The x4i Program

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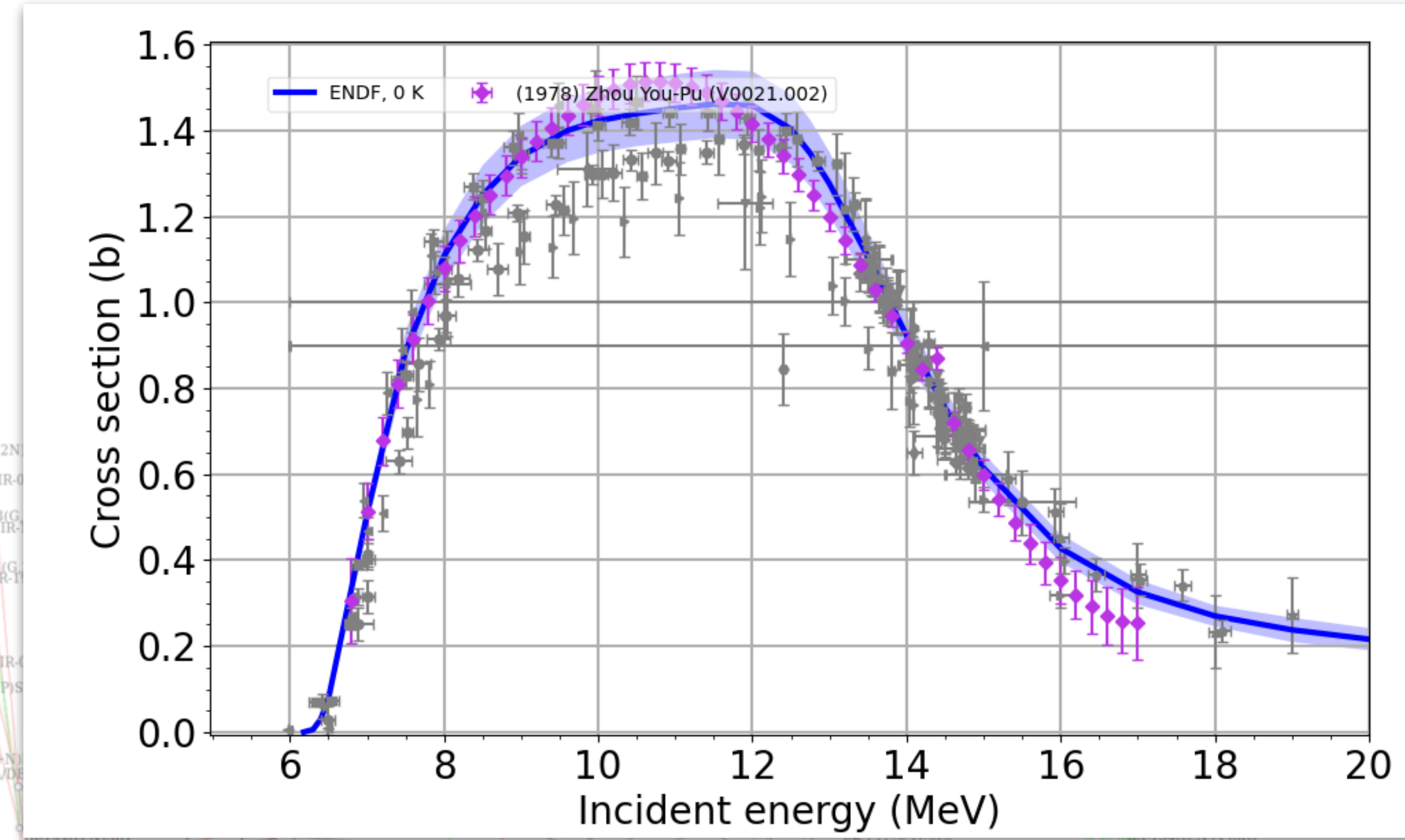
x4i Backstory

- Developed at LLNL by D. Brown as a lightweight API for EXFOR.
- Used to quickly assess evaluations for assembly of LLNL's Evaluated Nuclear Data Library series of libraries.



- GPL release in 2010 when D. Brown transitioned to BNL
- Used by FUDGE, ADVANCE, mainly for plotting and some ENDF data QA
- Modest use in SG-30 for checking EXFOR

In addition to use in ENDF QA, there are at least 2 (non-conference proceedings) papers that used x4i

J.A. Hirdt and D.A. Brown
Nuclear Data Sheets 131 (2016) 377–399

D. Boncioli, A. Fedynitch & W. Winter
Scientific Reports 7: 4882 (2017)
DOI:10.1038/s41598-017-05120-7

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Nuclear Data Sheets 131 (2016) 377–399

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Identifying Understudied Nuclear Reactions by Text-mining the EXFOR Experimental Nuclear Reaction Library

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The EXFOR library contains the largest collection of experimental nuclear reaction data available as well as the data's bibliographic information and experimental details. We text-mined the REACTION and MONITOR fields of the ENTRYs in the EXFOR library in order to identify understudied reactions and quantities. Using the results of the text-mining, we created an undirected graph from the EXFOR datasets with each graph node representing a single reaction and quantity and graph links representing the various types of connections between these reactions and quantities. This graph is an abstract representation of the connections in EXFOR, similar to graphs of social networks, authorship networks, etc. We use various graph theoretical tools to identify important yet understudied reactions and quantities in EXFOR. Although we identified a few cross sections relevant for shielding applications and isotope production, mostly we identified charged particle fluence monitor cross sections. As a side effect of this work, we learn that our abstract graph is typical of other real-world graphs.

CONTENTS

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OPEN

Nuclear Physics Meets the Sources of the Ultra-High Energy Cosmic Rays

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Denise Boncioli, Anatoli Fedynitch & Walter Winter

The determination of the injection composition of cosmic ray nuclei within astrophysical sources requires sufficiently accurate descriptions of the source physics and the propagation – apart from controlling astrophysical uncertainties. We therefore study the implications of nuclear data and models for cosmic ray astrophysics, which involves the photo-disintegration of nuclei up to iron in astrophysical environments. We demonstrate that the impact of nuclear model uncertainties is potentially larger in environments with non-thermal radiation fields than in the cosmic microwave background. We also study the impact of nuclear models on the nuclear cascade in a gamma-ray burst radiation field, simulated at a level of complexity comparable to the most precise cosmic ray propagation code. We conclude with an isotope chart describing which information is in principle necessary to describe nuclear interactions in cosmic ray sources and propagation.

Particles from space reaching the Earth with energies higher than 10^9 GeV are detected by ultra-high energy cosmic ray (UHECR) observatories such as the Pierre Auger Observatory[1] and the Telescope Array (TA) experiment[2]. UHECRs are expected to be accelerated in astrophysical sources and to travel through extragalactic space before they hit the Earth's atmosphere; they can interact with photons in both environments. The primary composition of UHECRs is still unknown; however, the mass composition measured by the Auger Observatory indicates heavier elements at the highest energies beyond $10^{9.3}$ GeV[3–6], *i.e.*, significantly heavier than helium and at most as heavy as iron. The study of interactions of nuclei is therefore critical for our understanding of cosmic ray astrophysics both within sources and during propagation.

Most of the literature, as for example[7–15], focuses on finding the right cosmic ray composition injected from the sources into the intergalactic medium, propagating it through the cosmic microwave background (CMB) and the extragalactic background light (EBL), which are thermal target photon fields, *i.e.*, relatively strongly peaked. The

Main features

- *Pure Python*
- Can read/write of EXFOR w/o information loss
- Comprehensive suite of unit tests
- *EXFOR reaction strings treated as a grammar*

Sample session

```
host$ python
Python 2.6.4 (r264:75706, Dec 22 2009, 09:45:51)
[GCC 4.0.1 (Apple Inc. build 5493)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> from x4i import exfor_manager, exfor_entry
>>> db = exfor_manager.X4DBManagerDefault()
```

- Indexes EXFOR library in a sqlitedb database but files stored in clear text on disk as raw EXFOR data

```
>>> x = db.retrieve(target='PU-
239',reaction='N,2N',quantity='SIG',author='Lougheed' )
>>> x.keys()
[u'13883']
>>> y = exfor_entry.X4Entry( x['13883'] )
```

Sample session

```
>>> y = exfor_entry.X4Entry( x['13883'] )
>>> y.keys()
['13883001', '13883002']
>>> type( y[1] )
<class 'x4i.exfor_subentry.X4SubEntry'>
```

- All classes inherit from dict, so is dict of dicts, therefore serialization to JSON should be “easy”

```
>>> y['1'].keys()
['BIB']
>>> y['1']['BIB'].keys()
['STATUS', 'REFERENCE', 'FACILITY', 'INSTITUTE', 'TITLE', 'INC-SOURCE',
'AUTHOR', 'HISTORY']
>>> y['1']['BIB']['REFERENCE']
REFERENCE  (J,RCA,90,833,2002)
>>> str(y['1']['BIB']['REFERENCE'])
'Radiochimica Acta 90, 833 (2002)'
```

- Class hierarchy follows EXFOR hierarchy

Sample session

```
>>> dss = y.getSimplifiedDataSets()
>>> dss.keys()
[('13883', '13883002', ' ')]
>>> print dss[('13883', '13883002', ' ')]
#  Authors:   R.W.Lougheed, W.Webster, M.N.Namboodiri, D.R.Nethaway,
K.J.Moody, J.H.Landrum, R.W.Hoff, R.J.Dupzyk, J.H.Mcquaid, R.Gunnink,
E.D.Watkins
#  Title:     239Pu And 241Am(N,2N) Cross-Section Measurements Near E(N)
= 14 Mev
#  Year:      2002
#  Institute: Lawrence Livermore National Laboratory, Livermore, CA
#  Reference: Radiochimica Acta 90, 833 (2002)
#  Reaction:  Cross section for 239Pu(n,2n)238Pu
#        Energy        Data          d(Data)
```

- Generate simplified versions of entries, in common units; no covariances (useful for plotting)
- Proper treatment of EXFOR pointers

EXFOR REACTION strings follow a grammar

- x4i contains grammar parser that understands EXFOR REACTION string
- Enables discovering covarying data sets and therefore identifying important datasets
    - J.A. Hirdt, D.A. Brown, Nuclear Data Sheets 131 (2016) 377–399
- Enables symbolic math
    - Piloted project with S. Hoblit (deceased) to automatically generate covariances

x4i Status

- Fedynitch fork available at
  https://github.com/afedynitch/x4i3.git
- Main repository at BNL at
  https://git.nndc.bnl.gov/dbrown/x4i.git
- GPL re-release planned with Python3.7 support
  - Updated EXFOR Dicts
  - Many many bug fixes
  - Refactored EXFOR db install
  - Collect tools developed at BNL & LLNL that use **x4i**