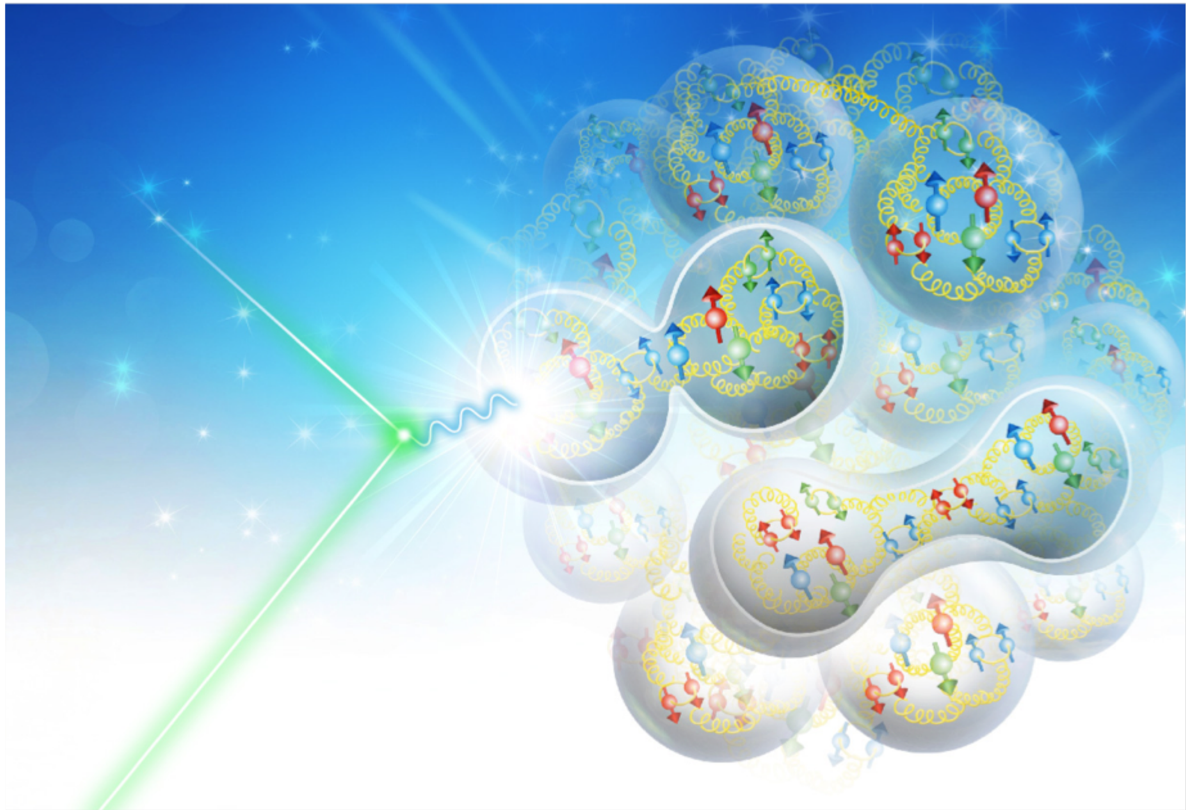
Open and new requirements: Nuclear Physics experiments

09/24 Geant4 Technical Forum at 4:00 p.m.

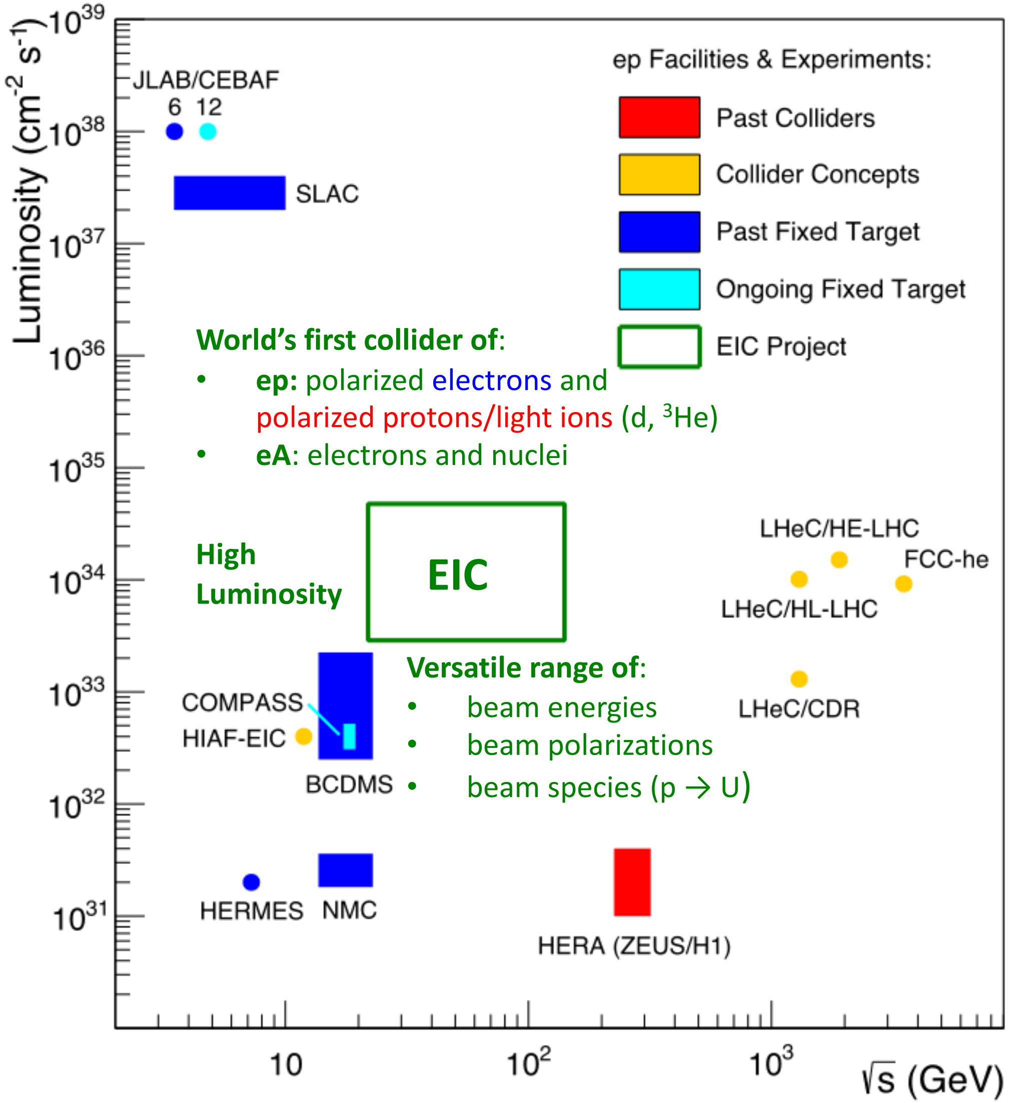
- highlight Nuclear Physics
- reports from JLAB 12 GeV Science programs (CLAS12, GlueX), RHIC (sPHENIX), and Electron-Ion Collider

Today Focus on Electron-Ion Collider

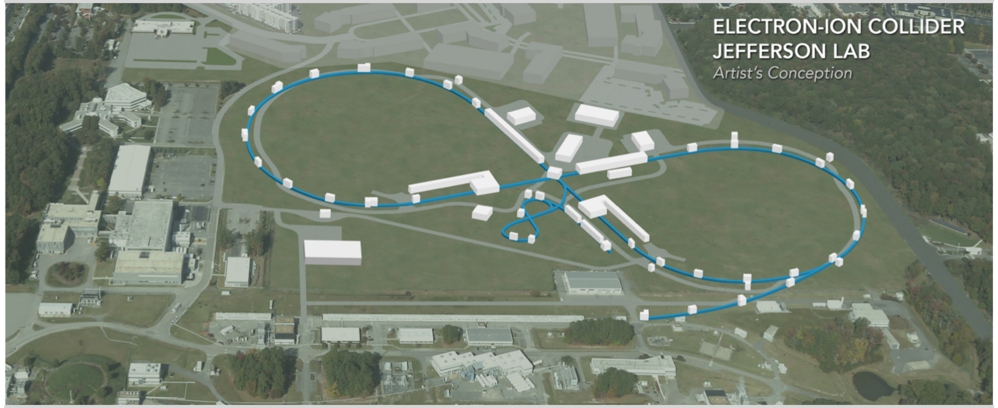
Markus Diefenthaler (EIC Center, EICUG)



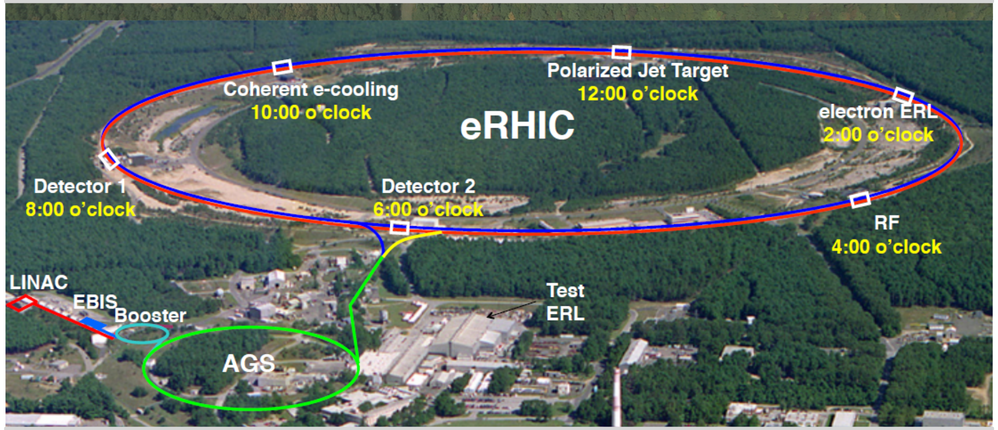
The Electron-Ion Collider: Frontier accelerator facility in the U.S.



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

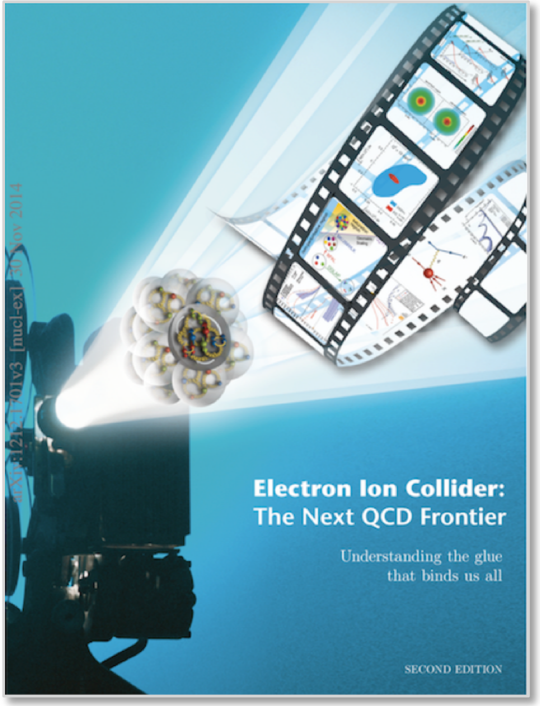


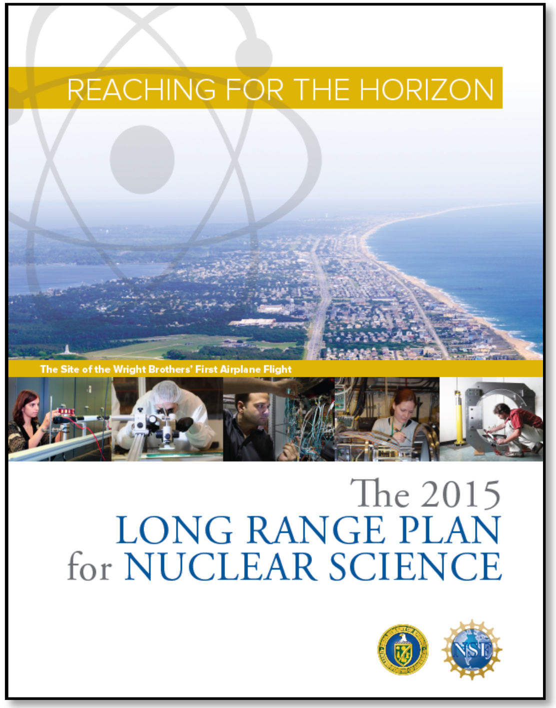
Proposal by Jefferson Lab

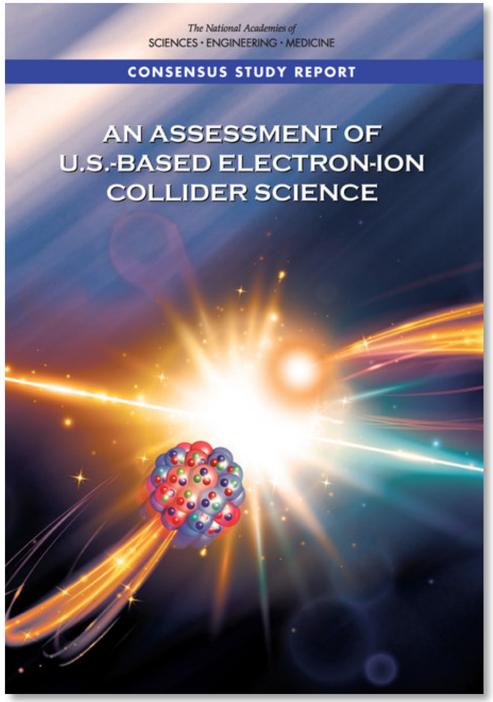


Proposal by Brookhaven Lab

Why an Electron-Ion Collider?







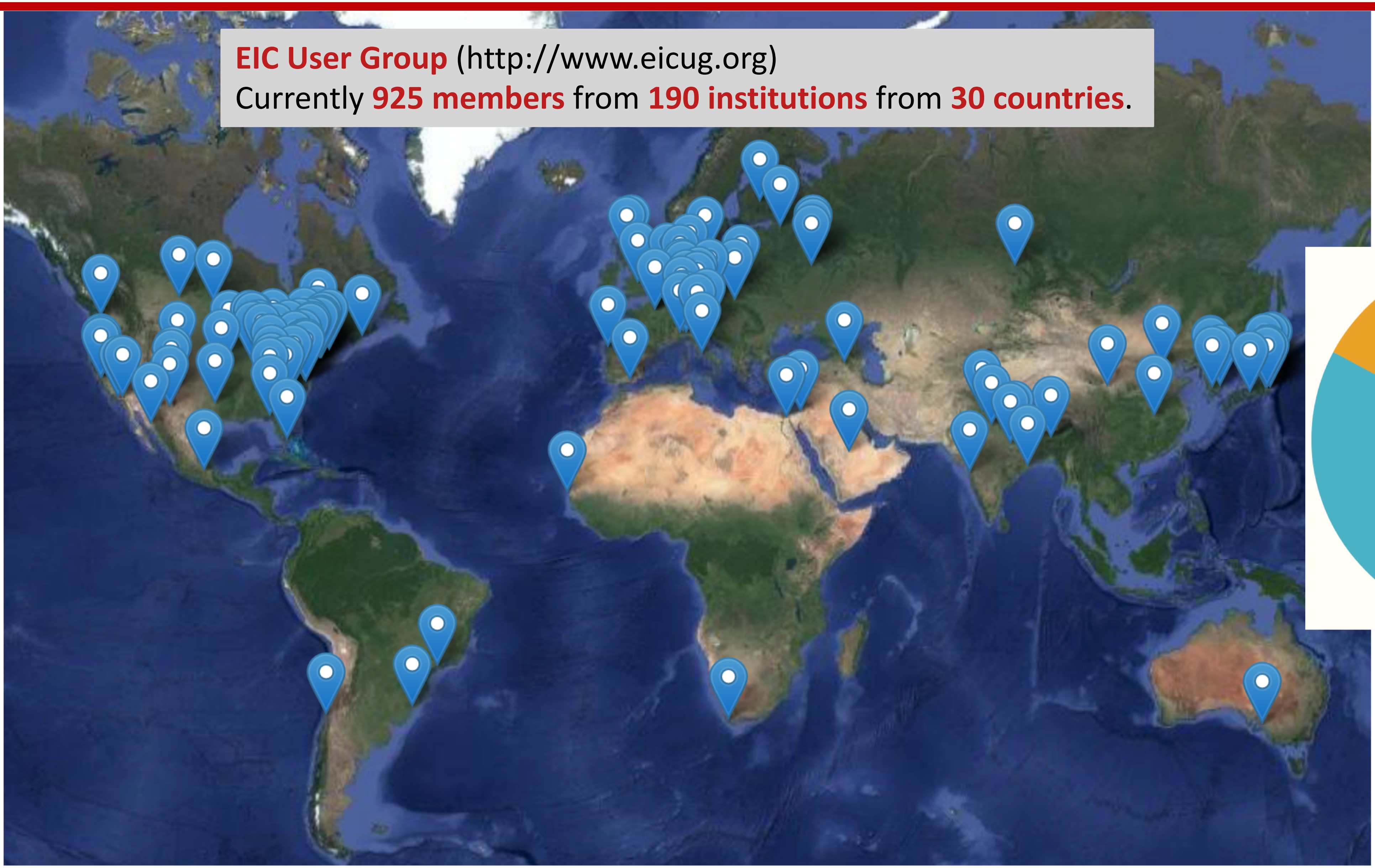
Right tool

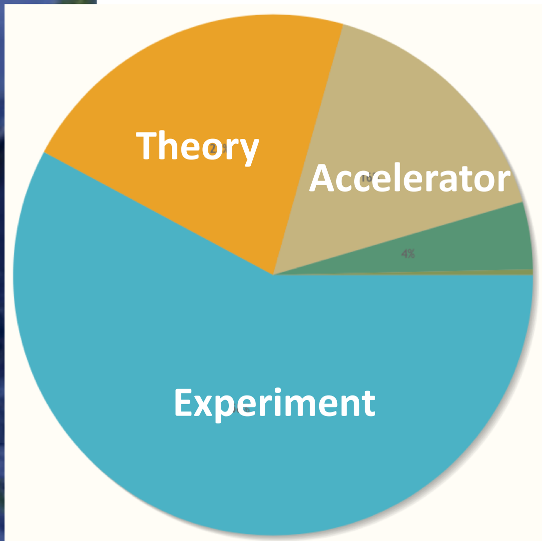
- to precisely **image quarks and gluons** and their interactions
- to explore the new **QCD frontier of strong color fields in nuclei**
- to understand **how matter at its most fundamental level is made**.

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.

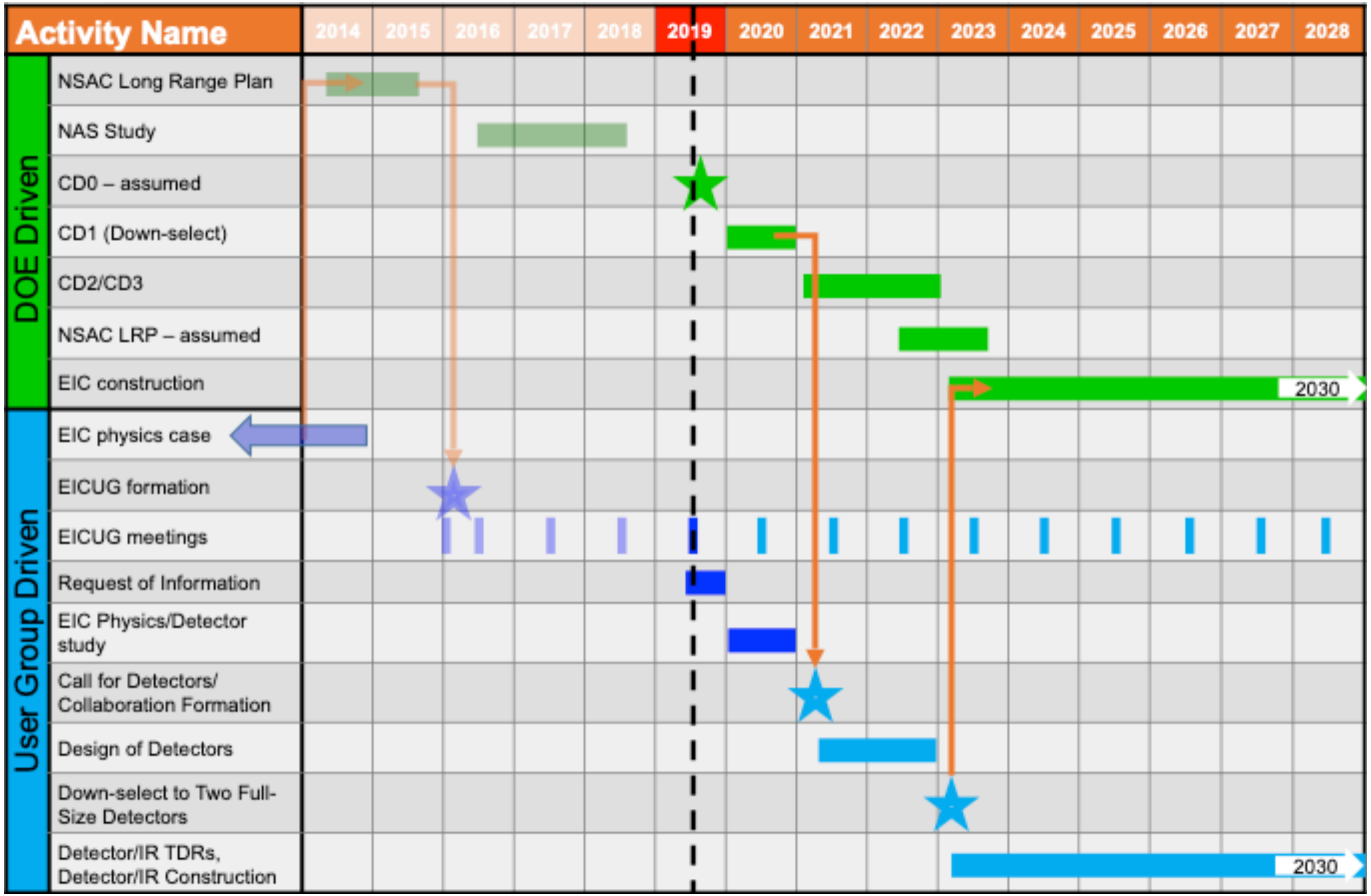
The worldwide EIC community

EIC User Group (http://www.eicug.org)
Currently **925 members** from **190 institutions** from **30 countries**.





Timeline

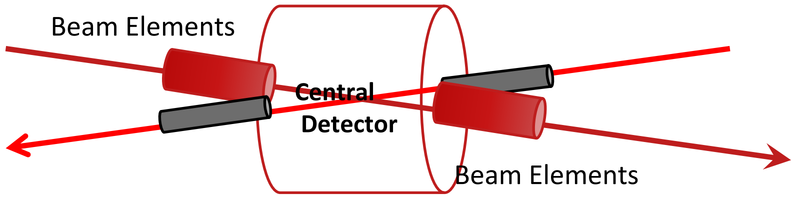


Activity Name
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
DOE Driven
NSAC Long Range Plan
NAS Study
CD0 – assumed
CD1 (Down-select)
CD2/CD3
NSAC LRP – assumed
EIC construction
2030
User Group Driven
EIC physics case
EICUG formation
EICUG meetings
Request of Information
EIC Physics/Detector study
Call for Detectors/ Collaboration Formation
Design of Detectors
Down-select to Two Full-Size Detectors
Detector/IR TDRs, Detector/IR Construction
2030

Machine-Detector Interface (MDI)

Integrated interaction region and detector design to optimize physics reach

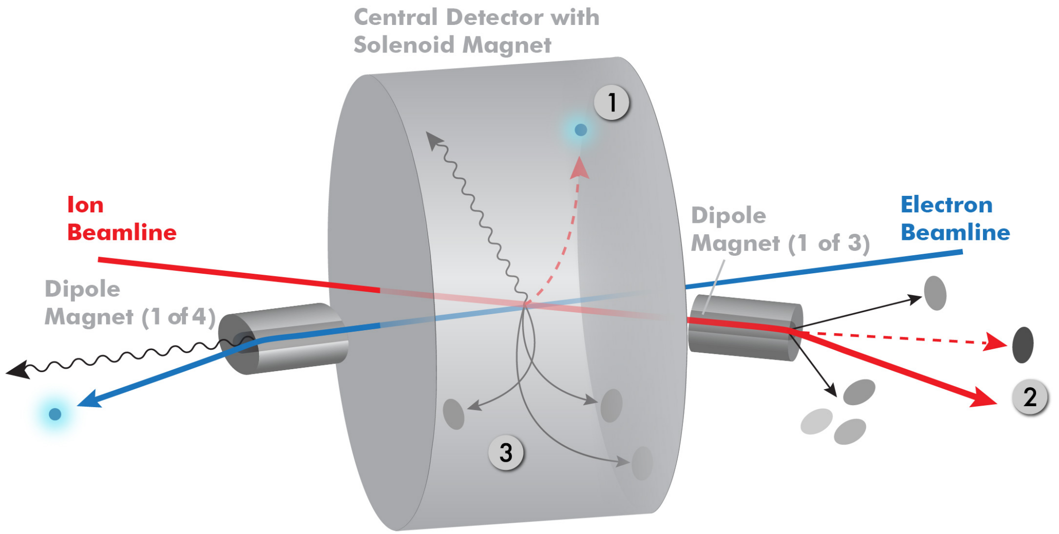
The aim is to get **~100% acceptance** for all final state particles, and measure them with good resolution.



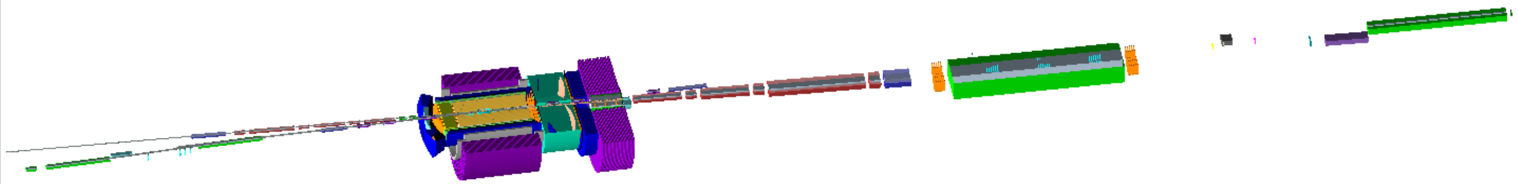
Experimental challenges:

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

Possible to get ~100% acceptance for the whole event.



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



Beyond MDI

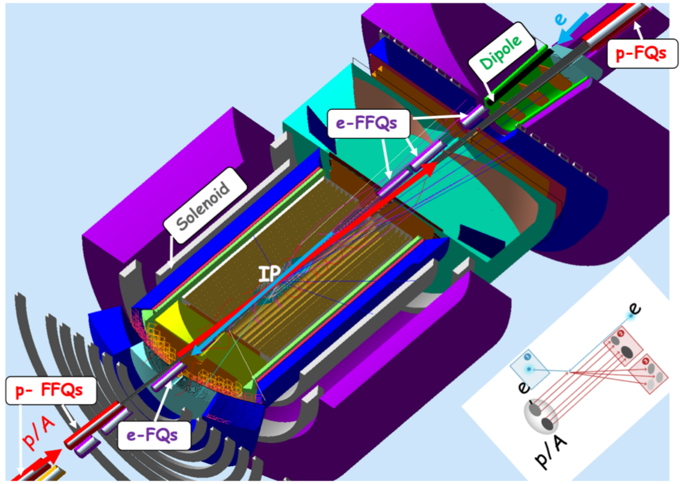
Integration of DAQ, analysis and theory to optimize physics reach

Integration of DAQ, analysis and theory

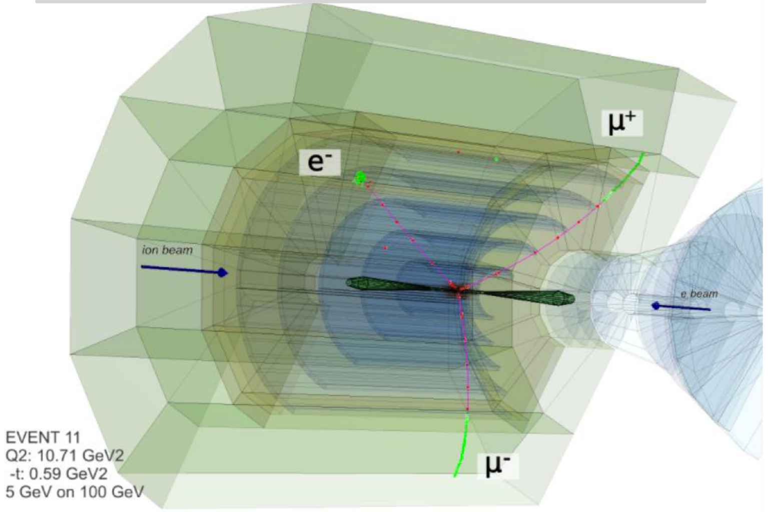
- research model with seamless data processing from DAQ to data analysis using A.I. and strong interplay of experiment - theory
- not about building the best detector
- but the best detector that fully supports streaming readout and fast algorithms for real-time analysis

Central detector concepts

JLEIC Detector



TOPSiDE (ANL)

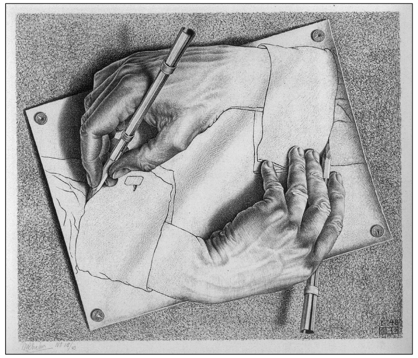


EIC Generic Detector R&D program, since 2011

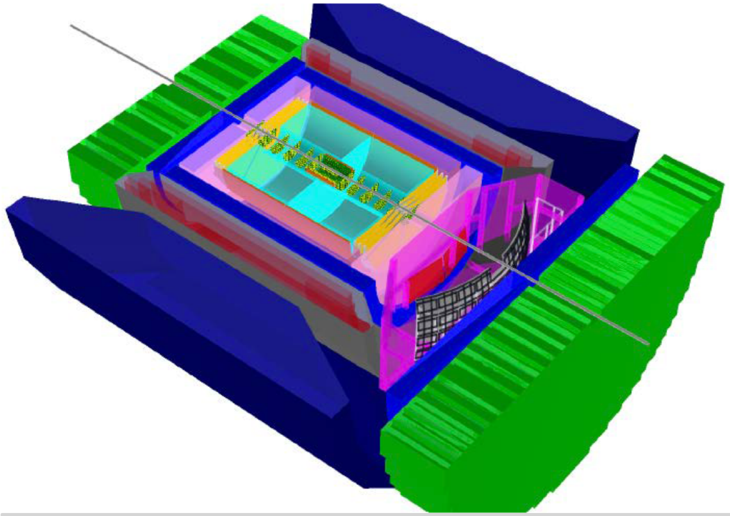
Electron-Ion Collider
Detector Requirements and
R&D Handbook

DRAFT 8 - December 15, 2018

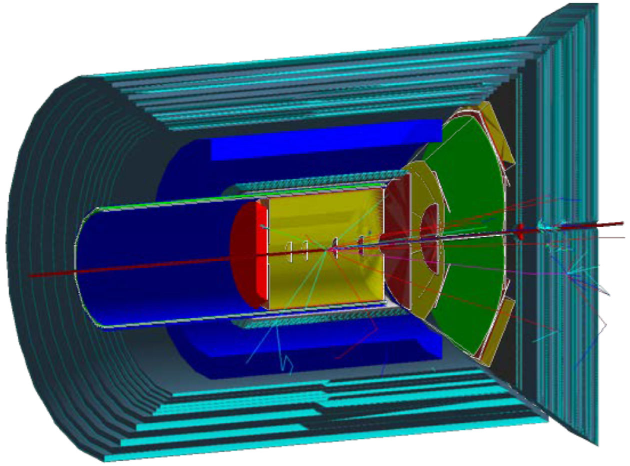
Editors:
Alexander Kiselev
Thomas Ullrich



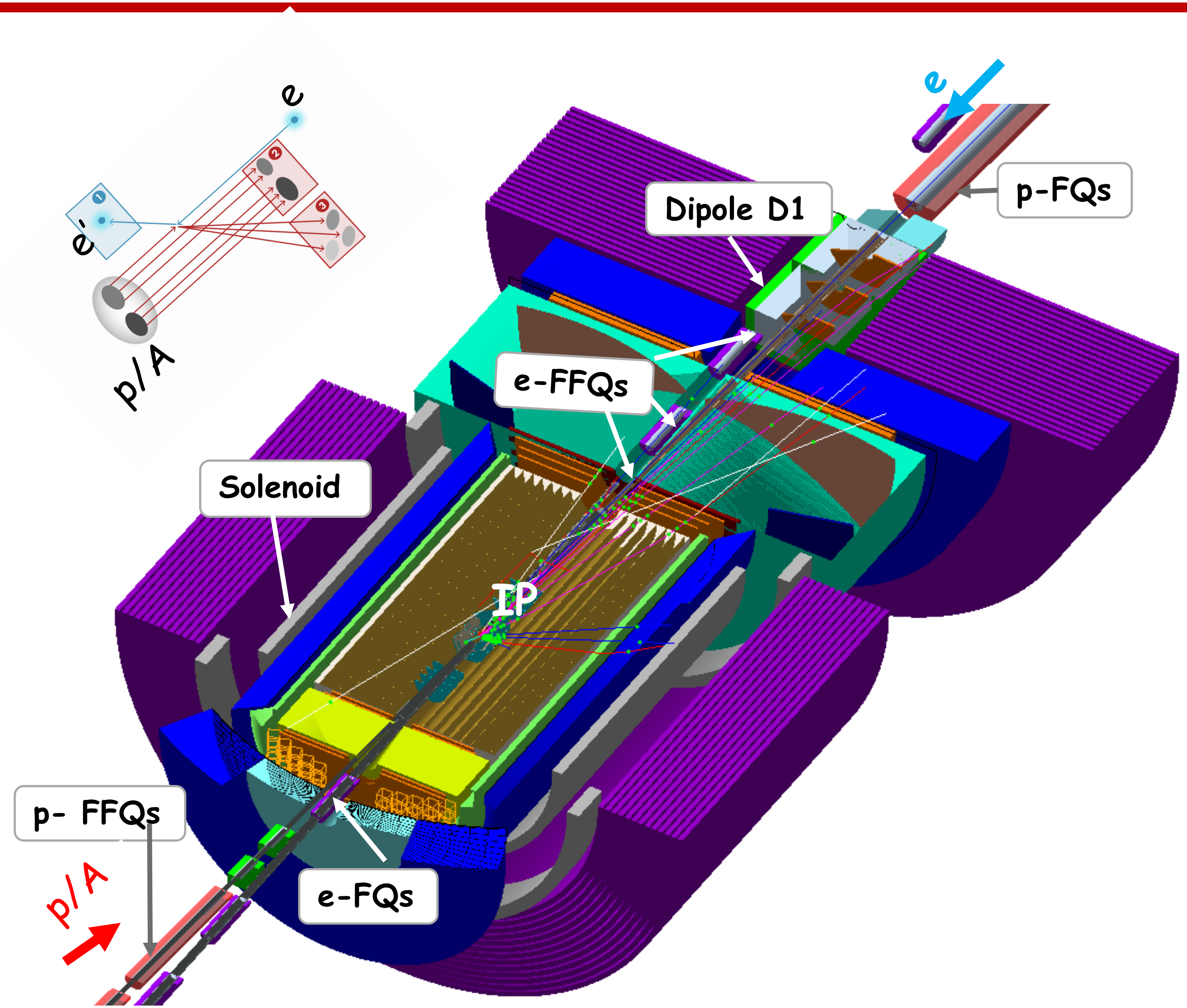
eRHIC Detector



eRHIC "Day 1" Detector

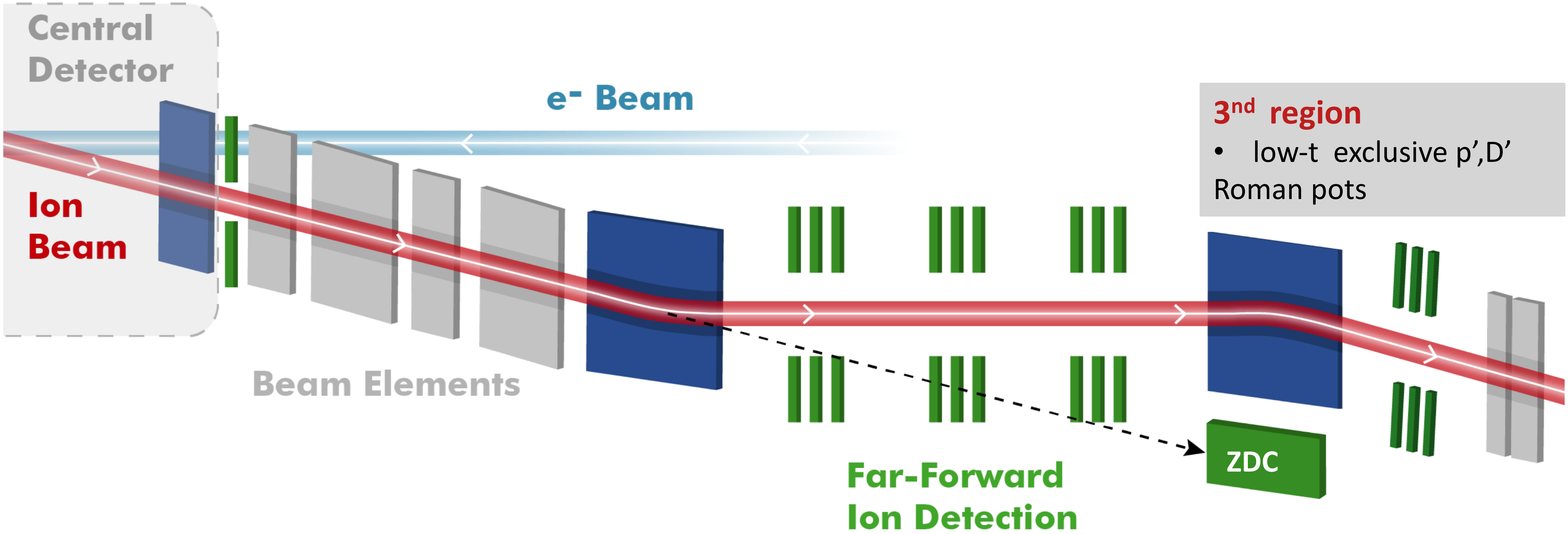


Central detector example



- **General purpose detector with** asymmetric design (due to asymmetric beam energy)
  - Solenoid: 2Tesla (ca 4m long, R ~ 1.6m)
  - currently 40cm IP shift
  - close to 4π coverage:
  - Barrel: -1.3 <η < 1.5
  - Endcaps: up to η ~ |3.5|
- Several options for **central tracking** (straw tubes, Drift chambers, all-Si)
- **Vertex detector** (barrel, disks along the beam line)
- **EM calorimeter** (crystals, glass)
- **Particle identification** (e,μ,π, K, p, etc): mRICH,DIRC, dualRICH

Forward-detection example



3rd region
- low-t exclusive p',D'

Roman pots

1st region for remnant
- high theta/ P_T spread particles, before FFQs beam elements

Small dipole is instrumented into the hadron-endcap covering angles up to ~3°
Silicon discs

2nd region
- decay products of (Λ, Σ, etc.)
- high-t exclusive p', D', etc.
- for neutrons: 10mrad cone - bore opening for particle passing through accelerator quads

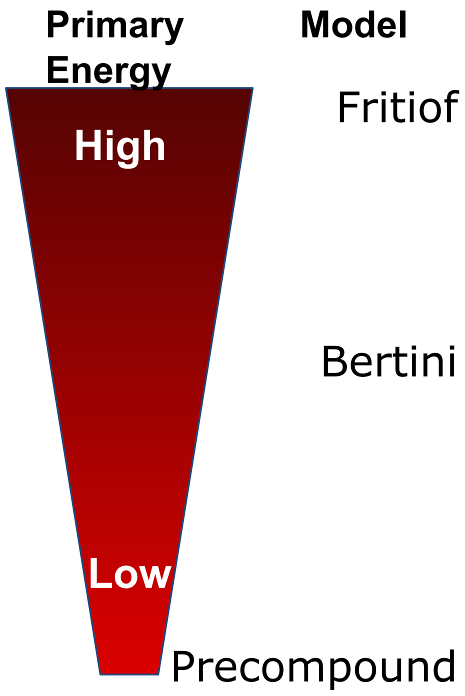
Roman pots, ZDC

Detector Simulation

- **Geant4 for full simulations**
- **collaboration with Geant4 International Collaboration**
  - **kiaison** Makoto Asai (SLAC)
  - knowledge transfer (e.g., sub-event parallelism or tessellated solids)
  - coordinate input for Geant4 validation based on EIC physics list maintained by SLAC Geant4 group
- **Detector Simulation R&D**
  - containers and tutorials for EIC detector simulations
  - fast simulations in Geant4?
    - For factor 2-10, technologies already exist (e.g. gflash or biasing in G4)
    - More needed? If so, how to develop technologies?

EIC

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



Jefferson Lab

Improved photo-nuclear and electro-nuclear reactions in Geant4

Status

- **High-energy physics** Photo-nuclear and electro-nuclear reactions implemented for simulating high-energy interactions in calorimeters. Relatively simple models were implemented (to speed up simulations) which produced good average behavior.
- **Nuclear Physics** Detailed modeling of photo-nuclear and electro-nuclear reactions required at energies of 15 GeV and below:
  - JLAB 12 GeV Science program with photon and electron beams
  - EIC detector and physics simulations related to forward collision products

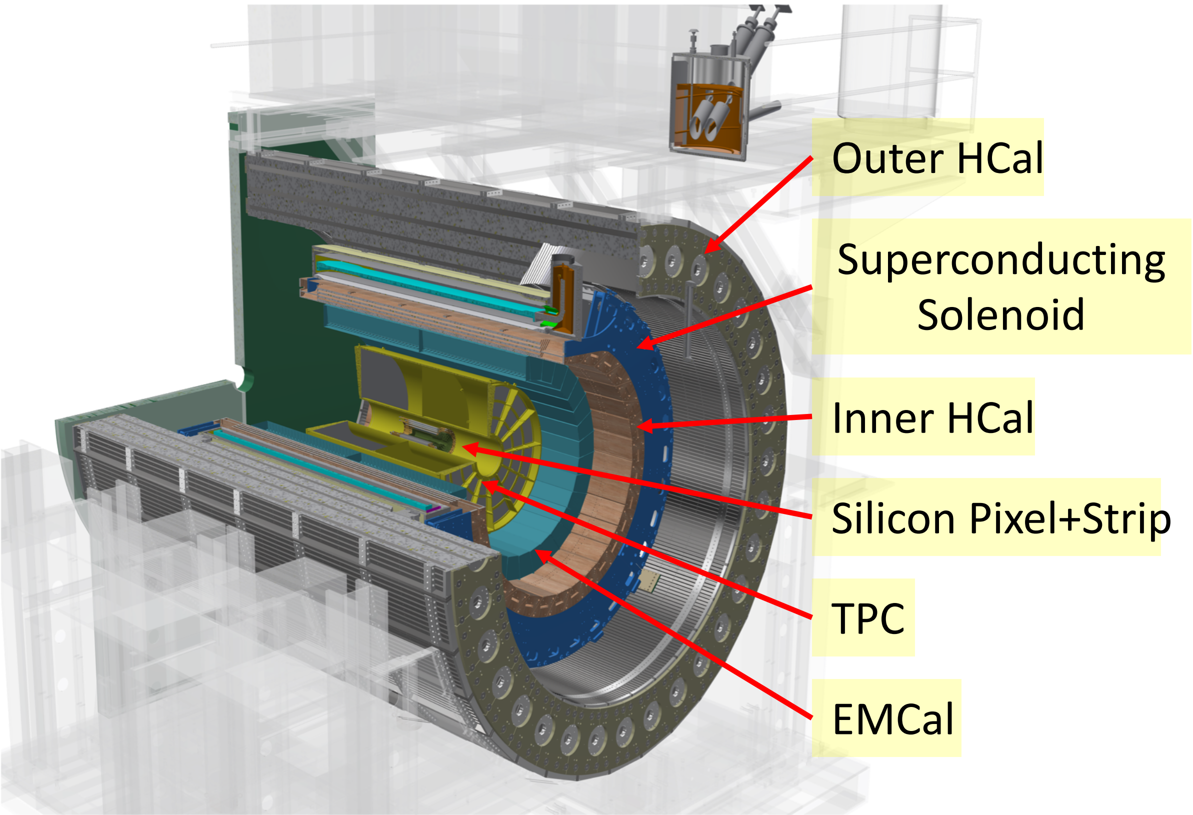
Requests

- Electro-nuclear models rely on Weizsacker-Williams approximation. Not sufficient for high-intensity and high precision electron scattering. The full, off-shell electron scattering vertex must be implemented for nucleons within the nuclear target.
- Bertini cascade has been shown to overproduce protons and neutrons in the form of a *knee* near the kinematic endpoints of reactions at 4.5 GeV. This appears to be unphysical and needs to be addressed.
- **Improvements** directly applicable at high-energy colliders:
  - detailed simulations of ultra-peripheral reactions
  - detailed simulations for reactions with low-energy fission products
  - further understanding for environmental and cosmic backgrounds for fundamental symmetry experiments

sPHENIX – Second Generation Heavy Ion Experiment at RHIC

Science mission:

Study the Quark Gluon Plasma structure at multiple scales



Typical collider detector

Full hadronic and electromagnetic calorimetry

→ Jet measurements

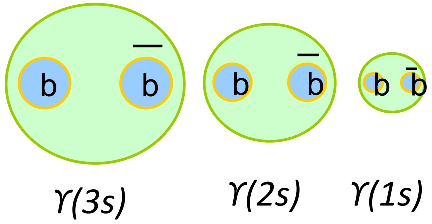
Precision Tracking system: Silicon pixel + Silicon Strip + TPC

→ Jet structure

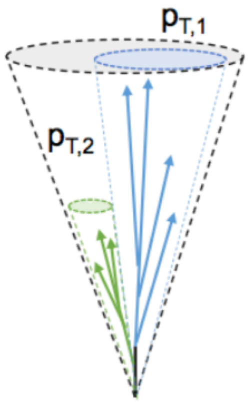
→ Resolve all three Upsilon states

3 year run plan, first beam in 2023

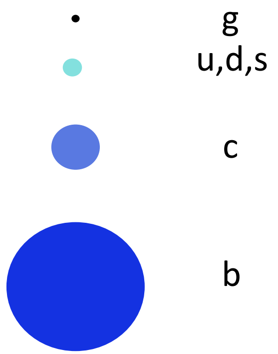
Quarkonium spectroscopy
vary size of probe



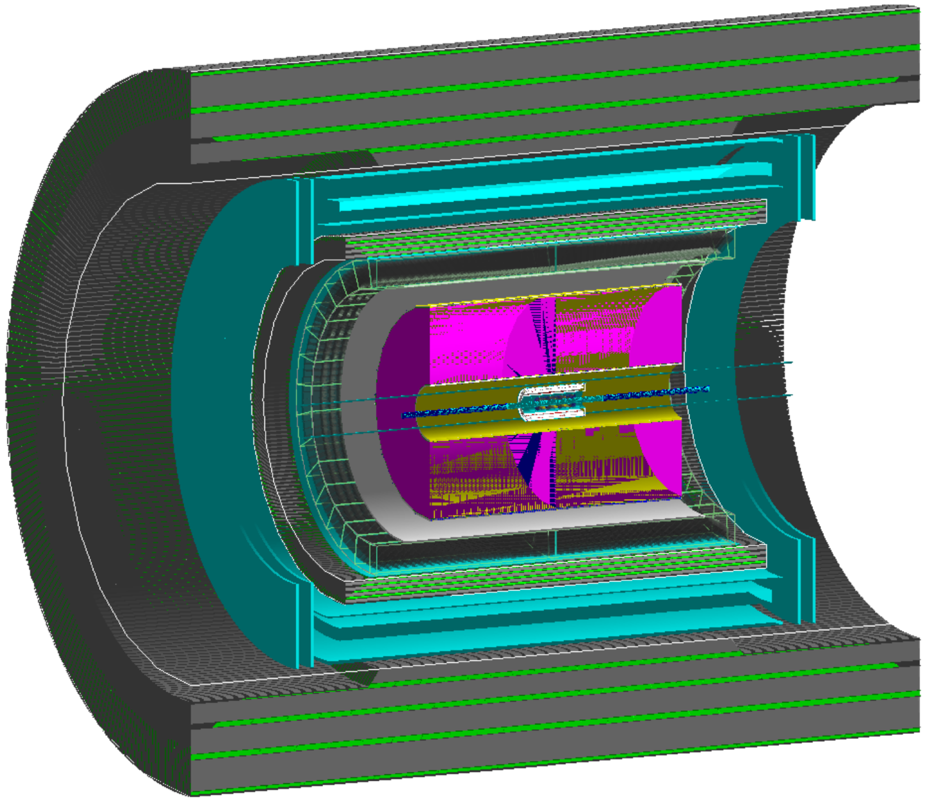
Jet structure
vary momentum/angular scale of probe



Parton energy loss
vary mass/momentum of probe



sPHENIX Simulations



Direct Impacts on sPHENIX detector design:

Design of hadronic calorimeters

- Plate tilt angle
- Material (Steel vs Al for inner HCal)

Energy Resolution and e/π separation for EMCal

Number of layers for the Silicon Strip detector

Thickness of the TPC central membrane

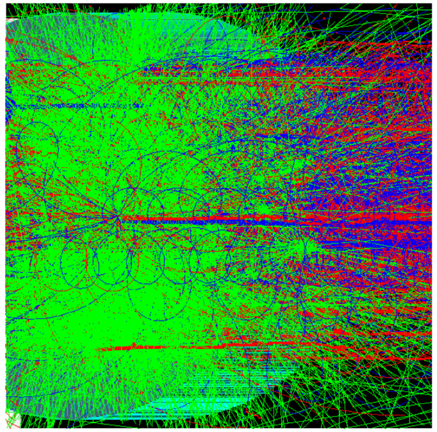
Ongoing:

Development of Tracking Algorithms, secondary vertex finding

TPC distortion correction development

Verification with Test Beam data, improve e/π separation

Jet finding and unfolding, upsilon reconstruction



Very peripheral heavy ion collision from hijing

Markus Diefenthaler

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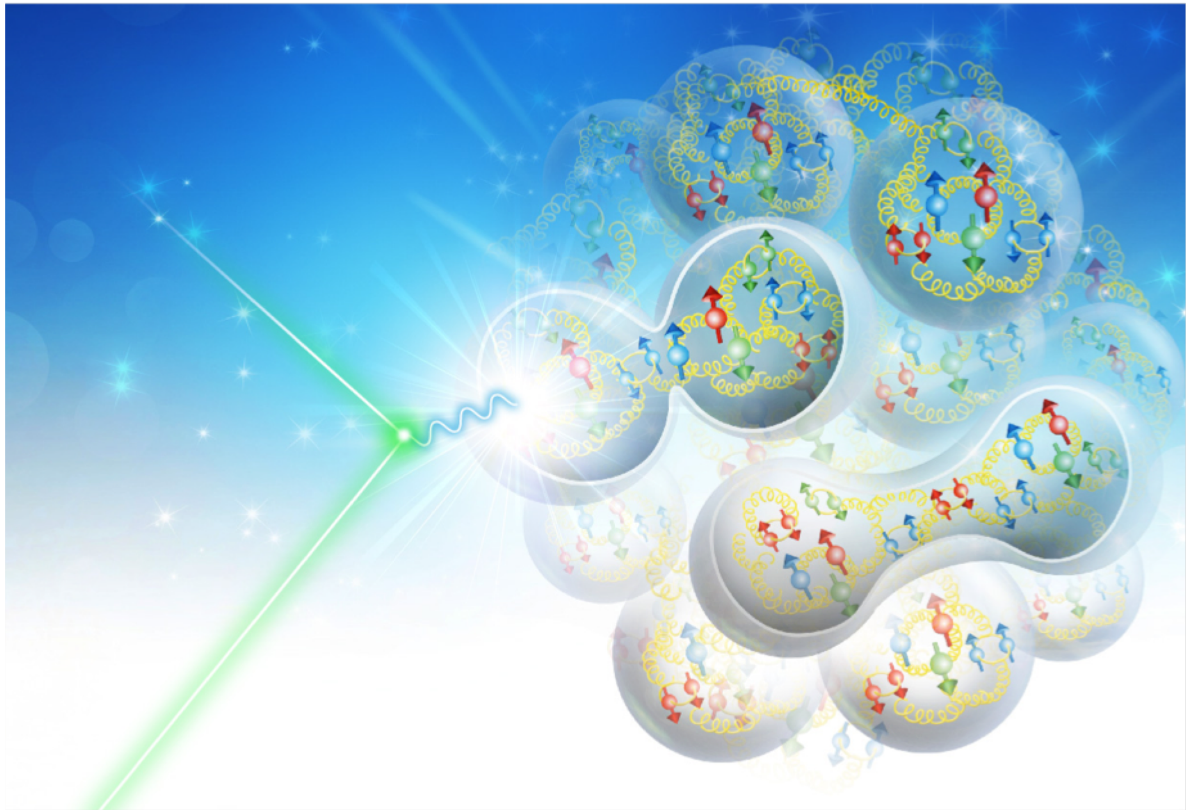
Summary

09/24 Geant4 Technical Forum at 4:00 p.m.

- highlight Nuclear Physics
- reports from JLAB 12 GeV Science programs (CLAS12, GlueX), RHIC (sPHENIX) and EIC
- requests, e.g., improvement of photo-nuclear and electro-nuclear reactions



A new frontier in Nuclear Physics:

- Electron-Ion Collider project
- EIC detector and physics simulations rely on Geant4
- maintain EIC physics lists
- knowledge transfer (e.g., sub-event parallelism or tessellated solids)