CLAS12 Rich Imaging Cherenkov Counter

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CLAS12 RICH Detector Workshop

RICH History

- 1960 Basic idea to determine the velocity of charge particle via measurement the Cherenkov angle (A. Roberts)
- 1977 First prototype (J. Seguinot and T. Ypsilantis)
- Workshops on Ring Imagine Cherenkov Counters (1993, 1995, 1998, 2002, 2004, 2007)

Thomas Ypsilantis (1928-2001)

Tom Ypsilantis played the leading role in the initial stage of the RICH technique around 1980.

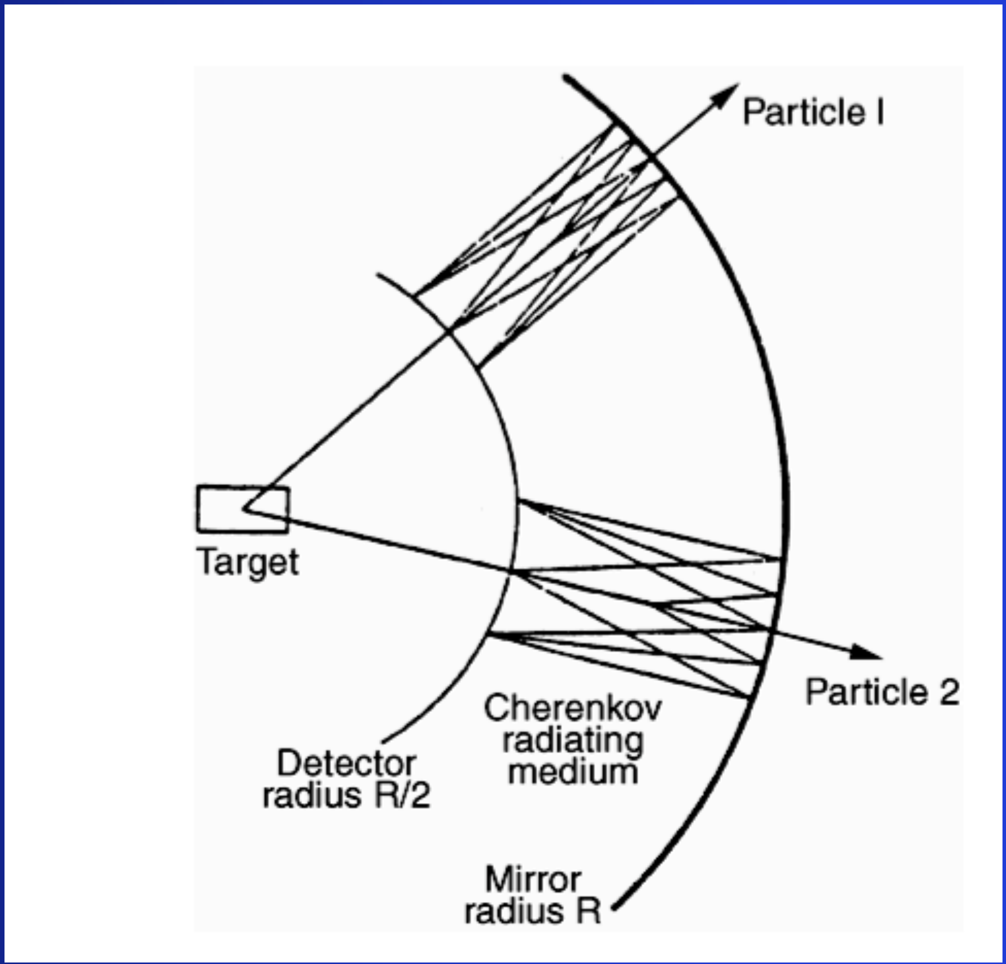
Tom Ypsilantis, Paris, ca 1983.

The acronym RICH was suggested by Tom as a joke, because the researchers were - it is true - poor in fact.

The original drawings of Tom Ypsilantis (1977)

Optical scheme of the spherical RICH

- New optics with focused Cherenkov images
- Experimental demonstration of that single UV photons can be detected by MWPC
- Proposal to use MWPC in drift mode to enable the two-dimensional imaging of the one-photoelectron UV photons



Experiments with RICH

- **Flavor physics**
  SPHINX(IHEP), BaBar (SLAC), CLEO (Cornell), HERA-B (DESY), LHCb (CERN), SELEX
- **Neutrino physics**
  Super-Kamiokande (Kamioka), SNO (Sudbury), ANTARES (Toulon), NESTOR (Pylos), Baikal (Lake Baikal), AMANDA (South Pole), MINOS(FNAL)
- **High p_T physics** (Higgs/Supersymmetry), CDF and D0 (Tevatron), ATLAS and CMS (LHC)
- **Hadron structure**
  HERMES (DESY), COMPASS (CERN)
- **Heavy Ions**
  HADES (GSI), STAR and PHENIX (Brookhaven), ALICE (CERN)
- **Space physics**
  AMS and EUSO (Space station)

SPHINX RICH 1989

- First RICH detector with small PMT photodetector matrix was build by Russian group at 1989, Serpukhov 70 GeV proton machine
- 2 matrixes with 736 1 cm in diameter PMT
- SF_6 (elegas) radiator with n=1.008
- π/K/p threshold 3.4/12/23 GeV

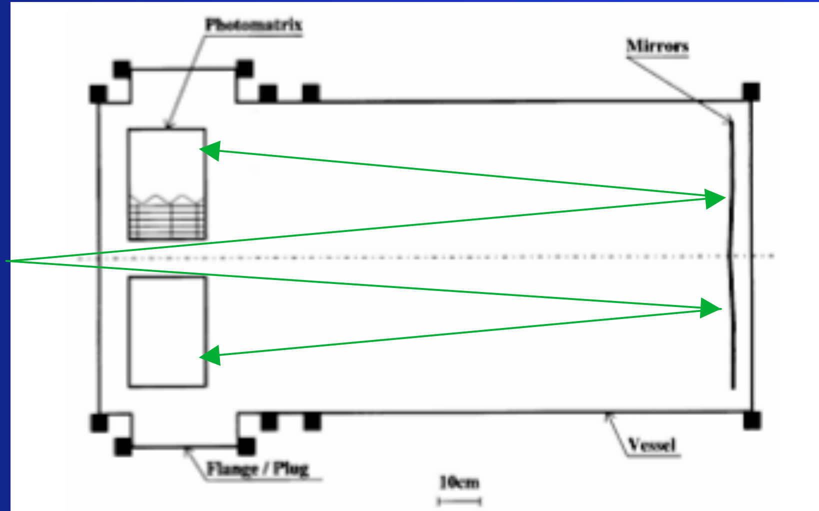
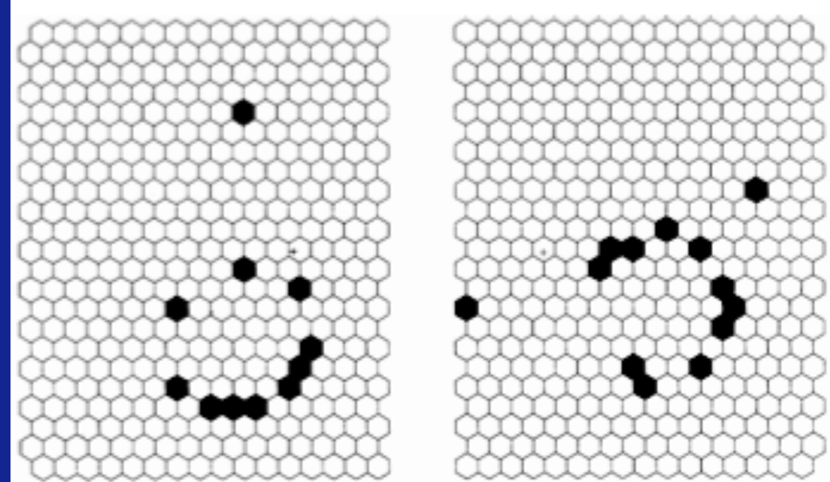
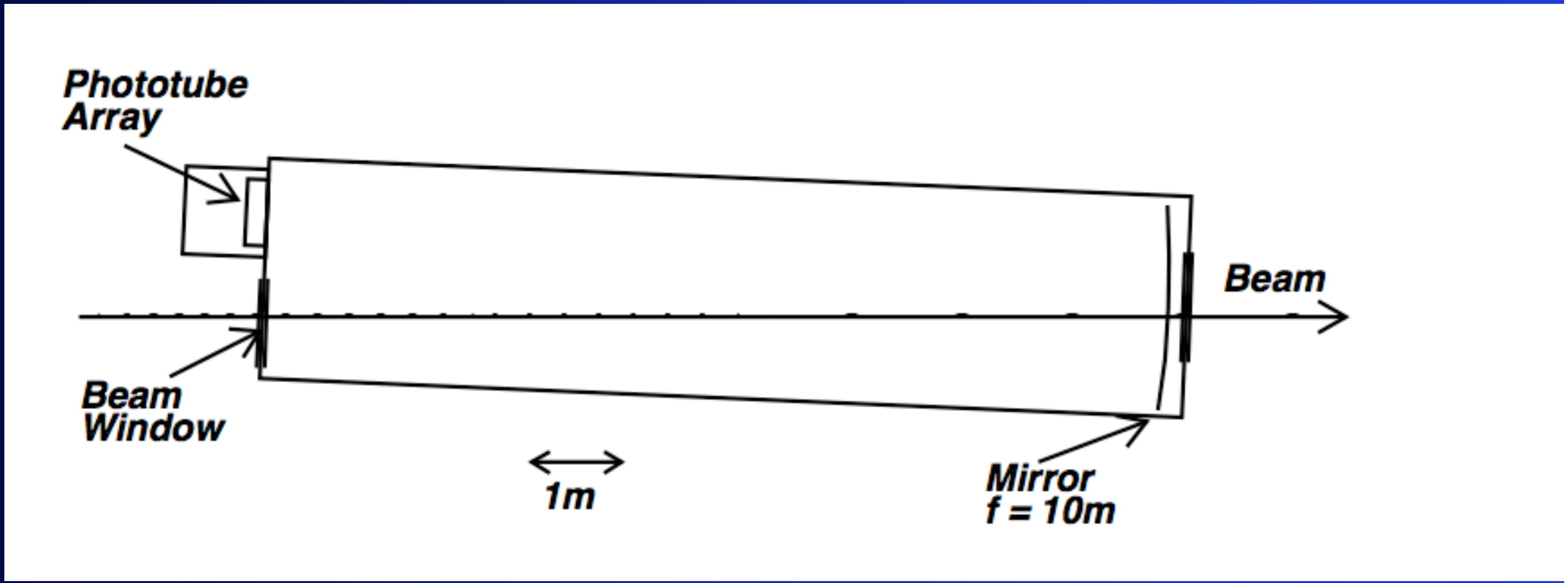


Fig. 1. Schematic view of the detector (cut in horizontal plane).



SELEX RICH



SELEX RICH Photo

Single event display SELEX RICH

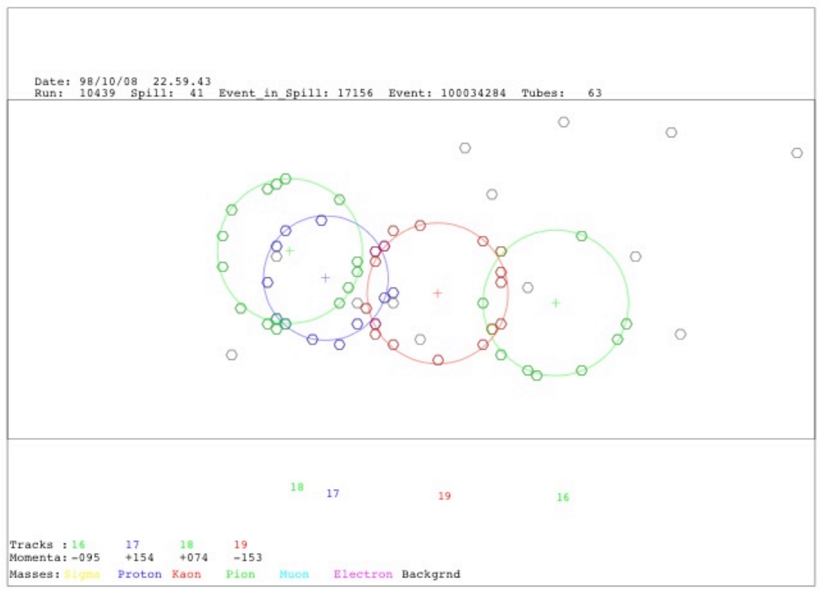


FIGURE 14. Single event display. The small hexagons represent a hit phototube, the circle shows the ring for the most probable hypothesis, and the numbers denote the track numbers, with there momenta shown at the bottom.

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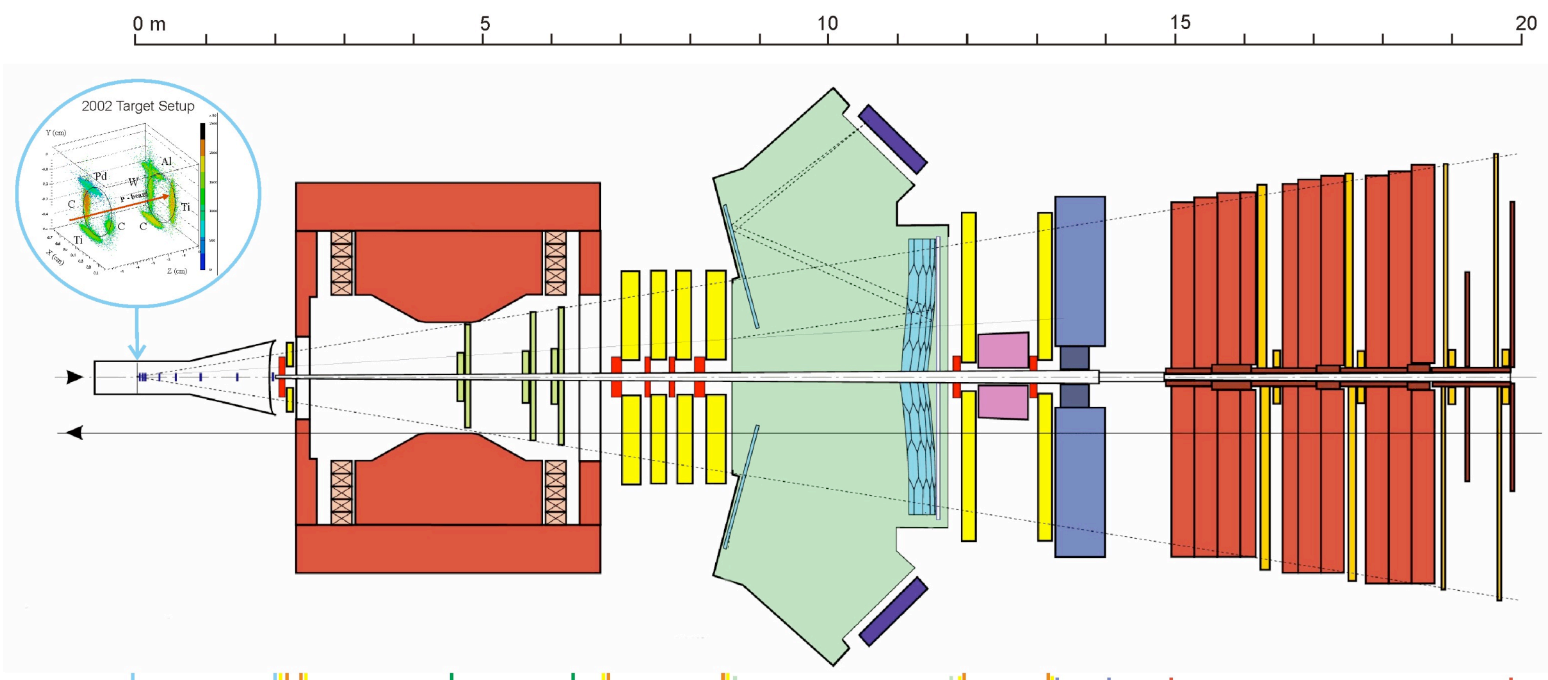
HERA-B



Target & Vertex
8 layers of double-sided Si-microstrips, movable on Roman-Pots; 8 wire-target (see above)

High p_T
3 superlayers gas, pixel and pad chambers; pre-trigger for high p_T tracks

Outer Tracker
7 superlayers of honeycomb drift chambers, 5 and 10mm cells

RICH
Spherical mirror inside C_4F_{10} radiator, Lens-enhanced multianode PMT focal plane.

Inner Tracker
7 superlayers of Micro Strip Gas Chambers with GEM-foil

Electromagnetic Calorimeter
W/Pb scintillator sandwich, shash-lik WLS readout with PMTs; energy-cluster pre-trigger

Muon System
4 superlayers of gas-pixel, tube & pad chambers; pad-coincidence pre-trigger

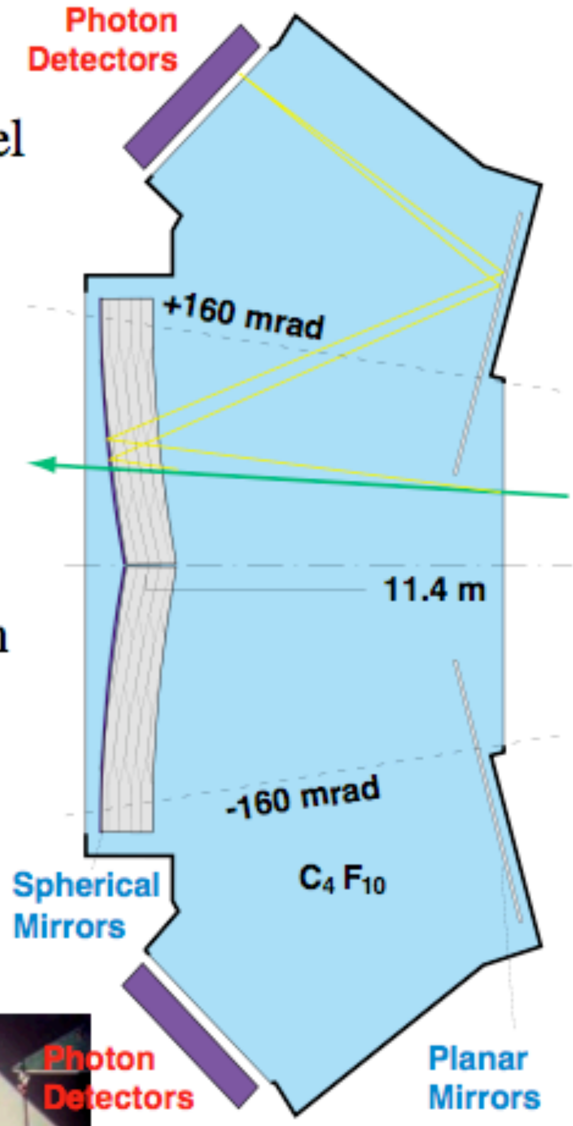
HERA-B RICH

❑ **Radiator**

- 100 m^3 stainless steel vessel
- C_4F_{10} $n = 1.00135$
- $\Theta_{Cherenkov} = 52$ mrad

❑ **Mirrors**

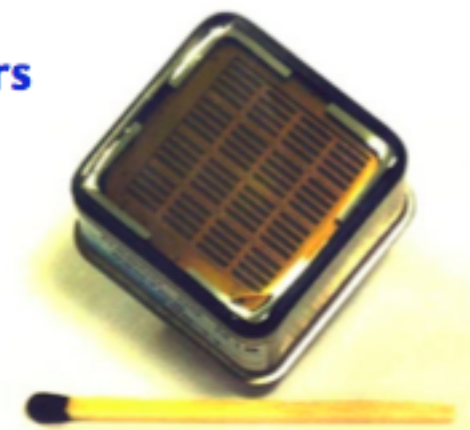
- Spherical ($r = 11.4$ m), tilted up/down, 80 hexagon based elements
- Planar mirrors move focal plane *above* and *below* flux of particles



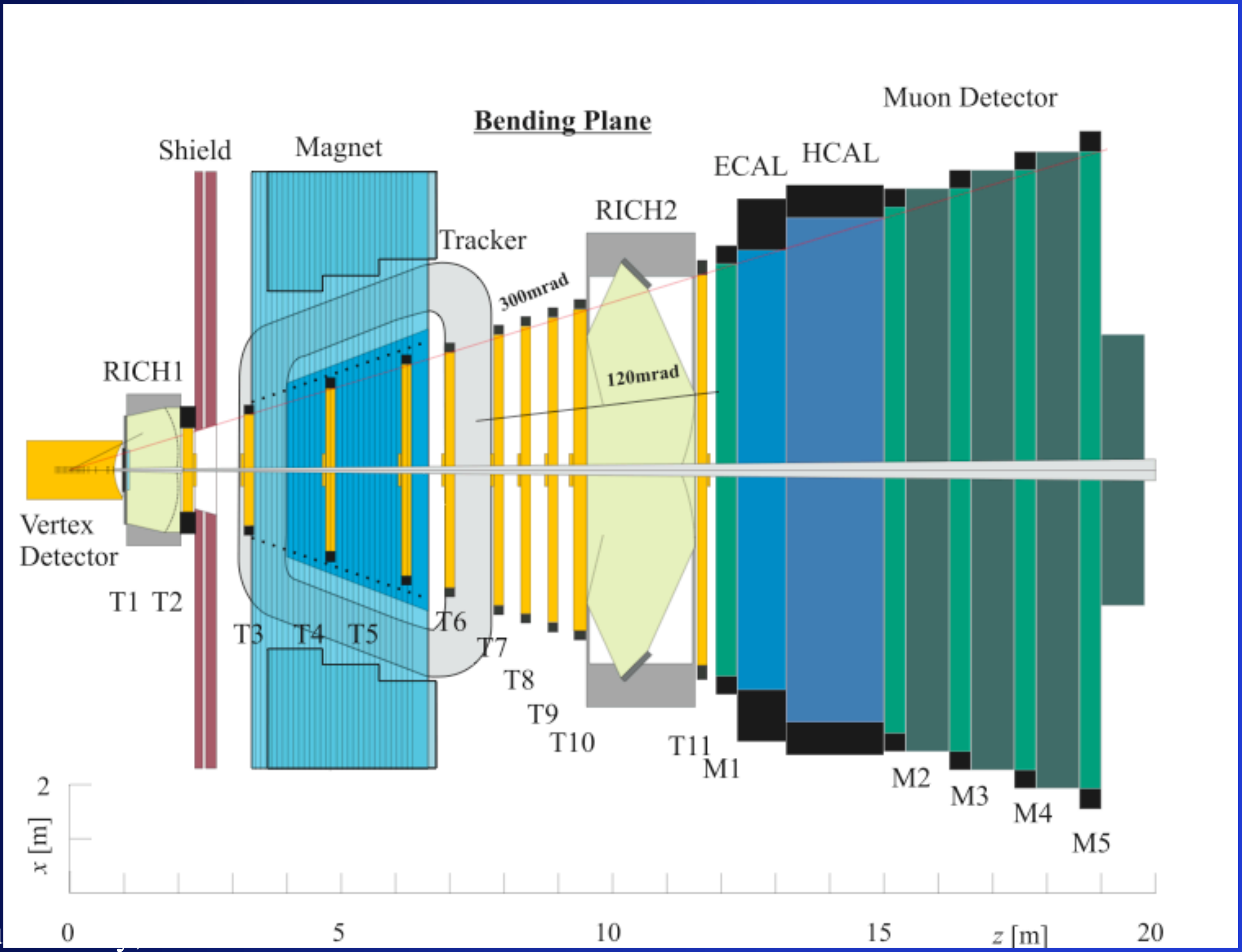
HERA-B RICH Photo Detector

❑ **Multi-Anode Photomultipliers**

- *Hamamatsu R5900* with 18×18 mm^2 photocathode
- *1500* with 16 anodes **M16**
  750 with 4 anodes **M4**



LHCb


Bending Plane
Muon Detector
Shield
Magnet
ECAL
HCAL
RICH2
Tracker
300mrad
120mrad
RICH1
Vertex
Detector
T1 T2
T3 T4 T5
T6
T7
T8
T9
T10
T11
M1
M2
M3
M4
M5
2
x [m]
0
5
10
15
z [m]
20

LHCb RICH-1

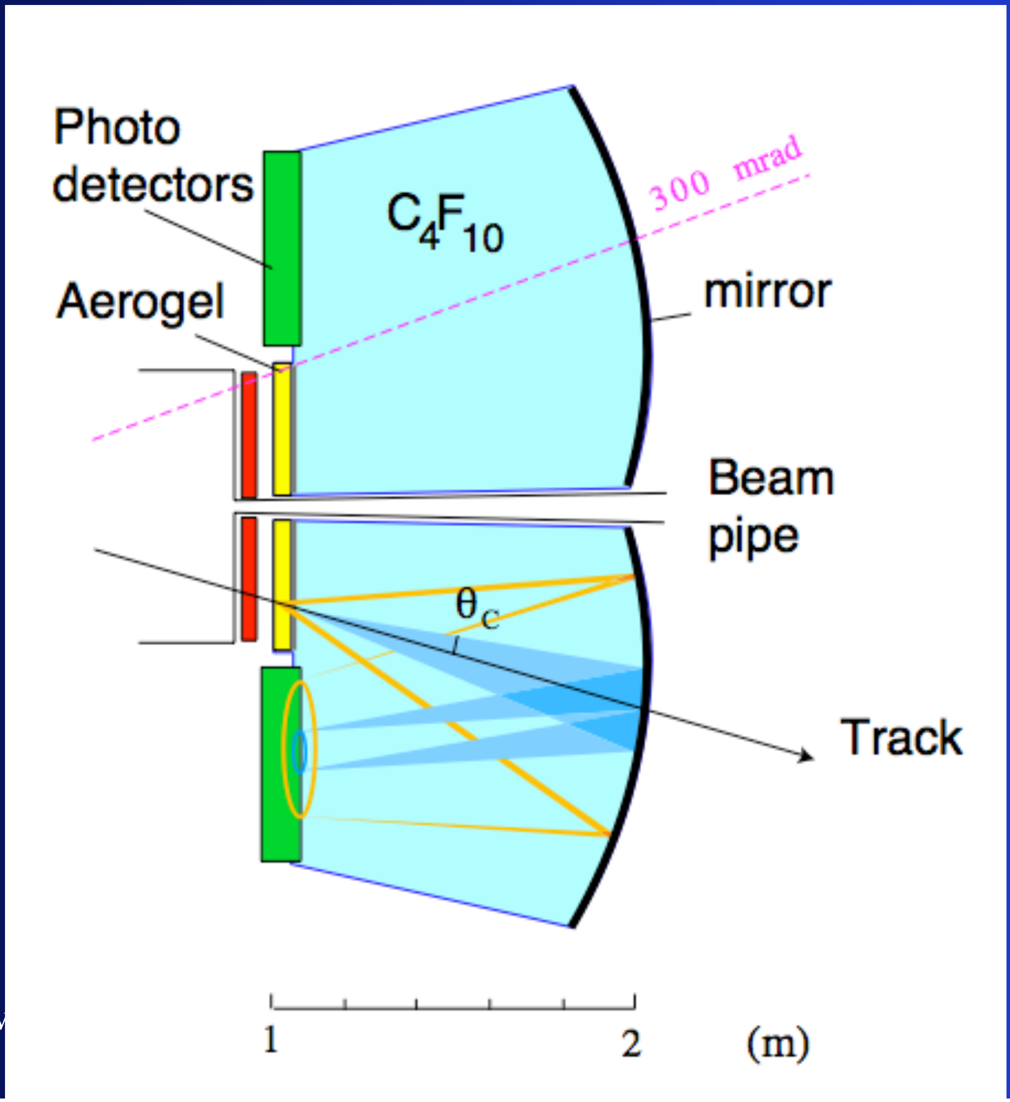
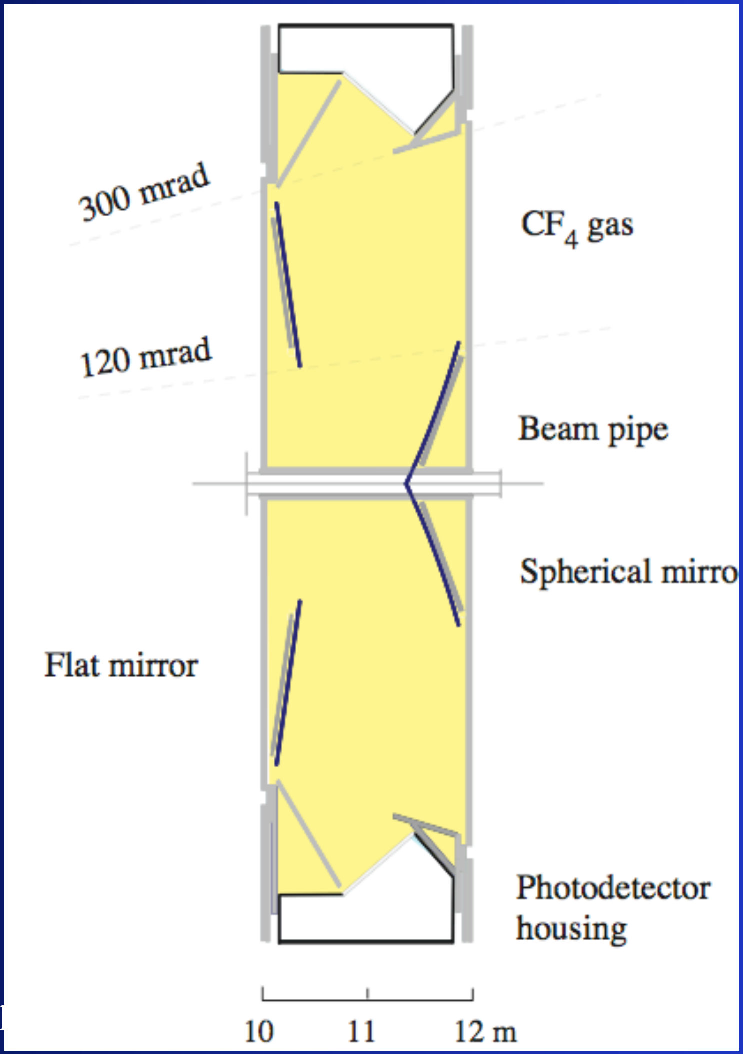
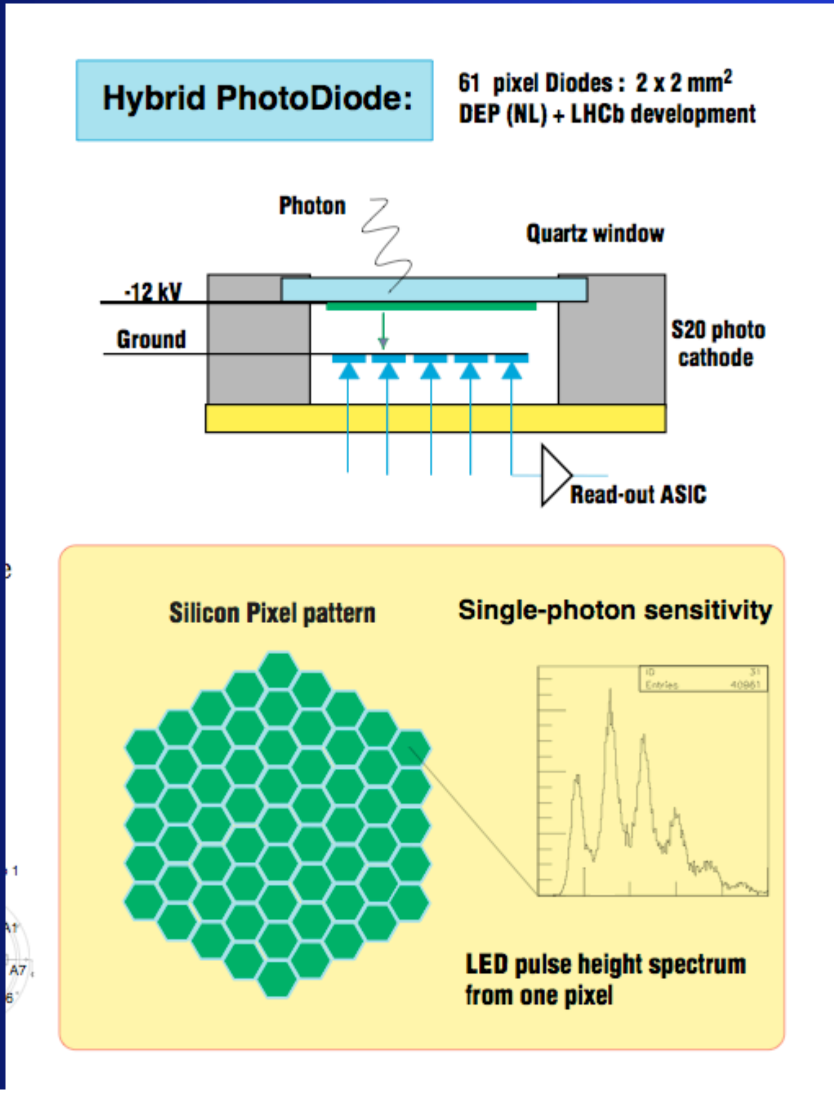


Photo detectors
C_4F_{10}
300 mrad
mirror
Aerogel
Beam pipe
θ_C
Track
1
2
(m)

LHCb RICH-2


300 mrad
120 mrad
CF_4 gas
Beam pipe
Spherical mirro
Flat mirror
Photodetector
housing
10
11
12 m

61-pixel Hybrid Photo-Diode
(HPD)



HPD

- HPD combines vacuum photo-cathode technology with solid state technology
- Photoelectron, released from a photo-cathode, is accelerating by an applied 20kV voltage onto silicon detector. Then it creates ~3000-5000 electron-hole pairs.
- The light pattern incident on the photo-cathode is imaged onto silicon matrix.
- No dead regions
- 30% QE at 200 nm
- Fast signal (rise-fall times of a few ns) and negligible jitter (<1 ns)

Hybrid Photo-Diode (HPD)

~ 3 m^2 area have to be equipped with photodetectors providing:

- Single Photon Sensitivity (200 - 600nm)
- 2.5 x 2.5 mm^2 granularity
- Fast readout (40 MHz)
- Active-area fraction > 70%

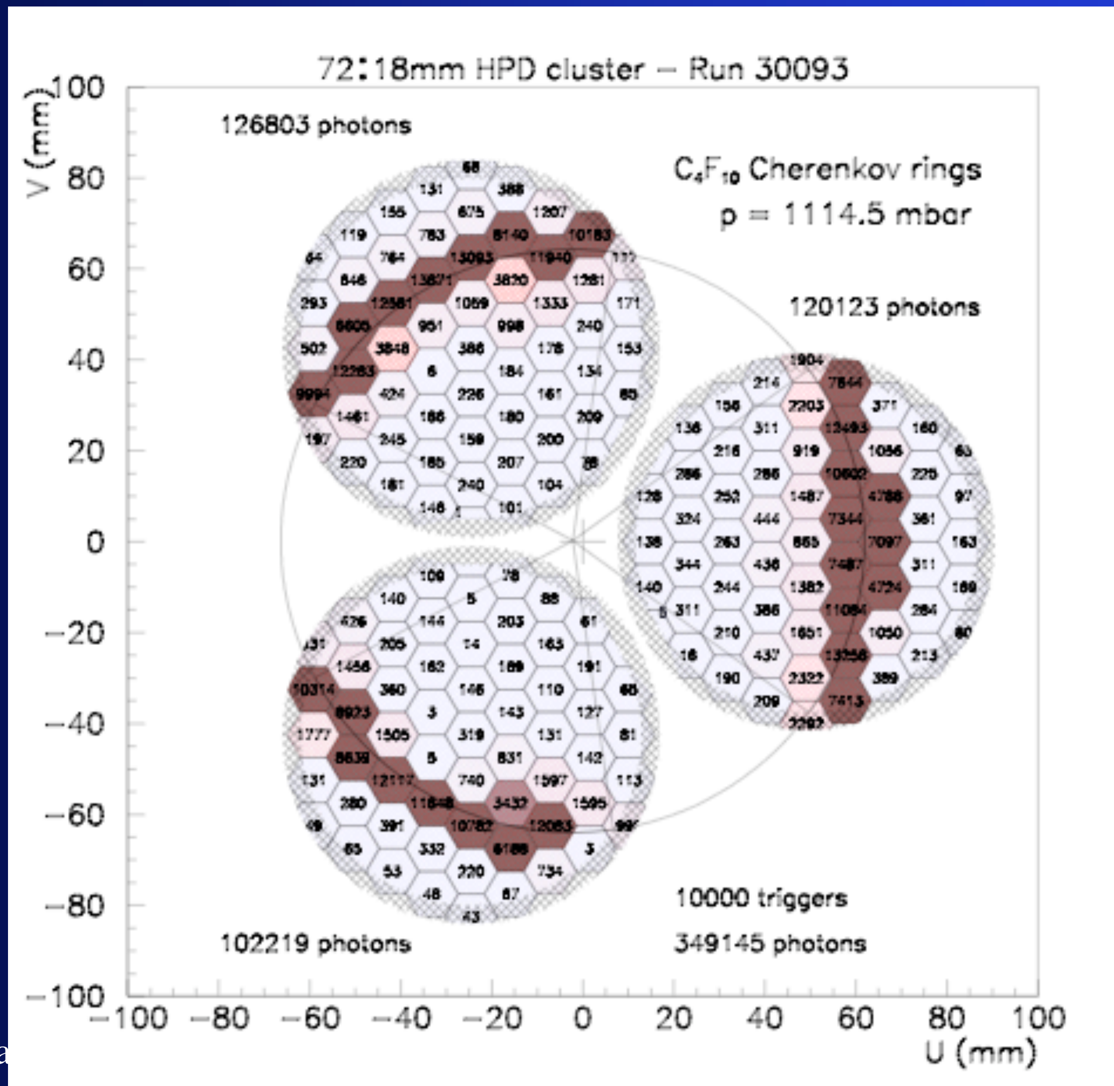
Hybrid Photo Diodes (HPD)

168 HPDs RICH1
262 HPDs RICH2

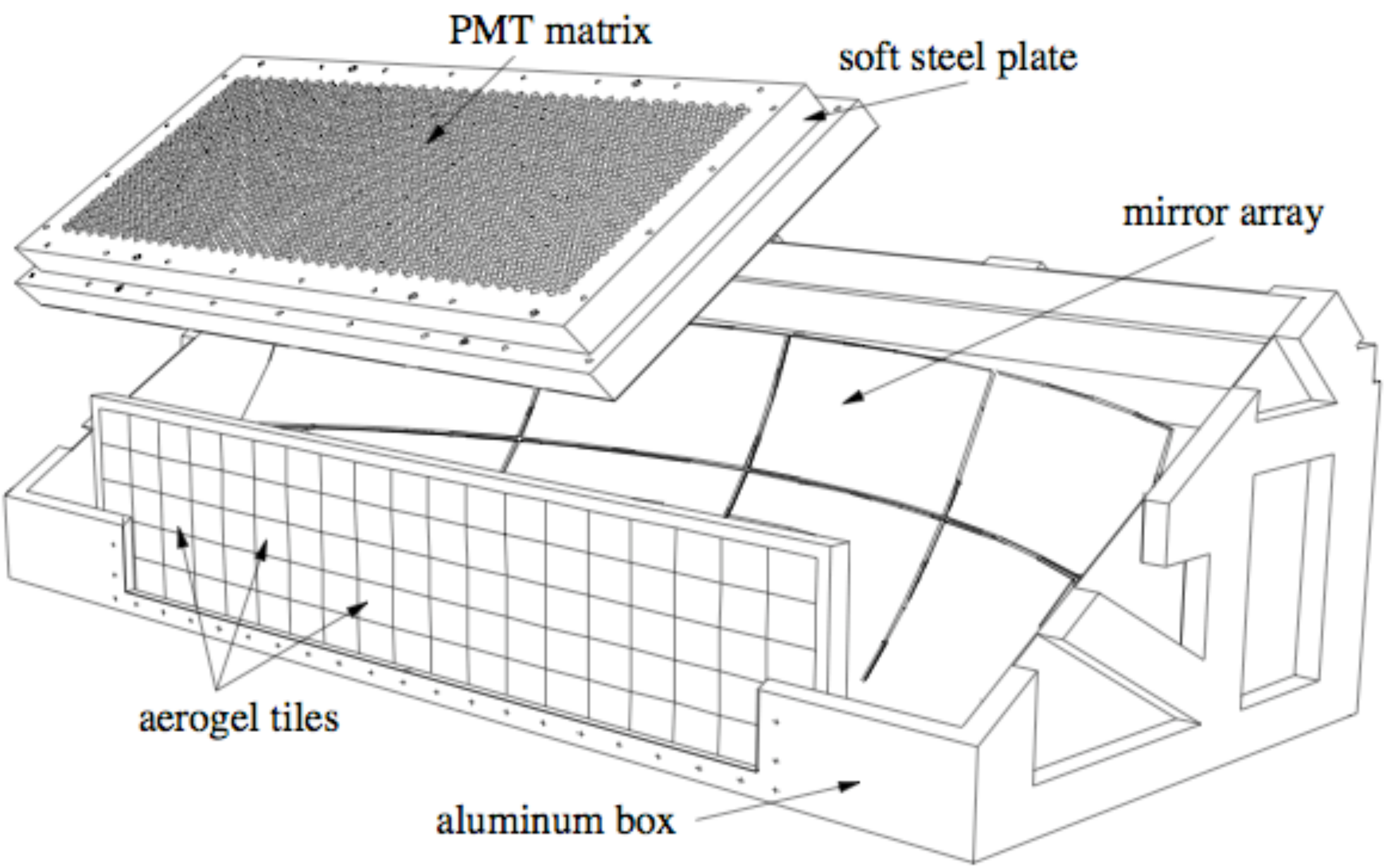
} 340 K channels

Display of Events

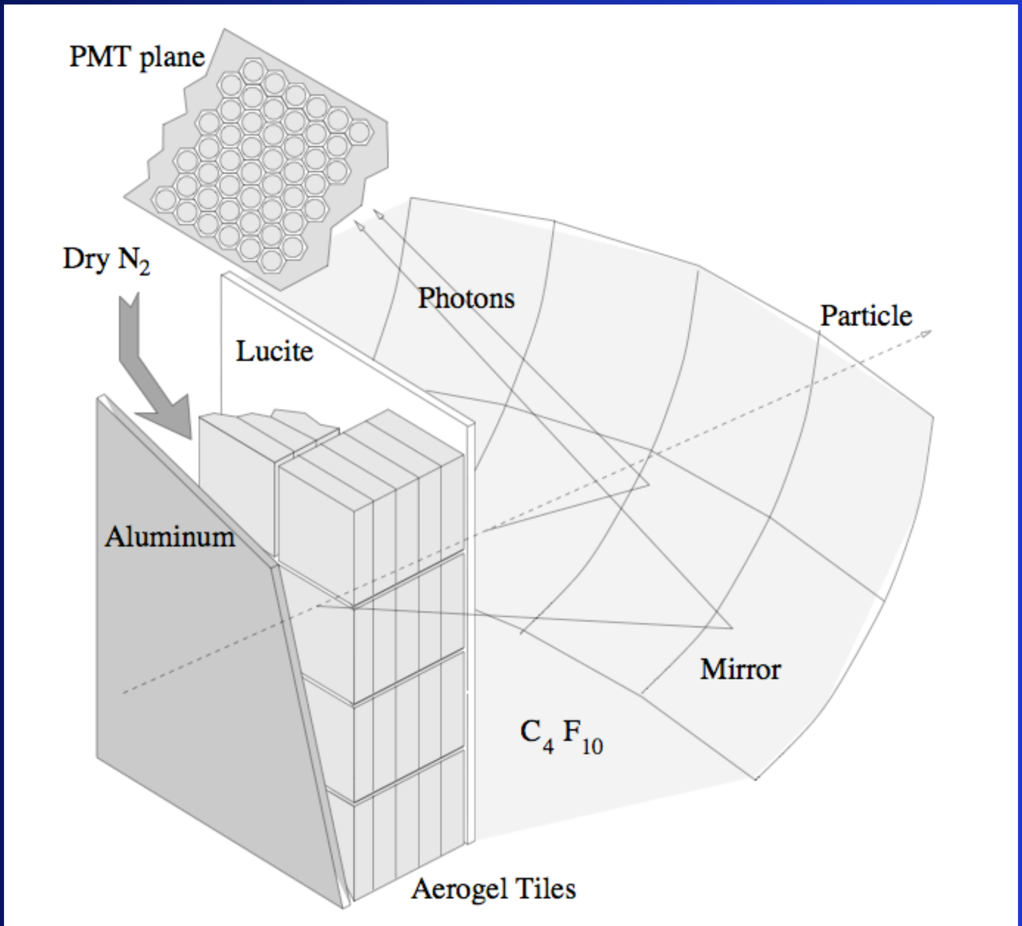
test run



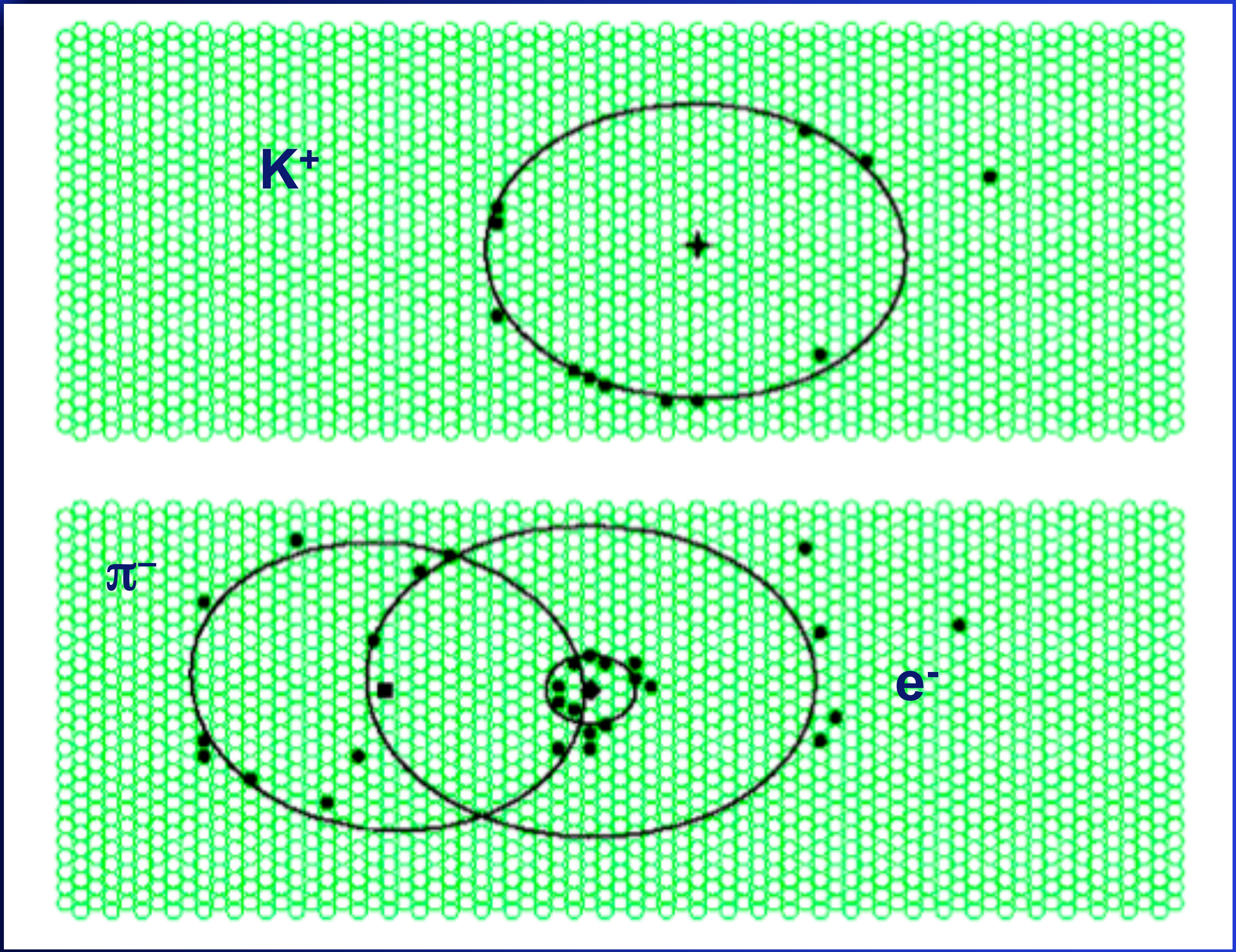
HERMES RICH


PMT matrix
soft steel plate
mirror array
aerogel tiles
aluminum box

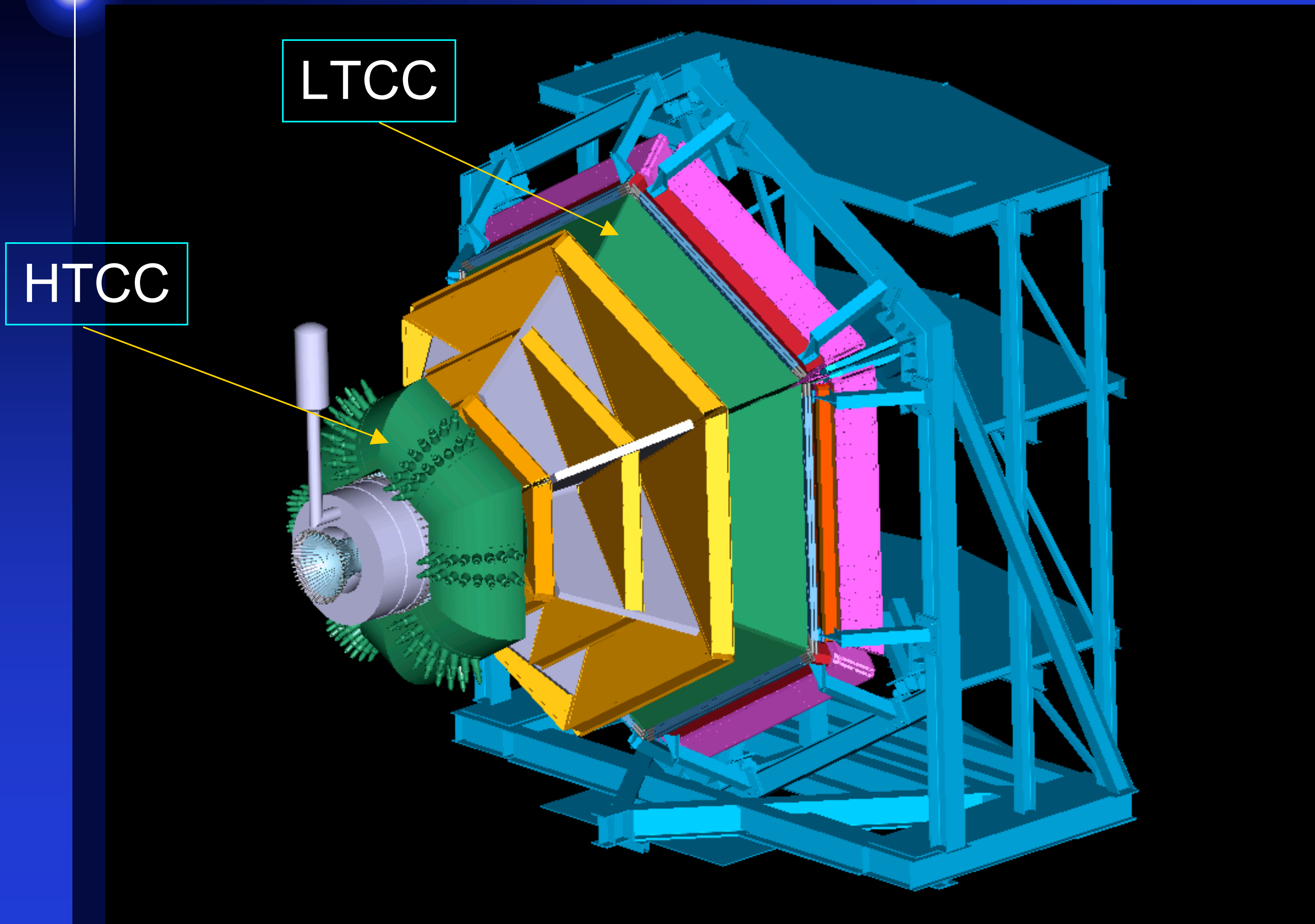
HERMES RICH


PMT plane
Dry N_2
Photons
Particle
Lucite
Aluminum
Mirror
$C_4 F_{10}$
Aerogel Tiles

HERMES Event Display



CLAS12



RICH radiator

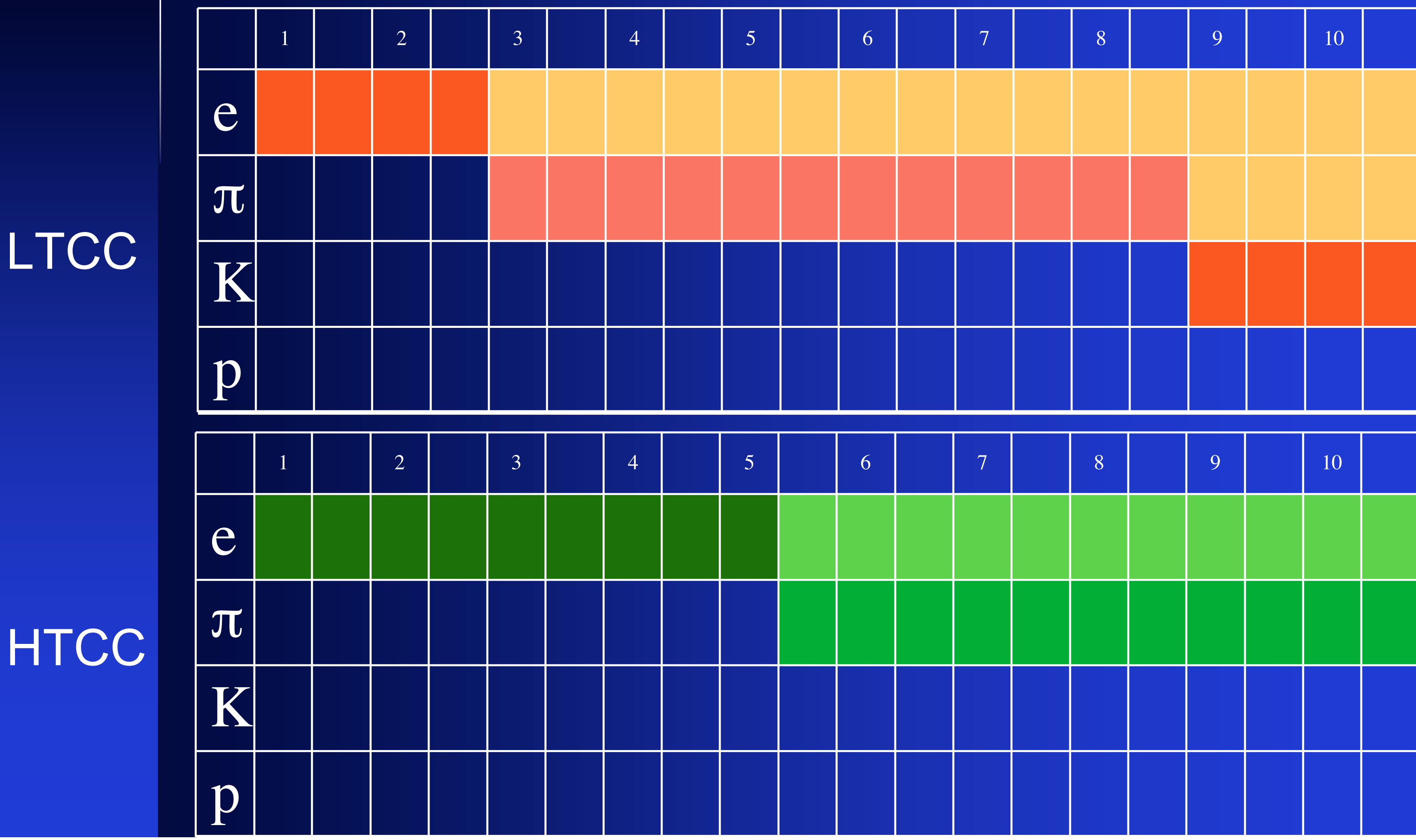
- Momentum range 2-10 GeV
- Difficult region to separate π/K/p since typical K threshold in gases > 9 GeV
- Possible solutions:
  - High pressure gas
  - Aerogel
  - Dual radiator aerogel+gas
- Dual radiator was first proposed for the LHCb experiment and was realized in the HERMES experiment

CLAS12 Threshold Cherenkov Counters

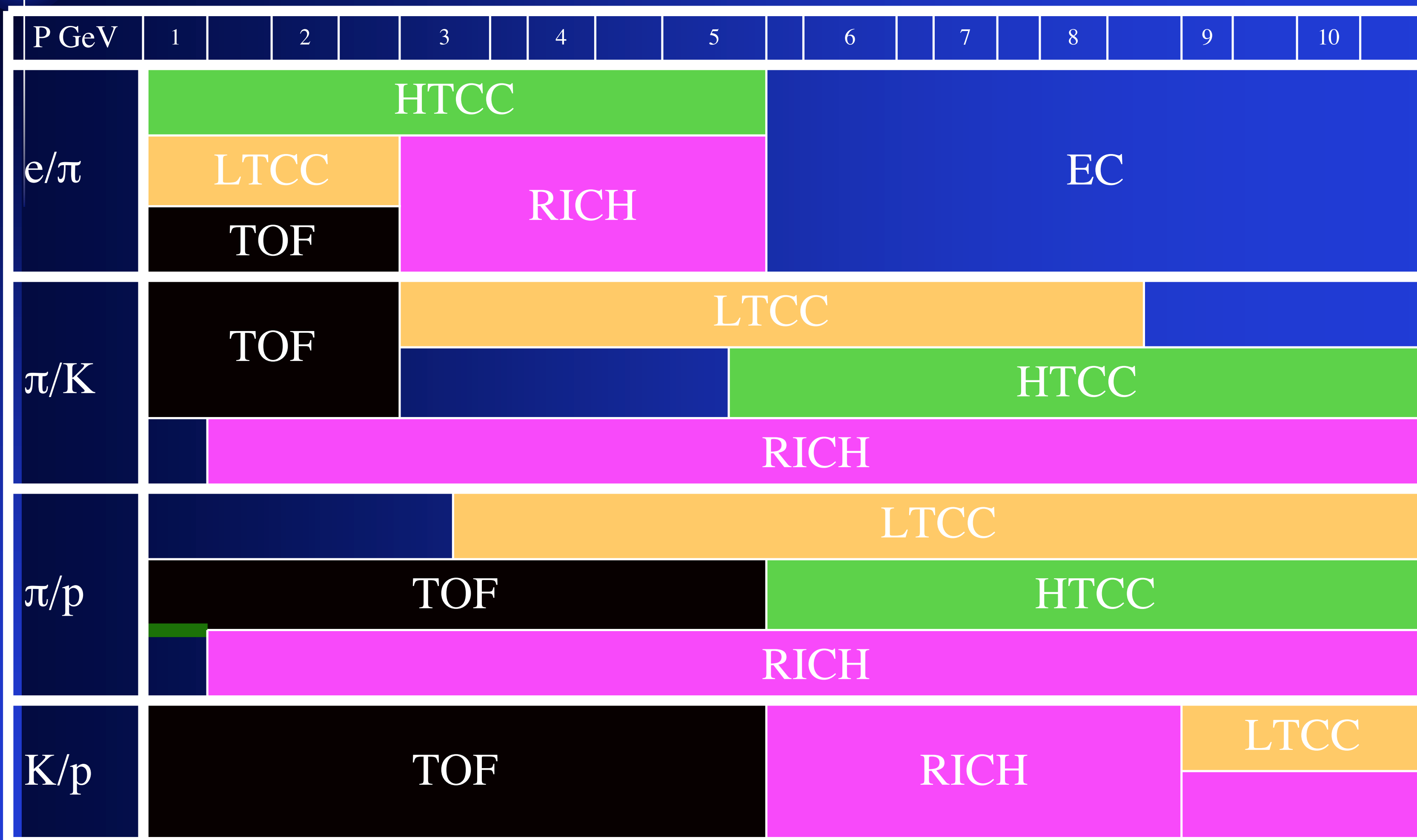
Momentum thresholds

		π	K	p
LTCC	C_4F_{10}	2.7 GeV	9.4 GeV	18 GeV
HTCC	CO_2	4.9 GeV	17 GeV	33 GeV
Aerogel	n=1.030	0.6 GeV	2.80GeV	3.8 GeV

Threshold Cherenkov Counters



CLAS12 e/π/p Separation



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Cherenkov's Formulas

- Cherenkov light emission angle

n- refractive index
β=v/c

$$Cos\theta_C = \frac{1}{n\beta}$$

- The number of photons N emitted per energy wavelength dλ and path length dl

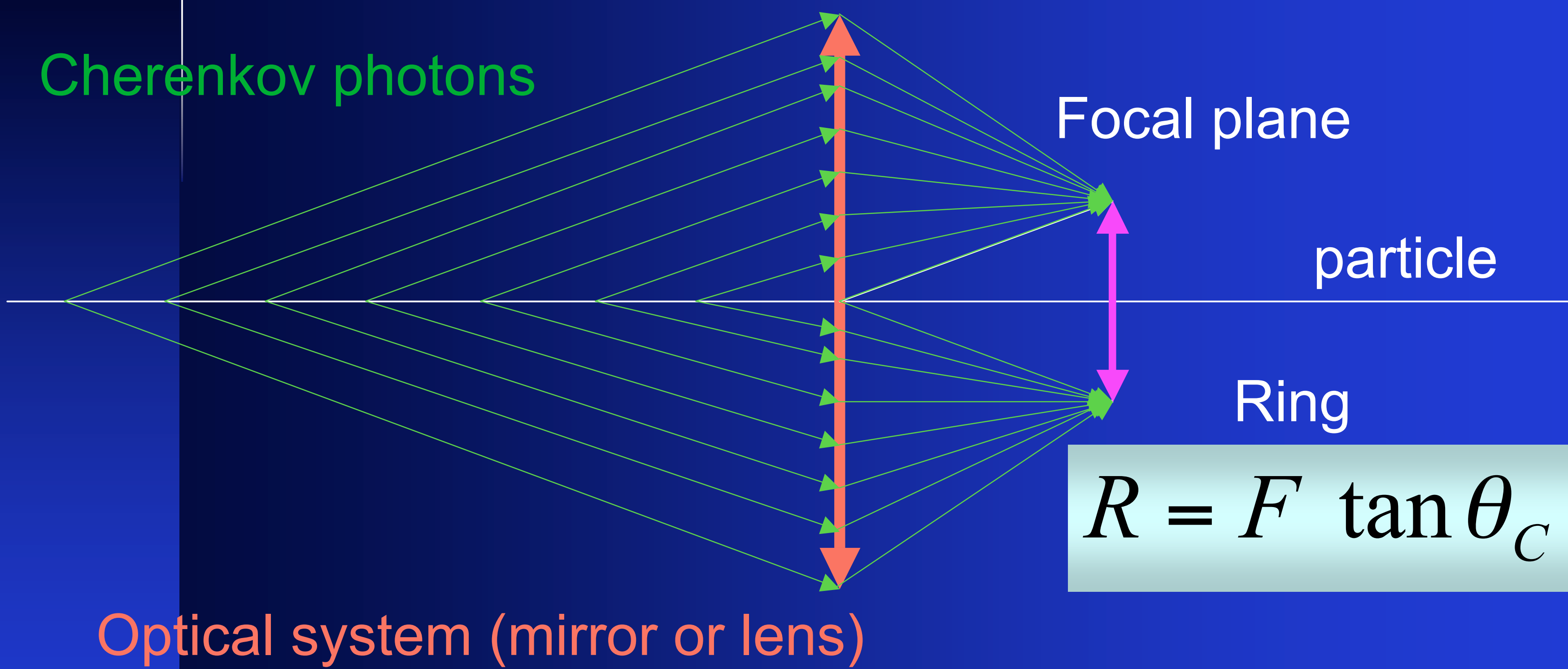
$$\frac{d^2N}{d\lambda dl} = \frac{2\pi\alpha}{\lambda^2} Sin^2\theta_C$$

- Number of photoelectrons

$$N_{Phe} = N_0 L\ Sin^2\theta_C$$

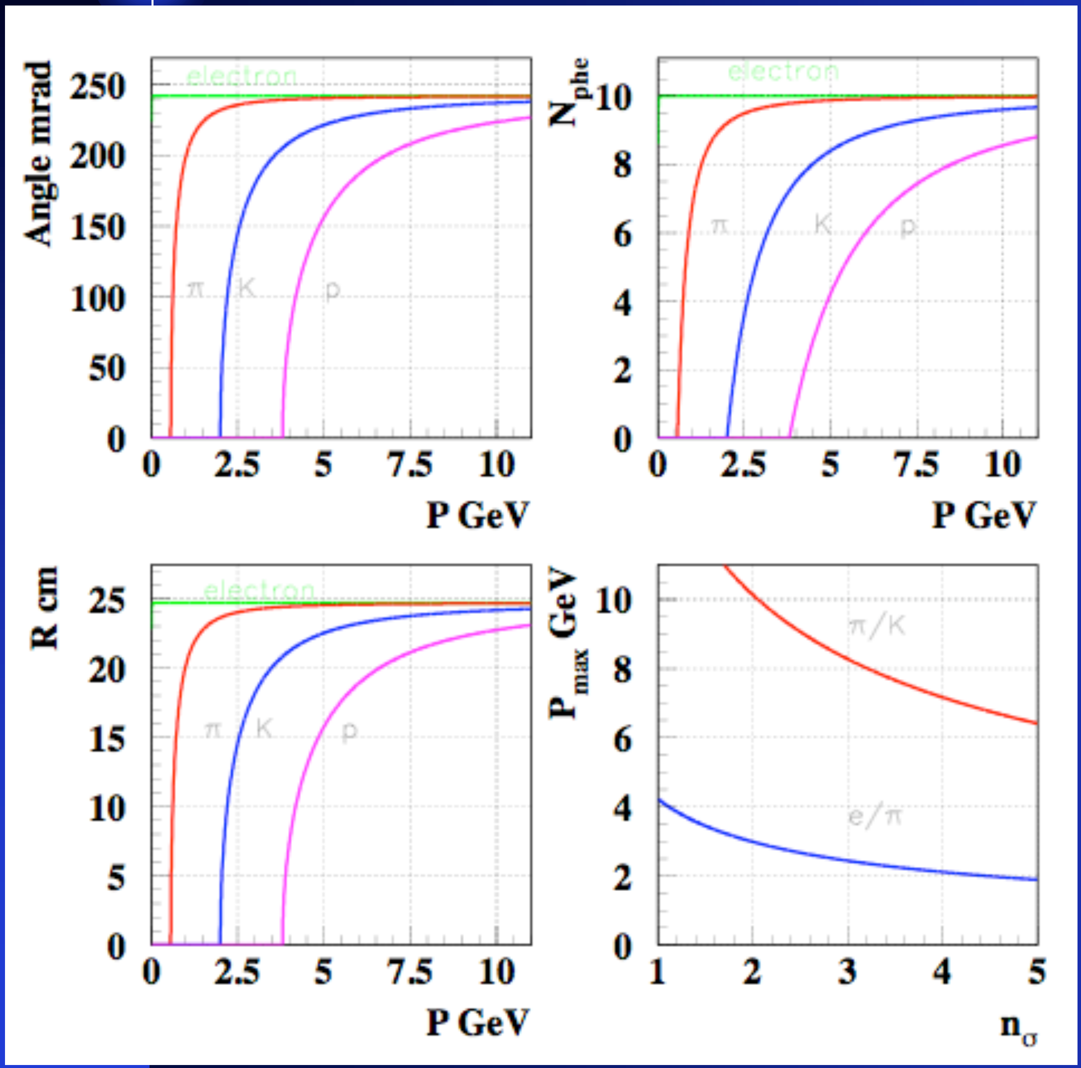
N_0 is the figure of merit and for GOOD detectors is around 100. So for gas Cherenkov detectors the number of photoelectrons usually is around 10-20

Radius of Cherenkov Ring



$$R = F \tan\theta_C$$

Aerogel n=1.030



$$Cos\theta_C = \frac{1}{n\beta}$$

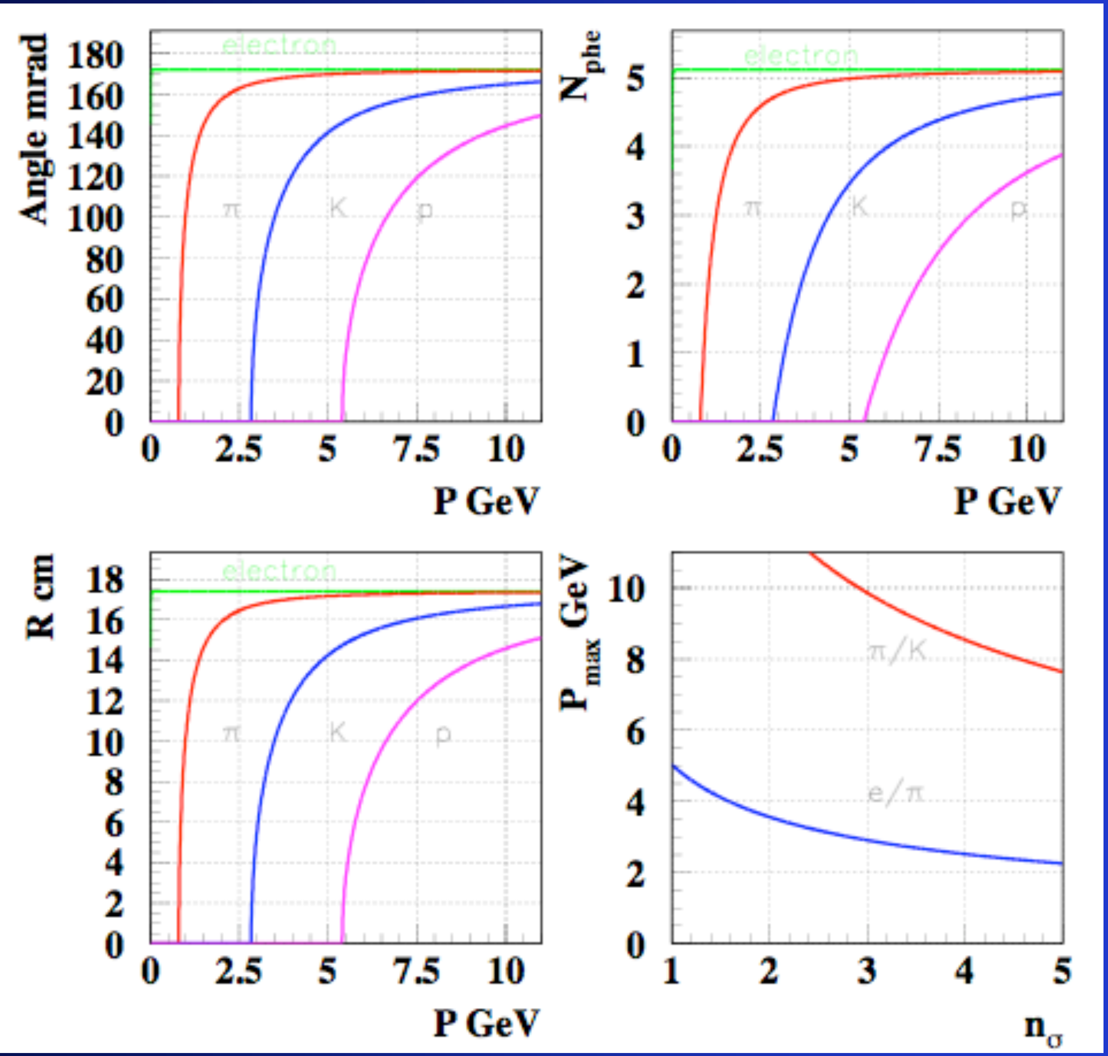
$$R = F \ \tan\theta_C$$

$$N_{Phe} = N_0 L \ Sin^2\theta_C$$

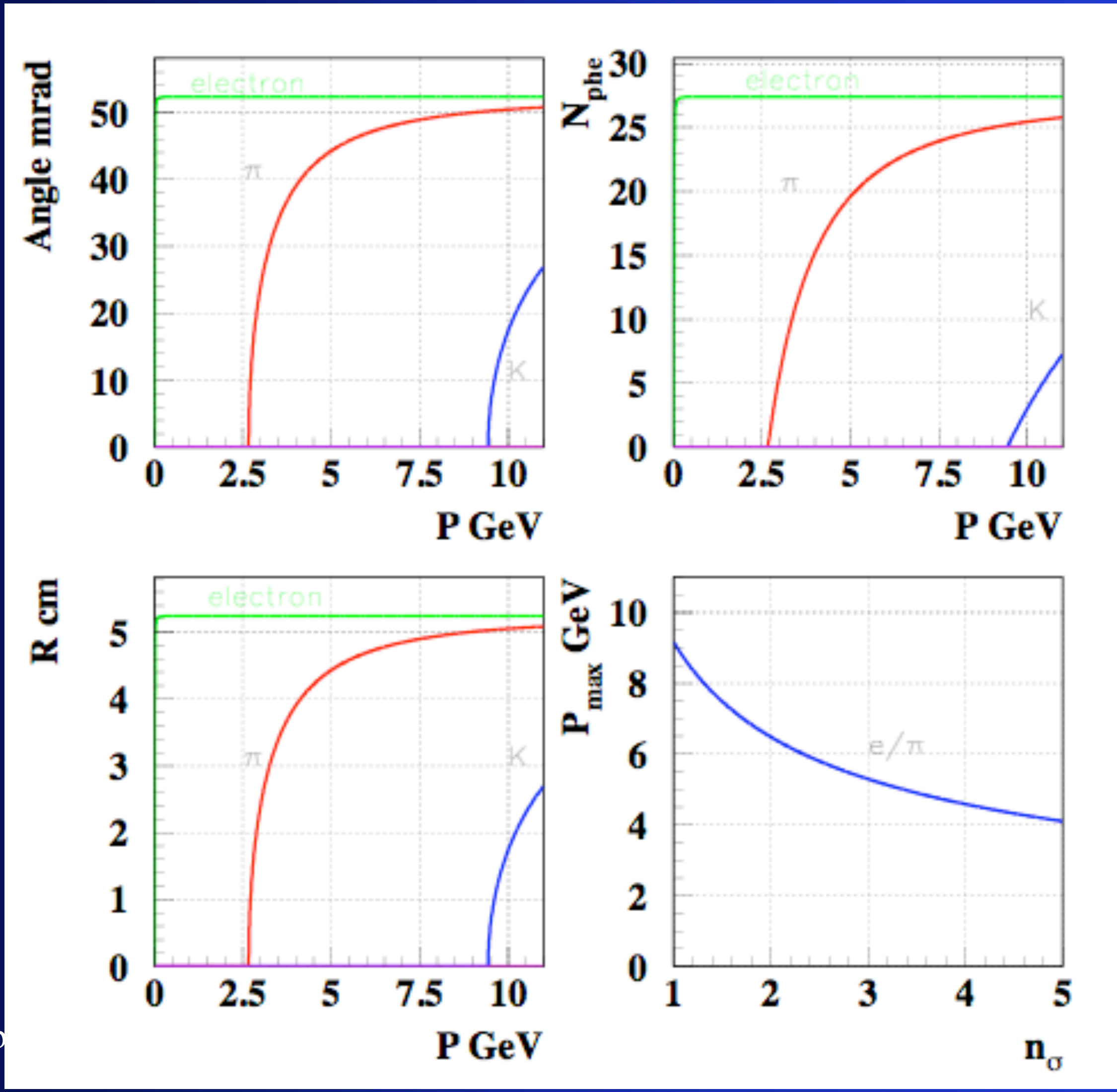
$$p_{\max} = \sqrt{\frac{m_1^2 - m_2^2}{2k_f n_\sigma}}$$

$$k_f = \frac{\tan\theta_{Cher}\sigma_\theta}{\sqrt{N_{phe}}}$$

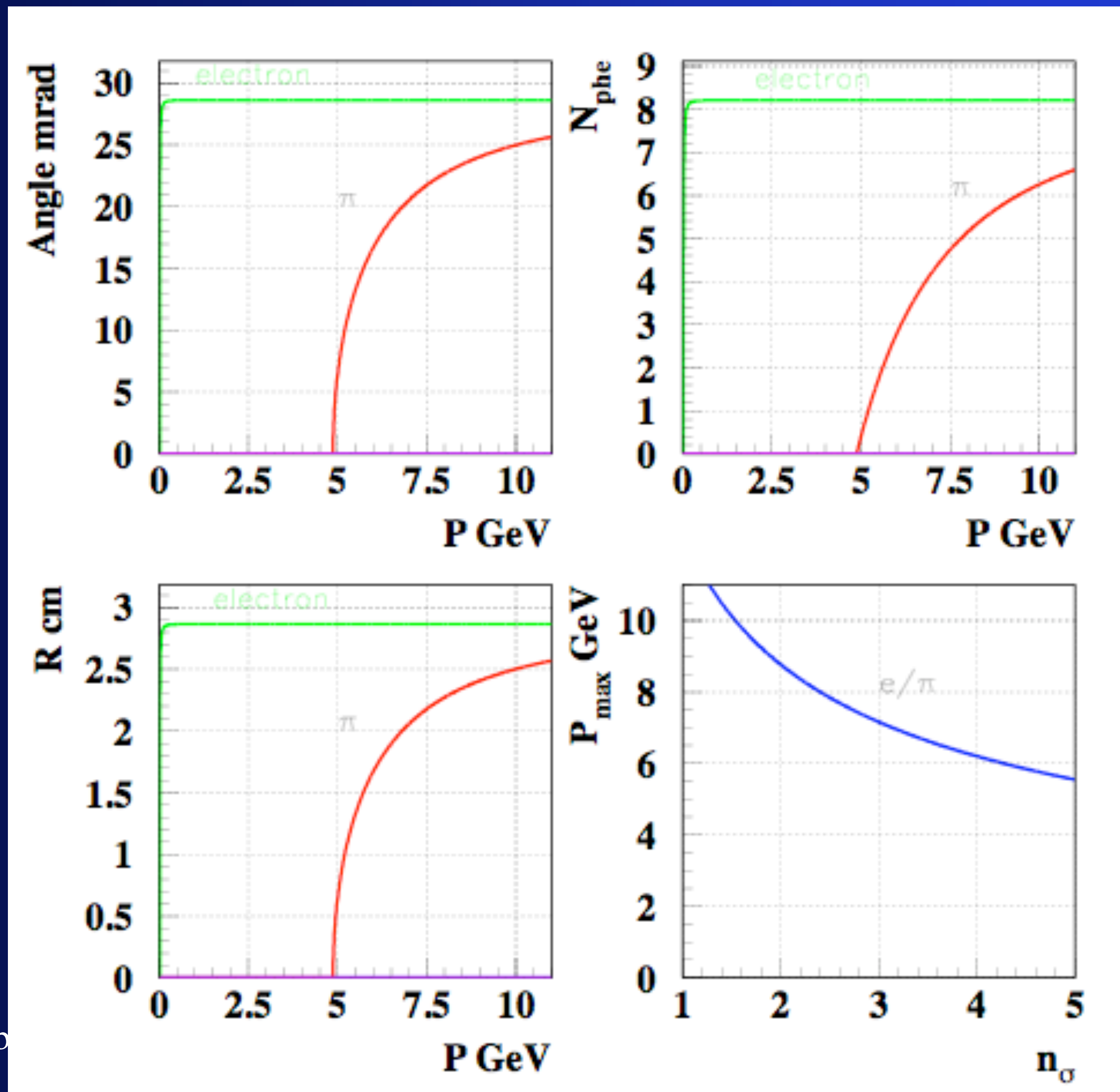
Aerogel n=1.015



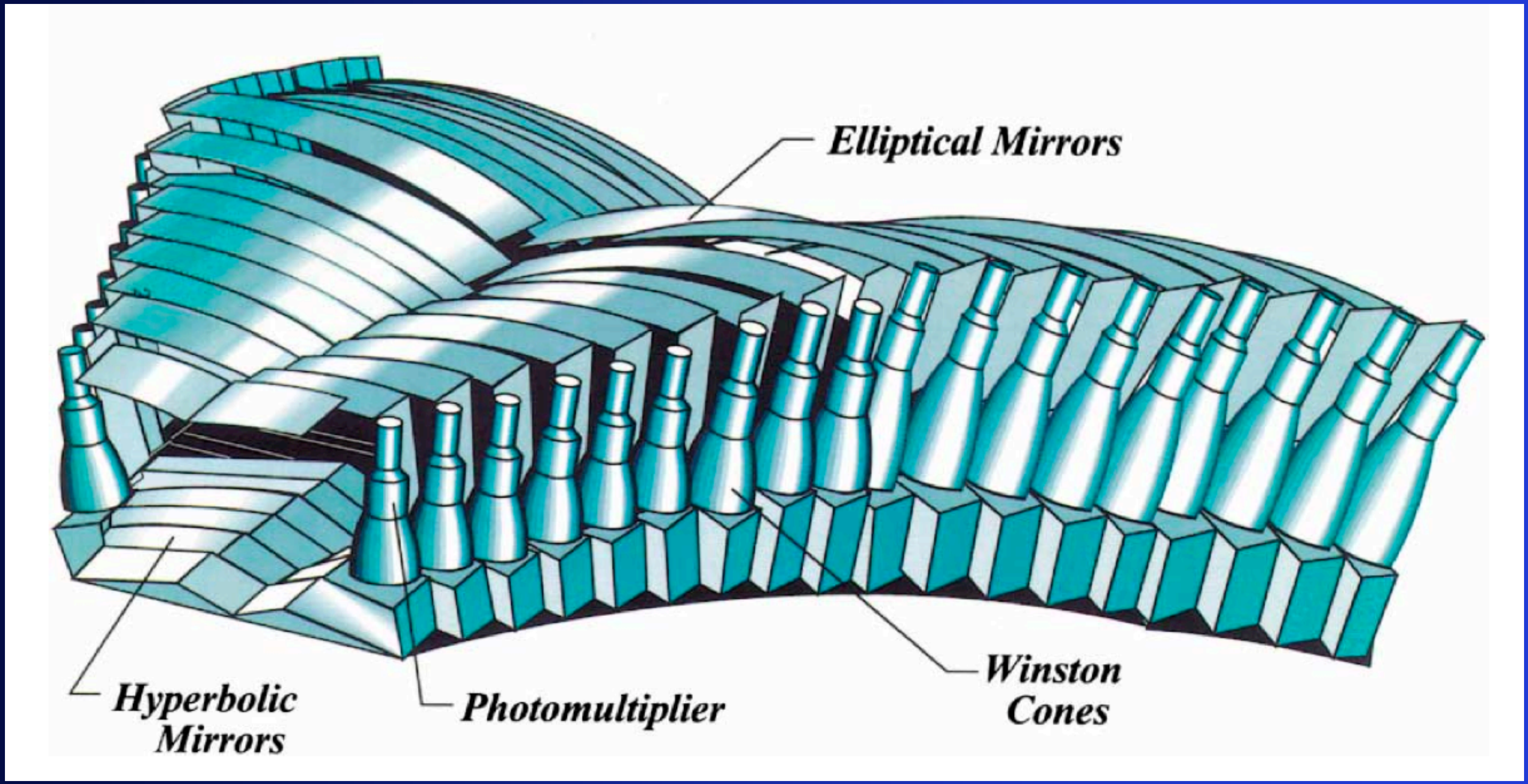
C4F10 radiator



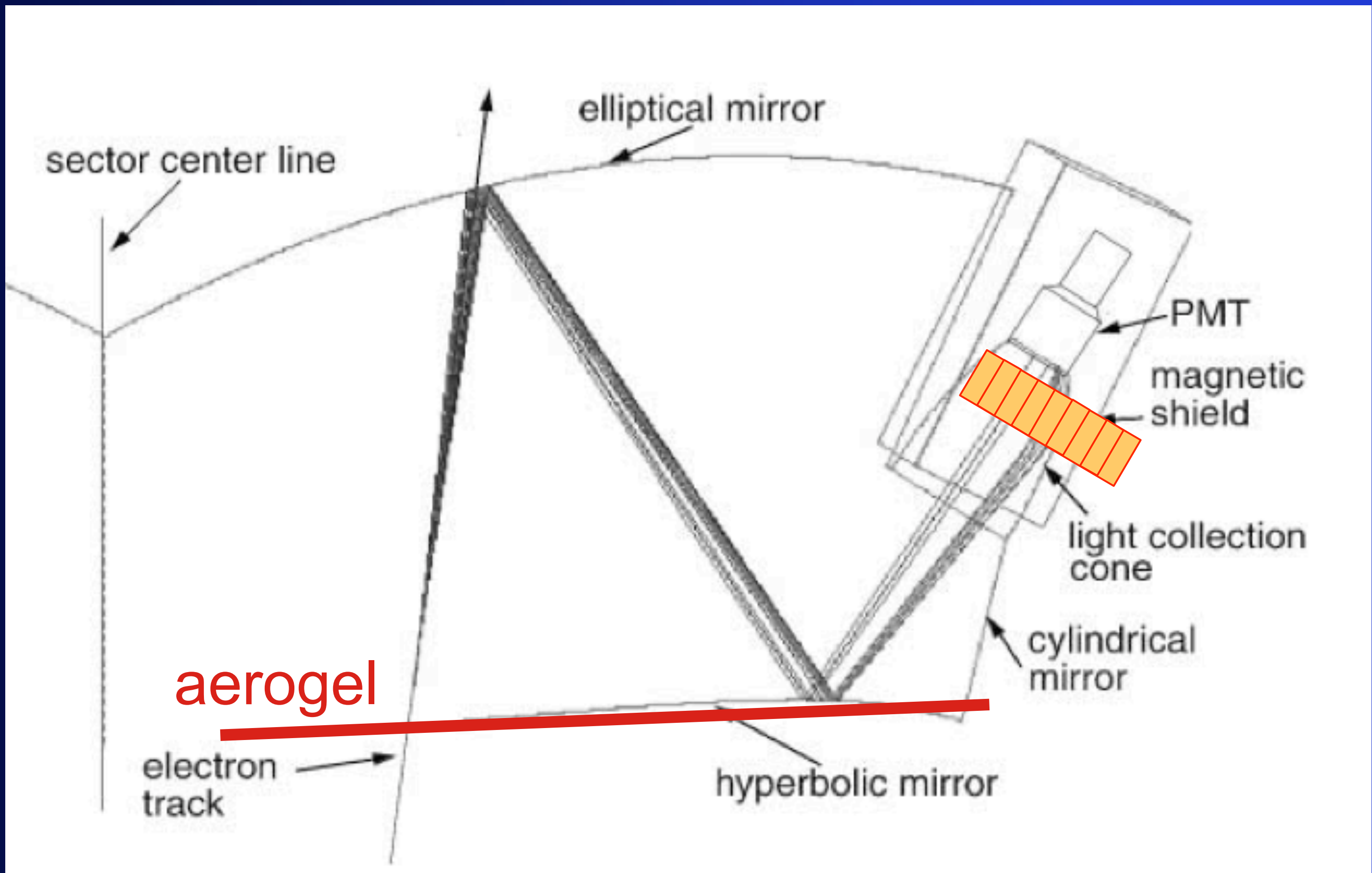
CO_2 radiator



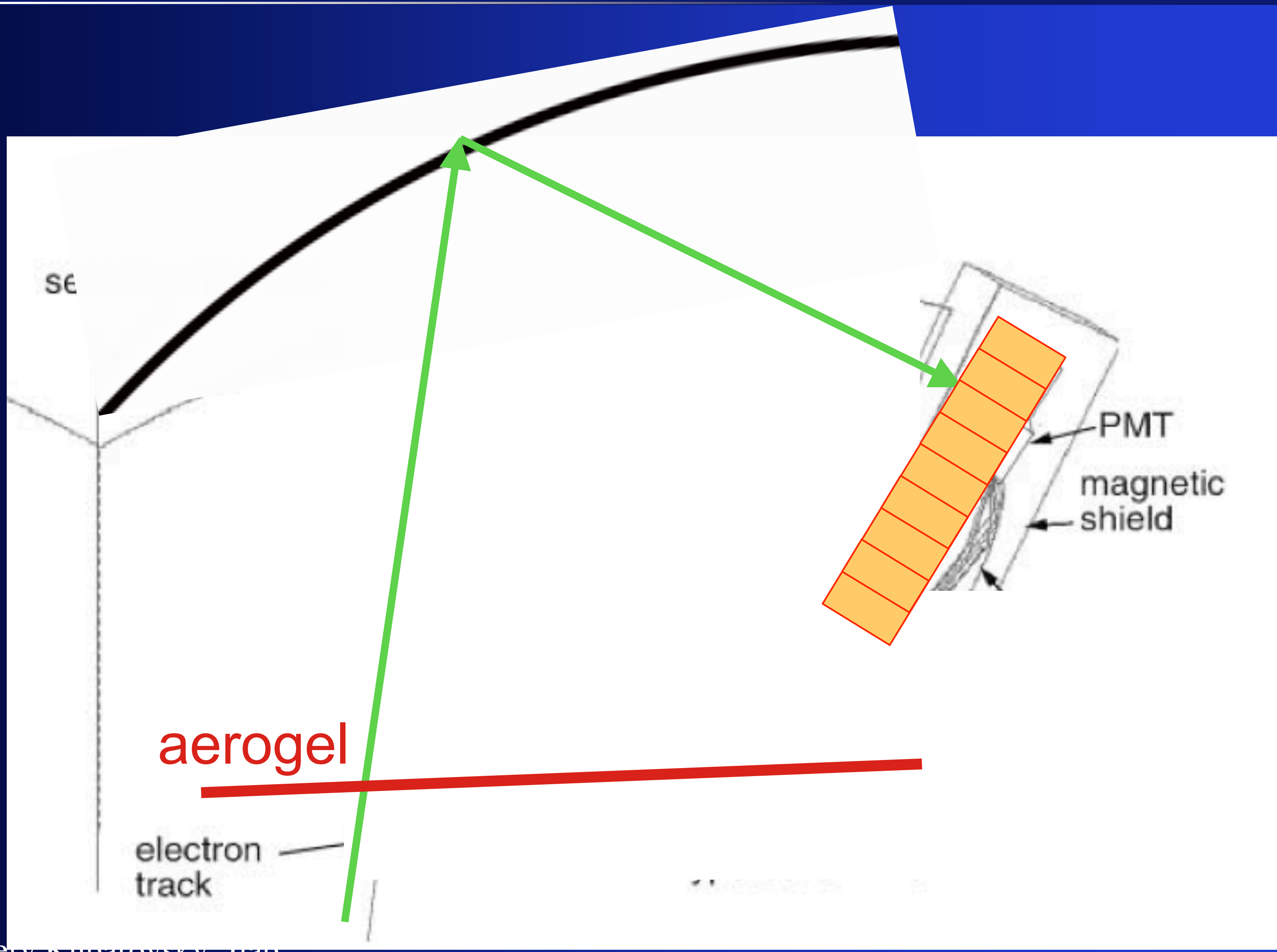
LTCC Optical Mirror System



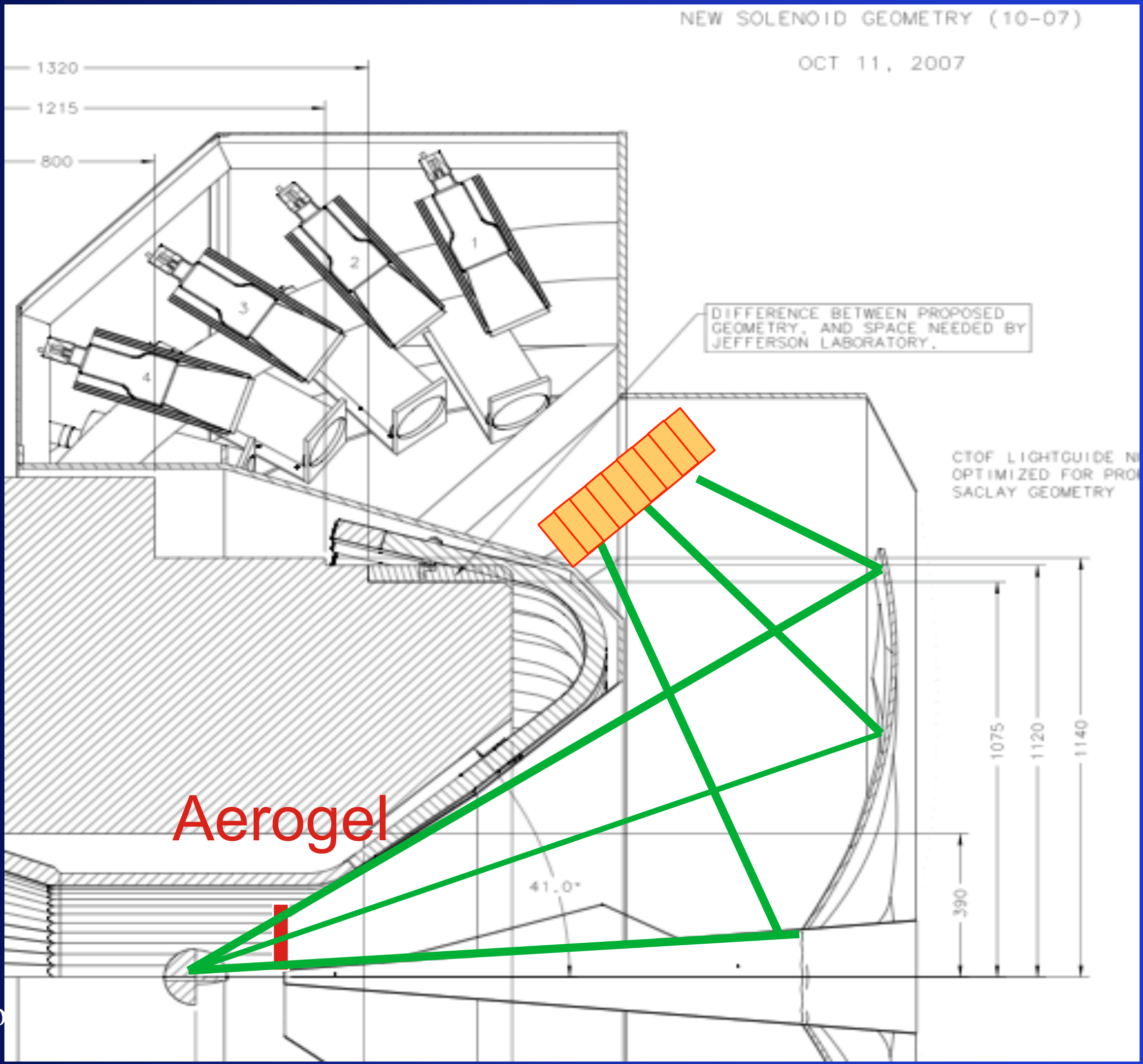
CLAS Optical Scheme



CLAS Optical Scheme

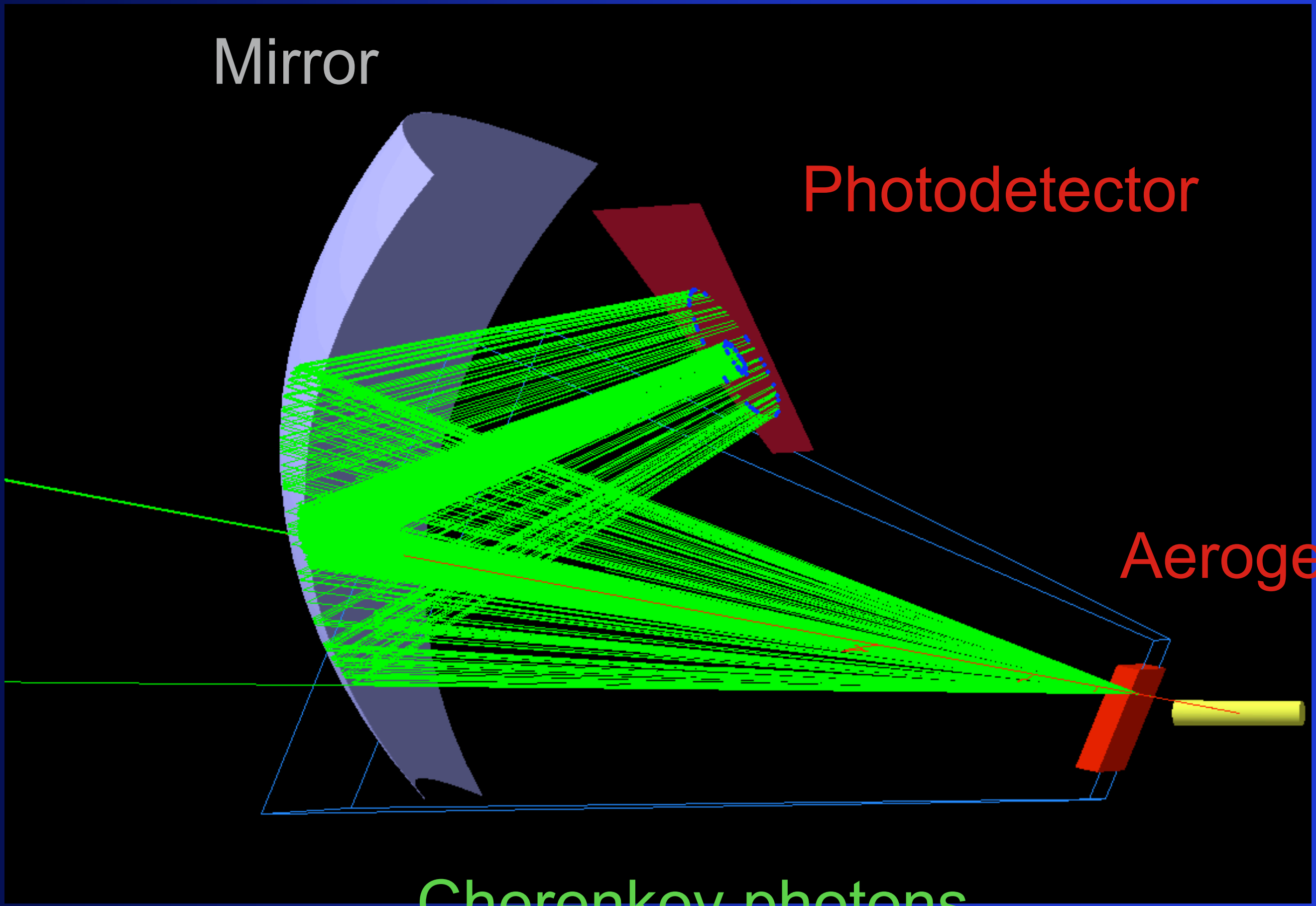


CLAS12 HTCC


NEW SOLENOID GEOMETRY (10-07)
OCT 11, 2007
1320
1215
800
DIFFERENCE BETWEEN PROPOSED GEOMETRY, AND SPACE NEEDED BY JEFFERSON LABORATORY.
CTOF LIGHTGUIDE N
OPTIMIZED FOR PRO
SACLAY GEOMETRY
Aerogel
41.0°
1075
1120
1140
390

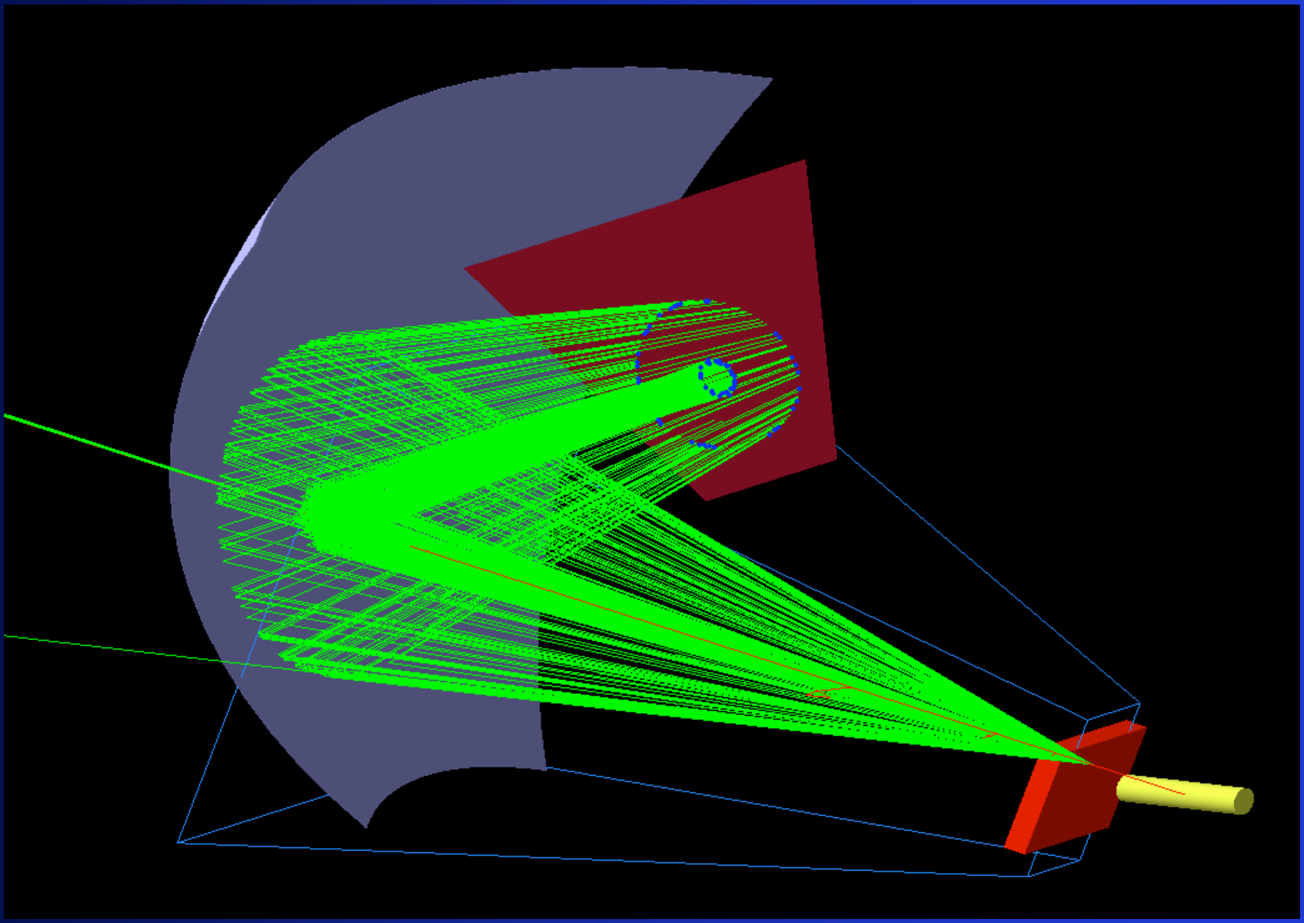
GEANT4 MC Simulation

Mauri Ungaro



Cherenkov photons

One more…



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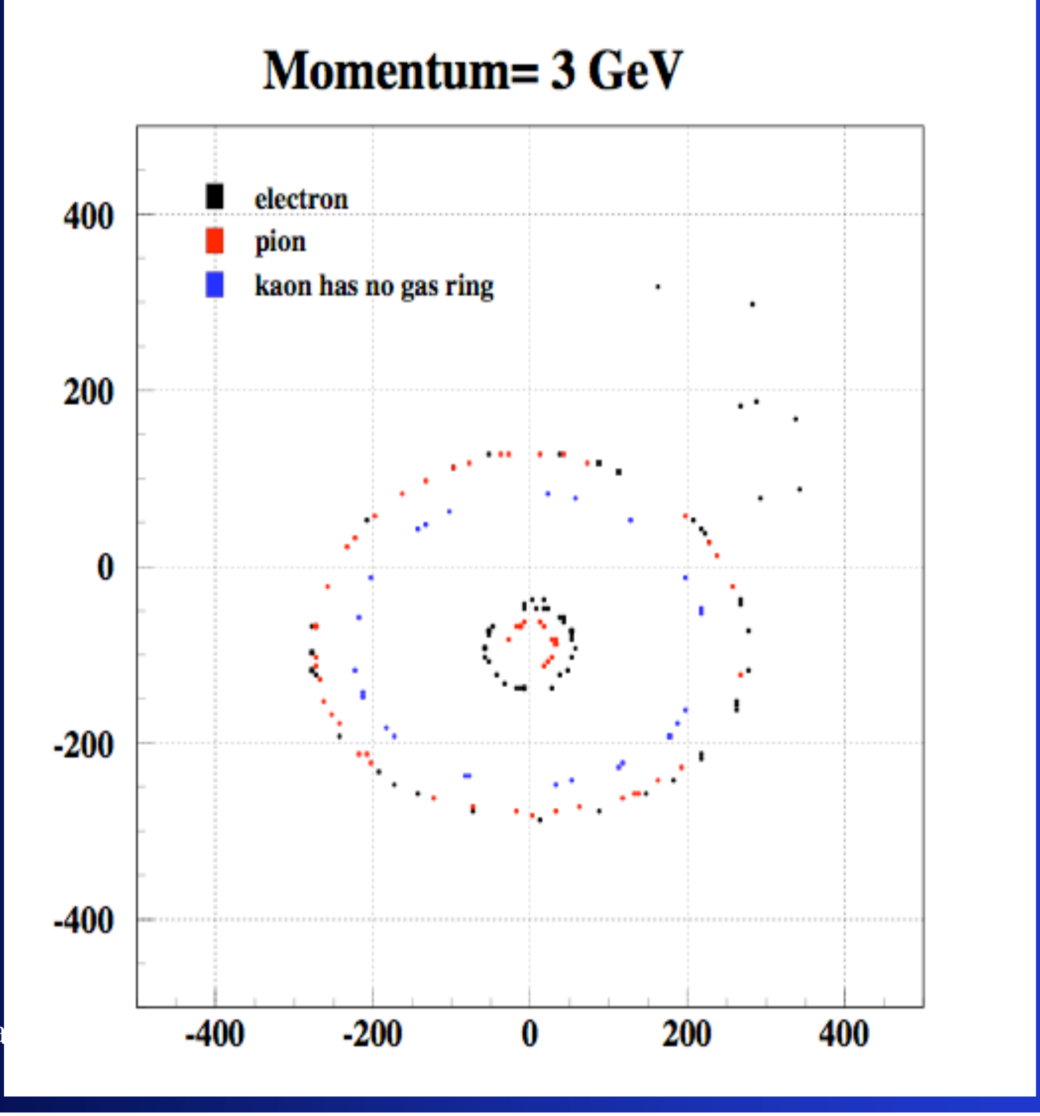
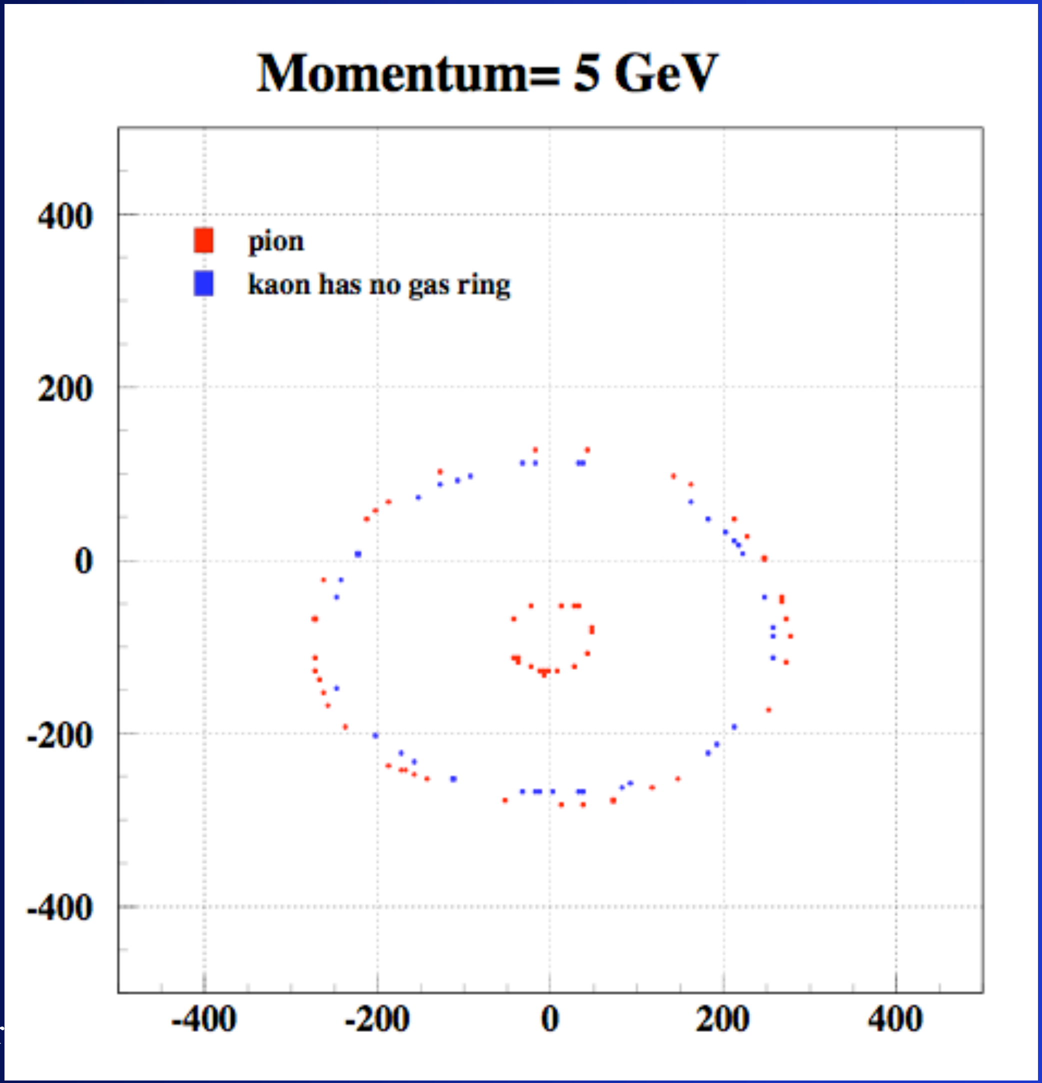
e/π Separation



π/K Separation



K/p Separation

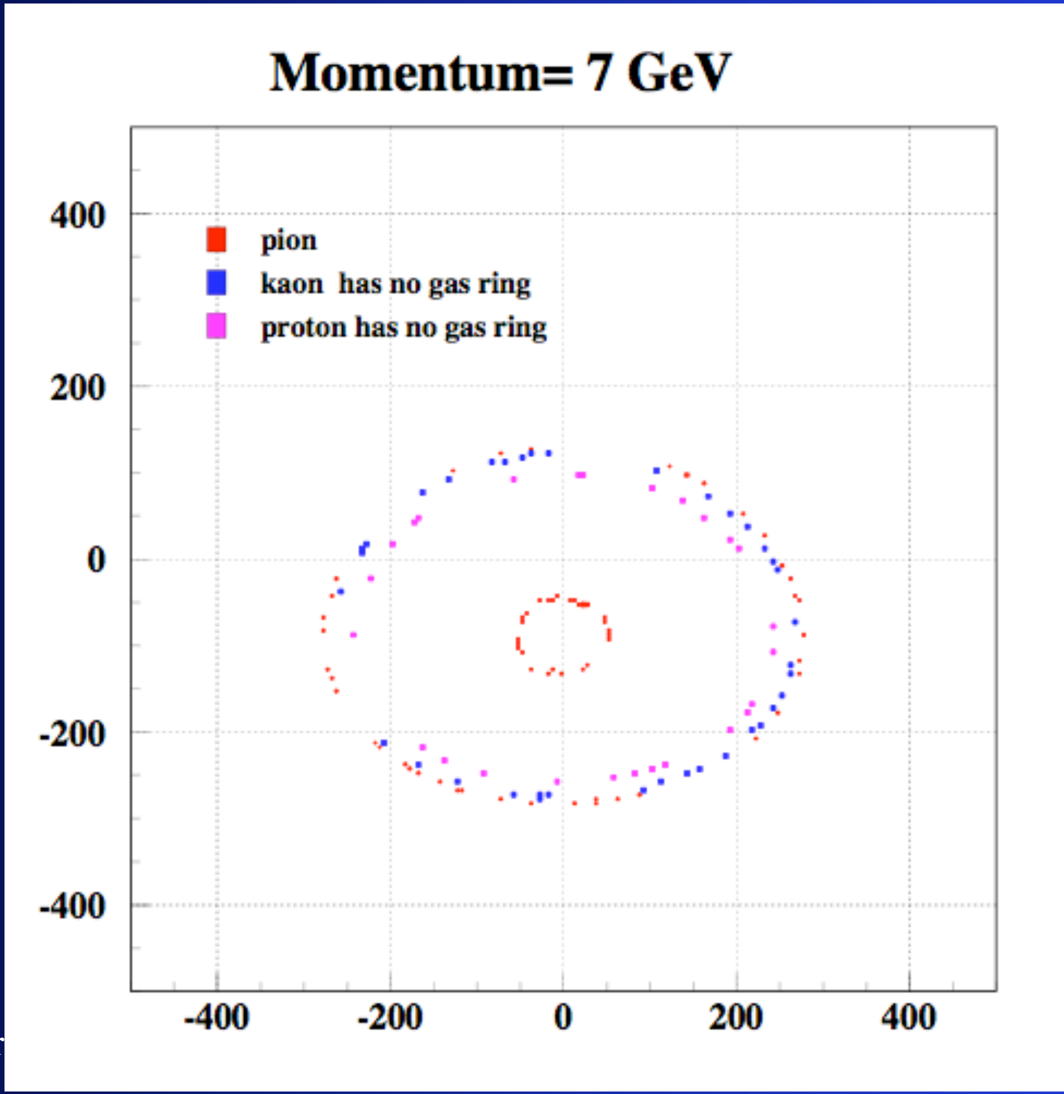
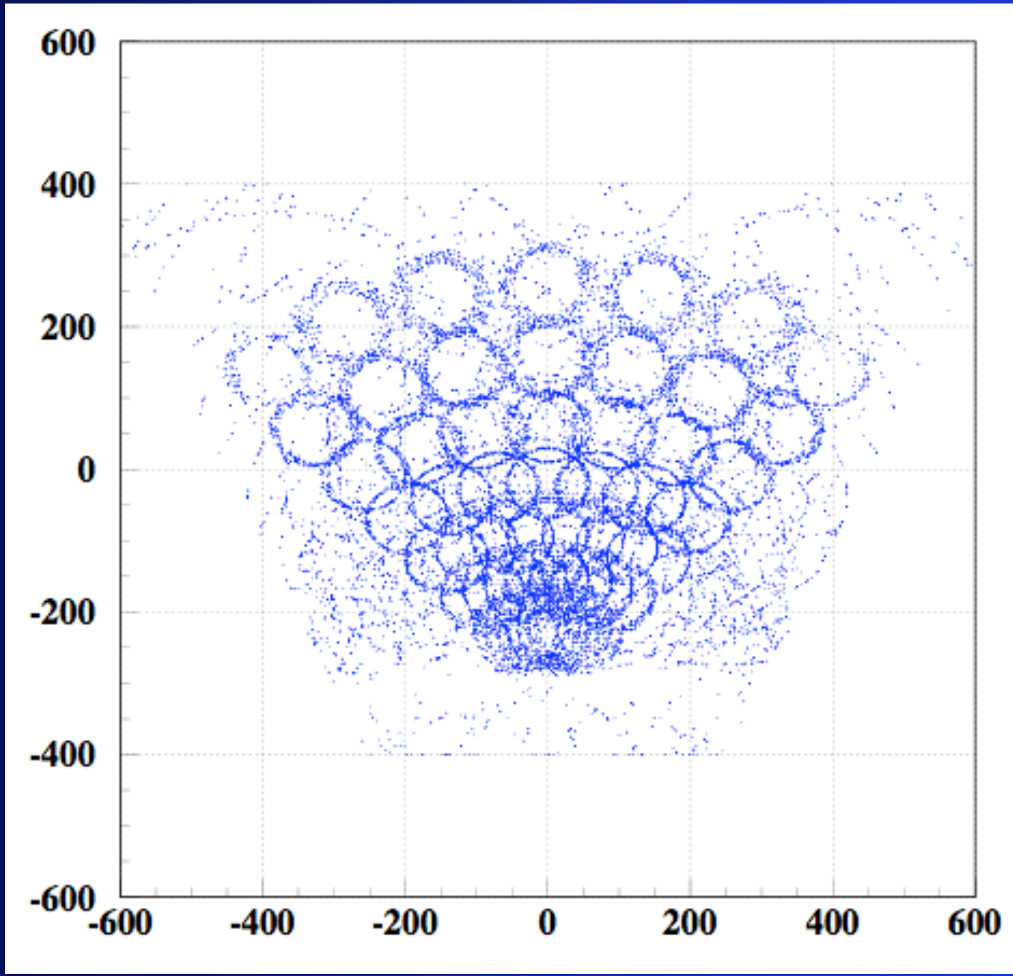


Image of one sector



Reconstruction Resolution
(aerogel radiator)

HERMES (single hit reconstruction resolution):

- Photon detector granularity - 5.6 mrad
- Aerogel tiles - 3. 0 mrad
- Aerogel refractive index - 1.1 mrad
- Mirror - 1.1 mrad
- Experimental resolution was estimated as 7.6 mrad. It translates to the radius reconstruction accuracy 0.8 cm.

CLAS can improve it using better detector granularity. We can expect 0.6 cm single hit resolution and around 0.2 cm radius ring resolution.

Gas radiator

- SELEX had the single photon resolution 5.5 cm with the biggest contribution coming from the size of the phototubes (1/2”)
- The ring radius resolution was measured at 1.56 mm.
- CLAS can improve the radius reconstruction due to the factor of 2 bigger the number of photoelectrons.

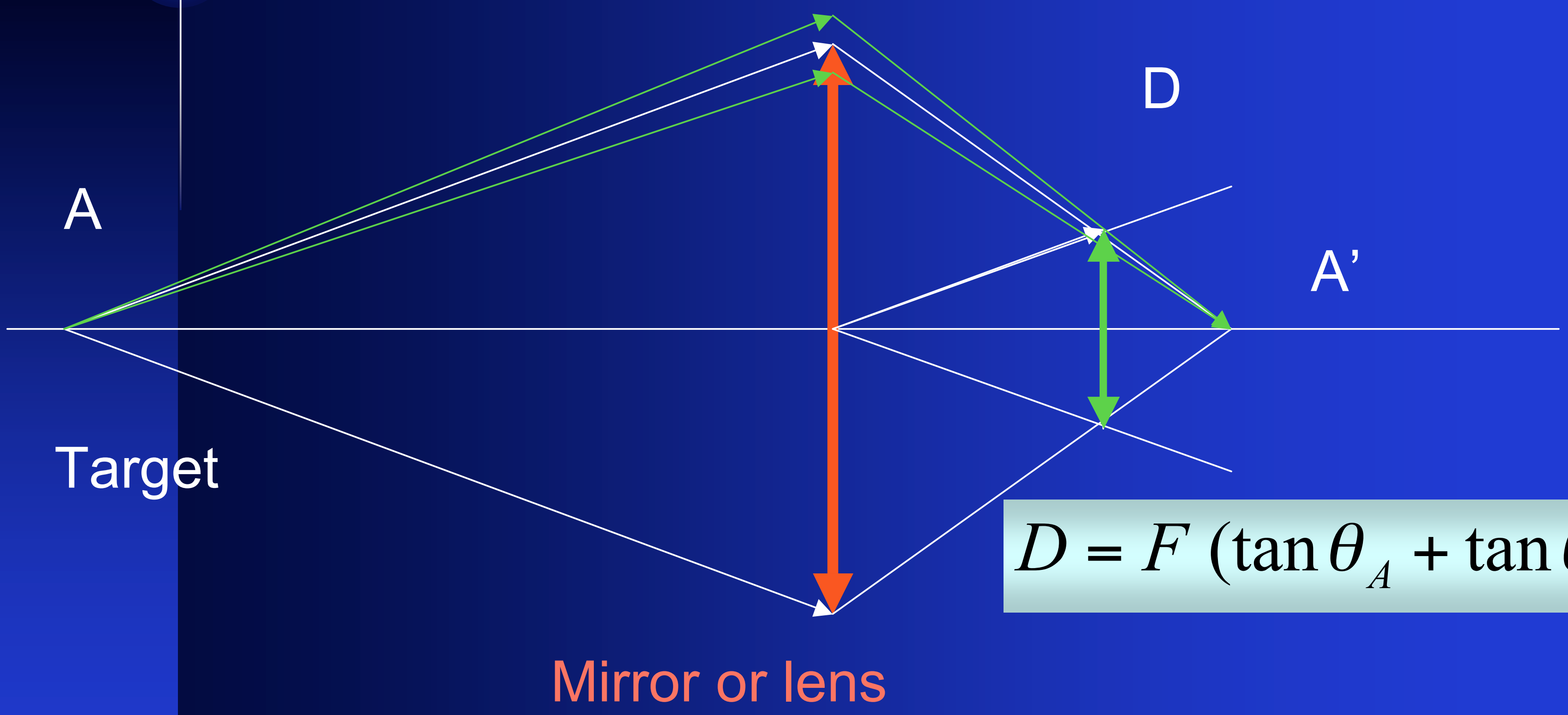
Photodetector

- Conventional small diameter PMT (like SPHINX, SELEX, HERMES)
- Multi-anode PMT (like HERAb)
- Hybrid Photodiodes (like LHCb)
- Micro-Channel Plates (MCP) or Avalanche Photodiodes working in a Geiger mode (SiPM)

Hamamatsu PMT

R760	Quartz bulb	1x1	13 mm diam.	$400
R7600U-06-M4	Quartz bulb	2x2	30x30 mm 18x18 mm	$800
H7546B-03	Quartz bulb	8x8	30x30 mm 18x18 mm	$2000

Detector Size



$$D = F\,(\tan\theta_A + \tan\theta_C)$$

Photomatrix

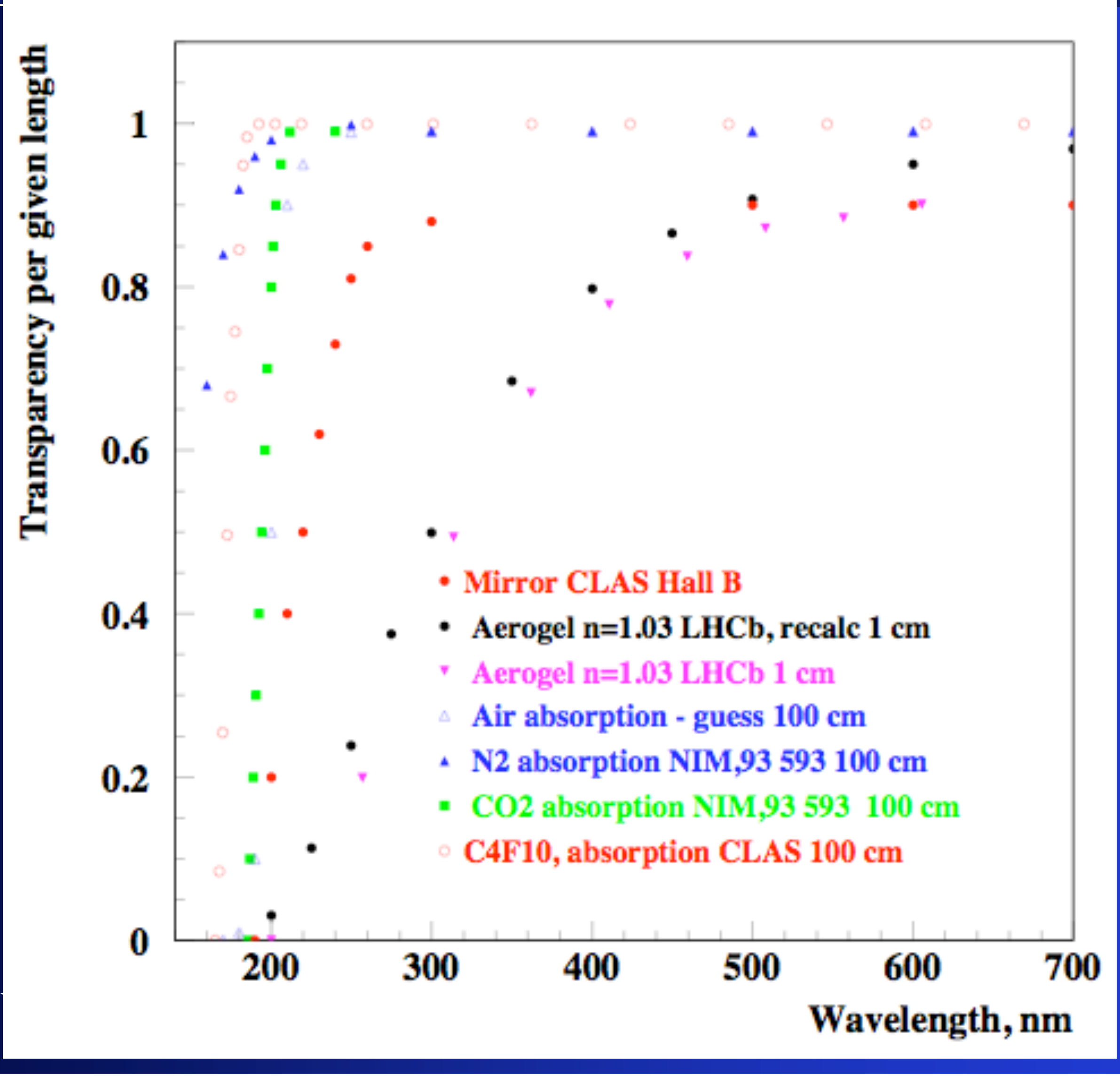
- The total active area of the photomatrix depends on the optics. Not optimized yet.
- For the 2 m radius mirror it is about ~1.5 m^2
- LHCb has 2.6 m^2 active area, HERAb- 2 m^2 and HERMES around 2 m^2, SELEX~0.7 m^2
- The number of the channels depends on the accuracy we need and money we will get.
- If we will use 1/2" PMT (like SELEX) we will get ~6700 channels (very preliminary)

Conclusion

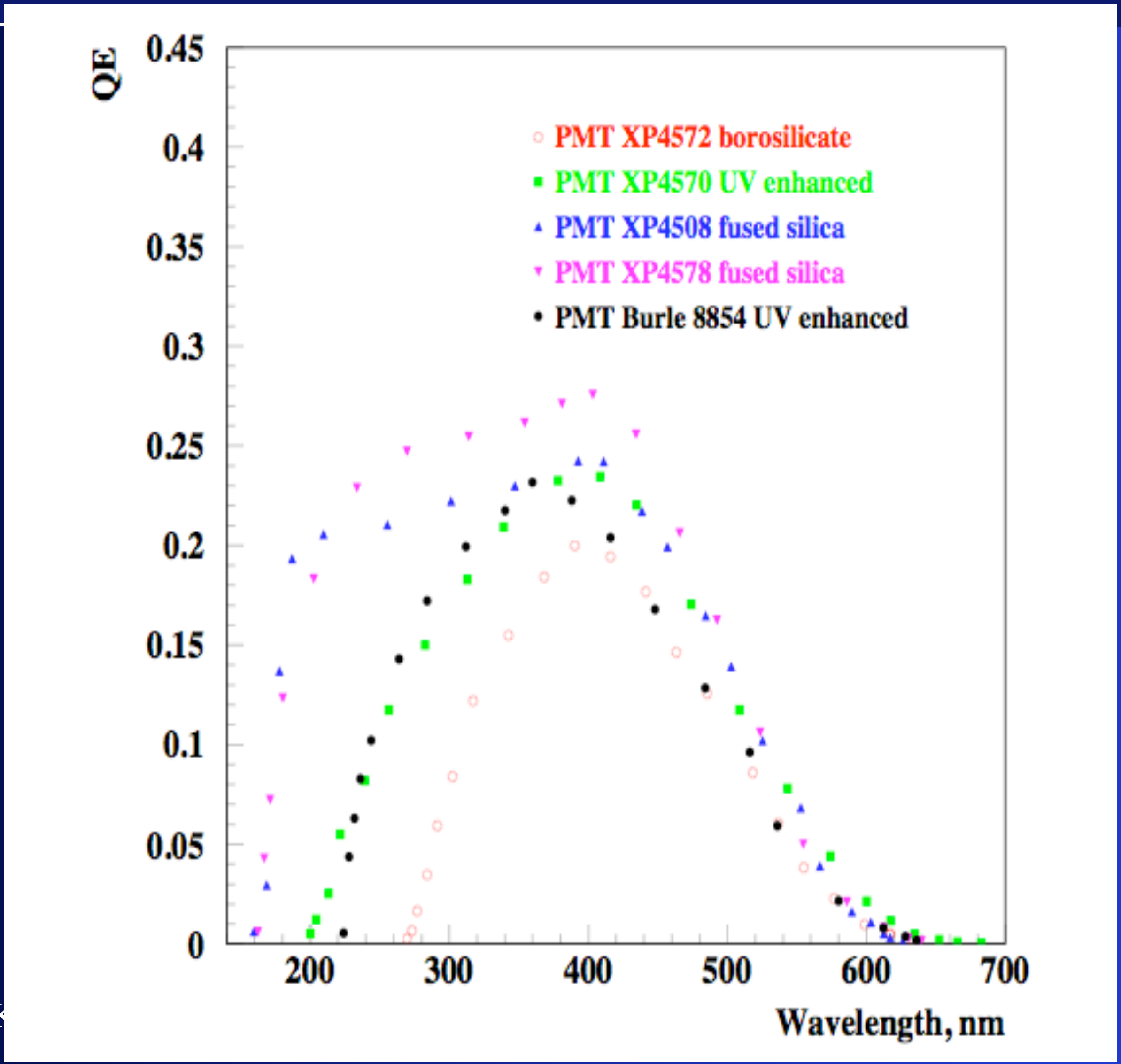
- Dual-radiator RICH detector provides reliable particle identification π/K/p in the momentum range of 2-10 GeV
- Particle ID will be significantly improved in comparison with the base line CLAS12 design what is especially important for rare processes
- RICH could be placed just after the target where HTCC is located
- Active detector area is about 1.5 m^2
- Total number of the channels has to be optimized. The rough estimate gives ~6700 channels
- Total cost is unknown for a moment

The End

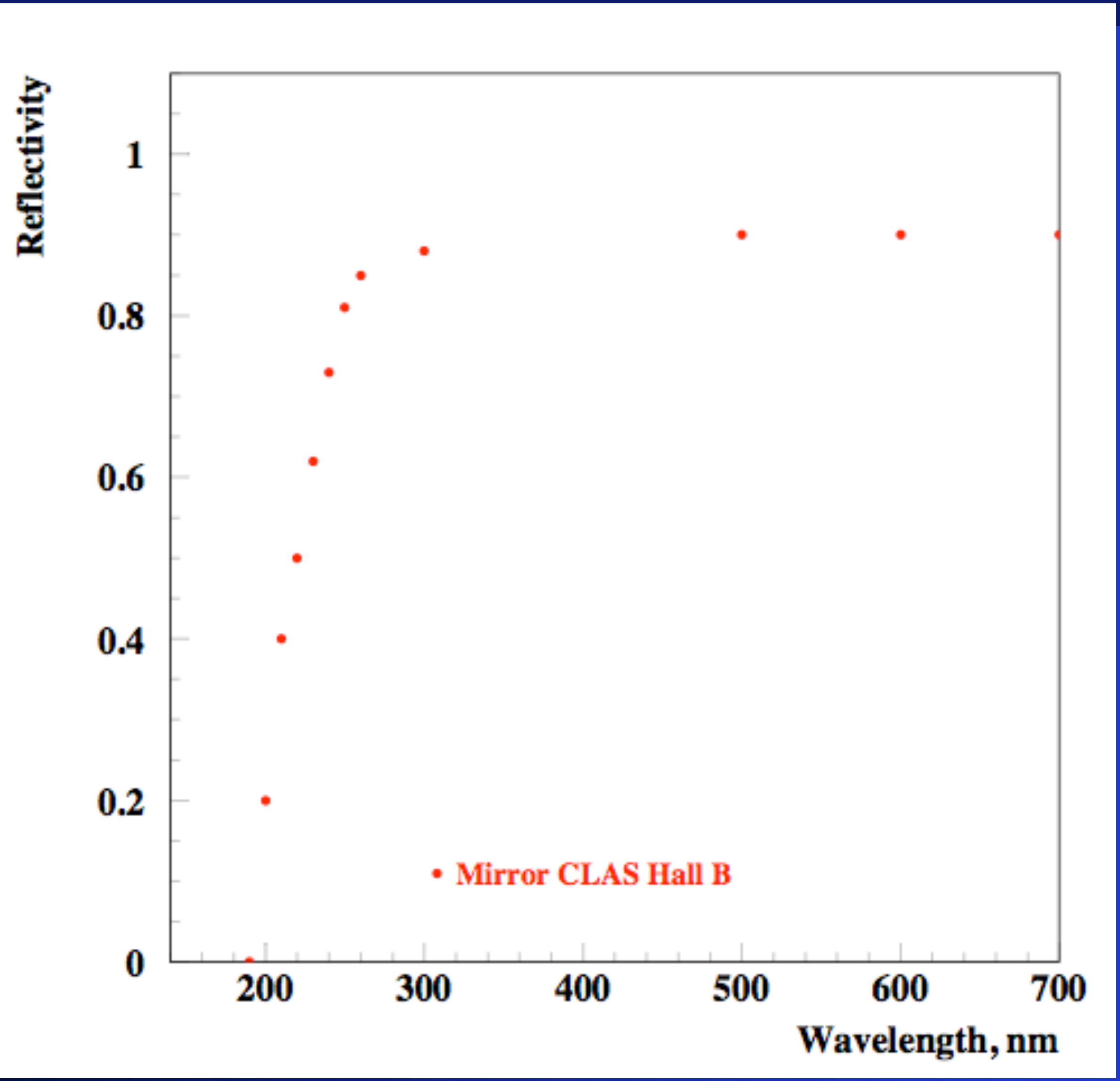
Gas Transparency



PMT Quantum Efficiency

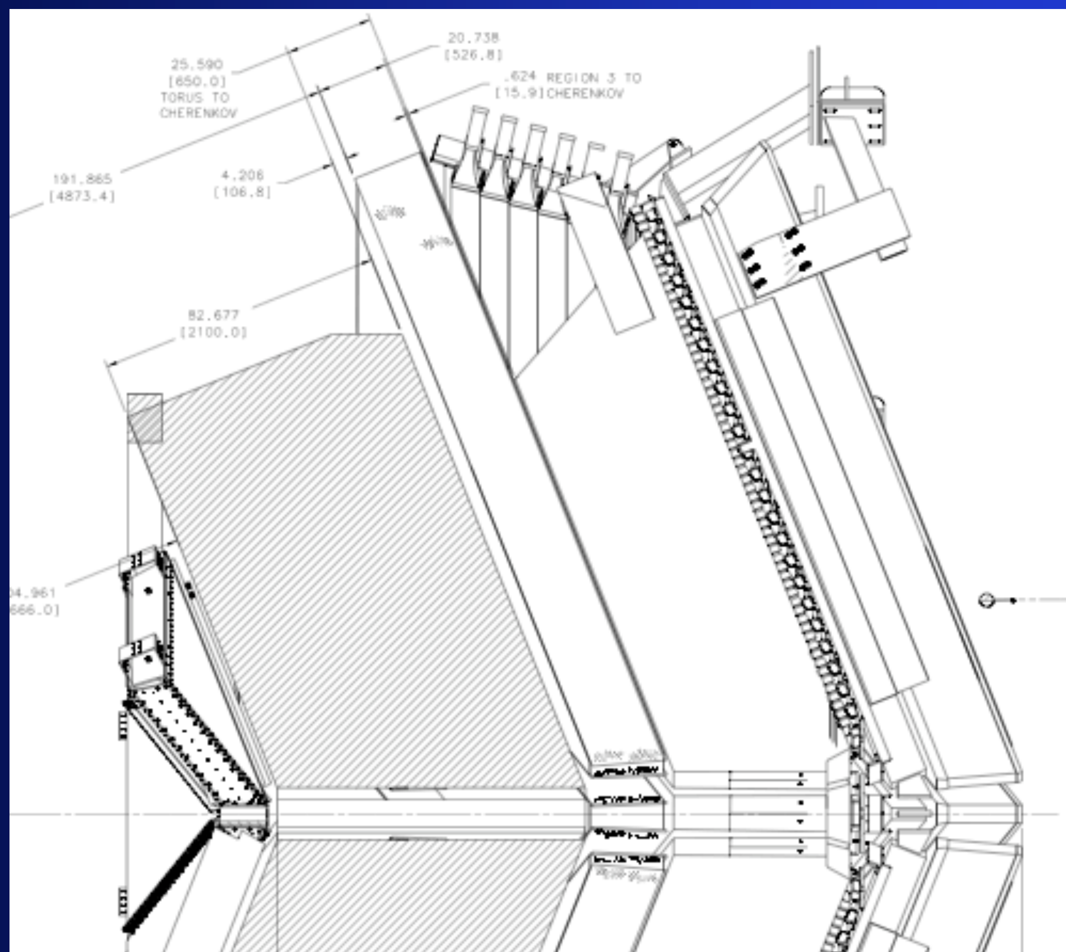


Mirror Reflectivity



Vale

CLAS12 LTCC



25.590
[650.0]
TORUS TO
CHERENKOV
20.738
[526.8]
.624 REGION 3 TO
[15.9] CHERENKOV
191.865
[4873.4]
4.206
[106.8]
82.677
[2100.0]

Another view