R&D Efforts in Cherenkov Imaging Technologies for Particle Identification Systems in Future Experiments

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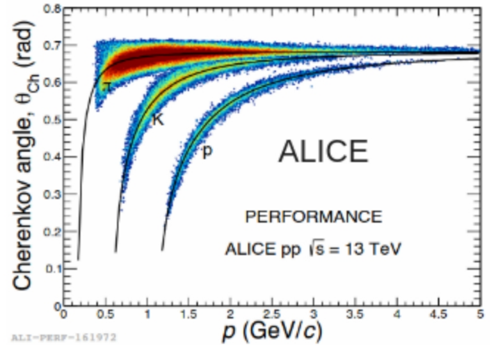
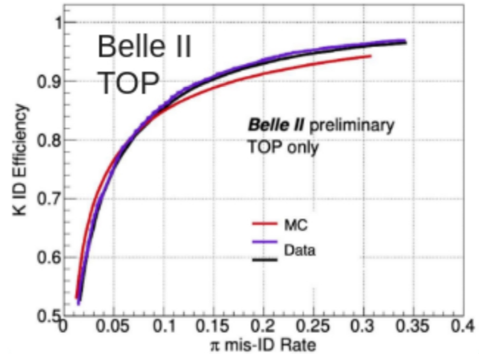
Outline:

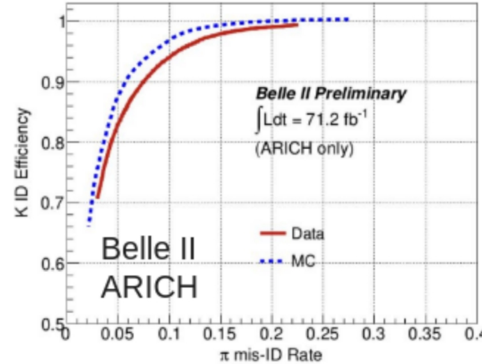
- Introduction
- R&D for Future experiments
- Conclusion

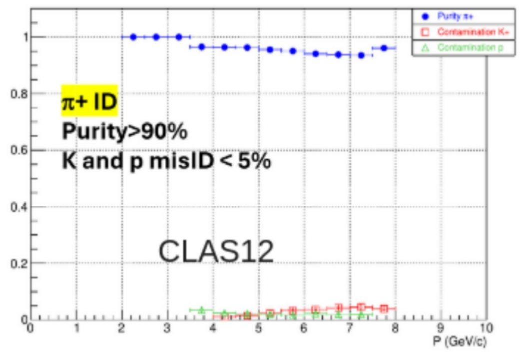
Introduction

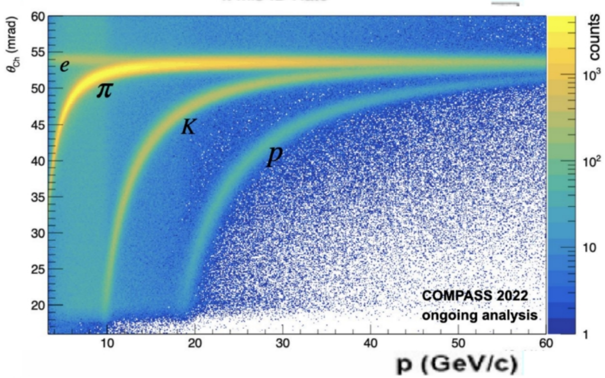
See Review talk on Cherenkov detectors in current particle and nuclear physics experiments by Kodai Matsuoka

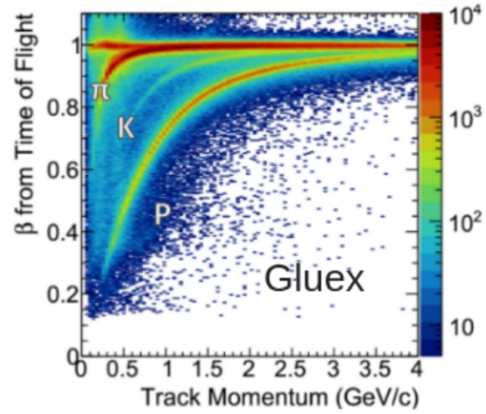


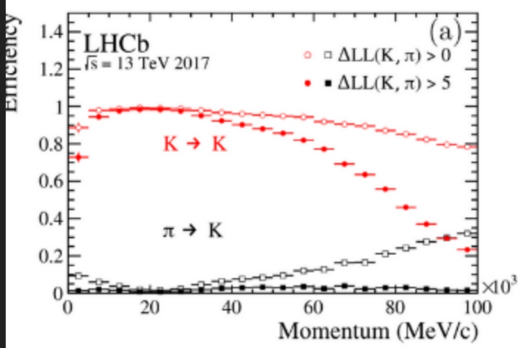


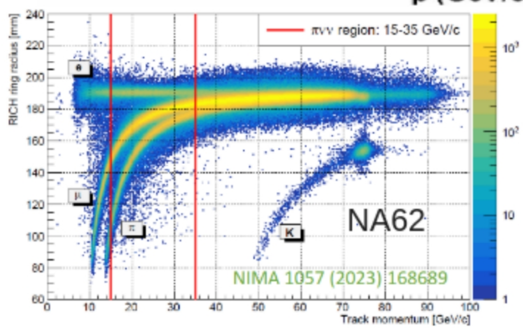












World Class existing Cherenkov Detectors!!

What about the future?

10:30 AM → 11:55 AM **R&D on Cherenkov light imaging systems for future experiments: Session I** — Ketteler-Saal

Conveners: Jochen Schwiening (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Silvia Dalla Torre (INFN - Trieste)

- 10:30 AM — **R&D Developments in Cherenkov Imaging Technologies for Particle Identification Systems in Future Experiments** — 30m
  Speaker: Chandradoy Chatterjee (INFN Trieste)
- 11:05 AM — **Status of the CBM RICH detector towards first beam in 2028** — 20m
  Speaker: Christian Pauly (Bergische Universität Wuppertal(BUW))
- 11:30 AM — **Status of the PANDA DIRC Detectors** — 20m
  Speaker: Albert Lehmann (Universität Erlangen(UErl))

1:15 PM → 3:20 PM **R&D on Cherenkov light imaging systems for future experiments: Session II** — Ketteler-Saal

Conveners: Jochen Schwiening (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Silvia Dalla Torre (INFN - Trieste)

- 1:15 PM — **The ePIC dual-radiator RICH detector** — 20m
  Speaker: Marco Contalbrigo (INFN Ferrara)
- 1:40 PM — **A Proximity-Focusing RICH Detector for the ePIC Experiment at the EIC** — 20m
  Speaker: Brian Page (Brookhaven National Laboratory)
- 2:05 PM — **hpDIRC Detector Development for the ePIC Experiment at the Electron-Ion Collider** — 20m
  Speaker: Dr Greg Kalicy (CUA)
- 2:30 PM — **The Upgrade II of the LHCb RICH system** — 20m
  Speaker: Claudio Gotti (INFN Milano-Bicocca)
- 2:55 PM — **TORCH detector concept and design** — 20m
  Speaker: Marion Lehuraux (University of Warwick)

4:30 PM → 5:45 PM **R&D on Cherenkov light imaging systems for future experiments: Session III** — Ketteler-Saal

Conveners: Jochen Schwiening (GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)), Silvia Dalla Torre (INFN - Trieste)

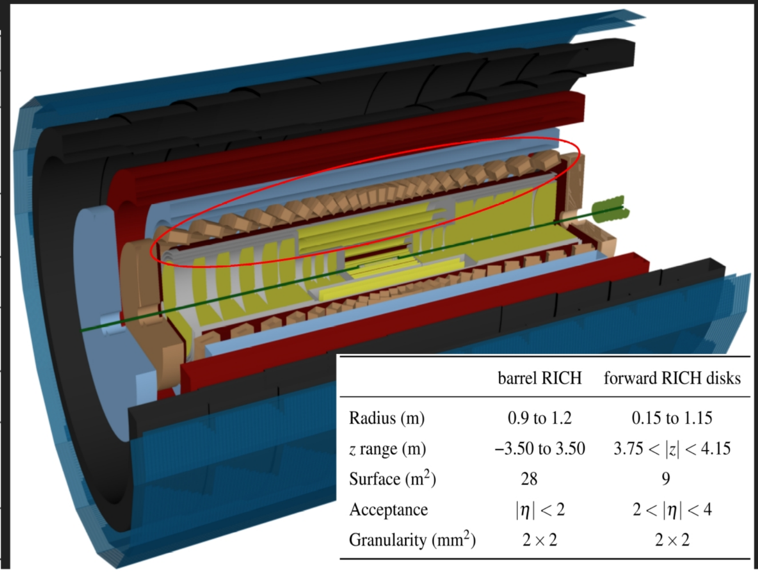
- 4:30 PM — **A DIRC-like TOF detector for PID at STCF** — 20m
  Speaker: Xuesen Lin (USTC)
- 4:55 PM — **Designing the ALICE 3 bRICH detector: simulation studies and beam test results** — 20m
  Speaker: Nicola Nicassio (CERN, University and INFN, Bari, Italy)
- 5:20 PM — **A RICH detector for the ALADDIN experiment** — 20m
  Speaker: Elisabetta Spadaro Norella (University and INFN of Genoa)

- ❑ 10 Talks in this session!
  Several talks from other sessions; PID algorithms, sensor technologies, technical aspects that are directly related to the future nuclear and particle physics experiments and upgrades of current experiments.
- ❑ Numerous posters!
- ❑ Common efforts in <u>multiple sectors</u>:
  MCP-PMT lifetime, SiPM dark count mitigation, Radiation hardness, Alternative for fluoro carbon radiators, electronics, software and many more → Common platform **<u>DRD4</u>** (**see talk by Massimiliano Fiorini**).
- ❑ LHC-EIC experiments are major enterprises.
  <u>BUT THEY ARE NOT ALONE!!</u>

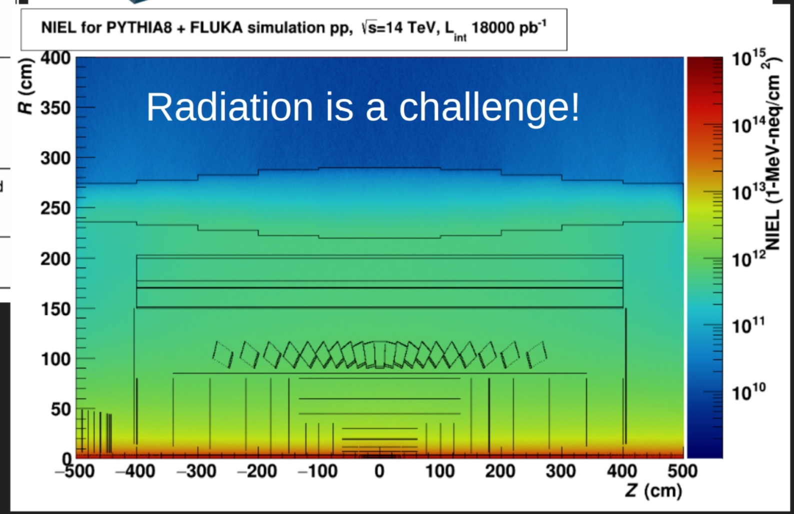
A **RICH** Legacy.

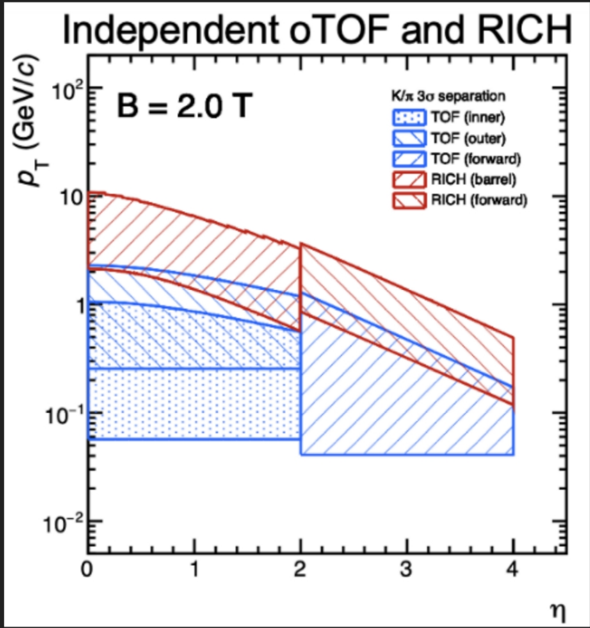
ALICE3 Upgrades

Physics goals		Subsystems and specifications	
Observable	**Uniqueness**	**TOF**	**RICH**
Multi-charm baryons	Observation of multi-charm baryons in AA collisions	**Outer/Forward** **$\sigma \sim 20$ ps**	Barrel **Forward**
D-Dbar correlations	Angular de-correlation of soft charm	**Outer/Forward** **$\sigma \sim 20$ ps**	Barrel **Forward**
Beauty mesons and baryons	Precision of 0.01 on elliptic flow	**Outer** **$\sigma \sim 20$ ps**	Barrel **Forward**
Quarkonia, $\chi_{c1}(3872)$	Measurement at low p_T and central rap.		
$\chi_{c1,2}$	P-wave charmonia in AA collisions	Outer $\sigma \sim 20$ ps	Barrel
Di-leptons (T, flow, χ-symm)	Time-evolution of thermal radiation; chiral symm. at μ_B=0	**Inner/Outer** **$\sigma \sim 20$ ps**	**Barrel**
Net-baryon fluctuations	6th order net-proton cumulants	**Outer/Forward** **$\sigma \sim 20$ ps**	**Forward**
Photon-jet, full jets	High-precision low-p_T, large-R jet modification		
Hadronic physics (femtoscopy, nuclei)	Charm-charm hadronic inter.; observation of charm-nuclei; (hyper)nuclei with A = 5 and 6	**Outer/Forward** **$\sigma \sim 20$ ps**	Barrel **Forward**
Searches in γγ in UPCs	ALPs m>0.1GeV and low coupling	Inner/Outer/ Forward $\sigma \sim 20$ ps	Barrel/Forward
Ultrasoft photons	Validity and limits of Low theorem		



	barrel RICH	forward RICH disks
Radius (m)	0.9 to 1.2	0.15 to 1.15
z range (m)	−3.50 to 3.50	$3.75 < \|z\| < 4.15$
Surface (m^2)	28	9
Acceptance	$\|\eta\| < 2$	$2 < \|\eta\| < 4$
Granularity (mm^2)	2×2	2×2



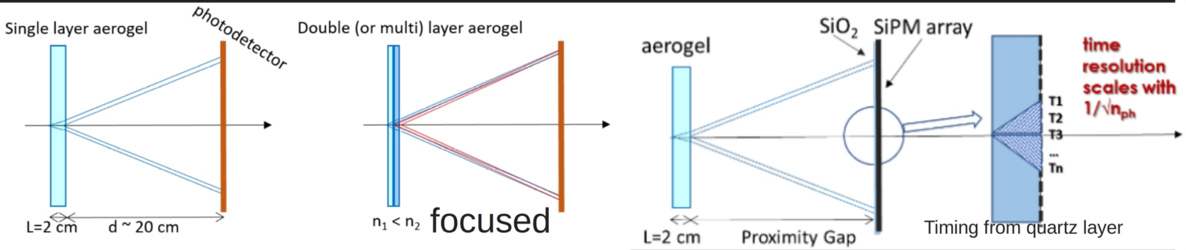


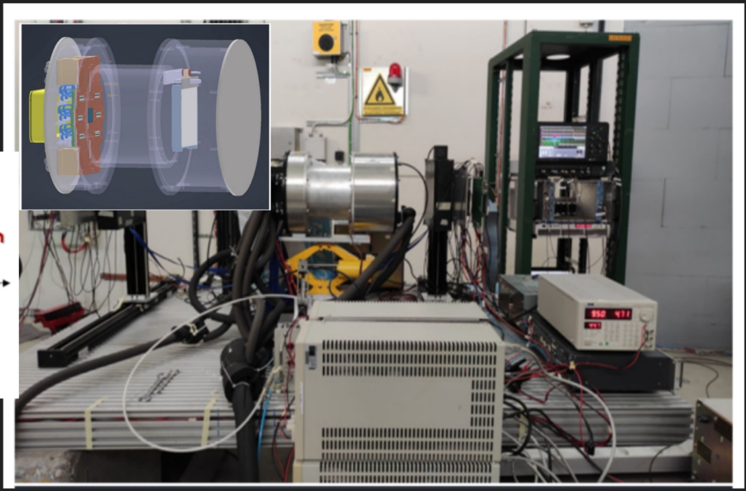
Talk by Nicola Nicassio

1. Majority of the ALICE3 physics programmes will require PID at endcap and barrel.
2. Proximity focusing RICH and Time of flight detectors are considered as baseline.
3. Novel ideas like merging TOF and RICH under exploration.
4. Synergistic studies for aerogel, sensors within ALICE and other experiments are happening.

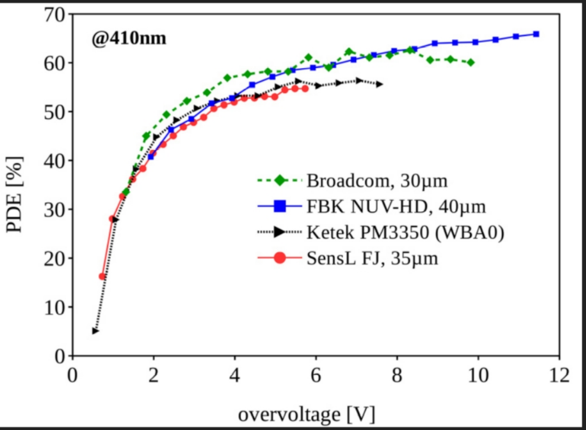
ALICE3 Upgrades

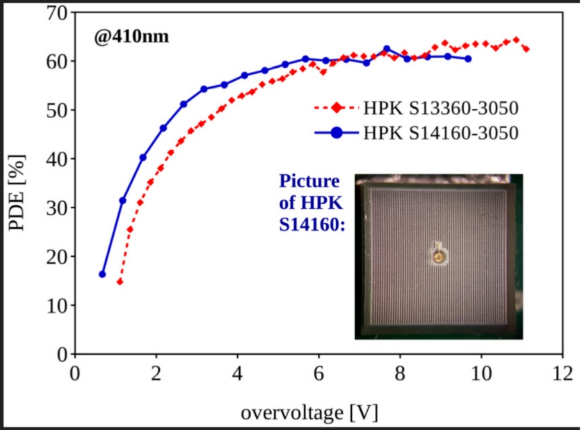
CERN-LHCC-2025-002



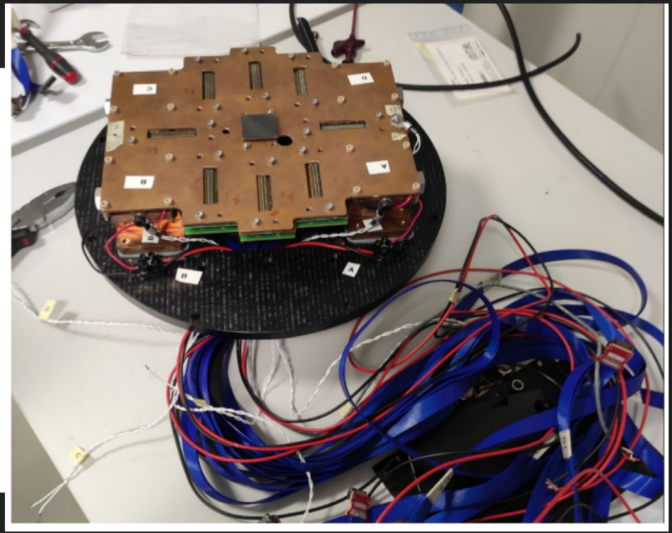


- Hydrophobic aerogel (n=1.03) synergistic to ePIC (EIC)
- Fill proximity gap with $C_5F_{10}O/N_2$ (20/80%) (n ~ 1.0006) extend electron identification.
- Low refractive index forces larger proximity gap





Talk by Nicola Nicassio



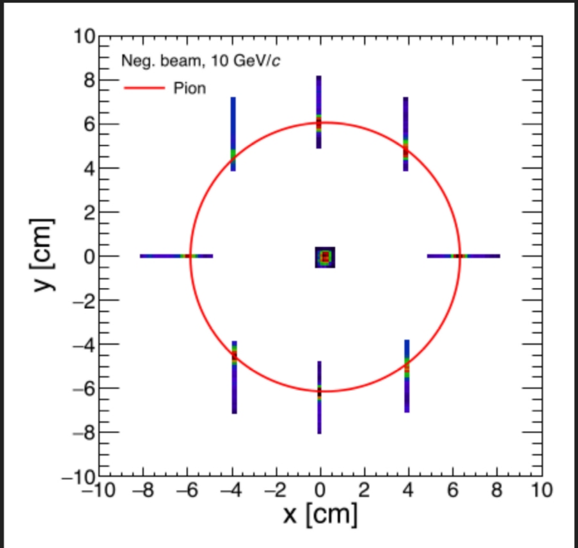
Different SiPM options and R&D ongoing! HRPPD is considered for Endcap RICH (limit to SiPM performance due to high radiation level)

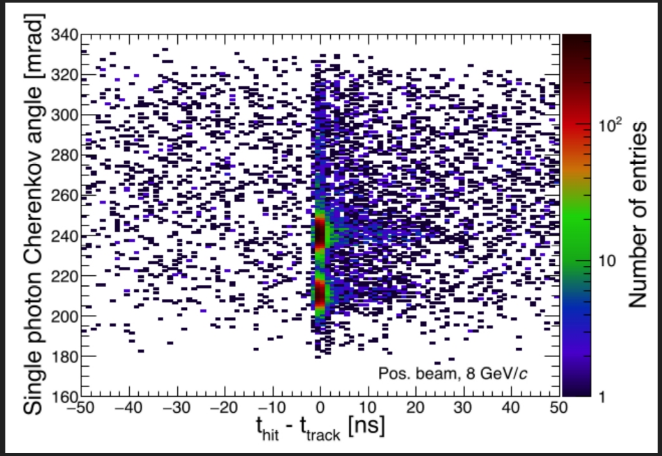
ALICE3 Upgrades

HPK S13361-3075AE-08 64 channel SiPM array used to detect photons from 1 mm thick fused silica window, acting as a second Cherenkov radiator.

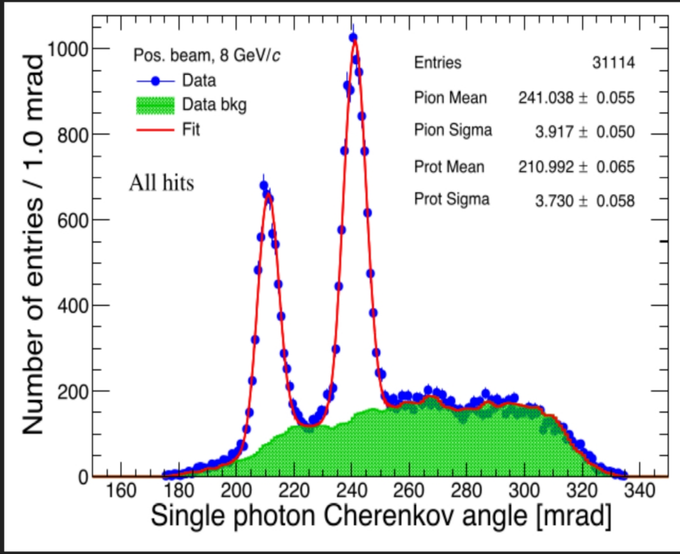
SiPM HPK S13552 128-channel linear arrays to detect Cherenkov photons from aerogel

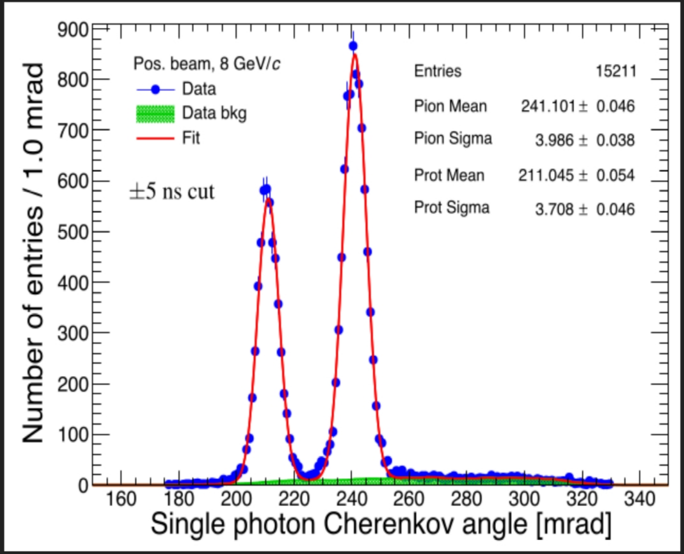
Talk by Nicola Nicassio





Eur. Phys. J. C (2025) 85:578

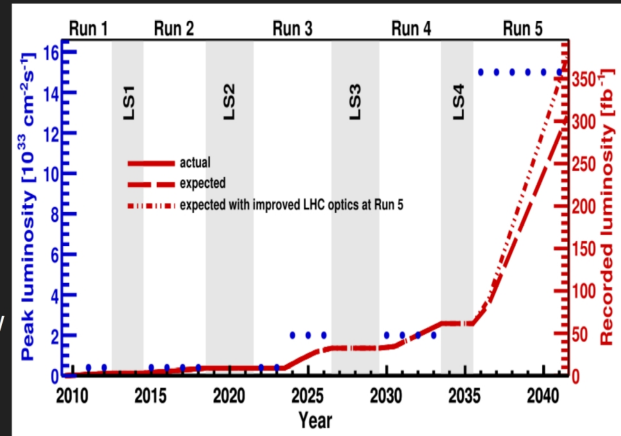


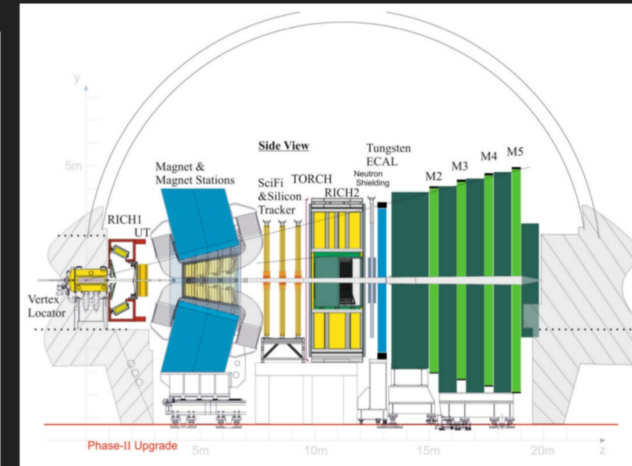


- Successful beam test compatible to Simulation studies. Matching SPE resolution and angle.
- PETIROC 2A ASIC had been used. Will be updated in future.
- Measurements with irradiated array and operated at -40°C will be tested as well.

LHCb Upgrade II

- ❑ LHCb upgrade II will allow key flavor physics measurements with unchallenged precision over a considerable time.
- ❑ within LHCb acceptance O(10^{14}) b hadrons will be produced($3x10^{11}$ b hadrons per fb^{-1}).
- ❑ RICH-1 and RICH-2 have to be adequately upgraded to cope with the new challenges.
- ❑ Insertion of new TORCH detector to enhance PID capabilities.

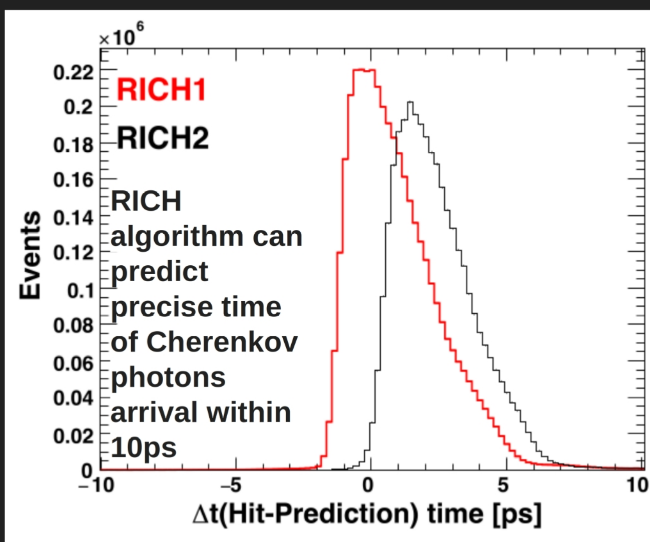




Dedicated LHCb upgrade talk by Claudio Gotti

Increasing luminosity essential to perform key flavor physics measurements.

Imposes severe challenges.
→ Requires exploitation of timing.
→ Minimize sources of SPE resolution error to retain similar RICH performance.



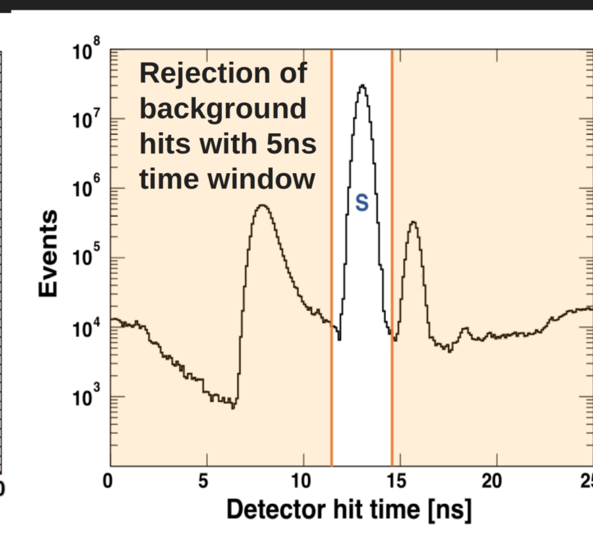
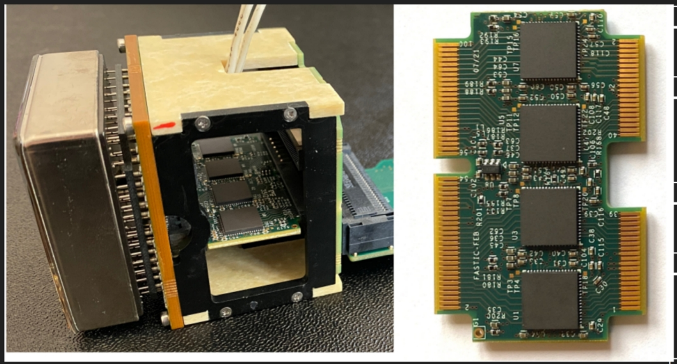


Photo-sensor Timelines:

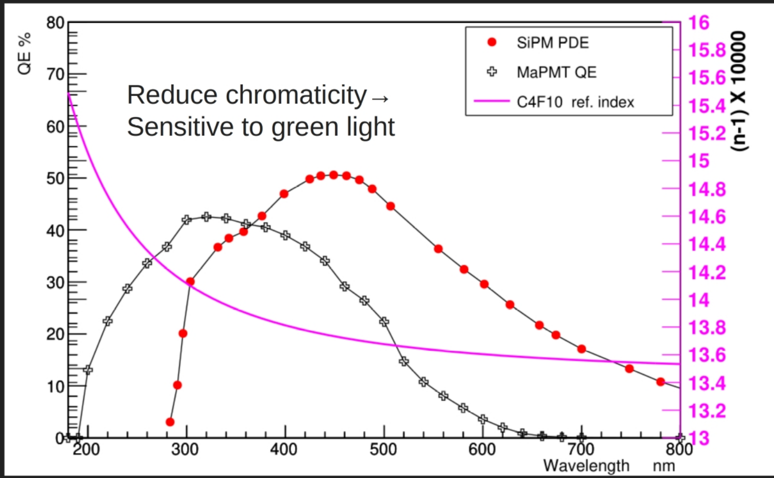
- ❑ 2010-2018: HPDs with embedded readout
- ❑ 2022-2026: Ultra bialkali MaPMTs with Claro ASIC
- ❑ **2030-2033: Fast ASIC FastRICH with MaPMTs**
- ❑ **2036-2044: New photon detectors with FastRICH**

LHCb Upgrade II

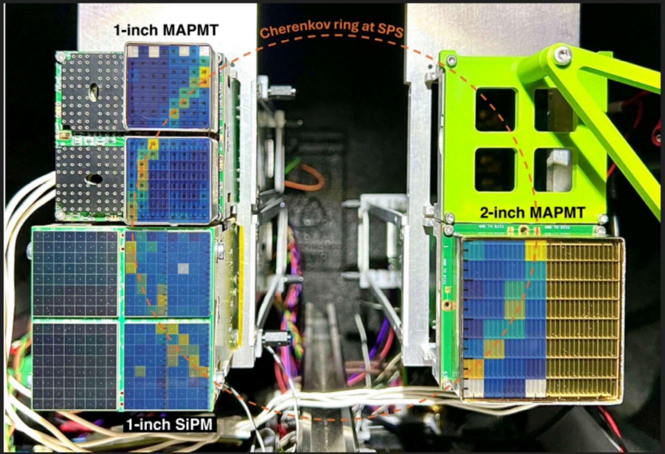


See Poster by Floris Keizer

- Compatibility to lpGBT and versatile link Plus.
- ASIC need to stand 2×10^{13} neq / cm^2 and 12 kGy at the RICH1.
- TOA ±2σ sensor symmetric time gate.
- Additional timing and digital functionality compared to CLARO.
- Power budget has to remain similar to CLARO.



https://doi.org/10.1088/1748-0221/20/03/P03034



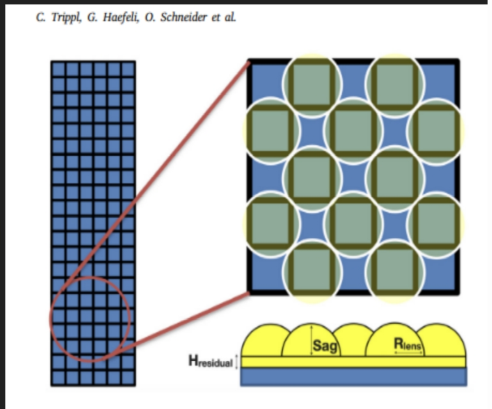
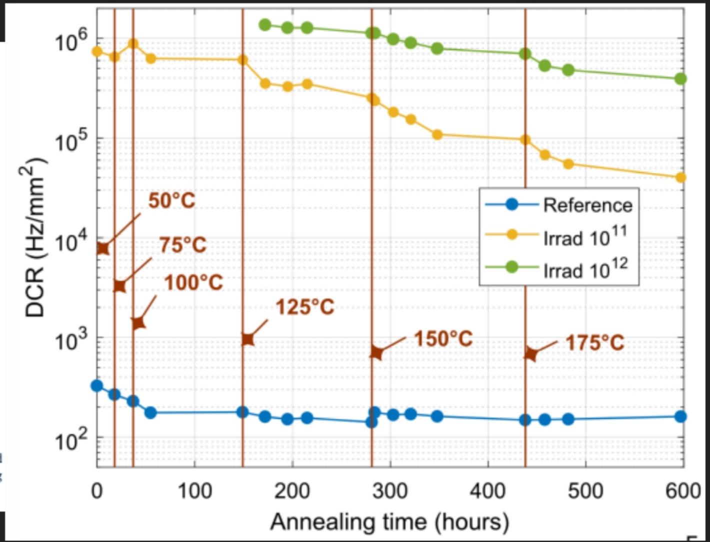


Fig. 1. Sketch of a SiPM channel for the LHCb SciFi Tracker with microlenses placed on every other pixel. A microlens is parameterised by the residual height H_{res}, its sag and the lens radius R_{lens}.



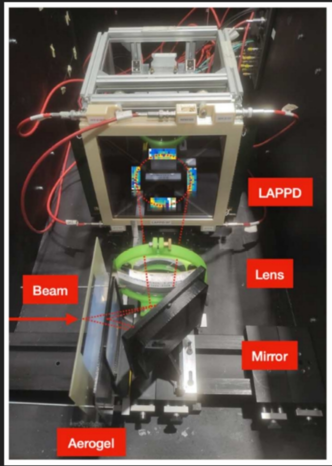
SiPM dedicated poster by Marco Guarise

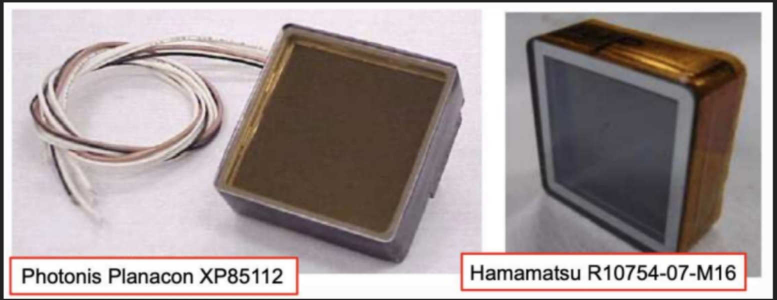
Beam test poster by Vlad-Mihai Placinta

SiPM have several advantages but also challenges.
MCP-PMTs are alternative?

LHCb Upgrade II

Poster by Daniel Foulds-Holt on LAPPD beam test





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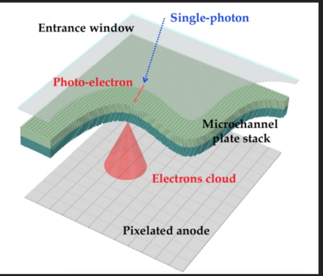
Low gain MCPs are also under investigation and ongoing R&D



- ❑ Extremely good time resolution < 40 ps.
- ❑ Custom pixelisation tailored for individual applications.
- ❑ Concerns related to lifetime and rate capability: R&D ongoing

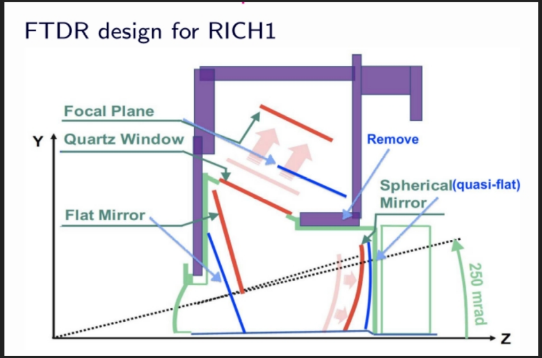
See Talk by Silvia Gambetta ICHEP 2024,

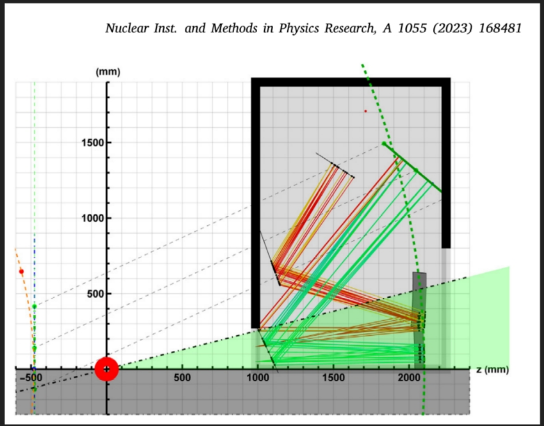
No preferred sensor choice at this moment, thorough R&D and upcoming beam tests will determine the choice!

- ❑ C_4F_{10} (GWP 8500 CO_2) and CF_4 (GWP 7000 CO_2).
- ❑ Fluoro-Ketones can become an alternative.
- ❑ Extensive R&D is foreseen on alternative radiator gas.
- ❑ *Optimized sensor choice and radiator gas should go hand in hand.*

(talk by Greg Hallewell)

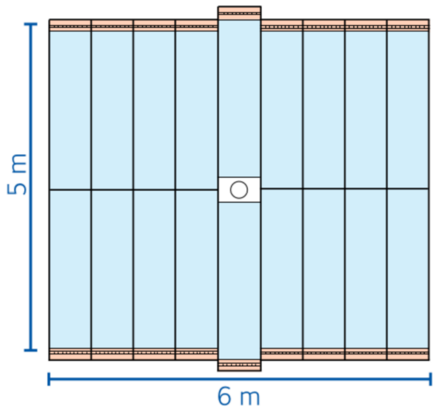
- ❑ Move flat mirrors into acceptance → Improves emission uncertainty → Requires R&D
- ❑ Increase spherical mirror curvature → Reduce occupancy and pixel error.

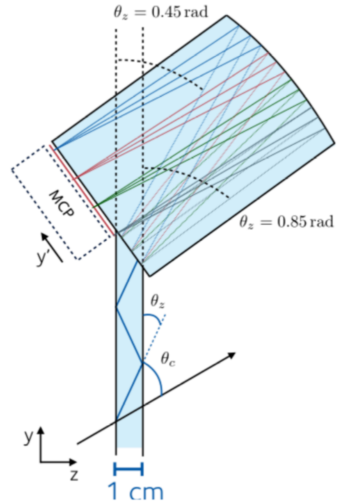




See Poster by Elisabetta Norella
Talk by Silvia Gambetta ICHEP 2024

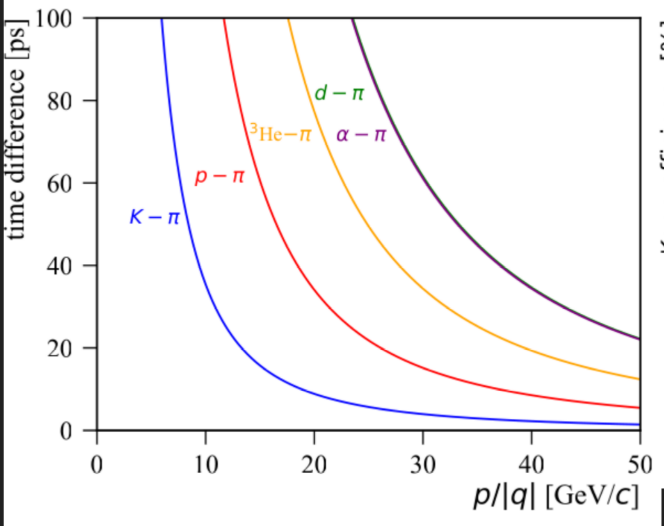
LHCb Upgrade II (TORCH)

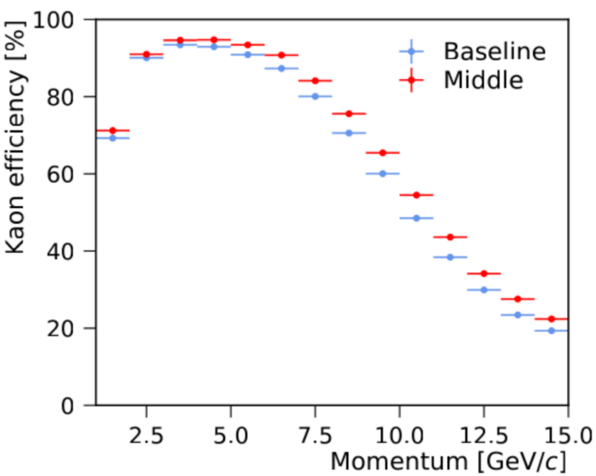


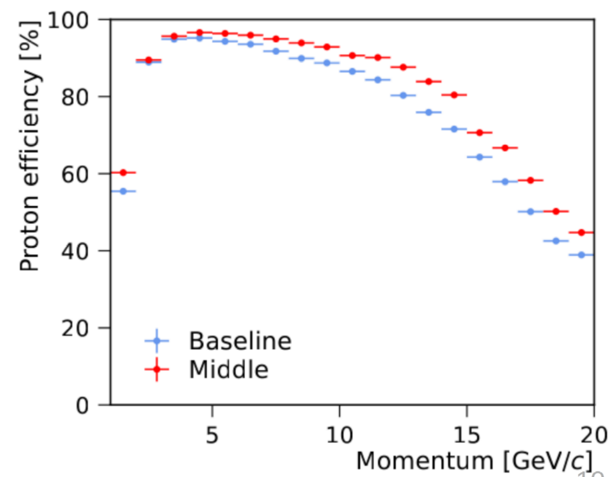


LHCb TDR 23;
LHCb scoping report

- ❑ Charged particles with momentum below 10 GeV/c can separate kaons and protons.
- ❑ Pions can be vetoed with number of detected photons. Challenging for high multiplicities events.
- ❑ TORCH-> General purpose timing detector. Per particle timing at 15 ps (30 detected photons) level for excellent low momentum pi/K/P separation. Similar requirement for HIKE.
- ❑ MPC-PMT as baseline. Improved life time and rate capabilities are of interest. Common goal of DRD4.
- ❑ SiPM are also considered. Concern related to radiation and large dark current.
- ❑ Synergistic to LHCb RICH upgrade II. SiPM cooling → common concern for SciFi and RICH
- ❑ FastRICH baseline ASIC → synergistic to RICH upgrade



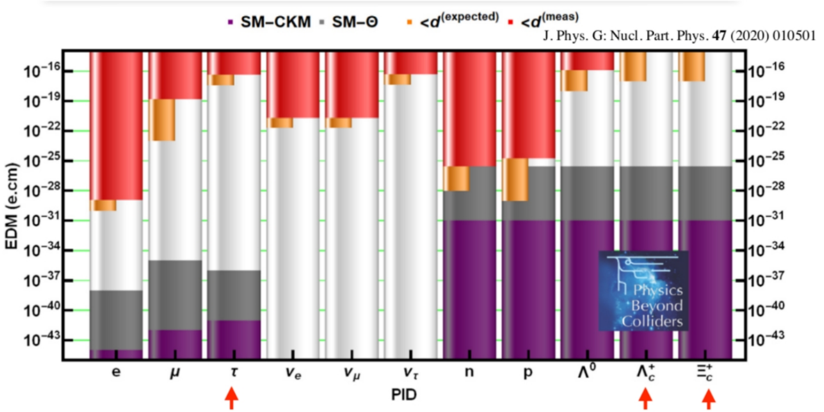


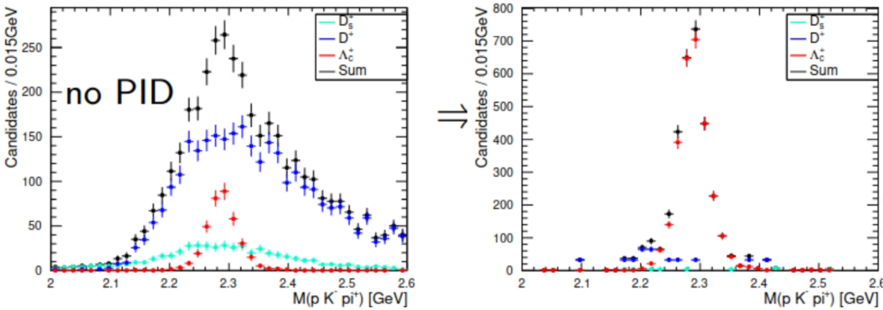


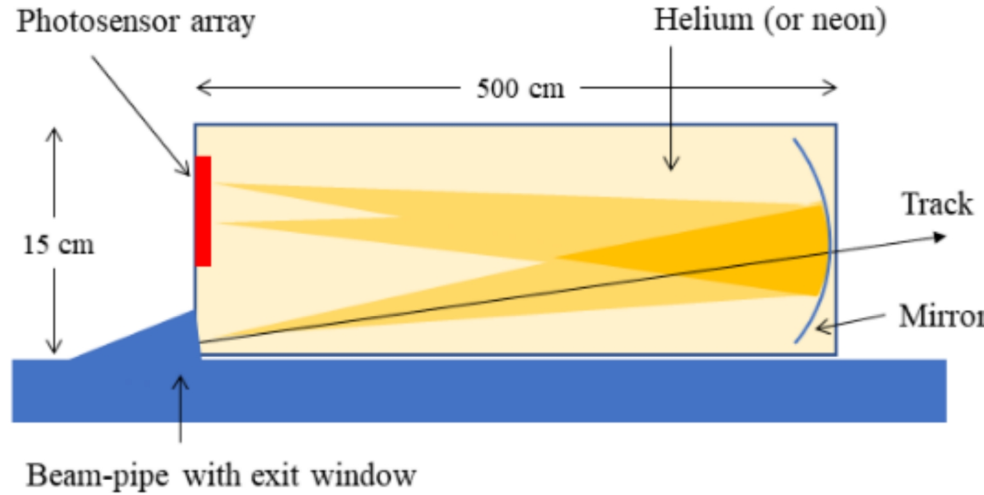
Talk by Marion Lehuraux

ALADDIN

Electromagnetic Dipole Moments

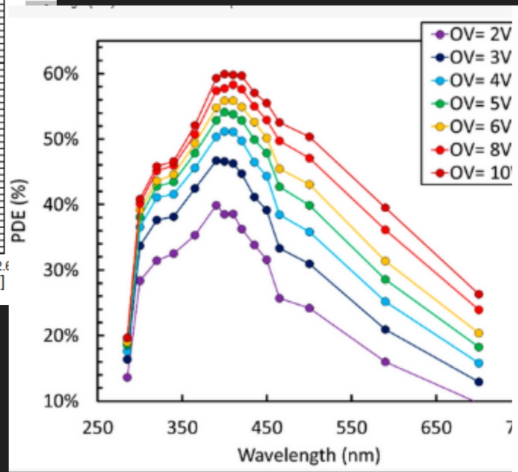






Microlens array? Hama or FBK NUV-HD 40 ?

He & MCP-PMT incompatible combination! Neon in reduced pressure? Can provide enough granularity?



CERN-LHCC-2024-011,

Planned to be installation during LS3.
Not in far future. Exisiting photo-sensor options are considered beside R&D.

Talk by Elisabetta Norella

HIKE-AMBER

3.1 Experimental layout

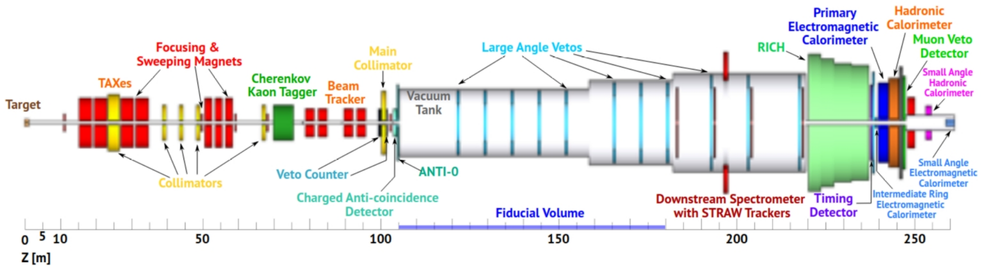
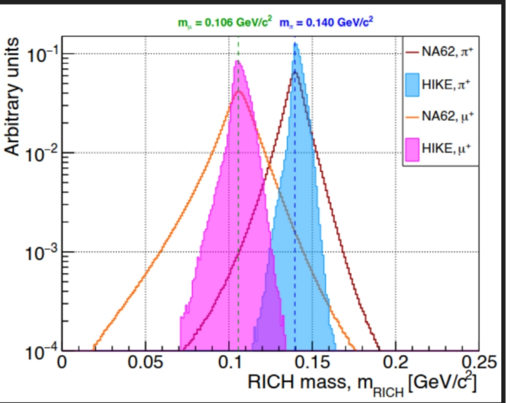
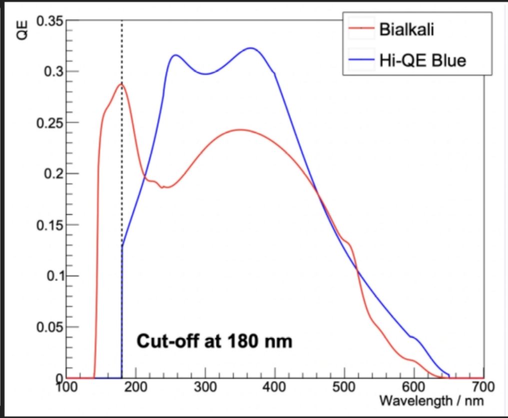


Figure 4: HIKE Phase 1 layout, with an aspect ratio of 1:10.

Talk by Angela Romano (at CERN Detector Seminar)
Cristina Lazzeroni (at SPSC open session)





Hike LOI: arXiv:2211.16586v1 [hep-ex] 29 Nov 2022

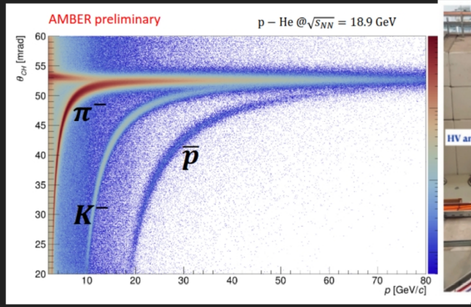
NA62 KTAG: Hamamatsu R7400-U03 and R9880-210. Peak QE 20-40%. Average rate varies from 3-5 MHz, area of 2.5 cm². SPE res 300 ps, 20 detected photon 70 ps.

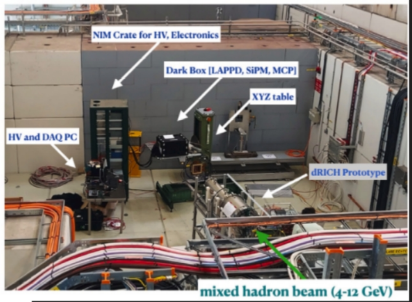
HIKE Phase 1: KTAG expected to **provide time resolution of 15–20 ps** (similar requirement as LHCb TORCH)

200 MHZ beam → 10 MHz/cm² detected photons. **SPE time res 50-70 ps.**

16 C/cm² accumulated charge with 10⁶ estimated gain 50% duty cycle. ALD coated MCP-PMTs.

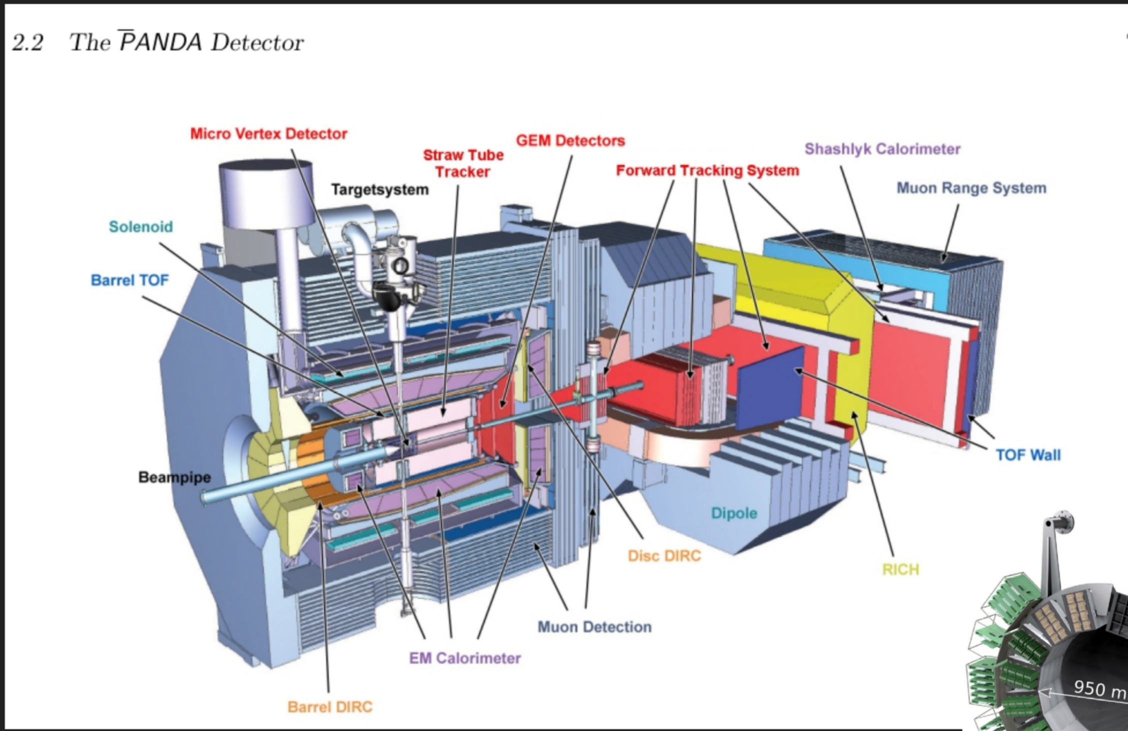
AMBER

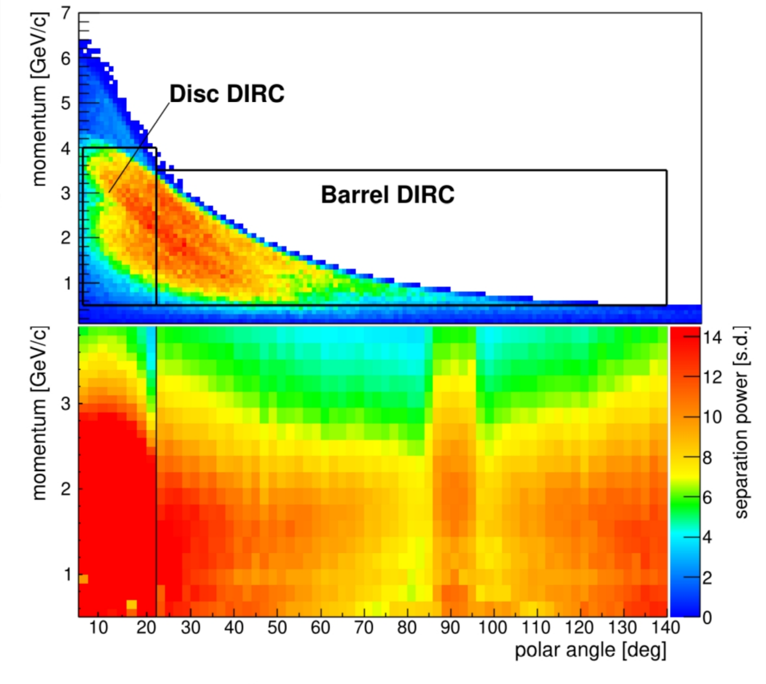


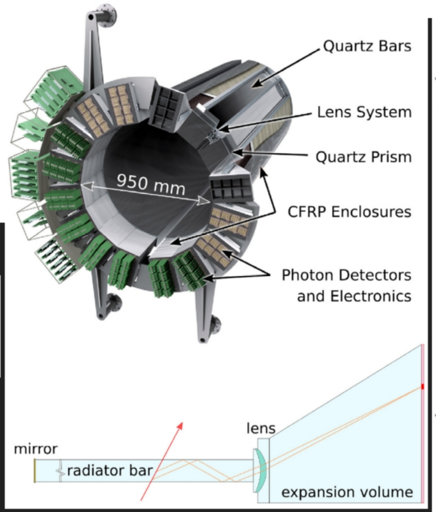


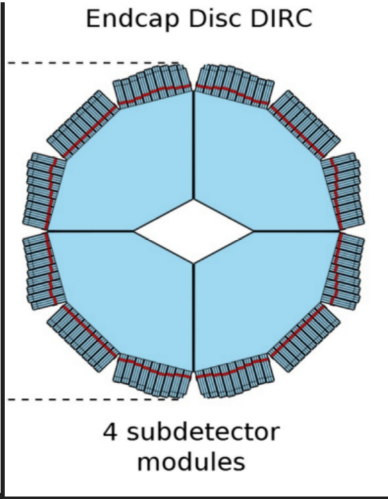
Identify poroton below 20 GeV/c, LAPPD/HRPPD is potential candidate for a proximity RICH-0. Synergistic to EIC.
See talk by Jinky Agarwala on LAPPD beam and magnetic field test for EIC application and beyond

PANDA DIRCs







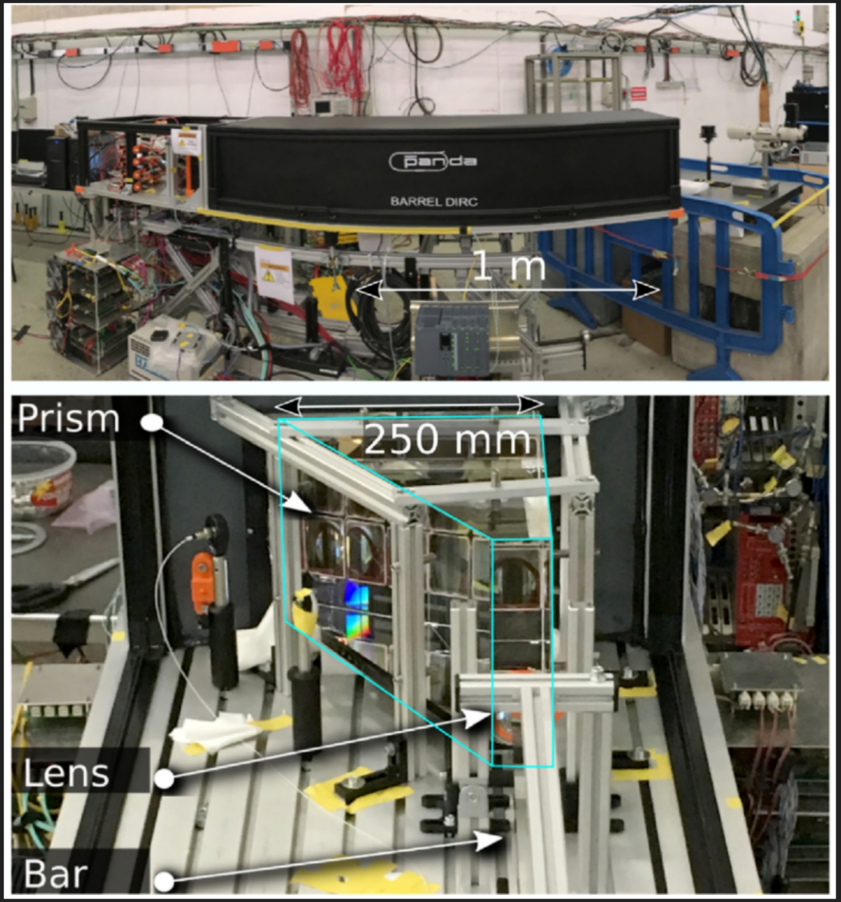


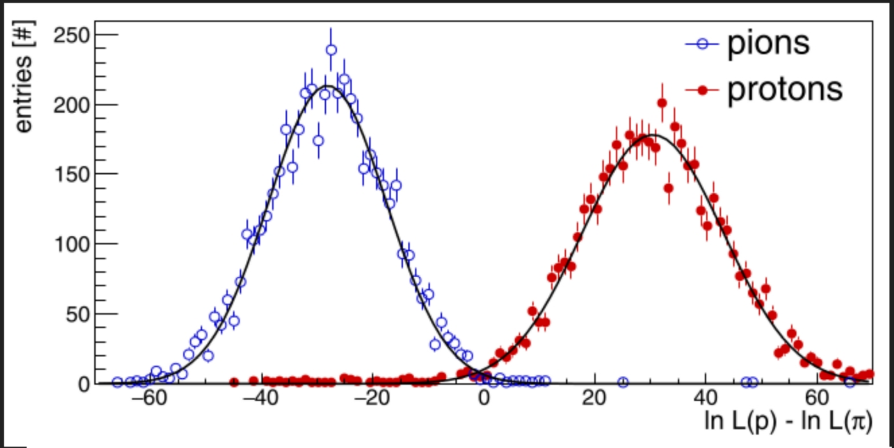
Panda barrel DIRC: J. Phys. G: Nucl. Part. Phys. 46 045001
Panda endcap DIRC: J. Phys. G: Nucl. Part. Phys. 49 120501

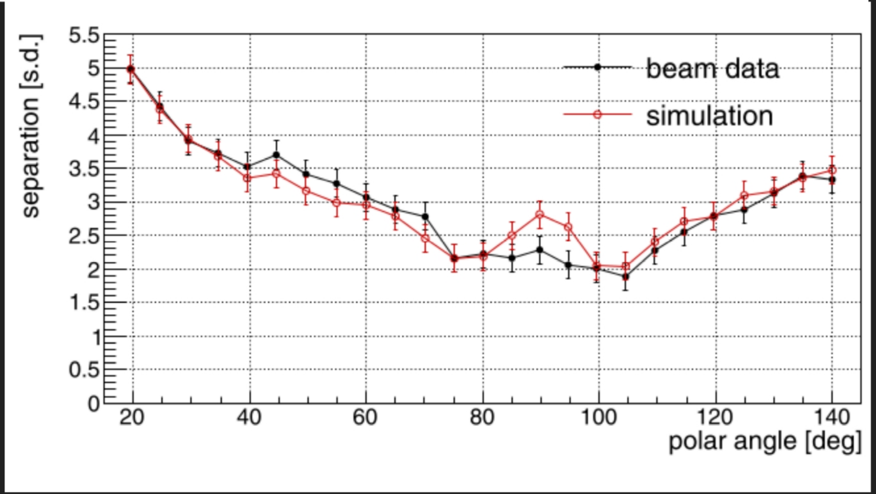
Talk by A.Lehmann on PANDA DIRCs

PANDA Barrel DIRC

Talk by A.Lehmann on Panda DIRC



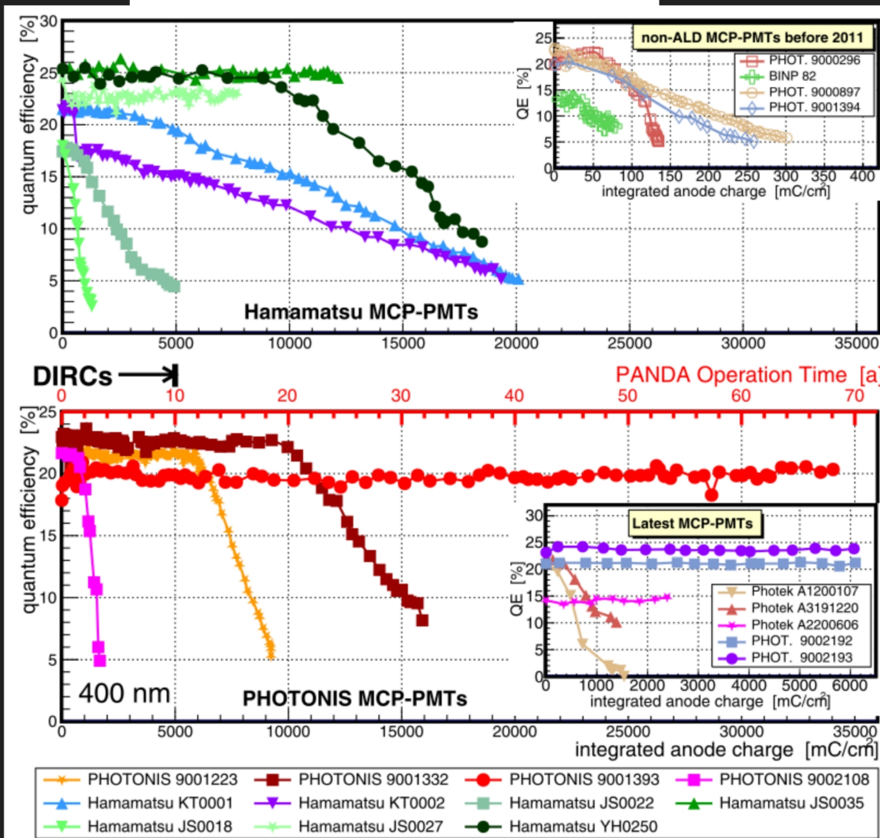


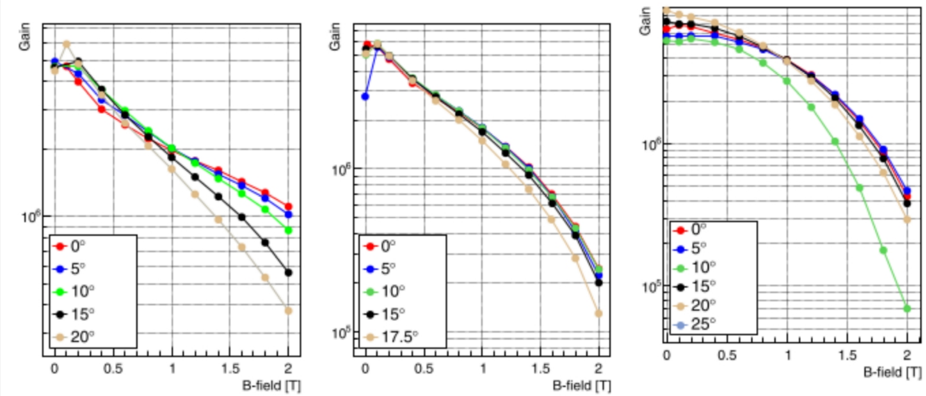


- ❑ Test beam studies demonstrated improved resolution with novel optics.
- ❑ Inspiration to future DIRC technologies (example: hpDIRC → ePIC see talk by G. Kalicy xpDIRC --> for future DIRC see Poster by Roman Dzhygadlo)

PANDA Barrel DIRC

Nuclear Inst. and Methods in Physics Research, A 1057 (2023) 168659

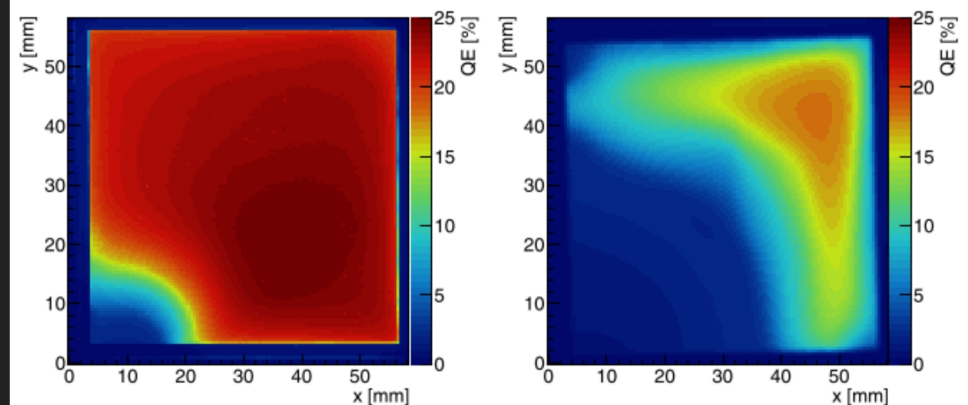




(a) Photek A1200116, 2760 V HV, 6 µm pore diameter, 8x8 anode pixels.

(b) Photonis 9002192, 2700 V HV, 10 µm pore diameter, 8x8 anode pixels.

(c) Photonis 943P541, 2950 V HV, 10 µm pore diameter, 3x100 anode pixels.



(a) Before illumination.

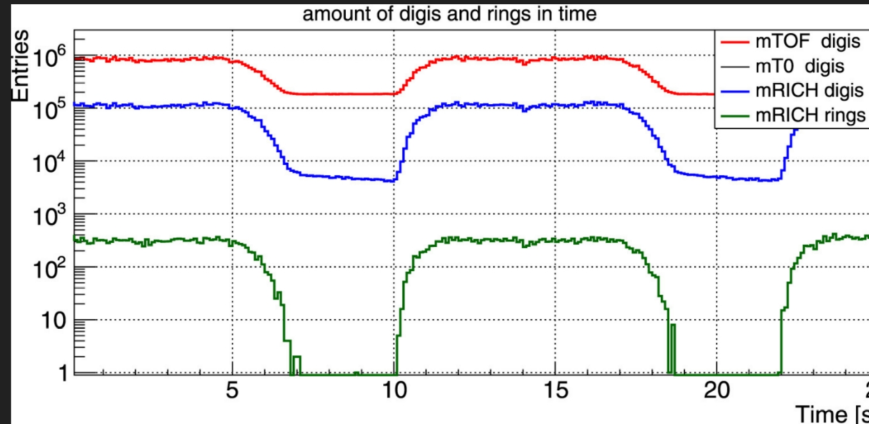
(b) Right half illuminated with 1.4 C cm^{-2} IAC, left half was permanently masked.

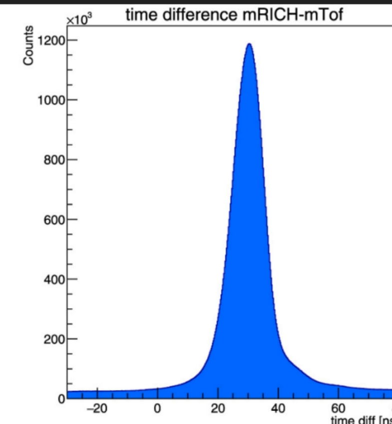
Talk by A.Lehmann on Panda DIRC

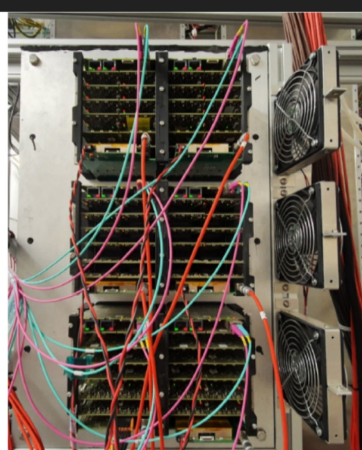
- ❑ Demonstrated MCP-PMTs coated ALD technique allows better lifetime.
- ❑ More MCP-PMT overview in the talk of Alexander Kiselev.

CBM RICH

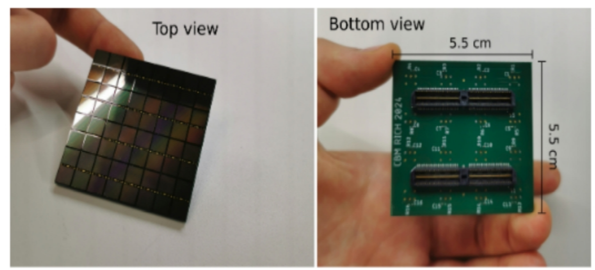
- MaPMTs (H12700) and DiRICH commonly developed for HADES is chosen as the baseline.
- Magnetic Shielding.
- Novel DAQ concept.
- Test prototypes of all sub-detectors → Mini CBM detector.
- Proximity RICH with same MultiAnode PMTs.
- Aerogel same as CLAS12. MiniRICH (mRICH)



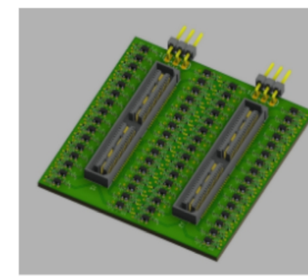




R&D: Silicon PMTs



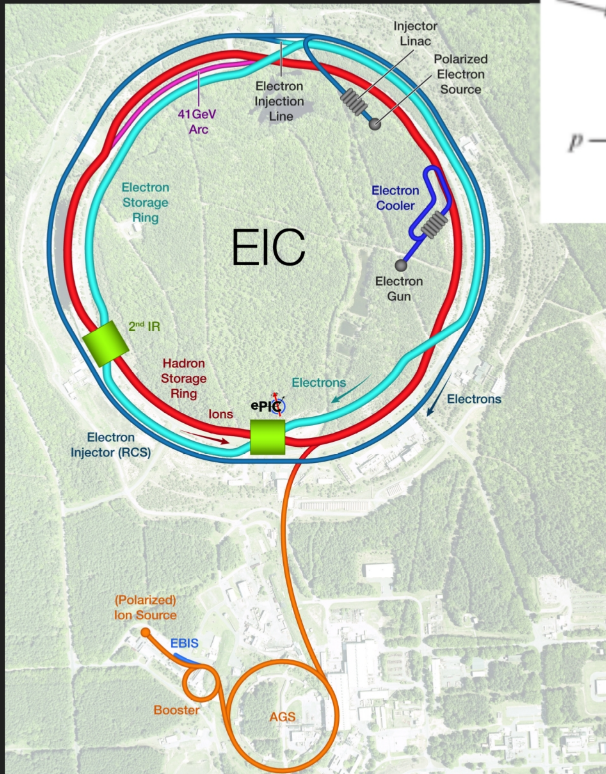
64x Broadcom AFBRS4N66P024

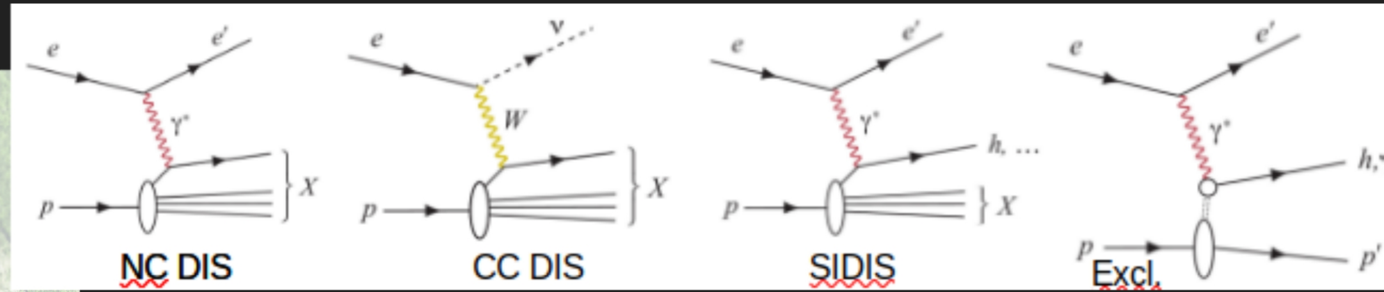


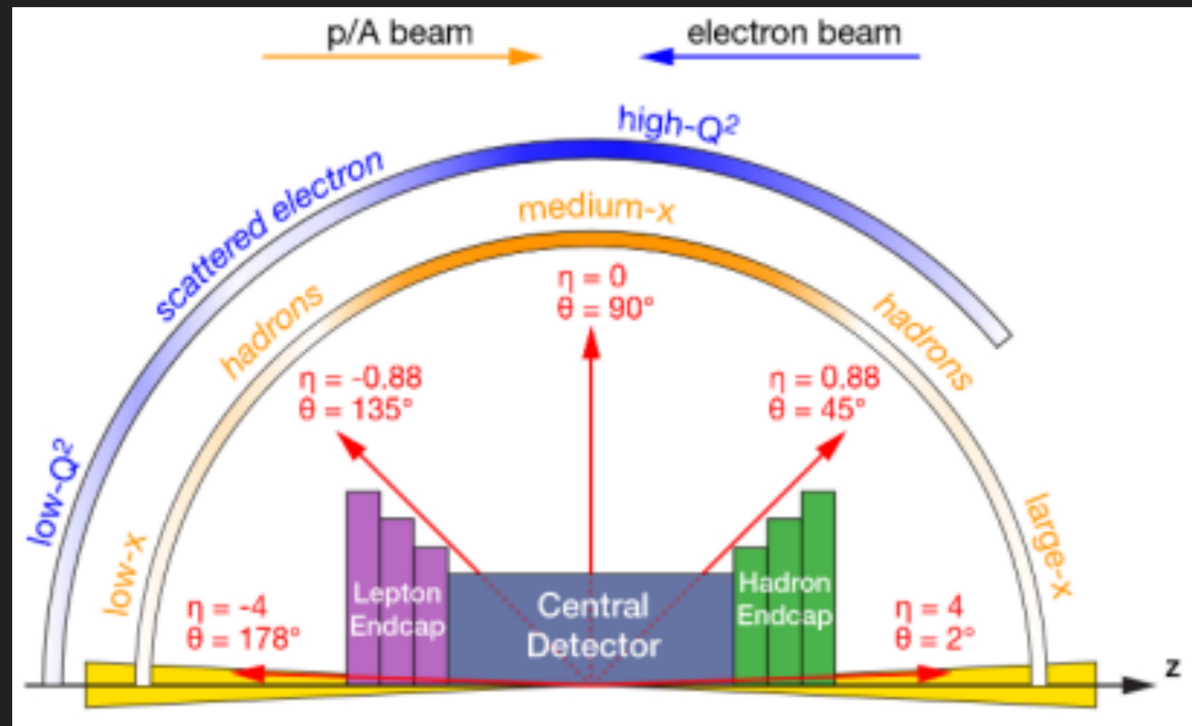
64 channel preamplifier
for adaption to DIRICH readout

Upcoming beam! → Talk by Christian Pauly
Posters by Martin Beyer, Sven Peter, Abhishek Deshmukh, Jesus Pena Rodriguez on several technical aspects

EIC

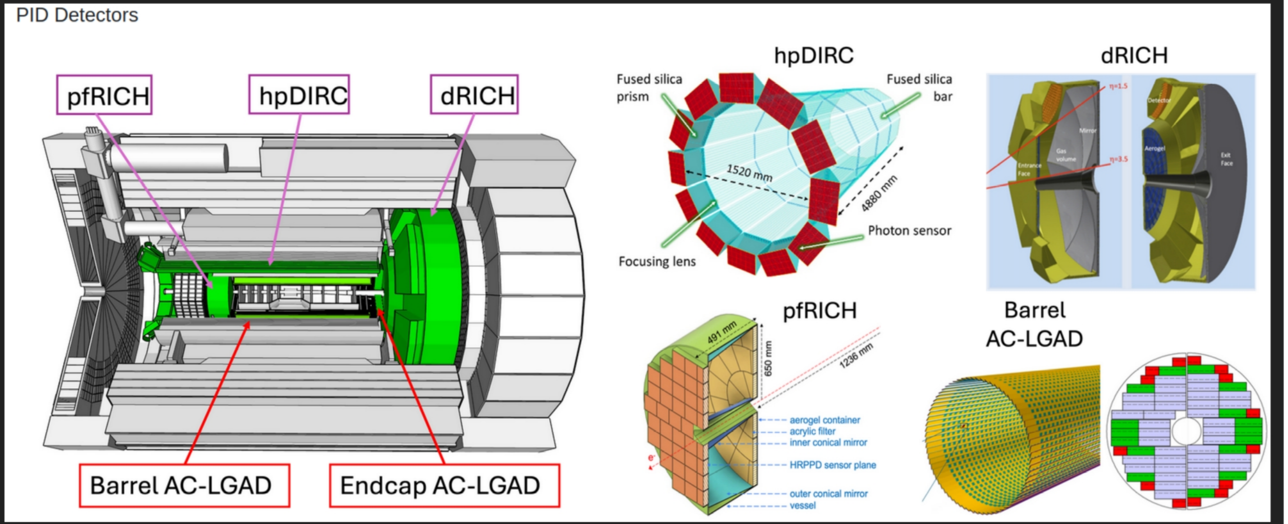


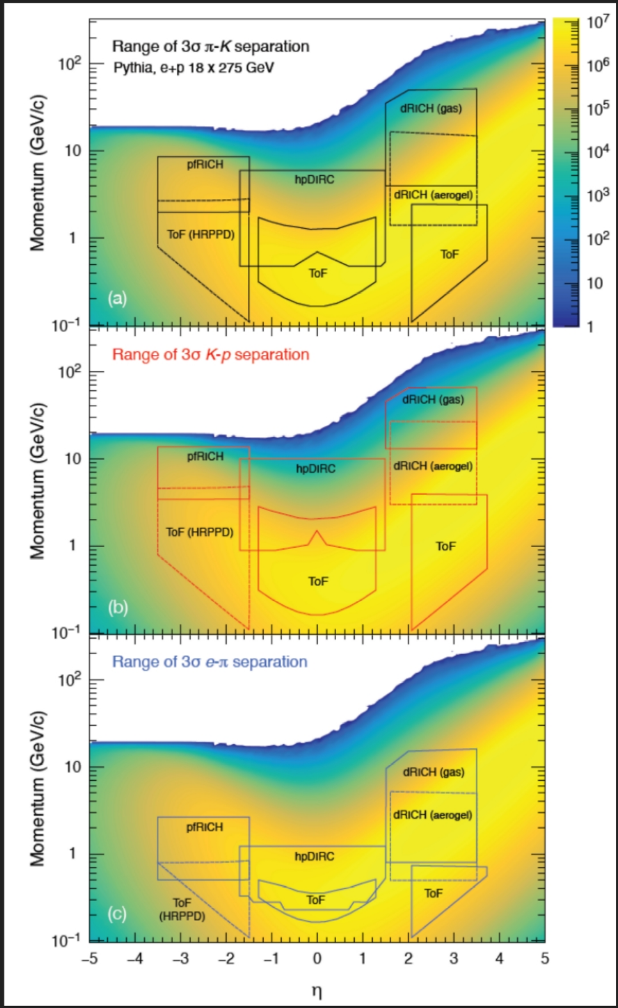




- Spanning over wide COM energy → 20 -141 GeV
- High luminosity → $10^{34} cm^{-2}s^{-1}$
- High polarization → (~70%) electron and light nuclei. Heavy nuclei up to Uranium
- Two possible interaction point.

ePIC detector and its PID





PID Requirements (3-sigma pion/kaon seperation)

Backward (-3.5 < η < -1.5)
- Up to 9 GeV/c

Central (-1.5 < η < 1.5)
- Up to 6 GeV/c

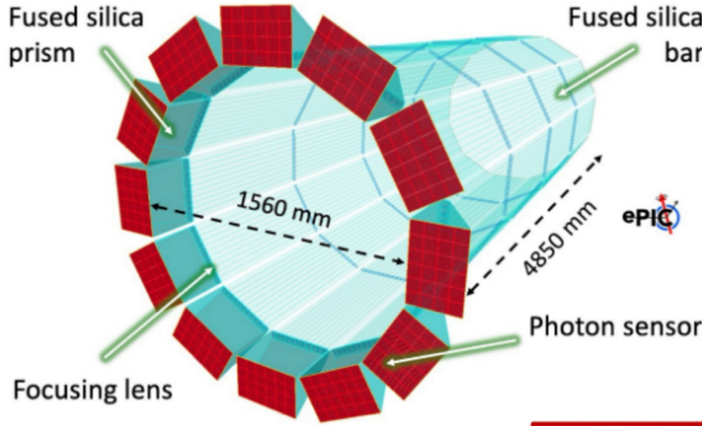
Forward (1.5 < η < 3.5)
- Up to 50 GeV/c

Wide phases-space for PID.

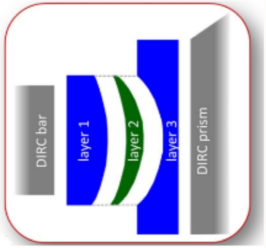
No single detector technology can deliver the full PID requirement.

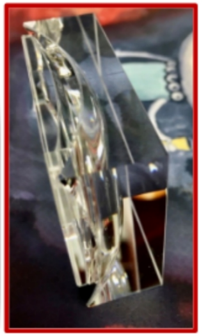
ePIC hpDIRC

- high-performance DIRC Concept:
  fast focusing DIRC, utilizing high-resolution 3D (x,y,t) reconstruction.
- Radiation-hard 3-layer spherical lens
  to reduce bar image size and shape imaging plane
- Lifetime-enhanced MCP-PMTs with fine anode segmentation
  to reduce pixel size
- Fast photon timing (Sensors + readout electronics)
  for chromatic dispersion mitigation and background rejection
- Narrow DIRC bars (refurbished BaBar DIRC bars)
- Predicted performance for central rapidity range $-1.5 \leq \eta \leq +1.5$:
  3σ π/K separation up to at least 6 GeV/c
- Simulation software validated with test beam data
  (synergy with PANDA BArrel DIRC)

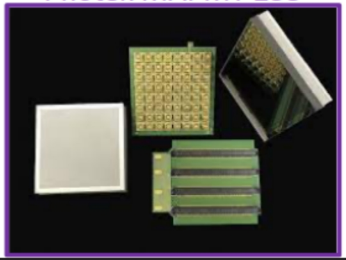


3-layer lens

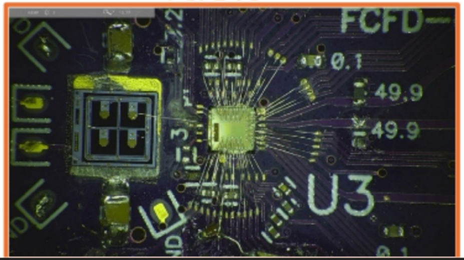




Photek MAPMT 253



FCFDv0



ePIC hpDIRC

- high-performance DIRC Concept:
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- Radiation-hard 3-layer spherical lens
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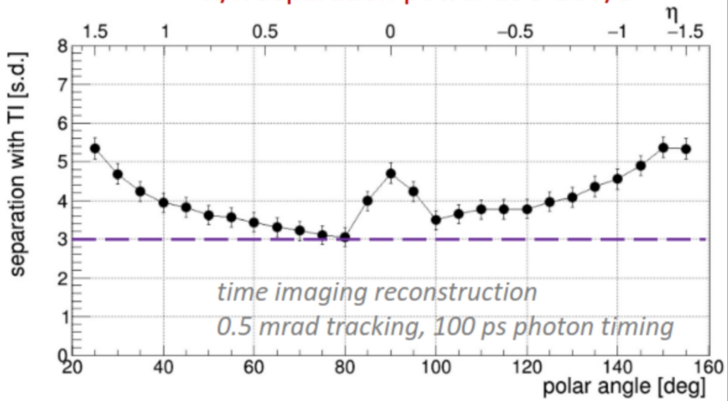
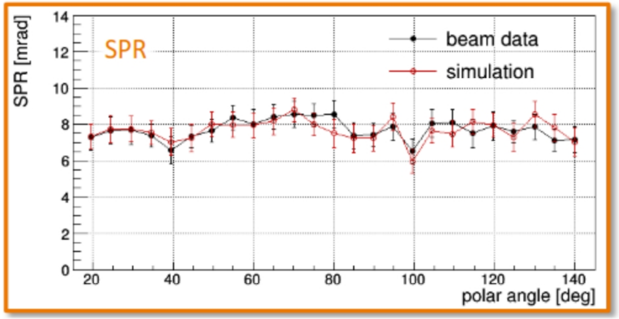
  3σ π/K separation up to at least 6 GeV/c
- Simulation software validated with test beam data
  (synergy with PANDA BArrel DIRC)

π/K separation power at 6 GeV/c

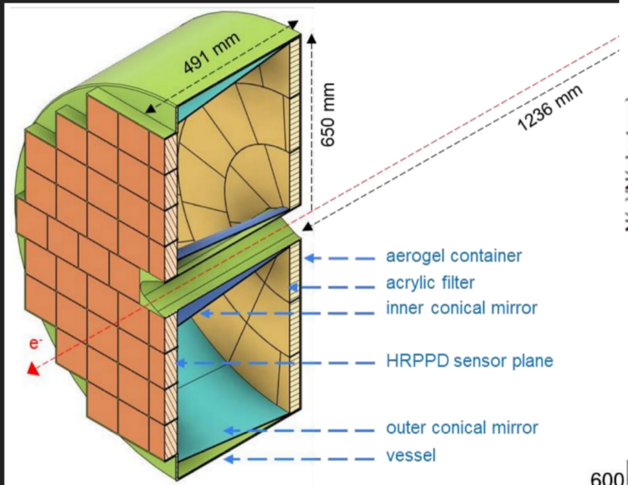


hpDIRC simulation studies performed with
- Stand-alone Geant4 simulation
- Single particles from particle gun
- ePIC magnetic field, no other ePIC subsystems
- 0.5 mrad tracking resolution

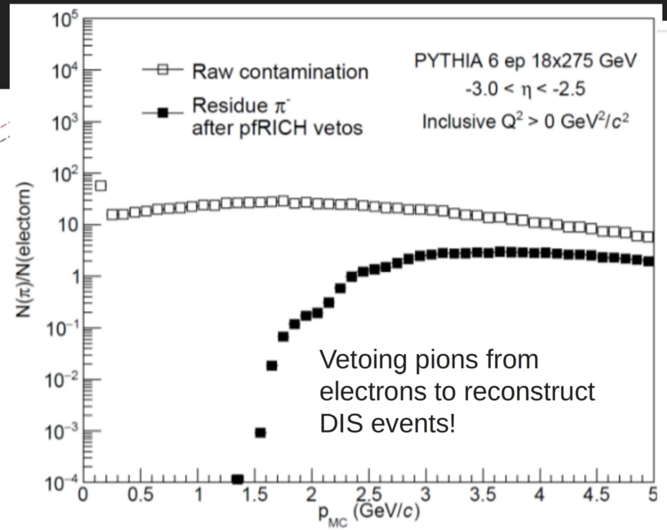
Test beam campaign with PANDA Barrel DIRC Group



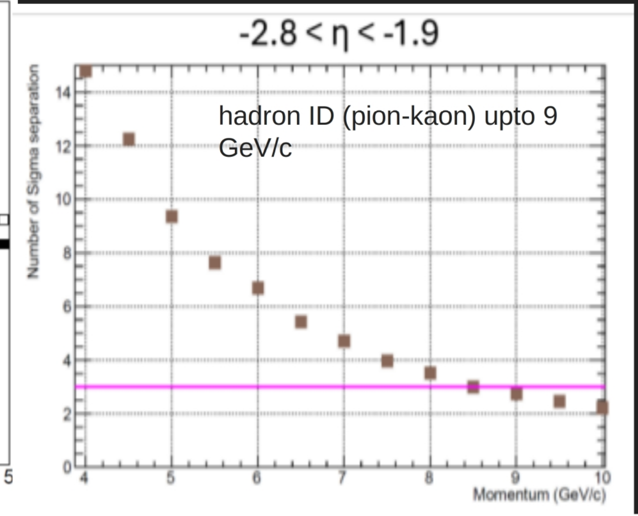
ePIC pfRICH



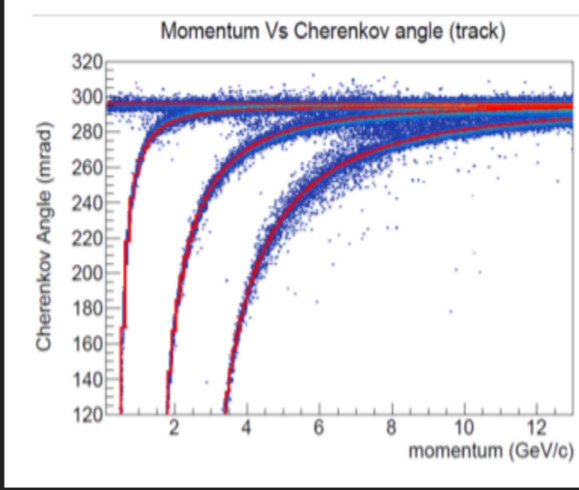
491 mm
650 mm
1236 mm
e-
aerogel container
acrylic filter
inner conical mirror
HRPPD sensor plane
outer conical mirror
vessel



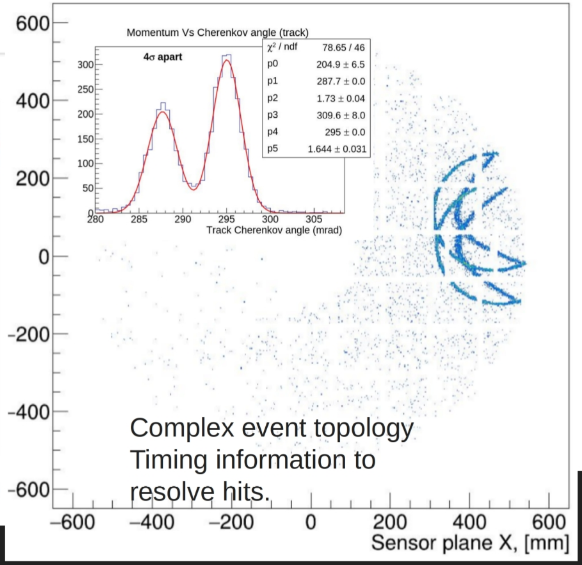
Raw contamination
Residue π⁻ after pfRICH vetos
PYTHIA 6 ep 18x275 GeV
-3.0 < η < -2.5
Inclusive Q² > 0 GeV²/c²
N(π)/N(electom)
p_MC (GeV/c)
Vetoing pions from electrons to reconstruct DIS events!



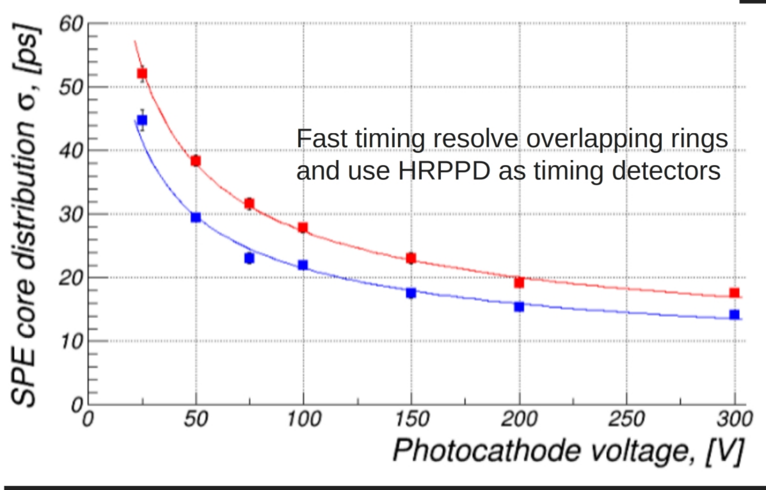
-2.8 < η < -1.9
Number of Sigma separation
hadron ID (pion-kaon) upto 9 GeV/c
Momentum (GeV/c)



Momentum Vs Cherenkov angle (track)
Cherenkov Angle (mrad)
momentum (GeV/c)



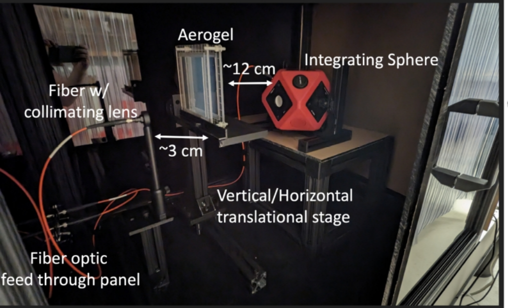
Momentum Vs Cherenkov angle (track)
4σ apart
Track Cherenkov angle (mrad)
Complex event topology
Timing information to resolve hits.
Sensor plane X, [mm]

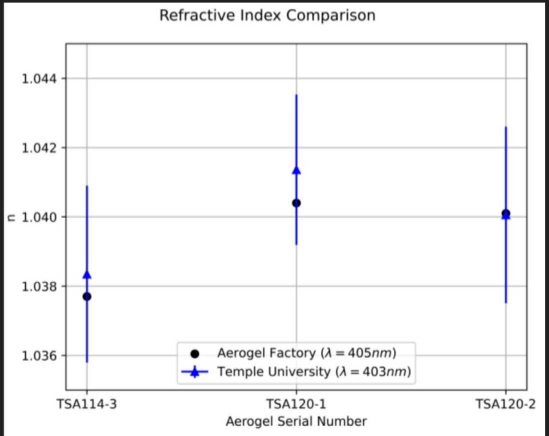


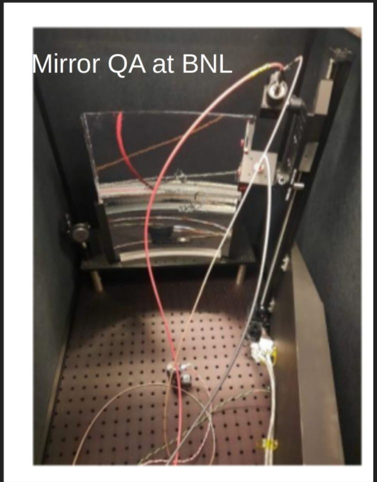
SPE core distribution σ, [ps]
Fast timing resolve overlapping rings and use HRPPD as timing detectors
Photocathode voltage, [V]

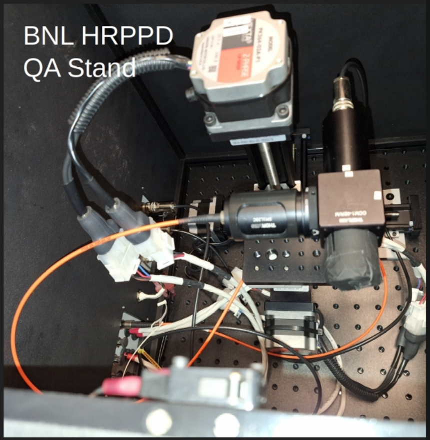
pfRICH R&D

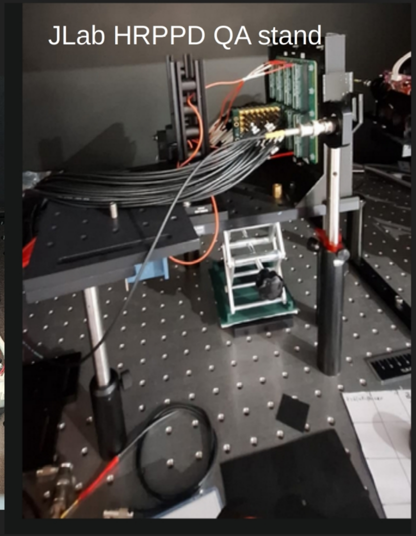
Aerogel Characterization

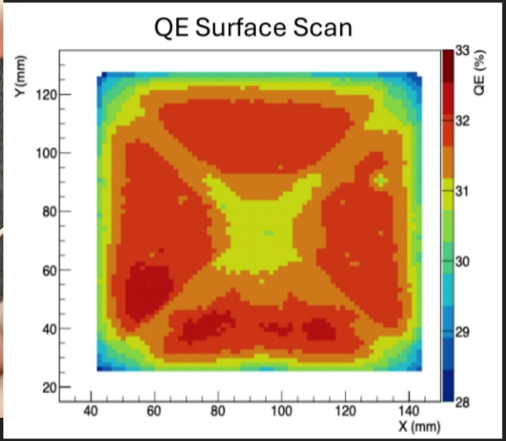








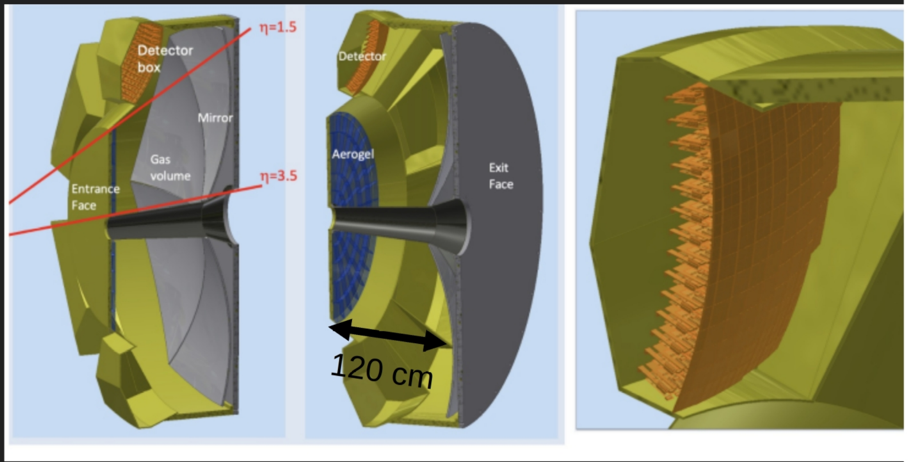


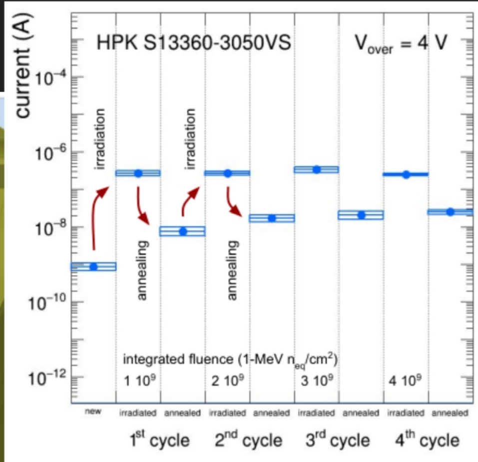


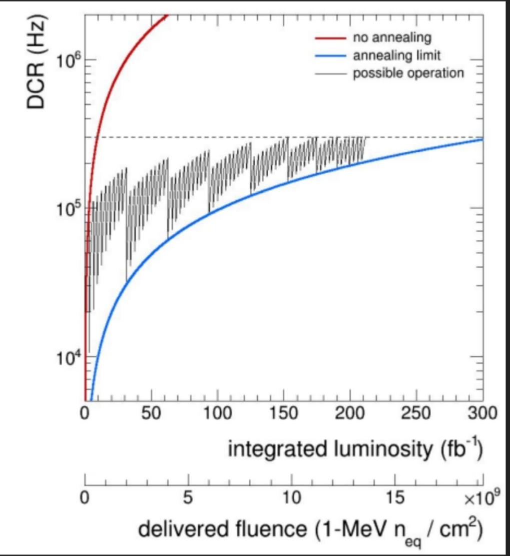
pfRICH Talk by Brian Page

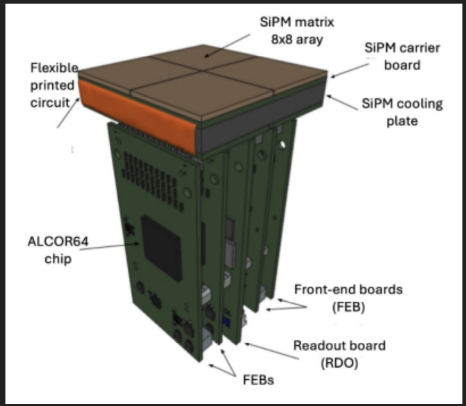
MCP-PMT review by Alexander Kiselev.
LAPPD/HRPPD talk by Jinky Agarwala.

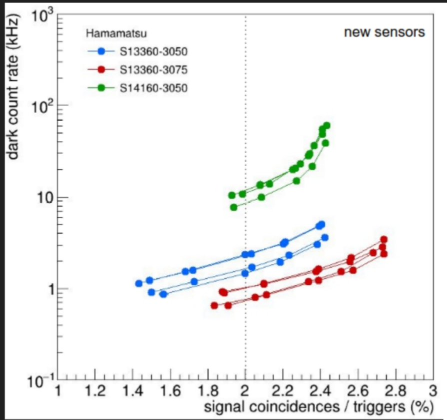
ePIC dual RICH

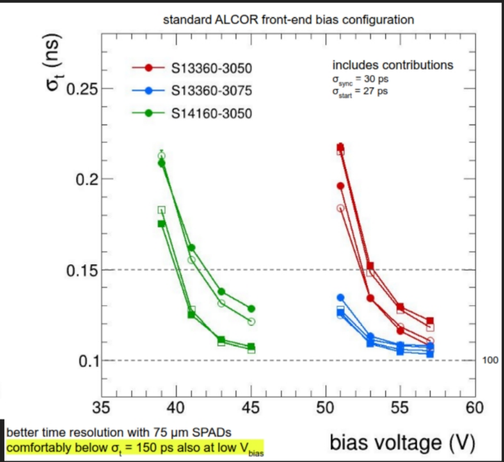


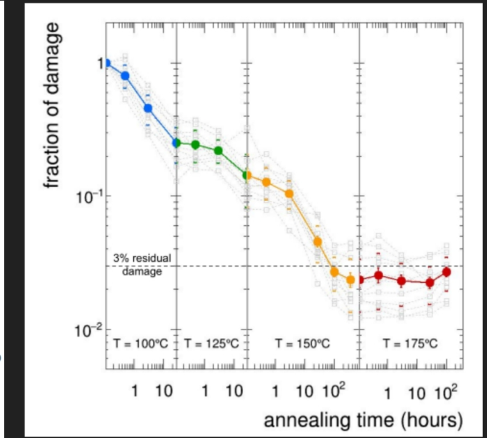












Poster by Cristina Ripoli

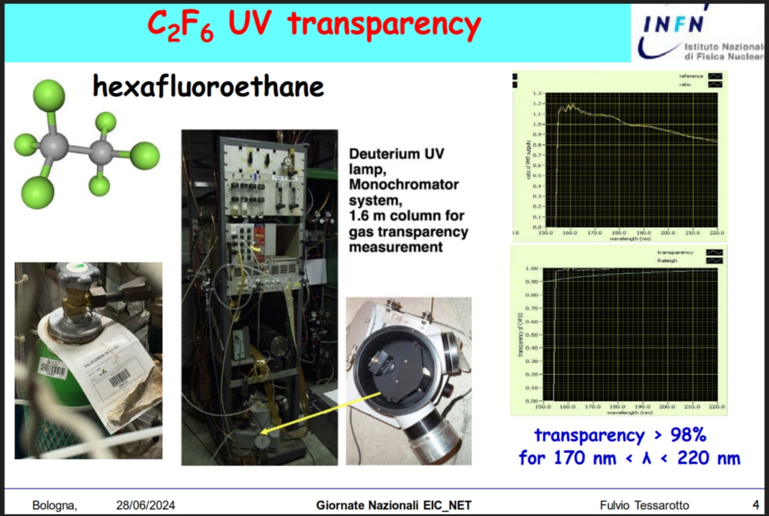
Online filters to handle large data flow are under study. **Promising results!!**

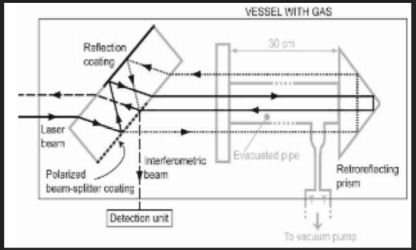
Talk by Cristian Rossi.

Extensive studies with SiPM sensors!

dRICH overview by Marco Contalbrigo

ePIC dRICH radiator

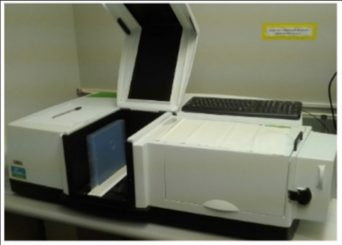




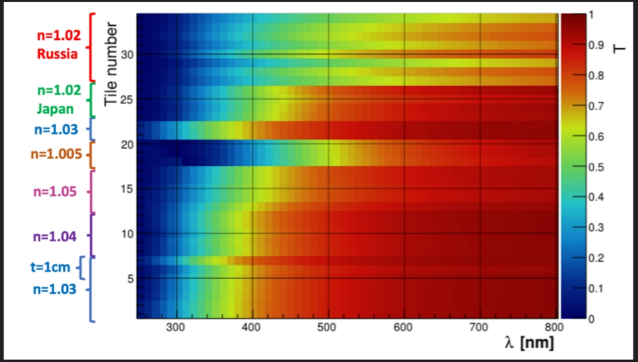
High GWP of C_2F_6, alternatives are under study.

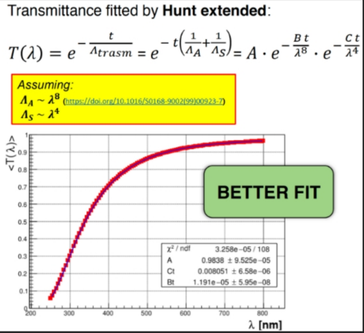
Talk by Fulvio Tessarotto

Figure 2. Top view of the Spectrophotometer Agilent – Cary 4000 at INFN Bari laboratories (left); Light spot on the aerogel tile (right).



Synergy with ALICE3 upgrade and pfRICH.

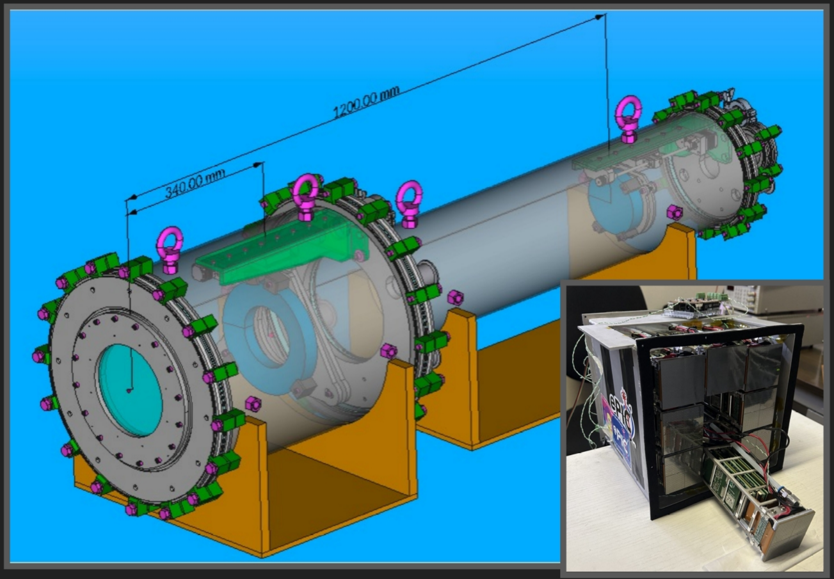


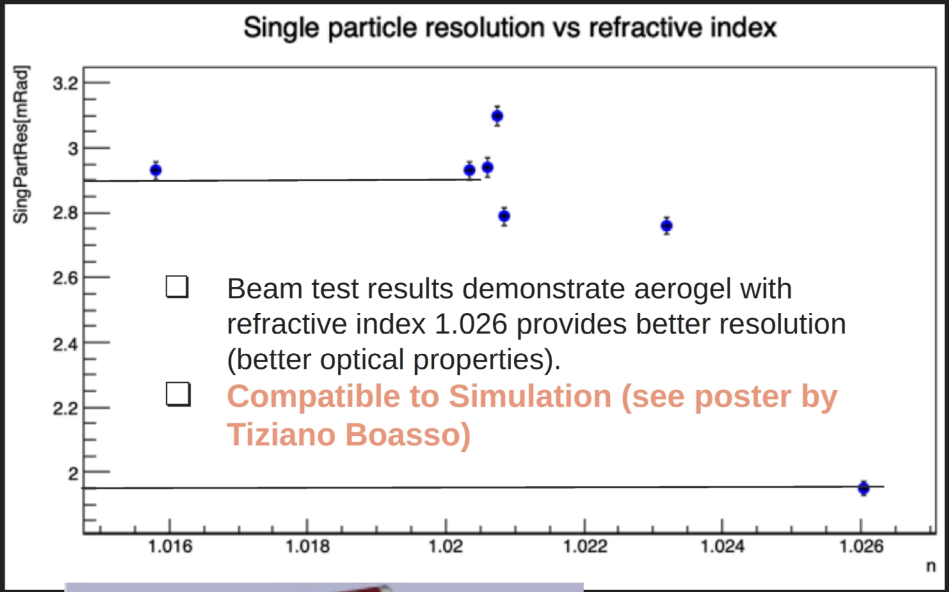


Poster by G. Volpe

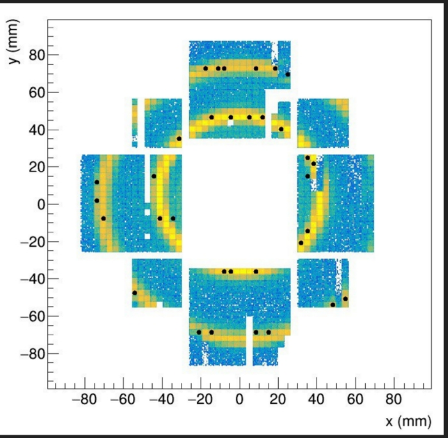
Potential synergies with pfRICH in software development, aerogel characterization, mirror coating and QA.

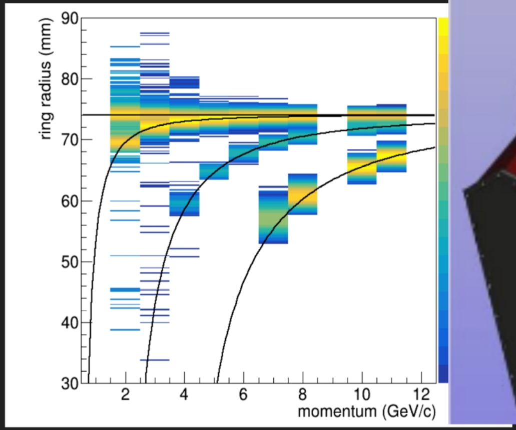
ePIC dRICH beam-test





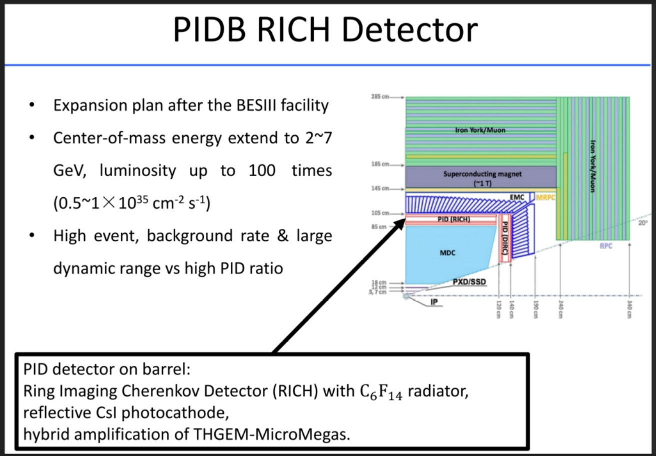
- Beam test results demonstrate aerogel with refractive index 1.026 provides better resolution (better optical properties).
- **Compatible to Simulation (see poster by Tiziano Boasso)**

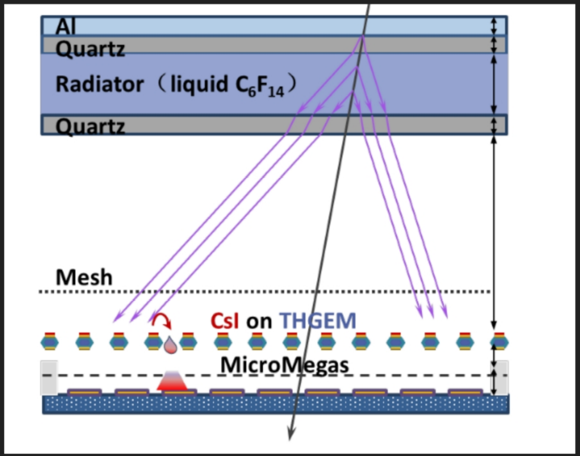


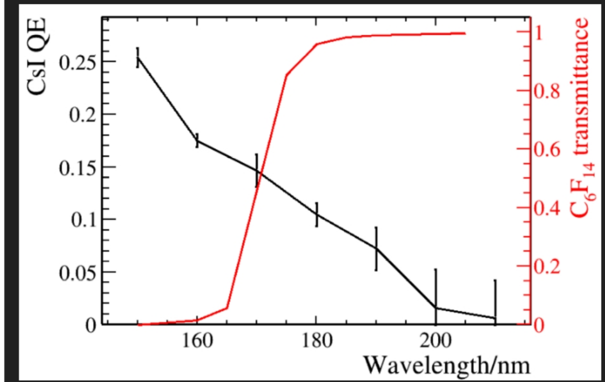


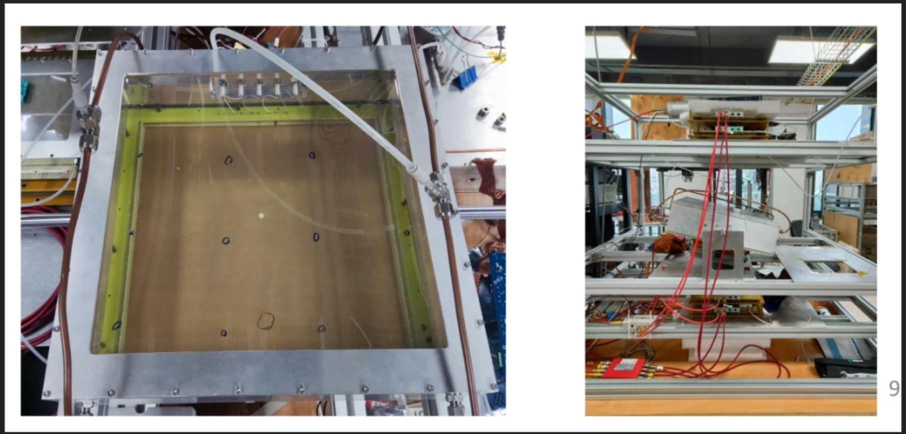
- **SiPM overview and beam-test results: Talk by Nicola Rubini.**
- **ALCOR readout: Poster by Roberto Preghenella**
- **Encouraging results from several beam test campaigns. Real-scale prototype to be tested.**

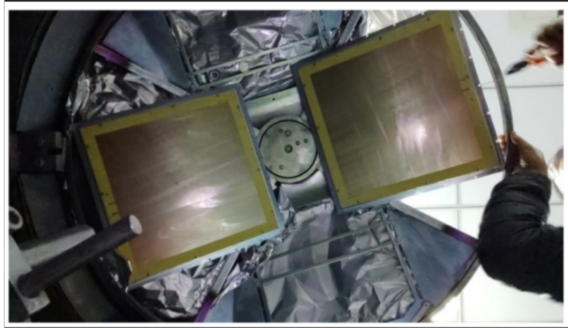
Super Tau Charm Facility (China)











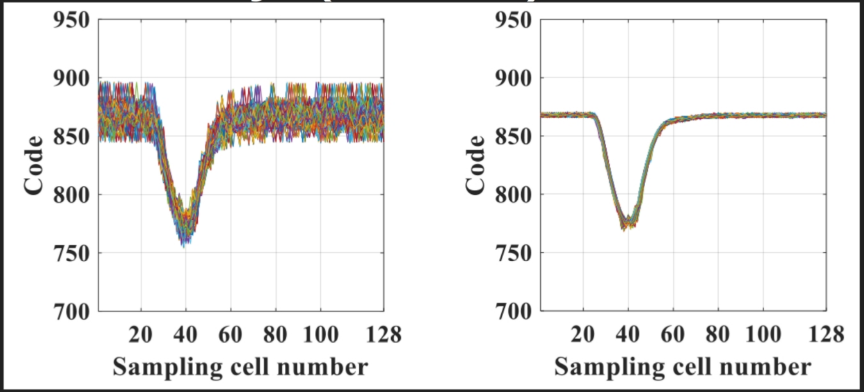
In house CsI coating.
Ongoing beam test

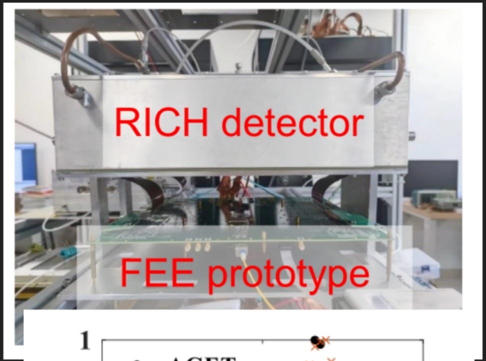
Possibility to use two layers of Micromegas to increase gain and reduce IBF.

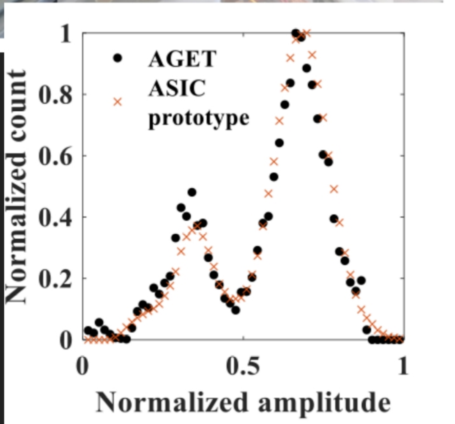
Super Tau Charm Facility (China)

Requirements for the readout electronics

	Requirement
Charge measurement range	48 fC
Equivalent noise charge (ENC)	0.5 fC @ 20 pF C_{in}
Time resolution	≤ 1 ns @ 16 fC @ 20 pF C_{in}
Total redout channels	~ 518,400 (can be reduced with encoding anode)
Dead time	< 66 μs/channel







^{55}Fe spectrum

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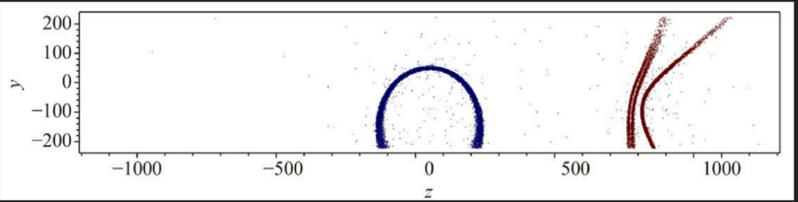
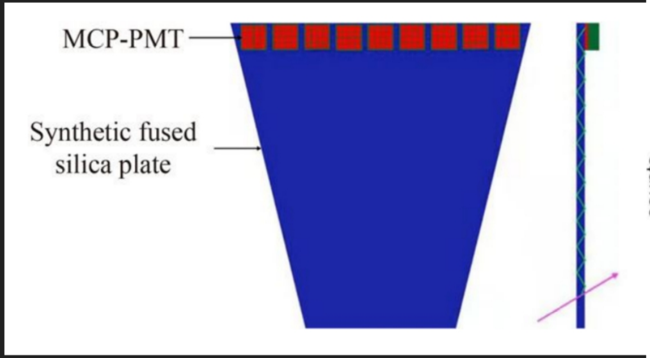
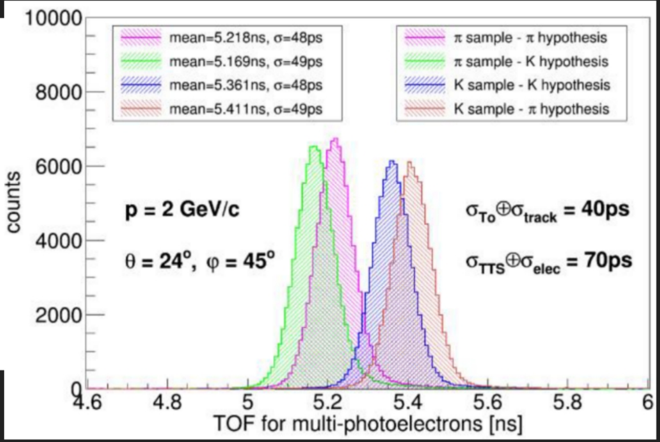
Custom Electronics and FEE!



DIRC like TOF





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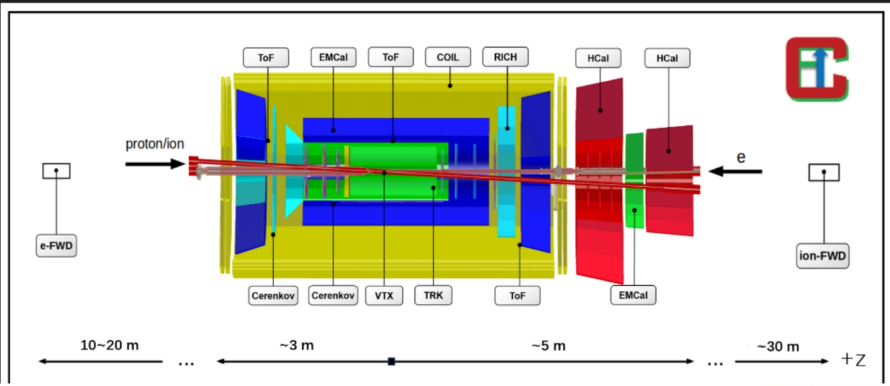
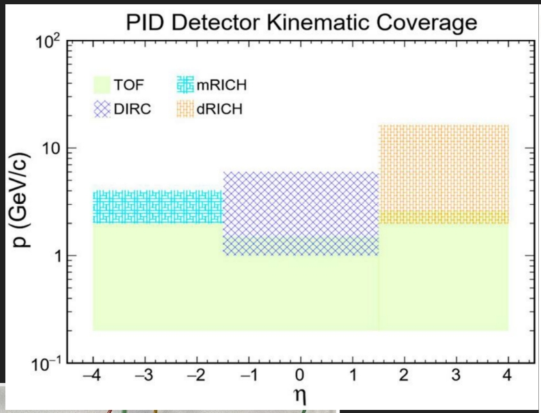
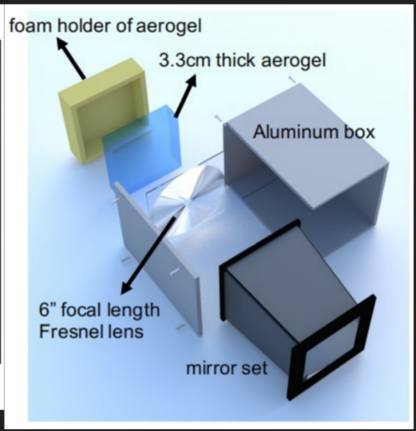
MCP-PMT from Chinese companies.
11C/cm^2 charge accumulation.
Can be a challenge to MCP-PMT life time.

Electron Ion Collider in China

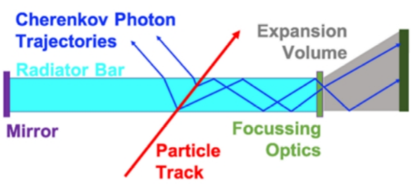
Modular RICH in e-Endcap
(MCP based)

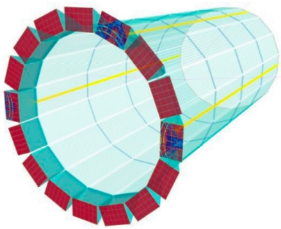


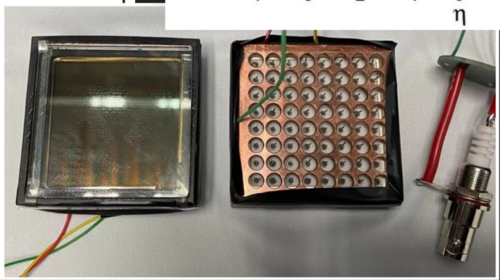




Inspired by Panda Design



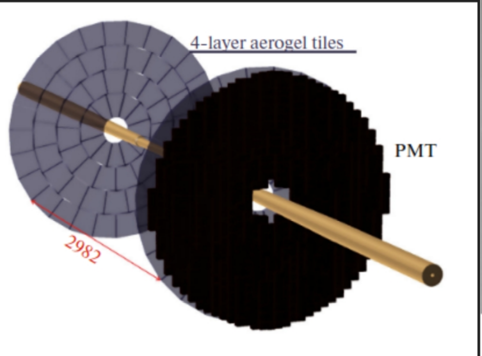




https://indico.phys.sinica.edu.tw/event/88/contributions/431/attachments/509/1263/PID_EIC_THU.pdf
(**EIC-Asia Workshop** Jan 2024)

Poster by Xin Li

SPD



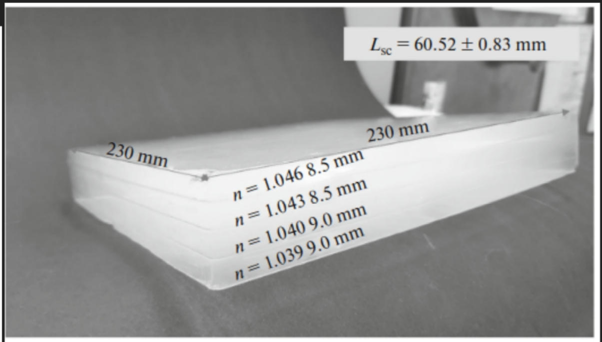
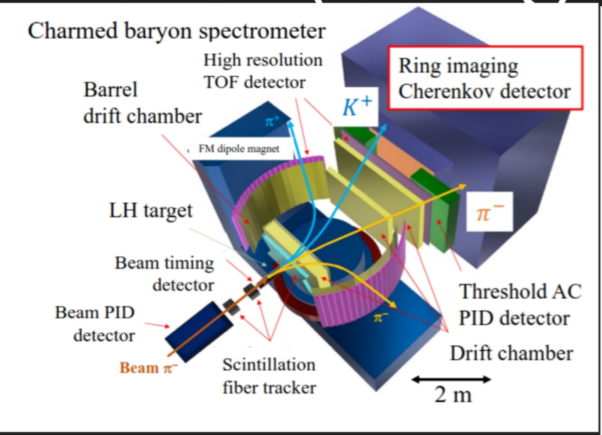
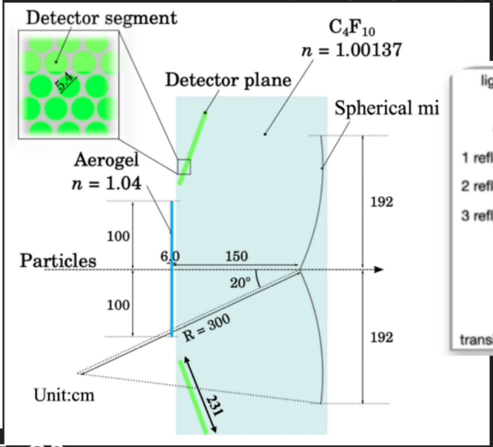


Fig. 3. The largest four-layer focusing aerogel Cherenkov radiator.

Commercial MCP-PMT produced by NNVT (North Night Vision Technology) China. Frontend developed by GSI (DiRICH); in house production is considered.

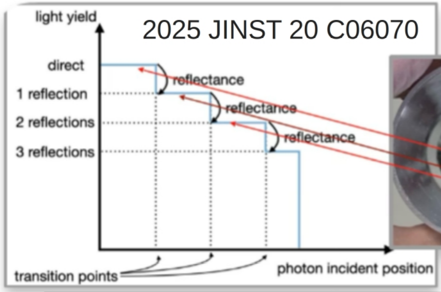
J-PARC (MARQ)

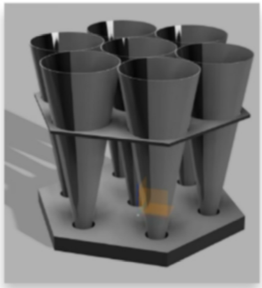




SiPM: Hamamatsu MPPC S13360-6075CS coupled to hollow conical concentrator. Increased light yield.

Poster by Ken Suzuki





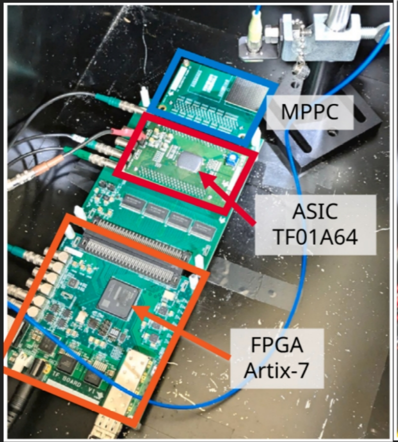
Aerogel (n=1.02) + SiPM based RICH for beam tag
Poster by Taiga Toda

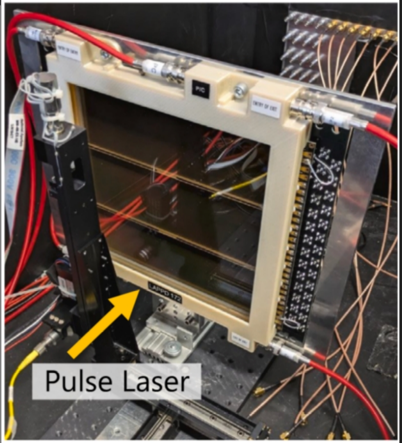
Below atmospheric pressure Novac gas $C_5F_{10}O$?
Challenging mechanics

Belle II Upgrade

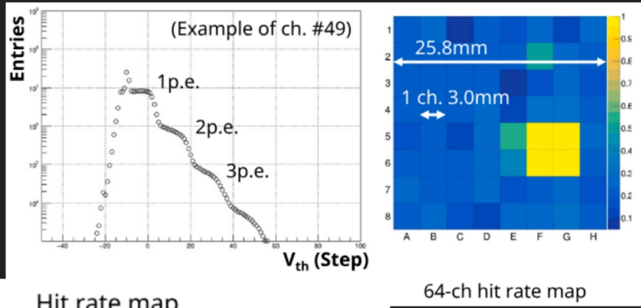
Poster by Shunsuke Kurokawa

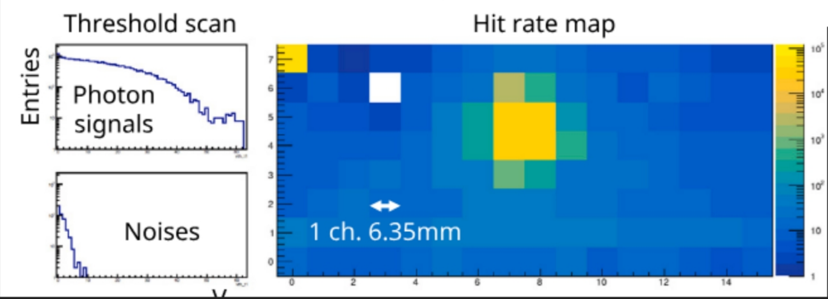
https://doi.org/10.1016/j.nima.2025.170695





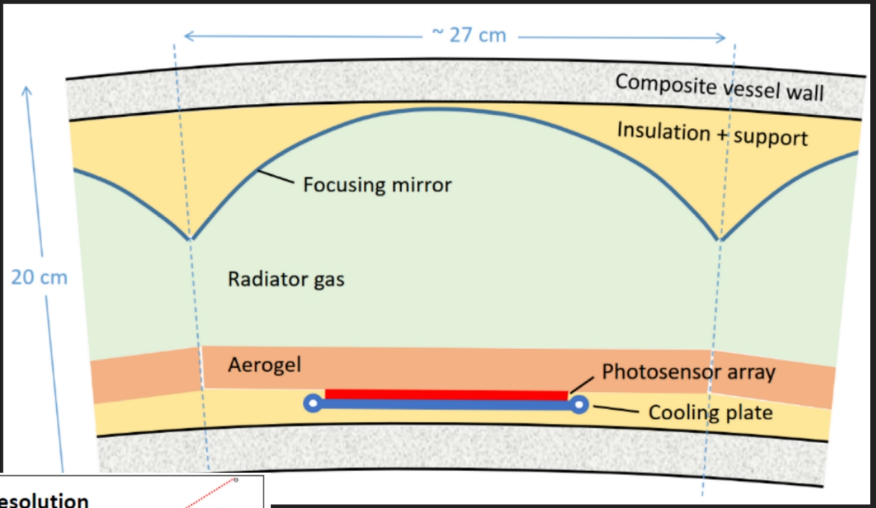
1) Early 2030s discontinuation in HAPD production & need for updating ASIC.
2) MPPC and LAPPD under consideration: developed two readout systems.





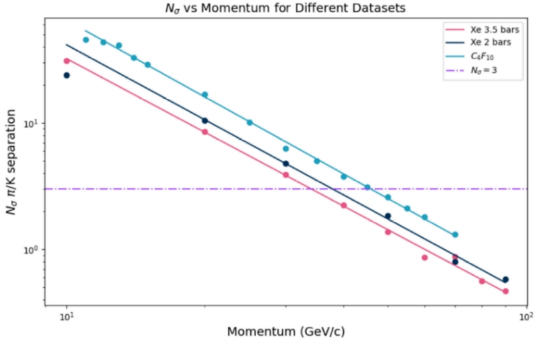
Dual Radiator RICH for FCC-ee

- A compact modular RICH for hadron ID at FCC-ee: ARC(Array of RICH Cells)
  Dual radiators (aerogel + unpressurised C_4F_{10} gas)
- Momentum range of interest = 1–40 GeV/c
- Timescale: earliest implementation in mid-2040s (prototype in 3-4 years) CLD experiment concept for FCC-ee
- Target a radial depth of 20 cm, and material budget of few % X0



- Pressurized Xenon can be an alternative to C_4F_{10} [Pezzulo24]

π/K separation – Xe



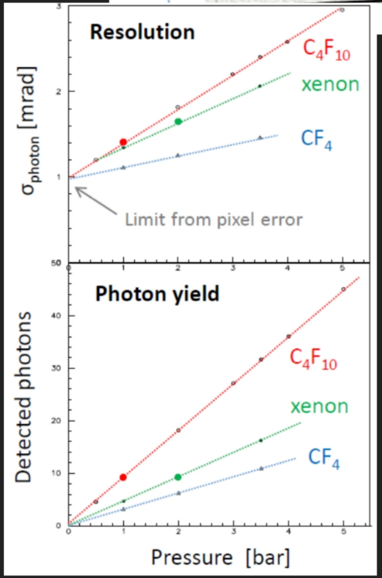
Radiator	Photon yield	Total error [mrad][a]
C_4F_{10} @ 1 bar	19	1.2
Xe @ 1 bar	10	1.2
Xe @ 2 bar	20	1.5
Xe @ 3.5 bar	35	1.9

[a] considering 0.5 mm × 0.5 mm pixels

Radiator	Max p [GeV/c]
C_4F_{10} @ 1 bar	45
Xe @ 2 bar	38
Xe @ 3.5 bar	33

Serena Pezzulo 15/17

Simulation of ARC alvaro.tolosa.delgado@cern.ch 11



- ❑ Highly compact. SiPM (FBK)
- ❑ Aerogel works as radiator as well as thermal isolation between SiPM and radiator gas.
- ❑ Alternative choice for radiator gas

Talk by Serena Pezzulo

Conclusions

1. Cherenkov imaging technology will be playing critical role in large number of particle and nuclear physics experiments in the future: essential for heavy ion physics, flavour physics, hadron physics, beyond SM and e+e- colliders. All-round applications.
2. SiPM and MCP-PMTs have emerged as the two main choices for photon detection. Only expectation is barrel RICH for Super Tau Charm Factory where CsI coated MPGDs technology has been chosen as default.
3. Extensive R&D program for Panda DIRC has demonstrated that MCP-PMTs coated with ALD have better lifetime. HRPPD/LAPPD (produced by INCOM) are considered as baseline sensor technology in ePIC and under consideration by LHCb upgrade II and ALICE 3 upgrade to meet their physics requirements R&D and testing are ongoing.
4. SiPM dark count mitigation, radiation hardness are common issues for many experiments and common efforts in R&D are ongoing. The ePIC dRICH collaboration has consistently played a major role in this sector.
5. Hydrophobic aerogels are default choice with varied refractive index. Default choice for ALICE 3, ePIC dRICH, pfRICH has been aerogel produced by Chiba University Japan. EIC China has also considered aerogel made by Tsinghua University. Required more R&D.
6. Conventional Radiator gas for high momentum PID faces challenge in the future due to high GWP. Currently, alternative choices are high pressure RICH or Fluoro-Ketone Novac gases. Apparently, not a small community is interested in Fluoro Carbon gases; ePIC, LHCb upgrade II are major collaborations but also EICc, CBM, J-PARC MARQ will use C_nF_{2n+2} gases. Requires systematic studies and multidisciplinary approach to address the progress. DRD4 collaboration is the ideal platform for such efforts.

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Thank you for your attention