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Photon detectors in Čerenkov light imaging – performance requirements for present and future experiments

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Photon detection in RICH counters: fundamental requirements

Specific requirements: individual counters

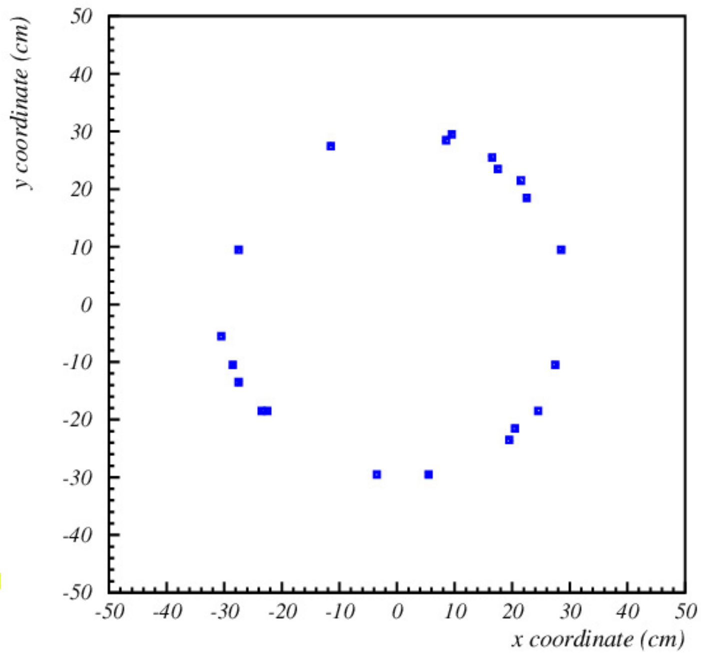
Summary

Photon detection in RICH counters: fundamental requirements

RICH counter: measure photon impact point on the photon detector surface

-> detection of single photons with

- sufficient spatial resolution
- high efficiency and good signal-to-noise ratio



Photon detection in RICH counters: special requirements

Special requirements depend on the specific features of individual RICH counter:

- Operation in (high) magnetic field
- High rate capability
- Very high spatial resolution
- Excellent timing (time-of-arrival information)

Photon detection in RICH counters: special requirements II

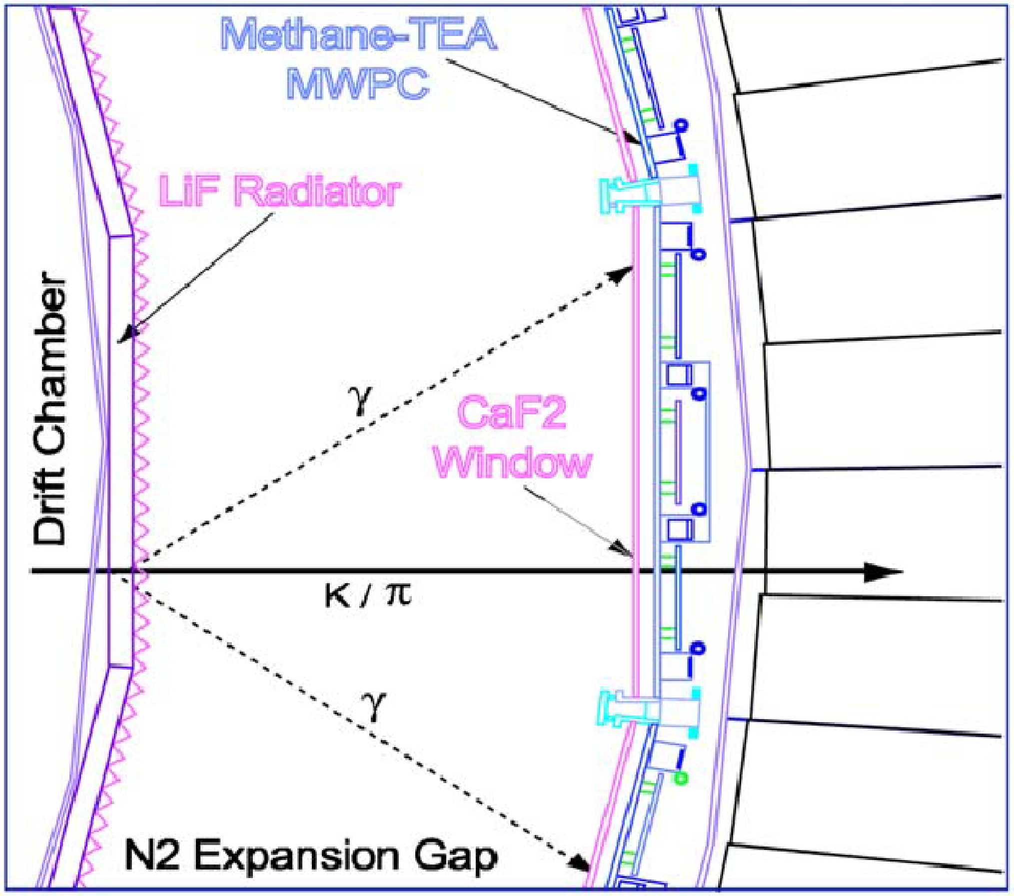
Specific features of individual RICH counters:

- CLEOIII RICH
- HADES, COMPASS, ALICE
- HERA-B RICH
- CMD RICH
- DIRC - BaBar
- Belle PID upgrades for the Super-B factory
- BaBar PID upgrade for the Super-B factory
- LHCb RICHes

+present photon detector R+D

CLEOIII RICH

Photon detection in a wire chamber with a methane+TEA mixture: Successful application of a technique some of us worked on 15 years ago.



CLEOIII RICH

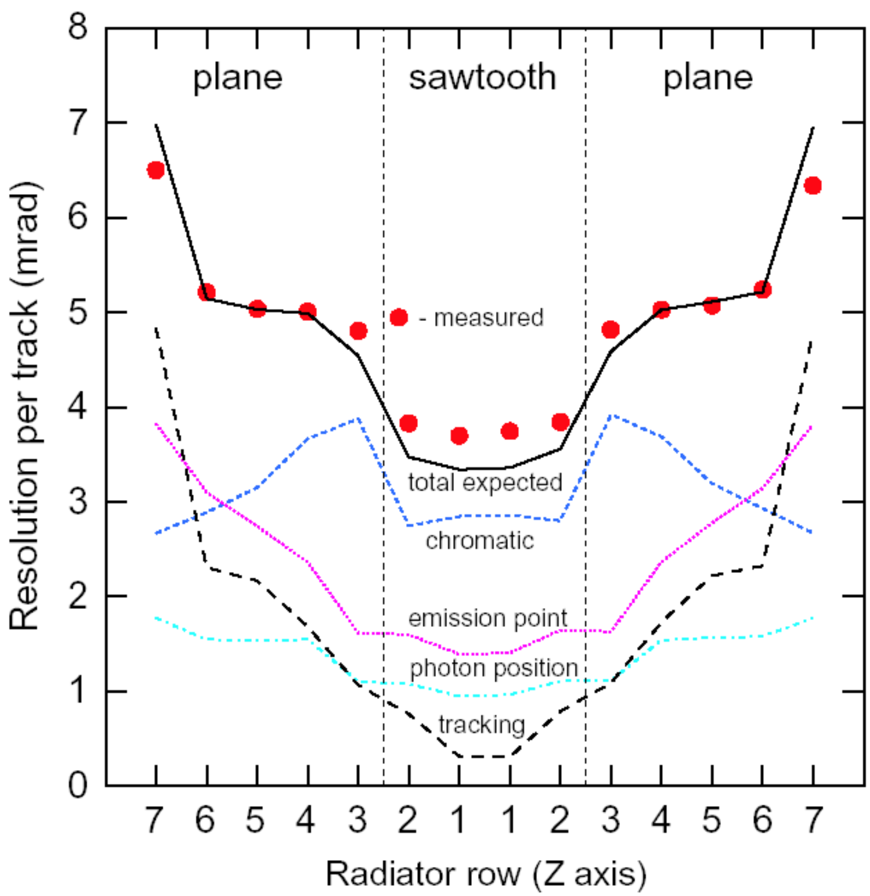


Fig. 2. Cherenkov angle resolution per track versus radiator ring for Bhabha events from data (solid points) and from the sum (solid line) of the different predicted components (as labelled).

The averaged values of the single-photon resolution (σ_θ), the photon yield (N_γ) and the Cherenkov angle resolutions per track (σ_{track}) from Bhabha and hadronic CLEO III events, for flat and sawtooth radiators

Event type	Type of radiators	σ_θ (mrad)	N_γ	σ_{track} (mrad)
Bhabha	Planar	14.7	10.6	4.7
	sawtooth	12.2	11.9	3.6
Hadronic	Planar	15.1	9.6	4.9
	sawtooth	13.2	11.8	3.7

- Excellent performace
- Good agreement with expectations
- Long term stability (4 years)

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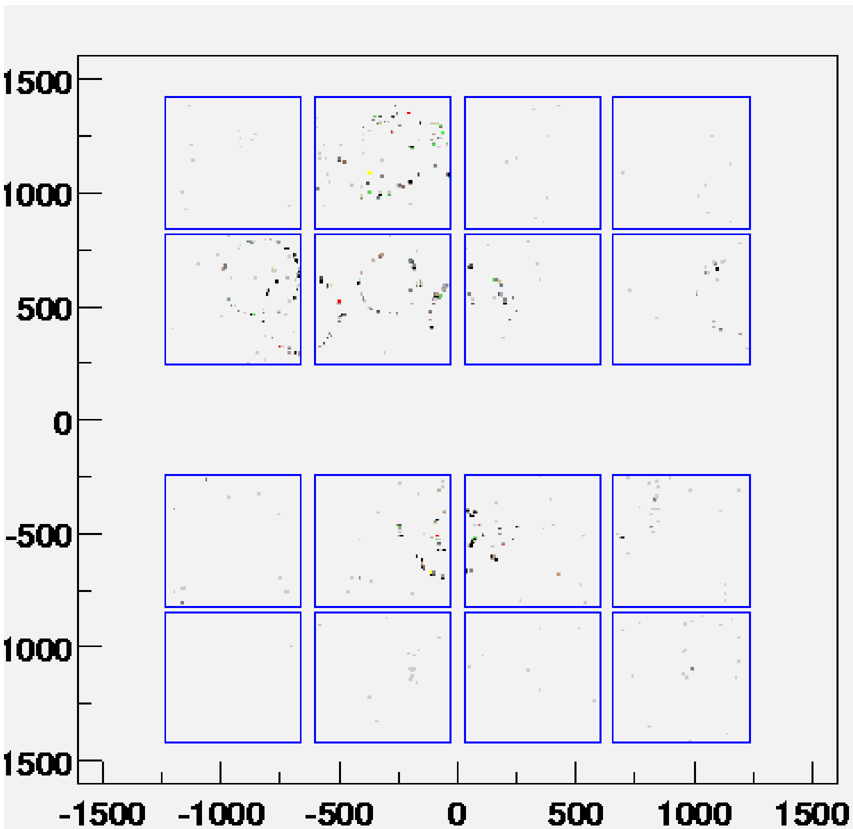
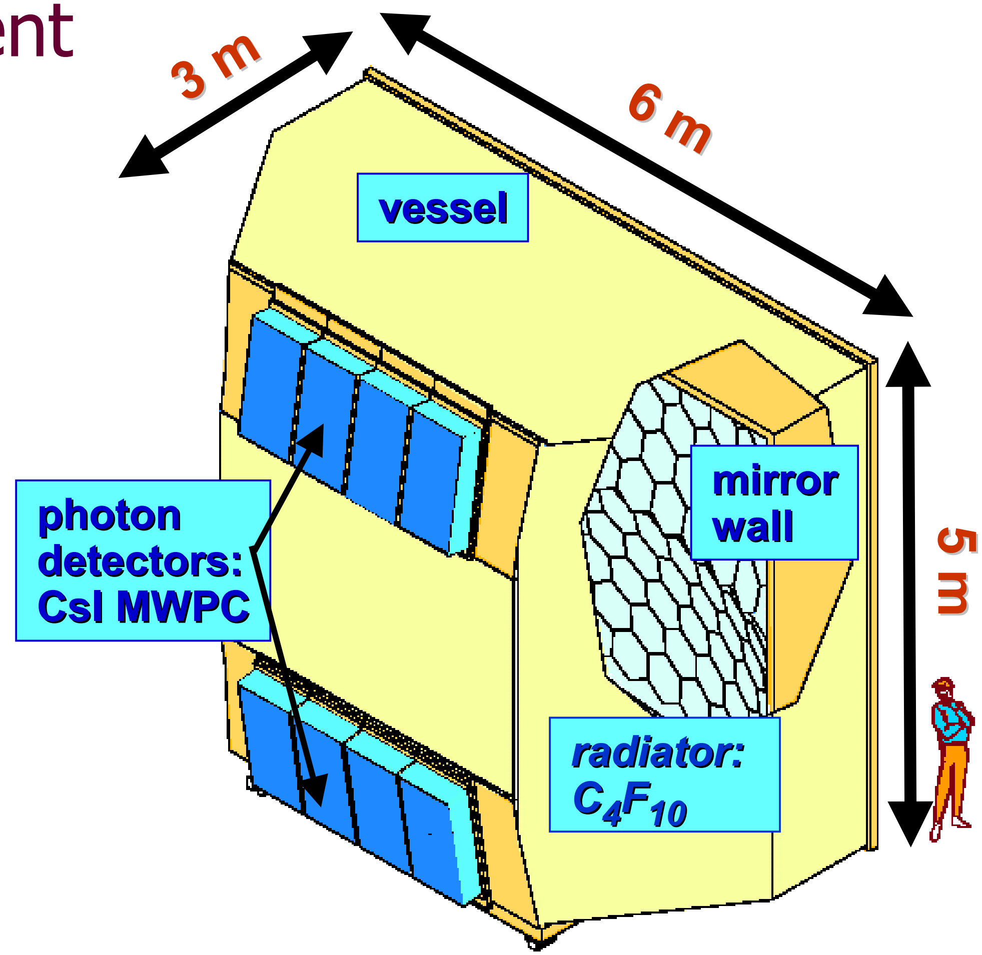
CsI based RICH counters: HADES, COMPASS, ALICE

COMPASS: calibation event





CsI based RICH counters: HADES, COMPASS, ALICE

COMPASS experience after 4 years of running
- Stable operation
- Excellent performance
- Good agreement with expectations

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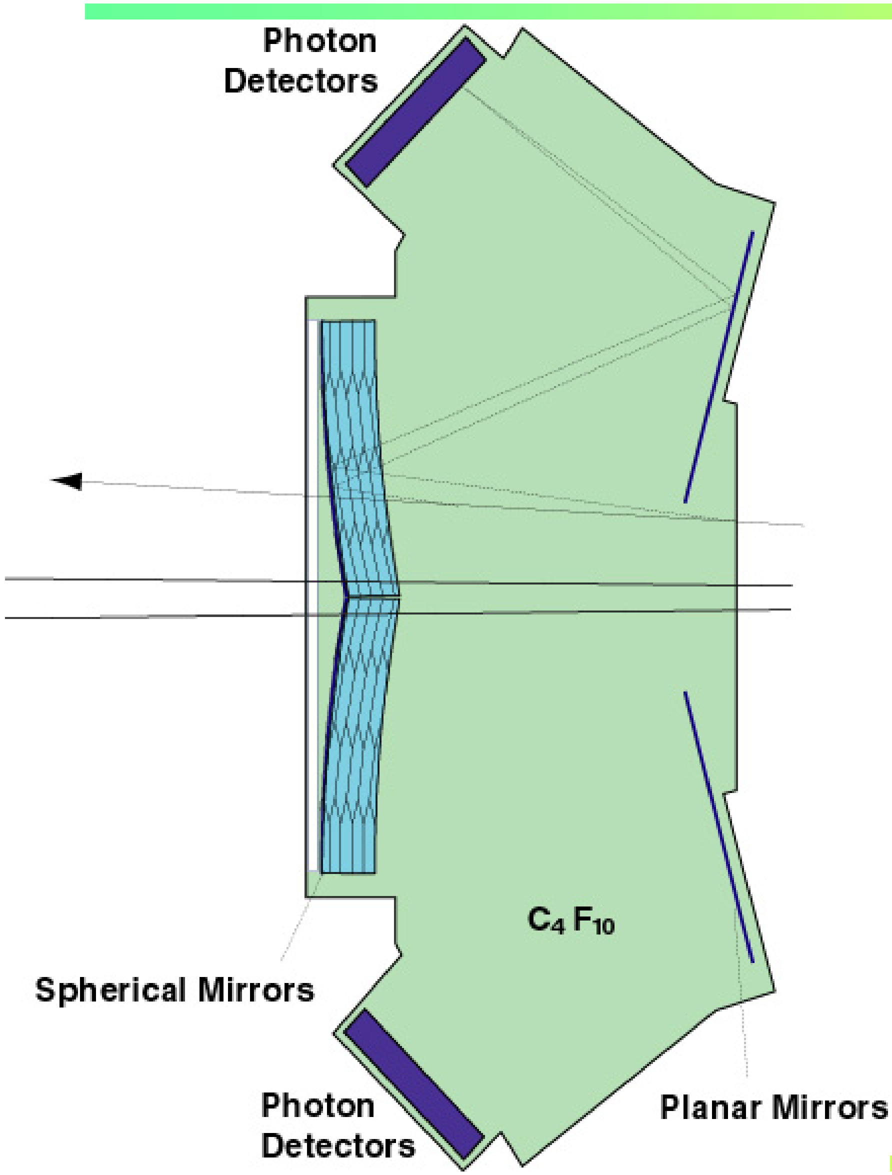
ALICE CsI chambers experience

Hoedlmoser→

Gas based detectors with solid photocathodes: can we make visible light sensitive stable photocathodes?

Breskin→

HERA-B RICH



Requirements:

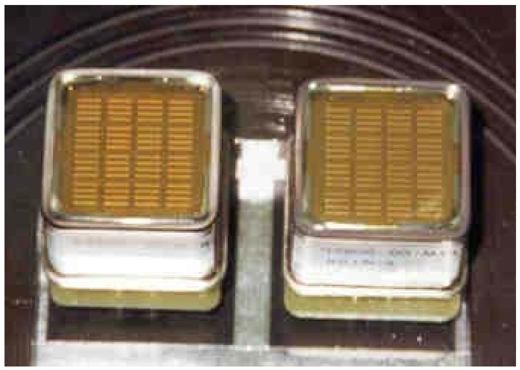
- High QE over ~3m²
- Rates ~1MHz
- Long term stability

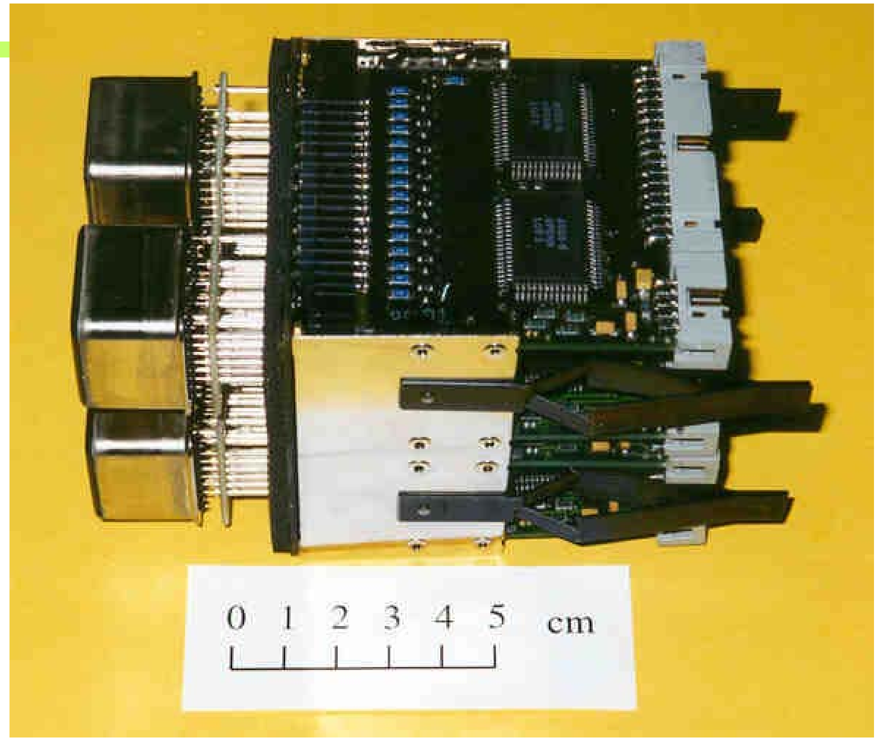
Gas based det. could not be used

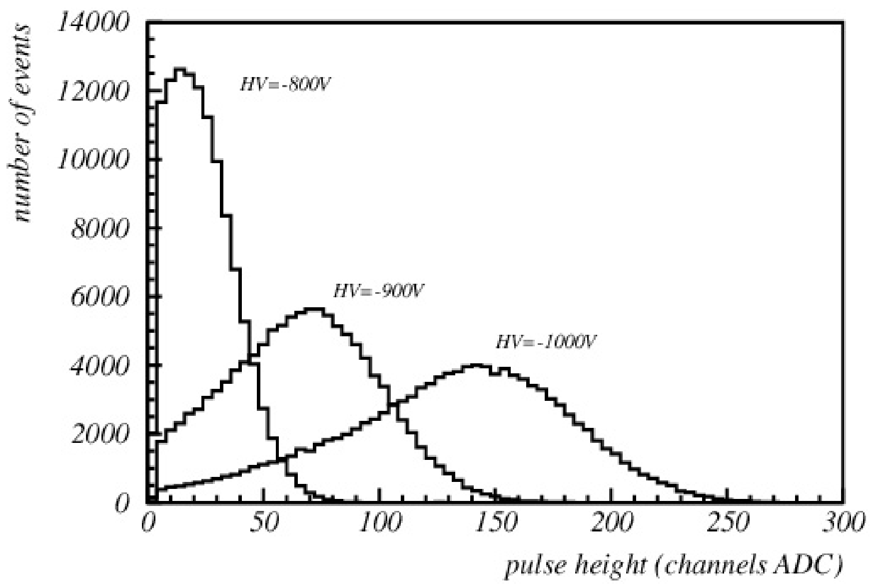
HERA-B RICH photon detector

Multianode PMTs:

R5900-M16 and R5900-M4







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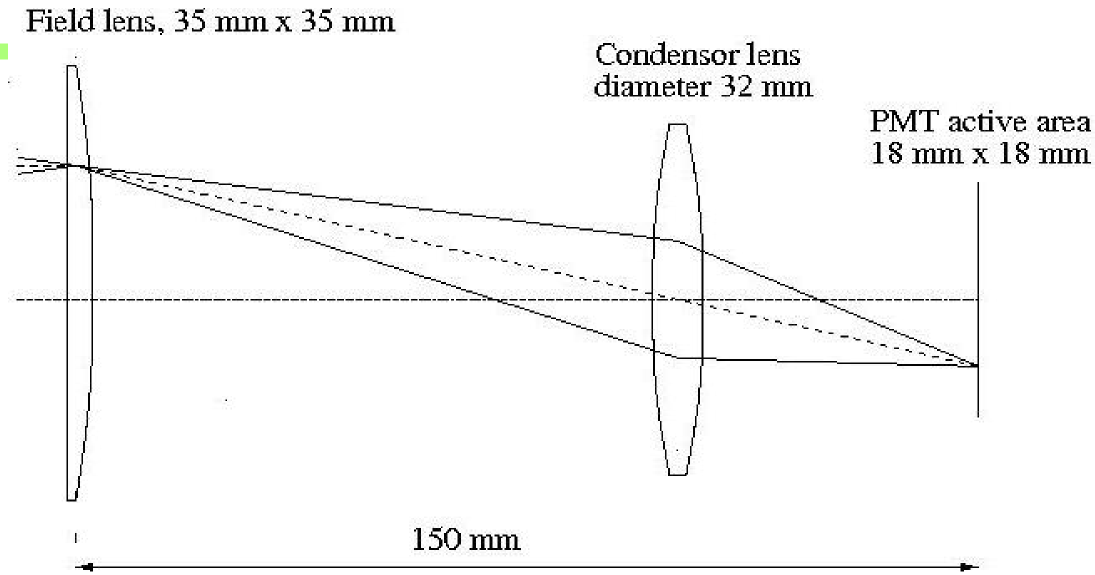
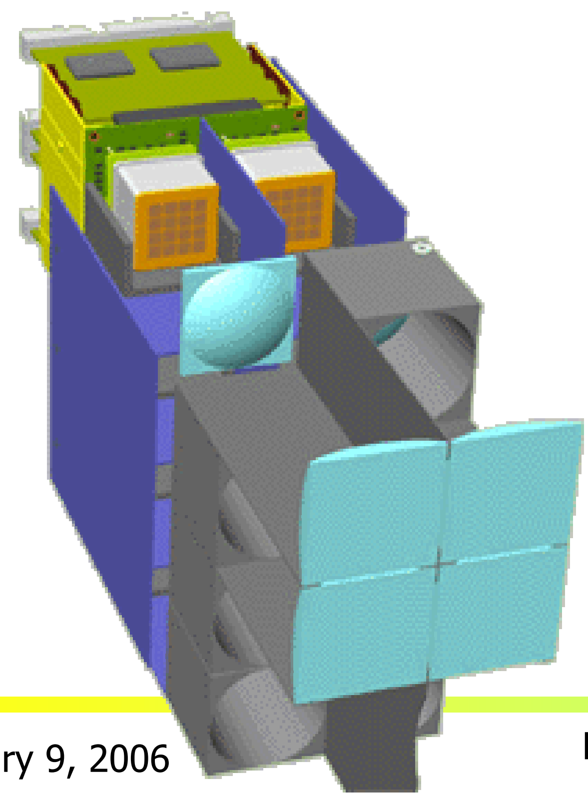
HERA-B RICH photon detector

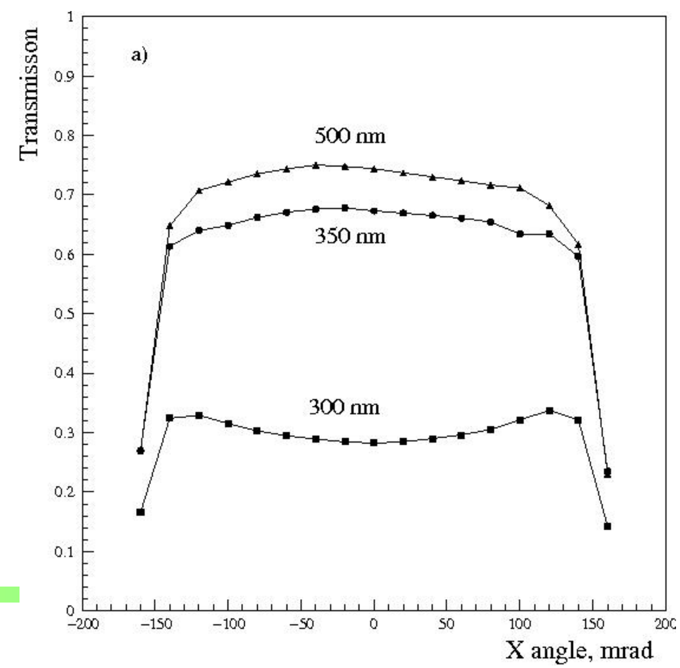
Light collection system (imaging!) to:

-Adapt the pad size

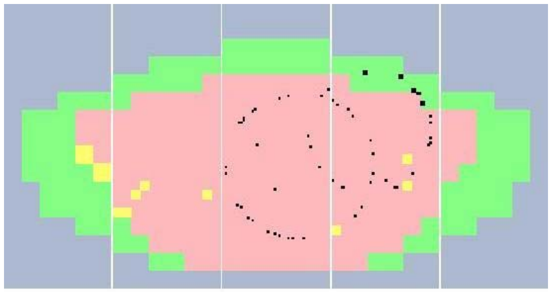
-Eliminate dead areas

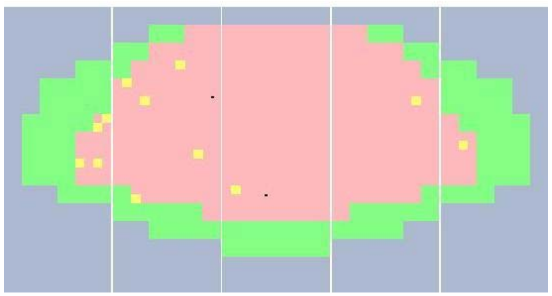






HERA-B RICH

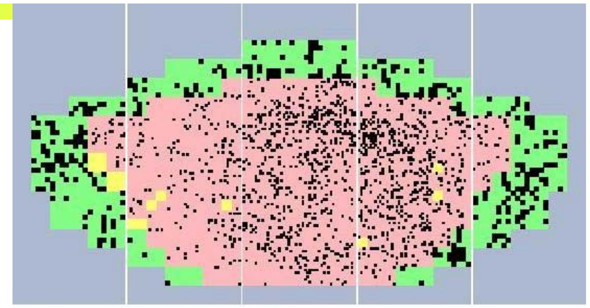


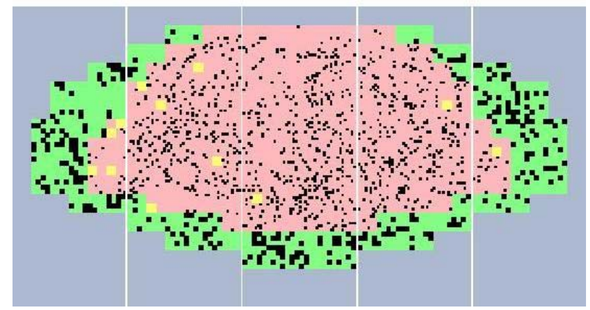


Little noise, very clear rings ←

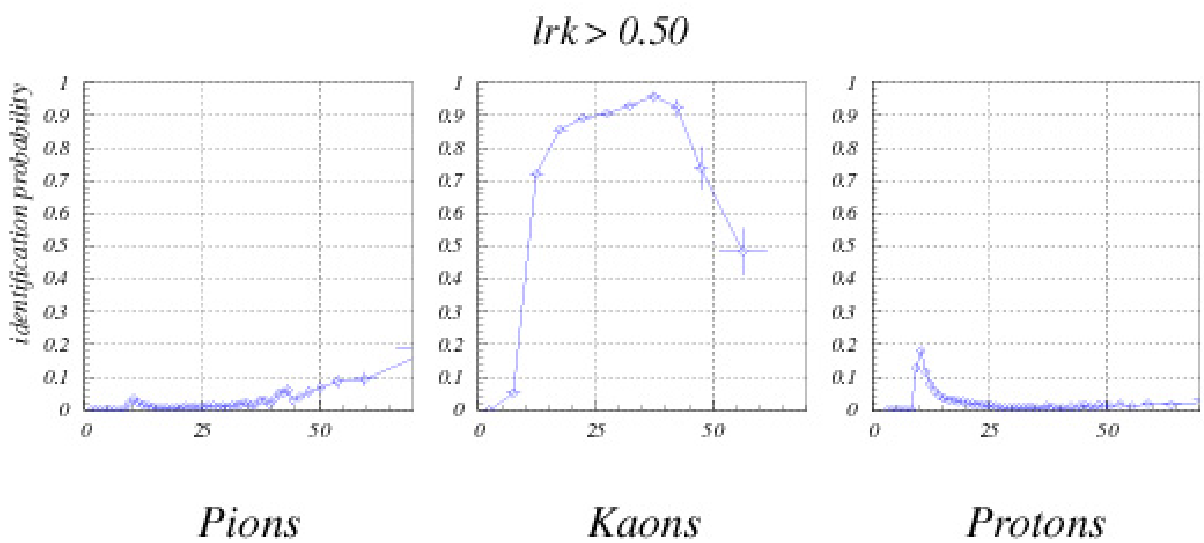
Typical event →

Still: it works actually very well!

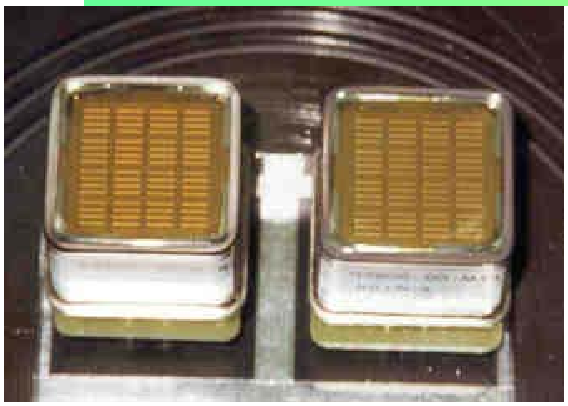




Kaon efficiency and pion, proton fake probability



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



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

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

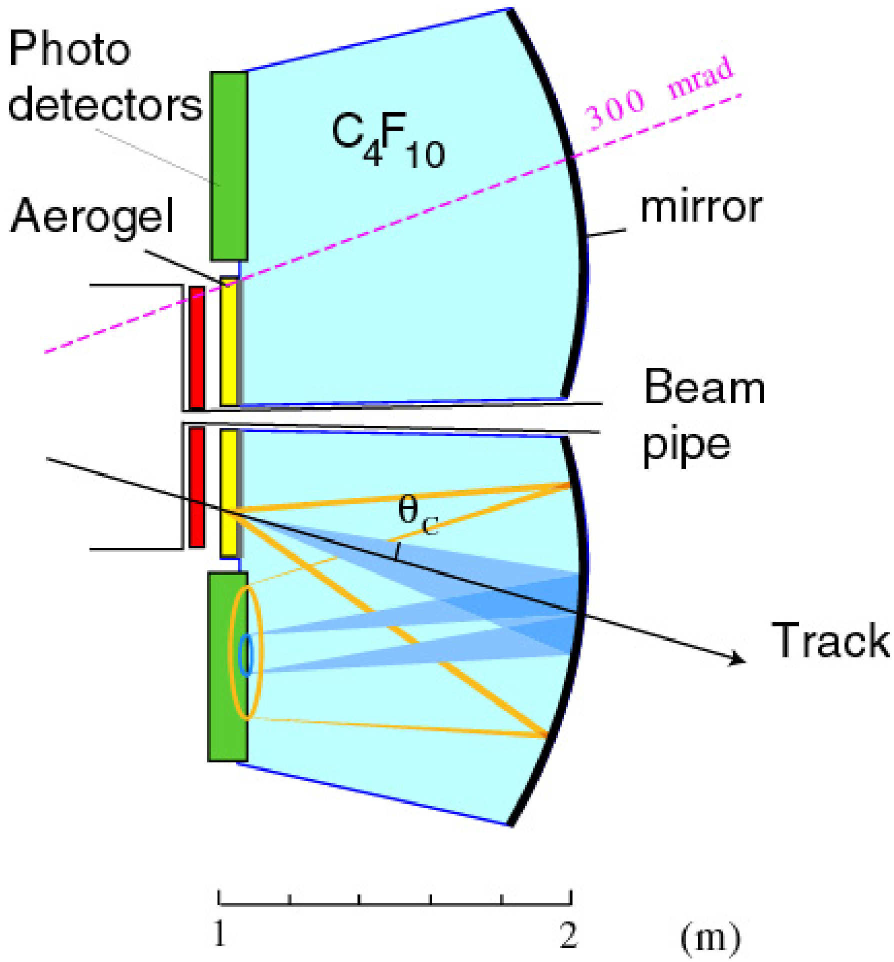
- In the meantime the same package comes without the nose at the sides - R7600

- and recently with an even better active area ratio (83%): R8900-03

- or use the H8500 (‘flat pannel’) PMT ->

52mm

LHCb RICHes



RICH 1

Need:

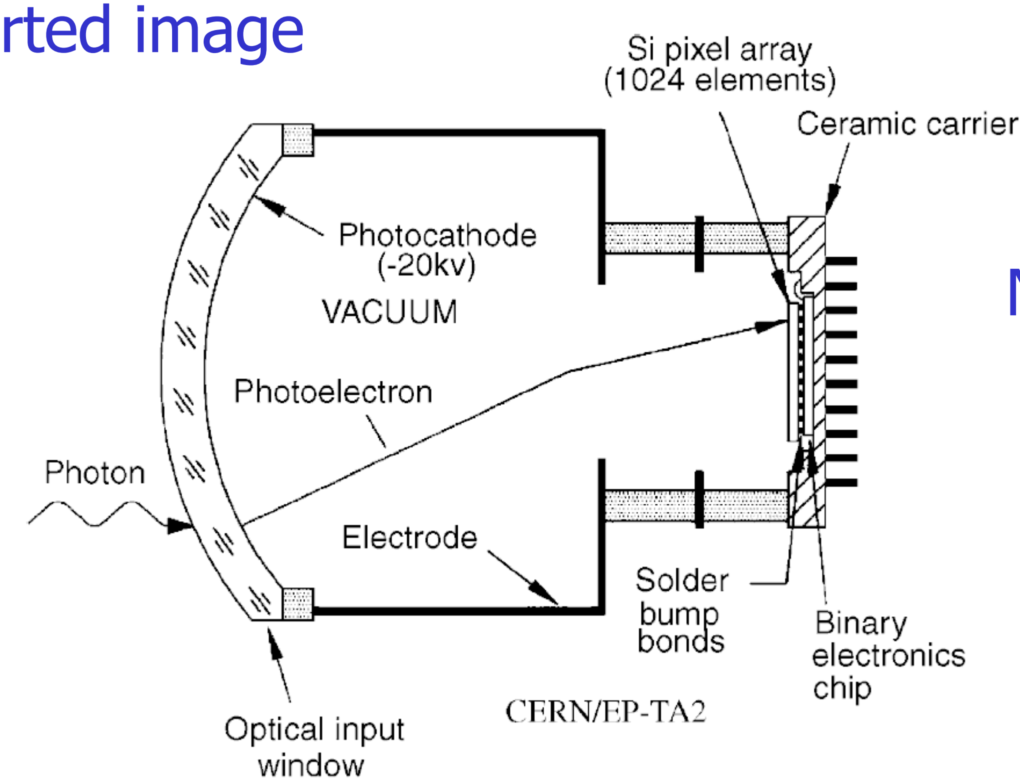
- Granularity 2.5x2.5mm^2
- Large area (2.8m^2) with high active area fraction
- Fast compared to the 25ns bunch crossing time
- Have to operate in a small magnetic field

R+D: two types of hybrid photon detectors, focusing type + MAPMT with a lens

LHCb RICHes

Final choice: hybrid PMT (R+D with DEP) with 5x demagnification

Magnetic field: does influence the operation – long path of the photo-electron -> two step shielding + parametrisation of the distorted image



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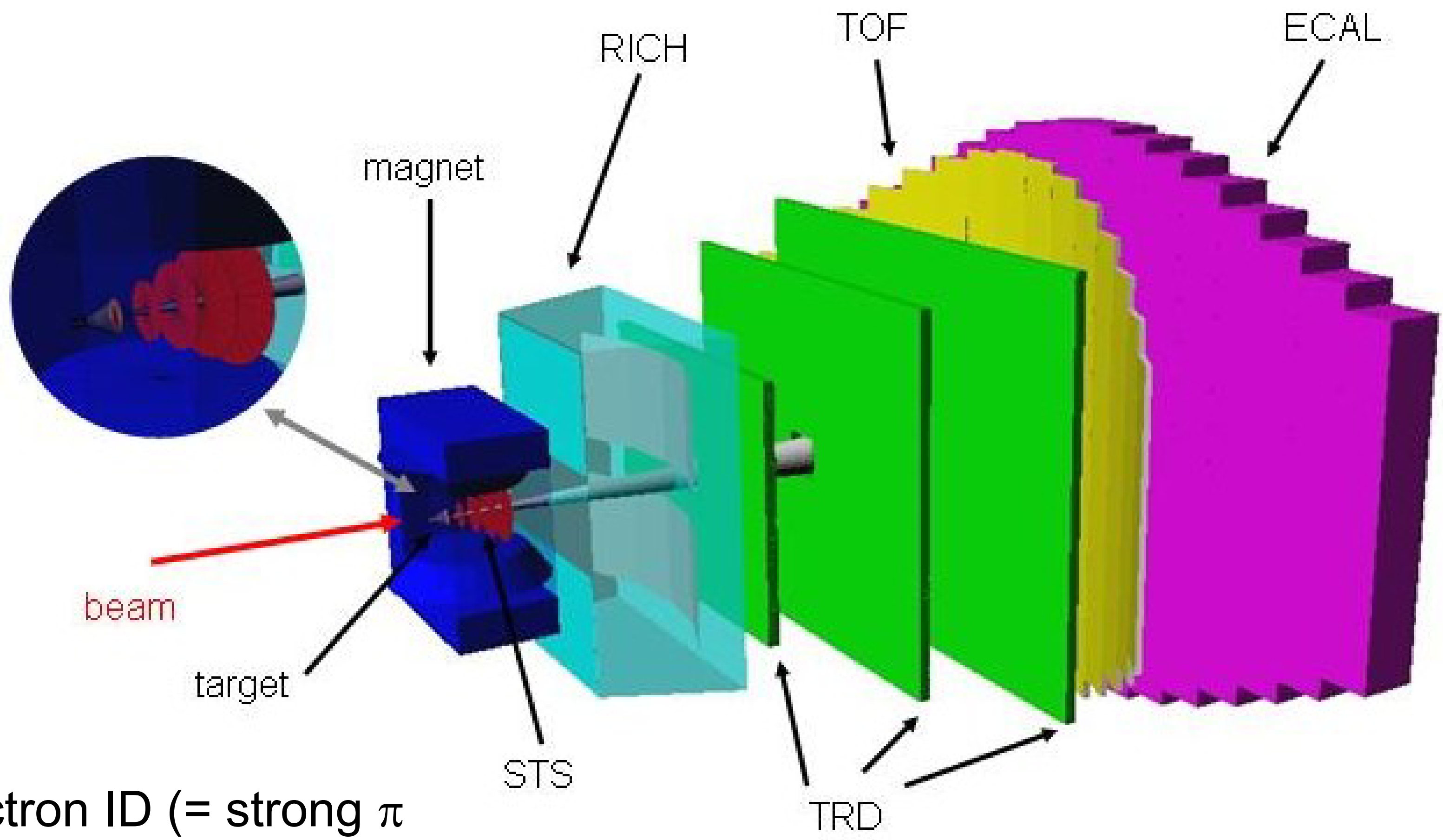
Joram→

CBM experiment at FAIR (GSI)

Compressed Baryonic Matter experiment



RICH: electron ID (= strong π suppression) and hadron ID

CBM RICH design

• 2.2m long radiator gas (γ_{th} > 40) vessel with beam pipe in the center

•photo-detector: PMT plane shielded by magnet yoke 2 x (280cm x 140cm)

•10MHz rates

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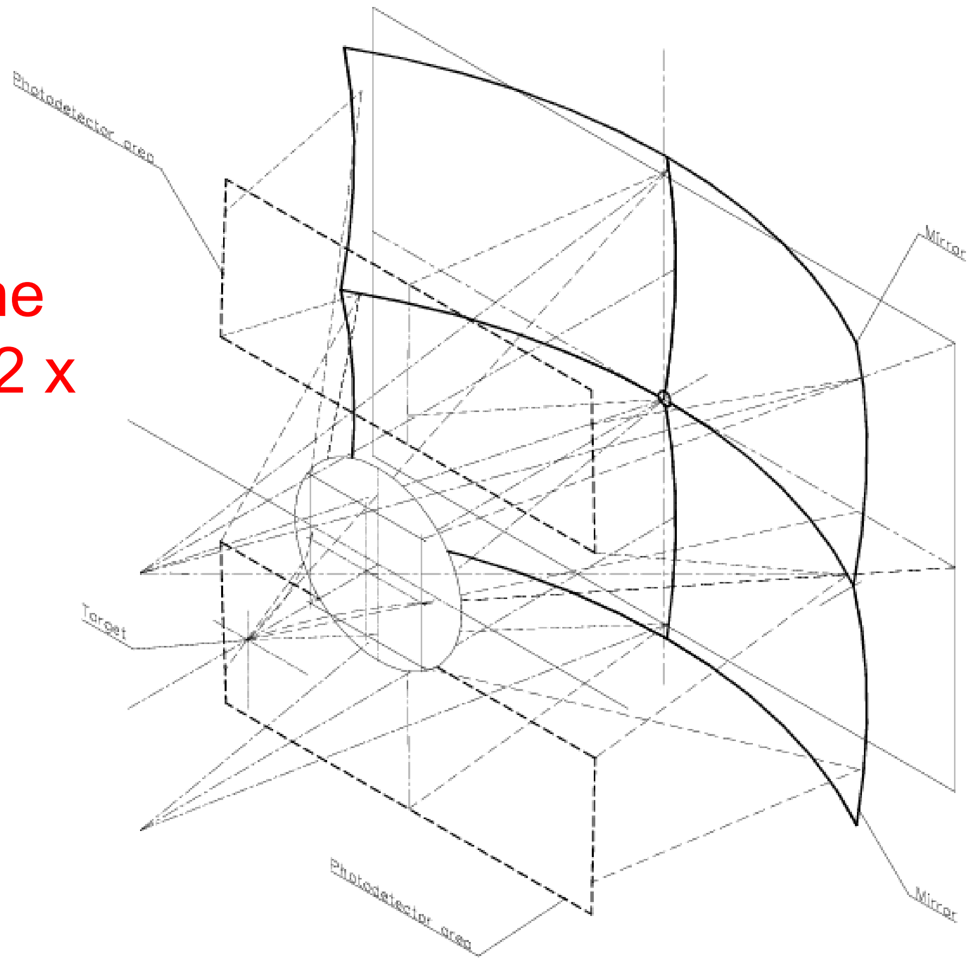
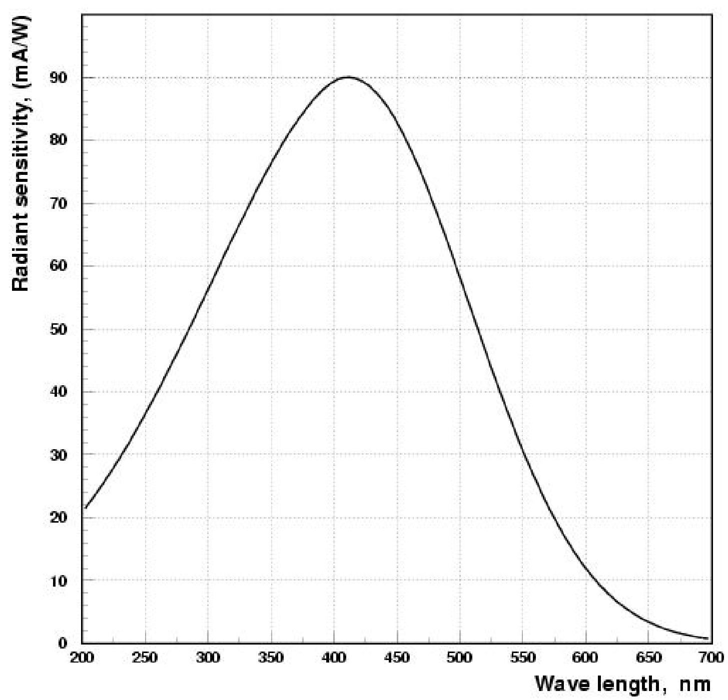


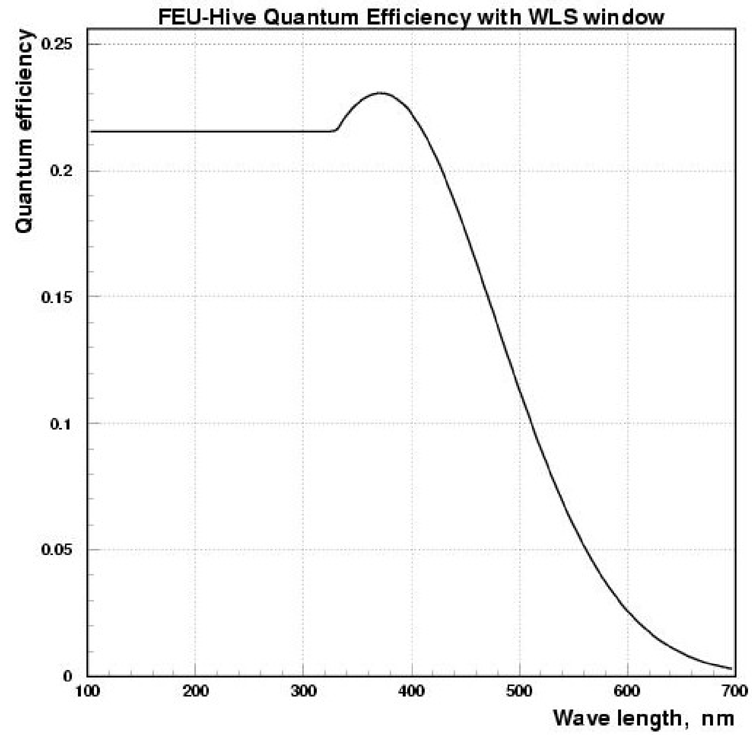
Looks very much like the HERA-B or LHCb RICHes

PMTs for CBM (IHEP Protvino + Moscow Electrolamp)

PMT FEU-Hive

- K_2CsSb photo-cathode, 25% quantum efficiency at λ = 410nm
- to be covered with transparanet WLS film (p-theraphenyl) → 22% qe for wide range
- ~90% geometrical efficiency



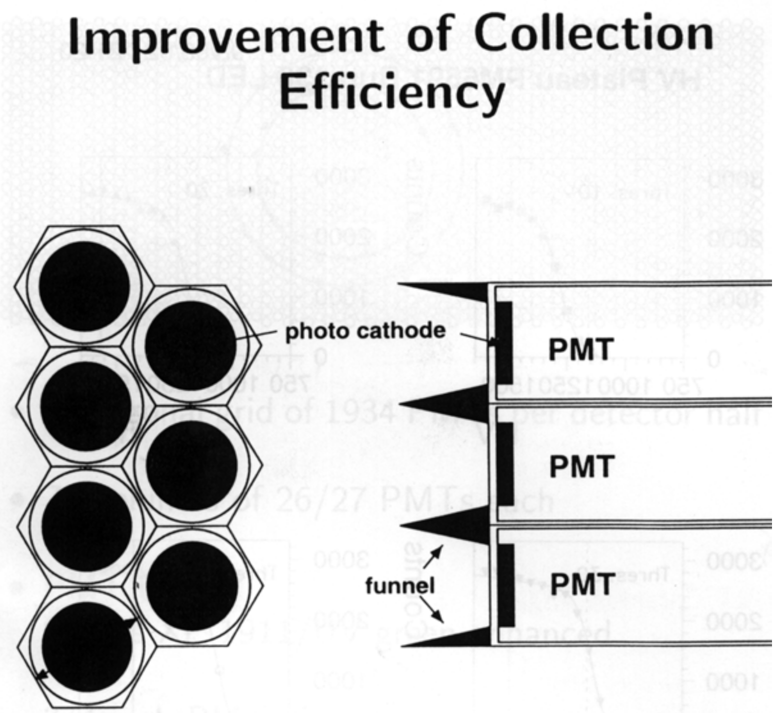


PMT FEU-Hive

- external PMT diameter 6mm
  photo-cathode diameter 5mm
  → ~10^5 channels per detector plane
- length 6cm
- high voltage ~ 2kV
- effective number of dynodes 12
- amplification 10^6

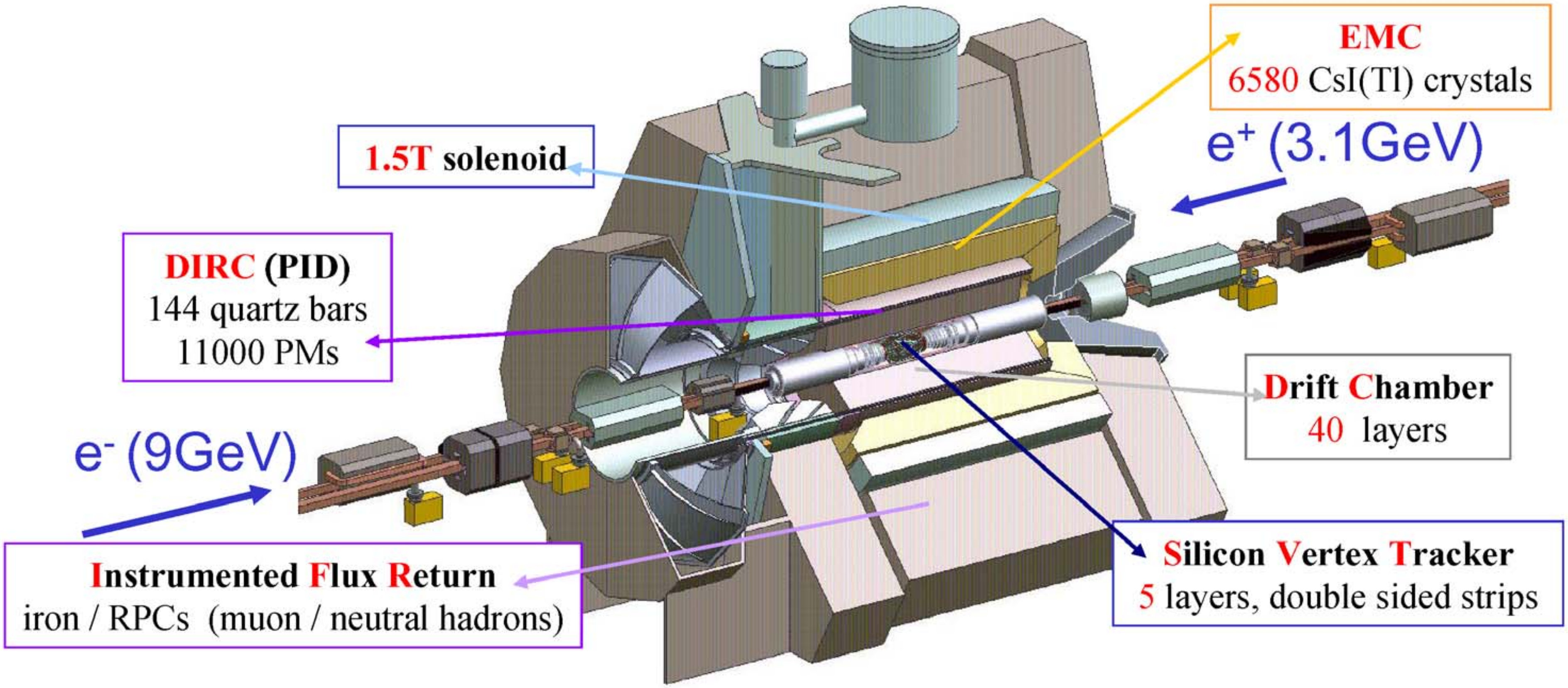
→ effective operation in one-photoelectron regime

- average signal time ~ 1ns



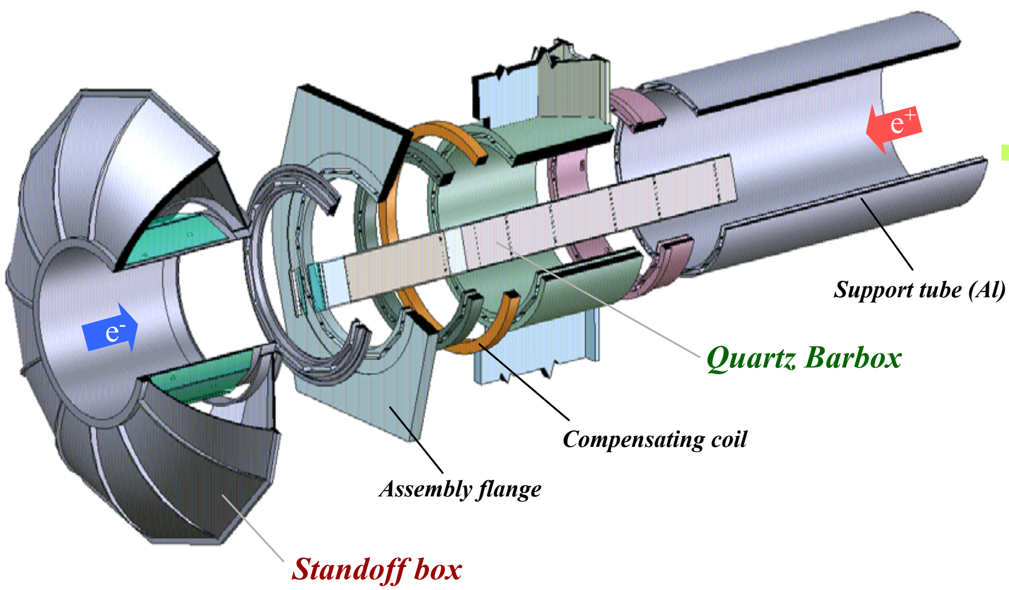
Photocathodes cover only 38% of the focal plane. This is increased to 92% by soft steel funnels with aluminum foil inserts.

BaBar spectrometer at PEP-II

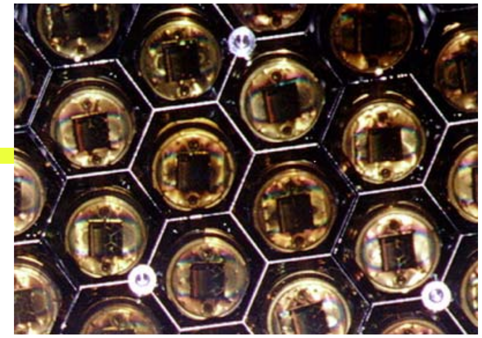


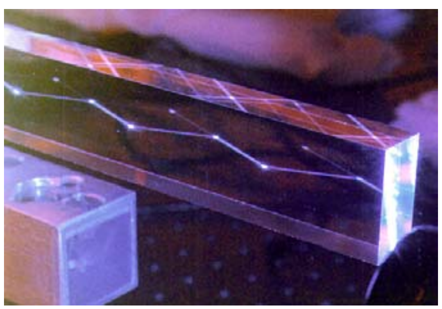
DIRC - detector of internally reflected Cherenkov light

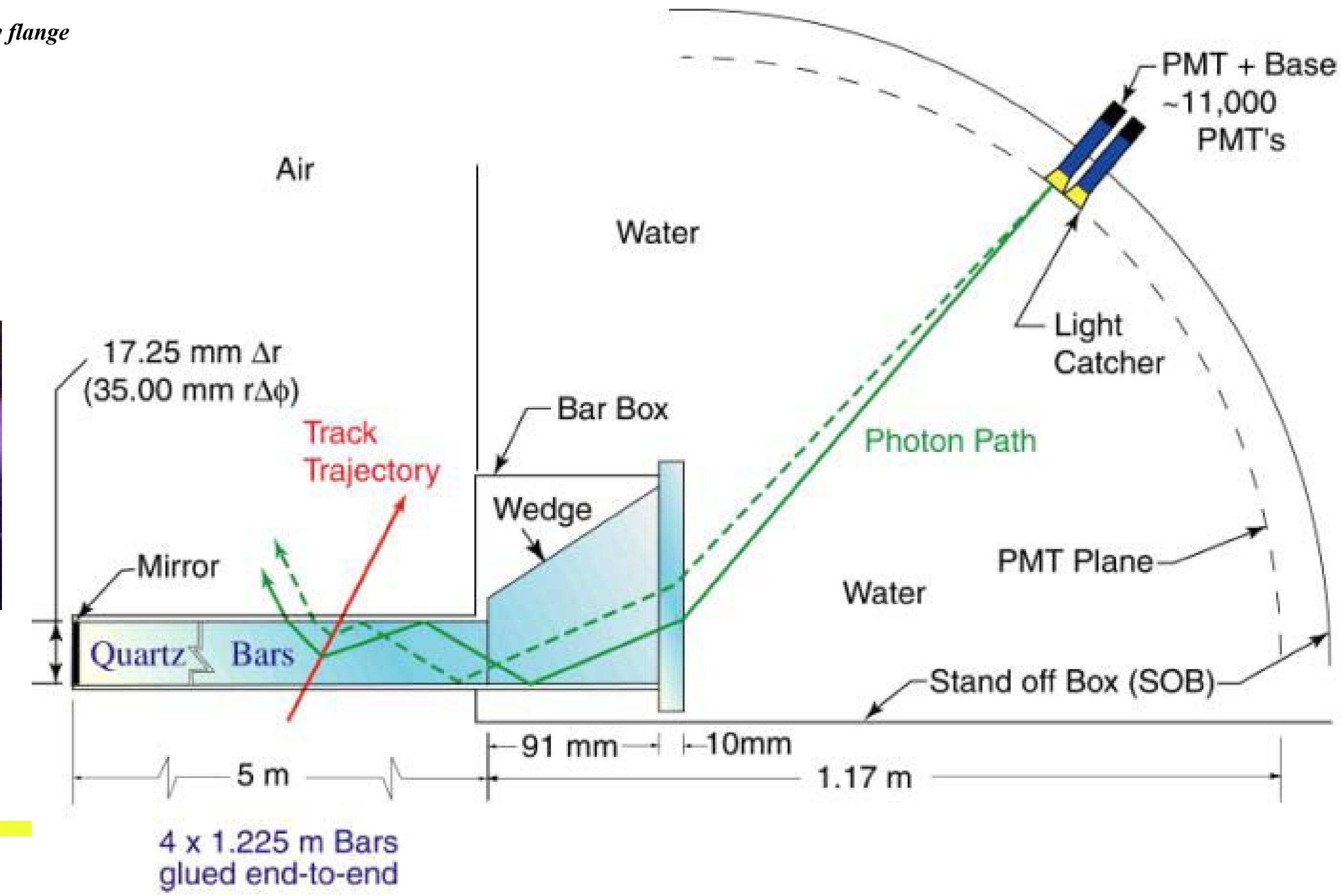
DIRC



e+
e-
Support tube (Al)
Quartz Barbox
Compensating coil
Assembly flange
Standoff box

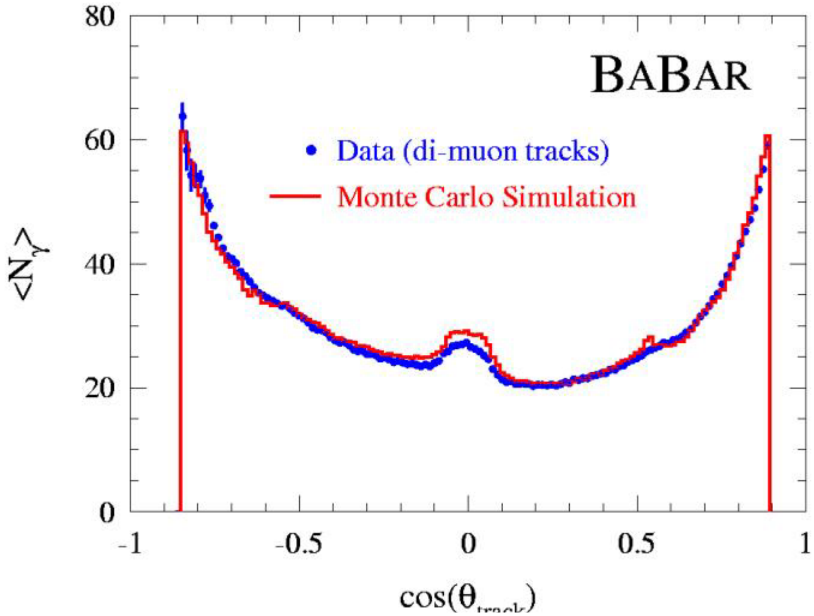


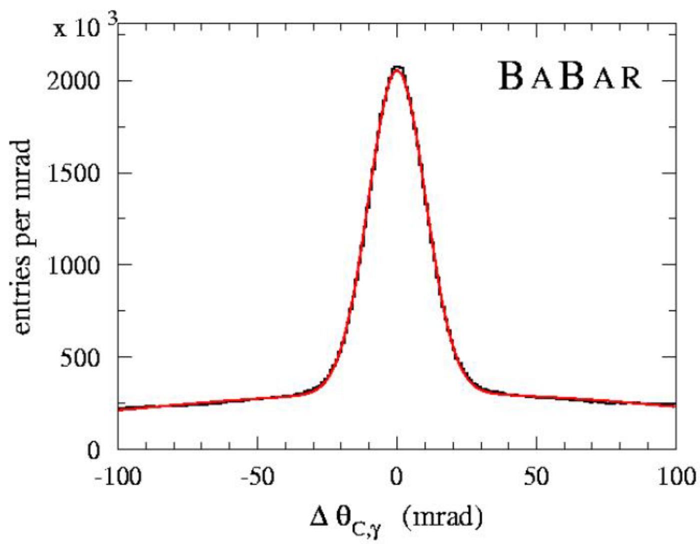




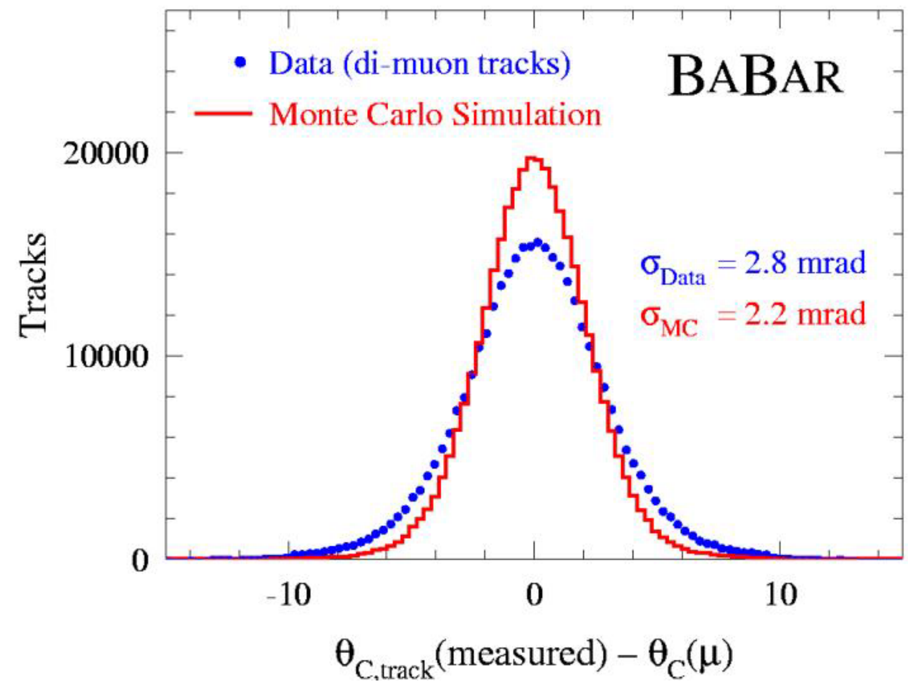
PMT + Base
~11,000
PMT's
Air
Water
Light
Catcher
17.25 mm Δr
(35.00 mm rΔϕ)
Bar Box
Photon Path
Track
Trajectory
Wedge
Mirror
PMT Plane
Water
Quartz
Bars
Stand off Box (SOB)
91 mm
10mm
5 m
1.17 m
4 x 1.225 m Bars
glued end-to-end

DIRC





Performance



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DIRC

Special features:

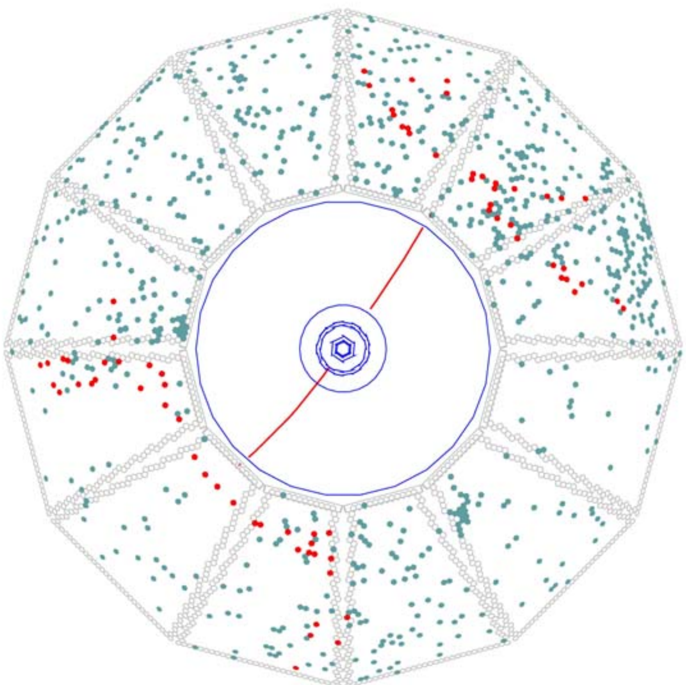
- Window in contact with water
- Background from high energy photon conversions in the water volume

Some PMTs were lost: window material reacted with water

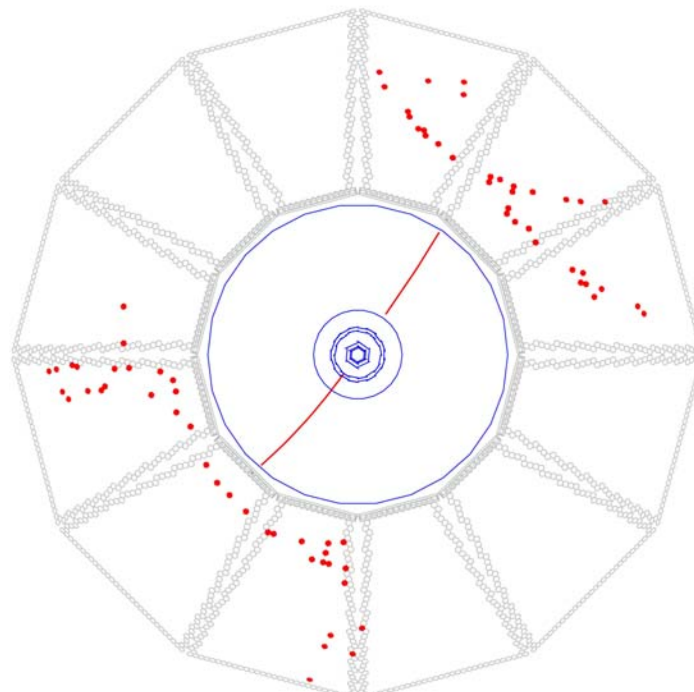
Elimination of background: use time of arrival of hits ->

DIRC

Babar DIRC: a Bhabha event $e^+ e^- \to e^+ e^-$



No time cut on the hits



With a +-4ns time cut

Timing information is essential for background reduction

DIRC

Special features:

- Operation with window in contact with water
- Background from high energy photon conversions in the water volume (stand-off box)

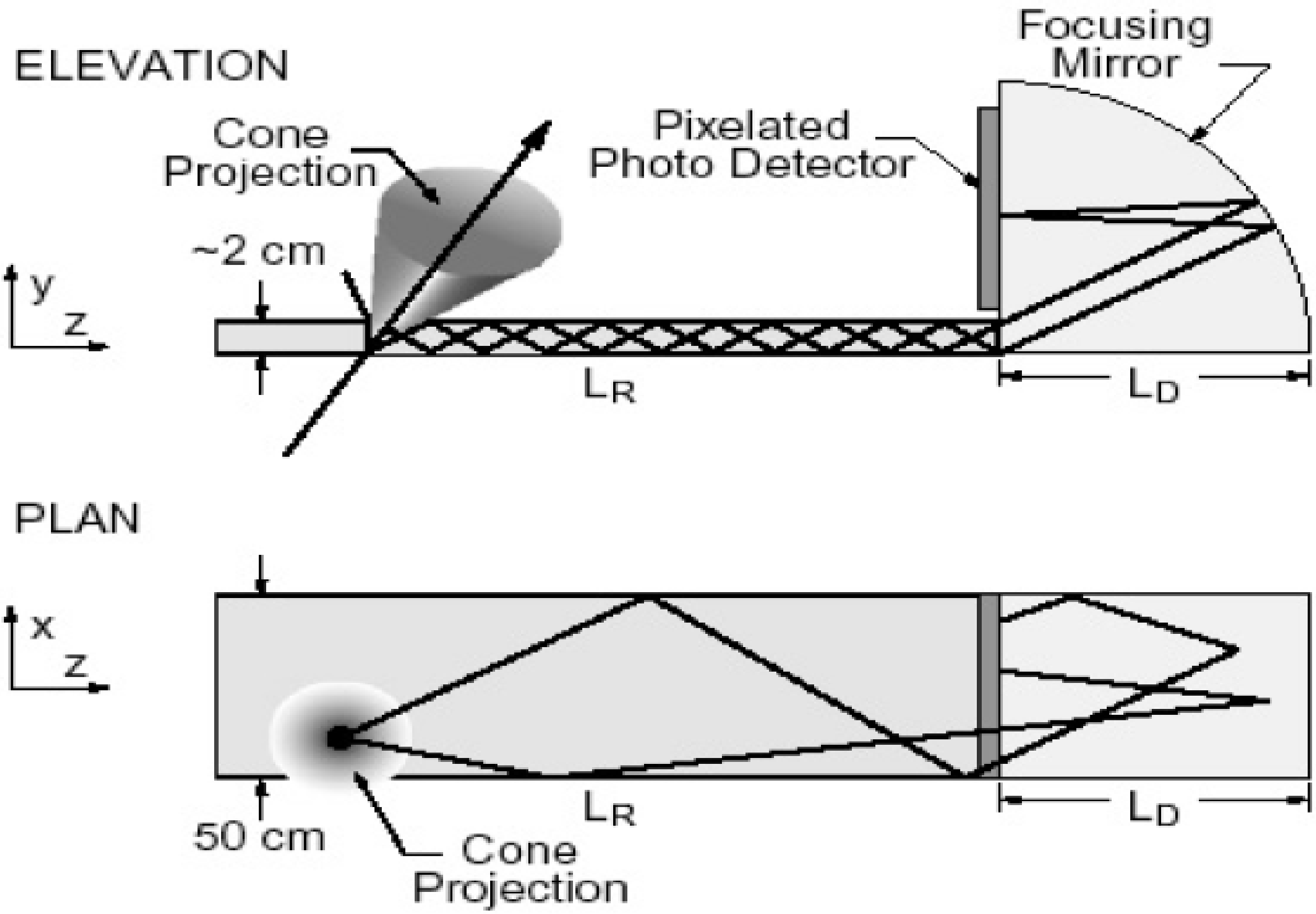
Some PMTs were lost: window material reacted with water

Elimination of background: use time of arrival of hits

Upgrade: step further: remove the stand-off box -> focusing DIRC

Focusing DIRC

Fast Focusing DIRC detector - schematic “design”



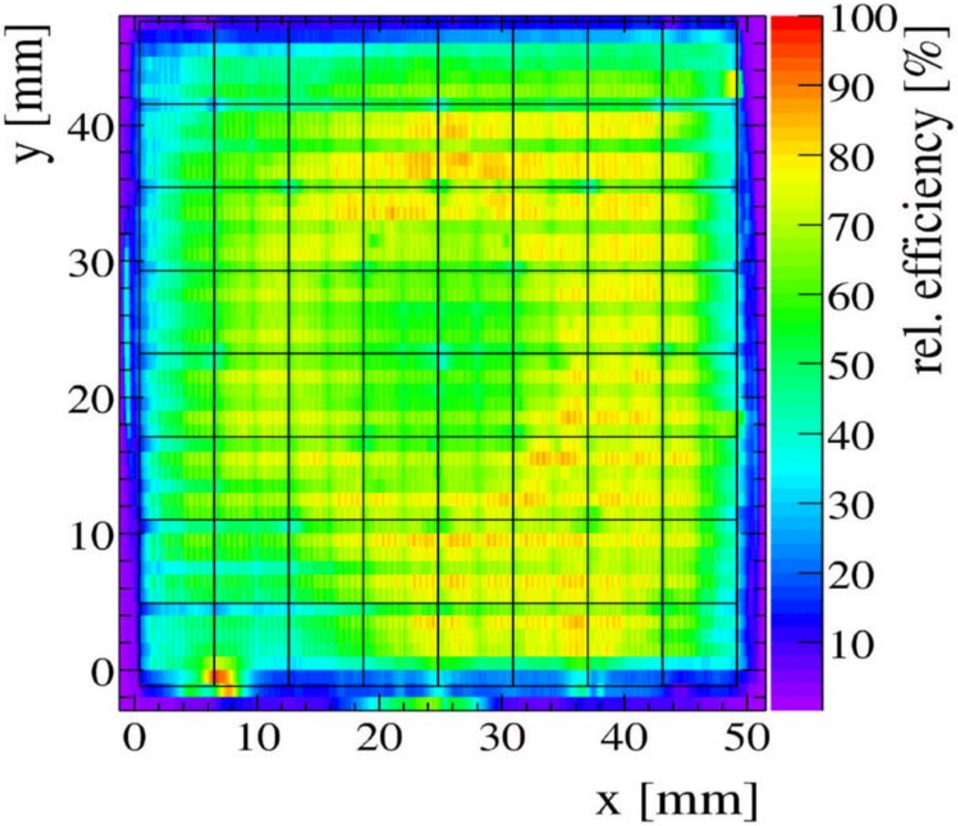
Focusing DIRC

Idea: measure two coordinates with good precision, use precise timing information to correct for the dispersion (group and phase velocity depend on wavelength)

Photon detector requirements:

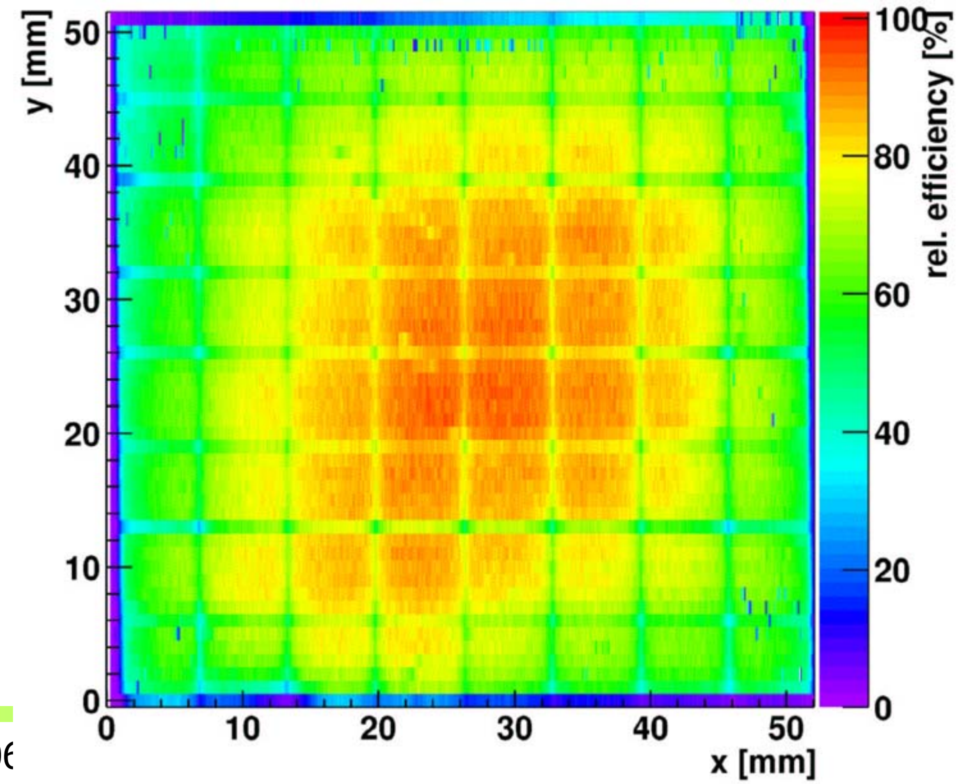
- Pad size ~5mm
- Time resolution ~50-100ps

Focusing DIRC photon detectors: relative efficiency

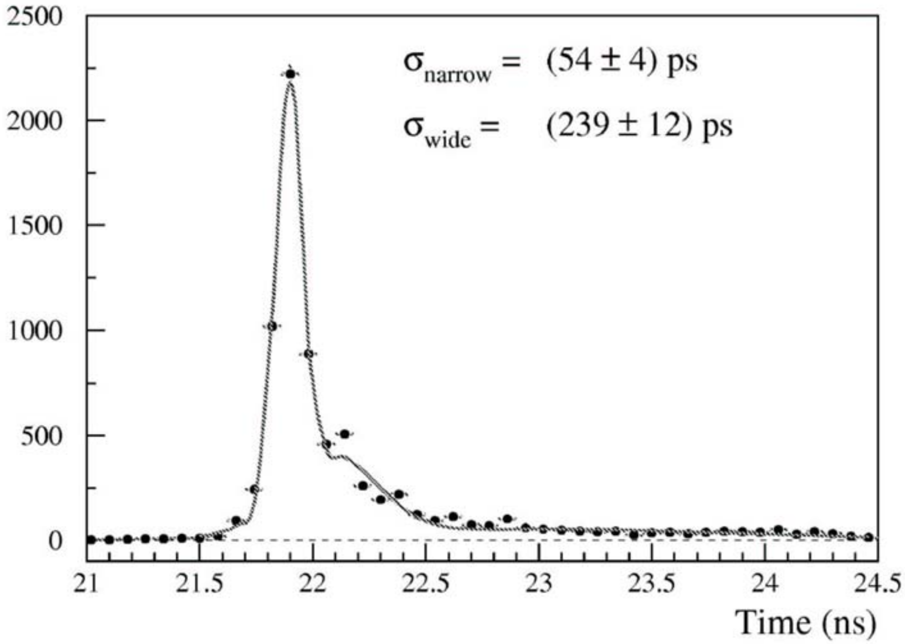


Burle 85011 MCP-PMT

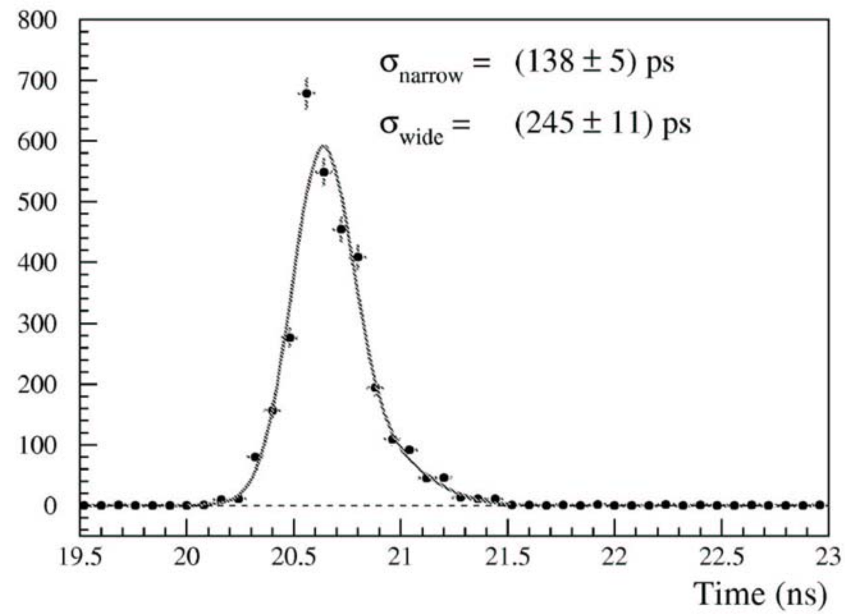
Hamamatsu H8500 (flat pannel)



Focusing DIRC photon detectors: time resolution



Burle 85011 MCP-PMT



Hamamatsu H8500 (flat pannel)

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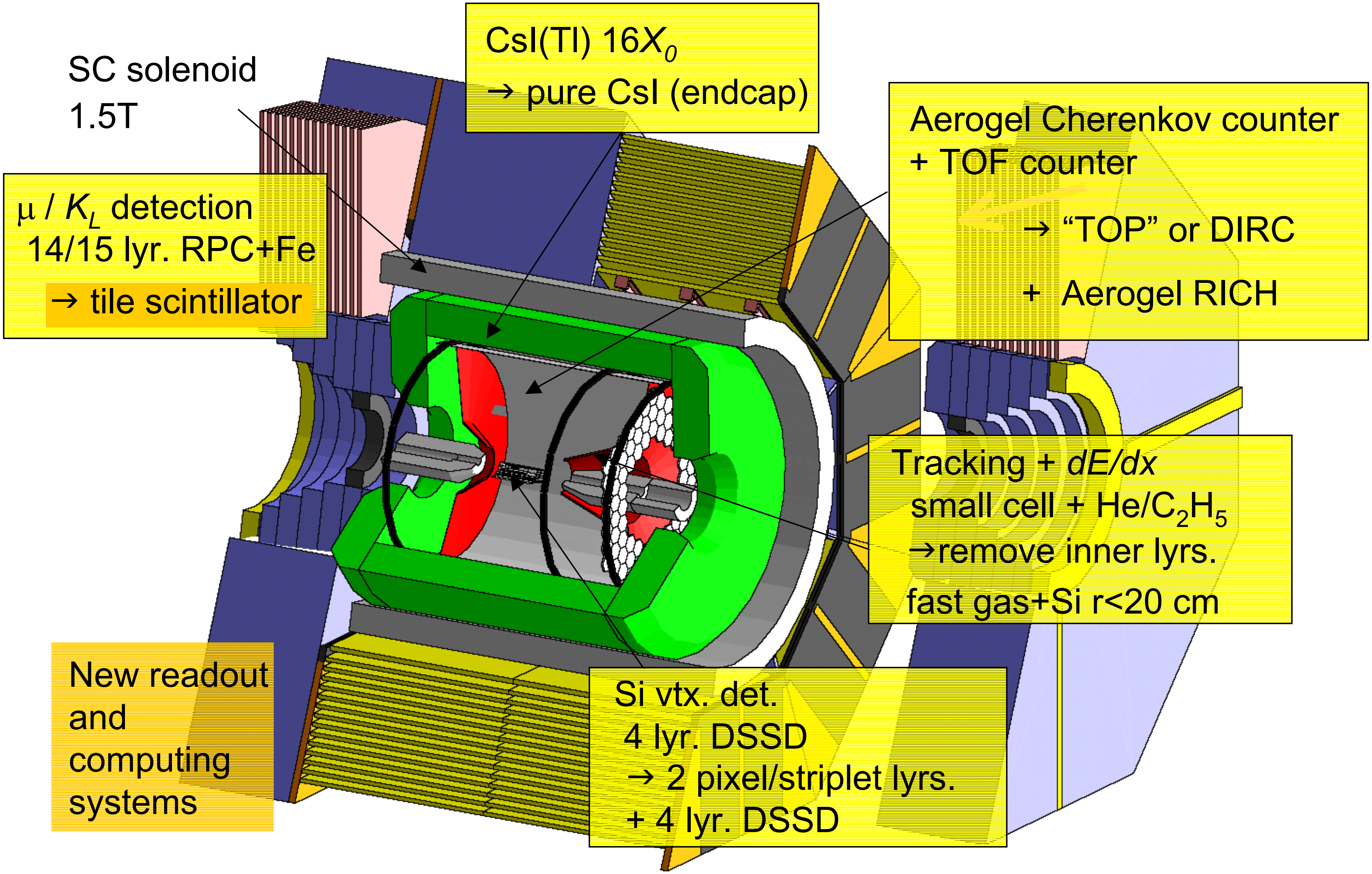
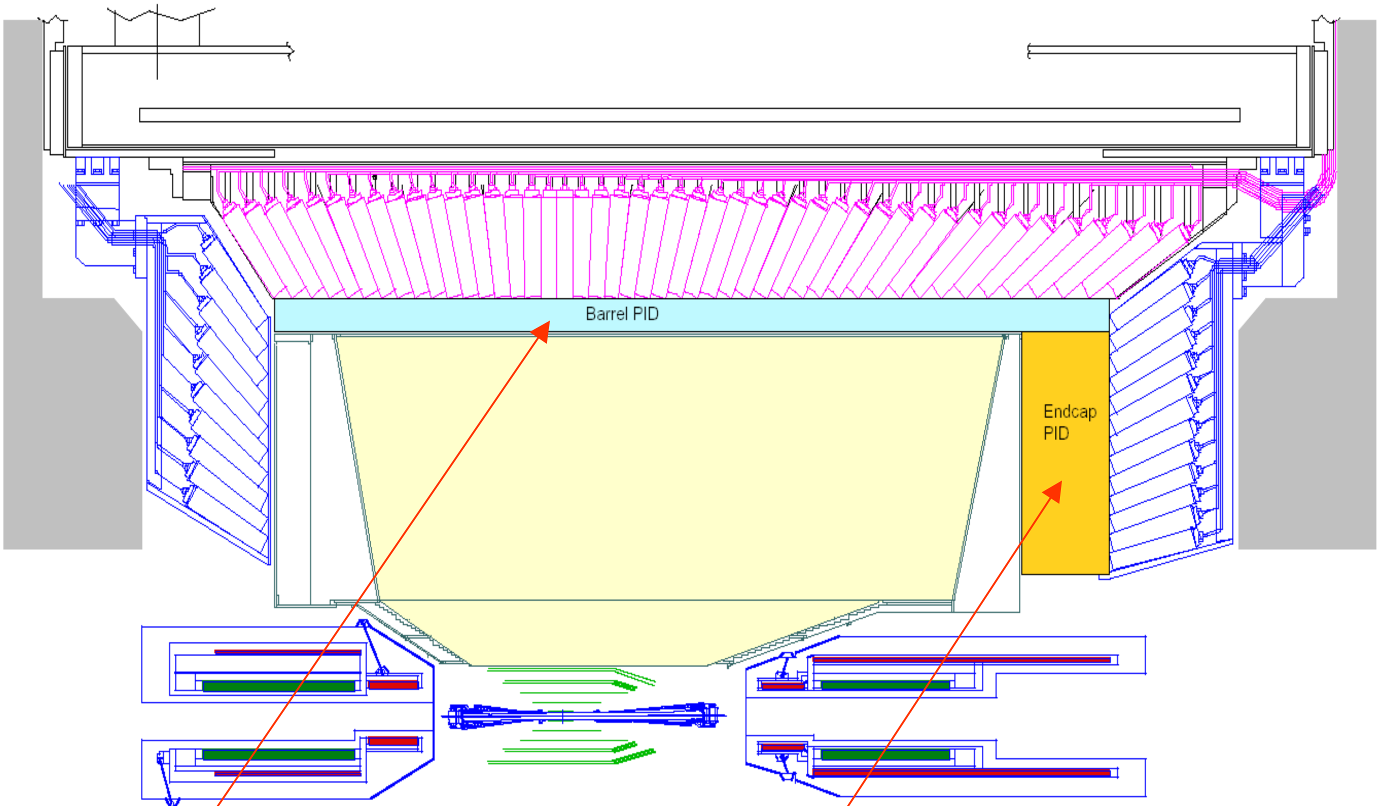
Belle Upgrade for Super-B



Belle upgrade – side view

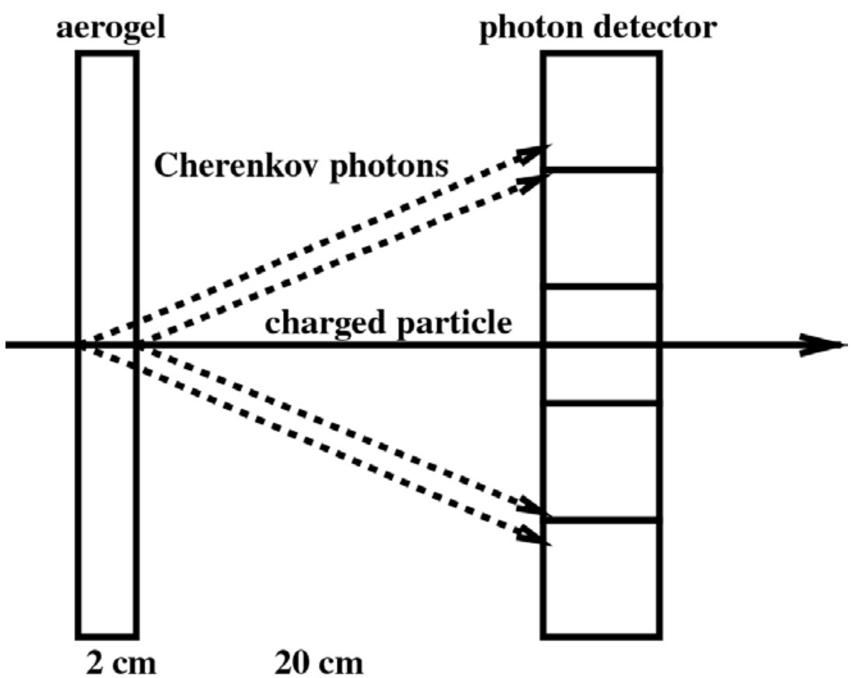


Two new particle ID devices, both RICHes:

Barrel: TOP or focusing DIRC

Endcap: proximity focusing RICH

Endcap: Proximity focusing RICH



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

$d\theta_c$(meas.) = σ_0 ~ 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

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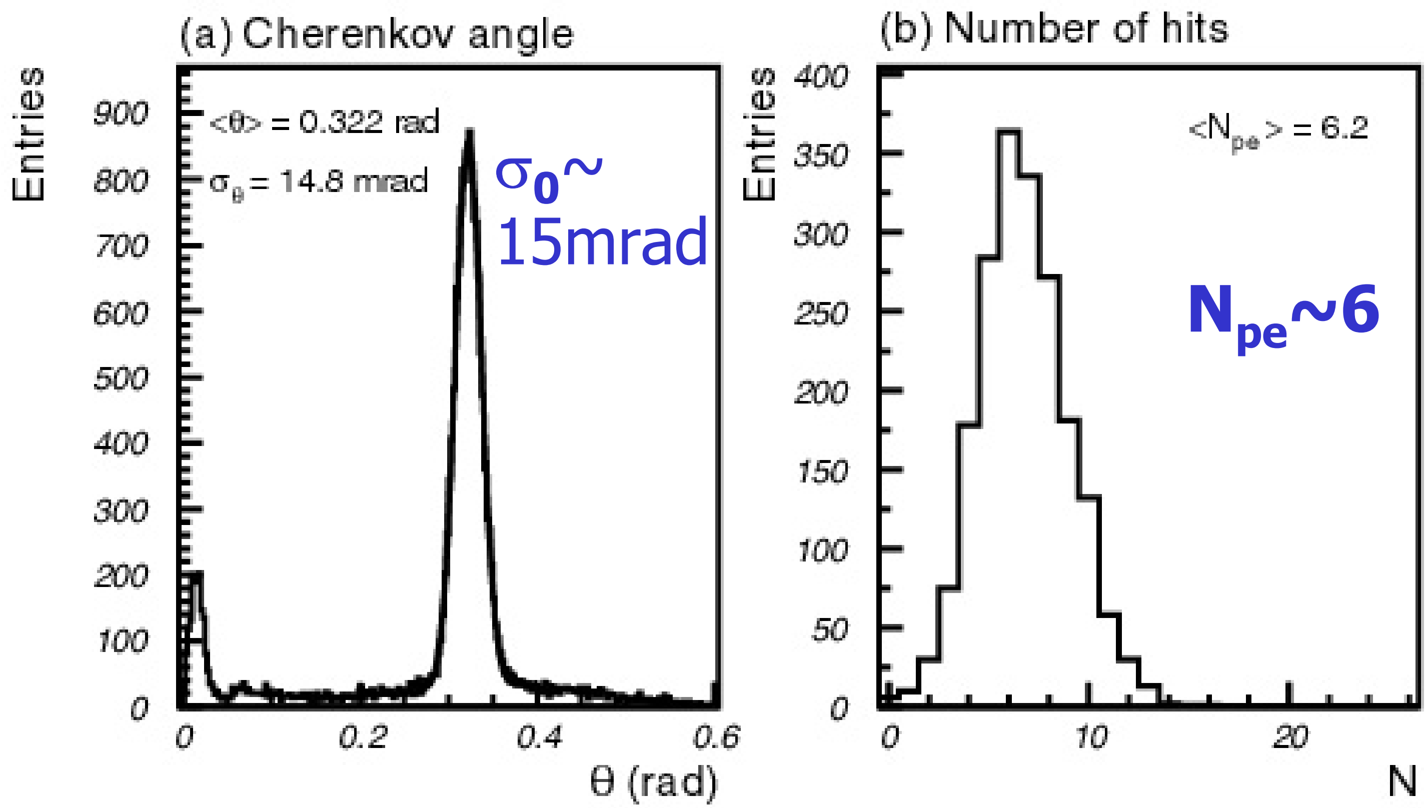
Beam test results with 2cm thick aerogel tiles:

$>4\sigma$ K/π separation

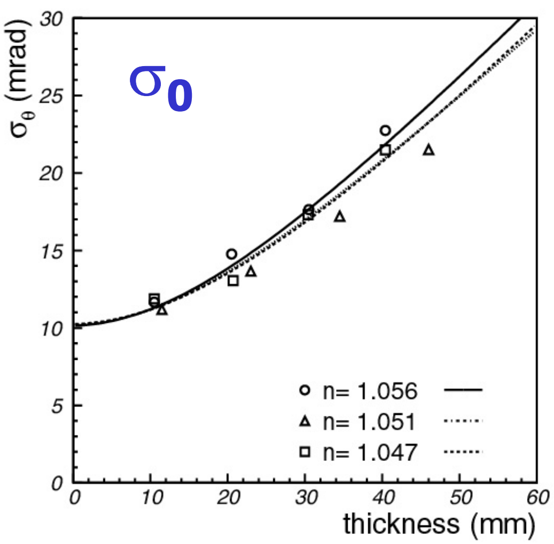


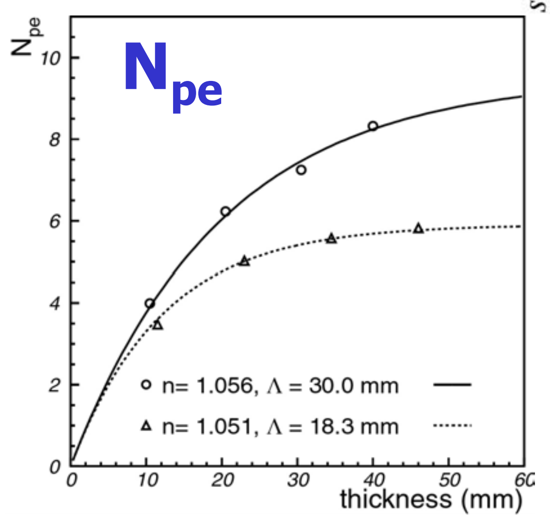
-> Number of photons has to be increased.

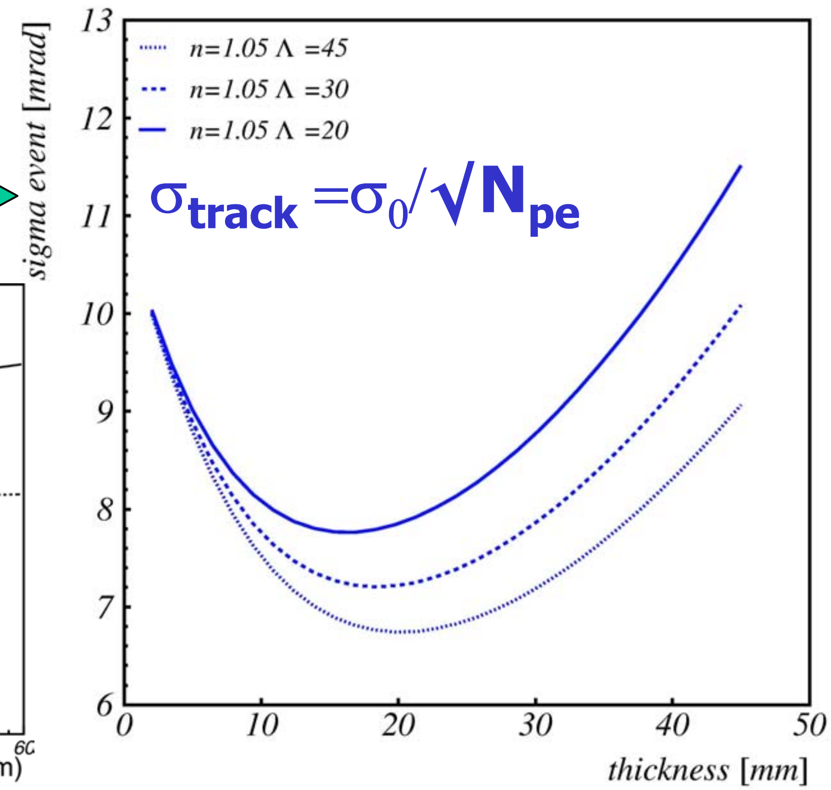
How to increase the number of photons?

What is the optimal radiator thickness?

Use beam test data on σ_0 and N_{pe}







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

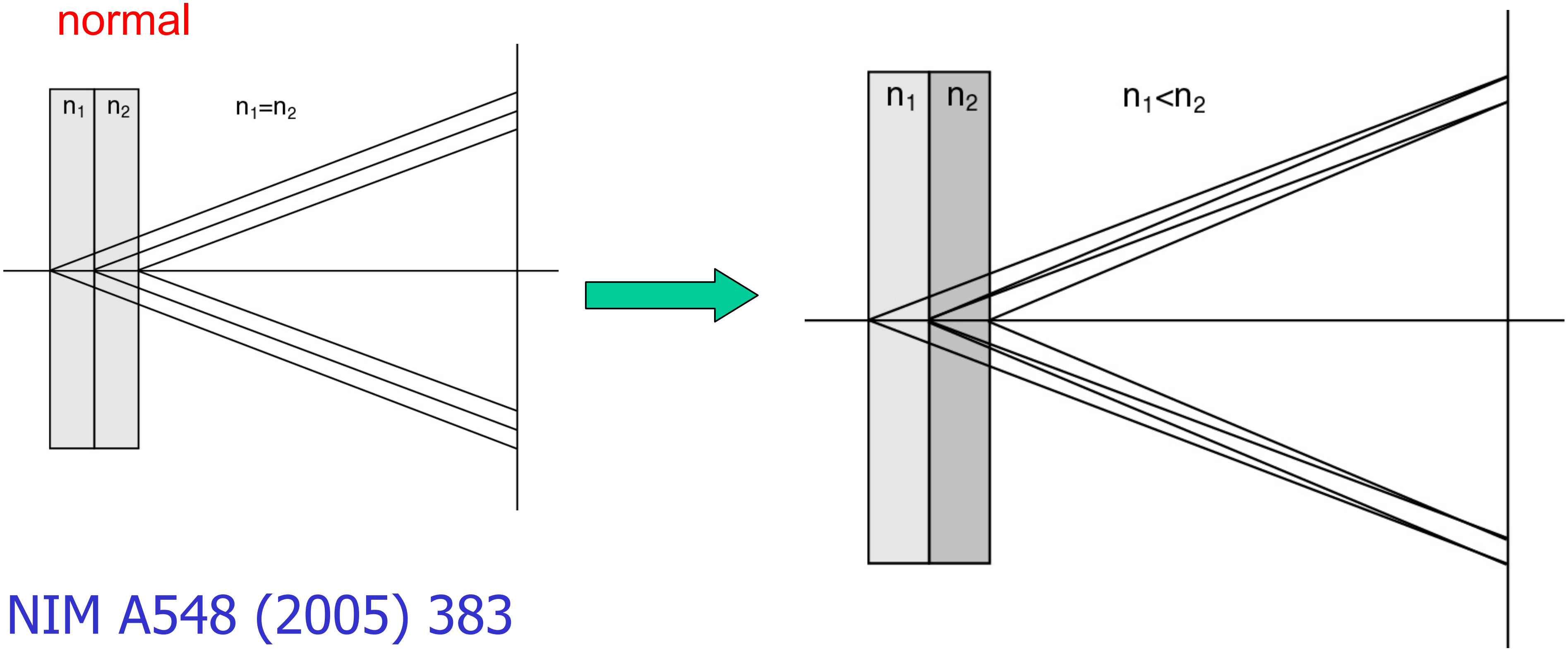
Optimum is close to 2 cm

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



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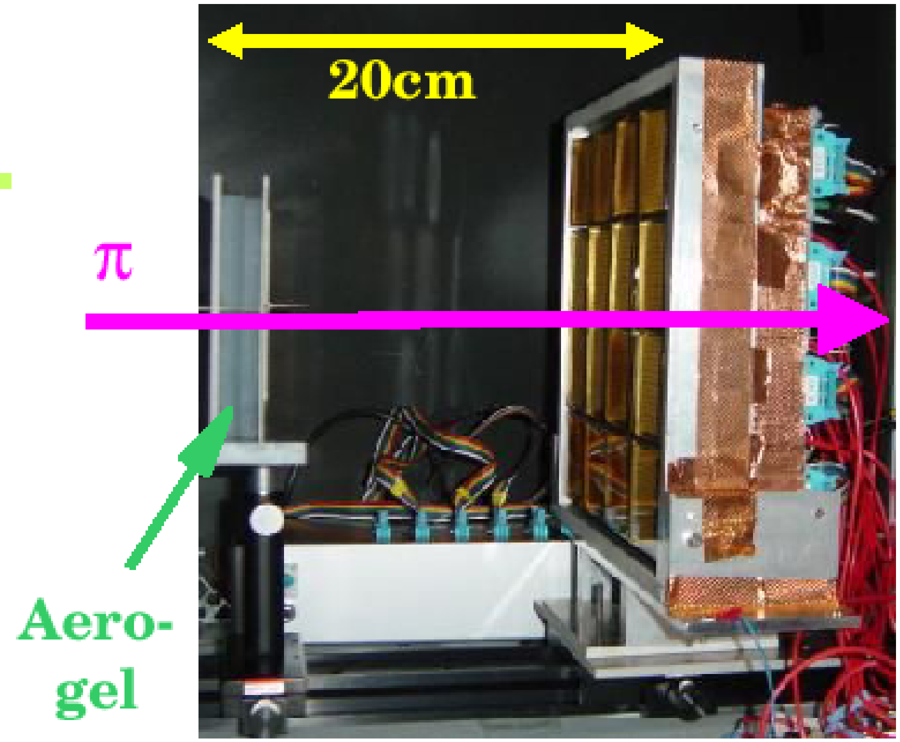
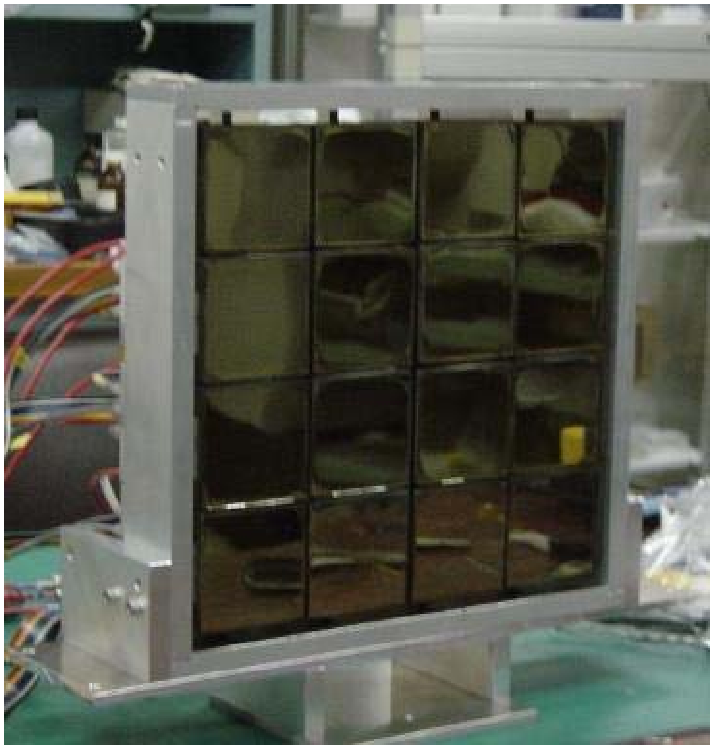
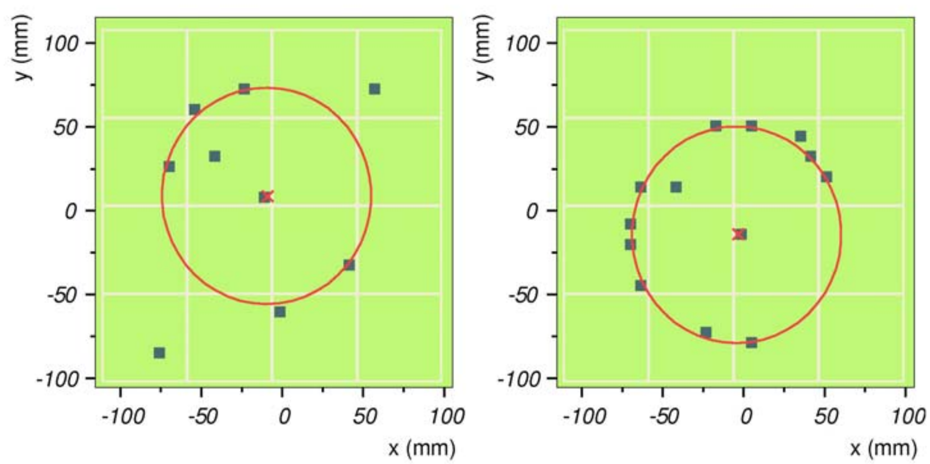
Beam tests





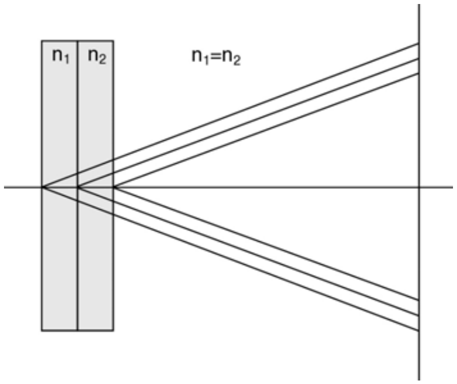
Photon detector: array of 16 H8500 PMTs

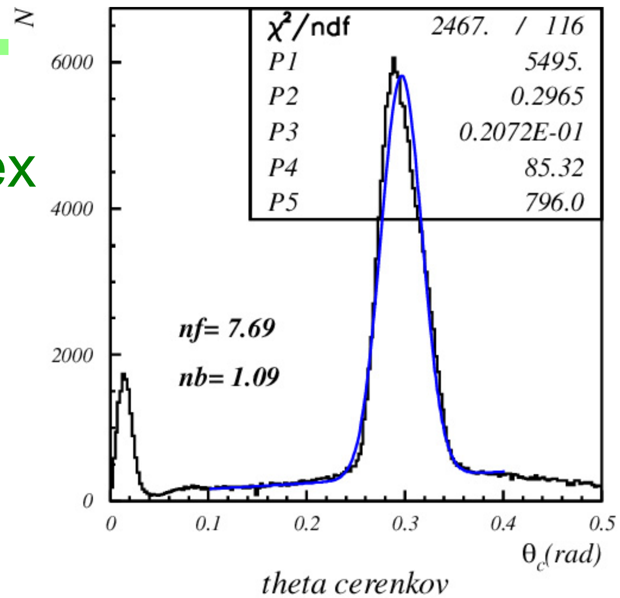
Clear rings, little background

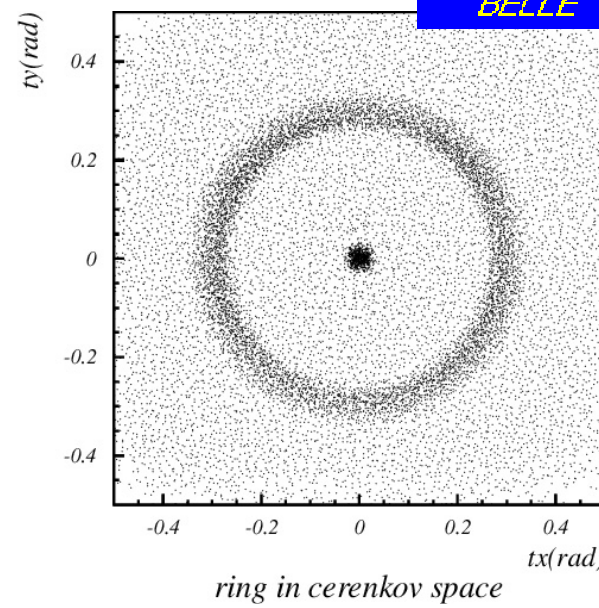


Focusing configuration – data

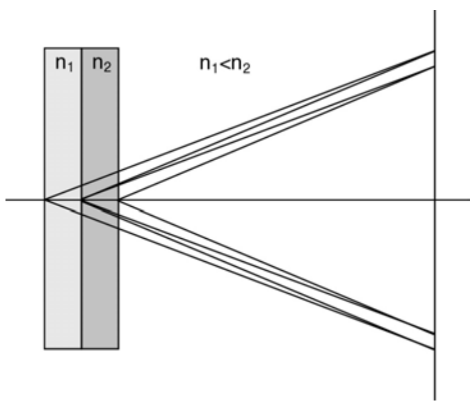
4cm aerogel single index

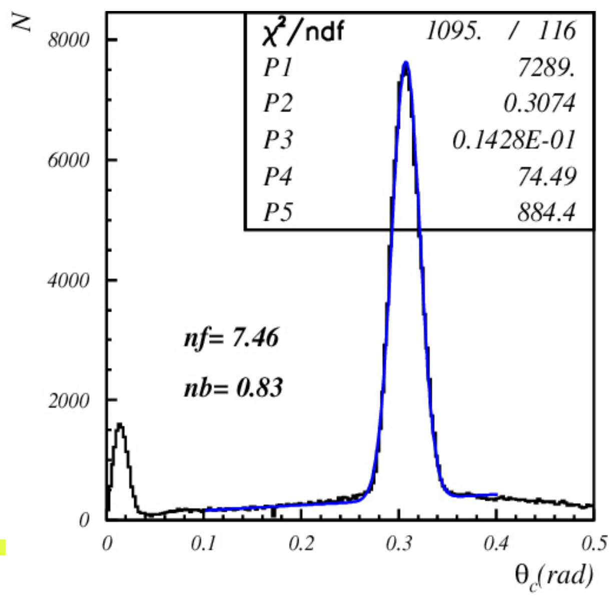


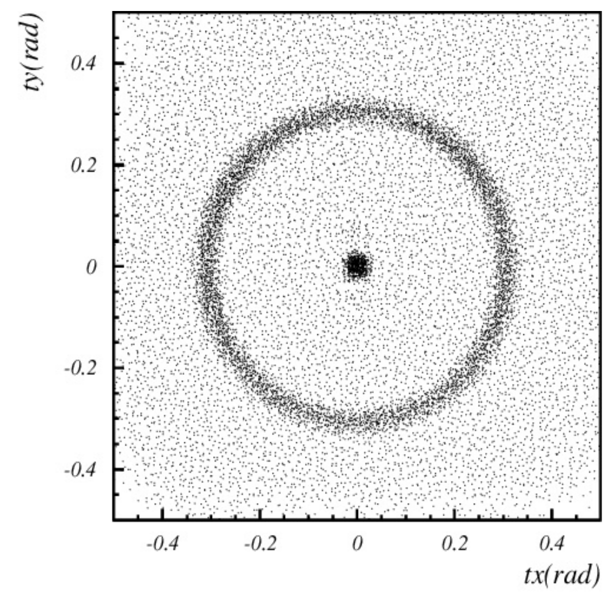




2+2cm aerogel



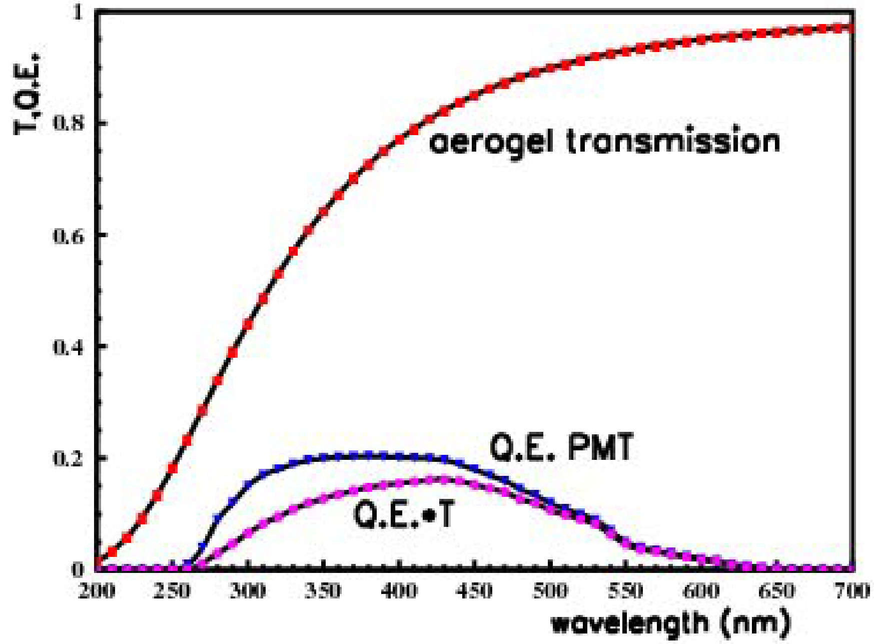




Photon detectors for the aerogel RICH

Needs:

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

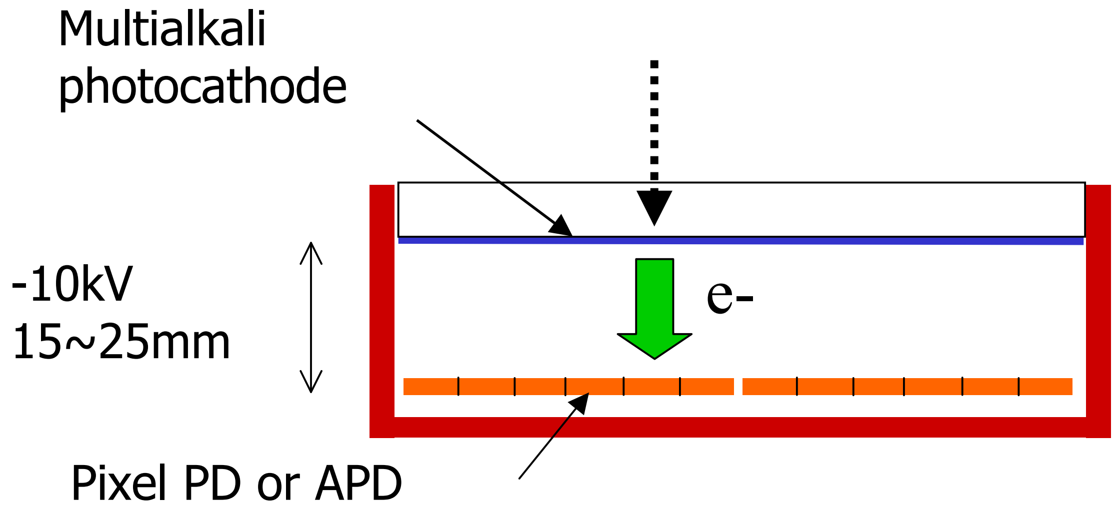


Candidates:

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

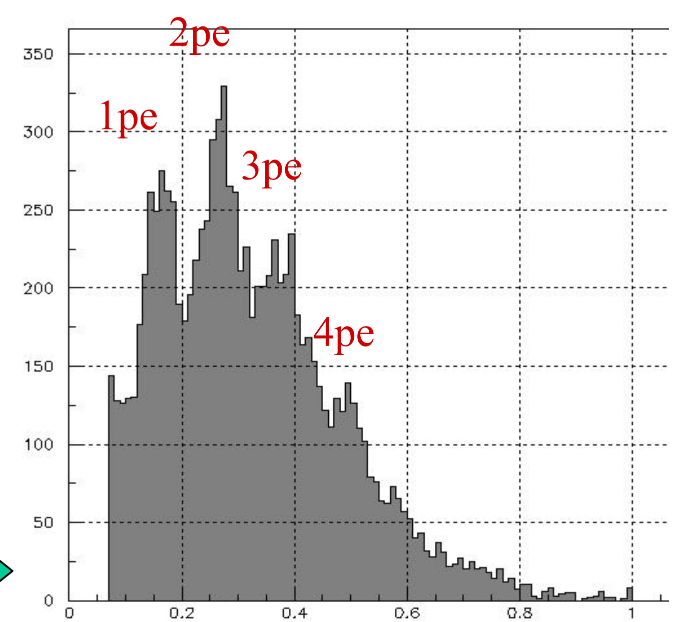
Development and testing of photon detectors for 1.5 T

Candidate: large area HPD of the proximity focusing type



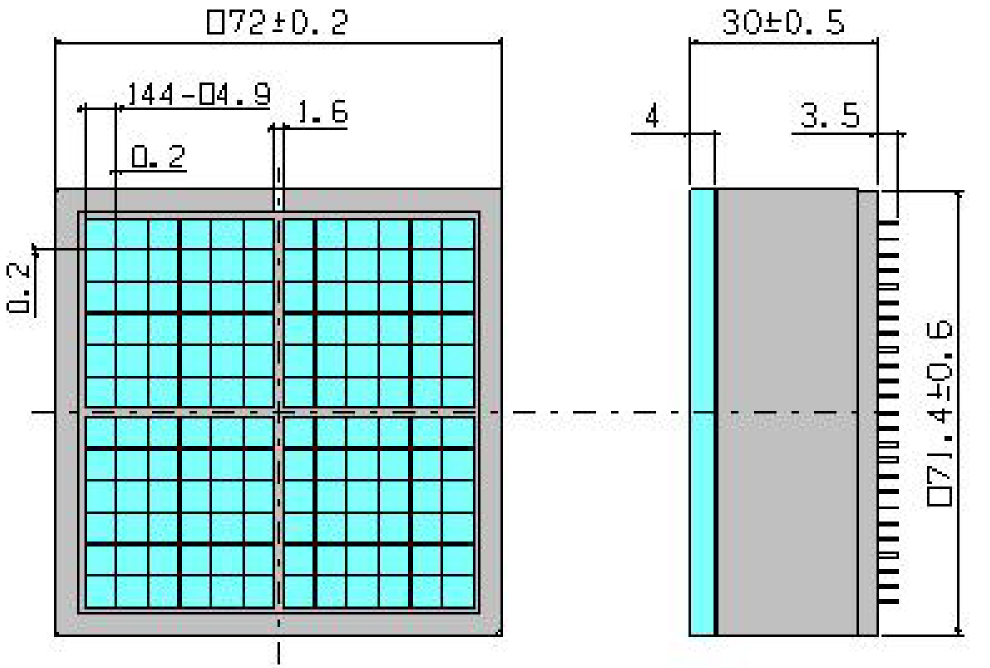
R&D project in collaboration with HPK

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



HPD development

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



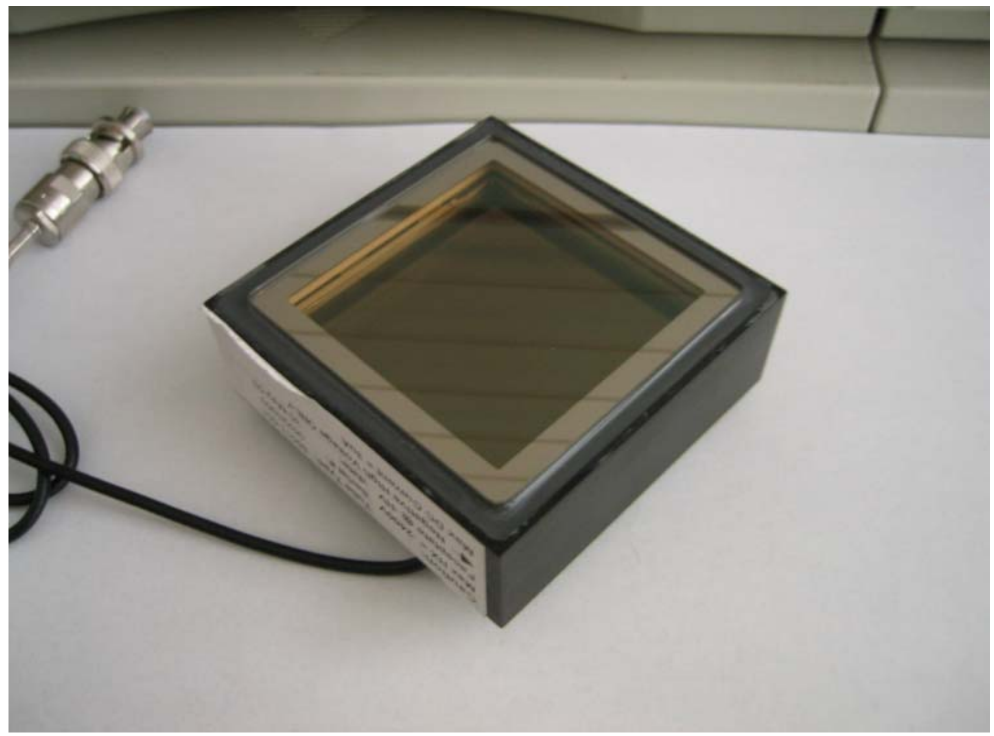
Ceramic HPD box

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

Photon detector R&D – Part 2: 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%

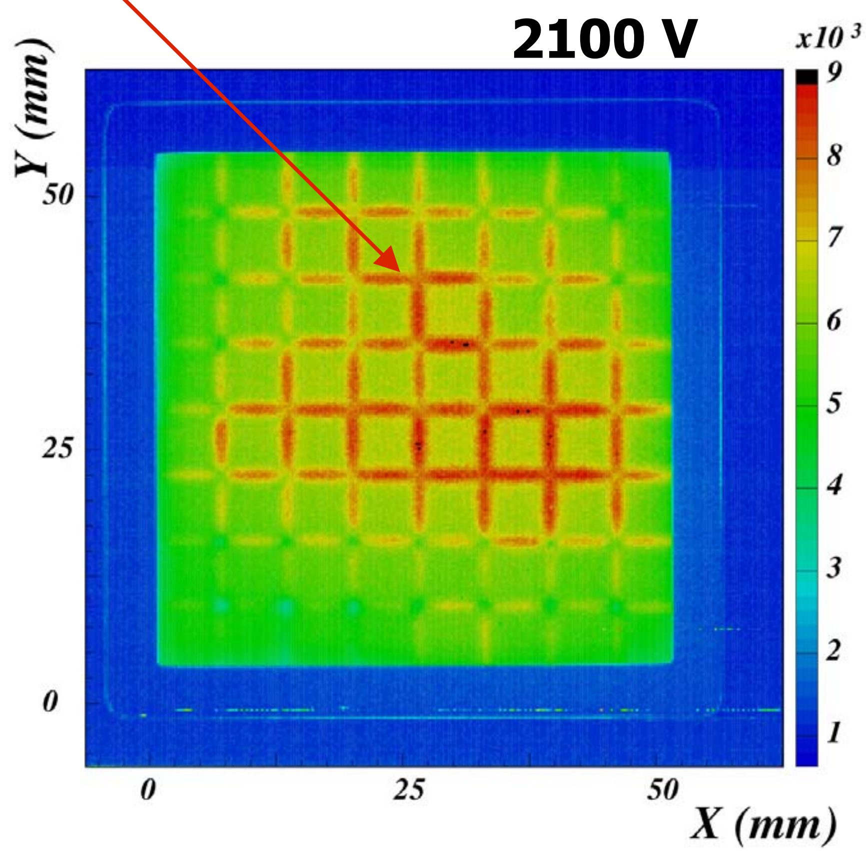


Photon detector R&D – Burle MCP-PMT bench tests

Proc. IEEE NSS 2004

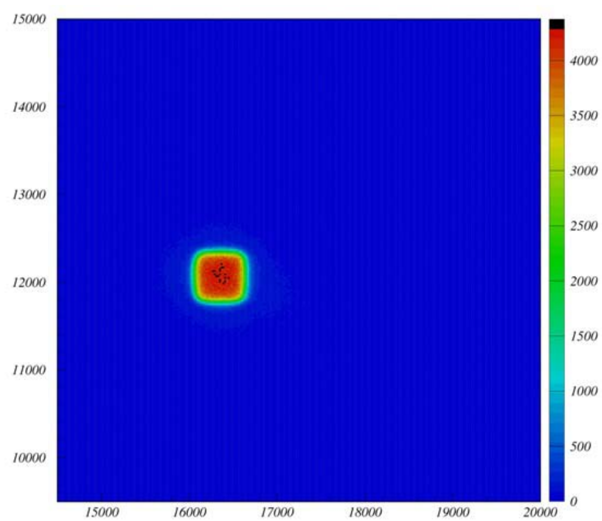
Study uniformity of the sensitivity over the surface

count rates - all channels: charge sharing at pad boundaries

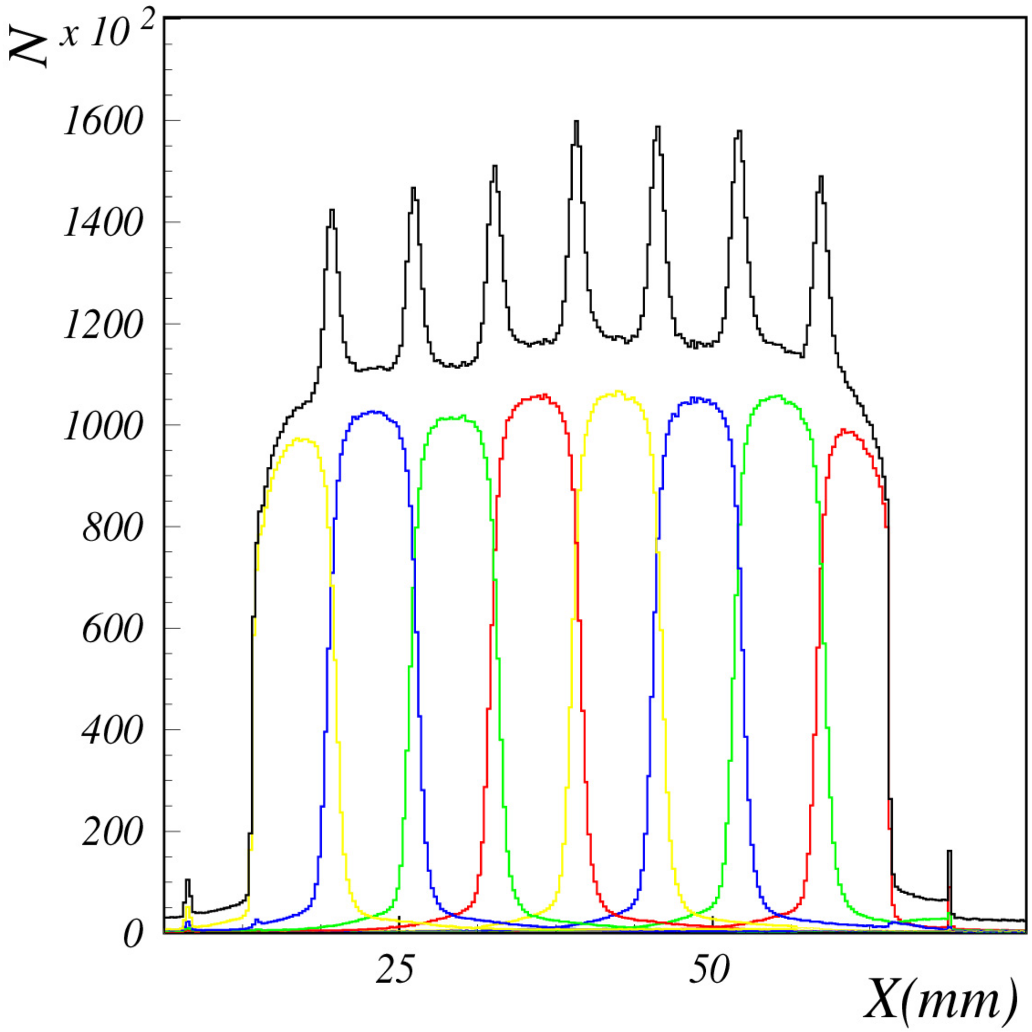


single channel response:

- 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

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%)

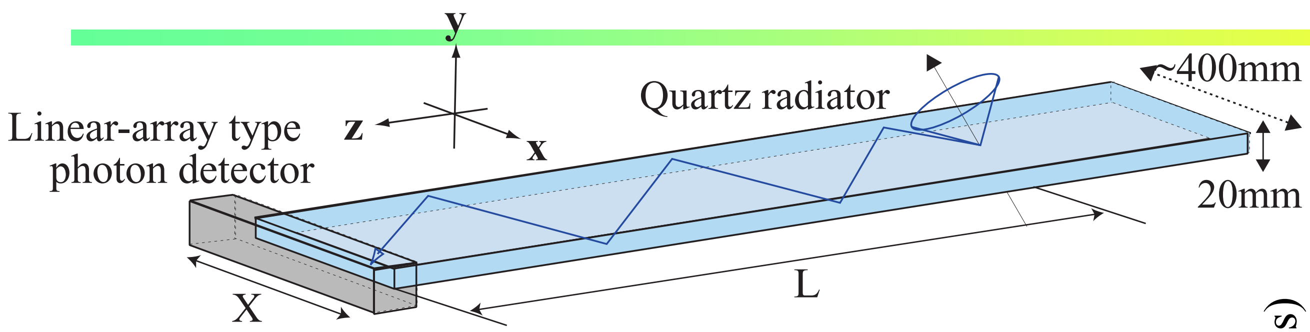
-> Extrapolation from the present data 4.5 ->8.5 hits per ring

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



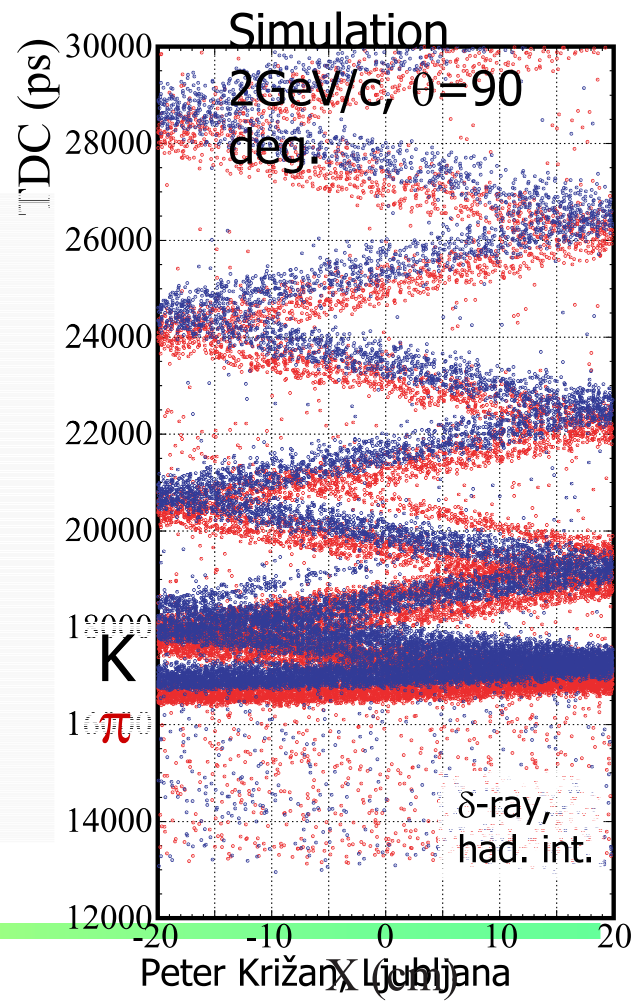
Time-of-Propagation counter:

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

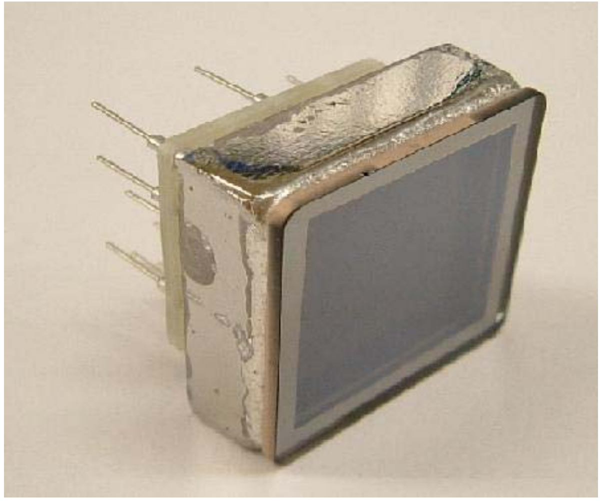


Belle barrel upgrade: TOP counter

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

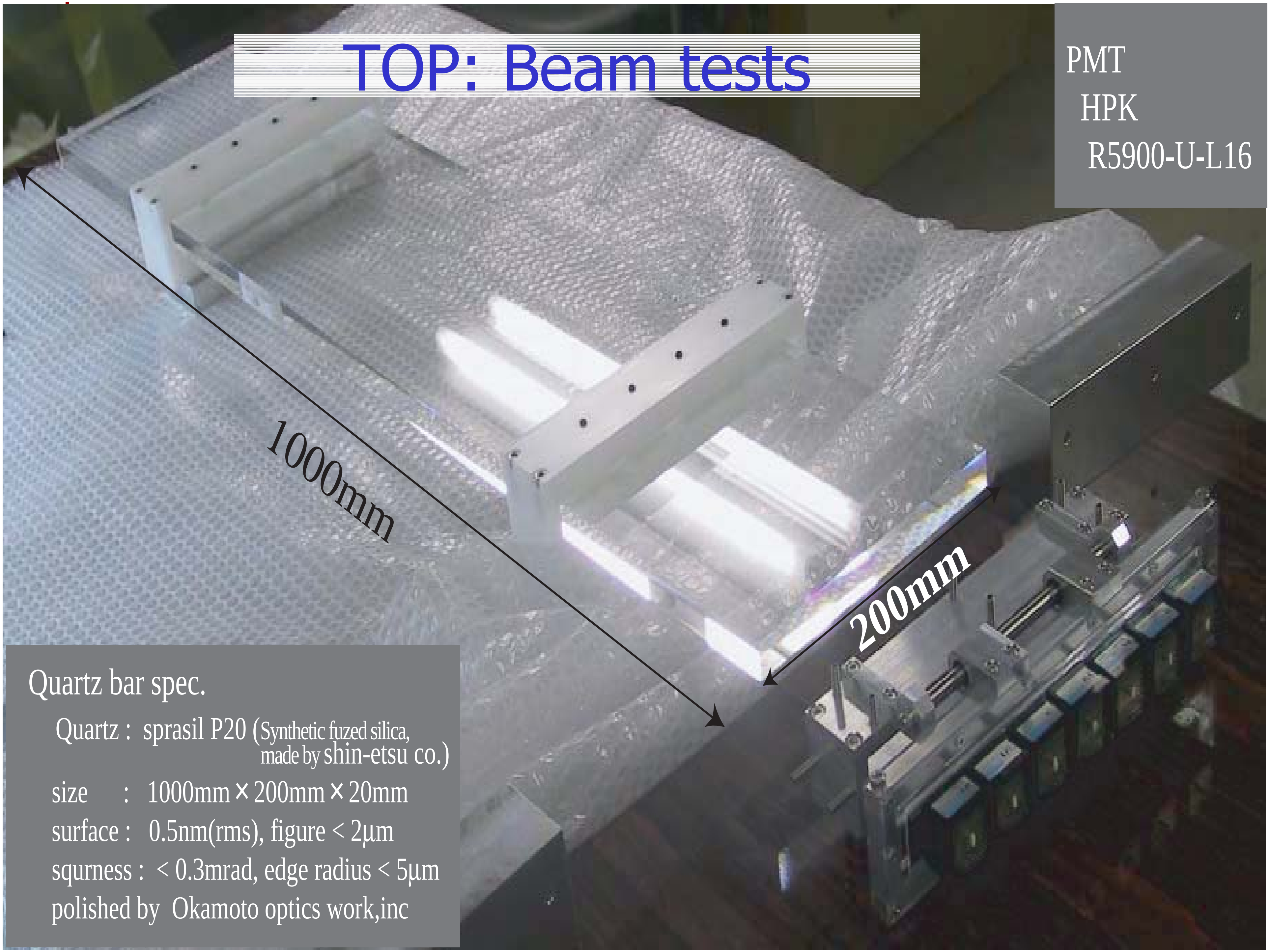
All: good time resolution at B=0

25μm pore tube does not work at 1.5T

NIM A528 (2004) 763

TOP: Beam tests

PMT
HPK
R5900-U-L16



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

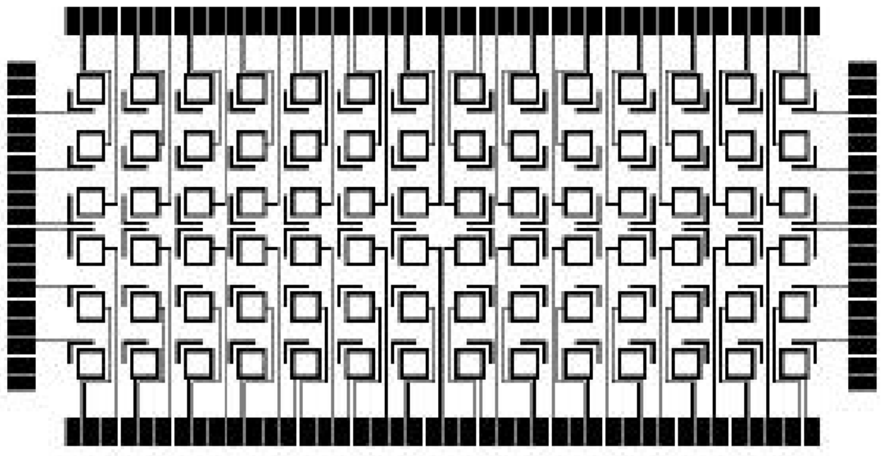
Ideal detector

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

→Single channel devices with a lot of dead area.

But:

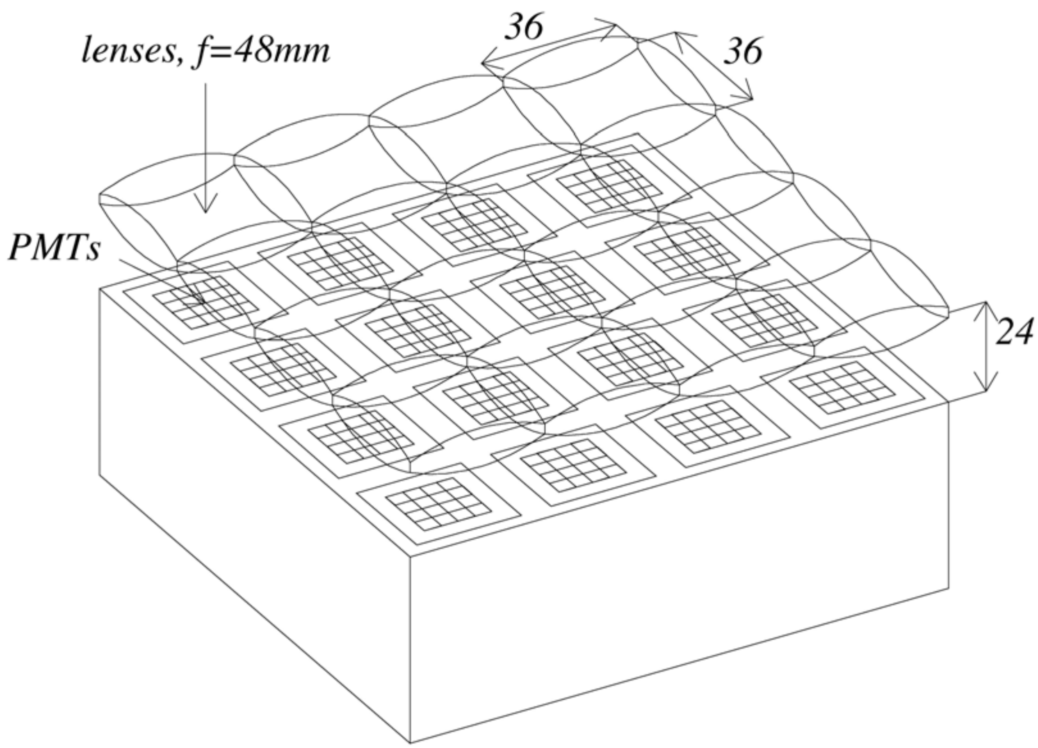
Single channel: much easier to compensate for the dead areas than in multi-channel devices

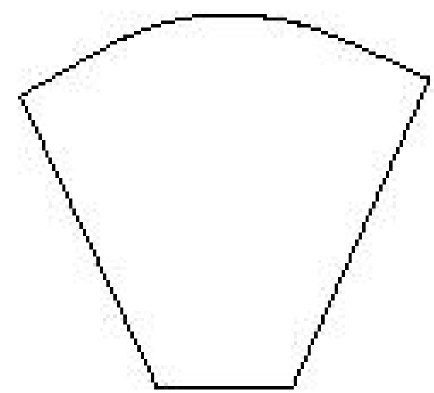


Light collection: single vs multi channel

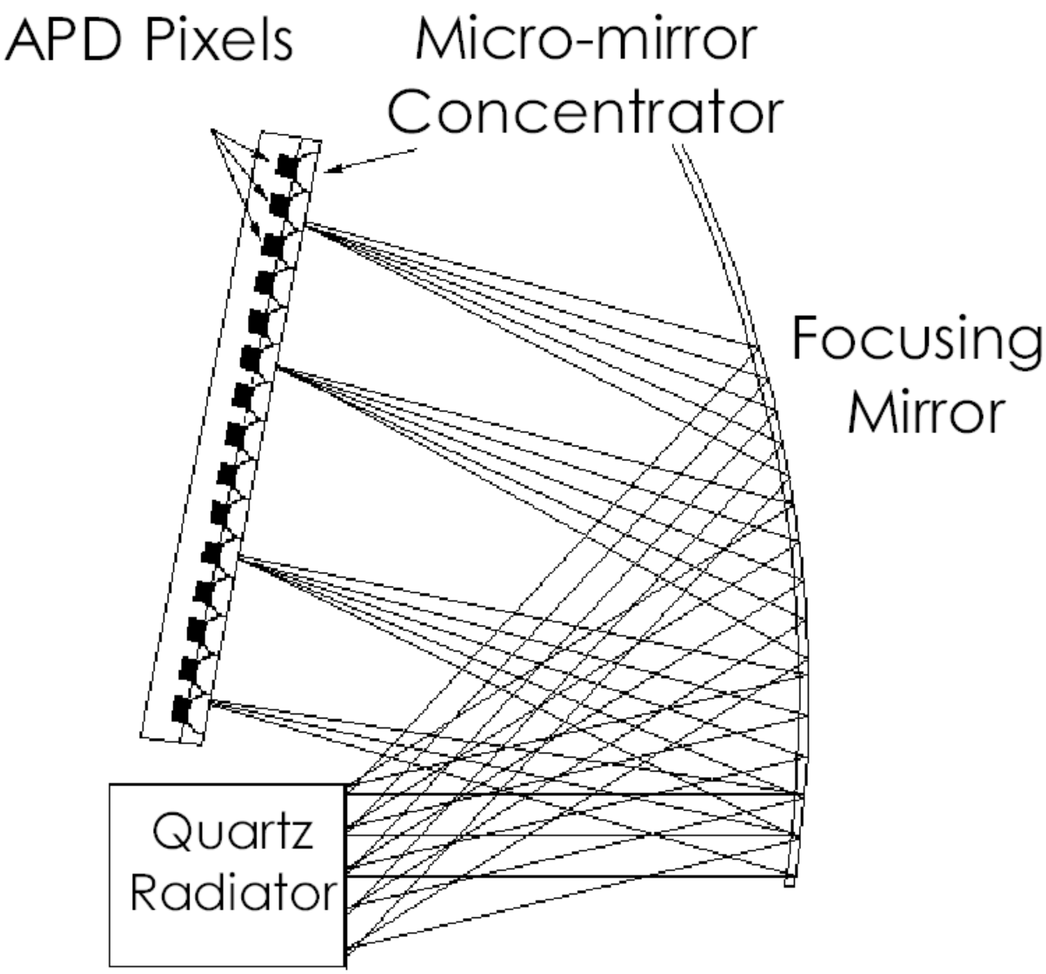
Multichannel device+imaging light collection system: Has a very limited angular acceptance

Single channel: combine a lens and mirror walls





Possible example: focusing DIRC



Summary: what types of detectors are needed?

- Modestly fast (few ns), large area detectors for B=0, visible light and UV, granularity few mm, high active area fraction
- Modestly fast (few ns), large area detector for B=1.5T, visible light (+red?), granularity few mm, high active area fraction
- Fast (<50ps), B=1.5T, ganularity few mm, visible light (+red?), strips (preferably some segmentation in the other coordinate as well) , high active area fraction in one direction

Summary: what types of detectors are needed?

→ Obviously accurate time information is getting important.

'Right timing is in most things the most important factor.'
Hesiod (~800 BC)

Concluding remarks

- A lot of activity in the RICH counter photodetector R+D
- Long term: many problems could be solved with an easy to handle semiconductor device
- I am looking forward to the talks of this meeting

Back-up slides

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)