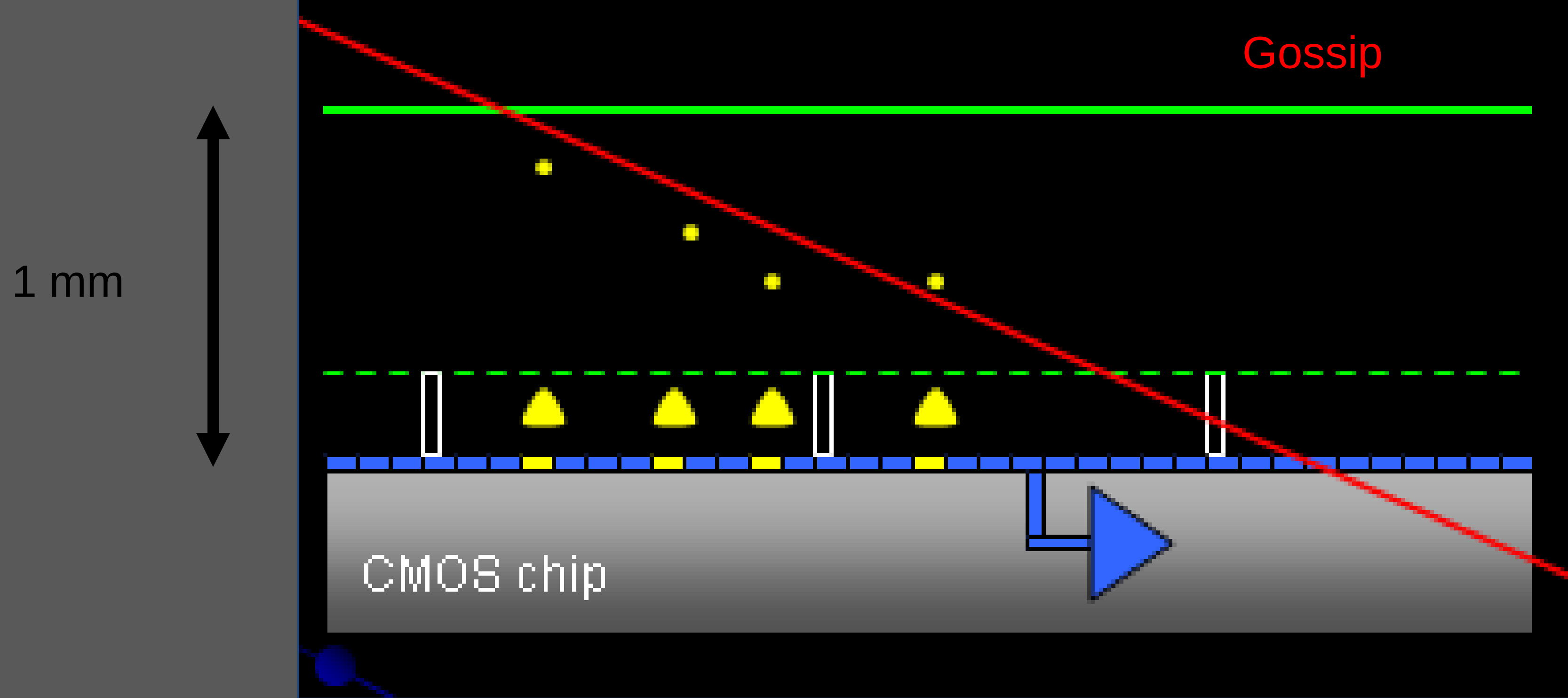
Pixel detectors: status, plans & applications of the gaseous GridPix/Gossip detector and a new vacuum electron multiplying detector

Harry van der Graaf, Nikhef, Amsterdam

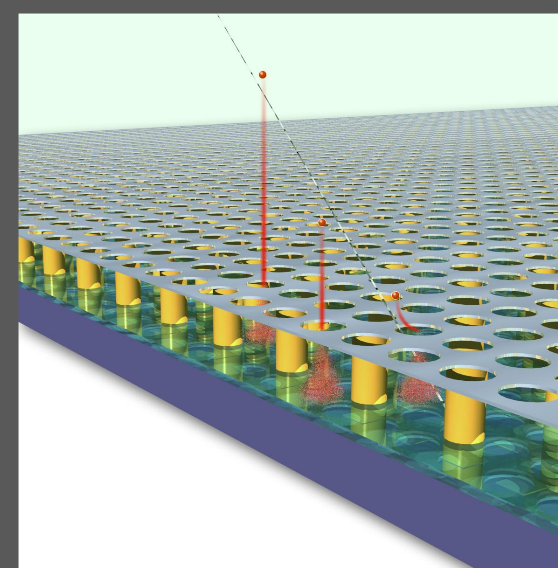
Monday Sept 5 KEK
Thursday Sept 7 Kamioka



GridPix: readout of TPC ionisation charge

Gossip: Gas On Slimmed SIlicon Pixels
Essential: thin gas layer (1 mm)

Gossip: replacement of Si tracker



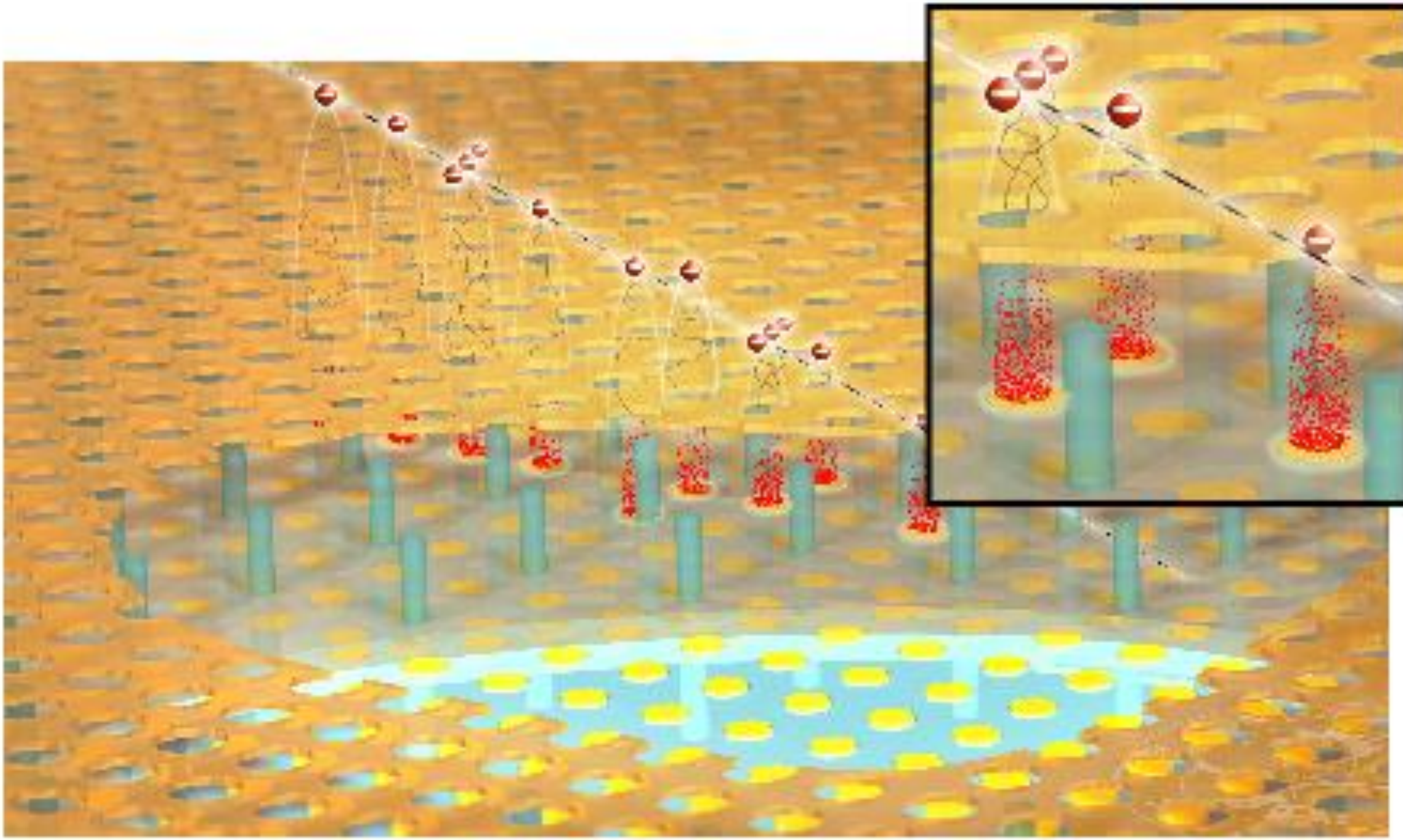
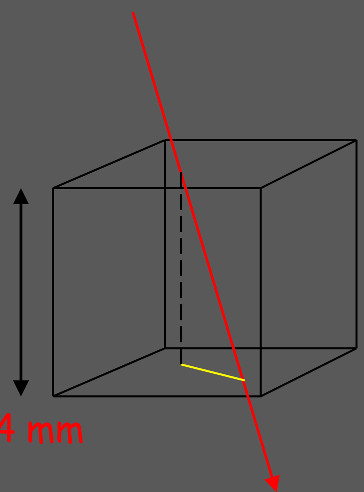


Fig.3: The GridPix detector: a passing fast charge leaves a track of ion-electron pairs in the gas volume above the readout chip. The liberated electrons drift towards the chip and cause an avalanche in the high-field region between the perforated electrode (green dashed line) and the microchip. The inset highlights the gas avalanche part of the detector.

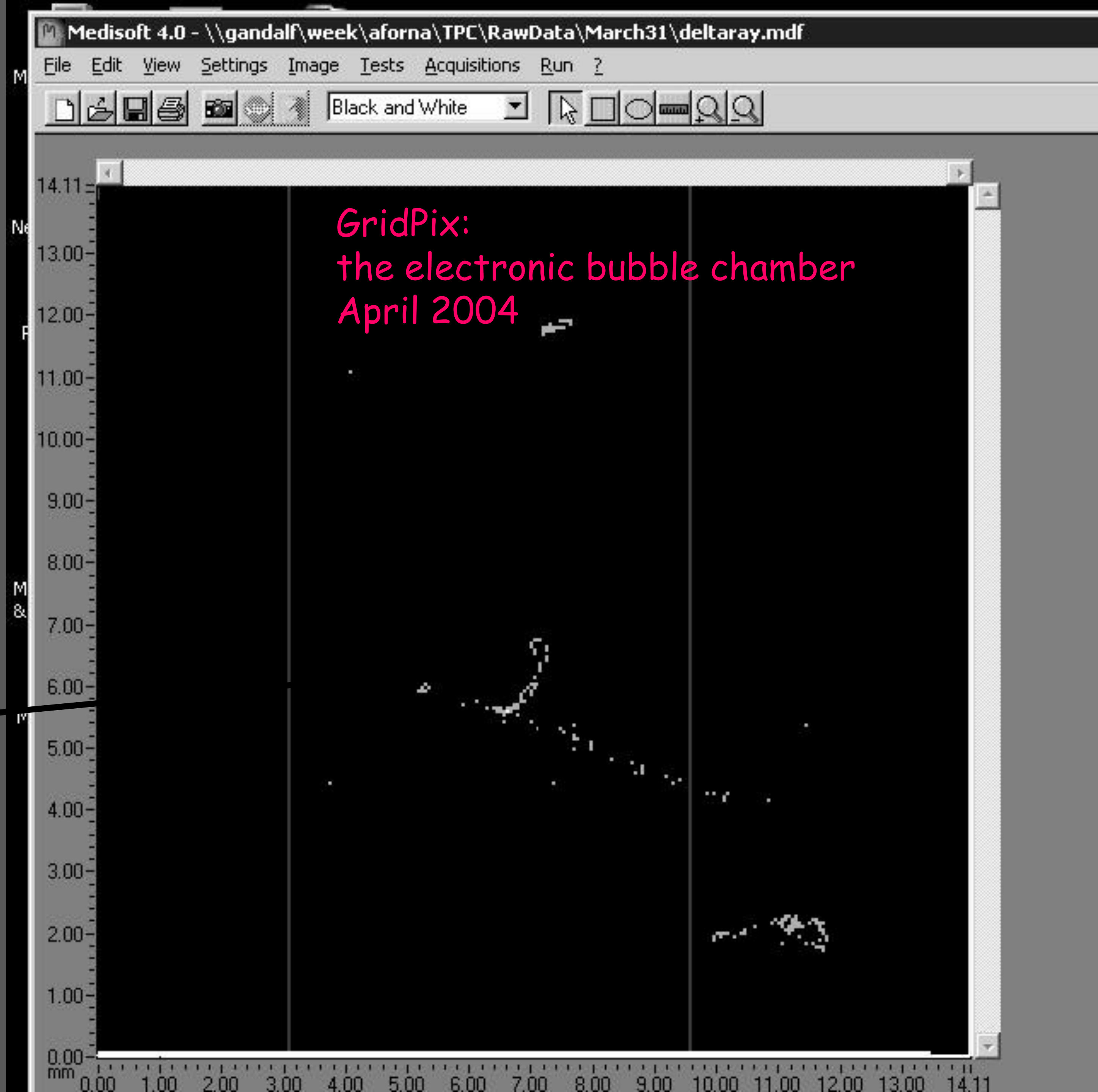
He/Isobutane
80/20
Modified MediPix

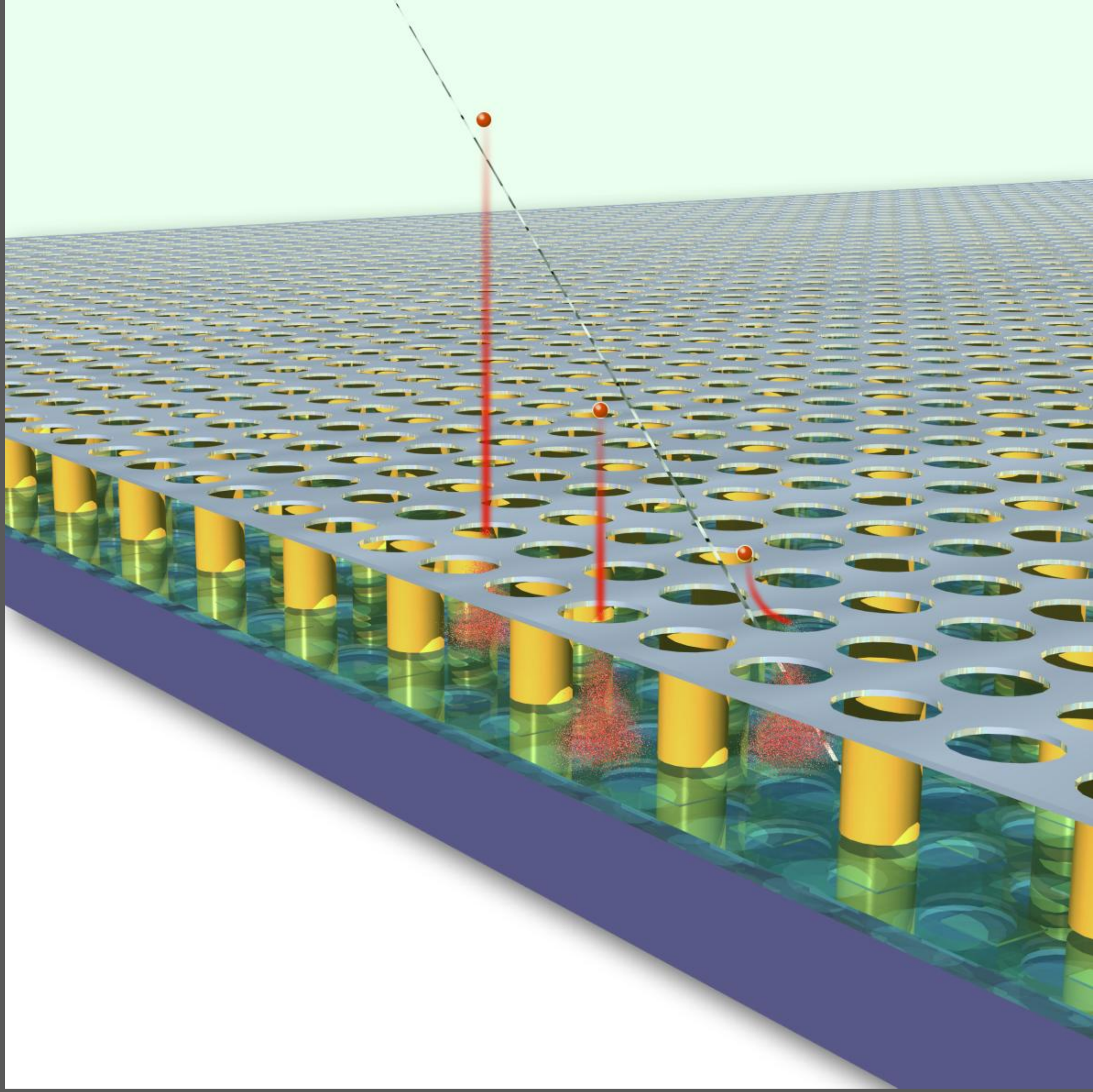


14 mm

δ-ray!

Efficiency for detecting single electrons:
< 95 %





Application of Micromegas

New:
- pixel chip as active anode readout
- MEMS made Micromegas: Integrated Grid InGrid

The MediPix2 pixel CMOS chip

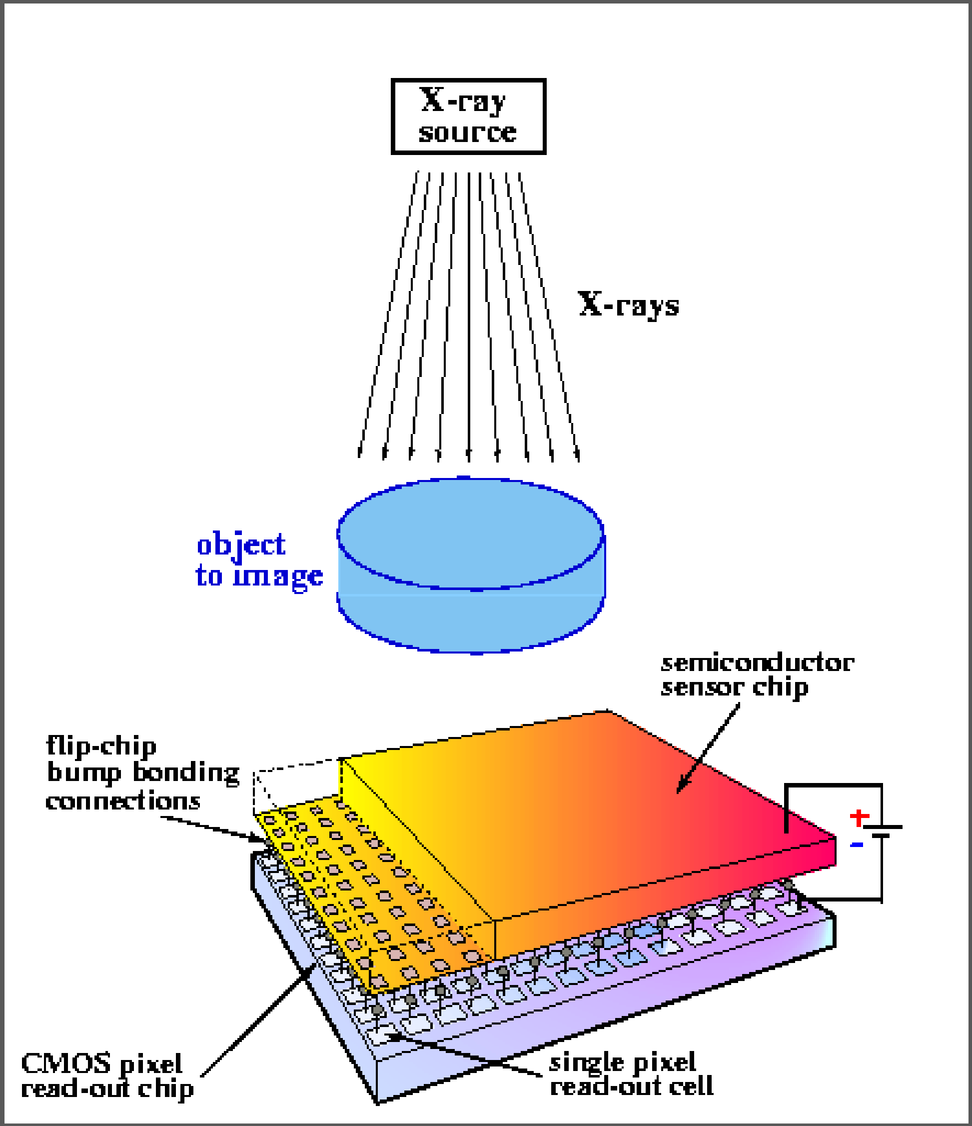
256 x 256 pixels
pixel: 55 x 55 μm²
per pixel:
- preamp
- shaper
- 2 discr.
- Thresh. DAQ
- 14 bit counter

- enable counting
- stop counting
- readout image frame
- reset

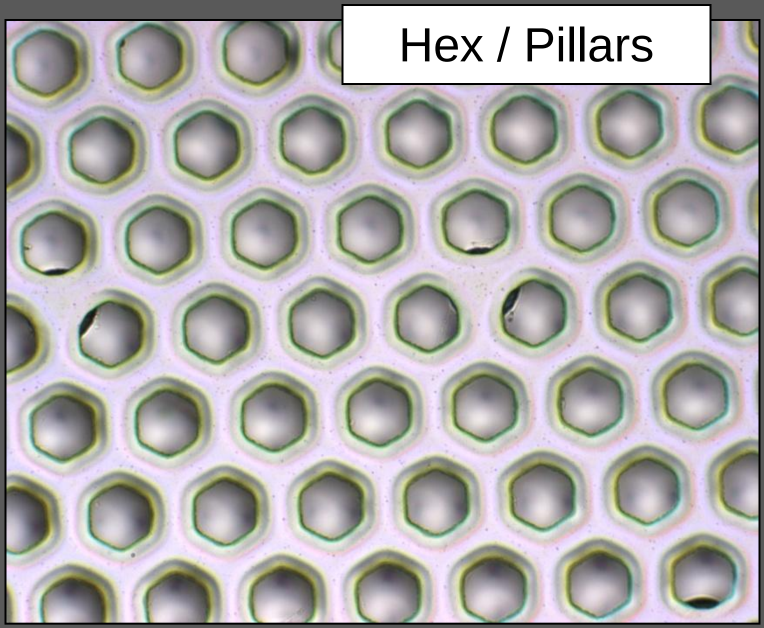
We apply the 'naked' MediPix2 chip without X-ray convertor!

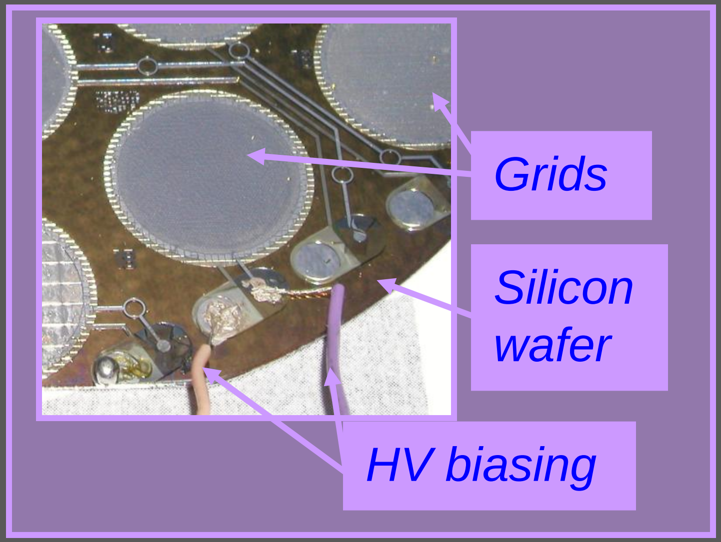
Applied chips:

Medipix-2
TimePix
PSI-46
FE-I4
TimePix-3: underway: submission Dec 2011



Wafer post-processing:InGrid



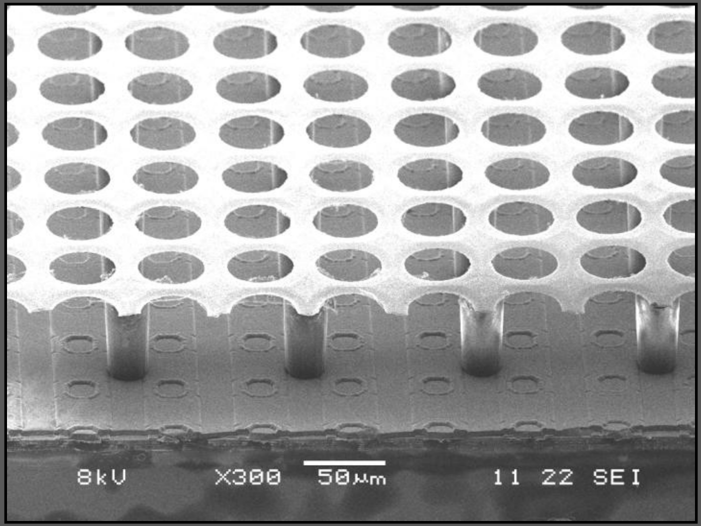


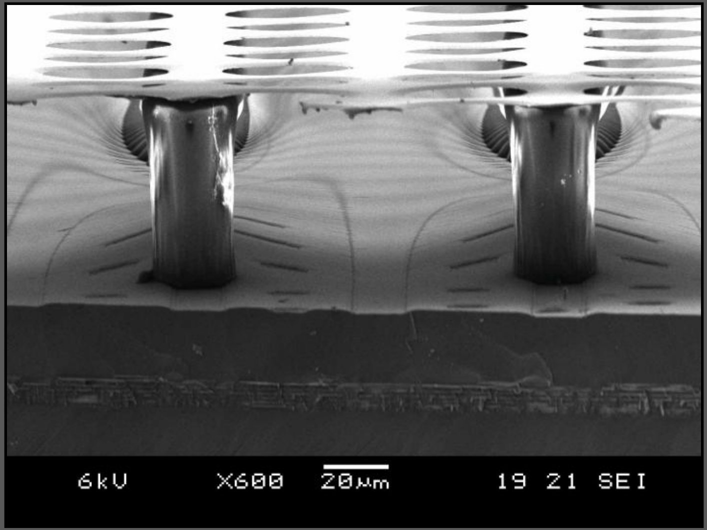
InGrid: an Integrated Grid on Si (wafers or chips)

- perfect alignment of grid holes and pixel pads
- small pillars Ø, hidden pillars, full pixel area coverage
- Sub-micron precision: homogeneity
- Monolithic readout device: integrated electron amplifier

Full post-processing of a TimePix

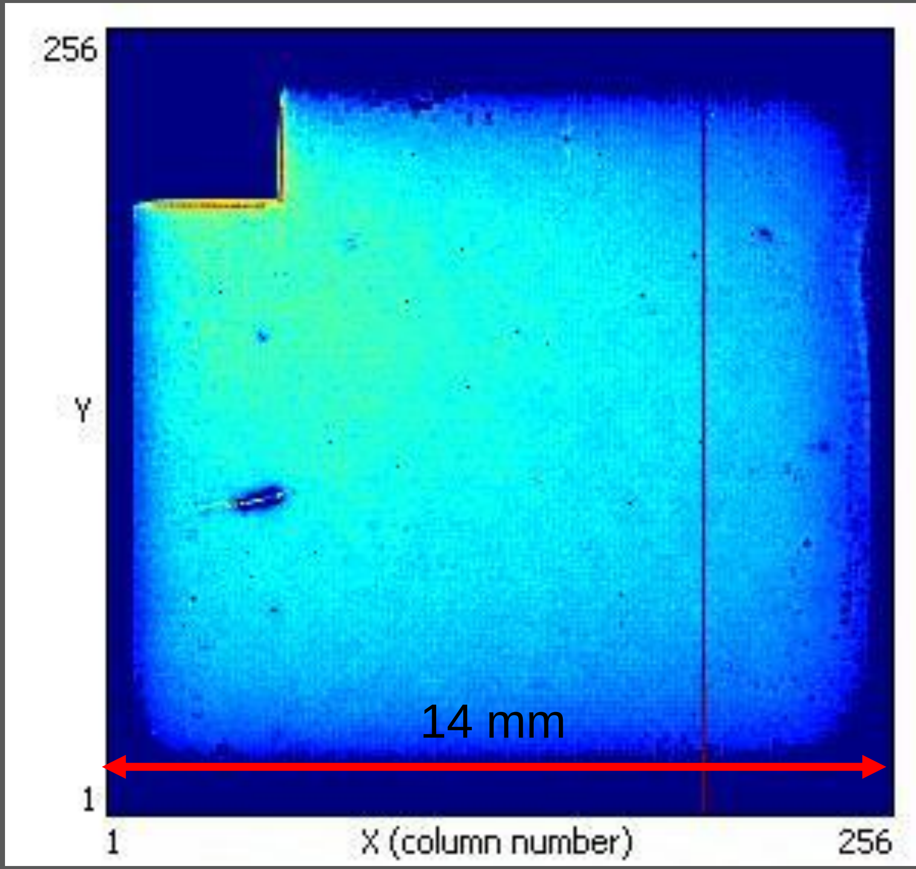
- Timepix chip + SiProt + Ingrid:





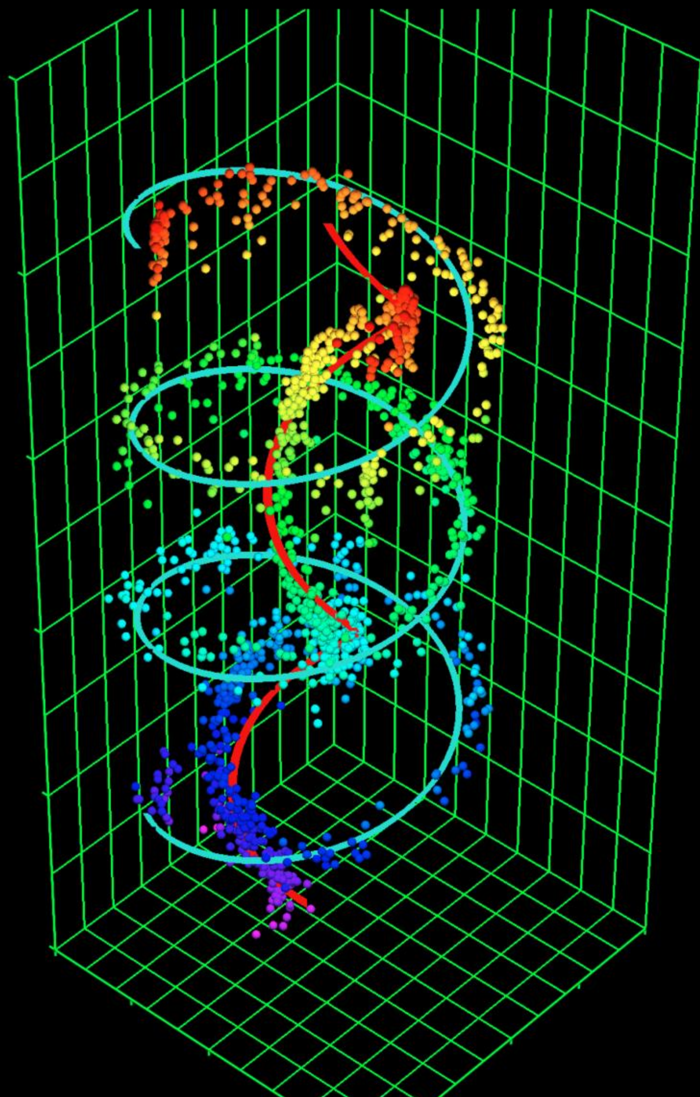
MESA+

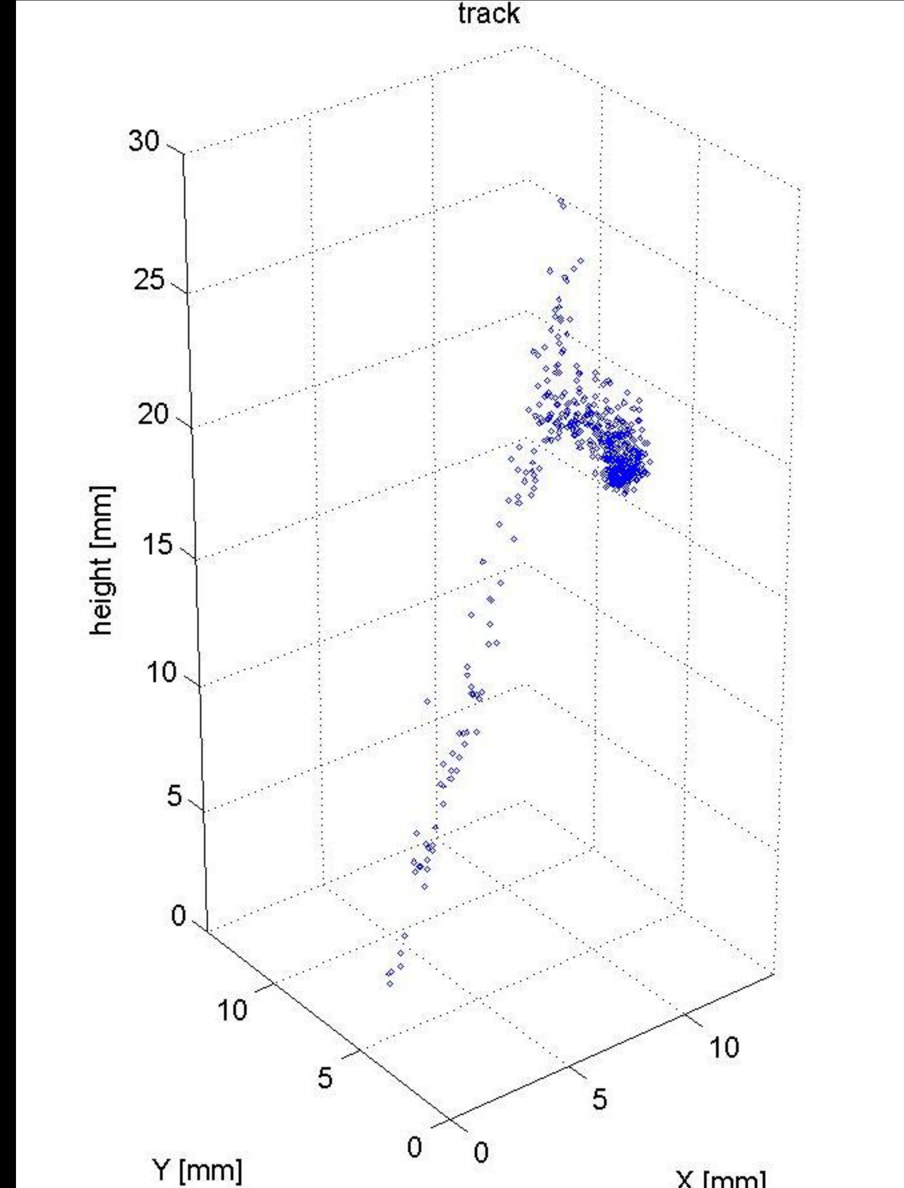
IMT Neuchatel



"Uniform"

Charge mode





two beta's from 90Sr in a 0.2 T B-field

100 GeV Muon in testbeam 2010 @ CERN

Gossip testbeam August 12 – 22 , 2010

Maarten van Dijk

Martin Fransen

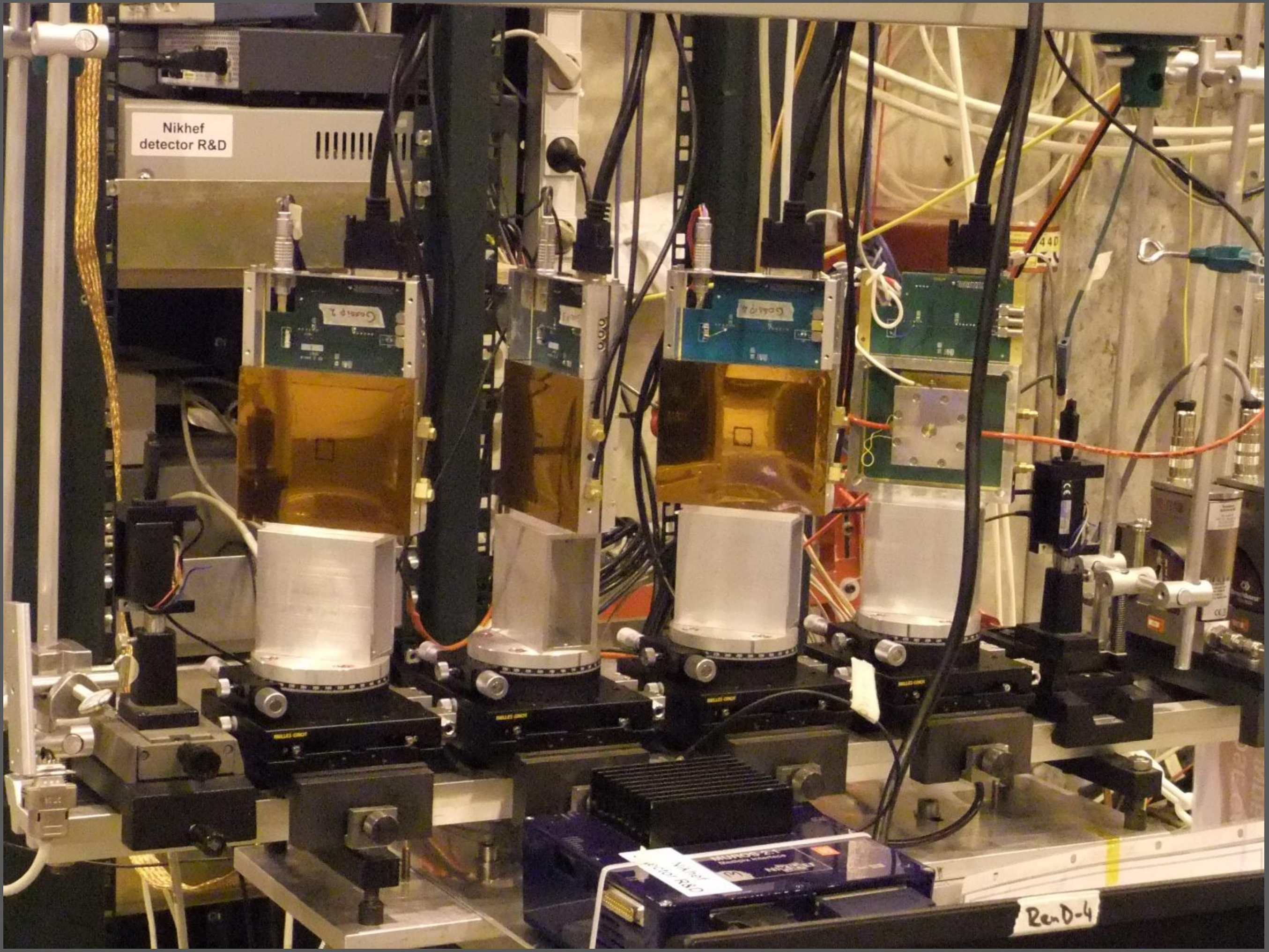
Harry van der Graaf

Fred Hartjes

Wilco Koppert

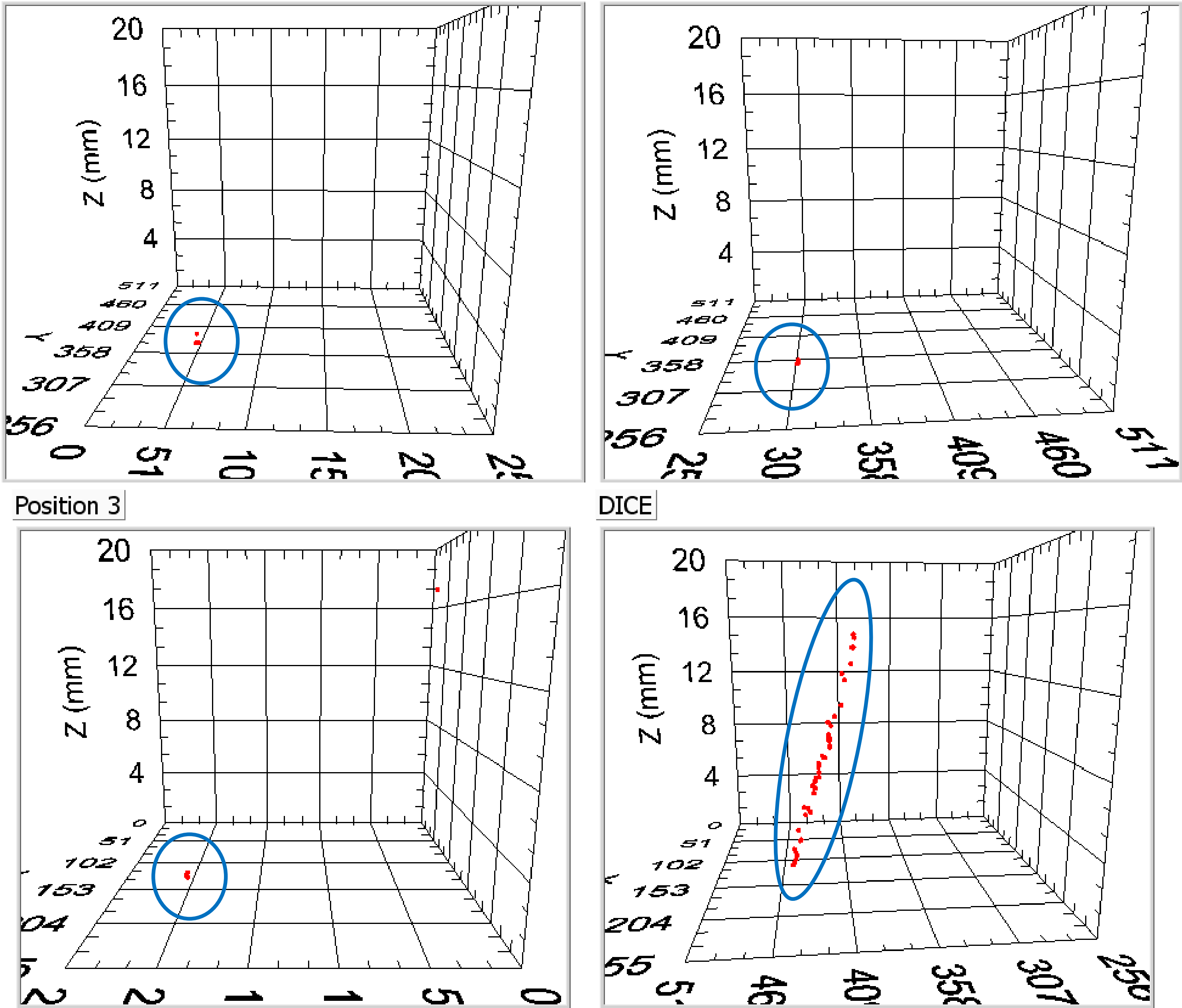
Sjoerd Nauta

Rolf Schön



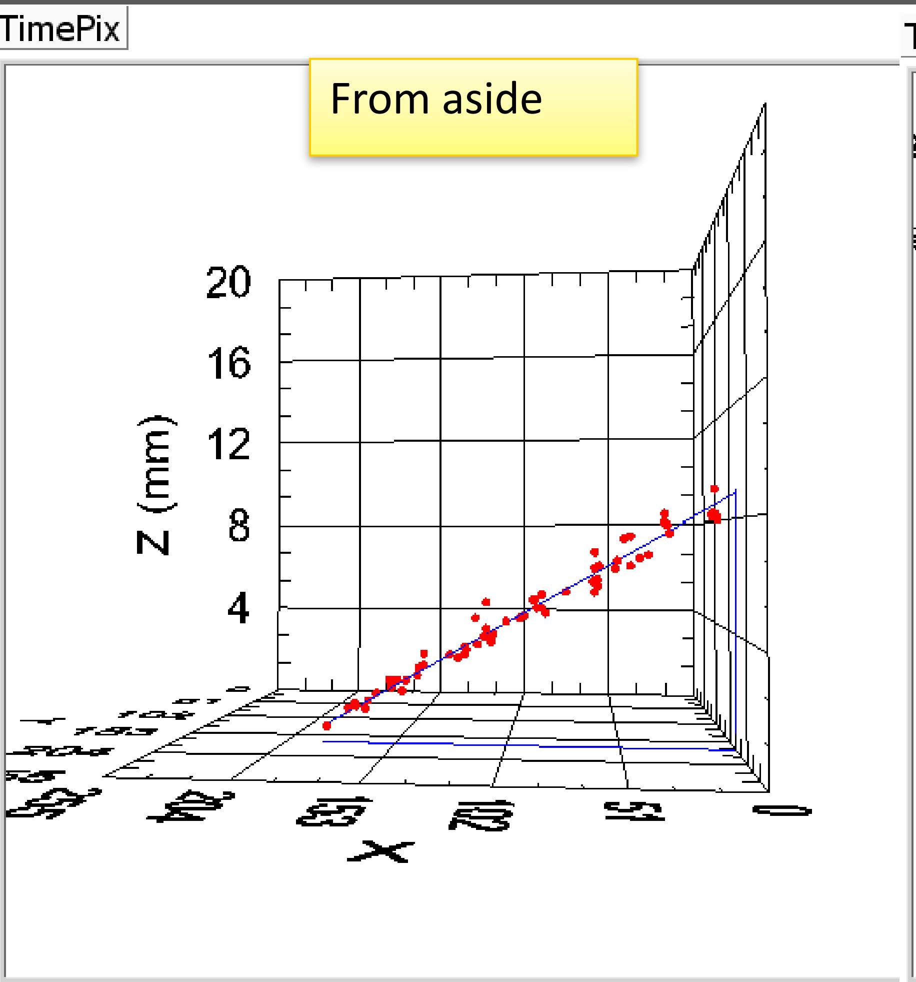
Testbeam Aug 2010, RD51/H4, SPS, CERN

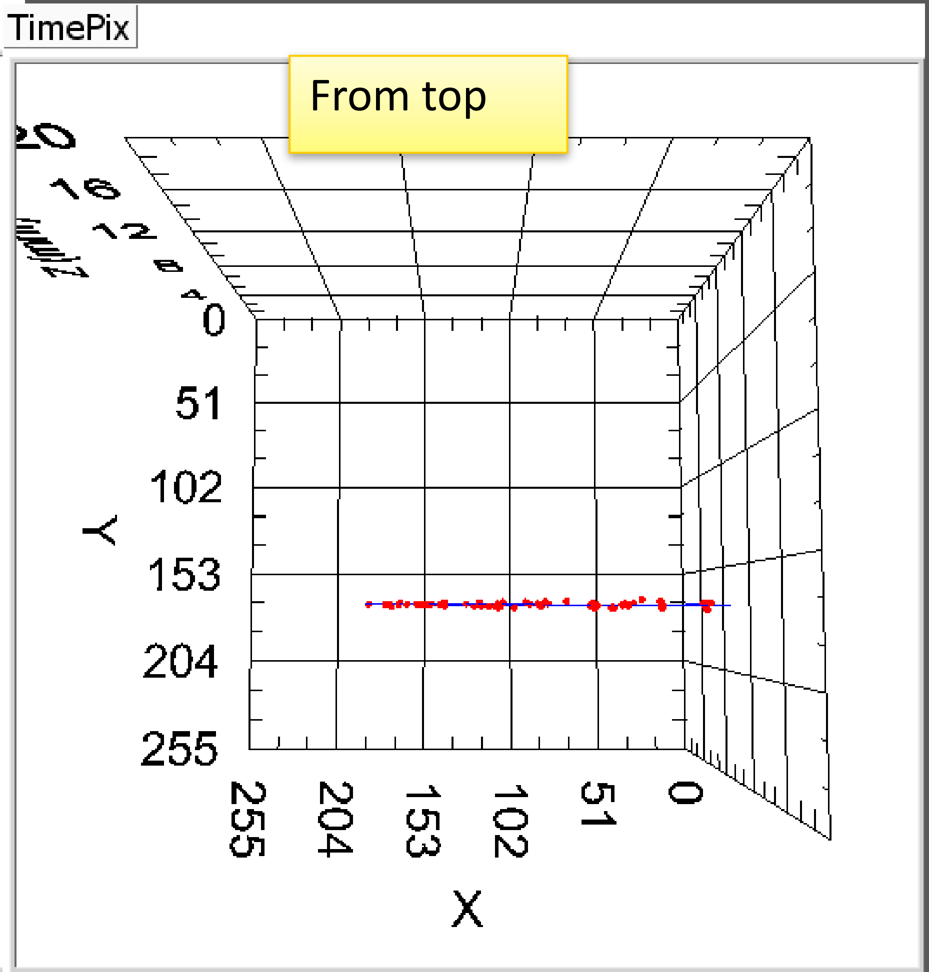
Typical event in all 4 detectors (angle 10°)



Typical event in GridPix under 45°

- Very small diffusion but big time slewing





Summary of Performance of Gossip

- track position resolution:15 μm: simulation 15 μm;
- single electron efficiency: > 90 %
- track detection efficiency: 99.6 %; simulation 99.4 %

Three new infrastructural issues:

- New gas
- miniHV
- ReLaXd readout interface for TimePix-Medipix

Gas versus Si (or Gossip versus Si detectors)

Pro:

- no radiation damage in sensor: gas is exchanged
- modest pixel (analog) input circuitry: low power, little space
- no bias current: simple input circuit
- low detector material budget: 0.06 % radiation length/layer
  typical: Si foil. New mechanical concepts
- low power dissipation : little FE power (2 μW/pixel); no bias dissipation
- operates at room temperature (but other temperatures are OK)
- less sensitive for neutron and X-ray background
- 3D track info *per layer* if drift time is measured
- gas is cheap (and *very* cheap wrt. Si sensors!), and light
- single (free drifting) electron sensitive

Con:

- Gaseous chamber: discharges (sparks): destroy CMOS chip
- gas-filled proportional chamber: 'chamber ageing'
- limit in spatial resolution due to low primary gas-particle
  interaction statistics
- Needs gas flow
- Parallax error: 1 ns drift time measurement may be required
- diffusion of (drifting) electrons in gas limits spatial resolution

There is a broad interest in GridPix chips

Commercial production is under development
at IZM-Fraunhofer, Berlin.

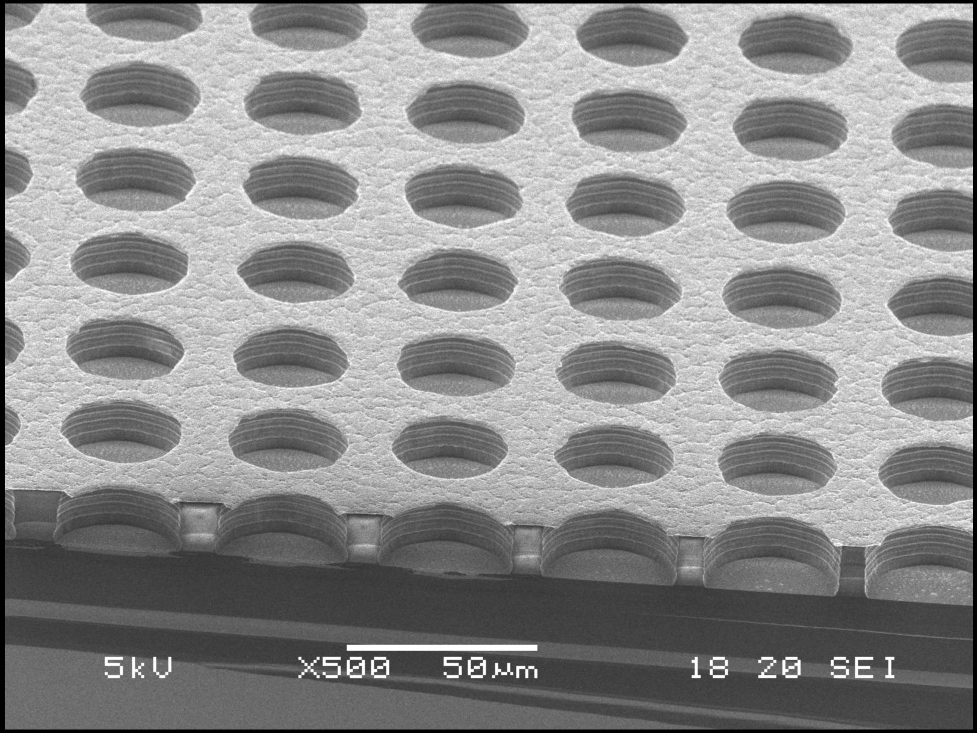
Goal:
to make robust InGrids on 8” wafers,
for a low price, in large numbers

IZM-Berlin
MESA+/Univ of Twente
Nikhef
Univ. of Bonn
Saclay

New R&D: the all-ceramic GridPix:

- Si TimePix chip
- SiNitride protection layer
- SiNitride InGrid

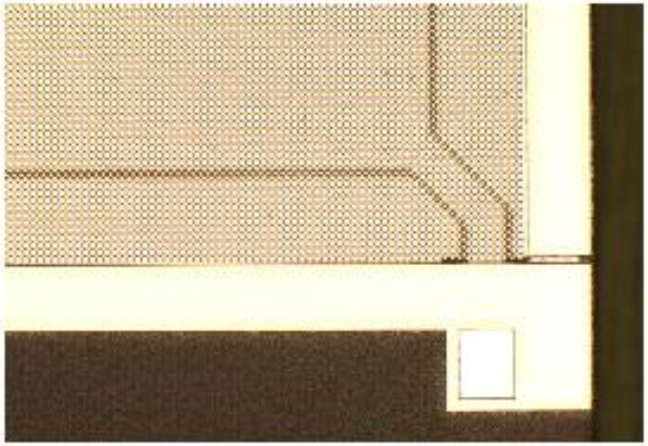
➔common thermal expansion coefficient: 6 x 10^{-6} K^{-1}

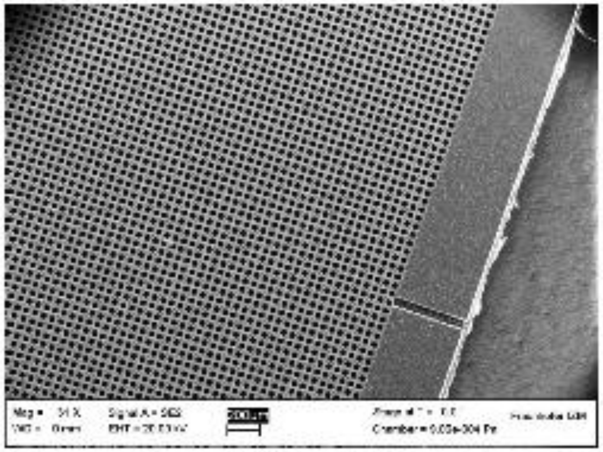


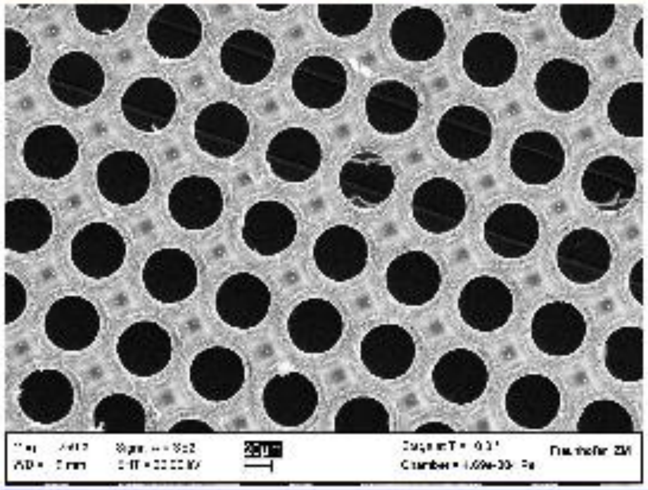
First GEMGrid with SiO2 as insulating spacer between grid and substrate
Victor Blanco Carballo, MESA+/Nikhef

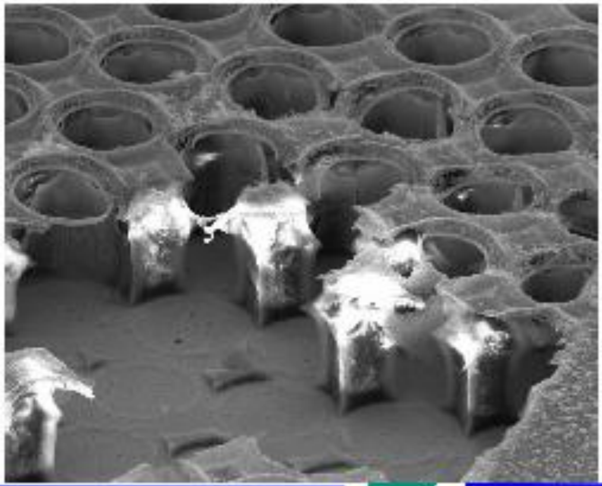
Processing of GEMGrid Test Chip (II)

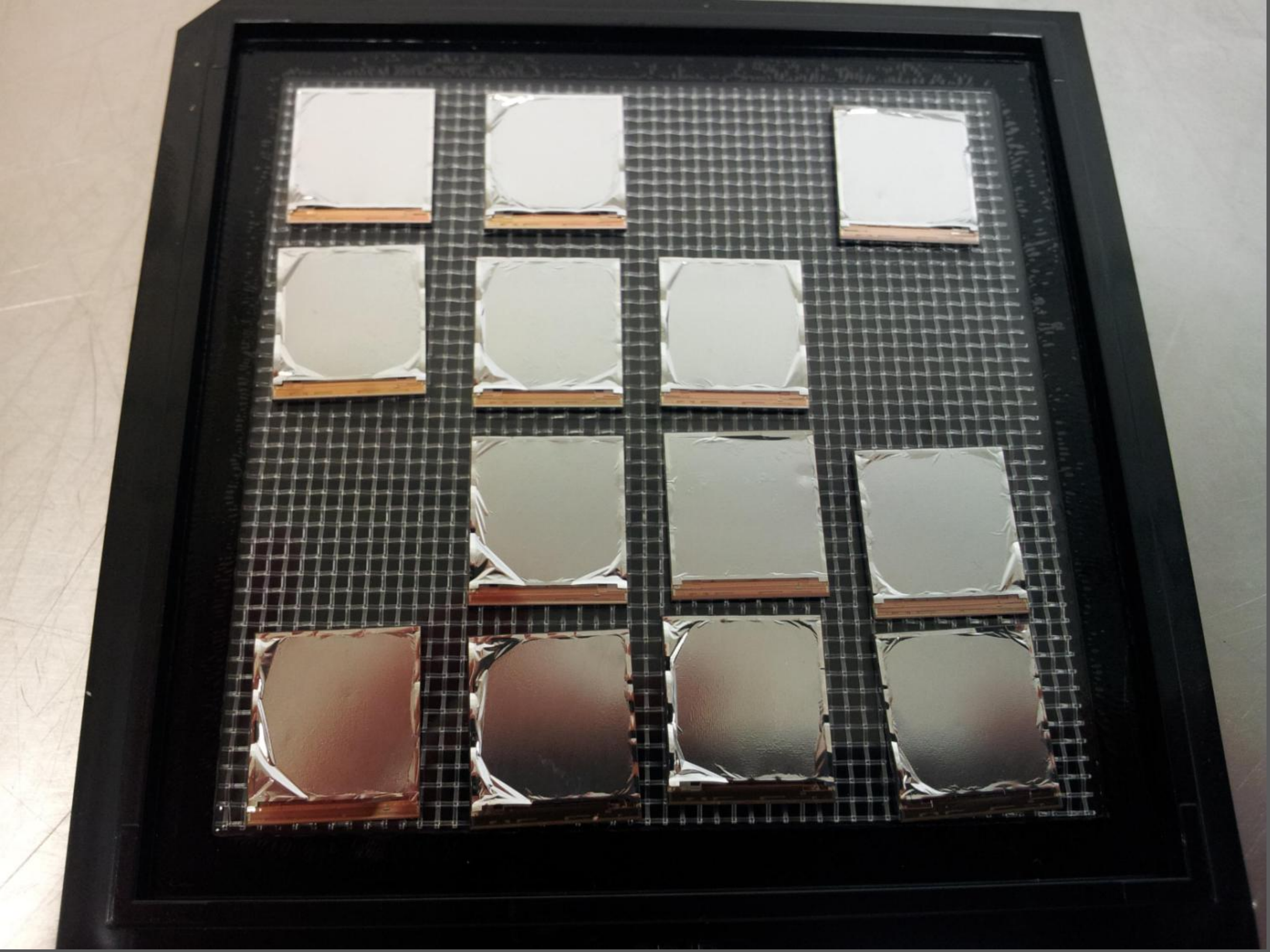
GEMGrid Test Chip after BCB Dry Etch











August 2011:

First
IZM GridPixs!

- wire bonding pads covered with SiNitride film

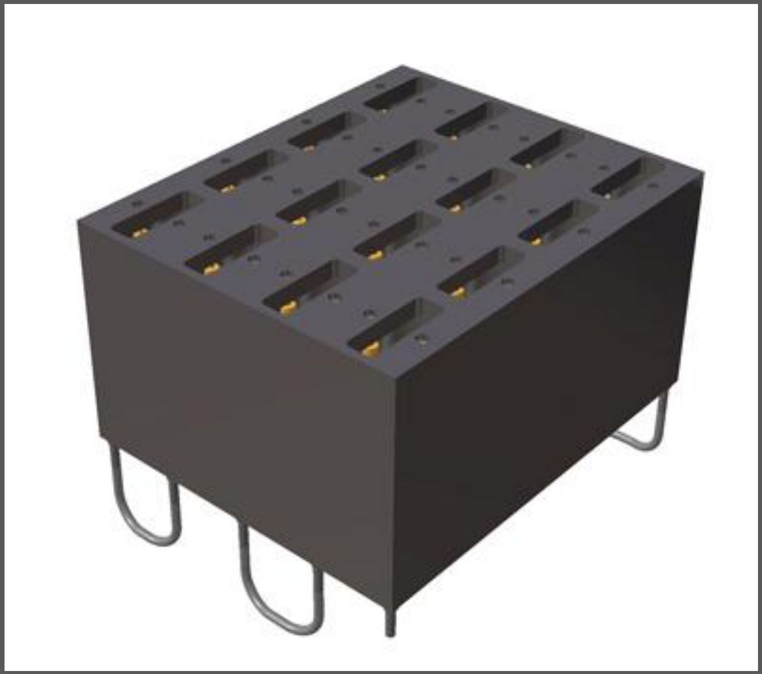
- InGrid peel-off at edges (due to unfortunate last correction treatment…..!)

- Good outlook to have low-cost mass production in October 2011 intentions to make available:

- GridPix chips
- ReLaXd readout system (Ethernet out)
- chip carrier boards
- DAQ & Control software

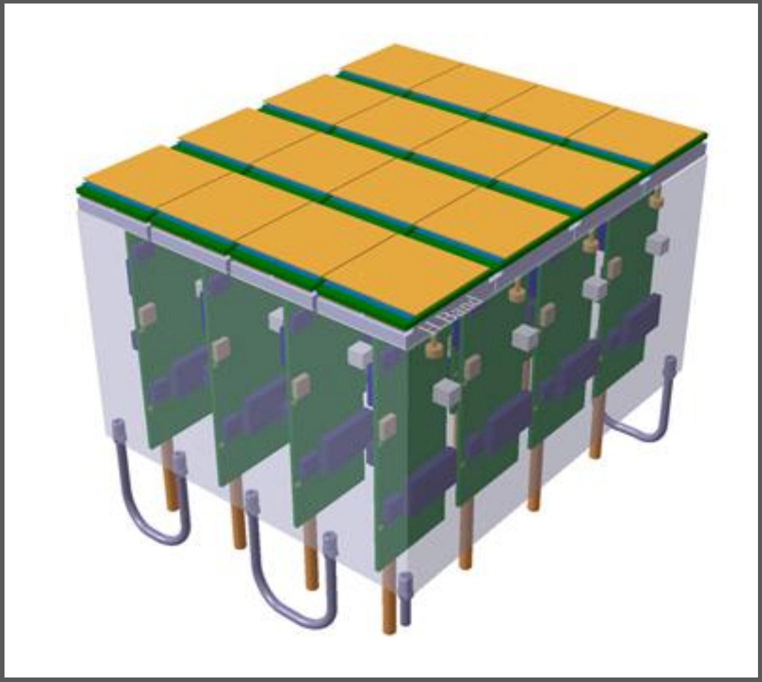
+

- NewGas system: pre-mix bottles
- miniHV High Voltage (low current) supplies



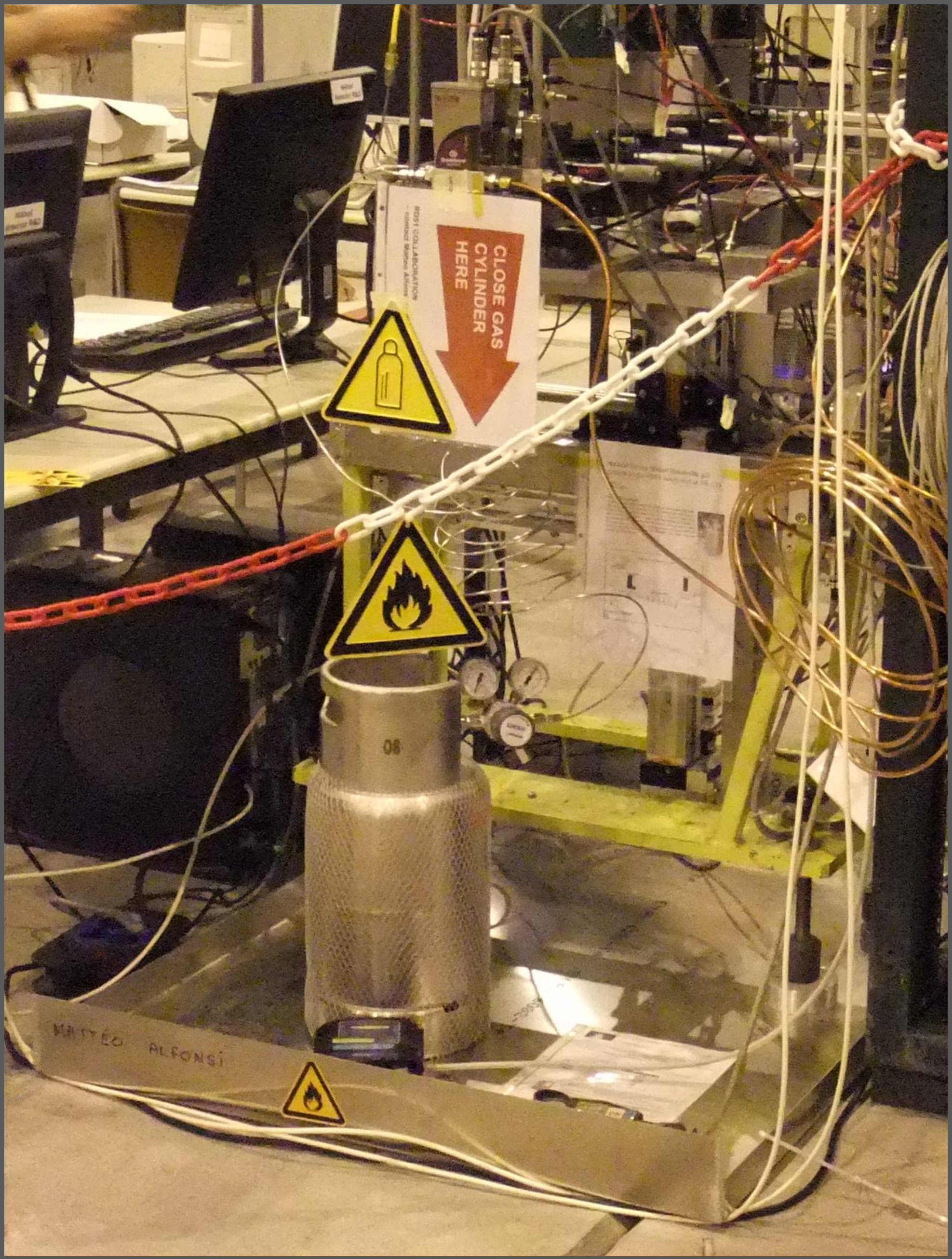
ReLaXd Readout

Support & CO_2 cooling!



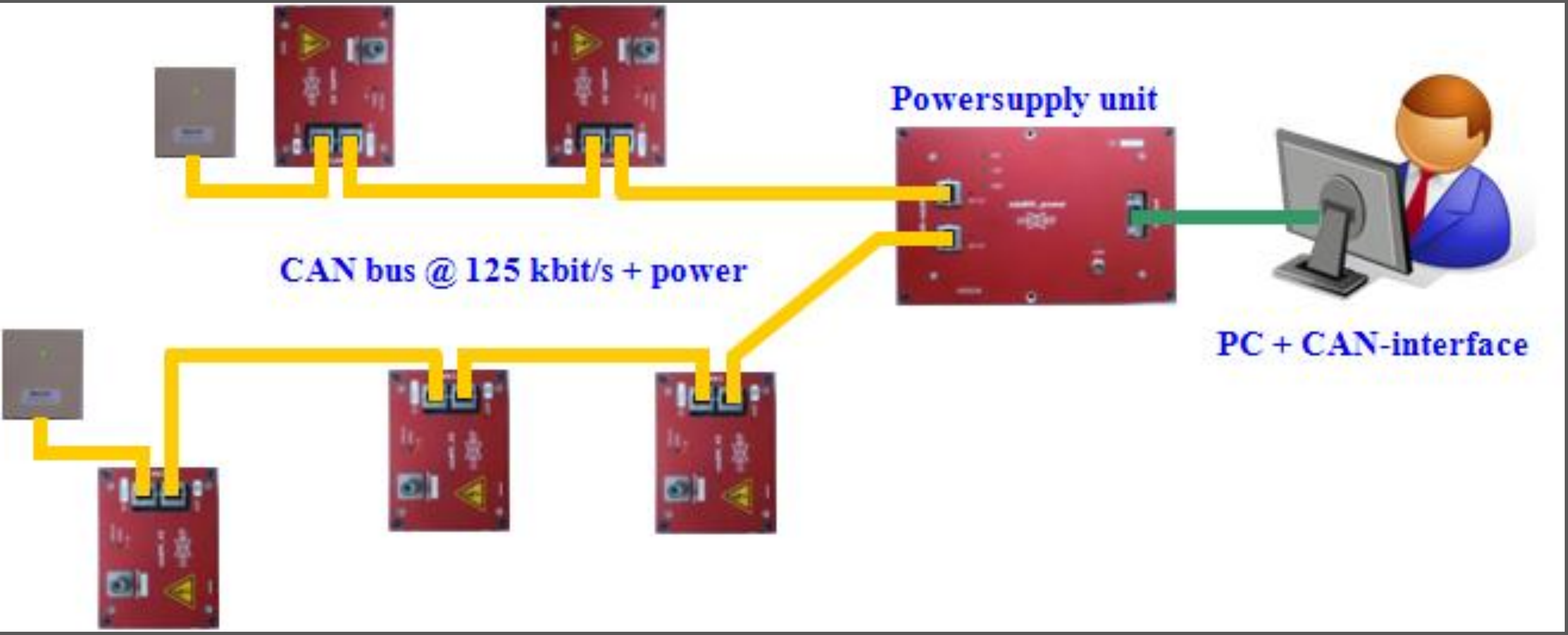
Special requirements for flammable gas

- Gas mixture from 120 l JSP gas bottle
- Whole gas system including bottle contained in leak tray
- Checking gas leaks by measuring deficit between input flow and exhaust flow
- Connected to flammable gas exhaust line



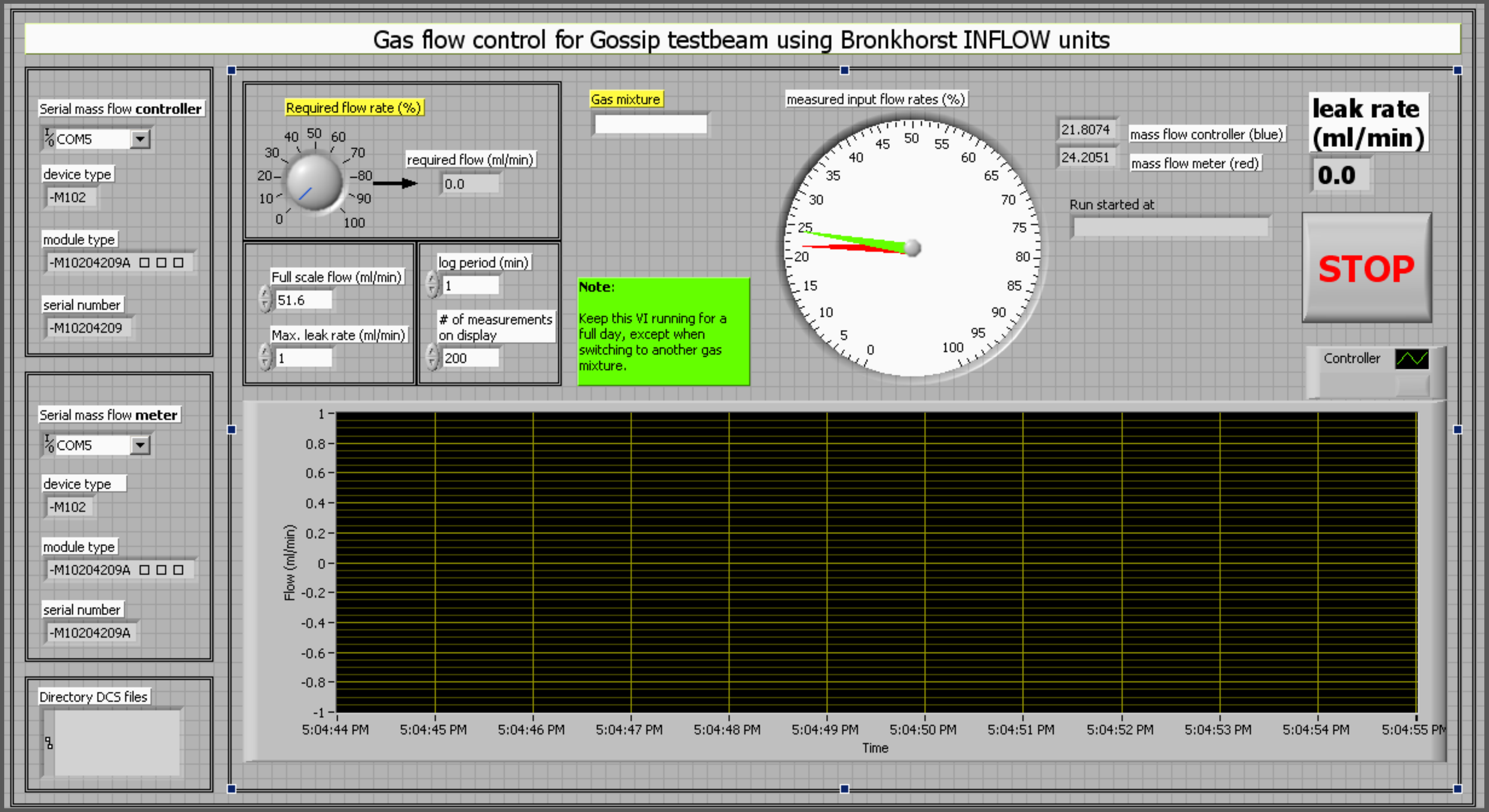
miniHV HighVoltage (low current) system

- HV: - 1000 V or – 2000 V
- Current: up to 5 µA
- current measurement: 20 pA resolution
- CAN bus (pc) controlled
- discharges are monitored & counted



LabView controlled gas system

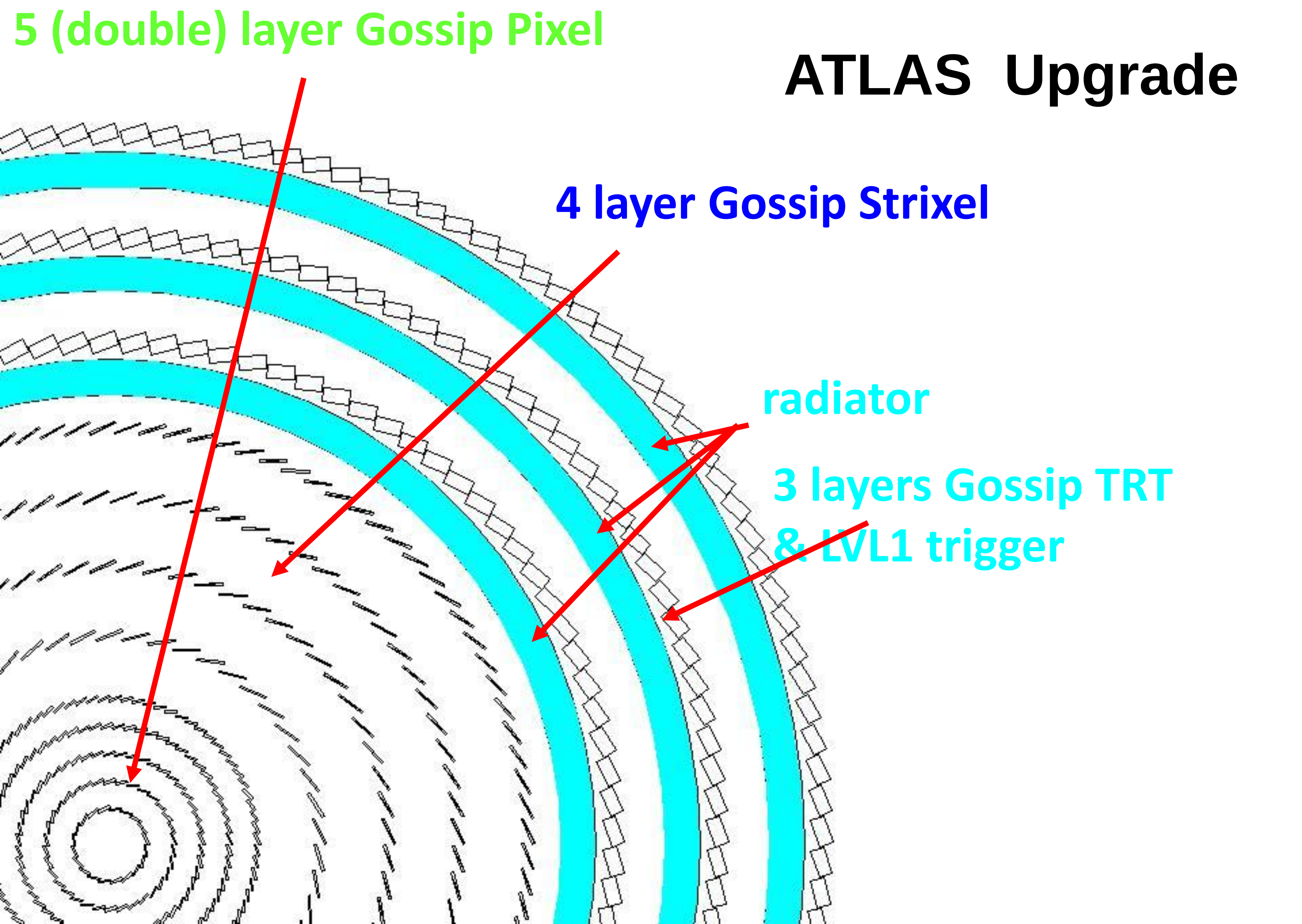
- Operation
  - Flow logged each minute
  - Alarm at leak rate > 3 ml/min
  - Shut off at integrated leak volume of 30 ml
- Gas flow set between 5 and 50 ml/min
  - Possible calibration error by factory (flow too low)



Applications of GridPix and Gossip

ATLAS:

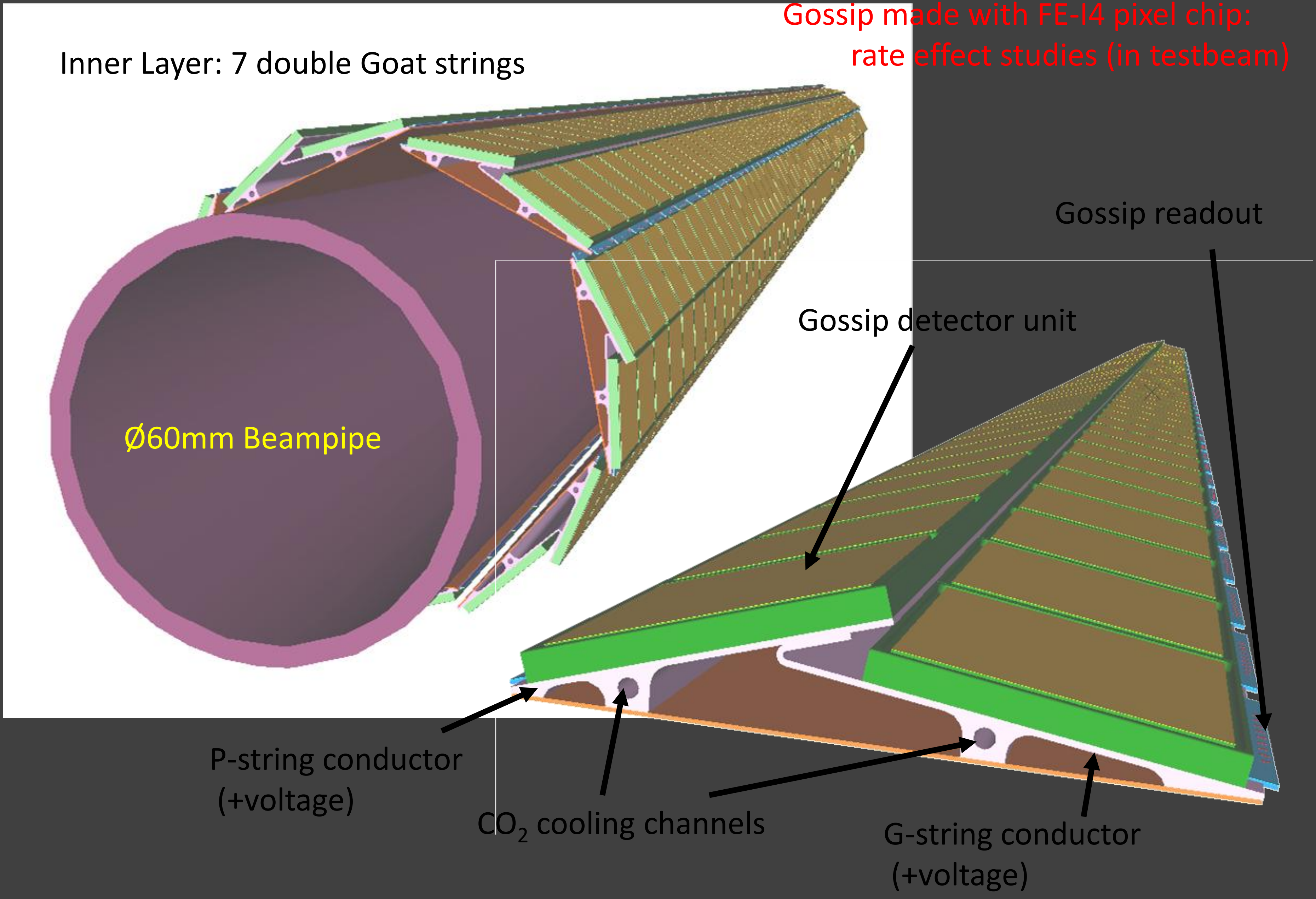
“The baseline ATLAS inner tracker upgrade is an all- silicon detector. New technologies such as GridPix and the Gossip version of it could become an alternative sensor technology to pursue for part of the detector. They would only be adopted in case of major performance or cost advantages over silicon technology, or if technical issues are found in the silicon projects in the next 2--3 years. The EB has considered the Gossip R&D proposal, and supports this R&D for a limited duration of 3 years to demonstrate and quantify performance, cost and reliability. In 2013, ATLAS will review the results and consider if there are sufficient elements for further pursuance of this technology for ATLAS”


5 (double) layer Gossip Pixel
ATLAS Upgrade
4 layer Gossip Strixel
radiator
3 layers Gossip TRT
& LVL1 trigger

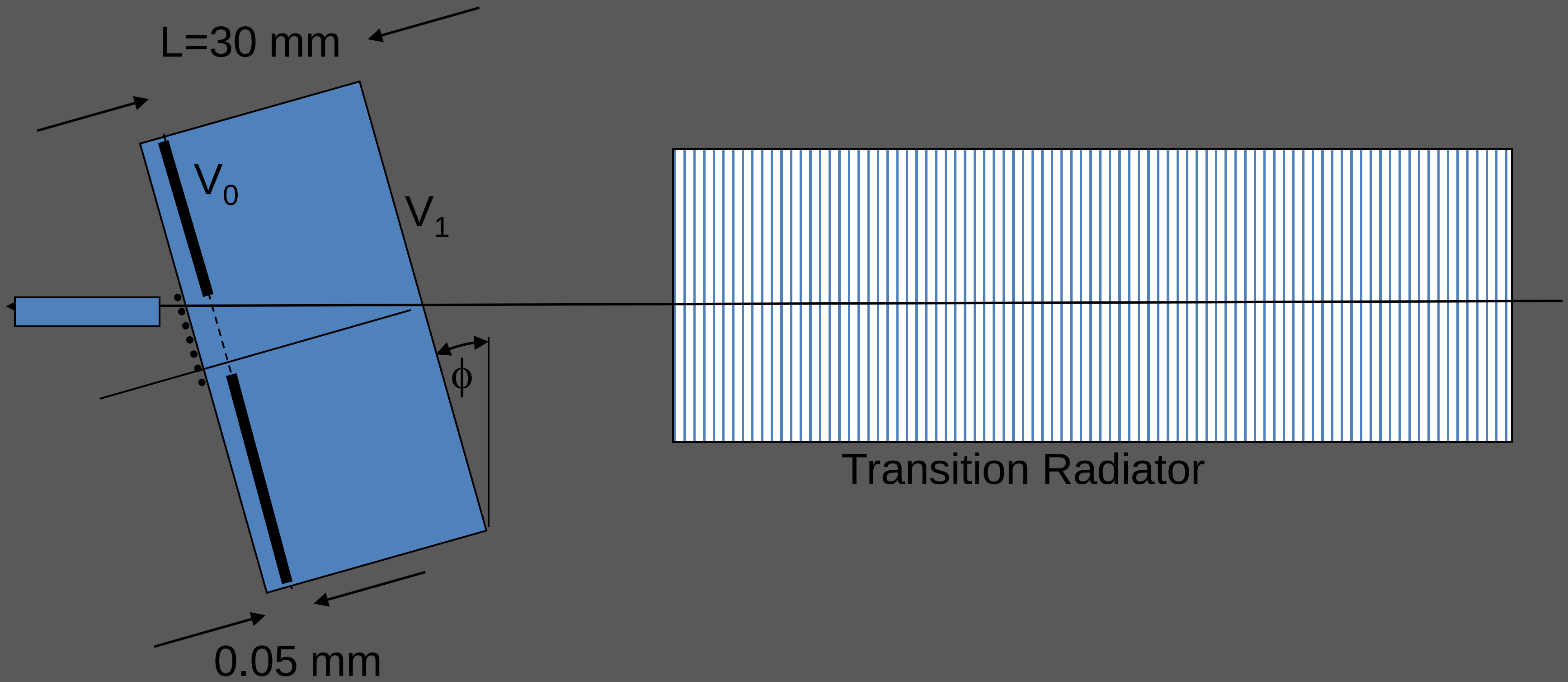
GOssip in ATlas

Alternative for TimePix:

Gossip made with FE-I4 pixel chip:
rate effect studies (in testbeam)



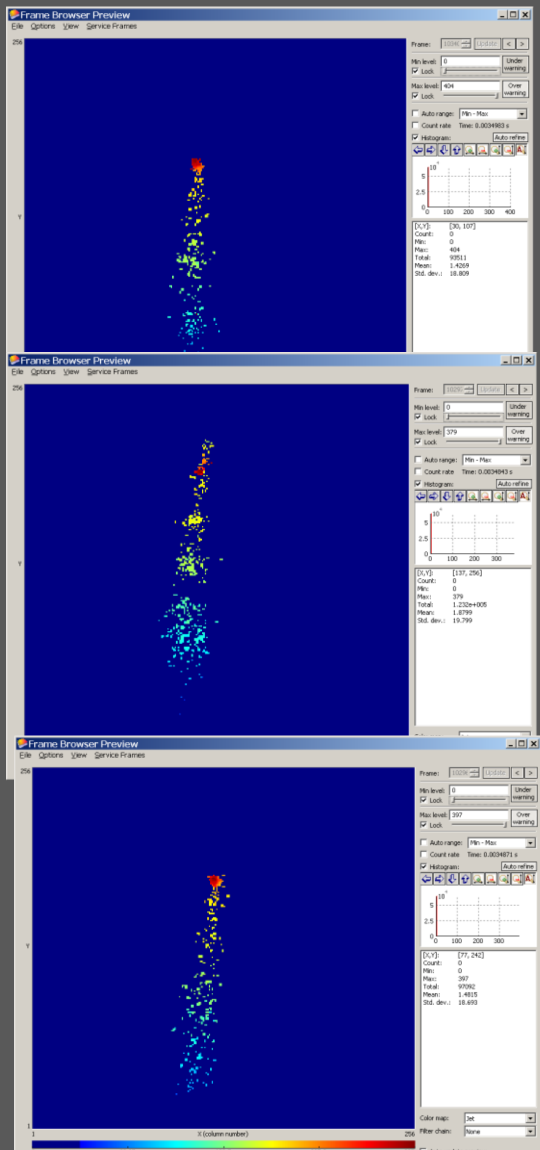
Testbeam Nov 5 – 12, 2007
PS/T9: electrons and pions, 1 – 15 GeV/c



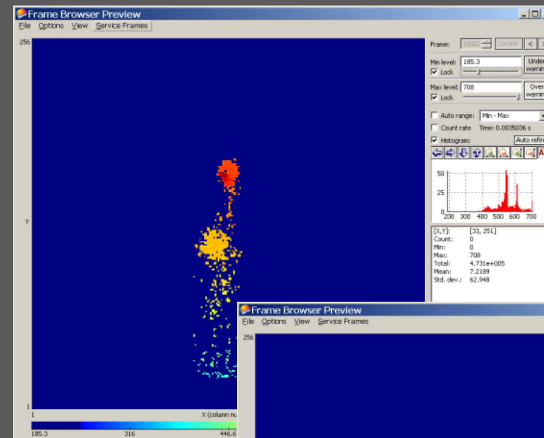
Anatoli Romaniouk, Serguei Morozov, Serguei Konovalov
Martin Fransen, Fred Hartjes, Max Chefdeville, Victor Blanco Carballo

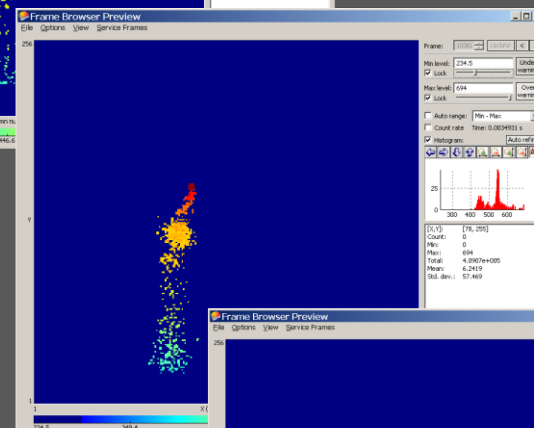
Particle Identification

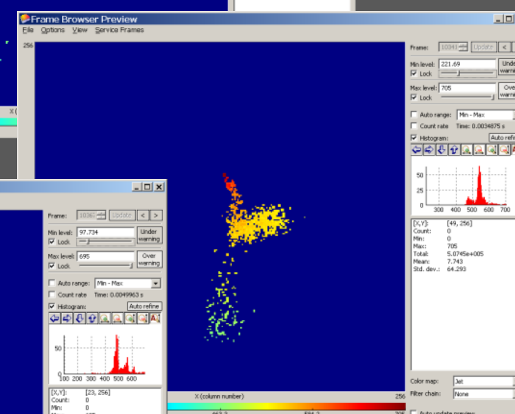
Samples pions (left) and electrons (right)

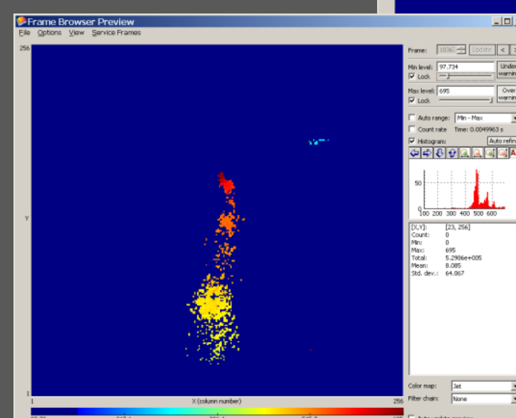


6 GeV/c



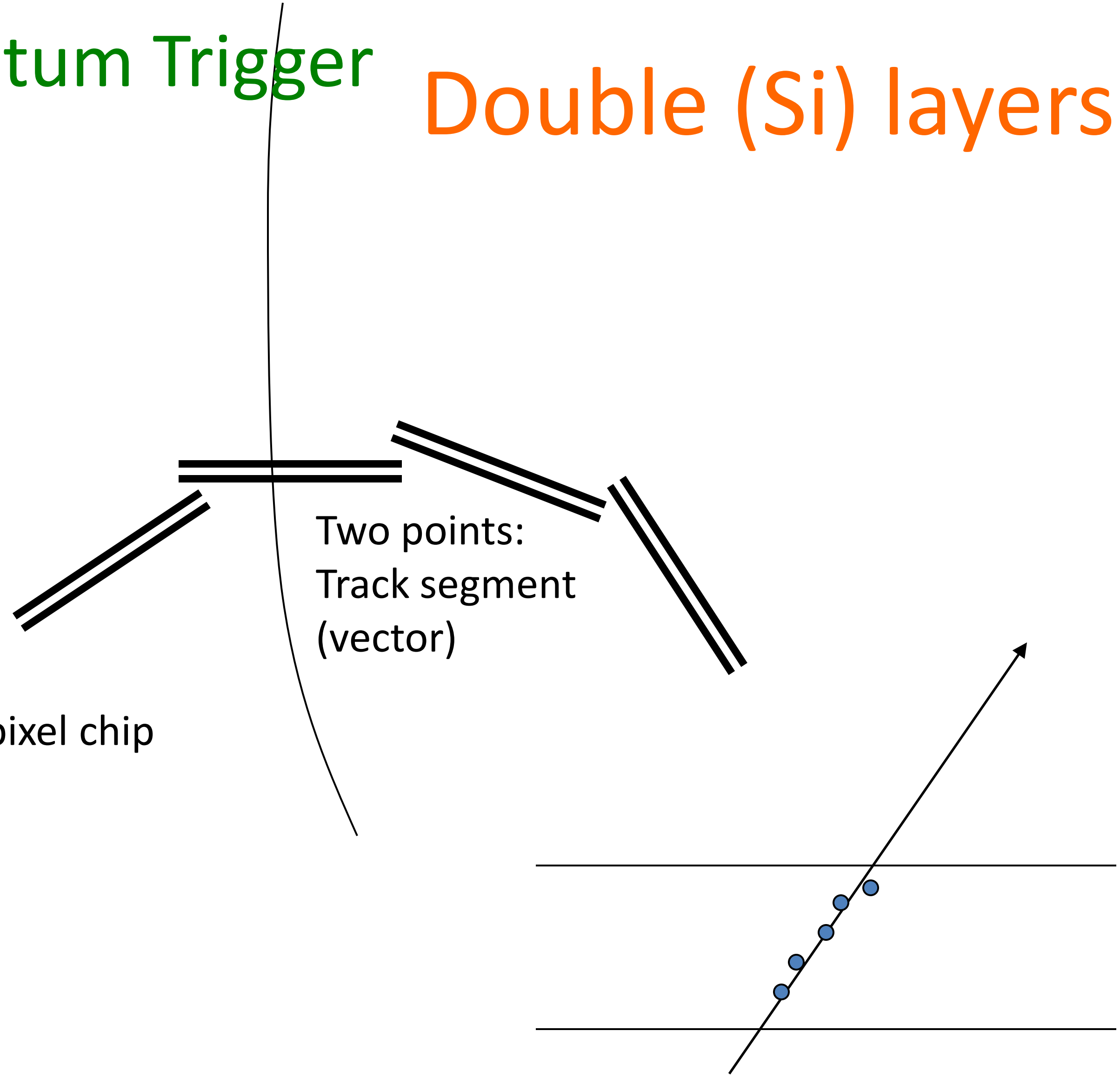


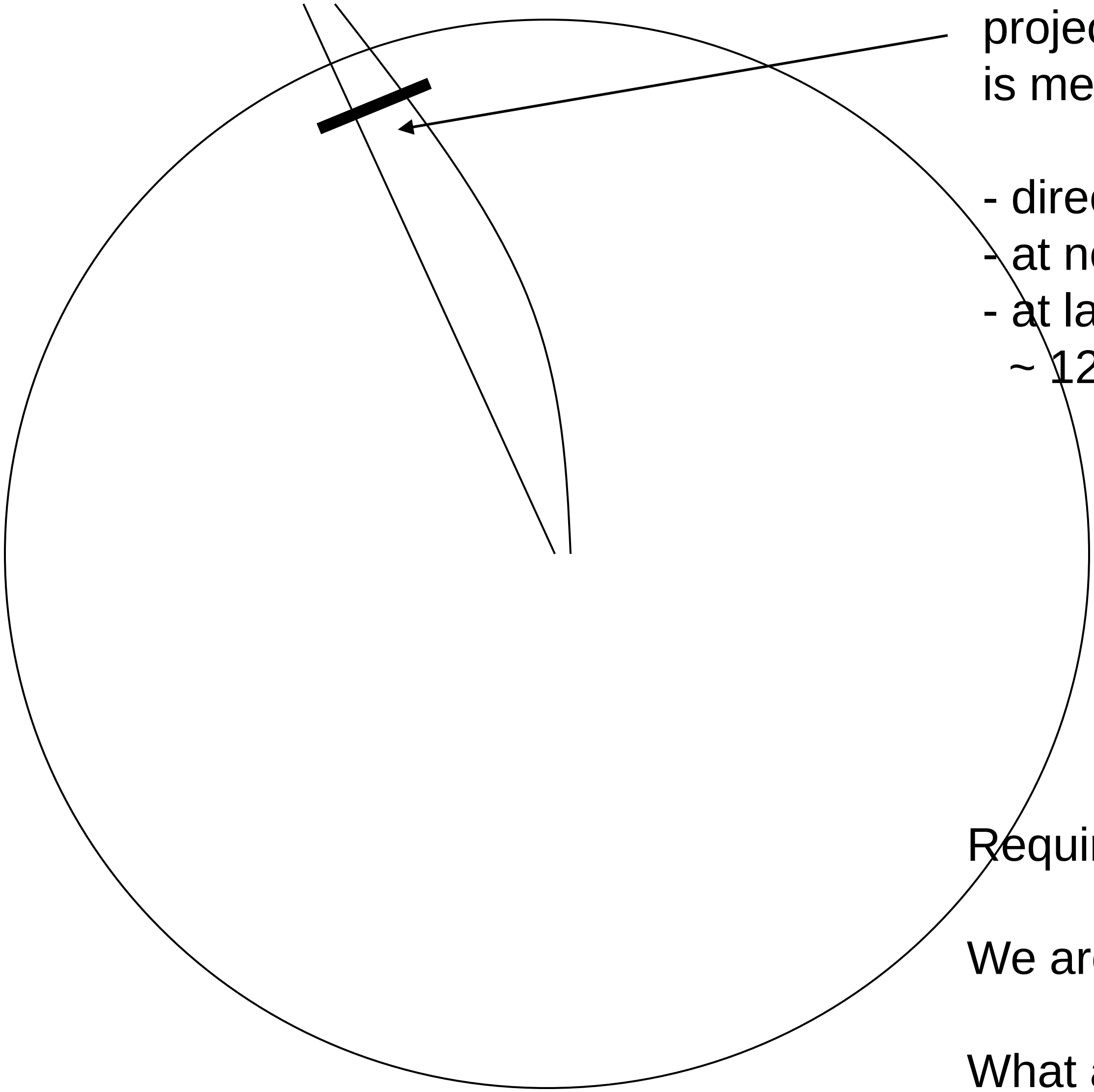




LVL1 Momentum Trigger

Double (Si) layers





projected track length
is measure for momentum:

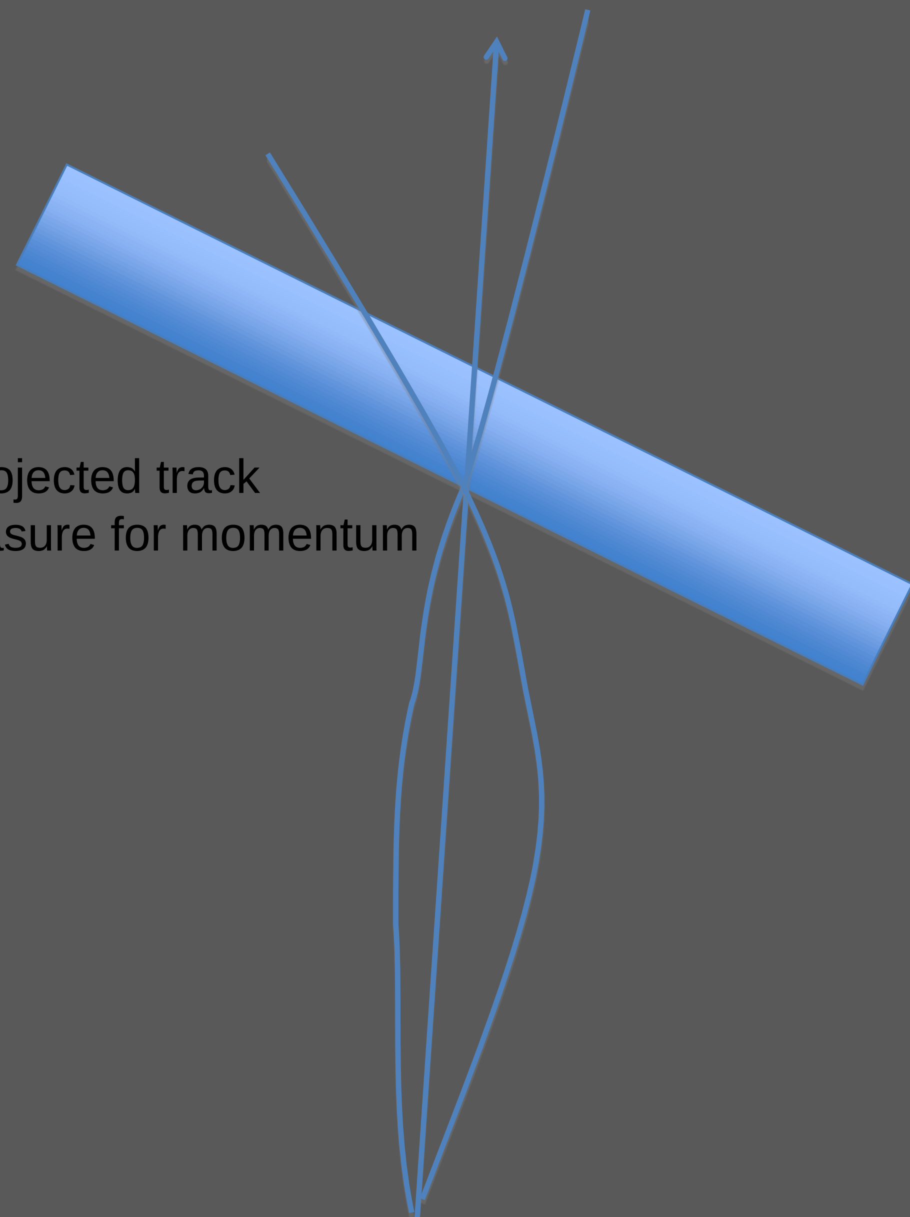
- directly available (LVL1)
- at no (extra) cost (mass, power)
- at larger R: gas drift gap ~20 mm
  ~ 12 BXs

Requires fast on-pixel chip processing

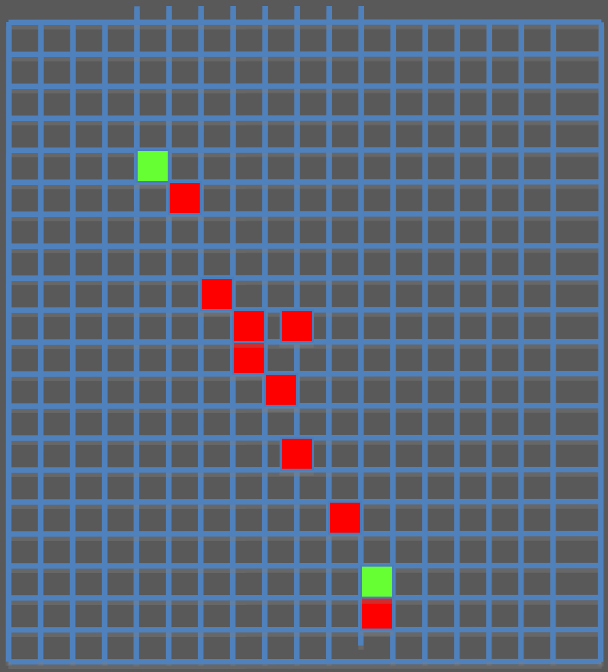
We are using 130 nm tech.

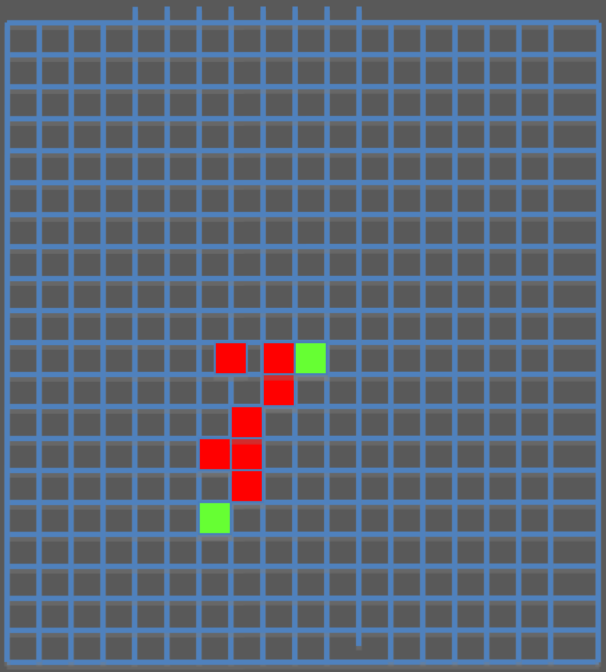
What about 45 nm tech?

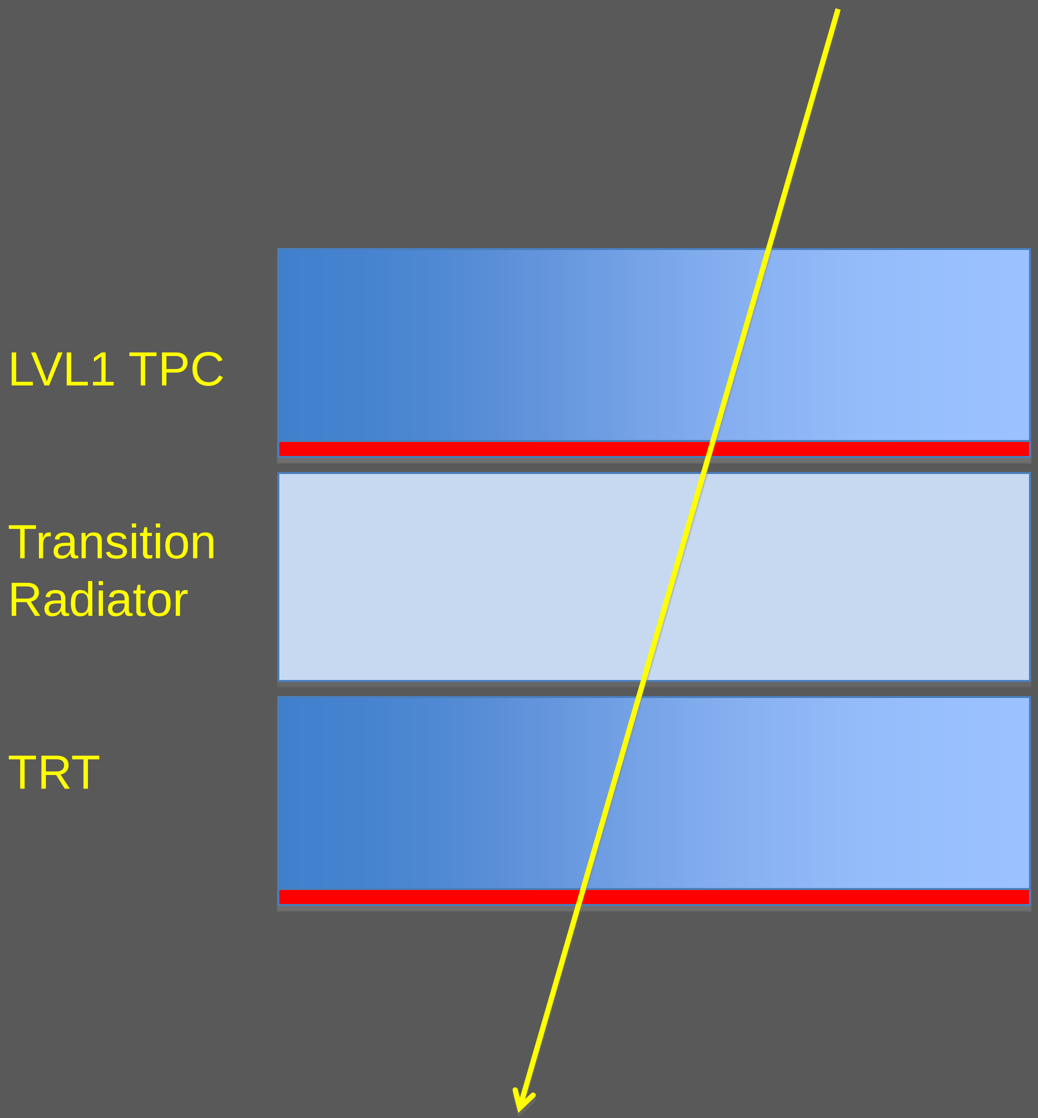
LVL1 trigger from inner tracker



Length of projected track
is direct measure for momentum







LVL1 trigger for threshold momentum

Particle Identification: electron-pion discrimination

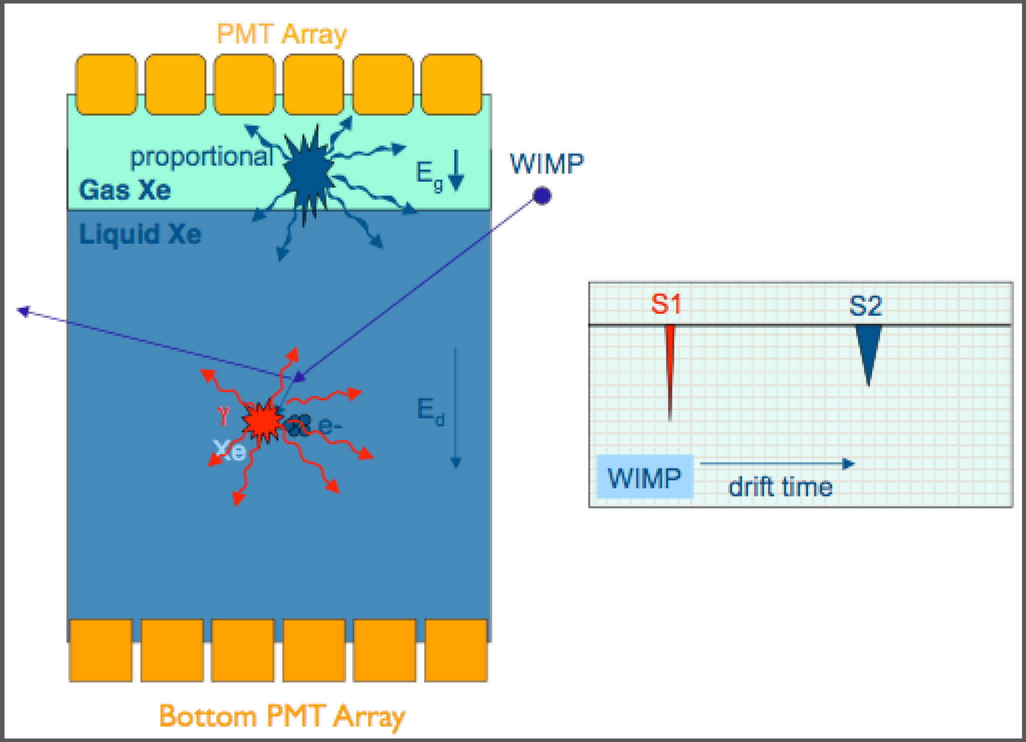
WIMP search, bi-phase Xenon

- GridPix TPC

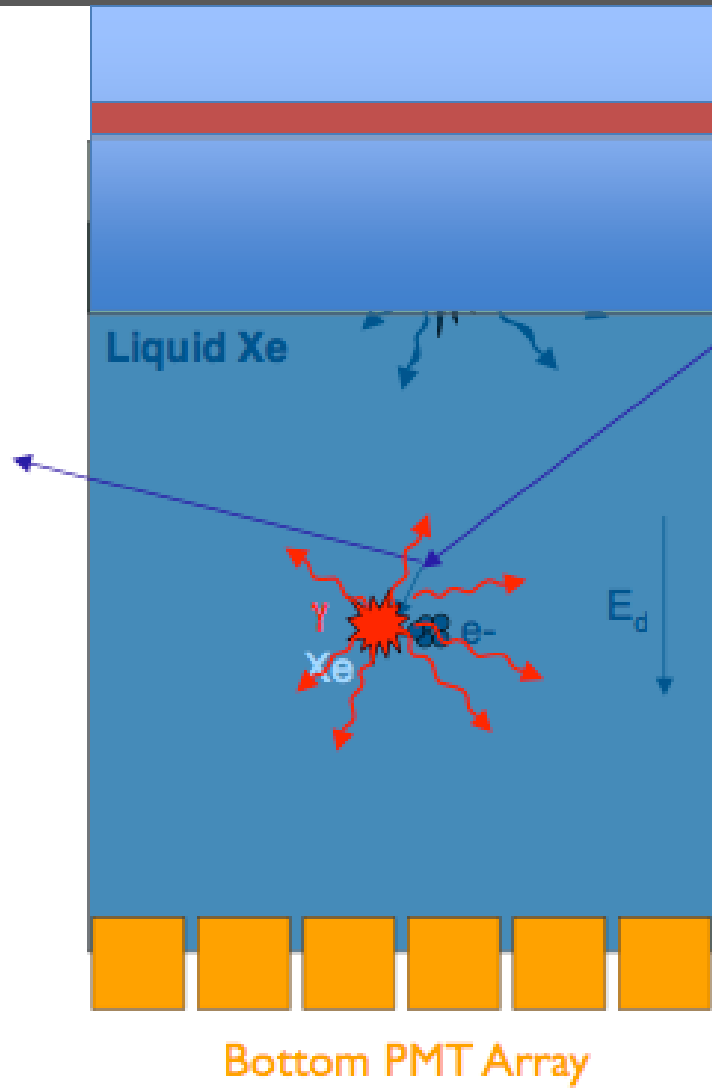
as

WIMP / DBD

detector

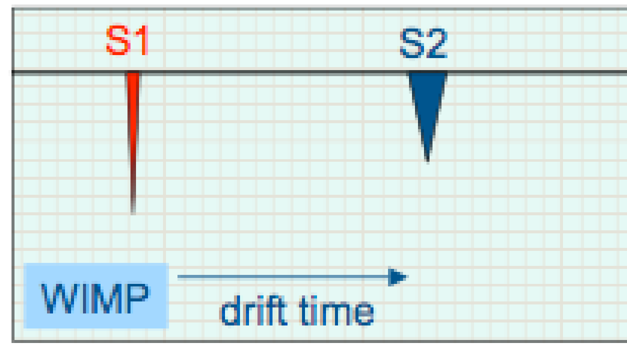


Source: Direct Searches for Dark Matter, Elena Aprile, EPS - HEP, July 21 2009, Krakow, Poland



In gas phase:
GridPix (=TimePix + InGrid)
with grid facing down!

WIMP

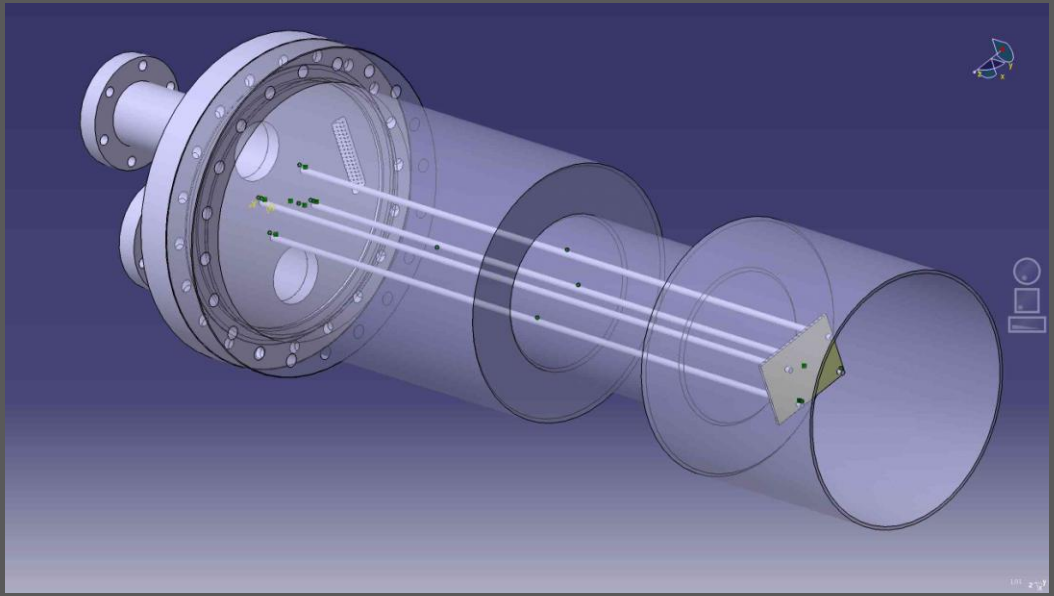


Detects single electron events with 99% efficiency!

[Essentially due to small pixel input pad capacity]

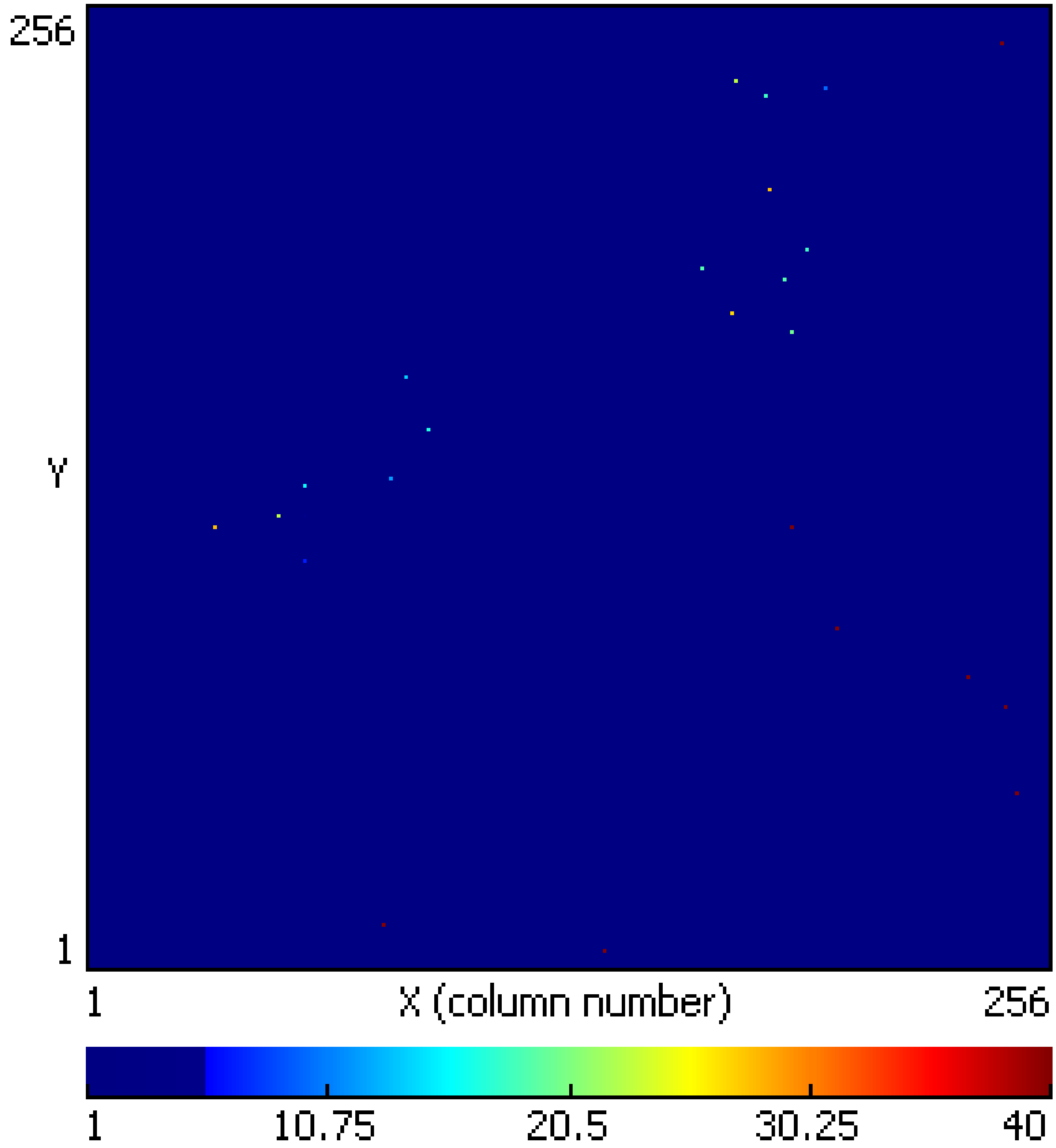
Gridpix in Xenon: Test setup

- Collaboration DARWIN/XENON



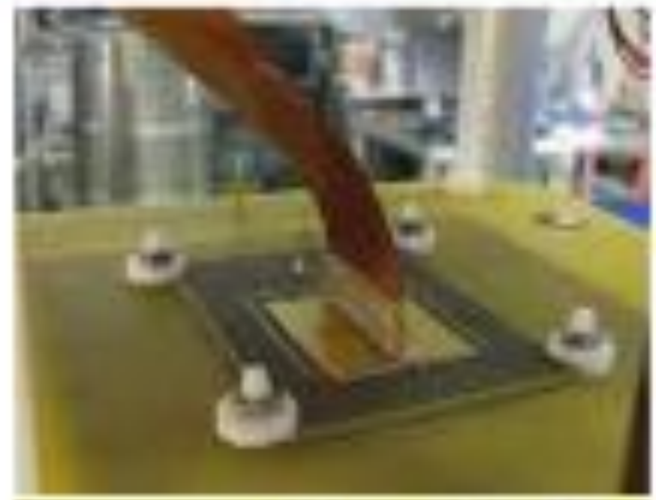
55Fe in pure argon,
HVgrid = 340 V
P = 1 bar
T = -70 C
at NLR cryostat

gain: ~ 200 !

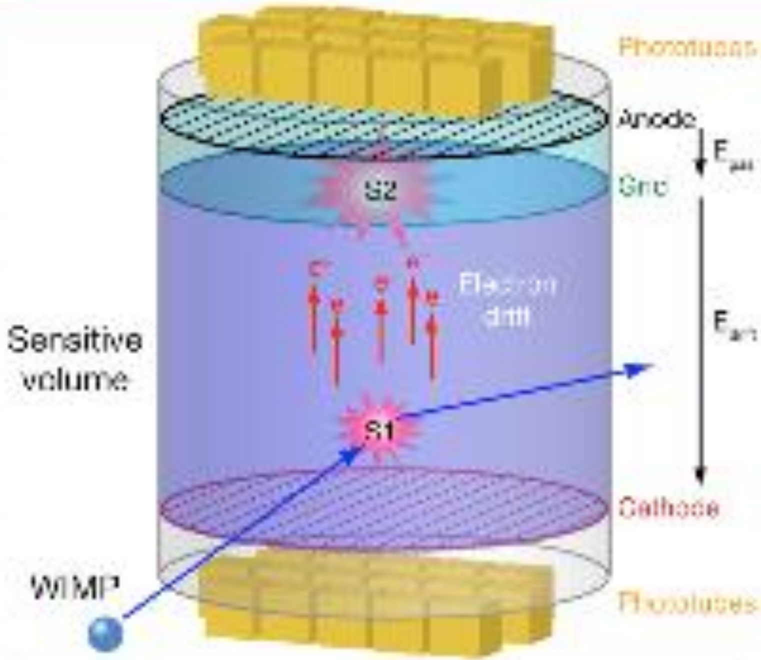


In Andre Rubbia's cryostate @ CERN

Setup

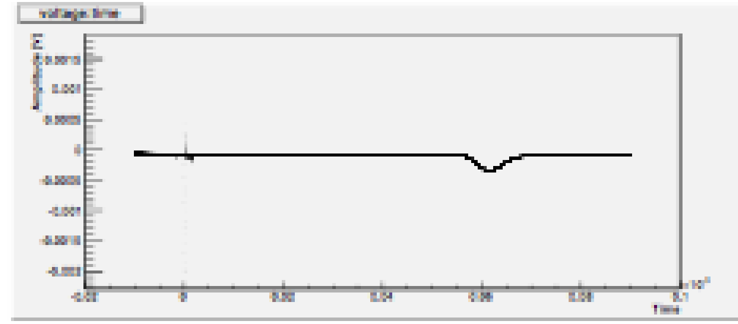


Xenon 100 experiment

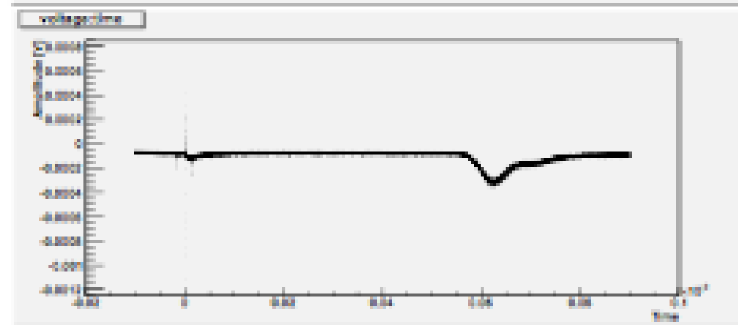


Measurements

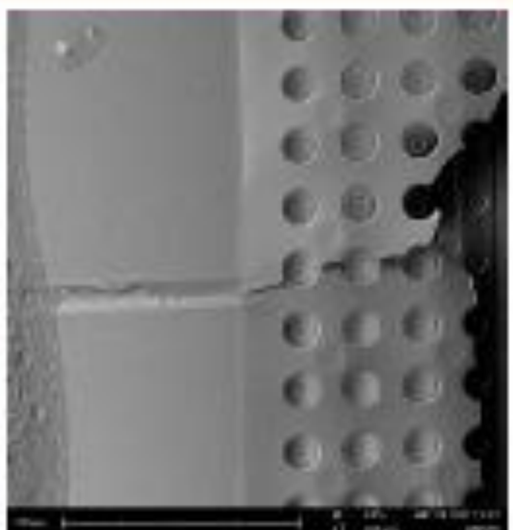
Cold GAr 150V



Cold GAr 600V



Visual and SEM view



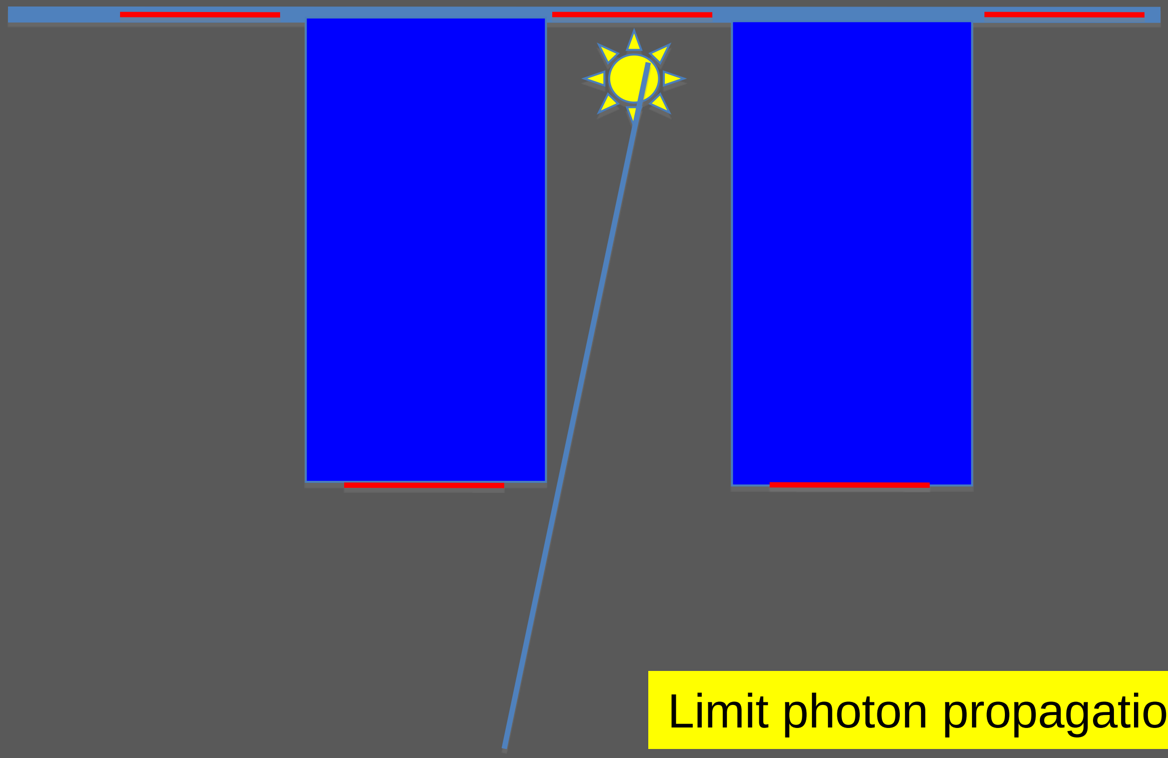
Results:

- TimePix functions well in LAr temperature (-180 C)

- In pure Argon, gas gain is limited to ~ 10. Confirmed by other (GEM & TGEM tests)
  UV light avalancje propagation?
  Needs to be understood: simulations. A gain of 300 would be sufficient.
  GEMGrid?

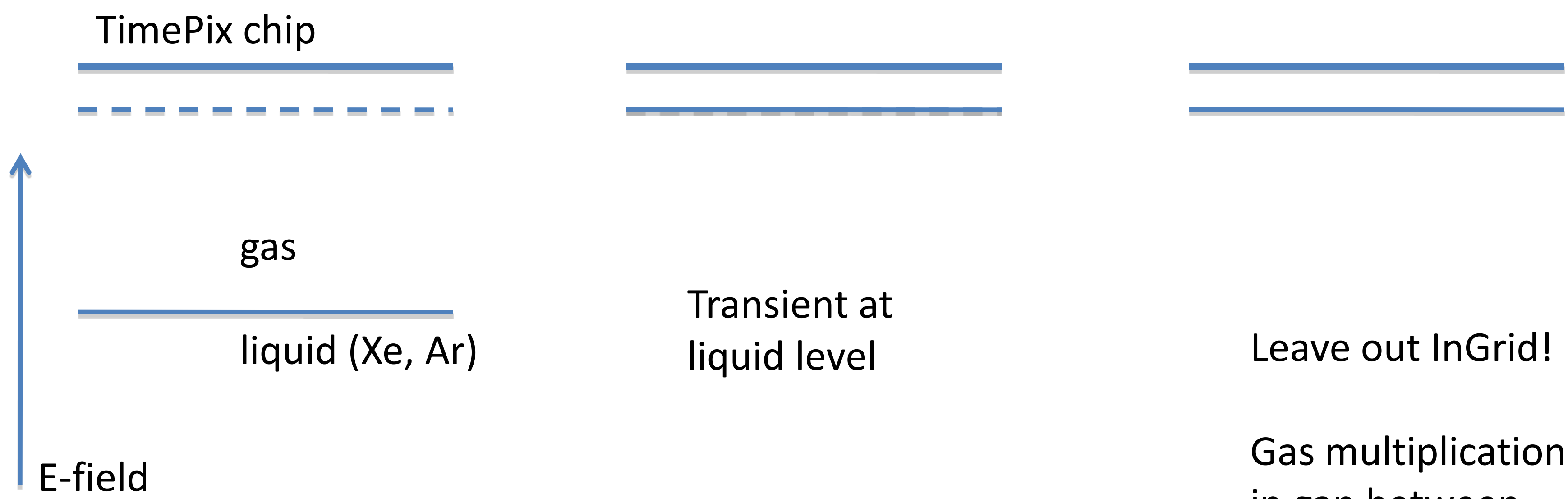
- InGrid collapses at low temperature, due to differences in thermal expansion
  of InGrid materials (epoxy, aluminium, Si).
  Requires all-ceramic GridPix: also good for outgassing.

Operation without quencher: pure Ar, Xe, at cryogenic temperatures



Limit photon propagation towards cathodes

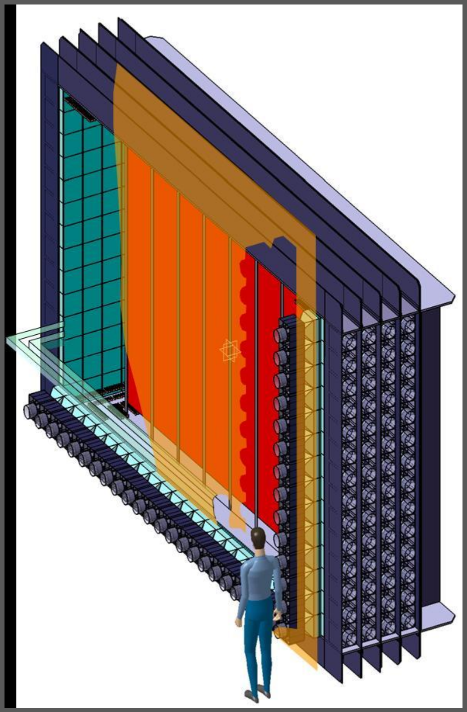
Of interest: RIKEN GEMs (with one electrode stripped!)
Just fix foil on TimePix chip



Gas multiplication
in gap between
chip and liquid surface!
Gap ~ 50 microns,
needs active feedback
control.

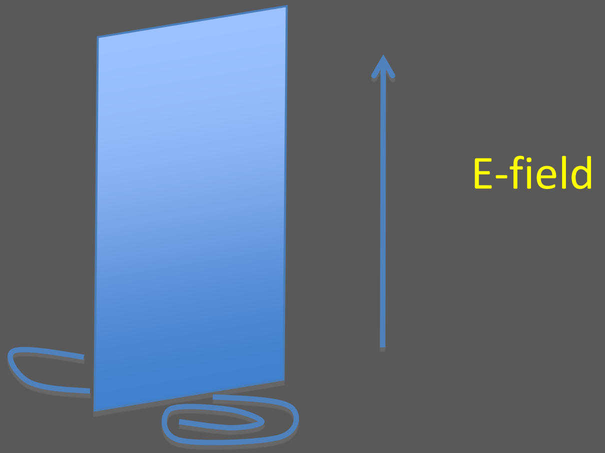
Gaseous 0-ν Double Beta Decay Experiments

superNEMO:
Geiger tracker+
scintillators



hyperNEMO

TPC with GridPix readout



B-field:
- Beta tracks contained in gas volume
- momentum measurement from init curvature
- total absorption: energy measurement

good energy resolution!

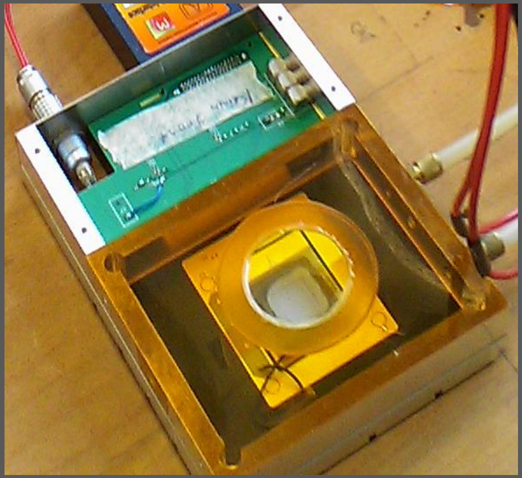
GridPix as photon detector

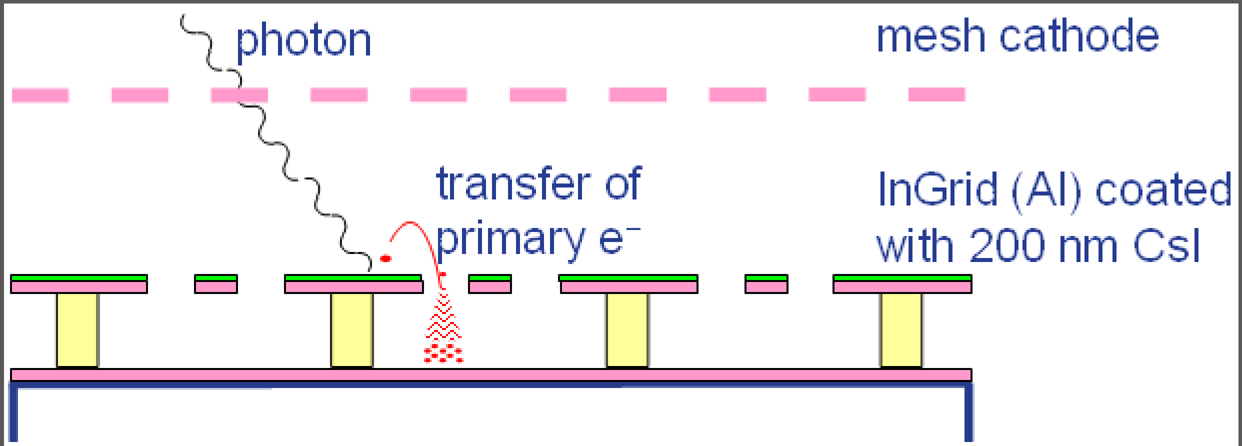
- Photon conversion on InGrid, possibly covered with CsI

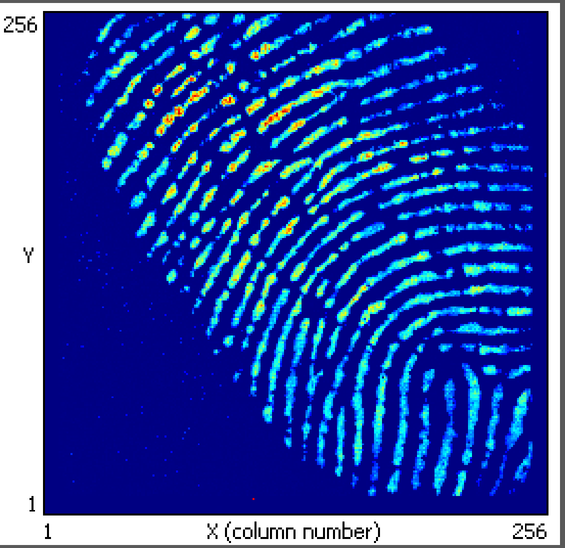
- Photon conversion in gas (100 eV – 1 MeV)

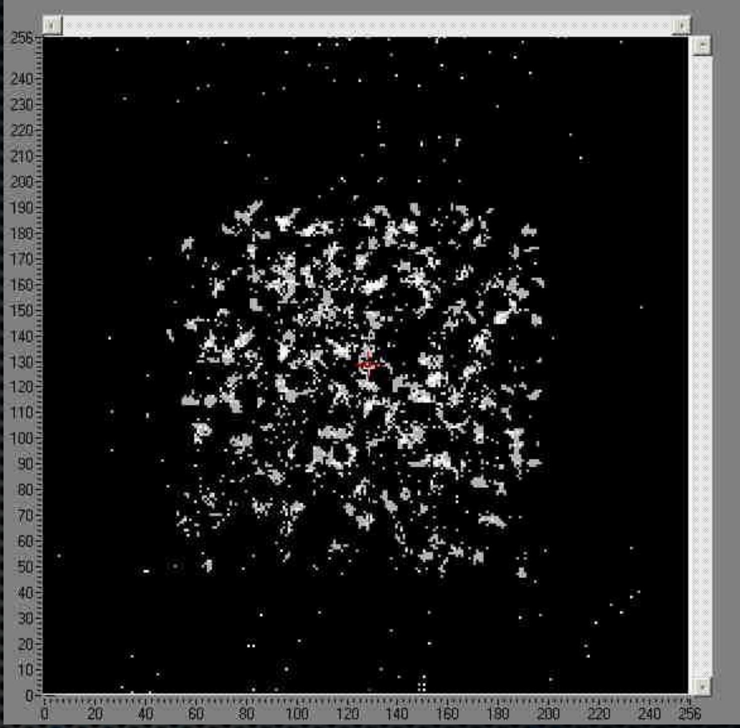
Gaseous Photomultiplier

- Photoelectric effect
- Future possibility:
  CsI layer on grid









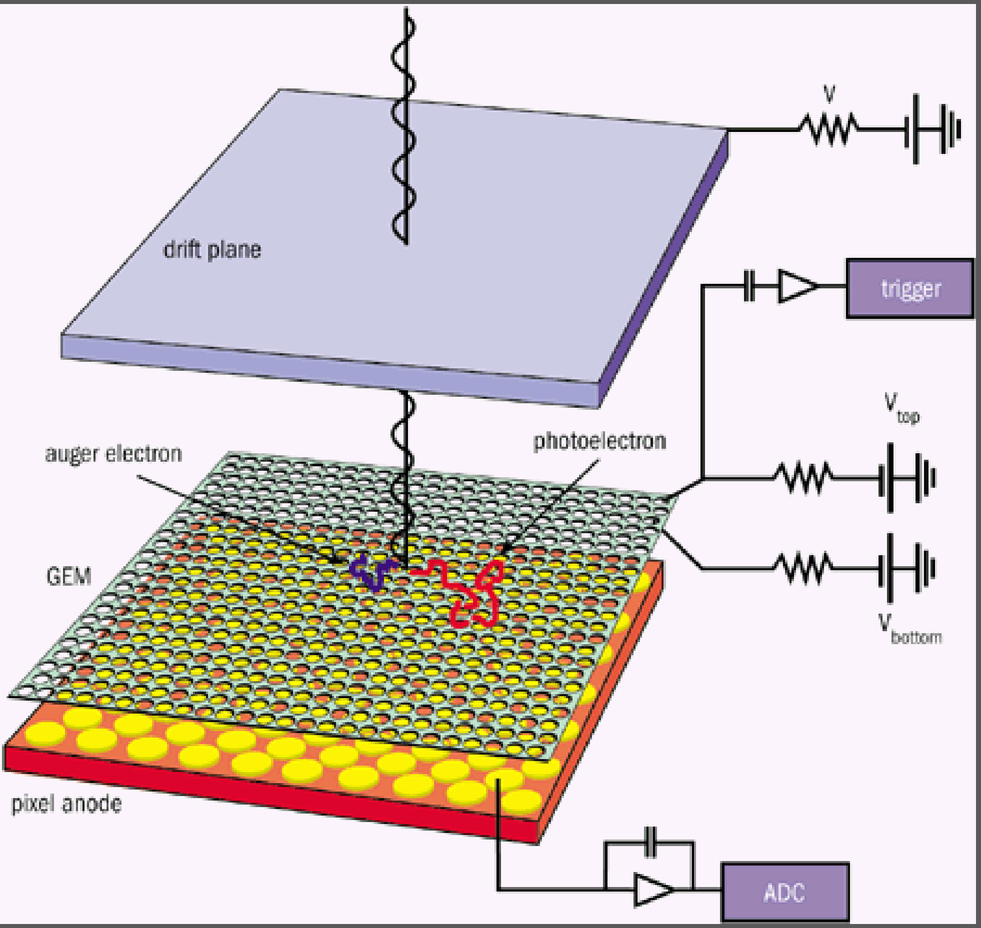
PolaPix

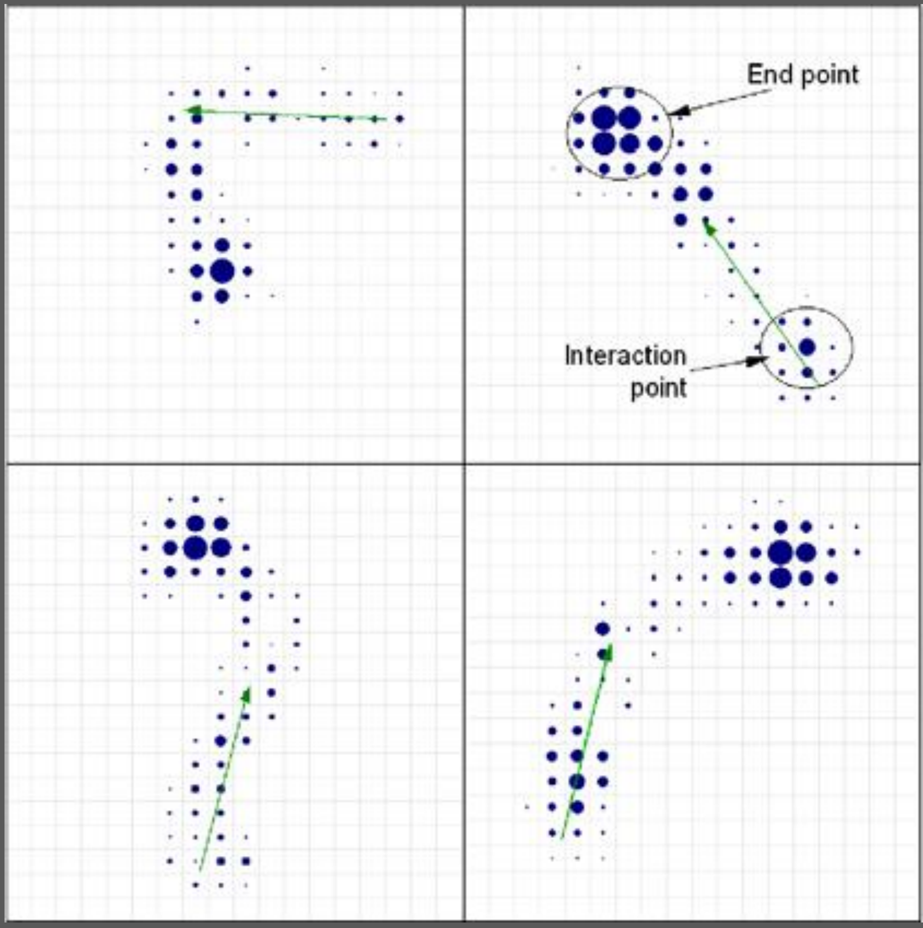
Using a GridPix detector for the 3D detection of polarized X-ray photons

Sjoerd Nauta - Nikhef

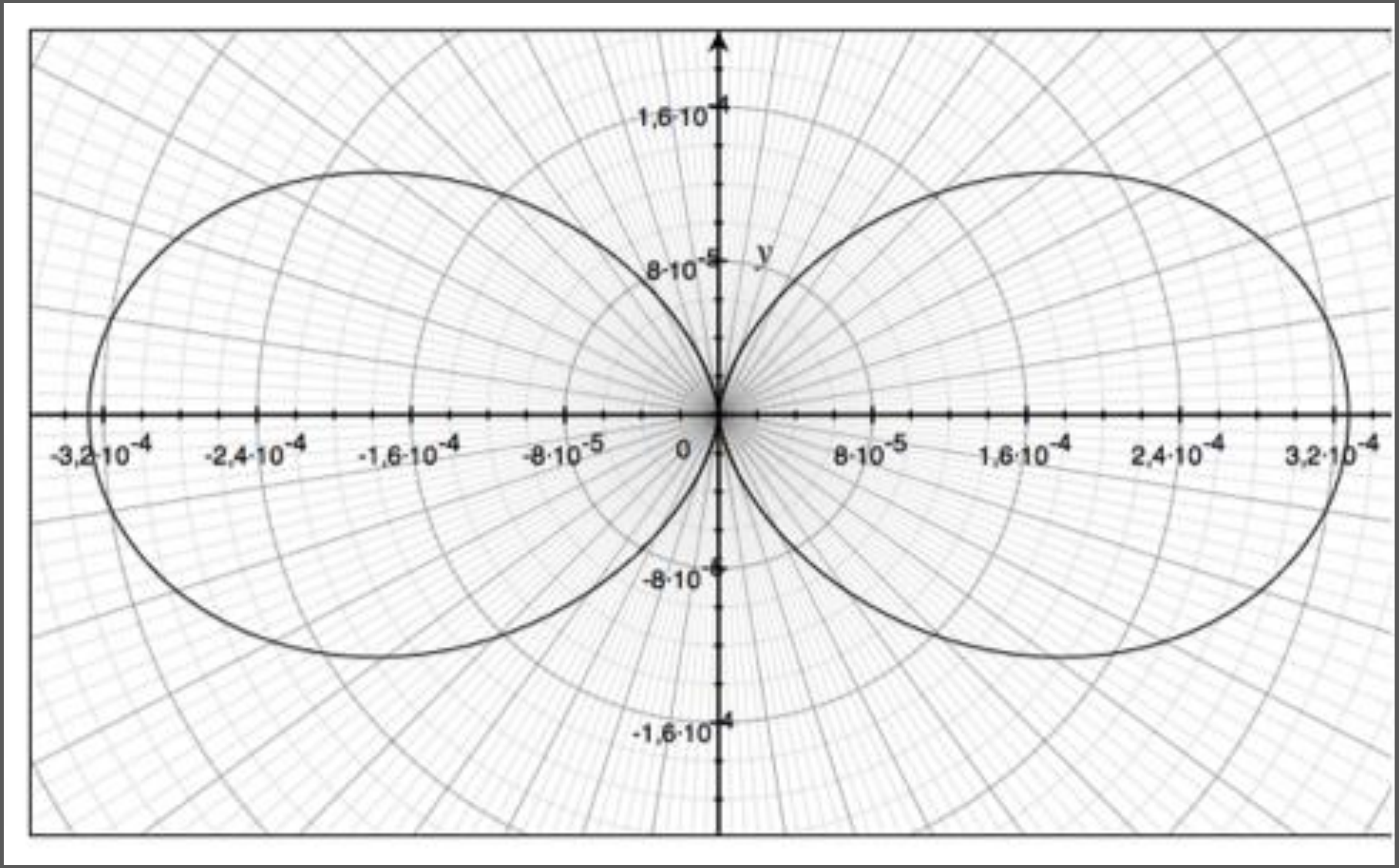
NIKHEF

TU Delft





X-ray Polarimeter proposed by R. Bellazzini



Distribution of direction of photo-electron of (fully) polarised X-rays

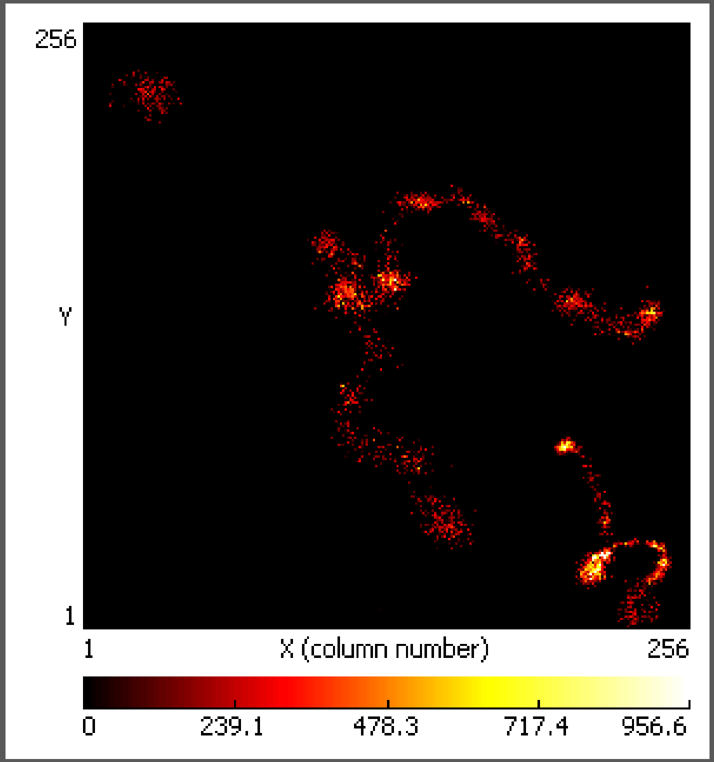
With ECAP/University of Erlangen

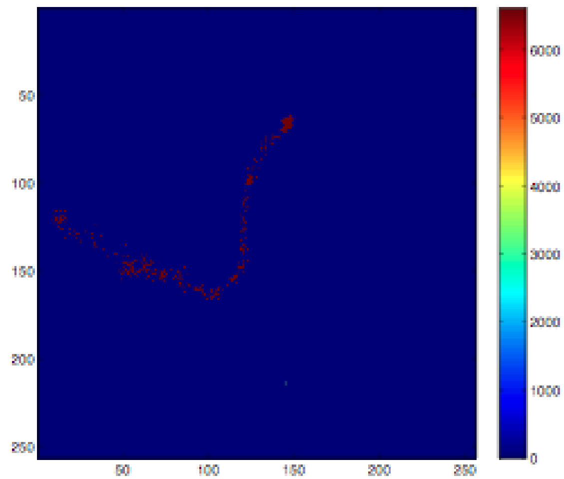
PolaPix

GridPix as (gas-filled) photon detector for applications in space observatories via tracking photo-electron or Compton-electron. Measurement of

- photon energy
- photon direction
- polarisation

in the range of 1 – 511 keV photons





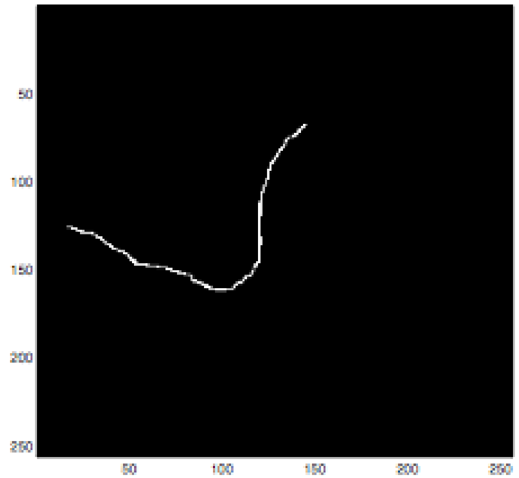
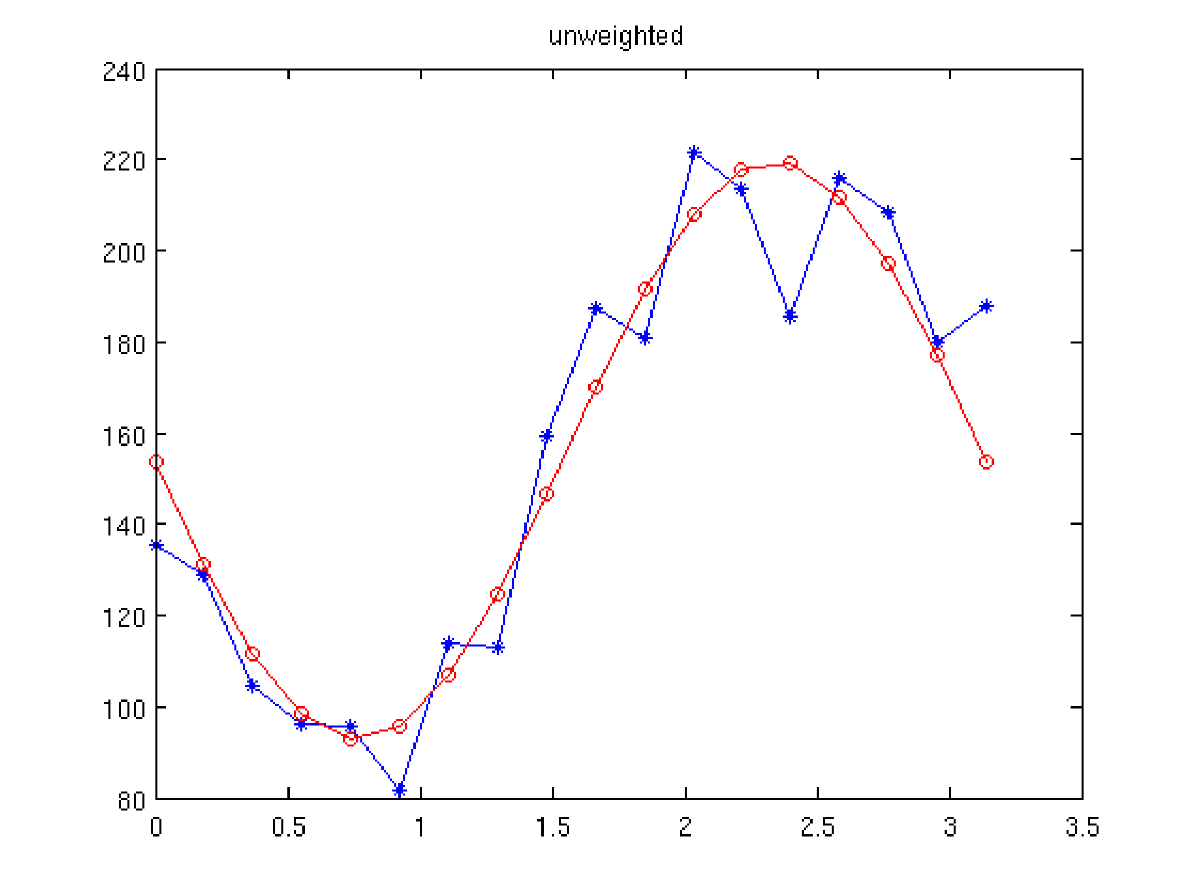


Figure 4.11: An example of a skeletonized track. On the left, the original measurement is shown, on the right the skeletonized version of the same track is shown. This picture has been made by the group at the university of Erlangen.

photo-electron
after photon interaction

Compton Scattered
(polarised) photons

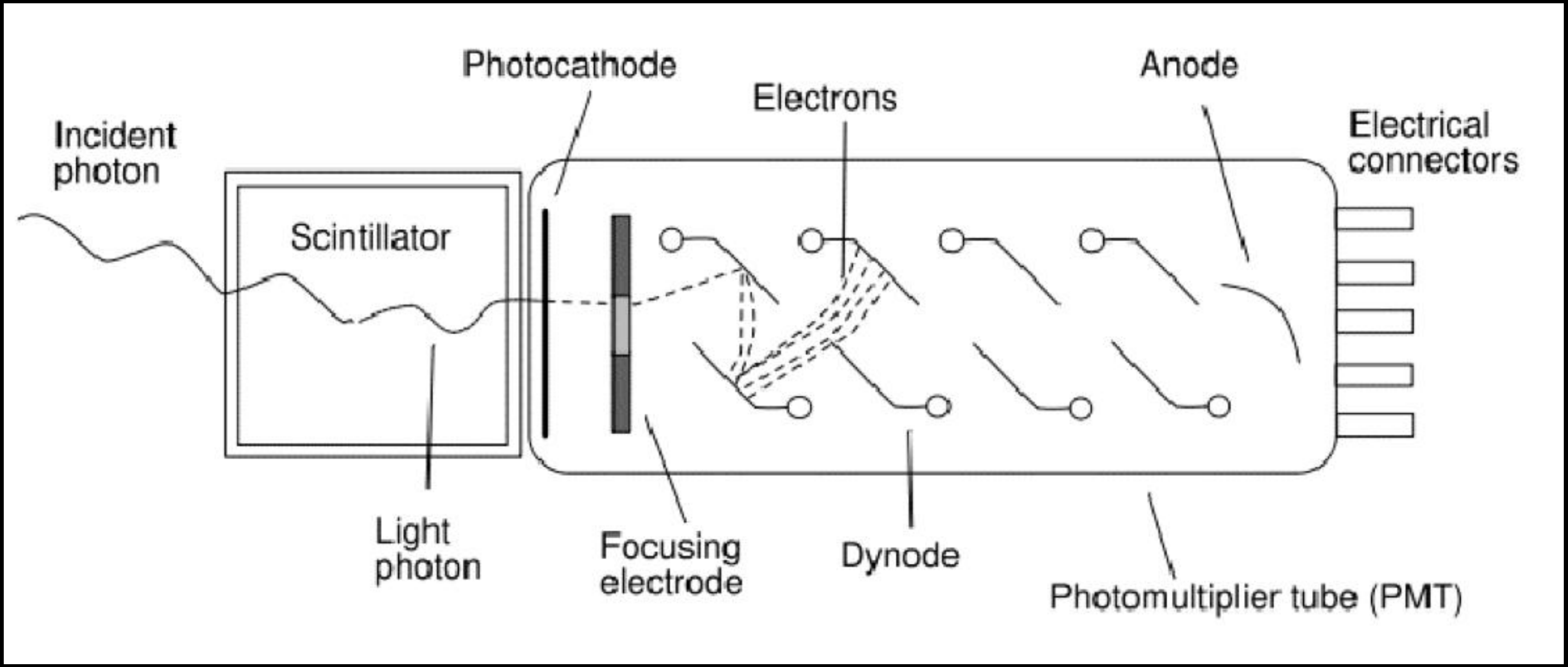


Thilo Michel (Univ. of Erlangen/ECAP)

A new solid state tracking detector: Electron Emission Membranes and a MEMS made vacuum electron multiplier

only ideas: no data

A very successful photon detector: the Photomultiplier (1934)



- good quantum efficiency
- rather fast
- low noise
- little dark current, no bias current
- radiation hard
- quite linear

- voluminous & heavy
- no position resolution
- expensive
- quite radioactive
- can't stand B fields

Reduce size of dynodes (volume downscaling):

- keep potentials as they were (V_{step} ~ 200 V)
- (non relativistic) electron trajectories same form, but smaller (volume)
- multiplication yield: identical
- 1st dynode: focussing, yield
- pixel input source capacity: only ~ 10 fF
- required gain ~1000 = 2.5^{4} = : 5 dynodes sufficient

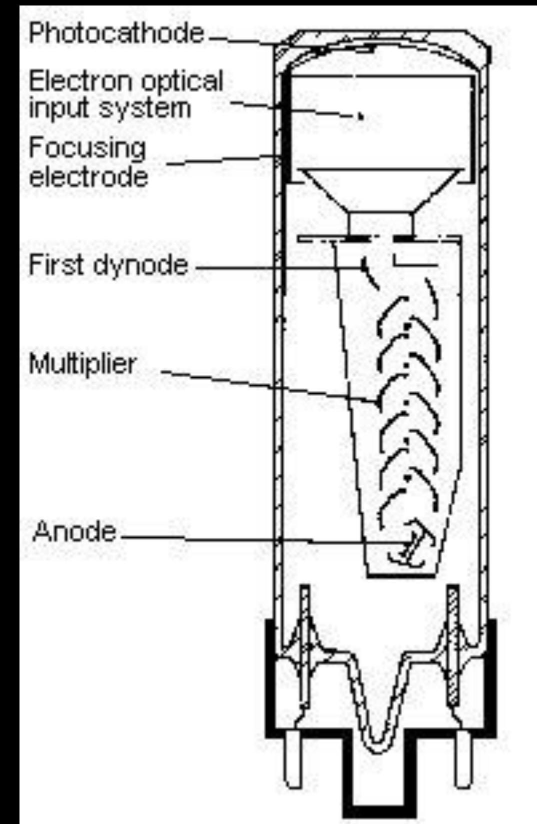
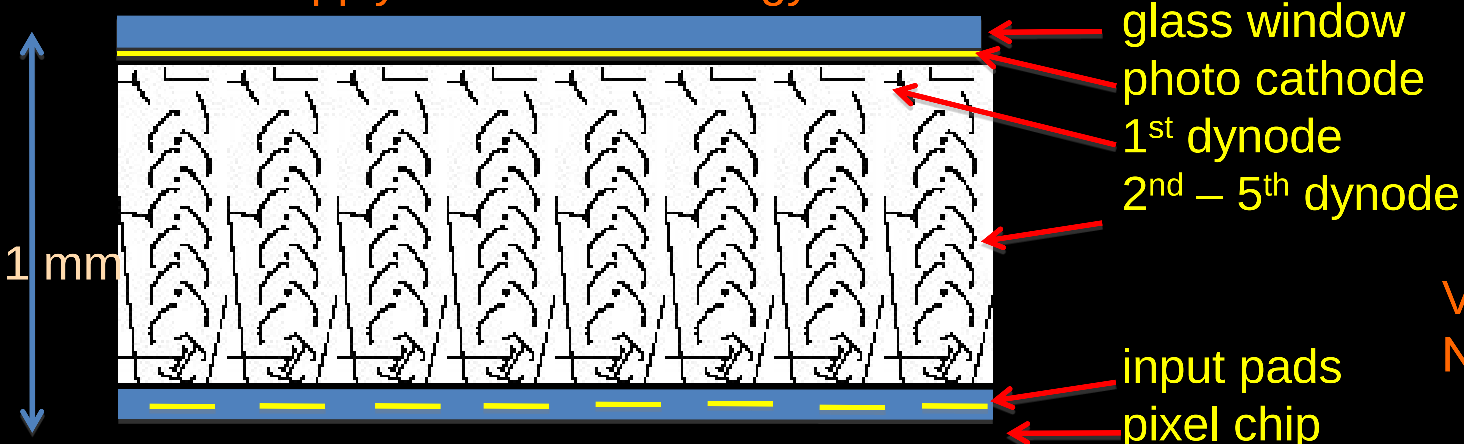


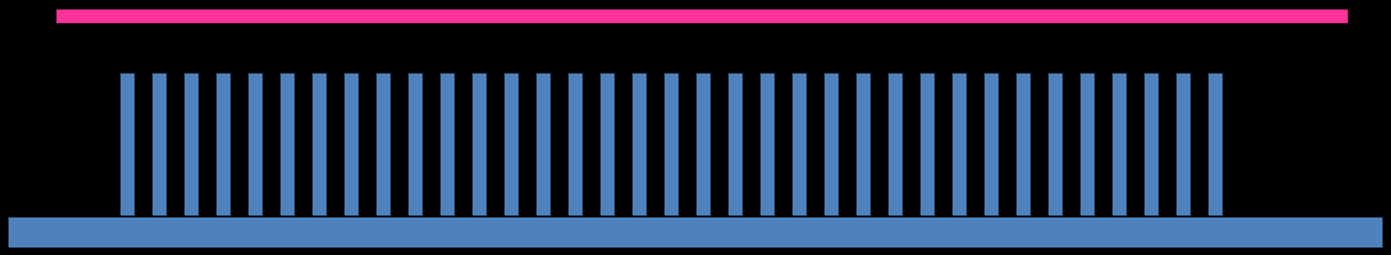
Fig. 8.1. Schematic diagram of a photo-multiplier tube (from *Schonkeren* [9.1])

Apply MEMS Technology



VACUUM!
No ‘gas amplification’

Use a MicroChannelPlate MCP?

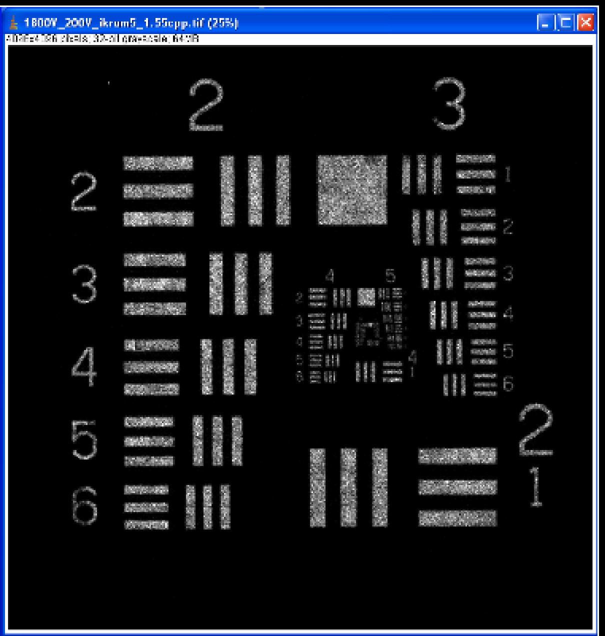


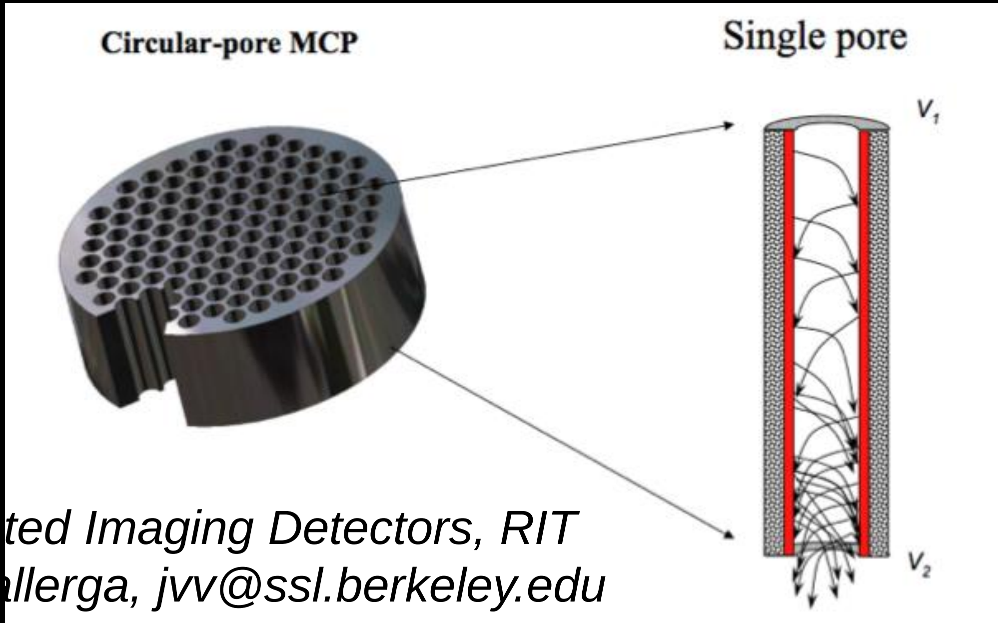
John Vallerga: TimePix + MCPs

We do not know how to make MEMS made MCP.

Problem: aspect ratio of holes

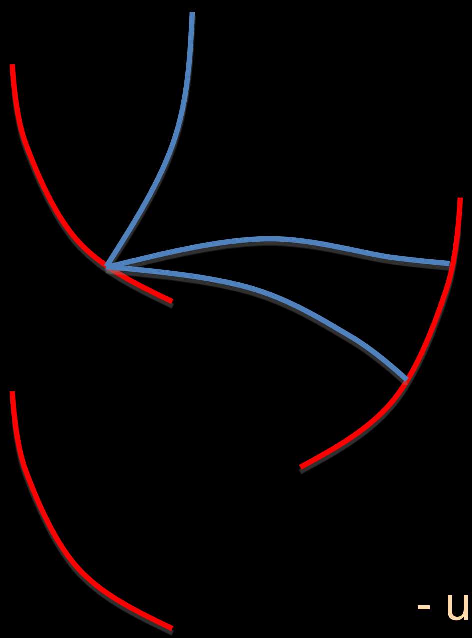
MEMS:micro electron mechanical systems

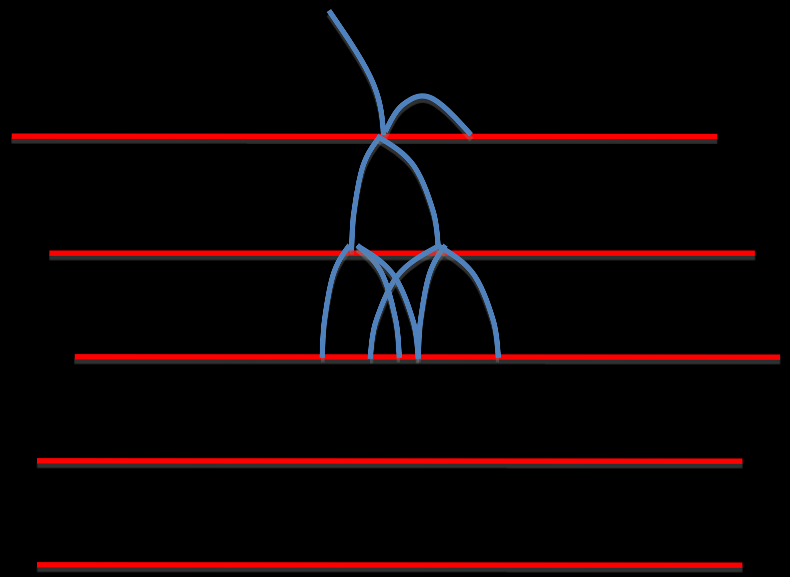




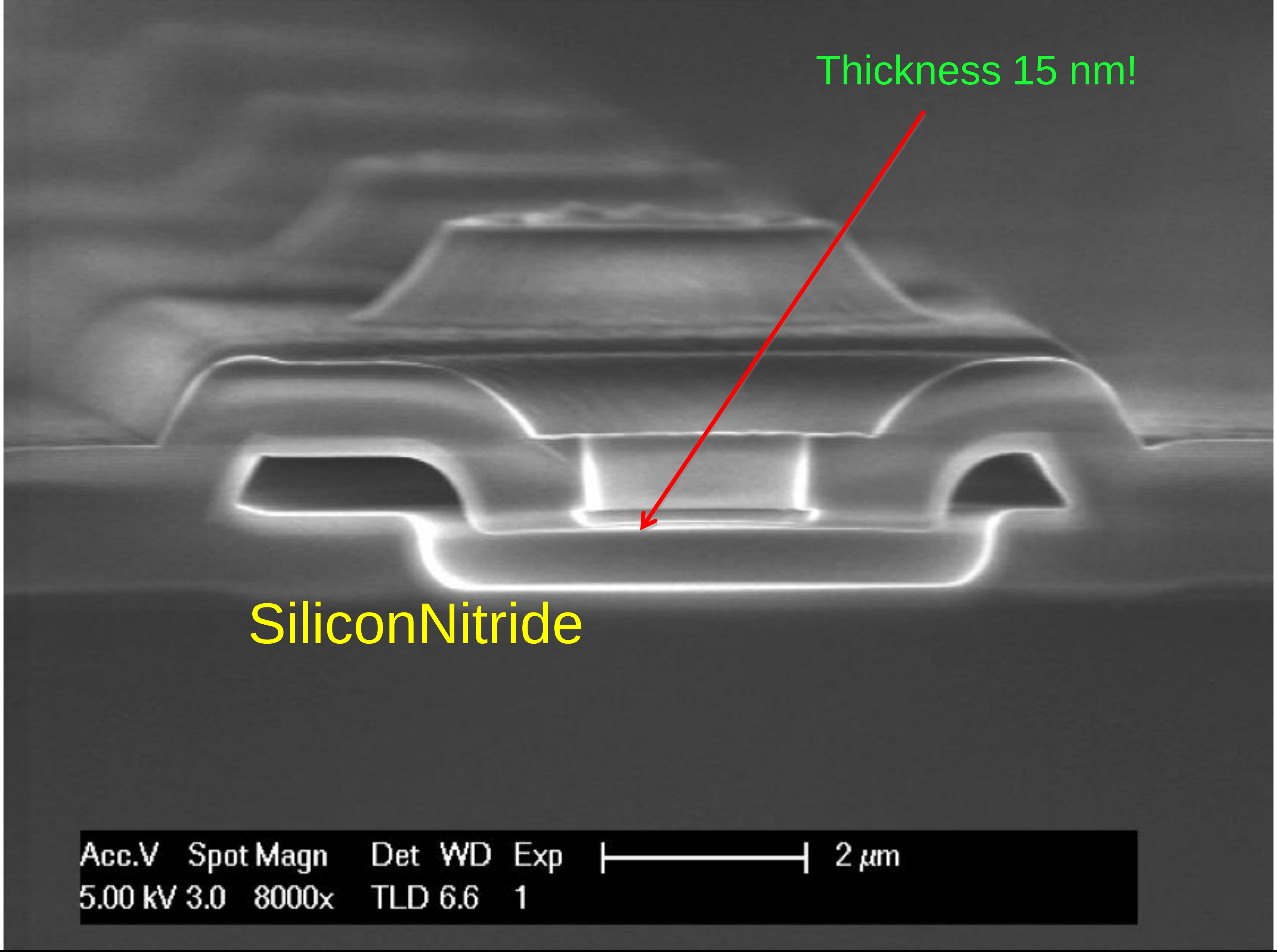
The transmission dynode: ultra thin (20 - 100 nm) layers

diamond
SiNitride (Si_3N_4) Si doped (SiRichNitride, SRN)
CsI
doped SiO_2

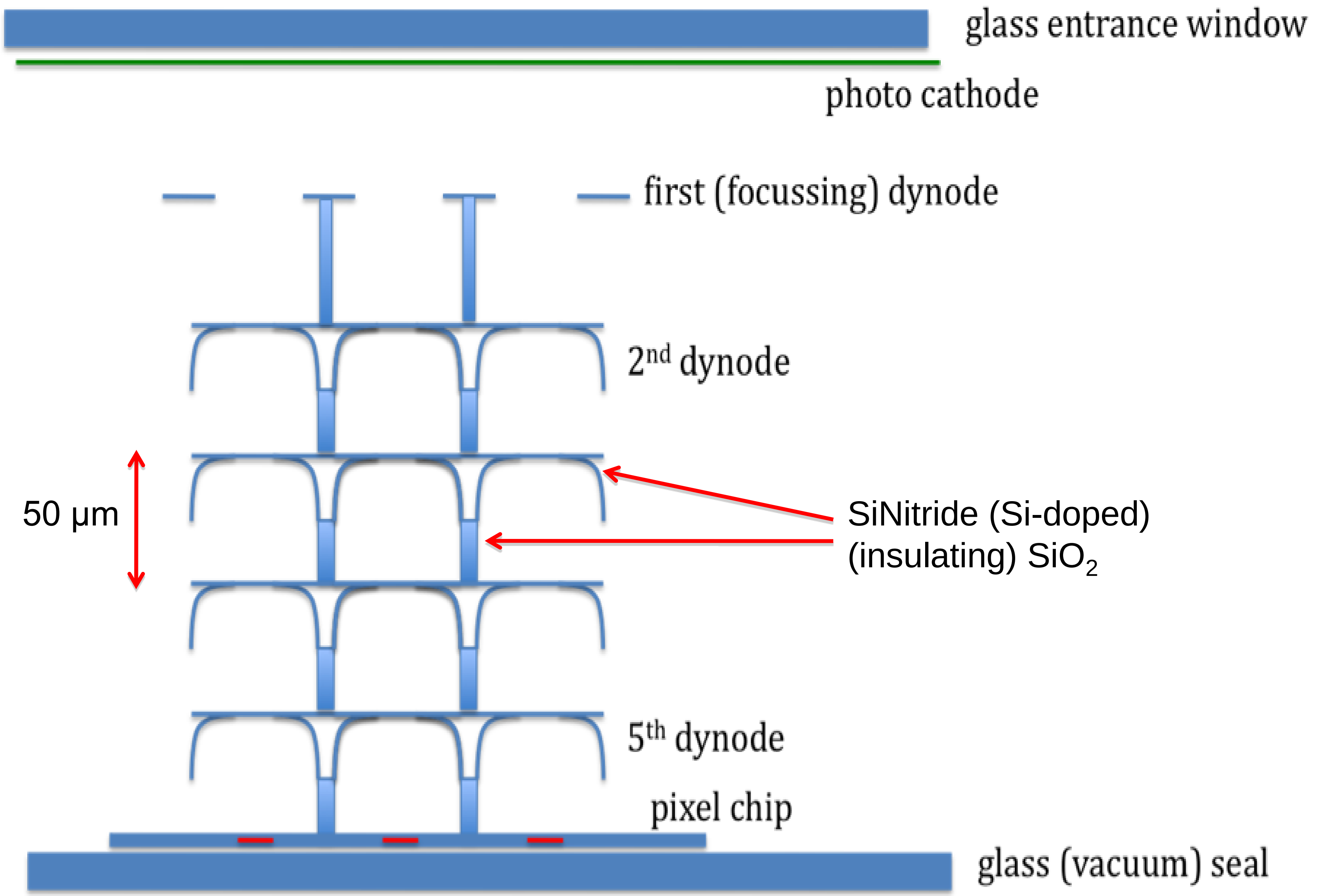


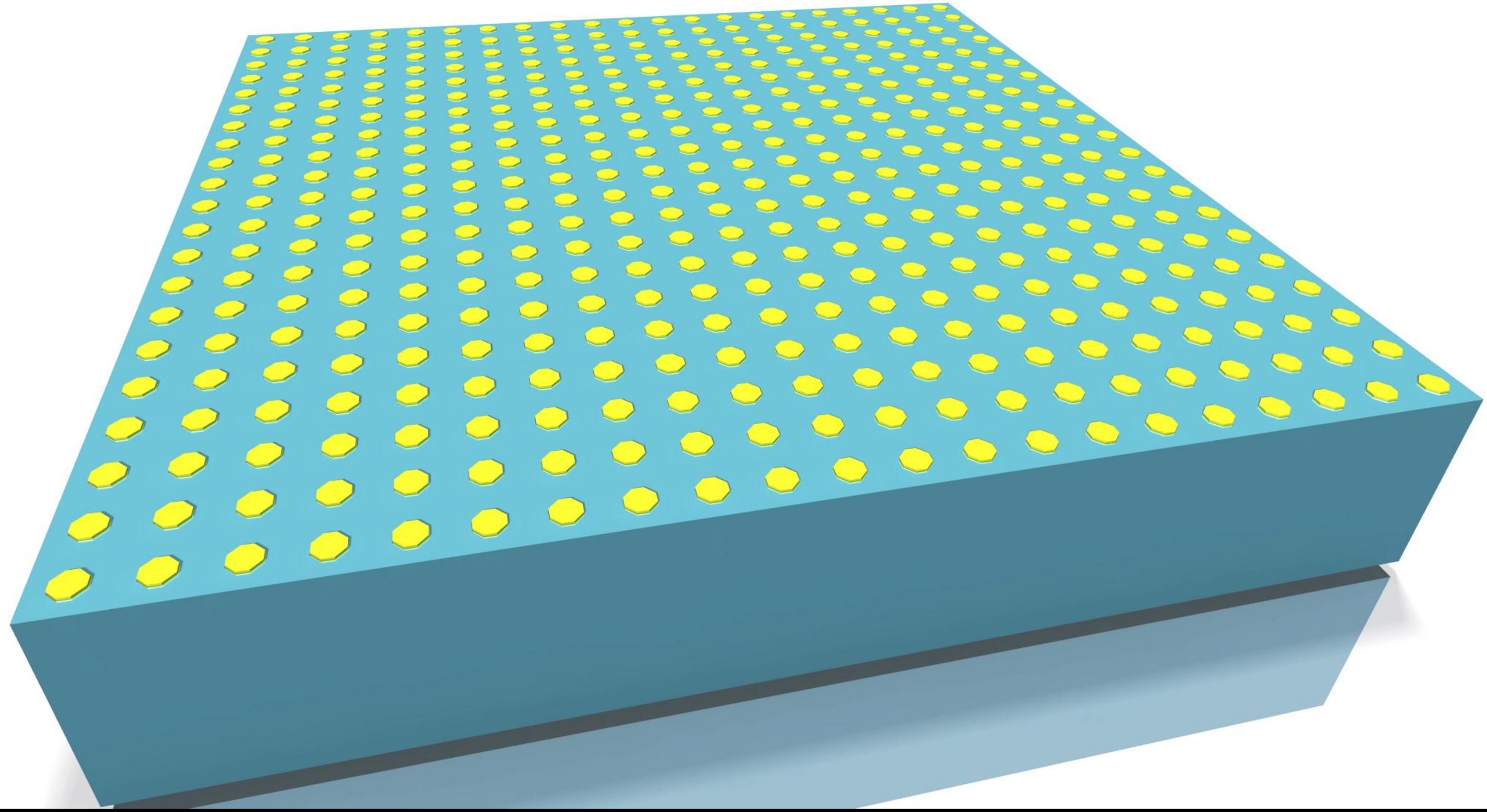


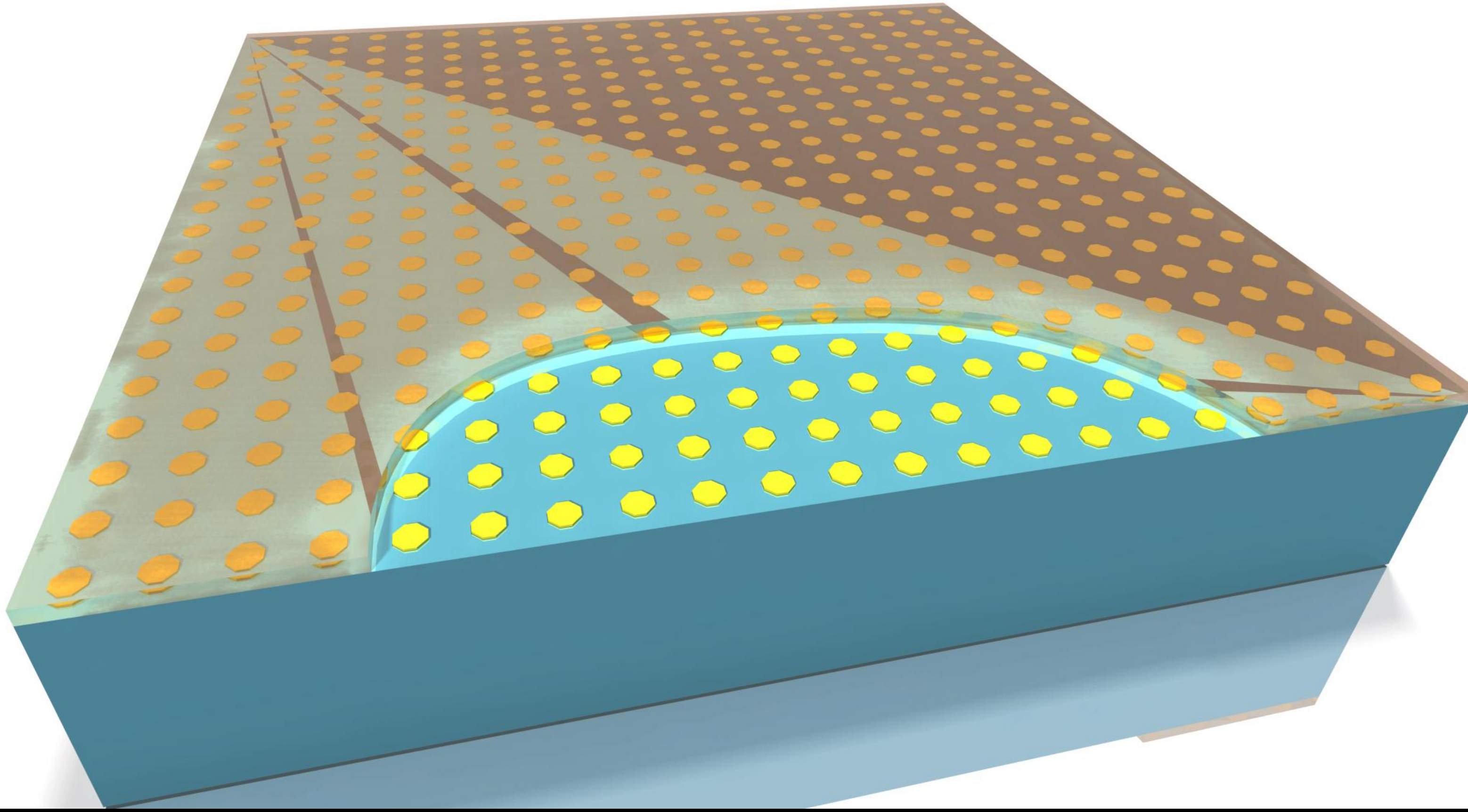
- ultra fast (single electron) detector: σ = 10 ps
- E-force much larger than Lorenz force: operates in B-field
- radiation hard
- low mass

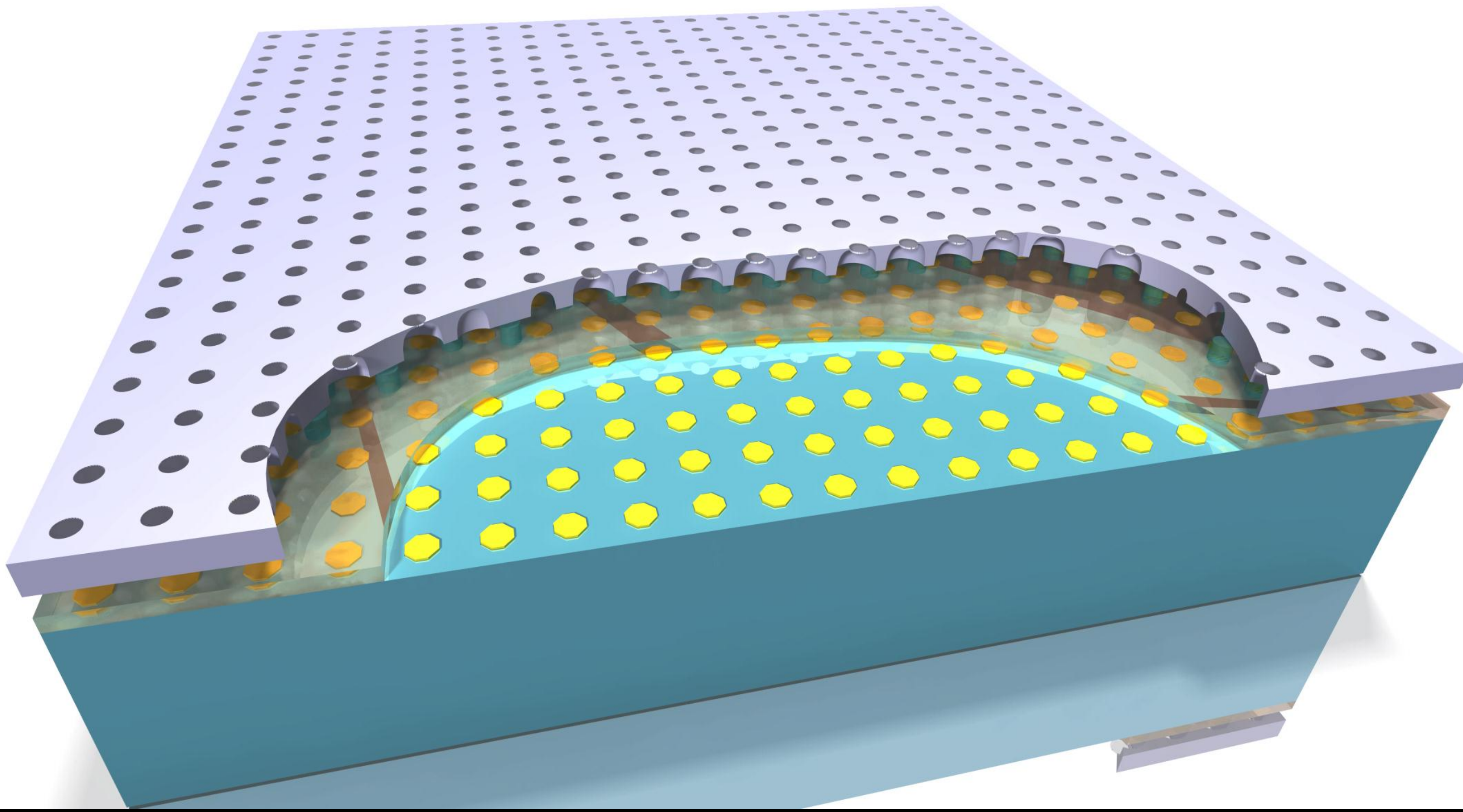


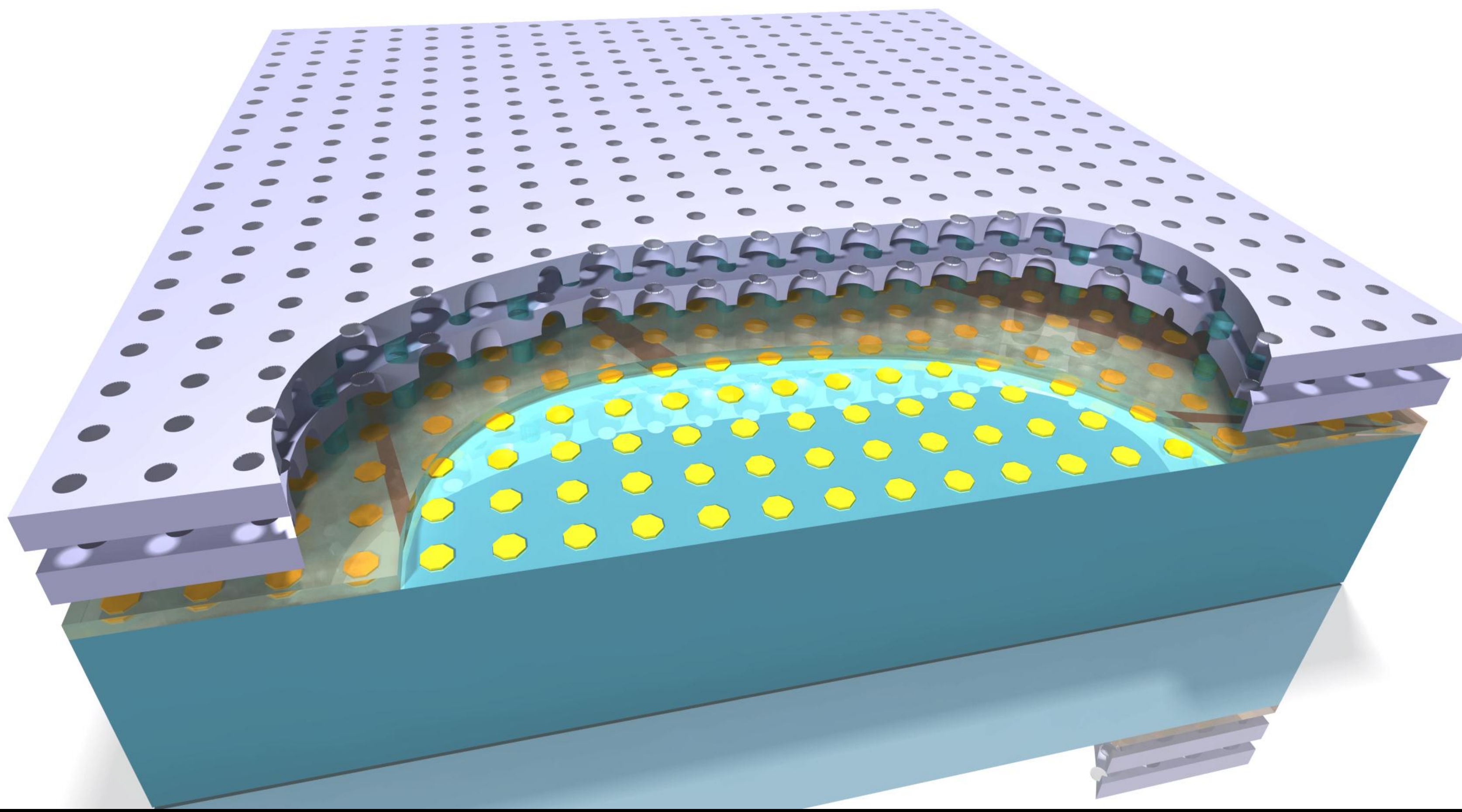
Delft University of Technology: DIMES

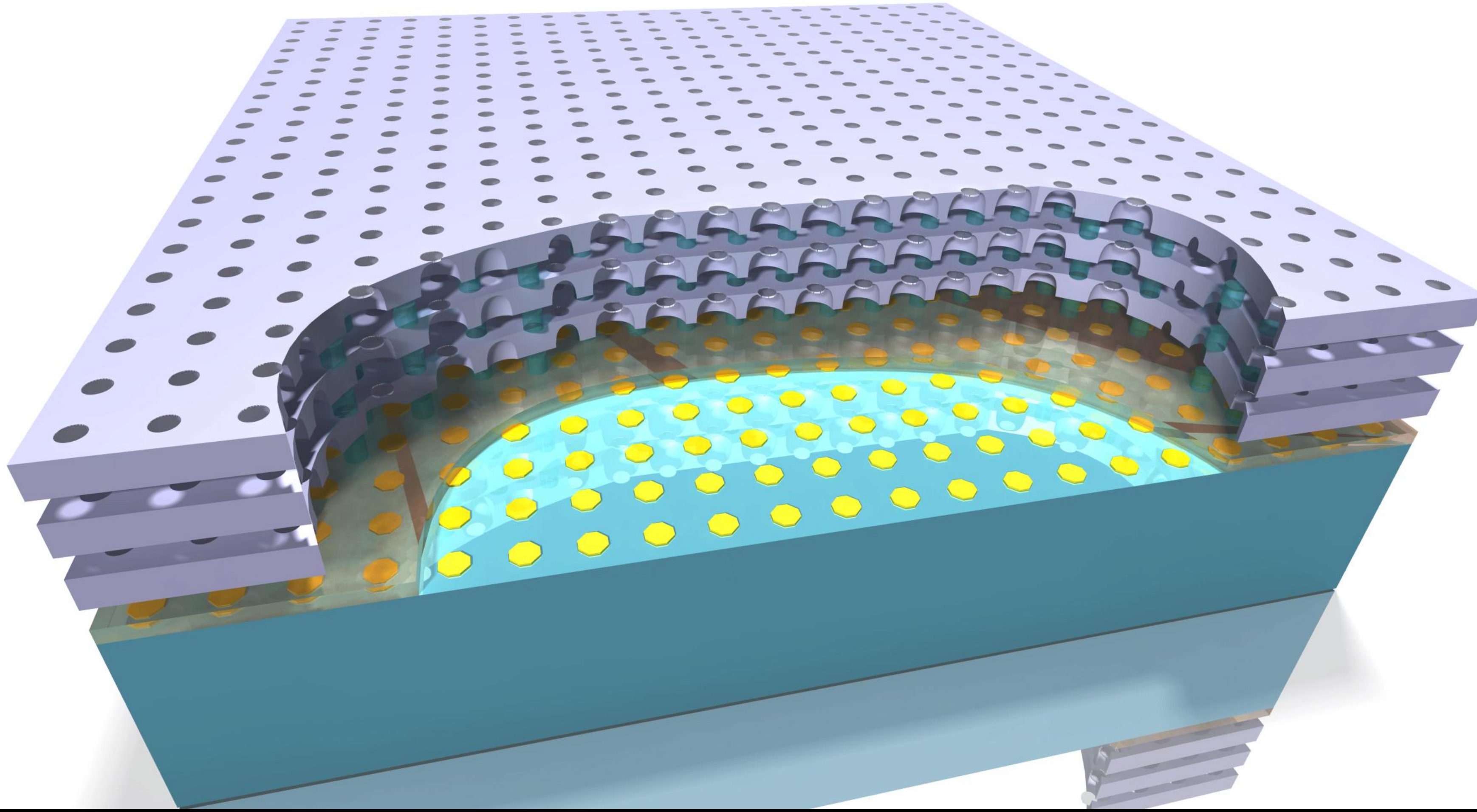

glass entrance window
photo cathode
first (focussing) dynode
2nd dynode
50 μm
SiNitride (Si-doped)
(insulating) SiO_2
5th dynode
pixel chip
glass (vacuum) seal

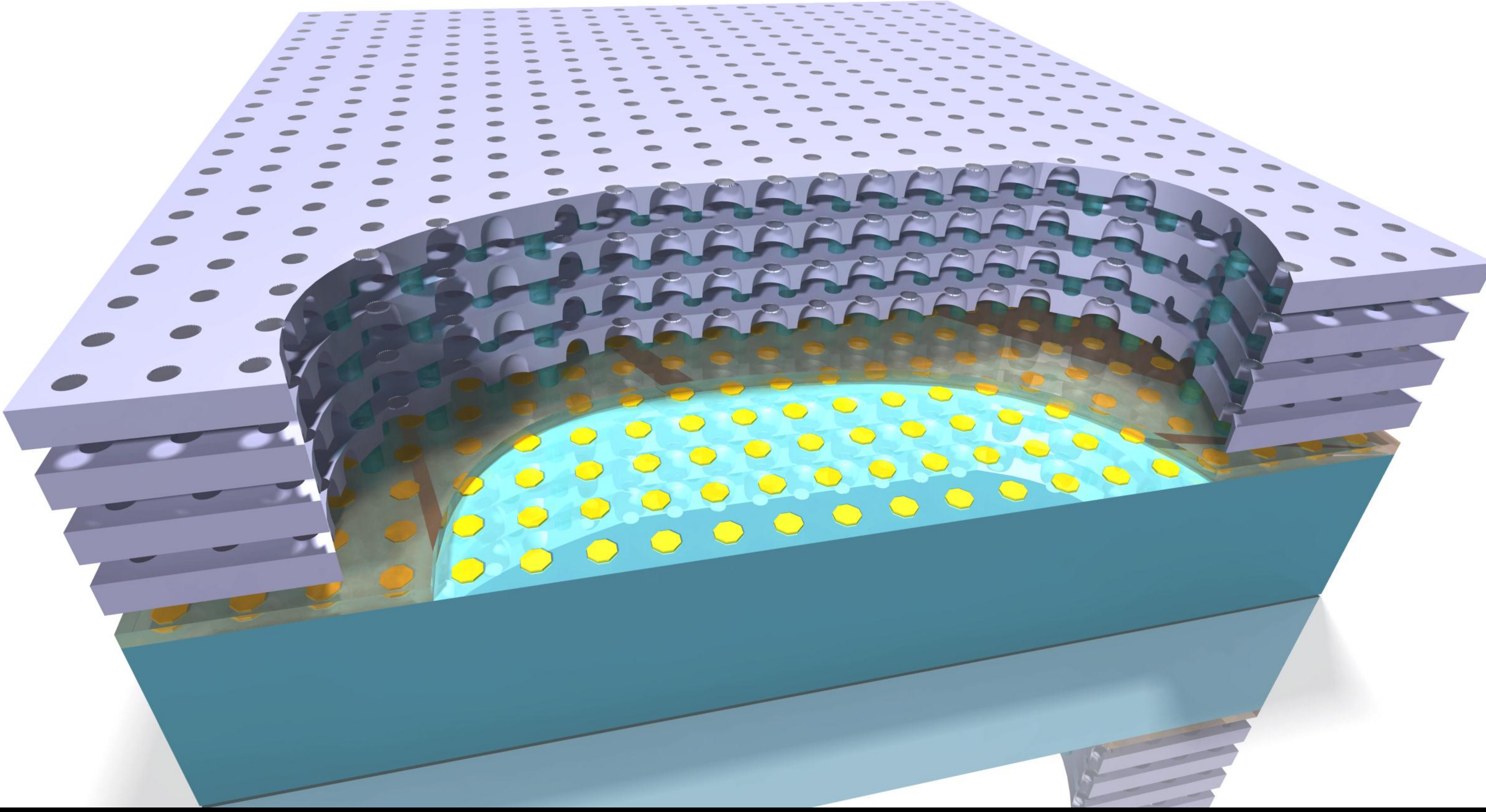


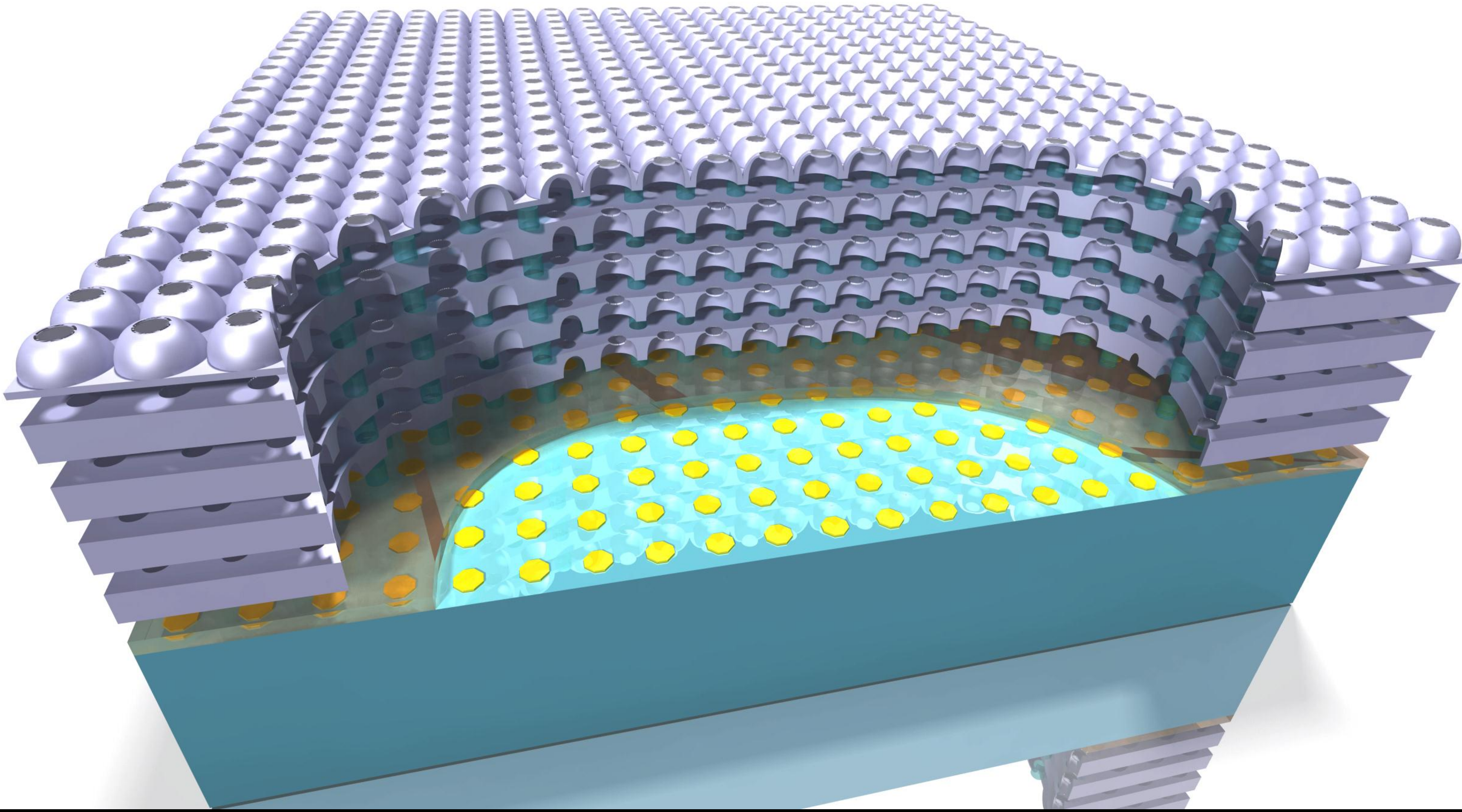


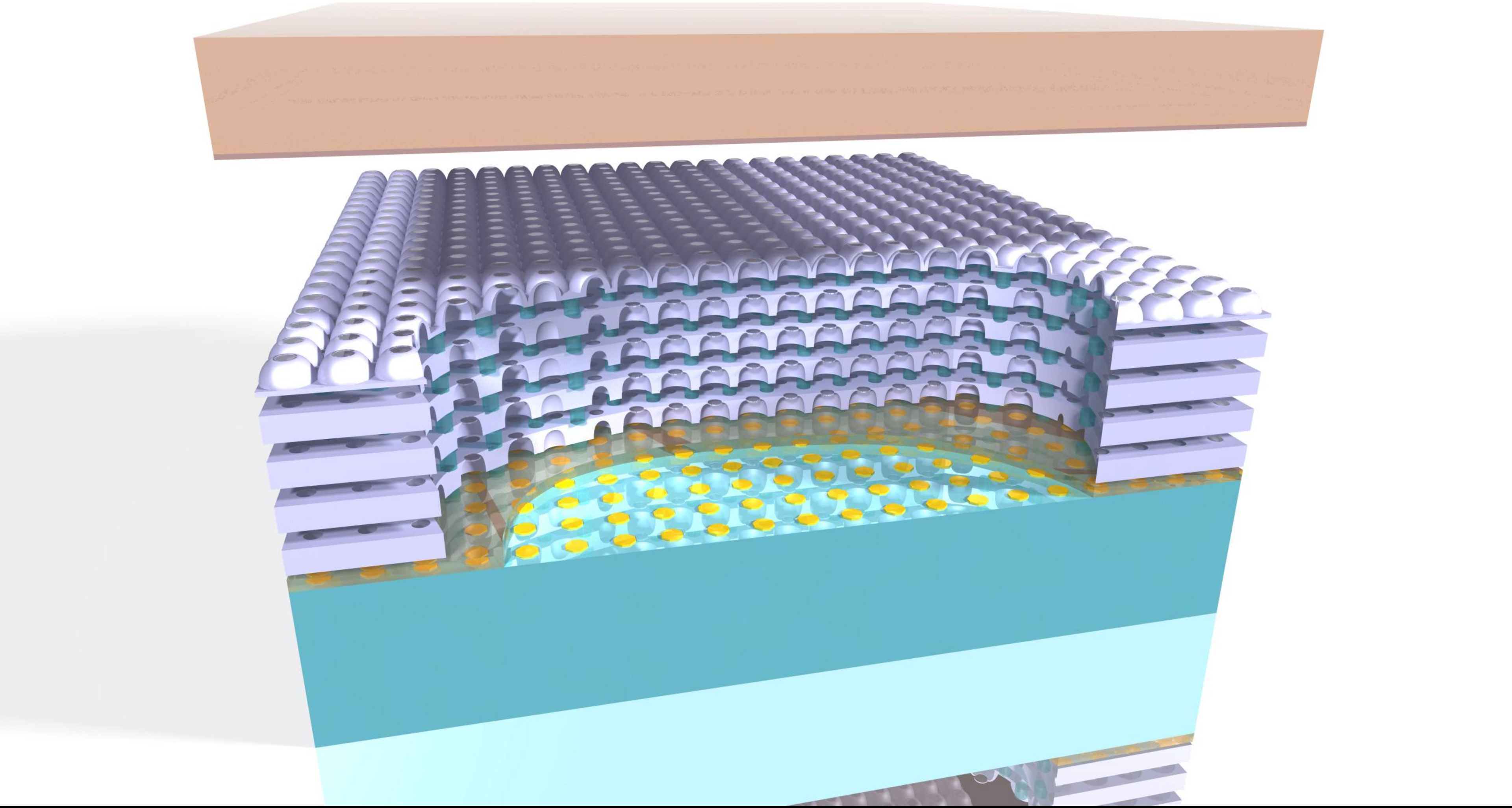






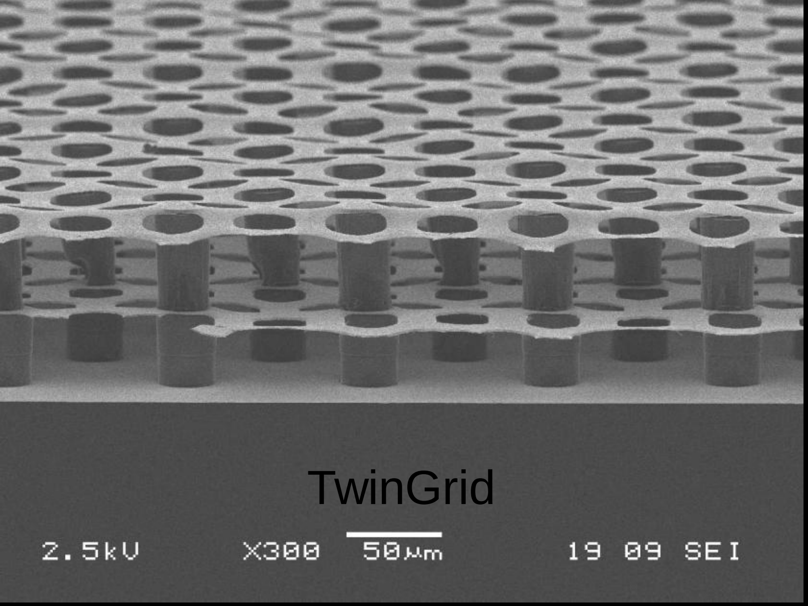


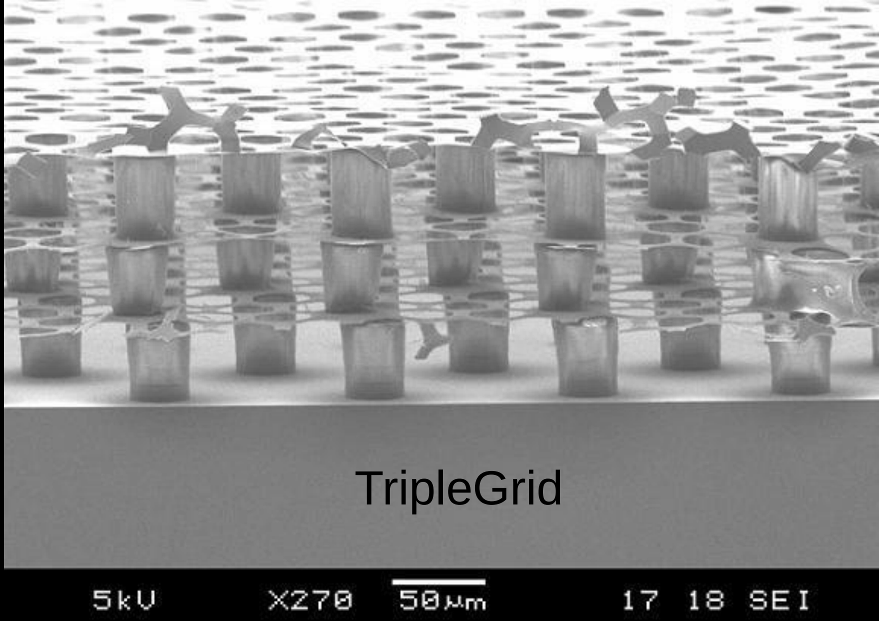




Essential:

- apply pixel circuitry: granularity, small source capacitance
- apply infinite high (free ballistic electron) mobility in vacuum!

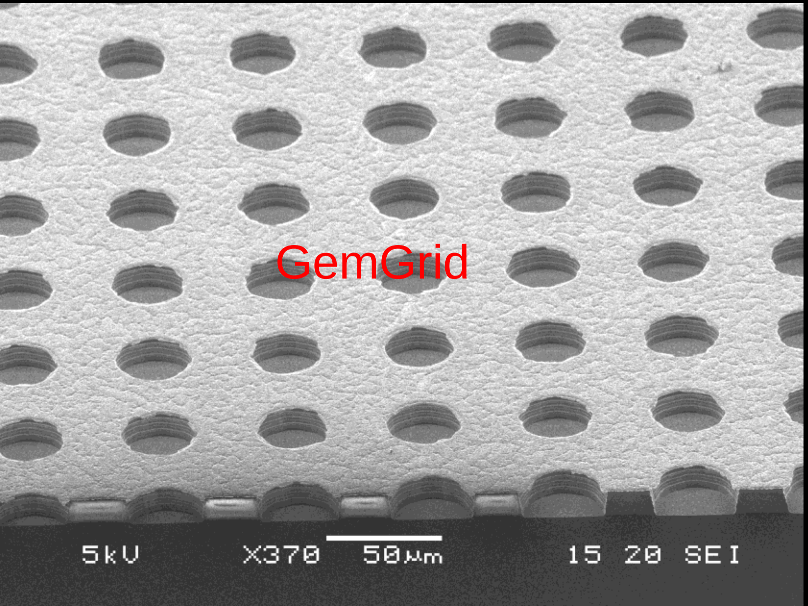


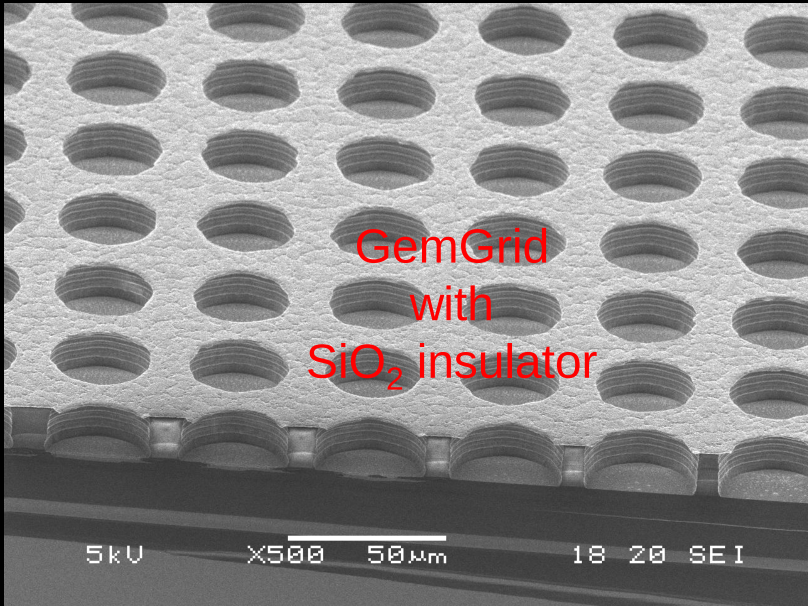


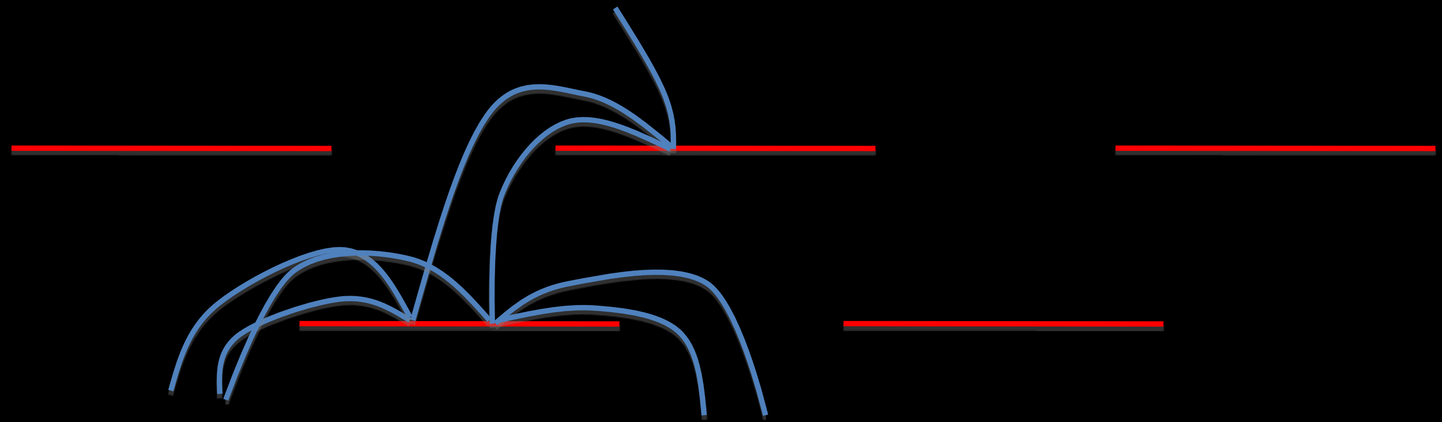
Development of MEMS technology

Wafer Post Processing

‘There is plenty of room at the top’ supported by Dutch Economical Affairs

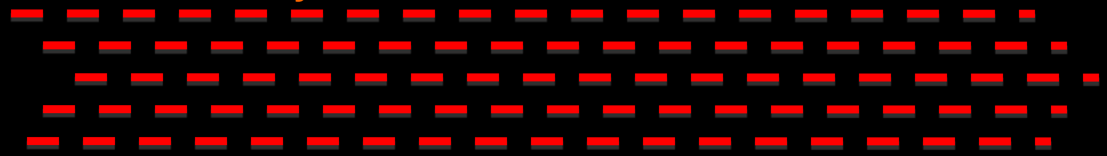


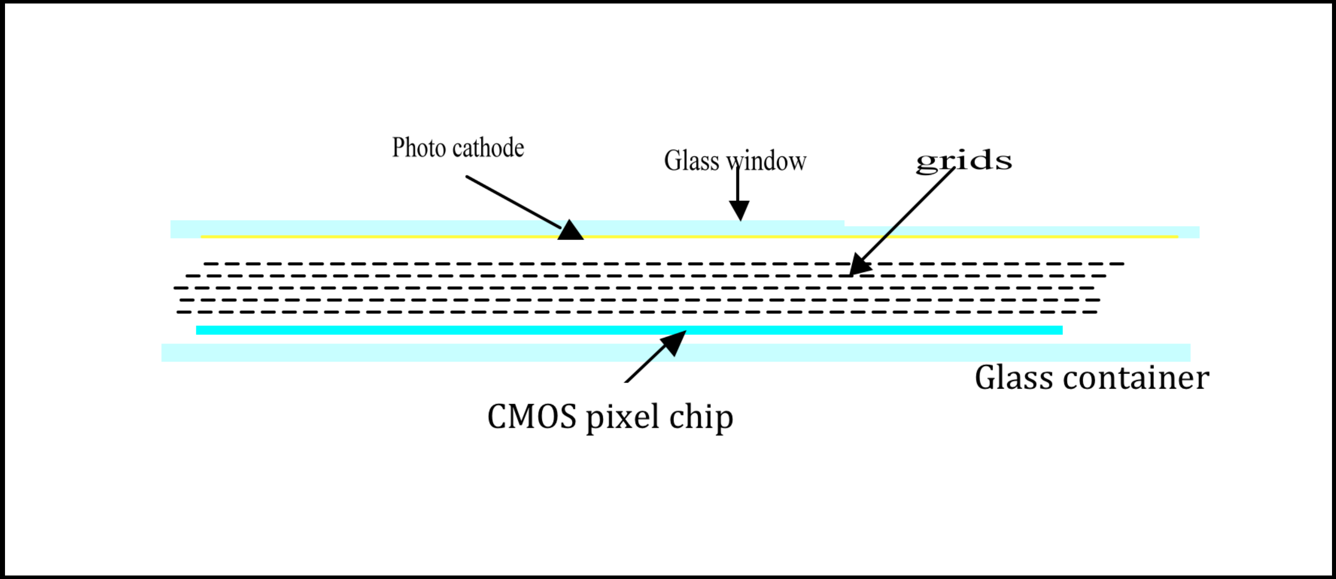


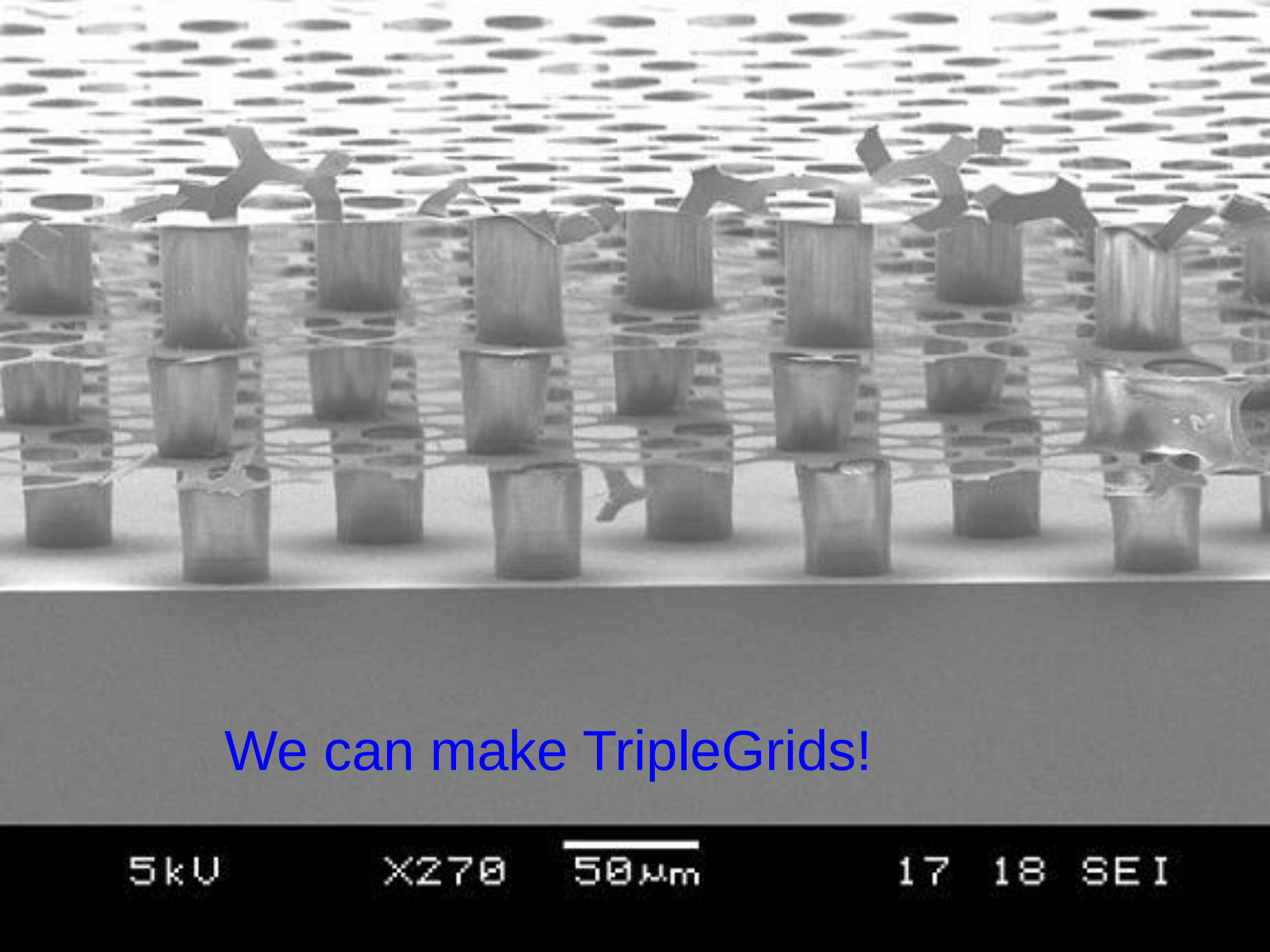


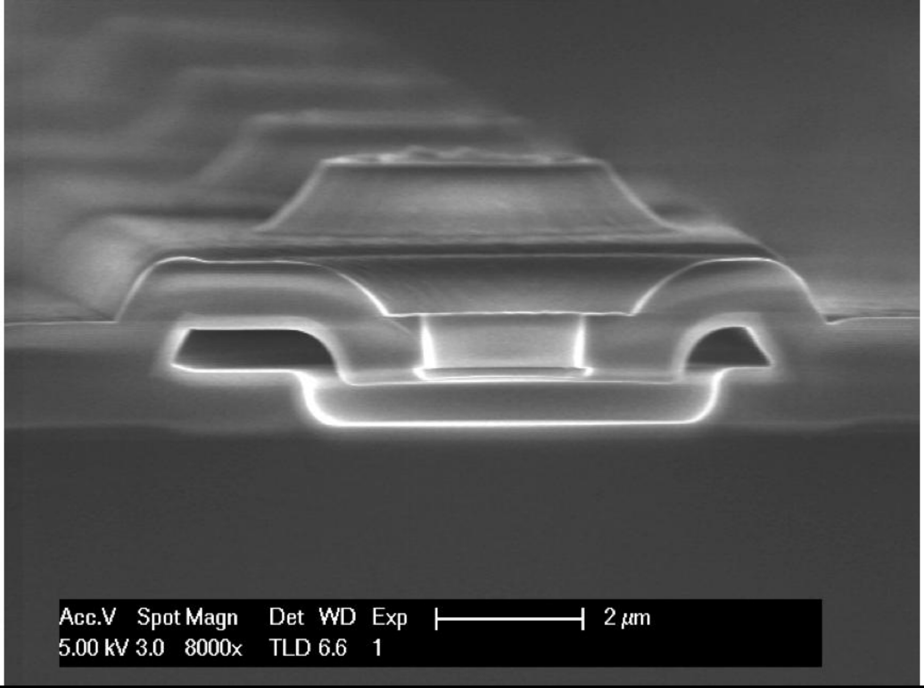
QuintGrid may be realized earlier

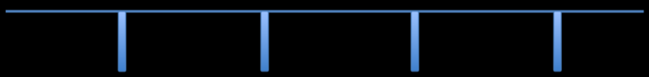
Development // Transmission Dynodes





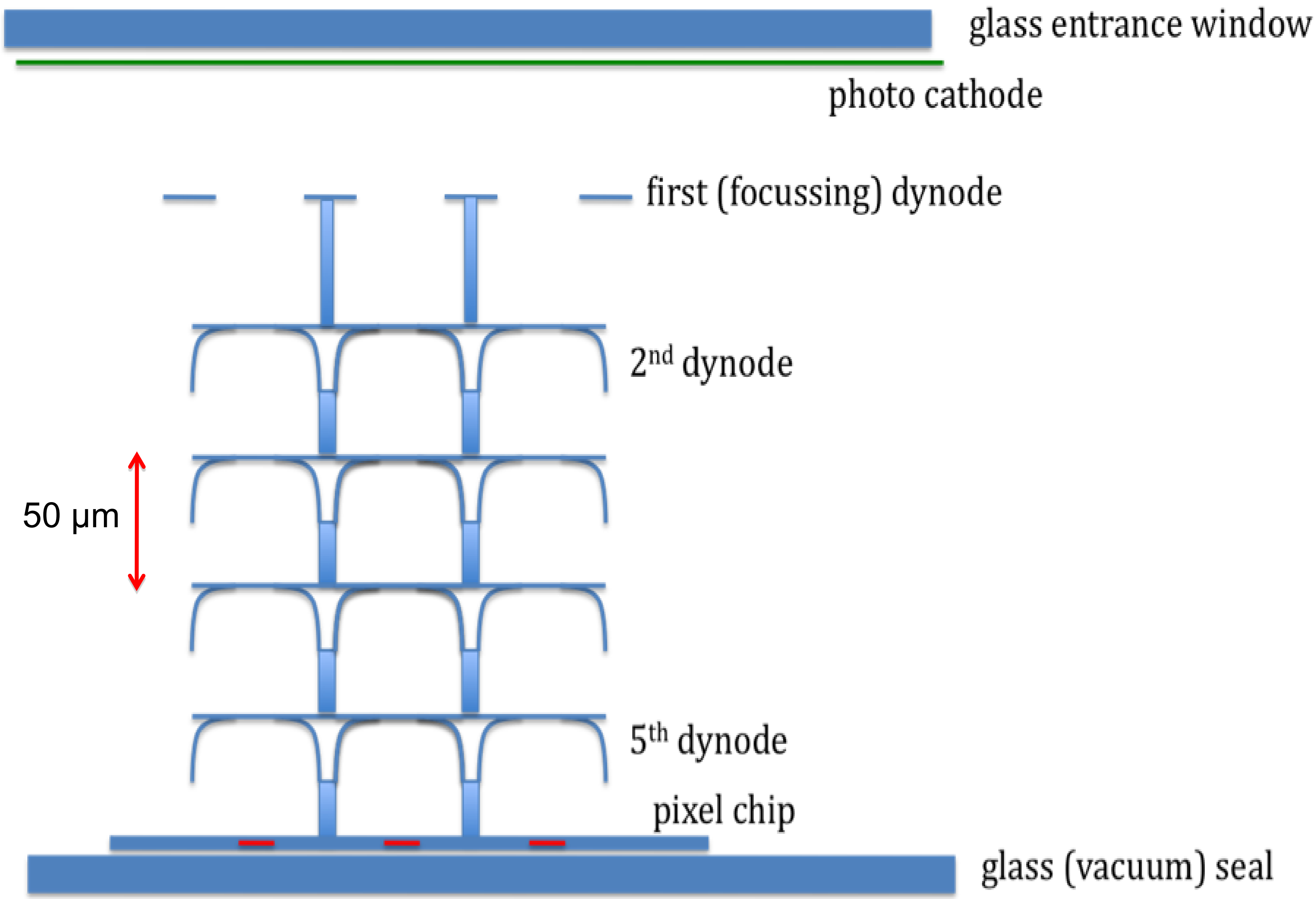

We can make TripleGrids!
5kV
X270
50µm
17 18 SEI

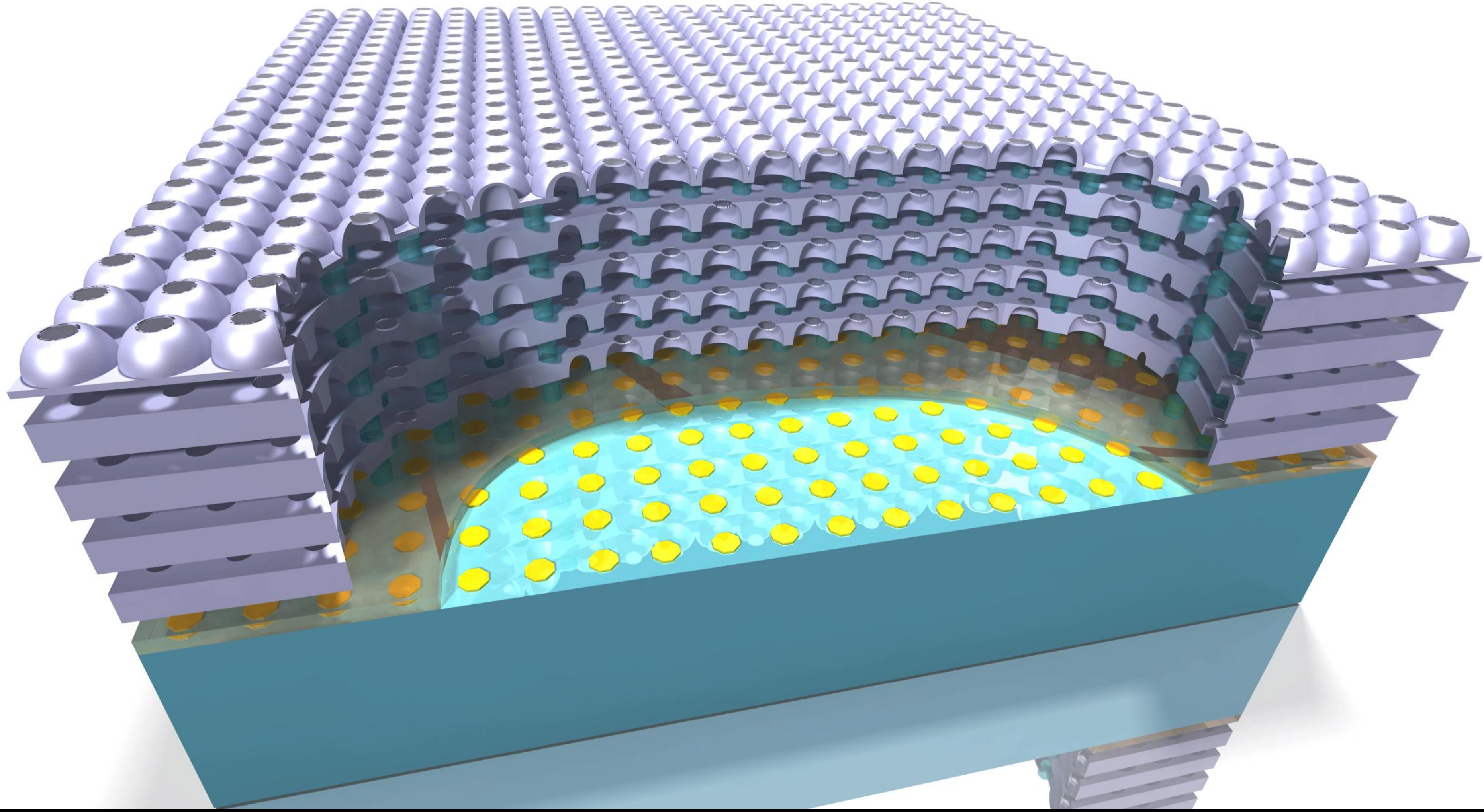




Reinforcement bars required:
creates dead regions

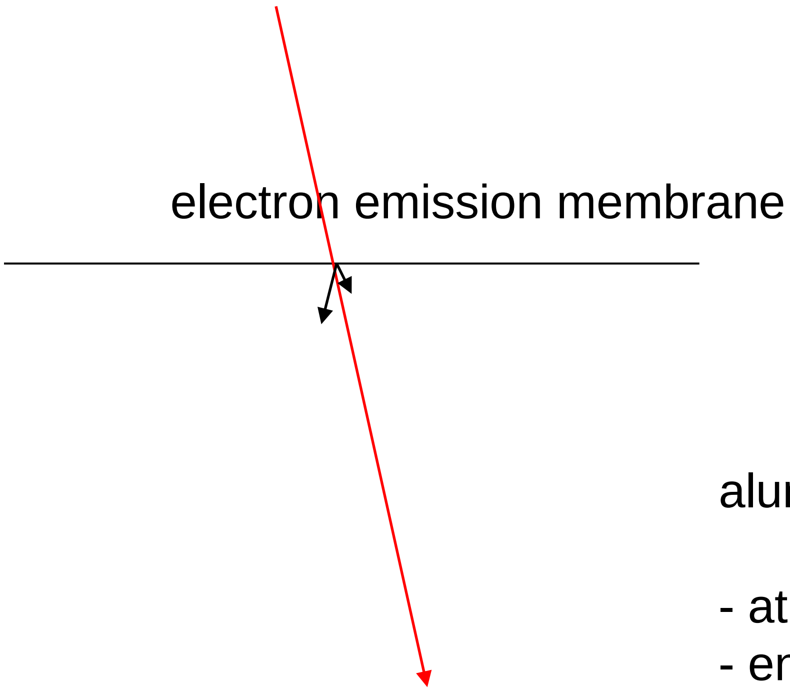
Problematic for 1st transmission dynode


glass entrance window
photo cathode
first (focussing) dynode
2nd dynode
50 µm
5th dynode
pixel chip
glass (vacuum) seal



For tracking of fast charged particles (MIPS):

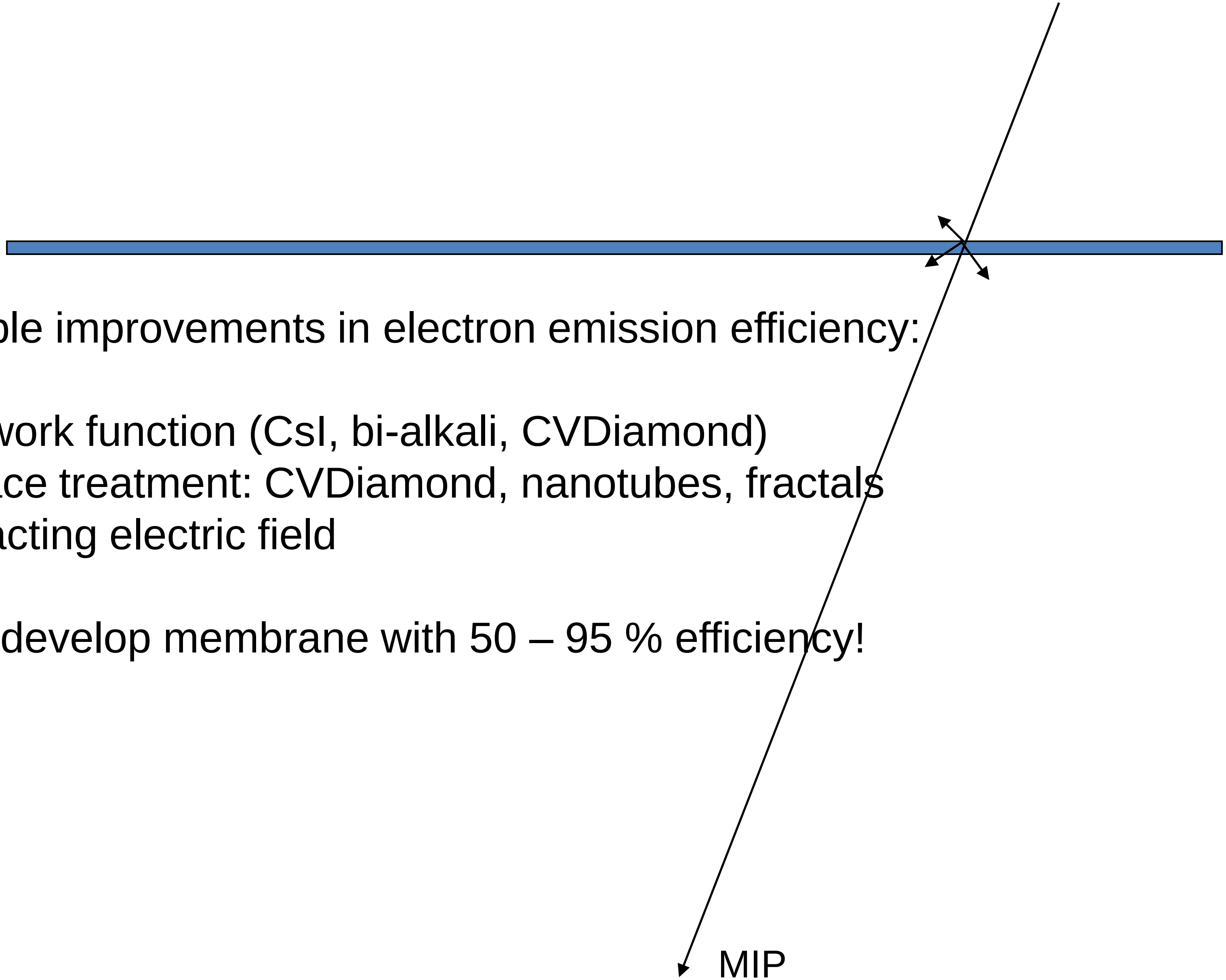
Replace photocathode by **Electron Emission Membrane**



Emits (at least one) electron at the crossing point of membrane surface and MIP, with a high probability

aluminium foil:

- at least 1 electron is emitted in 4 % of the cases
- energy of electron: 0 – 5 eV
- probability depends on surface condition
- increase to 6 % if layer of AlOxide is present

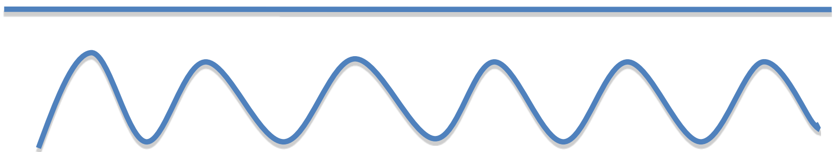


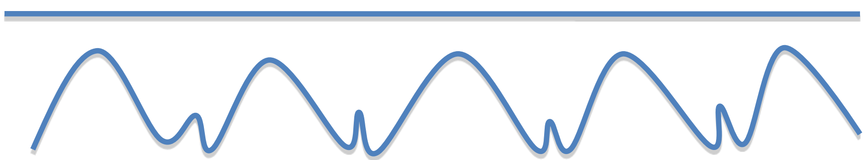
Possible improvements in electron emission efficiency:

- low work function (CsI, bi-alkali, CVDiamond)
- surface treatment: CVDiamond, nanotubes, fractals
- Extracting electric field

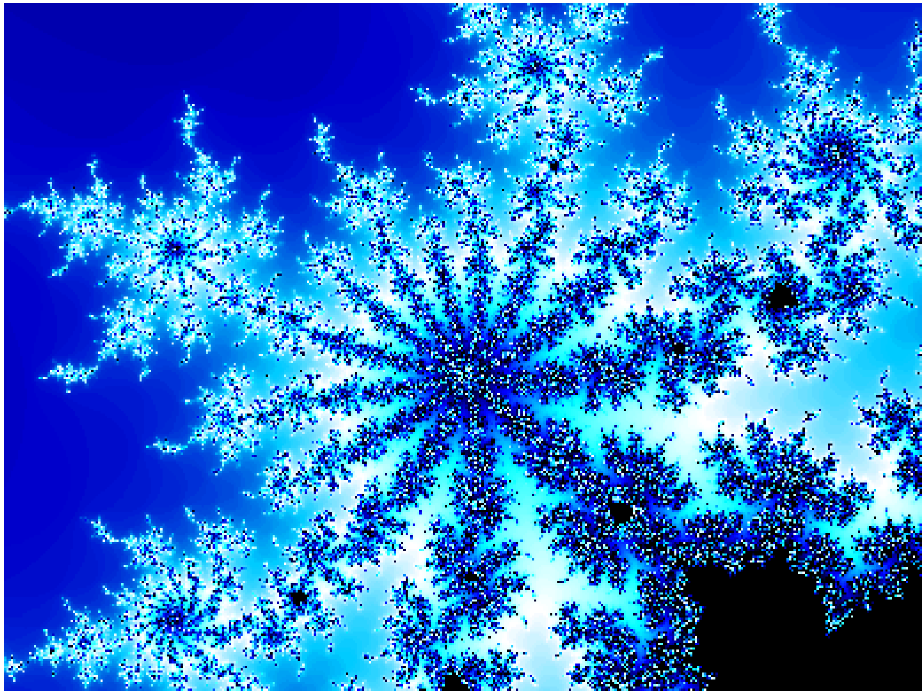
Try to develop membrane with 50 – 95 % efficiency!

Skin effect: only skin of ~ 50 nm participates in EE.
Rise of EE efficiency by surface enlargement: meandering, modulating, roughening





2nd order modulation, 3rd order.….fractals!
Extracting E-field: constant at surface



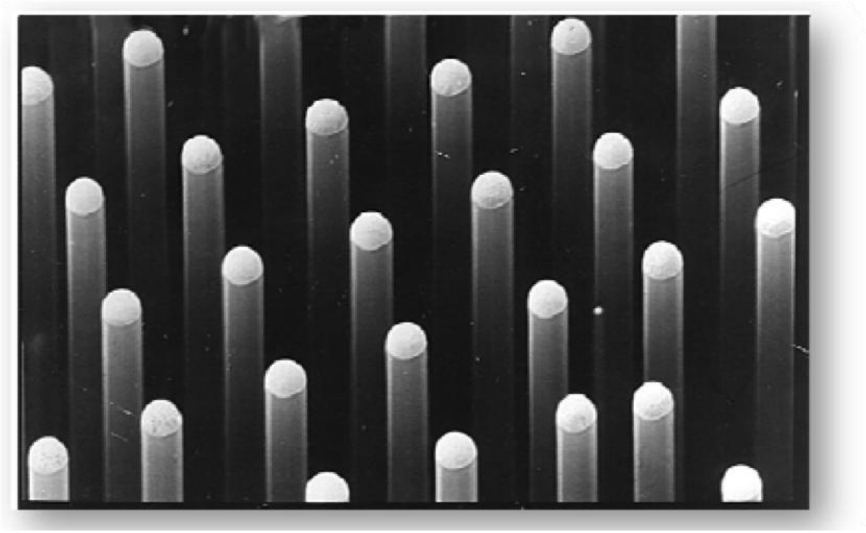
Work function

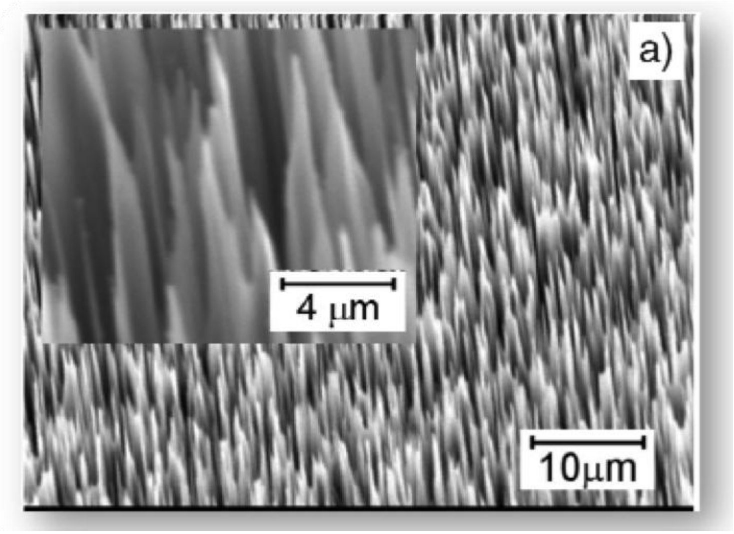
Interesting: - photo cathodes of PMs (bi-alkali etc)
- coating of dynodes of PMs

- Eff Alu, Cu: ~ 4 %
- Eff ceramics (Diamond, CsI, Si_3N_4): 10 - 20 %?

Exctracting electric field (close to cold electron emission)

- nano grass



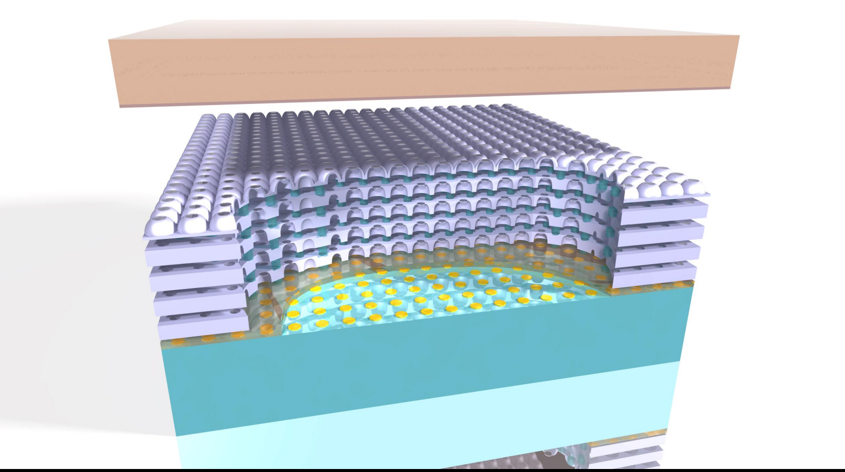


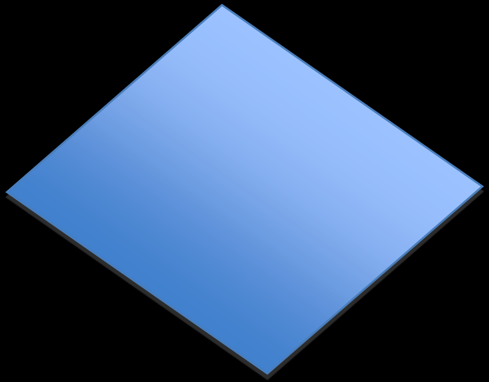
Conclusions

MultiPix
MEMS made vacuum electron multiplier integrated on pixel chip

MultiPix + ‘classical’ photo cathode
Timed Photon Counter TiPC Tipsy

MultiPix + Electron Emission Membrane
MIP tracking detector





1” x 1”, 2 mm thick

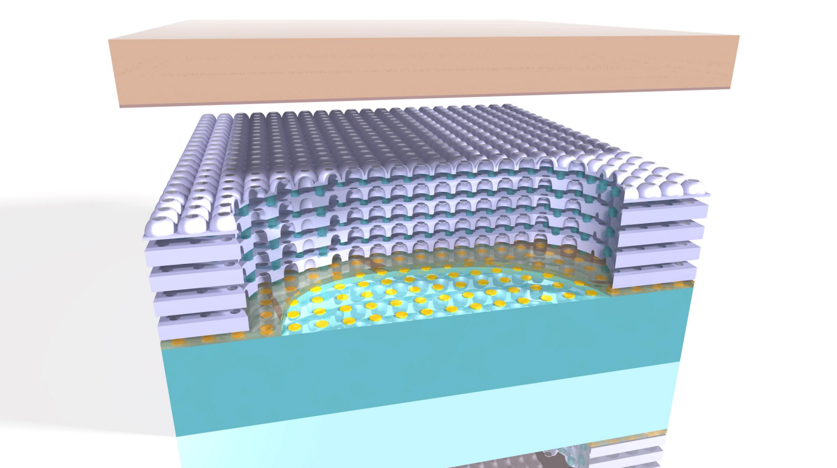
Timed Photon Counter TiPC Tipsy

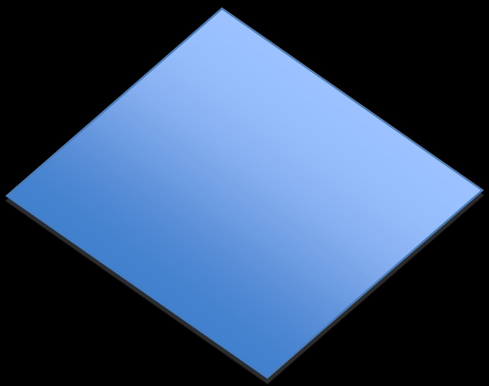
- good quantum efficiency
- ultra fast, ps time resolution
- low noise
- little dark current, no bias current
- radiation hard
- perfectly linear (high granularity)

- flat, thin & light
- 2D position resolution ~ 10 μm
- potentially cheap……!
- little radioactive
- can stand B fields

Potentially outperforms APDs, G-APDs, SPADs, dSiPMs, QUPIDs

Consumer application: 3D pictures by measurement Time-of-Flight…….!





1” x 1”, 500 μm thick

MIP Tracking detector

- moderate track efficiency 50 – 90 %
- ultra fast, ps time resolution
- low noise
- little dark current, no bias current
- radiation hard

- flat, thin & light
- 2D position resolution ~ 10 μm
- potentially cheap……!
- can stand B fields
- no 3D track vector info (GridPix)

Outperforms Si trackers in terms of time resolution
- high rate experiments
- BX timing: ILC/CLIC experiments