Development a picosecond MCP based particle detector

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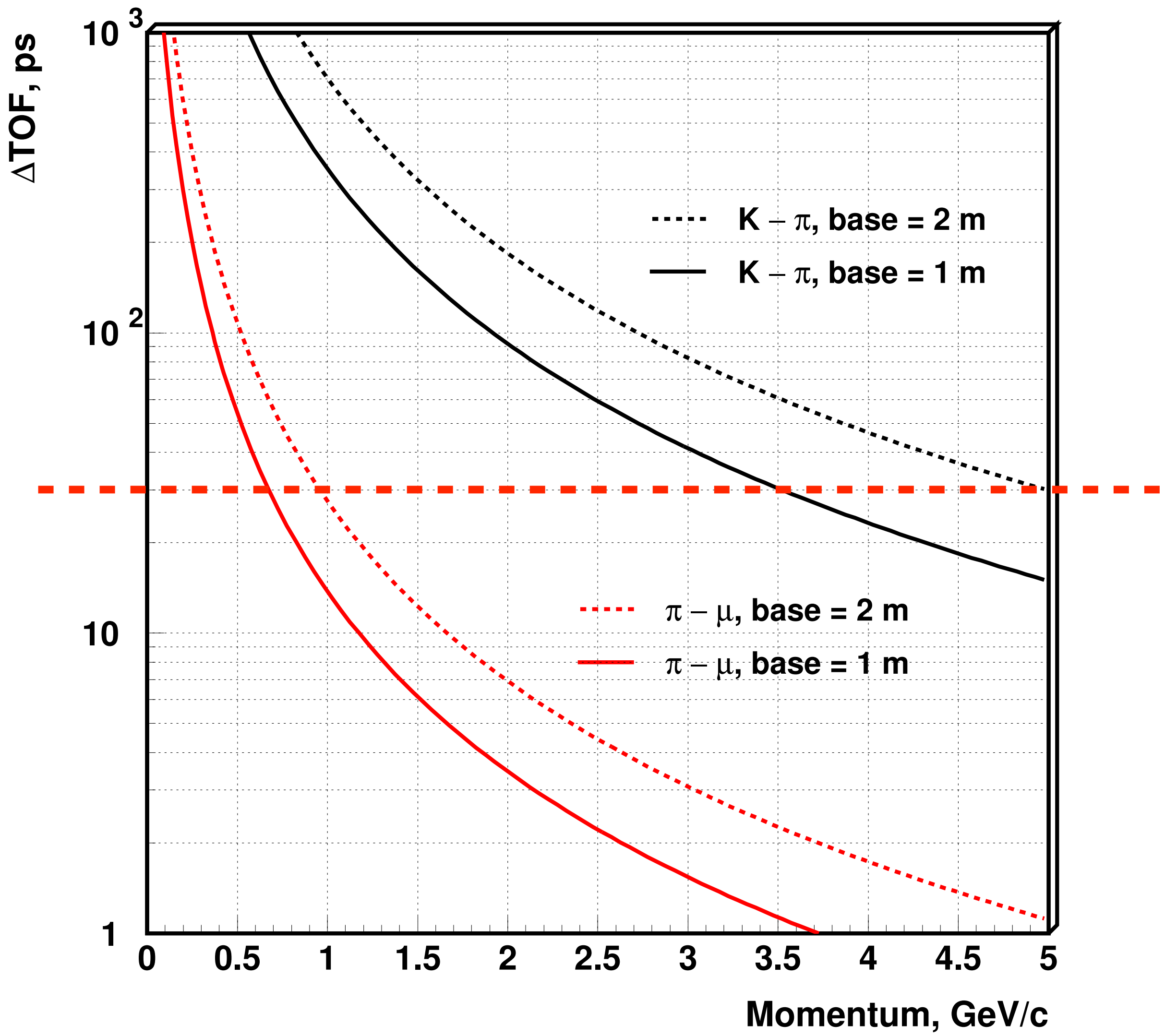
Outline

- Motivation
- Conception
- $N_{ph.e.}$ estimation
- Tests in magnetic field
- Prototyping
- Summary

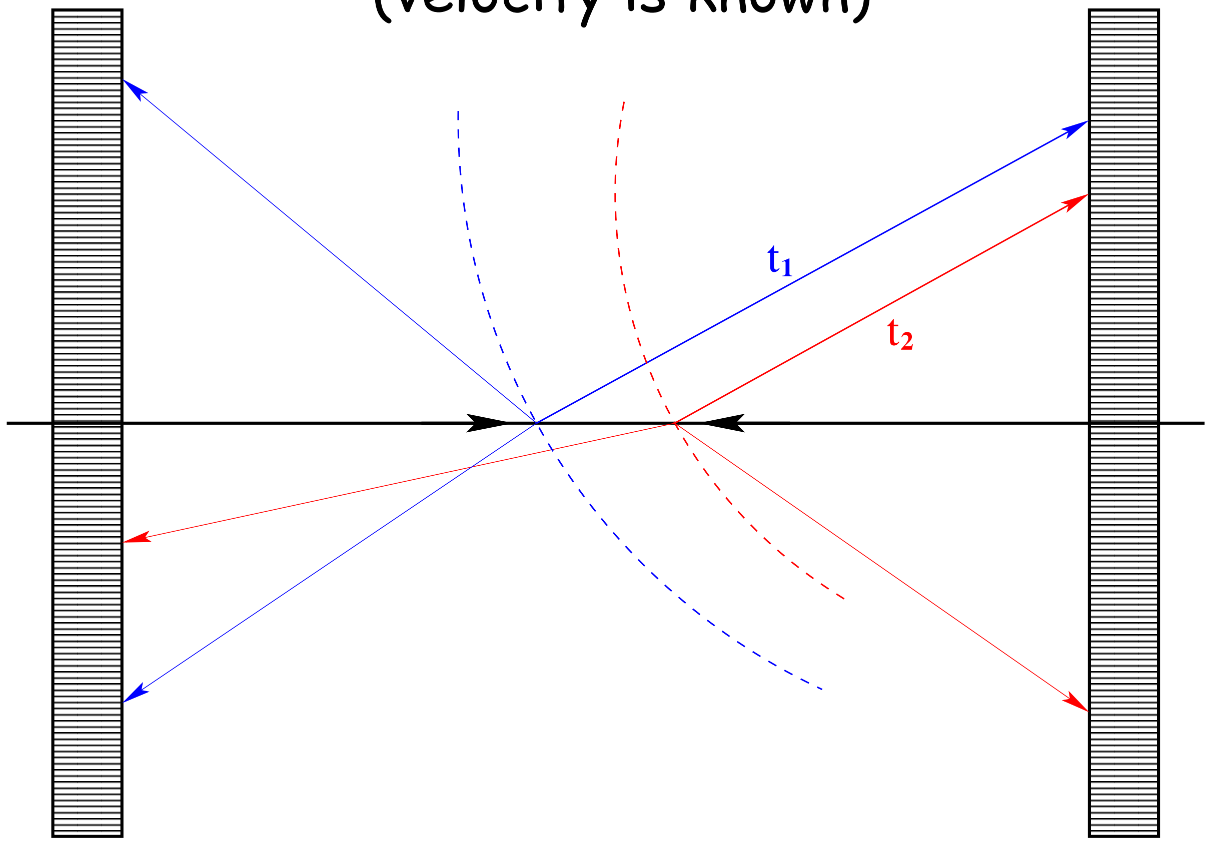
Motivation

Time of flight measurement can provide:

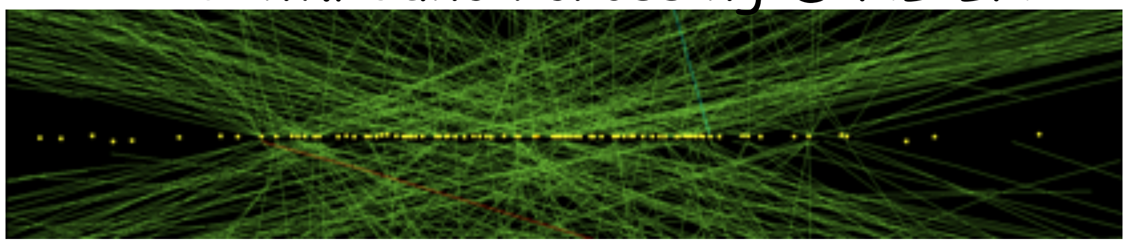
Measurement of velocity => PID
(flight distance is known)



Measurement of distance => VERTEX
(velocity is known)



~140 int./bunch crossing @ HL-LHC

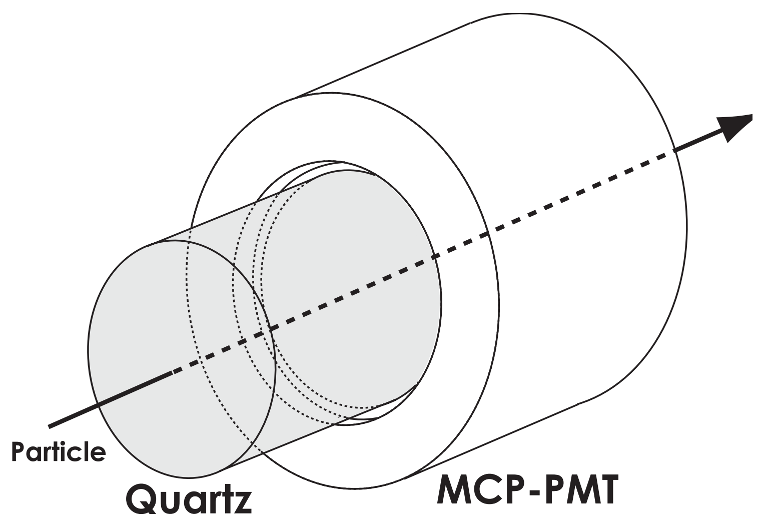


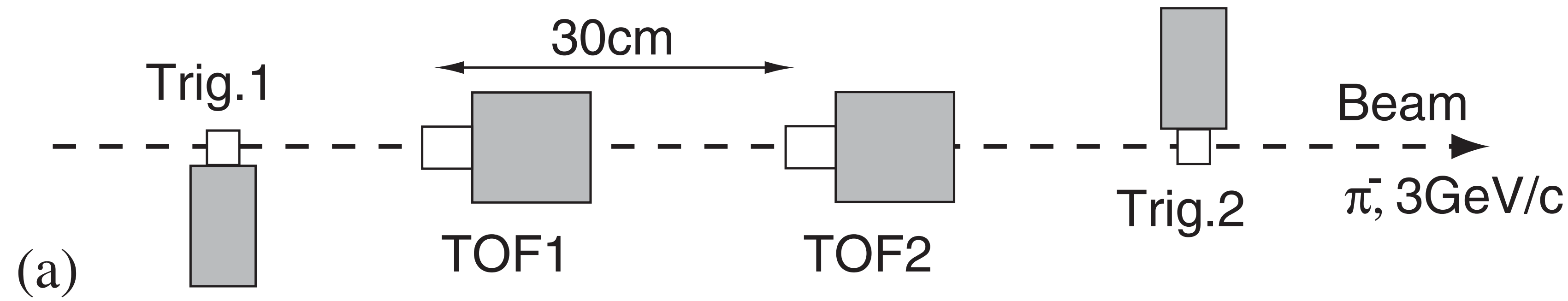
$\sigma_t \approx 10$ ps, 1 m distance
=> π/K separation up to 3.5 GeV/c

$\sigma_t \approx 10$ ps, $\beta = 1$
=> position resolution ~ 3 mm

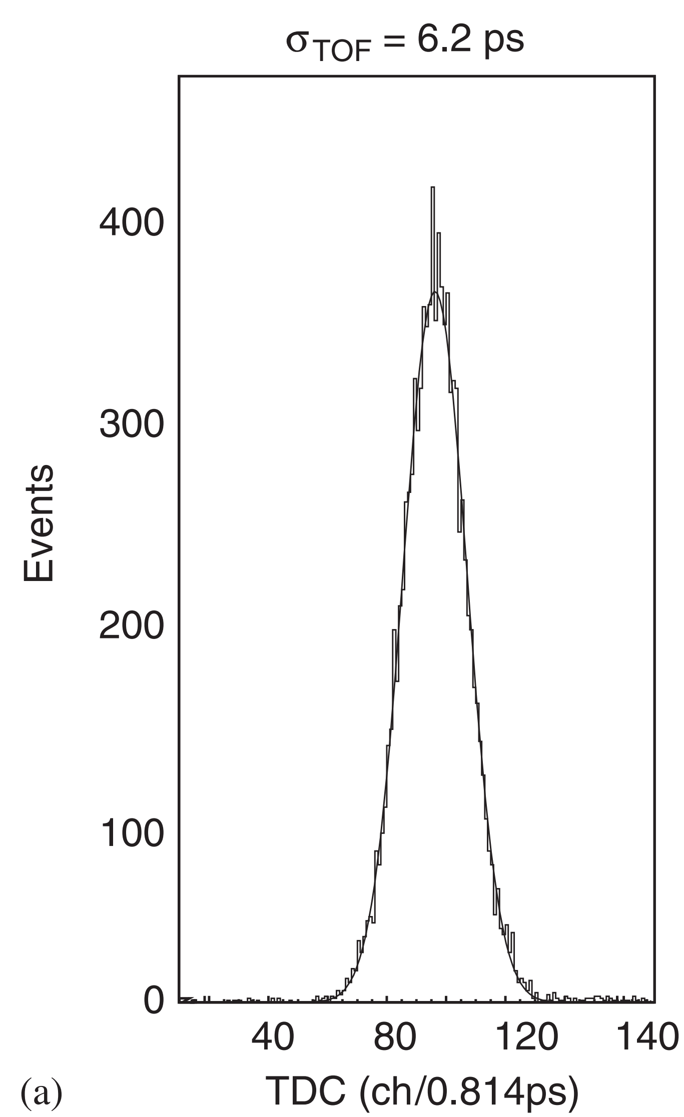
A 5 ps TOF counter

K. Inami et al., «A 5 ps TOF-counter with an MCP–PMT», NIM A 560 (2006) 303–308





- Hamamatsu MCP PMT
- MCP channel dia. = 6 μm
- Photocathode dia. = 11 mm
- Multialkali photocathode
- Quartz radiator ~1 cm thick



σ_{TOF} = 6.2 ps
while $\sigma_{circuit}$ = 4.1 ps

=> $\sigma_{intrinsic}$ ~ 4.7 ps

Requirements to the detector

(for endcap EMC of CMS at HL-LHC)

- sensitive area ~ 10x10 cm
- 100% efficiency to MIP
- ~ 10 ps time resolution for single MIP
- anode segmentation ~ 1 cm
- operation in magnetic field ~ 4 T
- lifetime > 10^{14} MIPs/cm^2
- radiation hardness > 10^{15} n_{eq}/cm^2

Conceptual design

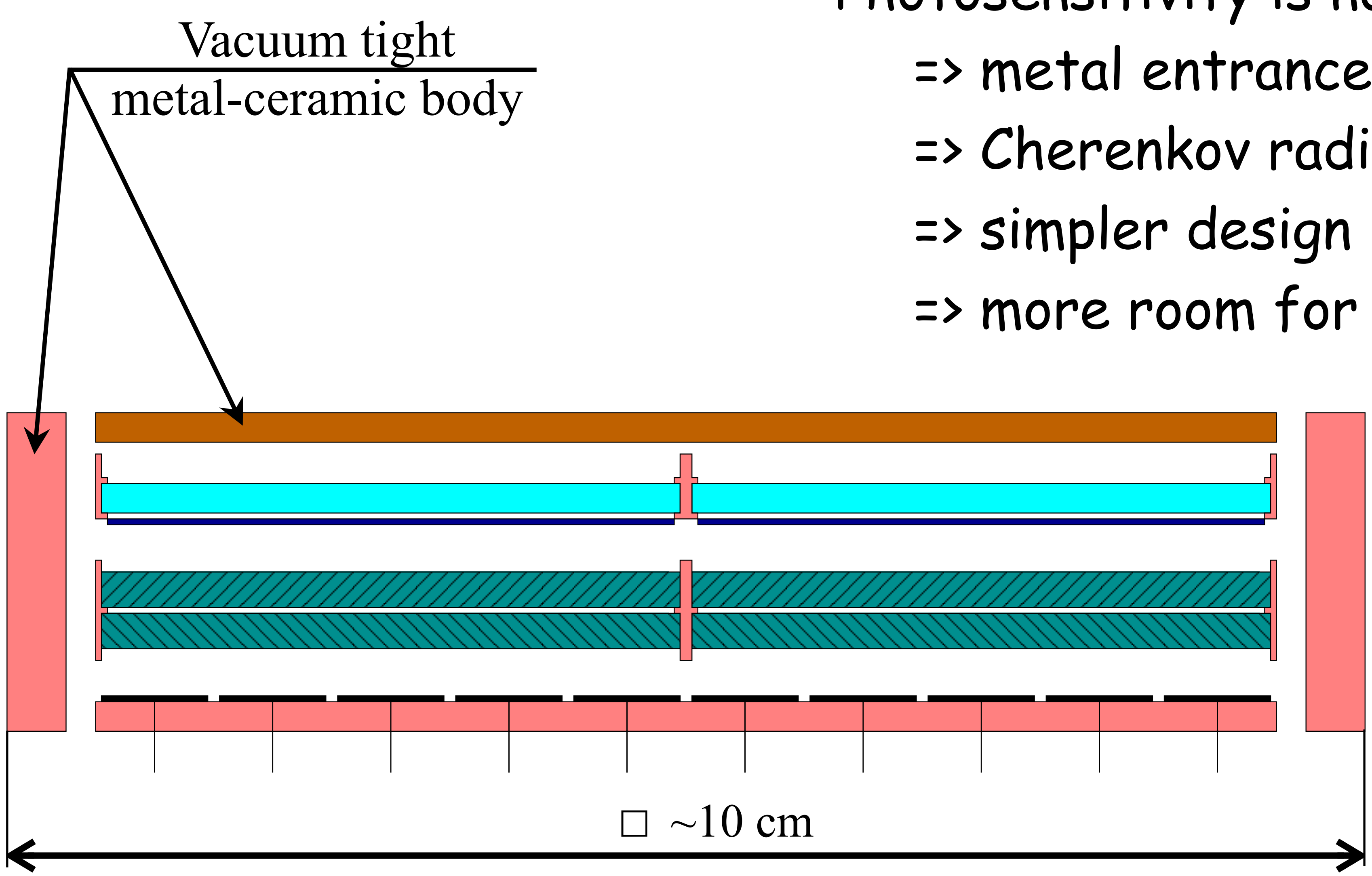
Photosensitivity is not needed:

=> metal entrance window

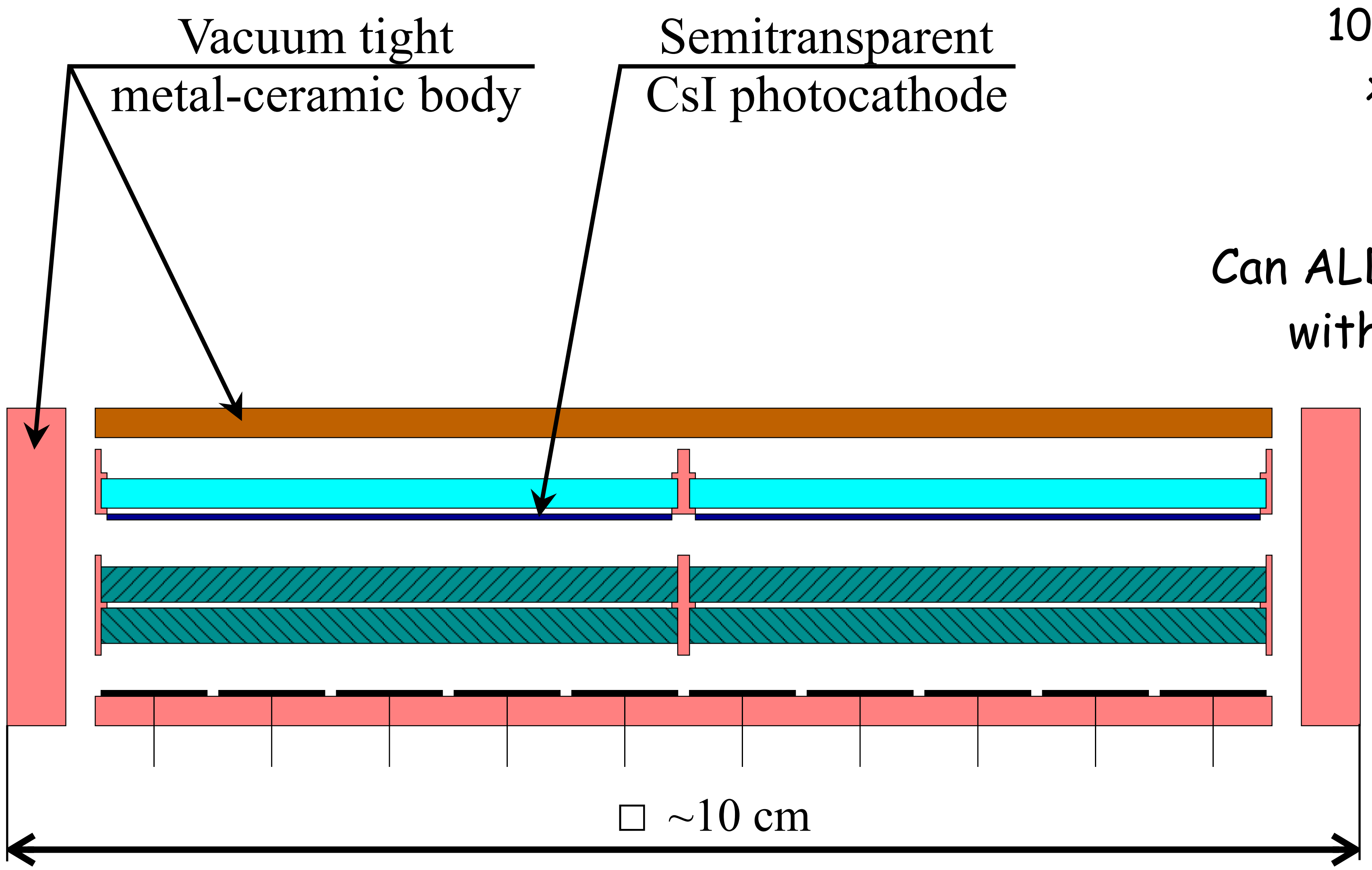
=> Cherenkov radiator inside vacuum volume

=> simpler design

=> more room for radiator optimization



Conceptual design



Lifetime:

10^{14} MIPs/cm^2

x 10 photoelectrons/MIP

x 10^6 gain x e

~ 200 C/cm^2

Can ALD MCP provide such lifetime with alkali-antimonide photocathode?

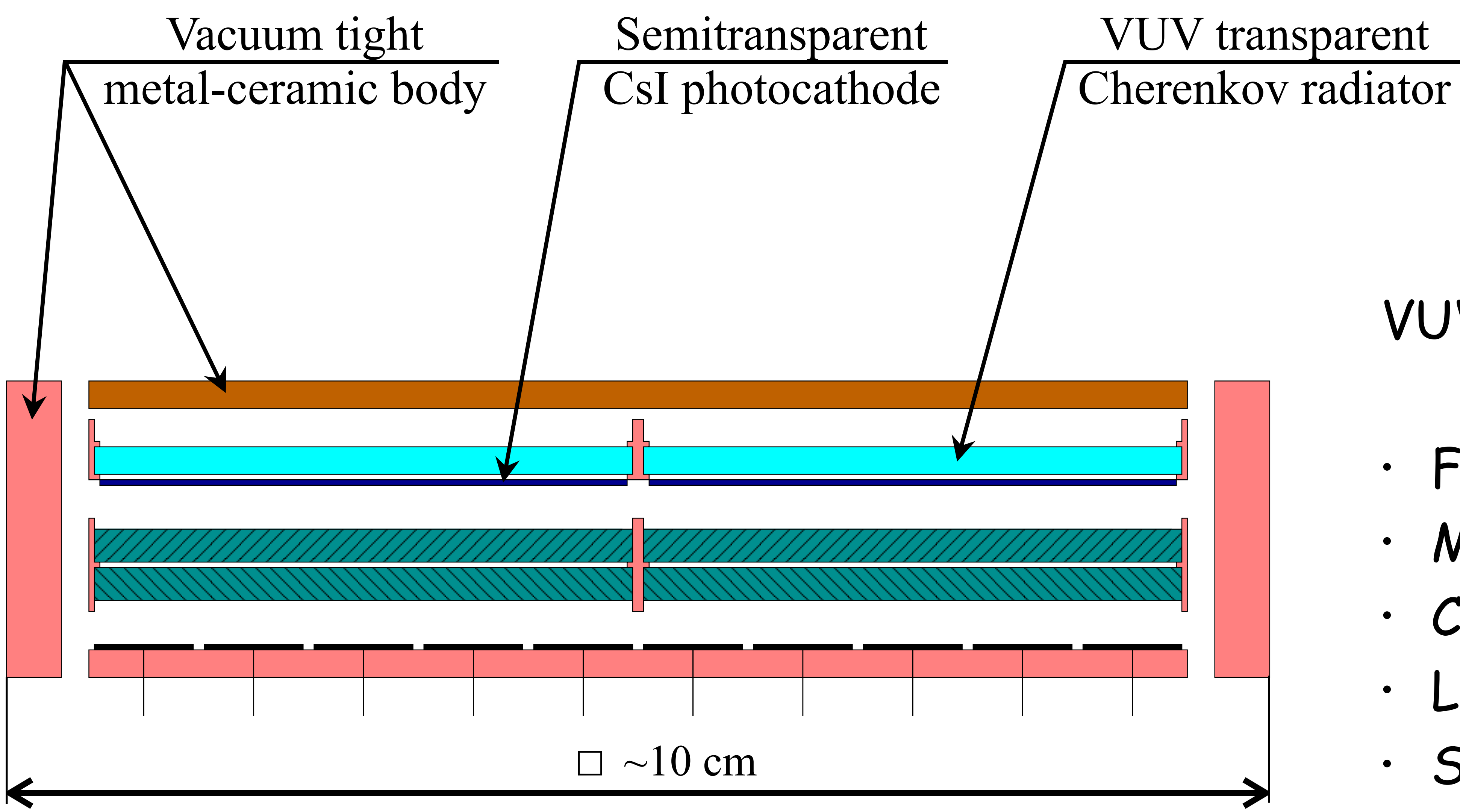
What about more stable photocathode?

=> CsI

Another reason:

simpler production and manipulation on large area

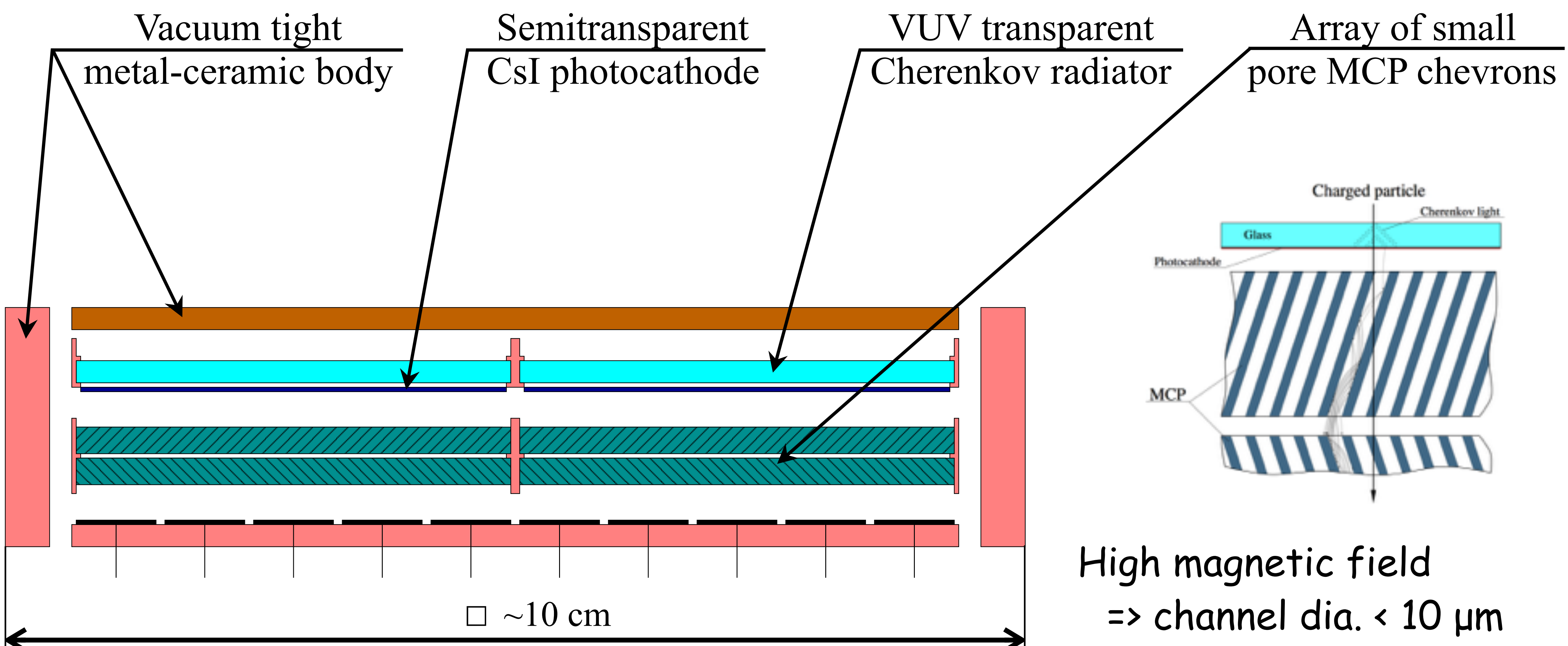
Conceptual design



VUV transparent materials:

- Fused silica SiO_2
- MgF_2
- CaF_2
- LiF
- Sapphire Al_2O_3

Conceptual design

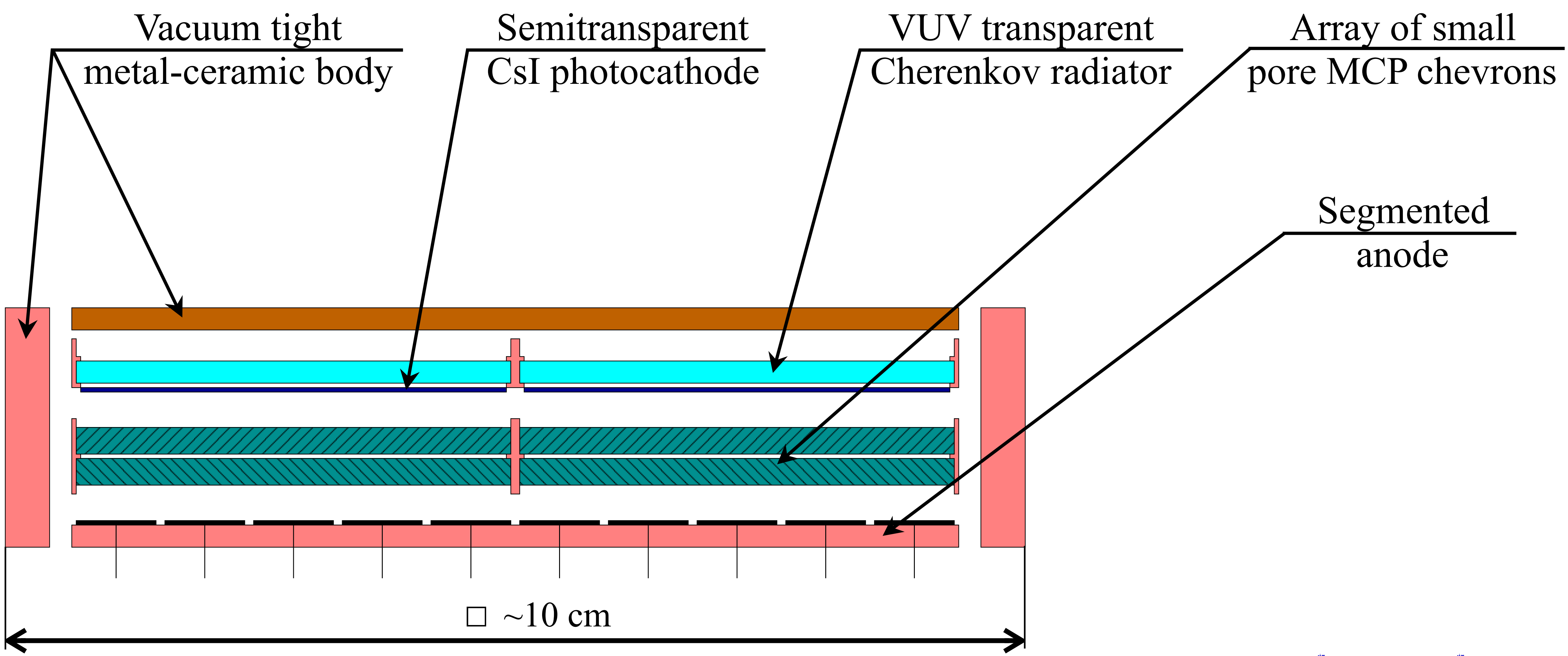


High magnetic field
=> channel dia. < 10 μm
Aspect ratio L/d = 40-60
=> MCP thickness ~ 0.5 mm

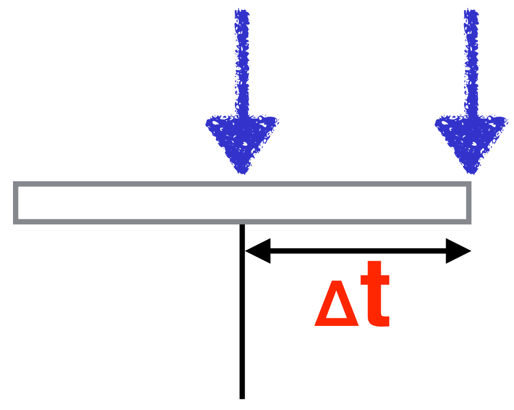
Problem:
mechanical stability of large size MCP.

Solution:
array of «small» MCPs inside single vacuum volume.

Conceptual design

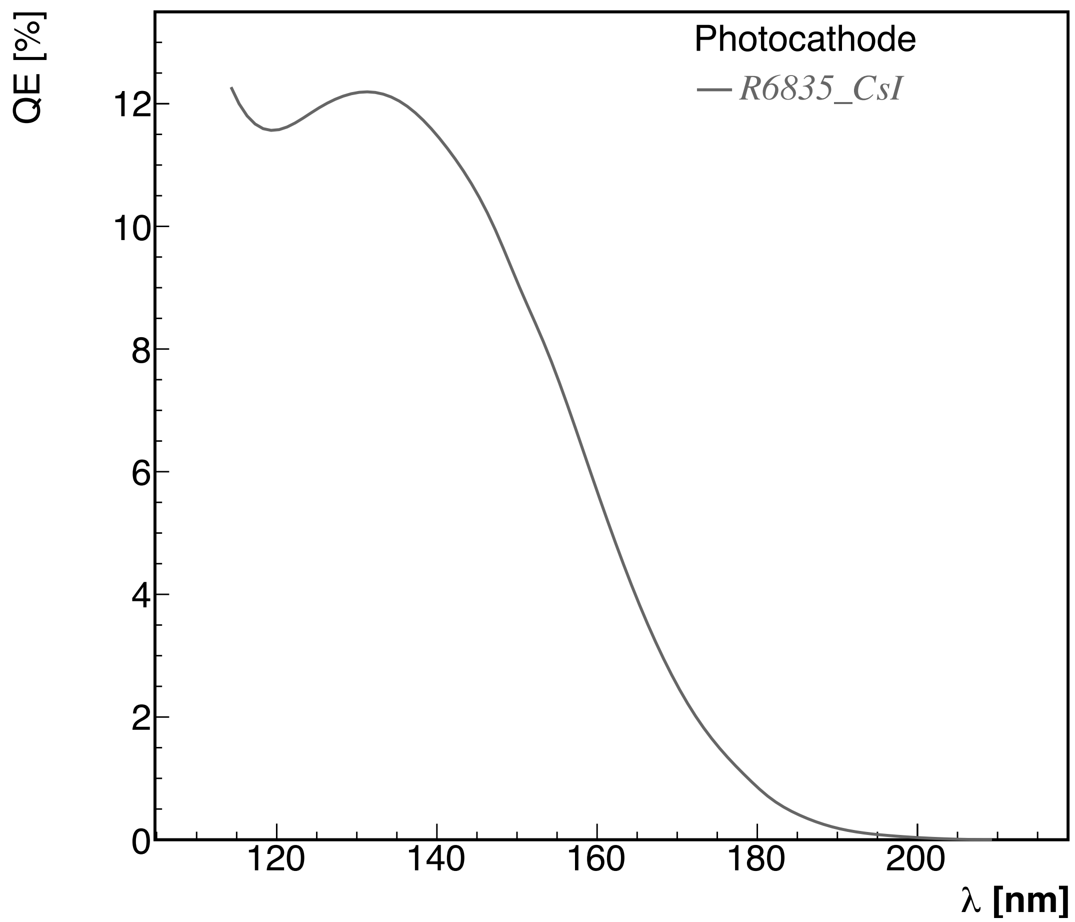


Anode size should be small enough
to avoid degradation of time resolution
~ 1 x 1 cm

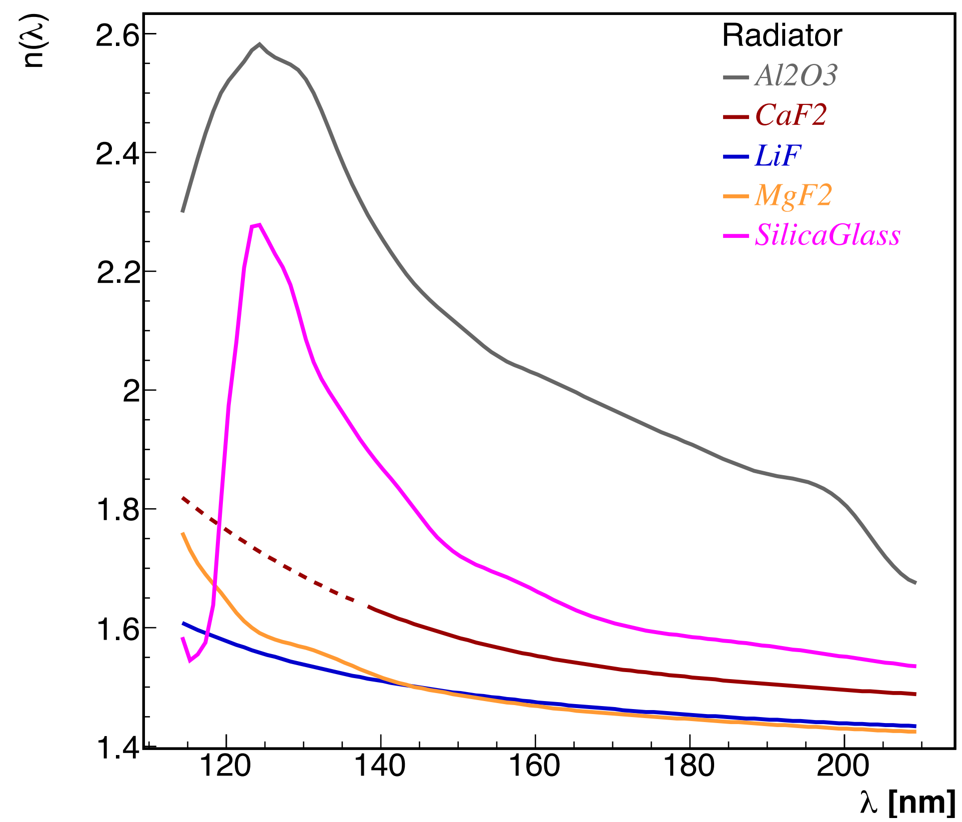


$N_{ph.e.}$ calculation

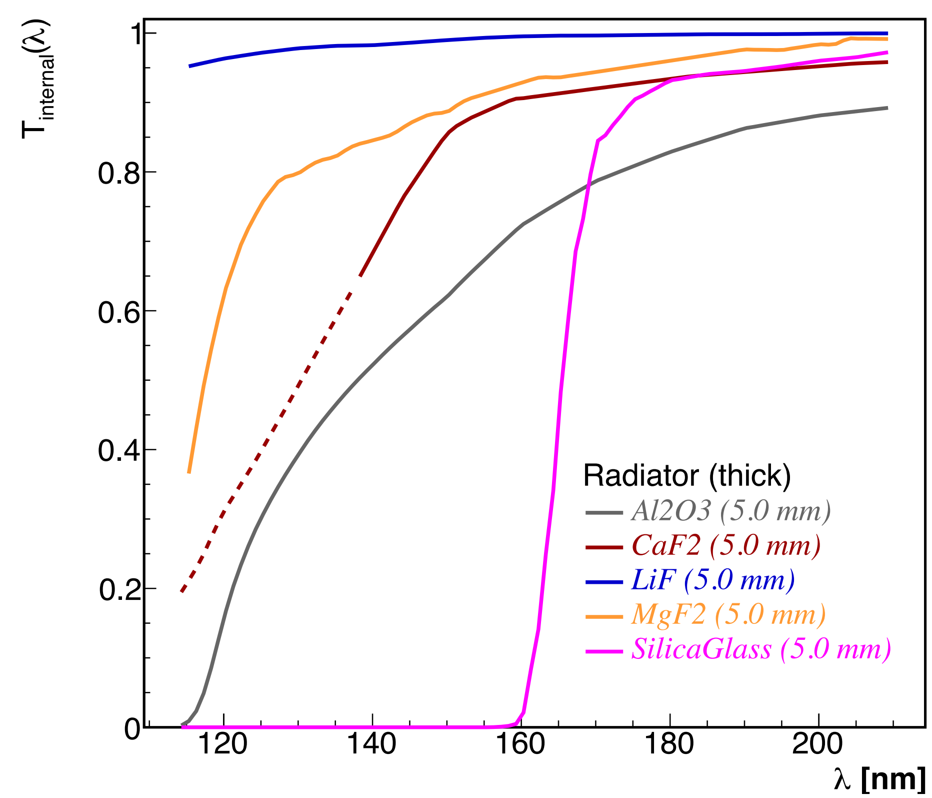
Analytical calculation of the number of photoelectrons and duration of the light pulse



QE of CsI photocathode
from specification
of Hamamatsu R6835 PMT

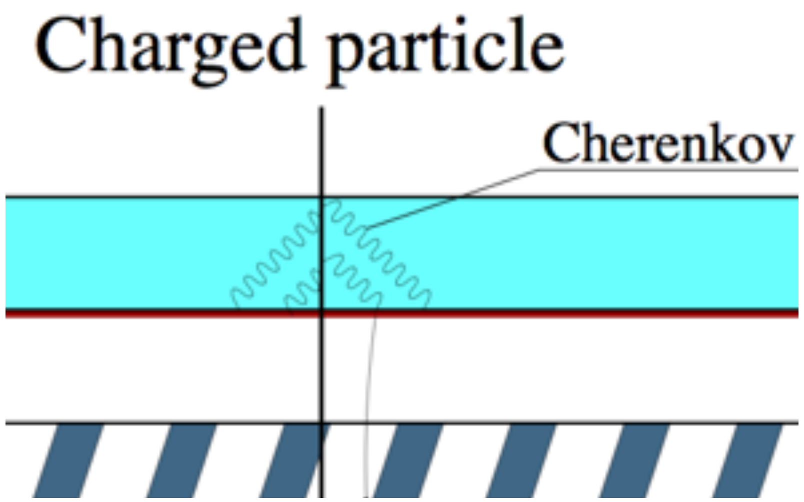


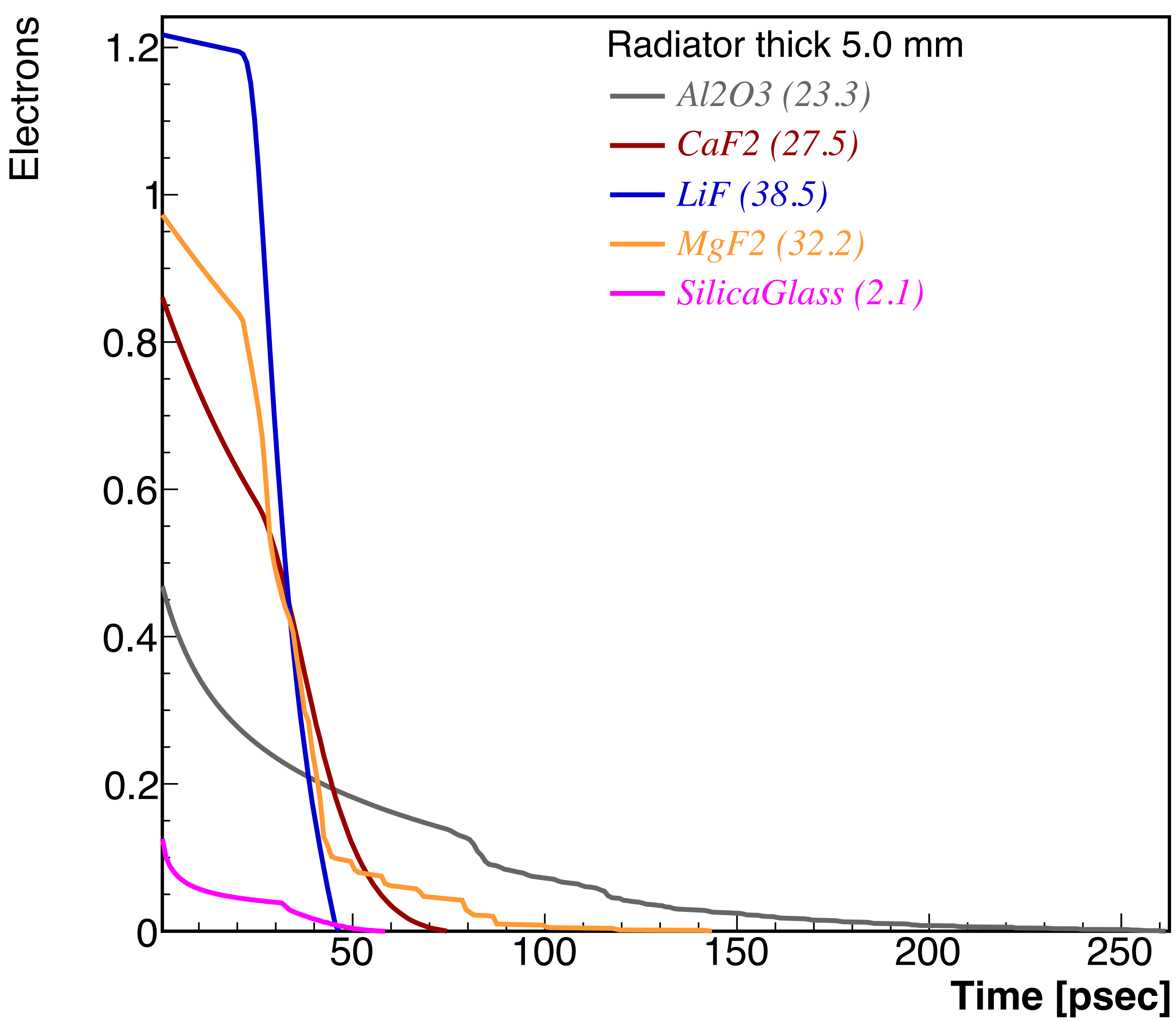
Refractive index
from publications



Internal
transparency
from publications

Results of calculations





Material	Total number of detected photons
LiF	23.1
MgF_2	19.3
CaF_2	16.5
Al_2O_3	14.0
Silica glass	1.3

MCP open area ratio = 60%

MCP time resolution ~30 ps

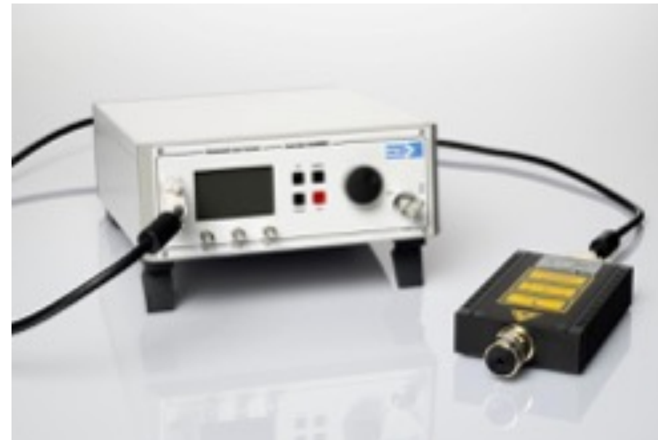
=> useful light pulse width σ < 30 ps

5 mm thick MgF_2 radiator provides ~ 20 ph.e. during first 50 ps

=> σ_t < 10 ps is expected

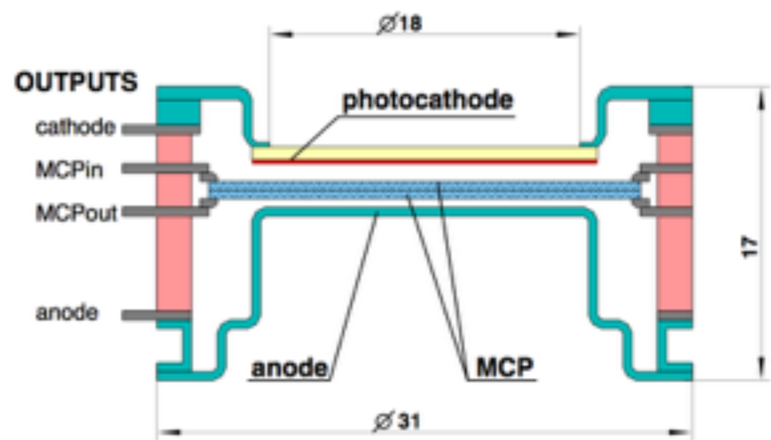
Magnetic test setup

SC solenoid with B up to 4.5 T



PiLas laser:

- λ = 823 nm
- FWHM = 30 ps



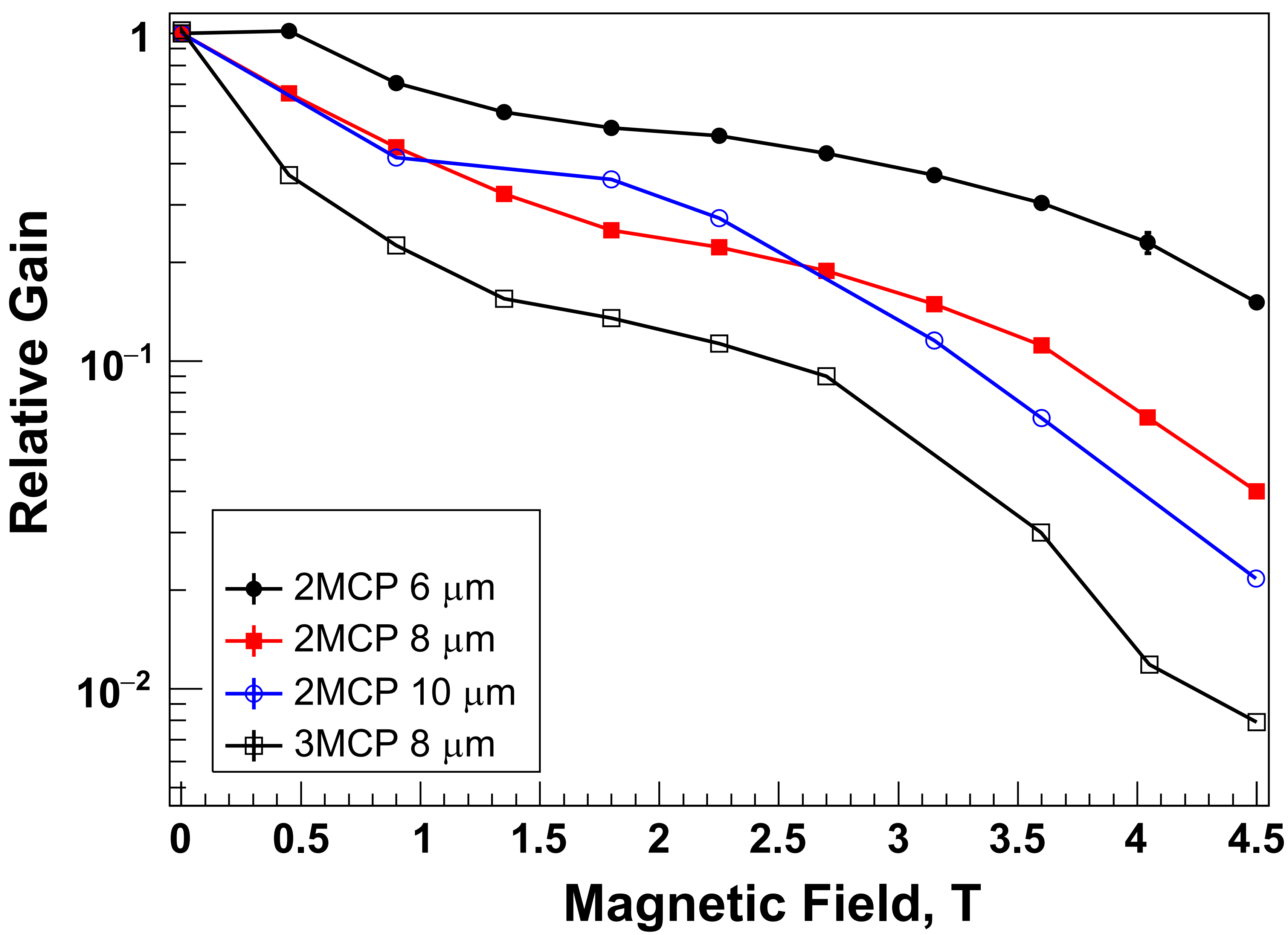
MCP PMT

- multialkali ph.c. ⌀18mm
- 2 or 3 MCPs
- 6, 8, 10 μm channel dia.

CAEN V1742 digitizer

- 12 bit ADC
- 5 GS/s

Magnetic test results

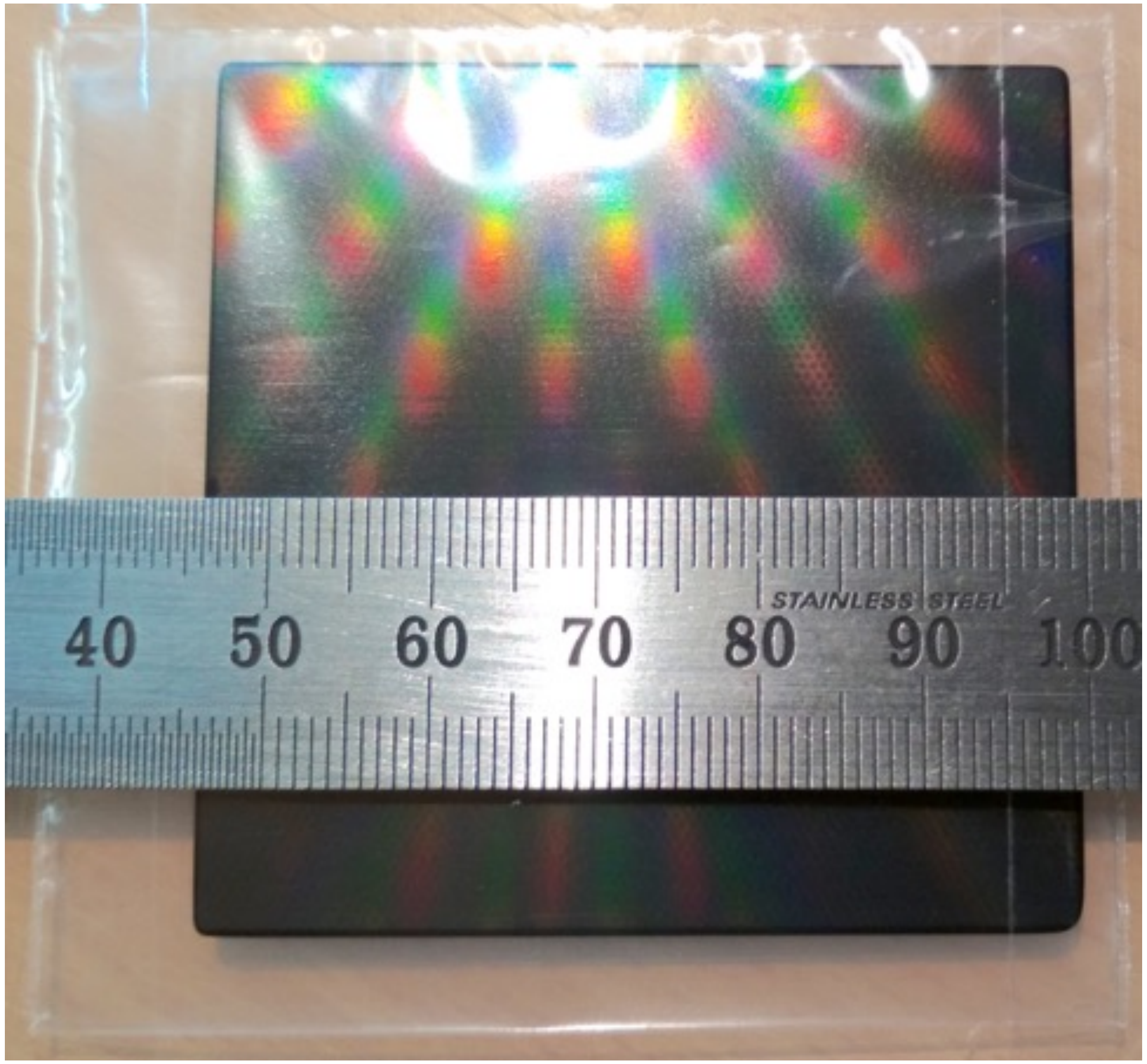


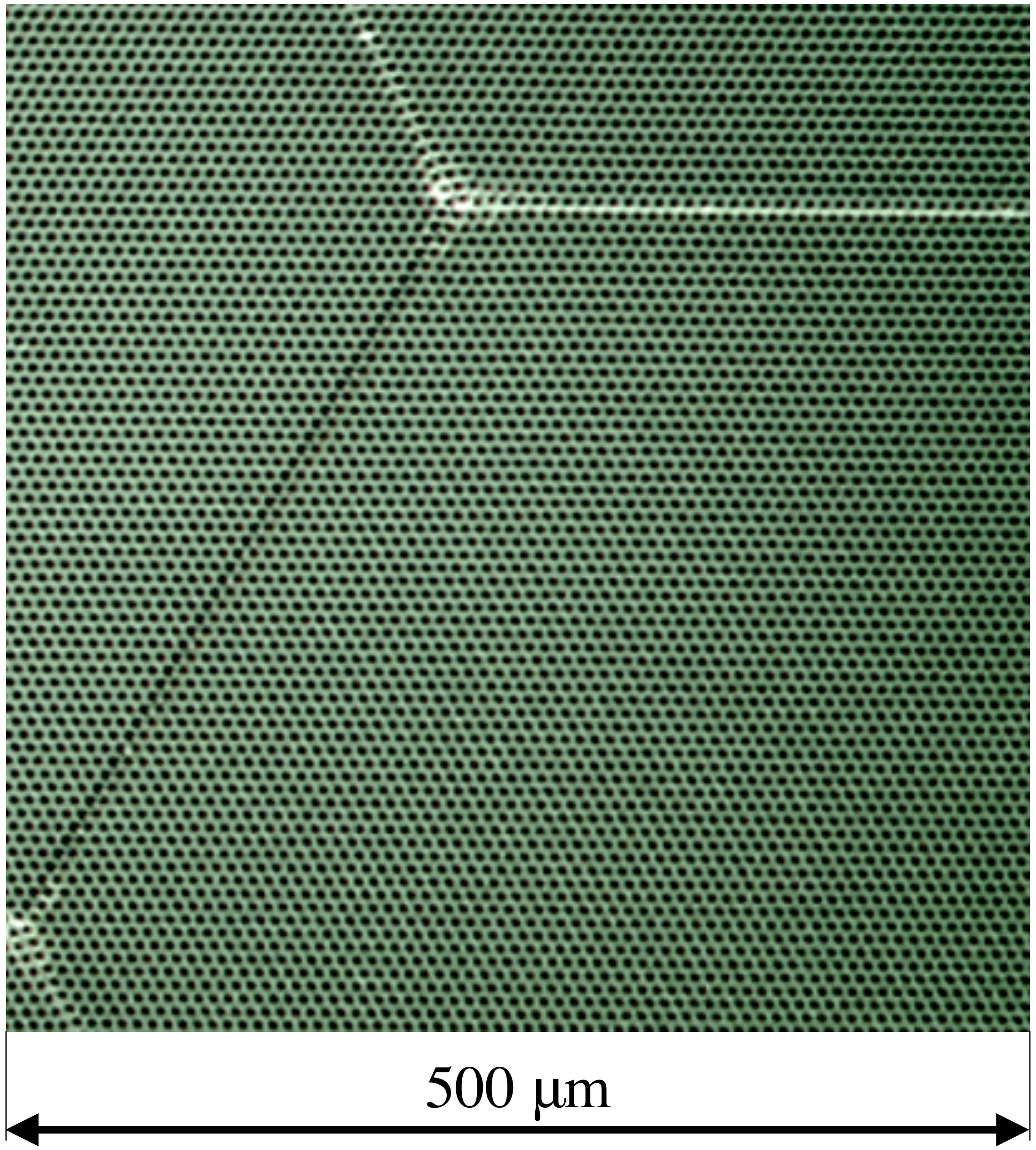
MCP type	Gain degradatin @ B=4T
Two MCPs 6 μm	4 times
Two MCPs 8 μm	15 times
Two MCPs 10 μm	25 times
Three MCPs 8 μm	80 times

A. Yu Barnyakov et al., NIM A845 (2017) 588-590

MCP 54x54-6

First sample of 5x5 cm MCP with 6 μm channel
developed by «Baspik» company (Vladikavkaz, Russia)

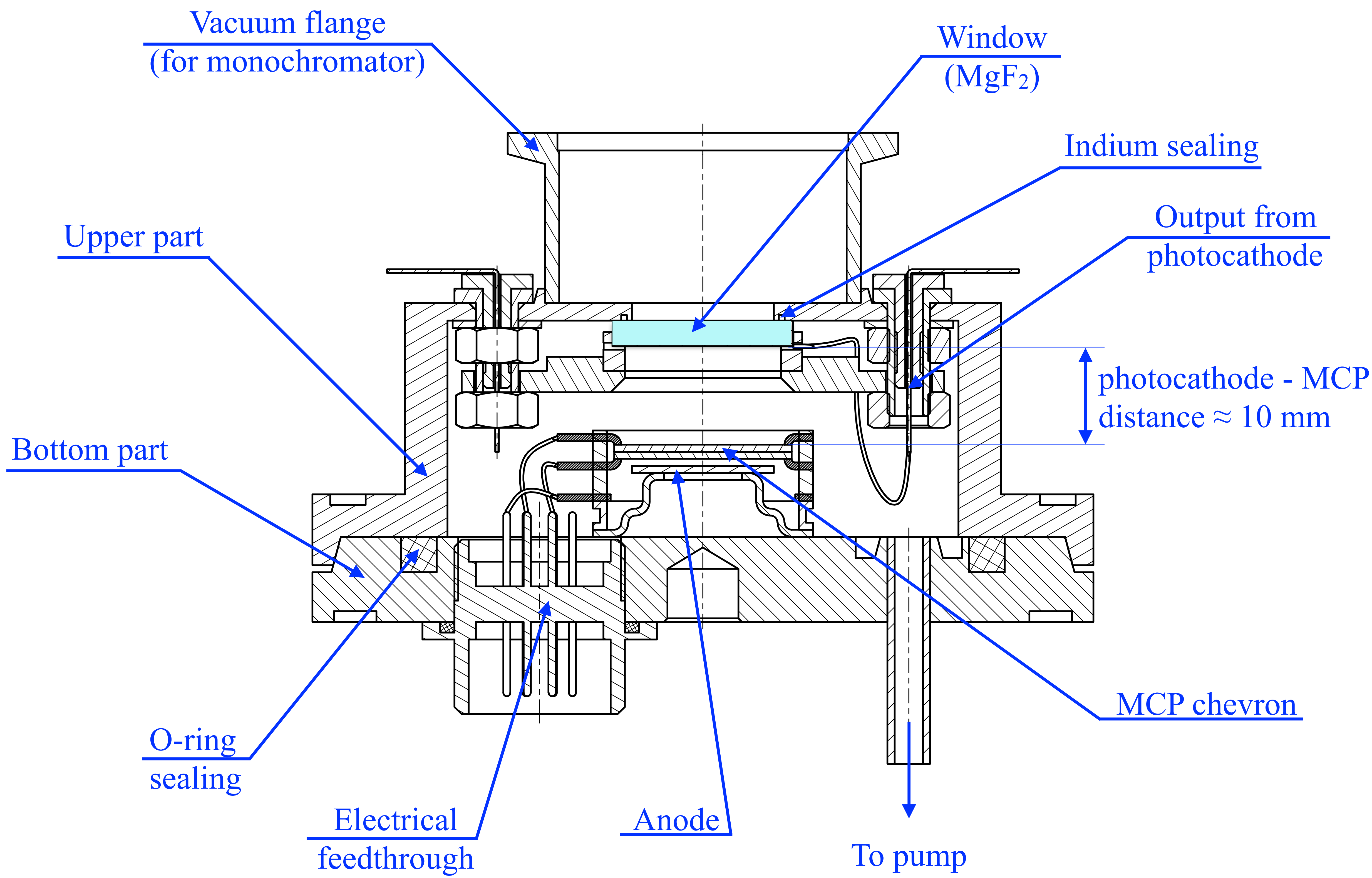




- MCP size 54.5 x 54.5 mm
- MCP thickness 390 μm
- channel diameter 6.3 μm
- open area ratio 67%
- gain >2000
- resistance 10 MΩ

"Small" prototype

for photocathode production mastering



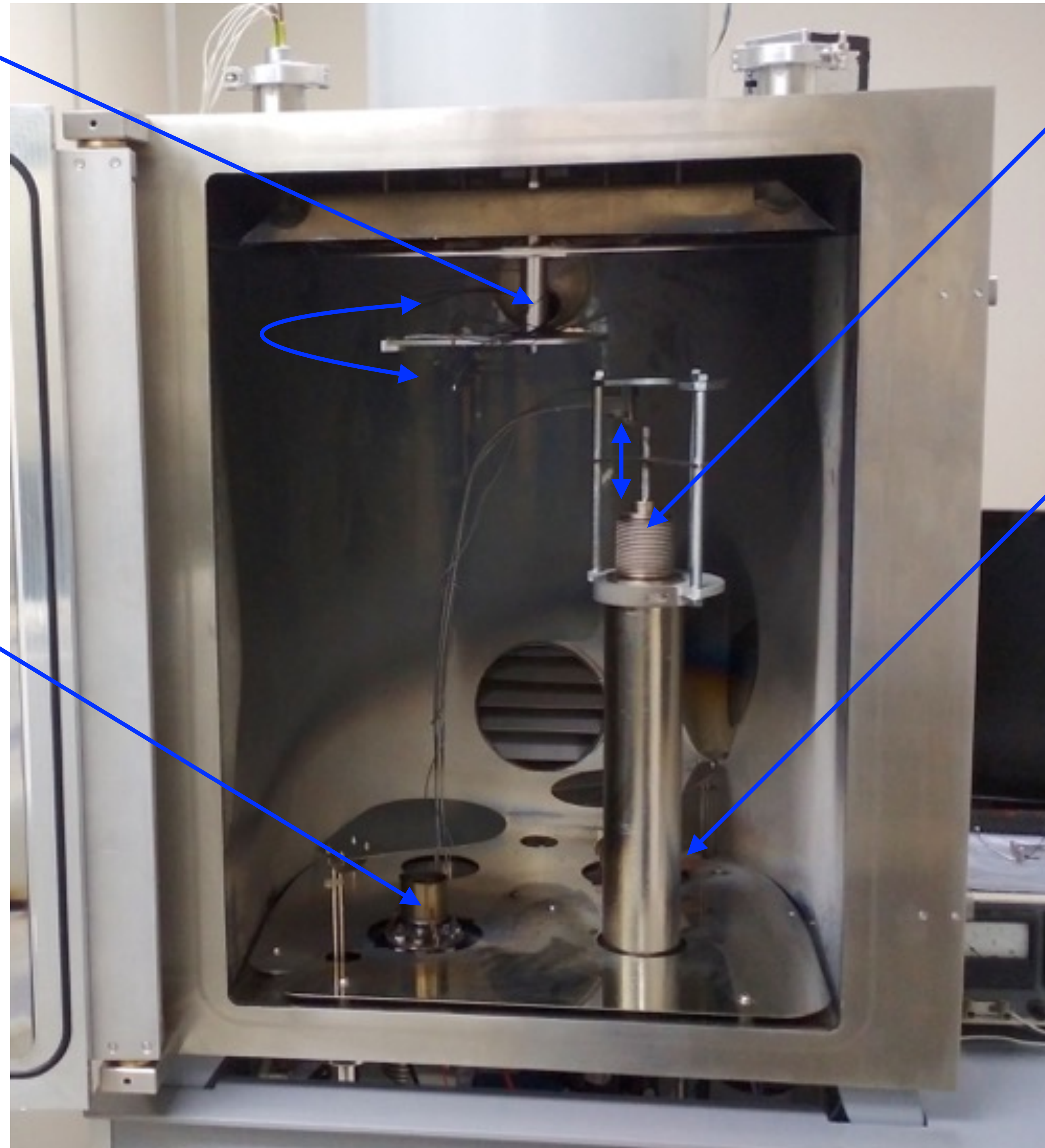
CsI photocathode production

Rotating holder
=> wafer positioning

Vertical movement
=> prototype closing

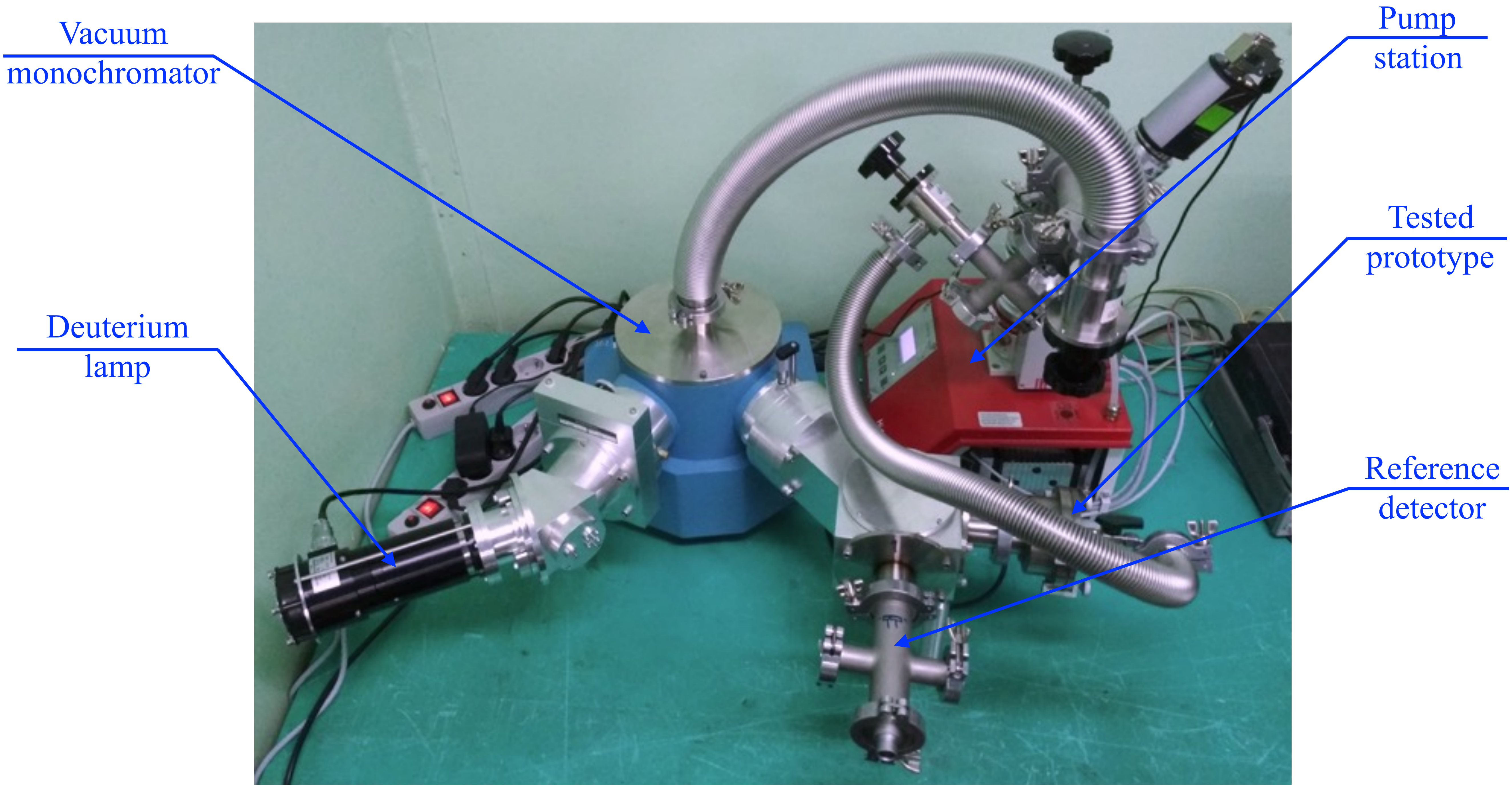
Resistive evaporator
=> CsI deposition

Electron beam
evaporator
=> deposition
of semitransparent
electrode(Cr, Ni)



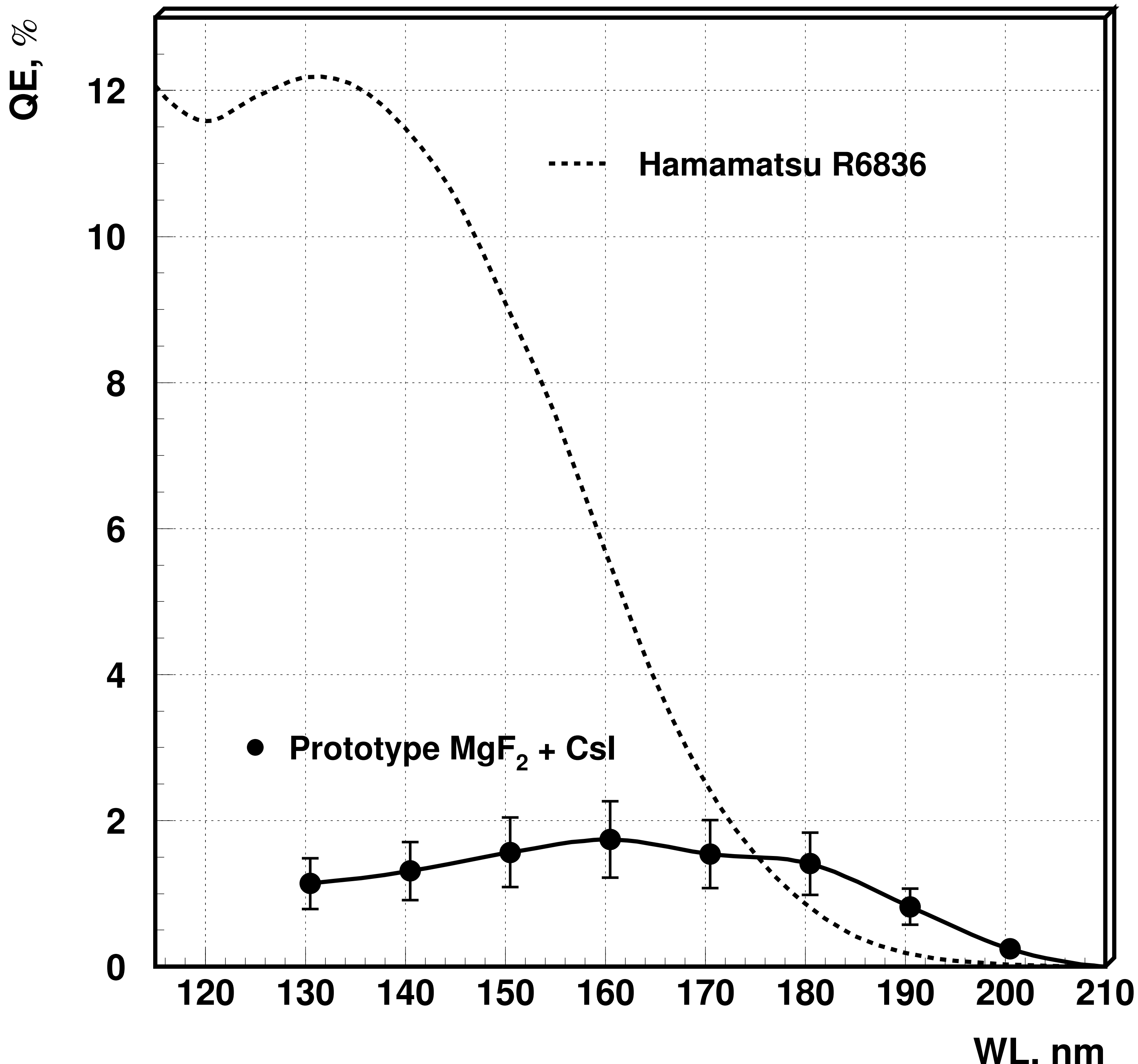
Deposition of thin metal electrode and CsI photocathode in the same vacuum cycle.
Vacuum sealing of the prototype after photocathode deposition.

QE measurement setup



QE measurement results

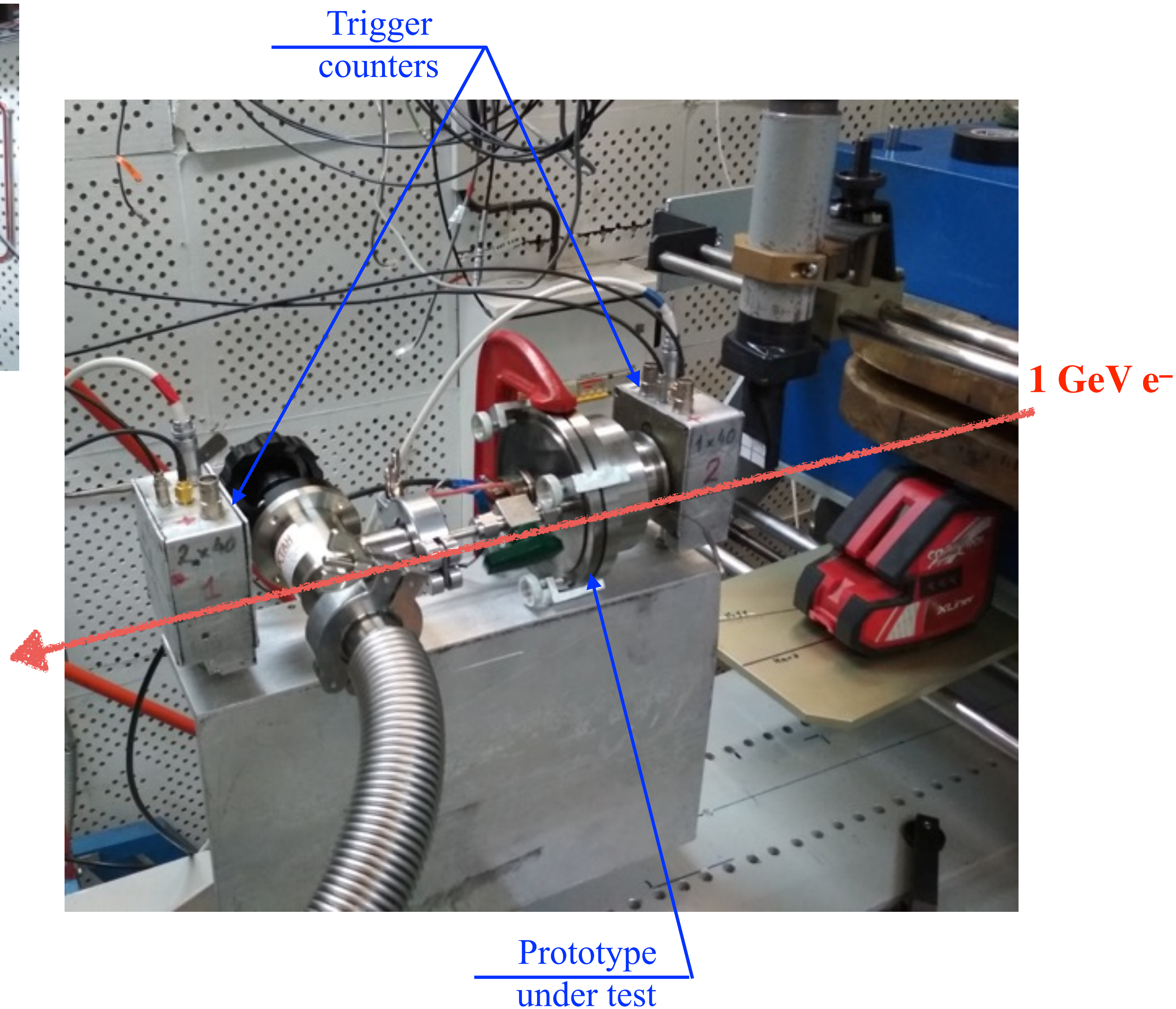
Five CsI photocathodes on MgF_2 window have been produced so far.



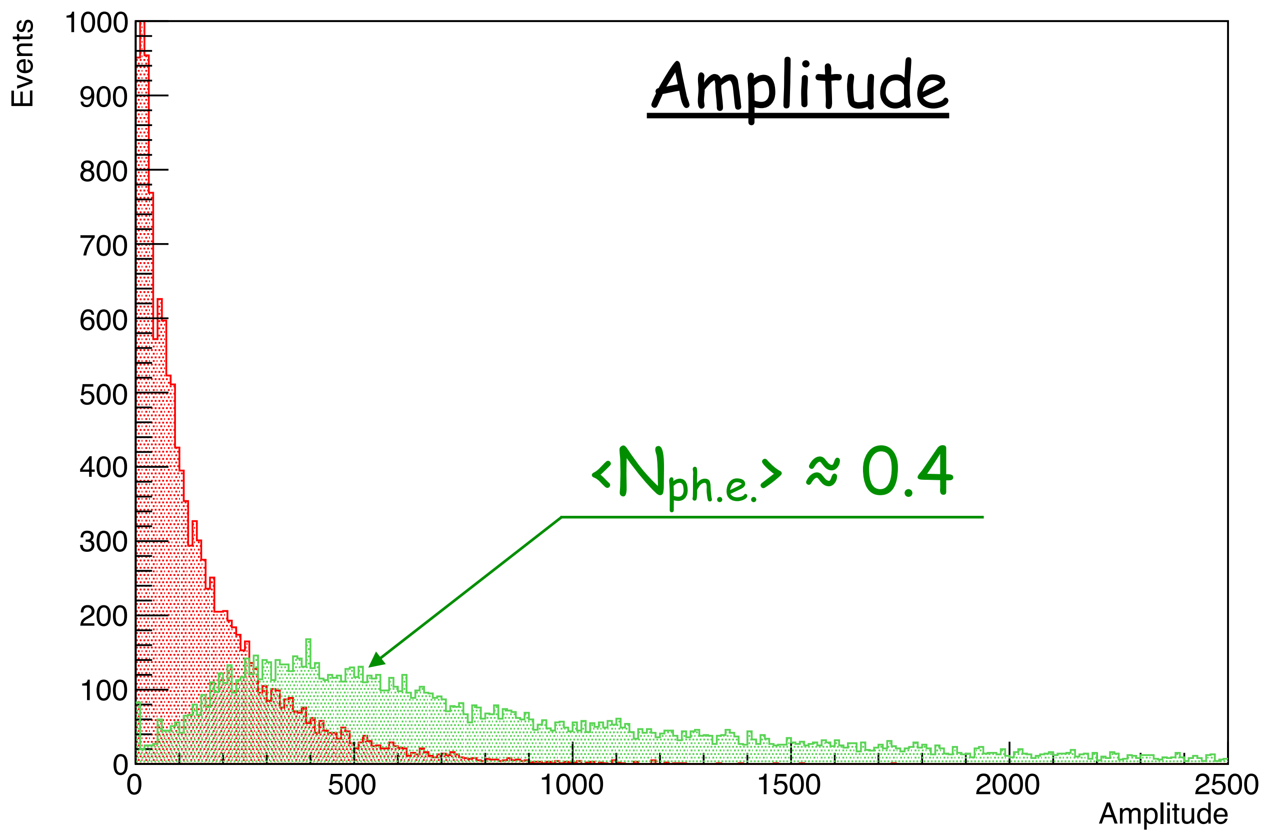
QE of the best sample.

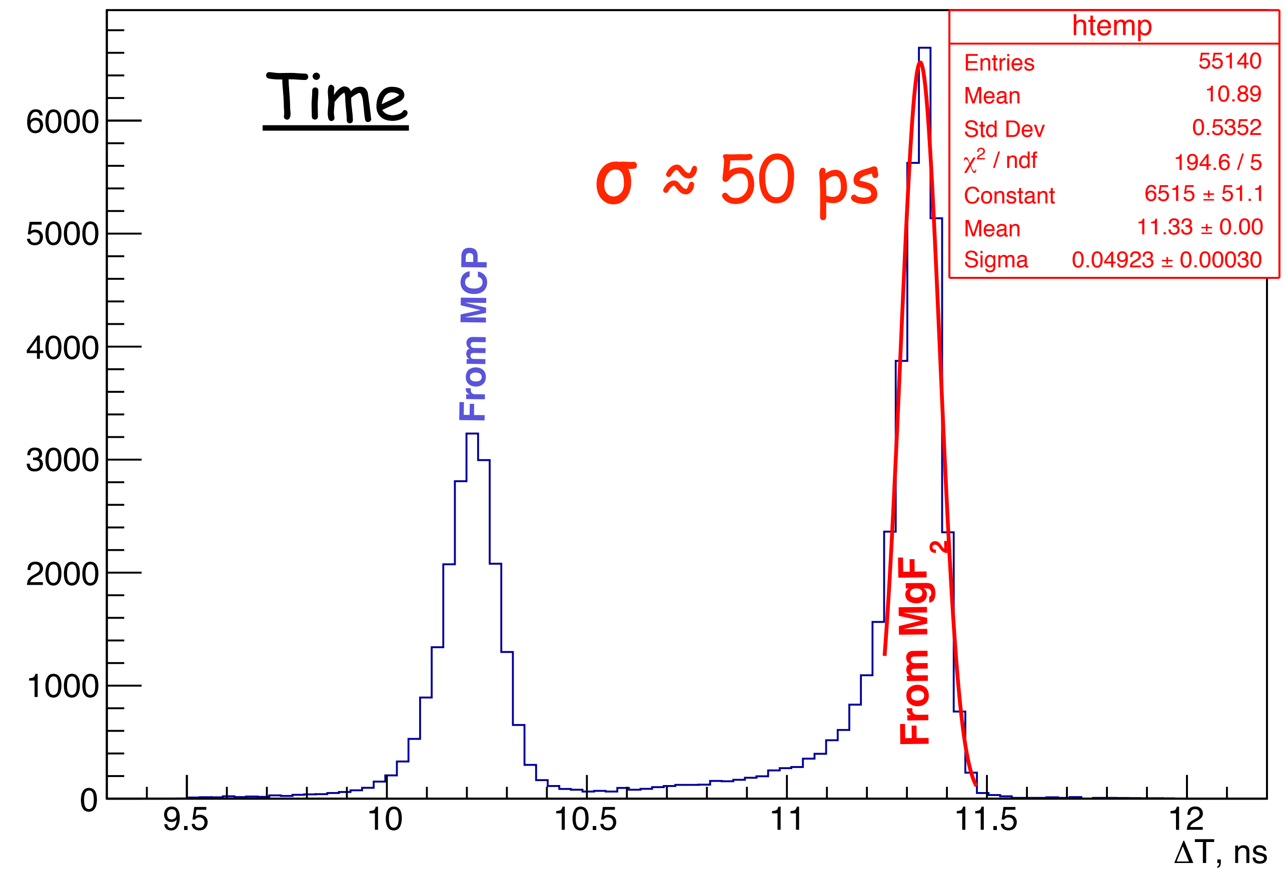
Beam test setup

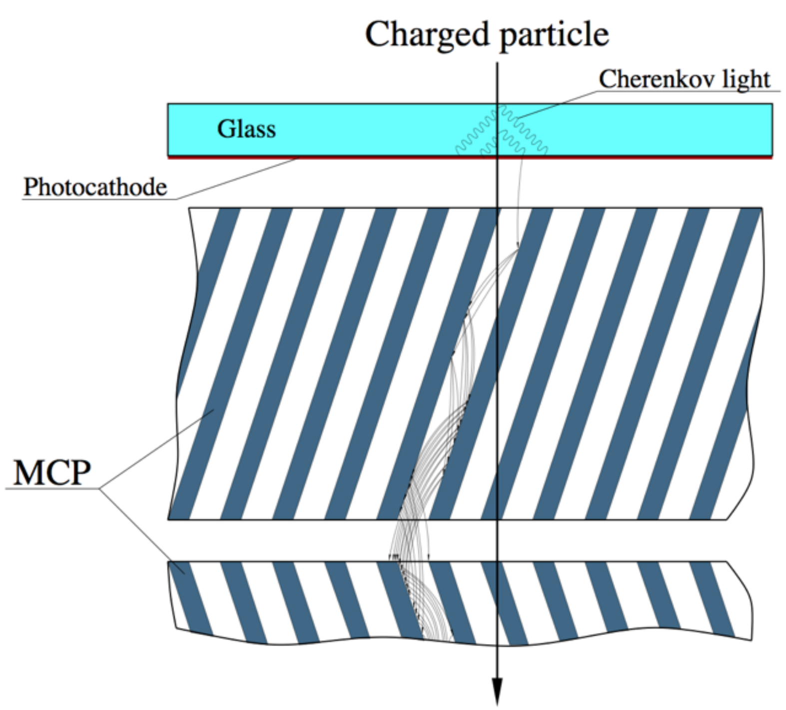
CAEN V1742 digitizer

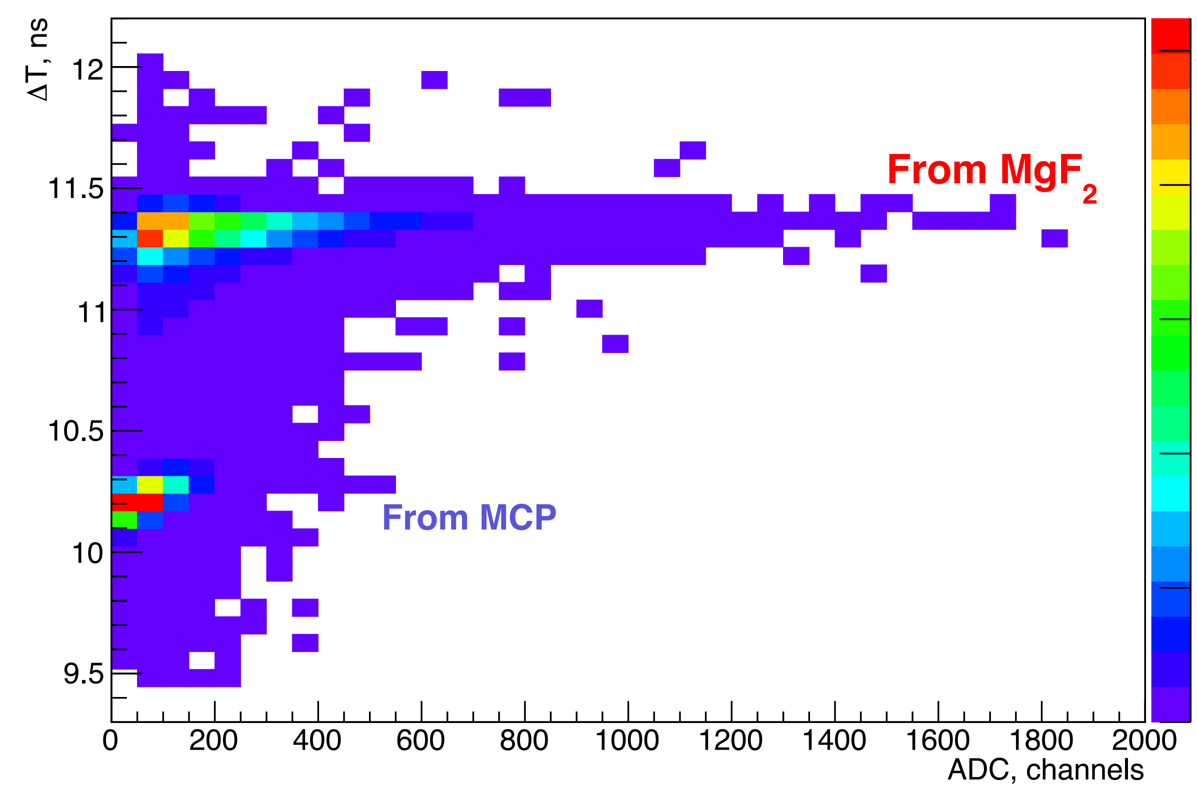


Beam test results







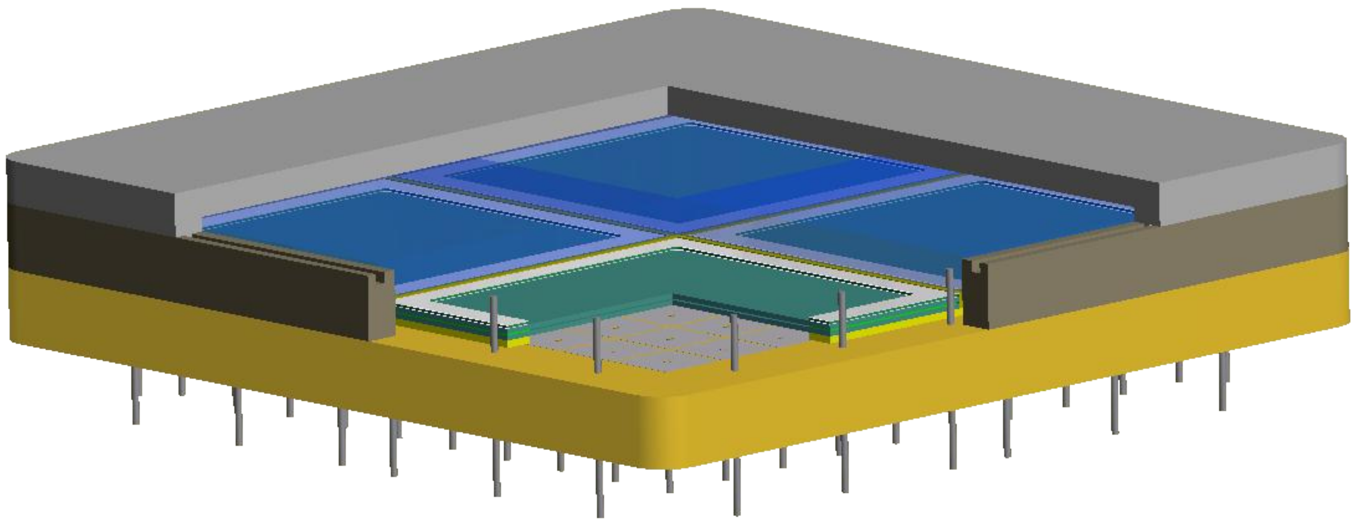


Summary

- Conceptual design of a "large area" MCP based TOF detector has been developed.
- According to calculations the time resolution < 10 ps is expected.
- The first sample of 5x5 cm MCP with 6 μm channel diameter has been produced.

Next steps:

- Optimization of CsI photocathode production
- "Large" prototype production and testing



Thank you!