Pixel TPC particle identification performance update

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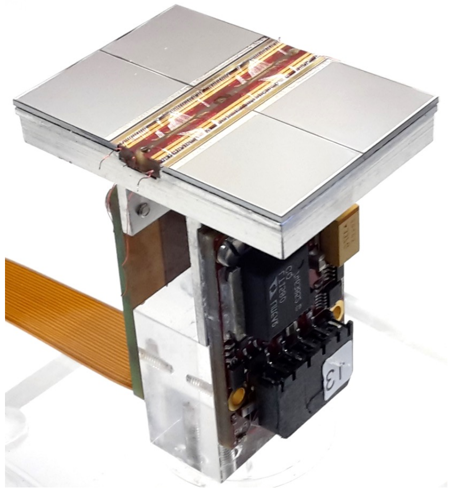
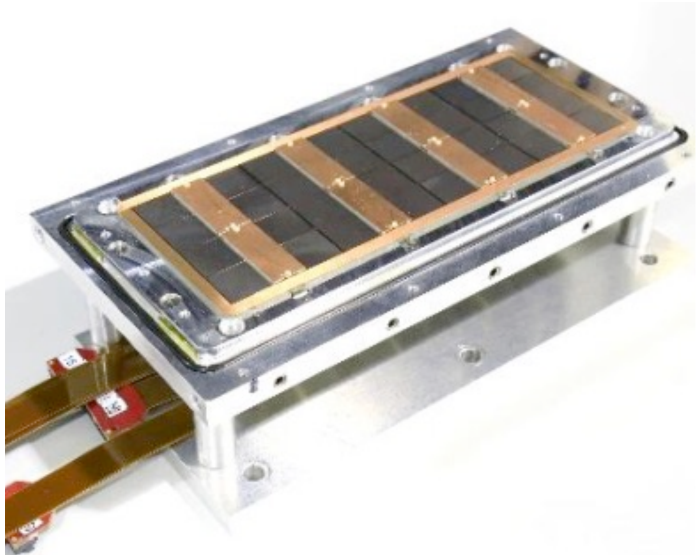


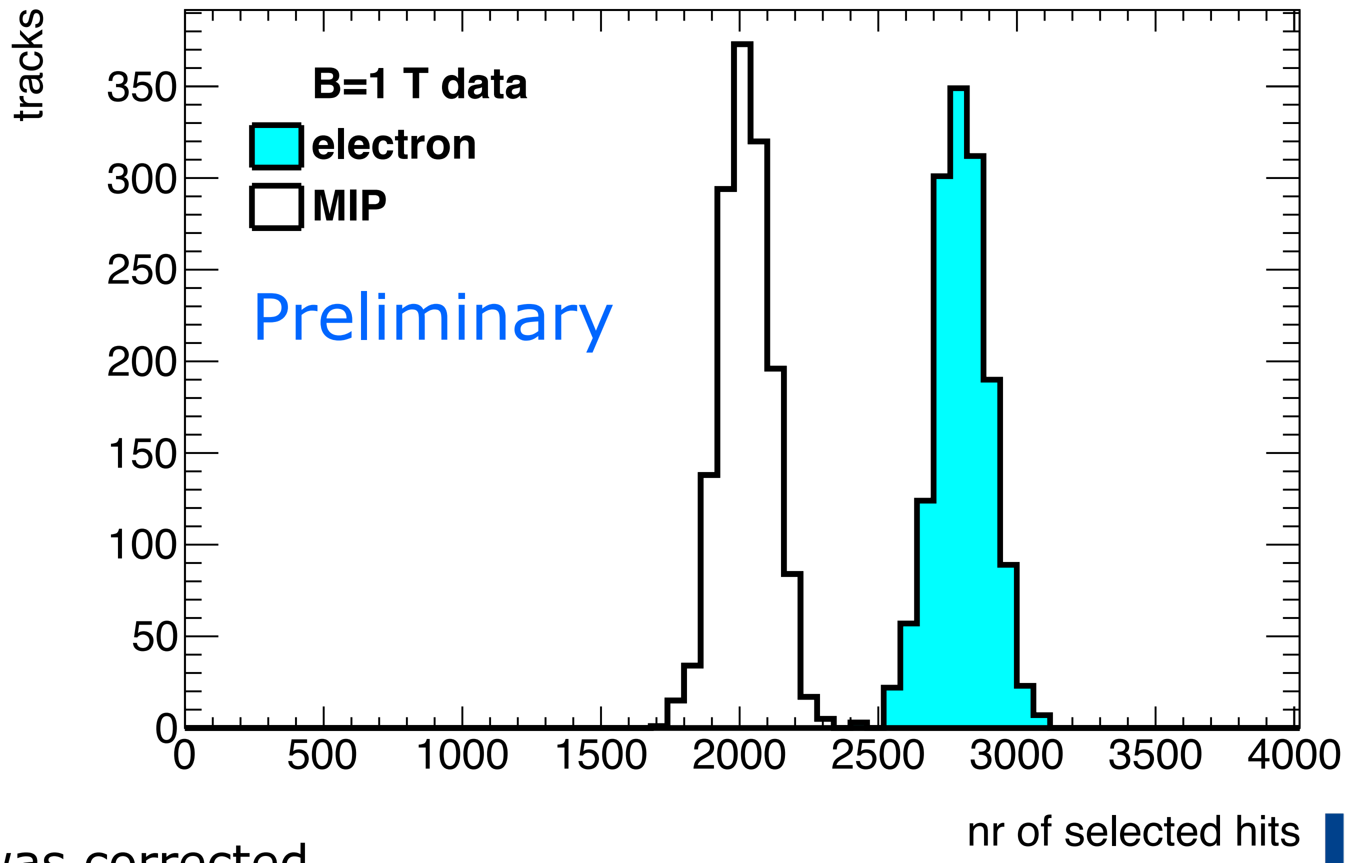


LCTPC Bonn meeting January 2025

DESY testbeam Module Analysis

PID performance truncation method

Electron resolution
3.6%
1 m track 60% and
coverage
Linearity MIP-e = 1.03
z drift=5-15 mm (flat)



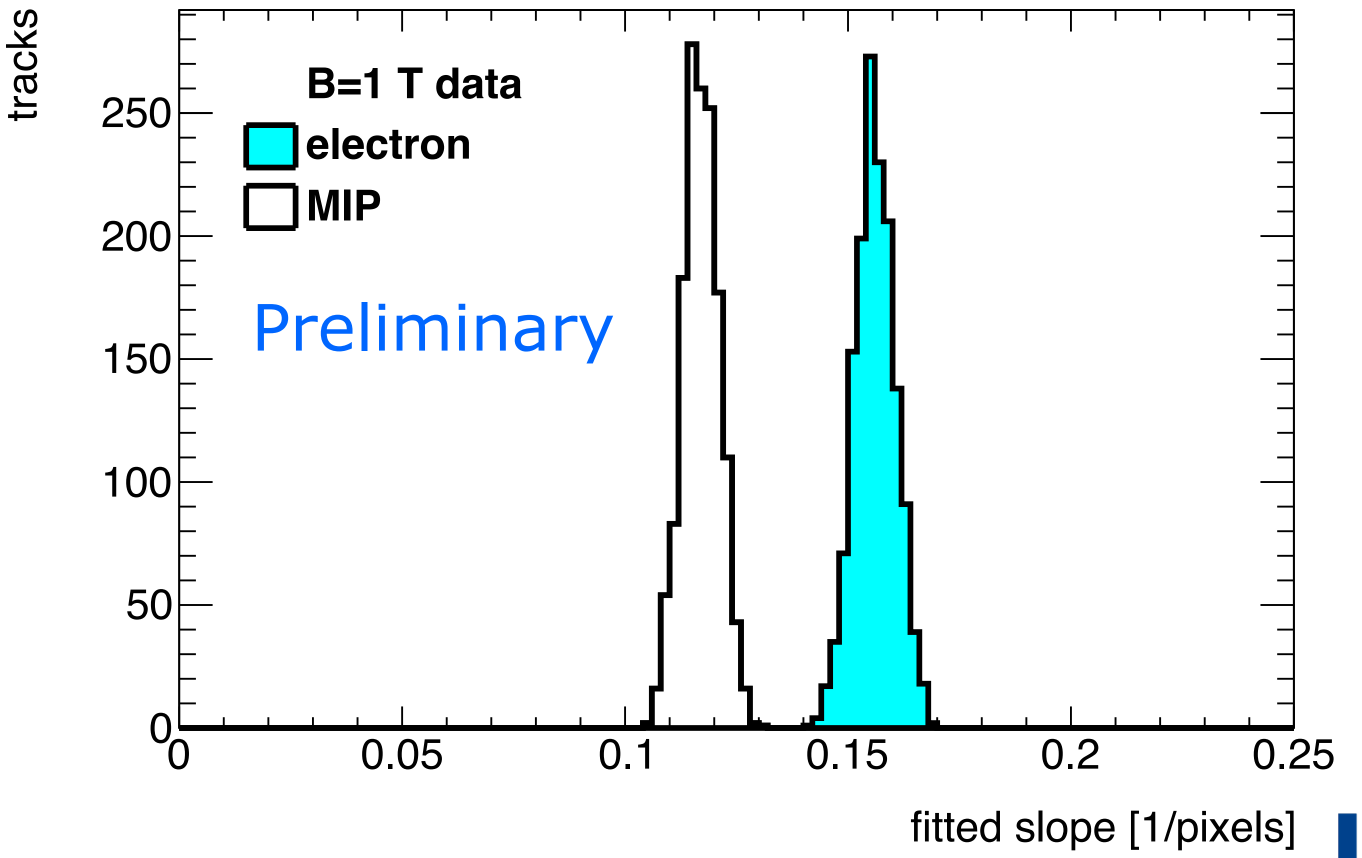
MIP in plot was corrected …
thanks Ulli

DESY testbeam Module Analysis

PID performance template fit method

Electron resolution 2.9%
1 m track 60% and coverage
Linearity MIP-e = 1.07

so syst uncertainty on resolution +7%



DESY testbeam Module Analysis

PID performance of a Pixel TPC

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

Preliminary

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

The truncation method has a slightly worse performance – as it is more sensitive to the hits than the template fit method – that is more sensitive to the number of clusters.

DESY testbeam Module Analysis

PID Performance extrapolated to the ILD detector

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

Template fit (Truncation)
electron resolution
2.9 (3.6)%

1 m track 60% and
coverage

ILD detector

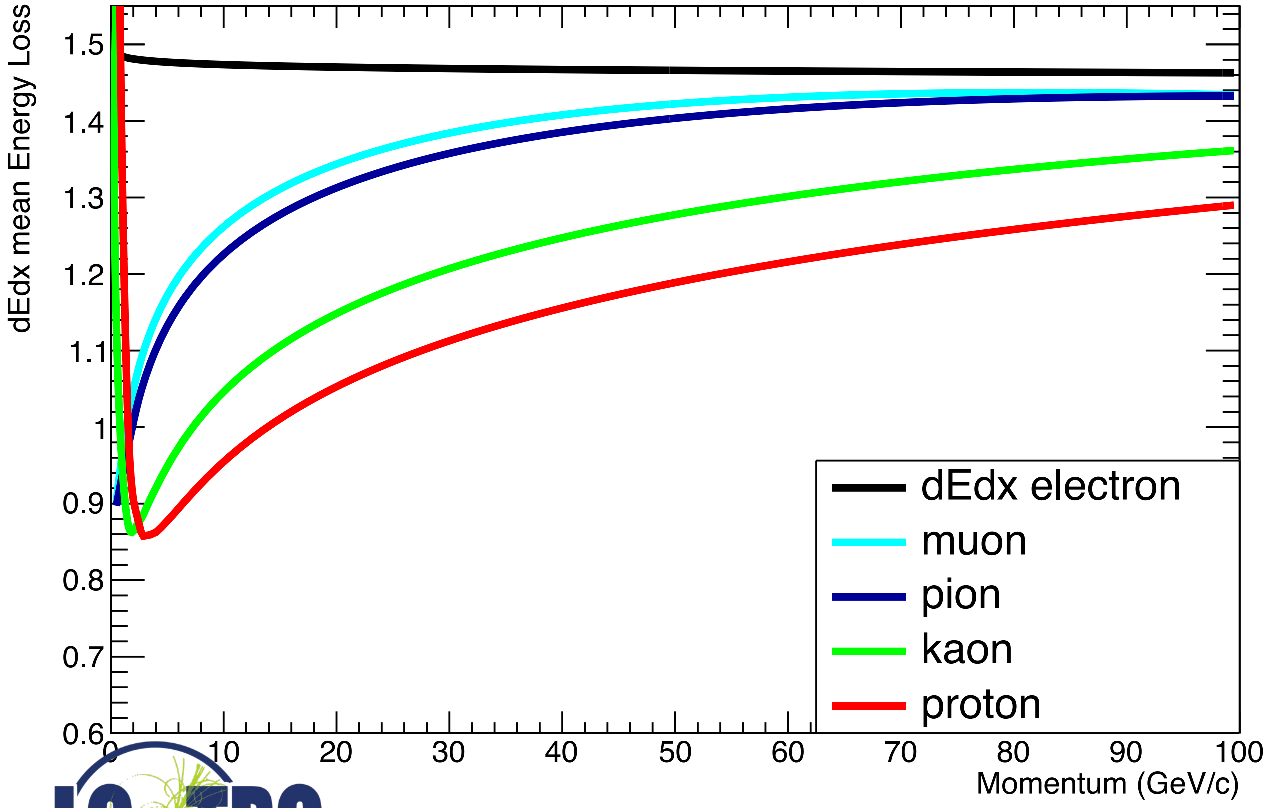
rInner = 329 rOuter = 1770 mm

electron resolution = 2.4 (3.0) %
at $\theta=\pi/2$

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

DESY testbeam Module Analysis

ILD dEdx performance



- From dEdx studies in ILD (Ullrich Einhaus)
- Extracted the ILC soft parametrisations for energy loss based on G4 and full simulation of the ILC TPC with T2K gas
- Link generated in 2020 with ILC soft v02-02 and v02-02-01

DESY testbeam Module Analysis

ILD Pixel TPC PID performance

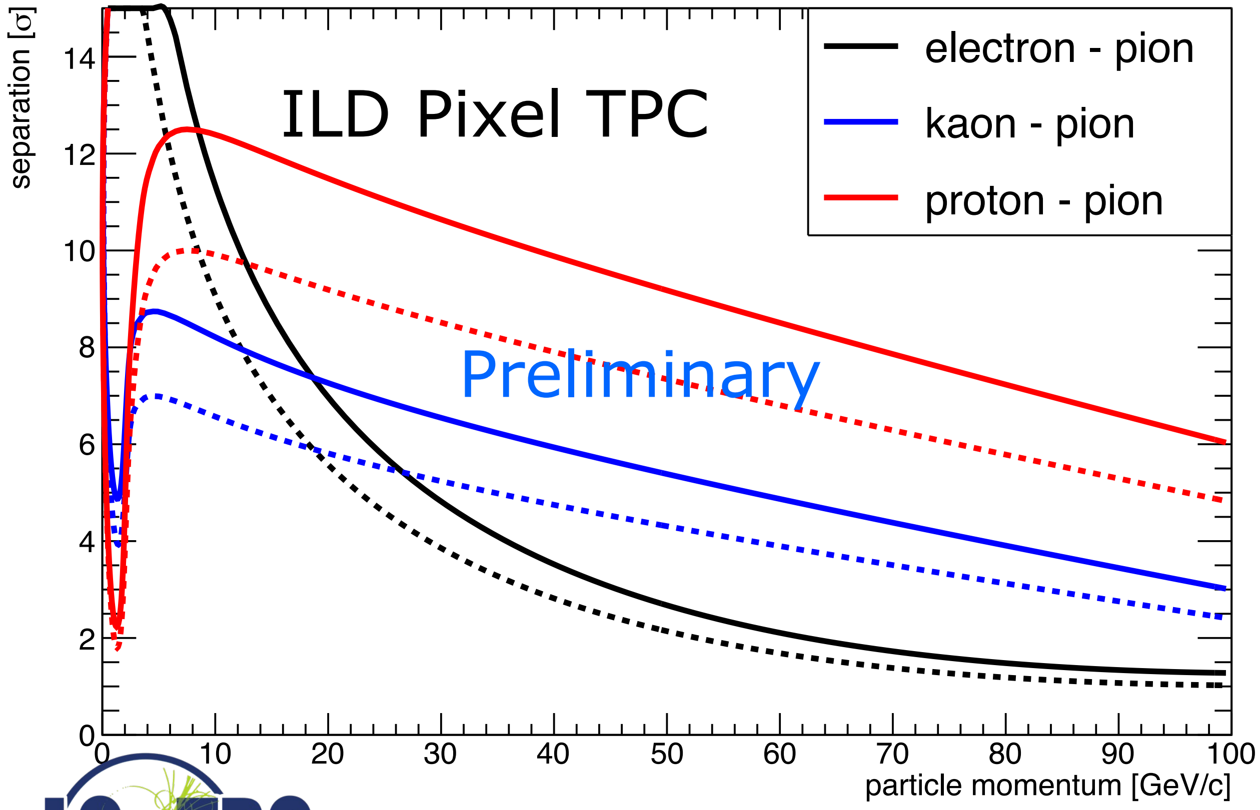
- ILD PID performance is evaluated using the ILD dEdx parametrisation
- For an ILD detecor with

rInner = 329 rOuter = 1770 mm
zMax = 2350 mm // half length

- The truncation and template fit method results at B = 1T for the electrons are used as resp. worse and best scenarios
- The performance plots assume cos $\theta = 0$ and the PID resolution scales as:
  $1/\sqrt{\text{track length} \ < \text{Eloss} >}$
- The separation between electrons, kaons, protons and pions is defined as
  $|<\text{Eloss } e,K,p> - <\text{Eloss } \pi>| \;/\; \sigma_{\pi}$

DESY testbeam Module Analysis

ILD pixel TPC PID performance



- ILD PID Performance for the two methods: template fit (solid), truncation (dashed)
- The expected pion-kaon PID separation for momenta in the range of 2.5-45 GeV/c at cos θ = 0 is more than 5.5(4.5)σ
- At a momentum of 100 GeV/c the separation is still 3.0(2.0)σ
- The expected pion-proton PID separation for momenta in the range of 2.5-100 GeV/c at cos θ = 0 is more than 6.0(4.8)σ

DESY testbeam Module Analysis

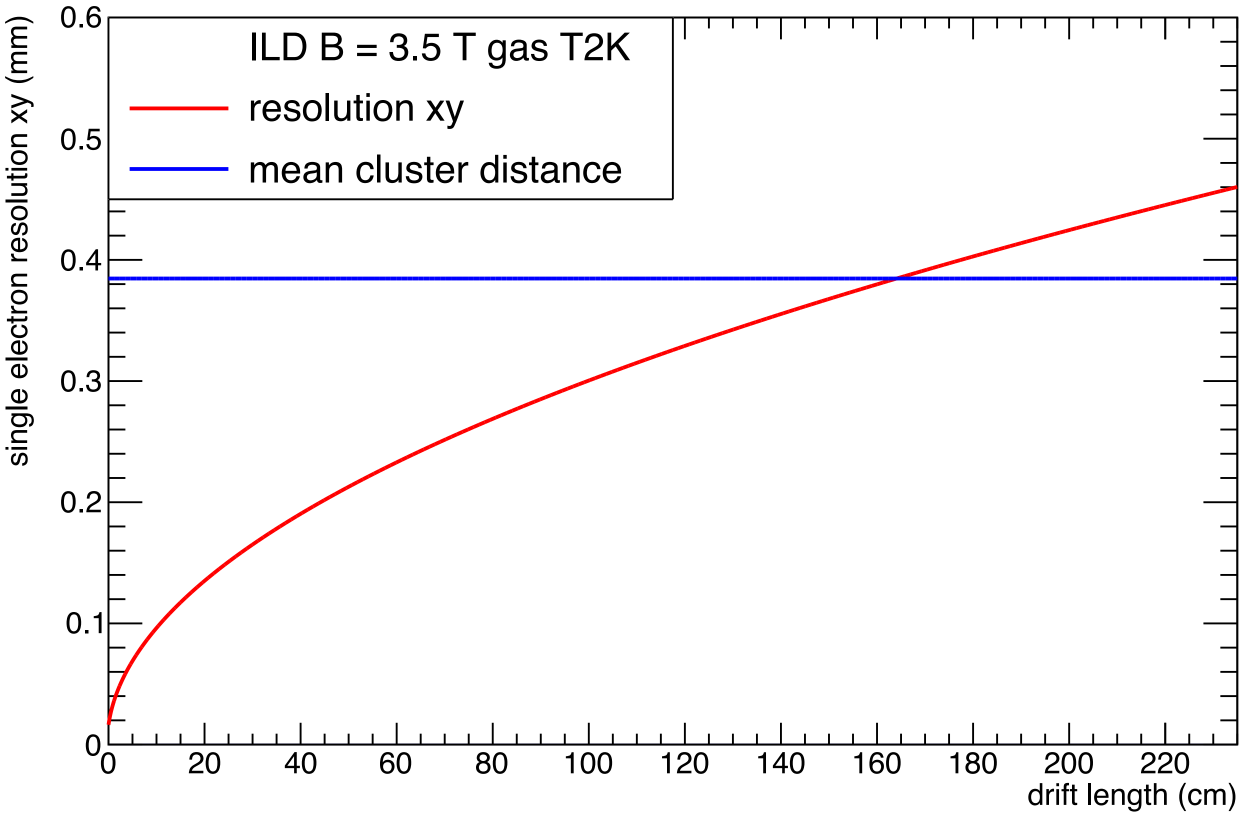
ILD pixel TPC PID performance as a function of the drift distance

- Question from Ron Settles (and also Ulrich Einhaus);
- Can one quantify what the impact of the longer drift is on the PID performance for the two mehods?
- One can analyse and quantify this by looking at the extremes
  - Ideal cluster counting that is possible if no diffusion is present
  - Truncation method that gives the performance for long drift distances
- First, concerning the ideal cluster counting
  - In the extrapolation a 60% Pixel TPC coverage is assumed
  - Note that per cm (100% in the senstive volume) we will have 26 primary clusters out of in total 100 single electrons

PDG clusters/cm	primary	total
T2K	26	100

DESY testbeam Module Analysis

ILD pixel TPC PID performance as a function of the drift distance



$D_T = 30\ \mu m/\sqrt{cm}$

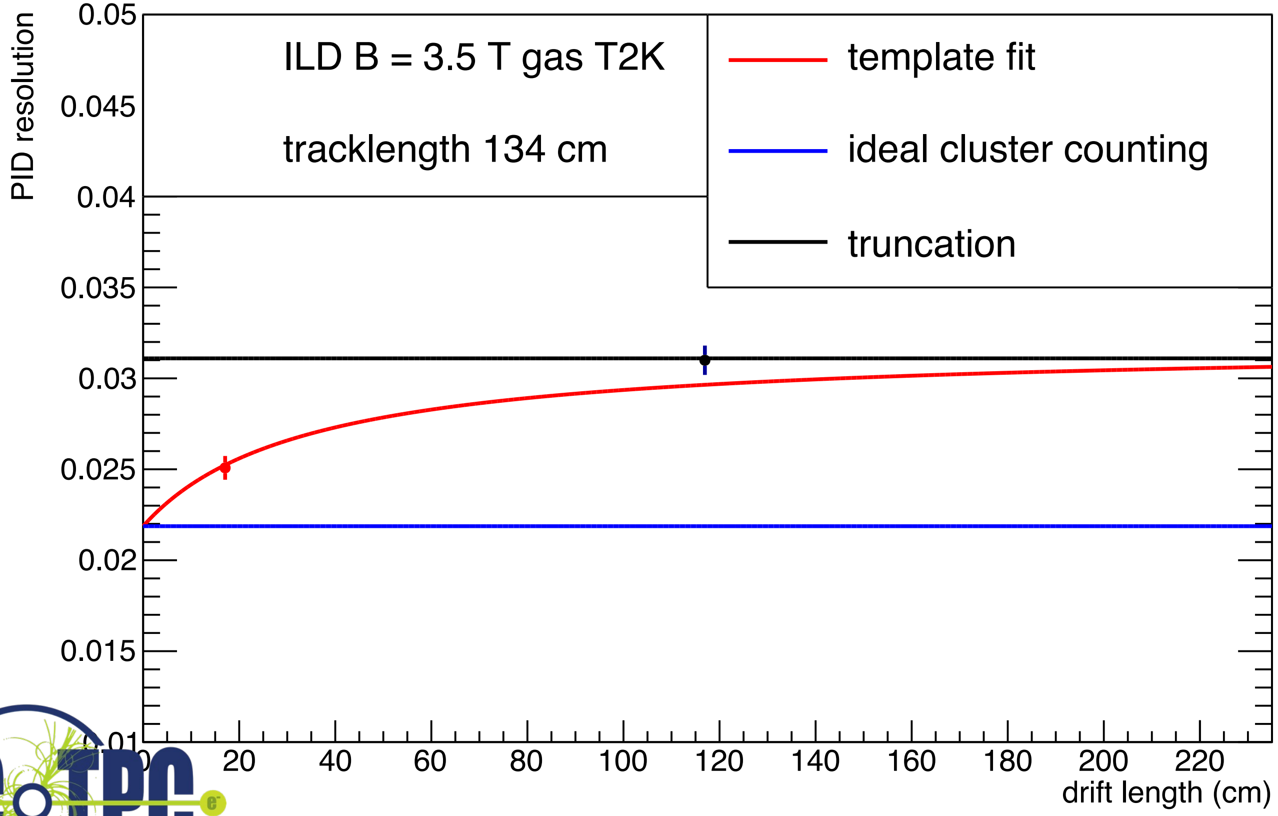
From the plot one can understand that one can do (some) cluster counting.

The mean electron distance assuming full smearing (long drift) is about 100 μm

DESY testbeam Module Analysis

ILD pixel TPC PID performance as a function of the drift distance

$D_T = 30\ \mu m/\sqrt{cm}$



Ideal cluster counting with 60% pixel coverage gives a PID resolution 2.2%.

The truncation method gives is the other extreme of 3.1%

The red curve is an interpolation based on the template fit method
The red point is corresponds to the testbeam single electron resolution 130 μm and a PID resolution of 2.5%

Running a Pixel TPC with Ne

For example Z run @ CEPC or FCCee

The idea is use in the TPC not the T2K gas. But another gas mixture that gives less hits. And a gas that is less sensitive to the beam background and more performant for dEdx (cluster counting)

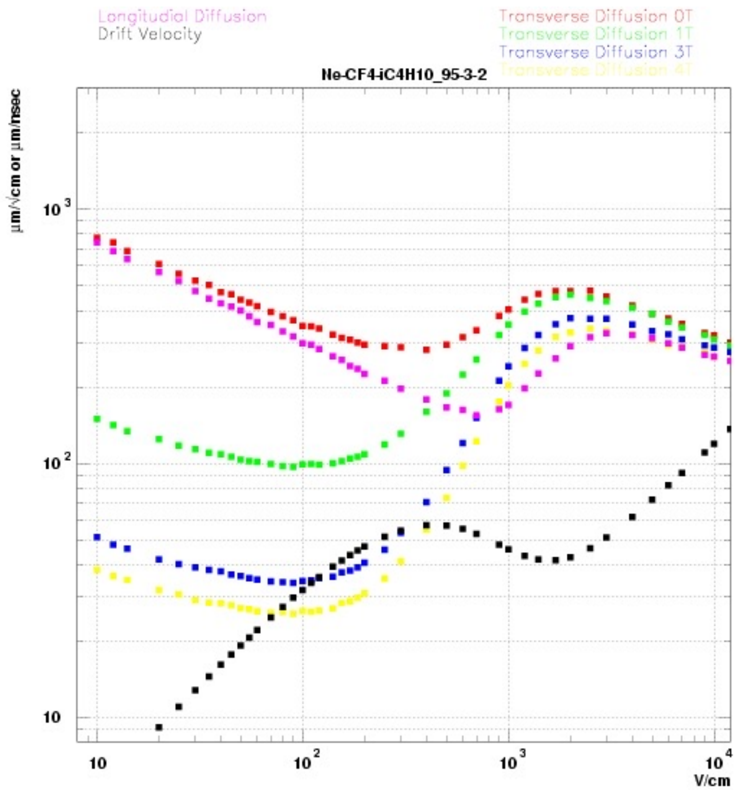
One could think of a Ne based gas.

- The advantage would be: the number of electrons /cm is lower by a factor of about 2.5 w.r.t. the T2K gas. The probability that the photons (from the beam-beam background) interact with Neon is also a factor of 5 lower.
- I am not absolutely sure but this could bring a factor 12.5 beam background reduction.

Running a Pixel TPC with Ne

For example Z run @ CEPC or FCCee

We could e.g. run with the Neon version of T2K gas: Ne:CF4:iCH4H10 95:3:2 and still reach low transverse diffusion: of about $D_T = 70\ \mu m/\sqrt{cm}$ at 2 T. Drift field 200 V/cm. Or $D_T = 30\ \mu m/\sqrt{cm}$ at 3.5 T

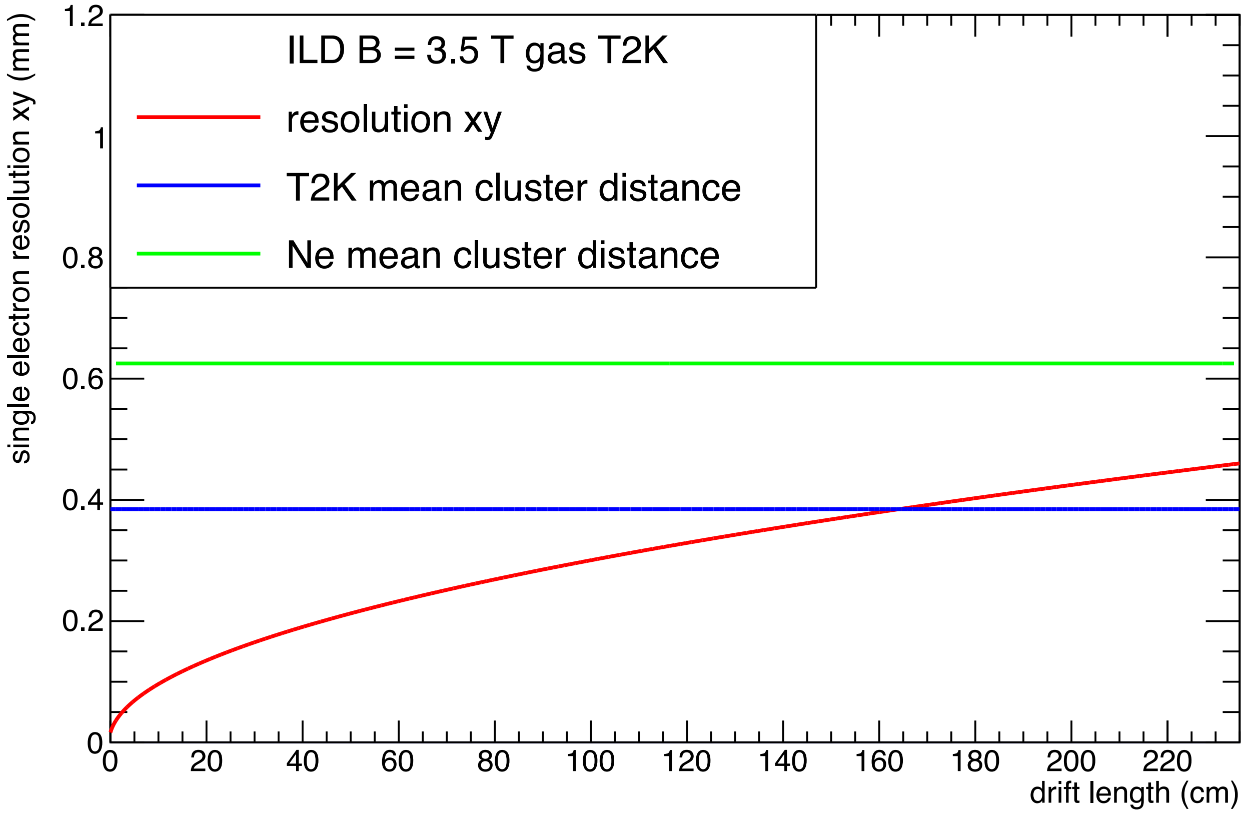


PDG clusters/cm	primary	total
Ne:CF4:iCH4	16.04	46
T2K	26	100

The disadvantage would be a TPC tracking resolution that is a factor 1.47 worse (than running with T2K).

Running a Pixel TPC with Ne

For example Z run @ CEPC or FCCee

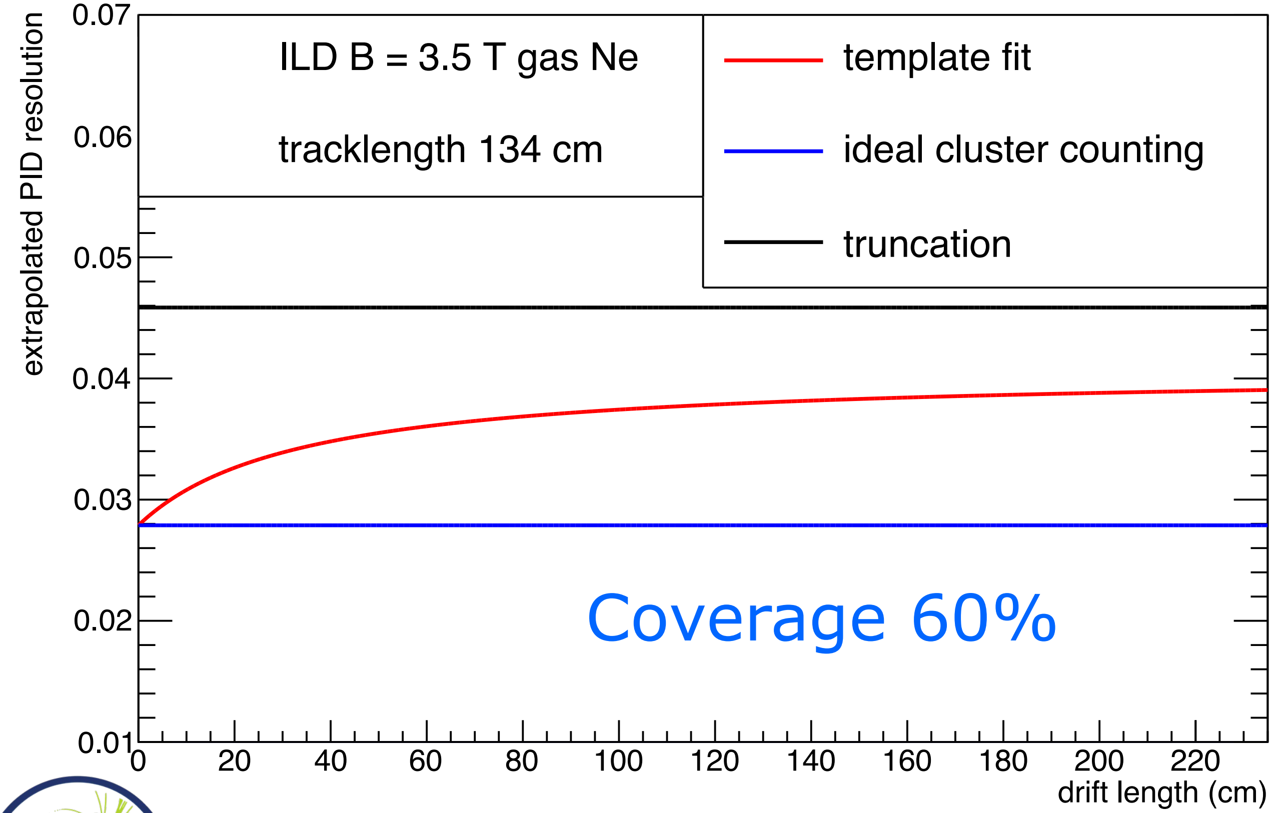


A clear advantage of Neon is the larger mean cluster distance and the lower number of electrons/cluster.

That makes it more suited for cluster counting in a Pixel TPC

Running a Pixel TPC with Ne

PID performance



A conservative extrapolation:

For truncation the resolution is scaled with the $1/\sqrt{N_{tot}}$
NB we know that the fluctuations in Neon will be smaller
For *ideal cluster* counting this is the best one can achieve.
For the template fit the function is scaled by $1/\sqrt{N_{clusters}}$
NB It is expected that the template fit will perform much better and come closer to the ideal cc curve

Running a Pixel TPC with Ne or Ar

For example Z run @ CEPC or FCCee

- The beam backgrounds for a Pixel TPC running `Ne:CF4:iCH4 95:3:2` are likely a factor 12.5 lower than running with the default T2K gas
  - It would be nice to have this confirmed/studied by D. Jeans
  - It is important for the Z running in view of limiting occupancies and distortions (due to the ion back flow)
- The price is a worse TPC tracking resolution at high momenta with a factor of about 1.5. For low momenta the track is less scattered in the Ne than in the Ar based gas. Note that in the ILD experiment the overall momentum resolution will be almost unaffected due to contribution of the Inner and Outer silicon trackers.
- A conservative extrapolation gives a PID resolution of 2.8-4% for Ne based gas in a Pixel TPC inside ILD at cos $\theta=0$ assuming 60% coverage. This can compared to the ILD PID resolution result of 2.5-3% for the T2K gas.
- It would be nice to take some test beam data with B field and this gas