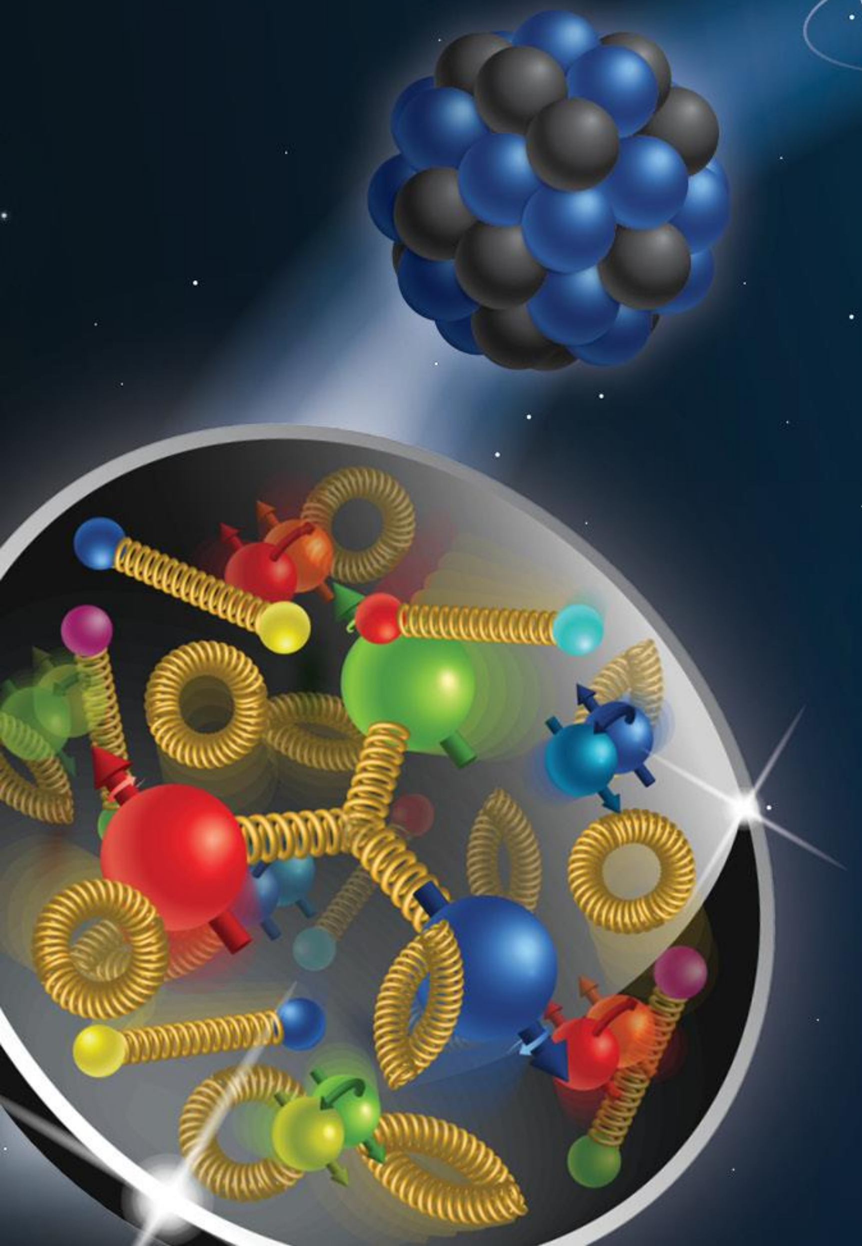


Electron Ion Collider Vacuum Considerations

Marcy Stutzman

For the EIC Interaction Region Background Collaboration

Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY Jefferson Lab U.S. DEPARTMENT OF ENERGY Office of Science

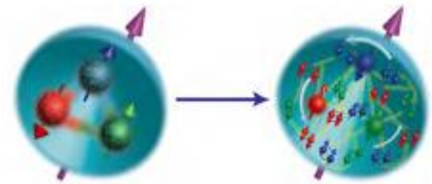
DOE Nuclear Physics Facilities

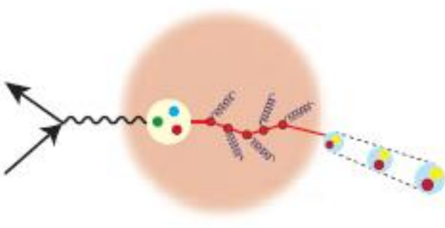
- US Department of Energy
  - Office of Science
    - Advanced Scientific Computing Research
    - Basic Energy Sciences
    - Biological and Environmental Research
    - Fusion Energy Sciences
    - High Energy Physics
    - **Nuclear Physics**
- Thomas Jefferson National Accelerator Facility
  - CEBAF: Continuous Electron Beam Accelerator Facility
    - **Polarized Electrons** on Fixed Targets
- Brookhaven National Lab
  - RHIC: Relativistic Heavy Ion Collider
    - Ion-Ion interactions in a **Collider**
- US Electron Ion Collider:
  - **Polarized electrons** and Ions **Colliding**
  - Located finalized: Will be built at BNL

Electron-Ion Collider Physics Goals

A new facility is needed to investigate, with precision, the dynamics of gluons & sea quarks and their role in the structure of visible matter

How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?
How do the nucleon properties emerge from them and their interactions?





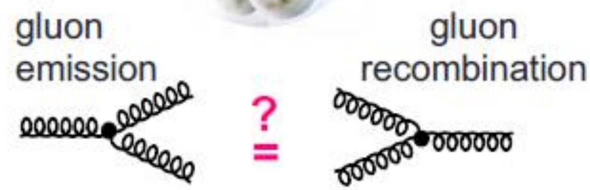
How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium?

How do the confined hadronic states emerge from these quarks and gluons?

How do the quark-gluon interactions create nuclear binding?

How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions?

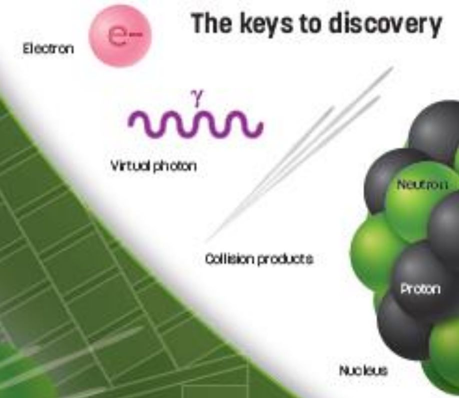
What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?

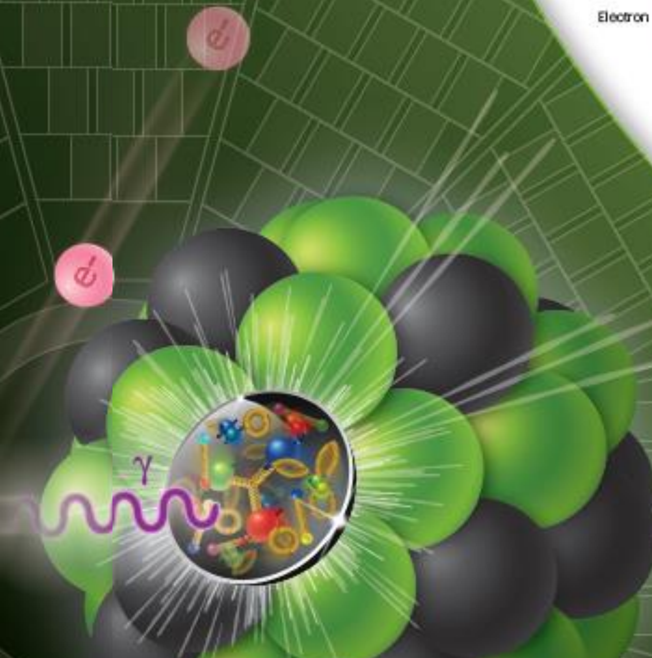


Inside an EIC Collision

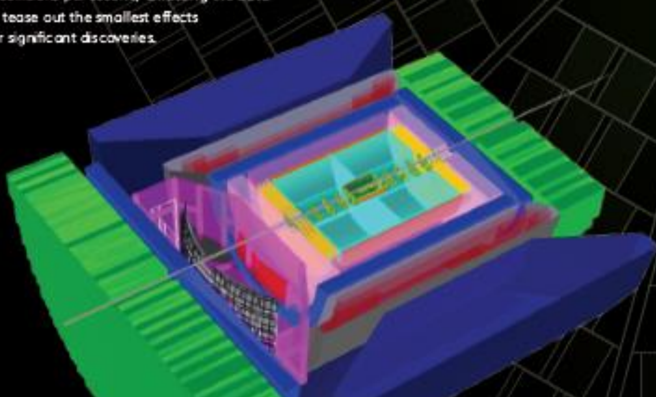
The Electron-Ion Collider (EIC) would consist of two intersecting accelerators, one producing an intense beam of electrons, the other a beam of either protons or heavier atomic nuclei, which are then steered into head-on collisions.

To meet the recommendations of the U.S. Nuclear Science Advisory Committee (NSAC), the accelerators will be designed so that both beams can be polarized to around 70 percent for electrons, protons, and light nuclei. This will allow physicists to alter the alignment to get insight into proton spin and other physics questions. As electrons scatter off particles in the other beam, virtual photons—particles of light that mediate the interaction—will penetrate the proton or nucleus to tease out the structure of the quarks and gluons within.





Electrons will be able to probe particles from protons to the heaviest stable nuclei at a very wide range of energies, starting from 20–100 billion electron volts (GeV), upgradable to approximately 140 GeV, to produce images of the particles' interiors at higher and higher resolution. At least one detector and possibly more would analyze thousands of particle collisions per second, amassing the data required to tease out the smallest effects required for significant discoveries.

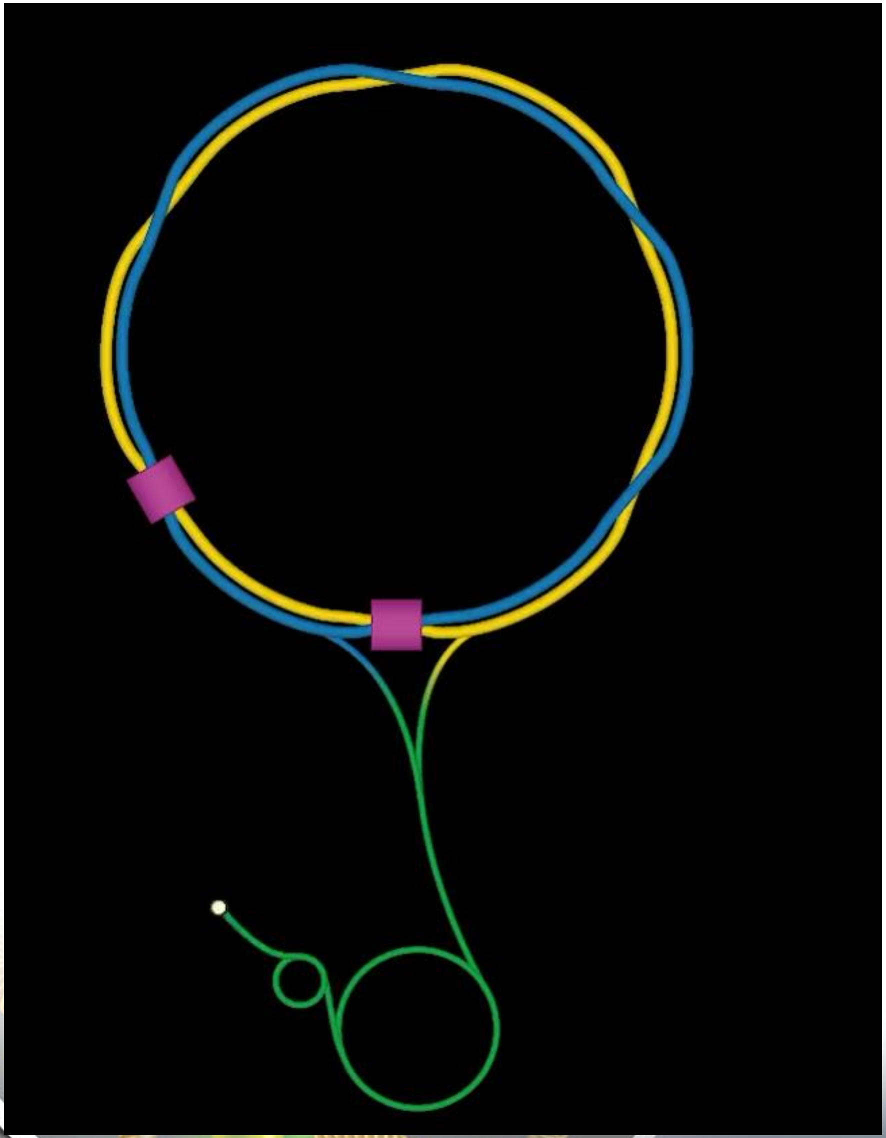


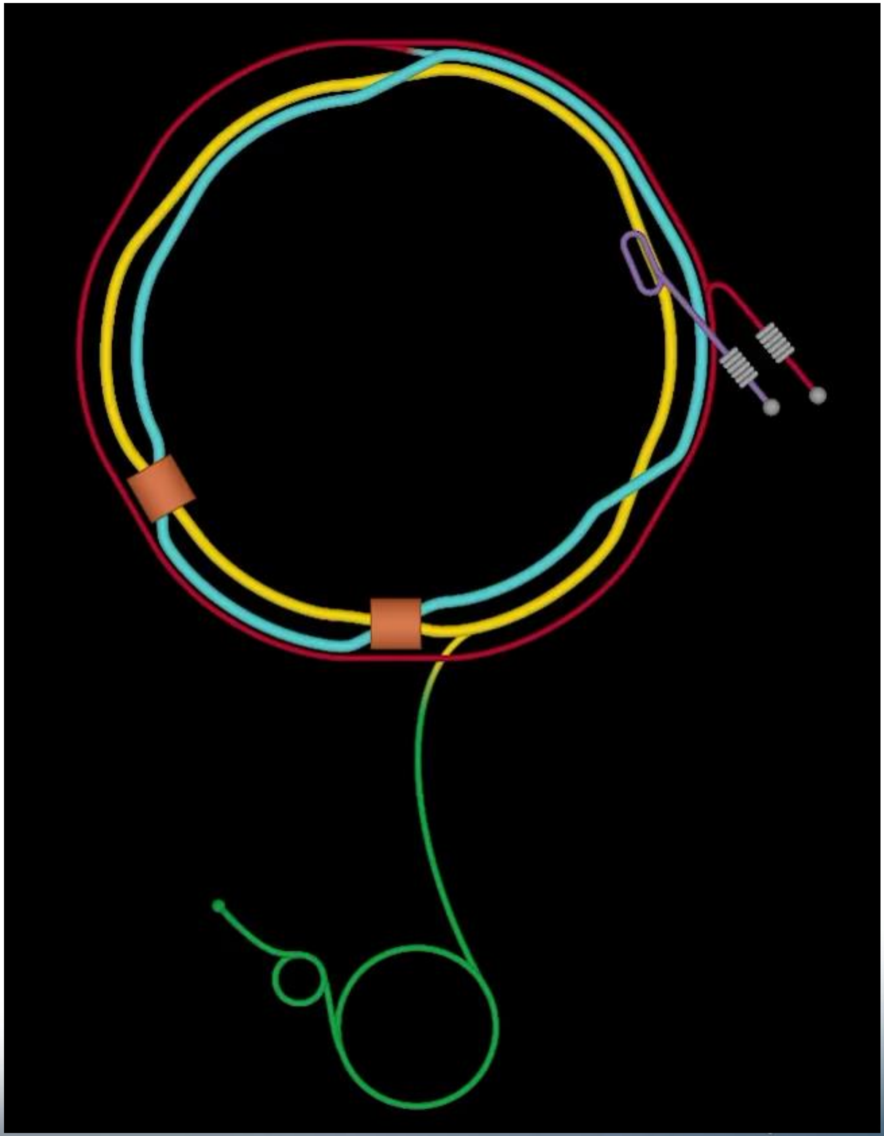
Building the EIC will require the same core expertise that led to the versatility of the polarized proton and heavy ion beams at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, and the unique polarized electron beam properties of the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility. These two Department of Energy laboratories have been collaborating on initial studies and developing designs that make use of key existing infrastructure and capitalize on investments in science and technology. Each design approach would require the development of innovative accelerator and detector technologies to answer the questions described in this brochure.

Building the EIC will maintain and continue to expand U.S. leadership in the fields of nuclear physics and accelerator science while also stimulating strong international collaboration. Since the publication of the NSAC recommendations, the community of EIC scientists has been growing rapidly—already more than 700 strong, from more than 150 institutions in 28 countries on 6 continents. This energized international community is working to tackle the scientific and technical challenges of building the world's most powerful microscope for studying matter.

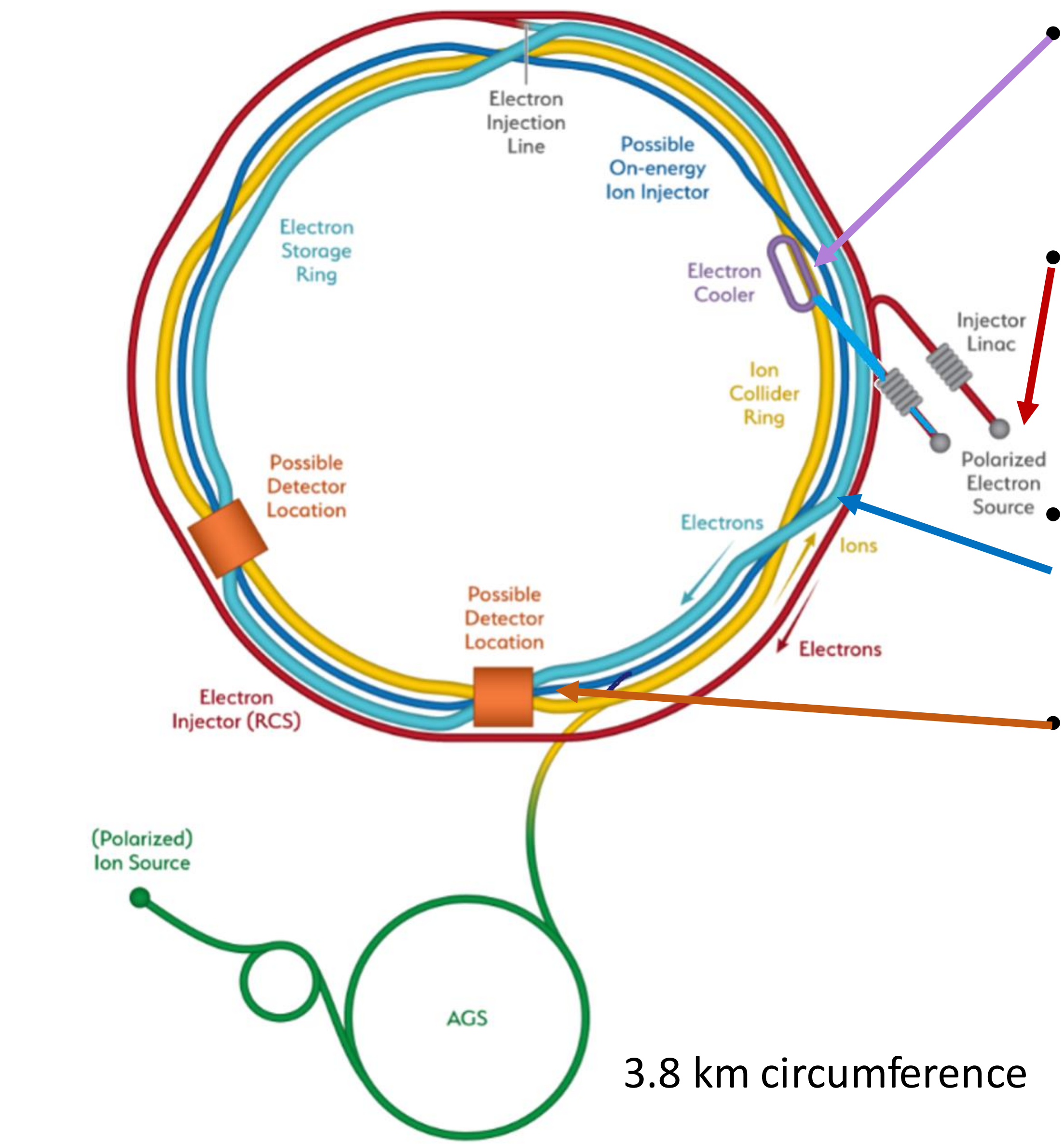
http://eicug.org/web/documents/public

From RHIC to Electron Ion Collider @ BNL



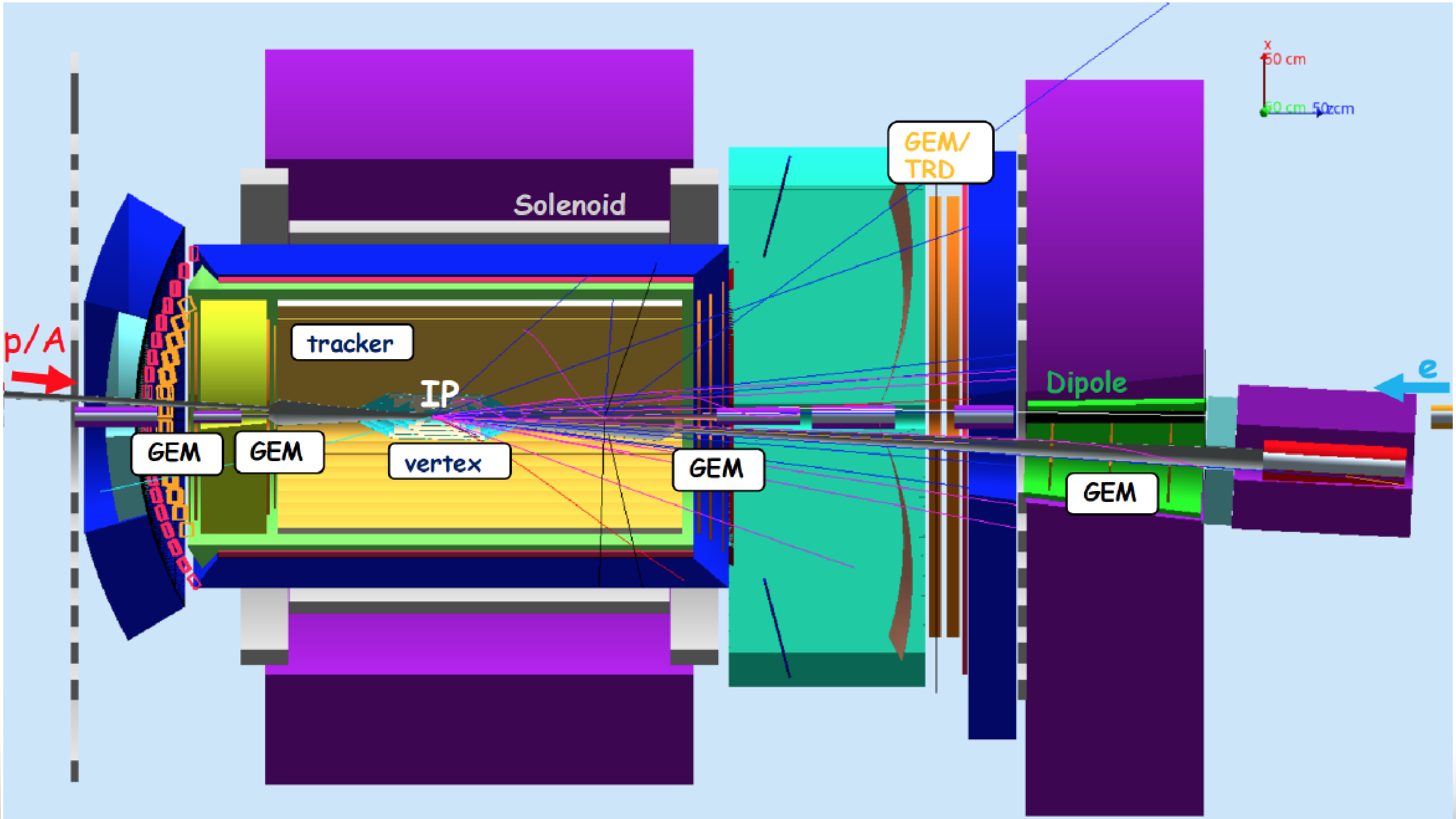


Electron-Ion Collider: BNL and JLab



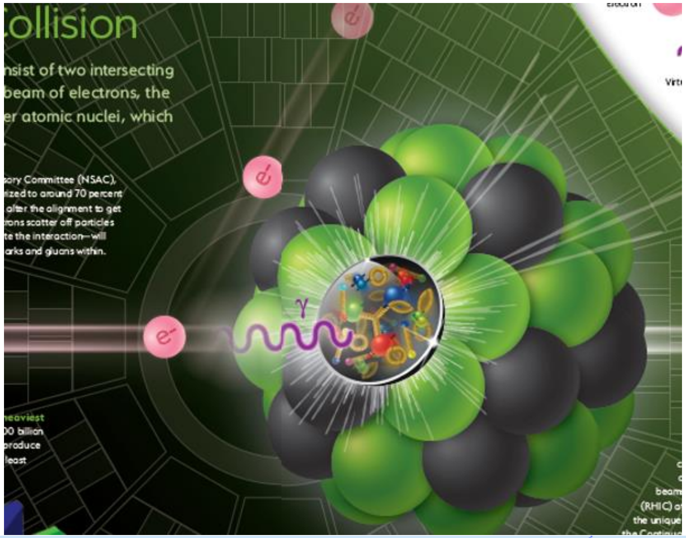
- Build Electron Cooler
  - High current electron source
  - JLab CIS Collaborating
- Build Polarized Electron Source
  - JLab Center for Injectors and Sources (CIS) Collaborating
- Design Beamline
  - JLab Center for Advanced Studies of Accelerators (CASA) collaborating
- Design Interaction Regions & Detectors
  - JLab Nuclear Physics, Electron Ion Center, Engineering and Vacuum collaborating

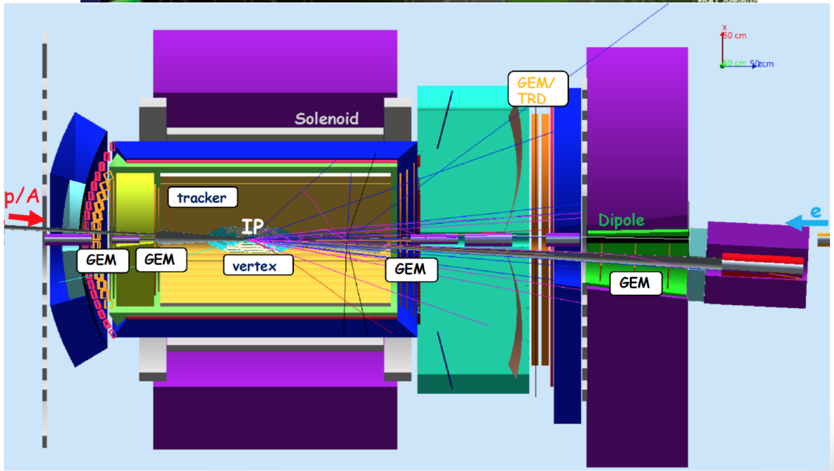
Nuclear Physics Detectors



Interaction Region Backgrounds

- Desired reactions
  - Electron Beam on Ion Beam
- Background Issues
  - Electron Beam: Synchrotron Radiation -> additional detector hits
  - Synchrotron radiation: additional gas desorption (thermal and photon stimulated)
  - Ion Beam: Collisions with residual gas in pipe -> additional detector hits





Interaction Region Systems

- Vacuum Chamber Design
  - Must be large enough beam and beam halo don't interact with walls
  - Impedance and/or Wakefield
    - heating due to image charge currents:
    - Limits diameter changes, pump ports,
- Vacuum pump layout
  - Driven by (very small) space between magnets, cryostats, and detectors
- Magnet Design
  - Driven by beam requirements
  - Dipole and quadrupole magnets bend/focus electron beam and creating Synchrotron Radiation
- Detectors to actually measure the physics…

Vacuum Chamber Materials Choices

- Accelerator vacuum materials choices
  - Aluminum
    - Low outgassing, weldable, low “z” lets particles through, good heat conduction
  - Copper
    - Outgassing ok, great thermal conductivity, higher “z”, requires brazing
  - Beryllium
    - Very low “z”, brittle, toxic, will be used in central region to let maximal particles through
  - Gold
    - Heavy – High “z”. Used in a thin coating to reduce low energy background photons
  - Non-evaporable Getter coatings
    - Reactive metals like Ti-Zr-V sputtered on pipes, provides distributed pumping

Calculating static pressure: no beam on

- Basic calculation
  - $P = \frac{qA}{S}$
  - q: Gas desorbed from walls, A: Area of walls, S: Pump speed, P: Pressure
- Other factors
  - Distance and pipe shape between system and pump
  - Screens in front of pump ports to mitigate wakefields
  - Different material outgassing rates, temperatures
- Test Particle Monte Carlo Software!

Vacuum Modeling Software: Molflow+

Test Particle Monte Carlo Simulation

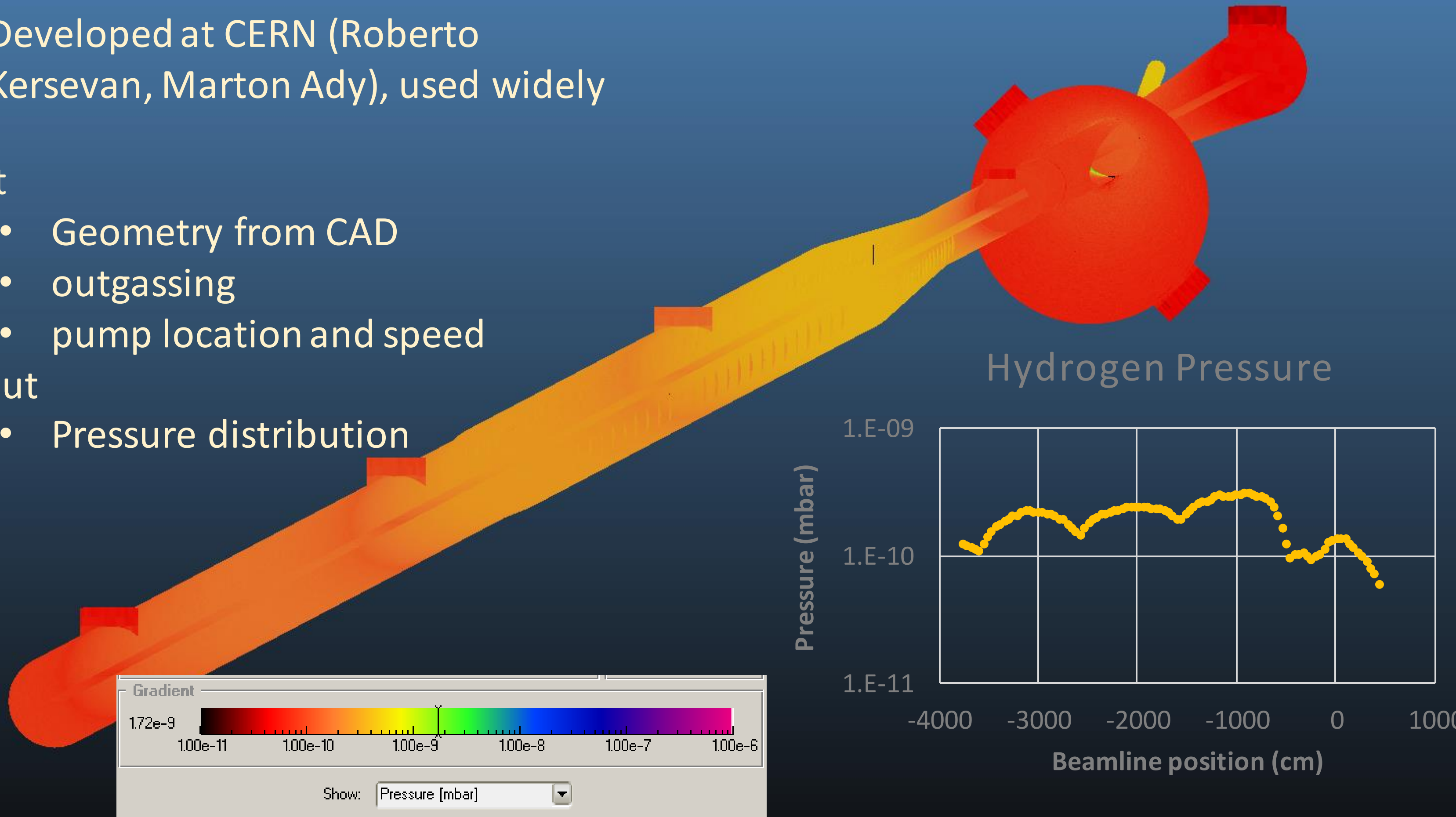
- Developed at CERN (Roberto Kersevan, Marton Ady), used widely

Input

- Geometry from CAD
- outgassing
- pump location and speed

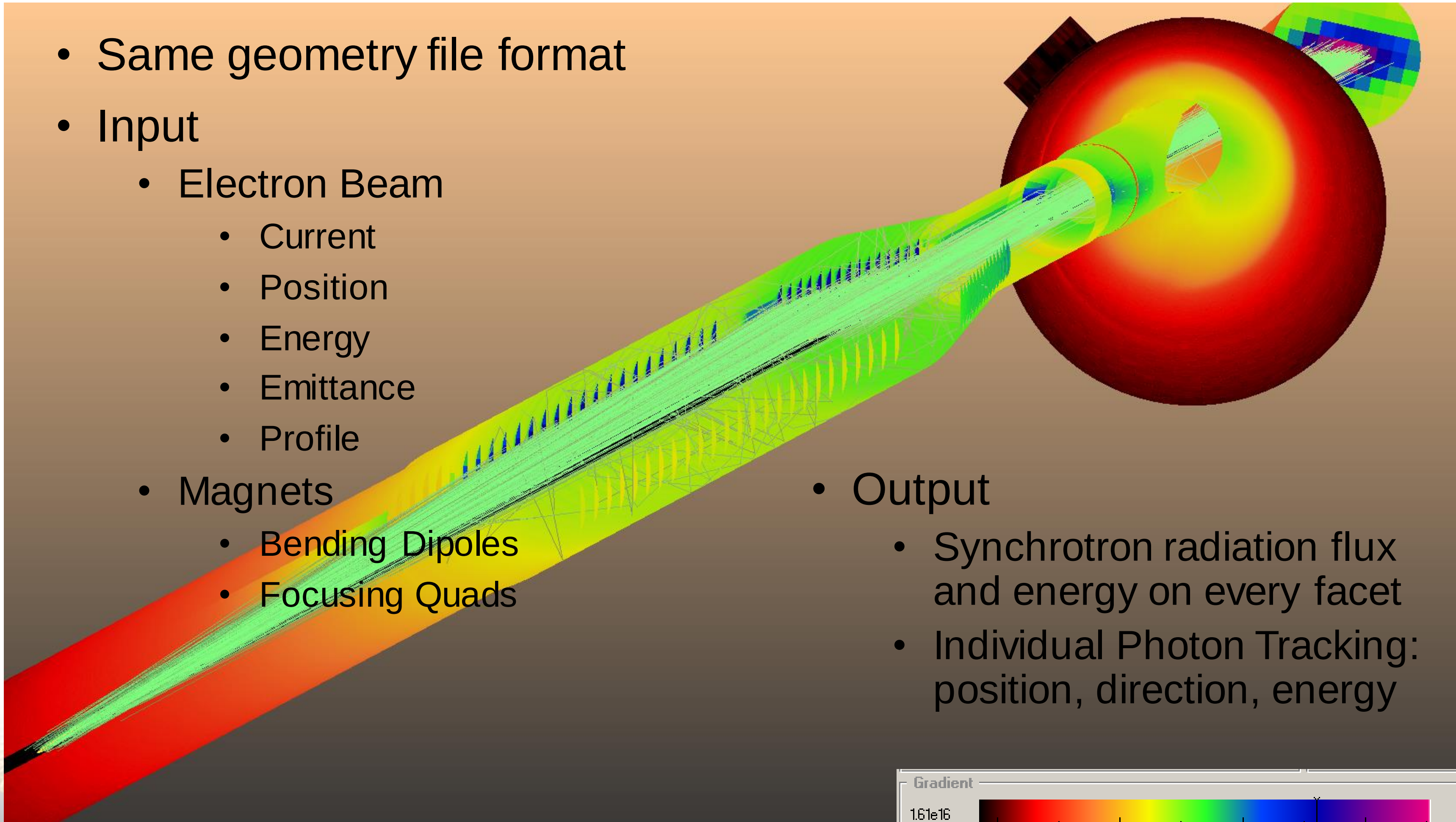
Output

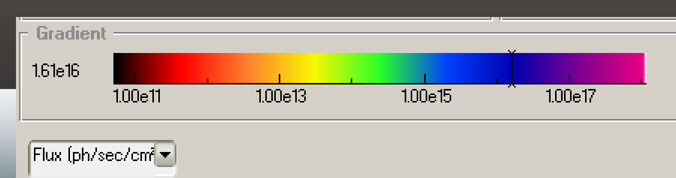
- Pressure distribution



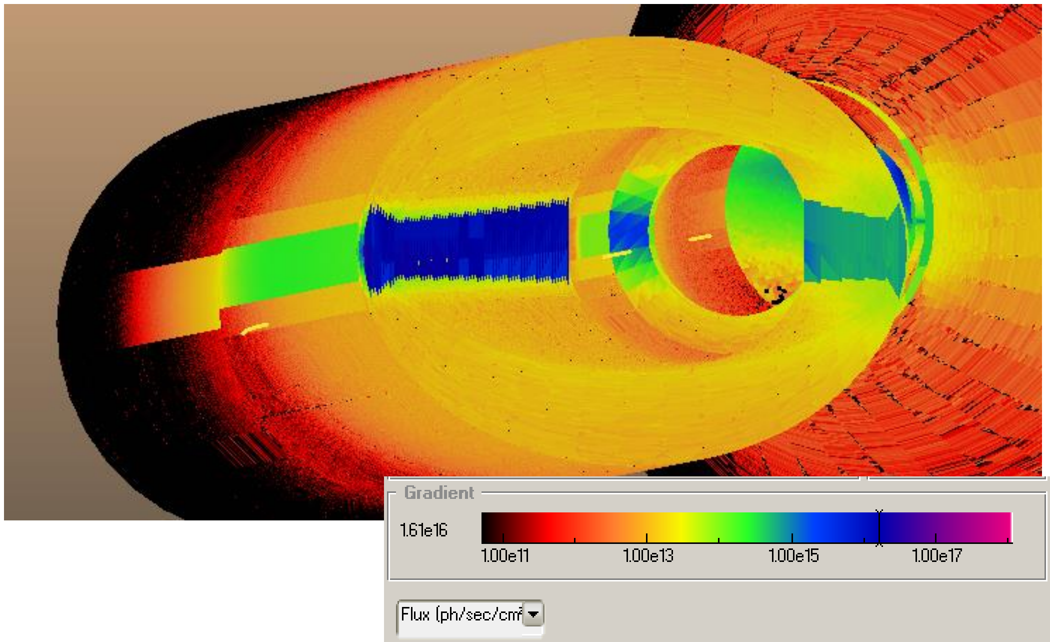
SynRad Software

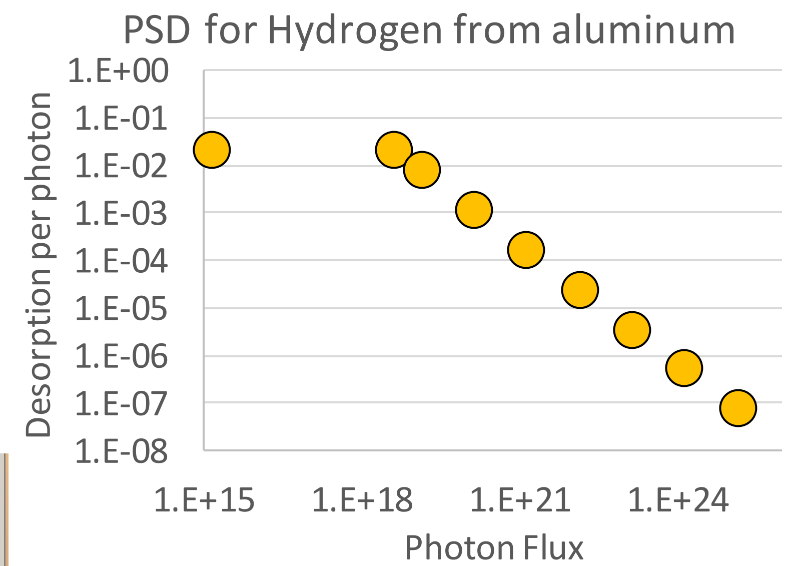
- Same geometry file format
- Input
  - Electron Beam
    - Current
    - Position
    - Energy
    - Emittance
    - Profile
  - Magnets
    - Bending Dipoles
    - Focusing Quads
- Output
  - Synchrotron radiation flux and energy on every facet
  - Individual Photon Tracking: position, direction, energy





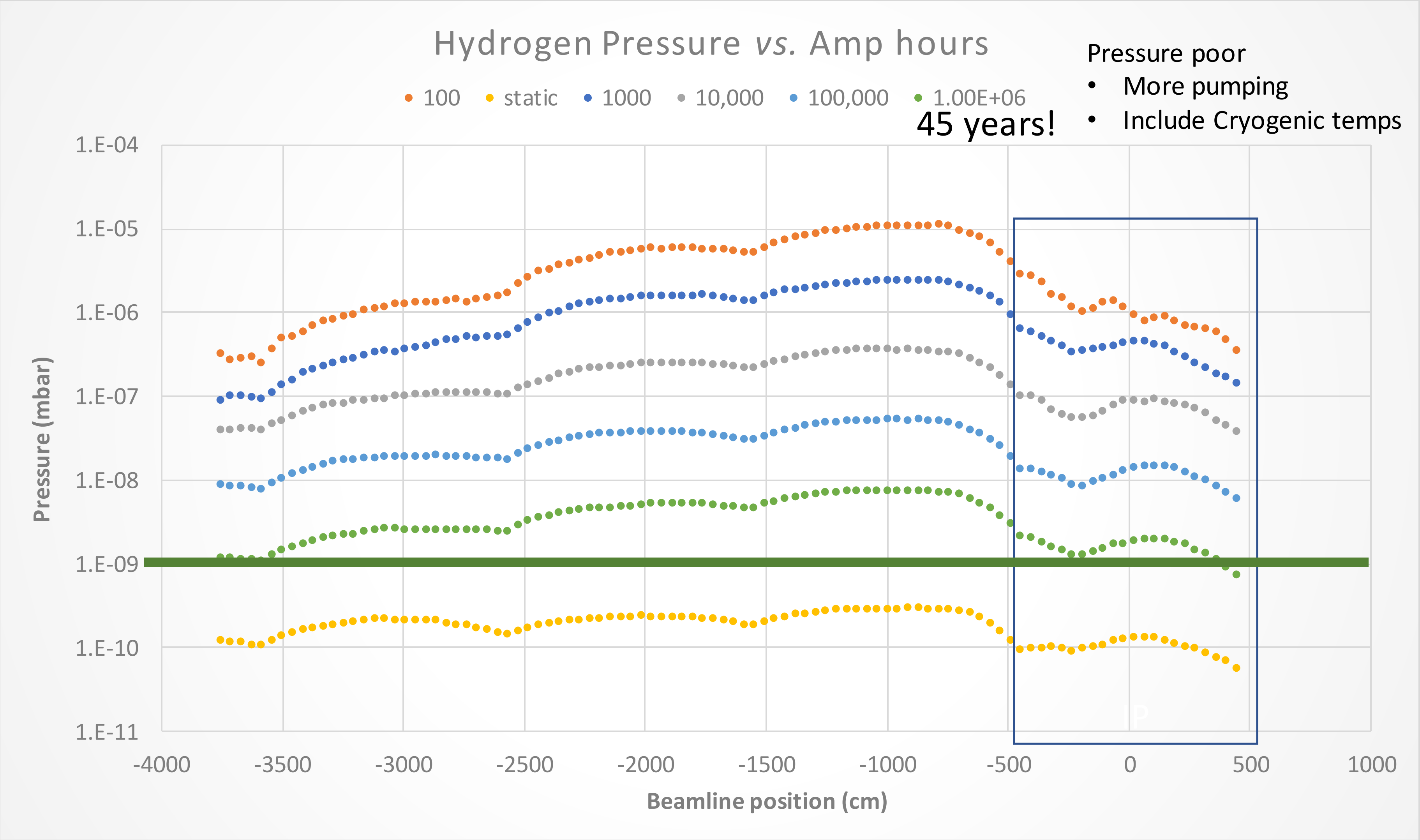
Coupled Synrad & Molflow+ dynamic vacuum





- Outgassing for each facet calculated due to the integrated flux
- Outgassing falls as system conditions
- Low energy photons included for PSD

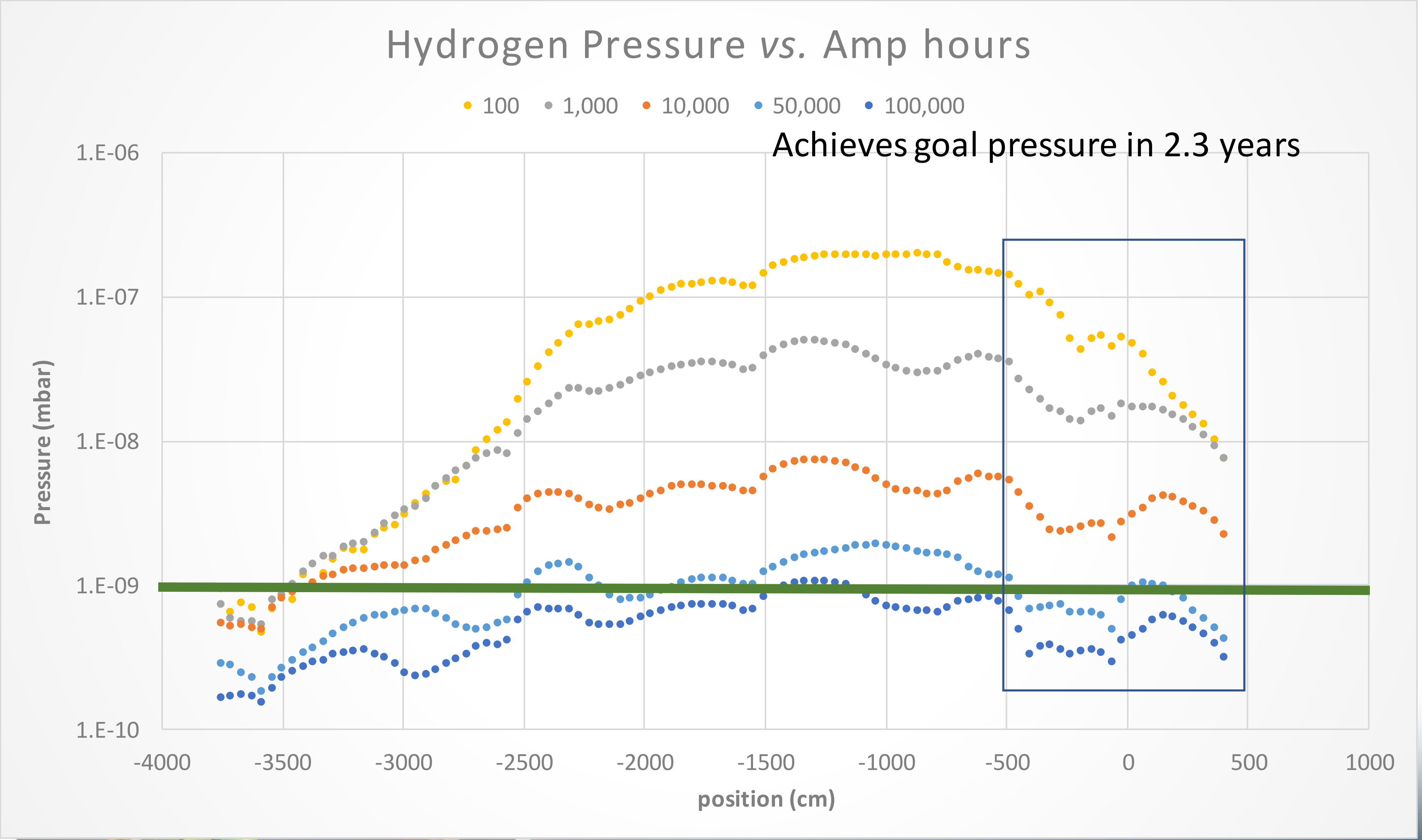
First results: Original pump configuration



Pressure poor

- More pumping
- Include Cryogenic temps

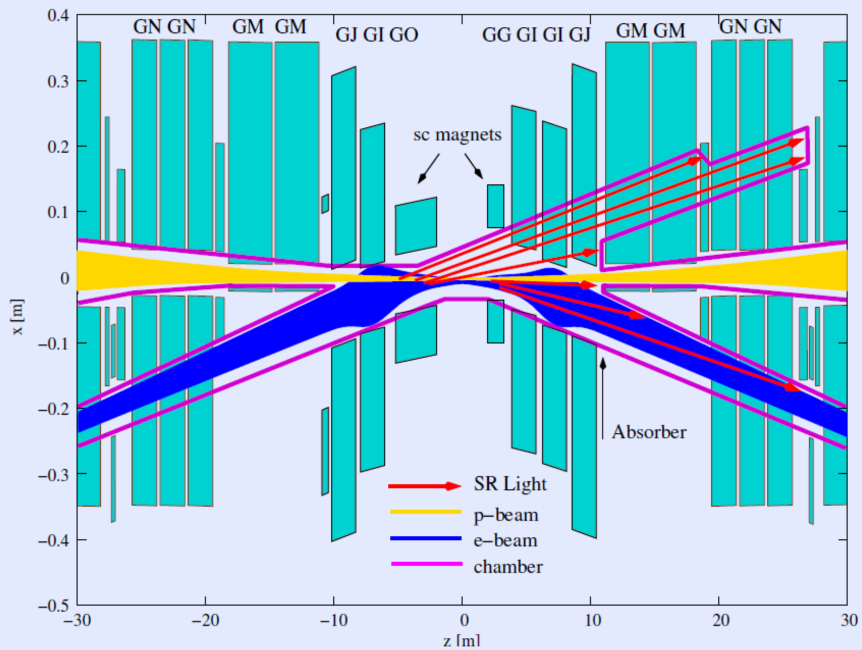
Add distributed NEG pumping



How important is background?

- HERA at DESY accelerator in Hamburg, Germany
  - Operated 1992 - 2007
  - Could not operate at desired currents: Vacuum in interaction region

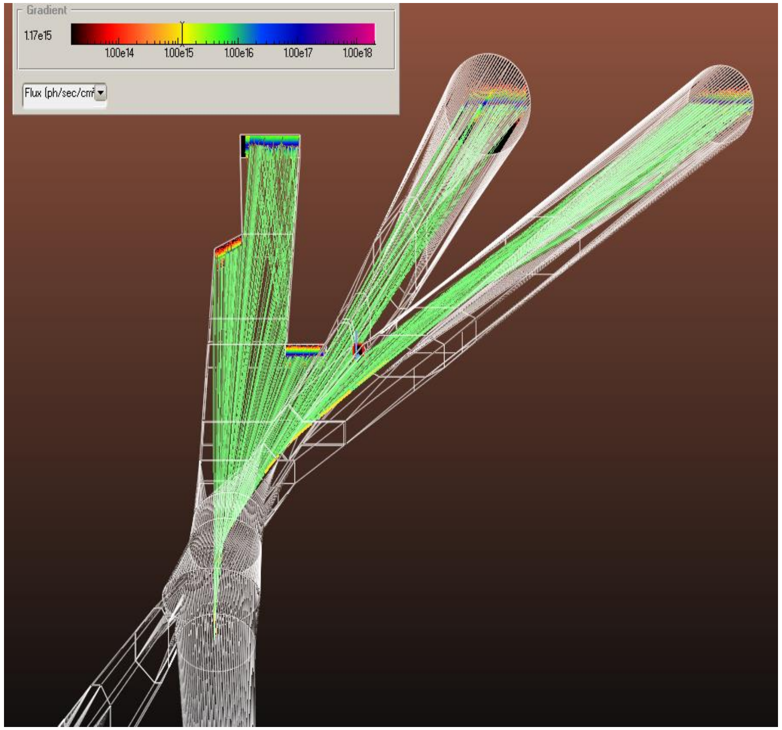
HERA interaction region

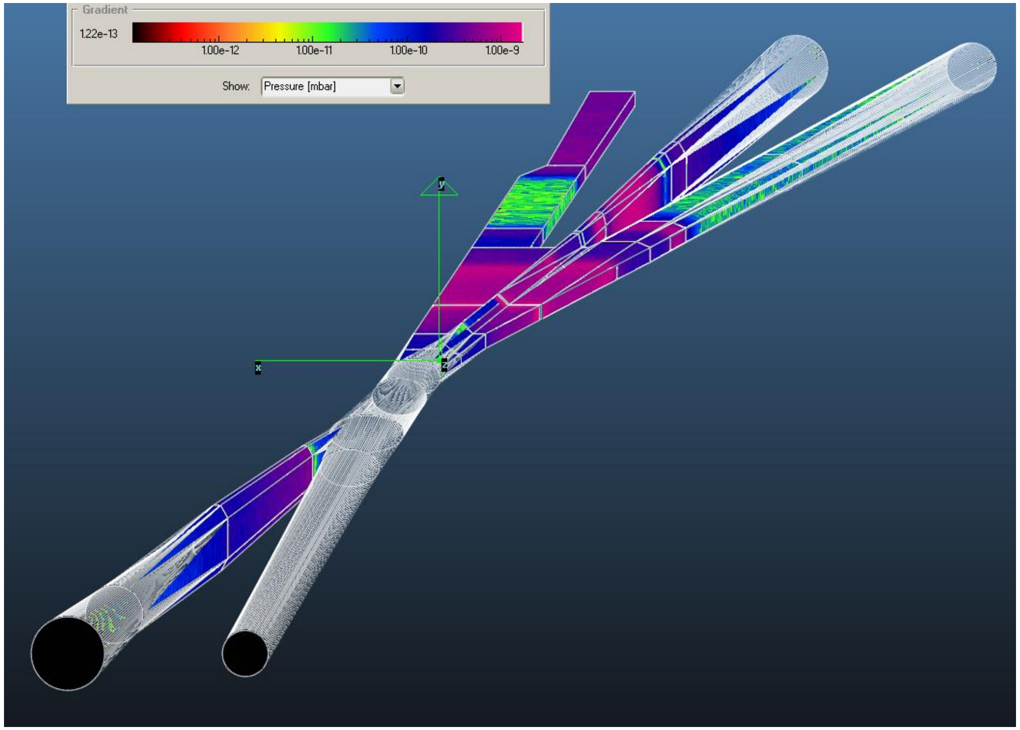


M. Seidel DESY, IR Mini-Workshop, IHEP Bejing'04

- Bending magnets for electron beam near IR -> Synchrotron Radiation

HERA Molflow+/Synrad simulations





- Student project: Adam Hutchinson
  - Generate 3D model of vacuum system from publications
  - Implement magnet design into SynRad
  - Determine vacuum profile, compare with operational experience

Lessons Learned from HERA

- Final Dipole ~30 m upstream rather than 5m
- Vacuum system design needs attention throughout project development

Ongoing Work

- System Design
  - Detector Change requires moving everything
  - Materials optimization
- Magnet and electron beam parameter changes
- Aperture changes
  - Beampipe to avoid beam halo interaction with walls
  - Final photon absorber optimization: reduce photons without hurting beam
- Pump layout needs to be optimized
  - Ion & Turbo pumps don't work well in strong magnetic fields needed for detectors

Scope of Electron-Ion Collider project

- Building EIC $2 Billion dollars
- First beam in about 10 years
- EIC collaboration: 1277 people from 256 institutions in 34 countries

- None of the physics will work if the vacuum in the interaction region doesn’t