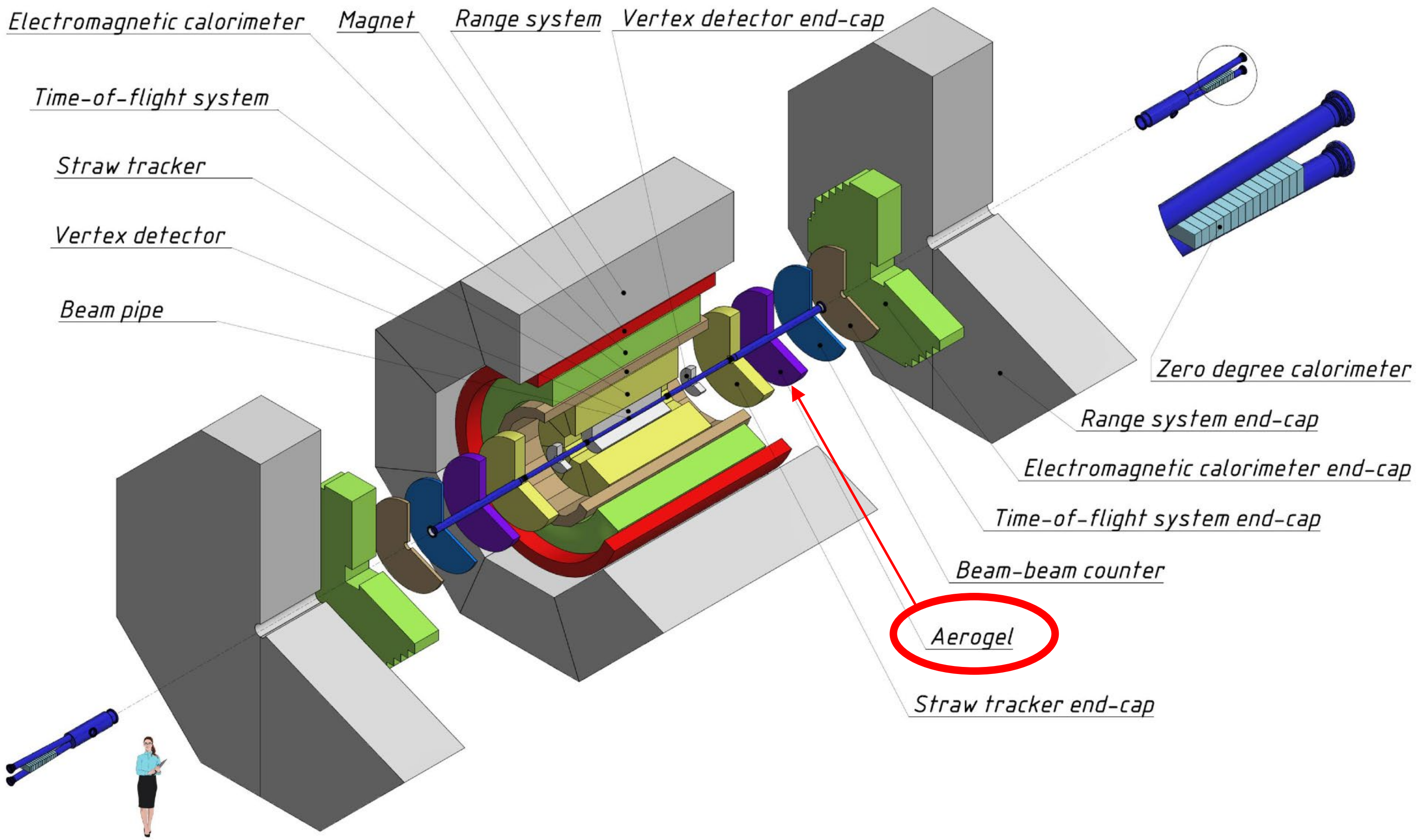
Aerogel RICH detector in the SPD endcap region

(proposal)

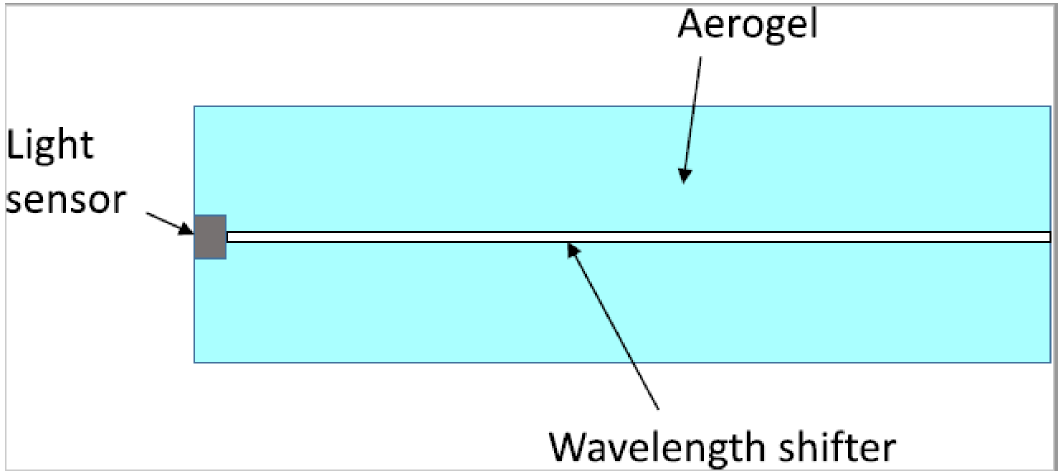
A.Kulikov SPD Collaboration meeting 25.04.2023

The task: particle identification, especially at high momenta where other methods, TOF and dE/dx, do not help.



In the SPD Technical Design Report: threshold aerogel counters similar to ASHIPH of the KEDR experiment.

Principle of detection: collection of the Cherenkov light to light sensors using wavelength shifter bars as a lightguide.

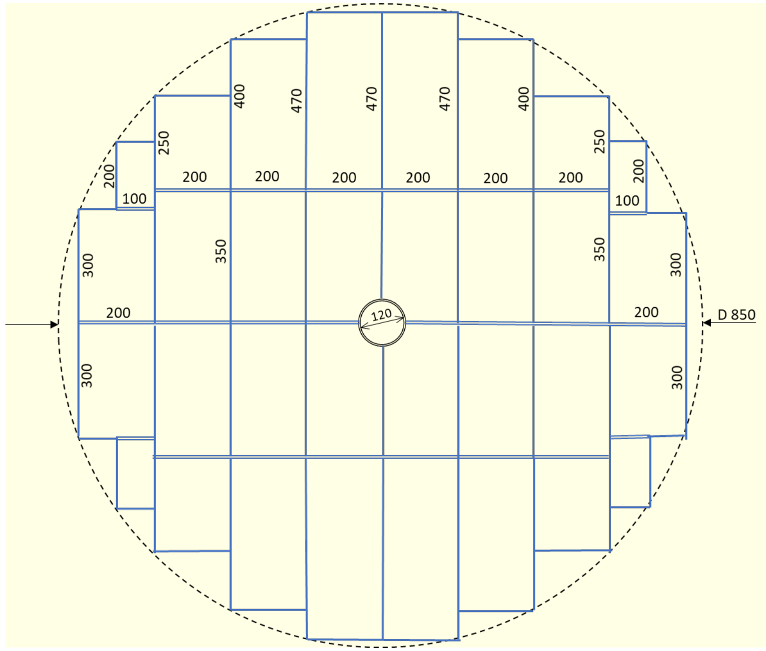


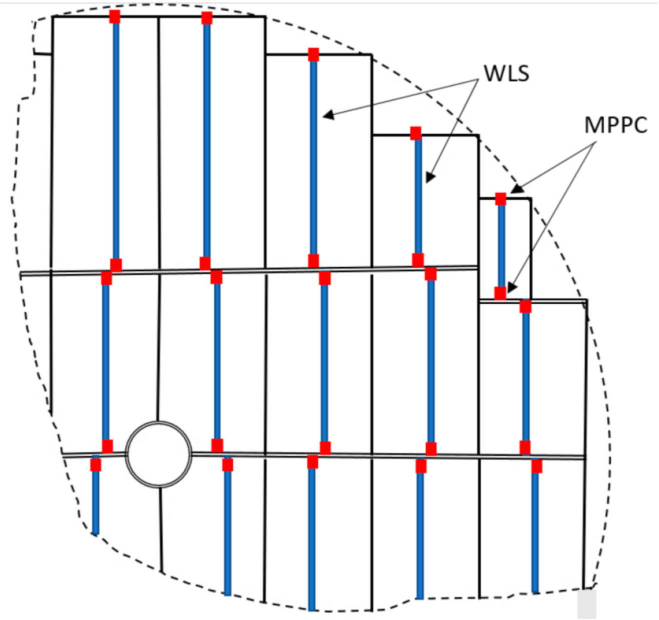
Drawbacks:

- plastic bar (shifter) in the working area,
- rather weak signal

π-K separation is possible in the 1-2.5 GeV/c momentum range.

TDR version: aerogel with n=1.02, 2 layers by 80 mm each, WLS bars are shifted with respect to each other. Readout with MPPC from both ends.

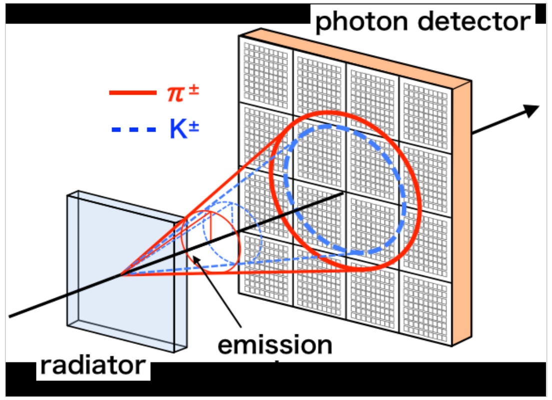




Estimation of the signal (maybe too optimistic): ~10 photoelectrons (a sum from both ends).

Another option of the Cherenkov detector for the endcap:
RICH detector.

This more advanced type of Cherenkov counters extends the momentum range of identification.



Principle of RICH

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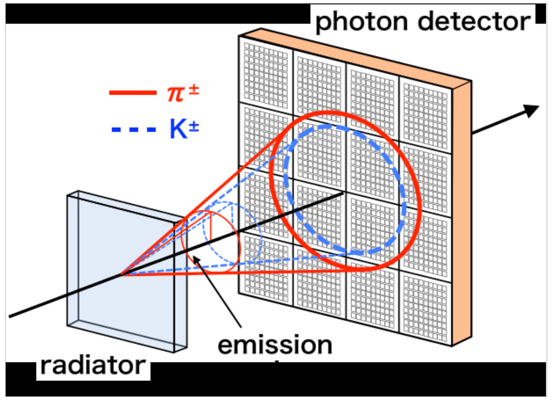

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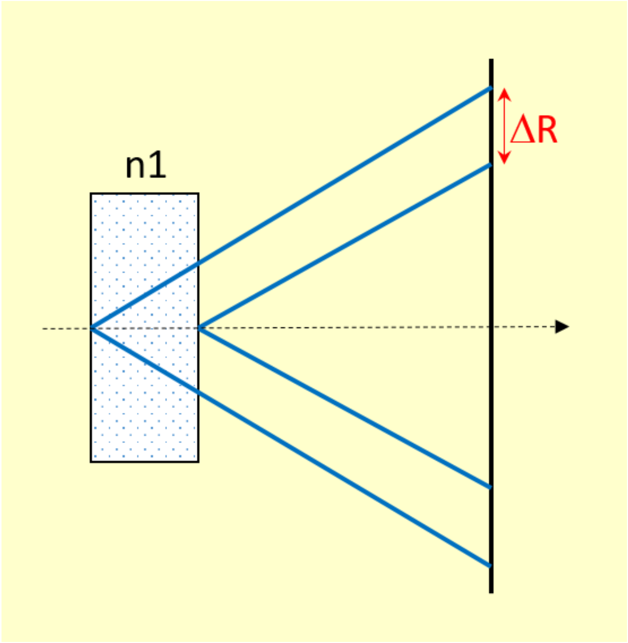
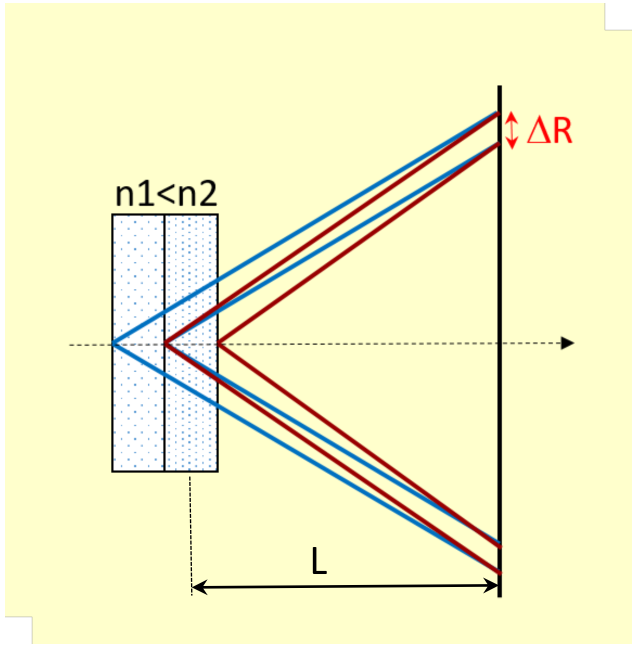




Proximity focusing RICH has two (or more) aerogel layers with different refraction indices n.

With optimal selection of the refractive indices, such structure allows to shrink the width of the Cherenkov ring and hence to decrease dependence of the Cherenkov angle resolution on the aerogel thickness.

In SPD the distance L ~200 mm between the aerogel and the detector plane is affordable.

There exists an optimum value of n_2 for a given n_1 :

$$n_2 - n_1 = d/(n_1 \cdot L) \cdot [n_1^2 - 1 - (mc)^2/p^2]$$

T.Iijima et al. NIM A548 (2005) 383

d – thickness of each of the two aerogel layers
L – distance from the center of the 2nd radiator to the detector plane
m, p – mass and momentum of a particle

For different particles (π,K,p) and momenta the optimum $\mathbf{n_2}$ is slightly different.

Example:
at $\mathbf{n_1=1.045}$, d=20mm and L=200mm the optimum n_2 values for pions and kaons are:

Momentum, GeV/c	1	2	3	4	5
n_2^{π}	1.052	1.053	1.054	1.054	1.054
n_2^{K}	-	1.048	1.051	1.052	1.053

The width of the ring ΔR is 3.5-6 mm at n_1=1.045 and L= 200 mm in the momentum range of 1 to 5 GeV/c.

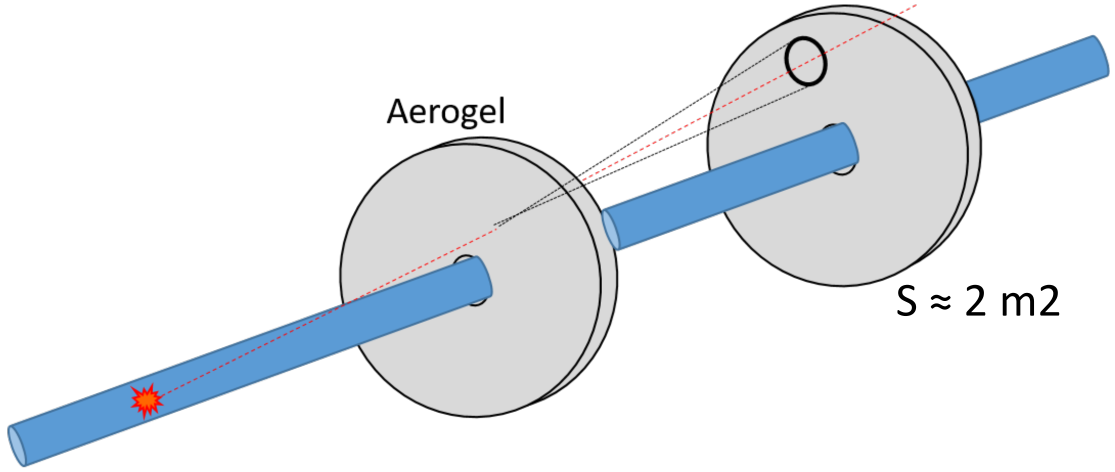
The Cherenkov ring radius is different for different momenta and particle types.

At n=1.05 and L=200 mm the radius R of the Cherenkov ring on the photon detector plane and the difference of radii ΔR for different particles (in mm) are:

Momentum GeV/c	R_{π}	R_K	R_p	$\Delta R_{\pi\text{-}K}$	$\Delta R_{K\text{-}p}$	$\Delta R_{\pi\text{-}p}$
1	58	---	---	---	---	---
2	63	39	---	**24**	---	---
3	63	54	12	**9**	42	51
4	63	58	43	**5**	15	20
5	63	60.5	51	**2.5**	10.5	12

Hence for particle identification up to 4 GeV/c, coordinate resolution of the photon detector is required not worse than 5 mm.

A photon detector is the most challenging and expensive part of a RICH detector.



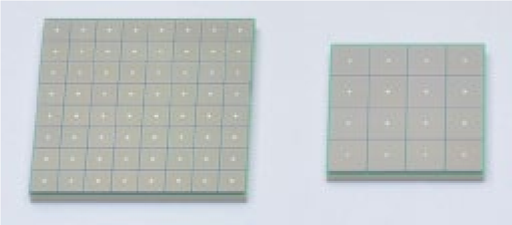
Requirements to the photon detector:

- ability to detect single photons
- high photon conversion efficiency
- coordinate resolution ≤ 5 mm
- operation in the magnetic field
- efficiency in the ultraviolet region

Photon detector in each of the endcaps should cover the surface about 2 m^2.

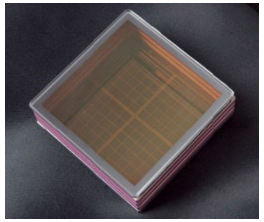
Options for the photon detector:

MPPC arrays



Example: Hamamatsu S13361 series

hybrid avalanche photodetectors (HAPD)



gas detectors: photocathode + MWPC (ALICE, HADES), GEM/Micromegas (COMPASS)

multi-anode photomultipliers

Example: Hamamatsu MCP PMT
R10754-07-M16

MPPC arrays

Hamamatsu MPPC arrays

S13361-3050-08 (3x3 mm sensitive area, 8x8 channels)

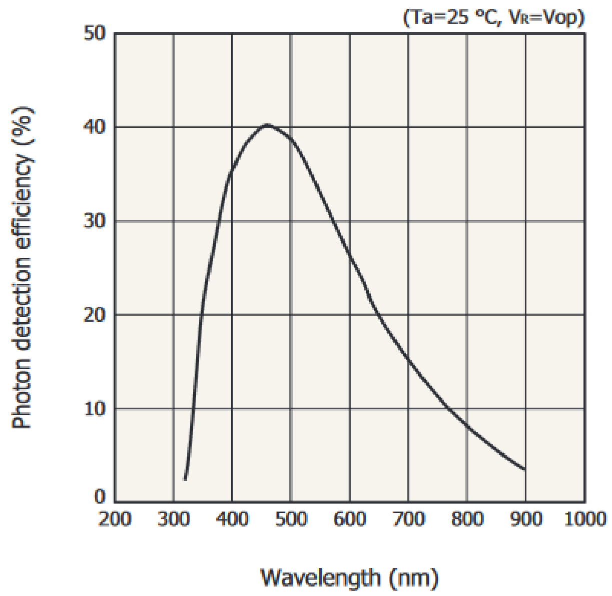
or S13361-6050-04 (6x6 mm sensitive area, 4x4 channels)

spectral response range 320 to 900 nm

PDE 40% at maximum (450 nm)

gain $1.7 \cdot 10^6$

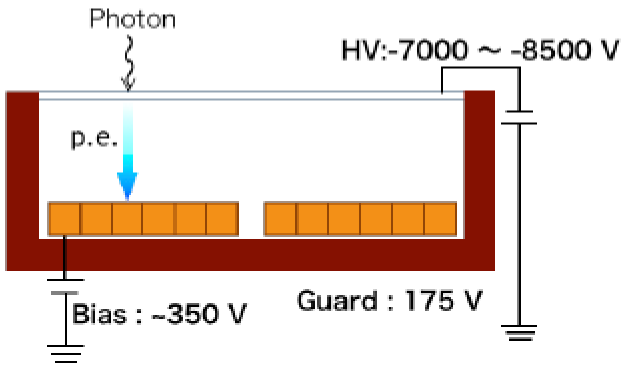
fill factor 74%



All parameters are good except one: dark count rate 0.5-1.5 MHz (at the 0.5 p.e. threshold).

This makes using of MPPC problematic in our system with $\sim 5 \cdot 10^4$-10^5 channels and a trigger-less DAQ.

Hybrid avalanche photodetectors



Specifications of the HAPD

Size	$73 \times 73 \times 28\,mm^3$
Number of APD chips	$2 \times 2 = 4$ chips
Number of channels	$12 \times 12 = 144$ ch
Channel size	$4.9 \times 4.9 mm^2$
Effective area	65 %
Photo-cathode material	Bialkali
Quantum efficiency	$\sim$28% at 400 nm
Bombardment gain	$\sim$1800
Avalanche gain	$\sim$40
Total gain	72000
Capacitance	80 pF

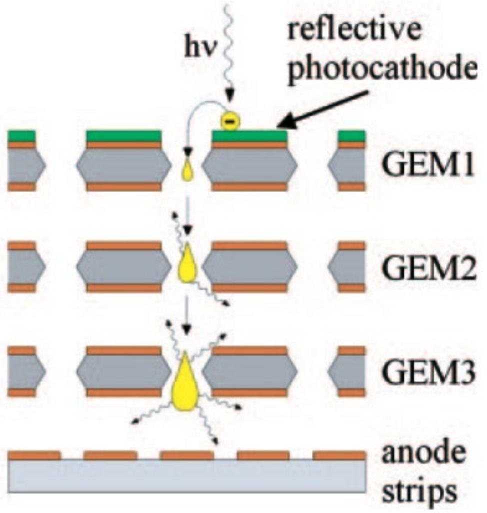
Excellent parameters but:

- developed by Hamamatsu especially for BELLE II
- HAPD is absent in the Hamamatsu production catalog
- for sure, not accessible for SPD.

Gas photon detectors

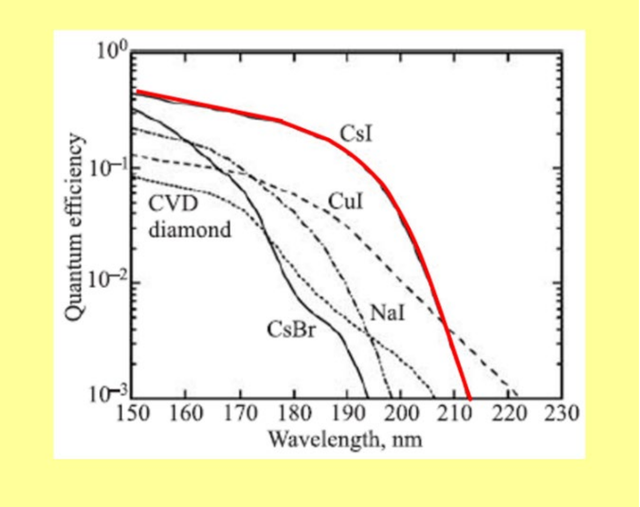
The early experiments: photon conversion in gases – TMAE (in DELPHI, SLD), TEA (in CLEO-III).

Since 2000s, RICH detectors with **solid state photocathodes** are mainly used.



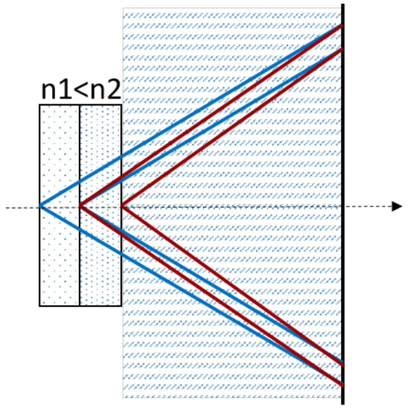
The best of the solid state photocathodes is **CsI** which has the highest QE among other photocathodes.

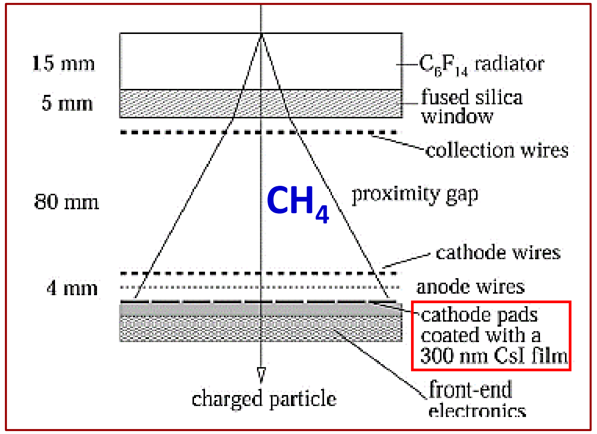
Quantum efficiency of CsI lies in the UV region, grows with decrease of the wavelength and reaches 40% at 150 nm.



Limiting factor:

A medium between the aerogel and a photon detector plane, and the window of the photon detector (if present) should be transparent for 140-200 nm wavelengths.
But an air is practically non-transparent below λ=185 nm.





ALICE RICH with CsI photocathode and MWPC detection

All proximity focusing RICH detectors with CsI work in an "open geometry", when the proximity gap is filled with the working gas of the wire chamber, CH_4 or CF_4, which are transparent for the ultraviolet.

The crucial factor excluding this option:

light scattering strongly increases with decrease of the wavelength $\sigma_{scat} \sim 1/\lambda^4$

↓

Most of 140-200 nm Cherenkov photons will completely lose their initial direction
or even not leave the aerogel volume!

No CsI/gas detectors with aerogel radiators has been built.

Multi-anode photomultipliers

Microchannel plate based multi-anode PMT
is a good choice:

- can work in the magnetic field
- good spectral response range
- high photon conversion efficiency
- high gain

Hamamatsu MCP PMT
R10754-07-M16

matrix 4x4 anodes
anode size 5.28x5.28 mm
PMT size 27.6x27.6 mm
QE = 23% at λ=380 nm
gain 10^6
~60% active area
thickness 17 mm

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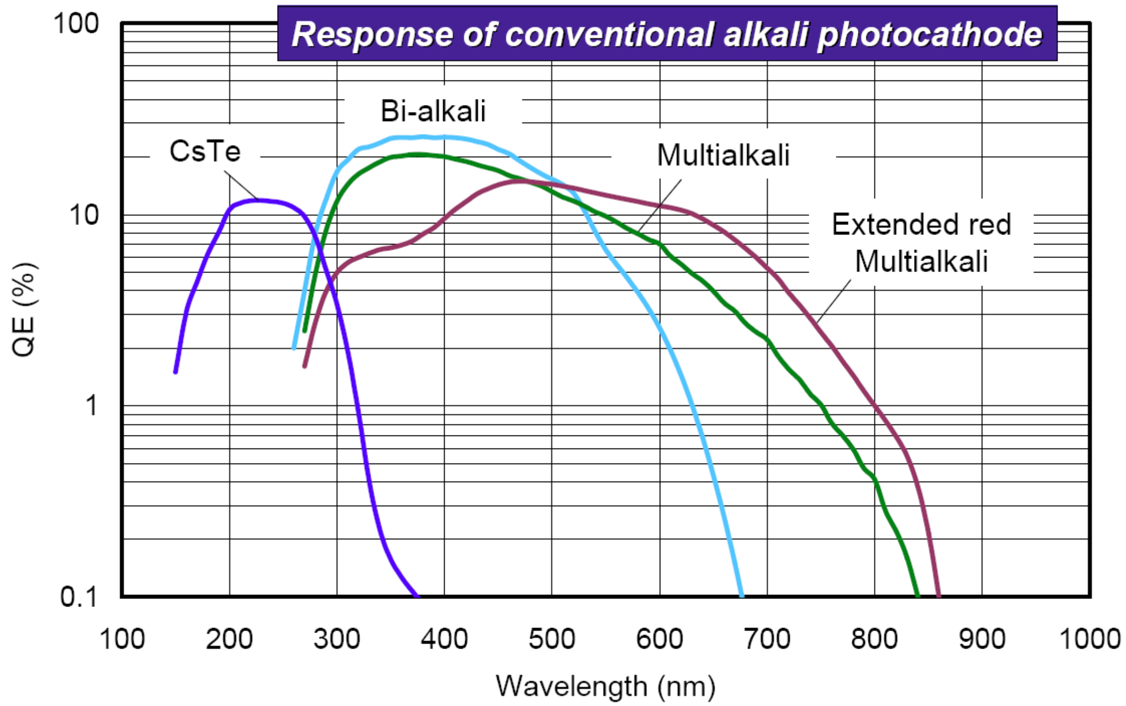
In Russia microchannel plates are produced by the Technological Center “Baspik” (Vladikavkaz).
Multi-anode PMT with these MCP could be produced by the enterprise “Ekran FEP” (Novosibirsk).

We are in contact with both companies.

How large signal can we have in SPD with the PMT as a photon detector?

The most suitable type of the photocathodes for detection of the Cherenkov light is bi-alkali (Sb-K-Cs, Rb-Sb-Cs), with sensitivity extending from ~260 to 650 nm and maximum QE≈20% between 300 and 500 nm.

$$N = 2\pi\alpha l\,(1/\lambda_1 - 1/\lambda_2)\,\sin^2\theta$$



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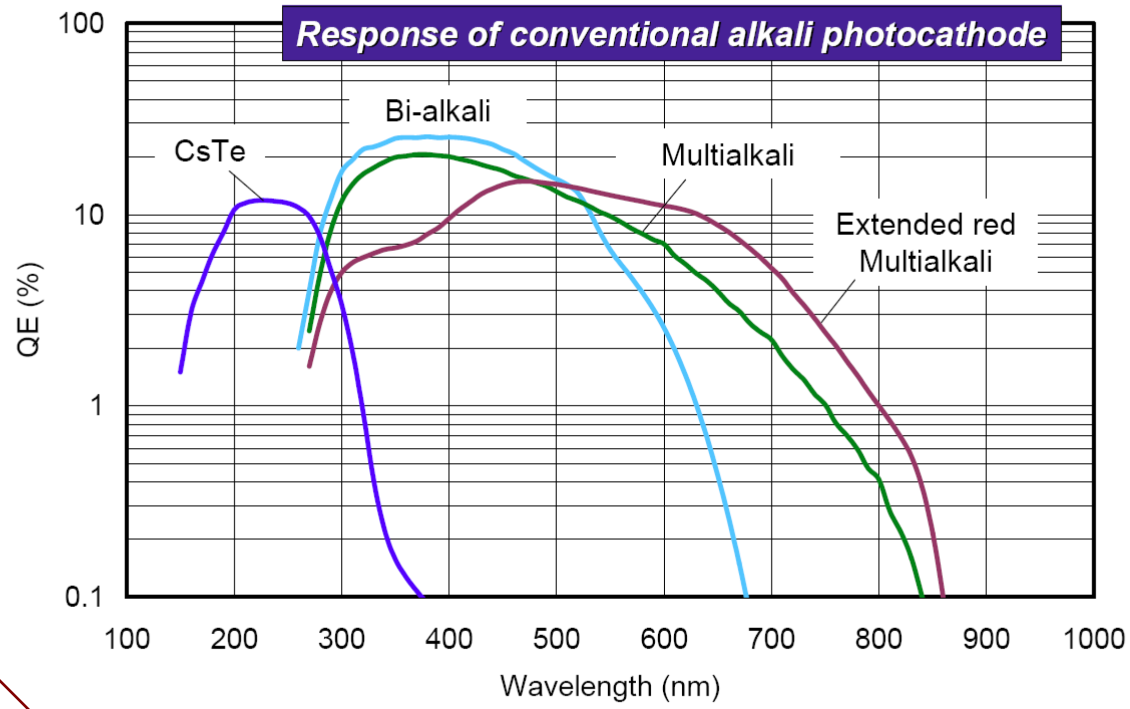
Parameters used in calculation of the p.e. number:

- effective area of the MCP 60%
- sensitive area of the detector 60%
- quantum efficiency 20% at 300-500 nm, 10% at 270-300 and 500-550 nm
- aerogel thickness 20 mm with n=1.045 + 20 mm with n=1.055



The number of photoelectrons calculated without account of the absorption/scattering in aerogel

	π	K	p
1 GeV/c	44	---	---
2	52	21	---
3	54	41	1
4	54	46	26
5	54	49	36

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Transmission length at λ=400 nm (from BELLE-II):

47 mm at n= 1.0451
36 mm at n= 1.0547

Then, in our case (20mm n=1.045 + 20mm n=1.055) transmission will be about 60%,

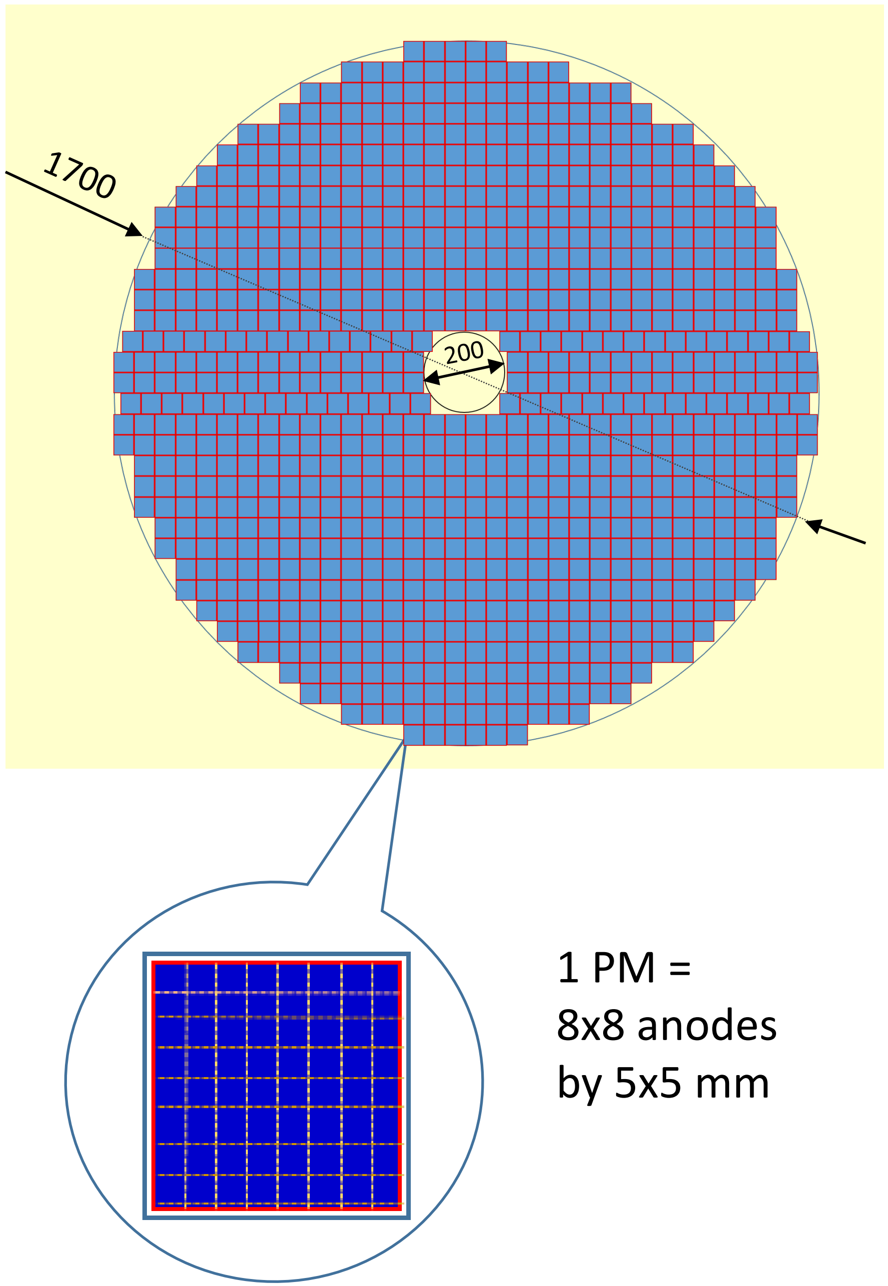
and the number of photoelectrons, i.e. points on the Cherenkov ring →

	π	K	p
1 GeV/c	28	---	---
2	33	14	---
3	34	26	---
4	34	29	17
5	34	31	23

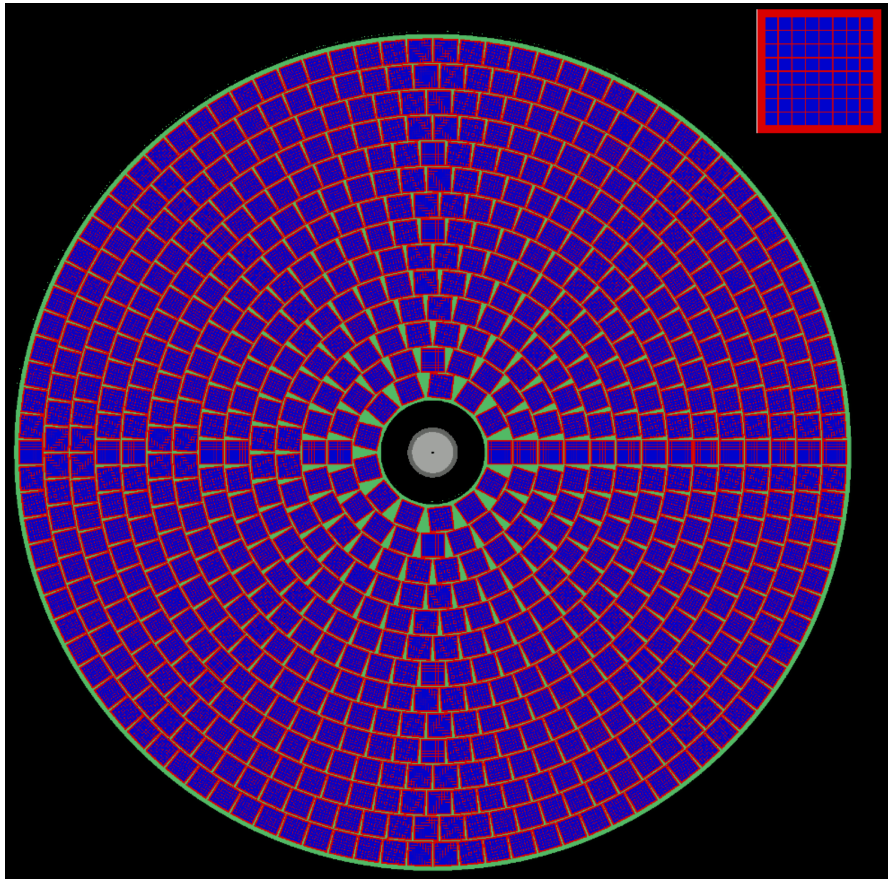
If we would have MCP PMT with 8x8 anodes, each anode 5x5 mm, and the PMT size 50x50 mm, then **to cover the aperture 2 m^2 of one endcap we need ~800 photomultipliers.**

With this granularity, a total number of the readout channels is ~51 000.

In reality, format of the matrix (8x8, 4x4, 12x12), anode pixel size, and PMT size are the subject for discussion and agreement with the manufacturers. The numbers of PMTs and of channels may change, accordingly.



Different arrangement of the photomultipliers is also possible (*A.Korsenev*).



Both companies, “Baspik” and “Ekran FEP” expressed their interest in developing the PMT with our technical specifications.

Feasibility of the aerogel RICH in SPD much depends on the quality and price of the photomultipliers, the price is not yet declared by the company.

We are waiting for cost estimation from the developers.

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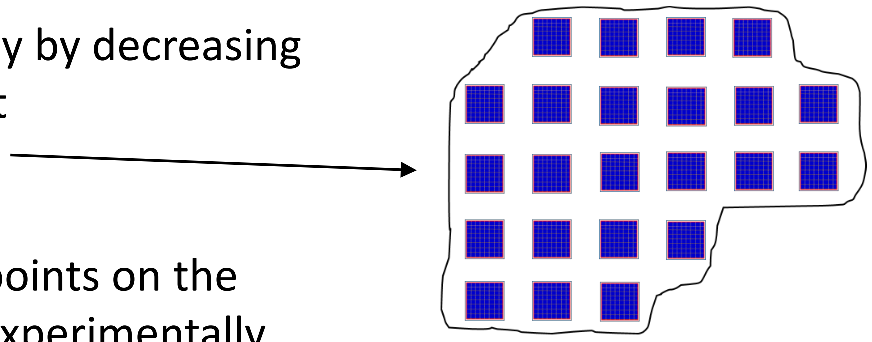
If the price is too high, we could probably save a part of money by decreasing the number of PMTs, placing them not closely side-to-side but with some gaps between them.



Of course, this is only admissible if the calculated number of points on the Cherenkov ring (~20-34), which is high enough, is confirmed experimentally and we may sacrifice a part of the sensitive area of the detector.

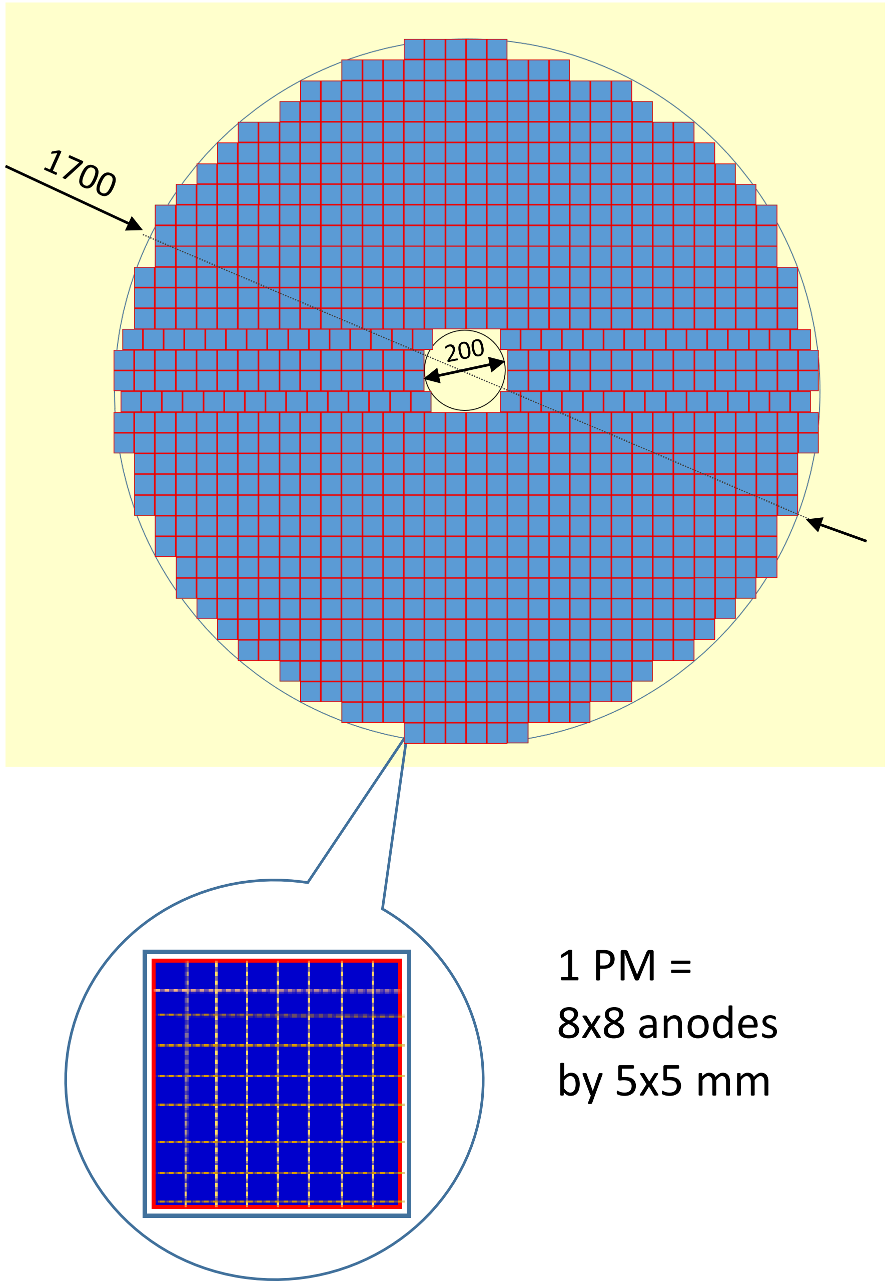
In this way we could reduce the price with coefficient up to 1.5-2.

Front-end electronics: the boards could be developed based on the chip (NINO analog) which is under development for the MRPC-TOF detectors.

With a gain 10^6-10^7 (easily obtained in the Baspik MCP) the signal fits the NINO chip parameters:

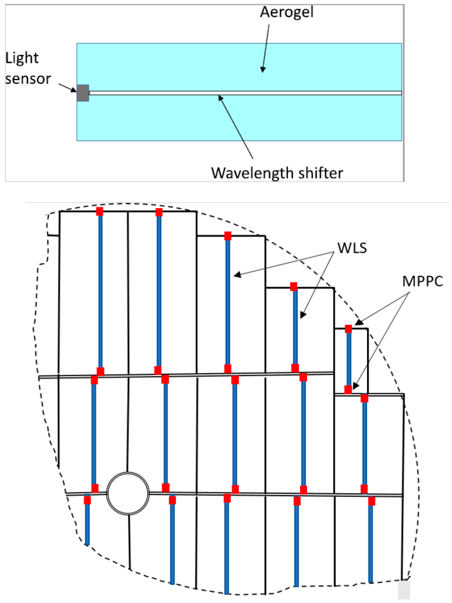
signal range 100fC – 2pC

discriminator threshold 10fC to 100 fC.

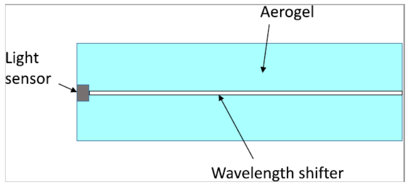


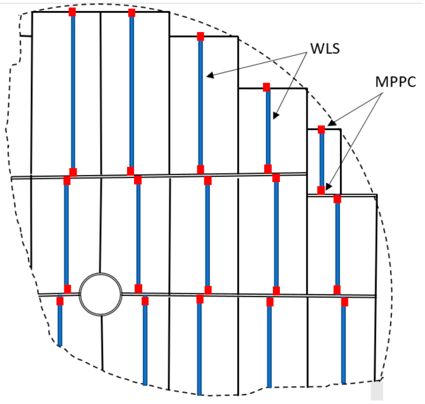
1 PM =
8x8 anodes
by 5x5 mm

Meanwhile, due to uncertainty with the price and availability of the multi-anode MCP PMT, we should not throw away the threshold version of the aerogel counter and keep it as a backup solution.



Whatever version of the Cherenkov endcap will be chosen, the threshold detector or the RICH one, we expect a strong involvement of the Erevan group in development and production of this detector.





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Thank you for attention!