a high Quantum Efficiency photocathode

NIKHEF

TU Delft

BROOKHAVEN NATIONAL LABORATORY

PHOTONIS

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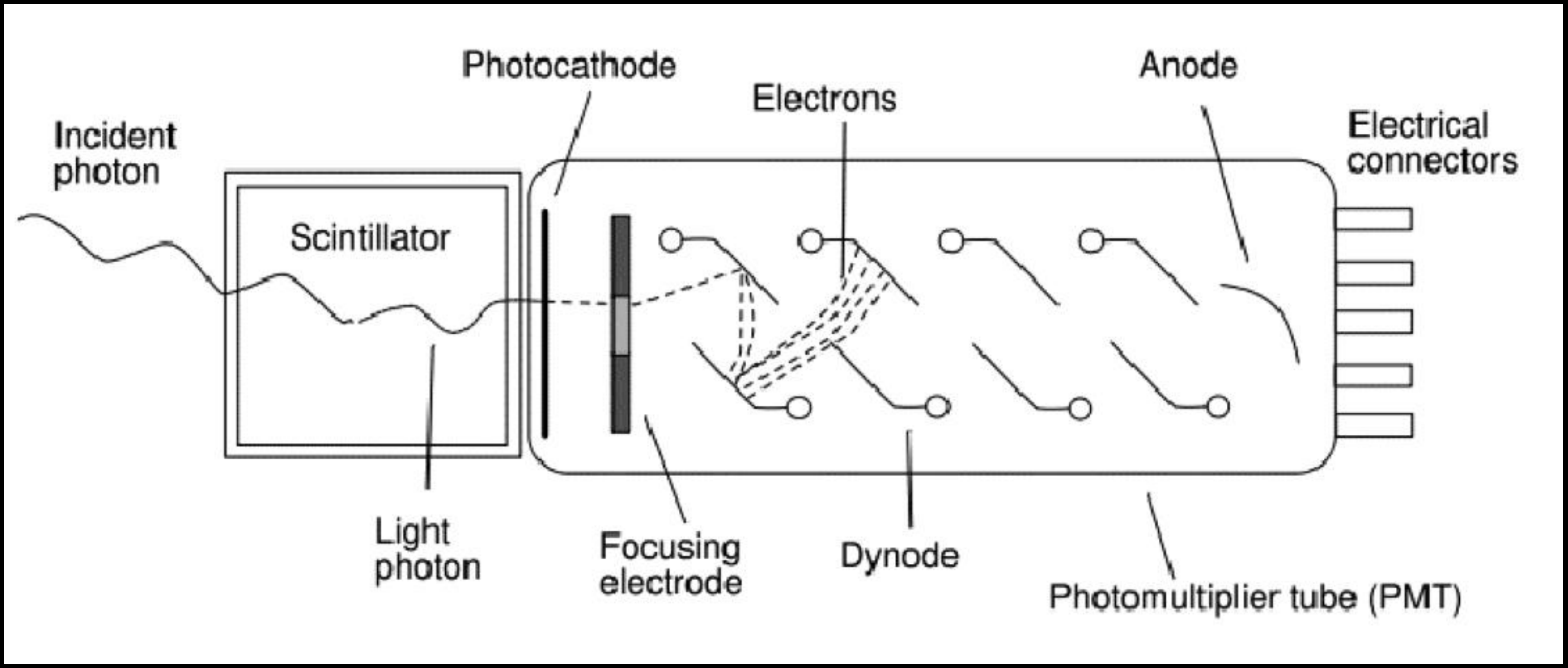
ATTRACT meeting
Nikhef
Amsterdam, January 12, 2018

single (digital) soft photon detectors

- **time resolution**
- **2D spatial resolution**
- **detection efficiency: Quantum Efficiency QE**

A very successful photon detector: the Photomultiplier (1934 -1936)



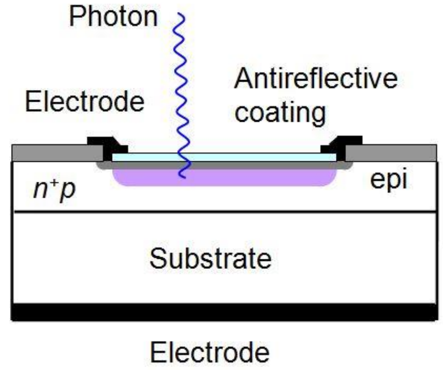
- ‘good’ quantum efficiency
- rather fast
- low noise @ high gain: very sensitive
- little dark current, no bias current
- radiation hard
- quite linear

- voluminous, bulky & heavy
- no spatial resolution, not even 1D
- expensive
- quite radioactive
- can’t stand B fields

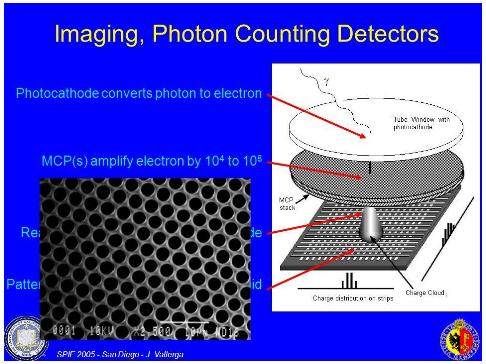
Amplification by multiplication: low noise!

(new) developments

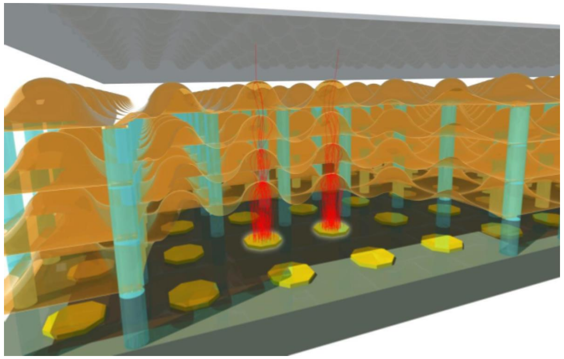
Si PMs



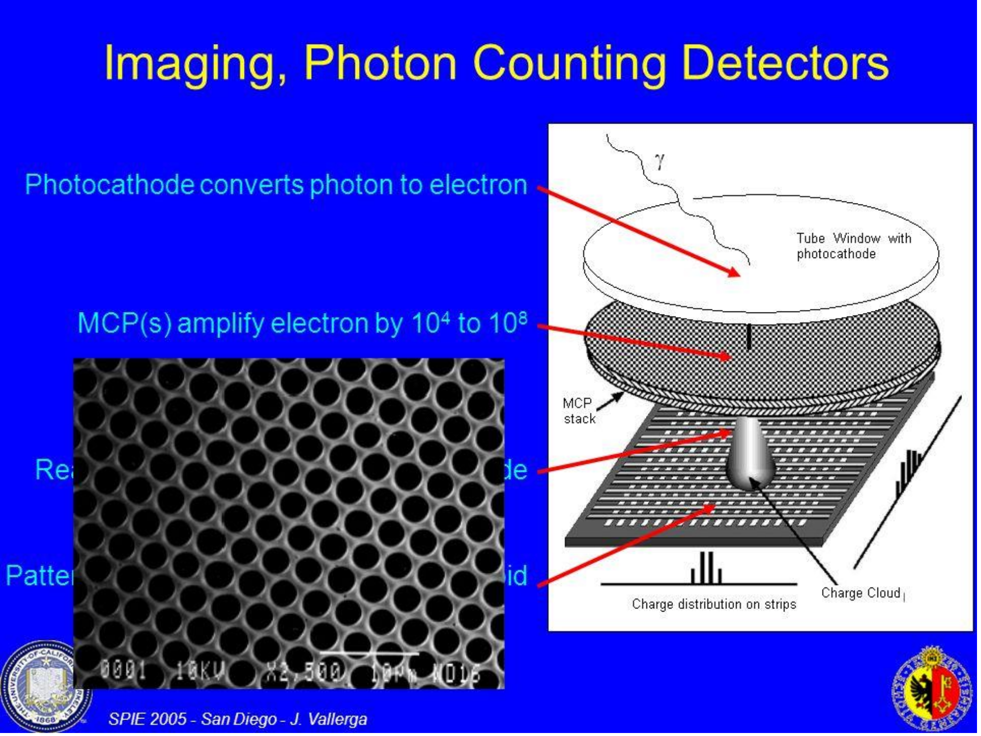
MCPs + pixel chip
Planacon Photonis
John Vallerga
Nicolas Wyrsch

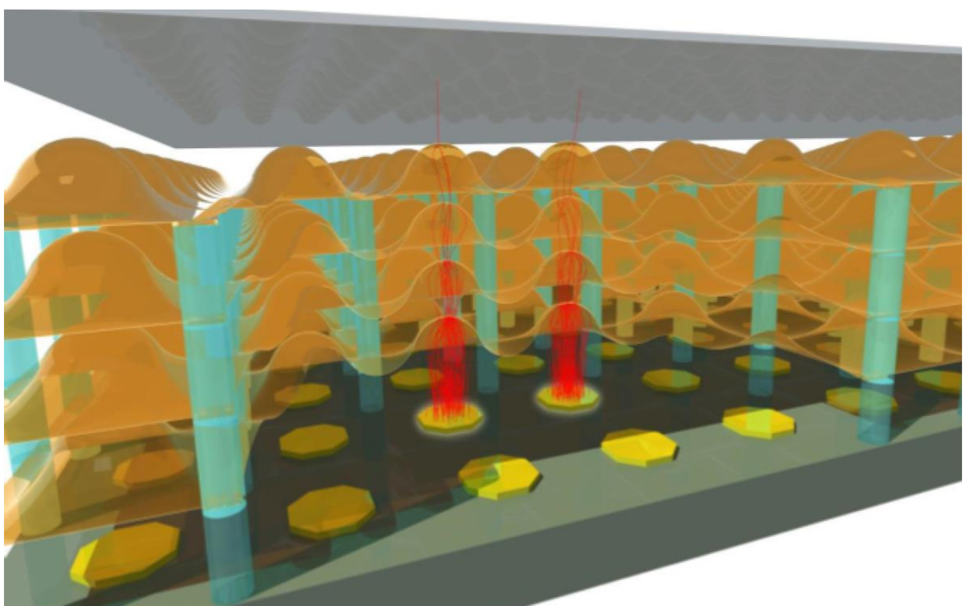


the Tynode: Tipsy
MEMBrane project



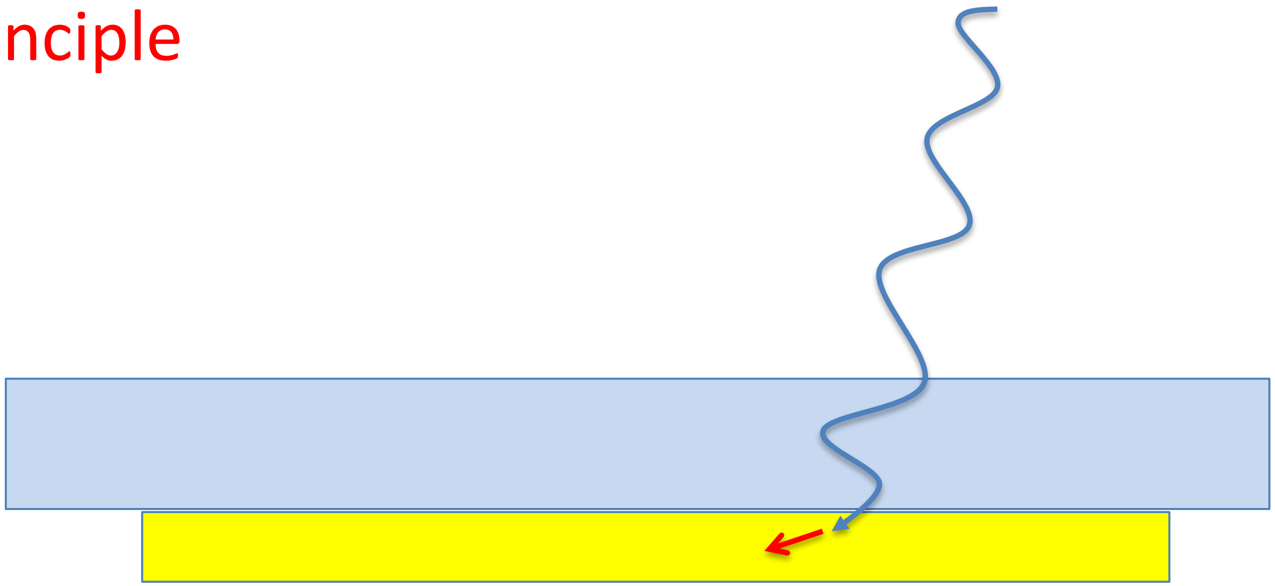
	noise	QE	ΔT
Si PMs	🔴	✔	🔵
MCPs + pixel chip	✔	🔵	✔
the Tynode: Tipsy	✔	🔵	✔✔





The QE of MCP- or Tynode- based detectors is (only) determined by the QE of photocathodes

Principle



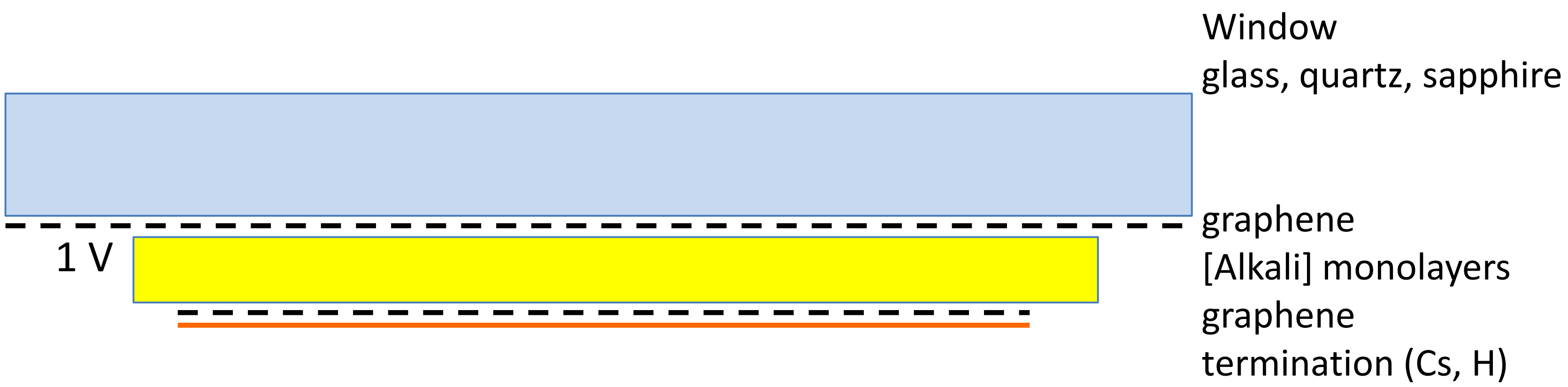
- absorption
- diffusion
- emission

QE never exceeded 0.5

real practical solutions (Photonis, Hamamatsu) are classified

Tipsy's only limitation: its efficiency equals the QE of photocathodes: 0.4 at best

Therefore: the High Quantum-Efficiency (QE) Photocathode

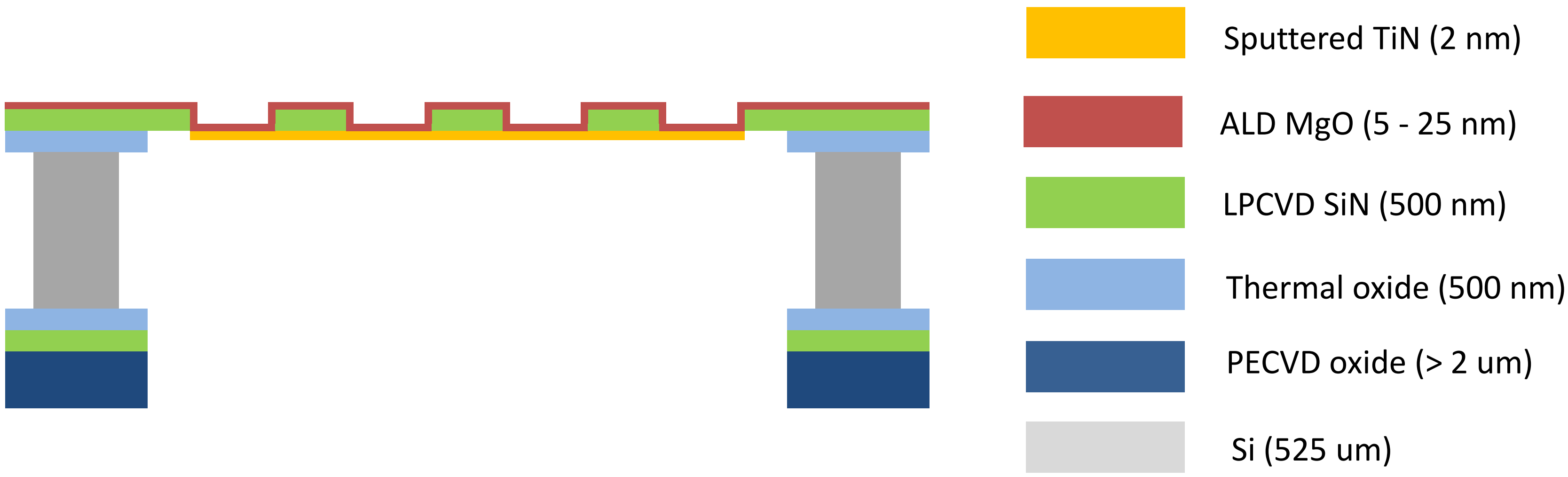


- *Active* photocathode: drift field pushing electrons to emission vacuum surface
- electric field created in between by potential defining graphene planes
- all layers build up individually by *atomic layer deposition* ALD
- electron emission stimulated by negative electron affinity by *termination*
- First designed after *ab initio* simulations of 3D atomic building blocks

Proposal *for theoretical concept* study: let is first understand the present state-of-the-art

Timed Photon Counter – Tipsy 0.0 – Fabrication of First Prototype

Finalized layout of MgO domes

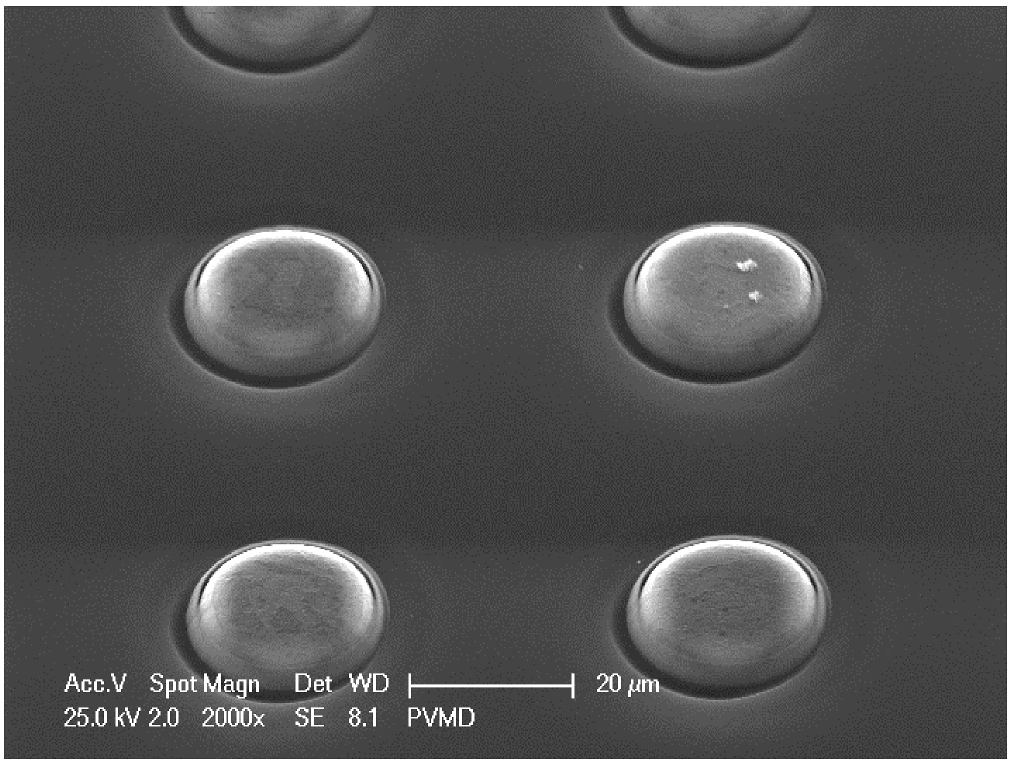


- We intend to manually stack 5 of these tynodes and place the stack above a TimePix-1 chip
- When in a close stack, we may achieve higher yields from close, extracting fields:
  There is a report[1] that, with a single Si membrane, yields of 200 has been reached due to a strong extracting field. We may have an even much higher extracting field!

1) Qin, Kim, Blick. APL **91,** 183506 (2007).

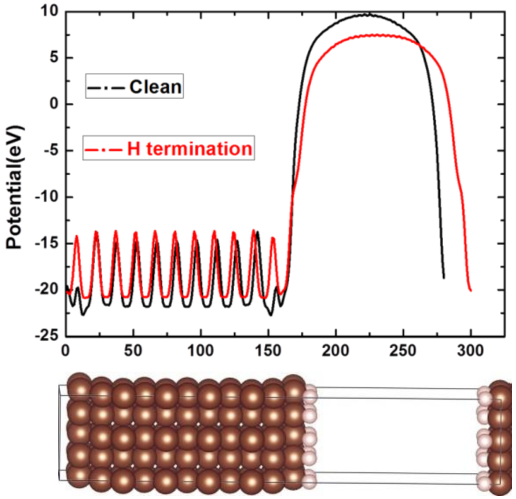
Atomic Layer Deposition: ALD

- In future: more single layer combinations expected to be possible
- Integration with graphene monolayers



Tipsy's ALD made MgO tynode + TiN conductive layer

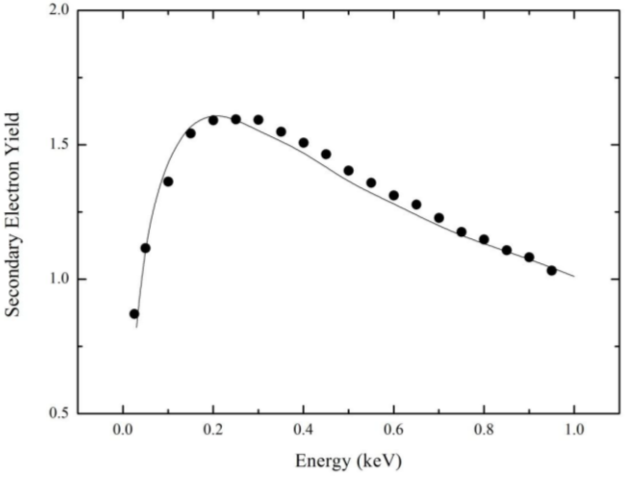
Density Functional Theory simulations



Electronic structure, work function, optical data

Vienna Ab-Initio Simulation Program
VASP

Monte Carlo simulations



The Cherenkov-ToF-PET scanner

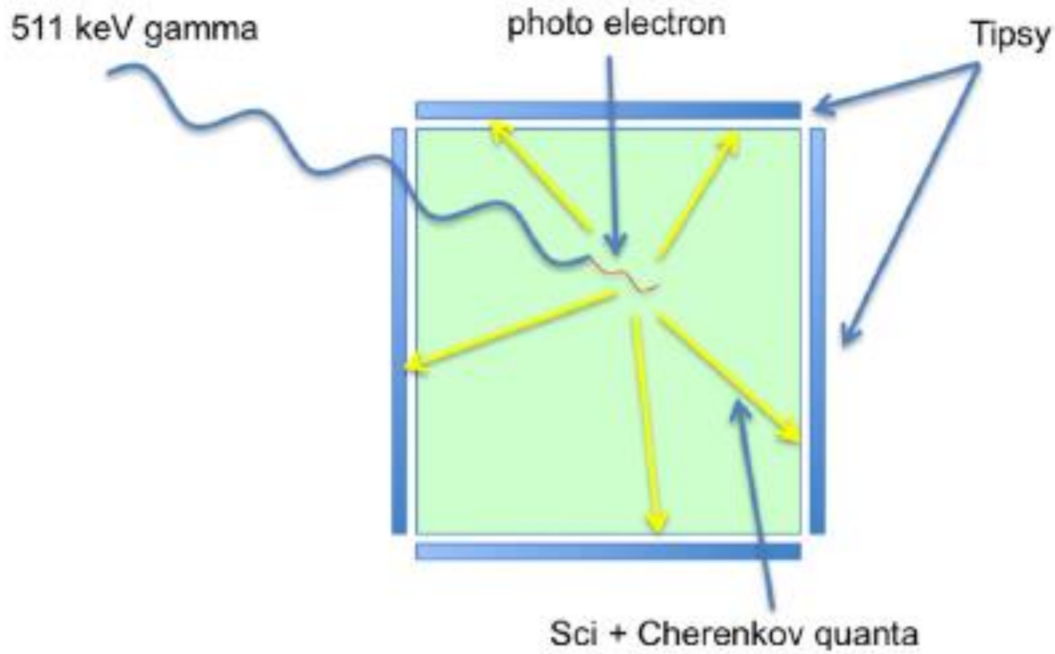
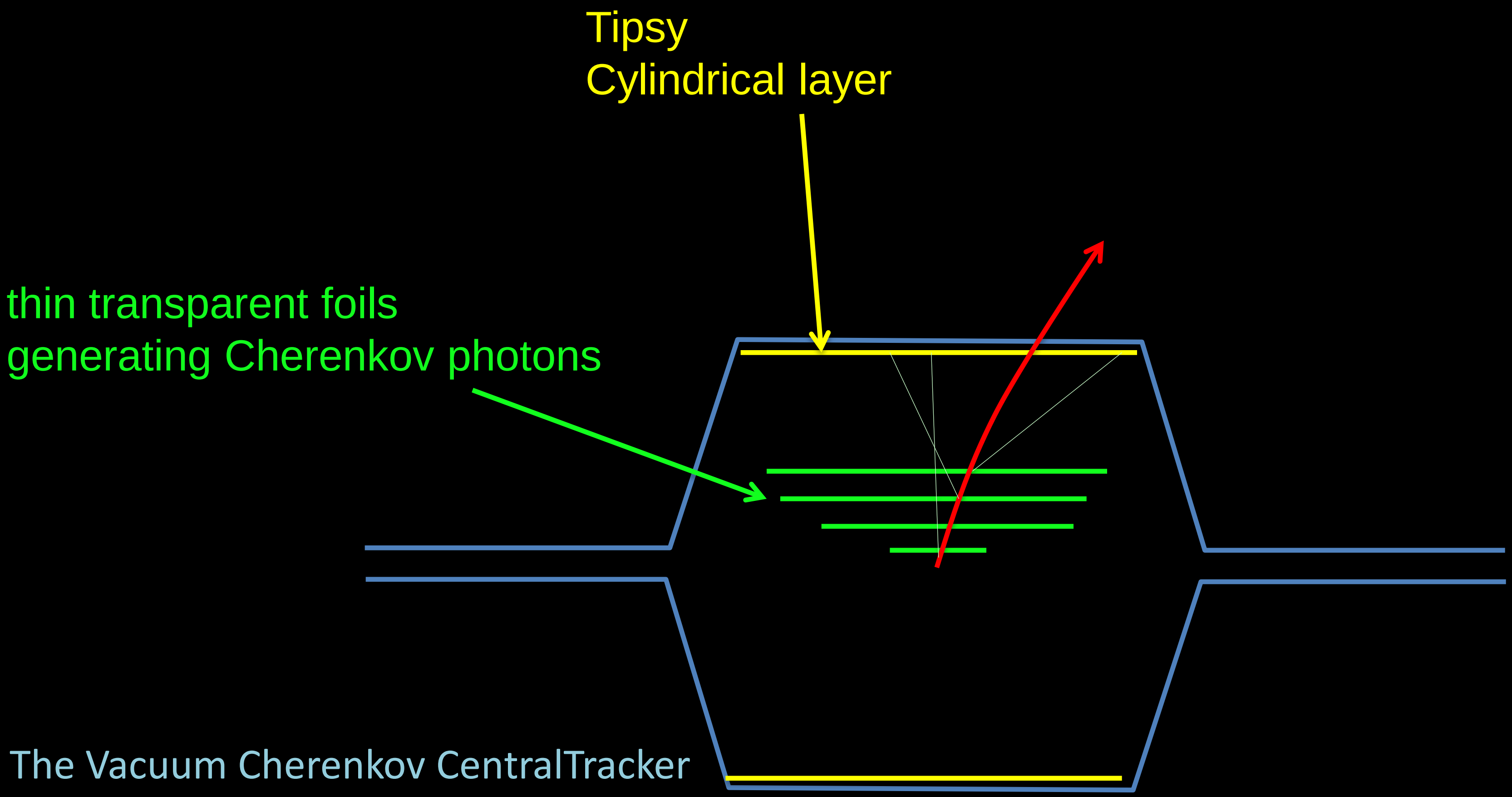


Fig. 5. A PET scanner detection element with Timed Photon Counter Tipsy soft photon detectors as readout. Cherenkov photons, created after the absorption of a 511 keV annihilation photon in a lead glass cube are read out at all six sides.

Future inner (central) tracker in collider experiments: the Cherenkov tracker

- very low detector mass
- Tipsy layer at safe distance from interaction point
- no extrapolation



The Vacuum Cherenkov CentralTracker

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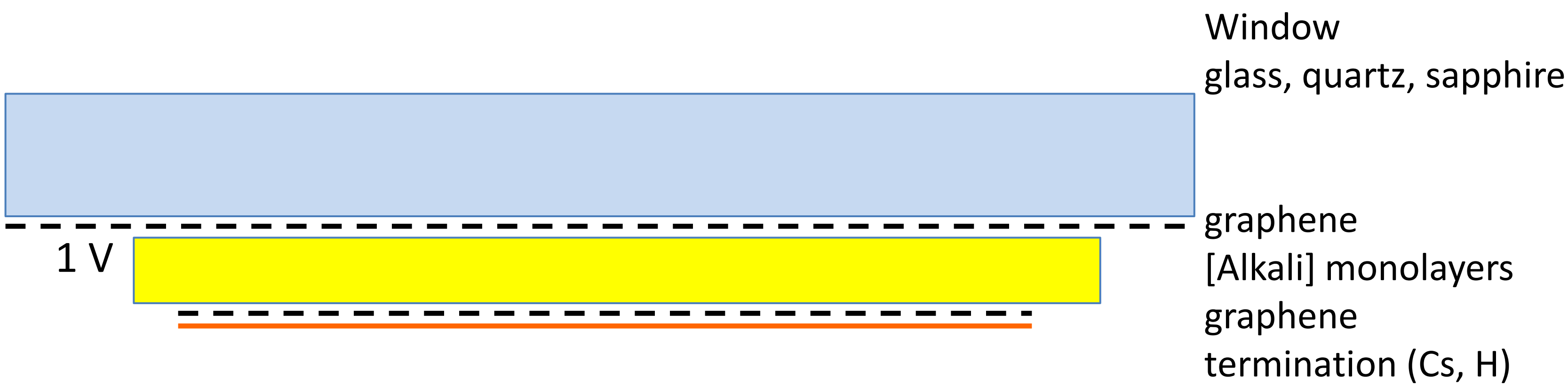
Therefore: the High Quantum-Efficiency (QE) Photocathode



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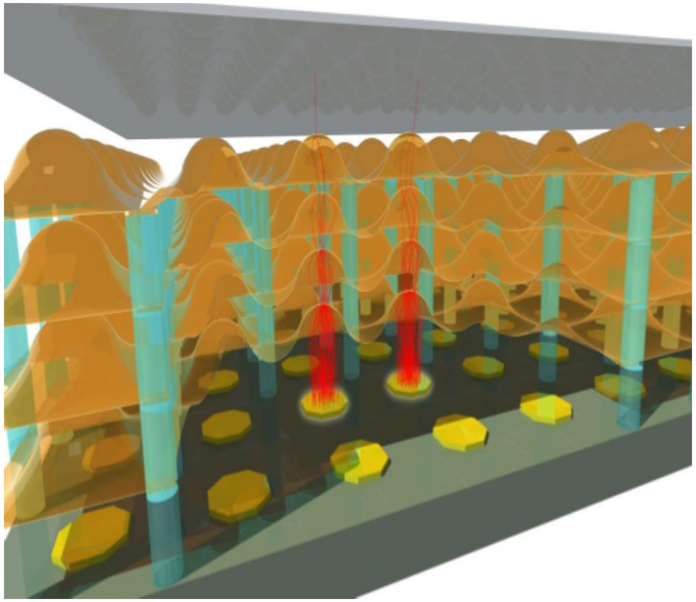

The Tynode: a Transmission Dynode with sufficient yield enabling the construction of Tipsy 0.0

On behalf of the Membrane project:

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H. van der Graaf et al.: The Tynode: A new vacuum electron multiplier.
Nucl. Instr. & Methods, in press. http://dx.doi.org/10.1016/j.nima.2016.11.064. T

H. van der Graaf et al.: Potential applications of electron emission membranes in medicine.
Nucl. Instr & Methods, special Medical Physics issue on "Advances in detectors and applications for Medicine". A809 (2016) 171-174. http://dx.doi.org/10.1016/j.nima.2015.10.084.