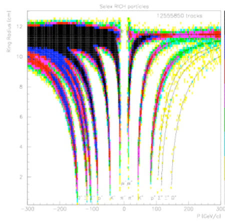
An Overview of RICH Detectors

From PID to Velocity Spectrometers



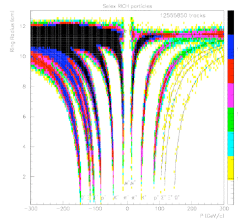
Peter S. Cooper, Fermilab

January 29, 2008

Goal - a broad overview for this afternoon's session

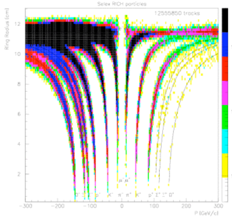
I. Introduction
II. Recent RICH history. A review of some experiments and their design considerations
III. RICH design criteria.
IV. Advanced techniques
V. Conclusions

Ring Imaging CHerenkov Counters



- Cherenkov light is emitted when a charged particle exceeds the speed of light in a medium (Cherenkov 1934, Cherenkov,Tamm & Frank, 1958 Nobel prize).
- RICH concept invented by Art Roberts Nim 9 (1960) 55.
- < ~1980
  - Single PMT threshold counters
  - Multi cell threshold counters
  - Differential counters ("analog" RICHs)
- 1980s
  - First RICHes
    - Omega (WA62) RICH at CERN
    - E665 RICH in muon experiment at FNAL
    - TMAE wire chambers as UV single photon detectors
  - Performance problems
  - PMTs too big and expensive for 1000+ pixel systems

RICH Design Equations



- Cherenkov threshold equation $\cos\theta_c = 1/\beta n$
- All light is emitted at a fixed Cherenkov angle to the direction of flight of a particle.

$\theta_c = \text{sqrt}\,[2\delta - 1/\gamma^2]$ $\delta = n-1$ radiator index of refraction

γ particle velocity

$N_{pe} = N_0 L \theta_c^2$ L radiator length

N_0 figure of merit

- Transforming that light to the focal plane of a mirror transforms a ring in angle space to a ring in coordinates.

$R = F\,\theta_c$ F mirror focal length

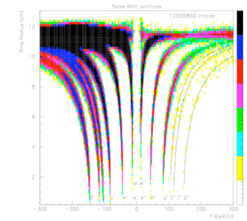
- Single photon counting - statistics really applies (no charge sharing)

$\sigma_{<R>} = \sigma_R / \text{sqrt}(N_{pe})$ σ_R photon pixel resolution

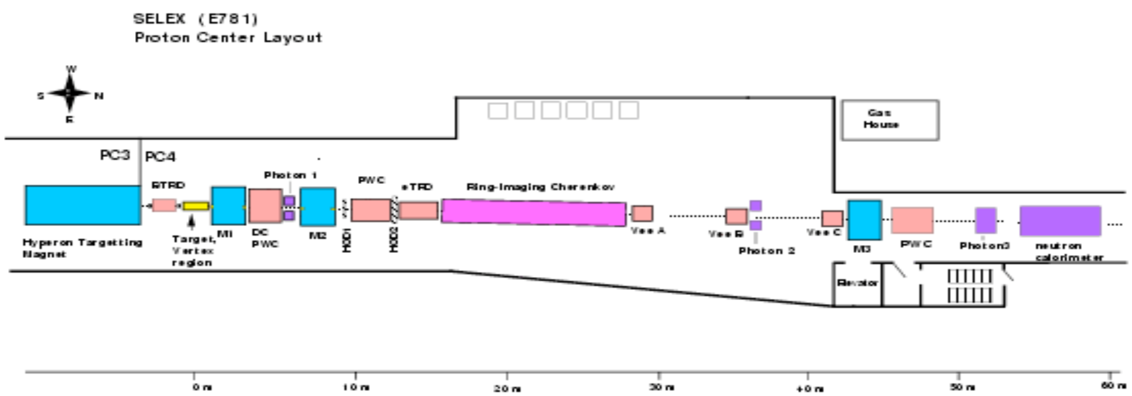
- Isochronous - all photons reach the focal plane at the same time

SELEX Experiment at Fermilab

Data taken 1996-7 in P-center @ FNAL



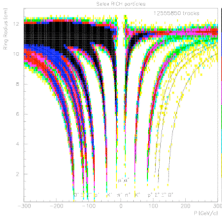
- Particle ID was critical
  - Separate charm from combinatoric background
  - Separate baryons from mesons
    - $\Lambda_c^+ \rightarrow p\ K^- \pi^+$
    - $D^+ \rightarrow \pi^+ K^- \pi^+$
- Full coverage above 22 GeV ($x_F > 3\%$)
- Good p / K /π separation required
- θ_c = 11.34 mrad, γ_{th}= 88, π threshold 12 GeV/c, Gas: Neon @ 1atm



Forward charm x_F>0.1
π^- p and Σ^- beams, 600 GeV
Typical boost ~100
RICH PID above 22 GeV
20 plane - 4 view svx - σ>4 μm

Multi-pixel PMT RICH

a good, old, idea



Requires
- radiator (usually gas)
- mirror
- position sensitive photon detector (a pmt array)

I designed this one for Selex, the charmed baryon experiment.

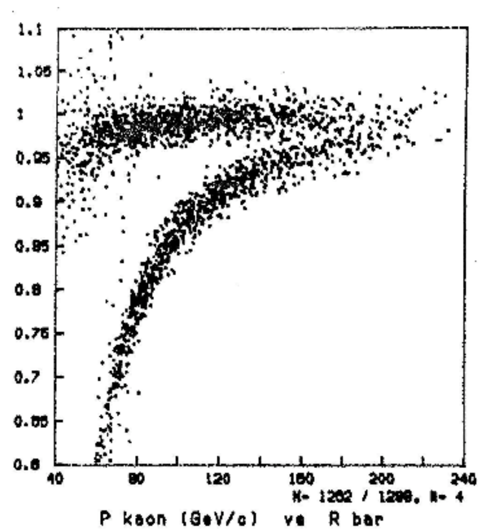
H387

A+ RICH COUNTER

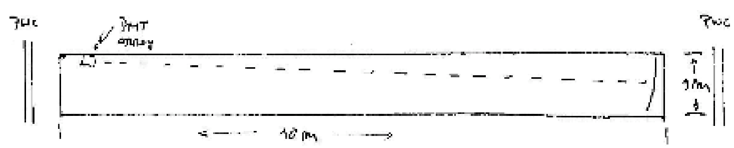
P. S. Cooper

16 - Nov - 1984

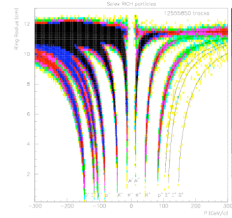
In this note I consider a design for a RICH (Ring Imaging CHerenkov Counter) to identify the K^- from $\Lambda^+ \to \Lambda^0 K^- \pi^+ \pi^+$ at the trigger level. I discuss here single particle response of the counter and a possible scheme for a K^- trigger within the event. I have not yet studied multi-particle response in detail, nor have detailed mechanical, optical or electronic designs been made.

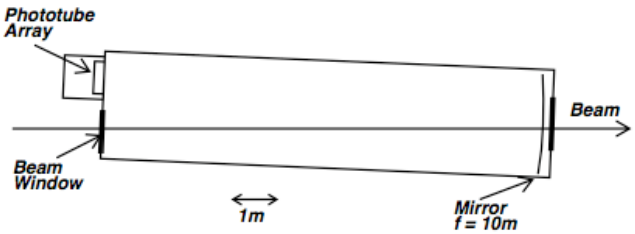


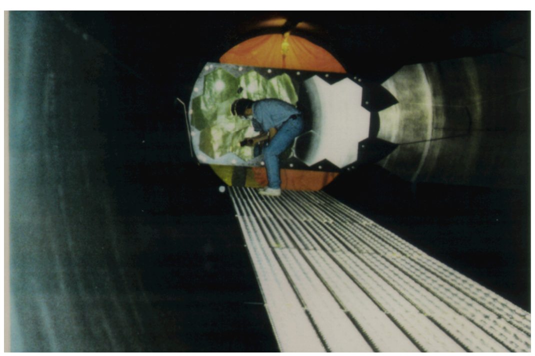
Physically the counter is 10 m long ~ 1 m in diameter with a single 36' spherical mirror. Essentially just like the E-715 counter only a little bigger.

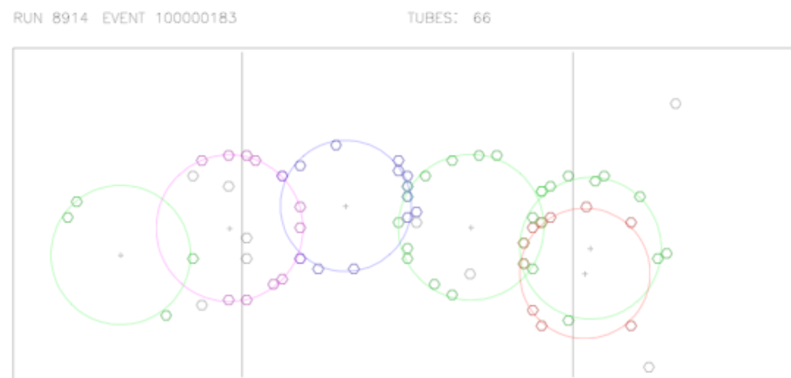


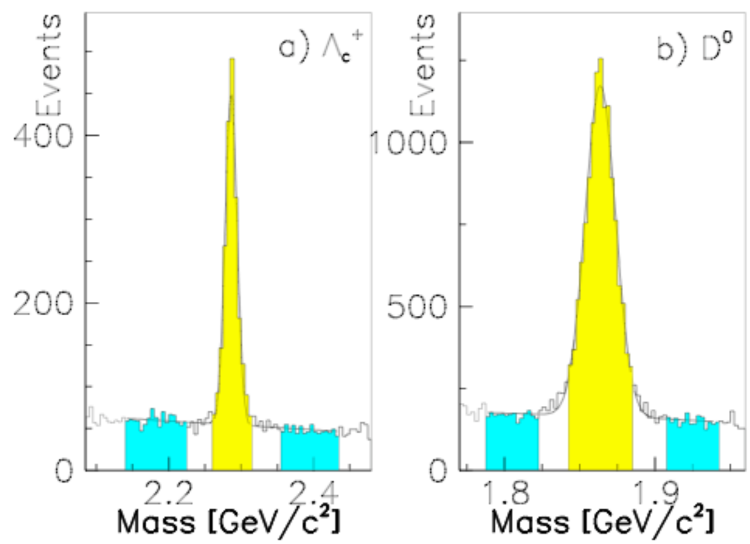
SELEX RICH




Phototube
Array
Beam
Beam
Window
1m
Mirror
f = 10m

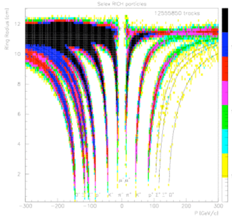


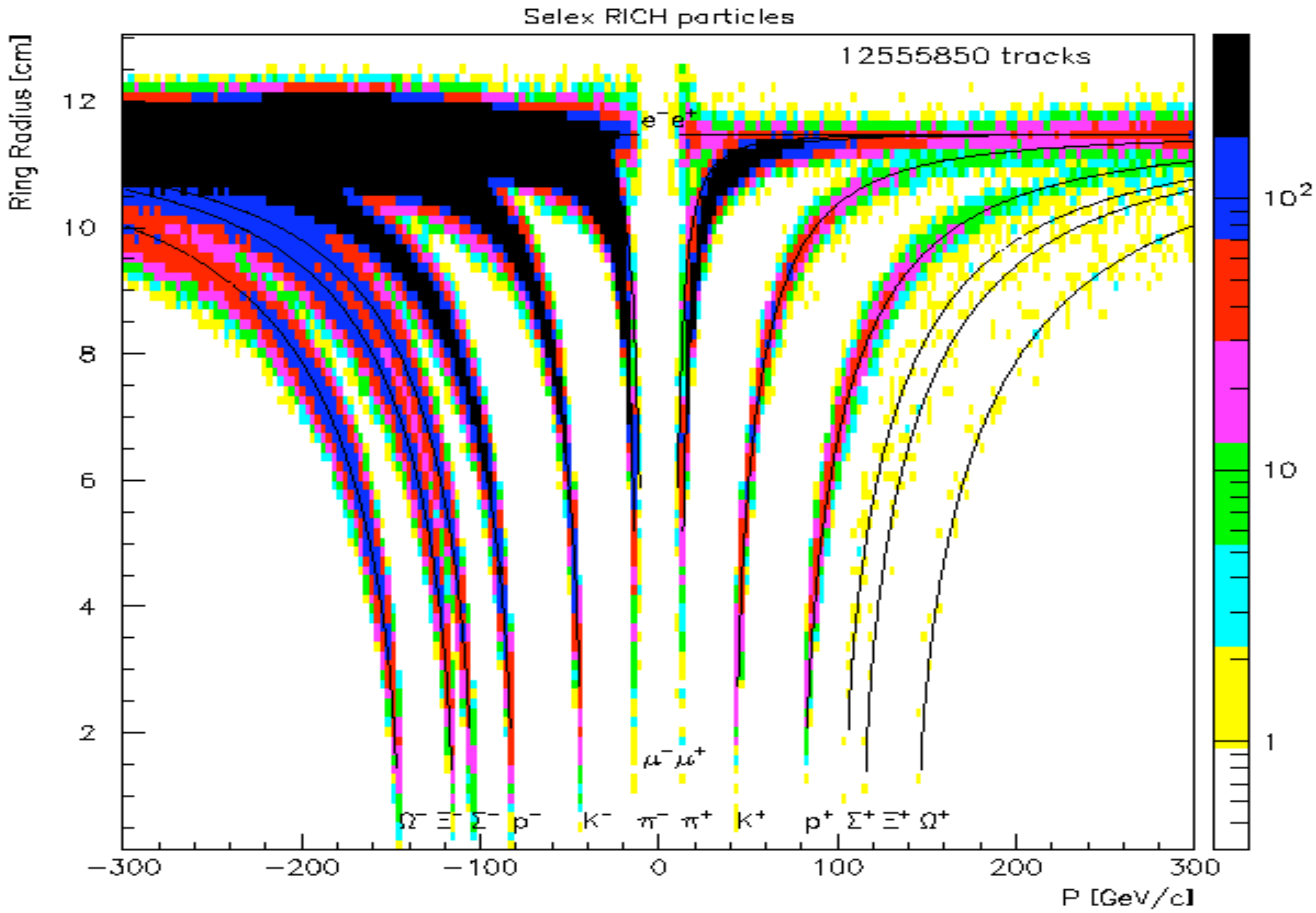

RUN 8914 EVENT 100000183
TUBES: 66


a) Λ_c^+
Events
400
200
0
2.2
2.4
Mass [GeV/c²]
b) D^0
Events
1000
500
0
1.8
1.9
Mass [GeV/c²]

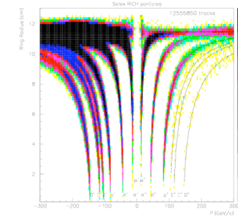
SELEX RICH

particle ID in a 600 GeV/c beam is fun!





Selex RICH Radius Resolution



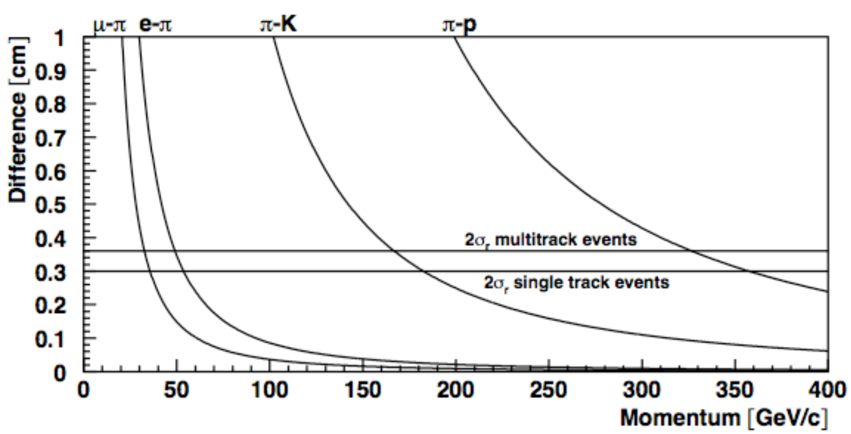
Resolution is pure geometry

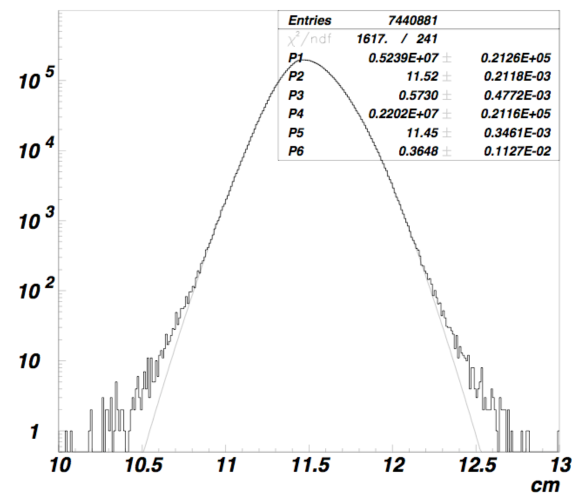
- Table gives single PMT resolution
- Ring resolution is $\sigma_R = \sigma / \mathrm{sqrt}(N)$

Resolution function is Gaussian for many orders of magnitude

Overlaping multiple rings are small

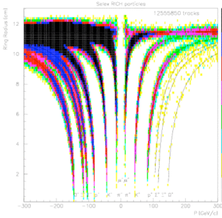
parameter	[mm]
Pixel size	4.03
Mirror alignment	2.06
Tracking resolution	3.0
Dispersion in Neon	1.2
Total predicted	5.54
Measured	5.5 ± 0.1



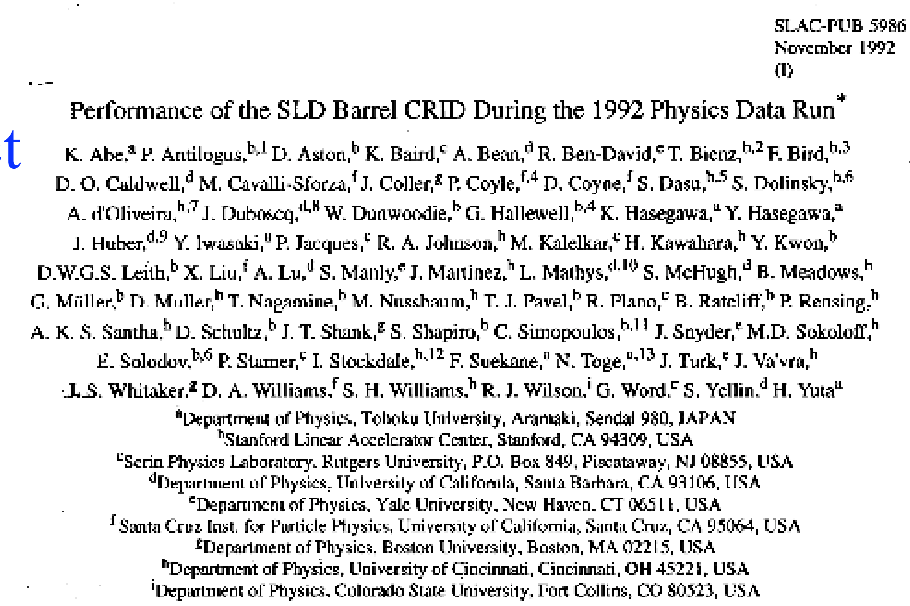


SLD CRID at SLAC

how not to do RICH PID



- Alternative design
  - TMAE wire chambers to detect UV Cherenkov photons.
- In this case (and some, but not all, others) dozens of people spent a dozen years and a dozen M$ for very small gains.
- **KISS**
  - pay for photodetectors that work
- This lesson was learned
  - the DIRC at Babar works well



SLAC-PUB 5986
November 1992
(I)

Performance of the SLD Barrel CRID During the 1992 Physics Data Run*

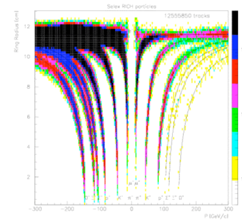
K. Abe,[a] P. Antilogus,[b,1] D. Aston,[b] K. Baird,[c] A. Bean,[d] R. Ben-David,[e] T. Bienz,[b,2] F. Bird,[b,3] D. O. Caldwell,[d] M. Cavalli-Sforza,[f] J. Coller,[g] P. Coyle,[f,4] D. Coyne,[f] S. Dasu,[b,5] S. Dolinsky,[b,6] A. d'Oliveira,[h,7] J. Duboscq,[d,8] W. Dunwoodie,[b] G. Hallewell,[b,4] K. Hasegawa,[a] Y. Hasegawa,[a] J. Huber,[d,9] Y. Iwasaki,[a] P. Jacques,[c] R. A. Johnson,[h] M. Kalelkar,[c] H. Kawahara,[b] Y. Kwon,[b] D.W.G.S. Leith,[b] X. Liu,[f] A. Lu,[d] S. Manly,[e] J. Martinez,[h] L. Mathys,[d,10] S. McHugh,[d] B. Meadows,[h] G. Müller,[b] D. Muller,[b] T. Nagamine,[b] M. Nussbaum,[h] T. J. Pavel,[b] R. Plano,[c] B. Ratcliff,[b] P. Rensing,[b] A. K. S. Santha,[h] D. Schultz,[b] J. T. Shank,[g] S. Shapiro,[b] C. Simopoulos,[b,11] J. Snyder,[e] M.D. Sokoloff,[h] E. Solodov,[b,6] P. Stamer,[c] I. Stockdale,[h,12] F. Suekane,[a] N. Toge,[a,13] J. Turk,[e] J. Va'vra,[b] J.S. Whitaker,[g] D. A. Williams,[f] S. H. Williams,[b] R. J. Wilson,[i] G. Word,[c] S. Yellin,[d] H. Yuta[a]

[a]Department of Physics, Tohoku University, Aramaki, Sendai 980, JAPAN
[b]Stanford Linear Accelerator Center, Stanford, CA 94309, USA
[c]Serin Physics Laboratory, Rutgers University, P.O. Box 849, Piscataway, NJ 08855, USA
[d]Department of Physics, University of California, Santa Barbara, CA 93106, USA
[e]Department of Physics, Yale University, New Haven, CT 06511, USA
[f]Santa Cruz Inst. for Particle Physics, University of California, Santa Cruz, CA 95064, USA
[g]Department of Physics, Boston University, Boston, MA 02215, USA
[h]Department of Physics, University of Cincinnati, Cincinnati, OH 45221, USA
[i]Department of Physics, Colorado State University, Fort Collins, CO 80523, USA

No PID performance curves ever shown

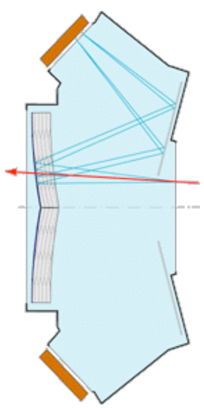
Hera-b RICH

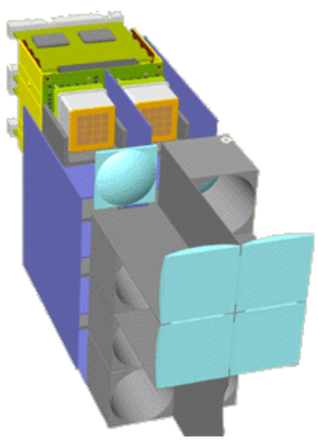
if only the experiment had worked as well as the RICH

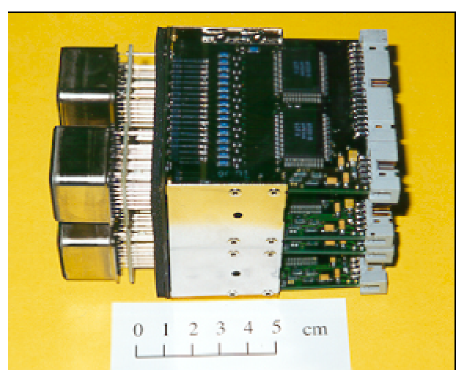


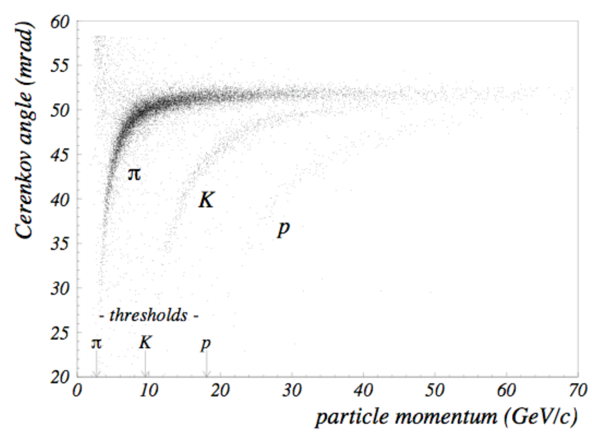
Multi-anode PMTs - the next step

- clever demagnifing lens optics to match Cherenkov photons onto Hammamatsu multi-anode PMTs
- Detector performance goals largely achieved
- The rest of Hera-B had more than a few problems

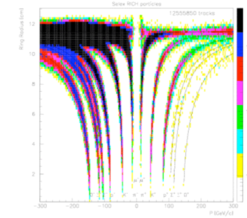






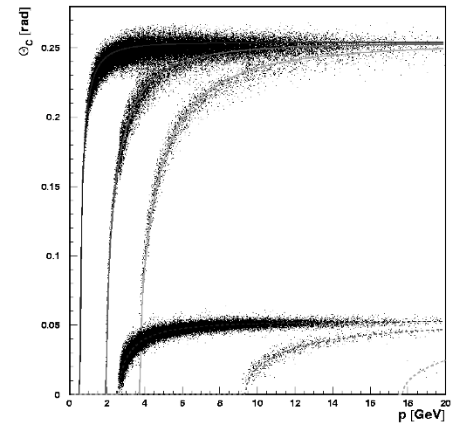


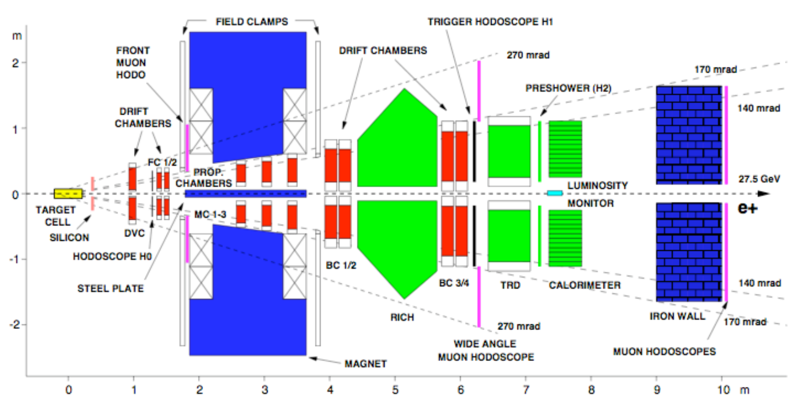
HERMES dual radiator RICH

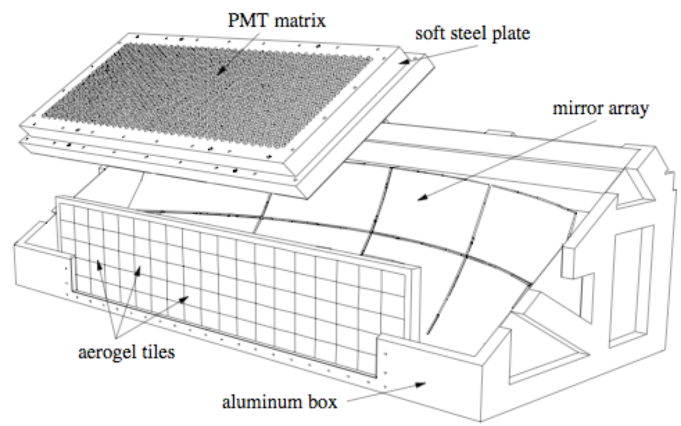


Two Cherenkov Radiators: gas and aerogel

- covers a broad momentum range with good separation and efficiency
- This was done with 3/4 PMTs *a-la* Selex
- You'll hear this again later in this session.



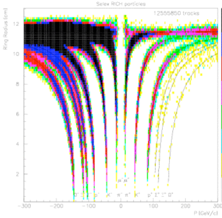




Shamelessly stolen from Hal Jackson's RICH2004 proceedings

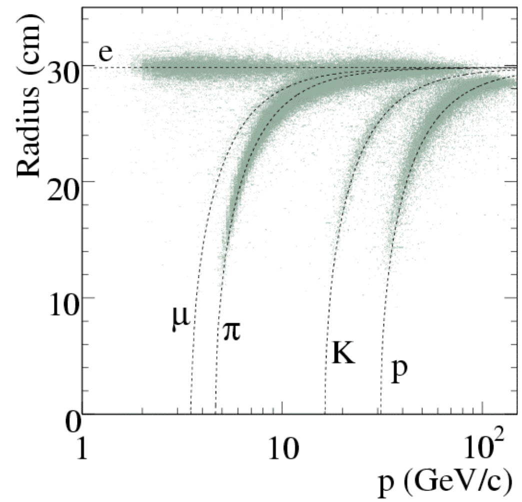
Main Injector Particle Production

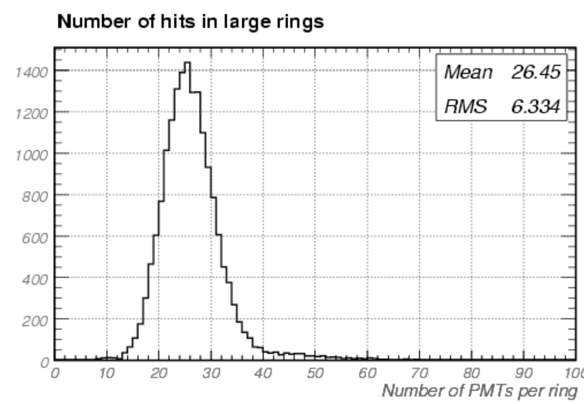
the SELEX RICH on CO_2



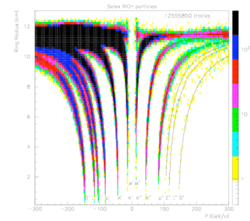
Selex Rich inherited by the MIPP experiment

- The experiment's goal is to measure particle production yields at the Fermilab 125 geV/c Main Injector
- They needed to shift the PID momentum scale by ~125GeV/c / 800GeV/c
- Changed working gas from Neon to CO_2
  - Higher index, lower threshold
  - Lots more light
  - Somewhat worse dispersion
- Same vessel and pmt array
- A fresh design would be 2-3m long, not 10m





PMT RICH Design Criteria



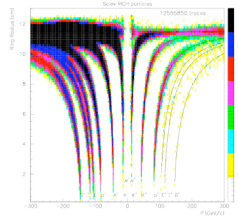
- Radiator
  - Index determines velocity threshold
  - All else follows from kinematics (**P** = $M\gamma\beta$)
  - Length and quantum efficiency gives photon yield $N_{pe}(\beta=1)$
  - Dispersion effects resolution

- Photon detector
  - Angular phase space of tracks to be IDed in units of θ_c^2 drive number of pixels, technology and cost.
  - Spectral range couples resolution, N_{pe}, and cost.

- Optics - get the Cherenkov light to the photon detector
  - Simple & cheap - or not, depending on the rest of the experiment

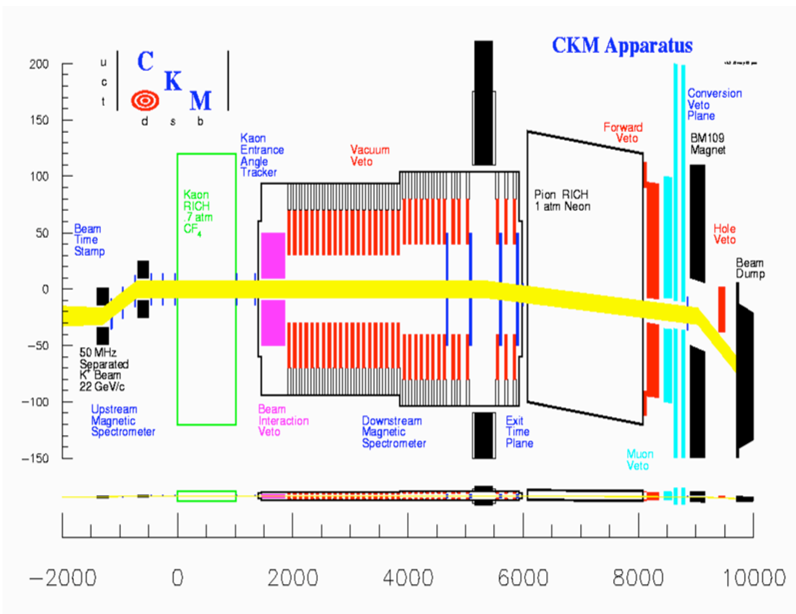
- Electronics - rates?, timing?, cost? Selex RICH readout as an MWPC plane.

Advanced Design Example - CKM
Ultra-rare (very high rate) Kaon decays

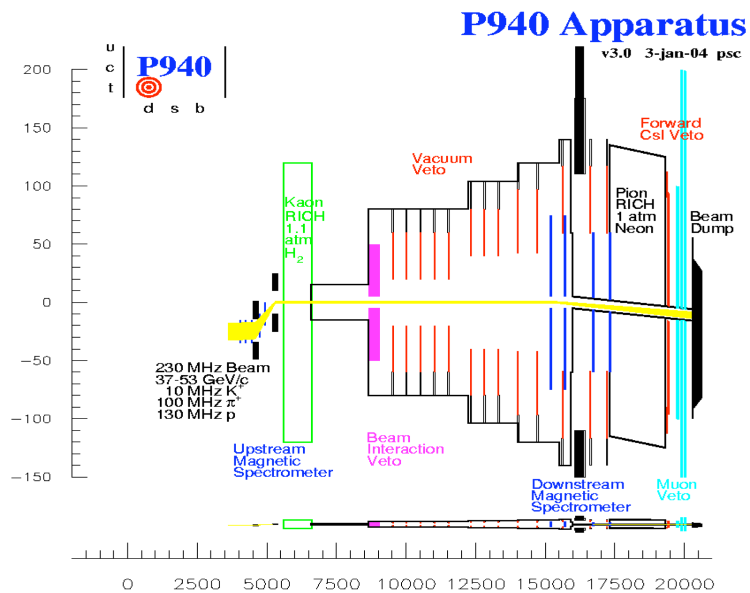


- Decay in flight ($K^+ \rightarrow \pi^+ \pi^0$, $K^+ \rightarrow \pi^+ \nu\nu$)
- Redundant high rate detectors and veto systems.
- RICHes used as high rate **vector velocity spectrometers [** $\beta\gamma(R)$, θ_x, θ_y; t **]**

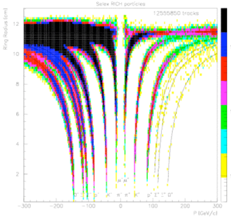
Separated 50 MHz K+ beam 22 GeV/c.



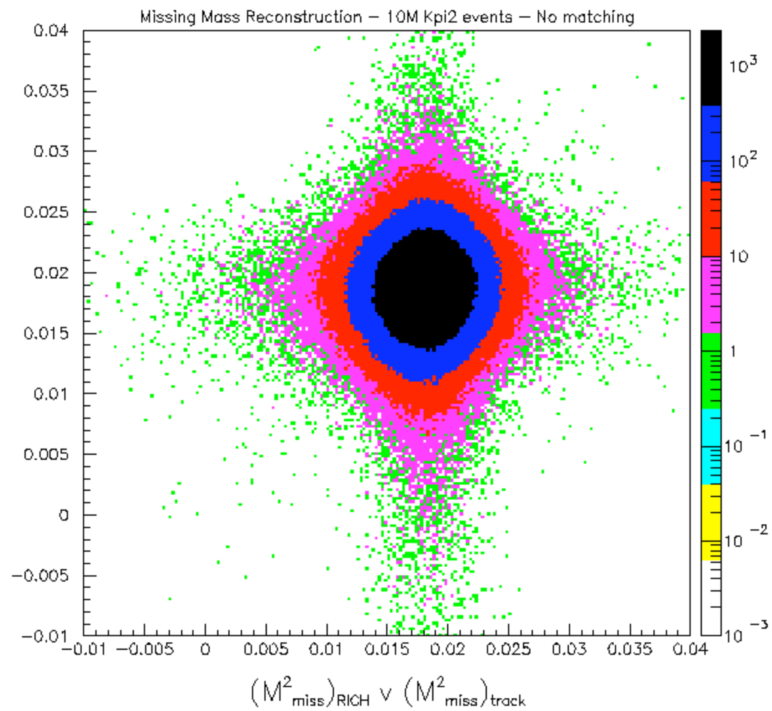
Un-separated 230MHz + beam 37-53 GeV



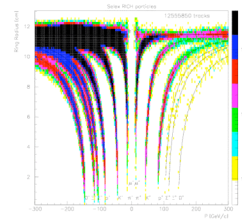
Simulated Spectrometer Performance



- Missing mass resolution for $M^2_{\pi^0}$ from $K^+ \rightarrow \pi^+ \pi^0$
- Matched resolution from momentum and velocity spectrometers
- Low non-Gaussian tails
- Uncorrelated measurements
- Sub nsec time resolution

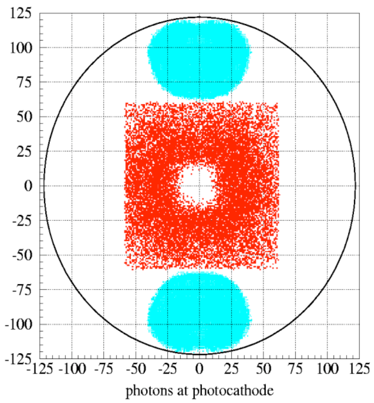


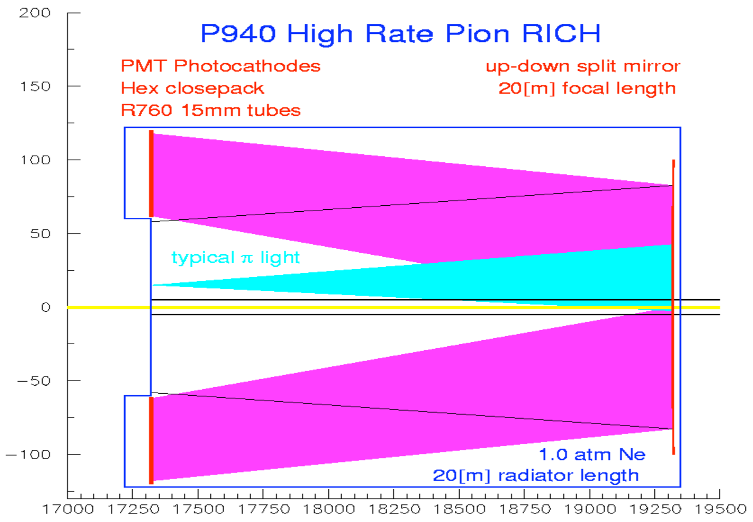
Pion RICH Redesign



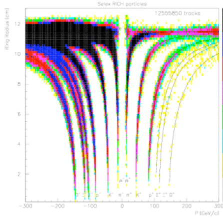
P940 Pion RICH Redesign

- 1 Atm Neon
- 20m radiator length
- Up-down split multi segment spherical mirror
- 20m focal length
- R760 PMT Photocathodes (2x~1500 tubes)
- Quartz tubes & windows (180nm)





Pion RICH simulated performance

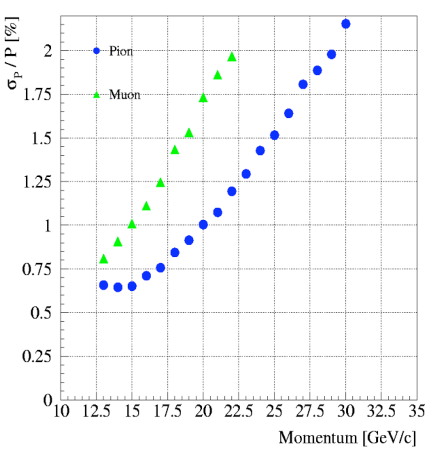


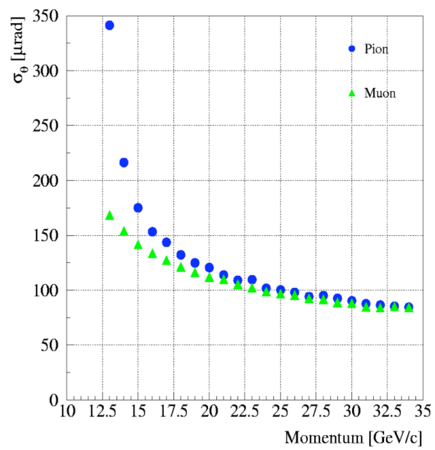
Only changes are

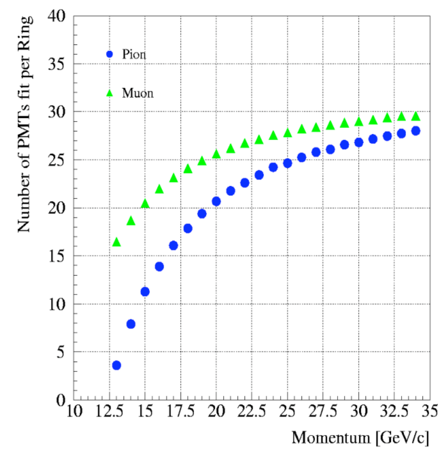
- Vacuum beam pipe
- Up-down split mirror
- Split photo-cathode

2% of photons lost to pipe

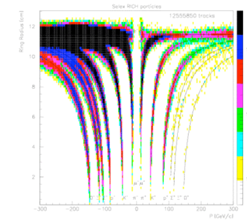
parameter	CKM / P940 (Ne)
flux [MHz]	~2
Radiation Lengths (x10^{-3})	63
Interaction Lengths (x10^{-3})	19
Maximum PMT rate [KHz]	~30
Vessel diameter [m]	4.44 (8ft)







Conclusions



- RICHes are now mature technology
  The early RICH history is now *history*.
  A mature technology has already produced physics results
  A good, simple, design will work as simply calculated

- Challenges for a CLAS12 RICH
  Geometry - getting the light out to the photo-detector
  Large solid angle

- Note
  If the radiator can be close enough to the target some charged hyperons will radiate *before* they decay.
  Direct hyperon PID. ($\gamma\beta c\tau \sim 18$ cm for a P=5 GeV/c Σ^-)