

# Specific Improvements to Reaction Theory

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# Aims of Nuclear Theory

- ◆ Not only: 'Calculate properties of nuclei'
  - Given effective nucleon-nucleon interaction  $V_{nn(n)}$ , find:
    - Ground state properties
    - Energy levels in spectrum
    - Transition densities between states
- ◆ Also: calculate nuclear reactions
  - Find cross sections for everything that happens in neutron+nucleus collision, for
    - Any nucleus  ${}^Z A$
    - Any neutron energy  $E_p < 200$  MeV
  - Derive optical potentials microscopically

# Relevant Reactions

## ◆ Direct Reactions

- Elastic, inelastic (collective, p-h), breakup, transfers, capture
  - use multi-channel quantum reaction theory

## ◆ Compound nucleus production & decay

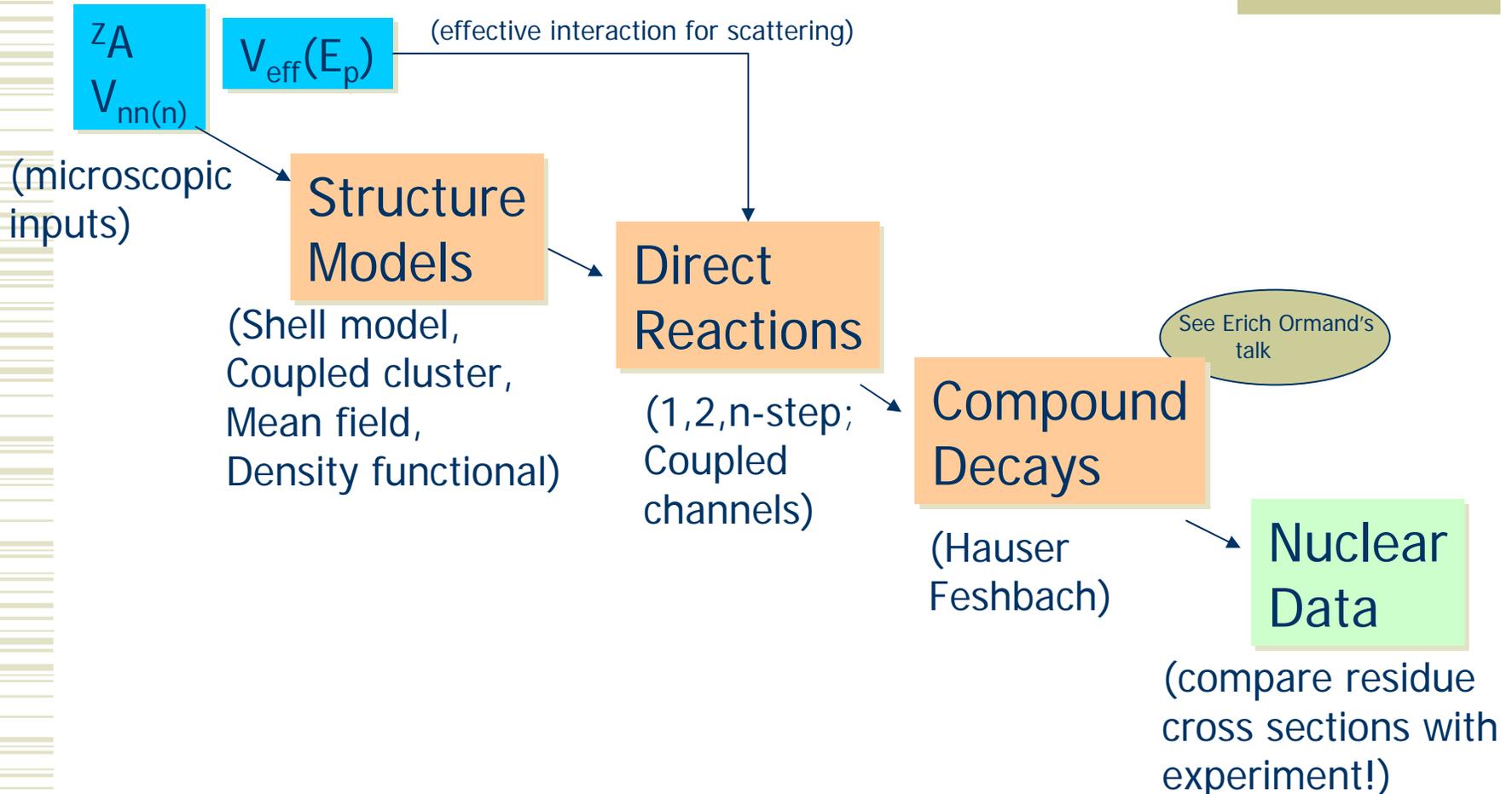
- Particle &  $\gamma$  emissions, fission
  - use statistical theories

◆ (also not forgetting 'pre-equilibrium' knockout)

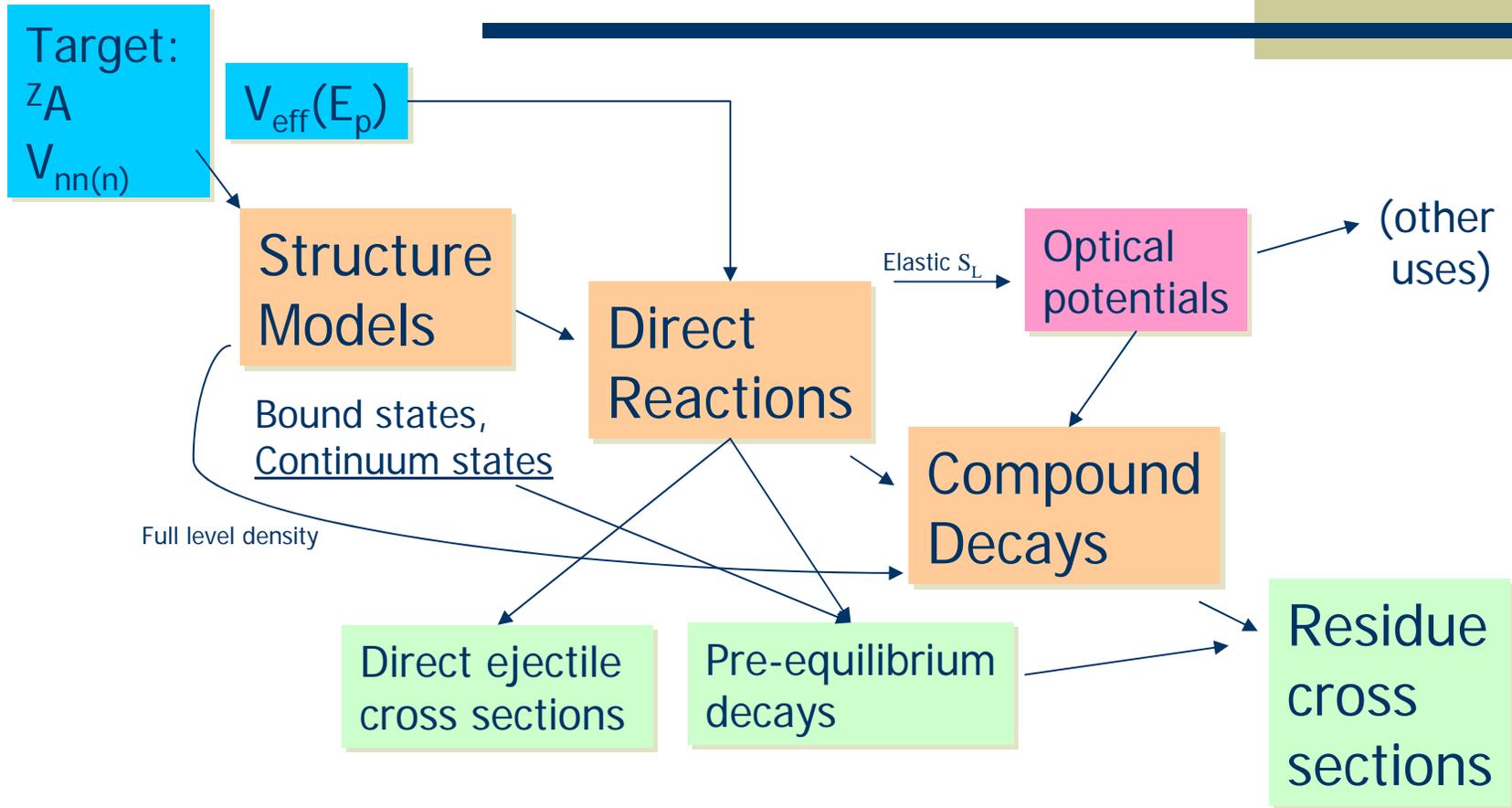
# Excitations: collective vs. microscopic

- ◆ Low-lying excited states are usually collective rotations or vibrations
- ◆ Higher-lying states begin with particle-hole (p-h) excitations, which 'spread' into surrounding 2p-2h, etc
- ◆ Can expand collective states as p-h sums
  - So: need reaction model for any p-h sum ...
  - Or, use deformed single-particle states
- ◆ Simple starting calculations
  - use uncorrelated single particle states in the mean field

# Overall: $n+A$ scattering at $E_p$



# More detail: n+A scattering



# Interfaces

- ◆ **Between structure and reactions:**
  - Transition densities, folded with  $V_{\text{eff}}(E_p)$  to give
  - Transition potentials
- ◆ **Between reactions and compound decay:**
  - Angular distributions of emission cross sections,
  - L-distributions of capture cross sections.
- ◆ **Between decay predictions and residue data:**
  - Something like ENDF (et al).

# Extensions

- ◆ Deformed single particle basis states
- ◆ Prime structure calculations with p-h transition operators
- ◆ Transfers:  $(n,d)$  pickup
  - Need structure of  $A-1$  system (at least  $\langle A-1|A \rangle$  overlap)
    - give non-local couplings: more difficult
    - Approximate: pickup from single particle states in the mean field
- ◆ Capture:  $(n,\gamma)$ 
  - Need structure of  $A+1$  system (at least  $\langle A|A+1 \rangle$  overlap)
    - easy in the long-wave length limit
    - Approximate: capture to single particle states in the mean field
- ◆ Fission:  $(n,f)$ 
  - More (!) difficult
  - Still: direct reactions give entrance resonances

# Relations to other work

- ◆ **Structure models for  $A+1$  system** gives:
  - Overlaps functions  $\langle A|B\rangle$
  - important information about  $V_{\text{eff}}(E_p)$  at least for  $E_p$  near resonances.
- ◆ Particle-hole excitation is just one **breakup** mode:
  - basic engine can also be used for CDCC,
  - extended CDCC breakup calculations, eg with deformed valence particle states.
- ◆ **Multistep direct theories** such as FKK
  - use various 'on-shell' and 'decoherence' approximations that need to be checked.

# Breakup Reaction Challenges

- ◆ Need reaction models with some/all of:
  - Recoil & Finite Range of projectile vertex.
  - Final-state (partial wave) interference
  - Nuclear and Coulomb mechanisms
  - Core excitation (initial and/or dynamic)
  - Final-state interactions:
    - between halo fragments (needed if resonances)
    - between fragments and target (needed if close in)
  - Multi-step Processes (higher order effects)
- ◆ Coupled channels for discrete & continuum states

# Computational Challenges

- ◆ Structure models (*ab initio*, DFT)
  - See the UNDEF proposal for SCIDAC
- ◆ **Reaction models**
  - Need for distributed solver for coupled second-order differential equations.
    - (can already distribute the 10-100  $J^\pi$  sets)
    - consider basis-expansion methods.
  - Density of 2p2h, 3p3h ... states grows rapidly!
    - can try various decoherence approximations



# Commitment

“Cross section calculations. If there is no [computer] time available, we will make it available.”

Ray Orbach, *this meeting*, Aug 10.

# The Way Forward

- ◆ Many calculations needed for AFC theory!  
(and so few theorists!)
- ◆ New needs, and new challenges, to connect structure theories with reactions, through to useful final cross sections.
- ◆ Now is unique opportunity for accepting grand challenges in reaction theory!