DRAFT 20210111

Addendum 2020 to the LCTPC MoA: Preparing for the LC

Overview

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. Evolution of the collaboration, of the work-package structure and of responsible persons are updated in the yearly Addenda.

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1 2020 Activities

As described in the MoA, the R&D preparation of the LCTPC is proceeding in three phases: **1**-Small Prototypes, **2**-Large Prototypes and **3**-Design. Presently the work is mainly in phase **2**, and will pass to phase **3** during the 'ILC Pre-Lab' preparations (see Sec.1.3 below).

1.1 The ILD LOI, the DBD and the IDR

The International Large Detector (ILD) Letter of Intent (LOI) was validated in 2009 and was followed by the Detailed Baseline Design (DBD) of the detector in 2013. The latter was the result of more understanding being put into the detector and its engineering. The Technical Design Report (TDR) of the International Linear Collider (ILC) accelerator, also completed in 2013, and the DBD were combined into one document: see https://arxiv.org/abs/1306.6327.

The ILD Interim Design Report (IDR),see https://arXiv:2003.01116 [physics.ins-det] 2 Mar 2020, was produced in order to compile the lastest infromation about the physics potential, the subdetector R&D, the machine-detector interface and the costing.

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1.2 The LC

The LCTPC properties were originally developed for the Tesla linear collider project and after that for the ILC (0.2-1.0 TeV with superconducting cavities). Other projects are also studying the possibility of employing a TPC as one of their subdetectors are welcome to profit from the information accumulated by the LCTPC collaboration.[1]

The ILC planning to be built in Japan is progressing well. It is envisaged to be staged: The first stage, at ∼250 GeV (precision measurements of the Higgs and related quantities to find indications of Beyond-the-Standard-Model (BSM) physics, is expected to last about a decade. With additional funding, the machine could be upgraded to stages at ∼350 GeV to ∼1000 GeV for further precision measurements of the top quark, gauge-boson couplings, Higgs self-coupling, and search for BSM. In addition, the 'Giga-Z' measurement, in which 10^9 Z-bosons are produced at the Z-peak with polarized beams, is under serious study by machine and detector physicists. Progress is regularly reported in the 'LC Newsline' http://newsline.linearcollider.org.

The collaboration and leadership, the international 'Linear Collider Collaboration' (LCC) with oversight committee 'Linear Collider Board' (LCB), were established to guide the efforts of the ILC, an arrangement that was approved by ICFA (International Committee for Future Accelerators).

[1] e.g.,http://cepc.ihep.ac.cn

1.3 The ILC International Development Team (IDT)

On August 2, 2020, ICFA announced the replacement of the LCC and LCB by the IDT as the first step towards the preparatory phase of the ILC project,with a mandate to make preparations for the ILC Pre-Lab in Japan. See https://icfa.fnal.gov/wp-content/uploads/ICFA_Stateme¡nt_August_2020.pdf for the ICFA statement.

2 Responsibilities 2020

Present groups and **Collaboration Board members** are:

2.1 Collaboration Board (CB) – Table 1

–Americas–	
Carleton/Triumf:	**Madhu Dixit** msd@physics.carleton.ca
Carleton U:	**Alain Bellerive** alainb@physics.carleton.ca
Victoria:	**Dean Karlen** karlen@uvic.ca
BNL:	**Alexei Lebedev** alebedev@bnl.gov
–Asia———-	
Tsinghua:	**Zhi Deng** dengz@mail.tsinghua.edu.cn
IHEP:	**Huirong Qi** qihr@ihep.ac.cn
Saha Kolkata:	**Supratik Mukhopadhyay** supratik.mukhopadhyay@saha.ac.in
Hiroshima:	**Tohru Takahashi** tohru-takahashi@hiroshima-u.ac.jp
Iwate:	**Shinya Narita** narita@iwate-u.ac.jp
KEK:	**Keisuke Fujii** keisuke.fujii@kek.jp
Kindai:	**Yukihiro Kato** katoy@hep.kindai.ac.jp
Saga:	**Akira Sugiyama** sugiyama@cc.saga-u.ac.jp
Kogakuin:	**Takashi Watanabe** takashi.watanabe@map.kogakuin.ac.jp
Nagasaki Inst AS:	**Ken Oyama** oyama_ken@nias.as.jp
–Europe———-	
Inter U Inst for HEP(ULB-VUB):	**Gilles De Lentdecker** gilles.de.lentdecker@ulb.ac.be
CEA Saclay:	**Paul Colas** paul.colas@cea.fr
Bonn:	**Jochen Kaminski/Klaus Desch** kaminski@physik.uni-bonn.de/desch@physik.uni-bonn.de
DESY/HH:	**Ties Behnke** ties.behnke@desy.de
Kiev:	**Oleg Bezshyyko** obezsh@gmail.com
MPI-Munich:	**Ron Settles** settles@mpp.mpg.de
Siegen:	**Ivor Fleck** fleck@hep.physik.uni-siegen.de
Nikhef:	**Peter Kluit** p.kluit@nikhef.nl
Lund:	**Leif Jönsson** leif.jonsson@hep.lu.se
CERN:	**Michael Hauschild/Lucie Linsen** michael.hauschild@cern.ch/lucie.linssen@cern.ch

2.2 Observers

'Observers' are groups or persons that could not sign the MoA but are being informed as to the progress, thus are included in the lctpc mailing list. Change of status from 'collaboration member' to 'observer' is possible and has taken place several times.

Observer groups (collaboration members which changed status in bold):
Rostock, Aachen, Cornell, Indiana, Montreal, MIT, Purdue, Stony Brook, Yale, LBNL, Louisiana Tech, U Tokyo, **Tokyo U A & T,** Mindanao, **LAL Orsay/IPN Orsay, Novosibirsk,** TU Munich, Freiburg, Karlsruhe, UMM Krakow, Bucharest, St.Petersburg.

2.3 New groups

The LCTPC collaboration (http://www.lctpc.org) is open to all, and a group wishing to join should contact us.

3 Further LCTPC Collaboration Information

3.1 Regional Coordinators (RC)

The RCs for 2007-2020 after selection of candidates in each region were elected by the CB members of the respective region. Previous RCs were
–Americas: **Dean Karlen** in 2007-10,
Alain Bellerive in 2011 to present.
–Asia: **Takeshi Matsuda** in 2007-09,
Akira Sugiyama in 2010 to present.
–Europe: **Ron Settles** in 2007,
Jan Timmermans in 2008-11,
Jochen Kaminski in 2012 to present.

Spokesperson selection: The RCs do not to have a predetermined rotation of RCs as their chairperson and spokesperson for the collaboration; he/she will be chosen by the RCs. Ron Settles had this function in 2007, and Jan Timmermans was elected as Chairperson/Spokesperson for 2008-11. Jochen Kaminski was chosen by the RCs as the Spokesperson for the following years up to present.

3.1.1 CB Chair

In 2009, the Collaboration Board decided that each year it will appoint one member to chair its meetings. Leif Jönsson agreed to chair the CB meetings in 2012-15, and was reappointed for this task in 2016-2018. Ivor Fleck replaced him in 2018.

3.1.2 Editorial Board (EB)

The purpose of the EB is to approve publications of the collaboration.

The EB is presently made up of: Alain Bellerive, Ties Behnke, Madhu Dixit, Takahiro Fusayasu, Keisuke Fujii, Leif Jönsson, Jochen Kaminski, Takeshi Matsuda, Ron Settles, Akira Sugiyama and Jan Timmermans. Takahiro Fusayasu has agreed to chair the EB in 2016 to present.

3.1.3 Speakers Bureau

The speakers bureau, installed in 2009 by the CB to monitor the LCTPC presentations at major conferences, is made up of the the three regional coordinators and one additional person per region. The RCs in 2009 were Jan Timmermans, Takeshi Matsuda and Dean Karlen; the persons per region were Paul Colas as chair up to December 2010, Yuanning Gao and Dan Peterson. The RCs that followed were Jochen Kaminski, Akira Sugiyama and Alain Bellerive and the regional persons were Jan Timmermans, Yulan Li and Dan Peterson in 2011-13; David Attie replaced Jan Timmermans in 2014. Dan Peterson chaired the meetings in 2012, Allain Bellerive for one year starting mid-2013, followed by David Attie mid-2014. Serguei Ganjour was chair in 2018-2019. Maxim Titov (maxim.titov@cea.fr) took over in 2020.

3.2 Technical Board (TB)

There were four original workpackages in the MoA (WP(1) Mechanics, WP(2) Electronics, WP(3) Software, WP(4) Calibration) which were supplemented by a fifth workpackage (WP(5) Coordination) in 2010 to prepare for the DBD; with the DBD finished, WP(5) will now oversee the R&D.

In general, the WP(1)-WP(4) structure was utilized at the beginning of the LCTPC collaboration, with individual workpackages meetings to discuss their issues. The structure is out-of-date now and is repeated here for historical completeness. Therefore the ‘conveners’ will be referred to as ‘contacts’.

There are bi-weekly meetings which include all workpackages convened by the collaboration spokesperson Jochen Kaminski. There are also regular meetings of the Asian groups and of the pixel groups.

The **TB members**, the ‘contacts’ for the workpackages and their email addresses, and the groups involved:

Table 2

Workpackage	→ Groups involved **Contact**
Workpackage(0) TPC R&D Program	LCTPC collaboration
Workpackage(1) Mechanics	
a) LP endplate design and	→ Cornell,Bonn, Desy/HH,Japan/China,MPI,Saclay up to 2017 **Dan Peterson** daniel.peterson@cornell.edu
Fieldcage development	→BNL,Desy/HH **Ties Behnke** ties.behnke@desy.de
b) GEM panels for endplate	→Bonn,Desy/HH,Japan/China **Akira Sugiyama** sugiyama@cc.saga-u.ac.jp
c) MicroMegas panels for endplate	→Carleton,IHEP,SahaKolkata,Saclay **Paul Colas** paul.colas@cea.fr
d) Pixel panels for endplate	→Bonn,Nikhef,Saclay **Jan Timmermans** jan.timmermans@nikhef.nl
e) Resistive anode for endplate	→Carleton,SahaKolkata,Saclay **Madhu Dixit** msd@physics.carleton.ca
Workpackage(2) Electronics	
a) Standard RO for the LP	→ Brussels,Cern,Desy/HH,Lund **Leif Jönsson** leif.jonsson@hep.lu.se
b) CMOS RO electronics	→ Bonn,Nikhef,Saclay **Harry van der Graaf** vdgraaf@nikhef.nl
c) Standard electronics for LCTPC	→ Brussels,Desy/HH,Lund, up to 2010 **Luciano Musa** luciano.musa@cern.ch
Workpackage(3) Software	
a) LP software/simulation/reconstruction	→ Bonn,Cern,Desy/HH,Victoria up to 2014 **Astrid Muennich** astrid.muennich@desy.de
b) LP DAQ	→Brussels,Lund **Gilles De Lentdecker** gilles.de.lentdecker@ulb.ac.be
c) LCTPC performance/backgrounds	→ Bonn,Carleton,Cern,Desy/HH,Japan/China **Keisuke Fujii** keisuke.fujii@kek.jp
Workpackage(4) Calibration	
a) Field map for the LP	→ Cern,Desy/HH **Lucie Linsen** lucie.linssen@cern.ch
b) Alignment	→ Cern,Desy/HH,Nikhef,JapaneseGroups **Takeshi Matsuda** takeshi.matsuda@kek.jp
c) Distortion correction	→ Desy/HH,MPI,JapenseGroups,Nikhef,Victoria **Dean Karlen** karlen@uvic.ca
d) Gas/HV/Infrastructure for the LP	→ Desy/HH,Saclay **Ralf Diener** ralf.diener@desy.de

WP(5) Coordination of LCTPC R&D

a) Advanced endcap and fieldcage	→ Desy/HH,Japan/China,MPI,Saclay
	Ties Behnke ties.behnke@desy.de
b) Advanced endcap/Electronics development	→Cern,Japan/China,Lund,Nikhef,Saclay
	Anders Oskarsson anders.oskarsson@hep.lu.se
	Leif Jönsson leif.jonsson@hep.lu.se
	up to 2010 **Luciano Musa** luciano.musa@cern.ch
	2011 **Eric Delagnes** eric.delagnes@cea.fr
Advanced endcap/power pulsing/cooling	→Desy,Japan/China,Lund,Nikhef,Saclay
	Takahiro Fusayasu fusayasu@cc.saga-u.ac.jp
c) Gating device	→ JapeneseGroups
	Akira Sugiyama sugiyama@cc.saga-u.ac.jp
d) ILD TPC Integration/Mach-Det Interface	→ Desy/HH,MPI,Saclay
	Volker Prahl volker.prahl@desy.de
	Ron Settles settles@mpp.mpg.de
e) ILD Contacts	
	Paul Colas paul.colas@cea.fr
	Akira Sugiyama sugiyama@cc.saga-u.ac.jp
f) LCTPC Software/Correction methods	→Bonn,Carleton,Desy/HH,JapaneseGroups
	up to 2014 **Astrid Muennich** astrid.muennich@desy.de
	from 2018 analysis coordinators **Paul Colas** paul.colas@cea.fr
	and **Peter Kluit** p.kluit@nikhef.nl
	from 2018 MarlinTPC coordinator **Oliver Schaefer** oliver.schaefer@desy.de
g) Pixel-Module Development	→Bonn,Carleton,Nikhef,Saclay
	up to 2015 **Michael Lupberger** michael.lupberger@cern.ch
	Jochen Kaminski kaminski@physik.uni-bonn.de
	from 2018 **Peter Kluit** p.kluit@nikhef.nl.
h) Testbeam	→ all groups
	Ralf Diener ralf.diener@desy.de
Lykoris	→ Desy/HH
	Uwe Krämer uwe.kraemer@desy.de
	Mengqing Wu mengqing.wu@desy.de

4 Future R&D, the LP and SPs

4.1 What has been learned

As written in Section 1, the R&D is proceeding in three phases: (1) Small Prototypes–SP, (2) Large Prototypes–LP and (3) Design.

Up to now during Phase(1), a summary of what has been learned:
–the MWPC option has been ruled out,
–the resistive-anode charge-dispersion technique was demonstrated,
–the MicroMegas option without resistive anode has been ruled out,
–gas properties have been well measured and the best drift-gas selected,
–many years of MPGD experience gathered,
–the best possible point resolution achieved,
–reliable assemblies of GEM-modules and MicroMegas-modules have been developed,
–CMOS pixel RO technology has been demonstrated and is being developed,
–the dE/dx resolution has been confirmed,
–design of the gating device has been successful.

Therefore the baseline options are MicroMegas with resistive anode with standard electronics, or GEM with standard electronics, or the pixel TPC (= MicroMegas integrated on a pixel chip).

The Phase(2) LP and SP tests are expected to continue and will be followed by Phase(3), the design of the LCTPC. A scenario for Phase(2) options is presented below in Table 3 which will be readjusted as the situation progresses.

4.2 Review of the ILD TPC R&D

The TPC R&D program and status has been reviewed several times, most recently by the ECFA Panel at Desy on Nov.4, 2013, at which the TPC gave a complete update of the situation. The Review Report is available as LC Note LC-DET-2014-001
at http://www-flc.desy.de/lcnotes.

4.2.1 2014 - 2020

Scenarios for the preliminary, improved and 'final' stages of R&D at the LP are summarized in the Table 3. Supplemental testing with SPs, which have been used extensively to date by the LCTPC collaboration (Section 4.1), may continue since there are still many issues which can be explored more efficiently using small, specialized set-ups.

Table 3		Scenarios, updated August 2020
		Large Prototype R&D
Device	Lab(years)	Configuration
Preliminary	Desy(2013-15)	Fieldcage⊕first endplates: GEM, MicroMegas, or pixel
Purpose: Test construction techniques using ∼10000 pad read-out channels to demonstrate measurement of the Desy test-beam or cosmics over 70cm tracklength, including development of correction procedures.		
Improved	Desy(2016-20)	Fieldcage⊕thinned endplate: GEM, MicroMegas, or pixel
Purpose: Continue tests using 10000 pad read-out channels to demonstrate measurement of the Desy test-beam or cosmics 70cm tracklength using LP1 thinned endplate and external detector. If possible, simulate a jet-like environment. Pixels tested the'100-chip' LP-module.		
Final	Desy(after 2020)	Fieldcage⊕advanced-endcap prototype: GEM, MicroMegas, or pixel
Purpose: Prototype for LCTPC design based on R&D results for items that are ready: mechanics, electronics, cooling, power pulsing, gating, and fieldcage		

Review of the TPC design, performance and engineering issues result in a constant reassessment of the R&D priorities. This Table 4 gives a short overview:

Table 4

-• Continue tests in the Desy test-beam or cosmics to perfect correction procedures
and to verify point, two-point, dE/dx resolutions
-• Continue to design/test gating device
-• Endplate/module/fieldcage studies
with a maximum of 25% X0 in the endplate including electronics/cooling
-• Software development for simulation and reconstruction
-• Electronics development: the design of a new readout chip is a most urgent
problem to be solved by the collaboration.
-• Powerpulsing/cooling tests using both LP and SP

More discussions on the tasks ahead were held at workpackage meetings 176/185/222/258 where more details can be found. The links for these meetings are
176–http://agenda.linearcollider.org/event/6097/
185–http://agenda.linearcollider.org/event/6251/
222–http://agenda.linearcollider.org/event/6786/

258–http://agenda.linearcollider.org/event/7510/
The latest update took place at the collabortion meeting on January 14, 2020. The detailed list of issues can be found in the document 22_planlist_new.pdf at https://agenda.linearcollider.org/event/8362/contributions/45066/.

The collaboration decided that it was not yet necessary to choose between options, because the performance of the LCTPC for the ILD is guaranteed by Tables 5 and 6 in Sec. 4.3, showing the performance expected based on the R&D efforts. However these technical choices will have to be made in order to design the LCTPC, as described in the following Sec. 4.2.2.

4.2.2 After 2020

After a positive decision in Japan, during the ILC Pre-Lab phase (Sec.1.3) a selection must be made from the different technological options – GEM, MicroMegas, resistive anode, pixel, electronics, gating device, endcap structure, cooling, mechanics, integration – to establish a working model for the design of the LCTPC. This will not rule out R&D continuing on other options.

4.3 Performance Goals

Understanding the properties and achieving the best possible point resolution have been the object of R&D studies of Micro-Pattern Gas Detectors – GEM, MicroMegas, and pixel; results from this work used to define the parameters in Tables 5 and 6.

These studies will continue for the next few years in order to improve on the performance. Upgrades to the preliminary design will be implemented where improvements have been established by R&D results and are compatible with the LC timeline.

Also noted is the study by the ILD collaboration of a "large" version with 1808 mm TPC outer radius and 3.5T B-field (the standard used up to now) and a new "small" version with 1460 mm TPC outer radius and 4T B-field. The Table 5 below is for the "large" version, Table 6 for the "small" version. The values in the two tables are approximations only and are presented for the purpose of comparison. [2] [3] [4] [5]

[2] The point resolution, 0.1 mm, for this year's tables was asumed 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 the talk on pixel simulation at the 264th WP meeting on 11 May 2017, https://agenda.linearcollider.org/event/7634/). Resolutions for both pad and pixel versions presented in that talk are used for the comparisons shown here in Tables 5 and 6.

[3] For the effective track length in both cases, small and large, 100mm has been added to the inner radius and 100mm subtracted from the outer radius, in order to account for fieldcages, mechanics and services.

[4] The overall tracking resolution (including silicon tracking) would be roughly $\simeq 2 \times 10^{-5}$ for the large version and $\simeq 3 \times 10^{-5}$ for the small version. Physics simulations using both versions have shown similar performance for the two: the large is better in several studies; however, the small is better in a few cases.

[5] For this dE/dx simple calculation, 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 5, large TPC, for pad/*pixel* electronics

Parameter	
B-flield	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
Number of pixels/timebuckets	$\simeq$ *$10^9/1000$ per endcap*
Pad pitch/ no.padrows	$\simeq 1\times 6$ mm^2 / 213
$\sigma_{\rm point}$ in $r\phi$	$\simeq$ 60 μm for zero drift, $<$ 100 μm overall
$\sigma_{\rm point}$ *in $r\phi$*	$\simeq$ *0.055mm/$\sqrt{12}$ for zero drift,0.4mm for max drift*
$\sigma_{\rm point}$ in rz	$\simeq 0.4 - 1.4$ mm (for zero – full drift)
2-hit resolution in $r\phi$	$\simeq$ 2 mm
2-hit resolution in rz	$\simeq$ 6 mm
dE/dx resolution	$\simeq$ 5 %
dE/dx resolution	$\simeq$ *4 %*
Momentum resolution at B=3.5 T	$\delta(1/p_t) \simeq 10^{-4}$/GeV/c (TPC only)
Momentum resolution at B=3.5 T	$\delta(1/p_t) \simeq$ *0.3$\times$ 10^{-4}/GeV/c (TPC only)*

Table 6, small TPC, for pad/*pixel* electronics

Parameter	
B-flield	4.0T
Geometrical parameters	r_{in} 329 mm, r_{out} 1460 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	$\simeq 5\times 10^5/1000$ per endcap
Number of pixels/timebuckets	$\simeq$ *5$\times$ $10^8/1000$ per endcap*
Pad pitch/ no.padrows	$\simeq 1\times 6$ mm^2 / 155
$\sigma_{\rm point}$ in $r\phi$	$\simeq$ 60 μm for zero drift, $<$ 100 μm overall
$\sigma_{\rm point}$ *in $r\phi$*	$\simeq$ *0.055mm/$\sqrt{12}$ for zero drift,0.4mm for max drift*
$\sigma_{\rm point}$ in rz	$\simeq 0.4 - 1.4$ mm (for zero – full drift)
2-hit resolution in $r\phi$	$\simeq$ 2 mm
2-hit resolution in rz	$\simeq$ 6 mm
dE/dx resolution	$\simeq$ 6 %
dE/dx resolution	$\simeq$ *5 %*
Momentum resolution at B=4 T	$\delta(1/p_t) \simeq 2\times 10^{-4}$/GeV/c (TPC only)
Momentum resolution at B=4 T	$\delta(1/p_t) \simeq$ *0.6$\times$ 10^{-4}/GeV/c (TPC only)*