Spin physics by HERMES using hadron identification with the Ring Imaging Cherenkov Counter

Yasuhiro Sakemi

Tokyo Institute of Technology

on behalf of the HERMES collaboration

Contents

- *Motivation*
- *A RICH detector for HERMES*
- *RICH Reconstruction and Particle Identification*
- *Detector Performance and Results*
- *Summary and Outlook*

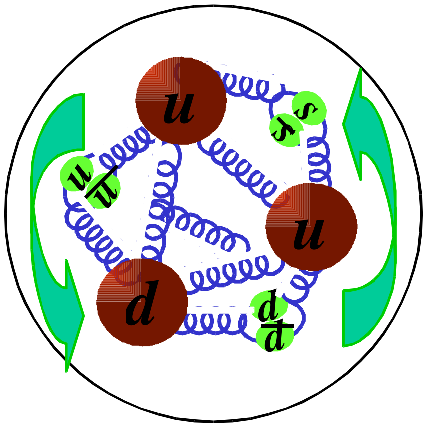
SPIN2000

14 th International Spin Physics Symposium

Osaka, October 18, 2000

Motivation

The spin structure of the proton :



$S_Z = \frac{1}{2} \quad = \frac{1}{2}$ *?? + ?G + L_Z*

where ?? ??u+?d+?s

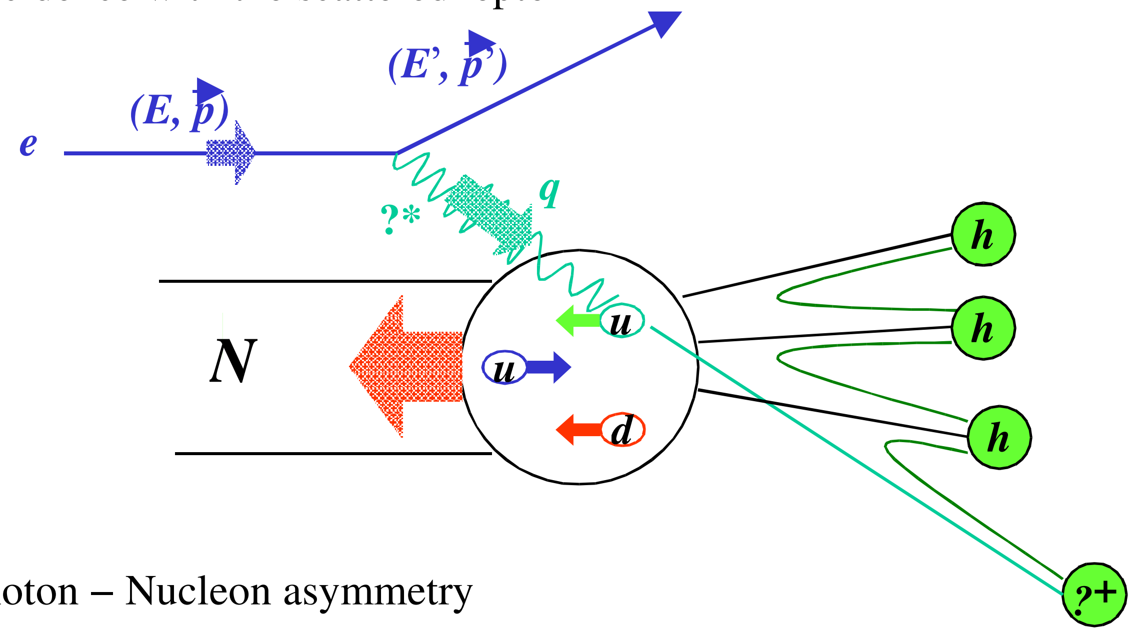
- Quark spin contribution (*??*) to the nucleon spin is found to be small in inclusive DIS experiments (EMC,SMC,SLAC,HERMES)
  - *?? ? ? $_q$(?q + ?$\bar{q}$) ~ 0.2 ... 0.4*
- What are the contributions of the different quark flavors ?
  - *The answer is only partially known.*
  - *e.g. Strange sea polarization* ***?s*** *has not yet been measured.*

- How at HERMES ?
  - *Hadron coincidence measurement in the polarized DIS*
  - *Particle identification with Ring Imaging Cherenkov Counter* ***(RICH)***
  - *Flavor tagging with the final state produced hadrons*

asuhiro Sakemi

Semi−Inclusive DIS

• In semi−inclusive deep inelastic scattering, a hadron h is detected in coincidence with the scattered lepton



• Photon – Nucleon asymmetry

Purity P

$$\underbrace{A_1^{\,h}(x,z)}_{\vec{A}} = ?_f \boxed{\frac{e_f^2\,?q_f(x)\,?D_f^h(z)}{?_{f'}\,e_{f'}^2\,?q_{f'}(x)\,?D_{f'}^h(z)}}\ \underbrace{\frac{?q_f(x)}{q_f(x)}}_{\vec{Q}}$$

where *(?q) q : (polarized) quark distribution*

$D_f^h(z)$: Fragmentation Function

• To extract quark polarization: $\vec{Q}$, solve $\boxed{\vec{A} = P ? \vec{Q}}$

? ***Purity $P = P_f^h(x,z)$*** *gives probability that a quark q(x) was struck when a hadron h(z) is detected*

? *Purities are spin−independent quantities*

(Fragmentation process spin−independent)

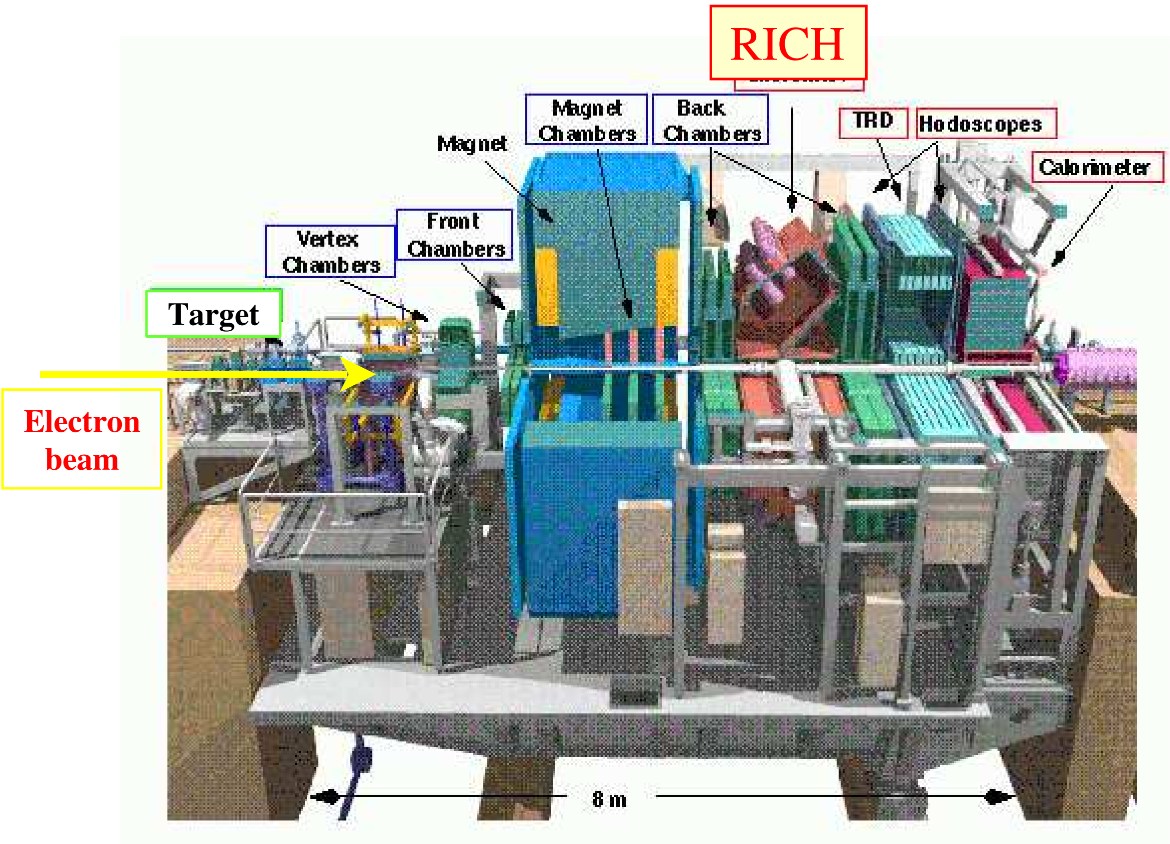
Complete Flavor Decomposition ? measure ?,K asymmetries

RICH identify ?, K, p

hermes

asuhiro Sakemi

HERMES Spectrometer



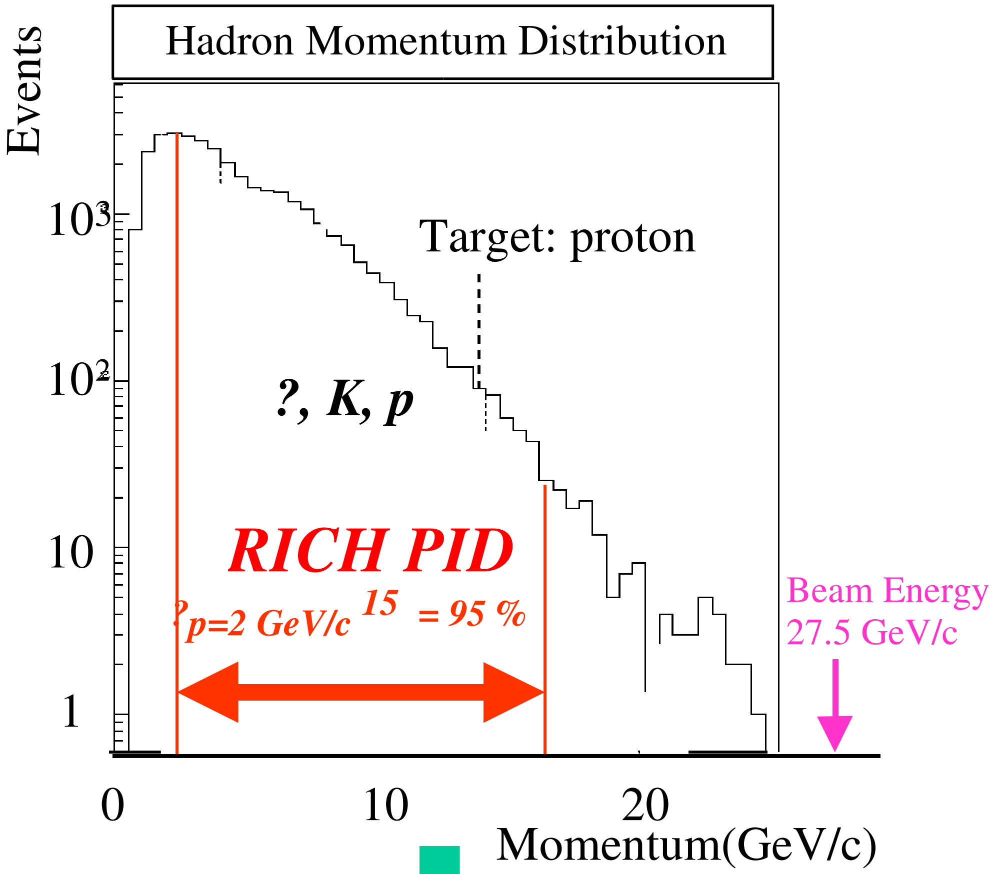
- 27.5 GeV longitudinally polarized electron beam
  - *polarization:* $P_{beam} \sim 55\ \%$
- Internal Target
  - *longitudinally polarized atoms: H, D,* ^{3}He
- Magnet: $B_y\,dz = 1.3$ Tm
- Track reconstruction: 57 tracking chamber planes
  - *?P/P = 0.7 % ~1.4% , ?? < 0.6 mrad*
  - *acceptance:* $0.02 < x < 0.8$ *for* $Q^2 > 1\ GeV^2$ *and* $W > 2\ GeV$
- Particle Identification
  - *Calorimeter, Preshower, TRD*
  - ***RICH : ?, K, P separation***

hermes

HERMES−RICH design

Requirements:

- *?,K,p identification over the momentum range : 2 GeV/c ~ 15 GeV/c*



Solution:

- *Dual radiator* : ***Aerogel*** *and* C_4F_{10}
  - *Cover almost all range of momentum of hadrons produced at HERMES*
  - *Identified hadron yield : increased*

    e.g.) Yield of ?~ 2 times increased compared to the threshold type cherenkov detector installed before RICH construction

hermes

asuhiro Sakemi

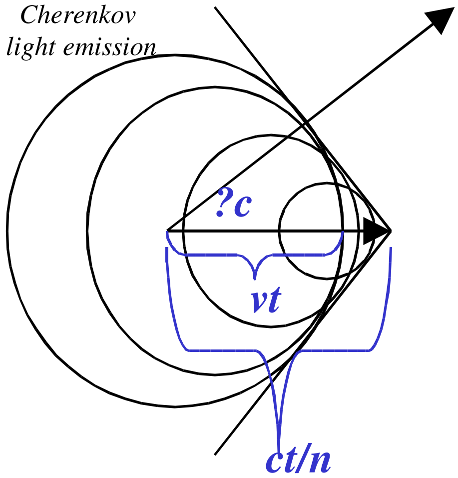
Aerogel and Gas Radiators

- **RICH**:*particle velocity (v) from cherenkov angle:*

$$\cos\theta_c = \frac{1}{\frac{v}{c}n}$$

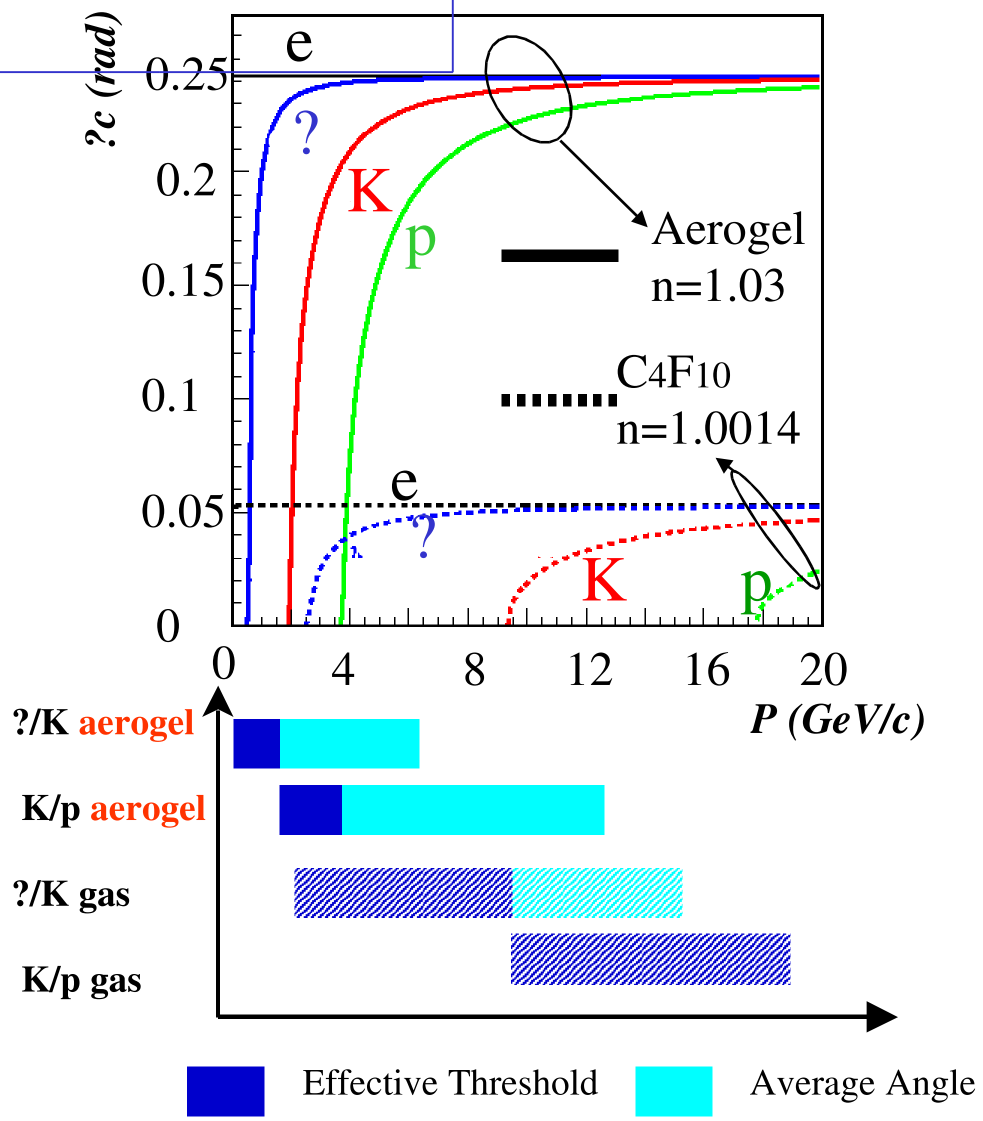
- Magnetic Spectrometer: *momentum (p):*

$$p = \frac{m_0 v}{\sqrt{1-\frac{v^2}{c^2}}}$$



Particle type (m_0) determine : Particle Identification (PID)

Relation between cherenkov angle and momentum

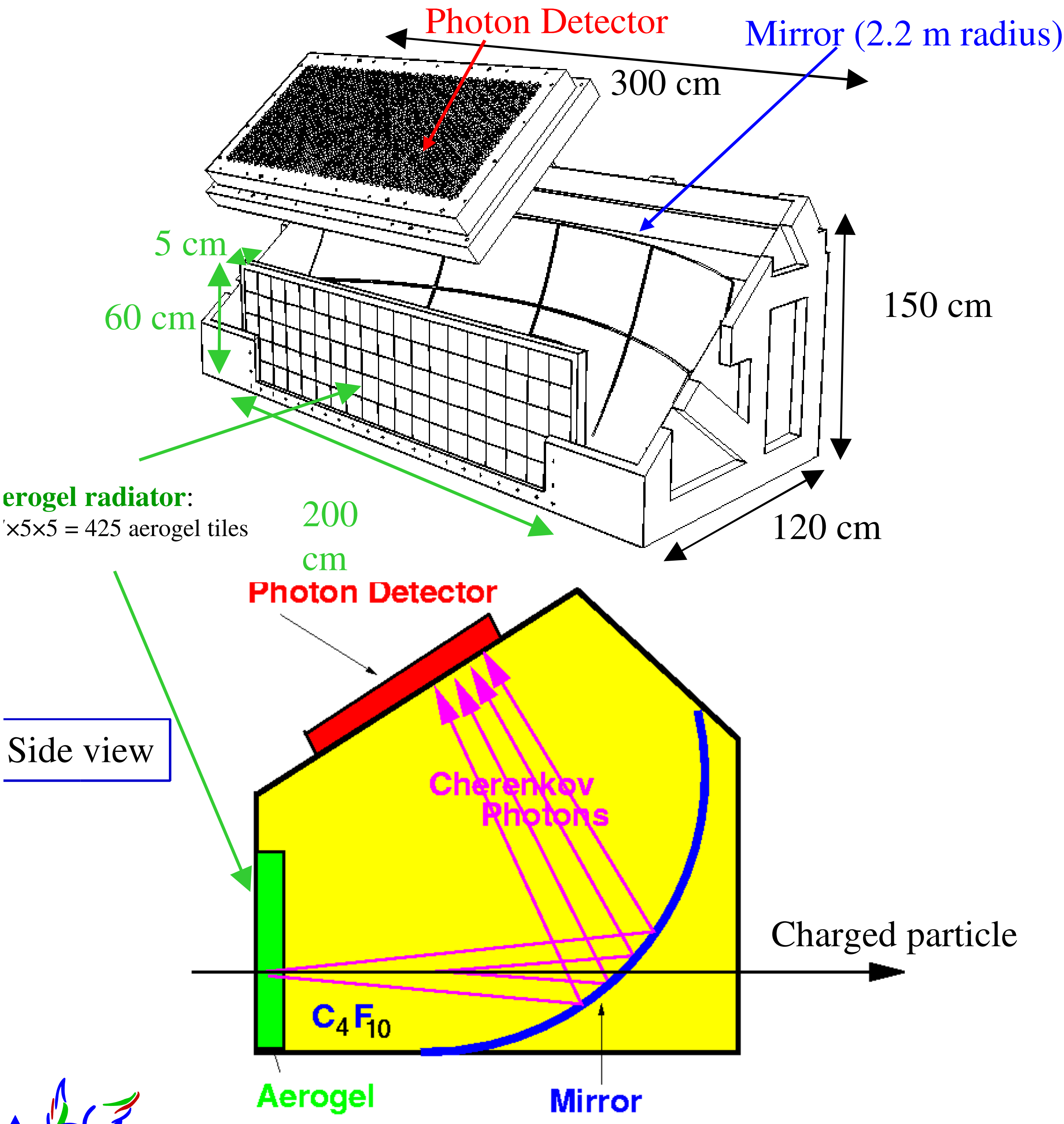


hermes

asuhiro Sakemi

Ring Imaging Cherenkov detector (RICH)

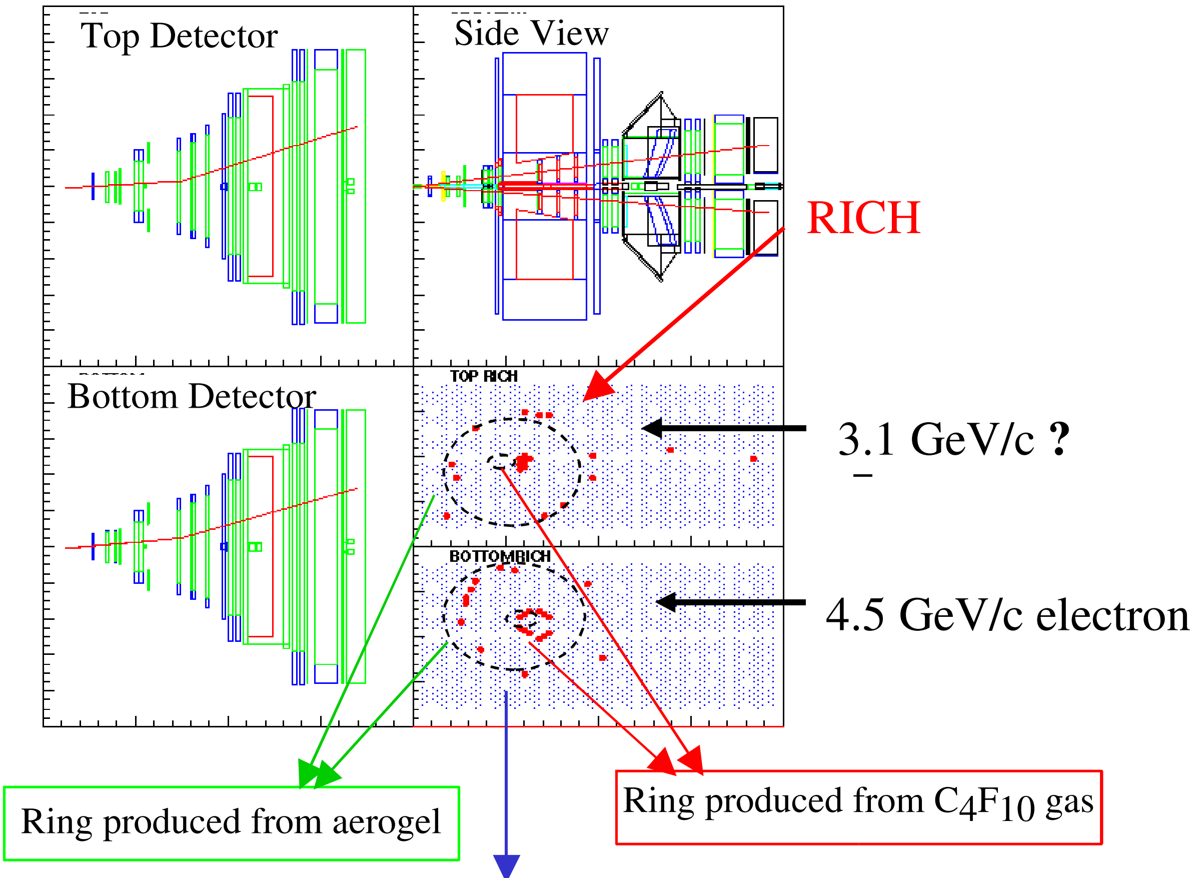
- 1998 June construction completed



Data obtained from RICH

- Hit position of photon detector arrays (PMTs)
- Two kinds of cherenkov rings are produced from dual radiators (aerogel and C_4F_{10})
- ring radius or cherenkov angle ~ depend on particle velocity

Typical ring images produced from the event (e+P –> e' + ? + X)



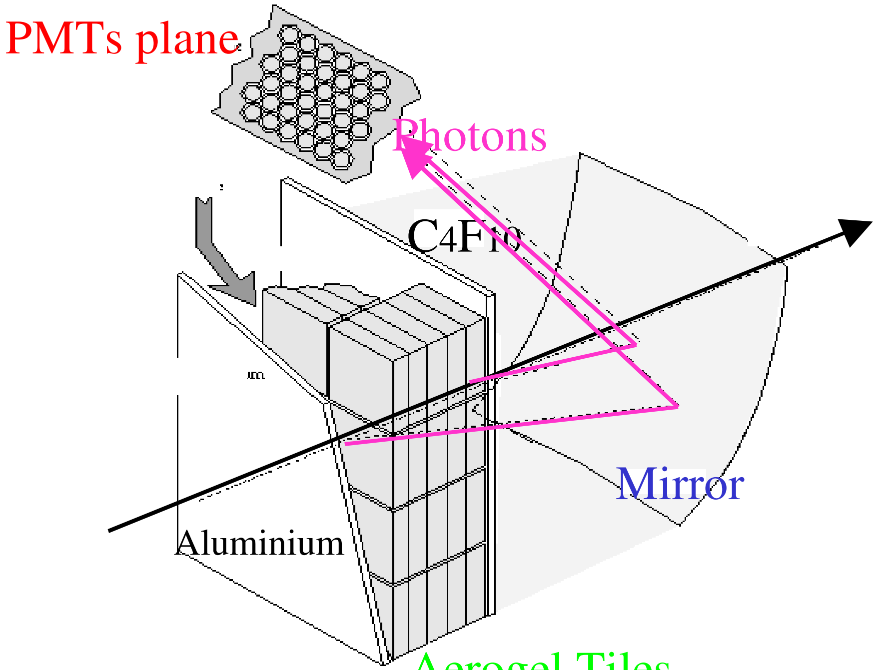
- Due to the imaging system, the rings are not actually circles, but deformed ellipses.
- Reconstruction of the cherenkov angle: by Inverse Ray Tracing using the PMT hits and the tracking information.

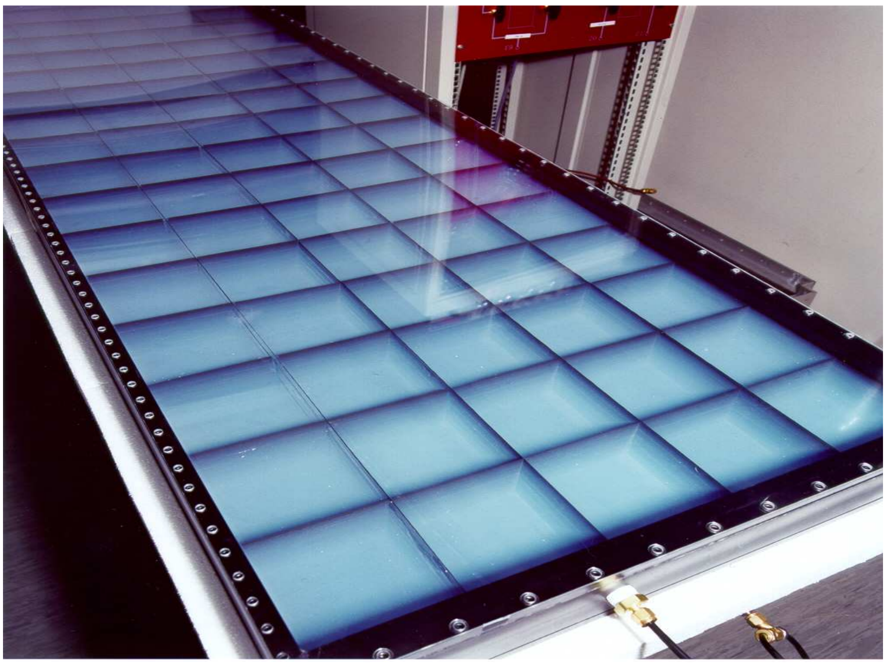
hermes

asuhiro Sakemi

The Aerogel Radiator

- $17 \times 5 \times 5 = 425$ aerogel tiles per (top or bottom) detector
- Aerogel tile size : $114 \times 114 \times 11.3$ mm^3
- Gas tight AL container filled with dry N_2
- Black sheets between tile stacks to absorb scattered and internally reflected light

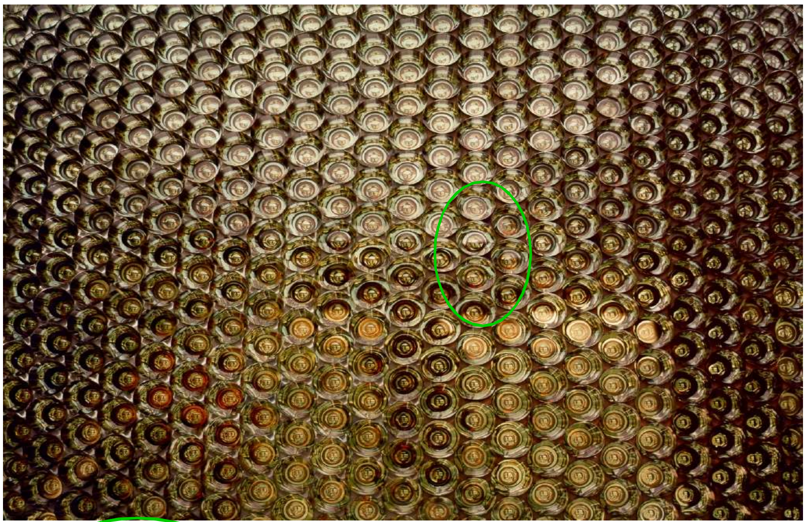




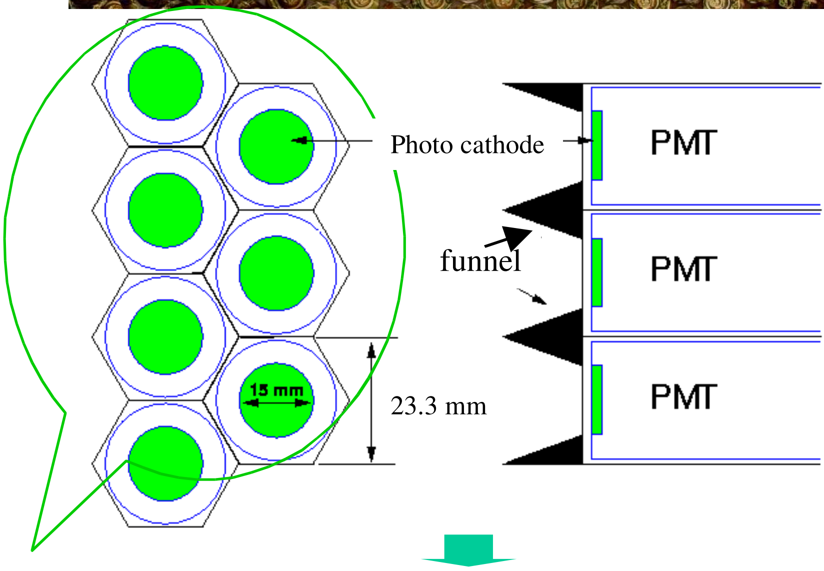
Photon Detector

Photon detector

- Hexagonal grid of 1934 PMTs per detector half
- PMT Type: Philips XP1911/UV
- 3/4 inch PMT diameter
- Active area increased to 91 % by reflective funnel cones



Front view



Side view

Readout

- 3864 PMT channels (top and bottom together)
- No analog information: use LeCroy PCOS4 system
- 1024 PMTs –> 64 preamp cards –> 4 back planes with FPGA –> 1 VME module

asuhiro Sakemi

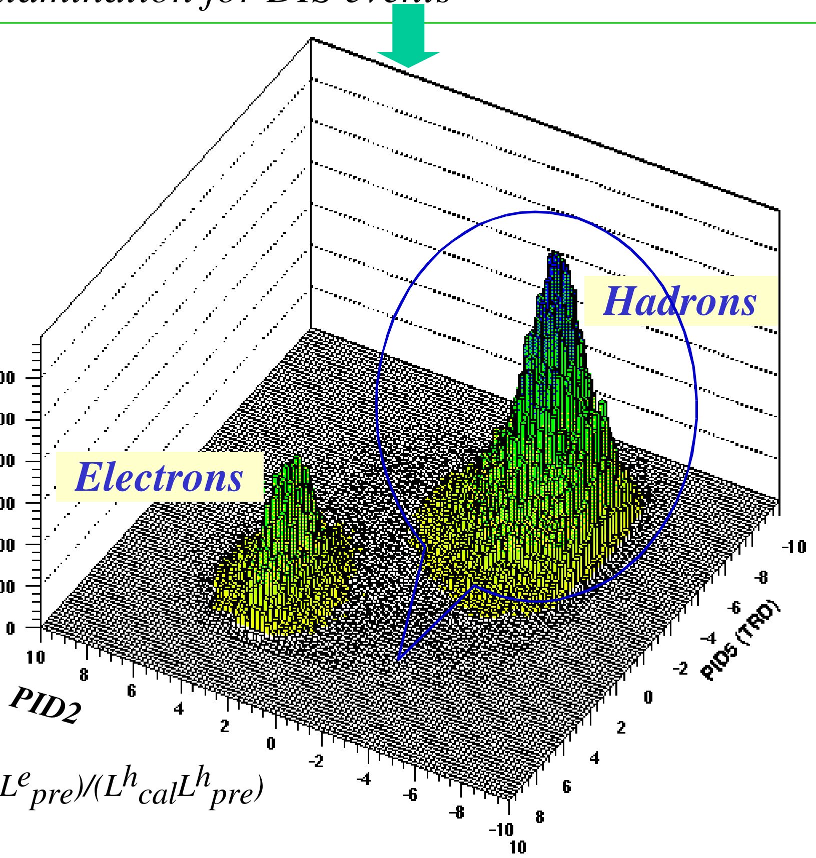
Front view of RICH

- Just before aerogel radiator installation
- The image of PMTs on the mirror can be seen

asuhiro Sakemi

Hadron – Electron separation

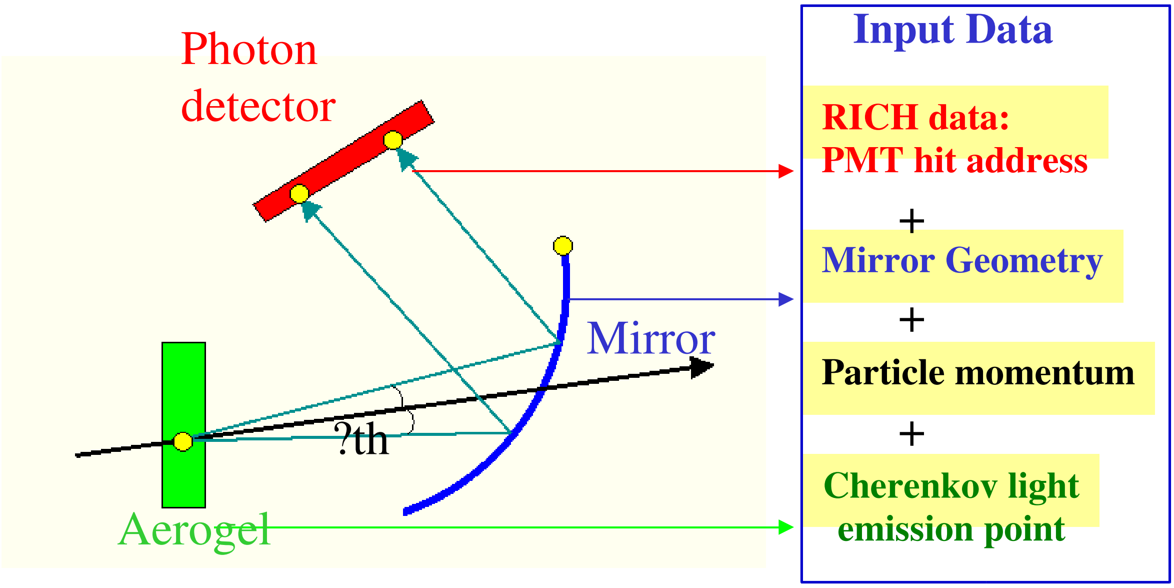
- **PID:step1: Hadron – Electron separation**
  - *Electron and hadron separation with calorimeter, preshower, and TRD*
  - *98 % electron identification efficiency with < 1 % hadron contamination for DIS events*



PID2 = $\log_{10} (L^e_{cal} L^e_{pre})/(L^h_{cal} L^h_{pre})$

- **PID:step2: Hadron (?,K,p) Identification with RICH**
  - *Method1 :* *Inverse Ray Tracing method(IRT) :*
    Reconstruction of the cherenkov angle by inverse ray tracing using the PMT hits and the tracking information
  - *Method2 :* *Direct Ray Tracing method (DRT) :*
    Construction of the expected hit probability densities for a given track and given particle type hypotheses by direct ray tracing

PID with Inverse ray Tracing (IRT)



PID with Inverse Ray Tracing

– *For each hit, calculate the cherenkov angle ?$_{th}$ which the photon would have to have been emitted.*
– *Impose windows on the obtained angular spectra based on the assumed particle type with measured momentum*
– *If there are entries in the above windows, calculate average angles <?> for each particle hypothesis*
– *Convert these average angles into likelihood for the given hypothesis with the eq*

$$\mathcal{L}(\langle\theta\rangle) = exp(-\frac{(\theta_{th} - \langle\theta\rangle)^2}{2\sigma^2_{\langle\theta\rangle}})$$

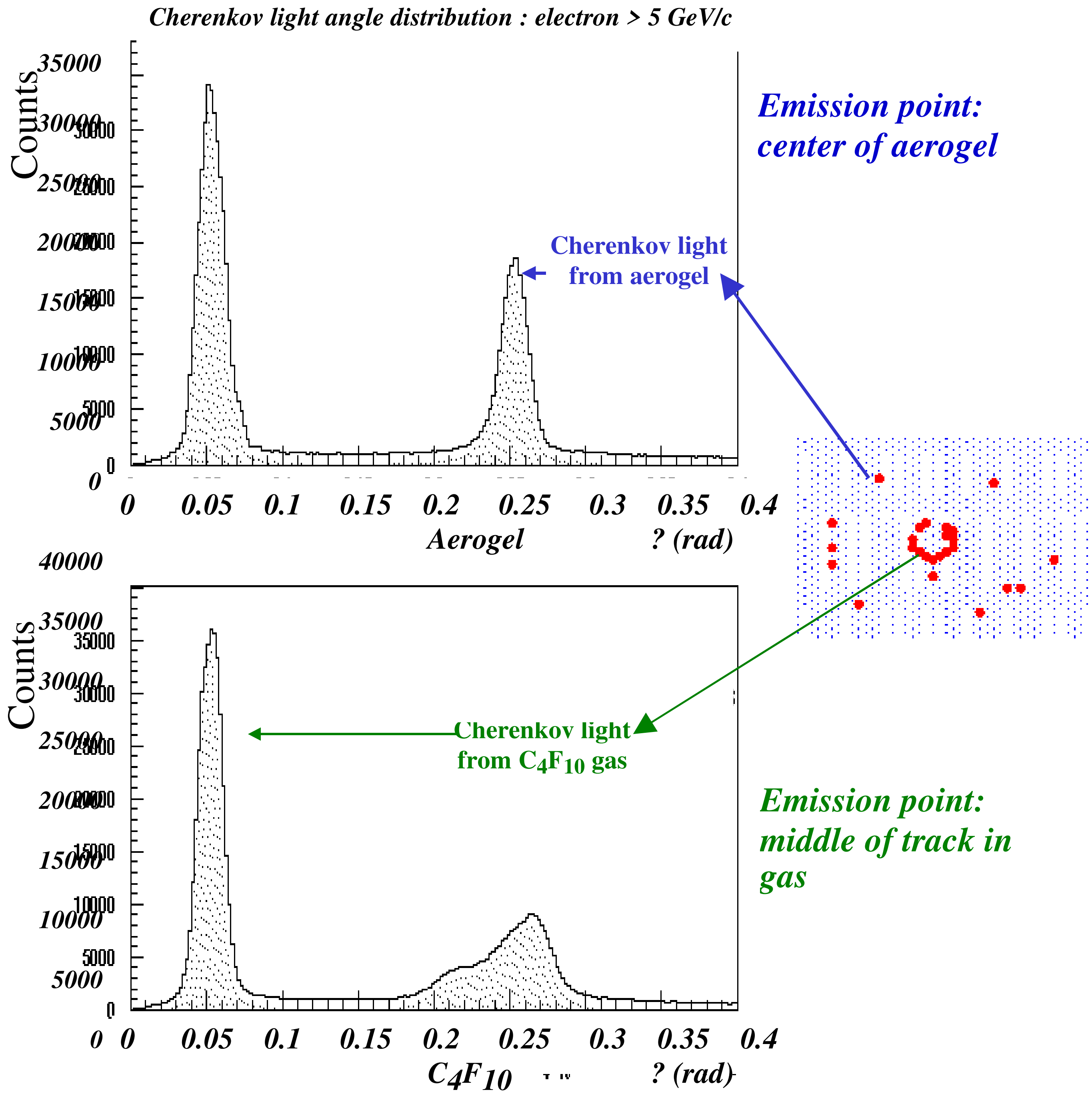
Output Variables

– *Reconstructed Cherenkov Angles*
– *Likelihood for each particle type*
– *Hadron Type*
– *Quality Parameters (Likelihood ratio): $r_{qp} = log\ (L_1 / L_2)$*

hermes

asuhiro Sakemi

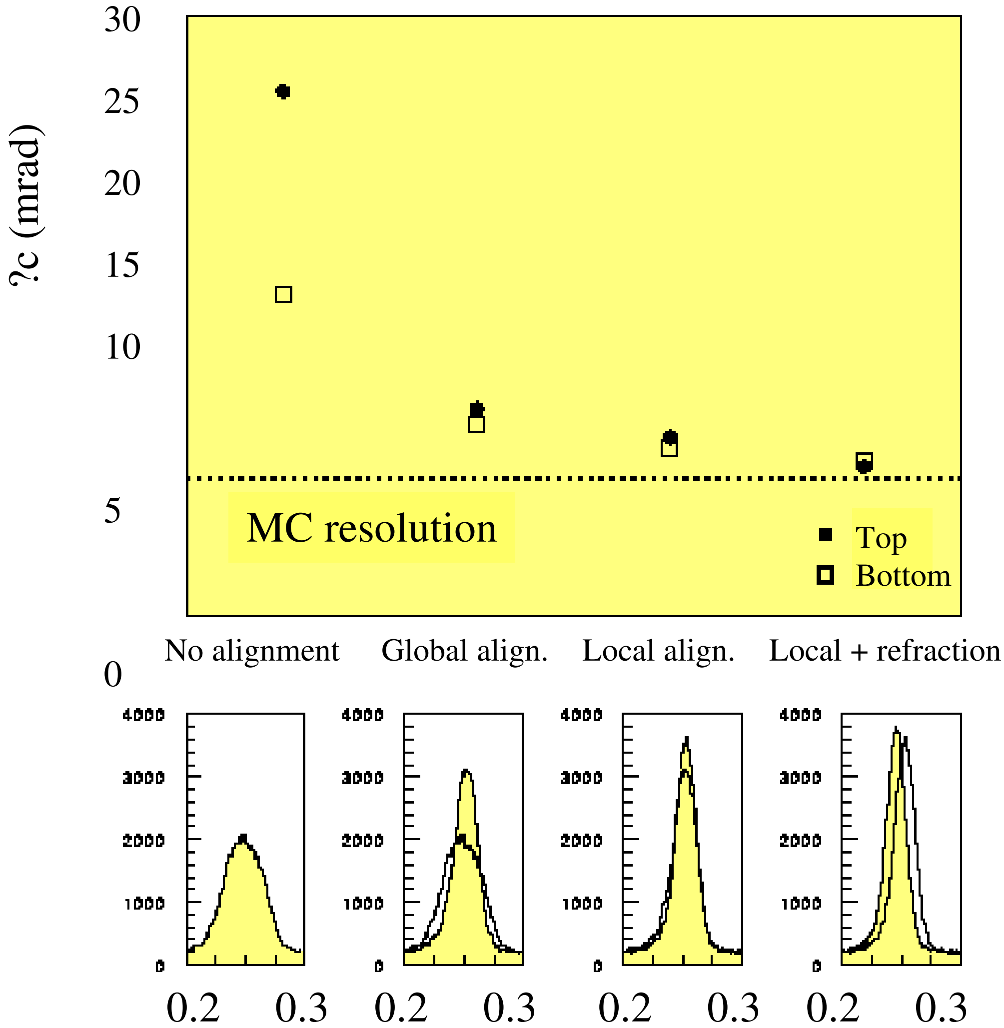
IRT spectra and PID



asuhiro Sakemi

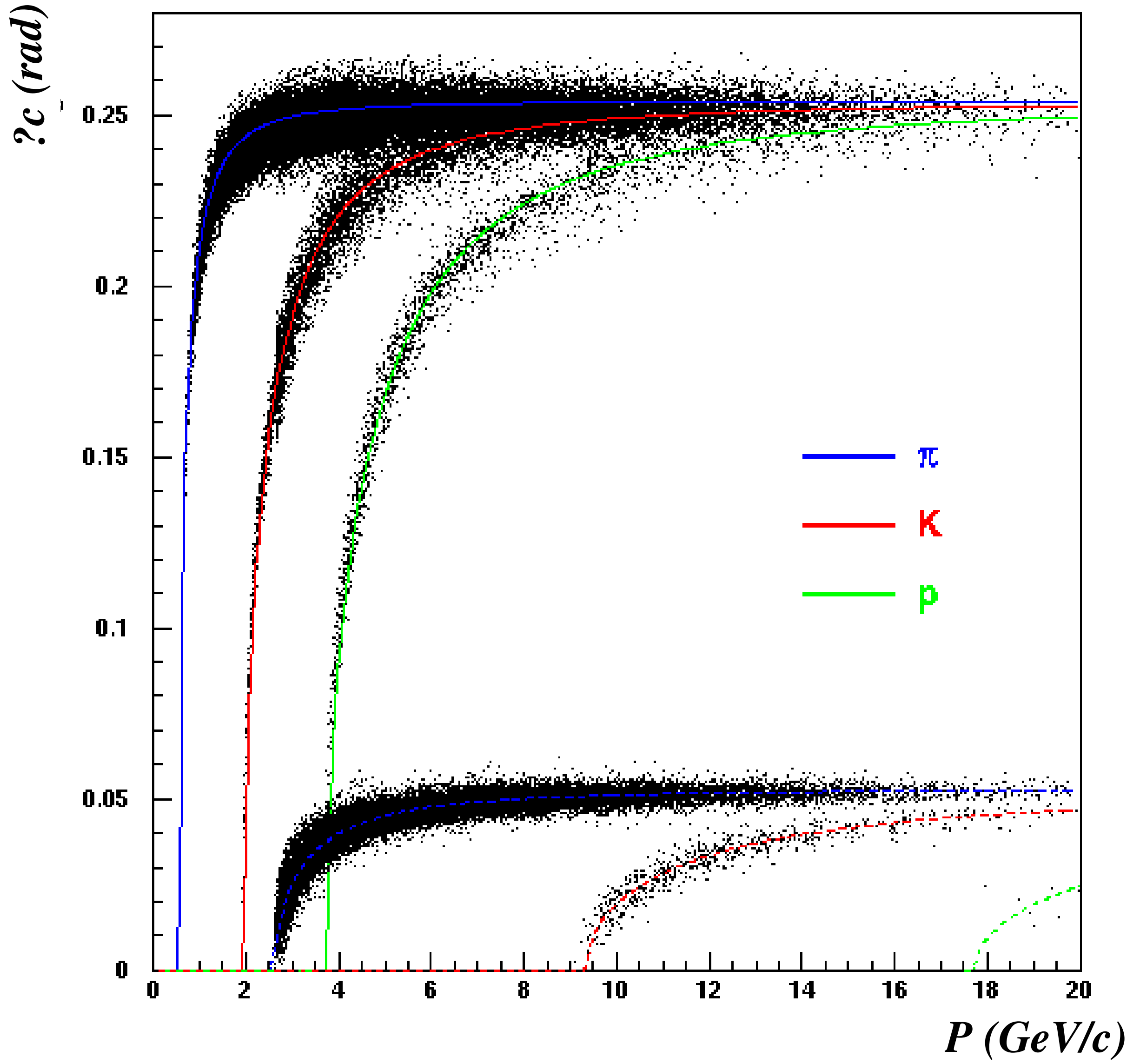
Single photon resolution

- Including
  - *Mirror alignment*
  - *Aerogel boundary correction*
- After the local alignment and the aerogel boundary correction, the single photon resolution is within 10 % of the value of about 7 mrad expected from Monte Carlo



asuhiro Sakemi

HERMES RICH – Average Angles



asuhiro Sakemi

Identification Probabilities

• A useful set of basic parameters are the identification probabilities P_t^i that a particle with the true type t is identified as type i ;

$$P_t^i = \frac{N_t^i}{?_j N_t^j}$$

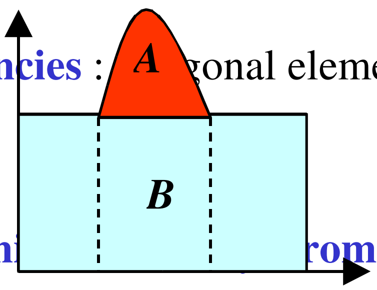
• Together they form the matrix $P = P_t^i$, which in the case of three particle types (?, K, p) has the form

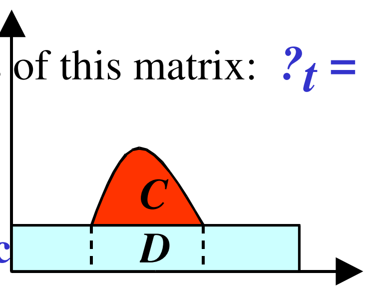
$$P = P(?, K, p) = \begin{pmatrix} P_?^? & P_K^? & P_p^? \\ P_?^K & P_K^K & P_p^K \\ P_?^p & P_K^p & P_p^p \\ P_?^X & P_K^X & P_p^X \end{pmatrix}$$

Invariant mass peak with one hadron identified

defi

Invariant mass peak with both hadron identified





• **Efficiencies** : ...gonal elements of this matrix: $?_t = P_t^t$

• **Determi... rom dec...**

(1) fill two histograms

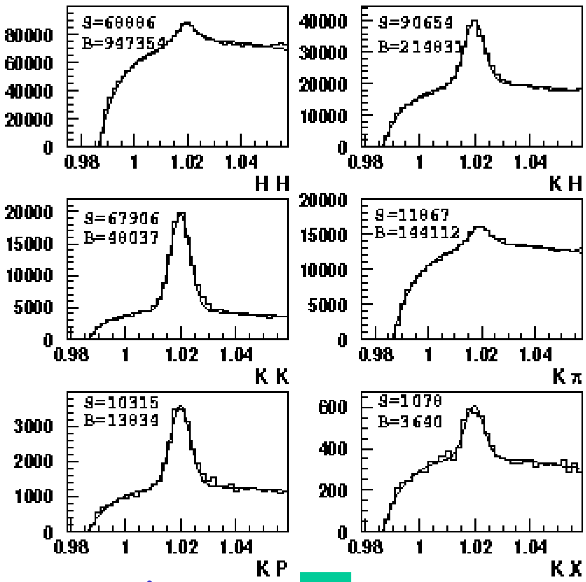
asuhiro Sakemi

e.g.) kaon pairs from ? decays will form a peak, if the invariant mass is constructed under the kaon pair hypothesis. Other hadron pairs will form a background without peak.

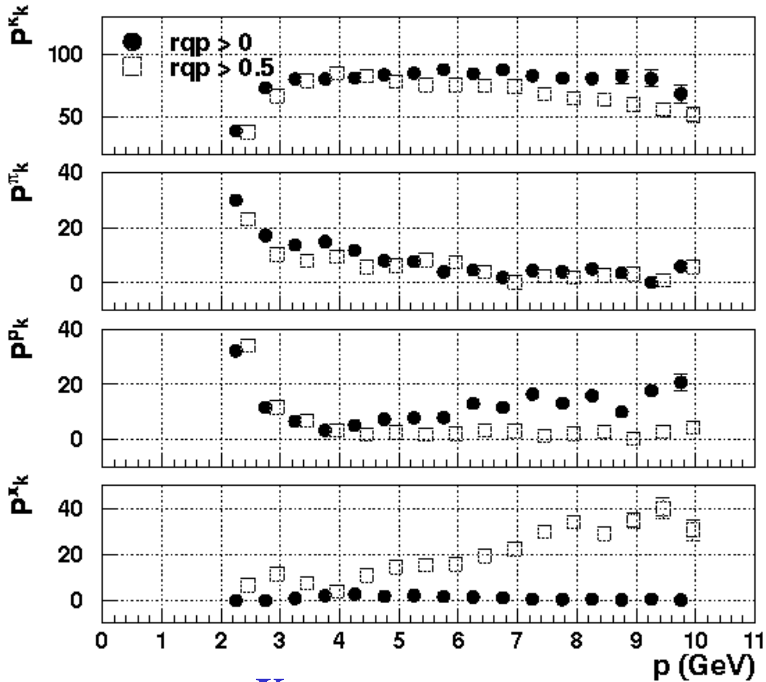
(2) The ratio of the two peak integrals gives the probability

Kaon Probabilities from ?? K$^+$K$^-$

Invariant mass spectrum



$P_k{}^i = C/A$

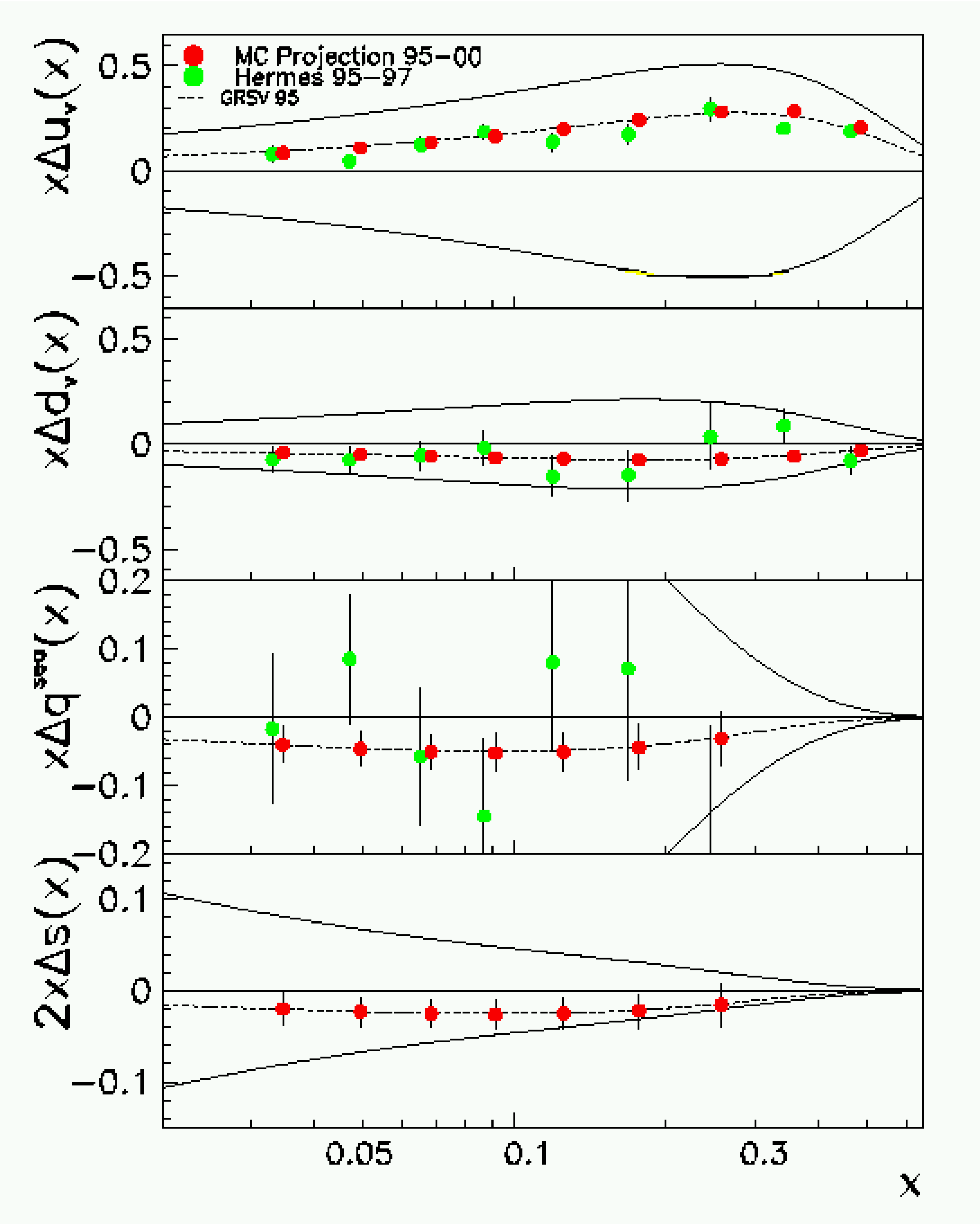


$?_K = P_K{}^K = 0.750$ *for P > 2 GeV/c*

$?_? = P_?{}^? = 0.915\ (?^0?\ ?^+?^-)$

$?_p = P_p{}^p = 0.726\ (?\ ?\ p?^-\ )$

Monte Carlo Projection up to 2000



Projection based on 8 × 10^6 DIS events with semi–inclusive K$^{\pm}$ asymmetries.

Summary and Outlook

Dual radiator RICH with aerogel and C_4F_{10} gas was developed

The HERMES RICH is operating routinely without problems

PID of ?,K,p over wide momentum range(2 ~ 15 GeV/c)

PID based on IRT is working

Extraction of efficiencies and purities from data is in progress

- *in the future*

Measurements of spin asymmetries of ?, K

– $A_1^{?\pm}, A_1^{K\pm}$

Complete flavor decomposition

– *?u, ?u, ?d, ?d, ?s ?s*

Information of strange sea polarization ***?s***