GENIE STATUS AND ROADMAP

Prof. Costas Andreopoulos

University of Liverpool, Department of Physics &
U.K. Research and Innovation, Science and Technology Facilities Council, Rutherford Appleton Lab

Outline

- GENIE3: A successful culmination of a 5-yr development effort
- GENIE3 legacy: Substantial new infrastructure, well-established/proven development paradigm, expanded core team
    - New goal: Accelerated product releases
- Scope for GENIE4 and GENIE5
- Developing GENIE4 roadmap / Current projects
- Opportunities for community contributions:
    - Help define and lunch new incubator projects
    - Contribute to incubator projects for open-source products

GENIE3 (Bear series)

- **First major release in 10-yrs**:
- **Culmination of a 5-yr development cycle** by tens of authors **- Far surpassed original scope of GENIE3**
- **Change in philosophy**
    - No longer a single "Default" comprehensive model, and unsupported / optional modelling elements enabled at user's risk (and almost always breaking consistency and global tune)
    - **Running <u>out of the box</u>: Several comprehensive models, characterised against data + tuned!**
- Important changes in the Generator framework and code structure.
- **Improved support for non-neutrino event simulation** (boosted dark matter, nucleon decay, n-nbar etc)
- **New GENIE products** (Comparisons, Tuning, Continuous Integration, Unit testing, +)
- **Expansion into new and distinct areas of work**: GENIE not just a "Generator group"
    - Development of the **GENIE global analysis of scattering data,** in collaboration with LHC physicists.
        - Enables emphasis on construction and characterisation of comprehensive models, physics tuning, uncertainties.
    - **Balancing of service** (Generator support) and **proprietary research** (global analysis / Generator tuning) tasks
    - Proprietary global analysis, but **benefits echoed widely to the whole community**
        - **Open-source Generator a vehicle for deploying GENIE global analysis results / tunes.**

GENIE3 (Bear series)

Available model configurations and tunes in GENIE 3.0.0

Limited scope in 3.0.0 - Only a first iteration: **New configurations and tunes in progress**

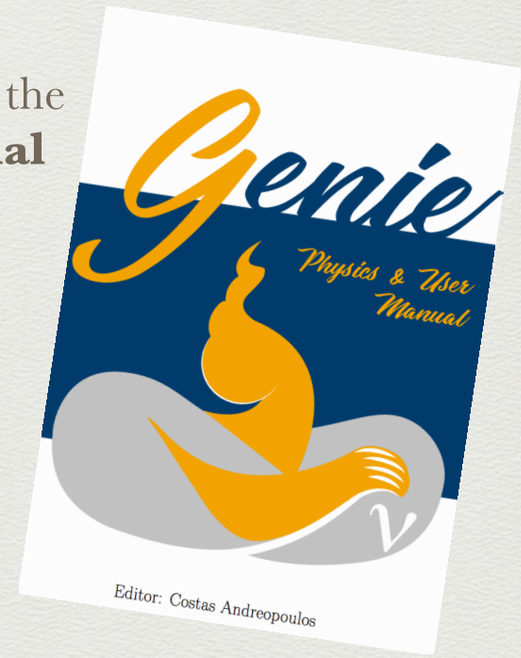
Release	Configuration	Brief description
v3.0.0	G00_00a	Historical GENIE default model configuration.
Tunes:	G00_00a_00_000	Historical tune for the old GENIE default model (not supported)
v3.0.0	G00_00b	Historical GENIE default configuration, including empirical 2p/2h.
Tunes:	G00_00b_00_000	Historical tune for the old GENIE default model (not supported)
v3.0.0	G18_01a	Update of the historical default, including diffractive and lambda production interactions and updated hA FSI.
Tunes:	G18_01a_00_000	Baseline tune
	G18_01a_02_11a	Implements the GENIE 2018a free-nucleon cross-section model re-tune using mainly bubble chamber CC1π, CC2π, and CC inclusive cross-section data
v3.0.0	G18_01b	As G18_01a, but hN for FSI.
Tunes:	G18_01b_00_000	Baseline tune
	G18_01b_02_11a	Implements the GENIE 2018a free nucleon cross-section model re-tune using mainly bubble chamber CC1π, CC2π, and CC inclusive cross-section data
v3.0.0	G18_02a	As G18_01a, with updated Berger-Sehgal model for RES and COH
Tunes:	G18_02a_00_000	Baseline tune. See [GENIE-DocDB-17] for corresponding plots and data-files.
	G18_02a_02_11a	Implements the GENIE 2018a free nucleon cross-section model re-tune using mainly bubble chamber CCQE, CC1π, CC2π, and CC inclusive cross-section data. See [GENIE-DocDB-18] for corresponding plots and data-files.
v3.0.0	G18_02b	As G18_01b, with updated Berger-Sehgal model for RES and COH
Tunes:	G18_02b_00_000	Baseline tune
	G18_02b_02_11a	Implements the GENIE 2018a free nucleon cross-section model re-tune using mainly bubble chamber CCQE, CC1π, CC2π, and CC inclusive cross-section data
v3.0.0	G18_10a	A theory-driven configuration. Similar to G18_02a. LFG nuclear model. Nieves models for CCQE and CC 2p/2h interactions
Tunes:	G18_10a_00_000	Baseline tune.
	G18_10a_02_11a	Implements the GENIE 2018a free nucleon cross-section model re-tune using mainly bubble chamber CCQE, CC1π, CC2π, and CC inclusive cross-section data
v3.0.0	G18_10b	A theory-driven configuration. Similar to G18_02b. LFG nuclear model. Nieves models for CCQE and CC 2p/2h interactions
Tunes:	G18_10b_00_000	Baseline tune.
	G18_10b_02_11a	Implements the GENIE 2018a free nucleon cross-section model re-tune using mainly bubble chamber CCQE, CC1π, CC2π, and CC inclusive cross-section data
v3.0.0	G18_10i	A theory-driven configuration. Similar to G18_10a. CCQE axial form factor parametrerised with z-exp.
Tunes:	G18_10i_00_000	Baseline tune.
v3.0.0	G18_10j	A theory-driven configuration. Similar to G18_10b. CCQE axial form factor parametrerised with z-exp.
Tunes:	G18_10j_00_000	Baseline tune.

Fast pace of change puts emphasis on need for **updated GENIE documentation**

3 new papers

- GENIE3 overview / project updates
- Free-nucleon retune in GENIE 3.0.0
- GENIE 3.0.0 comprehensive model characterization

Substantial effort to **upgrade** the GENIE Physics & User **manual**



Aim to make available in the next few weeks

New infrastructure and proven development paradigm: Accelerated product release cycles

- **Substantial new infrastructure** (Comparisons, Tuning, Continuous Integration): **Accelerated major release cycles.**
- **Capacity for producing new comprehensive models and tunes surpasses the capacity of experiments to consume / evaluate our tunes.**
  - Closer direct communication between experiments and the core GENIE team (this Forum)
  - Talk directly to us to make sure we prioritise your need for a model development, a systematic study, a tune or a new tool.

- **Enhancing a development paradigm that proved very successful:**
  - **Community contributions** in the implementation of new theoretical models
    - Under core GENIE team supervision (GENIE Working Groups and Executive Board):
      - Ensure GENIE standard of design, efficiency, consistency, integration, validation, documentation
  - **Continued core GENIE team effort in development of crucial empirical models (hadronization, FSI)**
  - **Integration by core GENIE team**
      - Development of comprehensive models, resolving model stitch up / extrapolation and double-counting issues.
      - Comprehensive model characterization and production of tunes

Scope of future major GENIE Generator releases

GENIE4 (Cheetah series) - Planned for ~Q1-Q2/2020

- Release of an **expanded set of GENIE Comprehensive Model Configurations**, including several new microscopic / theoretical calculations and improved empirical hadronic models.

- **Full deployment of new physics tuning results from the GENIE Global Analysis**, including hadronization tunes and nuclear cross-section data tunes.

- **Revamp the GENIE Reweight product, aiming to provide full support for all GENIE tunes**

  - including support for intrinsically non-reweightable systematic parameters (hadronic and nuclear simulations) considered in new GENIE global fits / tunes

GENIE5 (Dugong series) - Planned for ~end of 2022

- **First release of explicit Argon tunes** produced from a combined analysis of folded data distributions from the SBND experiment —> **Modelling work to underpin the early physics exploitation effort in DUNE**

GENIE4 roadmap

Launching new incubator projects by:

Reviewing needs for the GENIE4 tunes

- Reassessment of the uncertainties included in some of our data archives (Hadronization)
- Upgrades of existing data/MC comparisons to interface with our Professor tuning infrastructure (Hadronization)
- Implementation of missing data/MC comparisons (MINERvA, Hadronization)
- Misc technical upgrades in Tuning and Comparison products

Planning Reweight upgrades to support new tunes

Planning upgrades and new standardized interfaces to underpin new model implementation

Reviewing community physics modelling needs / identifying low-hanging fruits

In addition, we **review the status of several existing projects** that missed GENIE3 and stalled in recent months

Short-term goal (by ~end of March):
- Fully defined and understood projects / work plan (scope, deliverables, milestones, tasks, available manpower).
- Project prioritization + published GENIE4 roadmap

The community can influence GENIE4!

Send us your ideas/views and help us launch and define new projects.
Contribute to incubator projects included in the GENIE roadmap

The GENIE development model

GENIE provides **ample opportunity for collaboration and contribution**.
Evidenced from the large number of community contributions in GENIE3!

We are looking forward to include your contributions in GENIE4 too

Ultimately, all GENIE software products, documentation, tunes, model characterisations etc, are the sole **responsibility of the core GENIE team**.

The core GENIE team strives to provide validated and well-motivated simulations that **serve the needs of the entire community.**
GENIE is also required to **support and evolve models over a period of decades**.
This places stringent constrains on the development procedure.

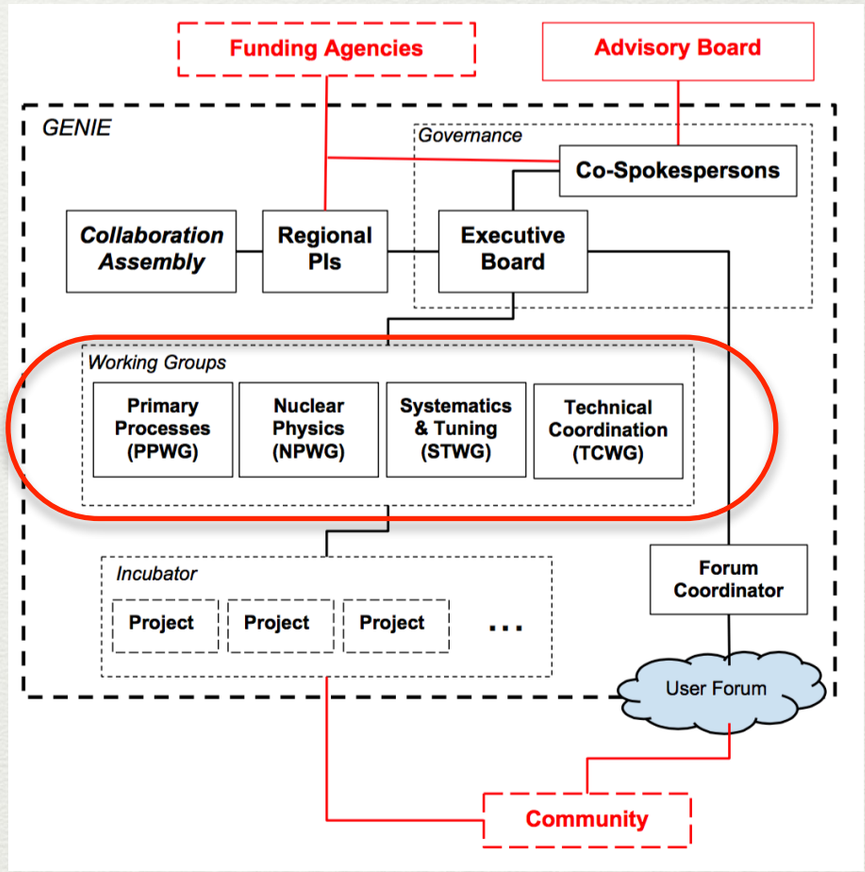
Only projects following the GENIE development model can be considered for inclusion in public releases of the GENIE products.
If you wish to contribute, please engage with the core GENIE team from the start!

The GENIE development model

GENIE development projects are under the **technical and scientific supervision of the GENIE WGs**, and under the **oversight of the GENIE Executive Board**.

GENIE Working Groups (WG):

- **Technical Coordination** WG (TCWG)
  Convenor: Robert Hatcher
- **Primary Processes** WG (PPWG)
  Convenor: Hugh Gallagher
- **Nuclear Physics WG** (NPWG)
  Convenor: Steve Dytman
- **Systematics and Tuning** WG (STWG)
  Convenor: Costas Andreopoulos



If your development project is not supervised by the above team,
there is **no route towards inclusion to a public release of a GENIE product**.
Again, potential contributors are asked to engage with the core GENIE team as early as possible!

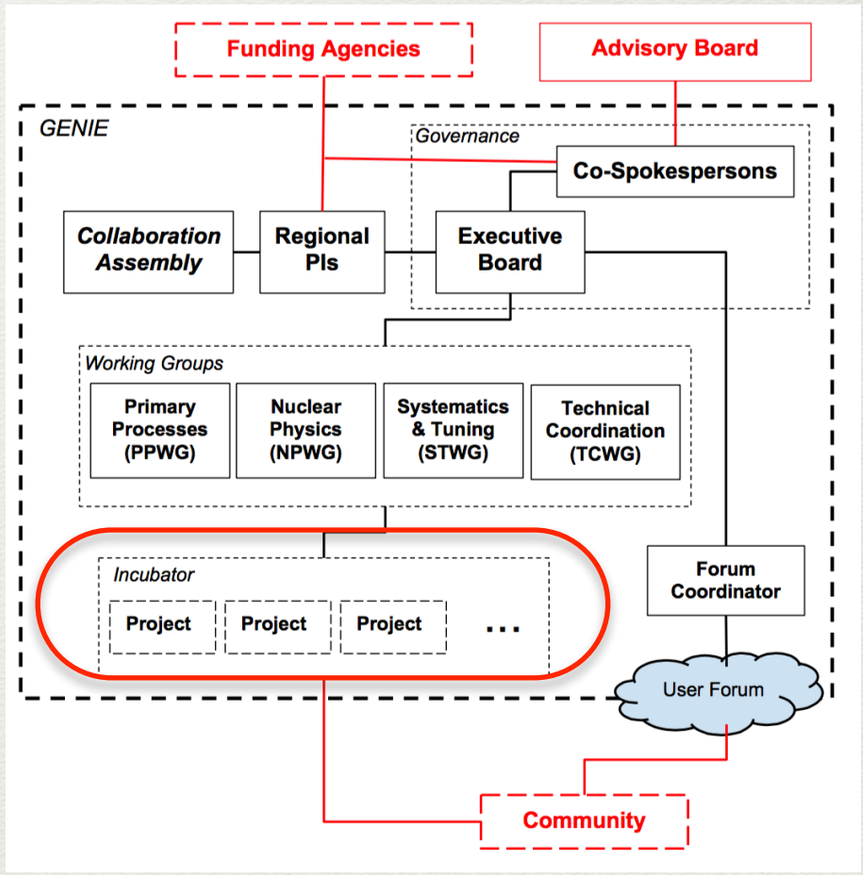
The GENIE development model

All GENIE projects take place within the **GENIE incubator** and follow a uniform procedure for the analysis of requirements, design, validation, review and deployment.

An incubator project has **4 phases**:
1) **Launch**, 2) **R&D** 3) **Graduation** 4) **Deployment**

It is geared towards **fast public deployment**, and clarifies the criteria that must be met.

Promotes a the development of **sustainable software**.
The exact **scope** and **deliverables** are agreed in advance.
A detailed **programme of work**, with specific **milestones**, is thought through in advance and is used to track progress.
Solutions to problems are **designed, not ad hoc**.
Well-specified **review points allow timely expert feedback**.



Not comfortable accepting the risks and loss of efficiency related with mismanagement and development shortcuts.

"*We don't have time to do this properly, but thank God we have the time to do this twice*" [Nick West]

Summary of Current Projects in the GENIE Incubator

Product	Project	Pri.	St.	E.R.	E.A.	Target release
Generator	very_high_energy_extension	H	I	5	10	
Generator	dis_amuval	M	D1	4	9	
Generator	hyperon_amuval	M	D0	4	2	
Generator	nubar_single_kaon_amuval	H	D0	8	2	
Generator	dcc_pions	M	D0	8	2	
Generator	lanl_zero_pion	M	D0	8	6	
Generator	correlated_fermi_gas	M	D0	5	7	
Generator	radiative_effects_for_electron_scat	M	D0	5	6	
Generator	nc_onegamma	M	D1	7	1	
Generator	susav2	H	D1	7	7	
Generator	susaM*	H	D2	7	8	
Generator	martini_mec	H	D0	3	2	
Generator	hadronization_pythia8	M	D1	3	8	
Generator	hadronization_herwig	L	D0	3	2	
Generator	mk1pi	H	D1	8	5	
Generator	coherent_rho	H	I	4	8	
Generator	nlo_extrapolation	L	D0	7	1	
Generator	geant_hadronic_interfaces	H	I	6	5	
Generator	bdm2	H	M	5	10	
Generator	refactorize_hadronization_and_decay	H	V	5	10	
Generator	sf_interface	L	D0	3	2	
Generator	0pi_theory_API	H	D0	5	5	

Product	Project	Pri.	St.	E.R.	E.A.	Target release
Comparisons	comparisons_minerva	H	D1	8	5	
Comparisons	comparisons_hadronization_upgrade	H	I	8	7	
Comparisons	comparisons_eA_upgrade	L	D0	5	1	
Comparisons	comparisons_hA_upgrade	L	D0	8	1	
Comparisons	comparisons_API_refactorization	H	D3	7	10	
Comparisons	comparisons_plotting_upgrade	H	D2	8	10	
Comparisons	professor_sampling	H	M	3	10	
Comparisons	hadronization_data_systematics	H	D0	10	5	
Tuning	hadronization_data_fit	H	D1	9	8	
Tuning	nuclear_tune	H	I	8	8	
Reweight	tune_io_and_configuring	H	D0	4	7	
Reweight	professor_response_func_reweight	H	D0	10	7	

Status: D(efinition) **0-3**, **I**(implementation), **V**(alidation), **R**(eview), **M**(erging)
D0: Expression of interest / Scope defined broadly; D1: Goals/Deliverables agreed; D2: Planning & Analysis - Milestones and tasks agreed; D3: Design agreed
Priority: L(ow), **M**(edium), **H**(igh)
Effort Required: 1 (Low), **2**, …, **10** (High)
Effort Available: 1 (Low), **2**, …, **10** (High)

Some additional project details in the GENIE web page

Extras

The GENIE Collaboration

Substantial expansion in the last few years
especially in terms of postdoc and student effort

Luis Alvarez-Ruso [9], **Costas Andreopoulos** [5,7], **Adi Ashkenazi** [4], **Christopher Barry** [5], **Francis Bench** [5], **Steve Dennis** [5], **Steve Dytman** [6], **Hugh Gallagher** [8], **Steven Gardiner** [3], **Walter Giele** [3], **Robert Hatcher** [3], **Or Hen** [4], **Libo Jiang** [6], **Rhiannon Jones** [5], **Igor Kakorin** [2], **Konstantin Kuzmin** [2], **Anselmo Meregaglia** [1], **Donna Naples** [6], **Vadim Naumov** [2], **Afroditi Papadopoulou** [4], **Gabriel Perdue** [3], **Marco Roda** [5], **Vladyslav Syrotenko** [8], **Jeremy Wolcott** [8], **Julia Tena Vidal** [5], **Julia Yarba** [3]

1. **CENBG, Université de Bordeaux, CNRS/IN2P3**
33175 Gradignan, France
2. **Joint Institute for Nuclear Research (JINR)**
Dubna, Moscow region, 141980, Russia
3. **Fermi National Accelerator Laboratory**
Batavia, Illinois 60510, USA
4. **Massachusetts Institute of Technology (MIT)** Dept. of Physics
Cambridge, MA 02139, USA
5. **University of Liverpool**, Dept. of Physics
Liverpool L69 7ZE, UK
6. **University of Pittsburgh**, Dept. of Physics and Astronomy
Pittsburgh PA 15260, USA
7. **UK Research and Innovation**, **Science and Technology Facilities Council**
Rutherford Appleton Laboratory, Particle Physics Dept.
Harwell Oxford Campus, Oxfordshire OX11 0QX, UK
8. **Tufts University**, Dept. of Physics and Astronomy
Medford MA 02155, USA
9. **University of Valencia**
Valencia, Spain

- 14 Faculty/Staff
- 7 Postdocs
- 5 PhD Students

Discussions with potential new collaborators to broaden capabilities
and coverage of the neutrino physics field