RICH counters for HERA-B and Belle PID upgrade

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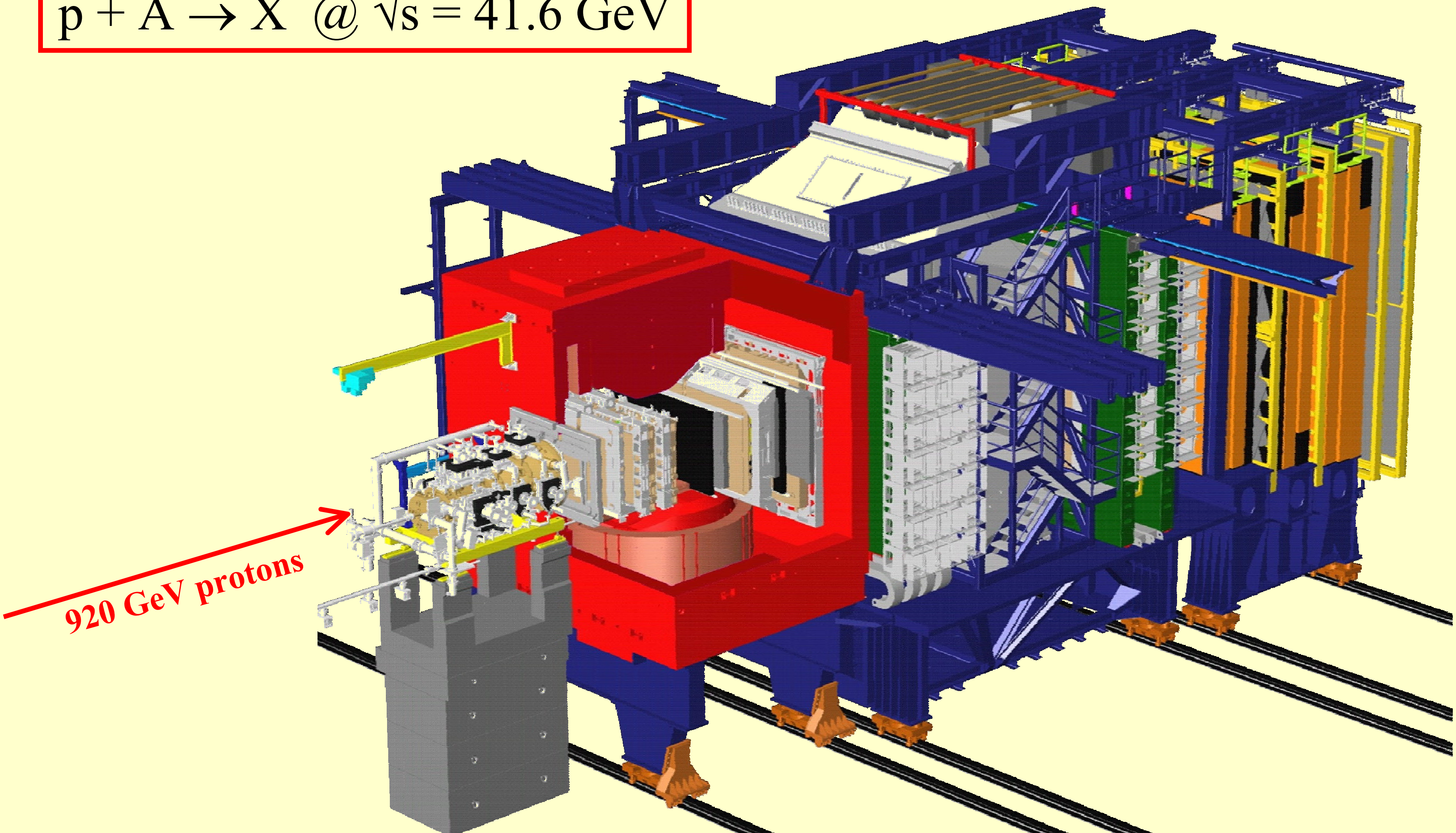
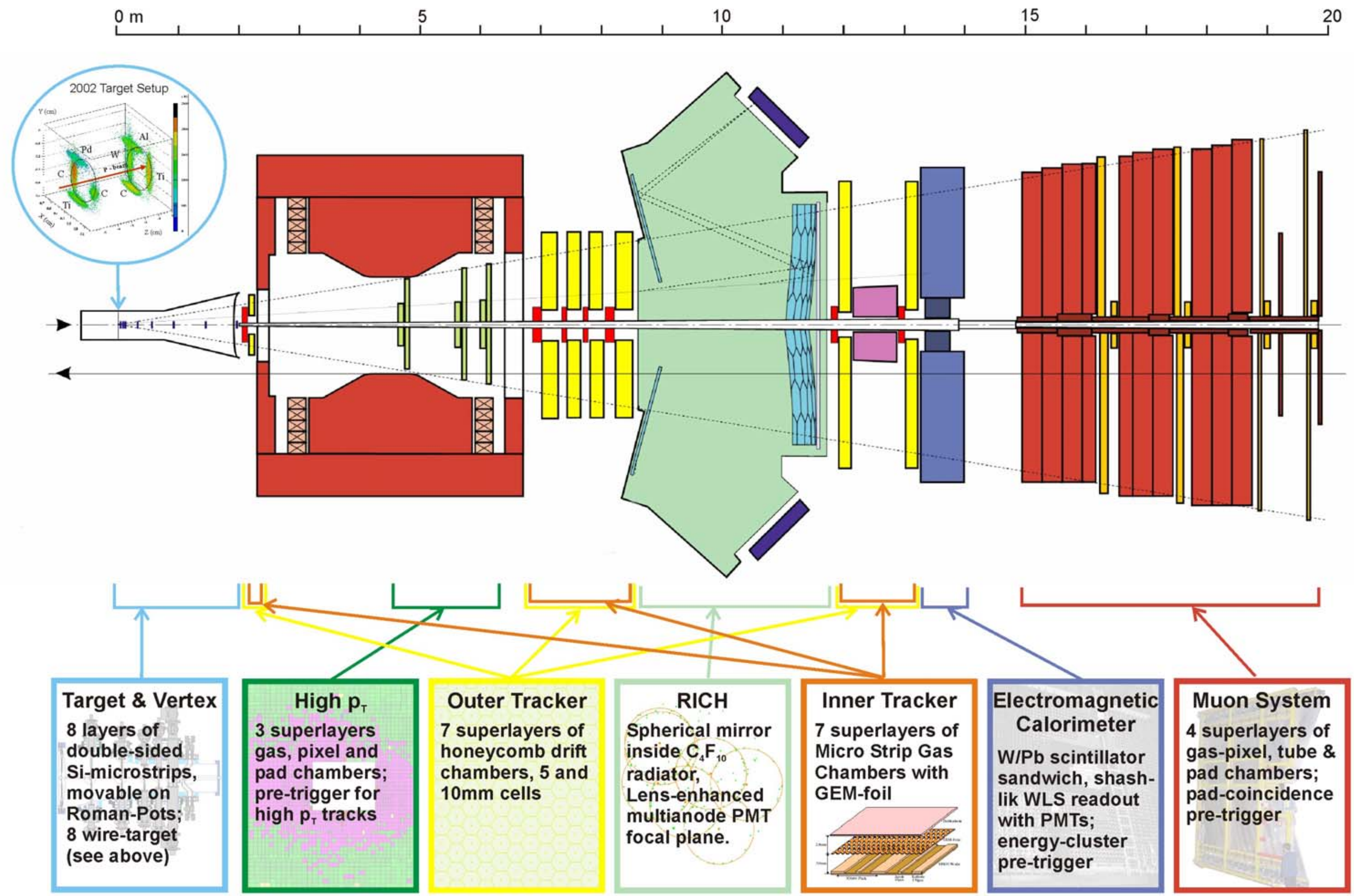
Summary

The HERA-B Experiment

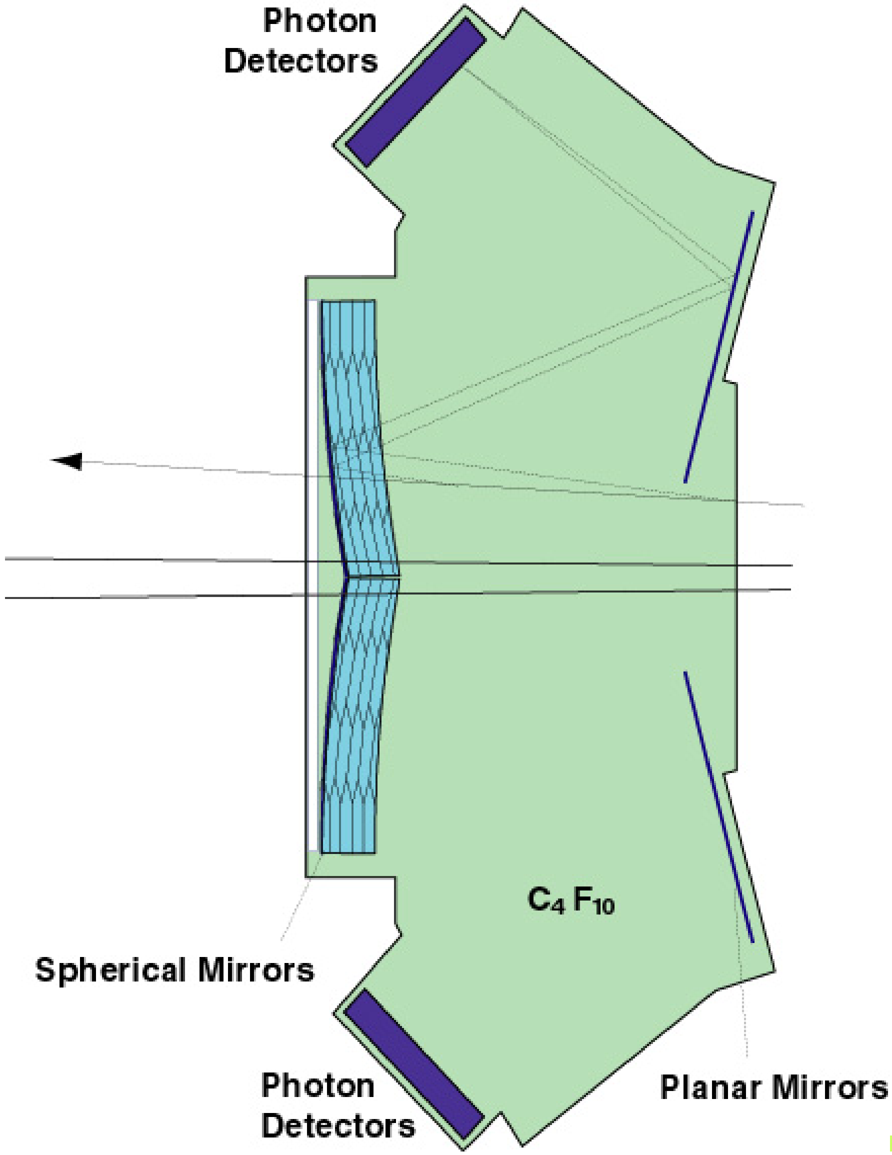
$p + A \rightarrow X \;\; @ \sqrt{s} = 41.6 \text{ GeV}$





0 m
5
10
15
20
2002 Target Setup
Target & Vertex
8 layers of double-sided Si-microstrips, movable on Roman-Pots; 8 wire-target (see above)
High p_T
3 superlayers gas, pixel and pad chambers; pre-trigger for high p_T tracks
Outer Tracker
7 superlayers of honeycomb drift chambers, 5 and 10mm cells
RICH
Spherical mirror inside C_4F_{10} radiator, Lens-enhanced multianode PMT focal plane.
Inner Tracker
7 superlayers of Micro Strip Gas Chambers with GEM-foil
Electromagnetic Calorimeter
W/Pb scintillator sandwich, shash-lik WLS readout with PMTs; energy-cluster pre-trigger
Muon System
4 superlayers of gas-pixel, tube & pad chambers; pad-coincidence pre-trigger

HERA-B RICH

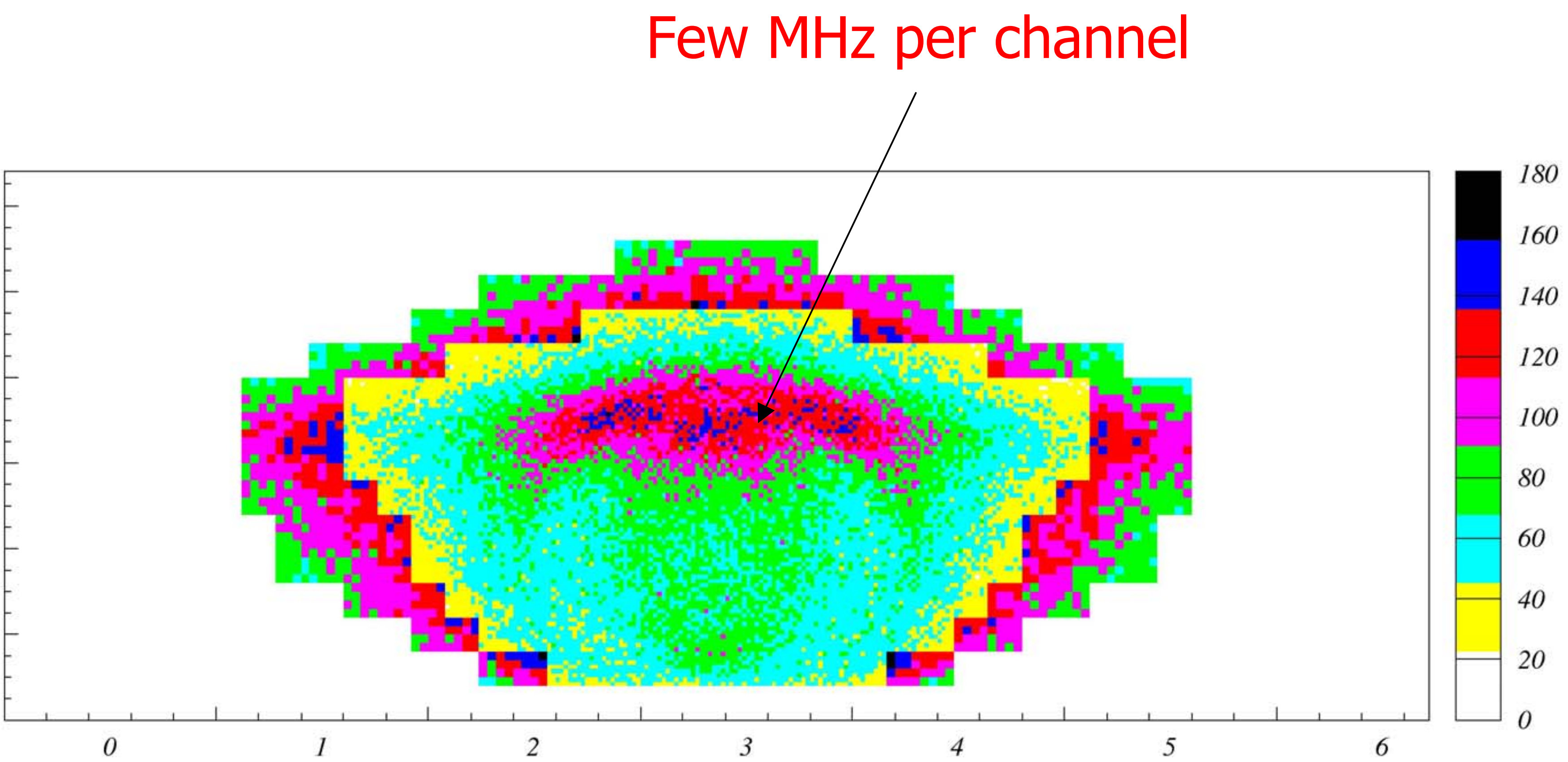


NIM A516 (2004) 445

Requirements:

- High QE over ~3m^2
- Rates ~1MHz per channel
- Long term stability

HERA-B RICH: rates on the photon detector



HERA-B RICH photon detector

Cadidates – original:

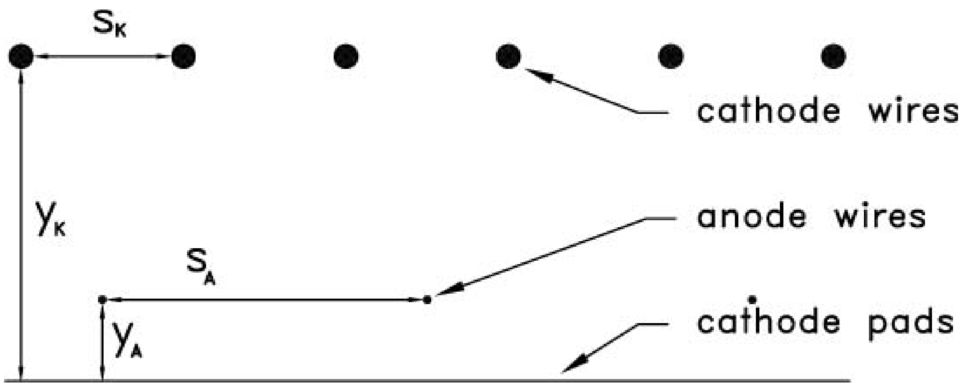
•CsI based wire chamber with pads

•TMAE based wire chamber with ‘egg-crate’ structure

Backup solution:

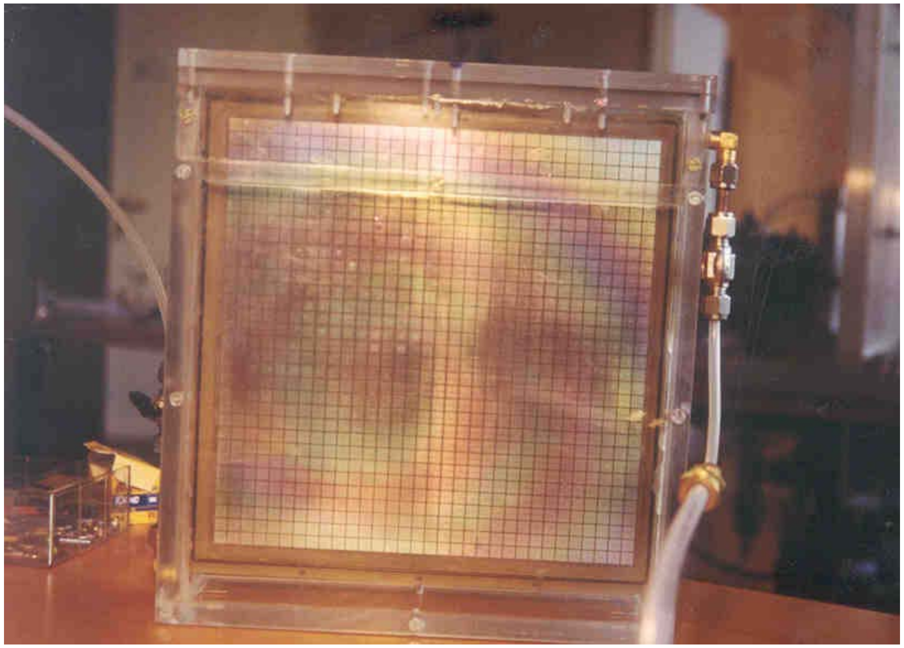
•Multianode PMTs Hamamatsu R5900 series

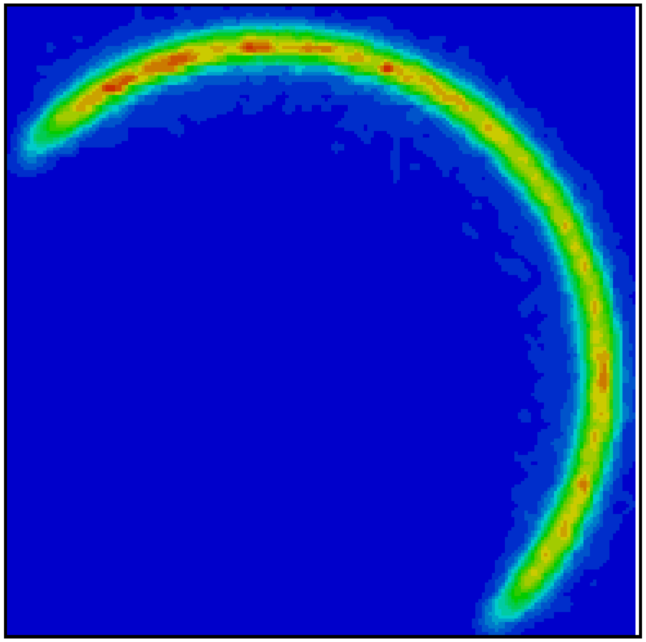
CsI chamber



A lot of very good results

→ NIM A300 (1991) 213; NIM A307 (1991) 145; NIM A364 (1995) 243





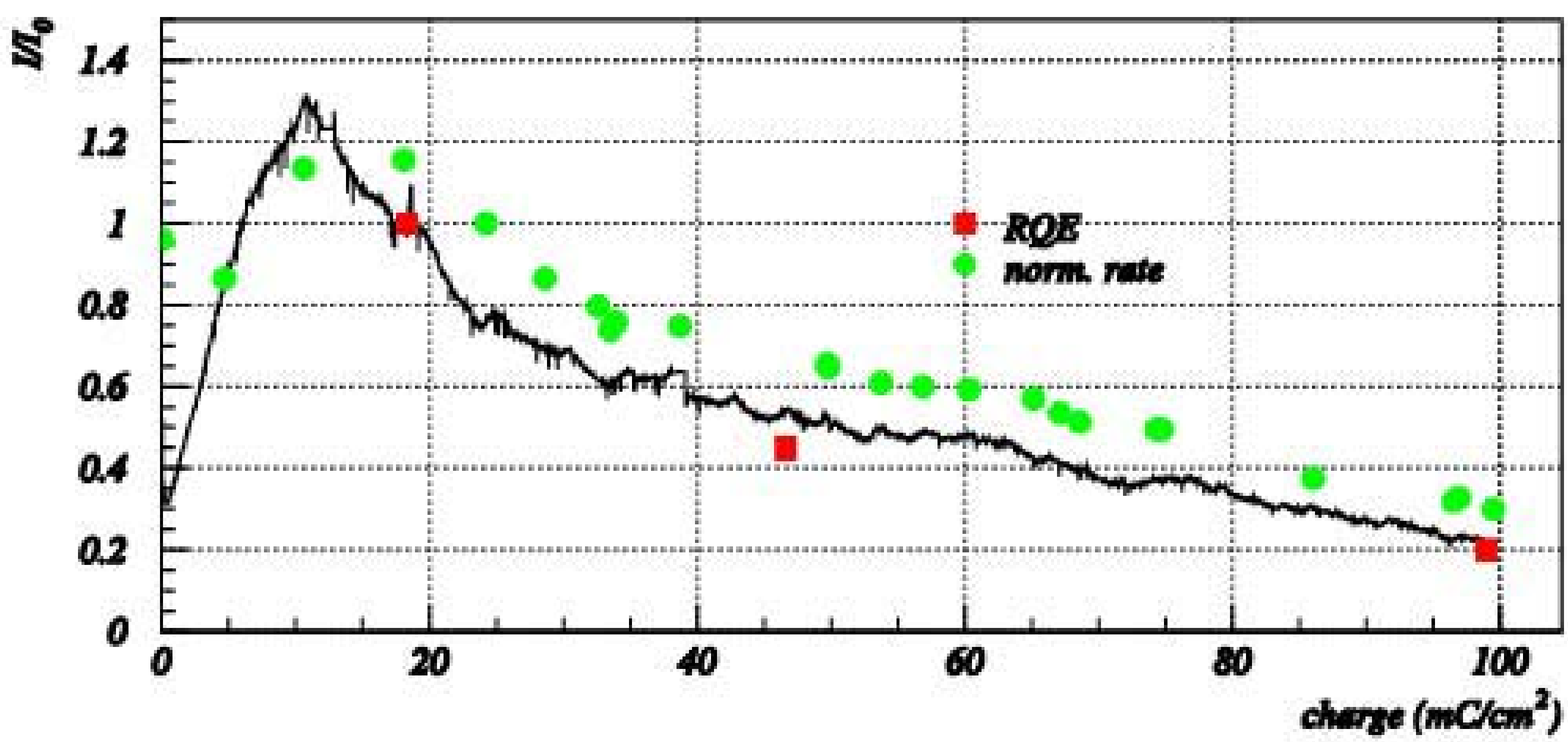
Beam test, accumulated rings

→ NIM A371 (1996) 151

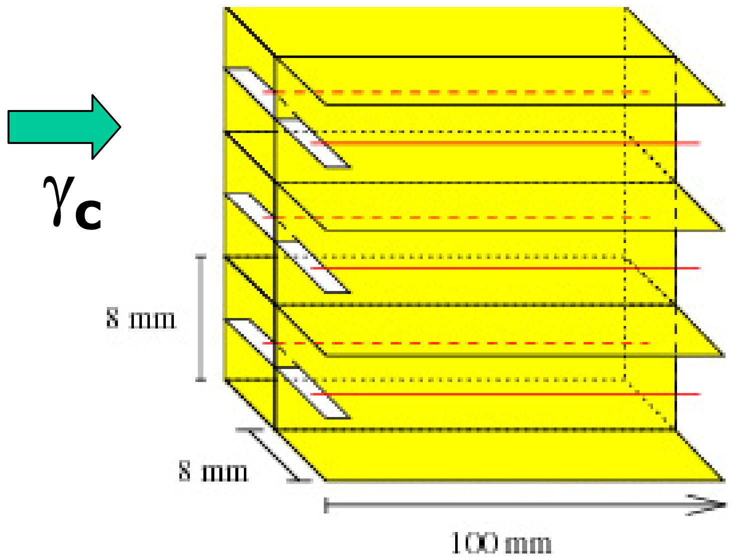
CsI chamber

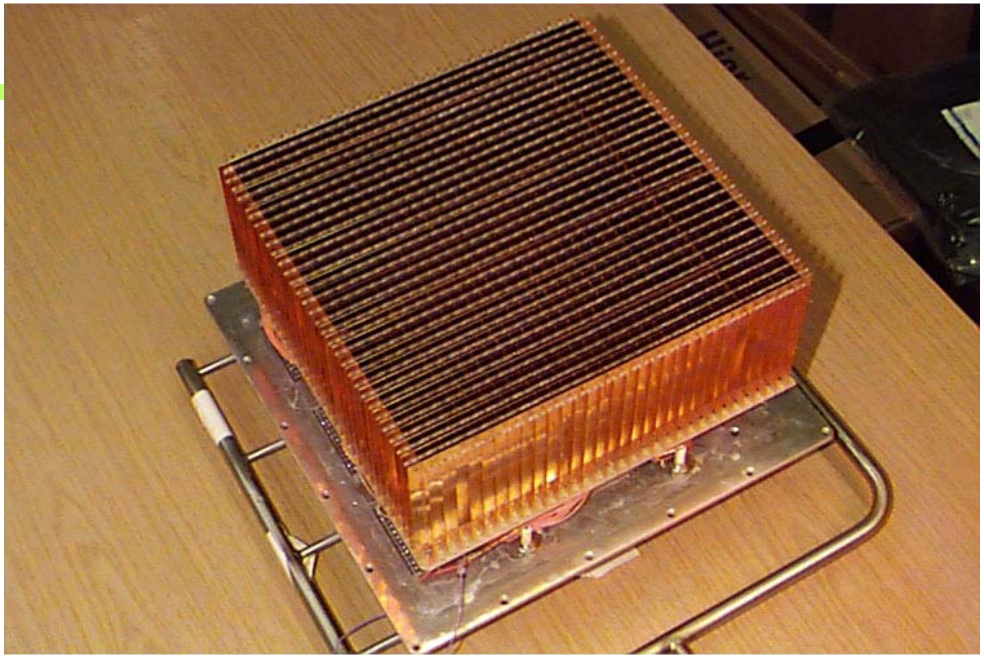
Show-stoppers for the use in HERA-B:

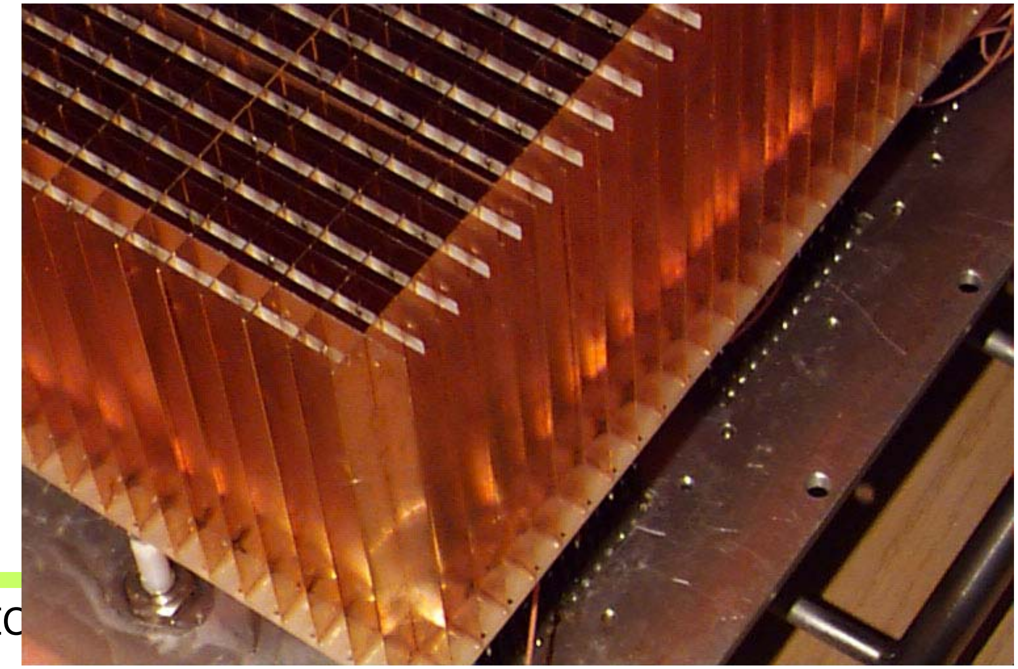
- High rate instabilities → NIM A371 (1996) 151
- Ageing → NIM A387 (1997) 146



TMAE chamber





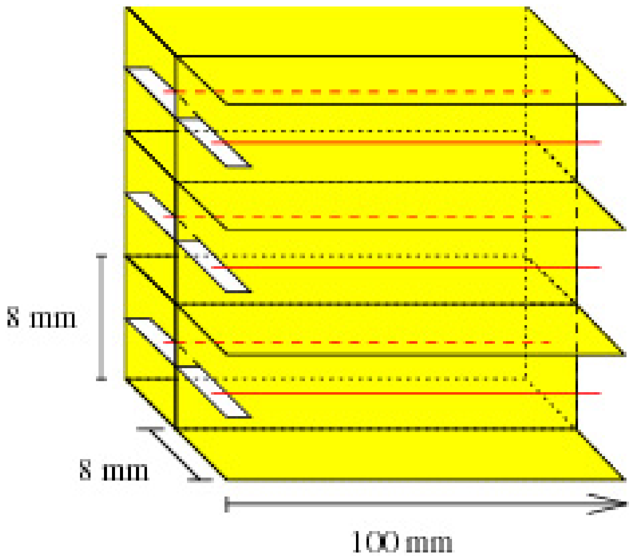


Photons enter the chamber from the left.

Optical thickness: along the anode wires.

Rather fast (<100ns)

TMAE chamber



Excellent performance:

•No feed-back photons

•Stable at high rates

NIM A371 (1996) 289

Show-stopper for HERA-B: ageing

NIM A414 (1998) 170

Possible remedy: heating in situ

NIM A515 (2003) 302

HERA-B RICH photon detector

Status in 1996:

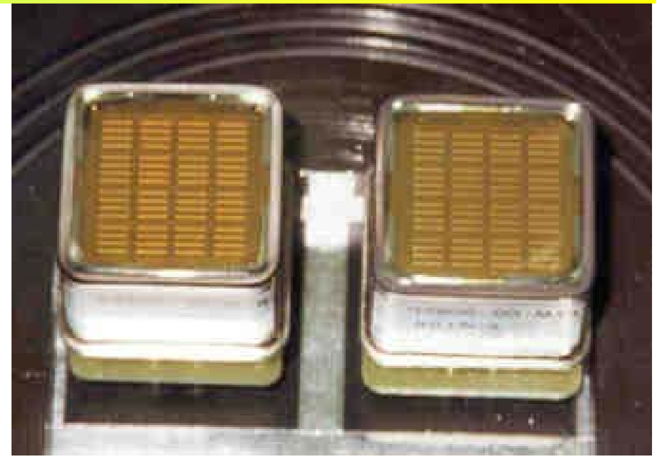
- TMAE and CsI have serious problems in long term operation at very high rates
- Hamamatsu just came out with the metail foil multianode PMTs of the R5900 series: first multianode PMTs with very little cross-talk
- Tested on the bench and in the beam: excellent performance →easy decision

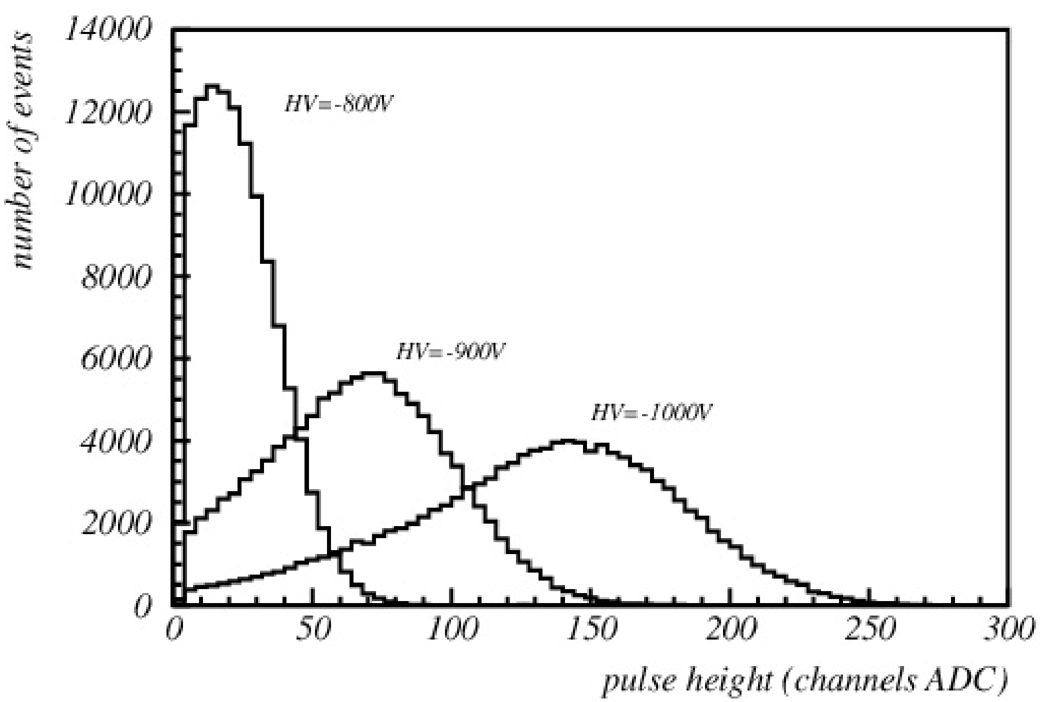
→ NIM A394 (1997) 27

Multianode PMTs

Hamamatsu

R5900-M16 (4x4 channels)
R5900-M4 (2x2 channels)





Key features:

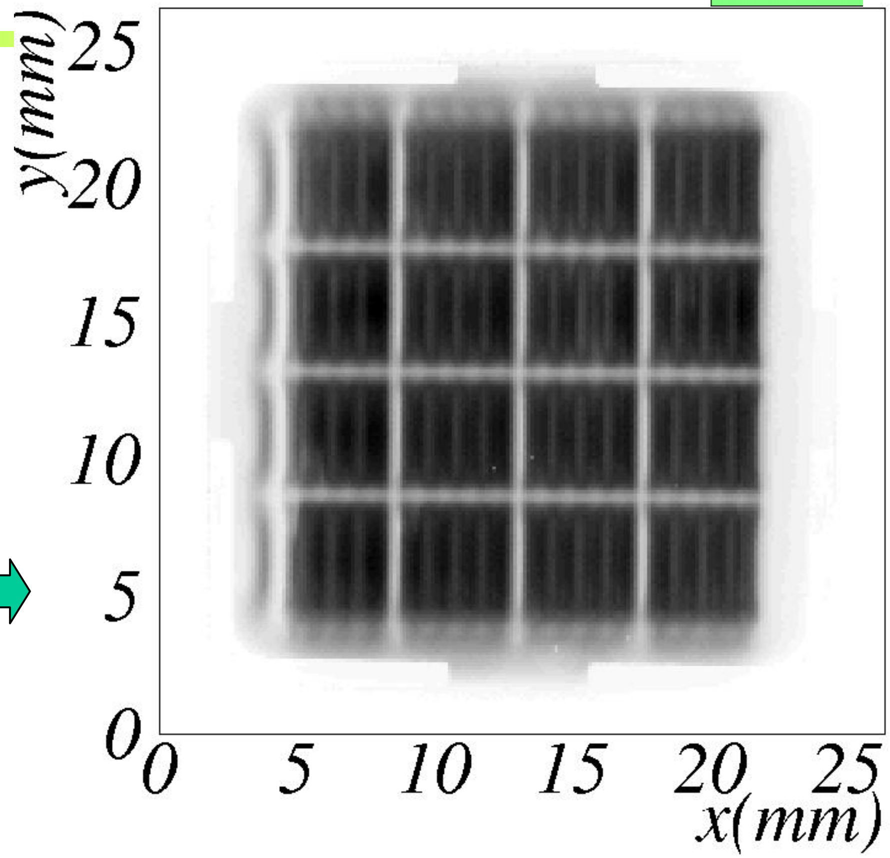
- Single photon pulse height spectrum
- Low noise
- Low cross-talk

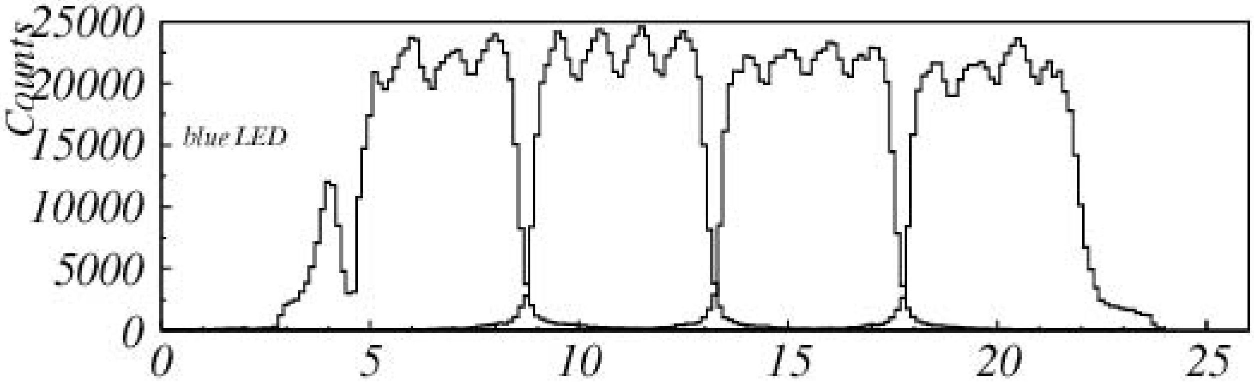
Multianode PMTs

Uniformity:

•Large variation (3-4x) in amplification – no problem in photon counting (in case of low noise)

•Good uniformity in QE x photo-electron collection efficiency

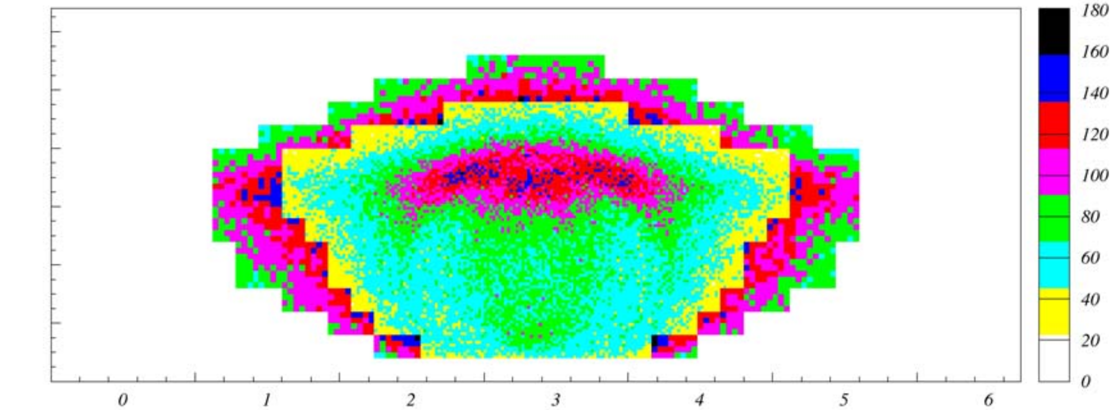




QE x collect. eff.

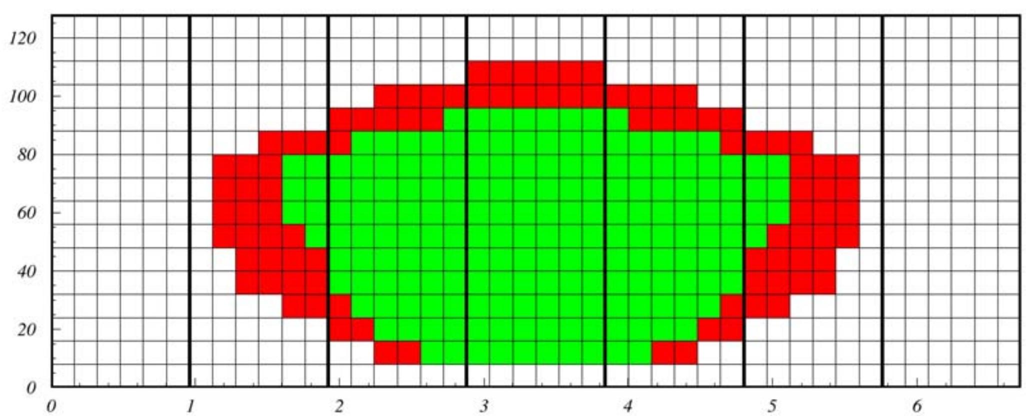
→ NIM A478 (2002) 391

HERA-B RICH tiling scheme



Match the occupancy and resolution needs:

Finer granularity in the central part

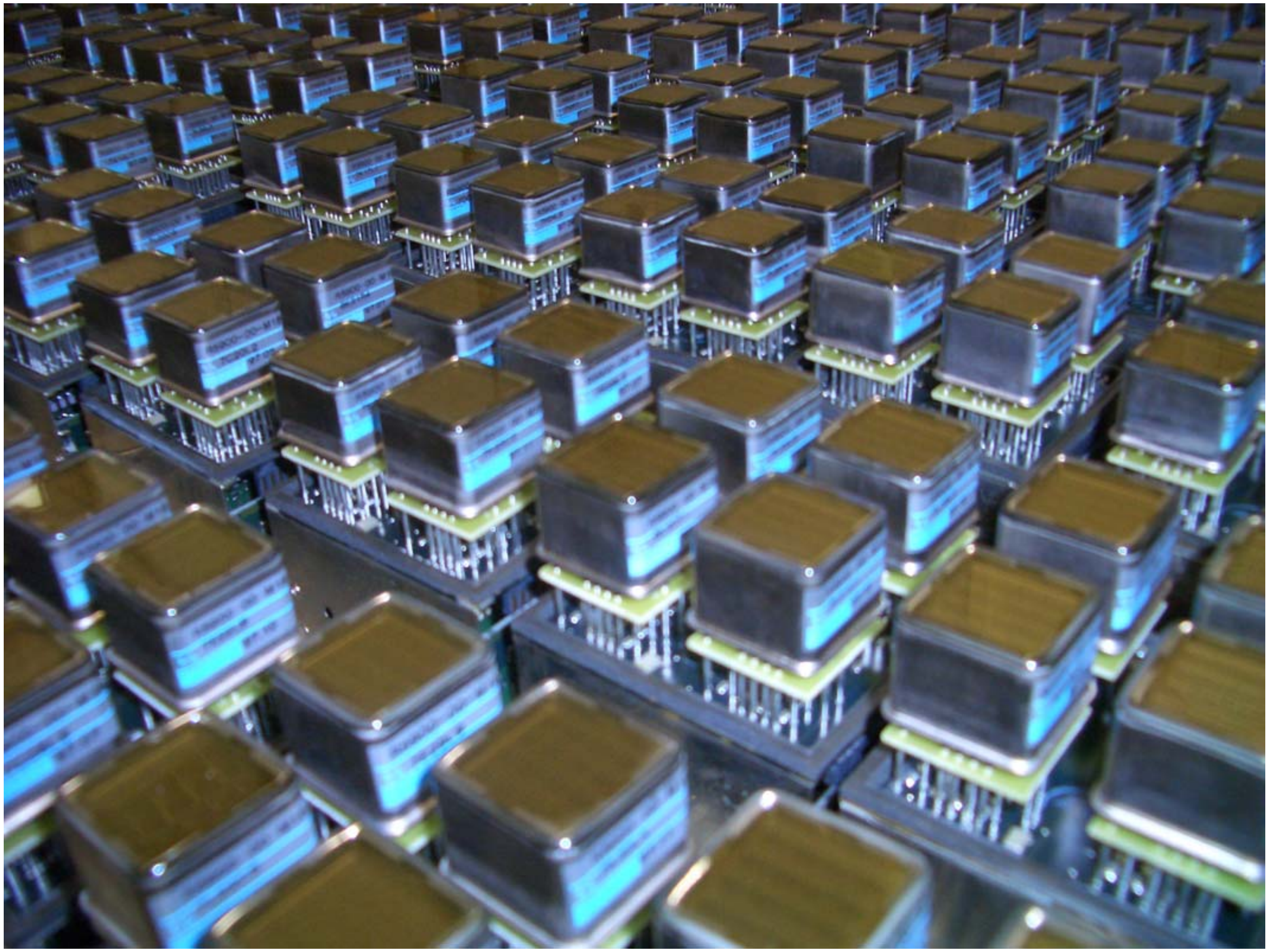


Upper detector layout

Upper detector half:

- M16 PMTs
- M4 PMTs

Multianode PMTs



Large statistics (2300 pcs) QA tests → NIM A442 (2000) 316

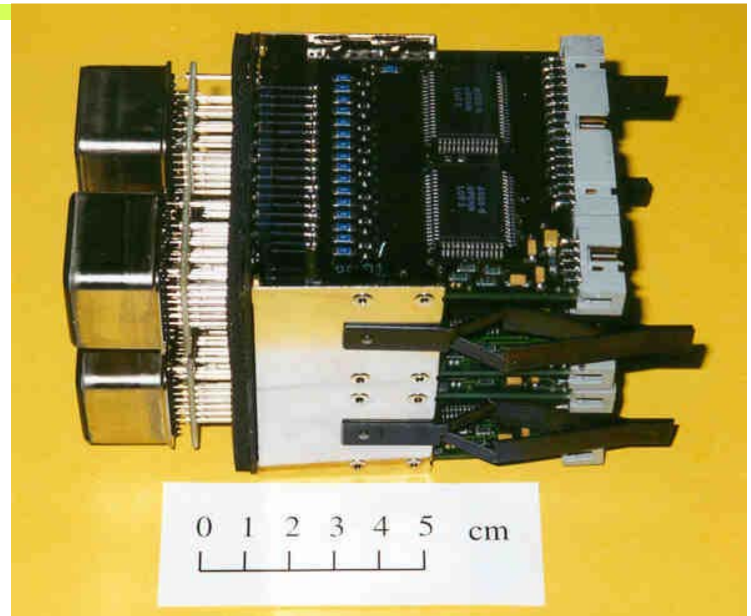
Multianode PMT read-out

Front-end readout electronics:

Based on ASD8 read-out chips

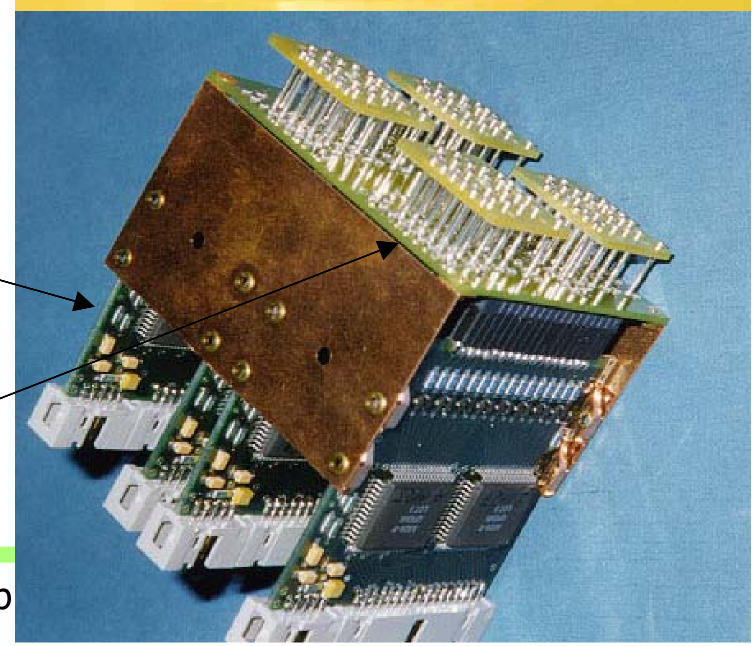
ASD8 = 8 channel amplifier, shaper and discriminator:

- ENC ~ 900 + 70/pF
- shaping time ~ 10ns
- sensitivity ~ 2.5mV/fC



ASD8 board:
16 channels (2 x ASD8 chips)
→NIM A541 (2005) 610

Voltage divider: integrated in the PMT base board

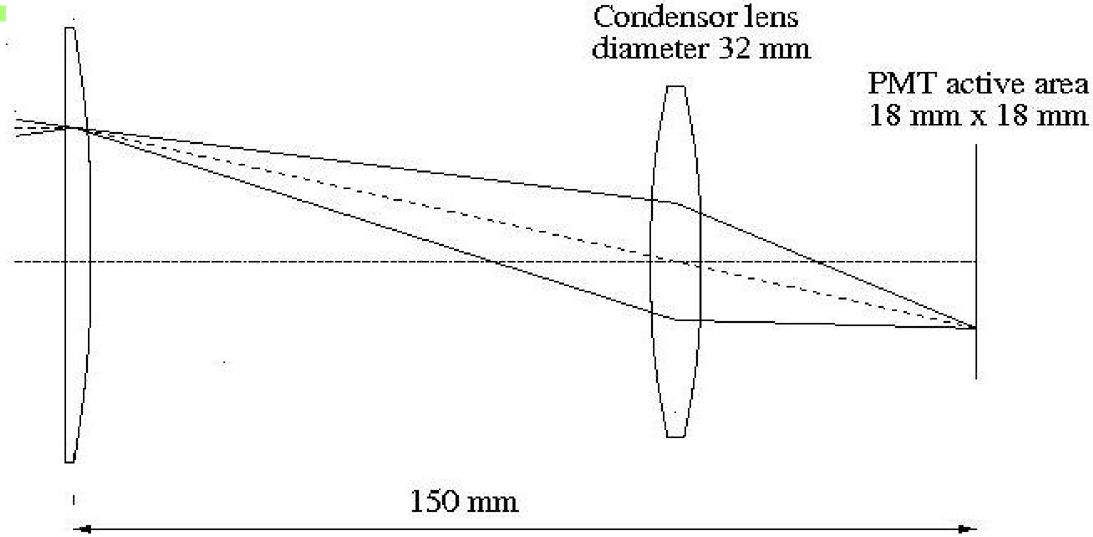


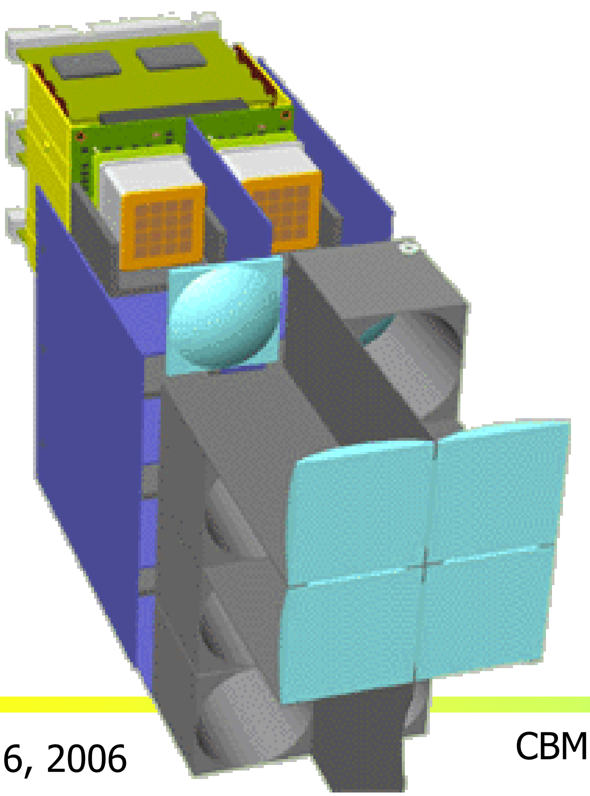
Light collection system

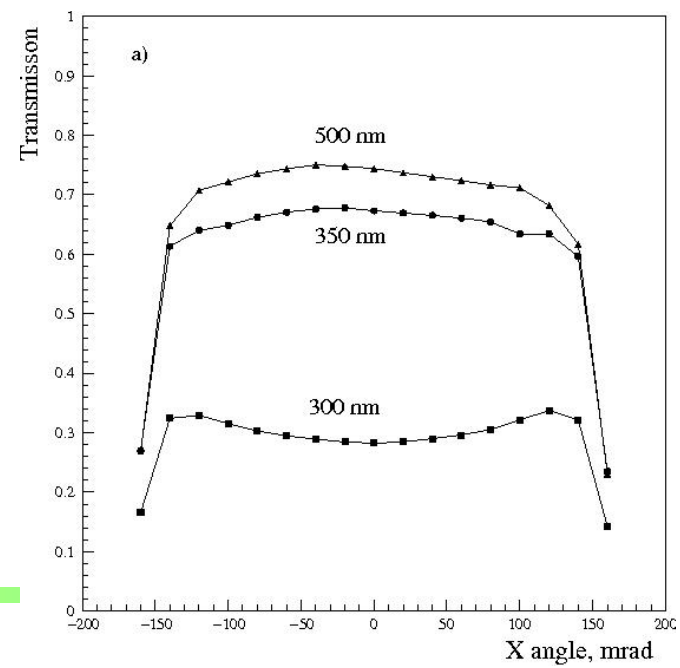
Light collection system (imaging!) to:

-Adapt the pad size

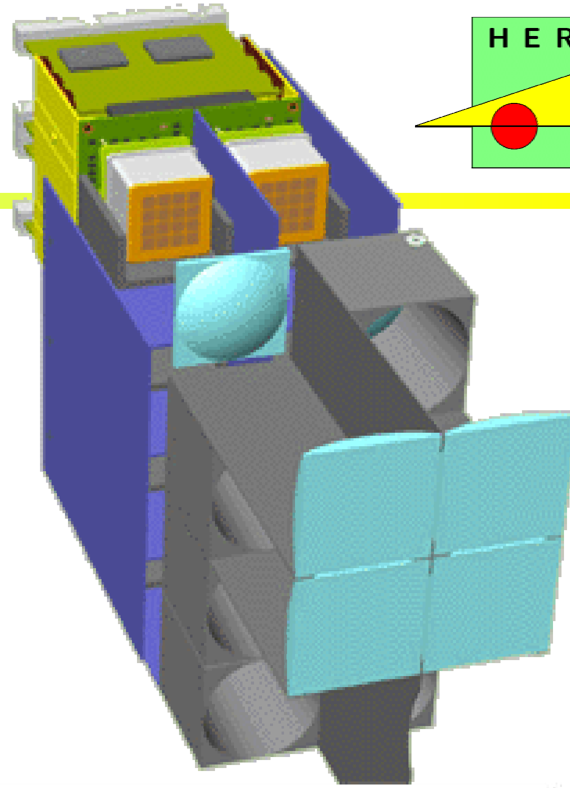
-Eliminate dead areas







Light collection system



Light collection system features:

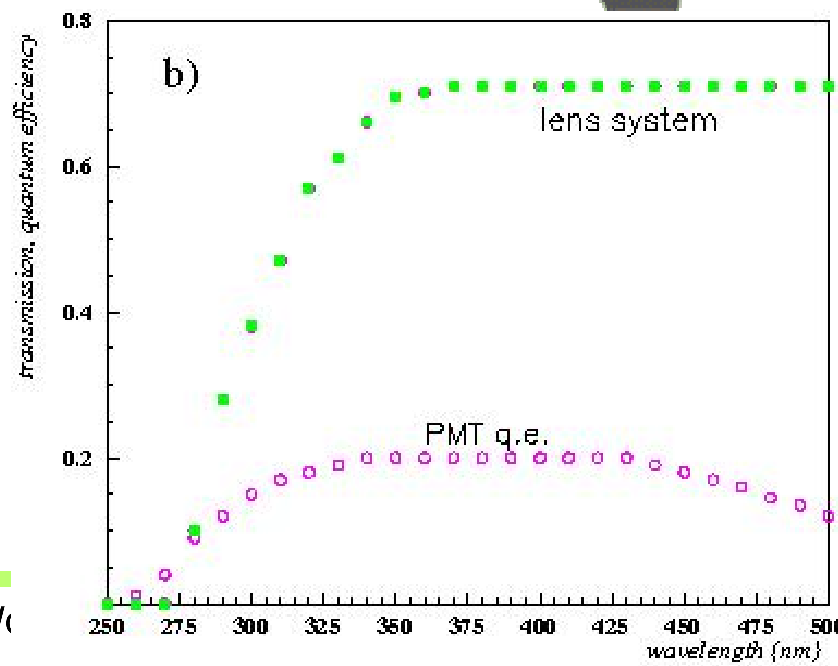
-Only slightly aspheric

-Easy to fabricate plastic lenses

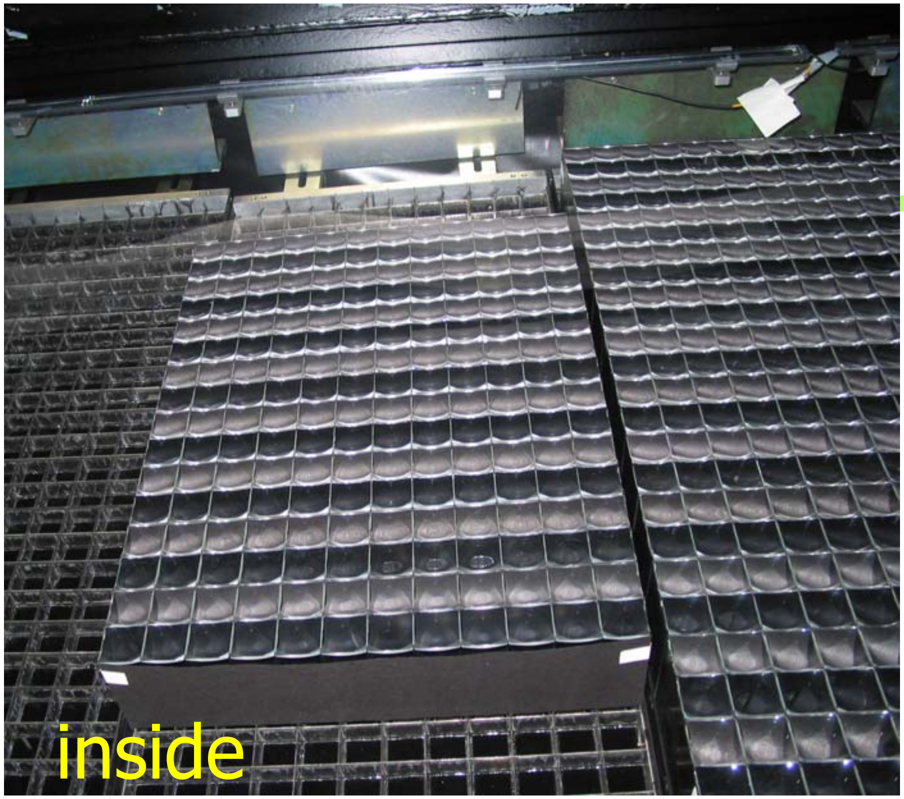
-Mold production, cheap

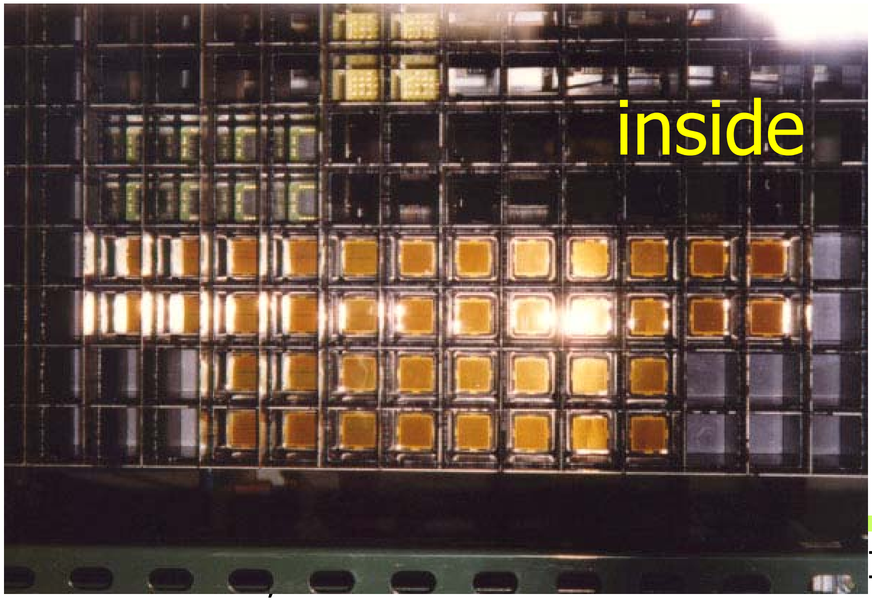
-Integrated into the support structure

T(λ) of the lens system,
QE (λ) of PMT →

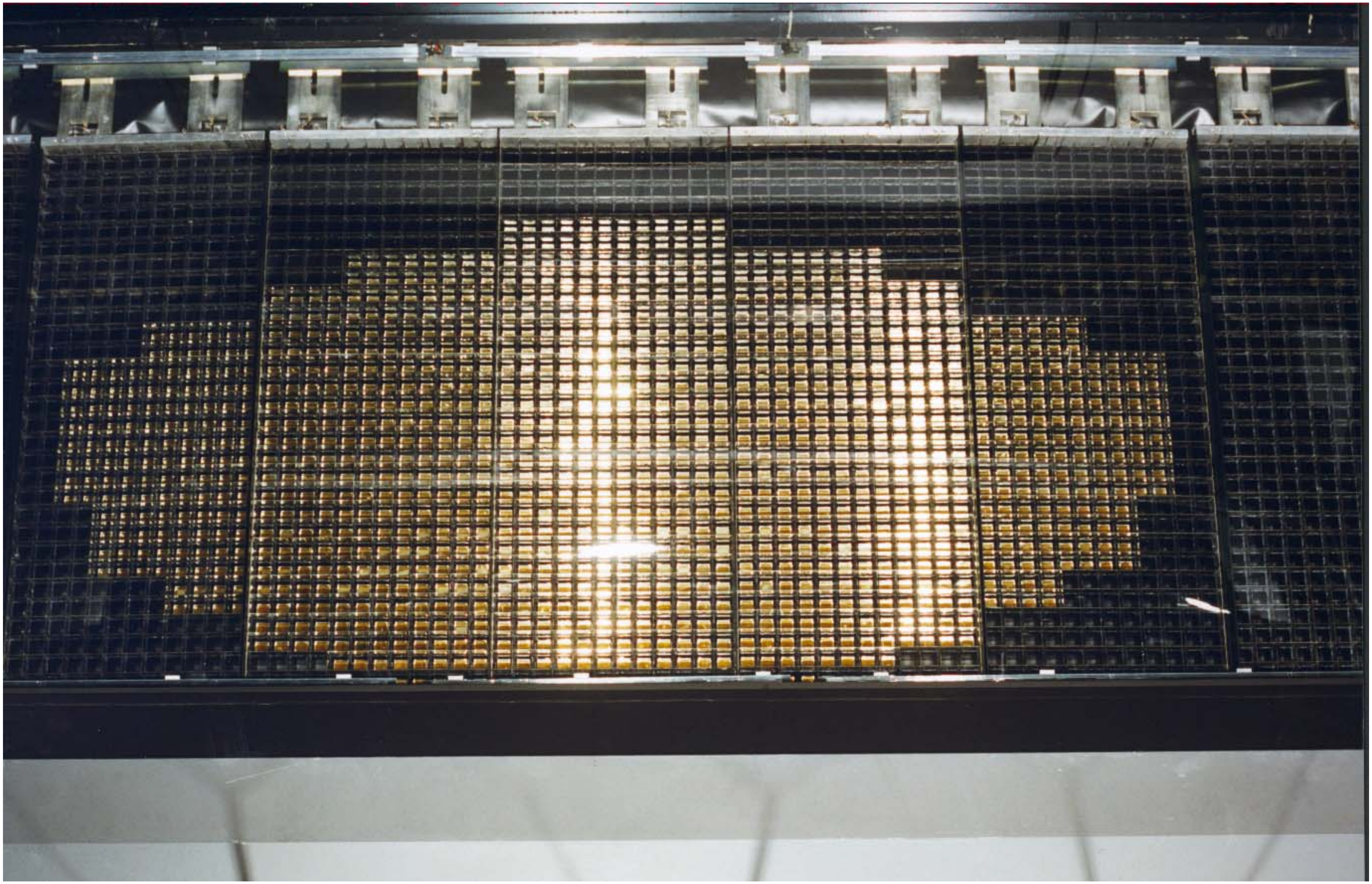


Mechanics





Photon detector: Upper half



Photon detector form

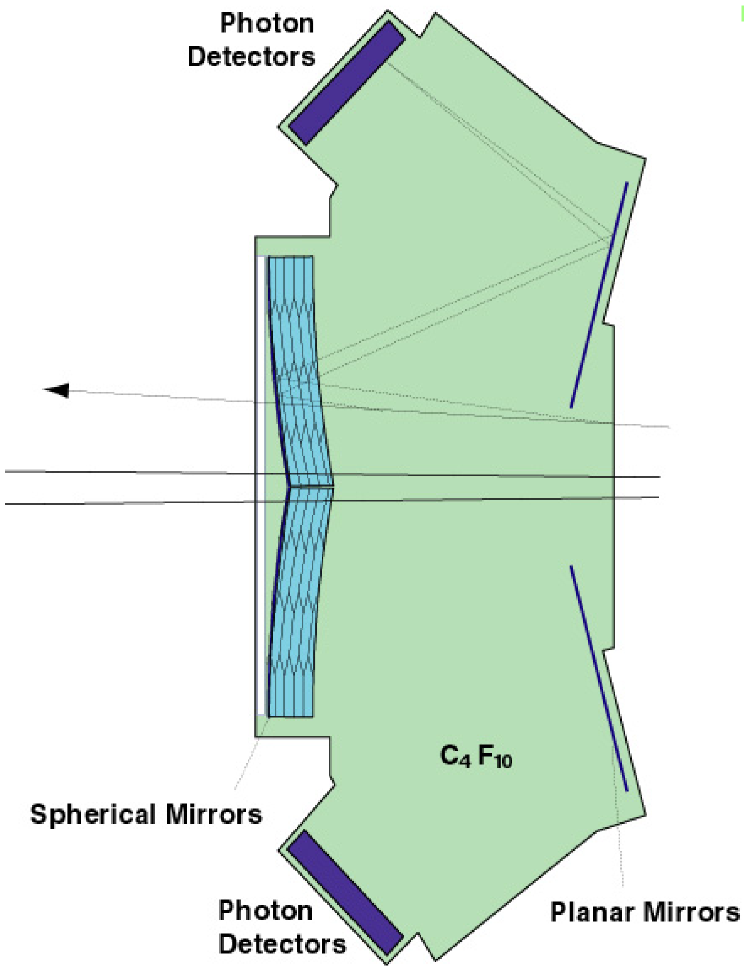
Minimize the error due to spherical aberration.

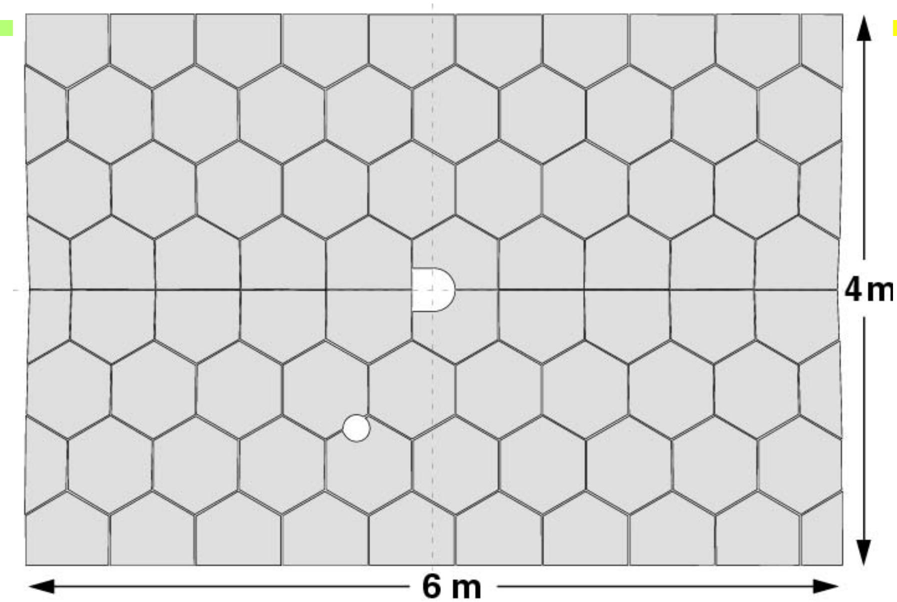
Specific: Mirror tilted by 9^0.

The optimal surface could be approximated by a deformed cyllinder, by about 20cm from the naive focal surface at R/2, and slightly tilted.

→NIM A433 (1996) 124

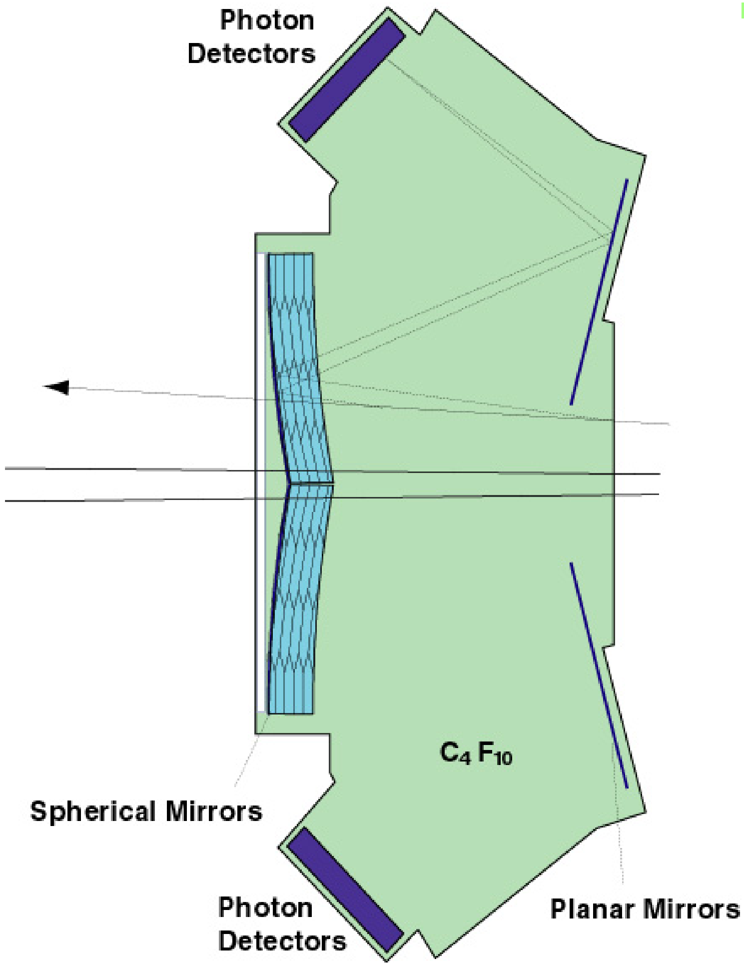
Mirrors





- Spherical mirrors: R=11.5m, hexagons of 7mm Pyrex glass, coated with 200nm Al and 30 nm of MgF_2
- Planar mirrors: rectangles of float glass

Mirrors

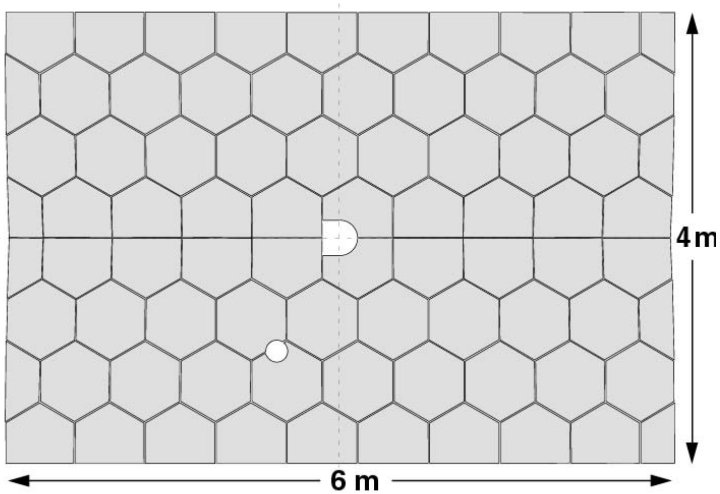


Each segment: computer controlled motors for alignment

Mirrors - alignment

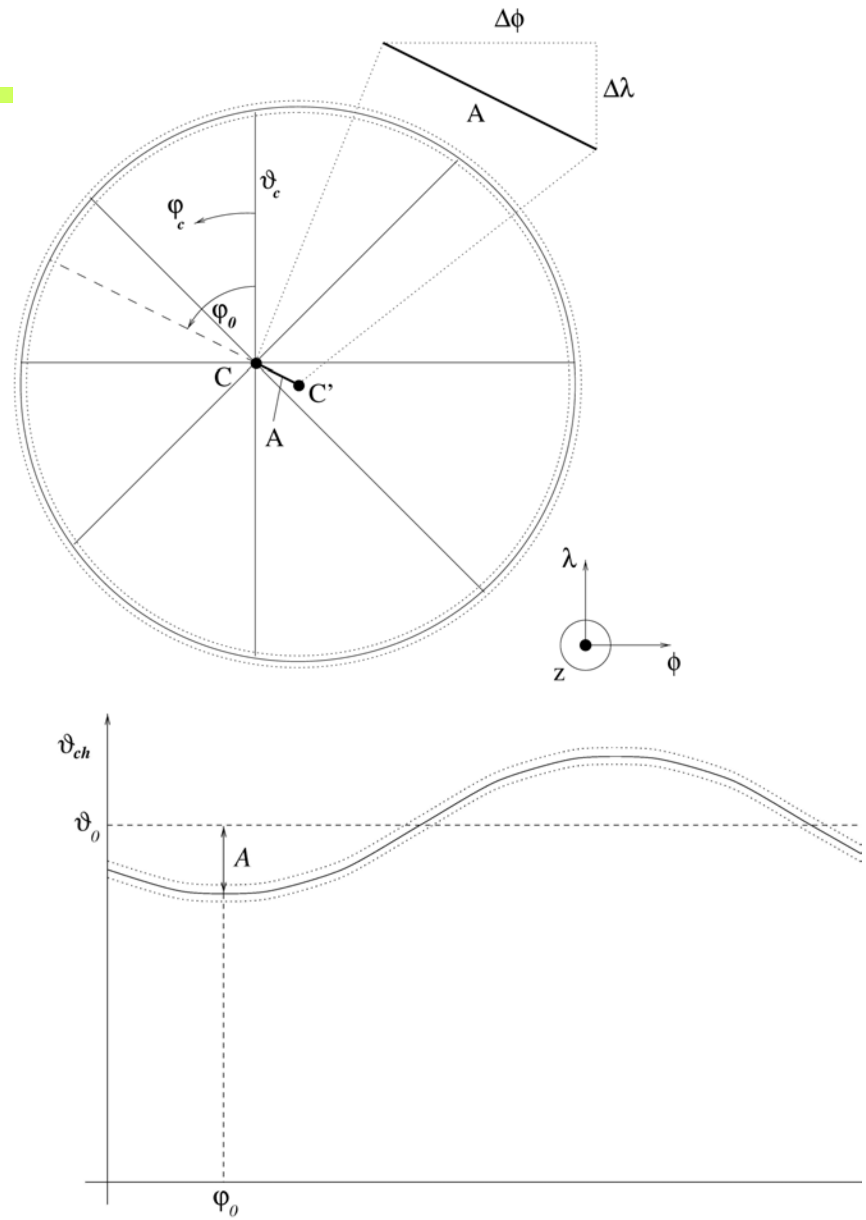
Initial alignment: with teodolite inside the vessel

Final alignment: using data

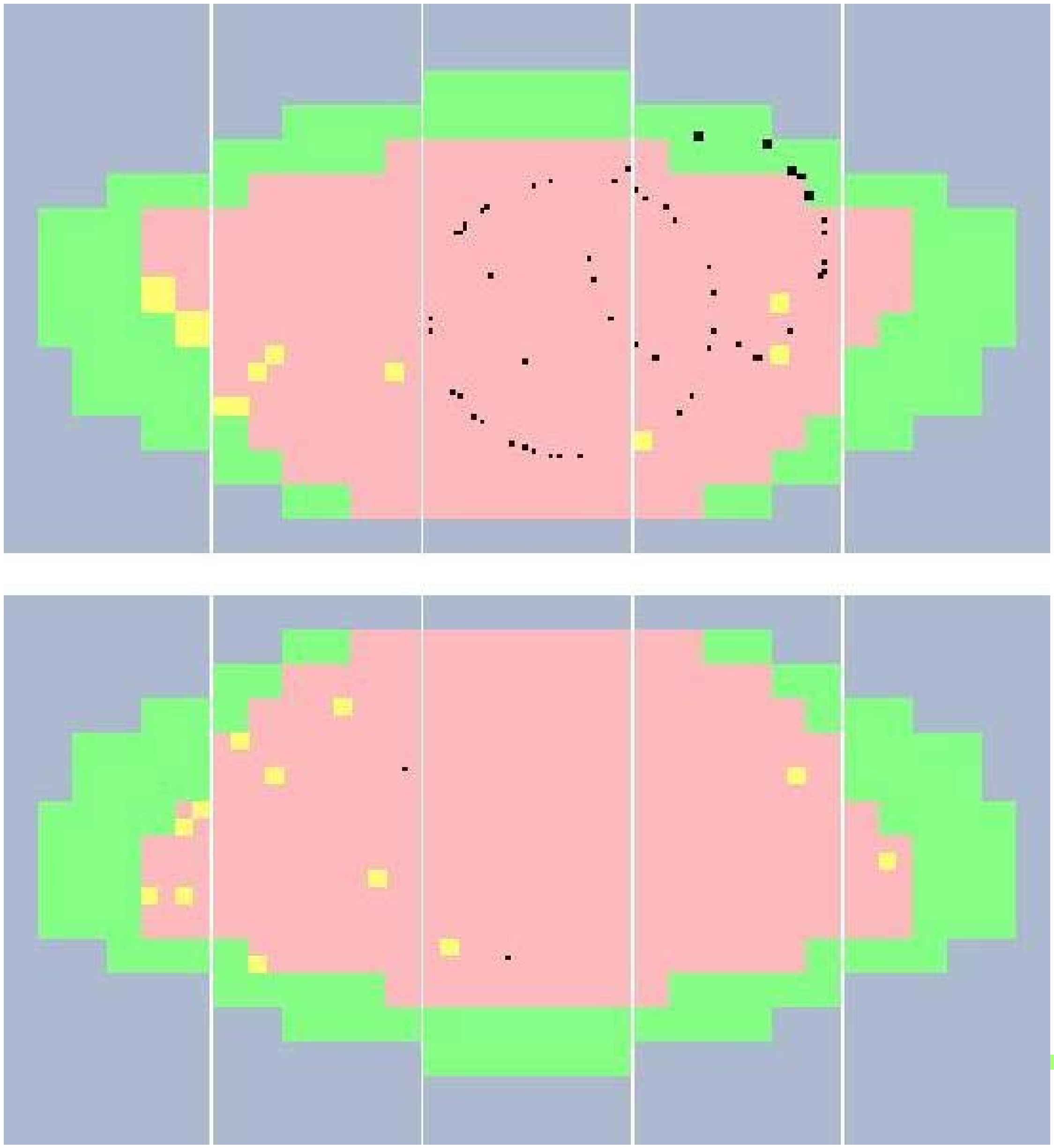


Use rings with photons from different mirror segments for relative alignment

→NIM A433 (1999) 408



HERA-B RICH performace



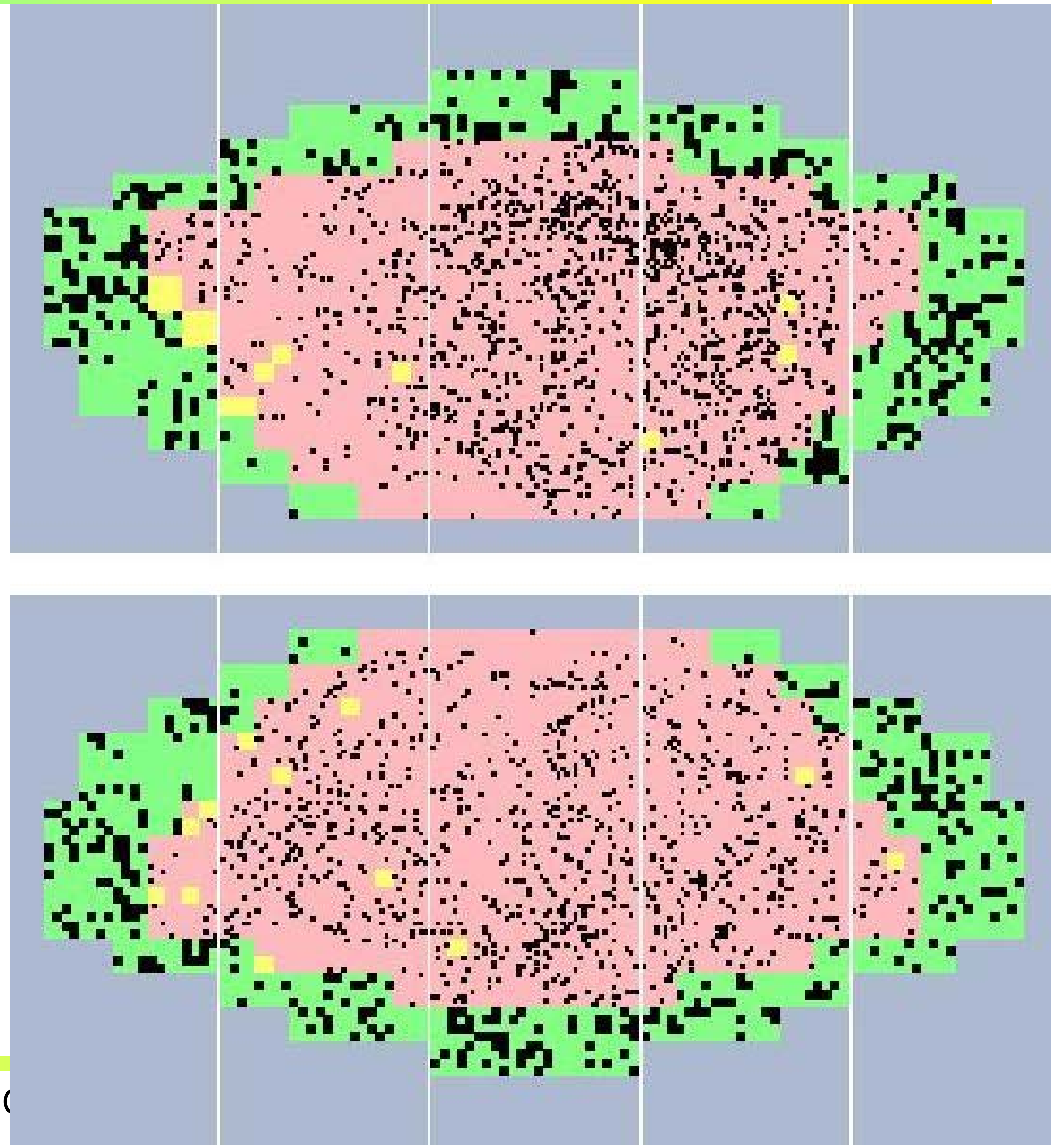
Little noise,

very clear rings

with ~30k read-out channels

Performance

Typical event...



Background mainly from other tracks → adapt the extented maximum likelihood analysis with expectation-maximisation algorithm

→NIM A433 (1999) 279

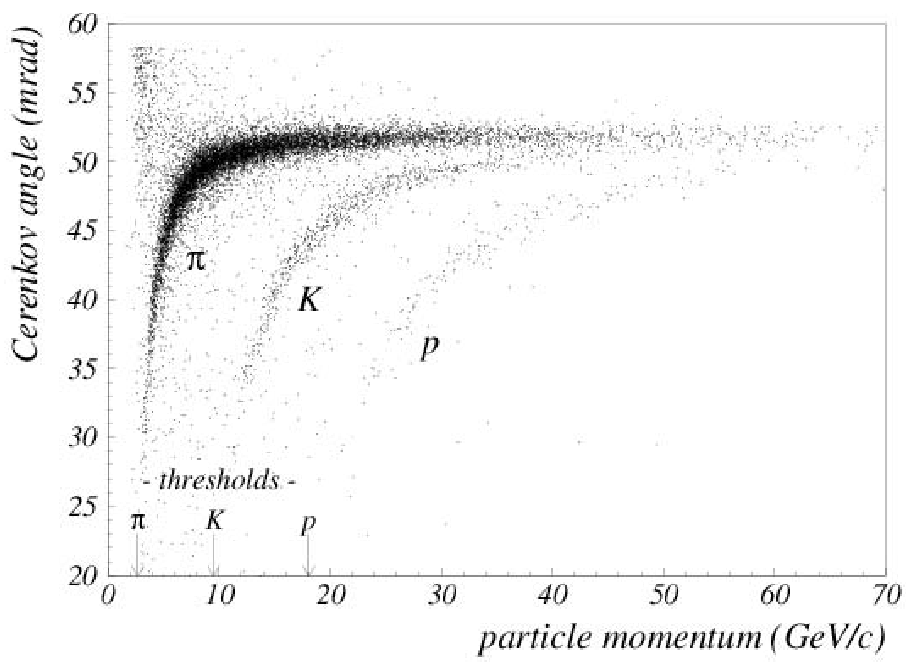
Performance

Figure of merit: N_0=42/cm (=expected)

Number of photons for =1 particles: 33

Single photon resolution:

- σ_0=0.8 mrad for finer granularity region (R5900-M16 tubes)
- σ_0=1.0 mrad for coarser granularity region (R5900-M4 tubes)



Well separated particle bands

Performace

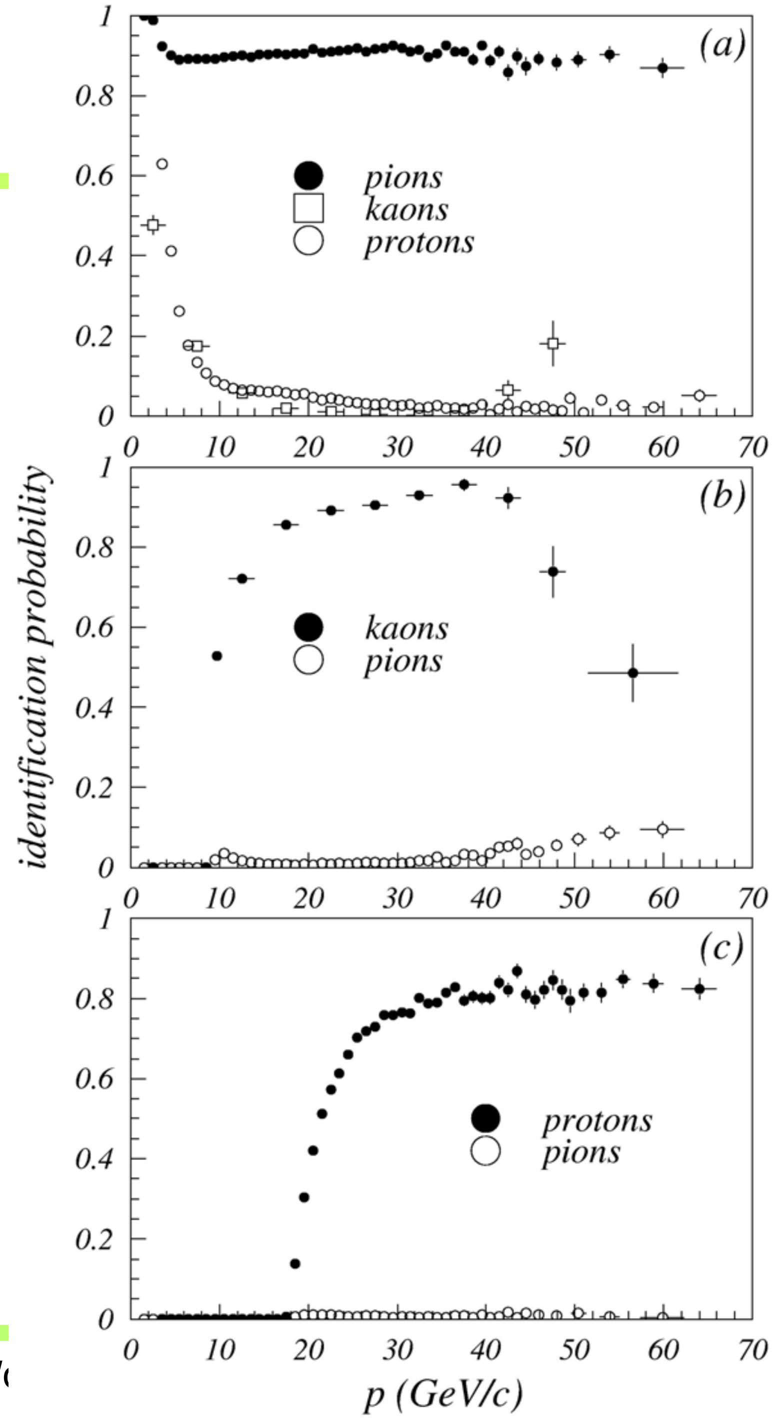
Idenfication of pions: pion efficiency, p, K fake probability

Idenfication of kaons: K efficiency, pion fake probability

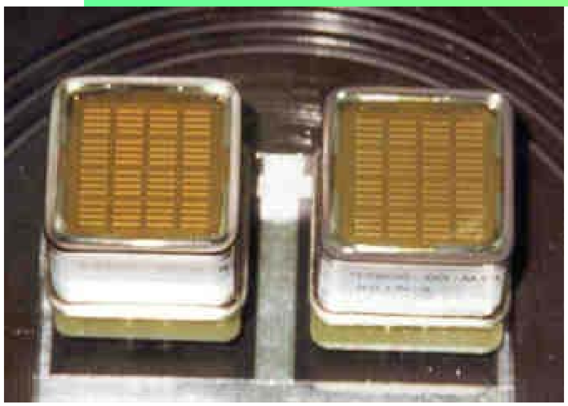
Idenfication of protons: p efficiency, K fake probability

It actually works very well!

→NIM A516 (2004) 445



HERA-B RICH photon detector: how could we do it today?



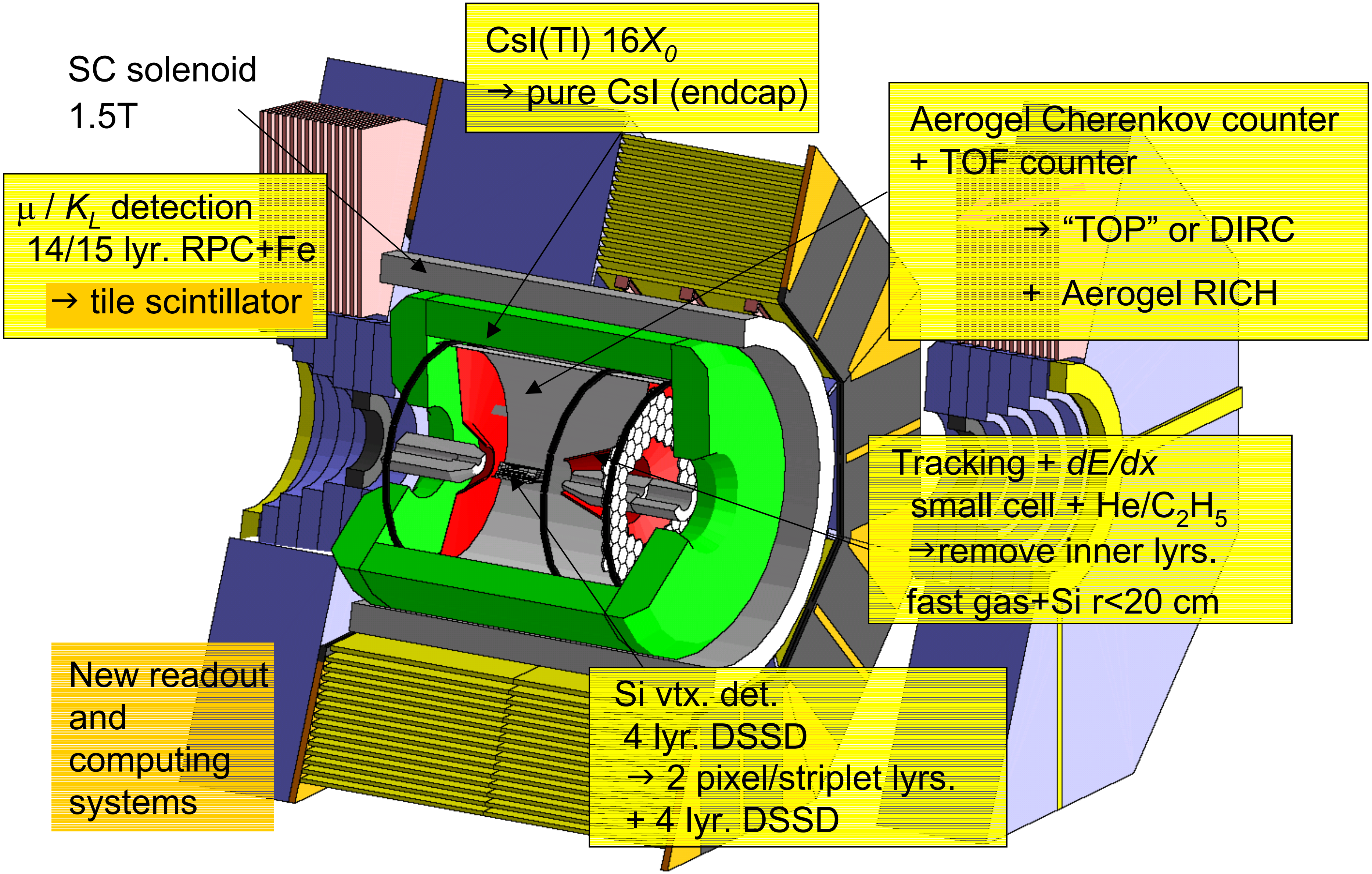
We employed R5900 PMTs with a rather low active area fraction of 25% (36% for dense packing) + optical system.

Today: could go for a better active a. ratio →

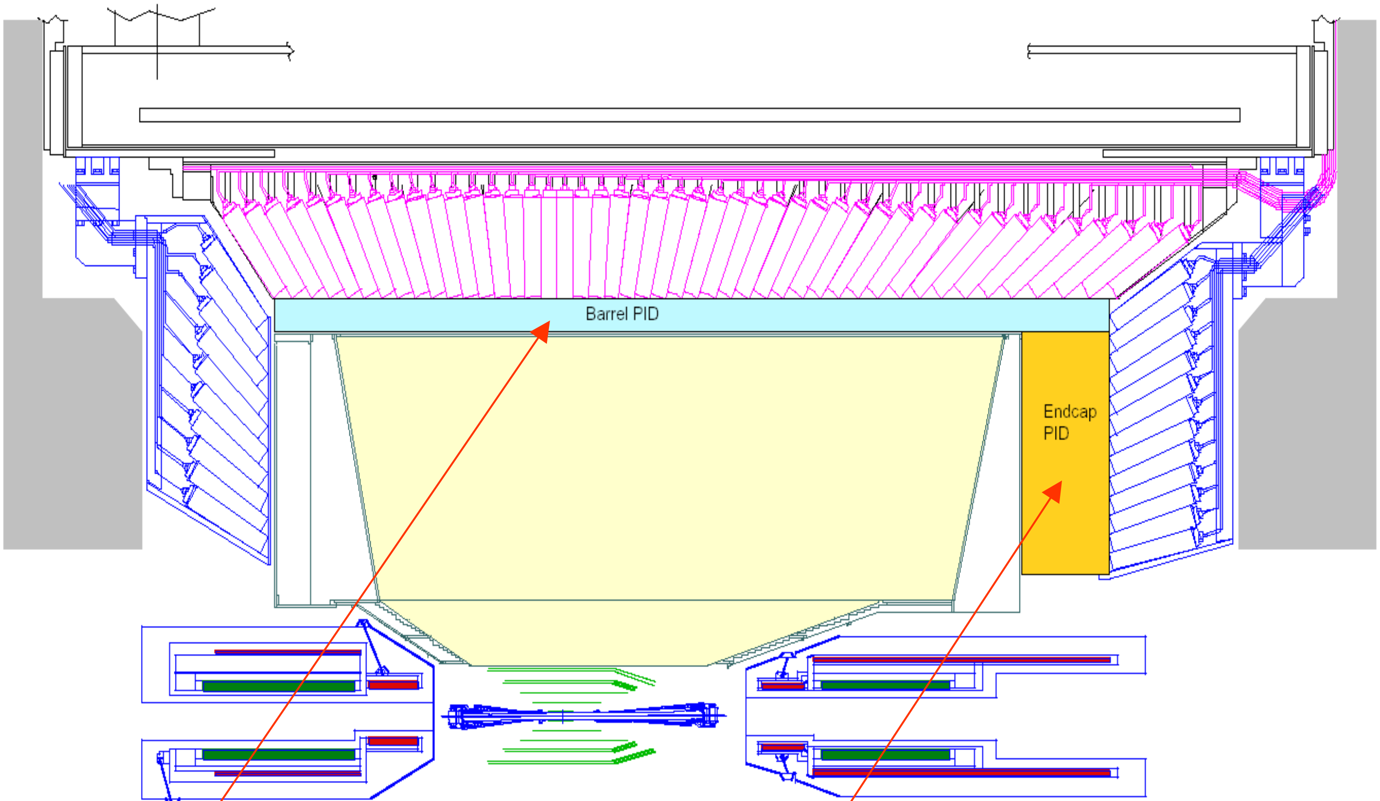
- In the meantime the same package comes without the nose at the sides - R7600
- and recently with an even better active area ratio (83%): R8900-03
- or use the H8500 ('flat pannel') PMT →

52mm

Belle Upgrade for Super-B



Belle upgrade – side view

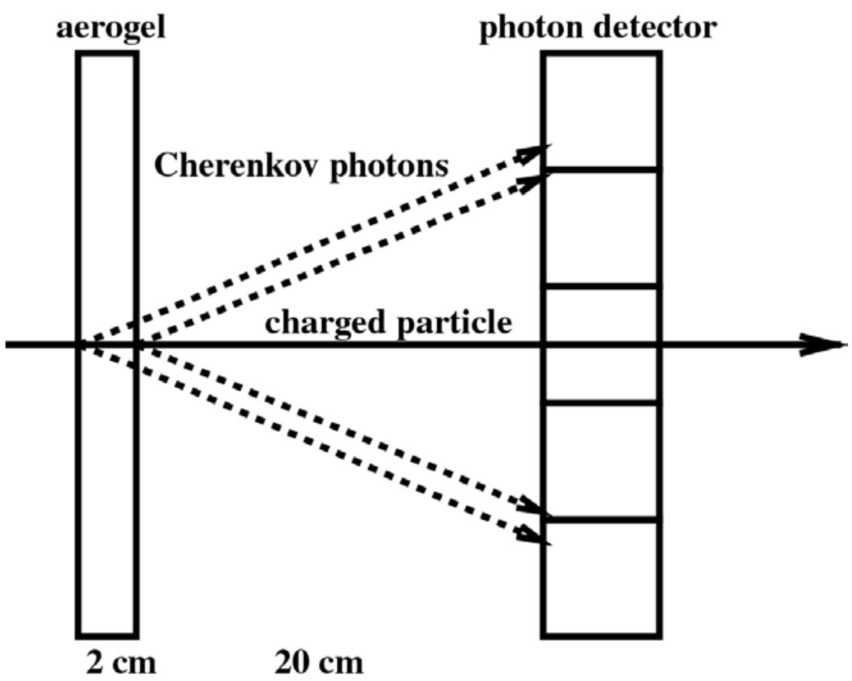


Two new particle ID devices, both RICHes:

Barrel: TOP or focusing DIRC

Endcap: proximity focusing RICH

Endcap: Proximity focusing RICH



K/π separation at 4 GeV/c
$\theta_c(\pi) \sim 308$ mrad (n = 1.05)
$\theta_c(\pi) - \theta_c(K) \sim 23$ mrad

$d\theta_c$(meas.) = $\sigma_0 \sim 13$ mrad
With 20mm thick aerogel and
6mm PMT pad size

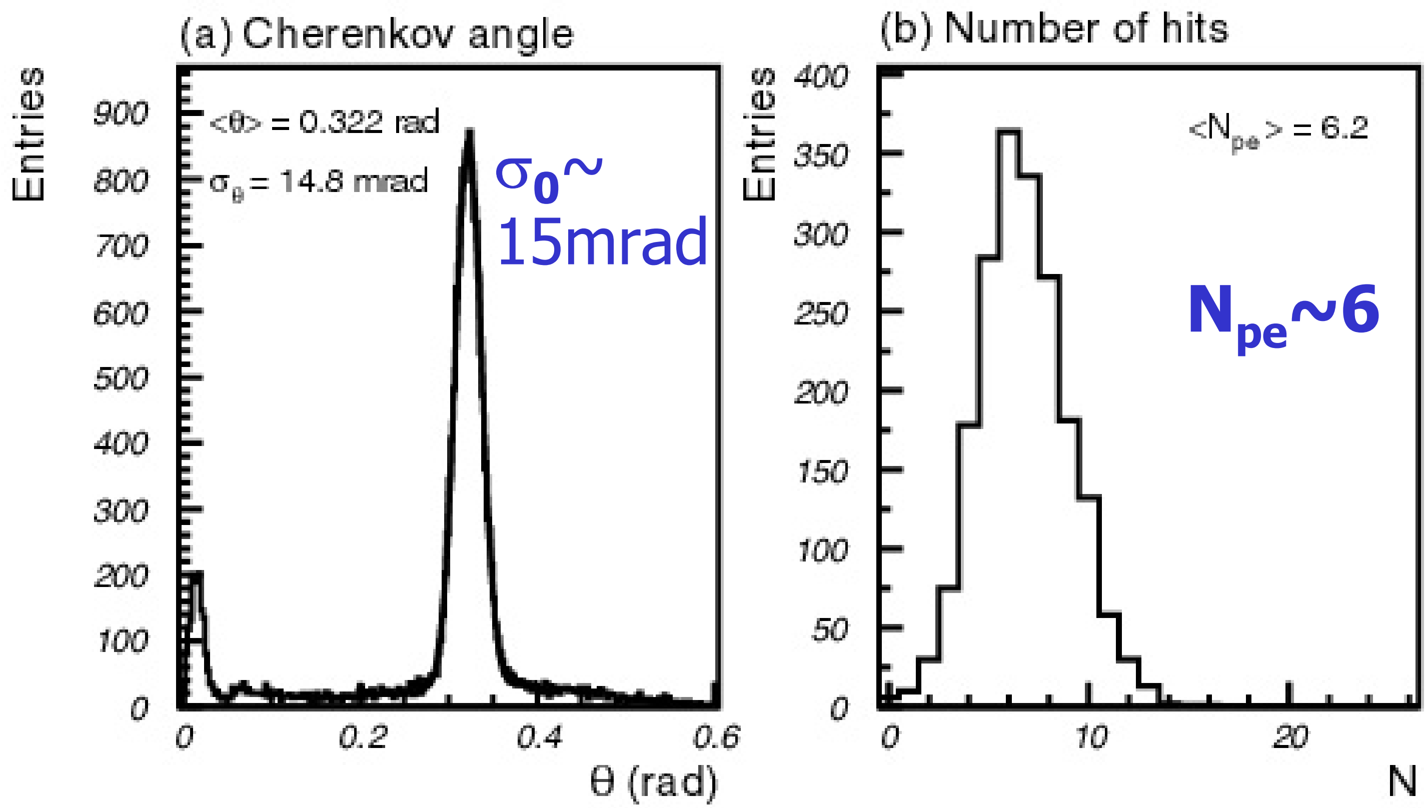
→ 6σ separation with N_{pe}~10

Beam test: Cherenkov angle resolution and number of photons

NIM A521 (2004)367; NIM A553 (2005) 58

Beam test results with 2cm thick aerogel tiles:

>4σ K/π separation

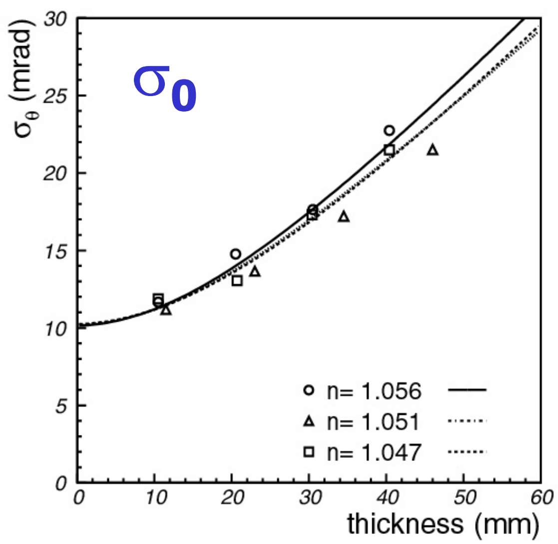


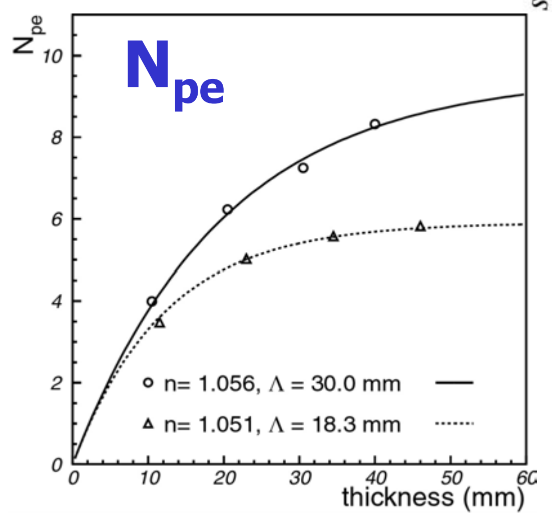
-> Number of photons has to be increased.

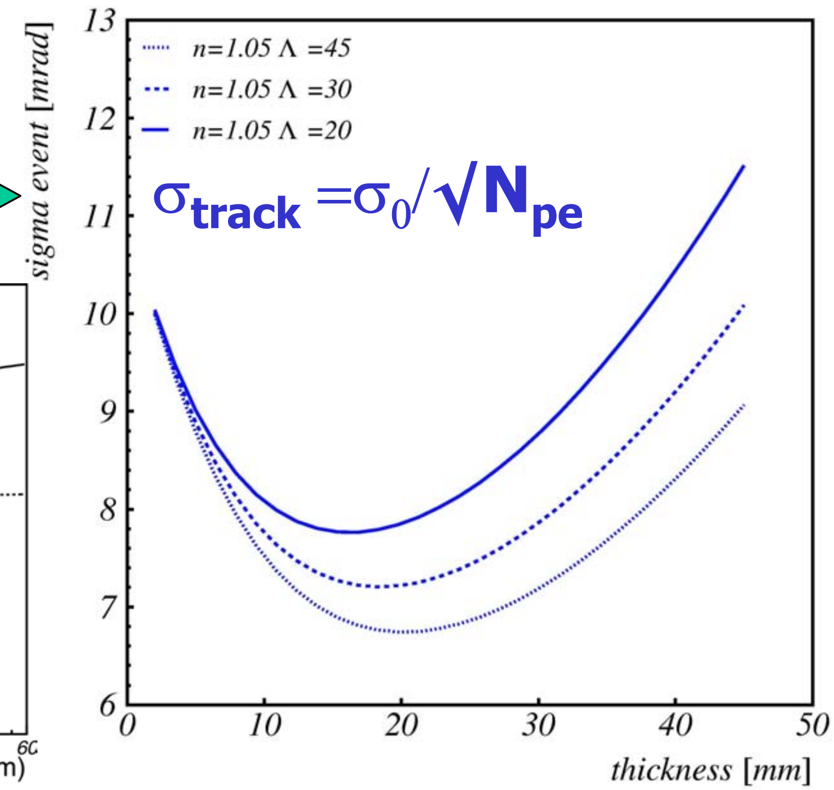
How to increase the number of photons?

What is the optimal radiator thickness?

Use beam test data on σ_0 and N_{pe}







Minimize the error per track: $\sigma_{track} = \sigma_0/\sqrt{N_{pe}}$

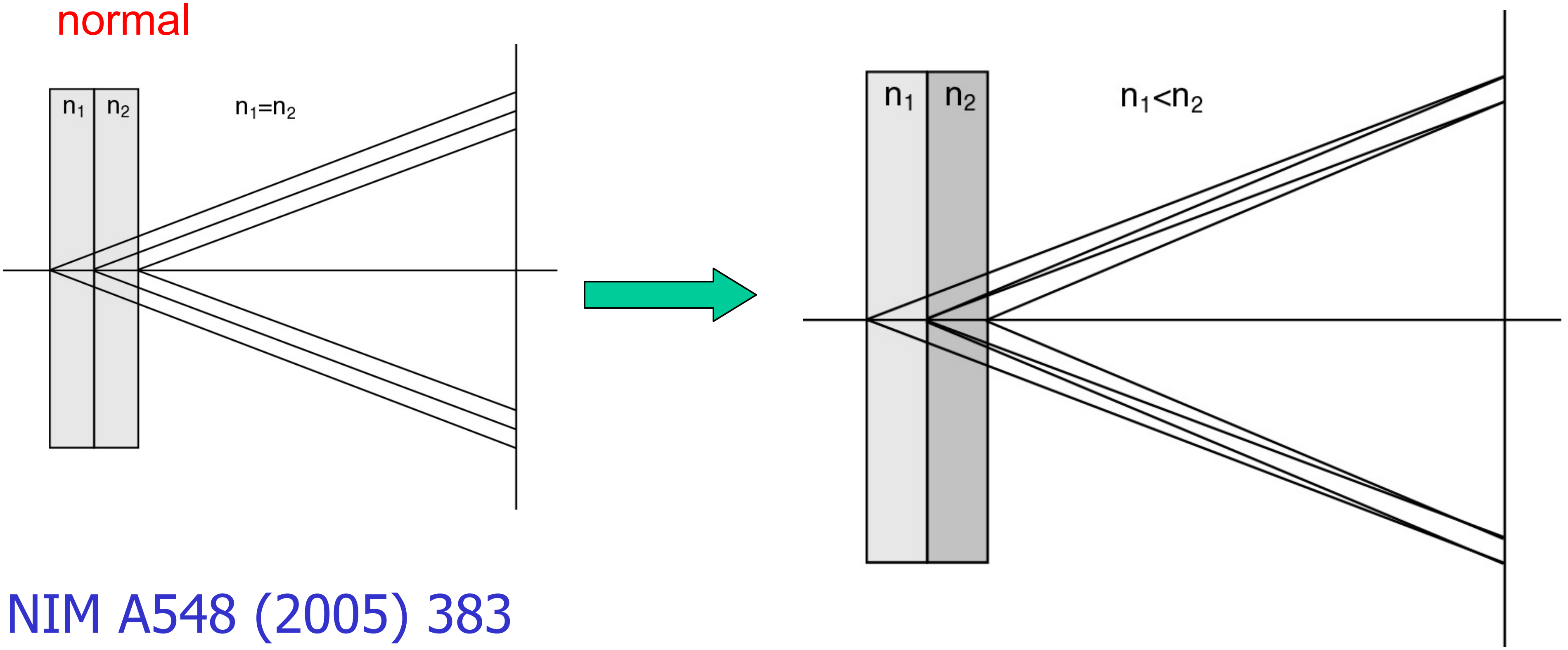
Optimum is close to 2 cm

Radiator with multiple refractive indices

How to increase the number of photons without degrading the resolution?

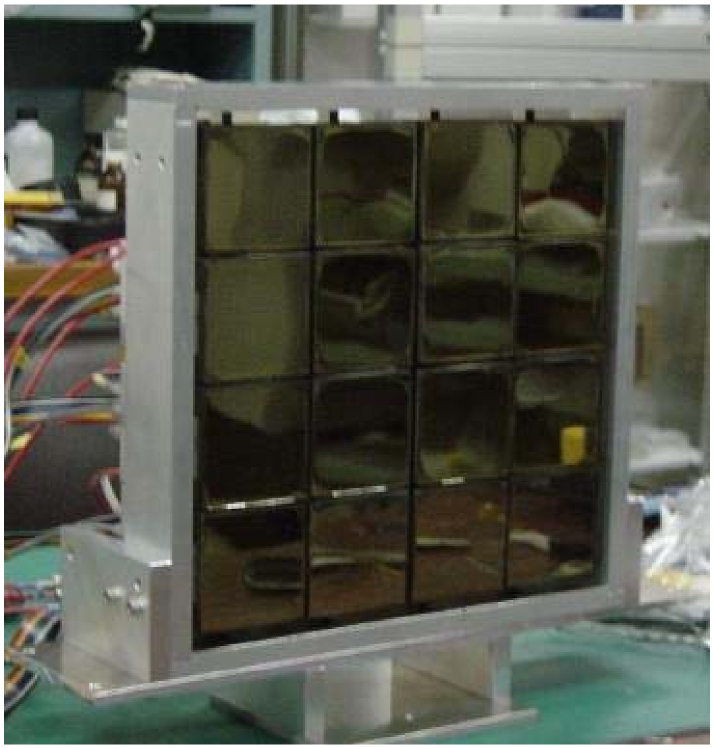
→ stack two tiles with different refractive indices: "focusing" configuration

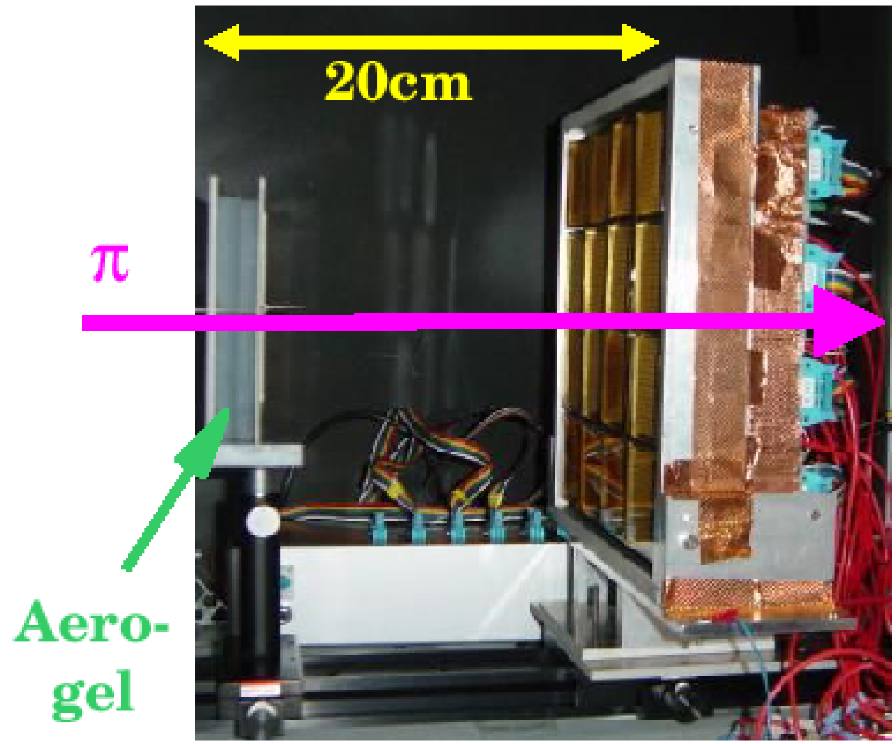
normal



NIM A548 (2005) 383

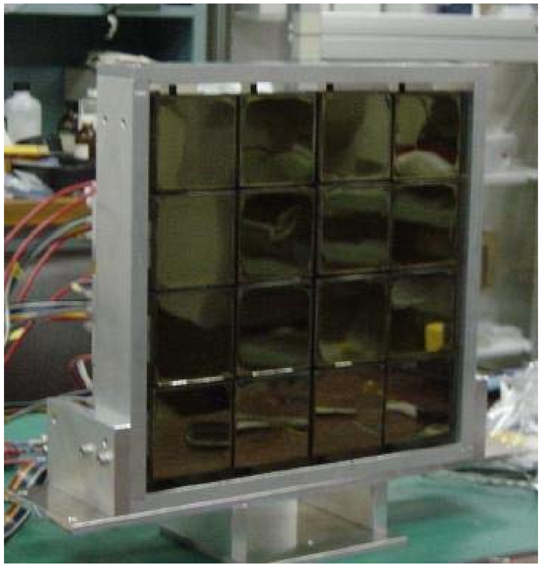
Beam tests



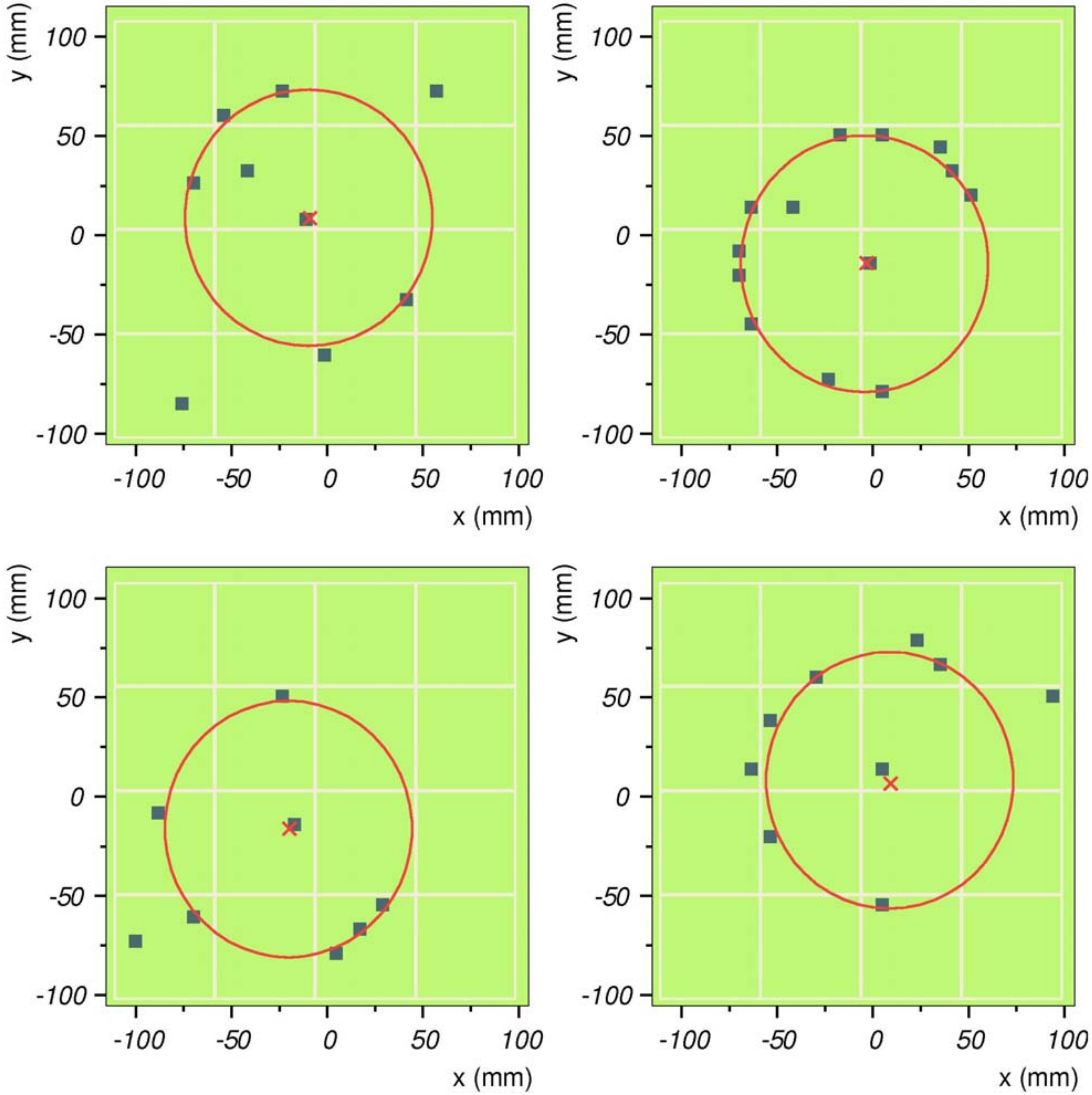


Photon detector: array of 16 H8500 PMTs

Beam tests: events



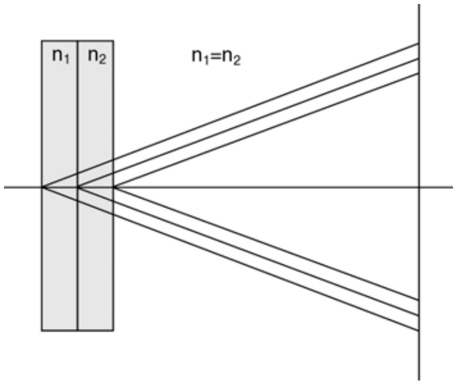
Photon detector:
4x4 H8500 PMTs

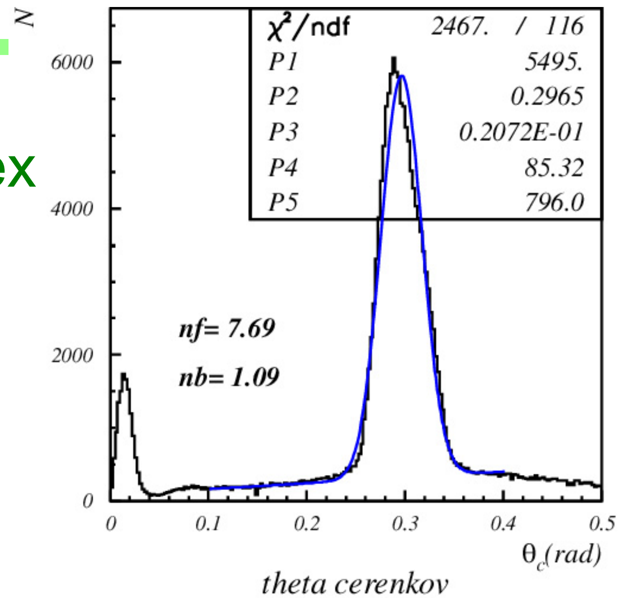


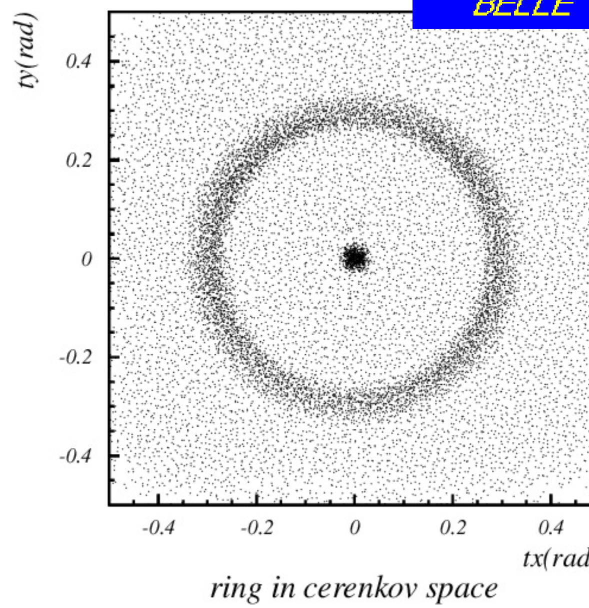
Clear rings, little background

Focusing configuration – data

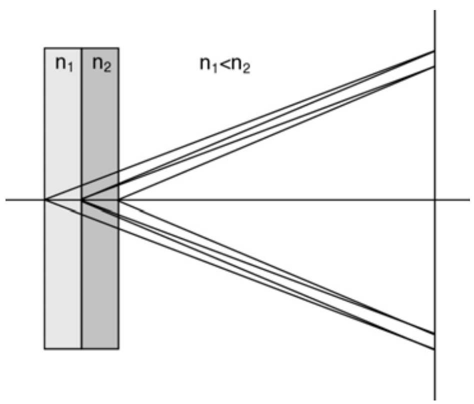
4cm aerogel single index

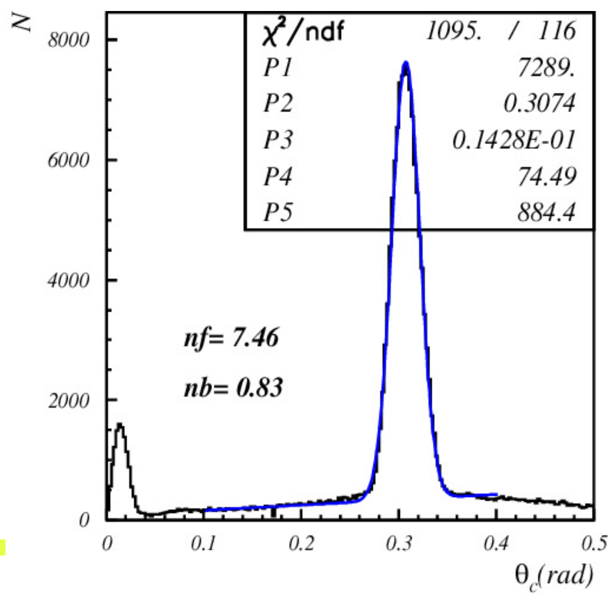


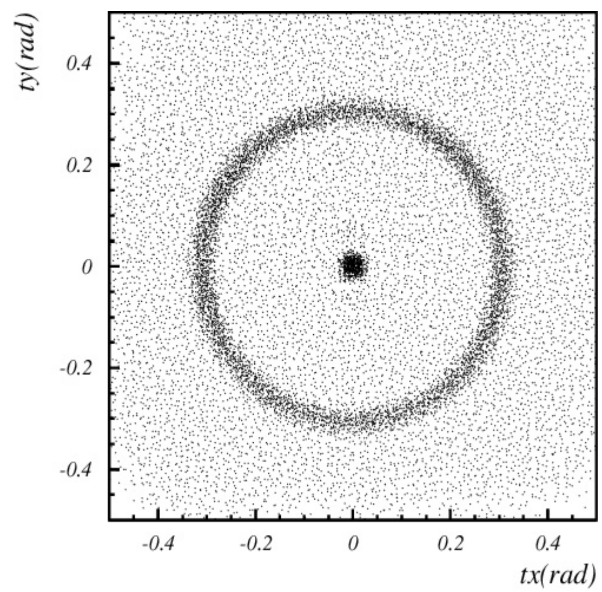




2+2cm aerogel



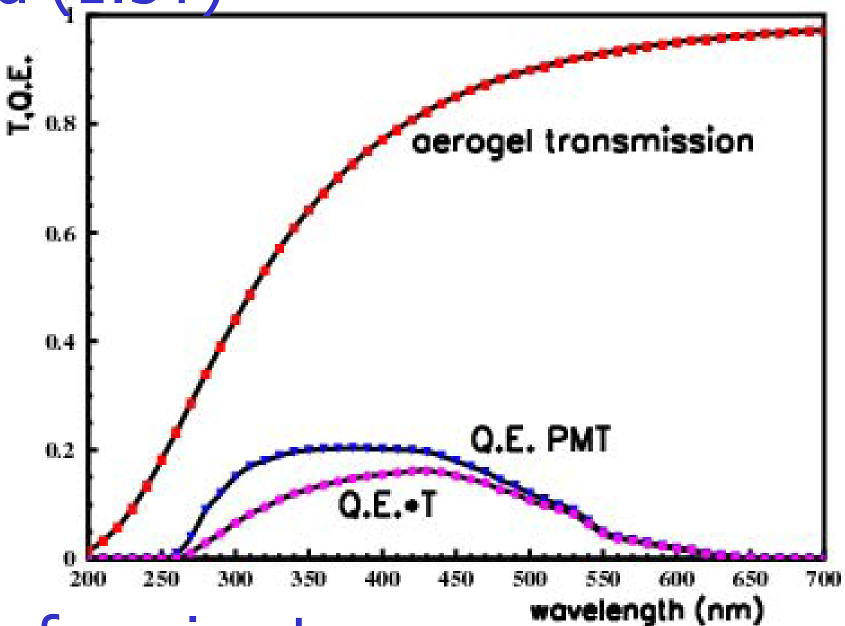




Photon detectors for the aerogel RICH

Needs:

- Operation in high magnetic field (1.5T)
- High efficiency at λ>350nm
- Pad size ~5-6mm



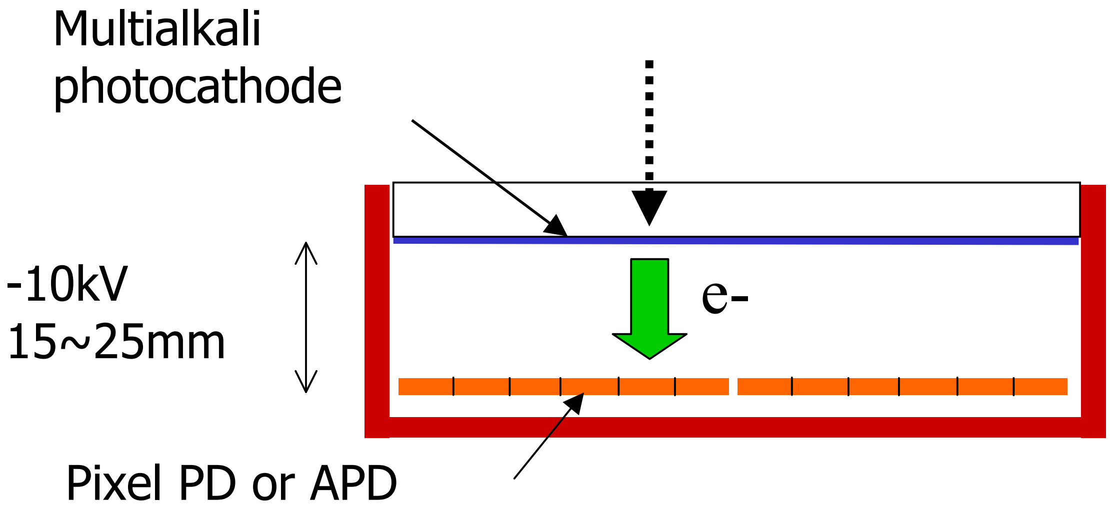
Candidates:

- large area HPD of the proximity focusing type
- MCP PMT (Burle 85011)

N.B. H8500 PMT unfortunately does not work in high B field

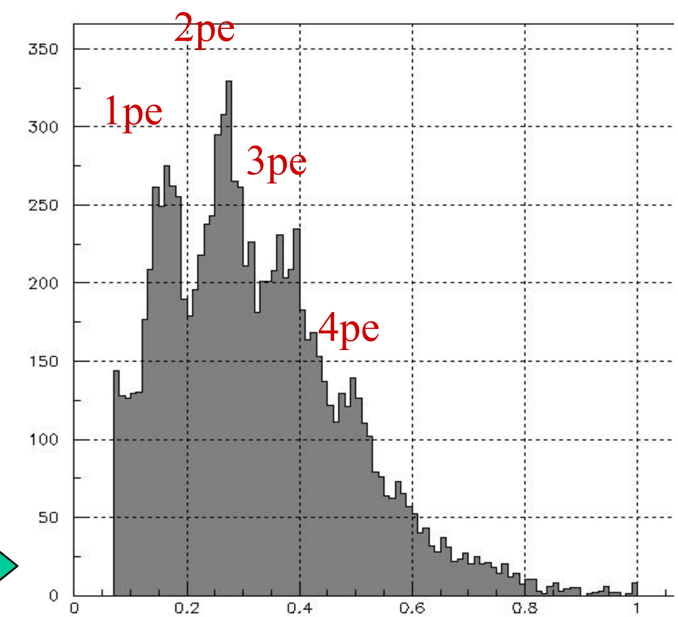
Development and testing of photon detectors for 1.5 T

Candidate: large area HPD of the proximity focusing type



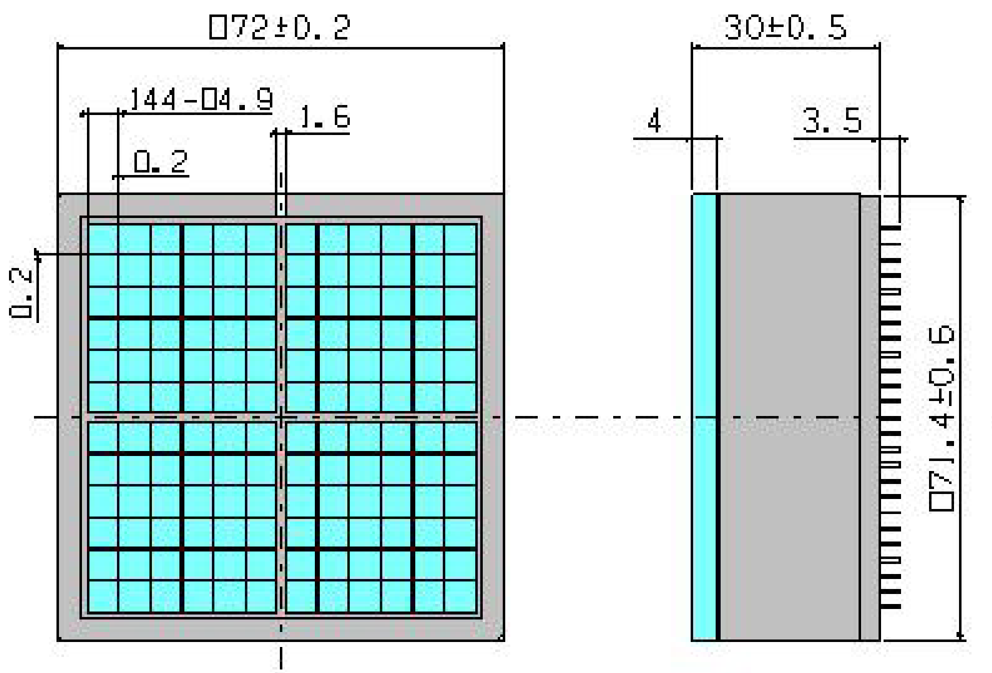
R&D project in collaboration with HPK

Tests with single channel and 3x3 channel devices look very promissing.



HPD development

59mm x 59mm active area (65%),
12x12 channels



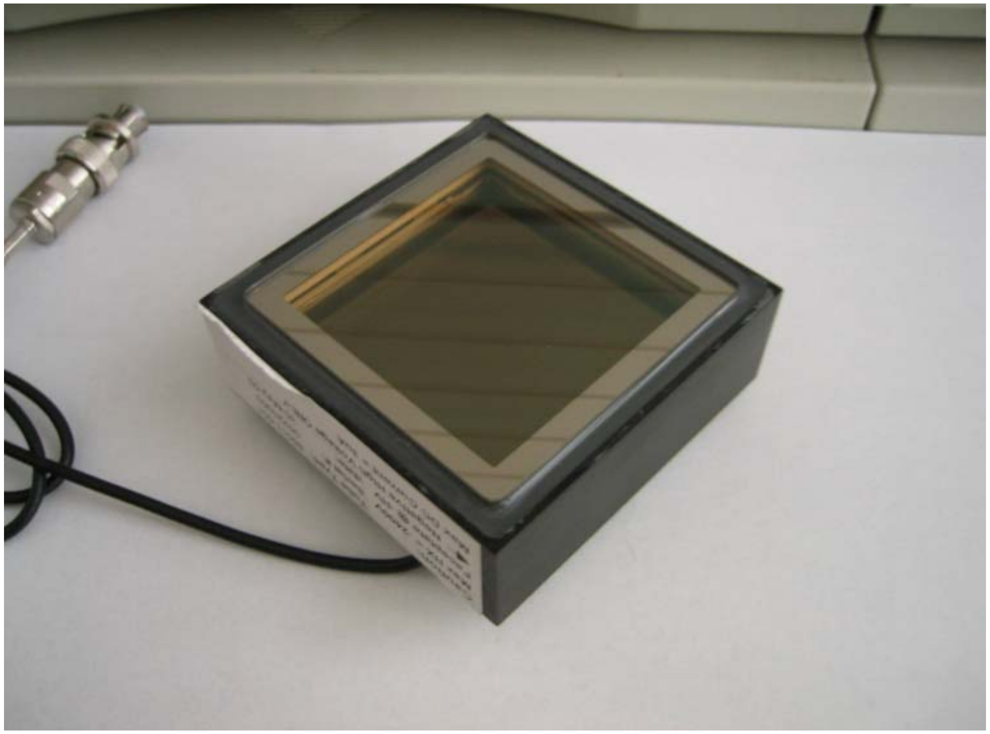
Ceramic HPD box

Several tests carried out. Problems with sealing the tube at the window-ceramic box interface.

Photon detector R&D: Burle MCP-PMT

BURLE 85011 MCP-PMT:

- multi-anode PMT with 2 MCPs
- 25 μm pores
- bialkali photocathode
- gain ~ 0.6 x 10^6
- collection efficiency ~ 60%
- box dimensions ~ 71mm square
- 64(8x8) anode pads
- pitch ~ 6.45mm, gap ~ 0.5mm
- active area fraction ~ 52%
- fast: ~55ps time resolution

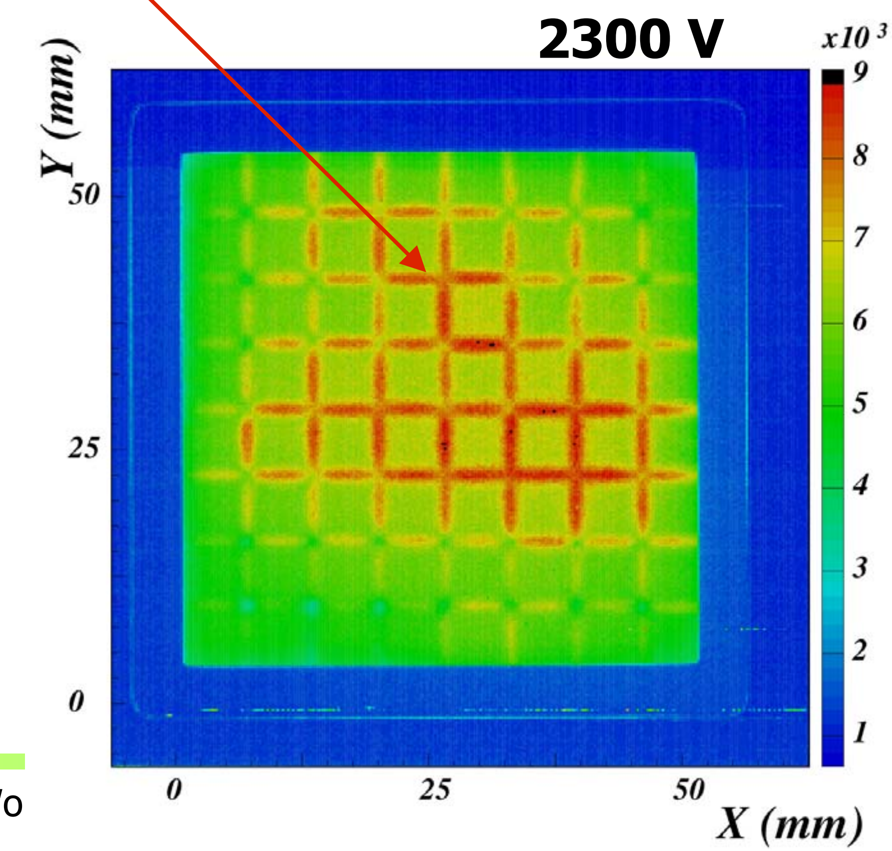


Burle MCP-PMT bench tests

Proc. IEEE NSS 2004

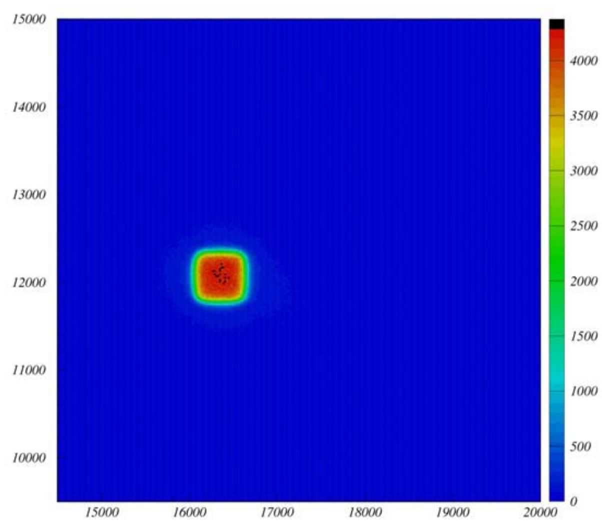
Study uniformity of the sensitivity over the surface

count rates - all channels: charge sharing at pad boundaries

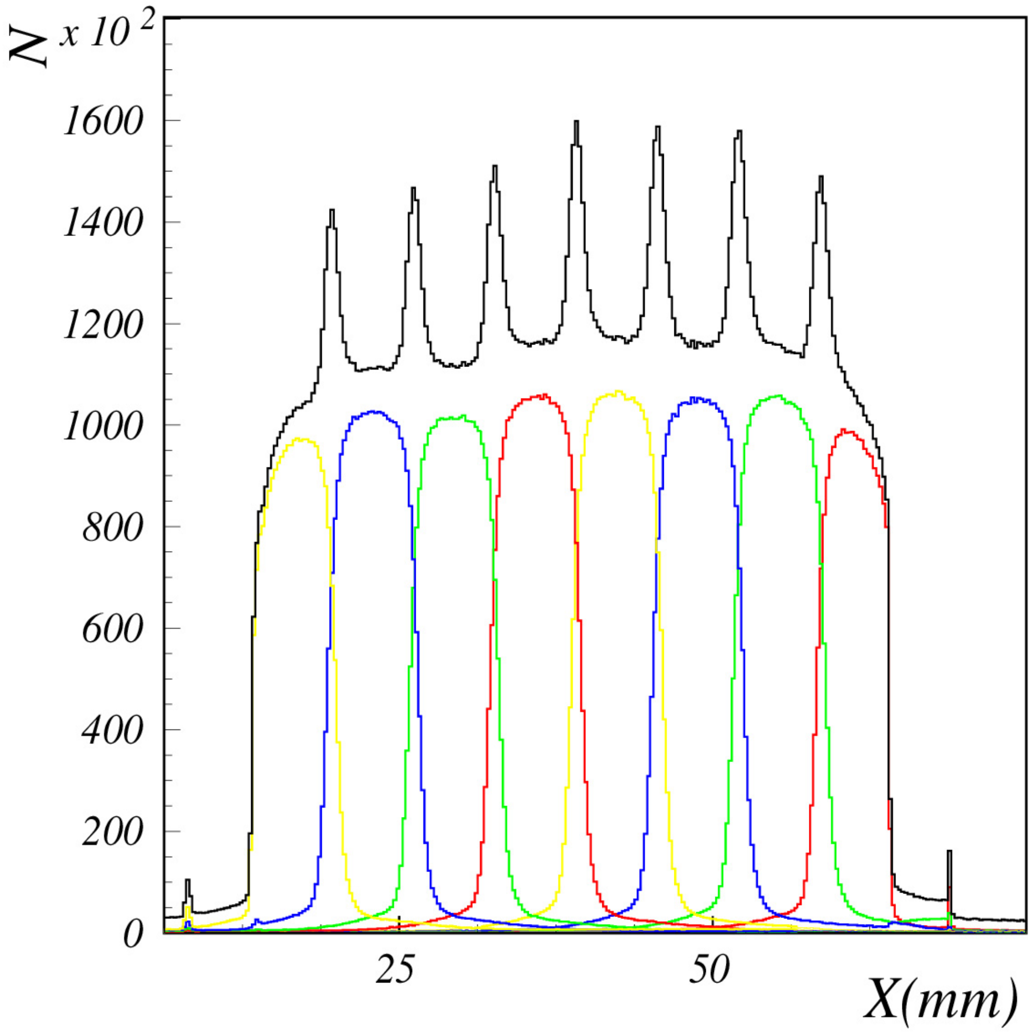


single channel response:

- uniform over pad area
- extends beyond pad area (charge sharing)



Burle MCP-PMT bench tests



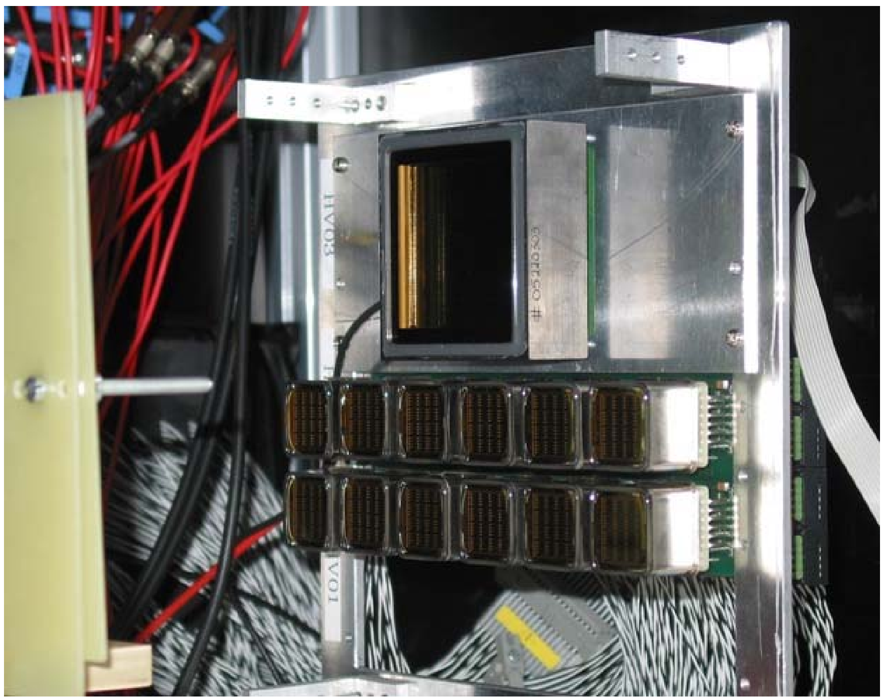
charge sharing at pad boundaries

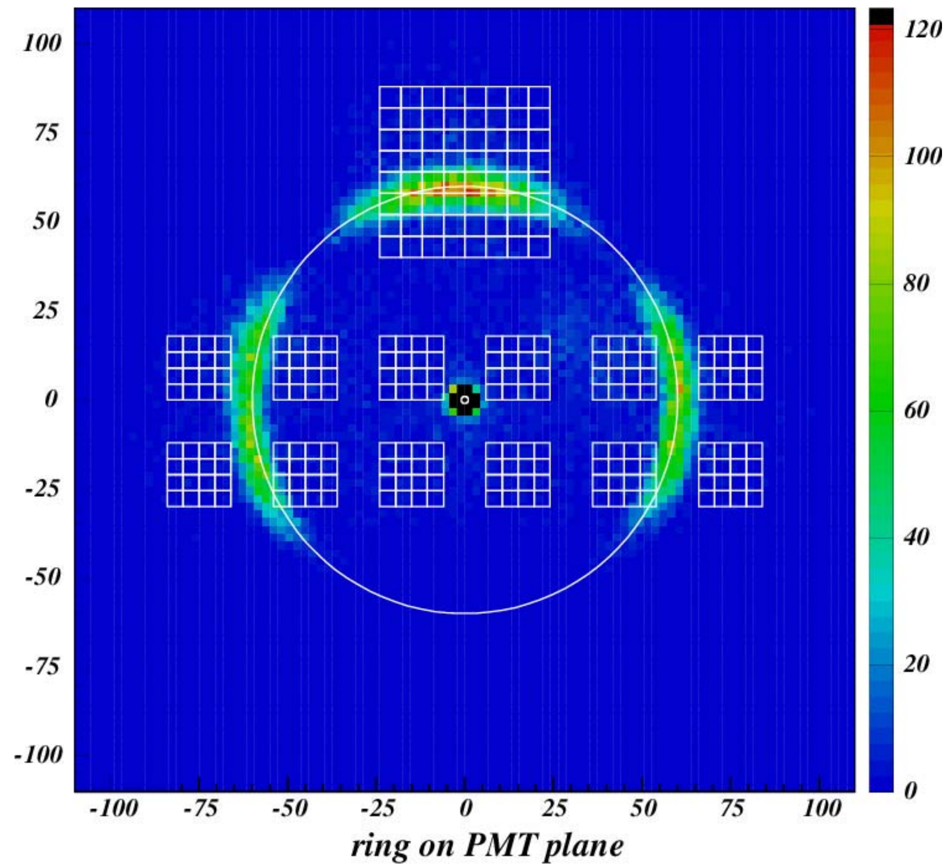
- slice of the counting rate distribution including the central areas of 8 pads (single channels - colored, all channels - black)

Proc. IEEE NSS 2004

Burle MCP PMT beam test

- **BURLE MCP-PMT** mounted together with an array of 12(6x2) **Hamamatsu R5900-M16 PMTs** at 30mm pitch (reference counter)





Burle MCP PMT beam test

Resolution and number of photons (clusters)

- σ_ϑ~13 mrad (single cluster)
- number of clusters per track N ~ 4.5
- σ_ϑ~ 6 mrad (per track)

-> ~ 4 σ π/K separation at 4 GeV/c

Open questions

Operation in high magnetic field:

- the present tube with 25μm pores only works up to 0.8T, for 1.5T need ~10μm
- 10μm version with 4 channels available since June, some tests done (Va'vra)

Number of photons per ring: too small. Possible improvements:

- bare tubes (52%->63%)
- increase active area fraction (bare tube 63%->85%)
- increase the photo-electron collection efficiency

(from 60% at present up to 70%)

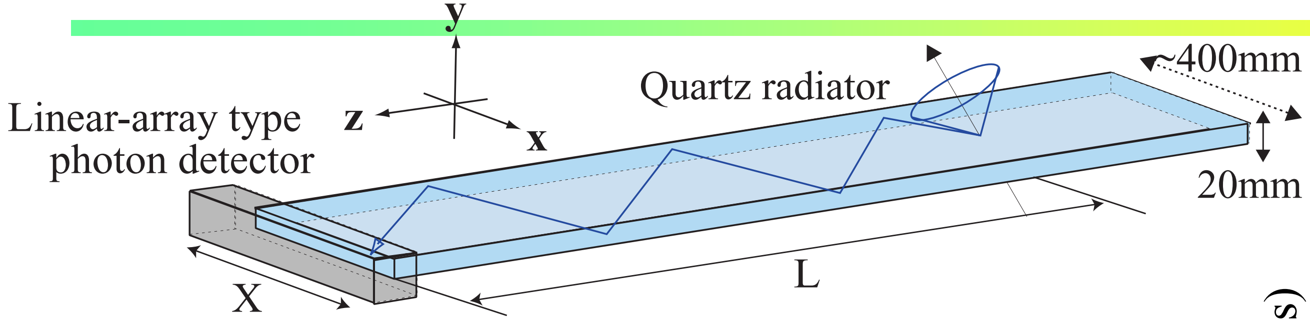
-> Extrapolation from the present data 4.5 ->8.5 hits per ring

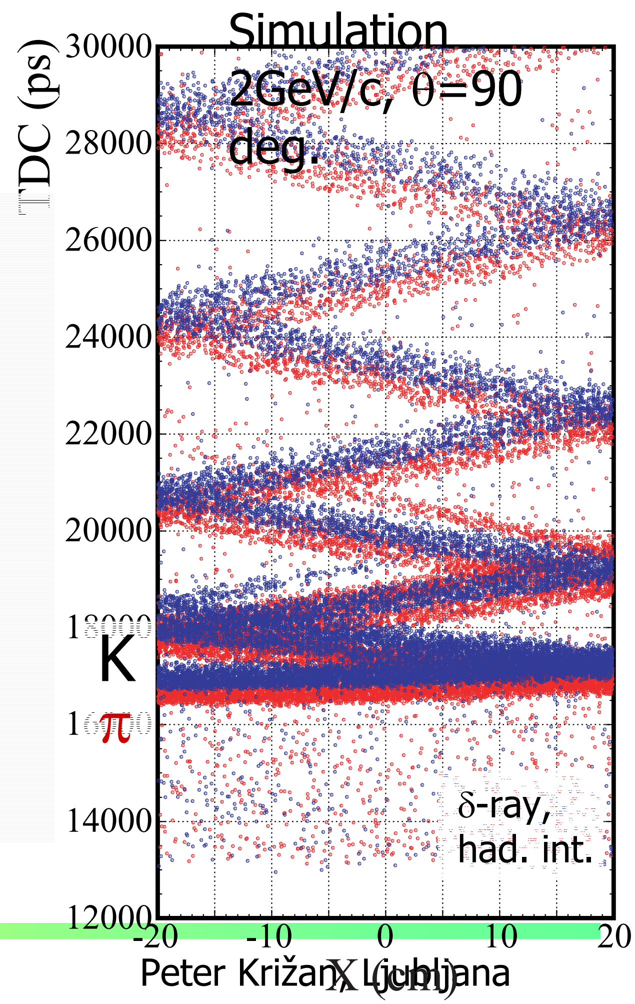
σ_ϑ: 6 mrad -> 4.5 mrad (per track)

-> >5 σ π/K separation at 4 GeV/c

Aging of MCP-PMTs ?

Belle barrel upgrade: TOP counter





Time-of-Propagation counter:

Measurement of

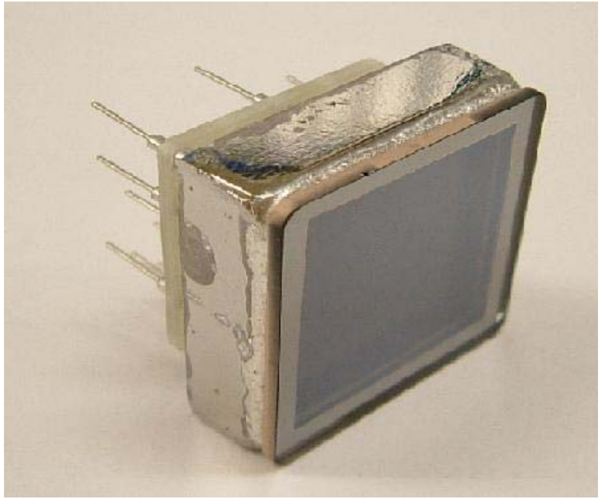
- One (or two coordinates) with a few mm precision
- Time-of-arrival

Excellent time resolution < ~40ps for single photons at B=1.5T

Belle barrel upgrade: TOP counter

Tests on the bench: amplification and time resolution in high magnetic field.

3 MCP-PMTs studied
- Burle (25μm pores)
- Novosibirsk (6μm pores)
- Hamamatsu (6 and 10μm pores)



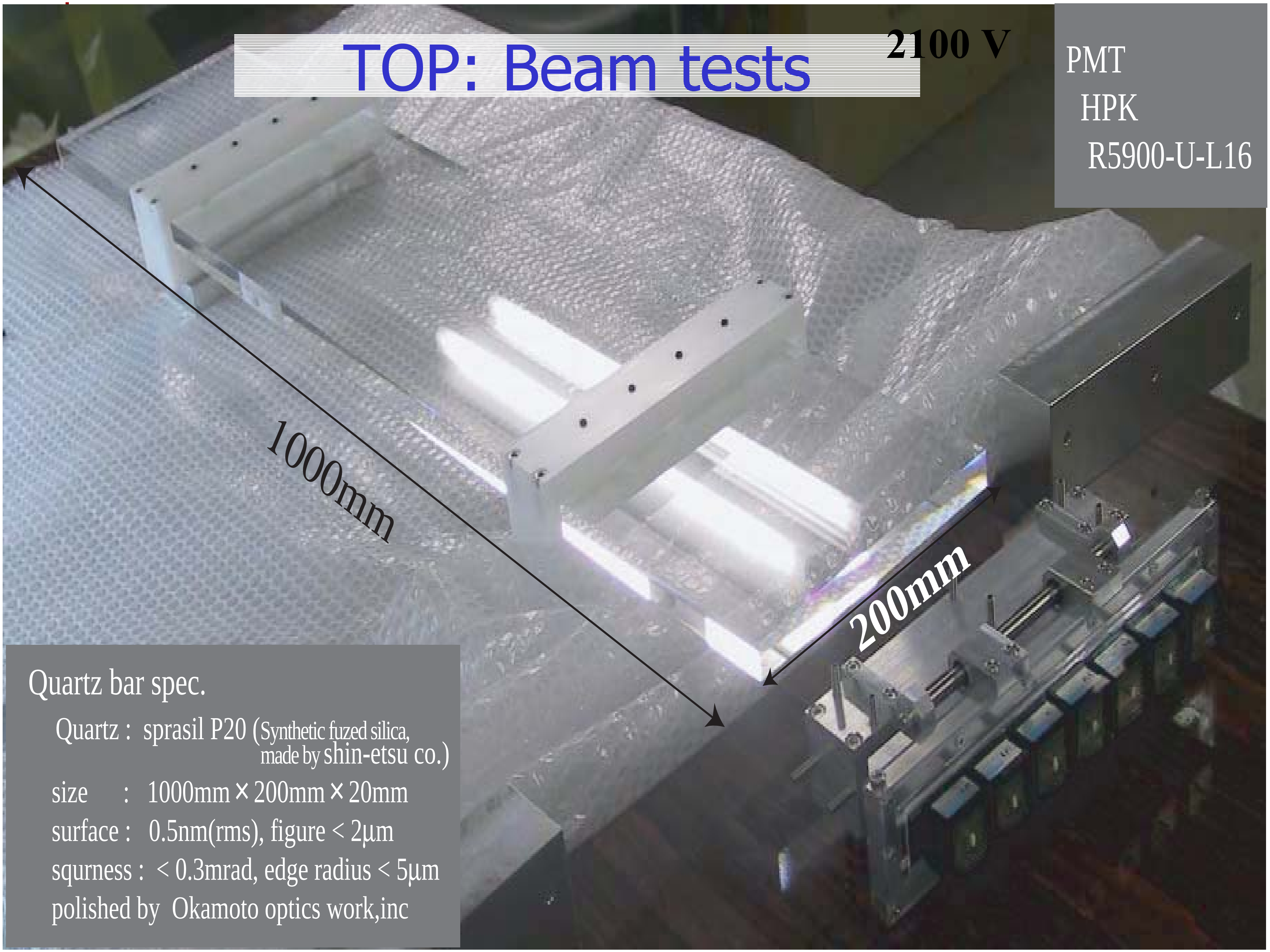
Hamamatsu SL10

All: good time resolution at B=0

25μm pore tube does not work at 1.5T

NIM A528 (2004) 763

TOP: Beam tests



Quartz bar spec.

- Quartz : sprasil P20 (Synthetic fuzed silica, made by shin-etsu co.)
- size : 1000mm × 200mm × 20mm
- surface : 0.5nm(rms), figure < 2μm
- squrness : < 0.3mrad, edge radius < 5μm
- polished by Okamoto optics work,inc

Summary

What are the messages from our experience for the CBM RICH designers?

- HERA-B RICH: R5900 MA PMTs have proven to be an extremly reliable and easy to use detector for Cherenkov photons. Excellent performance in very adverse conditions.
- Belle forward region PID upgrade: excellent performance of the flat pannel PMT (R8500) in beam tests; for operation in 1.5T field, Burle MCP PMT seems to be a good candidate (with some changes).

Back-up slides

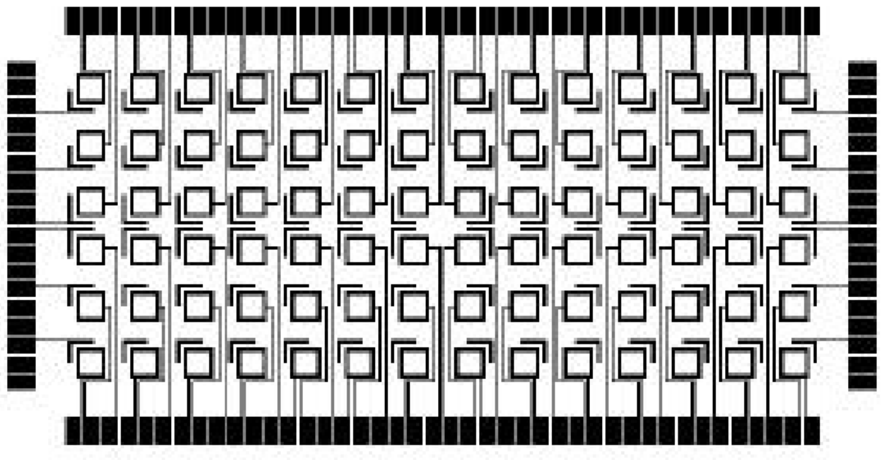
Ideal detector

For many application in RICH imaging: Si based detectors would be great!

→Single channel devices typically have a lot of dead area.

But:

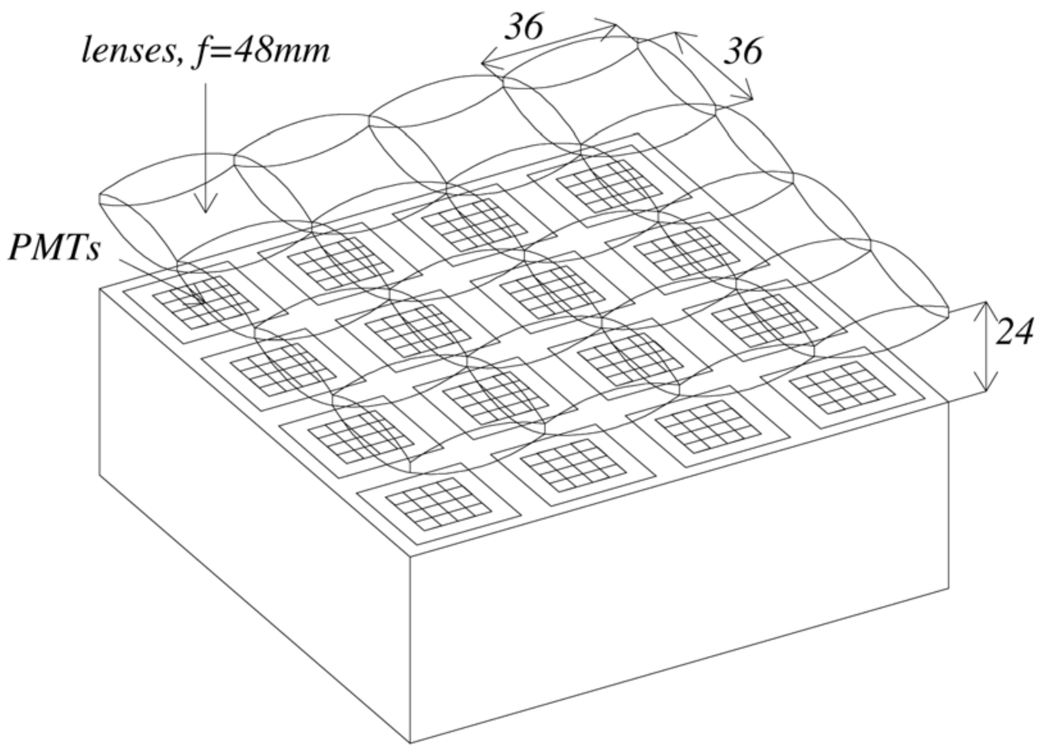
Single channel: much easier to compensate for the dead areas than in multi-channel devices

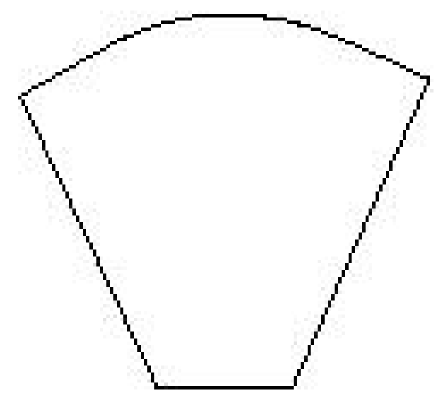


Light collection: single vs multi channel

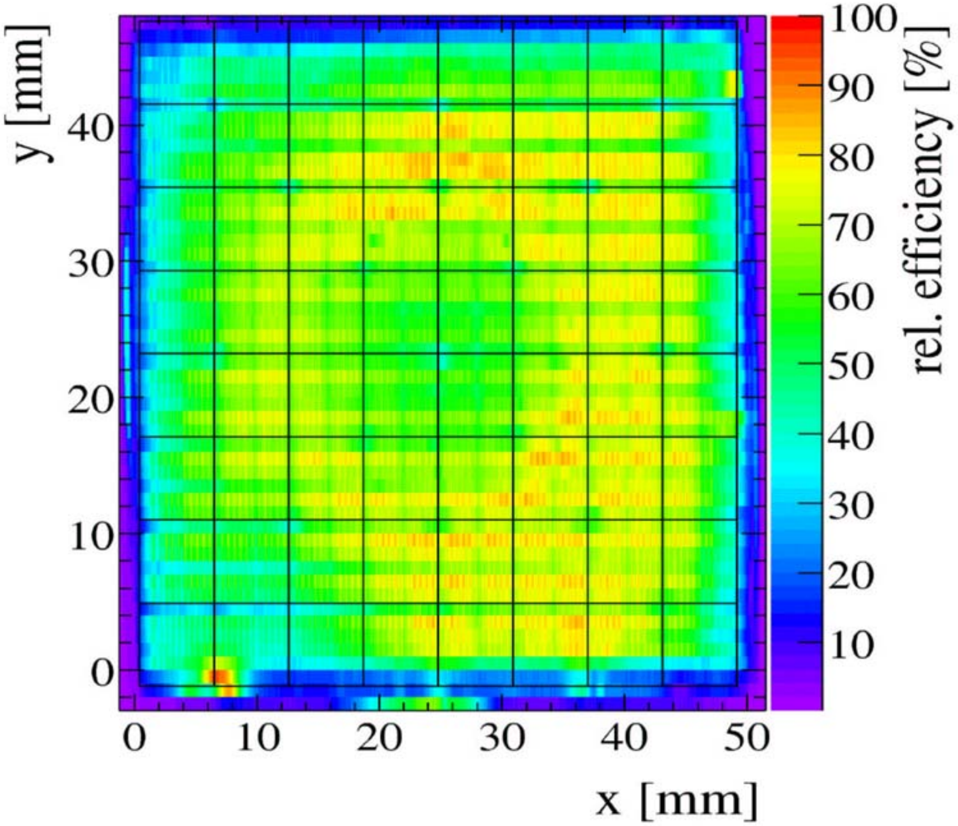
Multichannel device+imaging light collection system: Has a very limited angular acceptance

Single channel: combine a lens and mirror walls



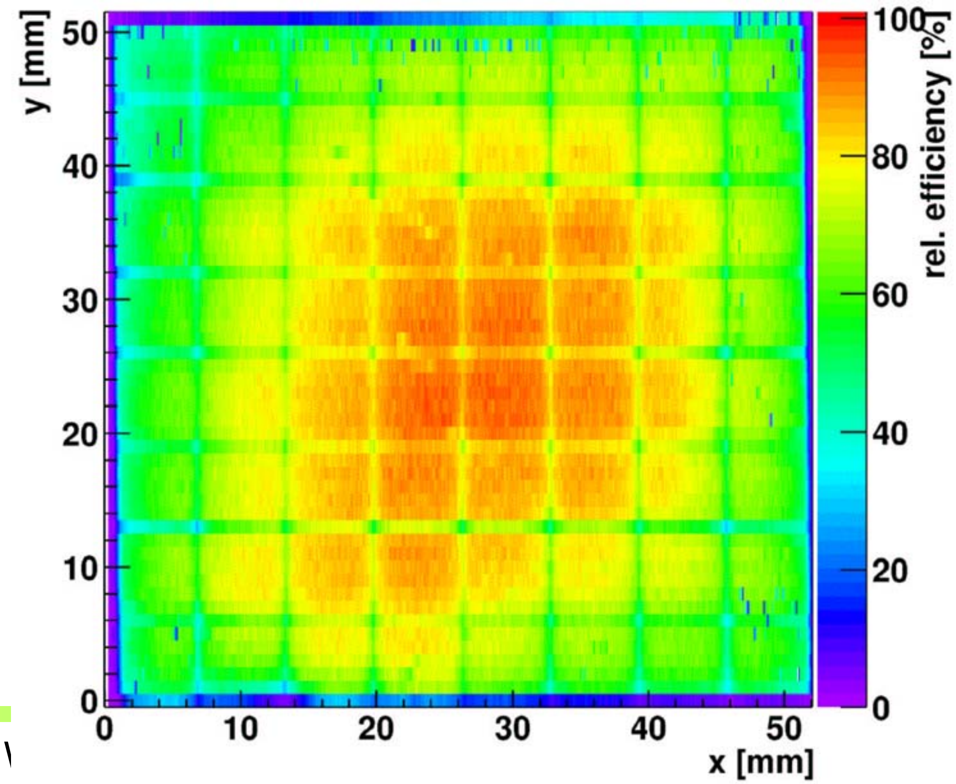


Focusing DIRC photon detectors: relative efficiency



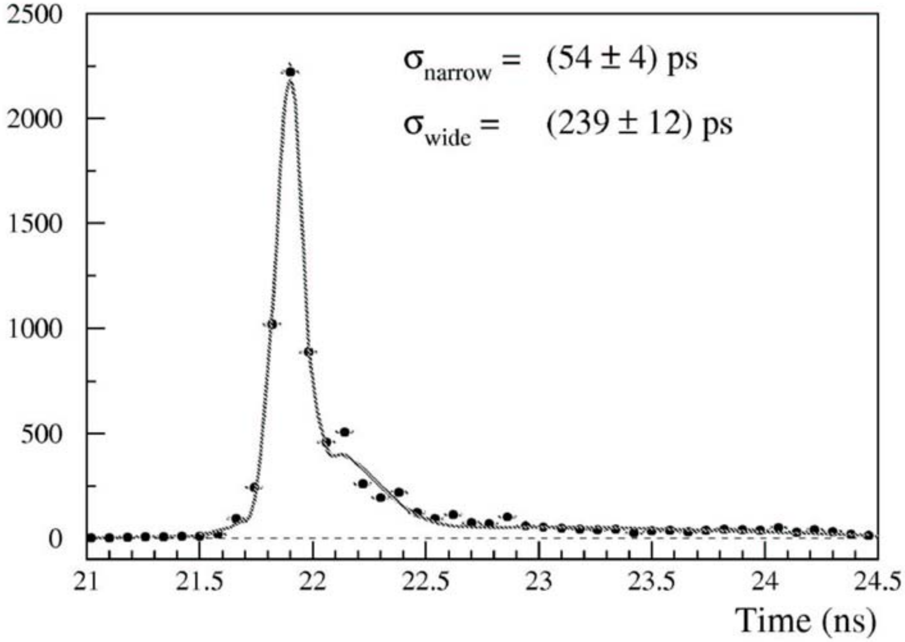
Hamamatsu H8500 (flat pannel)

Burle 85011 MCP-PMT



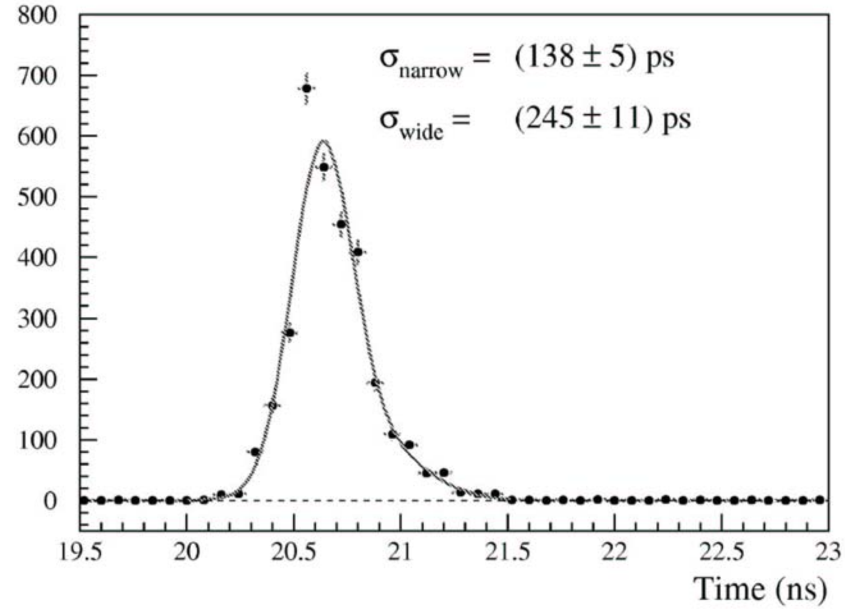
J. Va'vra et al, NIM A553 (2005) 96

Focusing DIRC photon detectors: time resolution



Hamamatsu H8500 (flat pannel)

Burle 85011 MCP-PMT



J. Va'vra et al, NIM A553 (2005) 96