EMPIRE-3.2

Nuclear reaction code system

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WANDA, Jan. 25 – Feb 3, 2021

LA-UR-21-20569

EMPIRE scope

Honorary Developer:
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- Incident energies up to ~150 MeV
- Projectiles: n, p, d, t, 3He, 4He, γ, and Heavy Ions (HI)
- Outgoing channels: projectiles (except HI), multi-particle emission, discrete levels (including isomers), γ lines, fission
- Reaction mechanisms: direct, pre-equilibrium and statistical model
- Provides: reaction cross sections, residue production cross sections, angular distributions, spectra (incl. PFNS), angle-energy distributions of reaction products
- Targets A > 20 (light nuclei excluded)
- Low energy range for neutron reactions covered by interface to Atlas of Neutron Resonances (to be updated)

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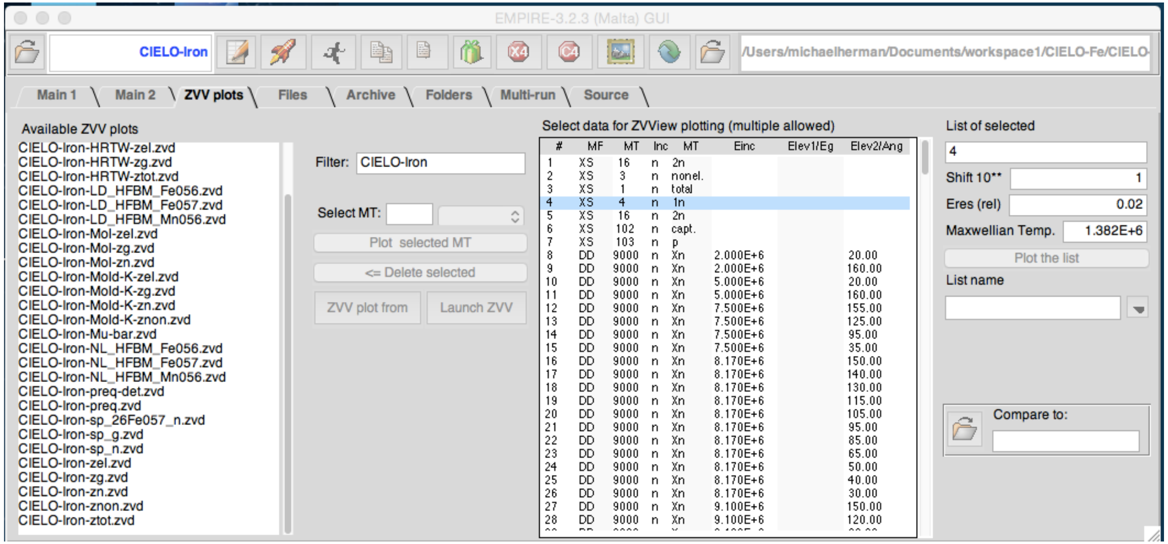
EMPIRE's convenience

- Operation via Graphic User Interface (GUI)
- Easy input (extensive use of defaults, built-in internal logic)
- Choice of reaction models (Fus. 7, Dir. 2, PE 3, LD 3, G-str. 6, Fiss. 5)
- Manipulation and verification of ENDF-6 files
- Interactive plots of experimental and calculated results
- Automated calculation of sensitivity matrices for Kalman fitting and covariances



EMPIRE-3.2 (Malta)

Nuclear Reaction Model Code

Neutron Resonances

Coupled Channels

DWBA

Optical Model

Multistep Direct

Multistep Compund

Exciton Model

Hybrid MC Simulation

HRTW

Hauser-Feshbach

Optical Model for Fission

ENDF Formatting

Verification

Kalman Filter

Covariances

EMPIRE-3.2 (Malta)

Nuclear Reaction Model Code

Atlas of n resonances

- Neutron Resonances

Direct reactions, absorption, T_{lj}

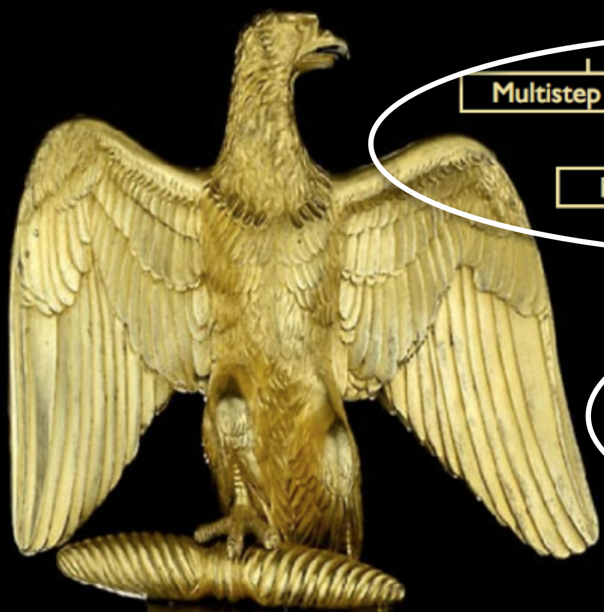
- Coupled Channels
- DWBA
- Optical Model

Pre-equilibrium

- Multistep Direct
- Multistep Compund
- Exciton Model
- Hybrid MC Simulation

Compound nucleus

- HRTW
- Hauser-Feshbach
- Optical Model for Fission



ENDF

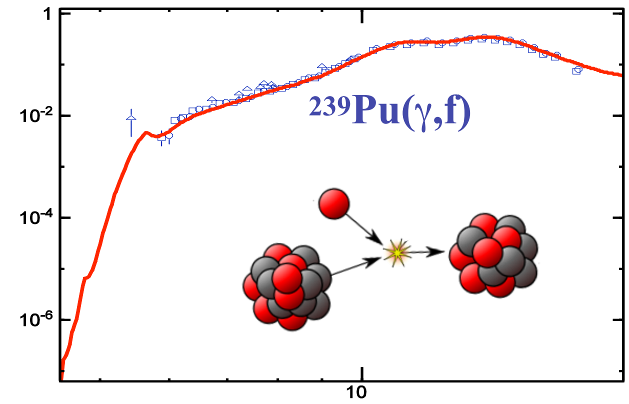
- ENDF Formatting
- Verification

Fitting & Covariances

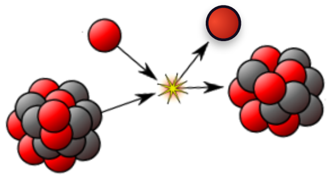
- Kalman Filter
- Covariances

Reaction models

- Fusion
  - Spherical optical model (ECIS-2006),
  - Coupled-channels (ECIS-2006, OPTMAN)
  - Distorted Wave Born Approximation DWBA
  - Simplified coupled-channels for HI (CCFUS)
  - distributed barrier model for HI
  - deuteron absorption
  - photo-absorption for incident gammas
  - ‘read in’

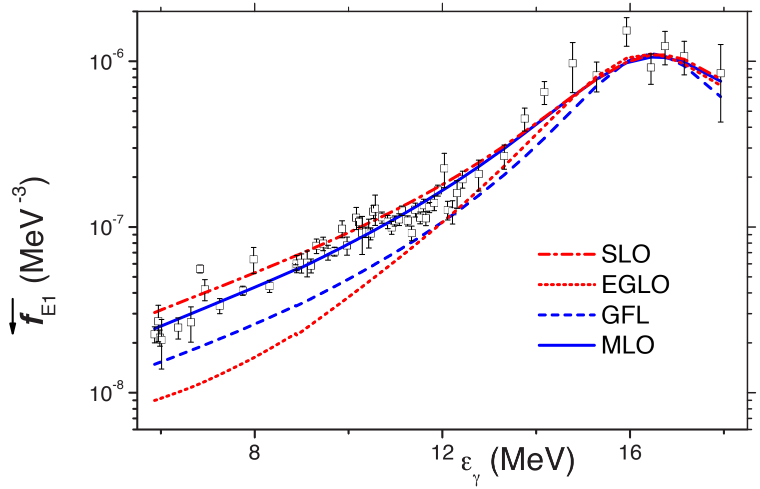


- Direct inelastic
  - Coupled-channels (ECIS-2006, OPTMAN)
  - Distorted Wave Born Approximation DWBA (ECIS-2006) can be used in addition to CC & for levels in the continuum



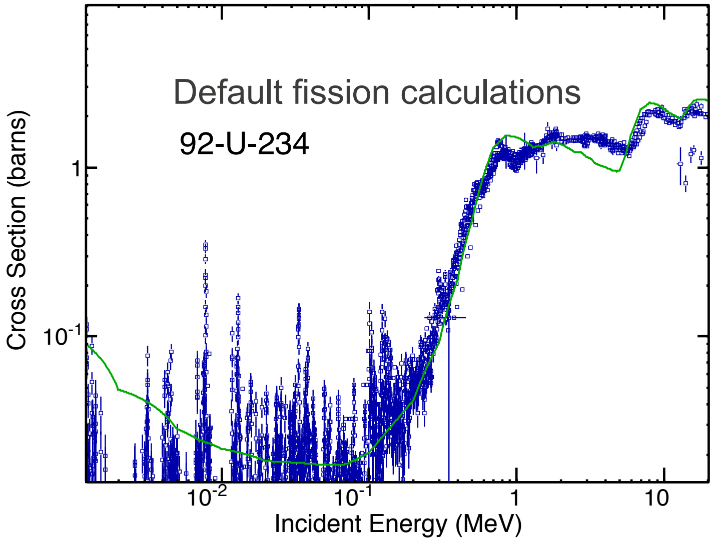
Reaction models (cont.)

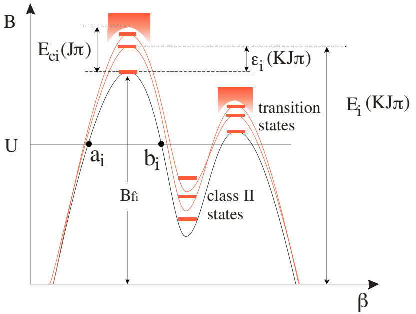
- Pre-equilibrium
  - TUL Multistep Direct (ORION + TRISTAN)
  - NVWY Multistep Compound with γ-emission
  - Exciton model (PCROSS)
  - Iwamoto-Harada model for complex particle emission (PCROSS)
  - Hybrid Monte Carlo Simulation (DDHMS) with multiple PE emission
- Compound nucleus
  - HRTW or Moldauer for widths' fluctuation
  - Multi-emission Hauser-Feshbach model with full γ-cascade
  - Engelbrecht-Weidenmueller transformation for direct-compound interference
- Level densities
  - EMPIRE Superfluid Model with dynamical deformation effects
  - Gilbert-Cameron
  - HFB microscopic tables (RIPL-3)
- γ-strength functions



Reaction models (cont.)

- Fission
  - Symmetric, single barrier fission for HI
  - More advanced fission for incident n, p and γ
    - multi-hump barriers
    - microscopic barriers
    - optical model for fission
    - multimodal fission
- Prompt fission neutron spectra (PFNS)
  - Los Alamos model
  - Kornilov model





Needed to improve predictive power

- Level densities
  - Collective lev. den. enhancements' dumping at higher energies
  - D_o out of stability line
  - Spin distributions
- Multiple preequilibrium > ~30 MeV
- Reliable theoretical models for going out of the stability line or…
- Experimental data to calibrate phenomenological input parameters

$1.3^5 = 3.7 = 370\%$ 5 emissions assuming 30%, fully correlated error for strong channels
$2.0^5 = 32 = 3200\%$ 5 emissions assuming 100%, fully correlated error for weak channels