Particle Identification with the ePIC detector at the EIC

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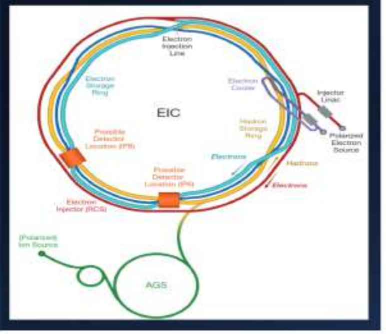
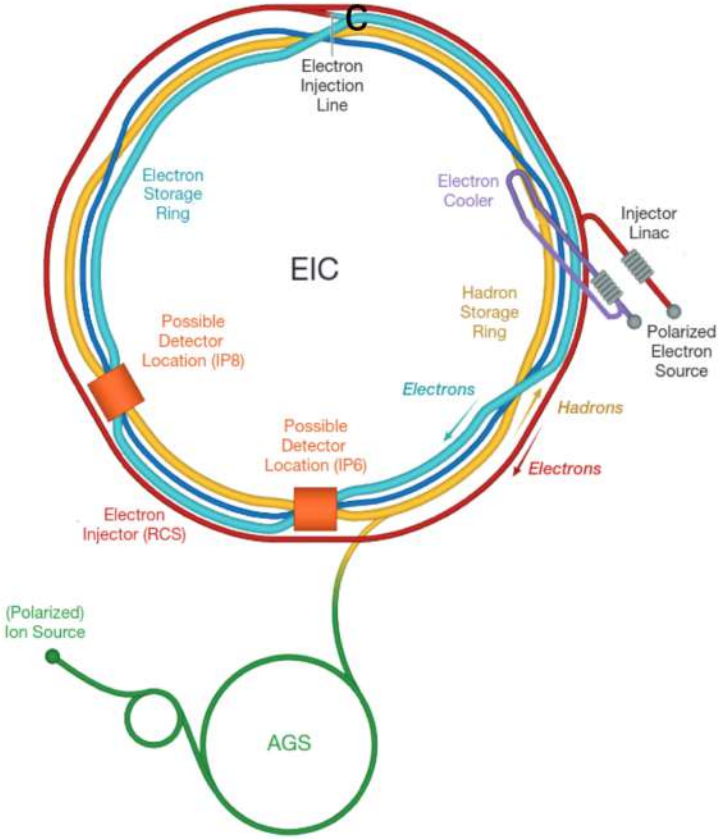
On behalf of the ePIC collaboration

OutLine:
1. Introduction to the EIC and ePIC
2. PID subsystems in ePIC

Introduction: ePIC at the EIC





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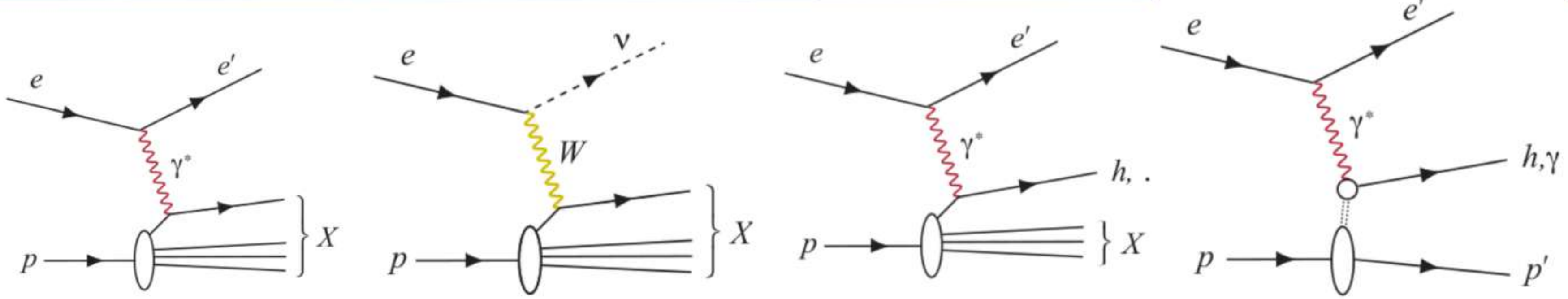
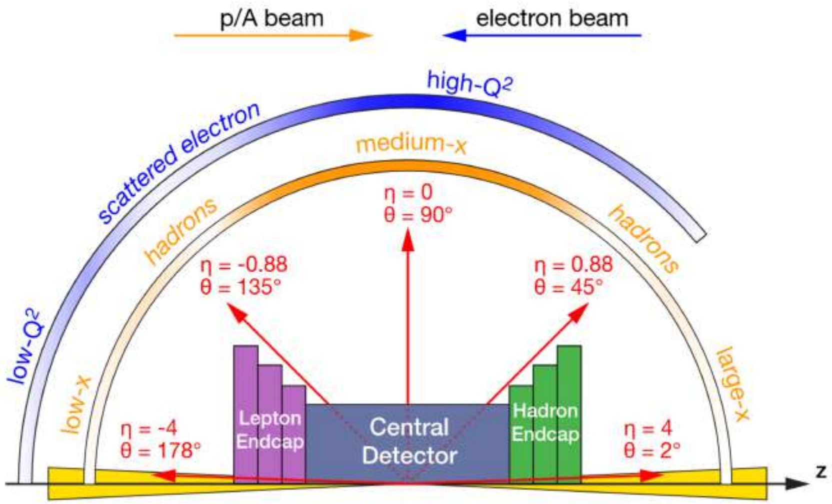
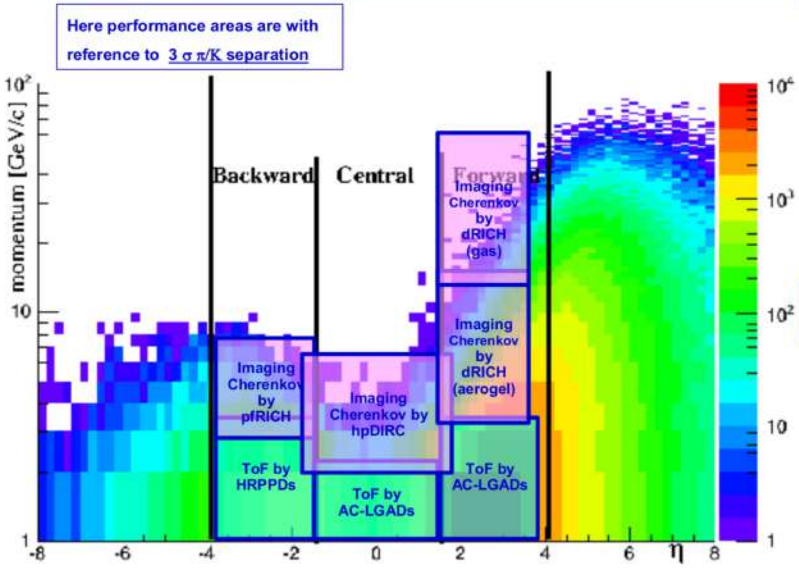




- Spanning over wide COM energy → 20 -141 GeV
- High luminosity → $10^{34}cm^{-2}s^{-1}$
- High polarization → (~70%) electron and light nuclei. Heavy nuclei up to U
- Two possible interaction point.

<u>Particle identification is crucial for several physics channels</u>

Introduction: ePIC



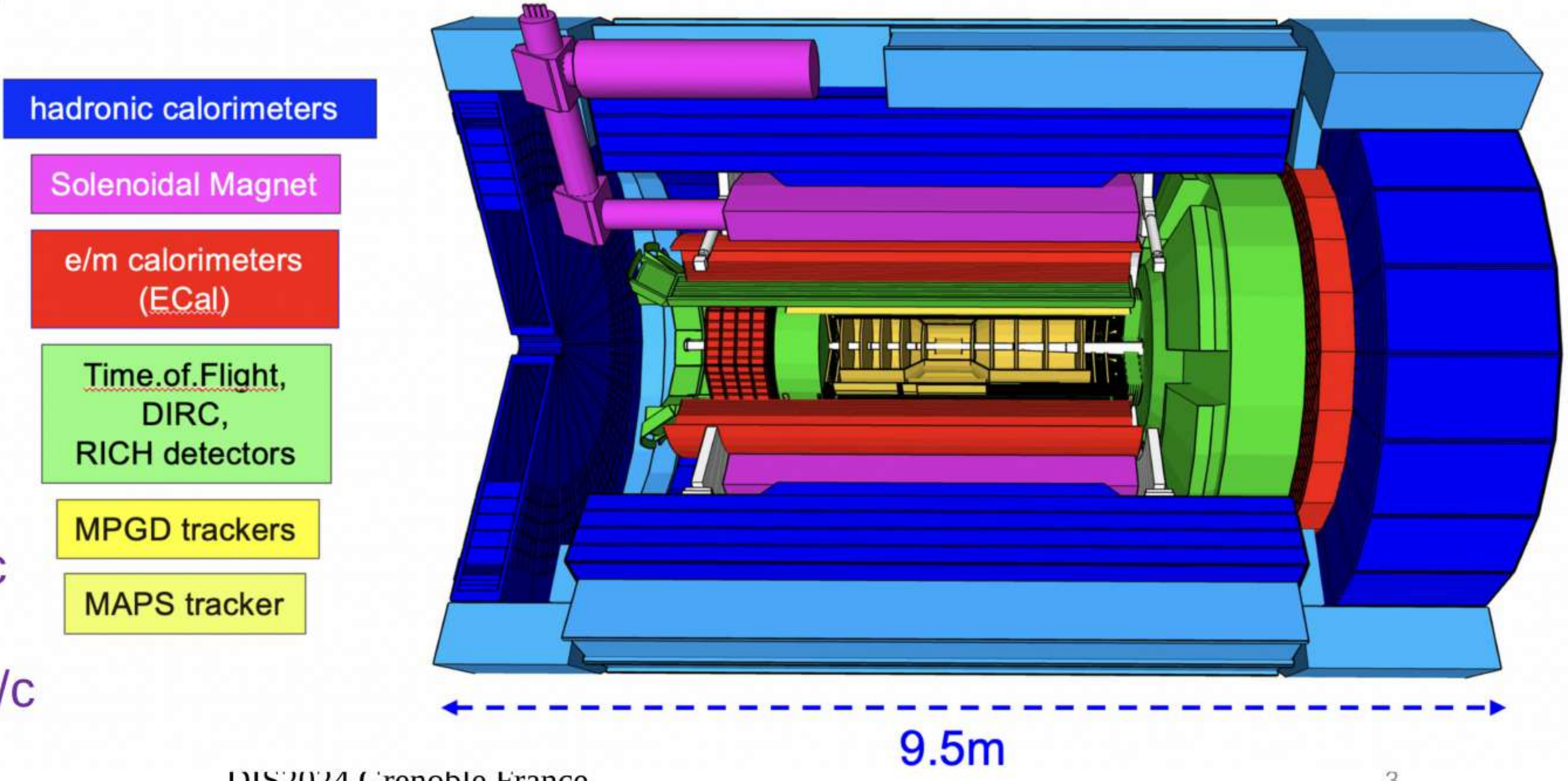
pi/K separation requirement

Backward
- Up to 9 GeV/c

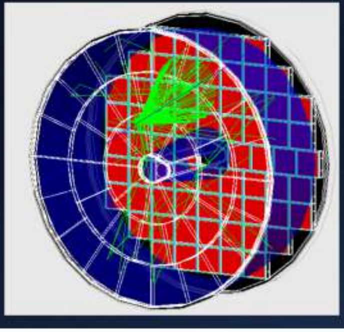
Central
- Up to 6 GeV/c

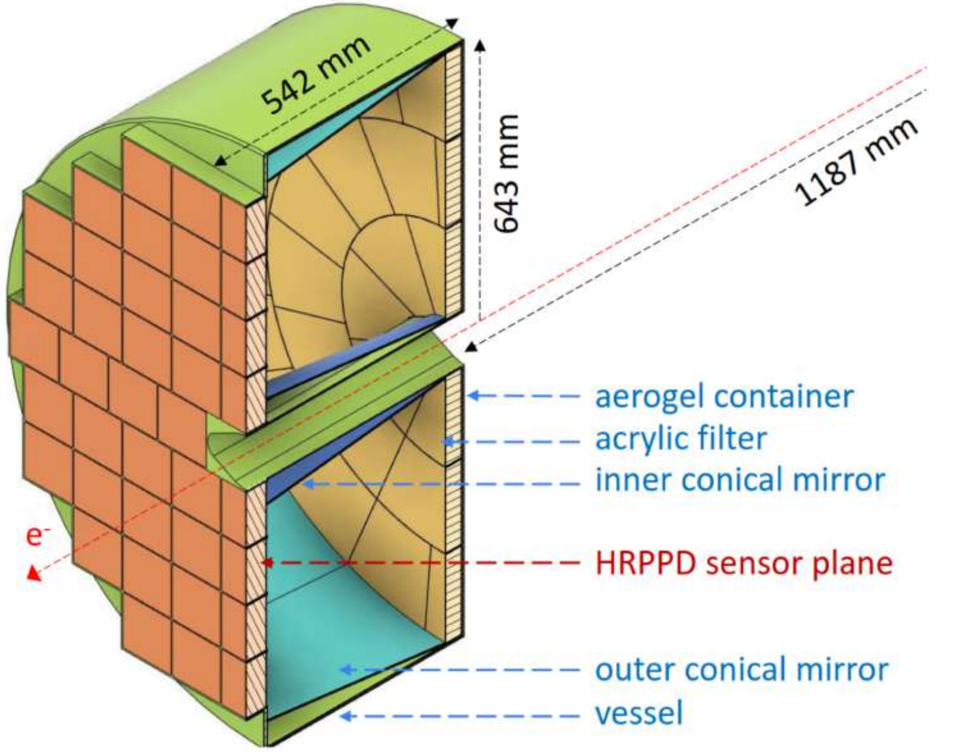
Forward
- Up to 50 GeV/c

Wide phase-space.
→ **Different PID technologies essential!**



Backward PID

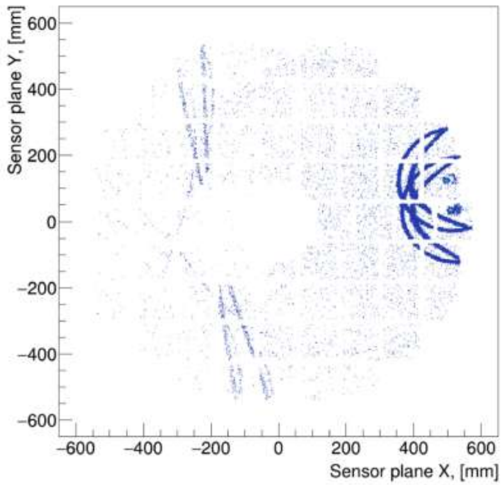


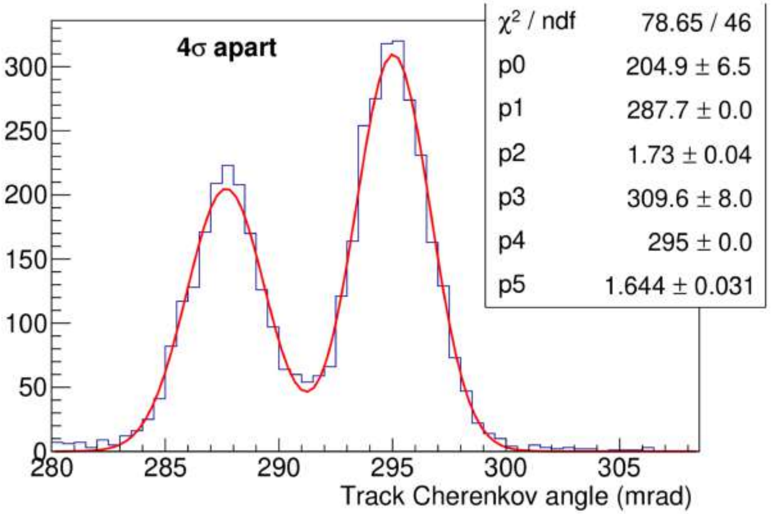


Serves as Time of Flight using HRPPD sensors!

e-endcap RICH for ePIC detector

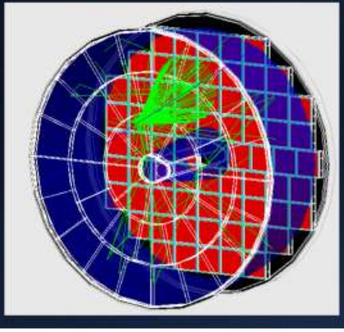
- A classical proximity focusing RICH
- Pseudorapidity coverage: $-3.5 < \eta < -1.5$
- Uniform performance in the whole $\{\eta,\phi\}$ range
- π/K separation above 3σ up to ~ 9.0 GeV/c and ~10-20ps t_0 reference with a ~100% geometric efficiency in one detector

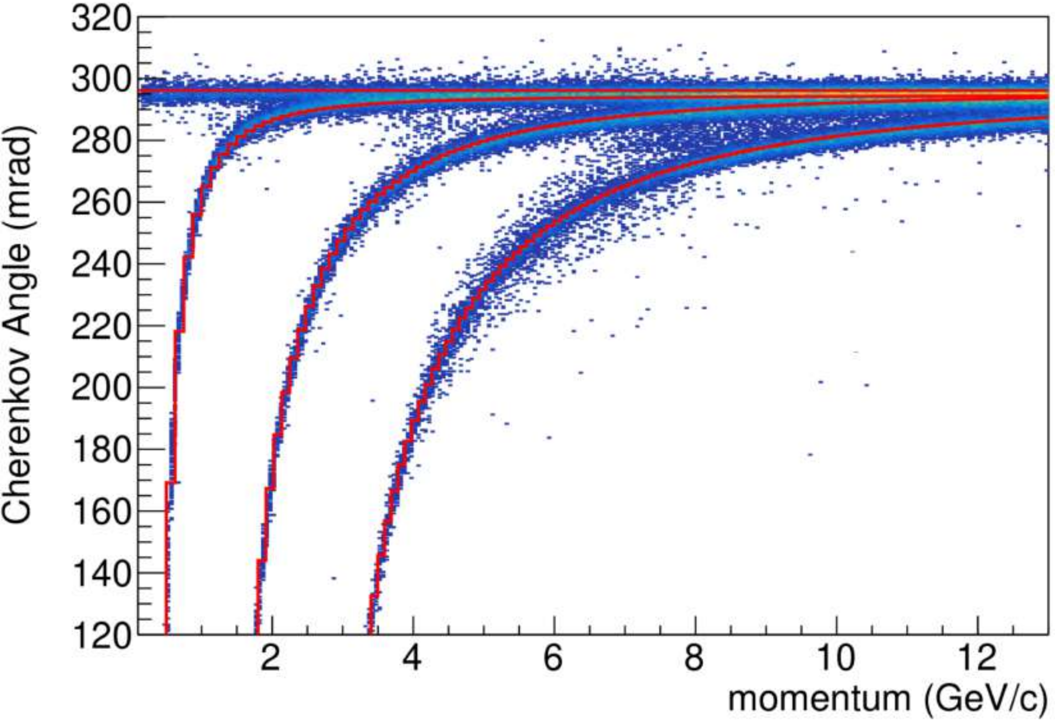




Sophisticated chi-squared analysis capable of performing efficient pid with complicated event topologies.

Backward PID (pfRICH performance)

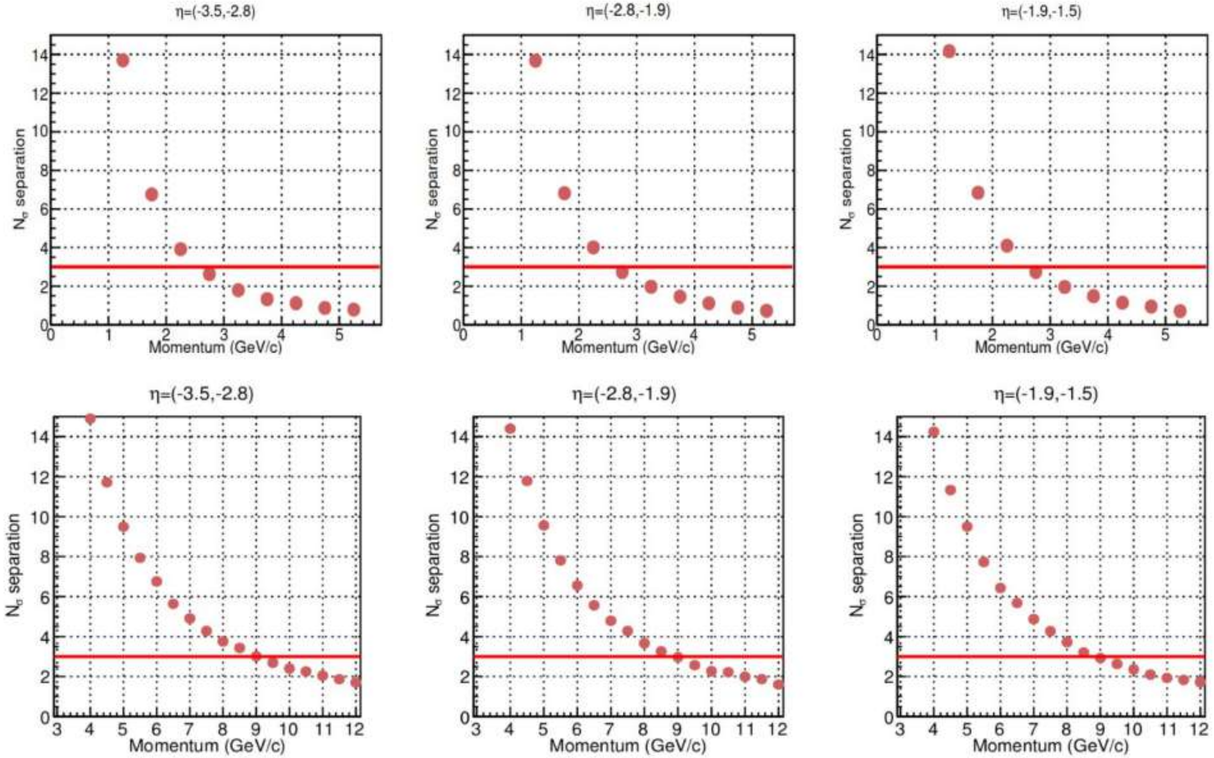




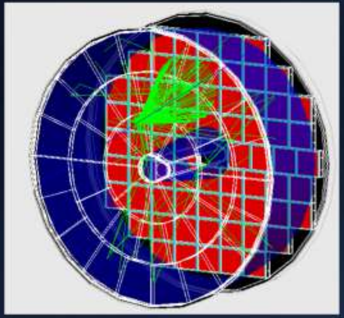
Performance: e/π & π/k separation

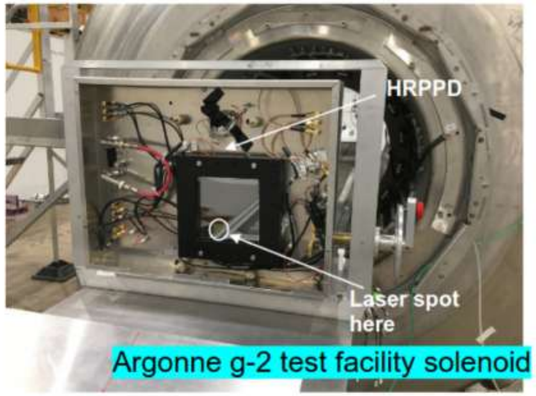
e/π

π/k



Backward PID (HRPPD)

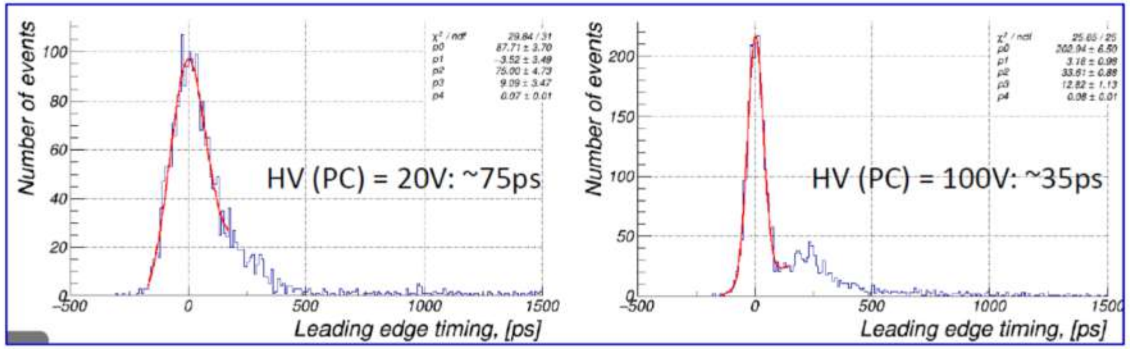


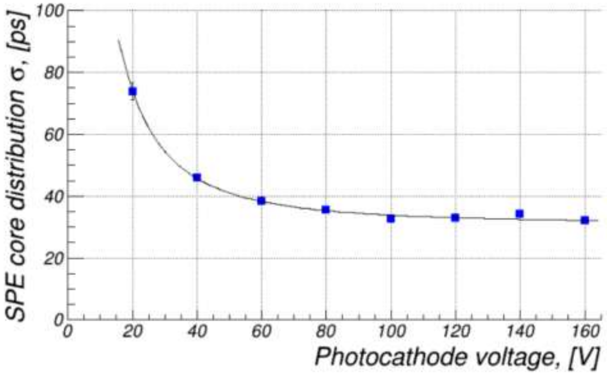


Beam tests at Fermilab

PS beam test at CERN

Magnetic field test at CERN



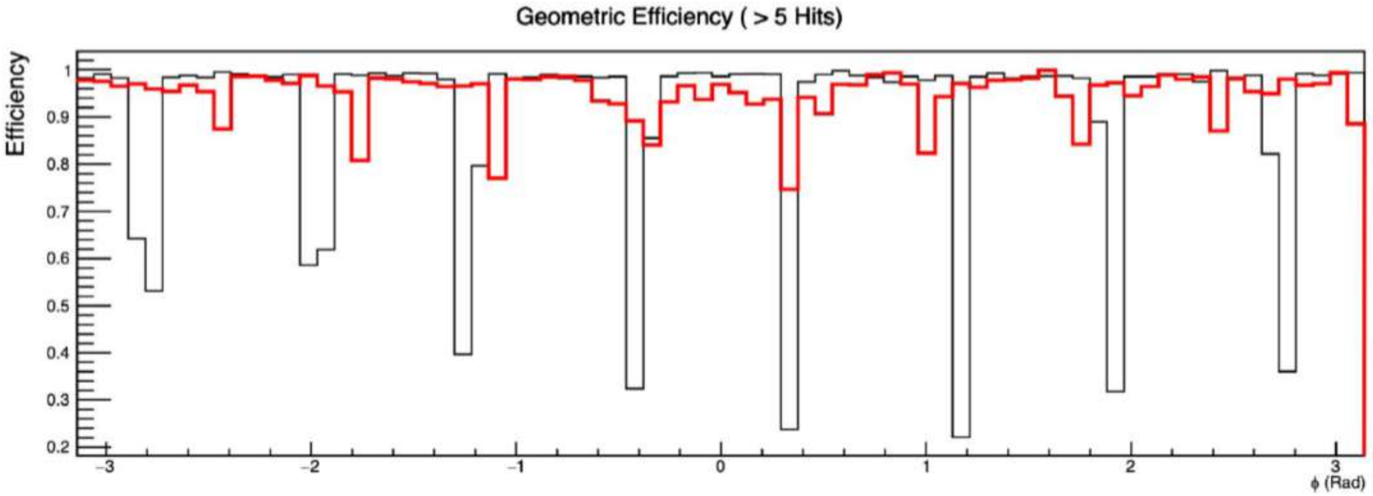


- ✔ **Sophisticated** PID algorithm for event level analysis: *Software used by dual RICH.*
- ✔ HRPPD as photo sensors: *cost effective alternative solution for DIRC.*
- ✔ <u>Potential application as a timing detector</u>.

Backward PID
(HRPPD for timing applications)

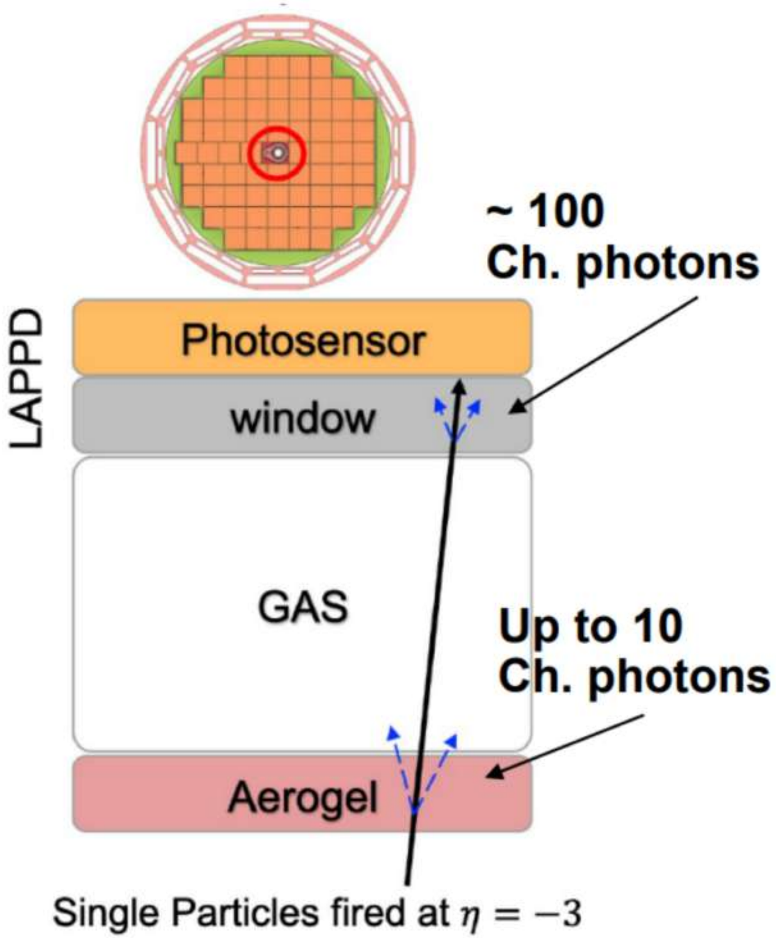
Backward Timing measurements → Cherenkov photon hits created

in the window of LAPPD.
Geometric efficiency of particles with more than 5 photons.
Timing resolution with nominal 50 ps/SPE provides
50/√6 ~ 20 ps timing resolution.

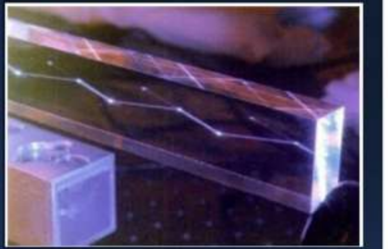


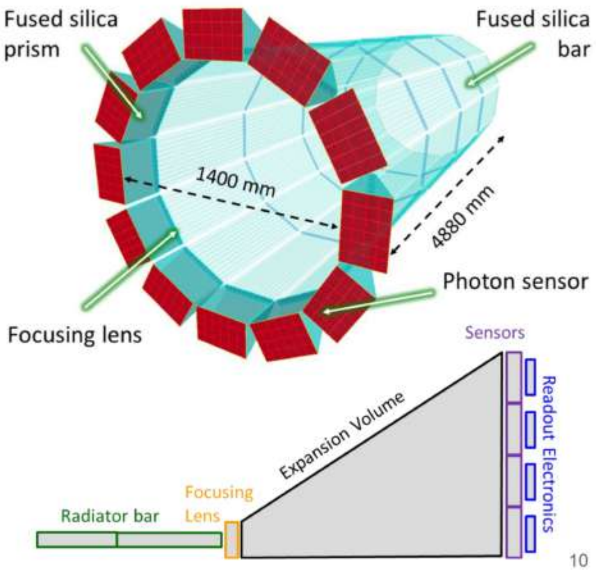
Red dips → ribs from Aerogel wall

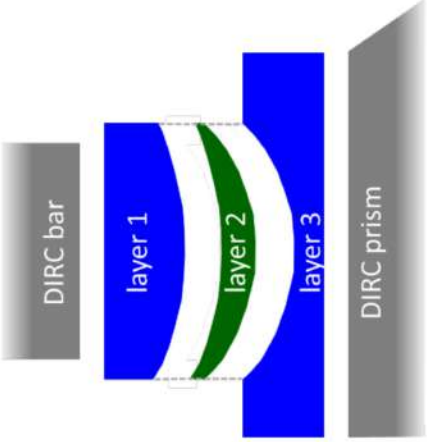
Black dips → ribs from window ceramic boundary

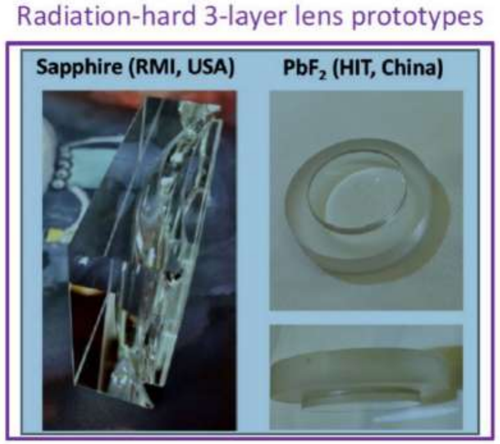


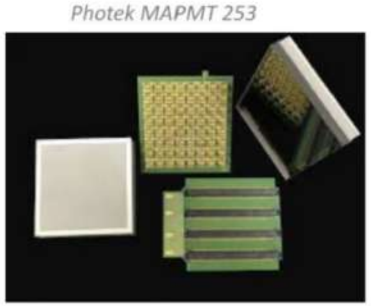
Central PID
hpDIRC





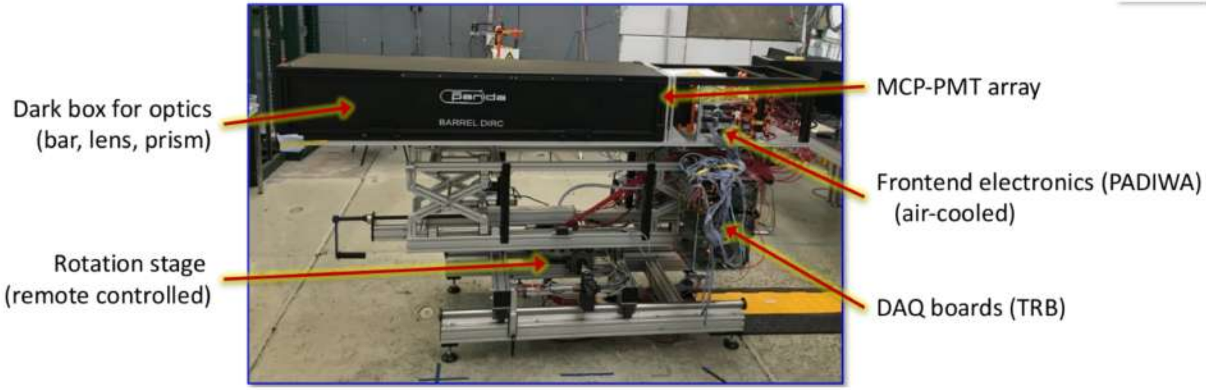






Baseline design with commercial MCP PMT sensors

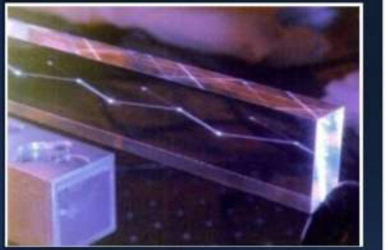
- Improved resolution.
- Key components:
  - Innovative focusing lens
  - Compact fused silica expansion.
  - Fast photon detection.

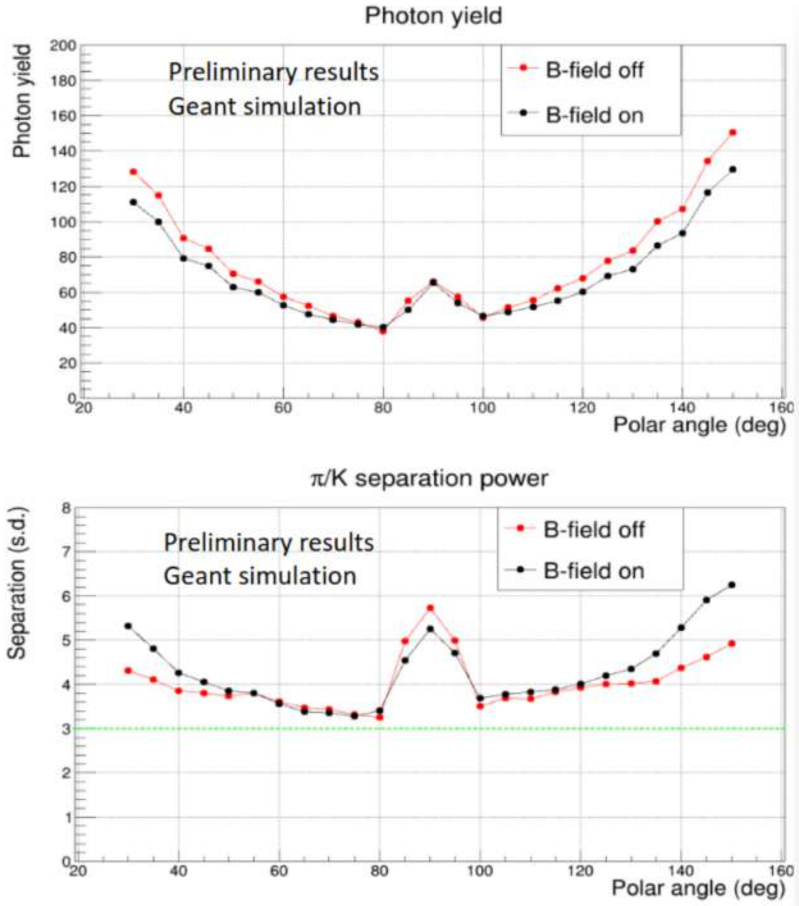


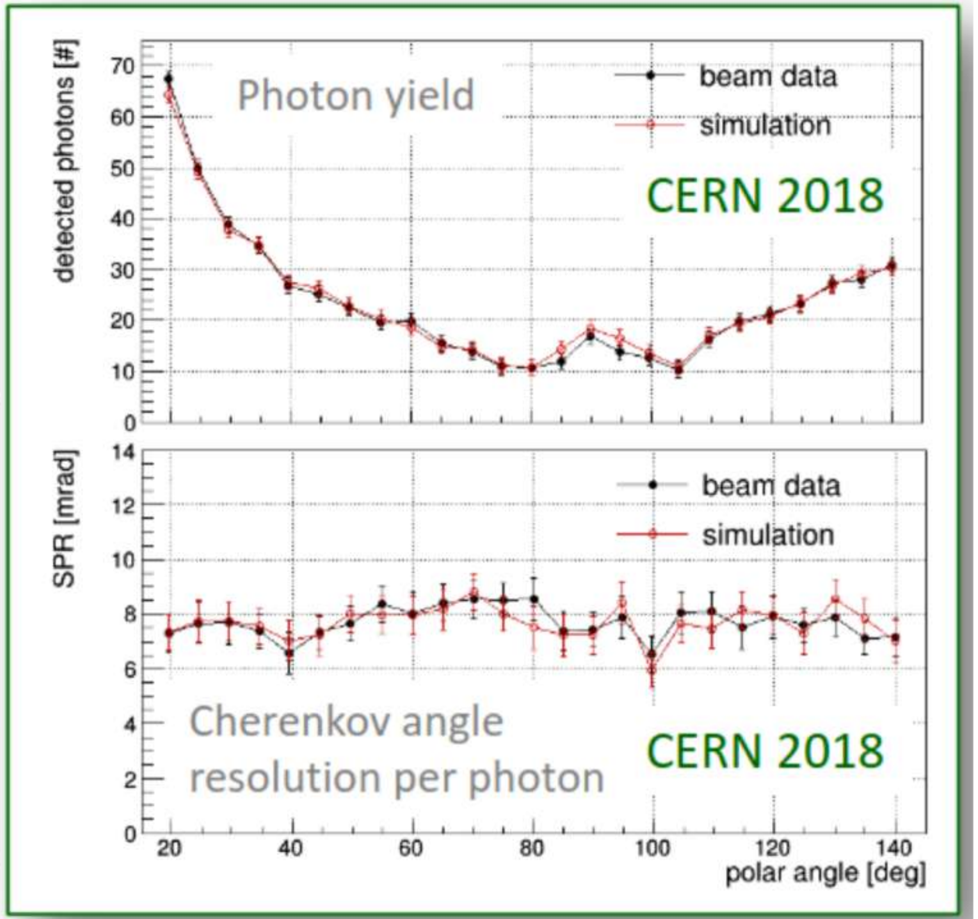
Beam test set up

A further option: HRPPDs

Central PID
hpDIRC

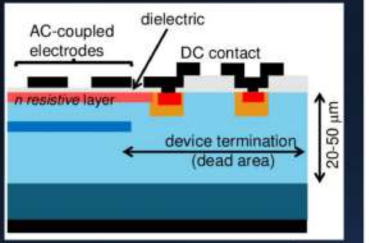




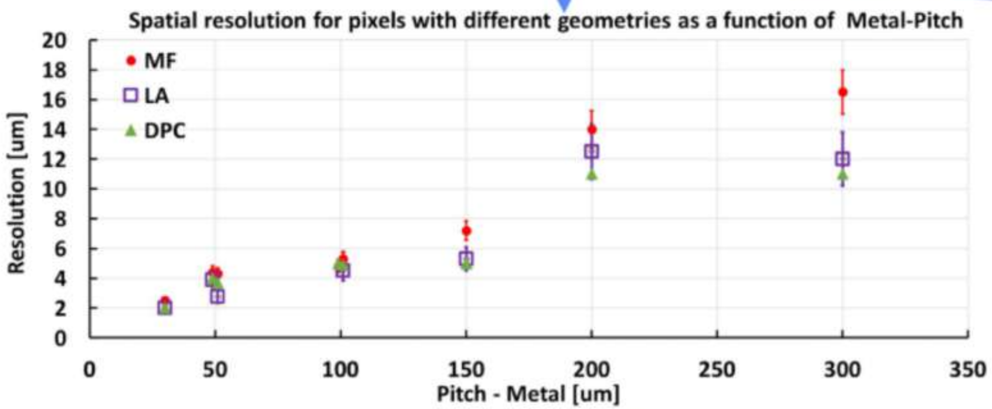


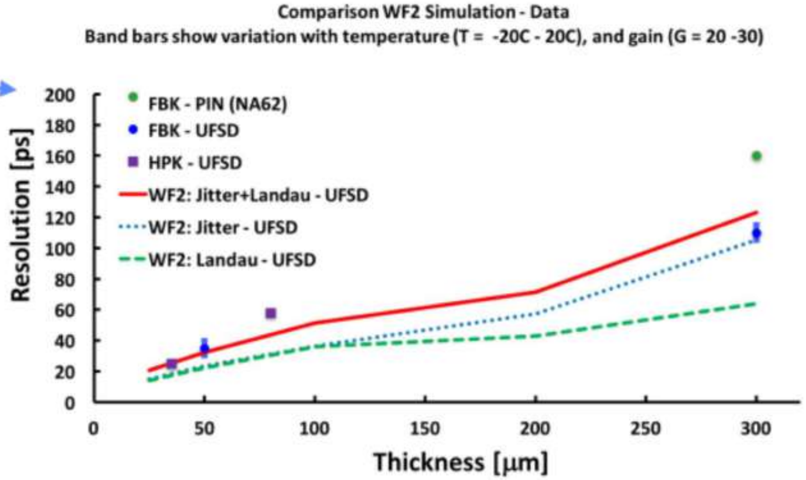
- 3D (X,Y,t) reconstruction thanks to fast photon detection sensor. Potential commonality with pfRICH for using HRPPD.
- Excellent agreement between simulation and beam test results. 3 sigma pi/K separation up to 6 GeV/c (covering -1.73<eta<1.73).

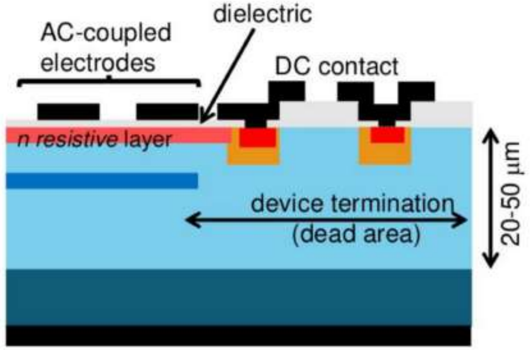
Central and Forwrad PID
TOF (AC-LGAD)

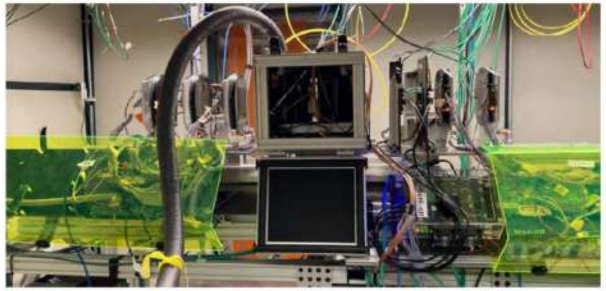


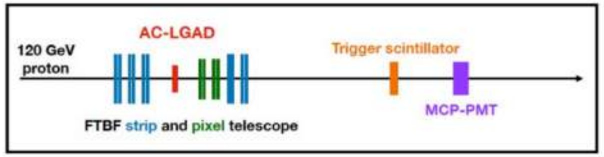
LGAD sensors provide fine space and time resolution

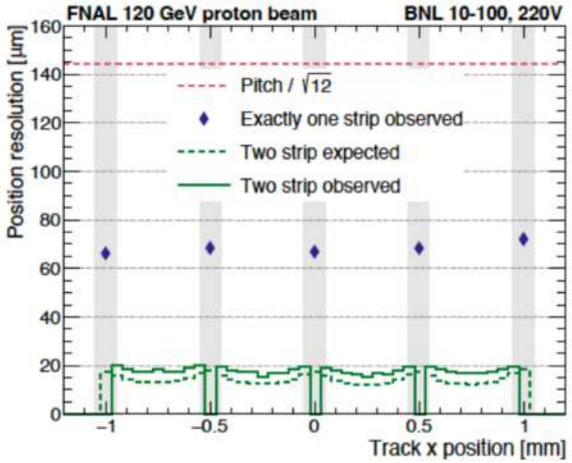


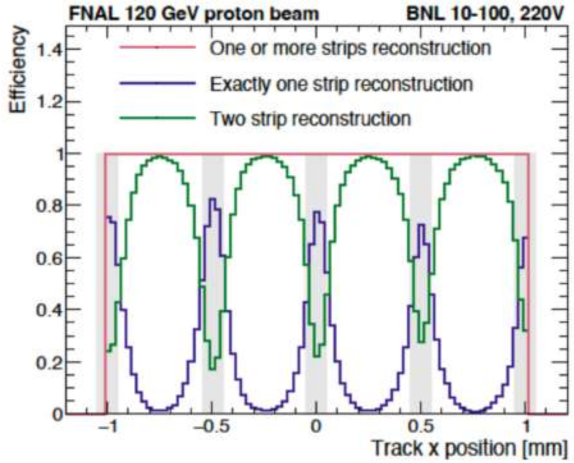






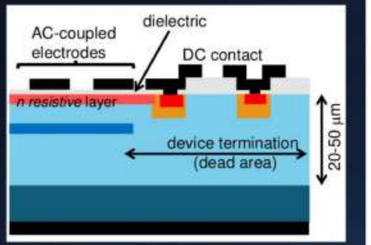


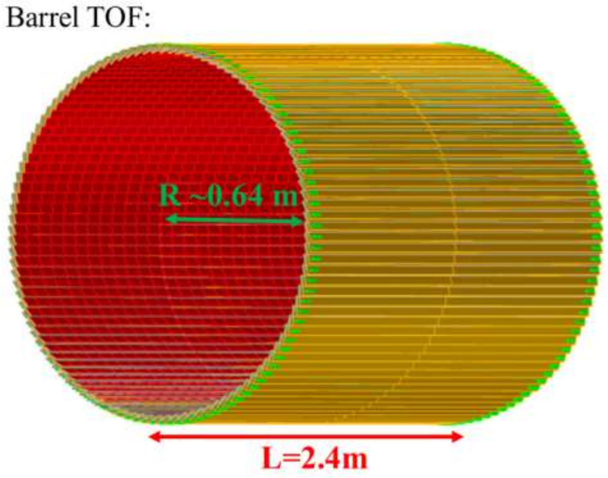




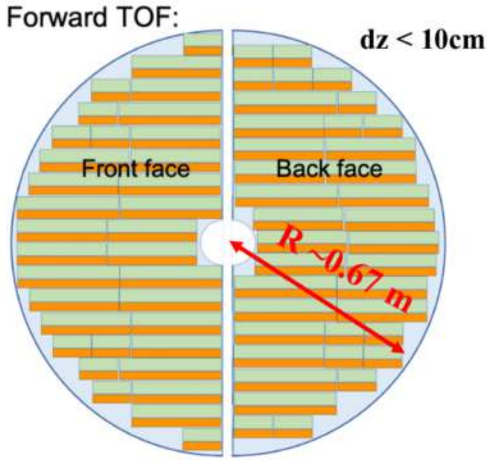
space resolution: **30 μm**
time resolution: **σ ~ 25 ps**

Central and Forwrad PID
TOF (Simulation studies)



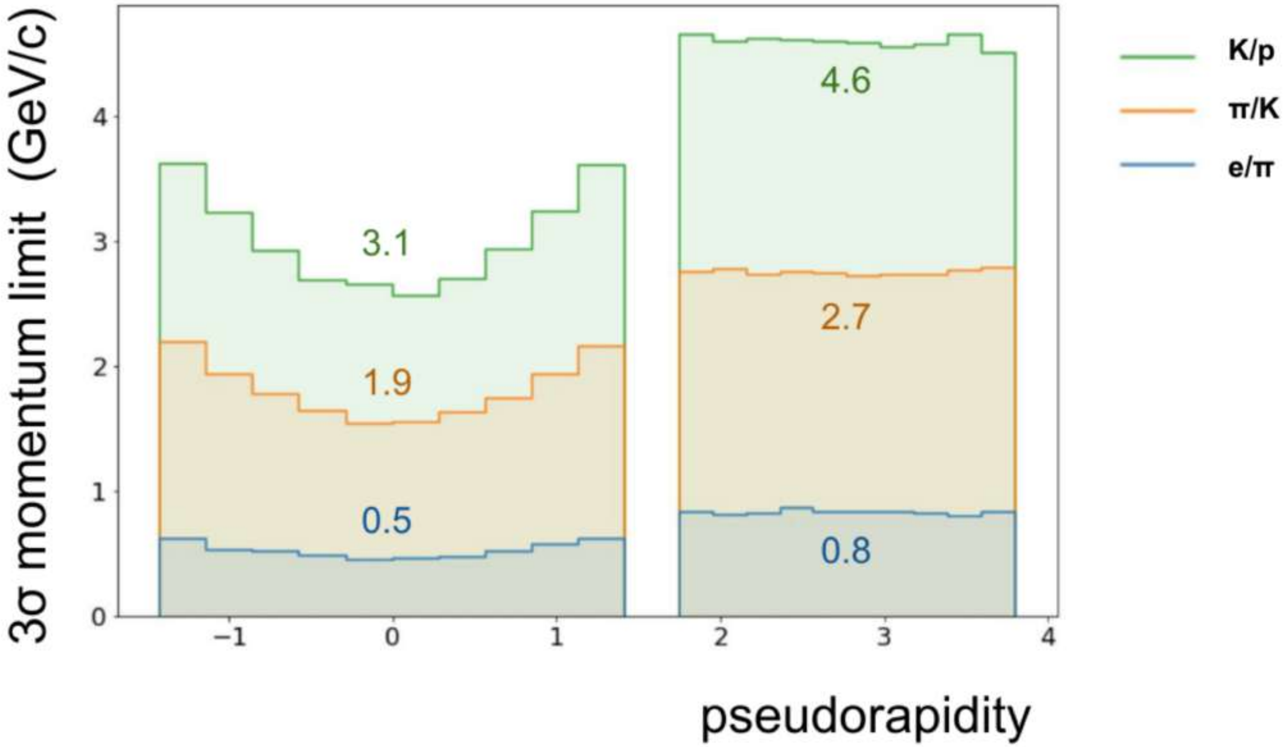


500 umX1cm strips
(1%X0)



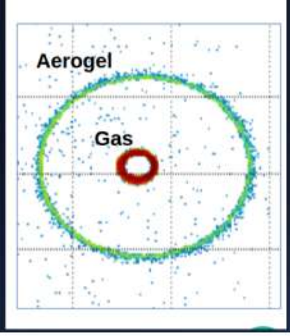
500 umX500um pixels
(~3%X0)

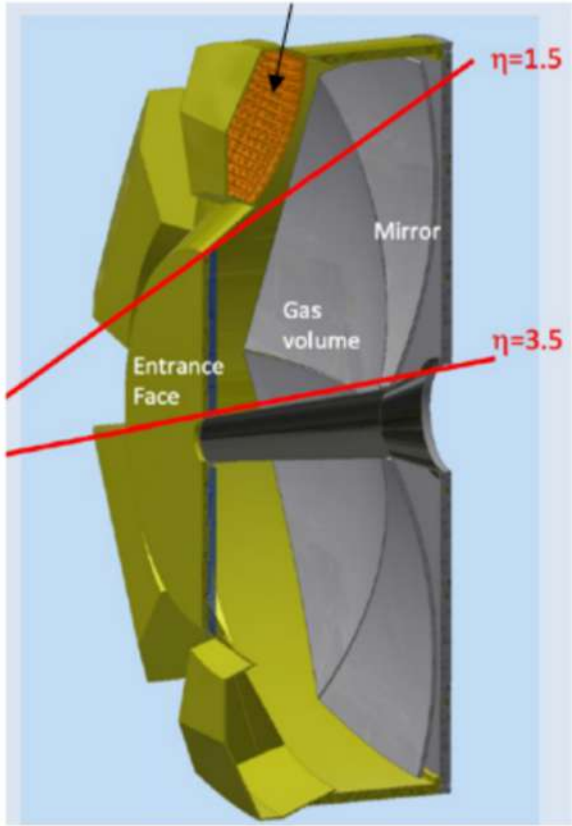
	PID coverage (π/K)
Forward (1.5<η<3.5)	$0.15 < p < 2.5$ GeV/c
Barrel (|η|<1.4)	$0.15 < p_T < 1.5$ GeV/c

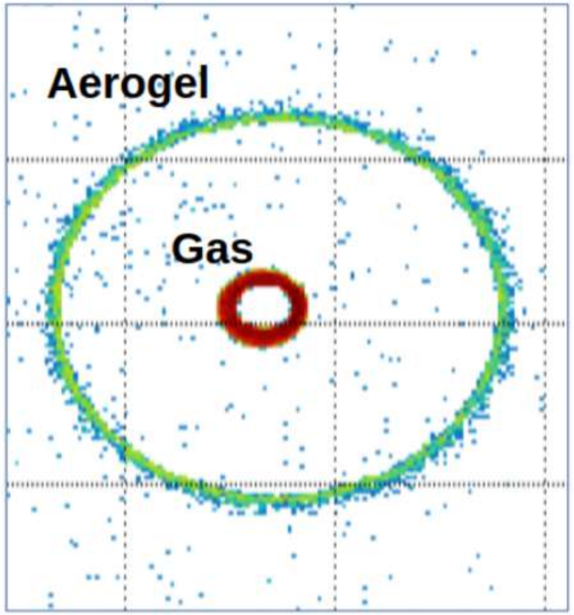


- ✔ Advanced geometric description in simulation,
- ✔ Physics performance studies,
- ✔ dedicated R&D with photosensors and
- ✔ readout commonality with pfRICH in readout ASIC

Forward particle identification

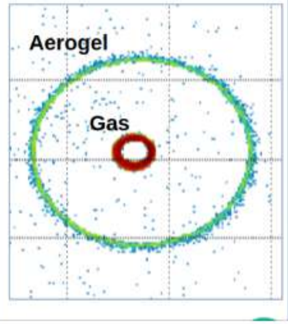


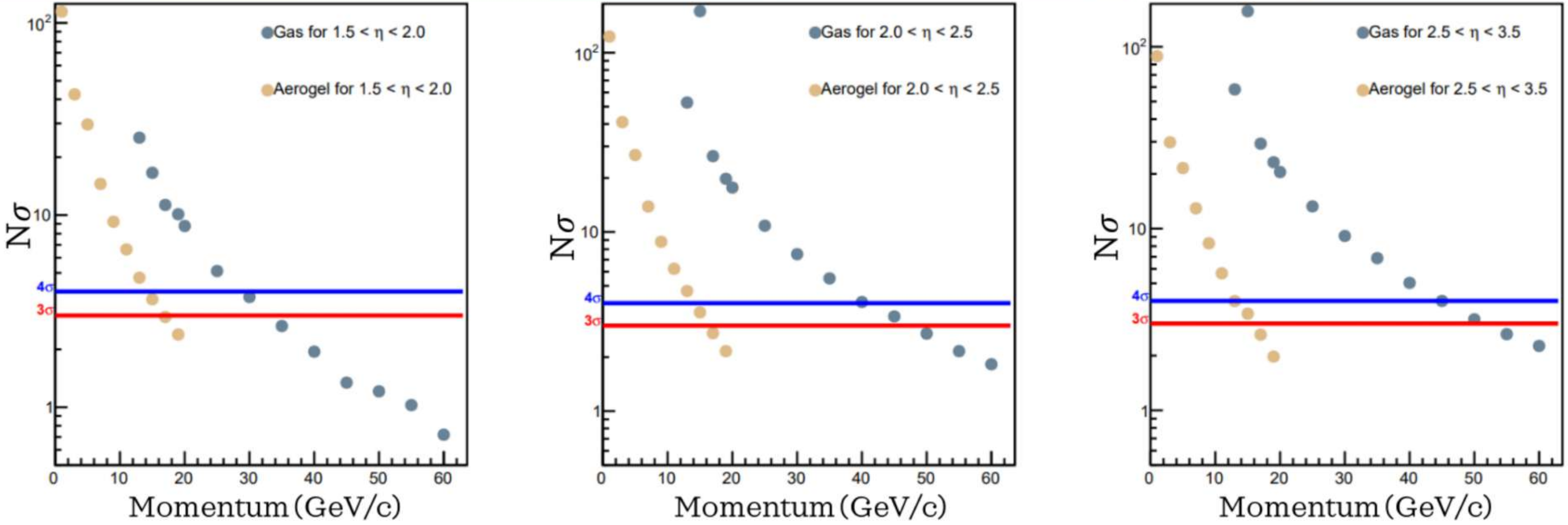




- Requirements:
  - **Wide acceptance** (+- 300 mrad/ 1.5<η≤3.5)
  - **High momentum coverage** up to 50 GeV/c π-K
    - Dual radiator (**aerogel (n ~1.02)**+ **C_2F_6 gas (n~1.0008)**)
- **Compact geometry**: short radiator space available
  - Smaller number of detected photons → Critical optical tuning and control over background hits.
- **Large sensor surface to be covered in magnetic field.**
  - Limited choice of photon-sensor (**SiPM as a cost effective solution**)
- Simulation contains: **6 identical sectors**
  - **Spherical mirror with radius 220 cm**
  - **SiPM sensors with realistic PDE and additional 70% safety factor**.
  - **Realistic parameters** for **aerogel** and **C_2F_6**

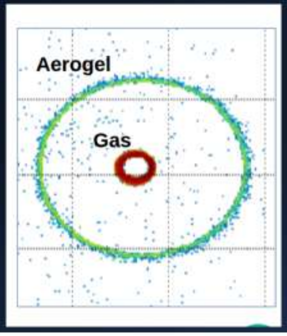
Forward particle identification
Performance studies



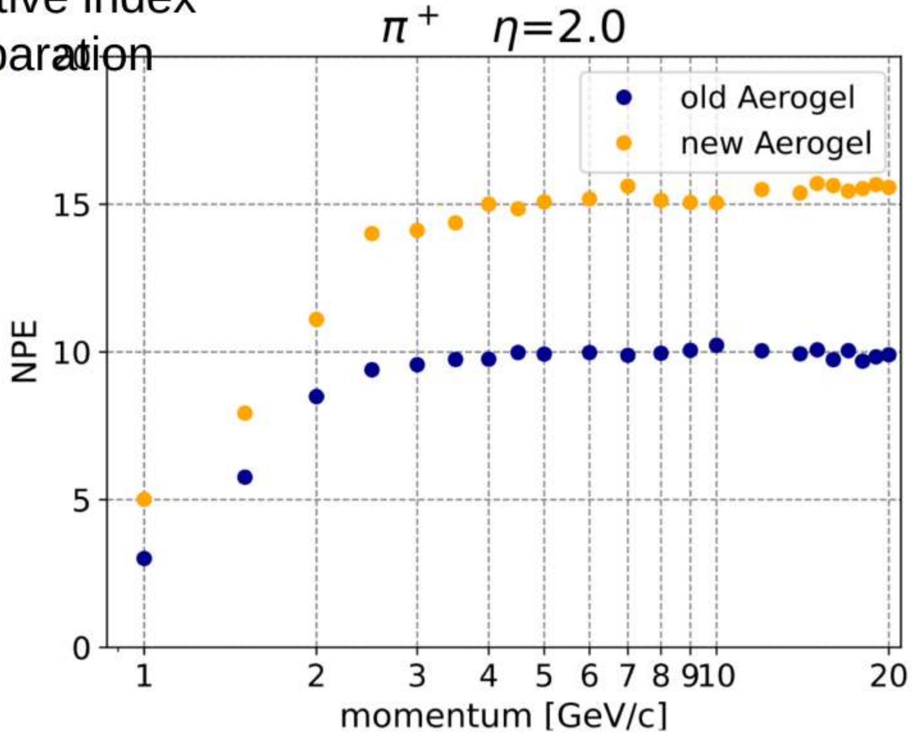


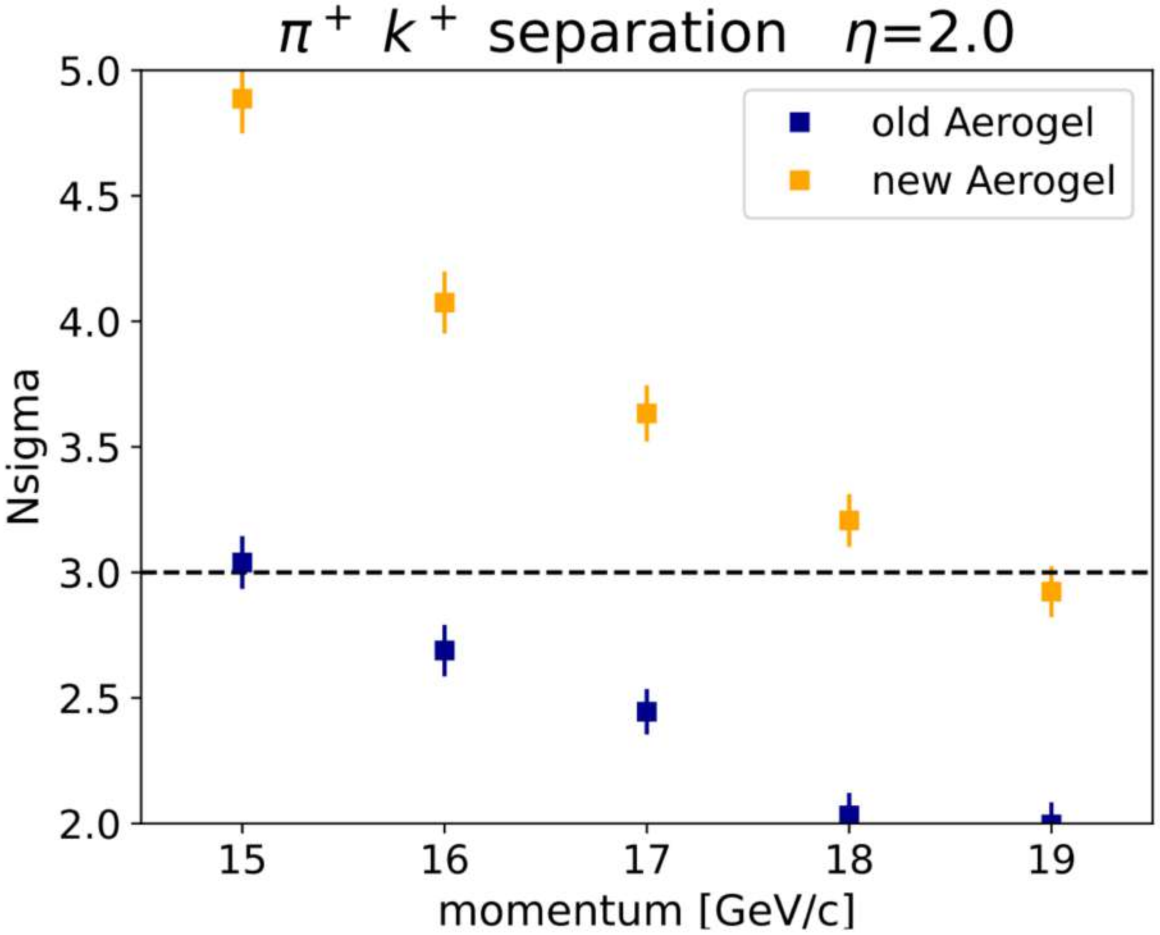
W/ **conservative 70% safety factor** 18 photo electrons are detected. Over a wide range of rapidity required resolution is achieved. Region affected w/ spherical aberration are limited in momentum (**6σ** sep. upto **20 GeV/c**).

Forward particle identification
Optimization of Aerogel

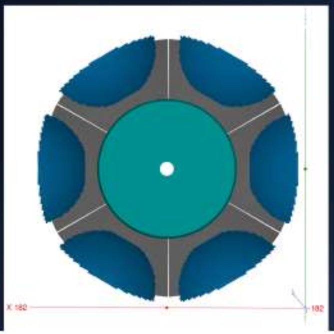


Optimization of new aerogel parameters.
→ Better optical properties.
→ Higher refractive index
→ Improved separation





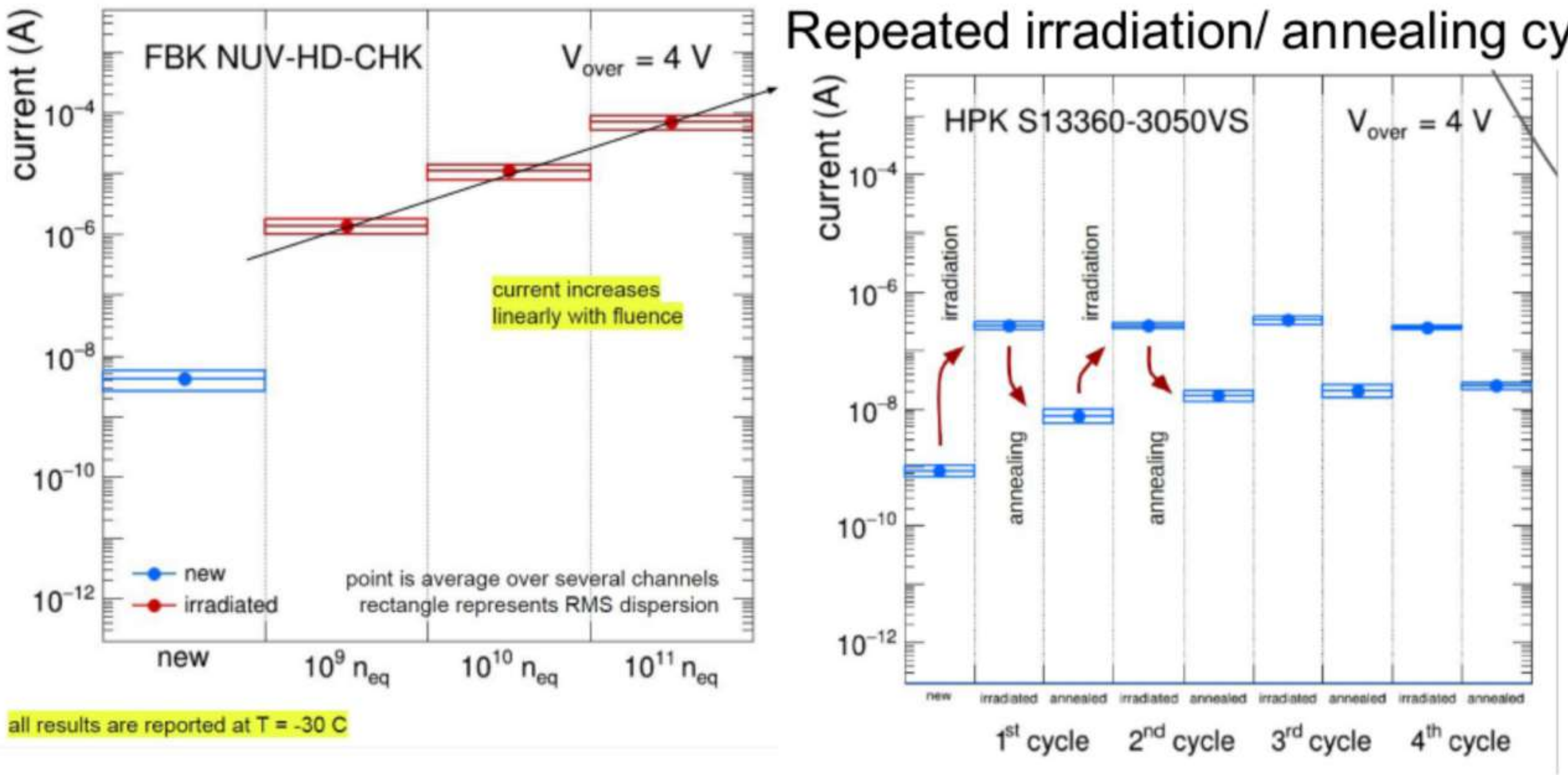
Forward particle identification:
SiPM sensor



- **pros**
  - cheap
  - high photon efficiency
  - excellent time resolution
  - insensitive to B field
- **cons**
  - large DCR, ~ 50 kHz/mm^2 @ T = 24 °C
  - not radiation tolerant
    - moderate fluence < 10^{11} n_{eq}/cm^2
- **R&D on mitigation strategies**
  - reduce DCR at low temperature
    - operation at T = -30 °C (or lower)
  - recover radiation damage
    - in-situ high-temperature annealing
  - exploit timing capabilities
    - with ALCOR (INFN) front-end chip

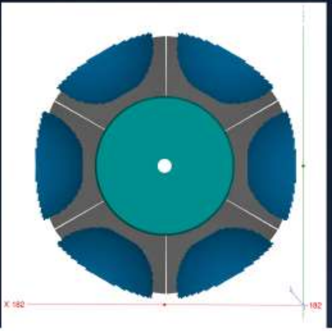
Different types of SiPMs have been studied.

Studies of radiation damage on SiPM

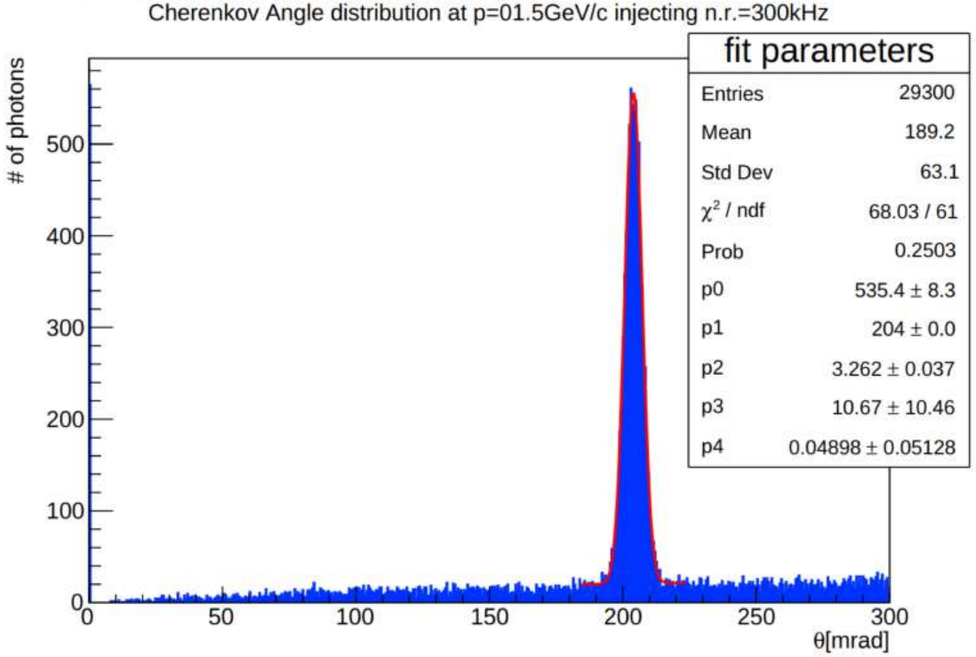


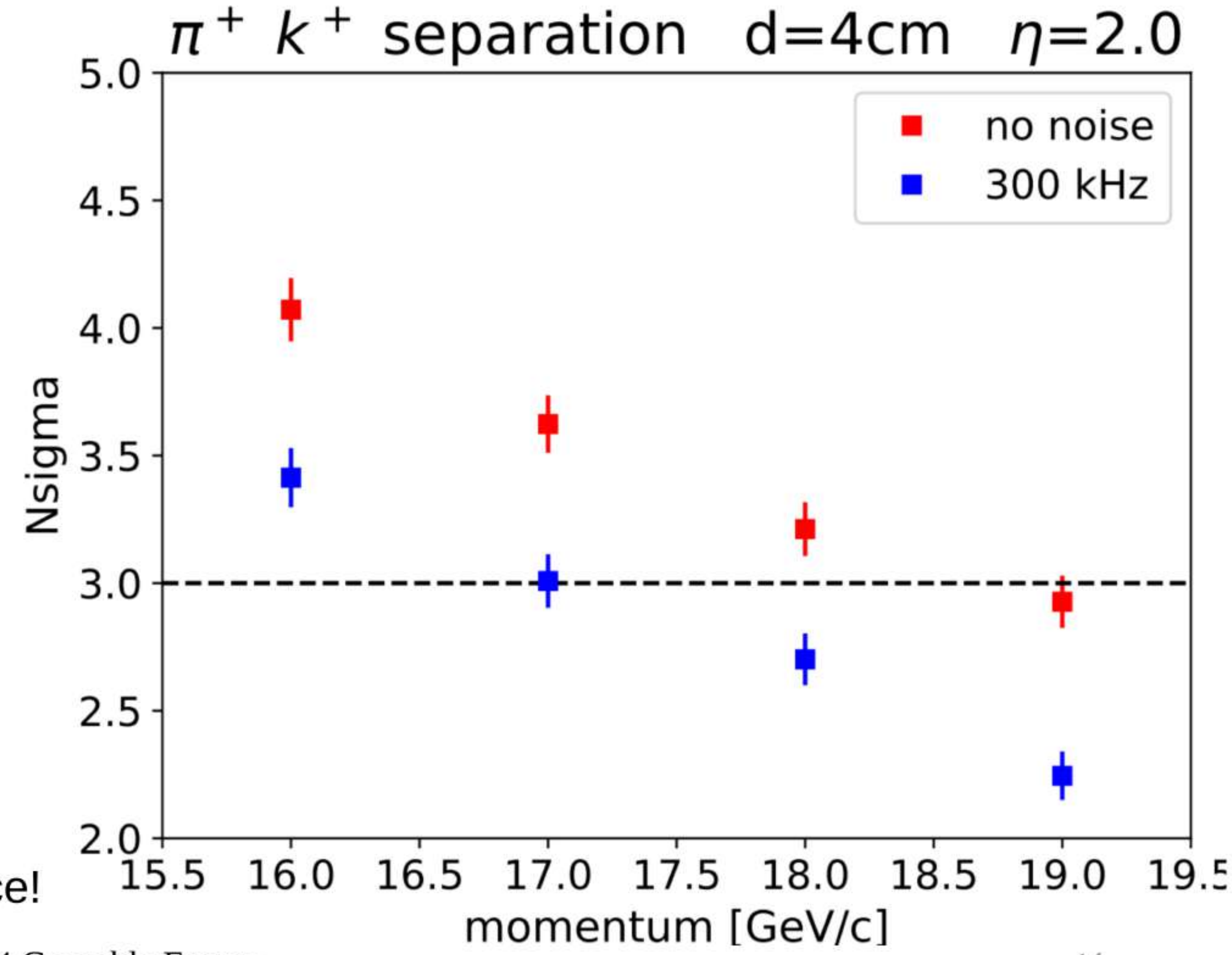
Maximum expected rate of DCR 300 kHz for each SiPM channel.

Forward particle identification
Simulation Studies of SiPM noise



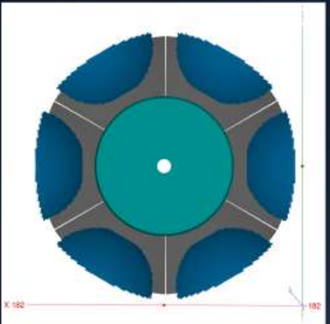
Intrinsic noise of SiPM
→ 300 kHZ of noise
→ 1ns time window

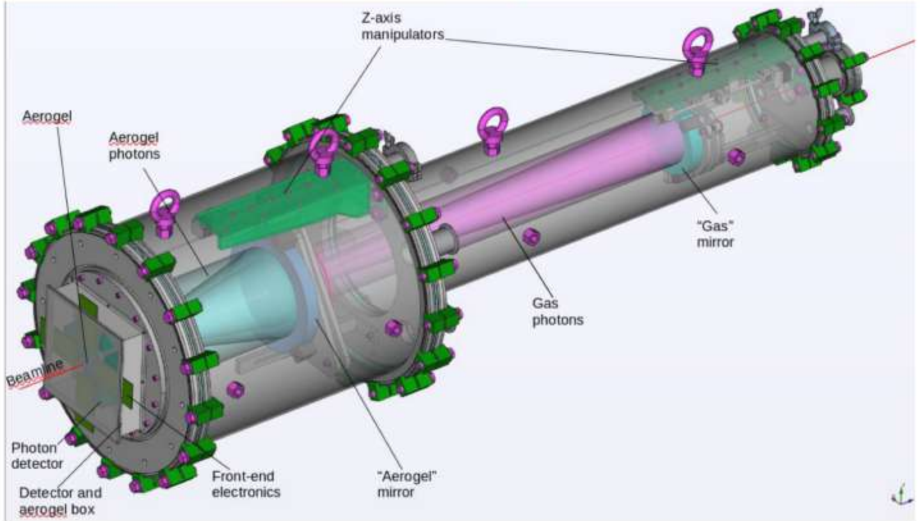


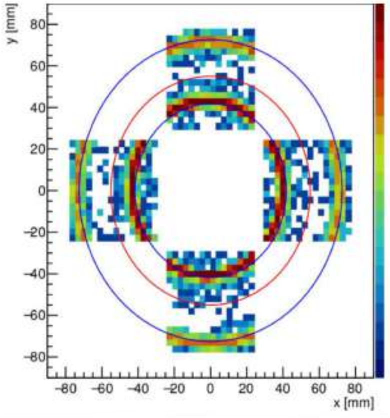


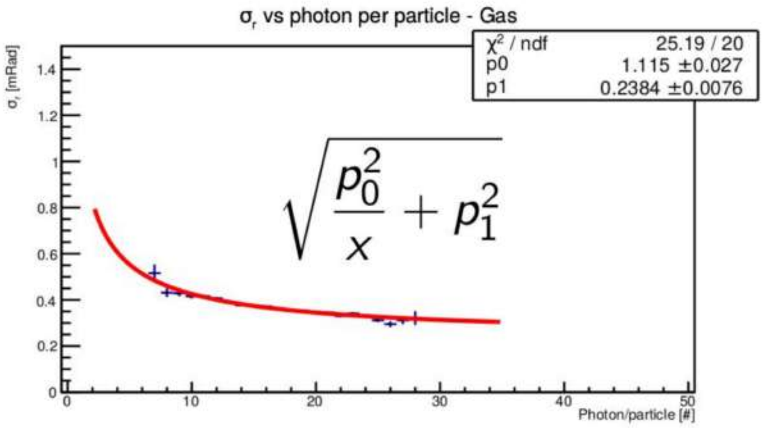
Reduction in aerogel performance by 1 GeV/c
New aerogel parameters helps to boost performance!

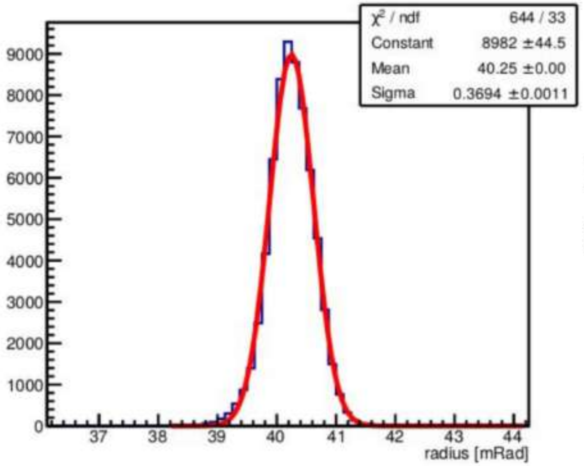
Forward particle identification:
Beam test @ CERN





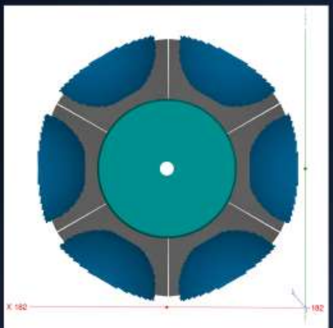




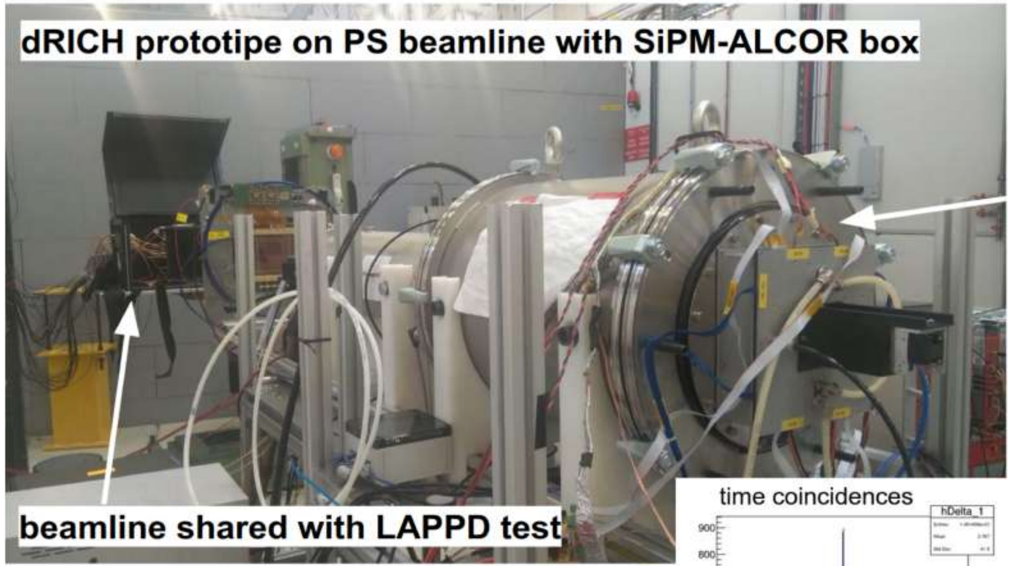


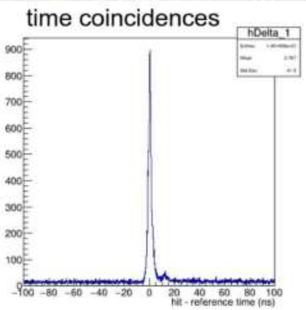
Ring angle and single particle resolution is in good agreement with simulation studies.

Forward particle identification:
Beam test @ CERN

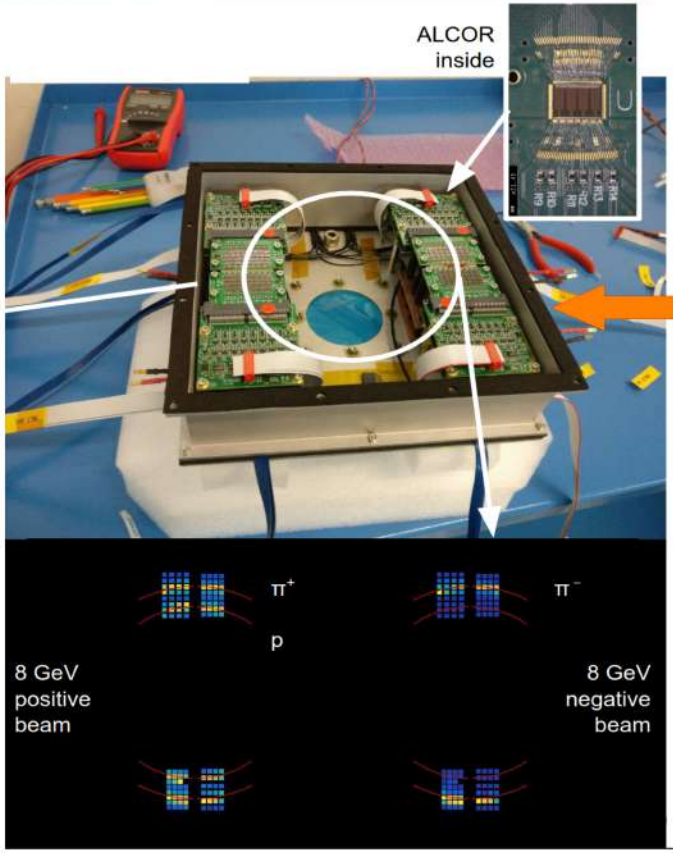


successful operation of SiPM with complete readout chain





SiPM sensors were **irradiated** (up to 10^{10}) and **annealed** (150 hours at T = 150 C)



- Compatible results between simulation and beam test for very forward high momentum PID.
- Ongoing R&D and beam test measurements are coupled with simulation studies.
- Commonality of reconstruction algorithm with pfRICH

PID @ ePIC : *Summary*

a. **Different PID technologies adopted by the ePIC collaboration to achieve desired physics goals**:

1. **AC-LGAD TOF**
2. **h**igh **p**erformance **DIRC**
3. **p**roximity **f**ocusing **RICH**
4. **d**ual radiator **RICH**

b. **Matured simulation and test beam results have validated the conceptual designs. Ongoing R&D exercises are focusing the risk minimization and optimization.**

c. **Preparation for the Technical design report is ongoing.**

References:

1. *TOF: EIC UG Meeting January 2023; https://indico.bnl.gov/event/17621/#b-7032-working-group-reports-v*
2. *TOF: Zhenyu Ye at POETIC 2023; https://www.ictp-saifr.org/wp-content/uploads/2023/05/yezhenyu_POETIC_20230505.pdf*
3. *DIRC: Nilanga Wickramaarachchi at DIS 2023; https://indico.cern.ch/event/1199314/contributions/5193192/attachments/2619099/4530710/DIS2023_hpDIRC_Nilanga.pdf*
4. *DIRC: EIC UG Meeting Januray 2023; https://indico.bnl.gov/event/17621/#sc-9-4-hpdirc*
5. *dRICH beam tests and photo-sensors: R.Preghenella at DIS 2023; https://indico.cern.ch/event/1199314/contributions/5193188/attachments/2619053/4528569/%5B20230326%5D%5BDIS%5D%20PID%20with%20EPIC%20at%20EIC.pdf*

S. Vallarino; https://indico.bnl.gov/event/19345/#2-prototype-data

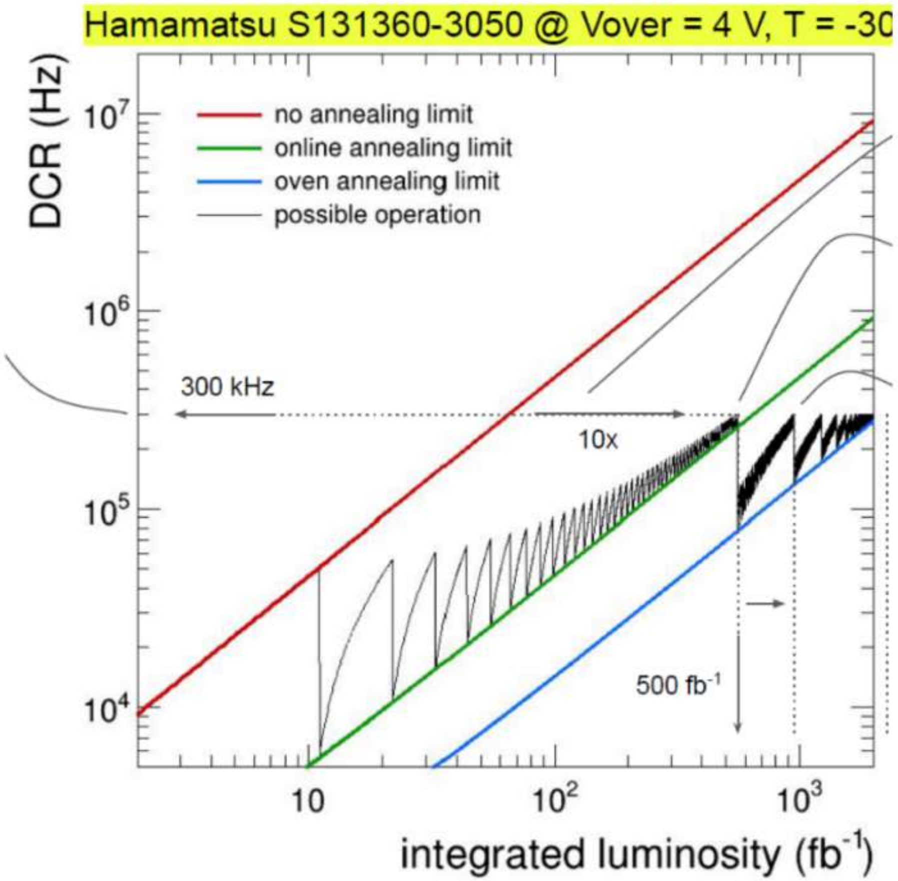
Back up

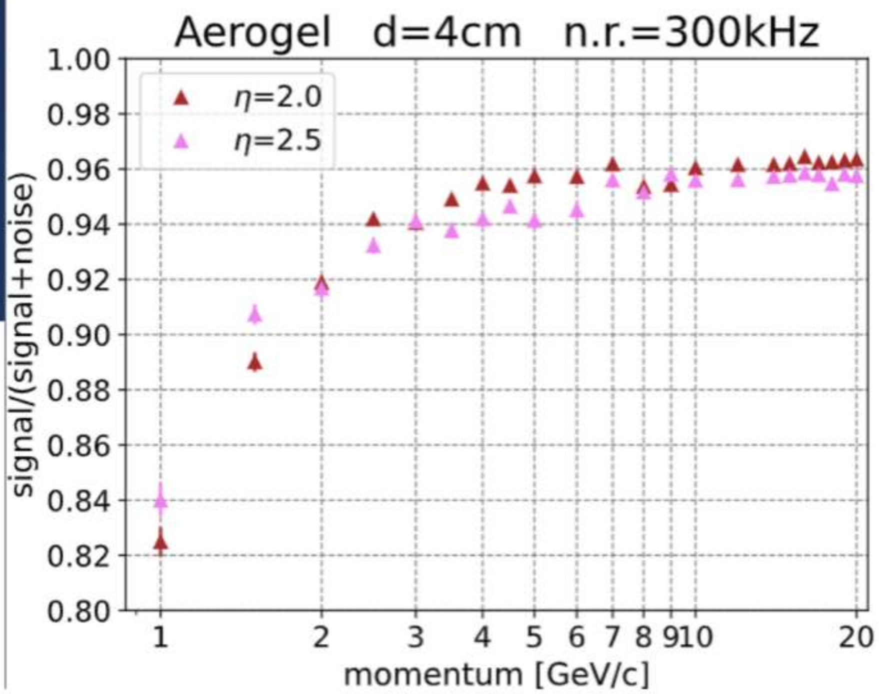
Backup-1: dRICH Aerogel performance

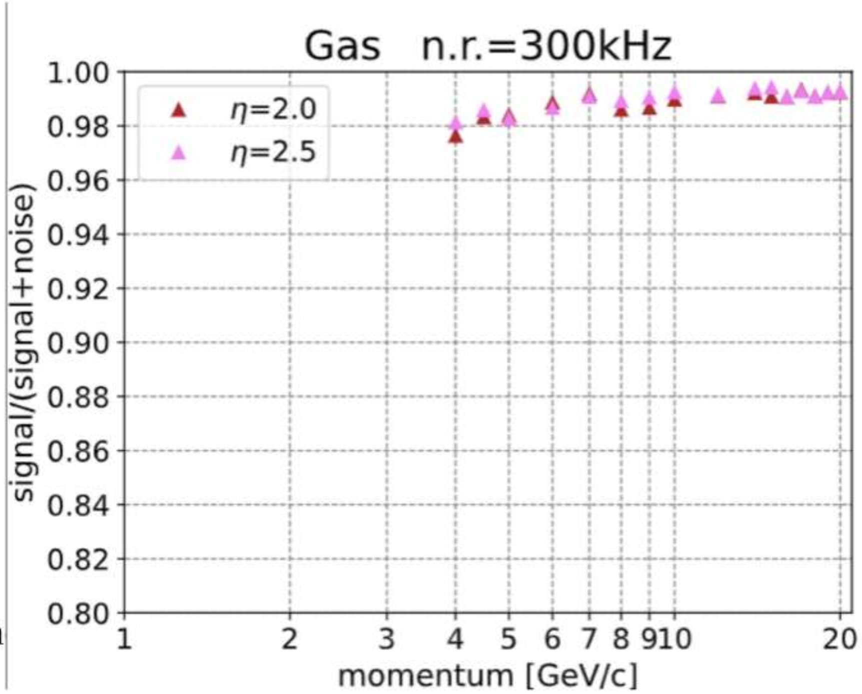
Noise (kHz)	Aerogel Thickness (cm)	Aerogel Type	3 σ limit π-K separation (GeV)
0	4	old	15
0	4	new	>18
300	4	new	17
0	6	new	19
300	6	new	18

Backup-2: dRICH SiPM noise rate

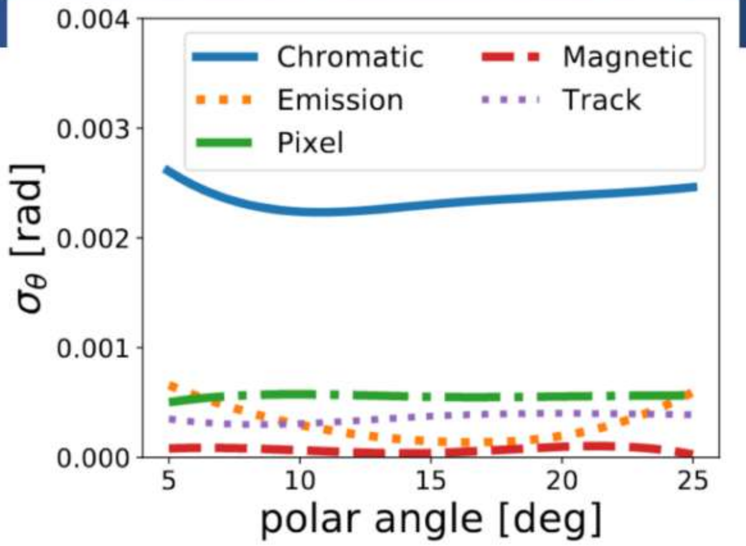
Ageing model

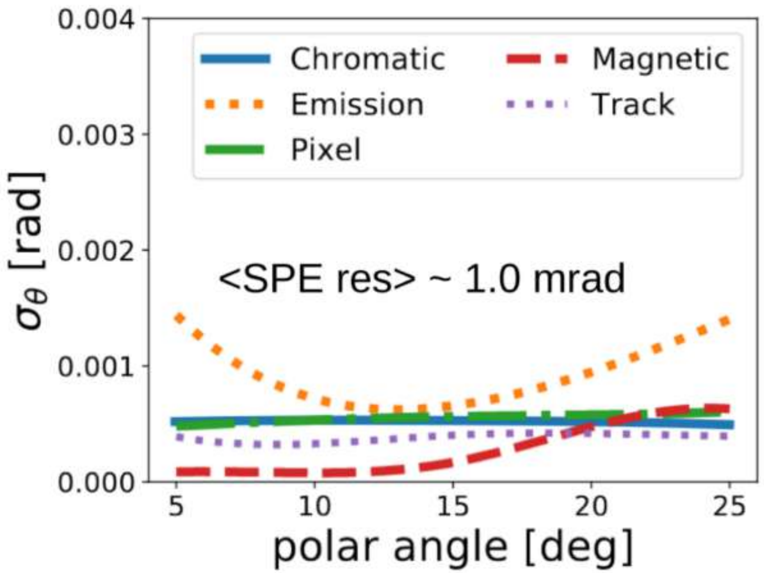


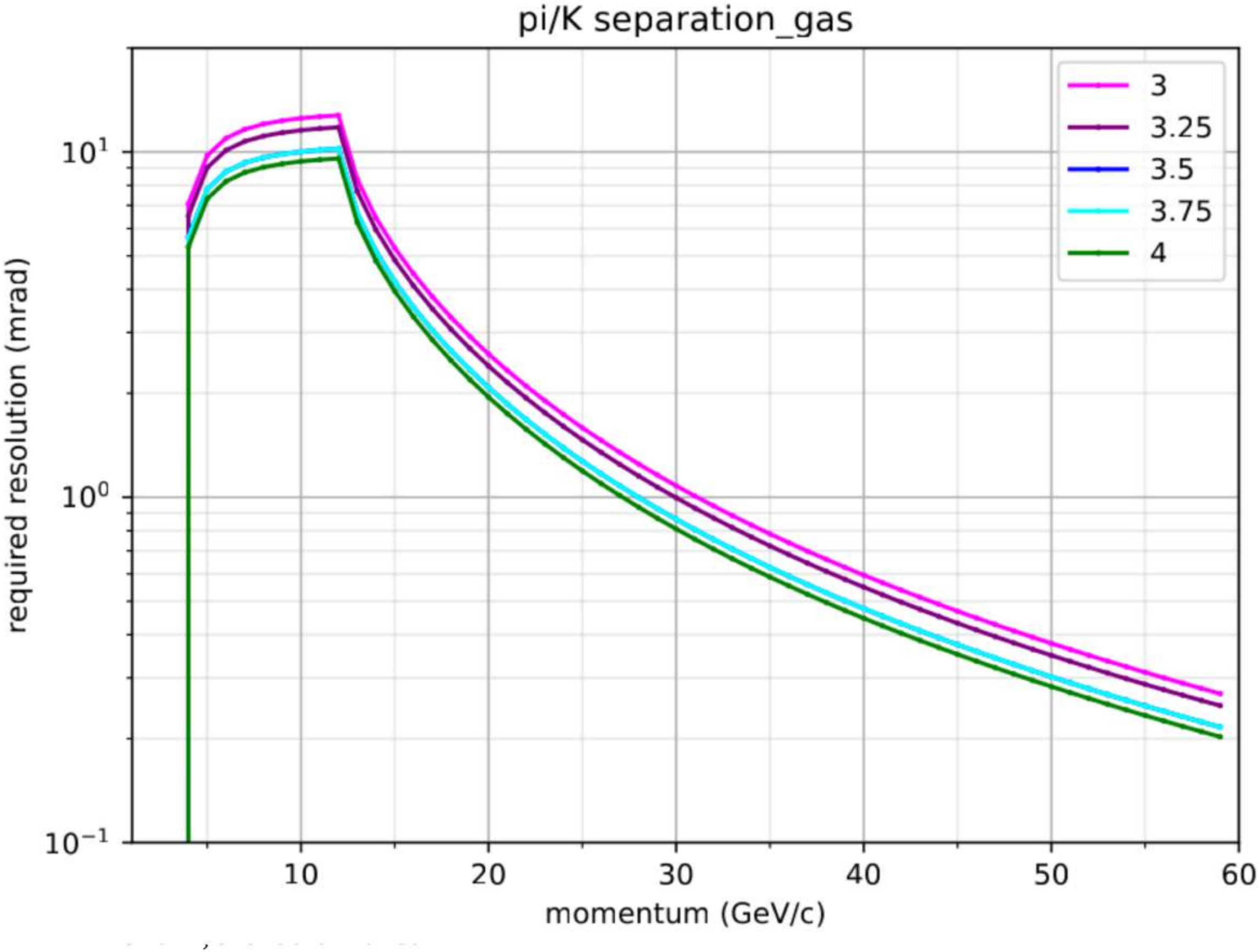




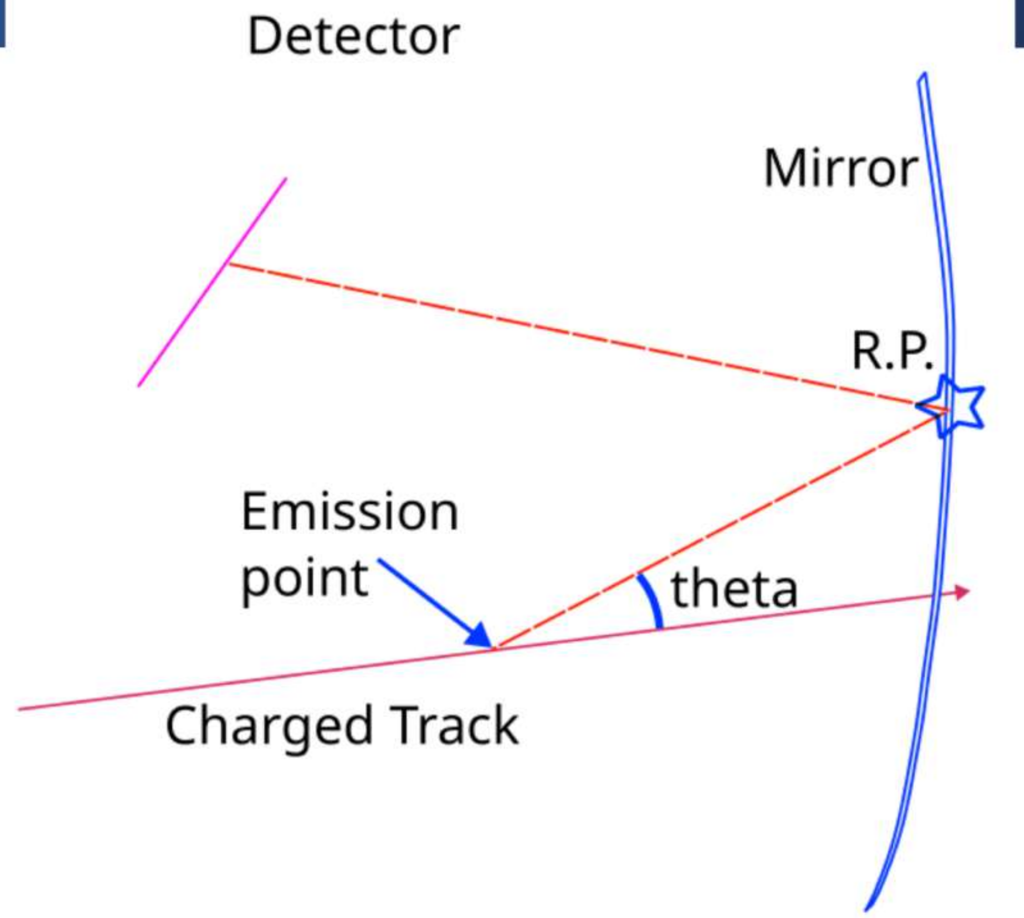
Backup-3: dRICH resolution contribution

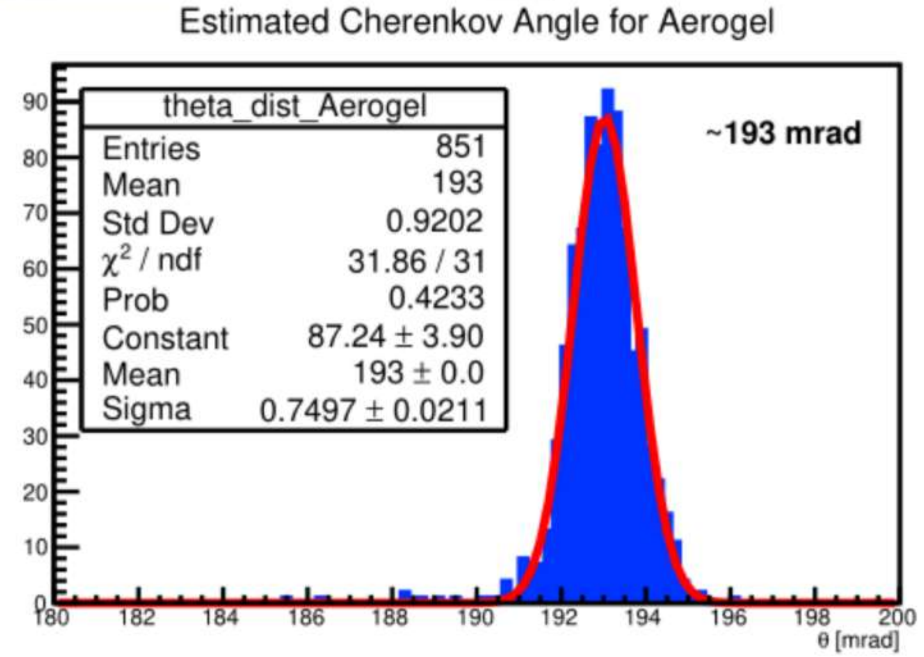


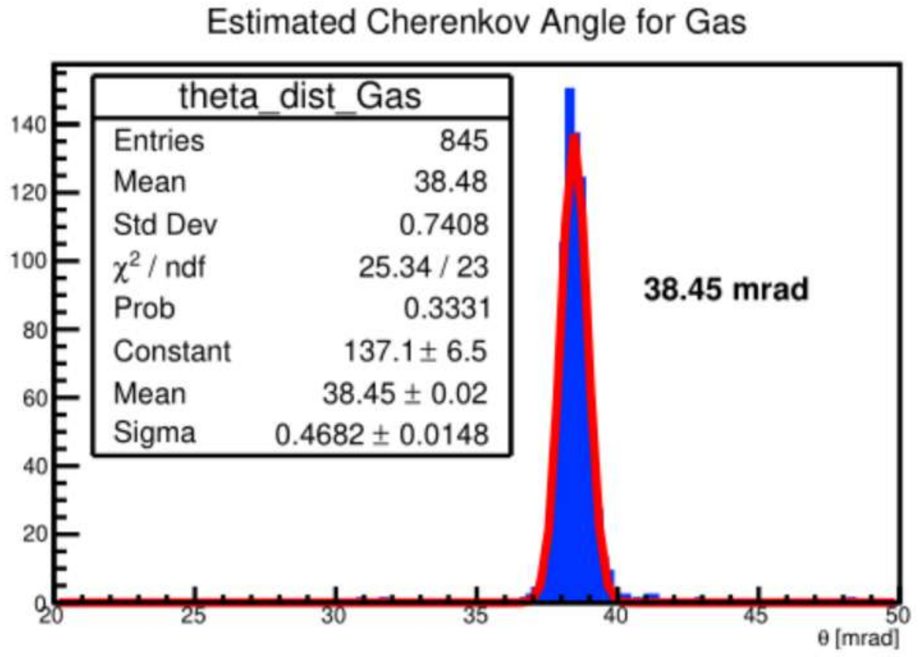




Backup-4: IRT

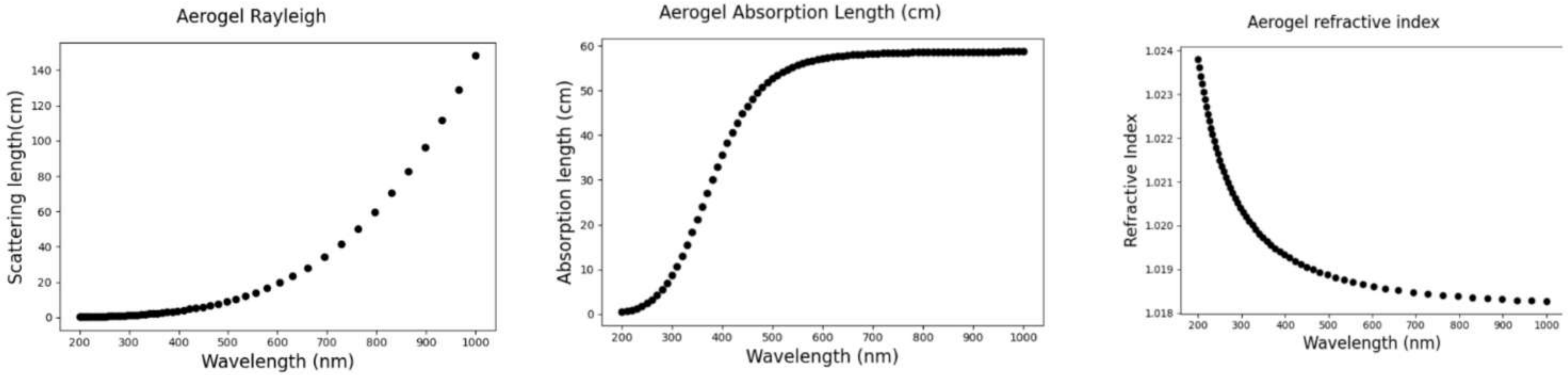

Detector
Mirror
R.P.
Emission point
theta
Charged Track


Estimated Cherenkov Angle for Aerogel
theta_dist_Aerogel
Entries 851
Mean 193
Std Dev 0.9202
χ² / ndf 31.86 / 31
Prob 0.4233
Constant 87.24 ± 3.90
Mean 193 ± 0.0
Sigma 0.7497 ± 0.0211
~193 mrad
θ [mrad]

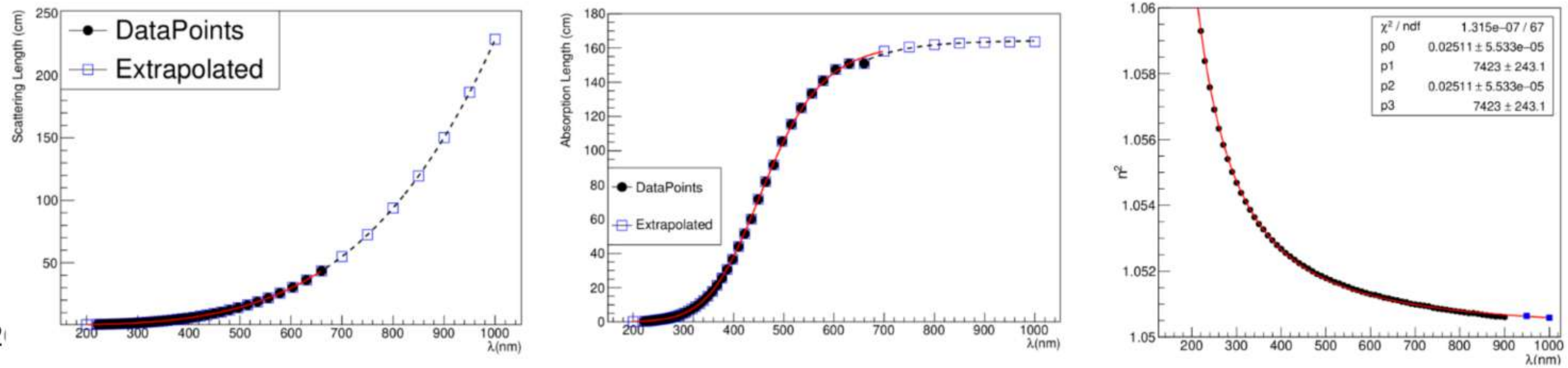

Estimated Cherenkov Angle for Gas
theta_dist_Gas
Entries 845
Mean 38.48
Std Dev 0.7408
χ² / ndf 25.34 / 23
Prob 0.3331
Constant 137.1 ± 6.5
Mean 38.45 ± 0.02
Sigma 0.4682 ± 0.0148
38.45 mrad
θ [mrad]

Backup-5: Aerogel parameters

Old aerogel Parameters

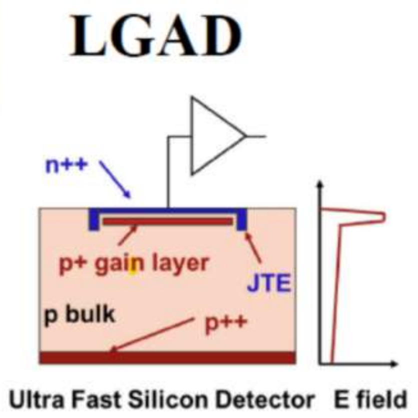


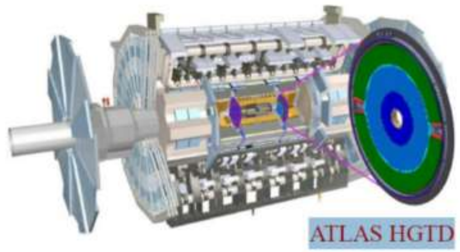
New aerogel Parameters

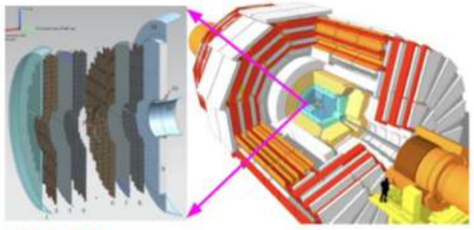


Backup-6: ALGAD
Fill factor

LGADs – 4D detectors







Excellent time and position resolutions

AC-LGAD provides

~ 100 % filling factor