

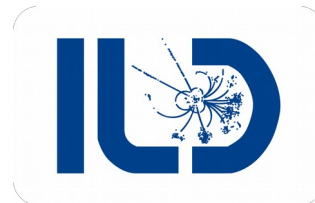
PID with High Granularity dE/dx

Recent Developments and Prospects

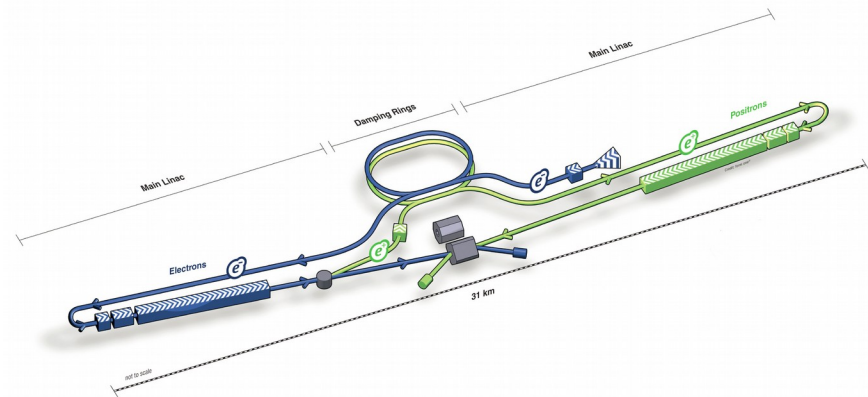
Ulrich Einhaus

4th FCC Physics and Experiments Workshop
12.11.2020

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

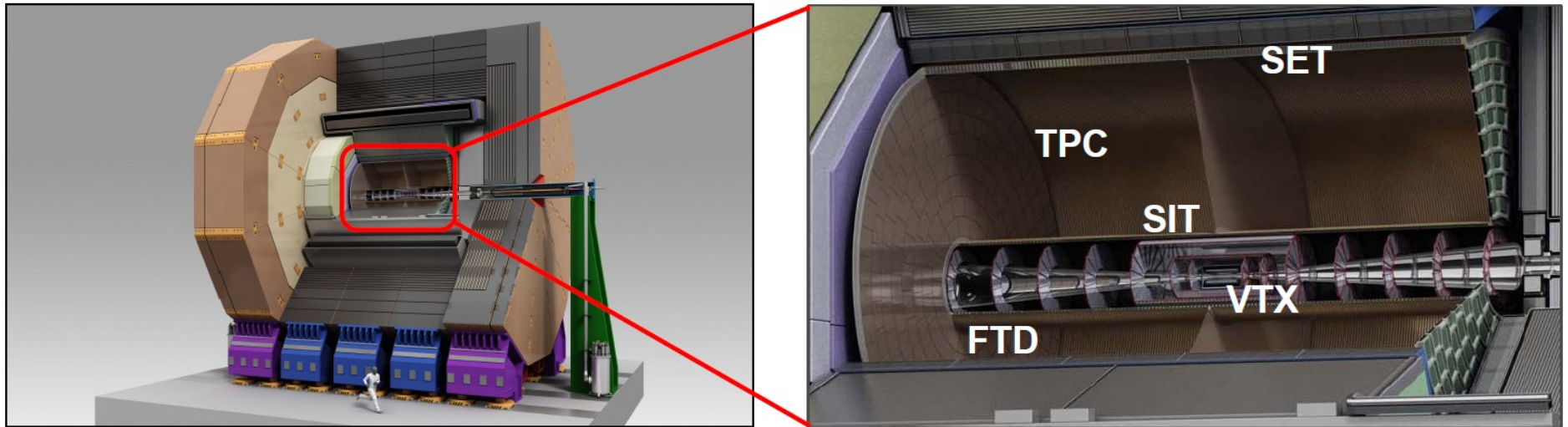


- The Linear Collider TPC Collaboration (LCTPC) develops readout options for TPCs for Linear Collider application, including high granularity opportunities.
 - Several readout options developed
 - Large prototype TPC + infrastructure at DESY II Test Beam Facility
- The proposed International Linear Collider (ILC) foresees 2 detectors, one of which, the International Large Detector (ILD), has a TPC as central tracker.
- ILC:
 - e^+e^- collider
 - 250-500 GeV, upgrade: 1 TeV
 - Polarised beams (80% e^- , 30% e^+)
 - Under political consideration in Japan



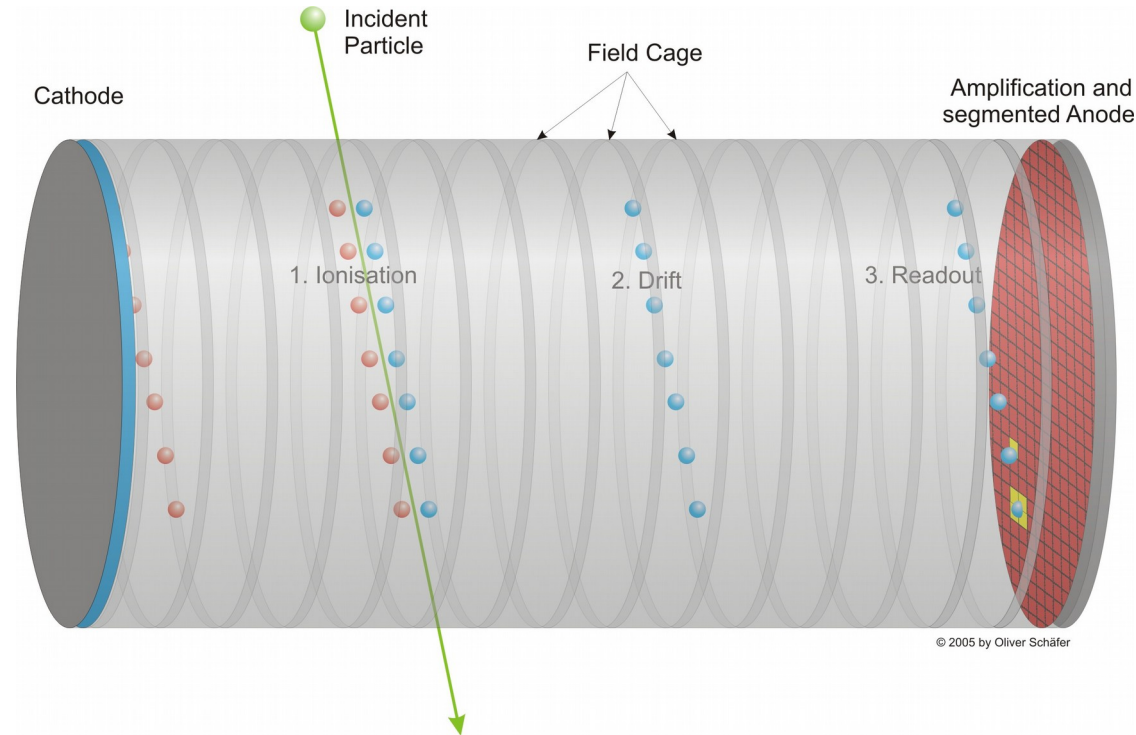
ILC Scheme | © www.forn-one.de

- ILD:
 - Multi-purpose detector optimised for Particle Flow and ILC environment
 - 3.5 T solenoid surrounding continuous tracker & highly granular calorimeter
 - $\sigma_{1/pt} = 2 \cdot 10^{-5} \text{ GeV}^{-1}$ (TPC alone: 10^{-4} GeV^{-1})



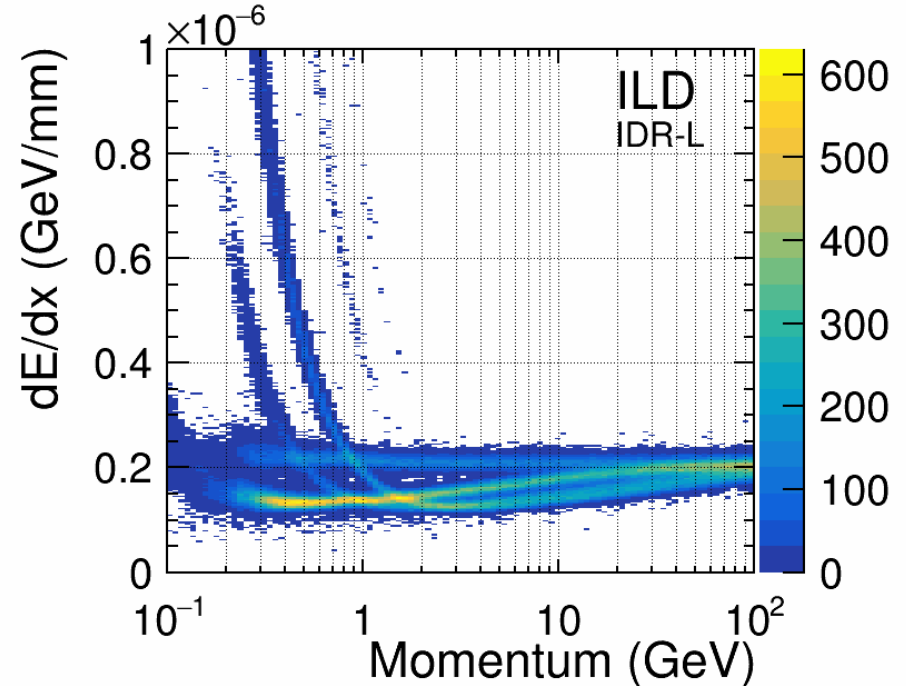
- **ILD TPC:**

- $330 \text{ mm} < r < 1770 \text{ mm}$ with 6 mm readout granularity (default); $|z| < 2350 \text{ mm}$
- 220 hits along track, excellent tracking efficiency down to low p
- Continuous tracking allows to find kinks, V0s, etc.
- Momentum resolution determines point resolution goal: $\sigma_{r/\phi} = 100 \mu\text{m}$
- 5 % X_0 in barrel, 25 % X_0 in end cap
- Gaseous tracker with T2K gas (95 % Ar, 3 % CF_4 , 2 % iC_4H_{10}) measures specific energy loss dE/dx ; resolution target: 5 %



- Conventional dE/dx method:
sum of all charge of a track
- Landau shaped \rightarrow large RMS
 \rightarrow mediocre correlation with the
average energy loss
- Partly compensated by applying
truncated mean etc.
- Empirical dependence of dE/dx resolution
on track length L and readout granularity G:
$$\sigma_{dE/dx} \sim L^{-0.47} \times G^{-0.13}$$

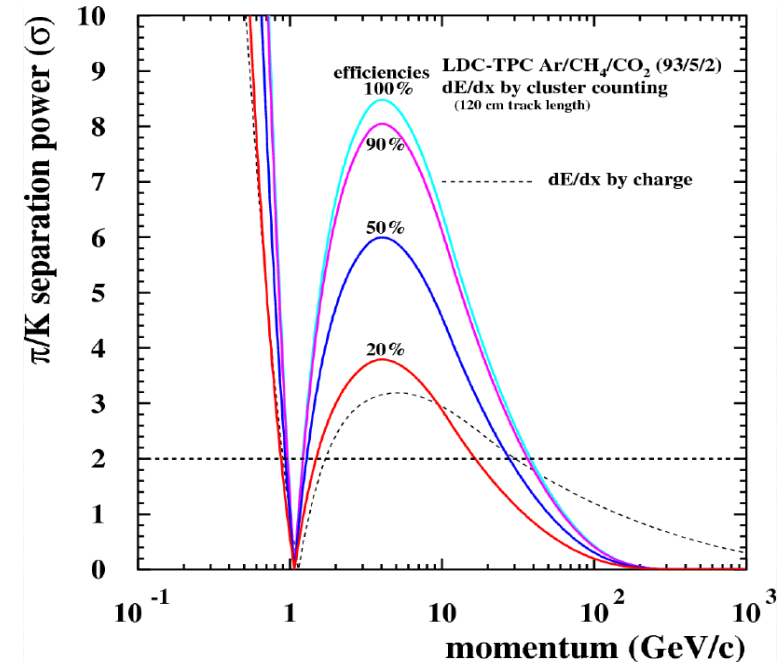
Blum, Riegler, Rolandi: Particle Detection with Drift Chambers



The ILD Concept Group: Interim Design Report
<https://arxiv.org/abs/2003.01116>

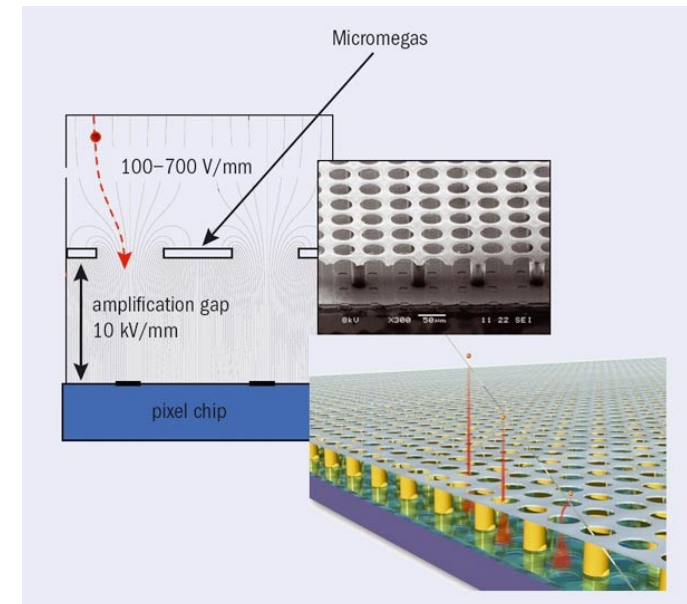
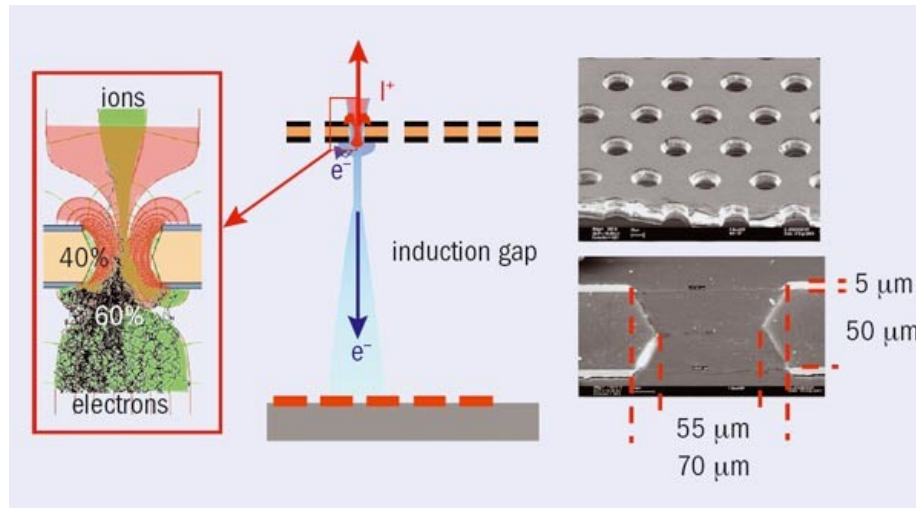
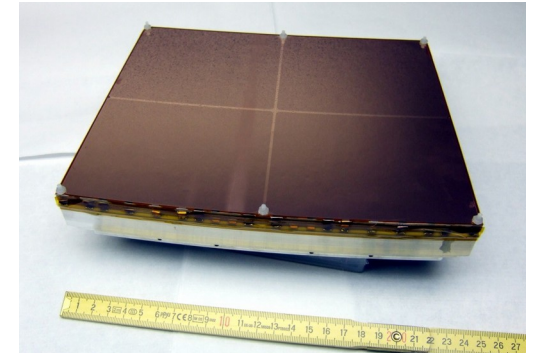
- Alternative approach: cluster counting
→ count number of ionising interactions
- Poisson shaped → better correlation with average energy loss
- Allows for better particle separation, but depends on counting efficiency
- Requires granularity similar to cluster distances $O(300\mu\text{m})$
- Number of reconstructed cluster is in general not proportional to average energy loss, so resolution is not a good measure instead use separation power:

$$S = \frac{|\mu_A - \mu_B|}{\sqrt{\frac{1}{2}(\sigma_A^2 + \sigma_B^2)}}$$



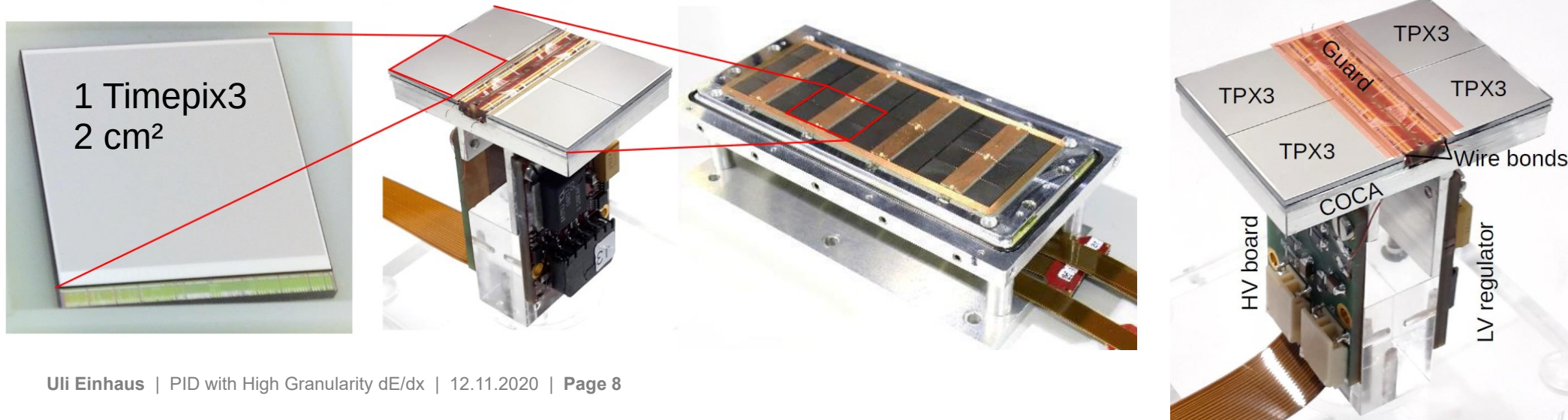
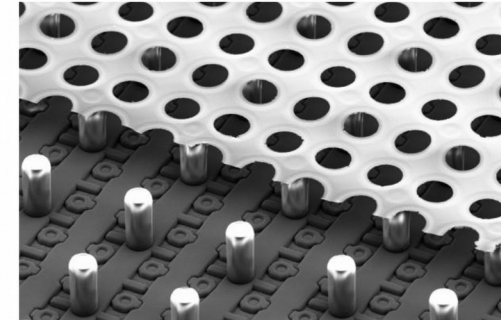
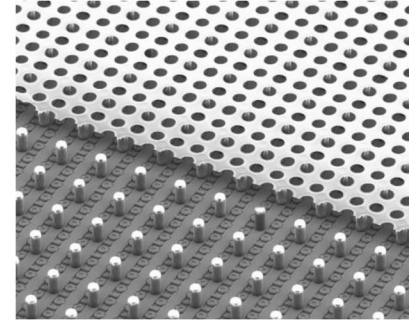
M. Hauschild: dE/dx and Particle ID Performance with Cluster Counting; at ILC Ws. Valencia 2006

- MPGD-based amplification; default pads of ~ 6 mm in r
- Pad-based readout with GEMs, by DESY, by KEK
- Pad-based readout with Micromegas, by CEA Saclay
- Modules have been developed and successfully tested in test beam campaigns

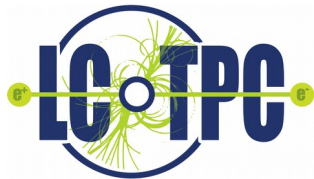
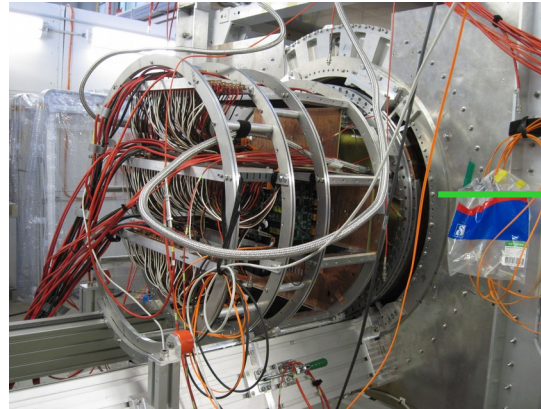


- Pixelised readout with Micromegas grown and etched on top of Timepix 3 ASIC: GridPix, by Nikhef & Uni Bonn
- Matching pitch of 55 μm of pixels and mesh, 65 k channels over 2 cm^2
- Detects individual electrons

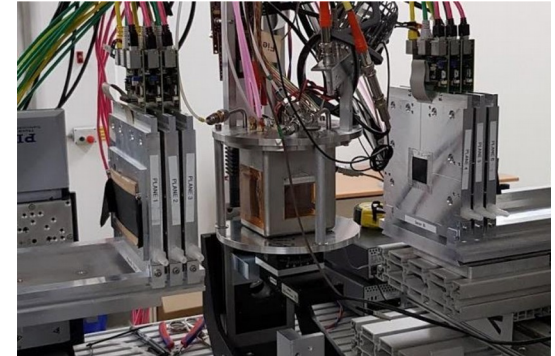
C. Ligtenberg: GridPix for future experiments
<https://indico.cern.ch/event/889369/contributions/4011330/>



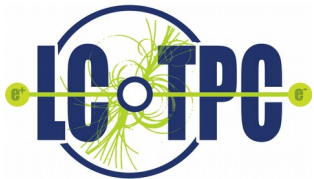
- dE/dx resolution extrapolated to ILD
- Pad-based systems, beam test @DESY II test beam facility:
 - 4.7 % (GEMs) <https://arxiv.org/abs/2006.08562>, paper in preparation
 - 4.6 % (GEMs) <https://arxiv.org/abs/1801.04499>
 - 5.0 % (Micromegas) <https://agenda.linearcollider.org/event/7826/contributions/41602/>



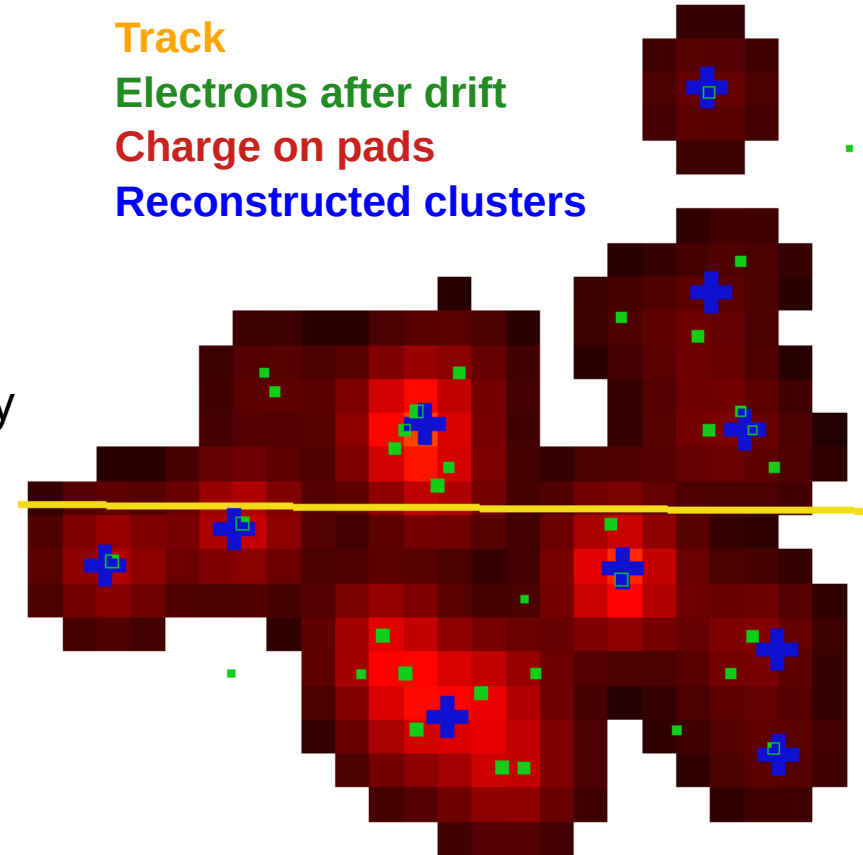
- Transformed to dE/dx resolution extrapolated to ILD
- GridPix, beam test at ELSA test beam @Uni Bonn
- 3.5 % by method 1: electron counting per 20-pixel intervals, 90 % truncated sum
- 3.4 % by method 2: cluster counting, by applying a weight w_i to every recorded electron, depending on the distance d_i to its successor; w_i extracted from simulation
- 3.26 % combined
- <https://arxiv.org/abs/1902.01987> (numbers revised since publication of proceedings)



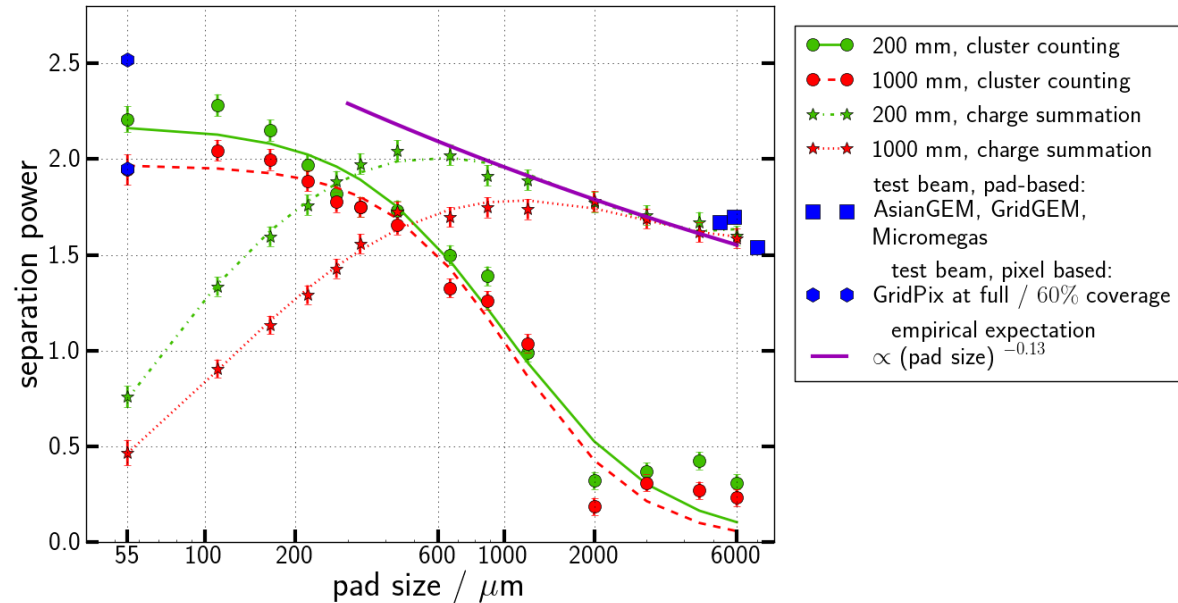
$$\mu' = \frac{1}{N_{\text{hits}}} \sum_{i=0}^{N_{\text{hits}}} w(d_i) d_i,$$



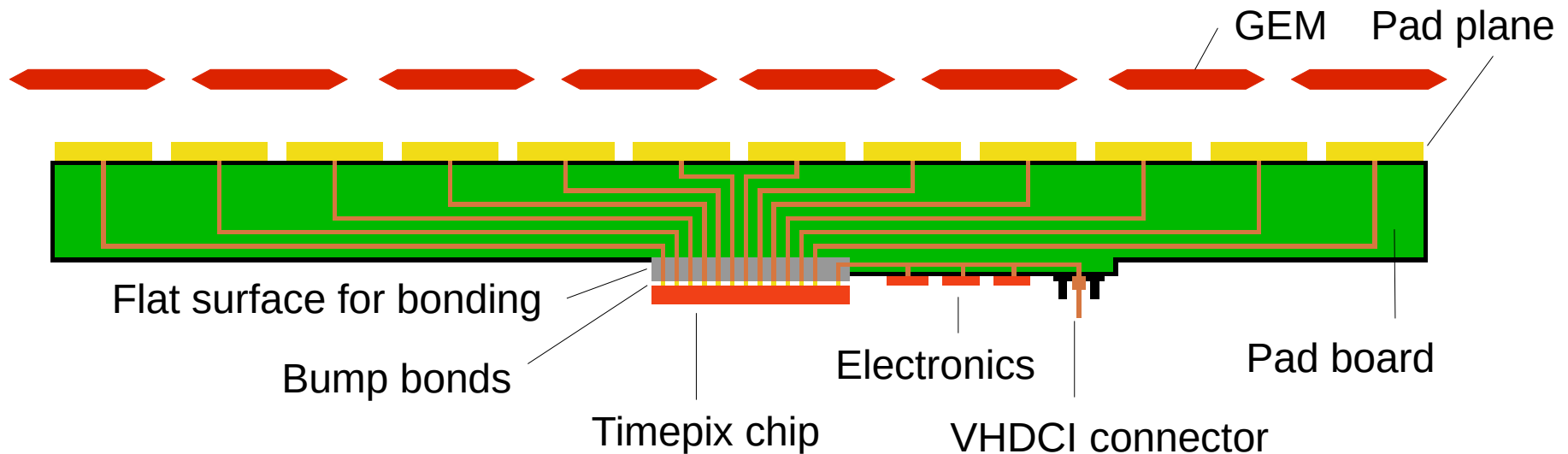
- Used MarlinTPC package of iLCSoft to simulate detailed ionisation, GEM amplification and varying square pad sizes
- Reconstructed clusters using Source Extractor software package [doi:10.1051 / aas:1996164](https://doi.org/10.1051/aas:1996164)
- Source Extractor looks for faint sources in 2D-sky maps; convolves with Mexican Hat, splits along minima/maxima and fits source profile
- Compare pions and kaons with constant track length of 300 mm
- Optimised amplification voltage (gain) for each pad size



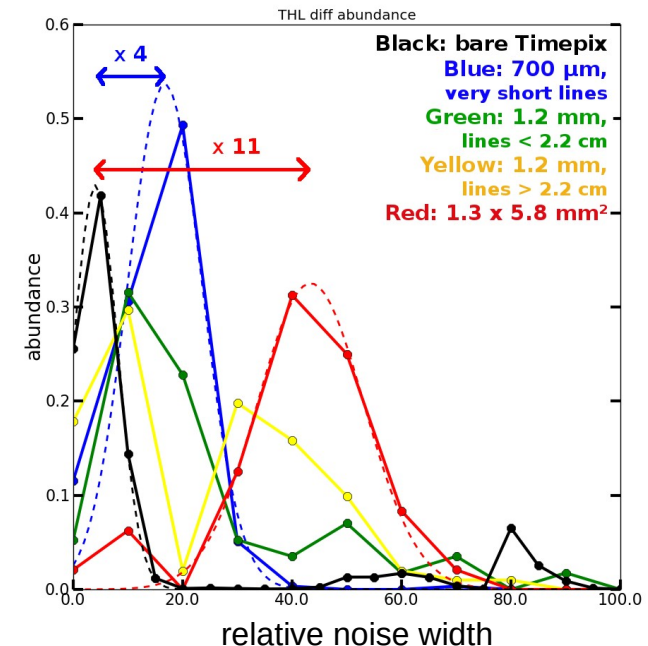
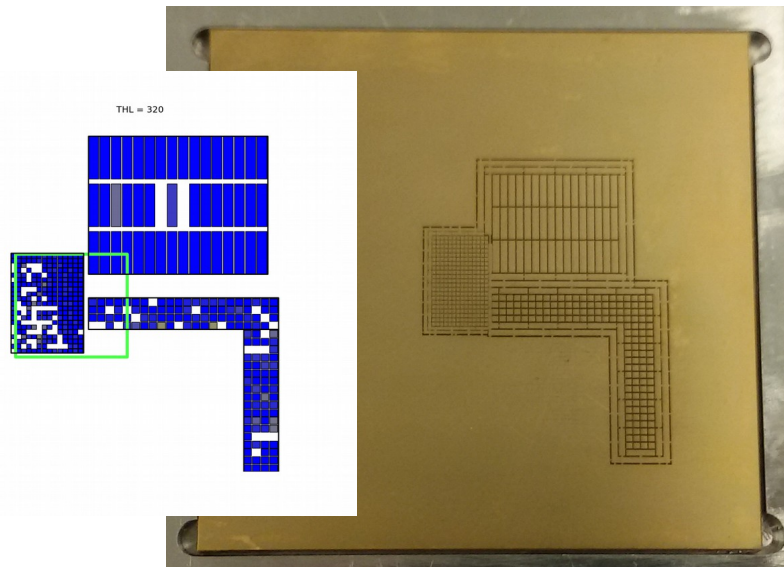
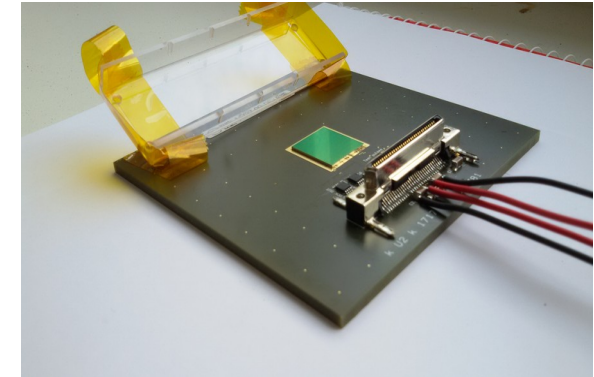
- Higher granularity helps for charge summation down to 0.5-1 mm, consistent with empirical expectation, gain $\sim 15\%$
- Cluster counting takes over below $200\ \mu\text{m}$, gain another 15%
- Simulation connects pad- and pixel-based test beam results, but GEM simulation loses applicability below $100\ \mu\text{m}$
- Anode coverage fraction is important parameter



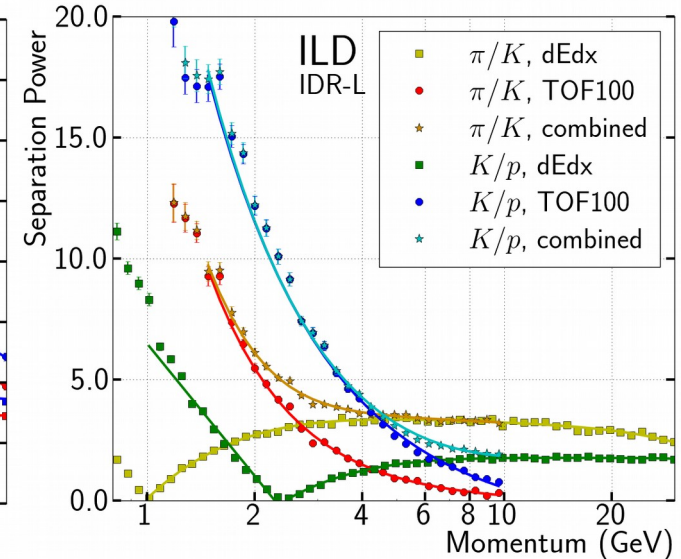
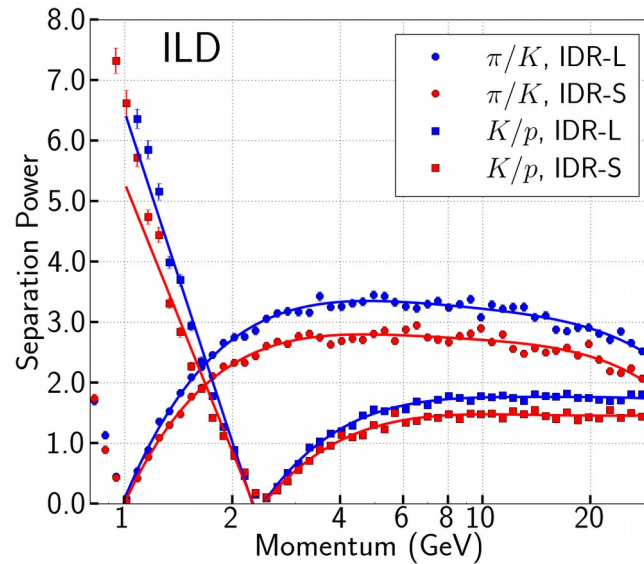
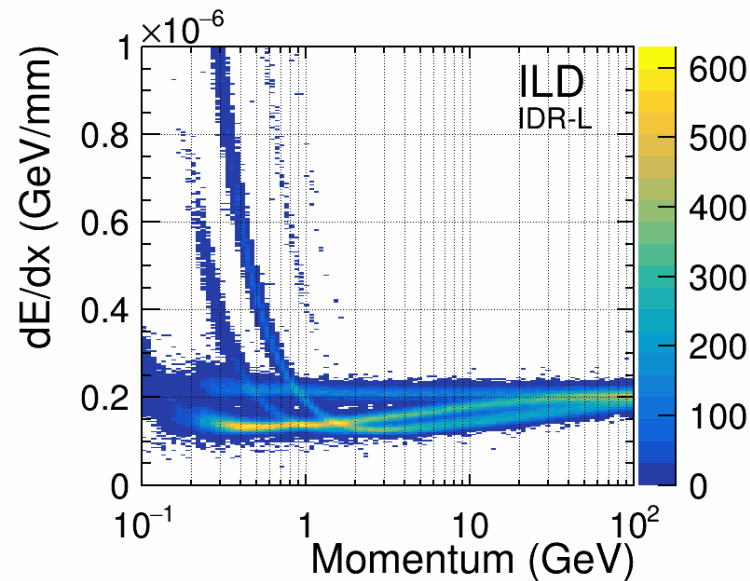
- Novel approach to enable intermediate-size pads
- Use pad plane on PCB, connect pixel chip directly on bottom side
- Pad size limited by feature size of PCB material to $700\ \mu\text{m}$
- Timepix ASIC, $55\ \mu\text{m}$ pixel pitch



- Challenge: bonding → successful gold-stud bonding @KIT, but lack of long-term thermo-mechanical stability
- Challenge: capacitive noise → threshold scan revealed that noise is up to ~ factor 10 increased, signal from GEM amplification is large enough for $S/N > 10$ and to reconstruct clusters in simulation

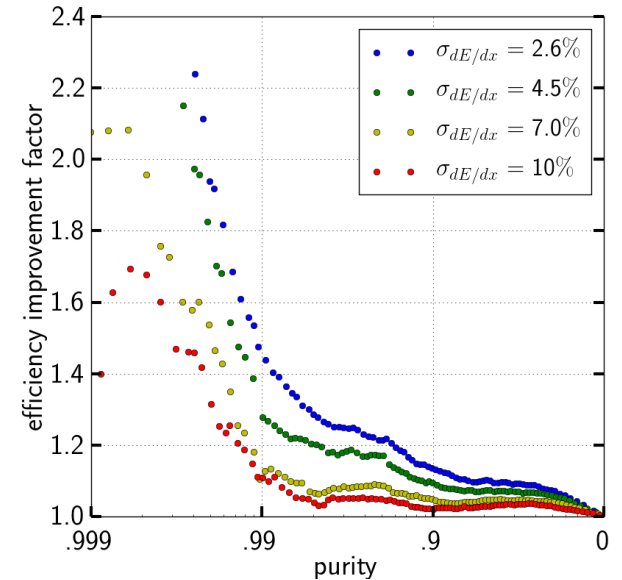
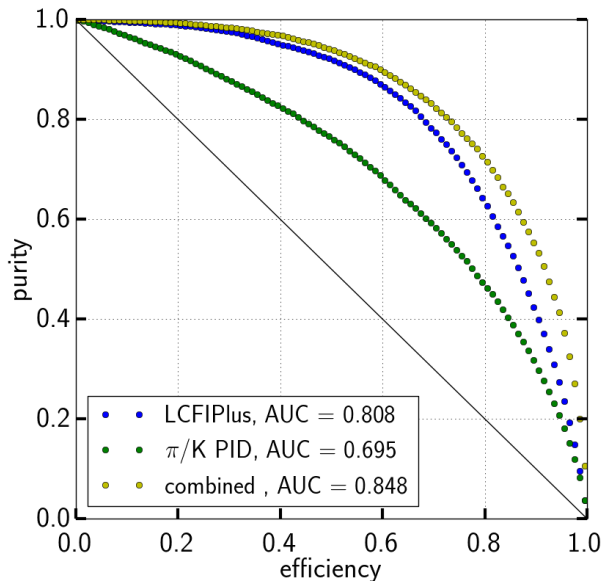
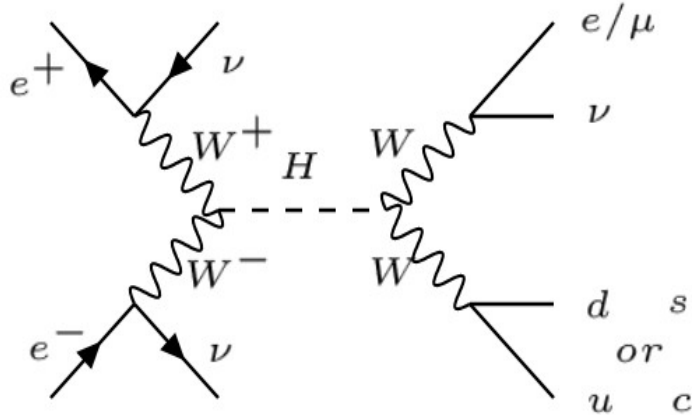


- In recent MC productions for ILD physics analysis dE/dx was added on TPC hit level, reconstructed to track dE/dx (70% truncated mean), which is used for subsequent particle identification



The ILD Concept Group: Interim Design Report
<https://arxiv.org/abs/2003.01116>

- Distinguish hadronic W decays by abundance and momentum of kaons via PID
- Use existing flavour tag (LCFIPlus) and add PID info (charged pions/kaon + V0s) to evaluate BDT: moderate effect
- Large effect at high requested purities, clear dependence on achievable dE/dx resolution



- Pad-based TPC readout structures with 6 mm granularity achieve the ILD target dE/dx resolution of 5 % (or better).
- Pixelised readout with a 55 μm granularity achieves a resolution of 3.5 % with dE/dx , and of 3.3 % if combined with cluster counting.
→ This should improve in future analyses!
- Simulation shows: the higher the granularity, the better the performance. Cluster counting kicks in at the pixel level $O(200\mu\text{m})$.
- PID can contribute to high level reconstruction and a large number of physics analyses, and clear dependencies on the PID performance can be observed.

Thank you for your attention!

Are there questions?