3D Particle Track Reconstruction in a Single Layer CdTe-Pixel Detector

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Friedrich-Alexander-Universität Erlangen-Nürnberg

IMPRS physics of light

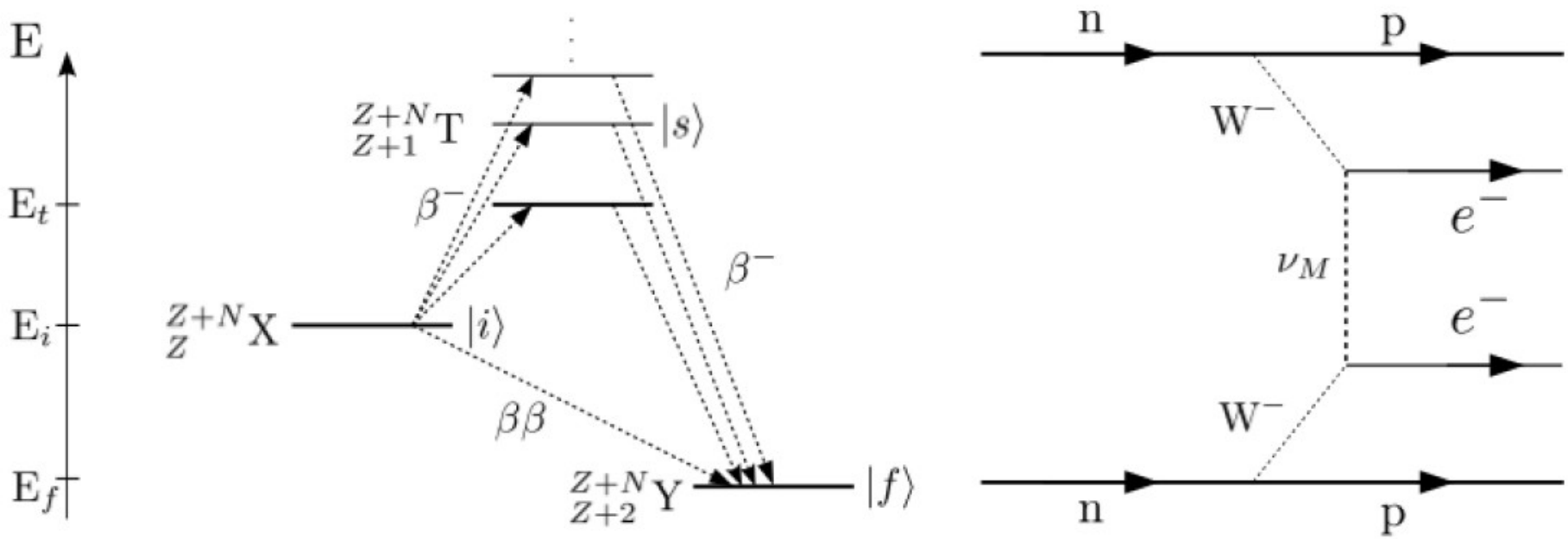
ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

I. Background Reduction By Tracking for 0vbb Search

About the Neutrinoless Double Beta Decay

Neutrinoless Double Beta Decay (0vbb):

$$2n \rightarrow 2p + 2e^-$$

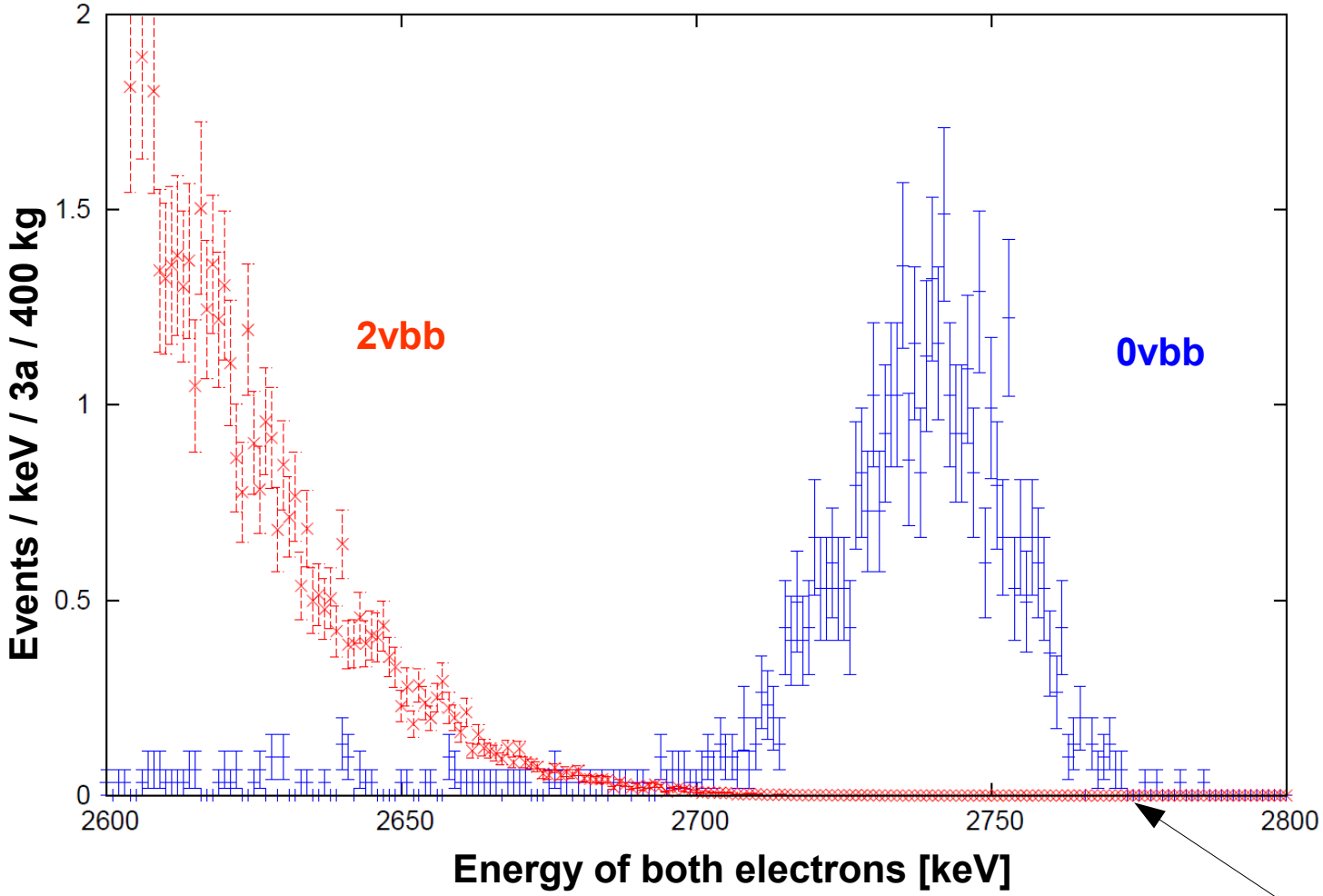


$$(T_{\frac{1}{2}})^{-1}_{0\nu\beta\beta} = G_{0\nu}(Q_{\beta\beta}, Z)\,|M_{0\nu}|^2\,\langle m_\nu \rangle^2$$

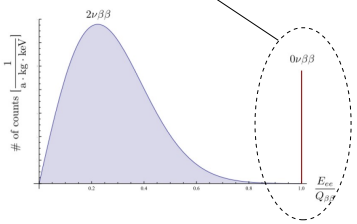
$$T_{0\nu} > 2 \cdot 10^{25} a$$

The Experimental Approach to the 0vbb: The Energy Signature

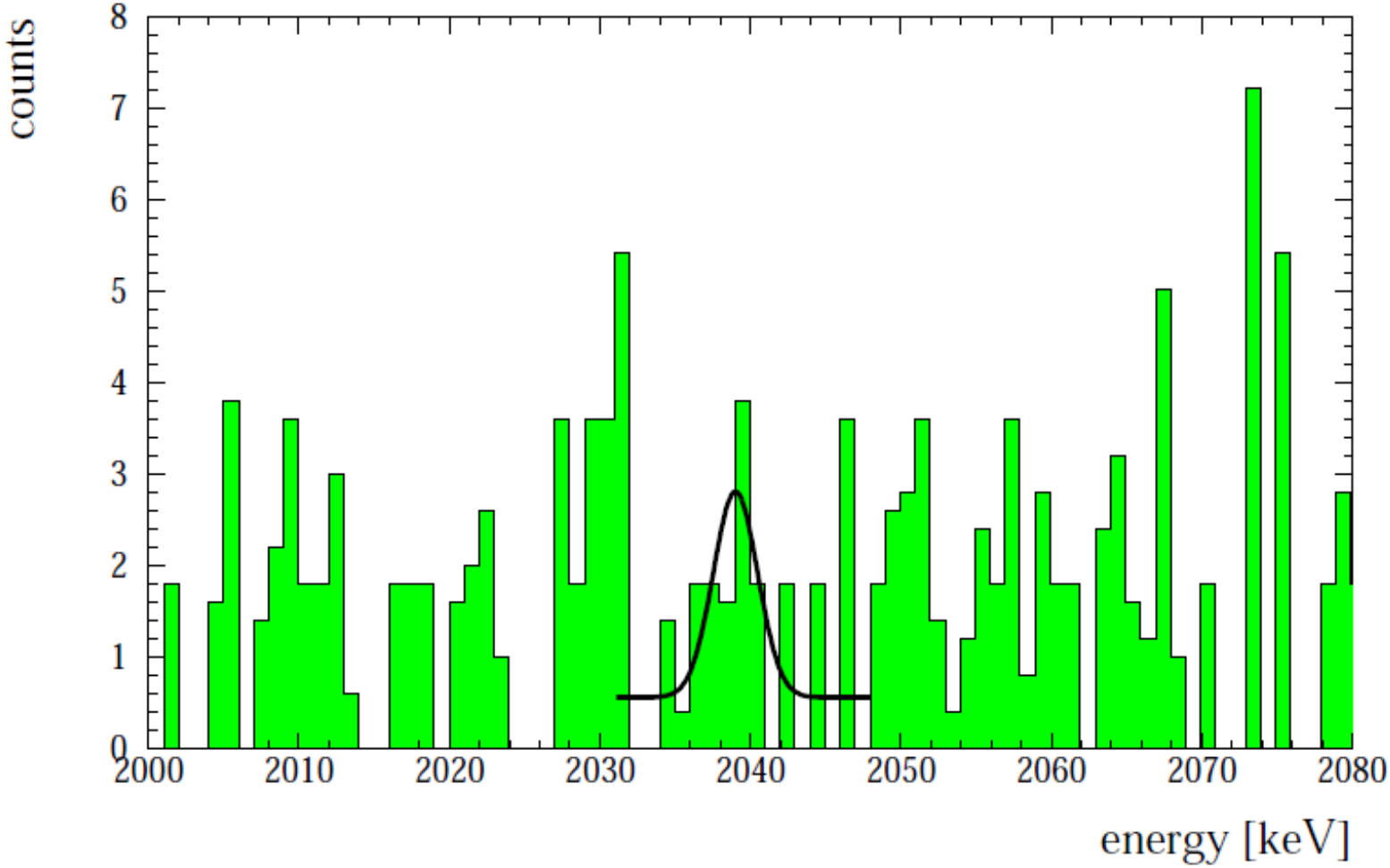
From T.Gleixner '11



Main Idea:
Build a highly precise particle calorimeter.



Main Problem: Background Reduction



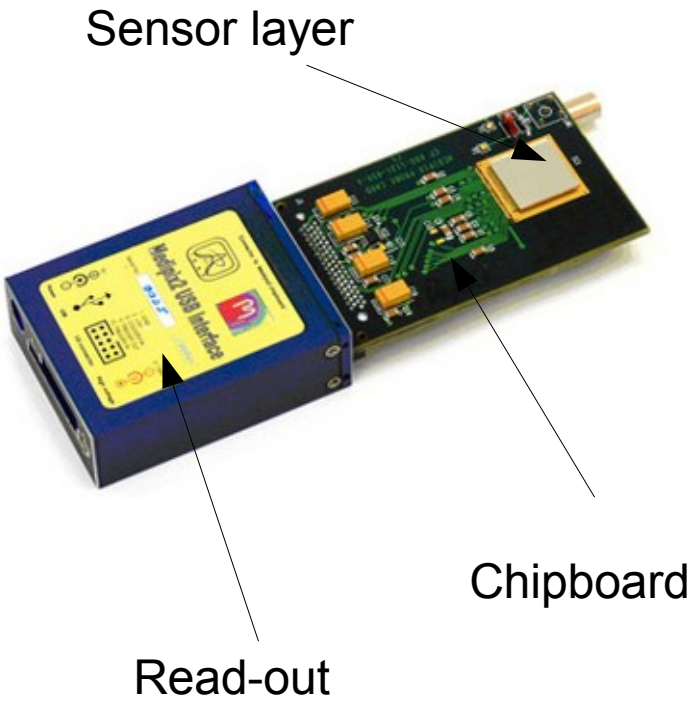
Result of the Heidelberg-Moscow Experiment with a Germanium Calorimeter ['02 H.V. Klapdor-Kleingrothaus].

The Timepix Detector

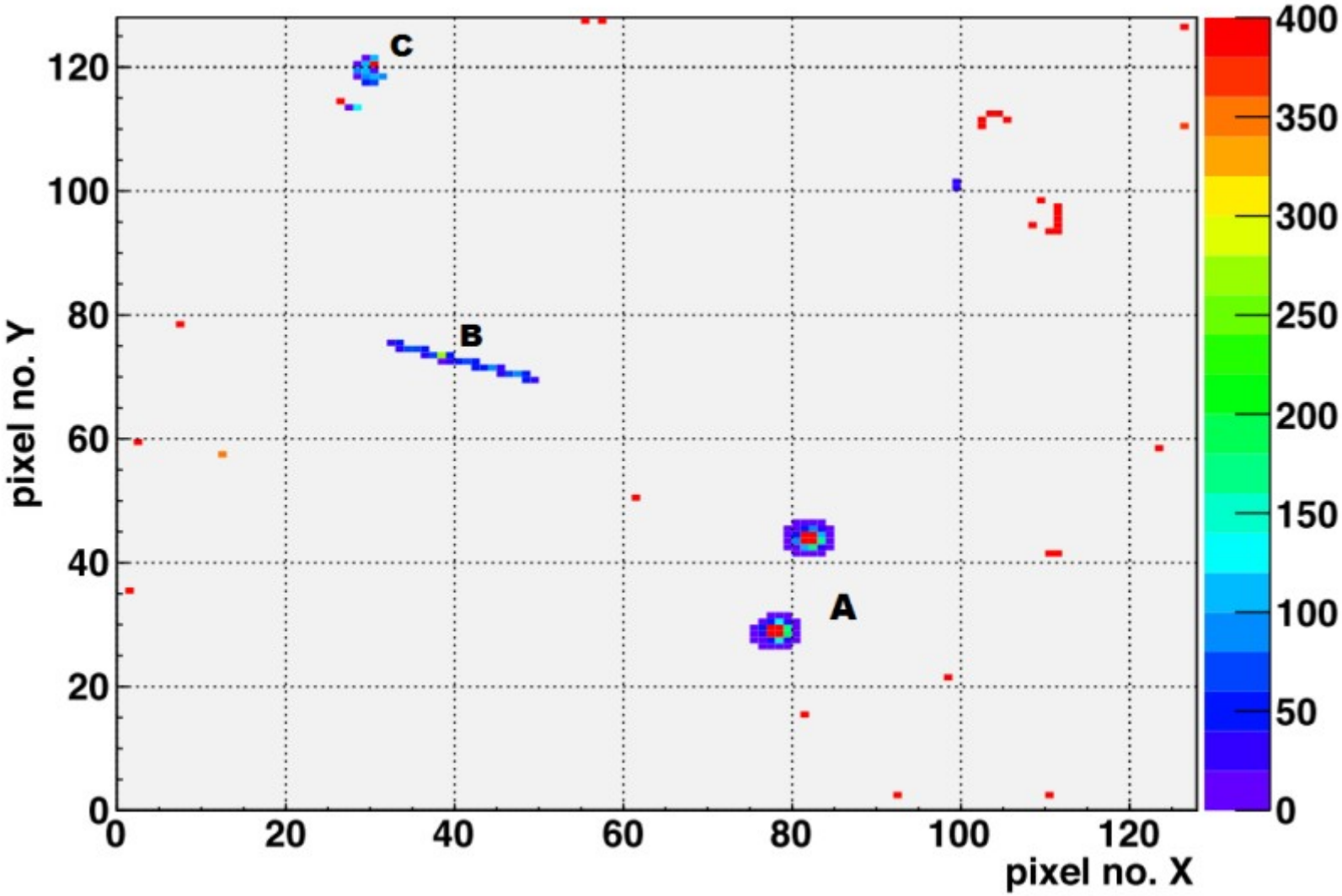
Timepix:
Pixelated Semiconductor X-ray Imaging Detector

Facts:
256 x 256 pixels per chip
55µm, 110 µm or 220 µm pixelsize
Si or CdTe Sensors
Energy measurement for each pixel
Threshold limit at about 5 keV

Conceptual:
Cd-116, Te-128 and Te-130 are 0vbb isotopes.

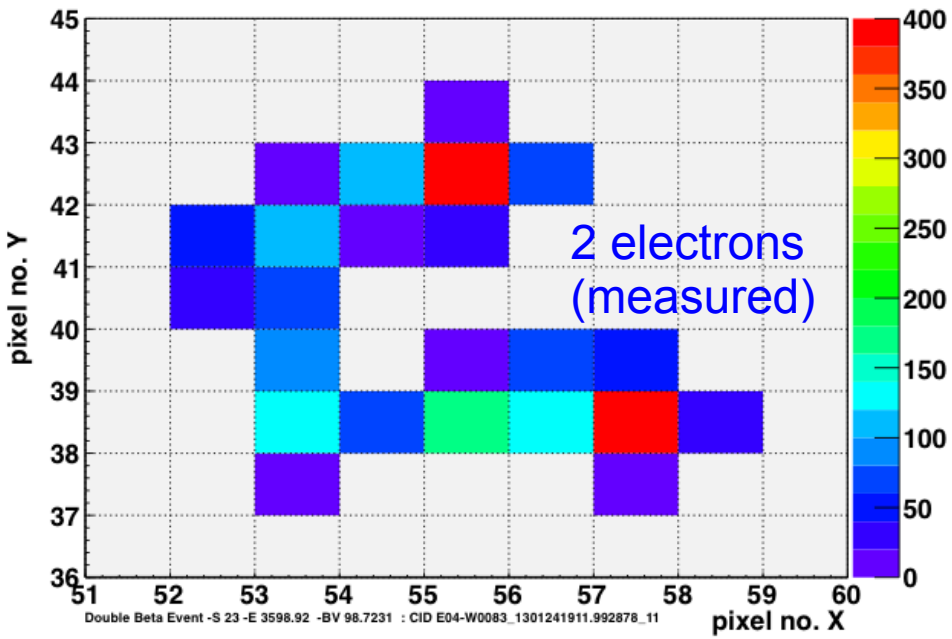


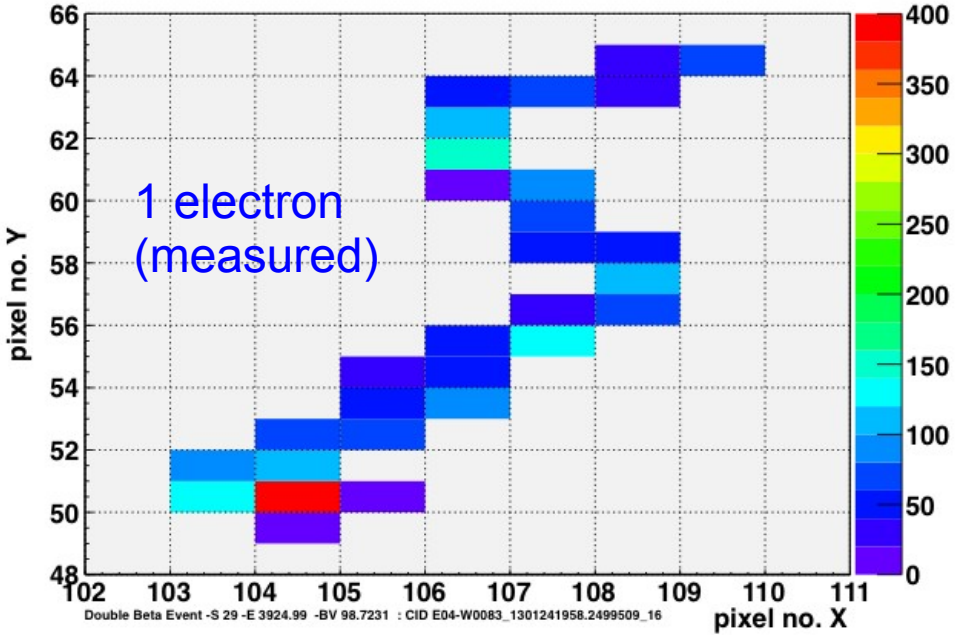
Tracks measured by a Timepix detector

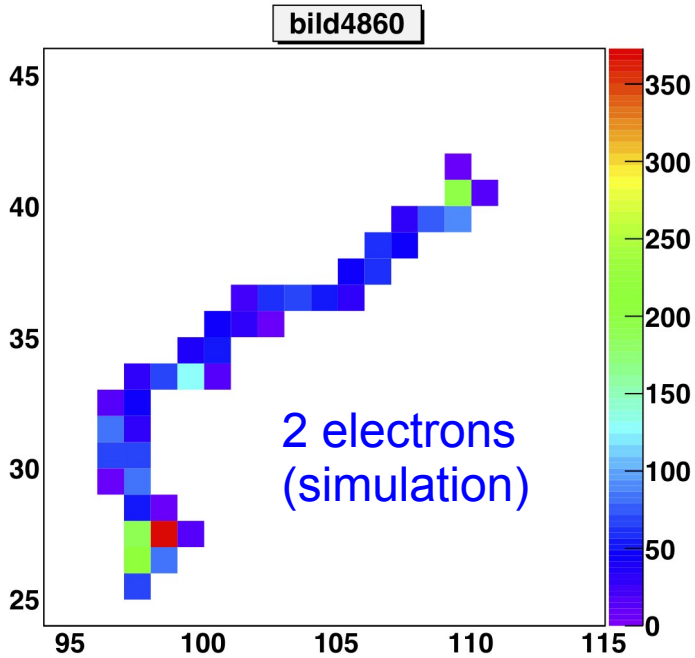


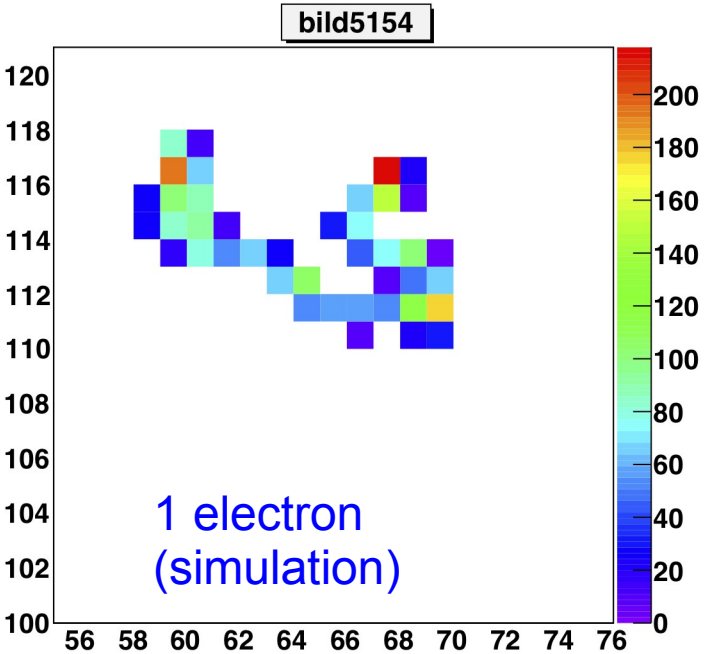
Question: How good can different sorts of background be identified?

Identification of Single Electron Tracks







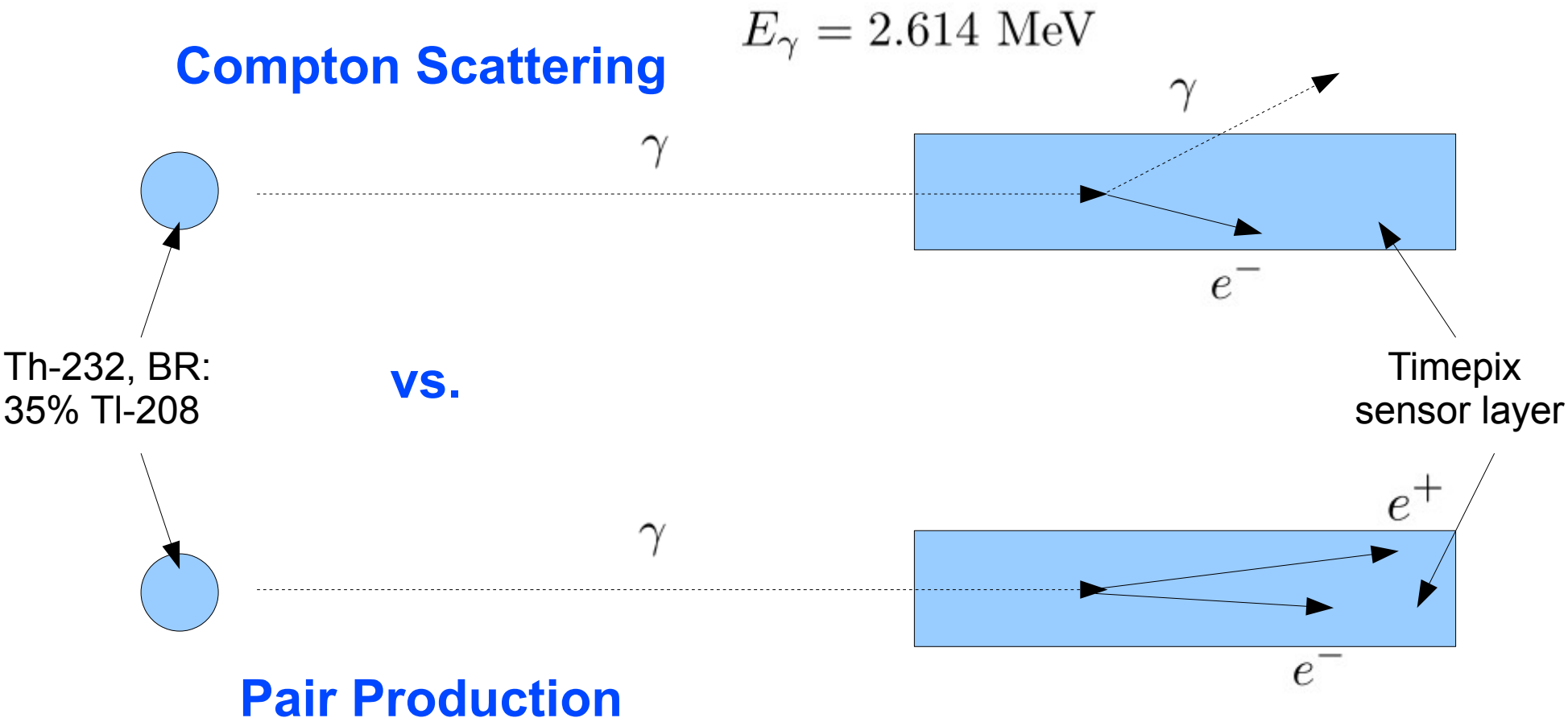


The Main Experiment with Thallium-208

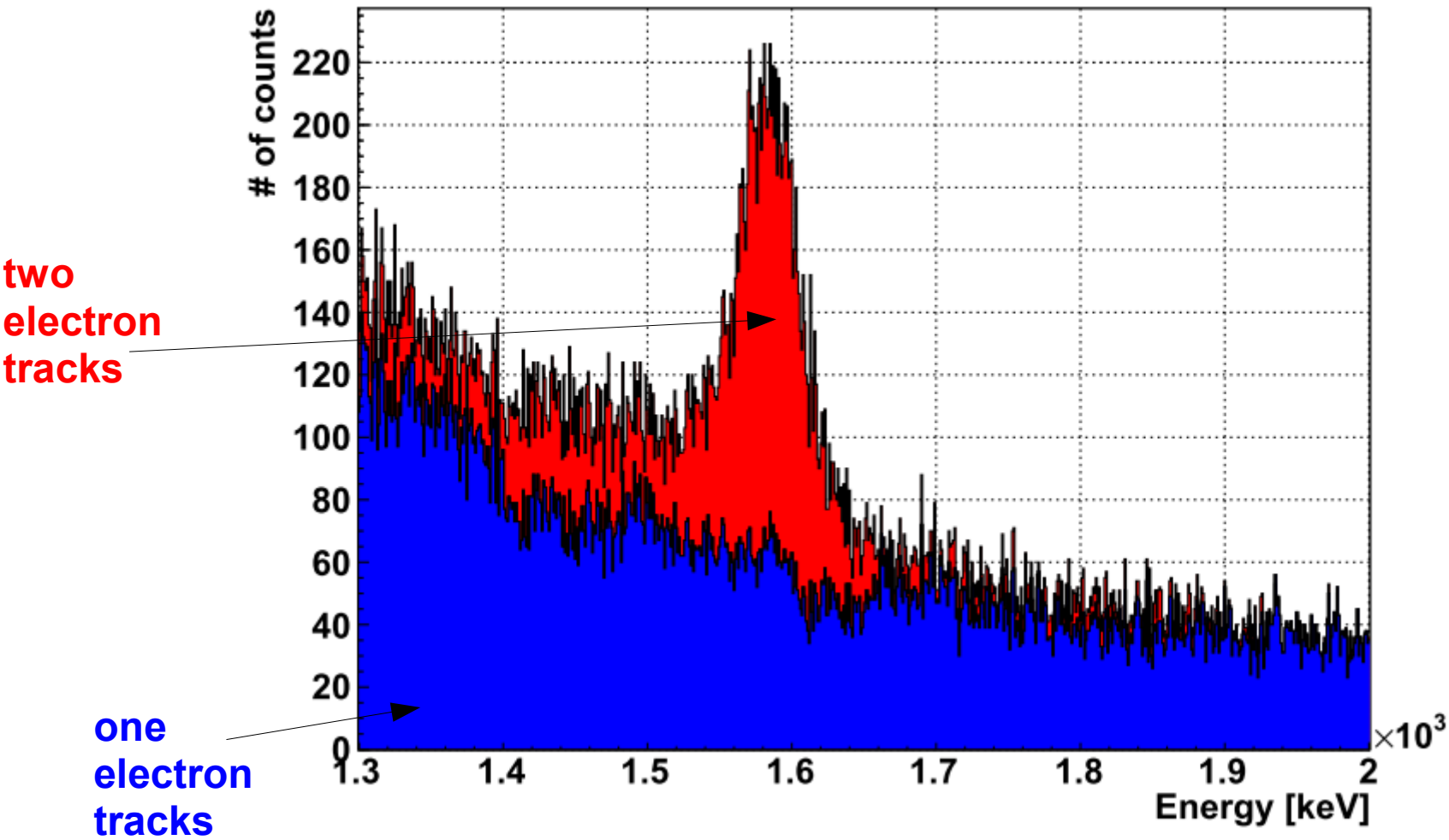
Idea:

Electron-Positron pair production events produce the same tracking signature as 0vbb events.

Use Tl-208 to induce pair production within the sensor.



The Reconstructed Spectrum in the Region of Interest



After event classification with **artificial neural networks** and taking into account misclassification errors.

What do we have so far?

2D tracking is pretty cool:

Highly accurate identification of alphas and muons (> 99.999 %)

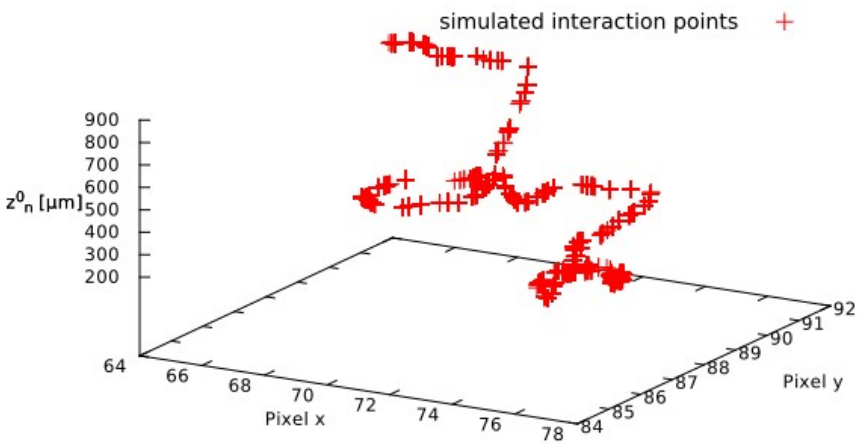
But:

We really need 3D tracking for better separation power between single- and two-electron events

II. 3D Reconstruction Algorithm

Developed by
Thomas Gleixner

What do we have so far?



Simulated electron event (2.8 MeV)

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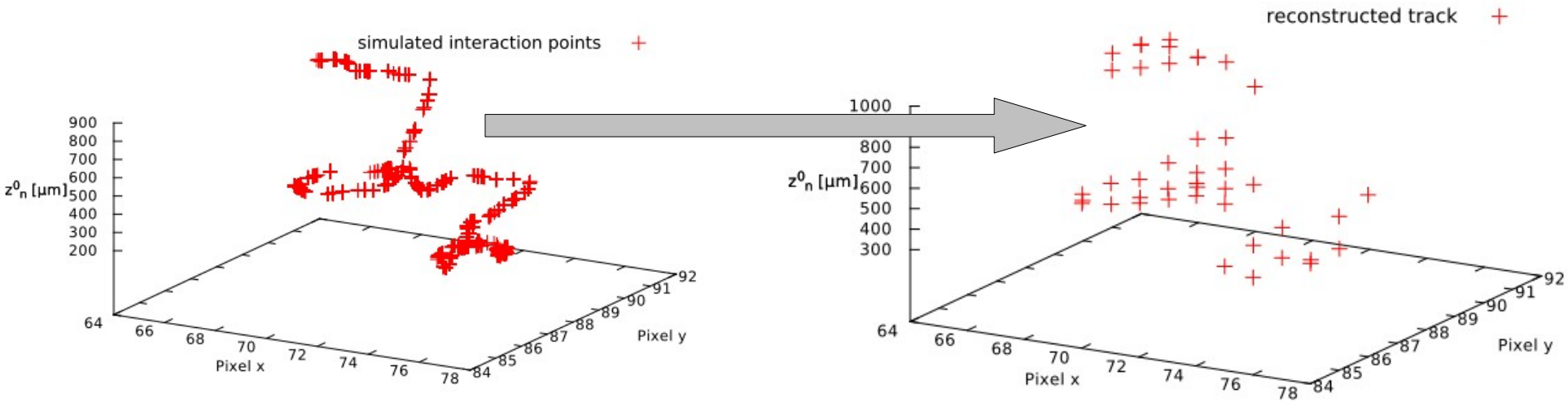

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Reconstructed electron event (2.8 MeV)

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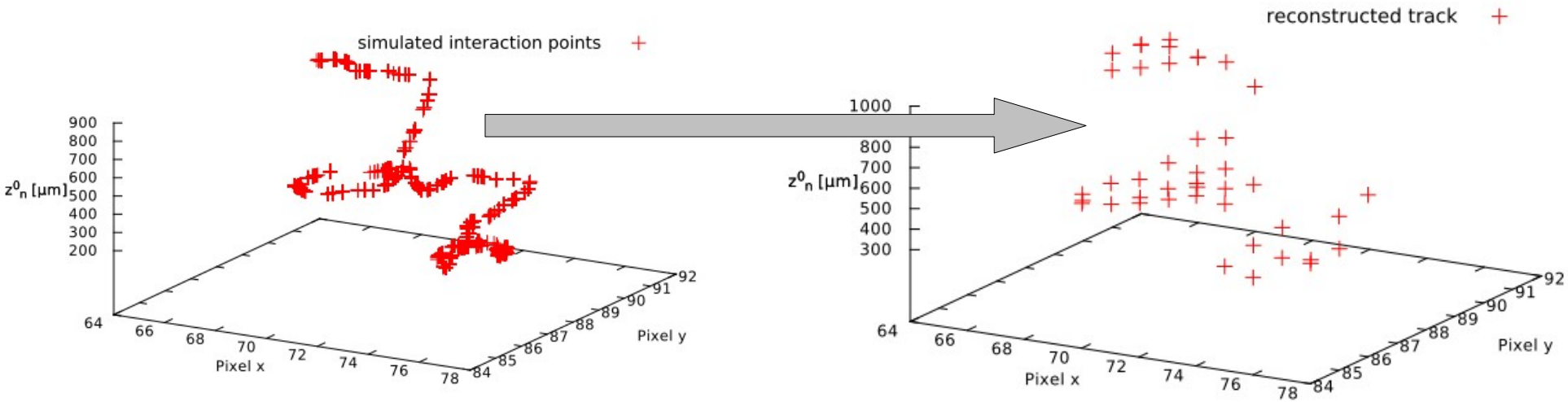
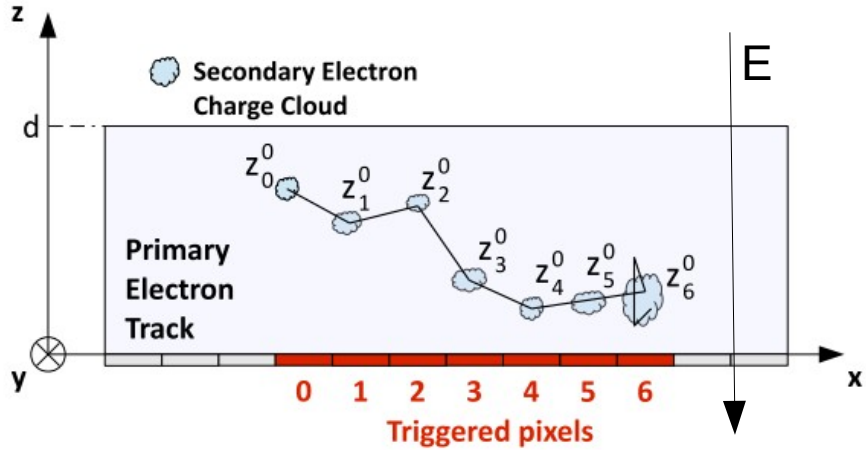


Simulated electron event (2.8 MeV)

Reconstructed electron event (2.8 MeV)

Goal:
Reconstruct the depth of interaction (z-coordinate) for every pixel

How does the algorithm work? I



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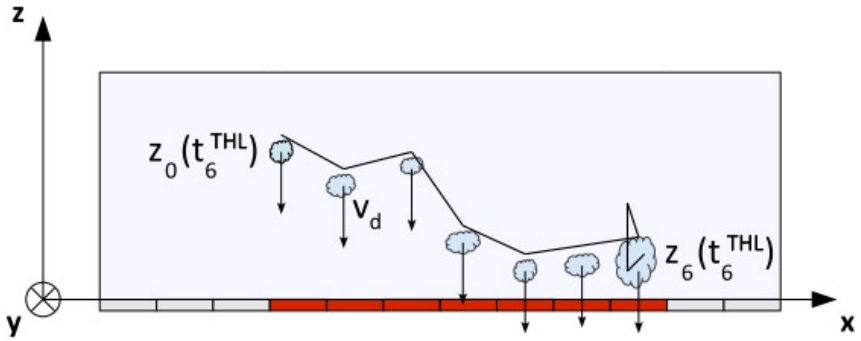

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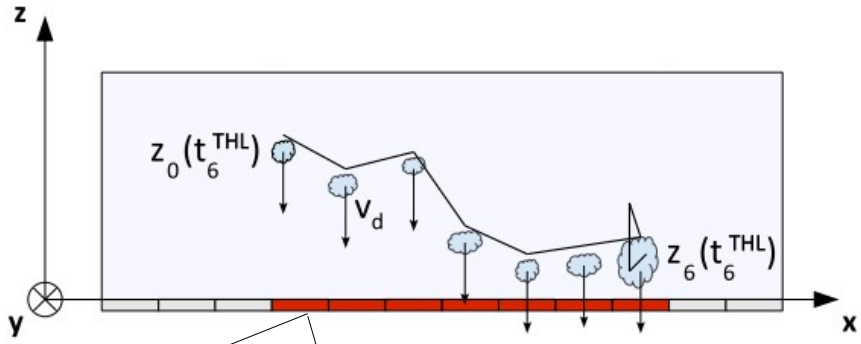
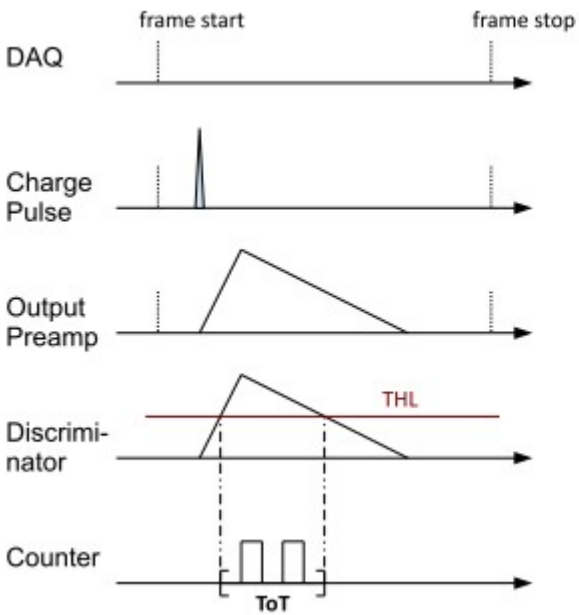
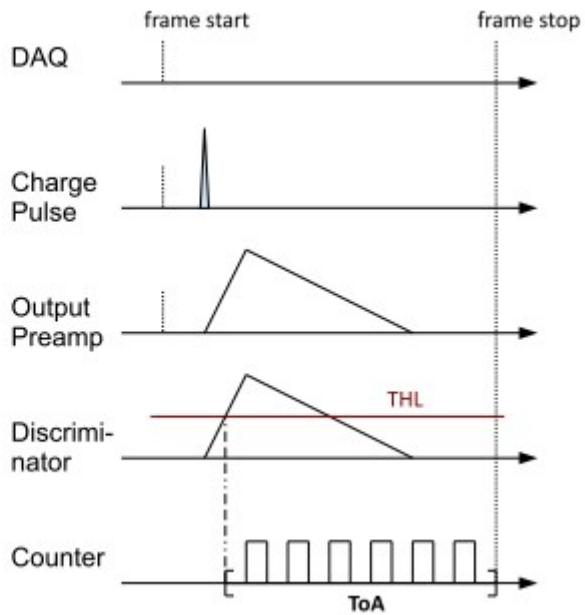


Time-over-threshold
~ deposited energy

Time-of-arrival
~ timing information





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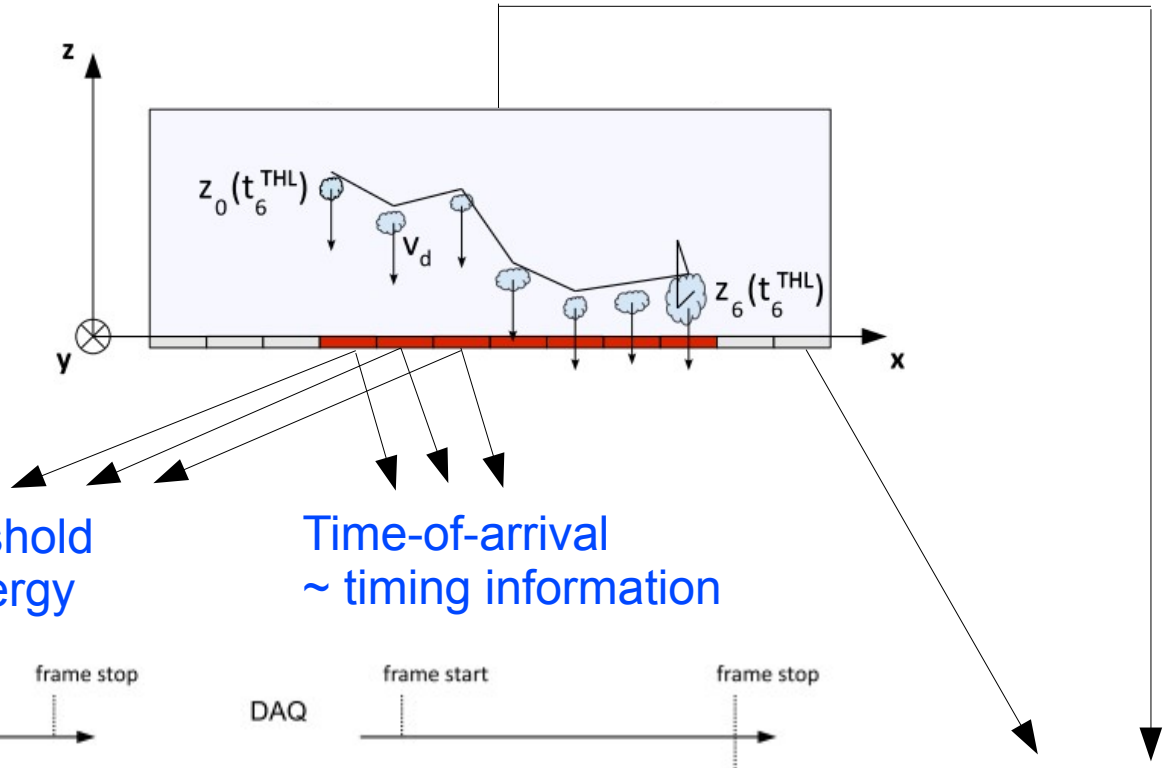

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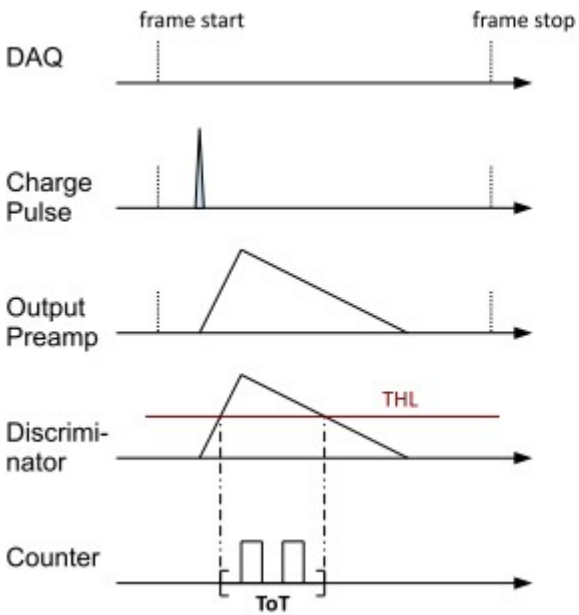
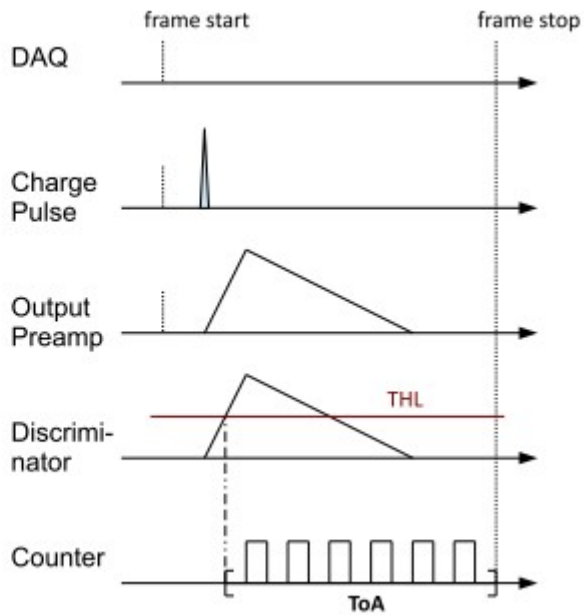
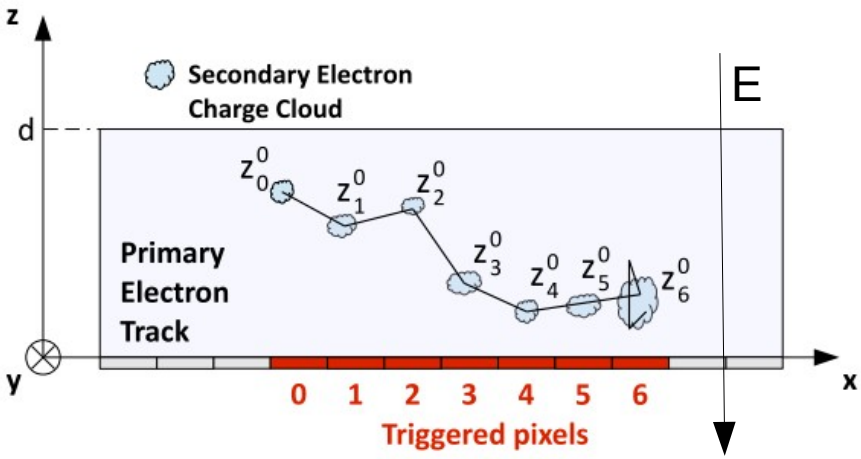




Cathode/Anode Signal Ratio

Has to be measured in every pixel !

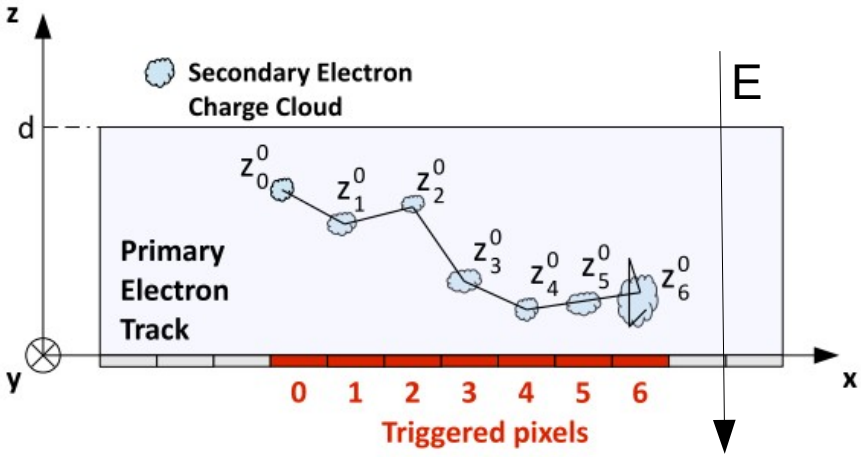
How does the algorithm work? II



Dependence of the electric field on the z-coordinate:

$$|E_z(z,U)| = U(f_2 + f_1 z + f_3 \exp(-f_4 U z))$$

How does the algorithm work? II



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Equation of motion in very pixel:

$$z(t) = z_0 + \int_0^t E(z(t'))\mu_z \mathrm{d}t'$$

$$= z_0 + \mu_z U \int_0^t f_2 + f_1 z(t') + f_3 \exp(-f_4 U z(t'))\mathrm{d}t'$$

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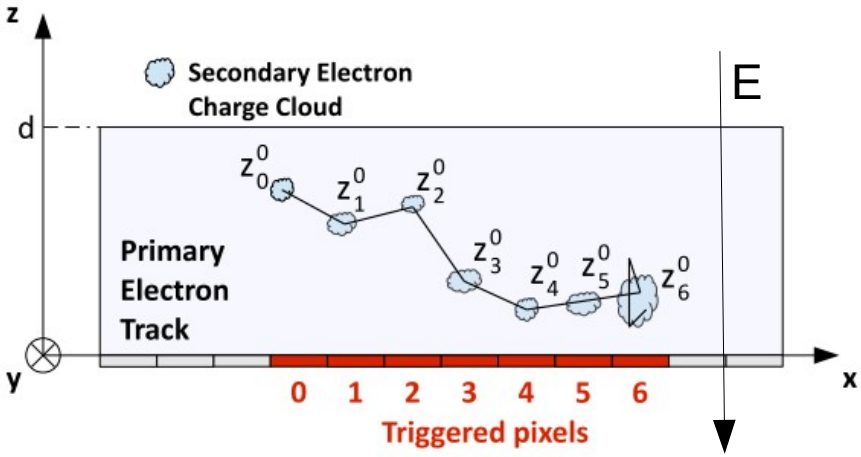

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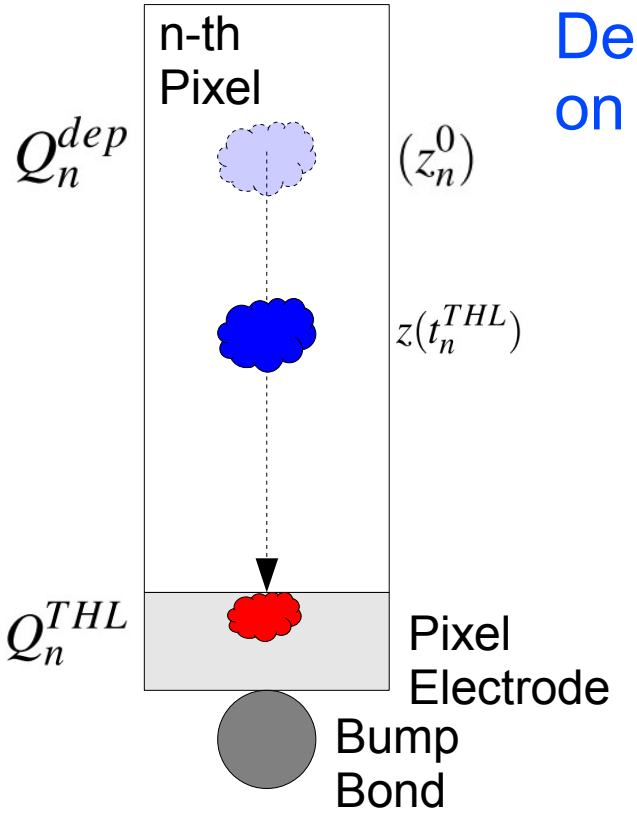
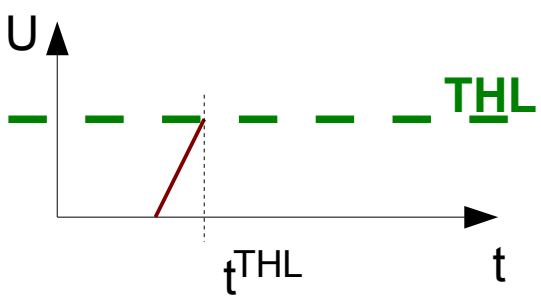
Cannot be solved analytically
→ Linearize on 20 000 intervals and solve numerically.

How does the algorithm work? III



Dependence of the induced charge
on the time after the event (in every pixel):

$$Q_n^{THL} = Q_n^{ind}(t_n^{THL})$$
$$= [W_{pot}(z(t_n^{THL})) - W_{pot}(z_n^0)]\, Q_n^{dep}$$



How does the algorithm work? III

Dependence of the induced charge on the time after the event (in every pixel):

Known from THL-Calibration

z(t) determined numerically

Known from Calculations

Known from ToT-Calibration and ToT-Measurement

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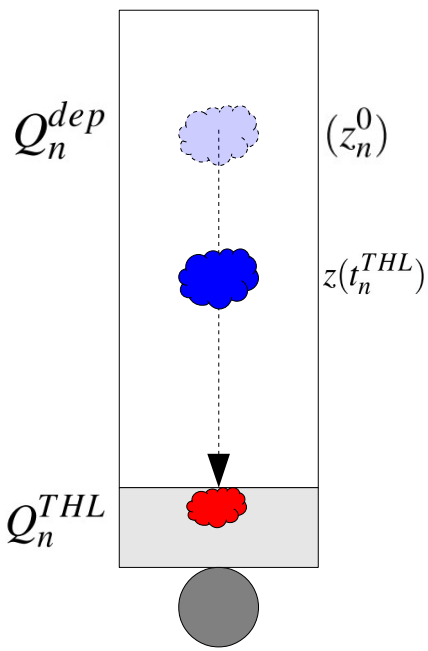
$$= [W_{pot}(z(t_n^{THL})) - W_{pot}(z_n^0)]\, Q_n^{dep}$$



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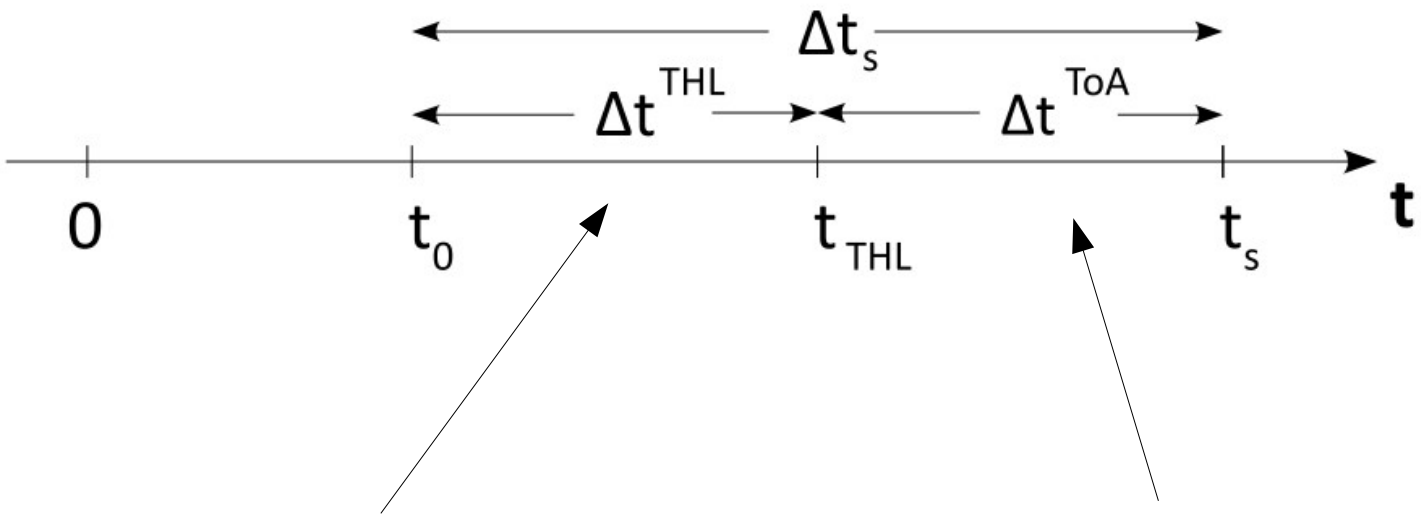
Determined from the ToA and the average depth of interaction

To be determined numerically

How does the algorithm work? IV

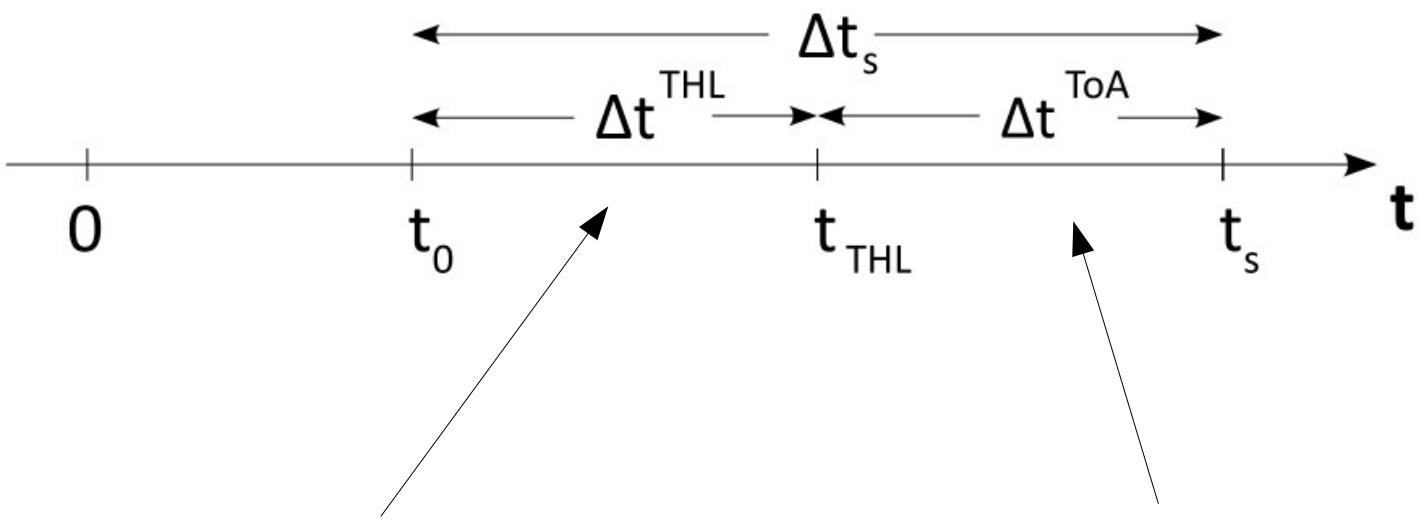


What we need to know

What we actually can measure (ToA)

How does the algorithm work? IV

Can be determined
By from the average depth
of interaction



What we need
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What we actually can
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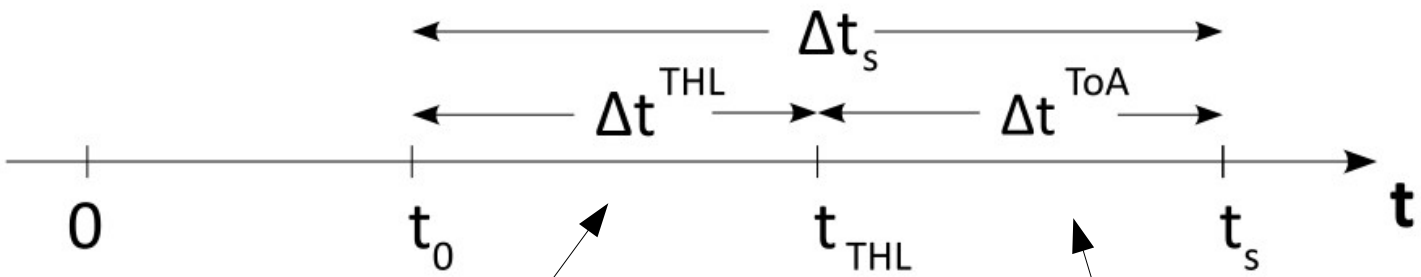
How does the algorithm work? IV

Can be determined
By from the average depth
of interaction

$$\Delta z = \langle z \rangle^{meas} - \langle z \rangle$$
$$= \langle z \rangle^{meas} - \frac{1}{Q}\sum_{0}^{N} z_n(\Delta t_s) Q_n^{dep}.$$

Determined by C/A
ratio



What we need
to know

What we actually can
measure (ToA)

Reconstruction Step by step

1. Compute z(t) numerically from E(z,U)

2. Determine the average deph of interaction from the Cathode/Anode ratio

3. Fix an arbitrary value for Δt_s and calculate the depth of interaction for every pixel from the ToT and ToA

4.Vary Δt_s and determine its correct value from the average depth of interaction. Repeat step 3.

III. Experimental Results

Performed at DESY
Thanks to Ralf Diener
And Dominik Dannheim

Experimental Setup

Problem:

Timepix cannot measure all necessary quantities in every pixel (no backside readout, either ToT or ToA)

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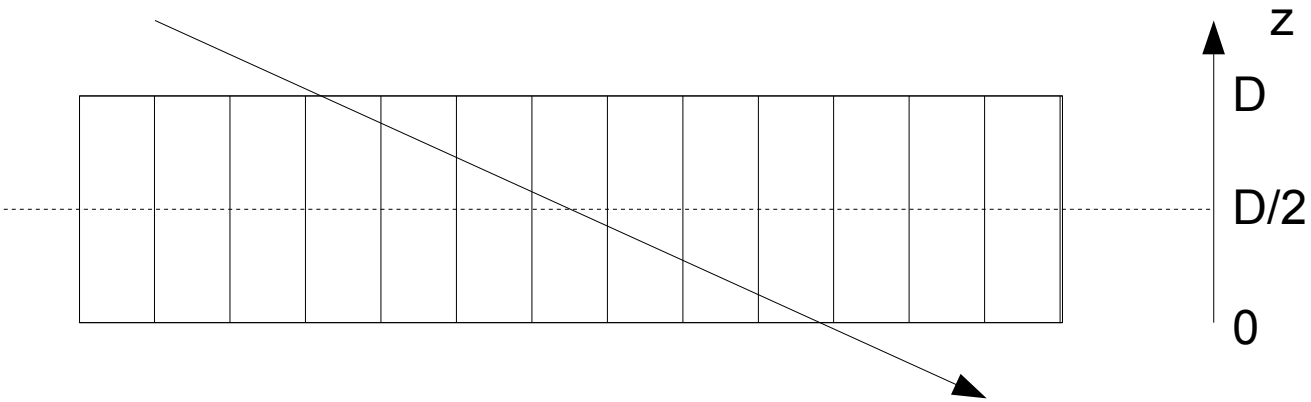
Solution:

Use minimal ionizing particles



→ nearly same energy deposition per pixel (no ToT measurement required)
→ average depth of interaction is in the center of the sensor

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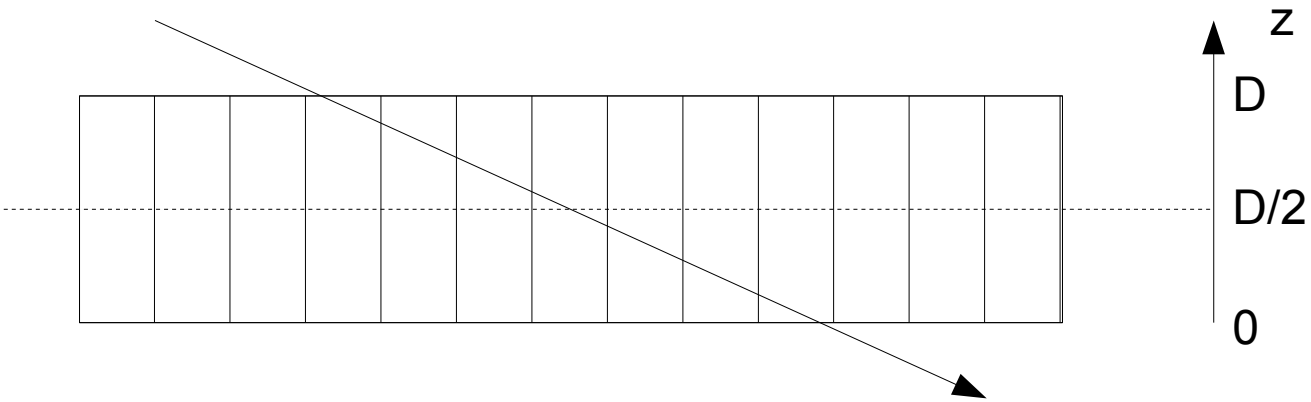

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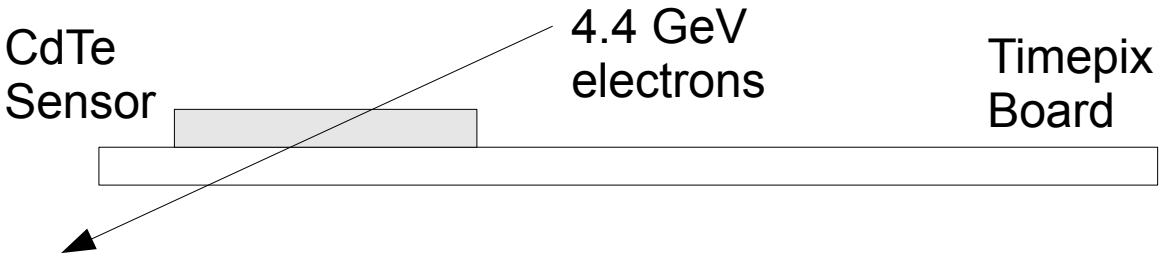
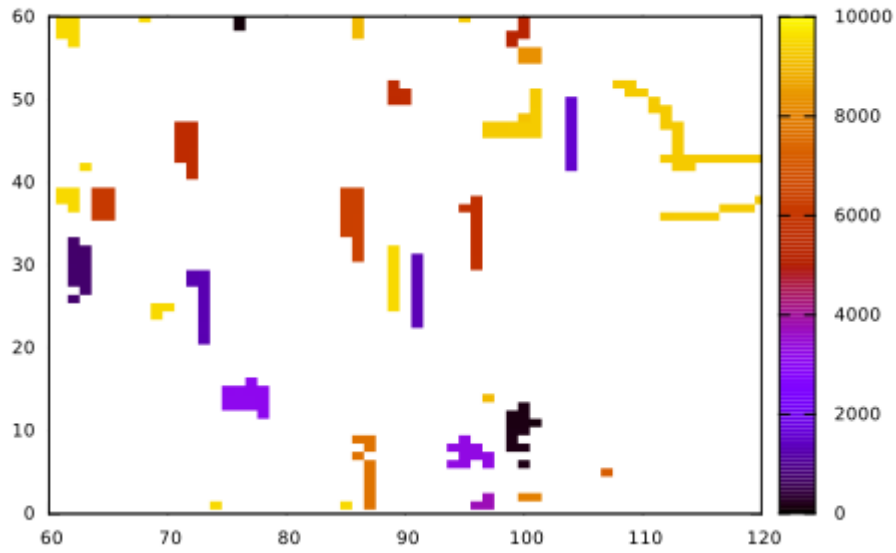
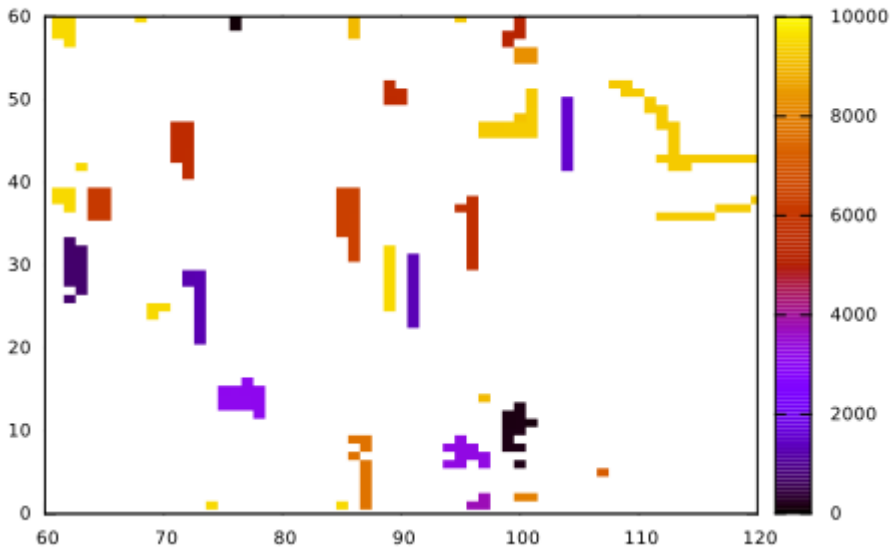


Example of tracks



Data taken in ToA mode
(10 ns clock), 48 V

Example of tracks



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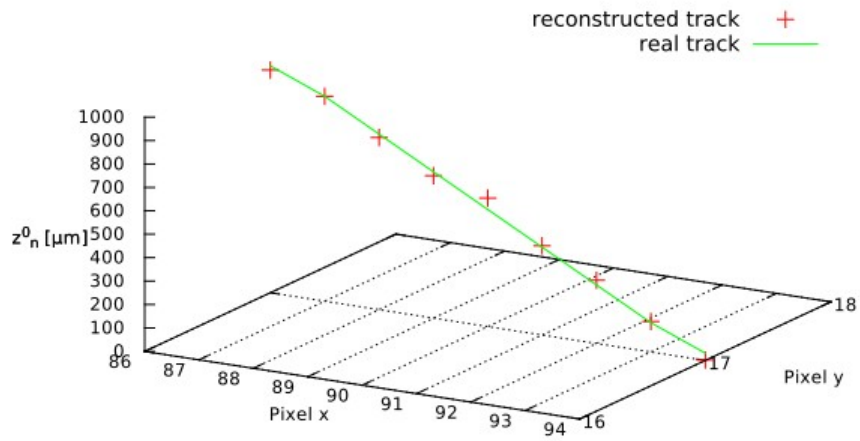
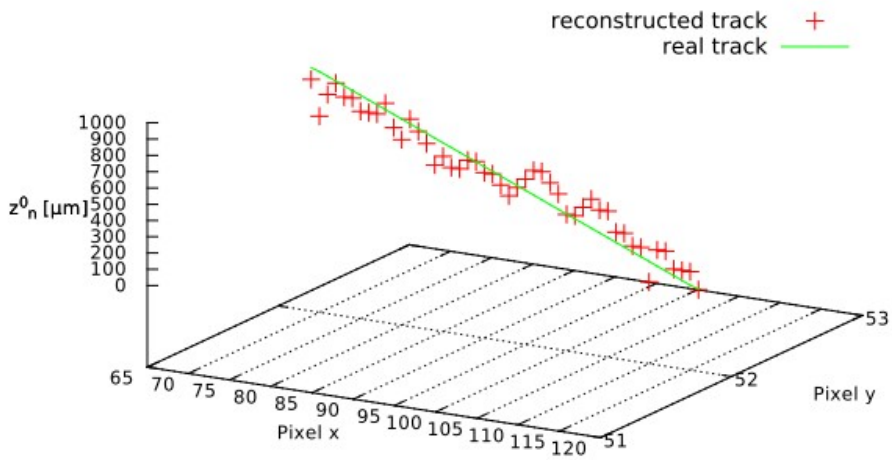
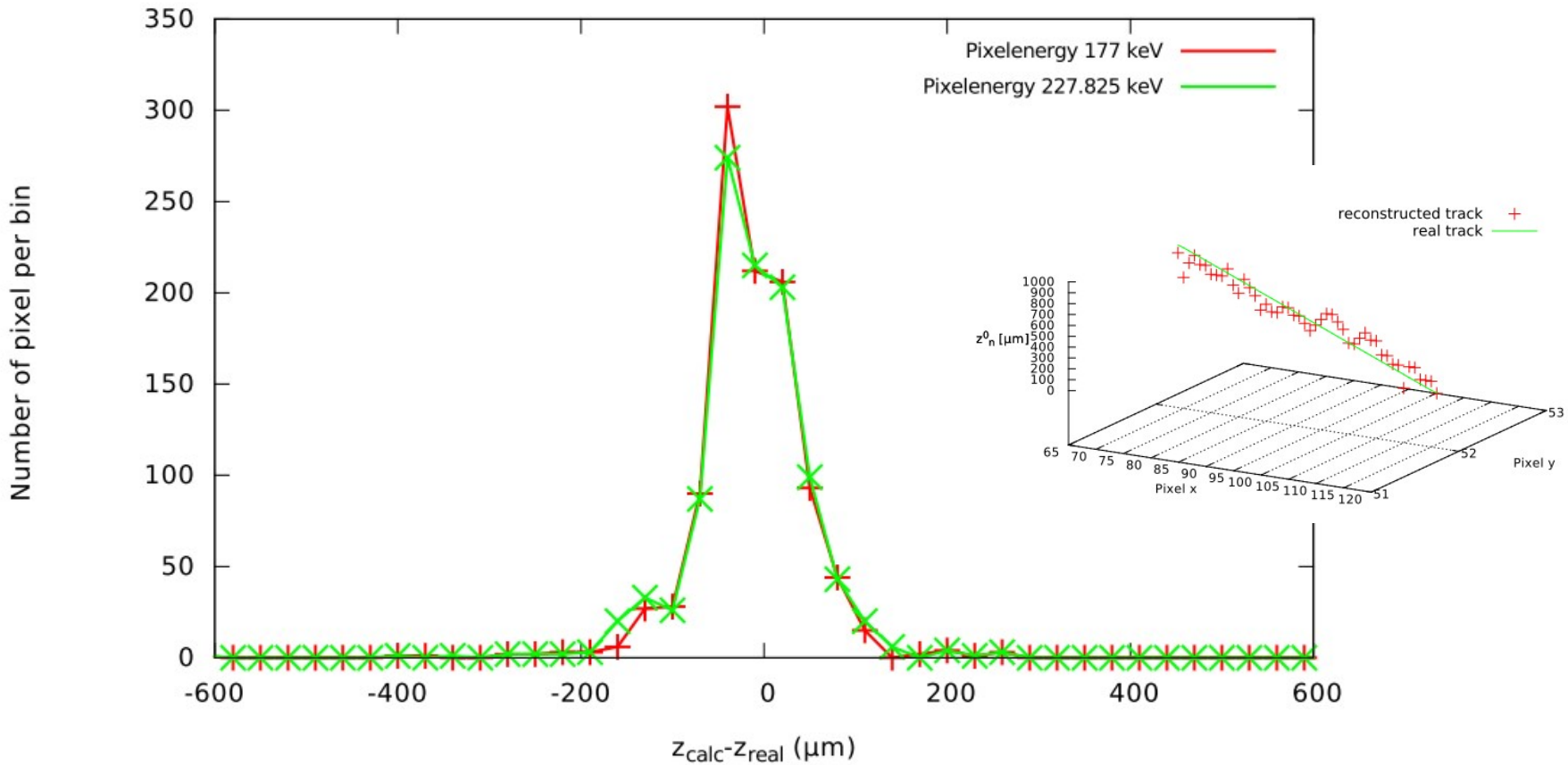


Reconstructed tracks



Results on the z-position resolution



Position resolution (calculated as the RMS): 64 µm !!

Conclusions and Outlook

3D Tracking in thin semiconductor detectors is possible !!

With Timepix (10 ns clock, 48 V, no ToT !) already a resolution of 65 µm achieved

! Timepix-3 is perfectly suited to be a voxel detector if backside signal readout is added !

Thank You for Your Interest

References

M. Filipenko et al.: Eur. Phys. J. C**73**, 2374 (2013)

A. Castoldi, et al., IEEE Trans. Nucl. Sci. **43**(1), 256 (1996)

W. Li, et al., IEEE Trans. Nucl. Sci. **47**(3), 890 (2000)

T. Michel et al.: Adv. High Energy. Phys. **2013**, 105318 (2013)

M. Filipenko et al.: arXiv:1403.5935v1

M. van Beuzekom, et al., in Proceedings of Science (SISSA, 2011), pp. 1–8