Addendum 2025 to the LCTPC MoA

Status of TPC Preparations for an e^+e^-Collider

The LCTPC Memorandum of Agreement (MoA), the groups which have signed it and the yearly Addenda are available at http://www.lctpc.org/e9/e56939/. The MoA was revised in 2016 and can be found at the above link. Updates in the collaboration are documented in the yearly Addenda.

The activities since reported in the Addendum 2023-24 consisted of regular workpackage meetings, but no new test-beam measurements. The Addendum 2023-24 at http://www.lctpc.org/e9/e56939/ also gives a brief history the organization of the LCTPC collaboration; **these have not changed so need not be repeated this year**.

In addition in the Addendum relates developments toward the next collider that have taken place up to now. A few of this year's recent or upcoming events are:
LC Vision Workshop 8-10Jan2025 at CERN https://indico.cern.ch/e/lcvision2025
Cold Copper Accelerator Technologies and Applications Workshop at Duke University on 13-14Jan2025 https://indico.slac.stanford.edu/event/9387
US Higgs Factory Workshop at Fermilab on 15-16Jan2025
Higgs Factory Coordination Consortium for Accelerators https://indico.fnal.gov/event/67453
Vienna Conference on Instrumentation https://vci2025.hephy.at
European Strategy foron Particle Physics https://europeanstrategy.cern

Executive Summary

A summary of what has been learned after two decades of R&D:
–the MWPC option ruled out,
–the resistive-anode charge-dispersion technique demonstrated,
–the MicroMegas option without resistive anode ruled out,
–gas properties well measured and the best drift-gas selected,
–the best possible point and momentum resolution achieved,
–reliable assemblies of GEM-modules and MicroMegas-modules developed,
–CMOS pixel RO technology successfully demonstrated,
–the dE/dx and dN/dx resolutions measured,
–gating device developed,
–two-phase CO2 cooling verified.

Therefore the baseline options are MicroMegas with resistive anode and standard electronics, GEM with standard electronics, and Pixel (= MicroMegas integrated on a Timepix chip).

The ILD collaboration simulated the physics performance of two versions for the detector: a "large" version with 1777 mm TPC outer radius and 3.5T B-field (the standard used up to now) and a "small" version with 1427 mm TPC outer radius and 4T B-field. Simulations showed that the large one, listed here, performs somewhat better. The CEPC (https://arXiv.org/abs/2203.09451) collider also has a detector option with TPC as central detector. Both are in the table: the parameters are for the ILD TPC; the performance similar for both. The detector for the FCC-ee is under study. [1] [2]

It is seen that digital option of a Pixel TPC gives the best performance, and should be the goal of future R&D in order to find and solve any problems.

[3] . [4] [5] [6] [7]

[1]e.g. *TPC RD for circular colliders* Talk by Paul Colas on 20250114 at the '8th FCC Physics Workshop at CERN' https://indico.cern.ch/event/1439509/

[2]e.g. *Talk by Daniel Jeans on 20241218 https://agenda.linearcollider.org/event/10557/contributions/56005/ attachments/40138/63634/TPC-BG-update-ild-swana-dec2024.pdf*

[3]The momentum resolution is proportiontal to 1/B according to Gluckstern's formula.(*see: R. L. Gluckstern, NIMA 24 (1963) 381-389*). At a B-field of 2T for Z-peak running for CEPC and FCC-ee, the momentum resolution is therefore 3.5/2 (4/2) times the value in the Table, i.e., 1.75 (2) $\times 10^{-4}$/GeV/c (TPC only) and *1.4 $\times$ 10^{-4}/GeV/c (60% cov, TPC only)*

[4]The point resolution, 0.1 mm was assumed to be the same for GEM and MicroMegas. The value for the pixel option was assumed to be 0.055mm/$\sqrt{12}$ for zero drift and 0.4mm for maximum drift: see page 7 of talk at the ILCX2021 workshop https://agenda.linearcollider.org/event/9211/contributions/58794/attachments/37527/58794/ILCX_pixelTPC_2021.pdf.

[5]For the effective track length 43.1mm has been added to the inner radius and 73.1mm subtracted from the outer radius, in order to account for fieldcages, mechanics and services.

[6]The overal tracking resolution (including silicon tracking) is $\simeq 2 \times 10^{-5}$.

[7]This dE/dx and dN/dx calculation is a back-of-the-envelope approximation, (Peter Kluit's presentation at https://agenda.linearcollider.org/event/10286/ shows realistic estimates for the pixel version) the assumption for the pixel TPC is that a track travels from the inner radius at the middle of the TPC ($r, \phi, z \simeq 429mm, \phi = K(constant), 0mm$) to the outer radius near the endcap ($r, \phi, z \simeq 1700mm(large), \phi = K, 2200mm$), ($r, \phi, z \simeq 1300mm(small), \phi = K, 2200mm$), that three-fourths to one-half of the track length ($ld \equiv$ long drift) uses the standard dE/dx (truncated mean) estimation with a resolution of $\sigma_{ld} \simeq 5$ %. and that one-fourth to one-half ($sd \equiv$ short drift) uses cluster counting with a resolution of $\sigma_{sd} \simeq 3$ %. The weighted mean is calculated with weights $\frac{1}{{\sigma_{ld}}^2}$ and $\frac{1}{{\sigma_{ld}}^2}$ for the ld and sd, respectively. The two errors are combined in the standard way: $\frac{1}{{\sigma_{hypotheticaltrack}}^2} = \frac{1}{{\sigma_{ld}}^2} + \frac{1}{{\sigma_{sd}}^2}$.

Table. ILD TPC and CEPC TPC for pad/*pixel* electronics.

Parameters are for the ILD TPC; the performance similar for both.

Parameter	
B-field	3.5T
Geometrical parameters	r_{in} r_{out} z 329 mm 1777 mm ± 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
Number of pixels/timebuckets	$\simeq$ *$10^9/1000$ per endcap*
Pad pitch/ no.padrows	$\simeq 1\times 6$ mm^2 / 220
σ_{point} in $r\phi$	$\simeq$ 60 μm for zero drift, $<$ 100 μm overall
σ_{point} *in* $r\phi$	$\simeq$ *0.055mm/$\sqrt{12}$ for zero drift,0.4mm for max drift*
σ_{point} in rz	$\simeq 0.4 - 1.4$ mm (for zero – full drift)
2-hit separation in $r\phi$	$\simeq$ 2 mm
2-hit separation in rz	$\simeq$ 6 mm
dE/dx,dN/dx resolution	$\simeq$ 5 %
dE/dx,dN/dx resolution	$\simeq$ *4 %*
Momentum resolution at B=3.5 T	$\delta(1/p_t) \simeq 1\times10^{-4}$/GeV/c (TPC only)
Momentum resolution at B=3.5 T	$\delta(1/p_t) \simeq$ *0.8× 10^{-4}/GeV/c (60% cov, TPC only)*