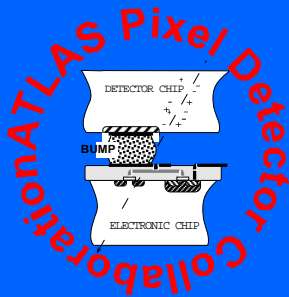
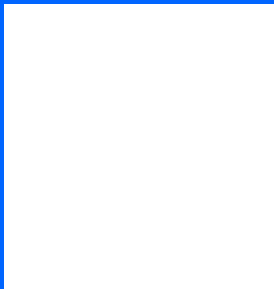


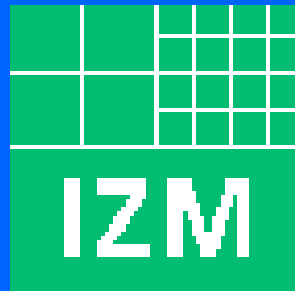
Pixel Detector Module using MCM-D Technology for the B-layer of the ATLAS Pixel Detector



Pixel 2000 Workshop



O. Bäcken
K.H.Becks
P.Gerlach
Ch. Grah



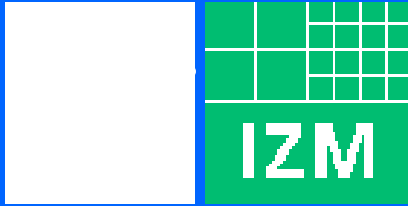
O.Ehrmann
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J.Wolf

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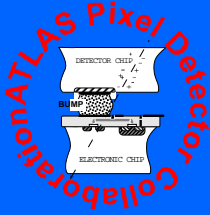
University of Wuppertal

www.atlas.uni-wuppertal.de

June 2000, Genova



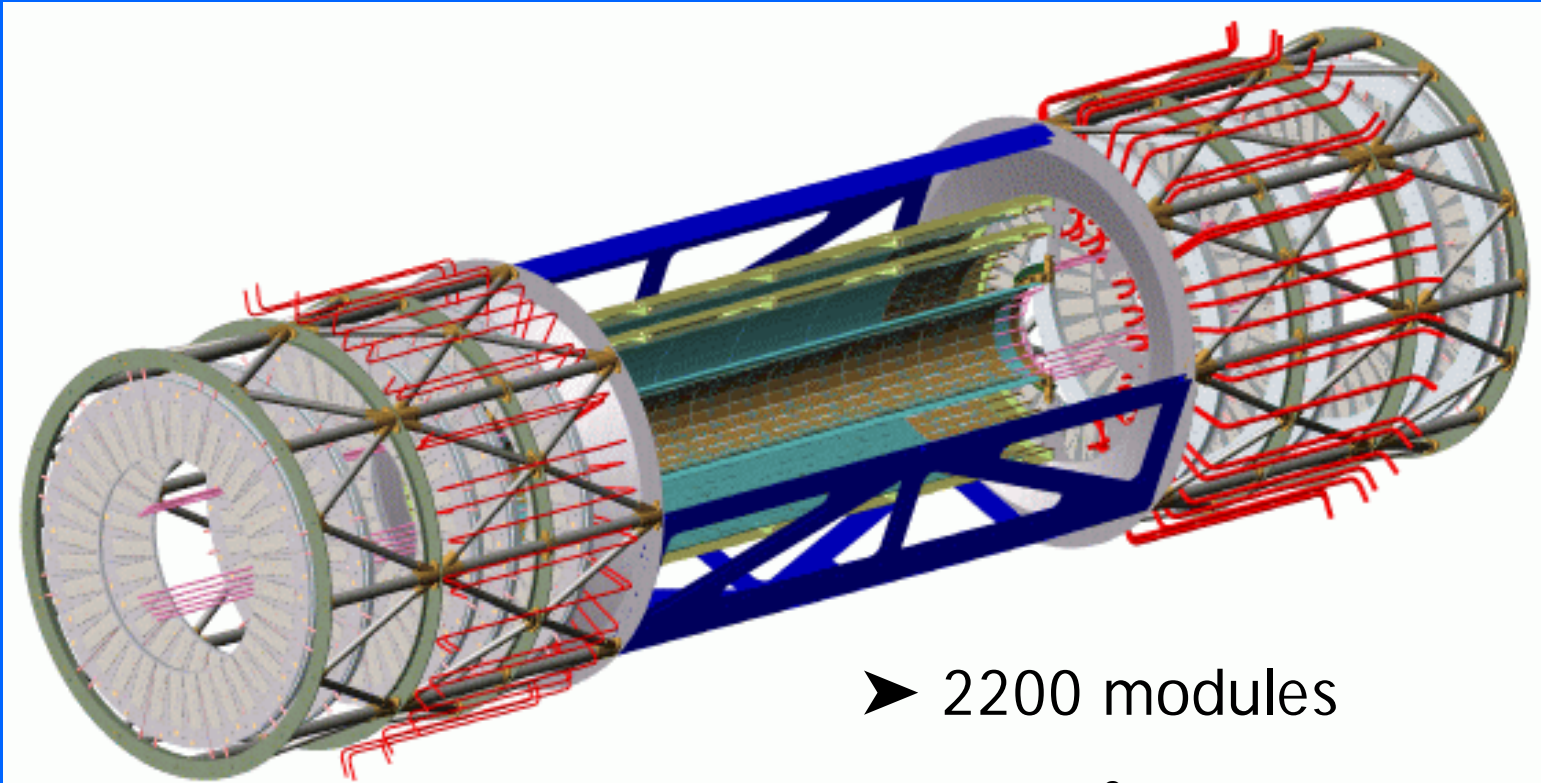
Overview



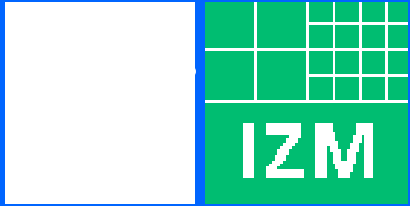
Ch.Grah

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- The concept of building modules in MCM-D technology
- MCM-D modules for the ATLAS Pixel Detector
- Measurements on Prototypes
 - Lab measurements on full scale module and single chip devices
 - Testbeam measurements on single chip devices
- Conclusion and Outlook



- 2200 modules
- 2.2 m² active Si
- 1 x 10⁸ channels



The basic structure of modules for the ATLAS Pixel Detector



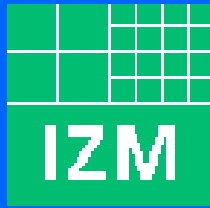
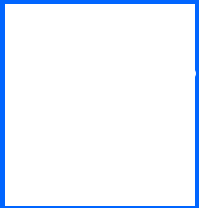
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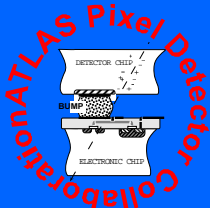
- Sensor tile (16.4 mm x 60.4 mm active area)

Main components which need to be contacted:

- 16 read out IC's, each providing 18 x 160 pixel unit cells (preamplifier, discriminator, digital readout; pixel cell size: 400 x 50 μm^2)
46080 connections in the pixel cell array per module with bump-bonding and flip-chipping as interconnection technique
- one module controller chip
- Idea of using a Thin Film technology to perform the signal interconnections and power distribution on the active sensor



MCM-D, a Thin Film Technology



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Multi Chip Module Deposited

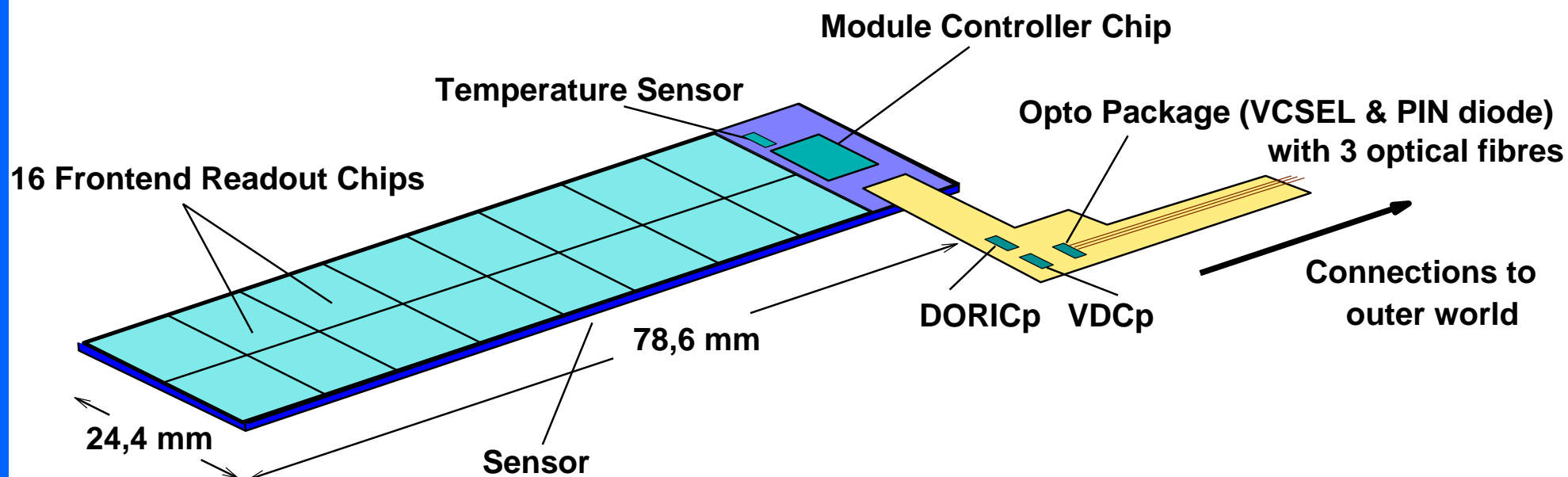
conductor layers

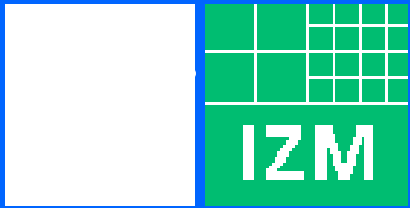
- Up to 5 copper layers:
 - magnetron sputtered up to 2 μm Ti/Cu/Ti
10 $\text{m}\Omega/\square$
 - additive electroplating up to 5 μm Ti/Cu
- Minimal width and spacing 10 and 20 μm
- Final metallisation:
 - electroless
 - 5 μm Ni:P / 200nm Au

dielectric layers

- "Spin-on" polymer: BCB (Benzocyclobutene / DOW:CYCLOTENE™)
- Photosensitive
- Specific dielectric constant $\epsilon_r = 2.7$
- Process temperatures :
 - 1h 220°C per layer
 - last layer 1h 250 °C
- Thickness / layer 4 - 10 μm
- Via $\varnothing > 20 \mu\text{m}$, Pad 30 μm

Pixeldetector Module





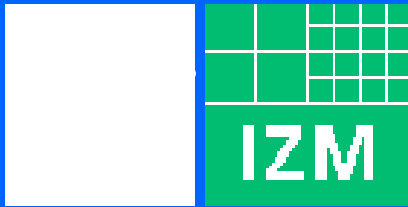
Advantages of modules in MCM-D technology



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- A robust, "easy-to-handle" module with bump-bonding as the only interconnection technique
- Signal lines in μ -strip configuration, so with low crosstalk and well defined impedance
- Allows routing in the pixel cell array to contact sensor and electronic cells which are not facing each other

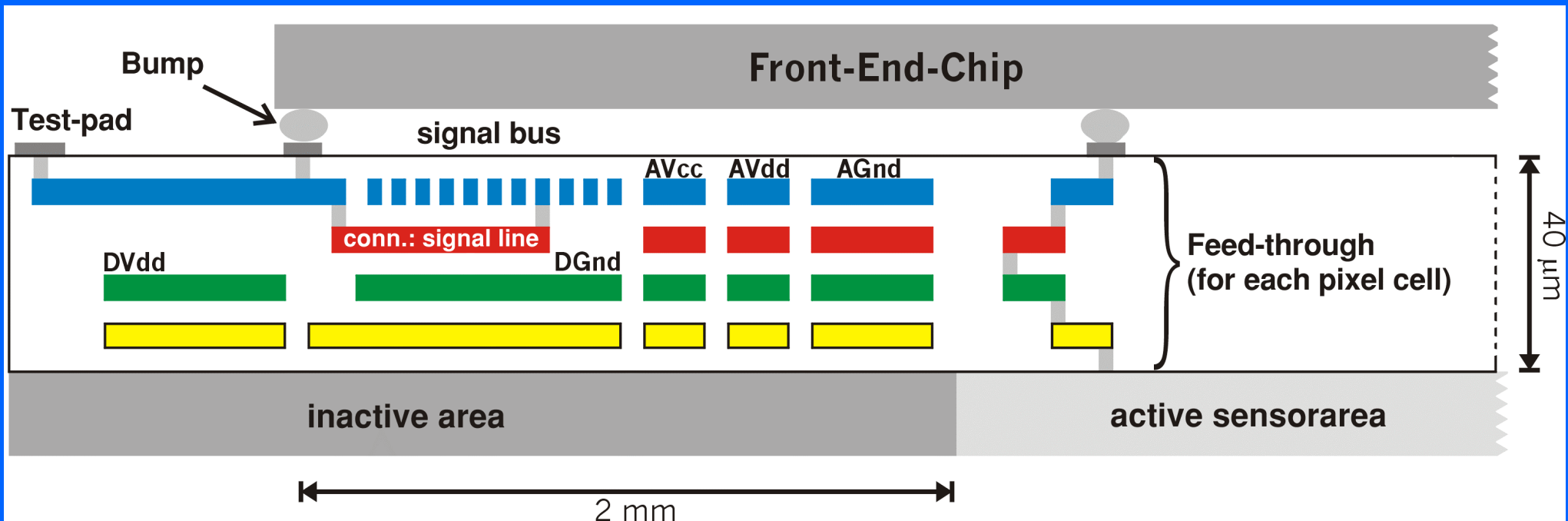


Schematic Cross-Section of a Bus System



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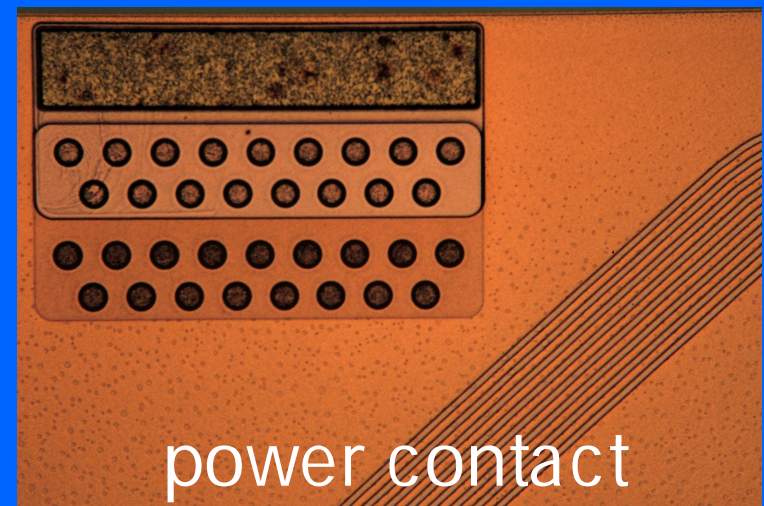
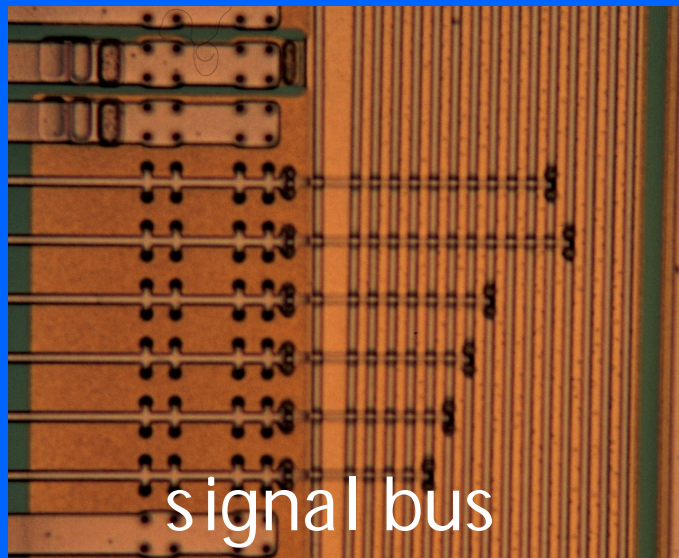
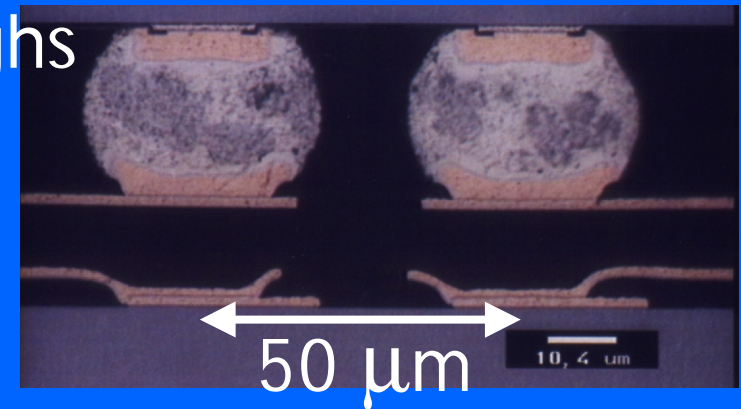
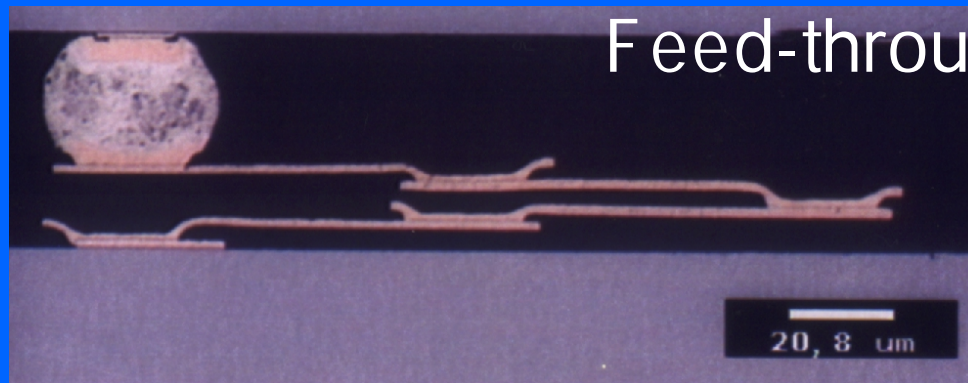
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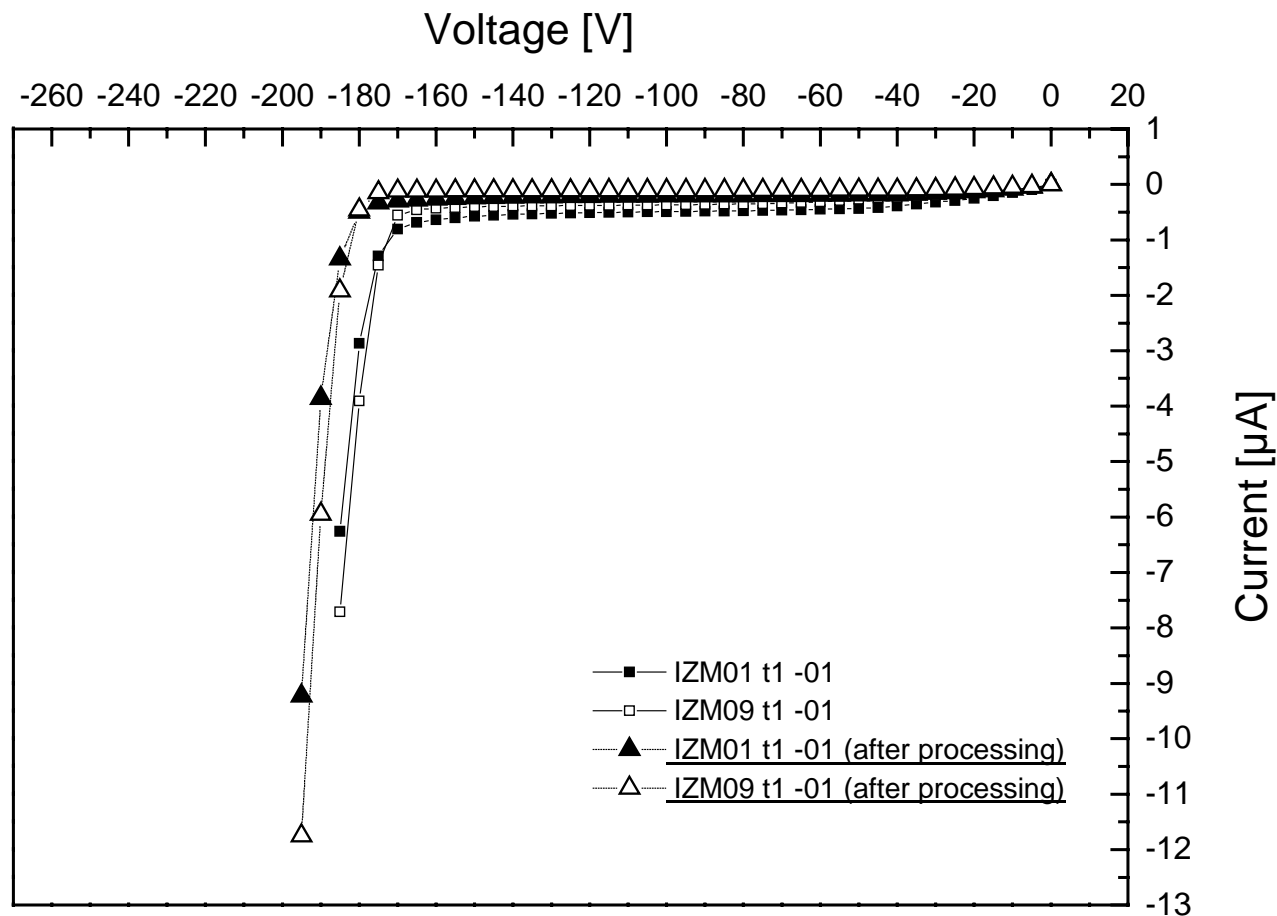


Some pictures of the MCM-D structures

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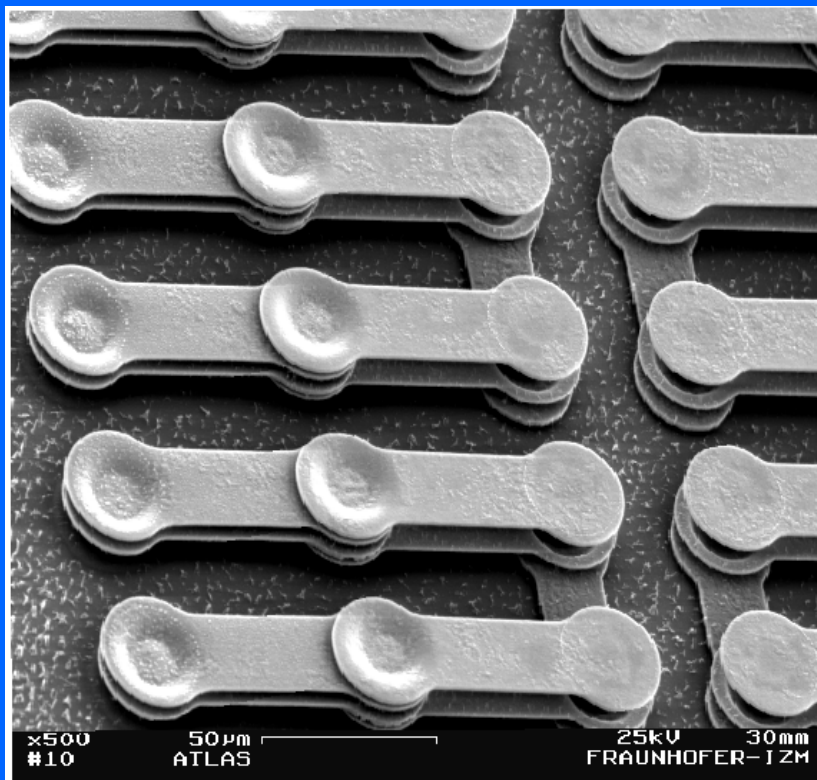
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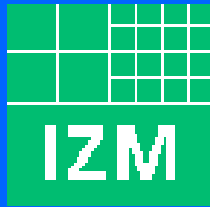
- Just two exemplary plots
- The sensor properties are not affected by the MCM-D technology

Feed-through structures

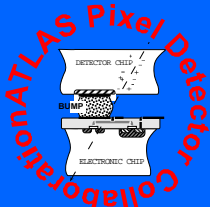


BCB etched for better visualisation

- Daisy-Chain interconnection
- Four copper layers
- $1.1 \cdot 10^6$ monitored vias with a diameter of $25\mu\text{m}$
- Measured defect rate
 $8.13 \cdot 10^{-6}$
 (9 defects of 1 105 920 vias)
- We expect 1.5 unconnected pixel/module



Full Scale Prototype Module

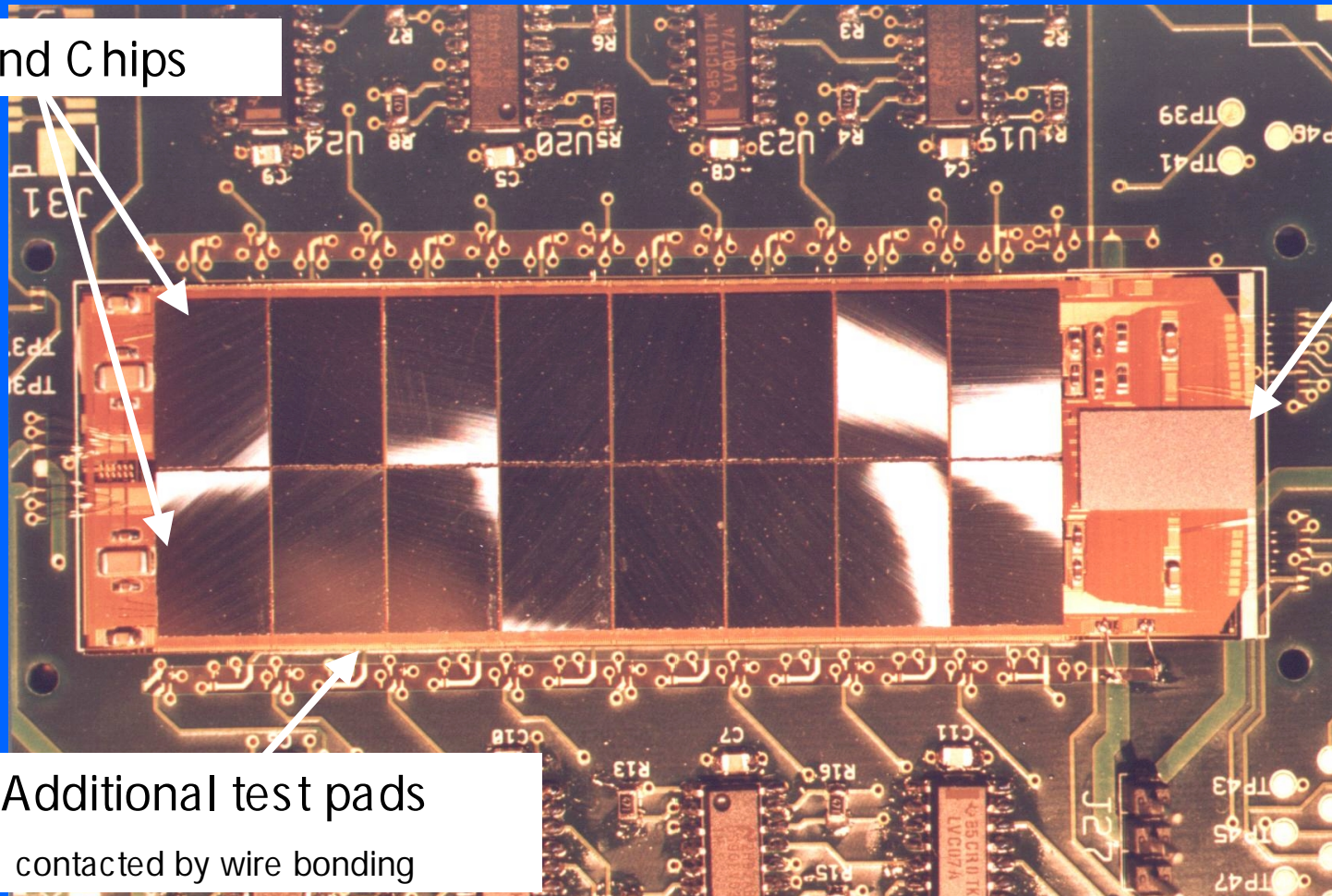


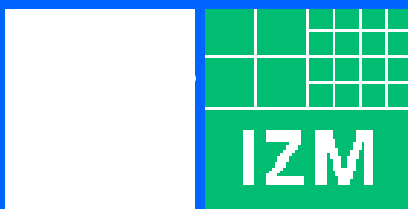
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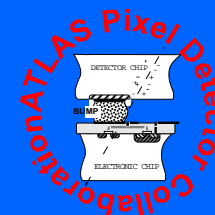
Frontend Chips

MCC





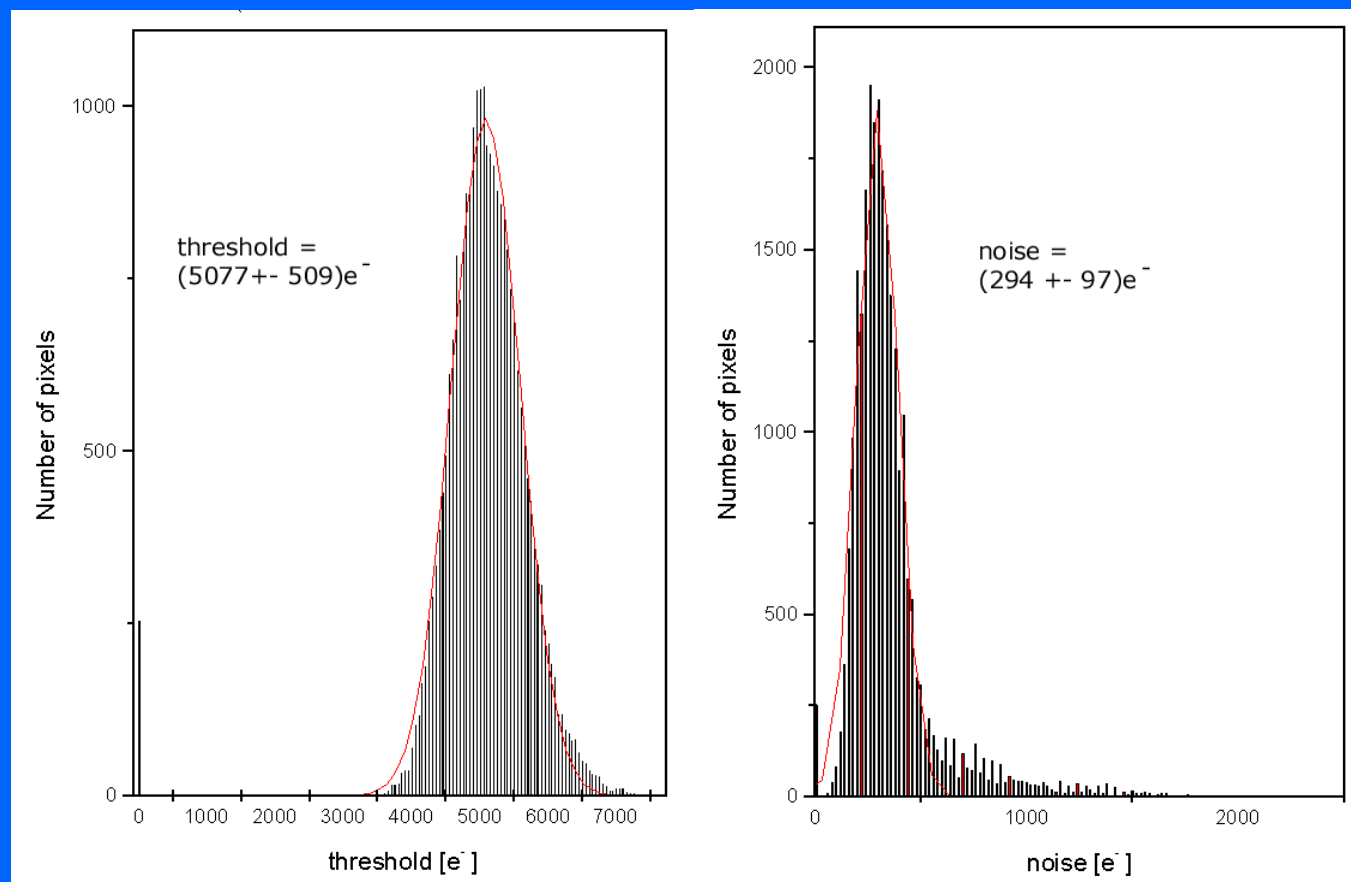
Threshold and Noise (Untuned Full Scale Module)



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The MCM-D Module shows encouraging performance regarding Threshold distribution and Noise performance

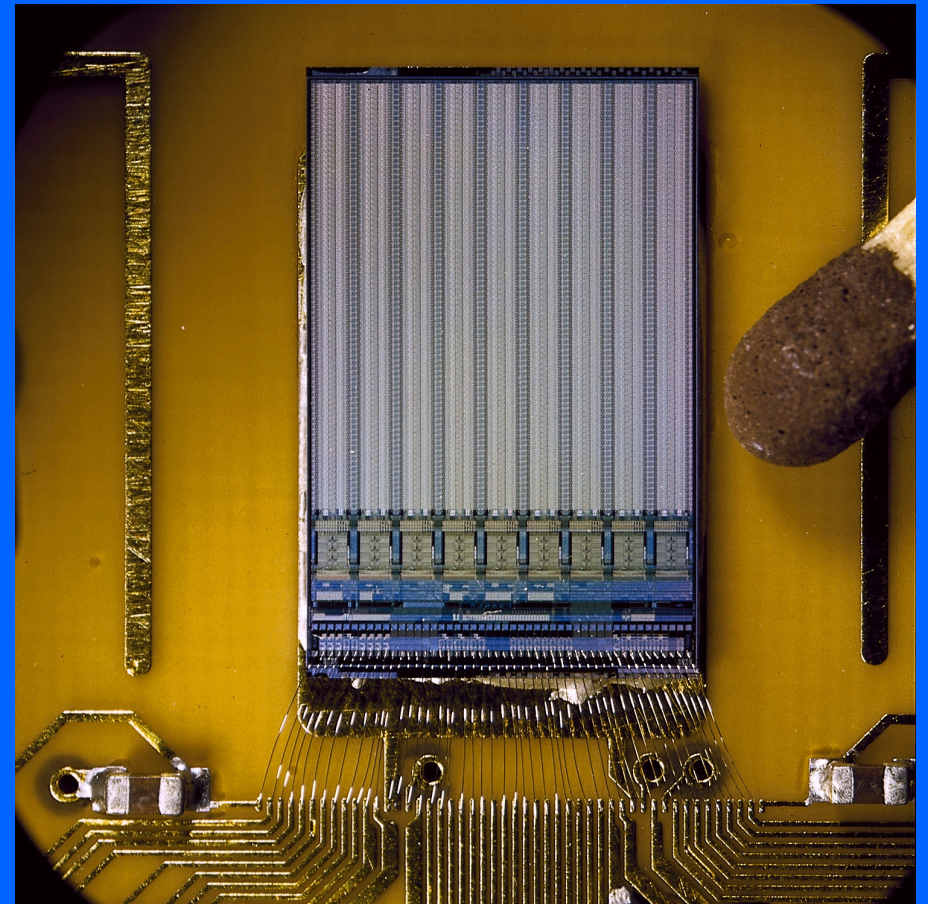


Module: MCM-D T1/Frontend B

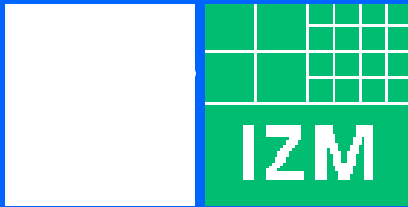
Pixel 2000, Genova

A Single Chip Module consists of:
Sensor cell array + MCM-D
interconnections +
Frontend chip

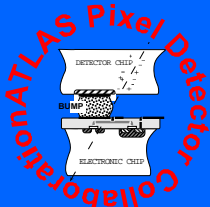
- Investigation of different
Feed-through layouts,
especially routing



Picture: Frontend C on Single Chip PCB



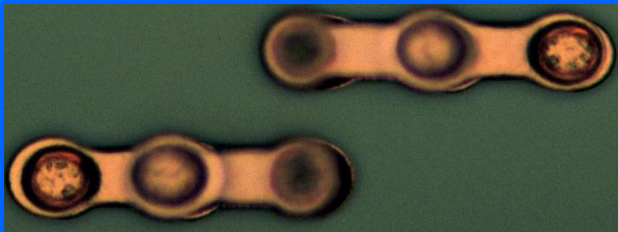
Feed-throughs in different layouts



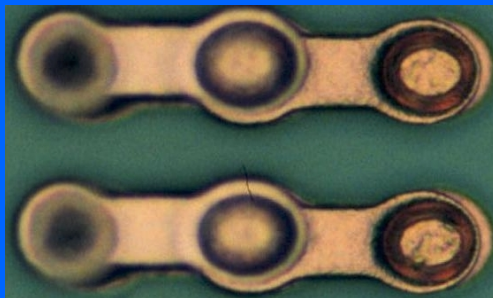
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Class $U_{400/600}$ (two columns at the border of the hybrid)



Class U (most common class)



Class R_1 (to neighbouring pixel cell)

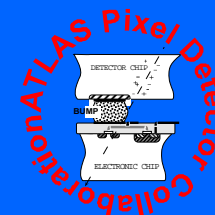
Class R_2 (skipping one cell)

Class R_3 (skipping two cells)



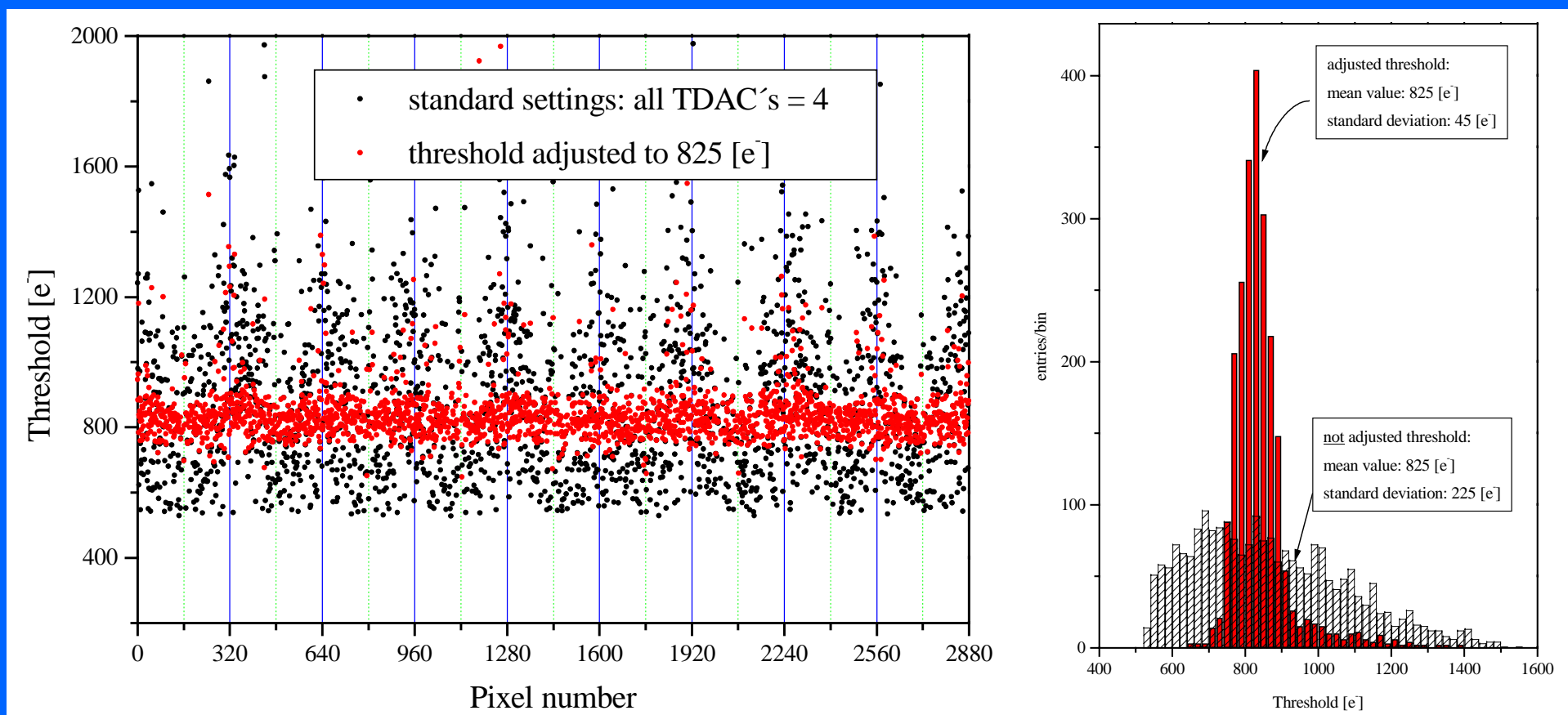


Threshold distribution (Single Chip)



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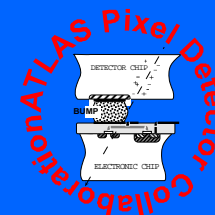
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Hybrid: MCM-D ST1/Frontend C

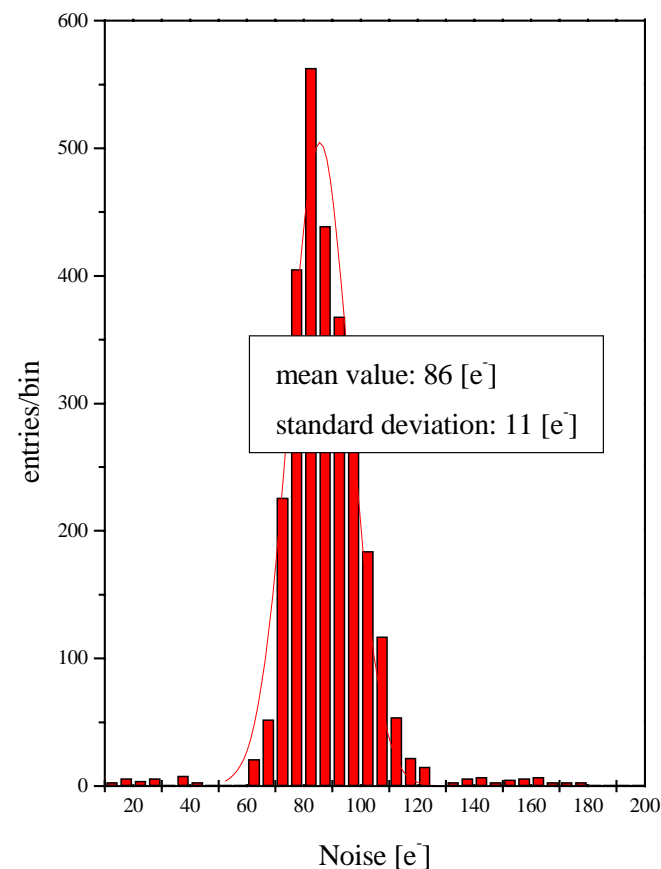
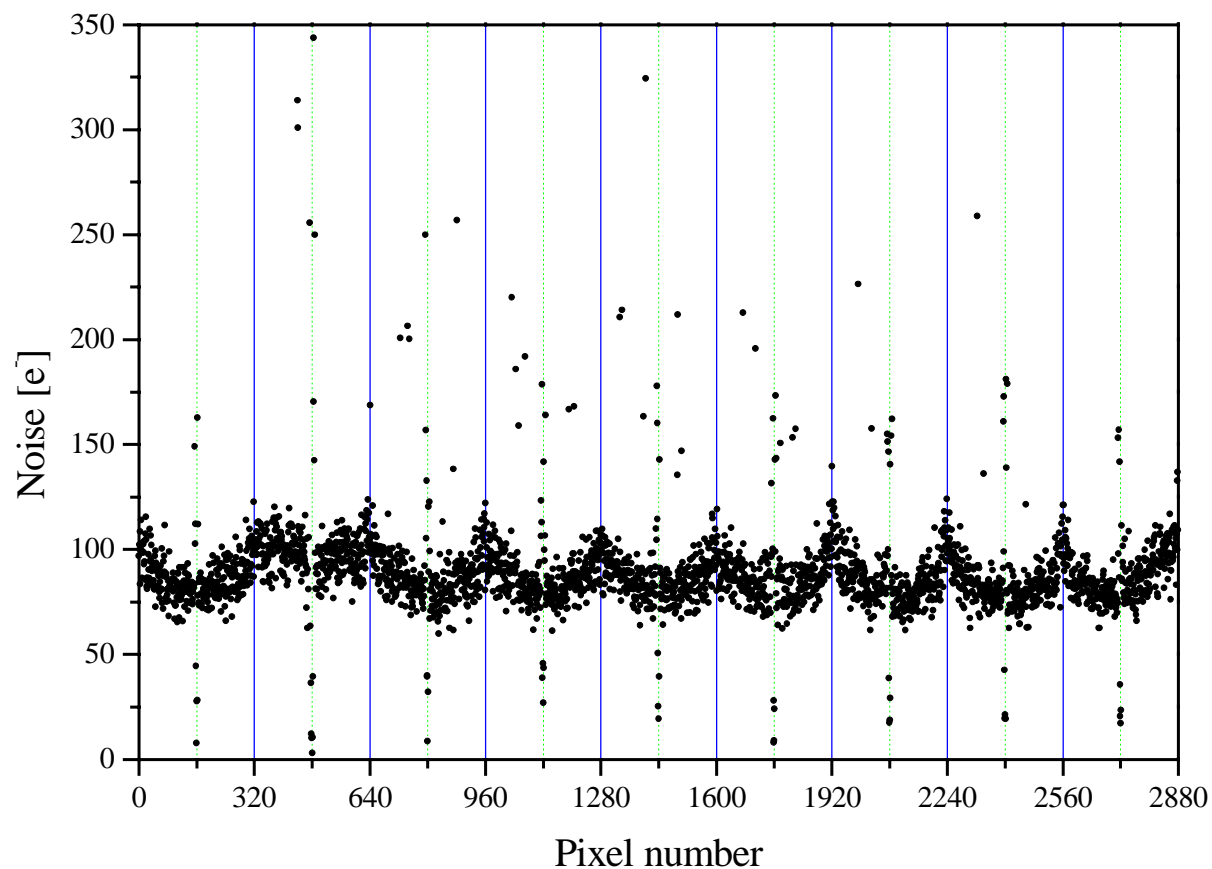


Noise distribution (Single Chip)



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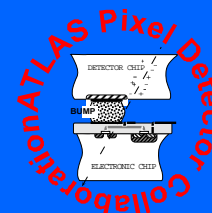
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Hybrid: MCM-D ST1/Frontend C



Summary of Noise measurements

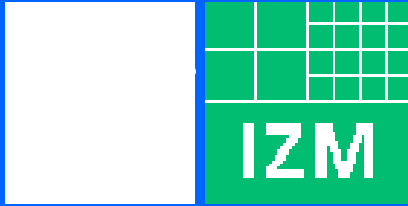


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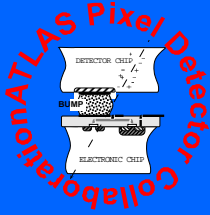
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hybrid	MCMD FeC- St1	MCMD FeC- St2
class	mean value \pm standard deviation [e^-]	
U ₄₀₀	79 \pm 10	130 \pm 12
U ₆₀₀	88 \pm 12	n/a
U	80 \pm 10	126 \pm 12
R1	93 \pm 10	136 \pm 12
R2	96 \pm 8	142 \pm 13
R3	94 \pm 8	151 \pm 15

There is no influence on the performance, due to Feed-throughs in MCM-D.
 As expected, the crossing of copper lines in different layers (classes R i)
 increases the Noise, due to the higher interpixel capacitance.



Crosstalk Measurements



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Crosstalk = fraction of charge that couples into the neighbouring pixel through the interpixel capacitance

Q \longrightarrow Pixel N (masked to read out)

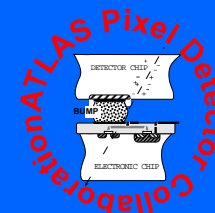
hits \longleftarrow Pixel N+1 (with threshold T)

$$\text{Crosstalk} = T / Q$$

For Pixel N+i similar

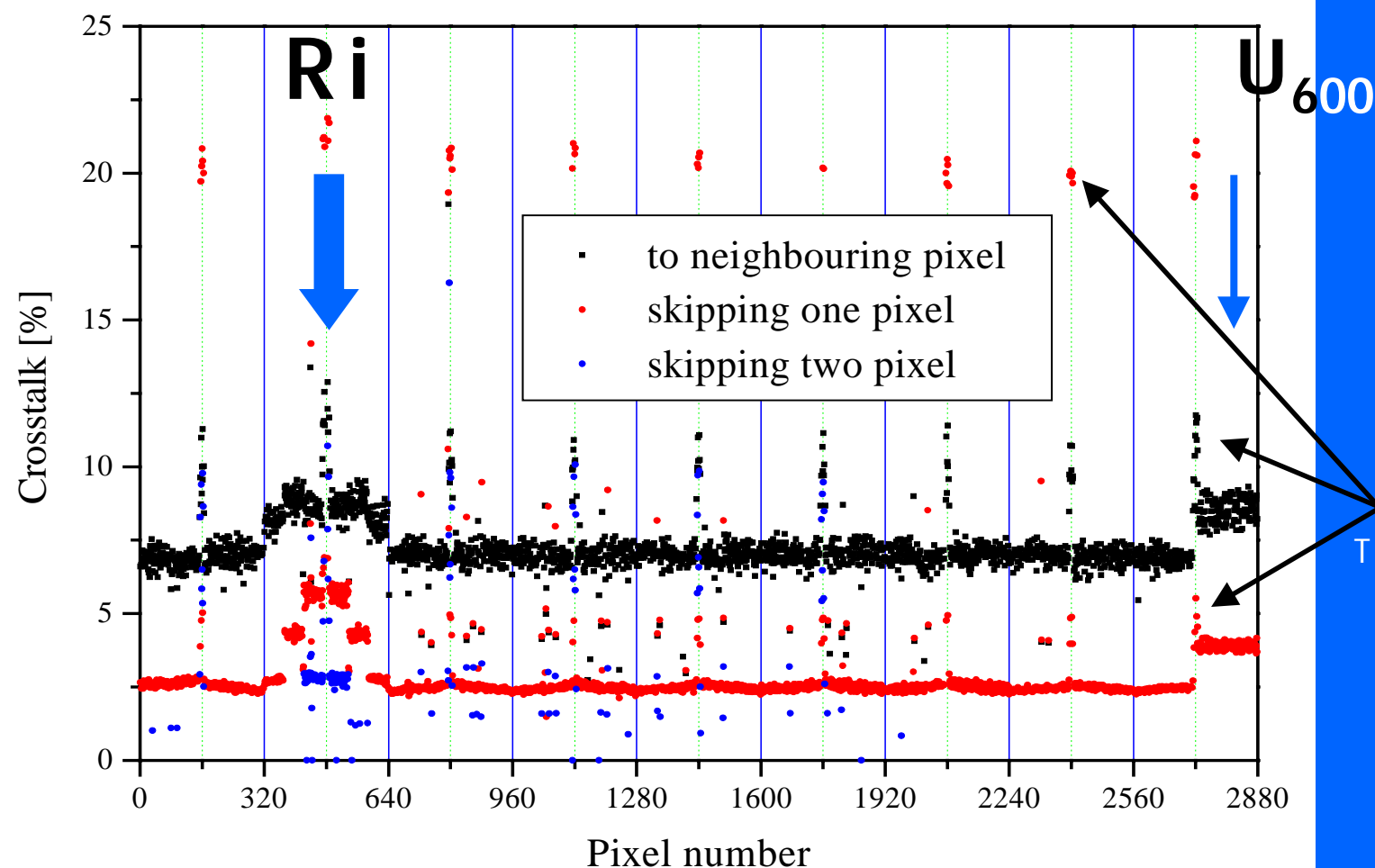


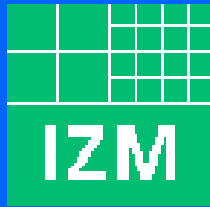
Crosstalk distribution (Single Chip)



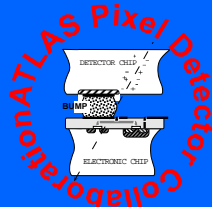
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Summary of crosstalk measurements



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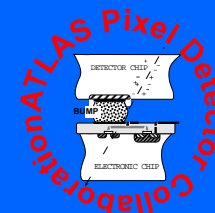
hybrid	FeC-St1			FeC-St2		
to pixel	N + 1	N + 2	N + 3	N + 1	N + 2	N + 3
class	mean value \pm standard deviation [%]					
U ₄₀₀	6,9 \pm 0,3	2,6 \pm 0,2	<1	2,8 \pm 0,8	1,6 \pm 0,4	1,1 \pm 0,2
U ₆₀₀	8,6 \pm 0,5	3,9 \pm 0,2	<1	n/a	n/a	n/a
U	7,0 \pm 0,3	2,5 \pm 0,1	<1	3,0 \pm 0,7	1,3 \pm 0,3	<1
R1	8,2 \pm 0,5	2,7 \pm 0,1	<1	4,6 \pm 0,9	1,6 \pm 0,3	<1
R2	8,9 \pm 0,5	4,3 \pm 0,2	<1	5,1 \pm 1,1	2,4 \pm 0,4	<1
R3	8,6 \pm 0,4	5,7 \pm 0,2	2,8 \pm 0,1	5,0 \pm 0,8	3,7 \pm 0,5	2,0 \pm 0,3

Note 1: There is no influence on the crosstalk, due to the Feed-throughs in MCM-D.

Note 2: The performance of class R1 and R2 layouts is comparable to the 600 μ m long sensor cells (U₆₀₀).



Source measurement



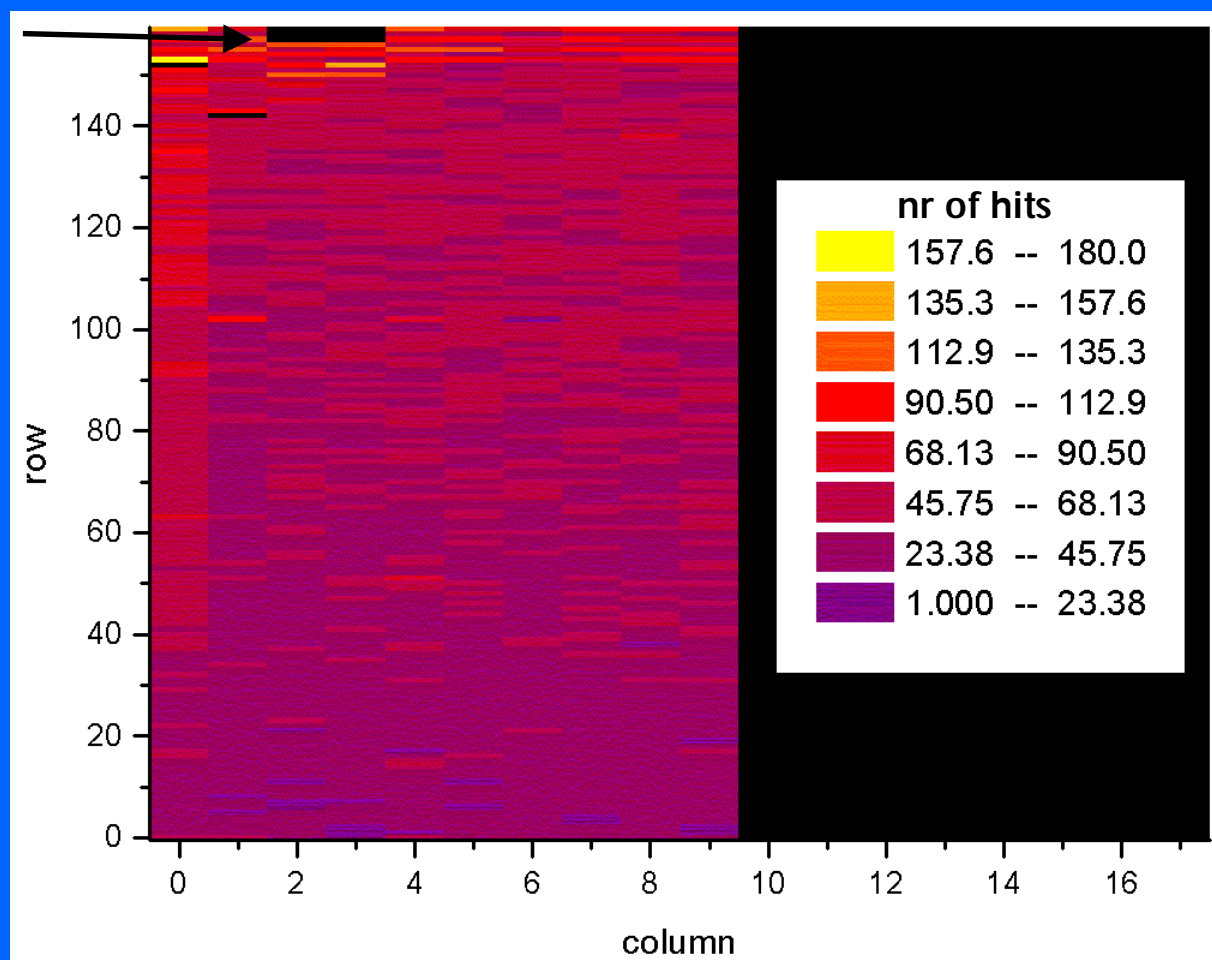
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Upper 3 cells not connected (by design)

The MCM-D
hybrid shows a
uniform
functionality.
Defects were
recognized as
bad bump
connections.

Am^{241} : Gamma-rays





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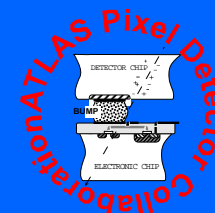
- [illegible]

H8 Telescope system

Pixel 2000, Genova

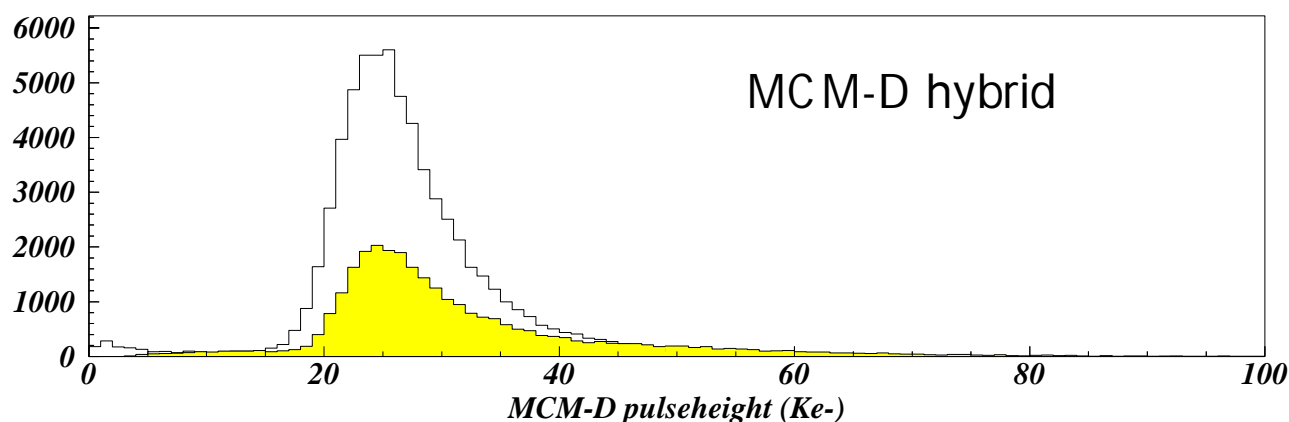
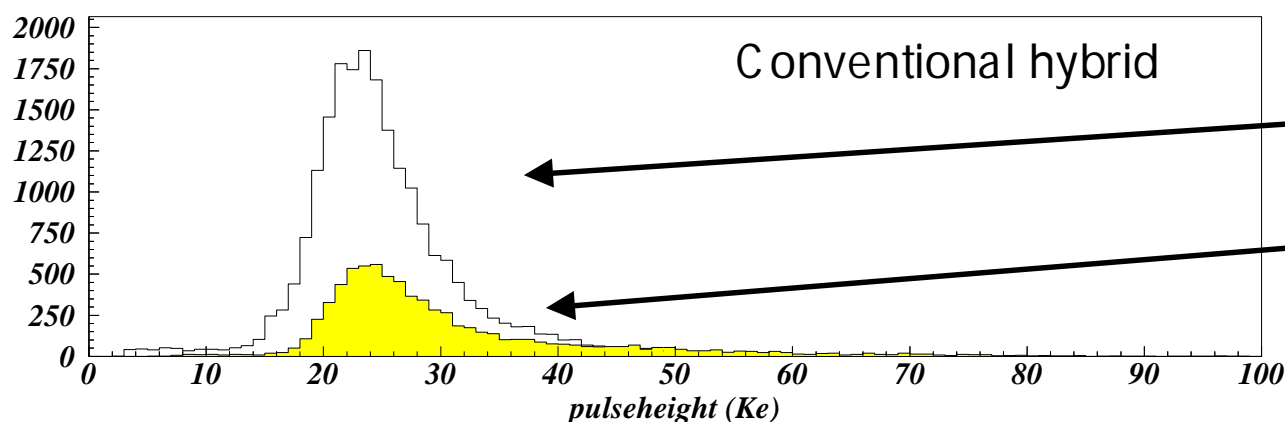


Reconstructed energy deposition



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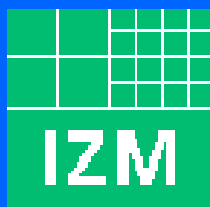
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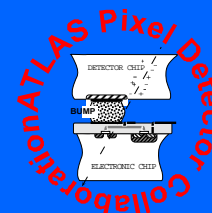
Single hit events

Double hit events
(added charges)

No charge loss can
be seen, due to the
MCM-D
structures



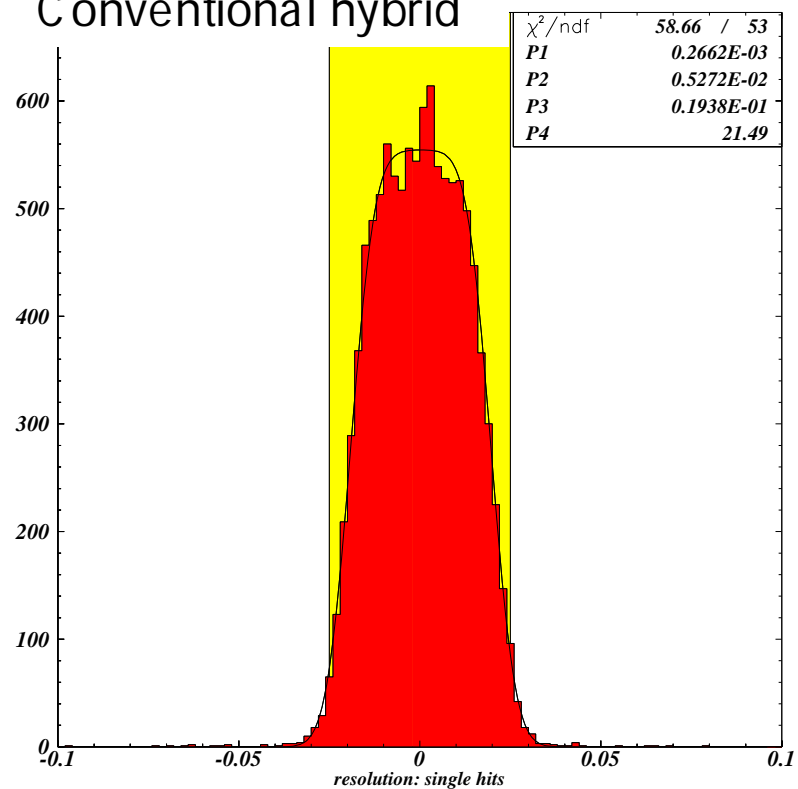
Single hit resolution



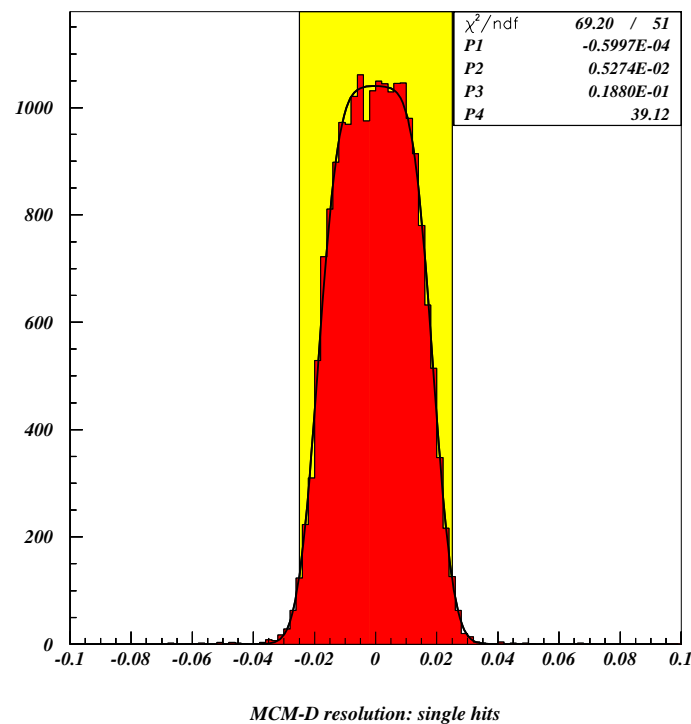
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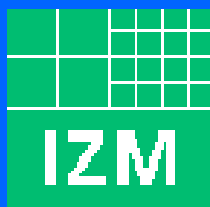
Conventional hybrid



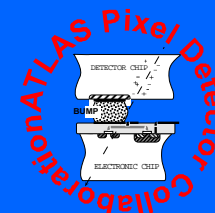
MCM-D hybrid



Difference between predicted (Telescope) and measured particle track
 P2: sigma of gaussian tail P3: width of plateau



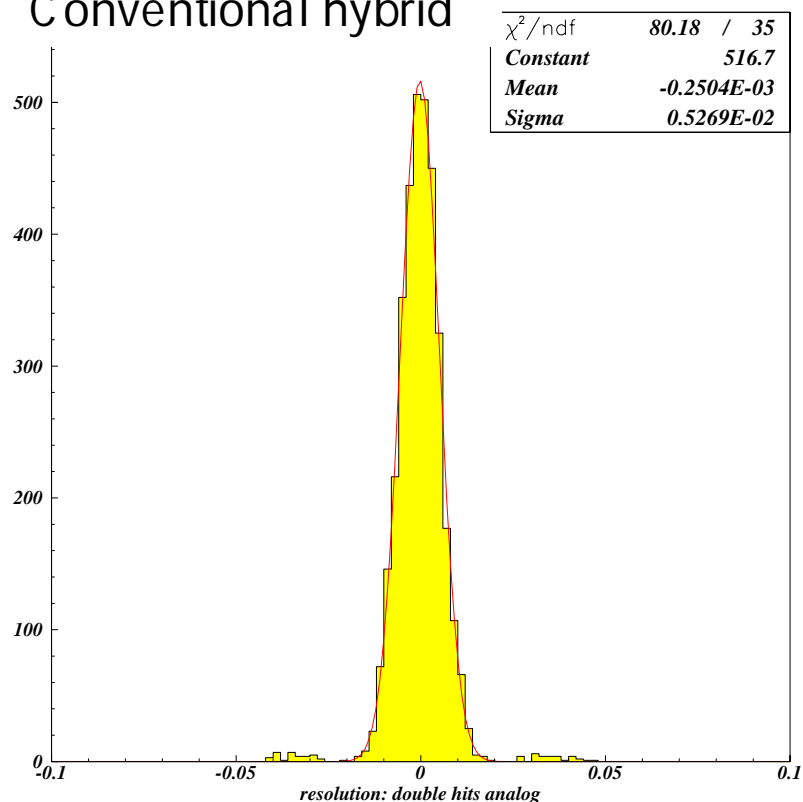
Double hit resolution



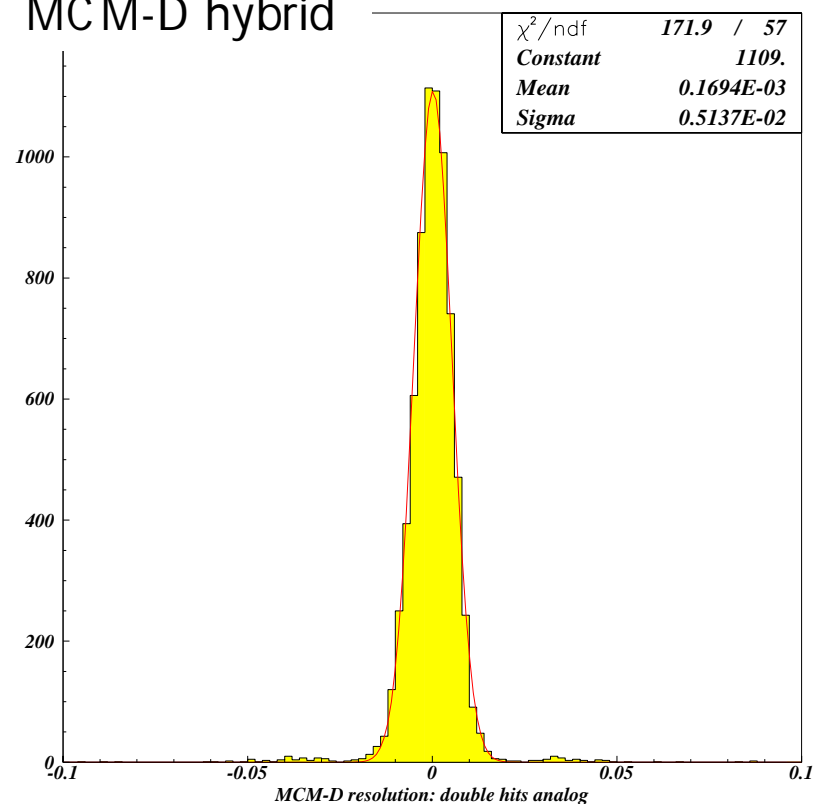
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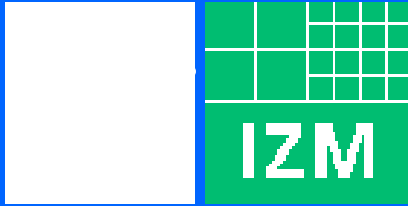
Conventional hybrid



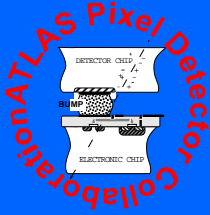
MCM-D hybrid



Double hit resolution: 5 μm (conventional and MCM-D hybrids)



Multi Chip Module-Deposited Conclusion



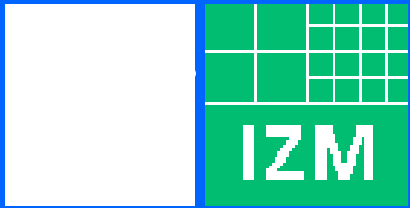
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- It is possible to build “easy-to-handle” Pixel Detector Modules with the MCM-D technique.
- The Sensor is not harmed / damaged by the processing.
- The signal and power distribution structures are able to drive full modules.
- No problems appeared due to the necessary connections between electronic and sensor cells.

Outlook:

- Explore the full potential of the MCM-D technique, modules with a homogeneous resolution may be build.



Further possibilities of the MCM-D technology



Ch.Grah

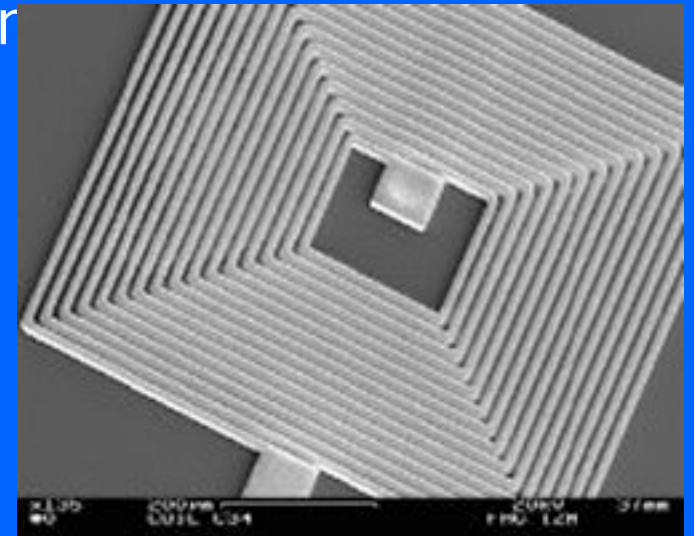
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The possibility of integrating passive components in MCM-D is under investigation

R and C:

Currently possible (due to the high process temperature this is not (yet) possible for our application!):

- 720 pF/mm² with Ta₂O₅ as dielectric
- 10-100 Ω/□ with TaN as resistor material



Inductor in MCM-D Technology