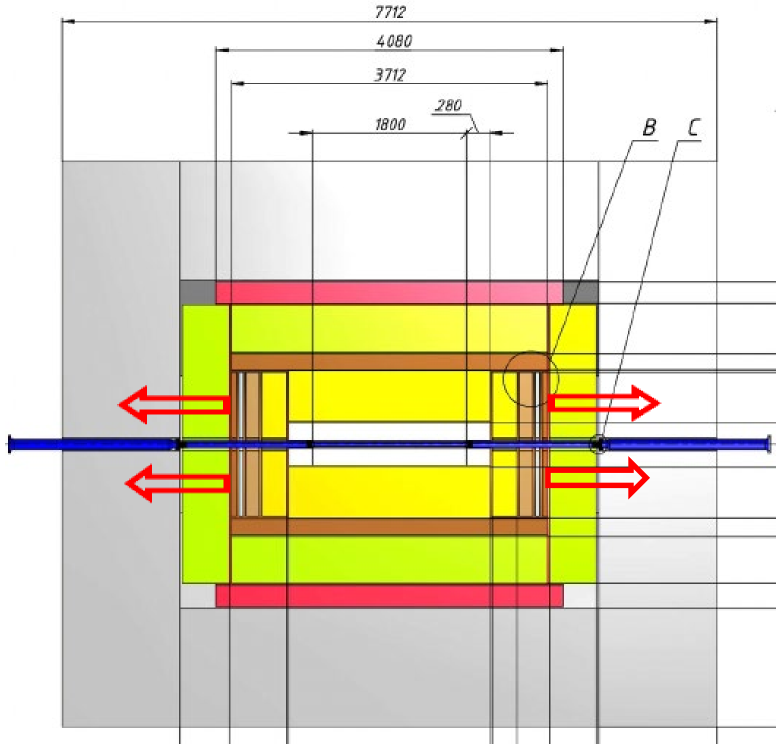
Once more about Cherenkov counters for SPD

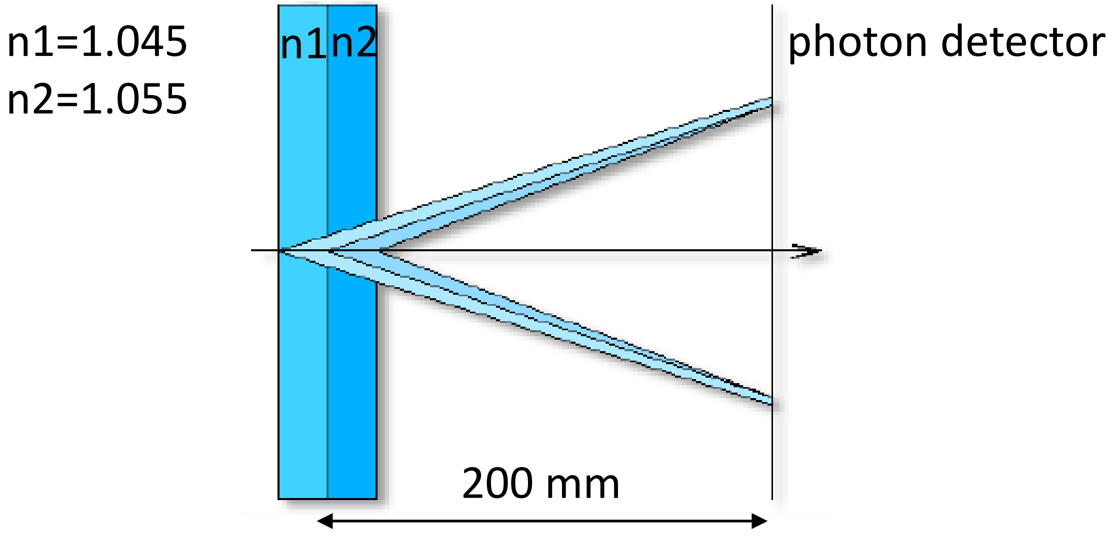
Due to possible increase of dimensions of the SPD setup, the space in the end-cap region available for the aerogel Cherenkov counter could be increased from 160 to ~300 mm.

This could be used to install there more sophisticated Cherenkov detector than suggested in TDR.



In his report on 12.01.2023 Alexander Korsenev considered different options of Cherenkov counters for SPD: threshold detectors, RICH and DIRC.

An attractive option among them for the end-cap region is a focusing aerogel RICH which could provide pi/K separation up to 4.0 GeV/c.
The main problem in constructing such a counter is creation of a photon detector which should be of a large area, ~2 m^2 per each end-cap and with a high granularity (≤ 5x5 mm^2) in order to distinguish the Cherenkov rings from π- and K-mesons at 4.0 GeV/c at the flight base of 200 mm.



There were compared the versions ASHIPH (*a la* KEDR, like in TDR) and ARICH (focusing aerogel)

	ASHIPH (n=1.02) d=80x2 mm	ARICH (n=1.45,1.55) d=20+20 mm
Диапазон K/π разделения	1 -- 2.5 GeV/c	~0.5 – 4.0 GeV/c
Объем аэрогеля, л	800	200
Стоимость аэрогеля	2 M$	0.5 M$
Размер по Z, мм	160	280
Сенсоры	MPPC S13360-3060, 3x3 mm	MPPC array S13361-3050, 8x8, 3x3 mm
PDE, gain	40%, $1.7 \cdot 10^6$	40%, $1.7 \cdot 10^6$
Количество сенсоров	~1 000	~7 000
Цена за шт.	30-40 $	~300 $
Стоимость сенсоров	30-40 k$	~2.1 M$
Число каналов	256	~450 000
Необходимость шифтеров	да	нет
Сложность софт-анализа	нет	да
Стоимость двух эндкапов без электроники	2.4 M$	≥ 3.5 M$

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Hamamatsu MPPC array was considered as a photon detector.

This choice suffers from two disadvantages:

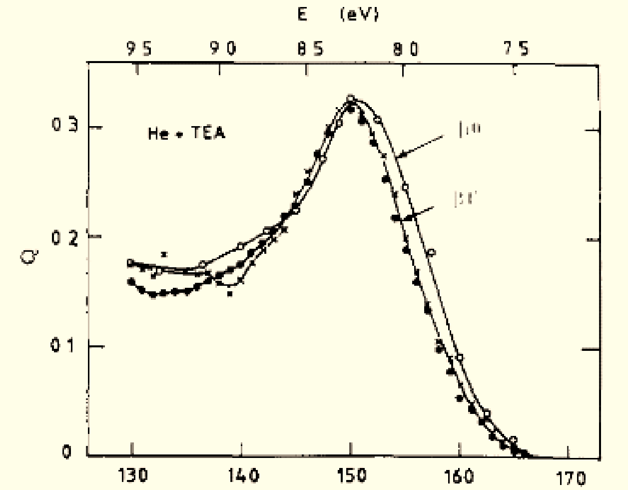
1) it is unlikely that in the current situation Hamamatsu (or Philips or ONSEMI) will agree to provide us with a large number (many thousands) of MPPC arrays.

Maybe even more important:

2) in our case MPPC should detect single photons → this requires very low threshold in electronics, less than 1 photoelectron → → this leads to high noise rate → this causes problems for the trigger-less DAQ.

Another choice could be a **gas photon detector**.

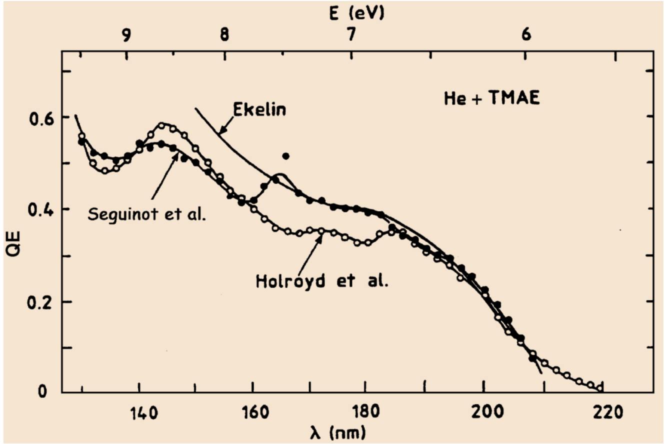
In the first RICH counters with the gas photon detectors there were used gases with photosensitive chemical agents like TMAE [Tetrakis-dimethylamine-ethylene] in the DELPHI and SLD experiments or TEA (Tri-Ethyl-Amin) in CLEO-III.



Quantum efficiency of TEA+He

Though successfully used, these agents have shown serious complications in practical applications:

- they are very toxic
- due to strong chemical activity, a very high purity of gases should be provided (no O_2 or H_2O) and cleanness of surrounding MWPC materials
- high operational temperature (in case of TMAE 40-45^o) in order to have reasonably short photo absorption length.

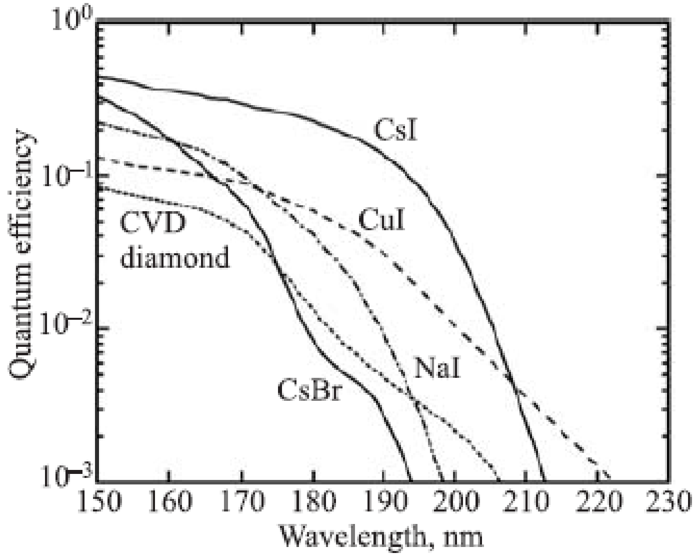


Quantum efficiency of TMAE+He (or Ar) gas

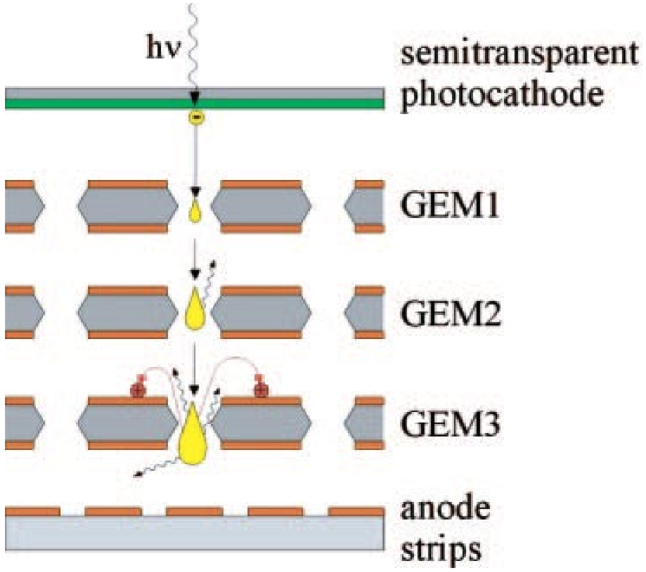
Since 2000s, the experiments started to use the gas photon detectors with solid state photocathodes, the best among them is CsI.

CsI photocathodes are used in conjunction with GEM and/or Micromegas detectors.

CsI photocathode is sensitive in the UV region and has the highest quantum efficiency among other non-transparent UV photocathodes.



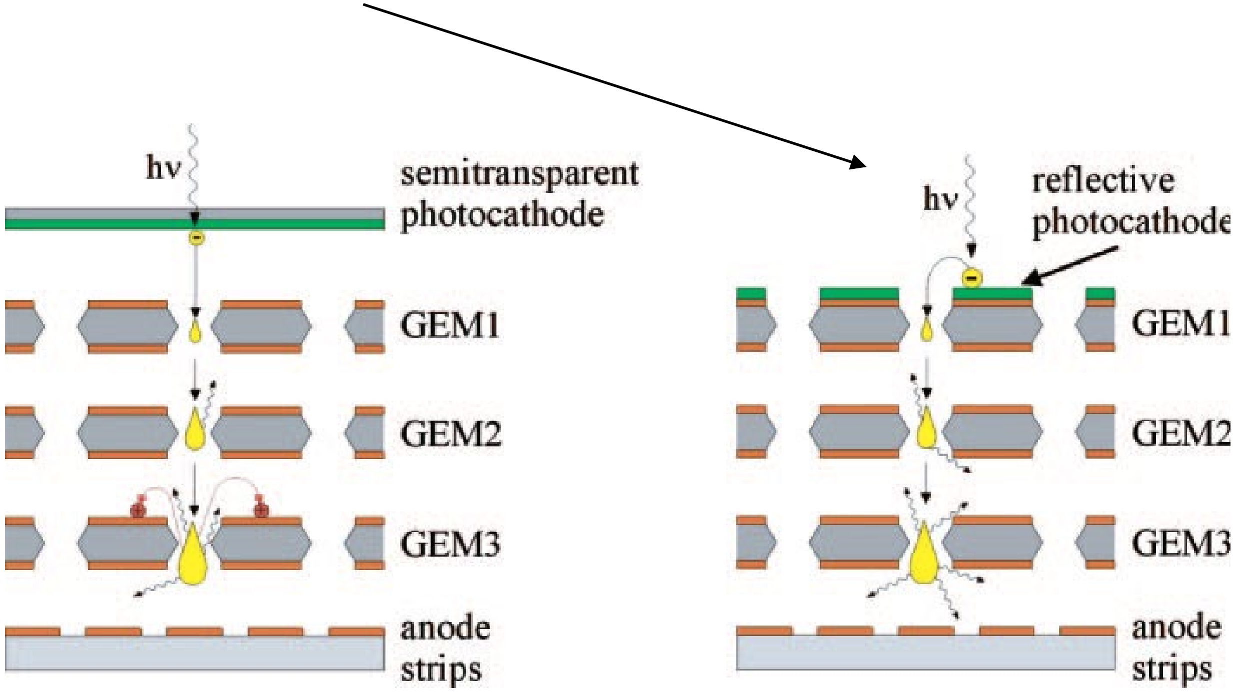
CsI photocathode can be either semi-transparent (evaporated on a layer)



CsI photocathode can be either semi-transparent (evaporated on a layer)

or

reflective (deposited either on the MWPS's cathode plane segmented into small pads or on the first layer of a triple-GEM structure).



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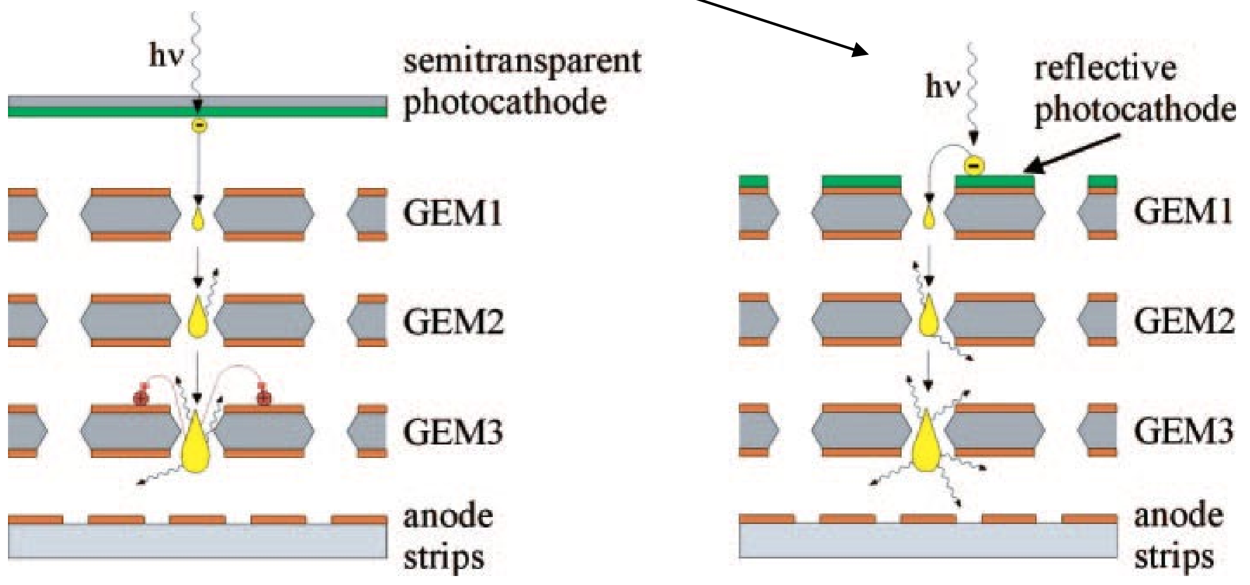
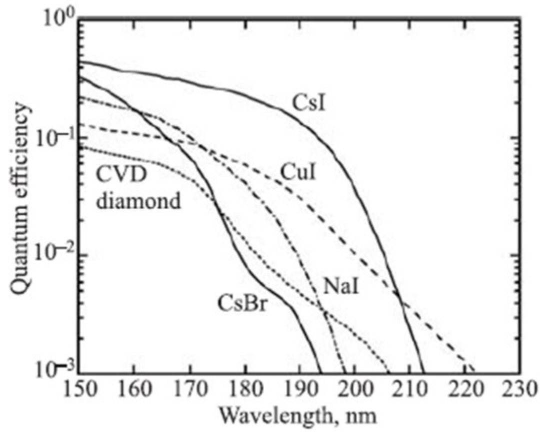


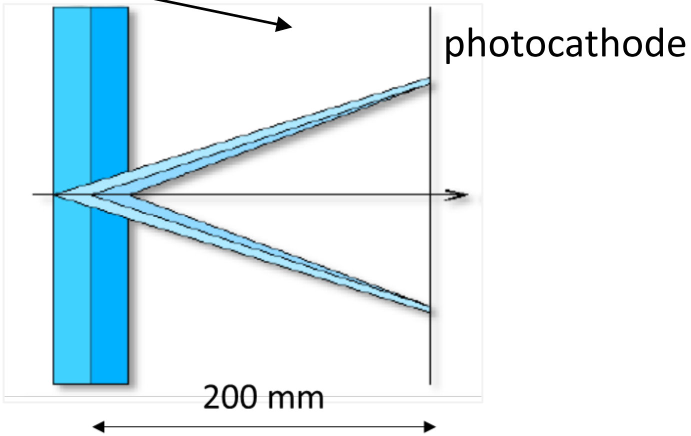
The sensitivity of the reflecting photocathodes is limited to the vacuum part of the UV spectrum, $\lambda < 210$ nm.

The optimum thickness of the CsI layer is 300-500 nm.

As seen in the figure, the quantum efficiency of the CsI photocathode grows with decrease of the wavelength and reaches 40% at λ = 150 nm.



Therefore, the medium between the aerogel and the photocathode should be transparent for VUV.

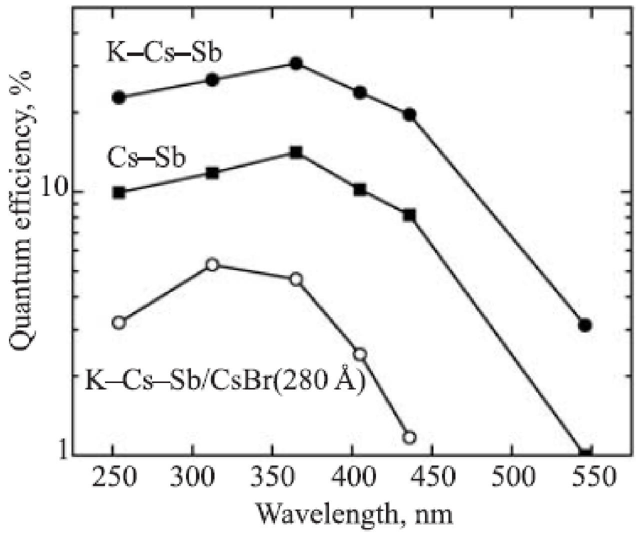


An air is practically non-transparent for the wavelength less than 185 nm.
Therefore, the space between aerogel and photocathode should be filled with another, UV-transparent gas.

A good transparency in the VUV region have noble gases (the lowest cut-off has He – 50 nm), CH_4, CF_4.

Sensitivity to both, visible and UV parts of the Cherenkov spectrum, is achieved with semi-transparent cathodes, in particular, Cs-Sb, Ru_2Te, K_2CsSb.

These cathode materials are very active chemically, react with almost all substances and cannot be exposed to the atmosphere. Therefore, they should be protected with a nano-layer (10 to 30 nm) of CsI or other substances non-interacting with the material of the photocathode. This makes production of such kind of photocathodes very complicated.



Quantum efficiency of the Sb-Cs and bialkali photocathodes

The technology of thin film photocathode production, both reflective and semi-transparent ones, has been well developed at CERN already 20 years ago [A.Braem et al., NIM A502 (2003) 205]. At that time it also existed in Roma and Munich.

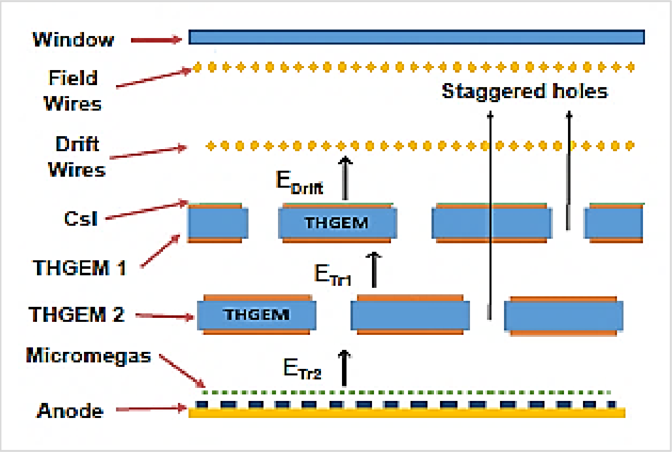
At the CERN facility, CsI photocathodes of up to 60x60 cm^2 could be produced.

A detector for measuring coordinates of the photoelectrons and hence to obtain the points on the Cherenkov ring could be one of micro-pattern gas detectors like GEM, Thick GEM, Micromegas or conventional MWPC.
In all cases a cathode pad readout should be arranged.

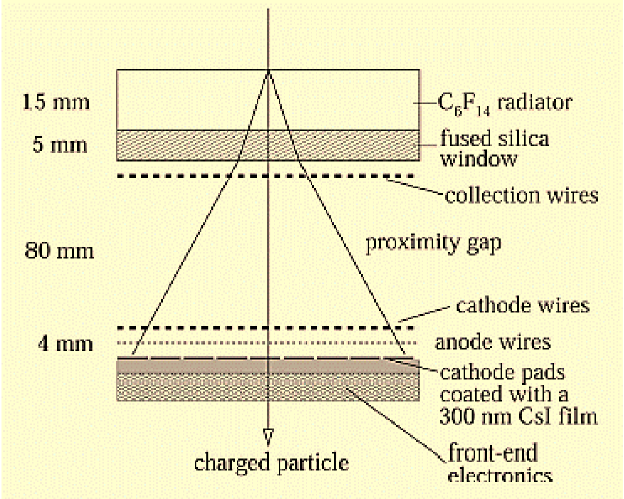
In our case (200 mm expansion gap), in order to distinguish the rings from pions and kaons at 4 GeV/c, the pads not more than 5x5 mm^2 are required.

RICH detectors with CsI reflective photocathodes and gas detectors have been implemented in ALICE,COMPASS, HADES, STAR.
In all these detectors the CsI active area exceeds 1m^2 (in ALICE the largest, 11m^2).

Examples:



Scheme of the COMPASS RICH-1



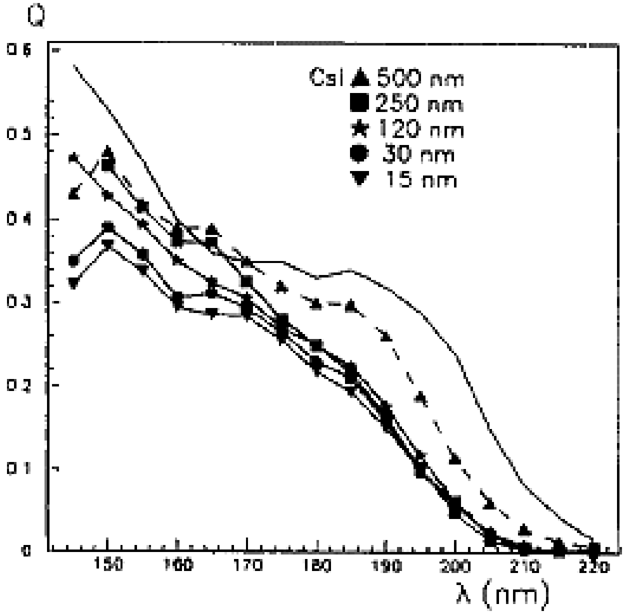
Scheme of the ALICE RICH

Let us estimate the number of hits on the Cherenkov ring in SPD end-cap.

$\cos\theta = 1/\beta n$

$N = 2\pi\alpha l\,(1/\lambda_1 - 1/\lambda_2)\,\sin^2\theta$ – number of Cherenkov photons emitted in the range between λ_1 and λ_2 on the length l.

We take λ_1=140 nm, λ_2=180 nm, n=1.05, l=4cm.



Quantum efficiency of reflective CsI photocathodes of different thicknesses.

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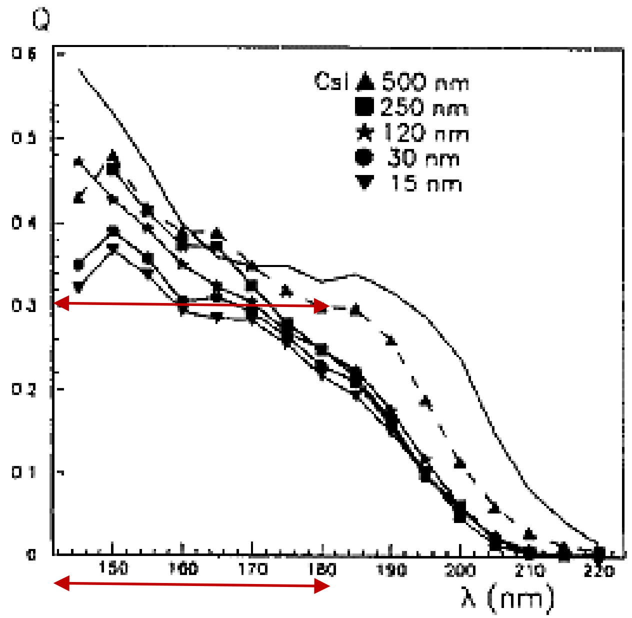
Quantum efficiency of a CsI photocathode in the range from 140 to 180 nm is ~30%.



Quantum efficiency of reflective CsI photocathodes of different thicknesses.

Momentum, GeV/c	β_π	β_K	β_p	$\sin^2\theta_\pi$	$\sin^2\theta_K$	$\sin^2\theta_p$
1	0.99	0.897	0.729	0.0745	---	---
2	0.998	0.97	0.905	0.0893	0.036	---
3	0.999	0.987	0.954	0.0911	0.0689	0.0033
4	0.999	0.992	0.974	0.0911	0.0783	0.0439

Momentum, GeV/c	N ph. π	N ph. K	N ph. p	**Np.e. π**	**Np.e. K**	**Np.e. p**
1	217	---	---	**65**	**---**	**---**
2	260	105	---	**78**	**32**	**---**
3	265	200	10	**80**	**60**	**3**
4	265	228	128	**80**	**68**	**38**

N ph. – number of Cherenkov photons

Np.e. – number of photoelectrons at the input of coordinate detector (if no absorption in a gas)

Np.e.=number of points on the Cherenkov ring.

Momentum, GeV/c	R_π	R_K	R_p	**ΔR π-K**	**ΔR K-p**	**ΔR π-p**
1	58	---	---	**---**	**---**	**---**
2	63	39	---	**24**	**---**	**---**
3	63	54	12	**9**	**42**	**51**
4	63	58	43	**5**	**15**	**20**

$R_{\pi,K,p}$ – radius of the Cherenkov ring **in mm** at the 200 mm distance (i.e. on the coordinate detector)

Strong and weak sides of the Aerogel RICH with a CsI gas photodetector in SPD

PRO	CONTRA
Increased momentum of identification (compared with the TDR threshold version)	Extensive R&D is required
4 times less amount of expensive aerogel (compared with TDR)	
No costly MPPC	Necessary to find a high quality producer of thin film coating (CsI)
Less noise inherent in MPPC	
There is experience of using GEM and Micromegas in JINR	

Let us compare the versions of aerogel counters in the end-caps of SPD.

	Threshold counter	RICH with MPPC (two different MPPC sizes)		RICH with CsI
	n=1.02 d=2x80 mm	n=1.45, 1.55 d=20+20 mm		
Range of PID, GeV/c	1-2.5	1-4.5	1-3.5	1-4.0
Aerogel volume, l	800	200		
Light sensors	Hamamatsu MPPC S13360-3060	Hamamatsu MPPC array S13361-3050	Hamamatsu MPPC array S13361-6050	CsI + GEM/Micromegas
Pixel size, mm	3x3	3x3	6x6	5x5
N channels	256	~450 000	~110 000	~160 000
N p.e.	10	up to 65		up to 80
Noise		High noise probable (threshold should be less 1 p.e.)		
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Questions:

- shall we start R&D activity? For which of the options?
- who (or which group) is interested to participate/to be a leader?

Thank you for attention