The gaseous QUAD pixel detector

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Pixel TPC

Single chip 2017
Quad 2018
Module 2019
TPC plane
GridPix technology

- Pixel chip with integrated Grid (Micromegas-like)
- InGrid post-processed @ IZM
- Grid set at negative voltage (300 – 600 V) to provide gas amplification
- Very small pixel size (55 µm)
- Detecting individual electrons

- Aluminium grid (1 µm thick)
- 35 µm wide holes, 55 µm pitch
- Supported by SU8 pillars 50 µm high
- Grid surrounded by SU8 dyke (150 µm wide solid strip) for mechanical and HV stability
Pixel chip: TimePix3

- 256 x 256 pixels
- 55 x 55 µm pitch
- 14.1 x 14.1 mm sensitive area
- TDC with 610 MHz clock (1.64 ns)
- Used in the data driven mode
  - Each hit consists of the pixel address and time stamp of arrival time (ToA)
  - Time over threshold (ToT) is added to register the signal amplitude
  - compensation for time walk
  - Trigger (for $t_0$) added to the data stream as an additional time stamp

- Power consumption
  - ~1 A @ 2 V (2W) depending on hit rate
  - good cooling is important
Single chip test in test beam Bonn (June 2017)

- ELSA: 2.5 GeV electrons
- Tracks referenced by Mimosa telescope
- Gas: Ar/CF$_4$/iC$_4$H$_{10}$ 95/3/2 (T2K)
- Electrons: $\sim$100 e/cm
- $E_d = 280$ V/cm, $V_{\text{grid}} = -350$ V

Published paper on 2017 testbeam: [https://doi.org/10.1016/j.nima.2018.08.012](https://doi.org/10.1016/j.nima.2018.08.012)
TimePix3 time walk correction

Time walk error: time of arrival depends on signal amplitude

Correction using Time over Threshold (ToT) as a measure of signal strength

\[ \delta Z_{\text{timewalk}} = \frac{c_1}{t_{\text{ToT}} + t_0} + Z_0 \]

Residual distribution improved

Higher order corrections did not yield further improvements

(Blum, Particle detection 2008)
Single hit resolution in transverse direction

\[ D_T = 306 \, \mu m/\sqrt{cm} \]  

(318 ± 7 \, \mu m/\sqrt{cm} \text{ expected})

Single hit resolution in pixel plane:

\[ \sigma^2_y = \sigma^2_{y0} + D^2_T (z - z_0) \]

Depends on:

- \( \sigma_{y0} = \text{pixel size} / \sqrt{12} \)
- Diffusion \( D_T \) from fit

Note that:

- A hit resolution of \(~250 \, \mu m\) is \(~25 \, \mu m\) for a 100-hit track (\(~1 \, \text{cm} \) track length)
- At \( B = 4 \, T \), \( D_T = 25 \, \mu m/\sqrt{cm} \)
Single hit resolution in longitudinal direction

\[ D_L = 226 \text{ } \mu\text{m}/\sqrt{\text{cm}} \]

(201 \pm 5 \text{ } \mu\text{m}/\sqrt{\text{cm}} \text{ expected})

Single hit resolution in drift direction

\[ \sigma_z^2 = \sigma_{z0}^2 + D_L^2 (z - z_0) \]

Depends on
- \( \sigma_{z0} \) from fit
- Diffusion \( D_L \) from fit

The additional ToT cut (>0.60 \( \mu \text{s} \)) was applied to avoid large time walk errors
Pixel dE/dx performance

- dE/dx resolution with truncated mean
  - From the single chip tracks; 1 m long tracks are made;
  - nr of electrons counted in slices of 20 pixel and reject 10% highest slices
  - Distances along track are scaled by 1/0.7 to get an estimation for the dE/dx of a MIP
  - Resolution is 4.1% for a 2.5 GeV electron and 4.9% for a MIP
- Separation $S = (N_e - N_{MIP})/\sigma_e$
- $8\sigma$ MIP-e separation for a 1 meter track

A pixel readout can in principle within the resolution (diffusion) separate primary from secondary clusters. dE/dx can be measured by cluster counting and performance separation enhanced.
Deformations in pixel plane (XY) and drift direction (Z)

- The RMS of the mean residuals is 7 μm in the pixel plane and 21 μm (0.3 ns) in the drift direction in the selected region.

How can we make an even better detector?
- Improve the quality (homogeneity) of the InGrid; redesign the dike and edges.
- Go to a large areas keeping the field distortions (at edges) minimal -> QUAD.
QUAD design and realization

- Four-TimePix3 chips
- All services (signal IO, LV power) are located under the detection surface
- The area for connections was squeezed to the minimum
- Very high precision 10 μm mounting of the chips and guard
- QUAD has an sensitive area of 68.9%
- DAQ by SPIDR

39.6 x 28.38 mm

series of QUADs

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QUAD test beam in Bonn (October 2018)

- ELSA: 2.5 GeV electrons
- Tracks referenced by Mimosa telescope
- QUAD sandwiched between Mimosa planes
  - Largely improved track definition
- Gas: Ar/CF$_4$/iC$_4$H$_{10}$ 95/3/2 (T2K)
- $E_d = 280$ V/cm, $V_{\text{grid}} = -300$ V
- Typical beam height above the chip: $\sim 1$ cm

Preliminary results will be presented here
QUAD time walk results

\[ \delta Z_{\text{timewalk}} = \frac{c_1}{t_{\text{ToT}} + t_0} + Z_0 \]

- Time walk correction works well
- Applied for all analysis results
QUAD single hit resolution

Transverse

Longitudinal

\[ D_T = 419 \, \mu m/\sqrt{cm} \]

\[ D_L = 259 \, \mu m/\sqrt{cm} \]
QUAD edge deformations

- Small deformations due to:
  - Dead zone between chips
  - Grounded region between chips
- Are corrected by:
  - Fitted correction function
  - Adding proper guard wire electrode
QUAD deformations in transverse plane (XY)

- After applying fitted edge corrections
- RMS of the mean residuals are 26 µm over the whole QUAD

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Next: QUAD as a building block

Cooling channels

8-QUAD module

Guard wires not yet installed
Conclusions

- Since 2017 three TimePix3 wafers were successfully equipped with an InGrid.
- A single chip GridPix detector from this production was reliably operated in a test beam in 2017.
  - Single electron detection => the resolution is primarily limited by diffusion.
  - Systematic uncertainties are low: < 10 µm in the pixel plane.
  - dE/dx resolution for a 1 m track is 4.1%.

- Preliminary results from a recent 2018 QUAD test beam were presented.
- Data quality and resolutions are similar to the single chip test beam results.
- Small edge deformations at the boundary between two chips are observed.
  - We will add guard wires to the module.
- A production of 14 QUADs is finished.
  - QUADs are installed in an 8-QUAD module.