EIC Calorimetry & Ancillary Detectors

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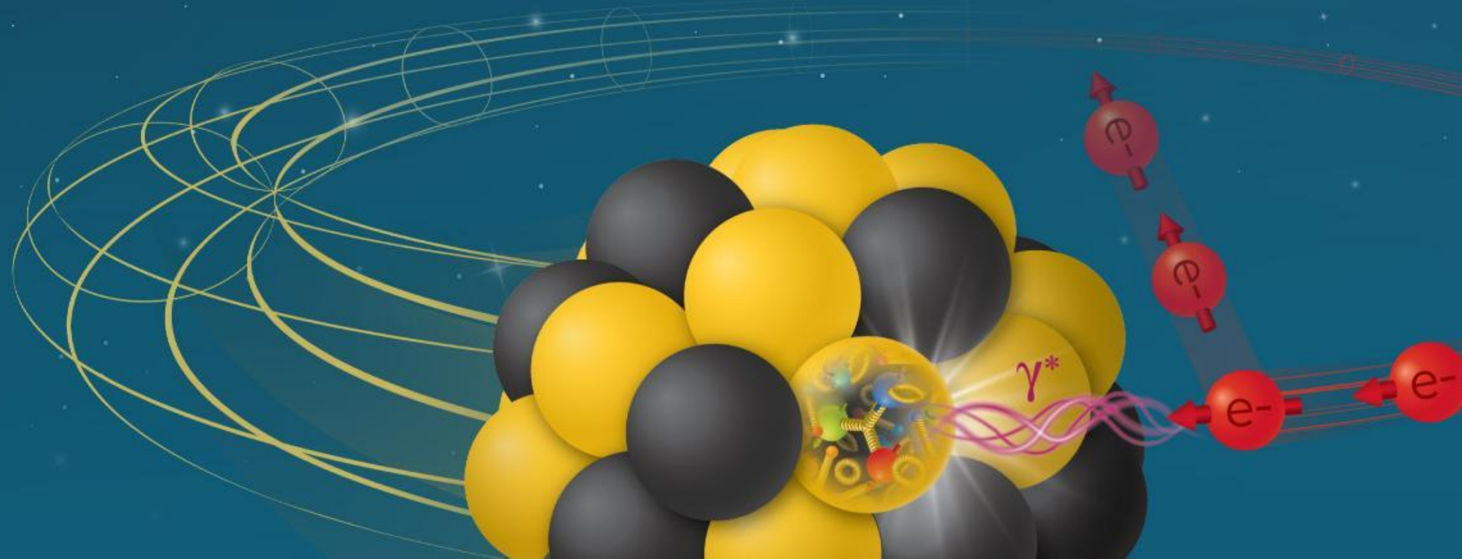
10th EIC DAC Meeting
June 11-13, 2025

Electron-Ion Collider

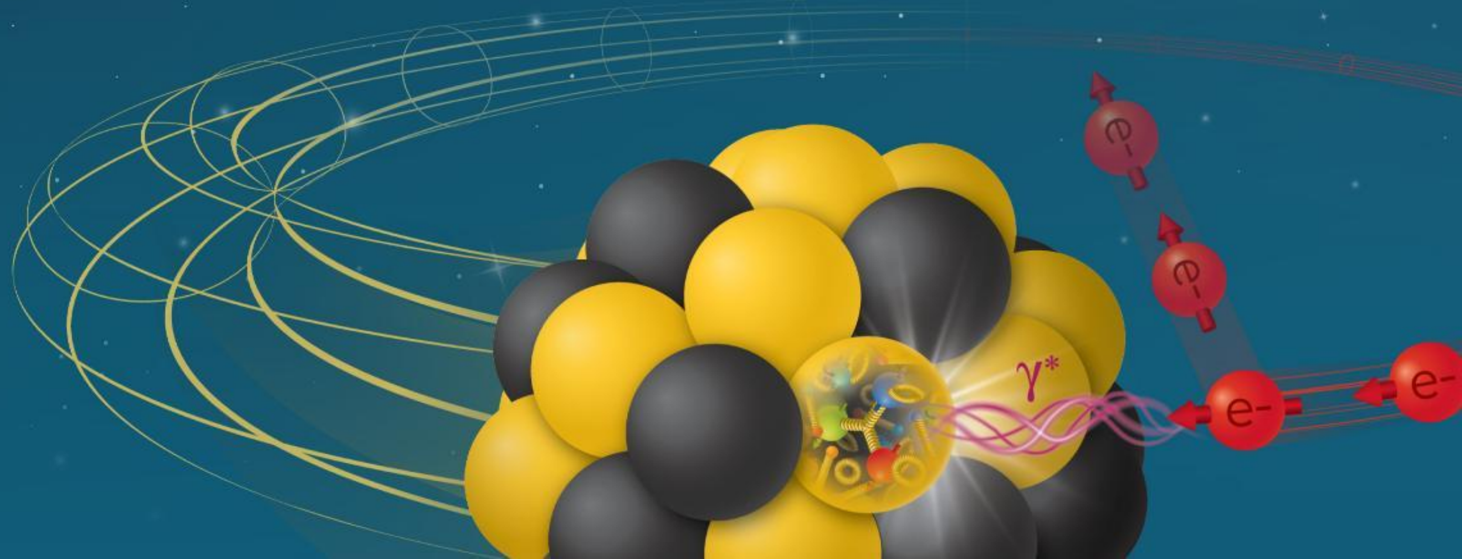


EM Calorimetry Requirements

WBS 6.10.05

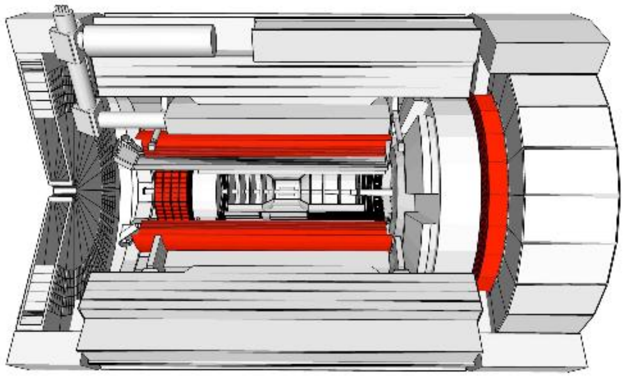
Alexander Bazilevsky

BNL



Electron-Ion Collider

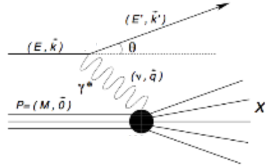
EMCal @ EIC



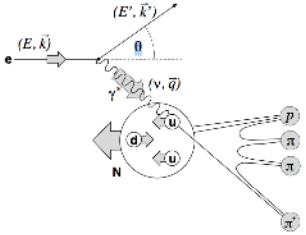
Electron/photon PID, energy, angle/position:

Coverage (in rapidity and energy), resolution, e/π, granularity

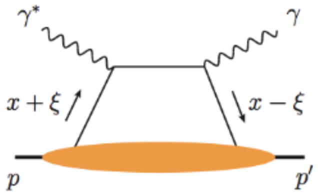
Inclusive DIS: scattered electron



Semi-Inclusive DIS: $\pi 0 \rightarrow \gamma\gamma$, HF $\rightarrow$ e

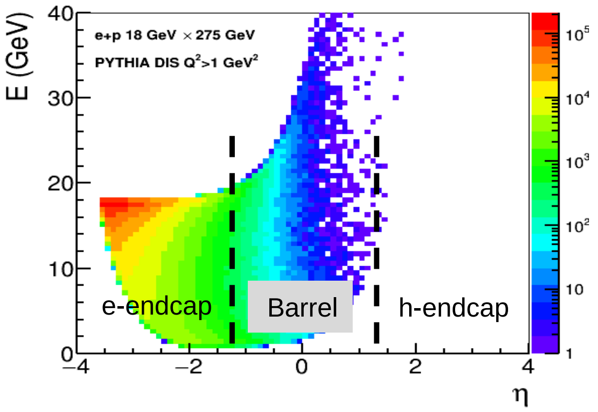


Exclusive DIS: DVCS photons, J/ψ→ee etc.

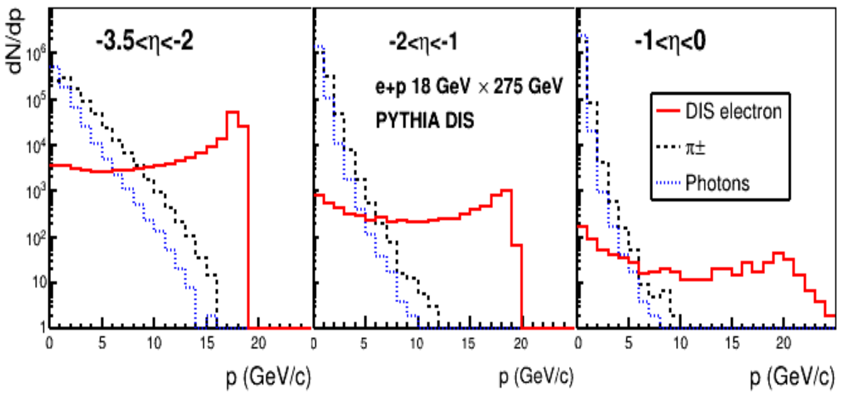


EMCal @ EIC Role

DIS e

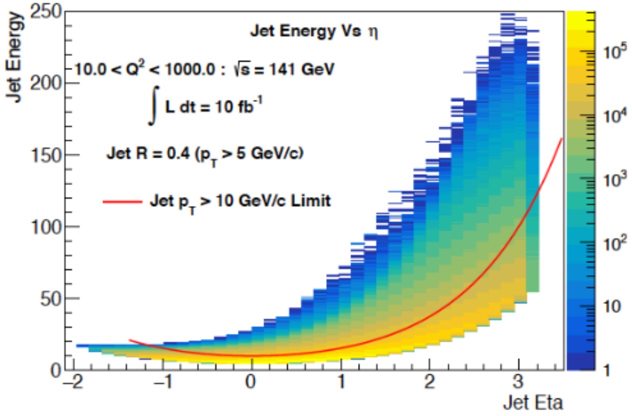


dN/dp vs p

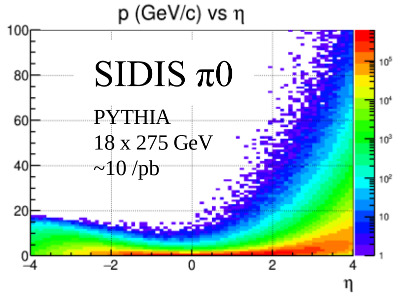


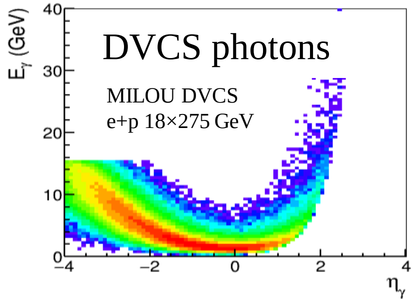
- Mainly barrel and backward
- Hadron suppression up to a factor of 10^4
- Energy/Momentum measurement is critical:
  $\frac{\sigma_{Q2}}{Q^2} \sim \frac{\sigma_{E'}}{E'}$; $\frac{\sigma_x}{x} \sim \frac{1}{y} \frac{\sigma_{E'}}{E'}$
- Highest resolution EMCal in the most backward region (due to degraded tracking mom. res.)
- Lowest material budget (to minimize Bremsstrahlung)

SIDIS Jets



- Assists Jet measurements
- Focus on forward acceptance
- Large dynamic range
- Benefits from e/h~1
- Participates in DIS kinematics reco through hadronic final state (JB)
- Decay photons define minimal energy boundary





- Photon and π0 measurements
- γ/π0 discrimination
- Benefits from good resolution and high granularity

EMCal @ EIC Requirements: Summary

As documented in YR and
“General, Functional, and Performance Requirements for the EIC Detector Systems”

	Electron endcap (Backward)	Barrel	Hadron endcap (Forward)
Energy Resolution	$\frac{(2-3)\%}{\sqrt{E}} \oplus 1\%$	$< \frac{10\%}{\sqrt{E}} \oplus 2\%$	$\frac{(10-12)\%}{\sqrt{E}} \oplus 2\%$
Shower Energy range	0.1−18 GeV	0.1−50 GeV	0.1−100 GeV
$\pi\pm$ suppression (helped by other subsystems)	Up to 10^4		
π^0/γ discrimination	Up to 18 GeV/c	Up to 10 GeV/c	Up to 50 GeV/c
Rad dose for 100 fb^{-1}	100 krad *Dominated by e-beam gas background*	0.1 krad	6 krad
Max hit rate per tower	70 kHz *Dominated by e-beam gas background*	15 kHz	10 kHz
Neutron flux, for 100 fb^{-1}	10^{10} /cm^2	10^9 /cm^2	10^{11} /cm^2
Limited space	Compact (small X_0)		
Material on the way	Minimized		

- Continuous acceptance (particularly from e-endcap to barrel)
- Photosensors and FEE tolerate magnetic field

EMCal @ EIC Requirements

Documented in “General, Functional, and Performance Requirements for the EIC Detector Systems” (see in pre-brief)

GENERAL REQUIREMENTS	
Name	Description
Electromagnetic Calorimetry Systems	
G-DET-ECAL.1	EMCal shall provide measurements of photons, including ones from pi0, eta and other decays; and shall play a key role to identify scattered and decay electrons and measure their kinematic parameters
G-DET-ECAL.2	EMCal subsystem(s) shall cover the backward, the barrel and the forward region.

FUNCTIONAL REQUIREMENTS		
Name	Description	Parent
Electromagnetic Calorimetry Systems		
F-DET-ECAL.1	Must fit in the available space.	G-DET.9 G-DET.10
F-DET-ECAL.2	The EMCal systems shall require adequate support structures, and survey marks to determine their physical location.	G-DET.9 G-DET.10
F-DET-ECAL.3	The EMCal systems shall require appropriate power and cabling to support operation of the detector elements.	G-DET.9 G-DET.10
F-DET-ECAL.4	Design must minimize the loss of functionality in transition between barrel and endcap regions.	G-DET-ECAL.2
F-DET-ECAL.5	Photosensors and readout electronics must tolerate the magnetic field in the subsystem location.	G-DET.9 G-DET.10
F-DET-ECAL.6	Must operate at full luminosity and expected background conditions (rad. dose, neutron flux).	G-DET-ECAL.1
F-DET-ECAL.7	Must provide adequate energy and position resolution for photon and electron measurements, and eID through E/p cut.	G-DET-ECAL.1
F-DET-ECAL.8	Shall provide discrimination between single photon and merged photon from pi0 decay.	G-DET-ECAL.1
F-DET-ECAL.9	Shall provide photon measurements down to 100 MeV.	G-DET-ECAL.1
F-DET-ECAL.10	Must provide timing sufficient to discriminate between different bunch crossings.	G-DET-ECAL.1
F-DET-ECAL.11	Material in front of EMCals will be minimized to the level not jeopardizing EMCal performance.	G-DET-ECAL.1

PERFORMANCE REQUIREMENTS		
Name	Description	Parent
Electromagnetic Calorimetry Systems		
P-DET-ECAL.1	The noise level per channel shall be low enough to provide photon measurements down to the minimal photon energy.	F-DET-ECAL.6
P-DET-ECAL.2	A cooling system shall be provided for the SiPM sensors where needed, with precise temperature control and gain correction for temperature drift.	F-DET.9
P-DET-ECAL.3	The monitoring system shall contain: Light system (LED or laser), test pulse (for electronics), dark current (for SiPM).	F-DET-ECAL.6 F-DET-ECAL.9

…and additional tables with specific requirements for each EMCal subsystem

EMCal @ EIC Interfaces

Documented in
“Interface Requirements for the EIC Detector Subsystems”
(see in pre-brief)

EMCal – DAQ/Computing

Interface ID	From	To	Description
I-DET-COMP-ONLINE.020	DET-ECAL	DET-COMP	A fiber connection will be provided from the DAQ system to the barrel ECAL's readout board to perform configuration, control, and data acquisition.
I-DET-COMP-ONLINE.021	DET-ECAL	DET-COMP	A network connection will be provided from the DAQ system to the barrel ECAL's slow controls interface.
I-DET-COMP-ONLINE.022	DET-ECAL	DET-COMP	A fiber connection will be provided from the DAQ system to the barrel ECAL's readout board for timing synchronization.
I-DET-COMP-ONLINE.023	DET-ECAL	DET-COMP	A fiber connection will be provided from the DAQ system to the backward ECAL's readout board to perform configuration, control, and data acquisition.
I-DET-COMP-ONLINE.024	DET-ECAL	DET-COMP	A network connection will be provided from the DAQ system to the backward ECAL's slow controls interface.
I-DET-COMP-ONLINE.025	DET-ECAL	DET-COMP	A fiber connection will be provided from the DAQ system to the backward ECAL's readout board for timing synchronization.
I-DET-COMP-ONLINE.026	DET-ECAL	DET-COMP	A fiber connection will be provided from the DAQ system to the forward ECAL's readout board to perform configuration, control, and data acquisition.
I-DET-COMP-ONLINE.027	DET-ECAL	DET-COMP	A network connection will be provided from the DAQ system to the forward ECAL's slow controls interface.
I-DET-COMP-ONLINE.028	DET-ECAL	DET-COMP	A fiber connection will be provided from the DAQ system to the forward ECAL's readout board for timing synchronization.

EMCal – HCal

I-DET-INF-BAR.001	DET-ECAL	DET-HCAL	The barrel ECAL will be supported by a structural support system that extends through the bore of the solenoid magnet and is supported by the barrel Hadron Calorimeter.
I-DET-INF-BAR.002	DET-ECAL	DET-HCAL	The weight of the barrel ECAL will be transferred to the barrel Hadron Calorimeter and must be accommodated by all intermediate and subsequent support systems.
I-DET-INF-BAR.004	DET-ECAL	DET-HCAL	The backward ECAL will be supported by an integrated support structure that is attached to the DIRC support frame.
I-DET-INF-BAR.007	DET-ECAL	DET-HCAL	The forward ECAL will be supported by the forward Hadron Calorimeter endcap. Because the forward ECAL must split into two parts to provide access to the barrel, each half must be independently affixed to the Hadron Calorimeter halves.
I-DET-INF-BAR.008	DET-ECAL	DET-HCAL	The weight of the forward ECAL will be transferred to the forward Hadron Calorimeter endcap and must be accommodated by all subsequent support systems.
I-DET-INF-FWD.004	DET-ECAL	DET-HCAL	The forward HCAL will support the weight of the forward electromagnetic calorimeter that is embedded within it.
I-DET-INF-INT.016	DET-ECAL	DET-HCAL	The backward position of the backward ECAL is limited by the backward Hadron Calorimeter and the adjacent cabling pathway that provides services to the interior detectors. Modifications to either must be coordinated.
I-DET-INF-INT.023	DET-ECAL	DET-HCAL	The exterior radius of the forward ECAL is limited by the interior bore of the barrel Hadron Calorimeter. Modifications to either must be coordinated.
I-DET-INF-INT.024	DET-ECAL	DET-HCAL	The forward position of the forward ECAL is limited by the forward Hadron Calorimeter. Modifications to either must be coordinated.

EMCal – Electronics

I-DET-ELEC.019	DET-ECAL	DET-ELEC	Bias voltage DC power provided from the electronics racks to support electronics in the silicon photomultipliers.
I-DET-ELEC.020	DET-ECAL	DET-ELEC	High voltage DC power will be provided from the electronics racks to support silicon sensors and gas detectors.
I-DET-ELEC.021	DET-ECAL	DET-ELEC	Low voltage DC power provided from the electronics racks to support electronics in the detector.
I-DET-ELEC.022	DET-ECAL	DET-ELEC	Bias voltage DC power will be provided from the electronics racks to support electronics the silicon photomultipliers.
I-DET-ELEC.023	DET-ECAL	DET-ELEC	High voltage DC power will be provided from the electronics racks to support silicon sensors and gas detectors.
I-DET-ELEC.024	DET-ECAL	DET-ELEC	Low voltage DC power will be provided from the electronics racks to support electronics in the detector.
I-DET-ELEC.025	DET-ECAL	DET-ELEC	Bias voltage DC power provided from the electronics racks to support electronics in the silicon photomultipliers.
I-DET-ELEC.026	DET-ECAL	DET-ELEC	High voltage DC power will be provided from the electronics racks to support silicon sensors and gas detectors.
I-DET-ELEC.027	DET-ECAL	DET-ELEC	Low voltage DC power provided from the electronics racks to support electronics in the detector.

EMCal – PID

I-DET-INF-BAR.006	DET-ECAL	DET-PID	The DIRC support system will provide support for the backward electromagnetic calorimeter.
I-DET-INF-INT.013	DET-ECAL	DET-PID	The backward position and shape of the barrel EMCAL is limited by the size and shape of the DIRC readout supports. Changes to the size or position of either must be coordinated with the other.
I-DET-INF-INT.014	DET-ECAL	DET-PID	The maximum size of the DIRC is limited to the interior bore of the barrel ECAL (and its support structures). Modifications to either must be coordinated.
I-DET-INF-INT.015	DET-ECAL	DET-PID	The forward position and shape of the barrel ECAL is limited by the backward face of the Dual RICH detector and the adjacent cabling pathway that provides services to the interior detectors. Modifications to either must be coordinated.
I-DET-INF-INT.017	DET-ECAL	DET-PID	The maximum backward location for the DIRC is limited by the position of the backward electromagnetic calorimeter. Modifications to either must be coordinated.
I-DET-INF-INT.018	DET-ECAL	DET-PID	The exterior radius of the backward ECAL is limited by the interior bore of the DIRC support system. Modifications to either must be coordinated.
I-DET-INF-INT.019	DET-ECAL	DET-PID	The backward ECAL must mitigated the heat generated by the backward RICH detector.
I-DET-INF-INT.020	DET-ECAL	DET-PID	The position of the backward ECAL in the forward direction is limited by the backward face of the pfRICH/mRICH detector. Modifications to either must be coordinated.
I-DET-INF-INT.025	DET-ECAL	DET-PID	The maximum forward location for the dRICH is limited by the forward ECAL and the adjacent cabling pathway that provides services to the interior detectors. Modifications to either must be coordinated.
I-DET-INF-BAR.003	DET-ECAL	DET-PID	The DIRC bar boxes will be supported by a frame inside the barrel Electromagnetic Calorimeter, that allows the boxes to be extracted using a system of rollers.
I-DET-INF-BAR.005	DET-ECAL	DET-PID	The weight of the backward ECAL will be transferred to the DIRC detector support and must be accommodated by all subsequent support systems.

EMCal– Infrastructure

I-DET-INF-BAR.001	DET-ECAL	DET-INF	The barrel ECAL will be supported by a structural support system that extends through the bore of the solenoid magnet and is supported by the barrel Hadron Calorimeter.
I-DET-INF-BAR.002	DET-ECAL	DET-INF	The weight of the barrel ECAL will be transferred to the barrel Hadron Calorimeter and must be accommodated by all intermediate and subsequent support systems.
I-DET-INF-BAR.003	DET-ECAL	DET-INF	The DIRC bar boxes will be supported by a frame inside the barrel Electromagnetic Calorimeter, that allows the boxes to be extracted using a system of rollers.
I-DET-INF-BAR.004	DET-ECAL	DET-INF	The backward ECAL will be supported by an integrated support structure that is attached to the DIRC support frame.
I-DET-INF-BAR.005	DET-ECAL	DET-INF	The weight of the backward ECAL will be transferred to the DIRC detector support and must be accommodated by all subsequent support systems.
I-DET-INF-BAR.006	DET-ECAL	DET-INF	The DIRC support system will provide support for the backward electromagnetic calorimeter.
I-DET-INF-BAR.007	DET-ECAL	DET-INF	The forward ECAL will be supported by the forward Hadron Calorimeter endcap. Because the forward ECAL must split into two parts to provide access to the barrel, each half must be independently affixed to the Hadron Calorimeter halves.
I-DET-INF-BAR.008	DET-ECAL	DET-INF	The weight of the forward ECAL will be transferred to the forward Hadron Calorimeter endcap and must be accommodated by all subsequent support systems.
I-DET-INF-BAR.014	DET-ECAL	DET-INF	Each half of the forward ECAL must be continuously supported and stabilized while it is moved between the opened and closed positions.
I-DET-INF-FWD.004	DET-ECAL	DET-INF	The forward HCAL will support the weight of the forward electromagnetic calorimeter that is embedded within it.
I-DET-INF-FWD.008	DET-ECAL	DET-INF	Each half of the forward ECAL must be continuously supported and stabilized while it is moved between the opened and closed positions.
I-DET-INF-INT.012	DET-ECAL	DET-INF	The exterior radius of the barrel ECAL (and its support system) is limited by the interior bore of the solenoid magnet. Modifications to either must be coordinated.
I-DET-INF-INT.013	DET-ECAL	DET-INF	The backward position and shape of the barrel EMCAL is limited by the size and shape of the DIRC readout supports. Changes to the size or position of either must be coordinated with the other.
I-DET-INF-INT.014	DET-ECAL	DET-INF	The maximum size of the DIRC is limited to the interior bore of the barrel ECAL (and its support structures). Modifications to either must be coordinated.
I-DET-INF-INT.015	DET-ECAL	DET-INF	The forward position and shape of the barrel ECAL is limited by the backward face of the Dual RICH detector and the adjacent cabling pathway that provides services to the interior detectors. Modifications to either must be coordinated.
I-DET-INF-INT.016	DET-ECAL	DET-INF	The backward position of the backward ECAL is limited by the backward Hadron Calorimeter and the adjacent cabling pathway that provides services to the interior detectors. Modifications to either must be coordinated.
I-DET-INF-INT.017	DET-ECAL	DET-INF	The maximum backward location for the DIRC is limited by the position of the backward electromagnetic calorimeter. Modifications to either must be coordinated.
I-DET-INF-INT.018	DET-ECAL	DET-INF	The exterior radius of the backward ECAL is limited by the interior bore of the DIRC support system. Modifications to either must be coordinated.
I-DET-INF-INT.019	DET-ECAL	DET-INF	The backward ECAL must mitigated the heat generated by the backward RICH detector.
I-DET-INF-INT.020	DET-ECAL	DET-INF	The position of the backward ECAL in the forward direction is limited by the backward face of the pfRICH/mRICH detector. Modifications to either must be coordinated.
I-DET-INF-INT.021	DET-ECAL	DET-INF	The bore of the backward ECAL must be designed to allow it to be inserted/removed over the existing beamline flanges.
I-DET-INF-INT.022	DET-ECAL	DET-INF	The interior radius of the backward ECAL is governed by the size of the beamline.
I-DET-INF-INT.023	DET-ECAL	DET-INF	The exterior radius of the forward ECAL is limited by the interior bore of the barrel Hadron Calorimeter. Modifications to either must be coordinated.
I-DET-INF-INT.024	DET-ECAL	DET-INF	The forward position of the forward ECAL is limited by the forward Hadron Calorimeter. Modifications to either must be coordinated.
I-DET-INF-INT.025	DET-ECAL	DET-INF	The maximum forward location for the dRICH is limited by the forward ECAL and the adjacent cabling pathway that provides services to the interior detectors. Modifications to either must be coordinated.
I-DET-INF-INT.026	DET-ECAL	DET-INF	The interior radius of the forward ECAL is governed by the size of the beamline. Modifications to either must be coordinated.
I-DET-INF-INT.065	DET-ECAL	DET-INF	The imaging layers must be cooled with an independent system (TBD).
I-DET-INF-INT.066	DET-ECAL	DET-INF	The barrel ECAL will require chilled water or LCW cooling to maintain a safe operating temperature.
I-DET-INF-INT.067	DET-ECAL	DET-INF	The backward ECAL will require chilled water or LCW cooling to maintain the temperature of the silicon photomultipliers, the electronics, and the crystals.
I-DET-INF-INT.068	DET-ECAL	DET-INF	The forward ECAL will require chilled water or LCW cooling to maintain a safe operating temperature.

EMCal – Magnet

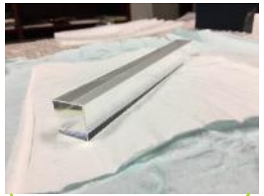
I-DET-INF-INT.012	DET-ECAL	DET-MAG	The exterior radius of the barrel ECAL (and its support system) is limited by the interior bore of the solenoid magnet. Modifications to either must be coordinated.

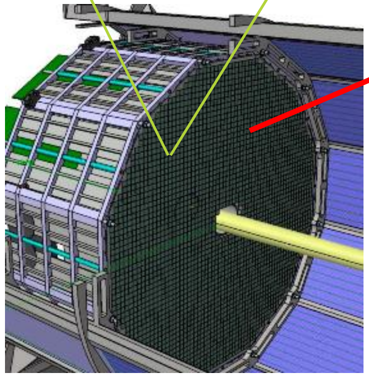
EMCal – Beam Pipe

I-DET-INF-INT.021	DET-ECAL	TBD	The bore of the backward ECAL must be designed to allow it to be inserted/removed over the existing beamline flanges.
I-DET-INF-INT.022	DET-ECAL	TBD	The interior radius of the backward ECAL is governed by the size of the beamline.
I-DET-INF-INT.026	DET-ECAL	TBD	The interior radius of the forward ECAL is governed by the size of the beamline. Modifications to either must be coordinated.

EM Calorimetry in ePIC@EIC

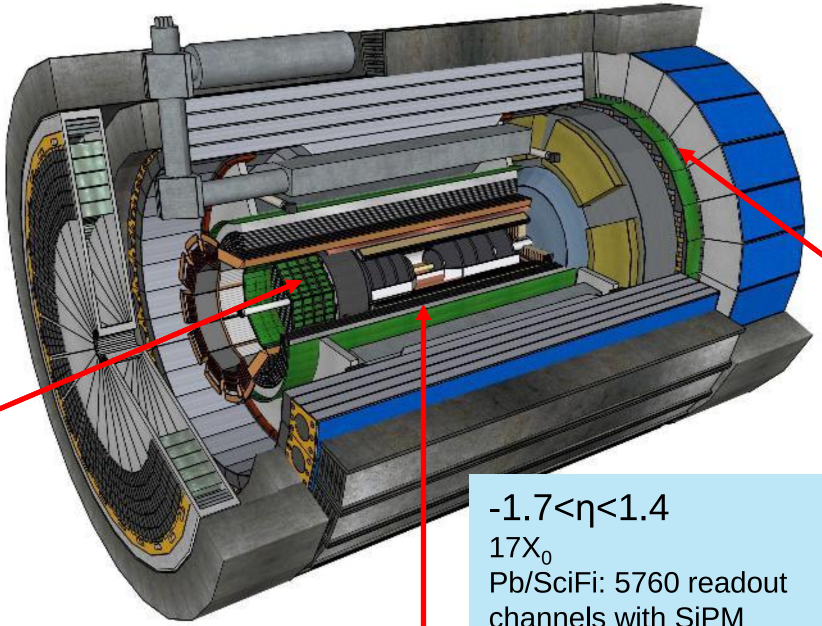
PbWO4



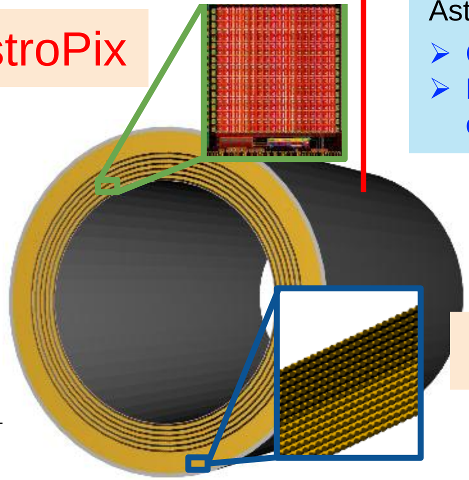


-3.5<η<-1.7
$22X_0$, ~3k crystals, SiPM readout

- High resolution
- High e/π separation for eID



AstroPix

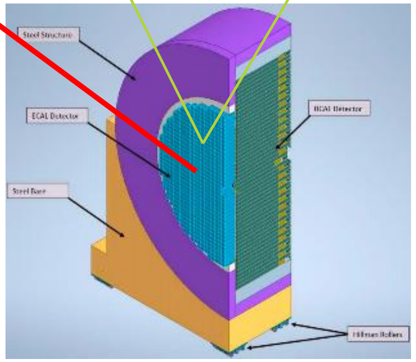


Pb/SciFi

-1.7<η<1.4
$17X_0$
Pb/SciFi: 5760 readout channels with SiPM
AstroPix: ~0.5B pixels

- Good resolution
- High e/π separation for eID

W/SciFi



1.4<η<3.7
$23X_0$, ~19k towers, SiPM readout

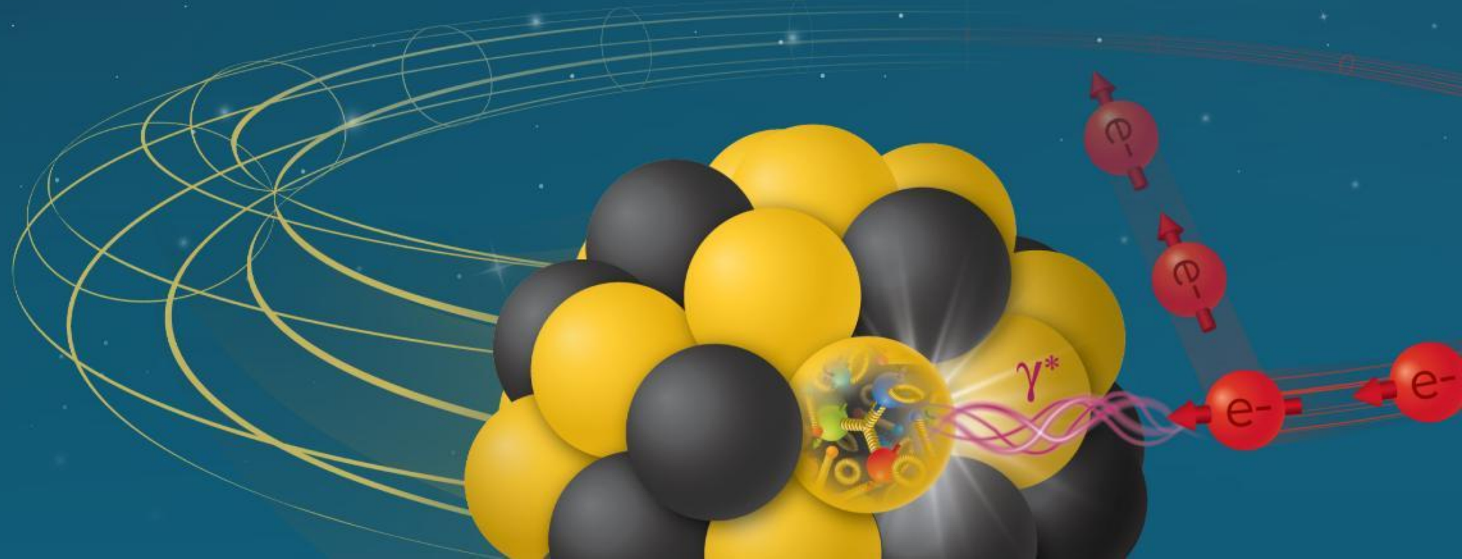
- Good resolution
- High granularity for π0
- e/h~1 for jets

Hadronic Calorimetry Requirements

WBS 6.10.06

Oleg Eyser

BNL



Electron-Ion Collider

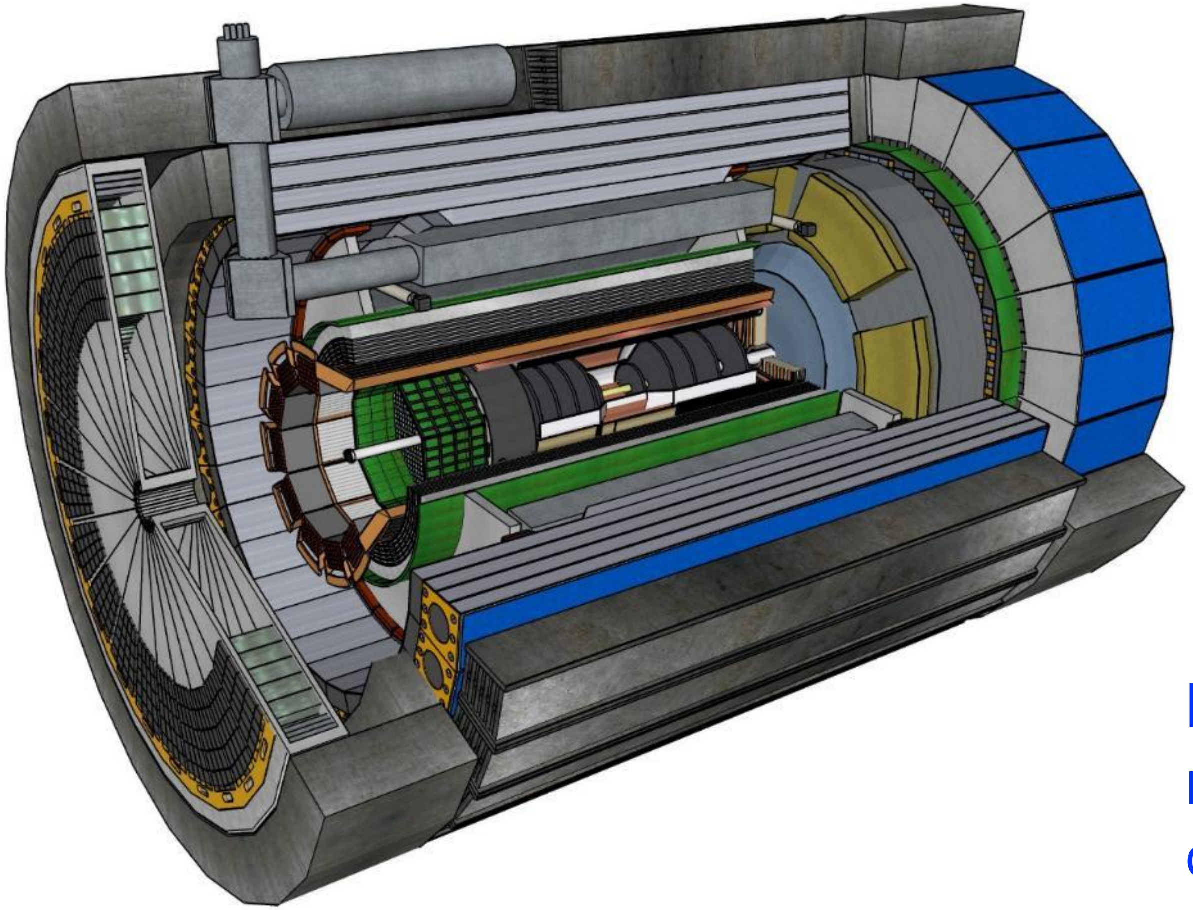
Hadron Calorimetry: Basic Requirements

(from EIC Yellow Report)

- In the mid-rapidity region, the energy resolution of hadron calorimeters is driven by single jet measurements.
- Neutral hadron isolation is also important for jet energy scale and resolution.
- In the forward and backward rapidity region diffractive di-jets need a good hadron energy measurement, with a resolution of the level of $\sigma(E)/E \approx 50\%/\sqrt{E} \oplus 10\%$.
- The requirement on the constant factor at the highest rapidities is driven by the need for good energy resolution where tracking dies out.
- A minimum energy threshold of $500\ MeV/c$ is assumed.

Hadronic Calorimeters

Hadronic calorimeter subsystem must provide hadron energy measurement, in particular for the jet neutral component identification (n, K_L), as well as to serve as a tail catcher for the e/m calorimeters.



LFHCAL

Longitudinally segmented steel/scintillator

Part of the solenoid flux return

Included in CD-3A LLP

NHCAL

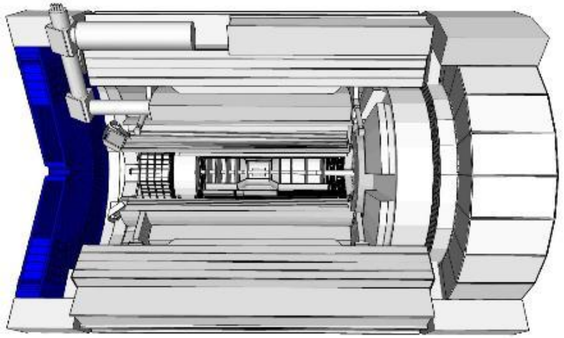
Steel/scintillator

BHCAL

Refurbished steel/scintillator

Outer sPHENIX HCAL

Requirements: NHCal



- Identification of neutral hadron jets, especially at low *x*
- Tail catcher for e/m calorimeter
- **NHCal is only needed for physics at EIC top energy**

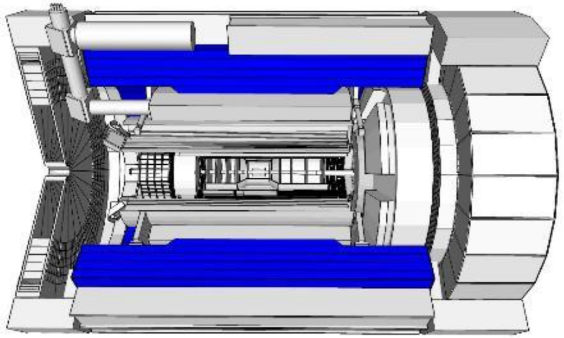
Functional Requirements:

- Shall accommodate the possibility of hadron energy measurements in the range up to few dozens of GeV and pseudorapidity down to -3.5
- Shall accommodate the ability to complement e/m calorimeter by tail catching capability for electron ID purposes, especially below $3 - 4\ \mathrm{GeV/c}$.

Performance Requirements:

- Must provide capability to cover pseudo rapidity range down to at least -3.5
- Shall provide capability to have energy resolution $\sigma(E)/E \sim 100\%/\sqrt{E} \otimes 10\%$ constant term.
- Must provide space to have tower depth of 3-4 interaction lengths (together with the e/m PWO crystal calorimeter) in order to suppress longitudinal leakage for relatively small hadron energies in the e-endcap.

Requirements: BHCal



- Precise reconstruction of jet energy
  - Jets at the EIC are relatively soft
  - Tracker provides a better determination of momentum over most of the kinematic coverage
  - HCAL provides a measurement of neutral hadrons
- Secondary determination of scattered electron kinematics from hadronic remnants
- Additional capability: muon identification

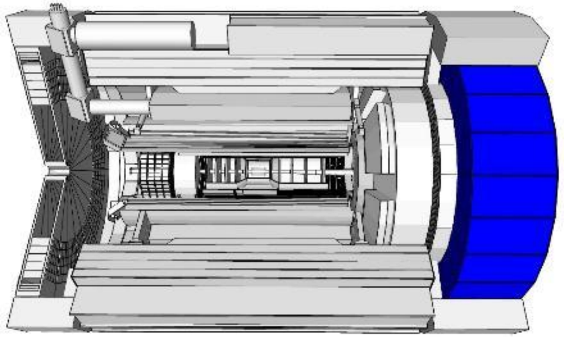
Functional Requirements:

- Shall be optimized to provide hadron energy measurements at relatively small jet energies (up to few dozens of GeV).

Performance Requirements:

- Should have a moderate energy resolution $\sigma(E)/E \sim 100\%/\sqrt{E} \otimes 10\%$.
- Must have sufficient granularity in azimuthal and polar angle to resolve neutral clusters.
- Shall have sufficient radial depth to contain medium energy hadronic showers past 2-3 interaction length material of the e/m calorimeter and the solenoid.

Requirements: LFHCal



- Must provide hadron energy measurements up to the highest hadron energies in a $250(p)\ x\ 18(e)\ \mathrm{GeV}$ beam configuration and pseudorapidity up to 3.5, with energy resolution defined by the community Yellow Report and subsequent ePIC simulation studies
  - Shall have energy resolution $\sigma(E)/E \sim 50\%/\sqrt{E} \otimes 10\%$.
  - The design must be coupled well with a compensated forward e/m calorimeter for high precision jet energy measurements.
- Must have tower depth of 6-7 interaction lengths (together with the e/m section) in order to avoid longitudinal leakage for highest energy hadrons at the EIC.
  - Granularity (transverse tower size) should be adequate to resolve deposits from different charged and neutral hadrons taking into account the local abundance, resulting in transverse tower sizes of at least $\sim 5x5\ \mathrm{cm}^2$ for $\eta < 2.5$ and $3x3\ \mathrm{cm}^2$ for $2.5 < \eta < 4$
  - Granularity (longitudinal tower size) should be adequate to allow for association of showers starting at different depth to the corresponding charged and neutral hadrons. At least 5 longitudinal segments should be read out to determine the shower maximum reliably. For higher rapidity the segmentation should be increased due to the higher particle density
  - The calorimeter structure must serve as part of the solenoid flux return
- Calorimeter absorber blocks in the volume allocated for the flux return must be partly built out of a magnetic steel with the permeability defined by the solenoid designers

Interfaces: NHCAL

Type	RelatedSystemID	InterfaceName	Description
MECH	DET-HCAL-FWD	Backward HCAL Support	The backward HCAL consists of two halves, each of which are support by an independent carriage.
MECH	DET-HCAL-FWD	Weight Transfer	The weight of each half of the backward HCAL will be transferred to the carriage that is supporting it.
MECH	DET-HCAL-FWD	Backward HCAL Mobility	Adequate clearance must be provided for either of the detector carriages to be rolled aside to allow access to sub-detectors within the barrel.
SPACE	DET-TRAK-BAR	Exterior Space Constraint	The exterior radius of the backward HCAL should be consistentent with the radius of the barrel HCAL, and is further limited by the position of the RCS beamline.
SPACE	DET-HCAL-BCK	Backward Space Constraint	The position of the backward HCAL is limited in the backward direction by the adjacent accelerator magnets.
SPACE	DET-TRAK-BAR	Forward Space Constraint	The position of the backward HCAL in the forward direction is limited by the backward face of the barrel HCAL and the adjacent cabling pathway (gap) that allows services and signal cables to connect to the interior detectors.
SPACE	IR-VAC	Interior Space Constraint	The interior radius of the backward HCAL is governed by the size of the beamline.
COOL	DET-INF-COOL-HVAC	Heat Rejection	Heat from the silicon photomultipliers and front end electronics will be rejected into the outside room via forced air.
ELEC	DET-ELEC	Low Voltage	Low voltage DC power will be provided from the electronics racks to support electronics in the detector.
ELEC	DET-ELEC	Bias Voltage	Bias voltage DC power will be provided from the electronics racks to support the silicon photomultipliers.
CONTROL	DET-COMP-ONLINE	Slow Controls	A connection from the DAQ system to the barrel HCAL's slow controls interface. CLARIFY with Data acquisition whether a slow control interface will be independent of the regular control interface.
DATA	DET-COMP-ONLINE	Data Transfer and Control Interface	A fiberoptic connection will connect the DAQ system to the backward HCAL's readouts to perform configuration, control, and data acquisition.
DATA	DET-COMP-ONLINE	Timing Interface	A fiberoptic connection will connect the DAQ system to the backward HCAL's readouts for timing synchronization.

Interfaces: BHCAL

Type	RelatedSystemID	InterfaceName	Description
MECH	DET-HCAL-BAR	Barrel HCAL Support	The barrel HCAL will be supported by a rolling carriage that allows the central detector to be moved between the assembly area and the experimental hall.
MECH	DET-HCAL-FWD	Sub-Detector Support	The barrel HCAL will support the weight of all of the sub-detectors and components within the central detector.
MECH	DET-HCAL-FWD	Weight Transfer	The cumulative weight of the HCAL and all of the sub-detectors it supports will be transferred to the detector carriage.
SPACE	DET-MAG	Exterior Space Constraint	The exterior radius of the barrel HCAL is limited by the detector carriage, the electronics platforms, and the RCS beamlime.
SPACE	DET-HCAL-BCK	Backward Space Constraint	The backward position and of the barrel HCAL is limited by the position of the backward HCAL and the adjacent cabling pathway (gap) that allows services and signal cables to connect to the interior detectors.
SPACE	DET-HCAL-FWD	Forward Space Constraint	The forward position of the barrel HCAL is limited by the position of the forward HCAL and the adjacent cabling pathway (gap) that allows services and signal cables to connect to the interior detectors.
SPACE	DET-MAG	Interior Space Constraint	The interior radius of the barrel HCAL is limited by the exterior radius of the solenoid magnet.
COOL	DET-INF-COOL-HVAC	Heat Rejection	Heat from the silicon photomultipliers and front end electronics will be rejected into the outside room via forced air.
ELEC	DET-ELEC	Low Voltage	Low voltage DC power will be provided from the electronics racks to support electronics in the detector.
ELEC	DET-ELEC	Bias Voltage	Bias voltage DC power will be provided from the electronics racks to support the silicon photomultipliers.
CONTROL	DET-COMP-ONLINE	Slow Controls	A connection from the DAQ system to the barrel HCAL's slow controls interface. CLARIFY with Data acquisition whether a slow control interface will be independent of the regular control interface.
DATA	DET-COMP-ONLINE	Data Transfer and Control Interface	A fiberoptic connection will connect the DAQ system to the barrel HCAL's readouts to perform configuration, control, and data acquisition.
DATA	DET-COMP-ONLINE	Timing Interface	A fiberoptic connection will connect the DAQ system to the barrel HCAL's readouts for timing synchronization.

Interfaces: LFHCAL

Type	RelatedSystemID	InterfaceName	Description
MECH	DET-HCAL-FWD	Forward HCAL Support	The forward HCAL consists of two halves, each of which are support by an independent carriage.
MECH	DET-HCAL-FWD	Sub-Detector Support	The forward HCAL will support the weight of the forward electromagnetic calorimeter that is embedded within it.
MECH	DET-HCAL-FWD	Weight Transfer	The weight of each half of the forward HCAL, and its embedded subdetectors, will be transferred to the associated carriage.
MECH	DET-INF-MECH	Forward HCAL Mobility	Adequate clearance must be provided for either of the detector carriages to be rolled aside to allow access to sub-detectors within the barrel.
SPACE	DET-HCAL-FWD	Exterior Space Constraint	The exterior radius of the forward HCAL should be consistentent with the radius of the barrel HCAL, and is further limited by the position of the RCS beamline.
SPACE	DET-TRAK-FWD	Backward Space Constraint	The position of the forward HCAL is limited in the backward direction by the barrel HCAL and the adjacent cabling pathway (gap) that allows services and signal cables to connect to the interior detectors.
SPACE		Forward Space Constraint	The position of the forward HCAL in the forward direction is limited by the B0 magnet. Clearly identify what the exterior boundaries of the central detector, both here and in backward HCAL.
SPACE	IR-VAC	Interior Space Constraint	The interior radius of the forward HCAL is governed by the size of the beamline.
COOL	DET-INF-COOL-HVAC	Heat Rejection	Heat from the silicon photomultipliers and front end electronics will be rejected into the outside room via forced air. DO WE NEED CW FOR COOLING HERE?
ELEC	DET-ELEC	Low Voltage	Low voltage DC power will be provided from the electronics racks to support electronics in the detector.
ELEC	DET-ELEC	Bias Voltage	Bias voltage DC power will be provided from the electronics racks to support the silicon photomultipliers.
CONTROL	DET-COMP-ONLINE	Slow Controls	A connection from the DAQ system to the forward HCAL's slow controls interface. CLARIFY with Data acquisition whether a slow control interface will be independent of the regular control interface.
DATA	DET-COMP-ONLINE	Data Transfer and Control Interface	A fiberoptic connection will connect the DAQ system to the forward HCAL's readouts to perform configuration, control, and data acquisition.
DATA	DET-COMP-ONLINE	Timing Interface	A fiberoptic connection will connect the DAQ system to the forward HCAL's readouts for timing synchronization.

Ancillary Detector Requirements

WBS 6.10.11
WBS 6.10.14.02

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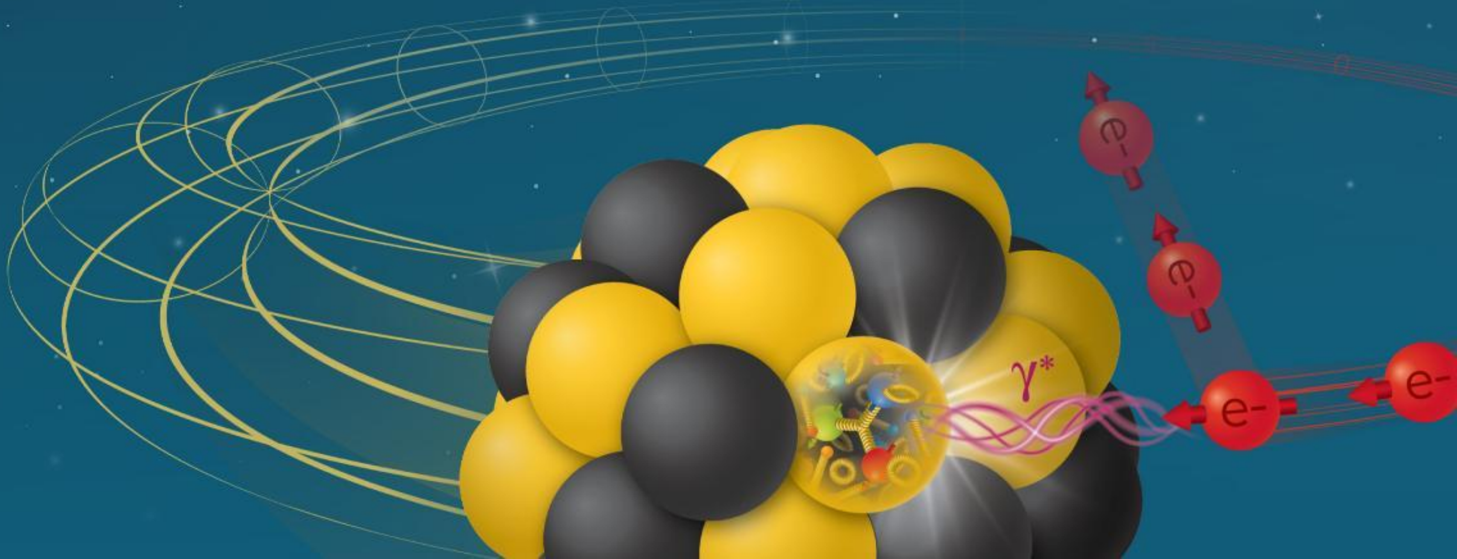
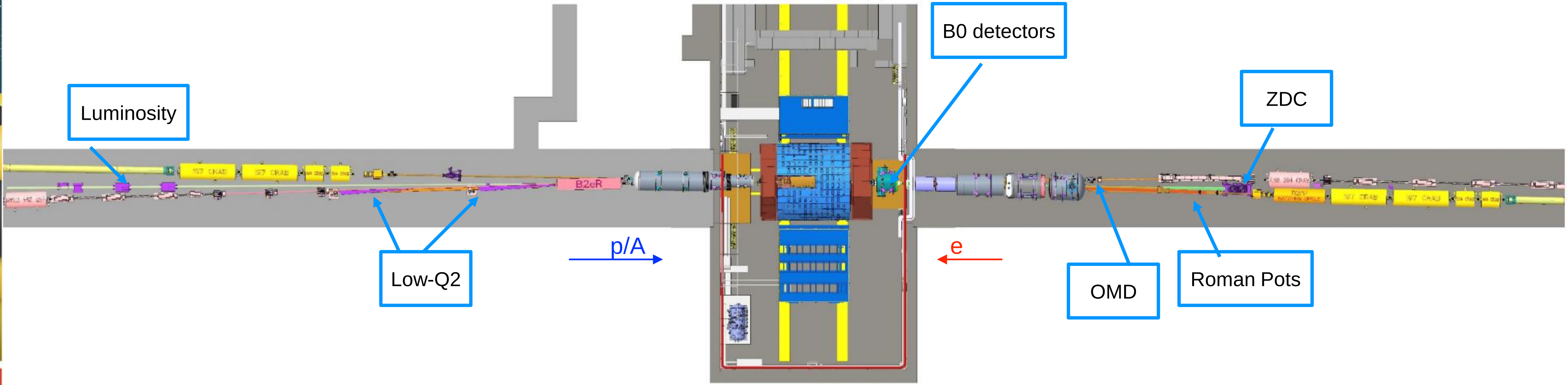


Electron-Ion Collider

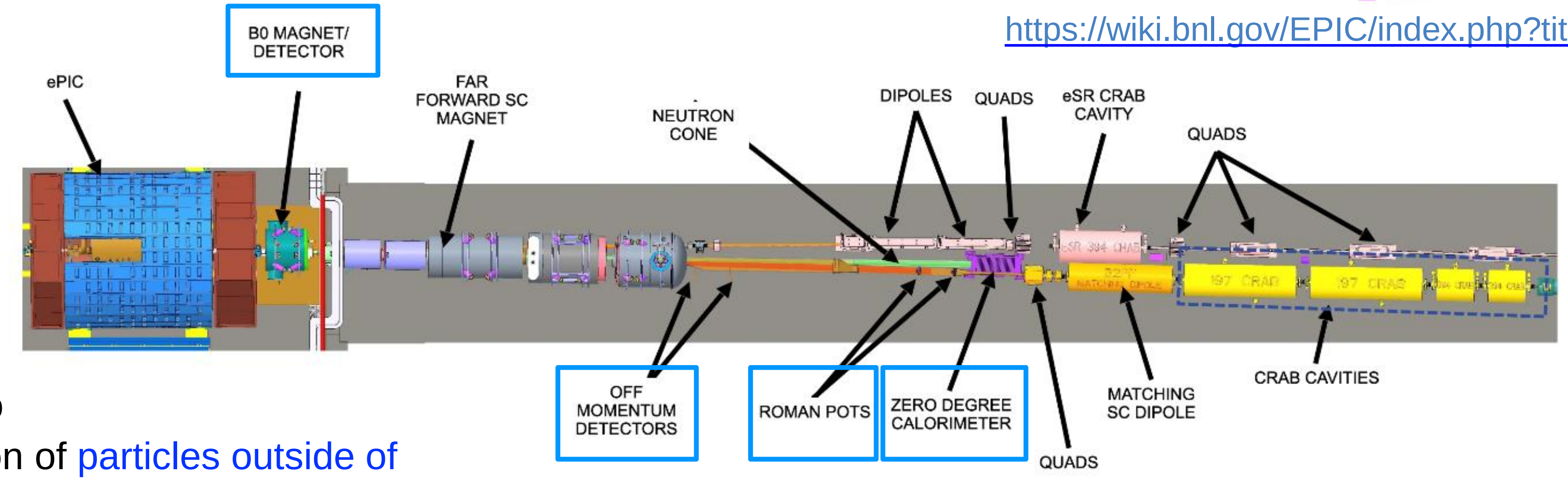
Requirements for ALL far-forward/backward detectors

- In total 6 sub-detectors (11 sub-components) distributed along the beam line within +/- 50m.
  - **Far-forward:** B0-detectors, RomanPots, Off-Momentum detectors (OMD), Zero Degree Calorimeter (ZDC)
  - **Far-backward:** Luminosity and Low-Q2 tagger
- ✓ Detectors should be **integrated with accelerator/vacuum** (see slide with interfaces)
- ✓ Should handle a **data rate** and operate reliably at a full projected EIC luminosity.
- ✓ Must be resistant to **extreme background conditions**, high neutron flux in particular, at the levels specified by the simulation studies. (Expected at ePIC (<1e12 MeV neutron equivalent fluence [TBD]).



Far-Forward Detectors (hadron outgoing)

https://wiki.bnl.gov/EPIC/index.php?title=FarForward



Those detectors have to

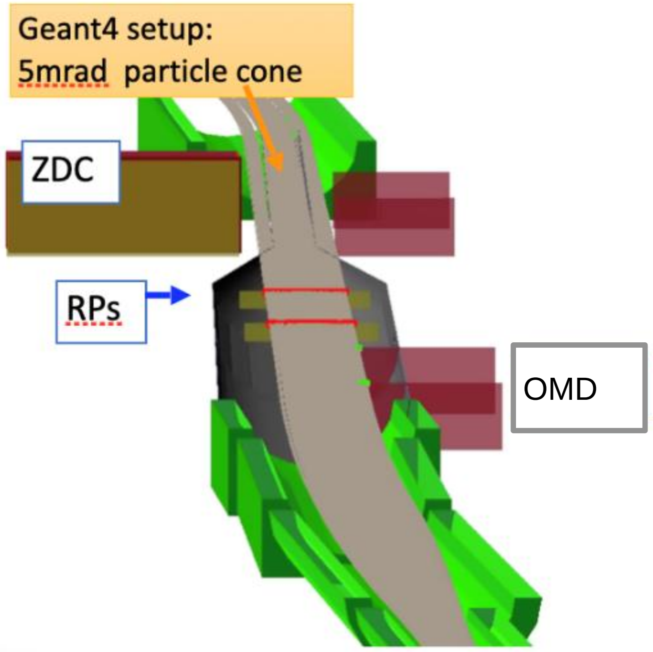
- provide reconstruction of particles outside of the central detector acceptance:
  - ✓protons at wide range of p_T^2
  - ✓protons from nuclear breakups **(with different rigidity)** P/P_{beam} **(**x_L**) <1**
  - ✓**neutrons**
  - ✓**photons**
  - ✓**particles from decays (**Λ, Σ**, etc)**
- veto nuclear breakups for eA running
- Operate under different CM energies

	Particles	Angle [mrad]	Distance from IP	Location	sub-systems
B0 detector	Charged particles Photons (tagged)	5.5 - 20	ca 6-7 m	After FHCAL, inside B0 magnet	Tracker & EMCAL
Off-momentum	Charged particles with different rigidity	0-5.0	ca 23-25 m	in vacuum	Tracker
Roman Pots	Protons Light nuclei	0*-5.0	ca 27-30 m	in vacuum , very close to the beam-core.	Tracker
ZDC	Neutrons Photons	0-4.0 (5.5)	ca 38 m	between beam-lines , ~ 3.5t	EMCAL/ HCAL

RPOTs: requirements

Roman-Pots -- small |t| value

0.0* $(10\sigma cut)$ < $\boldsymbol{\theta}$ < 5.0 mrad



$$\sigma(z) = \sqrt{\varepsilon \cdot \beta(z))}$$

$\sigma(z)$ is the Gaussian width of the beam

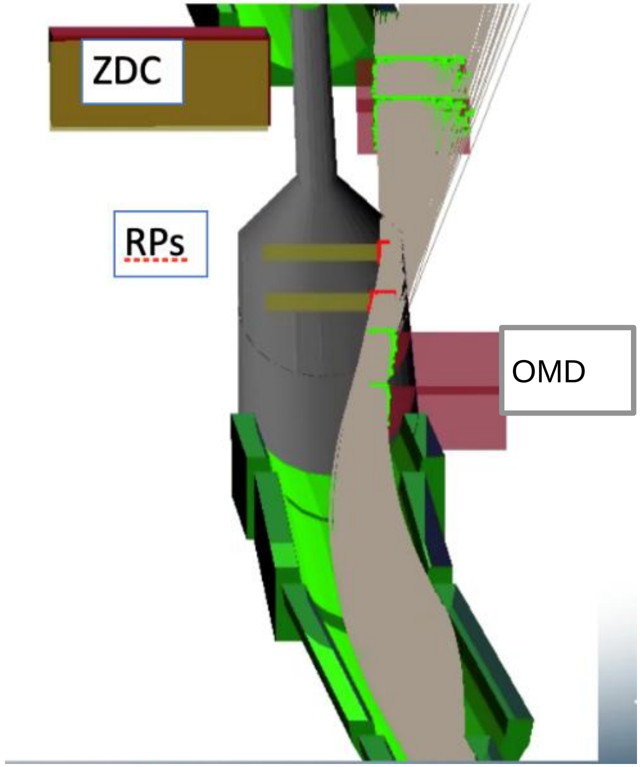
$\beta(z)$ is the RMS transverse beam size

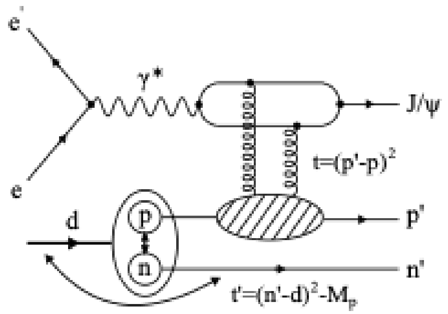
ε is the emittance.

- ✓ The Roman-Pots should provide measurements of **charged particles close to the beam core (** 0.0* $(10\sigma cut)$ < $\boldsymbol{\theta}$ < 5.0 mrad) (η > 6)
- ✓ **Movable** : as close as 10σ away from the beam; move out during beam injection
- ✓ RPs needs to be **integrated into the vacuum system =>** very close contact with accelerator to avoid negative impacts on the machine operation
  - ➞ **keep "minimal" components in vacuum.**
  - ➞ **cooling** of ~100 Watts per active layer (**conductive approach)**
- ✓ Insertion from top and bottom - need to minimize amount of material in front of ZDC
- ✓ **Good t-measurements** of far-forward charged particles
  - ➞ $\Delta p_T/p_T$< 10% for pT > 1GeV/c
  - ➞ **spatial resolution** in (x,y) < 140 um
  - ➞ **low material budget:** < 5% X0
  - ➞ **timing resolution** < 35 ps

Off-Momentum Detectors: requirements

(0.0 < $\boldsymbol{\theta}$ < 5.0 mrad, (η > 6))

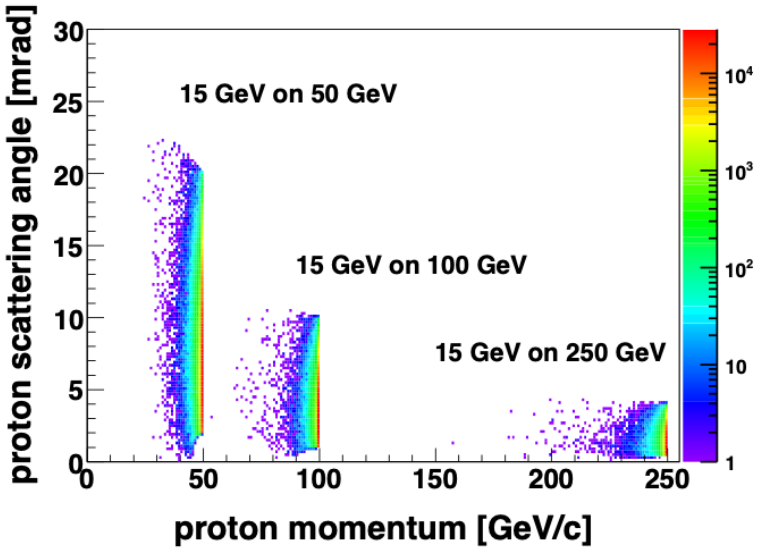




- ✓ Protons that come from nuclear breakup have a different magnetic rigidity than their respective nuclear beam (x_L<1)
- ✓ This means the protons experience more bending in the dipoles.
- ✓ As a result, **small angle (θ < 5mrad)** protons from these events will not make it to the Roman Pots, and will instead exit the beam pipe after the last dipole.
- ✓ Movable, Integration with the beam pipe is important.
  - ➞ $\Delta p_T / p_T$< 10% for pT > 1GeV/c
  - ➞ **spatial resolution** in (x,y) < 140um
  - ➞ **low material budget:** < 5% X0
  - ➞ **timing resolution** < 35 ps

B0-detectors: requirements

Full p_T coverage for forward-going protons is critical for EIC physics, but the high p_T-acceptance in RPOTs is limited by magnet's apertures => B0 detectors. Especially **important for low-energy operation.**

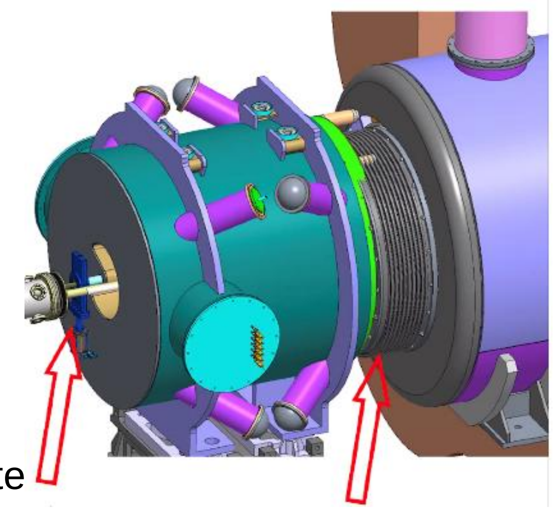


- B0-system should provide theta coverage in the range 5.5 < θ < 20.0 mrad (4.6 < η < 5.9) with respect to the hadron beam line.
  - ➞ Need to provide measurements of **charged particles**
    - $\Delta p_T / p_T$ < 7% for pT > 1GeV/c,
    - spatial resolution in (x,y) < 20um
    - low material budget: < 5% X0.
  - ➞ Need to provide measurements of forward **photons and pi0**: $\gamma + \gamma$ from π^0 separation to clearly isolate u-channel DVCS (B0-system shall measure **photons down to 100 MeV**. Energy resolution for photons σ(E)/E < 20%/sqrt(E) + (3)%

➞ **Limited space: must fit and be integrated into the warm area of the B0-dipole.**

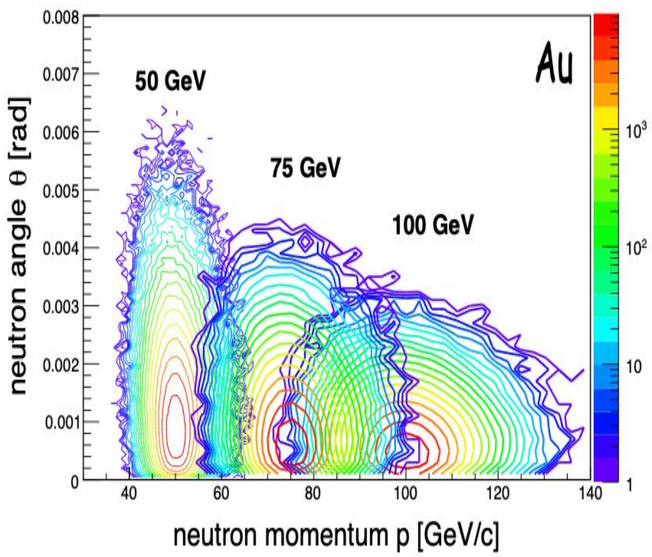
- Vacuum pump in front. Crossing angle: unequal space between beam-pipe and inner wall of the B0-bore.

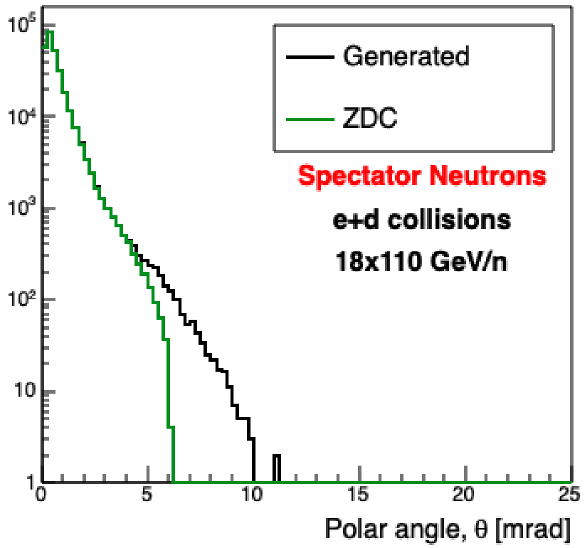
➞ B0 detectors and readout electronics must **tolerate the magnetic field** in the subsystem location.



Zero Degree Calorimeter: requirements

- ✓ The Zero Degree Calorimeter should provide measurements of neutral particles (**neutrons and photons**) => electromagnetic (EMCAL) and hadronic sections (HCAL)
- ✓ need **+/- 4 mrad** coverage => beam element free cone before the zero degree calorimeter to detect the breakup neutrons from heavy Ions
- ✓ For **neutrons** good measurements of t- (p_T) :
  - ➞ angular resolution $\sigma(\theta)/\theta < 2\text{mrad}/\sqrt{E}$
  - ➞ energy measurements $\sigma(E)/E < 50\%/\sqrt{E} + 5\%$
- ✓ For **photons**:
  - ➞provide photon measurements down to 100MeV.
  - ➞energy resolution $\sigma(E)/E < 10\%/\sqrt{E} + (1\text{-}3)\%$.
  - ➞angular resolution $\sigma(\theta)/\theta < 2\text{mrad}/\sqrt{E}$
- ✓ Must be compact enough to fit in the limited space allocated in the accelerator tunnel between beam-pipes (60x60x200 cm^3 at z-location 35.8 m)
- ✓ ZDC should provide a VETO for the charged particles



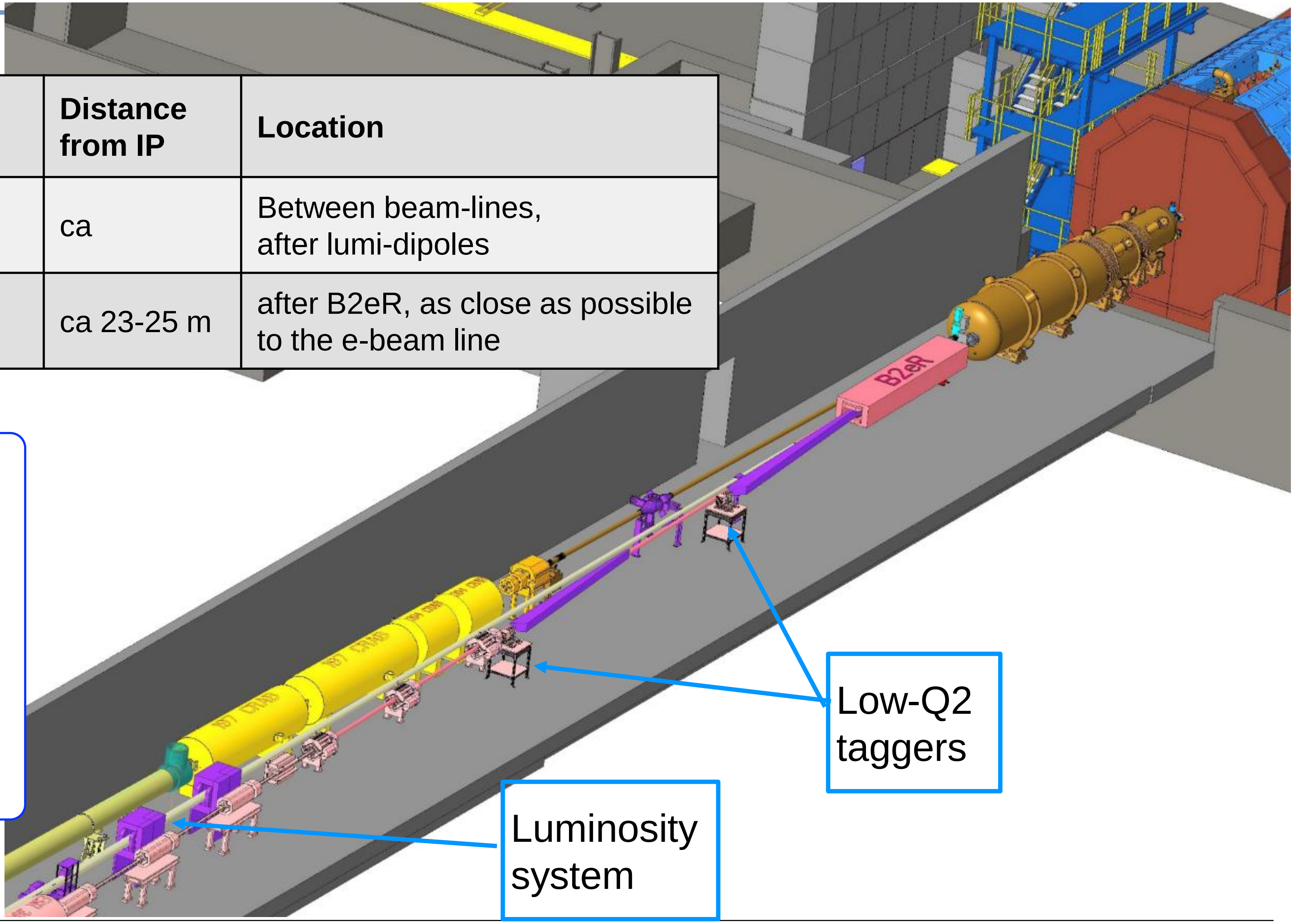


➞(interface) Transition region from larger beam pipe containing OMD to smaller pipe containing RP and **exit window for neutrals**

Far-backward (electron-outgoing) region

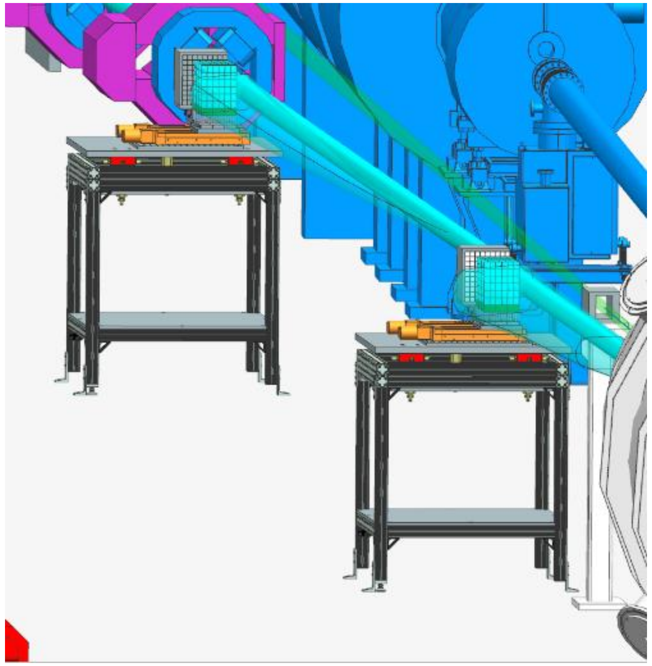
	Particles	Angle [mrad]	Distance from IP	Location
Luminosity	Photons/electrons	+/- 1mrad	ca	Between beam-lines, after lumi-dipoles
Low-Q2	electrons with different rigidity		ca 23-25 m	after B2eR, as close as possible to the e-beam line

- This area is designed to provide coverage for the low-Q^2 events (photoproduction, $Q^2 <\sim 1GeV^2$) . Need to measure a scattered electron position/angle and energy
- And luminosity detector (ep -> e'pγ bremsstrahlung photons)



Low-Q2: requirements

- The Low-Q^2 detectors will measure/tag scattered electrons with $Q^2 < 1$ GeV^2 in the far-backward region and complement the central detector (down to the he limits given by the divergence of the beam and beamline magnets.)
- Low-Q2 tracker:
- momentum resolution < 5%.
- timing resolution sufficient to resolve 10ns beam buckets
- The position of the Low-Q^2 tracker should be adjustable to accommodate different running conditions.
- Low-Q2 EMCAL with energy resolution for electrons $\sigma(E)/E < 10\%/\sqrt{E} + 3\%$.
- Low- Q^2 tracker should be able to measure the momentum of more than 10 electrons per bunch crossing and handle a data rate and operate reliably at a full projected EIC luminosity.
- LowQ2 system must be resistant to extreme background conditions (synchrotron radiation, bremsstrahlung events and slow neutrons in particular)



Luminosity: requirements

Requirements:

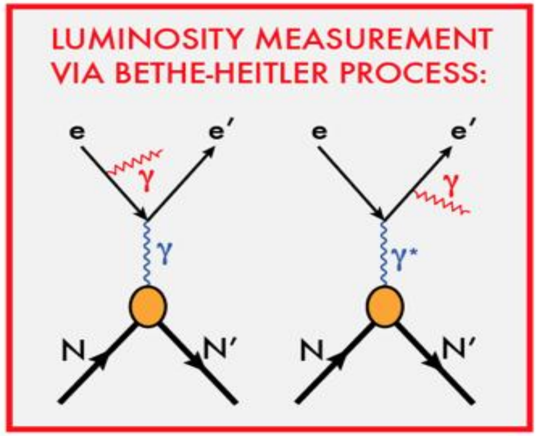
- Precise determination of **absolute luminosity at 1% level**
- Precise determination of **relative luminosity at 10^{-4} level** sorted by spin sates.

IR magnets should provide a +/- 1mrad "iron free" transportation for a cone of photons from IP.

Complementarity and redundancy (sensitive to different systematics)
-pair spectrometer (PS)
-direct photon calorimeter

➞Both should measure electrons with energy resolution of σ(E)/E < 15%/$\sqrt{E}$
➞Both should provide timing resolution sufficient to resolve 10ns beam buckets

The two luminosity detector dipoles must be connected by a beamline that is under vacuum with a conversion foil inside.
Direct photon calorimeter should have a radiation hard detector due to high synchrotron radiation load (maximum of annual local dose of about 7 MGy is expected with a top luminosity)



ep → epɣ, eA → eAɣ

σ_{BREMS} precisely known from QED (~0.5%) Bethe-Heitler 1934

- ➢ Luminosity measurements via **Bethe-Heitler process**
- ➢ Photons from IP collinear to e-beam
- ➢ First dipole bends electrons
- ➢ Photon conversion to e-/e+ pair
- ➢ Pair-spectrometer / direct photon calorimeter

Interfaces: far-forward detectors (RPOT/OMD, ZDC)

	InterfaceName	Description
OMD	Process Cooling	A cooling system will be required to remove heat from the tracking and readout electronics to prevent heat buildup.
OMD	Backward Space Constraint	The detector must be positioned after the B1APF dipole in the hadron going direction.
OMD	Beamline Integration	These detectors will be integrated with the outgoing hadron beamline and will be enclosed within it's vacuum system.
OMD	Forward Space Constraint	The detector must be positioned before the Roman Pots in the hadron going direction.
OMD	RF Shielding	This detector will generate RF radiation that the accelerator beamline must be shielded from.
OMD	Zero-Degree Calorimeter Interference	The size and placement of the detector should be designed to have minimal interference with the 4 milliradian neutron cone required by the zero-degree calorimeter.
RPOT	Process Cooling	A cooling system will be required to remove heat from the tracking and readout electronics to prevent heat buildup.
RPOT	Accelerator Interference	The Roman Pot detectors will come within 10 sigma of the center of the beam, and will impact the beam characteristics in a way that must be compensated for.
RPOT	Backward Space Constraint	The detector must be positioned after the off-momentum detectors in the hadron going direction.
RPOT	Beamline Integration	These detectors will be integrated with the outgoing hadron beamline and will be enclosed within it's vacuum system.
RPOT	Forward Space Constraint	The detector must be positioned before the B2PF magnet in the hadron going direction.
RPOT	RF Shielding	This detector will generate RF radiation that the accelerator beamline must be shielded from.
ZDC	Process Cooling	A cooling system will be required to remove heat from the calorimeter and readout electronics to prevent heat buildup.
ZDC	Neutron Cone Dependency	The placement of the Zero Degree Calorimeter is dependent on the neutron cone and should be positioned to optimize detector performance and resolution.
ZDC	Neutron Cone Interference	There should minimal interference within the 4 milliradian neutron cone in front of the Zero Degree Calorimeter detector.
ZDC	ZDC Placement	The Zero Degree Calorimeter will be positioned between the outgoing hadron and incoming electron beamlines.

Interfaces: far-forward detectors B0

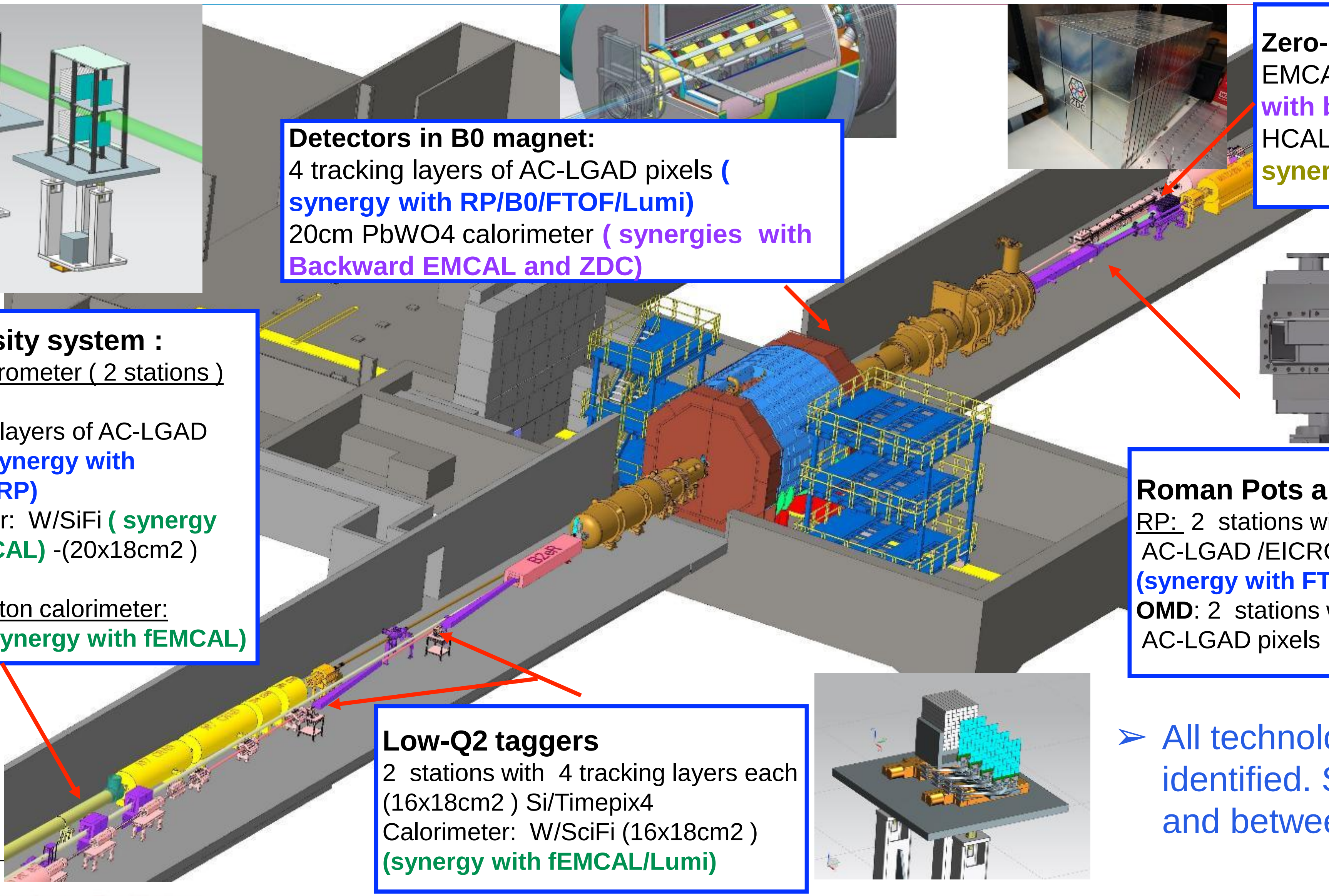
	InterfaceName	*Description*
B0	B0 Support System	The B0 detector will be supported in the interior of the B0 magnet and will be dependent on the B0 magnet design, and must be adequate to support the weight of the crystals and the tracking detectors.
B0	Exterior Space Constraint	B0 detector must fit entirely within the bore of the B0 magnet.
B0	Interior Space Constraint	The electron and hadron beam pipes must be contained within the B0 detector.
B0	Forward Space Constraint	Access to the B0 detector is constrained by the vacuum valve in front of the B0 magnet. 20 cm free space is needed for the B0 detector installations.
B0	Backward Space Constraint	The position of and accessibility of the B0 detector in the backward direction is limited by the cryostat containing the final focusing magnets.
B0	Process Cooling	A cooling system will be required to remove heat from the calorimeter and electronics readouts, to maintain an acceptable temperature.
B0	Low Voltage	The detector will receive DC power provided by the Detector Electronics group.
B0	Bias Voltage	The detector will receive DC power provided from the electronics racks to support electronics.
B0	High Voltage	The detector will receive DC power provided by the Detector Electronics group to support silicon sensors and calorimeter.
B0	Slow Controls	Network connection from the DAQ system to the B0 detector's slow controls interface.
B0	Data Transfer and Control Interface	Fiber connection from the DAQ system to the detector's readout to perform configuration, control, and data acquisition.
B0	Timing Interface	Fiber connection from the DAQ system to the detector's readout used for timing synchronization.

Interfaces for far-backward detectors (Low-Q2,Lumi)

	InterfaceName	*Description*
LowQ2	Process Cooling	Either a liquid or gas cooling system will be required to remove heat from the calorimeter, tracking and readout electronics, to maintain them at room temperature.
LowQ2	Beam pipe Exit Window	The performance of the LowQ2 detector will depend on the thickness and shape of the electron beam pipe exit window.
LowQ2	LowQ2 Beamline Proximity	The LowQ2 detector must be positioned as close as possible electron beam pipe in order to detector particles at a shallow angle from the electron beam.
LowQ2	Lumi-Dipole Interference	The LowQ2 detector should be position such that it receives minimal magnetic interference from the Lumi-Dipole.
LUMI	Process Cooling	A cooling system will be required to remove heat from the tracking and readout electronics to prevent heat buildup.
LUMI	Accelerator Feedback	The luminosity detector will provide fast feedback to the accelerator control system, allowing them to monitor conditions at the interaction point.
LUMI	Accelerator Interference	Detector must be positioned between the electron and hadron beamlines in the far backward area, and it's size and position are governed by the adjacent accelerator components. IR magnets should provide a +/- 1mrad “iron free” transportation for a cone of photons from IP.
LUMI	Beamline Alignment	The center of the luminosity detector must be positioned along the centerline of the incoming electron beam as it passes through the interaction point.
LUMI	Detector Placement	The detector must be positioned to avoid magnetic interference from adjacent beamline magnets.
LUMI	Dipole Cooling	The two dipoles in front of the detector will need LCW cooling. (Confirm this)
LUMI	Electronics Placement and Shielding	The detector electronics enclosures must be positioned near the detector and must be shielded from radiation.
LUMI	Placement	The luminosity detector must be positioned between 30 and 100 meters from the interaction point in the backward direction, and the dectors centerpoint must be positioned at beam level.

Backup

Technology Overview / Synergies



Detectors in B0 magnet:
4 tracking layers of AC-LGAD pixels **(synergy with RP/B0/FTOF/Lumi)**
20cm PbWO4 calorimeter **(synergies with Backward EMCAL and ZDC)**

Zero-degree calorimeter (ZDC)
EMCAL: PbWO4 calorimeter **(synergy with backward EMCAL/B0)**
HCAL: SiPM-on-Tile cal (reuse Fe-blocks, **synergy with Forward Insert HCAL.**)

Luminosity system :
Pair-spectrometer (2 stations)
each with:
2 tracking layers of AC-LGAD pixels **(synergy with FTOF/B0/RP)**
calorimeter: W/SiFi **(synergy with fEMCAL)** -(20x18cm2)

Direct photon calorimeter:
W/SciFi **(synergy with fEMCAL)**

Roman Pots and Off-Momentum detectors
RP: 2 stations with 2 tracking layers each
AC-LGAD /EICROC pixels
(synergy with FTOF/B0/OMD/LUMI)
OMD: 2 stations with 2 tracking layers each
AC-LGAD pixels (**synergy with FTOF/B0/RP/Lumi)**

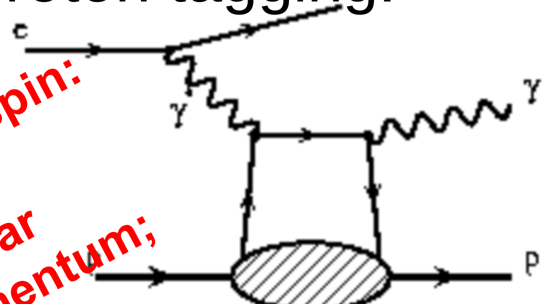
Low-Q2 taggers
2 stations with 4 tracking layers each
(16x18cm2) Si/Timepix4
Calorimeter: W/SciFi (16x18cm2)
(synergy with fEMCAL/Lumi)

- All technology choices have been identified. Synergy with central detector and between sub-components.

Forward physics overview

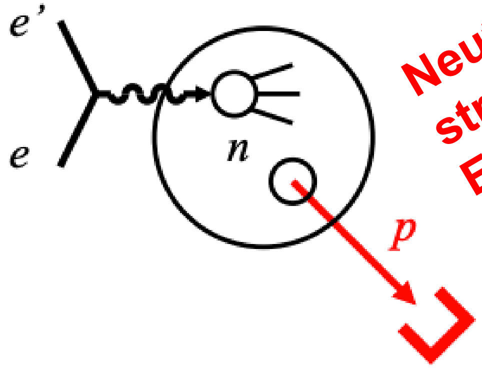
Lots of important final-states which require Far-Forward detectors!!

e+p DVCS events with proton tagging.



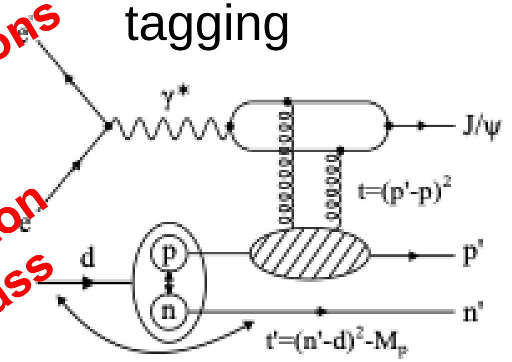
Proton spin: orbital angular momentum; imaging

DIS on the deuteron



Neutron structure; EMC effects

e+d exclusive J/Psi events with proton or neutron tagging

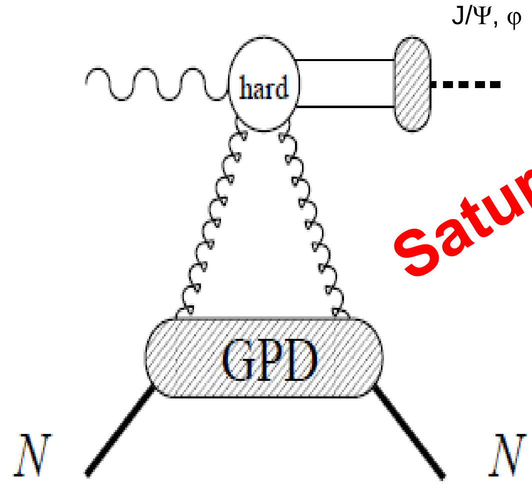


Gluons

Proton mass

Short-Range Correlations

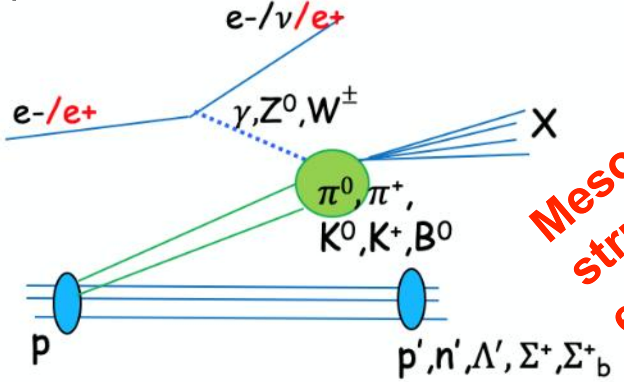
coherent/incoherent J/ψ production in eA



Saturation

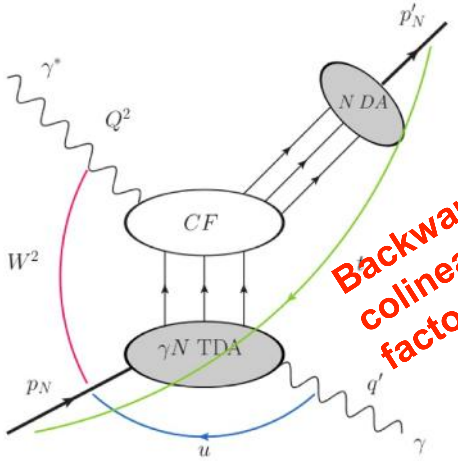
Sullivan process:

- ➢ with neutron tagging (ep→ (π) →e' n X) and Lambda decays ($\Lambda \rightarrow p\pi-$ and $\Lambda \rightarrow n\pi0$)



Meson structure

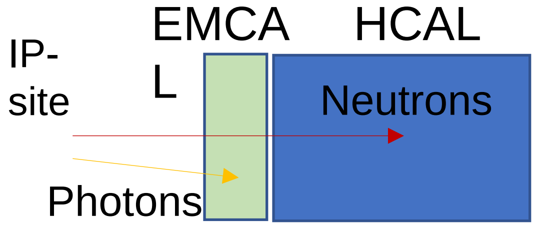
u-channel backward exclusive electroproduction



Backward-angle colinear factorization

Zero Degree Calorimeter: requirements

✓ The Zero Degree Calorimeter should provide measurements of neutral particles (**neutrons and photons**)



Zero-Degree Calorimeter

ZDC requirements summary

Physics Process	Final-state particles	Lumi Needs	Required HCAL E resolution	Required HCAL Angular Resolution	Required EMCAL E Resolution	Required EMCAL Angular Resolution	Notes
Spectator tagged e+d breakup	neutrons	1 fb-1 (free neutron); 20 - 100 fb-1 (nuclear effects)	$\Delta\sigma_E/E < 50\% \oplus 5\%$	$\Delta\sigma_\theta/\theta <$ 2 mrad $/\sqrt{E}$	N/A	N/A	Ref.1, Ref.2
Exclusive π^+ production	neutrons	20 - 100 fb-1			N/A	N/A	
Incoherent Vetoing of e+A events	neutrons/photons	10 fb-1	$\Delta\sigma_E/E < 100\%/\sqrt{E}$	N/A	100 MeV photon sensitivity	N/A	Ref. 3
u-channel backward VCS	photons	10 fb-1	N/A	N/A	$\Delta\sigma_E/E < 20\% \oplus 3\%$	< 1-2cm	Ref.4, Ref.5
Kaon structure functions	$\Lambda^0 \rightarrow n + \pi^0$	20 - 100 fb-1	$\Delta\sigma_E/E < 35-50\% \oplus 3-5\%$	$\Delta\sigma_\theta/\theta < 2$ mrad $/\sqrt{E}$	$\Delta\sigma_E/E < 20\%/\sqrt{E}$	$\Delta\sigma_\theta/\theta <$ 2 mrad $/\sqrt{E}$	Ref.6, Ref. 7,REQUIREMENTS

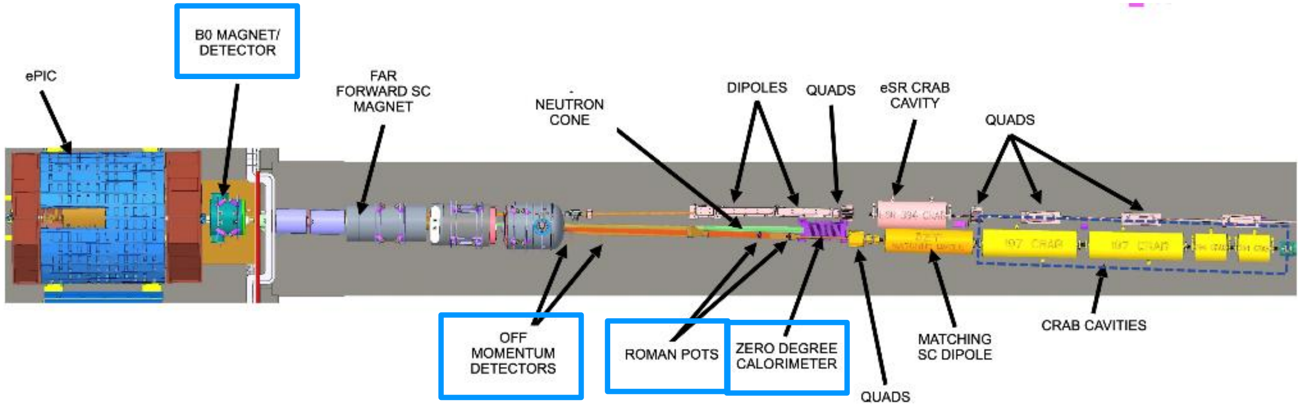
Far-forward: Technology and Participating Institutions

B0 detectors   DSTC: Zvi Citron (BGU)

✓ B0-tracker: (AC-LGAD pixels), B0-calorimeter (PbWO4)

DSL: Alex Jentsch (BNL)

Ben Gurion University of the Negev, Israel
Hebrew University of Jerusalem, Israel
Tel Aviv University, Israel



Zero Degree Calorimeter (ZDC)

DSTC:Yuji Goto, (Riken) Miguel Arratia (UCR)

✓ Zero Degree Calorimeter (ZDC):
EMCAL (PbWO4), HCAL(SiPM-on-Tile)

Riken, Japan
Kobe, Japan
Taiwan
South Korea
Kansas university, USA
PNNL, USA
UCR, USA

RomanPots and OMD   DSTC:Alex Jentsch (BNL)

✓ Roman Pots, Off-Momentum detectors: (AC-LGADs pixels)

AC-LGAD consortium :
BNL, USA
IJCLab - Orsay, France
OMEGA , France
IRFU/CEA-Saclay, France

Vacuum system design:
Brazil

Far-backward: Participating Institutions

Charge 5

Lumi - pair-spectrometer :

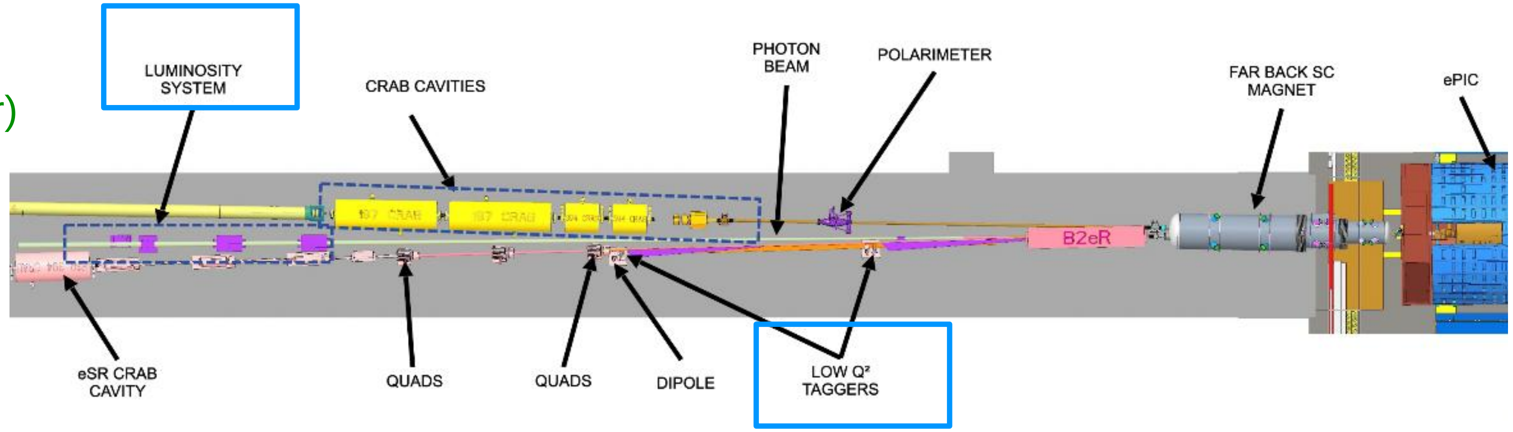
DSL/DSTC - Nick Zachariou (York)

✓ Lumi -PS: (AC-LGAD tracker, W-SciFi calorimeter)

York, UK · Prague, CZ

Kraków, Poland

JLAB/BNL · Houston, USA



Lumi - photon calorimeter:

DSL/DSTC - Krzysztof Piotrzwowski (Kraków)

✓ Lumi DP cal. (W-SciFi)

Kraków, Poland · Prague, CZ

York, UK

Low-Q2 tagger:

✓ Low-Q2 tracker (Timepix4), Low-Q2 calorimeter (W-SciFi)

DSL - Jaroslav Adam (Prague)
DSTC - Simon Gardner (Glasgow)

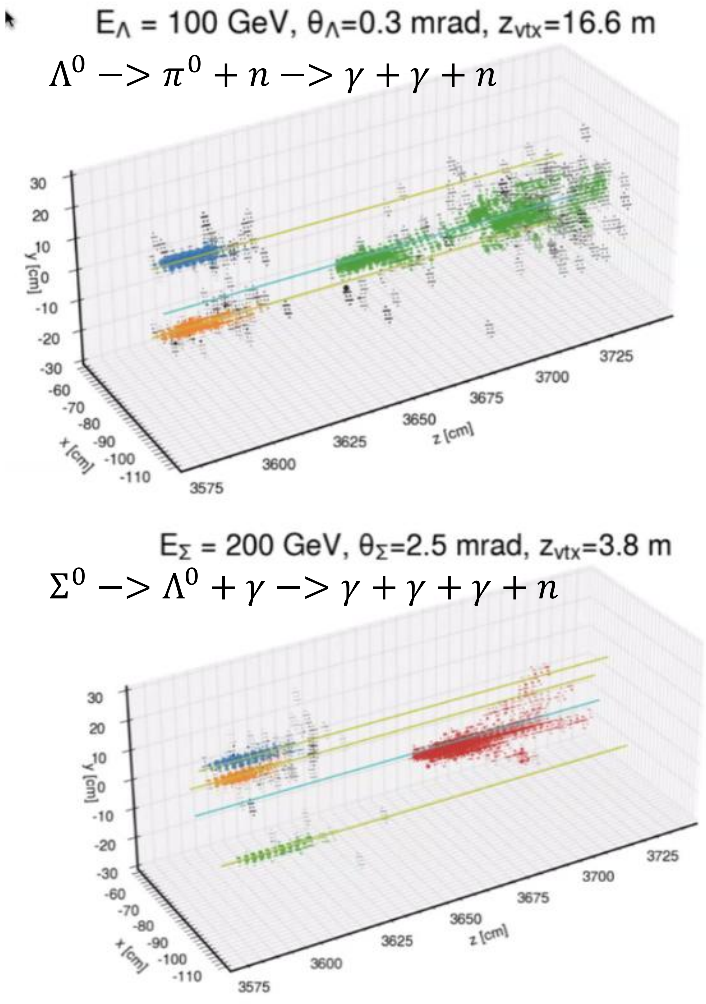
Glasgow, UK · W&M, USA

York, UK · Prague, CZ

ZDC Technology: HCAL SiPM-on-Tile

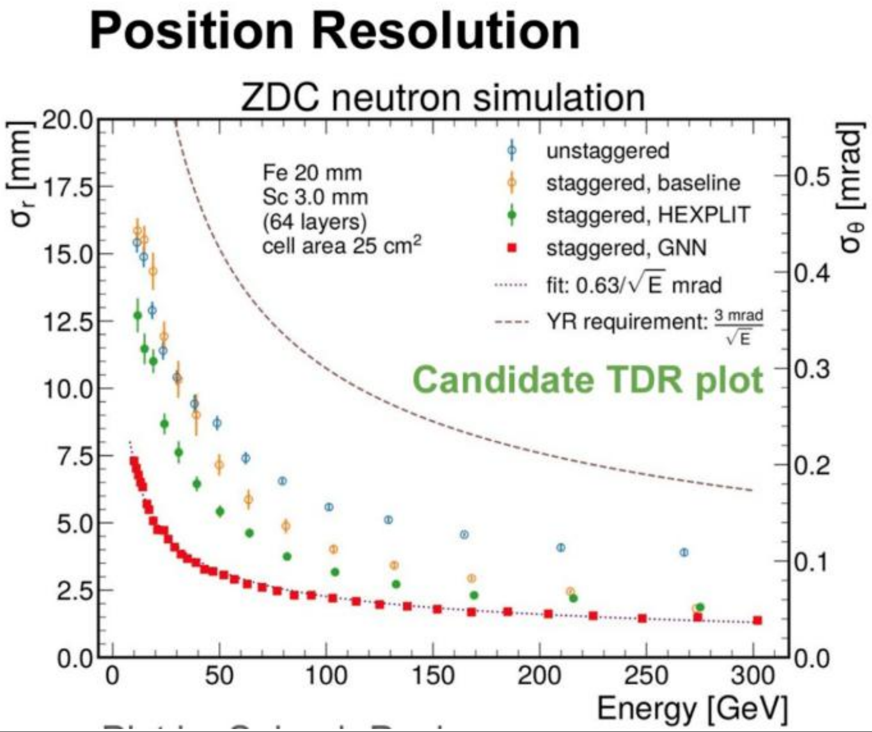
$\Lambda^0 -> \pi^0 + n -> \gamma + \gamma + n$

$\Sigma^0 -> \Lambda^0 + \gamma -> \gamma + \gamma + \gamma + n$



Important for meson form factor studies (with Lambda/Sigma in the target fragmentation - long decay-length)

Resolutions:
Λ^0 decay vertex: ~ 1 m
Λ^0 or Σ^0mass: ~ 7-10 MeV
θ resolution: ~ 50-100 urad



HEXPLIT design and algorithm described in *"Leveraging staggered tessellation for enhanced spatial resolution in high-granularity calorimeters"* NIMA 1060 (2024) 169044