

# Addendum 2018 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 last year and can be found at the above link. Evolution of the collaboration, of the work-package structure and of responsible persons are updated and listed in the yearly Addenda.

## 1 2018 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 could pass to phase **3** (Section 1.2) within the next year.

### 1.1 The ILD LOI and the DBD

The ILD Letter of Intent (LOI) was validated in 2009 and was followed by the the Detailed Baseline Design (DBD) of the detector in 2013. The latter was the result of more work being put into understanding 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:

<https://www.linearcollider.org/ILC/Publications/Technical-Design-Report>.

### 1.2 The LC

The LCTPC properties were originally developed for the Tesla linear collider project, then 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.<sup>1</sup>

Recent efforts are underway to have ILC built in Japan. It is envisaged to be staged: The first stage, at  $\sim 250$  GeV (precision measurements of the Higgs and related quantities to find indications of BSM  $\equiv$  Beyond the Standard Model" physics), is expected to last about a decade. With additional funding, the machine could be upgraded to stages at  $\sim 350$  GeV and  $\sim 500$  GeV or higher for further precision measurements of the top quark, gauge boson couplings and search for BSM. (Progress is regularly reported in the 'LC Newslines' <http://newslines.linearcollider.org>.)

The collaboration and leadership arrangement, the international 'Linear Collider Collaboration' with oversight committee 'Linear Collider Board' (LCC and LCB, see the LC Newslines), were established to guide the construction of the ILC. This mandate has been extended by ICFA (International Committee for Future Accelerators).

## 2 Responsibilites 2018

Present groups and **Collaboration Board members** are listed next.<sup>2</sup>

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<sup>1</sup>e.g., <http://cepc.ihep.ac.cn>

<sup>2</sup>NB. Tsinghua is being reorganized.

## 2.1 Collaboration Board (CB) – Table 1

–Americas–	
Carleton/Triumf:	<b>Madhu Dixit</b>
Carleton U:	<b>Alain Bellerive</b>
Victoria:	<b>Dean Karlen</b>
BNL:	<b>Alexei Lebedev</b>
–Asia———	
Tsinghua:	<b>NN</b>
Hubei:	<b>Fan Zhang</b>
IHEP:	<b>Huirong Qi</b>
Saha Kolkata:	<b>Supratik Mukhopadhyay</b>
Hiroshima:	<b>Tohru Takahashi</b>
Iwate:	<b>Shinya Narita</b>
KEK:	<b>Keisuke Fujii</b>
Kindai:	<b>Yukihiro Kato</b>
Saga:	<b>Akira Sugiyama</b>
Kogakuin:	<b>Takashi Watanabe</b>
Nagasaki Inst AS:	<b>Ken Oyama</b>
–Europe———	
Inter U Inst for HEP(ULB-VUB):	<b>Gilles De Lentdecker</b>
CEA Saclay:	<b>Paul Colas</b>
Bonn:	<b>Jochen Kaminski/Klaus Desch</b>
DESY/HH:	<b>Ties Behnke</b>
Kiev:	<b>Oleg Bezshyyko</b>
MPI-Munich:	<b>Ron Settles</b>
Siegen:	<b>Ivor Fleck</b>
Nikhef:	<b>Jan Timmermans</b>
Lund:	<b>Leif Jönsson</b>
CERN:	<b>Michael Hauschild/Lucie Linsen</b>

## 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 have been (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 2007-2018 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 2011-17.

–Asia: **Takeshi Matsuda** in 2007-09,

**Akira Sugiyama** in 2010-17.  
–Europe: **Ron Settles** in 2007,  
**Jan Timmermans** in 2008-11,  
**Jochen Kaminski** in 2012-18.

Spokesperson selection: The RCs decided 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. He was replaced by Ivor Fleck in 2018.

### 3.1.2 Editorial Board (EB)

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

The EB is made now 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 2016-18.

### 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 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, as did Alain Bellerive for one year starting mid-2013 and David Attie since mid-2014; Serguei Ganjour (serguei.ganjour@cea.fr) replaced him as European member and as chair of the speakers bureau in 2018.

## 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’, to be contacted for information.

There are now 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, are:

**Table 2****Workpackage**

Groups involved

**Contact**

<b>Workpackage</b>	<b>Groups involved</b>	<b>Contact</b>
Workpackage(0) TPC R&D Program	LCTPC collaboration	
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Workpackage(1) Mechanics		
a) LP endplate design and Fieldcage development	→ Cornell,Bonn, Desy/HH,JapaneseGroups,MPI,Saclay up to 2016	<b>Dan Peterson</b> daniel.peterson@cornell.edu
	→BNL,Desy/HH	<b>Ties Behnke</b> ties.behnke@desy.de
b) GEM panels for endplate	→Bonn,Desy/HH,JapaneseGroups,IHEP,Tsinghua	<b>Akira Sugiyama</b> sugiyama@cc.saga-u.ac.jp
c) MicroMegas panels for endplate	→Carleton,IHEP,SahaKolkata,Saclay	<b>Paul Colas</b> paul.colas@cea.fr
d) Pixel panels for endplate	→Bonn,Nikhef,Saclay	<b>Jan Timmermans</b> jan.timmermans@nikhef.nl
e) Resistive anode for endplate	→Carleton,SahaKolkata,Saclay	<b>Madhu Dixit</b> msd@physics.carleton.ca
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Workpackage(2) Electronics		
a) Standard RO for the LP	→ Brussels,Cern,Desy/HH,Lund	<b>Leif Jönsson</b> leif.jonsson@hep.lu.se
b) CMOS RO electronics	→ Bonn,Nikhef,Saclay	<b>Harry van der Graaf</b> vdgraaf@nikhef.nl
c) Standard electronics for LCTPC	→ Brussels,Cern,Desy/HH,Lund, JapaneseGroups,Tsinghua up to 2010	<b>Luciano Musa</b> luciano.musa@cern.ch
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Workpackage(3) Software		
a) LP software/simulation/reconstruction	→ Bonn,Cern,Desy/HH,Victoria, up to 2014	<b>Astrid Muennich</b> astrid.muennich@desy.de
b) LP DAQ	→Brussels,Lund	<b>Gilles De Lentdecker</b> gilles.de.lentdecker@ulb.ac.be
c) LCTPC performance/backgrounds	→ Bonn,Carleton,Cern,Desy/HH,JapaneseGroups	<b>Keisuke Fujii</b> keisuke.fujii@kek.jp
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Workpackage(4) Calibration		
a) Field map for the LP	→ Cern,Desy/HH	<b>Lucie Linsen</b> lucie.linszen@cern.ch
b) Alignment	→ Cern,Desy/HH,JapaneseGroups	<b>Takeshi Matsuda</b> takeshi.matsuda@kek.jp
c) Distortion correction	→ Cern,Desy/HH,MPI,JapaneseGroups,Victoria	<b>Dean Karlen</b> karlen@uvic.ca
d) Gas/HV/Infrastructure for the LP	→ Aachen,Desy/HH,Saclay	<b>Ralf Diener</b> ralf.diener@desy.de

## WP(5) Coordination of LCTPC R&D

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

## 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 MicroMegas option without resistive anode has been ruled out,
- gas properties have been well measured,
- many years of MPGD experience have been gathered,
- the best possible point resolution is understood,
- the resistive-anode charge-dispersion technique has been demonstrated,
- reliable assemblies of GEM-modules and MicroMegas-modules have been developed,
- CMOS pixel RO technology has been demonstrated,
- the dE/dx resolution has been confirmed,
- design of the gating device has been successful.

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 The 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-f1c.desy.de/lcnotes>.

#### 4.2.1 2014 - 2018

Possible scenarios are summarized in the Table 3. There are three stages foreseen for the LP with preliminary, improved and ‘final’ module-designs. Supplemental testing with the 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.

<b>Table 3</b>		Scenarios, updated November 2018
Device	Lab(years)	Large Prototype R&D Configuration
Preliminary	Desy(2013-15)	Fieldcage⊕first endplates: GEM, MicroMegas, or pixel <i>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.</i>
Improved	Desy(2016-18)	Fieldcage⊕thinned endplate: GEM, MicroMegas, or pixel <i>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.</i>
Final	Desy(after 2018)	Fieldcage⊕advanced-endcap prototype: GEM, MicroMegas, or pixel <i>Purpose: Prototype for LCTPC module design with items that are ready: mechanics, electronics, cooling, power pulsing, gating; new fieldcage and SAltro/GdSP channels</i>

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

**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
- Common DAQ for running the TPC and silicon trackers together
- 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
- Test all components of LCTPC for electron-attachment emissions into the TPC gas

More discussions on the tasks ahead were held at workpackage meetings 176/185/222/258 where more details can be found. The indico 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 collaboration decided that it was not yet necessary to choose between options, because the performance of the LCTPC for the DBD 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 may have to be made around the year 2019 in order to design the LCTPC, as described in Sec. 4.2.2 below.

#### 4.2.2 After 2018

Shortly after a positive decision in Japan, 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.

After 2018, the design of the ILD TPC could follow in preparation for the IDR (ILD Design Report).

### 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. The options are MicroMegas with resistive anode with standard electronics, or GEM with standard electronics, or the pixel TPC with CMOS electronics called “Ingrid” (MicroMegas integrated on a pixel chip).

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. <sup>3 4 5 6</sup>

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<sup>3</sup>The point resolution, 0.1 mm, for this year’s tables was assumed to be the same for GEM and MicroMegas. The value for the pixel option was assumed to be  $0.055\text{mm}/\sqrt{12}$  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 are presented there.

<sup>4</sup>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.

<sup>5</sup>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.

<sup>6</sup>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 ( $r, \phi, z \simeq 429\text{mm}, \phi = K(\text{constant}), 0\text{mm}$ ) to the outer radius near the endcap ( $r, \phi, z \simeq 1700\text{mm}(\text{large}), \phi = K, 2200\text{mm}$ ), ( $r, \phi, z \simeq 1300\text{mm}(\text{small}), \phi = K, 2200\text{mm}$ ), 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  $\frac{1}{\sigma_{sd}^2}$  for the  $ld$  and  $sd$ , respectively. The two errors are combined in the standard way:  $\frac{1}{\sigma_{\text{hypotheticaltrack}}^2} = \frac{1}{\sigma_{ld}^2} + \frac{1}{\sigma_{sd}^2}$ .

**Table 5, large TPC, for pad/pixel electronics**

Parameter	$r_{in}$	$r_{out}$	$z$
Geometrical parameters	329 mm	1808 mm	$\pm 2350$ 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	$\simeq 1 \times 6 \text{ mm}^2 / 213$		
$\sigma_{point}$ in $r\phi$	$\simeq 60 \mu\text{m}$ for zero drift, $< 100 \mu\text{m}$ overall		
$\sigma_{point}$ in $r\phi$	$\simeq 0.055\text{mm}/\sqrt{12}$ for zero drift, $0.4\text{mm}$ for max drift		
$\sigma_{point}$ 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	$\simeq 5 \%$		
<i>dE/dx resolution</i>	$\simeq 4 \%$		
Momentum resolution at B=3.5 T	$\delta(1/p_t) \simeq 10^{-4}/\text{GeV}/c$ (TPC only)		
<i>Momentum resolution at B=3.5 T</i>	$\delta(1/p_t) \simeq 0.3 \times 10^{-4}/\text{GeV}/c$ (TPC only)		

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

Parameter	$r_{in}$	$r_{out}$	$z$
Geometrical parameters	329 mm	1460 mm	$\pm 2350$ 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		
<i>Number of pixels/timebuckets</i>	$\simeq 5 \times 10^8/1000$ per endcap		
Pad pitch/ no.padrows	$\simeq 1 \times 6 \text{ mm}^2 / 155$		
$\sigma_{point}$ in $r\phi$	$\simeq 60 \mu\text{m}$ for zero drift, $< 100 \mu\text{m}$ overall		
$\sigma_{point}$ in $r\phi$	$\simeq 0.055\text{mm}/\sqrt{12}$ for zero drift, $0.4\text{mm}$ for max drift		
$\sigma_{point}$ 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	$\simeq 6 \%$		
<i>dE/dx resolution</i>	$\simeq 5 \%$		
Momentum resolution at B=4 T	$\delta(1/p_t) \simeq 2 \times 10^{-4}/\text{GeV}/c$ (TPC only)		
<i>Momentum resolution at B=4 T</i>	$\delta(1/p_t) \simeq 0.6 \times 10^{-4}/\text{GeV}/c$ (TPC only)		