Introduction to ANL group and its scientific potential and aspirations for the EIC

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Argonne National Laboratory

EIC User's Meeting
Argonne National Laboratory
July 7 – 9, 2016

Argonne
NATIONAL LABORATORY

3350 staff
15 research division

Physics division

- Great contribution to theoretical understanding of nucleon/nucleus
- Strong involvement in Jefferson lab physics program
- Strong past involvement in HERMES experiment at DESY
- Expertise in accelerator development

High Energy Physics division

- Strong past involvement in ZEUS experiment at DESY
- Built big stuff: ZEUS barrel calorimeter, ATLAS extended barrel…
- Strong involvement in detector R&D (recently for the ILC)
- Historical strength in perturbative QCD calculations

Argonne National Laboratory

- World class computing facilities
- Argonne Leadership Computing Facility

Great Opportunity to Contribute to EIC

Comprehensive program with 4 major thrusts

- Accelerator development
- Theory
- Detector R&D
- Physics/detector simulation

Strategic LDRD
(Laboratory Directed R&D) proposal

- Submitted in March
- Funding to be decided soon

LDRD Project Description Outline

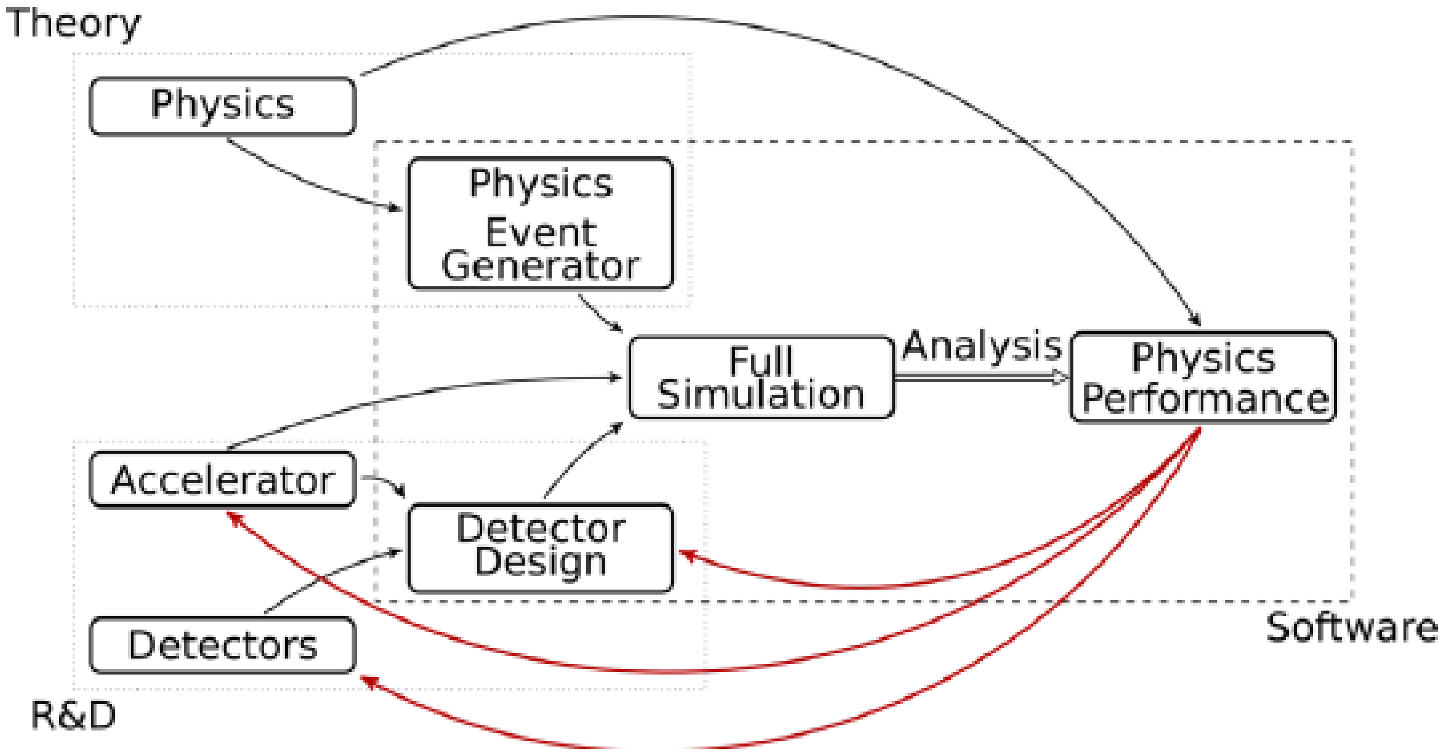
Proposal Title

A Strategic Scientific Program to establish Argonne Leadership in the Development of the Future Electron-Ion Collider

Scientific/Technical Opportunity

Hadron physics is a global endeavor with worldwide support comparable to that invested in the Large Hadron Collider (LHC) at CERN. In the U.S., an Electron-Ion Collider (EIC) has been identified in the 2015 Long Range Plan for Nuclear Science as the highest priority for a new facility construction, with the mapping of the gluon content of nucleons and nuclei identified as its central goal. The EIC will be a major construction project with a cost around $1.5B and probably the only new collider that will ever be built in the U.S. in our lifetimes. The EIC will have unique capabilities for collisions of polarized electrons with polarized protons, polarized light ions, and heavy ions at high luminosity and with versatile range of kinematics. These superior capabilities will allow unprecedented insights into the role of gluons, the carriers of the strong force, in building nucleons and nuclei and accounting for essentially all of the visible mass in the universe. It is obvious that the EIC is an exciting once in a lifetime opportunity that Argonne cannot afford to miss. The Argonne Physics (PHY) and High-Energy Physics (HEP) Divisions have joined efforts to develop a scientific program to strategically position the lab to play a leadership role in the development of the EIC. The goal of this proposal is to build a comprehensive program, by leveraging the expertise in the two divisions that would allow Argonne to have a significant role in all areas of the EIC: the physics program, simulations, detector and accelerator R&D and later the construction project.

Overview and strategy: Interplay of 4 Tasks



Accelerator – Theory – Detector R&D - Simulation

Who is involved

Cloet, Ian
Mezrag, Cedric
Boughezal, Radja
Bodwin, Geoffrey
Chekanov, Sergei
Magill, Stephen
Edmond Berger
Zhang, Jinlong
Armstrong, Whitney
Arrington, John
Hattawy, Mohammad
Potterveld, David
Mustapha, Brahim

Demarteau, Marcel
LeCompte, Tom
Plastun, Alexander
Hafidi, Kawtar
Holt, Roy
Geesaman, Don
Repond, José
Metcalfe, Jessica Erin
Xie, Junqi
Ye, Zhihong
Ostroumov, Peter
Conway, Zachary
Dennis Sivers

Task 4: Argonne EIC Accelerator Studies

Active since 2010

Ion injector for the JLab EIC

- Fully developed at Argonne (now part of baseline design)

Proposal to develop a new design of the ion complex

- Motivated by

  Recent improvements in SRF cavity performance
  Cost savings and reduced risk

- Use of compact linac and octogonal 3 GeV pre-booster

  To replace 8 GeV figure-8 booster ring based on super-ferric magnets
  Figure-8 shape not required to preserve ion polarization
  Siberian snakes for spin corrections

- Use existing electron storage ring as a ion booster

  Based on PEP-II room temperature magnets
  Figure-8 shape preserves ion polarization
  Acceleration of protons up to 11 GeV (appropriate for injection into storage ring)

Significant design and simulation effort

- Add RF sections into the electron storage ring
- Study feasibility of using electron spin rotators and flippers to manipulate ion polarization
- Study sequence of ion injection, acceleration and extraction from electron storage ring
- Develop alternative design of ion collider ring
- Study of the entire ion beam formation scheme preserving both luminosity and polarization
- Study alternative design of electron storage ring to achieve higher luminosity
- Consider higher field magnets in electron storage ring to achieve higher proton energies

Hardware-focused work on the pulsed superconducting ion Linac

- Study dynamic detuning inherent to the pulsed operation of QWRs (Quarter Wave Resonators)
- Design and preliminary testing of fast-mechanical tuners
- Test of prototype low level RF system for pulsed operation of SRF cavities
- Fabricate prototype QWR and HWR (Half Wave Resonators) cavities

Task 1: Argonne EIC Theory Studies

Collaboration of

1) Non-perturbative QCD (Physics division)

Dyson-Schwinger Equation approach

2) Perturbative QCD (High Energy Physics division)

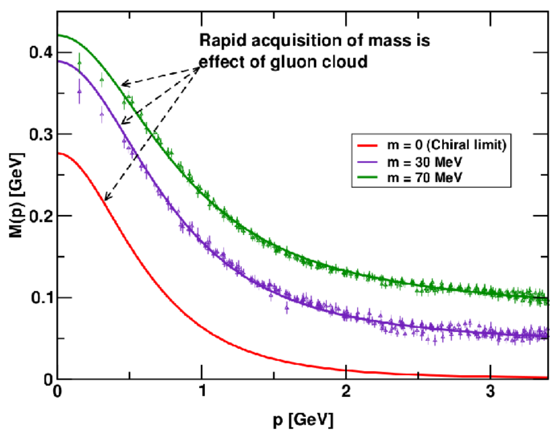
Higher-order QCD calculations, Quarkonium production, PDFs, Jet production

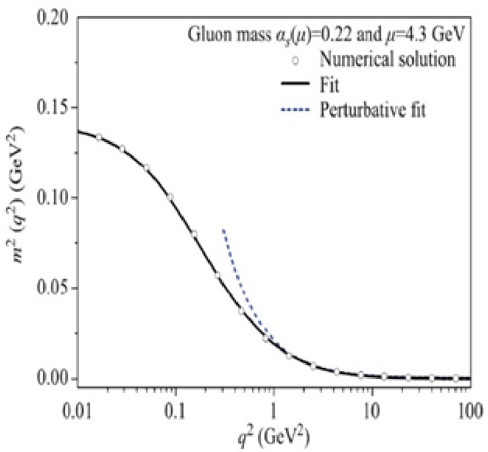
Goal

Calculation of observables that probe directly the gluon content of nucle-(on/i)-s
E.g. GPDs (Generalized Parton Distributions)
TMDs (Transverse-momentum dependent parton distributions)

Questions to be tackled

Where is the gluon field inside the nucleus?
Is the gluon radius of a nucleon smaller or larger than its quark radius?
How do the properties of the gluon field depend on the energy scale?
How does the running gluon mass effect the hadron structure?





Well-known result of running quark mass with energy scale

Now known from DSEs and lattice QCD that gluon has also a running mass with energy scale

What is its impact on hadron structure?

Can it provide another mechanism for gluon saturation?

Proposed effort

Formulate and solve the problem of computing the 3D gluonic content of nucleons
Develop the ability to extract gluonic observables from data
Compute 3D images of the gluonic structure of nucleons and nuclei
Combine lattice QCD simulations with DSE calculations extending the predictive power of each

Task 3: Argonne EIC Detector R&D

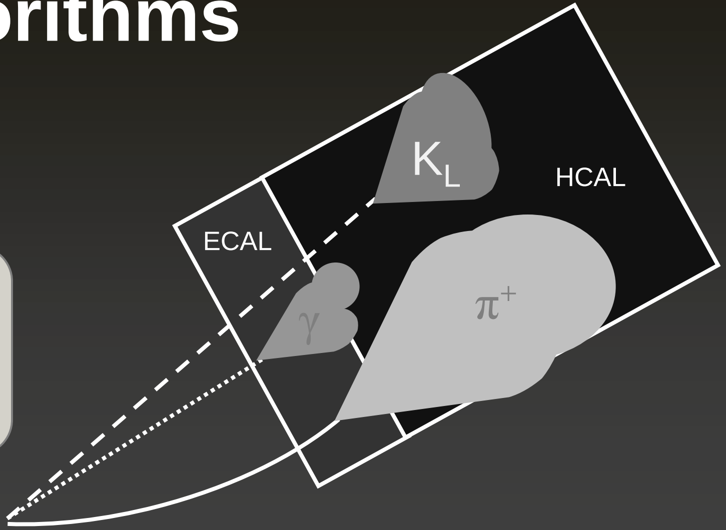
A) Development of Silicon Sensors with Excellent Timing

B) Turning the DHCAL Concept into a Mature Technology

C) Adapting MCP-PMTs for Use in TOF/RICH Detectors

But, before we get to this…

Digression I: Particle Flow Algorithms



The idea…

Charged particles	measured with the	**Tracker**
Neutral particles		**Calorimeter**

Particles in jets	Fraction of energy	Measured with	Resolution [σ/E_{jet}]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with 15%/√E	$0.07/\sqrt{E_{jet}}$
Neutral Hadrons	10 %	ECAL + HCAL with 50%/√E	$0.16/\sqrt{E_{jet}}$
Confusion	Required for 30%/√E		$\leq 0.24/\sqrt{E_{jet}}$

18%/√E

Requirements on detector

→ Need excellent tracker and high B – field
→ Large R_l of calorimeter
→ Calorimeter inside coil
→ Calorimeter with extremely fine segmentation

Figure of merit BR_l^2

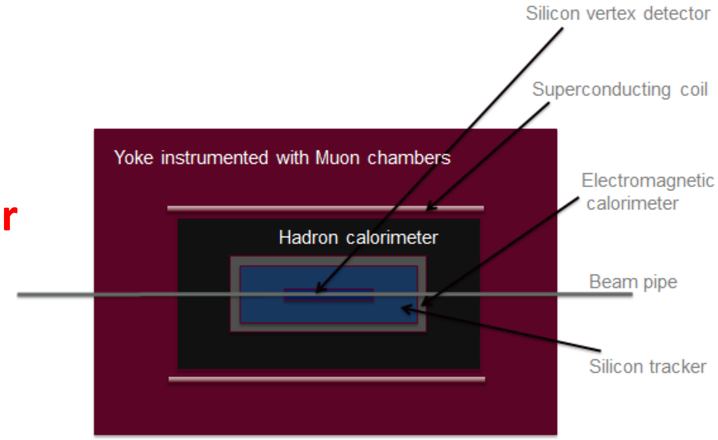
Digression II: Concept of a 5D Detector

ILC community developed concept and technologies for a **4D detector** optimized for the application of Particle Flow Algorithms

→ Energy + 3 spatial coordinates

The Argonne EIC group proposes to develop a **5D detector**

→ **Energy + 3 spatial coordinates + precision timing**



Particle identification (pion/Kaon/proton separation)

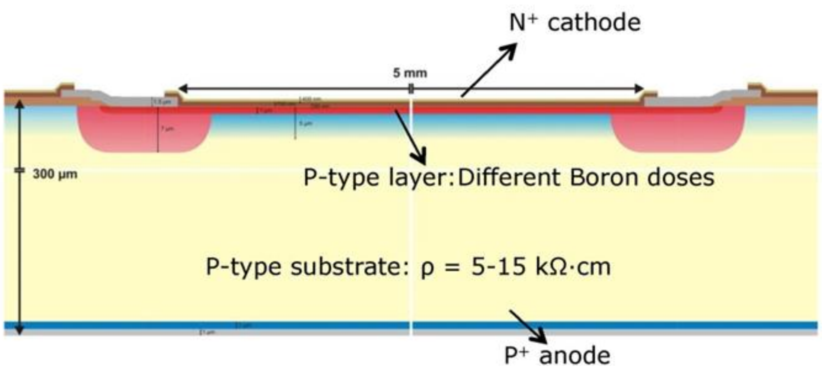
A significant amount of detector R&D is required, beyond the work performed by the ILC community

A) Development of Silicon Sensors with Excellent Timing

Timing of the order of 10 ps required for particle ID

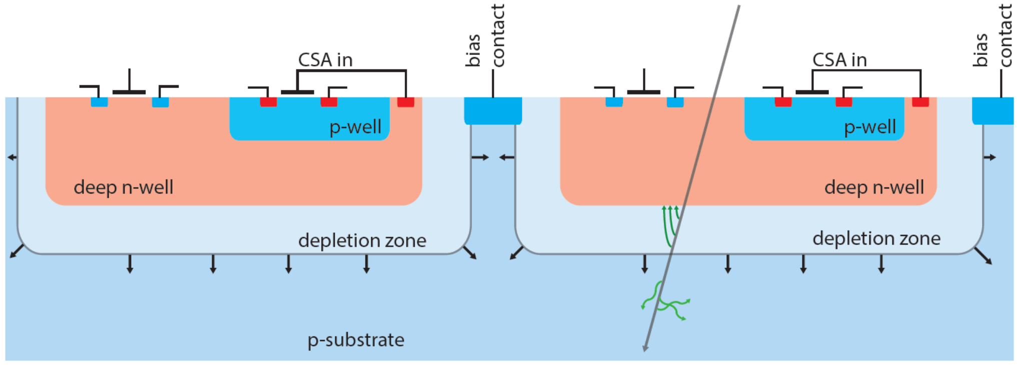
* Initially, explore **Low Gain Amplifying Detectors (LGAD)**

To date 50 ps resolution has been achieved
Explore different designs: addition of Boron/Gallium layers
Cost and radiation hardness might be an issue



* Later, explore **HVCMOS MAPS**

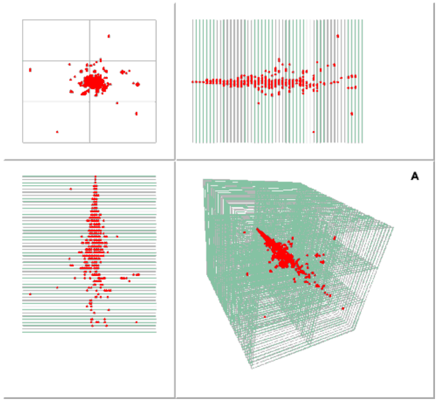
Factor of two cheaper
Integrated sensor and signal amplification
To date 1 ns timing resolution → long way to go!



For many more details see **Jessica Metcalfe**'s talk in the Detector R&D meeting

B) Turning the DHCAL Concept into a Mature Technology

Digital Hadron Calorimetry with Resistive Plate Chambers



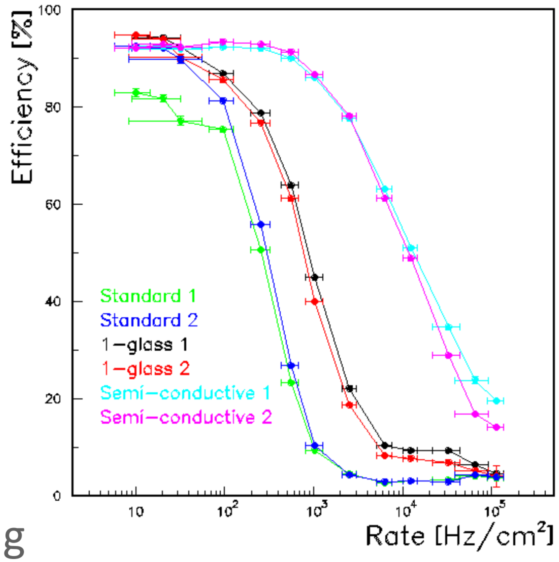
Developed for the ILC
Concept validated with large-scale DHCAL prototype

Lessons learned with the DHCAL

Calibration is challenging: solution → new chamber design (1-glass RPCs)
Rate limitation of RPCs: solution → use of semi-conductive glass

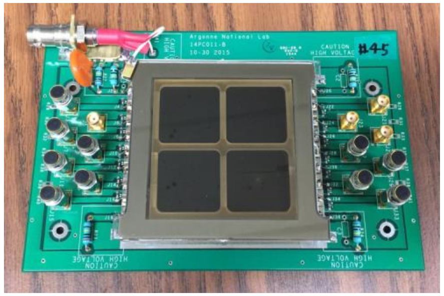
Further studies

Long-term tests of 1-glass RPCs
(monitor chemical changes of anode plate)
Long-term test of fast RPCs using semi-conductive glass
(monitor chemical/physical changes of resistive plates)
Development of a high voltage distribution system
Development of a gas recycling system



For more details see **J.Repond**'s talk in the Detector R&D meeting

C) Adapting MCP-PMTs for Use in TOF/RICH Detectors

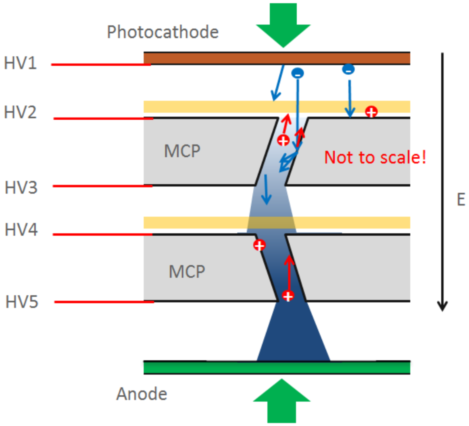


Micro-channel Plate Photomultipliers developed at ANL

So far > 10 working tiles produced

Adaption for use in **Time-of-Flight or RICH detector**

* Geometrical modifications

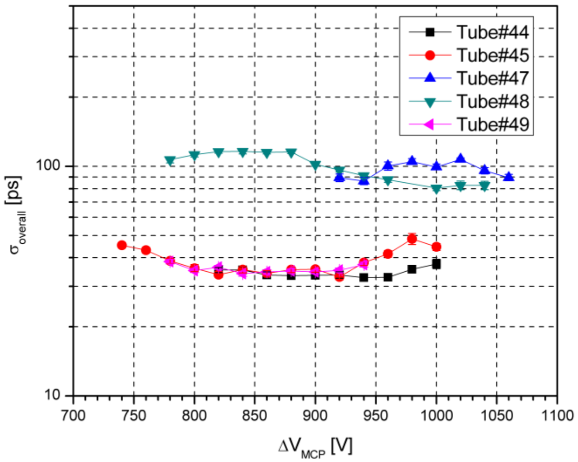


Reduce spacings (vertical, pores)

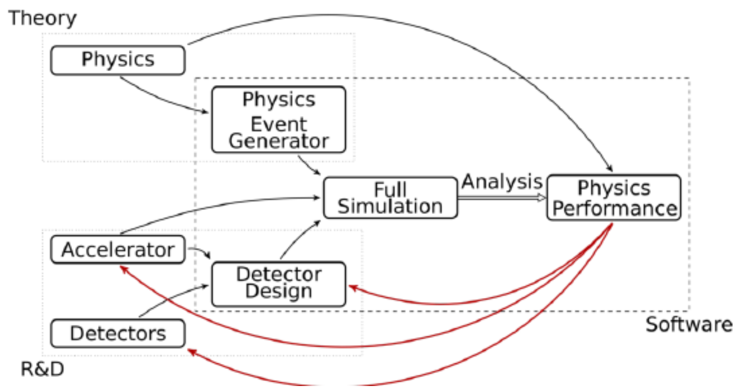
⟶ Improved timing (<10 ps)
⟶ Reduced sensitivity to B-fields

* Introduction of pad readout

⟶ Improved position resolution



Task 2: Argonne EIC Simulation Studies



Purpose

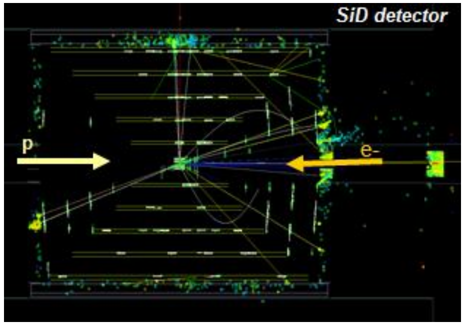
Fine-tune detector design and validate its performance
Provide guidance to detector R&D

Starting point

SiD detector concept developed for the ILC

Pure silicon tracker, imaging calorimeters, solenoid, muon chambers

Adapted to EIC environment



Proposed activities

Implementation of new processes into event generators
Detailed simulation of detector concepts
Physics driven optimization of detector performance

For more details see **S. Chekanov**'s talk in the Detector R&D meeting

Conclusions

Combining efforts

from Physics and HEP to create a strong EIC effort at ANL

Proposals

Submission of LDRD proposals and EIC detector R&D proposals

Effort contains 4 tasks

Accelerator (geared for now towards the JLab EIC)
Theory (based on Dyson-Schwinger framework and perturbative QCD)
Detector R&D (centered around a 5D detector)
Simulation (integrating physics, detector and accelerator)