Simulating Coherent Elastic Neutrino-Nucleus Scattering in SNOwGLoBES v. 1.3

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SNEWS2.0 Collaboration Meeting

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Overview of presentation

1. Goals of SNOwGLoBES development project
2. What has been accomplished
   a. Additional channel and cross-section files for Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) interactions
   b. Generation of CEvNS smearing matrices
   c. Implementation of liquid xenon detector type
3. Liquid argon and liquid xenon detector responses to Livermore flux
4. Remaining action items

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Purpose of update to SNOwGLoBES v. 1.3

SNOwGLoBES: Supernova Neutrino Observatories with General Long Baseline Experiment Simulator

Benefits of SNOwGLoBES:

- Fast
- Requires limited processing power (runs locally)
- Standard in supernova neutrino detection field
- Free of sensitive information

We now have detectors sensitive enough to exploit CEvNS as a SN neutrino detection mechanism, many of which are SNEWS2.0 collaboration member experiments.

Problem: CEvNS support was not built into SNOwGLoBES v. 1.2.

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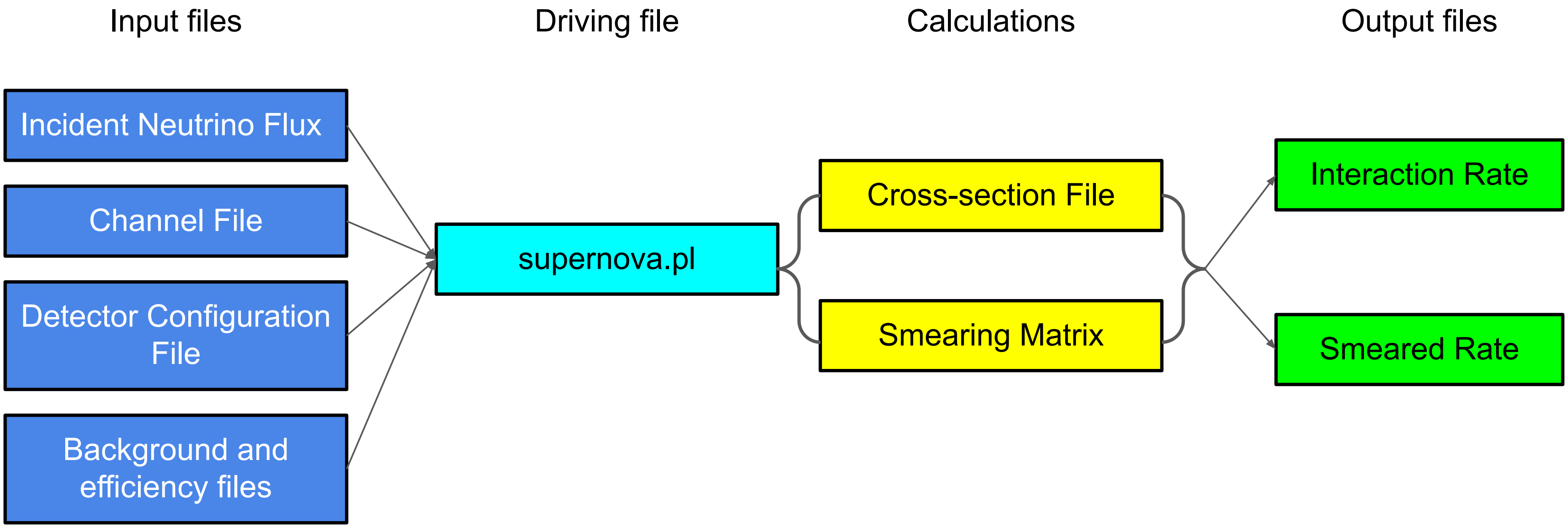
SNOwGLoBES Data Flow



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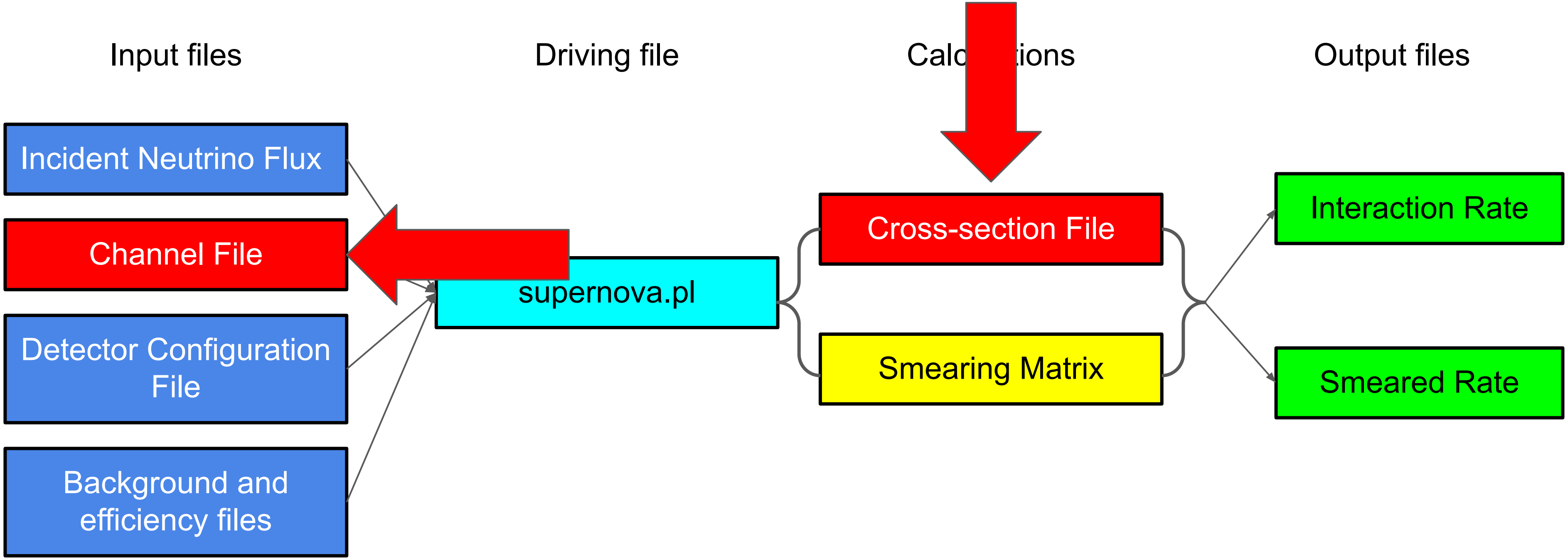
Channel and Cross-sections files added for CEvNS



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Files added to support CEvNS - continued

Channel files

- Listing of interaction types for a given detector - instructs SNOwGLoBES which interactions to simulate
- All channel files written and finalized for CEvNS interactions in Ar, Xe, and Ge

Cross-sections files

- Required to calculate interaction rates
- Written for CEvNS interactions in natural-abundance Ar, Xe, and Ge
- If the user wishes to alter the abundance fraction, a script to generate CEvNS cross-sections files with specified abundance is available in v. 1.3

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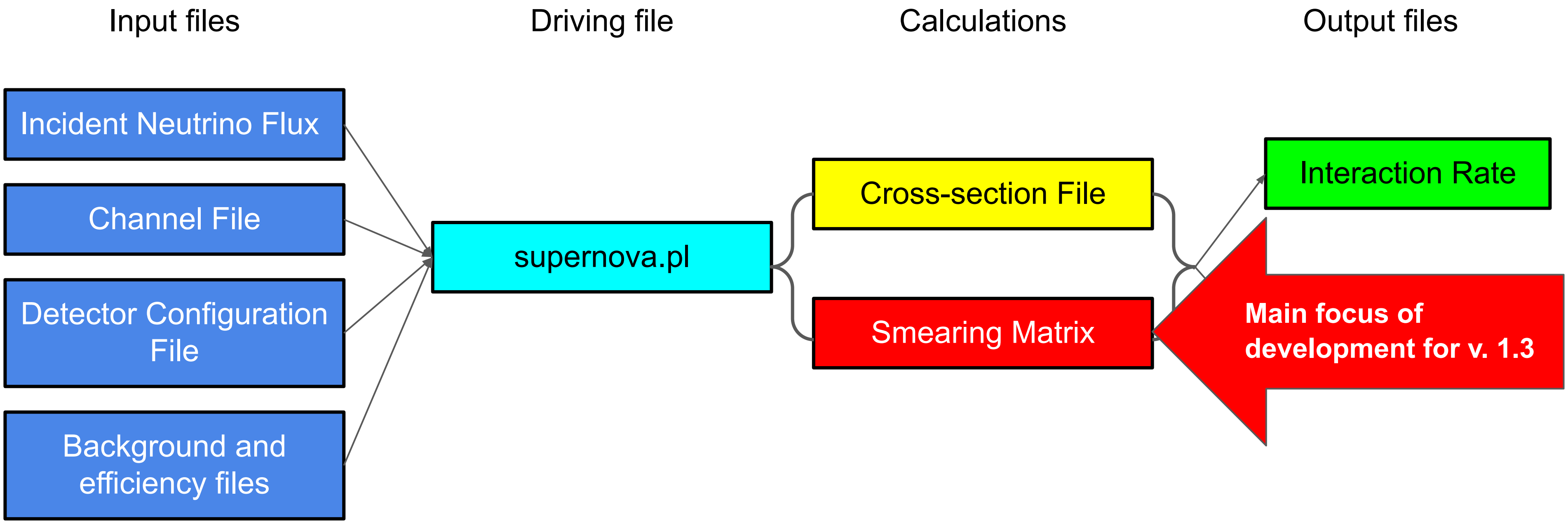
Changes to support CEvNS in v. 1.3 - continued



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Missing from SNOwGLoBES v. 1.2 - CEvNS smearing matrices

- Smearing matrix: Used by SNOwGLoBES to convert incident neutrino energy to energy deposited in the detector, subject to a user-selected detector resolution function
- Smearing matrices are generated via the script create_smearing_matrix.py, which allows the user to select:
  - Incident neutrino and detected energy ranges, number of bins
  - Interaction type
  - Detector material
  - Detector resolution function
- Generating CEvNS smearing matrices with create_smearing_matrix.py required a different method, and new supporting code on the back end
  - 8 months of development time

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New to v. 1.3 - Smearing matrix calculations handled by DukeCEvNS

DukeCEvNS is a program also written by Kate Scholberg (to whom we owe many thanks). We integrated DukeCEvNS with SNOwGLoBES to handle the smearing matrix calculations.

Benefits:

- CEvNS form factors are built into DukeCEvNS
  - Helm, Klein-Nystrand, and Horowitz (numerical) form factors available
- Handles isotope mixtures/relative abundances

New module written for DukeCEvNS - cevns_recoil_response.cc

- Based on user inputs, constructs an unsmeared "response file"
- create_smearing_matrix.py can access and apply the required detector resolution function to this file, then format it for use in simulations

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cevns_recoil_response.cc - why store response matrices?

```
energy(#coh_helm_Xe_nue_smear)<
@energy =
{0,199,1.0,1.0,1.0,0.9272441929174187,0.7249137738442225,0.5557182956719804,0.4324362
{0,199,0.0,0.0,0.0,0.07275580708258128,0.2726818233019602,0.33294919799002115,0.31038
{0,199,0.0,0.0,0.0,0.0,0.002404402853817414,0.11133250633799846,0.18895923491153432,0
{0,199,0.0,0.0,0.0,0.0,0.0,0.0,0.06816363609506534,0.12742373961773287,0.142079548115
{0,199,0.0,0.0,0.0,0.0,0.0,0.0,5.8211112828807667e-05,0.05618090149250651,0.097166328
{0,199,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0029568012150806024,0.05248547332853606,0.080076
{0,199,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.010216725761697321,0.05065383585761449,0.069
{0,199,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.021383187659118345,0.048957947375003565,
{0,199,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0007900587745785511,0.028897577732571827
{0,199,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.00894117573530761,0.0328124843446248
{0,199,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.018675322260354354,0.03451279853
{0,199,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.004801606831244213,0.02421365944
{0,199,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.013967932077522439,0.0271717
{0,199,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0038590156395811033,0.019526
{0,199,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.011920445569239213,0.022
{0,199,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.004354099311153949,0.016
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{0,199,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.005405125419991387,0
{0,199,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0005613679477638834,
```

Example smearing matrix for electron neutrinos interacting with a natural-abundance xenon detector. First few rows and columns shown - full matrix is 200 x 1600 elements.

- CEvNS smearing matrices are large - generating a new matrix from scratch is computationally expensive
- Building a brand new matrix just to change the detector resolution function is undesirable

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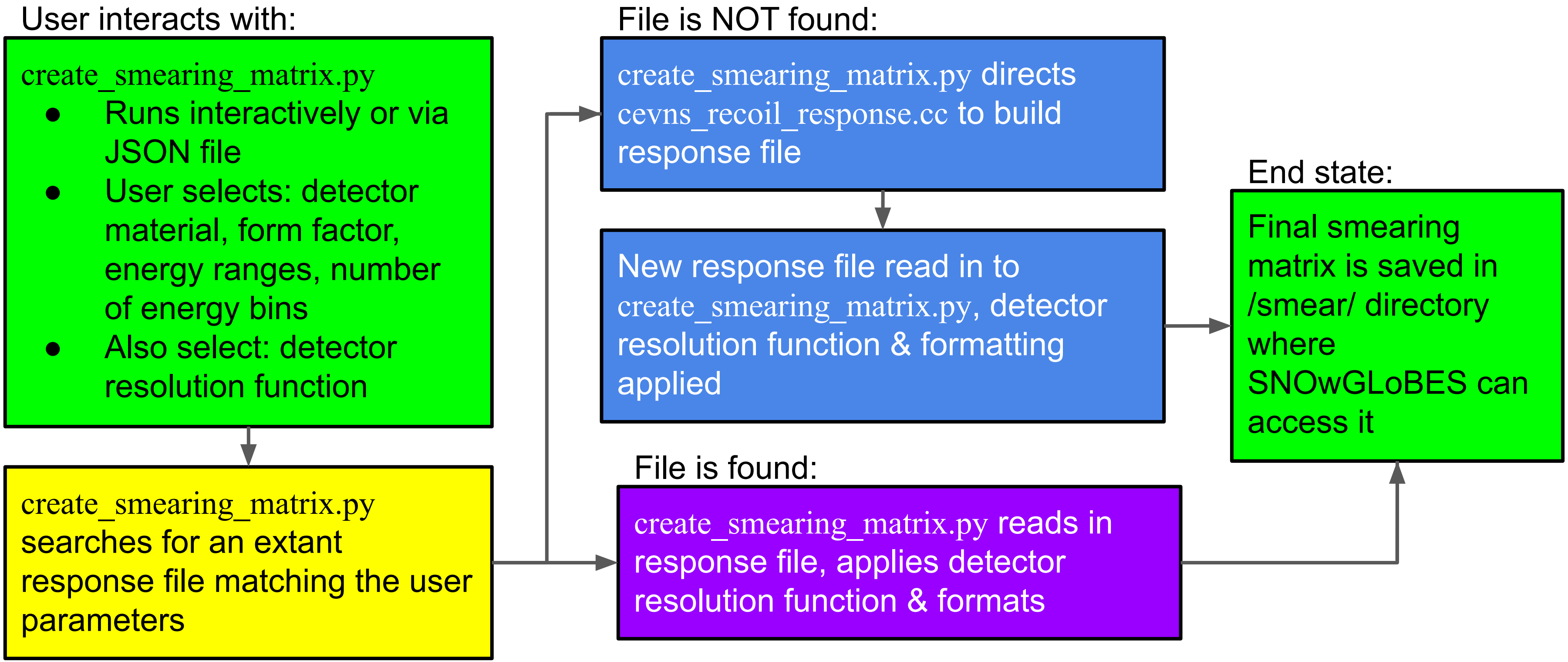
How CEvNS smearing matrices are built:



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Changes to driving file - supernova.pl

- Supernova.pl can now run two versions of SNOwGLoBES.
  - Custom energy range and bin numbers
  - Default binning (v. 1.2)
- The custom binning version was needed to set finer binning parameters for the CEvNS interactions.
- The run version can be set by the user through a terminal input.
  - This can be changed to better accommodate for SNEWPY's needs.

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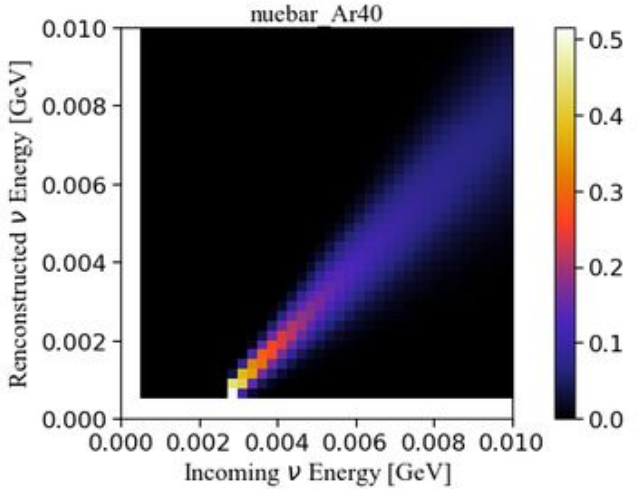

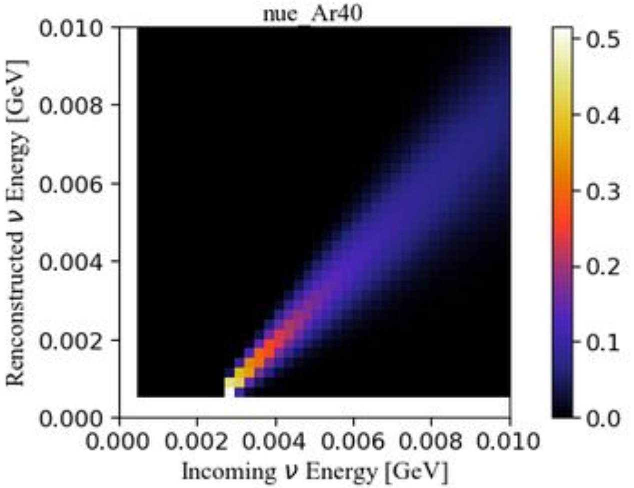

New to v. 1.3 - visualization tools

- Plotter.ipynb is a Jupyter notebook that contains plotting methods for the following:
  - Smearing matrix heat map - examples for charged-current interactions in Ar40 at left
  - Fluxes
  - Outfiles
  - Cross sections
- This notebook uses Matplotlib and Seaborn libraries for plotting, and the Pandas library for organizing the data.

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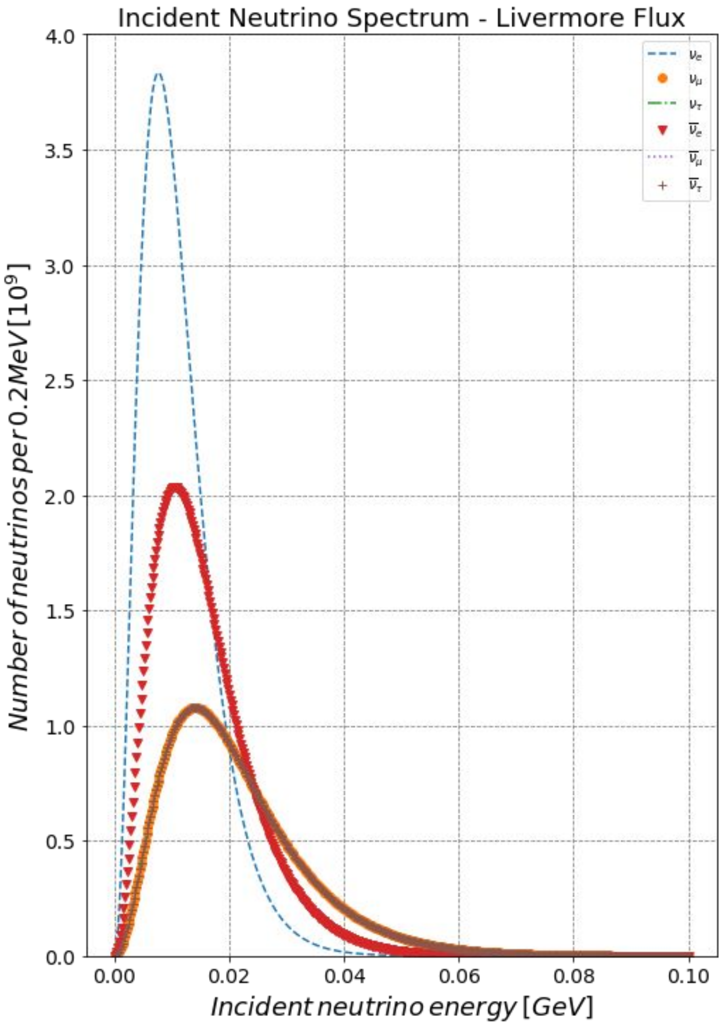

Example flux available in SNOwGLoBES - Livermore flux

Livermore “flux” is a simulated CCSN neutrino spectrum

- Actually a fluence - flux integrated over time of neutrino burst
- Neutrinos per cm^2 per energy bin arriving at Earth from a CCSN 10 kpc away

1e12 neutrinos in all six flavors

Incident neutrino energies from 0 to 100 MeV

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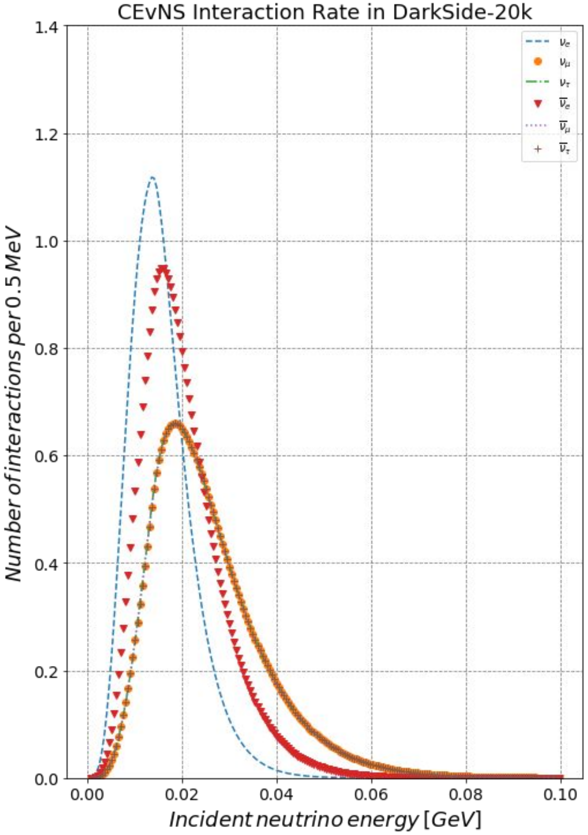
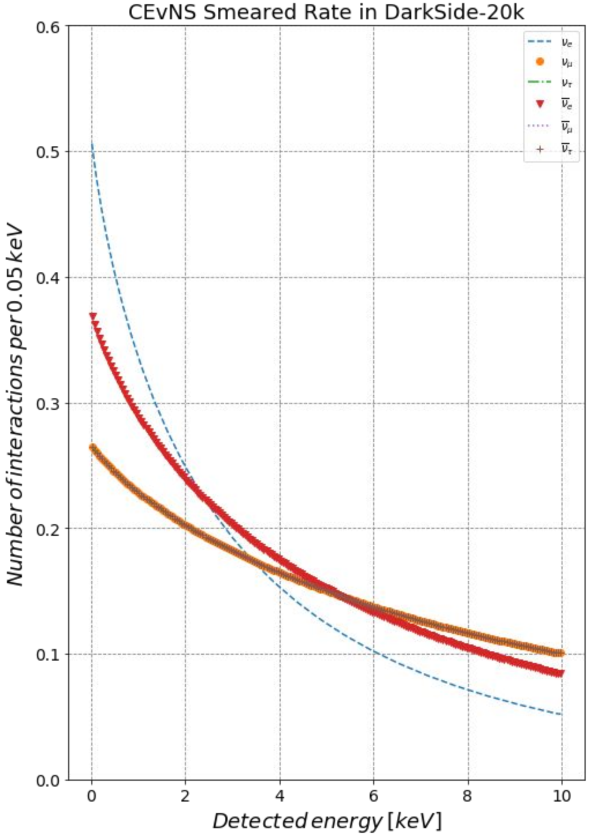
Liquid Argon Detector response to Livermore flux - DarkSide-20k





Interaction rate - events as a function of incident neutrino energy

Smeared rate - events as a function of energy deposited in detector

CEvNS interaction channels only. No smearing is applied to this simulation, and we have assumed 100% detection efficiency.

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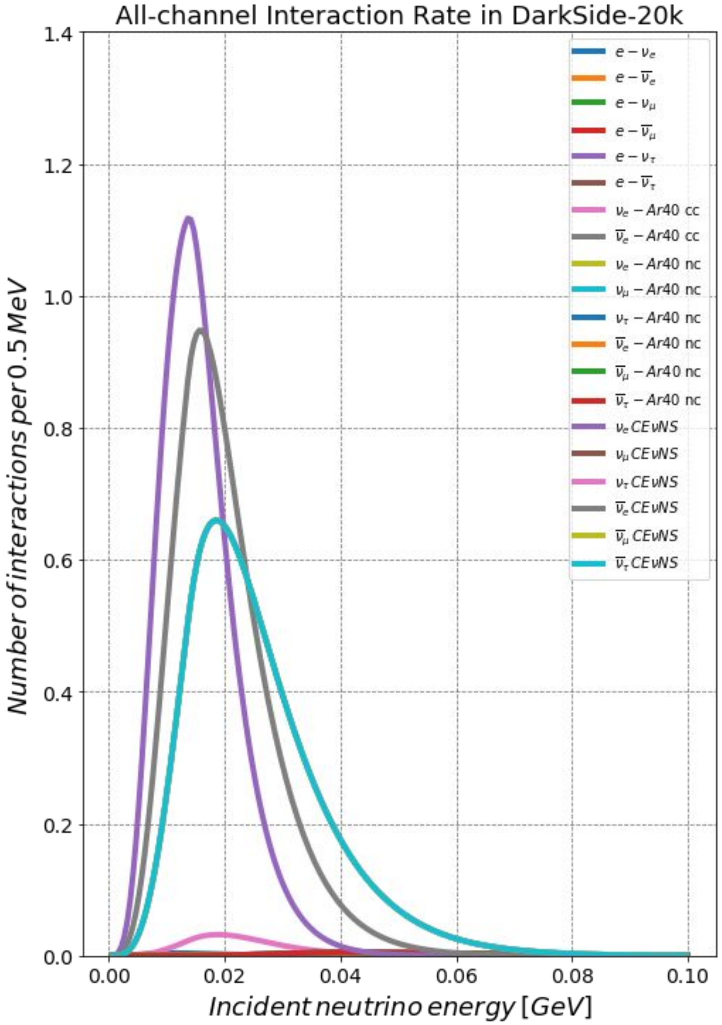

Liquid Argon Detector response to Livermore flux - DarkSide-20k

SNOwGLoBES v. 1.3 maintains functionality of all channels in v. 1.2

In simulation at left:

- No smearing applied
- Assumed 100% detection efficiency
- Q = 10 MeV for CC interactions (arbitrarily chosen)
- Total gamma-ray energy = 15 MeV for NC interactions (arbitrarily chosen)

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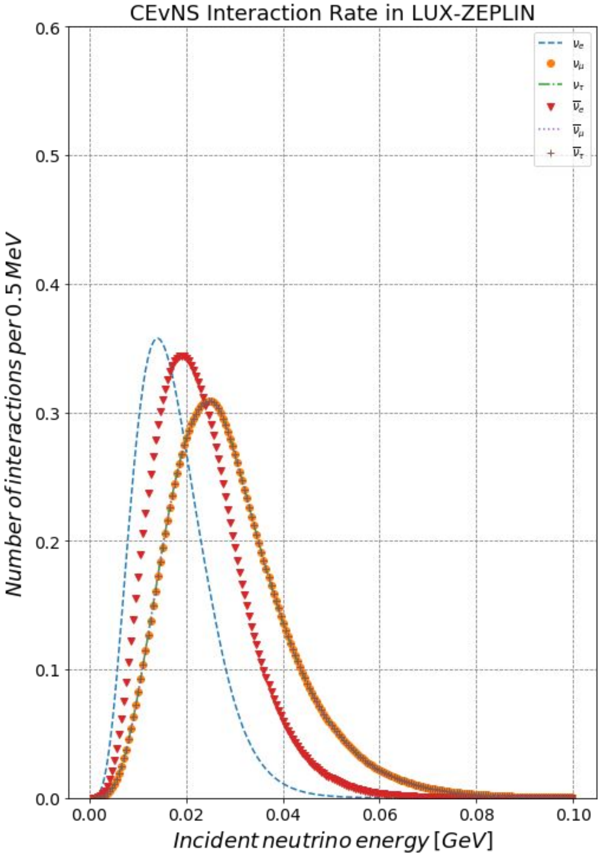
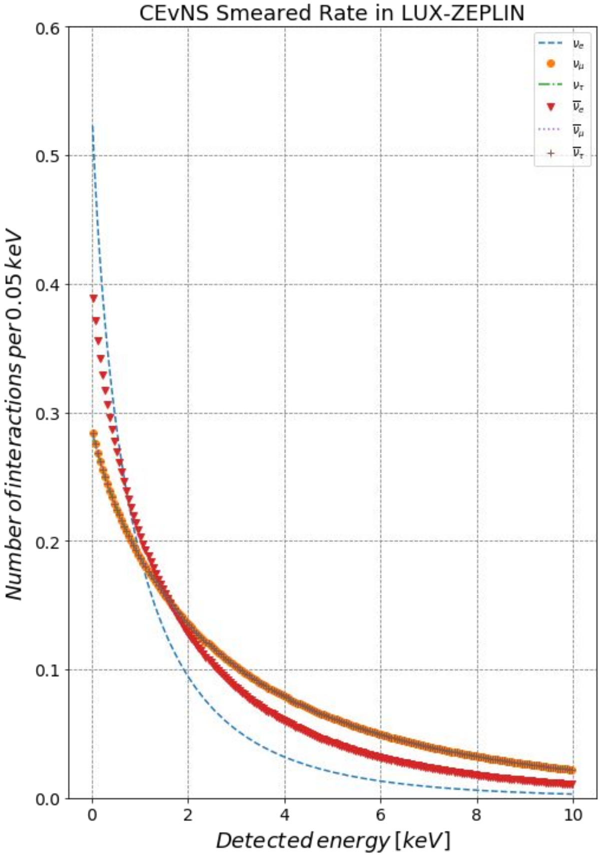
Liquid Xenon Detector response to Livermore flux - LUX-ZEPLIN





Same simulations are available for LXe detectors

- Interaction rate - events as a function of incident neutrino energy
- Smeared rate - events as a function of energy deposited in detector
- CEvNS interaction channels only. No smearing is applied to this simulation, and we have assumed 100% detection efficiency.

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Completed:

1. SNOwGLoBES v. 1.3 is capable of simulating CEvNS interactions in liquid noble element detectors.
2. A new script is available for CEvNS cross-section file generation allowing the user to alter their detector abundance.
3. The user can now choose energy ranges and binning for all detector types.
4. Significant quality of life improvements have been made - more visualization tools available, commenting of code more extensive

Remaining pre-release tasks:

1. Prepare a v. 1.3 user manual
2. Verify v. 1.3 changes are compatible with other SNEWS2.0 tools (SNEWPY)

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Any Questions?

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Supplemental slides - more about SNOwGLoBES code structure

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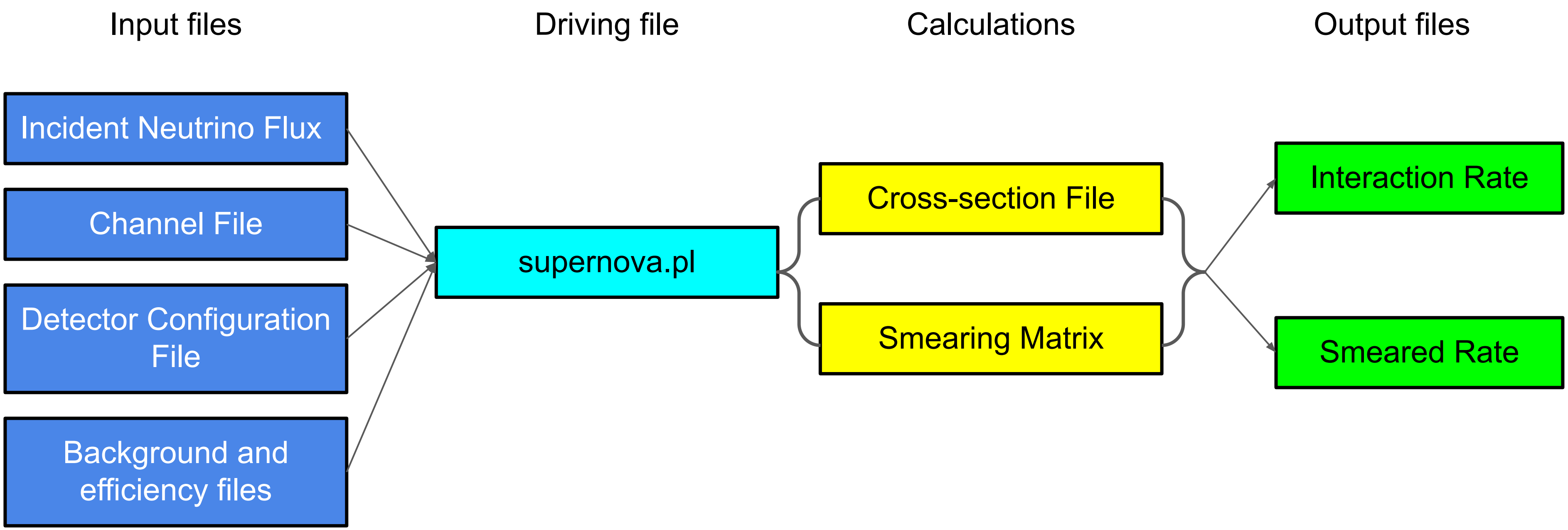
SNOwGLoBES Data Flow



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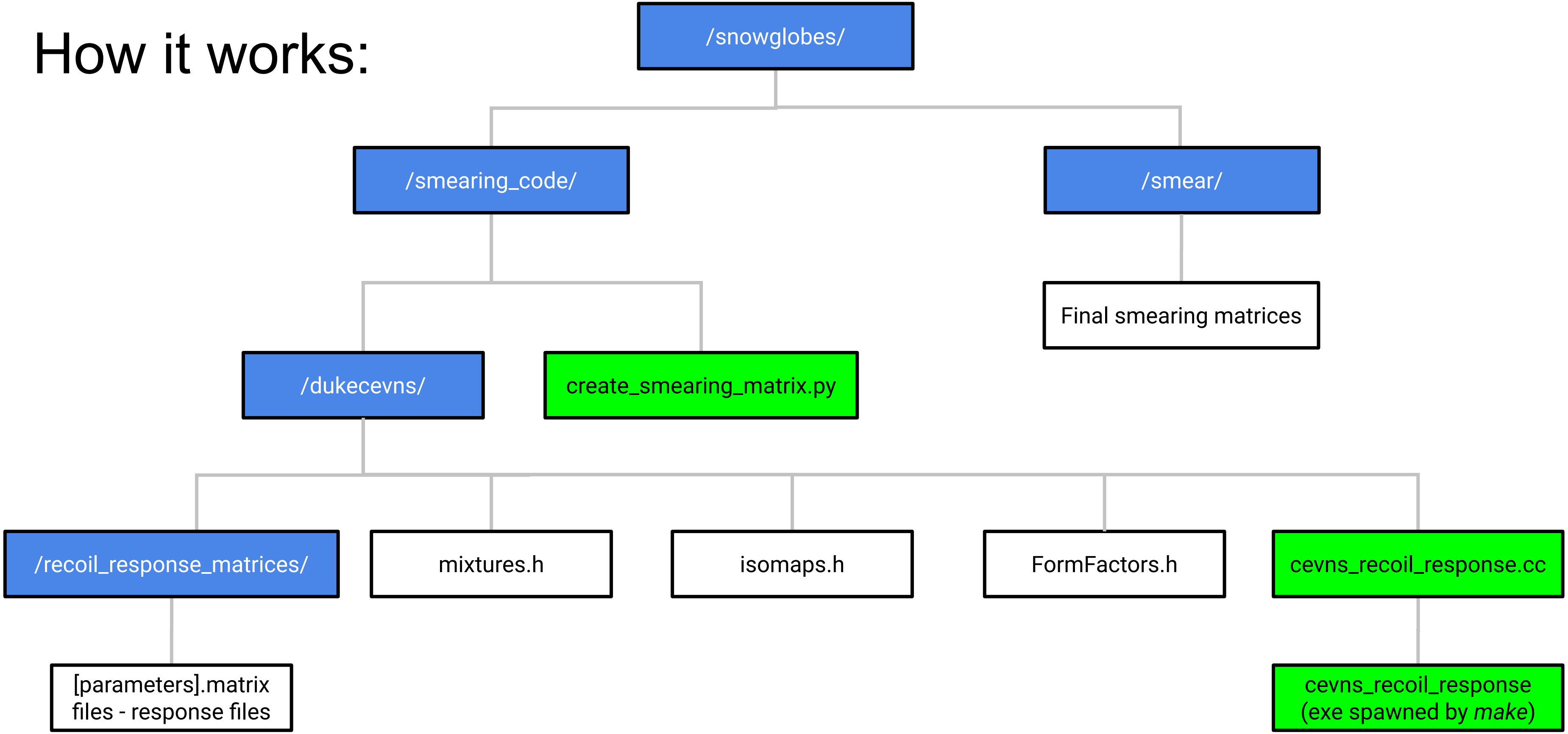
How it works:



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