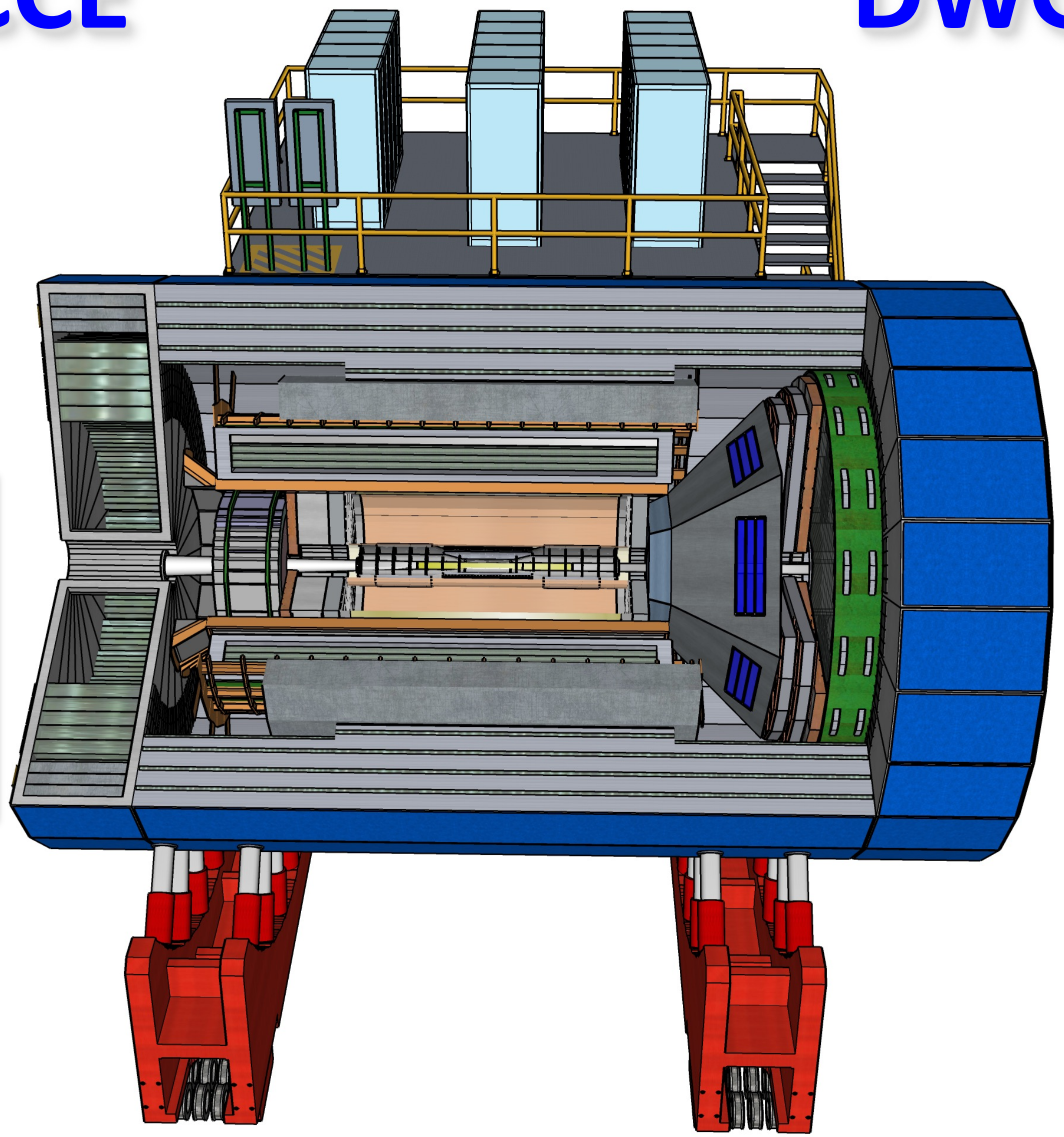
PID@ECCE DWG Meeting



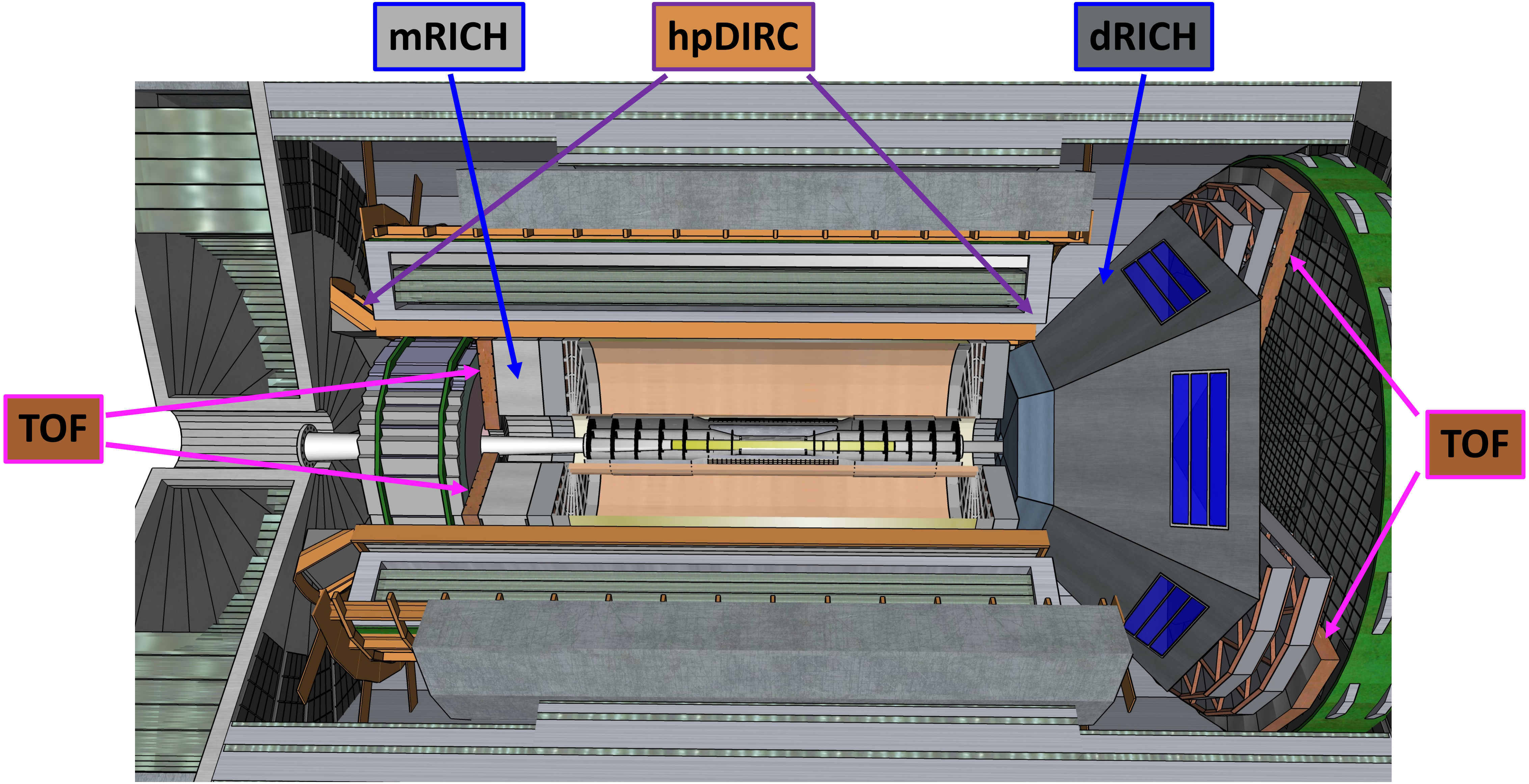
Greg Kalicy — CUA

Xiaochun He — Georgia State University

- Technologies
- Constrains
- Simulations
- Prototyping
- Integration

June 10th 2021

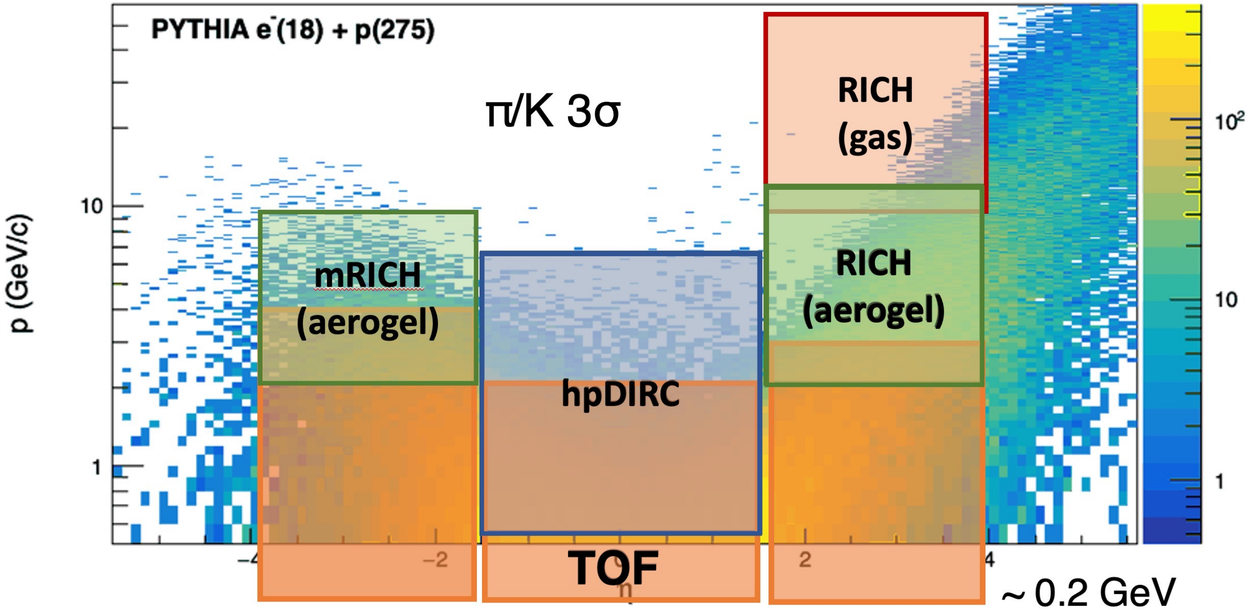
ECCE SketchUp Design

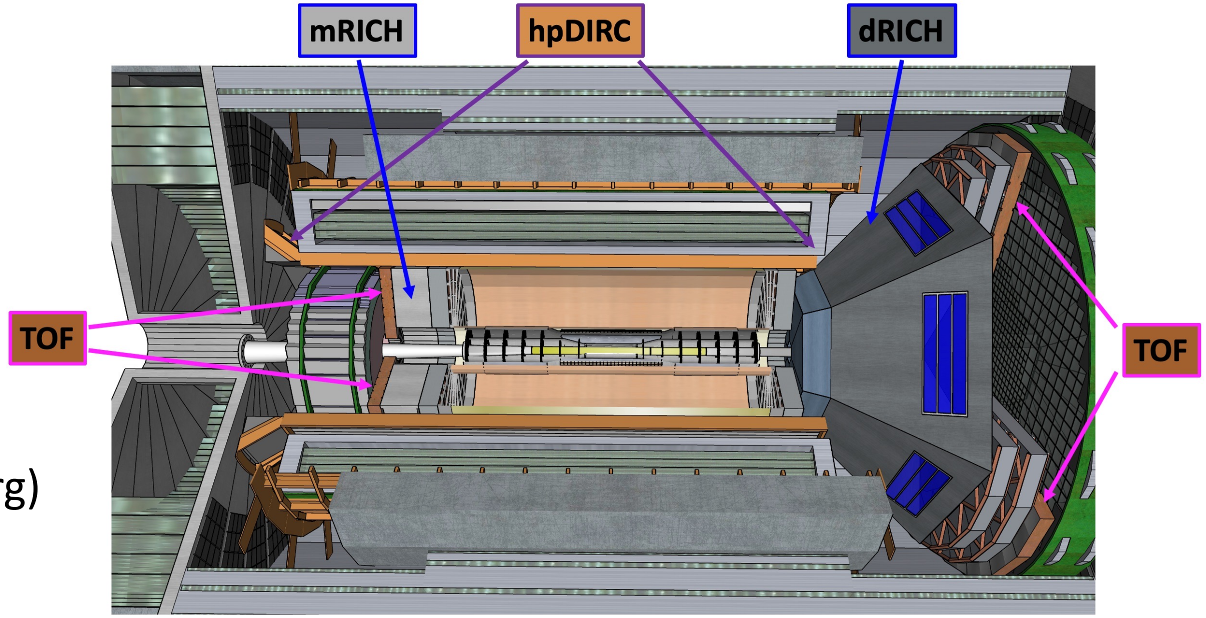


PID@ECCE

Our approach is to focus on well established solutions, take advantage of YR and EIC R&D program:

- **h-endcap**: **dRICH with two radiators** (gas + aerogel)
  π/K separation up to ~50 GeV/c
- **e-endcap**: **compact aerogel mRICH**
  π/K separation up to ~10 GeV/c
- **barrel**: **compact high-performance DIRC**
  π/K separation up to ~6-7 GeV/c
- **LGAD based TOF**:
  cover lower momenta down to ~0.2 GeV/c





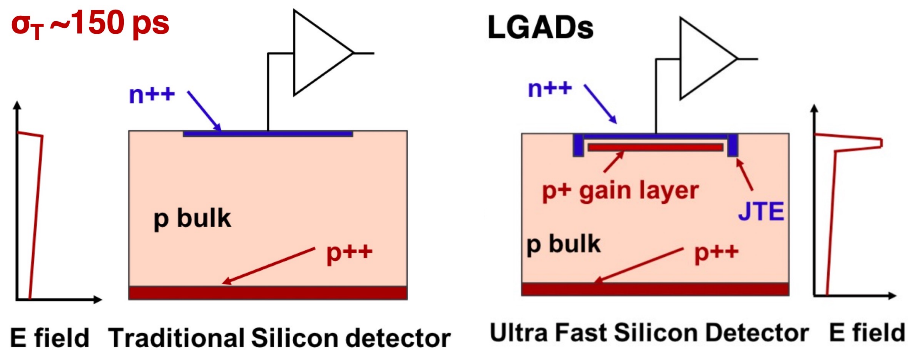
F4A Simulation status:

- **TOF** – fully implemented (missing material budget) (Wei Li)
- **mRICH –** reconstruction integration in progress (Murad Sarsour)
- **dRICH** – in progress (Christopher Dilks, Evaristo Cisbani):
- **hpDIRC –** in progress (Nilanga Wickramaarachchi, Chris Pikenburg)
- **Further AI optimization** (Cristiano Fenelli, William Phelps)

LGAD TOF

Overview:

- Low Gain Avalanche Diodes (LGADs)
- High E field → larger, faster signal → better timing resolution
- Cover low to intermediate momentum range with sufficient overlap with RICH to cover the full phase space required.
- Capability of providing additional tracking points taking advantage of excellent position resolution of LGADs

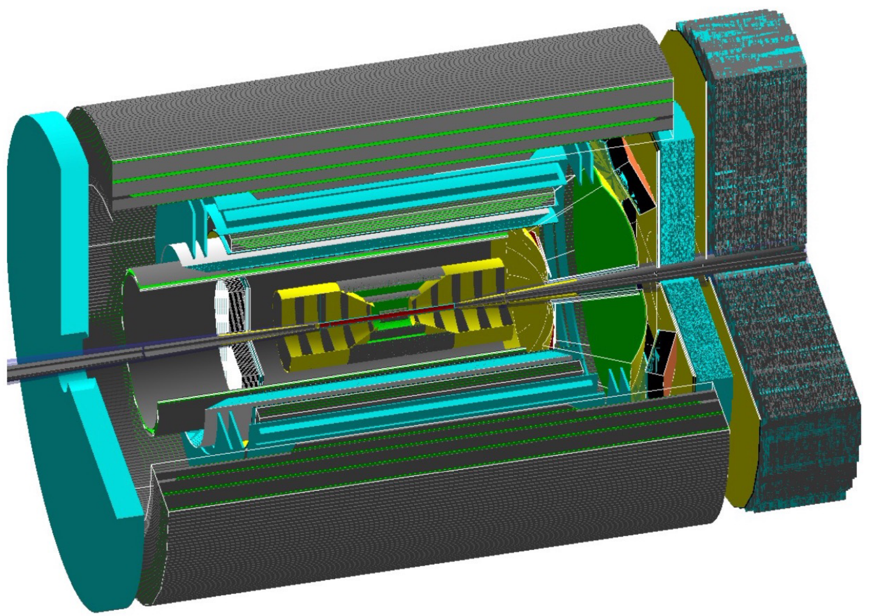


Specs:

- Position resolution: ~30 microns (500-micron pitch size). Alternative of 700-micron pitch for saving channels
- Time resolution: ~20 ps

F4A Simulation:

- Silicon layers with timing and position smeared to expected resolution
- Timing and path length of each track stored for calculating the velocity
- Material budget is dummy for now. Expect < 0.2% X_0 per two layers based on CMS ETL



LGAD TOF

- **Various options of silicon timing layers** in https://github.com/eic/fun4all_eicmacros/blob/master/common/G4_TTL_EIC.C, each of which can be turned on/off individually.

Baseline choice recommended:

Default:		R_{barrel}	Length	z location	$R_{endcap,in}$	$R_{endcap,out}$	η coverage	Area (m^2)
Backward Endcap	$ETTL_0$			-1.555	0.077	0.632	[-3.7,-1.6]	1.23
	$ETTL_1$			-1.585	0.078	0.62	[-3.7,-1.6]	1.19
Central Barrel	$CTTL_0$	0.92	3.6				[-1.34,1.34]	20.8
Forward Endcap	$FTTL_0$			2.87	0.116	1.527	[1.3,3.9]	7.28
	$FTTL_1$			2.89	0.117	1.538	[1.3,3.9]	7.39
Total area								37.89

- An **alternative arrangement** choice of moving central barrel layer closer to R=0.5 m with a total length of 2m right outside the all-silicon tracker should be considered, which will reduce the barrel layer area to 6.28 m^2 and total area to 23.37 m^2.

Pros:

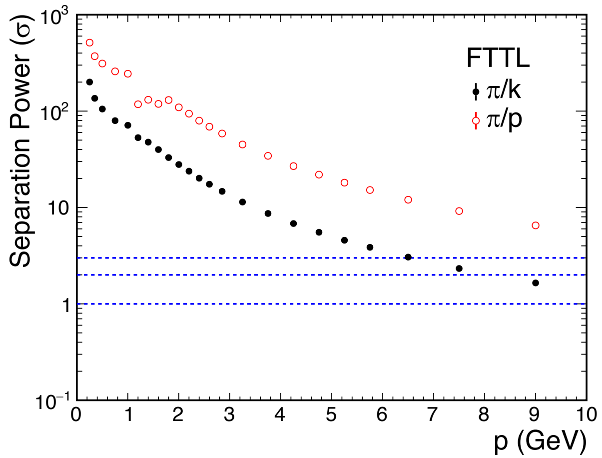
- This total area is comparable to CMS ETL so much more affordable (O($10M))
- Cover better low p region and still overlap well with DIRC to cover the full p region required

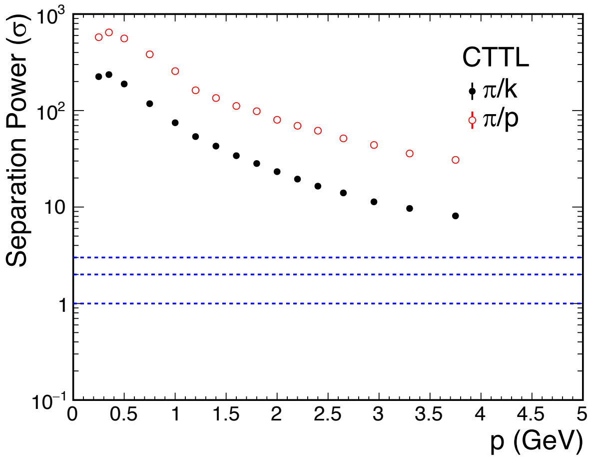
Cons: compromise some gain in momentum resolution

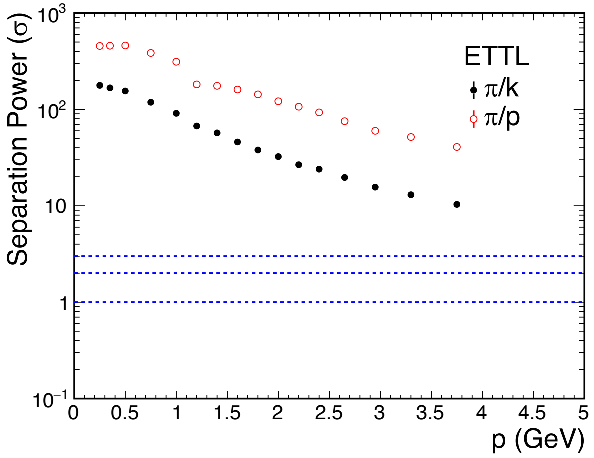
LGAD TOF PID PERFORMANCE

Forward (1<η<3.5): Central (lηl<1): Backward (-3.5<η<-1):

$\sigma_t = 0$ ps

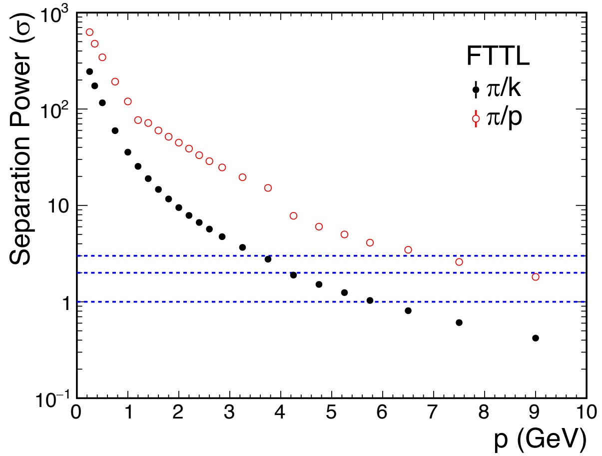


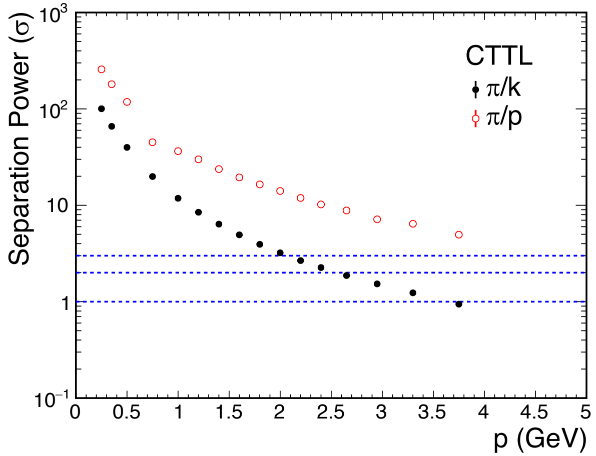


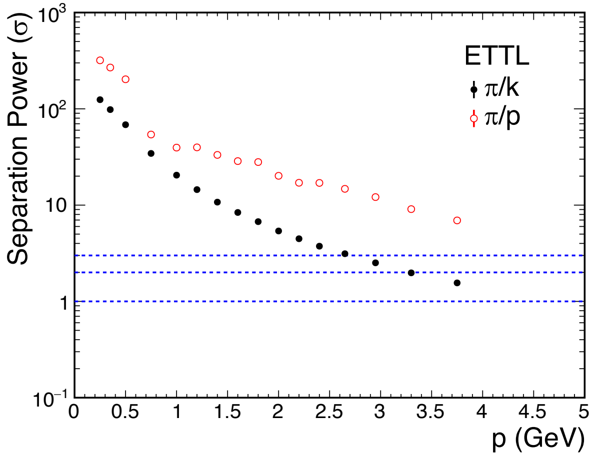


all uncertainties (t_0, t_f, L) included

$\sigma_t = 20$ ps





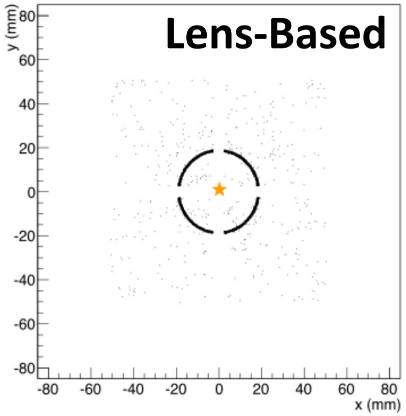


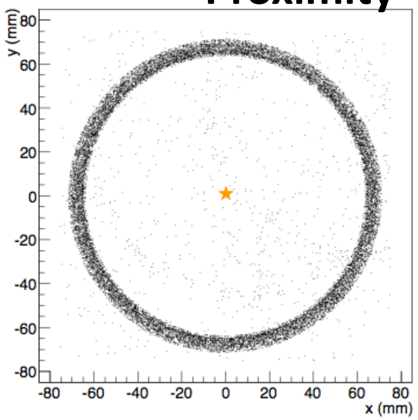
0.2-4 GeV 0.2-2.5 GeV 0.2-3 GeV

Path length uncertainties limit the ultimate PID performance to ~ 6 GeV/c

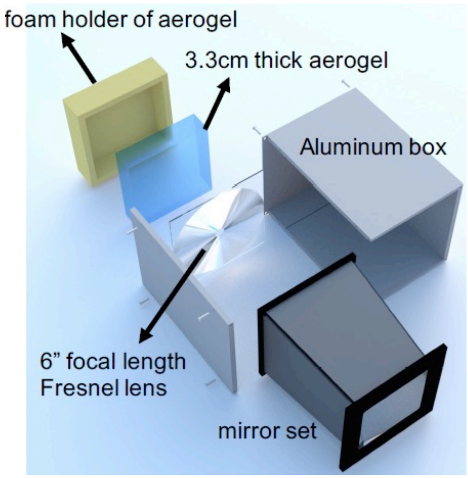
Modular Ring Imaging CHerenkov Detector (mRICH)

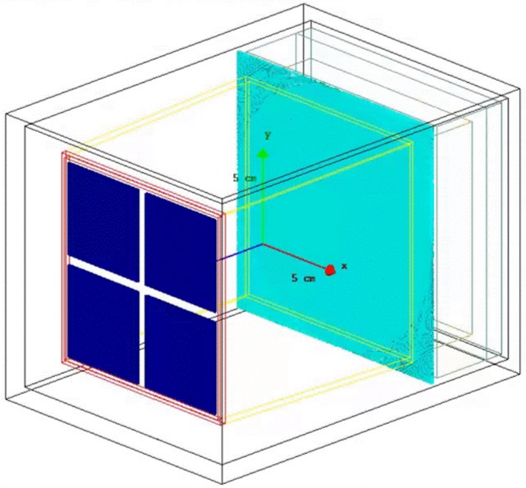
Overview:

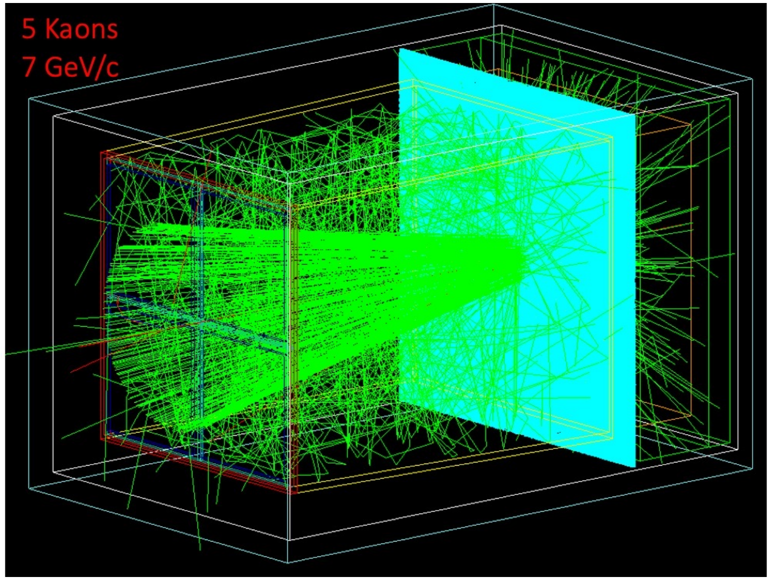
- Modular and compact RICH detector (~15x15x25 cm)
- Radiator: Aerogel, 11x11x3 cm and n=1.03
- Focusing: Fresnel lens with 6" focal length
- 

at 23 cm


- π/K separation up to 10 GeV/c and e/π separation up to 2 GeV/c.
- Sensors: Currently **assuming SiPMs but LAPPDs would be good alternative**



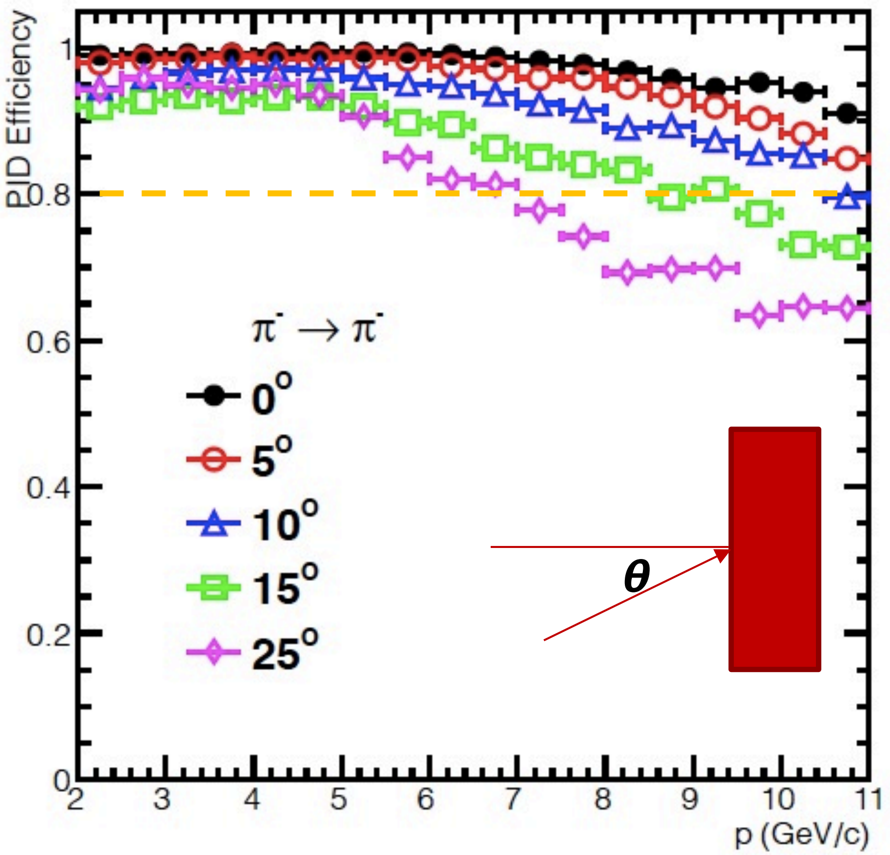


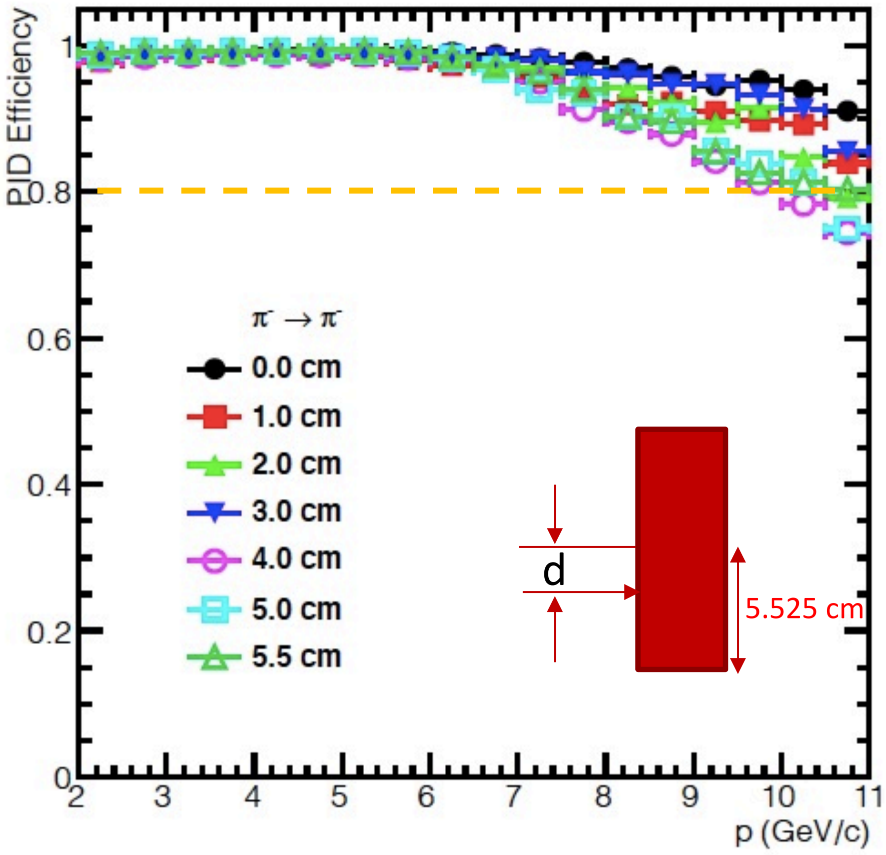


Systematic effects

- Emission point error: minimized at the lens focal plane
- Chromatic dispersion error: reduced by UV filtering (acrylic).
- Pixel size error: the uncertainty raised by pixel size, a, error

mRICH PID Performance / Single Module





- When incident perpendicular no impact even at the edge of the Aerogel
- Efficiency drops beyond 15°

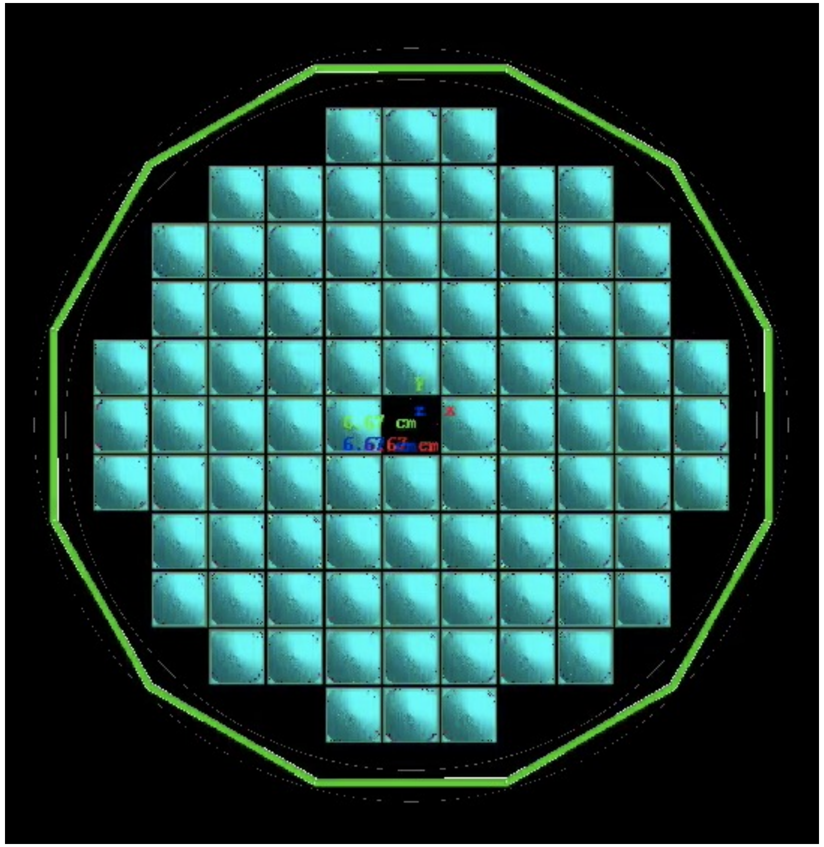
➡ **Projective setup if preferable!**

Construction code output: $\mathcal{L}_\pi, \mathcal{L}_K, \mathcal{L}_p$

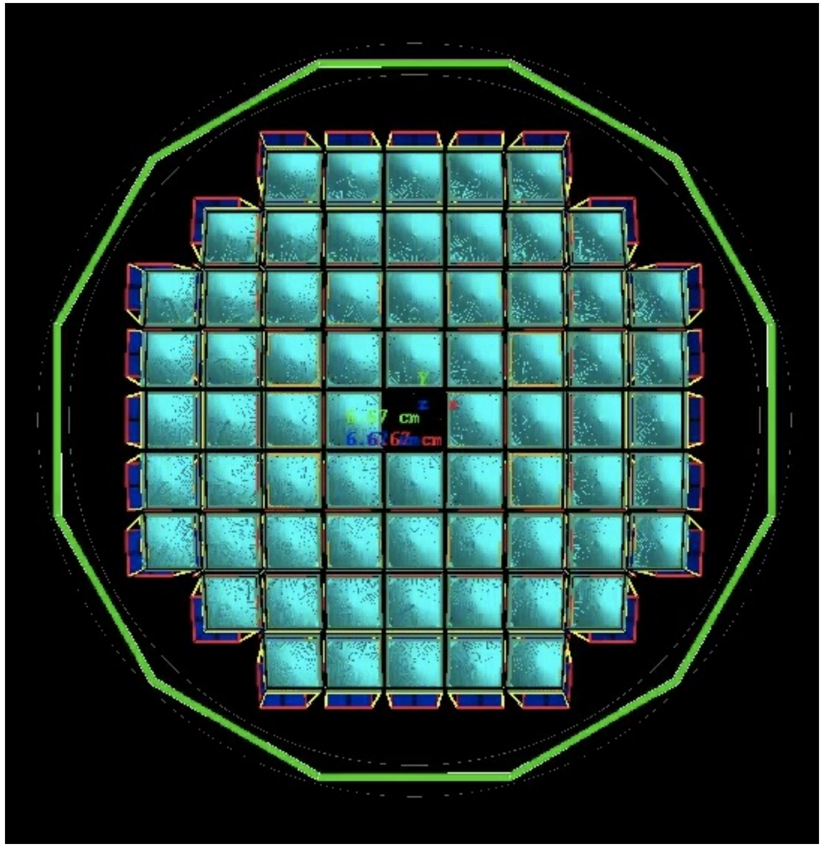
$\pi^- \to \pi^-: \mathcal{L}_\pi - \mathcal{L}_K > 0 \&\& \ \mathcal{L}_\pi - \mathcal{L}_p > 0$

mRICH Setup

Flat



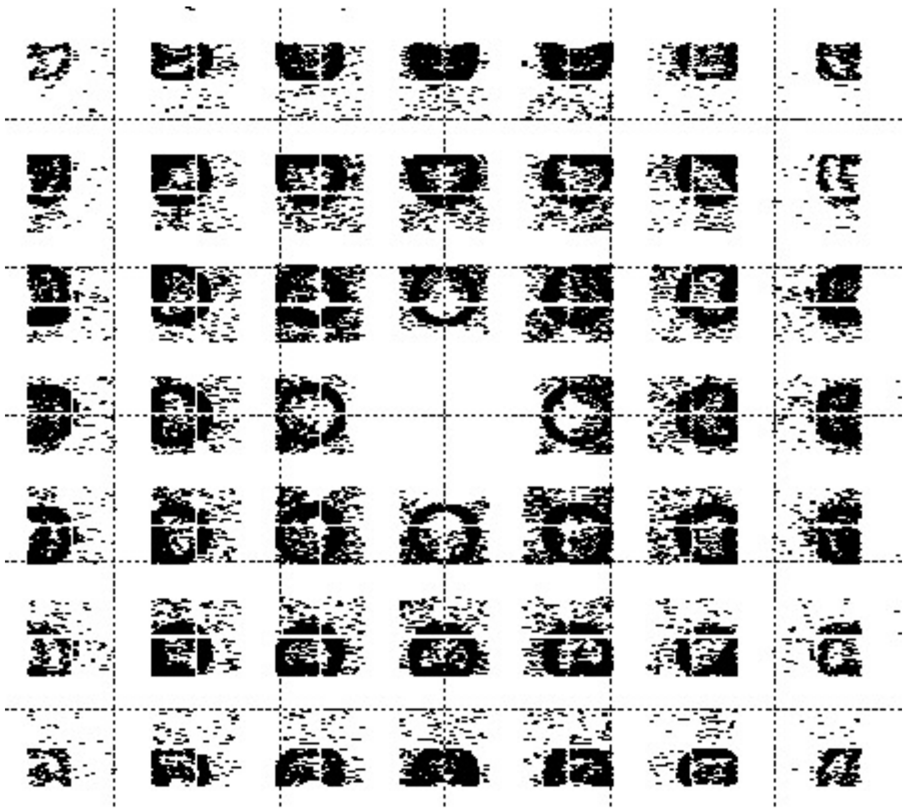
Projective



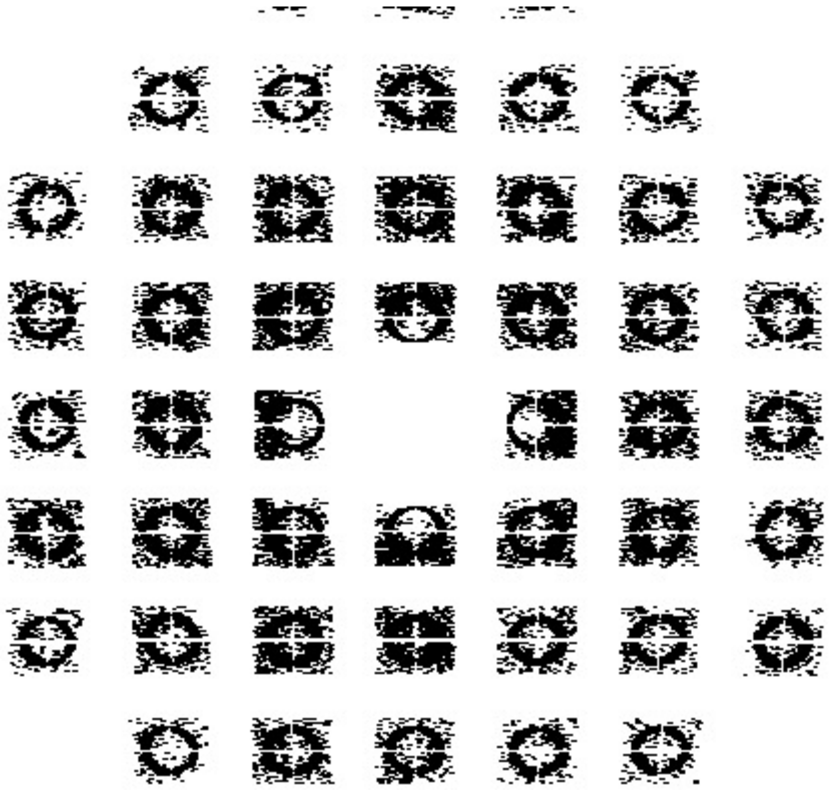
Current setup uses the minimum space between modules without overlap to fill up the space up to DIRC's frame. It required 88 modules for the flat case and 68 for projective

mRICH Setup

Flat



Projective

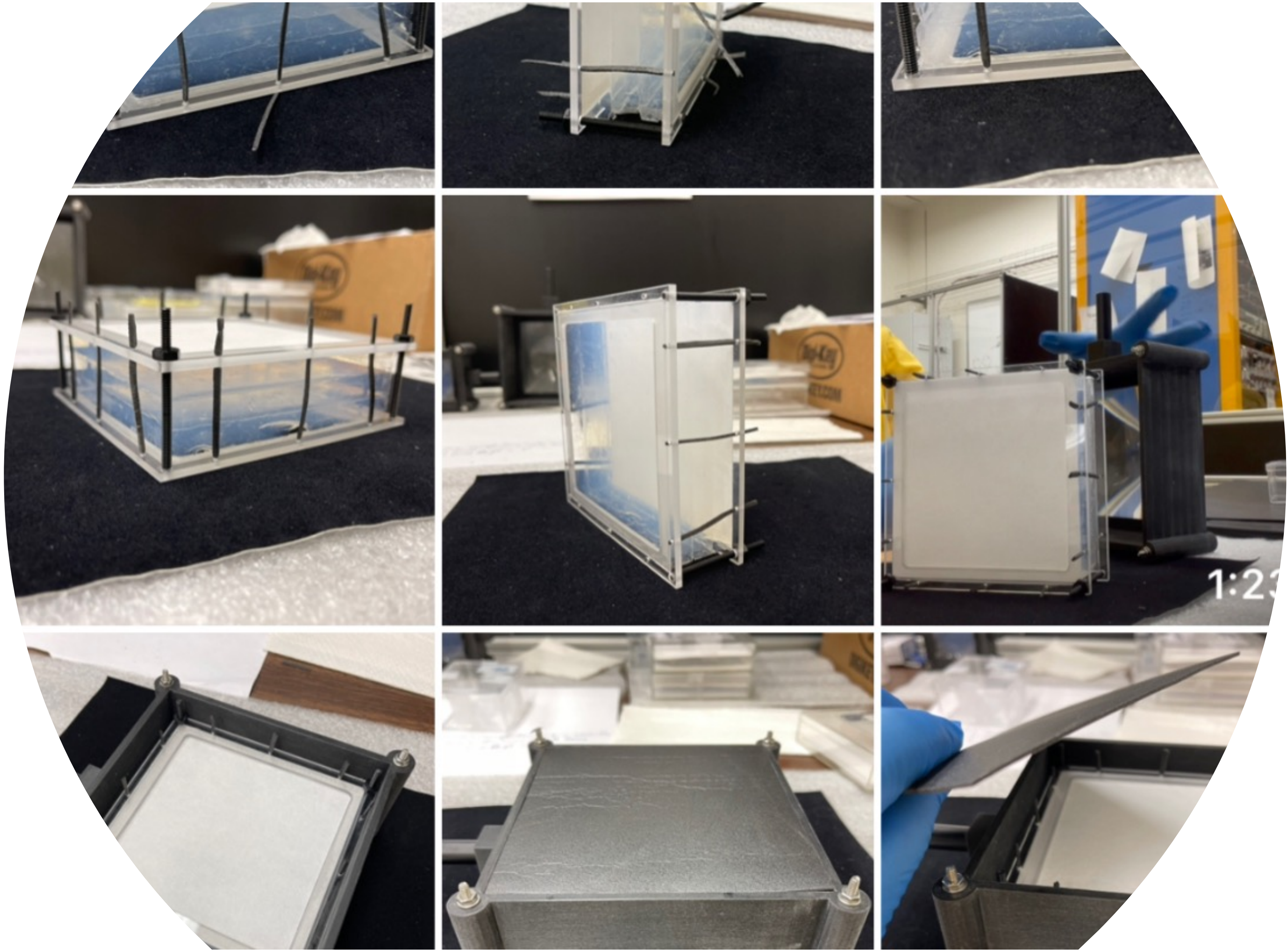


- x-y distribution for raw hits
- 8 GeV/c π^- randomly generated from (0,0,0) vertex at $-3.5<\eta<-1.5$ & full azimuth

mRICH &LAPPD Test Beam

Goals:

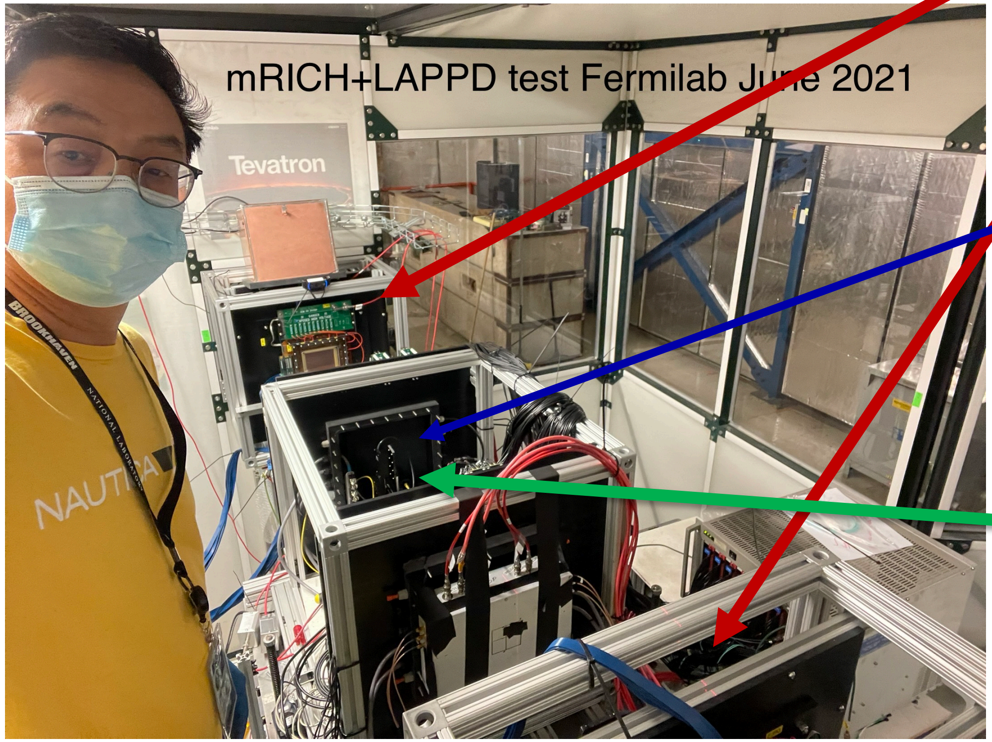
- Test mRICH with LAPPD with tracking capability
- Set requirement for minimum tracking resolution for mRICH (expected around 1 mrad)
- Determine per photon resolution (SPR) of mRICH
- Test and optimize the location of the photosensor plane (possibility to decrease size of modules)
- Plan to start taking data late on June 10, 2021



mRICH &LAPPD Test Beam

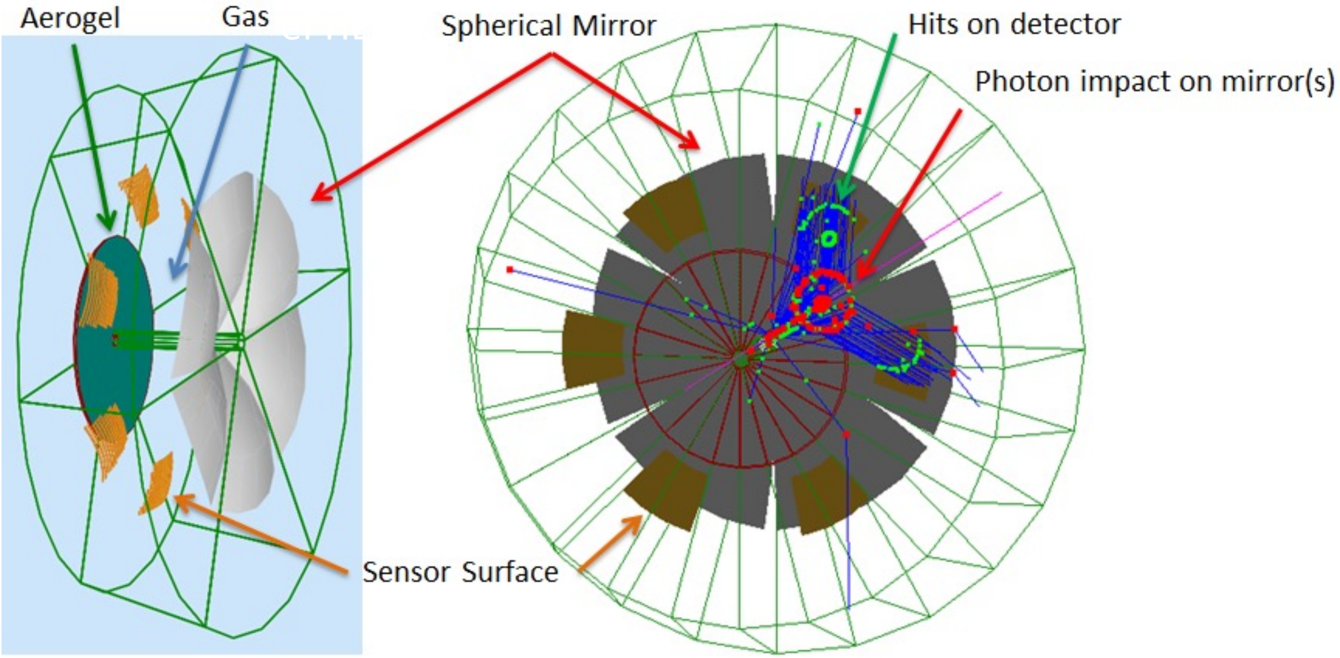
GEM tracking stations

LAPPD test stand



Aerogel + Fresnel lens to be mounted inside of the LAPPD test stand

dRICh baseline



Overview:

- **Hadron identification (p/K/p) from 3 to 50 GeV/c** (3 sigma) and **electron identification (e/p) up to 15 GeV/c**
- Covering **polar angles 5-25°** in the current implementation.
- **Photon detector out of acceptance** and far from the beam pipe in moderate magnetic field (~1/2 of central zone): less constraints on material budget (e.g. mechanical supports, shielding, cooling); neutron flux is also reduced
- Currently **assuming SiPMs but LAPPDs would be good alternative**

Radiators:

- Aerogel: 4 cm, $n_{(400nm)}$~1.02 + 3 mm acrylic filter
- Gas: 1.6m (1.1m ePHENIX), n_{C2F6}~1.0008

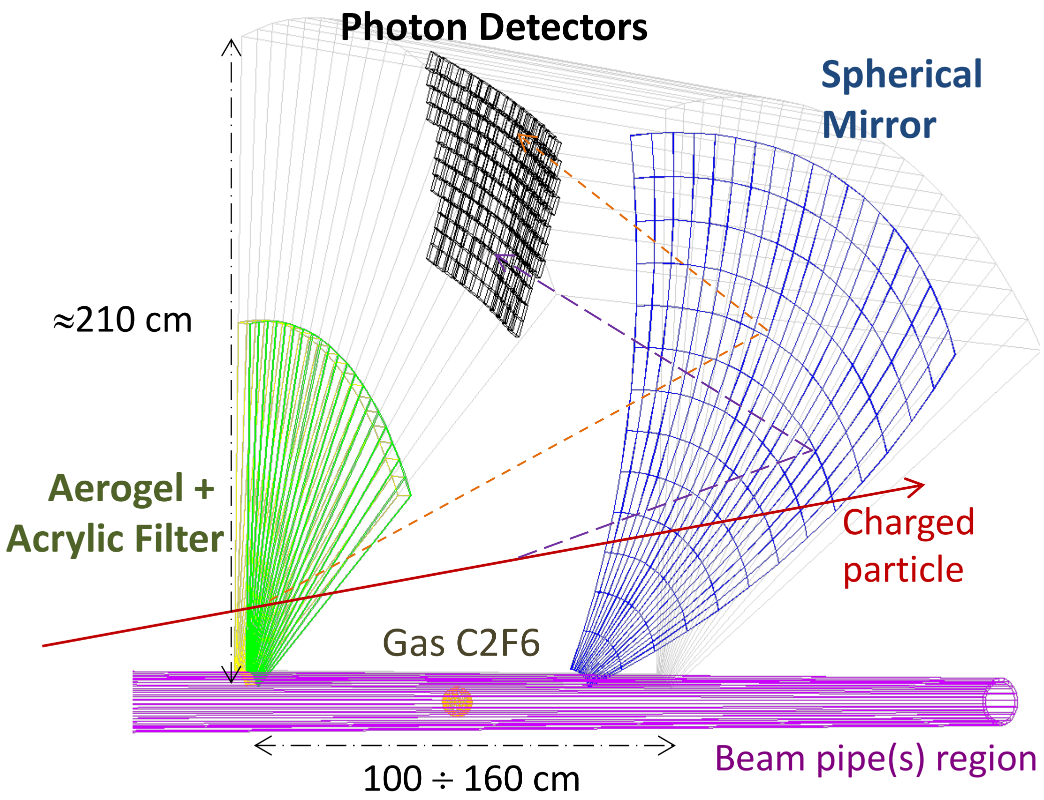
6 Identical Open Sectors (Petals):

- Large Focusing Mirror with R ~2.9m (~2.0m ePHENIX)
- Optical sensor elements: ~4500 cm^2/sector, 3 mm pixel size, UV sensitive, out of charged particles acceptance

dRICH single sector baseline geometry

Main semi-quantitative features:

- aerogel transverse size ~ ½ mirror transverse size
- mirror and photon surfaces are largely transverse to the beam
- optimal photo sensor surface is curved



Simplistic considerations

- Decrease longitudinal size:
  - improve chromatic aberration
  - tend to improve final photon acceptance
  - reduce number of gas photons
- Decrease transverse size
  - need to rotate mirror (and sensor)
  - may degrade chromatic aberration
  - reduce gas path length at smaller angles
  - photon detector may remarkably interfere with large angles aerogel photons

dRICH - MC External Assumptions

Tracking	
Angular resolution	σ = 0.5 mrad (1 mm over 2 m) – whole momentum range
Impact point resolution	σ = 0.3 mm
Momentum resolution dP/P	+/- few percent negligible effects in Cherenkov angle reconstruction
Magnetic Field	rested up to 3 Tesla Central Field in JL-MEIC spectrometer
Space Requirement	(based on original spectrometer constraints)
longitudinal length	JLEIC: ≈1.6 m, ePHENIX: ≈1.0 m
transverse radius	JLEIC: ≈2.5 m, ePHENIX: ≈2 m
beam pipe radius	<10 cm
Background	no direct external background only backrground produced by the simulated charged particle: Delta rays, Rayleigh scattering …

dRICh Simulated Performance

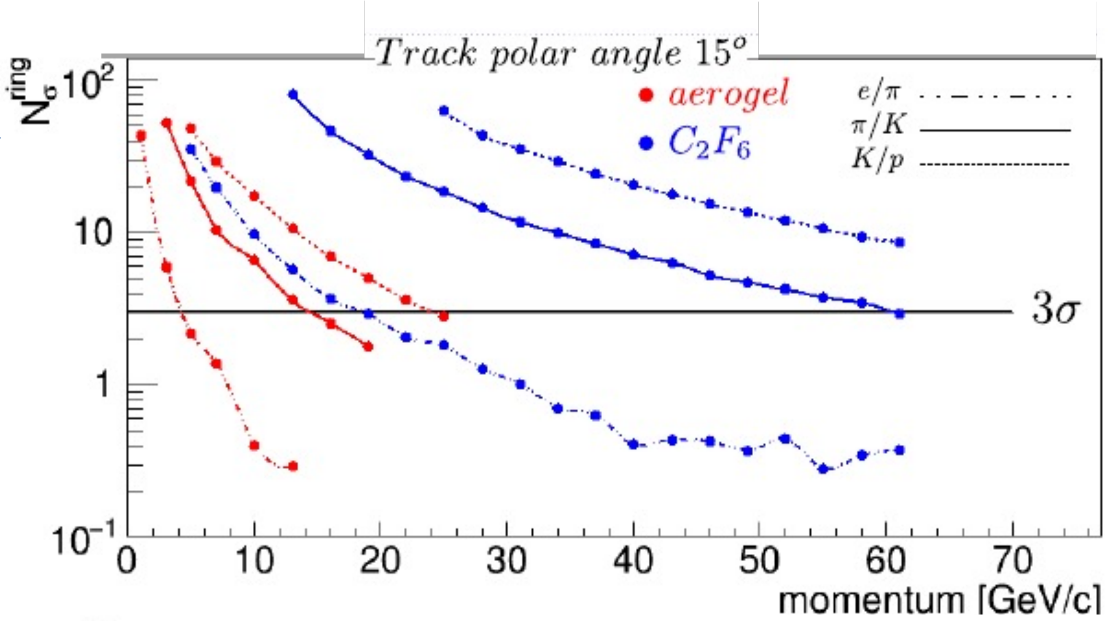
Optics manually optimized for 1.6 m

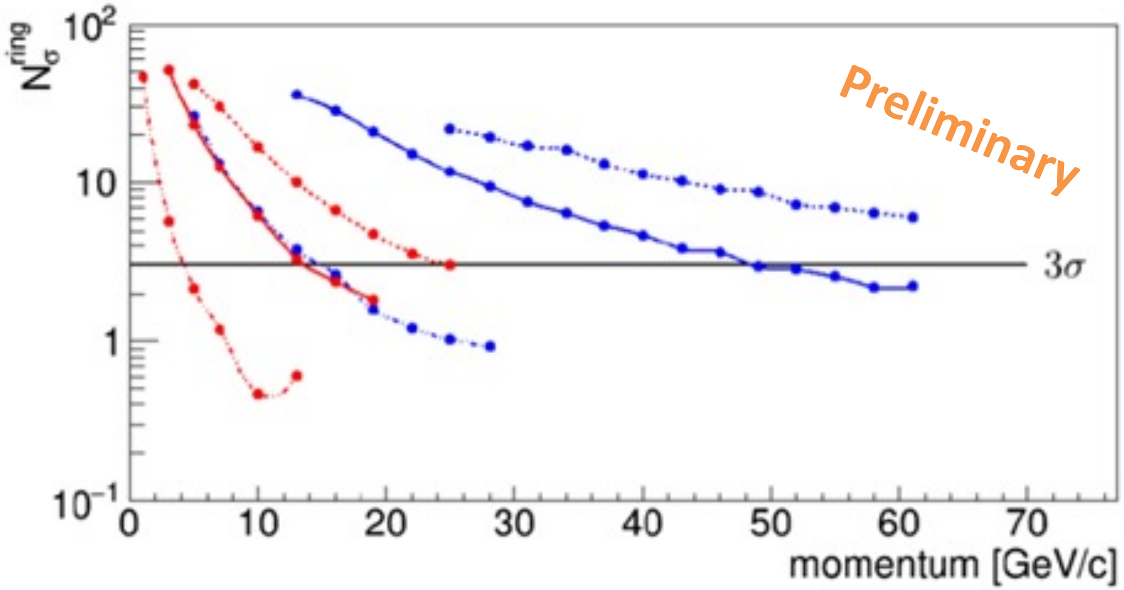
GEANT4 (GEMC) simulation includes:

- Acrylic Filter (<300nm) after the aerogel to minimize Rayleigh scattering
- Mirror quality from CLAS12
- PMT 3x3 mm pixel, QE from real CLAS12/PMT data (200-500 nm)
- **Tracking accuracy 0.5 mrad**
- **3T central magnetic field**

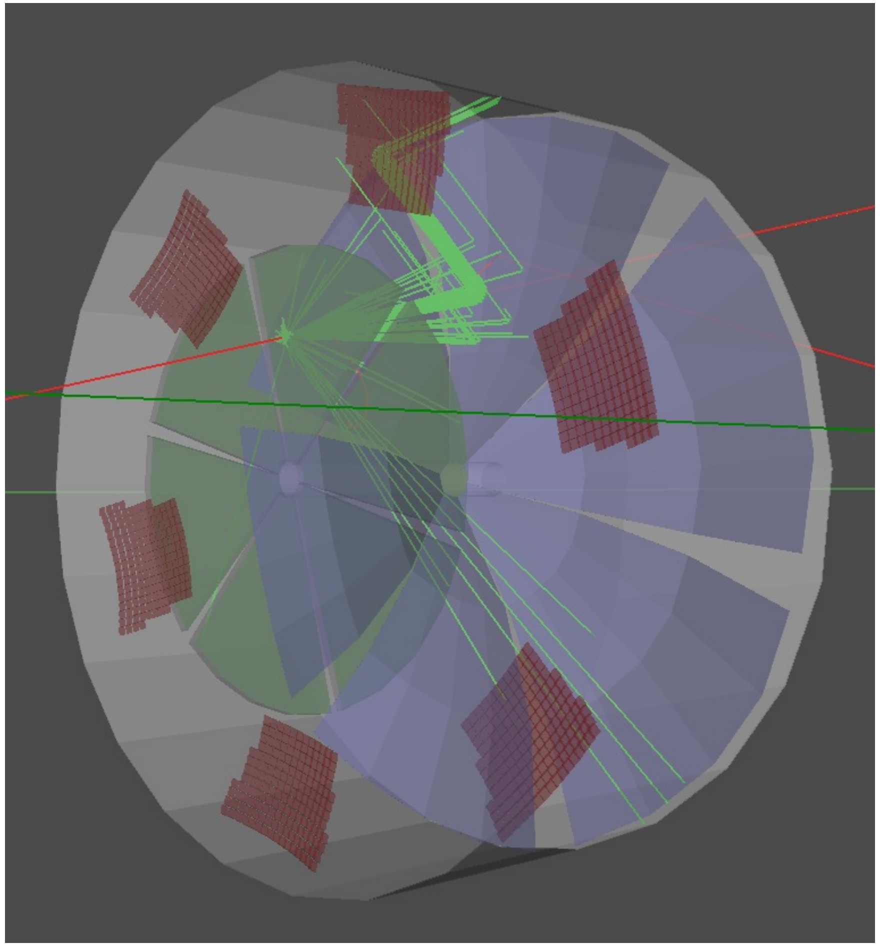
Cherenkov Angle reconstruction based on Inverse Ray Tracing

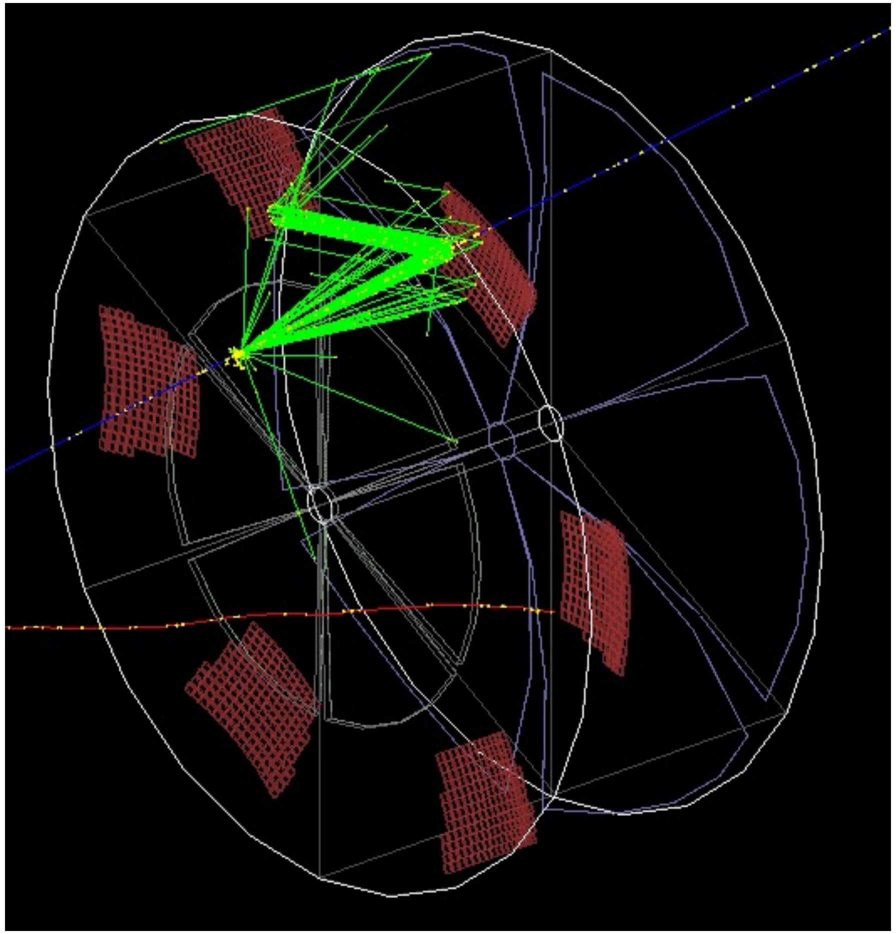
Optics barely adapted to ~1.0 m





dRICh in Fun4All

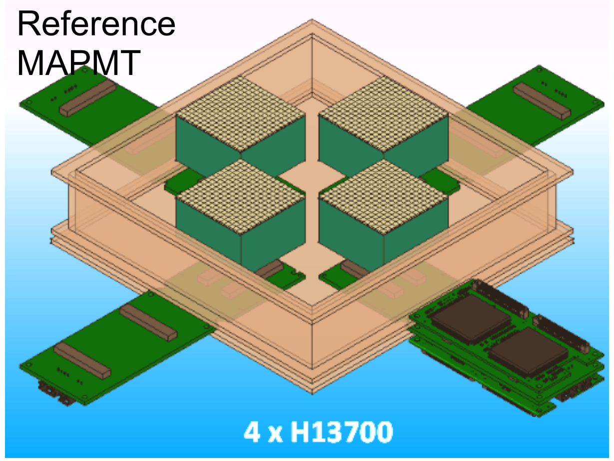


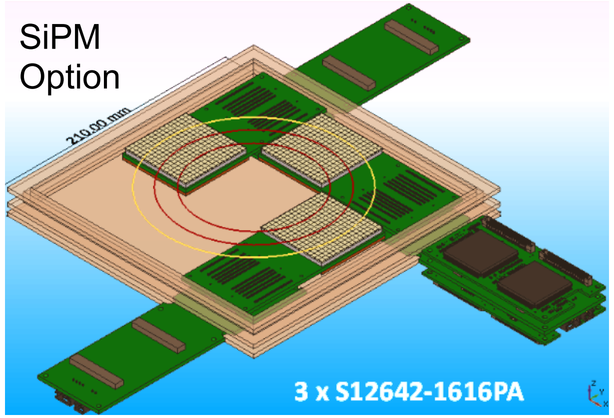


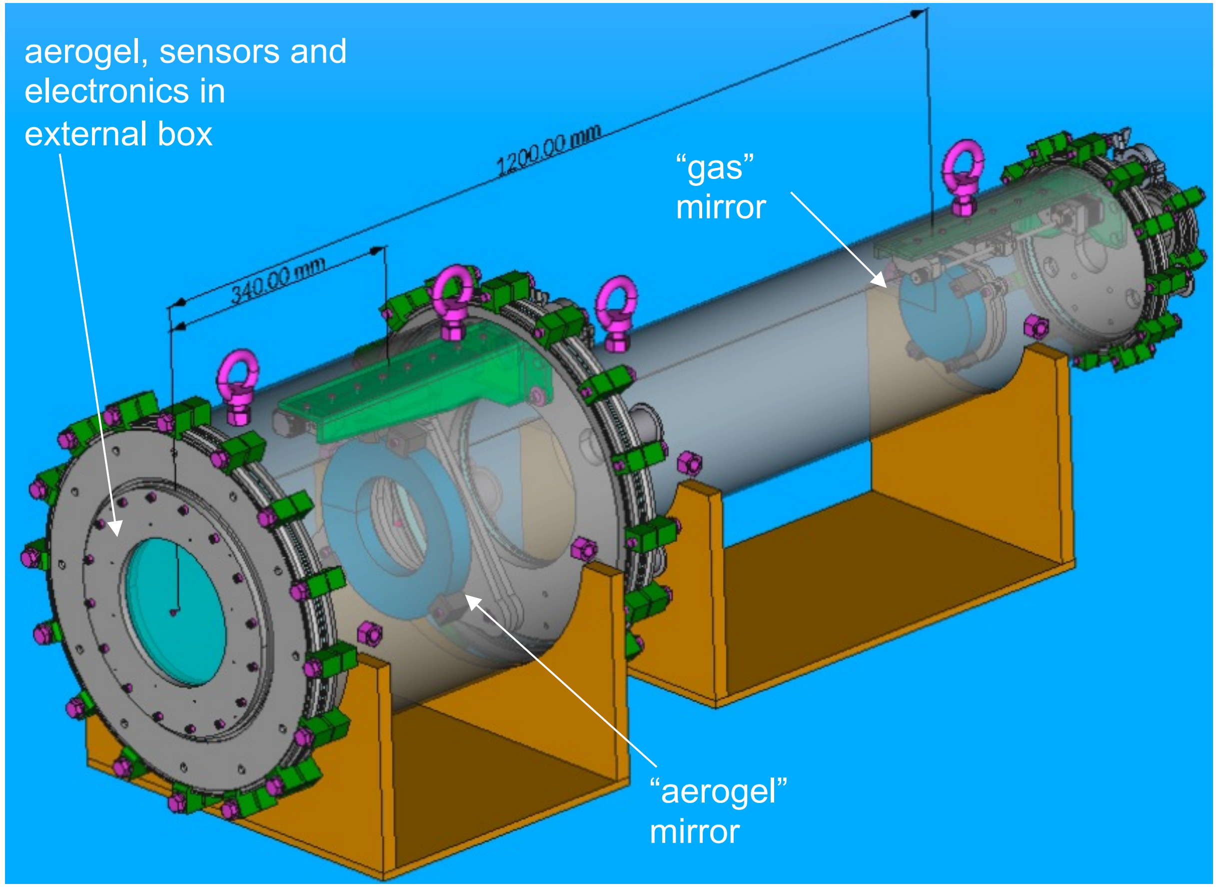
ESC/g4e: model exists and works in standalone package

F4A: Chris Dilks implemented the F4A version; all main methods defined, including stepping action; preliminary stand-alone tests underway

dRICh Prototyping







- Can use of high pressure gases
- Photosensors and aerogel box isolated from the gas tank
- Standard vacuum components, custom flanges

Also ongoing activities on Electronics and Photosensor development and characterization

Goal: validate the dRICh concept, benchmark simulation, compare components alternatives

Near term plan: First beam-test in Oct'21 @ CERN PS T10 (synergy with ALICE tests)

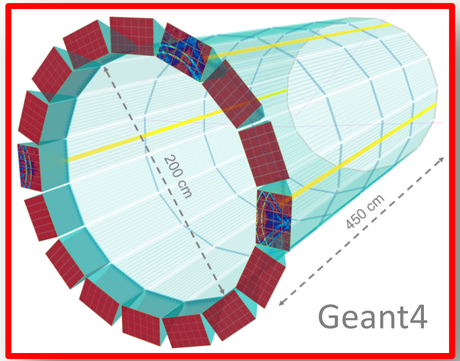
dRICh Key Hardware Components

Component	Function	Specs/Requirements	Critical Issues / Comments
Mechanics	Support all other components and services Keep in position and aligned	Large volume gas and light tightness; alignment of components	Technically demanding but feasible; no major challenges expected
Optics (Mirrors)	Focus (expecially for gas) and deflect photons out of particle acceptance and reduce sensor surface	sub-mrad precision reflectivity $\geq$ 90% low material budget	Spherical mirrors technology of CLAS12 suitable (optical fiber and/or glass skin); similar geometry; **Development for cost reduction**
Aerogel Radiator	Cover Low Mom. Range between TOF and Gas	$\geq 3\sigma$ π-K separation up to Gas region (~13 GeV)	Procurement: currently 1 active provider (2 main producers + 1 potential) **Long term stability assessment in conjunction with gas**
Gas Radiator	Cover High Mom. Range above Aerogel	$\geq 3\sigma$ π-K separation up to ~50 GeV and overlap to aerogel	Greenhouse gas: potential procurement issue **Search for alternatives**
Photon Detector	Single photon spatial detection	Magnetic field tolerant and radiation hardness; ~ few mm spatial resolution	MCP-PMT is likely doable, but expensive. LAPPD may represent an alternative. **R&D on SiPM:** a promising, quicky improving, wordwide pursued, and cheap technology.
Electronics	Amplify and shape single photon analog signal, convert to digital, transfer to DAQ nodes	Low noise Time res. ~ 0.5 ns μs signal latency	MAROC3 based readout available for prototyping; final choice will depend on sensor. **ASIC development for optimised streaming readout (discrimination vs sampling)**

hpDIRC

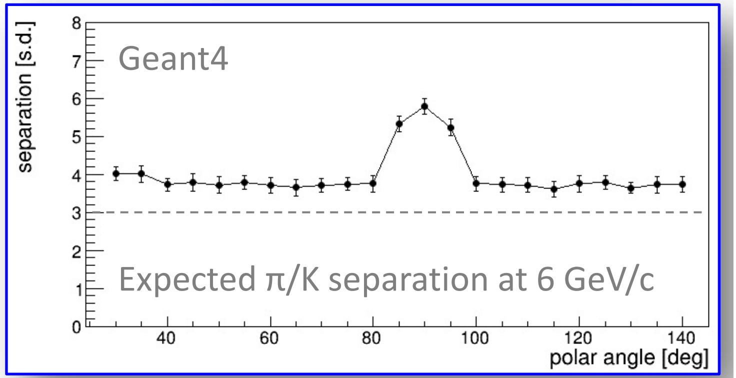
Concept:

- Fast focusing DIRC, utilizing high-resolution 3D (x,y,t) reconstruction
- Innovative 3-layer spherical lenses, compact fused silica expansion volumes
- Fast photon detection using small-pixel MCP-PMTs *(eRD14)* and high-density readout electronics *(eRD14)*



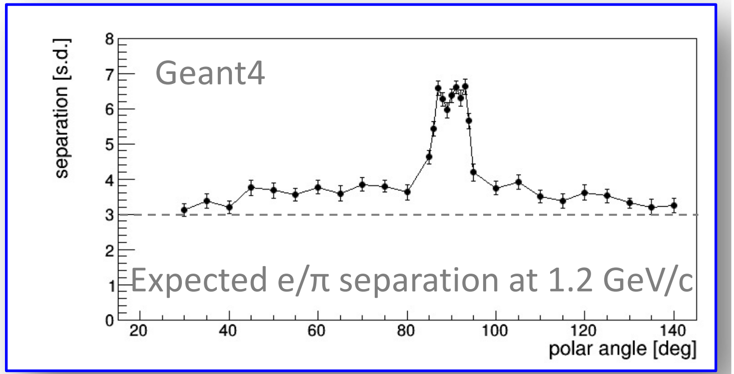
Excellent performance over wide angular range:

- ≥ 3 s.d. π/K up to 6 GeV/c, ≥ 3 s.d. e/π up to ~1.2 GeV/c
- Low momentum π/K identification in "veto mode" down to 0.2-0.3 GeV/c



Key Features:

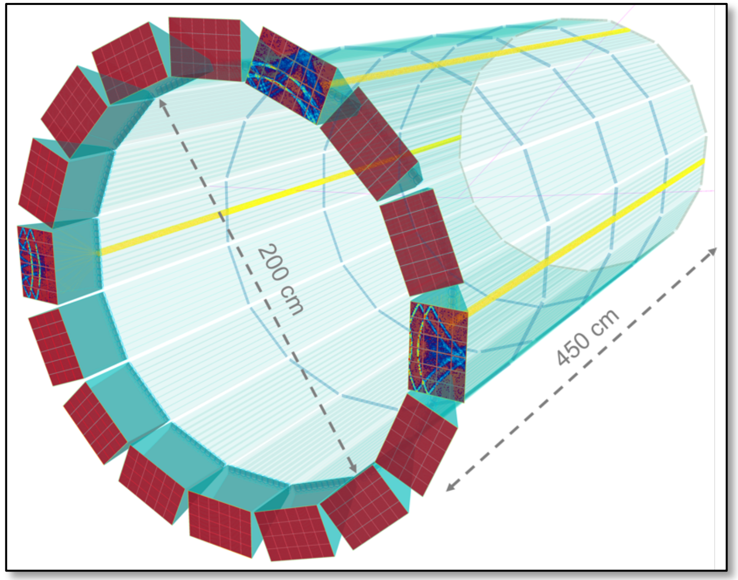
- **Radially compact** (8-10 cm; impact on cost of post-DIRC systems)
- **Flexible design** (to deal with sensor in B-field and detector integration)
- **Low demand on detector infrastructure** (no cryogenic cooling, no flammable gases)
- **R&D at advanced stage** (PID performance estimate based on test beam results, excellent agreement between detailed simulation and prototype data, fast simulation available)



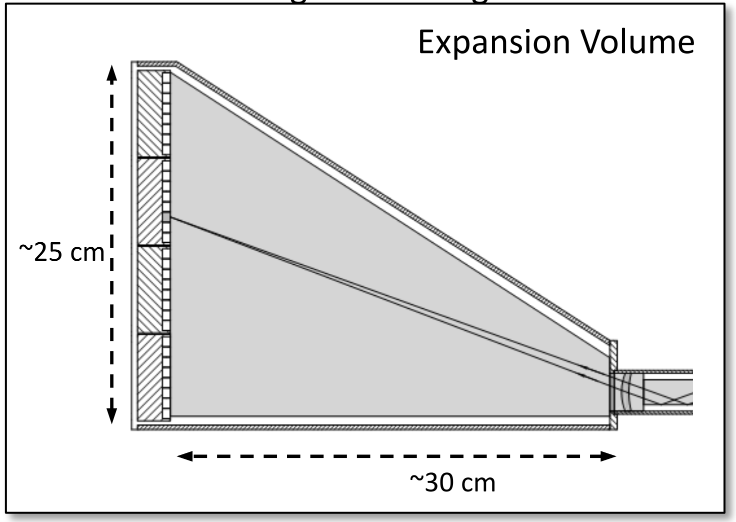
EIC hpDIRC Design Facts

- **Optimized geometry:** (based on discussions with the EMCal experts)
  - **69cm radius** for the barrel (70cm inner radius for the bars)
  - **425cm bar length** (works with both reused BaBar DIRC bars or new bars)
  - **12 bar boxes**, 10 long bars side-by-side in a bar box, 3 BaBar DIRC bars plus one half BaBar DIRC bar glued to form one long bar (or 3 BaBar DIRC bars plus one new short plate)
- Focusing optics:
  Radiation-hard 3-layer spherical lens
- Expansion volume:
  Solid fused silica prism: 24 x 36 x 30 cm^3 (H x W x L)
  Additional longitudinal space for MCP-PMTs, readout cards, cables: ~13cm
- Number of sectors, barrel radius and bar length can be optimized for integration, PID performance largely independent of barrel radius and bar length
- Expansion volume shape can be optimized for MCP-PMT magnetic field performance (tilted backplane) but length is directly related to performance

eRD14 generic design



eRD14 generic design



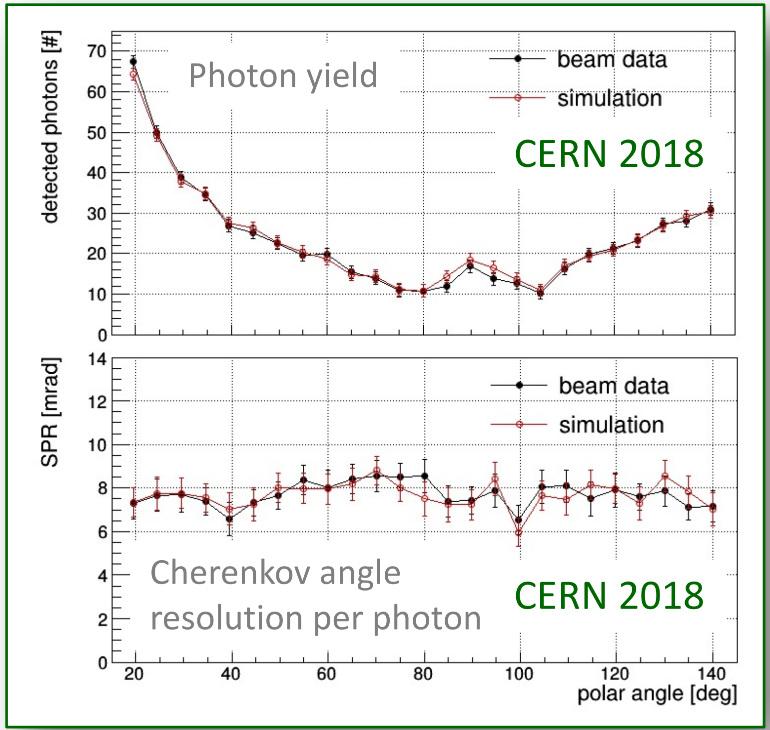
DIRC External Requirements/Assumptions

Tracking	
Angular resolution (at DIRC radius)	σ = 0.5 mrad at high momentum (for hpDIRC)
Position resolution (at DIRC radius)	Few mm
Momentum resolution (at DIRC radius)	Not very sensitive, post-DIRC track point(s) beneficial (non-Gaussian tails)
Magnetic Field	No specific B-field value assumed in simulation/reconstruction Favor 1.5 T solenoid field to match currently available MCP-PMTs
Space Assumptions	*(Note: length and radial location can be modified)*
Radius	69 cm (100 cm in hpDIRC standalone Geant4 simulation)
Radial thickness (in active region)	7-8 cm, including mechanical support
Total length (bars plus expansion volume)	455 cm (works with both reused BaBar DIRC bars or new bars)
Material budget (in active region)	~16-18% of a radiation length at normal incidence
Expansion volume size	24 x 36 x 30 cm^3 (H x W x L) fused silica prism (hpDIRC) Additional 13 cm behind prism for readout

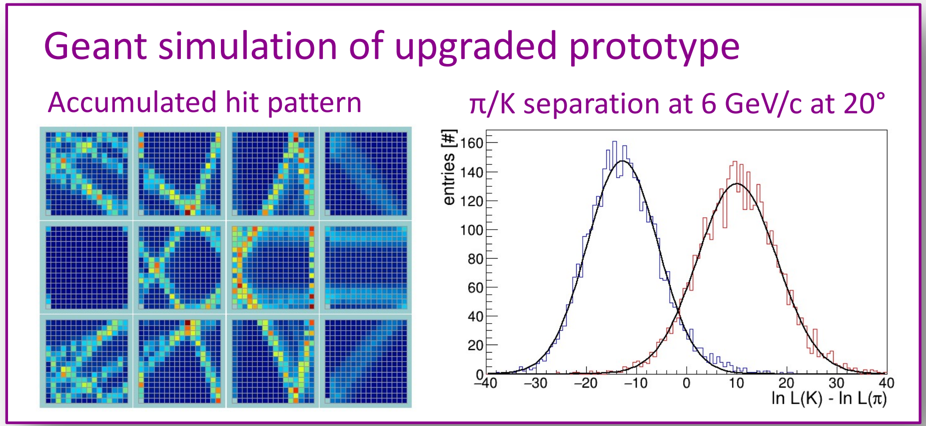
If there is a serious interest and budget to investigate option of reusing BaBar DIRC bars this effort would have to start soon due to expected phasing out of expertise at SLAC!

hpDIRC PID design validation

- Resolution and PID performance of system prototype
- PANDA Barrel DIRC prototype tested with particle beams at CERN (2015-18)
  (included 3-layer spherical lens – but older MCP-PMTs, larger pixels, slower electronics)
- Up to 5 s.d. p/π separation at 7 GeV/c (equivalent to 5.2 s.d. π/K at 3.5 GeV/c)
- Excellent agreement with simulation (same simulation used for hpDIRC)

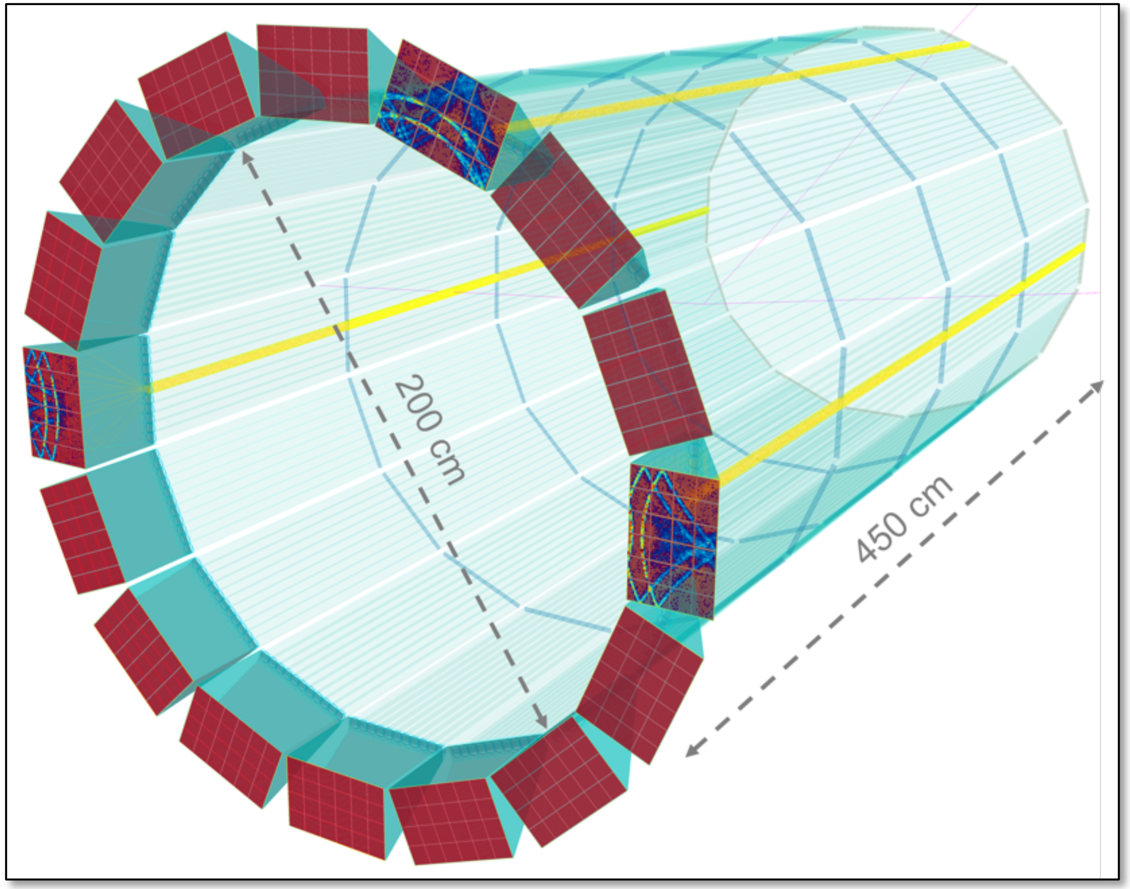


- Used this simulation to predict PID performance of upgraded prototype
  (new MCP-PMTs and electronics, 3mm pixels, improved PDE, 100ps timing)
- Expected π/K separation at 6 GeV/c at 20°: 3.1 s.d.
- Upgraded PANDA Barrel DIRC prototype (new sensors, new electronics) capable of hpDIRC PID performance validation in particle beams

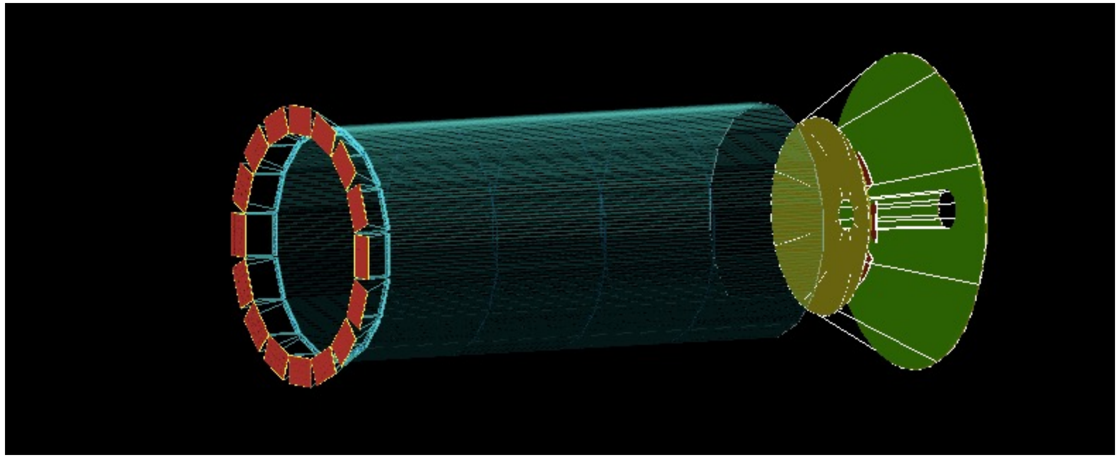


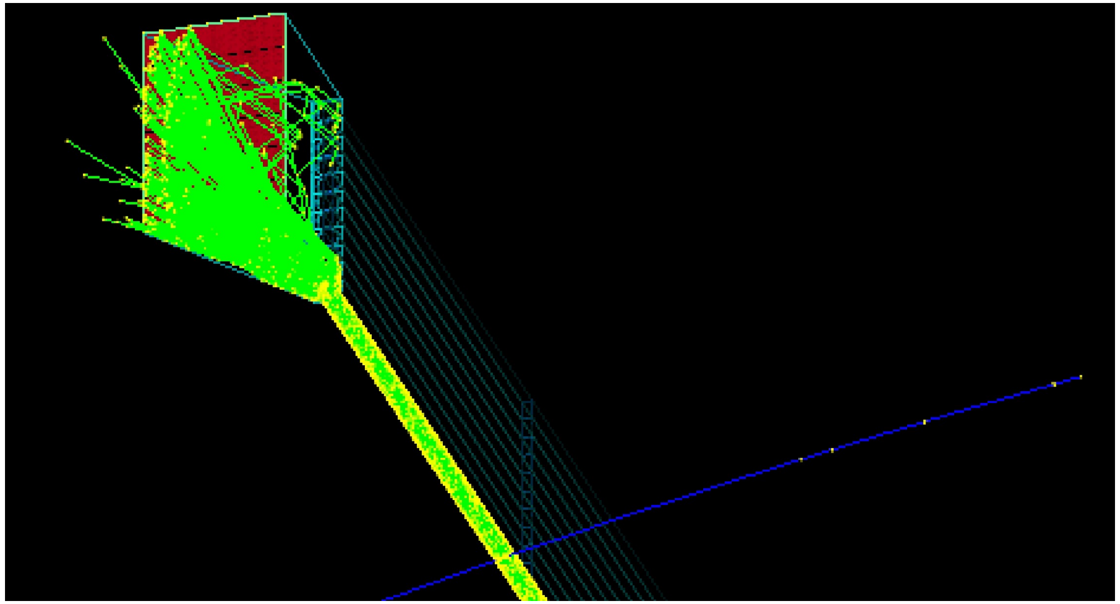
HPDIRC IN FUN4ALL

eRD14 generic design of hpDIRC in G4 stand alone package



eRD14 generic design in G4 stand alone package





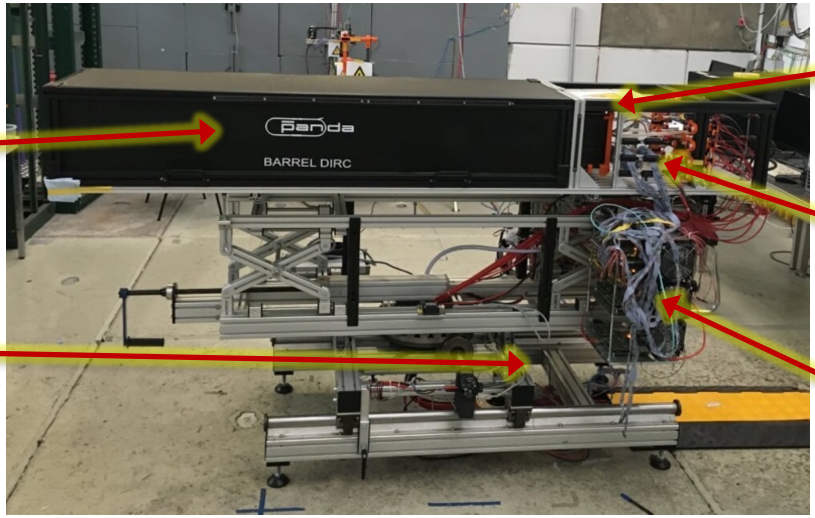
hpDIRC Validation

- PANDA Barrel DIRC prototype being transferred from GSI to U.S. (CUA/SBU) to start the hpDIRC prototype
- Development of cosmic ray telescope (CRT) at Stony Brook by CUA – GSI – ODU – SBU groups
- Performance tests in SBU hpDIRC lab starting this fall, potential beam test at Fermilab in 2023

PANDA Barrel DIRC Prototype

Dark box for optics (bar, lens, prism)

Rotation stage (remote controlled)

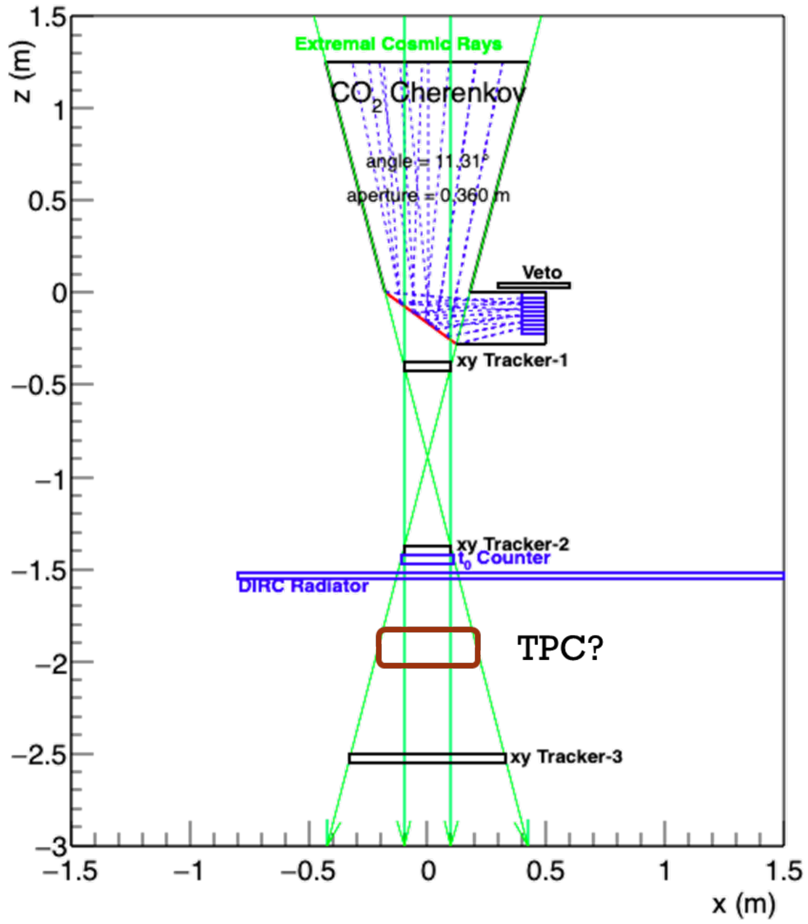


MCP-PMT array

Frontend electronics (PADIWA)(air-cooled)

DAQ boards (TRB)

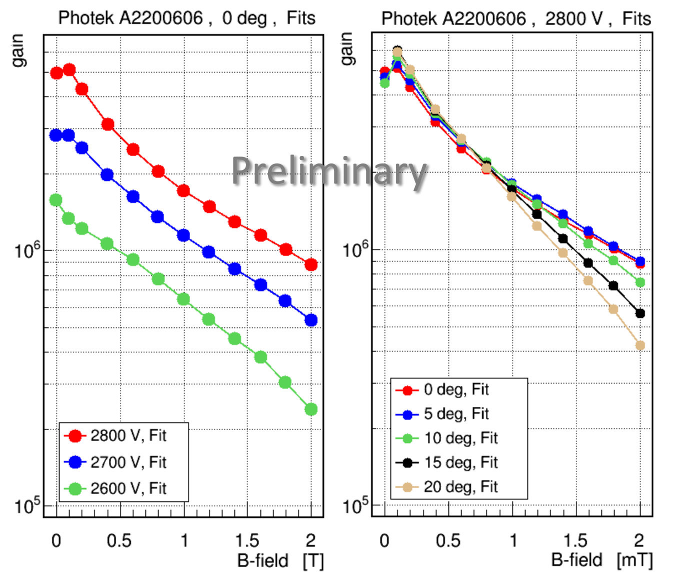
Preliminary CRT arrangement at SBU



Work in collaboration with SBU team
A. Deshpande, K. Dehmelt, T. Hemmick, S. Park

1. **All three Cherenkov systems are closely watching the LAPPD development as a potential sensor alternative.**
   - Potential for cost savings (DIRC) and simplification of the detector integration (mRICH, dRICH) and performance enhancement (mRICH)
   - All three system have proven baseline technology solutions (SiPM for mRICH and dRICH, commercial MCP-PMTs for hpDIRCs)

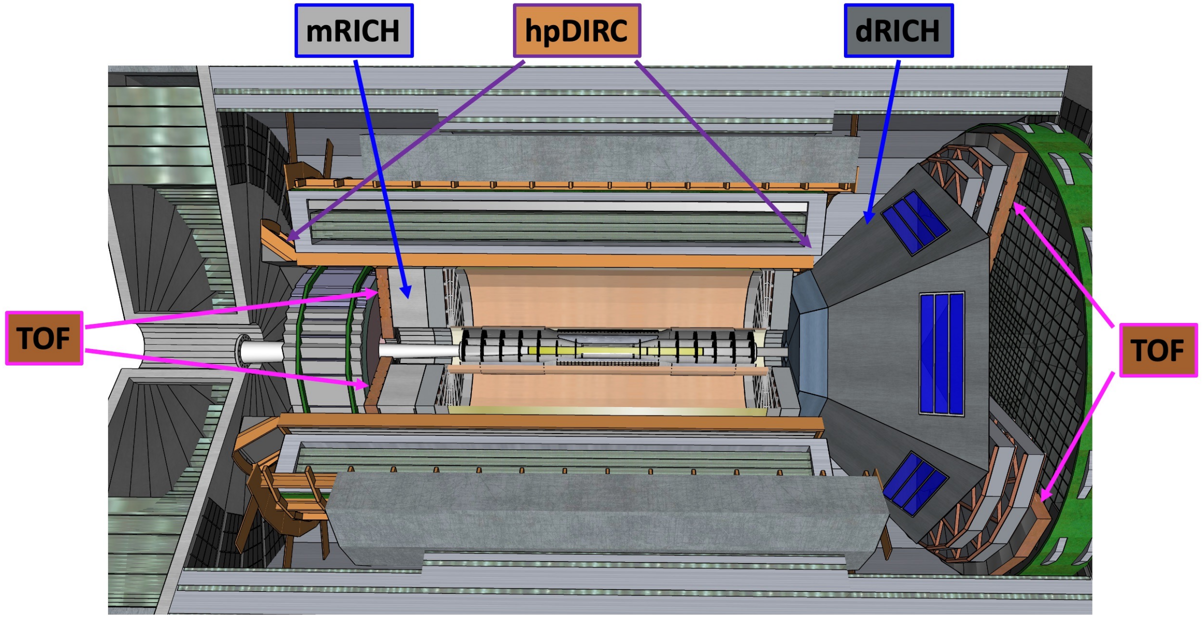
2. **Local magnetic field strength at the sensors location has to be investigated!**
   - Small-pore MCP-PMTs shown to be OK for fields up to 2 Tesla
     (see recent result from A. Lehmann et al. for 6µm-pore 2'' Photek AuraTek MCP-PMT)
   - If expected fields are too high: SiPM are alternative
     (challenges: dark noise, radiation damage, cooling, annealing, integration issues)



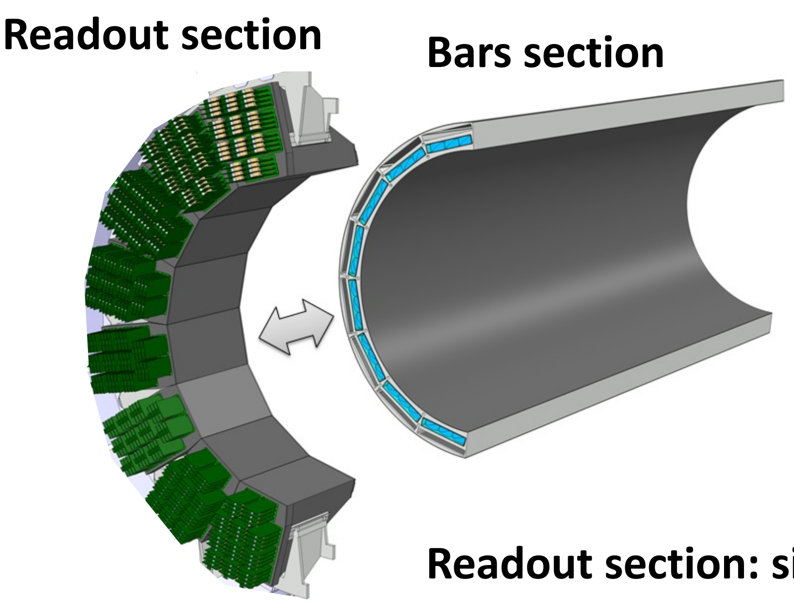
A. Lehmann et al, shown by J. Milnes, IEEE NSS, Nov. 2020

Summary

- **PID Configuration based on YR and EIC Generic R&D program**
  - **h-endcap**: **dRICH (**π/K *separation up to ~50 GeV/c)*
  - **e-endcap**: **mRICH (**π/K *separation up to ~10 GeV/c)*
  - **barrel**: **hpDIRC (**π/K *separation up to ~6-7 GeV/c)*
  - **LGAD based TOF (***lower momenta down to ~0.2 GeV/c)*



- **F4A Simulation advanced:**
  - **TOF** – fully implemented
  - **mRICH –** reconstruction integration
  - **dRICH, hpDIRC** – validation, porting reconstruction
- **Integration**
  - **mRICH –** modular design, allows to cover up space inside DIRC
  - **dRICH –** some flexibility longitudinal, transverse more critical (impacts the optics)
  - **hpDIRC –** Barrel length and radius have almost no impact on the performance while the bar width and thickness, and the prism size and shape, have a significant impact
- **Sensors**: Commercial solutions available and tested, development of LAPPDs observed.
- **Tracking requirements: 0.5 mrad** for dRICH and DIRC, maybe a little bit less constrained for mRICH



Example: Barrel DIRC in PANDA (smaller radius, shorter bars than hpDIRC)

- bars long enough to guide light to prism located outside crowded central region
- prism (30cm) inside B field, all mech. components aluminum alloy or CFRP
- modular design, bar boxes/prism boxes can be installed later or removed

Readout section: single unit