Operation of a GEM-TPC with pixel readout

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[1] now at CERN

Overview

1. Experimental Setup
2. Data Analysis
3. Spatial Resolution
4. Outlook & Conclusions

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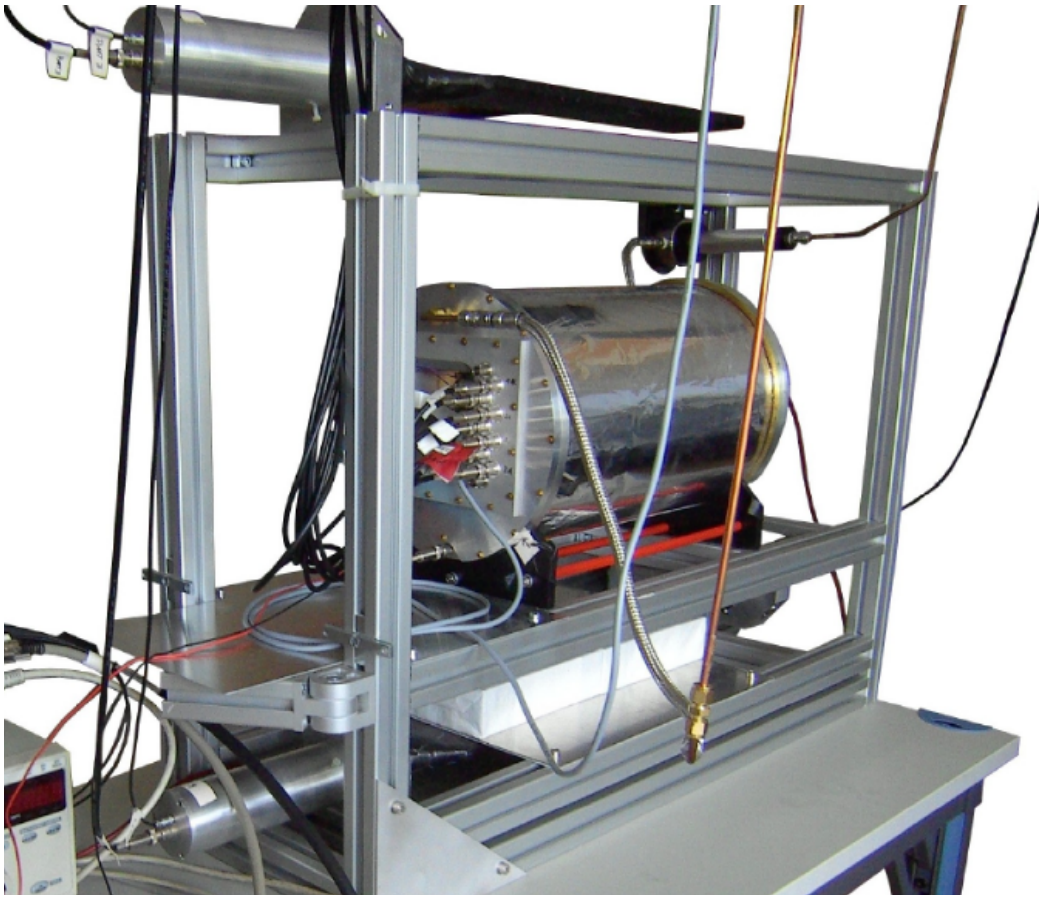
TPC Test-stand

ILC, CLIC or any other experiment with need for low material budget tracking detectors with high precision, high efficiency and robust particle identification may make use of a **T**ime **P**rojection **C**hamber.



TPC Prototype

- Drift length $26\,\mathrm{cm}$
- Inner diameter $23\,\mathrm{cm}$
- Material budget $1\,\%\mathrm{X}_0$

Setup

Trigger on cosmic rays
($\gtrsim 4\,\mathrm{GeV}$ Muons)
Drift gas is Helium with CO_2
(70/30)

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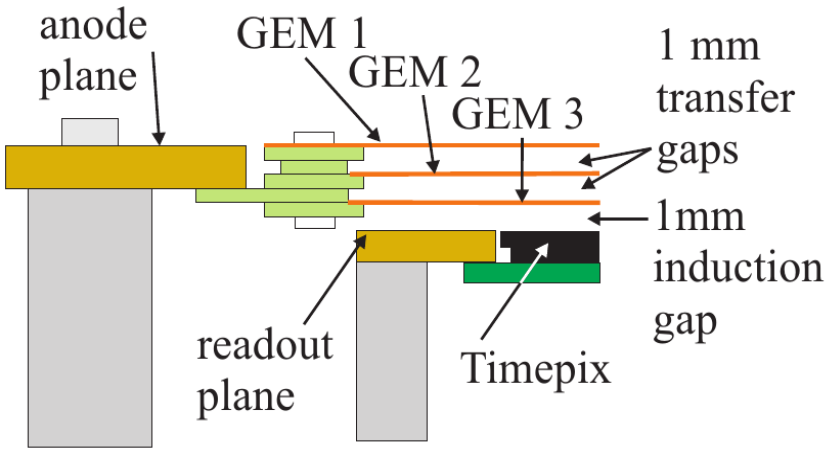
Gas Amplification



GEM Stack

- $U_{\mathrm{GEM}} = 415\,\mathrm{V}$
- Transfer fields $= 2.2\,\mathrm{kV/cm}$
- Induction field $= 3.0\,\mathrm{kV/cm}$

Simulation possible using ANSYS and Garfield++

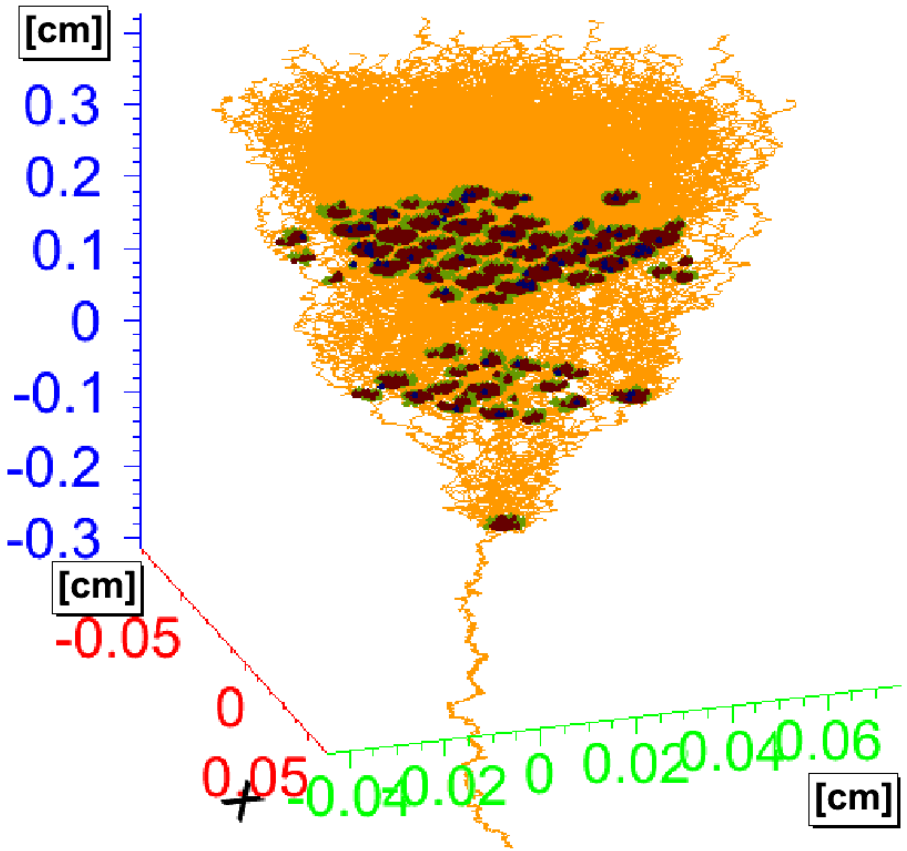


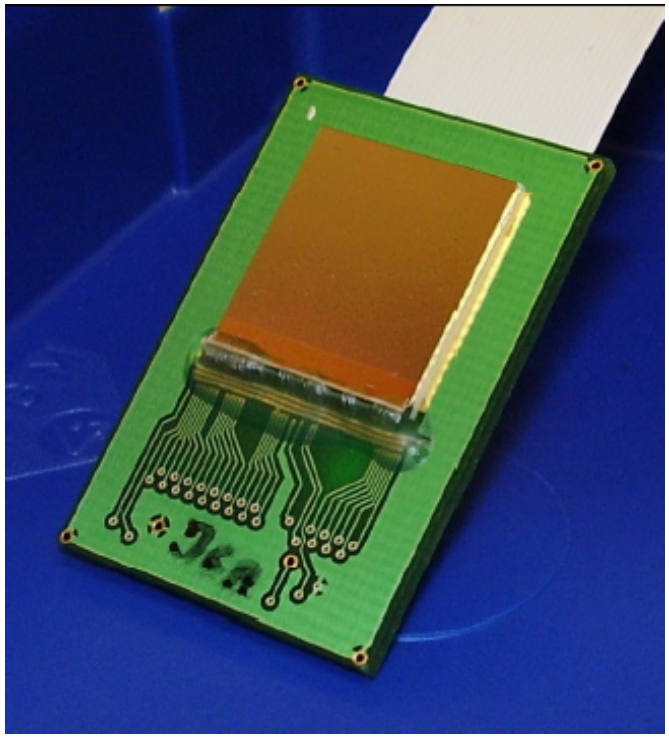
Figure: K. Zenker, C. Hasterok, GEM Simulation Studies, DESY/TU Dresden

Readout

Usually a TPC is read out with:

- pads ($\mathcal{O} \approx \mathrm{mm}^2$)
- wiring between pad and electronics

Both may limit the detector performance.



Our prototype is read out with the Timepix ASIC (developed at CERN):

- $256 \times 256\,\mathrm{pixels}$
- $55 \times 55\,\mu\mathrm{m}^2/\mathrm{pixel}$
- Noise $\approx 100\,\mathrm{e}^-$
- THL $\approx 350\,\mathrm{e}^-$

Each pixel holds a:

- CSA and a single threshold discriminator in the analog domain
- $14\,\mathrm{bit}$ counting logic in the digital domain

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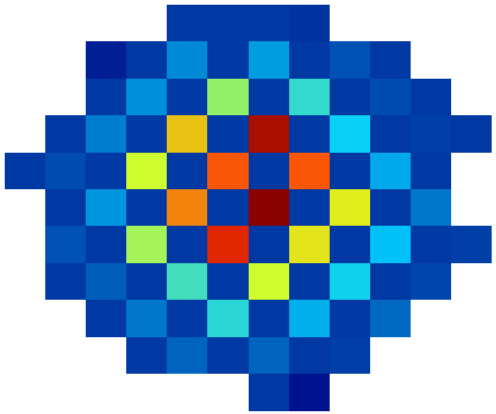
Chip operation

A pixel measures either:

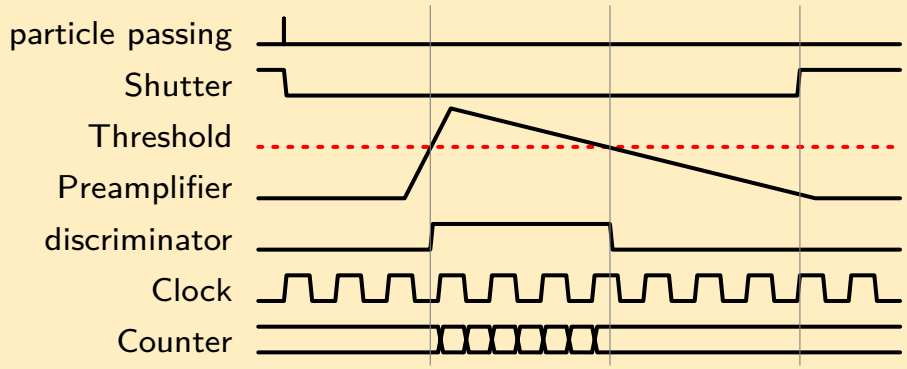
- the amount of charge
- or the arrival time of a hit

$\Rightarrow$ Configure the pixels in a checker board pattern.

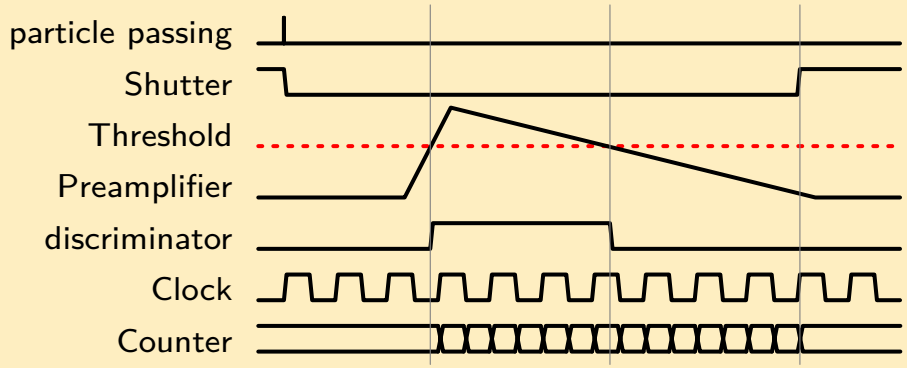


Blue to Red scaled: Charge
Dark blue: ToA in Clock Counts

Time over Threshold Mode



Time of Arrival Mode



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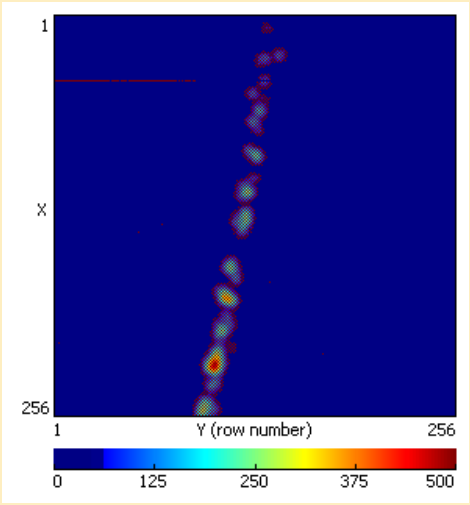
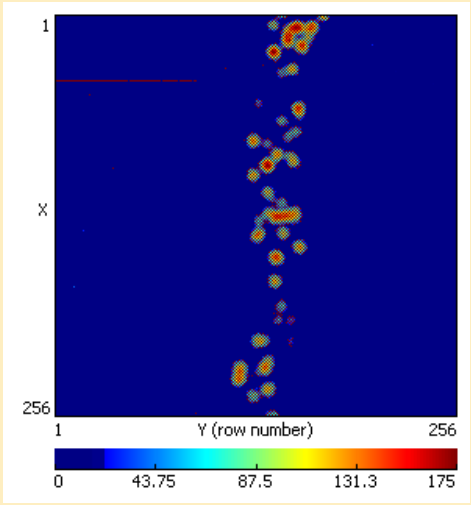
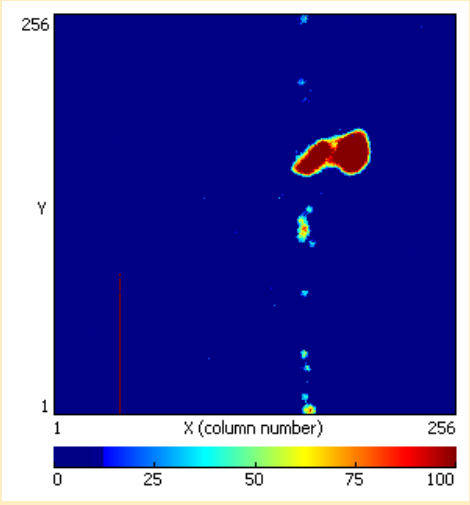
Example Event Displays



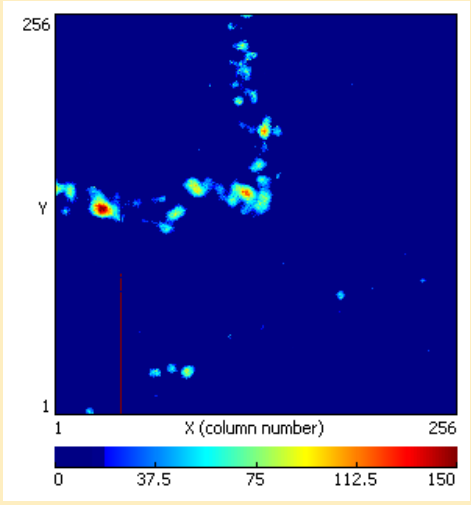
Track after short drift distance



Track after long drift distance



Event with δ-Electron



W-Event

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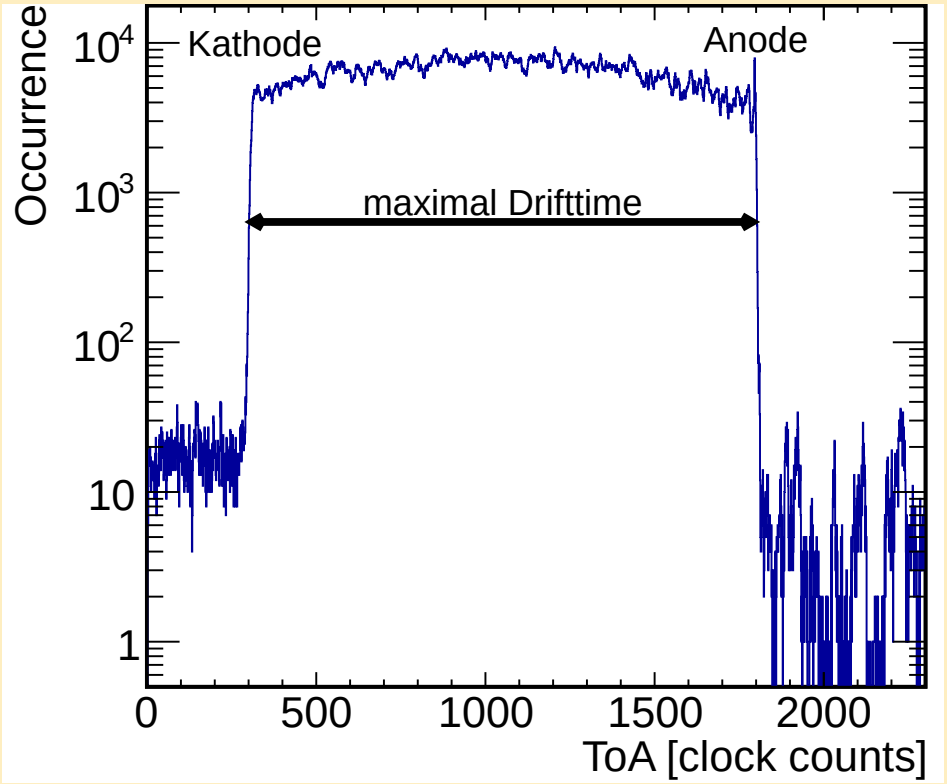
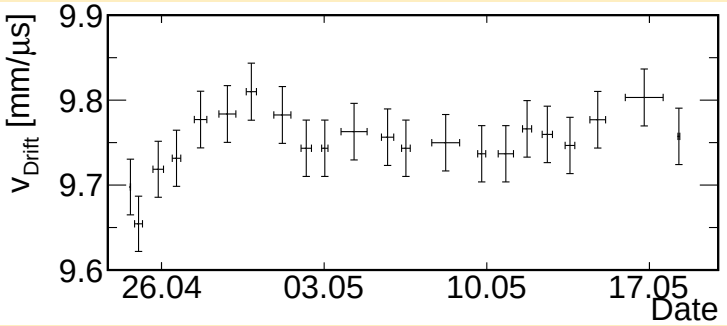
Rawdata

Arrival time spectrum



Mean drift velocity

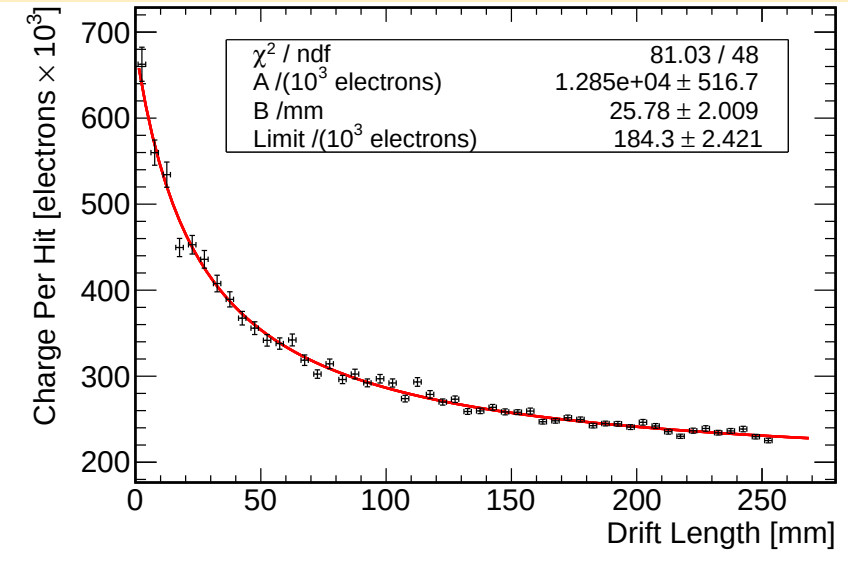


Measured drift velocity of $9.75\,\mu\mathrm{m/ns} \pm 0.8\,\%$ is in good agreement with Magboltz simulation.

Side effects in the arrival time spectrum are well understood.

Hit Properties

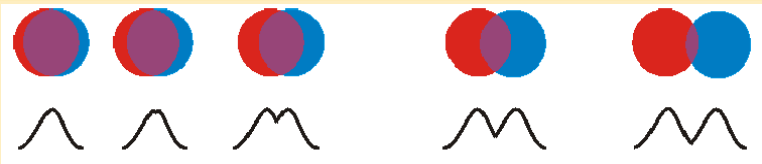
Mean charge deposition



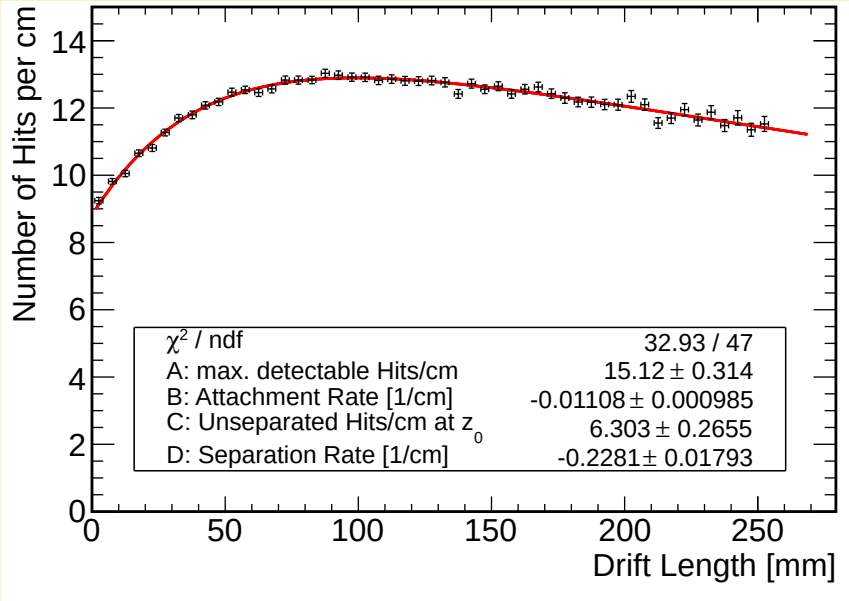
$$Q(z) = \frac{A}{B+z} + Limit$$

Deduced gas gain: $\approx 185\,\mathrm{k}$

Declustering

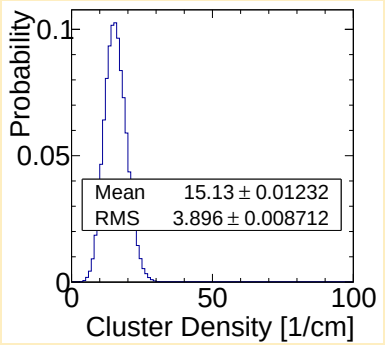


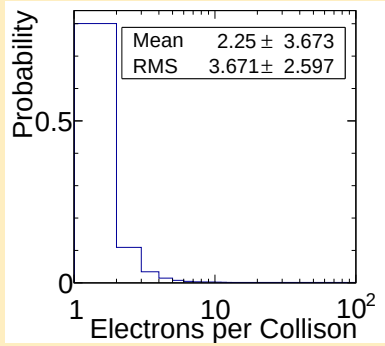
Ionization density



$$N(z) = Ae^{Bz} - Ce^{Dz}$$

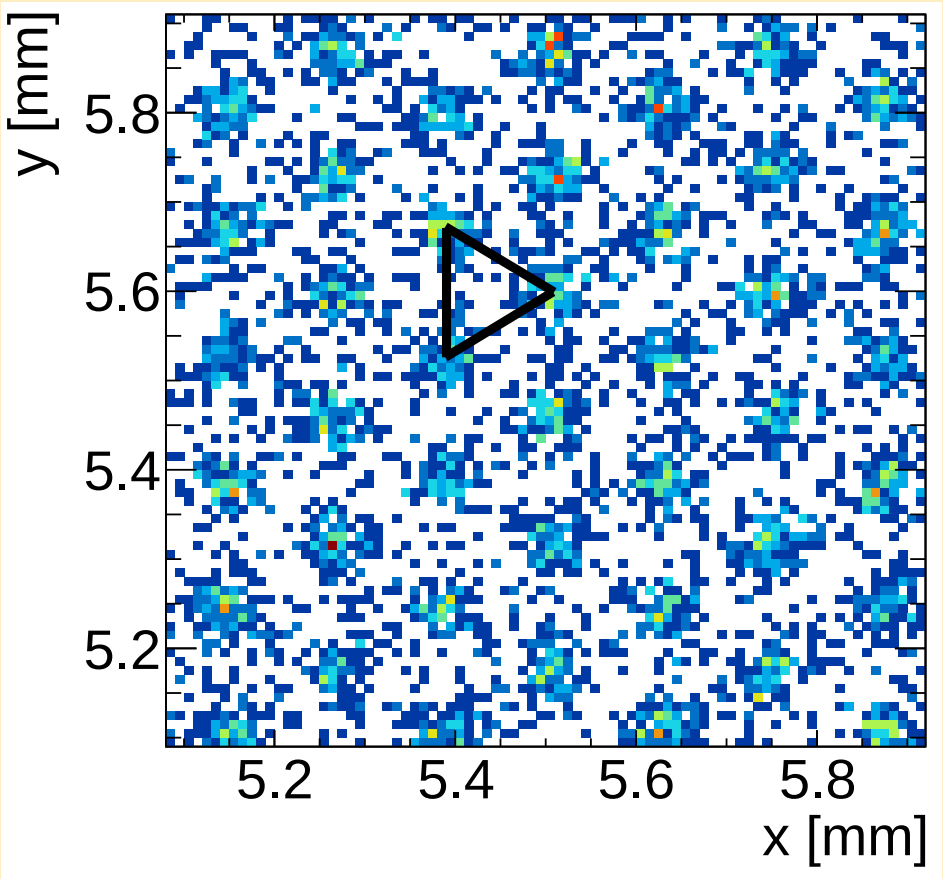
Simulations:





Chip Occupancy

Reconstructed centers of charge depositions (extreme zoom)



The hexagonal pattern of the GEM is visible in the data.
(Pitch: $140\,\mu\mathrm{m}$)
The spatial resolution for one single electron will never be better than the GEM resolution.
($\sigma_{GEM} \approx 40\,\mu\mathrm{m}$)

(This may be not the case for multi-electron clusters.)

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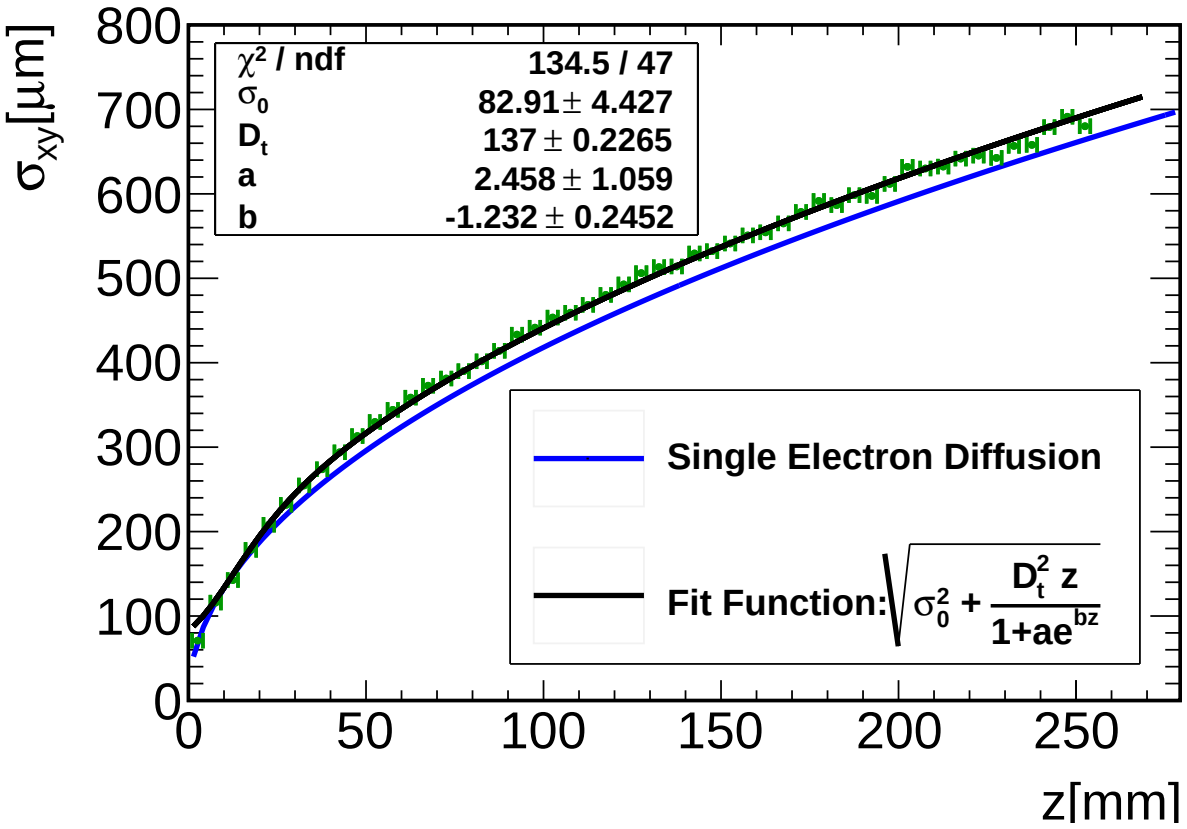
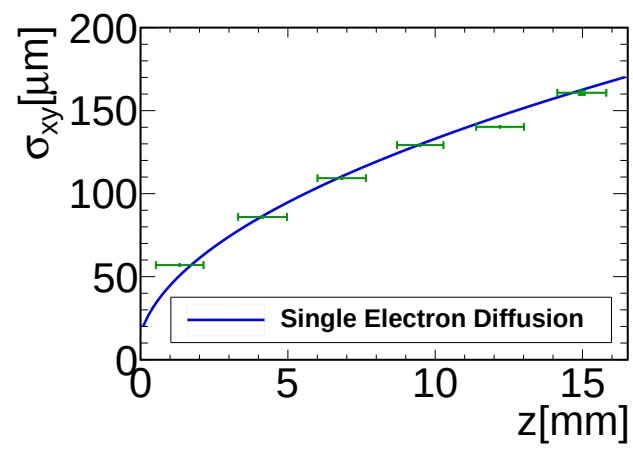
xy-Resolution



Short drift distances

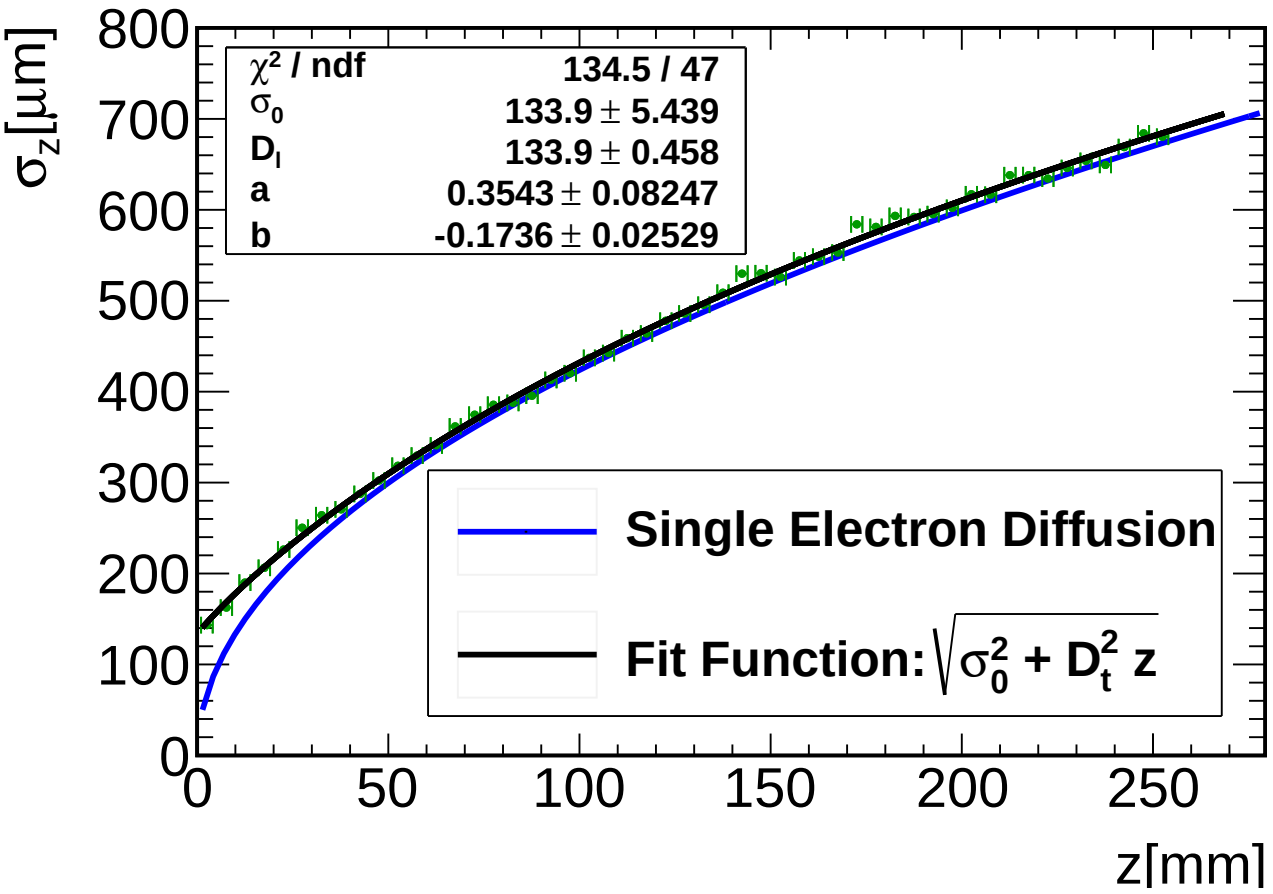


Intrinsic detector resolution is:

$$\sigma_0 \approx 50\,\mu\mathrm{m}$$

The spatial resolution of one primary electron is limited by the transverse diffusion during drift: $\sigma = D_t\sqrt{z}$.
For short drift distances a charge deposition may result from several electrons. This is taken into account by the fit function.

z-Resolution

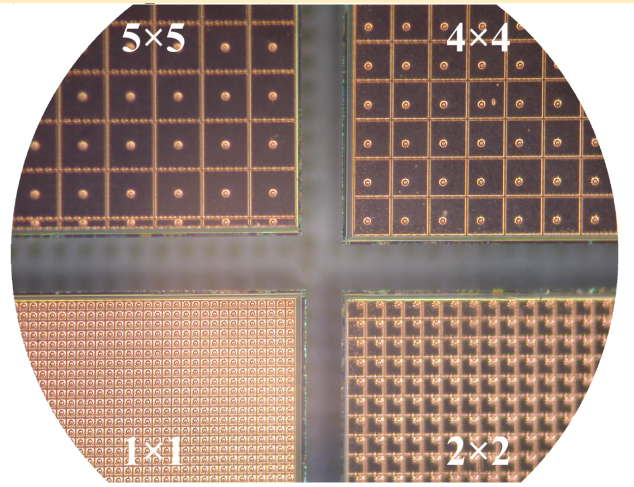


The spatial resolution of one primary electron is limited by the longitudinal diffusion during drift: $\sigma = D_l\sqrt{z}$

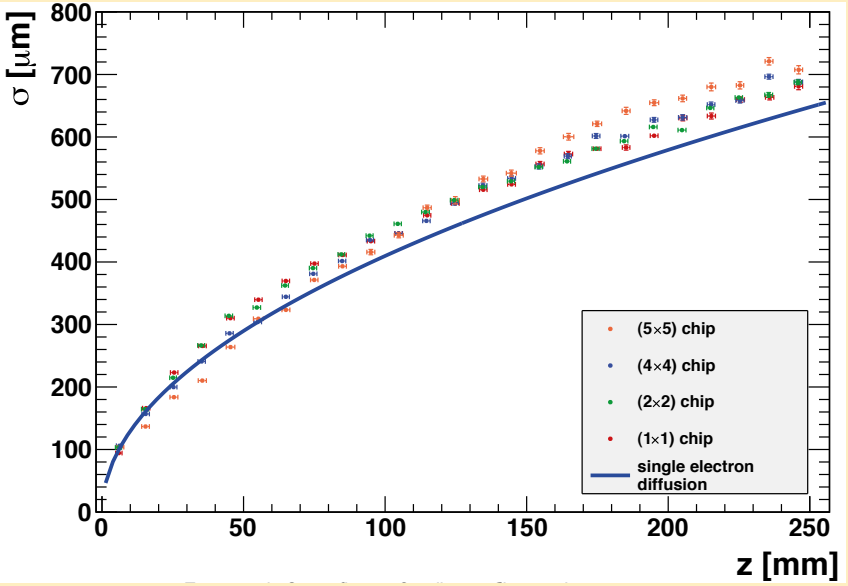
For drift distances larger than $50\,\mathrm{mm}$ the spatial resolution is close to the theoretical limit.

Outlook: Improvements by chip postprocessing

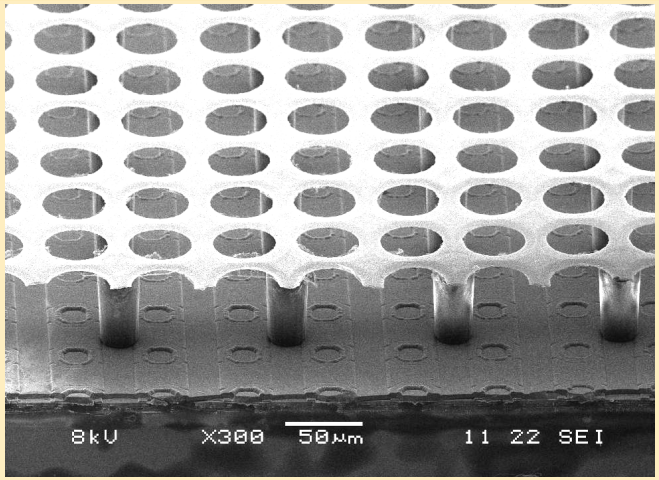
Pad enlargement



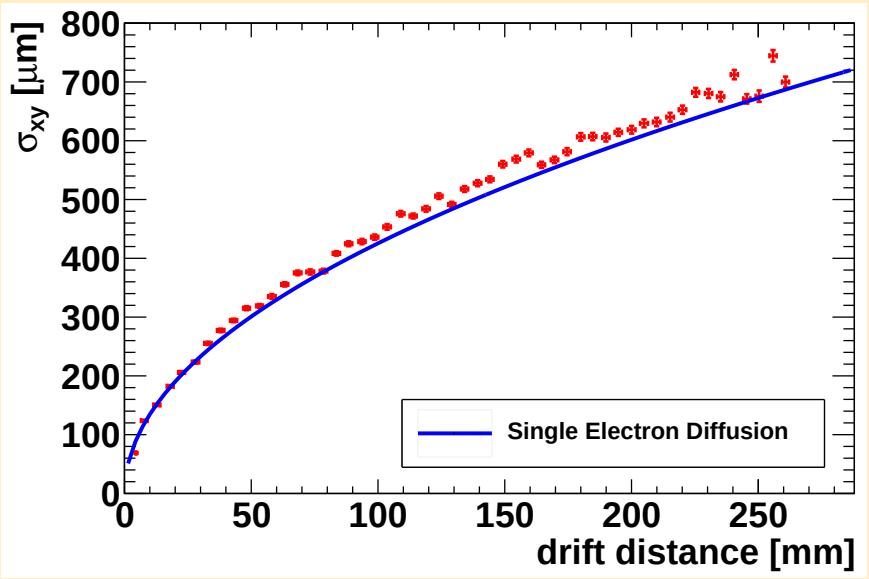
Transverse resolution:



Ingrid (Micromegas)



Transverse resolution:



Summary

- A TPC with maximized readout granularity has been successfully operated in several setups (He/CO_2 has been presented).
- The performance of the detector is close to the theoretical limit.
- No show-stoppers for large scale applications have been found.

The (near) Future

- Enhanced readout SRS is under development (RD51). This will allow readout of 100s of chips.
- The next generation chip, Timepix3, will have enhanced features.
- Enlarged pixels are subject to further investigations.
- Ingrid structures perform great, but need further research for large scale applications.

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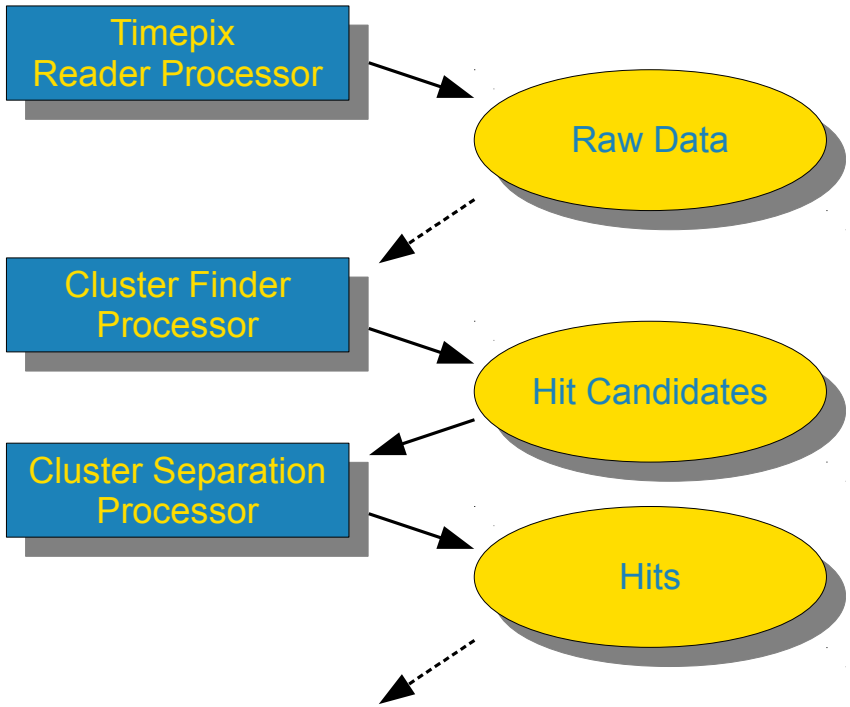
Thank you very much!

Do you have any Questions?

MarlinTPC & LCIO

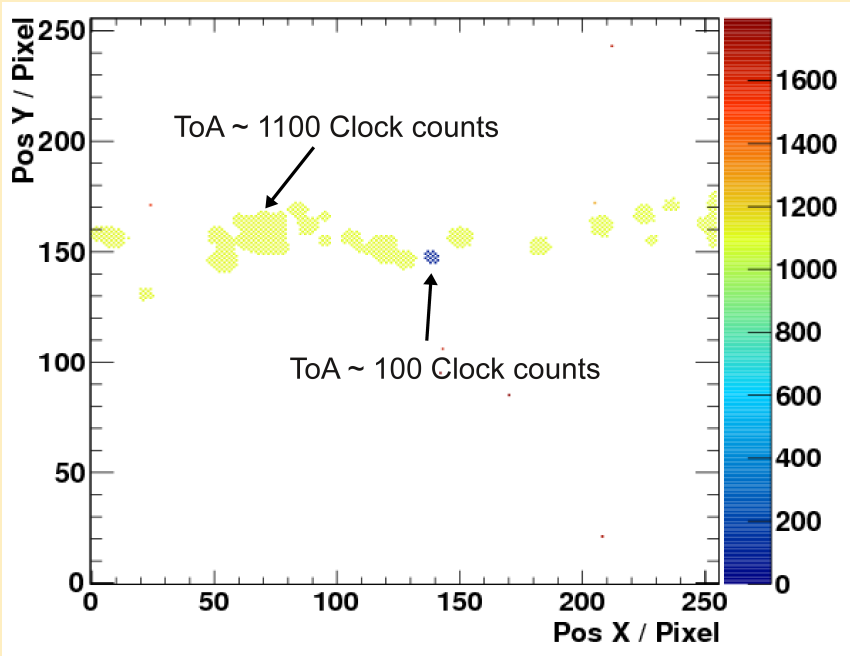
Modular **A**nalysis & **R**econstruction for the **Lin**ear Collider

- Developed within the LC-TPC collaboration
- Data processing is highly modular
- Each algorithm is encapsulated in a *processor*
- Unified data model LCIO is used
- Sequence and parameter of individual processors are defined in a XML steering file



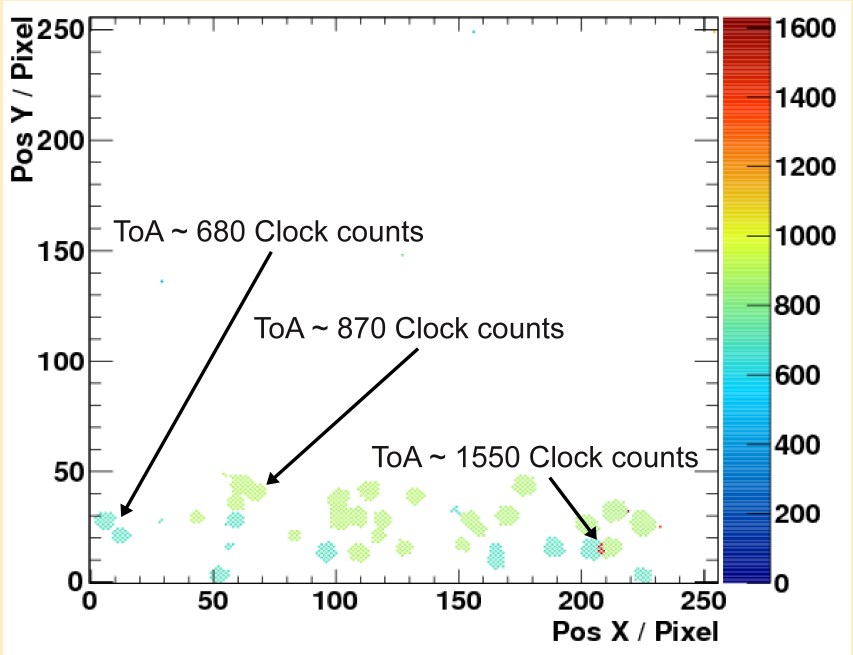
Backup: Late and Early Hits

Late Hit (Few Clock Counts)



The hit belongs obviously to the track but is 1000 clock counts of track ($\approx 18\,\mathrm{cm}$ drift).
Effect can be explained by attachment/detachment effects.

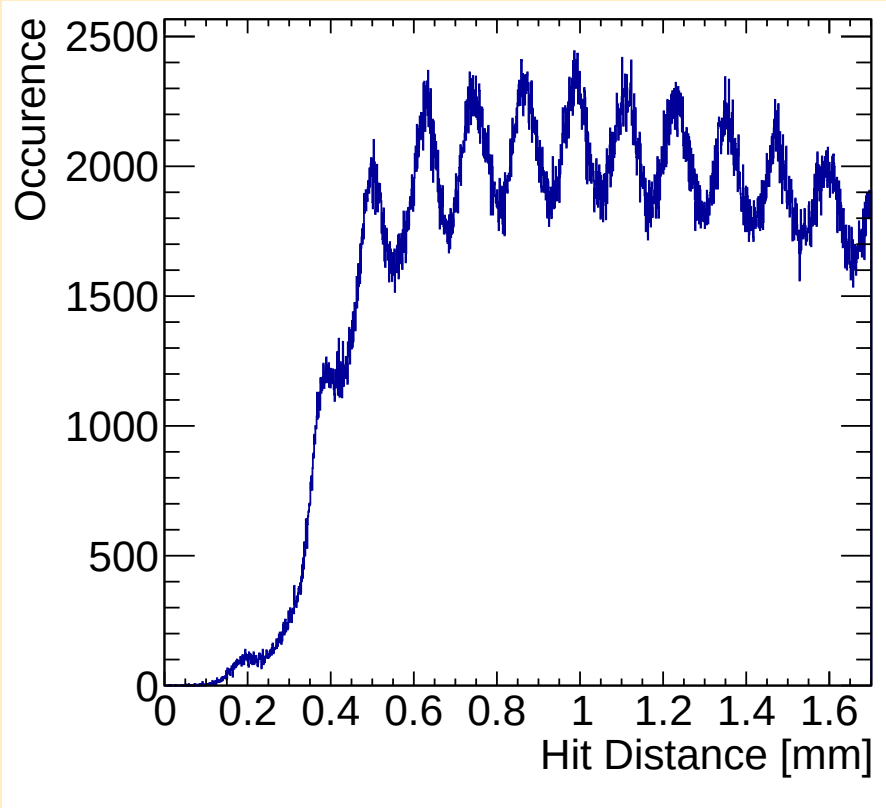
Early Hit (Many Clock Counts)



Due to a rare error in the chip logic counters are not reset between two events.
Thus pixels which are hit by electrons from two different tracks count the ToA twice.

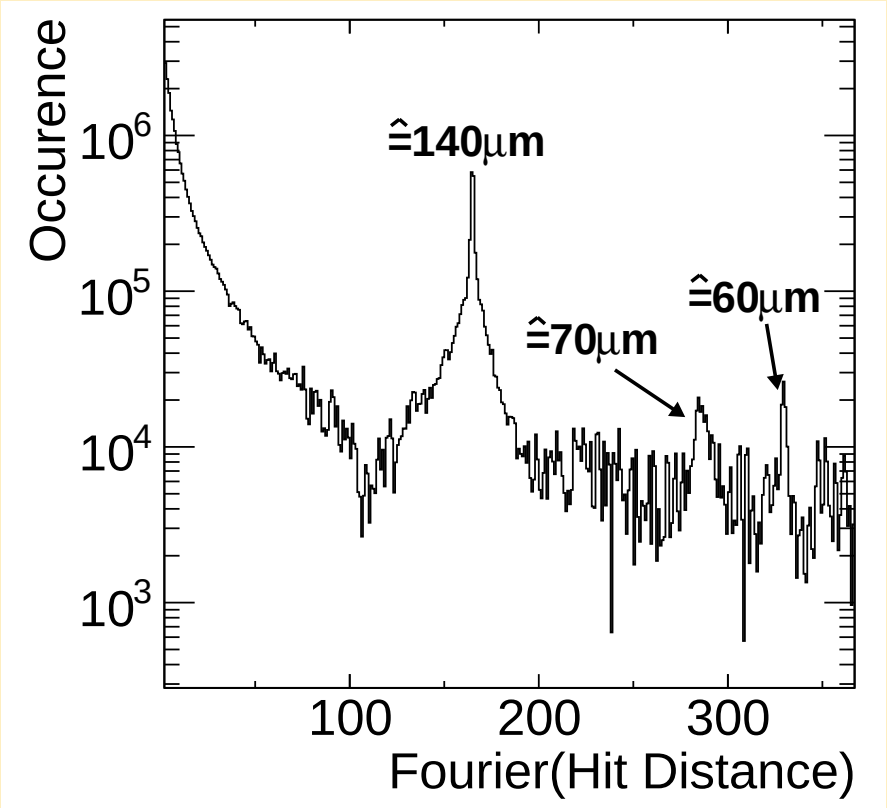
Backup: Separation Power

Distance of two hits in an event



Hits closer than $200 - 400\,\mu\mathrm{m}$ may not be separated by the current separation algorithm.

Sepctrum of left plot



The characteristic distances of the GEM are found in the spectrum of the distance between two hits.

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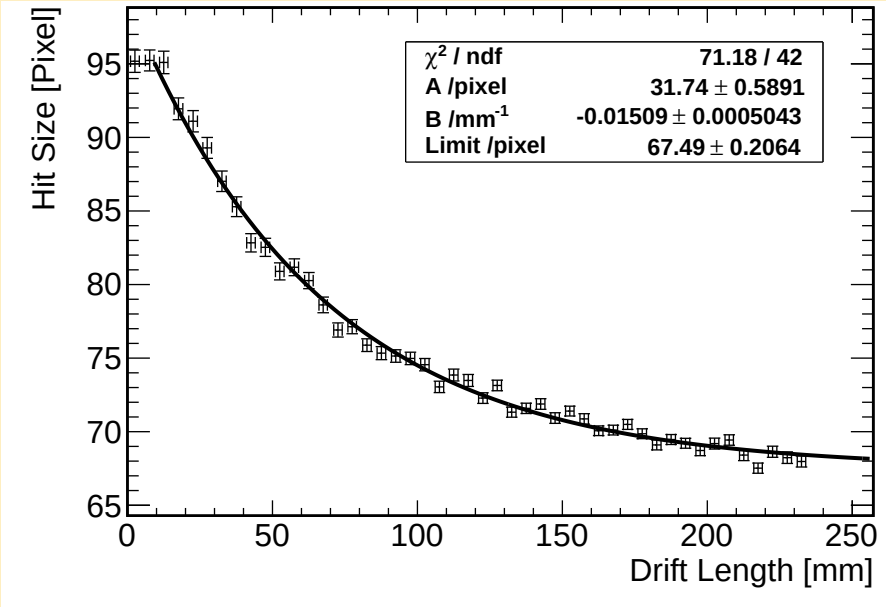
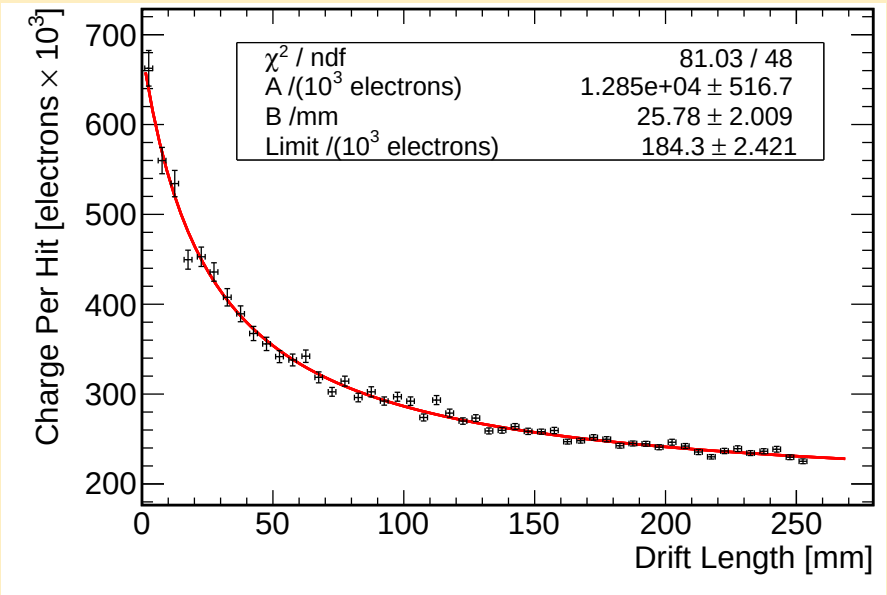
Properties of the Detected Charge Depositions

Mean Size of a charge deposition



$$N(z) = Ae^{Bz} + Limit$$

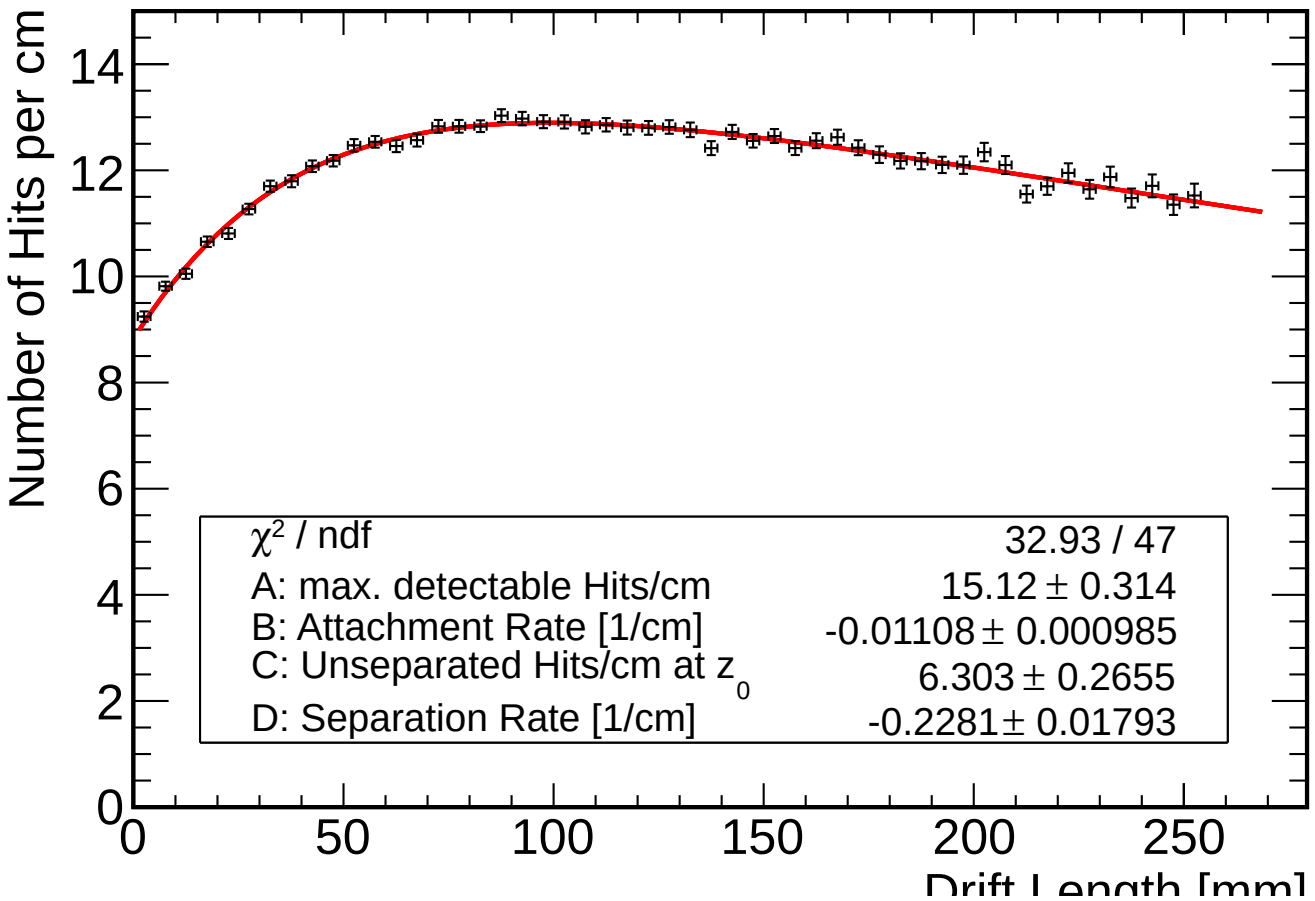
Mean charge deposition



$$Q(z) = \frac{A}{B+z} + Limit$$

Charge depositions get smaller with longer drift due to better separability.
Gas gain from charge per hit: $\approx 185\,\mathrm{k}$

Detected Ionization Density



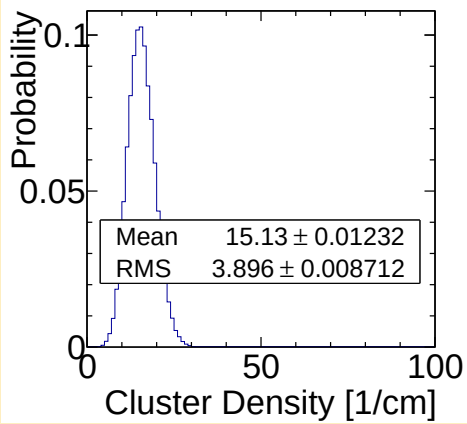
Rise due to declustering

Decrease due to attachment (O_2 content $\approx 10\,\mathrm{ppm}$)

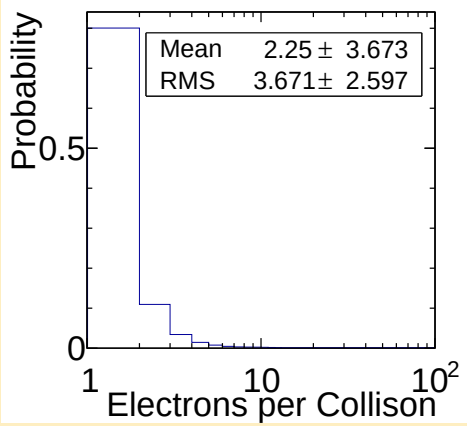
Data described by: $N(z) = Ae^{Bz} + Ce^{Dz}$

Simulations

Collisions per cm



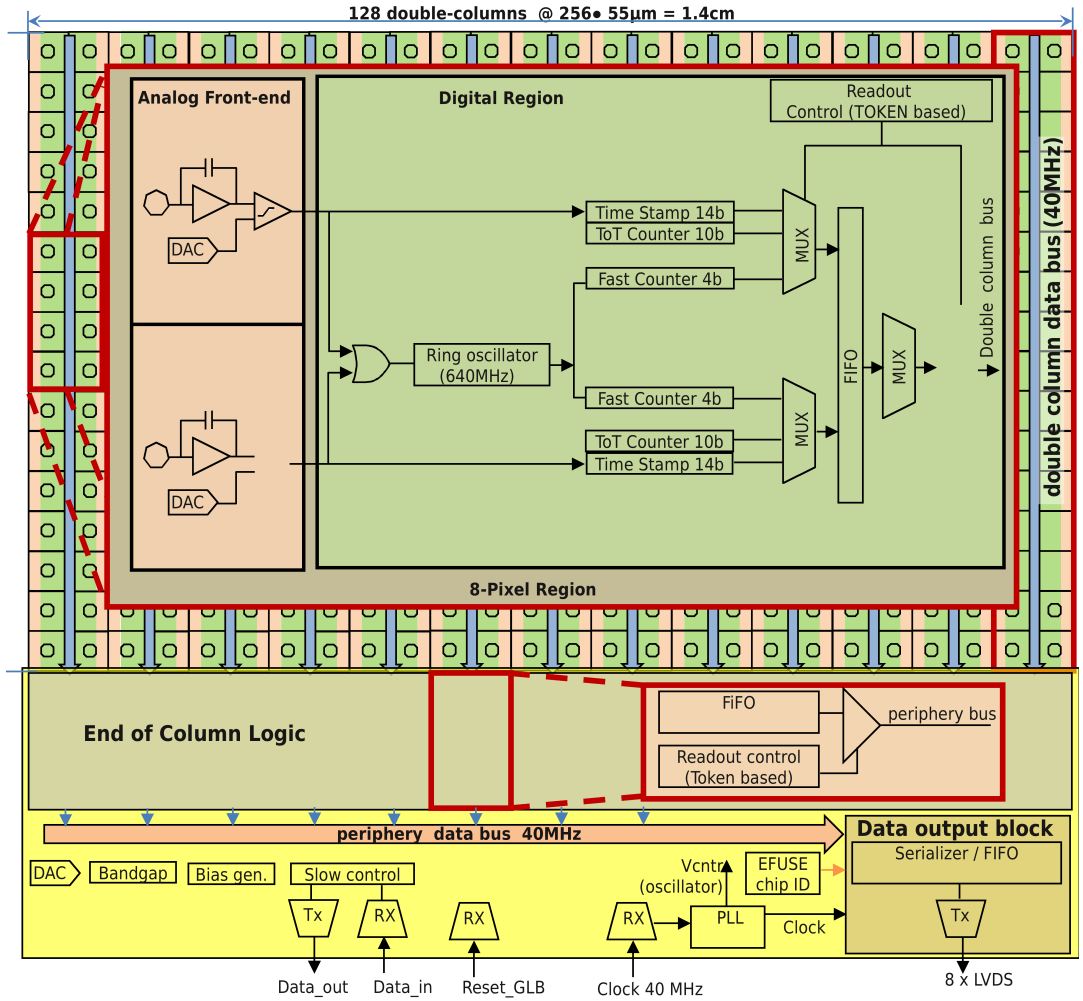
Electrons per collision



Outlook: Timepix successor

Timepix 3:

- $55 \times 55\,\mu\mathrm{m}^2$ per Pixel
- 8192 superpixel with 8 pixels each
- one $640\,\mathrm{MHz}$ oscillator per superpixel
- ToA accuracy: $1.6\,\mathrm{ns}$
- ToA range: 0 - $100\,\mu\mathrm{s}$
- ToA & ToT measured simultaneous.
- Sparse and frame-based high speed readout
- Rate up to $20\,\frac{\mathrm{MHz}}{\mathrm{cm}^2}$
- **Ready in spring 2012**



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Backup: Scalable Readout System

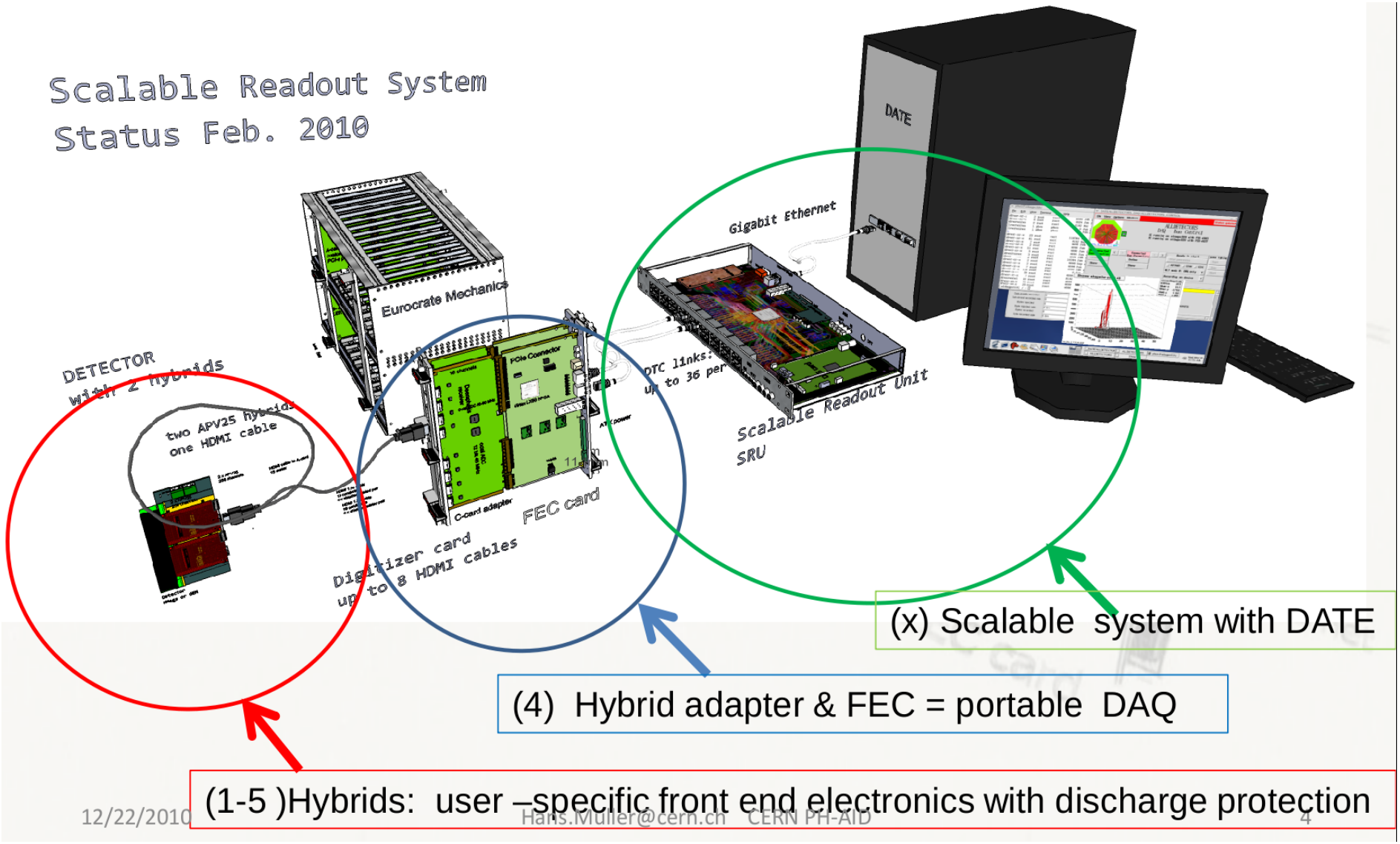

Figure: Hans Müller, CERN