Pixel Readout Electronics for Gas and Semiconductor Sensors

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Geneva, Switzerland

Micro Pattern Gas Detector Workshop, CERN

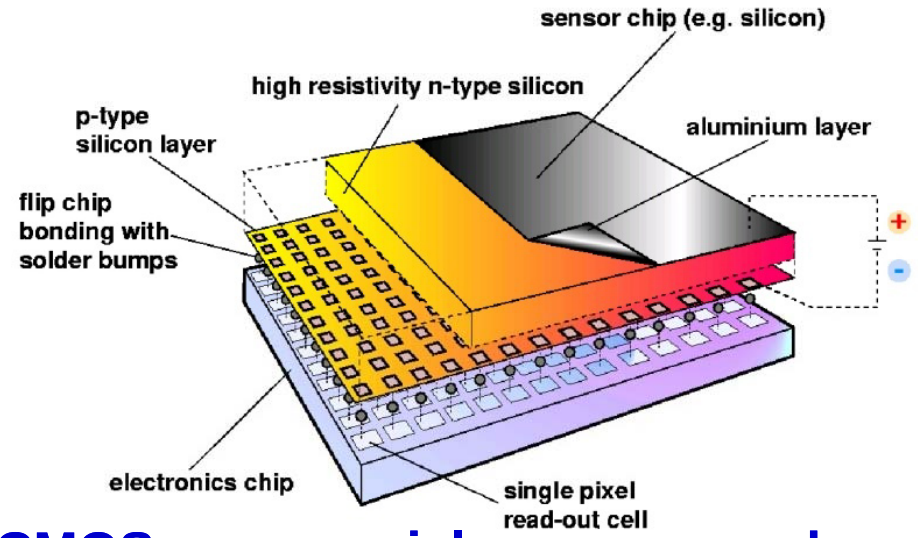
Outline

- Medipix2 – key results and limitations
- Timepix
- Medipix3 - Improving spectral resolution for X-ray imaging
- Vertex tracking in thin Si detectors using Medipix3
- Summary and conclusions
- A possible readout chip suitable for Gas and Si

The Medipix2 Consortium

- Institut de Fisca d'Altes Energies, Barcelona, Spain
- University of Cagliari and INFN Section thereof, Italy
- CEA, Paris, France
- CERN, Geneva, Switzerland,
- Universitat Freiburg, Freiburg, Germany,
- University of Glasgow, Scotland
- Universita' di Napoli and INFN Section thereof, Italy
- NIKHEF, Amsterdam, The Netherlands
- University of Pisa and INFN Section thereof, Italy
- Laboratory of Molecular Biology, Cambridge England
- Mitthogskolan, Sundsvall, Sweden,
- Czech Technical University, Prague, Czech Republic
- ESRF, Grenoble, France
- Academy of Sciences of the Czech Republic, Prague
- Universität Erlangen-Nurnberg, Erlangen, Germany
- University of California, Berkeley, USA

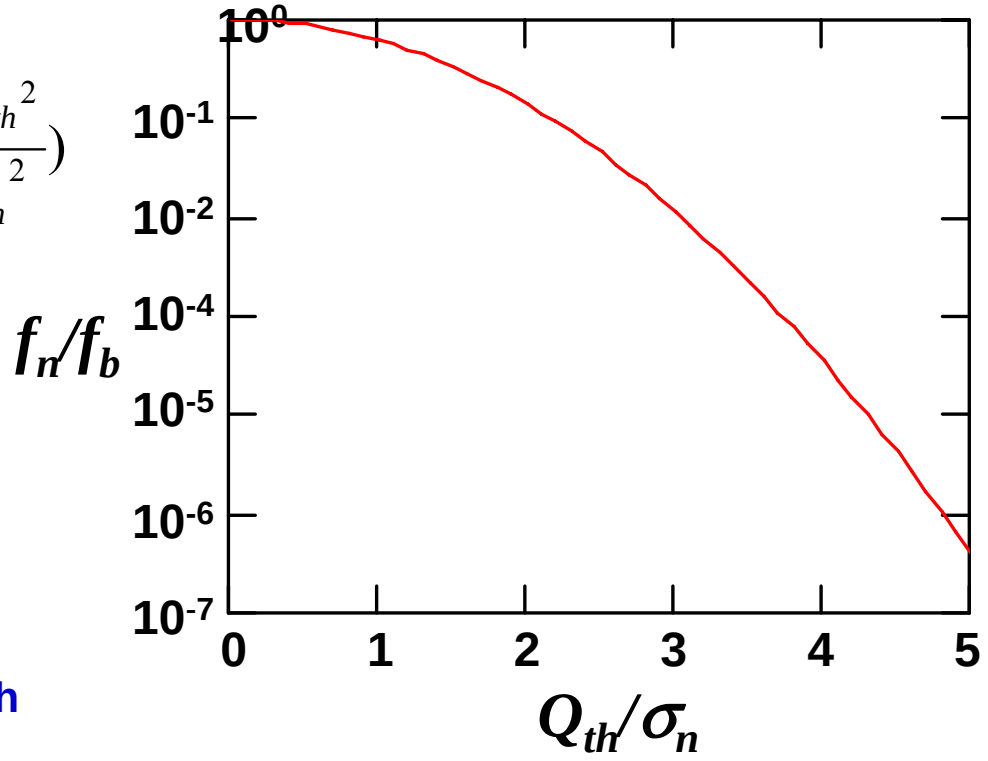
Why hybrid pixels?



- Any CMOS commercial process can be used
- The detector can be optimised for application
  - thin EPI or 3D Si for SLHC
  - Diamond
  - GaAs for mammography etc..
  - Gas….
- Sensor is usually fully depleted – prompt charge collection
- Optimal signal to noise at high rates – essential for clean pattern recognition….

Noise hit rate for a discriminator

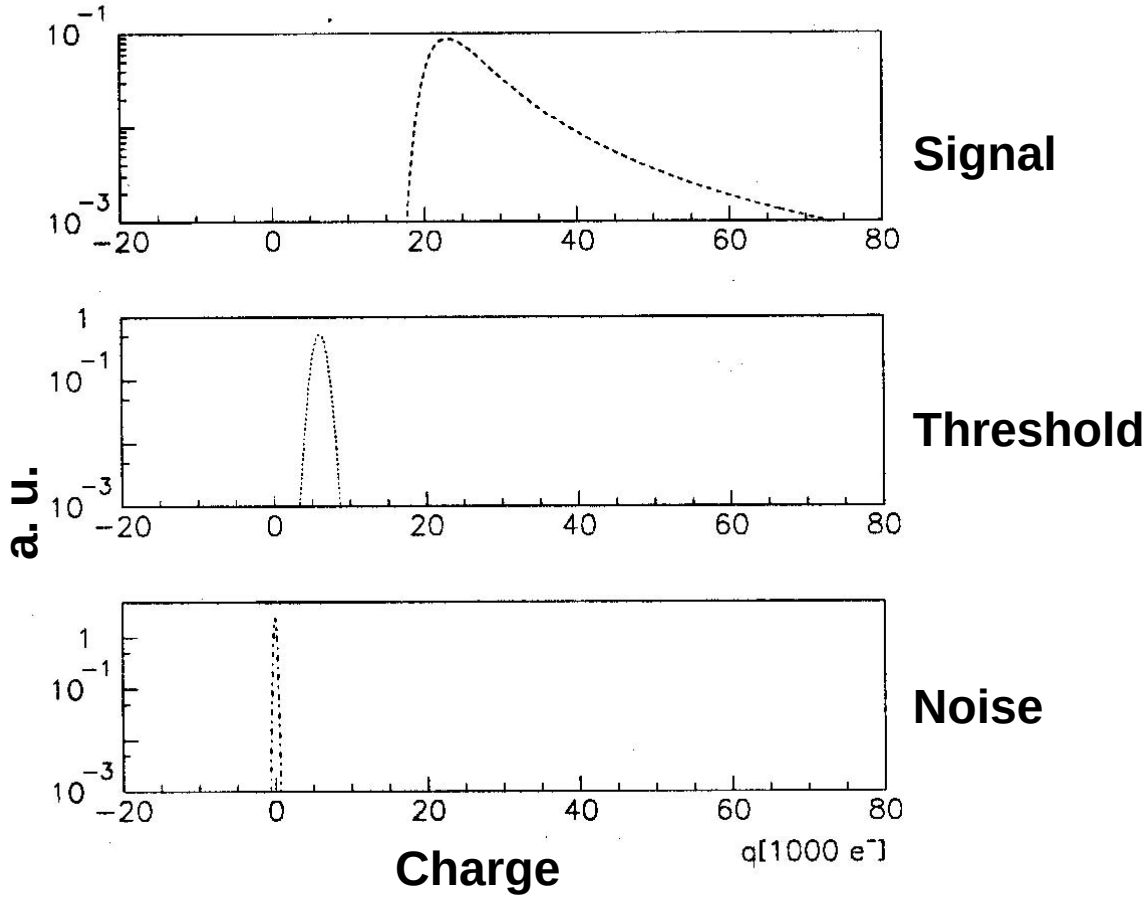
$$f_n = \frac{1}{\sqrt{3}} f_b \exp\left(\frac{-Q_{th}^2}{2\sigma_n^2}\right)$$



f_n = noise hit rate
f_b = system bandwidth
Q_{th} = threshold
σ_n = noise

In a large bandwidth system (such as an HEP experiment) noise and threshold variation must be kept very far from the threshold to produce clean event information.

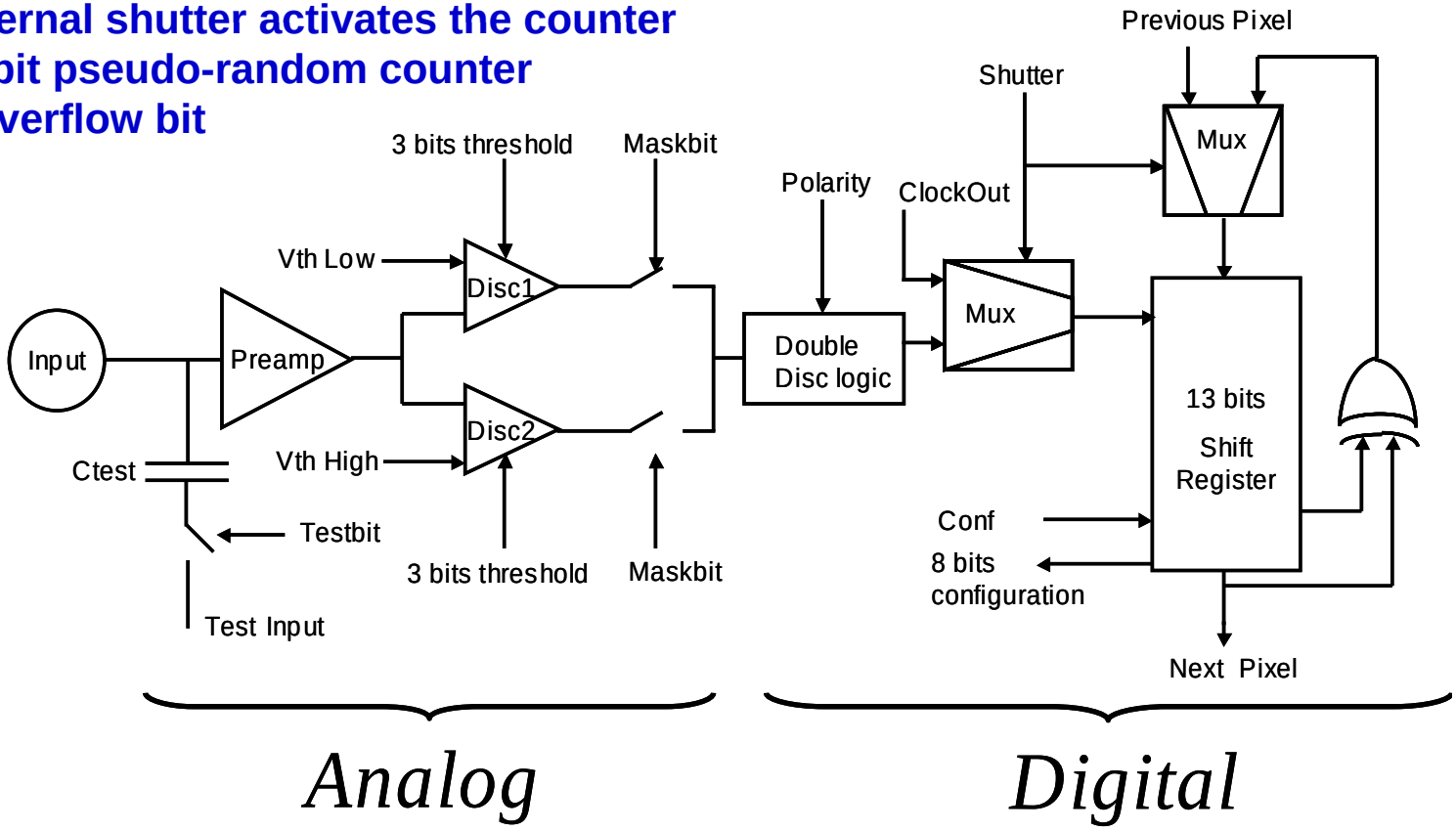
Signal, Threshold, Noise



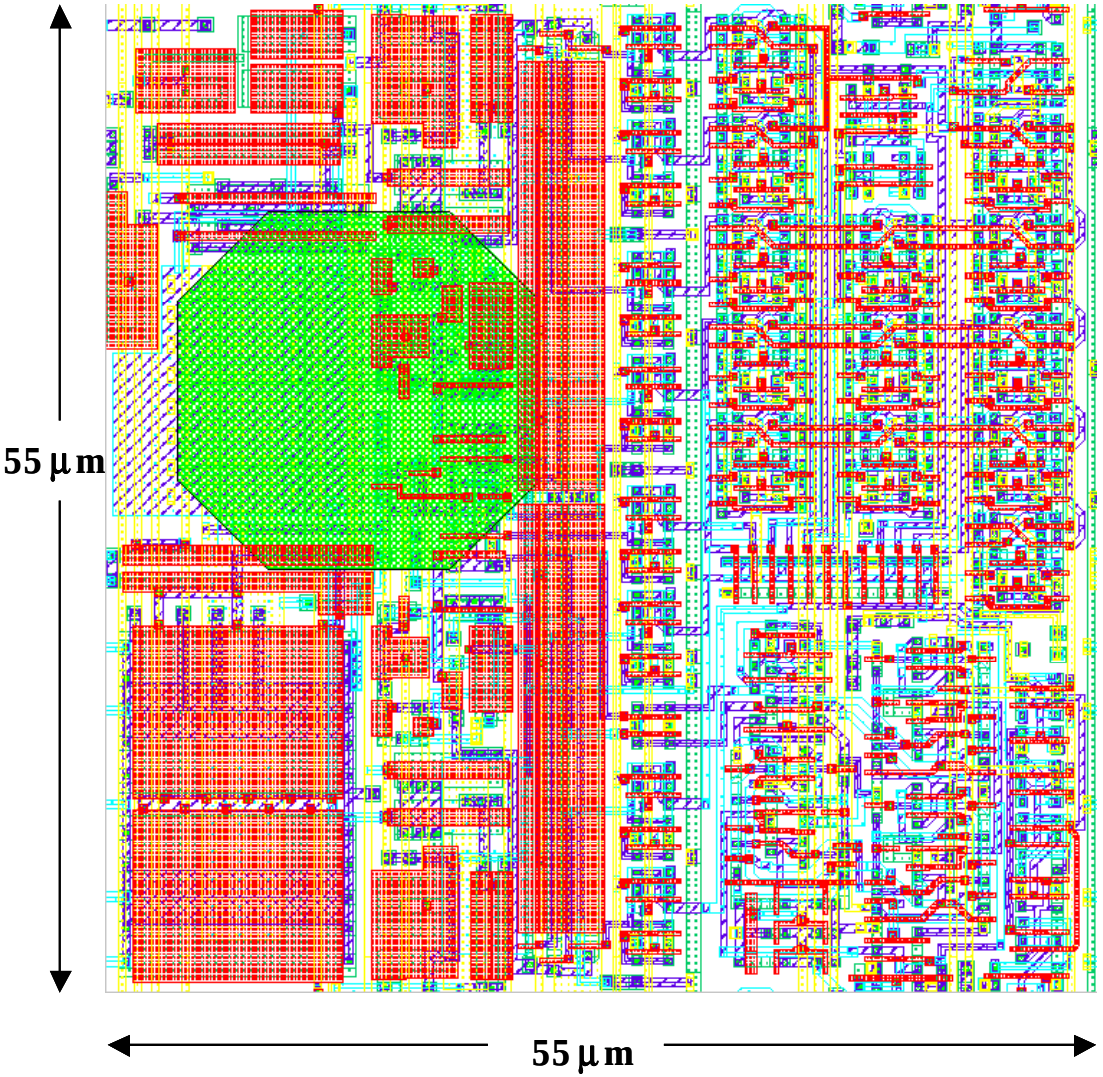
A good separation of signal, threshold and noise is achieved with hybrid pixels.
However, this argument does not take charge sharing into account…

Medipix2 Cell Schematic

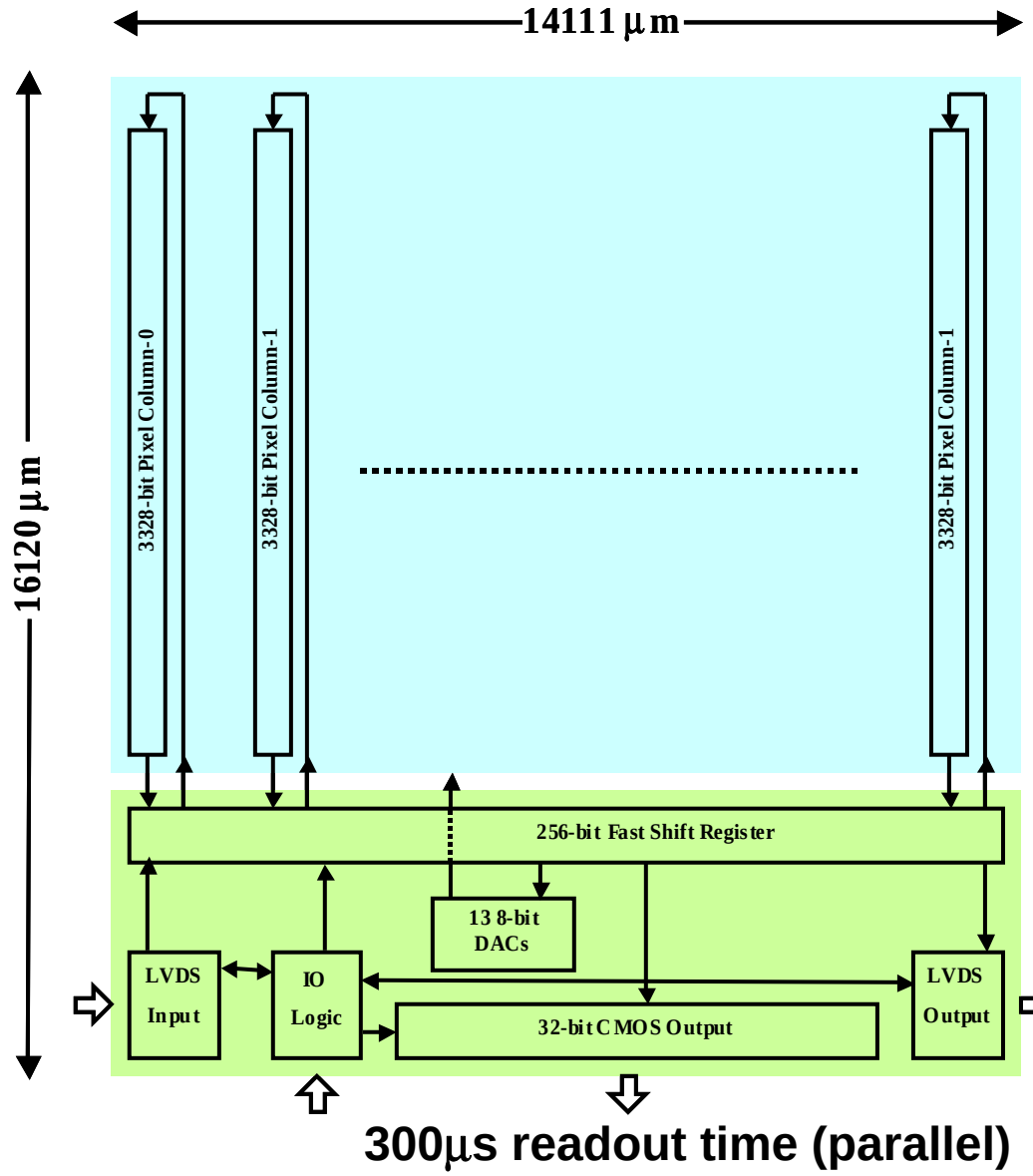
Charge sensitive preamplifier with individual leakage current compensation
2 discriminators with globally adjustable threshold
3-bit local fine tuning of the threshold per discriminator
1 test and1 mask bit
External shutter activates the counter
13-bit pseudo-random counter
1 Overflow bit



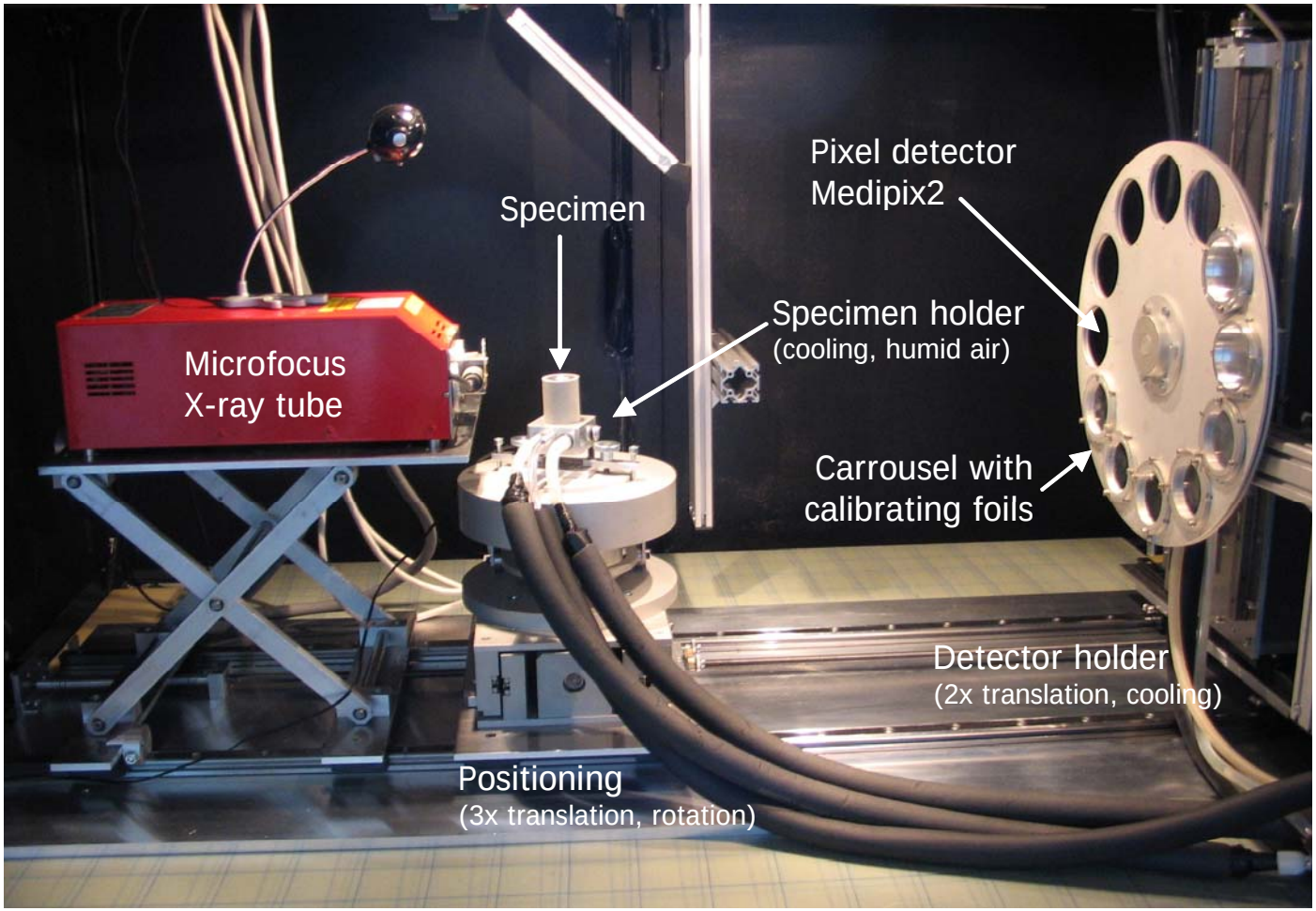
Medipix2 Cell Layout



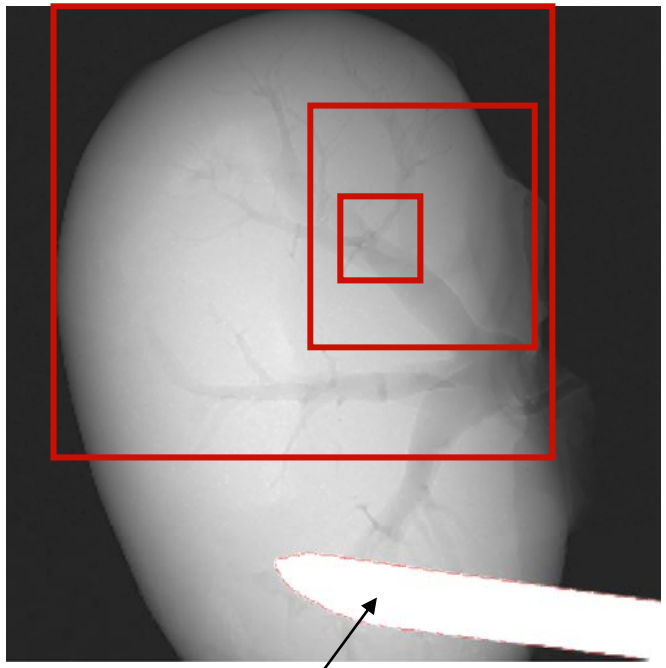
Medipix2 Chip Architecture



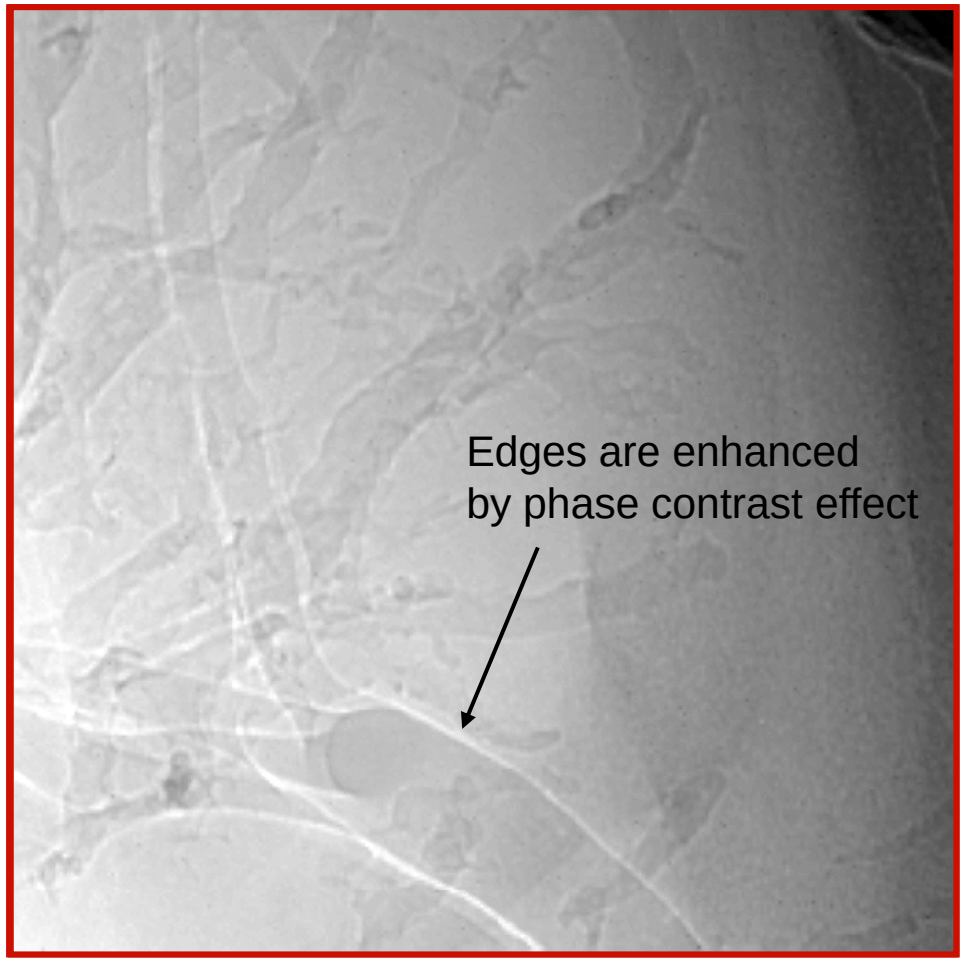
High resolution X-ray imaging using a micro-focus X-ray source(1)



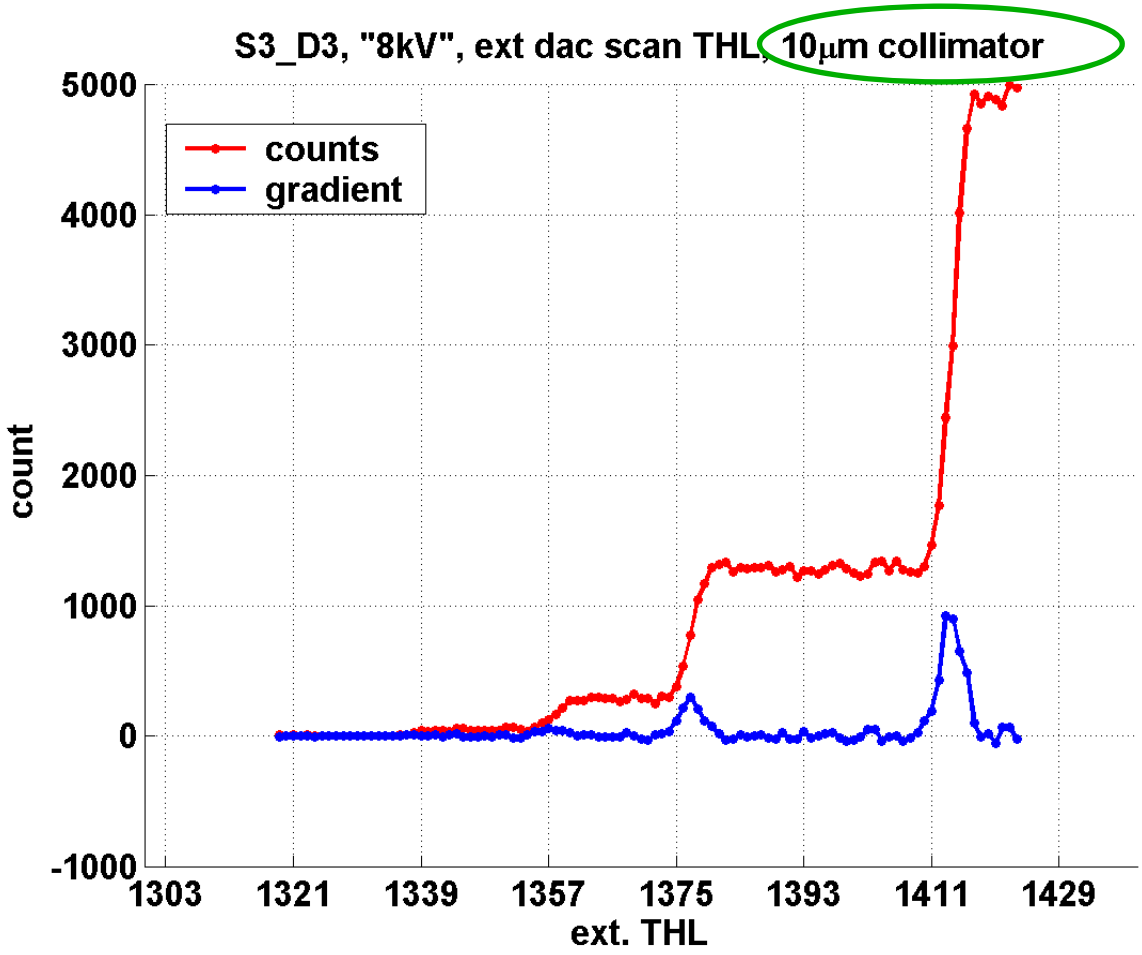
High resolution X-ray imaging using a micro-focus X-ray source(2)



Needle holding the sample



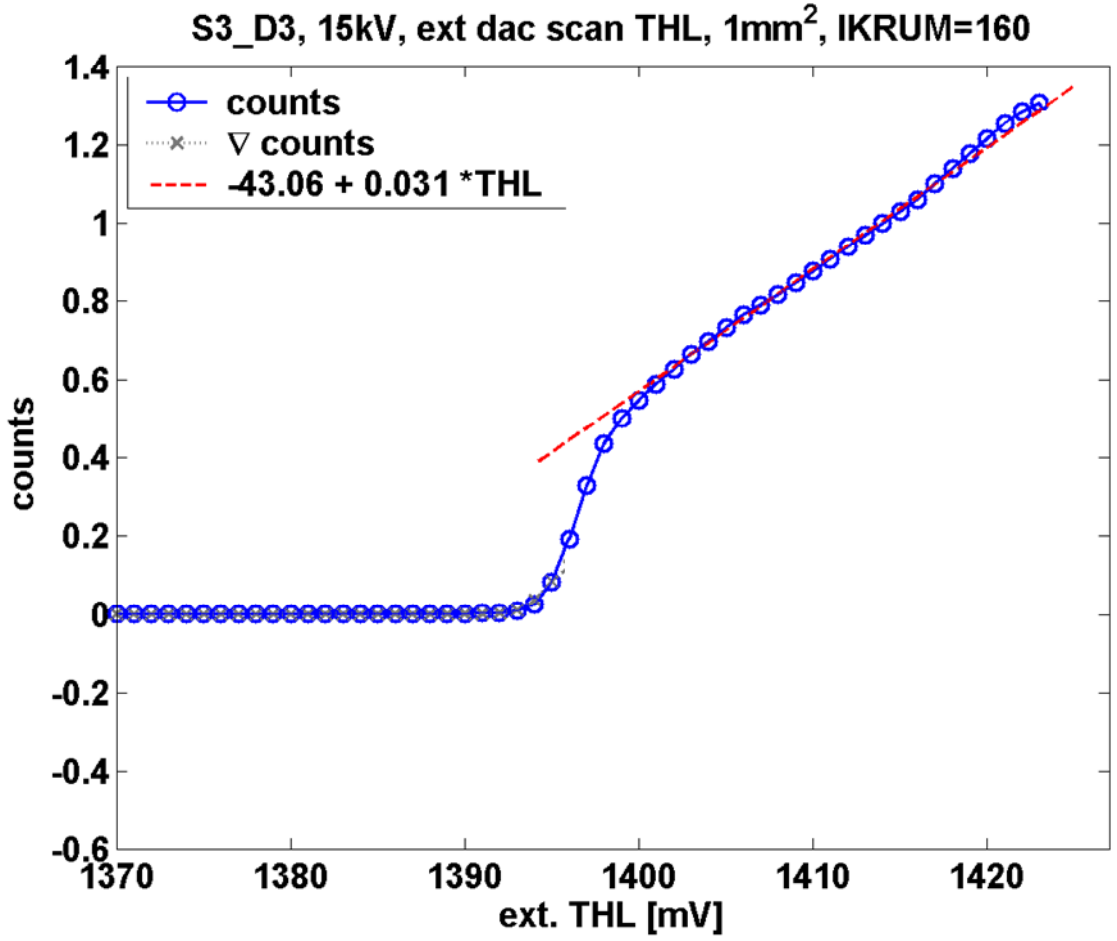
Calibration at ESRF – monochromatic pencil beam at pixel centre



Increasing threshold

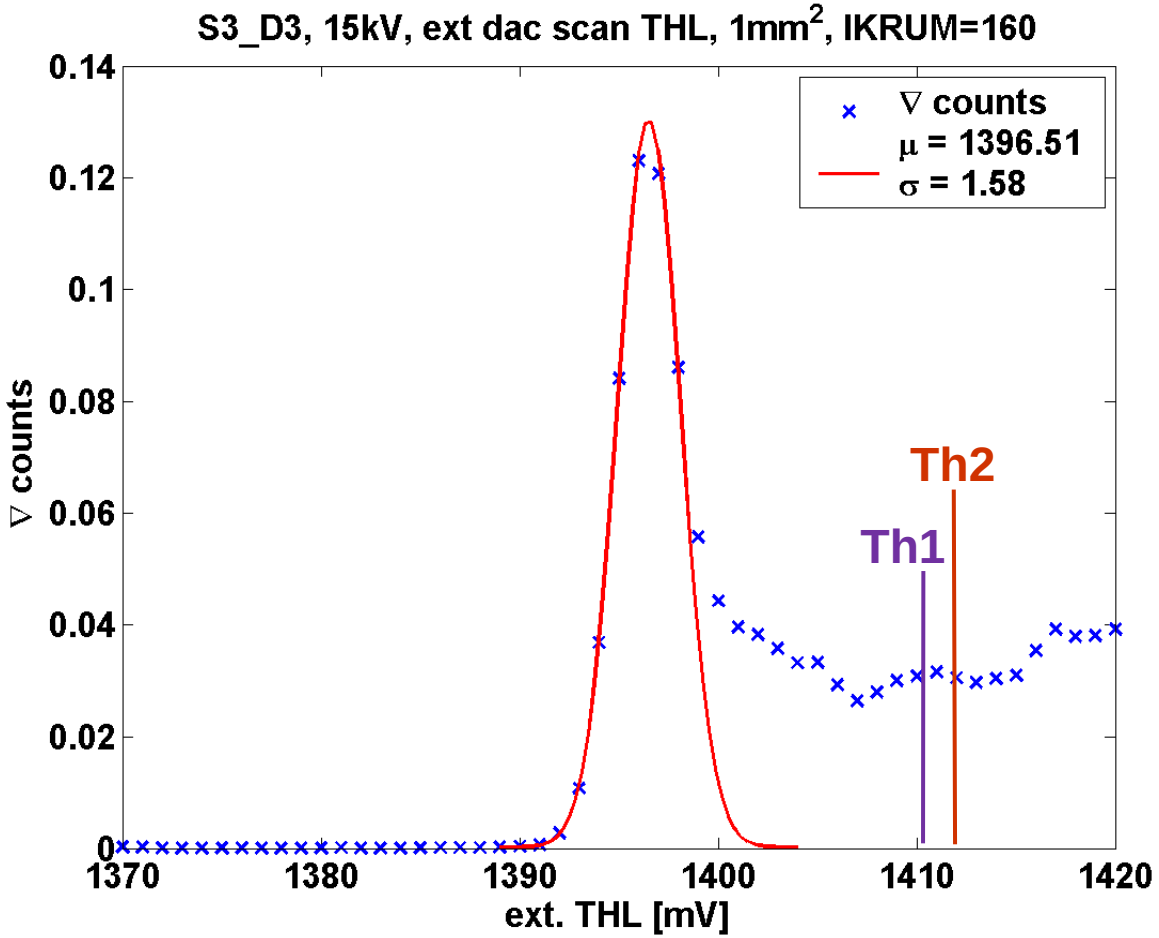
8kev plus harmonics….

Effect of Charge Sharing on Energy Resolution – monochromatic 1mm^2 beam



Increasing threshold

Effect of Charge Sharing on Energy Resolution – monochromatic 1mm^2 beam



Increasing threshold

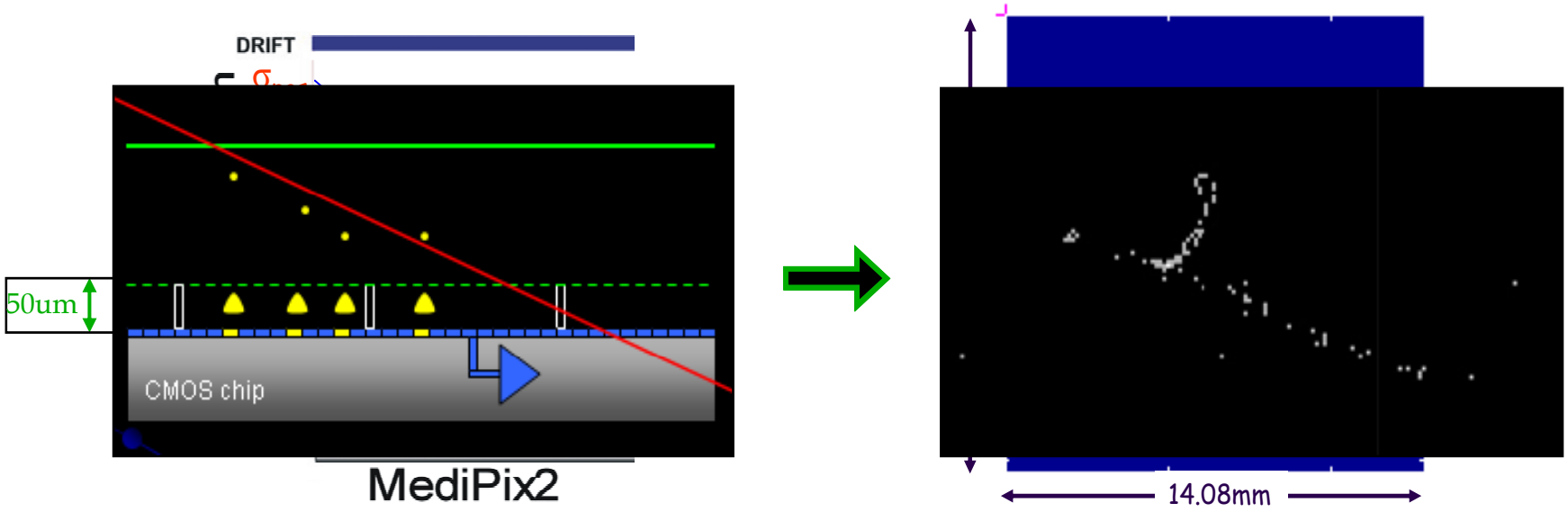
Performance and limitations of Medipix2 as an X-ray sensor

- **Single photon counting provides excellent noise free images**
- **Ideal in photon starved situations**

- **However, charge sharing in the sensor is an issue:**
  - **Flat field correction is sensitive to incoming spectrum**
  - **Energy resolution is limited by charge sharing tail**

From Medipix to Timepix

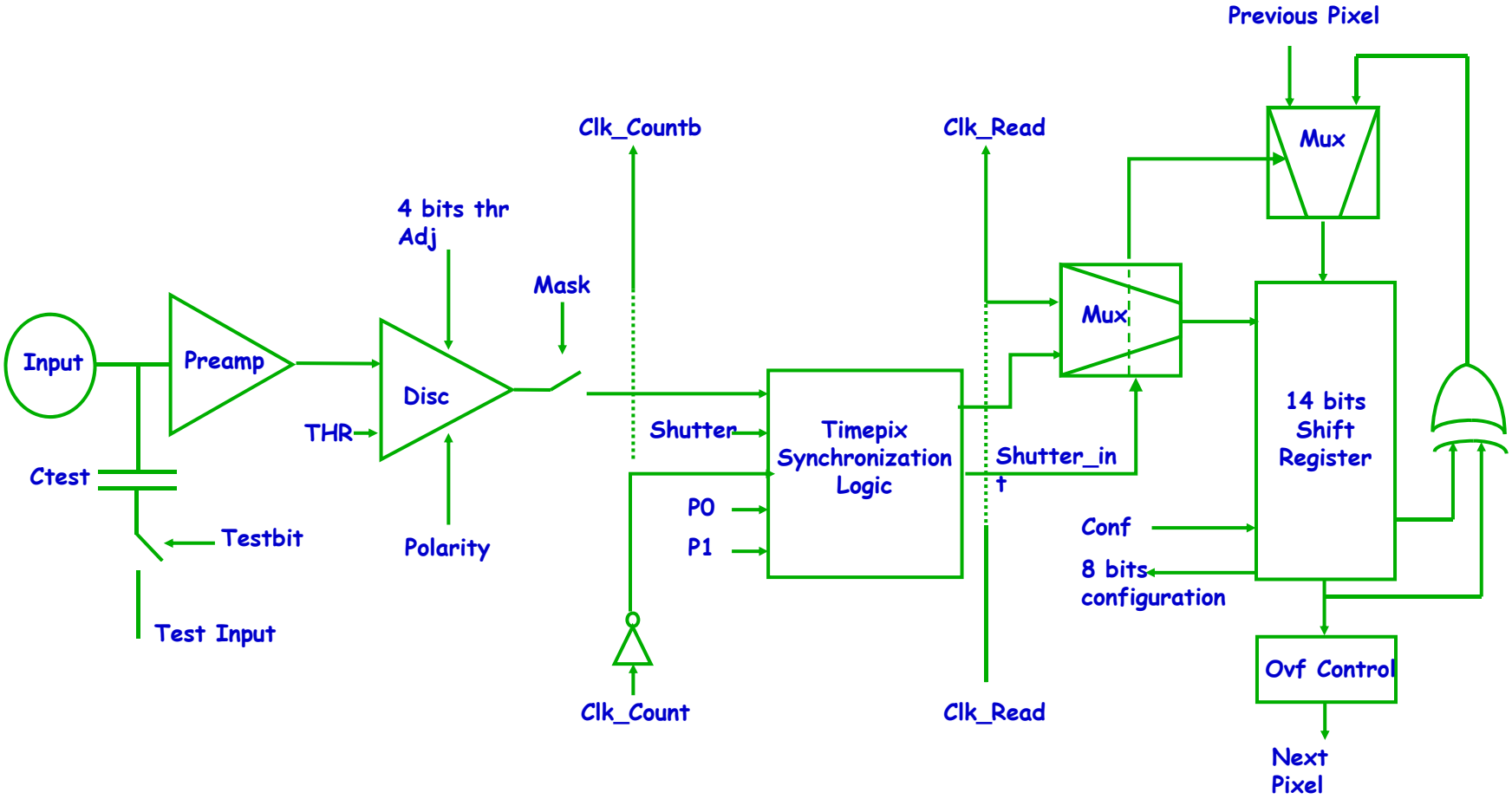
- A novel approach for the readout of a TPC at the future linear collider is to use a CMOS pixel detector combined with some kind of gas gain grid
- Using a *naked* photon counting chip Medipix2 coupled to GEMs or Micromegas demonstrated the feasibility of such approach



Motivation

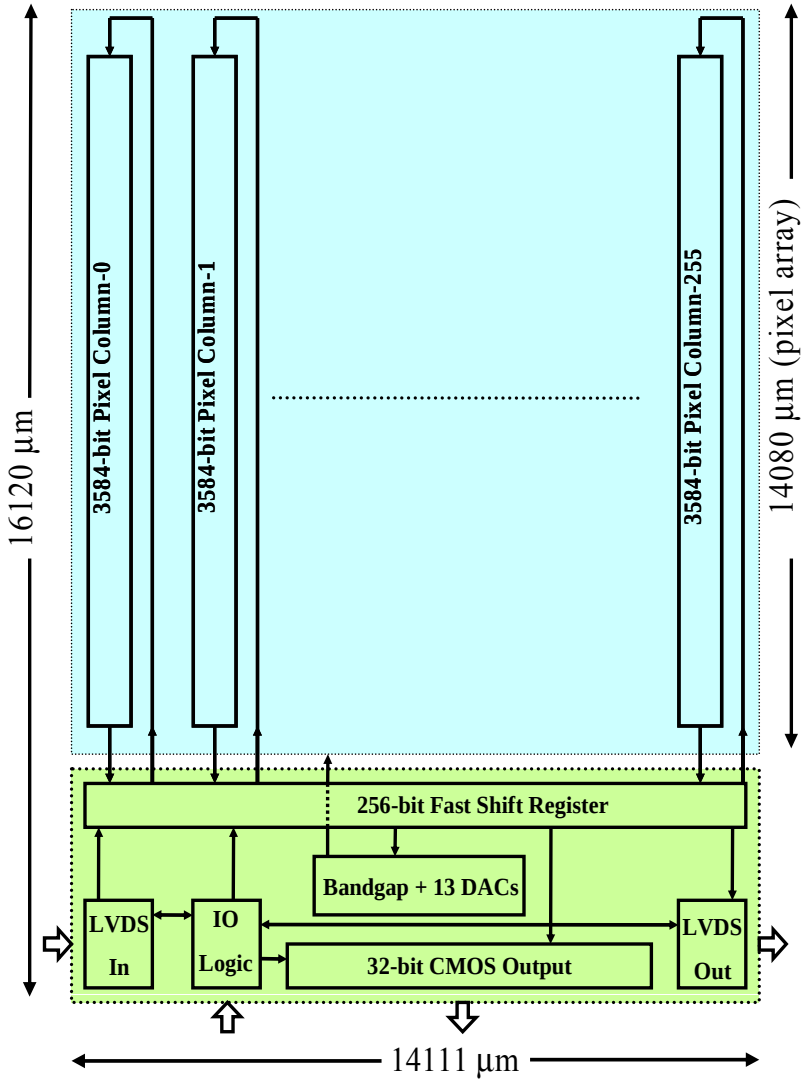
- **These experiments (by NIKHEF/Saclay, Freiburg 2004/2005) demonstrated that single electrons could be detected using a *naked* Medipix2 chip ⇒ 2D**
- **Did not provide information on the arrival time of the electron in the sensitive gas volume ⇒ 3D (position + time) !!!**
- **To further exploit this approach the Medipix2 has been redesigned to incorporate a time stamp with a tunable resolution of 100 to 10ns.**
- **Requirements:**
  - **Keep Timepix as similar as possible to Medipix2 in order to benefit from large prior effort in R/O hardware and software**
  - **Avoid major changes in pixel and/or readout logic – risk of chip failure due to poor mixed mode modeling**
  - **Eliminate 2nd threshold**
  - **Add possibility of programming pixel by pixel arrival time or TOT information**
- **This modification is supported by the JRA2/EUDET Collaboration (www.eudet.org)**

Timepix Schematic



Timepix chip architecture

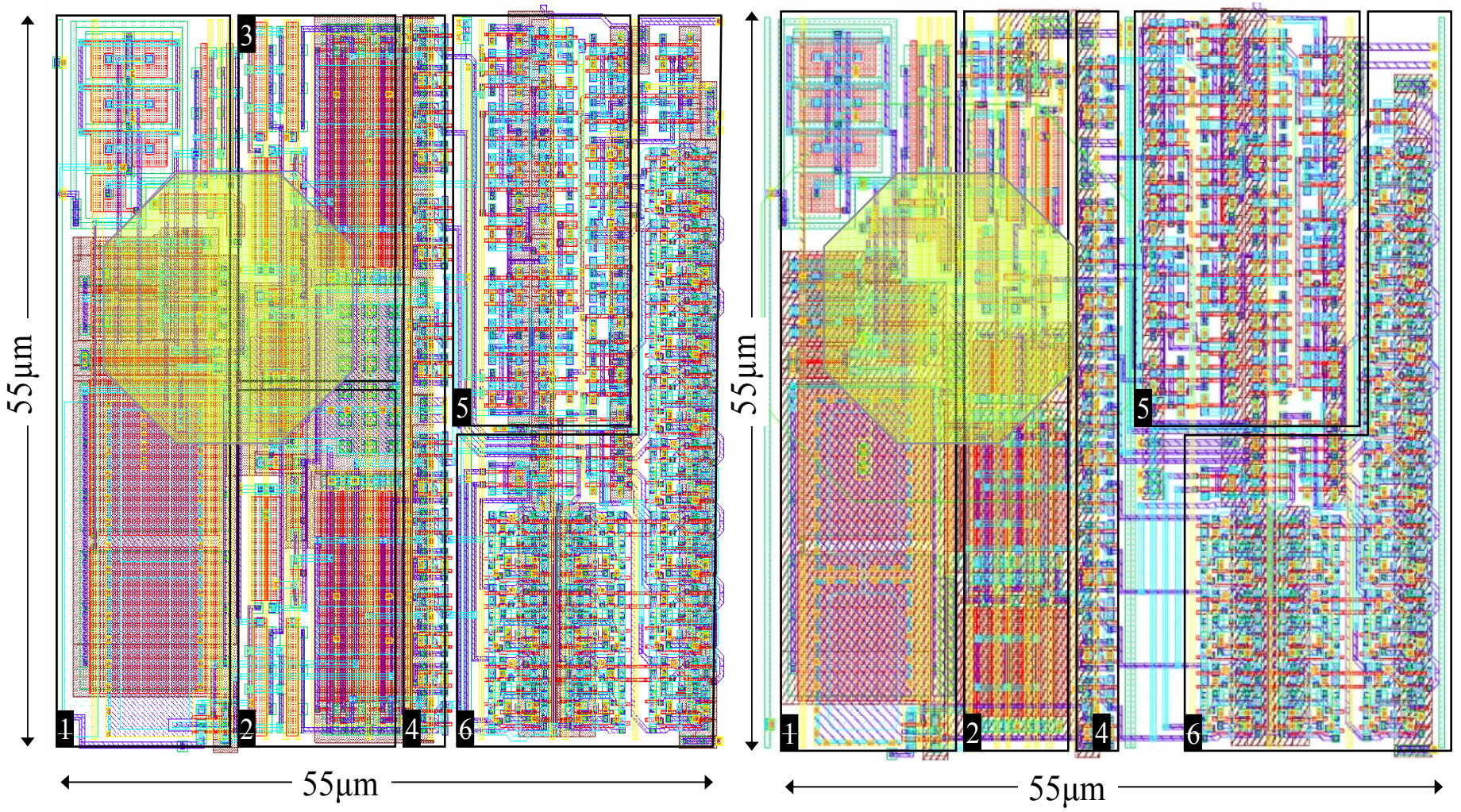
- **Chip architecture almost identical to Mpix2MXR20**
  - **M0=M1=1 and Shutter ON -> FClock used as Ref_Clk**
- **256x256 55µm square pixels**
- **Analog Power -> 440mW**
- **Digital Power (Ref_Clk=50MHz) -> 220mW**
- **Serial readout (@100MHz) -> 9.17 ms**
- **Parallel readout (@100MHz) -> 287 µs**
- **> 36M Transistors**



Timepix Layout status

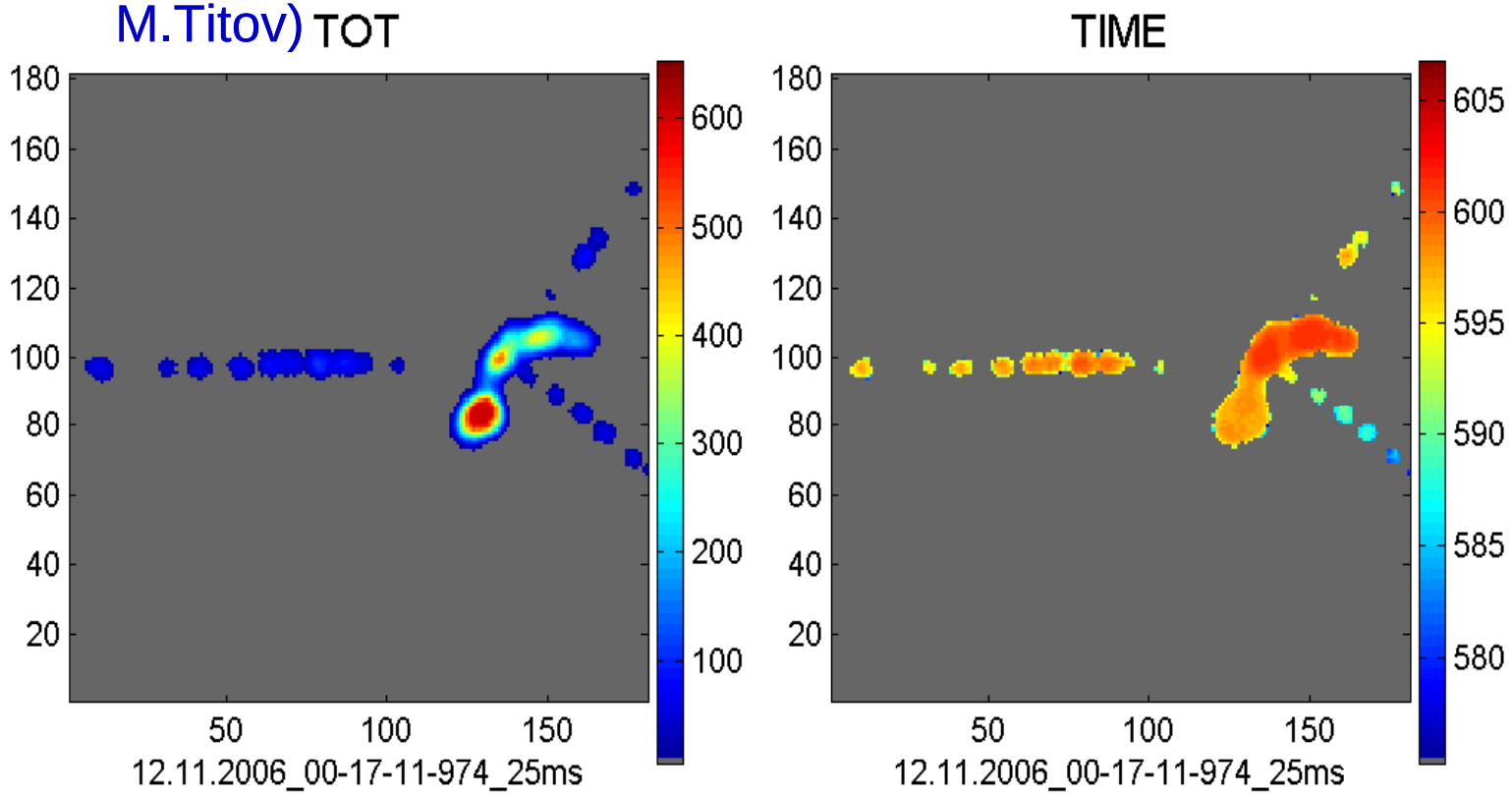
Mpix2MXR20 layout

Timepix layout



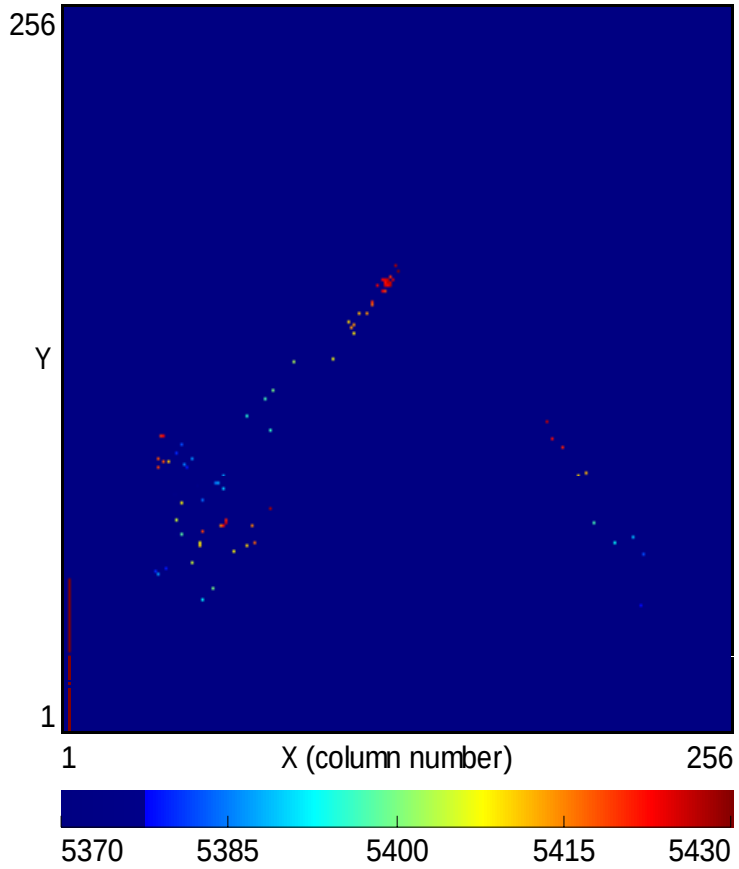
Timepix with 3-GEM detector

- DESY testbeam in November 2006 (A.Bamberger, M.Titov)



Timepix with Micromegas

- Nikhef January 2007 (thanks to J.Timmermans)



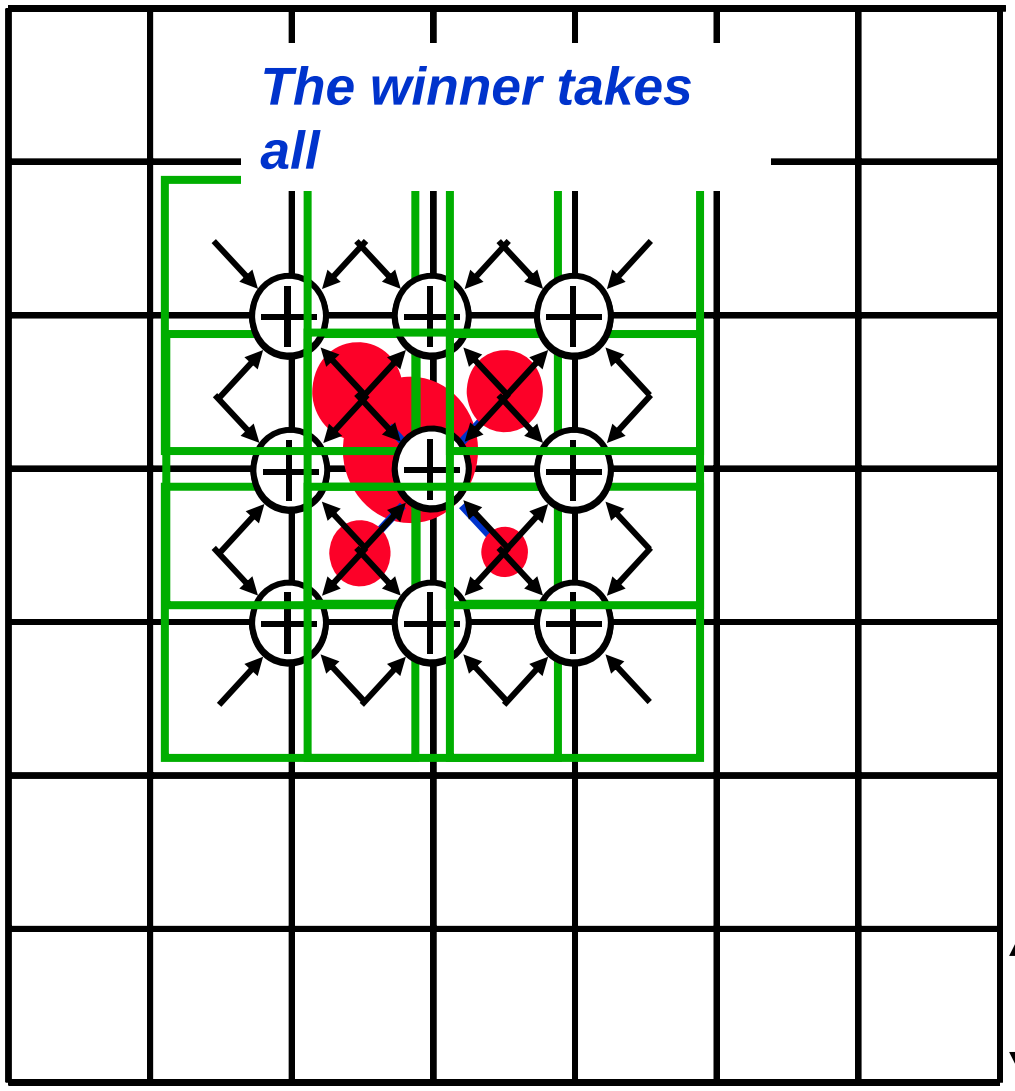
Timepix - summary

- Timepix development is driven by Time Projection Chamber readout for the International Linear Collider (EUDET consortium)
- Timepix will act as proof of principle for concept of CMOS TPC readout using existing Medipix2 readout system and software
- Initially foreseen for Time of Flight the chip is programmable to measure Time over Threshold – providing energy information in a low rate environment – or noise free integrated readout in higher rate environments

The Medipix3 Consortium

- University of Canterbury, Christchurch 8020, New Zealand
- CEA, Paris, France
- CERN, Geneva, Switzerland,
- Deutsches Elektronen-Synchrotron in der Helmholtz-Gemeinschaft, Hamburg, Germany
- Universitat Freiburg, Freiburg, Germany,
- University of Glasgow, Scotland
- Leiden Institute of Chemistry, Leiden University, The Netherlands
- NIKHEF, Amsterdam, The Netherlands
- Laboratory of Molecular Biology, Cambridge England
- Mid Sweden University, Sundsvall, Sweden,
- Czech Technical University, Prague, Czech Republic
- ESRF, Grenoble, France
- Universität Erlangen-Nurnberg, Erlangen, Germany
- University of California, Berkeley, USA
- VTT Information Technology, Espoo, FINLAND

Medipix3 – charge summing concept



- *The incoming charge processed is summed in every pixel cluster on an event-by-event basis*
- *The hit is assigned as a single hit*

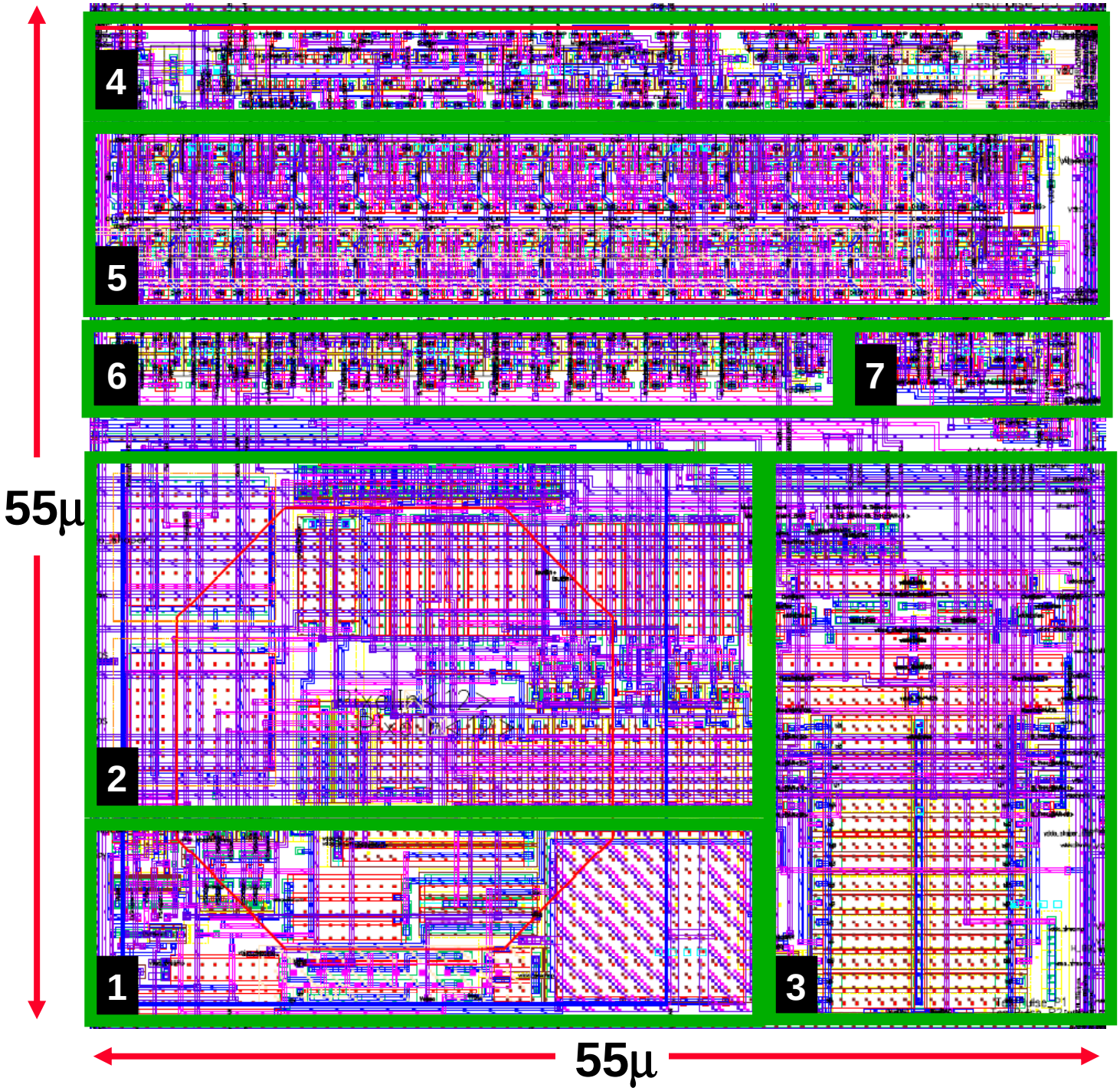
Medipix3 – pixel block diagram

BLOCK DIAGRAM PIXEL E

Input Pad
C_f
g_m
C_{test}
TestBit
Test Input
V_{fbk}
PolarityBit
GainMode
ThAdjustBit
ChSummingMode
From adjacent pixels (F, H, I)
x3
x1
x3
To adjacent pixels (A, B, D)
TH1
TH2
Disc
Disc
B_TH<0:3>
B_TH<4>
From adjacent pixels (A, B, D)
cluster common control logic + Arbitration circuitry
ModeContRW
DisablePixelCom
AdjustTHH
ModeCS_Cluster4
x2
Previous Pixel SR1
MUX
15 bits Shift Register SR1
Next Pixel SR1
To adjacent pixels (F, H, I)
Previous Pixel SR2
MUX
15 bits Shift Register SR2
Next Pixel SR2

ANALOG

DIGITAL



DIGITAL CIRCUITRY

4. Control logic (124)
5. 2x15bit counters / shift registers (480)
6. Configuration latches (152)
7. Arbitration circuits (100)

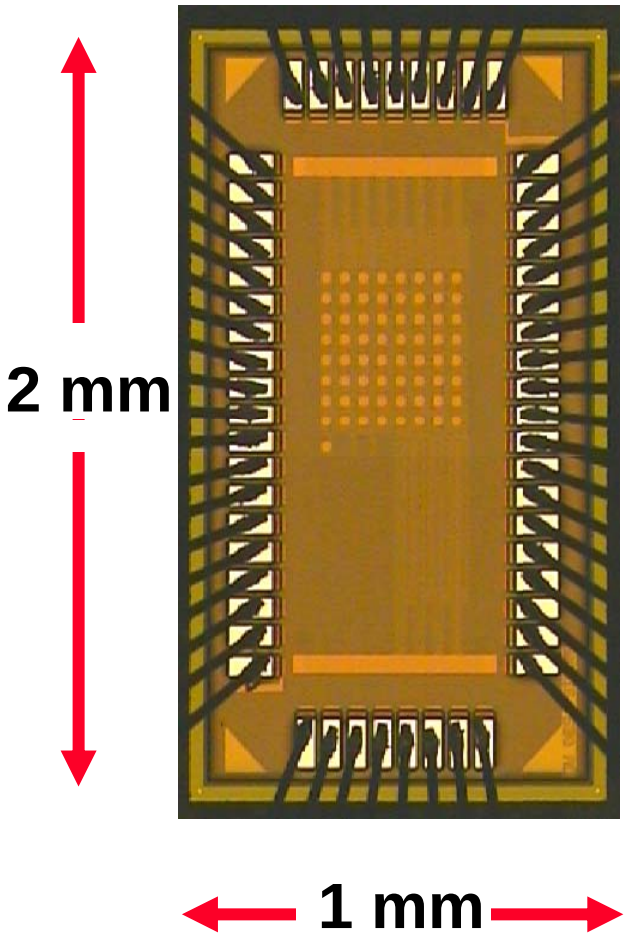
Total digital 856

ANALOG CIRCUITRY

1. Preamplifier (24)
2. Shaper (134)
3. Discriminators and Threshold Adjustment Circuits (72)

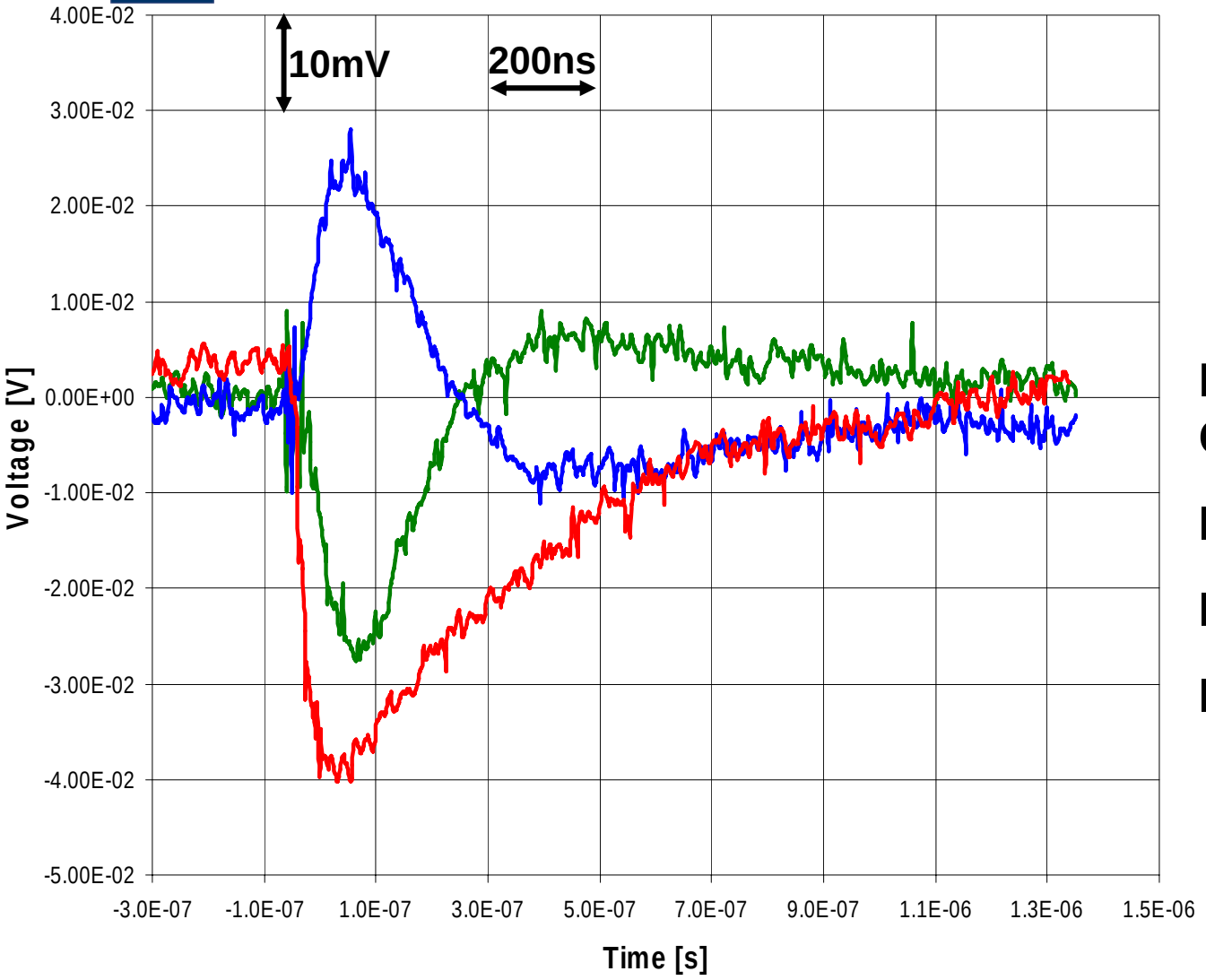
Total analog 230

The Medipix3 prototype chip



- 0.13μm technology
- 8 metal layers
- 8x8 pixel matrix

Pre-amp and shaper measurements



Response to a 3.71 Ke- input charge

Nominal Conditions

I_{CSA}=2μA

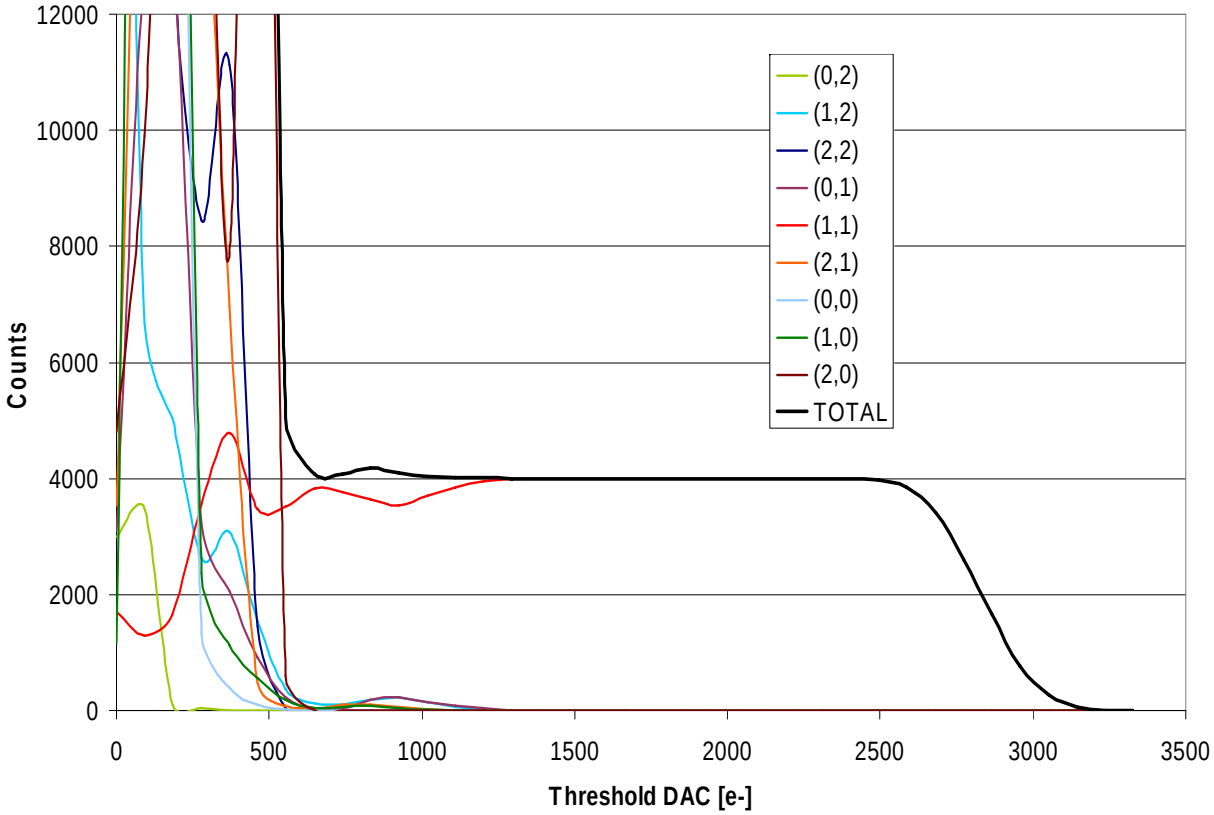
I_{RESET}=2.5nA

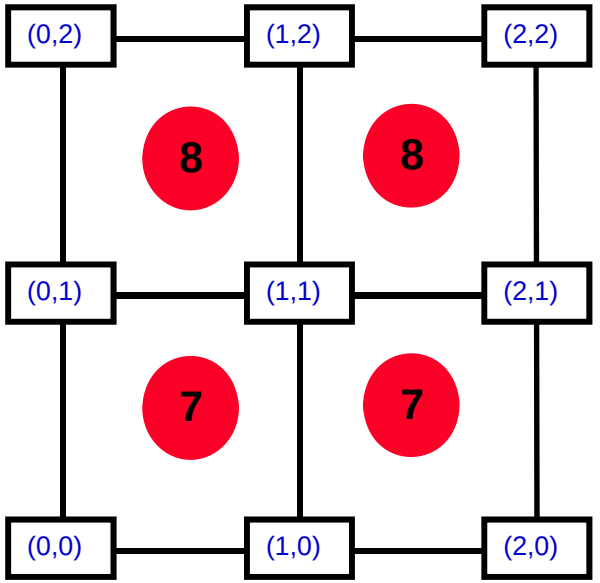
I_{SHAPER}=500nA

Medipix3 – charge summing measurements

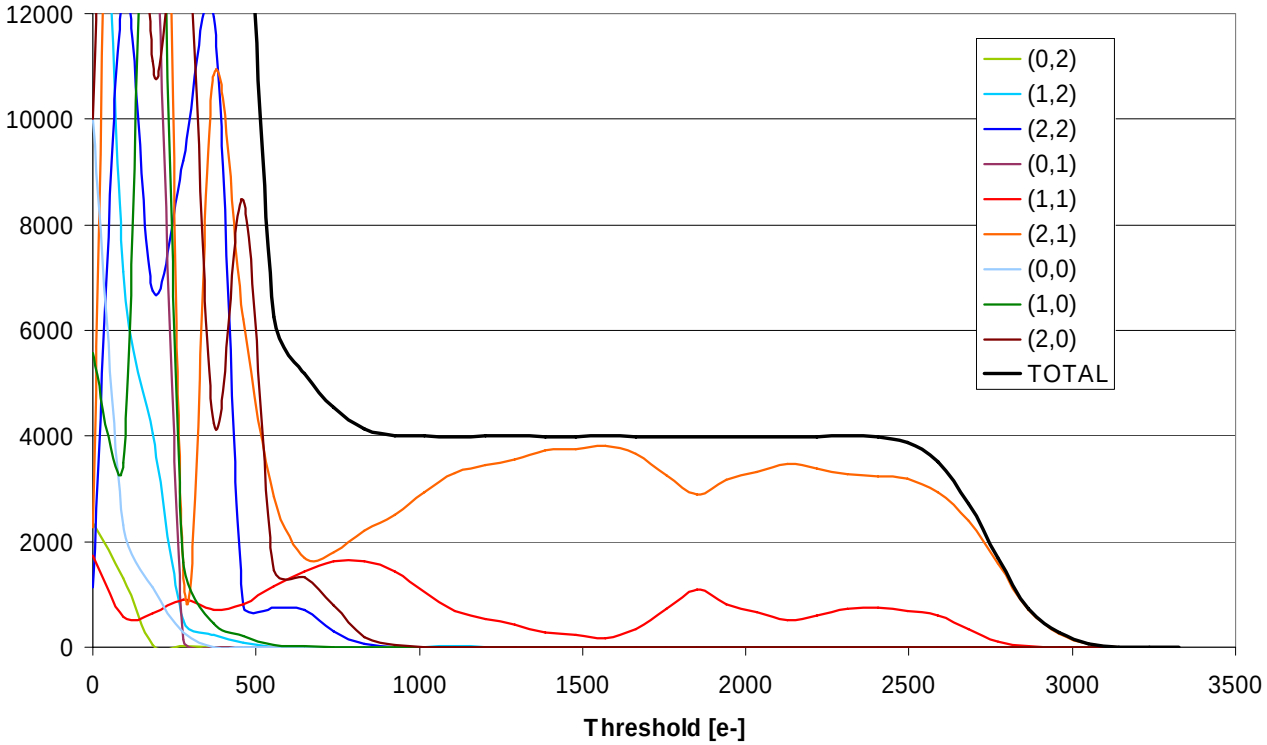
Input charge: 2.78Ke-
(30 DAC pulses)

4000 pulses





Medipix3 – charge summing measurements



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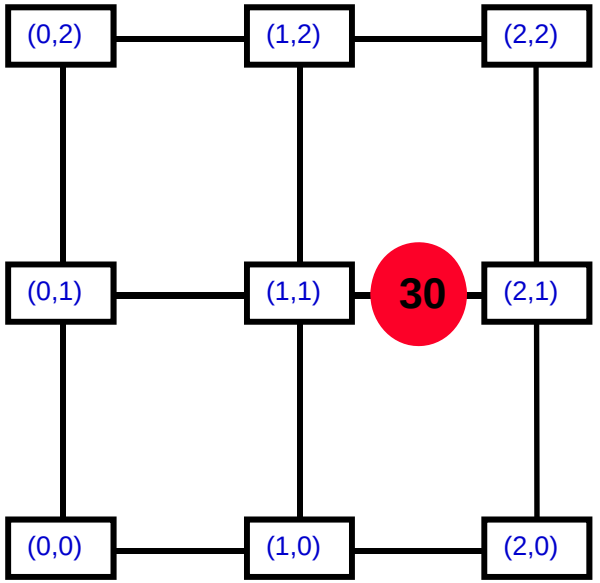

Medipix3 – charge summing measurements

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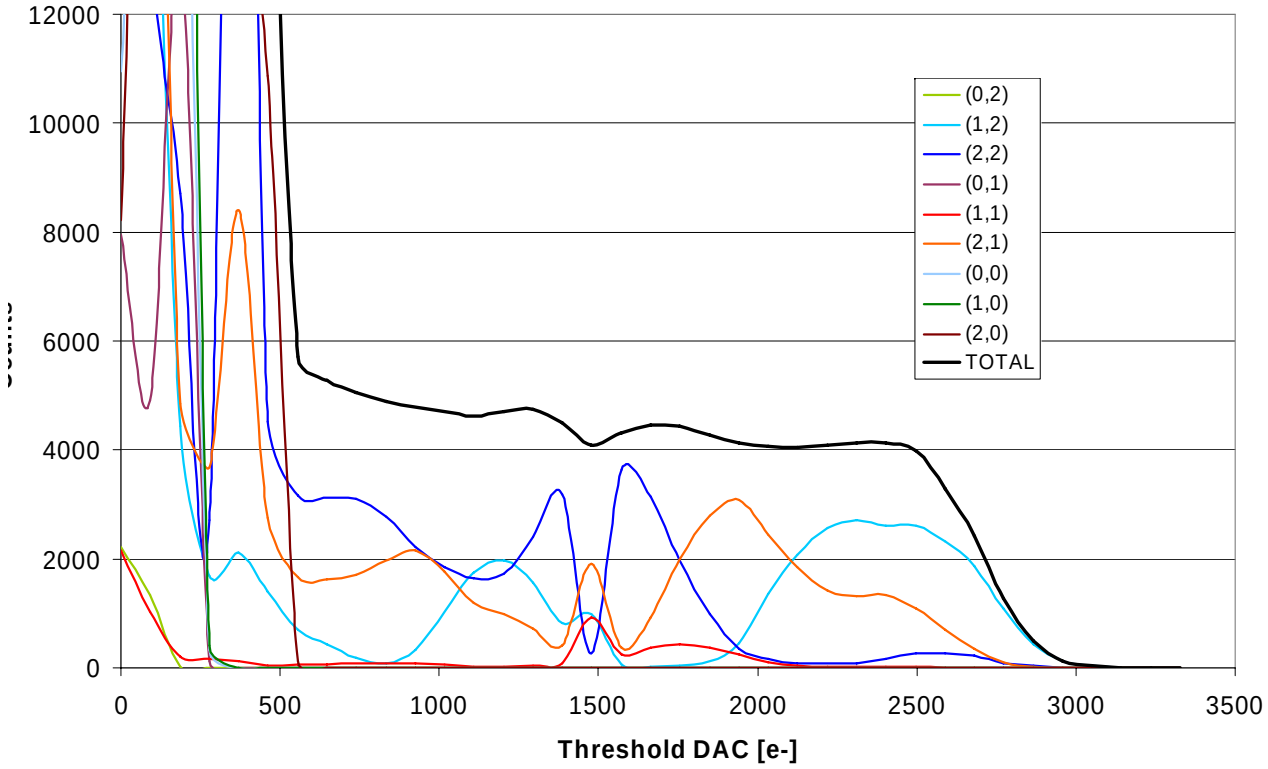
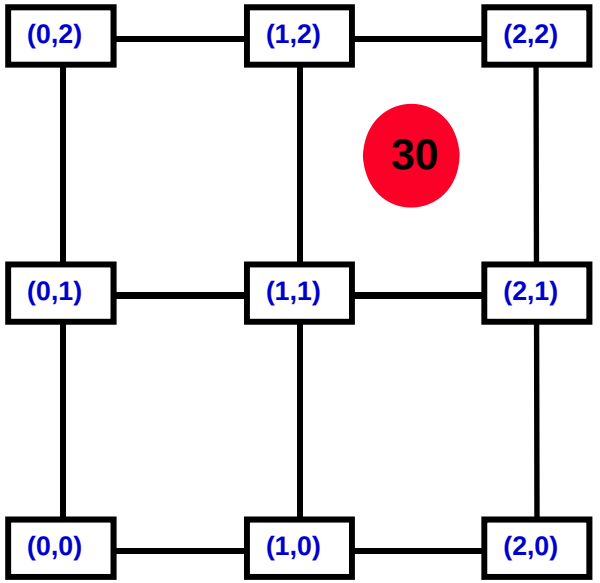


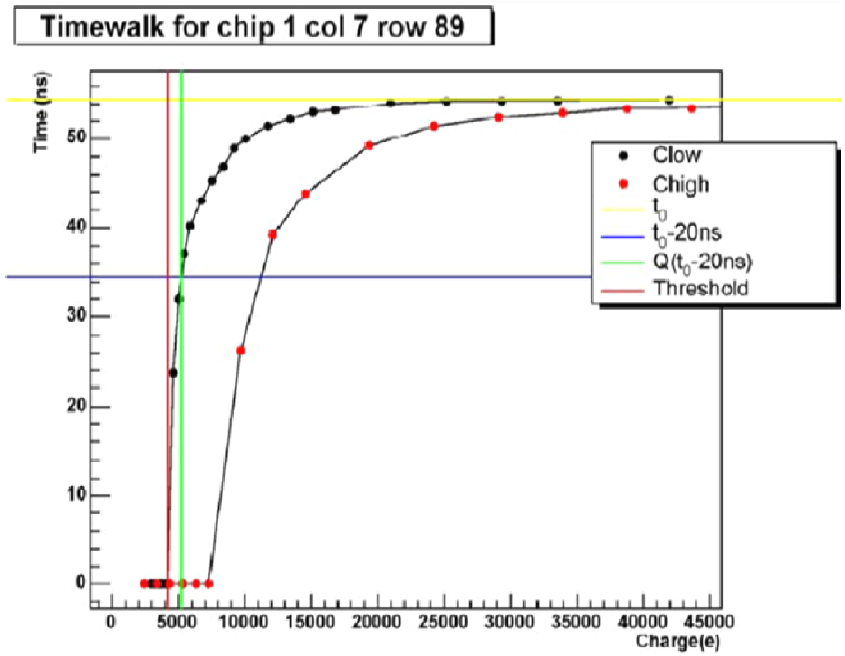


Medipix3 – electrical measurements summary

Front End Operating Mode	Single Pixel Mode	Charge Summing Mode
CSA Gain (C_F)	11.4mV/Ke- (C_F=14fF)	
CSA-Shaper Gain	65nA/Ke- (High Gain Mode), 30nA/Ke- (Low Gain Mode)	
Non linearity	<5% 9Ke- (High Gain Mode) , <2% 22Ke- (Low Gain Mode)	
Peaking Time	~100ns	
Return to baseline	<1μs for 4Ke- (nominal conditions), <300ns (tuning R_F)	
Electronic noise	72e^- r.m.s.	144e^- r.m.s.
Analog power dissipation	16.2μW (nominal conditions)	

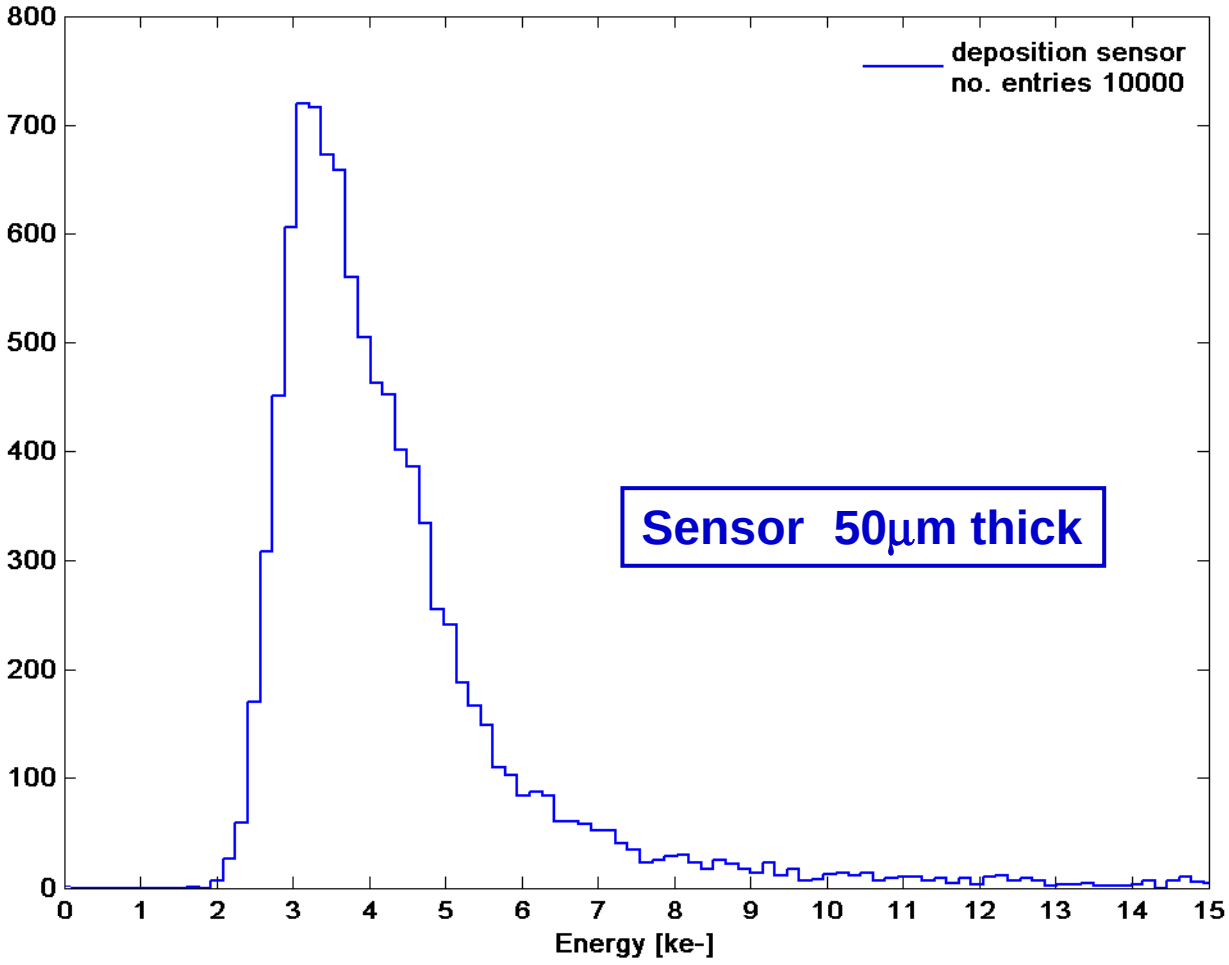
How about tracking at SLHC?

- Thin sensors desirable – less mass better spatial resolution
  - Low thresholds
- Clean readout still essential
  - Good separation threshold-noise
- Time walk can be an issue:



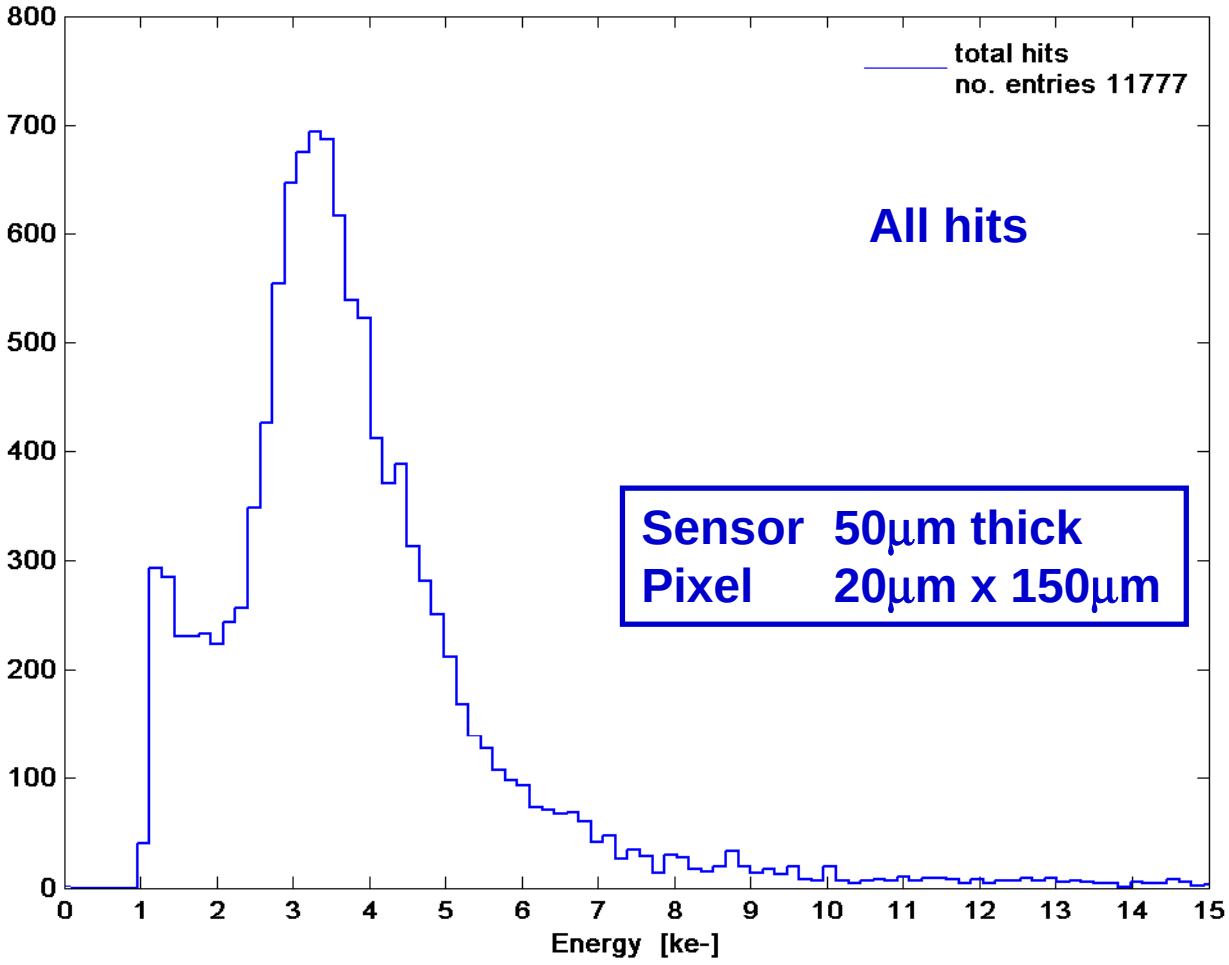
K. Einsweiller, ATLAS Pixel Detector, LBL Instrumentation Colloquim , 13 April 2005
See: http://instrumentationcolloquium.lbl.gov/The_ATLAS_pixel_detector.pdf

Charge deposition with MIPs – unsegmented Si

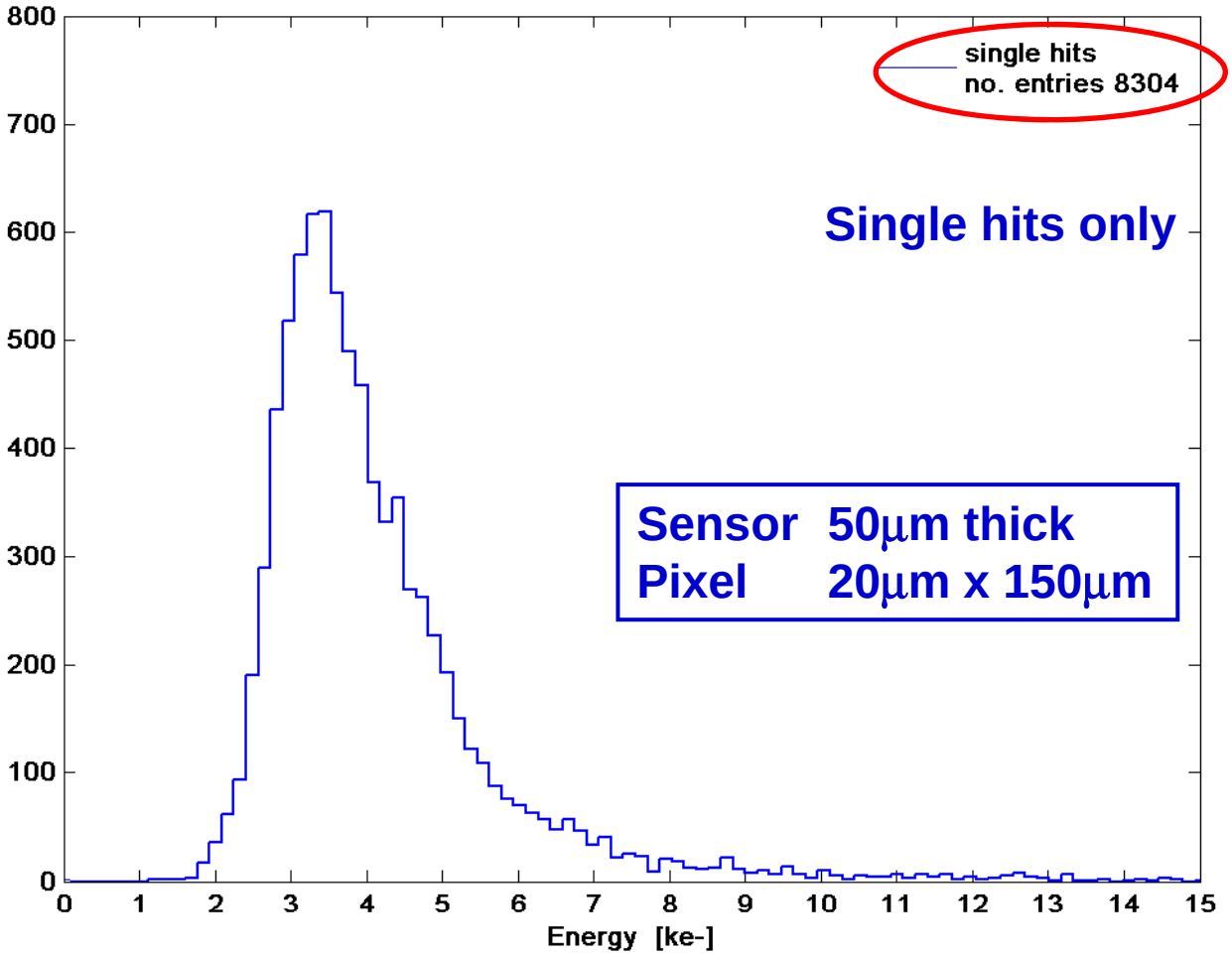


10 000 electrons 20MeV **0 deg angle of incidence**

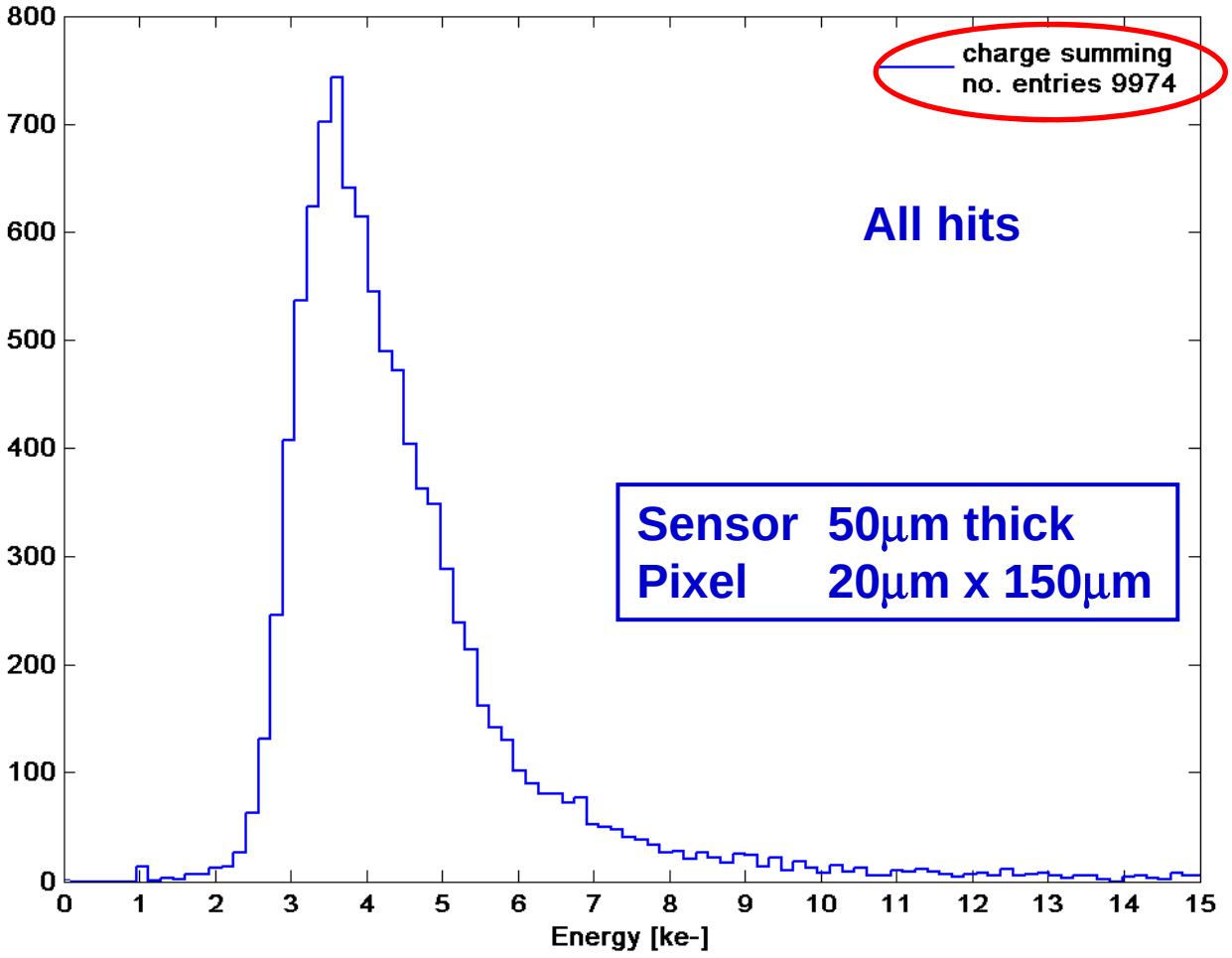
Charge detection – Conventional Readout



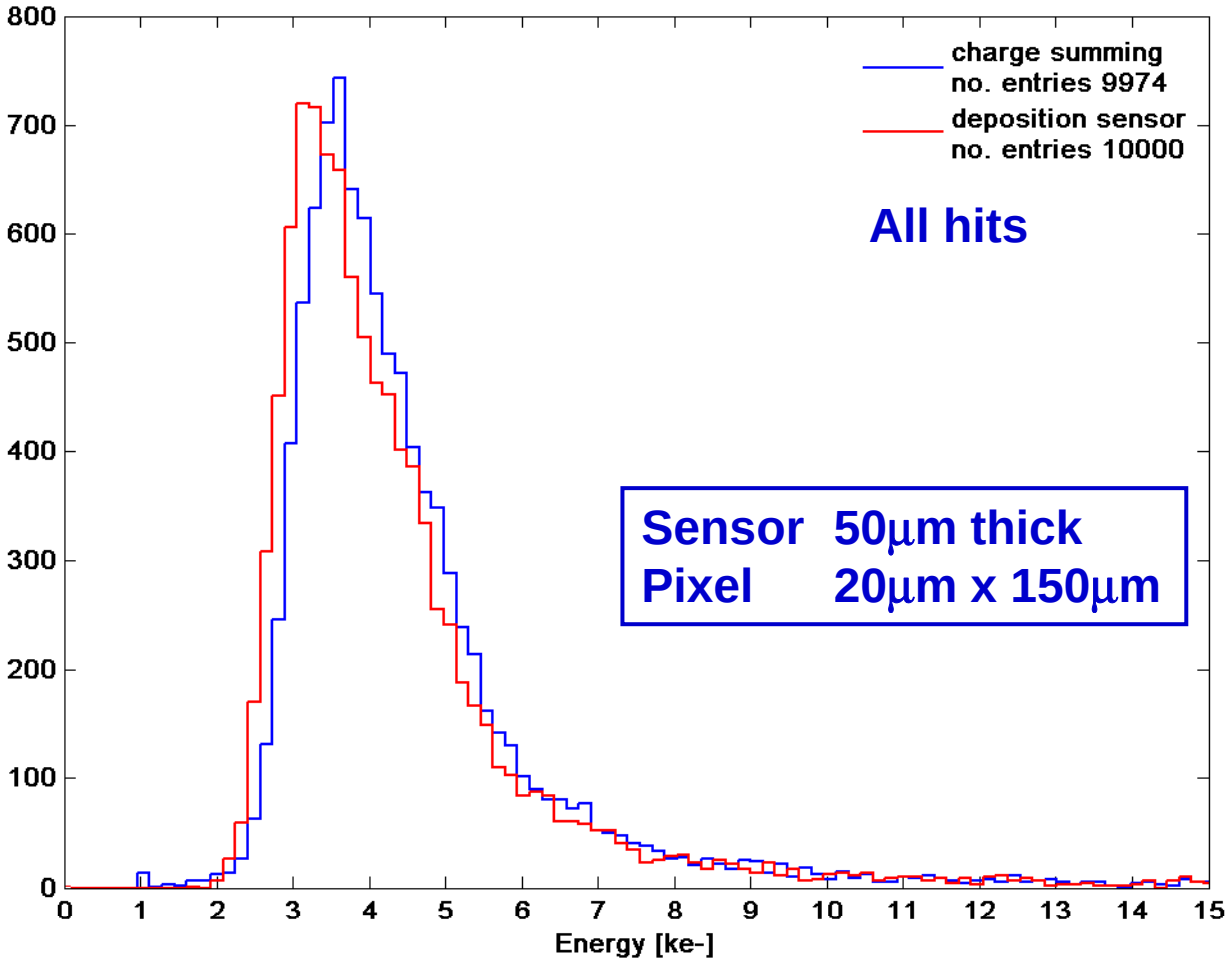
Charge detection – Conventional Readout



Charge detection – Charge summing Readout



Comparison
Charge deposition – Charge summing Readout



Summary

- The Timepix chip, although funded by EUDet, evolved from the successful Medipix2 development
- The ready availability of chips and readout systems led to the initial experiments with gas and Medipix2 and sped up enormously the exploitation of Timepix by the users
- The future Medipix3 chip although developed to solve a problem in single photon counting may provide a solution to very precise and clean tracking
- Given the length and cost of such developments it makes sense to cluster users around a single ASIC development (technology oriented development) …

Requirements for a general purpose gas and semiconductor readout chip

- Clean self-triggered readout
- Low and uniform threshold
- FAST-OR?
- High spatial resolution
- Combined energy and arrival time information

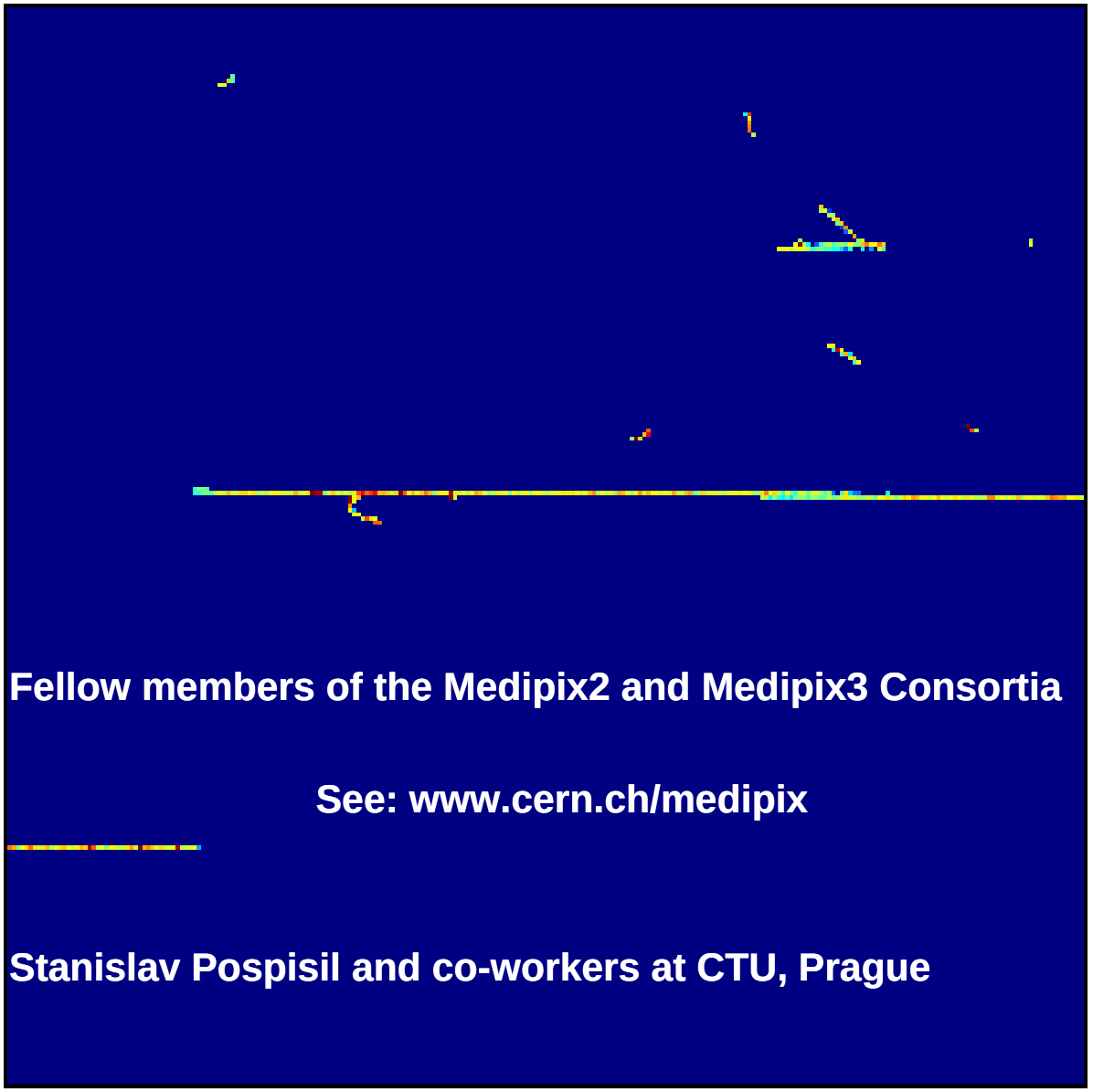
- How can this be achieved?

A Data Push Pixel Detector Readout Chip suitable for gas and Si (GasSiPix)

*** Idea developed together with Ruud Kluit of NIKHEF ***

- Take front end like Medipix3 or GOSSIPO-2 (suitable for semiconductor and gas readout)
- Charge summing may or may not be used to take YES/NO decision of hit
- For gas detectors include spark protection and shielding??
- Use precision time tag unit from Nikhef (GOSSIPO-2 V. Gromov) in pixel to measure time to 1-2ns
- Use TOT (sum or single channel) for energy measurement
- Chip may be inhibited by externally applied shutter and/or pushes data out spontaneously
- Detailed specs (noise, shaping time, readout architecture) to be worked out with users

Acknowledgements



Fellow members of the Medipix2 and Medipix3 Consortia

See: www.cern.ch/medipix

Stanislav Pospisil and co-workers at CTU, Prague