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Addendum 2022 to the LCTPC MoA: Preparing for the e^+e^-Collider

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. Updates in the collaboration are documented in the yearly Addenda; information from the preceeding year is repeated here for completeness.

1 2022 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 in phase **2** and will move to phase **3** as soon as an e^+e^-collider (Sec. 1.2) is approved.

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, which was the result of further work on 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://arxiv.org/abs/1306.6327.

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

1.2 The e^+e^-Collider Projects

The LCTPC properties were originally R&Ded for the Tesla linear collider (https://slidetodoc.com/tesla-linear-collider-project-overview-and-linac-technology/), after which the work continued for the ILC, both with superconducting cavities and for energies $\sqrt{s}\simeq$ 0.09-1.0 TeV.

The ILC 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 can 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. Moreover, 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.

Other collider projects are under study. They are summarized and evaluated in https://arXiv.org/abs/2208.06030 [physics.acc-ph] 11 Aug 2022. The e^+e^-collider proposals from 90 GeV - 1 TeV, include ILC,[1] CEPC,[2] CERC,[3] CLIC,[4] Cool Copper Collider (C3)[5] ERLC,[6] FCC-ee,[7][8] ILC with upgraded luminosity,[9] ReLiC.[10]

[1] https://arXiv.org/abs/1306.6352
[2] https://arXiv.org/abs/2203.09451
[3] https://arXiv.org/abs/2203.07358
[4] https://arXiv.org/abs/2203.09186
[5] https://arXiv.org/abs/2110.15800
[6] Journal of Instrumentation 16 (2021) P12025.
[7] Eur. Phys. J. C 79 (2019) 474
[8] https://arXiv.org/abs/2203.08310
[9] https://arXiv.org/abs/2203.07622
[10] https://arXiv.org/abs/2203.06476

At the ILD group meeting in Hamburg on Nov. 8,2022 (https://agenda.linearcollider.org/event/9849/), it was decided that the performance of an "ILD-like" detector at other colliders (than ILC) should be studied.

This is now happening for CEPC and FCC-ee. See footnote11 of the Tables in Sec.4.3..

1.3 The ILC International Development Team (IDT)

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 w-as approved by ICFA (International Committee for Future Accelerators).

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 ICFA_Statement_August_2020.pdf at https://icfa.fnal.gov/. In June 2021 the IDT submitted its report to ICFA describing the organization of the Pre-Lab:
see https://arxiv.org/abs/2106.00602. The Pre-Lab is not yet approved and is now under study by the Japanese government,

2 Responsibilities

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
Stony Brook:	**Klaus Dehmelt** klaus.dehmelt@stonybrook.edu
–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@phys.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

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):

Americas: **Cornell, Indiana,** LBNL, Louisiana Tech, **Montreal,** MIT, Purdue, Yale.

Asia: Mindanao, U Tokyo, **Tokyo U A & T.**

Europe: **Aachen,** Bucharest, **CERN,** Freiburg, Karlsruhe, UMM Krakow, **LAL Orsay/IPN Orsay, Novosibirsk, Rostock,** St.Petersburg, TU Munich.

2.3 New groups

The LCTPC collaboration (http://www.lctpc.org) is open to all, and a group wishing to join (or rejoin after **change of status**) should contact us.

3 Further LCTPC Collaboration Information

3.1 Regional Coordinators (RC)

The RCs for 2007-2021 after selection of candidates in each region were elected by the CB members of the respective region. The RCs:
–Americas: **Dean Karlen** 2007-10,
Alain Bellerive 2011-2022
Klaus Dehmelt 2023 present RC.
–Asia: **Takeshi Matsuda** 2007-09,
Akira Sugiyama 2010-21,
Shinya Narita 2021 to present RC.
–Europe: **Ron Settles** 2007,
Jan Timmermans 2008-11,
Jochen Kaminski 2012 to present RC.

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 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: Ties Behnke, Madhu Dixit, Takahiro Fusayasu, Keisuke Fujii, Leif Jönsson, Jochen Kaminski, Takeshi Matsuda, Ron Settles, Sinya Narita and Jan Timmermans. Takahiro Fusayasu agreed to chair the EB in 2016 to present. The most recent R&D study is available at https://arxiv.org/abs/2205.12160.

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, Alain 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 the chair in 2020. Huirong Qi agreed to be the regional person for Asia in 2021.

3.2 Technical Board (TB)

Originally, there were four original workpackages in the MoA (WP(1) Mechanics, WP(2) Electronics, WP(3) Software, WP(4) Calibration); these 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.

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 R&D meetings for the LCTPC collaboration, 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
	up to 2010 **Klaus Dehmelt** klaus.dehmelt@stonybrook.edu
	Ralf Diener ralf.diener@desy.de

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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
	up to 2021 **Akira Sugiyama** sugiyama@cc.saga-u.ac.jp
	Shinya Narita narita@iwate-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

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 ruled out,
–the resistive-anode charge-dispersion technique demonstrated,
–the MicroMegas option without resistive anode ruled out,
–gas properties well measured; the best drift-gas selected,
–the best possible point resolution achieved,
–reliable assemblies of GEM-modules and MicroMegas-modules developed,
–CMOS pixel RO technology successfully demonstrated,
–the dE/dx resolution confirmed,
–gating device developed,
–two phase CO2 cooling tested.

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 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.

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 - 2022

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).

Table 3		Scenarios, updated November 2022
	Large Prototype R&D	
Device	Lab(years)	Configuration
Preliminary	Desy(2013-15)	Fieldcage⊕first endplates: GEM, MicroMegas, or Pixel
Purpose: Test construction techniques using several thousand pad read-out channels using the Desy test-beam over 70cm tracklength, including development of correction procedures.		
Improved	Desy(2016-20)	Fieldcage⊕thinned endplate: GEM, MicroMegas, or Pixel
Purpose: Continue tests using several thousand pad read-out channels using the Desy test-beam 70cm tracklength using LP1 thinned endplate and external detector. If possible, simulate a jet-like environment. Pixels tested the'100-chip' LP-module.		
Final	LCTPC(after 2022) Collaboration	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 to perfect calibration procedures
and to improve point resolution, two-point separation, dE/dx resolution
-• Continue to design/test gating device
-• Endplate/module/fieldcage studies
with a maximum of 25% X0 in the endplate including electronics/cooling
-• Electronics development
-• Cooling tests will be especially important for the Pixel TPC because of the power needed.

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 collaboration 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/.

4.2.2 After 2022

After one of the collider options has been chosen (Sec. 1.2), a selection must be made from the different technological options – GEM, MicroMegas, Pixel, electronics, gating device, endcap structure, cooling, mechanics, integration – to establish a working model for the design of the LCTPC. The tables below indicate a direction for the next phase of R&D.

4.3 Performance Goals

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. The Table 5 below is for the "large" version, Table 6 for the "small" version (the values are back-of-the-envelope approximations). [11] [12] [13] [14] [15]

[11] 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 FC-ee (Sec.1.2), the momentum resolutions are therefore 3.5/2 (4/2) times the values in Table 5 (6), i.e., 1.75 (2) $\times 10^{-4}$/GeV/c (TPC only) and *1.4* $\times$ *10^{-4}/GeV/c (60% cov, TPC only)* in Table 5 and 3.6$\times$ 10^{-4}/GeV/c (TPC only) *2.8$\times$ 10^{-4}/GeV/c (60% cov, TPC only)* in Table 6. These are **factors of ca. 2 to 4 smaller** than at LEP.

[12] 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 0.055mm/$\sqrt{12}$ for zero drift and 0.4mm for maximum drift: see talk at the ILCX2021 workshop
https://agenda.linearcollider.org/event/9211/contributions/58794/attachments/37527/58794/ILCX_pixelTPC_2021.pdf;
the reference on p. 22 gives the resolutions on p.23 for both pad and pixel versions which are used for the comparisons in Tables 5 and 6.

[13] For the effective track length in both cases, small and large, 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.

[14] 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 have shown similar performance for the two.

[15] 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-field	3.5T
Geometrical parameters	r_{in} 329 mm, r_{out} 1777 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	$\simeq 1\times 6\ mm^2$ / 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 resolution	$\simeq 5$ %
dE/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	*$\delta(1/p_t) \simeq 0.8\times 10^{-4}$/GeV/c (60% cov, TPC only)*

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

Parameter	
B-field	4.0T
Geometrical parameters	r_{in} 329 mm, r_{out} 1427 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	$\simeq 1\times 6\ mm^2$ / 163
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 resolution	$\simeq 6$ %
dE/dx resolution	*$\simeq 5$ %*
Momentum resolution at B=4 T	$\delta(1/p_t) \simeq 1.8\times 10^{-4}$/GeV/c (TPC only)
Momentum resolution at B=4 T	*$\delta(1/p_t) \simeq 1.4\times 10^{-4}$/GeV/c (60% cov, TPC only)*