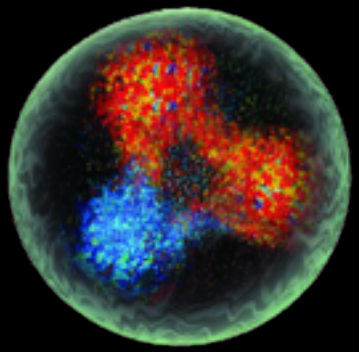
University of Glasgow

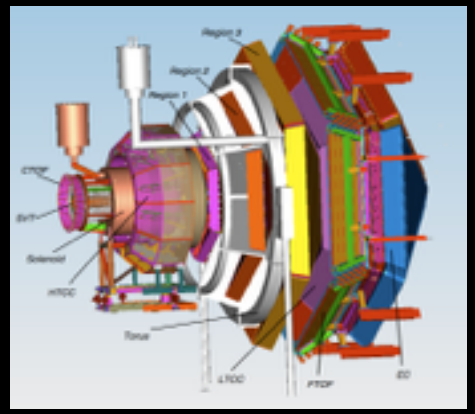
Jefferson Lab
EXPLORING THE NATURE OF MATTER

CLAS12 at Jefferson Lab



Daria Sokhan

University of Glasgow, UK



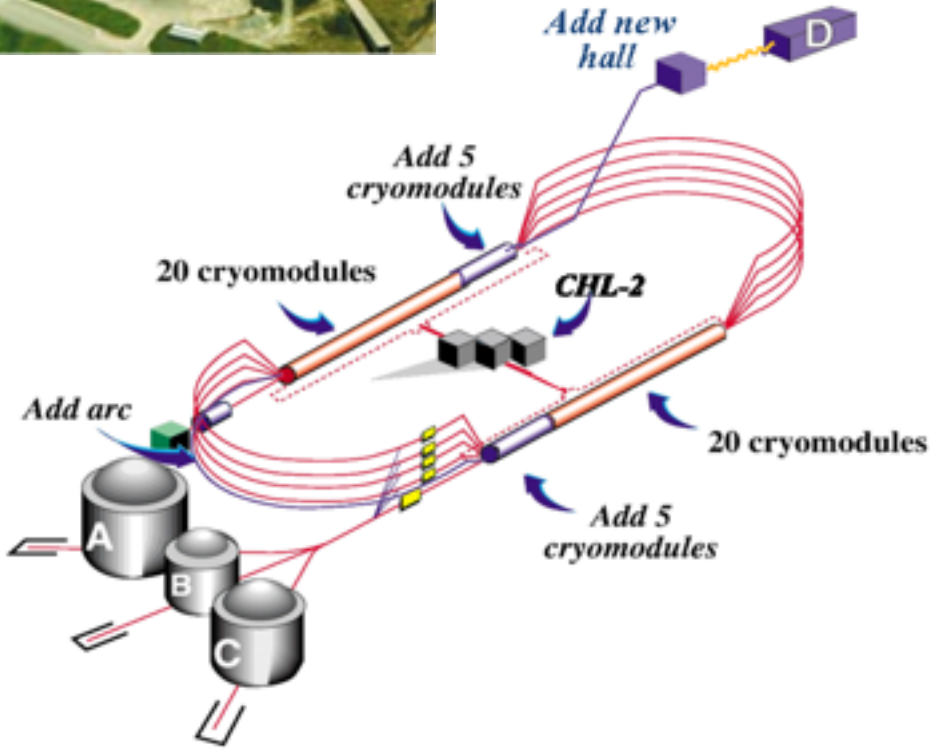
IPPP/NuSTEC Topical Meeting on Neutrino-Nucleus Scattering
IPPP, Durham, UK — 19 April 2017

Jefferson Lab

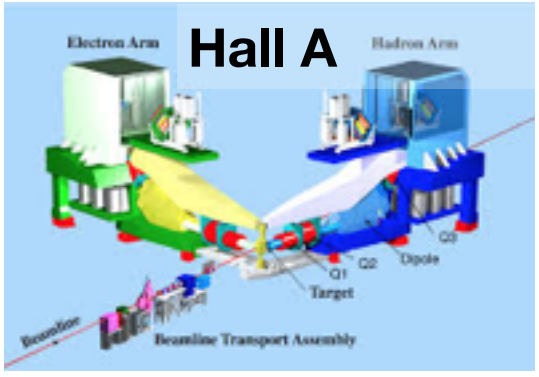
Jefferson Lab

CEBAF: Continuous Electron Beam Accelerator Facility.

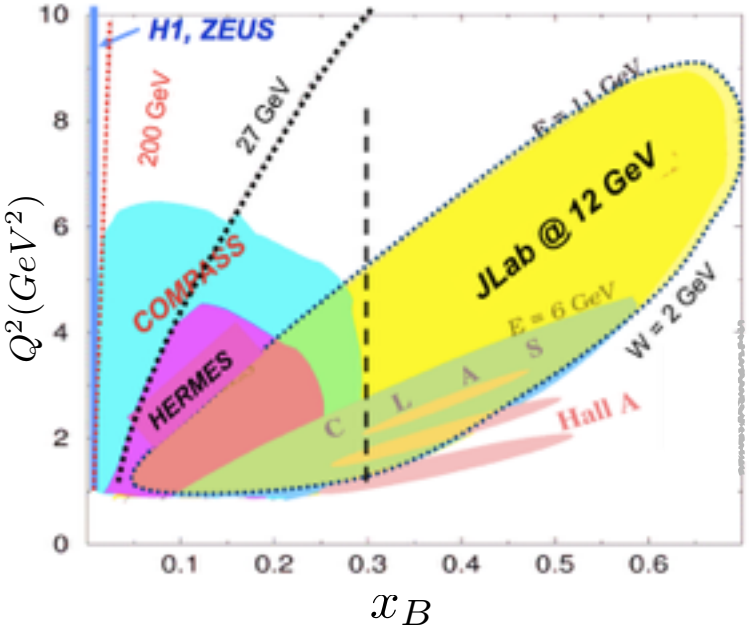
- Energy up to 11 GeV (Halls A, B, C), 12 GeV Hall D
- Energy spread $\delta E/E_e \sim 10^{-4}$
- Electron polarisation up to ~80%, measured to 3%
- Beam size at target < 0.4 mm



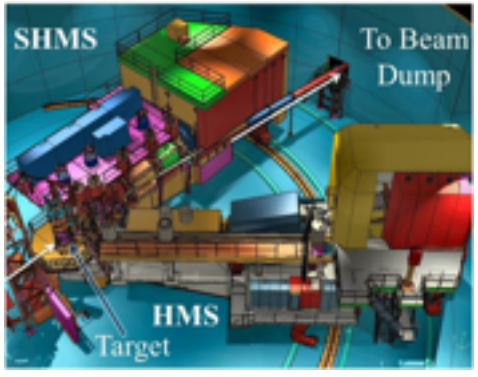
JLab @ 12 GeV



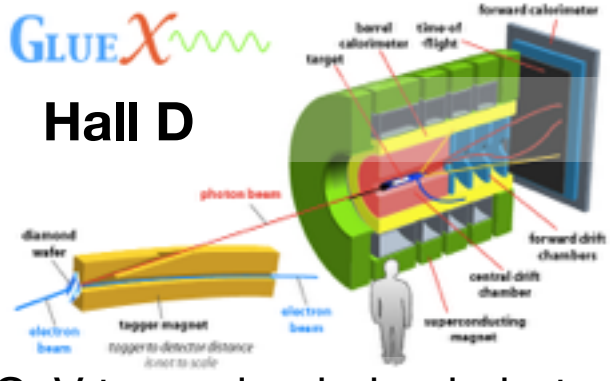
High resolution($\delta p/p = 10^{-4}$) spectrometers, very high luminosity, large installation experiments.



Hall C

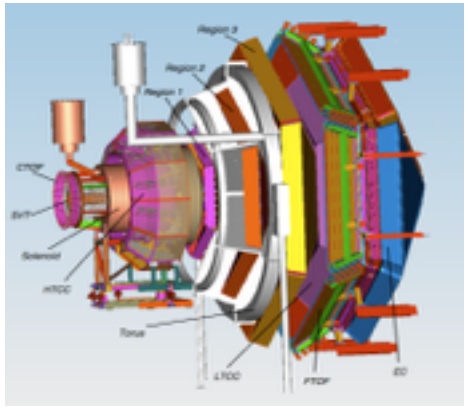


Two movable high momentum spectrometers, well-defined acceptance, very high luminosity.



9 GeV tagged polarised photons, full acceptance

Hall B: CLAS12



Very large acceptance, high luminosity.

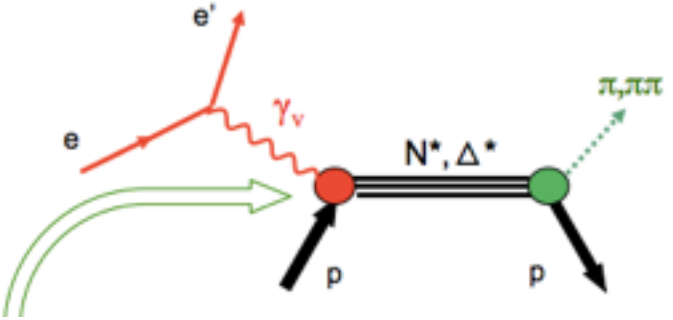
CLAS12

CLAS12 physics

- 3D and spin structure of the nucleon and nuclei: deep exclusive and semi-inclusive reactions, meson electro-production for study of Generalised Parton Distributions (GPDs), Transverse Momentum-dependent Distributions (TMDs).

- Neutron magnetic moment.

- Neutron F_{2n}: d/u ratio.



- Full range of Q^2, from quasi-real photons to ~ 9 GeV^2, for hadron spectroscopy: N* electroexcitation, search for hybrid mesons, role of glue and generation of mass.

- Medium modifications: in-medium structure functions, colour transparency.

Targets

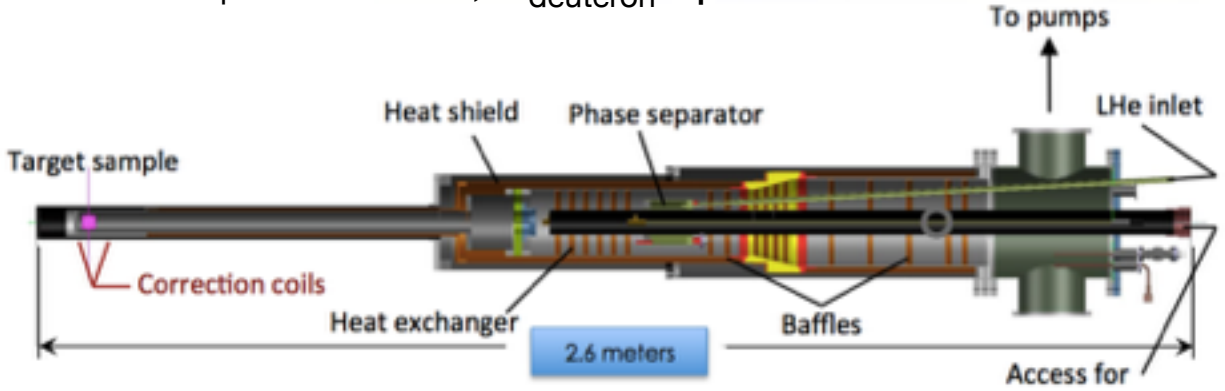
Unpolarised:

- Liquid H_2 ~ 2017/18
- Liquid D_2 ~ 2019
- Gas D_2 **(E12-06-113)**
- **Nuclear targets**
  ~ 2021 **(E12-06-117)**

- Transversely polarised frozen spin HD
  - He Dilution Refrigeration: ~200 mK needed for P > 80 %.
  - Target system being modified for electron beam.

~ 2021/22

- Polarised **^{7}LiH** and **^{7}LiD** **(E12-14-001)** ~ 2022
- Longitudinally polarised frozen NH_3 and ND_3 ~ 2019/20
  - Dynamic Nuclear Polarisation (DNP) of target material, cooled to 1K in a *He* evaporation cryostat.
  - P_{proton} > 80%, $P_{deuteron}$ up to 50%.



C. Keith (JLab)

CLAS12

Design luminosity

$L \sim 10^{35}\ cm^{-2}\ s^{-1}$

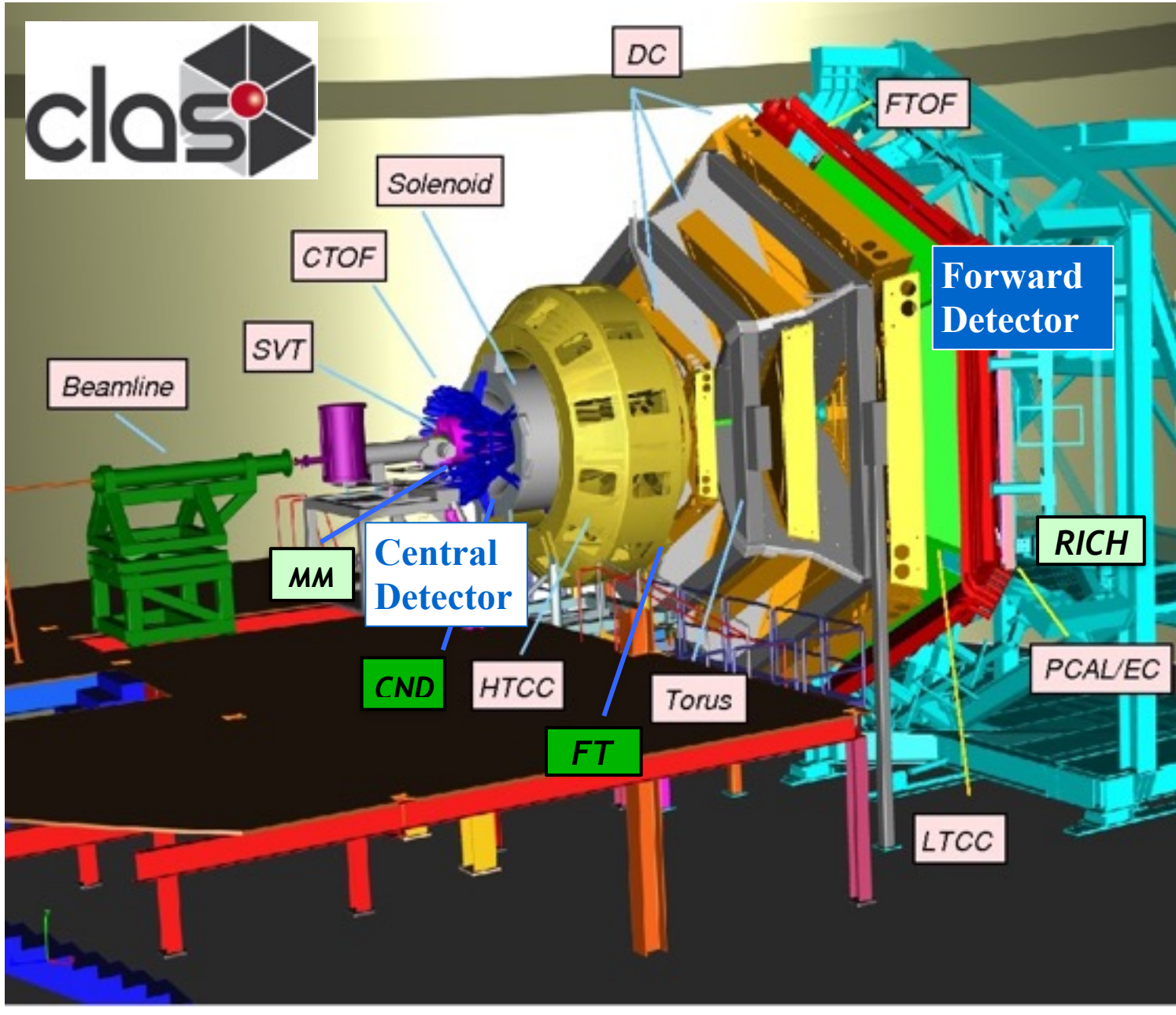
Acceptance for charged particles:

- **Central (CD),** $35^o < \theta < 125^o$
- **Forward (FD),** $5^o < \theta < 35^o$

Acceptance for photons and electrons:

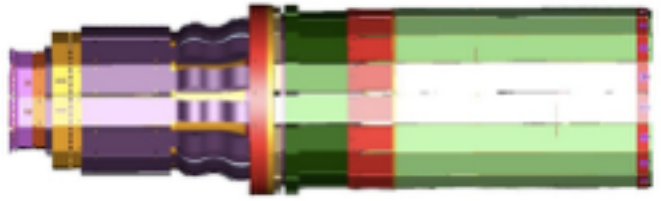
- **FT,** $2.5^o < \theta < 5^o$
- **EC,** $5^o < \theta < 35^o$

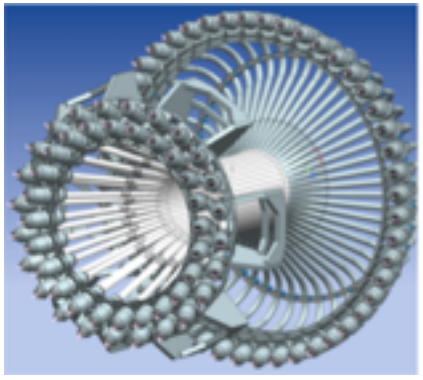
High luminosity & large acceptance:
Concurrent measurement of exclusive, semi-inclusive, and inclusive processes

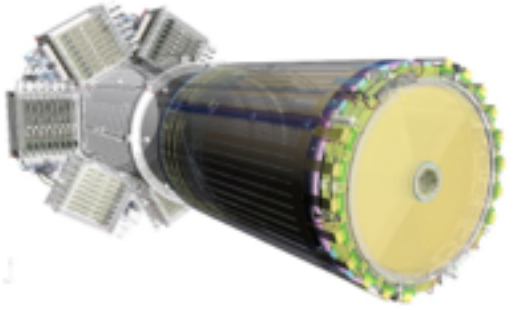


Central Detector

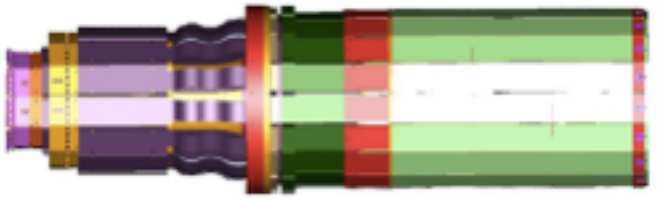
- Angular coverage: ~ 35 - 125 degrees polar, full azimuthal.
- A set of barrel detectors positioned around the target within the 5 T axial field of a superconducting solenoid magnet (Møller electron shield, field for tracking, field for polarised target):
  - Vertex trackers (SVT and MVT)
  - Time of flight system (CTOF)
  - Neutron detector (CND)



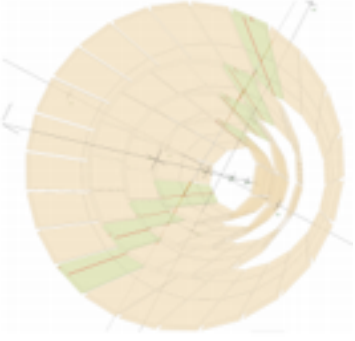




Silicon Vertex Tracker (SVT)



- Will measure momentum and determine vertex of charged particles.
- Four radial regions, azimuthally segmented, two Si layers in each region.



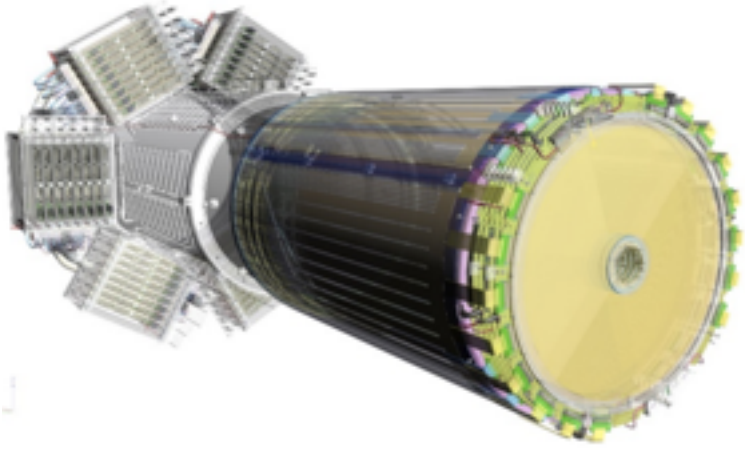
Angular coverage θ	35°–125°
Angular coverage Φ	~2π
Spatial resolution	50-65 μm
Momentum resolution	~6%
θ resolution	10–20 mrad
ϕ resolution	~5 mrad

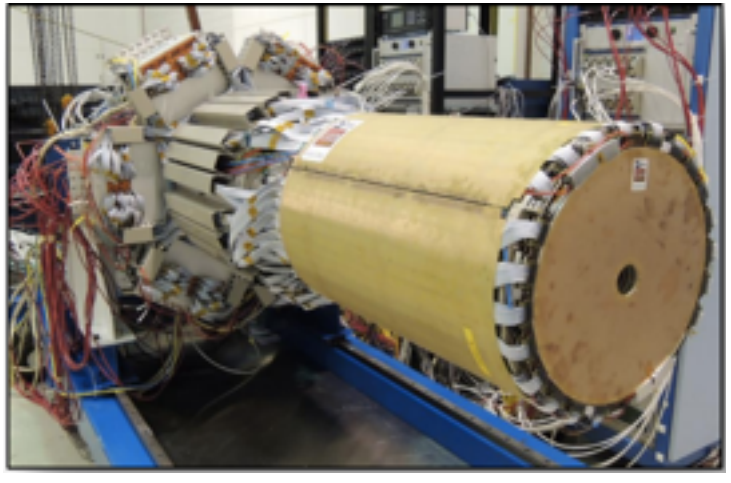
MicroMega Vertex Tracker (MVT)

- Improved track reconstruction in vicinity of target.

- Barrel tracker (18 cylindrical detectors in 6 layers, Ar + 10% C_4H_{10} gas), covers 35 - 125 deg, enhances polar angle resolution.

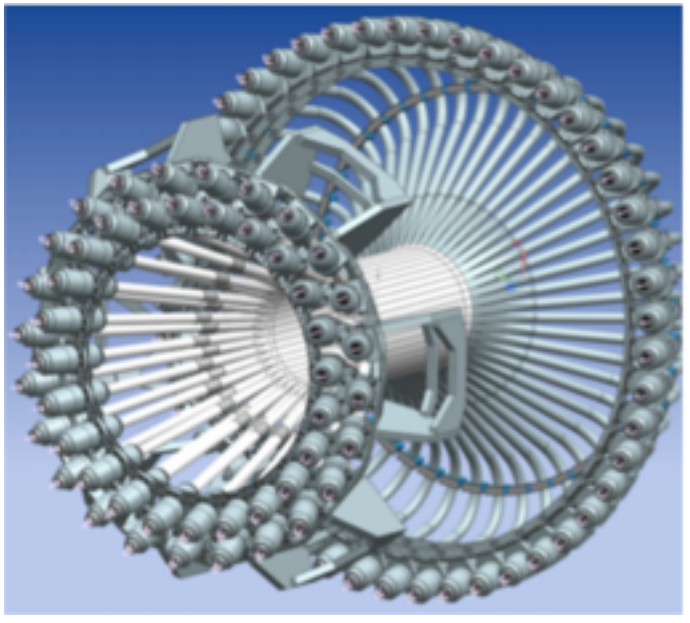
- Forward tracker (6 disk detectors, Ne + 10% C_2H_6 +10% CF_4 gas), covers 6 - 29 deg, improved vertex resolution by factor 3 - 10 compared to drift chambers.





Central Time-of-Flight (CTOF)

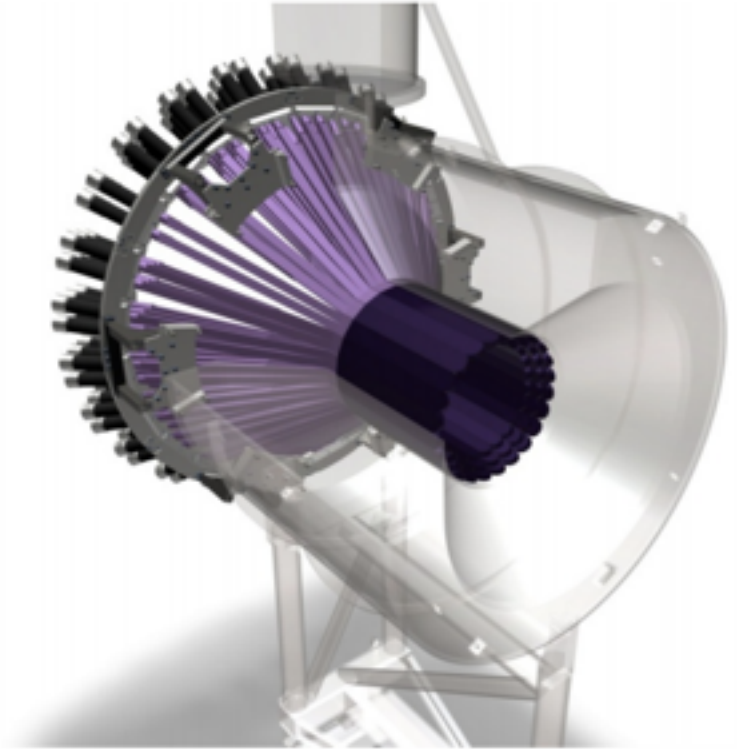
- Provides timing information for charged particle ID.
- Barrel of plastic scintillator paddles, double-sided PMT read-out via long focussing light-guides, 35 - 125 deg coverage, full azimuthal.
- Design resolution: 65 ps.

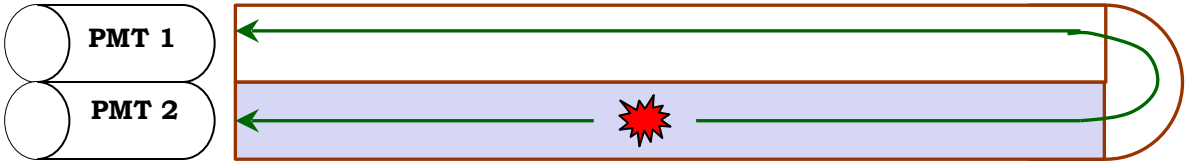


PID:	
π/K Separation	3.3σ separation up to 0.64 GeV
K/p Separation	3.3σ separation up to 1.00 GeV
π/p Separation	3.3σ separation up to 1.25 GeV

Central Neutron Detector (CND)

- Identification of neutrons (0.2 - 1 GeV/c) on the basis of timing.
- Three-layer barrel of plastic scintillators (40 - 120 deg), segmented azimuthally, PMT read-out upstream through long light-guides, pairs coupled via u-turn light-guides downstream.
- Neutron detection efficiency ~ 10%.
- Momentum resolution ~ 4 - 12%.

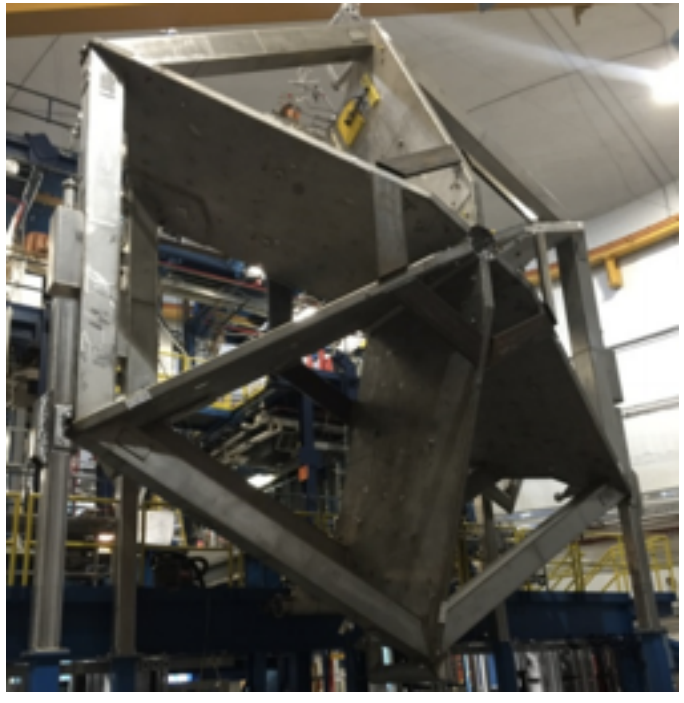


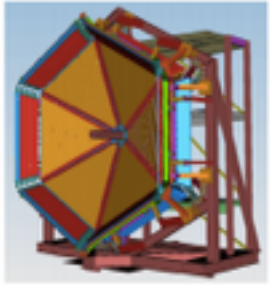


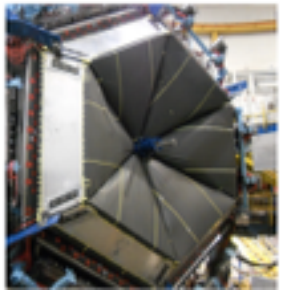
Forward Detector

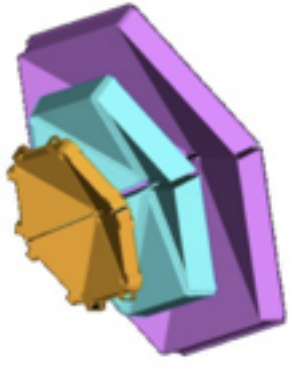
- Angular coverage: ~ 2.5 / 5 - 35 degrees polar.
- A set of detectors segmented into six sectors to fit within the regions of a superconducting toroidal magnet (peak field 3.58 T):

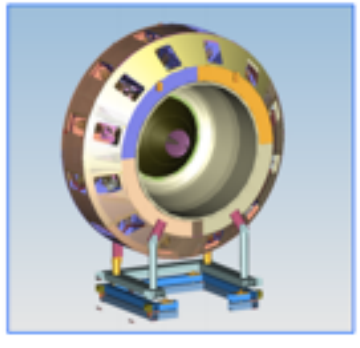
  - Cherenkov Counters (HTCC, LTCC, RICH)
  - Drift Chambers (DC)
  - Time of flight system (FTOF)
  - Calorimeters (PCAL/EC)
  - Forward Tagger (FT)







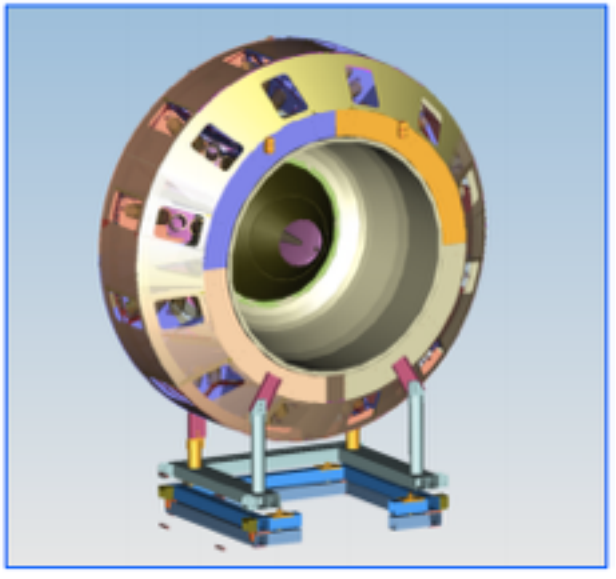




High Threshold Cherenkov Counter (HTCC)

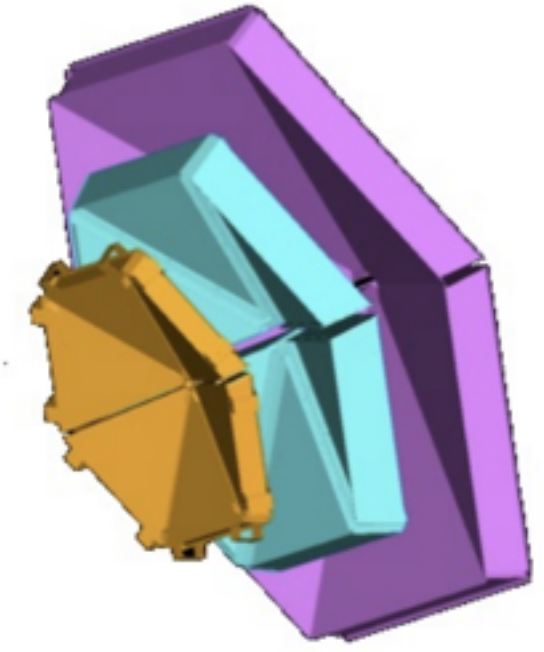
* Will provide fast trigger on scattered electrons, pion / electron discrimination.

* Multifocal mirror: 60 ellipsoidal composite mirrors, 8 PMTs in each sector.



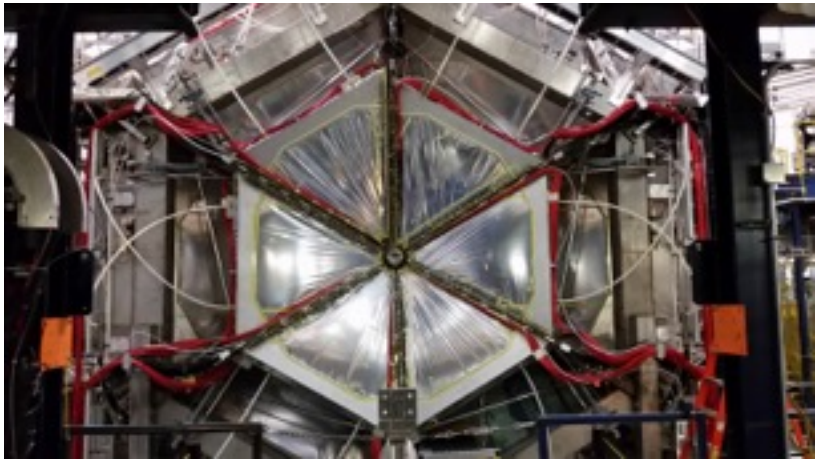
PARAMETER	DESIGN VALUE
Working Gas	CO_2@1atm, 25°C
Angular Coverage	θ= 5° – 35°; ϕ= 0° – 360°
Threshold	**15 MeV/c** (electrons)
Threshold	**4.9 GeV/c** (charged pions)
Rejection of pions at 2 GeV/c	~10^3 (99.9% electron detection efficiency)
Rejection of pions at 4 GeV/c	~0.5x10^3 (99.9% electron detection efficiency)

Drift Chambers



- Momentum of charged particles.
- Three regions (~2, ~3, ~4m from target), each with 6 sectors and 2 super-layers, hexagonal cells, 90%-10% argon-CO_2.
- Spacial resolution of each cell: 250 - 350 microns.

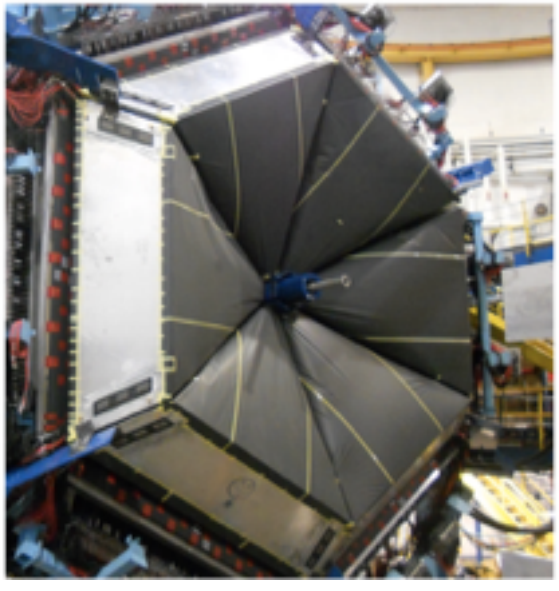
DC – Tracking Specifications	
PARAMETER	**SPECIFICATION**
Angular coverage	$5^o - 40^o$ (50% ϕ-coverage at 5^o)
Momentum resolution	$dp/p < 1\%$
θ Resolution	1 mrad
ϕ Resolution	1 mrad/sinθ
Luminosity	10^{35} cm^{-2} s^{-1}

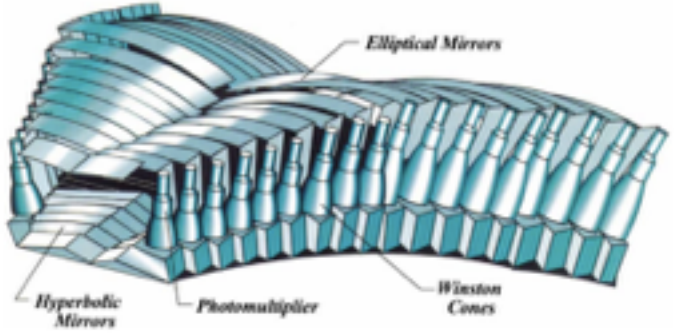


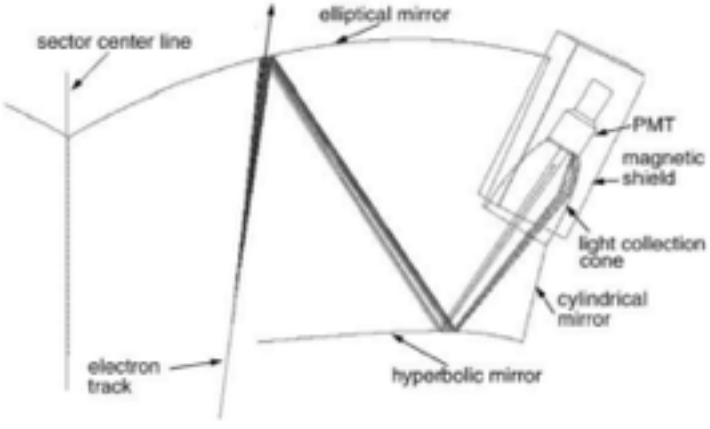
Low Threshold Cherenkov Counter (LTCC)

* Kaon / pion discrimination: 3.5 - 9 GeV/c.

* Six sectors of lightweight mirrors, light collecting Winston cones, PMTs, magnetic shields. Uses C_4F_{10} gas.

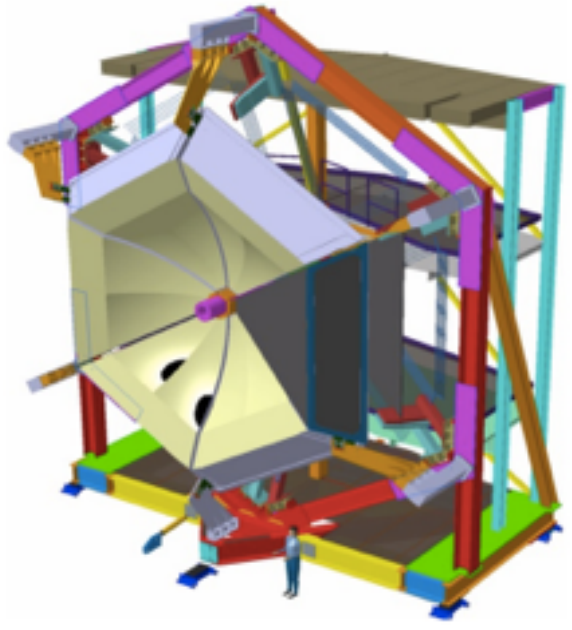






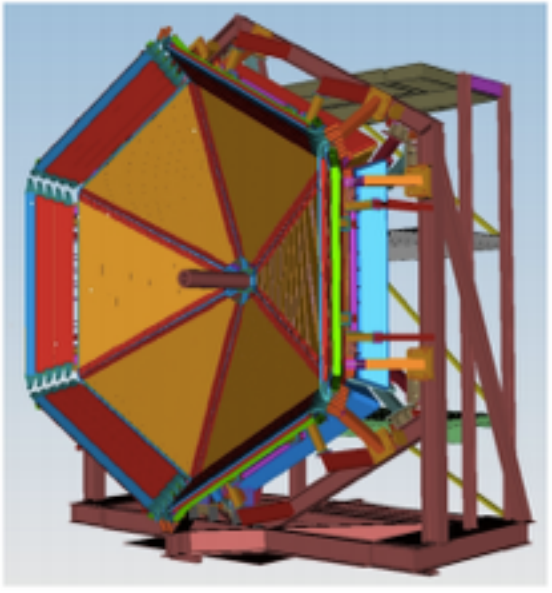
Ring Imaging Cherenkov Counter (RICH)

- Will replace one sector of the LTCC, improve particle ID in 3 - 8 GeV/c momentum range.
- Aerogel, multi-anode PMTs, mirrors.



PARAMETER	DESIGN VALUE
Momentum range	3-8 GeV/c
π/K rejection factor	Not less than 500
K/p rejection factor	Not less than 100
Angular coverage	5° to 25°

Forward Time-of-Flight



- Timing information and particle ID.
- Six sectors of plastic scintillator paddles, PMT read-out at both ends of each paddle.
- Coverage and resolution:

$$\theta : 5^\circ - 35^\circ, \phi : 50\% \; at \; 5^\circ, 85\% \; at \; 35^\circ$$

Design resolution: 60 to 160 ps.

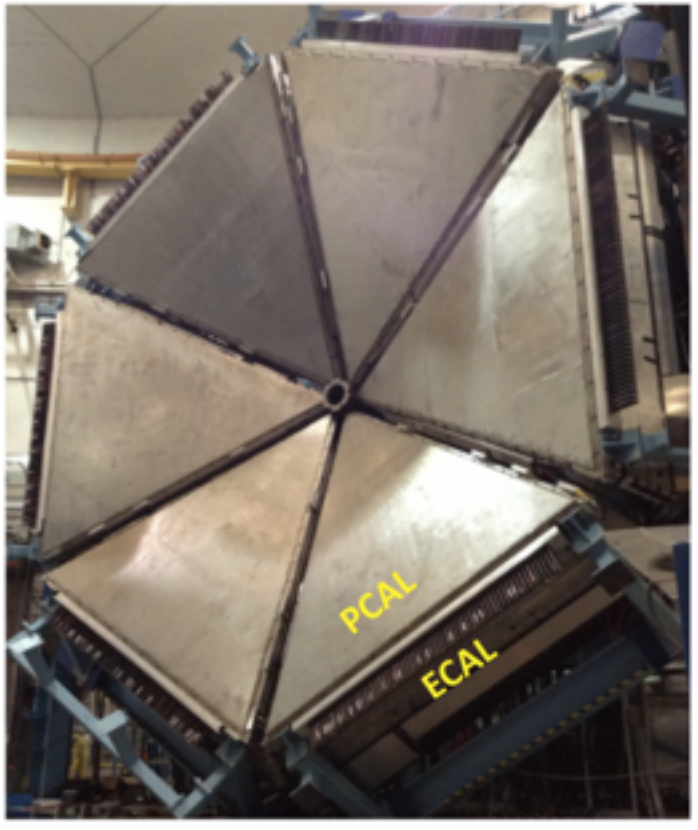
$$\theta : 35^\circ - 45^\circ, \phi : 85\% \; at \; 35^\circ, 90\% \; at \; 45^\circ$$

Design resolution: 140 to 165 ps.

PID:	
π/K Separation	4σ separation up to 2.8 GeV
K/p Separation	4σ separation up to 4.8 GeV
π/p Separation	4σ separation up to 5.4 GeV

Pre-shower and electromagnetic calorimeters (PCAL/EC)

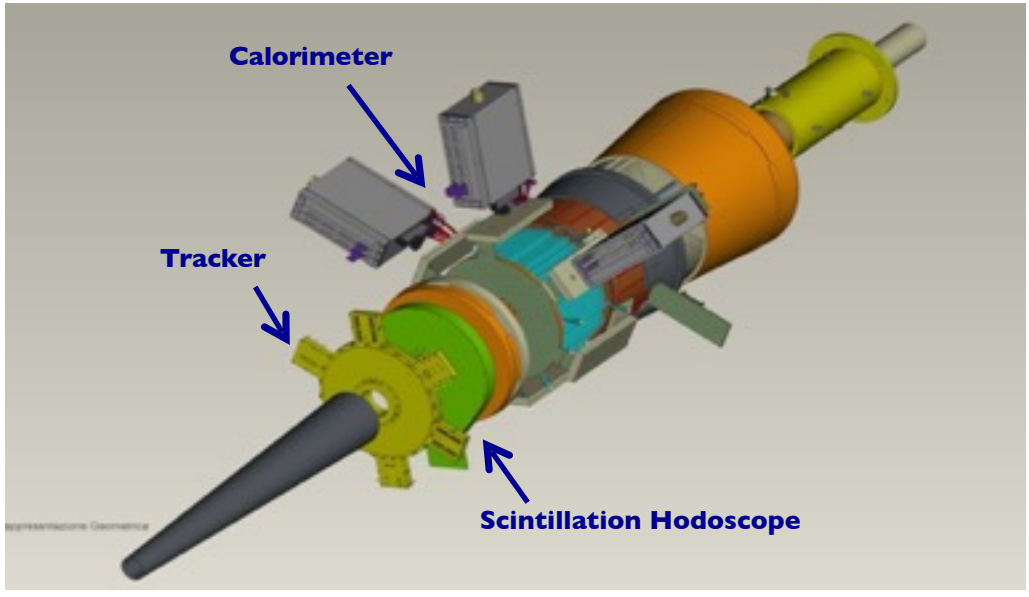
- Identification of electrons, photons, neutral pions and neutrons.
- Sampling calorimeters, six modules ~7m from the target, 54 layer scintillator strip / lead sandwich, 3 orientations, light via fibres to PMTs.
- Total thickness: ~ 20.5 radiation lengths.
- $\theta : 5^\circ - 35^\circ, \phi : 50\%\ at\ 5^\circ, 85\%\ at\ 35^\circ$
- Light-yield: 11-12 photoelectrons (p.e.) / MeV (PCAL), 3-4 p.e. / MeV (EC).



EXPECTED PERFORMANCE	VALUE
Energy resolution	10%/√E
Position resolution	0.5 cm
Time resolution	500 ps

Forward Tagger

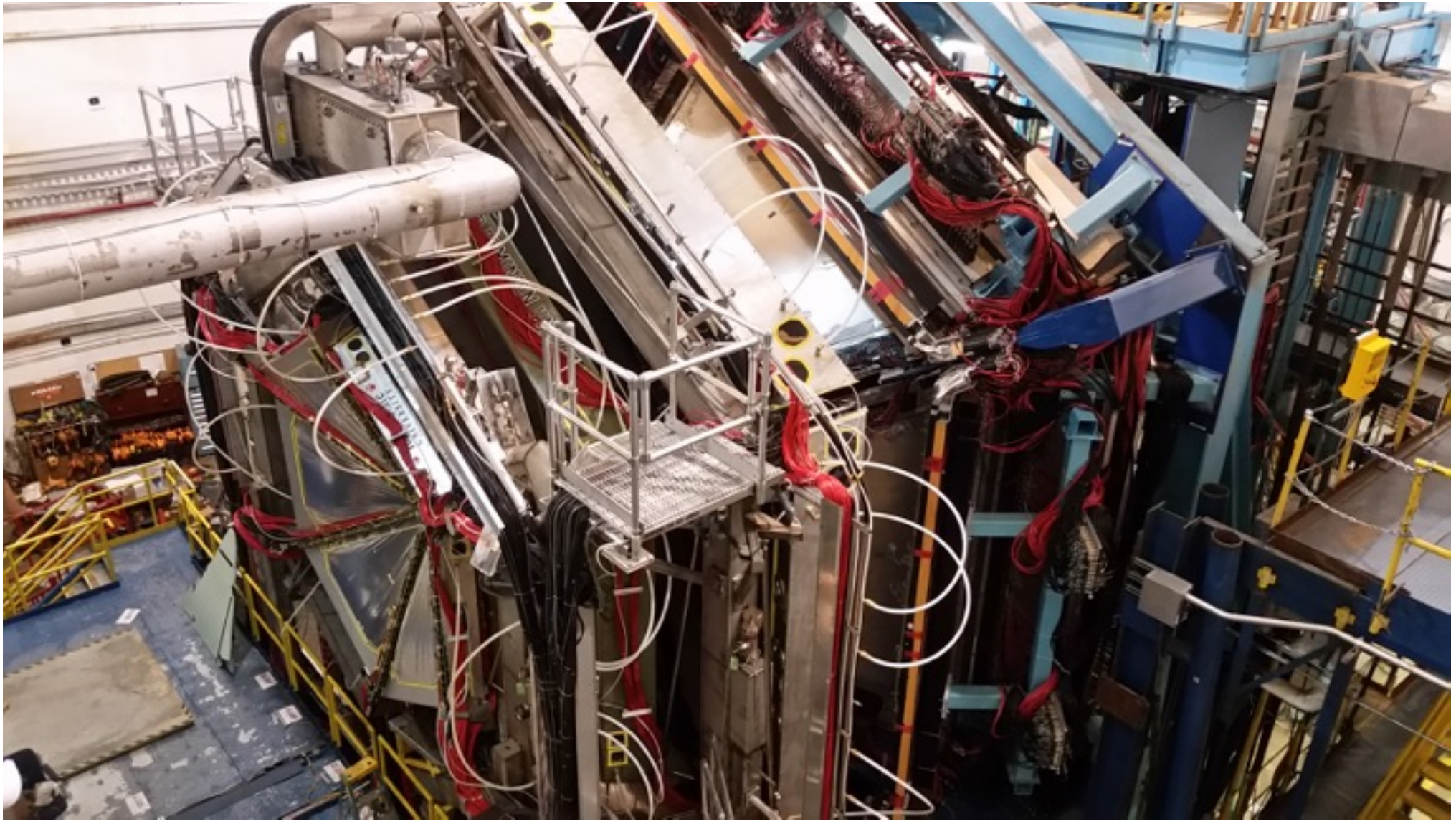
- Extends electron / photon detection down to 2.5 degrees.
- PbWO electromagnetic calorimeter read out with APDs, provides trigger.
- Micromegas tracker, 2 double-layers (~150 micron resolution).
- Hodoscope (2 layers of scintillator tiles, SiPM readout), separates electron and photons.



Funded by STFC with recent project (PPRP) grant (Edinburgh / Glasgow)

Expected Performance	VALUE
Azimuthal angular coverage	2.5° to 4.5°
EM shower energy range	E_{max}–E_{min}= (0.5 – 8.0) GeV
Energy resolution	$\sigma_E/E \leq 2\%/\sqrt{E(GeV)} \oplus 1\%$
Angular resolution	$\sigma_\vartheta/\vartheta \leq 1.5\,\%$, $\sigma_\varphi \leq 2°$
Time resolution	≤300 ps

Forward Detector: March 2017

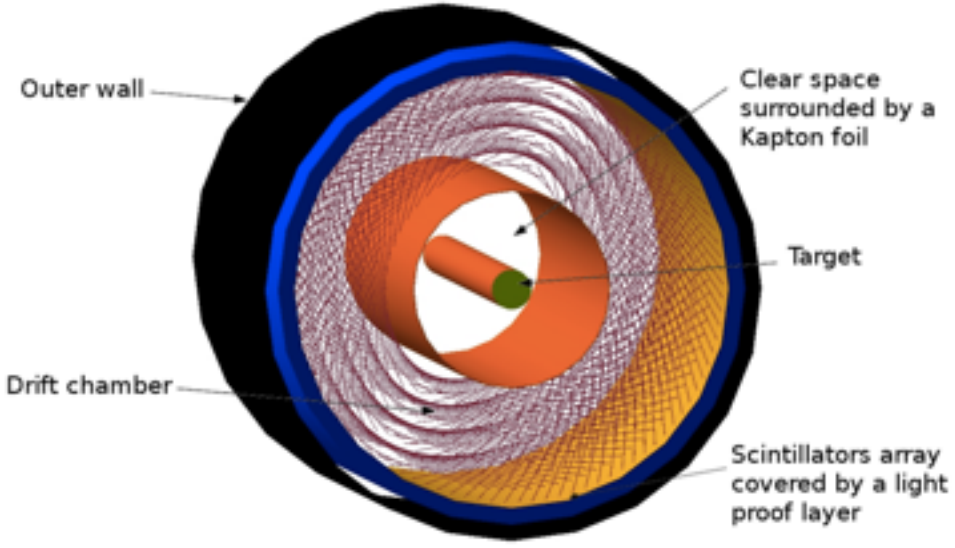


Additional detectors: RTPC

* Radial Time Projection Chamber (BONuS): detection of low energy recoils to study almost-free neutrons.
  Proposal approved (E12-06-113).

Tentatively ~ 2019

* ALERT: alternative detector to identify light ions up to ^{4}He, possible use in trigger.
  Proposal deferred at the last JLab PAC (RP12-16-011C).



K. Hafidi (Argonne)

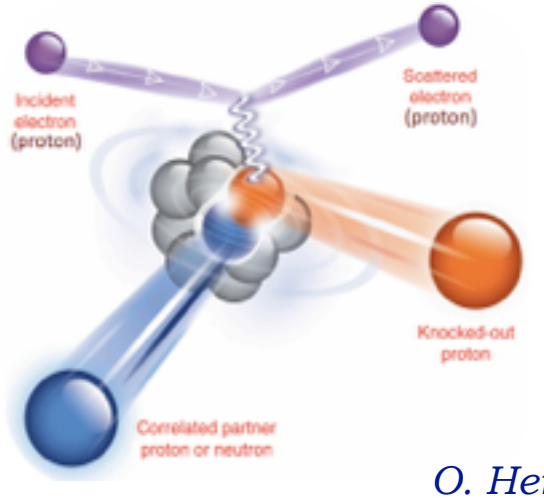
Require removal of SVT and barrel MVT.

Proton momenta: 70 - 250 MeV/c.

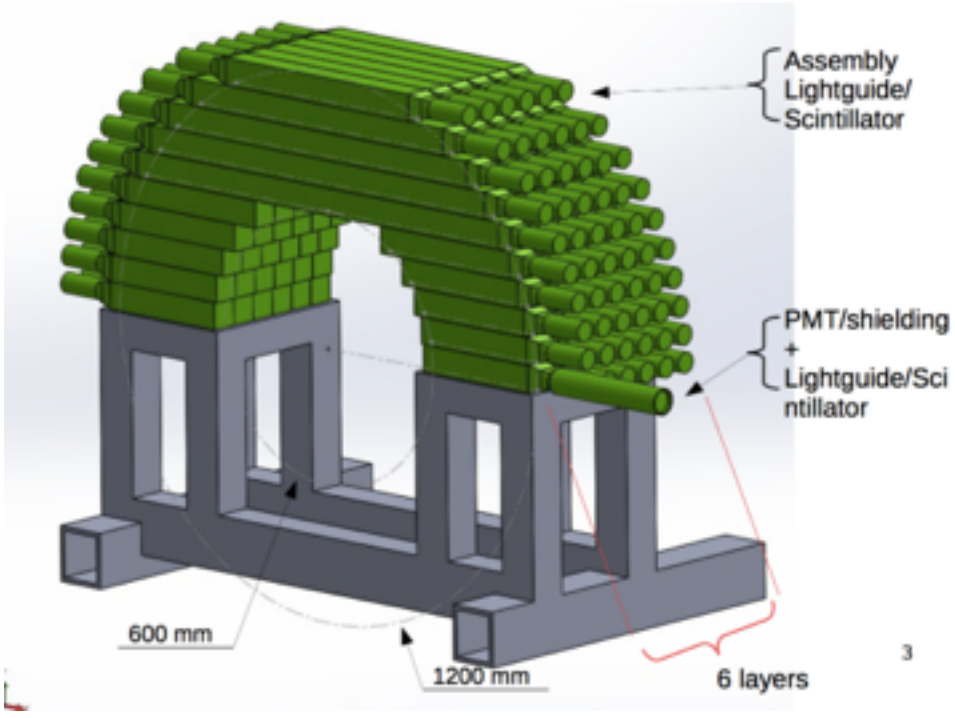
Additional detectors: Large Angle Neutrons

- BAND: Backward Angle Neutron Detector (a scintillator half-ring).
  Lab scattering angle coverage: 160 - 170 deg.
  Neutron momenta: 250 - 600 MeV/c.
  Neutron efficiency ~ 30%.
  Proposal approved (E12-11-003A).

Tentatively ~ 2020

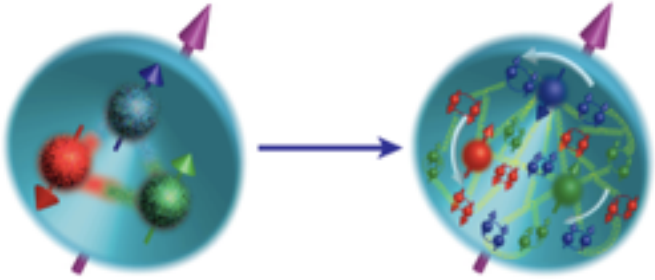


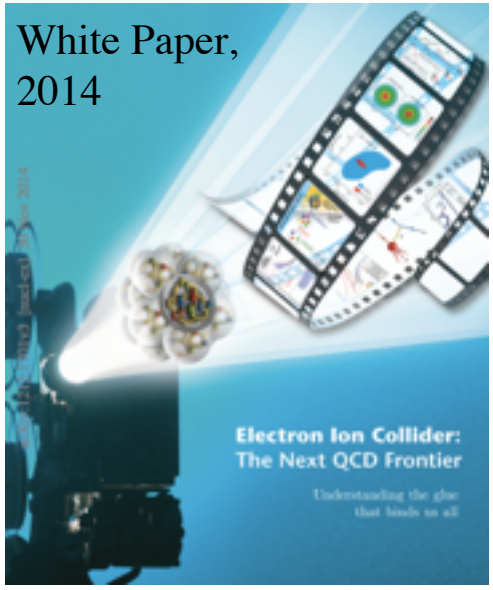
O. Hen (MIT)

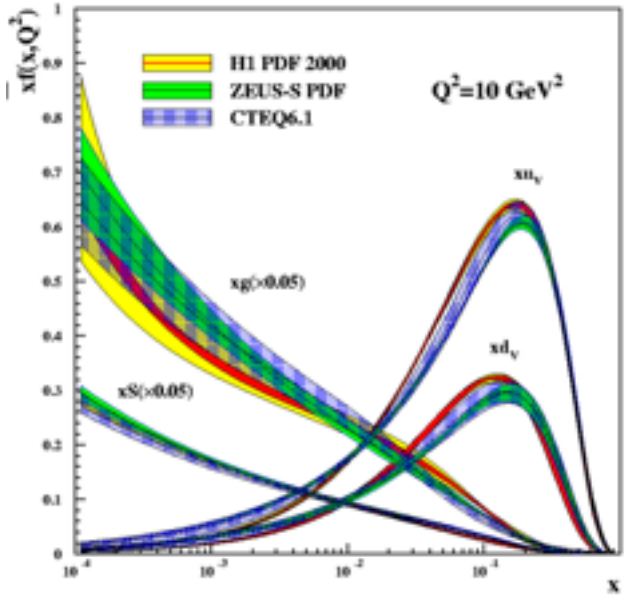


After JLab 12 GeV… the Electron-Ion Collider

- Two sites considered: JLab and Brookhaven National Lab
- Polarised *e* and light nuclei, unpolarised heavy nuclei
- Centre of mass energy range: 20 - 140 GeV
- High luminosity (10^{33} - 10^{34} $cm^{-2}s^{-1}$)
- High resolution detectors







- Gluon contribution to nucleon spin
- Tomography of the quark-gluon sea
- Saturation of gluon density
- Colour charge propagation in the nuclear medium

Fast evolving physics case… ~ 2030s

Summary

- CLAS12 will start taking data late this year.
- Current experimental programme for ~ 10 years of operation.
- Electron scattering experiments on nuclear targets: measurements relevant to neutrino-nucleus scattering can be made (eg: multiple proton knock-out, pion electroproduction…).
- A series of experiments with low-momentum recoil detection are in the planning.

Thank you