Photonuclear and photoatomic data for transport codes using GNDS, FUDGE and GIDI+

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LLNL nuclear data Infrastructure was rebuilt around the new GNDS standard, simplifying support for incident photon data

- GNDS (Generalized Nuclear Database Structure) is a new international standard for storing nuclear data, replacing several legacy formats including ENDF-6
  - GNDS format specification is available from https://www.oecd-nea.org/jcms/pl_39689/specifications-for-the-generalised-nuclear-database-structure-gnds?details=true (new version coming soon)
- FUDGE (For Updating Data and Generating Evaluations): LLNL infrastructure for generating, testing, visualizing and processing nuclear data.
  - FUDGE-v5.0 recently released on https://github.com/LLNL/fudge
- GIDI+ (General Interaction Data Interface +): C++ API for reading and sampling processed GNDS evaluations
  - GIDI+ version 3.22 recently released on https://github.com/LLNL/gidiplus

GNDS and associated codes are (mostly) particle agnostic, designed to support any projectile / target

- Each GNDS `reactionSuite' file stores a list of reactions for a combination of projectile and target, over a given incident energy range. Each reaction includes a cross section, Q-value and list of outgoing products with energy/angle distributions

- Photo-atomic and photo-nuclear data fit naturally into this scheme, with two caveats:
  - Processing code (FUDGE) must use relativistic treatment for incident photons
  - Photo-atomic evaluations use special-purpose containers for coherent and incoherent photon scattering:

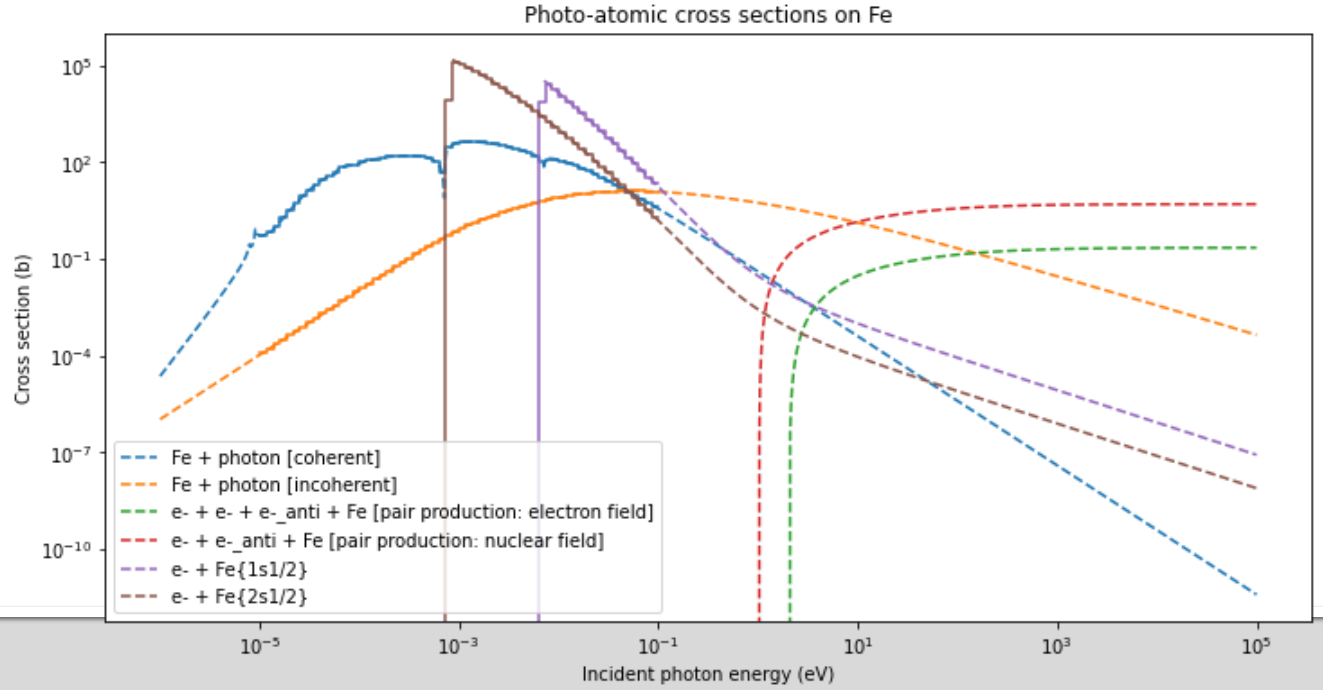
$$\frac{d\sigma_{\mathrm{coh}}(E,\mu)}{d\mu} = \frac{d\sigma_T(E)}{d\mu}\left\{[F(x,Z)+F'(E)]^2 + F''(E)^2\right\}$$

$$\frac{d\sigma_{\mathrm{incoh}}(E,\mu)}{d\mu} = S(x,Z)\frac{d\sigma_{KN}(E,\mu)}{d\mu}\,,$$

FUDGE supports processing for both Monte Carlo and deterministic transport

```
# convert ENDF-6 to GNDS:
python3 fudge/brownies/bin/endf2gnds.py  photoat-026_Fe_000.endf

# process (results stored in new GNDS file):
python3 fudge/bin/processProtare.py photoat-026_Fe_000.endf.gnds.xml \
    -mc -mg --groupFile groups.xml --fluxFile fluxes.xml \
    --gid photon=photon_electron --fluxID LLNL_fid_1
```



GIDI+ supports sampling outgoing photon energy/angle distributions

- Distributions may be first expanded by FUDGE into pointwise energy-angle spectra,
  - P(E' | E) x P(mu | E', E)
- or in the case of coherent / incoherent photo-atomic scattering GIDI+ samples directly from the parameterized form

GNDS, FUDGE and GIDI+ are freely available tools that natively support photo-atomic and photo-nuclear reaction data

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Summary:

- LLNL is switching to GNDS as primary method for storing and using nuclear data
- Codes FUDGE and GIDI+ support processing, reading and sampling GNDS data
- Photo-nuclear and photo-atomic data are natively supported by this toolkit, although some parameterized data forms for photo-atomic scattering require special treatment