Detectors for an Electron Ion Collider

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Instrumentation Division Seminar

February 26, 2014

What is an Electron Ion Collider… and Why?

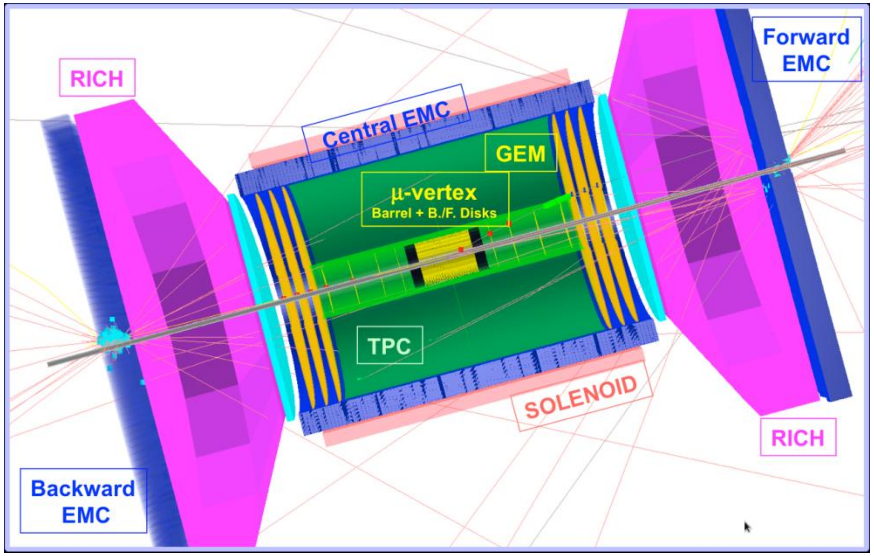
The eRHIC Design: an EIC at Brookhaven

Detector Requirements… the Golden Measurements
- A Model Detector

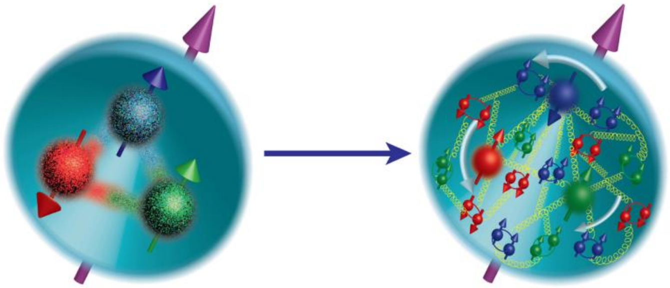
EIC Generic Detector R&D Program
- Enabling new/improved technology
- Building Collaborations

ePHENIX and eSTAR Letters of Intent

A Possible Timeline

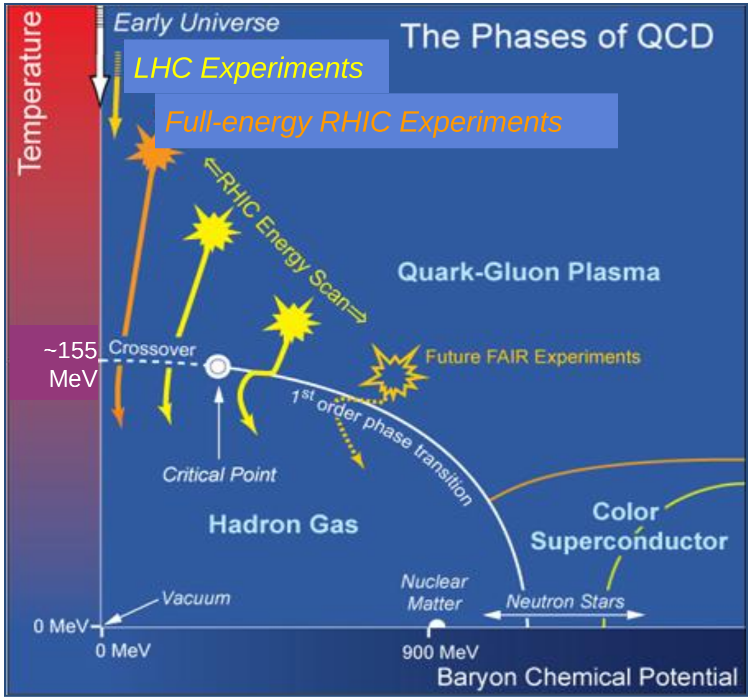


Unexpected richness of the natural world described by QCD



The substructure of the nucleon is not a simple system of 3 quarks.

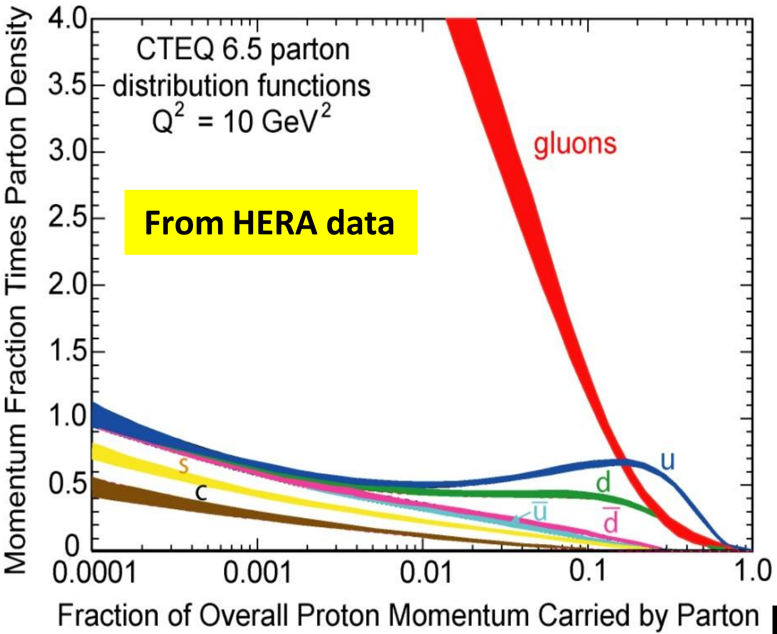
How does this complex dynamical system of quarks and gluons result in the nucleon spin-1/2?



At extreme values of temperature and density, nuclear matter reveals directly the quark and gluon degrees of freedom…

The Quark Gluon Plasma: a strongly-coupled "Perfect Liquid"… Condensed Matter of the strong force.

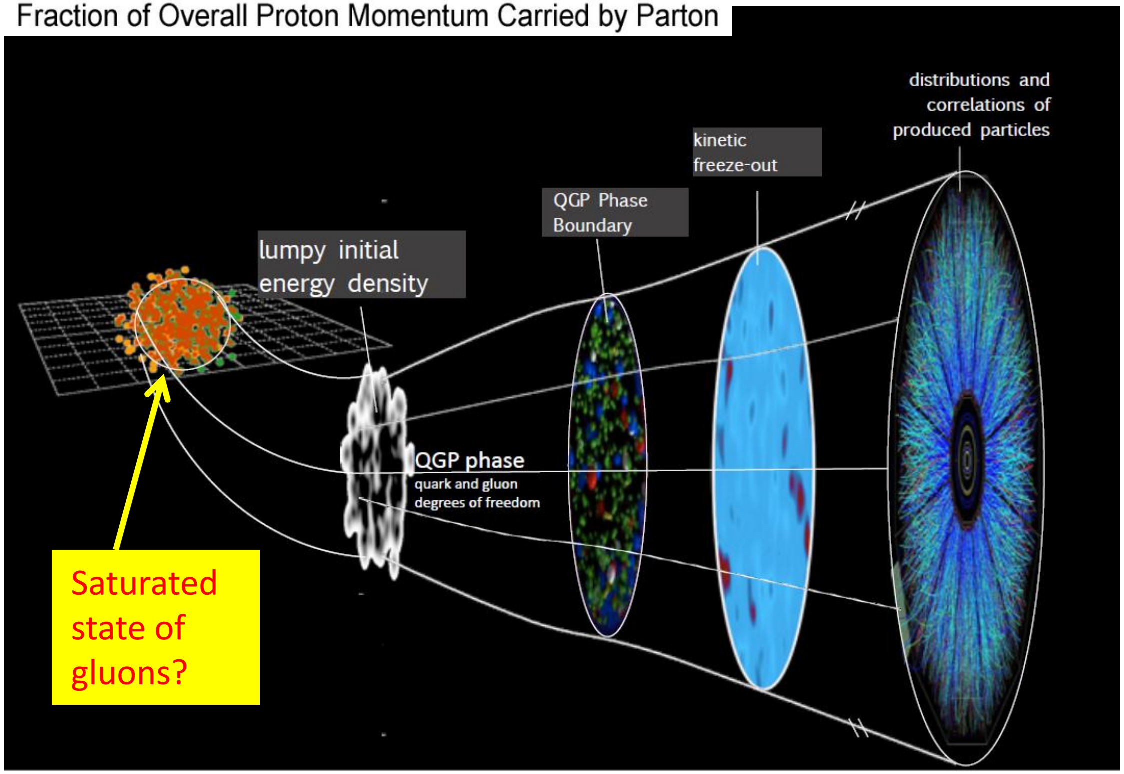
The formation and evolution of this QCD matter is dominated by the properties of gluons at high density.



At high energies, gluons dominate the structure of nucleons and nuclei

Gluons carry color charge, and interact with each other, unlike photons.

Unitarity (Froissart bound) predicts a saturated state at very small x.



Conjectured "Color Glass Condensate" may have universal properties, and form the initial state for the Quark Gluon Plasma produced in heavy ion collisions at RHIC and LHC.

Electron Ion Collider: The Next Frontier in QCD Research

Explore the structure of QCD matter with the precision of electromagnetic probes:

- **High energy collisions => Access the gluon dominated regime**
  e-nucleon cm energy ($\sqrt{s}$) up to ~150 GeV

- **High luminosity => Unprecedented statistical precision**
  e-nucleon luminosity ~10^{33}-10^{34} $cm^{-2}sec^{-1}$
  Sample sizes ~10-100 fb^{-1}

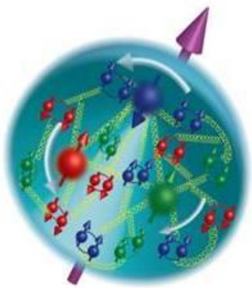
- **Polarized beams => Complete picture of the spin structure of the nucleon**
  Highly polarized electrons, protons, ^3He

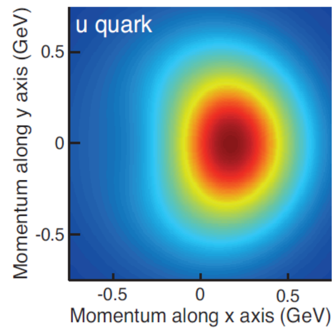
- **Ion beams up to the heaviest nuclei– Au, Pb, U**

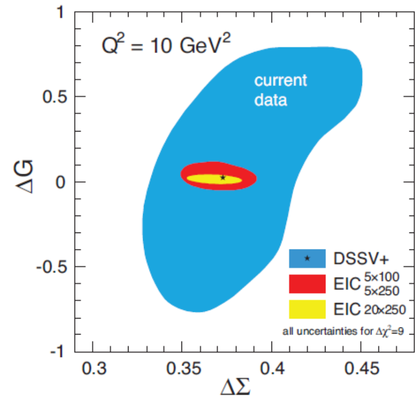
- **Multiple interaction regions**

The 2013 NSAC Subcommittee on Future Facilities identified the physics program of an Electron Ion Collider as **absolutely central** to the nuclear science program of the next decade.

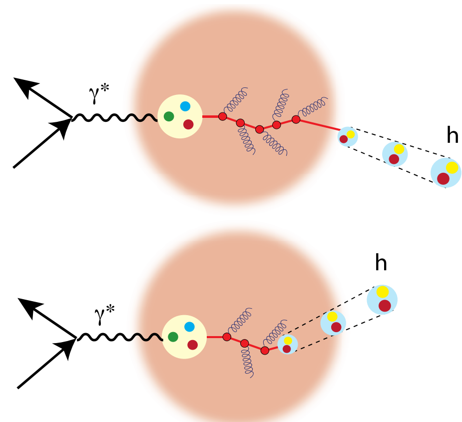
A Suite of Golden Measurements



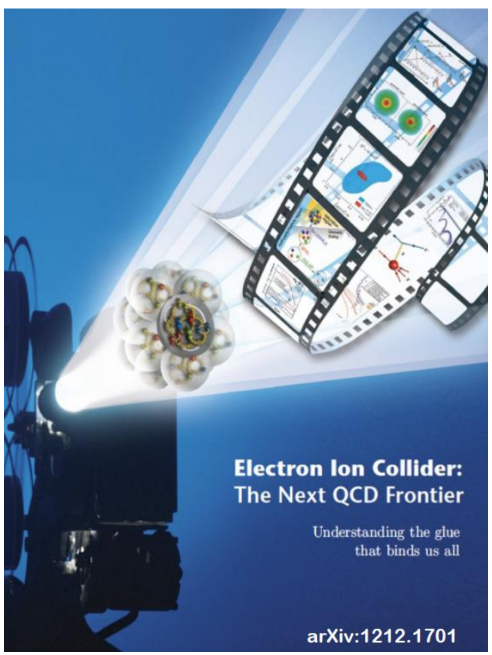




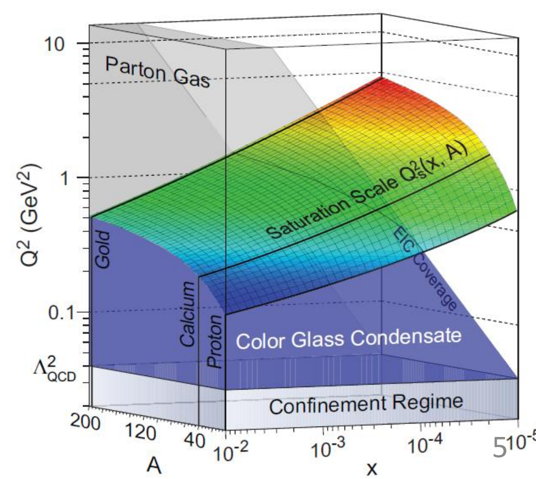
Precision measurements of proton structure



Microscopic processes: parton propagation in bulk nuclear matter.



High density phase of gluon matter (CGC) amplified in e-nucleus collisions



Two Visions for an EIC

Jefferson Lab: Medium Energy Ion Collider (MEIC)

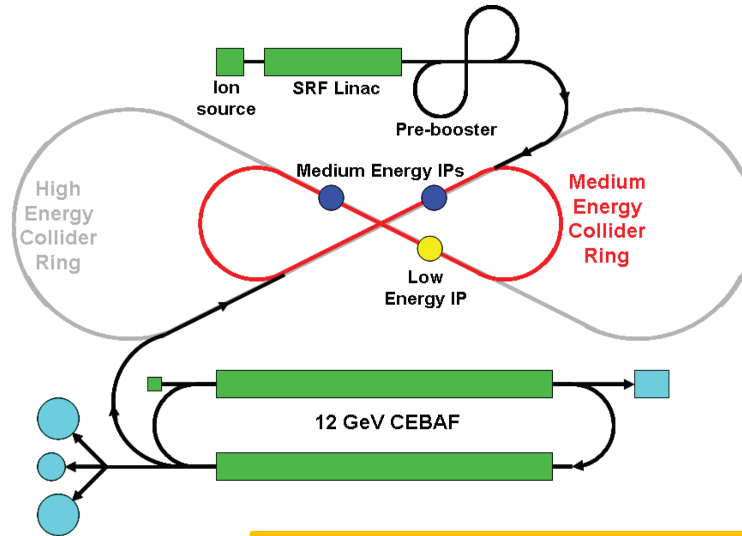
Ring-Ring design:

Add polarized proton/Ion accelerator complex to existing CEBAF electron accelerator.

3-12 GeV e^-/e^+

25-100 GeV protons

12-40 GeV/u ions



BNL: eRHIC

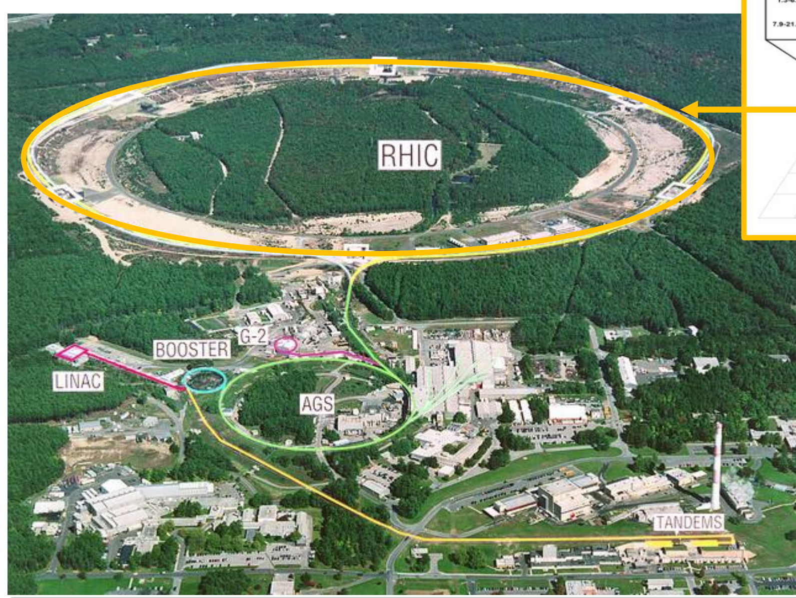
Linac-Ring design:

Add polarized electron Linac to existing RHIC complex.

16-20 GeV e^-

50-250 GeV protons

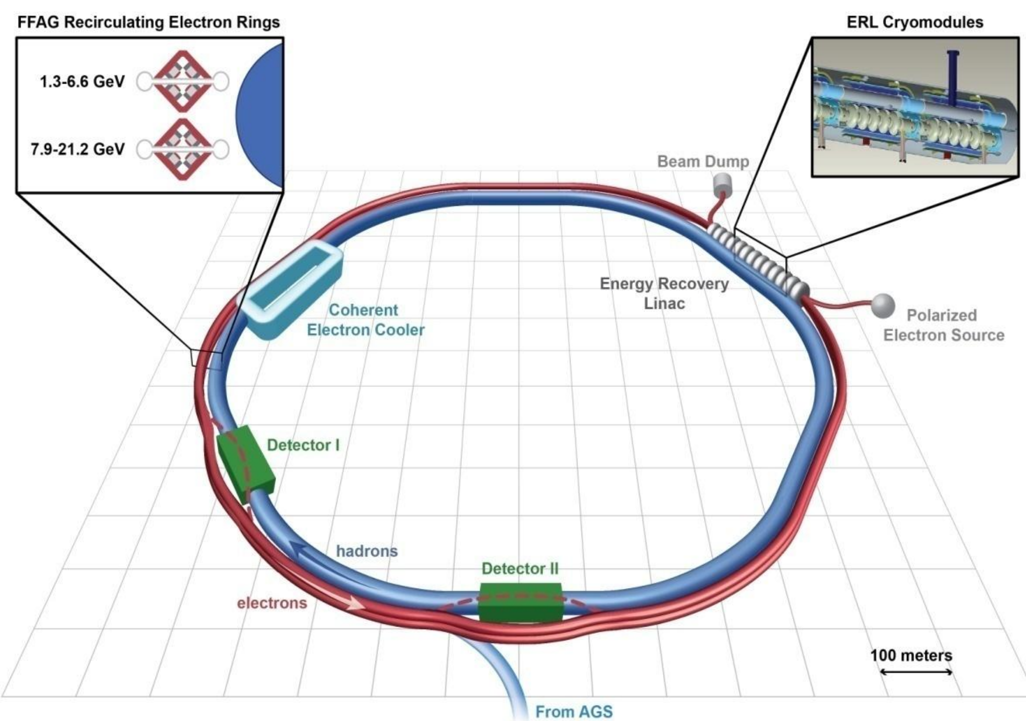
10-100 GeV/u ions



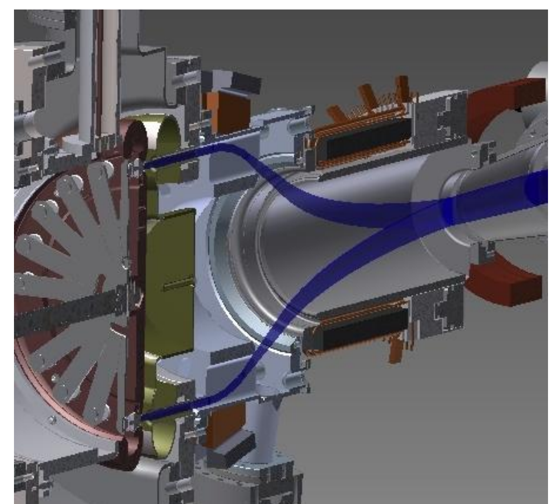
The eRHIC Design

Cost effective, technologically advanced accelerator concept.
Builds on $2 billion RHIC infrastructure.

- Electron beam accelerated with 1.33 GeV Energy Recovery Linac (ERL) via two FFAG transport rings inside RHIC tunnel collides with existing proton and ion beams:
  12 passes: 15.9 GeV, full luminosity   16 passes: 21.2 GeV, reduced luminosity
- Single collision of each electron bunch allows for large disruption, giving high luminosity (~10^{33}cm^{-2}sec^{-1}) and full electron polarization.
- Bunch collision frequency (~9 MHz) is same as for RHIC.

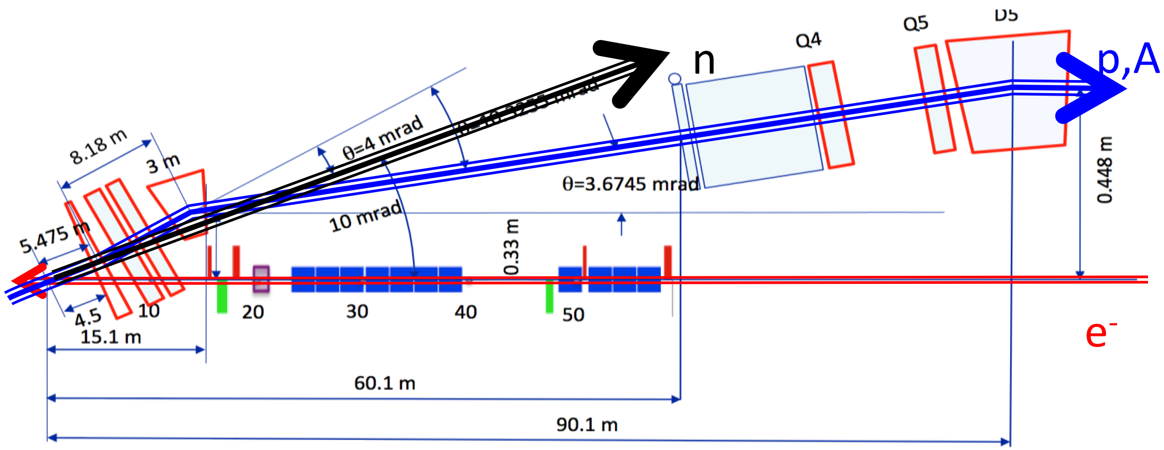


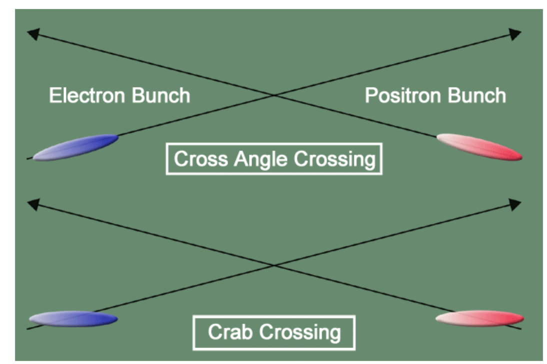
50 mA polarized electron gun
(Gatling gun)



eRHIC Interaction Region Layout

- 10 mrad beam crossing angle
- No magnetic bending of electron beam: minimize synchrotron radiation background
- Crab Crossing cavities required for high luminosity
- ± 4.5 m free space for detector

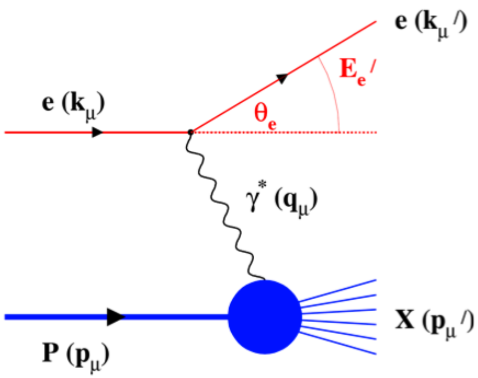




Magnet apertures allow tagging forward neutrons (ZDC), forward scattered protons (±10 mrad)

Detector Requirements for eRHIC

e + p/A → e + X



$$Q^2 = -(k - k')^2$$

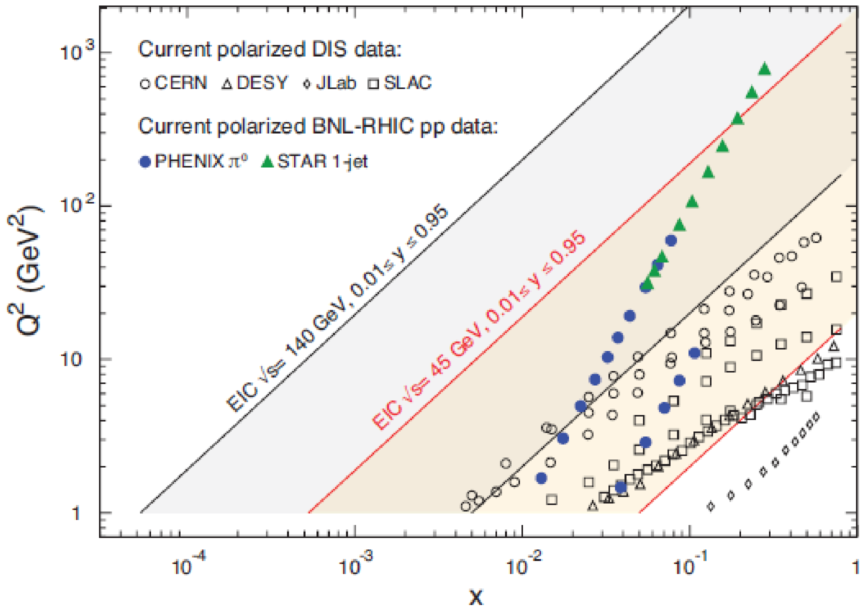
Squared momentum transfer to the scattered electron.
Large $Q^2 > 1$ GeV^2 ⟹ "hard scattering": resolve quarks and gluons.

Bjorken x variable: $x = Q^2 / (2p\cdot q)$

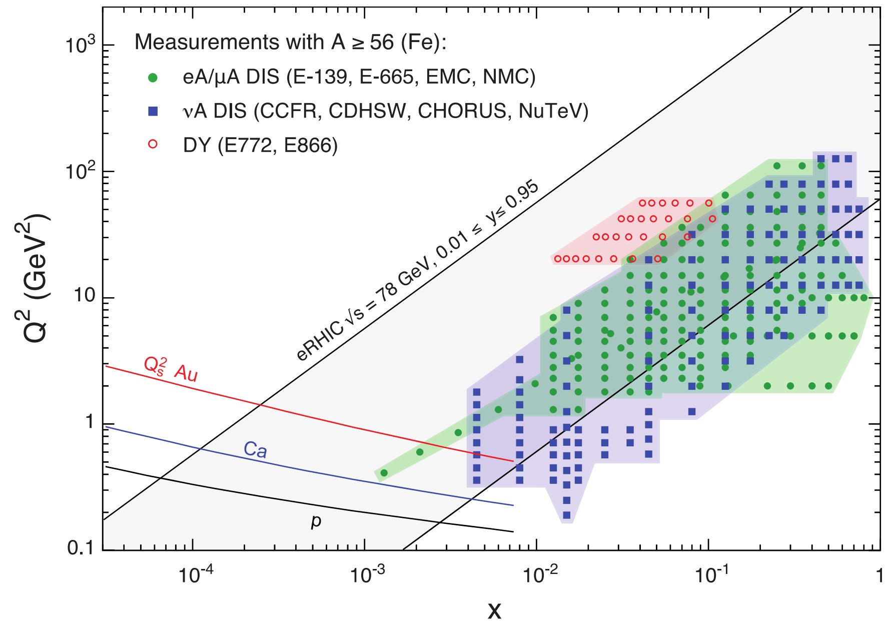
Momentum fraction of parton on which the photon scatters.
For a given Q^2, small x implies large collision energy.

Detecting the scattered electron is critical: defines parton kinematics through x and Q^2

Kinematic Landscape for EIC Physics



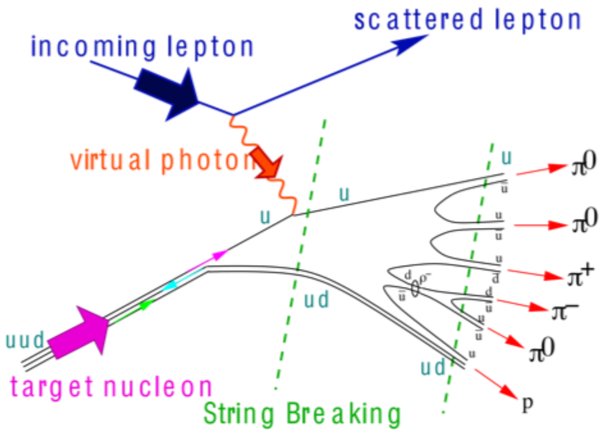
Polarized e-p Collisions



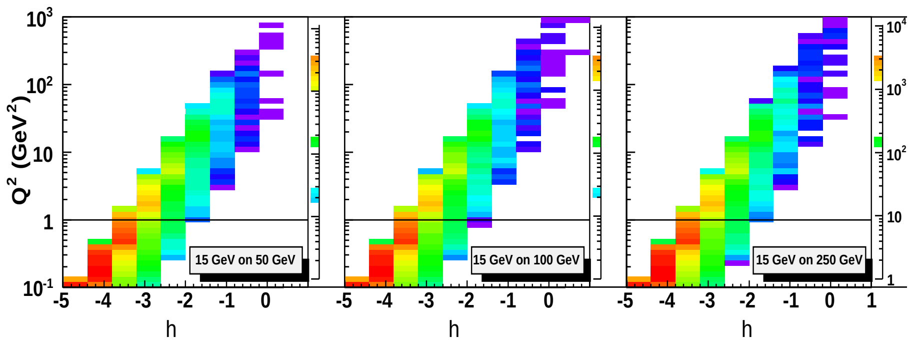
Electrons on Heavy Ions

Semi-Inclusive/ Exclusive DIS:

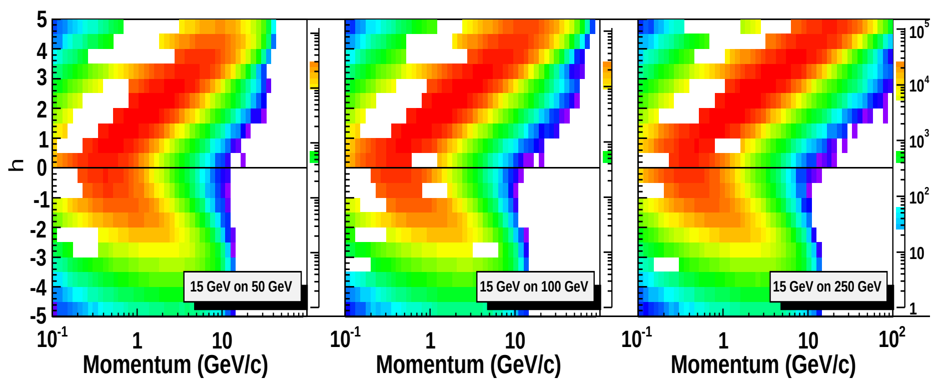
Measure one or more hadrons. Scattered electron is still the key.



- Hadron ID: K/π/p separation up to ~60 GeV/c
- Good electron/hadron separation required over wide angular range.
- For exclusive channels in e-p collisions, need to detect the outgoing proton → Roman pots.



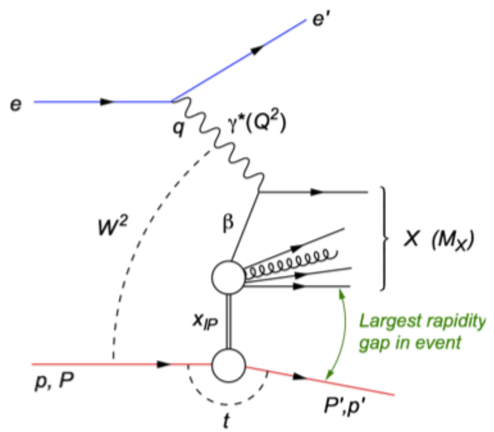
Q^2 vs. pseudorapidity for the scattered electron: 3 collision energies

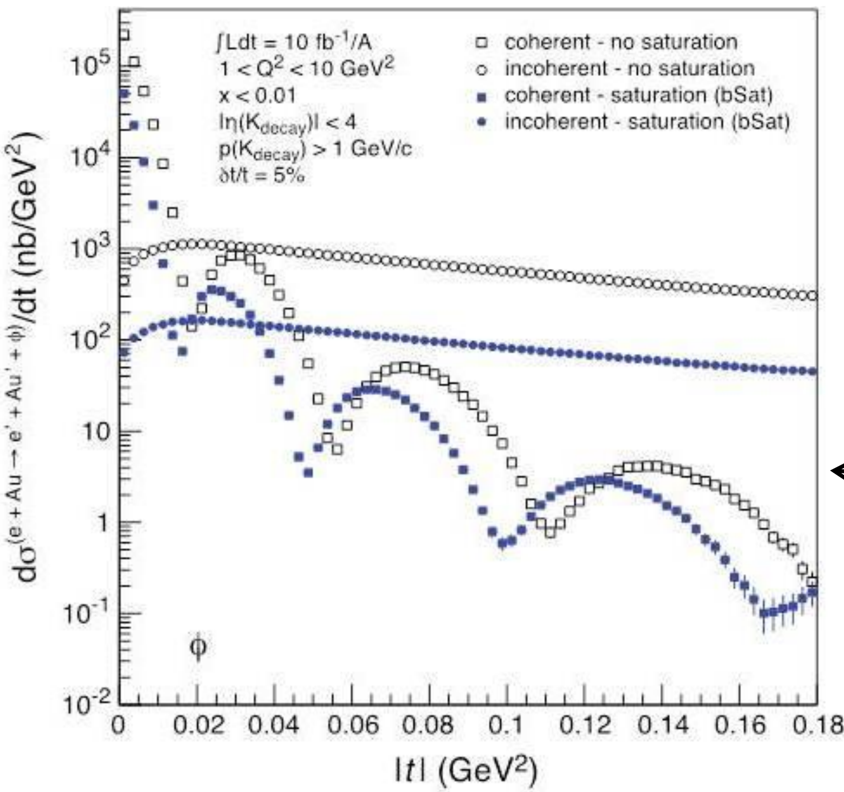


Pseudorapidity vs. momentum for produced pions: 3 collision energies

For more info see:
https://wiki.bnl.gov/eic/index.php/DIS:_What_is_important

Diffractive Scattering: Scattered proton or nucleus remains intact.





e – A diffractive scattering:

Coherent: nucleus remains intact
Inchoherent: nucleus breaks up, but nucleons remain intact

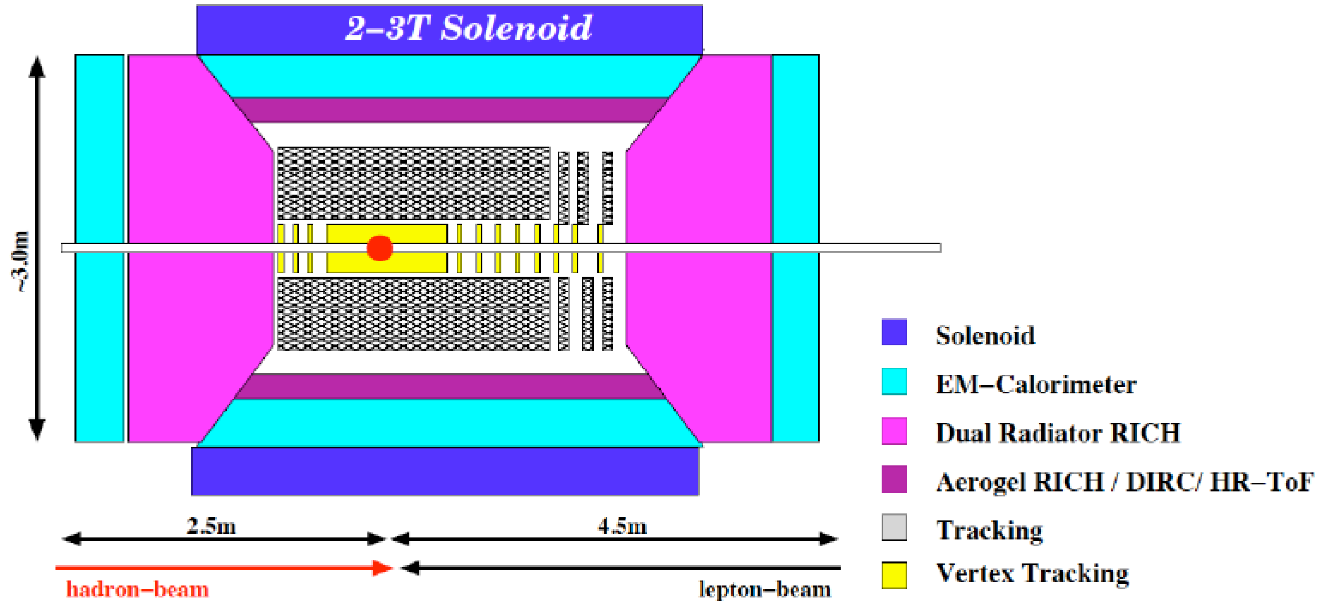
- Use Zero Degree Calorimeter to distinguish.

Diffractive vector meson production in e – Au collisions is a clean exptl. signature of gluon saturation.

Fourier decomposition gives spatial gluon distrib.

← **Diffractive φ production in e-Au collisions at eRHIC**

A Resulting Detector Concept



Compact, high resolution tracking, particle ID, EM calorimetry over full solid angle: $-5 < \eta < 5$

Low material density: low-momentum scattered electron

Downstream detectors for forward scattered electrons, protons, and break-up neutrons: ~ ±10 mrad

Electron Ion Collider Generic Detector R&D

Peer-Reviewed program established in 2011 to enable EIC experiments

Funded by DOE; managed by BNL: ~1M$-1.5M$/year

Focused on EIC "Golden Measurements" in the collider environment.

Coordinated efforts among CEBAF, RHIC, FAIR and HEP communities.

Initiating consortia of Universities and National Labs as a first step toward building scientific collaborations to successfully mount EIC experiments.

Standing Advisory Committee meets twice per year:

Marcel Demarteau (Argonne)
Ian Shipsey (Purdue)
Howard Wieman (LBNL, retired)

Carl Haber (LBNL)
Rick Van Berg (Penn)
Glenn Young (Jlab) Chair

Robert Klanner (Hamburg)
Jerry Va'vra (SLAC)

Proposals, Presentations, Committee reports at:
https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

An Activist Committee

- Early focus on simulation work to establish quantitative detector requirements:
    - Key physics measurements
    - Specific machine designs
- Match technologies to the specific EIC environment:
- Encourage collaborations between universities and national labs:
    - Carry design concepts through prototyping to full-scale tests
- Strong communication with world-wide developments (e.g. SiPMs, GEM development, etc.)

EIC Detector R&D: funded projects through January 2014

Prop. No.	Title	Contact	Institutions
RD 2012-5	Physics simulations	T. Ullrich	BNL
RD 2011-1	Tungsten fiber calorimeters	Huang/ C. Woody	UCLA, TAMU, Penn St., BNL, USTC
RD 2012-13	Forward EM pre-shower	W. Brooks	UTFSM (Valparaiso, Chile)
RD 2011-5	Radiation resistant Si PM	C. Zorn	JLab
RD 2011-6	Tracking/PID/Simulation	K. Dehmelt/ T. Hemmick	BNL, BNL/RBRC, Florida Inst. of Technology, Iowar State, LBNL, MIT, Stony Brook Univ., Temple Univ., Univ. Virginia, Yale Univ., JLab
RD 2012-3	Tracking: GEM & Micromegas	B. Surrow, F. Sabatie	CEA Saclay, MIT, Temple Univ.
RD 2011-3	DIRC -based PID	P. Nadel-Turonski	Catholic Univ. of America, Old Dominion Univ., Univ. of South Carolina, JLab, GSI Darmstadt
RD 2012-12	Forward RICH detector	V. Kubarovsky	JLab, INFN Frascati, INFN Ferrara, Christopher Newport Coll., UTFSM (Valparaiso, Chile)
RD 2013-5	10 Picosecond TOF: MCP-PMTs	M. Chiu	BNL, Howard Univ., Muhlenberg Coll., Univ. Illinois U-C, U. Mass. Amherst, Yale Univ.
RD 2012-15	Gem based TRD	Z. Xu, M. Shao	ANL, BNL, Indiana Univ., USTC (China), VECC (India)
RD 2012-11	Spin-light polarimeter	D. Dutta	Mississippi State Univ., Coll. Of William & Mary, Stony Brook Univ., Gutenberg Univ. (Mainz), UV Charlottesville, ANL, JLab
RD 2013-6	Polarimetry & luminosity monitor	E. Aschenauer	BNL, Byelorussian State Univ., Cracow Univ. Technology
RD 2013-2	Magnetic field cloaking device	A. Deshpande	Stony Brook Univ., RIKEN, BNL

Simulation tools

Compact, Fine Grain Calorimetry and Photon Detection

Simulations; Micropattern Tracking; Central & Forward Particle ID

Forward e-Tagging

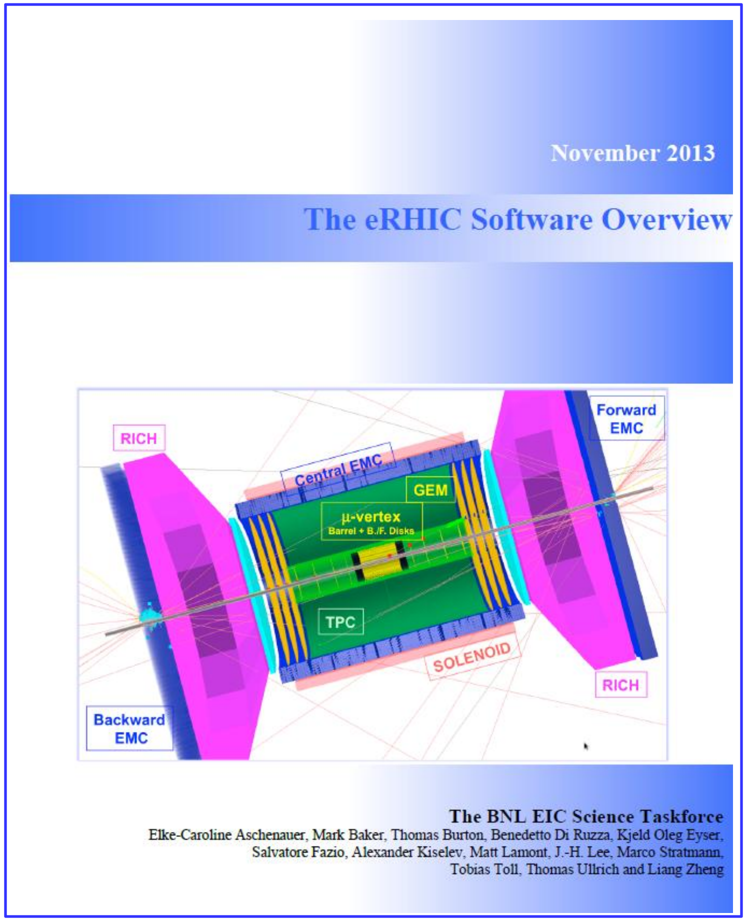
e-Beam Polarimetry; Lumi monitor

Detector/Beam Interface

Early Emphasis on Simulation Tools

Simulation studies to understand the specific technical requirements for EIC experiments:

Maximize acceptance and efficiency for each golden measurement while minimizing machine backgrounds, and backgrounds from other physics processes.



Software packages include Monte Carlo generators specially developed for e-p and e-A collisions at EIC energies.

Detector simulation packages: impact of detector responses on physics observables…

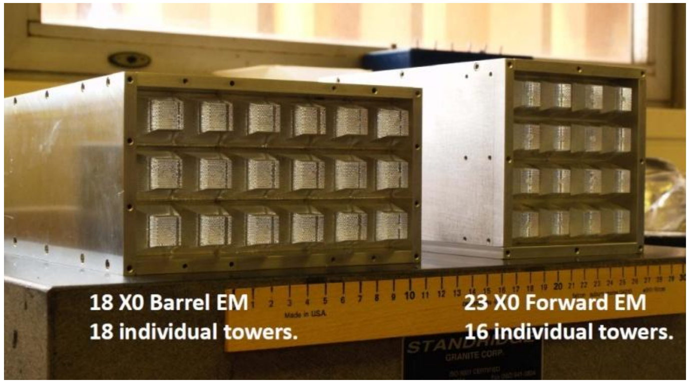
- EICRoot framework, based on FairRoot
- Fast smearing generator

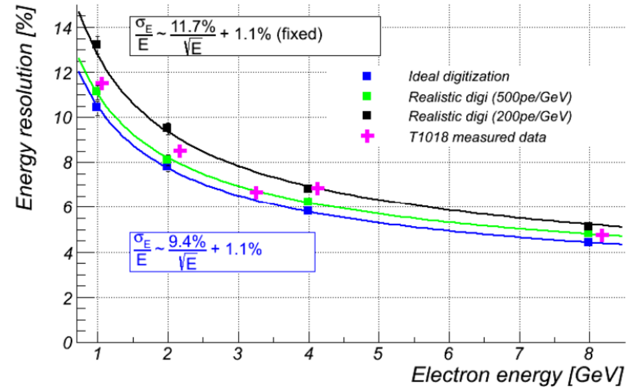
Long-term support and maintenance of these programs, essential for the design and implementation of EIC detectors, requires a sustained effort. Plans are in progress.

Compact EM Calorimeters

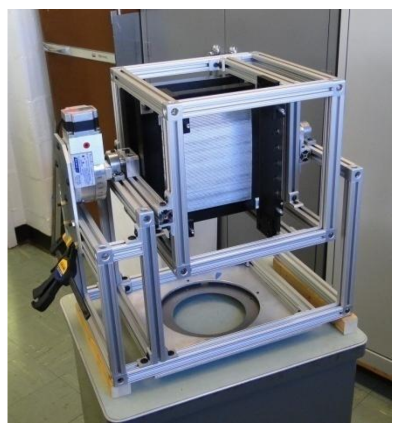
RD2011-1 Consortium: UCLA, BNL, Indiana U., Penn State, TAMU, USTC (China)

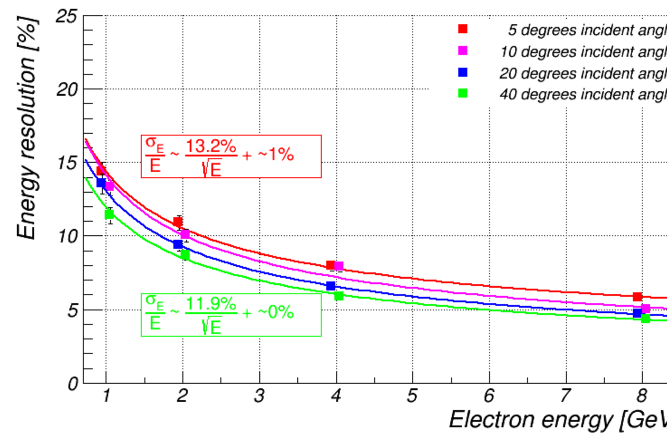
UCLA et al. W powder/scint. Fiber modules– Si PM readout





BNL et al. W plates and fibers– Si PM readout





1 mm W + 1 mm fiber

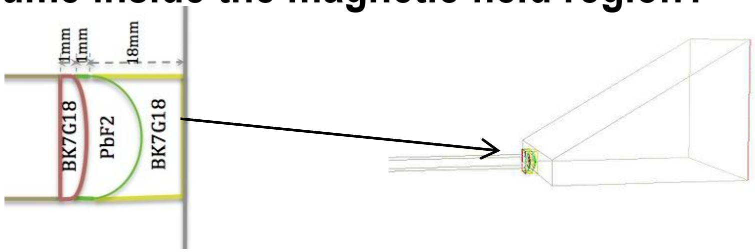
Close Coordination with STAR and PHENIX upgrade development

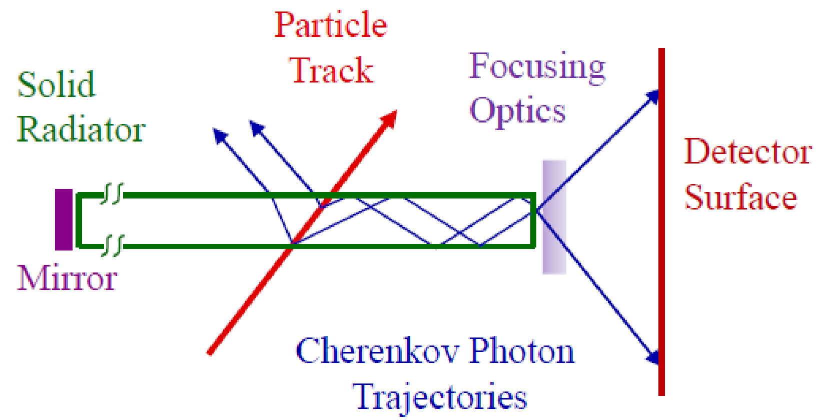
DIRC-based PID

RD2011-3: Jlab, GSI, Catholic Univ. of America, Old Dominion Univ., Univ. South Carolina

BaBar principle with compact readout:

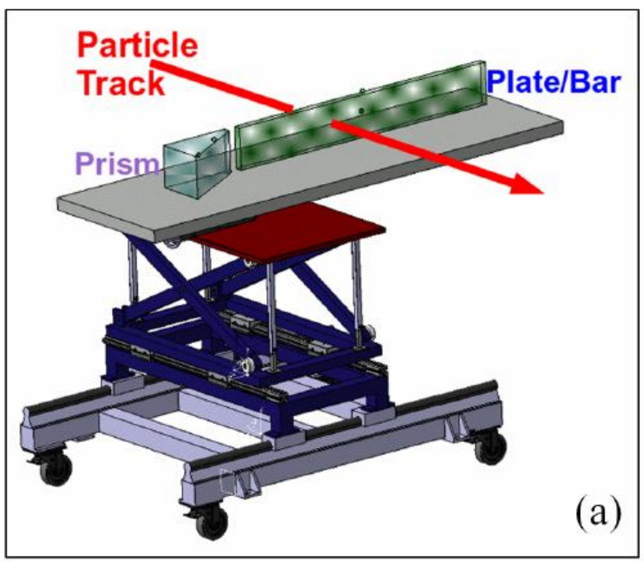
Hi index lens and compact expansion volume inside the magnetic field region?

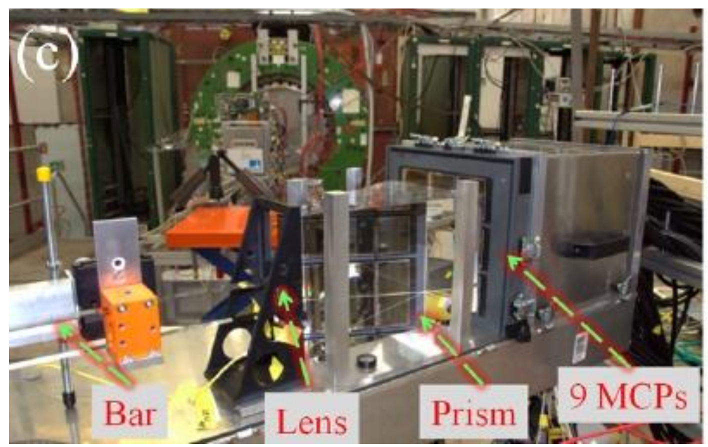




Si PM sensors

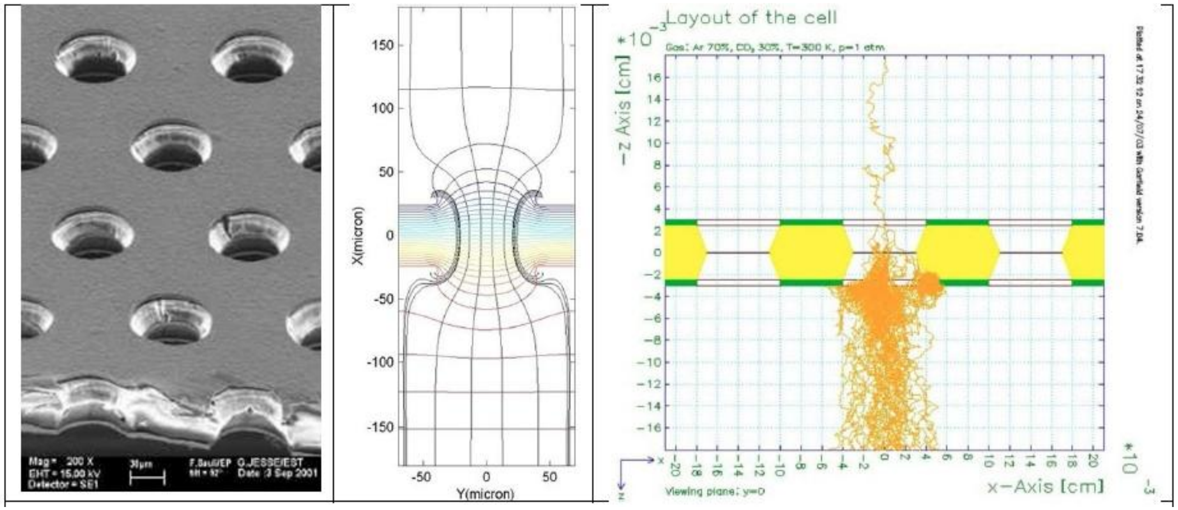
Aim for 3σ K/π separation at 6 GeV/c



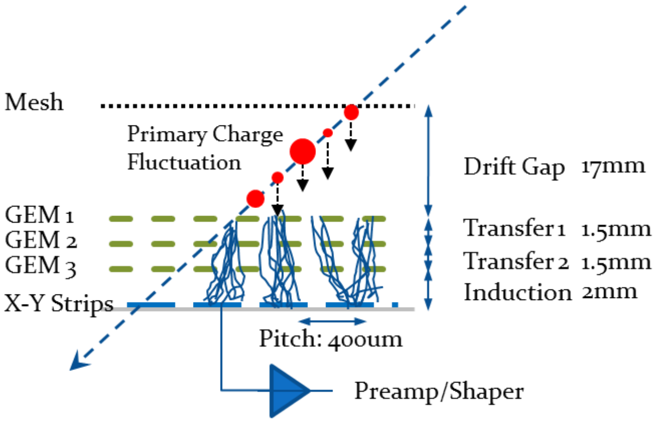


Close collaboration with PANDA development

Compact Tracking and PID with GEM Detector Technique



Basic structure is thin, self-supporting mesh realized by photolithographic techniques.



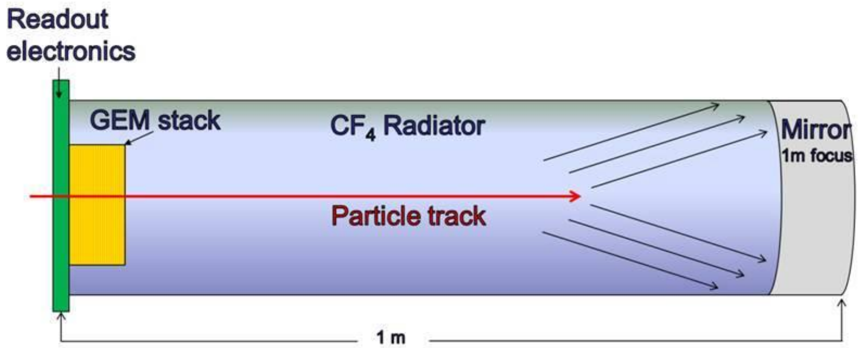
Mini-Drift GEM Chamber:

RD2011-6 Collaboration

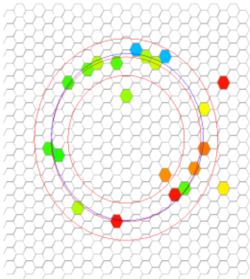
Considerable progress in recent years in developing manufacturing techniques, precision characterization, quality control, large area foils, reliable commercial sources, practical implementation of large systems.

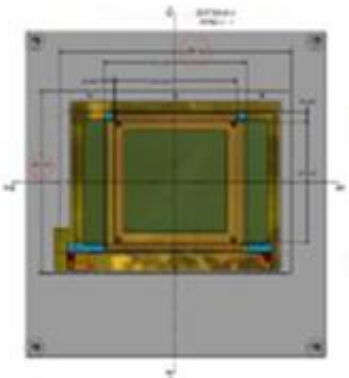
RD2011-6 Tracking and PID Collaboration

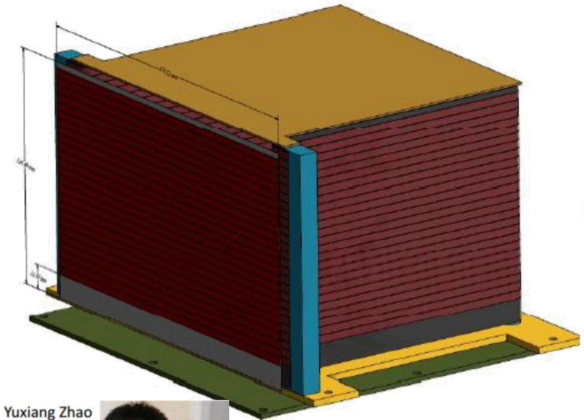
Stony Brook Univ., BNL, Florida Inst. Tech., Univ. Virginia, Yale Univ.



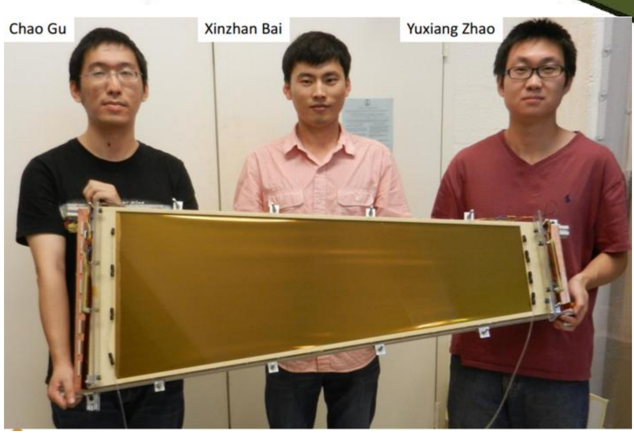
RICH with CsI-coated 5-GEM readout, UV reflecting mirror







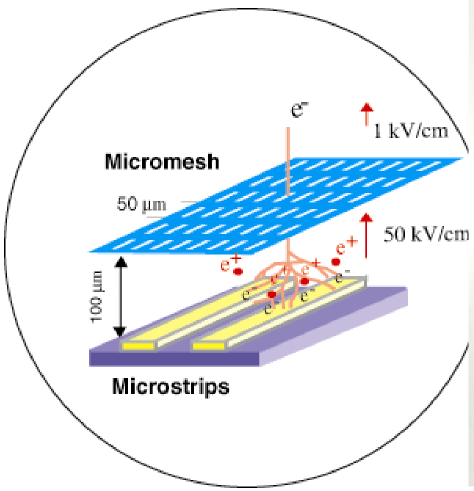
Prototype for compact TPC with GEM readout

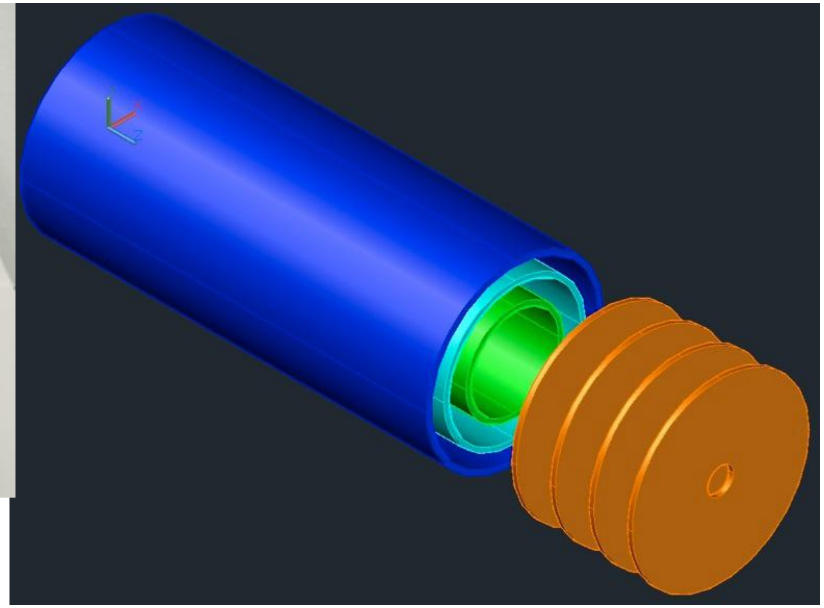


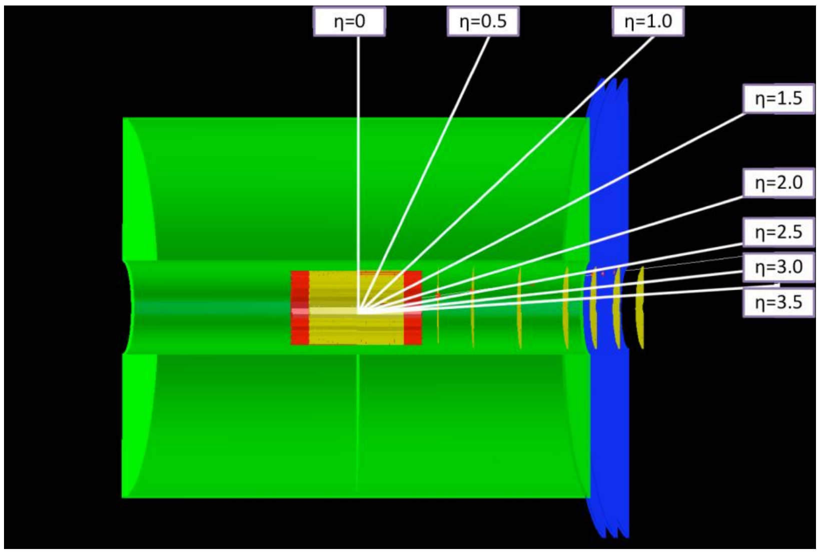
Large-area, "Compass-type" GEM sector with 2-D readout

RD2012-3: Forward GEM and Barrel MicroMegas Tracking

CEA Saclay, Temple Univ., MIT

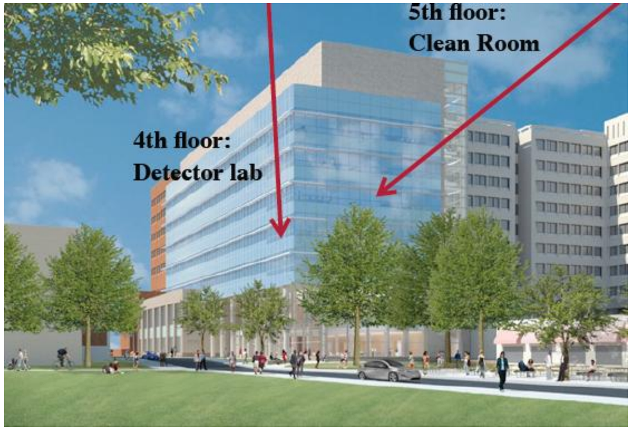






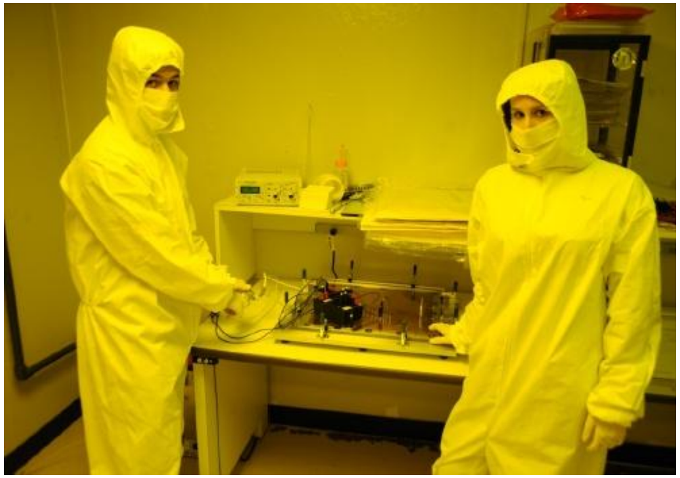
Cylindrical MicroMegas Barrel layers draw on CLAS12 development at Saclay.

RD2012-3: GEM Development Lab setup at Temple University

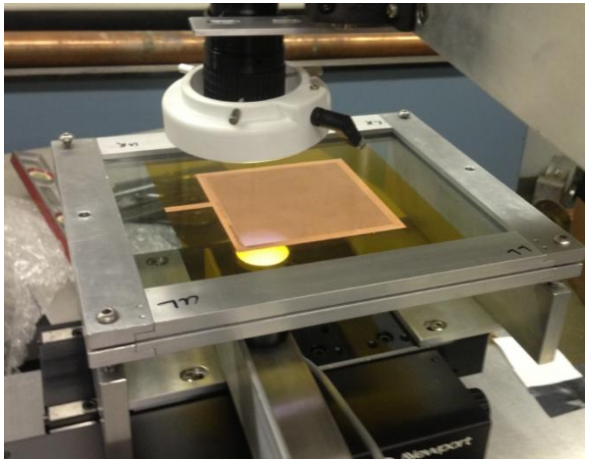


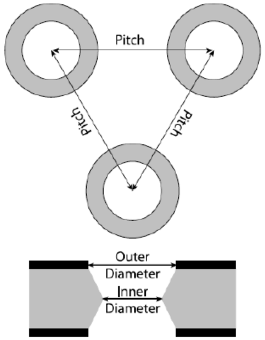
New Science Education & Research Center

500 ft^2 clean room
1000 ft^2 lab



Present clean room at Temple

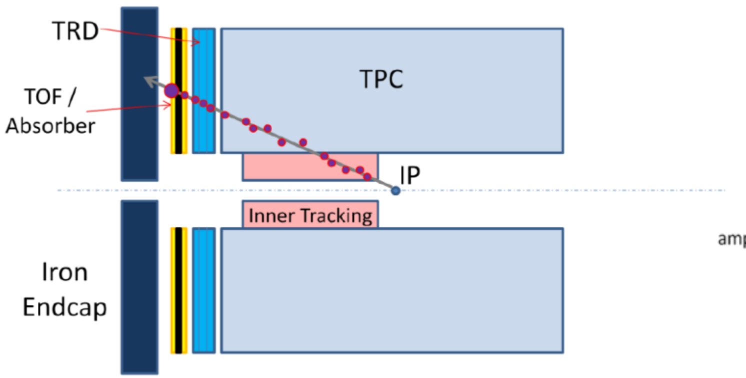


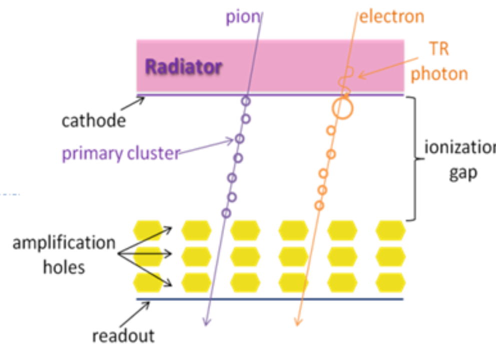


Precision optical scanner for GEM foil characterization

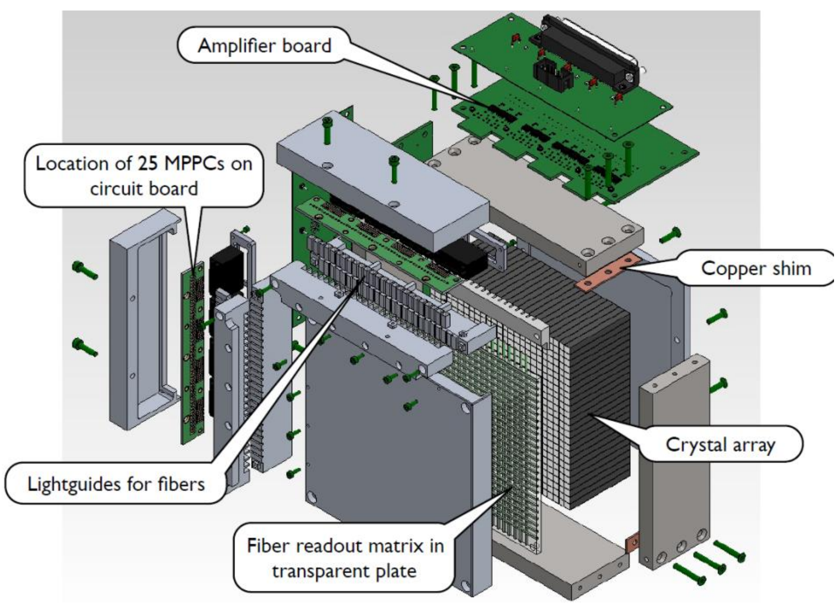
Forward Electron Tagging

RD2012-15 BNL, USTC (China) GEM-based End Cap TRD

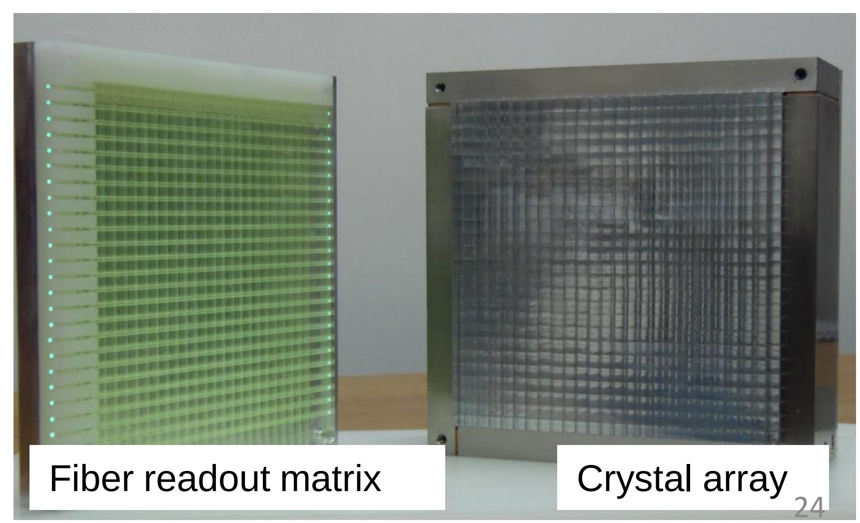




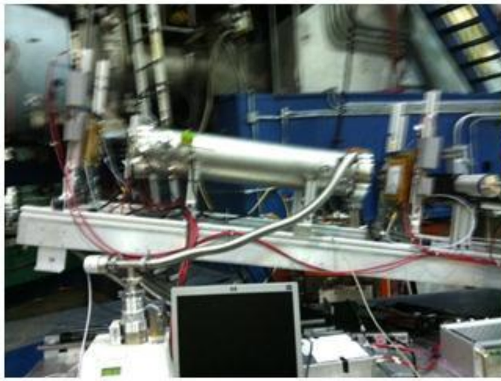
RD2012-13 UTFSM (Chile) Crystal-based pre-shower detector for forward EM calorimeters

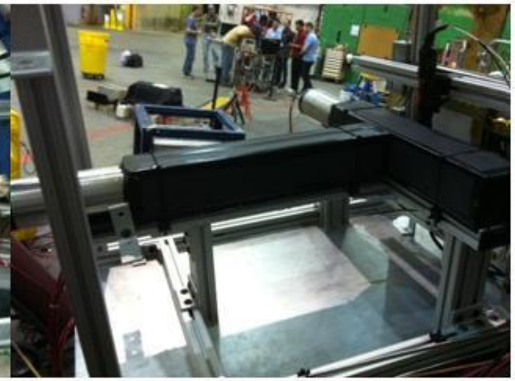


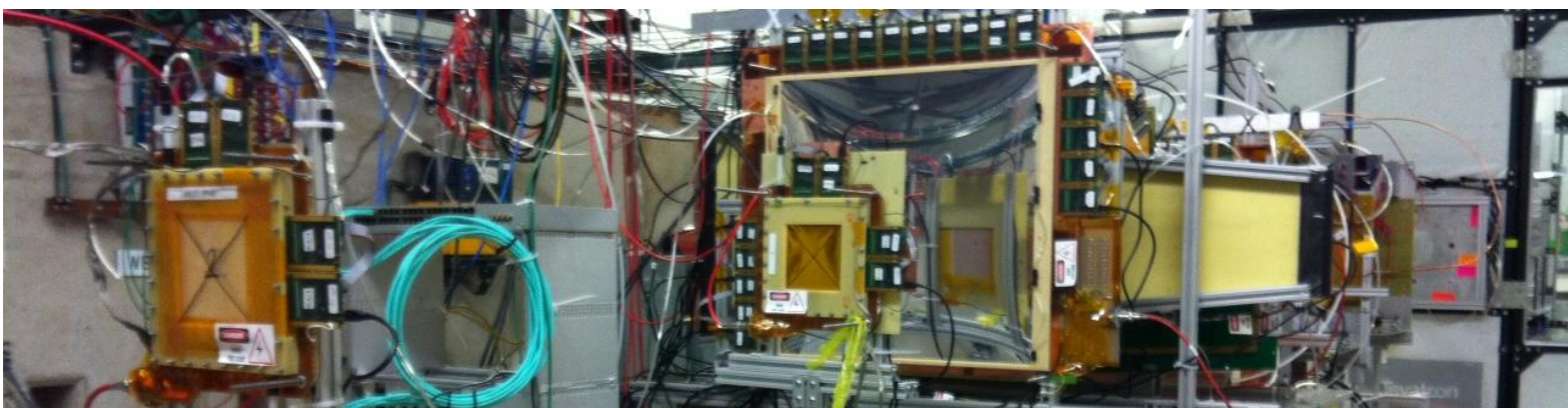
625 LYSO crystals in 10 x 10 cm array



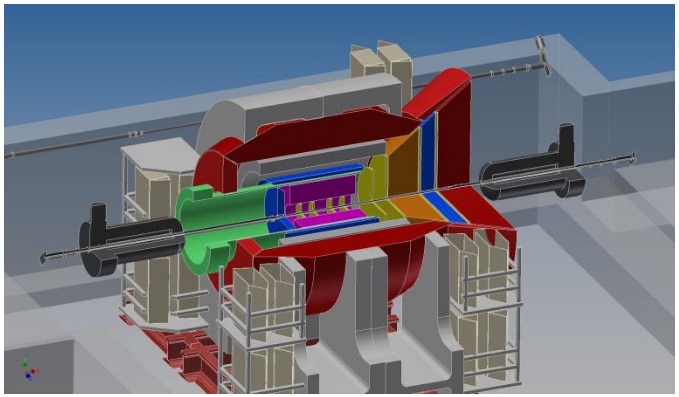
EIC Detector R&D at JLab, SLAC, Fermilab test beams







ePHENIX Concept

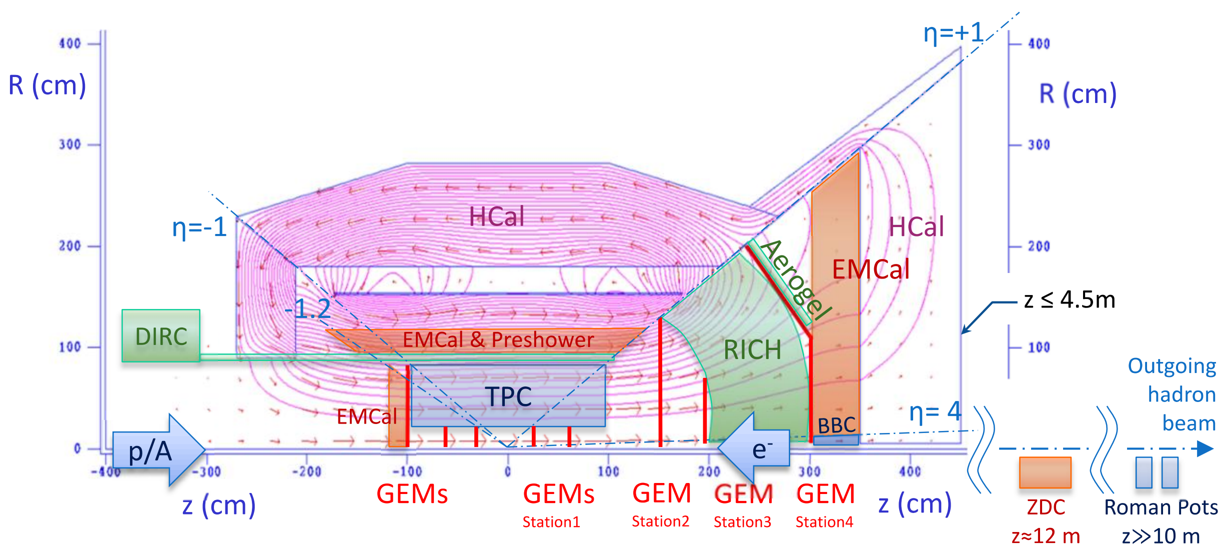


Proposed sPHENIX as starting point:

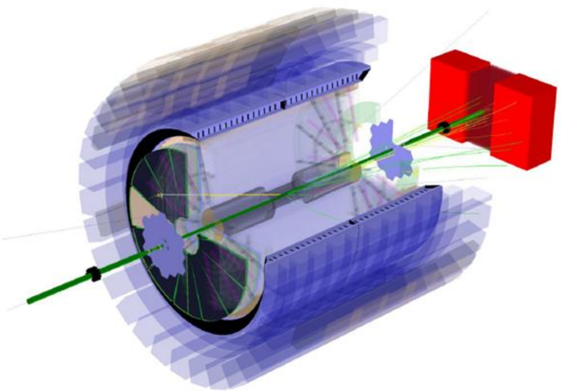
Utilizes 1.5 Tesla former BaBar Magnet.

Full EM calorimeter coverage over $-4 < \eta < 4$

- **High precision crystal calorimeter in e-direction**
- **Compact GEM and TPC tracking detectors**
- **Hadron PID via barrel DIRC, forward gas and Aerogel RICH**
- **Forward HCal coverage to η = 5 (diffractive production)**

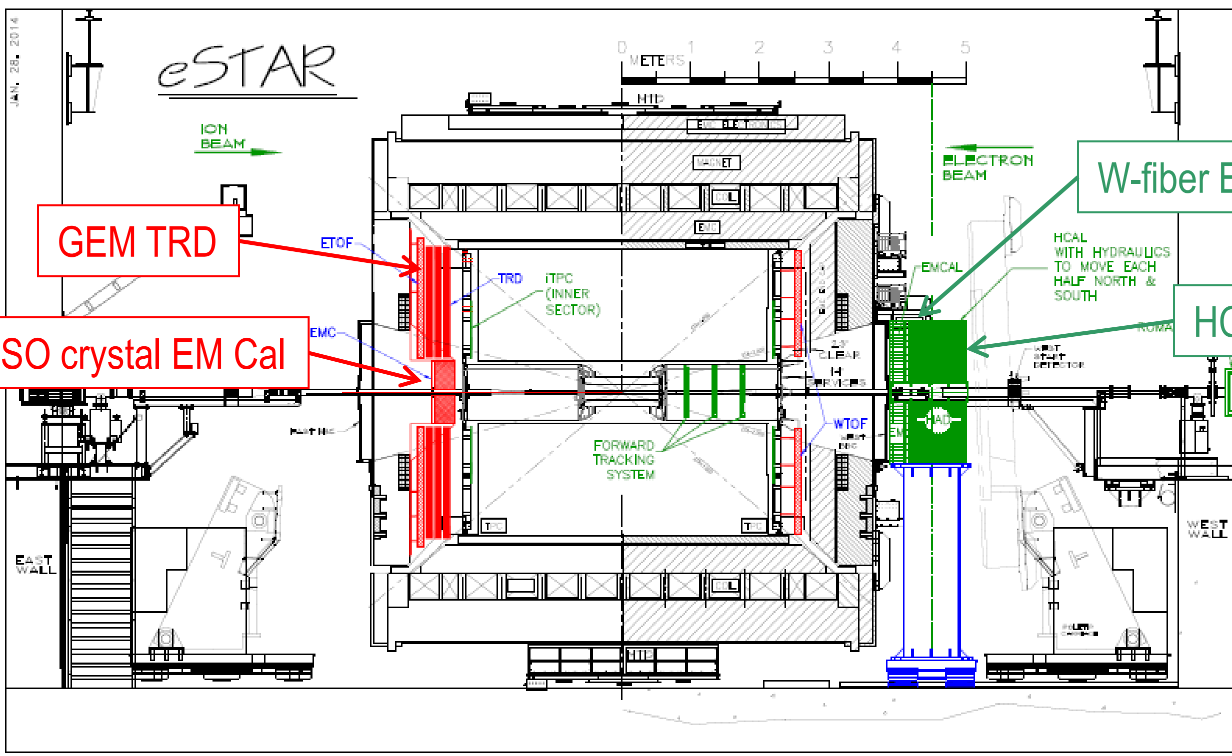


eSTAR Concept



Build on existing mid-rapidity tracking and PID with a suite of forward upgrades:

- **EndCap TOF walls covering η = 1-2 on each side**
- **GEM –based TRD and Crystal EM Calorimeter on electron-going side**
- **Forward GEM trackers and Calorimeters on hadron-going side**

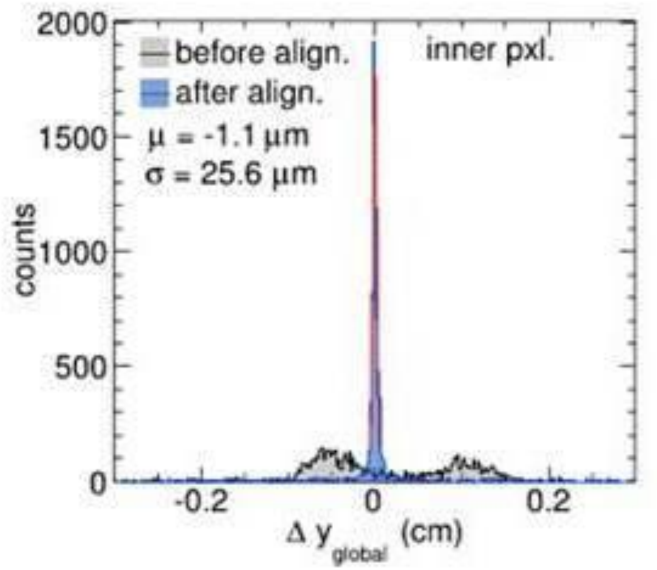


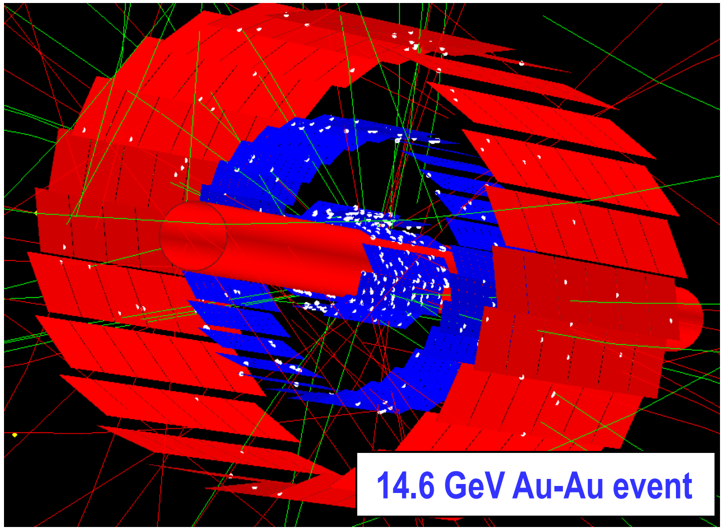
STAR Heavy Flavor Tracker

First large-scale use of MAPS technology

Innermost Pixel Layers use 400 Monolithic Active Pixel Sensors (MAPS): 3.6×10^8 pixels, 20.7 μm/pixel.

Alignment with cosmic rays





14.6 GeV Au-Au event

A Possible Timeline for transition from RHIC to eRHIC

Assumes NP Long Range Plan and DOE "CD-0" approval in 2015-2016