PHENIX Focus: Ring Image CHerenkov counter

K. Ozawa

For the RICH group

RICH in reality

Ring Image CHrenkov counter (RICH)

Contents:

- RICH in reality
  - Gas, Mirror, PMT and Electronics
- What can we do with this detector?
- How do we analyze data?

What a large detector!!

Large gas volume!
- 40 m^3 /arm

Large mirror!
- 20 m^2 /arm

So many PMT's!
- 2560 /arm

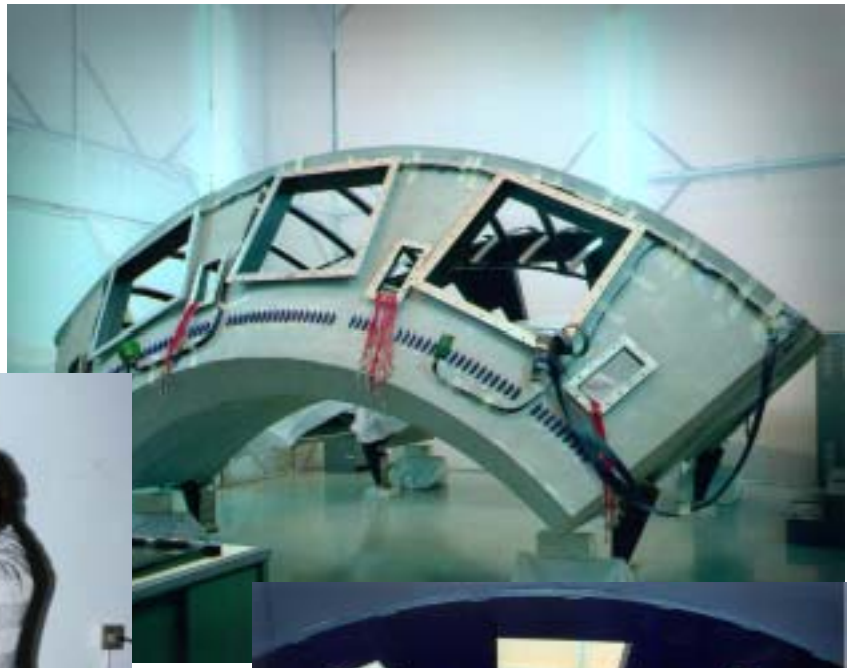
I hope
you will be interested in
electron measurements
and will be a subsystem
assistant after this talk.

Integration of RICH

Purpose of this section

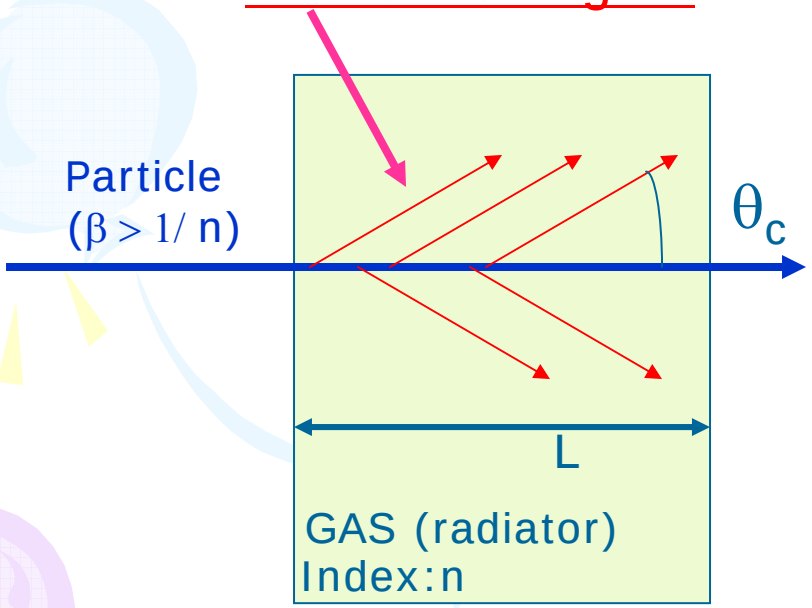
Be familiar with RICH components

- Gas vessel
- Mirror
- PMT and arrays
- Electronics



How do we use gas?

- When a particle travels in gas volume,
  - If particle speed exceeding the speed of light in gas (*c*/*n*)
  - Photons are radiated
  - Cherenkov lights!



Threshold of light emission

$\beta > 1/n$

Emission angle

$\cos\theta_c = (\beta n)^{-1}$

Light Yield

Proportional to L and $\sin^2\theta_c$

If momentum is known,

we can IDENTIFY particle using Cherenkov light measurements.

Specifics in PHENIX RICH

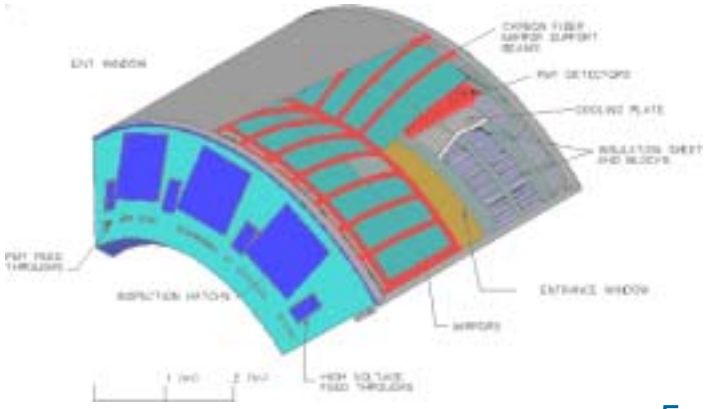
- Threshold depends on the reflection index of gas.
  - CO_2 : n=1.000410, γ_{th} = 35
    - P_{th} = Mass * γ_{th} * β_{th} = Mass * γ_{th} /n
    - Electron: 0.02 GeV/*c*, π: 4.9 GeV/*c*

➡ We can identify electron from 0.02 to 4.9 GeV/*c*.

➡ RICH is Primary electron ID device of PHENIX.

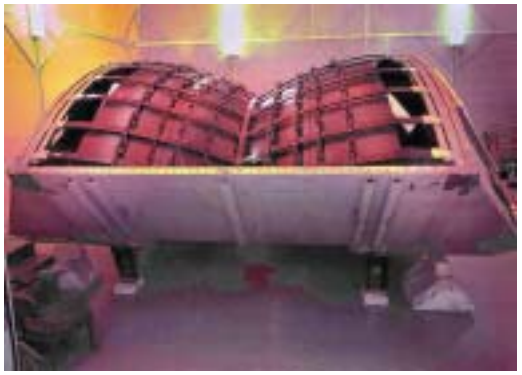
- Maximize Light Yield
  - the length of the radiator.
  - We need LARGE gas vessel.

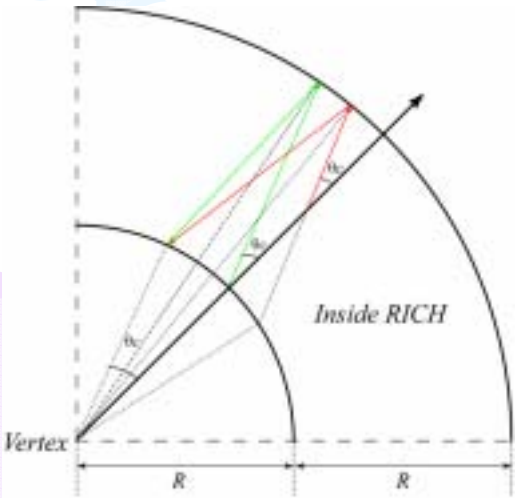
The vessels are designed and fabricated at Florida State University

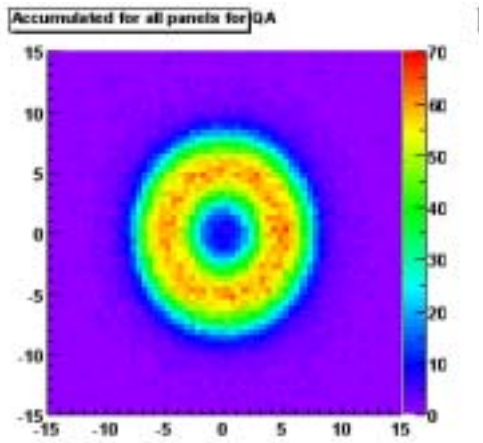


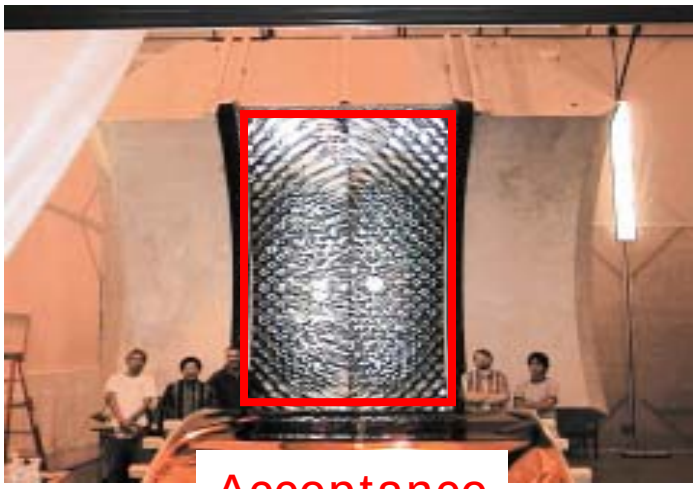
Mirror and ring

- Cherenkov photons emitted in parallel.
- Using **spherical mirror**, photons are focused on PMT surface.
  - Photons make a **ring**.





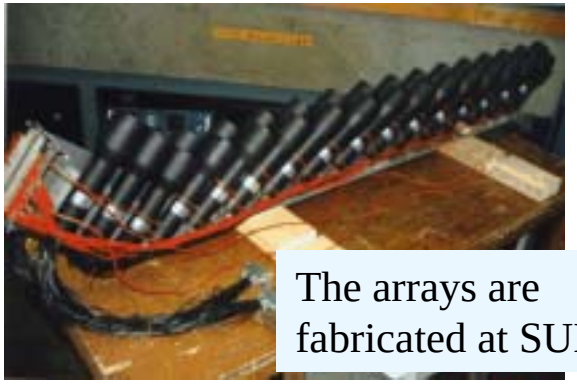




Acceptance

PMT and arrays

- Photon detection device
  - Hamamatsu H3171S
    - Cathode Diameter: 25 mm
    - Tube Diameter: 29 mm
    - Cathode: Bialkali
    - Gain: > 10^7
    - Operation Voltage: -1400 ~ -1800V
    - Rise Time: < 2.5ns
    - Transit Time Spread: < 750ps
- A Winstone cone
  - shaped conical mirror is attached to each PMT
  - Entrance: 50 mm, Cut off: 30°
- Supermodule (2x16 PMTs grouped)
  - 40 super-modules per one side
  - 4 sides * 40 * 2* 16 = 5120 PMTs
- 8 PMTs share the same HV channel



The arrays are fabricated at SUNY

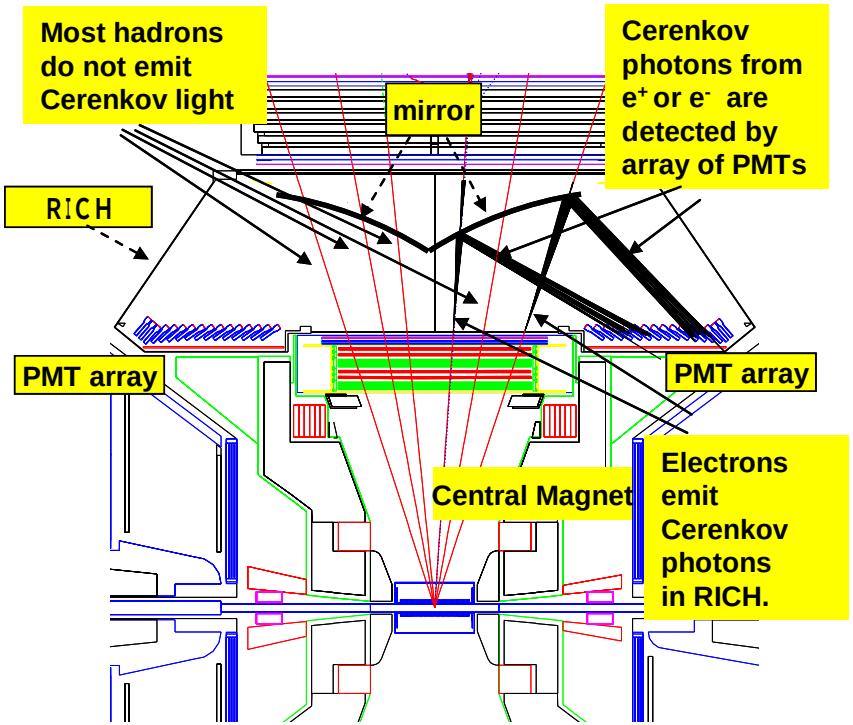
pixel size
1 degree x 1 degree

Electronics

- Readout Signals from 5120 PMTs
  - 0~10 Photon Detection with 10 bits
  - Time Resolution: ~ 200 ps
    - (For Background Rejection)
- Compactness
  - Processes 640 PMT Signals per Crate
  - 9U VME Dimensions
  - One Controller Module
  - Two Trigger Modules
  - Two Readout Modules
  - Ten Analog Modules

Summary of hardware

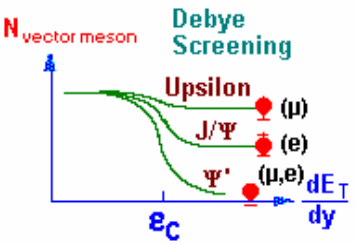
- Electron go thorough the RICH gas volume,
  - Cherenkov photons emitted
  - Photons are reflected by mirror and focused on the PMT surface
  - PMT detect photons

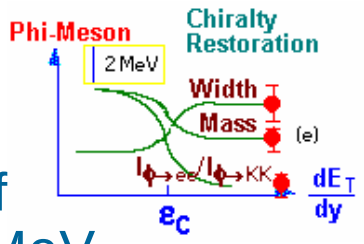


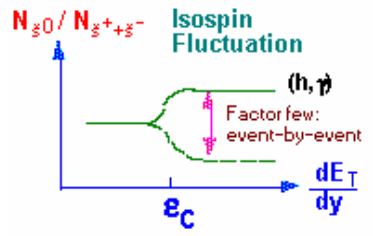
Identify electron from 0.02 to 4.9 GeV/*c*.

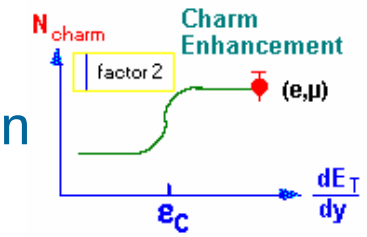
What can we do with RICH?

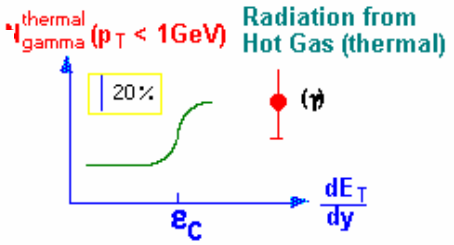
- Measure several kinds of proposed QGP signals.
  - Deconfinement
    - J/Ψ to e+e-
  - Chiral Symmetry Restoration
    - Mass, width, branching ratio of φ to e+e-, K+K- with δM < 5 MeV
  - Thermal Radiation of Hot Gas
    - Prompt γ * to e+e-
  - Strangeness and Charm Production
    - Production of φ, J/Ψ, D mesons
    - Single electron











Electron ID is essential for above measurements.

Charm production

- production mainly via gg fusion in earliest stage of collision
  - sensitive to initial gluon density
- additional thermal production at very high temperature
  - sensitive to initial temperature

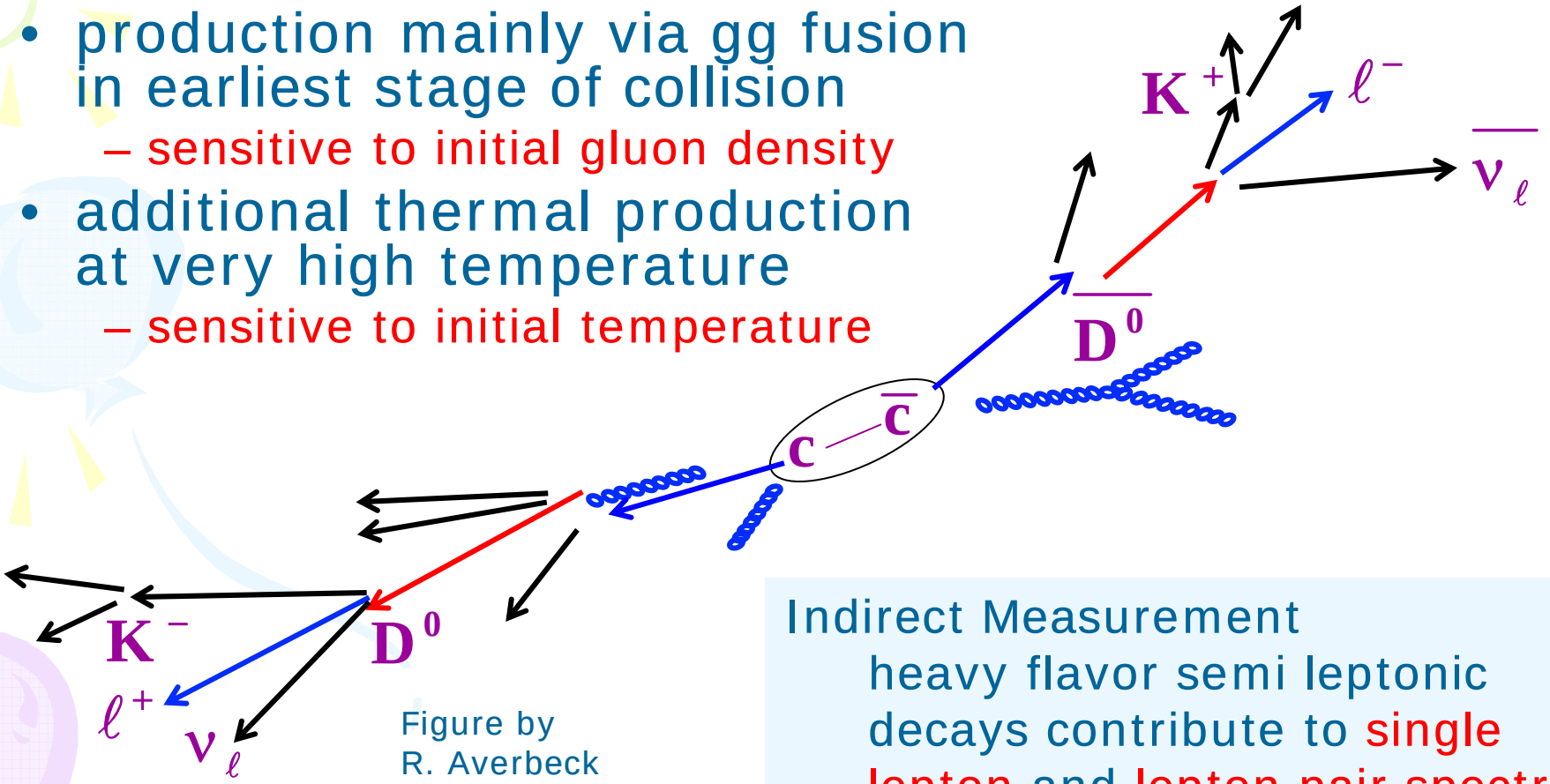
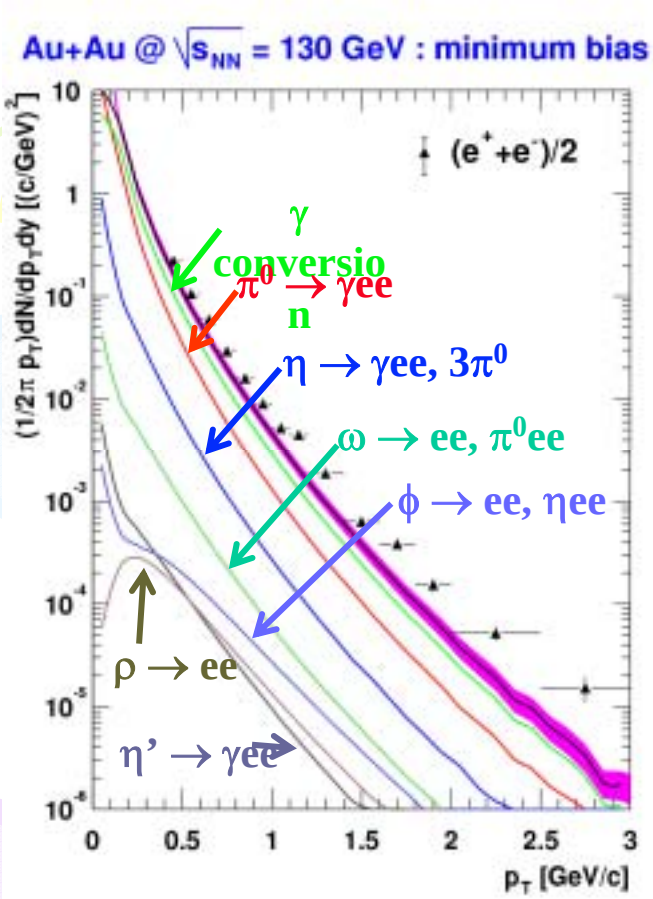


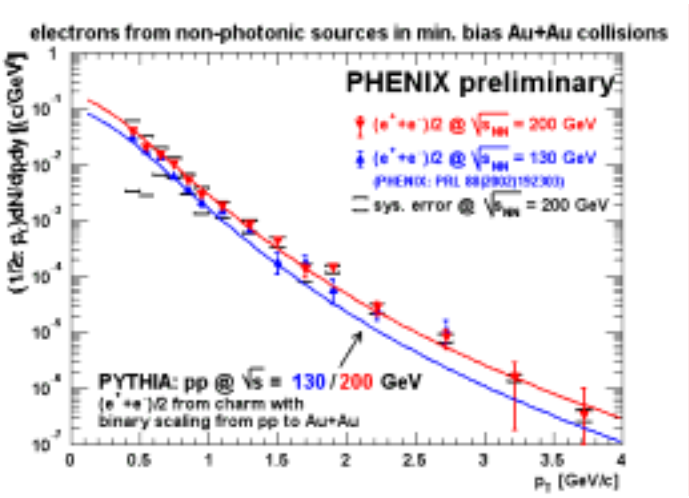
Figure by
R. Averbeck

Indirect Measurement
heavy flavor semi leptonic decays contribute to single lepton and lepton pair spectra

Single electron



- Electrons from photonic source is subtracted from inclusive spectrum.
  - Electrons from non-photonic source is consistent with PYTHIA results normalized by N_binary.

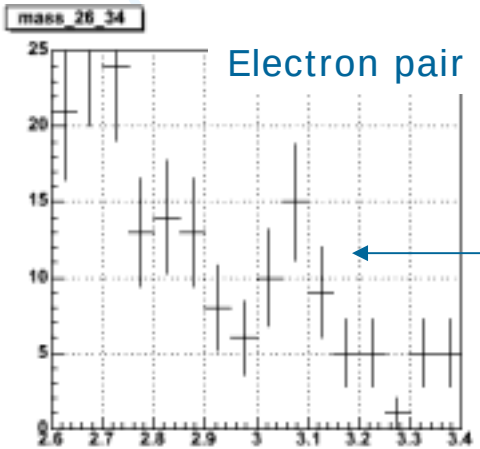


We will soon have a similar results for dAu data.

J/Ψ to e^+e^-

- J/Ψ suppression
  - Predicted by Matsui and Satz
    - Phys. Lett. B178, 416 (1986)
    - Debye screening mechanism
  - Consider normal nuclear absorption
- J/Ψ enhancement
  - Effects of recombination

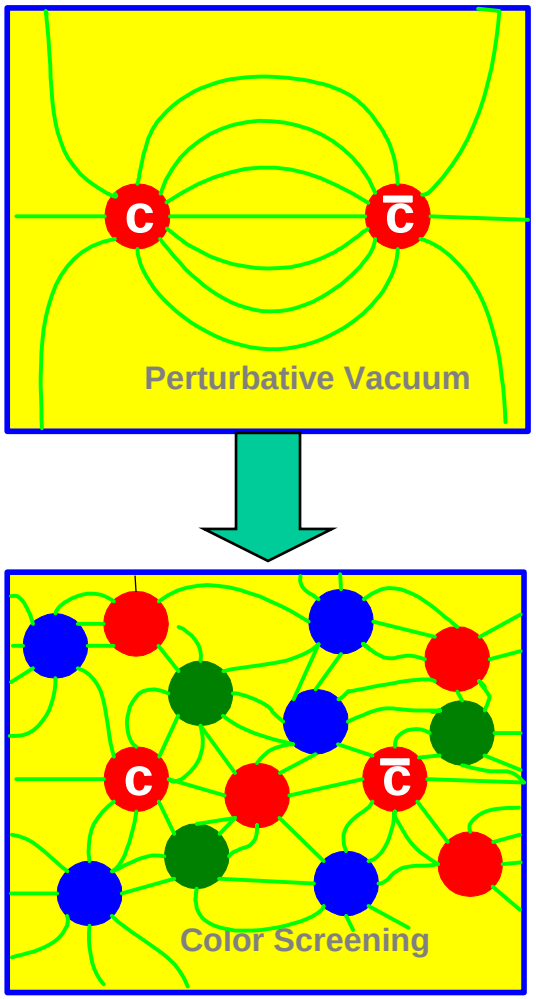
We have to measure J/Y yield carefully.



Electron pair Invariant Mass

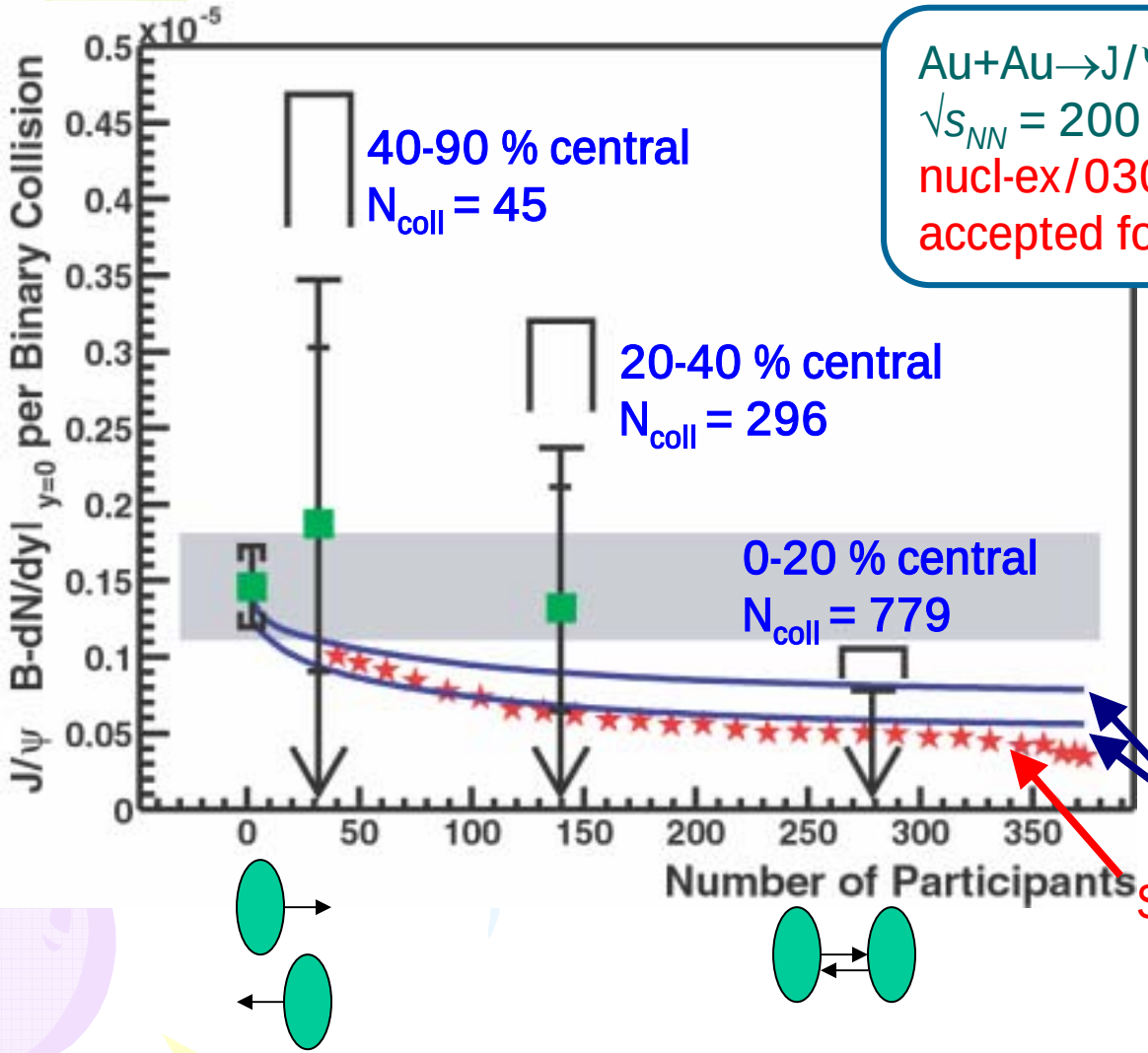
Run2 results

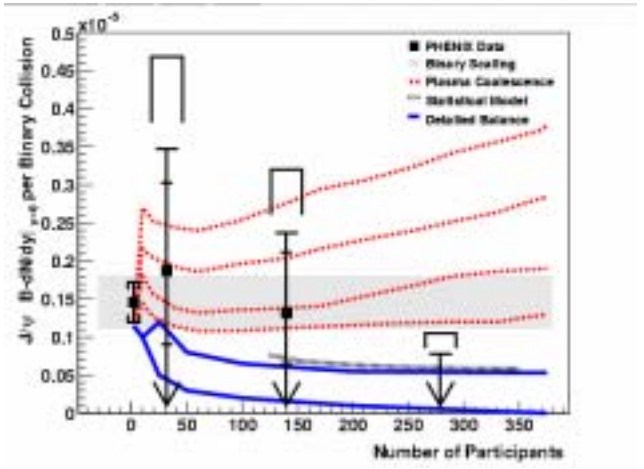
J/Ψ peak
(M = 3.09 GeV)



J/Ψ Results in Run2

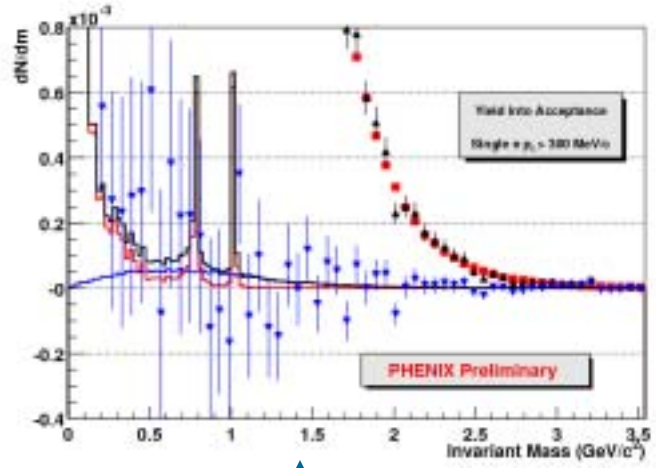
Au+Au→J/Ψ→e⁺e⁻ at
$\sqrt{s_{NN}}$ = 200 GeV
nucl-ex/0305030;
accepted for PRC

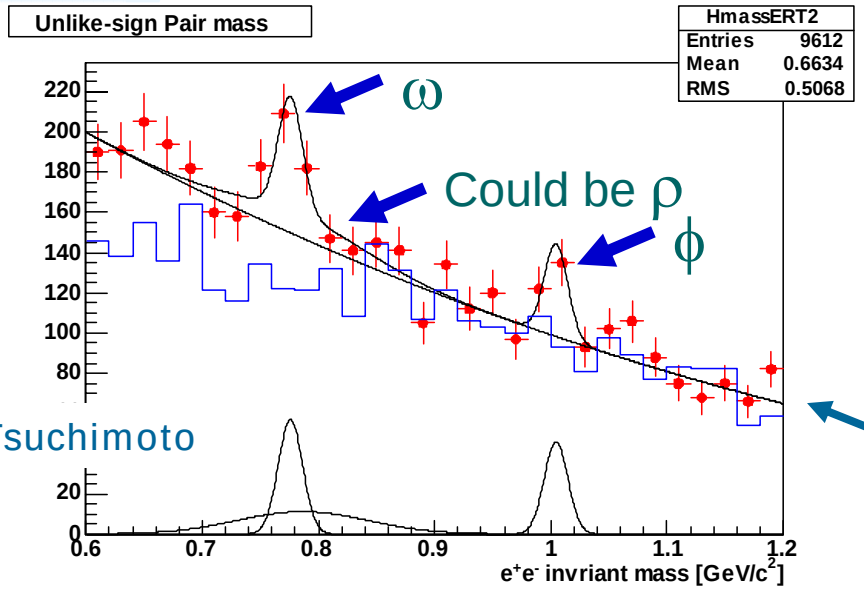




Low mass e^+e^- pair

- Chiral Symmetry Restoration
  - Mass, width of ρ, ω, ϕ to e+e-
- Thermal Radiation of Hot Gas
  - Prompt γ * to e+e-





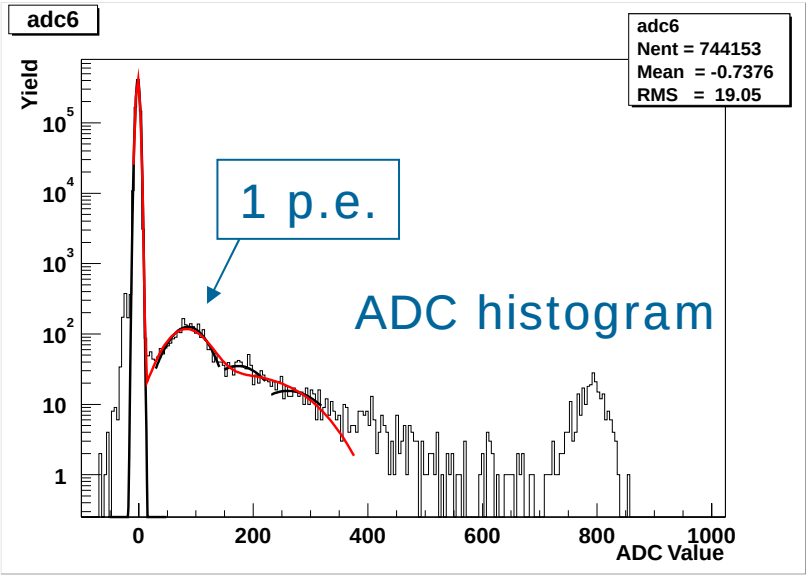
Y. Tsuchimoto

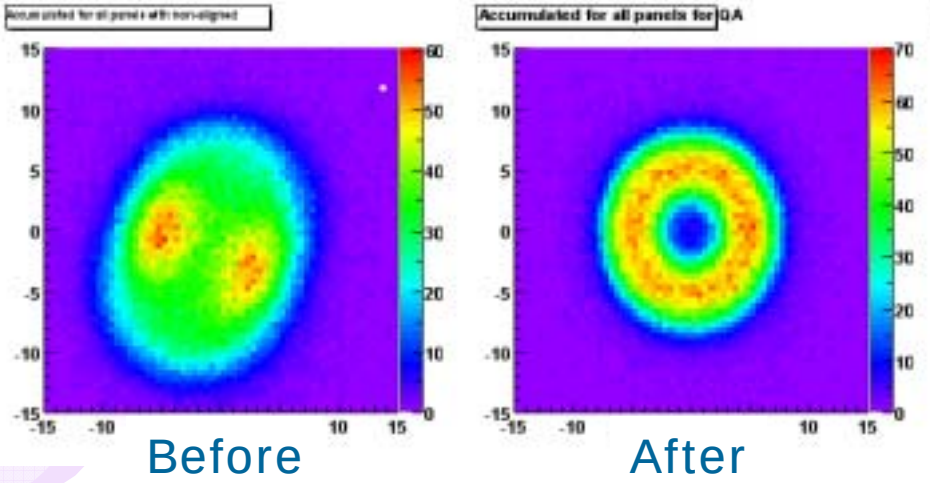
We did not yet get significant results in AuAu. NEED more statistics

Recently, we have an indication of peaks in dAu data.

How to analyze data?

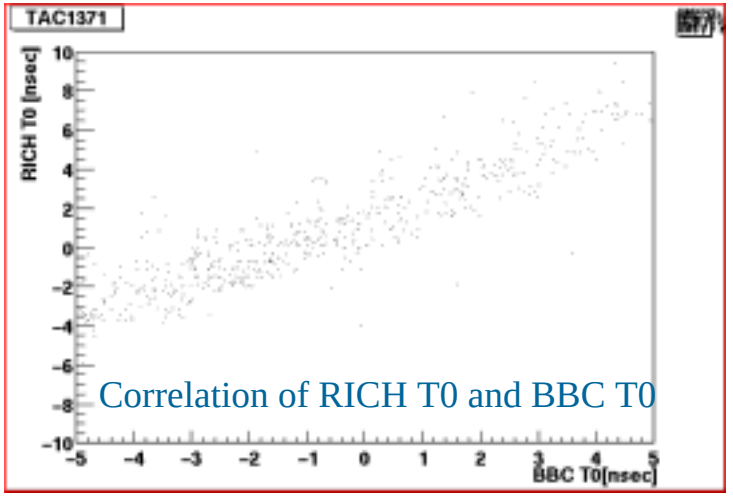
- Purpose of this section
  - Be familiar with electron ID parameters
- Calibration
  - Number of photo-electrons of each PMT
  - Timing of each PMT
  - Mirror alignment





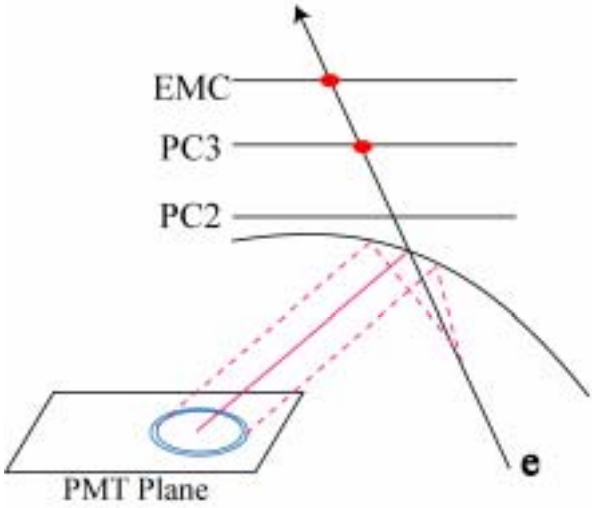
Before

After

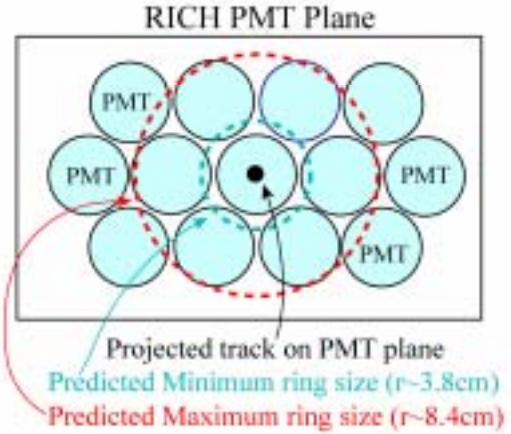


How to identify electrons?

- Main parameters in RICH
  - Distance between ring center and track projection (disp)
  - Number of hit PMT in a region (n0)
  - Number of photo-electron in a region (npe0)
  - Ring shape (chi2/npe0)



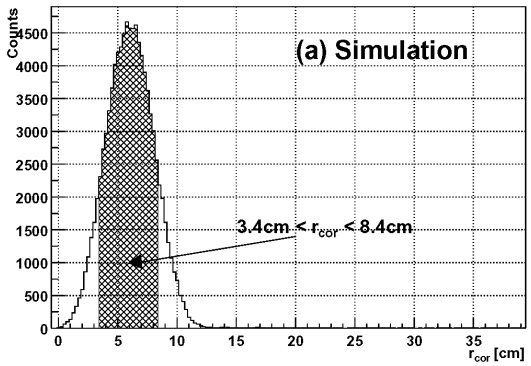
1. **According to the track information, projection point is calculated.**
2. **Find PMT hits near projection point in the region (3.4 cm < r < 8.4 cm)**
   Numbers come from position resolution of PMT hits.
3. **Above parameters are calculated using projection point and PMT hit information**

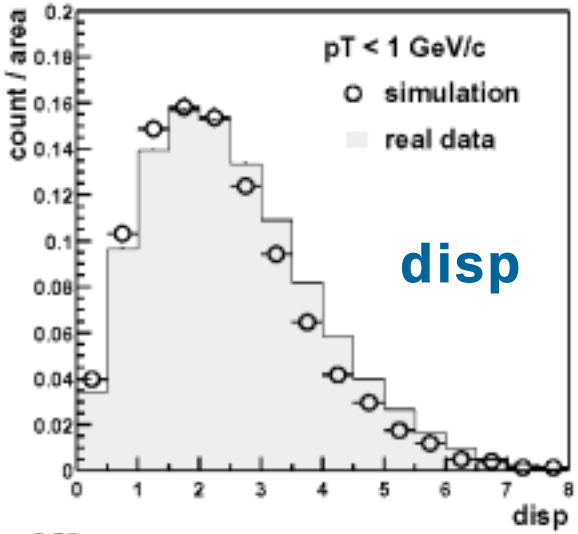


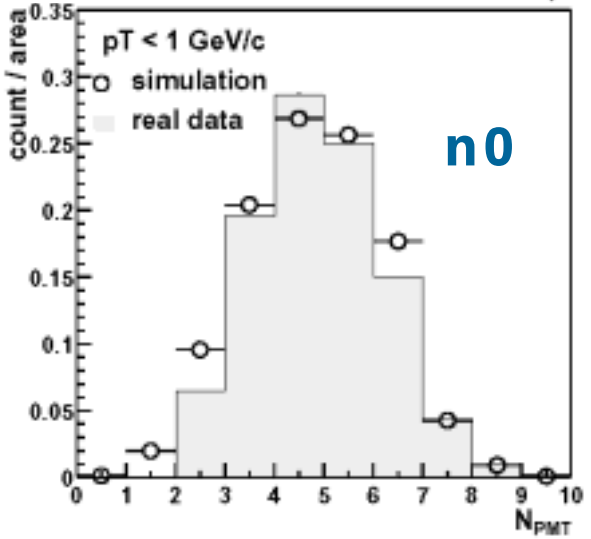
Track-Ring association

- Distance between projected track and ring center (disp)
  - Ring center is calculated weighted mean position of hit PMTs.
  - $R_{center} = (\Sigma_i n.p.e_i * R_i) / \Sigma_i n.p.e_i$
  - Also, npe0 = $\Sigma_i n.p.e_i$
- Number of hit PMTs in the region (n0)

Distance between R_{center} and hit PMT position

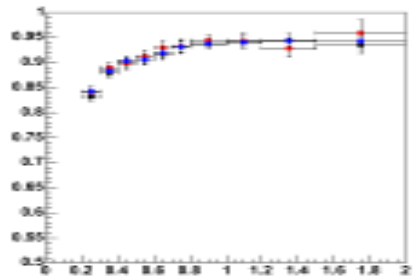




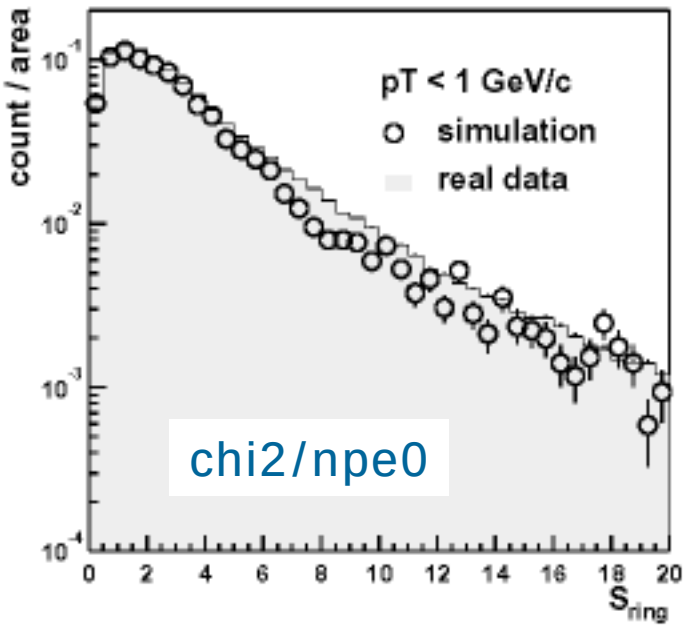


Ring shape

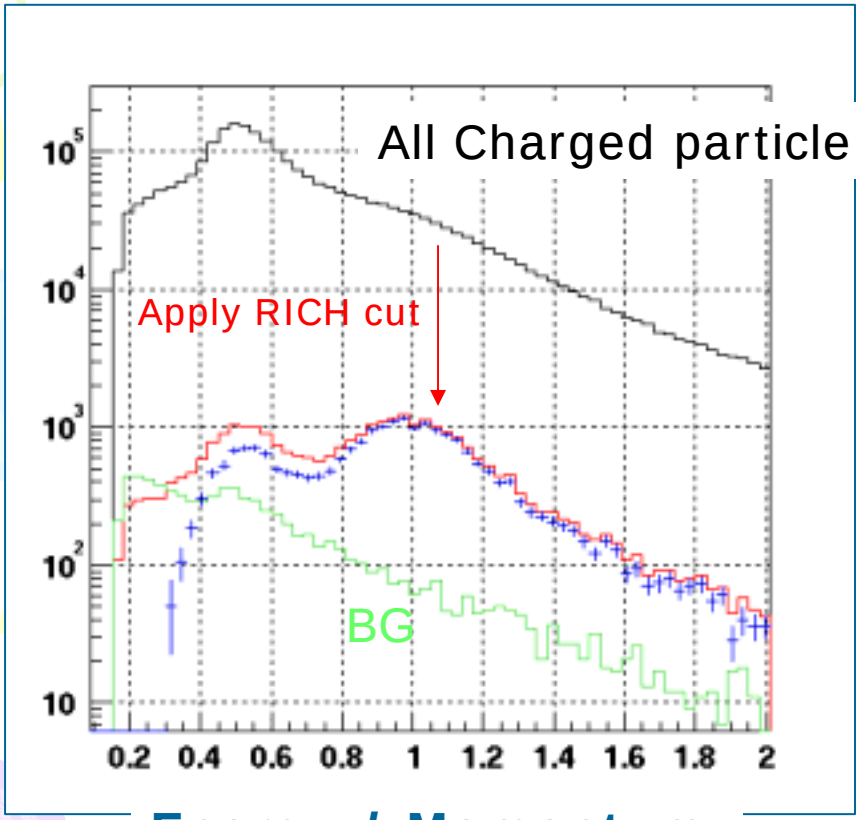
- Difference from expected ring shape are evaluated using the parameter below.
  - chi2 = $\Sigma_i ((R_i - R_0)^2 * n.p.e_i) / \Sigma_i n.p.e_i$
  - R_0 = 5.9 cm
    - Expected ring radius
  - Also, npe0 = $\Sigma_i n.p.e_i$
  -
- EID Efficiency is evaluated using both simulation and data.



Effiency Calculation using conversion peak by S. Lebedev



How good it is.



- Energy / momentum
  - For electron, it should be 1.
- RICH cut suppress back ground by about factor 100.

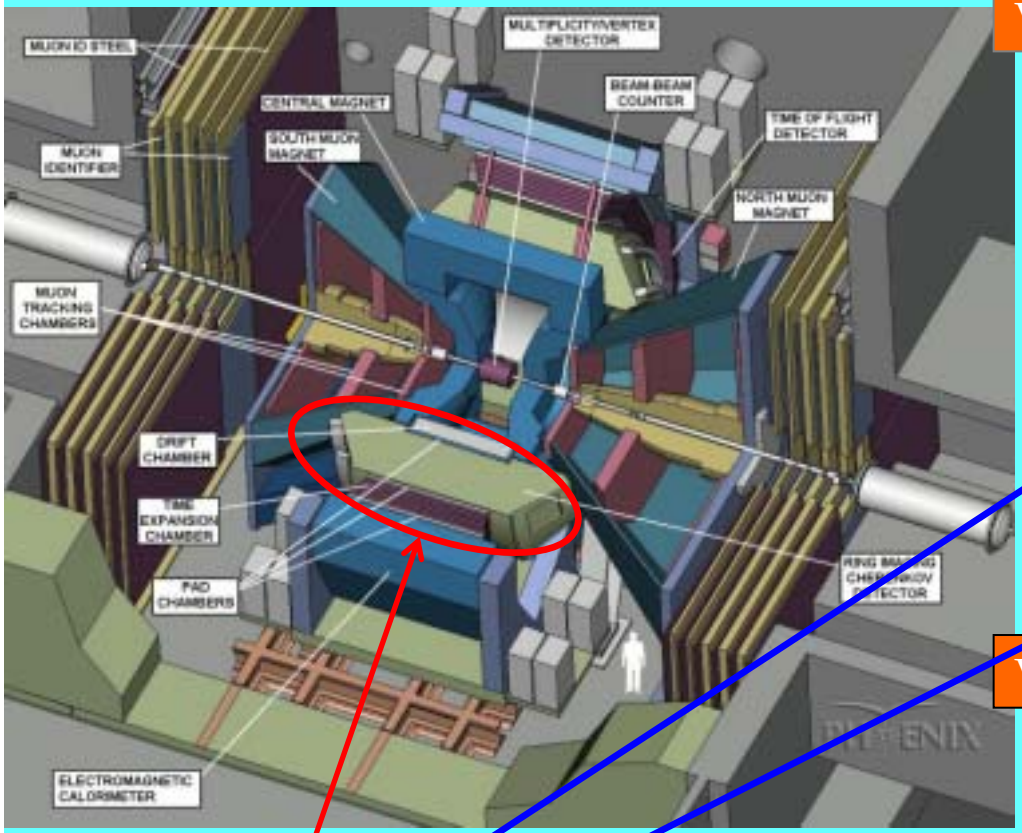
RICH works well.
We can continue making progress in QGP physics using electron measurements

Summary

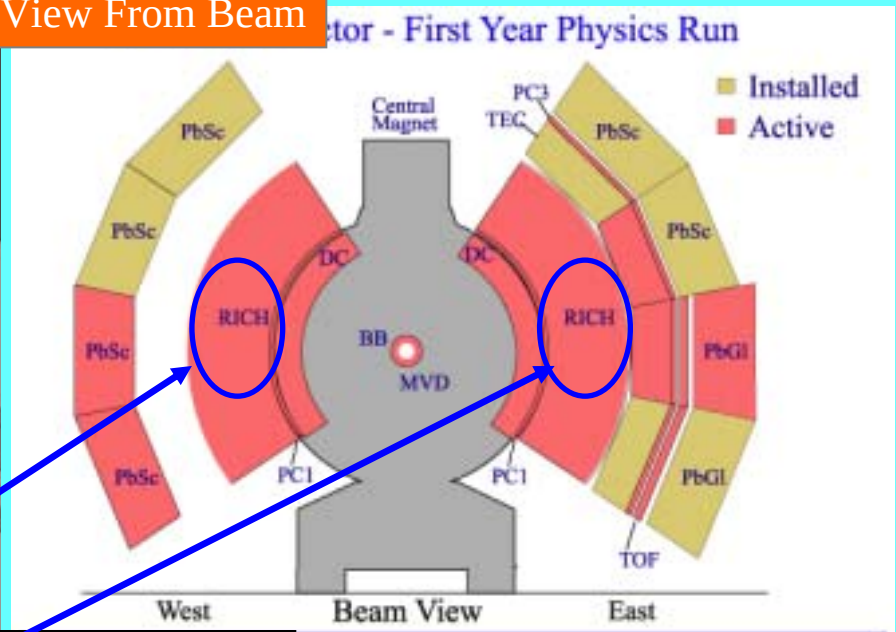
- RICH is a large detector and has very large gas volume to identify electrons using cherenkov lights.
- RICH is successfully constructed and operated without major problems.
- Electron identification is an essential issue to investigate QGP physics experimentally.
- Electron identification parameters of RICH are based on the charge information and the ring shape.
- I hope you are interested in these measurements and RICH operations.

Back Up from the last year

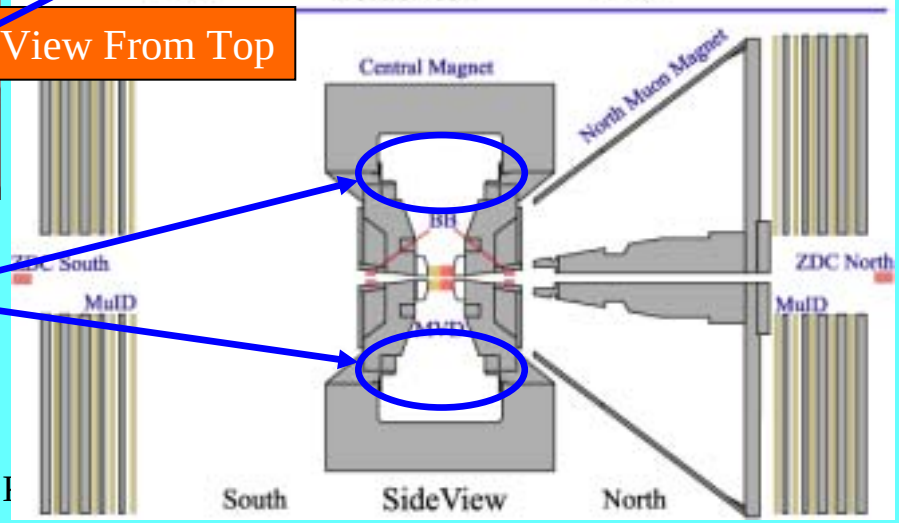
Look for the RICH in PHENIX Detector System



View From Beam



View From Top



This, *this*!, *this*!!, *and this*!!!

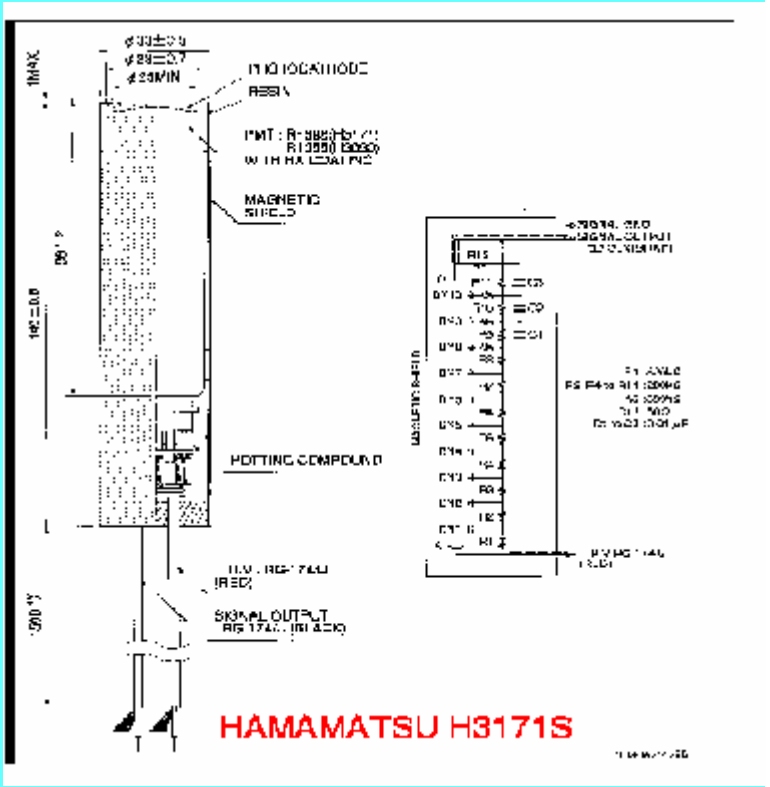
Central Arms
Coverage (E&W)
$-0.35 < y < 0.35$, $30^o < |\phi| < 120^o$

RICH PMT

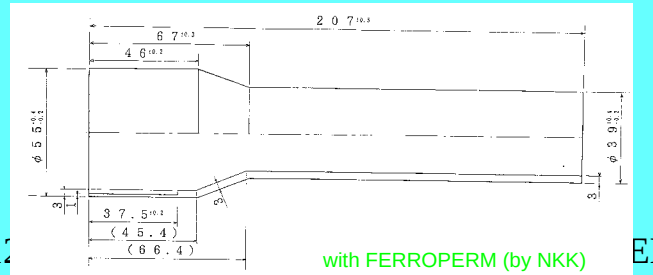
Hamamatsu H3171S

- Cathode Diameter: 25 mm
- Tube Diameter: 29 mm
- Cathode: Bialkali
- Gain: > 10^7
- Operation Voltage: - 1400 ~ -1800 V
- Dark current: < 100 nA at Gain=10^7
- Cathode Luminous: >70 (mA/lm)
- Blue Sensitivity: > 9(mA/lm)
- Quantum efficiency: >19% at 300 nm
  >5 % at 200 nm
- Rise Time: < 2.5ns
- Transit Time Spread: < 750ps

Total number of PMTs in RICH: 5120



- Each PMT is housed in a magnetic shielding case
  - First 900 PMTs: Soft iron and mu-metal
  - Other 4220 PMTs: FERROPERM (NKK)
- A Winstone cone shaped conical mirror is attached to each PMT to collect Cherenkov light
  - Entrance: 50 mm, Exit: 25 mm, Cut off: 30°

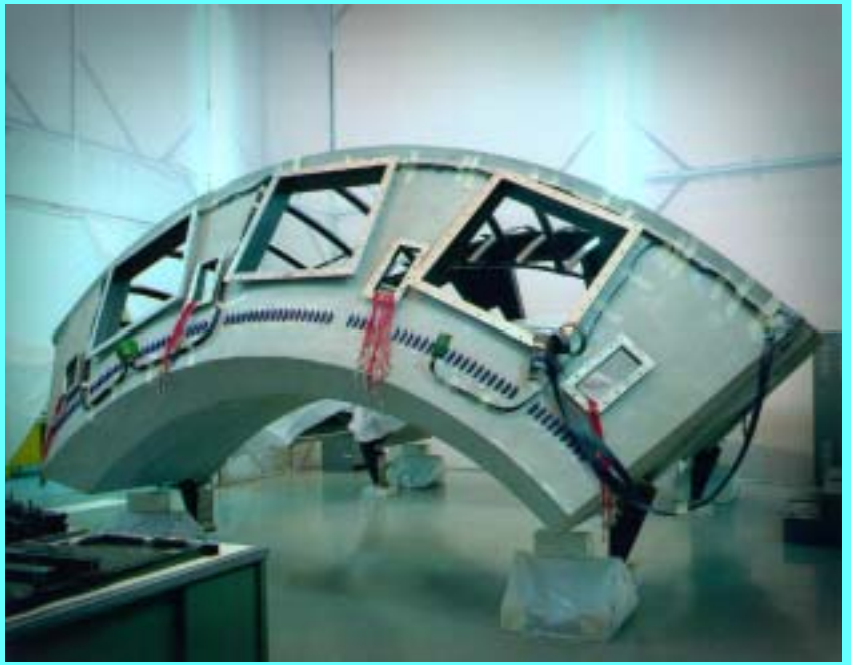


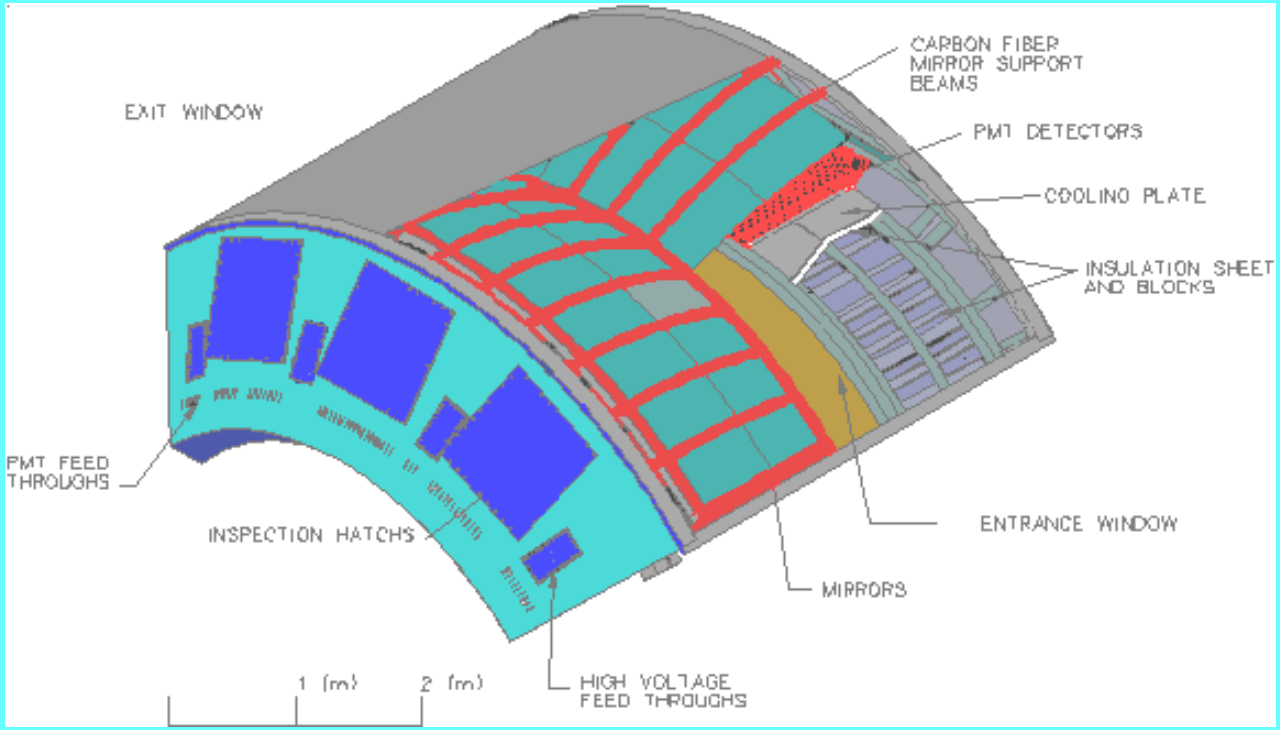
Magnetic Shielding Case design

Gas Vessel

- Two RICH detectors
  - One for each arm
  - Weight: 7250 kg / arm
  - Gas volume: 40 m^3 / arm
  - Radiator length: 0.9 - 1.5 m
- Mirror system
  - Radius : 403 cm
  - Surface area: 20 m^2 / arm
- Photon detector
  - 2560 PMTs/arm
- Radiation length
  - CO_2: 0.41%
  - Windows: 0.2%
  - Mirror panels: 0.53%
  - Mirror support: 1.0%
  - Total: 2.14%

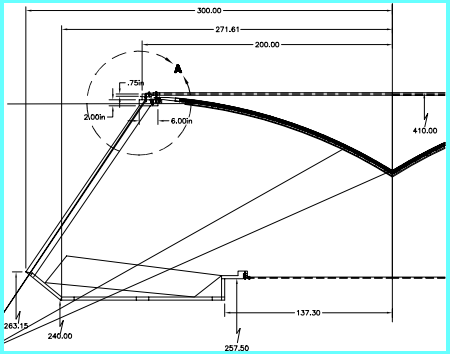
The vessels are designed and fabricated at Florida State University.

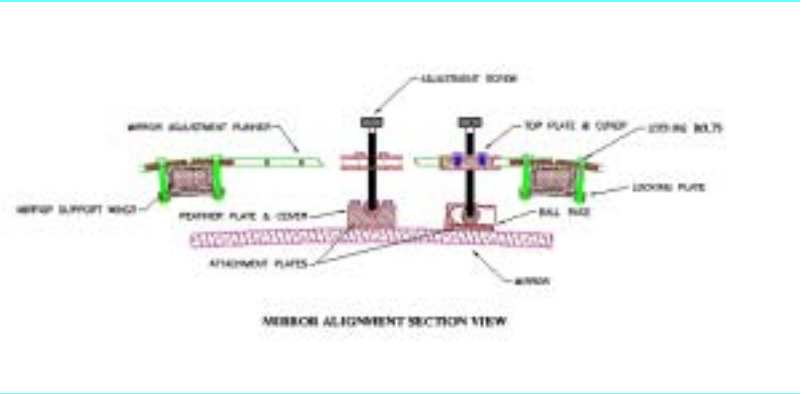




RICH Mirror

- Segmented spherical mirror
- Reflection surface
  - Aluminum made
- Mirror mounts are adjusted so that all optical targets are within 0.25 mm of the designed spherical surface.
  - graphite fiber epoxy
- Mirror support structure
  - graphite fiber, Delrin



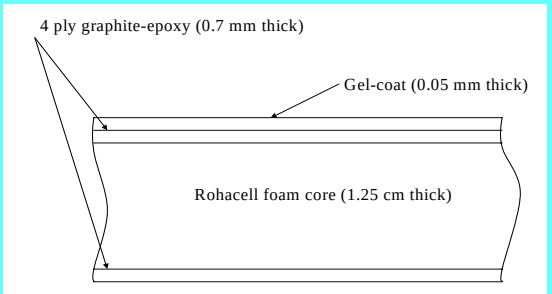


Design of 3 points mirror mounts

Mirror, mirror, mirror…

Mirror panels are mounted by adjustable 3 point mounts on the frame bars

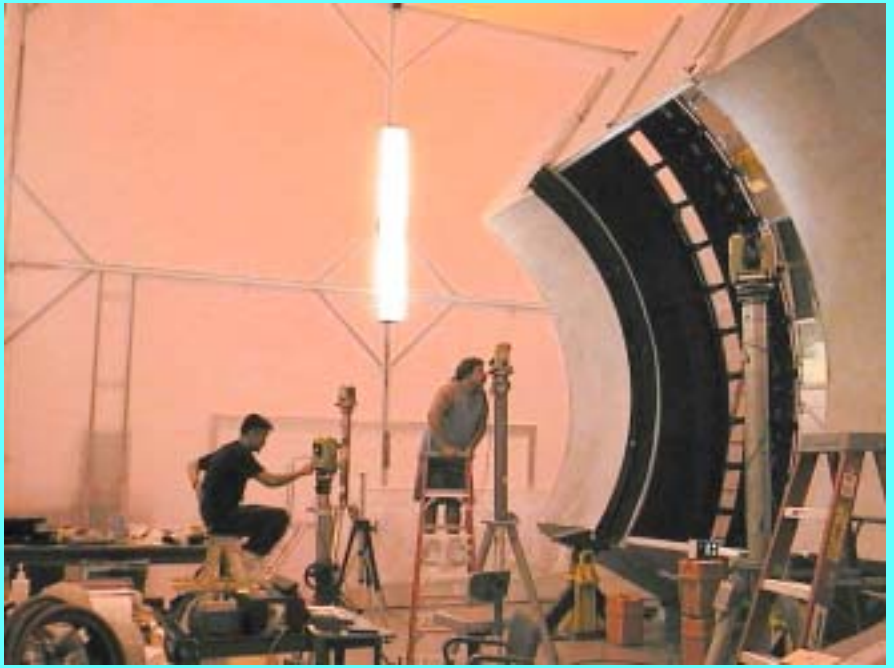
Completed mirror array of the first RICH



Structure of the mirror

RICH (mirror alignment)

- After mirrors are installed, the RICH vessel is rotated up in the same orientation as on PHENIX carriage
- Positions of optical targets placed on mirror surface were surveyed with a computerized theodolite system (MANCAT).



BNL survey crew were measuring the optical targets on the mirror during the mirror alignment.

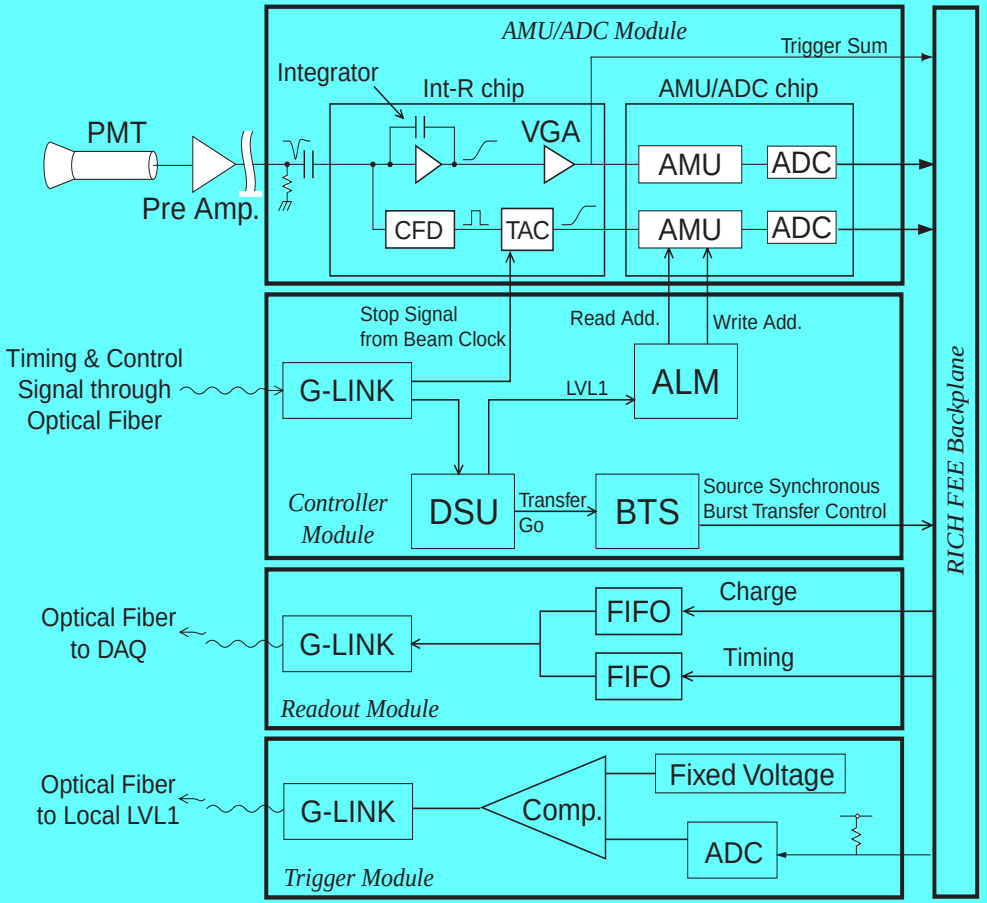
<u>Alignment calibration (Once in RUN)</u>

- Accumulate all the hit PMTs around tracks for totally 56 mirrors
  - 14(mirrors)*2(side)*2(arm)
  - Adjust mirror positions so that ring centers match projected points of tracks

Front End Electronics (FEE)

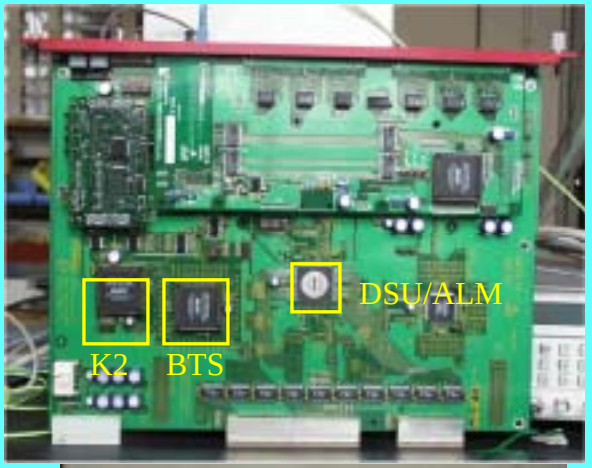
- Readout Signals from 5120 PMTs:
  - Zero~10 Photon Detection: 0pC~160pC (Signal Preceded by Pre-Amp(x10))
  - Time Resolution of ~ 200 ps (For Background Rejection)
- Very fast Operation (In old days)
  - 9.6 MHz RHIC Beam Clock
  - 25KHz Average Trigger Frequency
- Transfer to Data Collection Module (DCM)
  - Data Link using G-LINK
- Compactness
  - Processes 640 PMT Signals per Crate

Conceptual Design of RICH FEE



RICH-FEE Crate !

- 9U VME Dimensions
- One Controller Module
- Two Trigger Modules
- Two Readout Modules
- Ten Analog Modules



Controller Module

- Heap Management of Analog Memory Unit (AMU)
- Controls FEE synchronous to Master Timing System
- Controls Burst Transfer
- Generate AMU Write / TAC Stop Timing
- Slow Serial Control using ARCNET

Readout Module

- Transferring Data to PHENIX-DCM using G-LINK at the maximum speed of 800 Mbps
- G-LINK Transfer asynchronous to BUS Transfer inside RICH-FEE using four FIFOs (Depth: 9 events)

Analog Processing (AMU/ADC) Module

•64 Inputs, 64 Charge, 64 Timing and 16 Trigger Sum (4 PMT Sum) Outputs/Board

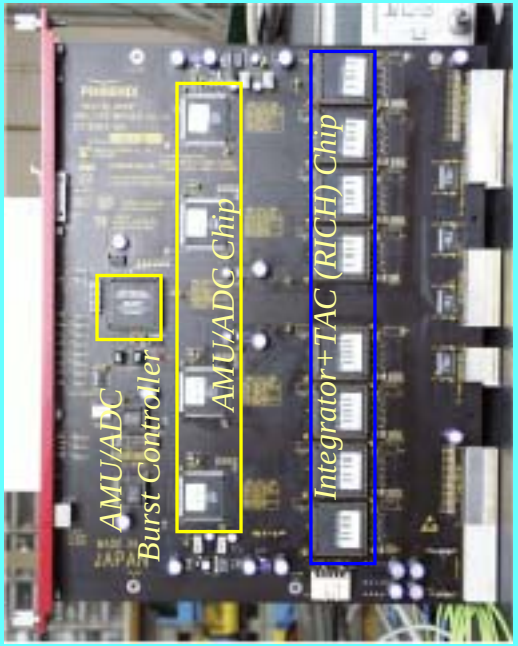
•Burst Transfer to Readout Module in 20-40MHz

• Serial Controllable ASICs on Board

  • 8 RICH Chips (8 Inputs, 8 Charge and Timing, and 4 Trigger Sum, each)

  • 4 AMU/ADC Chips(32 inputs, outputs, each: Random accessible analog memory+ADC)

•Each Analog Sum is summed over 5 boards in backplane, enabling RICH to construct the 4x5 PMT signal sums (trigger tile) which capture rings.



LVL-1 Module

•Accept 16 Trigger current sum inputs from 5 AMU/ADC boards

  •4*5 PMT sum is already made in the backplane

•Convert current signal to voltage signal

•Convert Digital signal to Digital data using FADC

•Compare the digitized data with threshold value

•Transfer trigger information to ERT Crate via G-Link