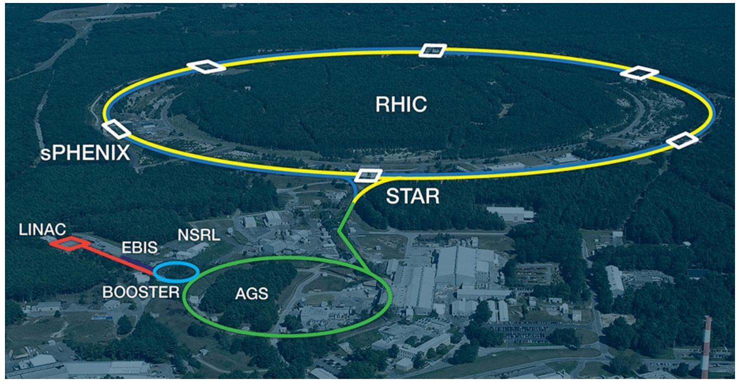
Concept of a Second Detector for the EIC

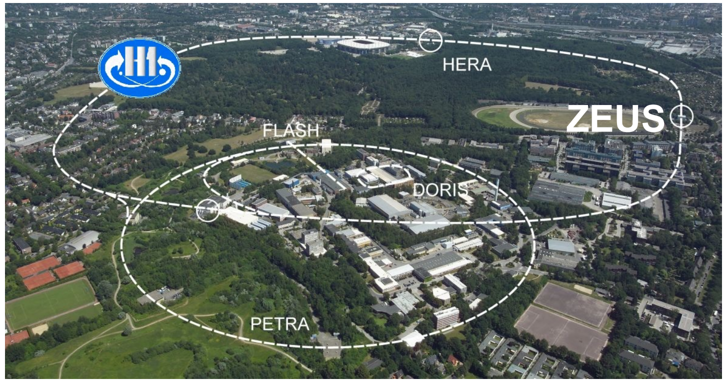
A Summary Report [arXiv:2602.04636]

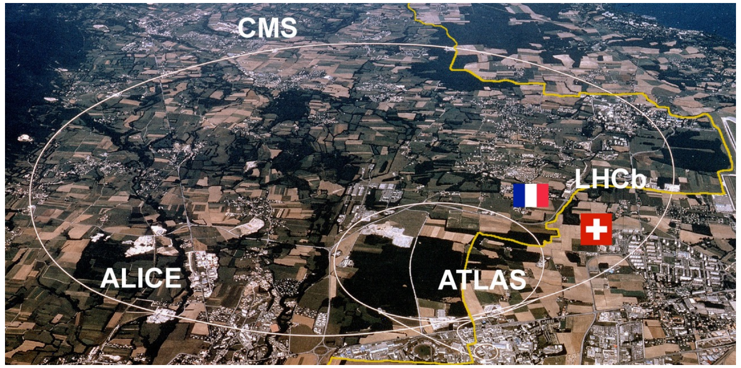
Cheuk-Ping Wong

07-13-2026

The Tales of Two Detectors







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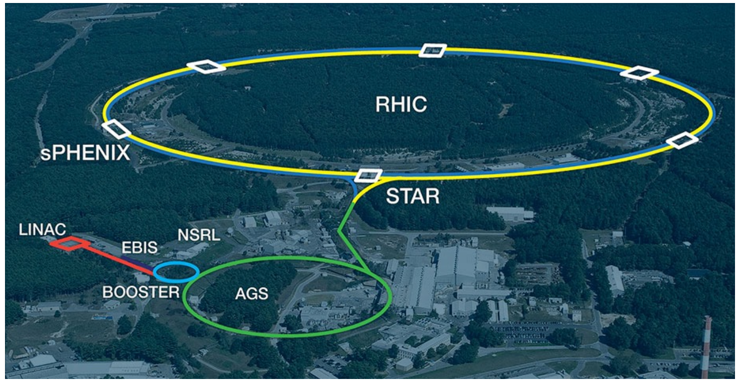
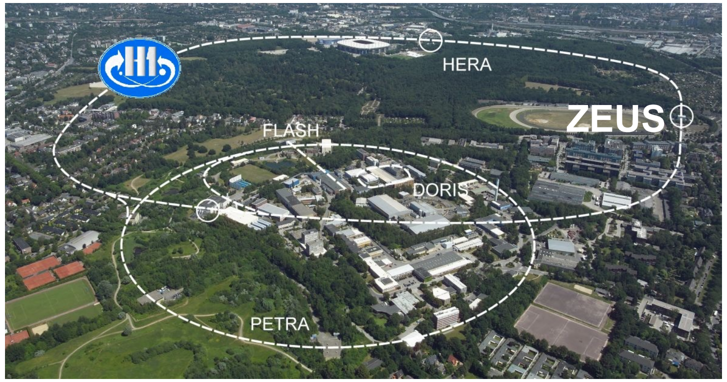
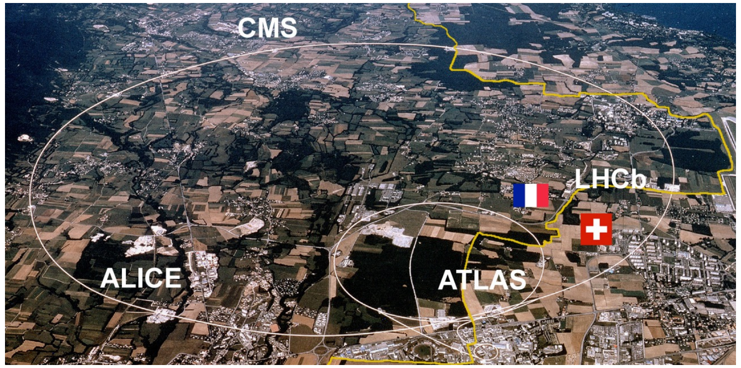
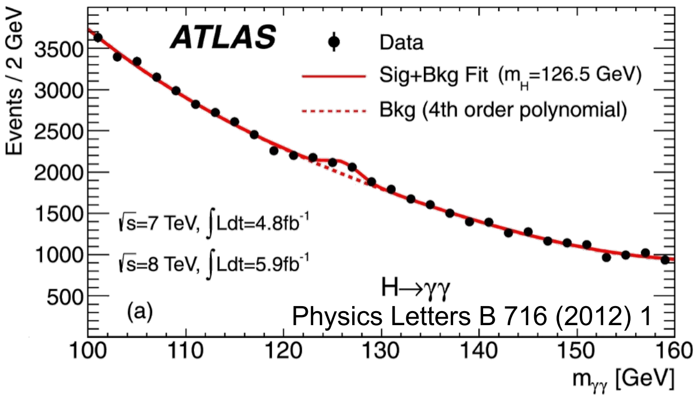


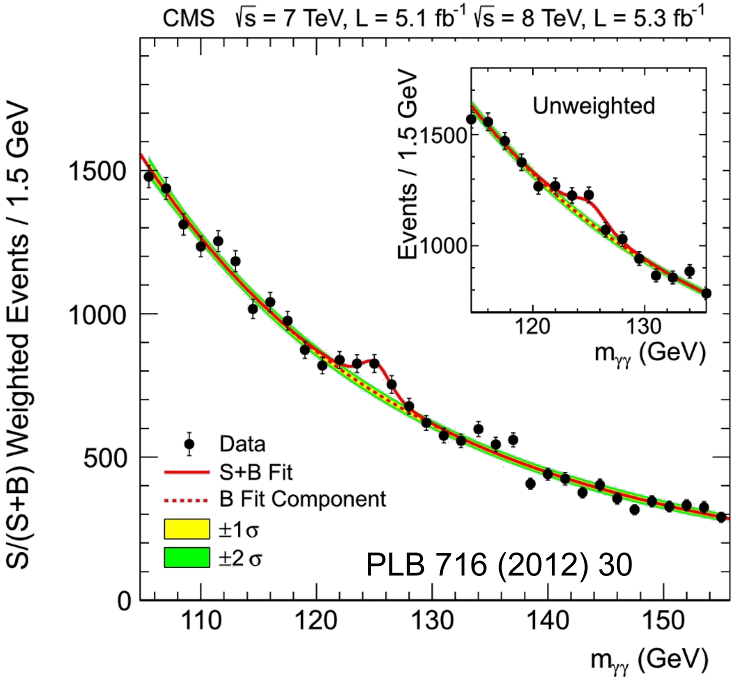




- Cross-checking → validate discoveries

Discovery of Higgs





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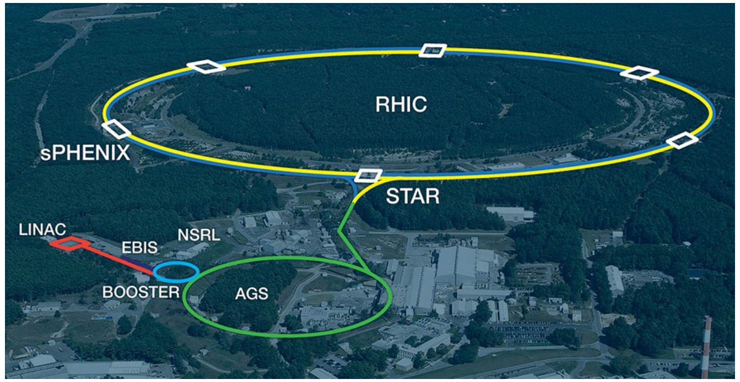

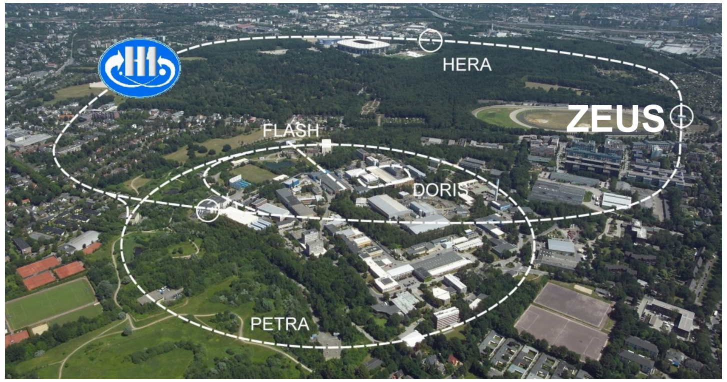

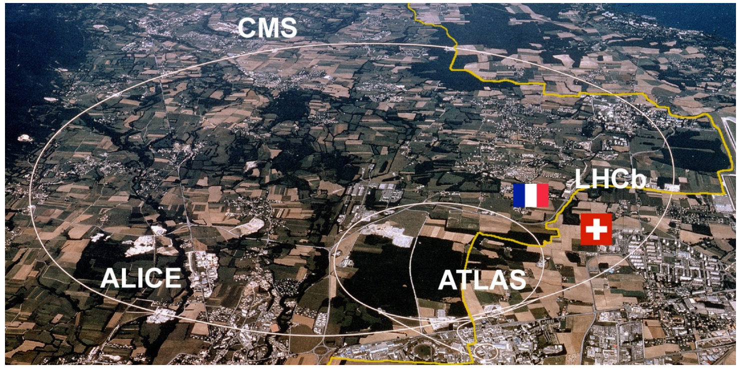

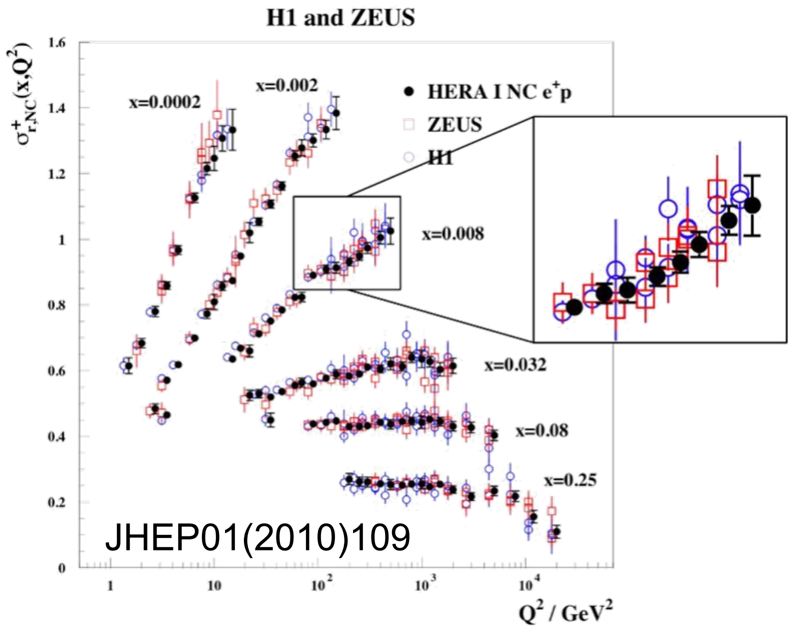

- Cross-checking → validate discoveries
- Cross Calibration → precision beyond $\sqrt{2}$ statistics

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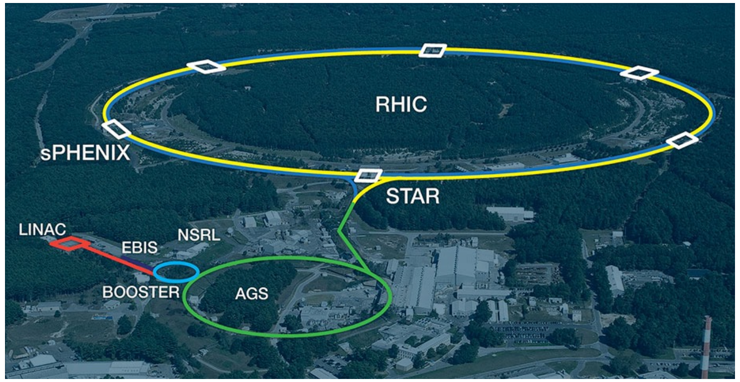
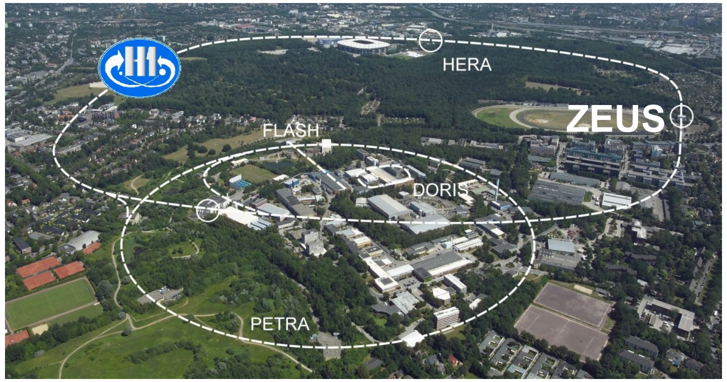
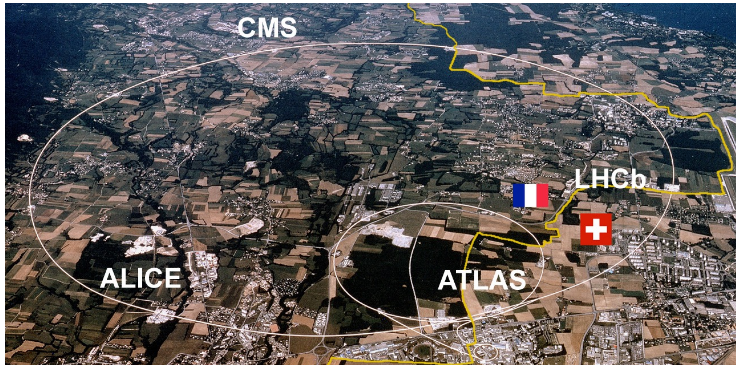
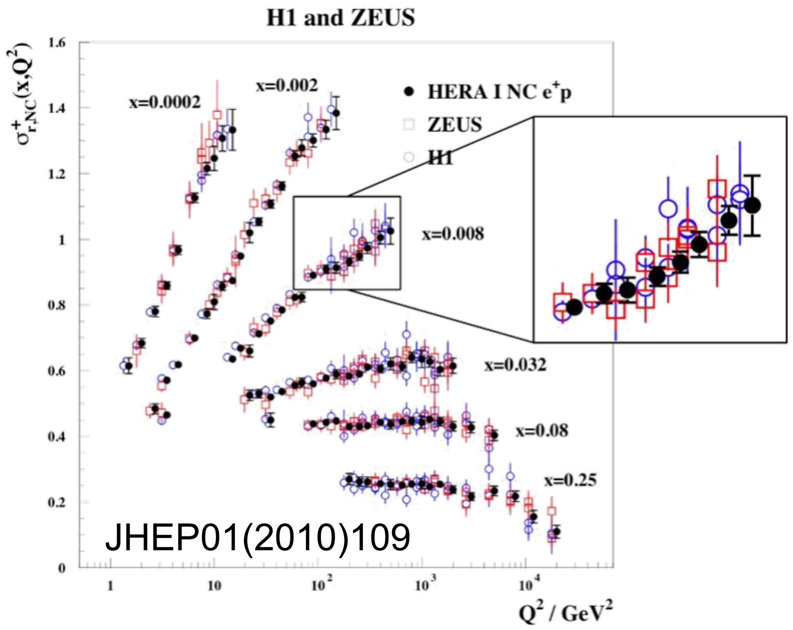


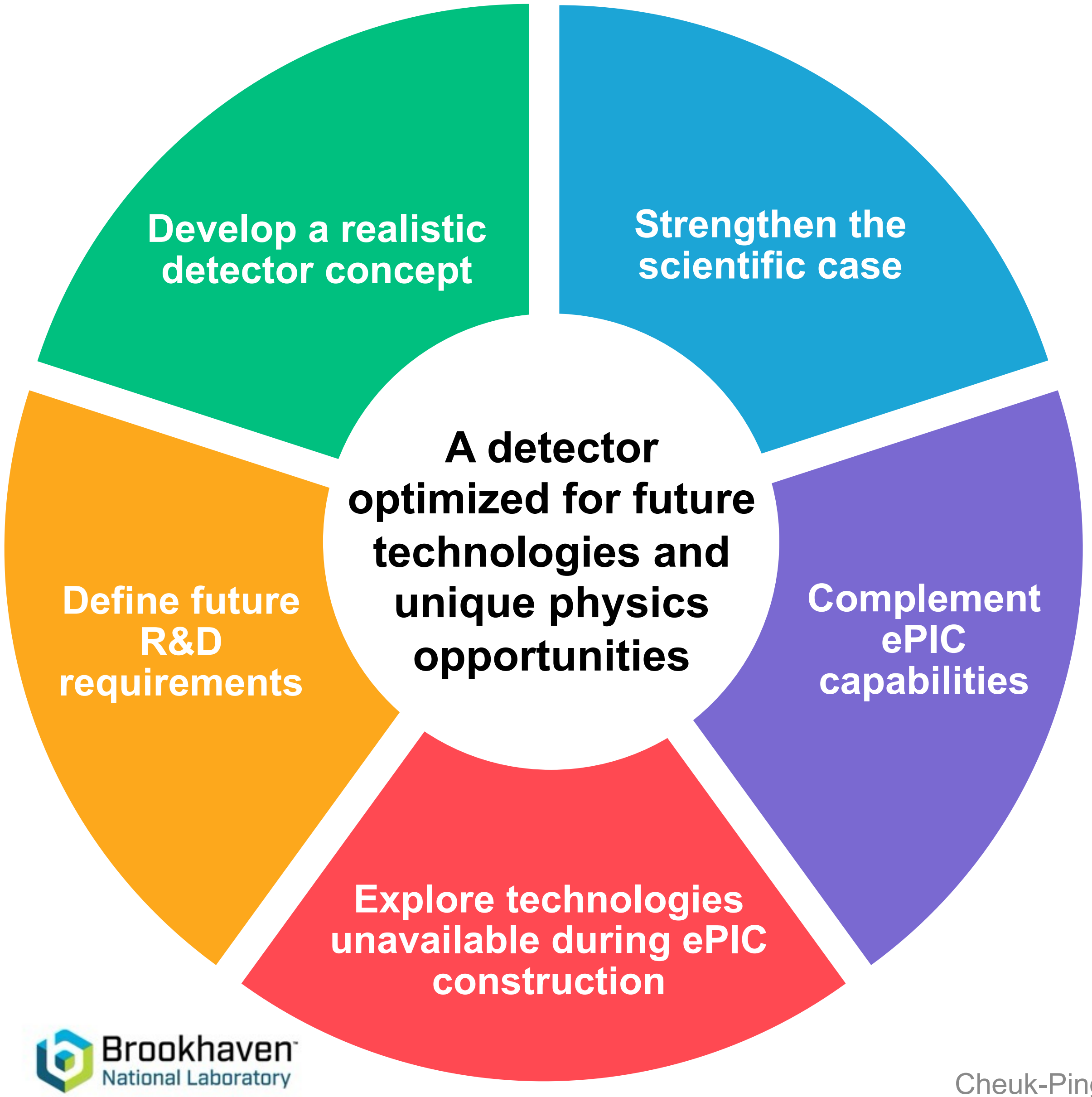






- Cross-checking → validate discoveries
- Cross Calibration → precision beyond $\sqrt{2}$ statistics
- Different physics focuses
- Technology Redundancy

Close-Out Paper Objectives



Second detector team at BNL

- Jihee Kim
- Cheuk-Ping Wong
- Thomas Ullrich
- Zhoudunmin Tu
- Brian Page,
- Elke Aschenauer
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- Oleg Kjeld Eyser
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- Evgeny Shulga
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Advanced DIRC	Grzegorz Kalicy
SciGlass	Tanja Horn
KLM	Anselm G. Vossen
Mini DIRC	Charles Hyde

Content

1. Potential facility upgrade
2. Secondary beam focus at IR8
3. Lessons learned at ePIC
4. Second Detector Concepts
   A. Tracking
   B. PID
   C. Calorimetry
5. Critical R&D
6. Synergies

Potential Facility Upgrade

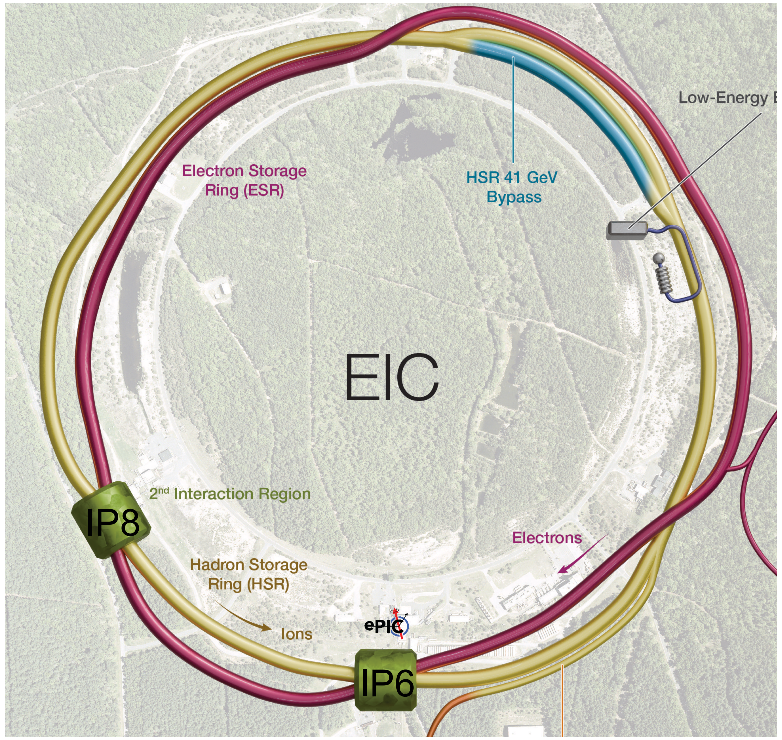
Potential facility upgrade	New scientific capability	Physics
Double-polarized eD collisions	Transversity distribution	Role of gluons in nuclear binding
Positron beams	Precision comparison between e^-p and e^+p	Quark axial, vector couplings
Real photon beams	Hadron spectroscopy	Complementary to LHCb and Belle II
Fixed-target [arXiv:2603.00265]	large-x physics	Complementary to JLab, STAR, LHCb and ALICE

- Ensure the second detector enables unique physics opportunities associated with potential facility upgrades
- Engage theorists to define the highest-priority measurements
- Translate these measurement goals into detector performance requirements.

Comparison between IP6 and IP8

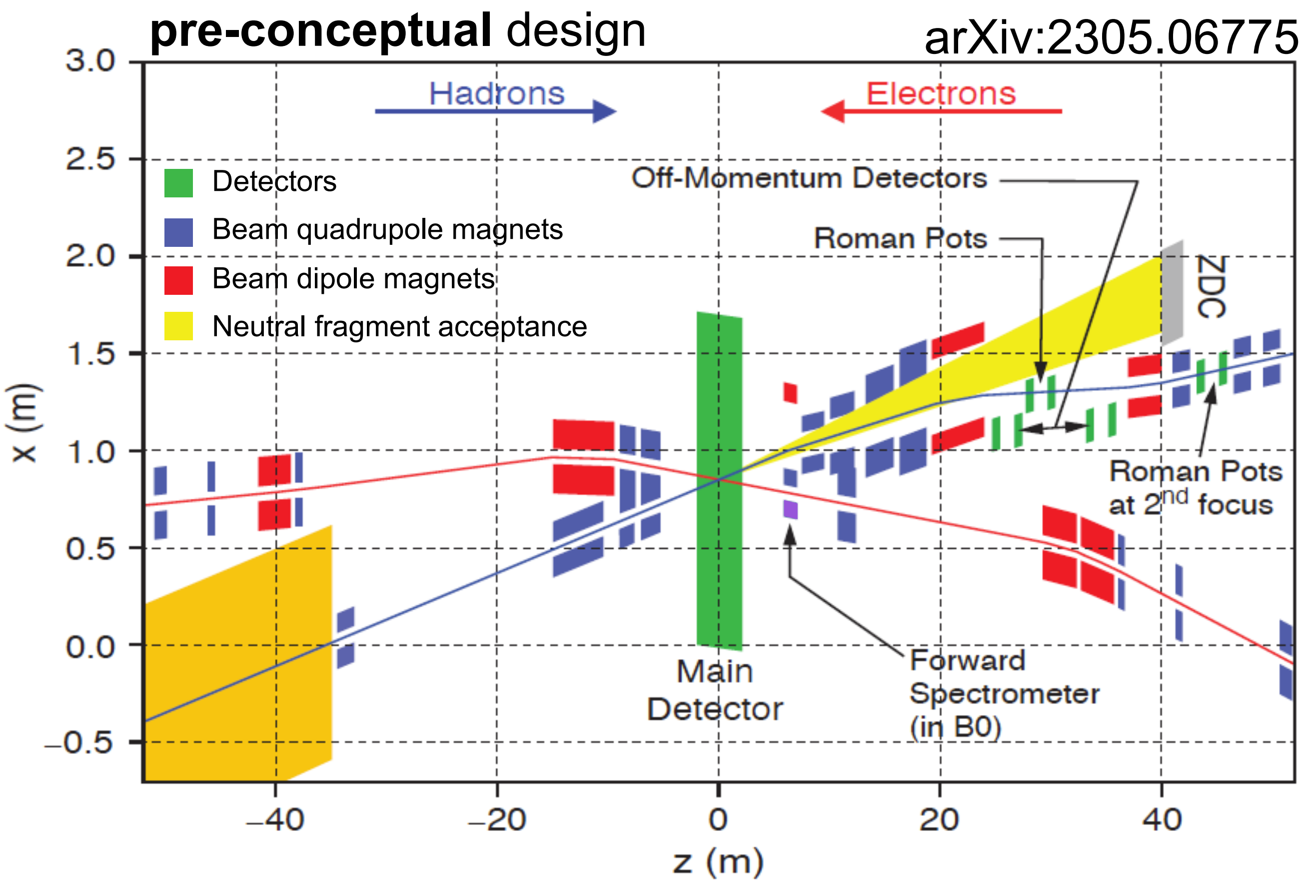
These studies were conducted before the decision to locate the second detector at IP12

	IP6	IP8
Globally	Same accelerator highlights and challenges	
Geometry	Ring inside to outside	Ring outside to inside
	25 mrad	**35 mrad** → more difficult to get acceptance at high η
	Different blind spots	
	Different far-forward detector acceptances	
Luminosity	Same luminosity capabilities at both IRs, but luminosity will be shared same center-of-mass energy coverage	
IR-Design	$0.2 < p_T < 1.3$ GeV	**2nd Focus** → improved low p_T acceptance at far-forward Roman Pots $x_L \sim 1$ → $p_T \sim 0$ (Further study needed for the feasibility of the IR magnets)



Enhanced low P_T acceptance, DVCS on nuclei, light ion tagging, diffraction, improved gluon imaging by detection of (A-1) nuclei

Secondary Focus Concept



What is a Secondary Focus?
Using beam optics to turn a momentum offset to a position offset at ~45 m downstream

Benefits

- Detect particles scattered at tiny angles
- Access low transverse momentum fragments
- Improved proton and ion tagging
- Better coherent/incoherent separation

Physics Impact
Critical for nuclear imaging and diffraction studies

Fragment Tagging Performance

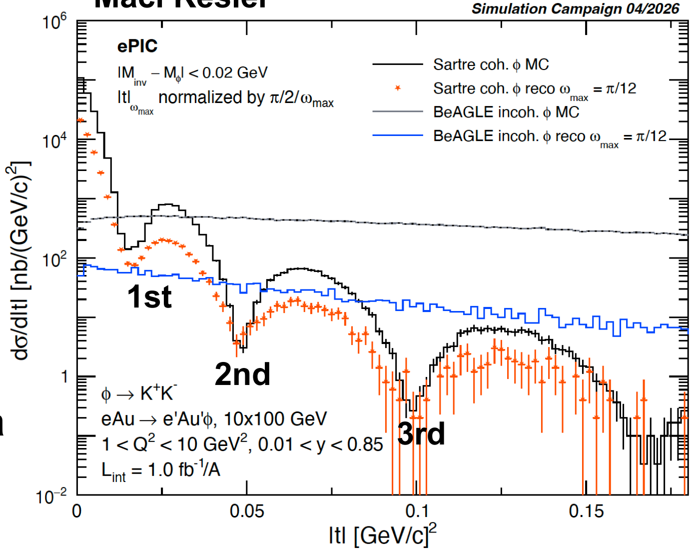
IR-8 Advantage
Secondary-focus Roman Pots can approach the beam more closely

Results
- Strong suppression of incoherent events than IR6
- Tagging light ion of coherent at a wider kinematic range than IR6 [PRD 113, 032018 (2026)]
- Potential observation of multiple diffractive minima →Improves 3D imaging of nuclei through diffractive measurements

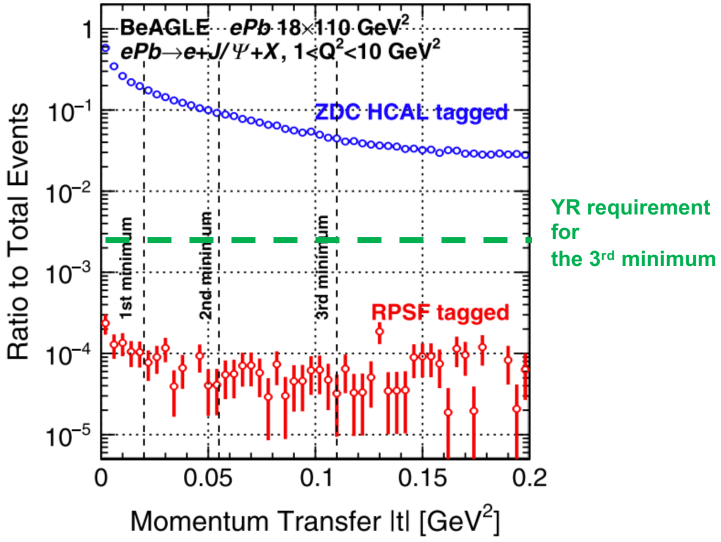
Unique Opportunities
- Detect a broad spectrum of nuclear fragments
- Study nuclear breakup mechanisms
- Search for rare isotopes
- Measure Lorentz-boosted gamma decays

Potential Impact
New insights into nuclear structure and fragmentation models

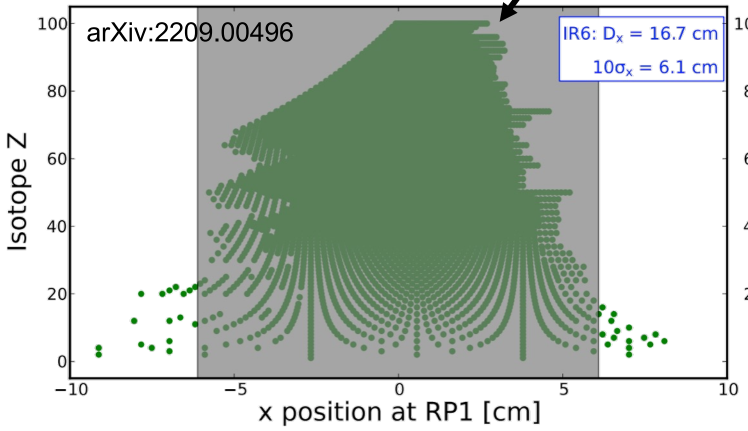
Maci Kesler

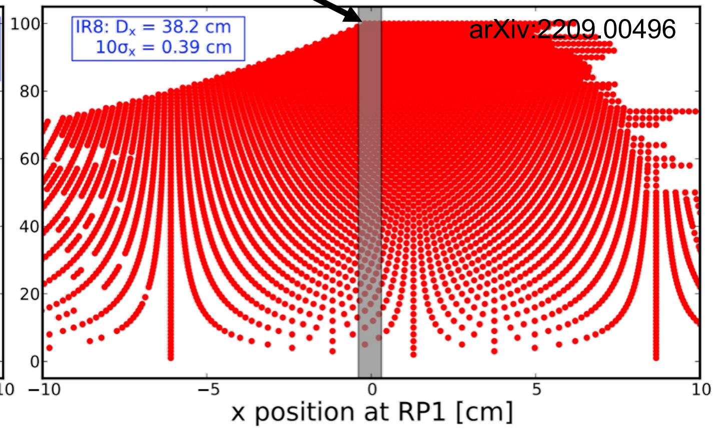


Jihee Kim, PRD 111, 072013 (2025)
fraction of remaining Incoh. events with tagging at IR8



Within beam envelop →unable to detect





Lessons Learned from ePIC

Area	Concerns	Suggestions
Tracking	Silicon-heavy • Limited hit redundancy • 2μs integration is susceptible to background • High cost Backward tracking performance is limited by space constraints	• Hybrid tracking system (e.g. silicon vertex + gaseous tracking) • Hybrid magnet: Standard solenoid + canted coils at both end
dRICH	complexity	Decouple into an aerogel RICH and a gas RICH
Timing requirements	Critical for t_0, tracking, PID & calorimetry	• MCP-PMT • Monolithic LGAD • Fast-timing MAPS
B0 detector	Obstruction from the beam	• Smaller-bore dipole magnet • Multilayer tracking system integrated with the central detector
Detector services integration	Limited space	Involve engineers earlier in the detector design process
Software	Lack flexibility for fast simulation studies	Dual-tier simulations framework: DD4hep & Delphes

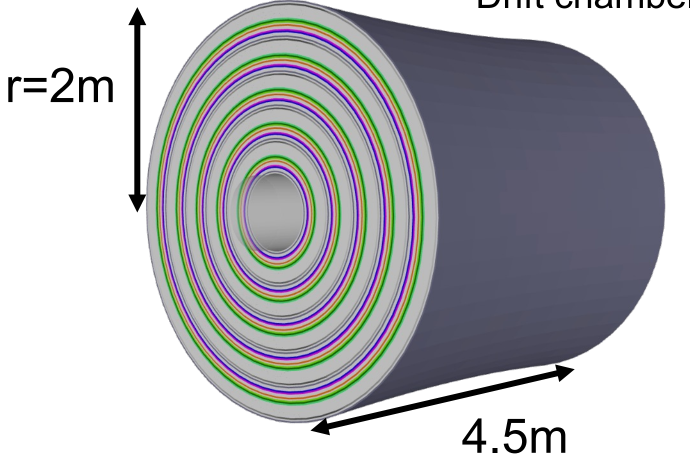
Tracking Strategy

Alternative Approach -- hybrid tracking system:

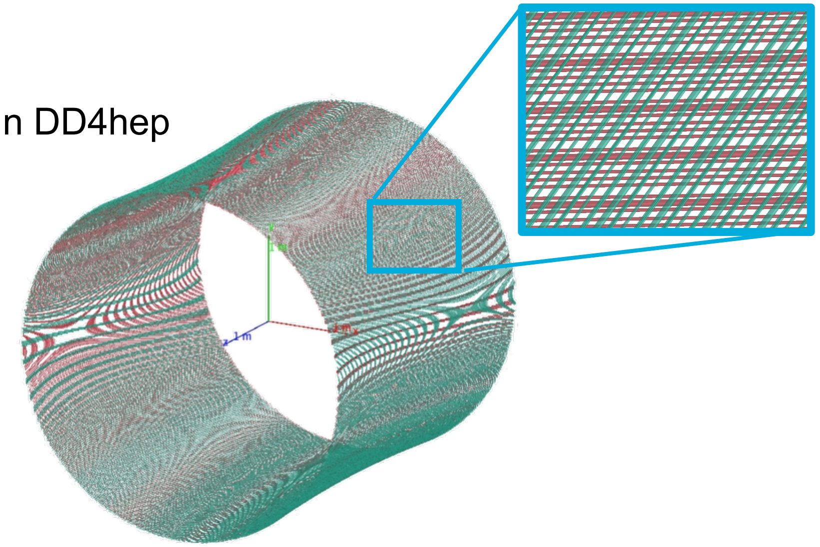
- Inner layers: silicon precision vertex/tracking detector
- Outer layer: gaseous tracker (TPC or drift chamber), scintillating fiber detectors

Advantages

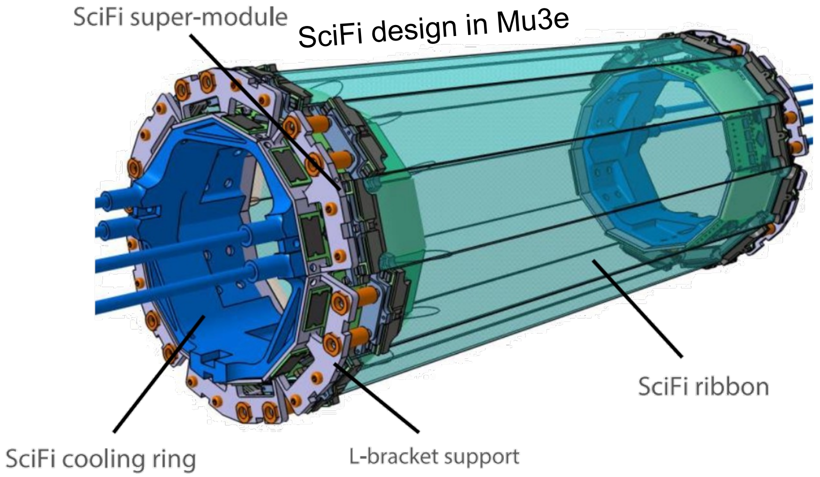
- Increased number of tracking points → improve hit redundancy
- Additional particle identification capability through dE/dx or cluster counting measurements



Drift chamber in DD4hep



SciFi design in Mu3e

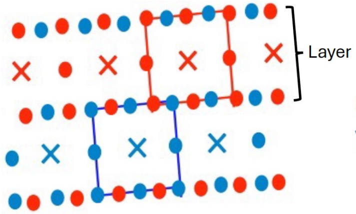


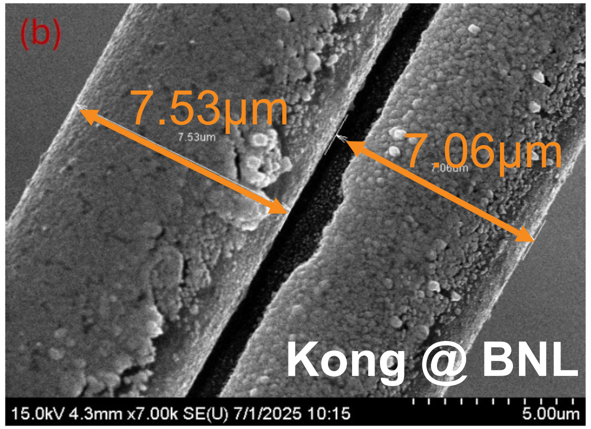
https://indico.fnal.gov/event/63406/contributions/297395/attachments/181880/249631/Mu3eTalk_RobertMihaiAmarinei_v2.pdf

Advanced Tracking Technologies

Drift Chamber (FCC-ee)

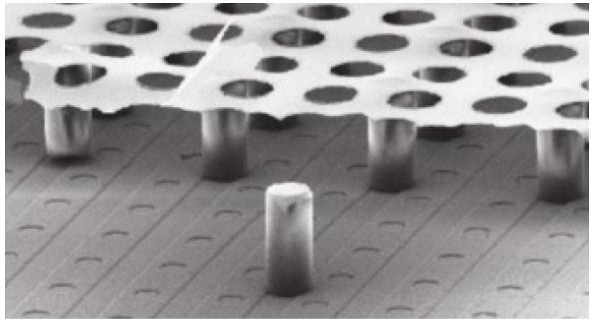
- Low material budget
  - Advanced wiring and cooling techniques
  - Lightweight gas mixture
  - Alternating wire orientations
- High field-to-sense wires ratio
- R&D at BNL on lightweight and highly conductive carbon-fiber wires with thin metallic coatings





GridPix

- Signal generation from only a few primary electrons
- Excellent spatial resolution 55x55μm^2
- TimePix3 timing resolution: 1.56ns



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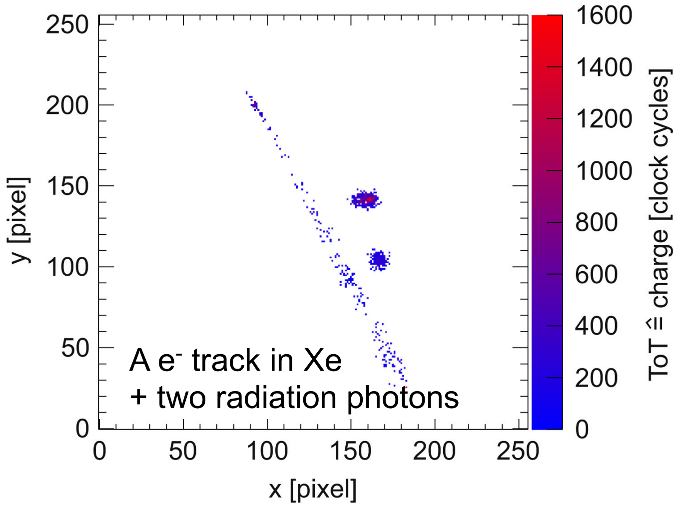
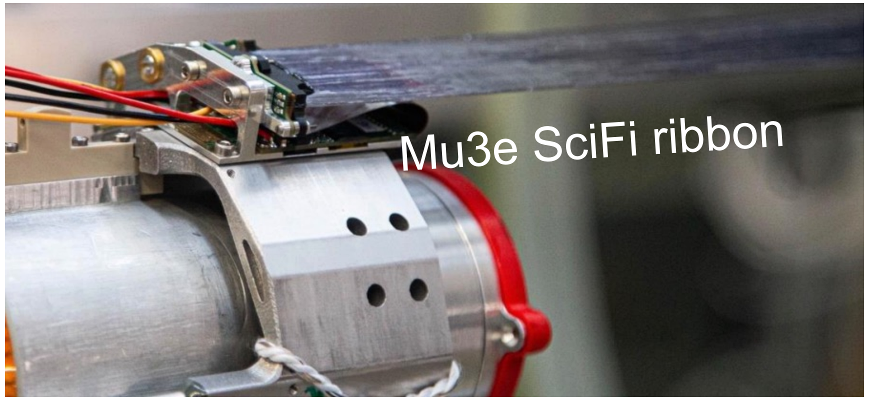


SciFi (Mu3e)

- Lower material budget of 0.2% through the removal of protective support structures
- Fast scintillation decay time (2.7 ns)
- R&D on improving sensor efficiency & radiation hardness of scintillating fibers



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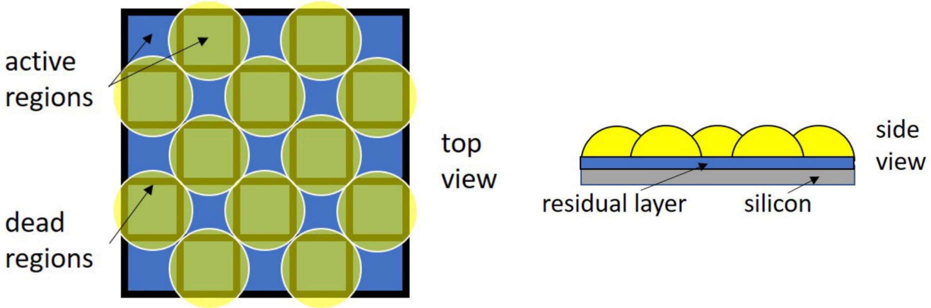

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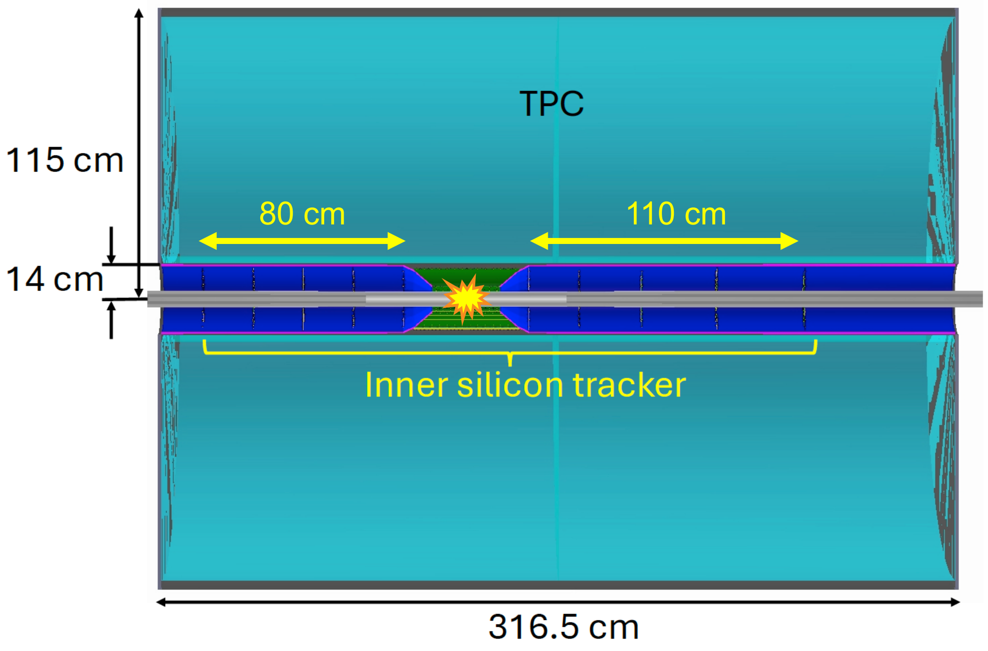
Silicon + TPC Tracking Simulation

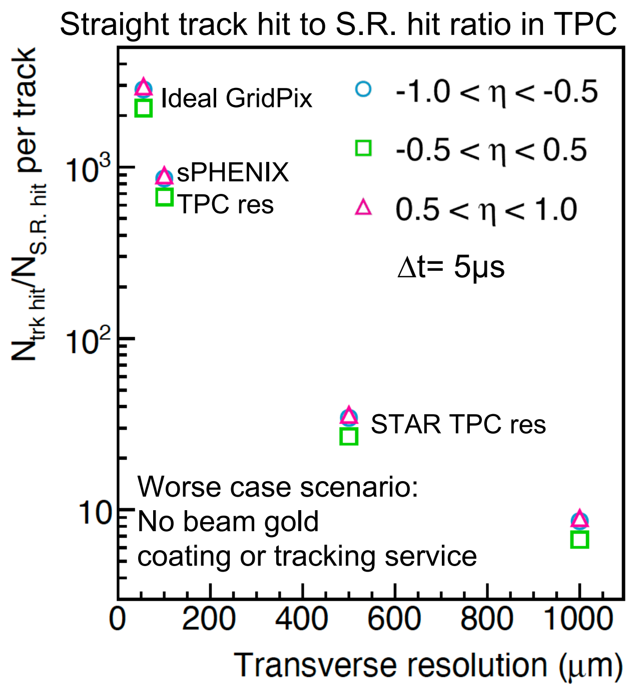


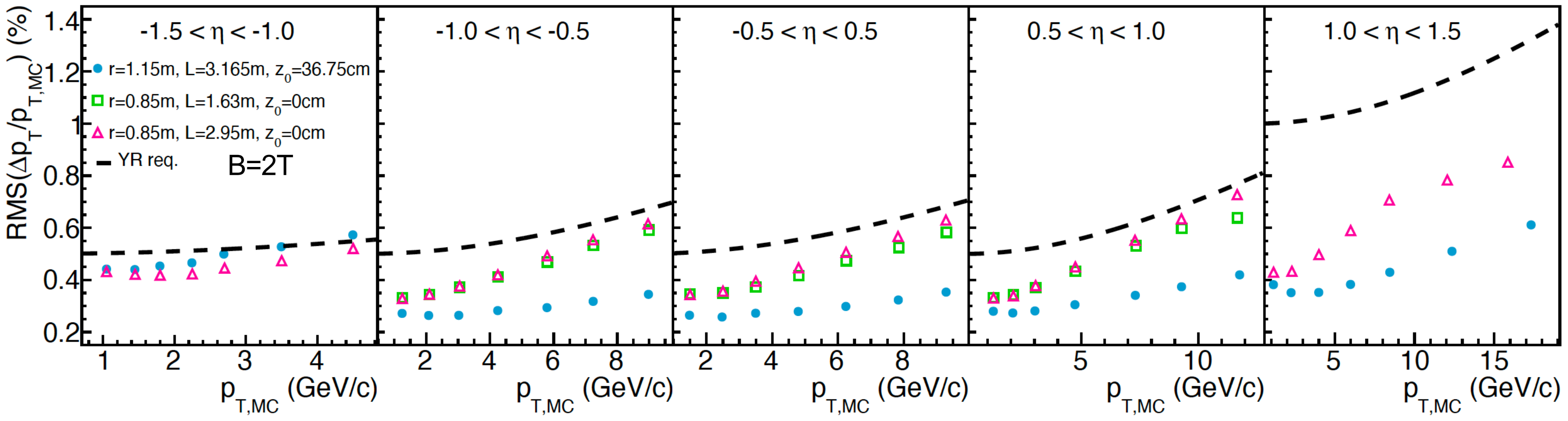
Inner silicon vertex/tracking

- 3-barrel-layer Vertex Silicon Tracker (VST)
- 5 Forward Silicon Tracker (FST) disks
- 5 Backward Silicon Tracker (BST) disks
- Based on the ITS2 MAPS stave design, incorporating ITS3 pixel technology with a 20 × 20 μm² pixel size

Outer TPC

- Gas mixture: $Ar/CF_4/iC_4H_{10}$ = 95:3:2
- Transverse dispersion: $6.3\mu m/\sqrt{cm}$
- Space-charge-induced position error: ~50 μm
- Pad-row spacing: 1 cm
- Intrinsic transverse resolution: ~55 μm (GridPix-based)
- ~100 space points per track for |η| < 1





Momentum resolution

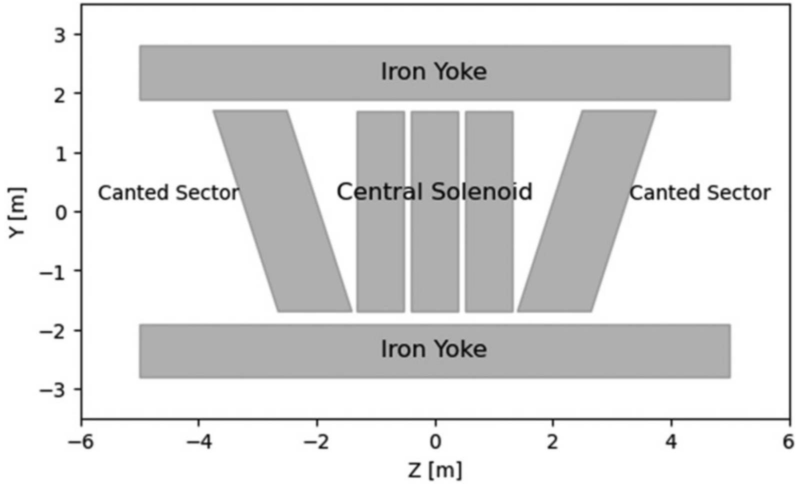
- **R = 0.85 m, L = 1.63 m**: Meets YR requirements for |η| < 1
- **R = 0.85 m, L = 2.95 m**: Meets YR requirements for |η| < 1.5
- Tracking performance degrades for |η| > 1.5 due to limited available space in the forward and backward regions.

Magnet

Large bore solenoid magnet
- Larger expansion volume → greater lever arm for high-p_T tracking
- High cost
- Increased cooling requirements
- High (low) field → bad for low (high) p_T measurement

Partially-canted solenoid magnet (ALICE)
- Standard solenoid coil + canted coils at both end
  → longitudinal B field at the center
  → Superimpose dipole fields at the endcap
- The canted coils are tilted in opposite directions
  →The dipole fields are in opposite directions
  →Avoiding the need for beam correction
- Improve performance in the backward and forward regions
- Requires detailed simulation studies to quantify performance gains, engineering complexity, and potential trade-offs

High temperature superconductors (FCC-ee)
- Thickness: ~25 mm
- Operation temperature 20 K → reduces cooling costs by a factor of 5
- Carbon-fiber honeycomb cryostat → reduces material budget by 14%



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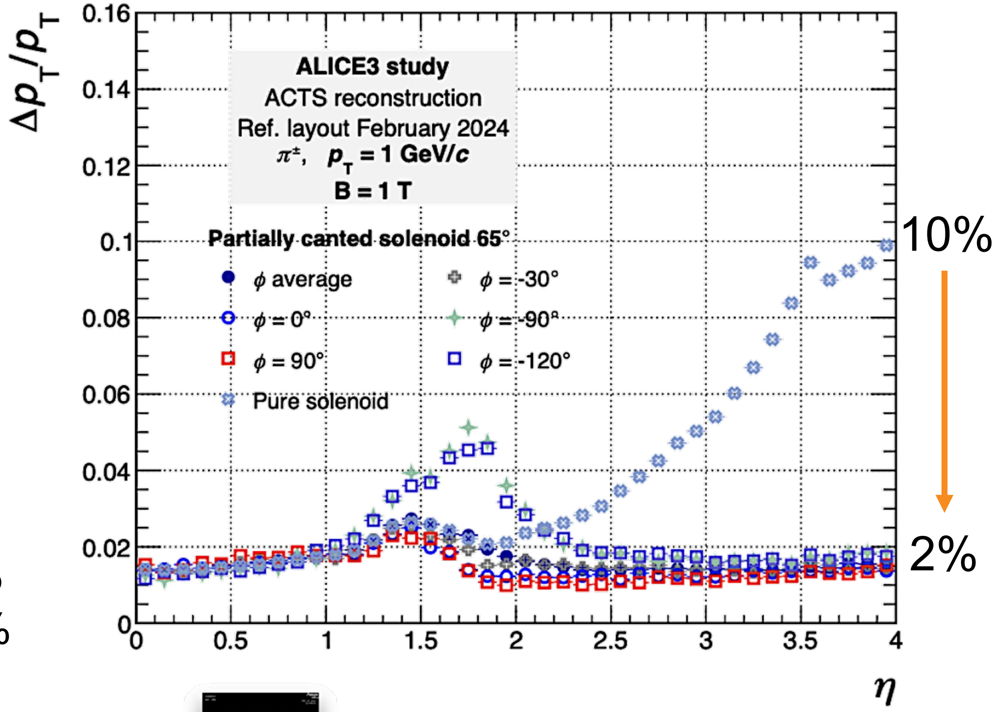
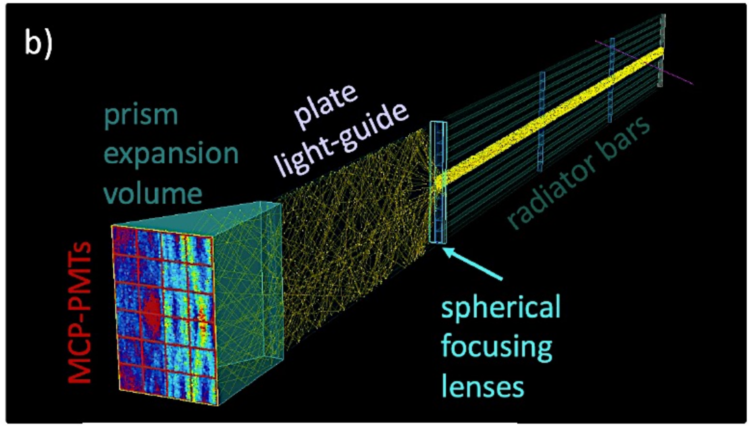


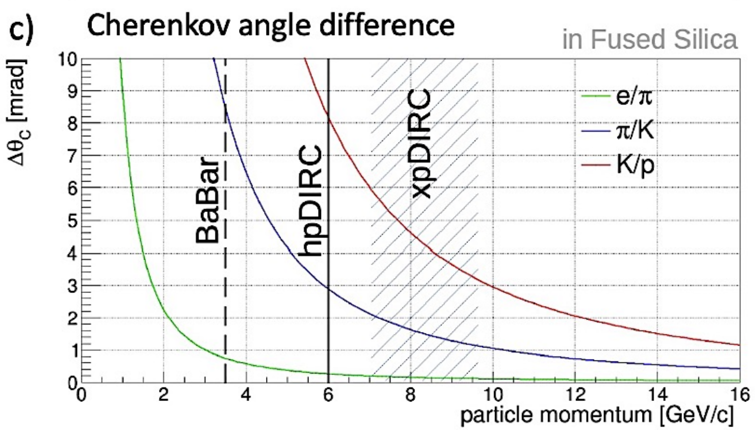
Partially canted

Particle Identification

xpDIRC

- Wide plate light-guide → Extended expansion volumes
- SiPM with acceptable dark count
- K/π separation up to 10 GeV





hpRICH

- Advancement in aerogel (n=1.014) and
- HRPPD: 75% geometric efficiency, pixel pitch=1.625 mm, peak QE=40% at 450 nm, 20 ps timing resolution
- hpRICH + single radiator gaseous RICH → pid up to 50GeV/c

AC-LGAD / TOF

- Reduced material budget enables implementation as an inner timing layer

TPC / drift chamber

- TPC dE/dx capability for |η| < 1 (TPC design in slide 15)

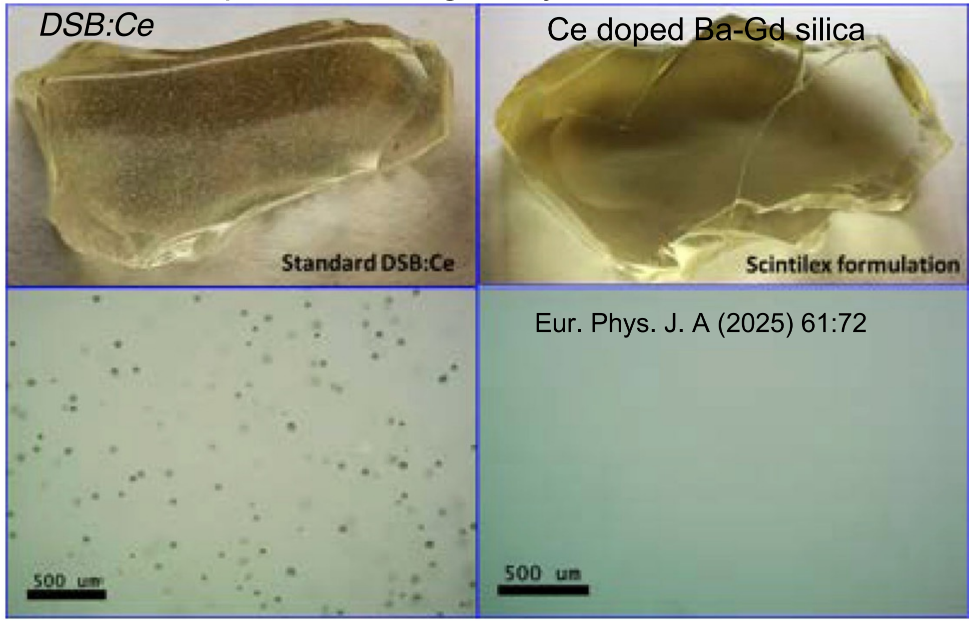
	dE/dx resolution = 6%	dE/dx resolution = 9%	dE/dx resolution = 12%
$e^{\pm}$ ID $\geq 3\sigma$	$1.35 < p < 2.9$ GeV/c	/	/
$\pi^{\pm}$ ID $\geq 3\sigma$	$0.2 < p < 0.5$ GeV/c	$0.3 < p < 0.45$ GeV/c	/
$K^{\pm}$ ID $\geq 3\sigma$	$0.15 < p < 0.3$ GeV/c	$0.15 < p < 0.25$ GeV/c	$0.15 < p < 0.25$ GeV/c
$p, \bar{p}$ ID $\geq 3\sigma$	$0.15 < p < 0.65$ GeV/c	$0.15 < p < 0.6$ GeV/c	$0.15 < p < 0.55$ GeV/c

- Cluster counting offers enhanced PID performance relative to conventional dE/dx methods
  - Requires timing resolution better than 10 ns
  - Timepix3 provides 1.56 ns timing resolution

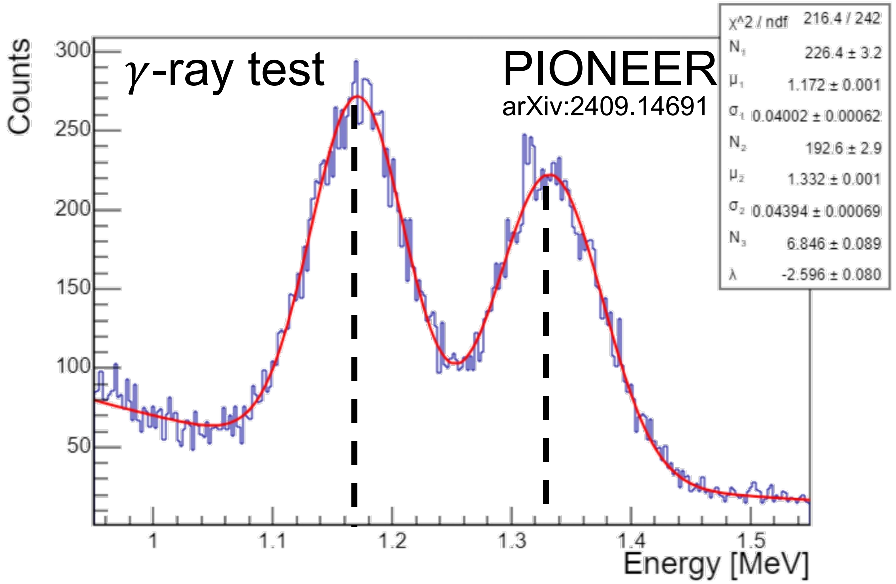
Electromagnetic Calorimetry

SciGlass – lower cost
- Radiation hard at 30Gy (EIC condition)
- Further investigation:
    - Expanding the high transmittance range beyond 600nm
    - Improve light-yield uniformity and timing timing

Improved homogeneity of SciGlass



LYSO– high performance
- ~200× higher light yield than PWO
  → Sensitive to low-energy photons and electrons (>1 MeV)
- Decay time of 40ns
- 5× more radiation hard than PWO
- σE/E = 1.5% at 70 MeV (arXiv:2409.14691)
- Small temperature dependence
- High material and production costs

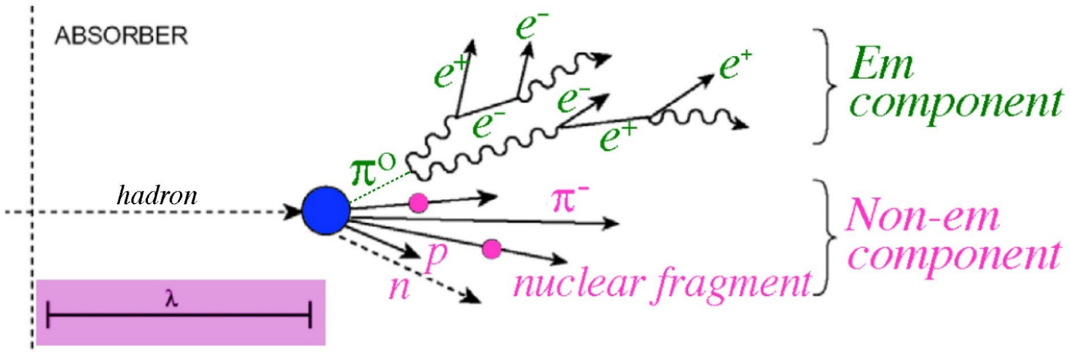


Dual-Readout Hadronic Calorimeter

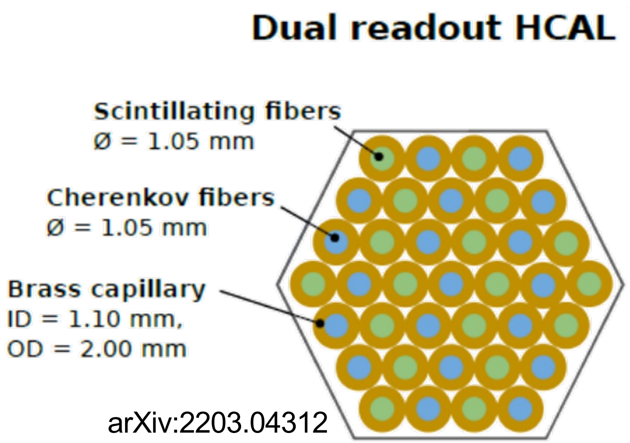
Limitation of Conventional HCAL
Event-by-event fluctuations in the E.M. shower fraction f_{em} degrade hadronic energy resolution

Dual-Readout Solution
- Measure scintillation light (non-E.M. showers) and Cherenkov light (E.M. showers) simultaneously
  →Determine f_{em} on an event-by-event basis
  $$\begin{cases} S \propto E\left[f_{em} + \left(\frac{h}{e}\right)_S \cdot (1 - f_{em})\right] \\ C \propto E\left[f_{em} + \left(\frac{h}{e}\right)_C \cdot (1 - f_{em})\right] \end{cases}$$
- Require spectral and timing separation
- Improves energy resolution to $30\%/\sqrt{E}$

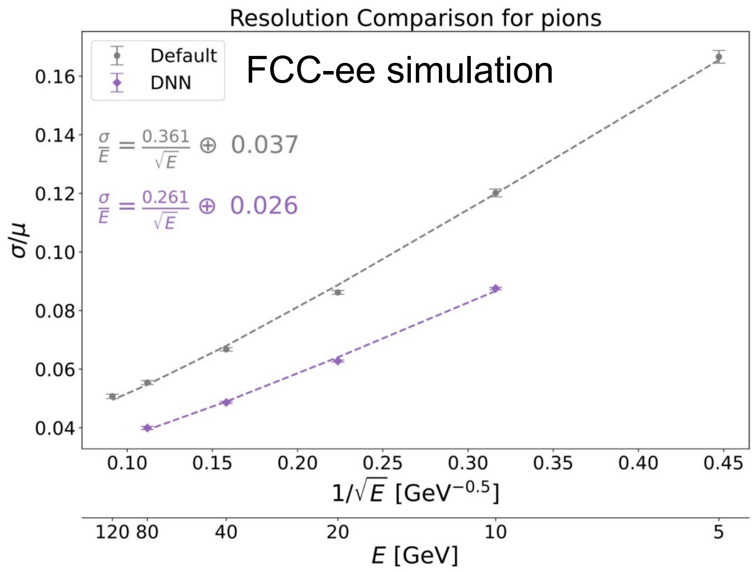
Expected Outcome
- Reduced missing-energy tails
- Better exclusivity cuts in deeply-virtual and photoproduction channels
- Improved jet energy and mass resolution for TMD and 3D structure functions



https://warwick.ac.uk/fac/sci/physics/research/epp/events/seminars/vivarelli.pdf



arXiv:2203.04312



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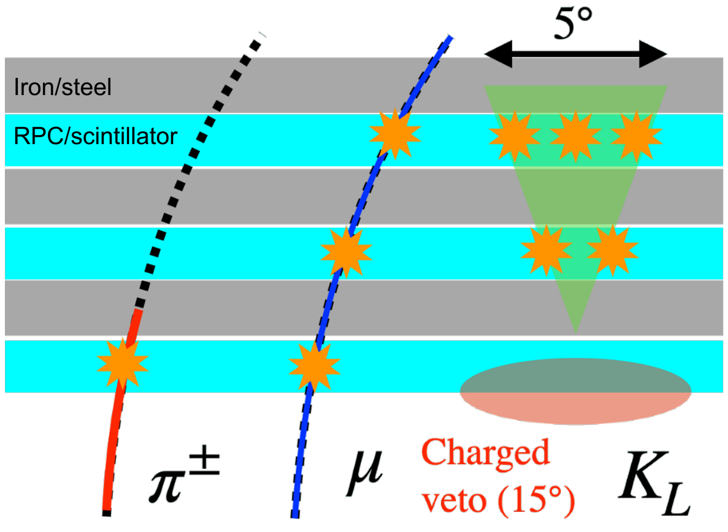
Muon Detection

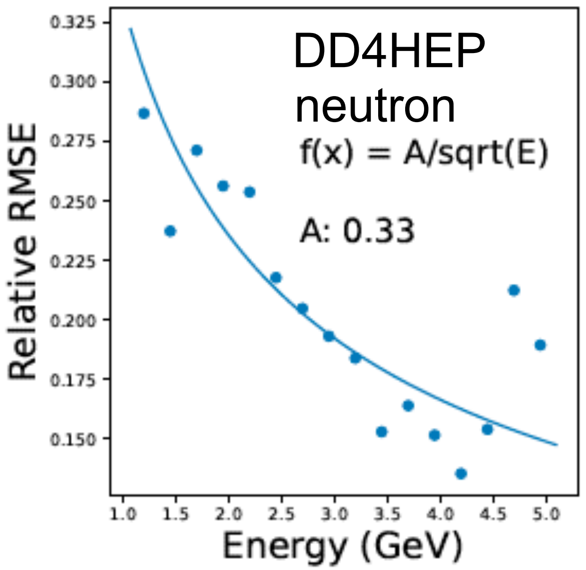
BELLE II KLM-like detector
Alternating passive iron/steel layer and active RPC/scintillator layer

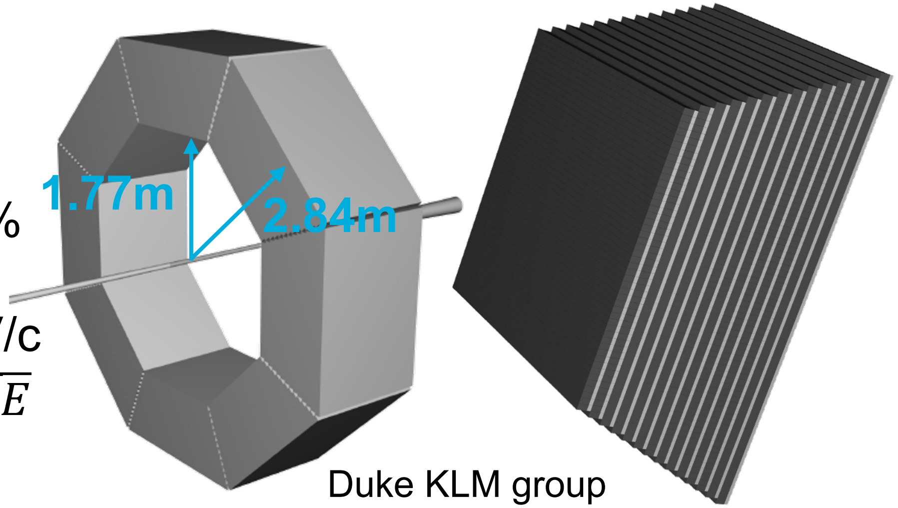
Benefits
- Heavy flavor studies
- Electroweak measurements
- Better particle identification
- Determine hadron momenta using time-of-flight
- Magnet flux return

DD4HEP simulations
- A steel-scintillator ratio of 73%:27%
- Timging resolution: 100 ps
- Good muon identification at 5 GeV/c
- Neutron energy resolution: $33\%/\sqrt{E}$

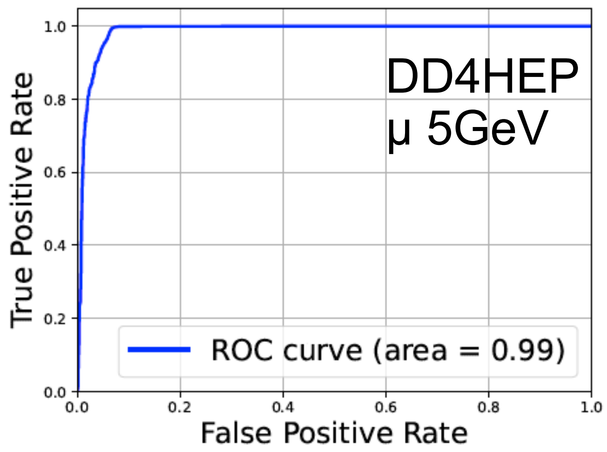


https://indico.belle2.org/event/14599/contributions/93876/attachments/35194/52138/B2SS2025_Detector.pdf





Duke KLM group



Critical R&D Areas

1. Generic glass scintillators for calorimeters
2. Continuation of EIC KLM R&D
3. Pressurized RICH
4. Z-Tagging Mini DIRC
5. GridPIX detector with low-mass and high-efficiency cooling
6. Development of high-precision and eco-friendly MRPC TOF detector
7. Development of double-sided thin-gap GEM-μRWELL for tracking
8. A fast-timing MAPS detector
9. Monolithic LGAD – improve space & time resolution
10. Large-area monolithic active pixel sensors
11. Scintillator fiber trackers for the ZDC and off-momentum detectors
12. Photonics-based readout and power delivery by light for superconducting nanowire detectors
13. Ultra-thin solenoid

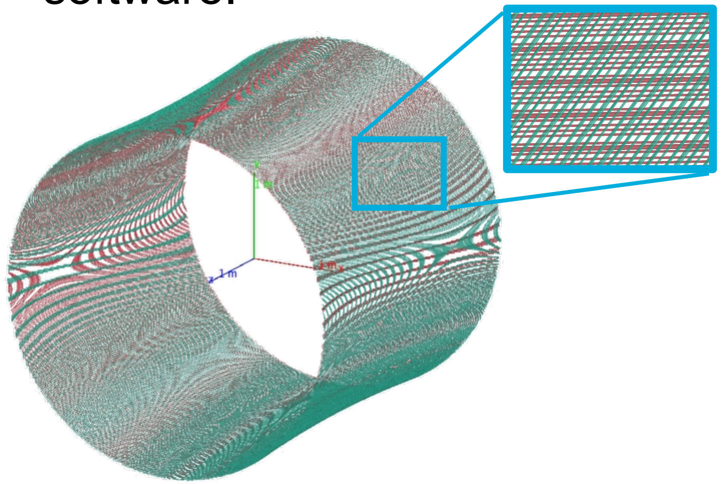
Synergies in HEP

Wide kinematic acceptance + Forward instrumentation

Extreme precision in central measurement

Area	EIC Requirement	FCC-ee Requirement	Shared Technology
Tracking & Vertexing	Wide acceptance; few-μm vertex precision for heavy flavor; low material budget	Exceptional momentum and impact-parameter resolution; vertexing beyond LHC benchmarks	MAPS, lightweight supports, advanced cooling
PID	$\pi/K/p$ separation from $\sim$0.3–10 GeV/c in central and backward rapidities and up to 50 GeV at forward rapidities	Efficient lepton/hadron ID; flavor tagging in clean e^+e^- environment	DIRC/RICH with SiPM readout; dE/dx; TOF with LGADs
Calorimetry	Hermetic EM+HAD calorimetry; backward–forward coverage; e/γ ID	PF calorimetry with fine granularity; excellent jet and γ/π^0 resolution	SiW-ECAL, imaging HCAL, SiPM-based readout
Timing	10–30 ps for TOF PID and background rejection	Sub-30 ps for pattern recognition, LLP searches	LGAD-based timing layers

A drift chamber model for the second detector has been implemented in DD4hep, based on a modified version of the IDEA detector software.



- EIC, FCC-ee, and Belle II share similar timelines and technical challenges
- Coordinated R&D efforts can reduce risk, leverage expertise, and lower development costs

Summary

Value of a Second Detector
- Broadens the EIC scientific reach
- IR-8 enables unique physics opportunities
- Complementary technologies reduce systematic uncertainties

Potential
- Advanced tracking, PID, timing, and calorimetry can exceed current performance
- Enables new measurements and expands the physics program

Toward Realization
- Roadmap for detector R&D, simulation, and implementation
- Synergies with EIC, FCC-ee, Belle II reduce risk and cost

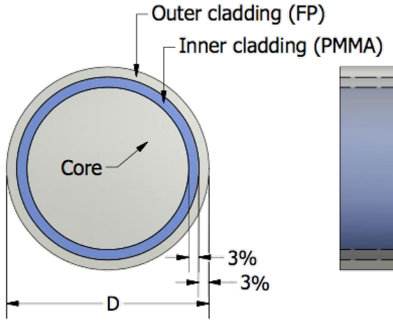
Take-Home Message
A second detector is not redundancy. It **expands EIC physics reach and impact**.

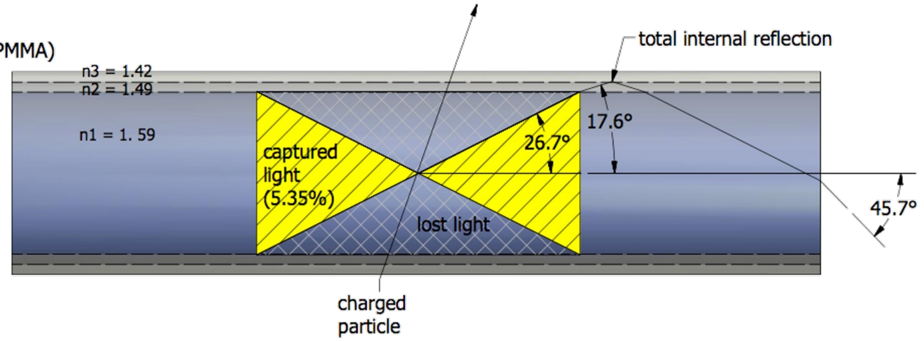
Back Up

Scintillating Fiber (LHCb)

LHCb: arXiv:2305.10515
CERN-DRDC-2024-001

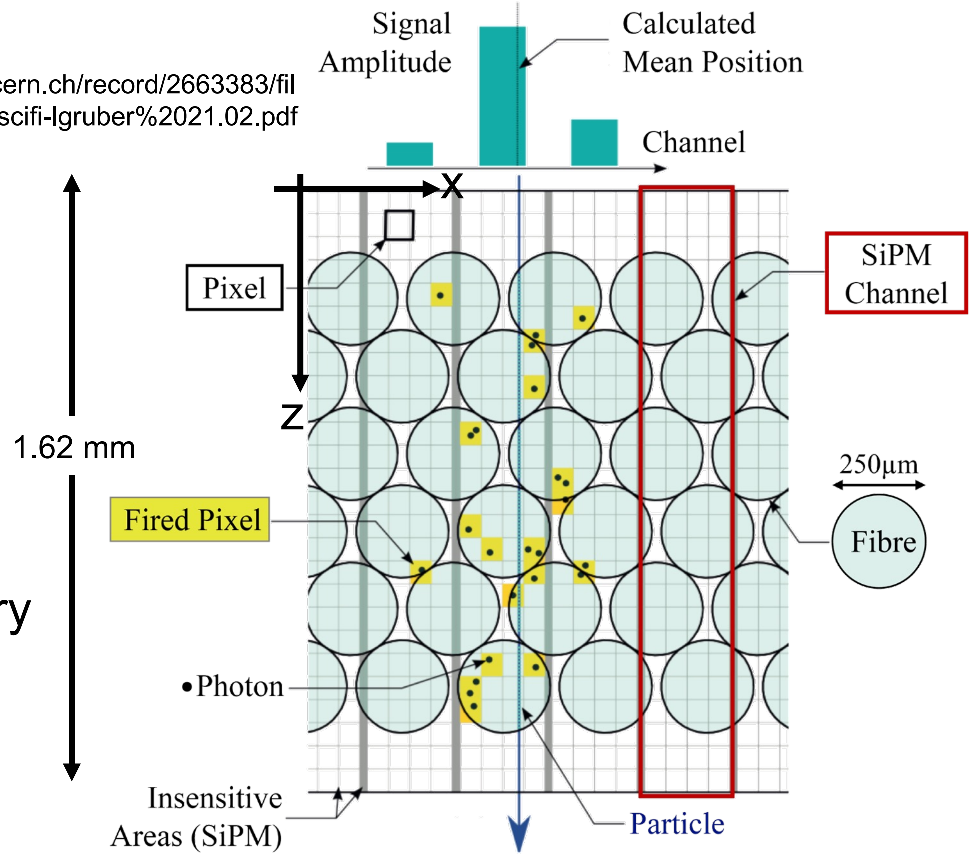
Double-clad polystyrene fiber
- D=250 um → hit pos. res. < 70 um
- 8k photons per MeV of ionization energy
- Excited electron decay times=2.4 ns
- Attenuation length~3.5 m





Hamamatsu SiPM (MPPC S13552 – H2017)
- Pixel size ~ 60 um
- <10% noise cluster rate with front-end clustering and -50 ℃ cooling using Novec

https://cds.cern.ch/record/2663383/files/vci2019-scifi-lgruber%2021.02.pdf



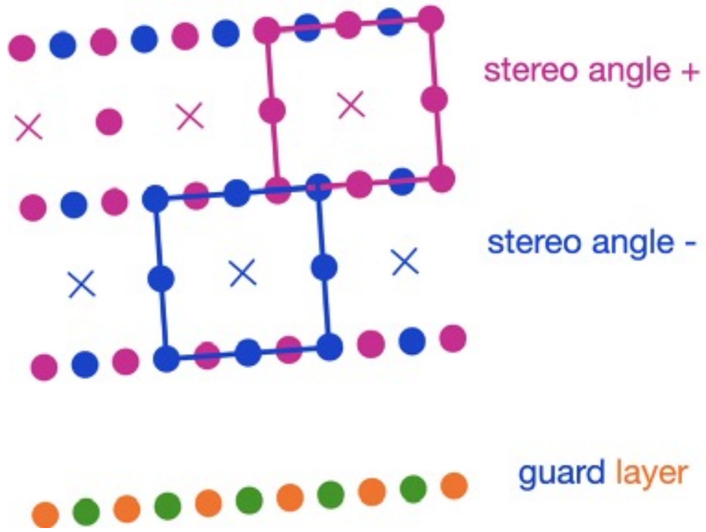
Material budget=1.1% x 12 layers

Technology advancement
- Scintillating fiber with improved radiation hardness
- Modify claddings to boost light yield
- Cryogenic cooled SiPMs with microlenses for light recovery

Brookhaven National Laboratory

IDEA: EPJ Plus (2022) 137:231
MEG II: NIMA 936 (2019) 501

Drift Chamber (IDEA/MEG II)

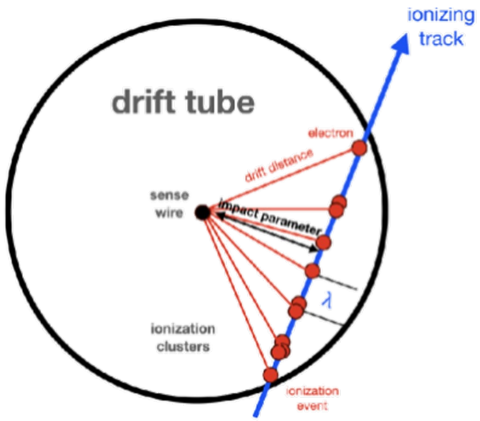


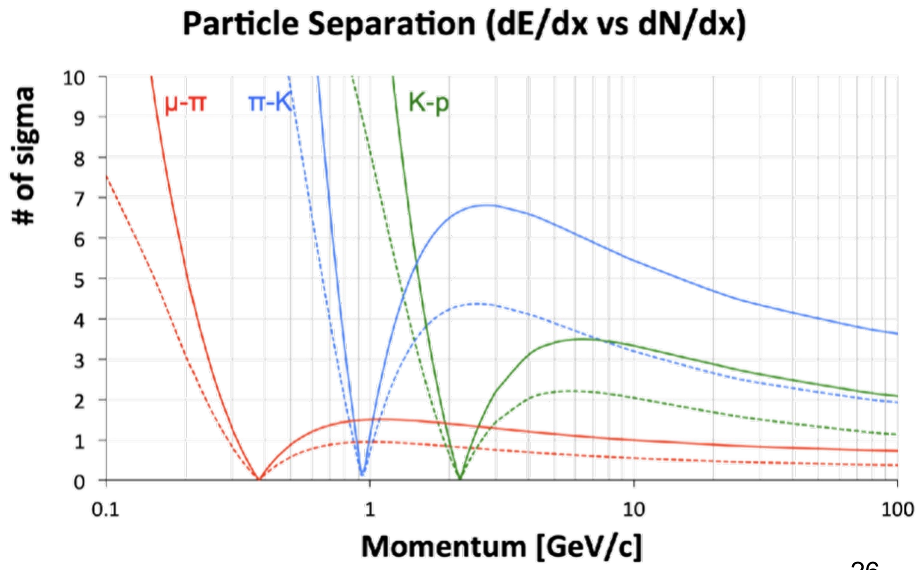
<u>Reduction of material</u>
by storing helium gas in the wire support endplates
IDEA: $0.016X_0$ ($0.05X_0$) in the barrel (forward and backward) region

<u>More uniform equipotential surface</u>
A high ratio of the field to sense wires and a high wire density by enmeshes the positive and negative stereo angle orientations
IDEA: 4 m long, r = 35-200 cm, 400k wires, res ~ 100 um

<u>PID capability</u> with the cluster counting method
Adding timing information to the wires to count individual ionizing events of the traversing track and dE/dx information

<u>Technology advancements</u>
- Carbon-fiber wire vs tungsten wire reduce X/X_0 by a factor of 5
- Low - mass service/cooling structures
- See Andy's slides from last week



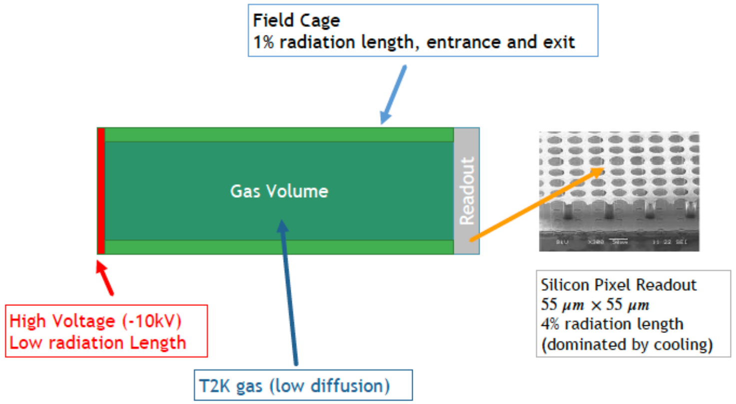


TPC/mini TPC

GridPIX aka miniTPC

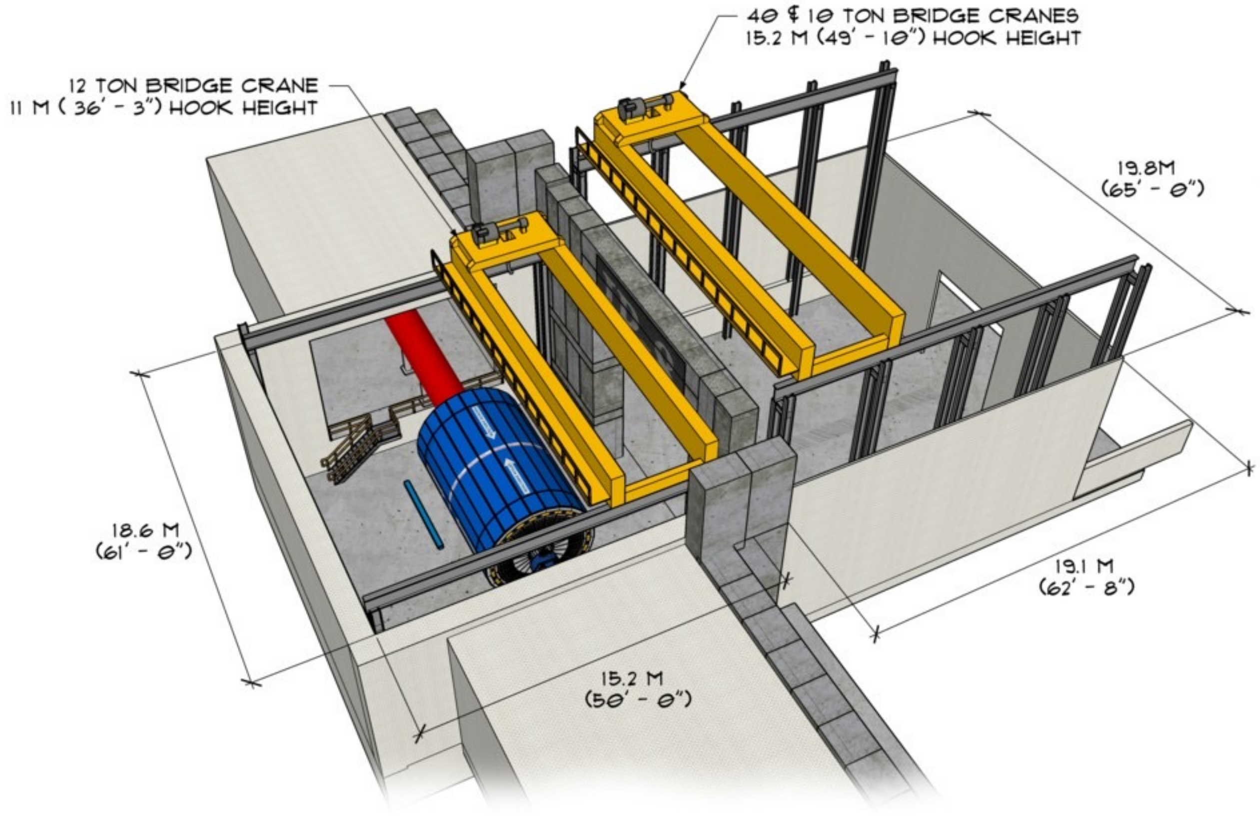
https://indico.bnl.gov/event/18414/contributions/76157/attachments/47563/80668/EIC_Technology_Inventory_Temple.pdf

- Basic idea: Small ΔR TPC with Si Pixel readout on one endcap
  - PID $(\pi - K - p)$ from 100 MeV/c to 800 MeV/c
  - Tracking with large number of hits (pattern recognition)
  - Works only in barrel (field!)
- GridPIX
  - Avalanche grid in front of 55 x 55 μm2 pixels.
  - >90% efficiency for single electrons.
  - Small area is not particularly expensive: 1800 chips (order/produce/test 3600) = $716k
  - Careful: 1.2-5.4 kW of power
  - Services bulky: Gas, power, cooling
  - Realistic X/X_0?

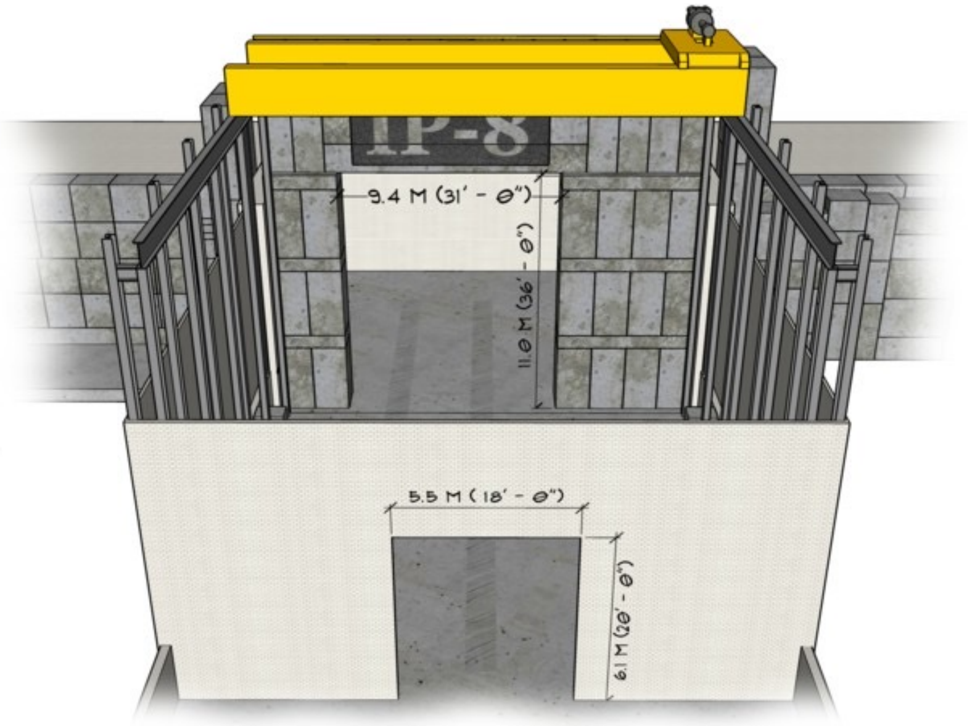


Reality check:
- Very compelling for D2
- Provided tracking an dE/dx (compare with ToF/AC-LGAD)
- Excellent Pattern recognition
- Less sensitive to backgrounds
- Generic R&D ongoing
- Need to see concrete prototype

IP8: Space Constrains



DIMENSIONS FOR IP-8 AND THE ASSEMBLY HALL



DOOR DIMENSIONS FOR IP-8 AND ASSEMBLY HALL

- The experimental hall in IP8 is wider than IP6, however detector access is still limited by the accelerator systems
- The assembly area for IP8 is significantly smaller than that of IP6

Disassembly of the detector and removal of sub-systems in the IP8 assembly area will require special considerations

Energy Loss vs Cluster Counting (Sec. 4.4.5)

- TPC configuration described in Sec.4.3.2
- An argon-based gas mixture at 1 atm yields approximately 20 clusters per centimeter.
- For a track at $\eta = 0$, the effective path length through the TPC is 1.15 − 0.14 = 1.01 m
- Assuming a pad row pitch of 1 cm results in about 100 hits per track.

Substituting these values into eq.(5) and (6) gives estimates of the relative uncertainties for both methods,

$$\frac{\sigma_{dE/dx}}{dE/dx} = 5.5\%$$

$$\frac{\sigma_{dN_{cl}/dx}}{dN_{cl}/dx} = 2.2\%$$