The HERA-B Ring Imaging Cherenkov System – Design and Performance

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University of Houston, HERA-B Collaboration

this RICH is a
joint effort of groups
from

University of Texas at Austin
University of Barcelona
University of Coimbra
DESY
University of Hamburg
University of Houston
University of Ljubljana & J. Stefan Institute
Northwestern University

Content

❑ Design

- RICH in HERA-B
- Radiator vessel and mirrors
- Focal plane layout
- Photon detector optics, mechanics, electronics

❑ Running

- Commissioning milestones
- Occupancies, distributions and events

❑ Performance

- Reconstruction software
- Rings (Number of photons)
- Resolution
- First particle identification

❑ Conclusion

RICH in HERA-B

❑ HERA-B

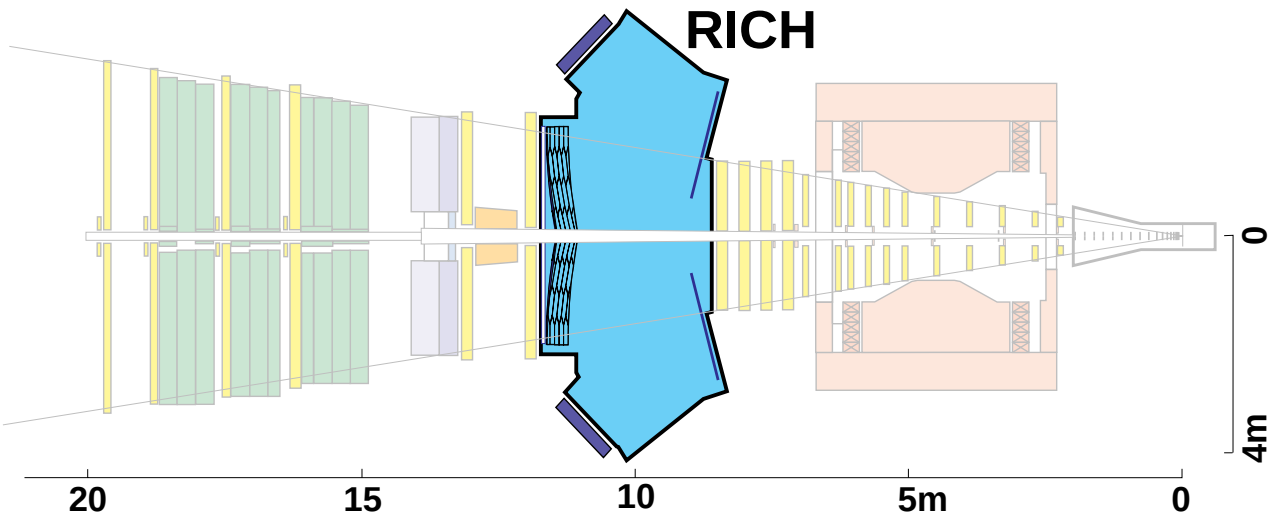
- Fixed target experiment at the 920 GeV HERA proton ring at DESY
- Goal: measure *CP* violation in *B*-system
- Hundreds of charged tracks every 96 ns

❑ RICH

- Particle identification; tag flavor of *B* decays
  3σ π/K separation for $10 < p < 75$ GeV/c
- full acceptance: ±160 mrad vertical,
  ±250 mrad horizontal (bending plane)

➤ Single RICH in the middle of the detector

➤ Photon detectors outside of particle flux



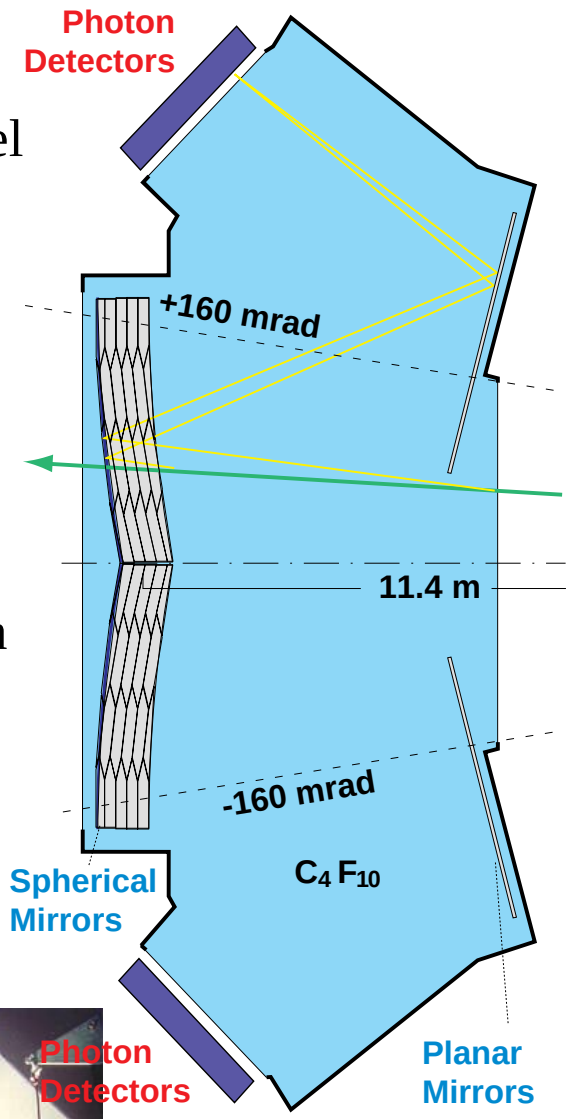
RICH at Large

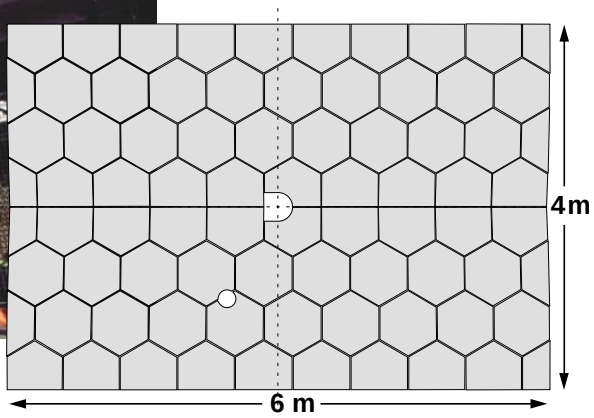
❑ Radiator

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

❑ Mirrors

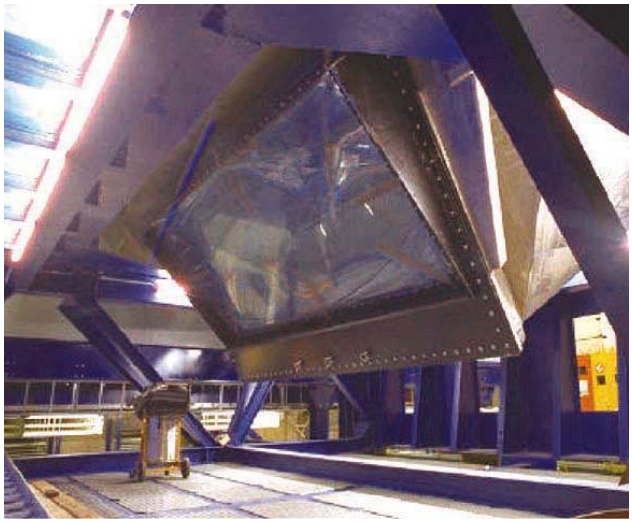
- Spherical (r = 11.4 m), tilted up/down, 80 hexagon based elements
- Planar mirrors move focal plane *above* and *below* flux of particles





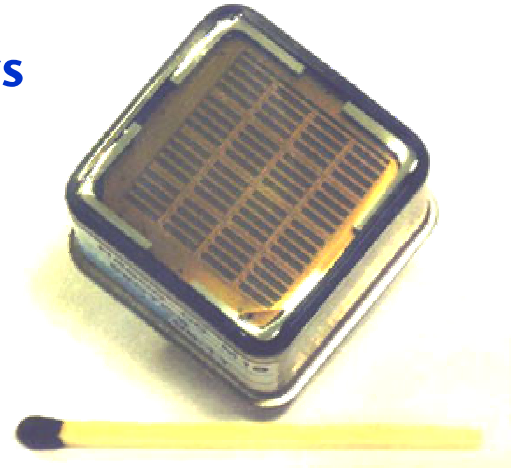
Photon Detector

❑ Focal Plane



- Best approximated by two cylinders
- Light exits through 2 mm thick UV grade *Plexiglas* windows
- Incidence angle $\approx 2\,\theta_C$ due to unknown z of photon emission and effect of magnetic field

❑ Multi-Anode Photomultipliers

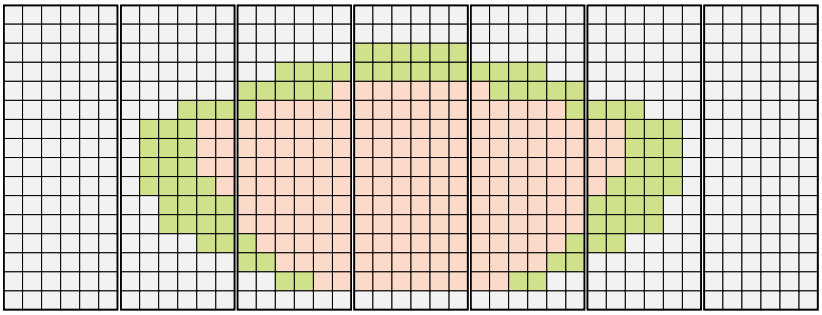


- *Hamamatsu R5900* with 18×18 mm^2 photocathode
- *1500* with 16 anodes **M16**
  750 with 4 anodes **M4**

❑ Mounting

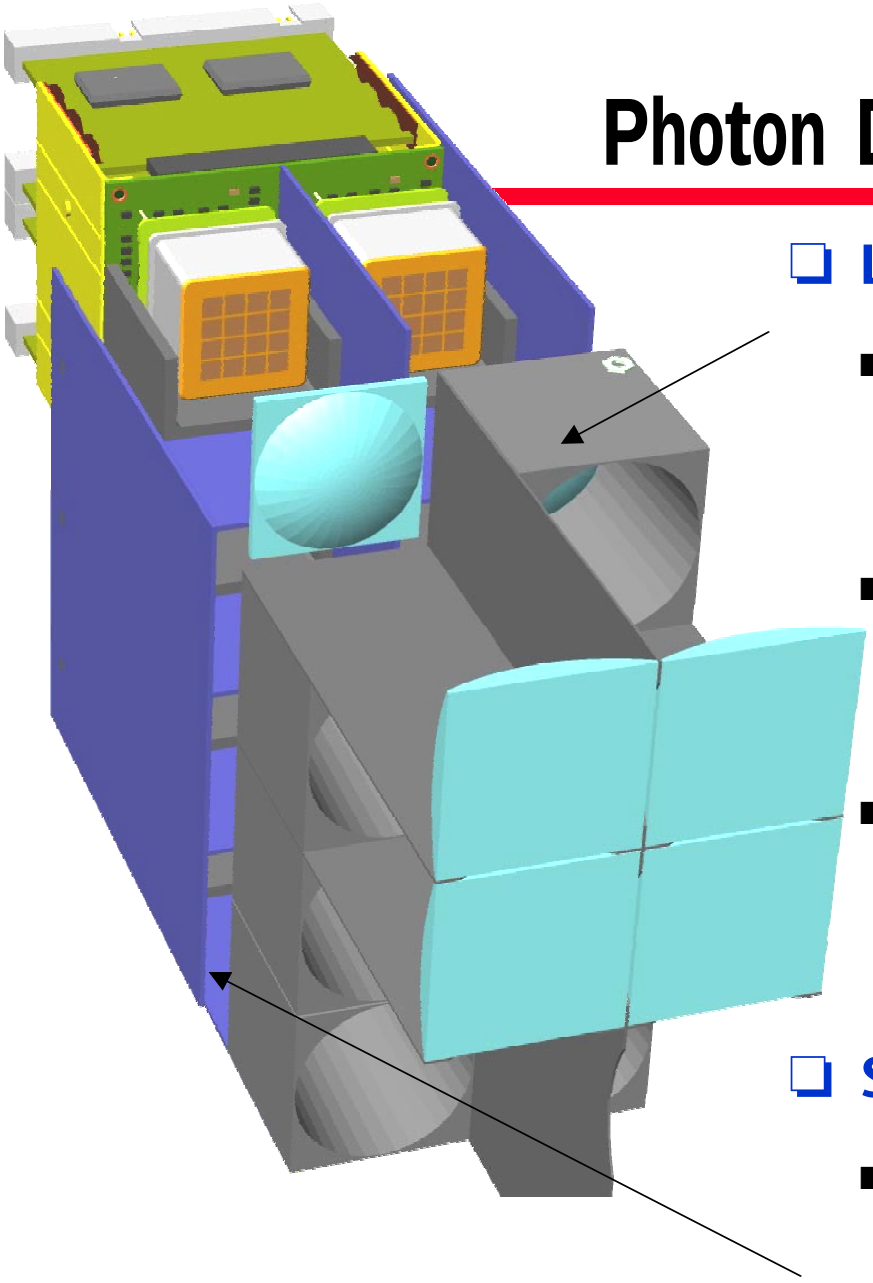
- Soft iron box (supermodule) with 32×12 mounting positions
- PMTs placed according to occupancy

empty



Supermodules in upper focal plane

Photon Detector Parts

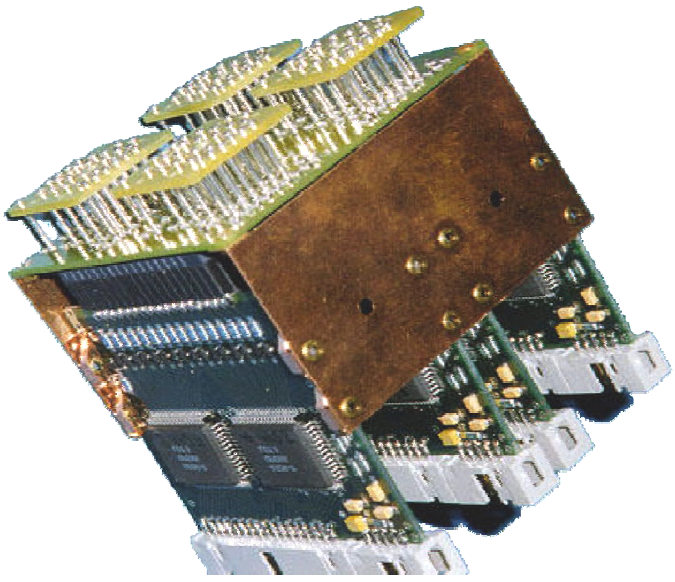


❑ Lens Module

- 2-lens telescope, maps 36 mm □ onto 18 mm □ photocathode
- Optimized aspheric lenses, molded from UV-acrylate
- Holder with 12 tele-scopes (2×6) placed on supermodule

❑ Supermodule

- Holds lenses and PMTs/electronics
- Provides magnetic shielding



❑ Electronics

- Passive base-board with socket for 4 PMTs (M16 or M4)
- 16ch amplifier-shaper-discriminator cards plugged in on back

Commissioning

❑ Radiator Vessel

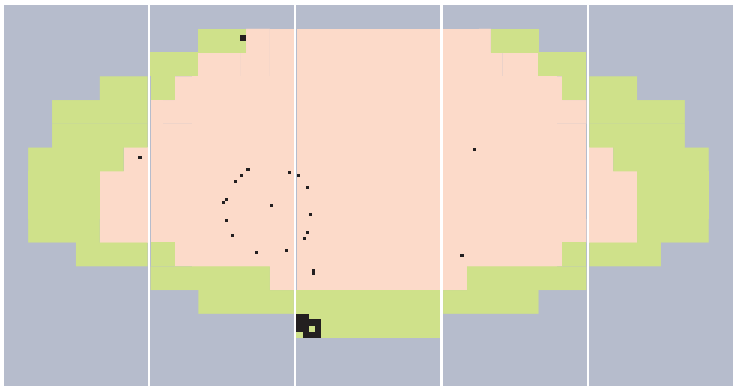
- Completed in *February 1998*
- Mirrors installed and aligned *April 1998*
- First C_4F_{10} fill end of *December 1998*

❑ Photon Detector

- 1488 M16 and 752 M4 PMTs (including front-end electronics) installed in *April 1998*
- Lens system completed in *May 1998*
- Readout chain for all 27,000 channels complete in *Summer 1998*

❑ Physics

- "First Light" with air as radiator on *August 19, 1998*
- First "Big Rings" using C_4F_{10} in *January 1999*

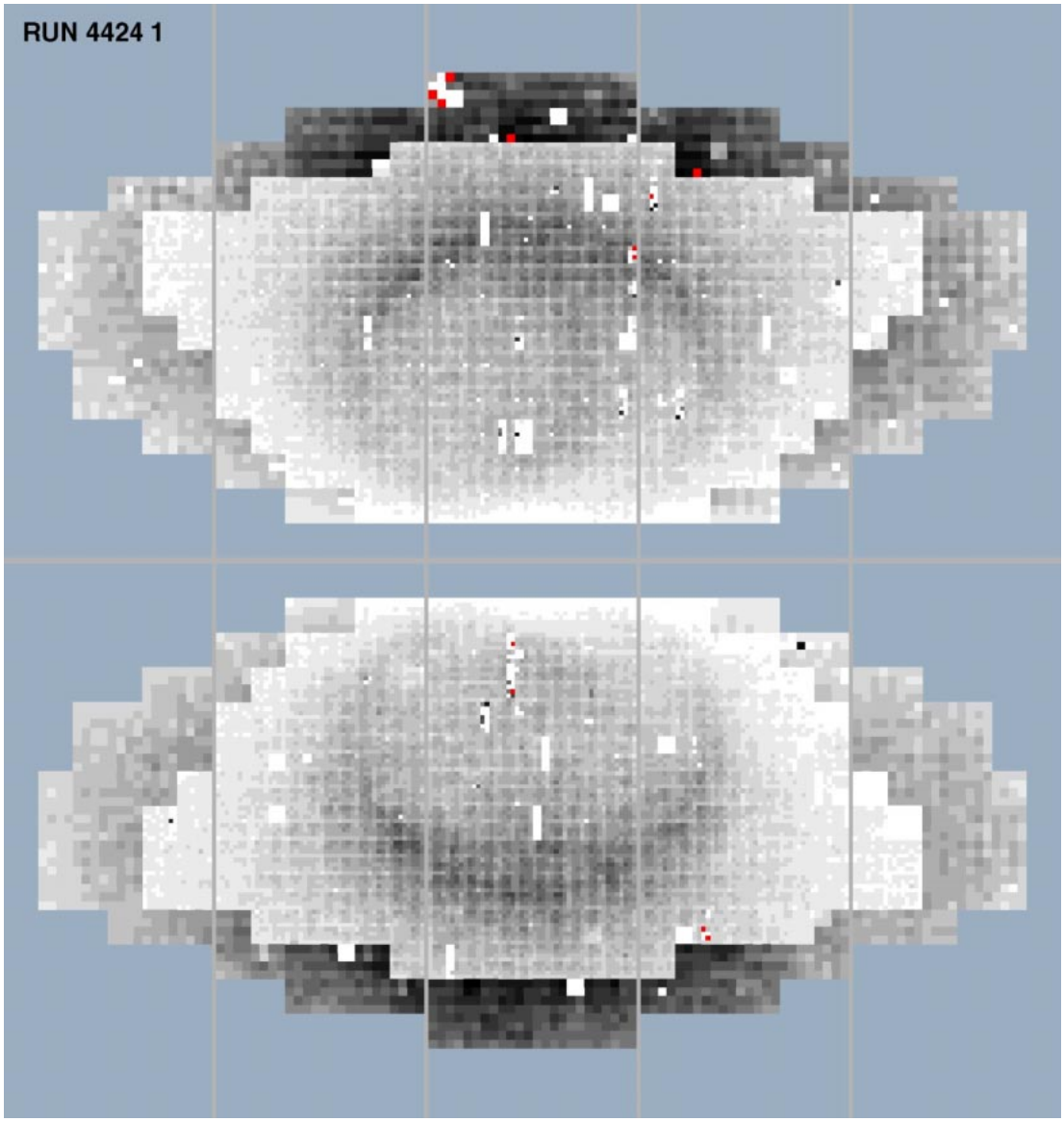


- Magnet-On data since *May 1999*

Performance

❑ Occupancy, C_4F_{10}, Magnet OFF

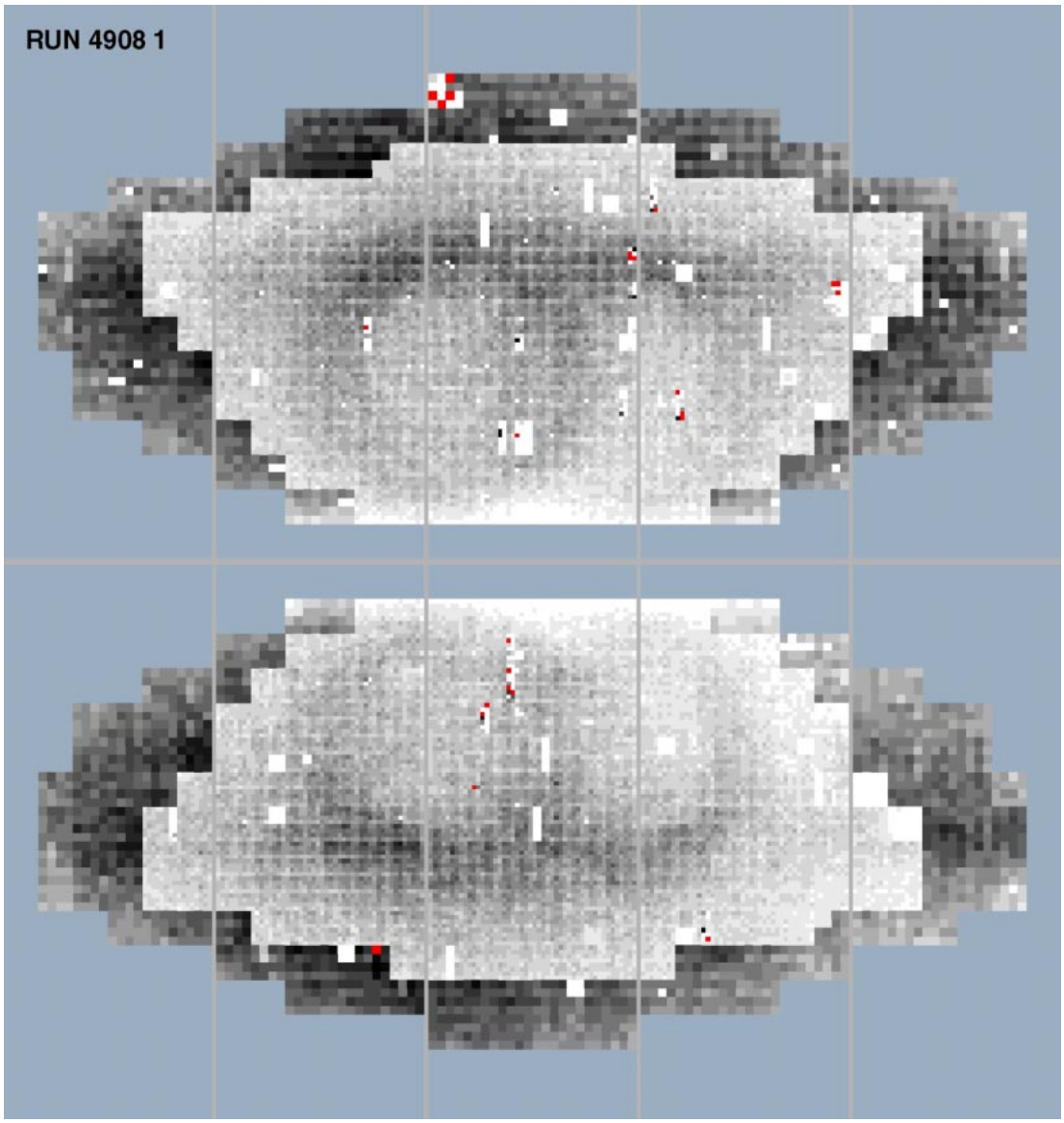
- System works as expected:
  - Low angle events populate center
  - M4s have four times more hits than M16s
  - Ring shared between upper and lower half
  - Few dead R/O cards and PMTs
  - Very few hot channels



Performance

❑ Occupancy, C_4F_{10}, Magnet ON

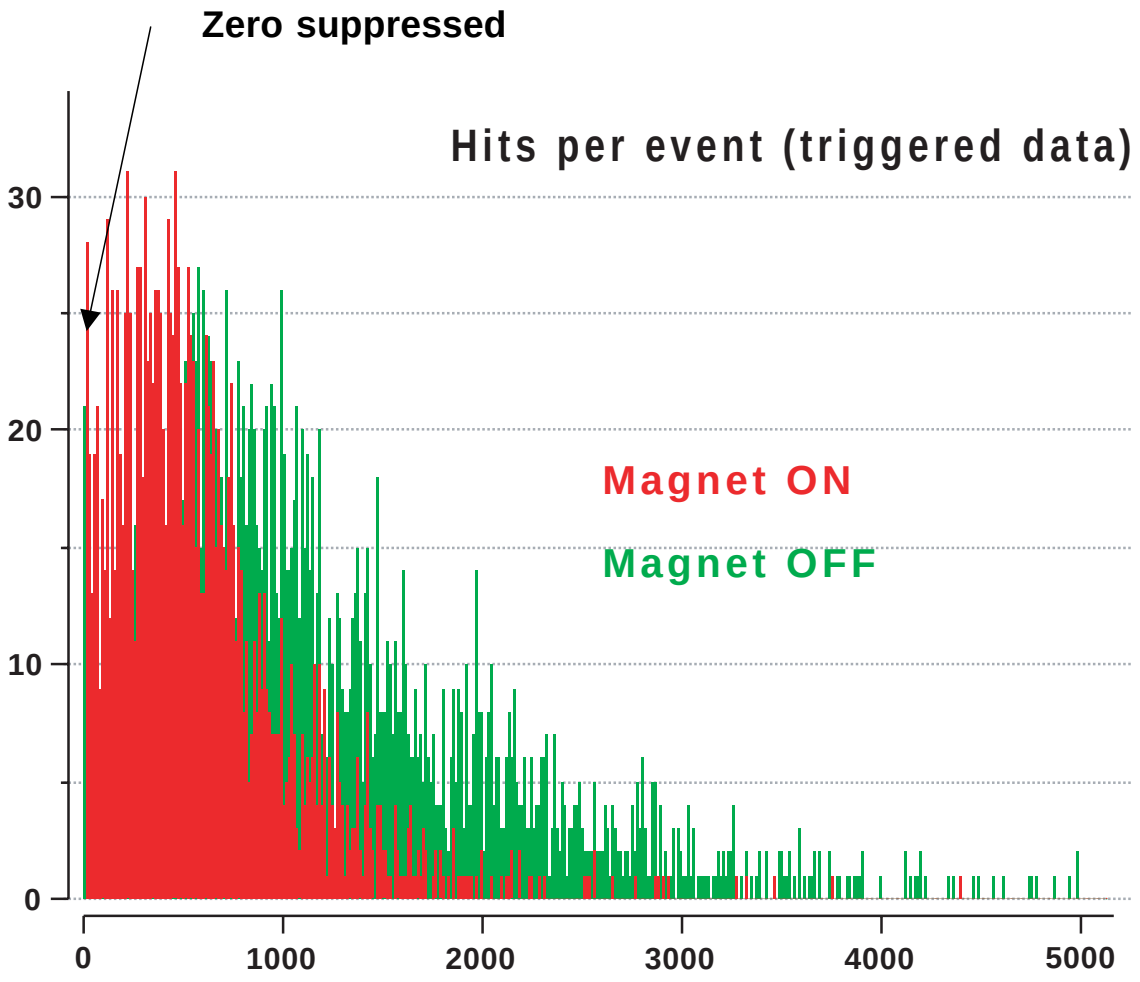
- The magnet really works:
  - Field separates charges
  - More even distribution of occupancy
  - Same dead R/O cards and PMTs
  - Most dead channels have been already *fixed* during recent shut-down



Distributions

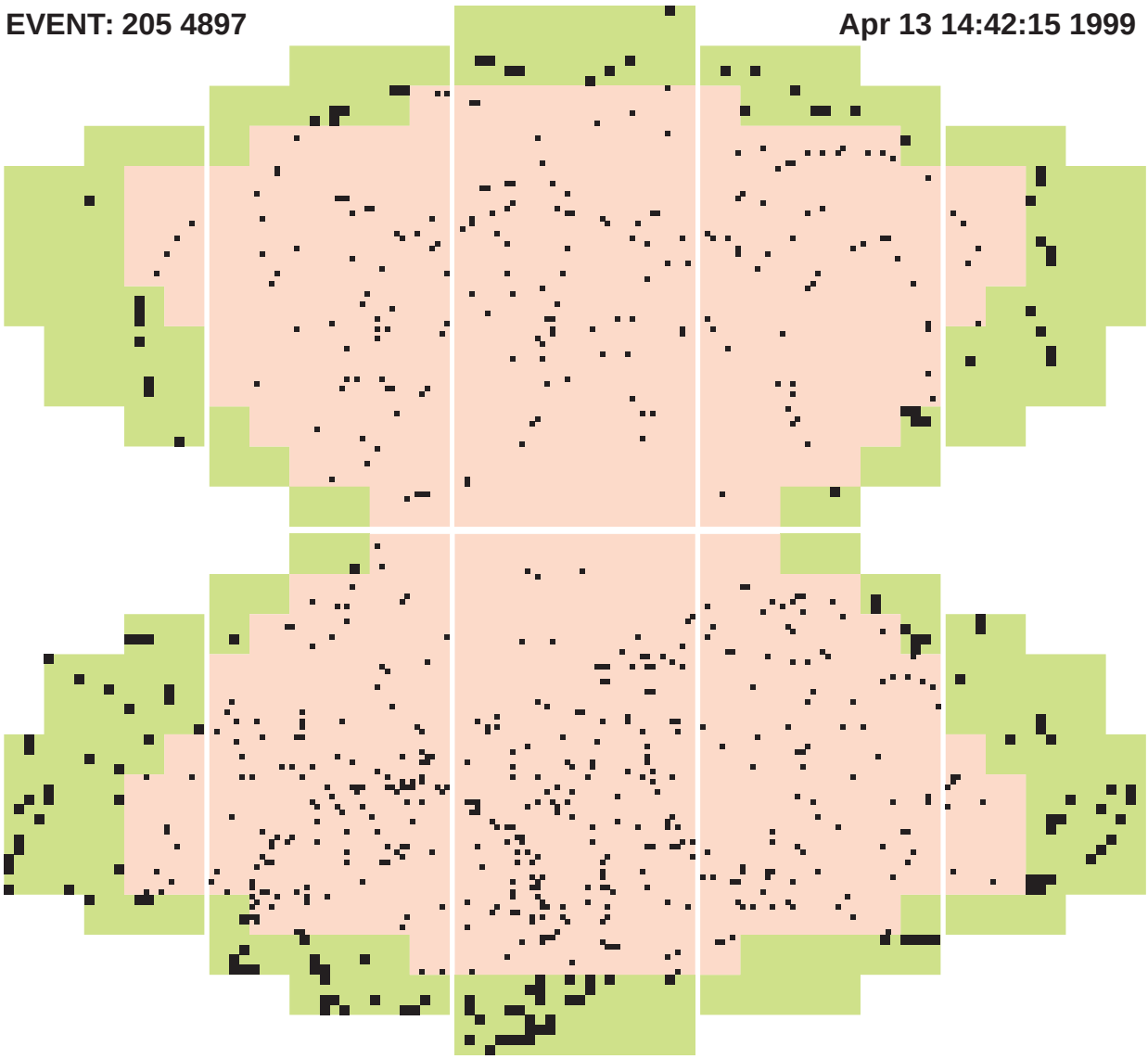
❑ Occupancy Comparison

- Magnet removes low-momentum junk
- Mean occupancy (including empty events)
  - magnet ON 422
  - magnet OFF 1155
- Triggered data bias towards events with high multiplicity



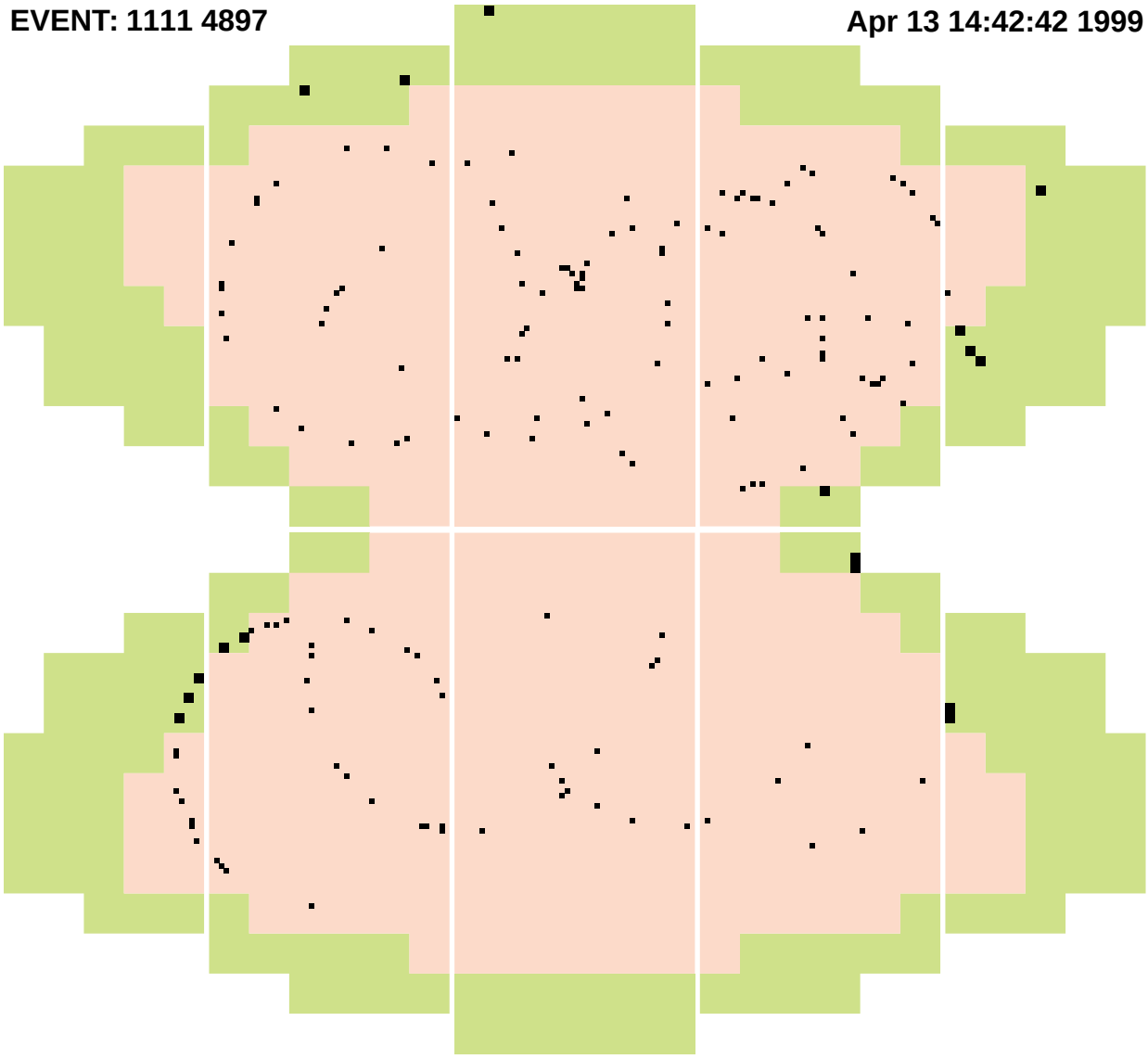
Events

- All Magnet On
- "Typical" (754 hits)



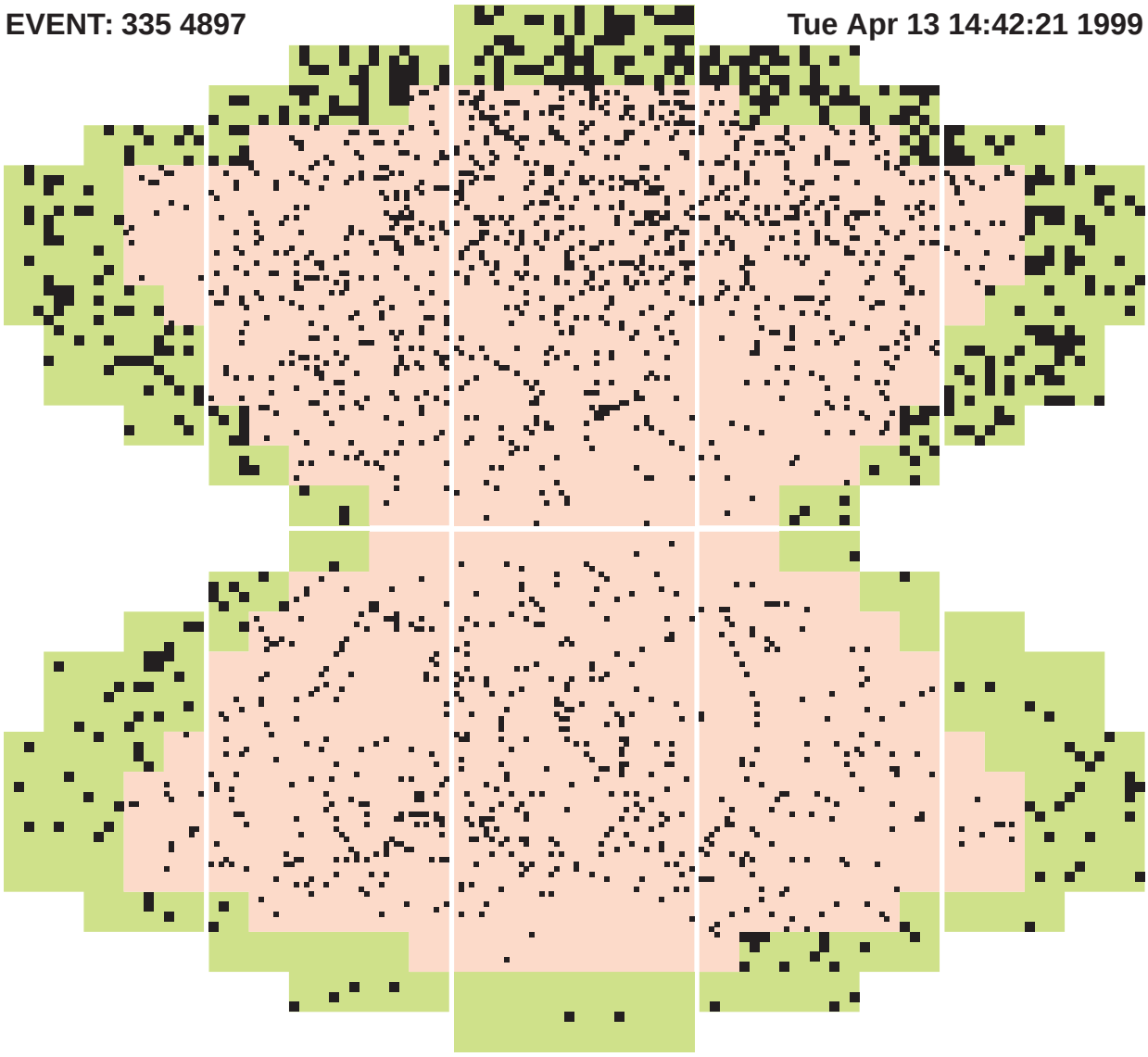
Events

- Good (172 hits)



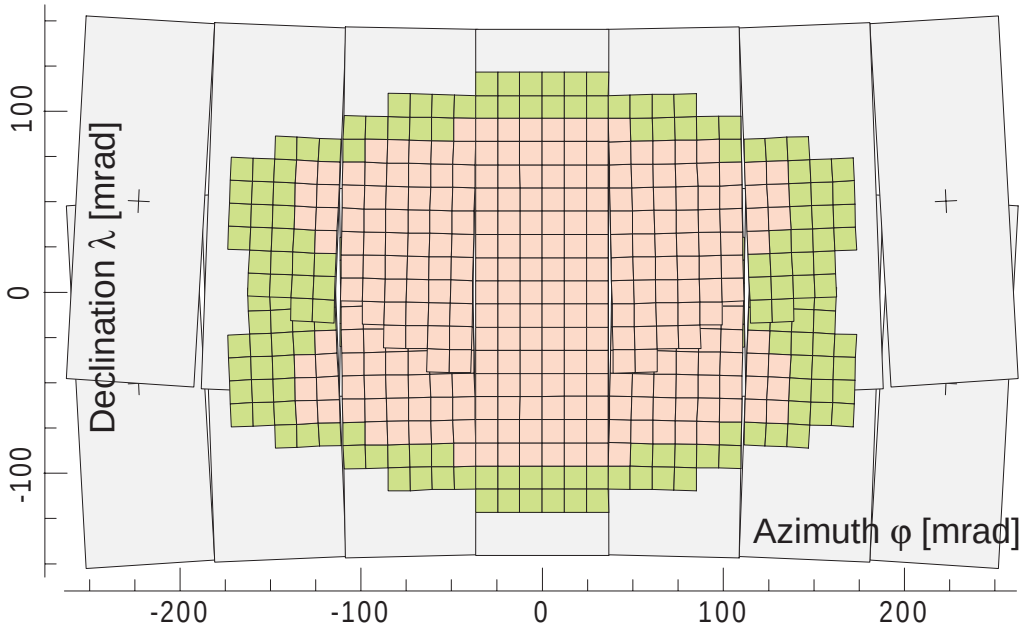
Events

❑ Bad (2184 hits)

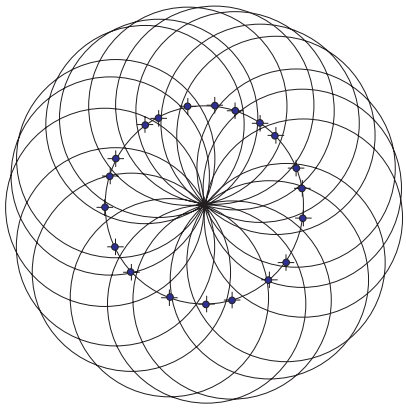


❑ Ring Reconstruction

- Detector mapped into λ-φ space



- Stand-alone ring search algorithm
  - Histogramming method
  - Ring of correct radius gives peak at center

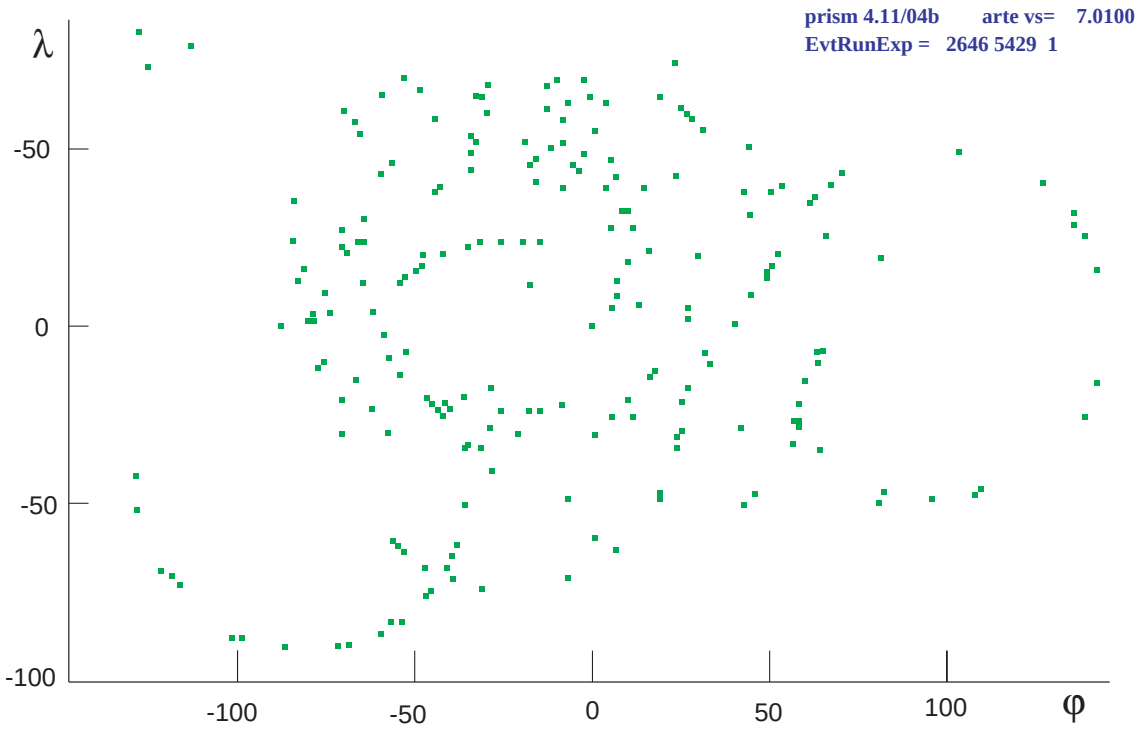


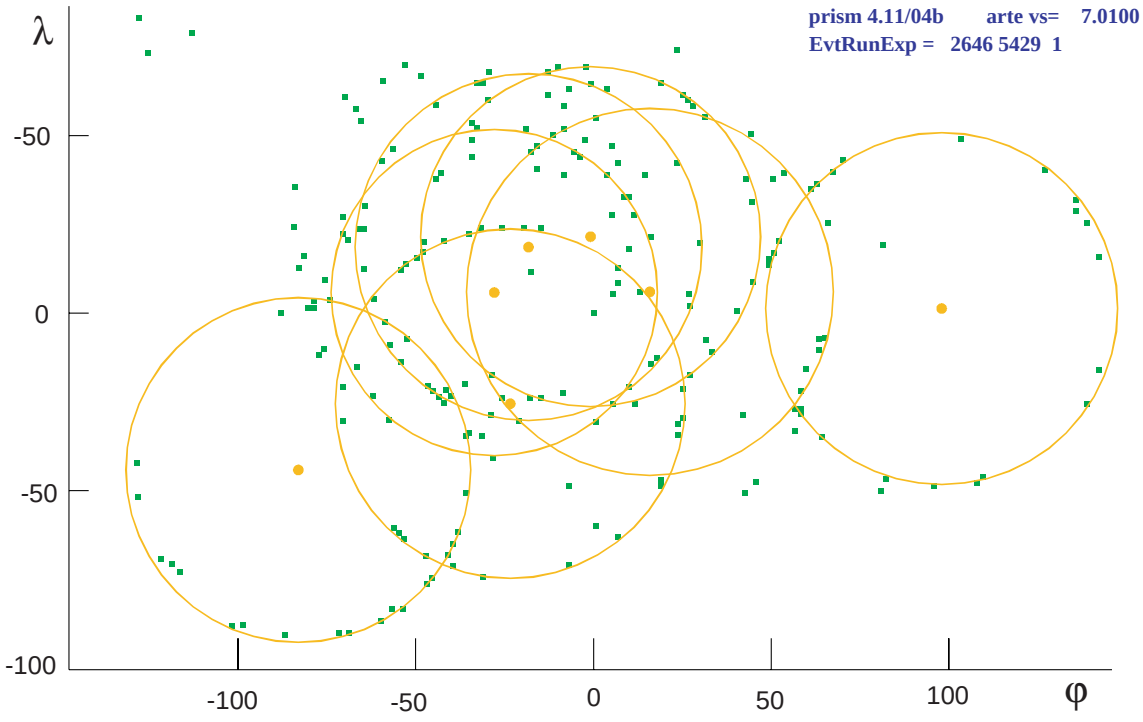
- Correct for distortions
- Refit „ellipse“ using Gaussian

➤ Implemented into standard HERA-B analysis

Reconstructed Rings

❑ Software finds rings

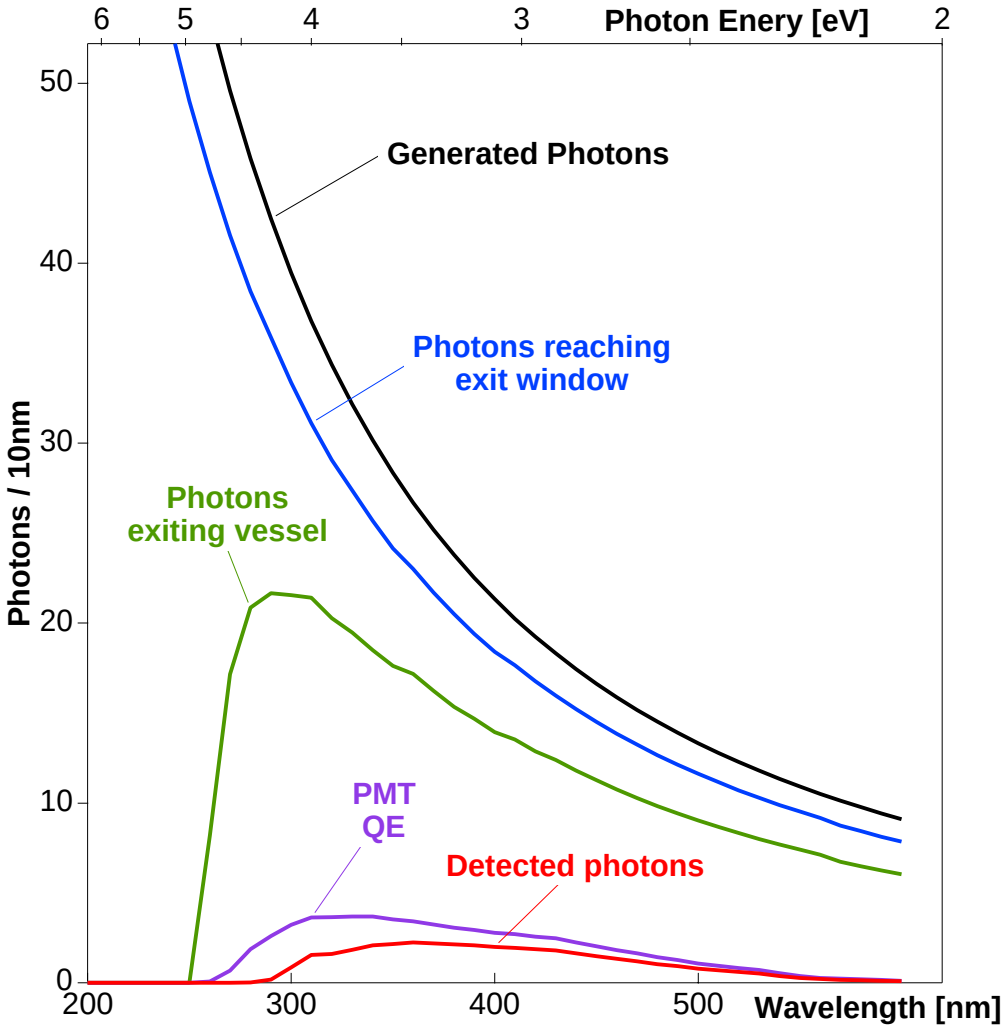




Predicted No. of Photons

❑ Simple Model

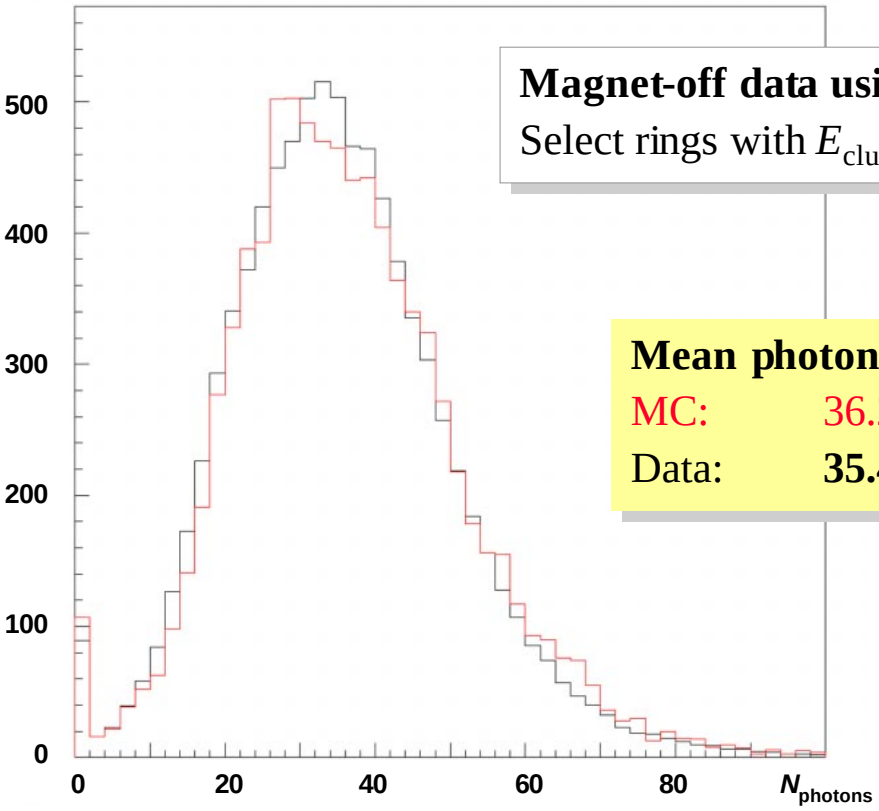
- Generation of Čerenkov light in pure C_4F_{10}
- Reflectivity of mirrors
- Window transmission
- PM quantum efficiency
- Telescope efficiency



Prediction for $\beta = 1$: 34 ± 2 photons / ring

Ring Analysis

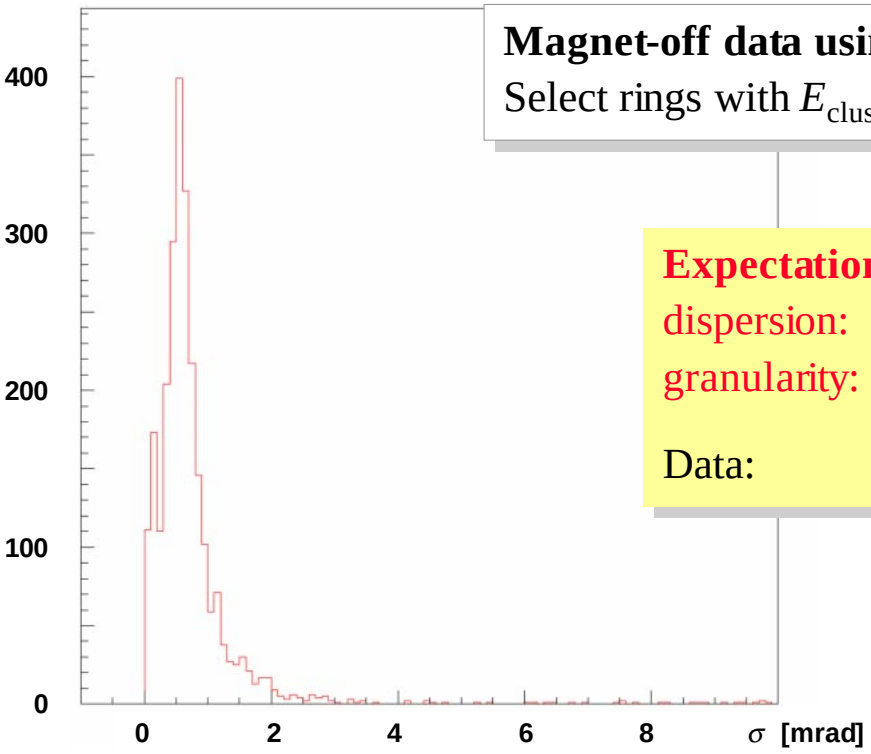
❑ Photons per Ring for $\beta = 1$ particles



Magnet-off data using Calorimeter:
Select rings with $E_{clust} > 8$ GeV

Mean photons / ring
MC: 36.2
Data: **35.4**

❑ Single hit resolution - Sigma of ring



Magnet-off data using Calorimeter:
Select rings with $E_{clust} > 8$ GeV

Expectation:
dispersion: 0.4 mrad
granularity: 0.5 mrad

Data: **0.65 mrad**

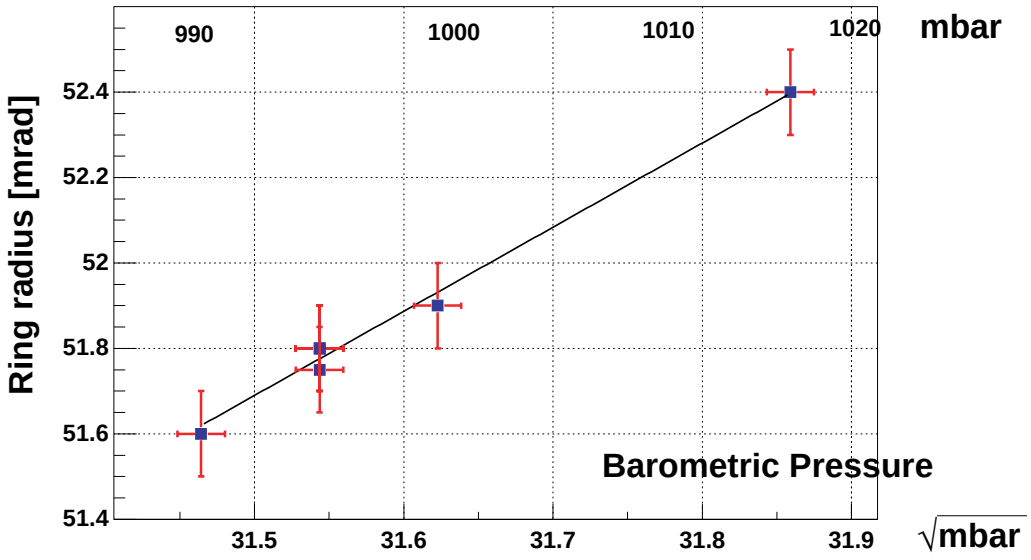
Very good Agreement !

Ring Variations

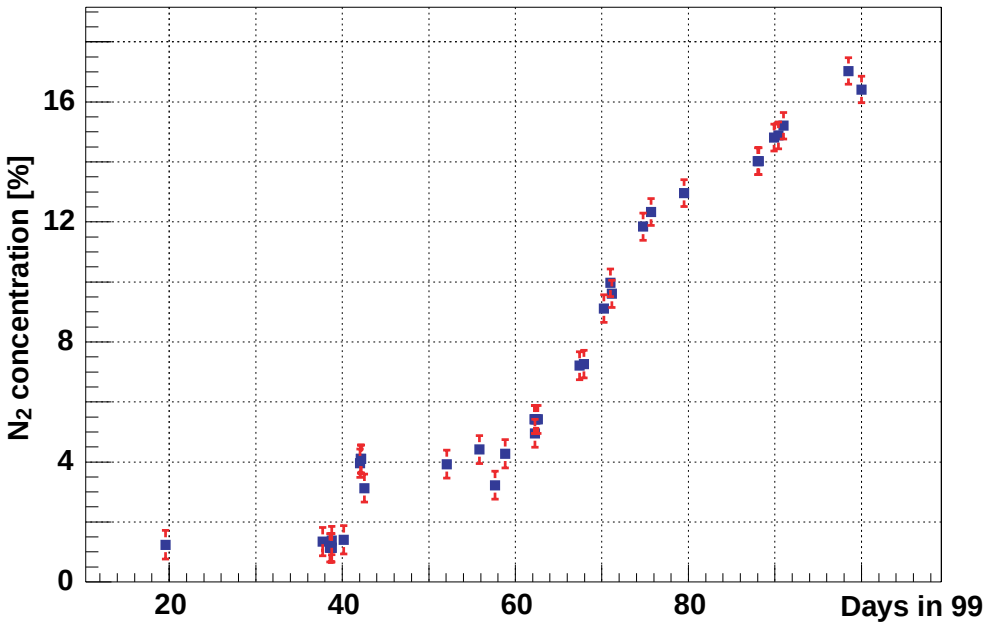
❑ Radiator Gas System

- C_4F_{10} „closed“ recirculation system
- Radiator at 1.5 mbar above atmospheric pressure

➤ Ring radius changes with weather



➤ We have some leaks !



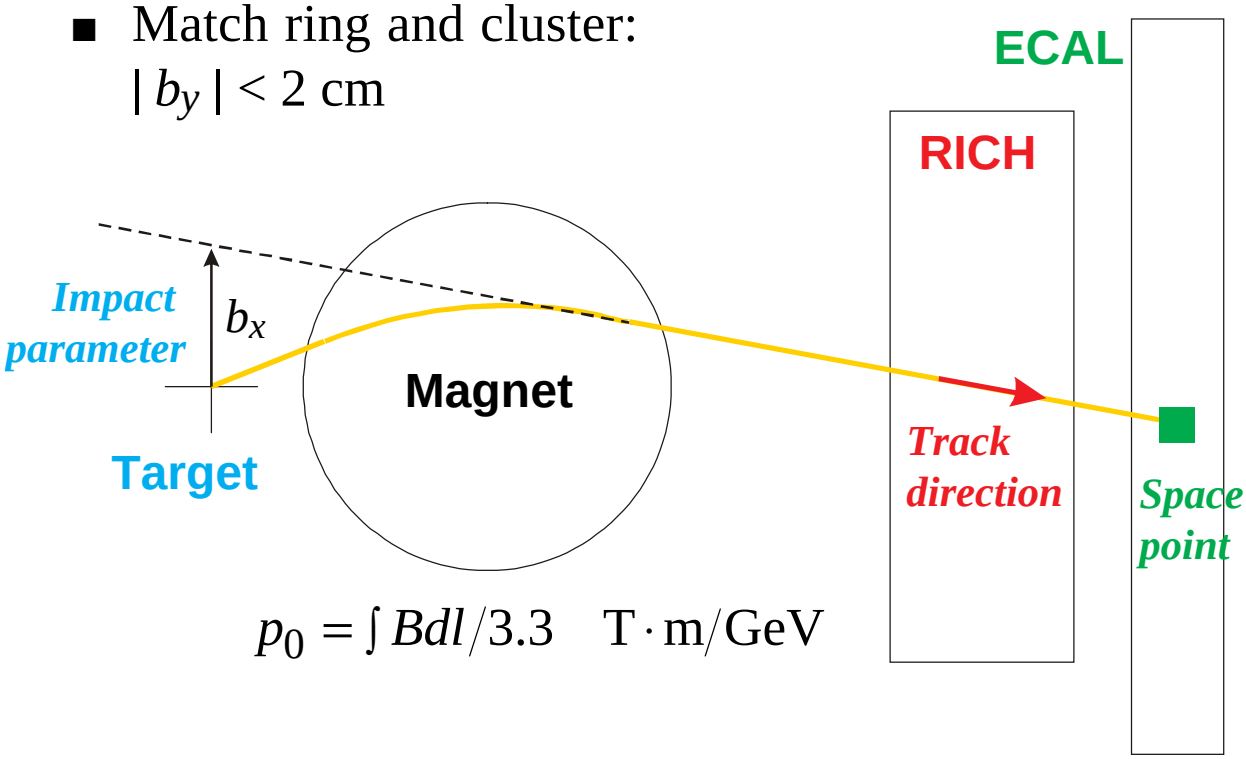
Particle ID

❑ Main task of RICH: Particle Identification

- No tracking yet, magnet on only recently

❑ Determine momentum with RICH and ECAL

- ECAL space point: $E_{\text{clust}} > 4$ GeV
- Track direction: RICH ring
- Match ring and cluster: $|\, b_y \,| < 2$ cm



$$p_0 = \int Bdl / 3.3 \quad \text{T} \cdot \text{m/GeV}$$

Momentum: $\dfrac{1}{p} = \dfrac{b_x}{p_0 z_{\text{bend}}} \approx \dfrac{b_x}{280\,\text{cm} \cdot \text{GeV}}$

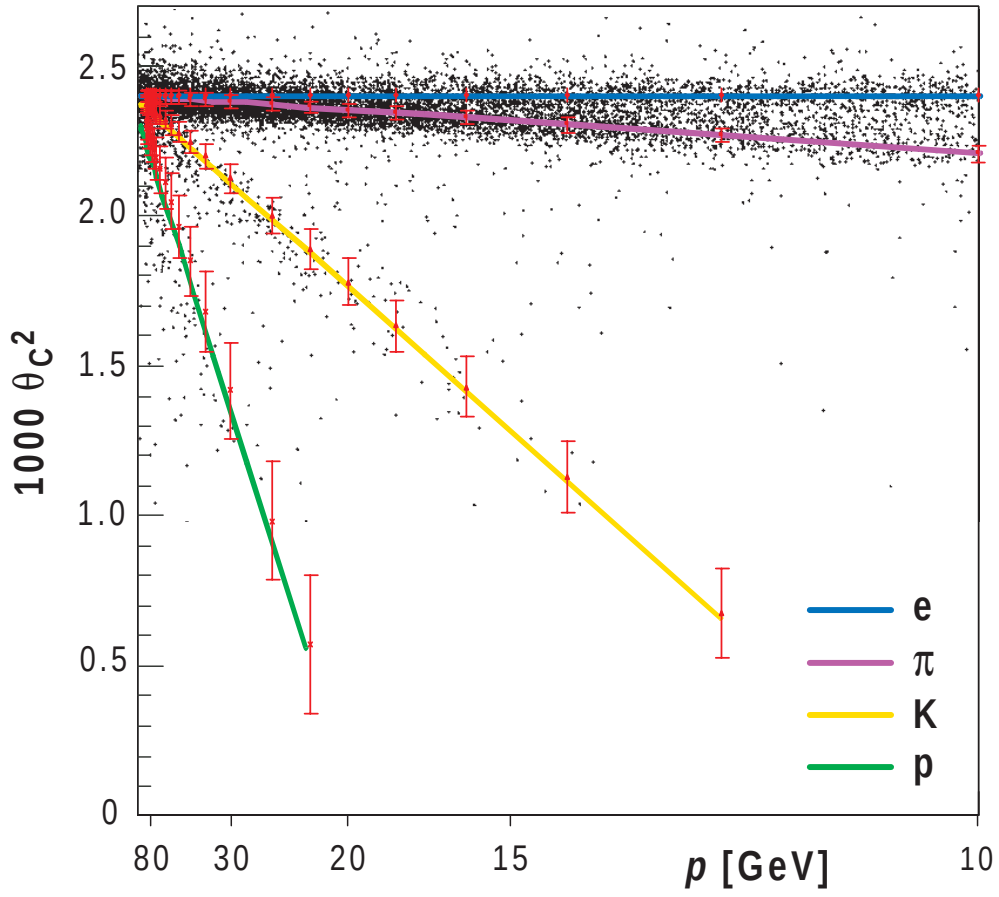
Resolution: $\dfrac{\delta p}{p} \approx 0.03 \oplus \dfrac{p}{280\ \text{GeV/c}}$

❑ RICH-ECAL measured quantities

- Čerenkov relation, $\cos\theta_C = 1/n\beta$, relates the angle to momentum:

$$\theta_C^2 = \theta_0^2 - \frac{m^2}{p^2} \qquad \theta_0 \equiv \text{“}\beta = 1\text{”}$$

- θ_C^2 vs. $1/p^2$: particles of same mass on straight lines



Conclusion

- RICH works as advertised
- Powerful Detector with great potential
- We are eager to see the rest of HERA-B being completed