CLAS12 RICH Detector Workshop

Jefferson Lab, January 2008

The HERA-B RICH Detector

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The RICH detector in HERA-B

The vessel

Perfluorobutane (C_4F_{10}) and the gas system

The mirrors

The photon detector

Hits and rings

Performance, particle identification

Conclusions

The RICH detector in HERA-B

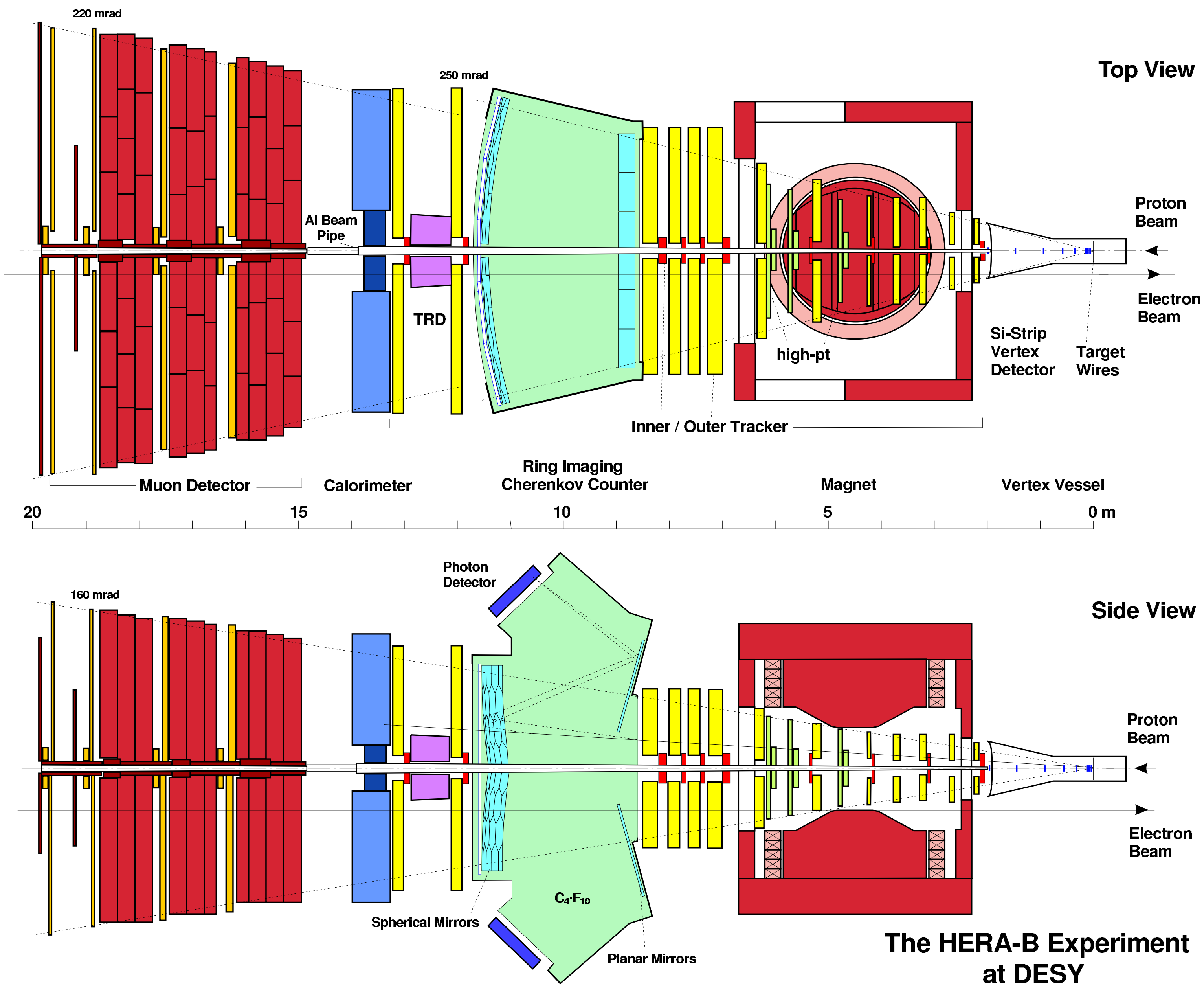
The HERA-B experiment was a large, fixed target experiment with several detectors.

RICH was designed to identify tagging pions and kaons in the range (~10) .. 50 GeV/c.

Close predecessor: **OMEGA RICH** at CERN, but HERA-B RICH had two major simplifications:

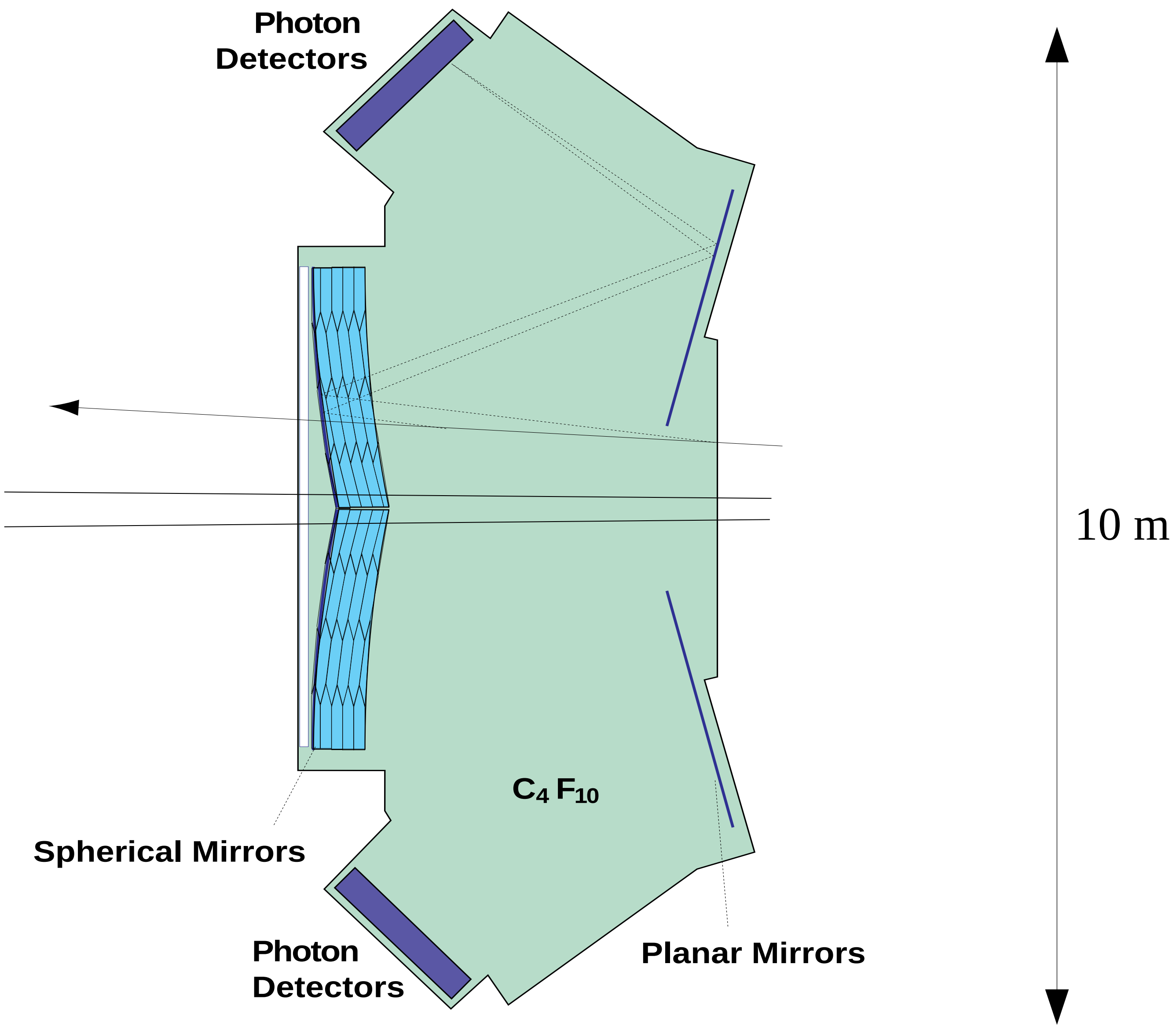
- Didn't operate in 170 - 230 nm range; hence:
  - no need for quartz windows on the vessel (UV-transparent plastic was used);
  - **requirement on gas purity is much lower** (10 ppm is the oxygen + water vapor limit in OMEGA RICH);
- Used multichannel PMTs instead of TMAE gas-based photon detectors.

But HERA-B RICH has more complex optical system, and more readout channels.



220 mrad
250 mrad
Top View
Al Beam Pipe
TRD
Proton Beam
Electron Beam
Si-Strip Vertex Detector
Target Wires
high-pt
Inner / Outer Tracker
Muon Detector
Calorimeter
Ring Imaging Cherenkov Counter
Magnet
Vertex Vessel
20
15
10
5
0 m
160 mrad
Photon Detector
Side View
Proton Beam
Electron Beam
C_4F_{10}
Spherical Mirrors
Planar Mirrors
The HERA-B Experiment at DESY

The vessel



Photon
Detectors
Spherical Mirrors
$C_4\,F_{10}$
Photon
Detectors
Planar Mirrors
10 m


nicht berühren
touch

Engineering calculations were correct, and there was no trouble in:

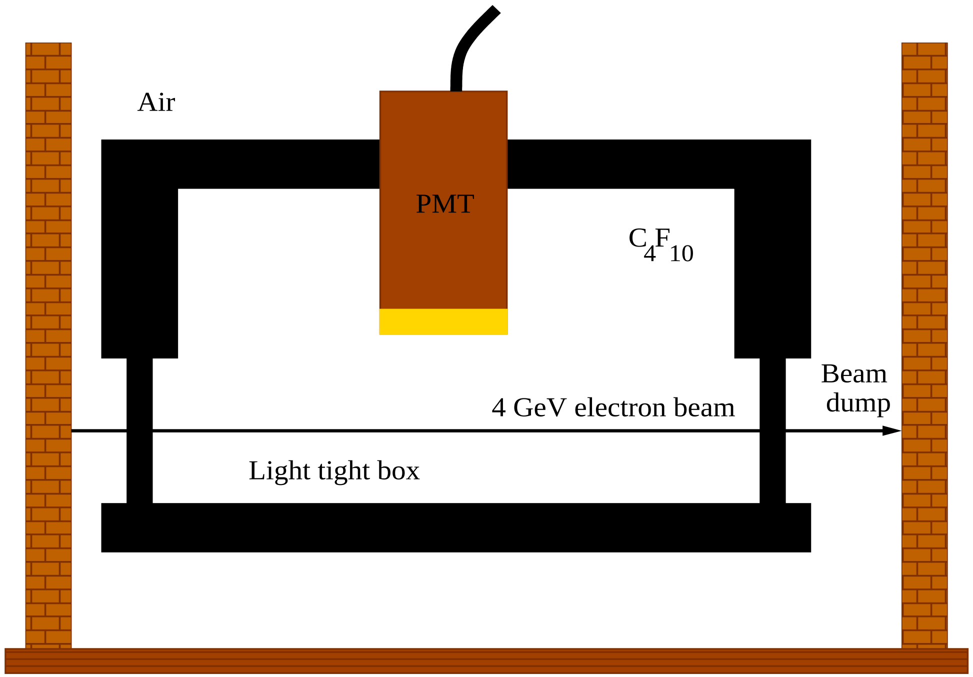
- General mechanical stability.
- Thickness and the way of attachment of plexiglas (Perspex, PMMA) windows.
- Vibrations to cause mirrors' misalignment.
- No local excessive heat generation.
- The mirror support wall (honeycomb structure of Al+epoxy) didn't deform over time.
- C_4F_{10} didn't cause deterioration of glues.
- No evident traces of ionization damage to gas, glues, optical surfaces.

What went wrong:

- There were leaks from connections of parts of the vessel.
- Particle windows seemed to protrude under gas's pressure too much, subjecting beampipes to danger.

Perfluorobutane (C_4F_{10}) and the gas system

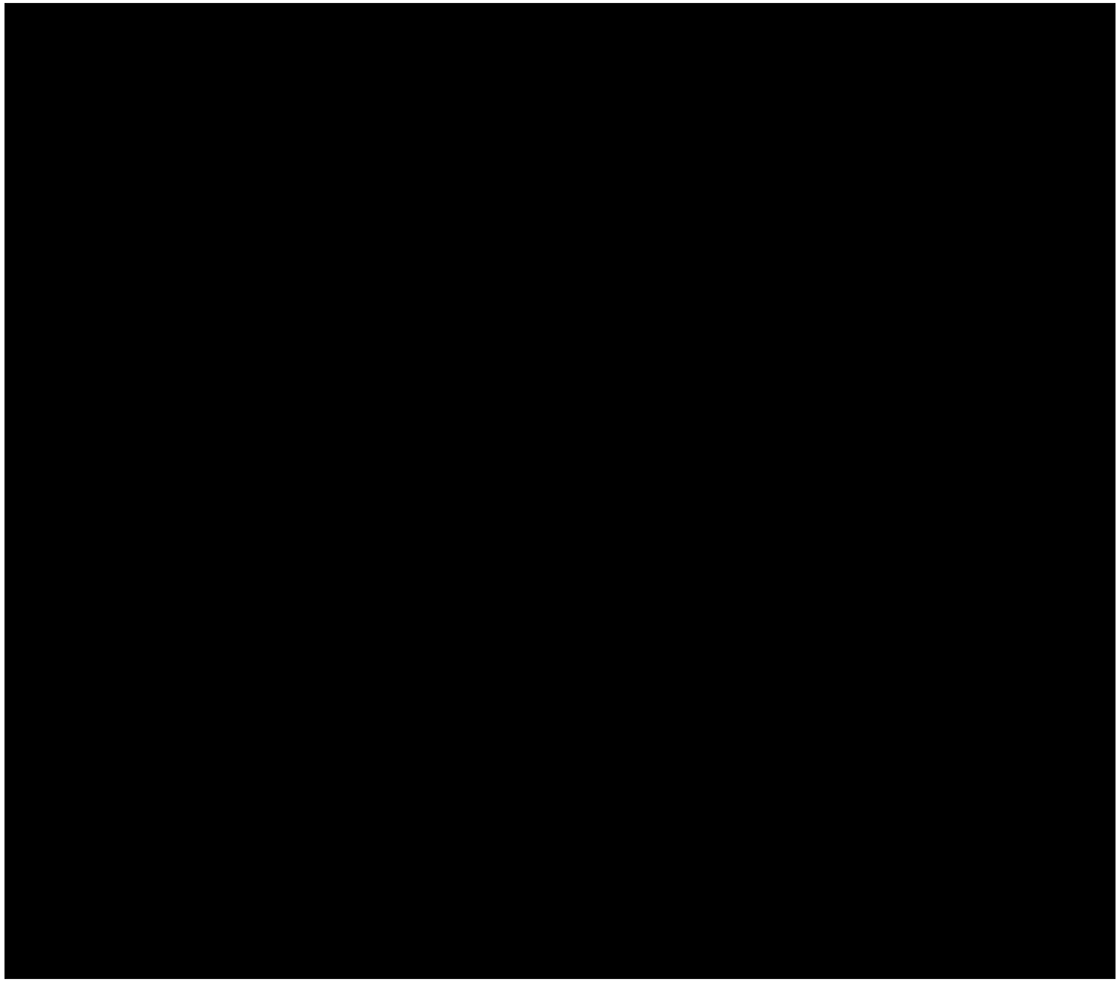
- Has high refractive index, low dispersion.
- Cherenkov angle for saturated tracks = 53 mrad. Ring radius = 300 mm.
- Low absorption and acceptable Rayleigh scattering in the working spectral range (330 – 550 nm).
- Scintillation is very low, as a rough measurement in test beam showed:



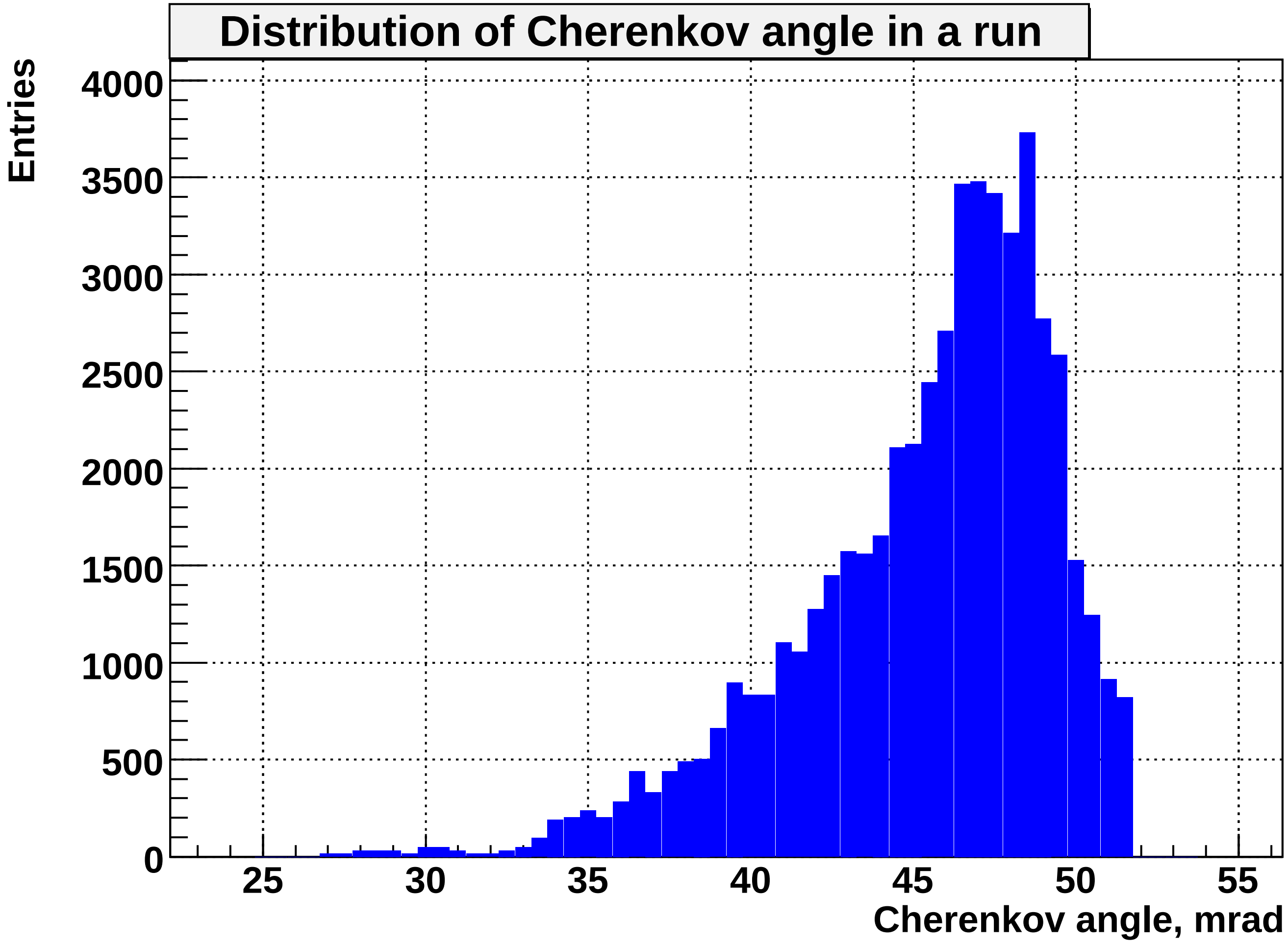
There are two ways to monitor the refractive index online:

1) Fabry-Perot interferometer, filled from vacuum to atmospheric pressure with gas.

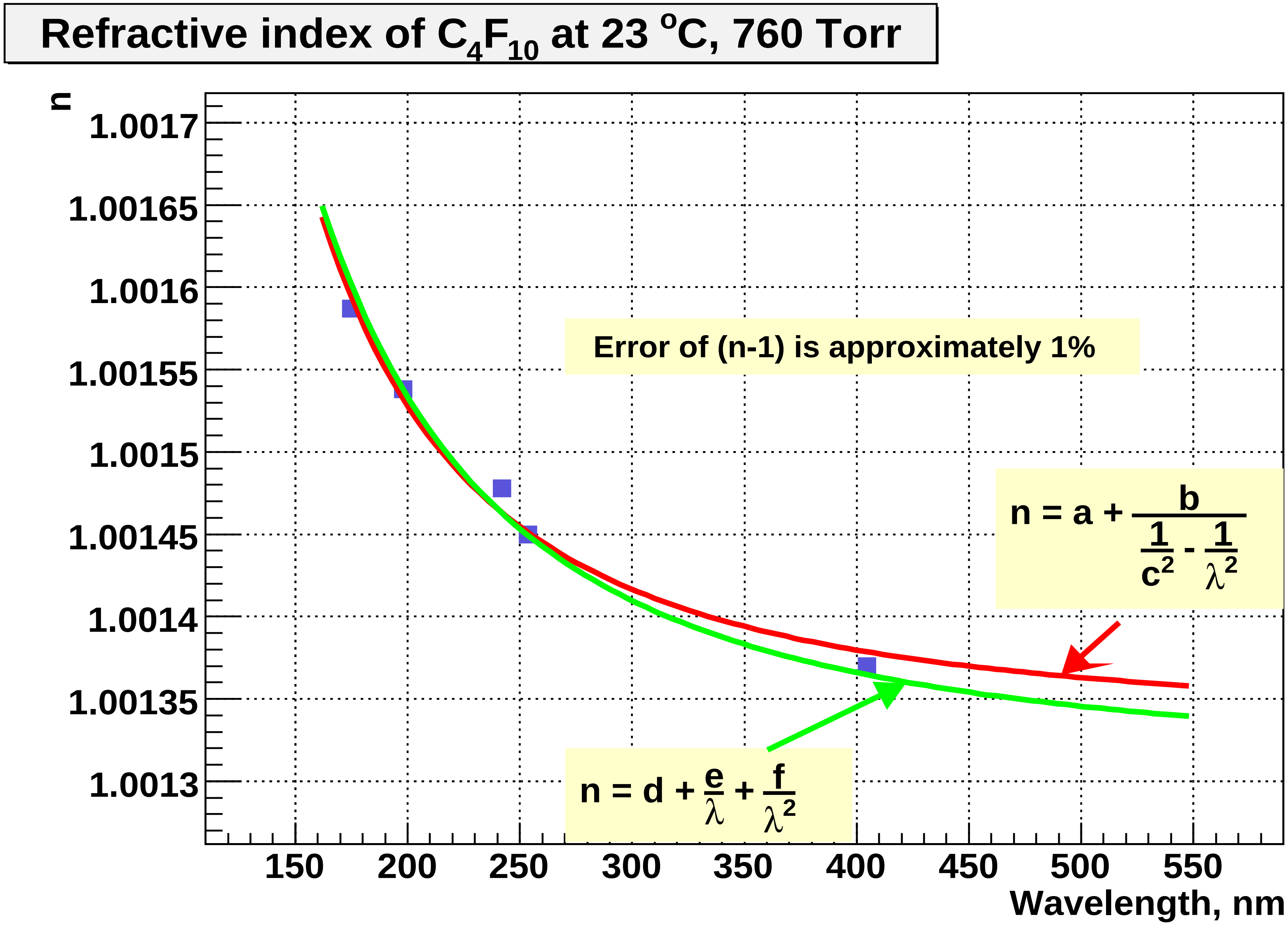
The method is very accurate, but requires some optical hardware, and putting of the interferometer on soft support.



2) Reconstruction of saturated tracks' radius:



Not accurate, but comes for free, and was used.


Refractive index of C4F10 at 23 oC, 760 Torr
n
1.0017
1.00165
1.0016
1.00155
1.0015
1.00145
1.0014
1.00135
1.0013
150
200
250
300
350
400
450
500
550
Wavelength, nm
Error of (n-1) is approximately 1%
n = a + b / (1/c2 - 1/λ2)
n = d + e/λ + f/λ2

Formula (line)	Fit parameter	Value
Red	a	9.98870E-01
Red	b	8.43531E-07
Red	c	5.40505E+01
Green	d	1.00131E+00
Green	e	1.76615E-03
Green	f	8.69244E+00

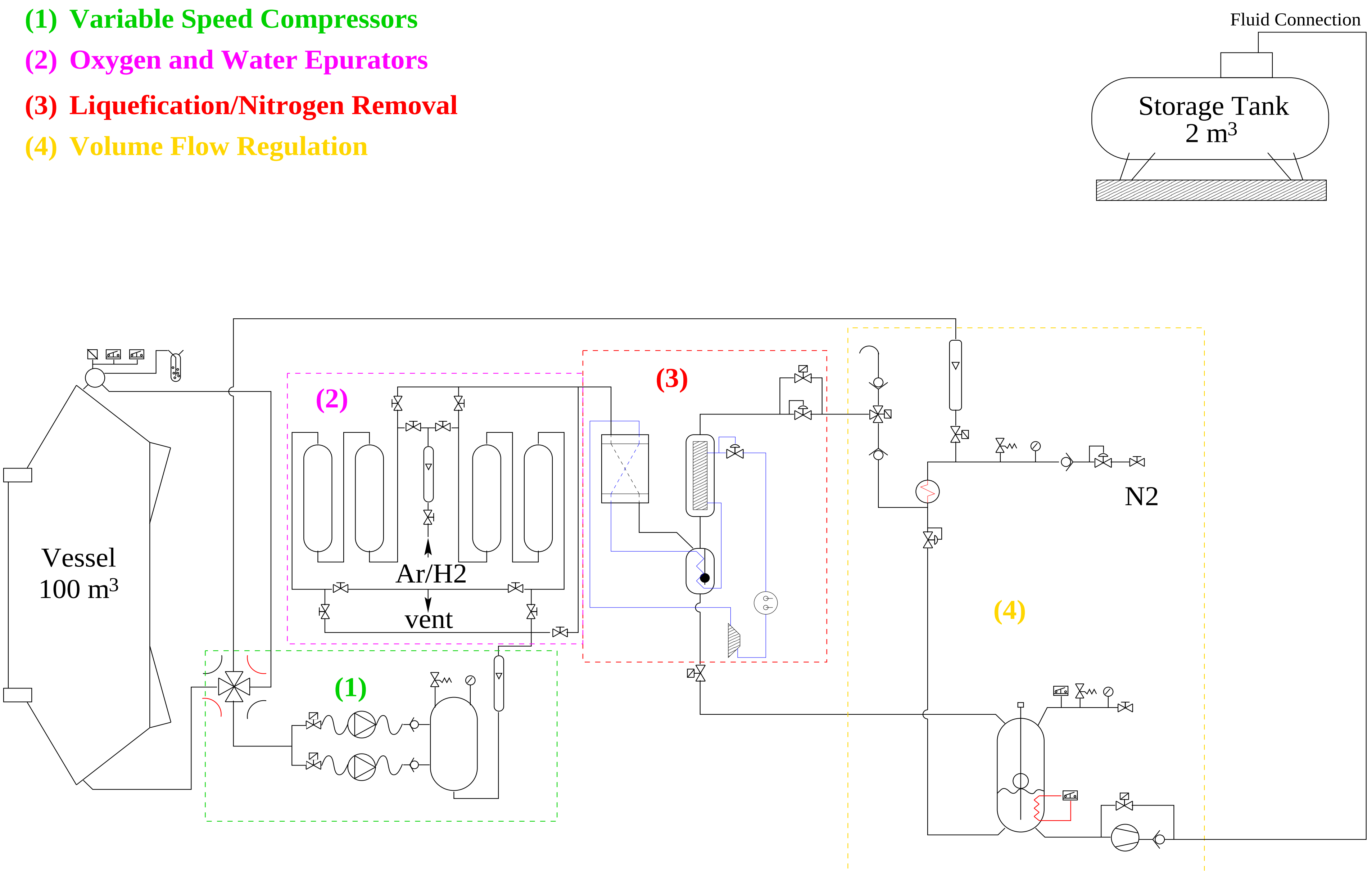
For pressure and temperature corrections:

$$n(P,T) - 1 = \left(n(P_{nom},T_{nom}) - 1\right)\cdot\left(\frac{P}{P_{nom}}\cdot\frac{T_{nom}}{T}\right)$$

There is ~2 degrees temperature difference over height (outside: 5 - 8 degrees);

There is 0.7 kPa pressure difference $\left(\rho g h\right)$;

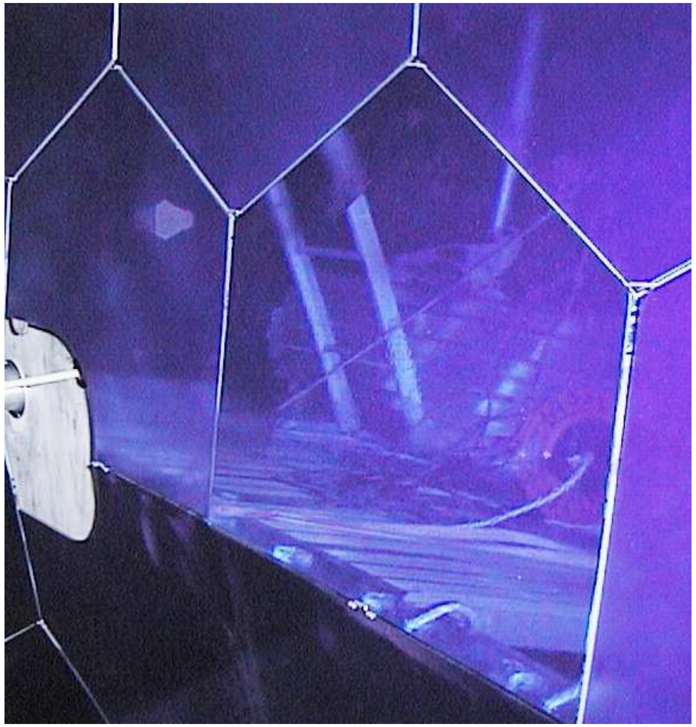
These result in 0.7% change of (n-1) over height.


(1) Variable Speed Compressors
(2) Oxygen and Water Epurators
(3) Liquefication/Nitrogen Removal
(4) Volume Flow Regulation
Fluid Connection
Storage Tank
2 m³
Vessel
100 m³
Ar/H2
vent
N2
(1)
(2)
(3)
(4)

The controller's rack
and
the compressor's rack
(of total 4 racks)

The mirrors

- **80** spherical (mostly hexagons) and **36** planar (rectangles) mirrors.
- 7 mm thick glass, aluminum reflective coating protected by thin MgF_2 layer.
- Hexagons are 0.72 m in diameter, rectangles are around 1 m in size.
- Mirrors need not have high optical quality.
- Spherical mirrors are within spectrometer's acceptance. Planars are partly.
- Tried several manufacturers; Glass Mountain Optics from Texas was the best.



Quality assessment:

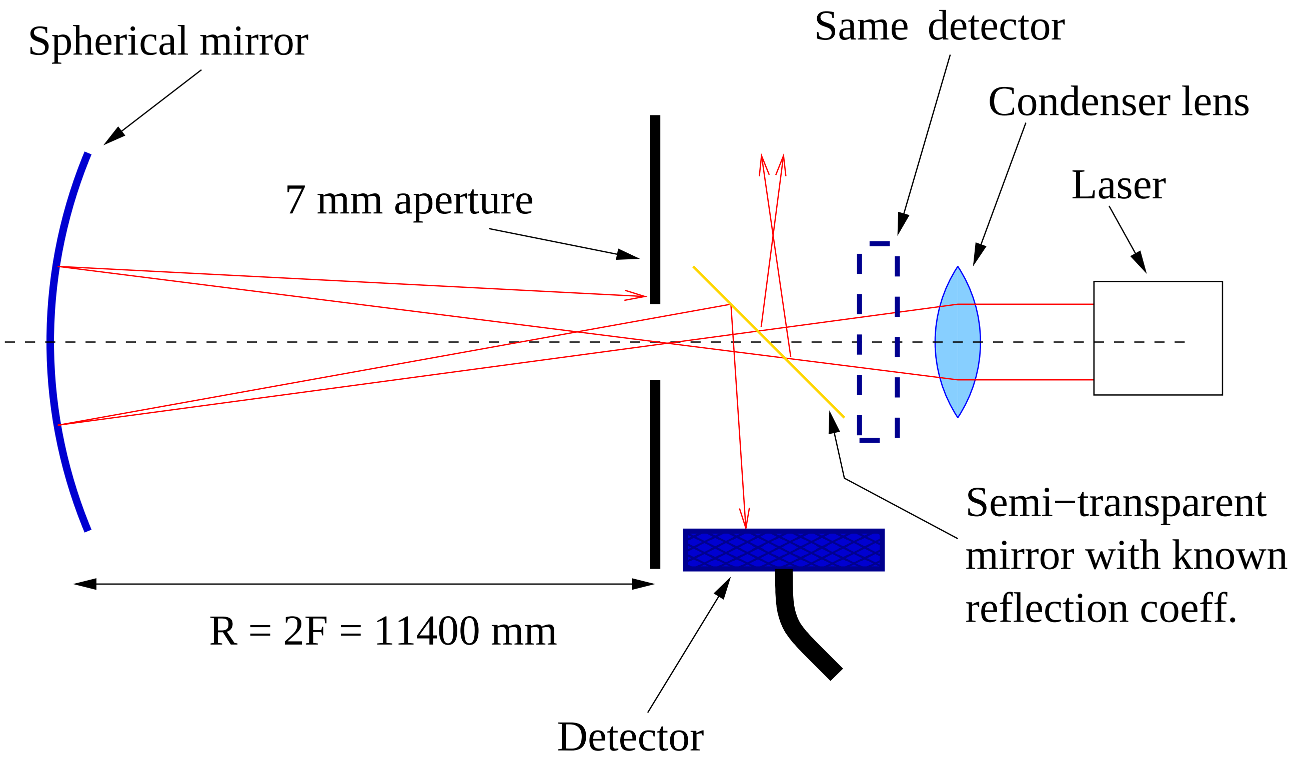
Spherical mirrors, two controls:

1. Total reflection back into aperture at 2F. Required that 90% of light passes through.
2. Ronchi test for defective areas.

Planar mirrors, with theodolite.

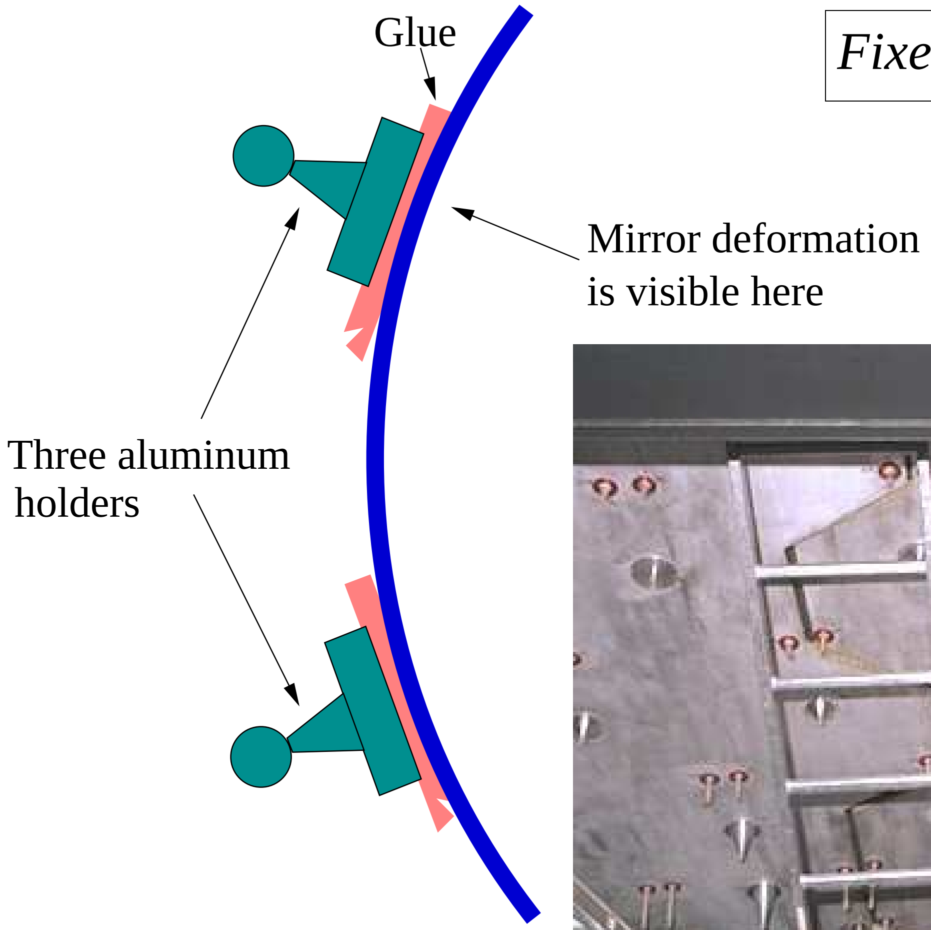
Requirements are weaker since they are closer to photon detector.

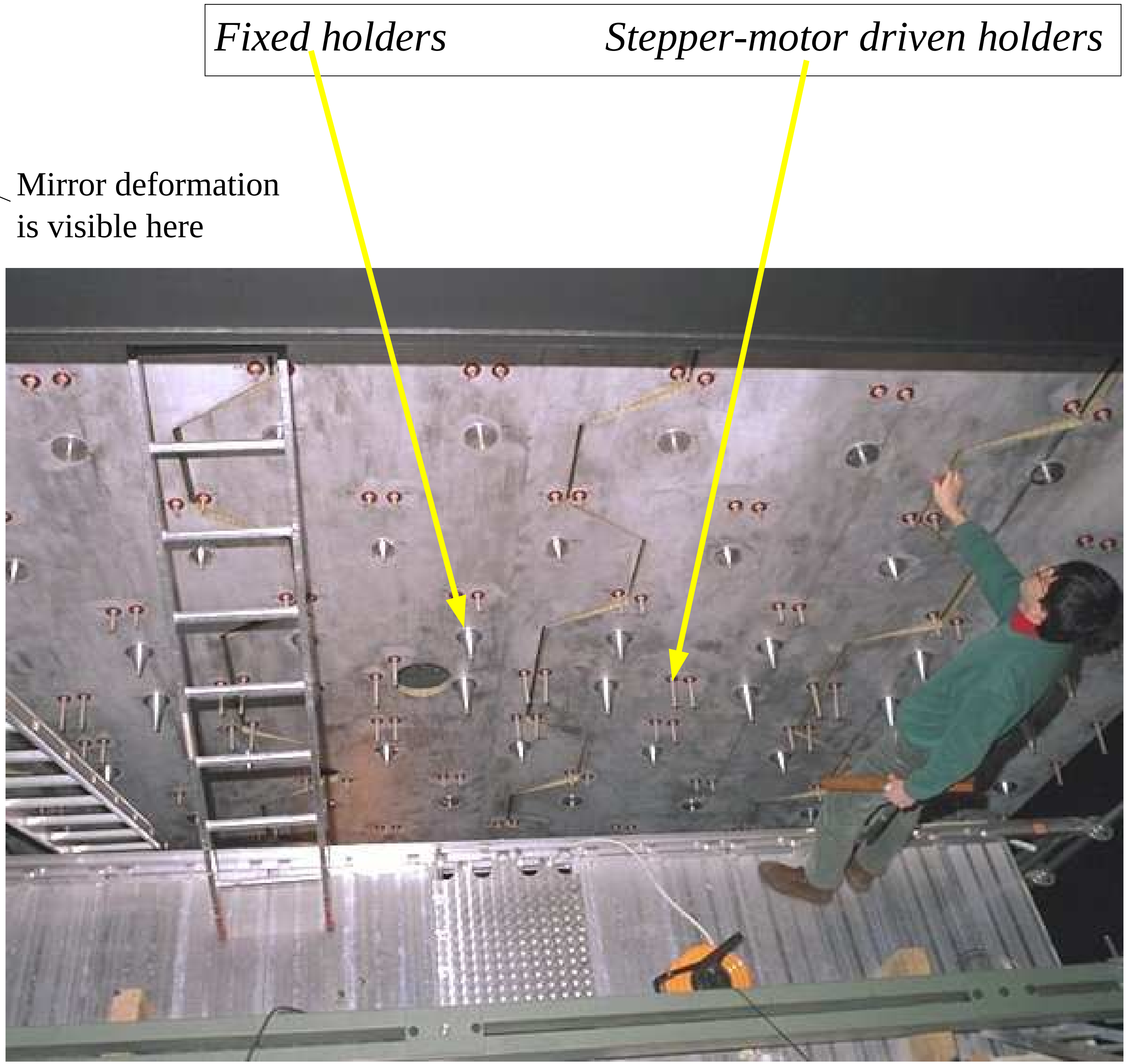
Just a **few** mirrors didn't pass the test.

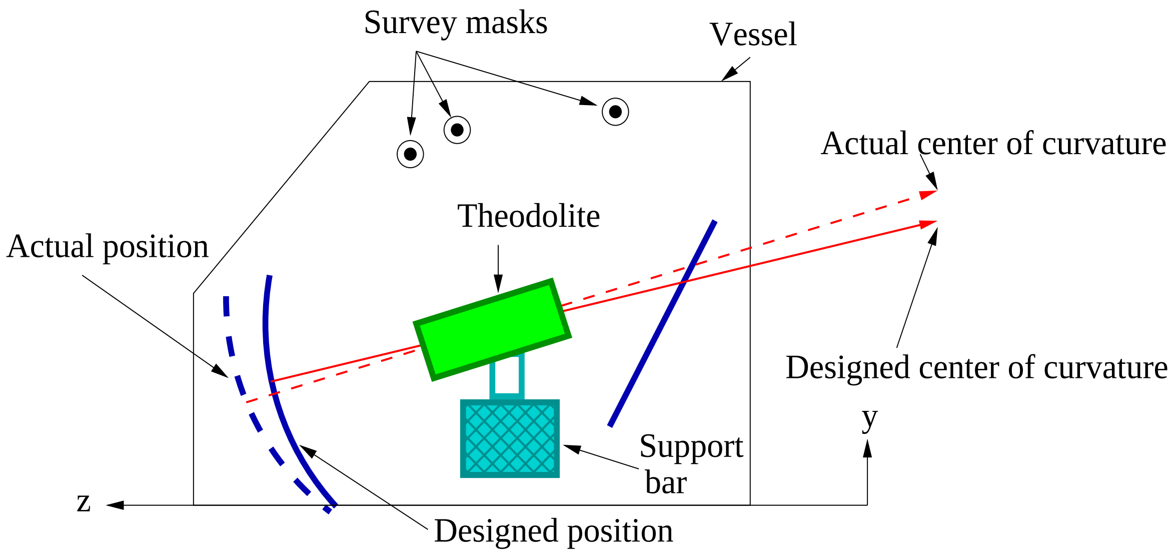


Suspension and alignment:

- Must allow for different temperature expansion of glass and support.
- Must be hard enough not to be deformed itself over long term.
- Rubber-like glues was used.
- Planar mirrors don't have the mechanical strength inherent to spherical ones.


Glue
Mirror deformation
is visible here
Three aluminum
holders


Fixed holders
Stepper-motor driven holders


Survey masks
Vessel
Actual center of curvature
Theodolite
Actual position
Designed center of curvature
y
Support
bar
z
Designed position

Mirrors: what was problematic

- Planar mirror support – is difficult, since they are partly within acceptance. The first attempt was unsuccessful.

Mirrors: what went without problems

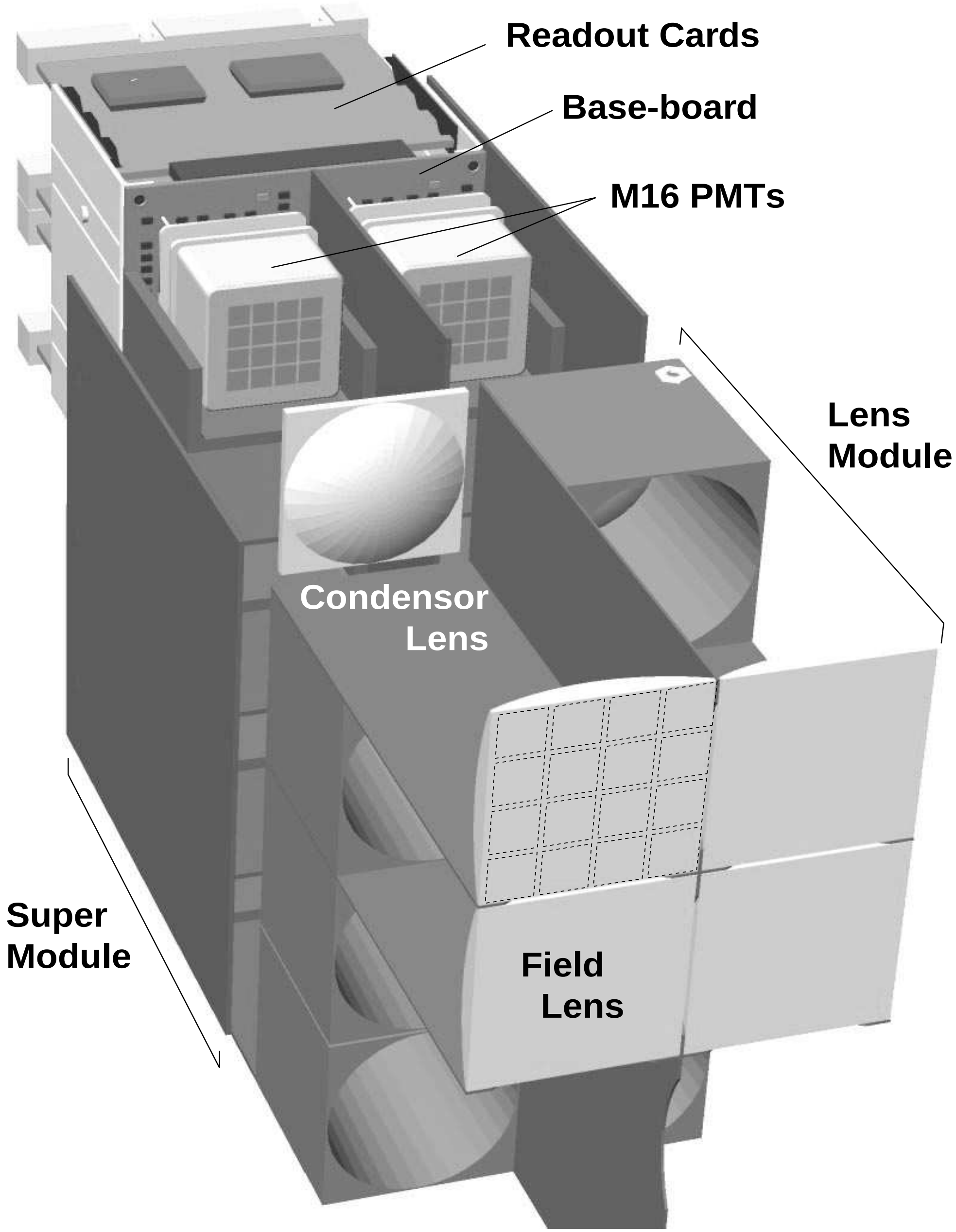
- Reflection coefficient: as expected, 0.82 - 0.94 within the working spectral range.
- Deformations within limits.
- Glues were strong enough.
- Alignment and the support wall held.
- Probably no aging (reduction of the reflection coefficient) occurred.
- No scattered reflection from the reflecting surfaces.
- An alignment-with-data routine later was run. Showed no misalignments worth a realignment of mirrors – was possible to compensate in software.

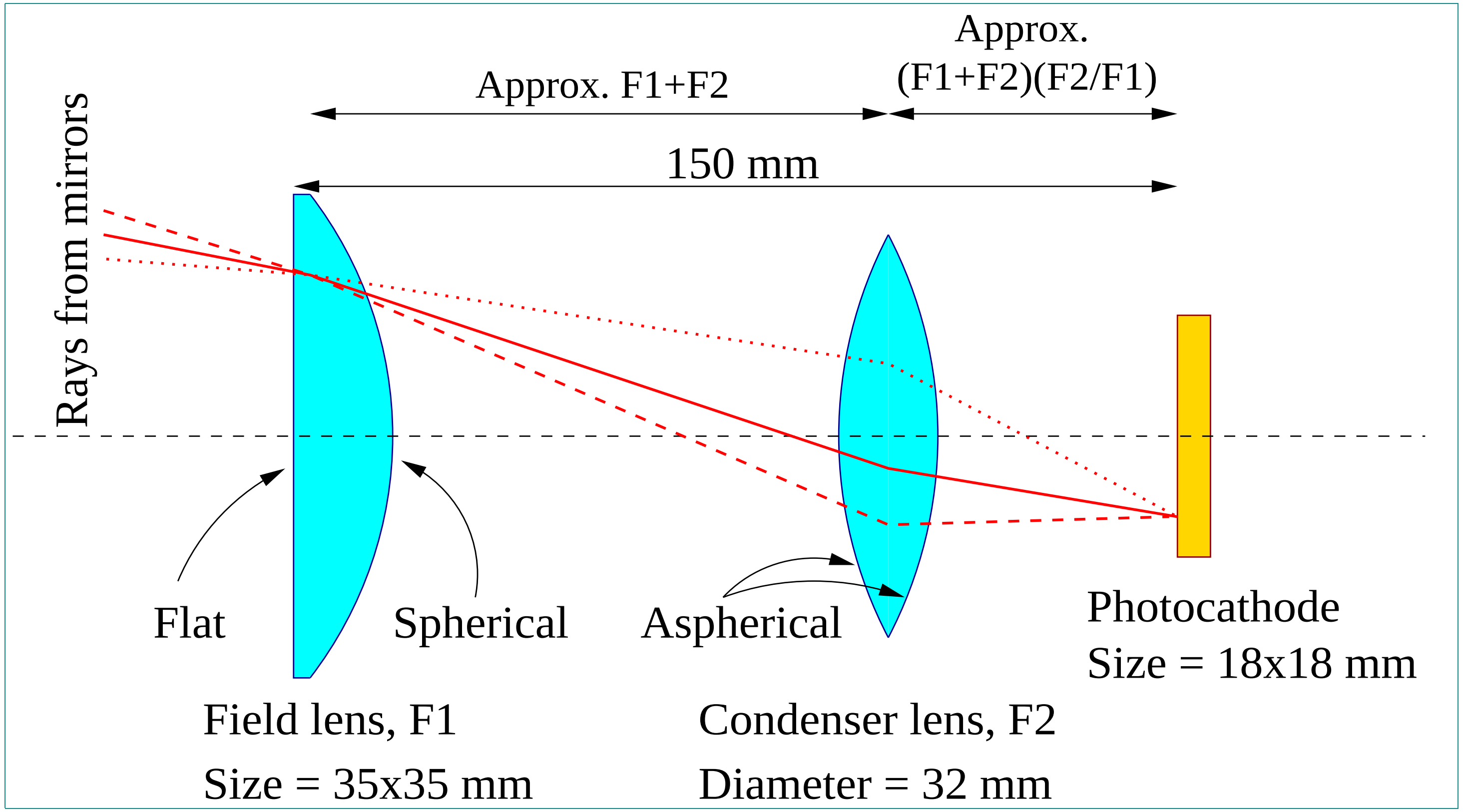
The photon detector

Two "home-made" systems based on CsI and TMAE gas were tested. Both showed enough sensitivity, but **unacceptable aging.**

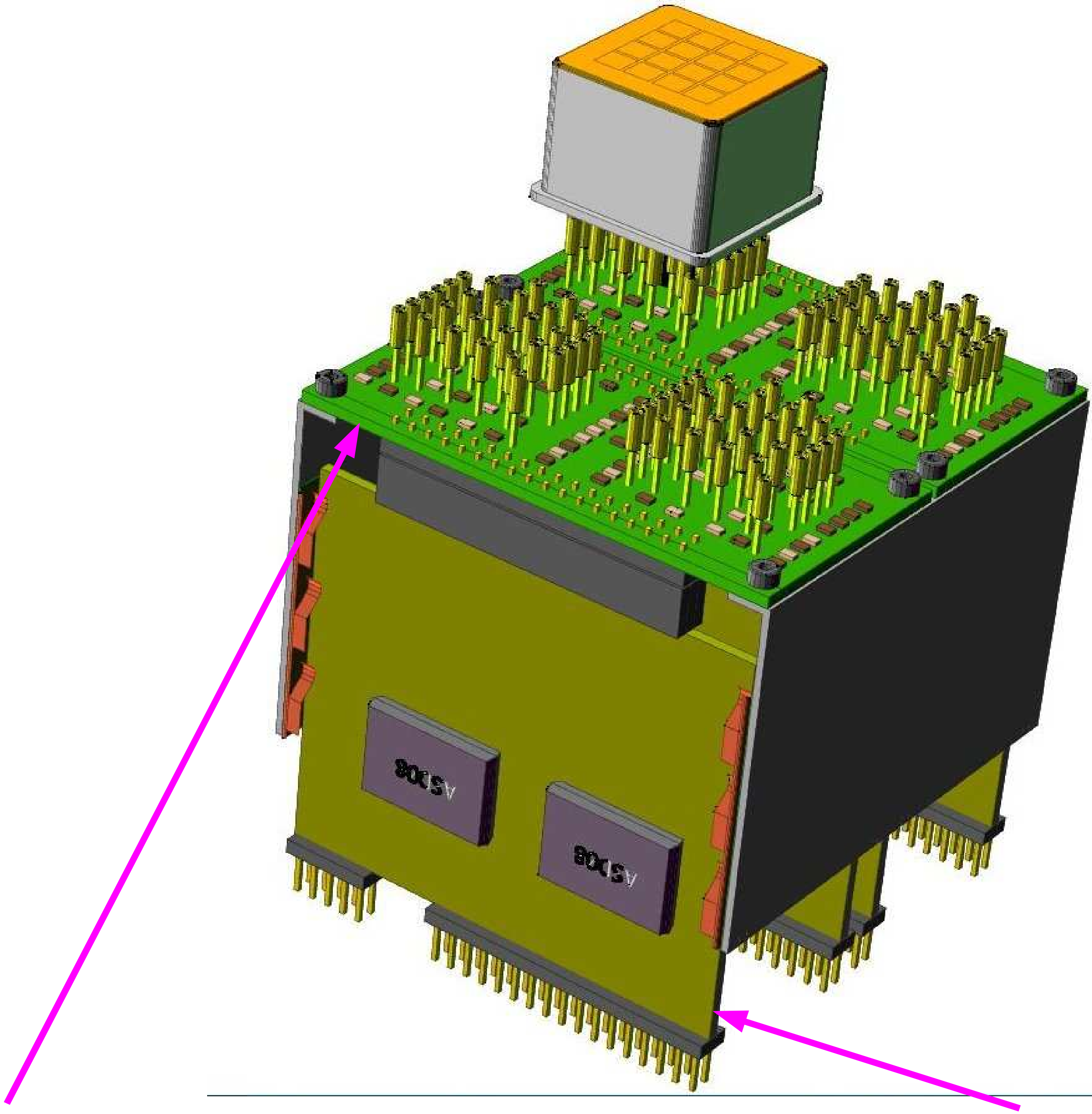
At the right time16- and 4-channel PMTs from Hamamatsu arrived. Tests showed good operation. Quantities: 1448 + 752 PMTs = 26816 channels.

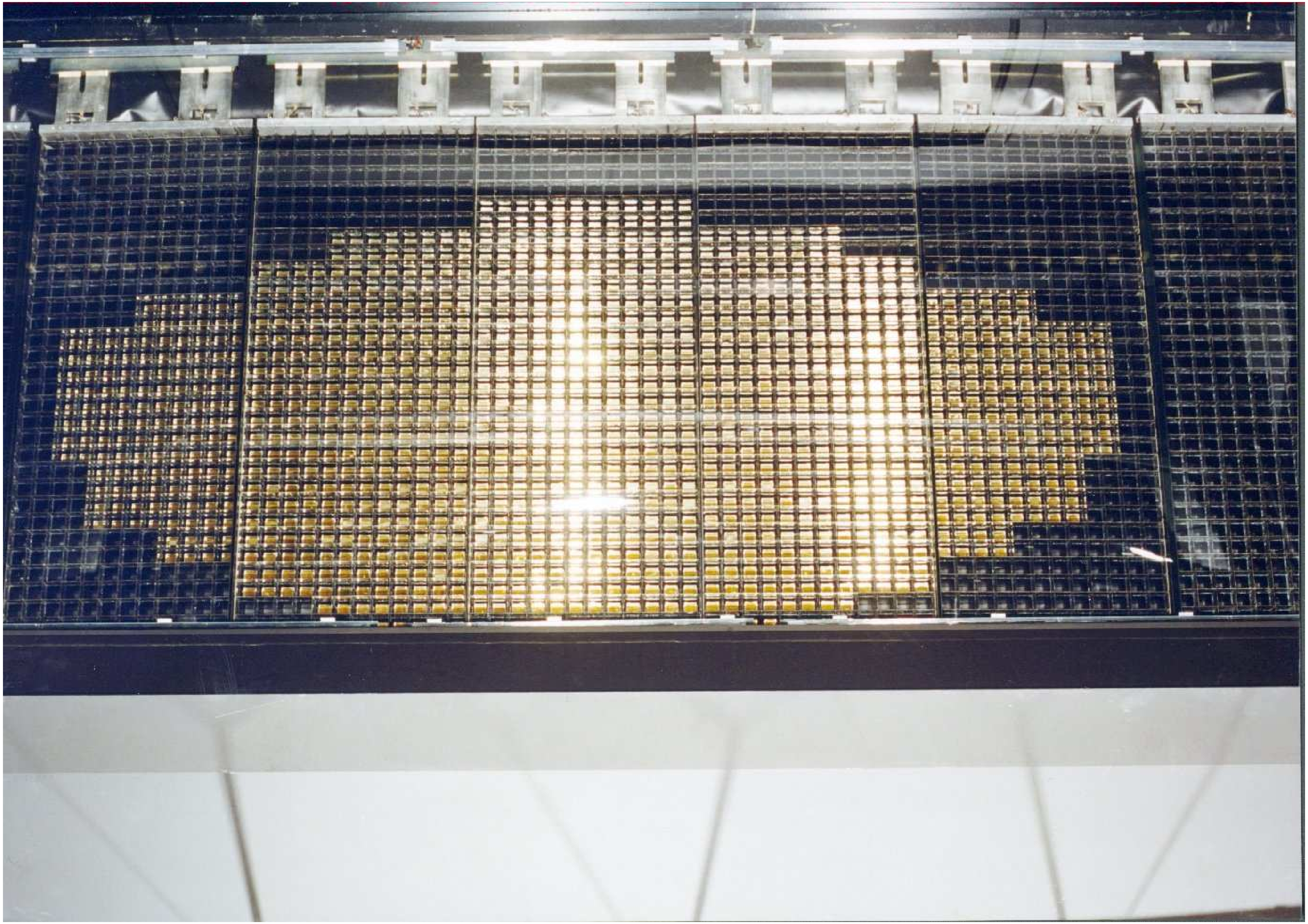
Demagnification of the focal plane image was necessary. Otherwise, covarage is around 50%. After several ideas, calculations and builds, a **two-lens telescope** was used:


Readout Cards
Base-board
M16 PMTs
Lens
Module
Condensor
Lens
Super
Module
Field
Lens

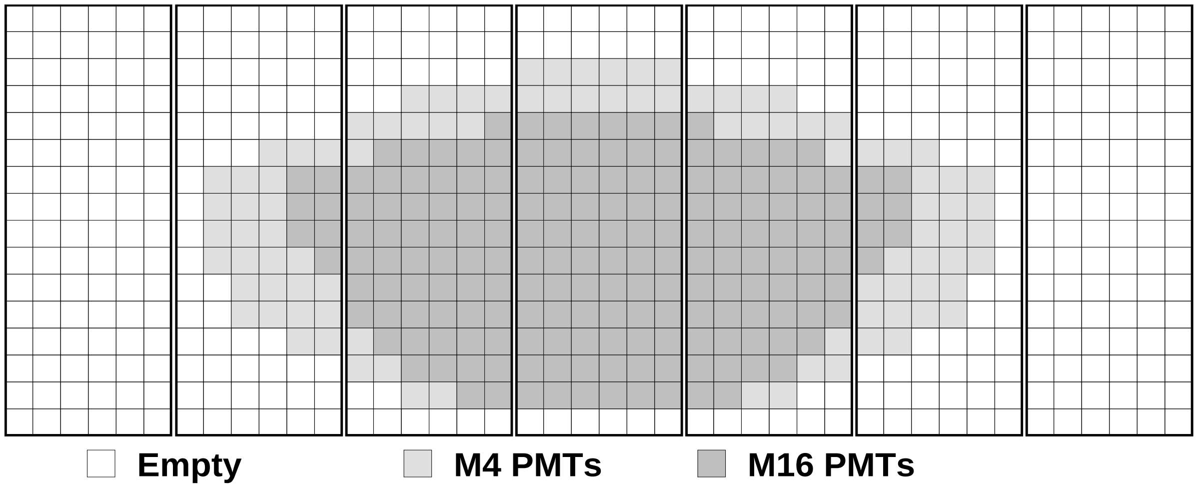


- UV transparent (cutoff around 250 nm) plastic was used for photon detector windows and lenses.
- Lenses made by injection molding by WAHL Kunststoffoptik, Germany.
- Transmission of the telescope depends on angles; is around 65 - 80%.
- Loss is due to reflection from uncoated surfaces. Causes cross-talk around 3%.

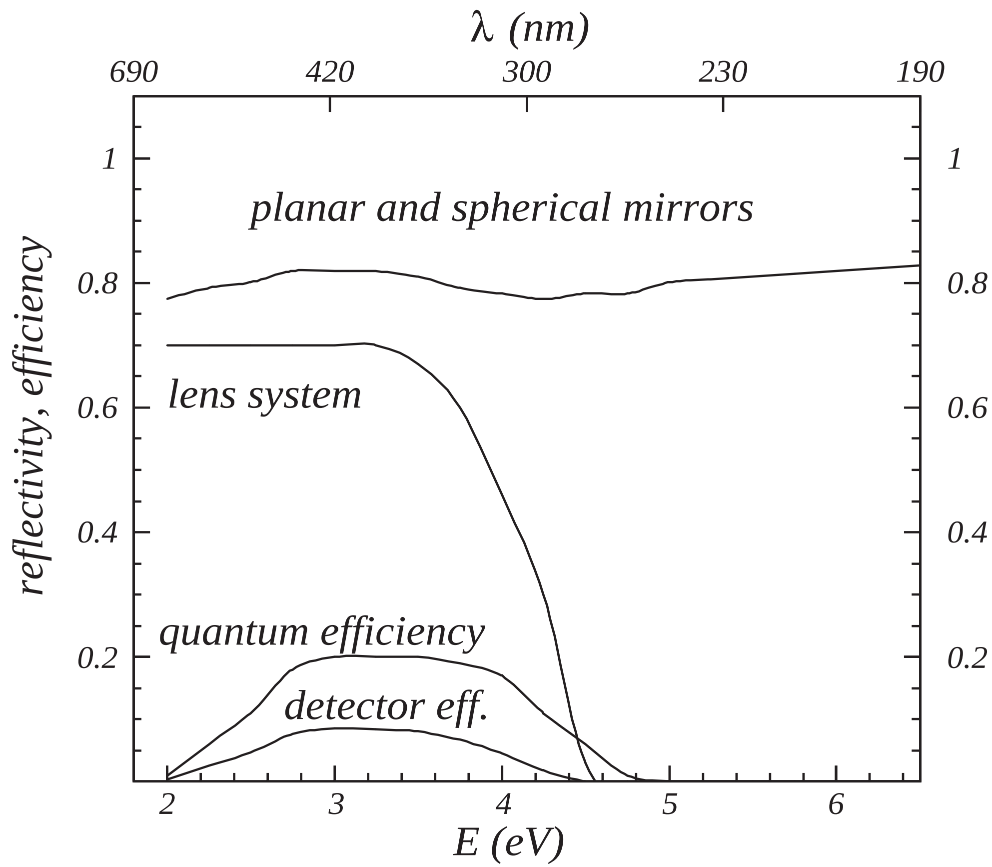

Power supply, bleeding circuit, load resistor
Amplifier, digitizer



Coverage of focal plane
(upper half)



Total and components'
spectral responses



Hits and rings

Single photon angular resolution σ_1 :

Error source	**Central part (M16s)**	**Peripheral part (M4s)**
Angular size of the cell	0.50 mrad	0.93 mrad
Dispersion in the gas	0.33 mrad	
Optical errors	0.25 mrad	
Multiple scattering	3.5 mrad/p [GeV/c]	
Total, for 20 GeV/c track	0.67 mrad	1.03 mrad

There are about N = 25 .. 35 photons per reconstractable ring.

But the resolution of ring's radius is not equal to $\frac{\sigma_1}{\sqrt{N}}$ because of rings overlapping, algorithm's behavior, and other factors. Estimated, $\sigma_{saturated\ radius} \approx 1\,\text{mrad}$.

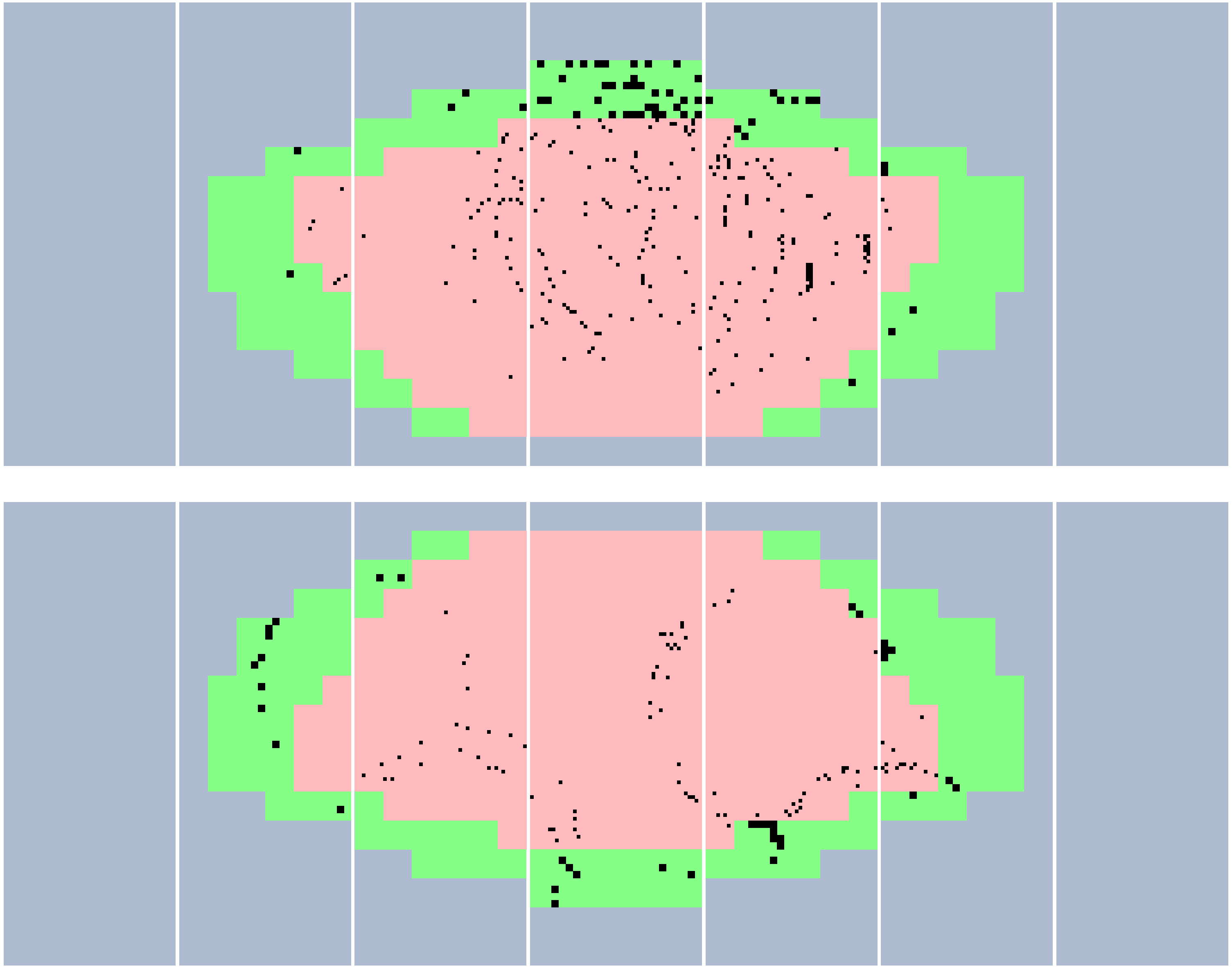
For pion/kaon separation, the usable range is 20 - 50 GeV/c of kaon's momentum.

Several ring reconstruction algorithms and their improvements were considered, suggested, developed, or tested:

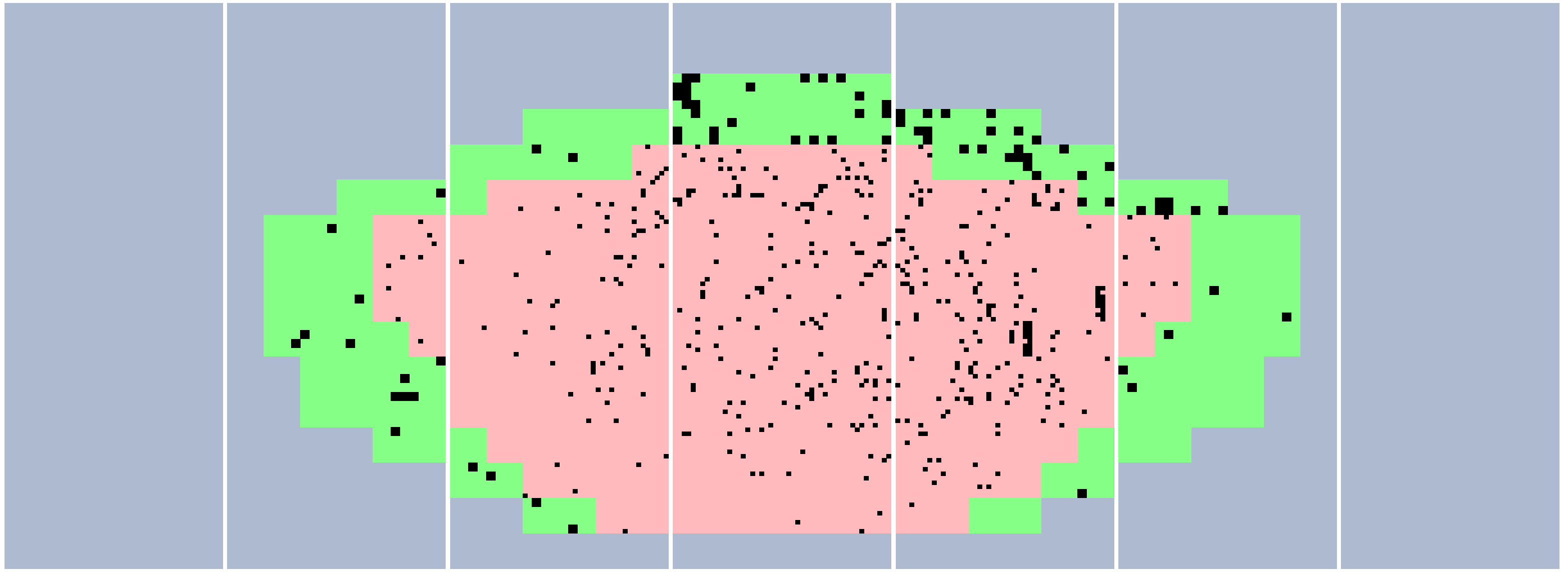
1. "Brute force:" scan of the whole two-dimensional angular space, with all reasonable radii.
2. Using tracking from other detectors, obtain ID likelihoods (no χ^2 minimization).
3. Hough transform, and its one-dimensional histogram modification.
4. Randomly thrown rings.
5. Triangular algorithms.
6. Iterative refinements.
7. More refinements (like using the missing hit information).

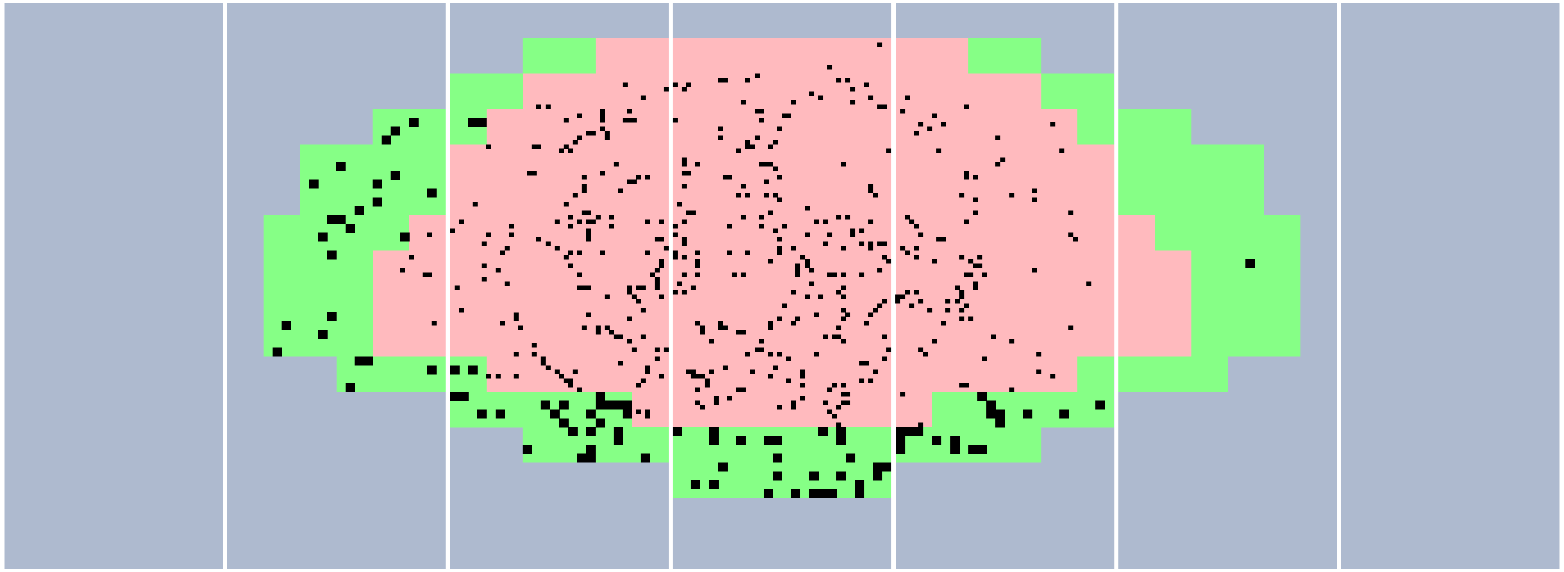
2, 3, 6, 7 were used.

FOCAL PLANE MAP

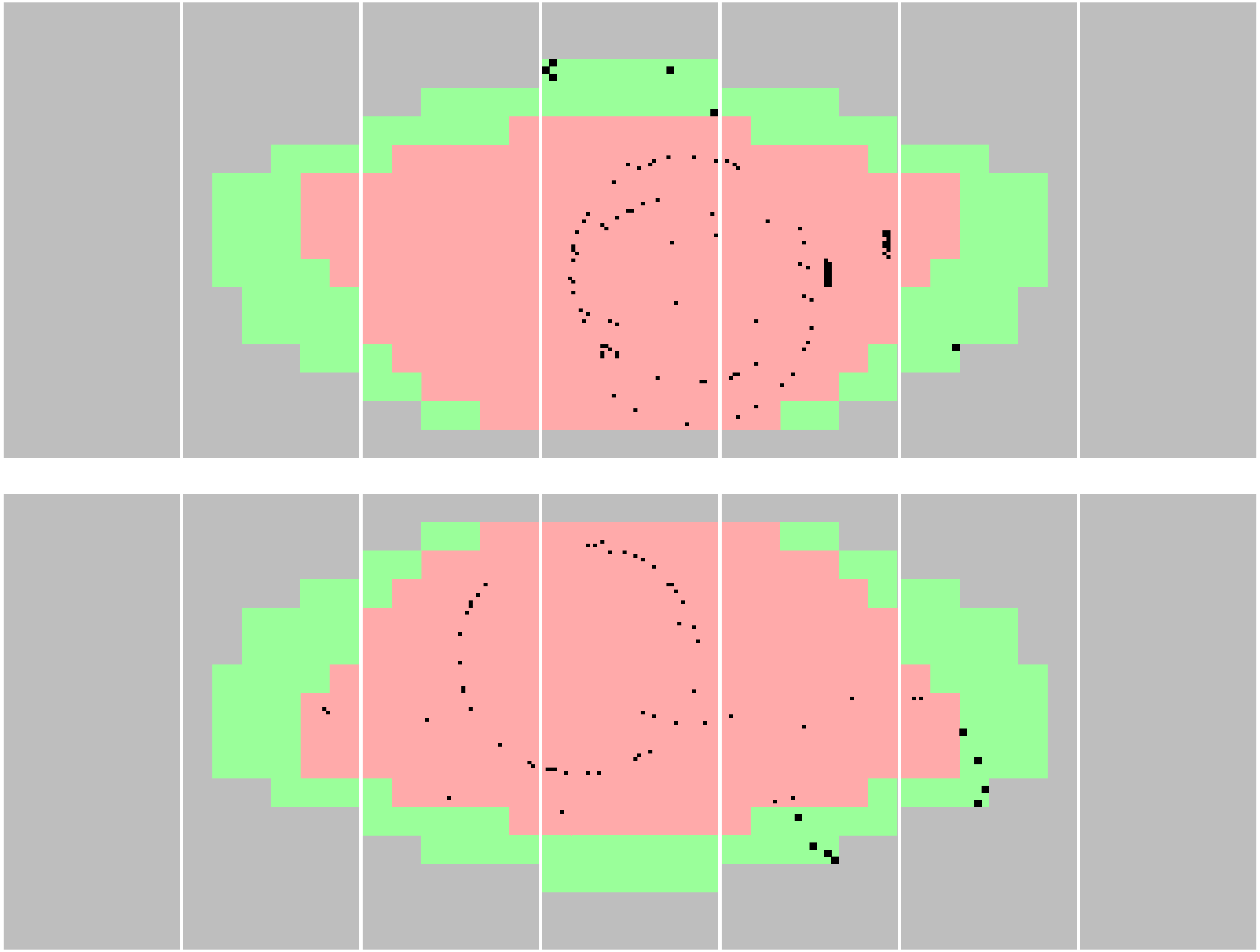


FOCAL PLANE MAP

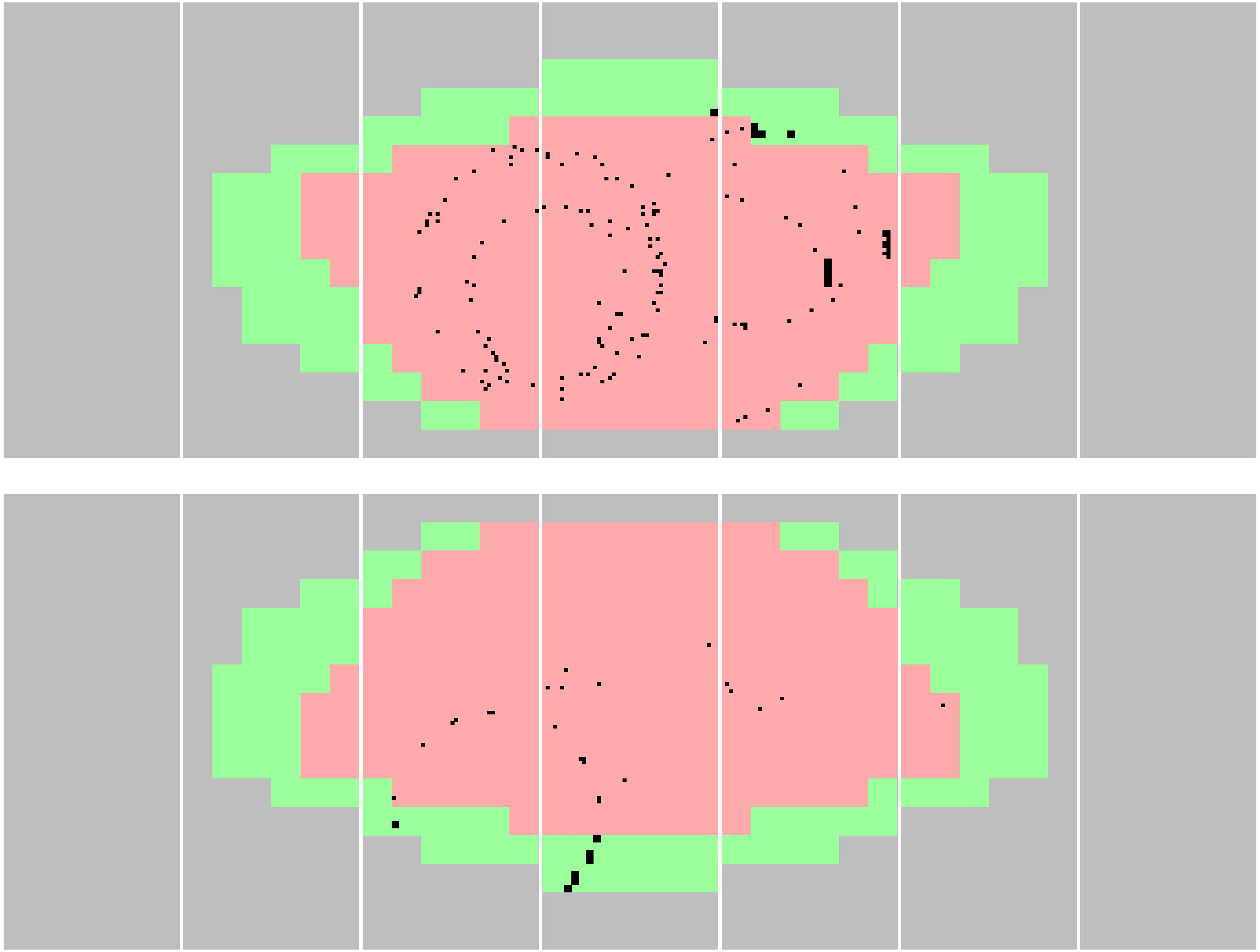


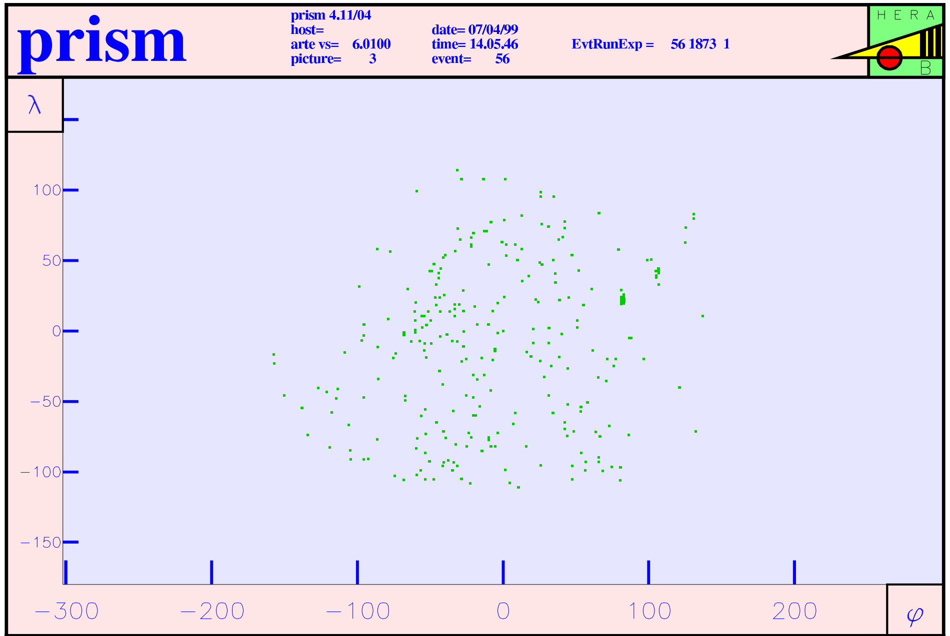


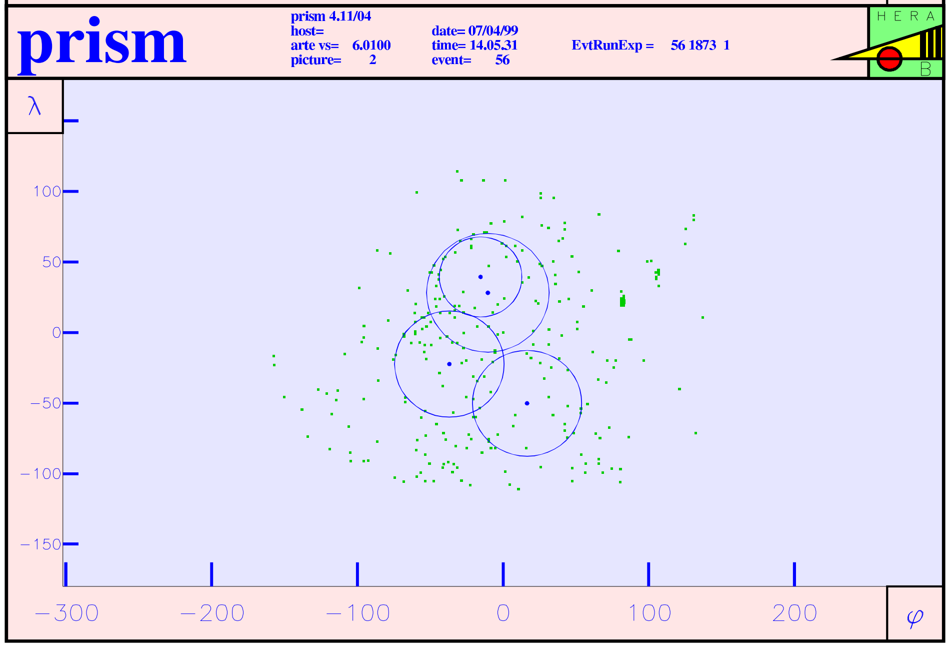
FOCAL PLANE MAP



FOCAL PLANE MAP




prism
prism 4.11/04
host=
arte vs= 6.0100
picture= 3
date= 07/04/99
time= 14.05.46
event= 56
EvtRunExp = 56 1873 1
HERA
B
λ
100
50
0
−50
−100
−150
−300
−200
−100
0
100
200
φ


prism
prism 4.11/04
host=
arte vs= 6.0100
picture= 2
date= 07/04/99
time= 14.05.31
event= 56
EvtRunExp = 56 1873 1
HERA
B
λ
100
50
0
−50
−100
−150
−300
−200
−100
0
100
200
φ

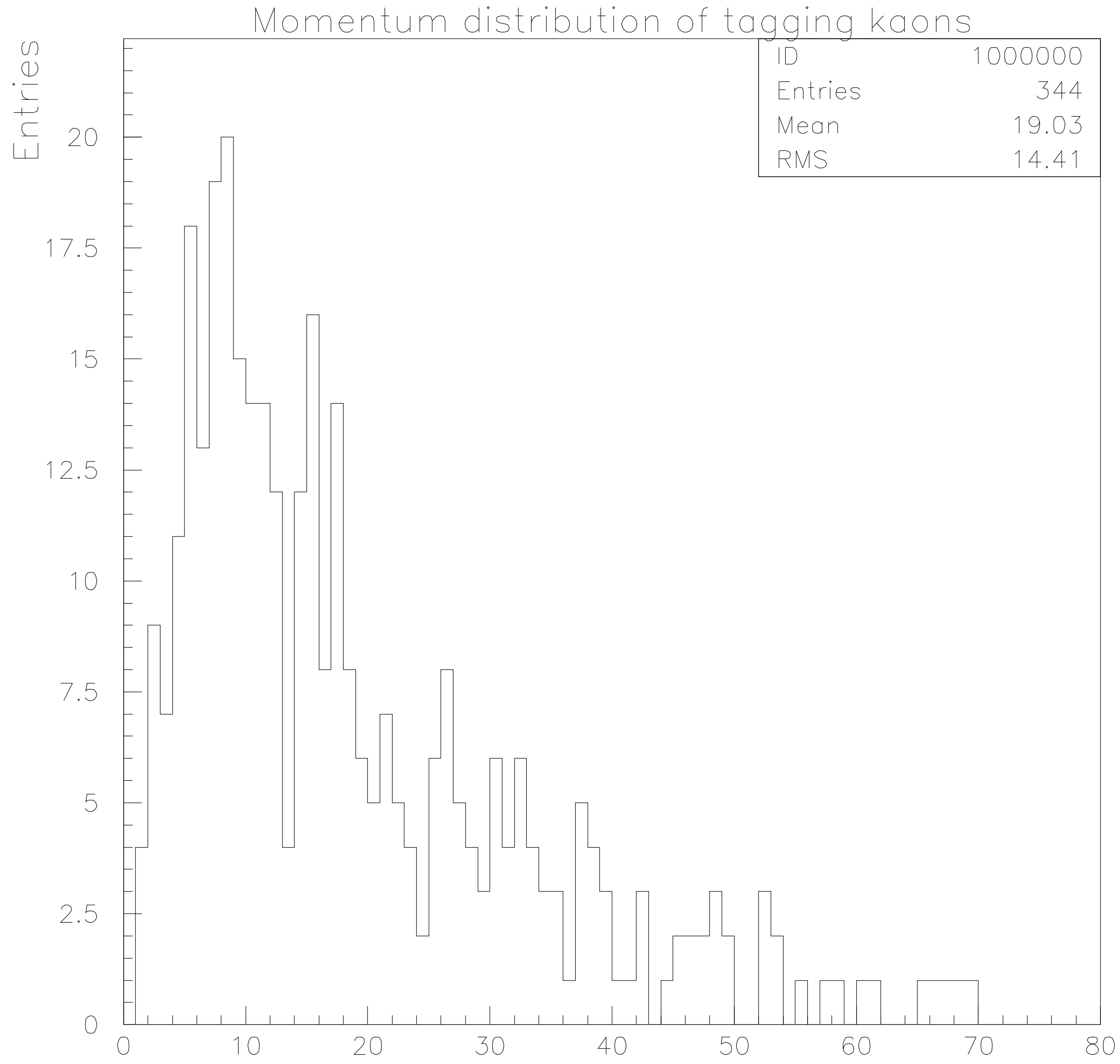
Performance, partice identification

Relative occurrence of the major charged particles, created at target, in momentum range 10 – 50 GeV/c:

```
pions:                1.0
kaons:                0.13
protons:              0.12
electrons + muons: less than 0.01
```

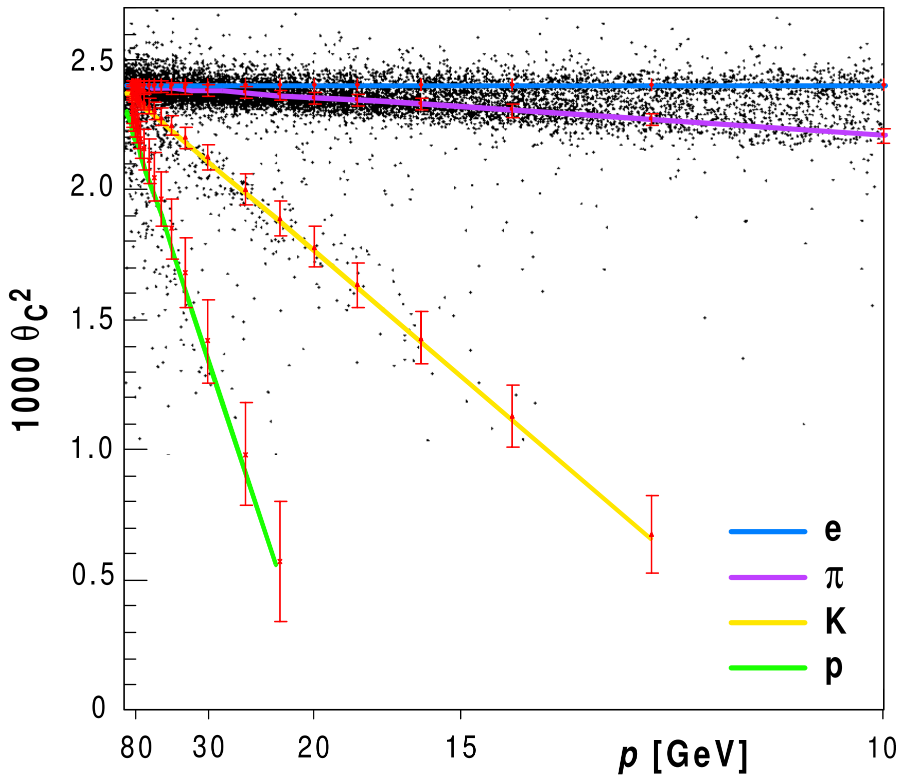
There are many other particles, mostly slow electrons, produced in the material of the spectrometer. RICH is not sensitive to them, but the drift chambers are.

Momenta (distribution is similar for all major particles):



Momentum, GeV/c

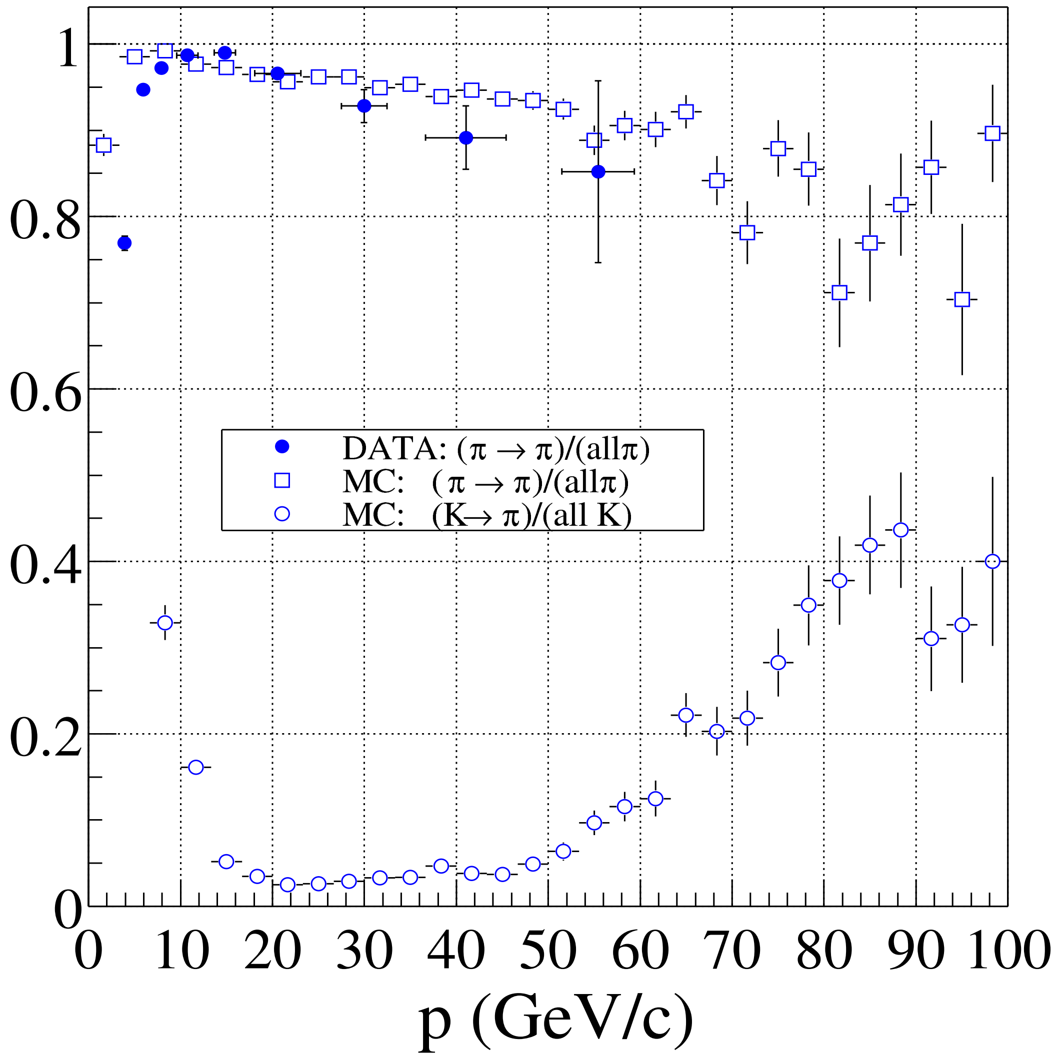
Particle bands:



2σ separation, with RICH + other tracking, is for momenta up to:

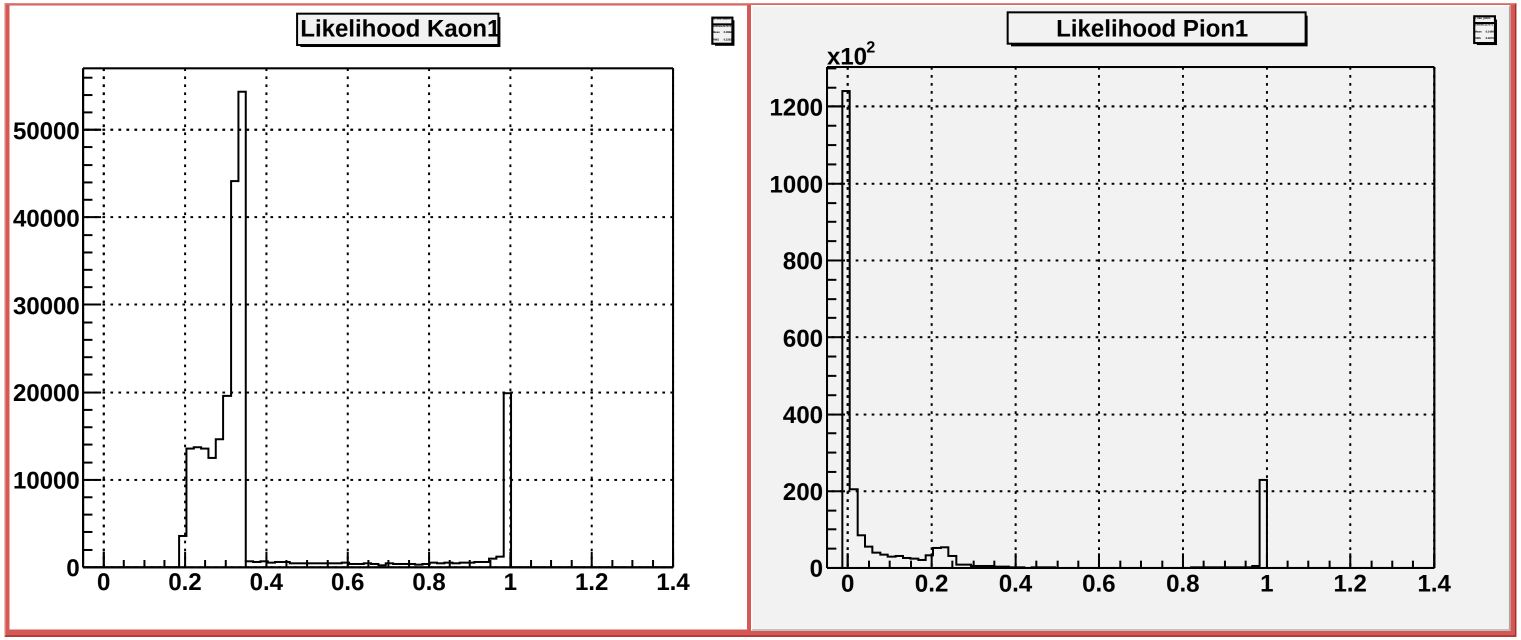
- for electrion/pion: 17 GeV/c
- for pion/kaon: 58 GeV/c

Monte Carlo and well-defined decays were used to assess the identification capabilities: $K_s^0 \rightarrow \pi^+ \pi^-$ $\Lambda \rightarrow p \pi^-$ $\bar{\Lambda} \rightarrow \bar{p} \pi^+$ $\phi \rightarrow K^+ K^-$



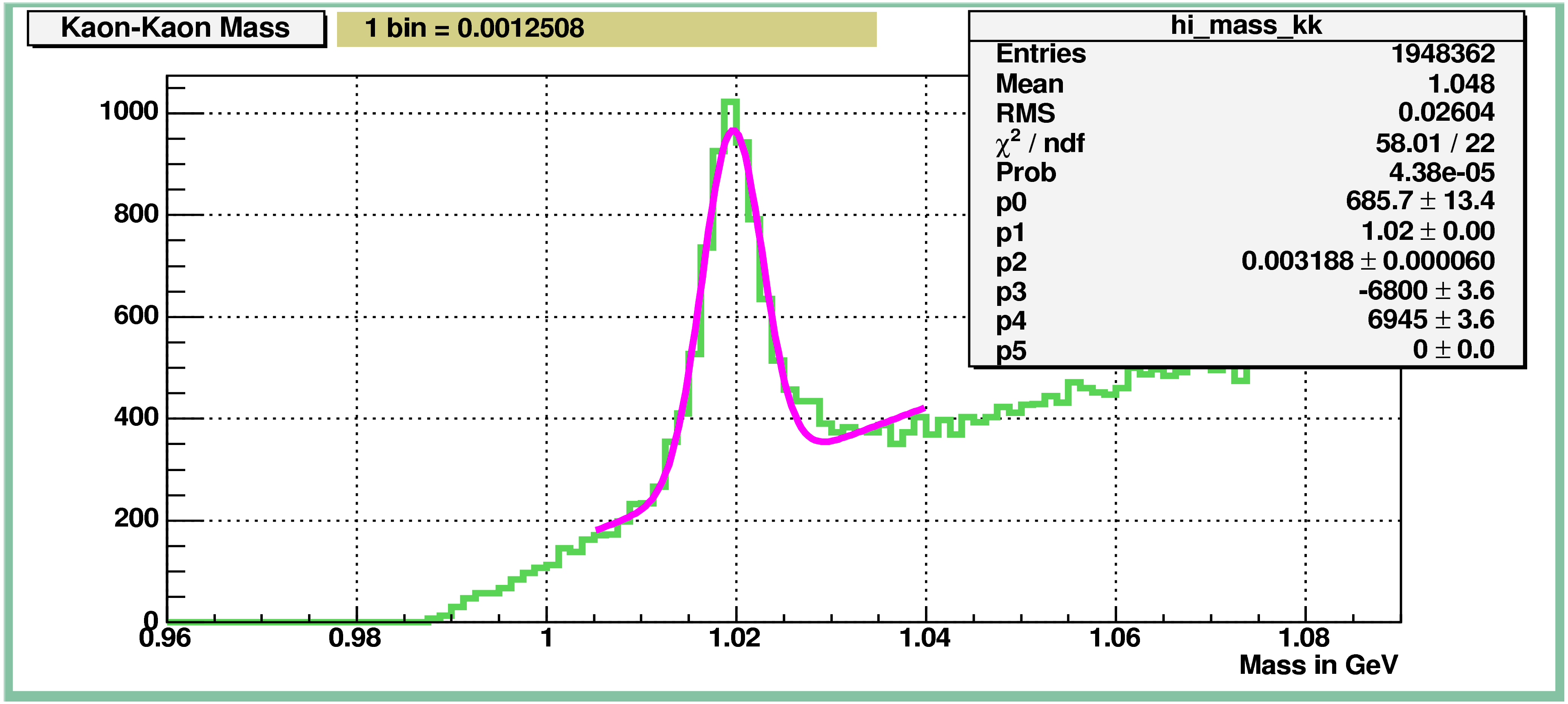
Uses of the RICH detector's information for HERA-B:

To every track, a likelihood of being a particle of a specific type is assigned:



Since RICH is an angular device, **tracks in RICH can give only the two angles**, not positions, of tracks through RICH. These can be compared to tracks and track segments from other trackers. (In HERA-B, **tracks are reconstructed by combining track segments** from subdetectors' reconstructions.)

High occupancy veto is easily achievable in RICH: take every 20th channel.



Kaon-kaon invariant mass after several cuts for Φ, with 30% of all data.

Conclusions

- The HERA-B detector worked and performed close to expectations.
- No aging was observed during several years of operation.
- The main parameters:
  - Around 27000 channels of PMT readout;
  - Around 30 photons per saturated ring;
  - Pion/kaon separation is possible up to around 50 GeV;
  - Resolution of ring radius is around 1 mrad;
  - Angular resolution of tracks inside RICH is 0.35 mrad.