DPG Session

- Di, 16:00–18:35 ST 3 T 44: Gaseoues Detectors

- 16:00 T 44.1 Gruppenbericht: A Prototype High Pressure Gas **Time Projection Chamber** for Future Long Baseline Neutrino Experiments — •Philip Hamacher-Baumann for the HPTPC collaboration
- 16:20 T 44.2 The contribution has been withdrawn.
- 16:35 T 44.3 Fake track studies for the ATLAS TRT in high pileup scenarios — •Patrick Bauer, Klaus Desch, and Christian Grefe
- 16:50 T 44.4 Commissioning of a new gas system for the Würzburg cosmic ray facility — •Thorben Swirski, Deb Sankar Bhattacharya, and Raimund Ströhmer
- 17:05 T 44.5 Developement of a low background low energy X-ray detector for IAXO — •Tobias Schiffer, Klaus Desch, and Jochen Kaminski
- 17:20 T 44.6 Setup of a prototype for the SHiP Straw Tracker Spectrometer — •Benedict Kaiser, Caren Hagner, Daniel Bick, Stefan Bieschke, and Walter Schmidt-Parzefall
- 17:35 T 44.7 Measuring the transverse diffusion with a Gas Monitoring Chamber — Philip Hamacher-Baumann, •Thomas Radermacher, Stefan Roth, and Jochen Steinmann
- 17:50 T 44.8 Studies on Temperature Effects in **GridPix**-based Detectors — •Lucian Scharenberg, Klaus Desch, Jochen Kaminski, and Tobias Schiffer
- 18:05 T 44.9 Study of ionizazion, apmplification and energy resolution in **GridPix** detectors — Klaus Desch, •Markus Gruber, and Jochen Kaminski
- 18:20 T 44.10 **ROPPERI** - A TPC readout with GEMs, pads and Timepix — •Ulrich Einhaus

ROPPERI

Readout Of a Pad Plane with ElectRonics designed for pIxels
-
A TPC readout with GEMs, pads and Timepix

Ulrich Einhaus (DESY)
Jochen Kaminski (Uni Bonn), Michele Caselle (KIT)
DPG Frühjahrstagung Aachen
26.03.2019

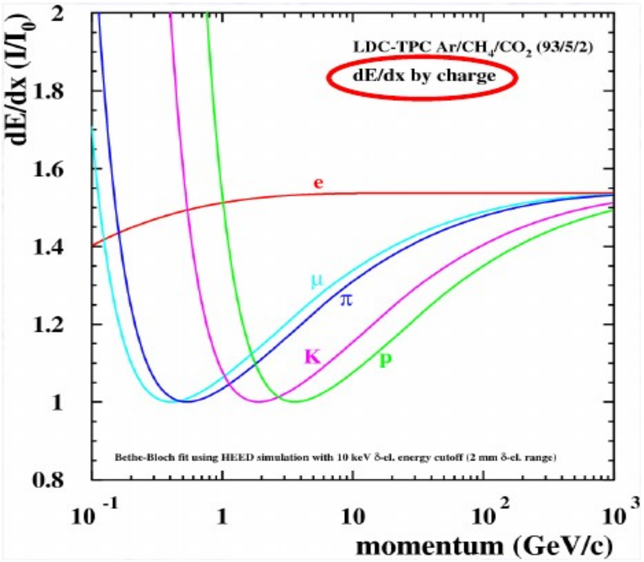
Content

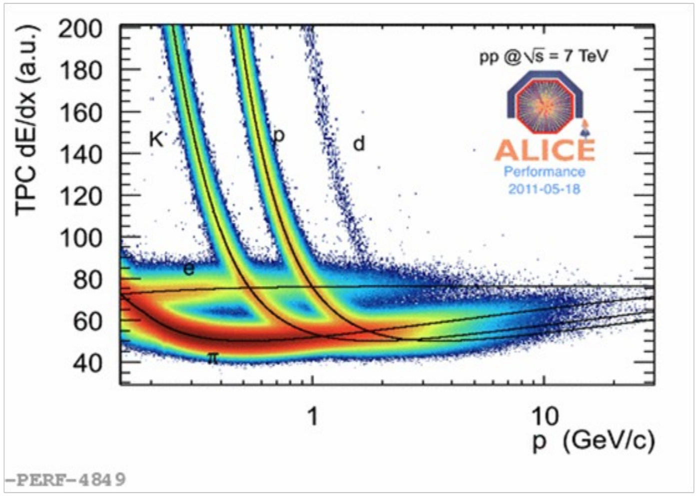
- Motivation: High Granularity dE/dx
- Software Simulation: Prospects
- Hardware Development: Feasibility

dE/dx in a TPC

- Energy loss measurement is an advantageous intrinsic capability of TPCs
- Via Bethe-Bloch curve in combination with momentum this leads to the identification of the particle species
- The measurement is usually done via charge summation
- Due to large fluctuations in each ionisation step like δ-electrons the charge / distance distribution is Landau shaped → large RMS → mediocre correlation with energy loss

M. Hauschild: dE/dx and Particle ID Performance with Cluster Counting; at ILC Ws. Valencia 2006





ALICE Collaboration: A Very High Momentum Particle Identification Detector
DOI: 10.1140/epjp/i2014-14091-5

dE/dx Resolution at High Granularity

- To increase resolution increase granularity

- Empirically found: $$\sigma(dE/dx) \propto L^{-0.34} \times N^{-0.13}$$
  - Introduce readout granularity G = N/L $$\sigma(dE/dx) \propto L^{-0.47} \times G^{-0.13}$$

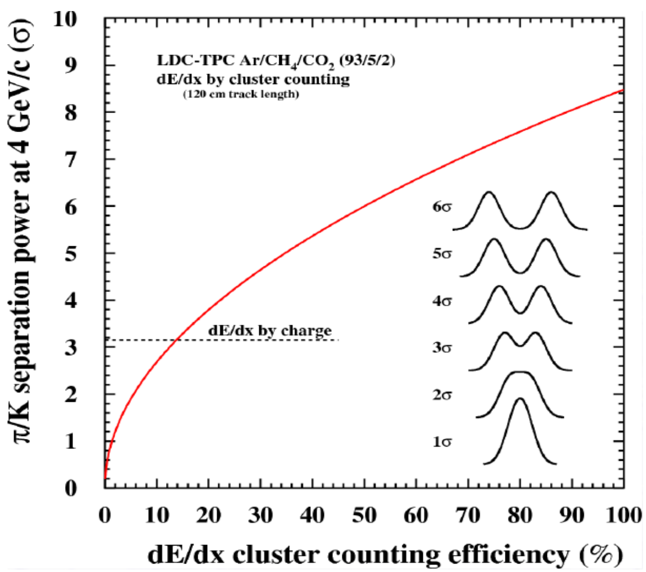
- Usual approach: Keep G constant, vary L (TPCs of different size, extrapolation of small prototype to full detector)

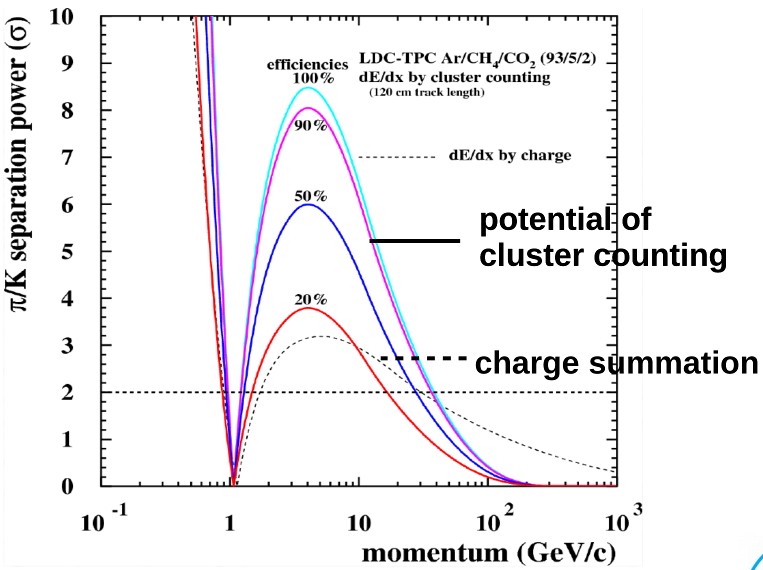
- Here: Keep L constant, very G
  This should improve dE/dx resolution with conventional method of charge summation for higher granularity.

Cluster Counting

- The number of ionisation steps / distance is Poisson shaped
  → smaller RMS → better correlation → better particle identification
- Counting clusters allows for improved particle separation compared to conventional charge summation
- Depends on fraction of identified clusters (counting efficiency)
  → Need sufficient granularity to identify clusters!

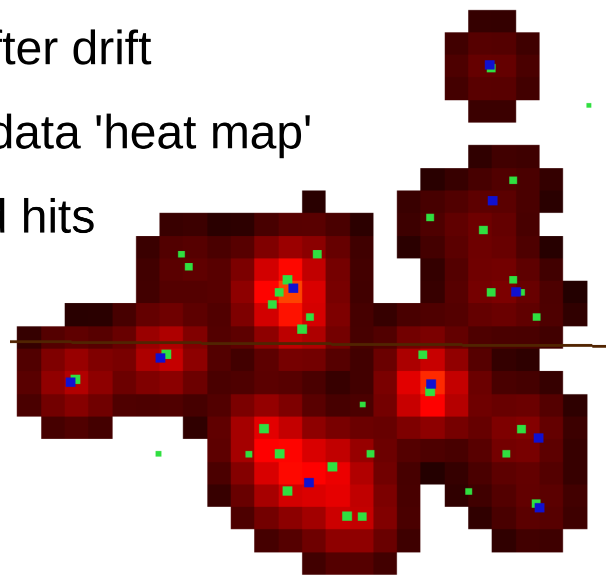
M. Hauschild: dE/dx and Particle ID Performance with Cluster Counting; at ILC Ws. Valencia 2006





Simulation: Software

- Simulation and reconstruction chain: MarlinTPC within the ILCsoft framework
- Cluster identification via external software 'Source Extractor' → returns 'hits' for tracking [http://www.astromatic.net/software/sextractor]
- Event display:
  - Green: electrons after drift
  - Red: digitised raw data 'heat map'
  - Blue: reconstructed hits
- Count number of reconstructed hits



Simulation

- Generate MCParticles
- Primary Ionisation
- Drift
- GEM Amplification
- Projection onto Timepix
- Timepix Digitisation

Reconstruction

- Export to .fits
- Source Extractor
- Import to .slcio
- Tracking: Hough Trafo

Analysis

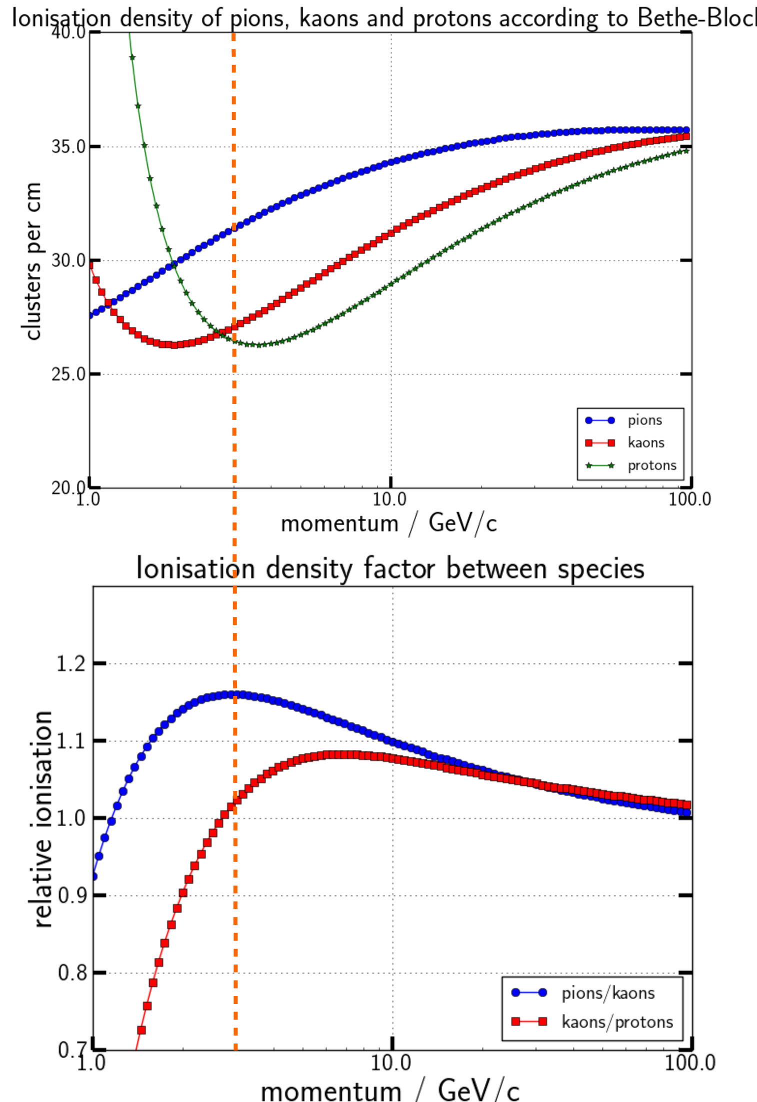
- Analysis e.g. cluster-hit identification

Studied Scenario

- Track length = 300 mm
- Compare pions and kaons at 3 GeV, relative ionisation difference of 15 %
- Cluster counting 'resolution' difficult to define
- Use separation power:

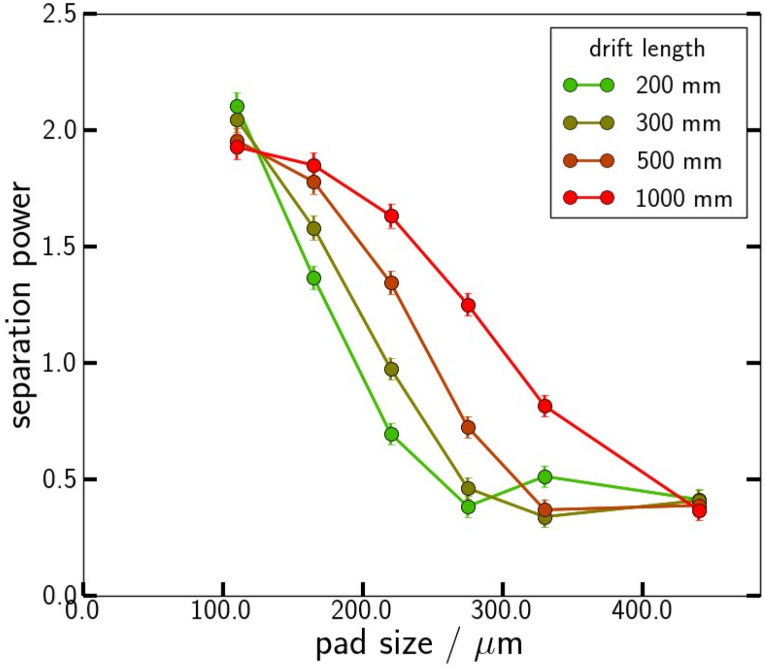
$$\rightarrow S = \frac{|\mu_\pi - \mu_K|}{\sqrt{\frac{1}{2}\left(\sigma_\pi^2 + \sigma_K^2\right)}}$$

- Use benchmark point to compare separation power of charge summation and cluster counting



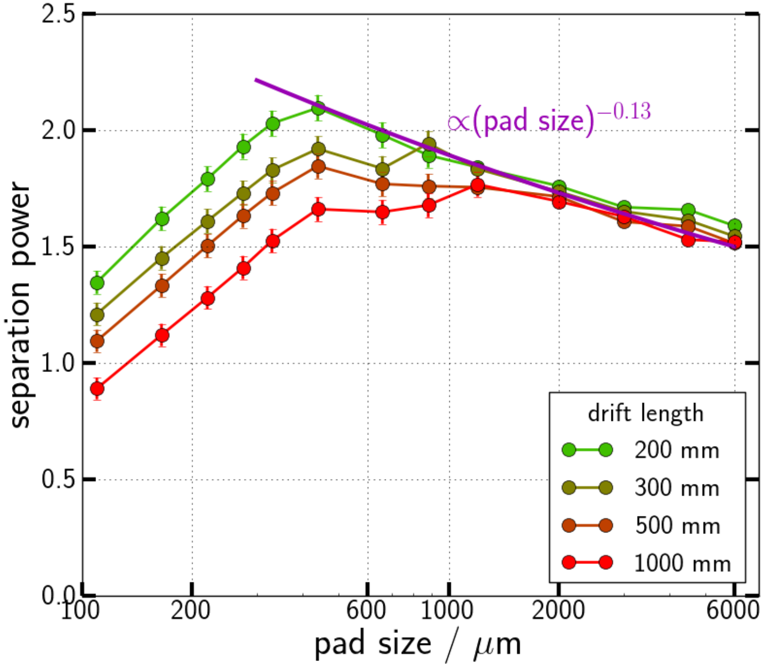
Simulation Results

Cluster counting



→ Need very high granularity, pad sizes < 200 µm!

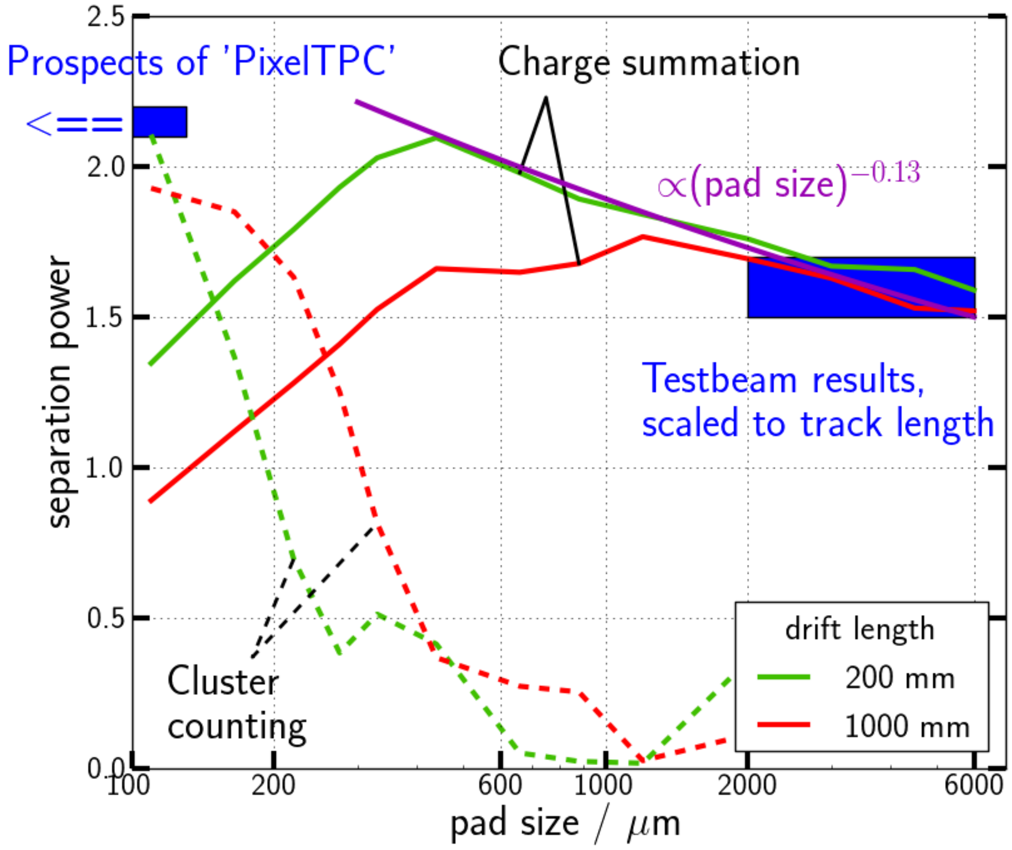
Charge summation



→ Get improvement down to ~ 500 µm pads, when threshold effects kill the signal

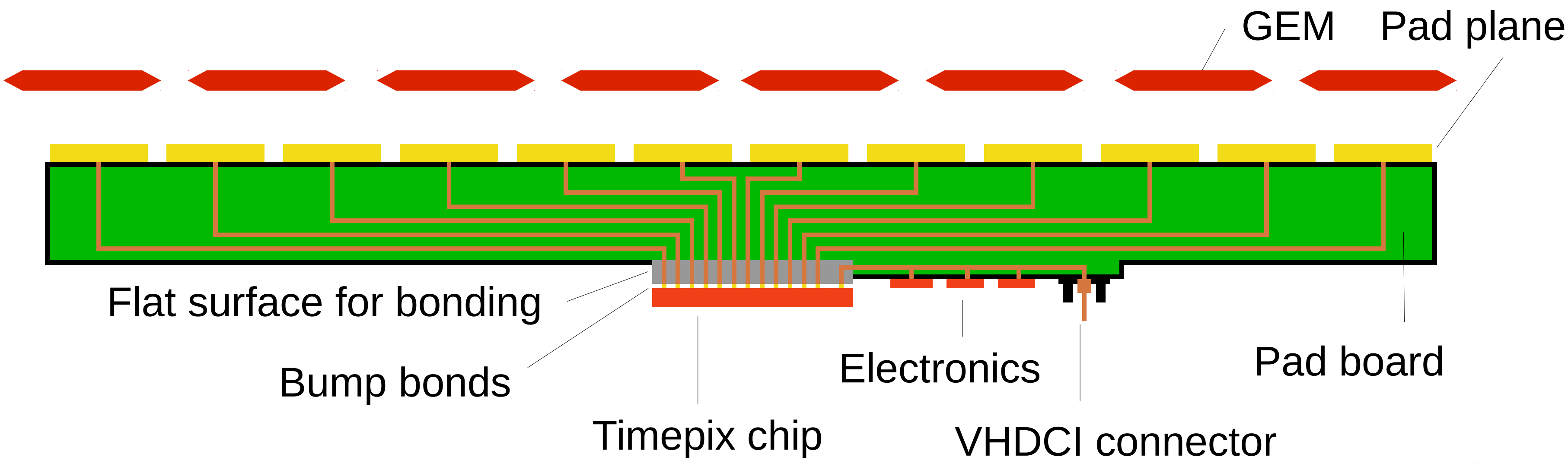
Simulation Results

- Combine results, compare to existing systems and test beam results, extrapolated to studied scenario:



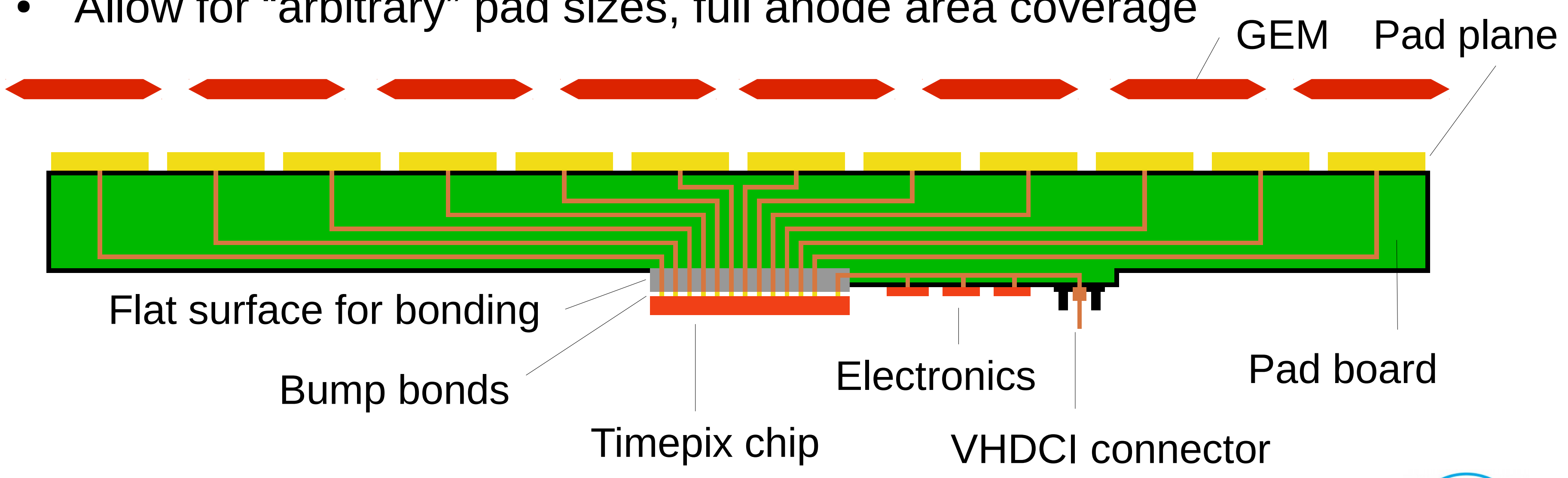
Hardware Ansatz

- GEMs, small pads, Timepix chip as readout electronics
- Connections from pads to chip are routed through the board, then bump bonded to the chip
- Timepix: 65,536 pixels, 55 µm pitch



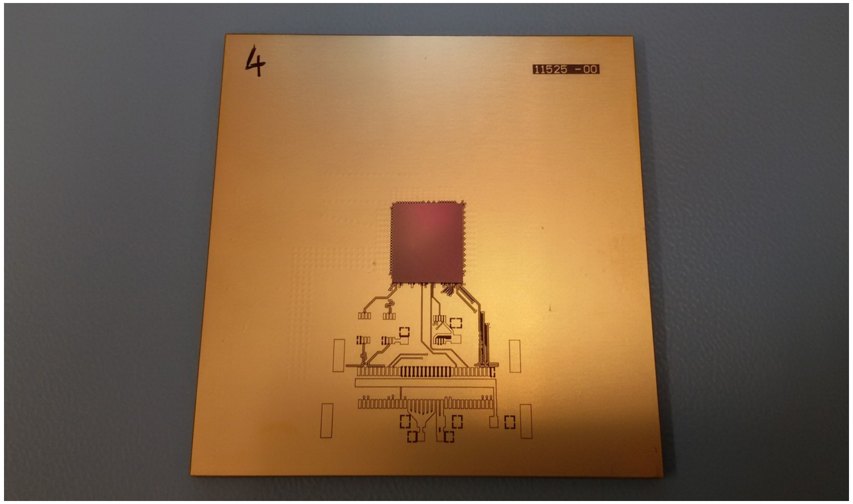
Benefits

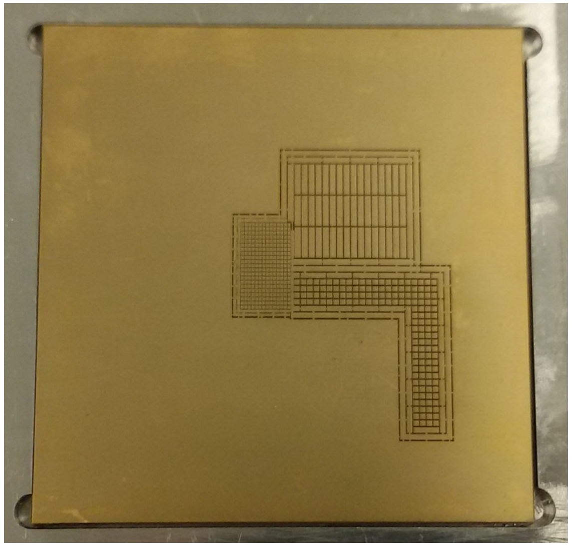
- Compared to the existing GEMs+pads system:
  - Higher granularity → better occupancy, double track resolution, possible cluster counting
  - Square pads, several pads per charge cloud → no $\tan^2\theta$ -effect
  - High integration: O(30) smaller footstep
- Allow for “arbitrary” pad sizes, full anode area coverage



Hardware: Concept

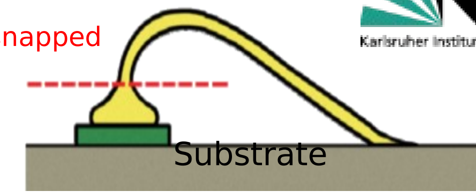
- PCB of 9 x 9 cm²
- 3 pad sizes and different connection lengths to be tested, smallest pads with shortest connections directly on the chip → influence of capacitance
- 500 channels connected in total
- To be used with 10 x 10 cm² GEMs in a small TPC
- Electroless Nickel Electroless Palladium Immersion Gold (ENEPIG) coating for bonding



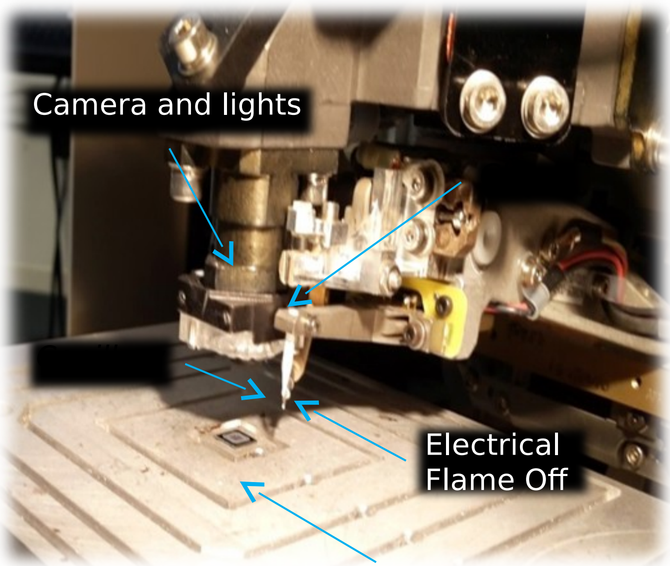


Stud Ball Bumping (SBB) process

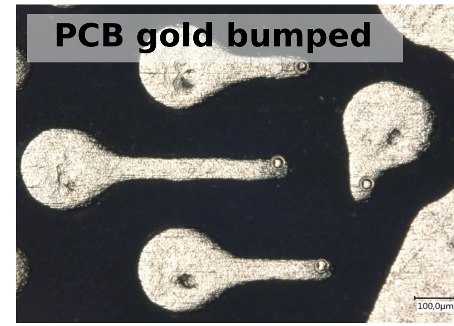
Gold stud bumping is an evolution of the ~ 60 years-old wire bonding process. **Gold stud ball**: the wire is snapped off after the ball is initially connected to the substrate



Gold Ball-wedge wire-bonding

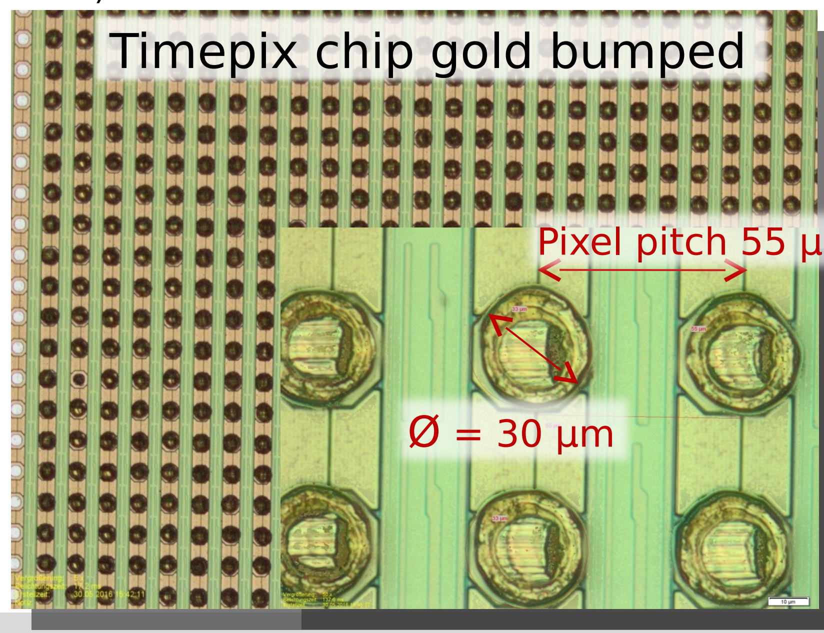


- ✓ **Low-cost process**: direct deposition on Al pad (No UBM, lithography process)
- ✓ **Fast deposition**: 20 bumps/s
- ✓ **Short setup time**: ideal for single die bump-bonding (i.e. prototype and R&D)

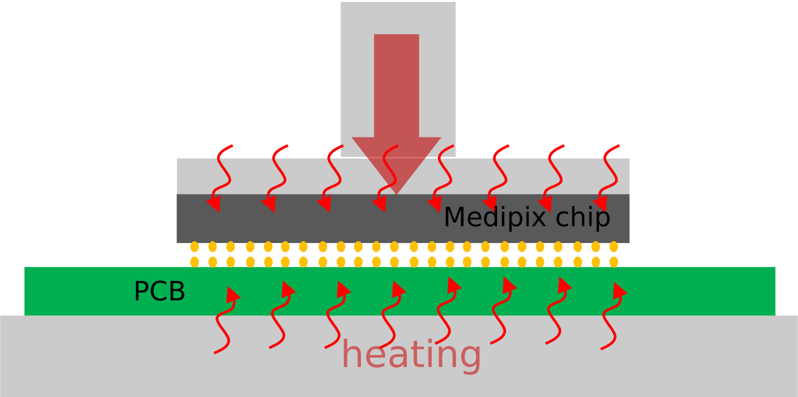


Achieved Bump & pitch size

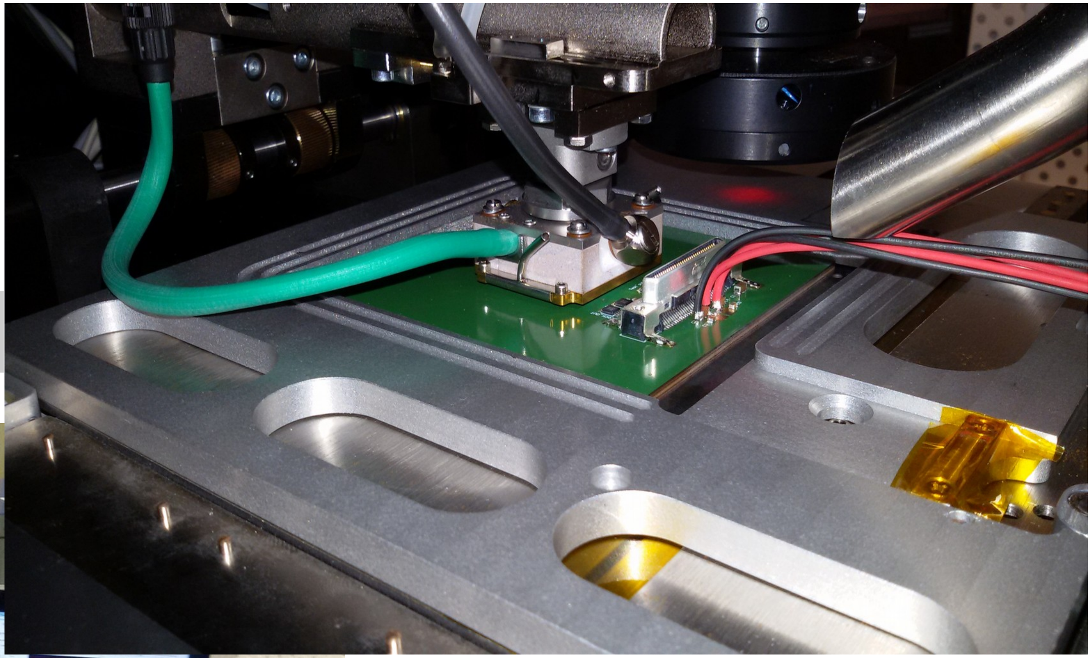
Au wire diameter (µm)	Bump diameter (µm)	Minimum pitch (µm)
25	60	100
15	30	50
12.5	23	35

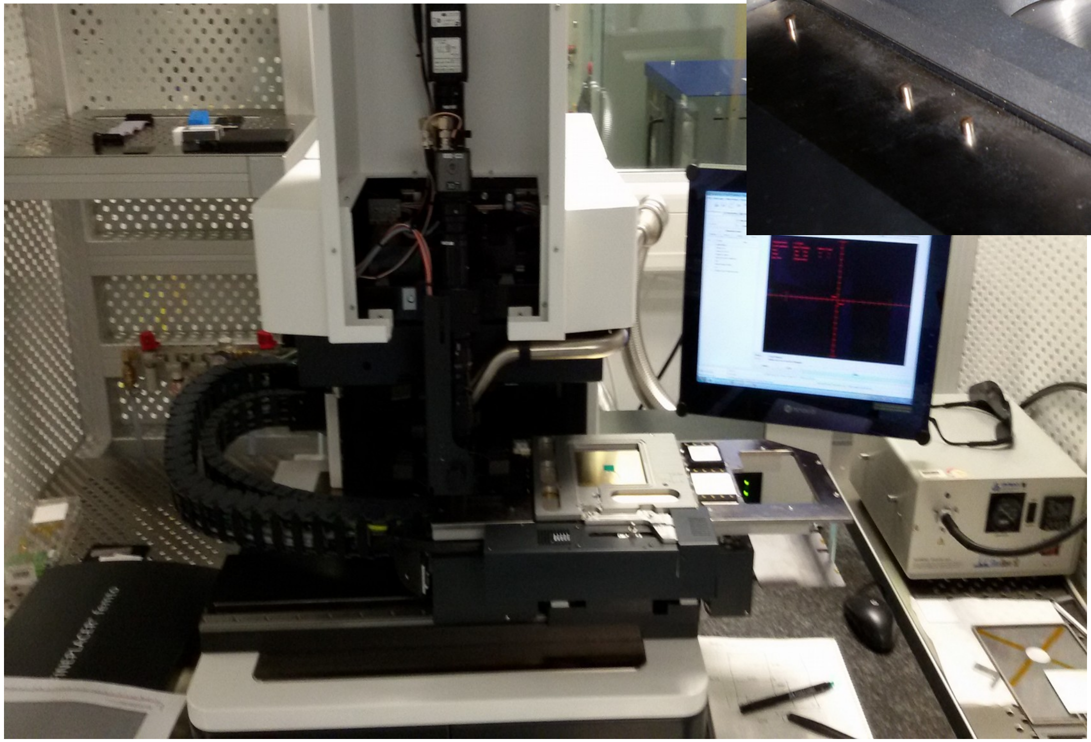


Flip-Chip Process - Bonding Maschine



Thermo-compression Bonding process





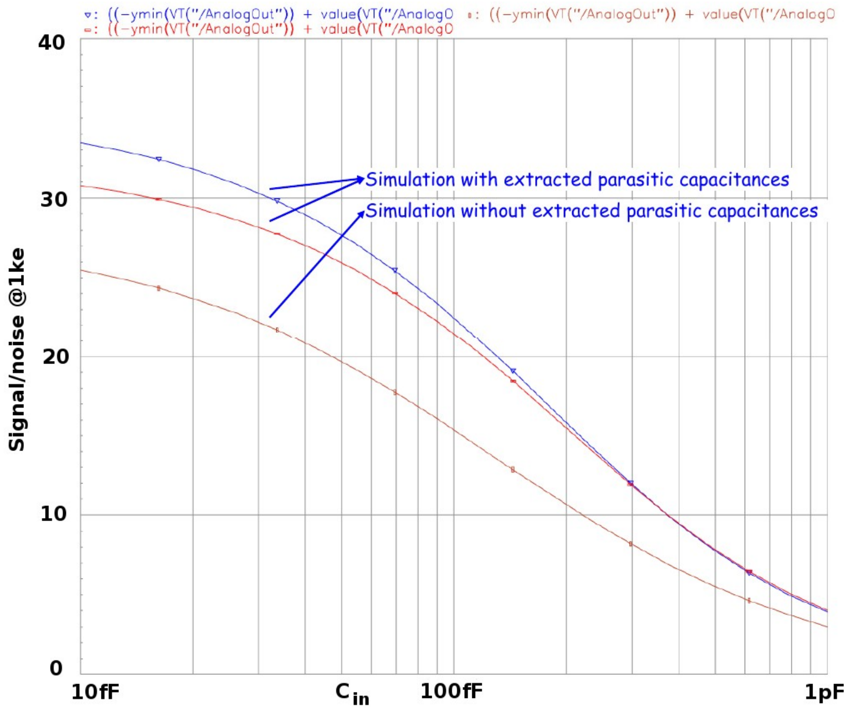
Hardware: Bonds vs. CTE

- Broken connections: no communication with chip, no data readout
- First time (?) bonding at 55 µm pitch directly from silicon to a PCB
- Problem: different coefficients of thermal expansion (CTE):
  - Si ~ 2.5 ppm/K, FR-4 ~ 15 ppm/K
  - → over 14 mm and at 250°C: ~ 40 µm offset

- Stability only given for ~ days-weeks
- Finally produced 3 working systems, immediately took (noise) data, but unable to inject a signal before breakdown

Hardware: Capacitance Challenge

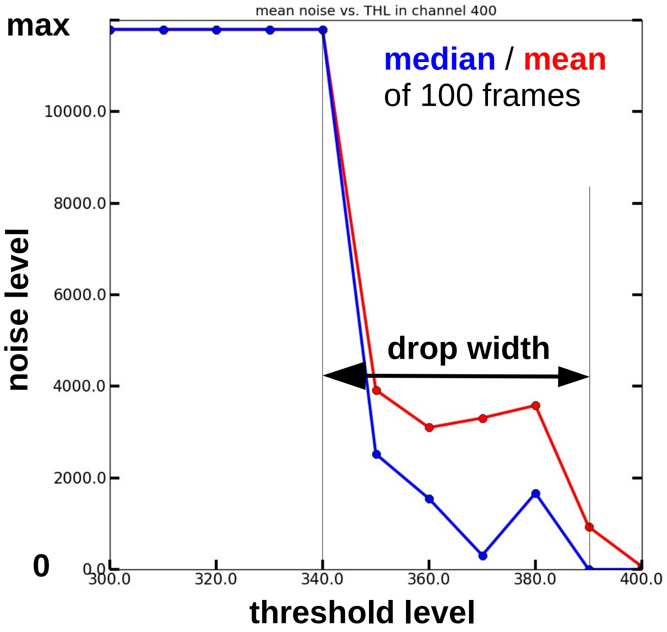
- With growing input capacitance the signal to noise ratio goes down
- Timepix was developed
  C < O(100fF)
- Capacitances:
  Pads: O(0.1pF)
  Lines: O(1pF/2.5cm)
  Bump bond connections: O(0.1pF)
- Gain for triple GEM stack: 2k-5k, potential for significant increase

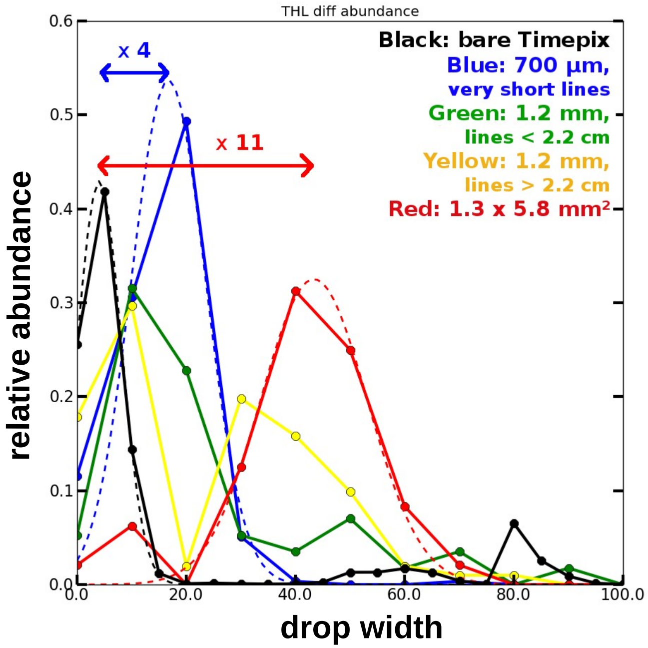


X. Llopart: Timepix Manual v1.0

Hardware: Noise data

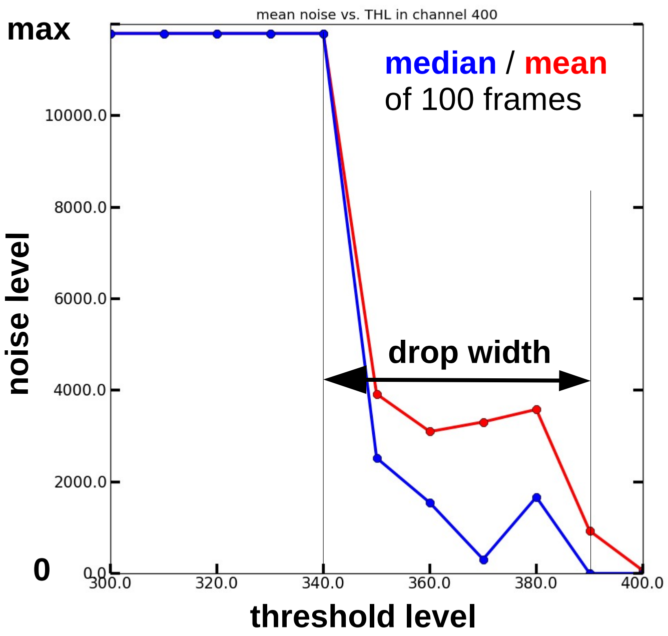
- Took noise data 'threshold runs':
  - For each channel measure the noise level at different thresholds
  - Check the necessary threshold increase to move a channel from being in constant firing to being constantly silent: drop width
  - This drop width is be proportional to the equivalent noise charge (ENC)

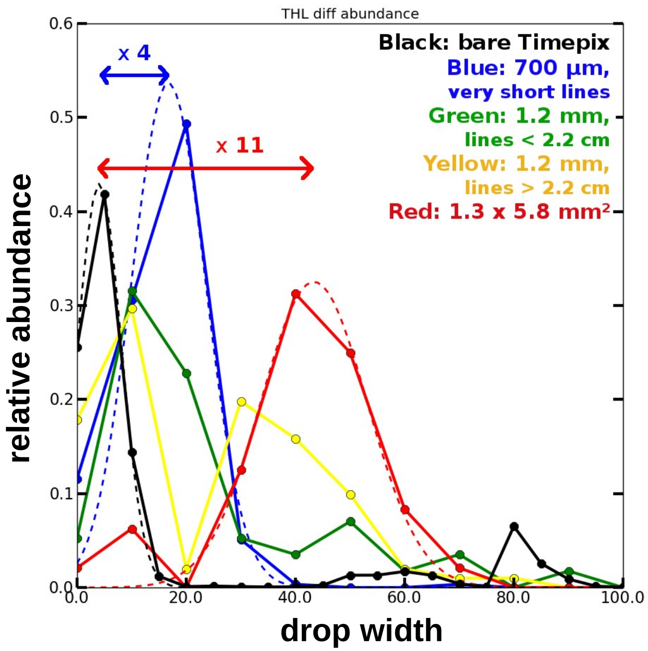




Hardware: Noise data

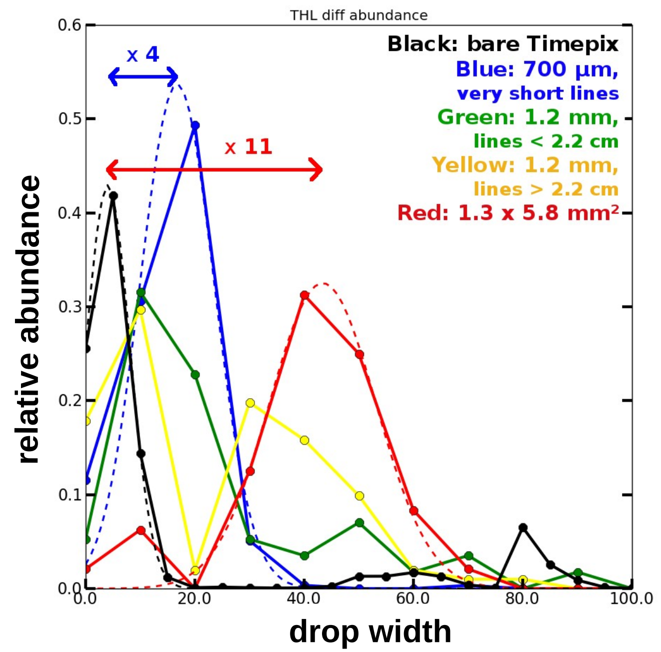
- Absolute noise drop width is difficult to interpret
  → compare ROPPERI system to bare Timepix
  → compare large pads, long lines to small pads, short lines
- Largest pads about 11 times as noisy as bare Timepix, with a known ENC of ~ 90 electrons





Hardware: Noise data

- Absolute noise drop width is difficult to interpret
  → compare ROPPERI system to bare Timepix
  → compare large pads, long lines to small pads, short lines
- Largest pads about 11 times as noisy as bare Timepix, with a known ENC of ~ 90 electrons
- Estimate for the signal/noise:
  - Assume 1000 electrons noise
  - 1.2 x 1.2 mm² pads receive between 10k and 20k electrons from GEMs at usual amplification voltages
  - → S/N >= 10



Summary

- Prospects of a high granularity TPC readout: improved PID.

- Simulations show decreasing pad sizes improves dE/dx by charge summation for down to ~ 500 µm.
  Cluster counting benefits only kick in below ~ 200 µm.

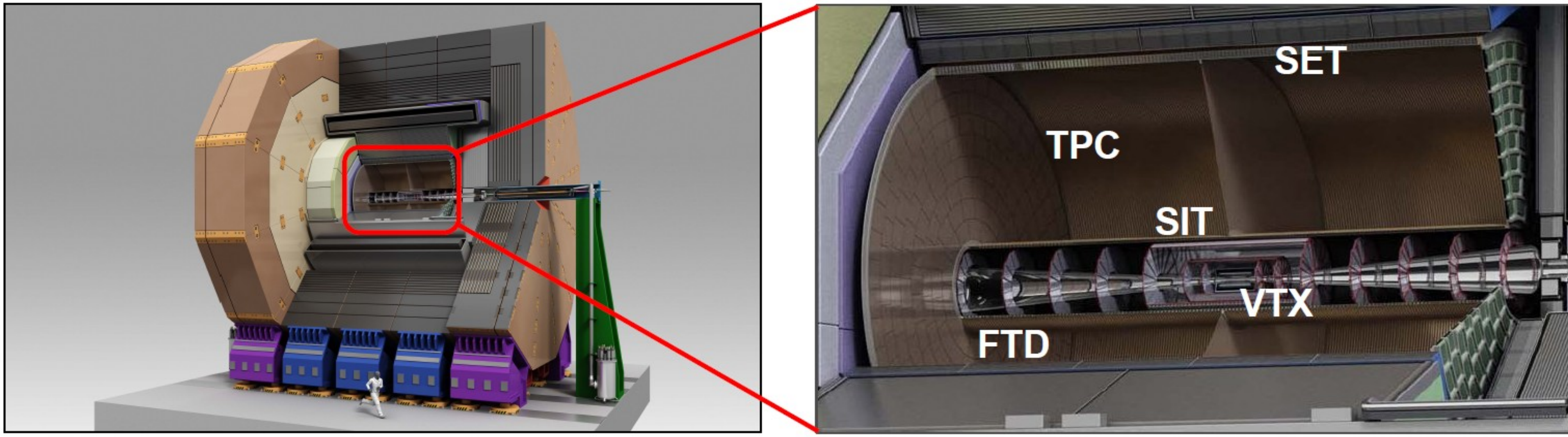
- The ROPPERI system was produced and tested.
  It aims to combine flexibility and low cost with high granularity and a small electronics footprint.
- Showed a estimated S/N >= 10 → general feasibility is given.
- Mechanical stability is an open issue, new materials need to be tested.

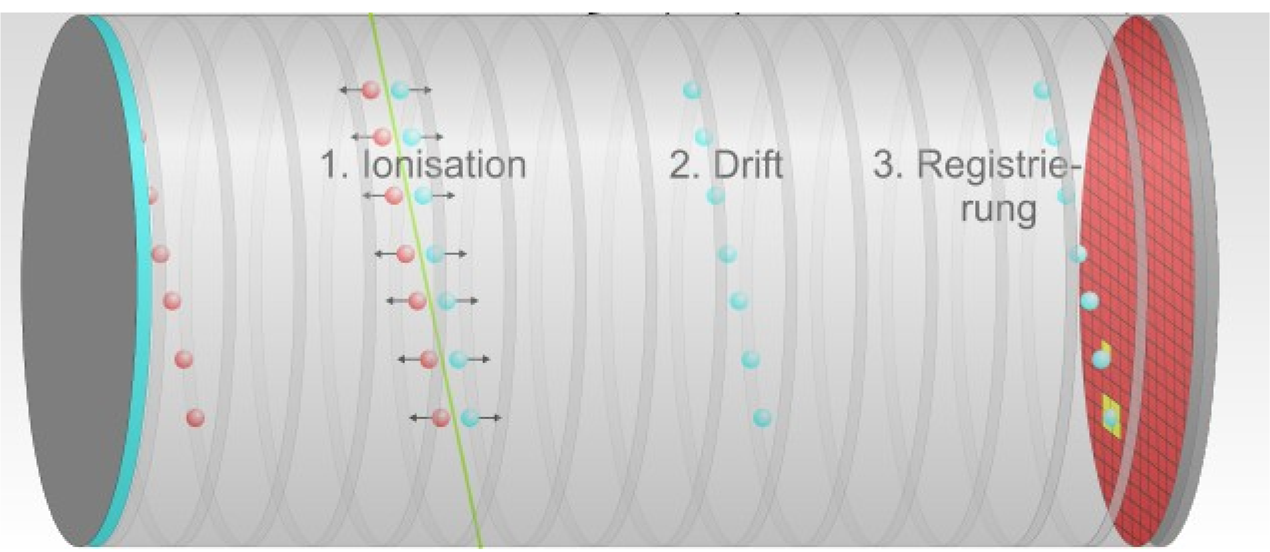
Special thanks to:
Markus Gruber, Patrick Pfistner and Sumera Kousar!

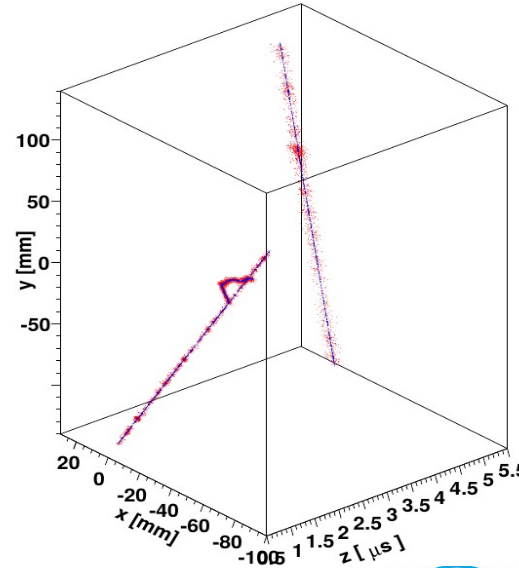
Dankeschön!
Fragen?

Backup

ILD TPC





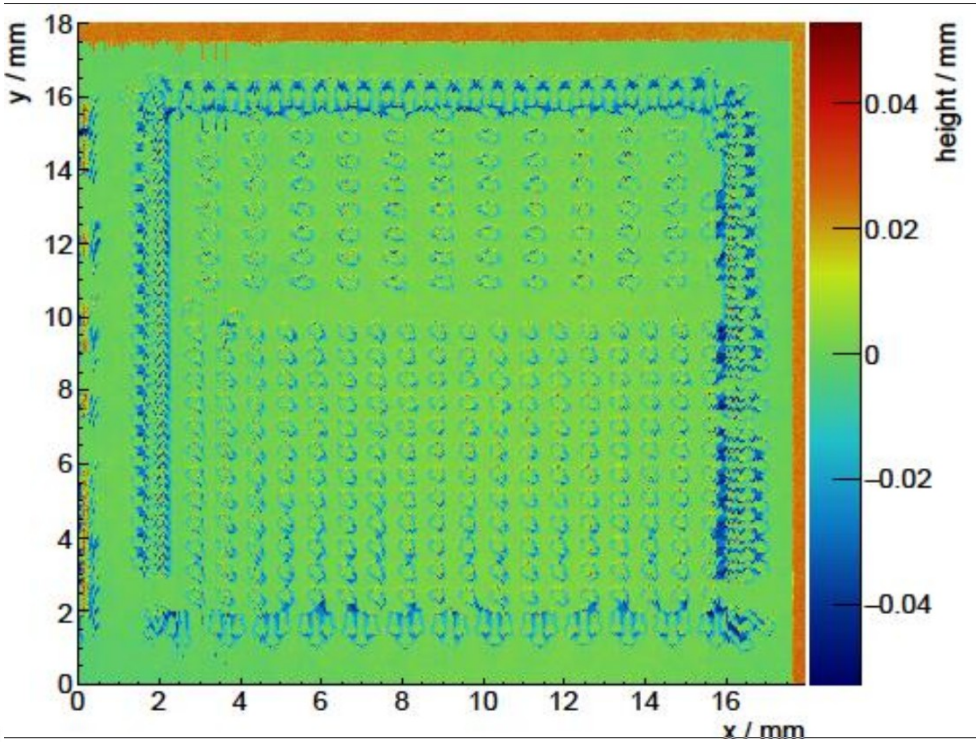


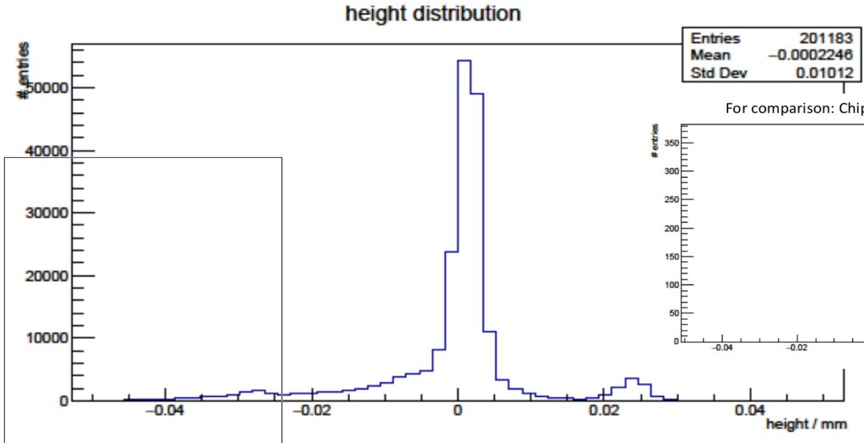
Diss. A. Münnich

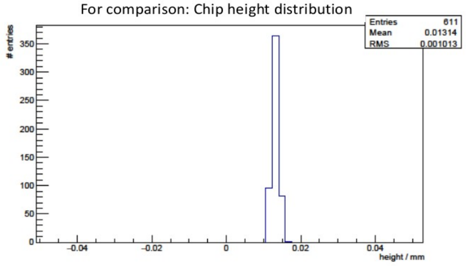
DESY.

Hardware: Flatness

- Sufficient flatness of few µm required for bonding
- Measured after chip came off

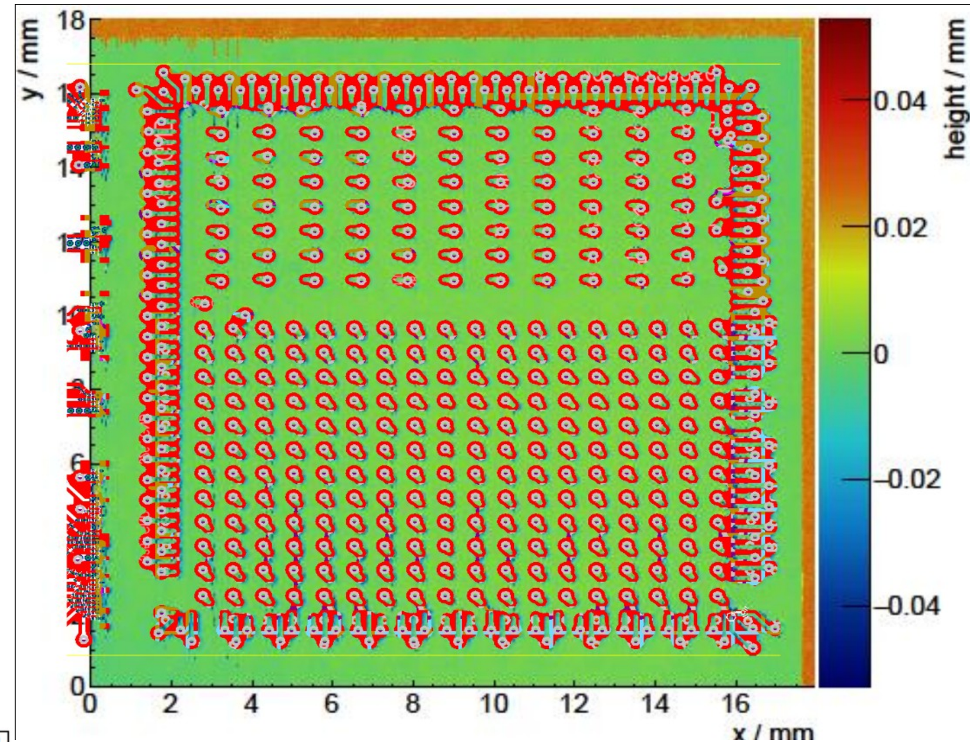


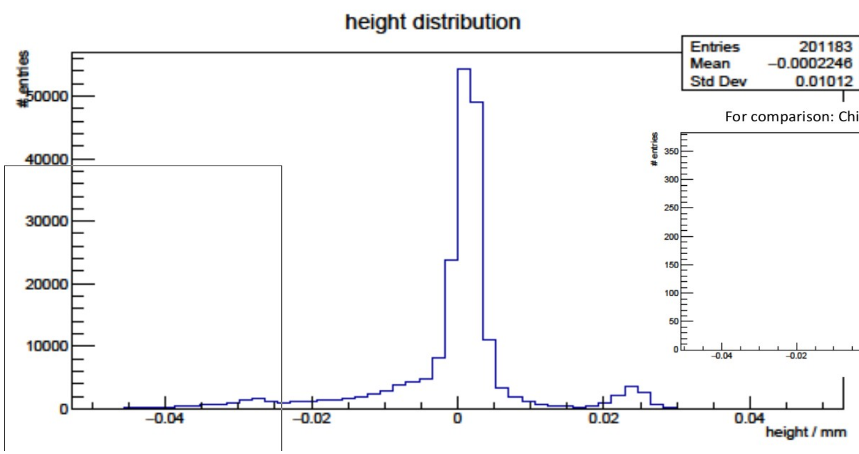


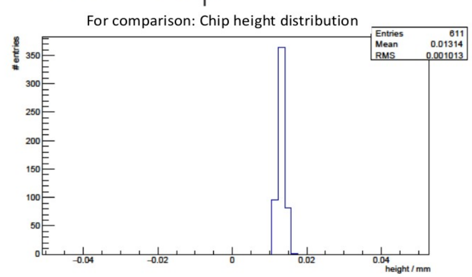


Hardware: Flatness

- Sufficient flatness of few µm required for bonding
- Measured after chip came off
- Maps design file very well
- Central peak FWHM: 5 µm, areas without metalisation and gold studs visible



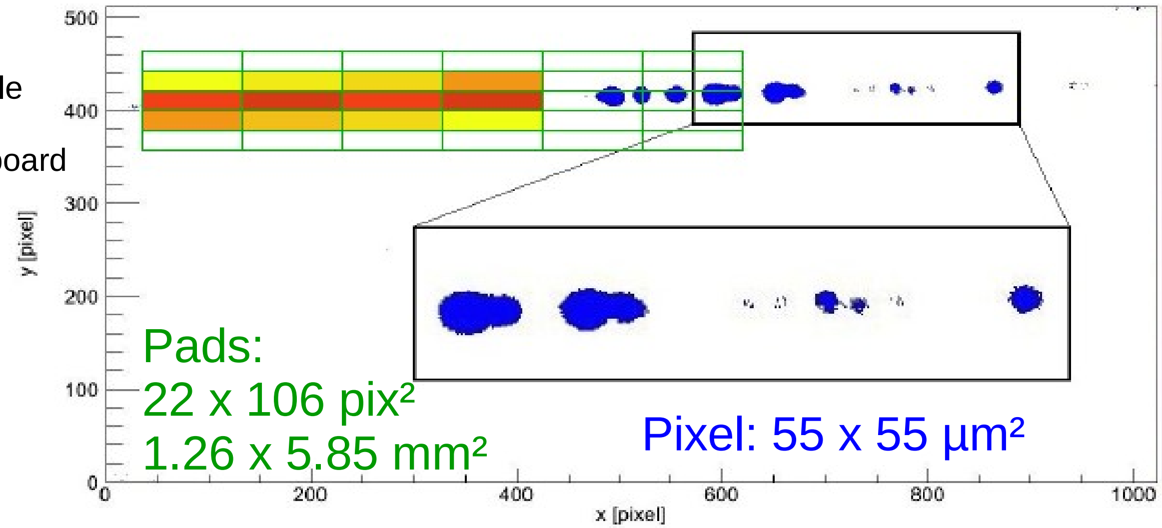




Idea: intermediate solution between pads and pixels

M. Lupberger: The Pixel-TPC:
first results from an 8-InGrid module

Here: GEMs + bare Timepix-Octoboard

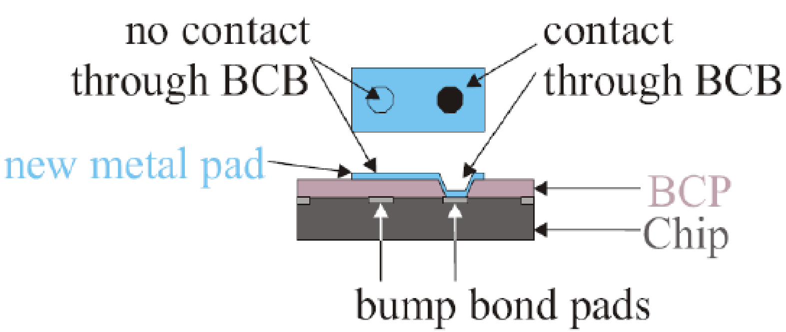


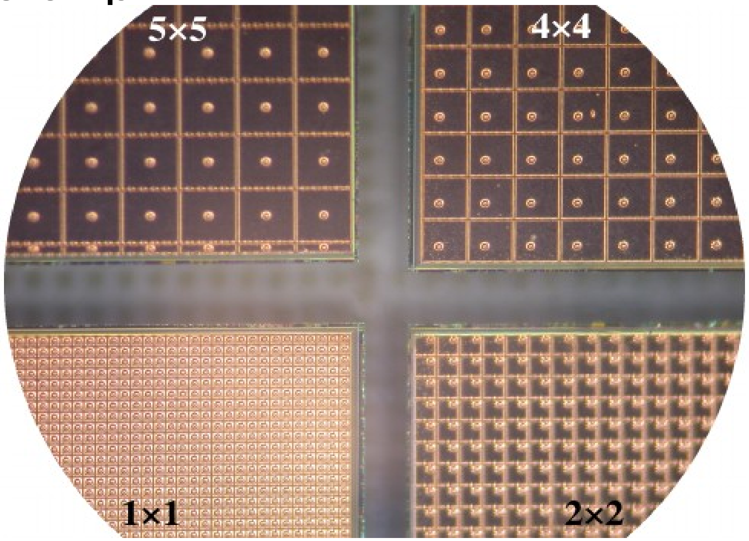
- Clusters contain the primary information of the ionisation
- For a GEM-based system: Can we find a solution to resolve clusters?
- What is the optimal pad size to
  - improve double hit and double track resolution,
  - do cluster counting for improved dE/dx?

    → O(200µm)

Former Tests with GEMs + pixels

- GEMs + Timepix, by Uni Bonn and Uni Freiburg
  - Charge depositions spread continuously over O(100) pixels (compared to Micromegas)
  - High gains (60k to 100k) necessary for signal/noise
- Large pixels by adding metal pads to chip

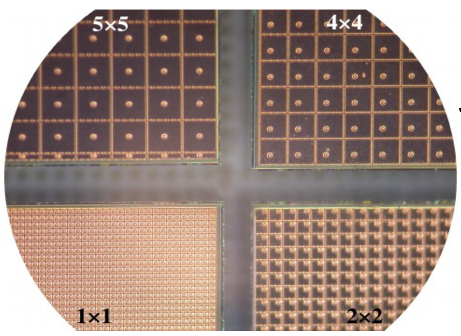


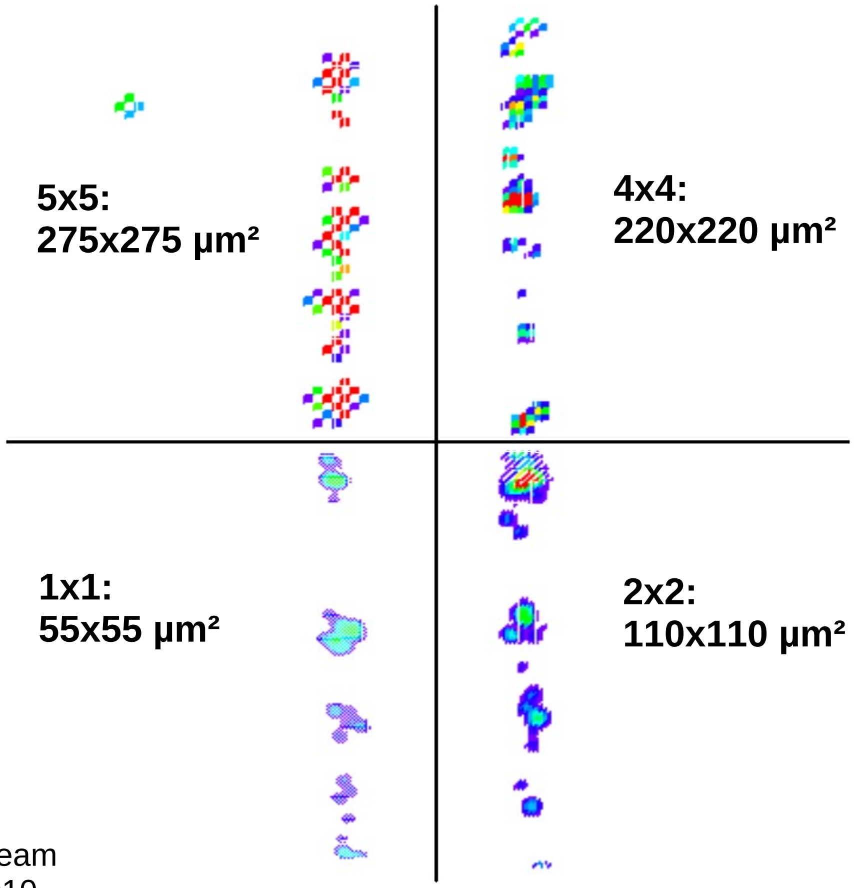


J. Kaminski: Measurements during the October test beam with the GEM-TPC and Timepix; at RD-51 meeting 2010

Former Tests with GEMs + pixels

- Clusters visible with large pixels → How large can one go?
- Similar to our approach
- But: still need up to 120+ chips per module
- Utilize full chip!
- Utilize full anode area!





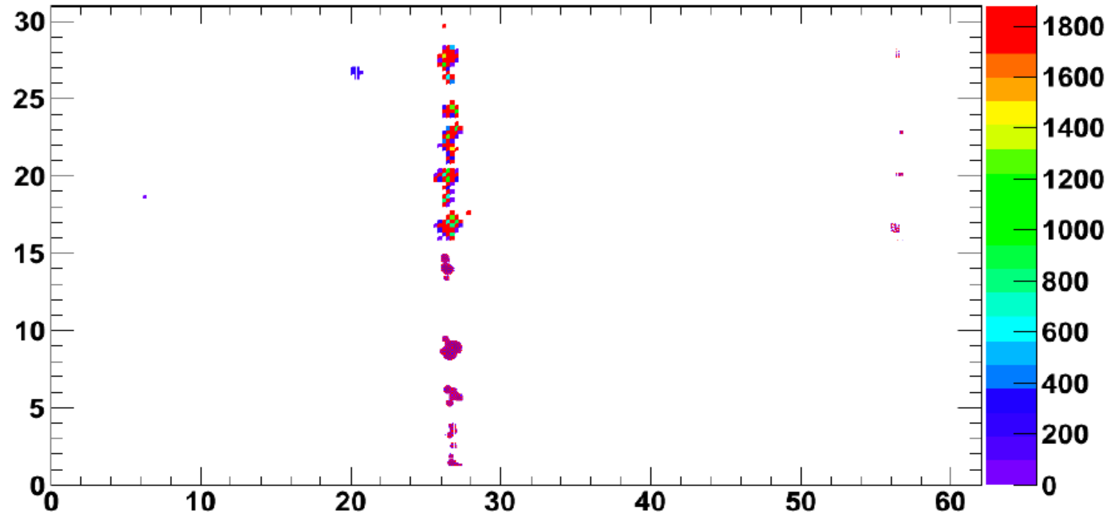
J. Kaminski: Measurements during the October test beam with the GEM-TPC and Timepix; at RD-51 meeting 2010

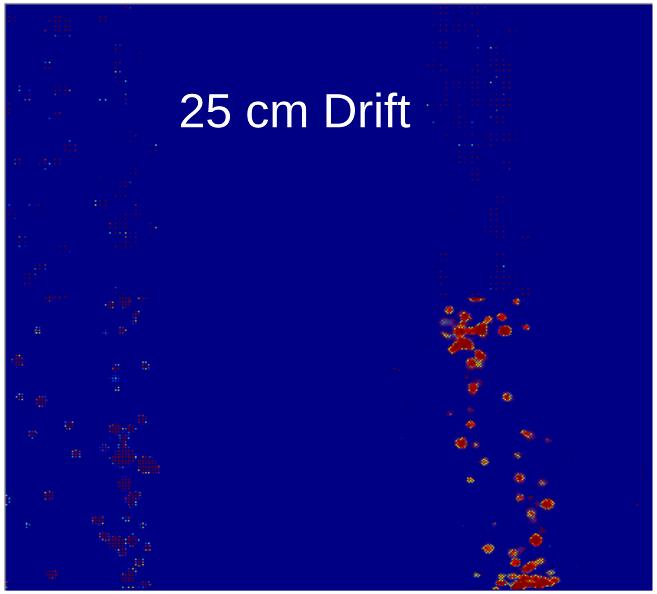
GEMs + pixels: event displays

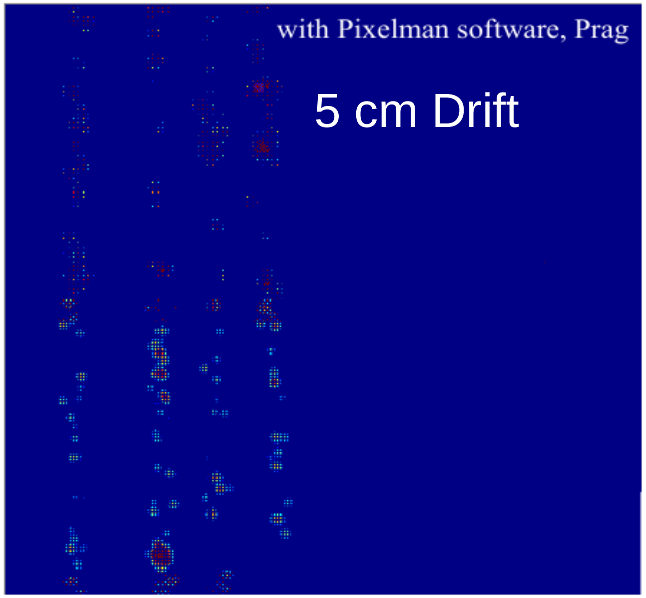
- Large pixels Timepix

  [5x5 | 4x4]

  [1x1 | 2x2]



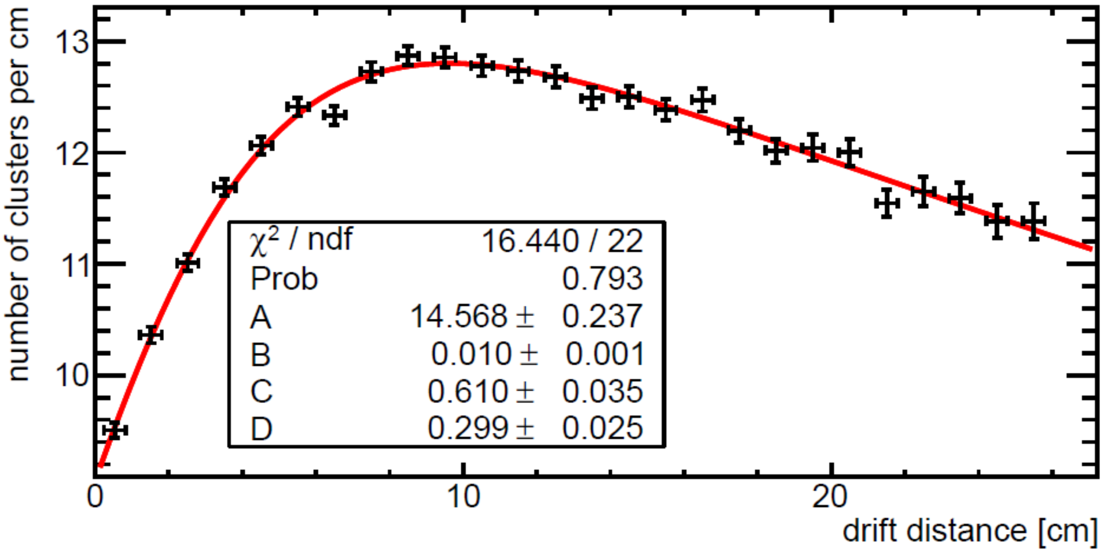




J. Kaminski: Measurements during the October test beam with the GEM-TPC and Timepix; at RD-51 meeting 2010

Cluster counting efficiency

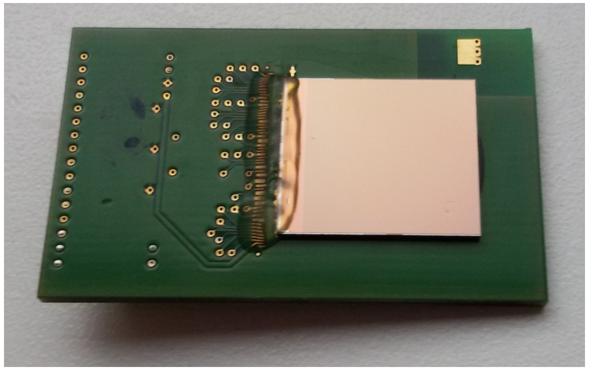
- Here:
  - He:CO_2 70:30
  - Expected: 15.15 clusters/cm
  - Approaches without absorption 14.6 clusters/cm

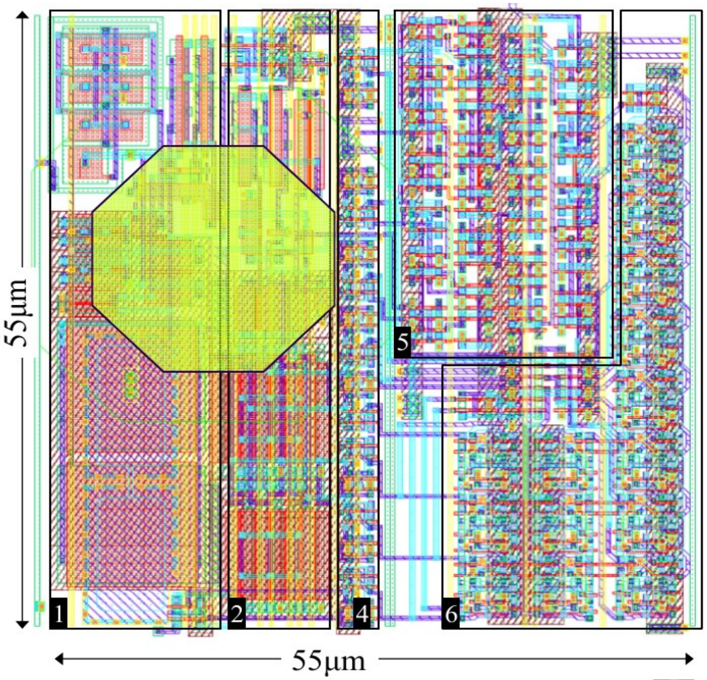


Dissertation: C. Brezina

Readout: Timepix

- Advancement to the Medipix chip (RD51, CERN) with the capability for time measurement
- Geometry:
  - 256 x 256 pixels, 55µm pitch
  - 1.4 x 1.4 cm^2 active area
- Pixel floor plan:
  octagon: Al opening for input signal
  1: preamplifier
  2: discriminator/digitisation
  4: configuration
  5: mode selection
  6: 14-Bit shift register (max. 11810)

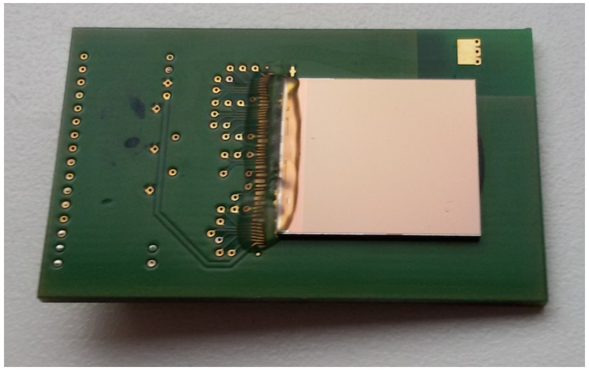


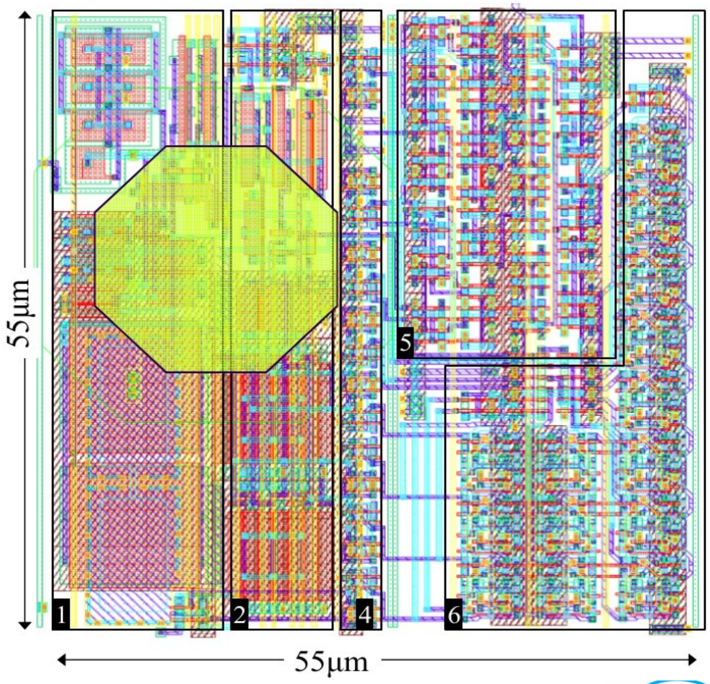


X. Llopart: Timepix Manual v1.0

Readout: Timepix

- Mode selection (per pixel) in 5:
  - "Time of arrival" (ToA) gives timing information
  - "Time over threshold" (ToT) gives charge information
  - For the Timepix3 (2^{nd} generation) both modes can run simultaneously
- External reference clock with up to 100MHz / 10ns
- During a given shutter window the register counts and is read out afterwards (serial 10ms, parallel 300µs)

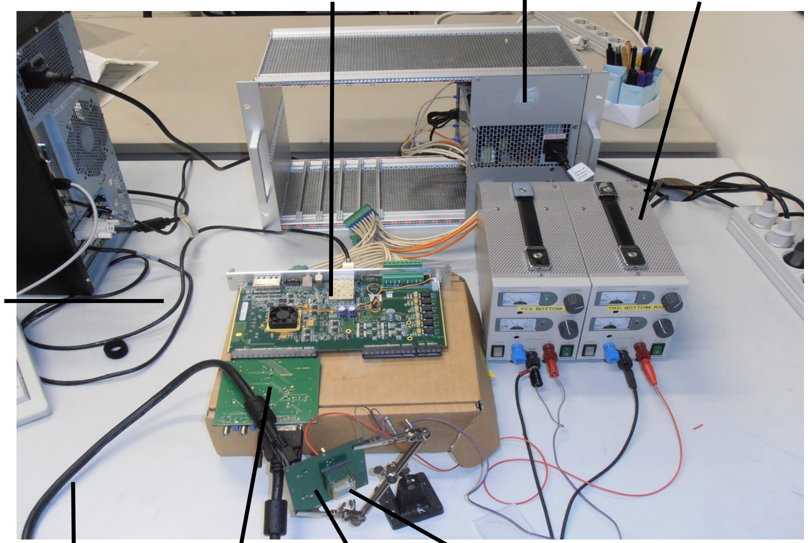


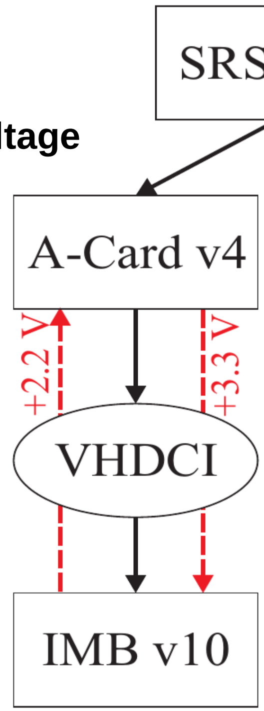


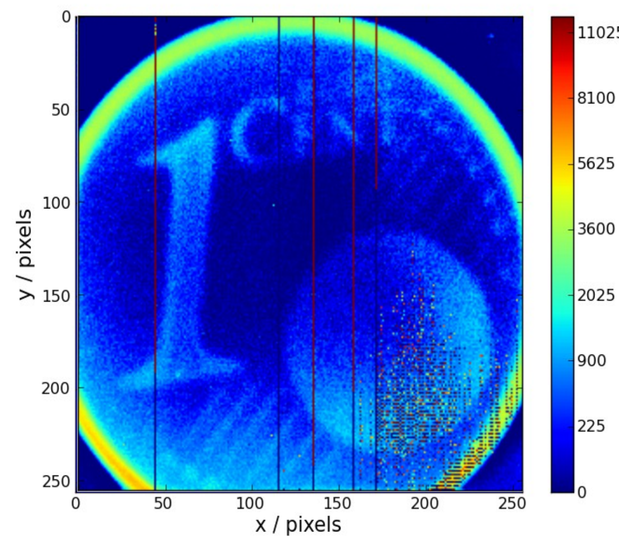
X. Llopart: Timepix Manual v1.0

Hardware Readout Setup

- Readout chain based on the Scalable Readout System (SRS) from CERN established







Timepix3

- Simultaneous modes “time of arrival” and “time over threshold”
- To be used after proof-of-principle
- Exchange of information and experience with photon science groups at DESY (member of Timepix3 collaboration)

UNIMOCS prototype TPC