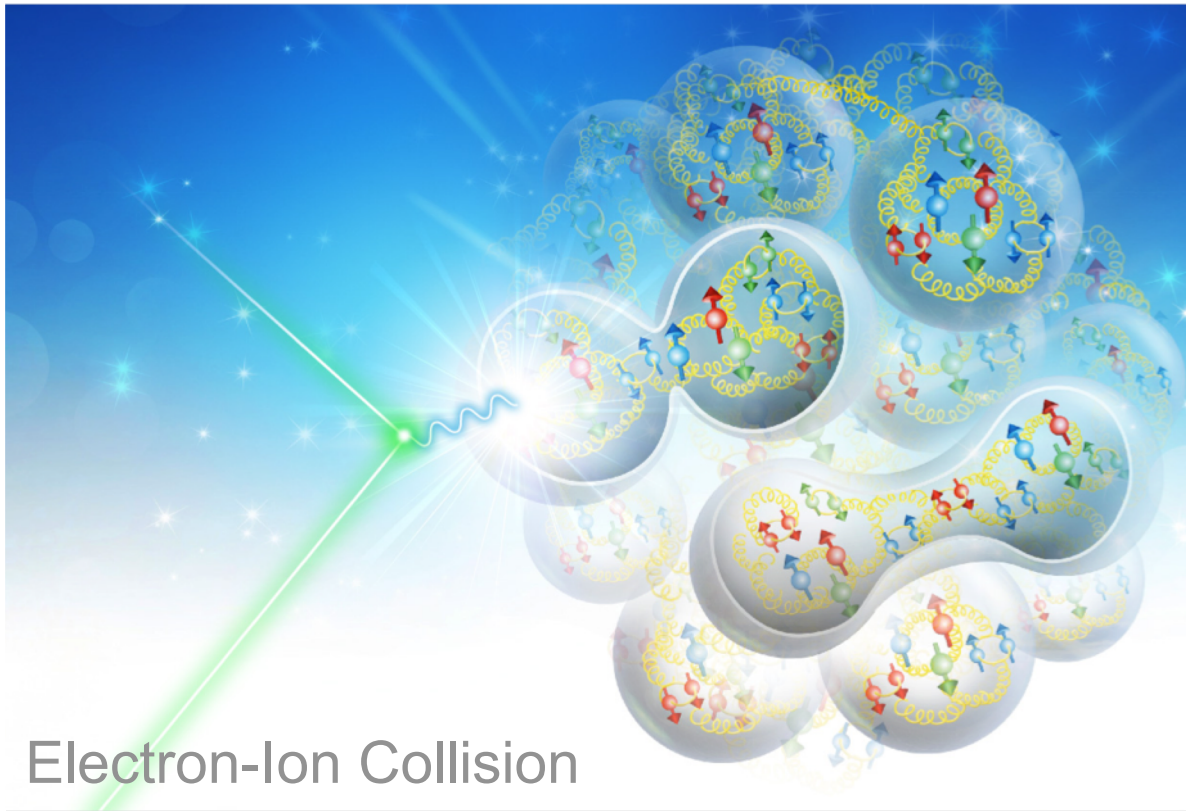
Software & Computing Initiatives for the EIC



Markus Diefenthaler (EIC^2, Jefferson Lab)

Electron-Ion Collision

Jefferson Lab

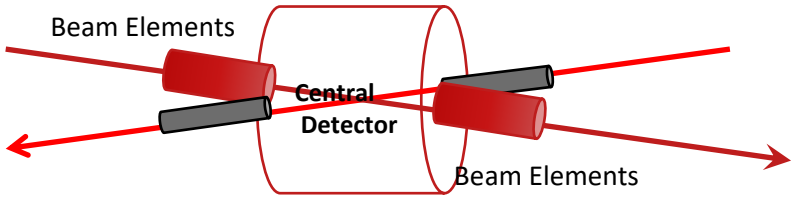
Unique aspects of an EIC

Accelerator, detector, and computing design

Machine-Detector interface (MDI)

Integrated interaction region and detector design to optimize physics reach

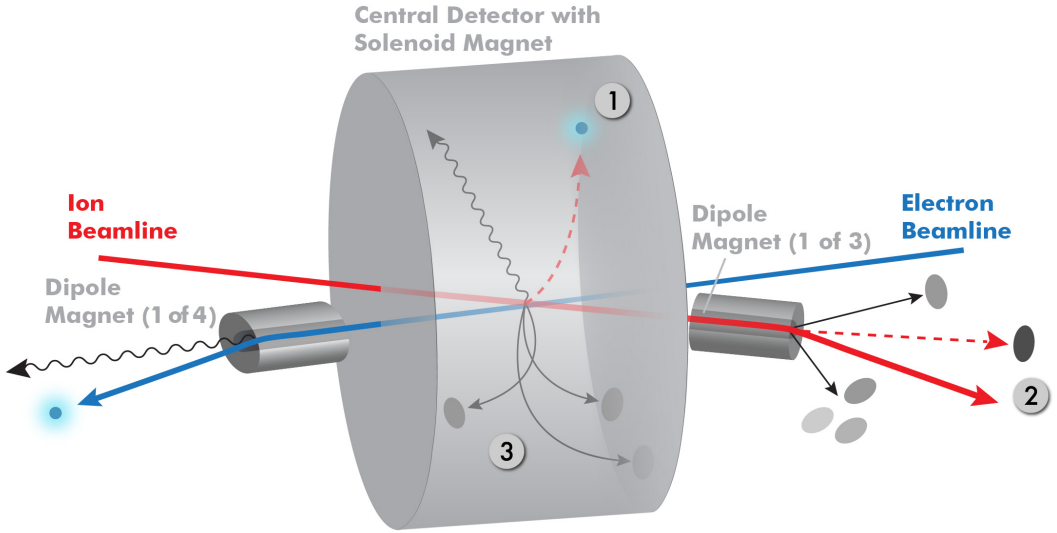
The aim is to get **~100% acceptance** for all final state particles, and measure them with good resolution.



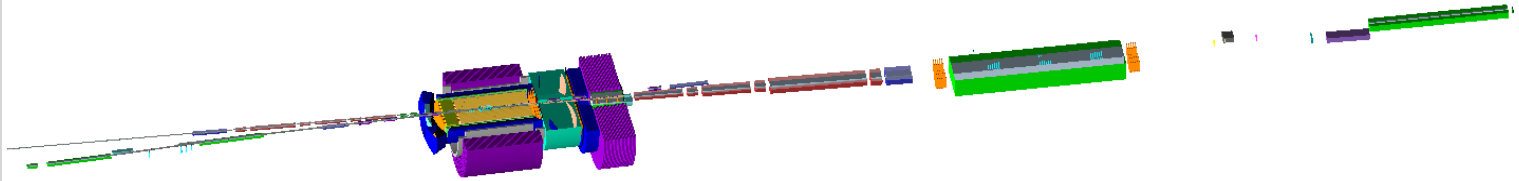
Experimental challenges:

- beam elements limit forward acceptance
- central Solenoid not effective for forward

Crossing angle of 50 mrad (JLEIC)
Possible to get ~100% acceptance for the whole event.



Geant4 simulation of JLEIC IR and detector region (80m)



Beyond MDI

Integration of DAQ, analysis and theory to optimize physics reach

Integration of DAQ, analysis and theory

- research model with seamless data processing from DAQ to data analysis:
  - streaming detector readout and (near) real-time analysis using AI (alignment, calibration, reconstruction, physics analysis)
  - not about building the best detector
    - but the best detector that supports **Machine – Detector – Analysis interface**

Computing Vision for the EIC

“The purpose of computing is insight, not numbers.”

Richard Hamming (1962)

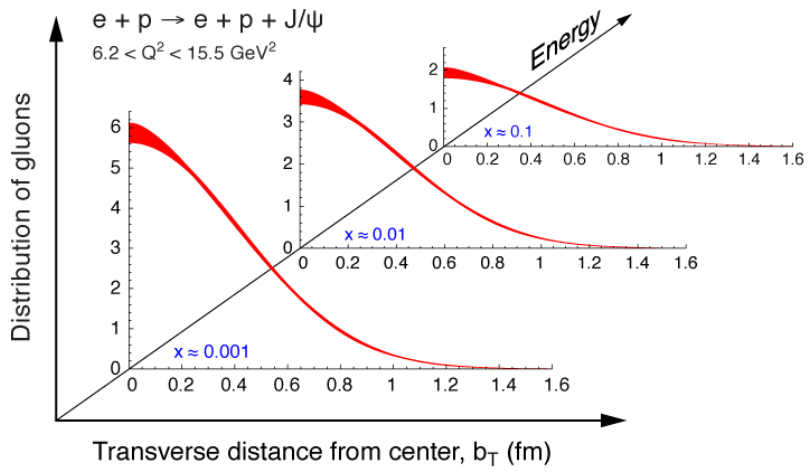
Computing Challenges in Nuclear Physics

unique w.r.t. HEP

NP experiments driven by beam intensity, polarization, exquisite control of background and systematics

multi-dimensional challenges

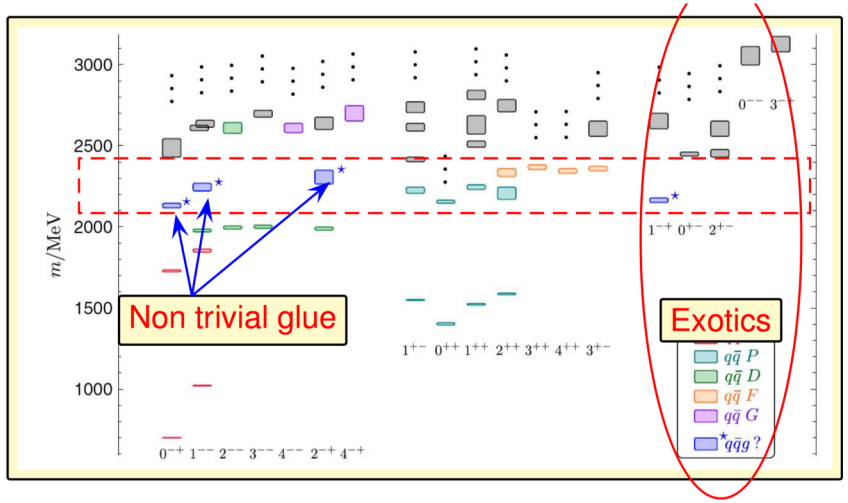
example 3D imaging of quarks and gluons



high statistics in five or dimensions and multiple final-state particles

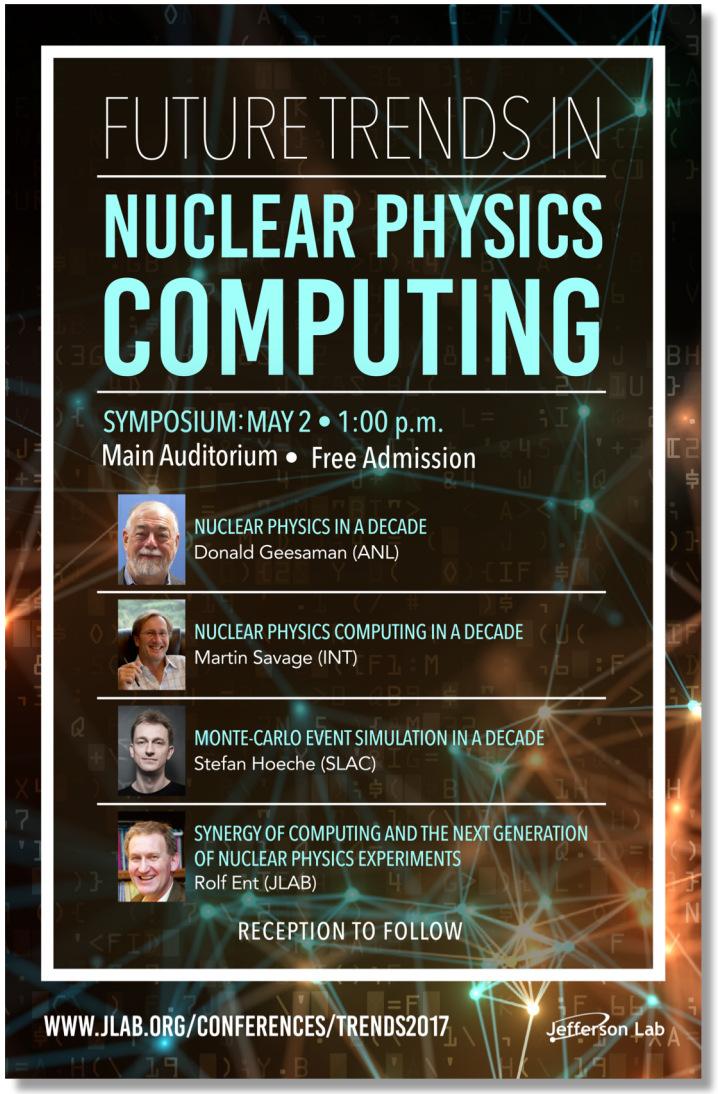
multiple channel challenges

example discovery search of gluon-based exotic particles (PWA, 1000s of waves)



strongly iterative analysis for reliable, model-independent analysis

Future Trends in Nuclear Physics Computing



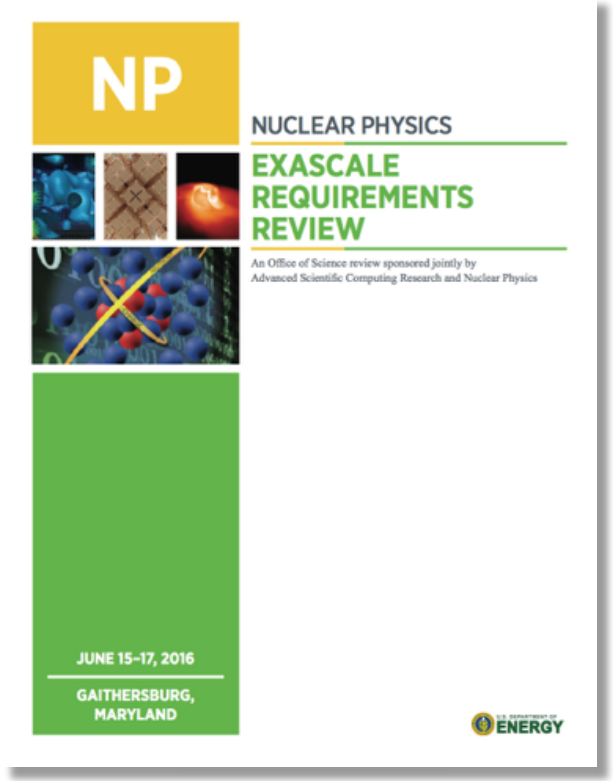
Donald Geesaman (ANL, former NSAC Chair) *"It will be* ***joint progress of theory and experiment*** *that moves us forward, not in one side alone"*

Martin Savage (INT) *"The next decade will be looked back upon as a* ***truly astonishing period in Nuclear Physics*** *and in our understanding of fundamental aspects of nature. This will be* ***made possible by advances in scientific computing*** *and in how the Nuclear Physics community organizes and collaborates, and how DOE and NSF supports this, to take full advantage of these advances."*

Implications of Exascale Computing

Past efforts in lattice QCD in collaboration with industry have driven development of new computing paradigms that benefit large scale computation. These capabilities underpin many important scientific challenges, e.g. studying climate and heat transport over the Earth.

The EIC will be the facility in the era of high precision QCD and the first Nuclear Physics facility in the **era of Exascale Computing**. This will affect the interplay of experiment, simulations, and theory profoundly and result in a new computing paradigm that can be applied to other fields of science and industry.

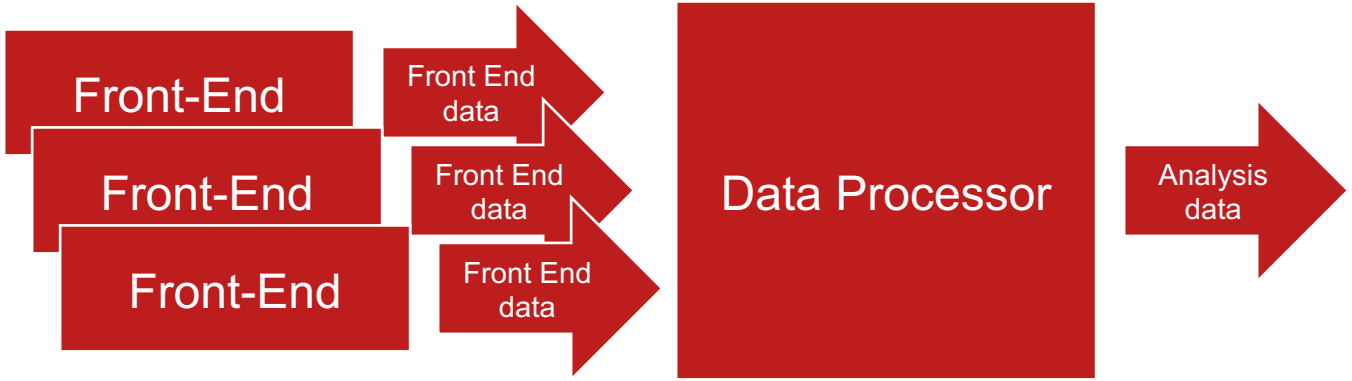


Petascale-capable systems at the beamline

- **unprecedented compute-detector integration**, extending work at LHCb
- requires fundamentally new and different algorithms
- computing model with AI at the DAQ and analysis level and a compute-detector integration to deliver **analysis-ready data from the DAQ system**:
  - responsive calibrations in (near) real time
  - real-time event reconstruction and filtering
  - physics analysis in (near) real time

A similar approach would allow **accelerator operations** to use real-time simulations and artificial intelligence over operational parameters to tune the machine for performance.

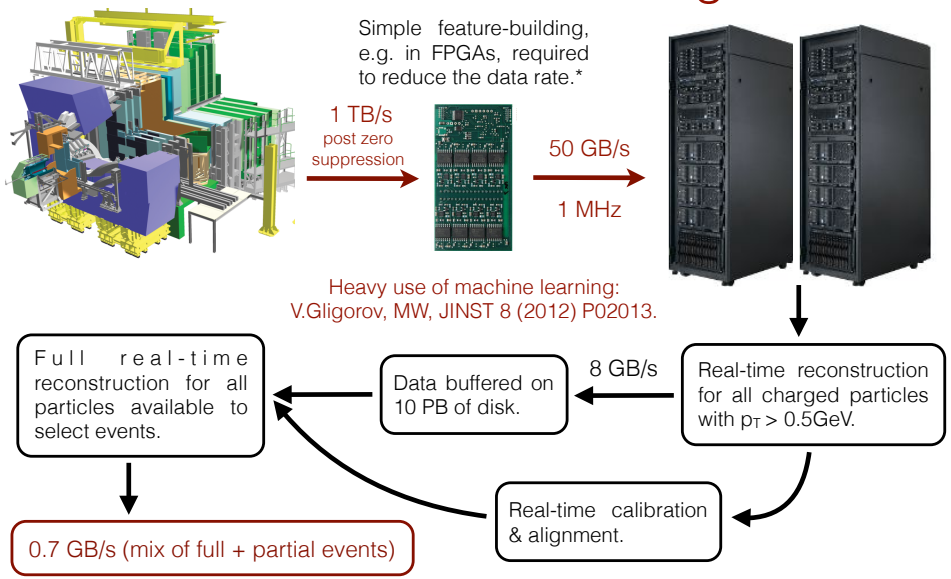
Streaming Readout and Real-Time Processing



LHCb Example

JINST 8 (2013) P04022

Real-Time Processing



*LHCb will move to a triggerless-readout system for LHC Run 3 (2021-2023), and process 5 TB/s in real time on the CPU farm.

Data Processor

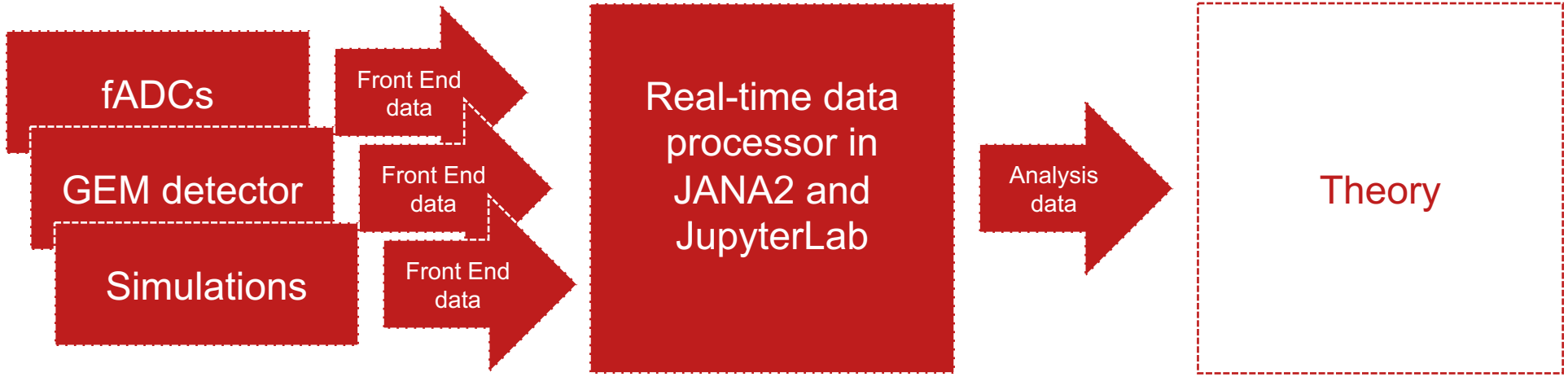
- assembles the data into events
- outputs data suitable for final analysis (**Analysis data**)

Features (among others)

- ideal for machine learning
- automated calibration and alignment
- real-time reconstruction of events
- event selection and/or labeling into analysis streams
- automated anomaly detection
- responsive detectors (conscious experiment)

LDRD project at Jefferson Lab

Integration of DAQ and analysis in streaming readout prototype



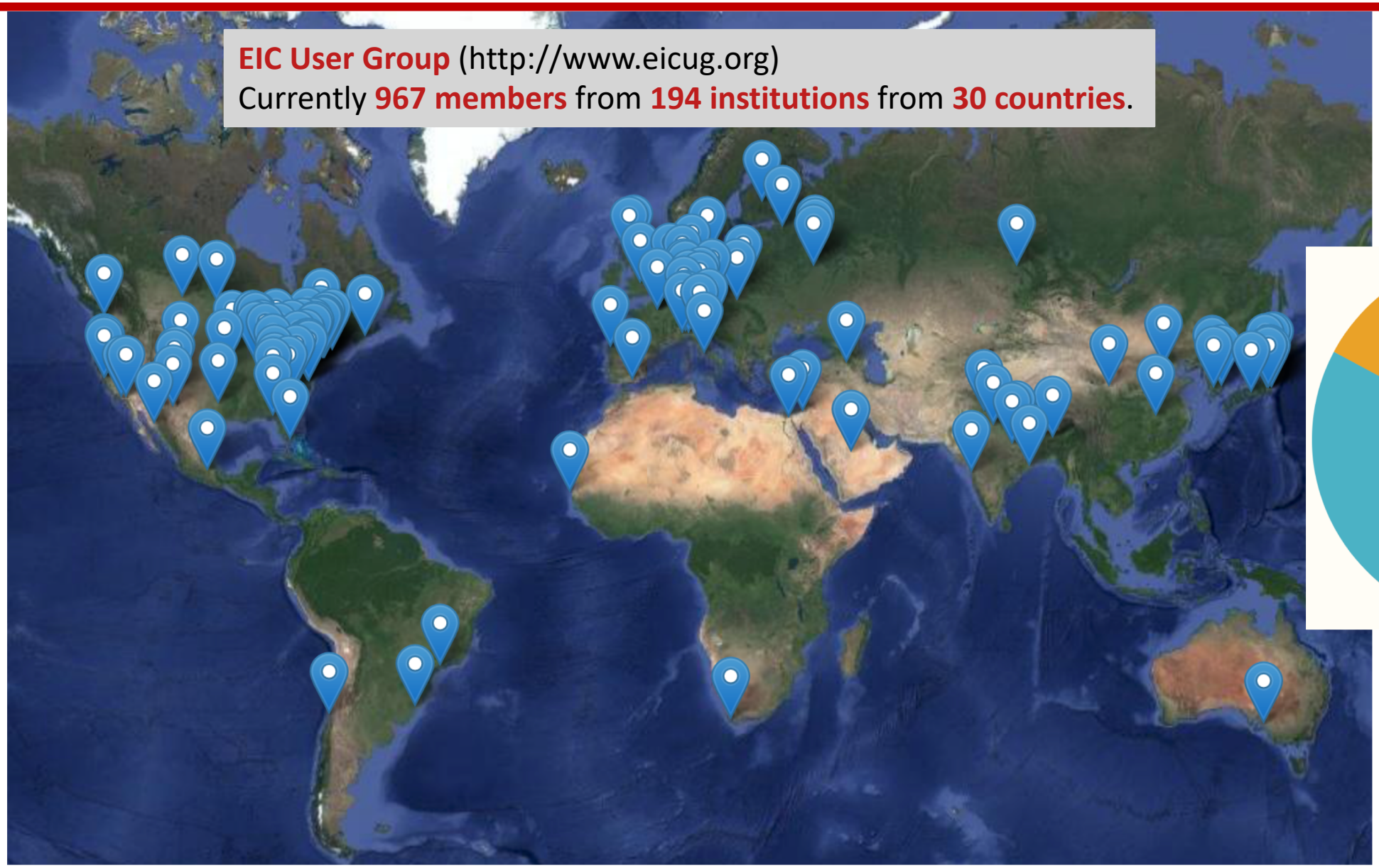
FY20 deliverables

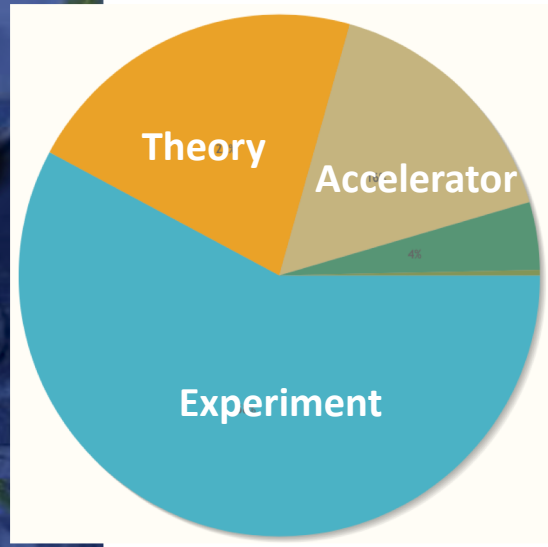
- automated data (quality) monitoring using AI
- automated calibrations of a GEM detector using AI

Engaging with the worldwide EIC community

EIC User Group Software Working Group

The worldwide EIC community





EICUG Software Working Group

45 members

Mailing list eicug-software@eicug.org
subscribe via Google Group
Repository http://gitlab.com/eic
Website https://software.eicug.org

Subscribe to Google Group

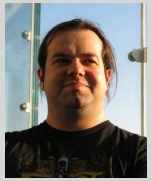
Growing core group


M. Asai (SLAC)


N. Brei (JLAB)


A. Bressan (Trieste)


W. Deconinck (Manitoba)


M. Diefenthaler (JLAB)


J. Furletova (JLAB)


S. Joosten (ANL)


K. Kauder (BNL)


A. Kiselev (BNL)


D. Lawrence (JLAB)


C. Pinkenburg (BNL)


M. Potekhin (BNL)


D. Romanov (JLAB)


T. Wenaus (BNL)

Charge for EICUG Software Working Group

The EICUG Software Working Group's initial focus will be on **simulations of physics processes and detector response** to enable quantitative assessment of measurement capabilities and their physics impact. This will be pursued in a manner that is accessible, consistent, and reproducible to the EICUG as a whole.

It will embody simulations of all processes that make up the EIC science case as articulated in the white paper, eventually integrating new processes under request and with the help of interested communities within the EICUG. The Software working group is to **engage with new major initiatives that aim to further develop the EIC science case**, including for example the upcoming INT program(s), and is anticipated to play key roles also in the preparations for the EIC project(s) and its critical decisions. The working group will build on the considerable progress made within the EIC Software Consortium (eRD20) and other efforts. The evaluation or development of experiment-specific technologies, e.g. mass storage, clusters or other, are outside the initial scope of this working group until the actual experiment collaborations are formed.

The working group will be open to all members of the EICUG to work on EICUG related software tasks. It will communicate via a new **mailing list** and organize **regular online and in-person meetings** that enable broad and active participation from within the EICUG as a whole.

User requests

Ongoing EIC project
Software ✓
Documentation ✓
Requests none

EIC User Group
Common Software ✗
Common Documentation ✗
Requests software, documentation

EIC Generic Detector R&D projects
Software ✓
Documentation ✗ - ✓
Requests common software

Example projects
- ANL: TOPSiDE LDRD
- BNL: eRHIC preCDR
- JLAB: JLEIC preCDR

Focus on (pre)**CDRs and site selection as part of CD1** using existing lab software

Focus on preparation of EIC collaborations
- further develop EIC Science
- examine detector requirements
- work on detector designs
- work on detector concepts

requires simulations of physics processes and detector response

Request from Thomas Ullrich, manager of the R&D program:
- in most cases only GEANT simulations are needed:
  - no need for sophisticated framework
  - no need for elaborate tracking
- a simple *lite setup* with a well defined geometry description standard might get them a long way as long if it is EIC wide and easy to use

Building an EIC Software community

EIC Software Groups (beyond the simulation effort at the labs)

High Energy Physics

CERN ROOT
Possible collaboration

HEP Software Foundation
Started collaboration

MCnet
Started collaboration

SLAC Geant4
Established collaboration

Nuclear Physics

EIC Software
EIC Software Consortium
Community Endorsement ✗
Funding ✓ (EIC Generic Detector R&D)
EICUG Software Working Group
Community Endorsement ✓
Funding ✗

Same software suite Seamless data processing from DAQ to data analysis using AI

EIC Streaming Readout Consortium
Community Endorsement ✗
Funding ✓ (EIC Generic Detector R&D)

EIC Software for wider community

Workflow environment for EICUG

to use (tools, documentation, support) **and**

to grow with user input (direction, documentation, tools)

Single point of entry

HOME | JOIN EICUG | SCIENCE | ORGANIZATION | PHONEBOOK | CALENDAR | SOFTWARE | DOCUMENTS | MEDIA | LOGIN

Home » EIC Software

EIC Software

Software Working Group

The EICUG has formed a Software Working Group that collaborates with EIC Software initiatives and other experts in NP and HEP on detector and physics simulations for the EIC. The short-term goal of the working group is to meet in FY20 the requirements for common tools and documentation in the EICUG. The current work focusses on a common Geant4 infrastructure for the EIC that allows geometry exchange between the eRHIC and JLEIC concepts.

JupyterLab

The Software Working Group has adapted JupyterLab as a collaborative workspace to further develop EIC Science, to examine detector requirements, and to work on detector designs and concepts. JupyterLab is a web-based interactive analysis environment to create and share documents that contain the analysis code, the narrative of the analysis including graphics and equations, and visualizations of the analysis results. This will allow the EICUG not only to pursue simulations in a manner that is accessible, consistent, and reproducible to the EICUG as a whole, but also to build a collection of analyses and analysis tools in the fully extensible and modular JupyterLab environment. A quick start tutorial for fast simulations is available on the website for EIC Software.

Important links

Mailing list	eicug-software@eicug.org (subscribe via Google Group)
Repository	http://gitlab.com/eic
Website	https://software.eicug.org

JupyterLab environment

- **collaborative workspace** to create and share Jupyter Notebooks
- **web-based interactive analysis environment** accessible, consistent, reproducible analyses
- **fully extensible and modular** build a collection of analyses and analysis tools
- **bridge to modern data science**, e.g.,
  - *Nature* **563**, 145-146 (2018): “Why Jupyter is data scientists’ computational notebook of choice”
  - more than three million Jupyter Notebooks publicly available on GitHub

07/23 EIC Software Tutorial

Dmitry Romanov (JLAB) introduced EIC simulations in JupyterLab environment.

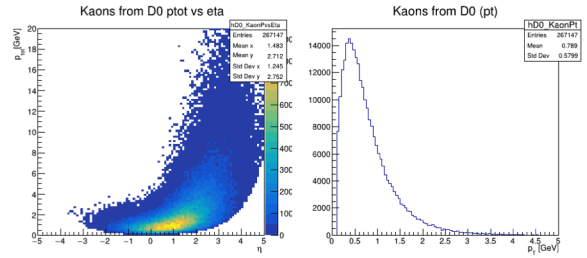
Quickstart https://eic.gitlab.io/documents/quickstart/

Jupyter Notebooks

- **writing analysis code**

```
[4]: jana.plugin('hepmc_reader') \
     .plugin('jana', nevents=10000, output='hepmc_sm.root') \
     .plugin('eic_smear', detector='jleic') \
     .plugin('open_charm')

[4]: eJana configured
     plugins: hepmc_reader,eic_smear,open_charm

[5]: jana.source('../data/herwig6_20k.hepmc')

[5]: eJana configured
     plugins: hepmc_reader,eic_smear,open_charm
     sources:
     ../data/herwig6_20k.hepmc

[6]: jana.run()

     Total events processed: 10001 (~ 10.0 kevt)
```

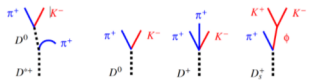
- **visualization of results**



- **narrative of the analysis**

Open charm

The high luminosity at the EIC would allow measurements of open charm production with much higher rates than at HERA and COMPASS, extending the kinematic coverage to large $x_B >\sim 0.1$ and rare processes such as high-p_T jets. Heavy quark production with electromagnetic probes could for the first time be measured on nuclear targets and used to study the gluonic structure of nuclei and the propagation of heavy quarks through cold nuclear matter with full control of the initial state.



Software design

Escaping complexity scaling trap

- provide interfaces to internal layers
- interaction between layers must be clear

Modularity each layer must be replaceable

simple	JupyterLab web interface
moderate	analysis scripts, python
complex	eJANA, plugins, C++
expert	JANA, eic-smear, ROOT, Geant4

Simulations of physics processes and detector responses

Simulation of physics processes

Simulation of detector responses

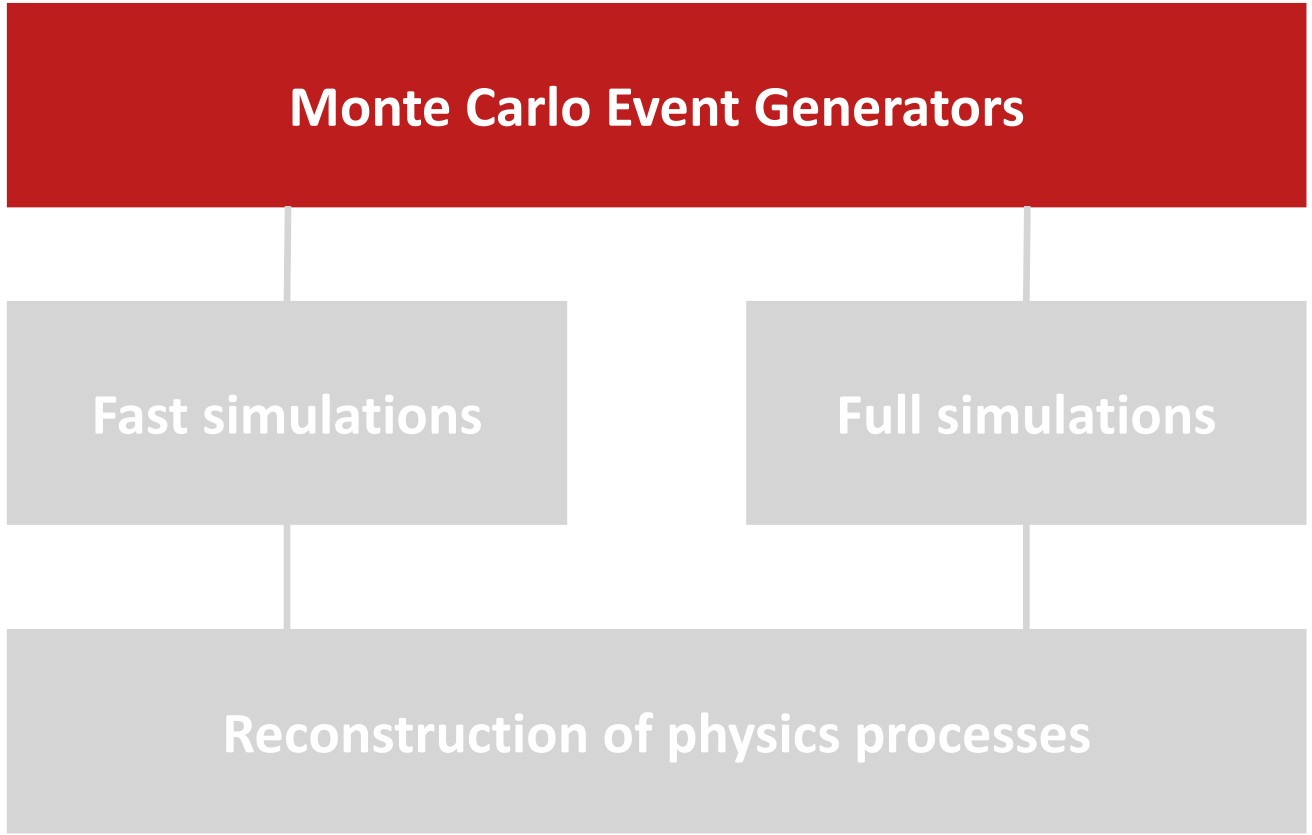
Physics analysis

Simulations of physics processes and detector responses

Simulation of physics processes

Simulation of detector responses

Physics analysis



Workshops: MCEGs for future ep and eA facilities

MCnet 16 institutions, 80+ scientists

Workshop series

- EICUG—Mcnet collaboration
- started as satellite workshop during POETIC-8

Goals

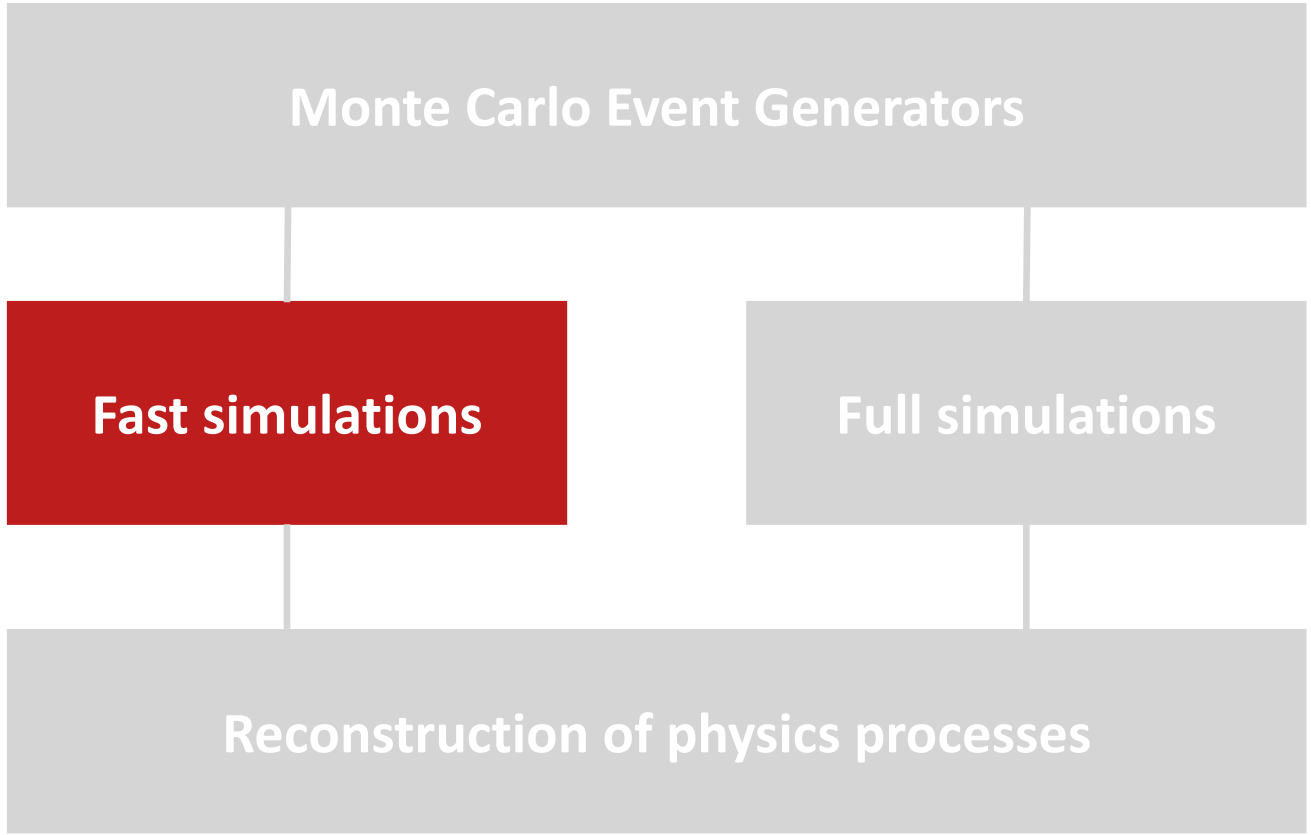
- requirements for MCEGs for ep and eA
- R&D for MCEGs for ep and eA

Simulations of physics processes and detector responses

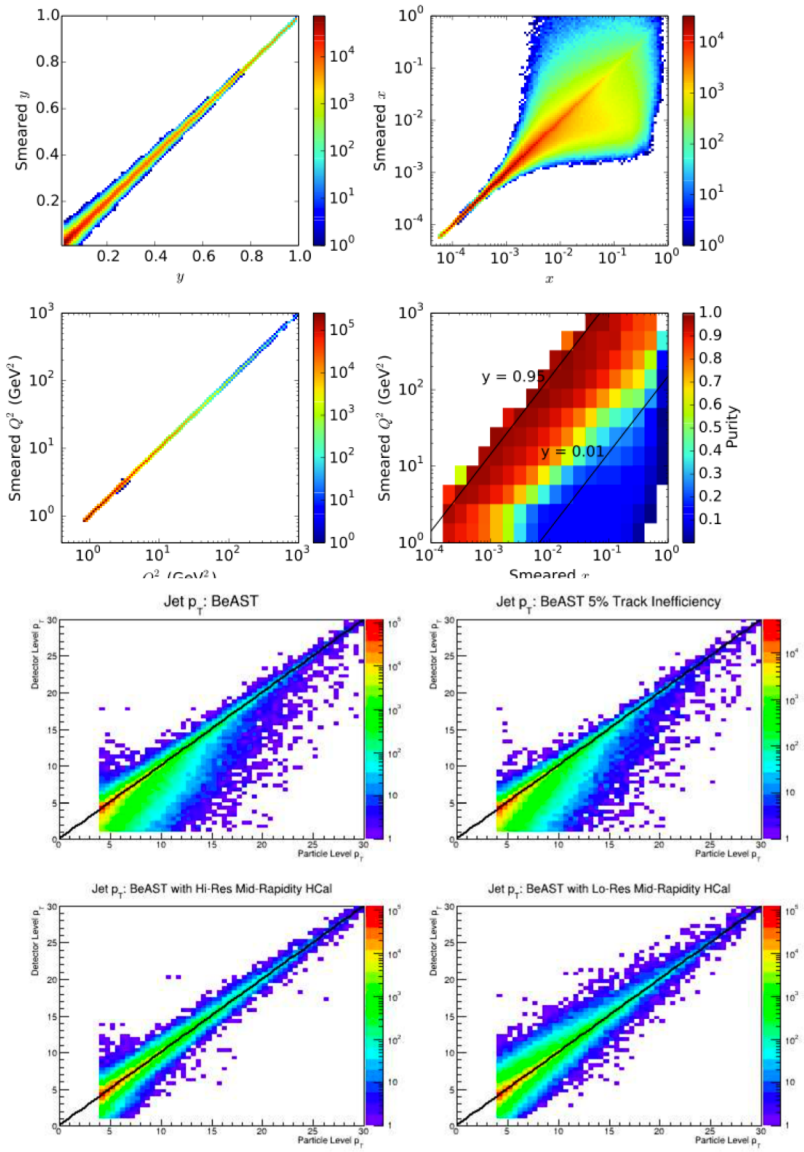
Simulation of physics processes

Simulation of detector responses

Physics analysis



eic-smear



Fast simulations using ROOT, ideal for questions like

- *"Given a (known) detector performance, how well can I measure some physics observable(s)?"*
- *"If I need to measure X to some precision, what detector performance do I need?"*
- Used extensively for **EIC White Paper**

Features

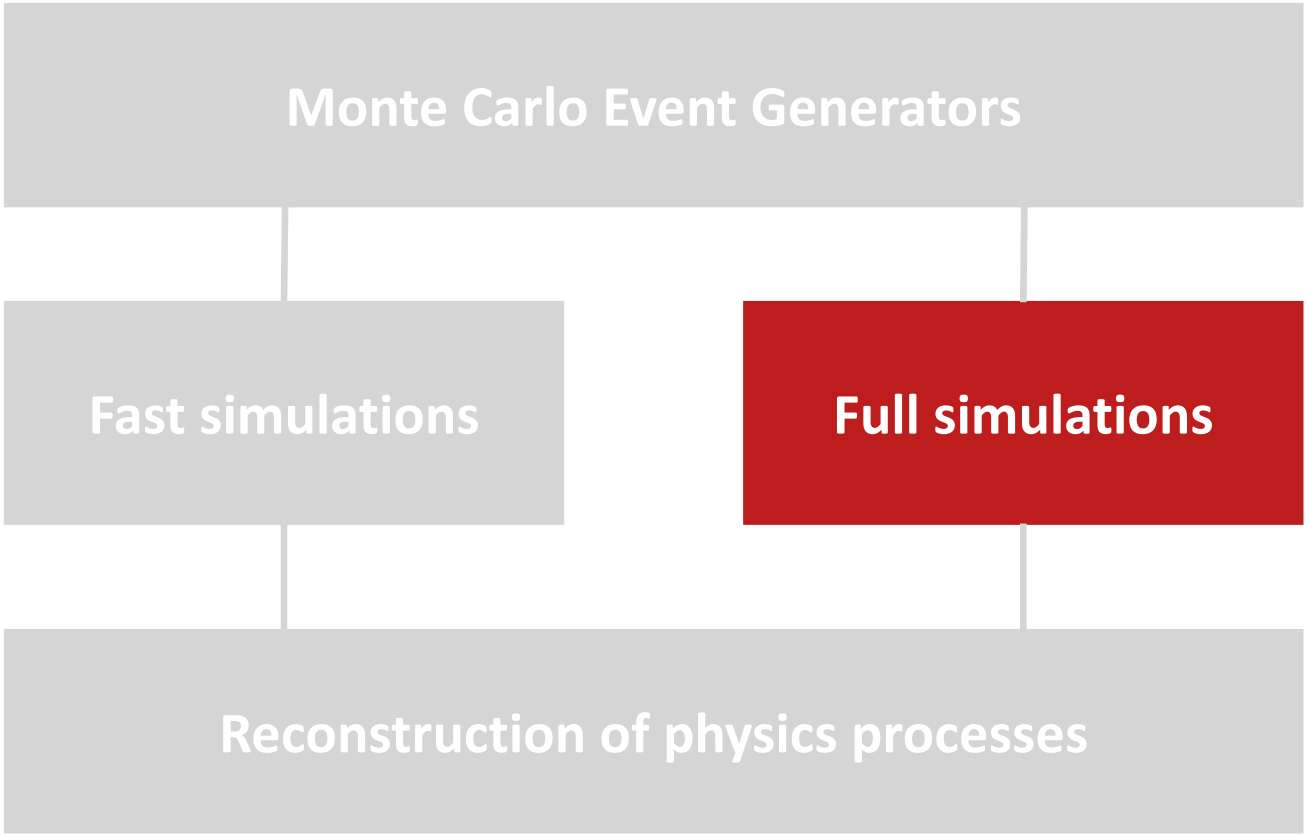
- interface to MCEGs for ep and eA smearing of overall detector performance:
  - can be easily modified in user code
  - includes acceptance effects
  - parametrizations for BeAST, ePHENIX, JLEIC and others
- ROOT trees for MC Truth and smeared information

Simulations of physics processes and detector responses

Simulation of physics processes

Simulation of detector responses

Physics analysis



Examples for existing EIC Software

ANL TOPSiDE detector concept (ILC software variant)

BNL BeAST detector concept: EICroot (FairRoot variant)

BNL ePHENIX detector concept (Fun4All)

JLAB JLEIC detector concept (eJANA)

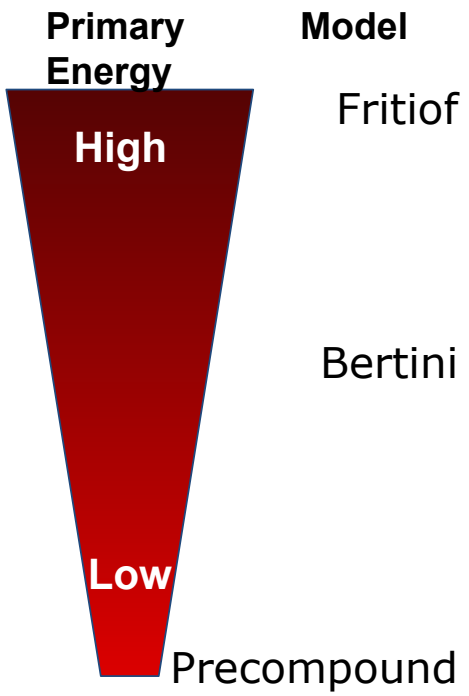
Used for various EIC detector and physics studies including NAS reports, white papers, pre-conceptual design reports, etc.

Detector Simulation

- **collaboration with Geant4 International Collaboration**
  - liaison: Makoto Asai (SLAC)
- **Detector Simulation R&D**
  - containers and tutorials for EIC detector simulations
  - coordinate input for Geant4 validation based on EIC physics list maintained by SLAC Geant4 group

EIC

- energy range is different from LHC
- validation, tuning and extension including test beam studies



09/24 Geant4 Technical Forum on EIC

- EIC detector and physics simulations rely on Geant4
- knowledge transfer (e.g., sub-event parallelism or tessellated solids)
- maintain EIC physics lists
- **request** improved photo-nuclear and electro-nuclear reactions

Common Geant4 infrastructure

Goals

- meet requirements by EIC community fully
- meet requirements by EIC community by end of 2019

Approach

- common repository for detector R&D for tEIC
- common detector description in Geant4 (C++)
- common detector naming convention for EIC
- common definition of parameters and their management
- common API/class design for sensitive detector stepping action
- possible common hits output structure
- concise document and template on how to implement and integrate subdetector in the detector concepts for the EIC

Common Geant4 infrastructure with flexible accelerator and detector interface

Existing tools will be able to **use common Geant4 infrastructure** without loosing any functionality.

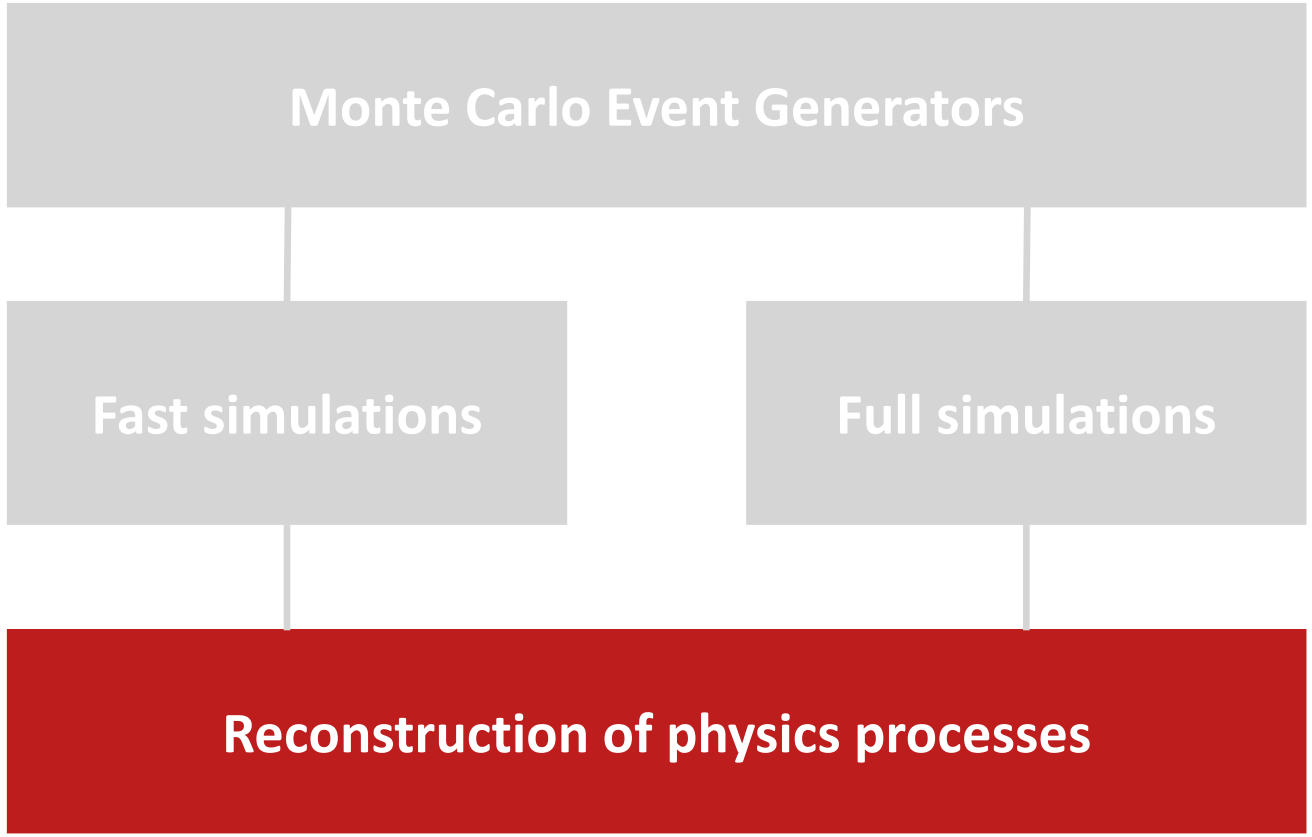
Existing prototypes for common Geant4 infrastructure: EIC Software Sandbox, fun4all, g4e

Simulations of physics processes and detector responses

Simulation of physics processes

Simulation of detector responses

Physics analysis



Reconstruction of physics processes

EIC Software Consortium

Modular tracking software

- for detector concepts and testing new algorithms (e.g., (D)NN for track finding)
- based on EIC tracking tools at ANL, BNL, JLAB

Completed feasibility study

- similar requirements and similar tracker outline for all proposed EIC detectors
- similar dataflow: simulation -> digitization -> track reconstruction

Started development

- define libraries and interfaces (material db, reconstructed hits)
- setup sandbox environment

Priority after common Geant4 infrastructure with flexible accelerator and detector interface

ACTS from ATLAS software towards a common track reconstruction software

Yue-Shi Lai (LBL) evaluating ACTS for EIC

eJANA Include existing tools, e.g., **EicRoot tracking**, into workflow environment

Markus Diefenthaler (EIC^2, Jefferson Lab)

mdiefent@jlab.org

Electron-Ion Collider

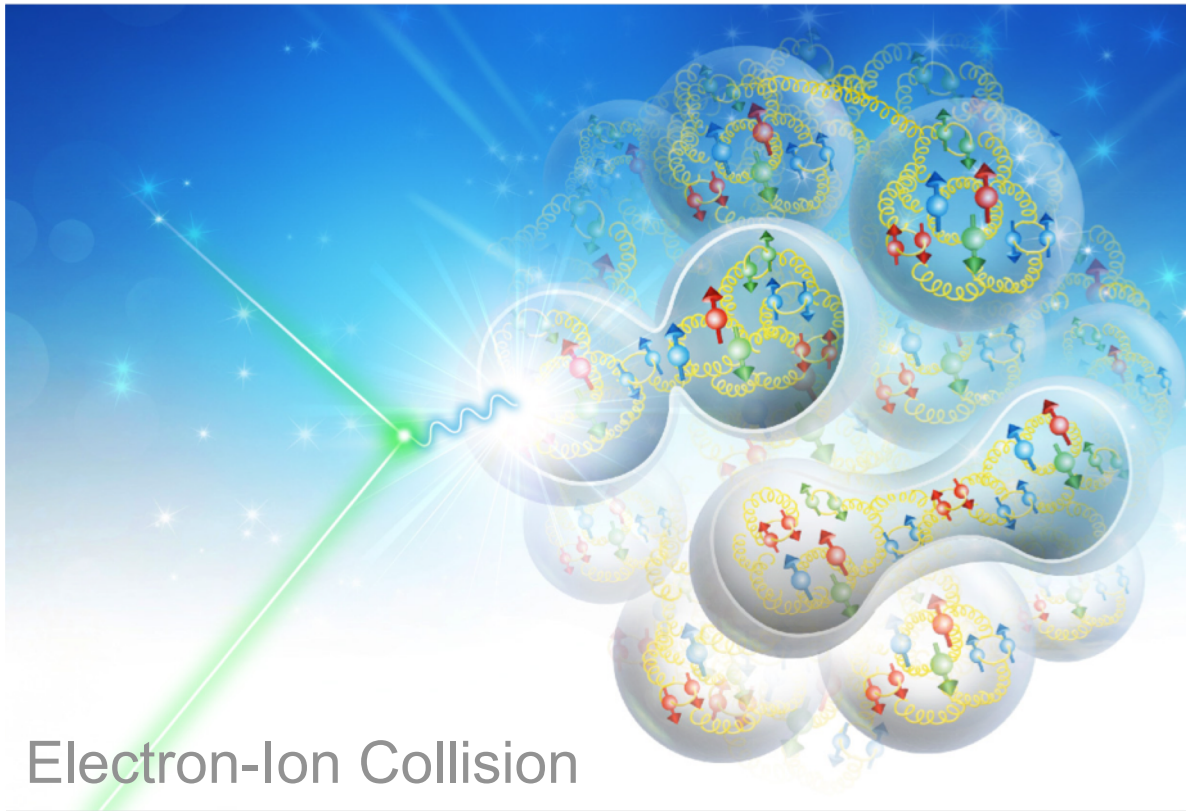
- precision study of the nucleon and the nucleus at the scale of sea quarks and gluons
- extremely broad science program

Computing vision of the EIC

- Machine – Detector – Analysis interface
- seamless data processing from DAQ to data analysis using AI

Workflow environment for EICUG

- flexible, modular analysis ecosystem
- **grow with user input** excited to support EIC Physics and Detector Conceptual Development
- collaborate with Software & Computing Initiatives in HEP



Jefferson Lab