Photocathode manufacturing at the CERN workshop

Some physics, technology and cooking*)

Christian Joram
CERN PH/DT

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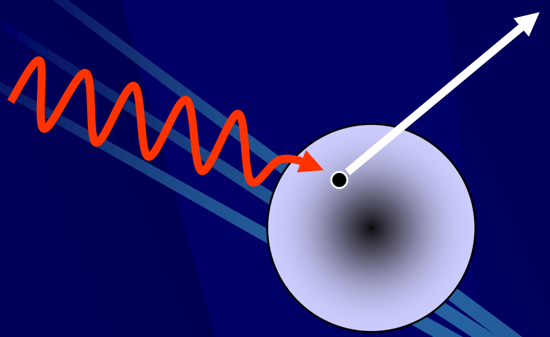
*) Disclaimer:
(1) I did my last evaporation in 2009 and may have forgotten details.
(2) I'm not - and never was - an expert for gaseous photodetectors.

See also: A. Braem et al., Technology of photocathode production, Nucl. Instr. Meth. A 502 (2003) 205–210

Outline

- Short recap of photodetection
- Production of reflective CsI photocathodes for gaseous detectors
- Production of visible light photocathodes for vacuum phototubes

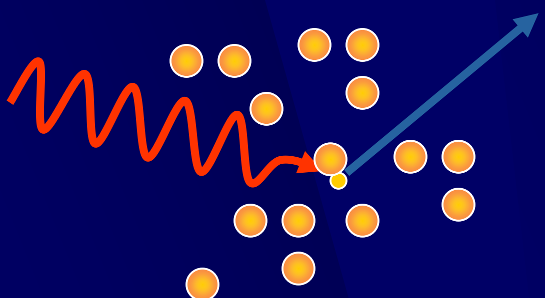
Photoelectric effect



Absorption of photon
Emission of atomic electron

$$E_e = h\nu - E_b$$

Photo effect in gases (liquids)



Threshold ~ E_b relatively high.

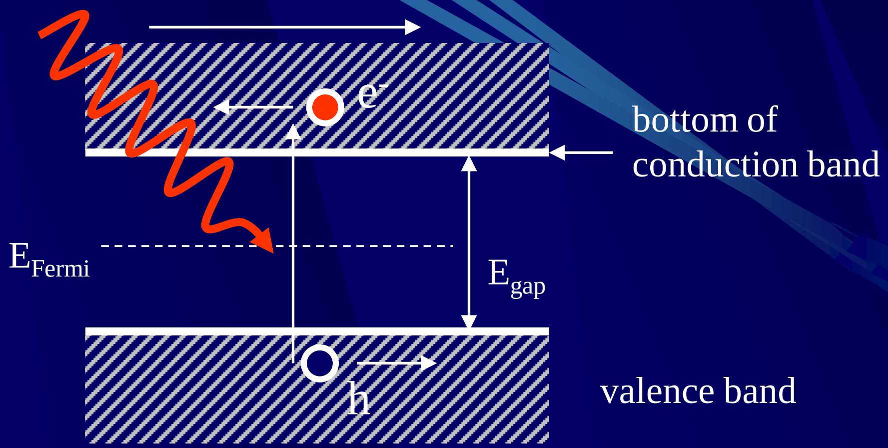
$E_\gamma = h\nu > 6$ eV, $\lambda < 200$ nm

Examples: TMAE, TEA, admixed to counting gas of MWPC

Photo effect in (crystalline) solids

A. Internal photo effect
(electron stays inside the medium)

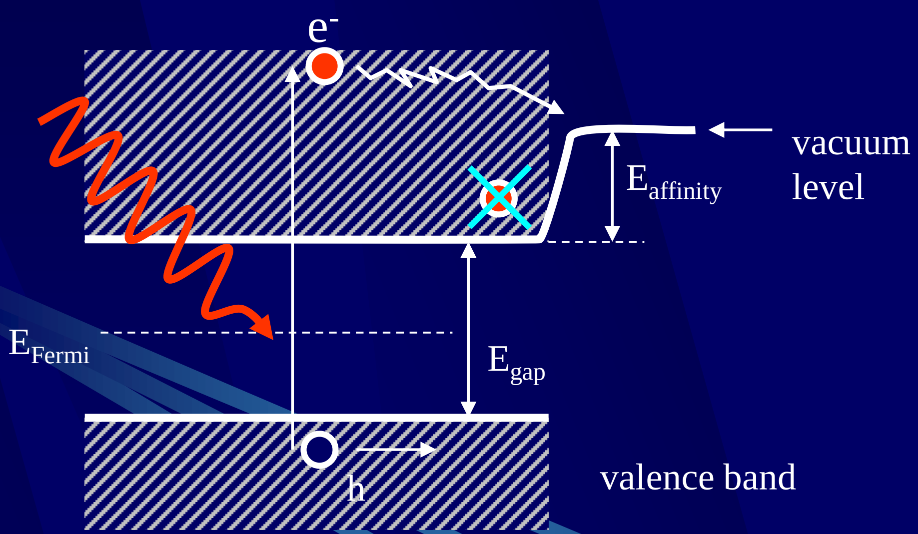
auto polarization (pn doping), optional
external electric field



Threshold = band gap E_{gap}, relatively low,
e.g. 1.2 eV (Silicon)

Application: Solar cell, photodiode, SiPM, …

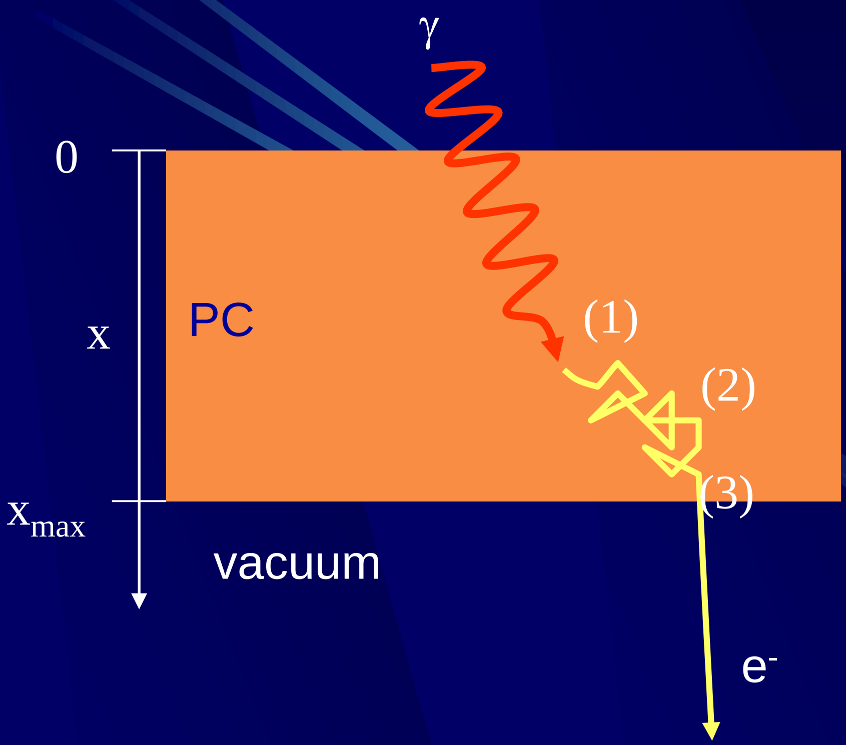
B. External photo effect
(electron is ejected from the medium
into the vacuum)



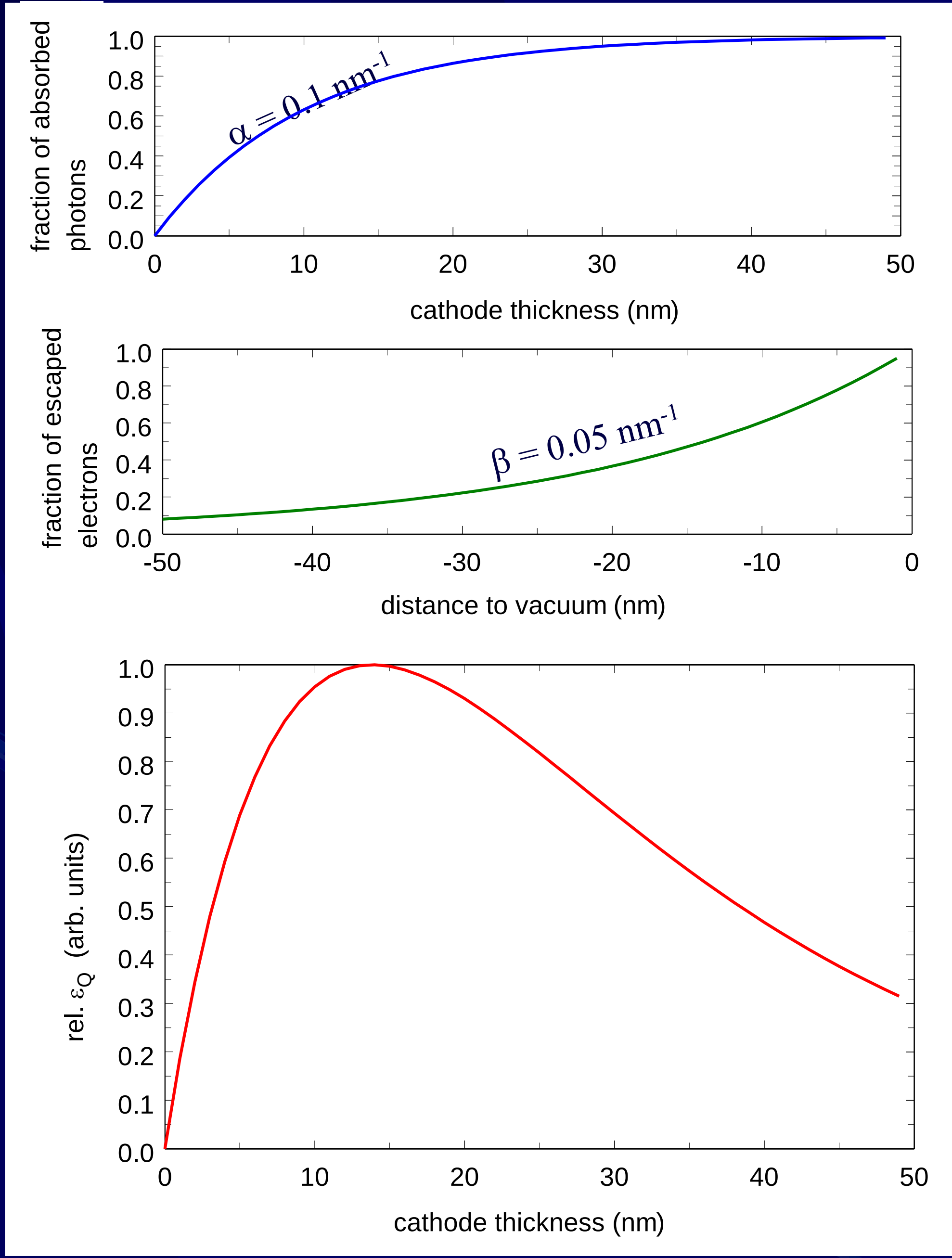
Application: Photomultiplier, HPDs, …

Thin film photo cathode

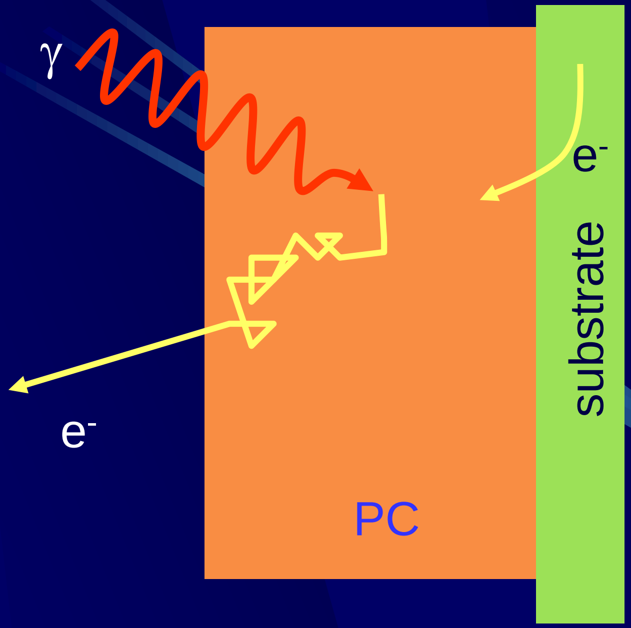
Semitransparent photocathode



1. (1) Light absorption
2. (2) e- propagation
3. (3) e- escape



Opaque photocathode
(also called reflection mode)



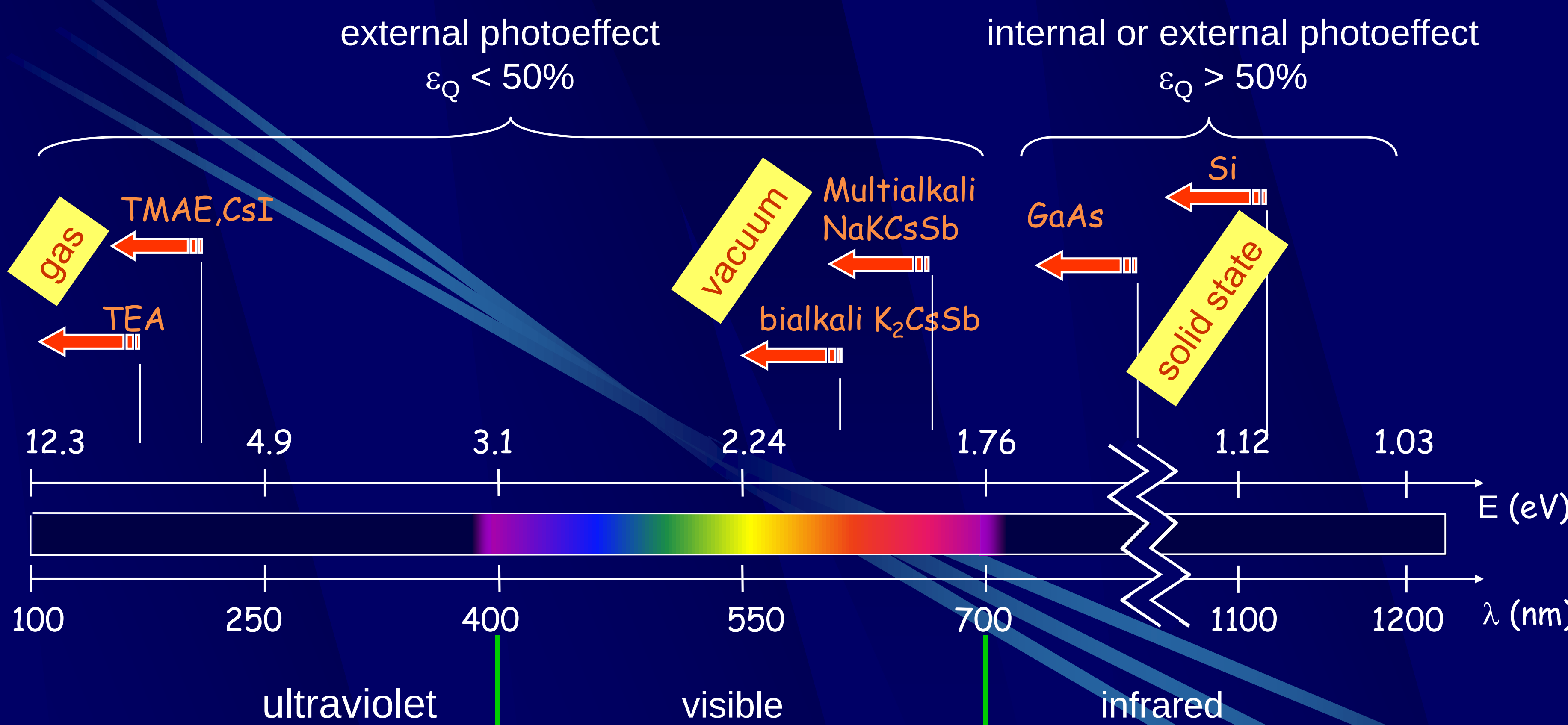
Example: CsI photocathodes (300 nm thick)

Thickness not critical.

Possible limitation: resistivity of layer.

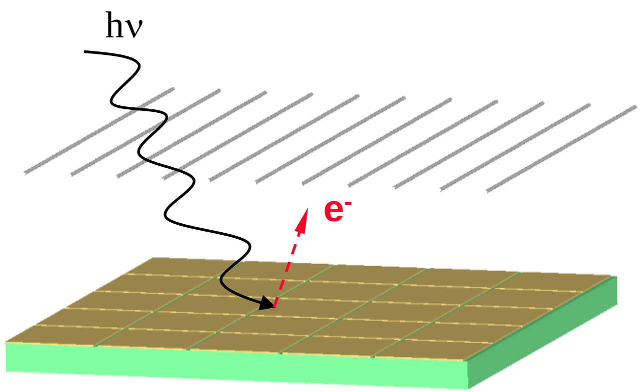
Different photocathodes and their thresholds

$\varepsilon_Q = \text{Q.E.} = N_e / N_\gamma$



- Photon detection involves often materials like K, Na, Rb, Cs (alkali metals). They have the smallest electronegativity → highest tendency to release electrons.
- Most photocathodes are VERY reactive; Exceptions: Si and CsI.

Reflective CsI photocathode for MWPC / MPGD based photodetectors



- Cost effective for large area photodetection planes

(modules up to ~ 60x60 cm^2)

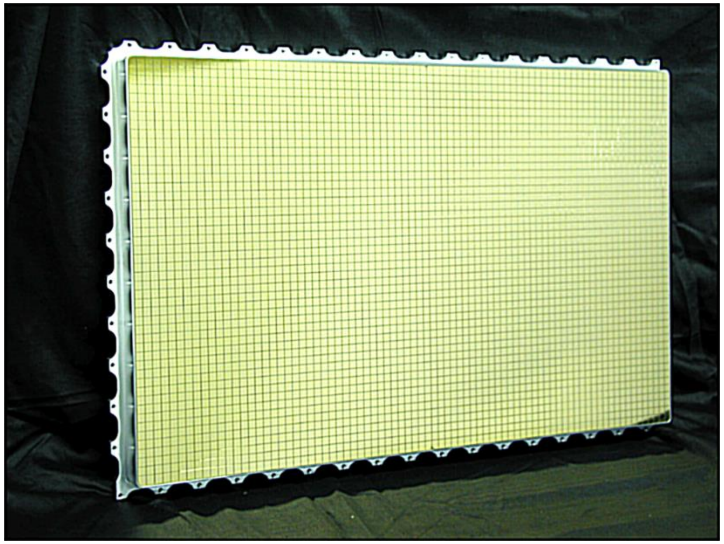
- Robust and transferable

(in moisture free environment)

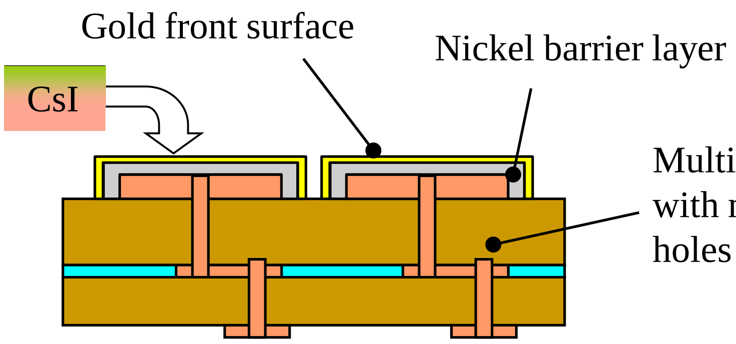
- Very sensitive to humidity !

Requirements:

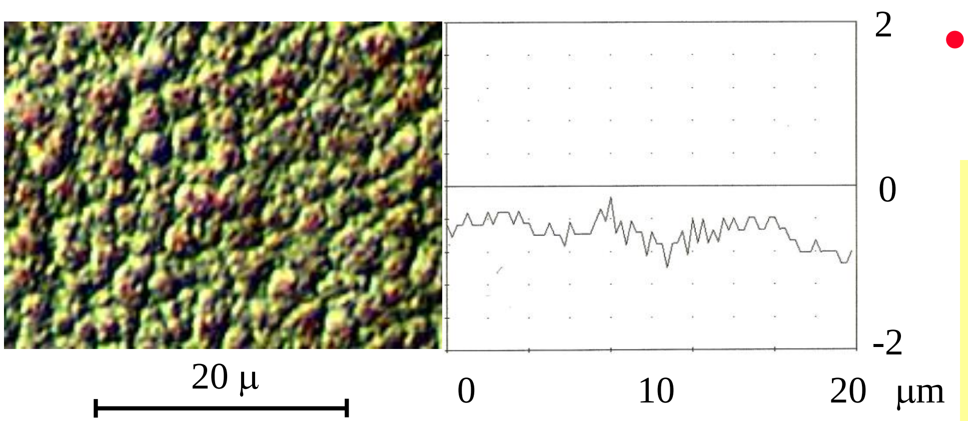
- High QE over 7.75 - 6.2 eV range
- Uniform QE response
- Stable in time (years)



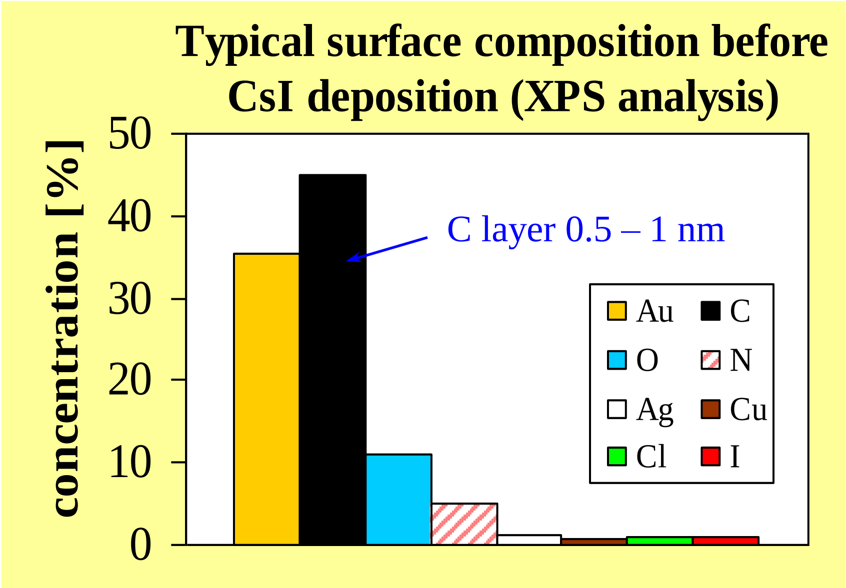
CsI substrate : Printed circuit board !



- Ni and Au barrier layers on top of Cu pads (~8x8 mm^2)
- Standard Electro-plating technology



- Rough surface, cleaned ultrasonically under strong detergent

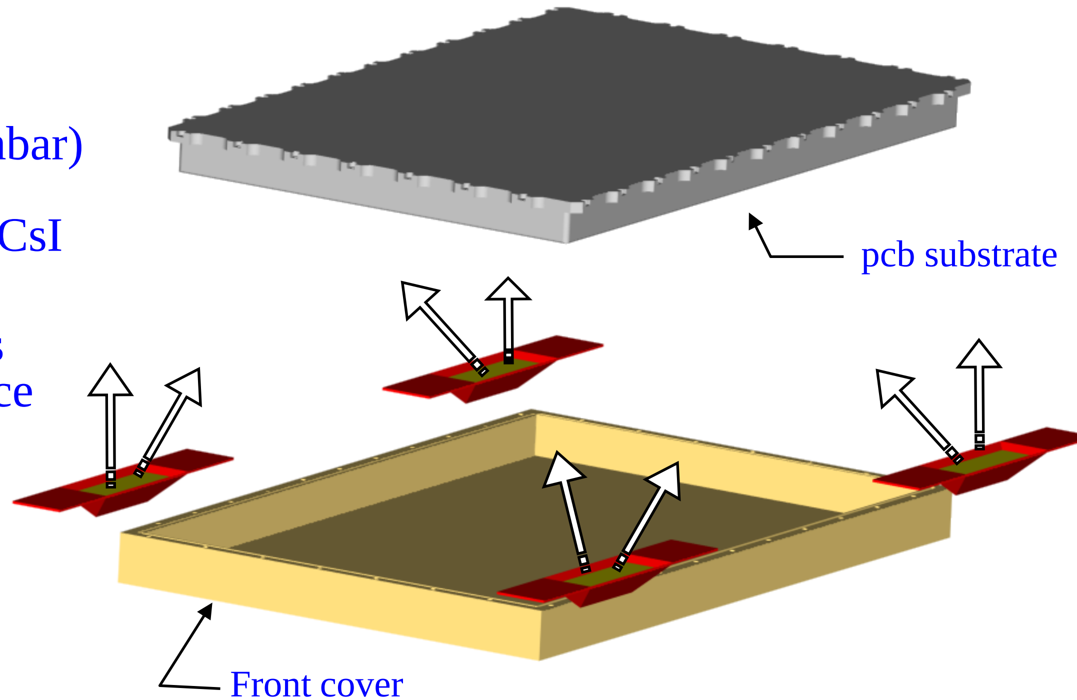


- Vacuum baking limited to 60°C

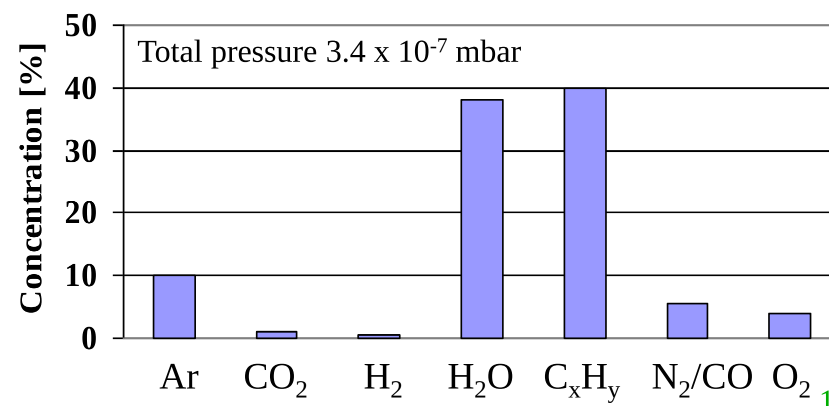
→ residual impurities left under the CsI coating

CsI vacuum evaporation process

- High vacuum technology (~10^{-7} mbar)
- Simultaneous evaporation from 4 CsI sources:
  → 300 nm uniform (±10%) thickness distribution over the full surface
- Slow deposition rate (~1 nm/s):
  → Min. CsI dissociation
  → Little or no reaction with residual gasses
- Thermal treatment during and after CsI deposition (~8 hrs at 60°C)
- In situ QE evaluation under vacuum
- In situ encapsulation under dry Argon before transfer onto MWPC

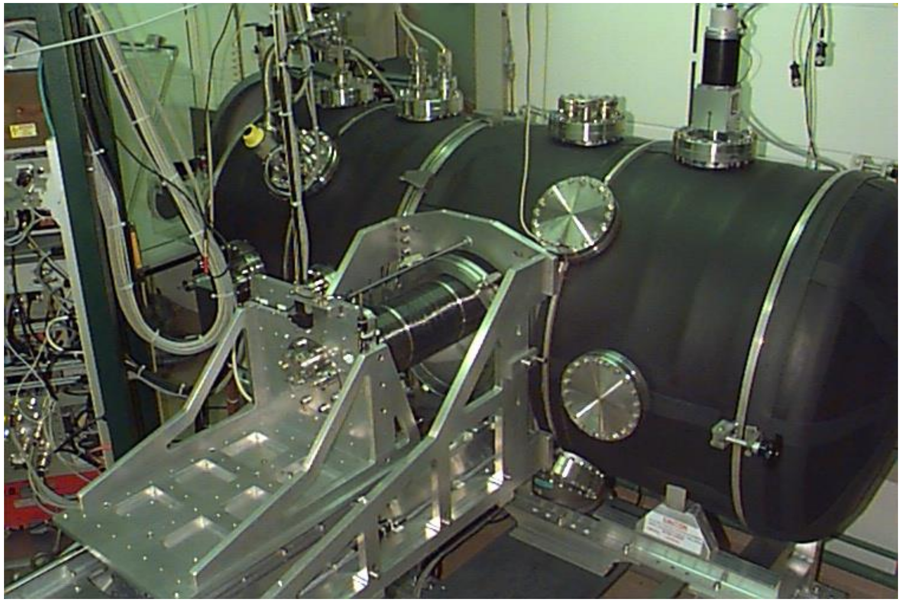


Residual gas before CsI deposition on HMPID PC38



The CsI production plant

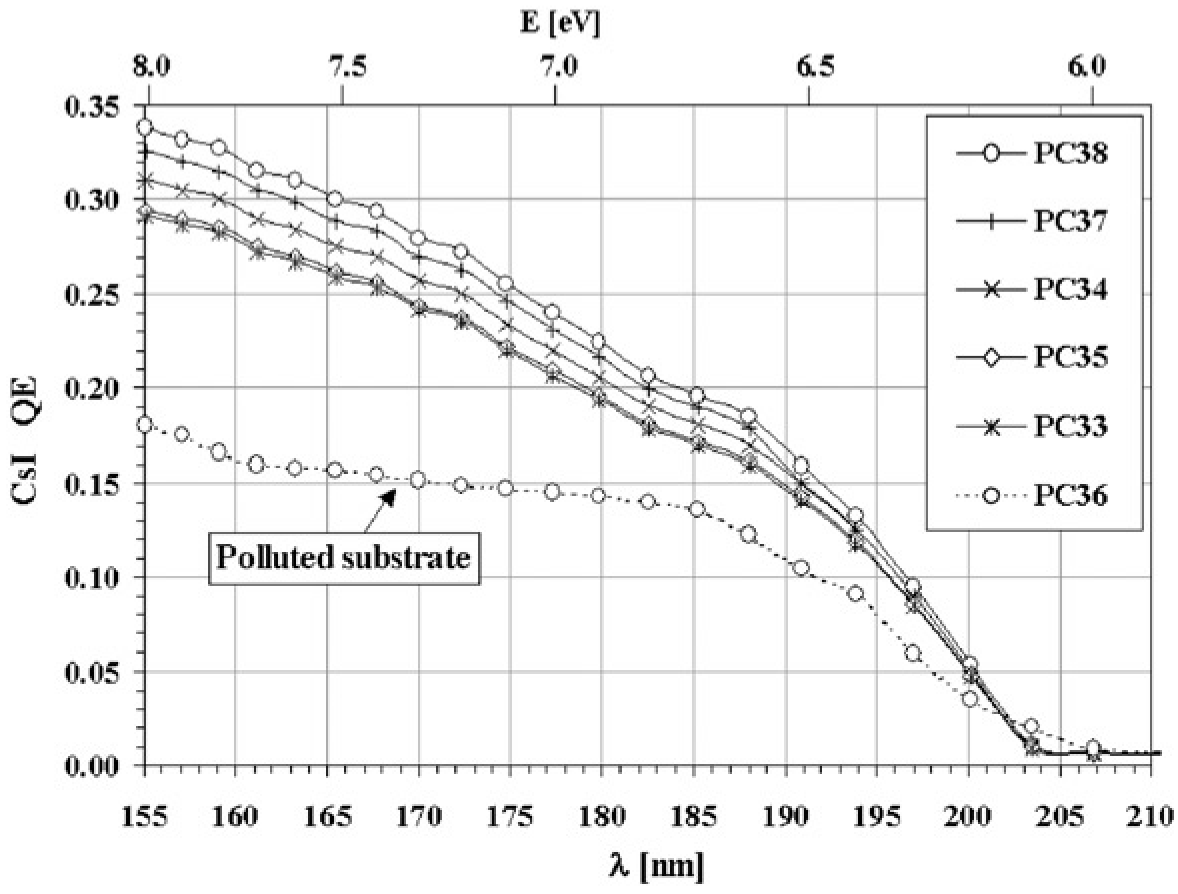
- Photocathode modules up to 60 x 60 cm^2
- Transfer facility of CsI films under inert gas
- Max. production capacity of 2 PCs /week



- In situ CsI QE evaluation under vacuum (summer 2002)

Some QE results

(prototype planes for ALICE HMPID)



Thin Film Visible Light Cathodes

All classical VL photocathodes are based on alkali-antimonides.

Their very reactive nature has a number of consequences:

- The alkalis must never be in contact with air (not even in minute quantities
- The K, Na, Cs and Rb vapor are generated from dispensers which contain the alkali metal bound in a non-reactive metal chromate. The dispenser releases the vapor only once heated to >~500°C.
- The vacuum (prior to evaporation) must be very good ($<10^{-8}$ mbar) and not contain reactive stuff like H_2O, O_2, C_xH_y. Ideally just H_2.
- The substrate surface, usually consisting of glass, quartz, Sapphire, and a certain material thickness below must be clean (i.e. free of water, hydrocarbons, anything else). → The substrate must be baked out, if possible at T>300°C.
- The photodetector must be sealed in-situ. Even short contacts with any reactive atmosphere will completely destroy the photocathode.

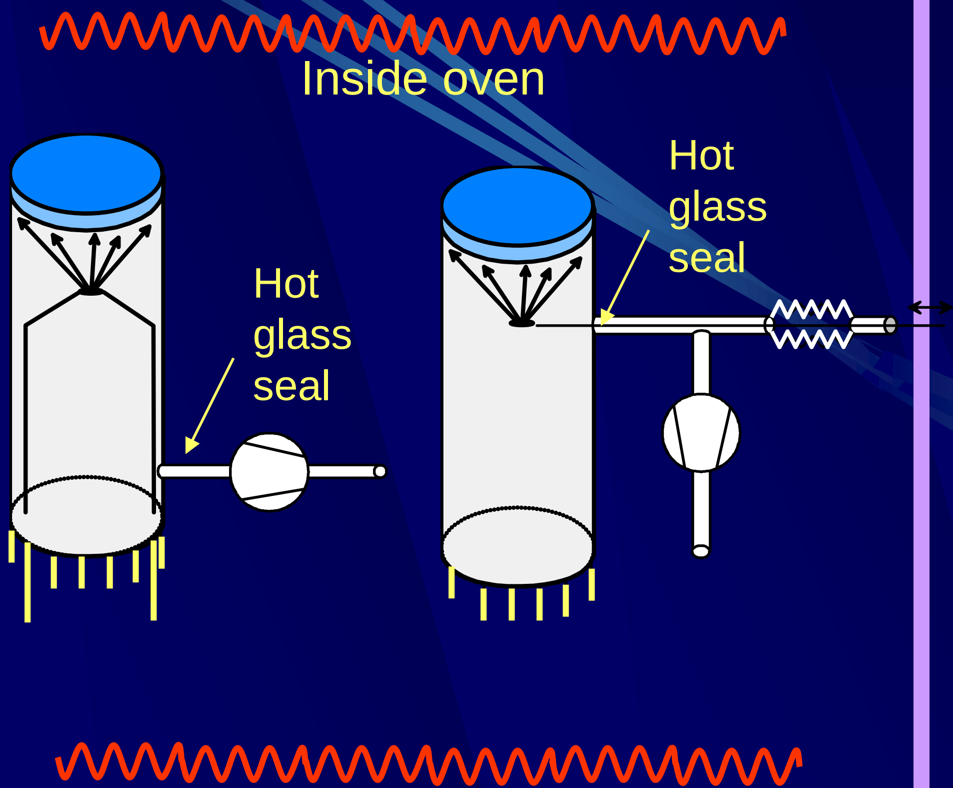
Photo SAES getters

- During photocathode processing, the substrate must be kept at elevated temperature (T~130-160°C, process dependent).

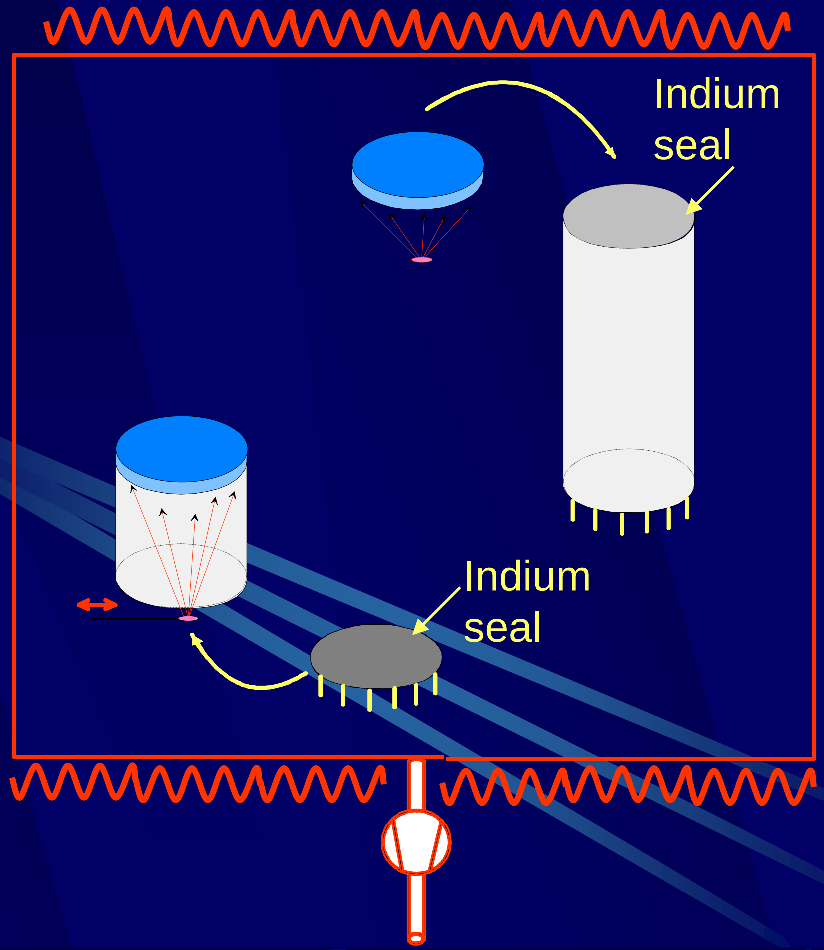
Phototube fabrication

comparison of process types (very schematic)

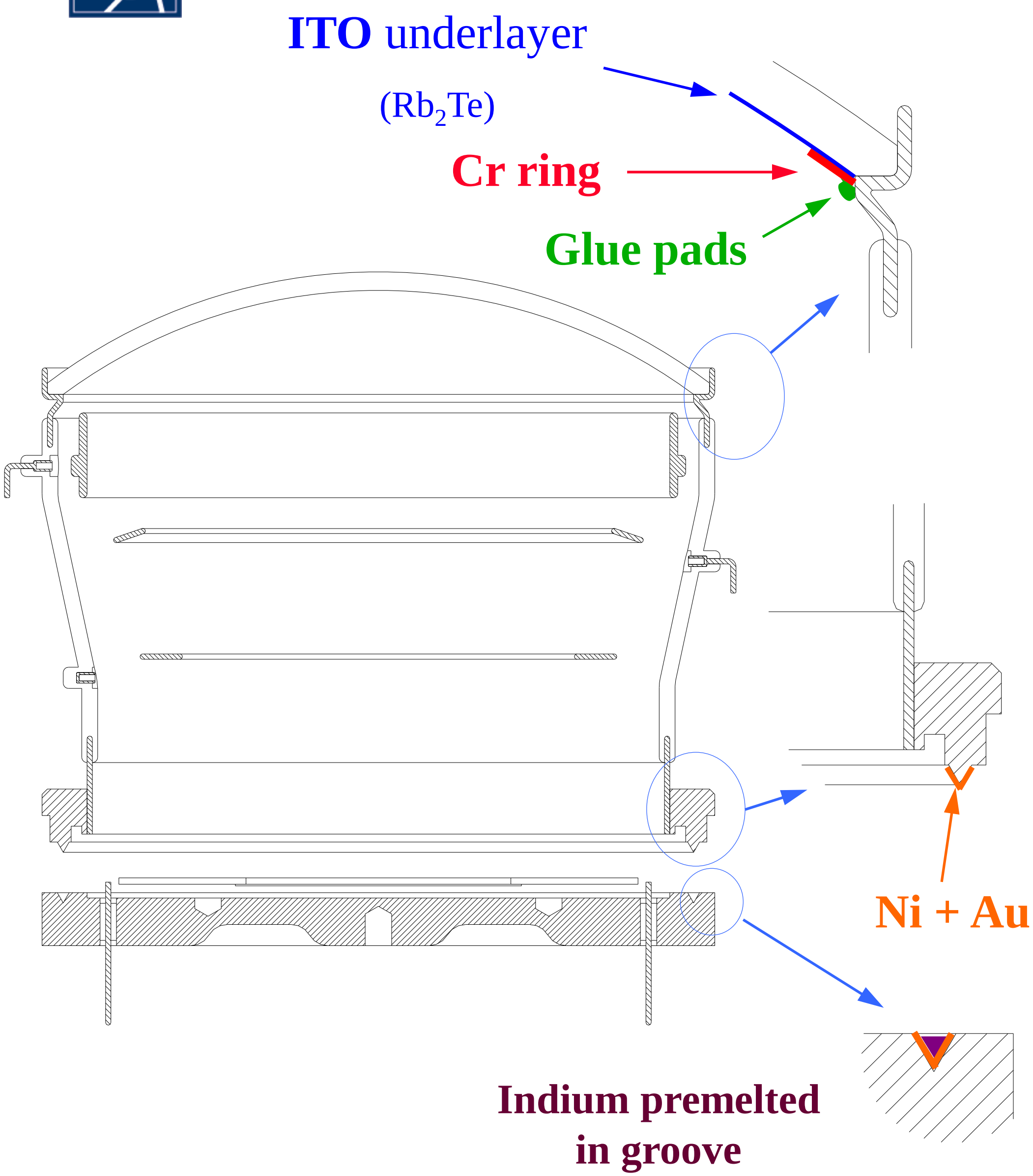
Internal - PMTs



external(transfer) - HPDs



Preparation of HPD envelopes

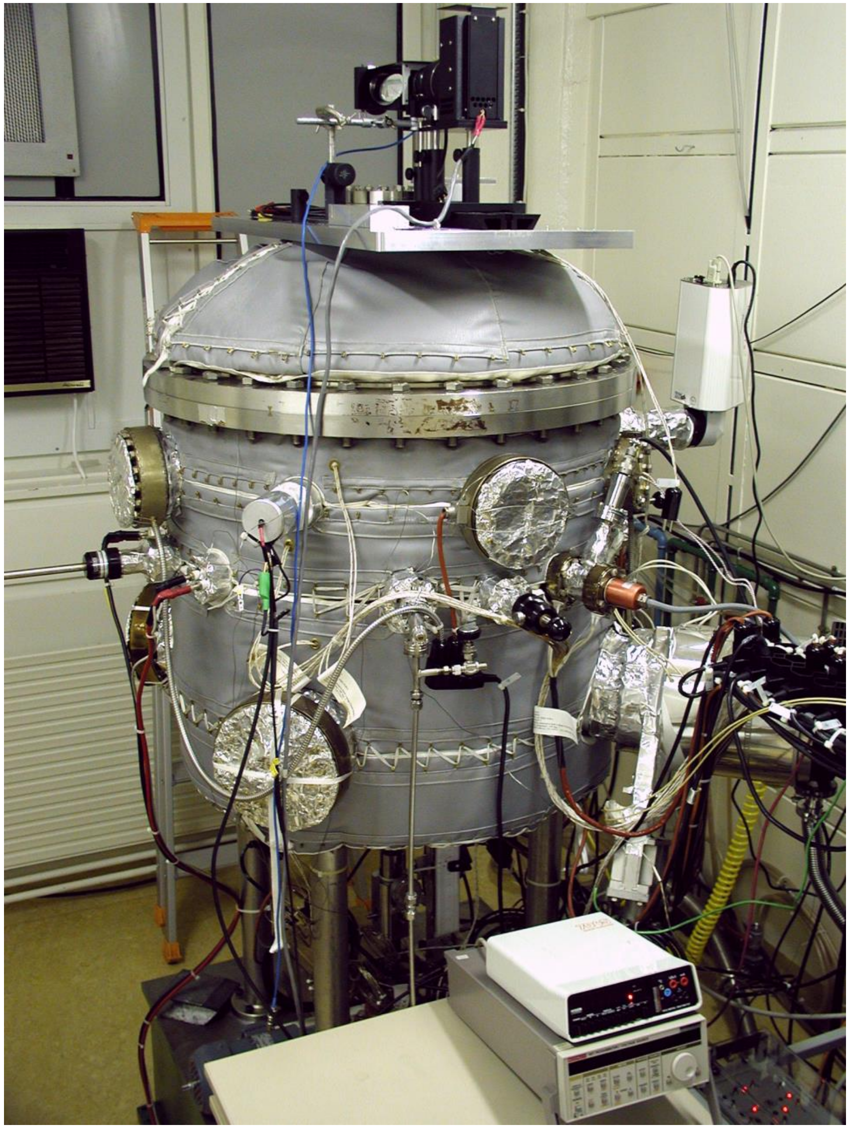


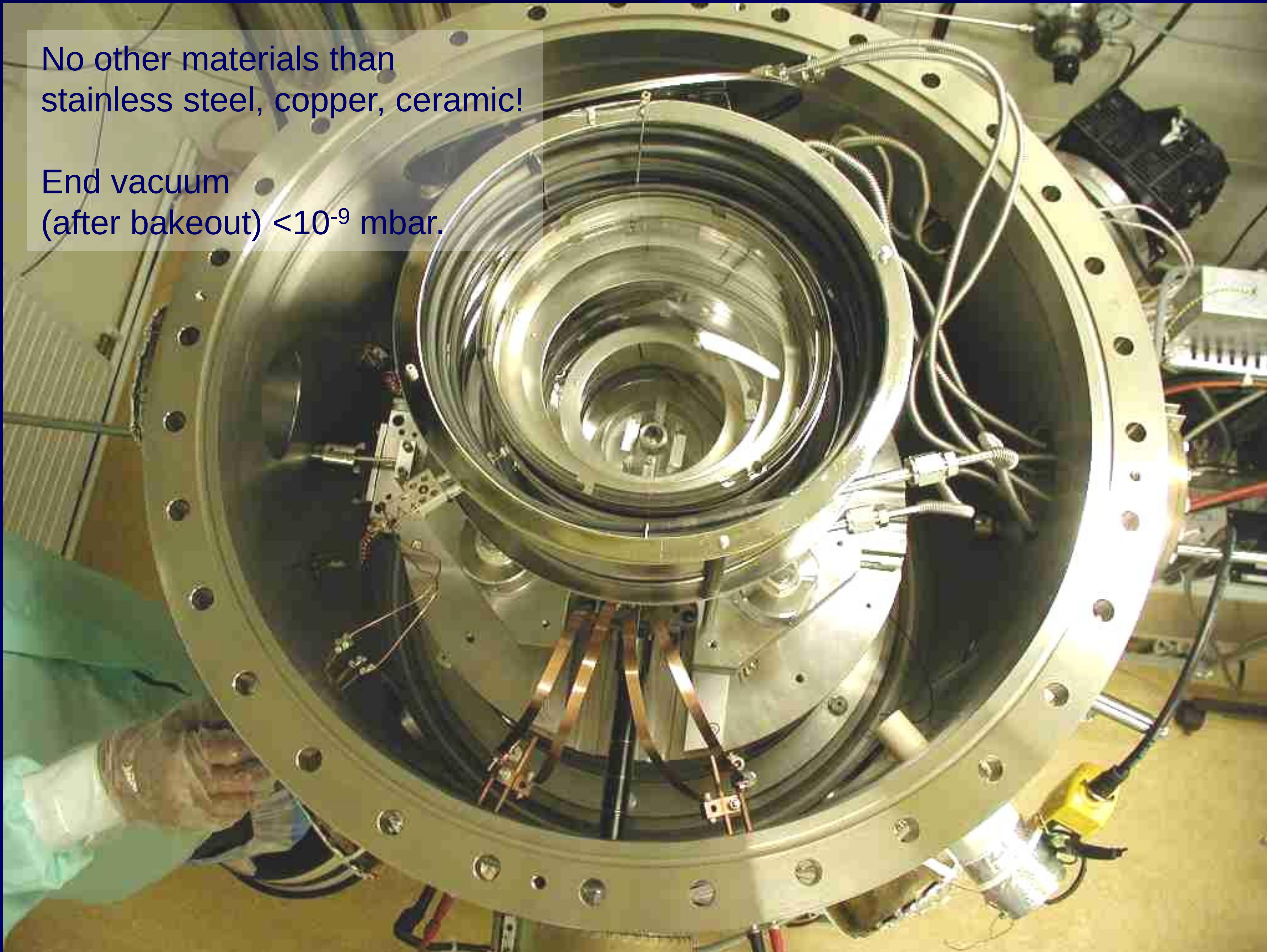
- Polishing :
  - metal parts for high E fields environment (excessive noise produced by ionisation/excitation of residual alkali vapours)
  - Glass window (as standard cleaning procedure)
- Chemical etching
  - On glass parts: NaOH, aqua regia, tartaric acid solution.
  - On metal parts: conc. HCl, $CH_3COOH/HNO_3/HCl$ solution.
- Deposition of connection layer ITO (Rb_2Te) / Cr / glue pads
- Deposition of Ni + Au interdiffusion layers on indium sealing surfaces

Procedure allows to fully recycle used envelopes and bases.

The CERN plant for external processes

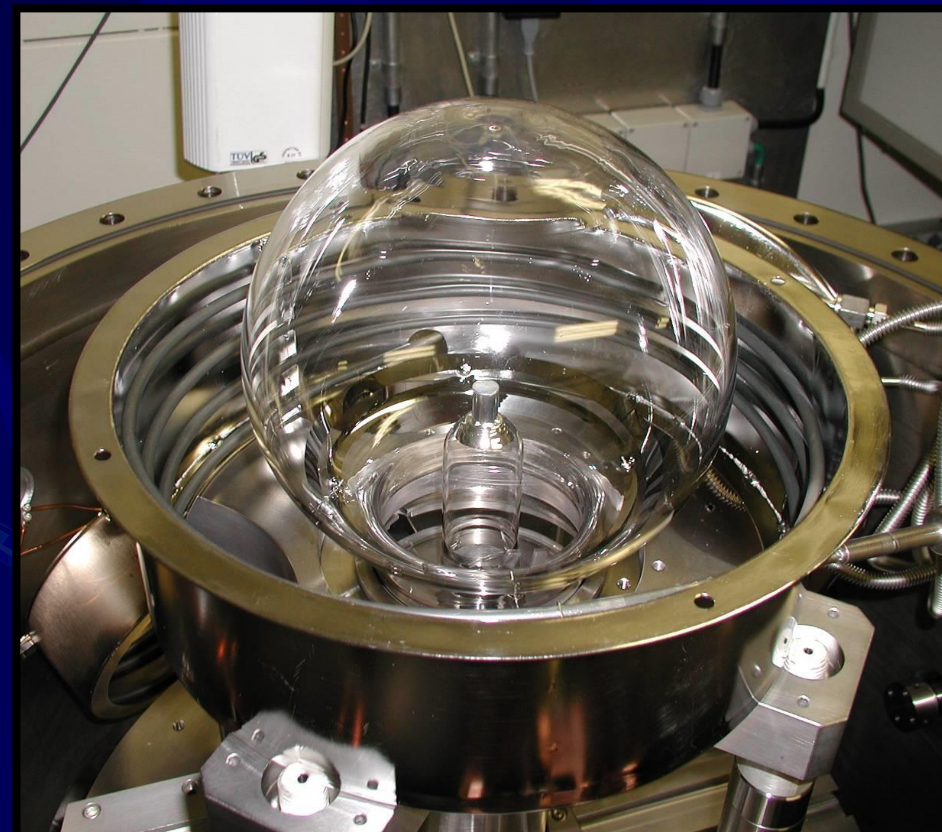
- Coat substrates up to ϕ 10”
- Adapted to UV–VIS PCs, from 200 to 600 nm
- Press mechanism for cold indium encapsulation (2.5 tons)
- Production capacity limited to
  1 PC / week





No other materials than stainless steel, copper, ceramic!

End vacuum (after bakeout) $<10^{-9}$ mbar.



UHV processing chamber

Full bake-out 72 hrs

Tank at 160°C

HPD tube 300 °C

Before processing:

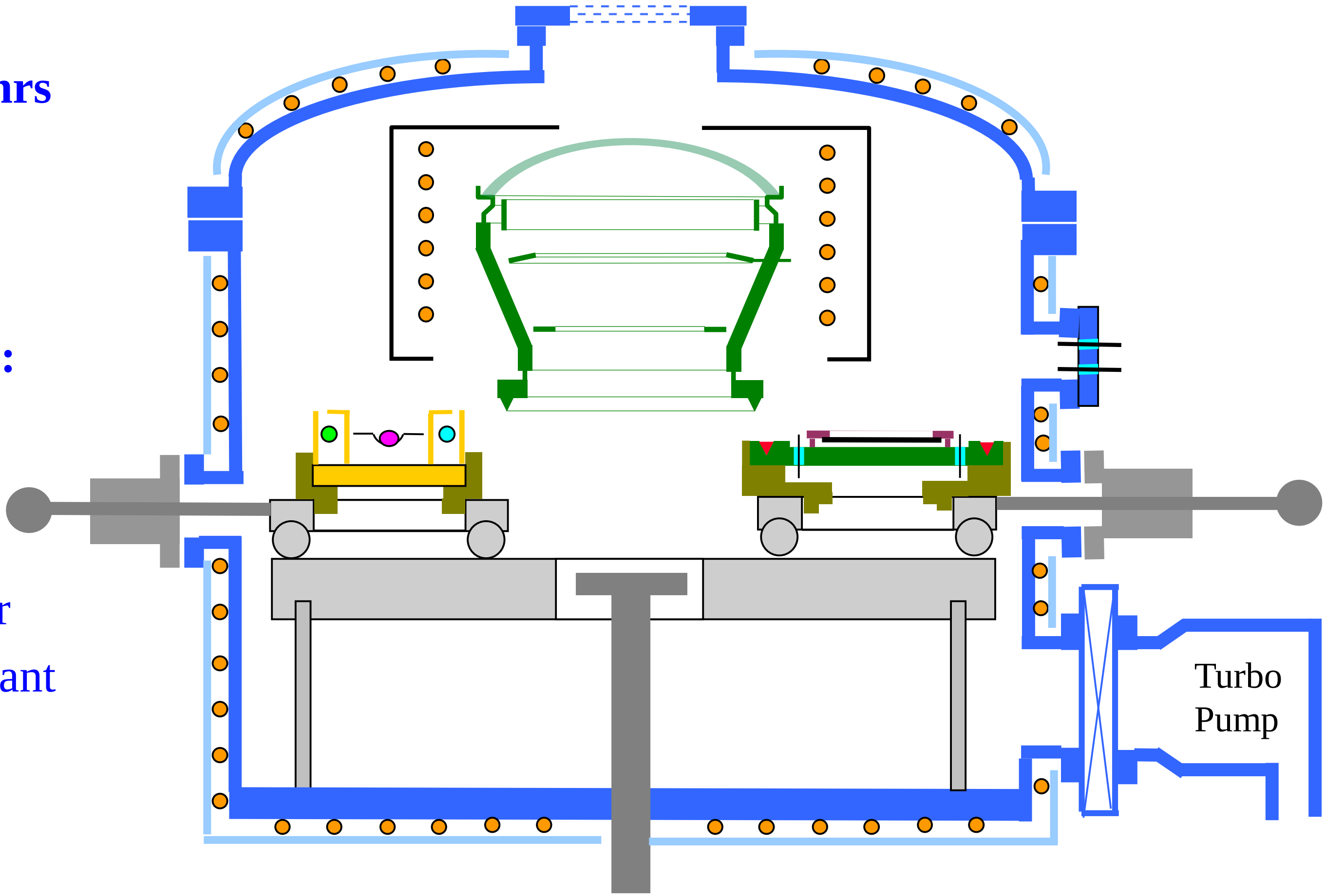
Tank and HPD window at 160 °C

$P < 5 \times 10^{-9}$ mbar

$P_{H2O} < 1 \times 10^{-9}$ mbar

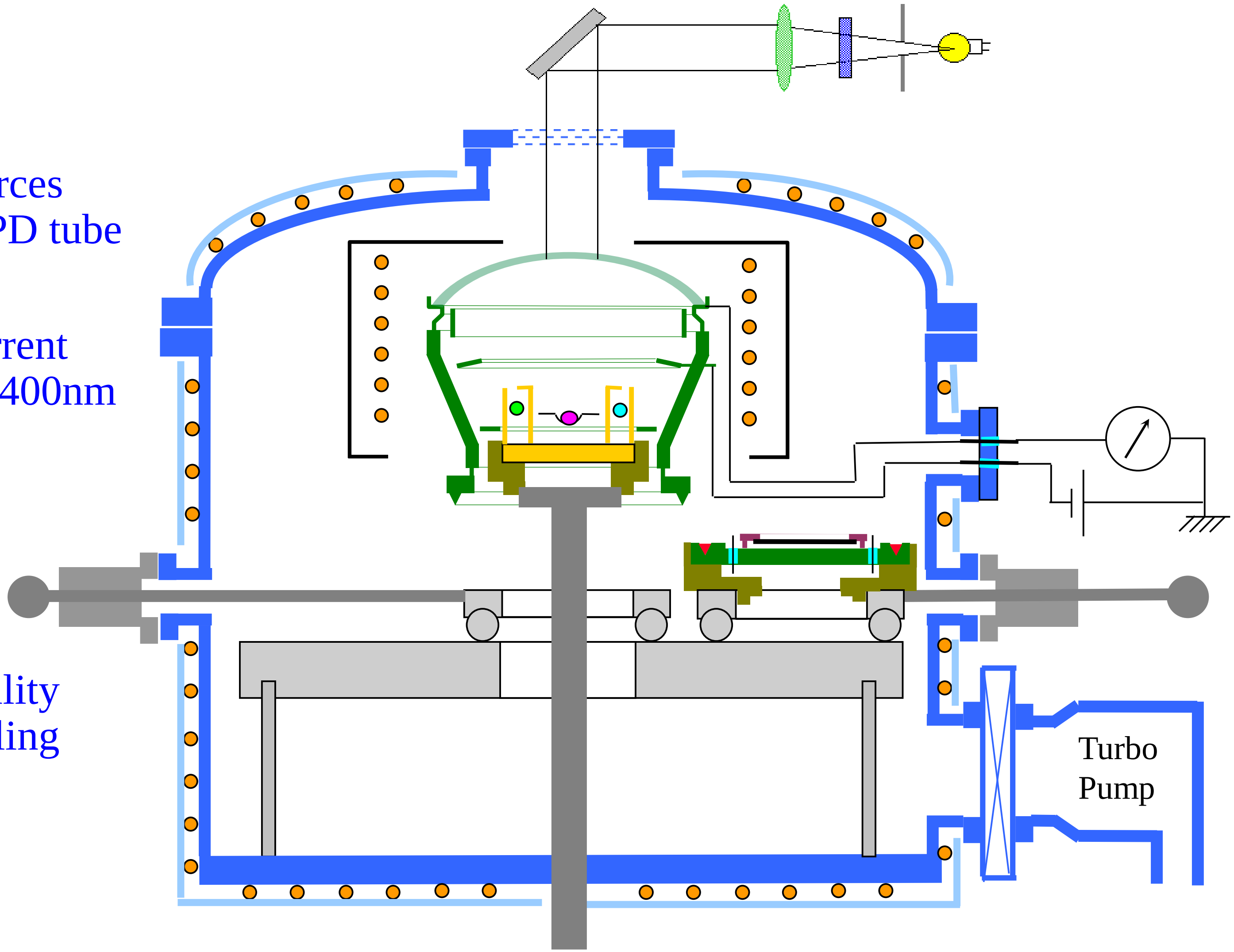
No other contaminant

(CO, C_xH_y….)



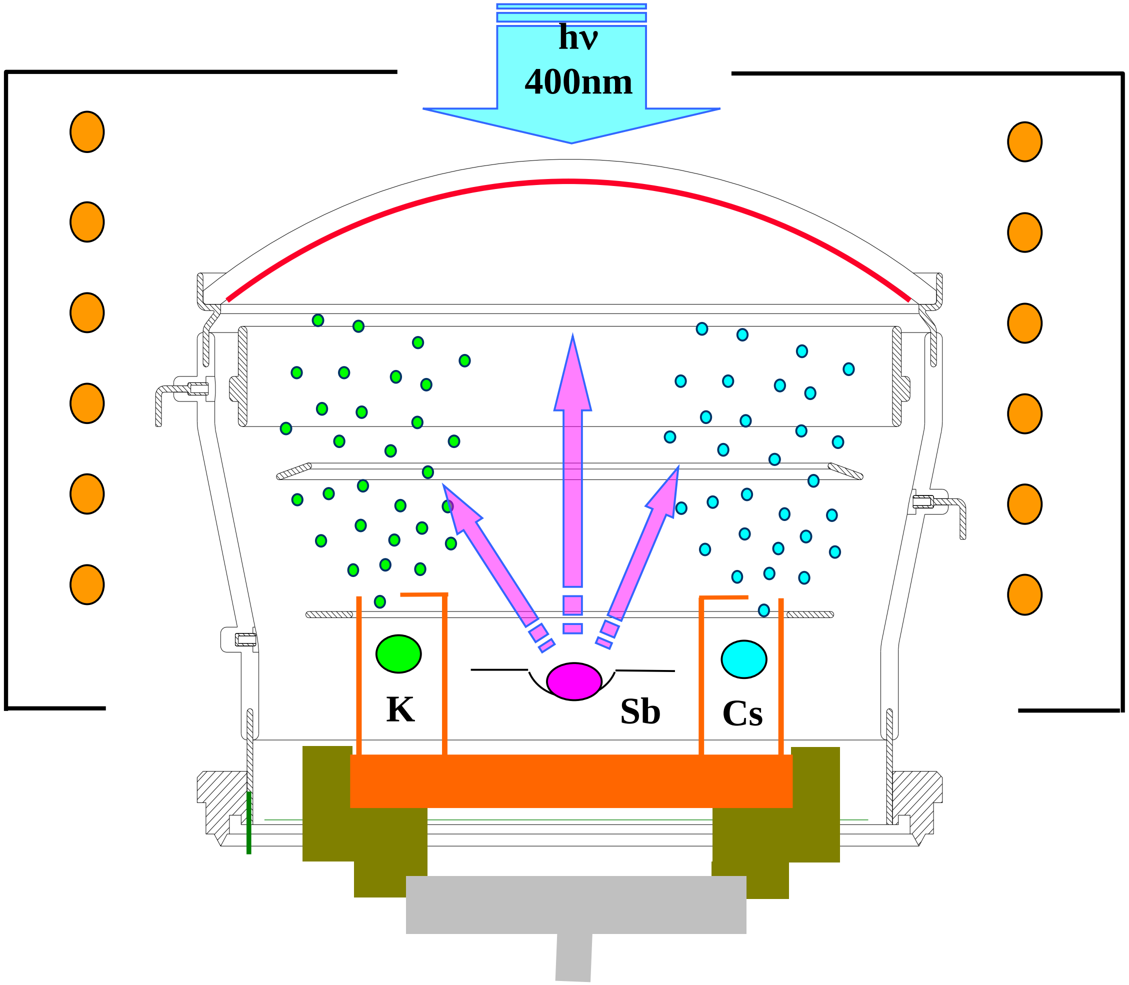
"external" photocathode process

- Sb, K and Cs sources pushed inside HPD tube
- Photoelectron current monitoring at λ=400nm
- QE vs λ and stability check before sealing



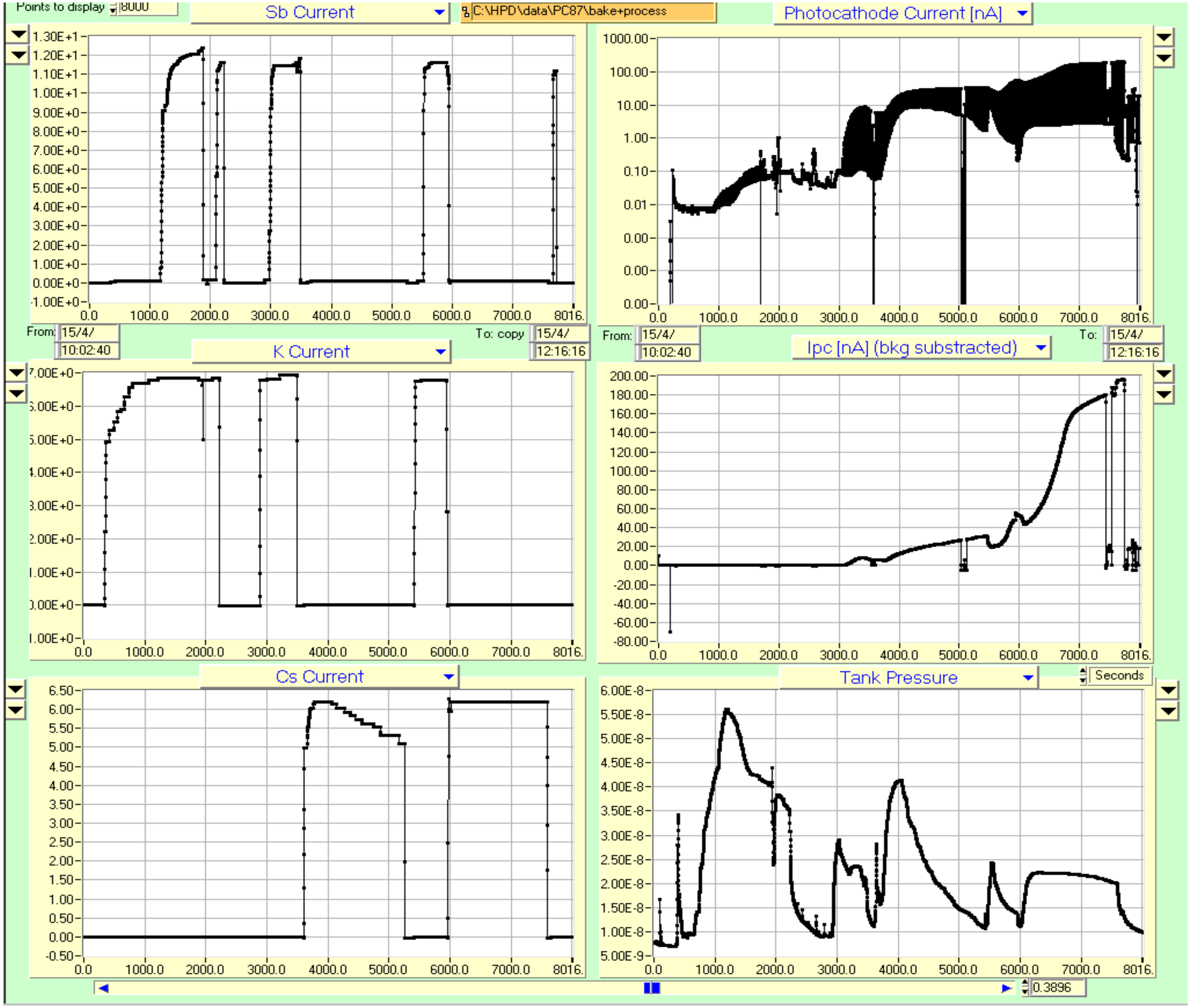
Co-evaporation process (K_2CsSb)

- Window at 160 °C
- Sb : ballistic evaporation
  K, Cs: diffuse evaporation
- Co-evaporation of
  K and Sb → K_3Sb
- Cs evap. → K_2SbCs
- Optimisation of pc current.
  → 2 – 3 iterations of
  Sb, K and Cs evap.



Permanent photocathode current monitoring

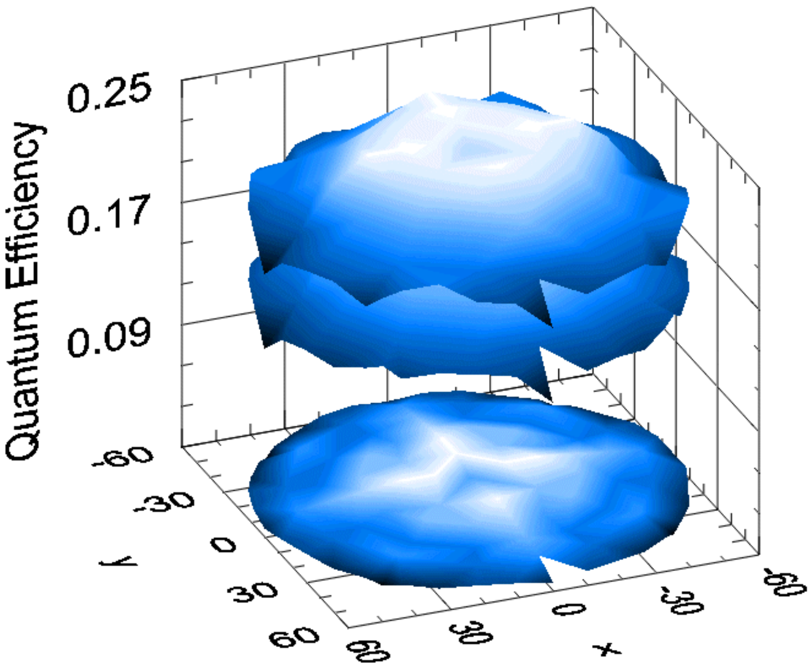
PC87



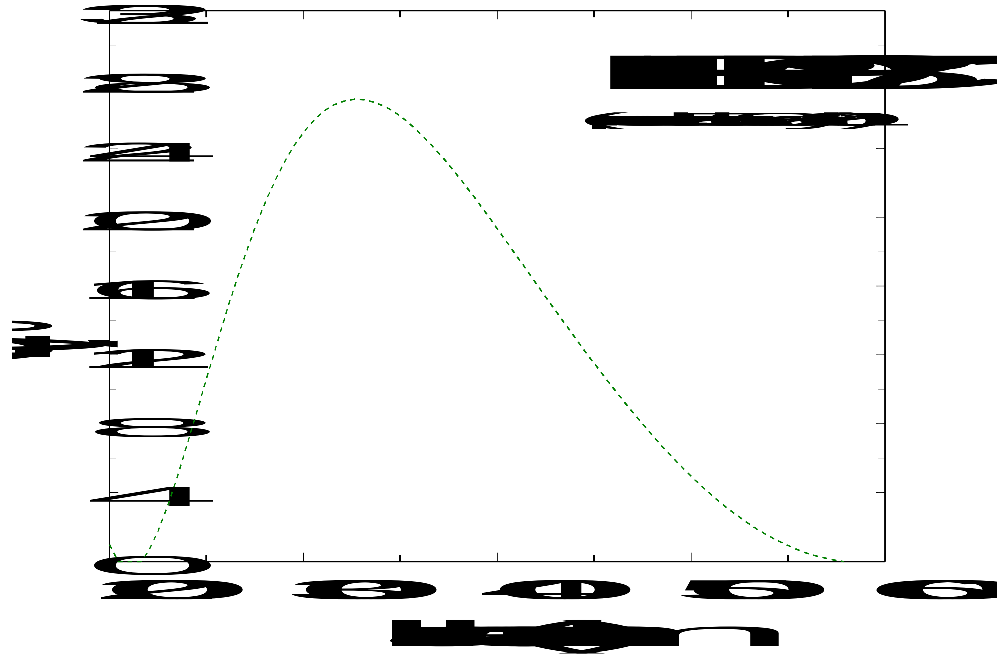
Log. scale.
Lamp on/off

Linear scale.
Background subtracted
(lamp off).

QE of K_2CsSb cathodes

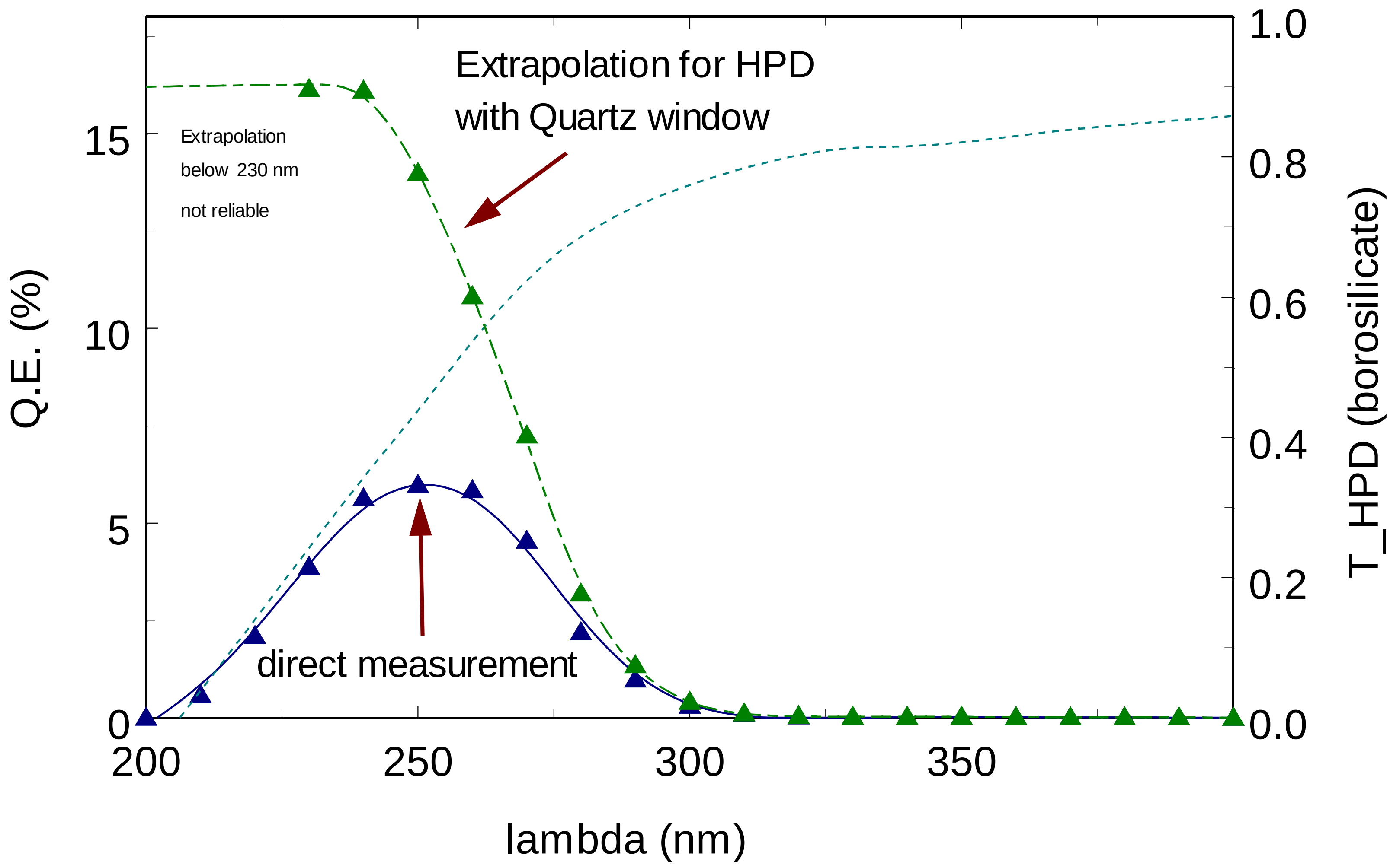


Radial dependence of HPD (PC68) QE for λ=230, 290 and 350 nm.



- QE uniformity over the surface is better than 10%

Photocathode 96 Rb_2Te (ITO - 3nm)



Various prototype HPD-like tubes produced (up to 10 inches)

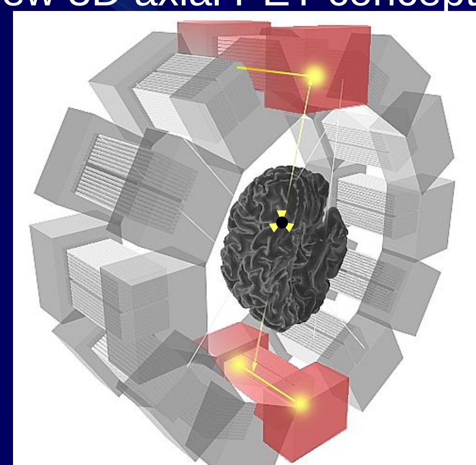
10''

5''

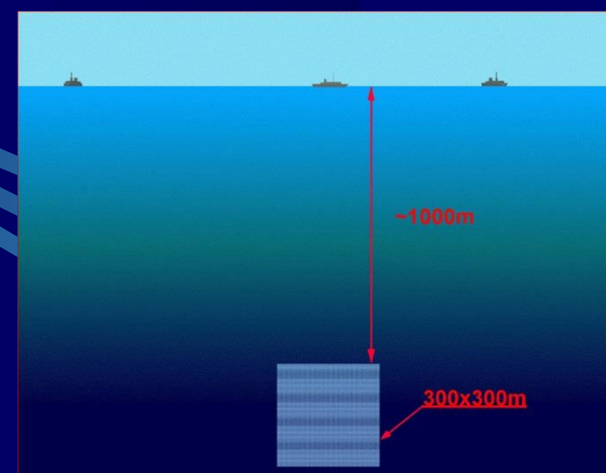
8''

CLUE =
Cherenkov Light Ultraviolet Experiment

New 3D axial PET concept



Underwater Neutrino Detector



Conclusions

- CsI photocathode production is a very mature and reproducible technology.
- The CERN plant allows to routinely produce CsI PCs up to 60 x 60 cm^2.
- Alkali-antimonide visible light photocathode production is technologically challenging. It requires lots of dedicated infrastructure and experienced manpower.
- A plant at CERN is available but has not been used since 6 years. Experts have retired or went to other fields.
- Re-activation and transformation for gaseous photodetectors is not excluded but would require very substantial efforts.