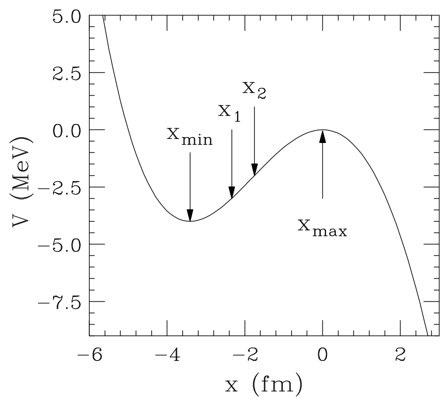
It takes a finite time (transient time) for the equilibrium to occur. The transient fission rate can be larger or smaller than the equilibrium depending on the initial conditions.

Most studies assume an initial suppression of fission (fission delay) – during which light particle emission can occur and cool the system and reduce fission probability.

GEMINI incorporates a simplistic fission decay (step function)
$\Gamma_Z = 0$ for time $< t_{transient}$

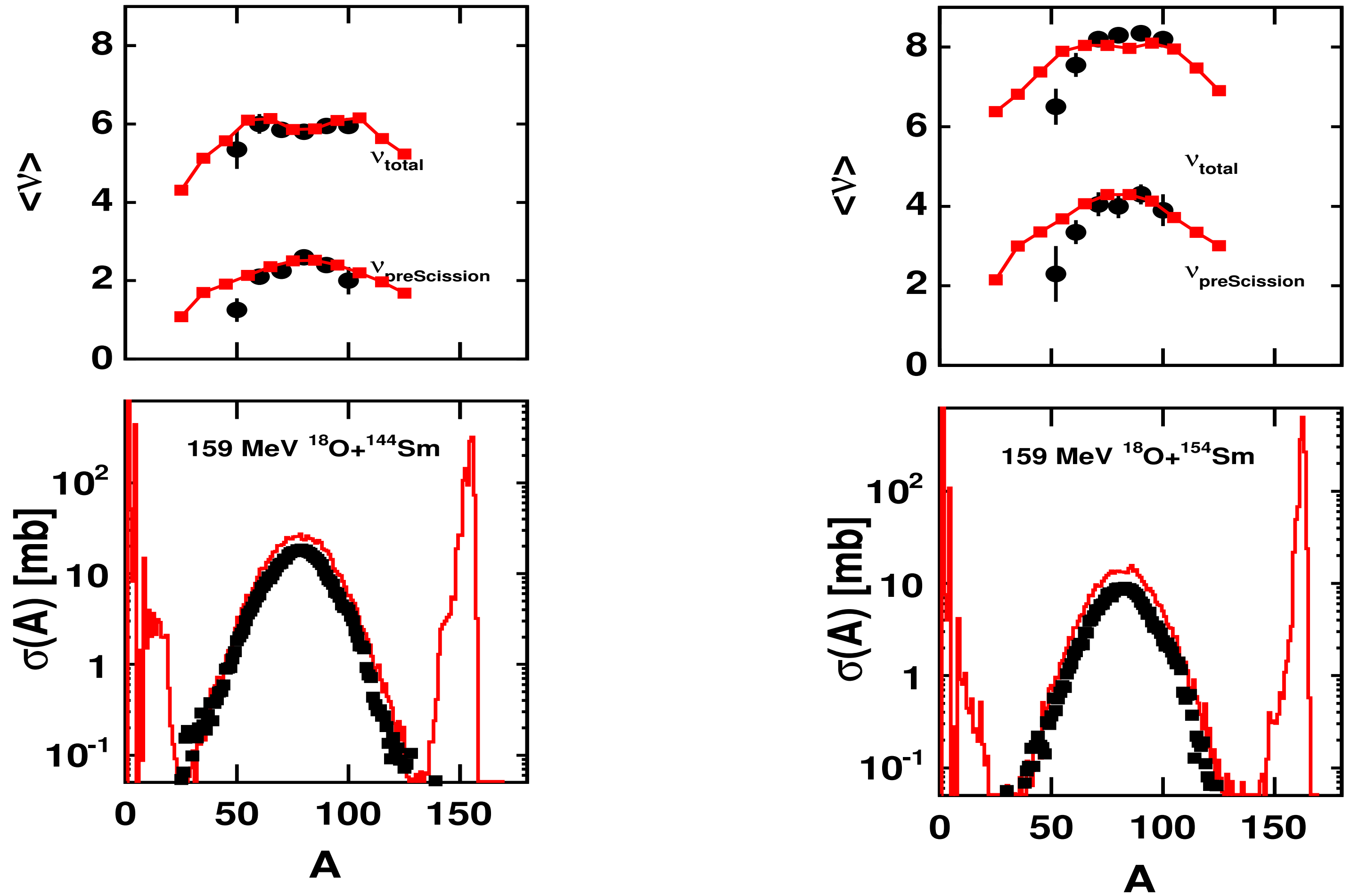
C. Schmitt et al., PRL **99** 042701 (2007)
transient time for initially spherical systems= 3.3×10^{-21}s
K.X. Jing PLB **518**, 221 (2001)
10×10^{-21} s
Doesn't have much affect for the data I showed.





Charity, arXiv:nucl-th/0406040v1
Langevin simulations

Saddle-to-Scission time = 7 zs



Modification to GEMINI that uses a scission-point model.
Asymmerty-dependence of scission potential from touching spheres.
Evaporation of neutrons from saddle-to-scission.

Conclusions

- GEMINI has the correct treatment of angular momentum
- GEMINI seems to work reasonable well for light compound nuclei, but I am not sure why.
- GEMINI doesn't work for heavy systems-problems with the fission yield and width of mass distribution

  a) few dimensions

  b) new barriers will help (Wigner Correction?)

  c) Could interpolate from systematic of fission mass distributions

  after including fission delays and saddle-to-scission time.

  d) A simplistic scission-point model for mass distributions gives good results (could include shell effects to get double humped distributions)
- Lower Coulomb barriers for alpha + Li+Be. emission for heavy systems
- Large temperature dependence of level-density parameter for heavy systems