

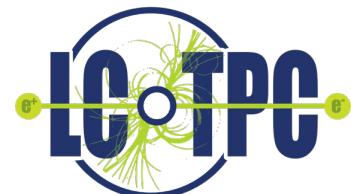
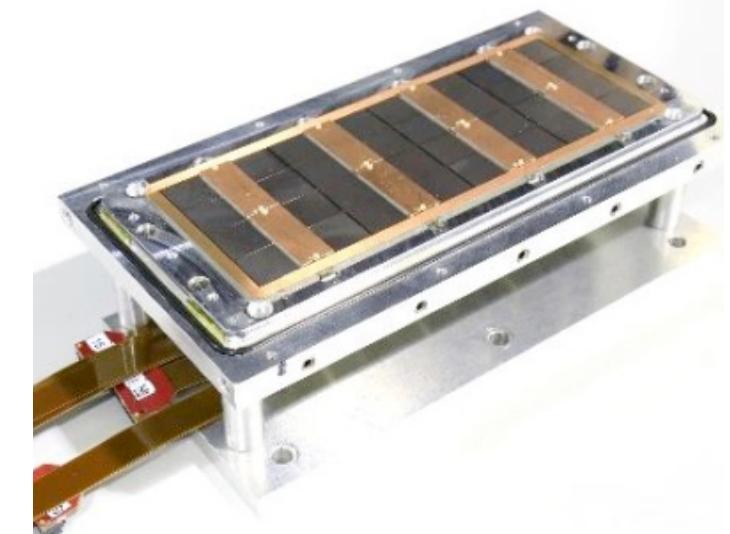
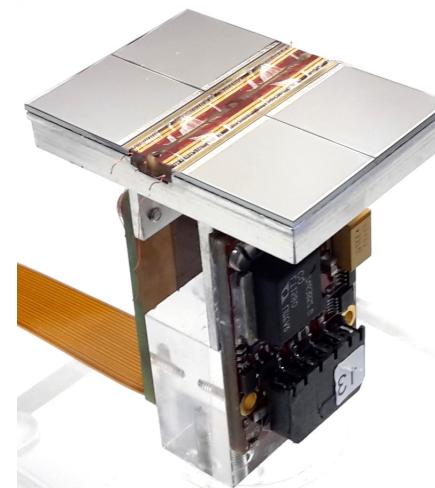


A Pixel TPC as a central tracker



Yevgen Bilevych, Klaus Desch,
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der Graaf, Fred Hartjes, Jochen

Kaminski, Peter Kluit,
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Cornelis Ligtenberg,
Gerhard Raven, and
Jan Timmermans

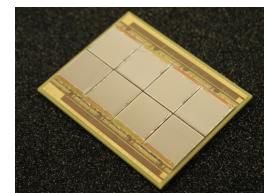


LCTPC at DESY January 2026

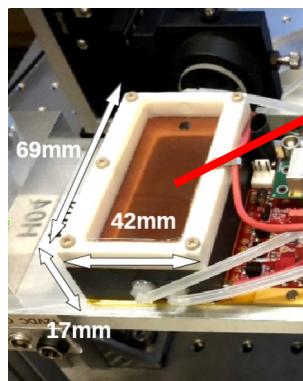


Peter Kluit (Nikhef)

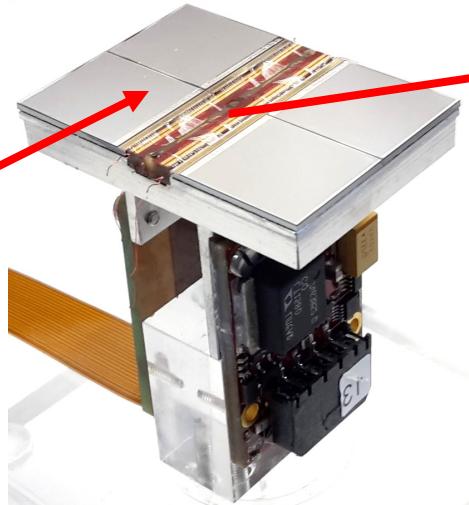
Pixel TPC



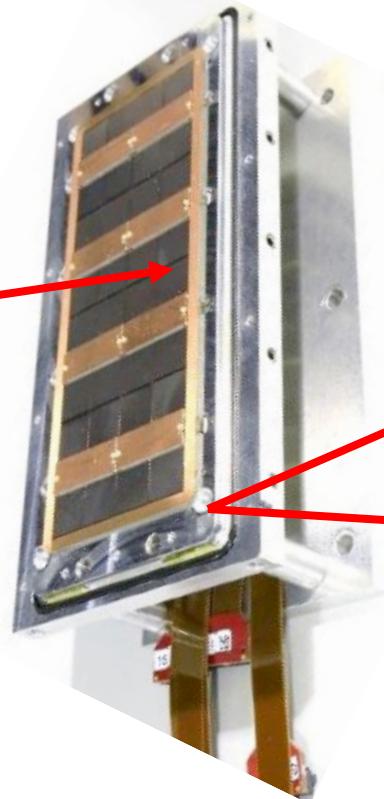
(Octopuce)



(TimePix1)
(2007-14)

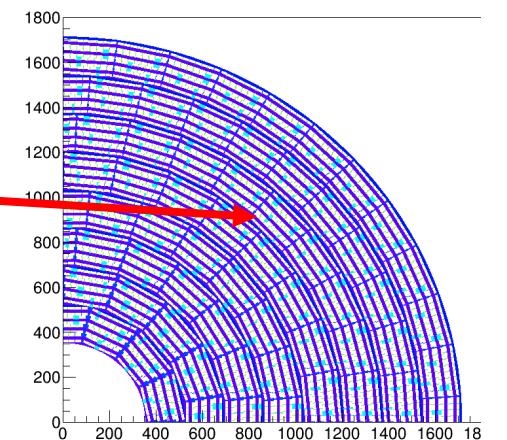
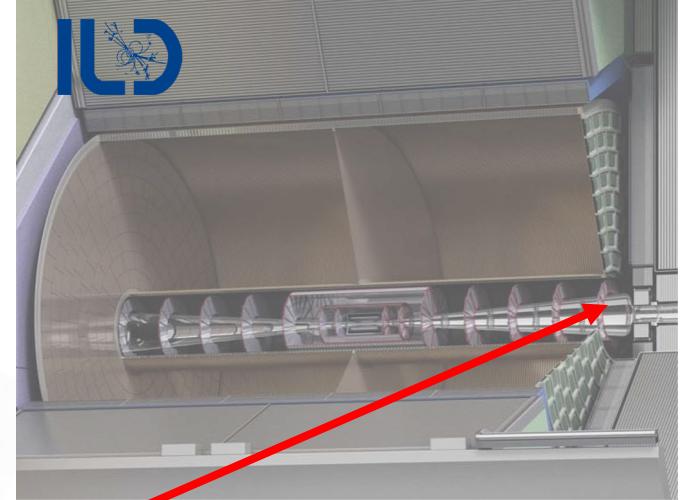


TPX3 chip
2017



Quad
2018

Module
2019



TPC plane



TPC requirements

The R&D on a TPC for a e.g. Linear Collider is done in the LCTPC collaboration

Requirements for a TPC from the ILC TDR

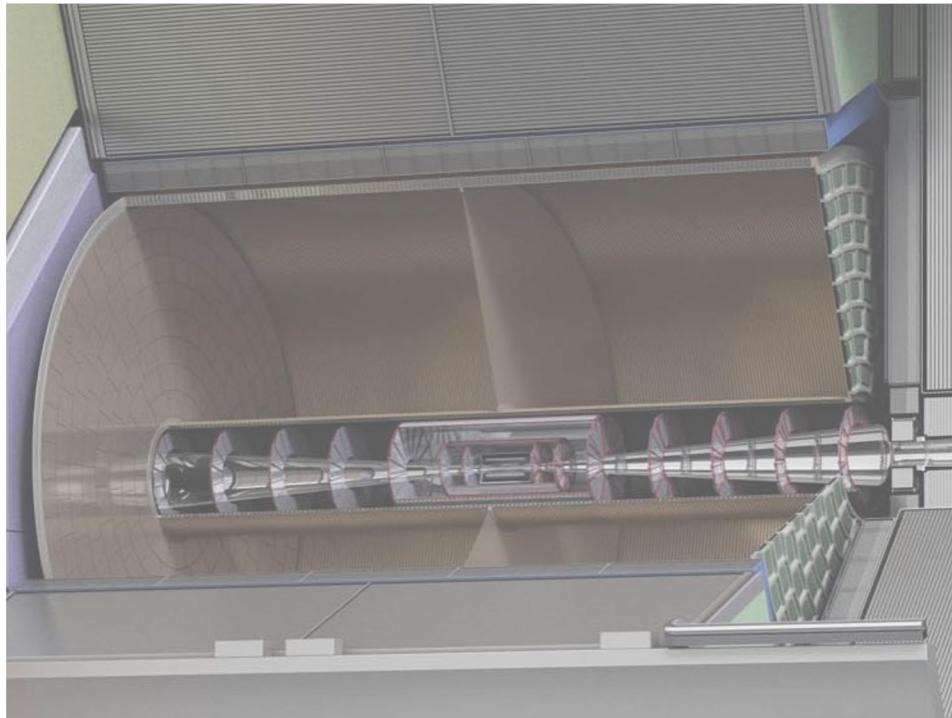
Table, large TPC, for pad/pixel electronics

Parameter	
B-field	3.5T
Geometrical parameters	r_{in} 329 mm r_{out} 1808 mm z ± 2350 mm
Solid angle coverage	Up to $\cos \theta \simeq 0.98$ (10 pad rows)
TPC material budget	$\simeq 0.05 X_0$ including outer fieldcage in r $< 0.25 X_0$ for readout endcaps in z
Number of pads/timebuckets	$\simeq 10^6/1000$ per endcap
<i>Number of pixels/timebuckets</i>	$\simeq 10^9/1000$ per endcap
Pad pitch/ no.padrows	$\simeq 1 \times 6 \text{ mm}^2 / 213$
σ_{point} in $r\phi$	$\simeq 60 \mu\text{m}$ for zero drift, $< 100 \mu\text{m}$ overall
σ_{point} in $r\phi$	$\simeq 0.055\text{mm}/\sqrt{12}$ for zero drift, 0.4mm for max drift
σ_{point} in rz	$\simeq 0.4 - 1.4 \text{ mm}$ (for zero – full drift)
2-hit separation in $r\phi$	$\simeq 2 \text{ mm}$
2-hit separation in rz	$\simeq 6 \text{ mm}$
dE/dx resolution	$\simeq 5 \%$
dE/dx resolution	$\simeq 4 \%$
Momentum resolution at $B=3.5 \text{ T}$	$\delta(1/p_t) \simeq 10^{-4}/\text{GeV}/c$ (TPC only)
<i>Momentum resolution at $B=3.5 \text{ T}$</i>	$\delta(1/p_t) \simeq 0.8 \times 10^{-4}/\text{GeV}/c$ (60% cov, TPC only)



- ILD like detector concept with a TPC central tracker can be used for FCC
- Challenging tracking precision
 - driven by (Z) Higgs running
- For Z running the requirement on $\delta(1/p_t)$ can IMO be loosened by e.g. a factor 10 (LEP like)

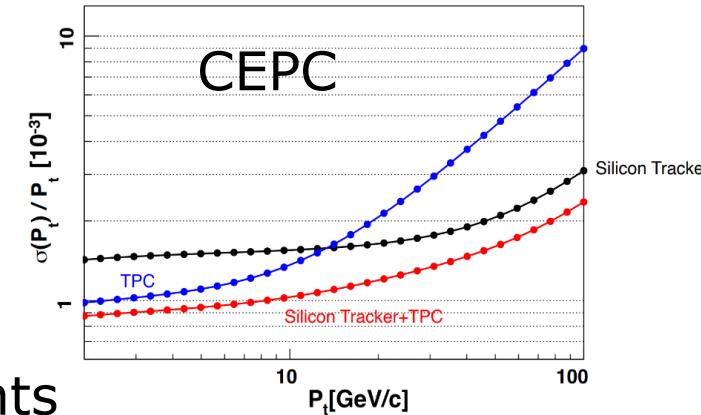
ILD TPC layout



- Material budget is
 - $0.01 X_0$ TPC gas
 - $0.01 X_0$ inner cylinder
 - $0.03 X_0$ outer cylinder
 - $< 0.25 X_0$ endplates (incl readout)
- Note the very low budget in the barrel region. Material budget can be respected by different technologies like GEM, MicroMegas and Pixels
- TPC is sliced between silicon detectors VTX, SIT and SET
- pixel readout is a serious option for the TPC readout plane @ ILC/FFC-ee/CLIC/CEPC colliders

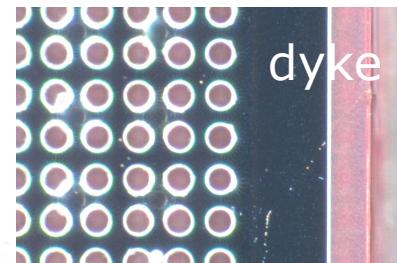
Why a (pixel) TPC as a central tracker

- Low material budget that allows high precision tracking
- Continuous 3D tracking (x,y, t) and track following
 - Excellent v0 reconstruction
 - Ideal for particle flow and combined calorimetry
- TPC is sliced between silicon detectors
 - provides required momentum resolution and constraints
- Very powerful particle identification based on dEdx
 - for electrons (suppress pions)
 - for kaons ($H \rightarrow ss$) and protons
- TPC excellent option for FCCee WW, ZH, tt etc running
- Running at the Z is challenging due to beam and synchrotron backgrounds
- A pixel TPC combines a large drift volume with a silicon read out plane
 - tracking with high granularity and low systematic uncertainties due to “silicon” precision (1-10 μm) in the production process
 - the best (see slides) PID performance dEdx and cluster counting

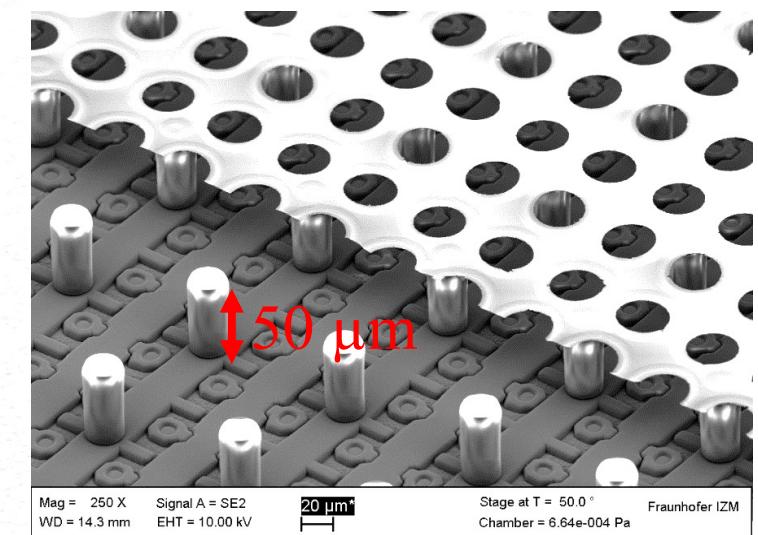
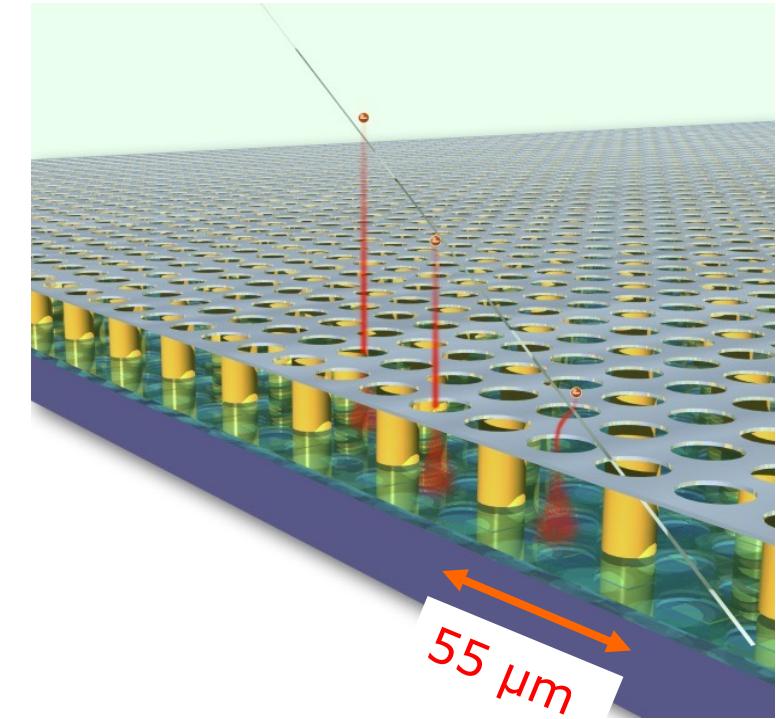
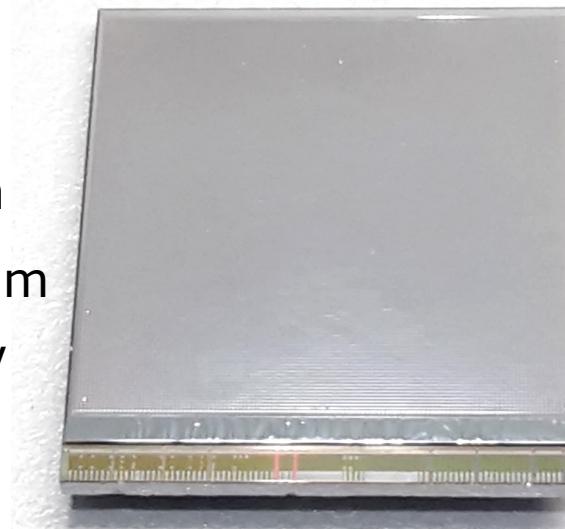


GridPix technology

- Pixel chip with integrated Grid (Micromegas-like)
- InGrid post-processed @ IZM (in 2025 @ Bonn)
- Grid set at negative voltage (300 – 600 V) to provide gas amplification
- Very small pixel size (55 μm)
- detecting individual electrons

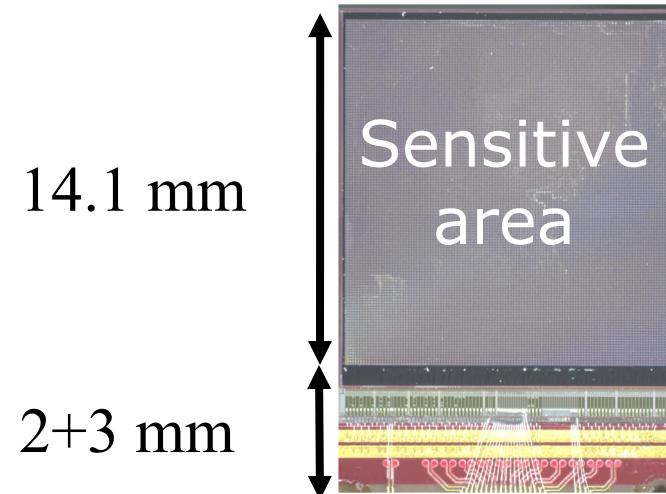
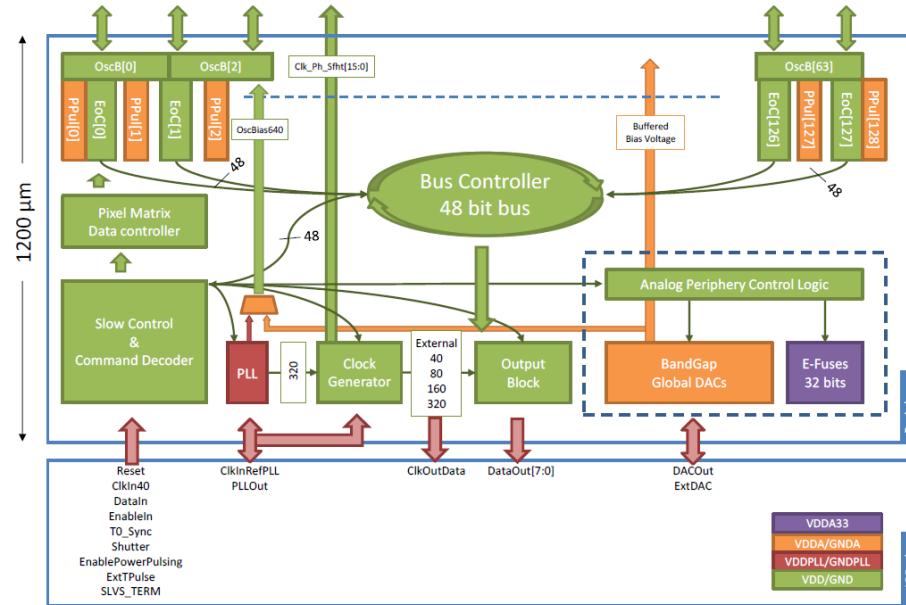


- Aluminium grid (1 μm thick)
- 35 μm wide holes, 55 μm pitch
- Supported by SU8 pillars 50 μm high
- Grid surrounded by SU8 dyke (150 μm wide solid strip) for mechanical and HV stability



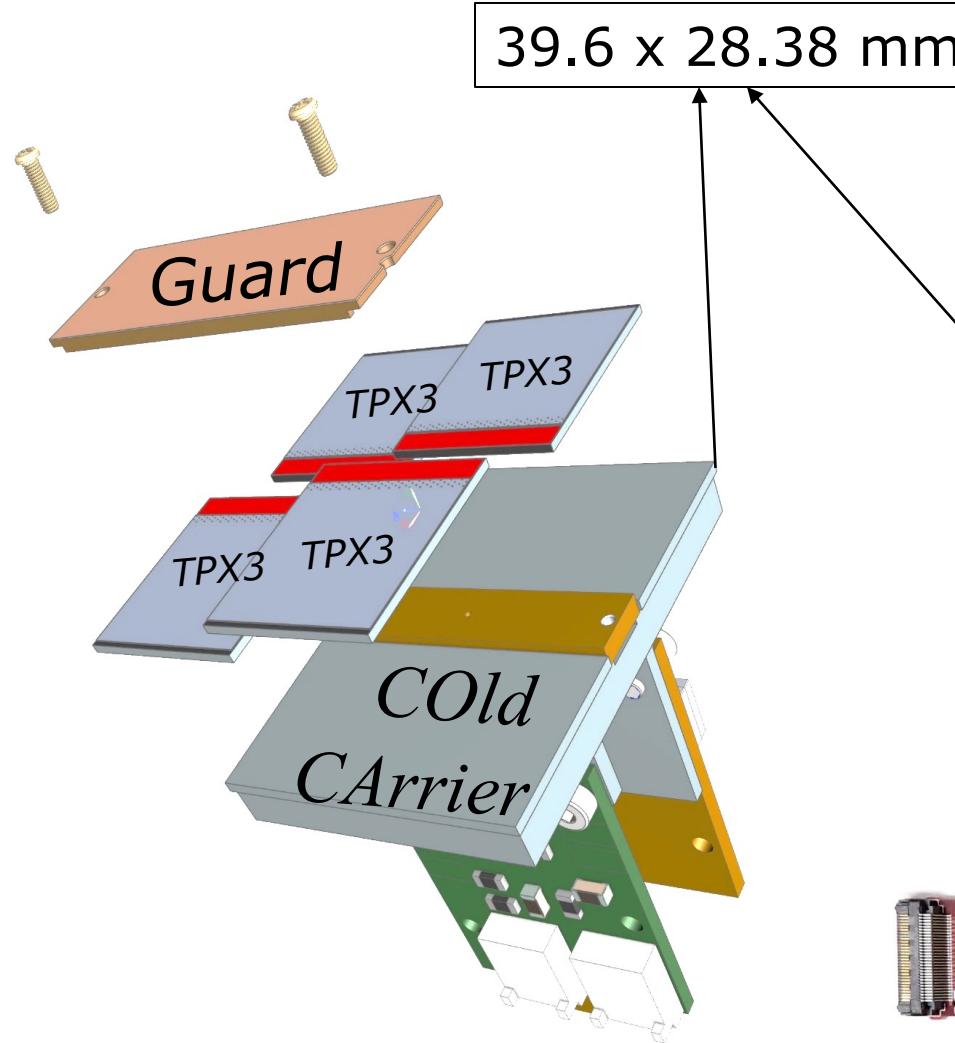
Pixel chip: TimePix3

- 256 x 256 pixels
- 55 x 55 μm pitch
- 14.1 x 14.1 mm sensitive area
- TDC with **640 MHz clock** (1.56 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
 - $\sim 1 \text{ A} @ 2 \text{ V}$ (2W) depending on hit rate
 - good cooling is important

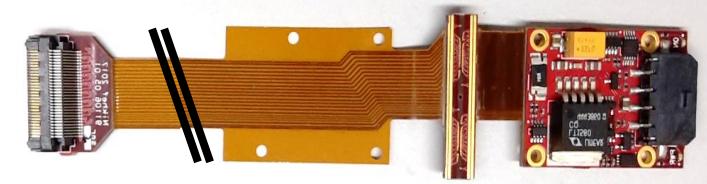
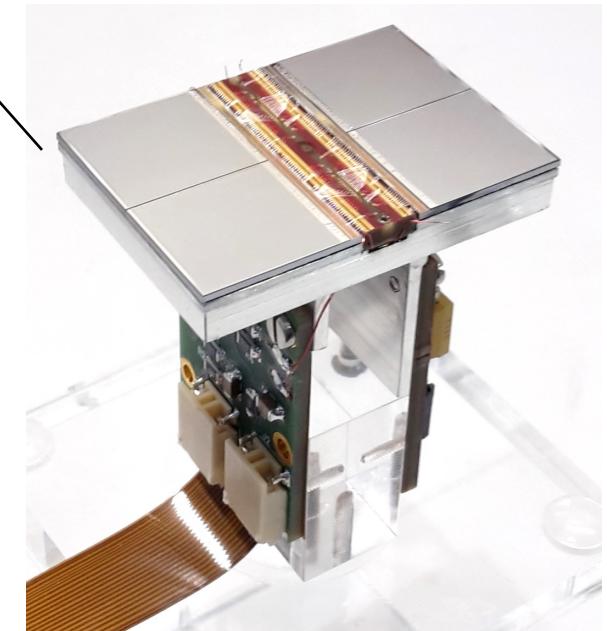


QUAD design and realization

- 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 a sensitive area of 68.9%
- DAQ by SPIDR board

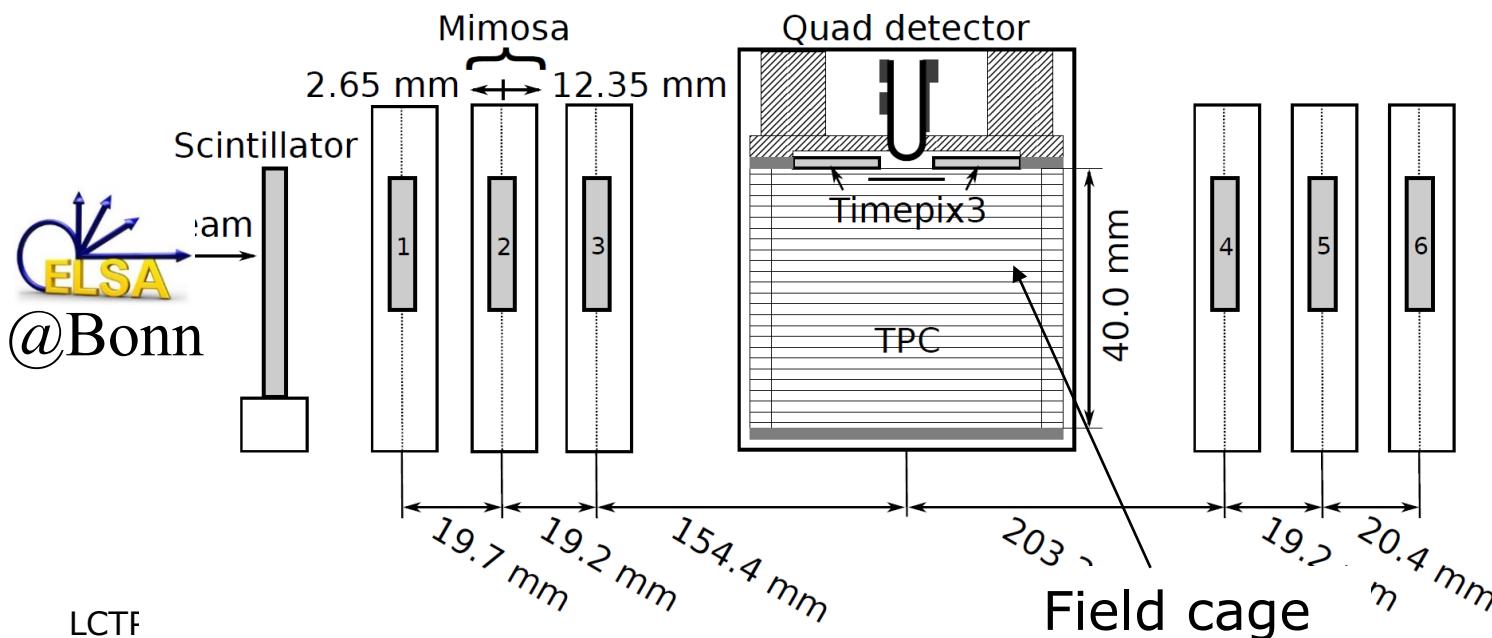


series of QUADs

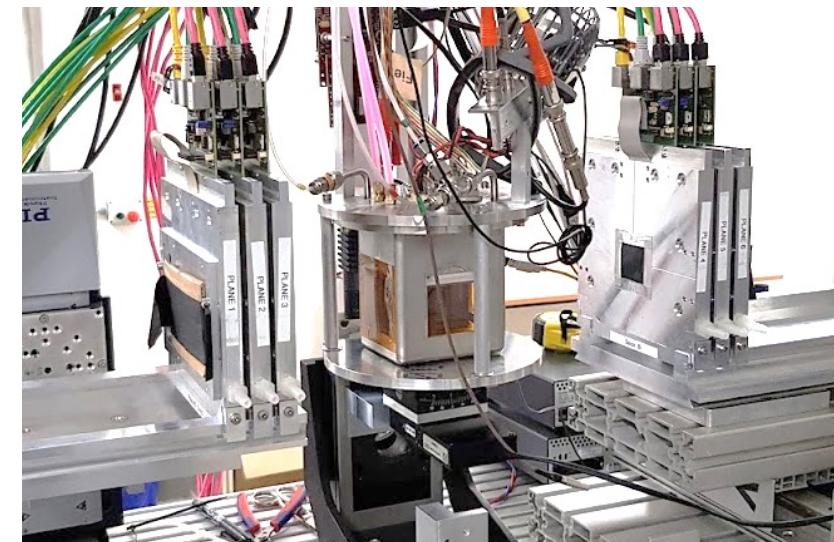


QUAD test beam in Bonn (October 2018)

- ELSA: 2.5 GeV electrons
- Tracks referenced by Mimosa telescope
- QUAD sandwiched between Mimosa planes
 - Largely improved track definition
 - 6 planes with $18.4 \mu\text{m} \times 18.4 \mu\text{m}$ sized pixels
- Gas: Ar/CF₄/iC₄H₁₀ 95/3/2 (T2K)
- $E_d = 400 \text{ V/cm}$, $V_{\text{grid}} = -330 \text{ V}$
- Typical beam height above the chip: $\sim 1 \text{ cm}$

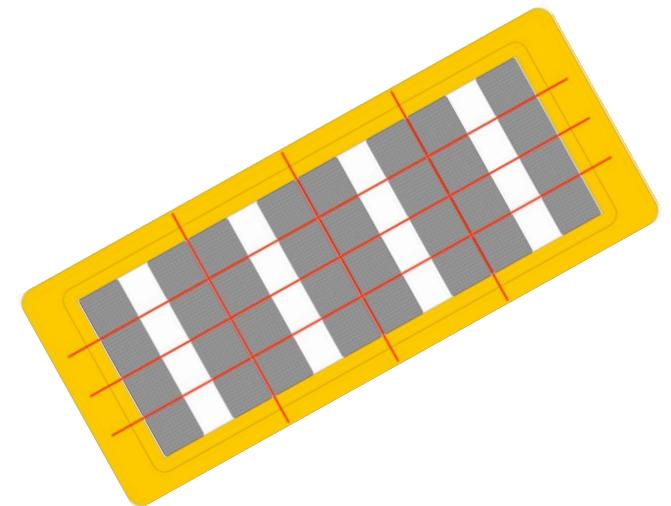
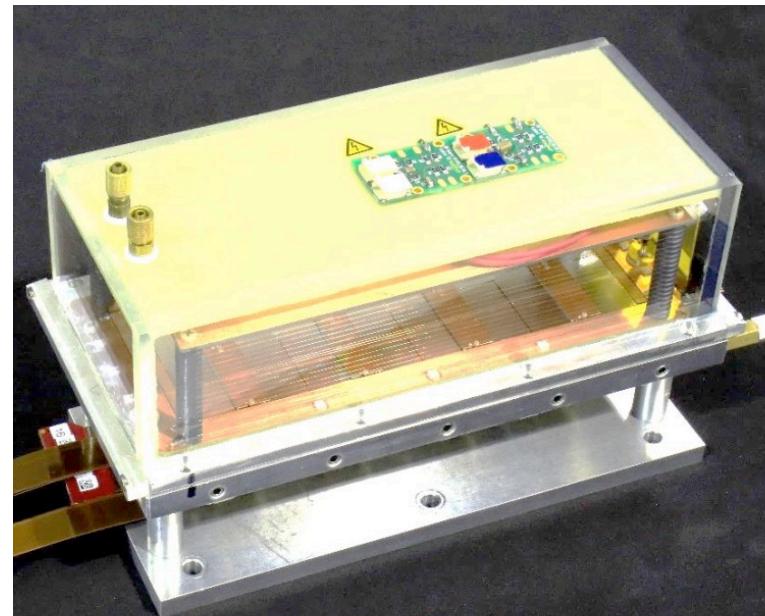
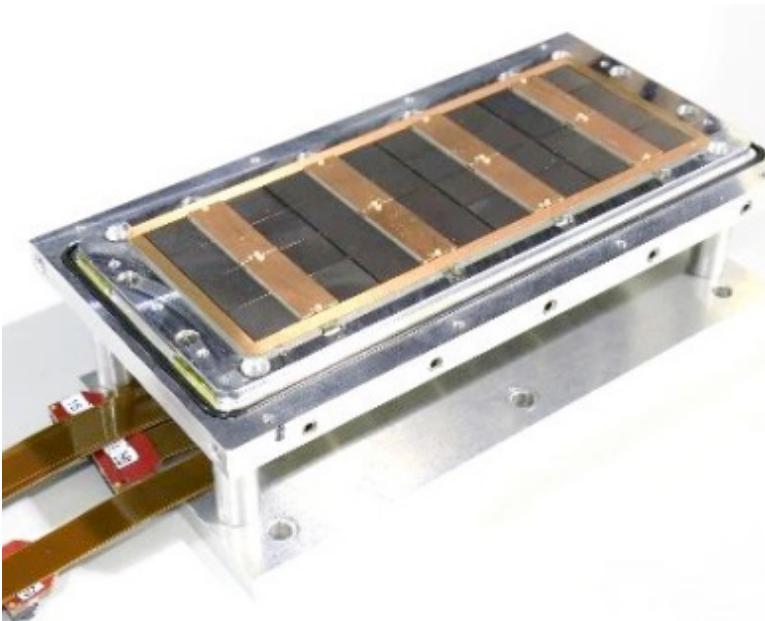


Published NIMA
<https://doi.org/10.1016/j.nima.2019.163331>

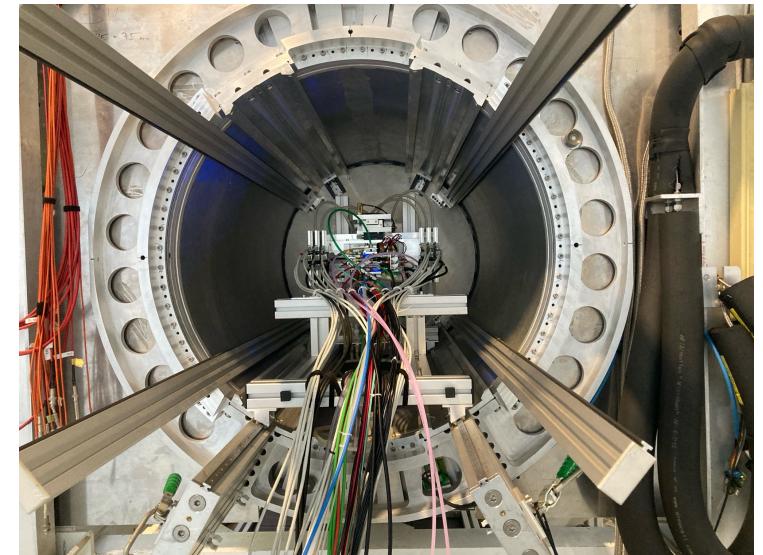
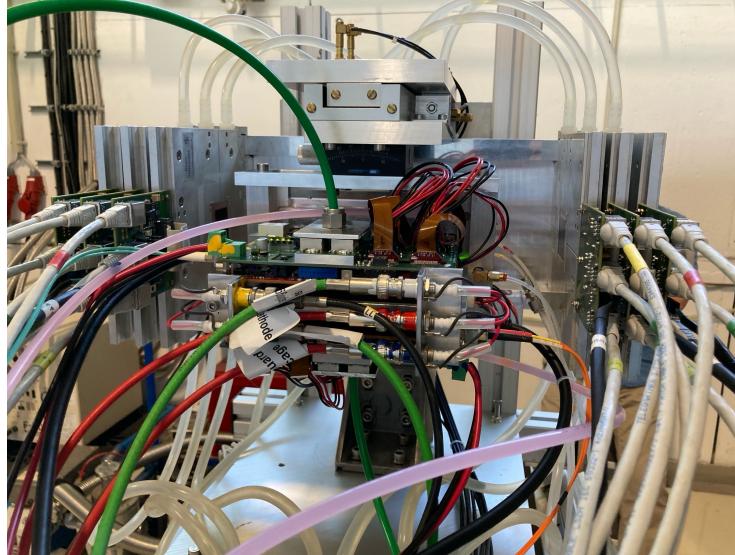


QUAD as a building block

8-QUAD module (2x4 quads) with field cage



in red guard wires

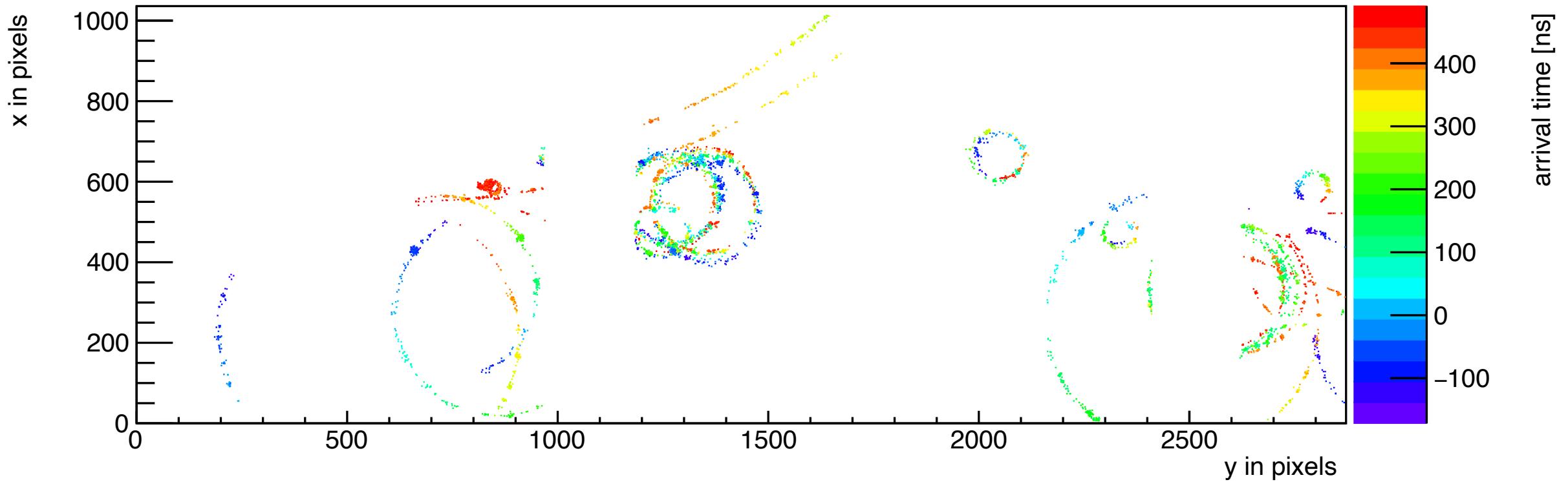


Mounting the 8 quad module between the silicon planes
sliding it into the 1 T PCMAG solenoid

DESY LCTPC-Pixel Testbeam

Run 6969 Event 2

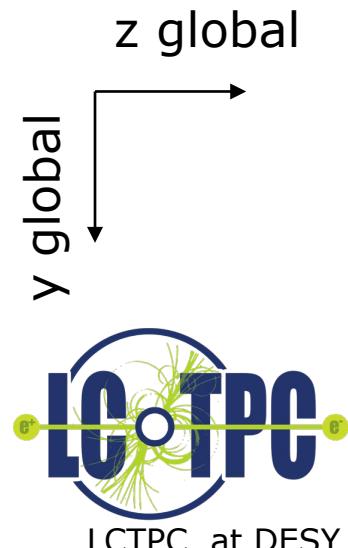
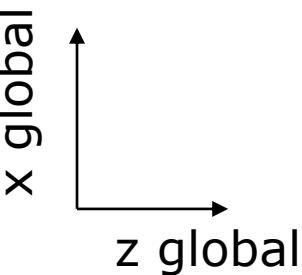
Bfield 1.0 T beam momentum 6 GeV/c



LCTPC at DESY January 2026

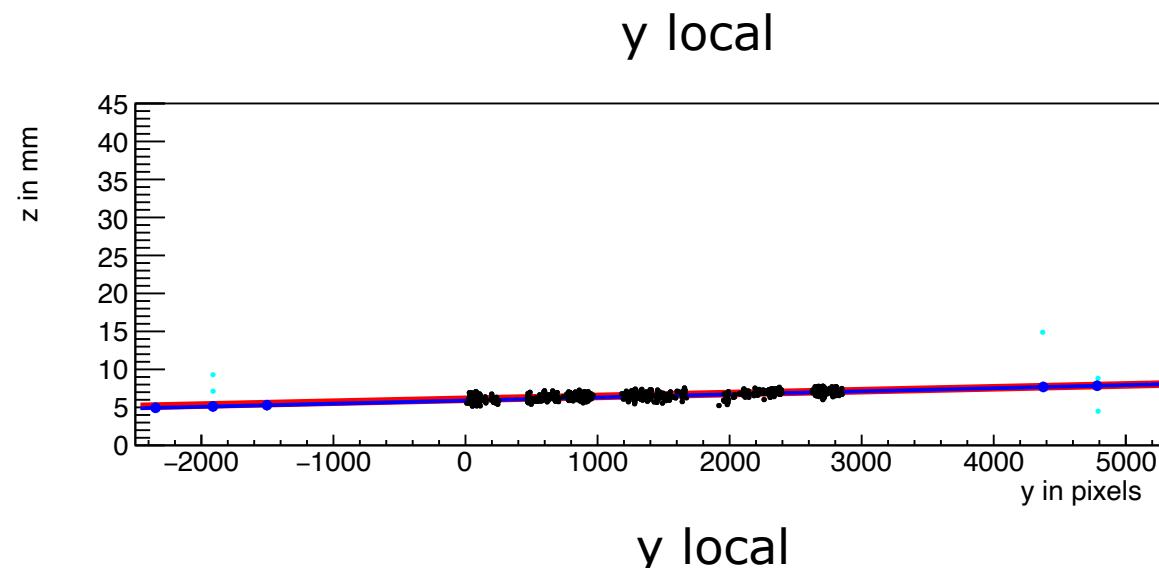
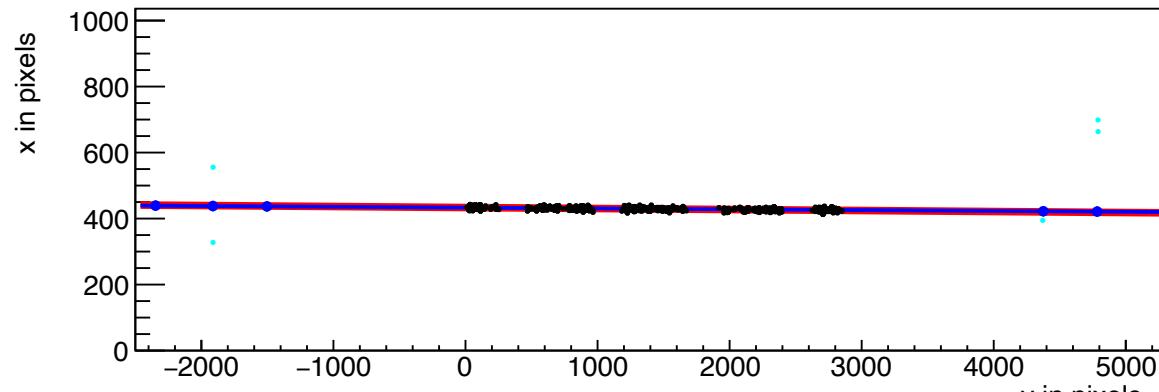
Peter Kluit (Nikhef)





DESY testbeam Module Analysis

DESY LCTPC-Pixel Testbeam Run 6916 Event 12 Bfield 0 T beam momentum 6 GeV/c



Event display with module and telescope

TPX3 track 1130 hits

$\chi^2_{xy} = 677.5/1128$

$\chi^2_z = 775.9/1069$

Asymmetric tail outlier removal applied 1071 hits in z kept.

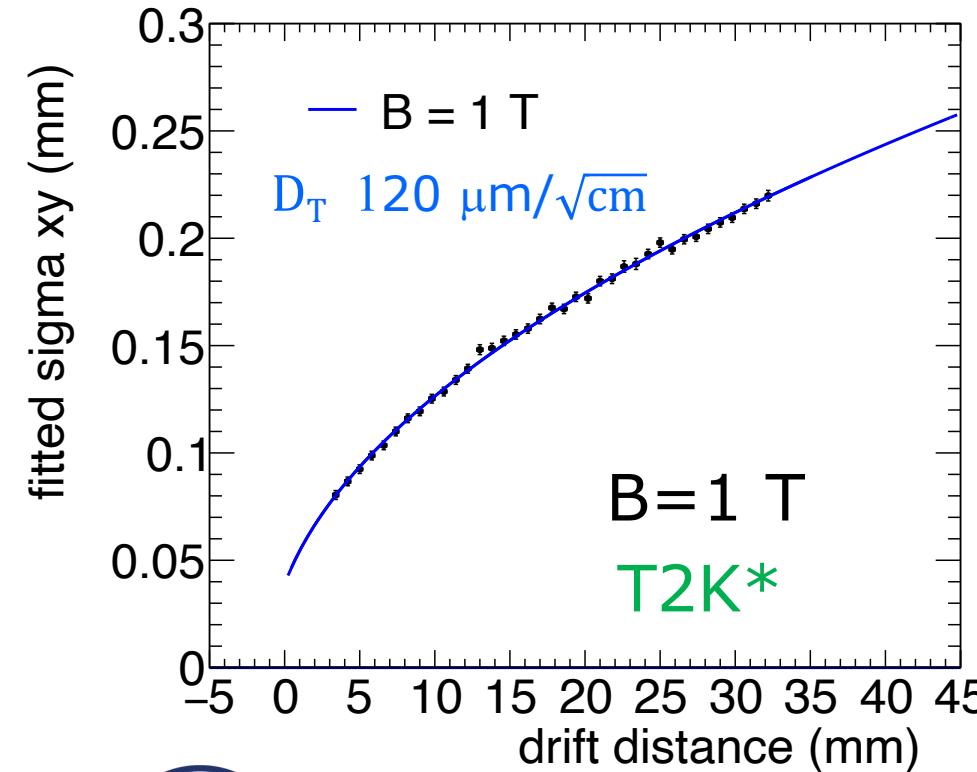
TPX3 track hits

Telescope track hits (off track green)

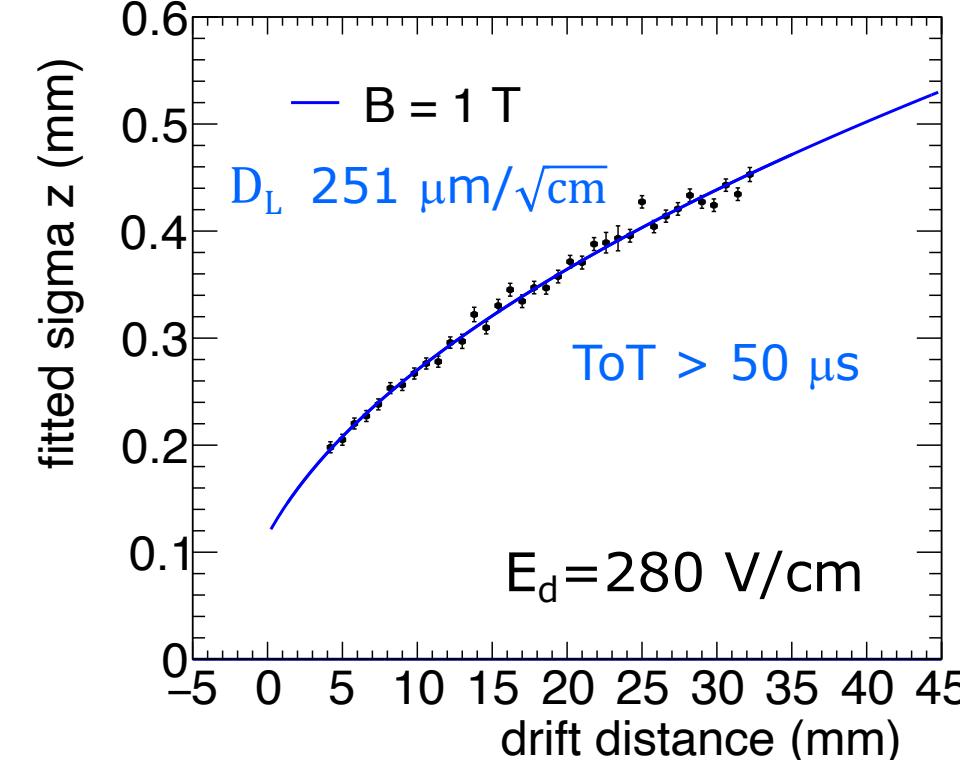
B=1 T p=5 and 6 GeV

UNIVERSITÄT BONN

Fitted resolution



$$\sigma_{xy, z}^2 = \sigma_{xy, z_0}^2 + D_{xy, z}^2 (z - z_0)$$



$$\sigma_{xy, z_0}^2 = \sigma_{\text{pixel}}^2 + \sigma_{\text{xy tele}}^2$$

$$\sigma_{\text{pixel}}^2 = 55^2/12 \mu\text{m}^2$$

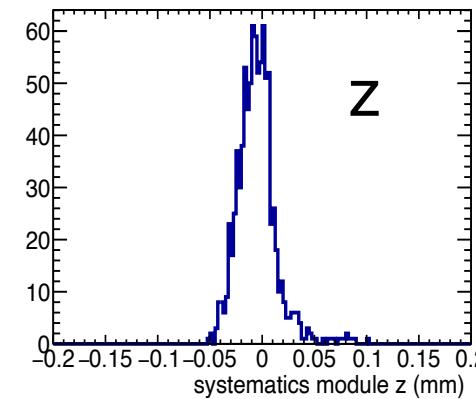
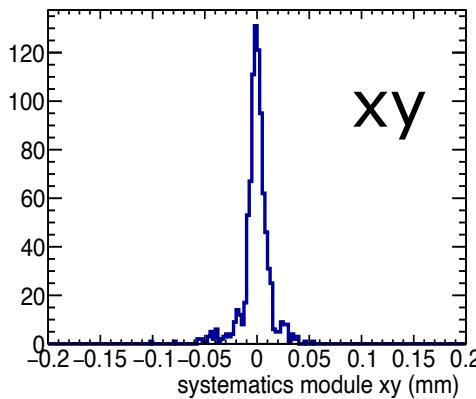
$$\sigma_{\text{xy tele}} = 42 \mu\text{m}$$

Magboltz gives for
 $D_T = 121 \mu\text{m}/\sqrt{\text{cm}}$

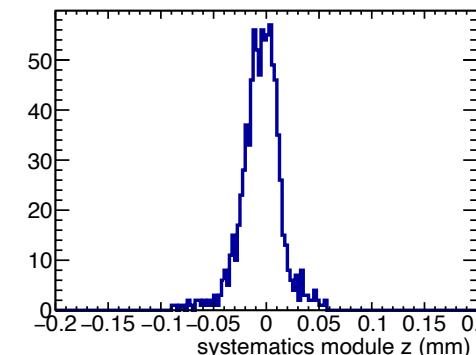
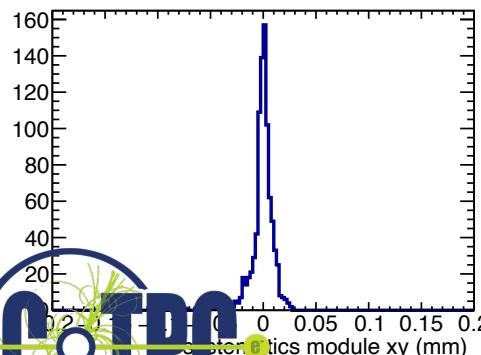
$\text{T2K}^* = \text{T2K gas}$
with O_2 and H_2O

Distribution of mean residuals in the module plane

Method row



Method column



B=1 T data set

method	rms (stat) xy	bins xy	rms (stat) z	bins z
row	13 (2) μ m	896	19 (5) μ m	896
column	11 (2) μ m	880	20 (5) μ m	880

* We did not include the 4 corner chips and (11), 14, 8, 13 and 19. These are affected by the field cage and the short in chip 11.

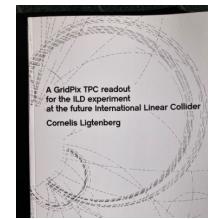
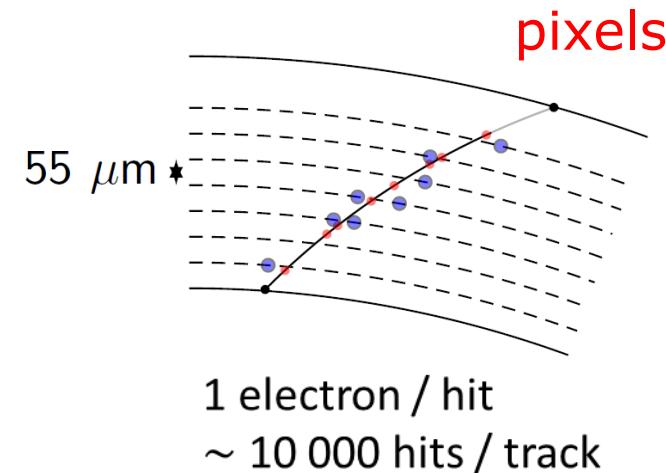
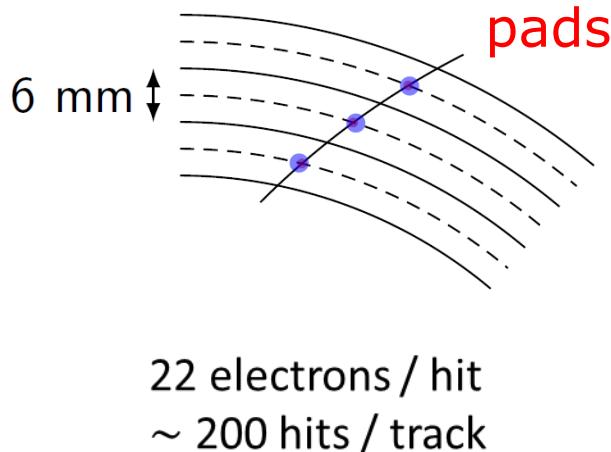
- The results of the 8 Quad Module in the DESY test beam in June 2021 have been presented
- One chip (nr 11) out of 32 was disconnected due to a short*
- In run 6916 e.g. 964 tracks were selected with 1009 hits on track
- The tracking precision: position 9 (xy) 13 μm (z) in angle 0.19 (dx/dy) 0.25 (dz/dy) mrad for a module or tracklength is 157.96 mm
- The diffusion coefficients at $B=0$ T $D_{xy} = 287 \mu\text{m}/\sqrt{\text{cm}}$ $D_z = 273 \mu\text{m}/\sqrt{\text{cm}}$
- The diffusion coefficients at $B=1$ T is $D_{xy} = 120 \mu\text{m}/\sqrt{\text{cm}}$ $D_z = 251 \mu\text{m}/\sqrt{\text{cm}}$
 - In agreement with Magboltz $D_{xy} = 121 \mu\text{m}/\sqrt{\text{cm}}$

*the chip was successfully repaired in 2023 Bonn

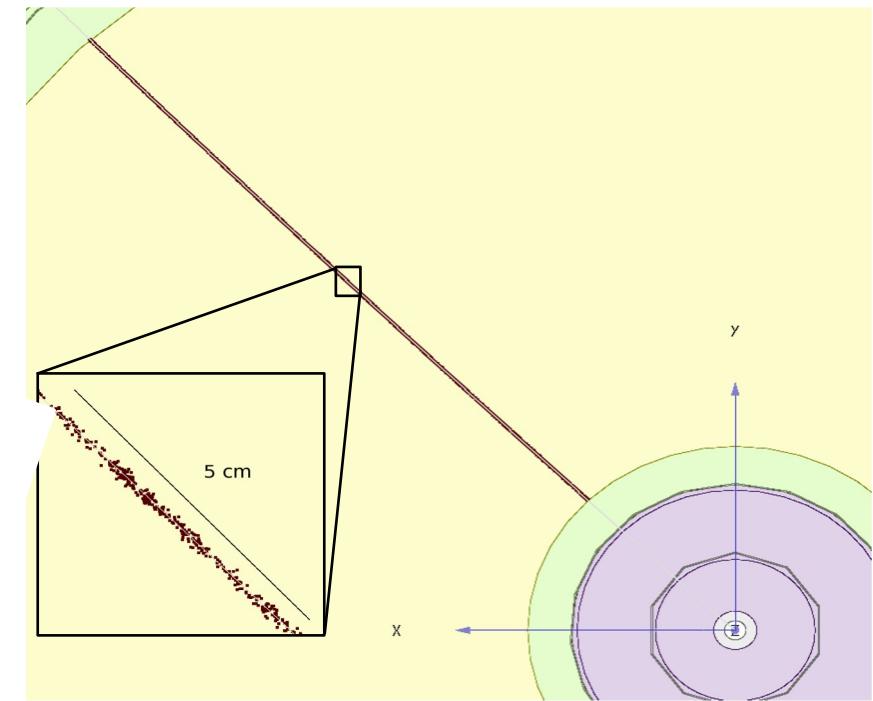
- Results for the module showed that:
 - the HV of the guard wires was well tuned
 - $B=0$ T rms residuals in the module plane xy 13 μm and z 15 μm
 - The results are compatible with (very) high stats quad measurement
 - $B= 1$ T rms residuals in the plane xy 13 μm and z 20 μm ;
- High tracking precision is demonstrated with small systematics
 - deformations xy stay below 13 μm
- Published in [Nucl. Instrum. Meth. A 1075 \(2025\) 345](#)
Towards a Pixel TPC part I: construction and test of a 32-chip GridPix detector

Simulation of ILD TPC with pixel readout

- To study the performance of a large pixelized TPC, the pixel readout was implemented in the full ILD DD4HEP (Geant4) simulation
- Changed the existing TPC pad readout to a pixel readout
- Adapted Kalman filter track reconstruction to pixels



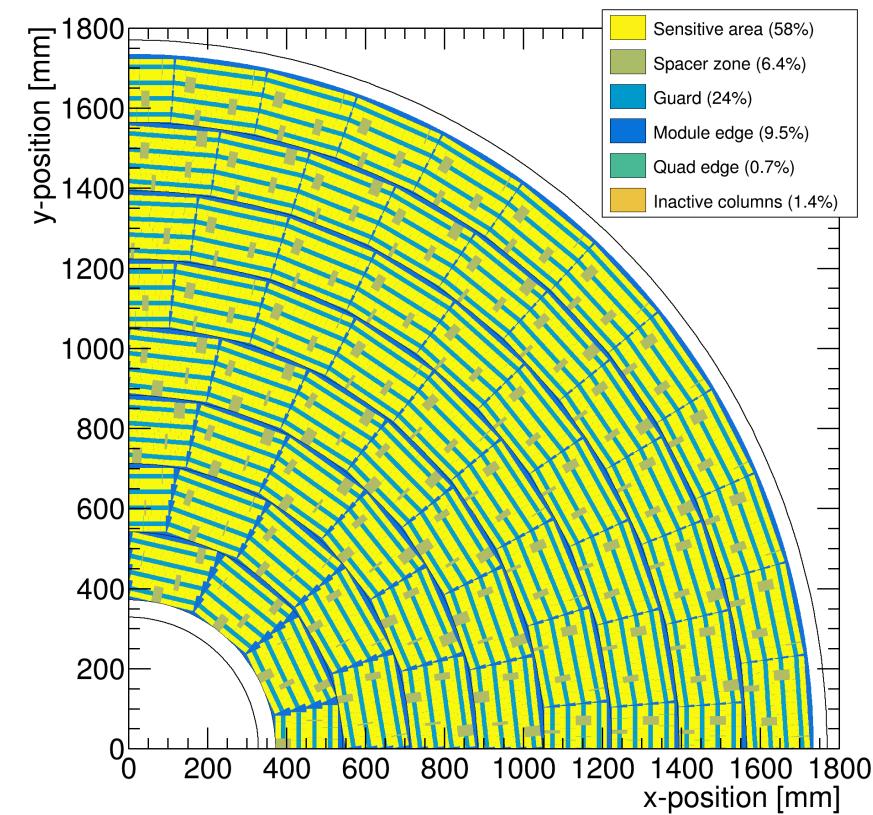
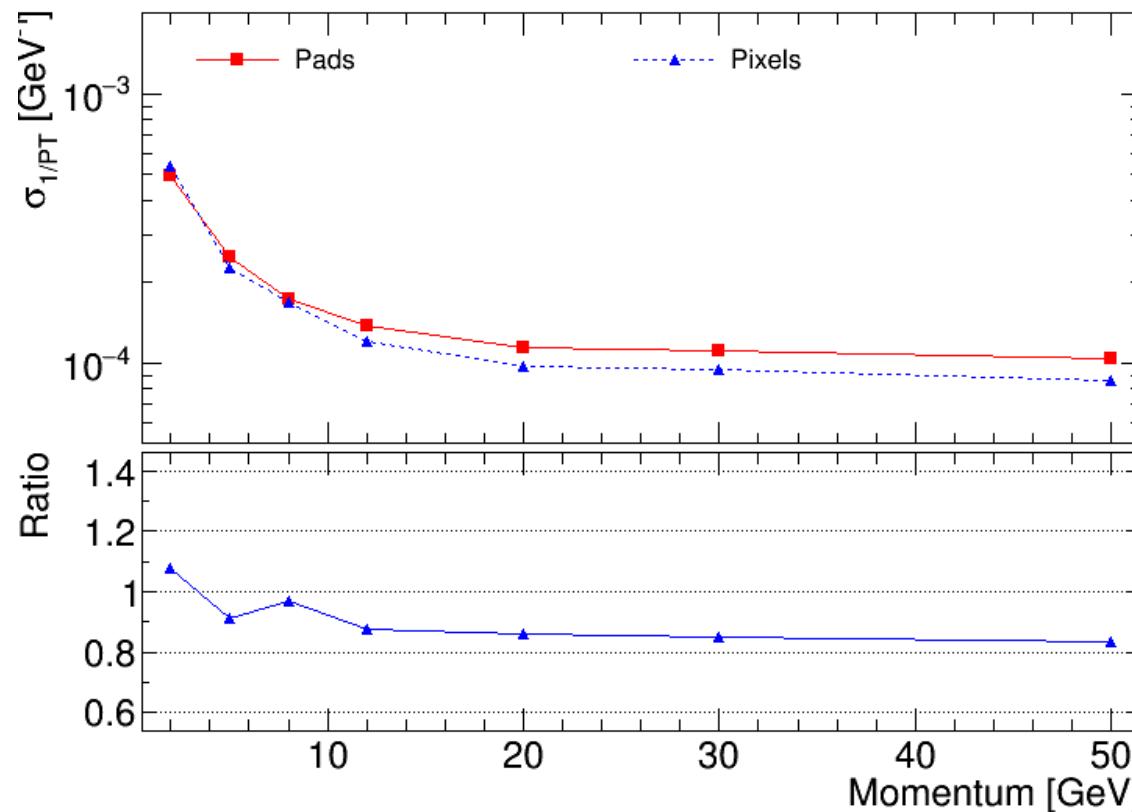
details: PhD [thesis](#)
Kees Ligtenberg 2022



50 GeV muon track with
pixel readout

Performance of a GridPix TPC at ILC

- From full simulation the momentum resolution can be determined
- Momentum resolution is about 15% better for the pixels with realistic coverage (with the quads arranged in modules coverage 59%) and deltas.



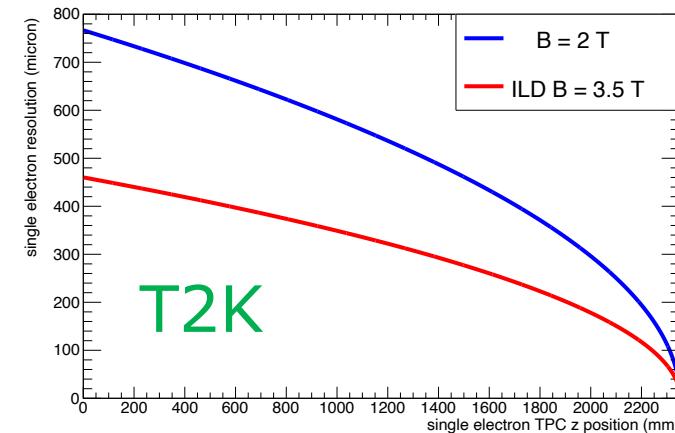
ILD tracking Performance for a Pixel TPC based on test beam

Running at $B=3.5$ T improves the resolution

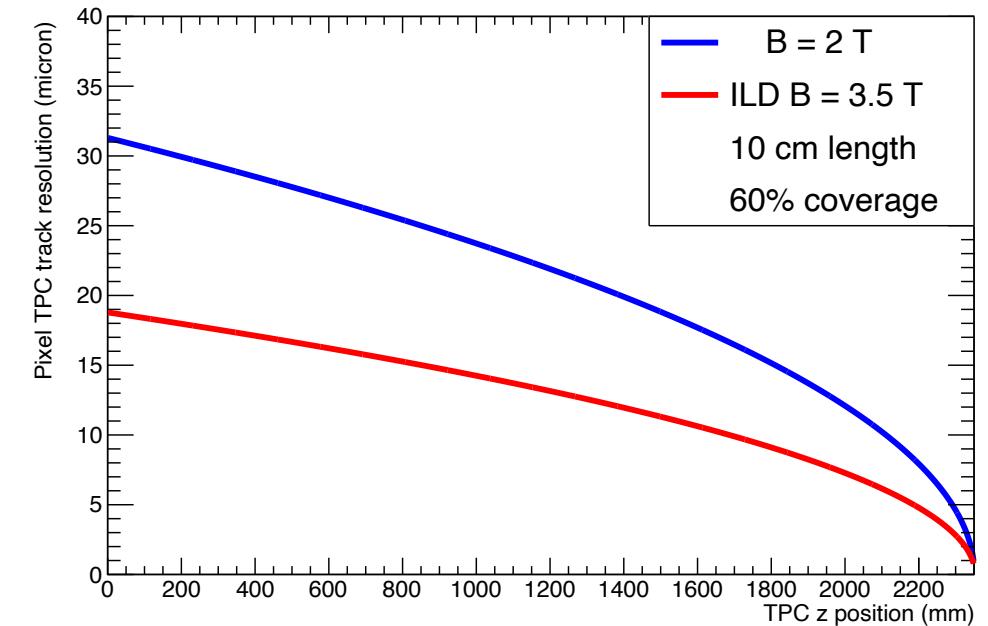
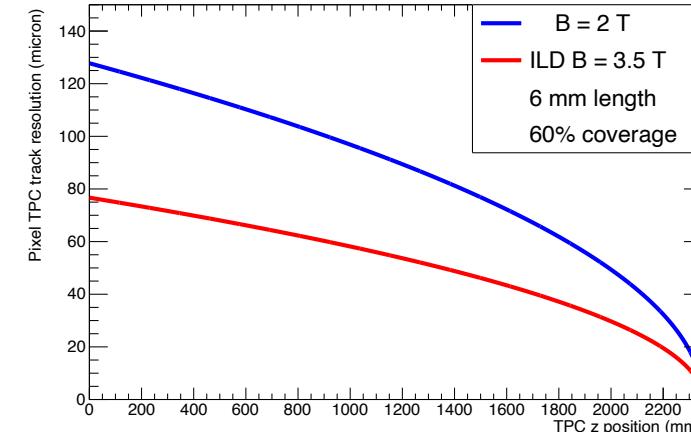
Single electron resolution

6 mm track("pad") resolution

10 cm track resolution



T2K

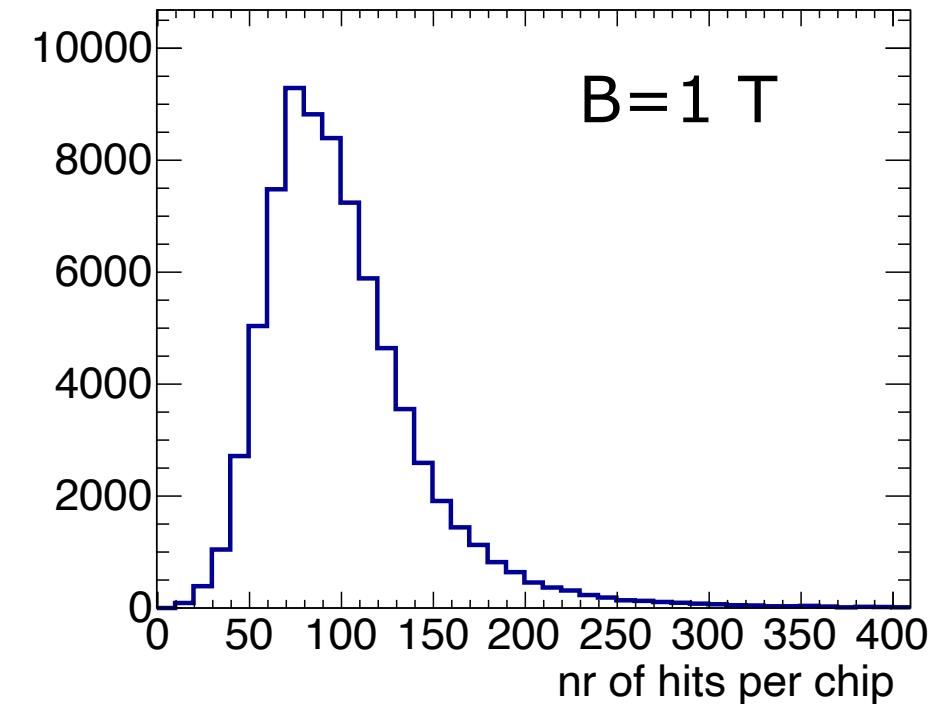
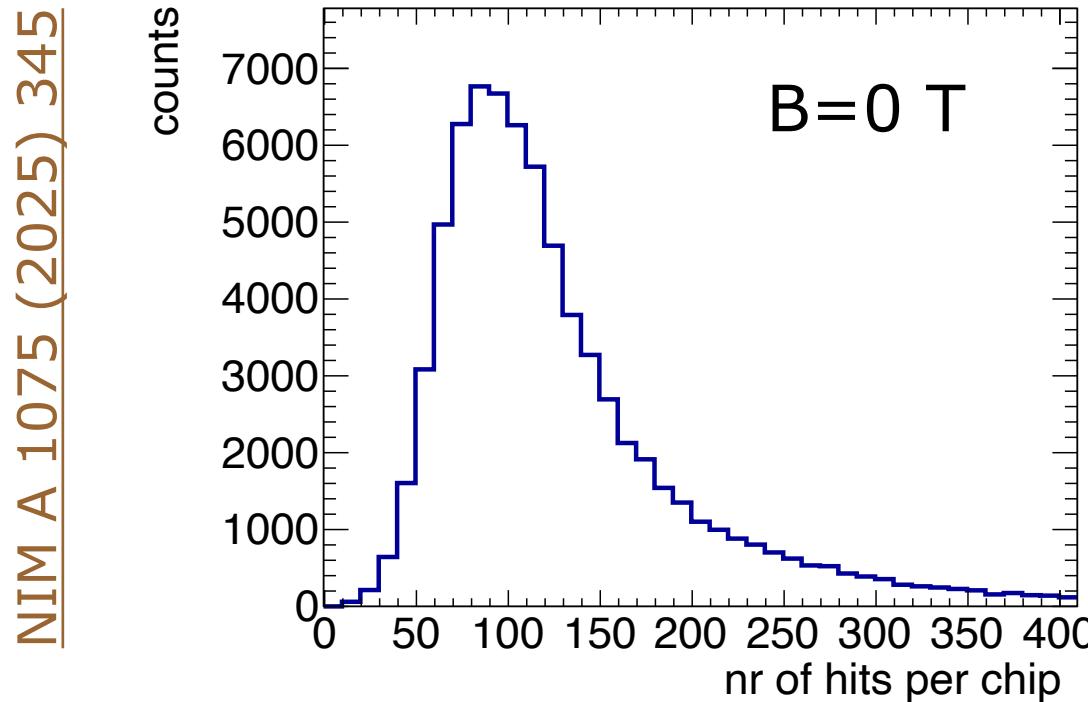


Each 10 cm we have a point with a resolution of < 18 (31) μm on the track
Comparable to performance of a silicon detector (but TPC gas material).

Particle identification (PID) performance

- It is possible to study in test beam data the dE/dx or dN/dx of electrons
- The Pixel TPC has measurements with $55 \mu\text{m}$ pixel size
- It detects single electrons with an efficiency $> 85\%$
- This allows to measure the number of clusters (hits) as a function of the distance along the track dN/dx (dE/dx) with high granularity
- The advantage of hit counting in a Pixel TPC is – due to the digital read out – that one is not including the fluctuations from the multiplication process in the charge measurement
- Using e.g. a pad readout, the charge is used as a measure of dE/dx
 - This readout has a larger granularity and includes avalanche fluctuations
 - One has to go to very small pads ('pixels') to measure the clusters

Testbeam PID performance



- $B=0$ T has a large Landau tail
- $B=1$ T smaller Landau tail and a more gaussian distribution
- An electron crossing 8 chips in the module has about 1000 hits

Combine chips to form a 1 m long track with 60 % coverage for electrons

- Method 1 "dEdx truncation": reject large clusters and then run dEdx @ 90% using slices of 20 pixels along track (xy) (gives nr of selected hits). A large cluster has more than 6 hits in 5 consecutive pixels.
- Method 2 "Template fit": fit the slope of the N_{scaled} minimum distance (d) in xy distribution with an exponential function ($N_{\text{scale}}(d)$ =defines the inverse weights):
$$N(d)_{\text{scaled}} = N_{\text{scale}}(d) N_{\text{observed}}(d)$$
$$N(d)_{\text{scaled}}$$
 is then fitted for each track with $N_0 \exp(-\text{slope } d)$
- ✓ Calculate the PID observable for electrons and MIP (==70% of hits)
 - method 1 = nr of selected hits, method 2 = fitted slope
 - Resolution is $\sigma = \sigma(\text{PID})/\text{PID}$ (for σ we use the rms)



PID performance method “dEdx truncation”

Electron resolution

3.6%

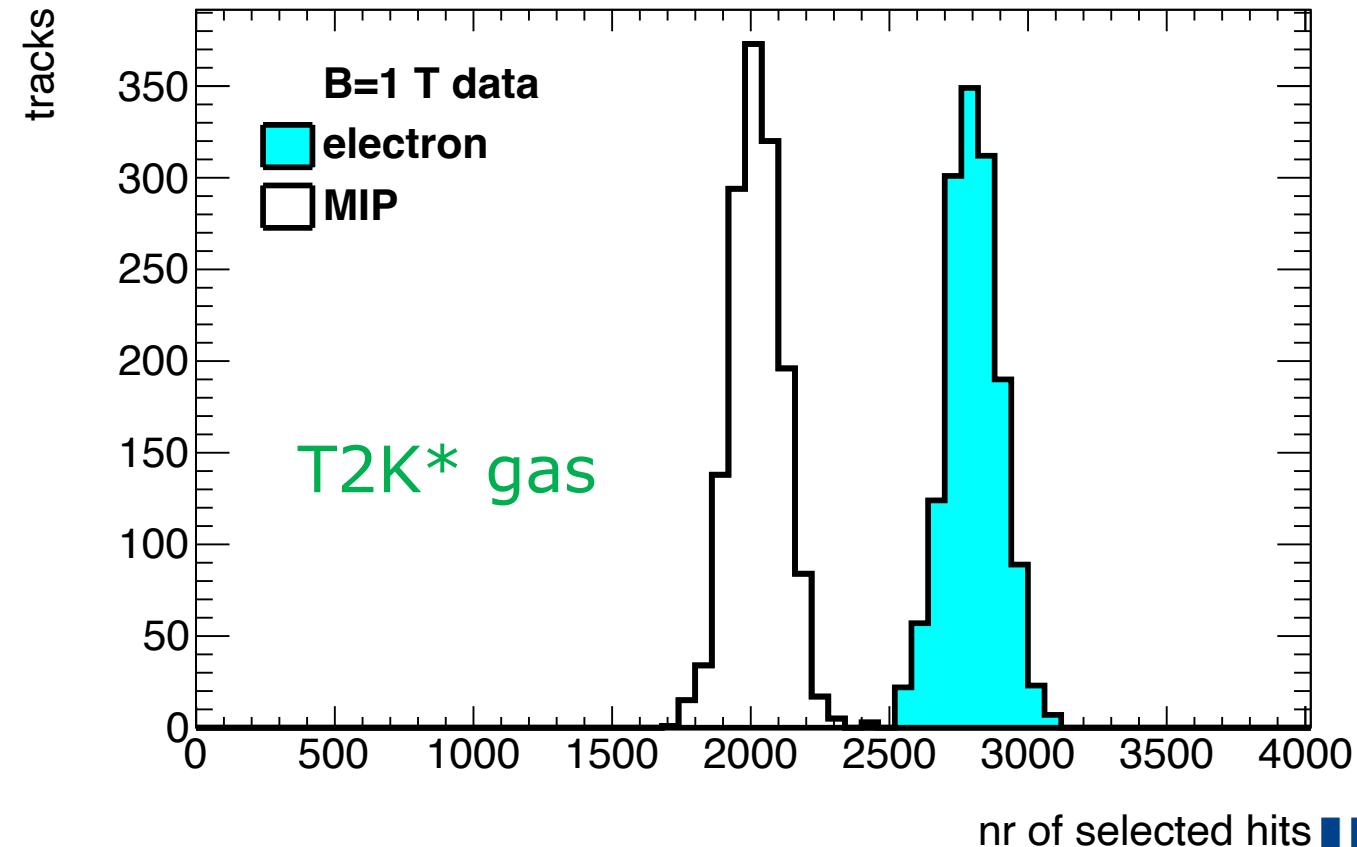
1 m track 60% and
coverage

Linearity $MIP-e = 1.03$
 z drift=5-15 mm (flat)

MIP distribution is obtained
by dropping 30% of the hits



LCTPC at DESY January 2026



Peter Kluit (Nikhef)

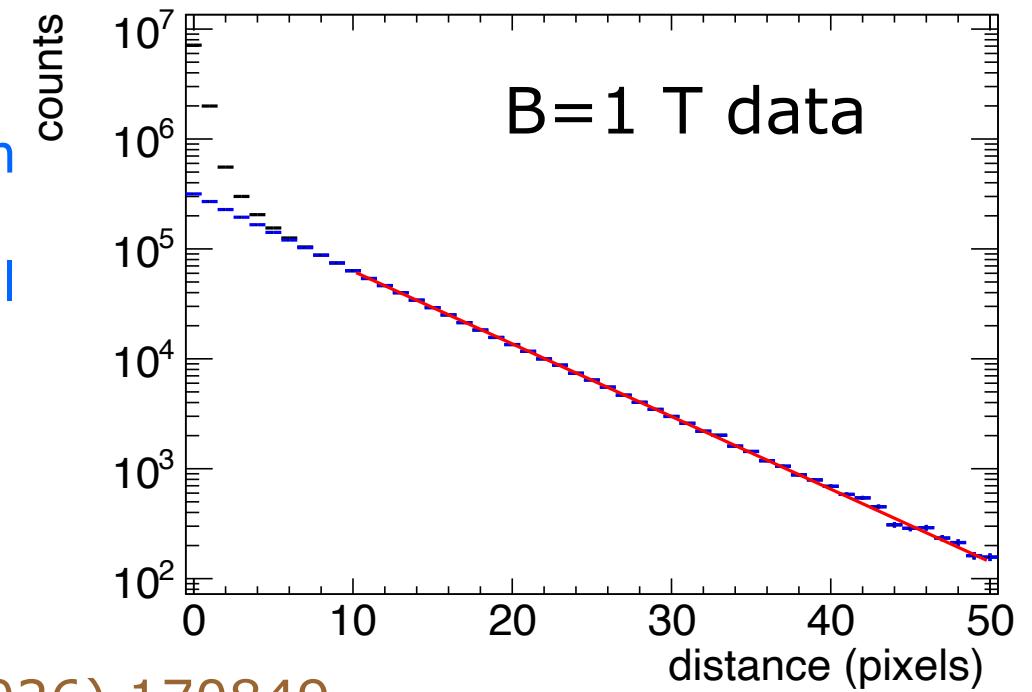
PID performance method "Template fit"

Calculate minimum distance between the hits.

The slope of the distribution is related to the number of primary clusters /cm

The diffused peak at $d < 10$ (black) comes from clusters with more than 1 hit. Weights are applied at $d < 10$ to the follow the exponential cluster distance distribution (blue). In red the exponential function.

Per 1 m track the slope is fitted to the full distance distance distribution using a ML fit.



PID performance method “Template fit”

Electron resolution

2.9%

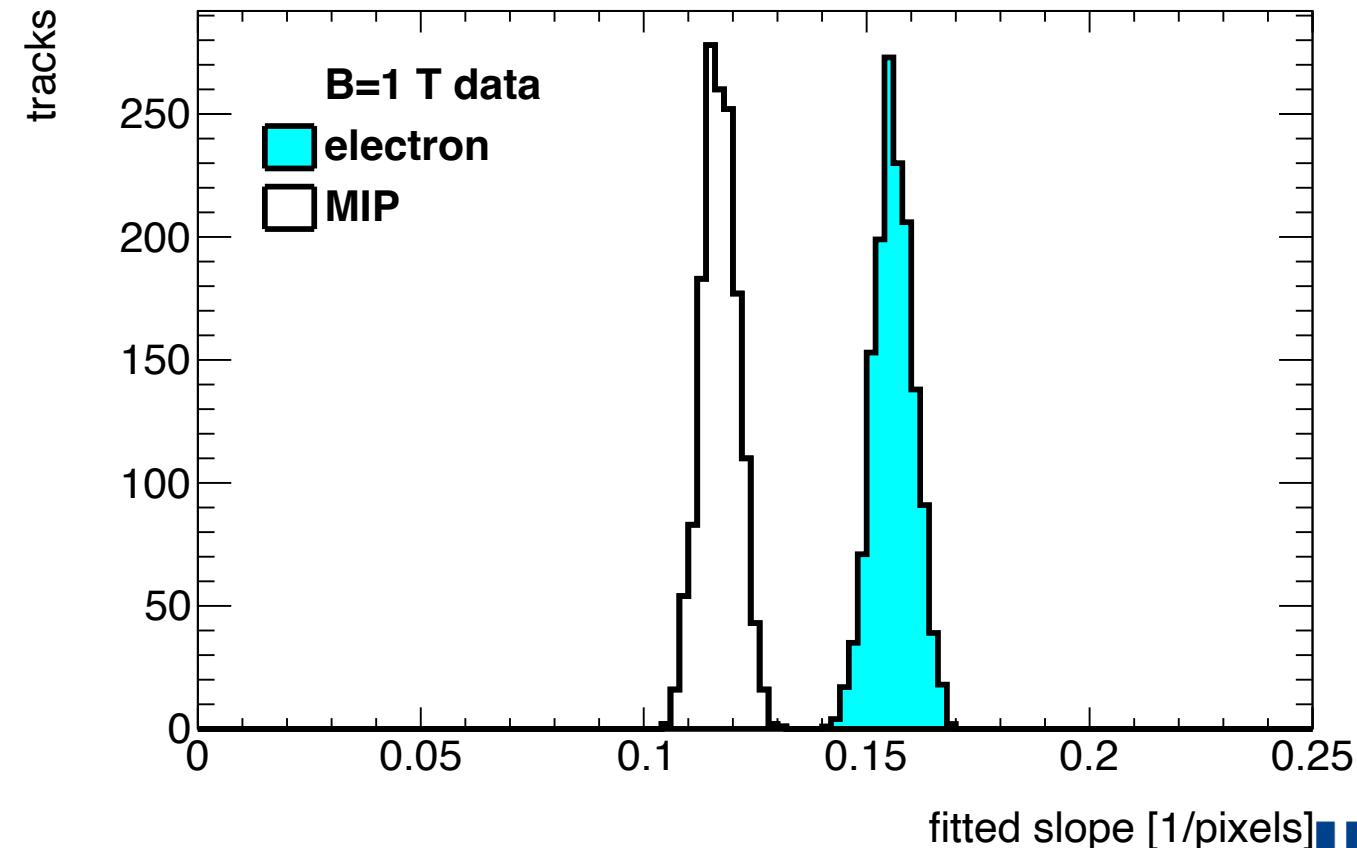
1 m track 60% and
coverage

Linearity MIP-e = 1.07

Ideally this is 1. A number
larger than 1 means that
the resolution is +7% larger



LCTPC at DESY January 2026



Peter Kluit (Nikhef)



Summary of PID performance

The PID resolution for electrons from data by combining tracks to form a 1 m long track with realistic coverage ~60% coverage.

Method	B=0 Resolution (%)	B= 1 T Resolution (%)
(1) dEdx truncation	6.0	3.6
(2) Template fit	5.4	2.9

The resolution for B=0 is worse than of the B=1 T data because of the larger fluctuations, that were already observed at the chip level.

Published as "Towards a Pixel TPC part II: particle identification with a 32-chip GridPix detector", [Nucl. Instrum. Meth. A 1081 \(2026\) 170849](#)

dEdx Performance extrapolated to the ILD detector

Test beam B = 1 T
p=5,6 GeV/c

electron resolution 2.9(3.6)%
for method 2 (1)

1 m track 60% and coverage

ILD detector

rInner = 329 rOuter = 1770 mm
halflength (z) = 2350 mm
electron resolution = 2.5(3.0)%
at $\theta=\pi/2$ for method 2 (1)

Assume Pixel TPC performance at
B = 1 T at p = 5,6 GeV/c

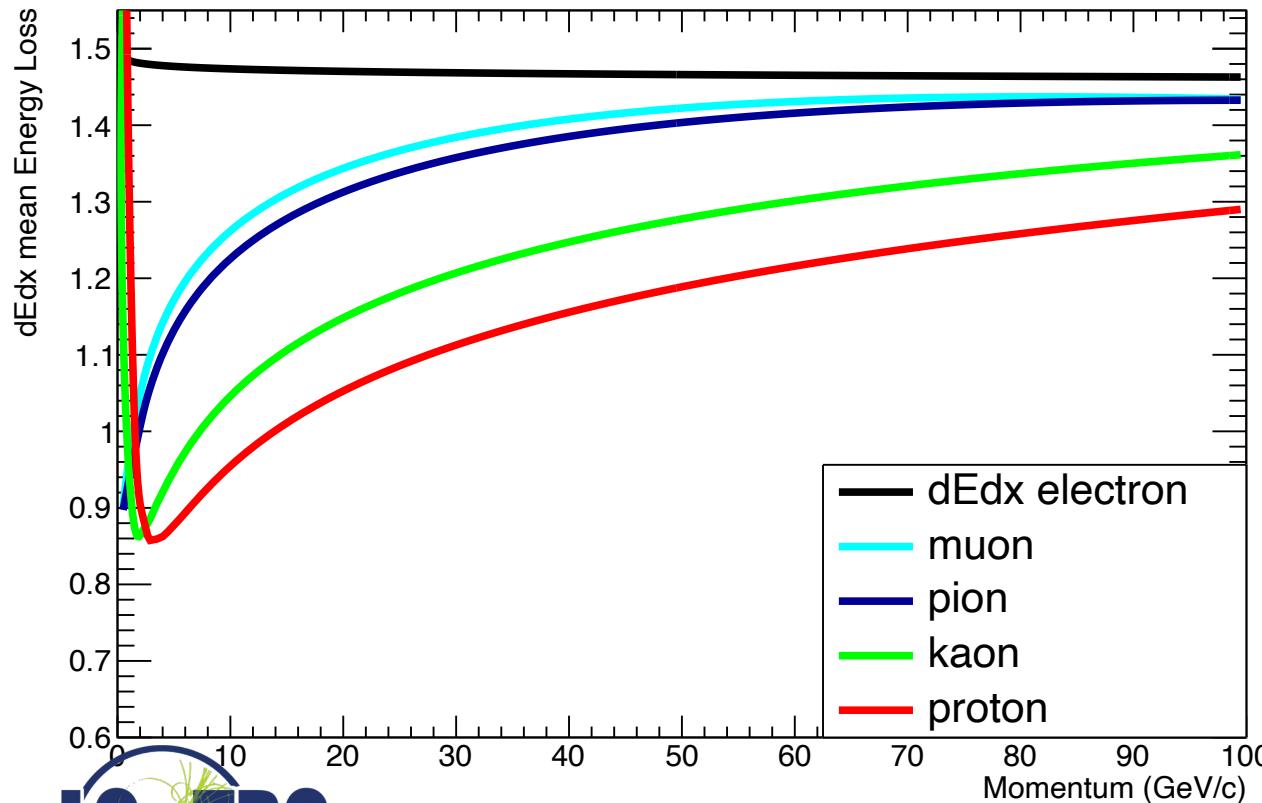


LCTPC at DESY January 2026

Peter Kluit (Nikhef)

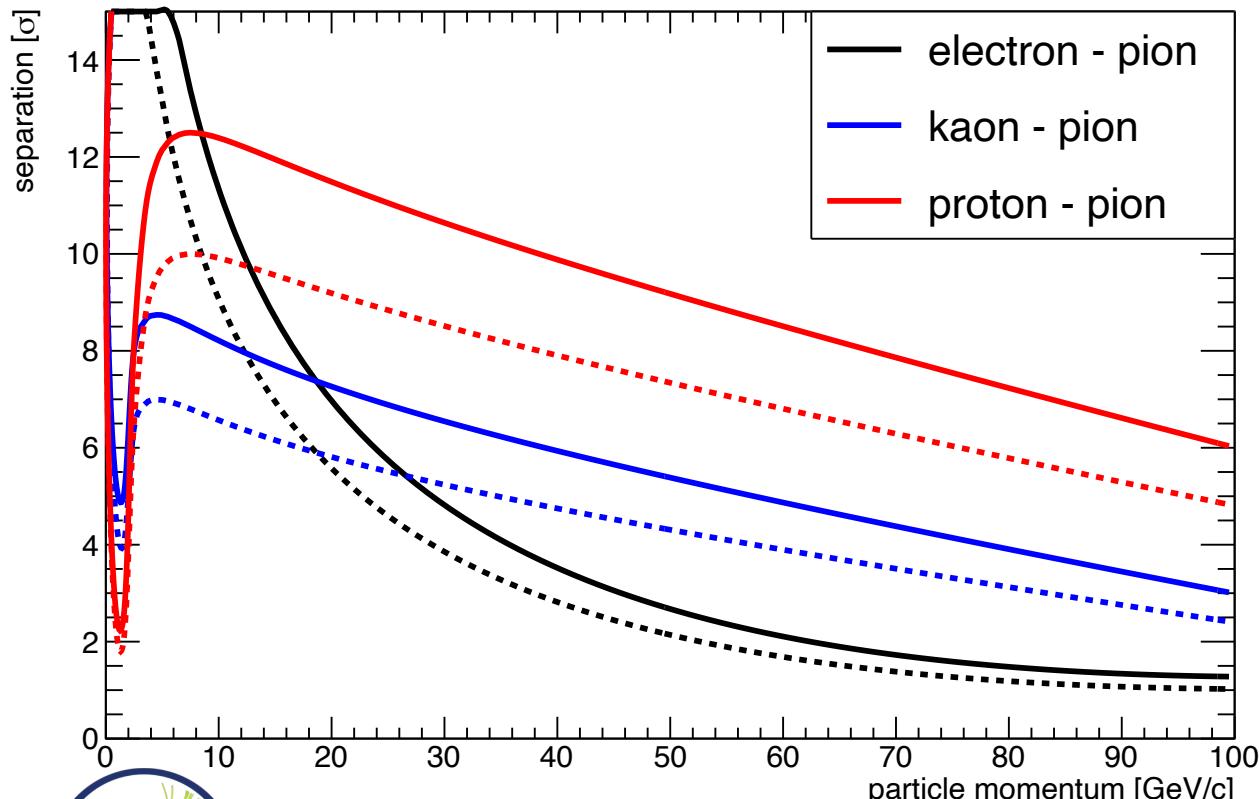


ILD dEdx performance for T2K gas



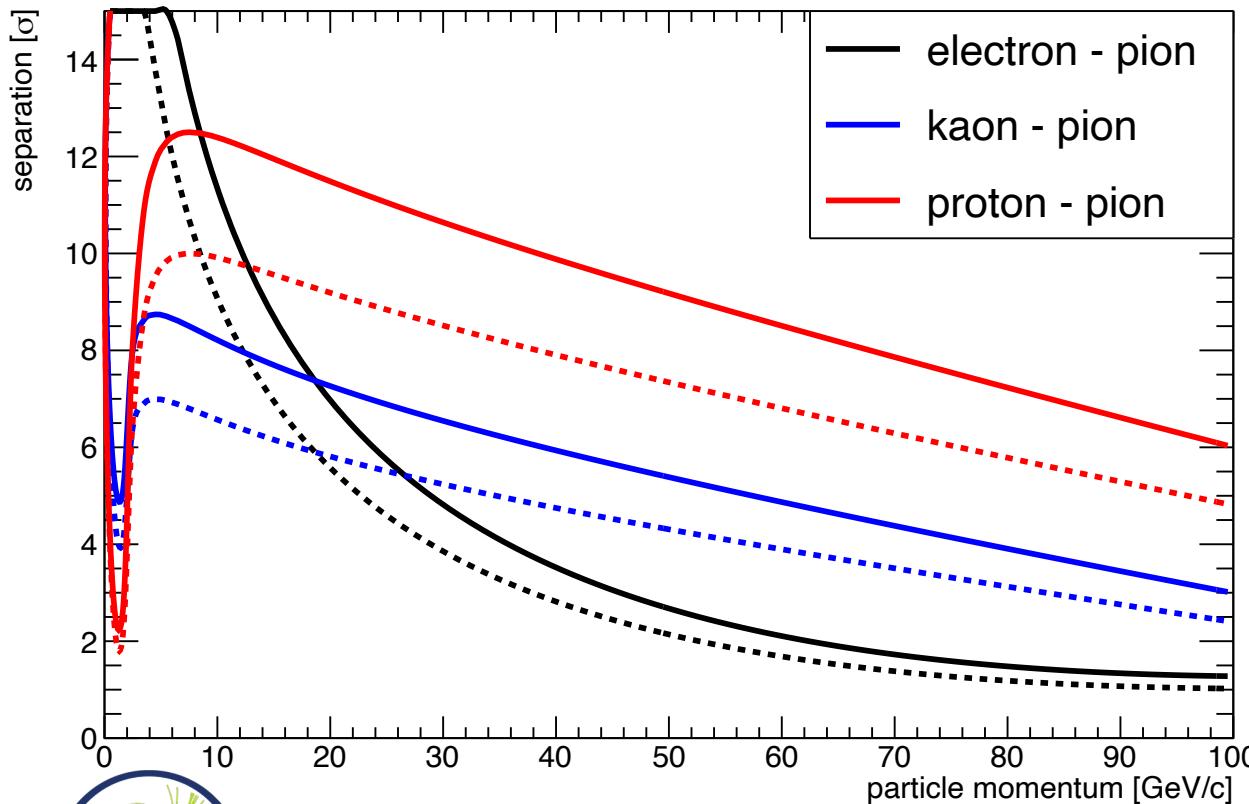
- Ullrich Einhaus performed dEdx studies in ILD and extracted the ILC soft parametrisations for energy loss based on G4 and full simulation of the ILD TPC with T2K gas
- [Link to the software](#). Samples were generated in 2020 with ILC soft v02-02 and v02-02-01

Pixel TPC PID performance



- ILD Performance with specified detector dimensions for particles at $\cos \theta = 0$
- Pixel TPC resolution from electron $p = 5$ (6) GeV test beam (for $B = 1$ T) of 2.5% and 3% (--- = method 1) at $\cos \theta = 0$
- Separation electron pion defined as: $|\langle \text{Eloss e} \rangle - \langle \text{Eloss } \pi \rangle| / \sigma_\pi$
- Separation pion kaon as: $|\langle \text{Eloss } \pi \rangle - \langle \text{Eloss K} \rangle| / \sigma_\pi$

Pixel TPC PID performance

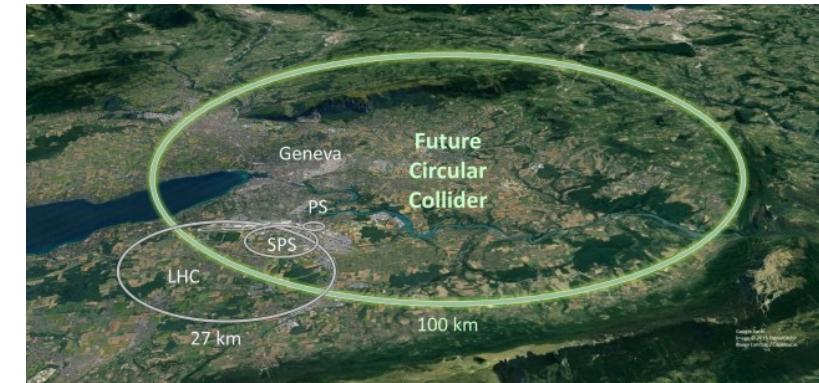


- The expected pion-kaon separation for momenta in the range of 2.5-45 GeV/c at $\cos \theta = 0$ is more than $5.5(4.5)\sigma$ for the two resolution scenarios.
- At a momentum of 100 GeV/c the separation is still $3.0(2.0)\sigma$.
- Protons can be separated from pions for momenta in the range of 2.5-100 GeV/c with more than $6.0(4.8)\sigma$.

- The PID resolution for an electron with $p=5,6$ GeV/c of 1 m track length with 60% coverage is measured to be 2.9(3.6)% at $B = 1$ Tesla.
- The extrapolated PID resolution for an ILD detector is 2.4% (3%)
- This allows for particle identification and separation of kaons from pions up to momenta of 45 GeV with more than 5.5σ (4.5σ) for $\cos \theta = 0$. The separation increases up to $\cos \theta = 0.85$ (see back up slide).
- As demonstrated, the digital read out of a pixel TPC with a small pixel size allows to perform hit and cluster counting
- Currently a coverage of ~60% is realized with the TPX3 chip. Using the next generation TPX4 chip with Through Silicon Via's will allow to enlarge the coverage and increase the PID and tracking performance. The R&D is part of the DRD1 program

A Pixel TPC at a circular collider

At the FCCee a pixel TPC as a central tracker – sliced between silicon detectors as in the ILD concept detector - is well suited to carry out the WW, ZH and tt physics program.



At the CEPC a pixel TPC is selected as one of the baseline CDR/TDR detectors

A more challenging situation for a TPC is running at the Z and in particular the FCCee Tera Z program with $L = 140 \ 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ and Z bosons produced at a rate of $\sim 40 \text{ kHz}$ and huge beam backgrounds*.
A 10 Giga-Z FCCee physics program looks realistic with a GridPix pixel TPC and an improved FCCee MDI design.

*For detailed studies/questions/answers see backup slides

Conclusions: Pixel TPC at a circular collider

- The performance of a pixel TPC based on GridPixels has been studied based on prototypes and test beam measurements. It provides
 - high precision continuous tracking with a low material budget
 - very powerful particle identification
- At the FCCee a pixel TPC as a central tracker – sliced between silicon detectors as in the ILD concept detector - is well suited to carry out the WW, ZH and tt physics program.
- A 10 Giga-Z FCCee physics program looks realistic with the proposed pixel TPC and an improved FCCee MDI design.
- After years of R&D, a pixel TPC has become a realistic viable option for experiments
- R&D on a Pixel TPC with GridPix devices with reduced ion back flow based on the TPX3 or TPX4 ASICs are part of the DRD1 program
- One could consider to use Ne as a TPC gas for the Tera-Z running

Backup plots

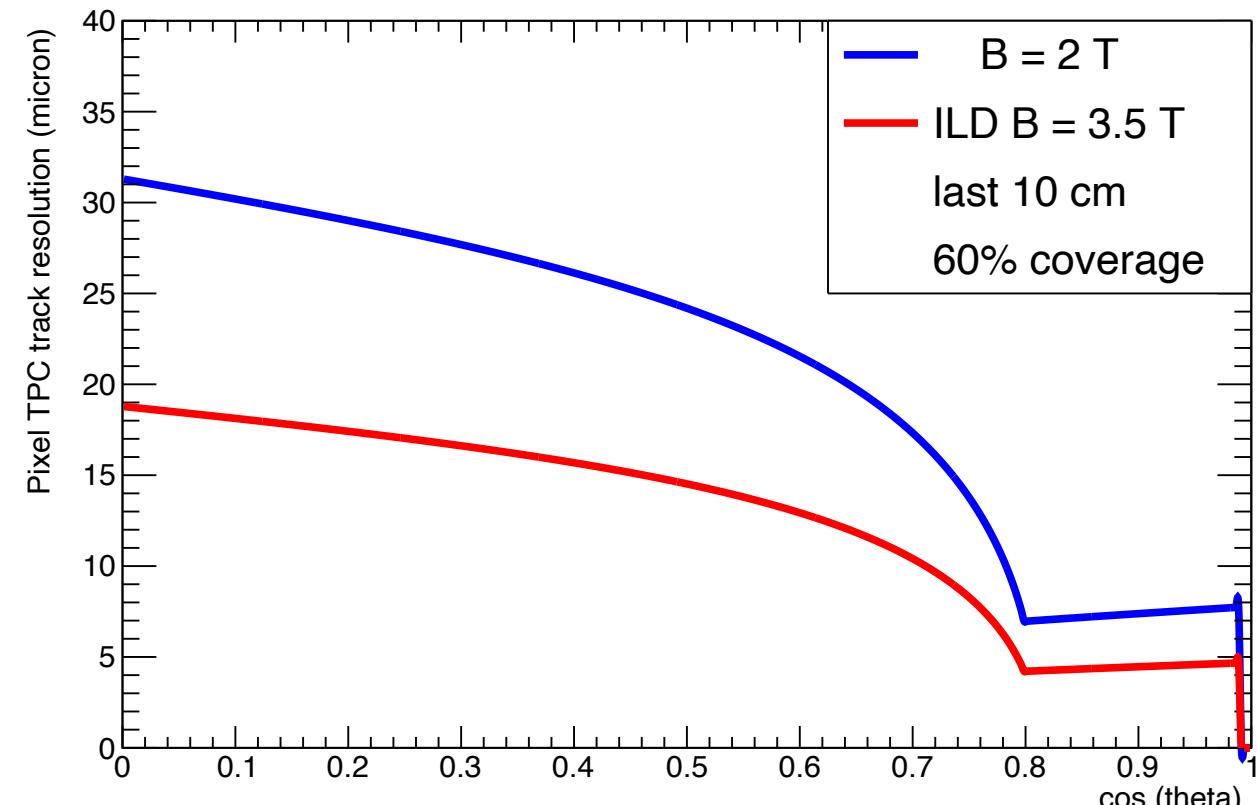
ILD tracking Performance for a Pixel TPC based on test beam

The last 10 cm track provides very high resolution 'point' in the endcap ($\cos \theta > 0.8$). This is due to the short drift distance and the high resolution pixel readout.

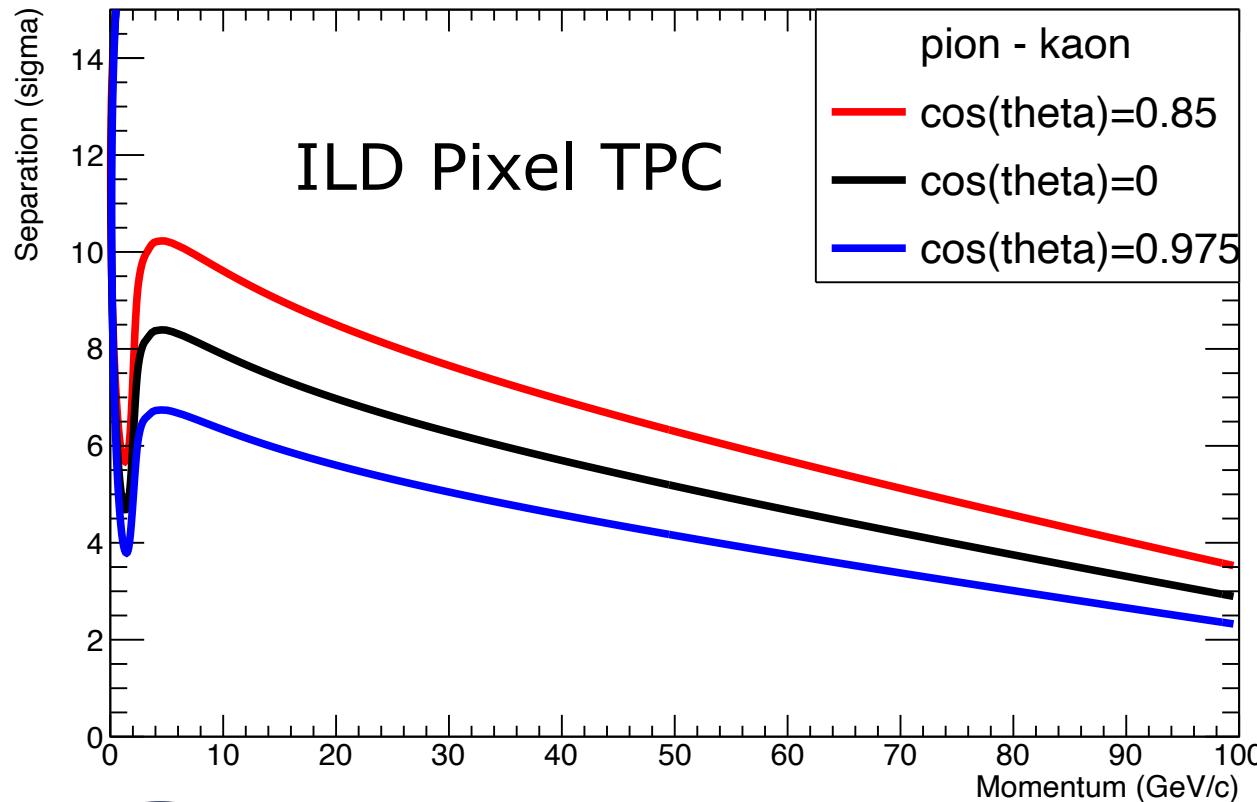
One use the endcap 'point' to calibrate out (part of) the TPC distortions.



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Pixel TPC dEdx performance acceptance



- Separation pion kaon $|<\text{Eloss } \pi> - <\text{Eloss K}>| / \sigma_\pi$
- Separation pion kaon for different $\cos(\theta)$ values due to the track length dependence
- For $\cos(\theta)=0$ till 0.95 the separation lies between the black and red curves. Only above 0.95-0.975 the separation drops till the blue curve.
- Excellent performance over very large polar angle range

A Pixel TPC at a circular collider

- **Can a pixel TPC reconstruct the Z events?**
 - The TPC total drift time is about $30 \mu\text{s}$
 - This means that there is on average 1.2 event / TPC readout cycle
 - YES: The excellent time resolution: time stamping of tracks $< 1.2 \text{ ns}$ allows to resolve and reconstruct the events
- **Can the current readout deal with the Z rate?**
 - Link speed of Timepix3 (in Quad): 2.6 M hits/s per $1.41 \times 1.41 \text{ cm}^2$ **In the module testbeam we tested up to rates of 5.7 kHz**
 - YES: This is sufficient to deal with hits from Z's in high luminosity Z running
 - Expect about 90 kHz/cm² from hadronic Z decays@inner radius
- **What is the current power consumption?**
 - No power pulsing is possible at a circular collider (at e.g. ILC power pulsing is possible)
 - Current power consumption TPX3 chip $\sim 2\text{W}/\text{chip}$ per $1.41 \times 1.41 \text{ cm}^2$
 - So: good cooling is important but no show-stopper.
 - In LCTPC, CO₂ cooling has been developed and tested for the MM read-out technology
 - To save power the TPX3/4 chips can be run in LowPowerMode: **reduction factor 10.**

A Pixel TPC at a circular collider

- The importance of the beam background and the optimization of the FCCee machine detector interface MDI
 - Hit rates from beam background are significant (wrt hits of Z decays)
 - The beam background study presented in the [October 2024 ECFA meeting](#) by Daniel Jeans (for a 2 T B field) would correspond to a sizeable background rate of about 300 MHz/cm² (@inner radius).
 - Since October 2024, the FCCee MDI has improved. A study summarizes the reduced [beam background results](#).
 - Recently the [synchrotron background](#) was studied that turns out to be very large for tracking detectors. Clearly it is important to reduce this background substantially.
 - The Pixel TPC – due to the high granularity – has an occupancy of < 1% for 300 MHz/cm² (@inner radius). The read-out speed of the current TPX3 has to be upgraded to cope with the large background rates. R&D for a fast read-out based on TPX3/4, like the VeloPix (LHCb) is needed.

A Pixel TPC at a circular collider

- What about track distortions?
 - Not an issue for running at cms energies of WW, ZH, tt
 - There are two important sources of track distortions of the TPC drift field:
 - the slowly drifting primary ions (from Zs and background)
 - the ions produced in the amplification process flowing back (IBF)
 - At the ILC gating is possible to reduce the IBF; at FCC-ee this is not realistic, for a Pixel TPC a double grid is the best solution (see below)
- Is it possible to reduce the IBF for a pixel TPC?
 - IDEA: by making chip with a double grid structure (see back up slide)
 - This idea was already realized as a 'TWINGRID' NIMA 610 (2009) 644-648
 - For GEMs for the ALICE TPC this was also the way – use several GEMs to reduce IBF
 - The IBF* can be easily modelled and with a hole size of 25 μm an IBF of $3 \cdot 10^{-4}$ can be achieved and the value for IBF*Gain (2000) would be 0.6.
 - YES: the IBF can be reduced. It needs R&D that can be done in the detector lab in Bonn.

* Measured IBF of single grid GrixPix is 1.3% and IBF*Gain (2000) is 26.

A Pixel TPC at a circular collider

- What would be the size of the TPC distortions at a TeraZ factory?
 - Tera-Z studies by Daniel Jeans and Keisuke Fuji show that for FCC-ee this means: distortions from Z decays up to $< O(100)$ μm .
 - The problem is that the beam and synchrotron backgrounds are by far the dominant source for the ions in the TPC volume. The beam distortions by beam backgrounds are less than 1 cm as the latest studies by Daniel Jeans shows. The synchrotron backgrounds are largest and the reduction of that background –by optimizing the MDI – is important for all detectors.
 - There is also an idea to operate the TPC with a Neon based gas that could bring the backgrounds down by a factor of 40. This needs study.
 - It can be argued that in an ILD like detector the distortions can be mapped out using the silicon VTX-SIT/SET detectors. See e.g. the backup slide on fitting out TPC distortions.

A Pixel TPC at a circular collider

- A 10 G Z FCCee physics program* could be carried out, but
 - It needs a lot of power to process the large amounts of background hits in the tracking detectors
 - It needs more study to reduce the backgrounds by an improved MDI
 - Fitting techniques should be studied to correct for the TPC distortions
 - The current TPX3 read out should be optimized to cope with the high readout rate and minimise the power consumption

* The physics case for a Tera Z physics program seems IMO rather weak

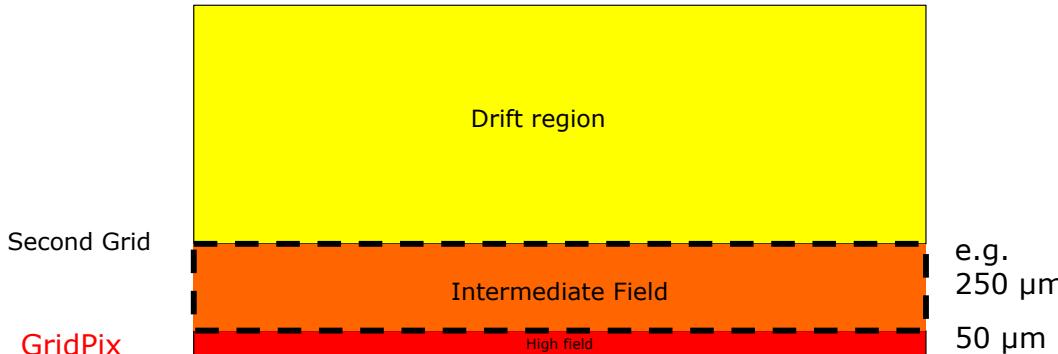
Fitting out and reducing TPC distortions

- It is possible to **map out distortions** using e.g. muons from Z decays
 - E.g. by fitting the 3D spatial distribution as a function of time as was done by ALEPH and more recently by ALICE. Using this distribution the hits positions are corrected and the TPC track refitted.
- However, with **silicon trackers around the TPC**, more elaborate methods can be used. One can use the track predictions based of the silicon trackers SIT and SET to correct on a track-by-track level the TPC track.
 - One can use as a constraint that the extrapolated positions and angles agree with the measured in the SIT and SET.
 - Practically, one can e.g. correct the TPC track parameters
- The ultimate way is a **fitting technique** similar to ATLAS. In the ATLAS track fit the common systematics is fitted out for sets of Muon hits. For ILD @ FCC the fit would fit free parameters in the distortion model, while using as a constraint the SIT and SET position and direction measurements.
 - The simplest case is a model where the strength (amplitude) and radial dependence would be scaled and a model is used for the 3D extrapolations.

Reducing the Ion back flow in a Pixel TPC

The Ion back flow can be reduced by adding a second grid to the device. It is important that the holes of the grids are aligned. The Ion back flow is a function of the geometry and electric fields. Detailed simulations – validated by data - have been presented in [LCTPC WP #326](#).

With a hole size of $25 \mu\text{m}$ an IBF of $3 \cdot 10^{-4}$ can be achieved and the value for IBF*Gain (2000) would be 0.6.



	Ion backflow	Hole 30 μm	Hole 25 μm	Hole 20 μm
Top grid	2.2%	1.2%	0.7%	
GridPix	5.5%	2.8%	1.7%	
Total	$12 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	
transparancy	100%	99.4%	91.7%	