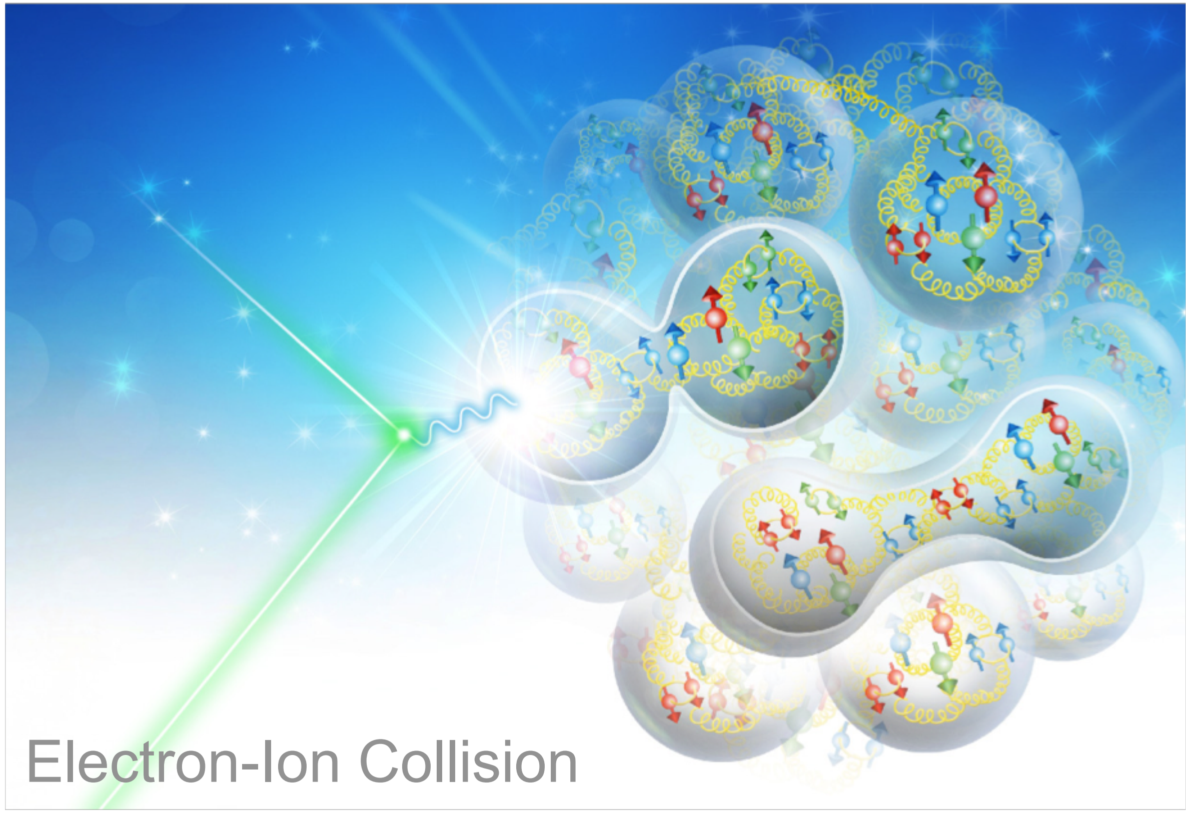
Software Initiatives for the Electron-Ion Collider

ESC

EIC SOFTWARE CONSORTIUM

Markus Diefenthaler (Jefferson Lab)

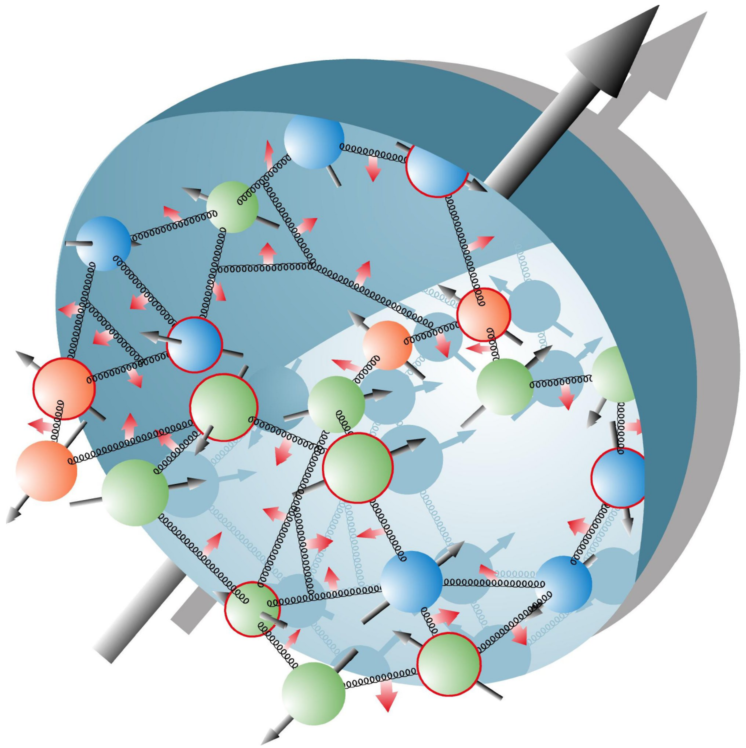

Electron-Ion Collision

A New Frontier in Nuclear Physics

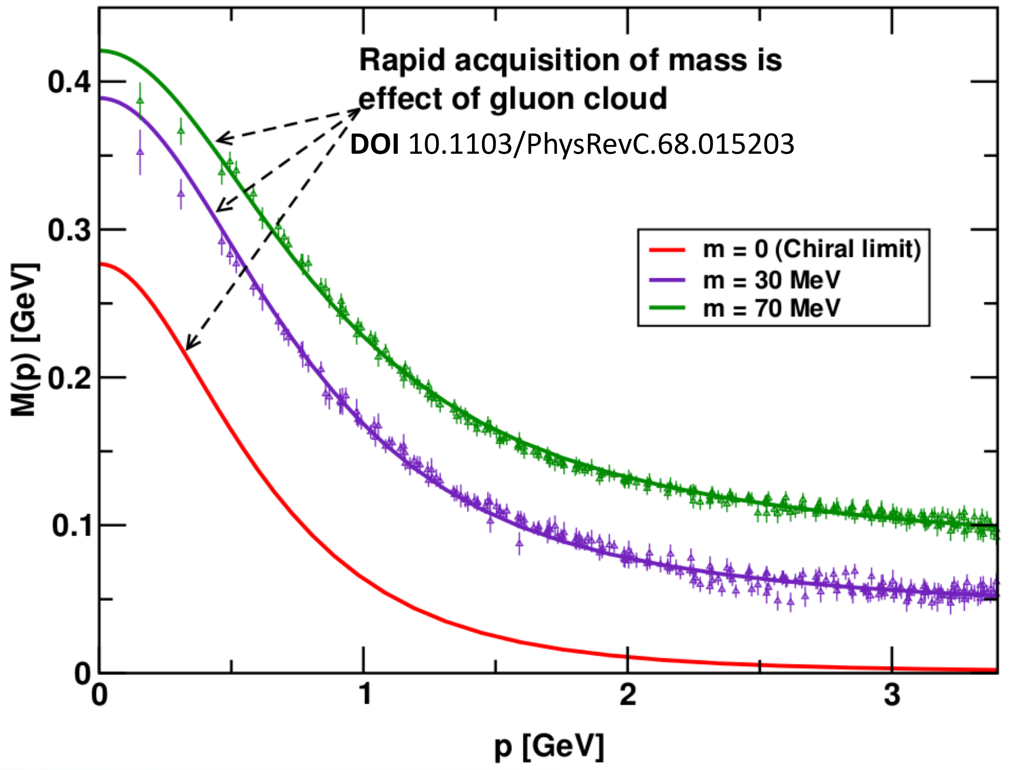
The Electron-Ion Collider (EIC)

The dynamical nature of nuclear matter

Nuclear Matter Interactions and structures are inextricably mixed up.



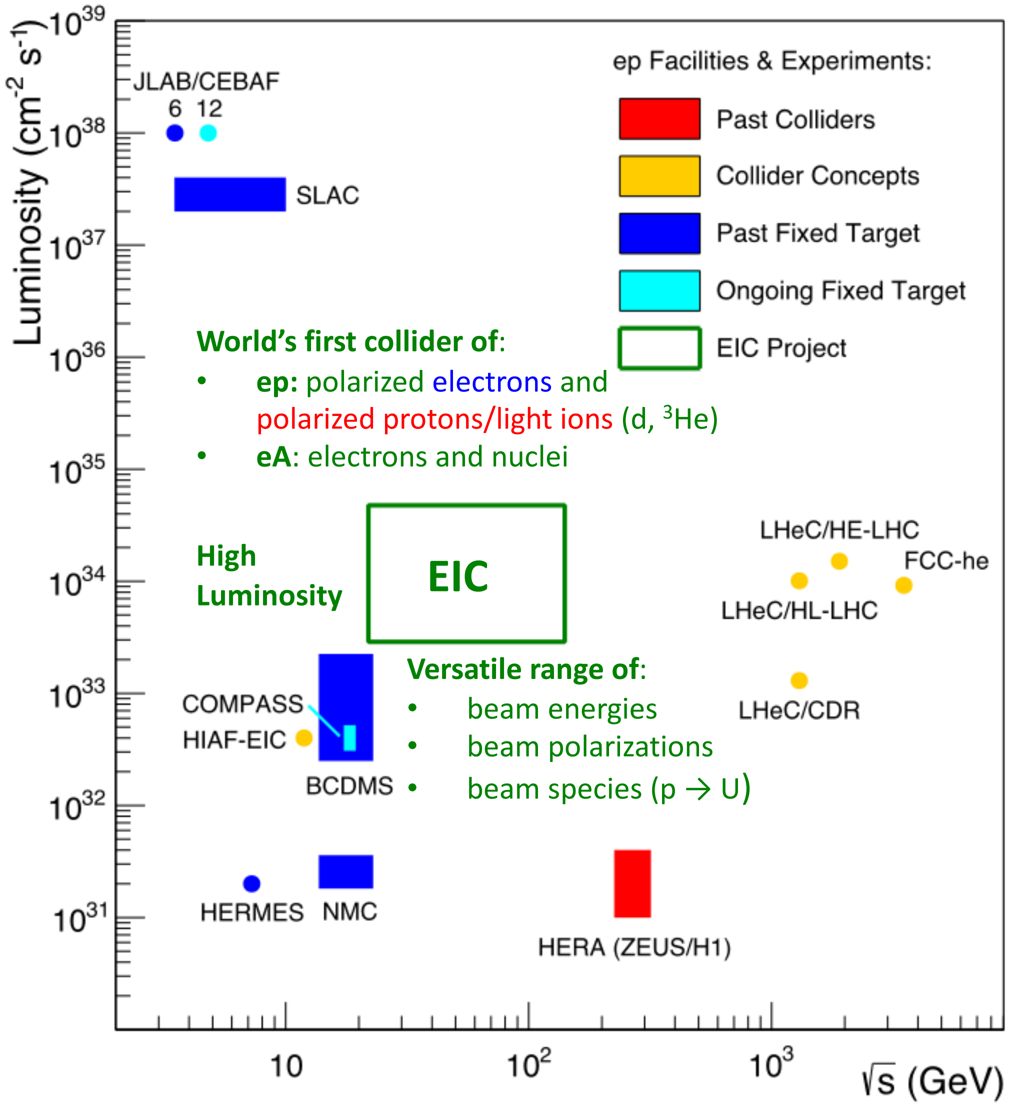
Observed properties such as mass and spin emerge out of the complex system.



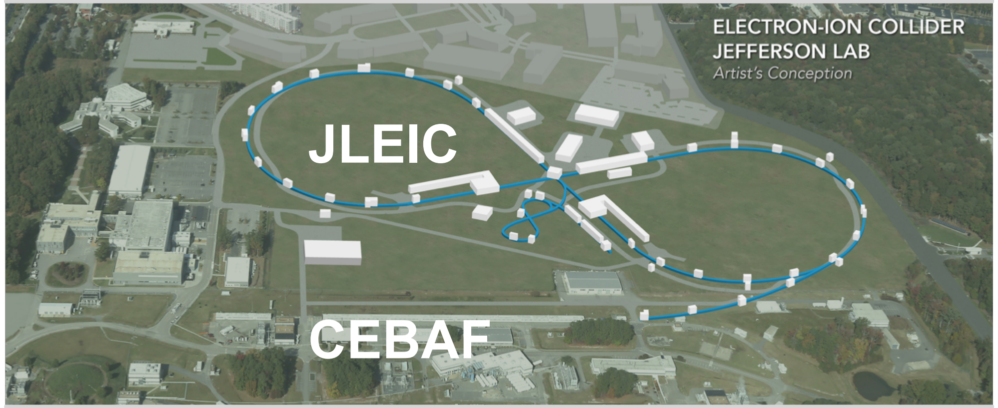
Ultimate goal Understand how nuclear matter at its most fundamental level is made.

To reach goal precisely image quarks and gluons and their strong interactions in nuclear matter.

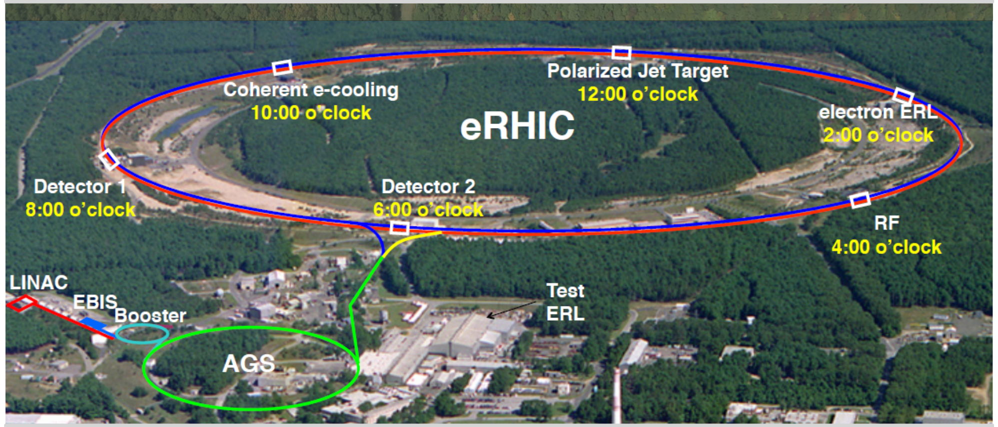
The Electron-Ion Collider: Frontier accelerator facility in the U.S.



Highest priority for new construction
for the U.S. Nuclear Physics program



Proposal by Jefferson Lab

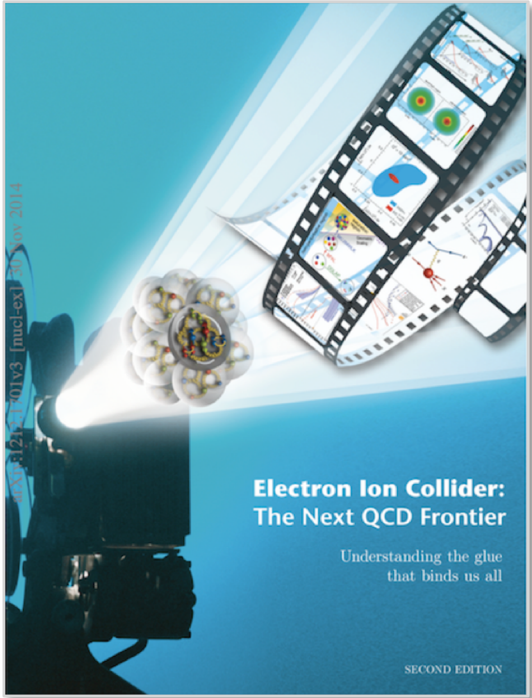


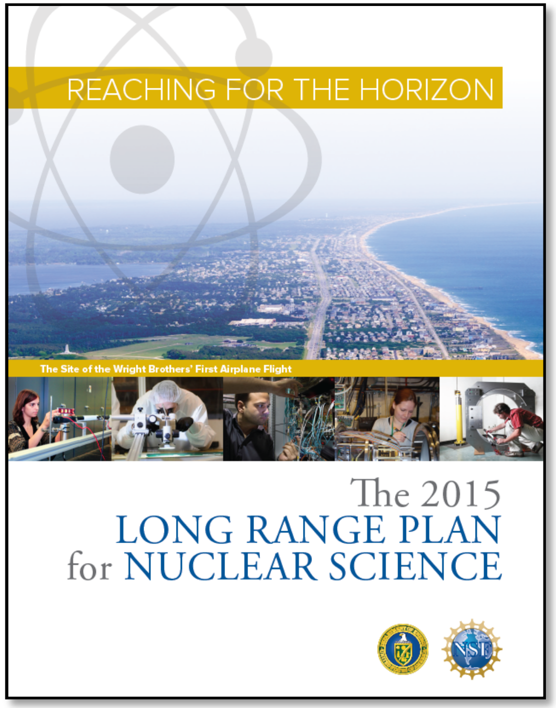
Proposal by Brookhaven Lab

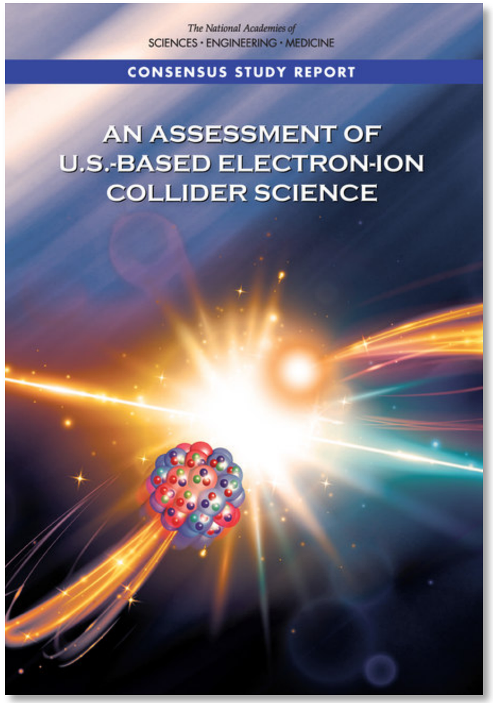
Why an Electron-Ion Collider?

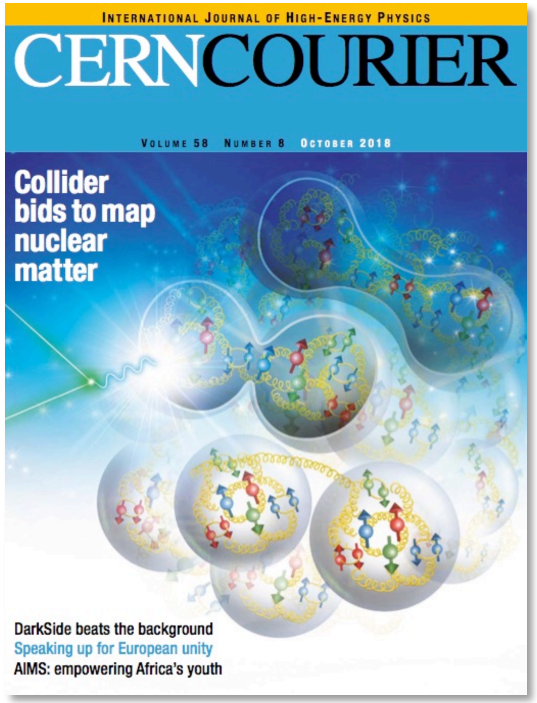
Right tool:
- to precisely **image quarks and gluons** and their interactions
- to explore the new **QCD frontier of strong color fields in nuclei**
- to understand **how matter at its most fundamental level is made**.

Understanding of nuclear matter is **transformational**, perhaps in an even more dramatic way than how the understanding of the atomic and molecular structure of matter led to new frontiers, new sciences and new technologies.









Software Initiative for the EIC

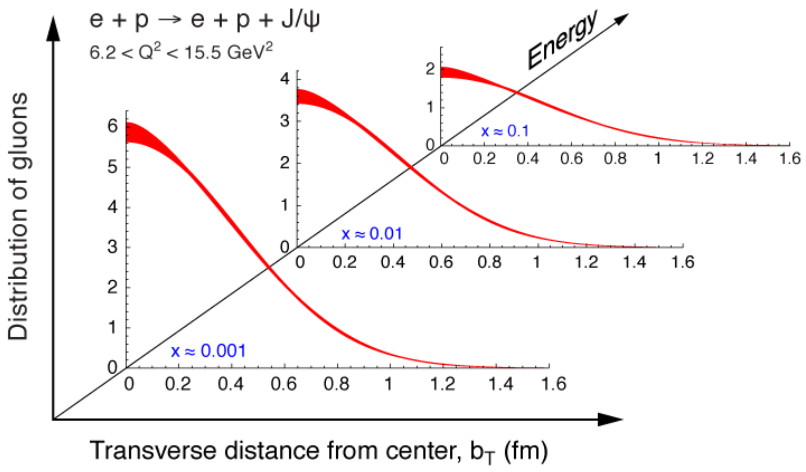
EIC Software Consortium

Computing Challenges in Nuclear Physics

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

multi-dimensional challenges

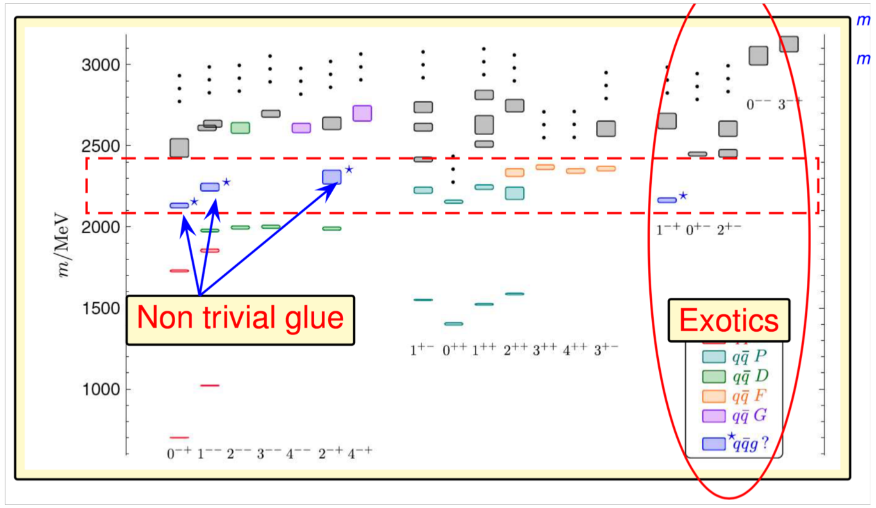
example 3D imaging of quarks and gluons



high statistics in five or more dimensions and multiple particles

multiple channel challenges

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



strongly iterative analysis for reliable, model-independent analysis

Existing software frameworks for the EIC

ANL TOPSiDE detector concept (ILC software variant)

BNL BeAST detector concept: EICroot (FairRoot variant)

BNL ePHENIX detector concept (fun4all)

JLAB JLEIC detector concept (GEMC)

Software Review by EIC Community in November 2017

- EicRoot, Fun4All , GEMC, and the ANL software are actively maintained.
- The analysis environments for the EIC will be chosen when the EIC experimental collaborations will form.
- Until then, we will examine the **requirements** for the EIC analysis environment and work on the **R&D** aspects of the EIC analysis environment.

EIC Software Consortium

ESC members

ANL, BNL, JLAB, LUND, INFN, SLAC, Trieste, W&M

Part of EIC Generic Detector R&D program

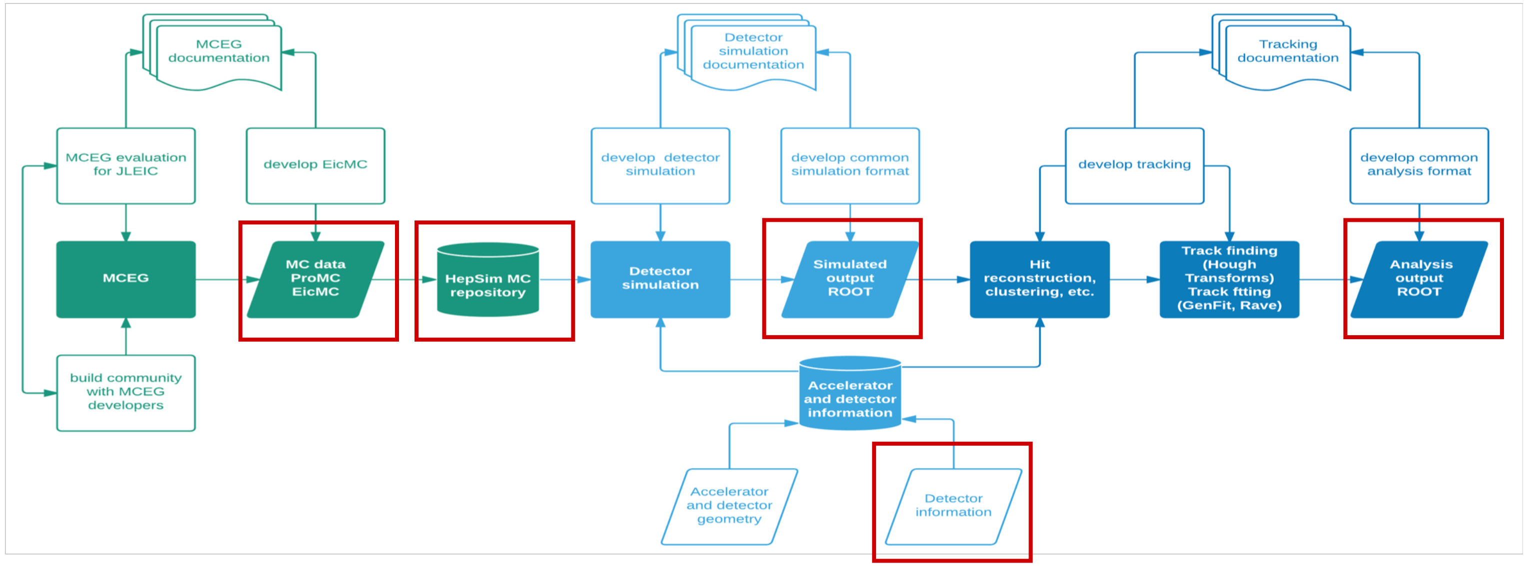
ESC goals and focus

- continue work on common interfaces (e.g., geometry, file formats, tracking)
- explore new avenues of software development (e.g., artificial intelligence)
- **reach out to the EIC community**
    - communicate present status of EIC software
    - bring existing EIC software to end users
    - produce publicly available consensus-based documents on critical subjects
    - provide vision for the future

Common interfaces

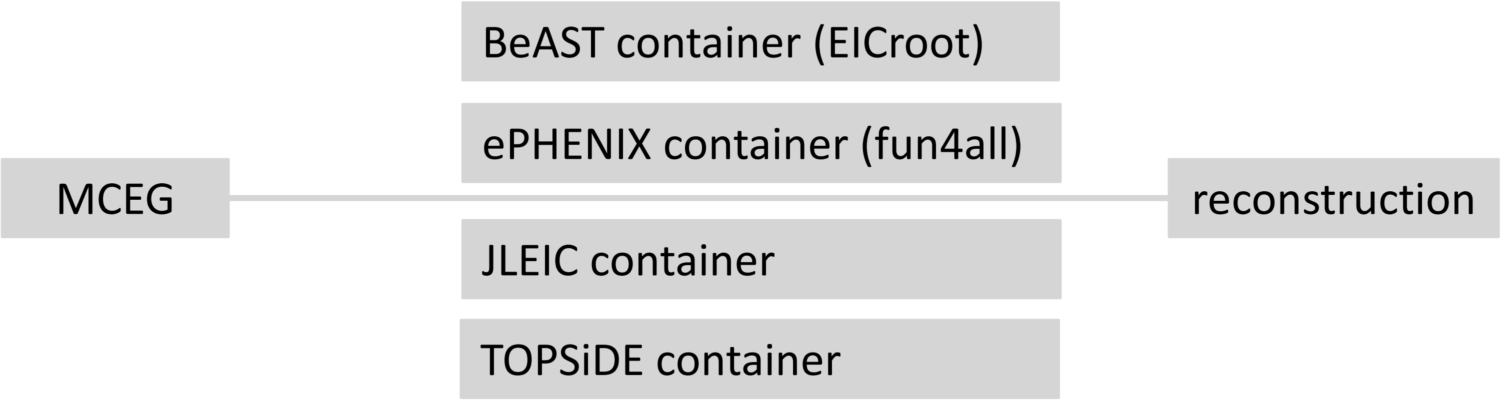
Advice from ILC effort

- facilitate interoperability
- focus on exchange detector designs and data
    - get the event data model right and keep it open
    - pick a detector definition which is exchangeable



Norman Graf (SLAC)

“It’s very difficult to ~~herd cats~~ keep physicists from re-inventing the wheel and writing new software packages.“



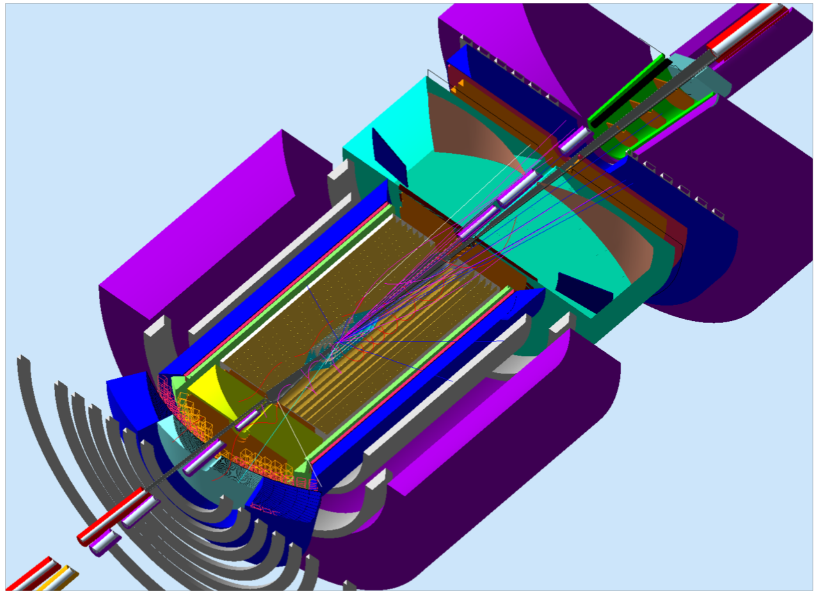
EIC User Group

EIC User Group (EICUG)
Currently **856 members** from **182 institutions** from **30 countries**.

Physicists around the world are thinking about and are defining the **EIC science program**.

EICUG Software Working Group

- simulations of physics processes and detector response to enable quantitative assessment of measurement capabilities and their physics impact
- Build on ECC with conveners chosen from ESC



Jefferson Lab

Computing Vision for the EIC

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

Richard Hamming (1962)

Computing trends and EIC Computing

EIC rates

- expected data rates similar to next phase LHCb
- not enormous rates creates opportunity for other initiatives

Think out of the box

- The way analysis is done has been largely shaped by kinds of computing that has been available.
- Computing begins to grow in very different ways in the future, driven by very different forces than in the past (e.g., Exascale Computing Initiative).
- This is an unique opportunity for Nuclear Physics to think about new possibilities and paradigms that can and should arise (e.g., real-time physics analysis).

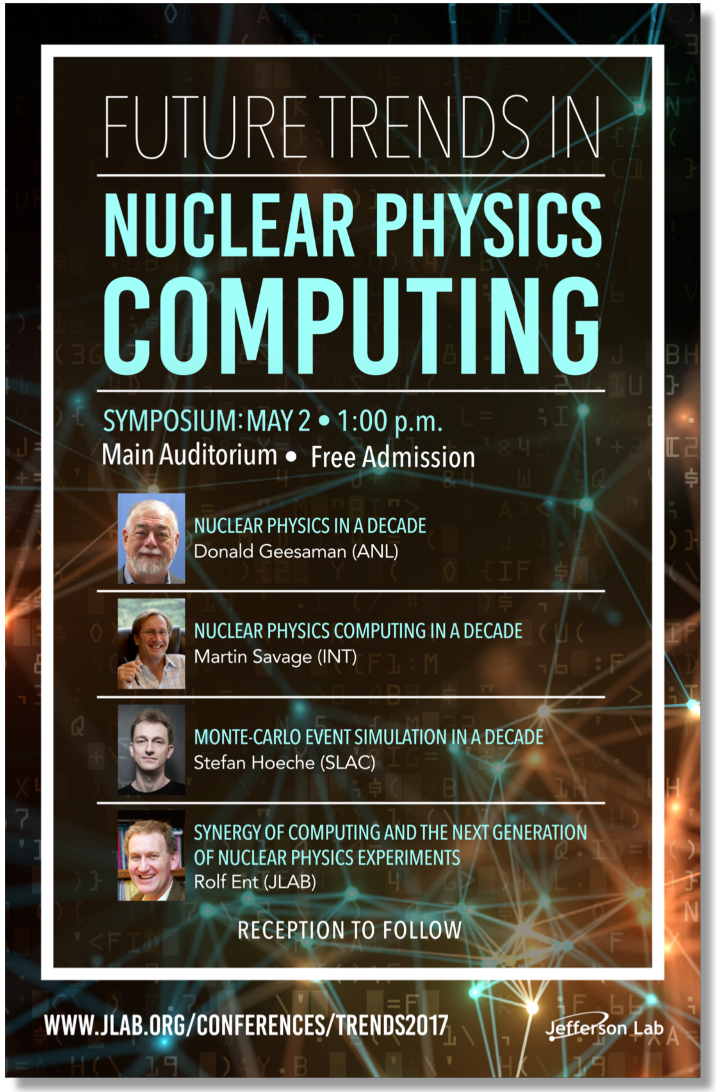
Future compatibility hardware and software

- **Exascale Computing** Most powerful future computers will likely be very different from the kind of computers currently used in Nuclear Physics.
- This requires a modular design with structures robust against likely changes in computing environment so that changes in underlying code can be handled without an entire overhaul of the structure.

User centered design to enhance scientific productivity

- Engage wider community of physicists, whose primary interest is not computing, in software design to:
  - understand the user requirements first and foremost
  - make design decisions largely based on user requirements.

Future Trends in Nuclear Physics Computing



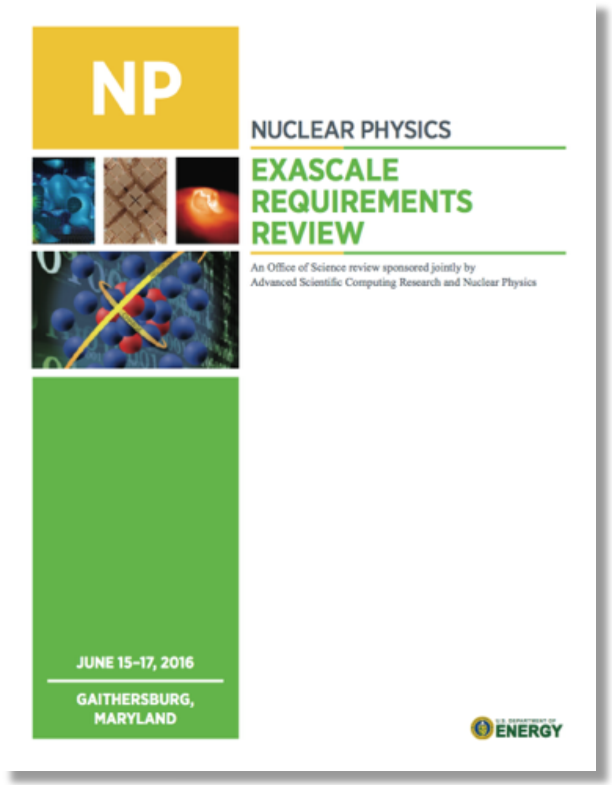
Donald Geesaman (ANL, former NSAC Chair) *"It will be **joint progress of theory and experiment** that moves us forward, not in one side alone"*

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.

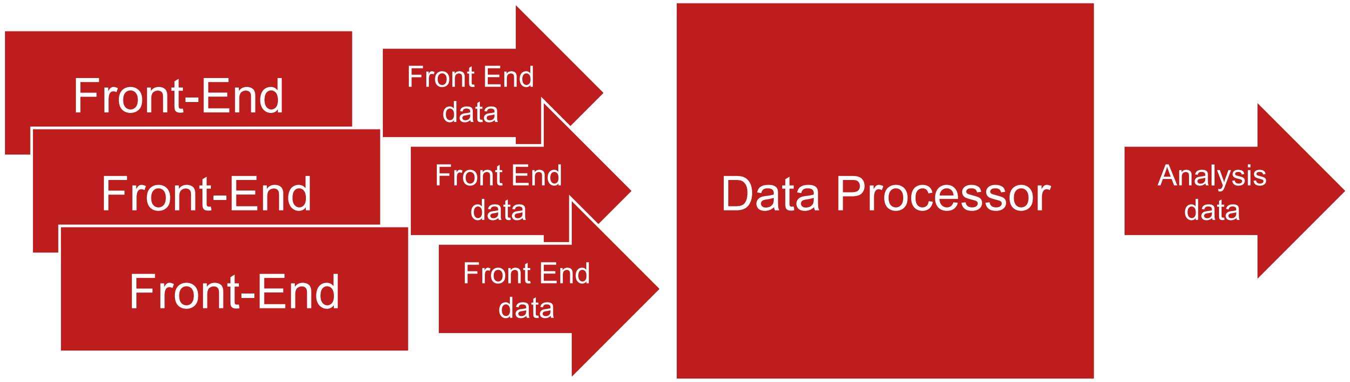


Petascale-capable systems at the beamline

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



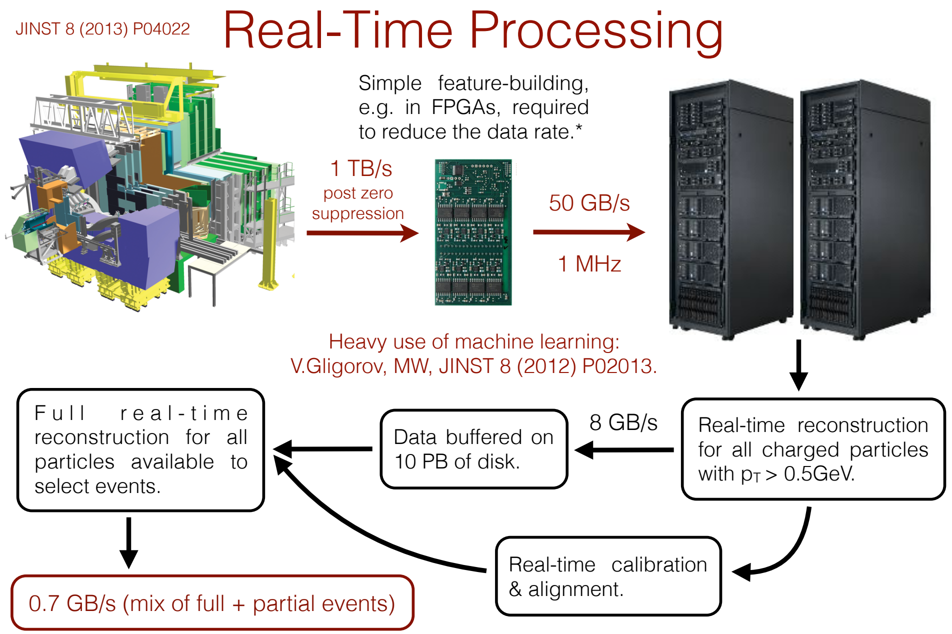
Data Processor

- 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)

LHCb Example



*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.

EIC Software Consortium (ESC)

Software projects for the EIC

ESC Initiatives

Monte Carlo Initiative

- collaboration with MCnet

- online catalogue of MCEGs

- EICUG documents:
  - MCEG requirements
  - MCEG event model

- MCEG R&D:
  - containers and tutorials for EIC MCEGs
  - library for QED radiative effects

Example MCEG container

Pythia8 with Jupyter notebook interface

Pythia 8 standalone

This notebook gives a basic idea of the Pythia 8 event generator, by using the Python interface of Pythia 8. You can adjust a set of parameters and choose from different different histograms to be plotted.

First, lets import all neccessary modules.

```
In [1]: import os, sys, pythia8
        from plotting import MULTIHIST
        import py8settings as py8s
```

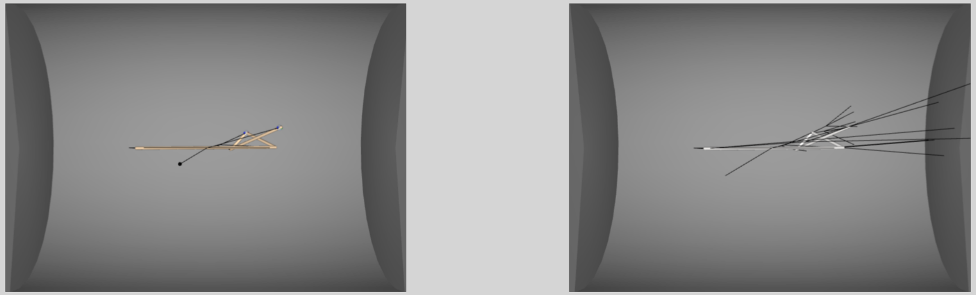
Now we create a Pythia 8 object and apply the settings to define the incoming beams. More settings can be adjusted later.

```
In [2]: # Setup pythia, apply beam settings.
        pythia = pythia8.Pythia()
        py8s.beam_settings(pythia)
```

You can now set the parameters for the incoming beams:

beam A id [Beams:idA]	e-
beam B id [Beams:idB]	p
beam frame type [Beams:frameType]	2: back-to-back beams with different energies, set Beams:eA and Beams:eB
CMS energy for Beams:frameType = 1 [Beams:eCM]	65.7
beam A energy for Beams:frameType = 2 [Beams:eA]	10.8
beam B energy for Beams:frameType = 2 [Beams:eB]	100

Visualization of ep collision



Detector Simulation

- **collaboration with Geant4 International Collbaboration**
  - liaison: Makoto Asai (SLAC)
- reach out to EIC Community
  - online catalogue of detector simulations
- **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

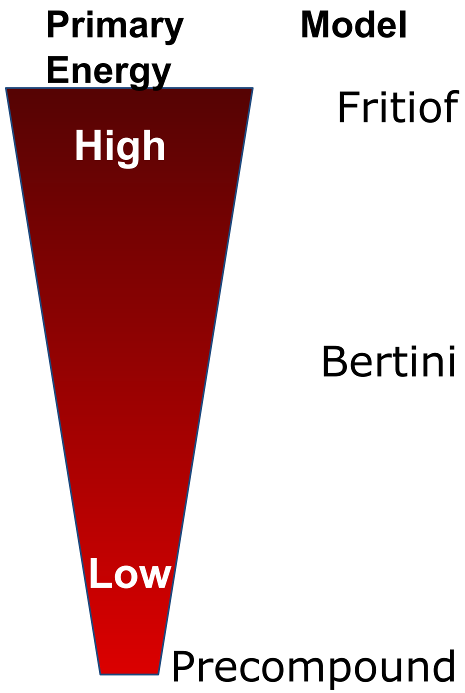
Technical forum on EIC as part of

09/23 – 09/27 Geant4 Collaboration Meeting (JLAB)

coordinate with EIC Detector R&D

EIC

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



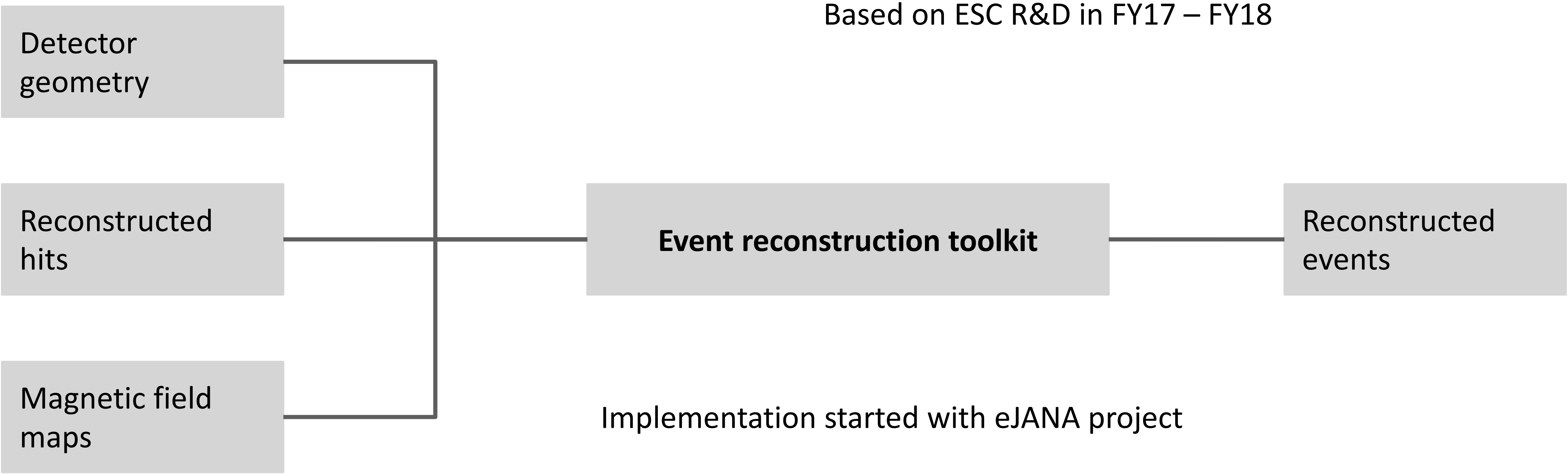
Community reference reconstruction

Charge *"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.*

Modular reconstruction based on EIC tracking tools (ANL, BNL, JLab)

- for interoperability of lab software tools
- for comparing / validating EIC results
- for testing new algorithms

Based on ESC R&D in FY17 – FY18



Implementation started with eJANA project

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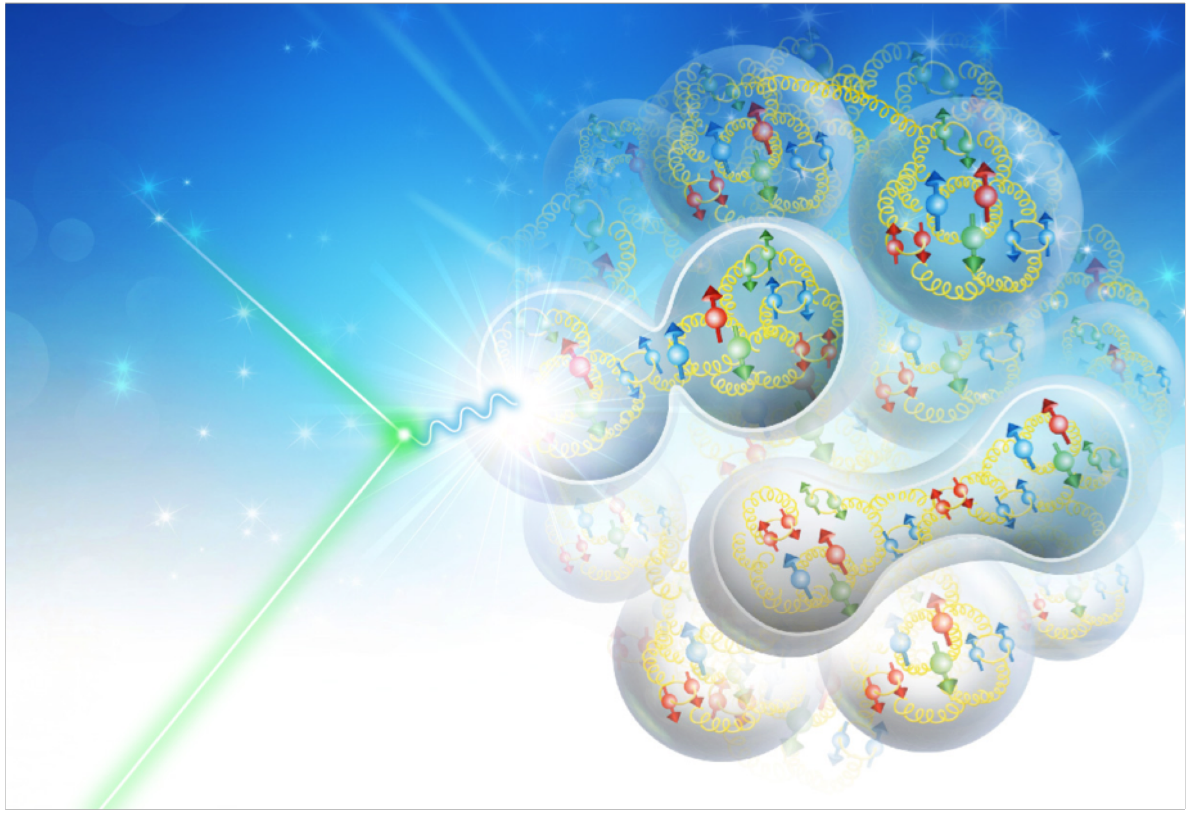
Summary

Electron-Ion Collider (EIC)

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



Computing vision for the EIC

- seamless data processing from DAQ and trigger system to data analysis using artificial intelligence
- integration of DAQ, analysis and theory
- flexible, modular analysis ecosystem

Software Initiatives for the EIC

- EIC Software Consortium
- EICUG Software Working Group
- Website https://eic.gitlab.io