classical gaseous

The Quad: a general purpose modular readout system for TPCs

+ reaching transmission secondary electron yield TSEY = 5.2

Harry van der Graaf
Nikhef & TU Delft

8th Symposium on Large TPCs
Diderot University
Paris, France, Dec 6 2016

From Micromegas to GridPix Detectors

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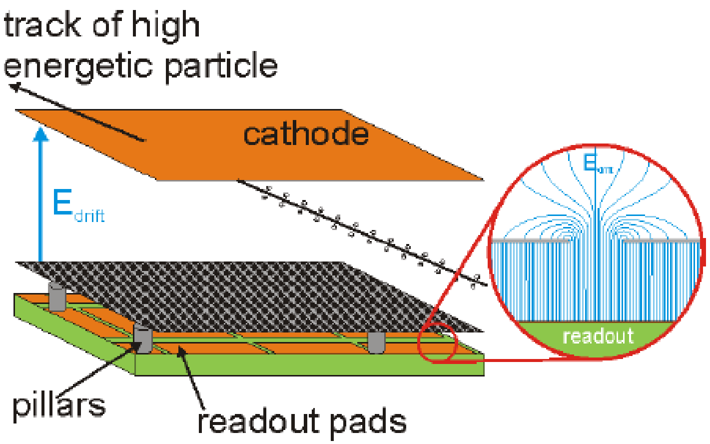
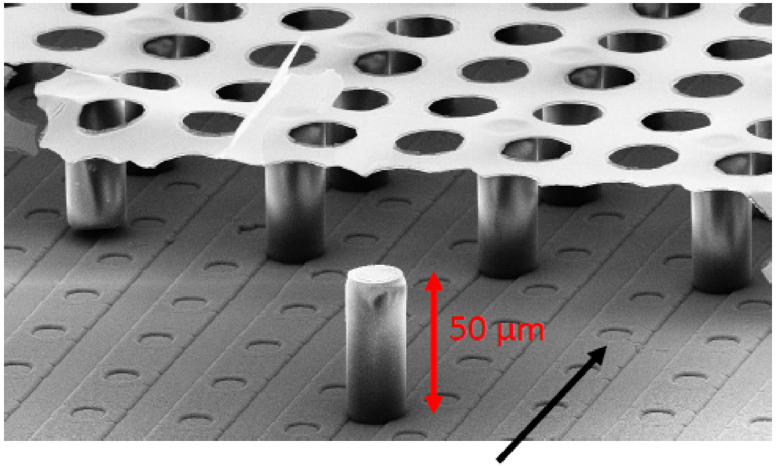
Micromegas



GridPix



Standard charge collection:

- Pads of several mm²
- Long strips (~10 cm length, ~200 µm pitch)

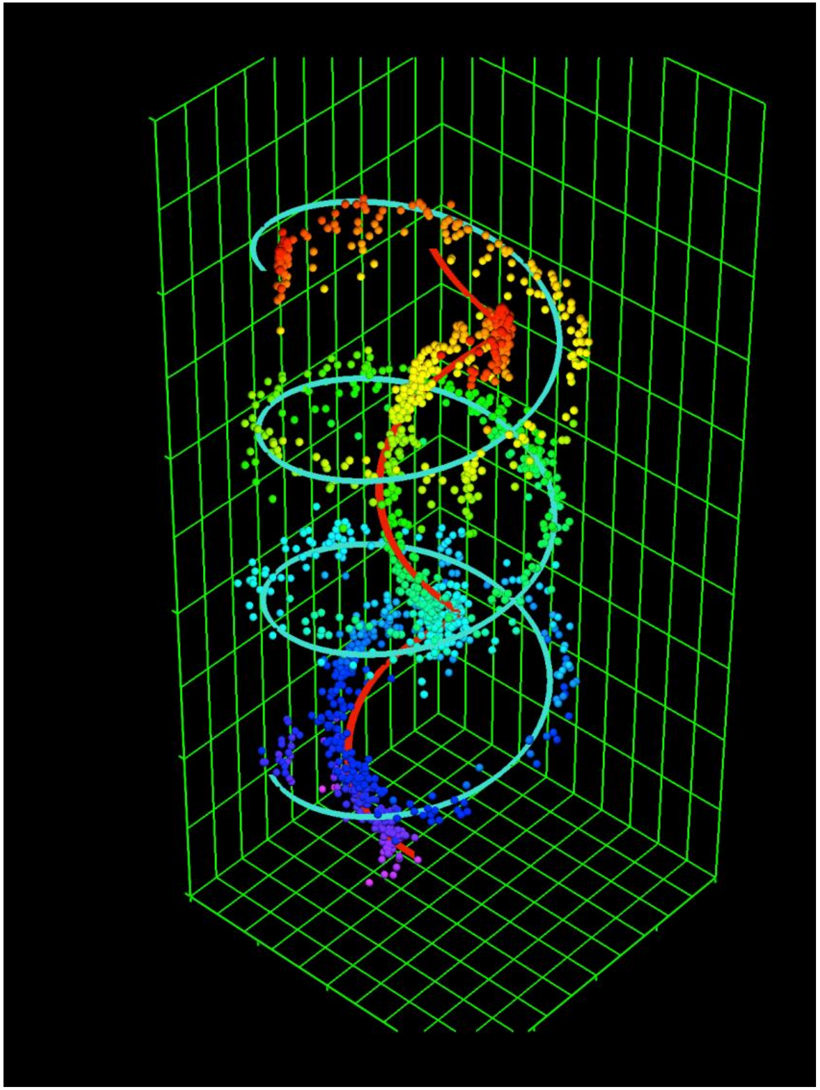
Diffusion within gas amplification region:

- Ar:CH_4 90:10 → σ ≈ 25 µm
- Ar:iC_4H_{10} 95:5 → σ ≈ 25 µm

Smaller pads/pixels should improve spatial resolution
Invention of the GridPix in 2006 at Nikhef

Use **bump bond pads** of a readout ASIC as charge collecting anodes

Production of Micromegas structure directly on top of pixelized readout ASIC through photolithographic postprocessing



2007: GridPix with functioning protection layer
the ultimate TPC detector:

- single electron sensitive
- extract ALL info of primary electrons in gas
- only gas diffusion limits TPC performance
- (and pixelsize)

2007 – 2016:

1. attempt GridPix mass production on wafers: wafer post processing (InGrid)
2. Improve protection layer: no faults permitted

Applications III – Large Area GridPix Detector

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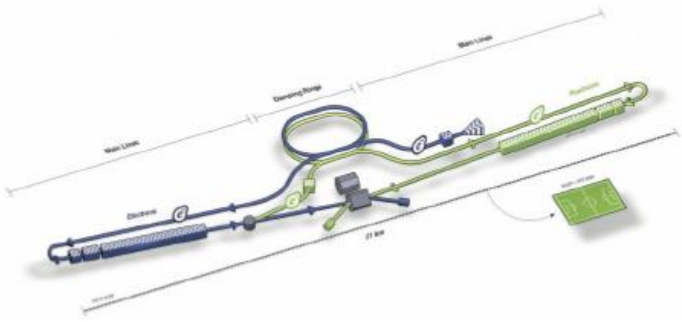
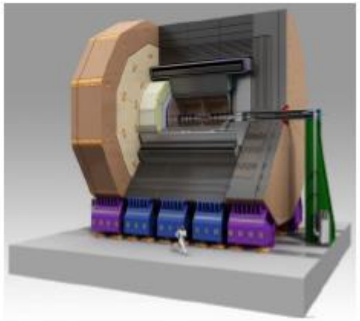
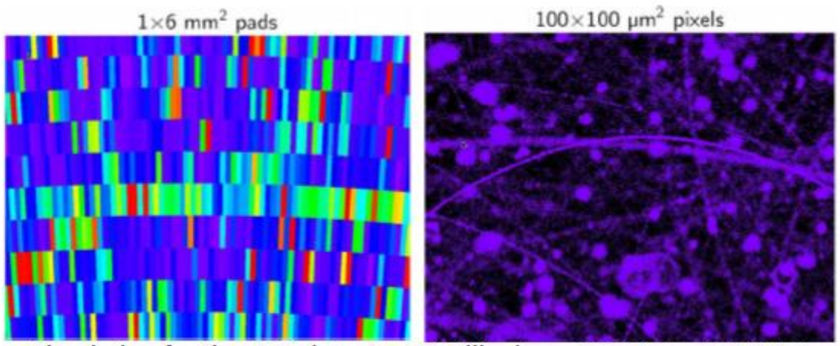


International Linear Collider:
- Linear e^+e^- collider with $\sqrt{s}$ = 500 GeV – 1 TeV

International Large Detector:
- One of two ILC general purpose detectors
- Foresees a central TPC as main tracker

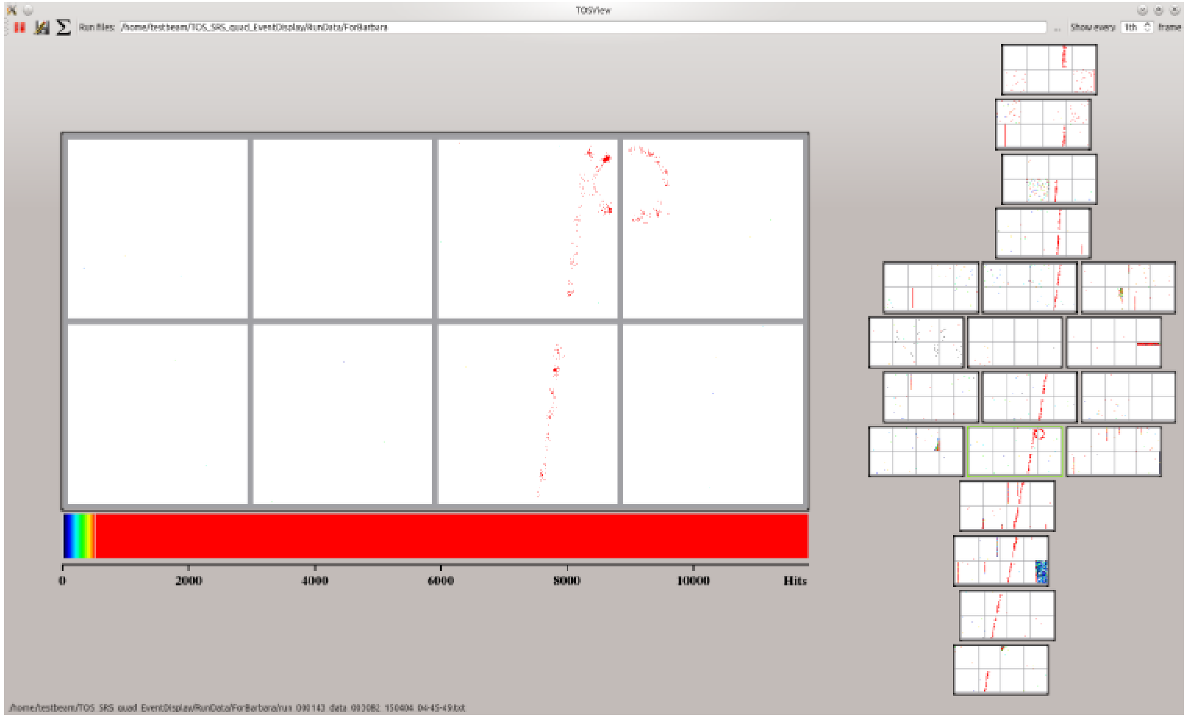




Simulation for the CLIC detector, M. Killenberg, LCD-Note-2013-005

- High occupancy through background processes (γγ → hadrons, e^+e^- → pairs/beam halo)
- Use of GridPixes would minimize the occupancy
  → better track finding, δ-ray removal
  → improved dE/dx by primary e^- counting
  →pad plane and readout electronics fully integrated
- For full readout of ILD-TPC about 50,000 to 60,000 GridPixes are needed (2 endcaps with 10 m² each)
  → need to prove large area coverage and scalability

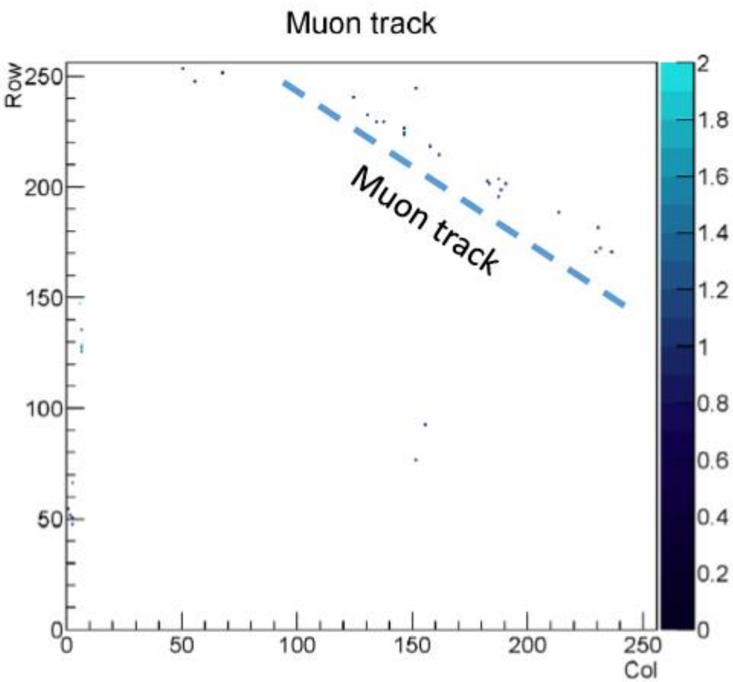
Applications III –
Large Area GridPix Detector

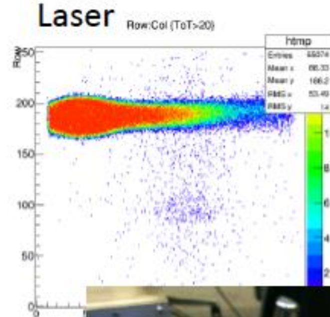


First Timepix3 GridPix

In collaboration with Nikhef LEPCOL group:
F. Hartjes, K. Heijhof, P. Kluit, G. Raven,
J. Timmermans, S. Tsigaridas, H. van der Graaf

- First Timepix3 wafer has been successfully processed at IZM Berlin
- First tests with Timepix3 GridPix were performed at Nikhef some days ago





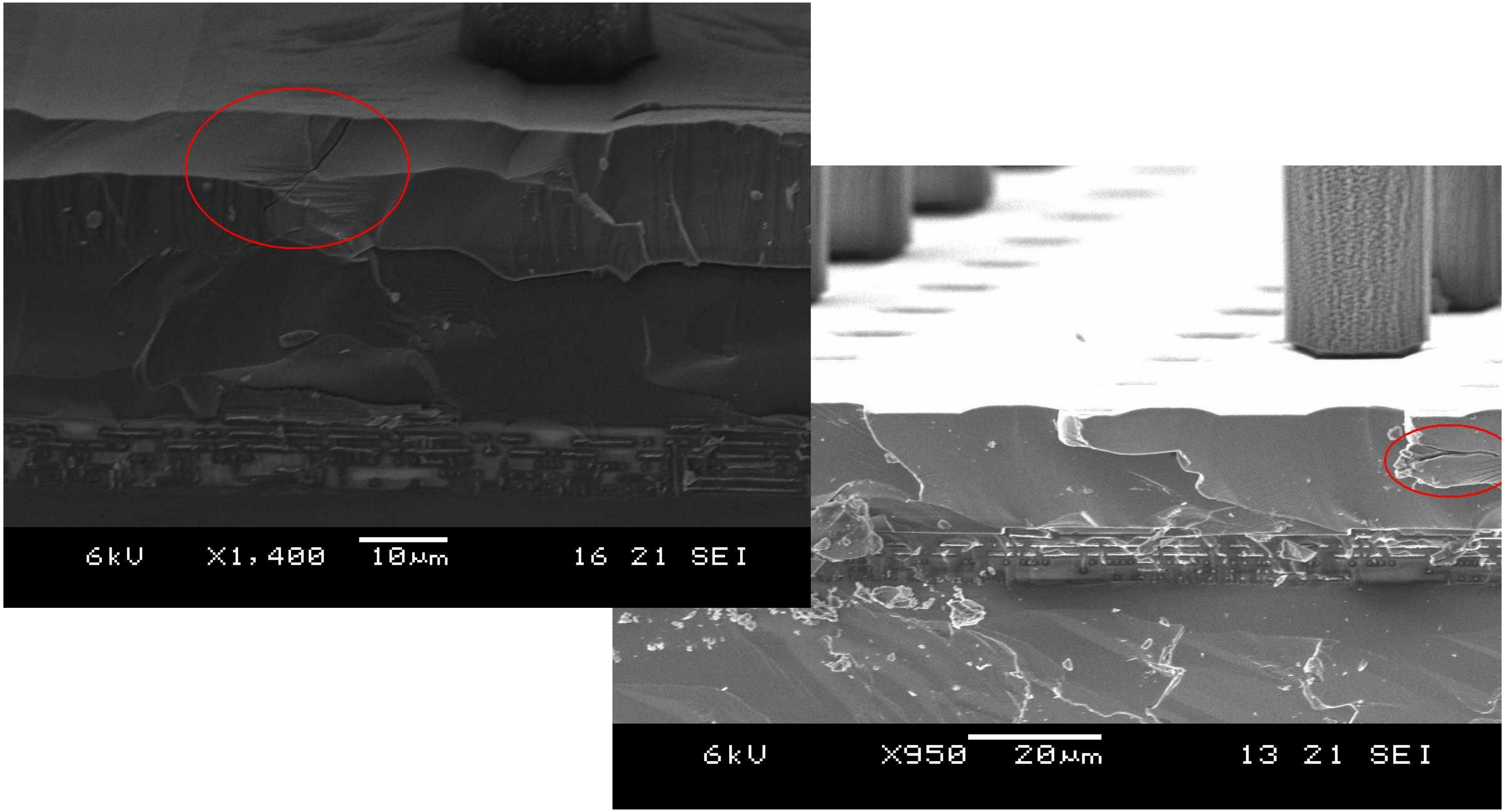


Fig 6. SEM images of a cut-open GridPix chips, clearly showing the SiNitride protection layer on top of the chip, of which its metal layers are well visible. A fault in the form of a cavity is identified and indicated.

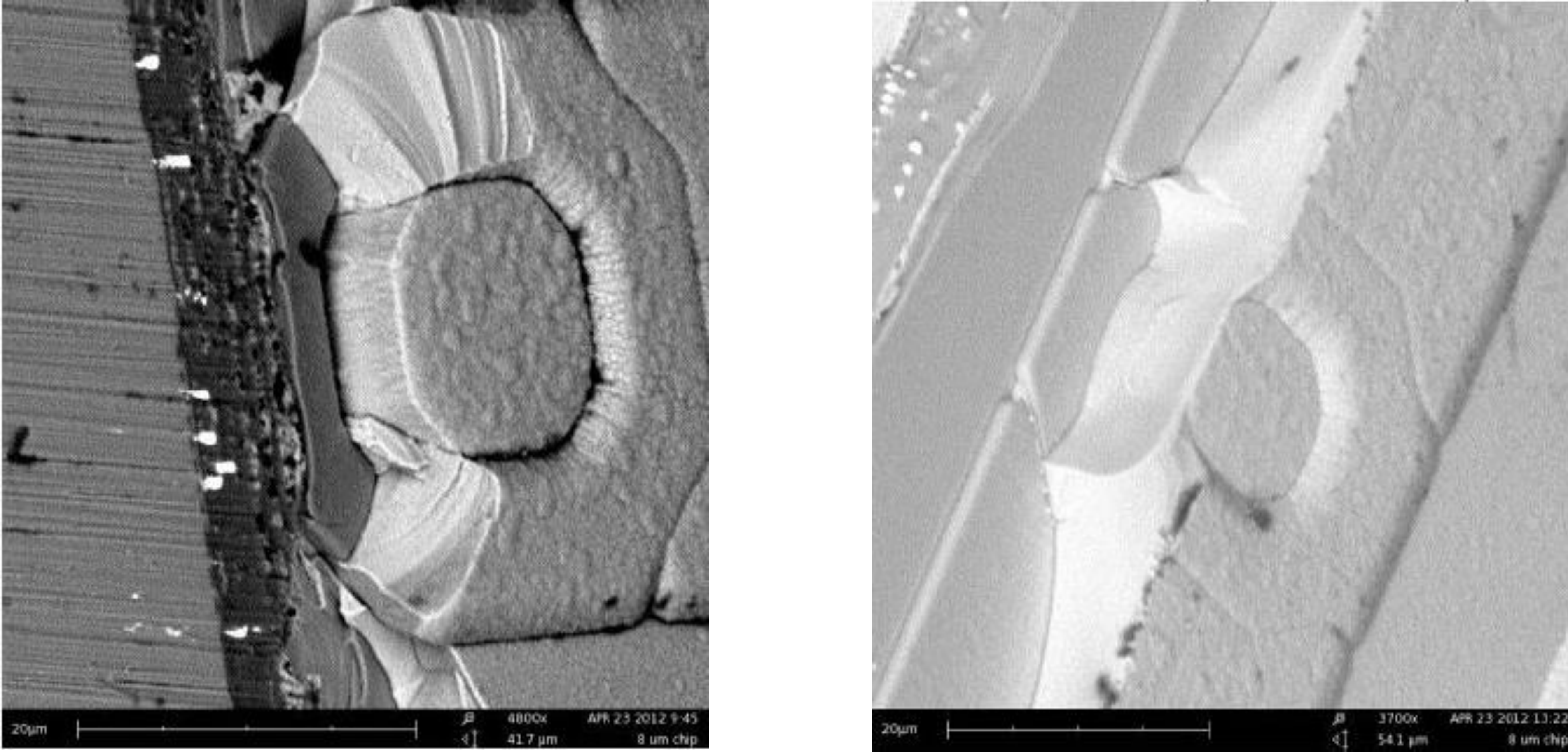


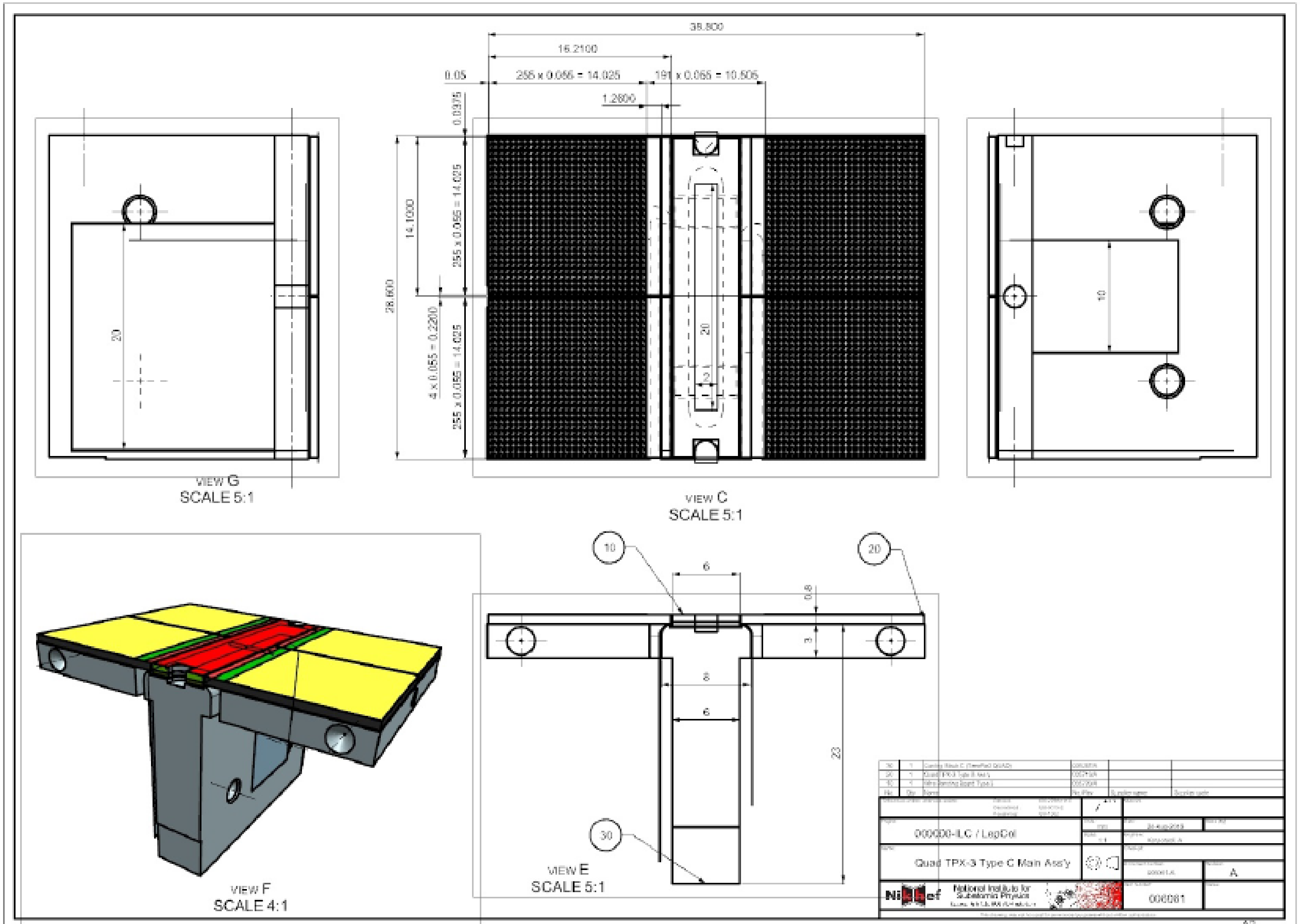
Fig 7. The pixel input pads of the TimePix 1 chip cause a well-known irrigularity acting as seed for a cavity (defect) in a protection layer to be deposit. Left: edge variation seeds cavity, right: no problem

New opportunity:

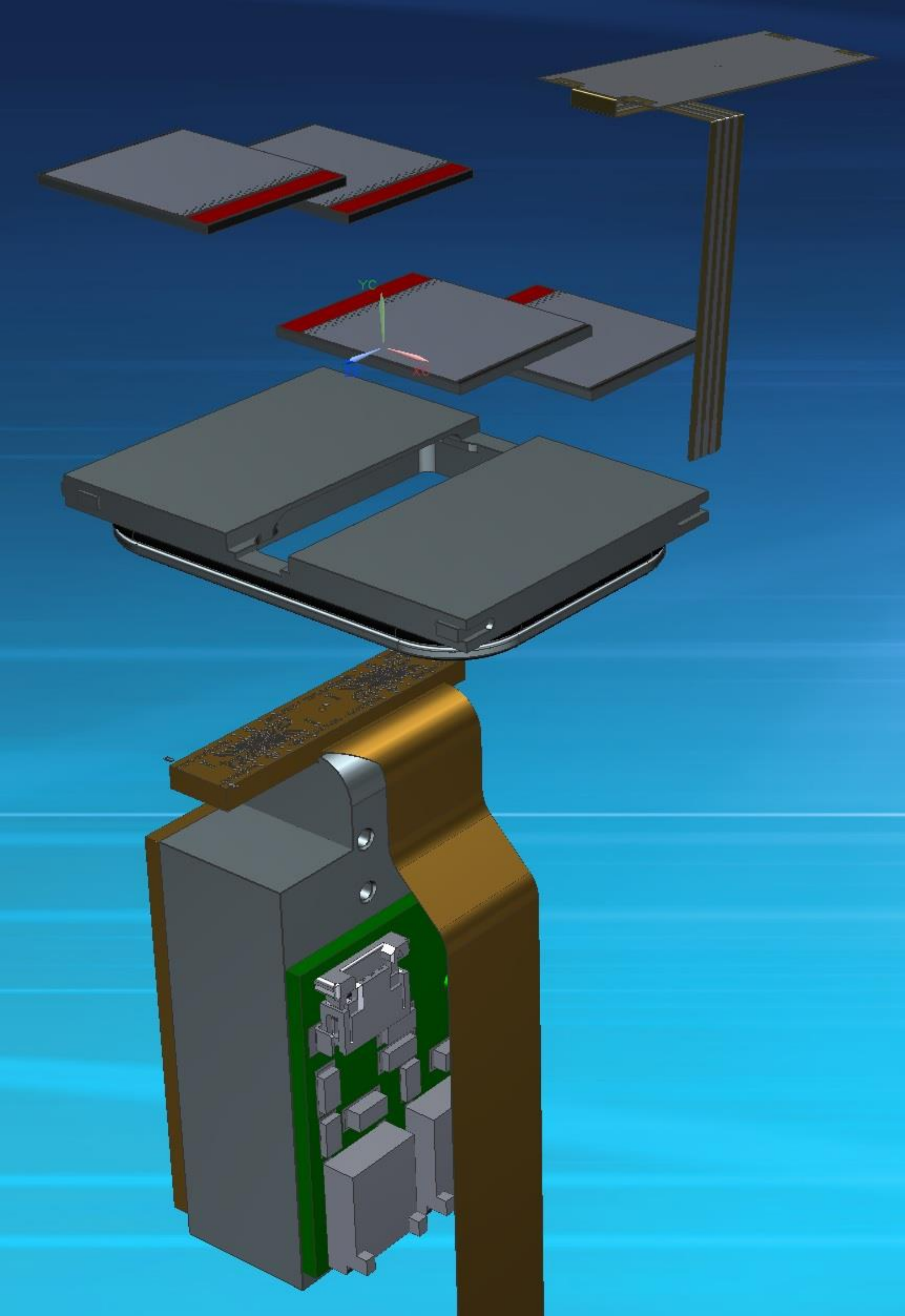
- IZM-Berlin can now (2016) make much better (fault free) SiNitride protection layer
- A series of Timepix-3 based GridPixes has been made, better discharge proof
- Bonn and Nikhef have started the LepCol project: GridPix for the TPC for ILC

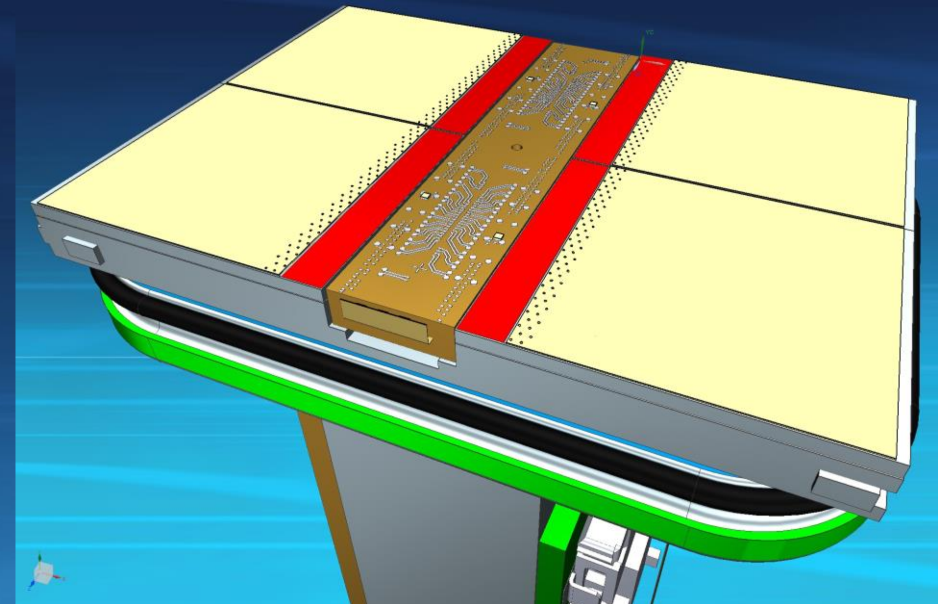
- Modular system: small basic surface modules, exchangeable, repairable
- Large number of feedthrough's (50/GridPix chip)
- cooling required
- Readout with SPIDRE system; each Quad connected with multichannel Concentrator

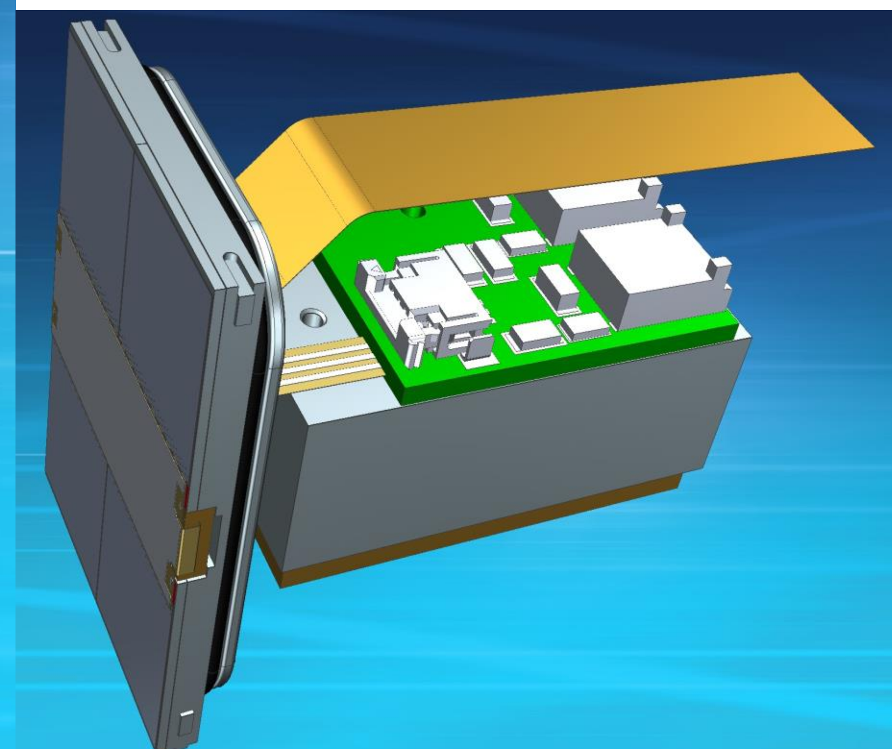
Quad TPX-3 Type C Main Ass'y (006081_A1 & 006057_A1)

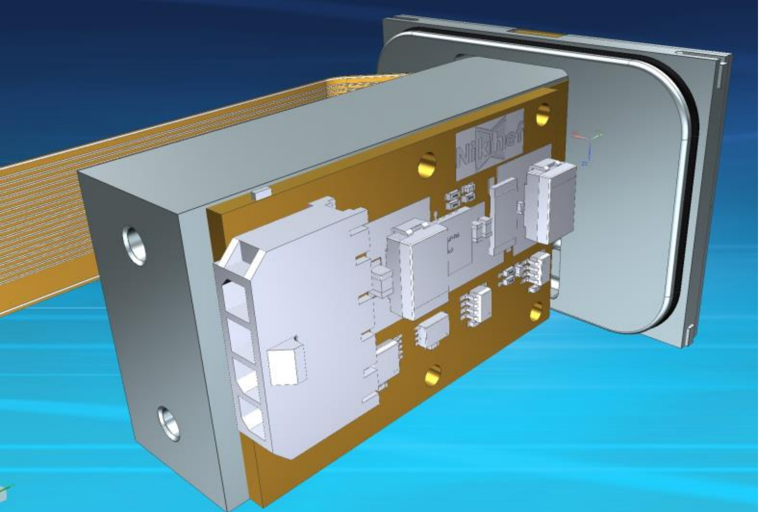
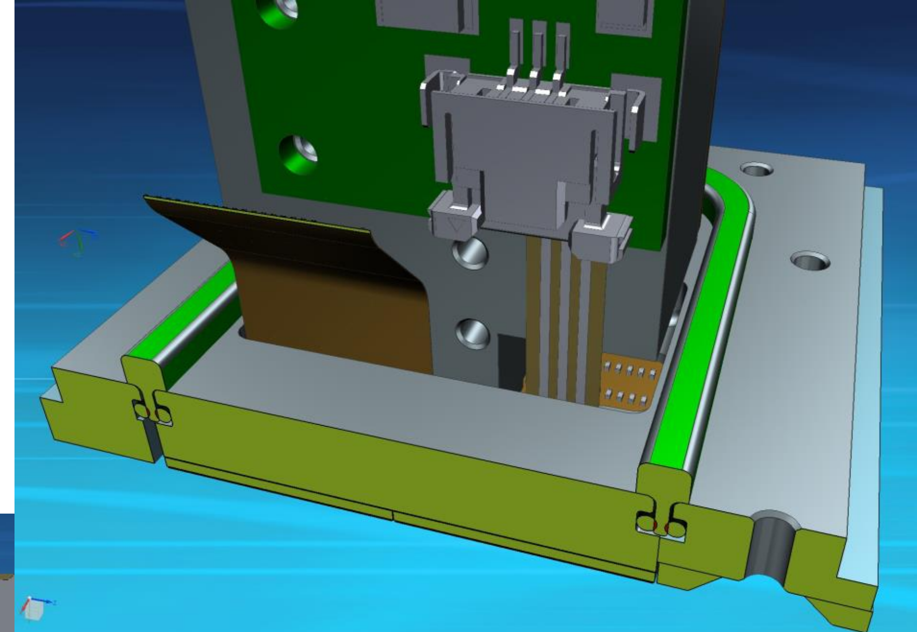
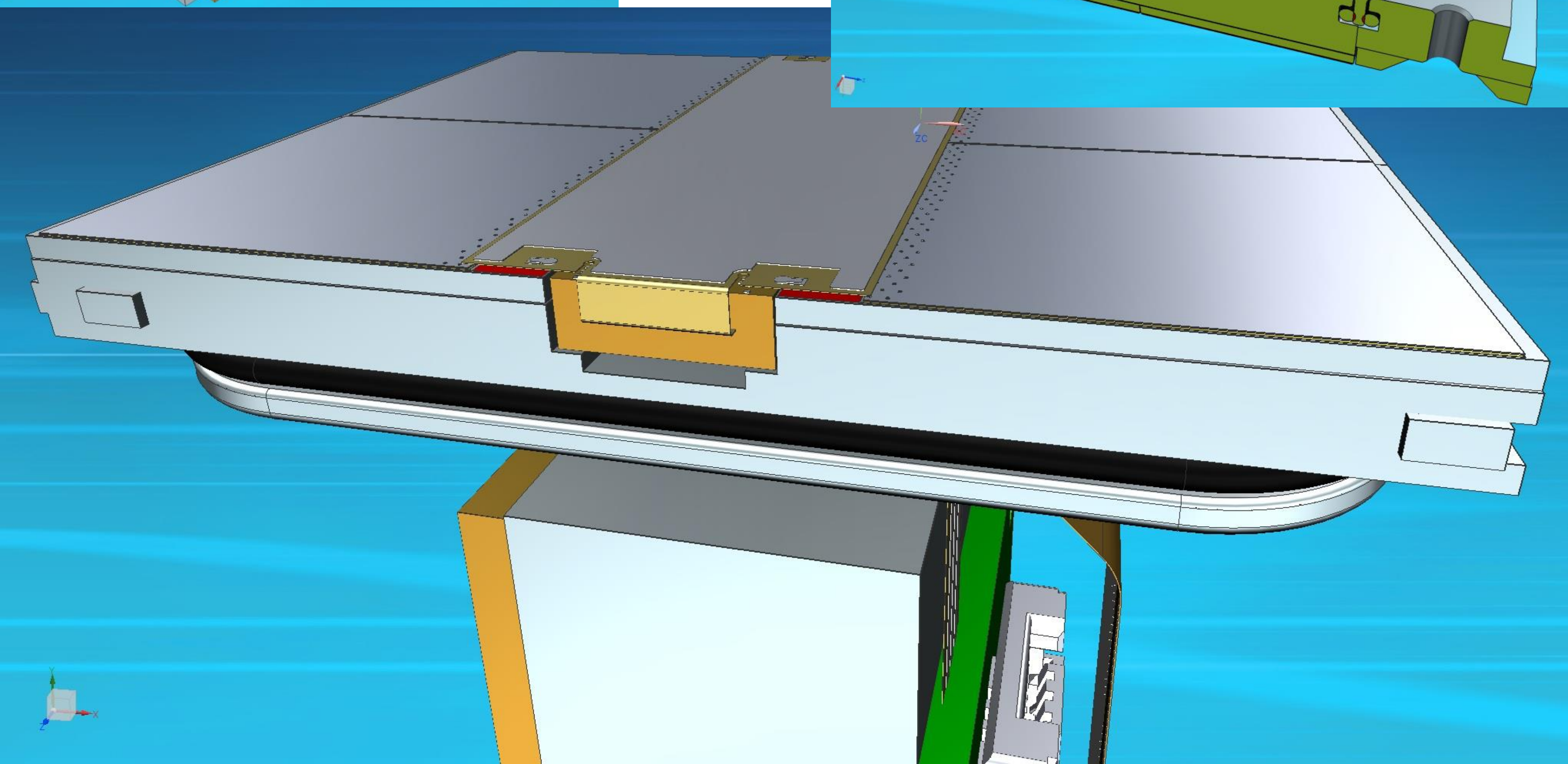


Quad TPX-3 Type A/ Type B Main Ass'y (006066_A1/006075_A1) A.Korporaal-Nikhef







- single primary electron sensitive
- electron detection efficiency > 90 %
- data driven hit-pixel output @ 2.2 Gb/s
- modular system: basic unit includes 4 TPX-3 GridPix (28 mm x 40 mm)
- fiducial surface: 60 % of total (peripheral electronics & wire bonds (TSV!)

- Should become available for third users
- Future new versions:
    - larger basic units
    - better surface efficiency: Through Silicon Via's (TSVs), reduced peripheral area

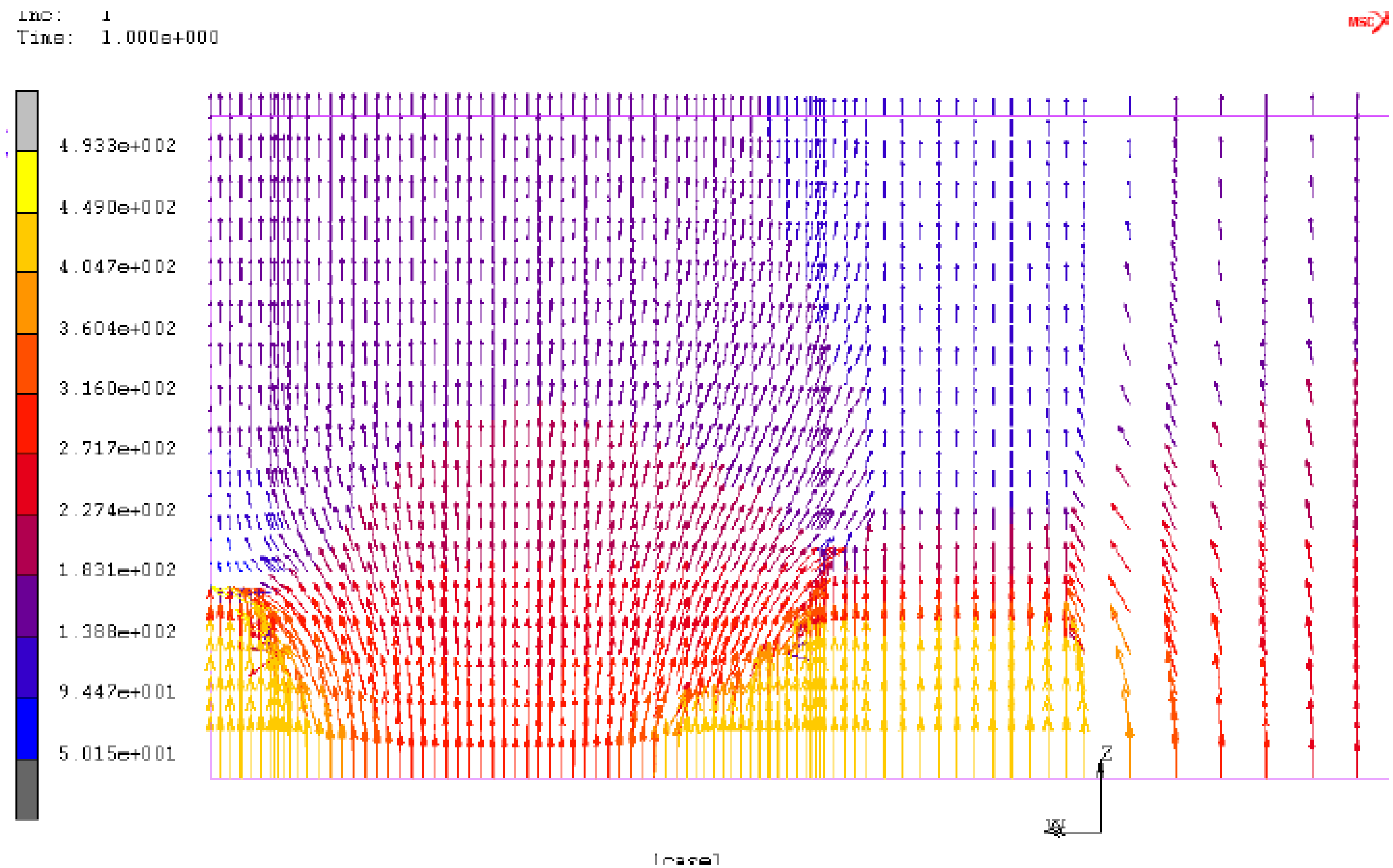
Drift Field Focusing

‘dead’ area between GridPix fiducial areas
distortion of electric drift field

What about a controlled drift field distortion?
Focusing may reduce dead area

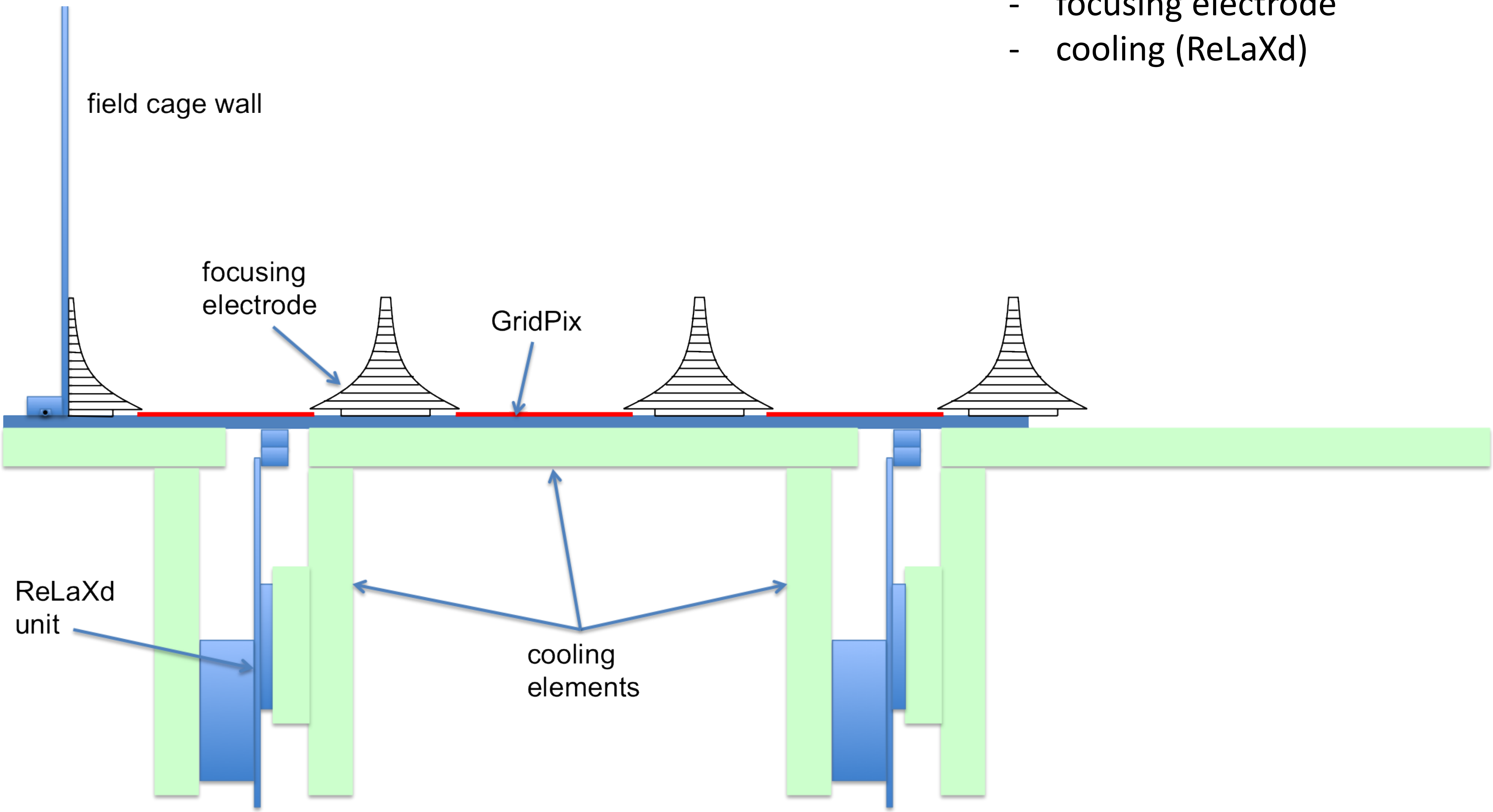
QuadFocus

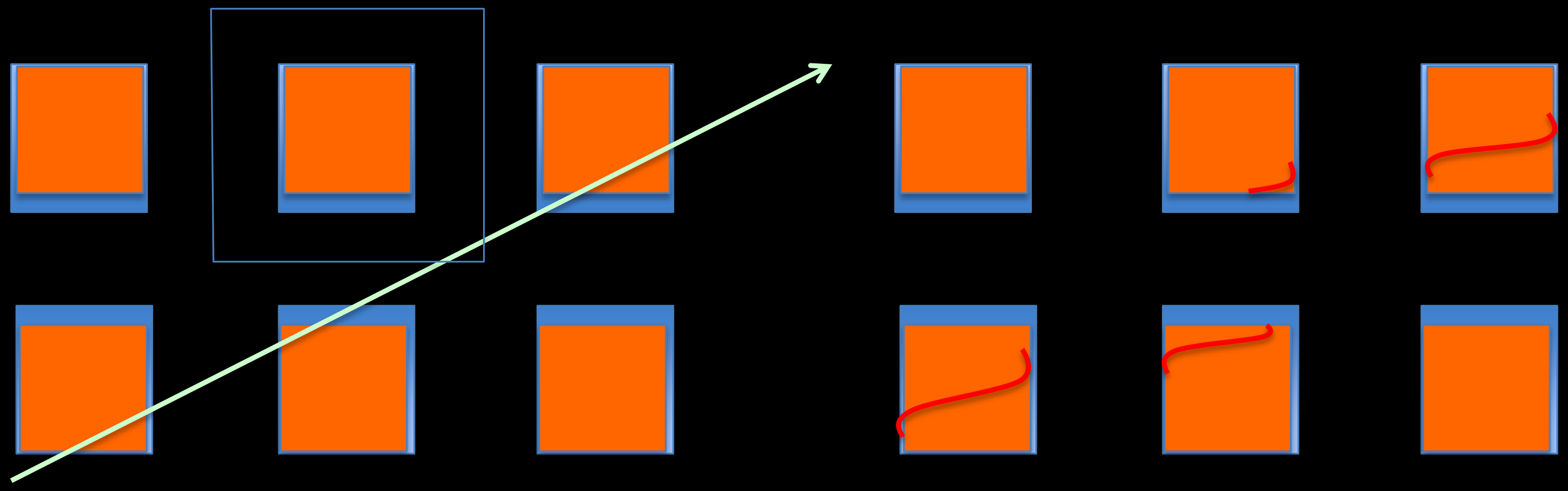
- 3D simulation
- Upper part homogeneous E-field
- Lower part controlled focused E-field



work:

- pcb
- focusing electrode
- cooling (ReLaXd)



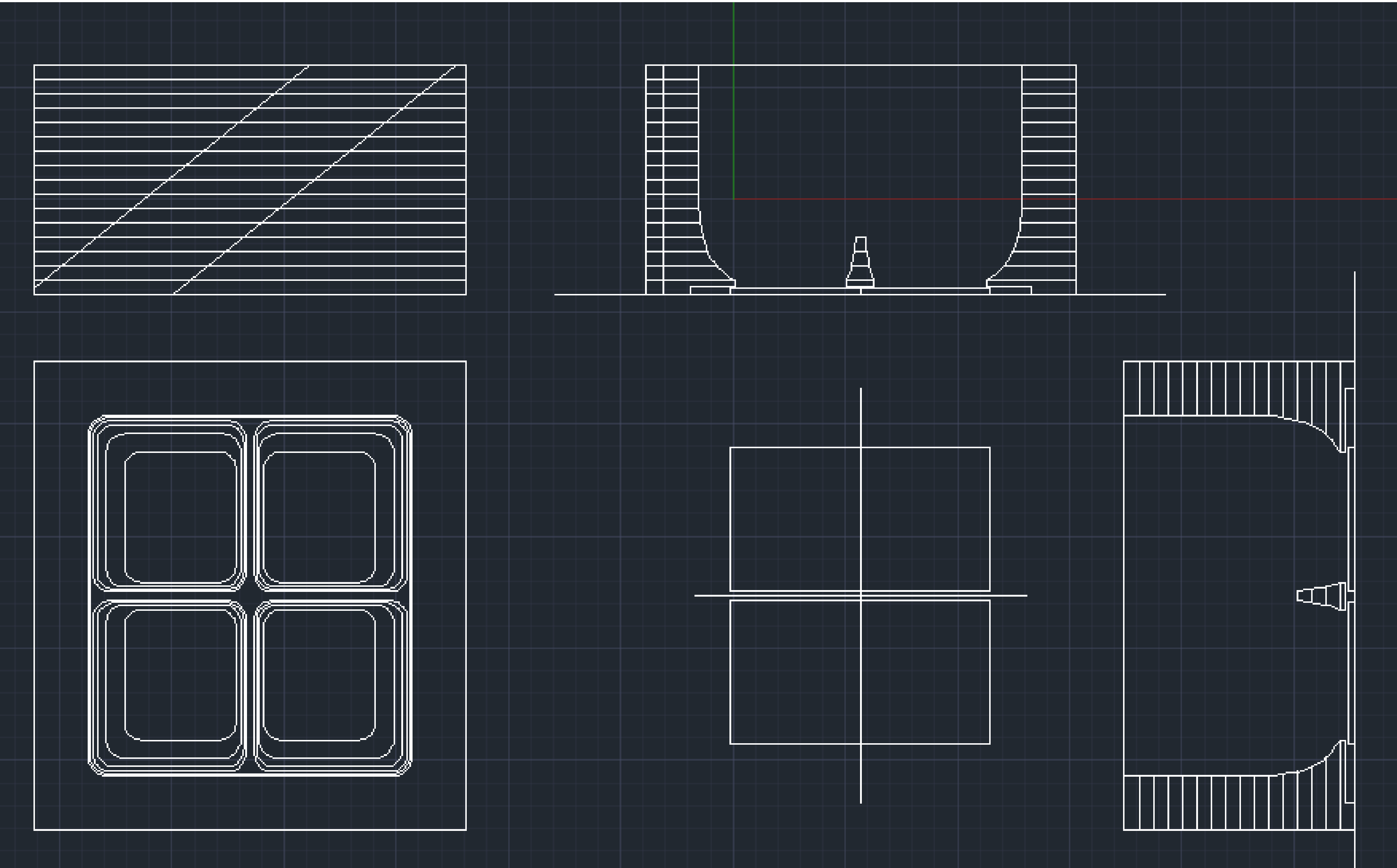


Autocalibration

- get initial f(X,Y)➔ (X’,Y’) from 3D e-field
- make scatter plots of residials
- modify f(X,Y) until residuals are minimized

Basic correction: X’ = C X, Y’ = C Y

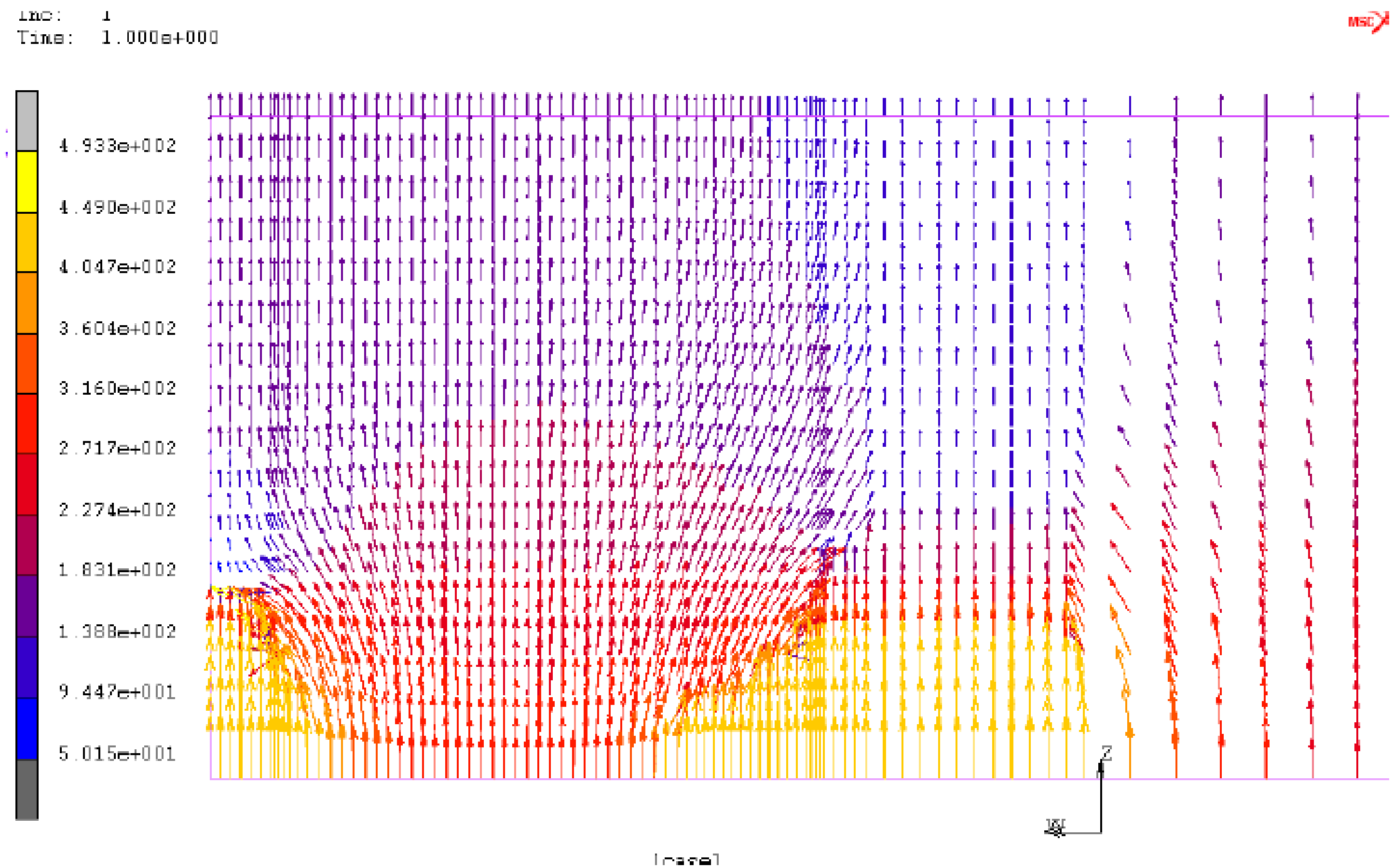
+ E x B effect



Focusing drifter for Quad TimePix on ReNexd

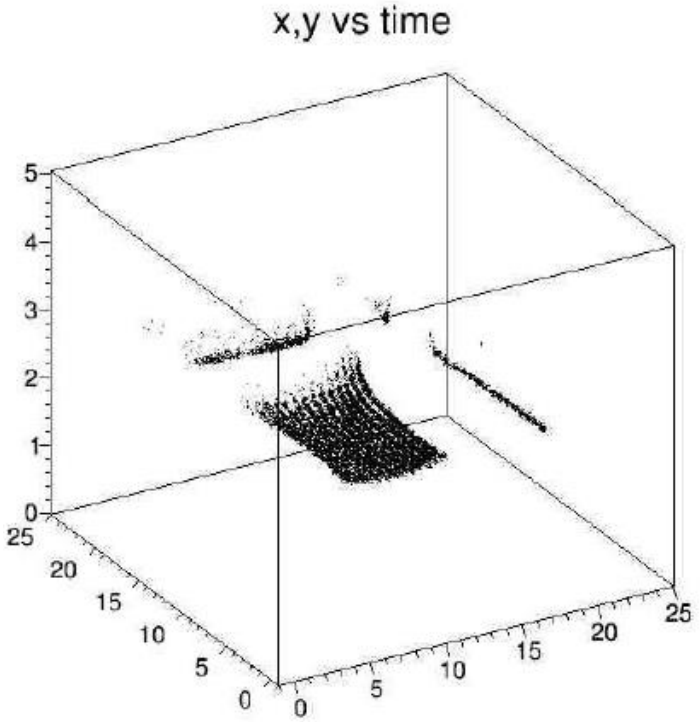
QuadFocus

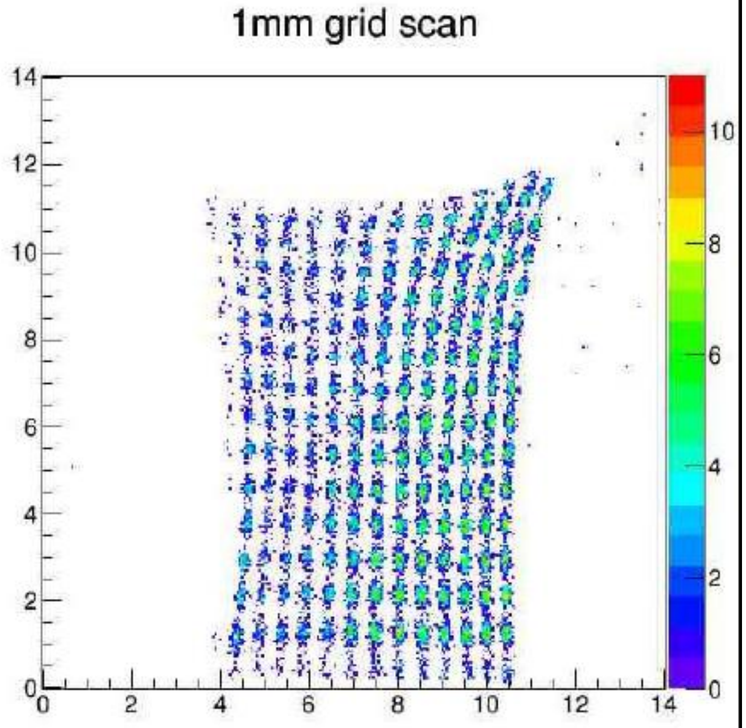
- 3D simulation
- Upper part homogeneous E-field
- Lower part controlled focused E-field



E-field deformations

- Single chip electron depositions in 1[mm] grid
- Height drift due to longer path
- No dead spot between chips

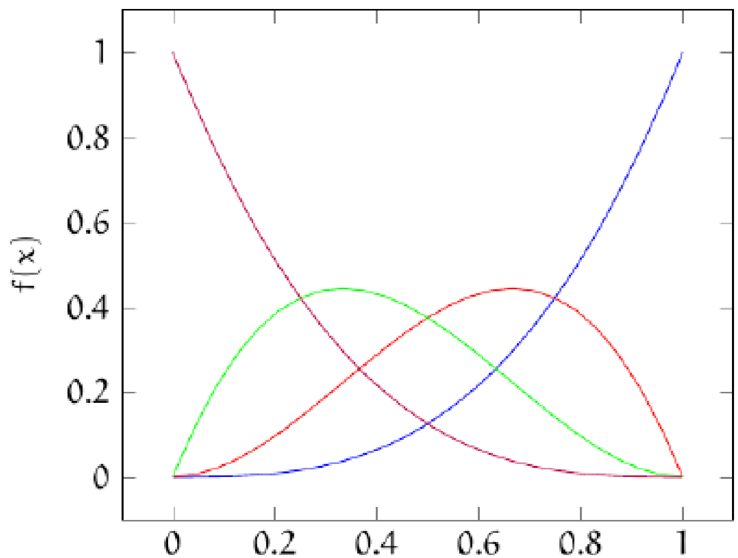




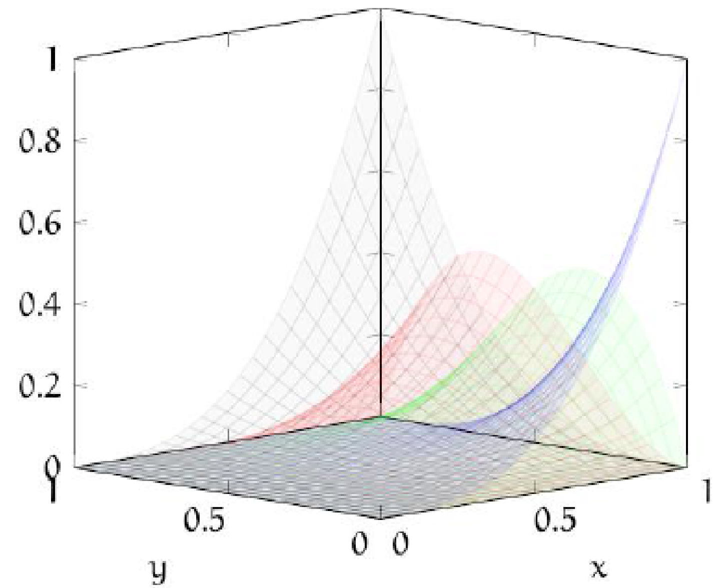
measured with focused UV N_2 laser with 3D adjustable focal point

BiCubic interpolation

- Cubic interpolation in 2 dimensions
- 2 functions: F(x,y)->x' and G(x,y)->y'



4 1D base functions



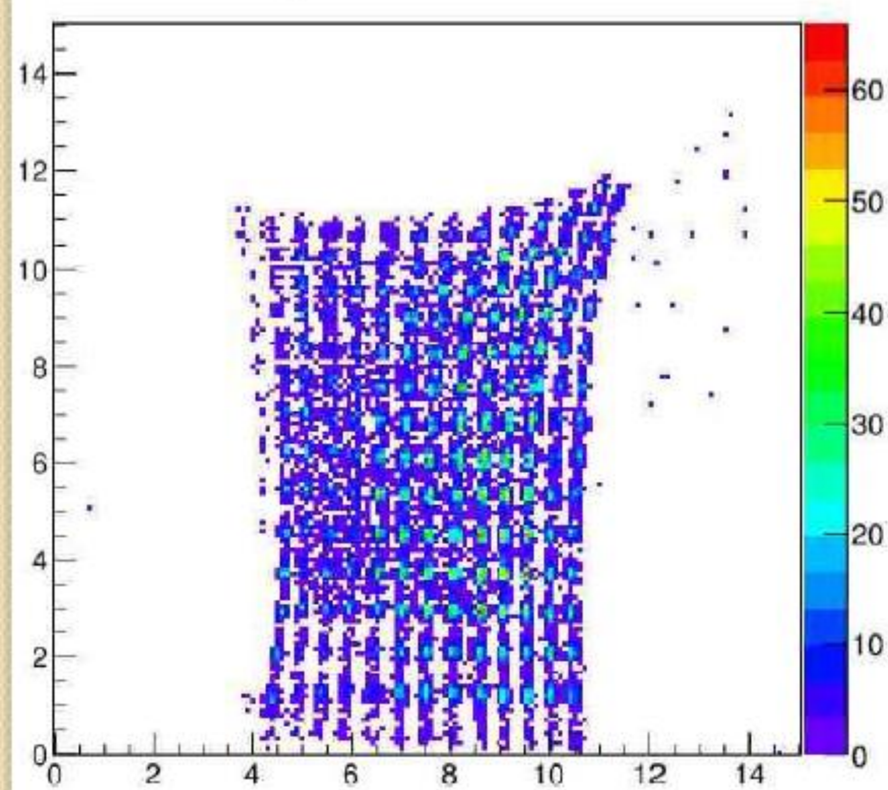
4 of the 16 2D base functions

- Weighted addition of 16 base functions gives smooth surface
- Datapoints and smoothness provide conditions

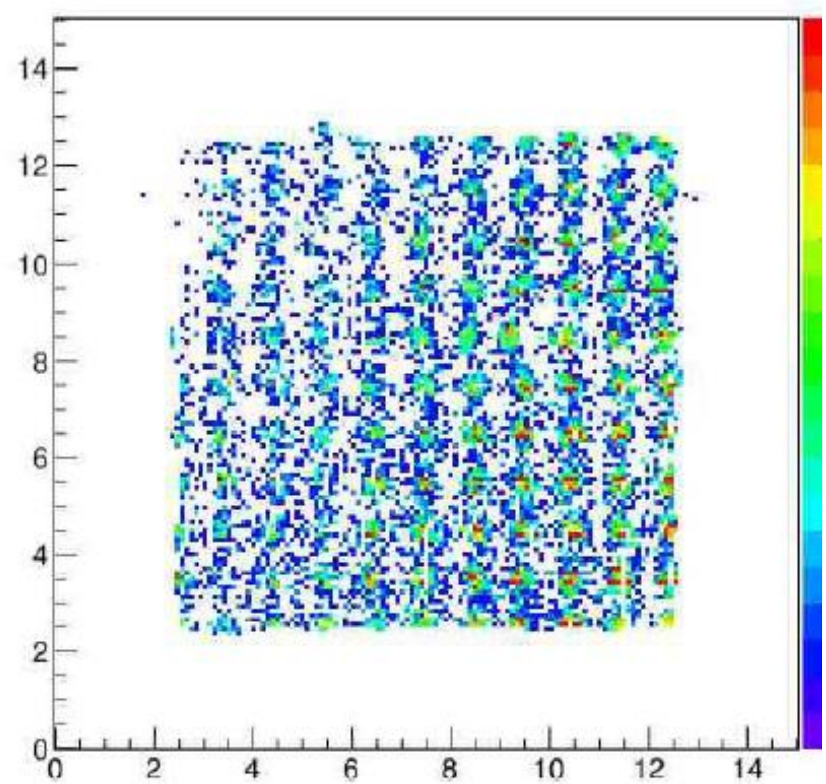
E-field deformations

- 1mm grid scan
- Transforming deformed grid gives uniform grid
- Improvement for spots near the edge

Original Grid

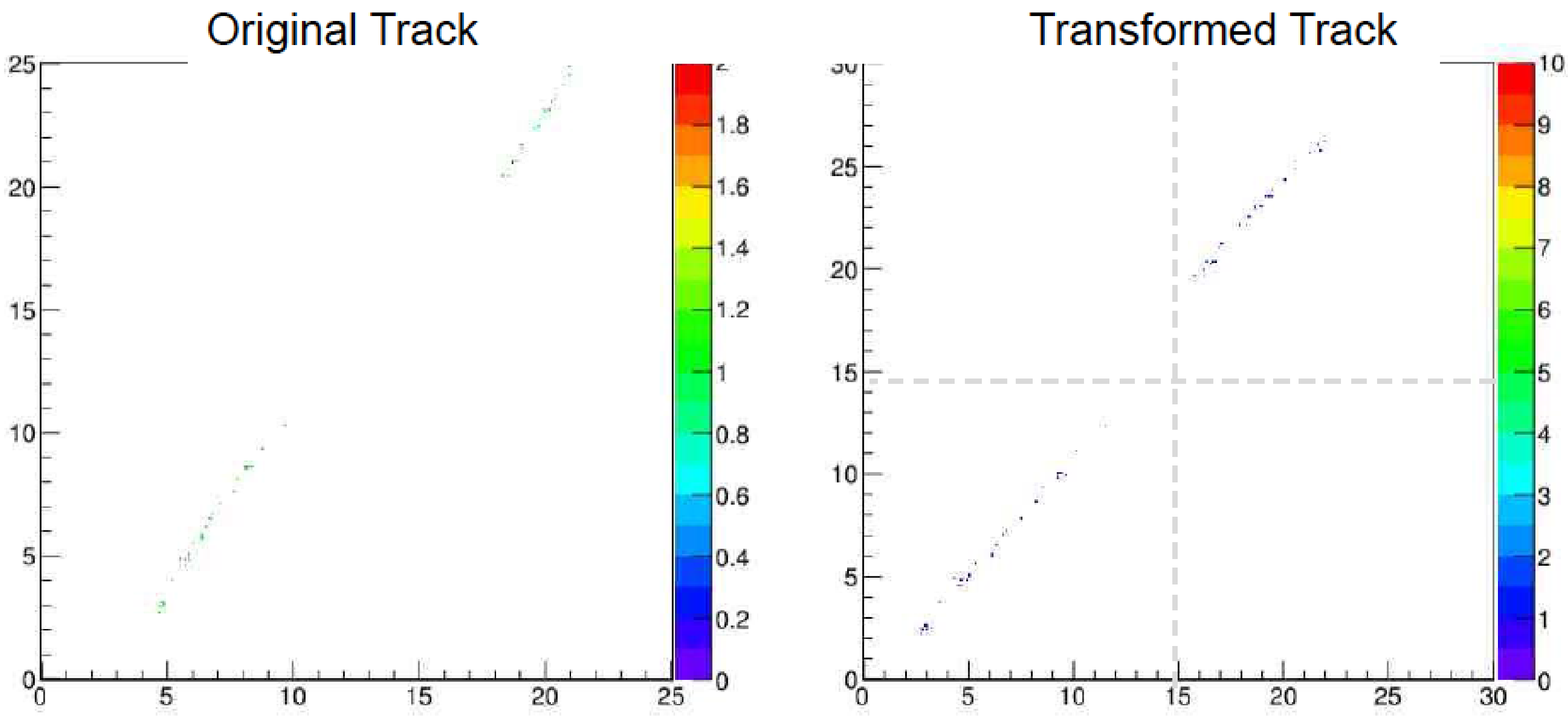


Transformed Grid

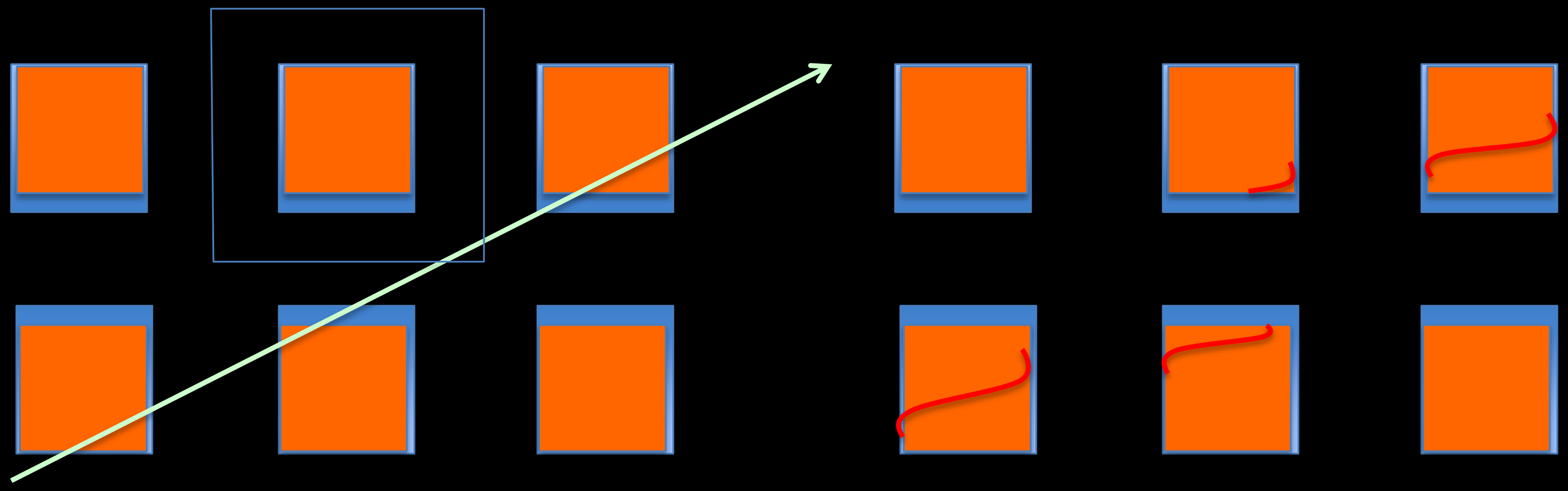


E-field deformations

- Tracks on multiple chips are straightened
- Resulting angle 45 degrees as expected
- Needs distance between chips



Results from Testbeam T10 (CERN PS), Nov 9 – 12 2016)



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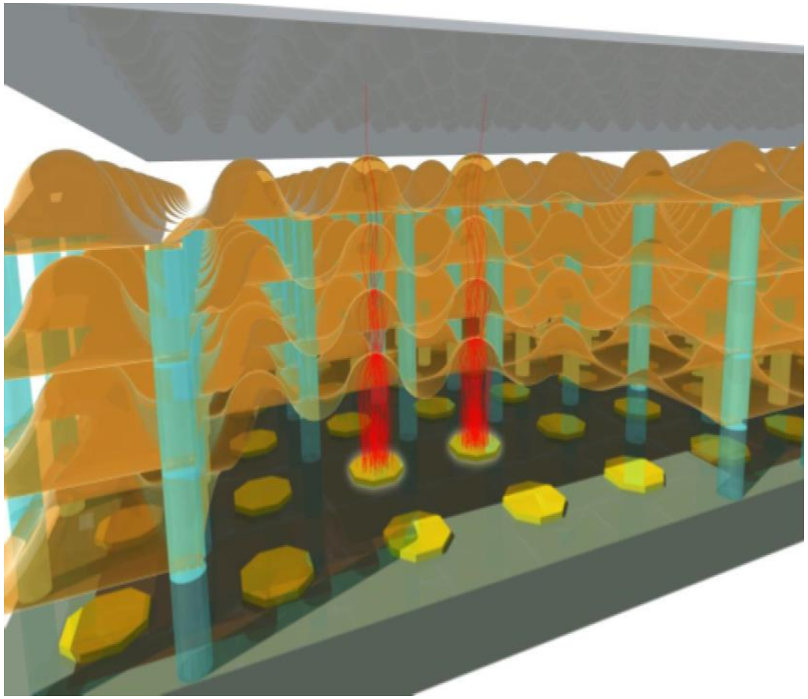


The Tynode: a Transmission Dynode with sufficient yield enabling the construction of Tipsy 0.0

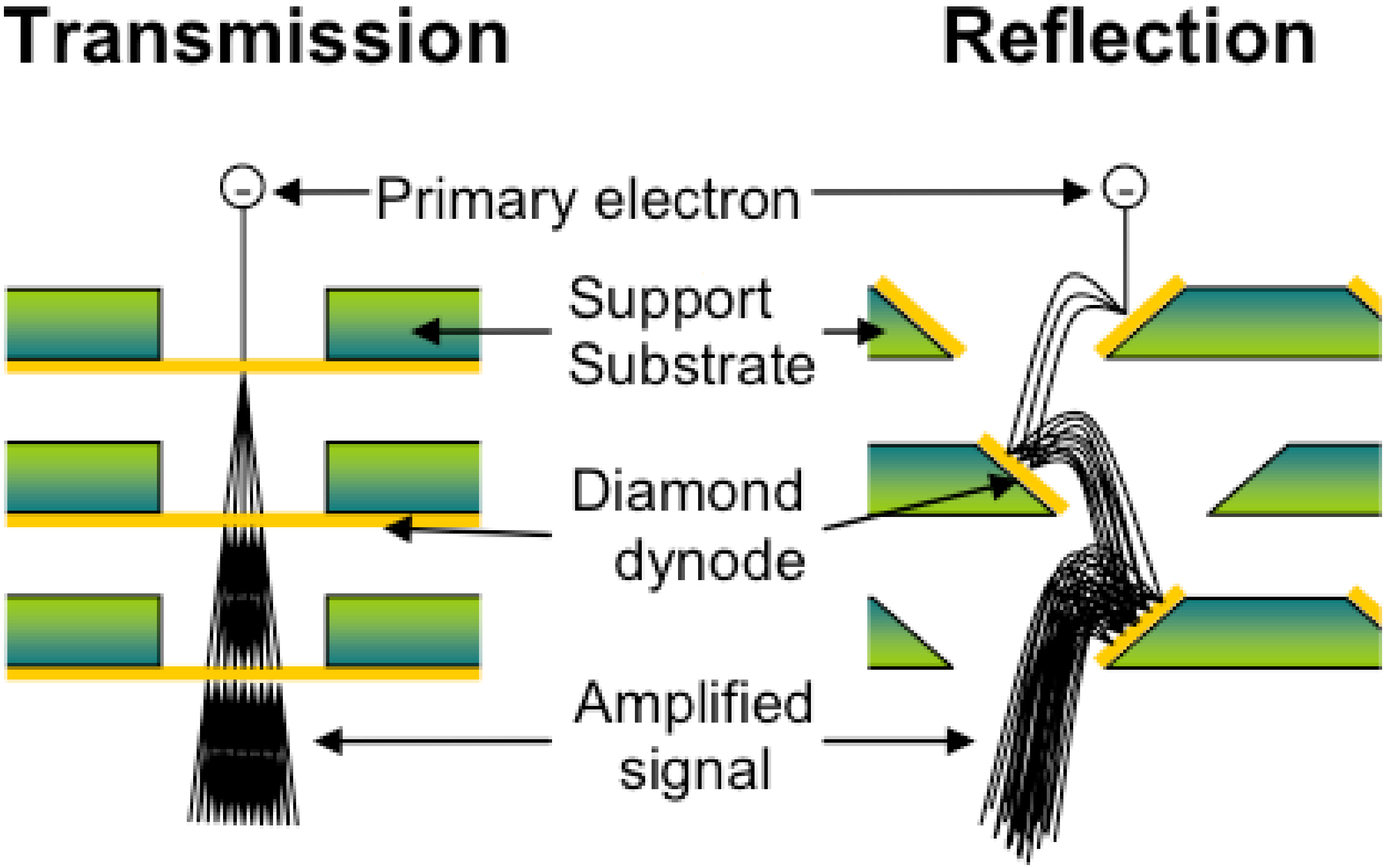
On behalf of the Membrane project:

Harry van der Graaf, Conny C.T. Hansson
Hong Wah Chan, Shuxia Tao, Annemarie Theulings, Violeta Prodanović, John Smedley, Kees Hagen, Yevgen Bilevych, Lina Sarro, Gert Nützel, Serge D. Pinto, Neil Budko, Behrouz Raftari

Supported by ERC – Advanced 2012 “MEMBrane” 320764

European Research Council

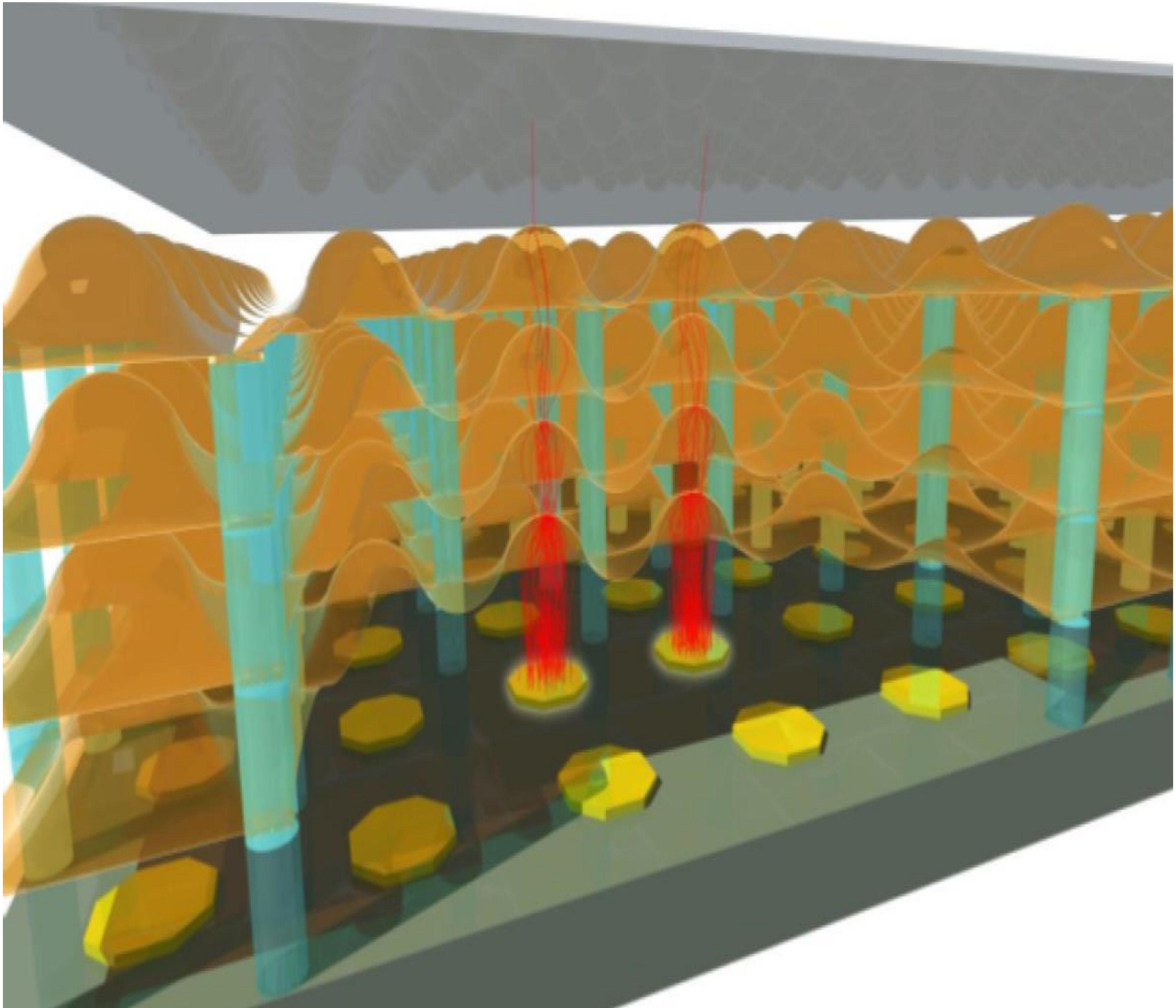
NIKHEF TUDelft BROOKHAVEN NATIONAL LABORATORY PHOTONIS



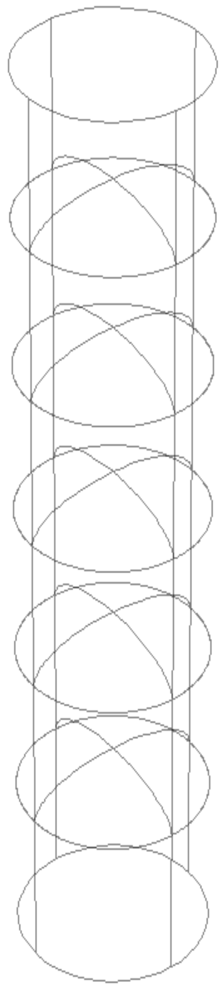
New: the Transmission Dynode

Tynode®

Trynode®



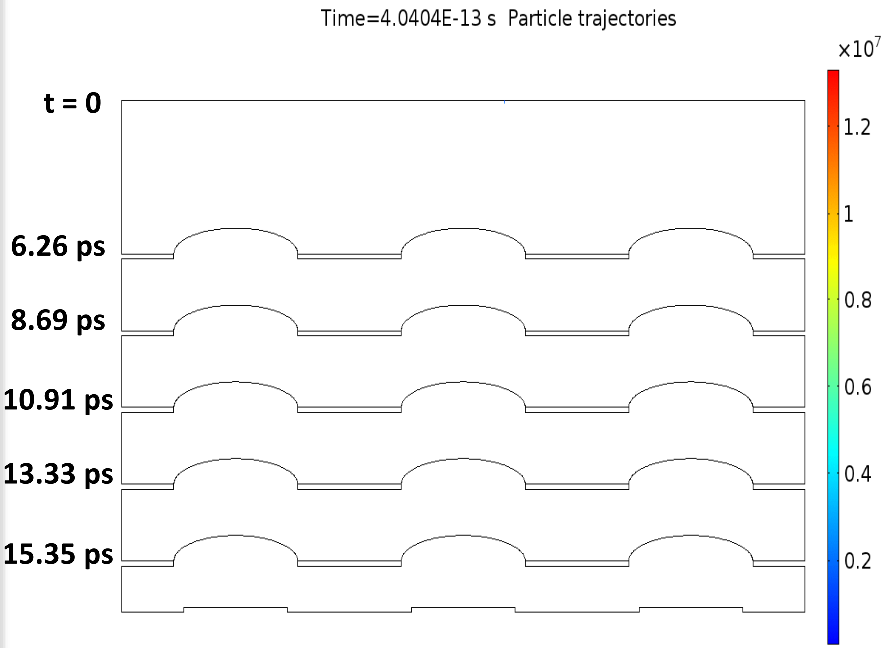
The Transmission **Dynode** → Tynode



- Similar to PMT dynodes, but with amplification through transmitted secondary electrons through nanoscale thickness membranes (**Tynodes**)
- The Tynodes offer effectively **dark noise free** electron multiplication
- A **compact device** (see top right) can be fabricated with a photocathode on top stacked tynodes and collector readouts on the bottom.
- The pixelated detector allows for **spatial resolution** (imaging)
- The high bias field between the membranes, and the tailored dome shape of the membranes allow for **operation in high B-field.**

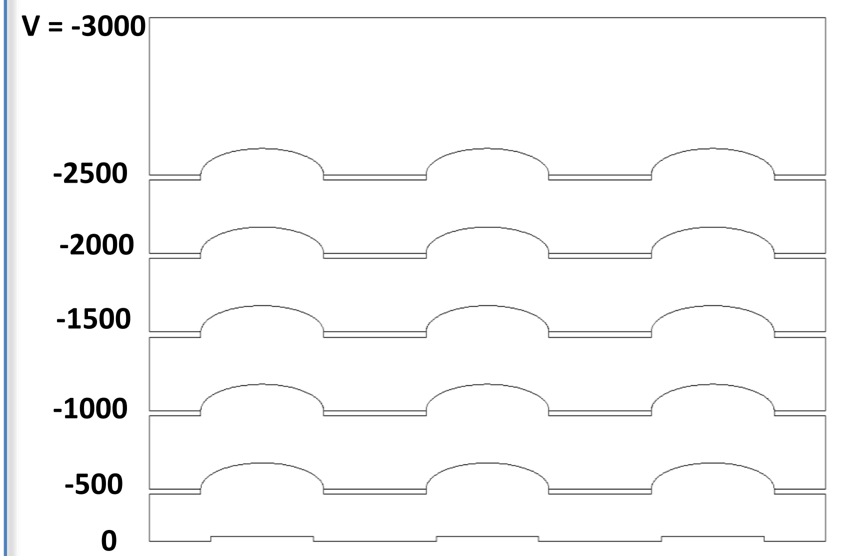
Stacked Tynodes Simulations

More compact → faster detector



- Simulated device thickness ≈ 100 microns
- Time between tynodes ≈ 5 ps
- Time spread of generated electron cloud below ps timeframe (path uniformity)

Performance in magnetic fields



- Operational in 1 T magnetic fields

The Timed Photon Counter – TiPC – “Tipsy”

Photocathode ⟶ Tynodes ⟶ TimePix chip

TimePix chip:

- 256 by 256 pixels with 55 μm pitch
- Surface = 1.4 cm by 1.4 cm

Matching Tynodes (Transmission Dynodes):

- Diameter = 30 μm
- Pitch = 55 μm
- Separation = 25 μm

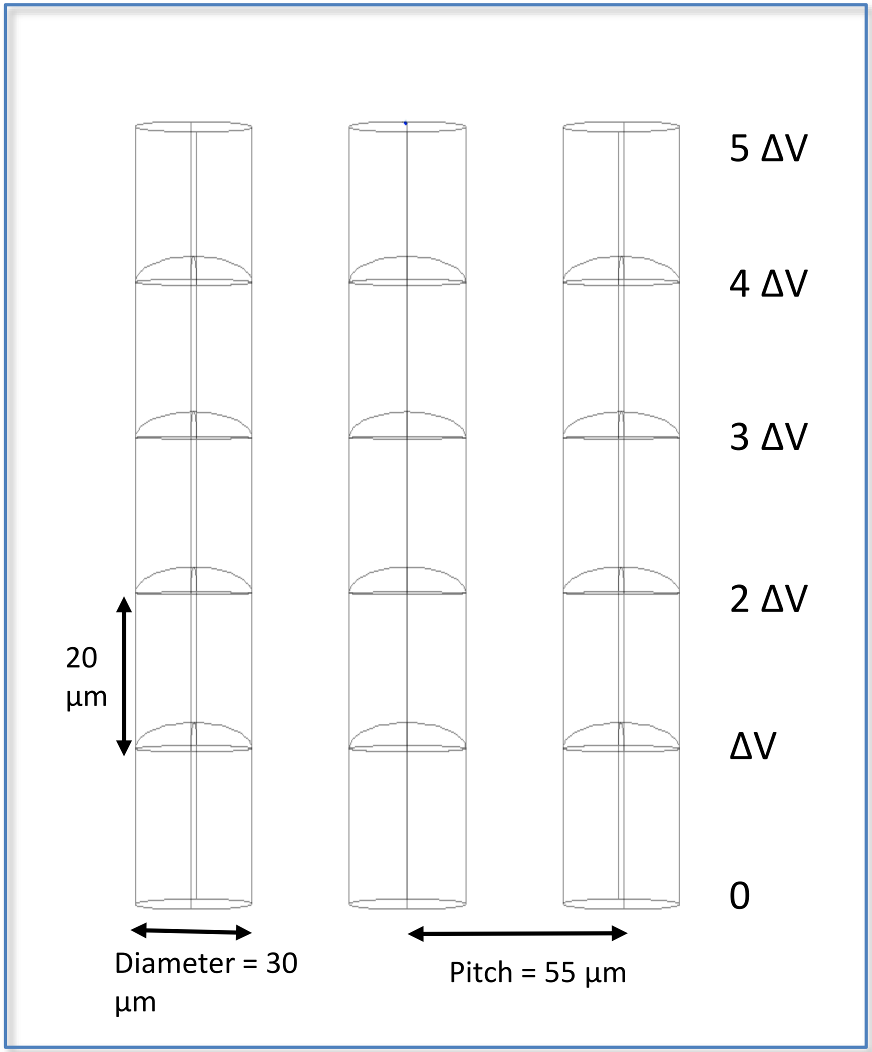
Sensor Charge Requirements:

	Timepix 1 (2006)	Timepix 3 (2013)	Timepix FG
Min. detectable charge	>750 e-	>500 e-	**>60 ke-**

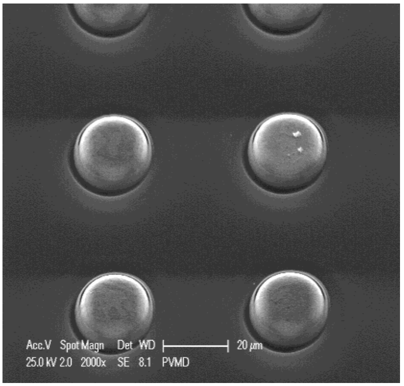
Tynode gains:

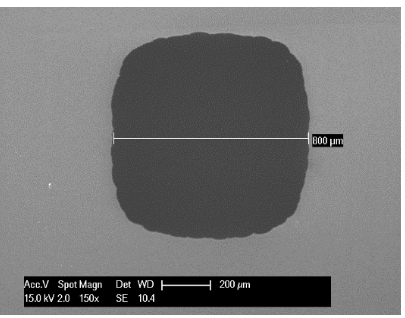
Gain = $\delta^N = 4^5$ = 1k → threshold

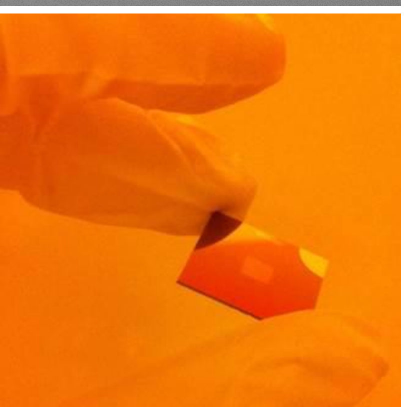
Gain = $\delta^N = 4^8$ = 60k → 1 Volt digital



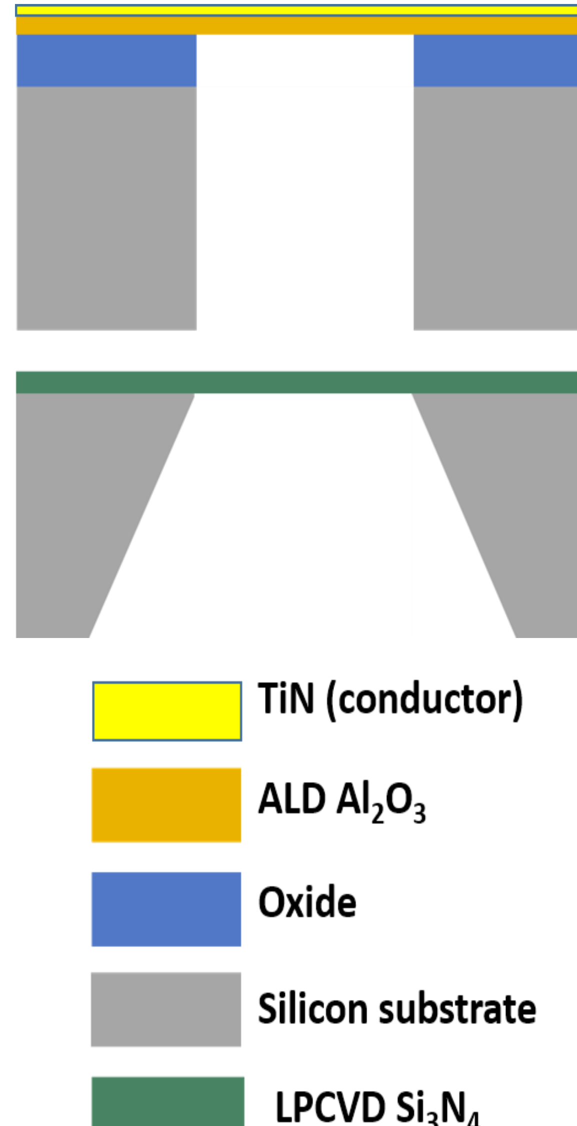
Membrane Fabrication





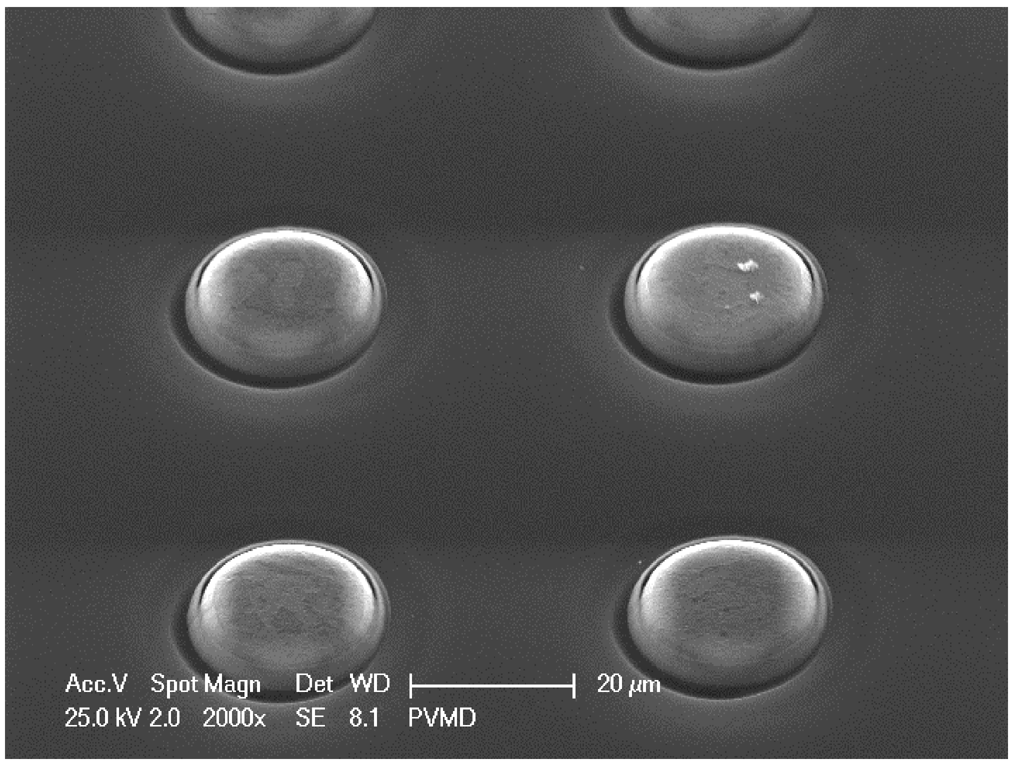


- Fabrication through combinations of lithography, etching, and atomic layer deposition
- Materials considered: Si_3N_4, Si-rich Si_3N_4, Al_2O_3, SiC, MgO
- TiN used as conductive layer to reduce charging effects with minimal effect on secondary electron yields.
- Array of tynodes
  - Thickness: 5-40 nm
  - Diameters: 10, 20, 30 µm
  - Array size: 256 by 256
- Large area tynodes for testing purposes
  - Thicknesses: 40-200 nm
  - Diameters: 50, 100, 300, 1000 µm

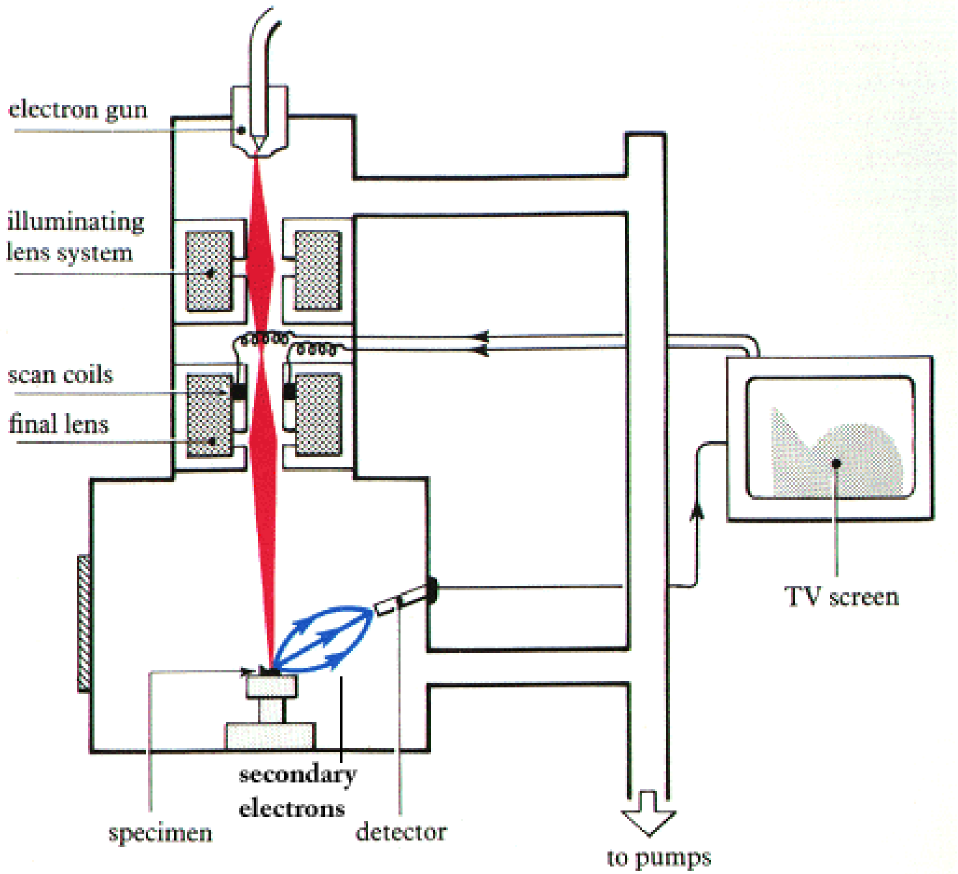


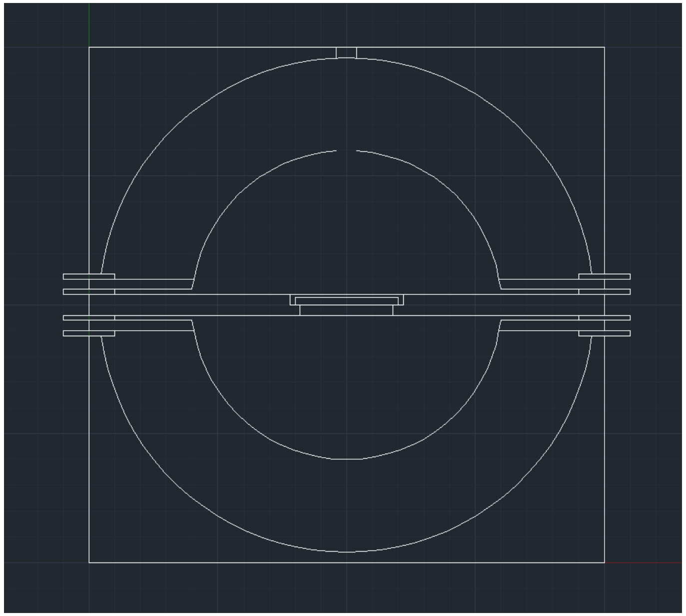
Path towards first prototype

- We have created many tynodes of various sizes and materials
- Most recently, we have achieved transmission yields of >3 with 5 nm MgO membranes, coated with 2.5 nm TiN, without other special surface treatments
- Now working towards building a first prototype device



SEY Measurement 1 in SEM





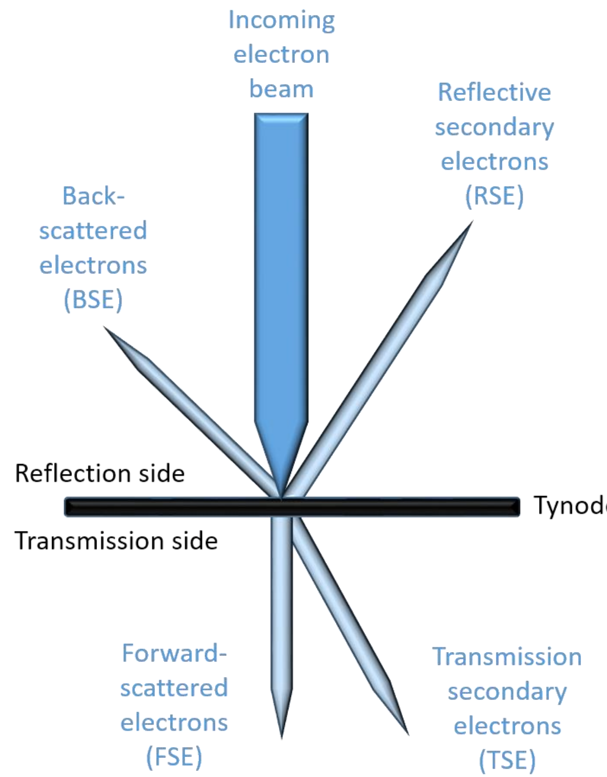
Dual Faraday Cup in SEM made at Nikhef

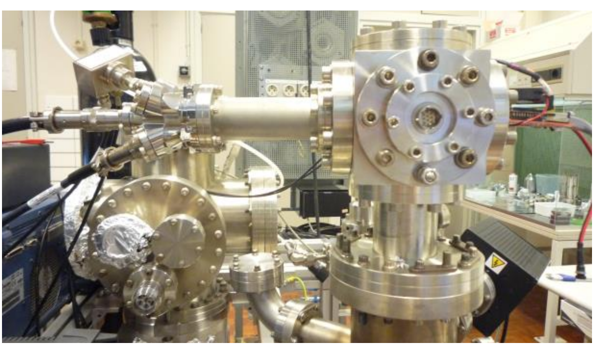
SEM/TEM to measure reflection/transmission SEY@ Particle Optics Group TU Delft by **Alexander and Kees**

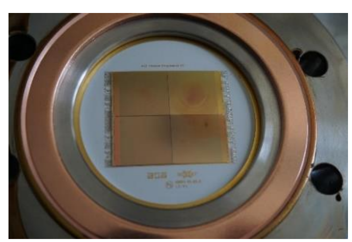
Measurement Techniques

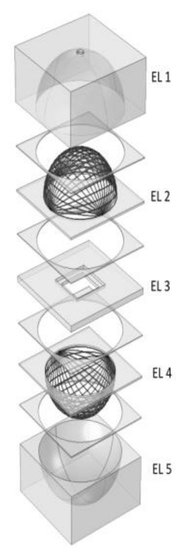
Search for material and/or surface treatment for transmission yield goal of 4.

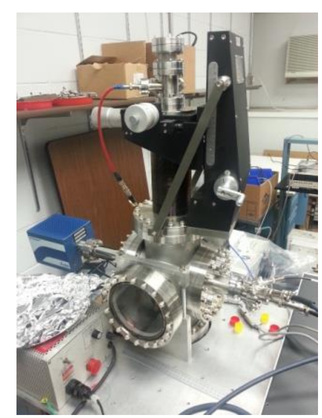
- Collaboration using four unique vacuum systems optimized for different aspects of dynode/tynode measurement
- Reflected and transmitted secondary electron yields for different membranes or thin films
- Measure under different electron beam fluxes or pulsing schemes
- Consider different surface terminations for improving electron yields





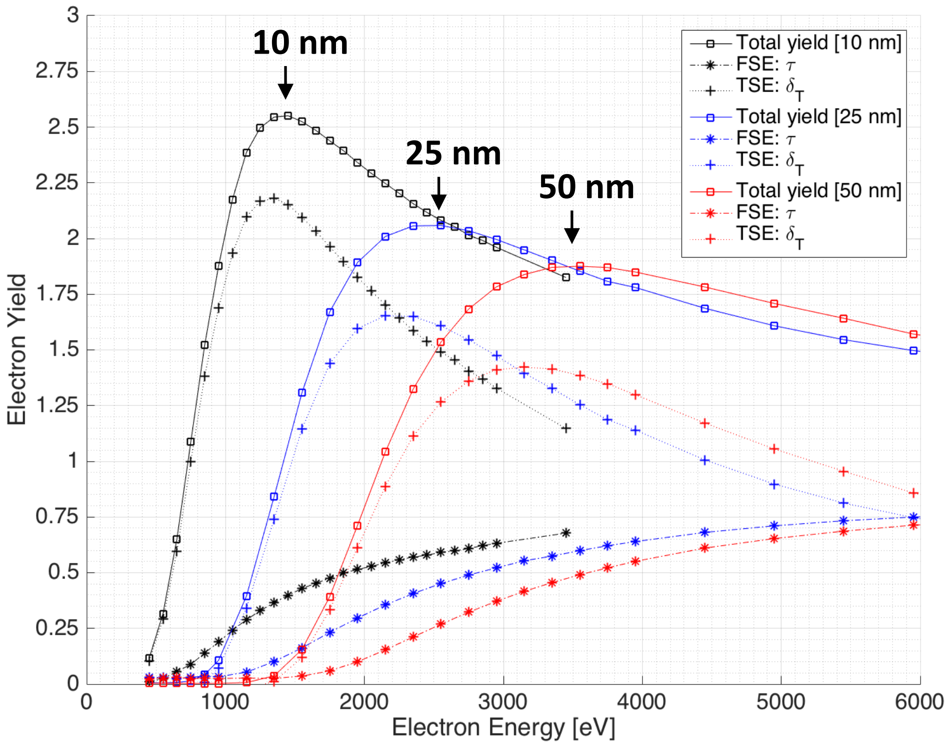




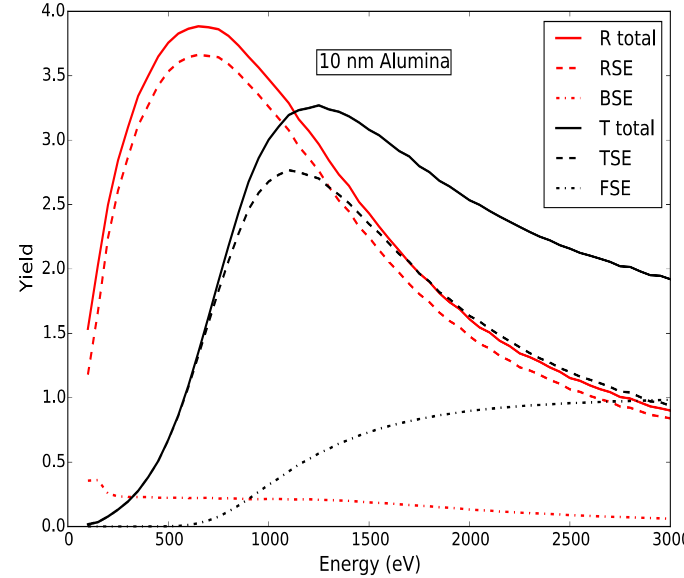


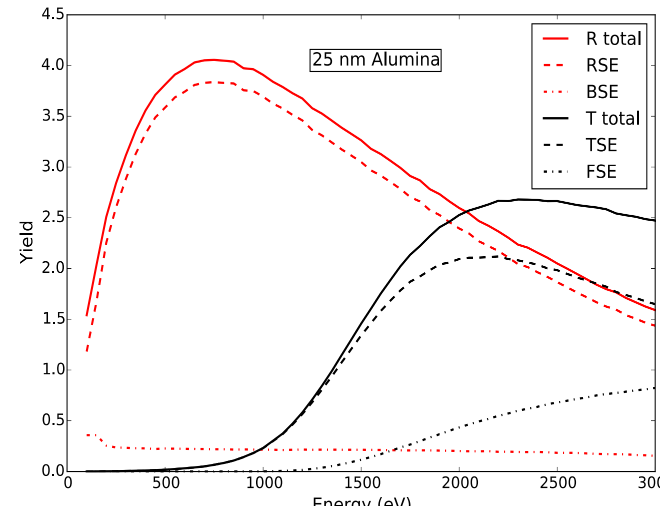
Al_2O_3 Measurements and Simulation

Measurement



Simulations





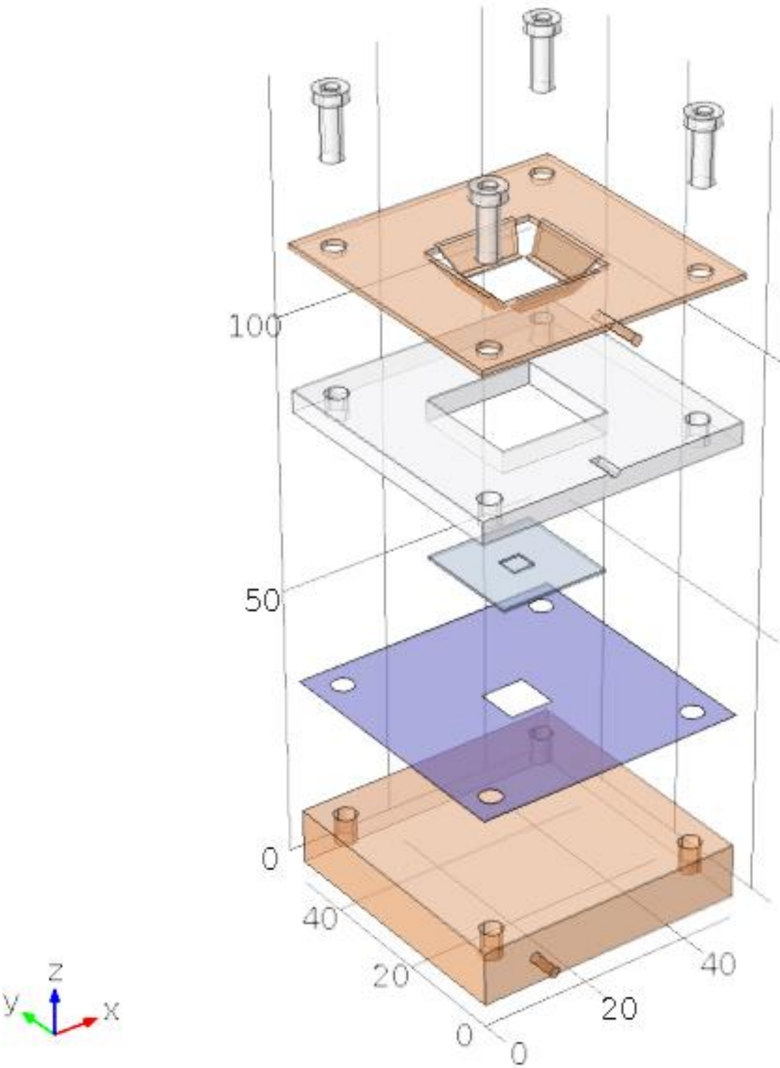
- A decrease in yield, combined with increase in optimum primary electron energy is observed as a function of sample thickness
- Good correlation to measurements seen for the simulations.

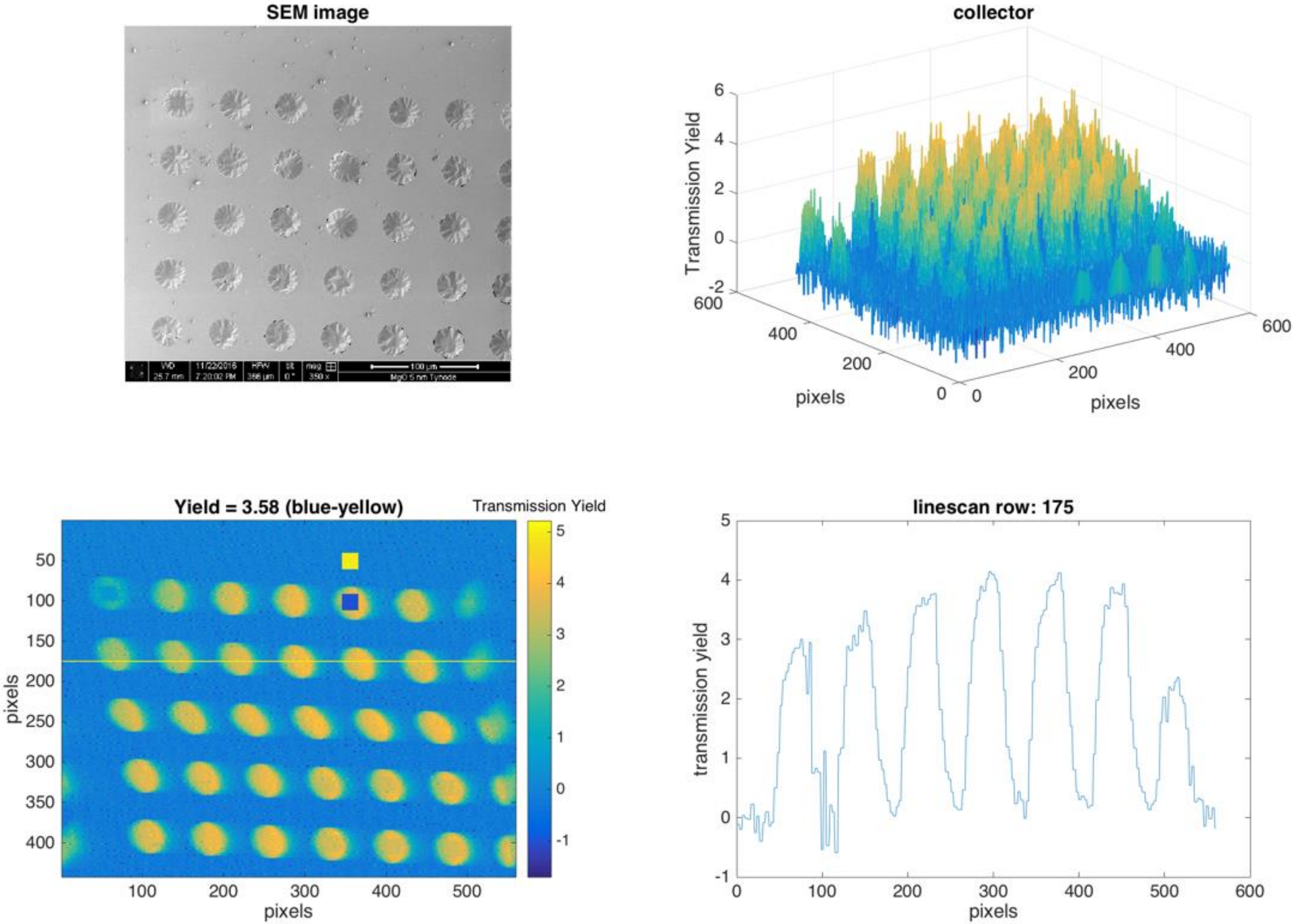
SEM measurement setup: E-field setup
Sample: MgO [5nm] + TiN [2.5 nm]. 64x64 array with 30 um diameter. (Same sample when we obtained ~ 3.2)

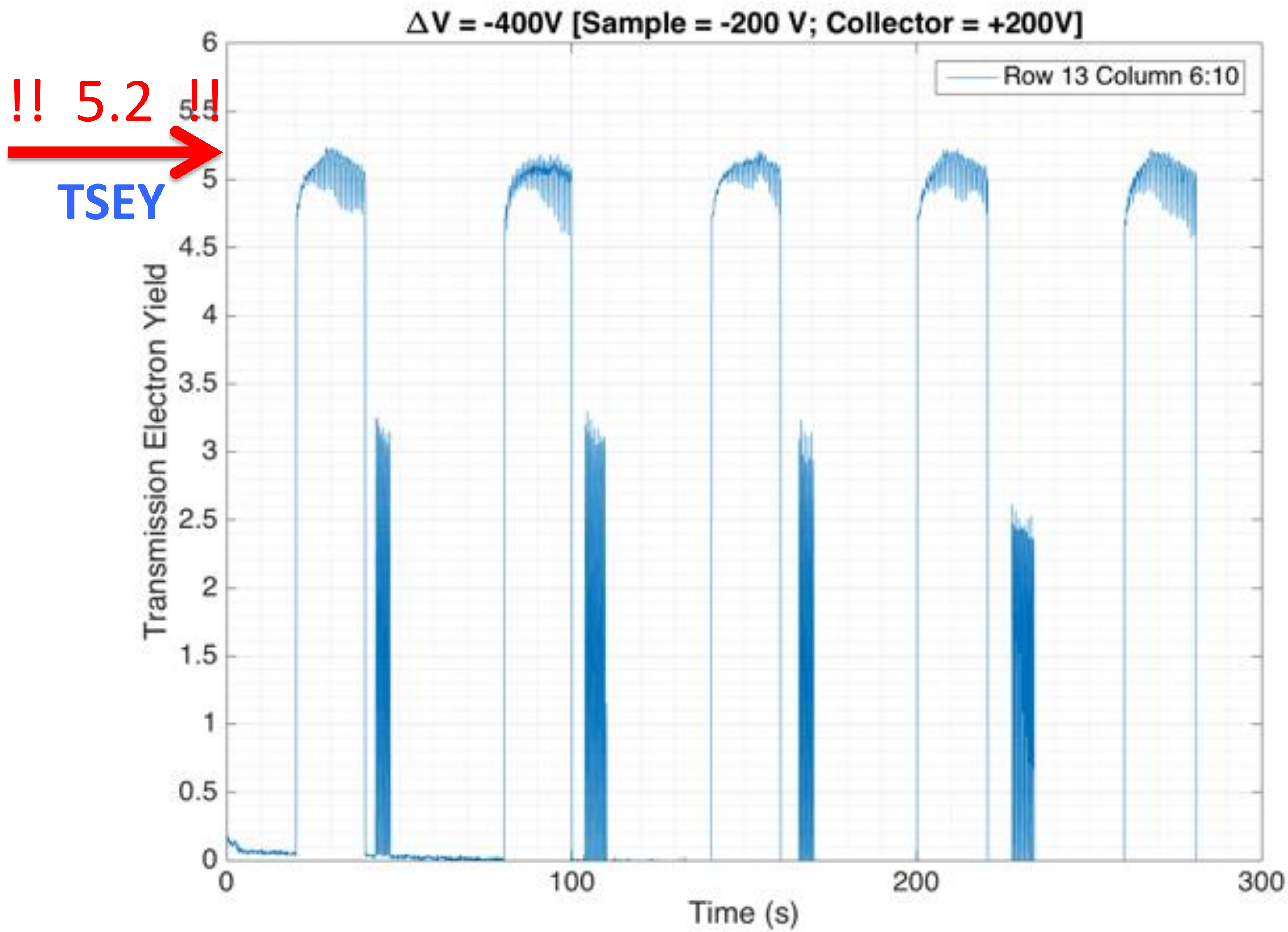
Electron beam energy: 1500 eV
Electron beam current: 0.12025 nA
HFW: 12.8 um
Magnification: 10000x
Distance between Tynode and collector: 30 um - 100 um (?)

Method:
- Apply bias
- measure background
- Irradiate a Tynode for 20 sec.
- Locate next Dynode
- repeat 5 times

Calculation: TEY = I_collector / I_beam



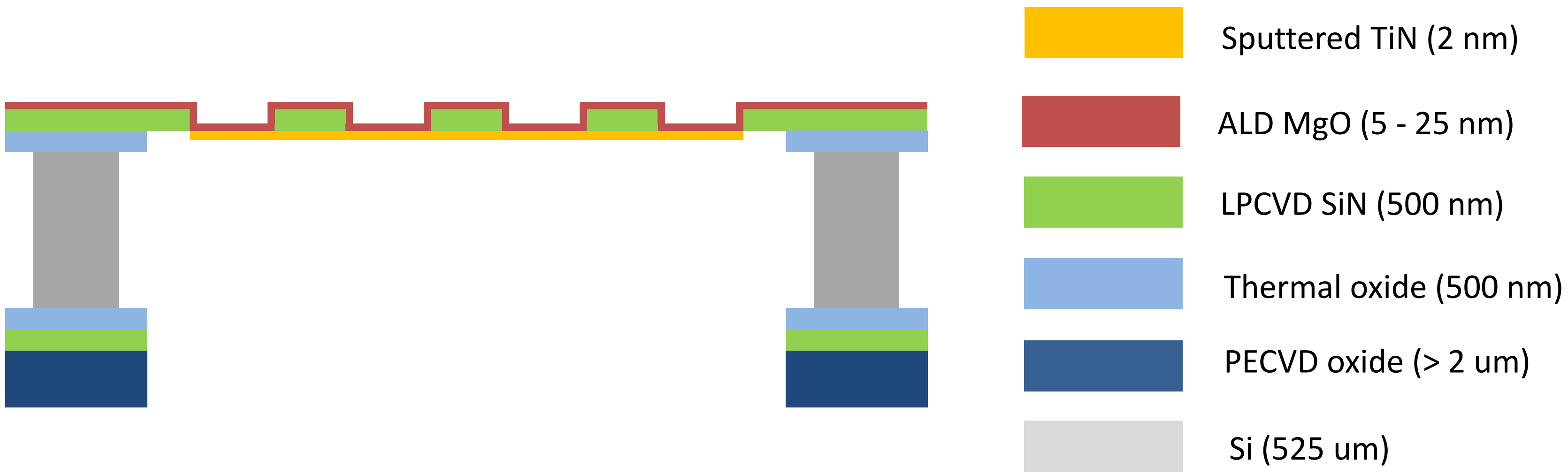

SEM image
collector
Transmission Yield
pixels
pixels
Yield = 3.58 (blue-yellow)
Transmission Yield
pixels
pixels
linescan row: 175
transmission yield
pixels



ΔV = -400V [Sample = -200 V; Collector = +200V]
Row 13 Column 6:10
!! 5.2 !!
TSEY
Transmission Electron Yield
Time (s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
0
100
200
300

Timed Photon Counter – Tipsy 0.0 – Fabrication of First Prototype

Finalized layout of MgO domes



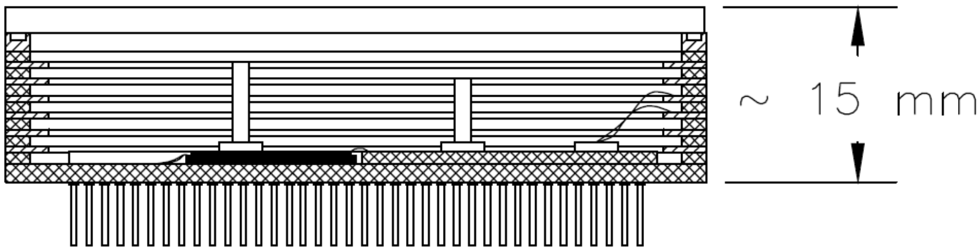
- We intend to manually stack 5 of these tynodes and place the stack above a TimePix-1 chip
- When in a close stack, we may achieve higher yields from close, extracting fields: There is a report[1] that, with a single Si membrane, yields of 200 has been reached due to a strong extracting field. We may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

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

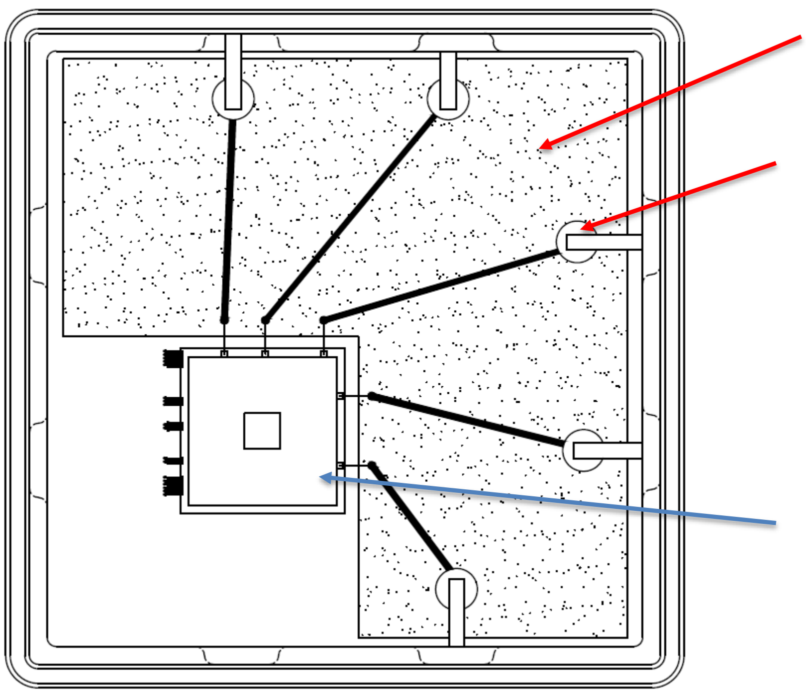
Concept - Fabrication Tipsy 0.0 into a Photonis PLANACON™ Style Device

TimePix-1 pixel chip on Kyocera carrier board

- Ultra high vacuum compatible, sealing with Planacon window, photocathode compatible



Tipsy 0.0 will be limited to the 10 ns bin size of TPX-1 or 1 ns bin size of TPX-3 a new TimePix NN with 10 ps time resolution



Fan-out ceramic with metalized top-traces for HV distribution

Metal studs and weld ribbons to electrode rings

Backside metalized ASIC (TIMEPIX) with tynodes eutectic bonded into envelope + wirebonds classical gaseous

The Quad: a general purpose modular readout system for TPCs

+ reaching transmission secondary electron yield TSEY = 5.2

Harry van der Graaf
Nikhef & TU Delft

8th Symposium on Large TPCs
Diderot University
Paris, France, Dec 6 2016