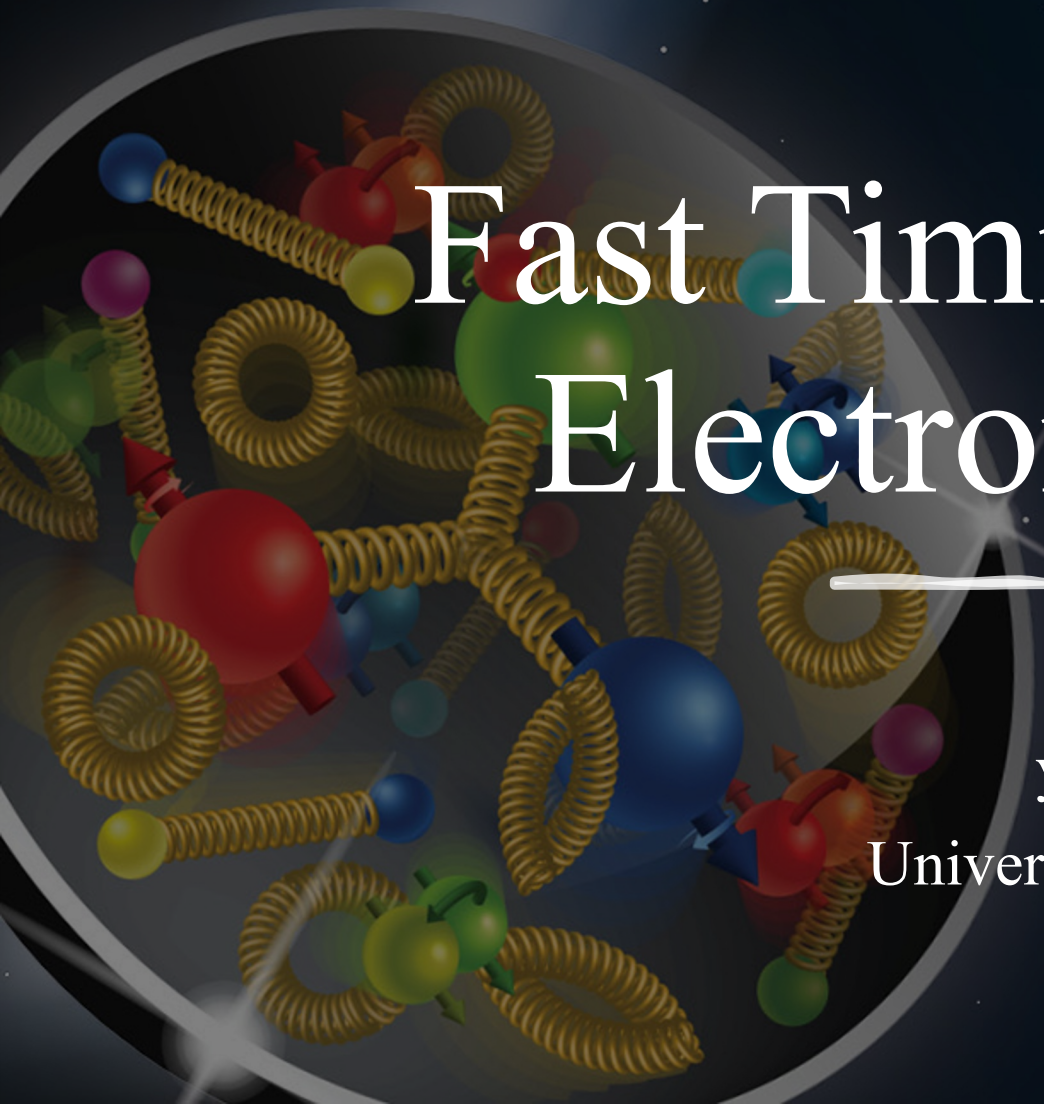

Fast Timing Detectors at Electron Ion Collider

Zhenyu Ye

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University of Illinois at Chicago

Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY

Jefferson Lab

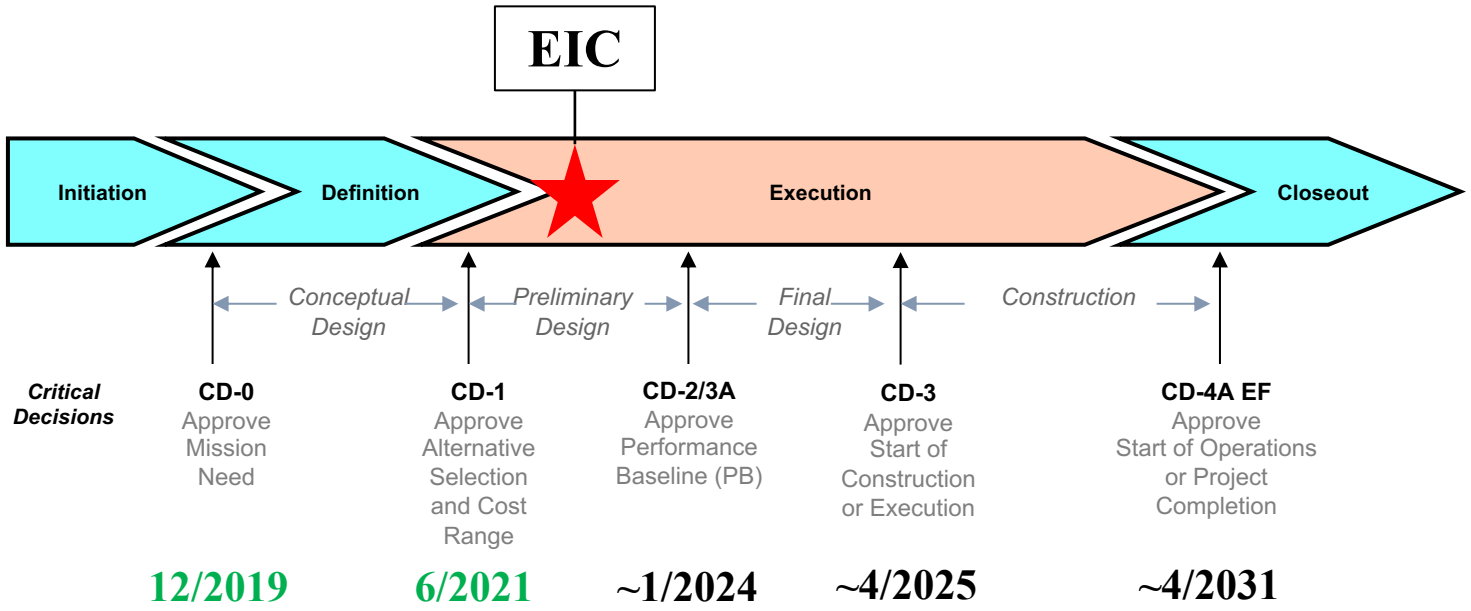
U.S. DEPARTMENT OF ENERGY | Office of Science

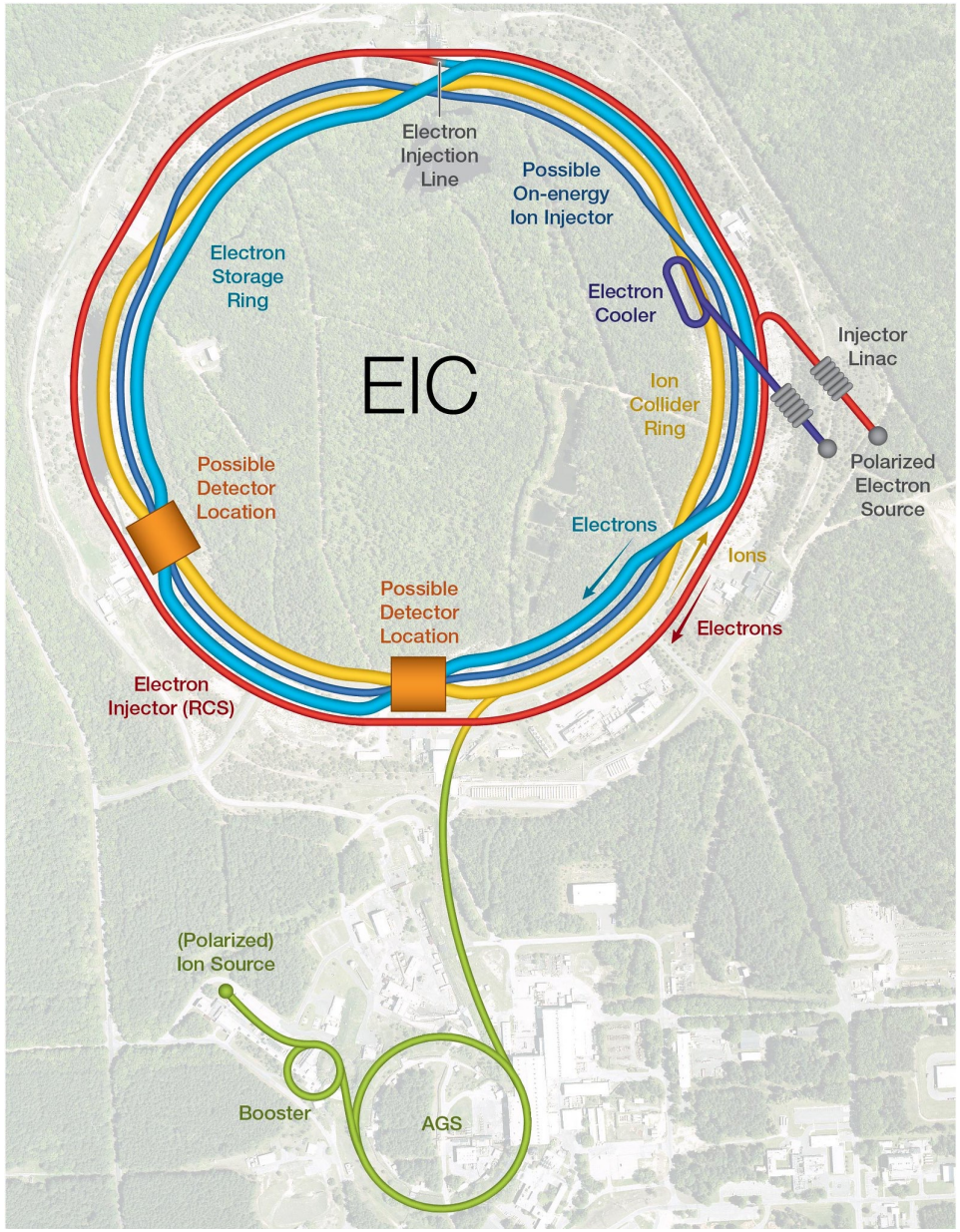
Electron Ion Collider (2031-)

[4] EIC CDR

Design Goals

- High Luminosity: L= 10^{33}–10^{34} $cm^{-2}s^{-1}$, 10–100 fb^{-1}/year
- Highly Polarized Beams: ~70%
- Large Center of Mass Energy Range: E_{cm} = 20–140 GeV
- Large Ion Species Range: protons – Uranium
- Large Detector Acceptance and Good Background Conditions
- Accommodate two Interaction Regions (IR)

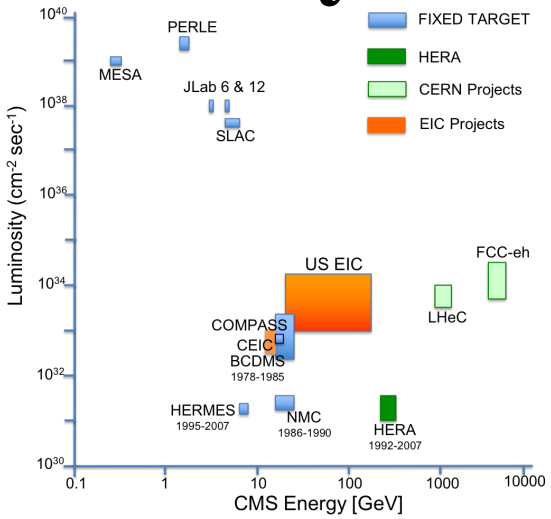


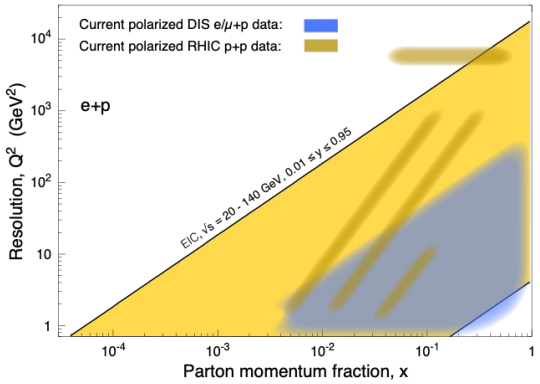


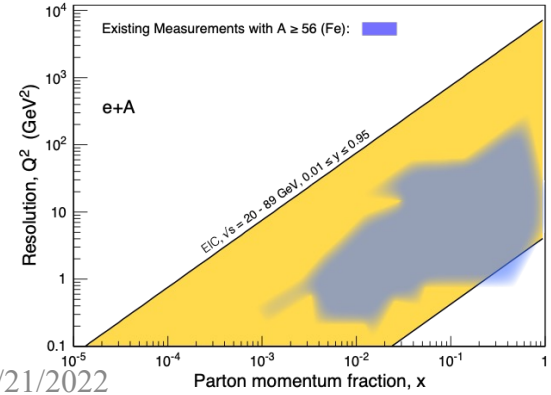
Electron Beam: 5-18 GeV Ion: 40, 100-275 GeV

EIC Physics

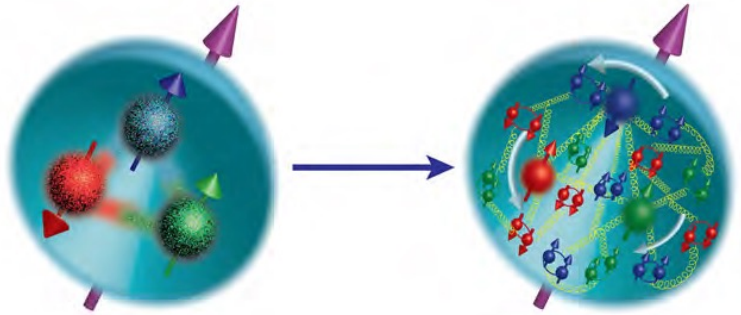
[5] EIC Yellow Report

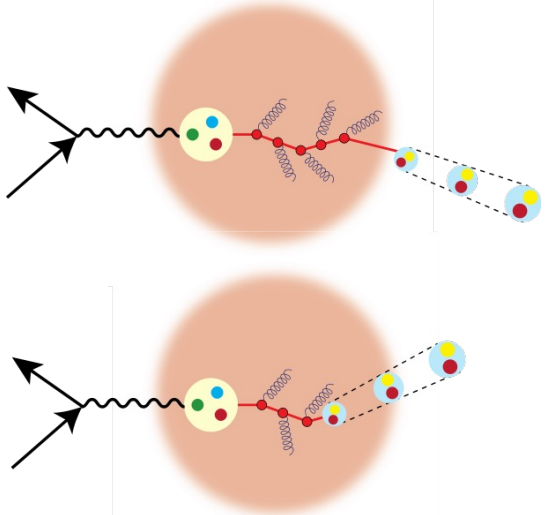






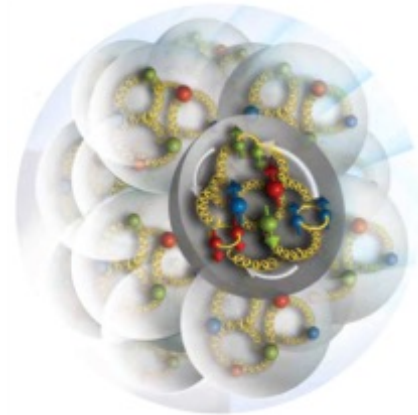
How are the gluons and sea quarks, and their spins, distributed in space and momentum inside the nucleon? What is the role of orbital motion in building the nucleon spin?





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?

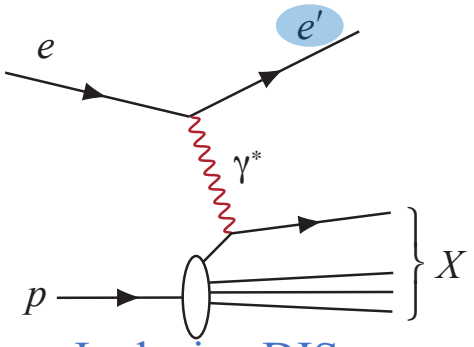
How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions? What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?



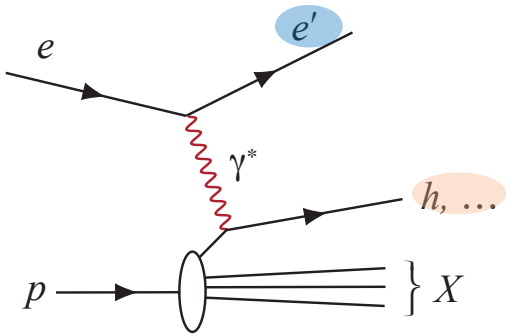
EW, BSM, …

Among the highest priority of US Nuclear Physics, endorsed by National Academy of Science, Engineering and Medicine (NAS)

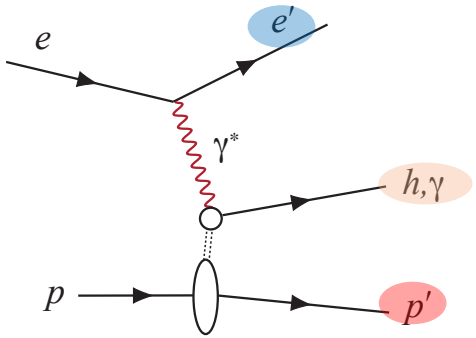
EIC Detectors



Inclusive DIS



Semi-inclusive DIS



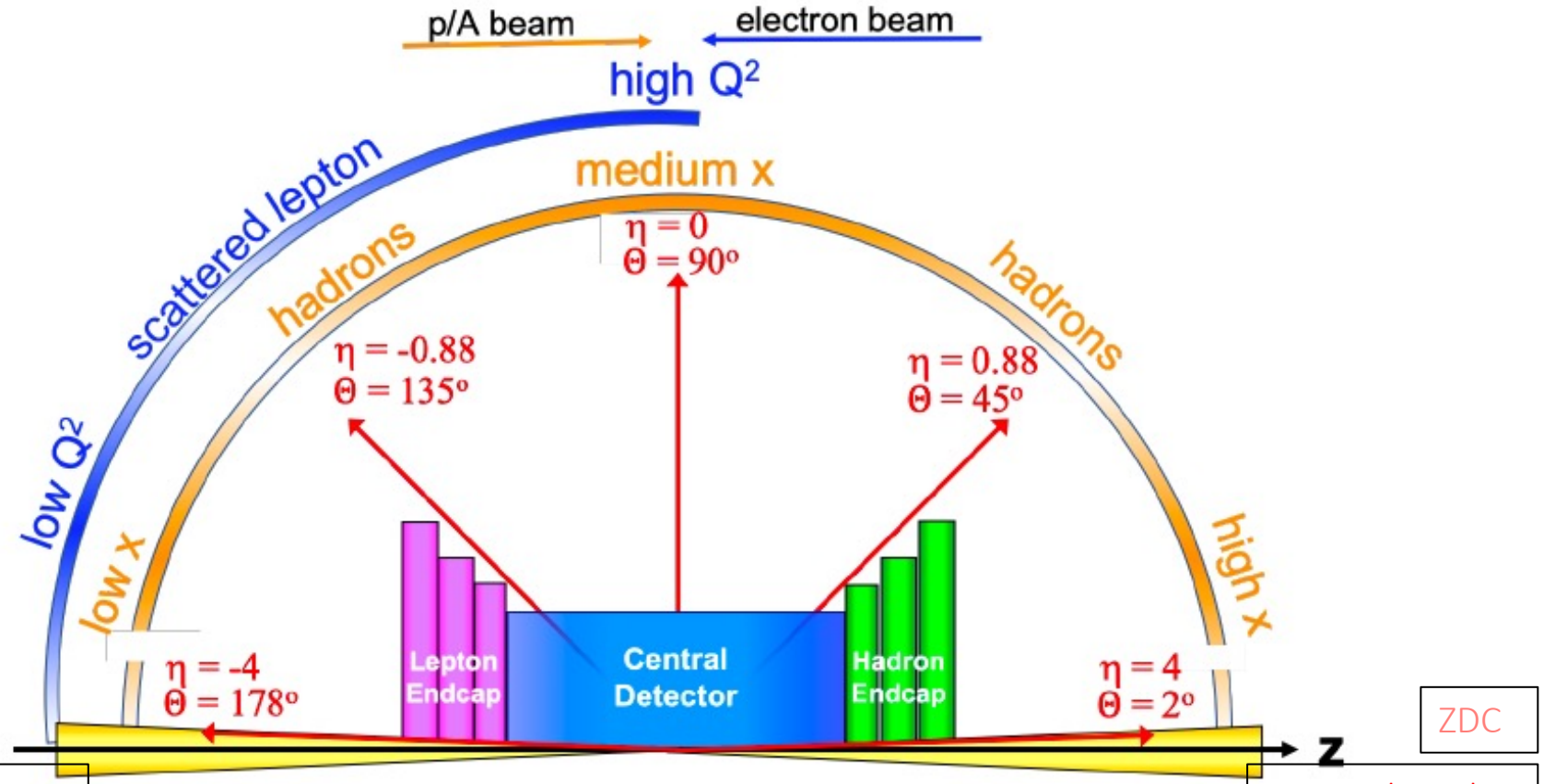
Exclusive

Detector-1 (project detector)

- IP6 (25 mrad crossing angle with crabbing)
- Addresses EIC science program as outlined in the EIC white paper and NAS report
- Ready for Day-1 operations in ~2031
- Working towards pre-TDR/CD-2

Detector-2 (strong comm. interests)

- IP8 (35 mrad crossing angle)
- Complementary to Detector-1
- Require development of 2nd IR
- Ready 2-5 years after Detector-1
- Development at WG level



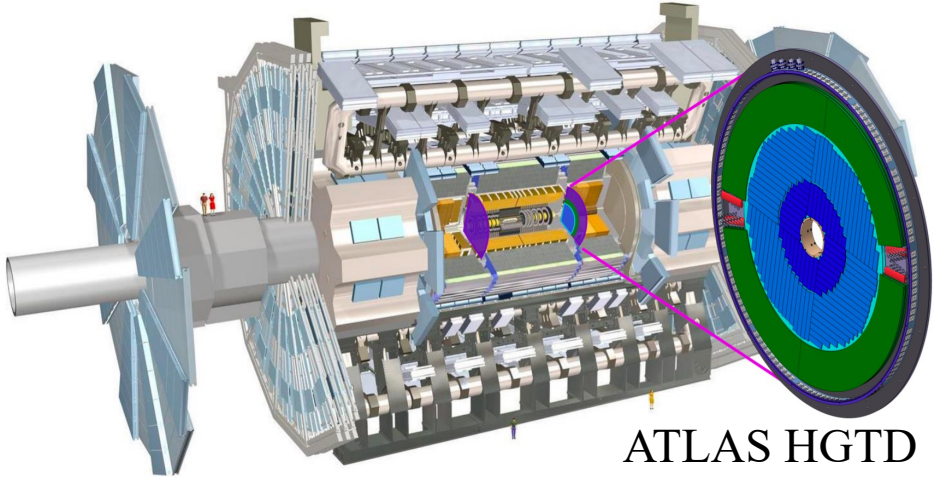
AC-LGAD for EIC

- Precise timing detectors based on DC-LGAD being built by ATLAS (6.4 m^2) and CMS (14 m^2) for data taking in 2028+.

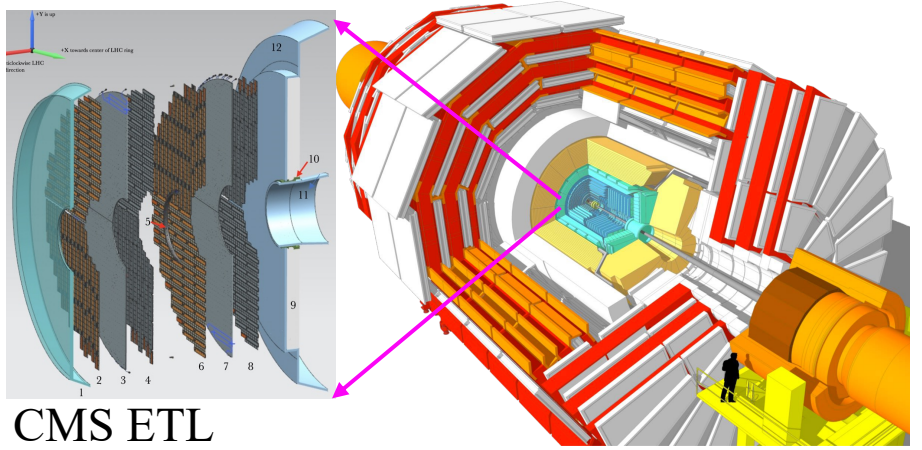
- AC-LGAD can not only provide precise timing resolution similar to DC-LGAD, but also 100% fill factor and much better spatial resolution thanks to charge sharing.

- AC-LGAD proposed for EIC experiments
  - TOF PID and tracking for central detectors
  - timing and tracking for forward detectors

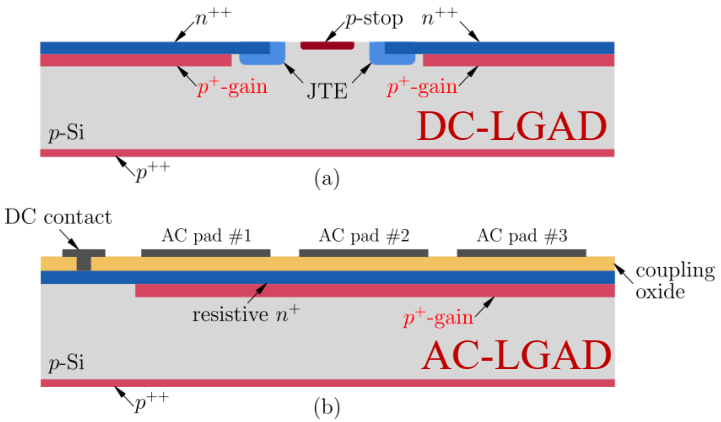
  with common designs in sensor, ASIC etc. where possible.

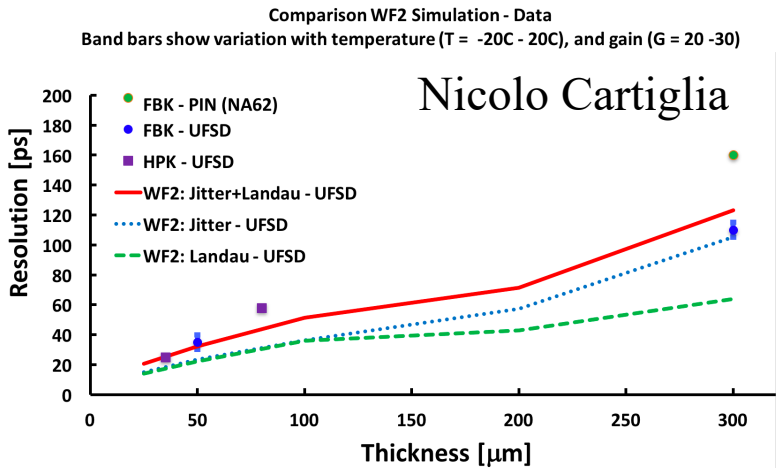


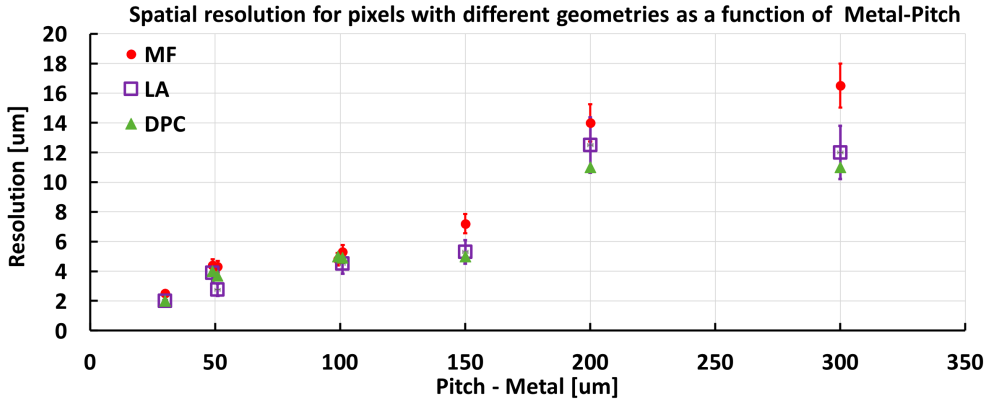
ATLAS HGTD



CMS ETL







EIC Detector-1 Reference Design

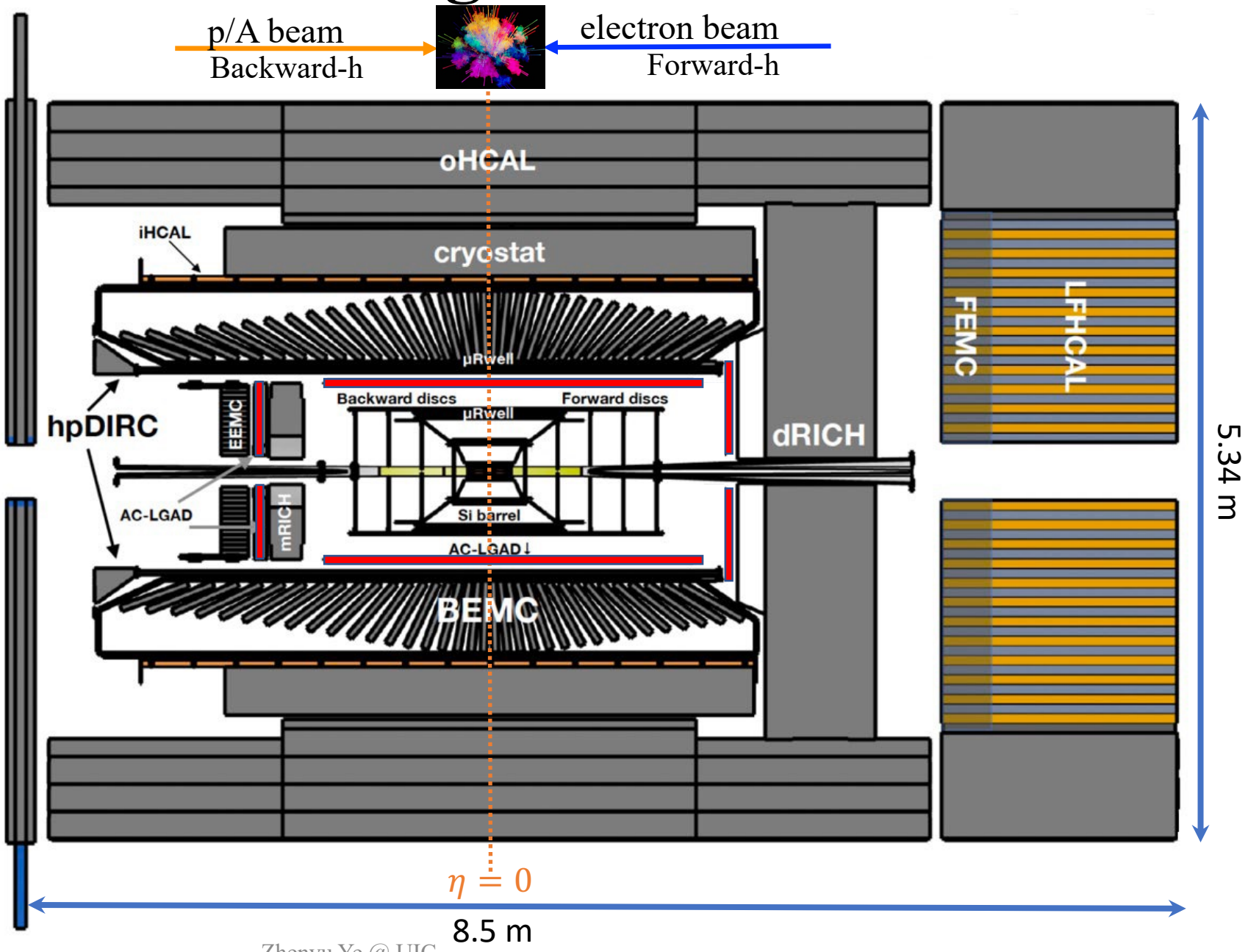
[6] EIC DPAP

Tracking:
- Si MAPS
- AC-LGAD (~30 μm)
- μRWELL

PID:
- hp-DIRC
- mRICH
- dRICH
- AC-LGAD (~30 ps)

Calorimetry:
- SciGlass Barrel EMCal
- PbWO EEMCal
- Longitudinally separated EM+Hcal
- Inner HCal (instrumented frame)
- Outer HCal (sPHENIX re-use)

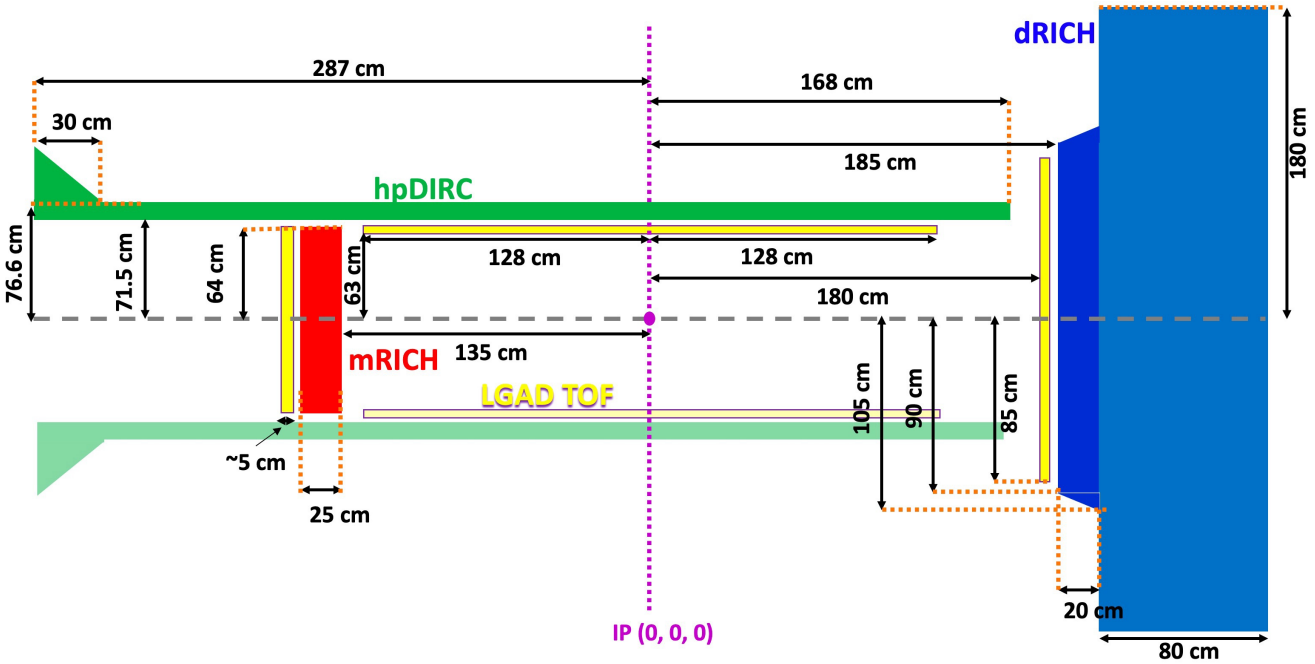
Different to LHC
- lower momentum
- lower occupancy
- less irradiation

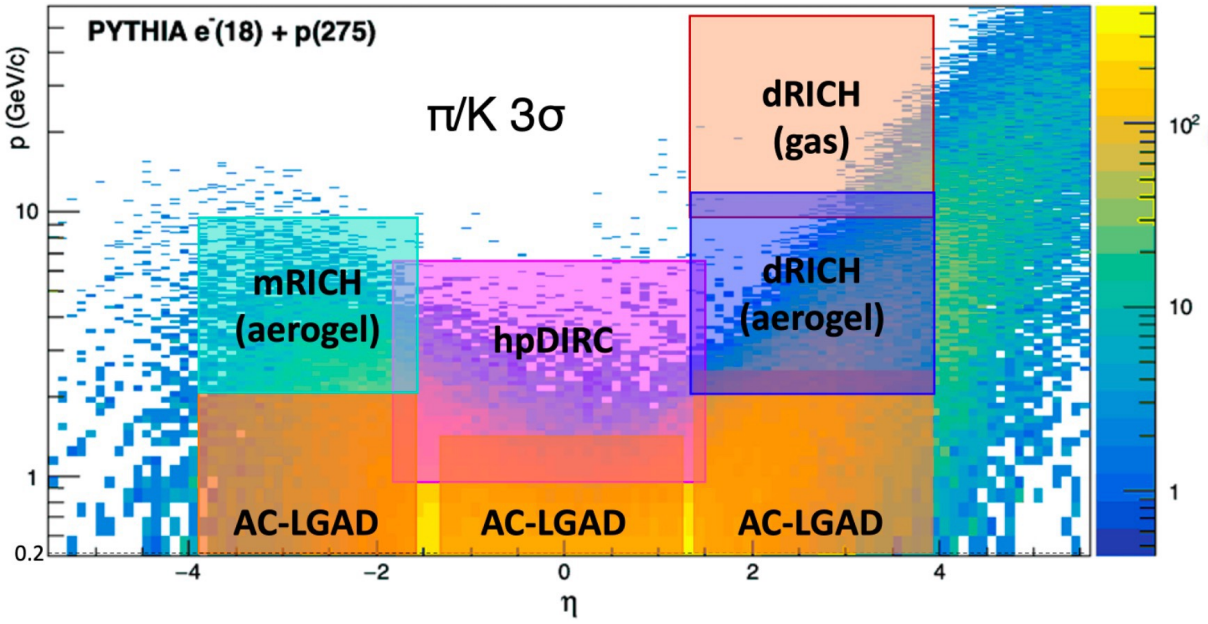


AC-LGADs in Central Detector: TOF PID + Tracking

Explore **AC-LGAD** technology and leverage established LHC **DC-LGAD** detector designs to minimize cost and risk

- **Time-of-flight for e/π/K/p identification** at low-to-intermediate p range
- Provide a **high spatial resolution point for tracking**





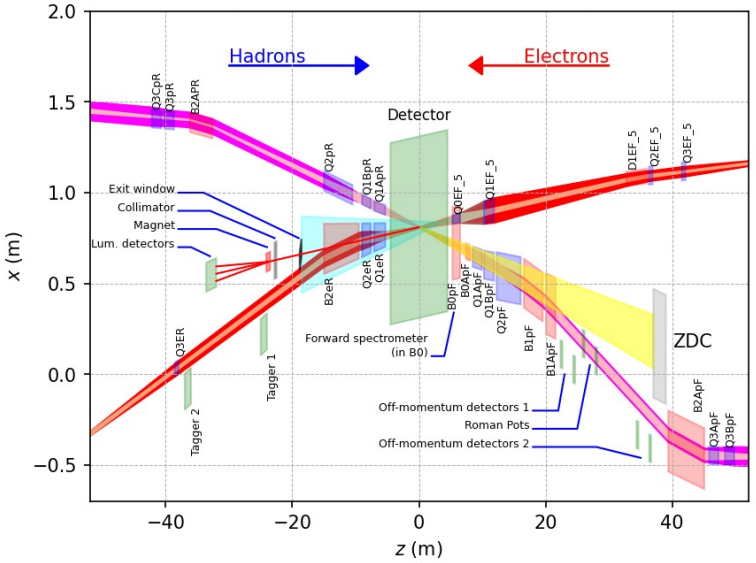
Reference Design (optimization ongoing)

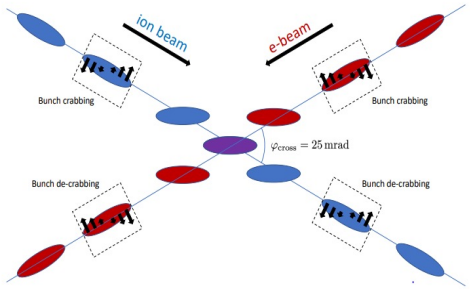
- Timing resolution: ~25 ps per hit
- Position resolution: ~30 μm with 500 μm pitch
- Material budget: ~8% X0
- Total area: ~ 15 m^2

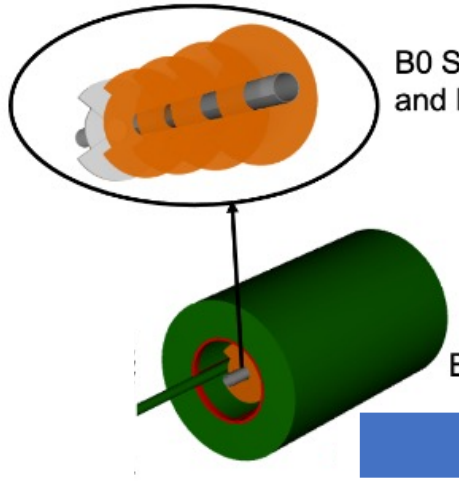
TOF PID coverage

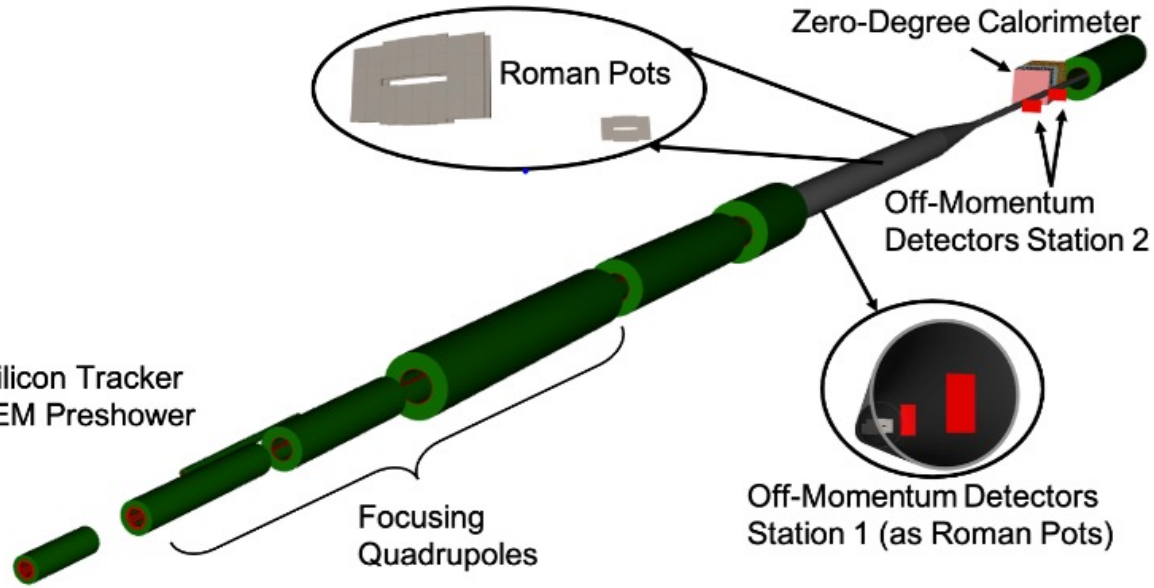
- ETTL: $-3.7<\eta<-1.74$ $0.15 < p < 2.5$ GeV
- FTTL: $1.5<\eta<3.5$ $0.15 < p < 2$ GeV
- CTTL: $|\eta|<1.4$ $0.15 < p_T < 1.5$ GeV

AC-LGADs in Forward Detectors: Timing + Tracking



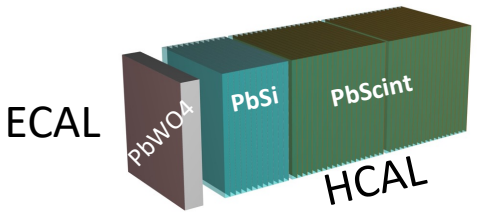






Technologies defined

- Silicon: AC-LGAD & MAPS
- ZDC:
  - ECAL (PbWO4)
  - HCAL (PbSi + PbScint)

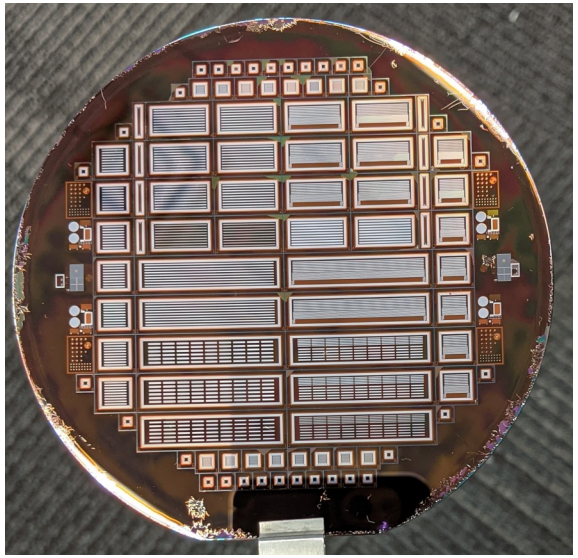


Detector	Angular accept. [mrad]	p_T coverage
ZDC @ ~30m	θ<5.5 ($\eta > 6$)	p_T<1.3 GeV
Roman Pots	0*<θ<5.0 ($\eta > 6$)	*Low p_T(t) cutoff (beam optics)
Off-Momentum Detectors	0.< θ < 5.0 ($\eta > 6$)	Low-rigidity particles from nuclear breakups
B0 forward spectrometer	5.5 < θ < 20.0 (4.6< η < 5.9)	High p_T(t)

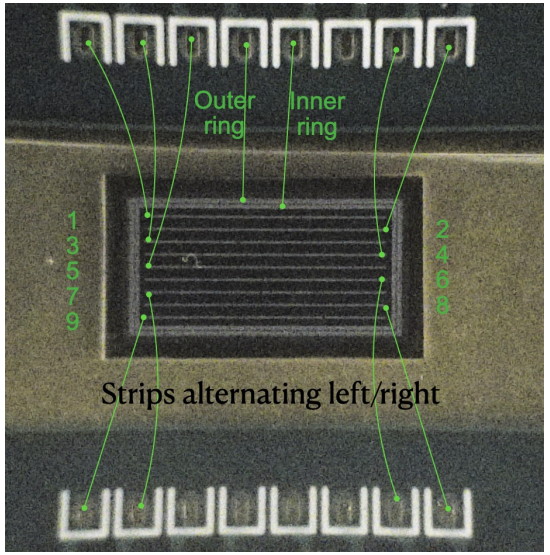
eRD112: Sensor R&D

[7] eRD112 R&D Proposal

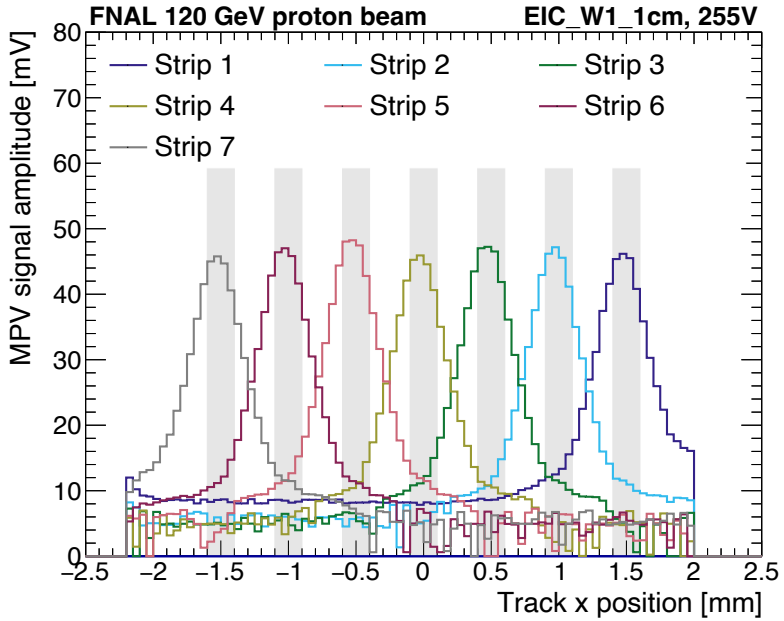
- **R&D Goals**
  - 15-20 ps timing resolution, O(~30μm) position resolution where needed
  - Minimal readout channel density (strip, rectangular pixel) for reduced power, material and cost
- **Plan**
  - Produce and test large area sensors with thinner active volume to achieve the desired timing resolution
  - Optimize implantation parameters and AC-pad segmentation through simulation and real device studies
  - Engage commercial vendors to improve fabrication process and yield



AC-LGAD Sensor Wafer
by BNL IO 2021



500 um*1cm strip AC-LGAD sensor
mounted on test board

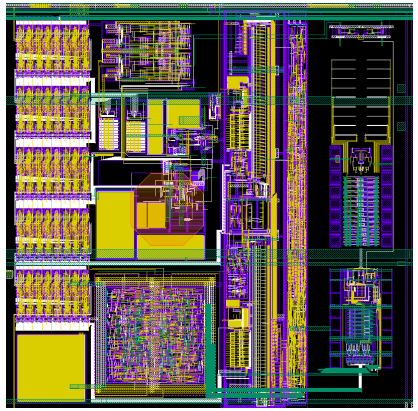


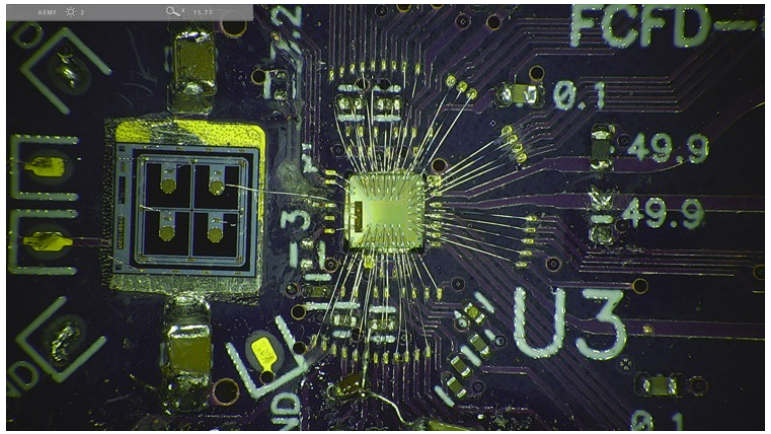
Signal amplitude vs x position at
2022 Fermilab test beam

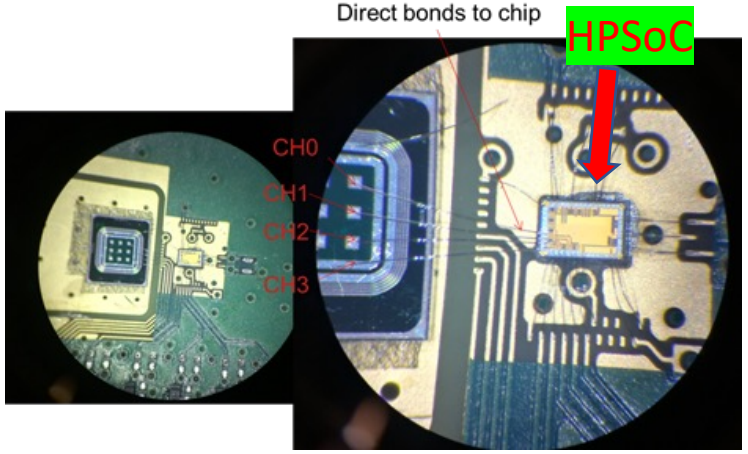
eRD112: ASIC R&D

[7] eRD112 R&D Proposal

- **R&D Goals**
  - 15-20 ps jitter with minimal (1-2 mW/ch) power consumption, match AC-LGAD sensors for EIC
- **Plan**
  - Utilize the design and experience in ASICs for fast-timing detectors from ATLAS and CMS, and investigate common ASIC design and development for TOF/Tracking and RP/B0







EICROC by Omega/Irfu/AGH

- Preamp, discri. taken from ATLAS ALTIROC
- I2C slow control taken from CMS HGCROC
- TOA TDC adapted by IRFU Saclay
- ADC adapted to 8bits by AGH Krakow
- Digital readout: FIFO depth8 (200 ns)

FCFD by Fermilab

- Adapt the Constant Fraction Discriminator (CFD) principle in a pixel paired with a TDC, one time measurement gives the final answer.
- Charge injection consistent with simulations: ~30 ps at 5 fC, and <10 ps at 30 fC
- Tests with beta sources and beam are planned

HPSoC by Nalu Scientific LLC

Parameter	Specification
Channel no.	100+ (pitch 300-500 μm)
Process	65nm CMOS
Sample rate	10 GSa/s
Bandwidth	2 GHz
No. bits	10
Supply Voltage	1.0V (2.5V for digital I/O)
Timing accuracy	5ps
Front-End stage	Embedded TIA
Buffer length/channel	256 samples
Power/channel	<2mW
On-chip integration	Sampling, Digitization, Calibration, Feature Extraction, Data Fusion

Summary and Outlook

- **AC-LGAD** is the selected technology by EIC Detector-1 for timing and tracking in central and far-forward detectors. Other fast timing technologies could be considered for Detector-2
  - **Opportunity**: new detector technology development; multi-million and multi-year projects.
  - **Challenge**: strict detector performance requirements; tight schedule.

    TOF WG Mailing list: eic-projdet-tofpid-l@lists.bnl.gov
    Indico page: https://indico.bnl.gov/category/414

- **eRD112**: develop sensor, ASIC, and other key components for AC-LGAD detectors at EIC
  - **Approach**: having common design and with combined R&D efforts for different detectors when possible.

eRD112 Mailing list: https://mailman.rice.edu/mailman/listinfo/lgads-eic
Indico page: https://indico.bnl.gov/category/323/

Timeline – What is Coming for EIC

❑ CD-0 approval	December 19, 2019
❑ Community-wide Yellow Report effort	Dec 2019 – Feb. 2021
❑ CD-1 review (includes CDR)	January 26-29, 2021
❑ Call for Collaboration Proposals for Detectors	March 6, 2021
❑ CD-1 approval	June 29, 2021
❑ DOE/OPA Status Review	October 19-21, 2021
❑ Status Update to Federal Project Director	June 28-30, 2022
❑ Cost and Schedule Event(s)	May-June 2022
❑ Technical Subsystem Reviews	Jan. – Dec. 2022
❑ OPA Status Review	January 2023
❑ Preliminary Design Complete & Review	May 2023
❑ Final Design/Maturity Readiness for CD-3A Items	May 2023
❑ CD-2/3A review (expectation), requires pre-TDR	~October 2023
❑ CD-2/3A (expectation)	~January 2024
❑ CD-3 review (expectation)	~January 2025
❑ CD-3 (expectation), requires TDR	~April 2025

- **Everyone is VERY welcome to join eRD112 and other EIC detector/physics efforts.**

EIC Users Group Meeting @ Stony Brook University, July 26-29, 2022, https://indico.bnl.gov/event/15342/

References

[1] Electron Ion Collider: The Next QCD Frontier - Understanding the glue that binds us all (2012), arXiv:1212.1701

[2] Reaching for the Horizon: The 2015 Long Range Plan for Nuclear Science (2015), link

[3] An Assessment of U.S.-based Electron-Ion Collider Science (2018), link

[4] Electron Ion Collider Conceptual Design Report (2021), link

[5] Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report, arXiv:2103.05419

[6] EIC Detector Proposals and Advisory Panel Report (2022), link

[7] eRD112: EIC AC LGAD R&D Proposal (2022), link