EIC detectors

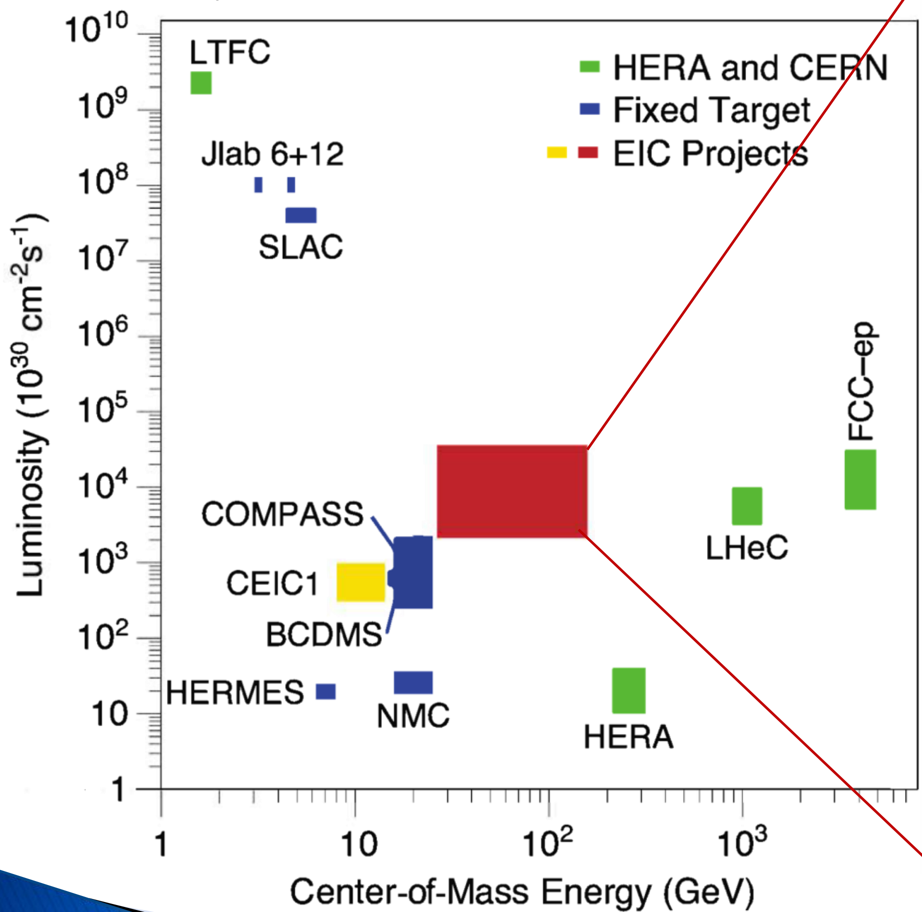
Jin Huang (BNL)
For the EIC user group

BROOKHAVEN NATIONAL LABORATORY

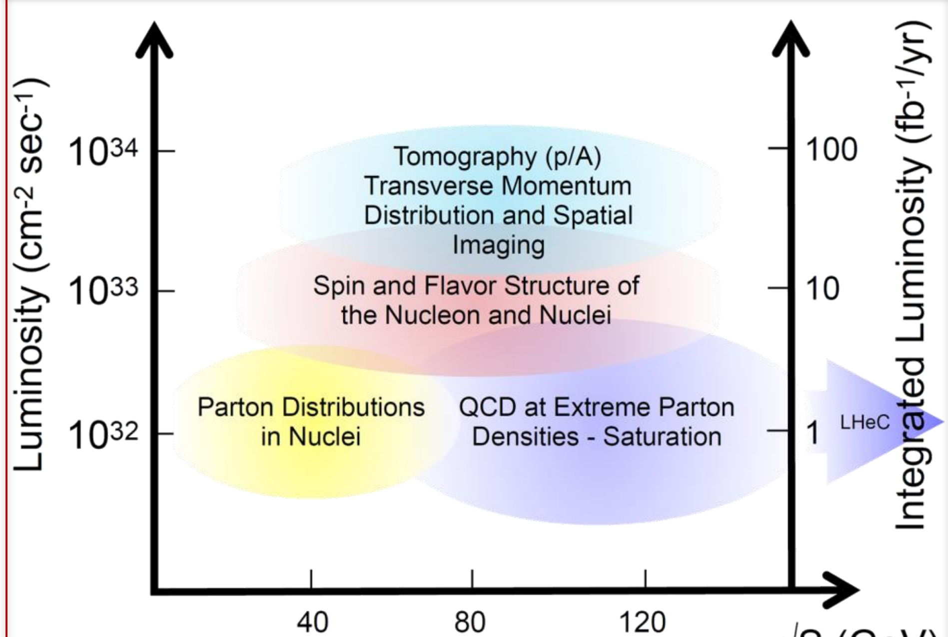
e+p/A landscape with EIC

See also: M. Sievert Thu AM

Simplified based on work of M. Klein, R. Ent, U. Klein



- ⇨ Nuclear beam
- ⇨ Polarized hadron beam
- ⇨ ≥100x HERA luminosity

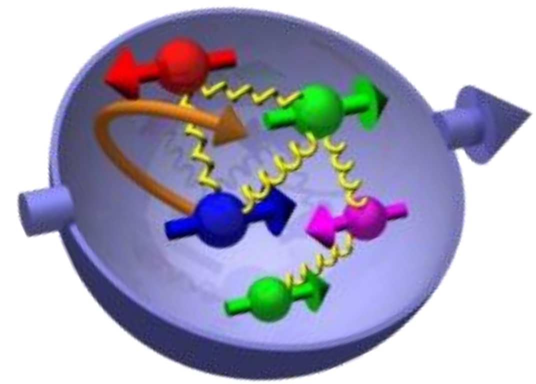


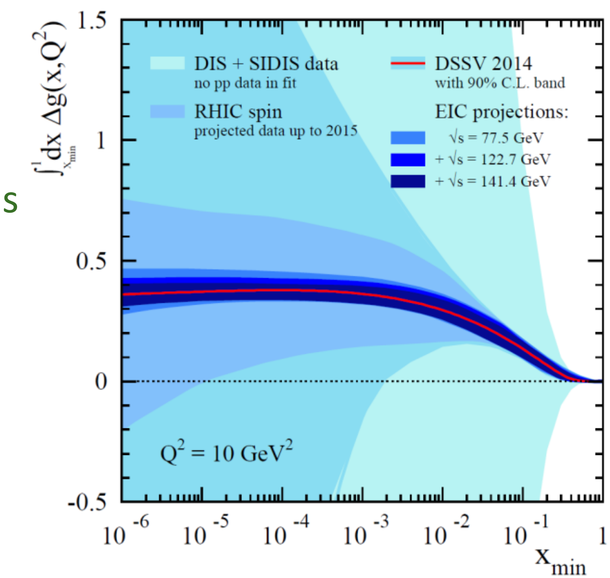
Courtesy: Bernd Surrow

Physics goals → Detector requirement - Nucleon as a laboratory for QCD

See also: M. Sievert Thu AM

- The compelling question:
  How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?
- Deliverable measurement using polarized electron-proton collisions
  - The longitudinal spin of the proton, through Deep-Inelastic Scattering (DIS)
  - Transverse motion of quarks and gluons in the proton, through Semi-Inclusive Deep-Inelastic Scattering (SIDIS)
  - Tomographic imaging of the proton, through Deeply Virtual Compton Scattering (DVCS)
- Leading detector requirement:
  - Good detection and kinematic determination of DIS electrons
  - Momentum measurement and PID of hadrons
  - Detection of exclusive production of photon/vector mesons and scattered proton
  - Beam polarimetry and luminosity measurements

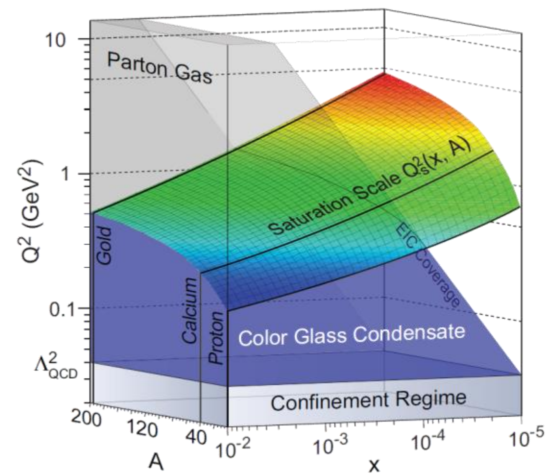


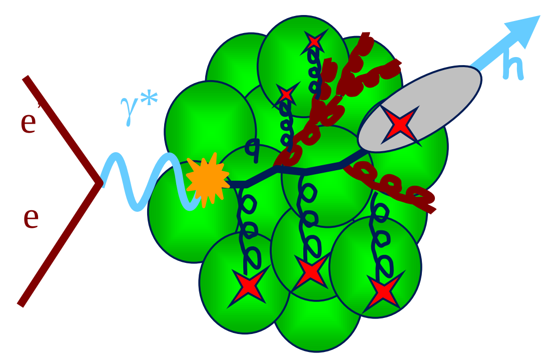


Physics goals → Detector requirement - nucleus as a laboratory for QCD

See also: M. Sievert Thu AM

- The compelling questions:
  - Where does the saturation of gluon densities set in?
  - How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?
- Deliverable measurement using electron-ion collisions
  - Probing saturation of gluon using diffractive process and correlation measurements
  - Nuclear modification for hadron and heavy flavor production in DIS events; probe of nPDF
  - Exclusive vector-meson production in eA
- Leading detector requirement:
  - Large calorimeter coverage to ID diffractive events
  - Displaced vertex for heavy flavor quark tagging
  - Detection/rejection of break-up neutron production in eA collisions

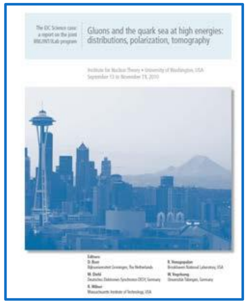




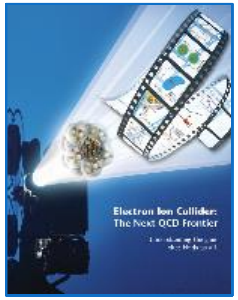
Towards EIC in the past decade

Time

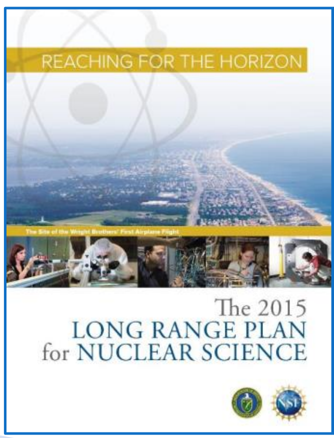
2011 2012 2013 2014 2015 2017 2018 2019 2020



arXiv:1108.1713



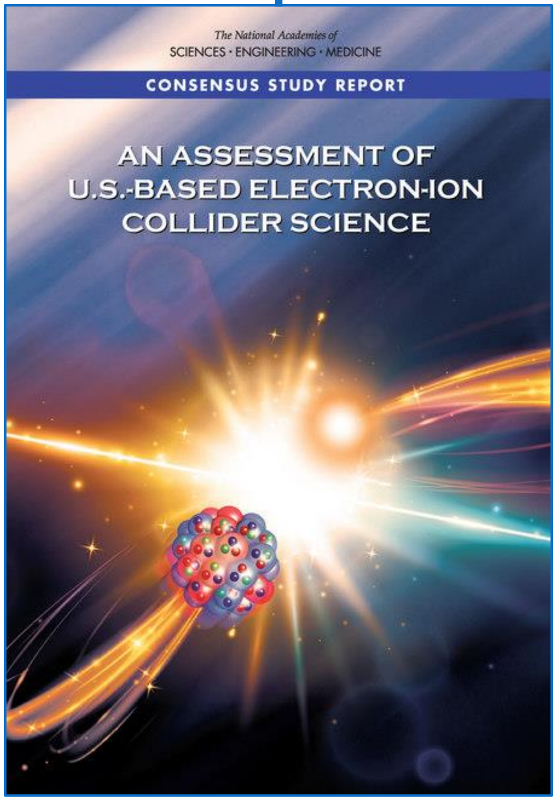
arXiv:1212.1701



RECOMMENDATION III

Gluons, the carriers of the strong force, bind the quarks together inside nucleons and nuclei and generate nearly all of the visible mass in the universe. Despite their importance, fundamental questions remain about the role of gluons in nucleons and nuclei. These questions can only be answered with a powerful new electron ion collider (EIC), providing unprecedented precision and versatility. The realization of this instrument is enabled by recent advances in accelerator technology.

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.



DOE
CD-0
(mission need)

CD-0 announcement and site selection

- Secretary Brouillette approved Critical Decision-0, “Approve Mission Need,” for the EIC on December 19, 2019.
- January 19, 2020 DoE announces CD-0 and that BNL will be the host of the EIC

ENERGY.GOV

Department of Energy

U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

JANUARY 9, 2020

Home » U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

WASHINGTON, D.C. – Today, the **U.S. Department of Energy (DOE)** announced the selection of Brookhaven National Laboratory in Upton, NY, as the site for a planned major new nuclear physics research facility.

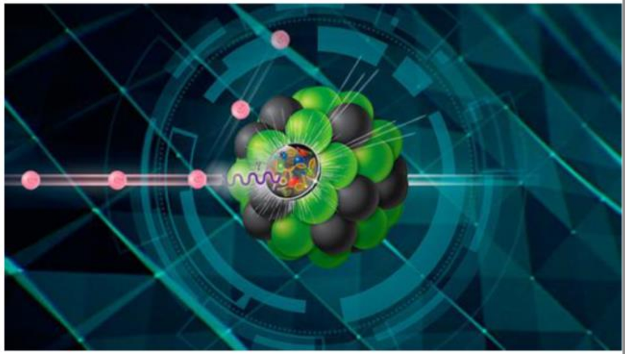
The Electron Ion Collider (EIC), to be designed and constructed over ten years at an estimated cost between $1.6 and $2.6 billion, will

A communication resource from the **world's particle physics laboratori**

Department of Energy Selects Site for Electron-Ion Collider

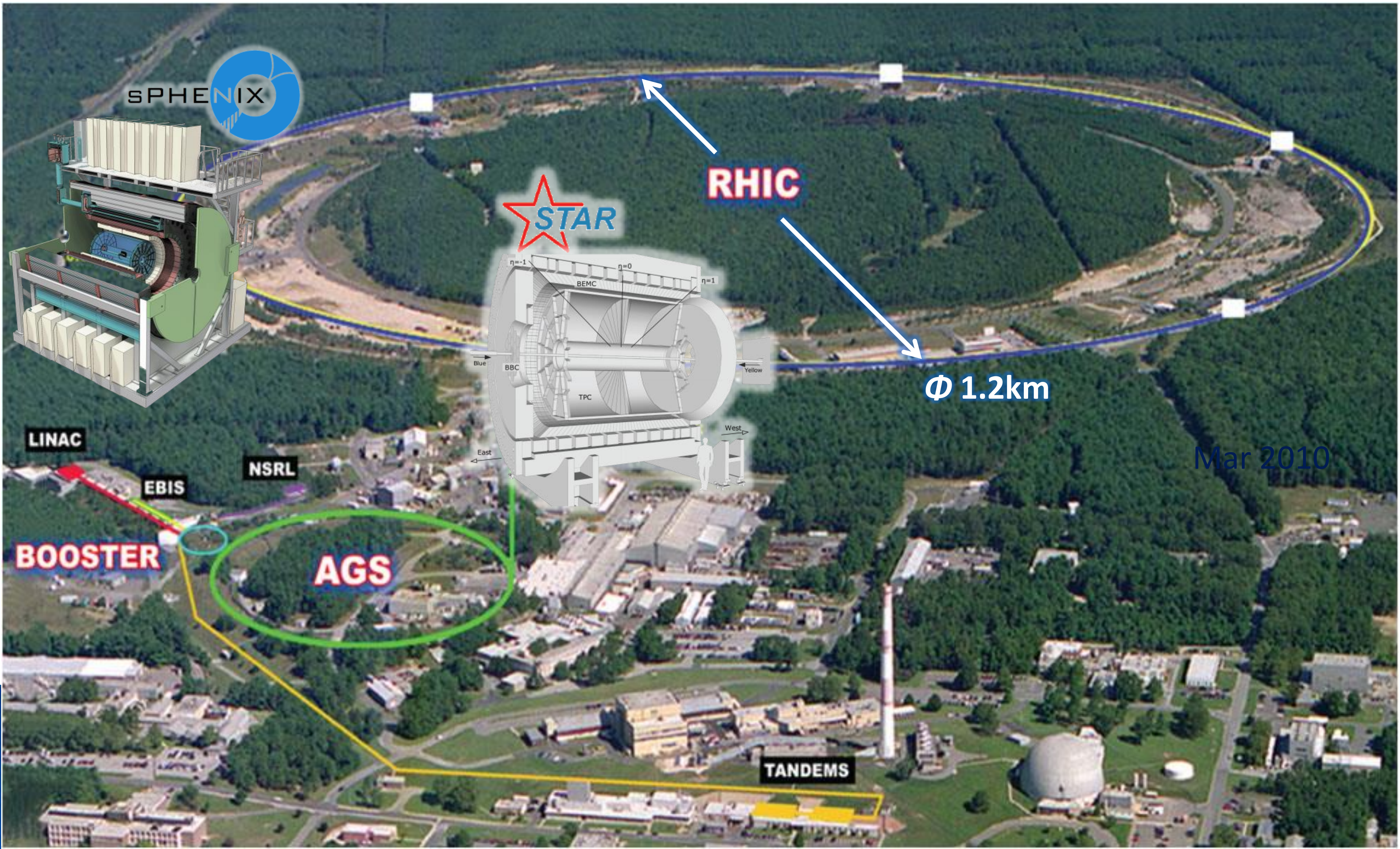
10 January 2020 - Brookhaven National Laboratory

New facility to be located at Brookhaven Lab will allow scientists from across the nation and around the globe to peer inside protons and atomic nuclei to reveal secrets of the strongest force in nature



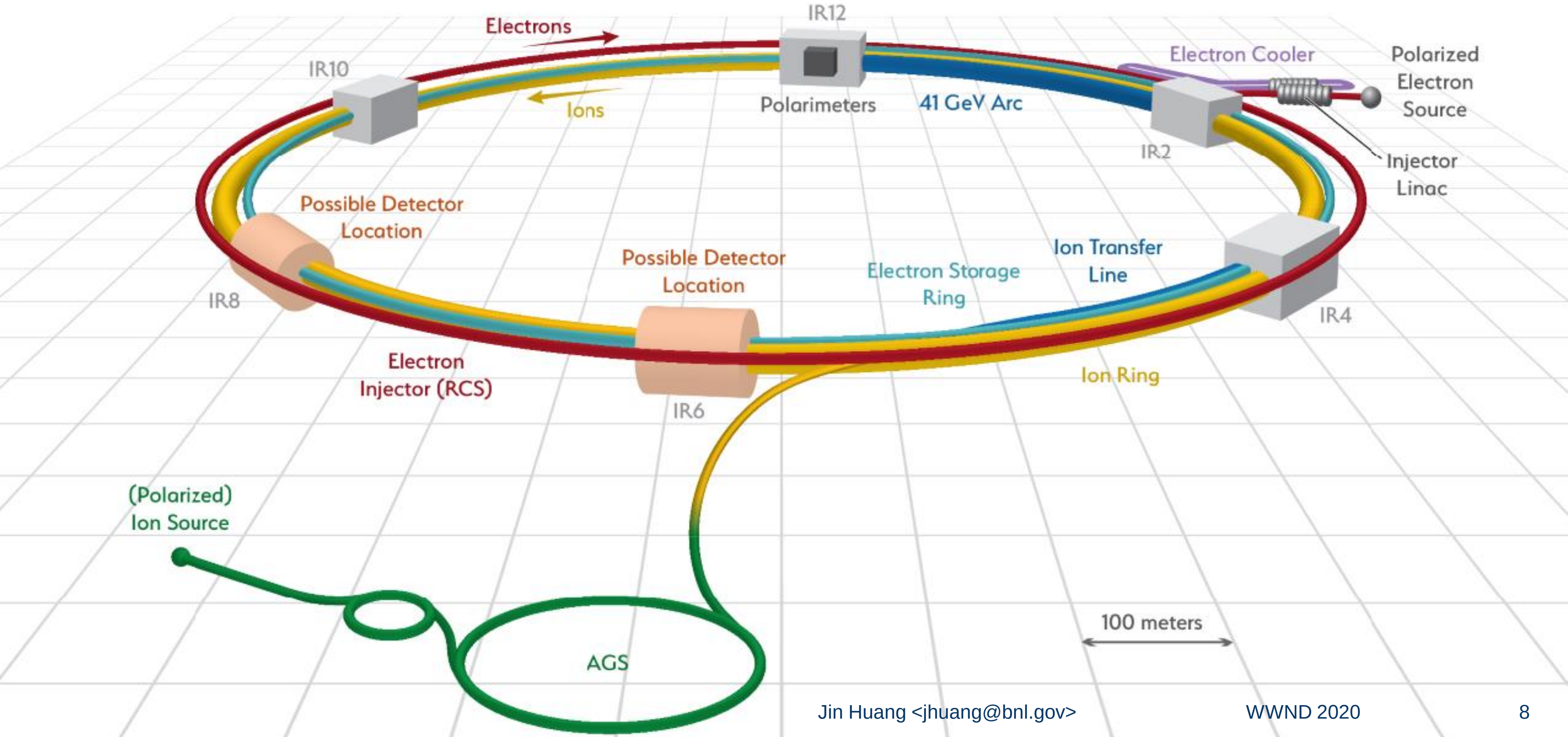
UPTON, NY– Yesterday, the U.S. Department of Energy (DOE) named Brookhaven National Laboratory on Long Island in New York as the site for building an Electron-Ion Collider (https://www.bnl.gov/eic/) (EIC), a one-of-a-kind nuclear physics research facility. This

Relativistic Heavy Ion Collider mid-2020s



RHIC transition to the EIC [eRHIC pre-CDR]

- Highly polarized electron and nucleon beams, Ion beams from D-> U or Pb.
- Hadrons up to 275 GeV, Electrons up to 18 GeV
- √s = 20 GeV -141 GeV, supporting two IPs
- High luminosity $10^{34} cm^{-2} s^{-1}$ (≥ 100x HERA luminosity)



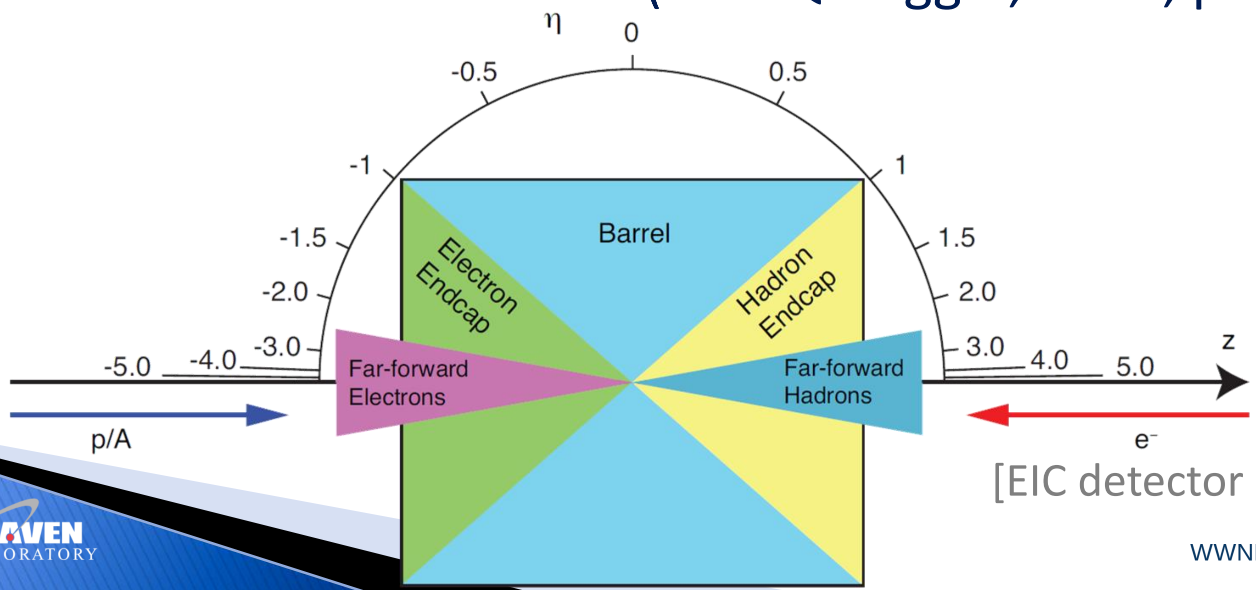
EIC: unique collider
→ unique detector system challenges

	EIC	RHIC	LHC → HL-LHC
Collision species	$\vec{e}+\vec{p}, \vec{e}+A$	$\vec{p}+\vec{p}/A, A+A$	$p+p/A, A+A$
Top x-N C.M. energy	140 GeV	510 GeV	13 TeV
Bunch spacing	10 ns	100 ns	25 ns
Peak x-N luminosity	10^{34} cm^{-2} s^{-1}	10^{32} cm^{-2} s^{-1}	10^{34} → 10^{35} cm^{-2} s^{-1}
x-N cross section	50 μb	40 mb	80 mb
Top collision rate	500 kHz	10 MHz	1-6 GHz
$dN_{ch}/d\eta$ in p+p/e+p	0.1-Few	~3	~6
Charged particle rate	4M N_{ch}/s	60M N_{ch}/s	30G+ N_{ch}/s

- EIC luminosity is high, but collision cross section is small ($\propto \alpha_{EM}^2$) → low collision rate
- But events are precious and have diverse topology → large acceptance
- Background and systematic control is crucial → precision detectors

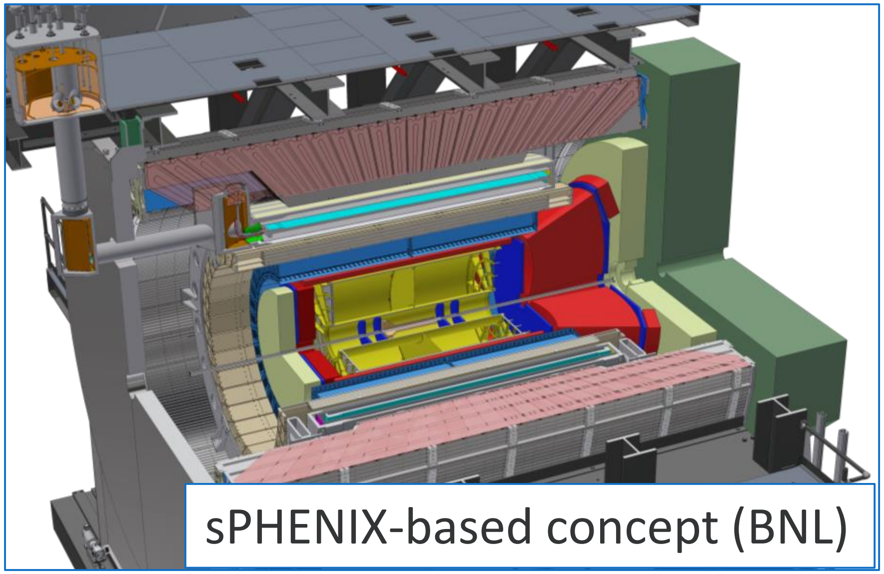
Common EIC Detector features

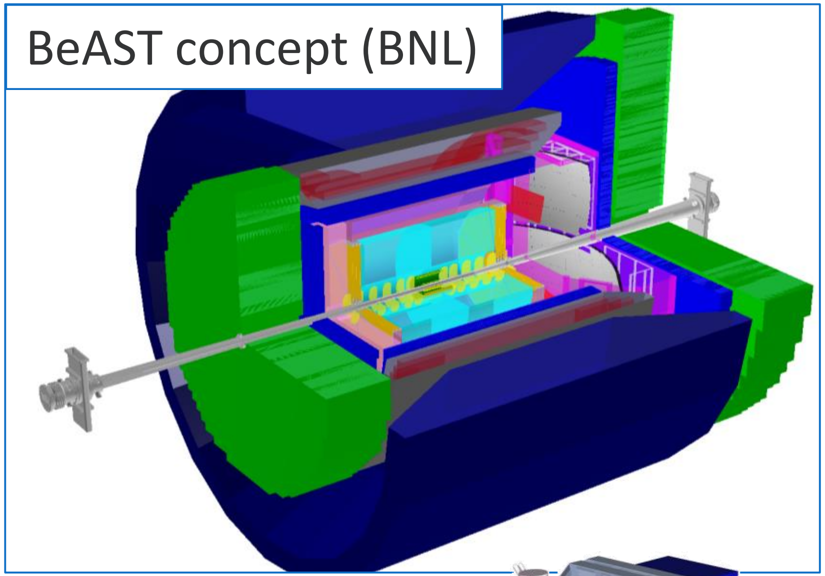
- **Central**+ **forward**/**backward** tracker layout,
  hermetic coverage in tracking/calorimetry/PID for $|\eta|<4$
  - Low material budget in the tracker volume
  - 1.4 – 4.0 T central solenoid field, moderate $\vec{p}$ resolution (~1% level)
  - Large area PID coverage
  - Moderate-to-high vertex resolution (<20 μm or so)
  - Moderate EMCal and HCal energy resolution
- Advanced **far forward** instrumentation (Roman Pots, ZDC, etc)
- **Far backward** instrumentation (Low Q^2 tagger, lumi., polarimeter)

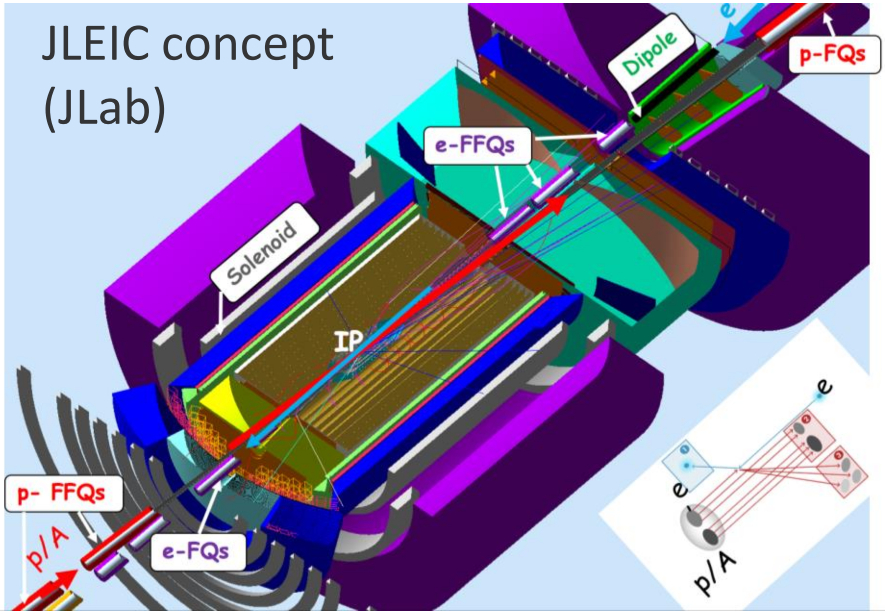


[EIC detector handbook]

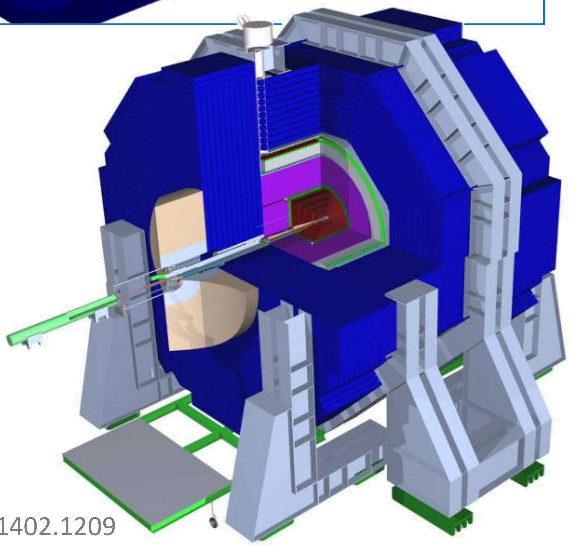
Early EIC Detector Concepts







TOPsiDE concept (ANL)



References reports :
- ePHENIX LOI: arXiv:1402.1209
- eRHIC design report, preCDR: arXiv:1409.1633
- MEIC (JLEIC) design summary: arXiv:1504.07961
- On-going development and updates

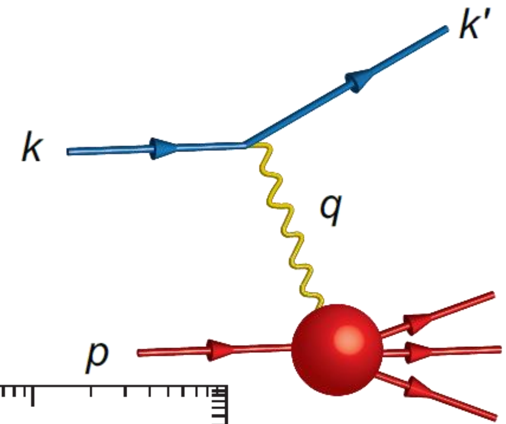
EIC instrumentation efforts

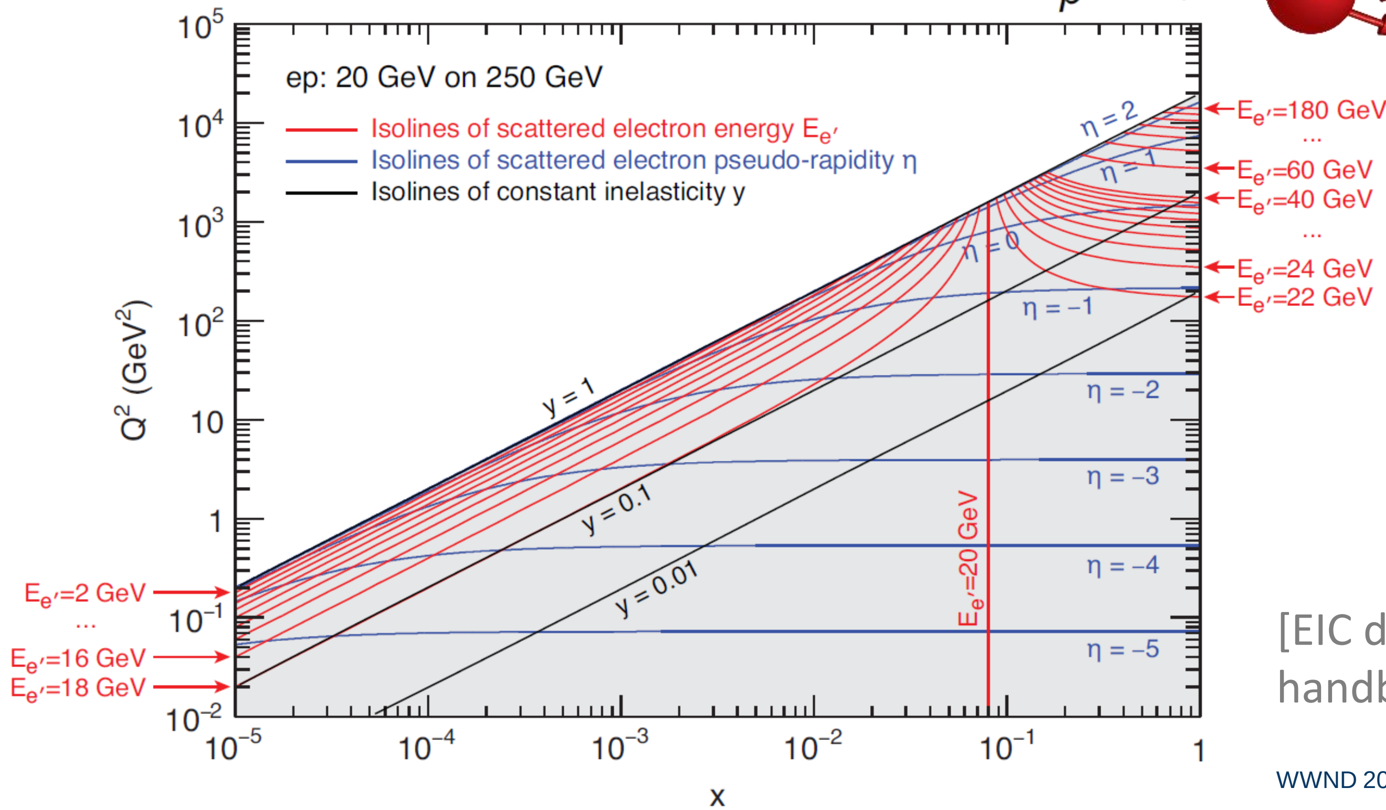
- EIC generic R&D: https://wiki.bnl.gov/conferences/index.php/EIC_R%25D
  - Started 2011 @ BNL, in association with JLab and the DOE
  - 10-11 projects supported per FY, covering all aspects of major EIC detector components. Open to international groups
- EIC user group yellow report initiative: http://www.eicug.org/web/content/yellow-report-initiative
  - Advance physics studies and detector concepts in preparation for the realization of the EIC
  - Recently started, 1st workshop end-March at Temple Univ.
  - Three top level working groups: physics, detector, accelerator
- EIC-related NP experiments: e.g. many EIC instrumentation are used and tested in large scale in STAR-forward upgrade and sPHENIX

Detector drives & R&D highlight – DIS

Tagging the L.O. struck quark kinematics with scattered electron

→ Wide angle electron overage



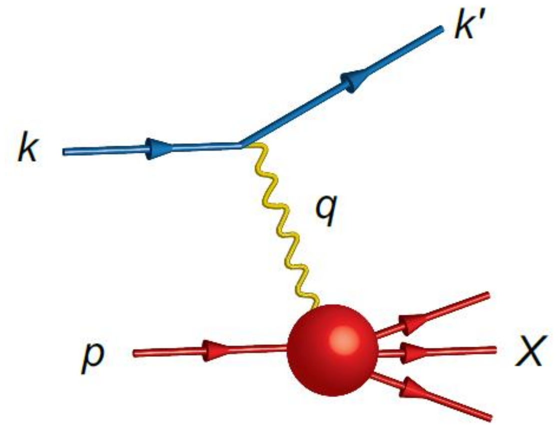


[EIC detector handbook]

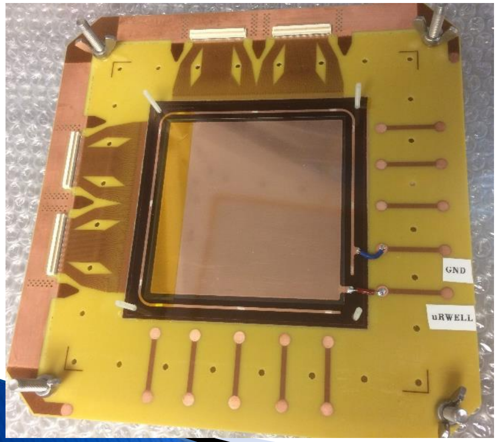
Detector drives & R&D highlight – DIS

Tagging the L.O. struck quark kinematics with scattered electron

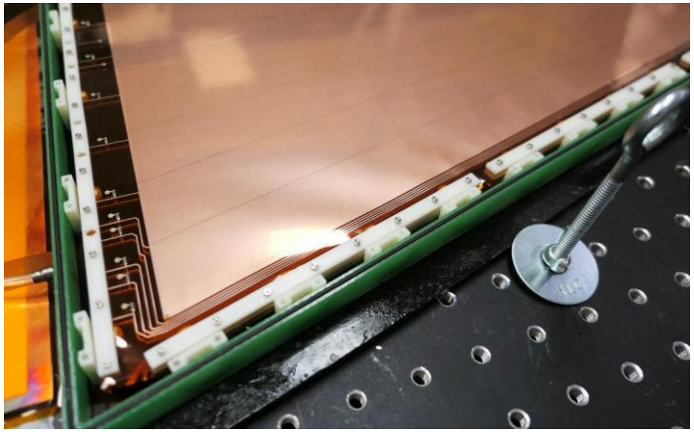
→ Low mass main tracker over large acceptance: GEMs, μRWELL, Compact TPC, MAPS outer tracker



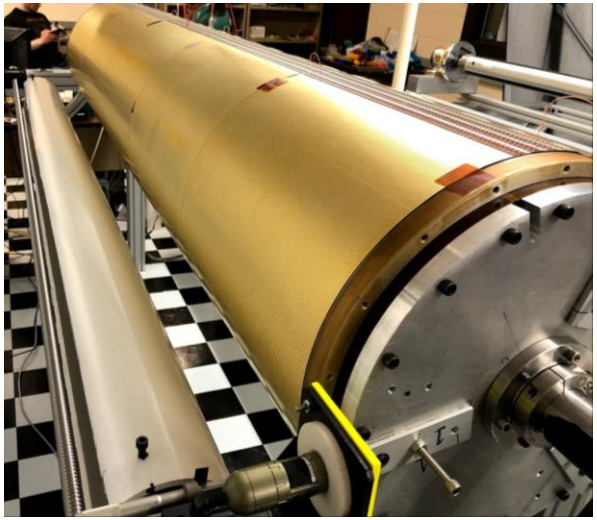
μRWELL, 2D readout (eRD6)



Large area GEM (eRD6)



TPC field cage (sPHENIX)



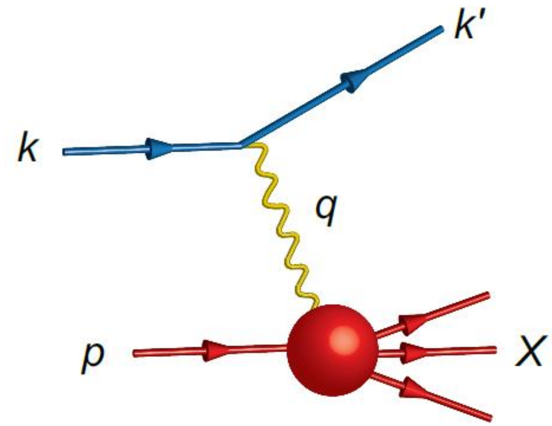
Detector drives & R&D highlight – DIS

Tagging electron

→ Identify electrons with EM Calorimeters and PID det.

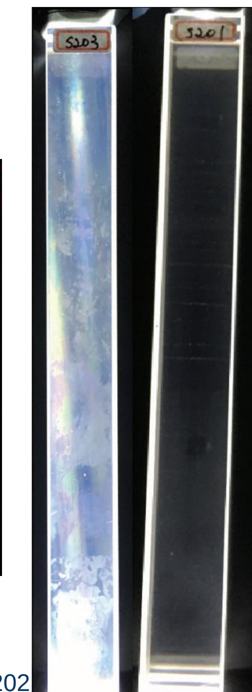
Tagging out-going quark with jet

→ Hadronic calorimeter



W-Scifi Compact EMCal (eRD1, sPHENIX)

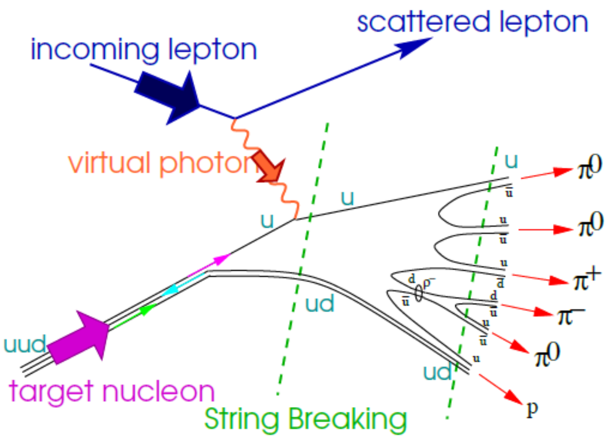
Scint. glass, $PbWO_4$ (eRD1)



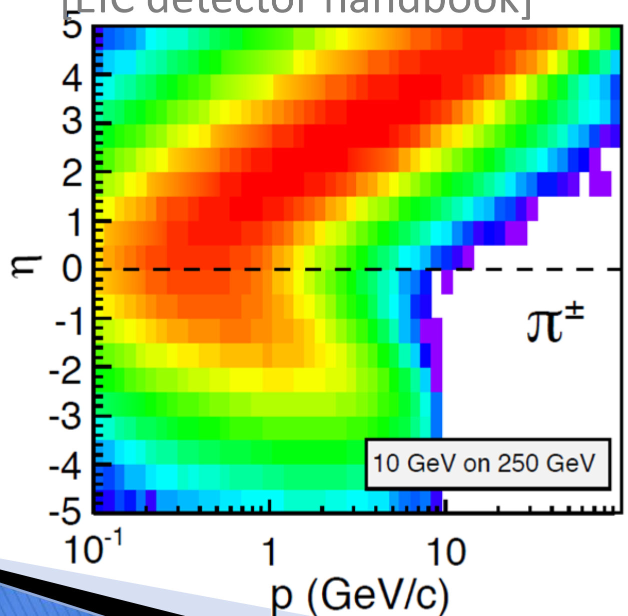
Detector drives & R&D highlight – SIDIS

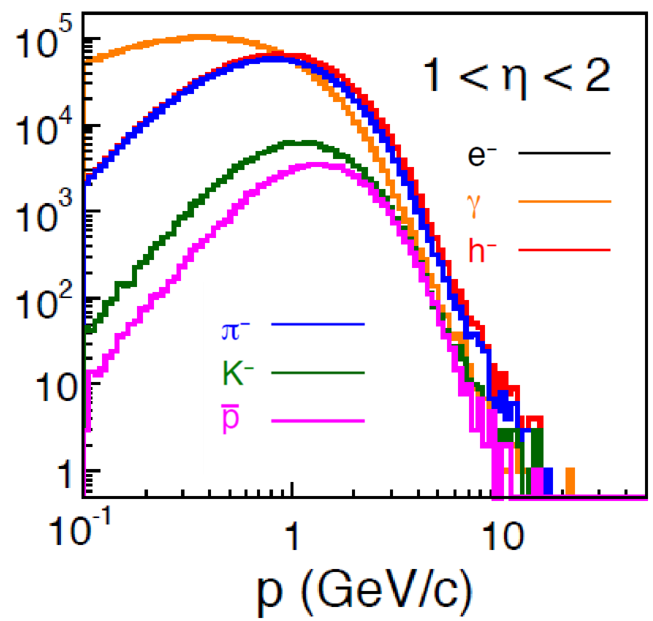
Tagging the struck quark flavor with a fragmenting hadron

→ Hadron measurement in large acceptance



[EIC detector handbook]

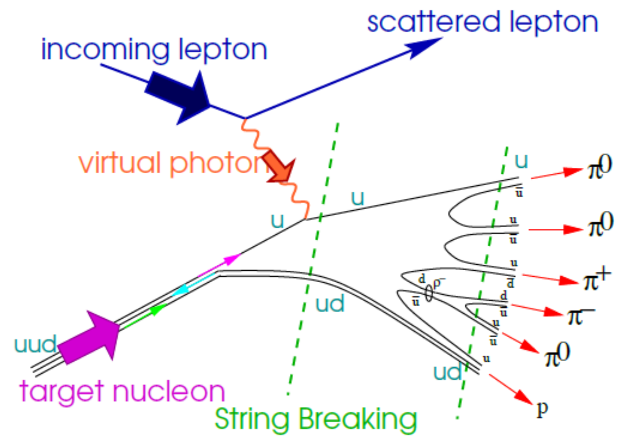




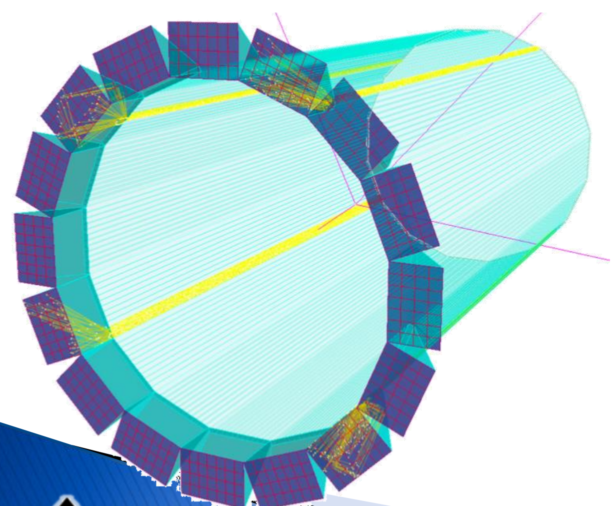
Detector drives & R&D highlight – SIDIS

Tagging the struck quark flavor with a fragmenting hadron

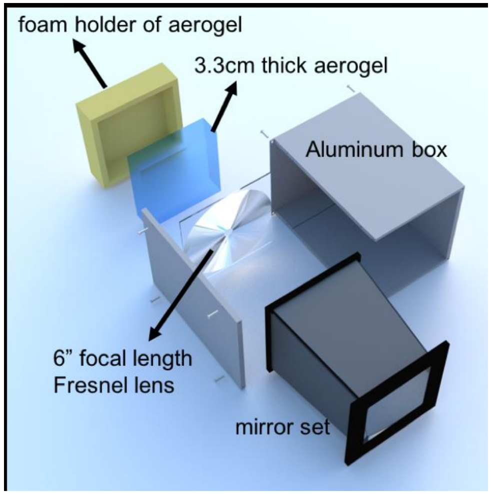
→ Hadron Particle ID: Aerogel & gas RICH, DIRC, ToF, dE/dx



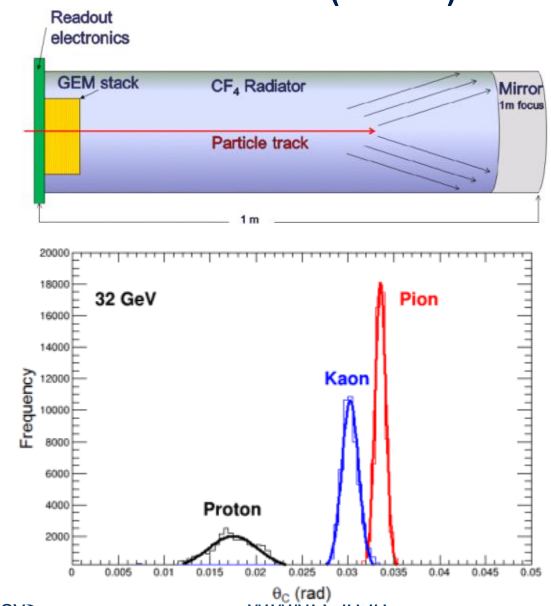
DRIC (eRD14)



Modular AeroGel RICH (eRD14)



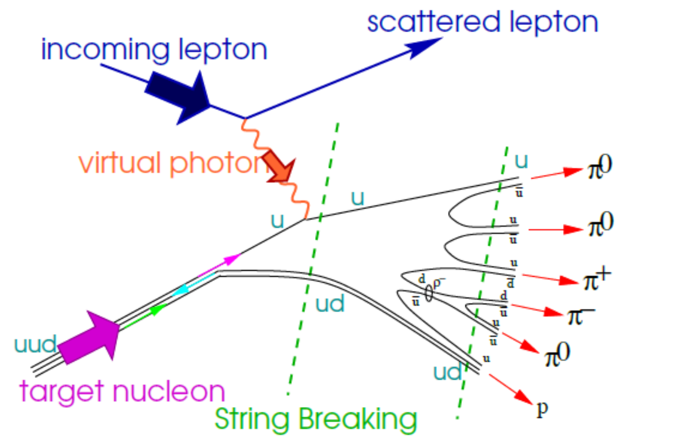
Gas RICH (eRD6)



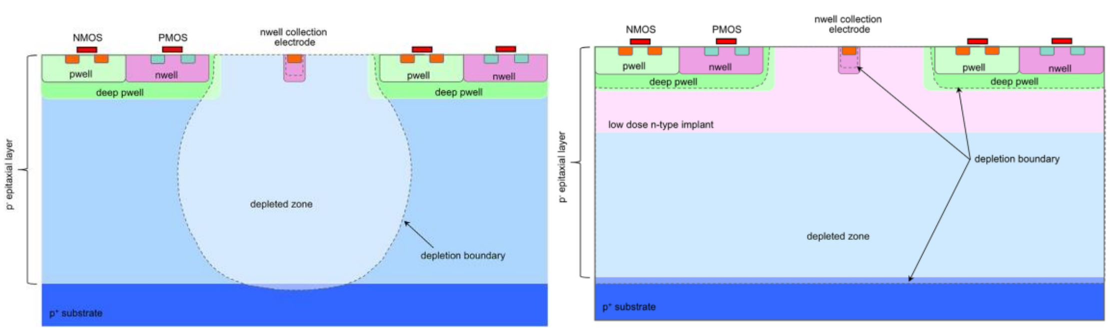
Detector drives & R&D highlight – SIDIS

Tagging the struck gluon with heavy flavor production

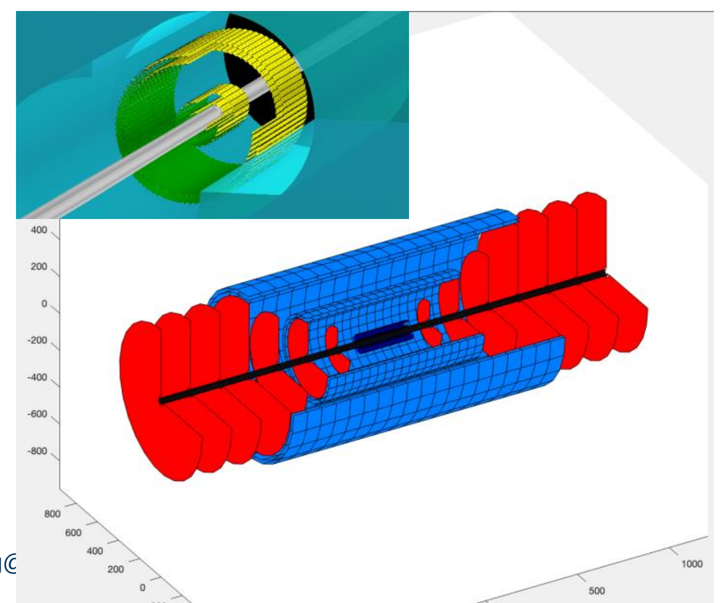
→ Precision vertex tracker



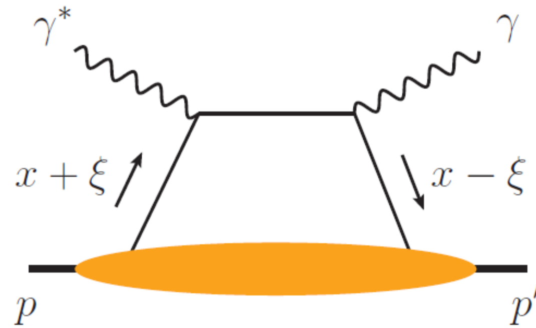
MAPS, dMAPS (ALICE, sPHENIX, eRD16, eRD18)



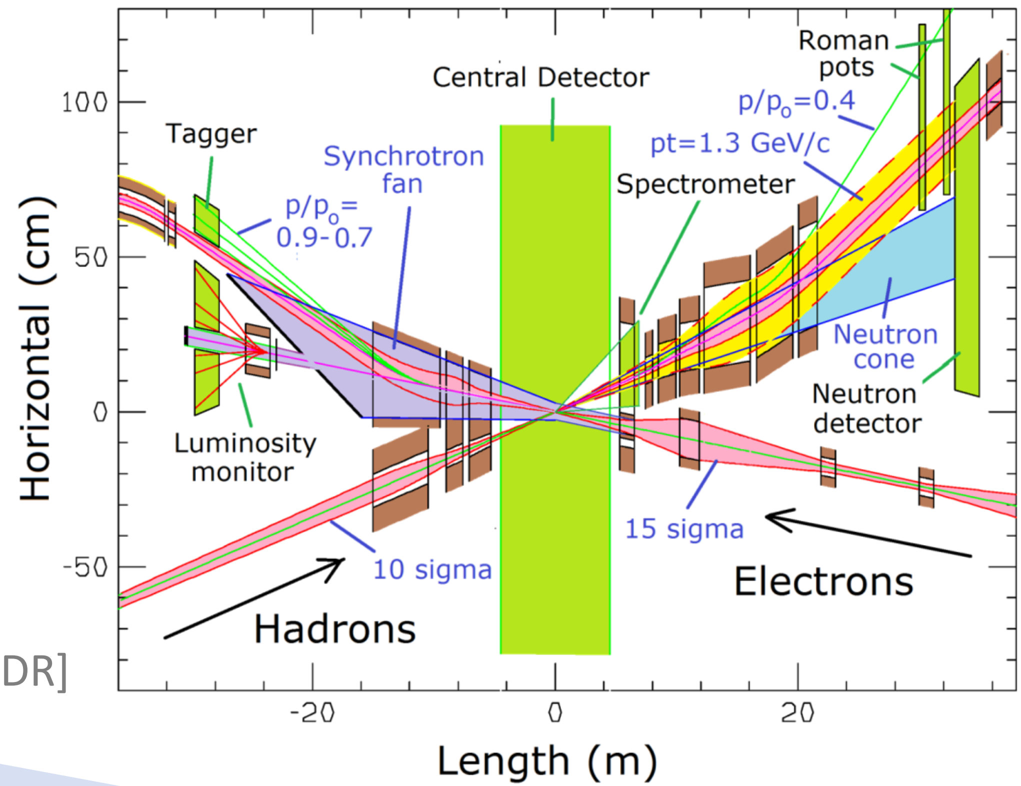
Tracker simulation (eRD16, eRD18)



Detector drives & R&D highlight – Exclusive processes

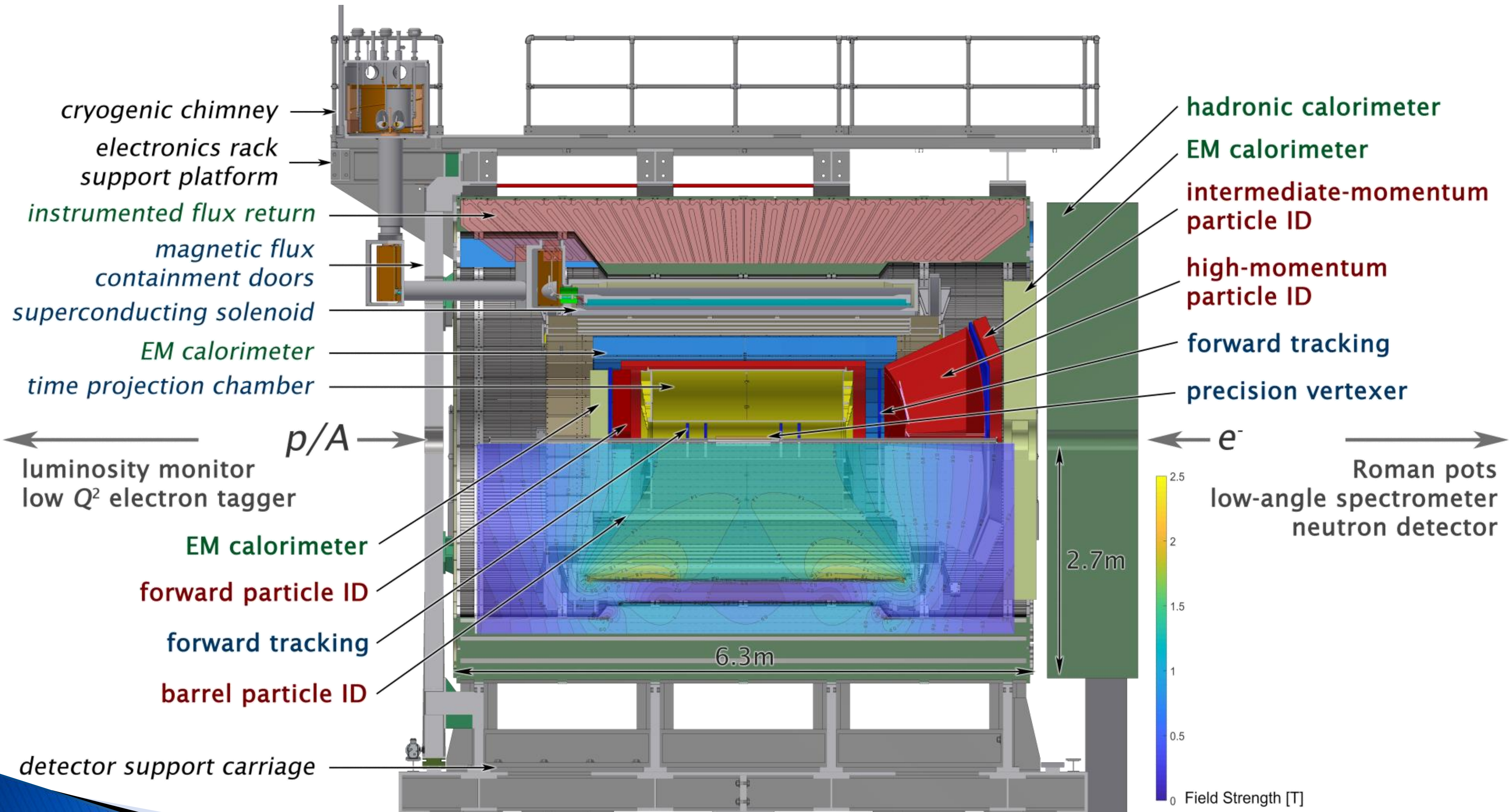


- Hermiticity
- (also DIS) require unprecedented integration of detector and accelerators
  - Lumi. monitor
  - Low Q^2 tagger
  - Far-forward spectrometer
  - Roman pots
  - ZDC



[eRHIC pre-CDR]

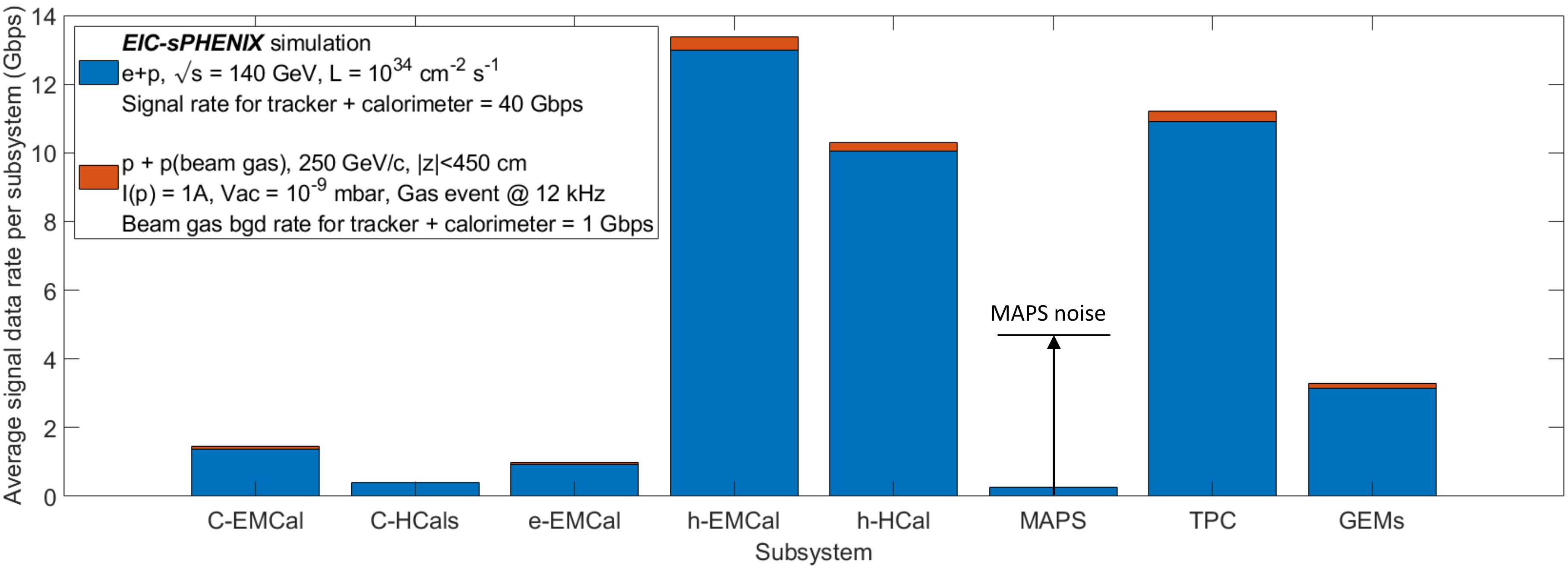
It will be a challenging integration



One detector concept shown as illustration [sPH-cQCD-2018-001: https://indico.bnl.gov/event/5283

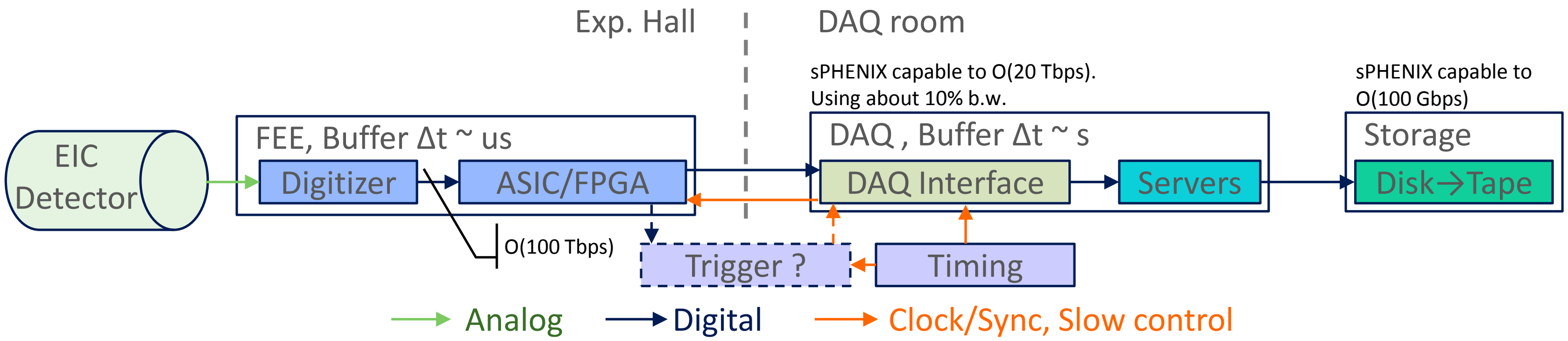
Collision signal data rate

- $e + p$ cross section (50 μb) << $p + p$
  - All collision signal ~ 100 Gbps @ 10^{34} cm^{-2} s^{-1} & 500kHz collision trigger-less readout
  - Less than sPHENIX peak disk rate (15kHz Au+Au triggered + pile up)
- Background and noise control will be critical for EIC



[sPH-cQCD-2018-001: https://indico.bnl.gov/event/5283/]

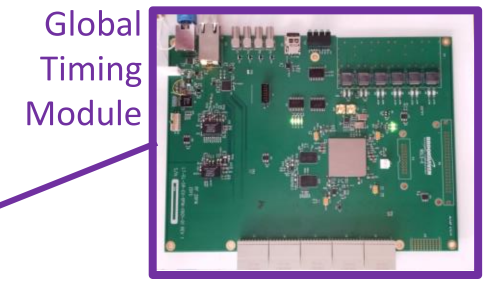
Strategy for an EIC real-time system

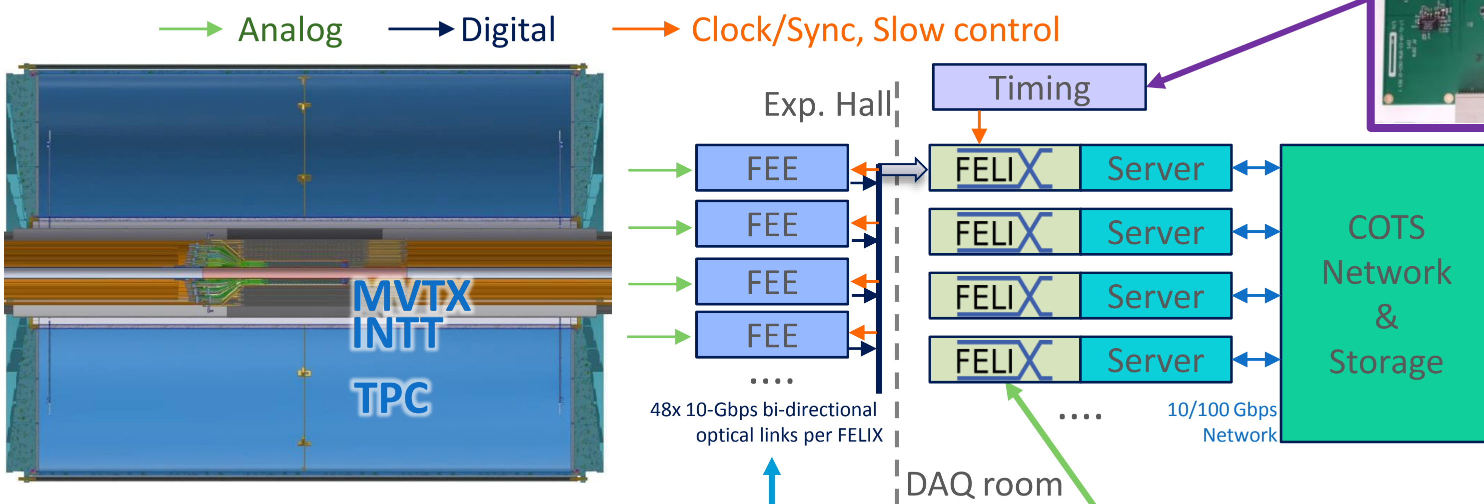


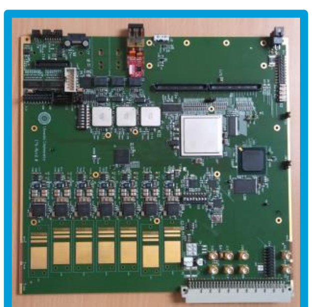
- For the signal data rate from EIC (100 Gbps), we can aim for filtering-out and streaming all collision in raw data without a hardware-based global triggering
- One possible strategy :
  - Full streaming readout front-end (buffer length : μs)
  - → DAQ interface to commodity computing (e.g. ATLAS/sPHENIX FELIX)
  - → Disk/tape storage of streaming time-framed zero-suppressed raw data (buffer length : s)
  - → Collision event tagging in offline production (latency : days)

An application of this strategy: sPHENIX trackers

Both MAPS and TPC technology are proposed use in EIC too
Hybrid with triggered calorimeters







MVTX RU, 200M ch
ASIC: ALPIDE

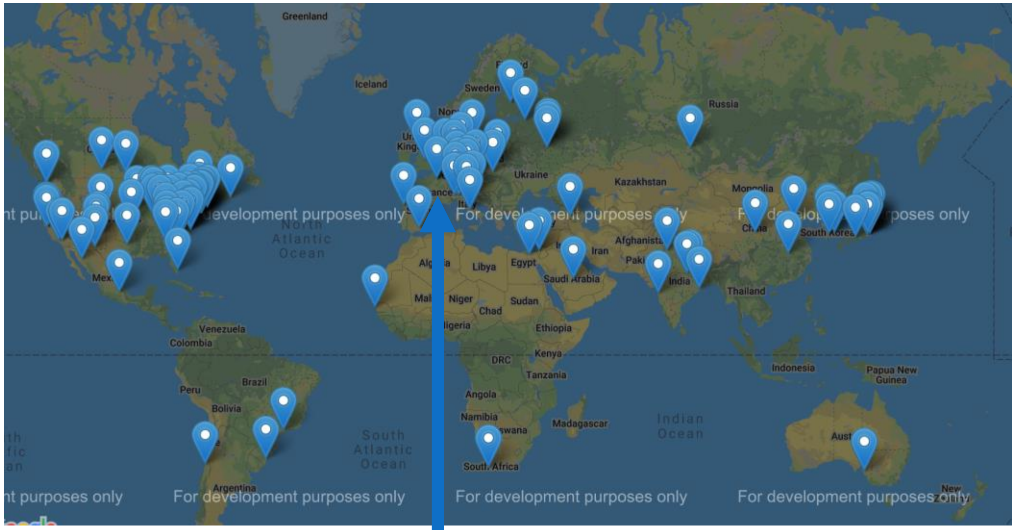
INTT ROC, 400k ch
FPHX

TPC FEE, 160k ch
SAMPA

BNL-712 / FELIX v2 x48
Streaming ASIC → DAQ

EIC user group

- EIC user group established in summer 2016
- 1033 members 211 institutions in 31 countries
- Welcome to join the yellow report studies : http://www.eicug.org/web/content/yellow-report-initiative
- Next user group meeting: Aug 2020 @ Miami https://indico.bnl.gov/event/7352/



Summary

- EIC physics driven unique detector requirement: strong emphasis on low radiation length tracker, large acceptance hadron PID, and unprecedented detector-accelerator integration
- Exploring new paradigm of DAQ for EIC: streaming readout time framed hits, triggerless DAQ, event building selection offline
- EIC specific R&D funded in the last decade, early application to many on-going experiments at JLab and BNL
- Ongoing Yellow Report initiative to define the detector requirement

Extra information

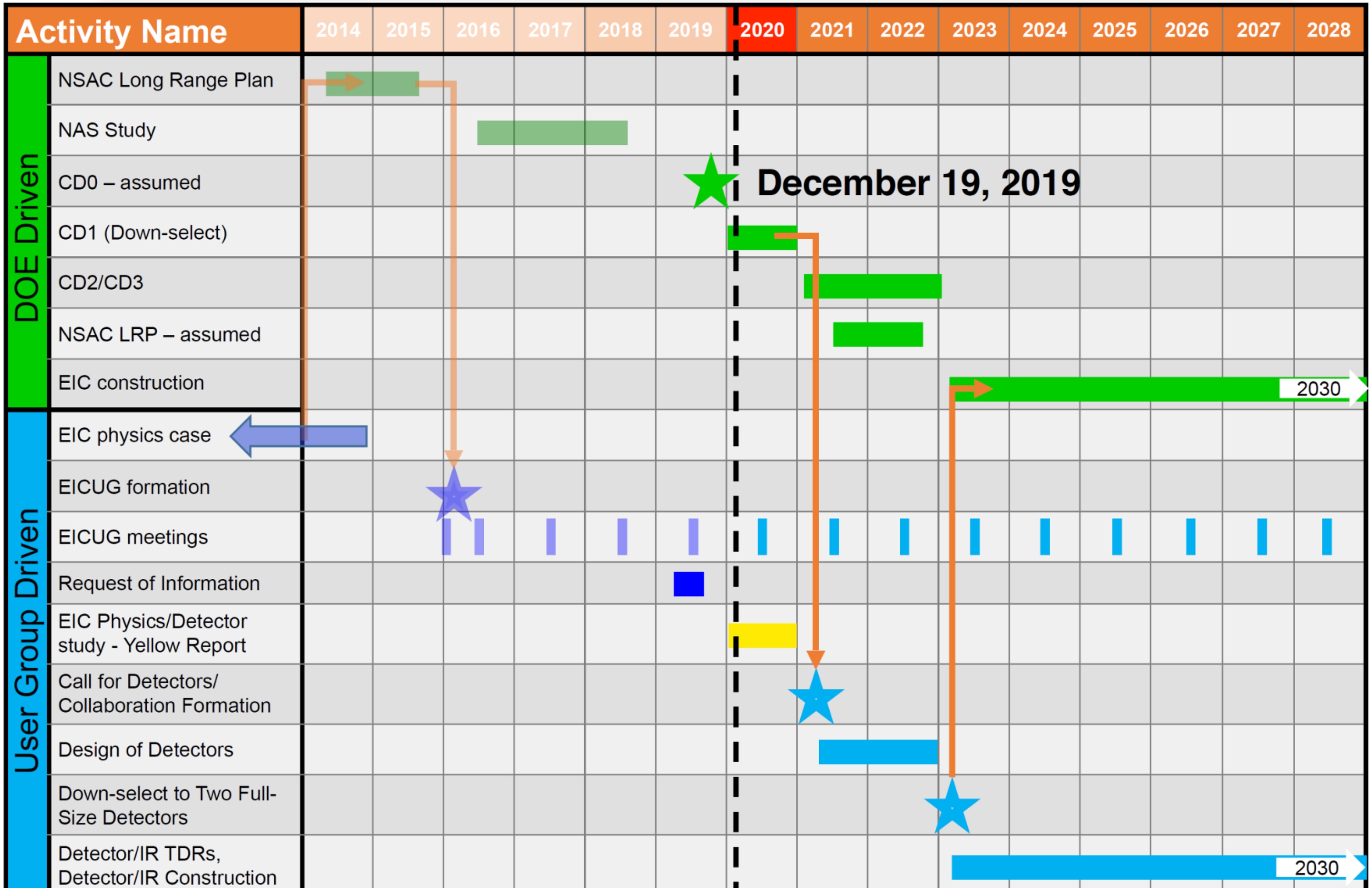
FY'21 Congressional Budget Request (pg. 361):

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2021[a]	12/19/19	4Q FY 2021	4Q FY 2021	4Q FY 2023	4Q FY 2024	4Q FY 2024	N/A	4Q FY 2032

CD-0 – Approve Mission Need for a construction project with a conceptual scope and cost range
Conceptual Design Complete – Actual date the conceptual design was completed (if applicable)
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Estimated/Actual date the project design will be/was complete (d)
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D work
CD-4 – Approve Start of Operations or Project Closeout

Vision for a Timeline - Paris EICUG Meeting



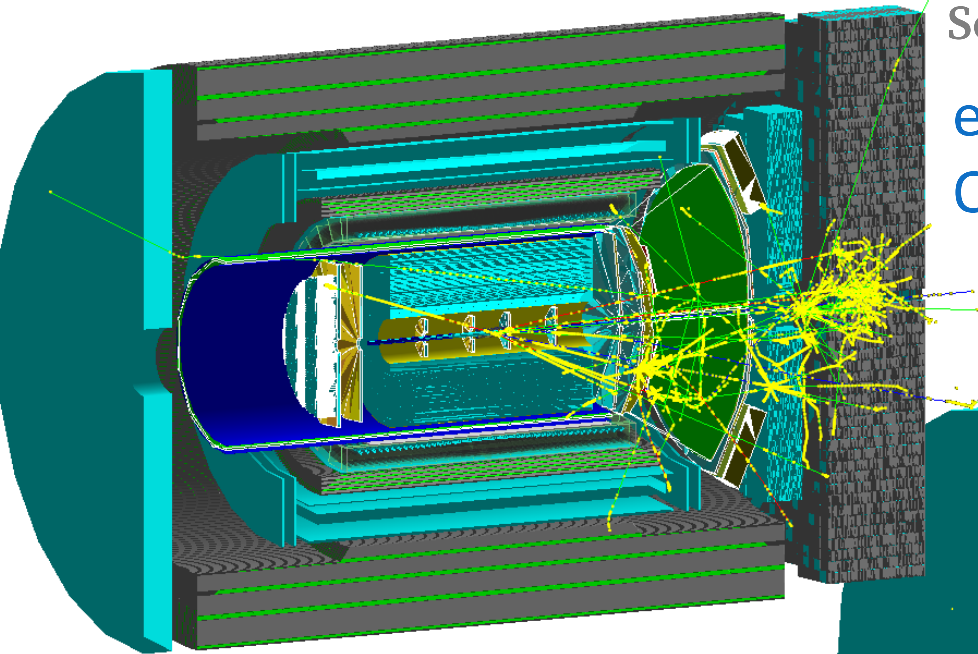
EICUG Remote Meeting
Philadelphia, PA, January 23, 2020

Bernd Surrow

Rate in Geant4 full detector simulation Sum collision + beam gas

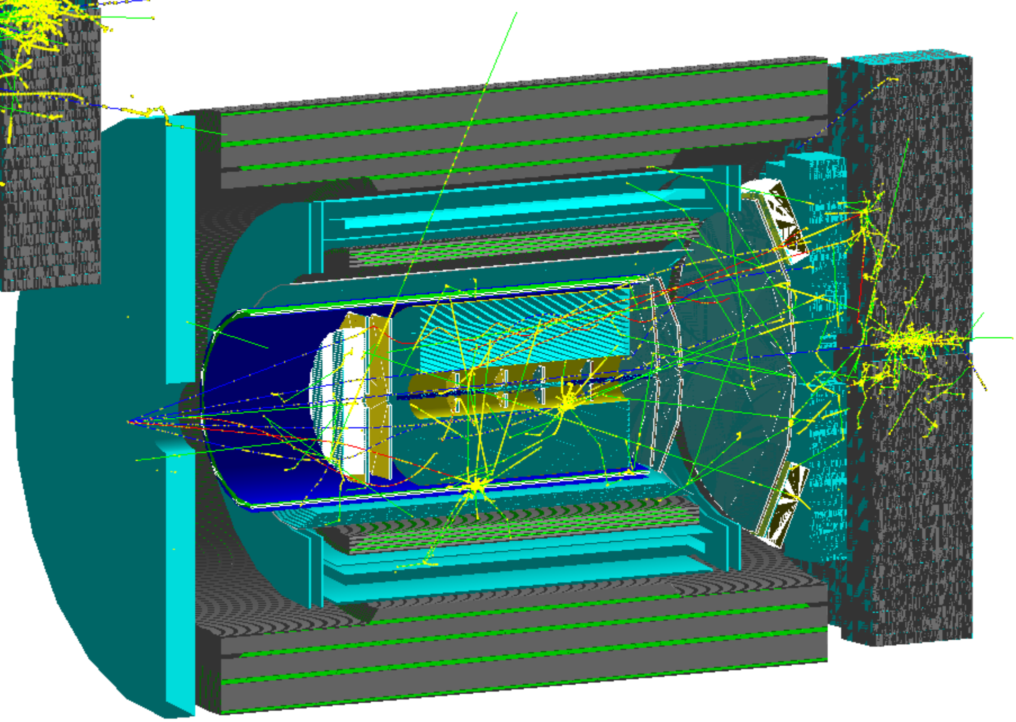
sPH-cQCD-2018-001: https://indico.bnl.gov/event/5283/ , Simulation: https://github.com/sPHENIX-Collaboration/singularity

See also next talk: C. Pinkenburg

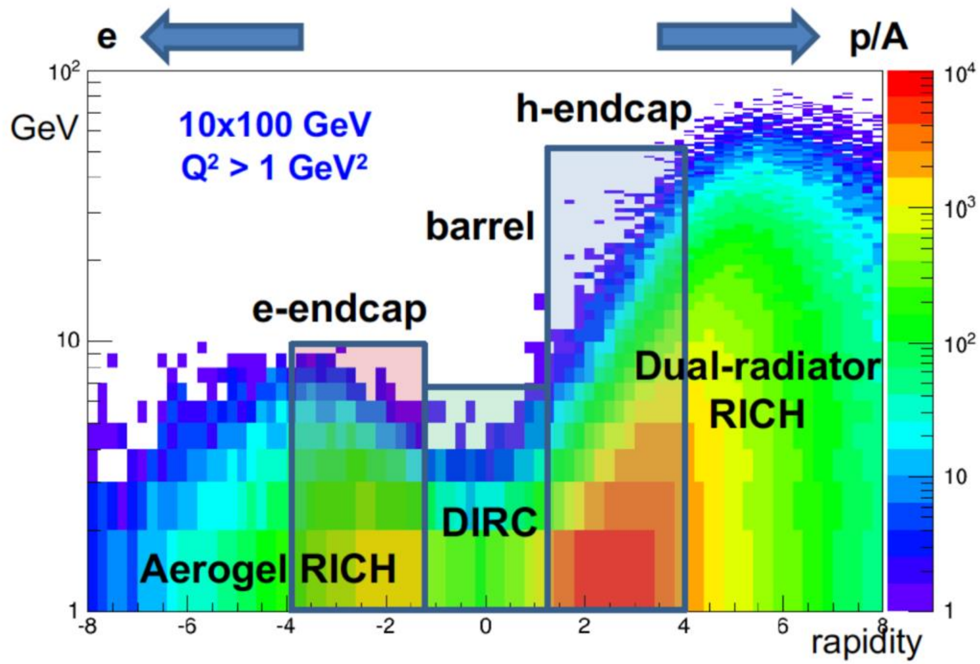


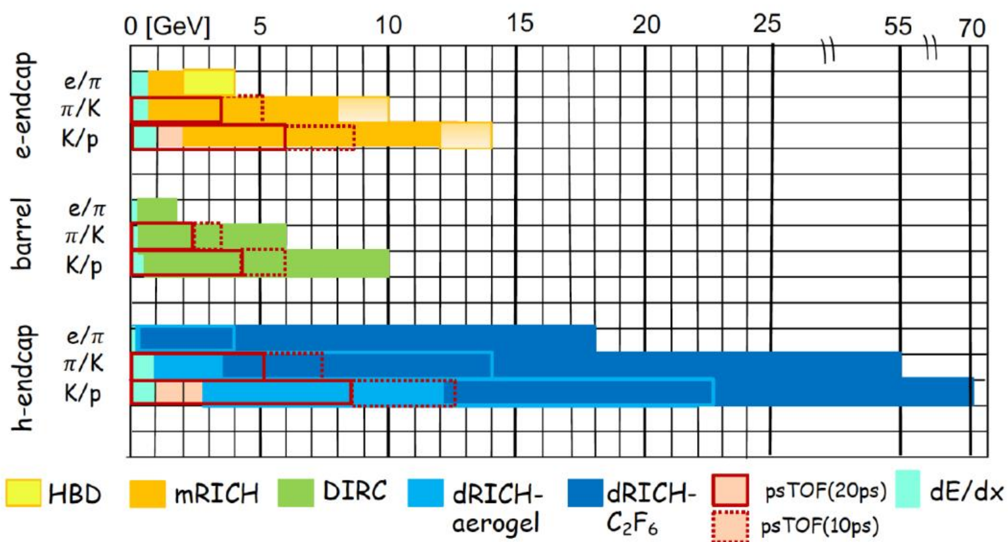
Beam gas event
p + p, 275 GeV/c
at z=-4 m

e+p DIS 18+275 GeV/c
$Q^2 \sim 100\ (\mathrm{GeV}/c)^2$



Hadron PID solution for EIC



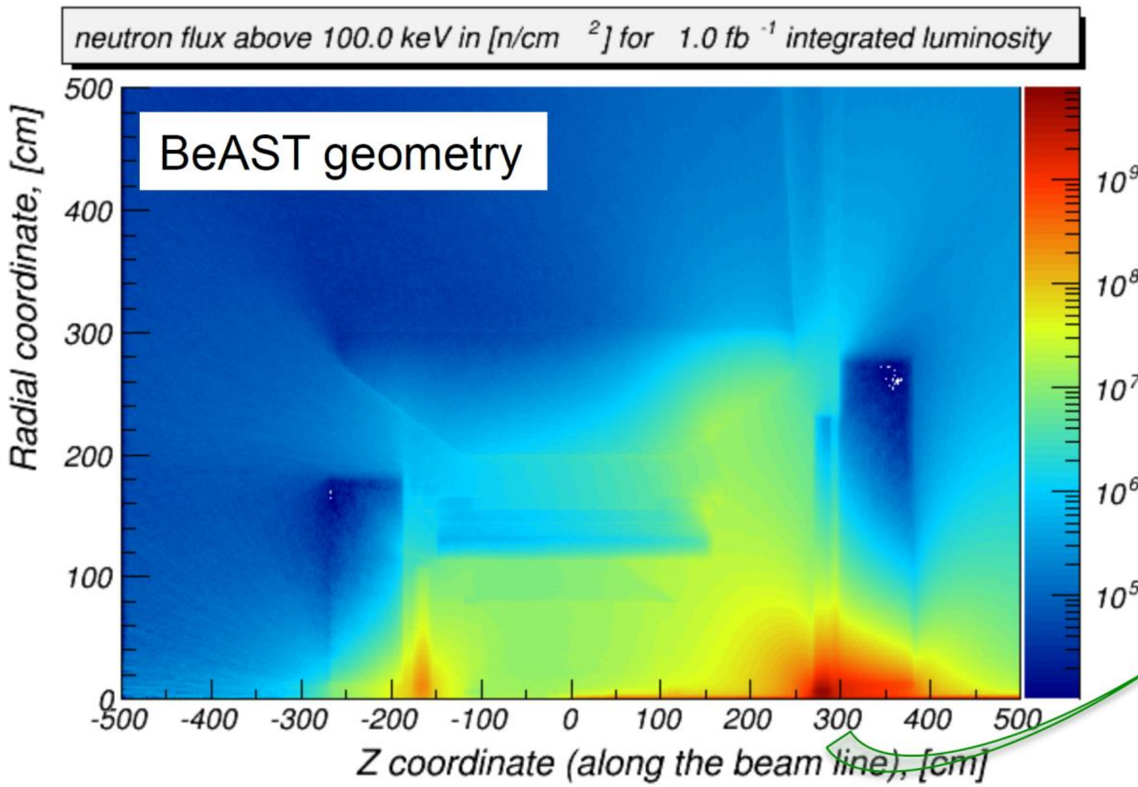


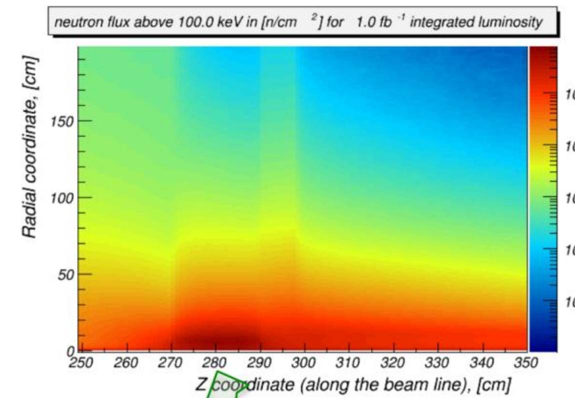
- **h-endcap:** a RICH with two radiators (gas + aerogel) is needed for π/K separation up to ~50 GeV/c
- **e-endcap:** A compact aerogel RICH with π/K separation up to ~10 GeV/c
- **barrel:** A high-performance DIRC provides a compact and cost-effective way to cover the area with π/K separation up to ~6-7 GeV/c

- TOF and/or dE/dx in a TPC can cover lower momenta

Neutron fluence from primary interactions

The quantity: Fluence = "a sum of neutron path lengths"/"cell volume" for N events





-> forward EmCal: up to ~5*10^9 n/cm^2 per fb^{-1} (*inside the towers*); perhaps ~5 less at the SiPM location;

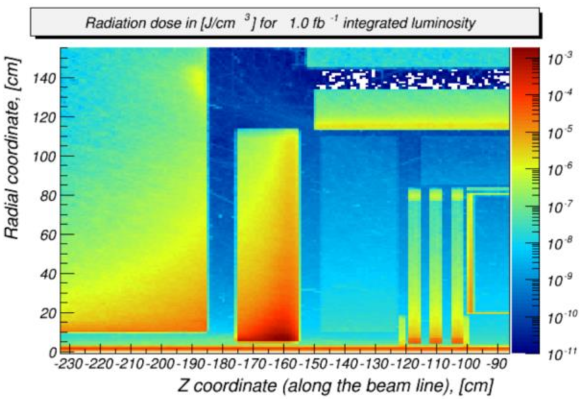
NB: "standard" EIC run at ~10^{33} cm^{-2}s^{-1} luminosity is 10 fb^{-1}

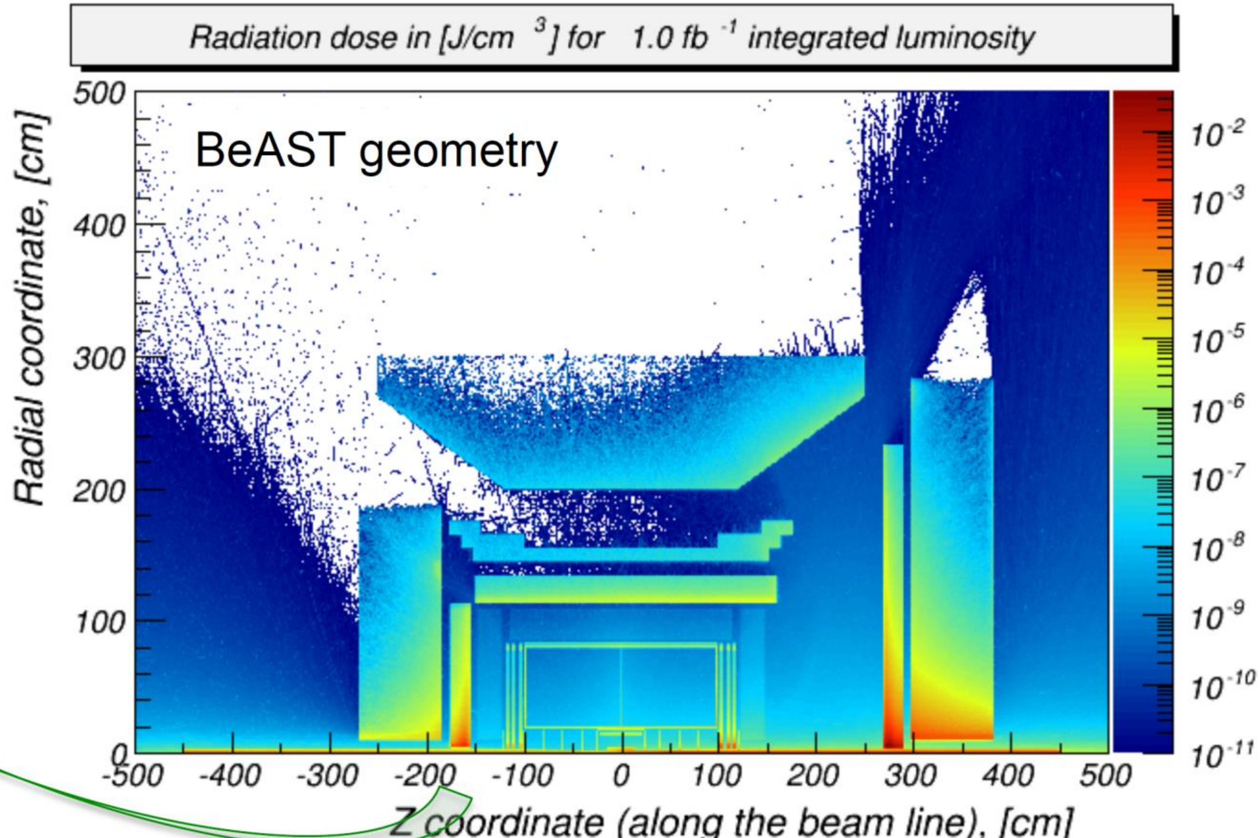
The numbers look OK, but:

- Beam line elements not incorporated in the simulation
- Thermal neutrons are not accounted
- Close to beam line: ~10^{34} cm^{-2}s^{-1} over ~10 years would exceed ~10^{11} n/cm^2

Radiation dose from primary interactions

<u>The (primary) quantity</u>: E_{sum} = "a sum of dE/dx"/"cell volume" for N events





-> crystal EmCal: up to ~$2 \cdot 10^{-3}$ J/cm^3 per fb^{-1} (close to beam line)

1 rad = 0.01 Gy & [Gy] = [J/kg] & PWO density ~8g/cm^3 -> ~250 rad/year

(at "nominal" luminosity ~10^{33} cm^{-2} s^{-1})

-> looks OK?