μ-RWELL Detector @ EIC

End Cap Tracker R&D Status in Korea

Seonho Choi, KSHEP, Jeju, June 12, 2026

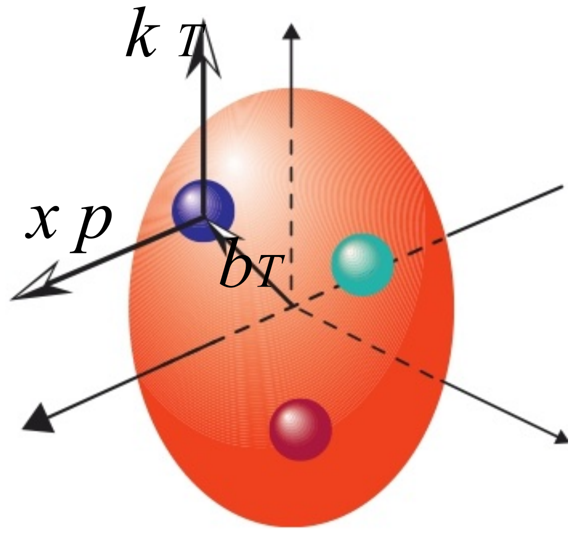
Contents

EIC Physics (= QCD Physics)

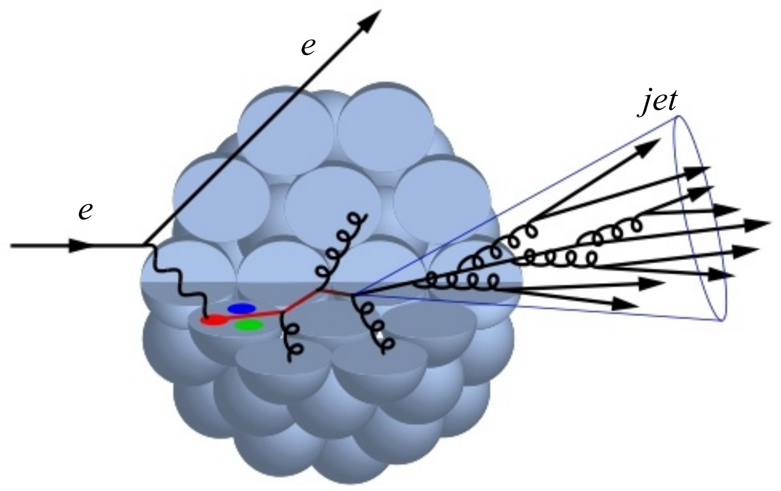
Investigate with precision the universal dynamics of gluons to understand the emergence of hadronic and nuclear matter and their properties

Central Questions:

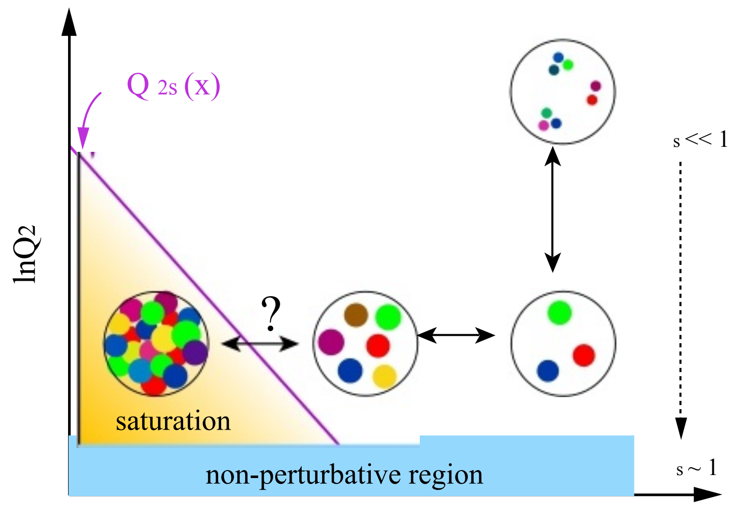
- How are sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties emerge from them and their interactions?



- How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium? How do confined hadronic states emerge from these quarks and gluons?



- What happens to the exploding gluon density at low-x in hadronic matter? Does it saturate at high energy, giving rise to a gluonic matter with universal properties?



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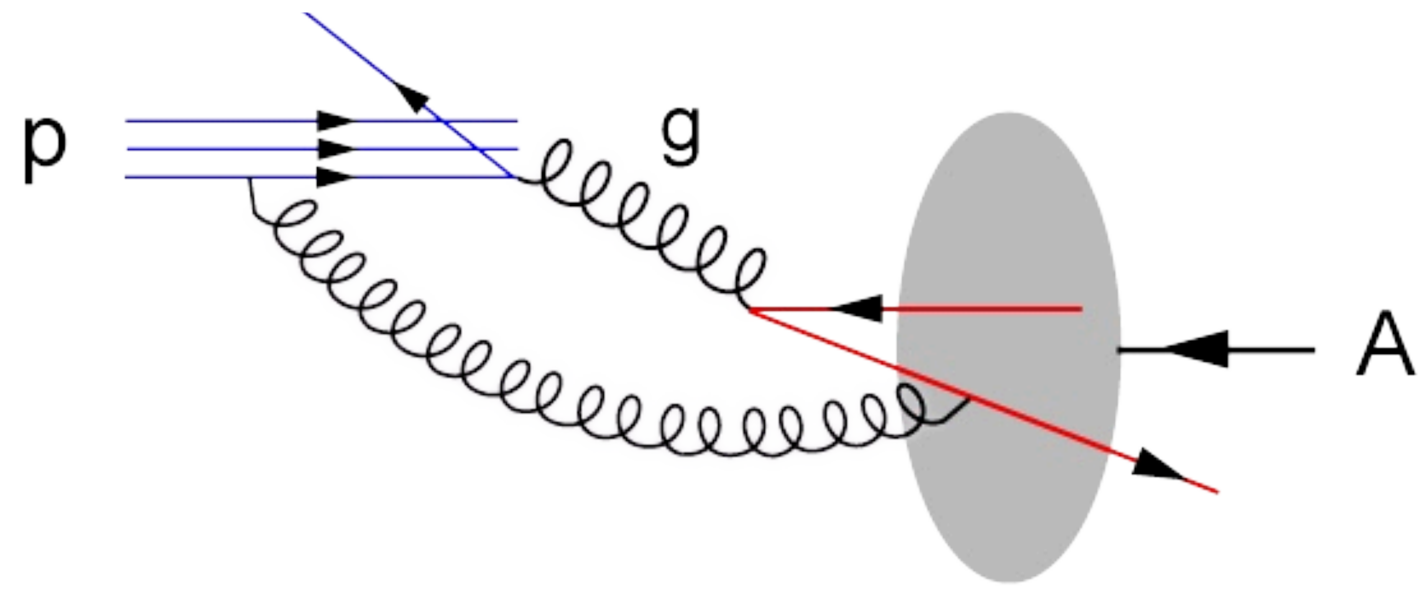
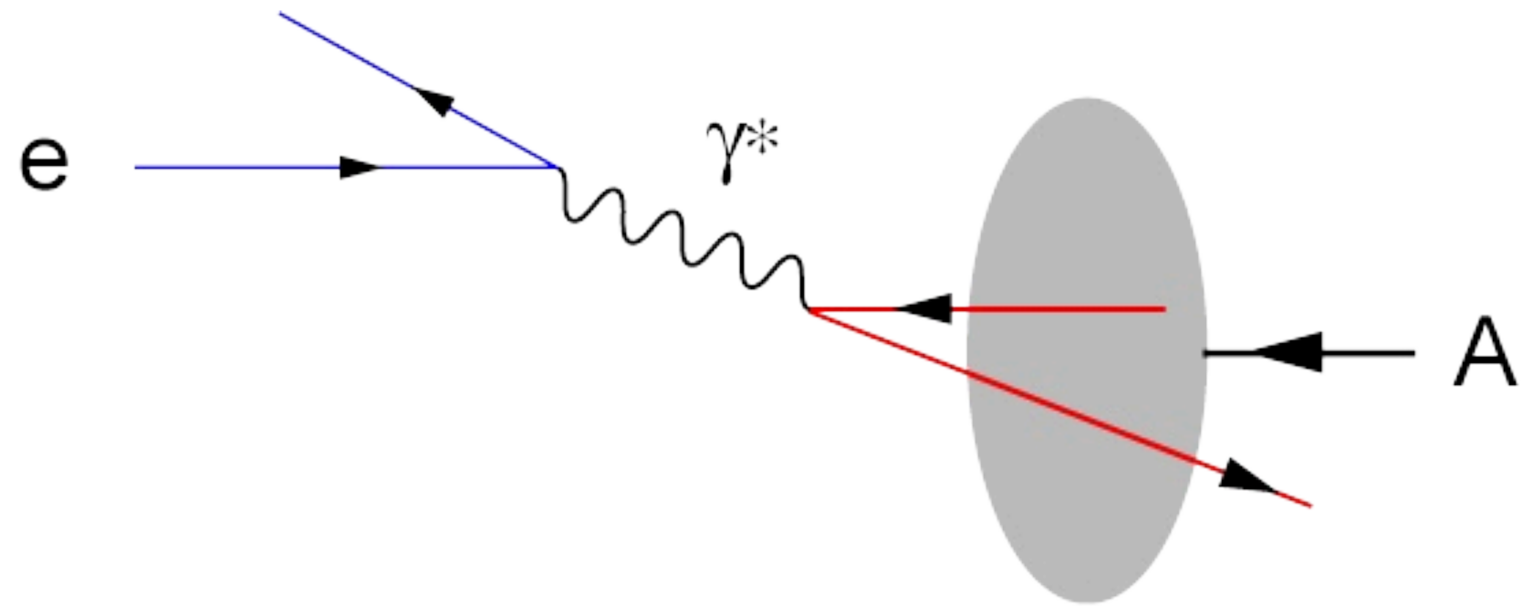
What Can Provide Answers?

Hadron-Hadron



- Test QCD
- Probe/Target interaction directly via gluons
- lacks the direct access to x, Q^2

Electron-Hadron (DIS)



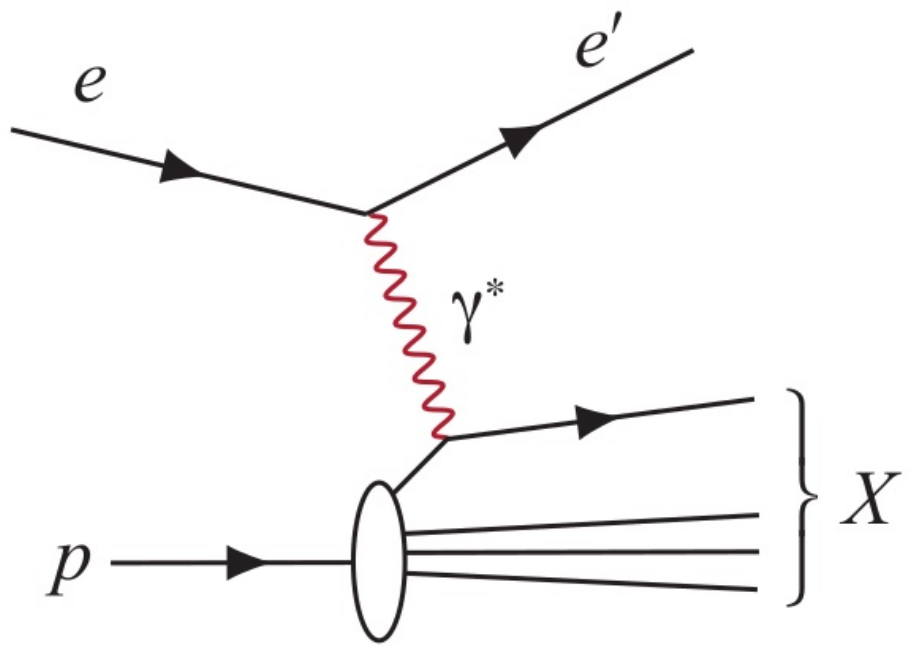
- Explore QCD & Hadron Structure
- Indirect access to glue
- High precision & access to partonic kinematics

Both are complementary and provide excellent information on properties of gluons in the nuclear wave functions

Precision measurements $\Rightarrow$ **DIS** due to unprecedented exact knowledge of QED

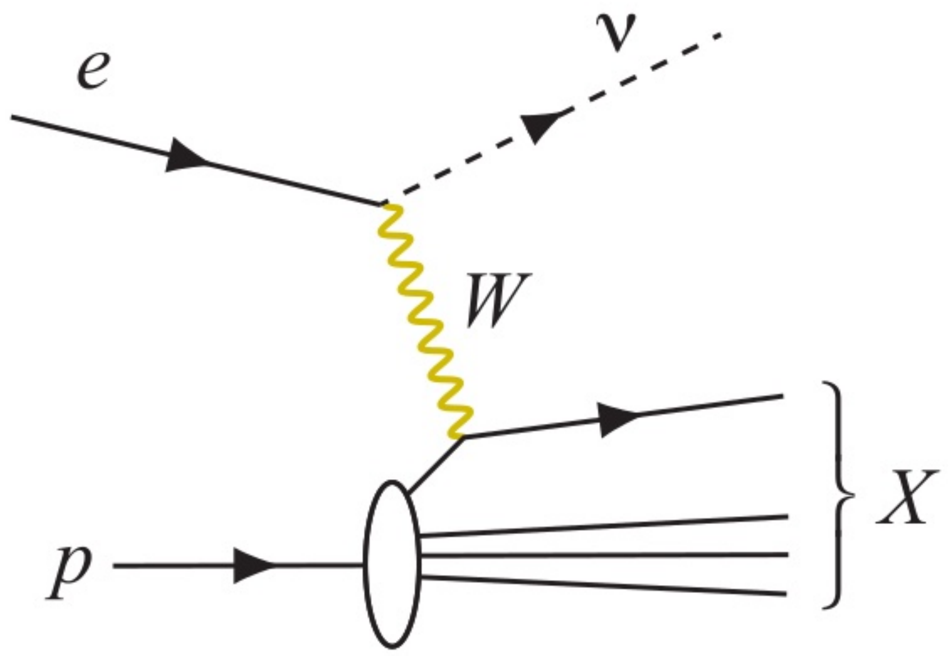
General: Category of Processes to Study

DIS event kinematics - scattered electron or final state particles (CC DIS, low y)



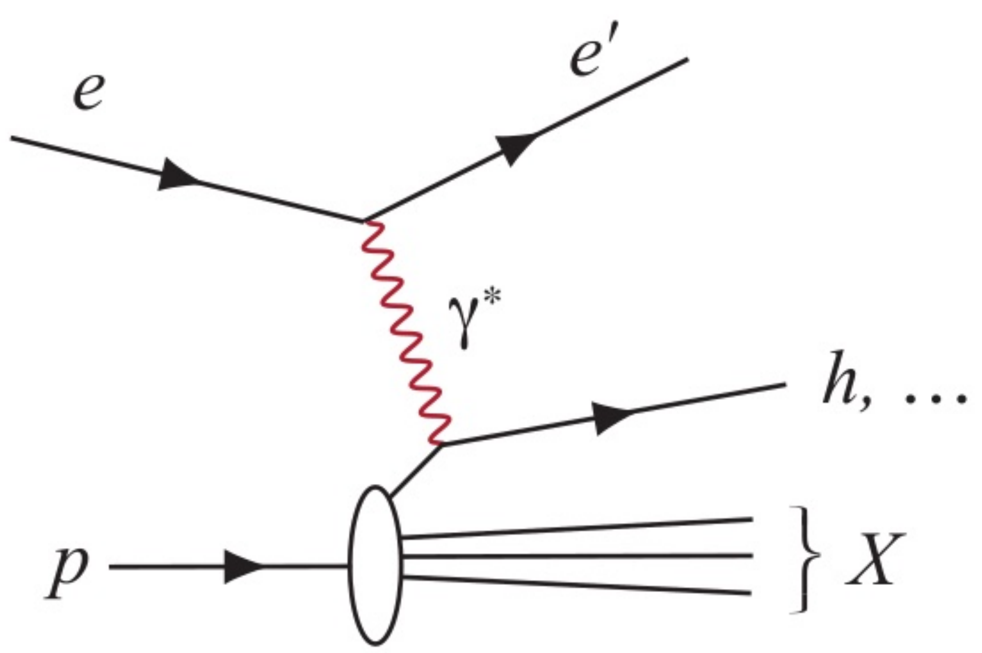
Neutral Current DIS

- Detection of scattered electron with high precision - event kinematics



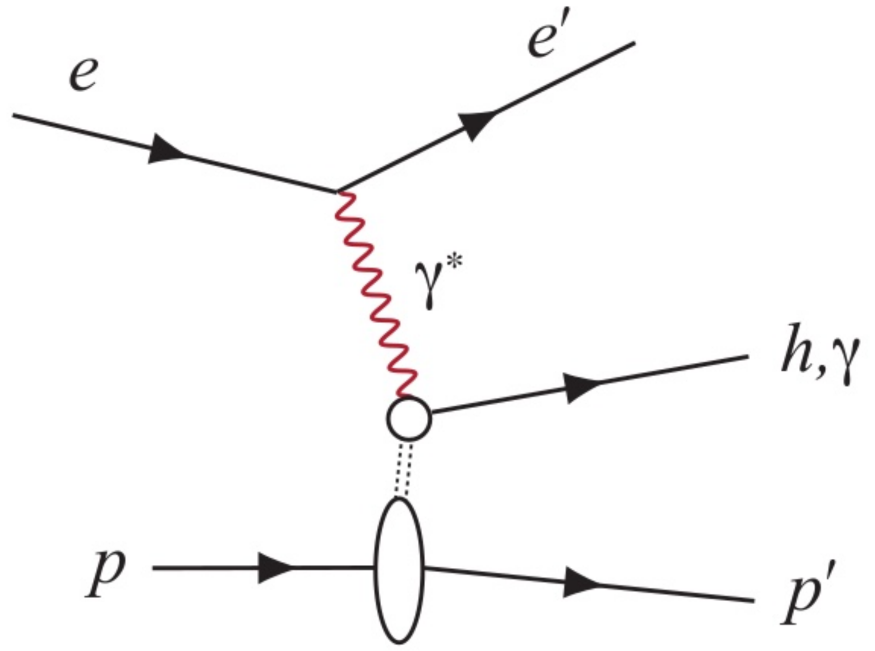
Charged Current DIS

- Event kinematics from the final state particles (Jacquet-Blondel method)



Semi-Inclusive DIS

- Precise detection of scattered electron in coincidence with at least 1 hadron



Deep Exclusive Processes

- Detection of all particles in event

Parton Distributions in nucleons and nuclei

Spin and Flavor structure of nucleons and nuclei | **Tomography Transverse Momentum Dist.**

QCD at Extreme Parton Densities - Saturation | **Tomography Spatial Imaging**

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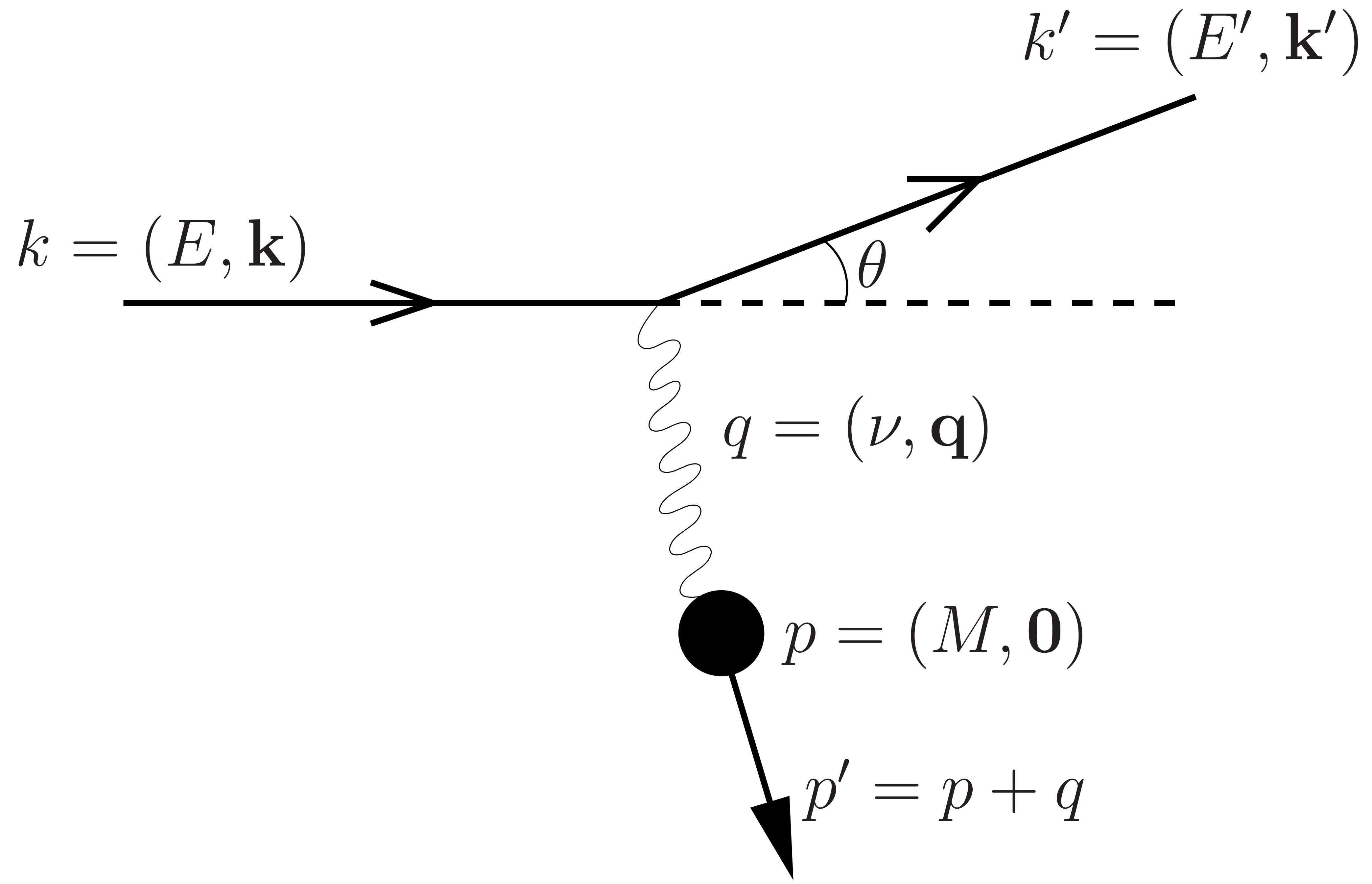
Kinematics in the Lab frame



4-momentum transfer

$$q = k - k'$$

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

$$\simeq -2k \cdot k' = -2EE'(1 - \cos\theta) = -4EE' \sin^2 \frac{\theta}{2}$$

Kinematics (Cont)

- *Elastic* scattering: $p'^2 = p^2 = M^2$

$$q^2 = -2p \cdot q = -2\nu M \qquad \text{so} \qquad \nu = E - E' = -\frac{q^2}{2M}$$

- *Inelastic* scattering: $p'^2 \neq M^2$

$$W \equiv p'^2 = (p+q)^2 = M^2 + 2M\nu - q^2$$

- Usually, define $Q^2 = -q^2$ **4-momentum transfer squared ~ Spatial resolution of the probe**

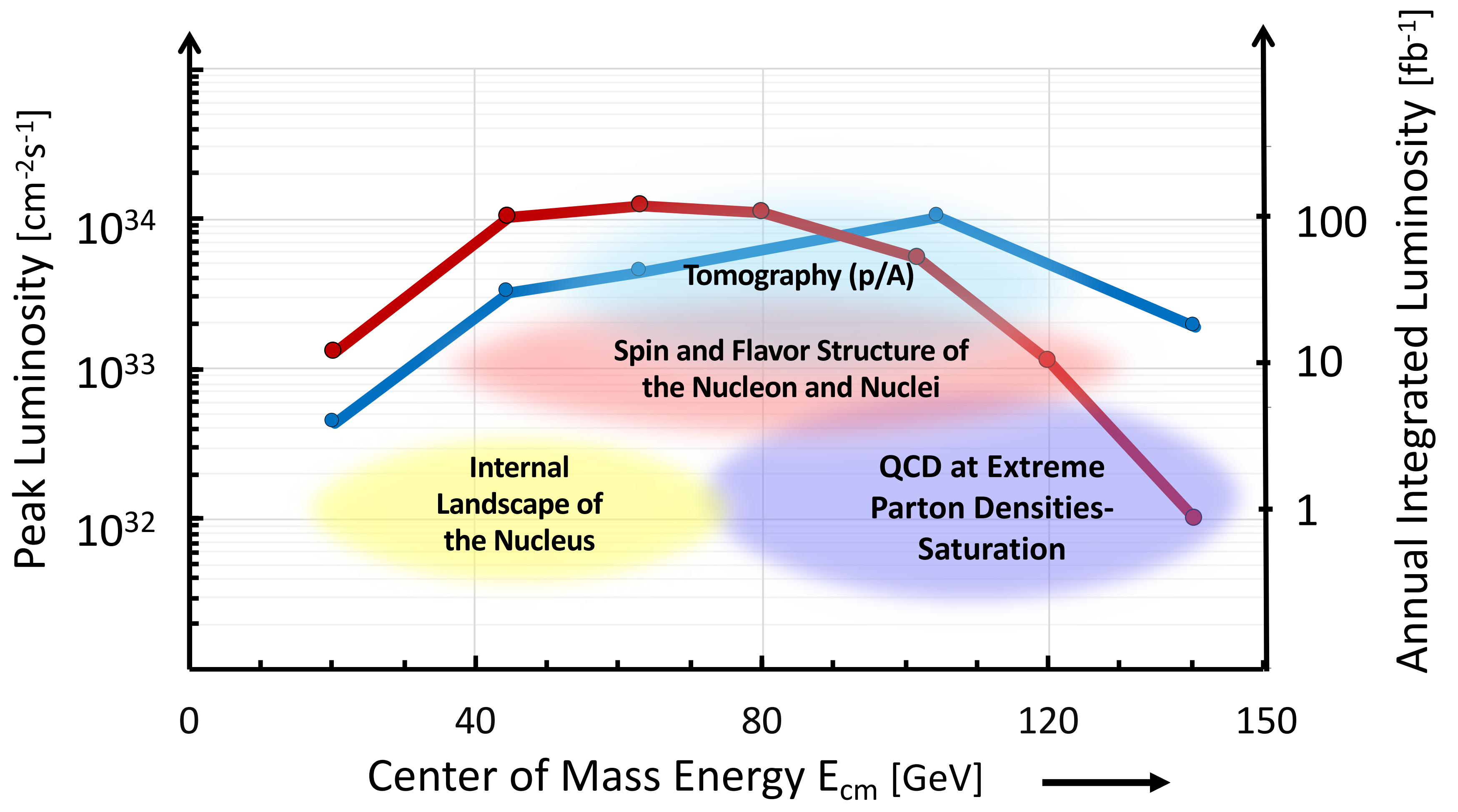
$$\frac{Q^2}{2M\nu} \equiv x$$

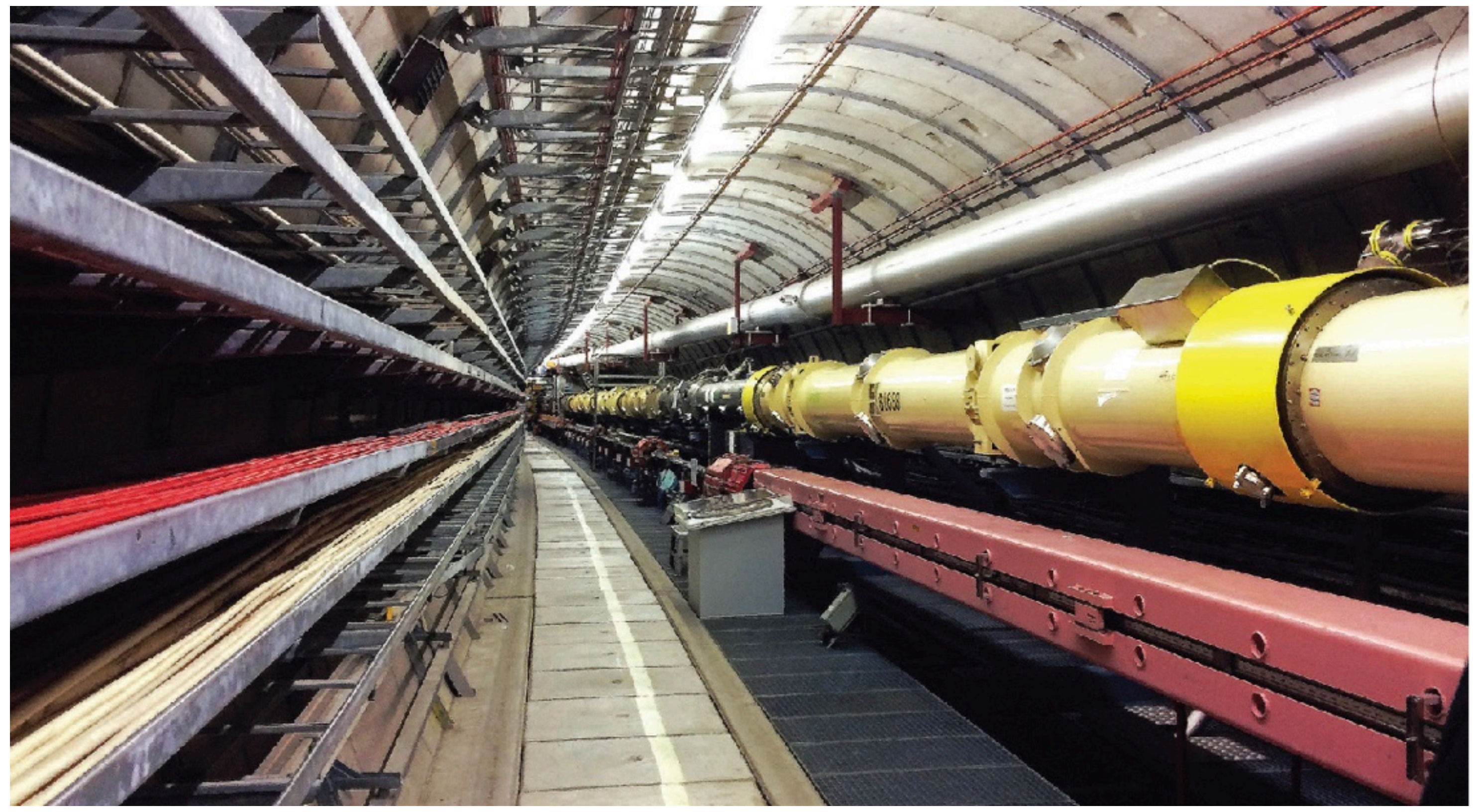
Bjorken x = momentum fraction of partons inside the hadron

- $x \leq 1$

What Else?

- Access to gluon dominated region and wide kinematic range in x and Q^2
  - ➡ Large center-of-mass energy range $\sqrt{s}$ = 20 -140 GeV
- Access to spin structure and 3D spatial and momentum structure
  - ➡ Polarized electron and proton and light nuclear beams ≥ 70% for both
- Accessing the highest gluon densities ($Q_S^2 \sim A^{1/3}$)
  - ➡ Nuclear beams, the heavier the better (up to U)
- Studying observables as a fct. of x, Q^2, A, etc.
  - ➡ High luminosity (100x HERA): $10^{33\text{-}34}$ cm^{-2} s^{-1}

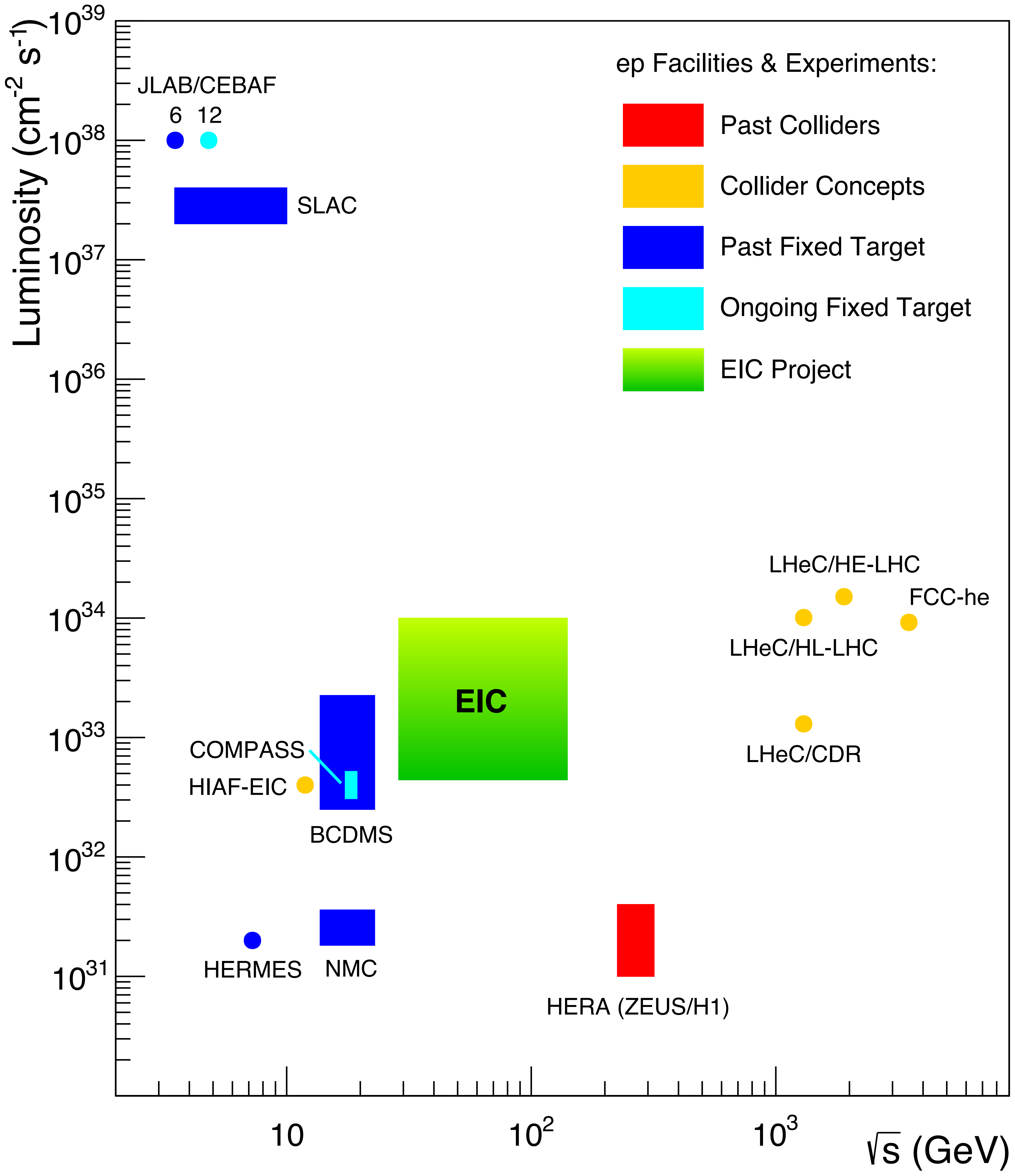




HERA@DESY

Siberian Snakes, RHIC

Landscape of DIS: The Uniqueness of EIC



- EIC cannot compete with e+p at HERA (√s = 318 GeV)
- EIC's strength is polarized e↑+p↑ and e+A collisions
- Here the kinematic reach extends substantially compared to past (fixed target) coverage
  - Q^2×20, x/20 for e+A
  - Q^2×20, x/100 for polarized e↑+p↑

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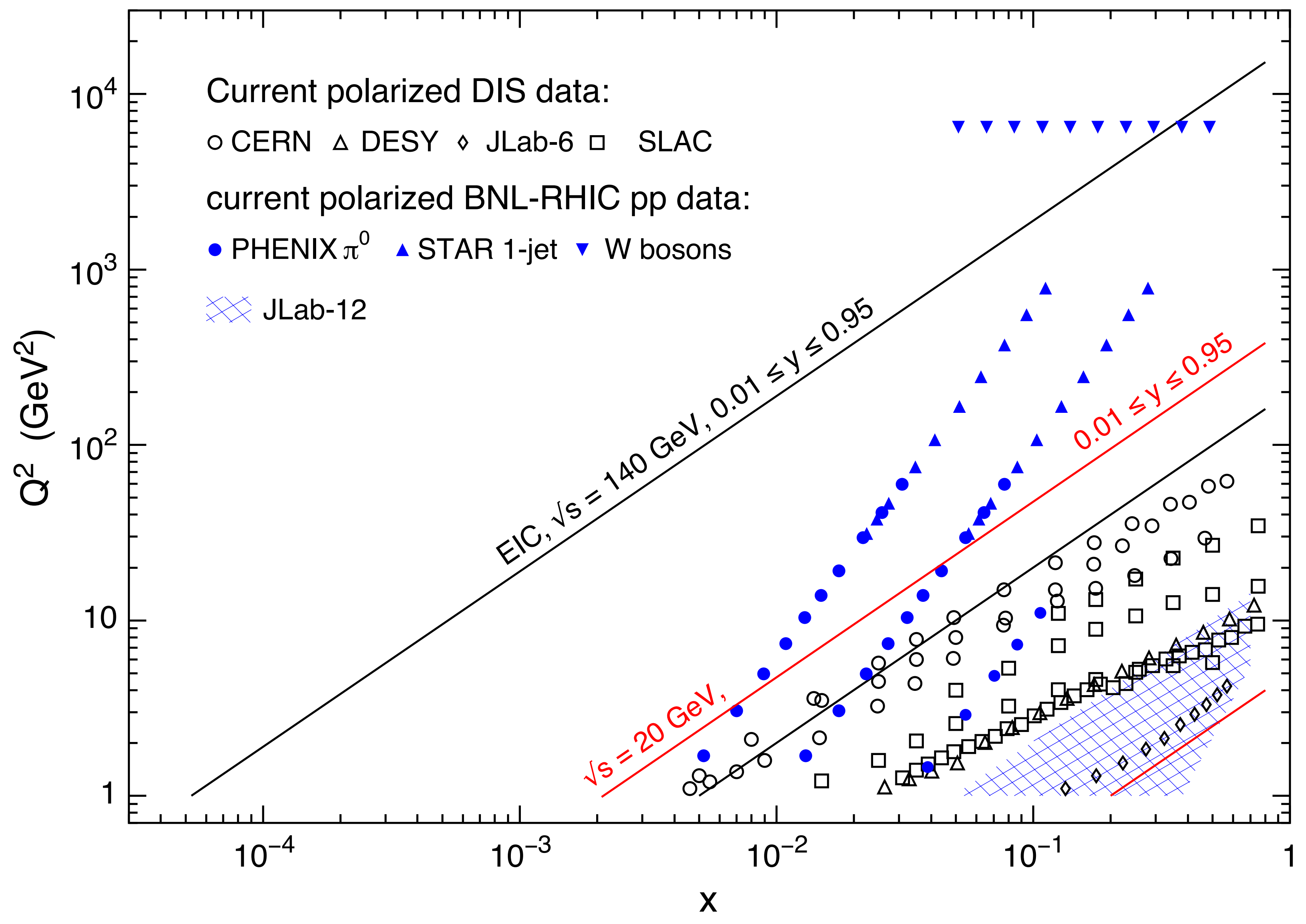
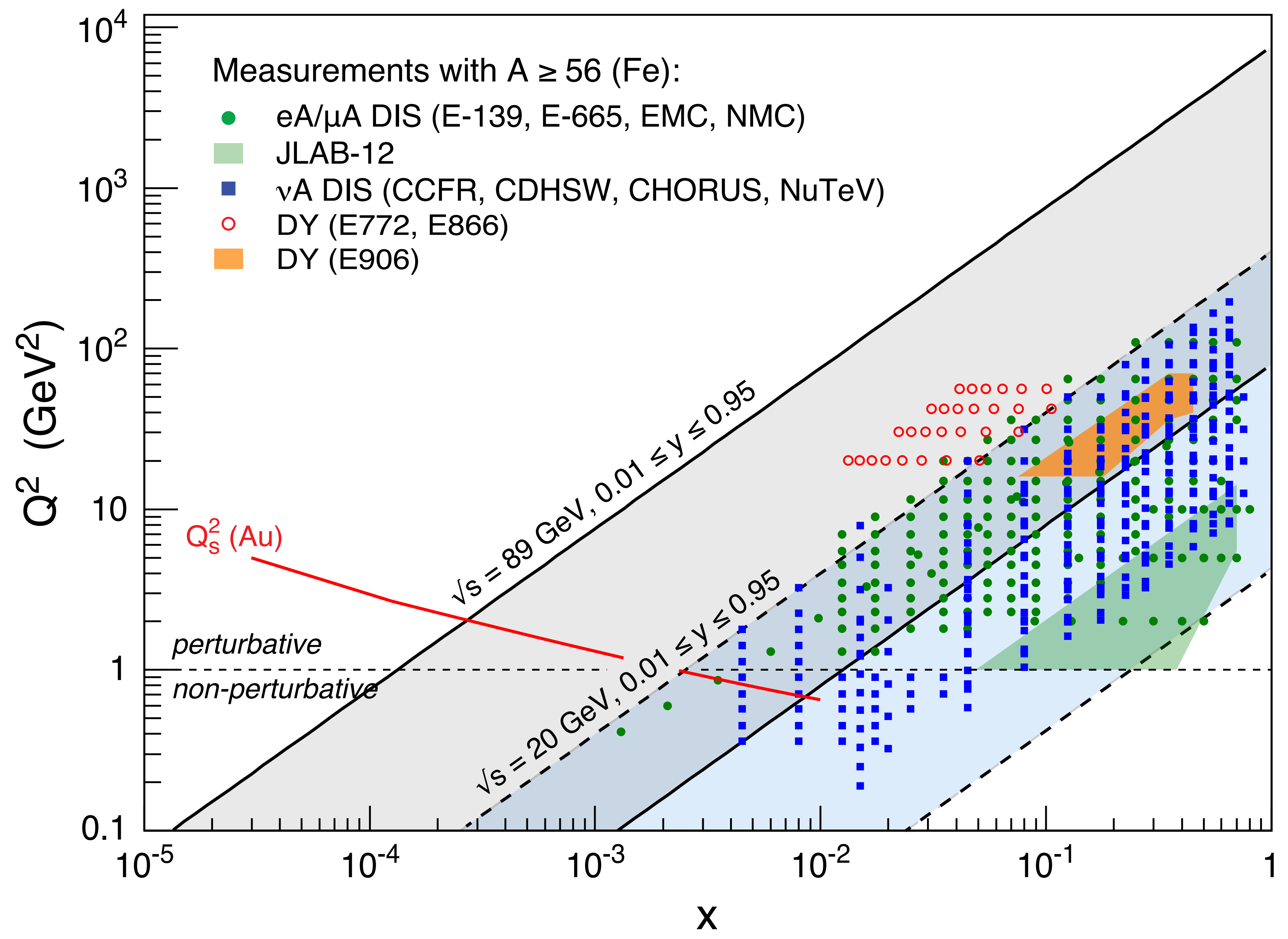
Landscape of DIS: The Uniqueness of EIC





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The Electron-Ion Collider

A Frontier Accelerator in the USA

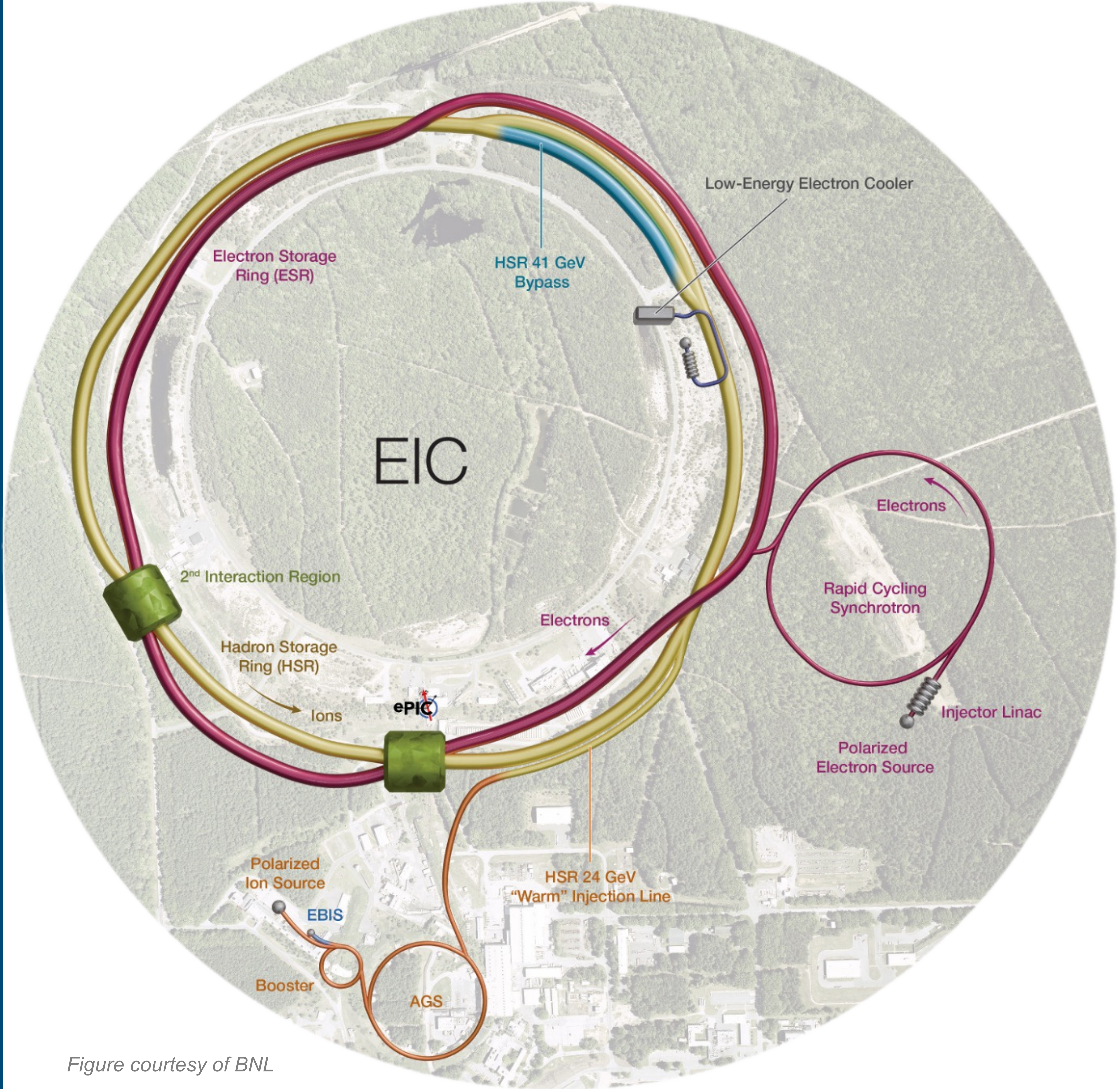

Figure courtesy of BNL

World's first collider of:

- Polarized electrons and polarized protons
- Polarized electrons and light ions (d, ^{3}He)
- Electrons and heavy ions (up to Uranium)

A versatile machine:

- Beam polarizations up to 70%,
- Versatile range of beam species
- Versatile range of center of mass energies, E_{cm} = 29 – 140 GeV

A high luminosity machine

- up to $\mathcal{L} = 10^{34}$ cm^{-2} s^{-1}
- At peak luminosity, the e-p signal event rate will be about 500 kHz

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Physics-Driven Detector Design

Inclusive DIS requires fine binning in x_B, Q^2:

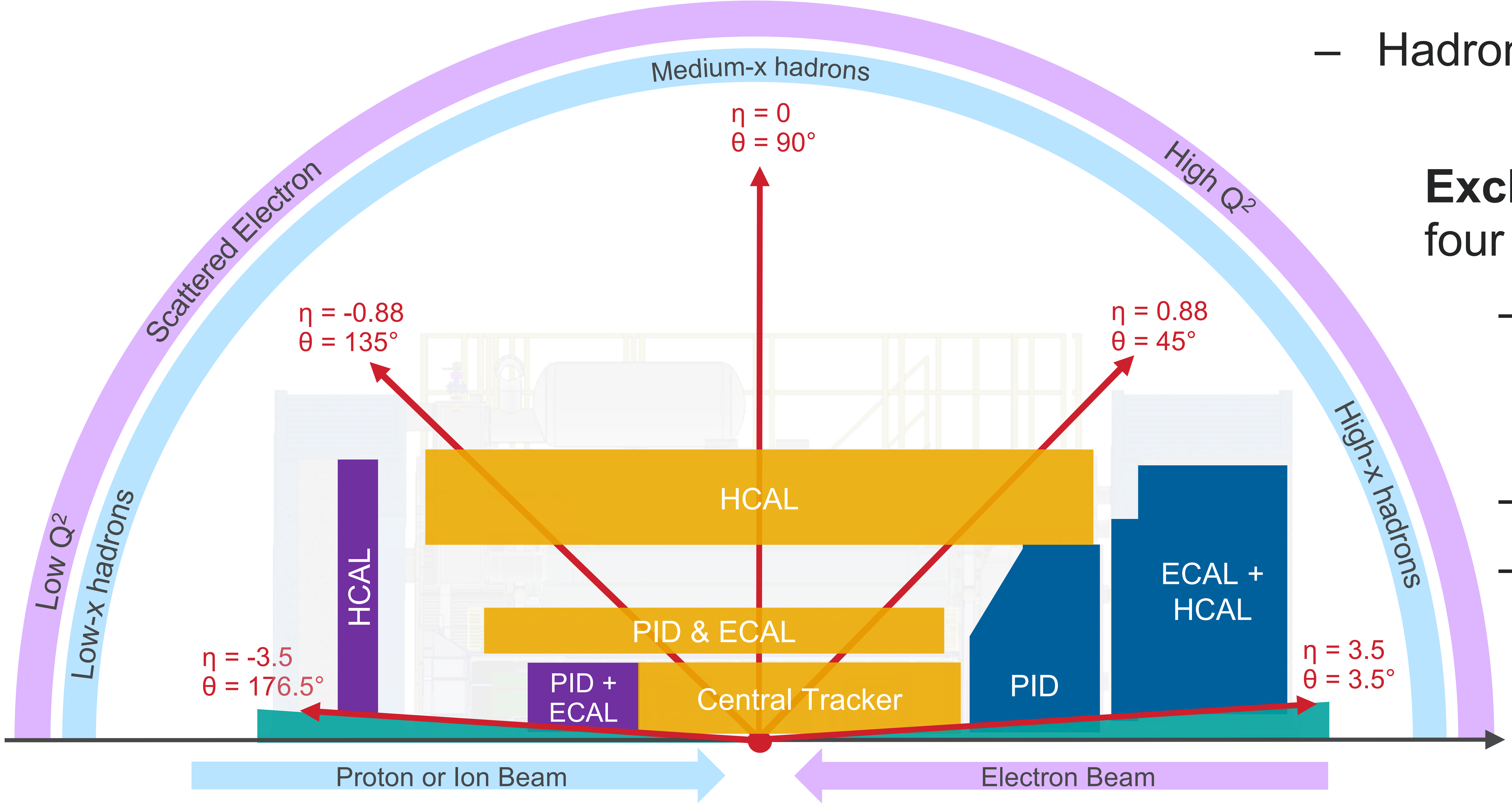
- Large angular coverage for wide phase space reach
- Excellent EM-calorimetry with PID support for e/π separation, and good electron energy resolution
- Fine resolution tracking with low mass

Semi-inclusive DIS requires binning in five or more variables (x_B, Q^2, z, p_T, φ_h , …):

- Fine p_T resolution
- Extended PID systems for hadron identification
- Hadron calorimetry for jet physics

Exclusive processes require binning in four or more variables (x_B, Q^2, t, φ_h , …):

- Extend acceptance at extremely small scattering angles by far forward detectors
- Fine vertex resolution by tracking
- Highly granular EM-calorimeters to separate γ/π^0



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The Central ePIC Detector

Magnet
- New 1.7 T SC solenoid, 2.8 m bore diameter

Tracking
- Si Vertex Tracker MAPS wafer-level stitched sensors (ALICE ITS3)
- Si Tracker MAPS barrel and disks
- Gaseous tracker: MPGDs (μRWELL, MMG) cylindrical and planar

PID
- high performance DIRC (hpDIRC)
- dual RICH (aerogel + gas) (forward)
- proximity focussing RICH (backward)
- ToF using AC-LGAD (barrel+forward)

EM Calorimetry
- imaging EMCal (barrel)
- W-powder/SciFi (forward)
- $PbWO_4$ crystals (backward)

Hadron calorimetry
- FeSc (barrel, re-used from sPHENIX)
- Steel/Scint – W/Scint (backward/forward)

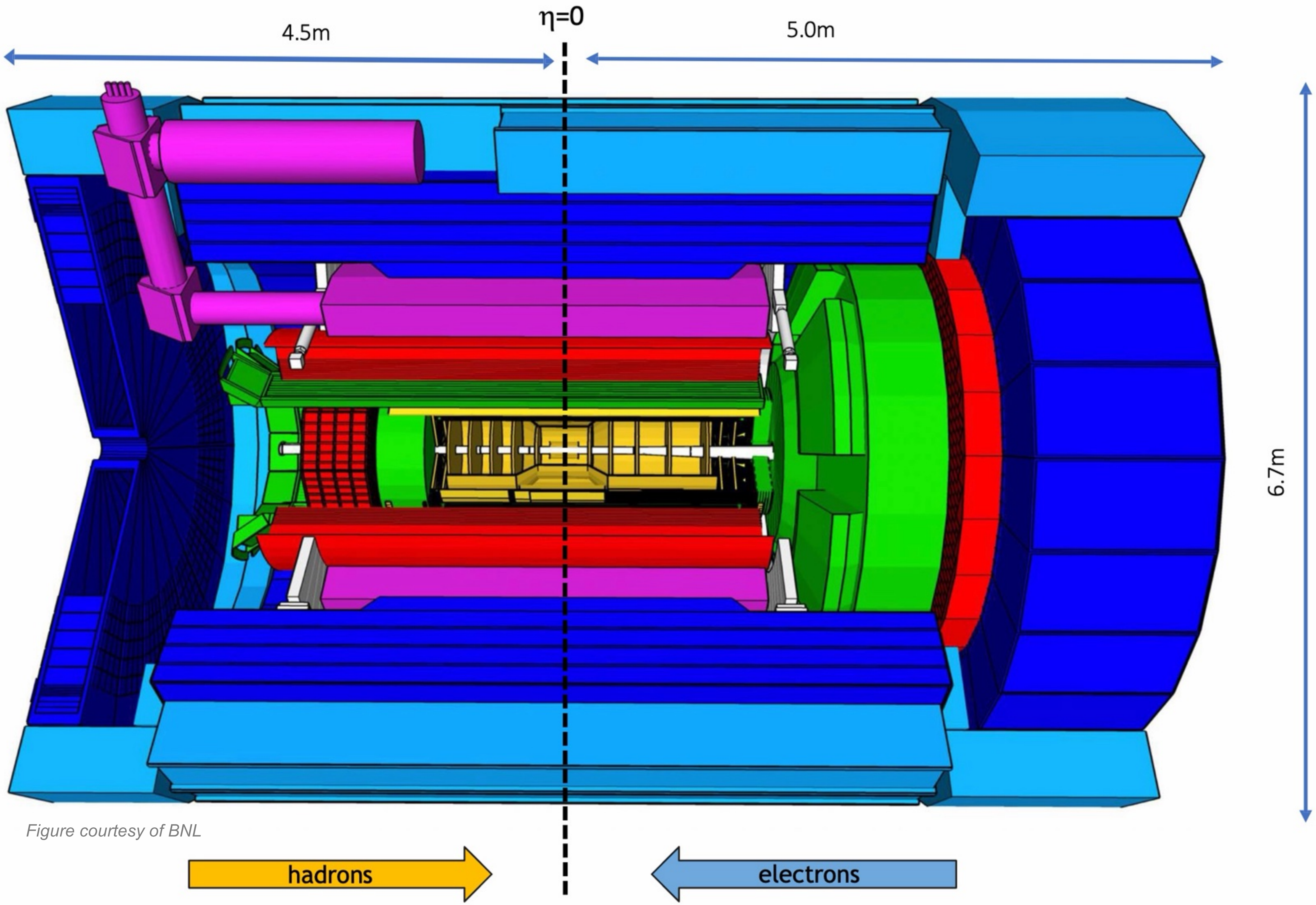

Figure courtesy of BNL

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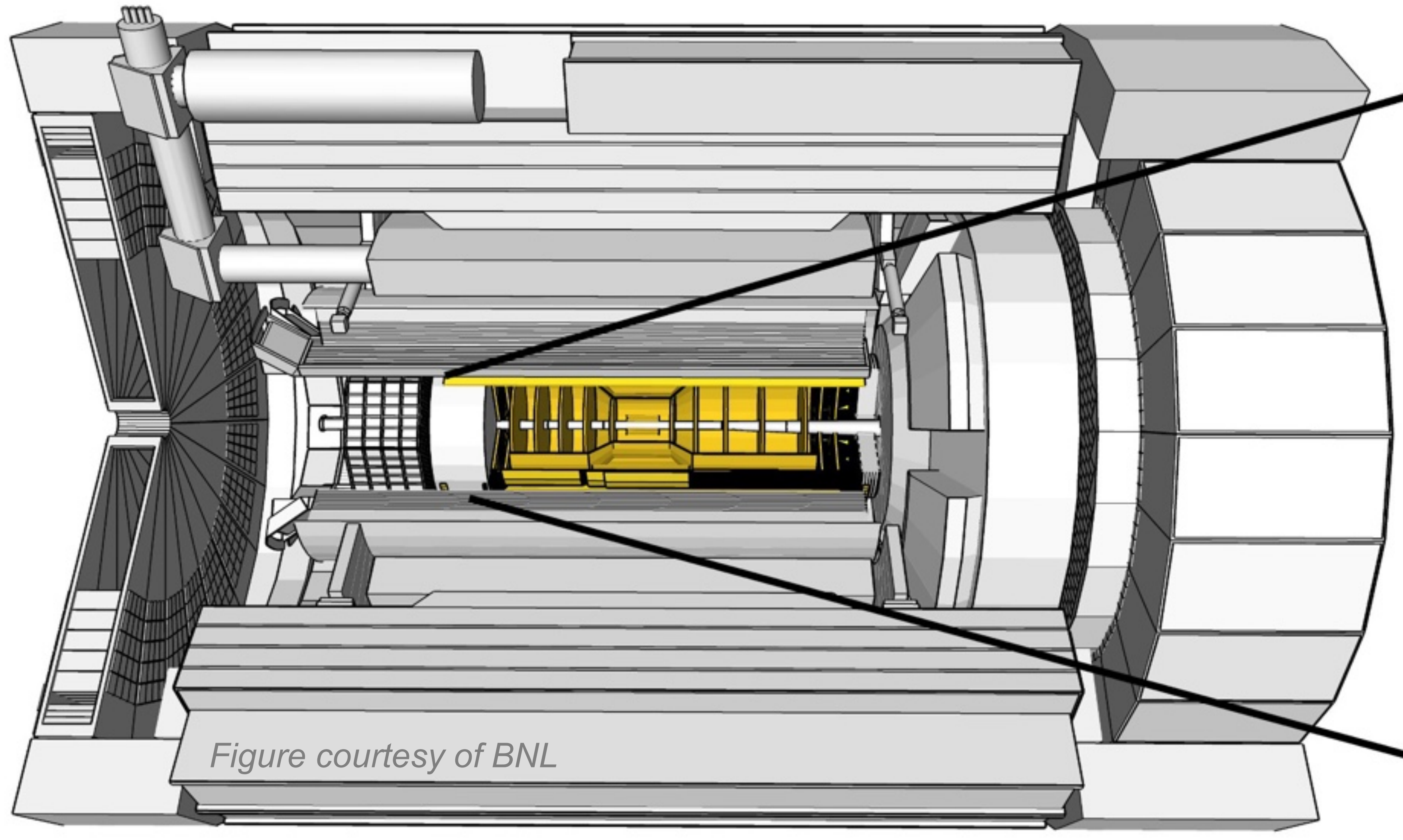
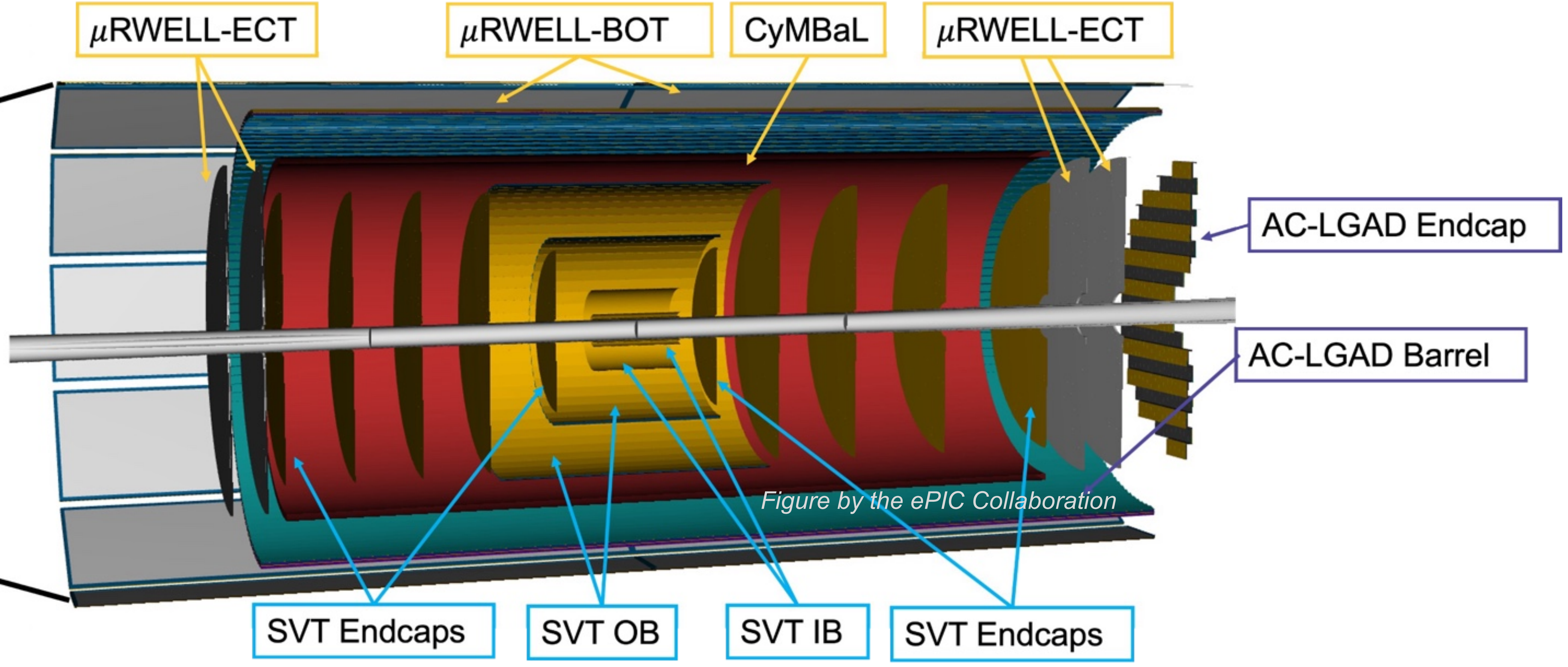
The Tracking System





Tracking Requirements:

- High spatial resolution 20µm/pT⊕ 5µm
- Excellent momentum resolution 0.05%pT⊕0.5%
- Low material budget

- Good pattern recognition efficiency
- Sufficient time resolution to resolve 10ns bunch crossing
- Good angular resolution for the DIRC

Detector Solutions

- Ultra-low-mass **barrel vertex tracker** using ALICE ITS3 curved MAPS technology, with 20µm pixel pitch and 0.05% X/X_0
- **Outer barrel and endcap silicon tracker** using new ITS3-based EIC Large Area Sensors (LAS), with 20µm pixel pitch and 0.55% X/X_0

- **MicroMegas barrel tracker** (CyMBaL) with X/X_0
- **GEM-µRWell barrel and endcap tracker** with 10ns time resolution, 150µm spatial resolution and 1-2% X/X_0

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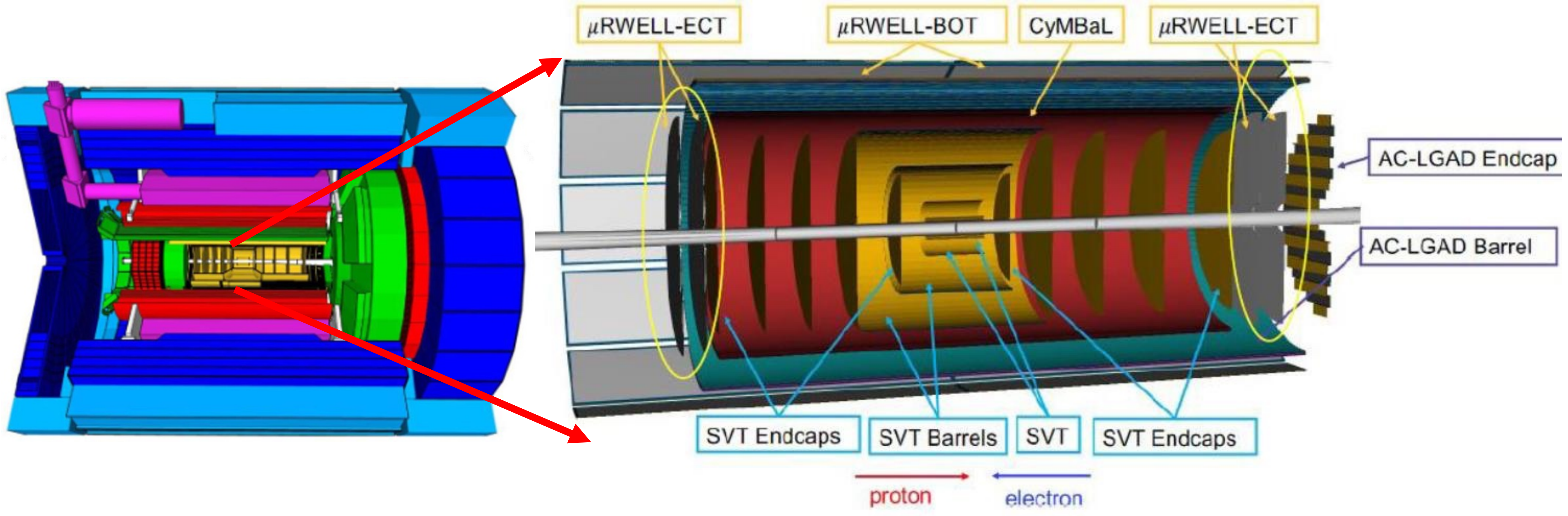
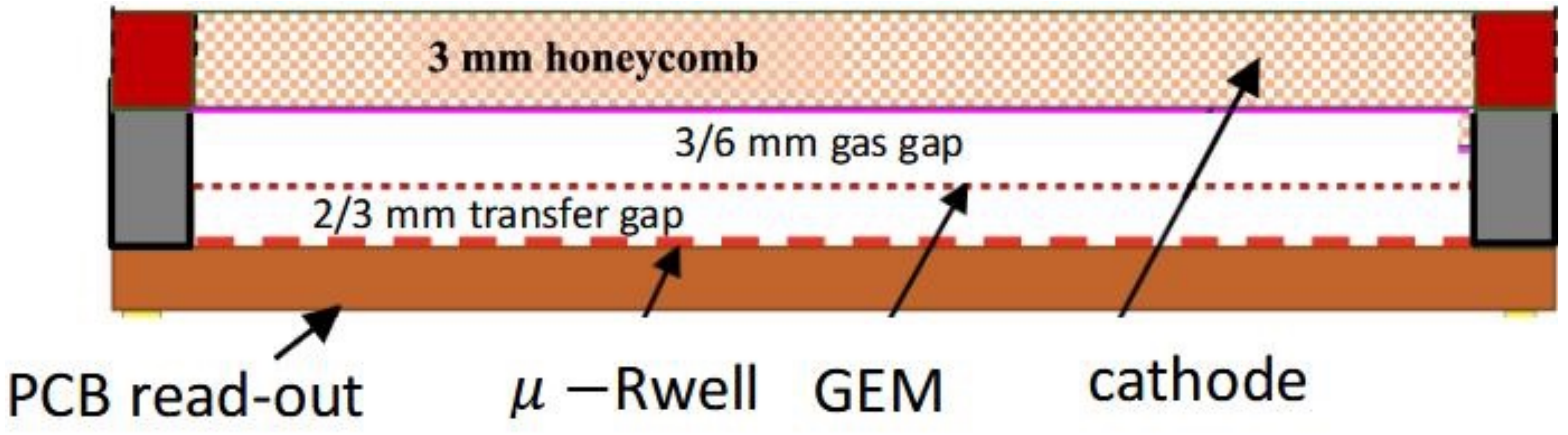
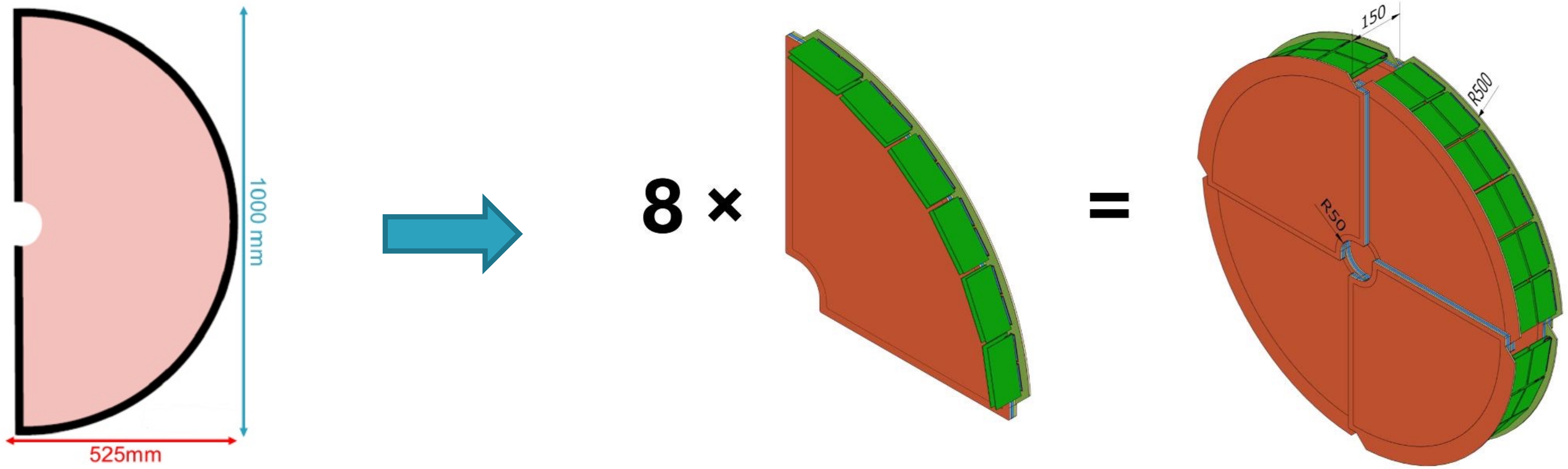
2. ePIC Experiment – ECT







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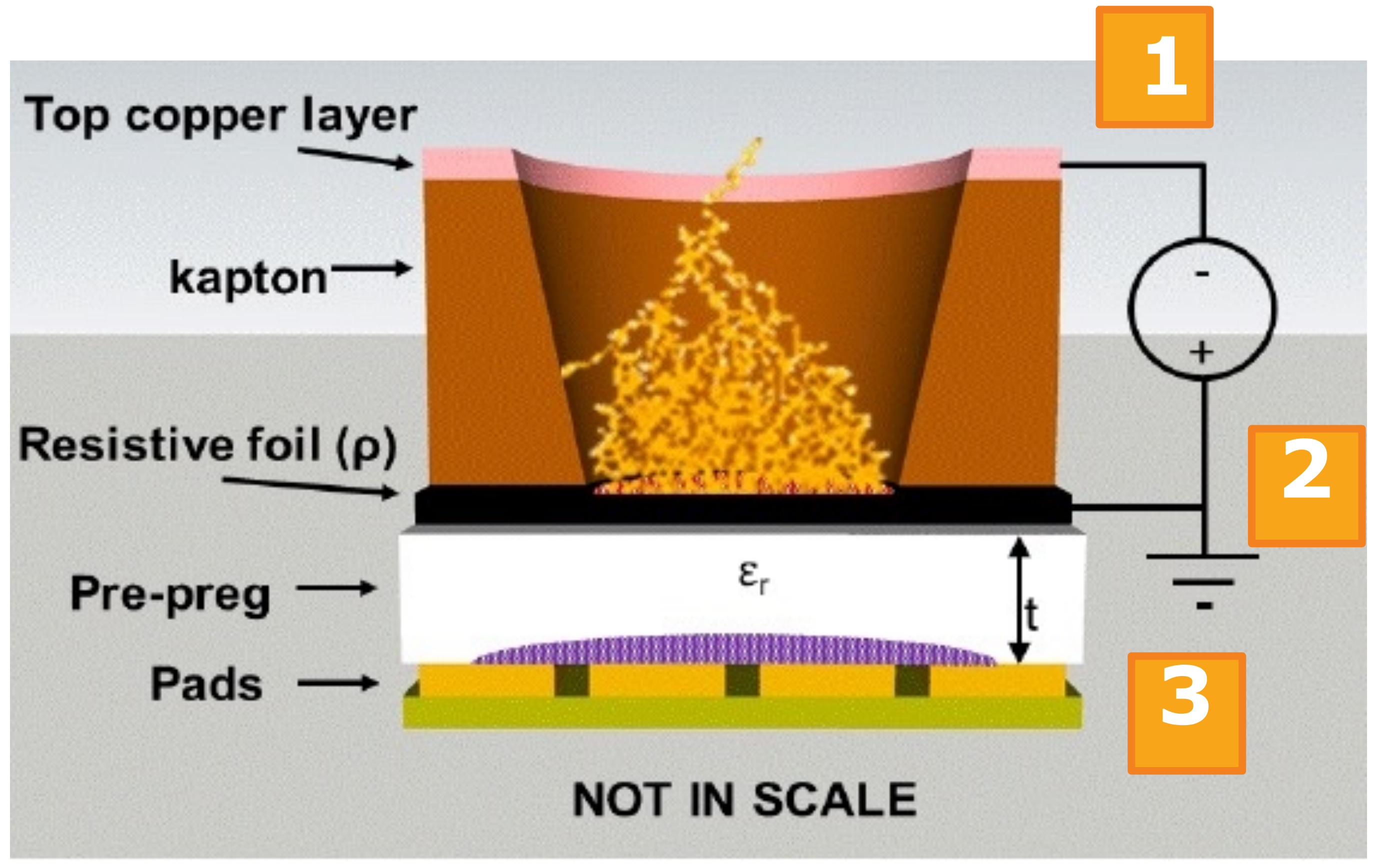
The µ-RWELL

The **µ-RWELL is a resistive MPGD** composed of two elements:

- **µ-RWELL_PCB**
- **Cathode**

The µRWELL_PCB is realized by coupling the **resistive (grounded) amplification stage** with the **readout PCB** through a thin **prepreg foil.**



1 a **WELL** patterned **kapton foil** (with a **Cu-layer on the top**) acts as **amplification stage**

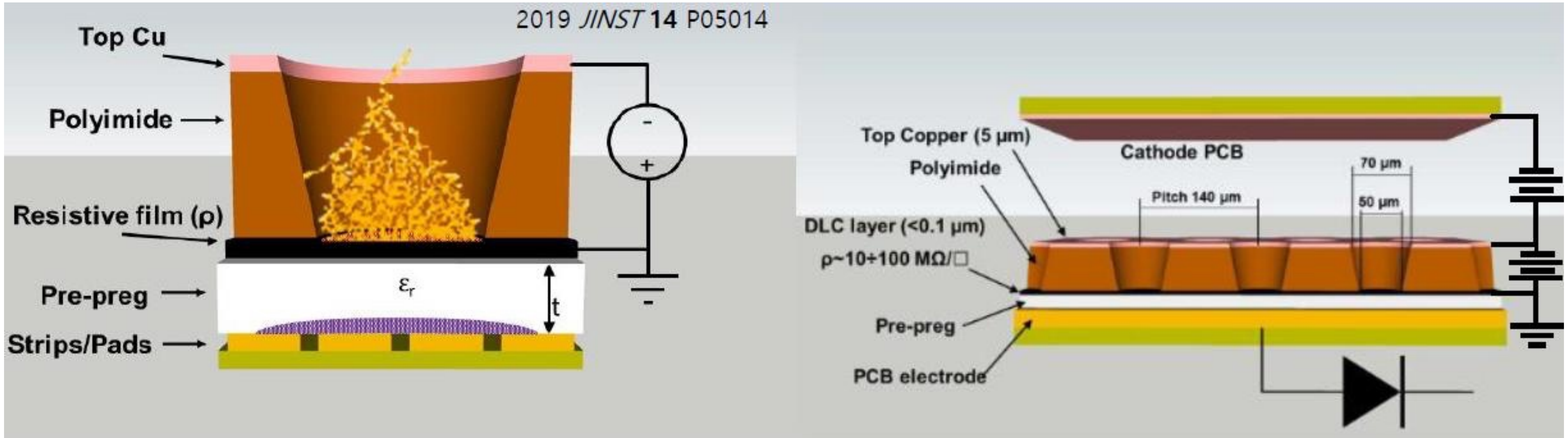
2 a **resisitive DLC** layer(*) (Diamond-Like-Carbon), with **ρ~40÷100 MΩ/□**

3 a standard **readout PCB** with **pad** segmentation

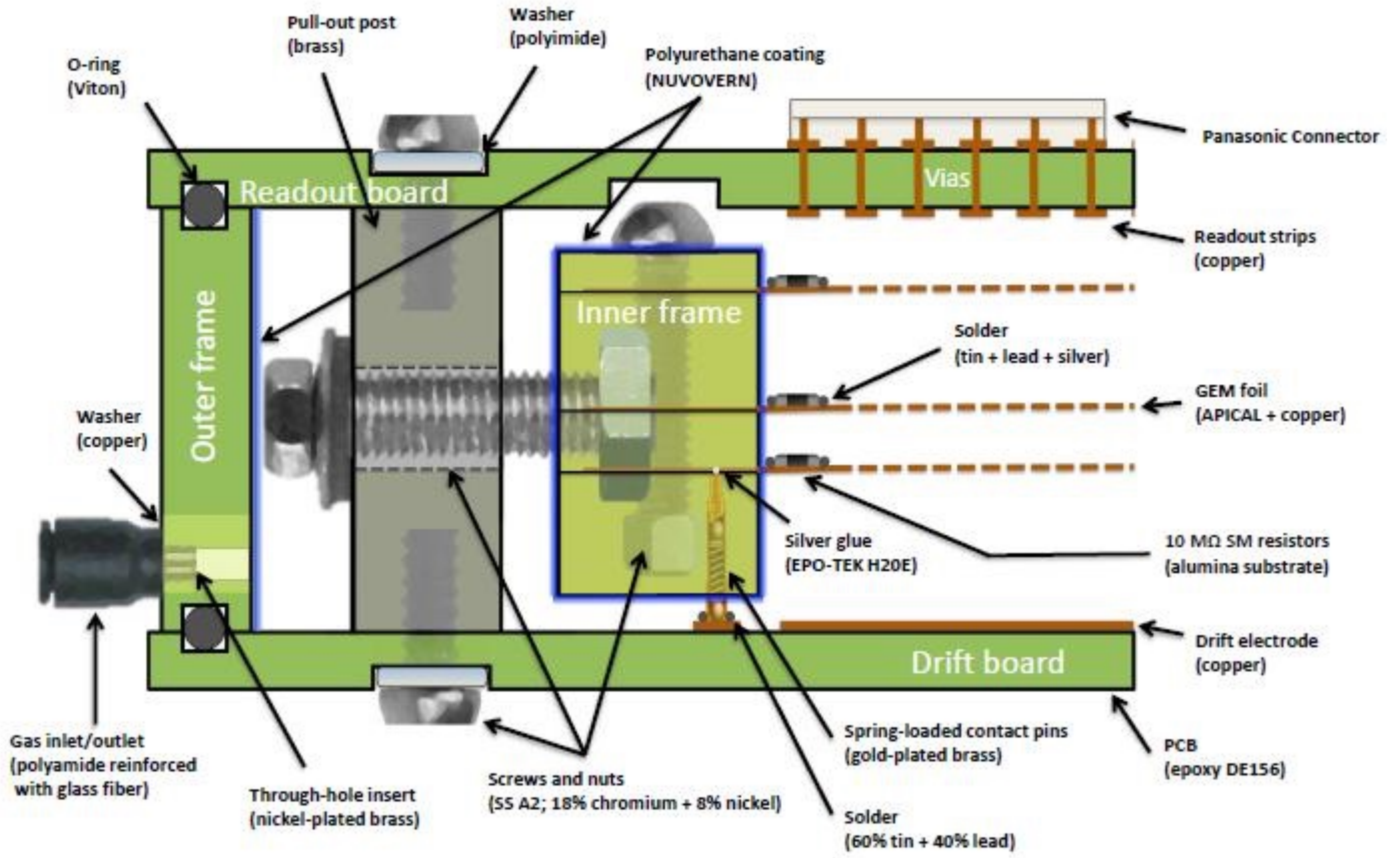
(*) DLC foils are currently provided by the Japan Company – BeSputter. New DLC machine @ CERN (Max DLC size: 50x200 cm2)

1. Introduction to μRWELL

- Micro Resistive WELL, a resistive variant of GEM
  - Resistive layer, DLC, prevents streamer from evolving discharge
  - No spatial separation between the avalanche and induction region is required
  - → Self-rigidity ⇒ Simpler detector structure ⇒ Cost effective



- Position resolution ~ $70\mu m$
  Time resolution ~ 5-7 ns



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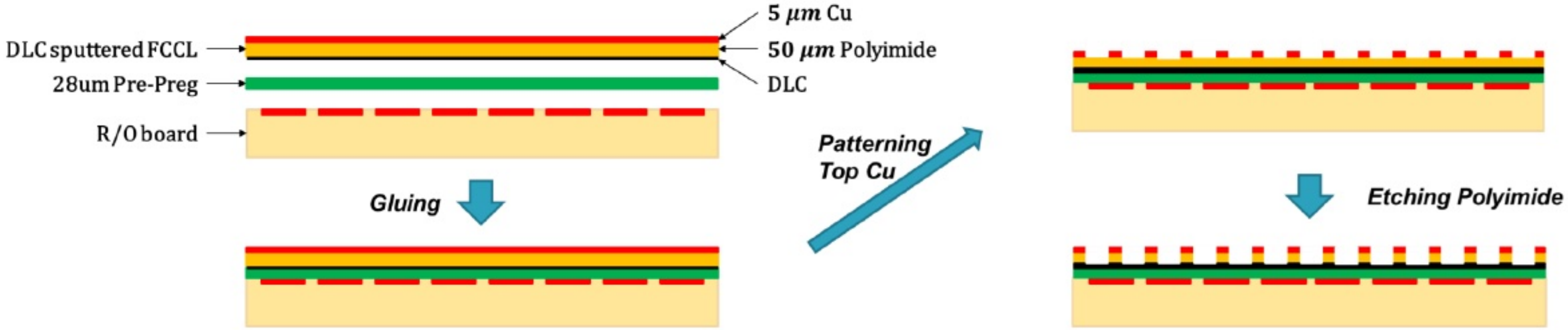
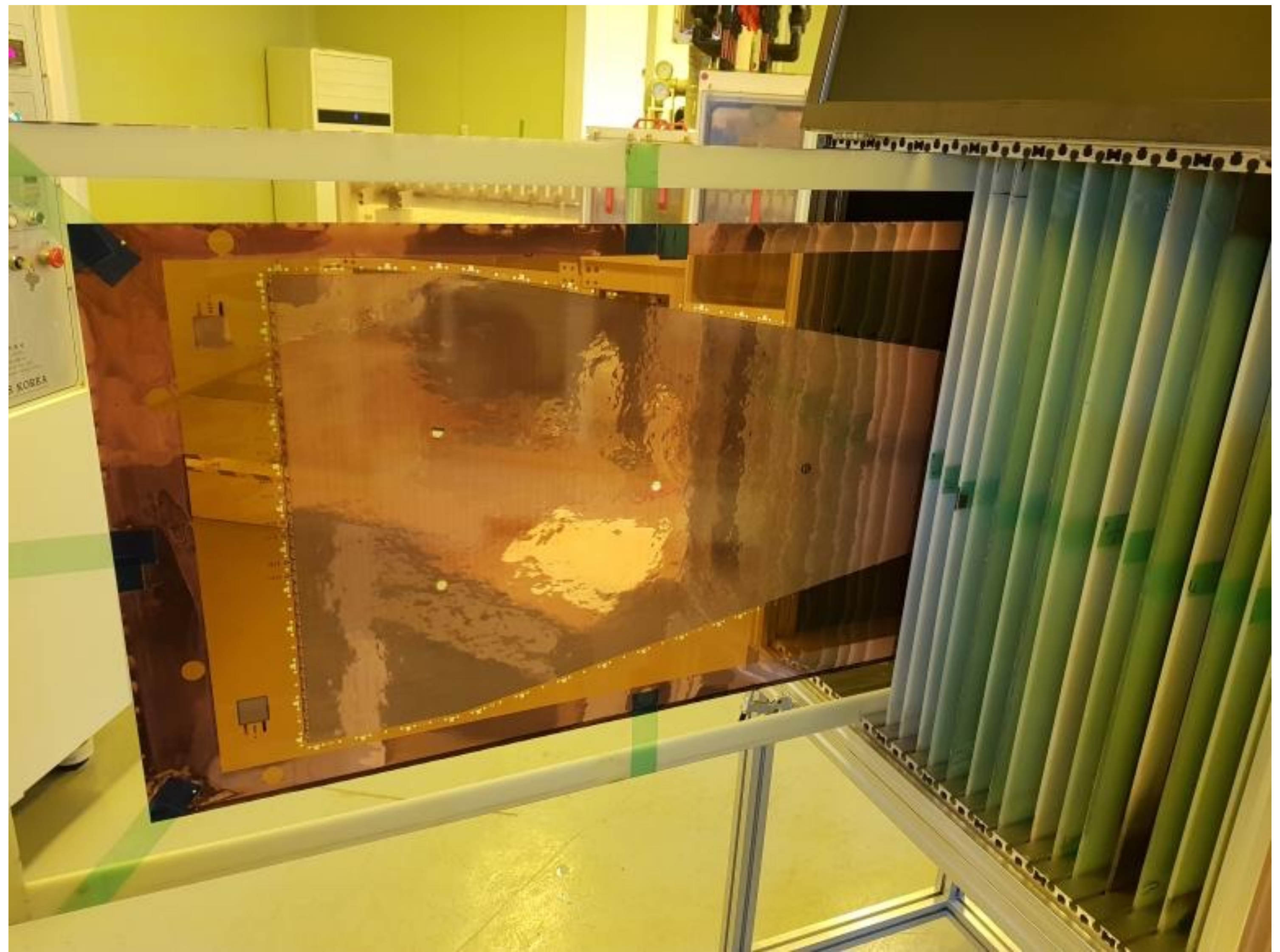
1. Introduction to μRWELL

- GEM and μRWELL share production process



- Gluing
- Cu etching
- PI etching
- Cleaning to give HV stability

- DLC-FCCL
  - Sputtering
  - Will be done in CERN MPT
  - Looking for domestic companies as well



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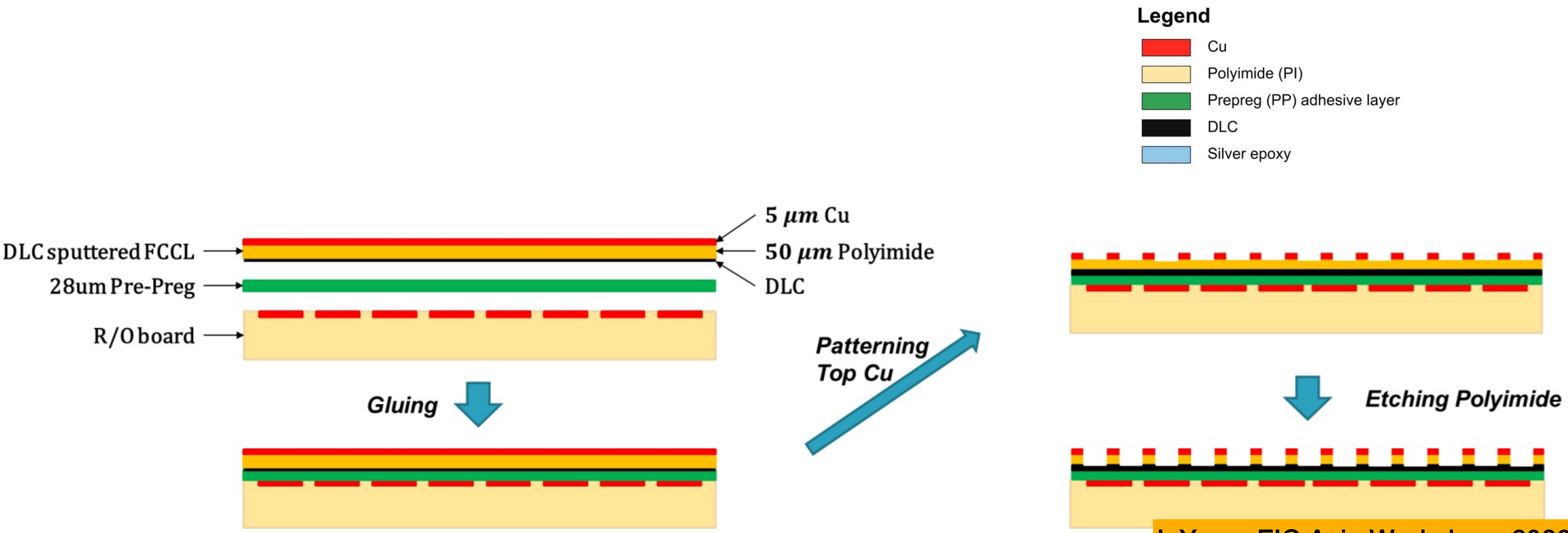
5. R&D Status: μRWELL Production Overview

- Production flow

- DLC-FCCL → gluing → 1st Cu etching → PI etching → 2nd Cu etching → Ag epoxy pasting → Chemical/electrical cleaning



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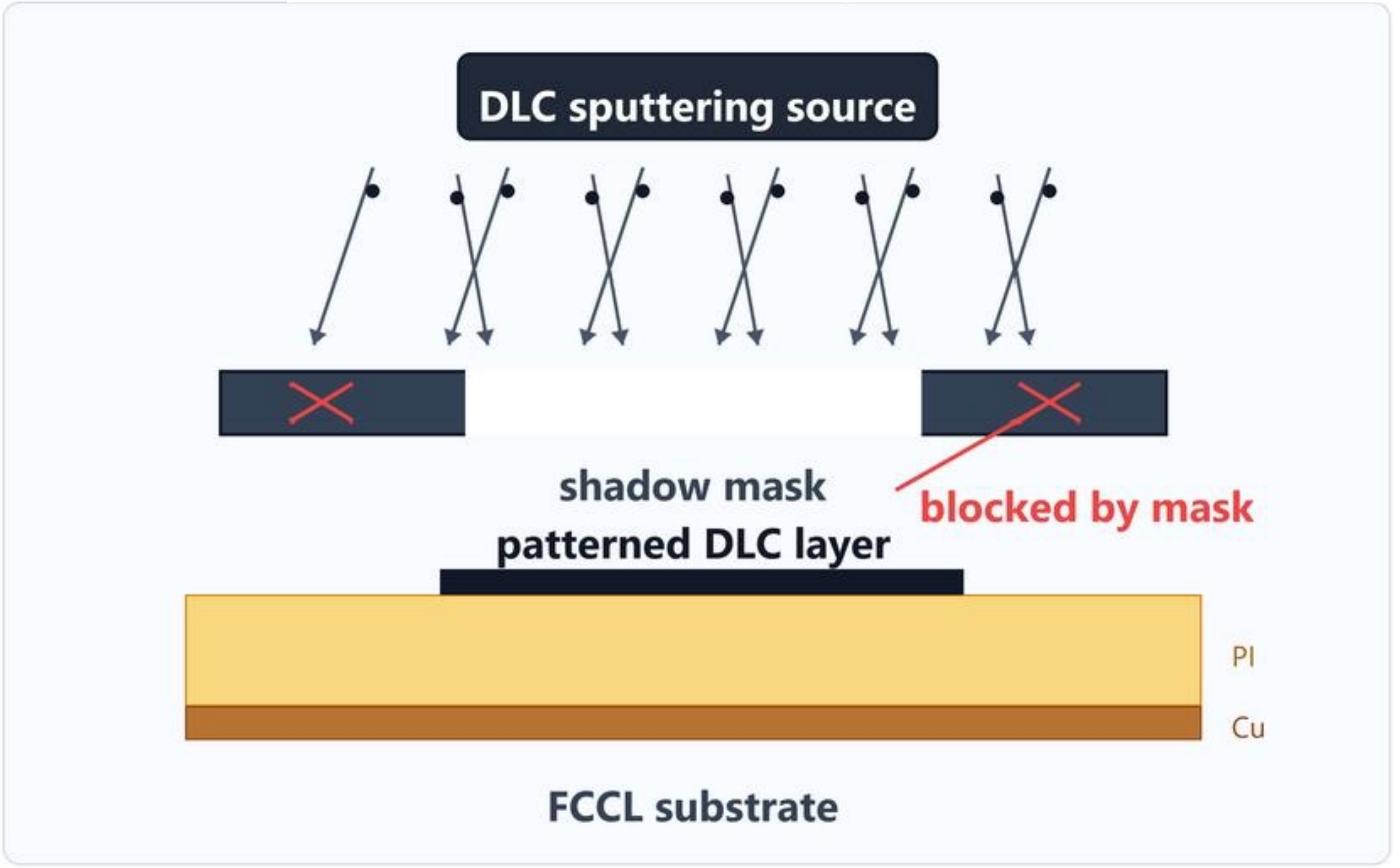
5. R&D Status: DLC-FCCL sputtering & patterning

- Domestic DLC-FCCL trials
  - 25 cm x 25 cm sample produced by J&L
  - confirmed as a good-quality sample by a CERN
- Current status
  - sputtering parameters still under optimization
  - progress faster than initially expected
- DLC patterning
  - CERN MPT uses sanding process
  - shadow-mask sputtering under study as a faster option

	Left	Center	Right
Top	$35.5\ M\Omega/sq$	$27.6\ M\Omega/sq$	$29.1\ M\Omega/sq$
Middle	$37.3\ M\Omega/sq$	$30.0\ M\Omega/sq$	$30.0\ M\Omega/sq$
Bottom	$48.9\ M\Omega/sq$	$45.5\ M\Omega/sq$	$43.6 M\Omega/sq$
	Target range	$20 - 80 M\Omega/sq$	

Sanding @ CERN



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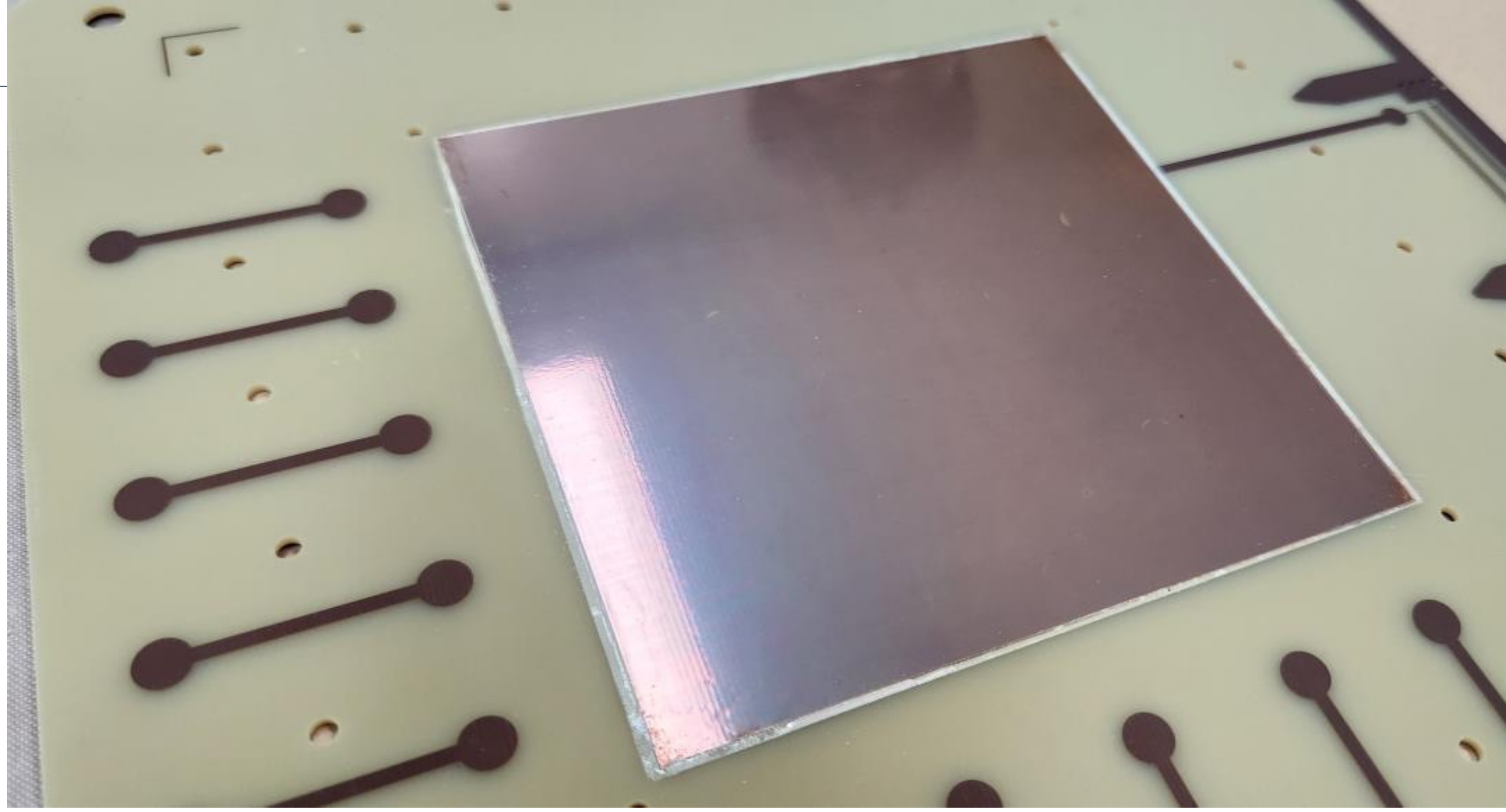
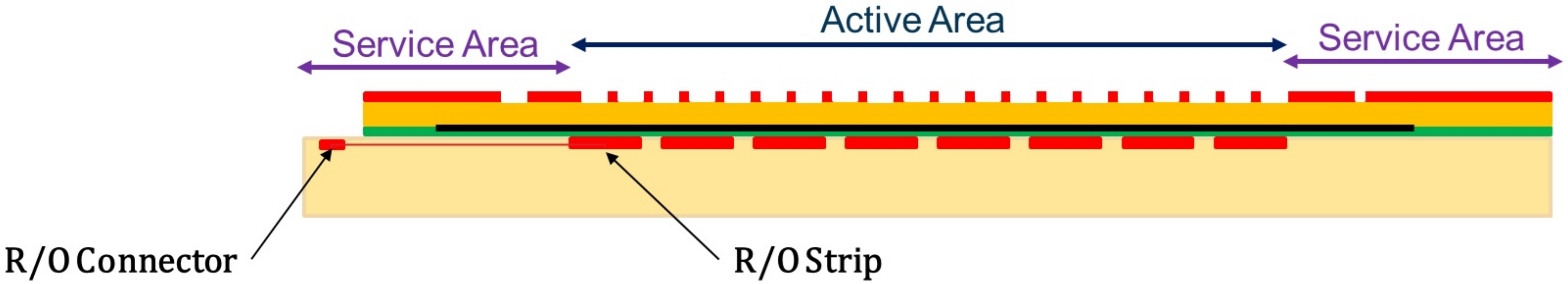
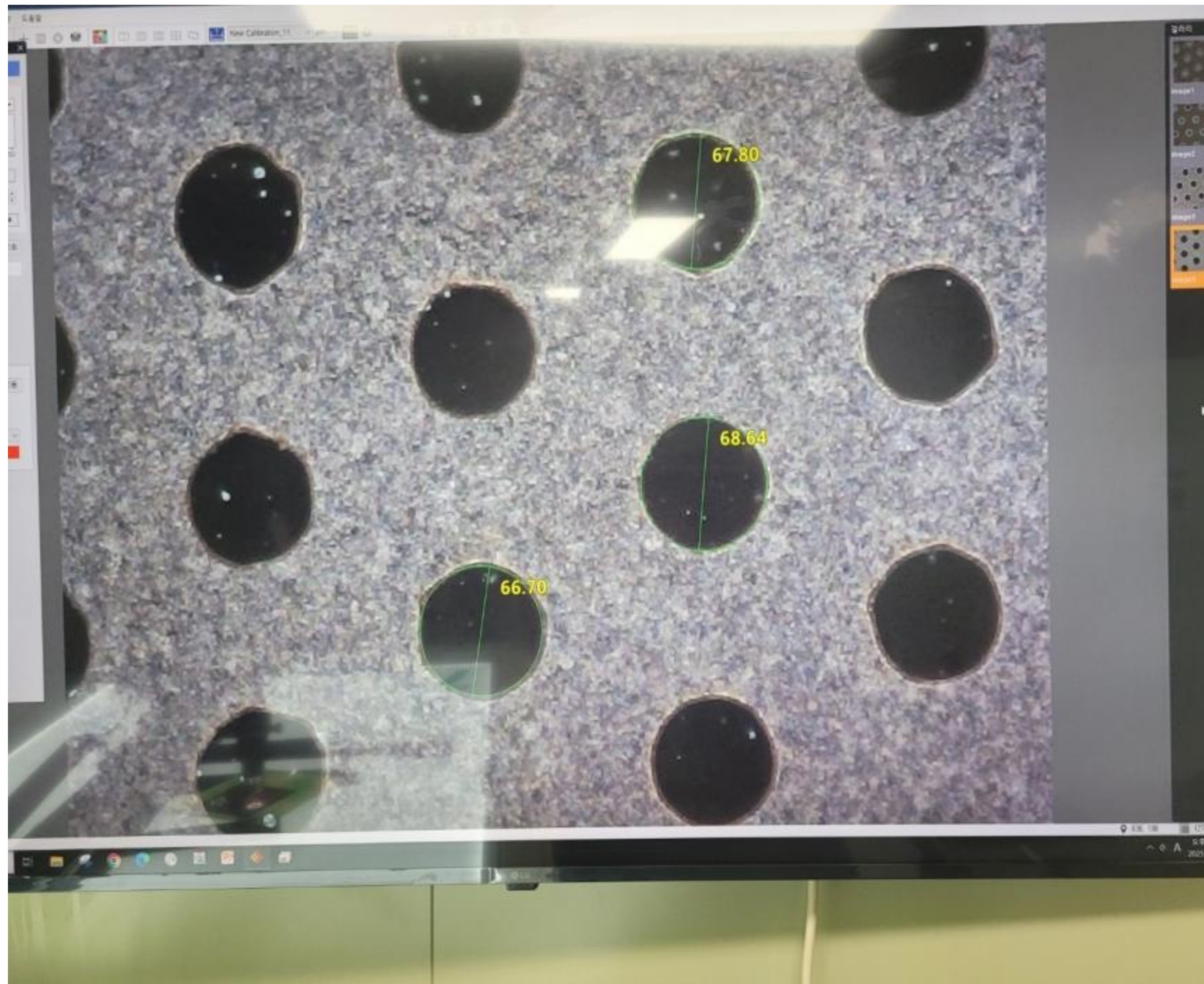
5. R&D Status: Gluing & Cu etching

- DLC-FCCL gluing
  - vacuum hot press of DLC-FCCL and readout PCB
  - lower T/P than standard PCB process
  - suitable resin identified; stable bonding achieved



- Cu etching
  - same process as GEM foil production
  - no major issue observed





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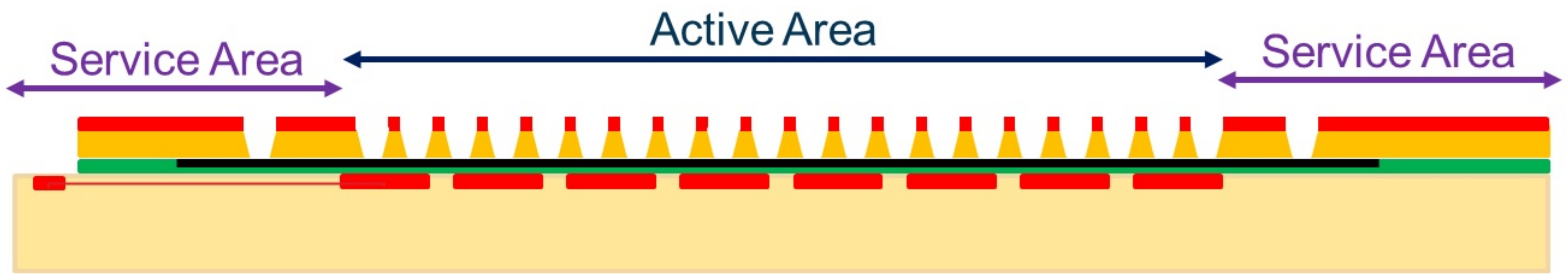
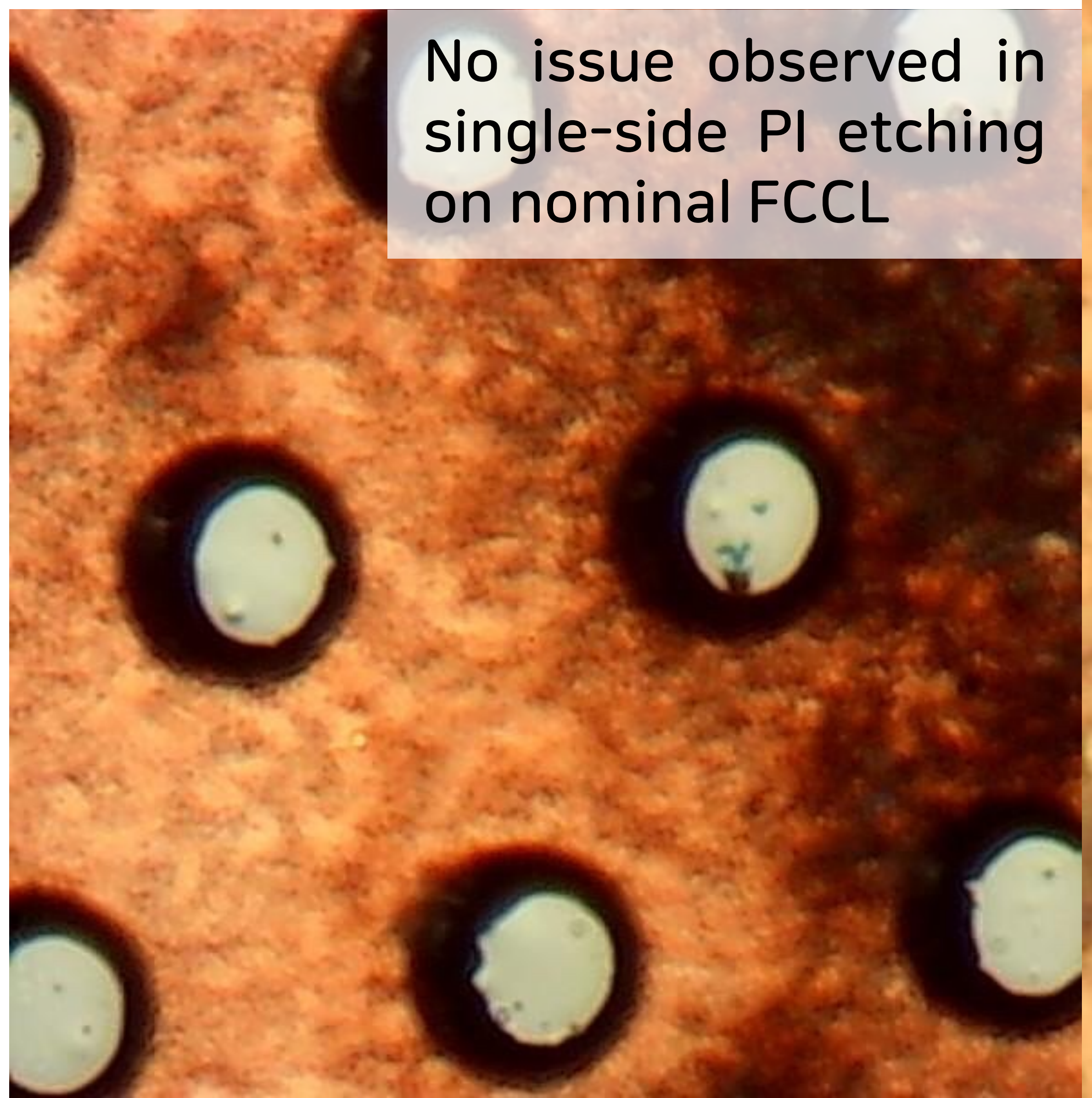
5. R&D Status: PI etching

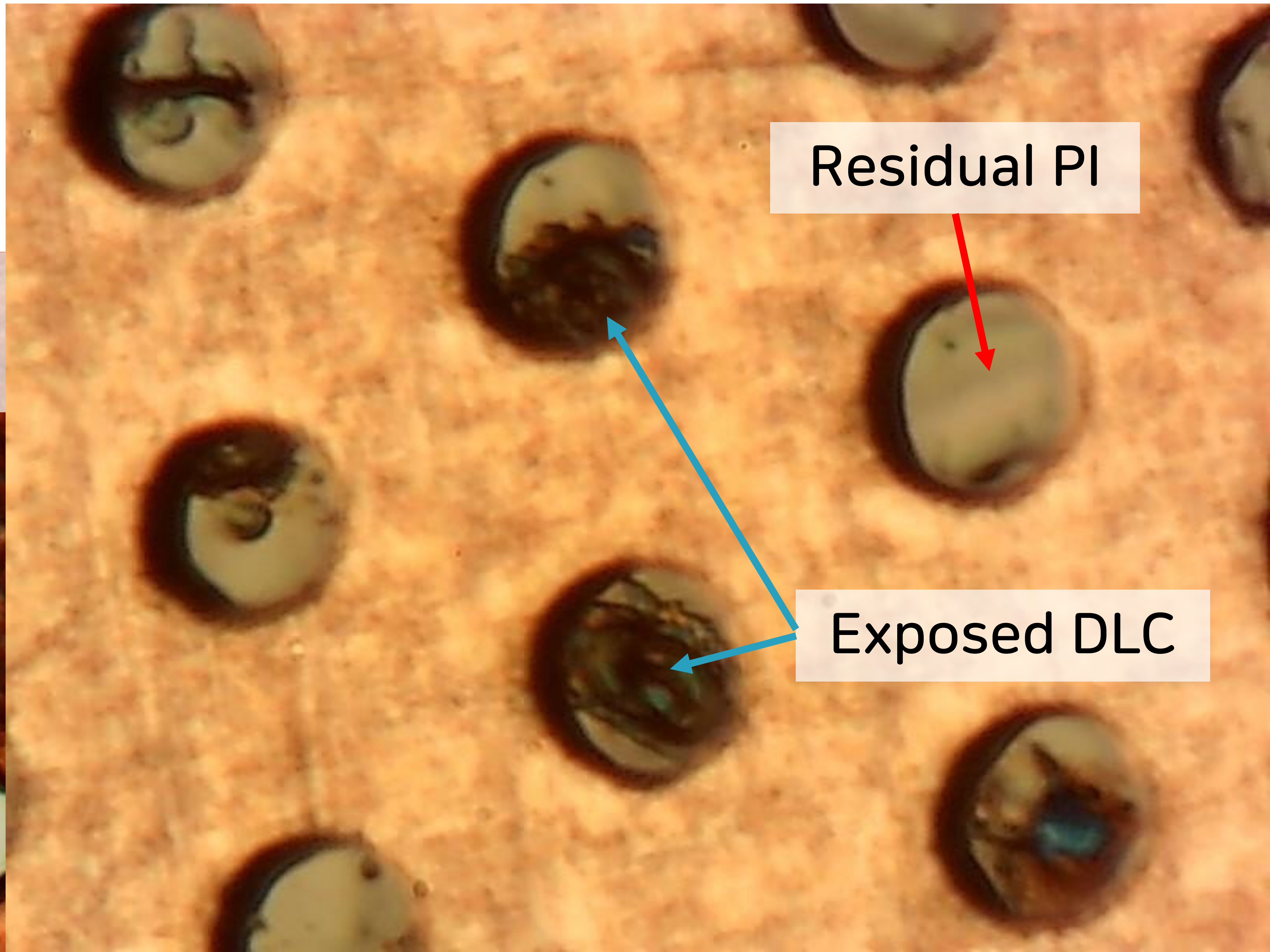


- PI etching remains under optimization
  - residual PI tends to remain near the DLC interface

- Possible origin
  - modified PI properties during gluing
  - DLC/PI interface affected by sputtering conditions

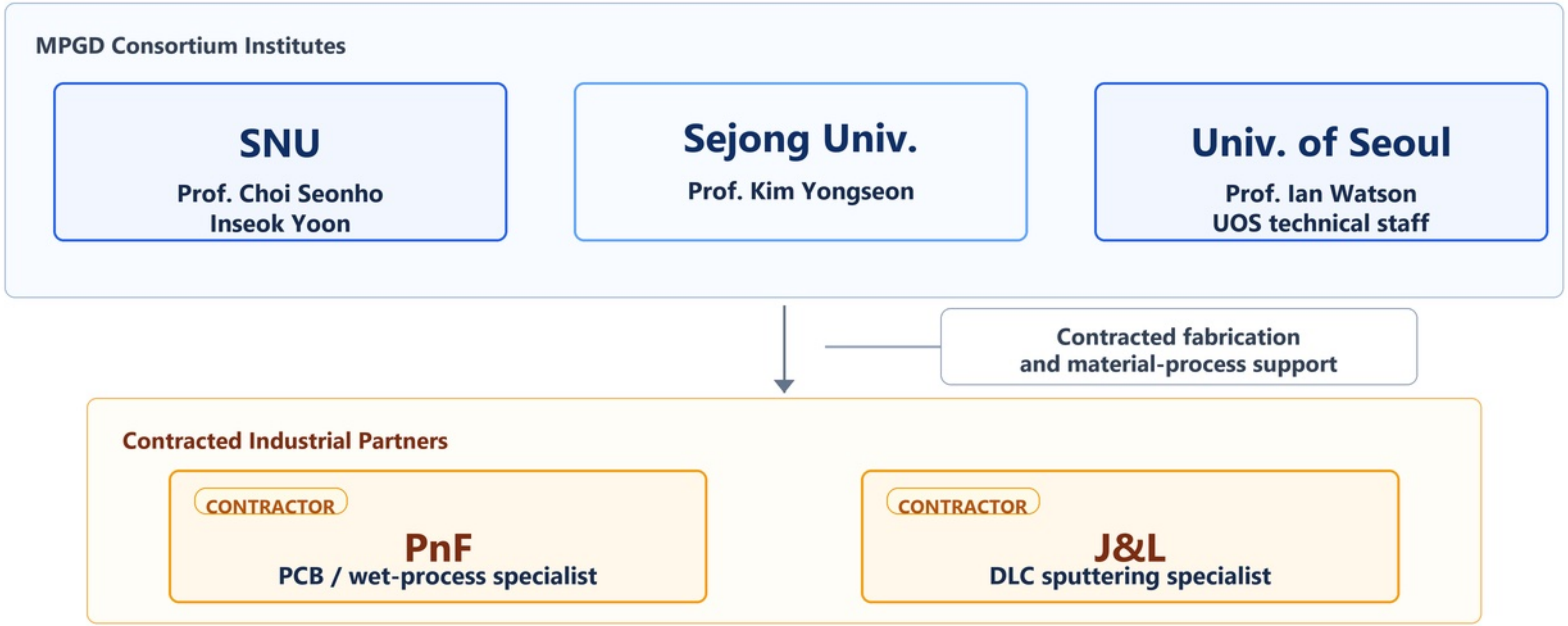
- Ongoing R&D
  - etching chemistry and process parameters
  - CERN MPT technical advice ongoing





4. Korean MPGD Consortium: Structure

GEM/microRWELL production, with participation in assembly, QC, and integration



- 6-years / 3,584 M KRW national project
  - schedule and budget adjustable through coordination

- Cost-effective contribution path
  - KCMS GEM infrastructure and personnel redirected to ePIC
  - established production and QC experience

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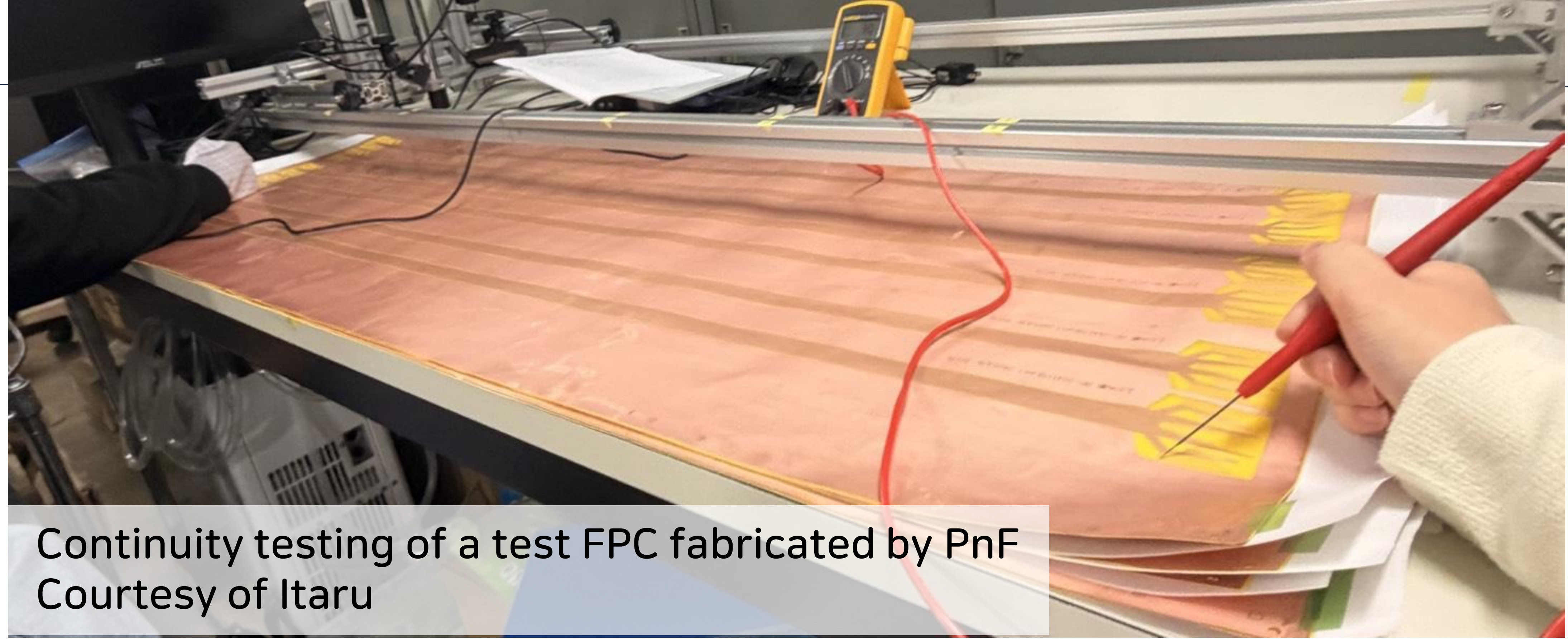
7. Additional Interest: BTOF Signal FPC


Continuity testing of a test FPC fabricated by PnF
Courtesy of Itaru

- Technical basis from KCMS GEM production
  - fine-patterning on large-area FCCL
  - directly relevant to BTOF signal FPC production

- Feasibility test
  - fine-pitch long FPC test production completed
  - no major technical issue observed

- Possible Korean support if needed
  - interface with Korean industrial partners
  - Equipment/infrastructure support if difficult for RIKEN to execute administratively
  - To facilitate smooth production progress

- Sincere gratitude to the Japanese BToF group for proposing this collaboration opportunity

Summary

- Stable Korean framework for ePIC detector contribution is now in place
  - ICC-based coordination and national project structure

- Korean MPGD consortium formed for ePIC ECT contribution
  - GEM/μRWELL production
  - participation in assembly, QC, and integration

- Proven MPGD production capability
  - CMS GEM production completed in Korea
  - infrastructure and personnel redirected to ePIC

- R&D and validation path established
  - DLC-FCCL and μRWELL PCB process R&D ongoing
  - validation against CERN MPT reference before ECT production use

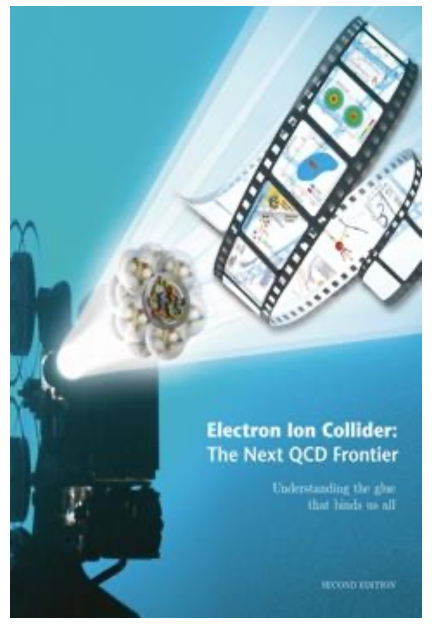
Issues already foreseen

- Budget shortfalls
    - Current budget assumed partial support from KCMS for GEM facilities
    - At least 20% increase (additional 700 MKRW) to cover the deficit
- Schedule delay of EIC
    - Installation, validation etc will happen later than the current budget period.
    - Either additional budget or modifications of the total period and annual budget profile

More important

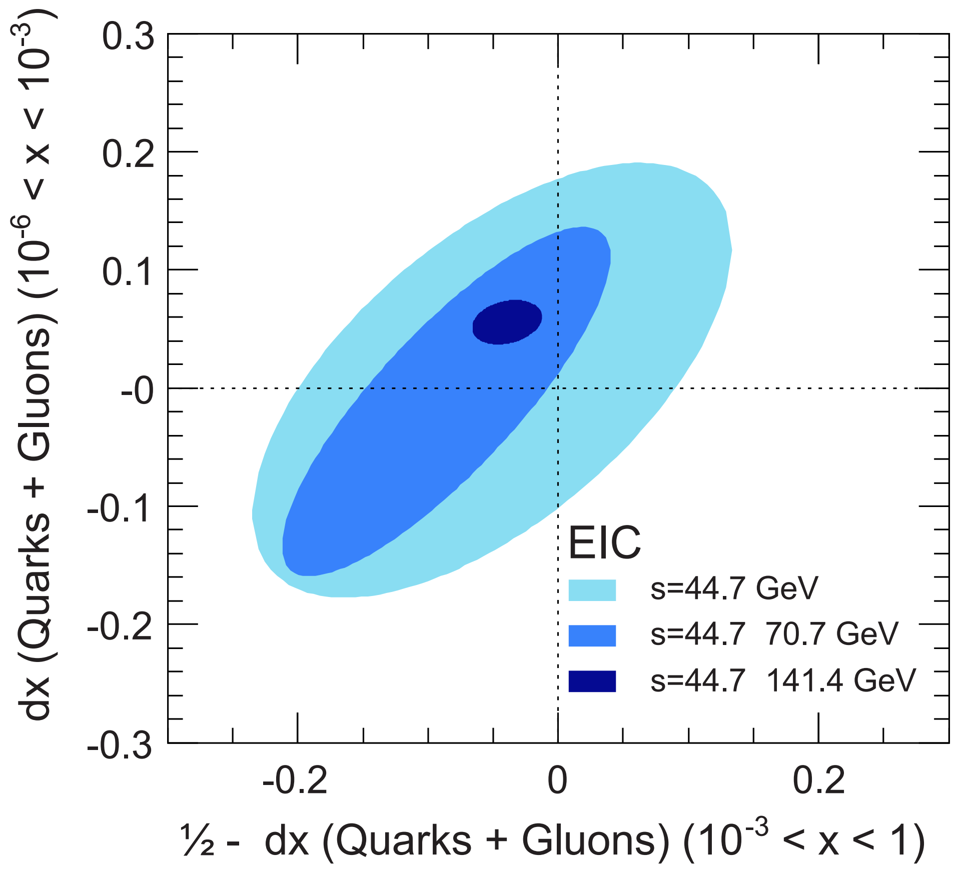
- Necessary to establish sizable workforce for physics programs
  - Current budget is limited only to the construction of the detector
  - In analogy, an entry fee to EIC
- Harvesting returns from this small investment
  - Continuous development of new physics program
    - Collaboration with theory group is essential
  - Need to increase the pool of hadron physicists
    - Especially for Jefferson Lab”ish” physics
      - DIS, SIDIS, DVCS and “conventional” nuclear physics with e+A scattering

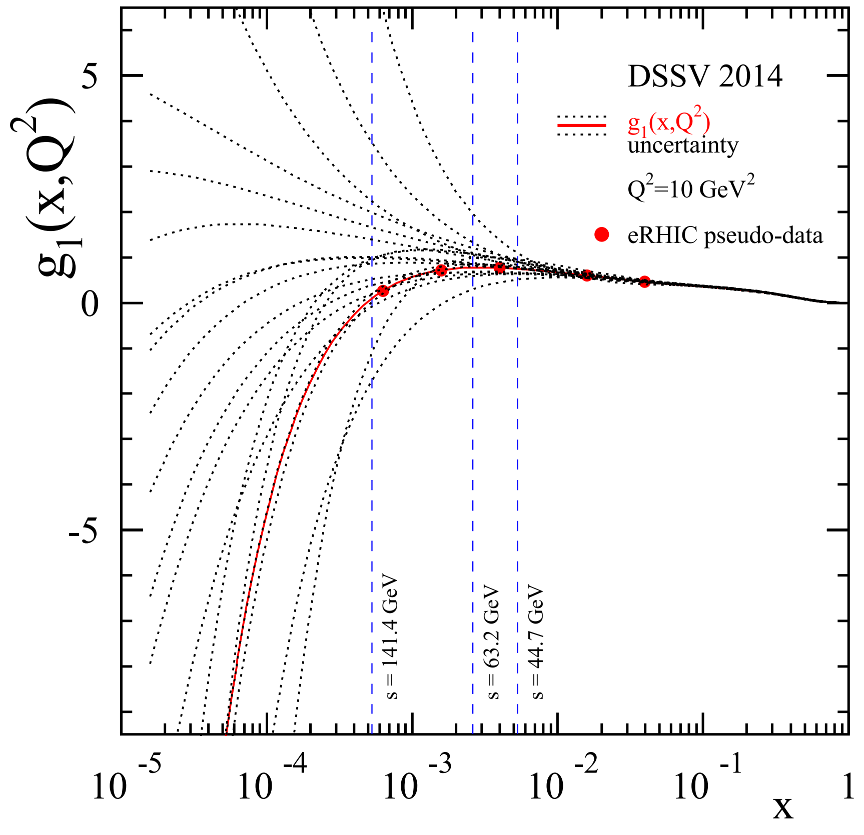
EIC White Paper selected highlights

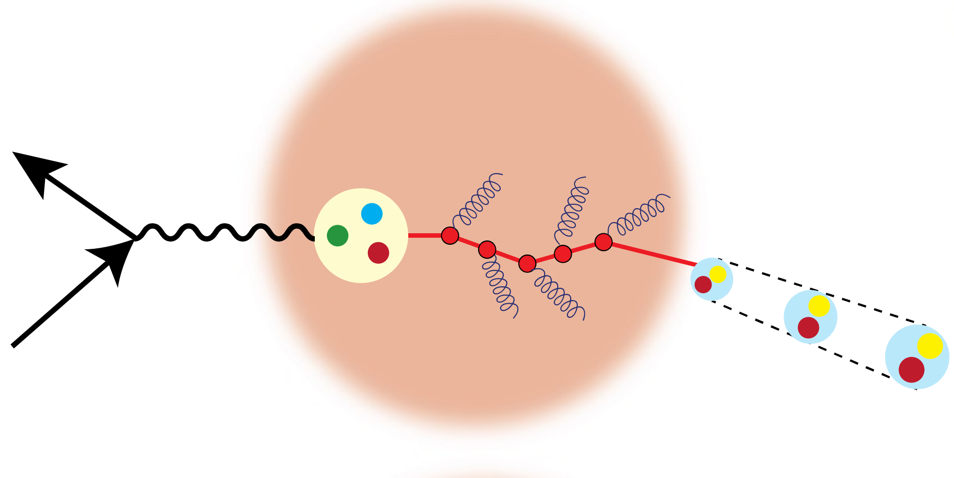


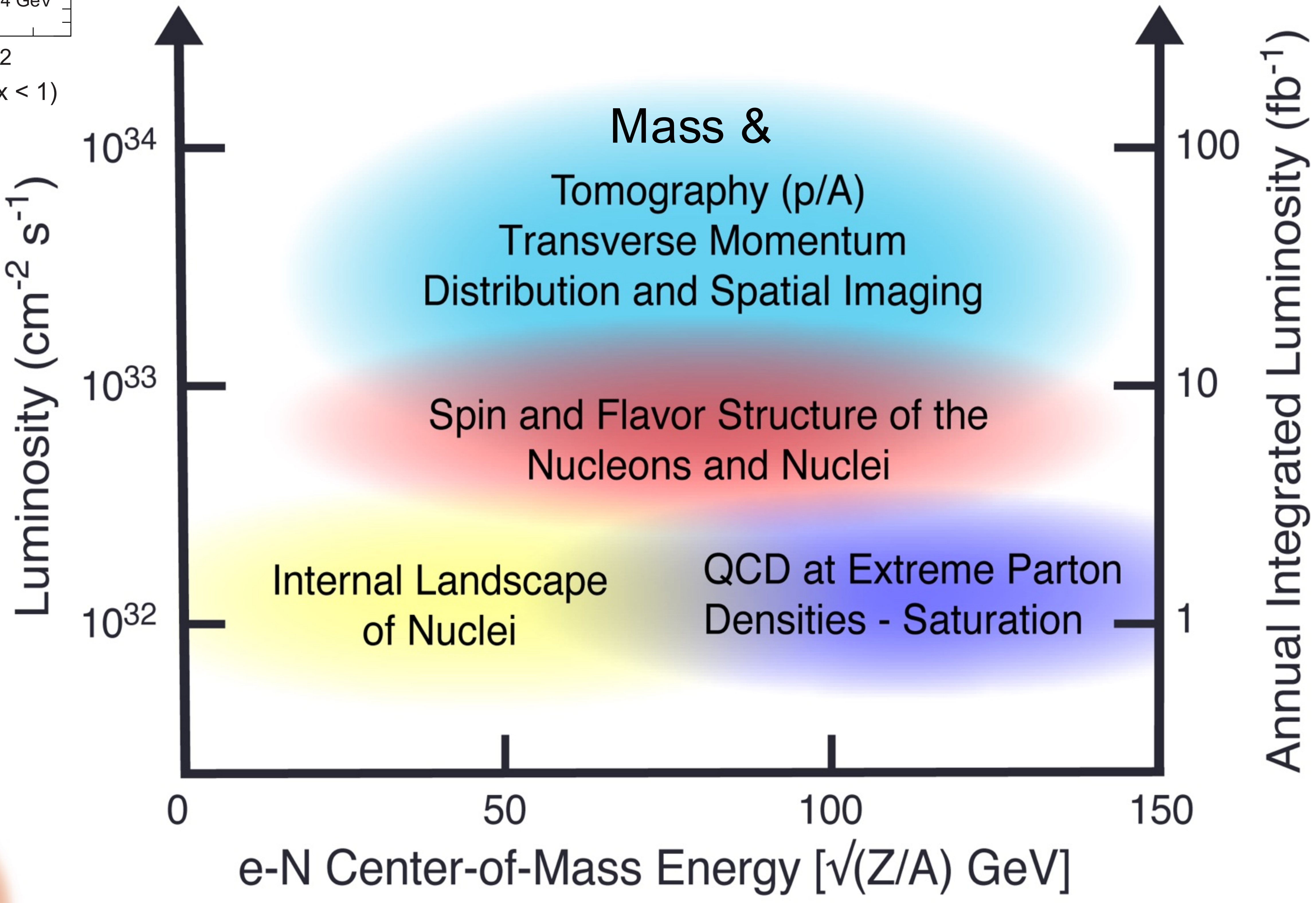
A. Accardi et al.
https://doi.org/10.48550/arXiv.1212.1701
A. Deshpande, Z. Meziani & J. Qiu Editors

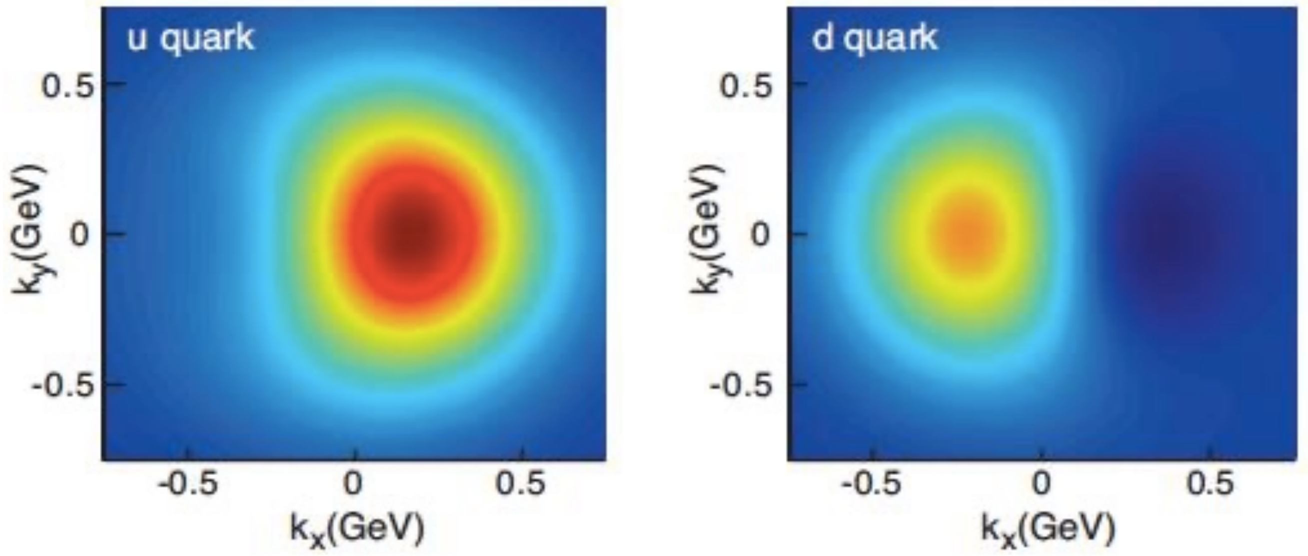
Longitudinal Spin contribution from quark and gluons

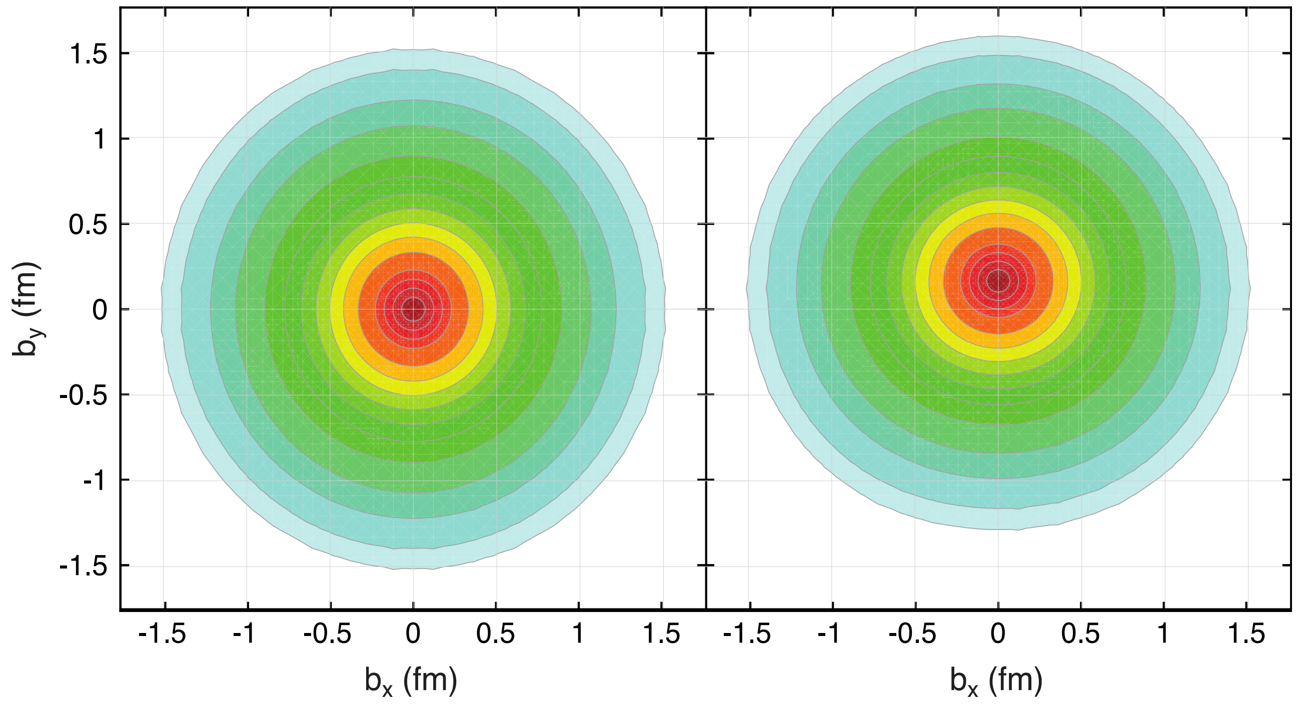


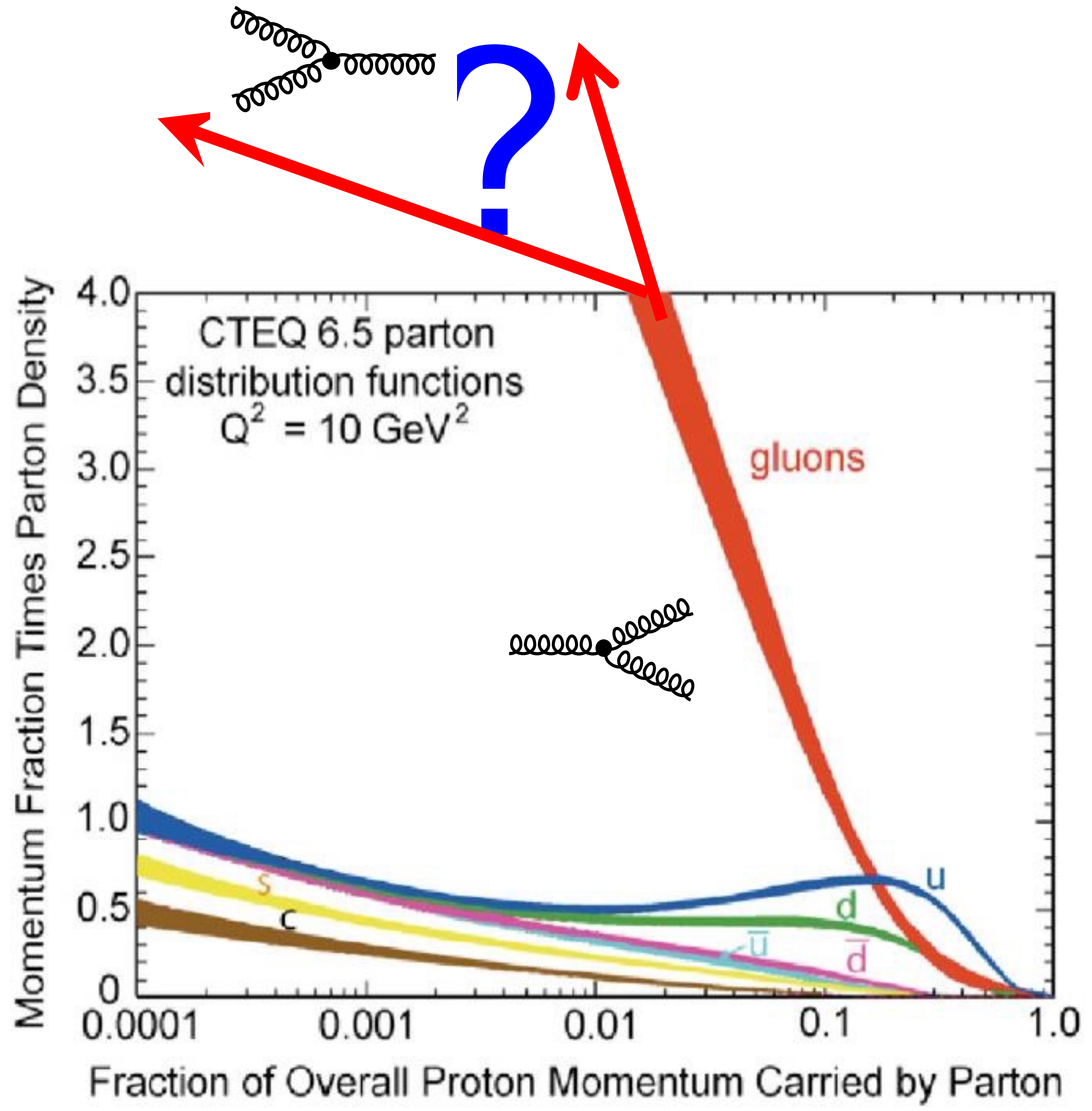












A. Deshpande, INPC 2025

Thank you