

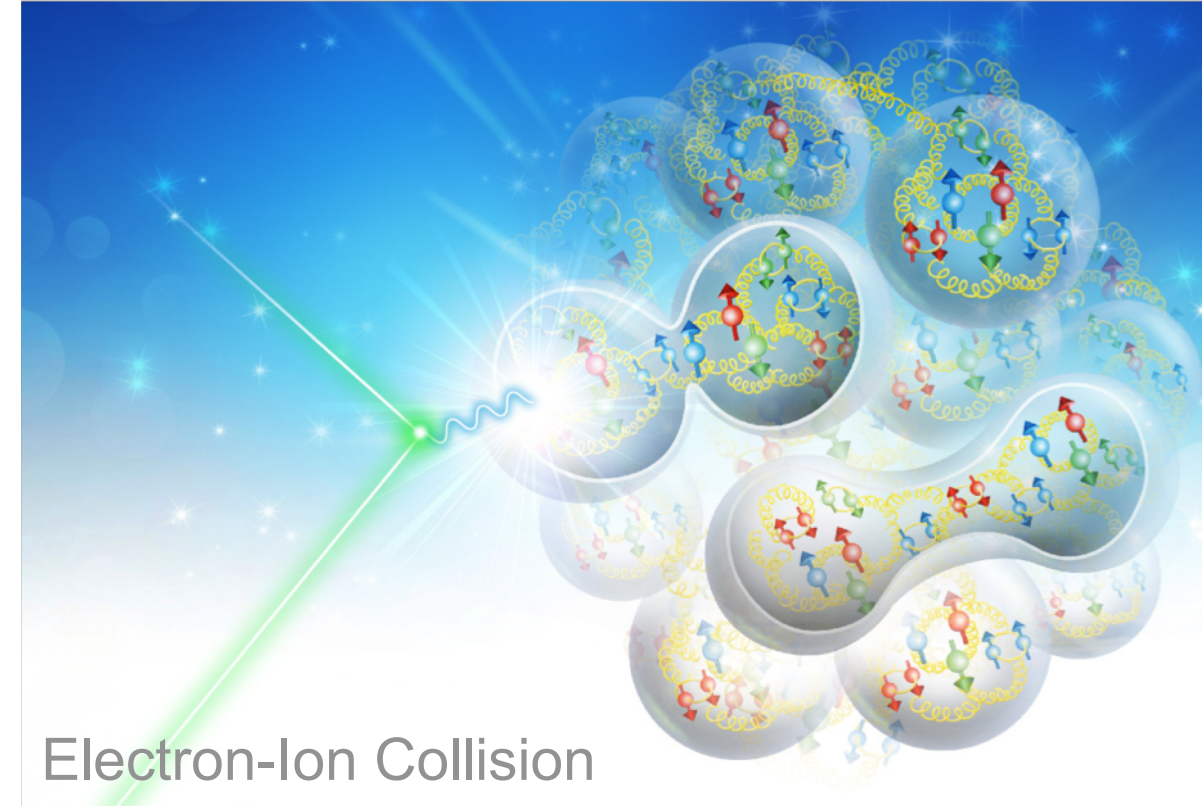
Software Initiatives for the Electron-Ion Collider



EIC SOFTWARE CONSORTIUM

Markus Diefenthaler (Jefferson Lab)

Jefferson Lab



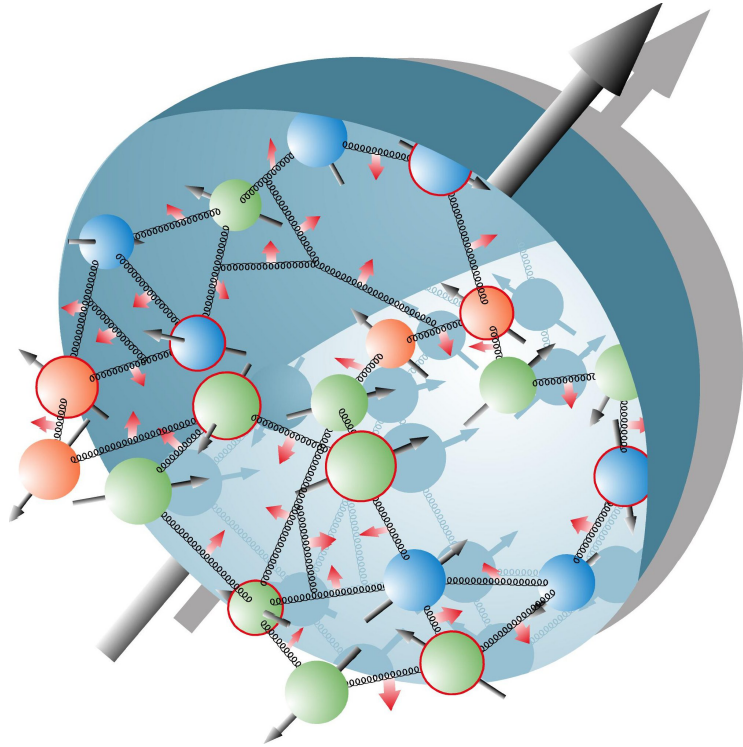
Electron-Ion Collision

A New Frontier in Nuclear Physics

The Electron-Ion Collider (EIC)

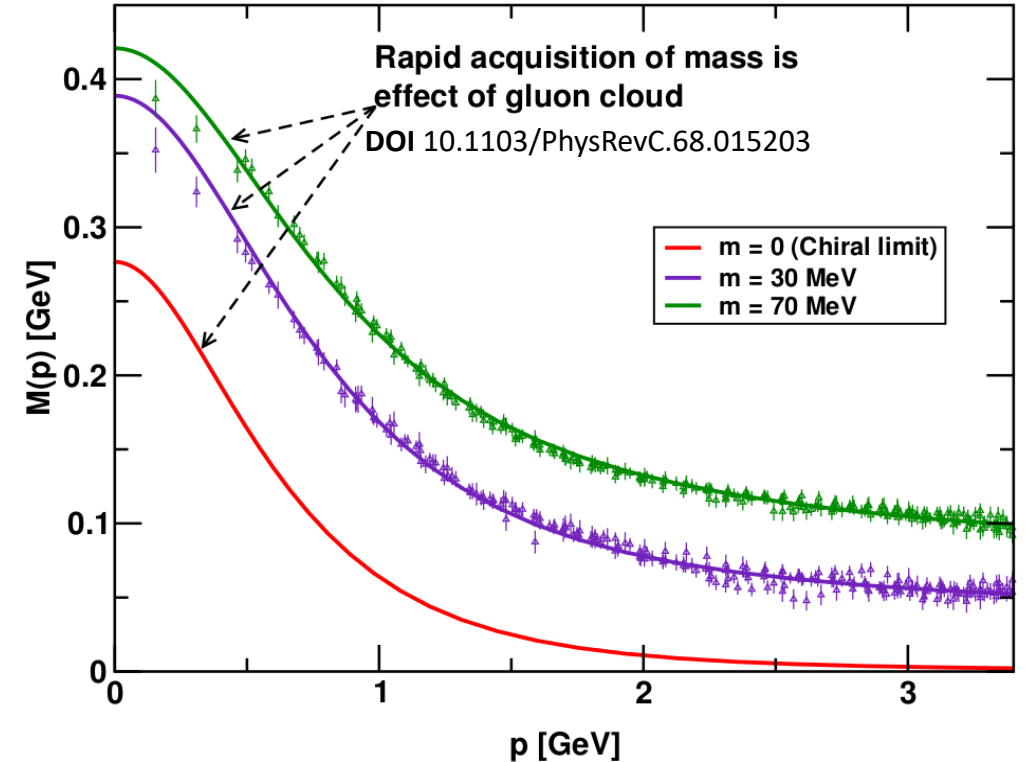
The dynamical nature of nuclear matter

Nuclear Matter Interactions and structures are inextricably mixed up.



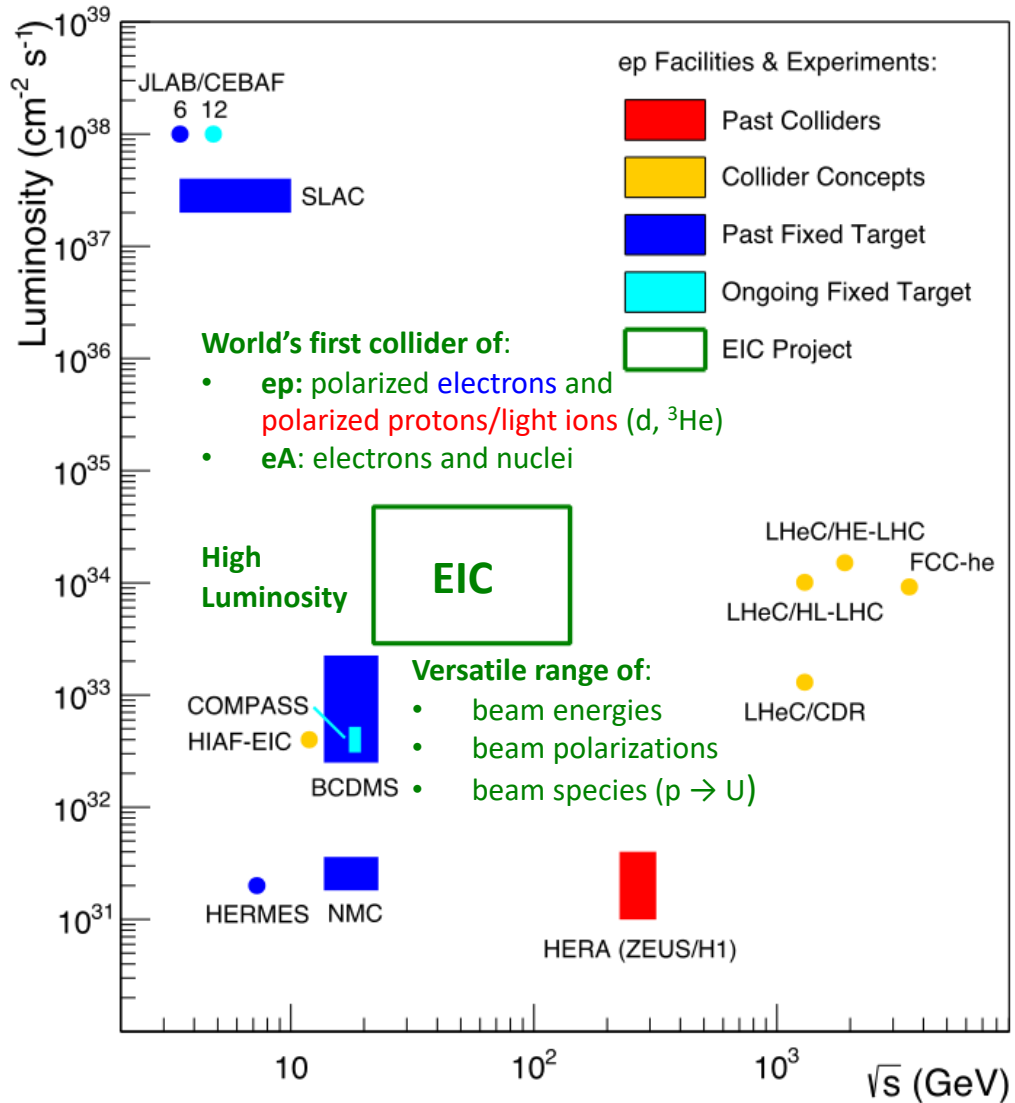
Ultimate goal Understand how nuclear matter at its most fundamental level is made.

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

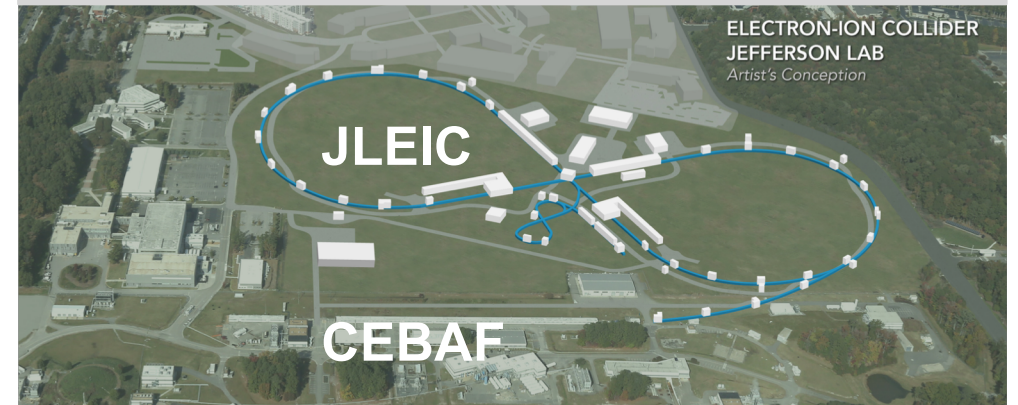


To reach goal precisely image quarks and gluons and their strong interactions in nuclear matter.

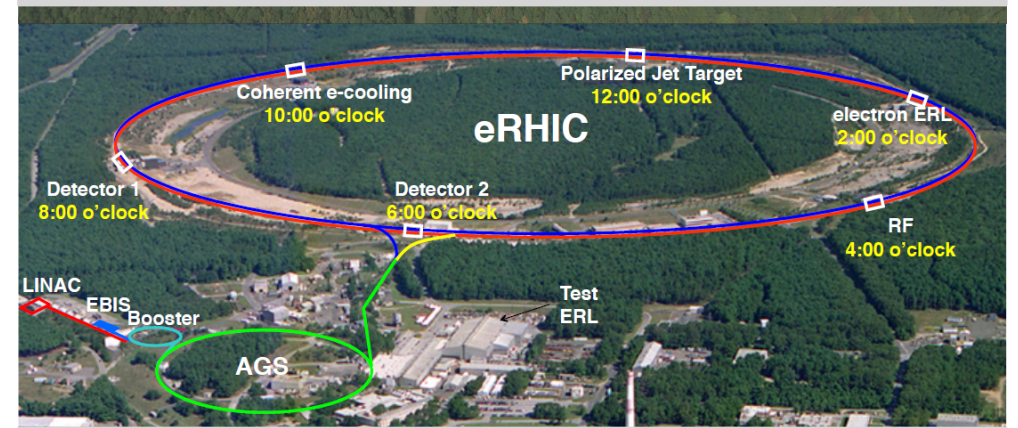
The Electron-Ion Collider: Frontier accelerator facility in the U.S.



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



Proposal by Jefferson Lab



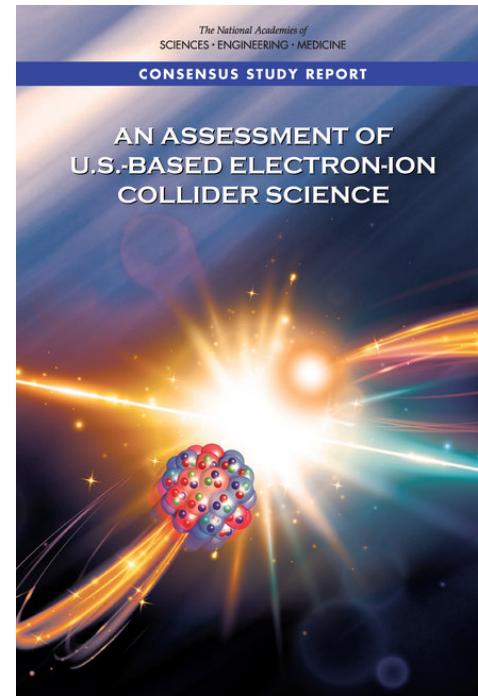
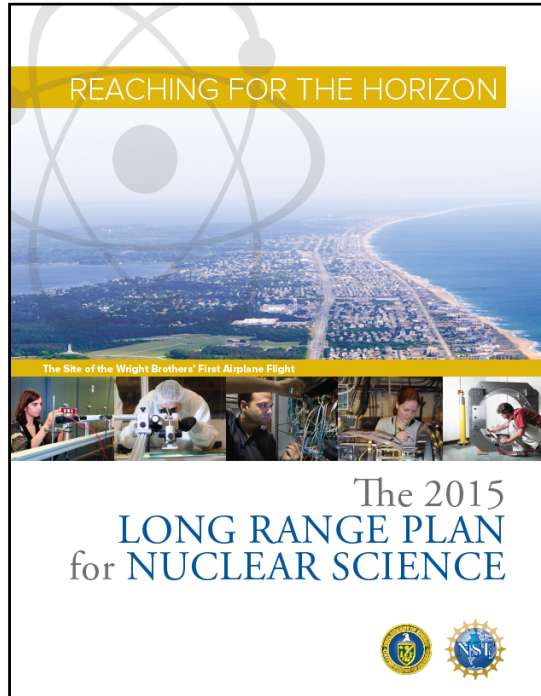
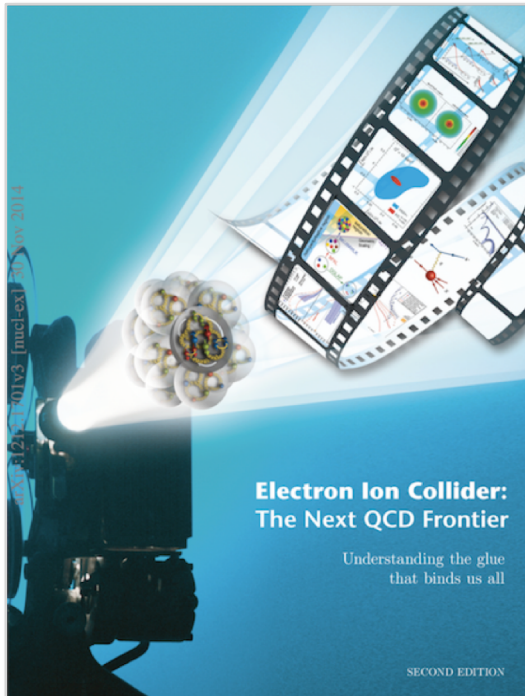
Proposal by Brookhaven Lab

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

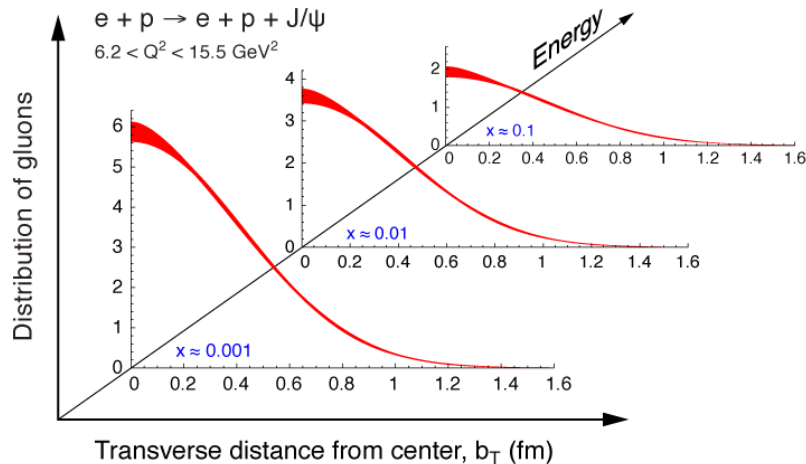
EIC Software Consortium

Computing Challenges in Nuclear Physics

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

multi-dimensional challenges

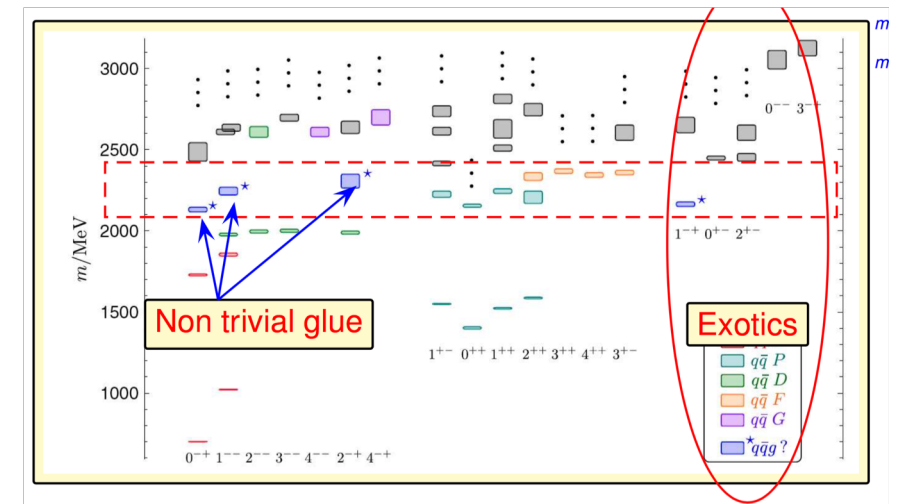
example 3D imaging of quarks and gluons



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



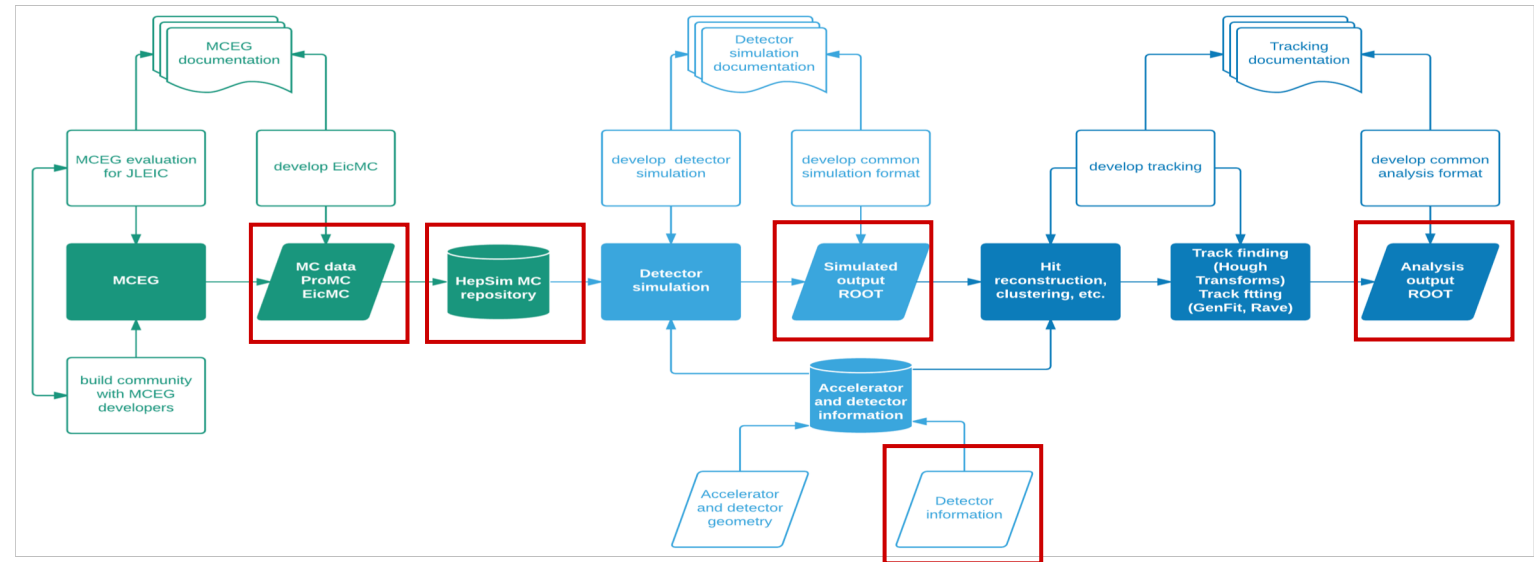
ESC goals and focus

- 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

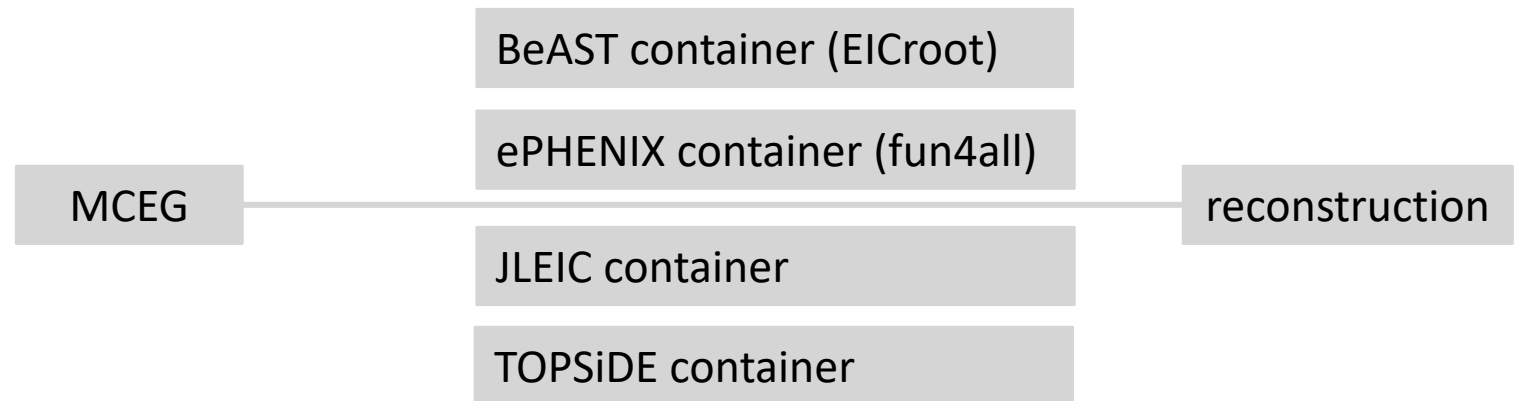
Advice from ILC effort

- 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)

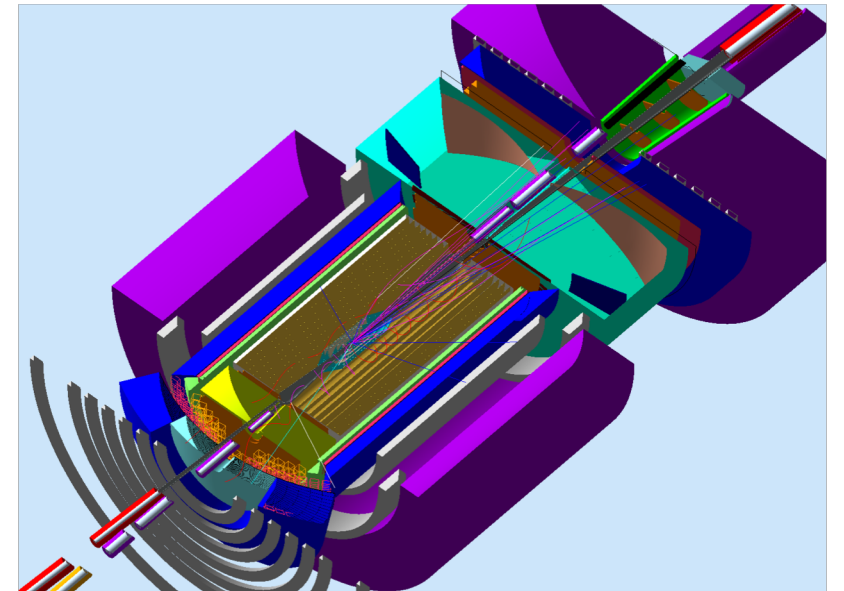
Currently **856 members** from **182 institutions** from **30 countries**.



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



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).

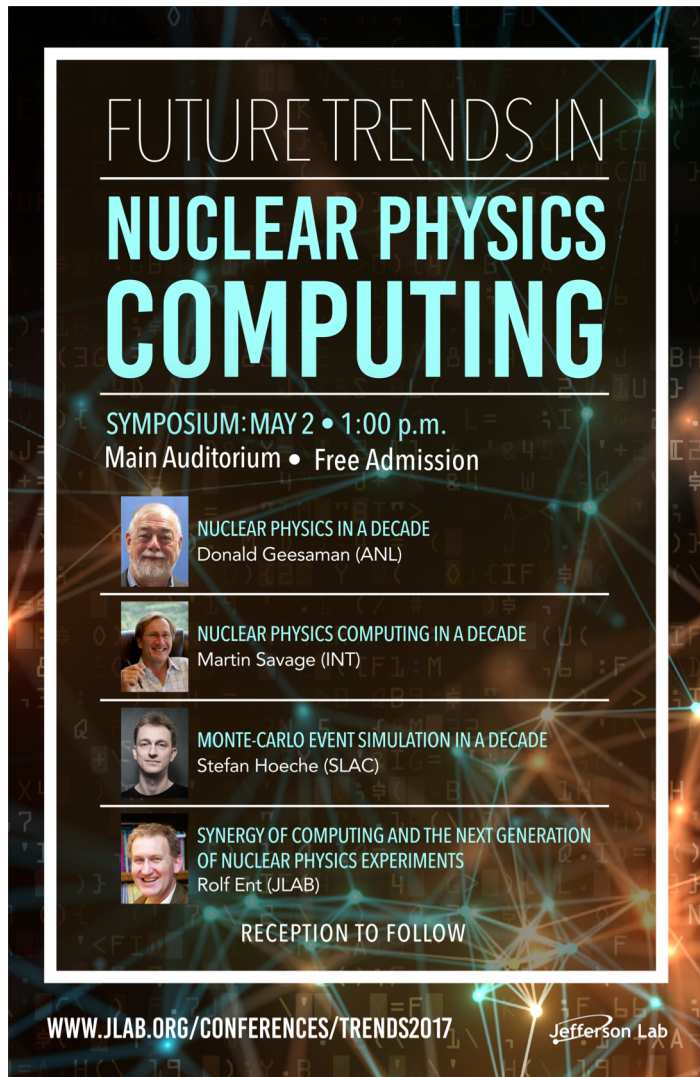
Future compatibility hardware and software

- **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





The poster features a dark background with glowing blue and orange network-like patterns. The title 'FUTURE TRENDS IN NUCLEAR PHYSICS COMPUTING' is prominently displayed in white and cyan. Below the title, the event details are listed: 'SYMPOSIUM: MAY 2 • 1:00 p.m. Main Auditorium • Free Admission'. Four speakers are featured with their names and affiliations: Donald Geesaman (ANL), Martin Savage (INT), Stefan Hoeche (SLAC), and Rolf Ent (JLAB). The Jefferson Lab logo is at the bottom right, and the website 'WWW.JLAB.ORG/CONFERENCES/TRENDS2017' is at the bottom left.


FUTURE TRENDS IN
**NUCLEAR PHYSICS
COMPUTING**

SYMPOSIUM: MAY 2 • 1:00 p.m.
Main Auditorium • Free Admission

 **NUCLEAR PHYSICS IN A DECADE**
Donald Geesaman (ANL)

 **NUCLEAR PHYSICS COMPUTING IN A DECADE**
Martin Savage (INT)

 **MONTE-CARLO EVENT SIMULATION IN A DECADE**
Stefan Hoeche (SLAC)

 **SYNERGY OF COMPUTING AND THE NEXT GENERATION
OF NUCLEAR PHYSICS EXPERIMENTS**
Rolf Ent (JLAB)

RECEPTION TO FOLLOW

WWW.JLAB.ORG/CONFERENCES/TRENDS2017

Jefferson Lab



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

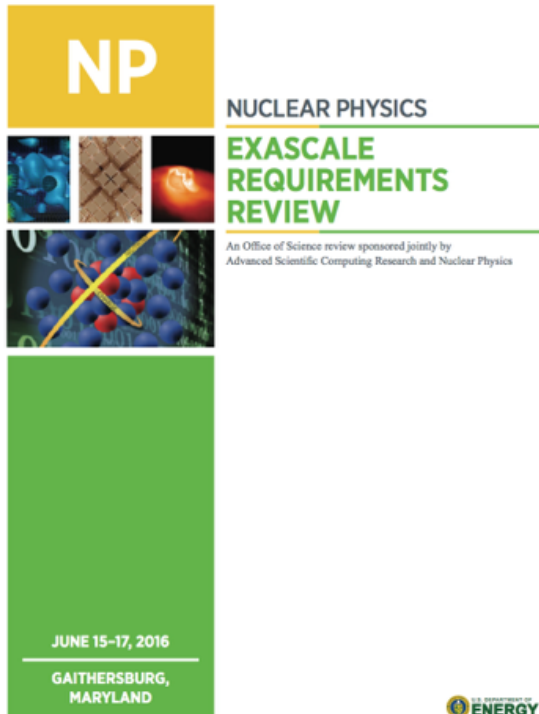


Martin Savage (INT) *"The next decade will be looked back upon as a **truly astonishing period in Nuclear Physics** and in our understanding of fundamental aspects of nature. This will be **made possible by advances in scientific computing** and in how the Nuclear Physics community organizes and collaborates,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

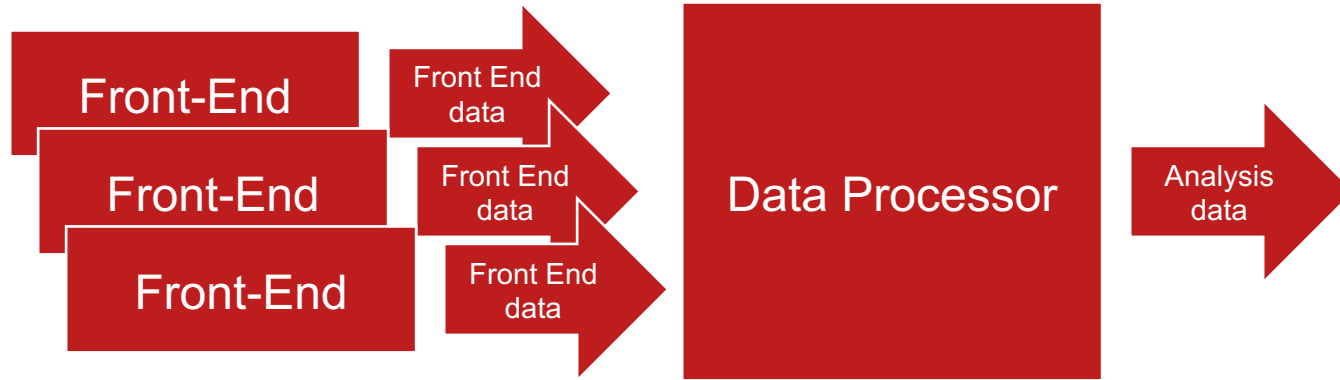


Petascale-capable systems at the beamline

- **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



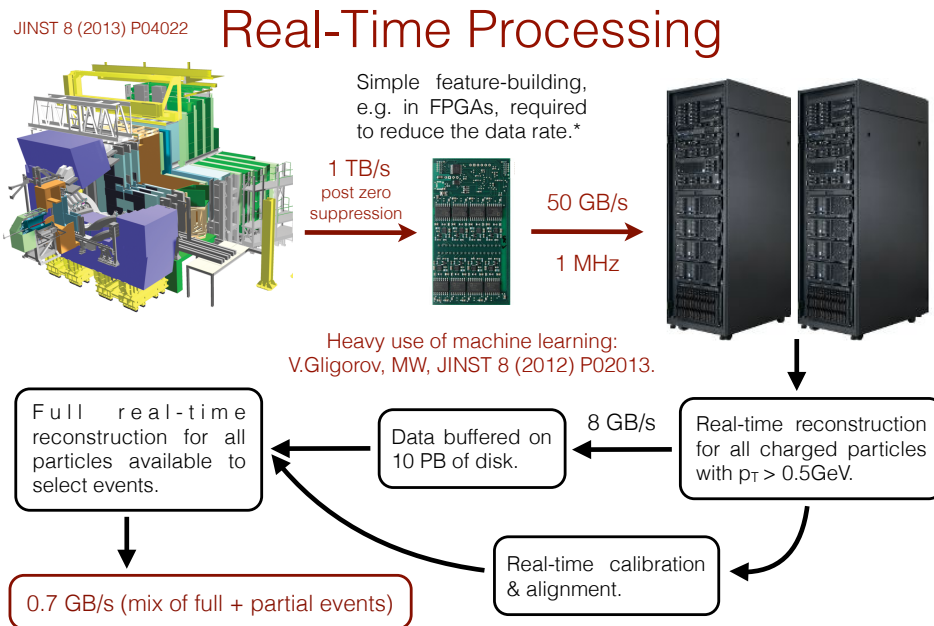
Data Processor

- 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



The poster for the Machine Learning Seminar features a vibrant background of glowing, intersecting lines in shades of blue, purple, and pink, creating a sense of depth and technology. The text is overlaid on a white triangular shape.

EIC² Jefferson Lab
EIC Center at Jefferson Lab

TUESDAY, NOVEMBER 6

MACHINE LEARNING SEMINAR

Machine Learning Seminar
CEBAF Center F113

- 11:00 **Opportunities for infusing physics and domain knowledge into AI/ML algorithms**
Prof. Animeshree Anandkumar (Caltech)
- 13:00 **DOE Scientific Machine Learning & AI Overview**
Dr. Steven Lee (DOE Advanced Scientific Computing Research)
- 13:30 **Study of neural network size requirements for approximating functions relevant to particle physics**
Jessica Stietzel (Notre Dame)
- 14:00 **NERSC's Machine Learning strategy**
Dr. Wahid Bhimji (NERSC)
- 14:30 **Discussion**
- 15:30 **Tag jet identification through the use of neural networks**
Anne-Katherine Burns (William & Mary)
- 15:50 **Machine intelligence applications for particle physics at Fermilab**
Dr. Aristeidis Tsaris (Fermilab)
- 16:30 **Overview of bayesian optimization applied to the GlueX case**
Cristiano Fanelli (MIT)

www.jlab.org/indico/event/247



The poster for MCEGs features a scenic view of a city at dusk, with buildings and a church spire reflected in the water. The text is overlaid on a white diagonal band.

February 20-22, 2019
DESY Hamburg, Germany

EIC User Group and MCnet present

MCEGs

for future ep and eA facilities

PROGRAM

- Updates to general-purpose MCEG for ep /eA
- Status of NLO simulations for ep/eA
- GPDs and TMDs in MCEGs
- QED+QCD effects in ep/eA simulations

ORGANIZERS

- Elke-Caroline Aschenauer (BNL)
- Andrea Bressan (INFN Trieste)
- Markus Diefenthaler (JLAB)
- Hannes Jung (DESY)
- Simon Plätzer (University of Vienna)
- Stefan Prestel (Lund University)

www.desy.de/mceg2019



The poster for the EIC Software Meeting features a night view of a city with historic buildings and a canal. The text is overlaid on a white rectangular box.

EIC

Software Meeting

May 20-21, 2019
Trieste, Italy

We will discuss the status of the simulation software for the EIC and will provide the tutorials for simulation tools. There will be contributions by members of the EIC Software Consortium and the EICUG Software Working Group as well as members from the HEP community. The meeting will also include a joint session with the INFN School on "Machine learning in High Energy Physics" that will be held in parallel to our meeting.

Organizers:
Andrea Bressan (INFN Trieste), Markus Diefenthaler (JLab), Alexander Kiselev (BNL)

For More Information:
<https://agenda.infn.it/event/17249/>

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 necessary modules.

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

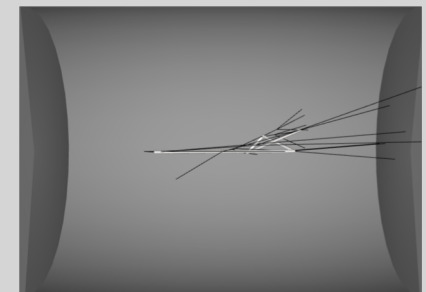
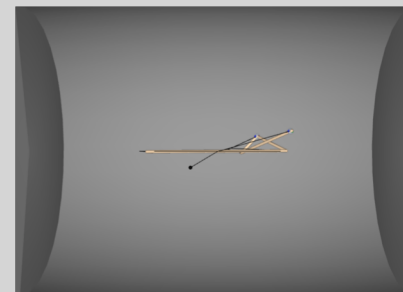
Now we create a Pythia 8 object and apply the settings to define the incoming beams. More settings can be adjusted later.

```
M 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 Collaboration**
 - 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

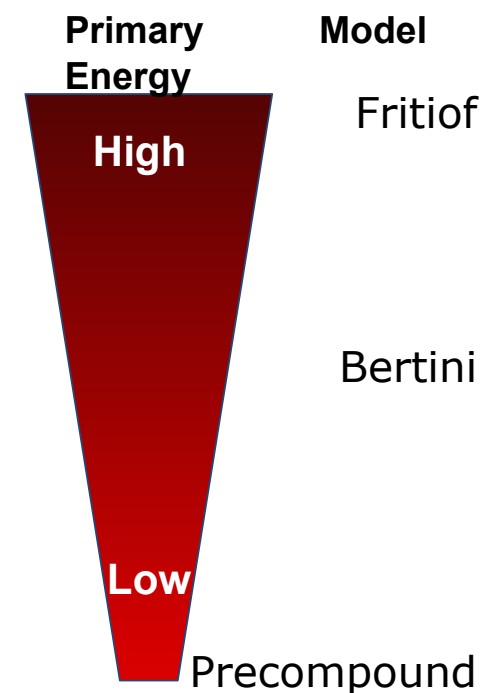
Technical forum on EIC as part of

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



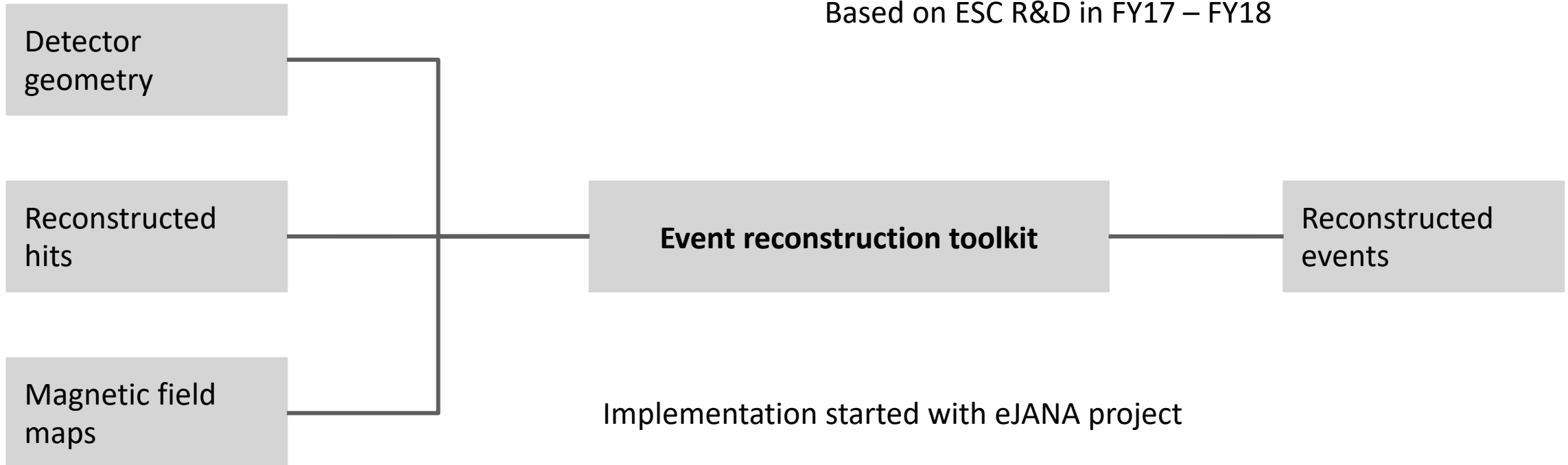
Community reference reconstruction

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



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>

