Development and Construction of PHENIX Aerogel Cherenkov Detector

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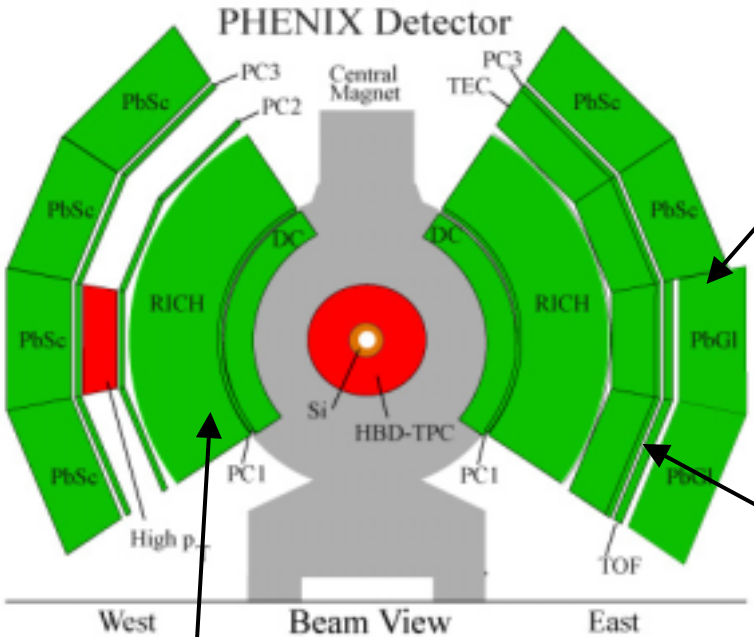
PHENIX High p_T Upgrade Project

High p_T Upgrade Team: BNL, CNS-Tokyo, JINR-Dubna, Tsukuba

The remarkable feature of the PHENIX detector is capability of particle identification (PID). The present TOF & RICH configurations leave some gaps in the PID. By the addition of an aerogel threshold Cherenkov detector with the refractive index of 1.011, those gaps would be bridged. Hadron particle identification can be achieved seamlessly up to pt of 8 GeV/c.

Intense research and development aimed to design, construct and install in the PHENIX detector have been dedicated. The detector, segmented into 160 cells, has been installed half in the W1 sector of PHENIX. Each cell has aerogel volume (22(z)x11(phi)x12(r)cm^3), followed by an integration cube viewed by two 3" PMTs. The beam test done at KEK shows that positional uniformity with this configuration is the best of all configurations studied. To eliminate dead space, every other cells along z-direction are flipped in the radial direction. With this configuration, all the sensitive aerogel volumes are kept in one plane, which contributes to the uniform detector response. Construction and Installation were finished. The Aerogel Cherenkov Detector is working in Run4.

Detectors – Particle Identification



<Electromagnetic Calorimeter>

The EMCal system consists of a total of 24768 individual detector modules divided between the Pb-Scintillator calorimeter which provides 75 % of azimuthal coverage and Pb-glass calorimeter in the rest of the acceptance. Both energy and timing measurements in EMCal are critical for the electron and photon identification and for the trigger.

<Time-of-Flight>

The TOF detector is a primary particle identification device for charged hadrons in PHENIX. The TOF consists of 10 panels. Each panel houses 96 slats of plastic scintillator with PMTs attached at both ends. The timing resolution of 100 psec allows 4sigma pi/K separation up to 2.4 GeV/c, 4sigma K/p separation up to 4 GeV/c.

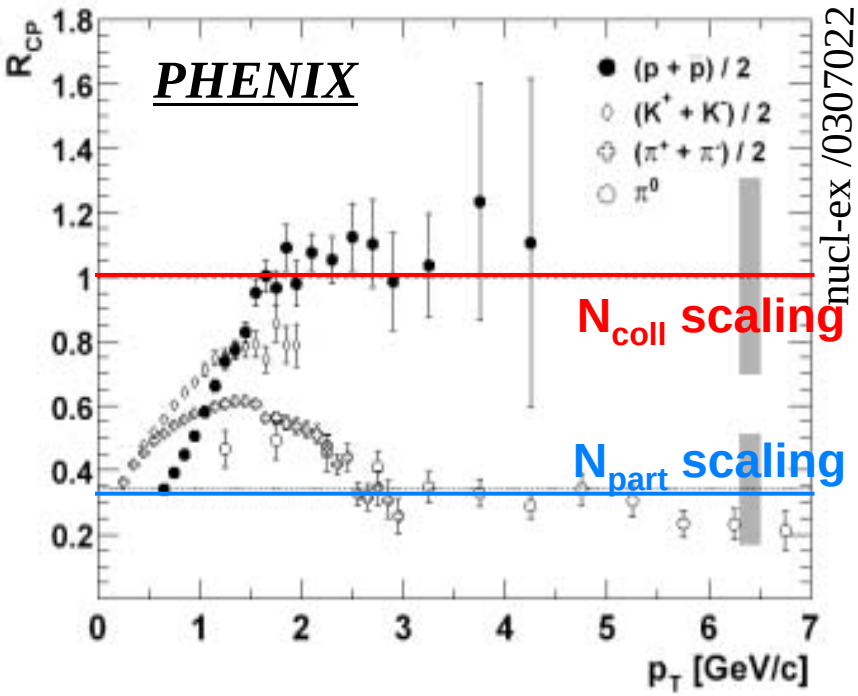
<RICH>

The RICH is the primary device for electron identification in PHENIX. It is a threshold gas Cherenkov detector with a high angular segmentation to cope with the high particle density. RICH can be filled with ethane (pion threshold of 3.5 GeV/c) or CO_2 (pion threshold of 4.9 GeV/c). The radiator length, from the entrance window to the surface of the mirror, varies from 0.9 m at theta = 90deg to 1.5 m at theta = 70deg and 110deg.

Physics Motivation

High p_T Phenomena with Identified Particles

Proton Puzzle

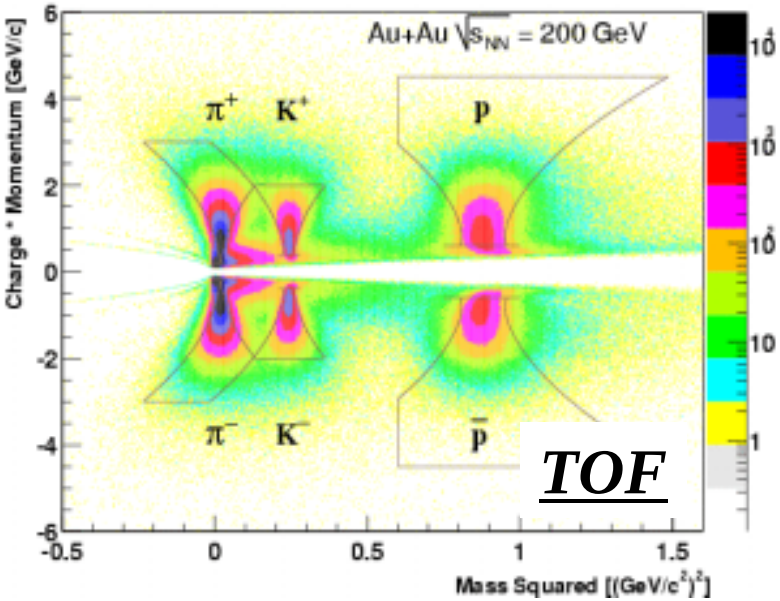


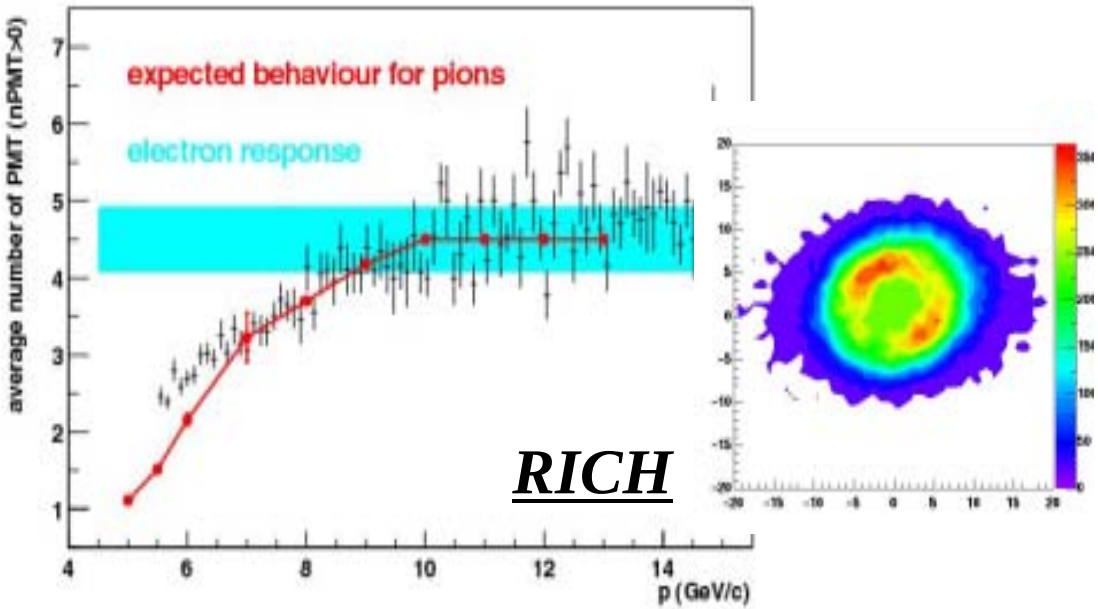
$$R_{CP} = \frac{\mathrm{Yield}^{0-10\%} / \langle N_{coll}{}^{0-10\%} \rangle}{\mathrm{Yield}^{60-92\%} / \langle N_{coll}{}^{60-92\%} \rangle}$$

Hard scattering in nucleon collisions produce jets of particles. The suppression of high-p_T particles can be described in terms of "jet quenching" (Parton energy loss via gluon radiation in dense medium). Large suppression of pions at high p_T is observed, while protons follow binary scaling. By extending PID capability, we can measure the transition region to Jet fragmentation.

And, More Topics:
- Flavor tagging of jets (charm jets with kaons)
- Azimuthal anisotropy etc.

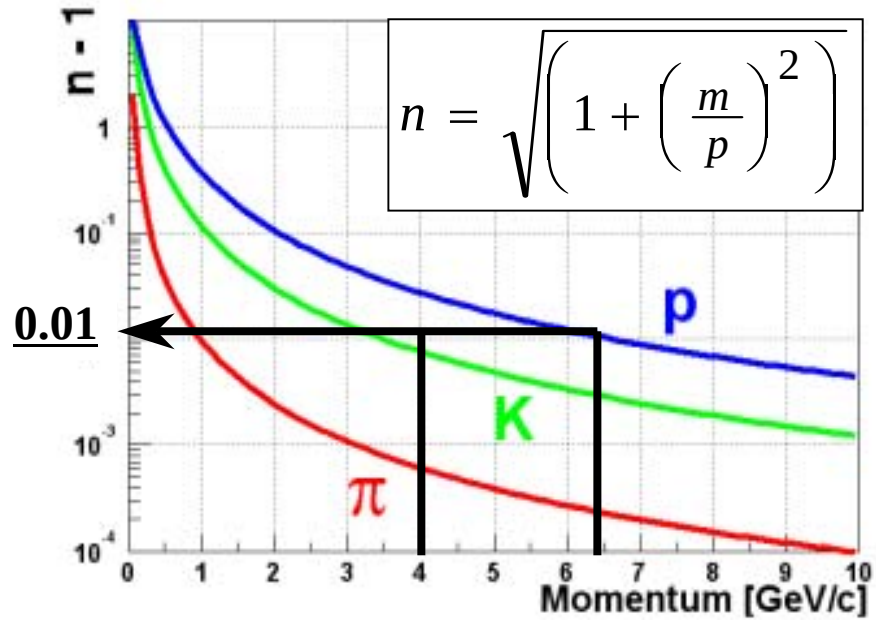
Particle Identification Capability (Currently)





PID extension toward High p_T

Silica aerogel has refractive index between gases and liquids. Aerogel can be used as Cherenkov radiator in the momentum region.



$$n = \sqrt{\left(1 + \left(\frac{m}{p}\right)^2\right)}$$

Aerogel threshold Cherenkov Detector (n=1.01)

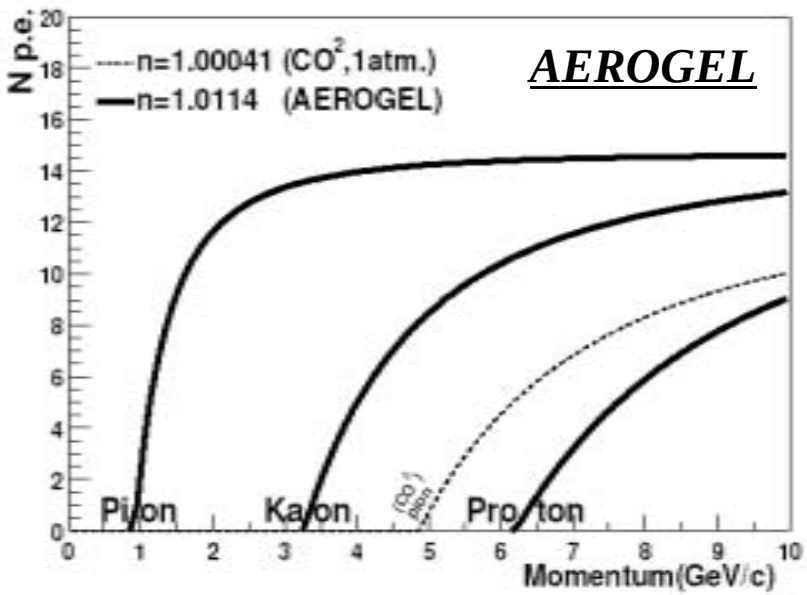
The addition of the Aerogel detector with the refractive index of 1.011 can combine with the TOF, RICH, EMCal to extend hadron identification to 8 GeV/c.

		Pion-Kaon Separation	Kaon-Proton Separation
TOF	σ ~100ps	**0 – 2.5**	**0 – 4**
RICH	n=1.00041 γ th ~ 35	**5 – 17**	**17 -**
AEROGEL	n=1.011 γ th ~ 6.8	**1 – 4**	**4 – 7**

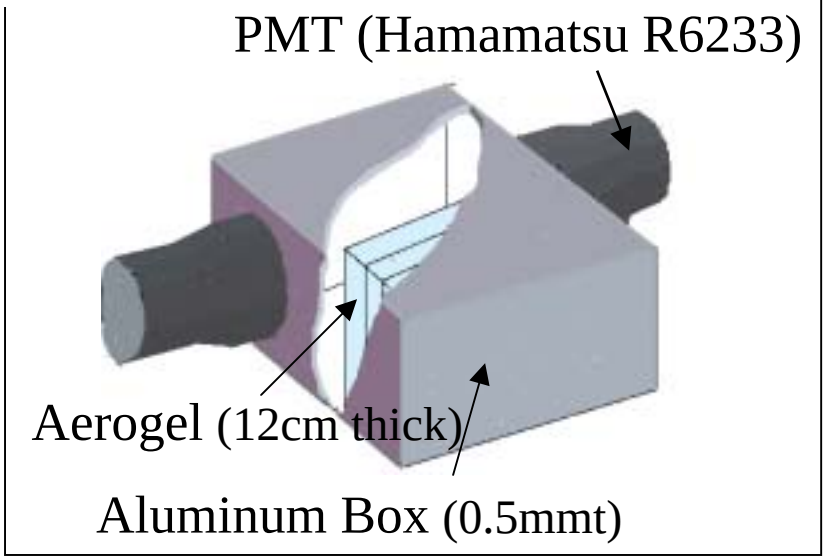
Detector Cell – R&D

Aerogel (SP-12M, Matsushita)

- Colloidal foam of SiO_2
- Low refractive index: n = 1.011
- Rayleigh scattering
- Hydrophobic
- Long-term used at KEK-Belle

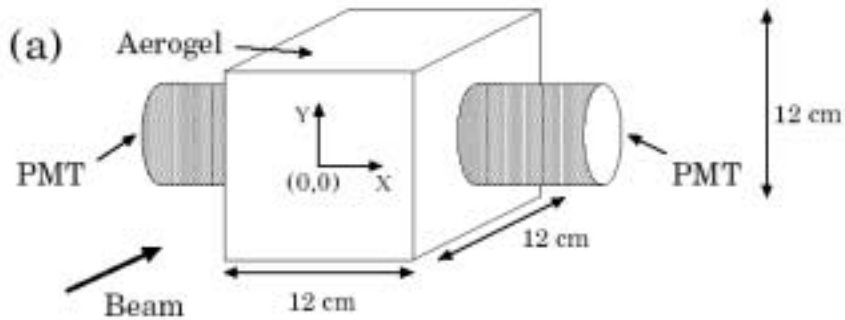


Integration Cube Type



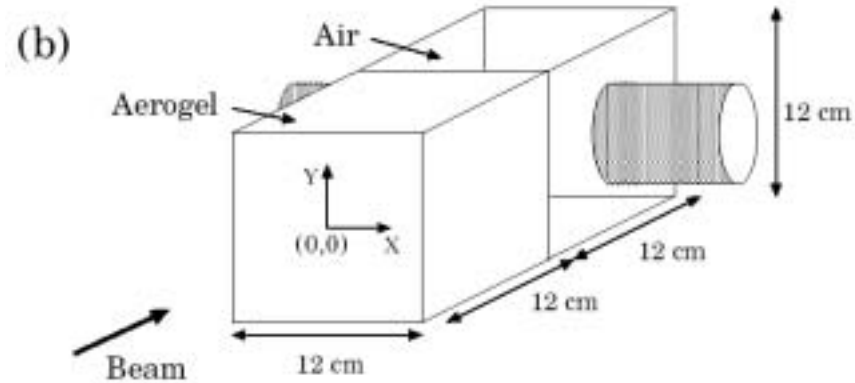
The cell, made by 0.5mm thick aluminum, has three parts, aerogel Cherenkov radiator, integration air cube and PMT/base part. Each cell has aerogel volume (22(z)x11(phi) x12(r)cm^3), followed by integration cube viewed by two 3" PMTs. The inner surface is lined with highly reflective diffusive sheet (GORETEX) for better light collection.

Conceptual Cell Design



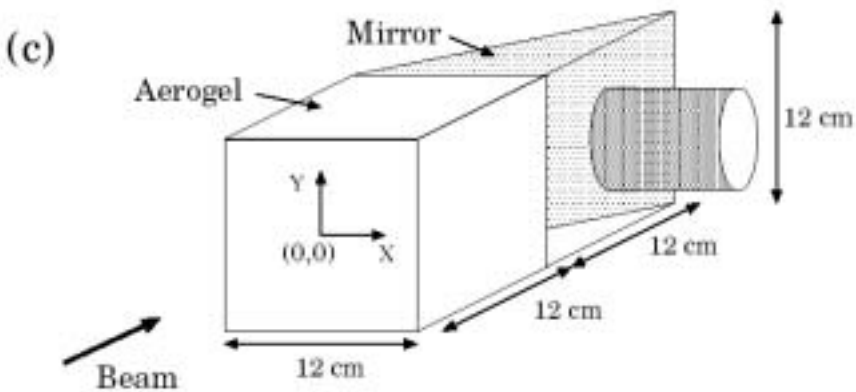
Belle Type

- Collect scattered light in aerogel



Integration Cube Type

- With Integration Cube of Air



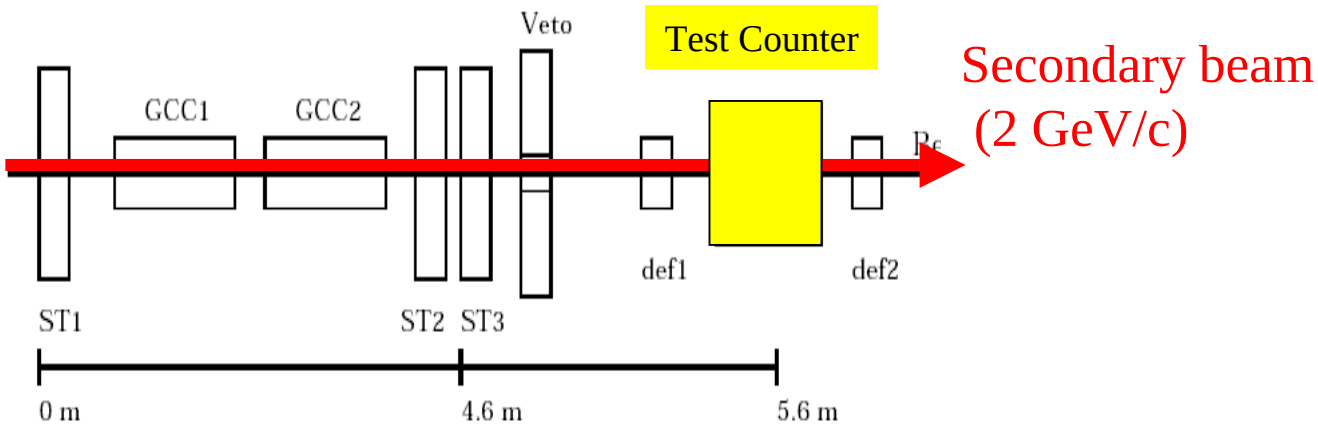
Mirror Type

- Light focused on PMT by Flat Mirror

Points:

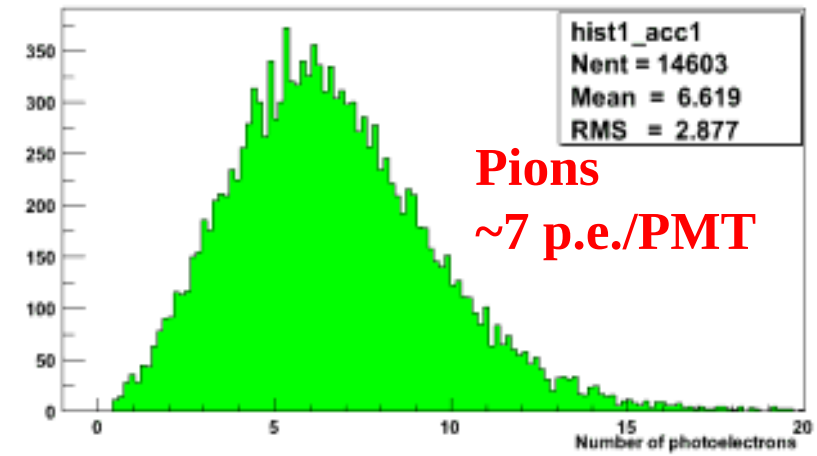
- **Directionality of Cherenkov emission**
- **Scattering property of Aerogel**

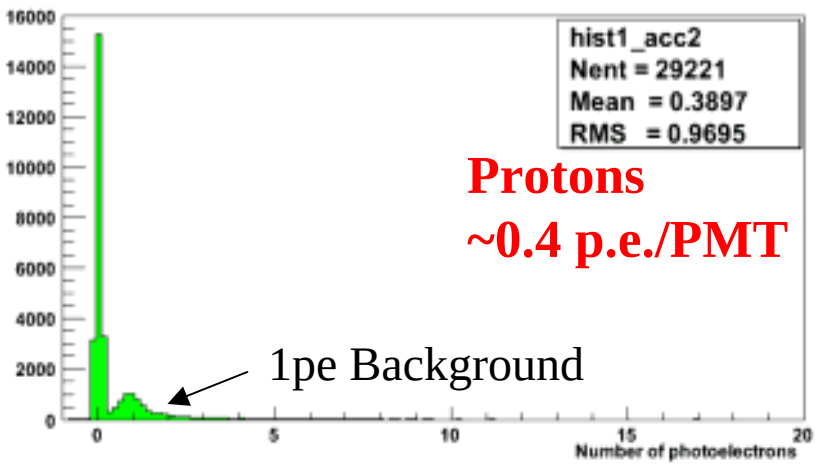
Test Beam at KEK-PS

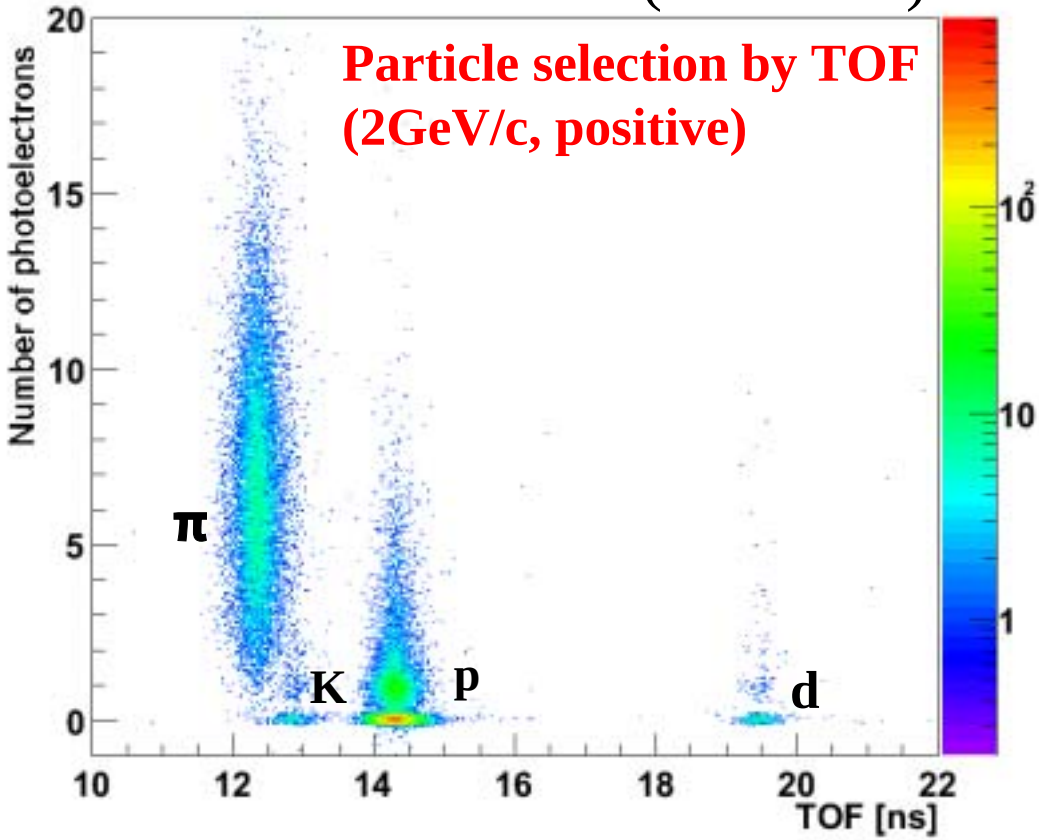


Performance (Integration Cube Type) – Test Beam

(n=1.0114)

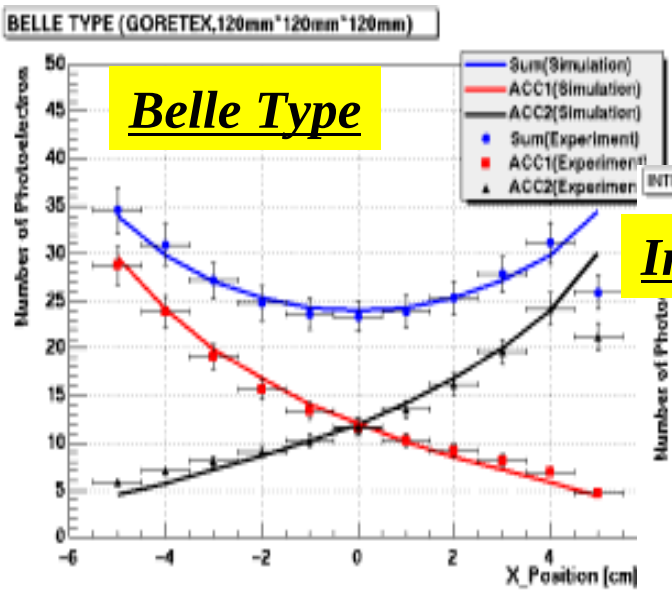




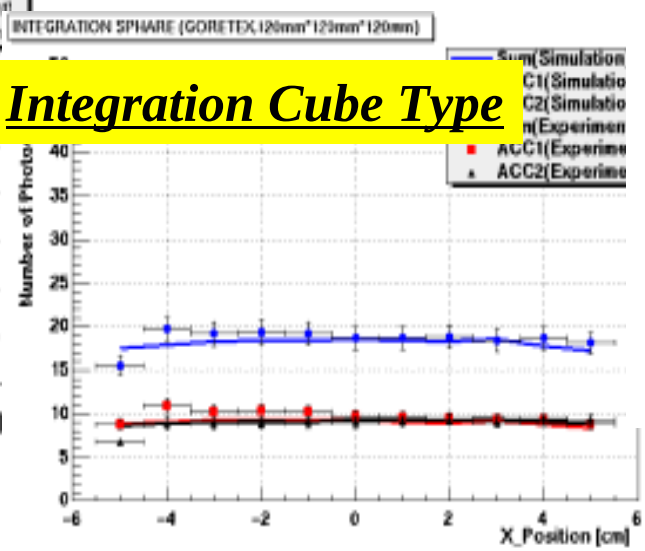


- **Clear separation of protons and pions observed.**
- **Detection Efficiency : 97.2 % (3.8 σ separation)**
- **Amount of photons other than Aerogel-Cherenkov is small.**

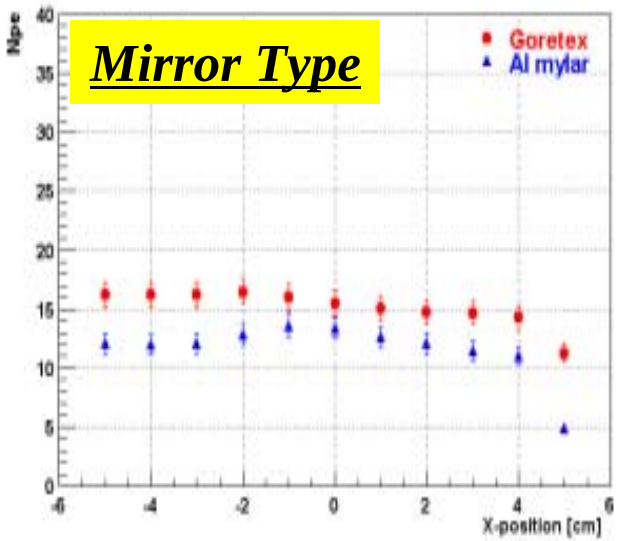
Comparison of Prototypes (n=1.017)



Strong position dependence.



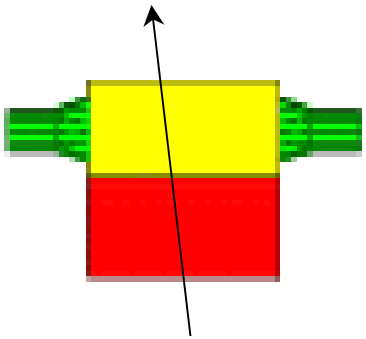
Uniform light collection.



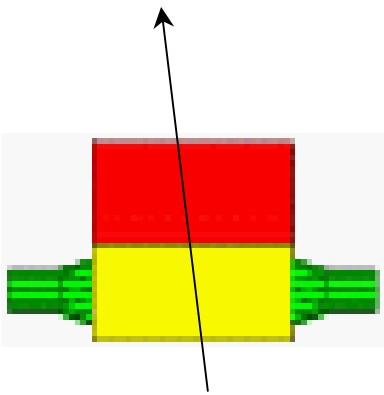
Mirror works to collect scattered light rather than directed light. PMT is located at –6cm.

Final Cell Design: Integration Cube Type
- Reasonable light yield: ~15 pe (n=1.017)
- Uniformity of the light yield, thanks to Integration Cube.
- Stacked and Installed in limited space

Cell Orientation

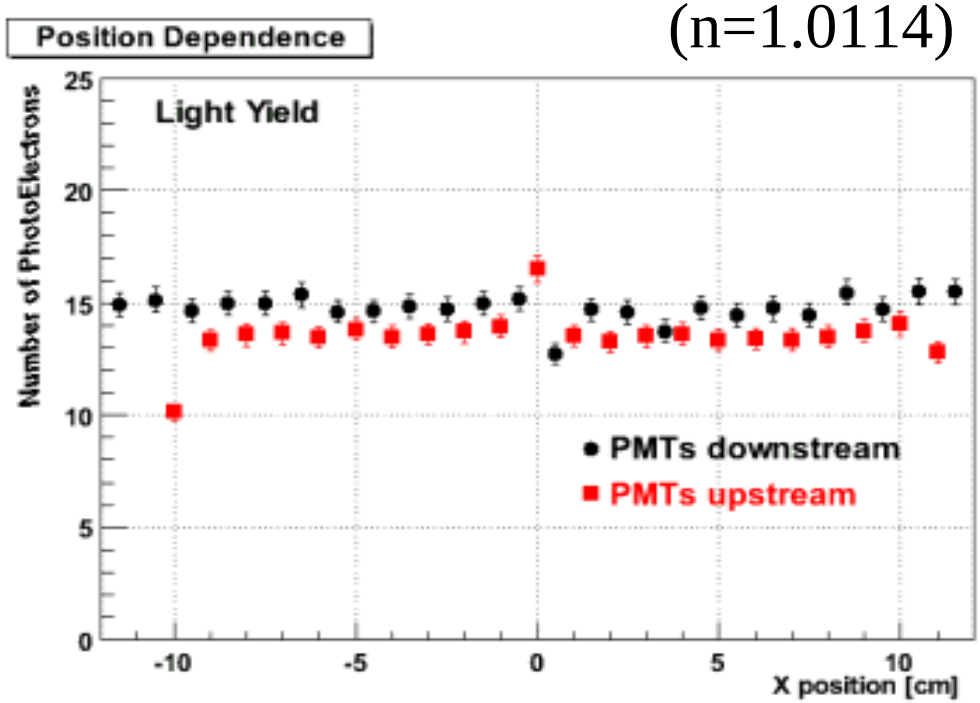


PMTs downstream



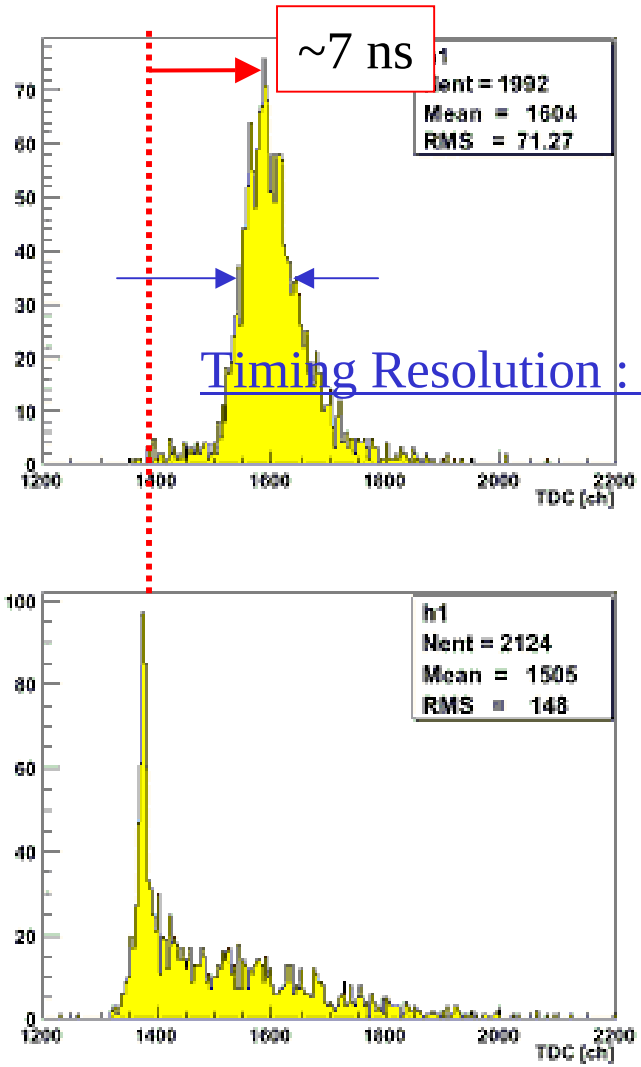
PMTs upstream

(n=1.0114)



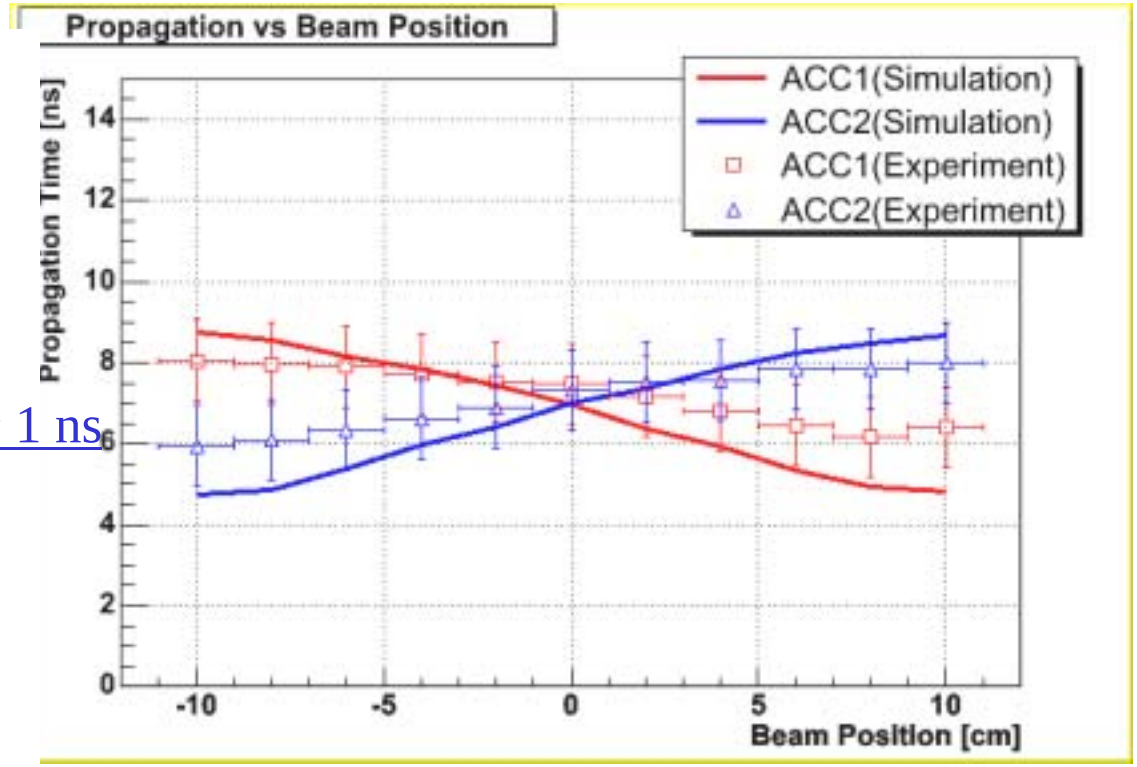
Test beam results show that the average light yield per cell is > 14 photoelectrons with both PMTs. The integration cube is essential for uniformity of the light yield. The light yield differs only by 10 – 20 % due to the alternate orientation.

Timing Information



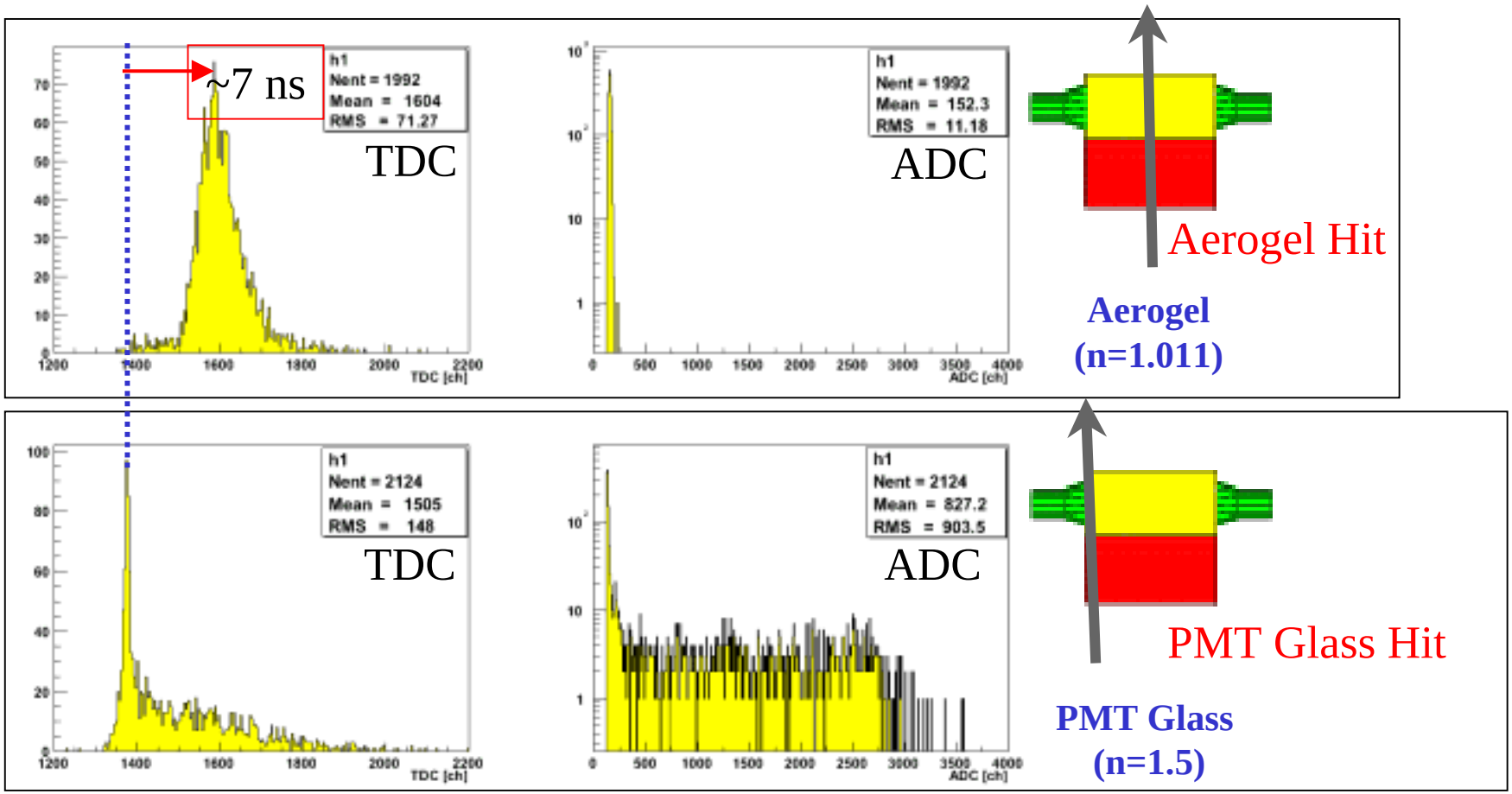
TDC distribution

Timing Resolution : ~ 1 ns



- **Propagation time : ~ 7 ns**
  (t=0 is defined as the time of PMT hits.)
- **Max. 2 ns difference observed**
  between PMT1 and PMT2.

Background Rejection (By One PMT)

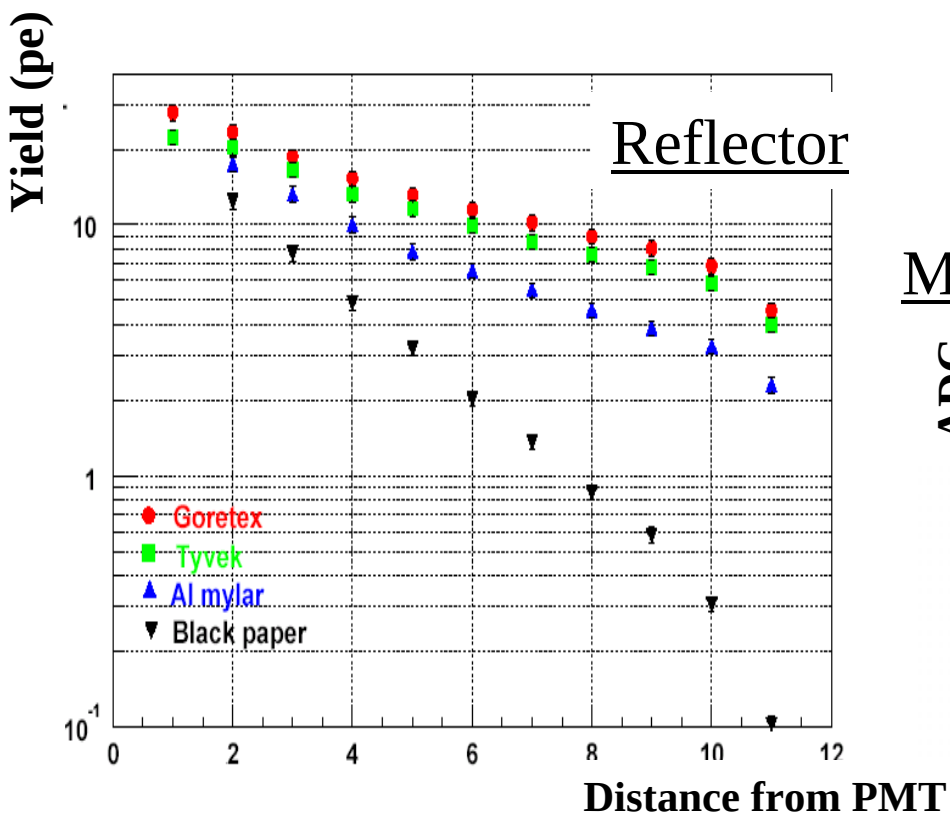


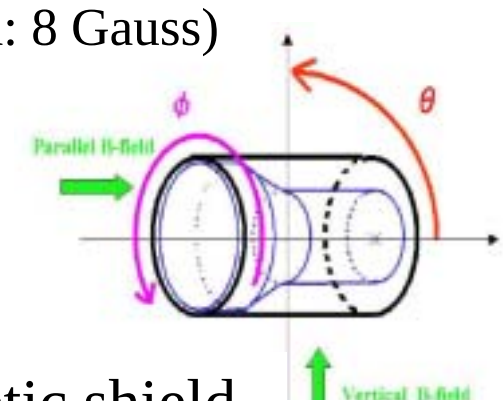
- By using the timing and amplitude of signals, events in hitting PMT can be distinguished.

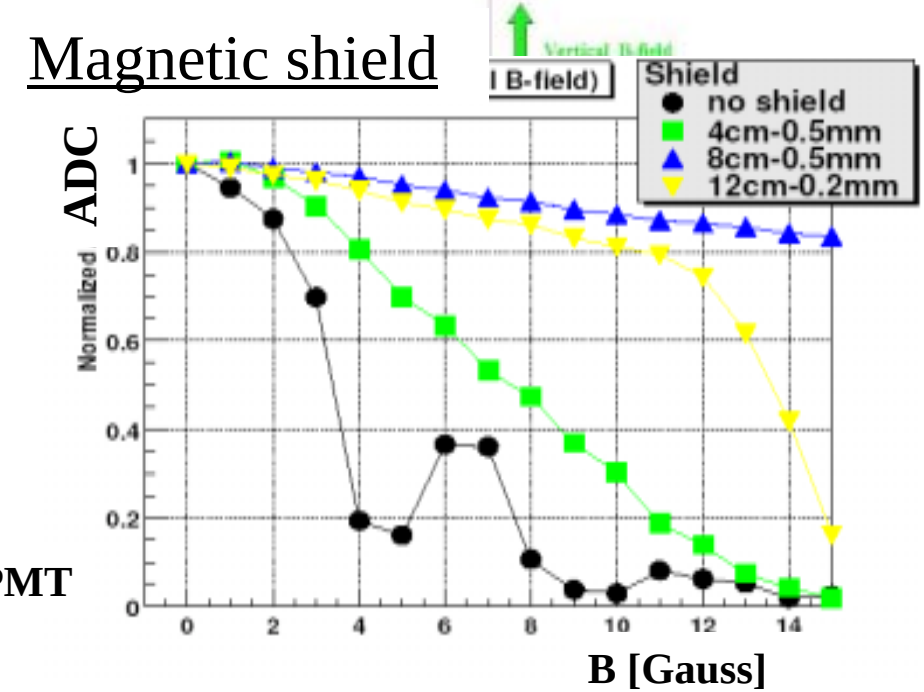
- Not only with the tracking, PMT hit is self-detectable.

Optimization – Design parameters

- Cell dimensions, shape (Cross-sectional size, Aerogel thickness)
- Reflector (key component for light collection)
- Magnetic mu-metal shield (under fringe field: 8 Gauss)



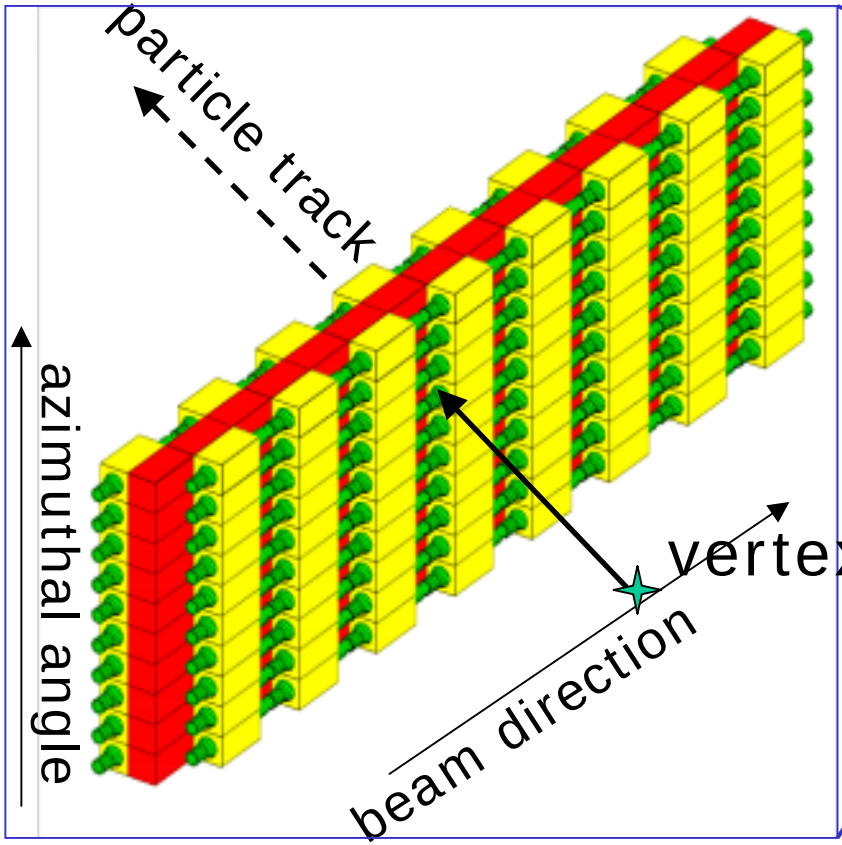




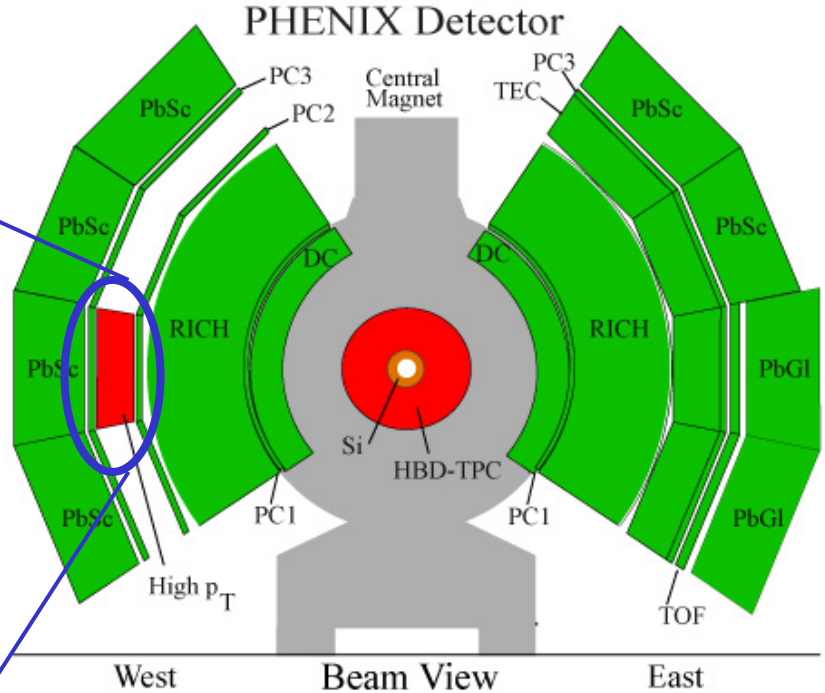
Design Specification

Location: 4.5m from vertex
Acceptance: Δtheta=53deg (Δeta=0.7), Δphi=14deg, Ω=0.2str
Cherenkov radiator: Silica aerogel (n=1.0114)
Pion threshold: 0.9GeV/c
Kaon threshold: 3.3GeV/c
Proton threshold: 6.2GeV/c
Light yield: ~15 pe (2PMTs) – Good uniformity
Detection efficiency: 97.2% (3.8 σ separation)
Segmentation: 160cells – Keep the occupancy < 10%
Readout: PMTs (320ch)

Detector Overlook



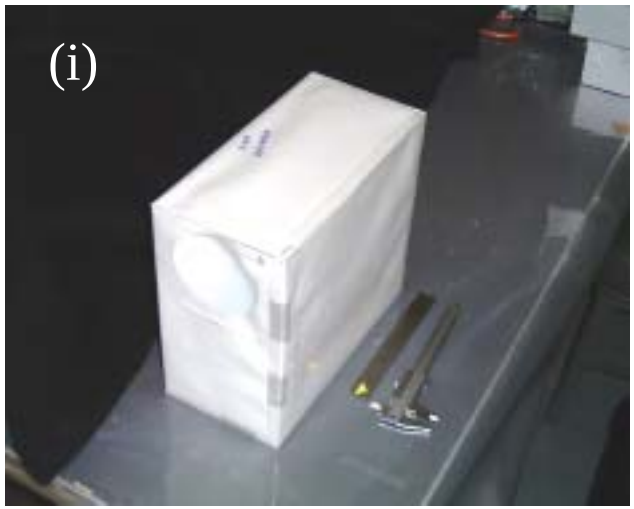
RED: Aerogel
YELLOW: Integration Cube
GREEN: PMT



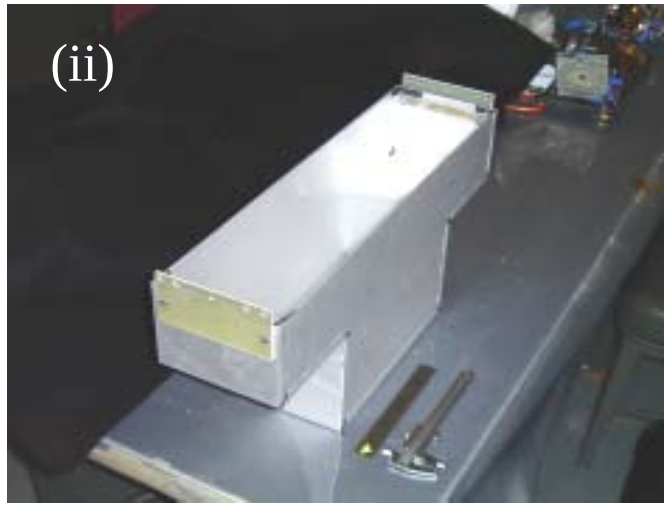
The Aerogel detector is composed of 160 individual cells. The cells are stacked into an array 10 cells high by 16 cells wide. To minimize dead space, cells have been stacked reversing the cell orientation in alternate rows. All sensitive volumes are kept in one plane, contributing to the uniform detector response. In this design, half the cells have particles entering in the reverse direction.

Construction (August ~ October of 2003, BNL)

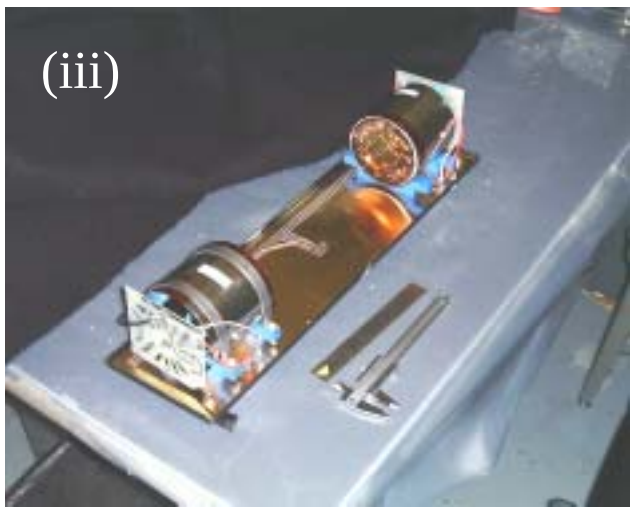
Cell Assembly



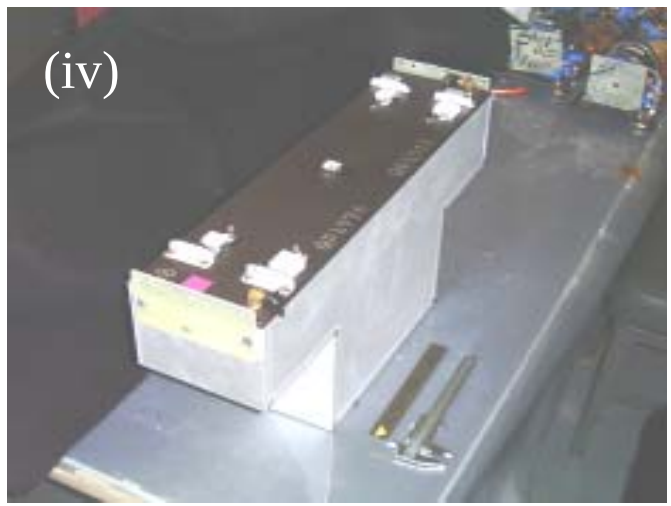
(i)Aerogel in Goretex box



(ii) then put into Al-box



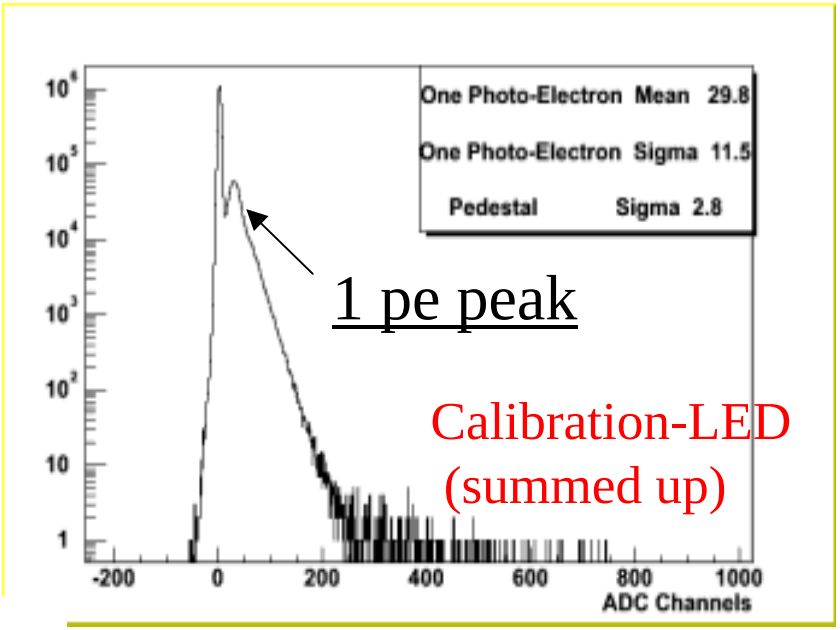
(iii) and put the lid w/PMTs&LED

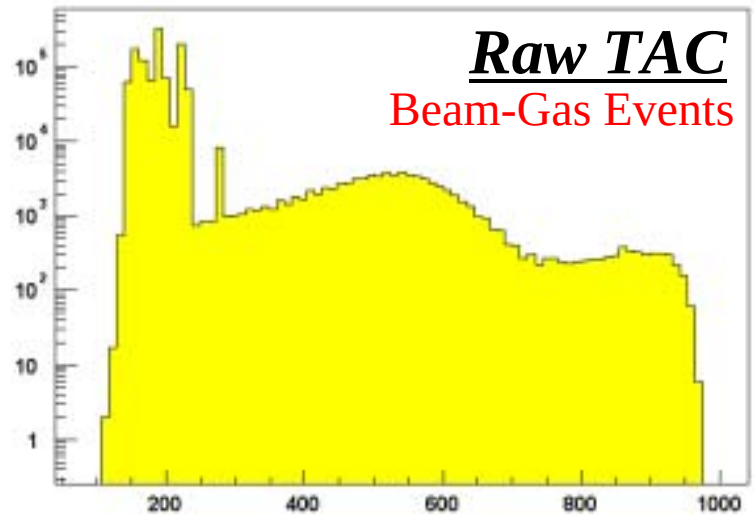


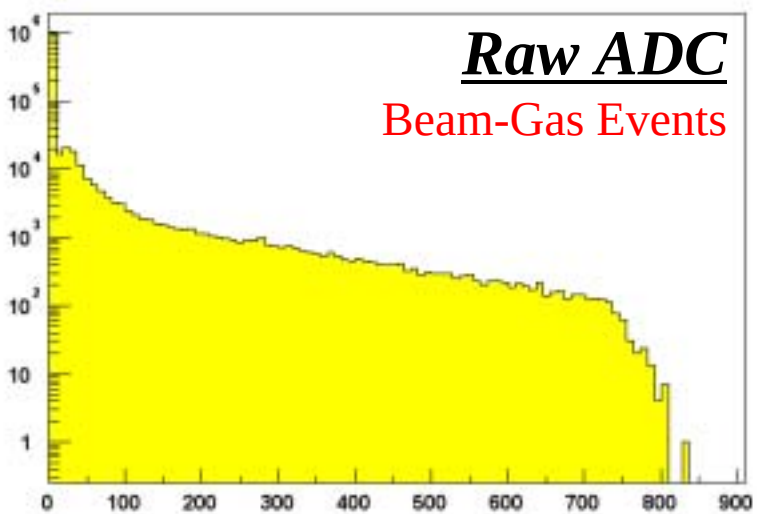
(iv) Completion

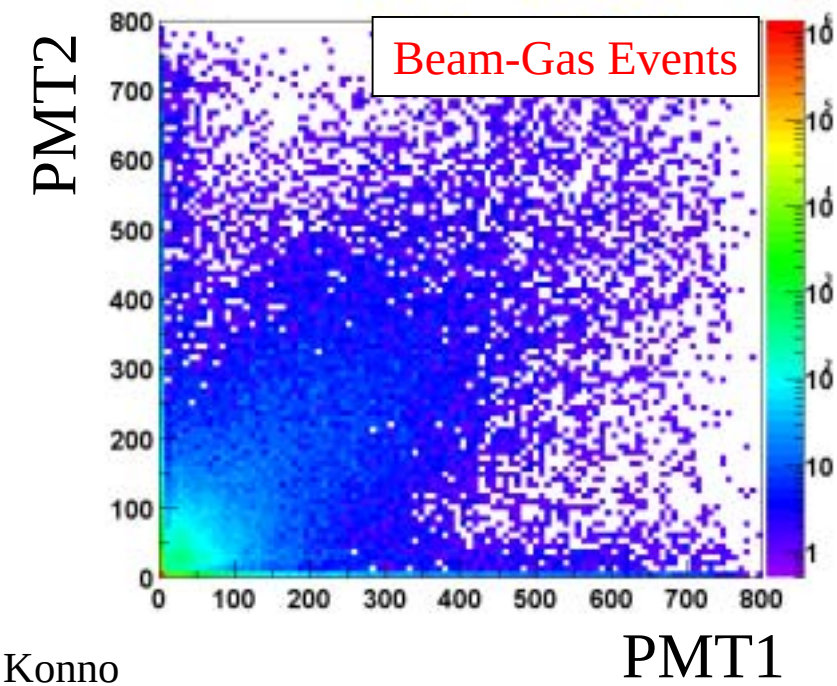
Installation (November 2003)

Performance plots – Calibration-LED, Beam-Gas Events









Summary

- ✓Final cell design – Integration Cube Type
- ✓We have very uniform response of the light yield.
- ✓By using the timing and amplitude of signals, events in hitting PMT can be distinguished.
- ✓Detector construction finished half.
- ✓Aerogel Cherenkov Detector (half) has been installed in PHENIX.
- ✓In Jan. of 2004, Physics Run (Run4, Au+Au) started.
- ✓Collision data has been taken.

Future plans:

-4 m^2 of Full Aerogel detector by Run5

-Additional TOF detector behind Aerogel

Once the TOF and Aerogel array are completely installed in PHENIX, it will be possible to individually identify pions, kaons protons to ~8GeV/c in p_T.