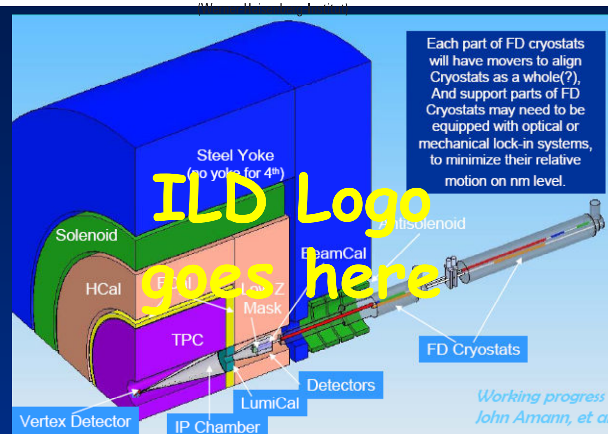
Max-Planck-Institut für Physik

Worldwide Study of the Physics and Detectors for Future Linear e+ e- Colliders



TPC R&D for an LC detector @

1. √s < 1 TeV

2. √s > 1 TeV

Ron Settles MPI-Munich
CLIC'09 Workshop

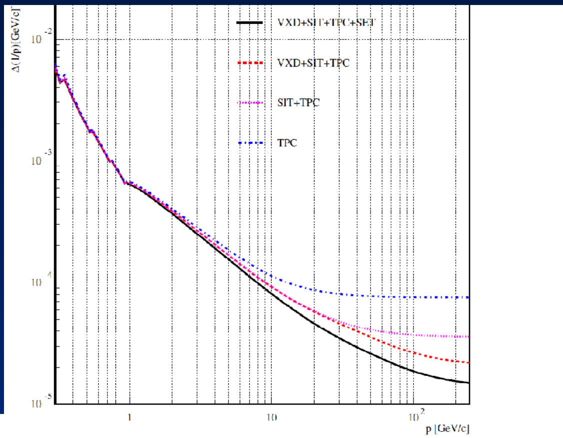
1. $\sqrt{s}$ < 1 TeV

To put TPC in perspective:

info mainly from LOI and recent lctpc collaboration meeting

Coherent layout of detector:

- -VTX:perf,,min.material
- -TRK:perf.,min.material
- -CALO:granularity



3.2 ILD DETECTOR PERFORMANCE

3.2.1 ILD Tracking Performance

The tracking system envisaged for ILD consists of three subsystems each capable of standalone tracking VTX, FTD and the TPC. These are augmented by three auxiliary tracking systems the SIT, SET and ETD, which provide additional high resolution measurement points. The momentum resolution goal[25] is

$$\sigma_{1/p_T} \approx 2 \times 10^{-5}\,\mathrm{GeV}^{-1},$$

and that for impact parameter resolution is

$$\sigma_{r\phi} = 5\,\mu\mathrm{m} \oplus \frac{10}{\mathrm{p(GeV)}\sin^{3/2}\theta}\,\mu\mathrm{m}.$$

3.2.1.1 Coverage and Material Budget

Figure 3.2-2a shows, as a function of polar angle, θ, the average number of reconstructed hits associated with simulated 100 GeV muons. The TPC provides full coverage down to $\theta = 37°$. Beyond this the number of measurement points decreases. The last measurement point provided by the TPC corresponds to $\theta \approx 10°$. The central inner tracking system, consisting of the six layer VTX and the two layer SIT, provides eight precise measurements down to $\theta = 26°$. The innermost and middle double layer of the VTX extend the coverage down to $\theta \sim 16°$. The FTD provides up to a maximum of five measurement points for tracks at small polar angles. The SET and ETD provide a single high precision measurement point with large lever arm outside of the TPC volume down to a $\theta \sim 10°$. The different tracking system contributions to the detector material budget, including support structures, is shown in Figure 3.2-2b.

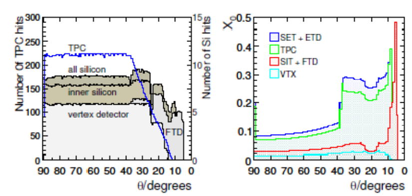
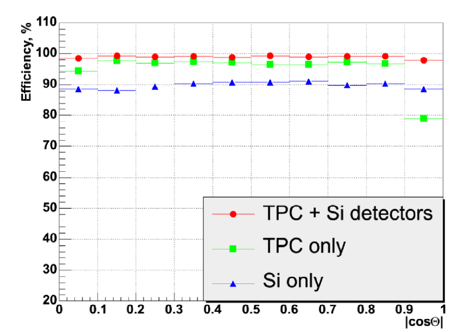


FIGURE 3.2-2. a) Average number of hits for simulated charged particle tracks as a function of polar angle. b) Average total radiation length of the material in the tracking detectors as a function of polar angle.

P_t > 1 GeV/c



Performance Requirements

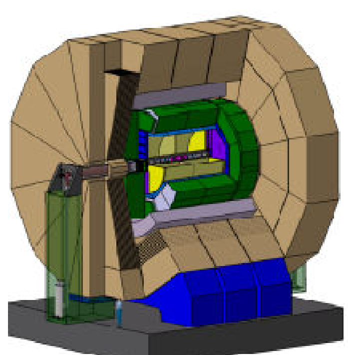


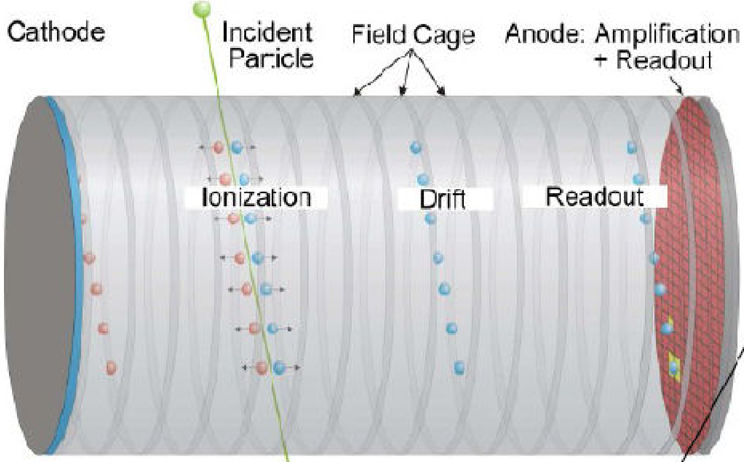
FIGURE 1.2-1. View of the ILD detector concept.

LC-TPC Motivation/Goals

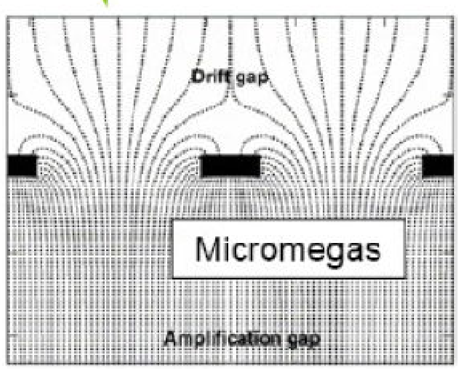
...to be tested@the R&D where possible...

- continuous 3-D tracking, easy pattern recognition throughout large volume, well suited for large magnetic field
- ~99% tracking efficiency in presence of backgrounds
- track-topology stamping to 2 ns together with inner silicon
- minimum of X_0 inside Ecal (<4% barrel, ~15% endcaps)
- σ_{pt} ~ 100µm (rφ) and ~ 500µm (rz) @ 4T
- 2-track resolution <2mm (rφ) and <5-10mm (rz)
- dE/dx resolution <5% -> e/pi separation, for example
- easily maintainable if designed properly, in case of beam accidents, for example
- design for full precision/efficiency at 20 x estimated backgrounds

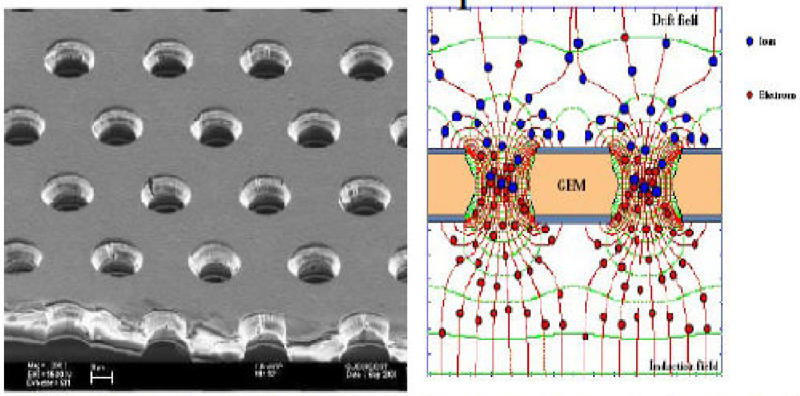
TPC with MPGD



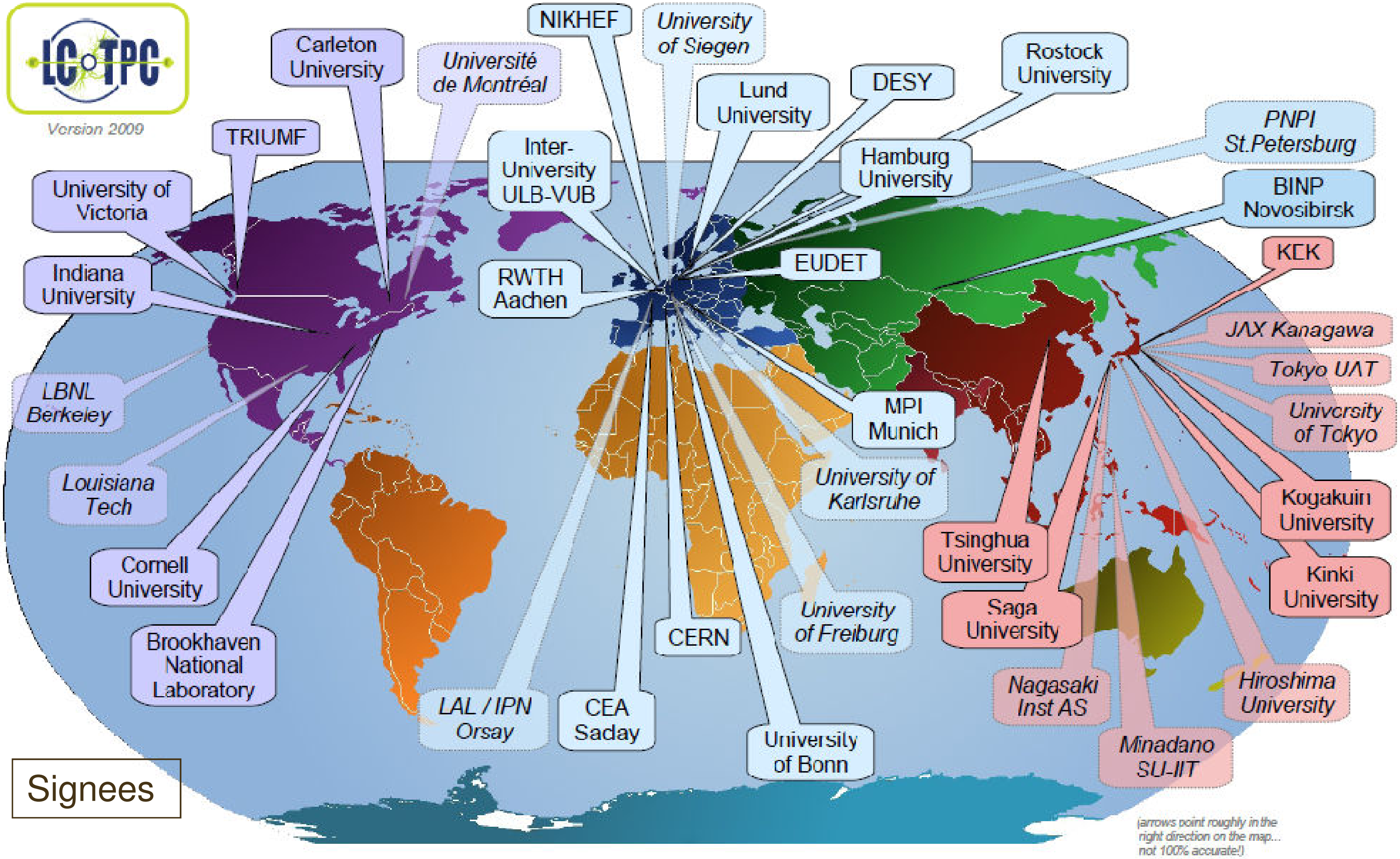
MicroPatternGasDetector
MPGD
not limited by E x B effects



Gas Electron Multiplier GEM



TPC Collaboration 2009



TPC R&D Planning

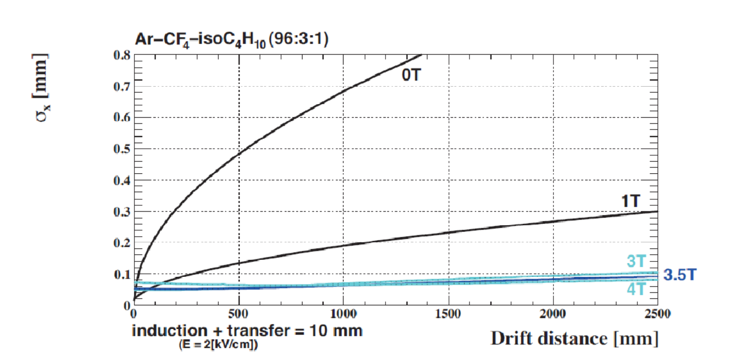
- 1) Demonstration phase
  - Continue work with small prototypes (SP) on mapping out parameter space, understanding resolution, etc, to improve the design of an MPGD TPC.
- 2) Consolidation phase
  - Build and operate the Large Prototype (LP), Ø ~ 90cm, drift ~ 60cm together with SIT prototype, with EUDET infrastructure as basis, to test manufacturing techniques for MPGD endplates, fieldcage, electronics. The LP has been built now and testing of the options is underway.
- 3) Design phase
  - During phase 2, the decision as to which endplate technology to use for the LC TPC will be taken and final design started.

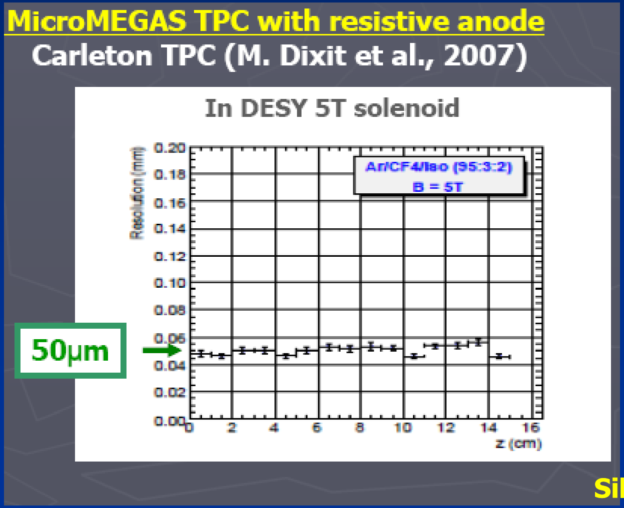
LCTPC performance goals

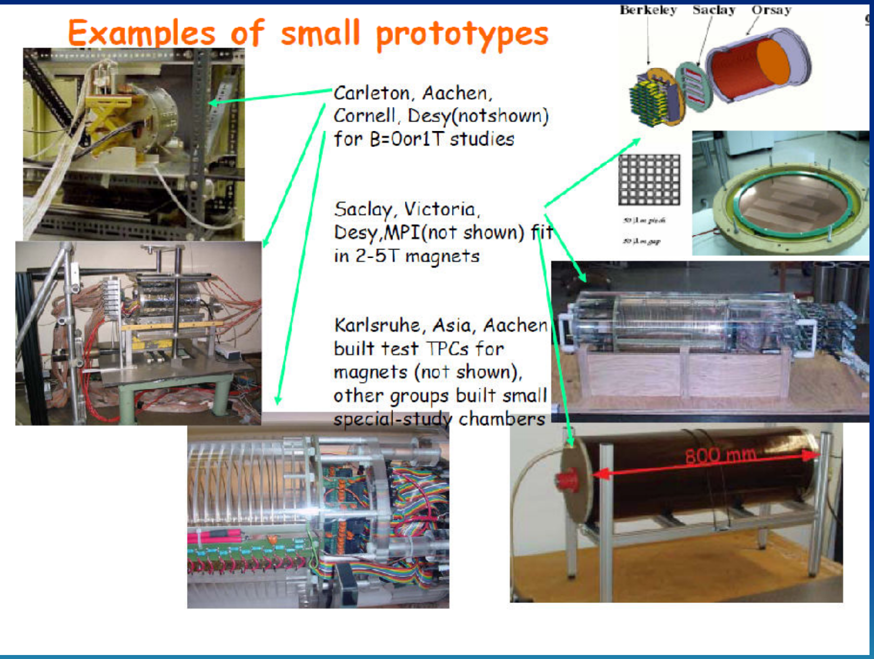
- R&D plans/options

Present goals based on results from small prototypes using cosmics or beams at KEK, DESY, CERN. Three options left →

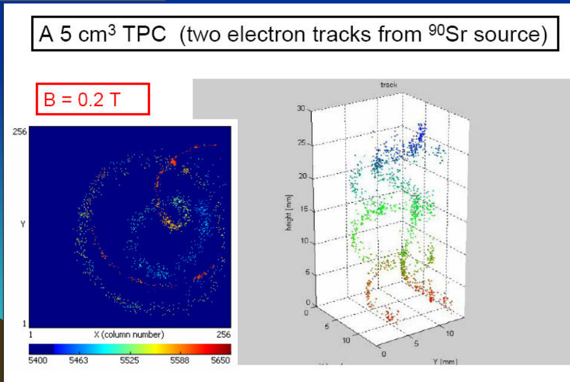
GEM gas-amplif. for a TPC







Silicon Pixel Readout for a TPC



TPC R&D summary to date

- Now several years MPGD experience gathered
- Gas properties rather well understood
- Limit of resolution understood
- Resistive-anode charge-spreading demonstrated
- CMOS RO demonstrated
- Gas-amplification techniques ruled out with SPs
  - MWPC
  - Micromegas without resistive-anode
- Work in progress with the Large Prototype

Large Prototype TPC

Performance goals…

LCTPC Collaboration

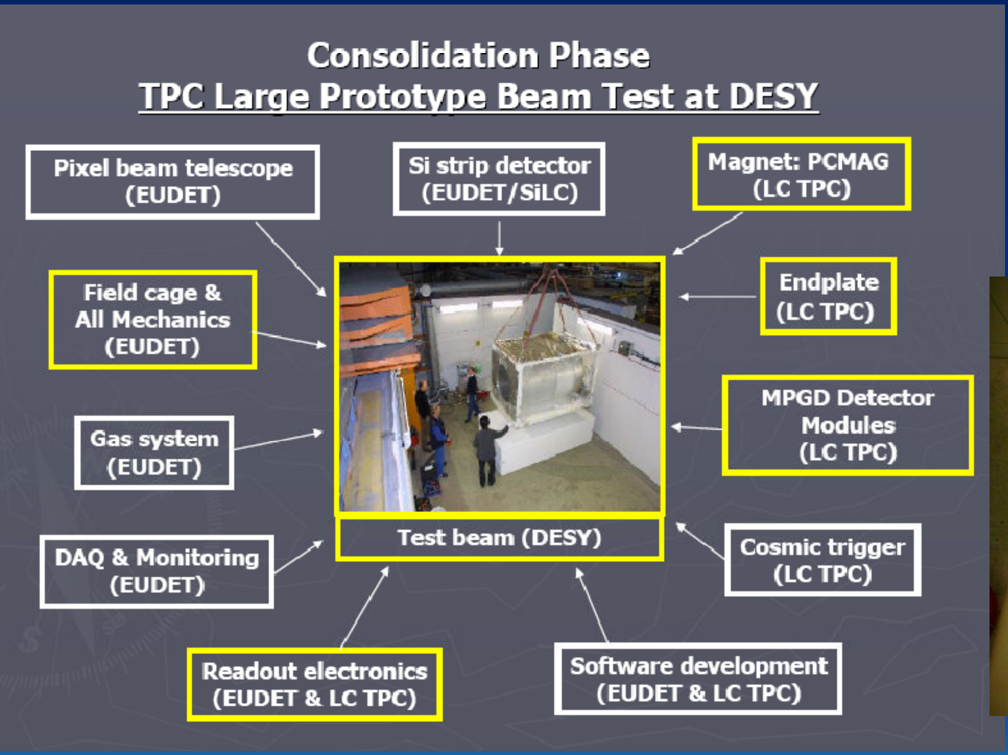
- Performance goals and design parameters for a TPC with standard electronics at the ILC detector

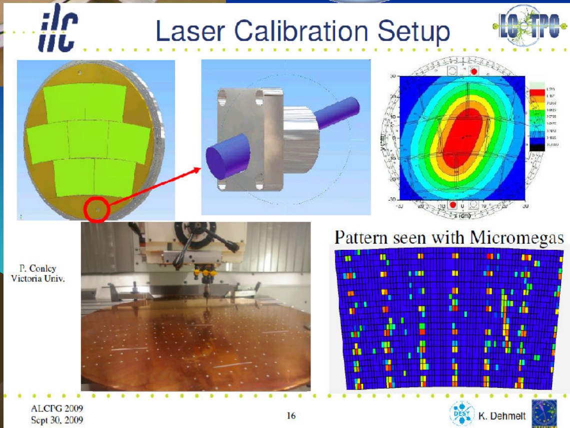
Size	$\phi = 3.6$m, L = 4.3m outside dimensions
Momentum resolution (3.5T)	$\delta(1/p_t) \sim 9 \times 10^{-5}$/GeV/c TPC only ($\times$ 0.4 if IP incl.)
Momentum resolution (3.5T)	$\delta(1/p_t) \sim 2 \times 10^{-5}$/GeV/c (SET+TPC+SIT+VTX)
Solid angle coverage	Up to $\cos\theta \simeq 0.98$ (10 pad rows)
TPC material budget	$\sim 0.04X_0$ to outer fieldcage in r $\sim 0.15X_0$ for readout endcaps in z
Number of pads/timebuckets	$\sim 1\times10^6$/1000 per endcap
Pad size/no.padrows	$\sim$ 1mm$\times$4–6mm/$\sim$200 (standard readout)
σ_{point} in $r\phi$	$< 100\mu m$ (average over $L_{sensitive}$, modulo track ϕ angle)
σ_{point} in rz	$\sim$ 0.5 mm (modulo track θ angle)
2-hit resolution in $r\phi$	$\sim$ 2 mm (modulo track angles)
2-hit resolution in rz	$\sim$ 6 mm (modulo track angles)
dE/dx resolution	$\sim$ 5 %
Performance	$> 97\%$ efficiency for TPC only ($p_t > 1$GeV/c), and $> 99\%$ all tracking ($p_t > 1$GeV/c)
Background robustness	Full efficiency with 1% occupancy
Background safety factor	Chamber will be prepared for 10 $\times$ worse backgrounds at the linear collider start-up

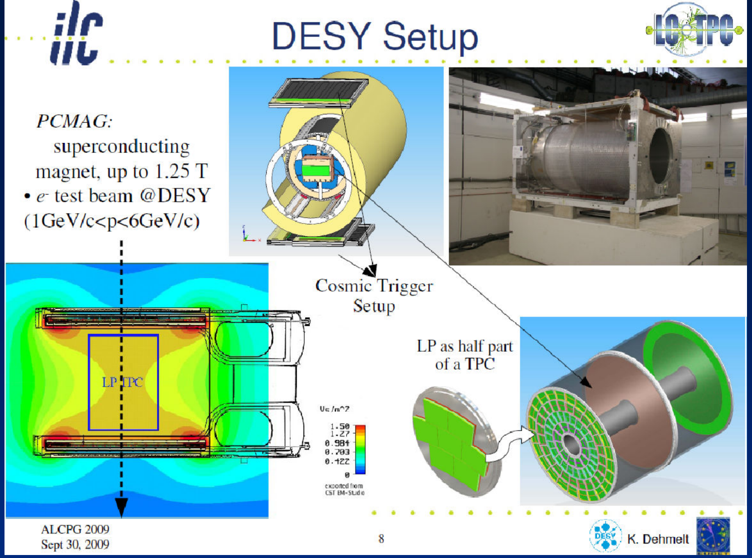
with MPGD

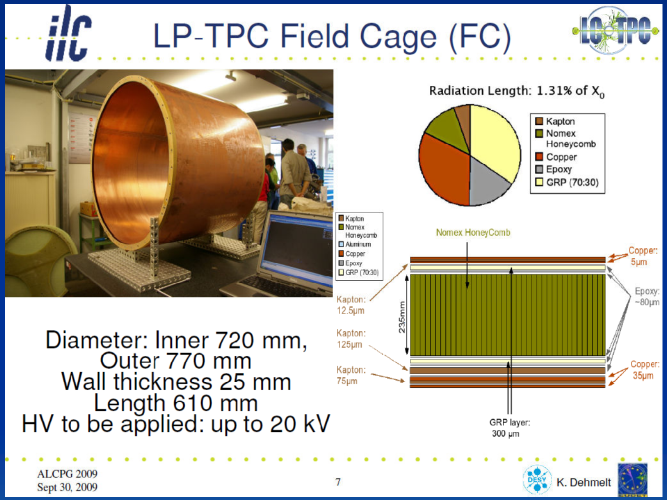
LCTPC performance goals…

…to be verified (or revised) after tests on the Large Prototype:



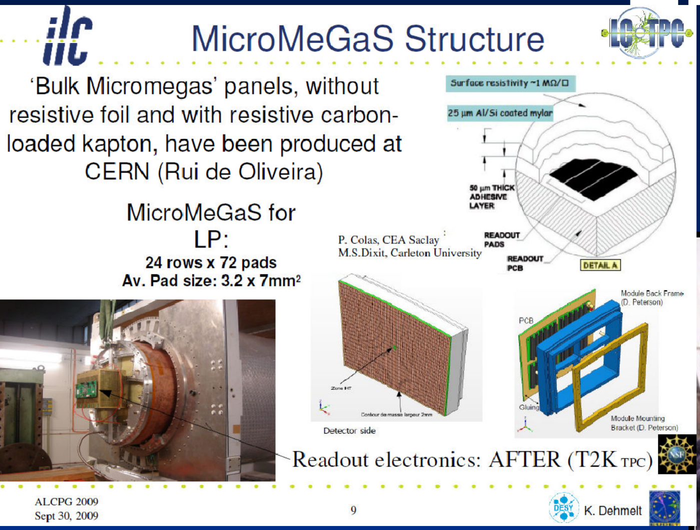


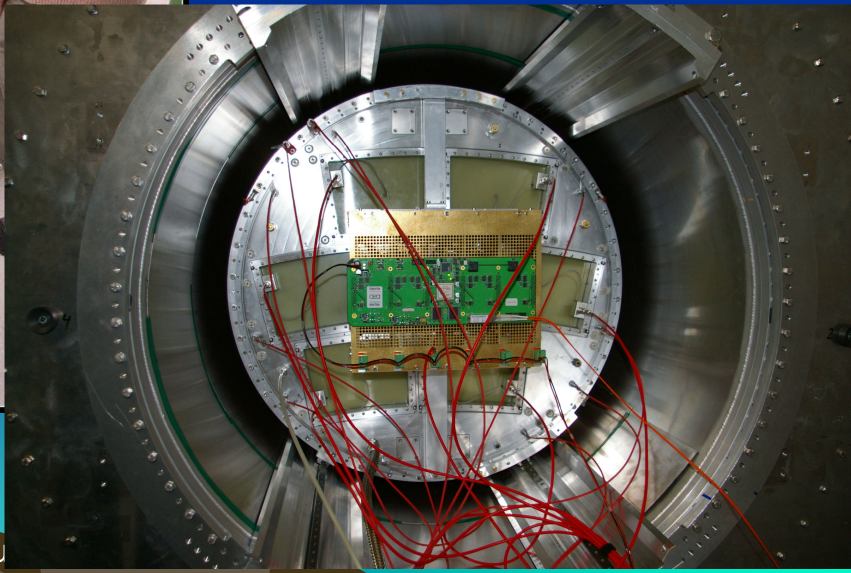




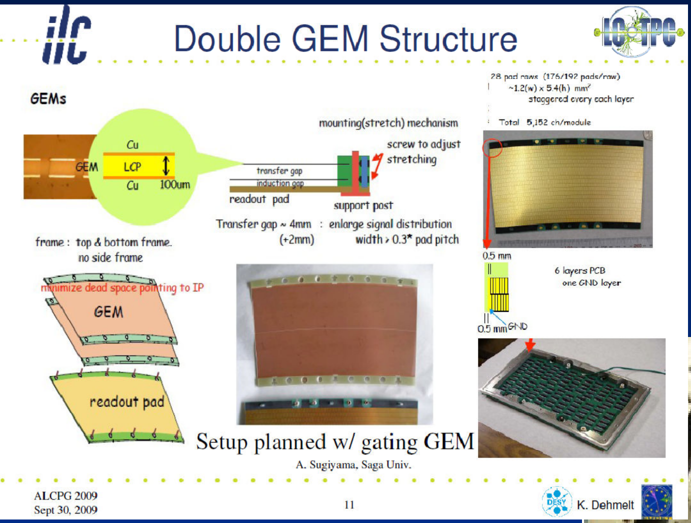
- Software goals: Develop MarlinTPC to reconstruct:
  - Technology's signals (GEM, Micromegas, Pixel)
  - Correct distortions (B,Efields)

LP - MicroMeGaS



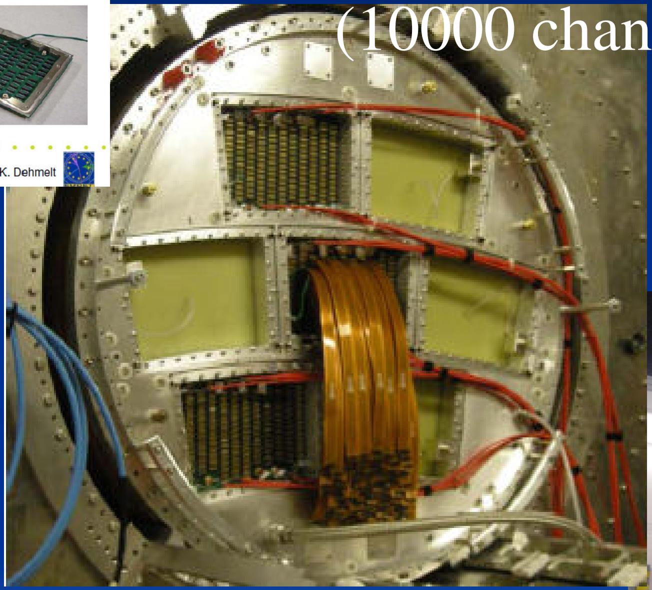


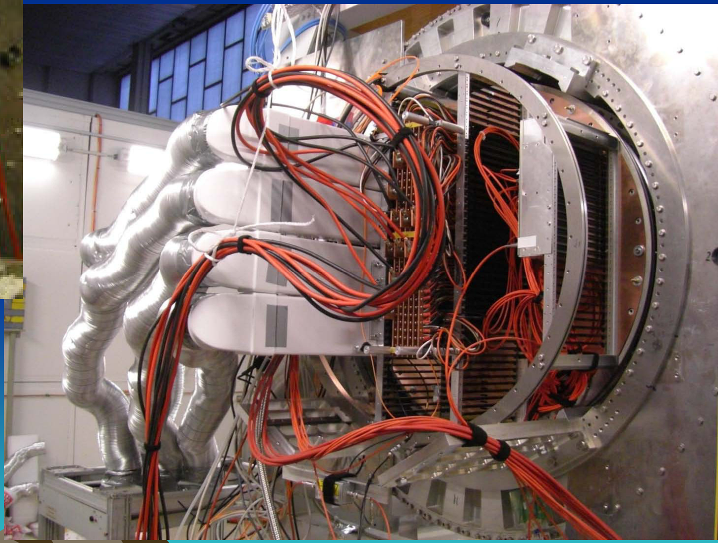
Double GEM



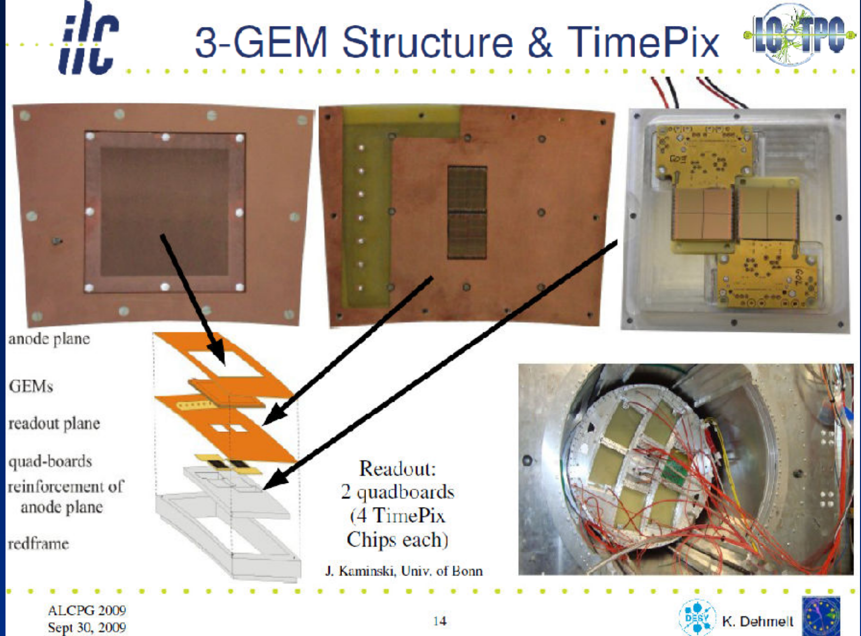
About 3200 channels readout electronics (Altro/Alice) CERN&Lund

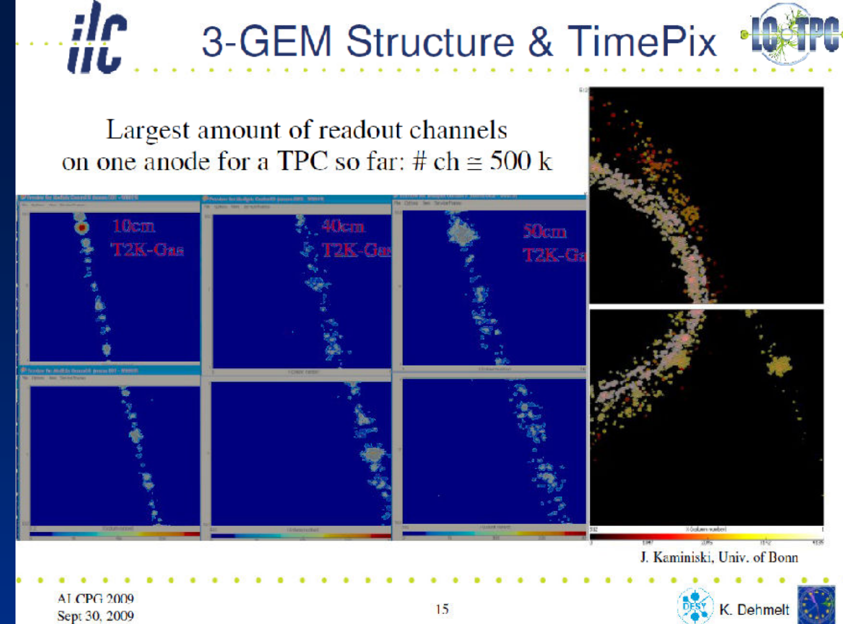
(10000 channels later in 2009)





Triple-Gem being prepared by Desy group


3-GEM Structure & TimePix
anode plane
GEMs
readout plane
quad-boards
reinforcement of anode plane
redframe
Readout: 2 quadboards (4 TimePix Chips each)
J. Kaminski, Univ. of Bonn
ALCPG 2009
Sept 30, 2009
14
K. Dehmelt


3-GEM Structure & TimePix
Largest amount of readout channels
on one anode for a TPC so far: # ch ≅ 500 k
10cm T2K-Gas
40cm T2K-Gas
50cm T2K-Gas
J. Kaminski, Univ. of Bonn
ALCPG 2009
Sept 30, 2009
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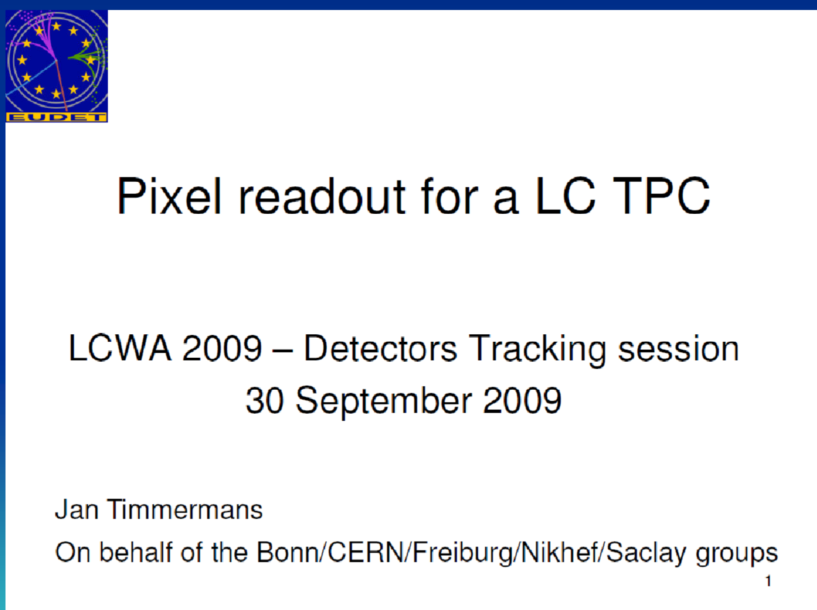
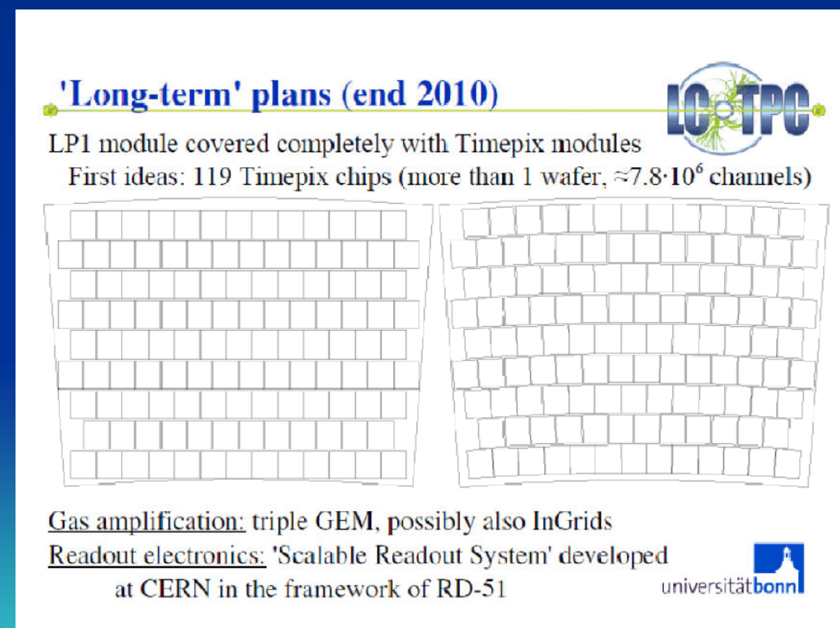
K. Dehmelt


Pixel readout for a LC TPC
LCWA 2009 – Detectors Tracking session
30 September 2009
Jan Timmermans
On behalf of the Bonn/CERN/Freiburg/Nikhef/Saclay groups
1


'Long-term' plans (end 2010)
LP1 module covered completely with Timepix modules
First ideas: 119 Timepix chips (more than 1 wafer, ≈7.8·10⁶ channels)
Gas amplification: triple GEM, possibly also InGrids
Readout electronics: 'Scalable Readout System' developed at CERN in the framework of RD-51
universitätbonn

For details, see talks in alcpg09-tracking session Wednesday afternoon and Friday morning: Klaus, Hirotoshi, Jan, Aurore, Winfried, Alberto, Steve, Takeshi.

HEPHY
Institut für Hochenergiephysik

LPTPC Silicon Envelope
Status & Plans

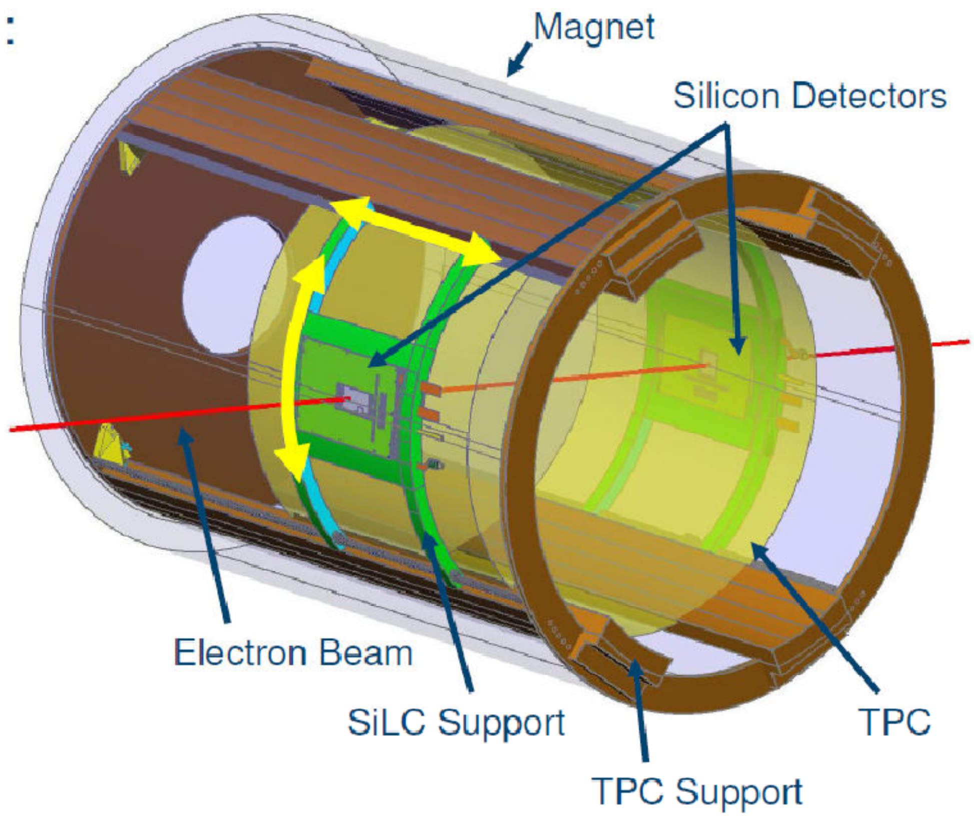
HEPHY+Karlsruhe

This work is performed within the SiLC R&D coll

Introduction

the idea is known:

Improve the resolution of the Large Prototype TPC by adding a precise measured point of the track (order of 10µm), inside the gap, between magnet and TPC, on both sides of the TPC.



21.09.2009 Stephan Hänsel – LCTPC collaboration meeting 2009 2

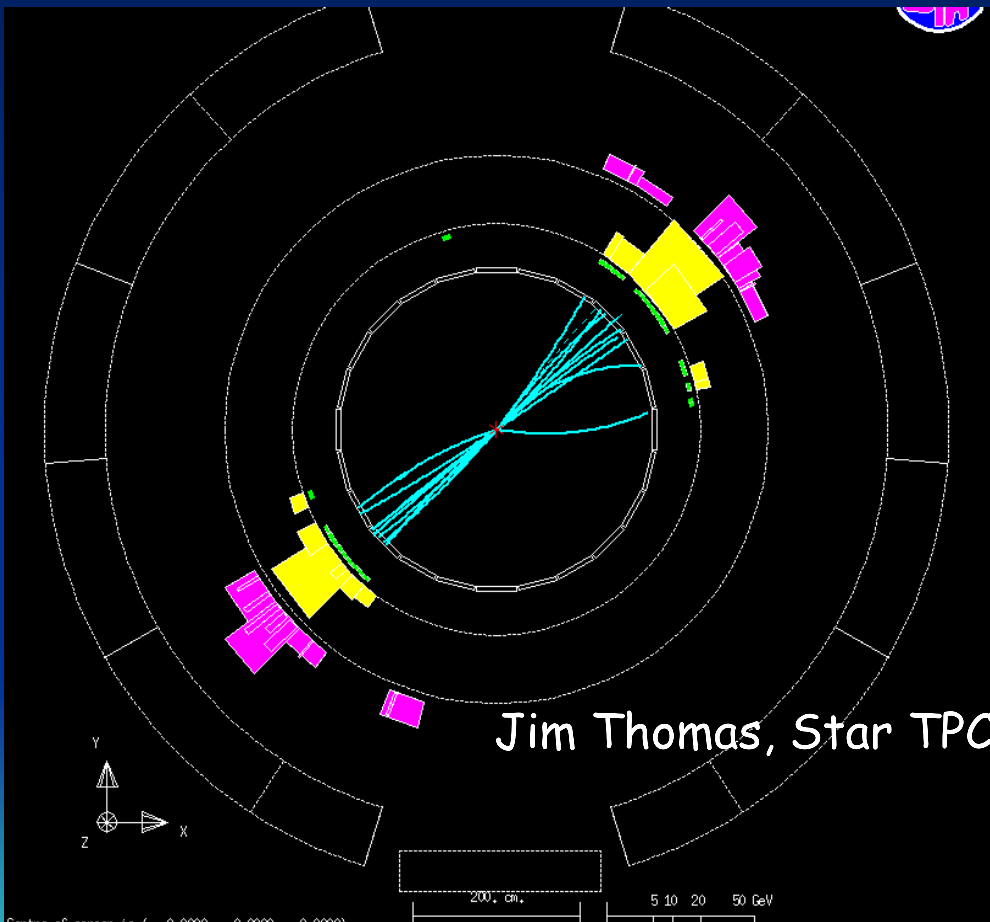
Near future plans (~2010)

- 7 modules Micromegas w. T2K electr. in 'flip-chip' mounting (7x1700 ch.)
- Up to 4 modules of (Asian) double-GEM + gating-GEM w. 10,000 ch. ALTRO electr.
- Development of new 'stiffer' GEM module/mounting
- Development S-ALTRO 0.13um chip; 16ch prototype Spring 2010; final 64ch version needs funding
- New endplate (some funding available):
  - Thinning of present design: could reach close to .15 X_0 (2 yrs)
  - New technology (e.g. C) or spaceframe design study (~3 yrs)
- Development "full" endplate module w. Timepix (64/119 chips)
- Development new fieldcage w. laser tracking capability, including improved HV cathode connection

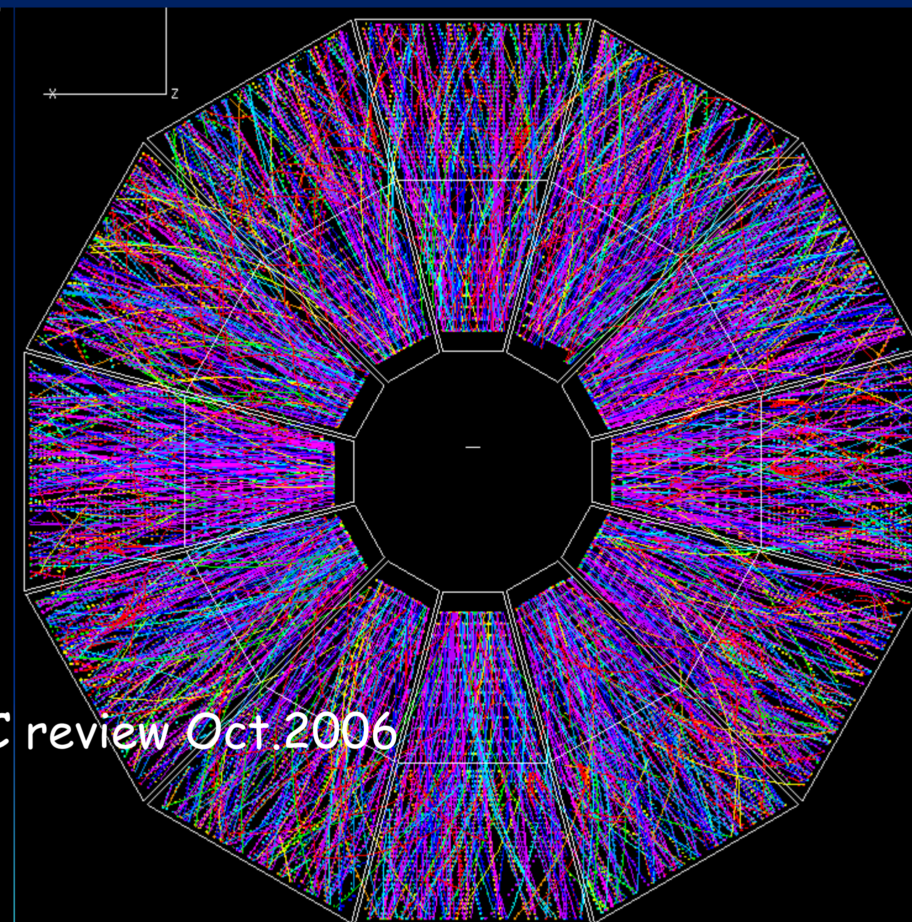
Backgrounds

Jet Physics … it is easier to find one in e^+e^-

Jet event in e^+e^- collision



STAR Au+Au collision



Jim Thomas, Star TPC review Oct.2006

assumed for ILD, 150 BXs of beam-related background correspond to a voxel occupancy of approximately 0.05 % (the TPC voxel size is taken to be 1 mm in the ϕ direction, 6 mm in r and 5 mm in z).

Figure 1.2-5 shows the TPC hits for a single $t\bar{t}$ event at $\sqrt{s} = 500$ GeV overlayed with 150 BXs of pair-background hits. On average there are 265,000 background hits in the TPC, compared to the average number of signal hits of 23100 (8630 from charged particles with p_T >1 GeV). Even with this level of background, the tracks from the $t\bar{t}$ event are clearly visible in the $r\phi$ view. A significant fraction of the background hits in the TPC arise from low energy electrons/positrons from photon conversions. These low energy particles form small radius helices parallel to the z axis, clearly visible as lines in the rz view. These "micro-curlers" deposit charge on a small number of TPC pads over a large number of BXs. Specific pattern recognition software has been written to identify and remove these hits prior to track reconstruction. (Whilst not explicitly studied, similar cuts are expected to remove a significant fraction of hits from beam halo muons.) Figure 1.2-6 shows the TPC hits after removing hits from micro-curlers. Whilst not perfect, the cuts remove approximately 99 % of the background hits and only 3 % of hits from the primary interation and the majority of these are from low p_T tracks. Less than 1 % of hits from tracks with p_T >1 GeV originating from the $t\bar{t}$ event are removed.

This level of background hits proves no problem for the track-finding pattern recognition software, as can be seen from Figure 1.2-7. Even when the background level is increased by a factor of three over the nominal background no degradation of TPC track finding efficiency is observed for the 100 events simulated. This study demonstrates the robustness of TPC tracking in the ILC background environment.

These conclusions are supported by an earlier study based on a detector concept with $B = 3.0$ T, a TPC radius of 1.9 m and TPC readout cells of $3 \times 10\,\mathrm{mm}^2$. This earlier study used a uniform distribution of background hits in the TPC volume, but included a very detailed simulation of the digitised detector response and full pattern recognition is performed in both time and space. The TPC reconstruction efficiency as a function of the noise occupancy is presented in Section ??; there is essentially no loss of efficiency for 1 %

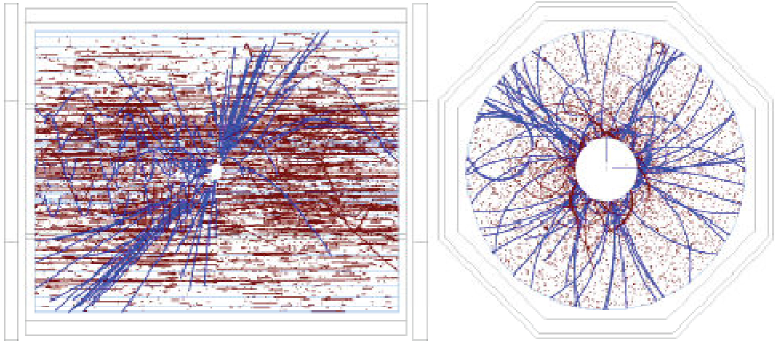


FIGURE 1.2-5. The rz and $r\phi$ views of the TPC hits from a 500 GeV $t\bar{t}$ event (blue) with 150 BXs of beam background (red) overlayed.

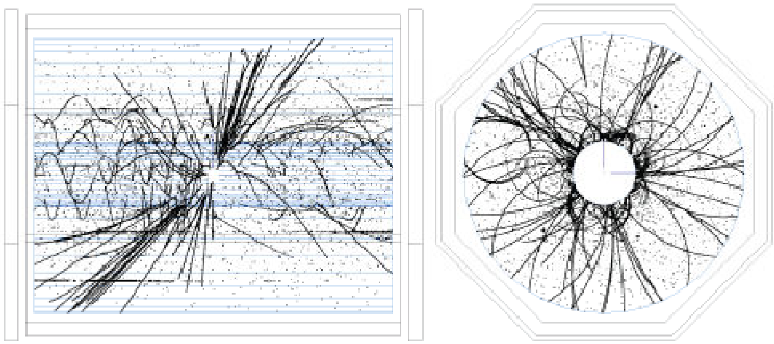


FIGURE 1.2-6. The same event as the previous figure, with the micro-curler removal algorithm applied. This is the input to the TPC track finding algorithm.

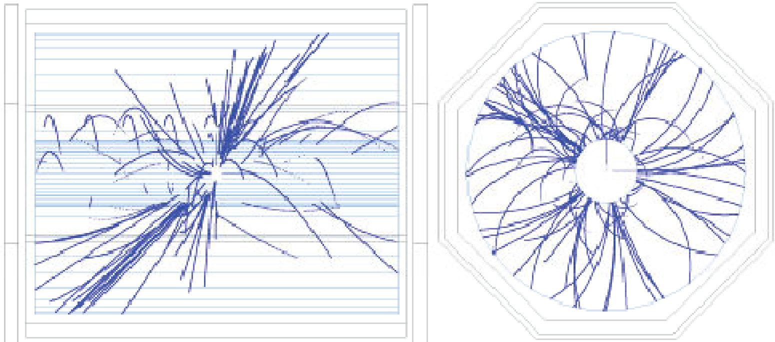


FIGURE 1.2-7. The same event as the previous plot, now showing the reconstructed TPC tracks.

occupancy (uniformly distributed through the TPC). It should be noted that this level of occupancy is twice the nominal occupancy at the TPC inner radius and about fifty times the typical total occupancy in the TPC.

1.2.2.2 Background in the Vertex Detector

The impact of background in the vertex detector (VTX) depends on the assumptions made for the Silicon read-out time. If one were to assume single BX time-stamping capability in the vertex detector, the anticipated background level is negligible. However, it is anticipated that the readout of the Silicon pixel ladders will integrate over many BXs. For the studies presented here, it is assumed that vertex detector readout integrates over 83 and 333 BXs for the inner two and outer four layers respectively. For the silicon strip-based SIT detector, single BX time-stamping is assumed. Hence the background hits which are superimposed on the physics event correspond to 1 BX in the SIT, 150 BXs in the TPC and 83/333 BXs in

Occ. @ ILC < 0.1%

⇒

Occ. @ Clic ~ 3%

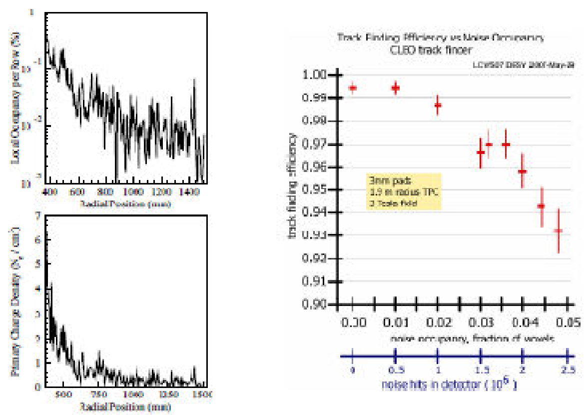


FIGURE 4.3-4. Occupancy for $xyz = 1 \times 5 \times 5\mathrm{mm}^3$ voxels (left, top) and space charge(left, bottom) due to the major beam-beam effects (beamstrahlung photons, electron-positron pairs and neutrons) as simulated in [83]. Study of the tracking efficiency in the presence of backgrounds (right); this study [89] assumed a conservative voxel size of $3 \times 10 \times 40\mathrm{mm}^3$.

ciency in the presence of backgrounds which will be discussed here. There are backgrounds from the collider, from cosmics or other sources and from physics events. The main source is the collider, which gives rise to gammas, neutrons and charged particles due to $\gamma\gamma$ interactions and beam-halo muons being deposited in the TPC at each bunch-crossing [78]. Simulations of the main sources [83] arising from beam-beam effects–gammas, pairs and neutrons–under nominal conditions indicate an average occupancy of the TPC of less than 0.1%, Fig. 4.3-4 (left). The TPC track finding remains robust at these occupancies, the continuous 3D-granularity tracking is inherently simple and suffers no loss in efficiency with a uniform 1% noise occupancy as demonstrated by the study in Figure 4.3-4(right).

Since the backgrounds at the beginning of operation could be much larger until the linear collider machine is well understood, the LCTPC is preparing for an occupancy of 10%.

Corrections for non-uniform fields

Both fields, (A) magnetic and (B) electric, can have non-uniformities which must be corrected. The (C) chamber gas will play a crucial role in minimizing corrections.

(A) Magnetic field

Non-uniformity of the magnetic field of the solenoid will be by design within the tolerance of $\int_{\ell_{drift}} \frac{B_r}{B_z} dz < 2-10\mathrm{mm}$ as used for previous TPCs. This homogeneity is achieved by corrector windings at the ends of the solenoid. At the ILC, larger gradients will arise from the fields of the DID (Detector Integrated Dipole) or anti-DID, which are options for handling the beams inside the detector at an IR with ±7 mrad crossing-angle. This issue was studied intensively and summarized in [90], where it is concluded that the TPC performance will not be degraded if the B-field is mapped to around 10^{-4} relative accuracy and the procedures outlined below (under **Alignment**) are followed. These procedures will lead to an overall systematic error

Next steps, from the LOI:

- 2009-12 Continue R&D on technologies at LP, SP, pursue simulations, verify performance goals (see next slide)
- 2009-11 Plan and do R&D on advanced endcap; power-pulsing, electronics and mechanics are critical issues.
- 2011-12 Test advanced-endcap prototype at high energy and power-pulsing in high B-field.
- 2013-18 Design and build the LCTPC.

At the beginning of the period 2012-18, the selection must be made from the different technological options – GEM, MicroMegas, resistive anode, pixel, electronics, endcap structure – to establish a working model for the design of the LCTPC. This design will be used for the ILD proposal in 2012 and include pad segmentation, electronics, mechanics, cooling and integration, so that performance, timeline and cost can be estimated reliably. [2] For the technology selection, a scenario could be that questions must be answered as to which options give the best performance based on R&D results from LP, SP, electronics and endcap studies. Main performance criteria could be endcap thickness and $\sigma_{\rm point}$, double-hit and momentum resolution for single tracks and for tracks in a jet environment. Choice of criteria to use will be decided over the next two years.

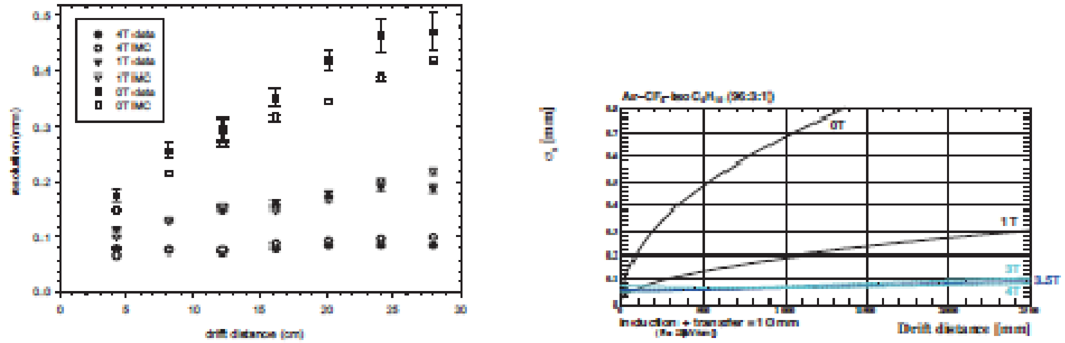


FIGURE 4.3-5. (left): Example of resolution results from a small prototype [92] measurements with TDR gas, $ArCH_4CO_2$ (95-3-2); other candidate gases are e.g. P5 and $ArCF_4$Isobutane. (Right): Theoretical resolution for $ArCF_4$Isobutane (96-3-1) gas (right), based on an algorithm [79] verified during SP studies.

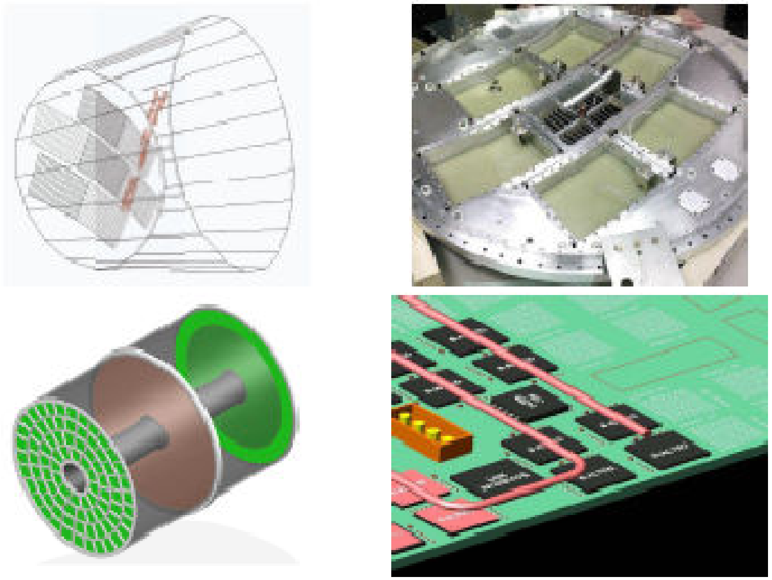


FIGURE 4.3-6. (Top left): Event display from the LP beam tests. (Top right) View of the Endcap subdivision as used for the Large Prototype. (Bottom left)Conceptual design of enplate for LCTPC. (Bottom right) Possible layout of PCB, electronics and cooling for the LCTPC.

‘After LOI’ bottom line:

We LCTPC have to make certain decisions and write them up by the end of 2012…

TPC R&D Priorities

1a) advanced endplate studies (max. 15% X0 including cooling)
1b) continue tests in electron beam for correction procedures
2a) future tests in hadron beam
 a) for momentum resolution
 b) for two-track resolution in a jet environment
2b) powerpulsing/cooling tests, both on LP and SP
3) ion backflow studies:
 a) simulations of ion sheets for Gem, Micromegas
 b) design/test gating device

Road map for test beams

Table 1: LCTPC R&D Scenarios for Large Prototype and Small Prototypes.

Large Prototype R&D		
Device	Lab(years)	Configuration
LP1	Desy/Eudet(2007-2010)	Fieldcage⊕2 endplates: GEM+pixel, Micromegas+pixel
		Purpose: Test construction techniques using ∼10000 Altro or T2K channels to demonstrate measurement of 6 GeV/c beam momentum over 70cm tracklength, including development of correction procedures.
LP1.5	FLorCern/Aida?(fp7)	Fieldcage⊕2 endplates: GEM+pixel, Micromegas+pixel
		Purpose: Continue tests using 10000 Altro or T2K channels to demonstrate measurement of 100GeV beam momentum over 70cm tracklength, in a jet environment and with ILC beam structure using LP1.
LP2	FLorCern/Aida?(fp7)	Fieldcage⊕endplate: GEM, Micromegas, or pixel
		Purpose: Prototype for LCTPC including gating and other options, demonstrate measurement of 100GeV beam momentum over 70cm tracklength, and in jet evironment and ILC beam structure, test prototype LCTPC electronics/PP.

Small Prototype R&D Examples		
Device	Lab(years)	Test
SP1	KEK(2007-2009)	Gas tests, gating configurations
SP2,SP3	FLorCern(2009-2011)	Performance in jet environment
SPn	LCTPC groups(2007-2012)	Performance, gas tests, dE/dx measurements, continuation of measurements in progress by groups with small prototypes

Bottom line for testbeam: move LP to hadron beam end of 2010

Design team being set up after discussions at LCTPC collaboration mtg 21 Sept

TPC design/performance discussion at LCTPC collaboration meeting 20090921

Overview Ties Behnke

Mechanics design
---overall mechanics
tolerances for alignment Dan Peterson, Ron Settles

---fieldcage Peter Schade

---advanced endcap Dan Peterson

---overall structure Robert Volkerborn, Michael Carty

---mpgd+gate Akira Sugiyama

---cooling CO2 from Nikhef?

Electronics
---sAltro
Luciano Musa
Magnus Mager
Antoine Junique

---power-pulsing etc
Takahiro Fusayasu

R&D steps(incl. beam)2009-2012
---LP issues/plans
Klaus Dehmelt

---engineering R&D
LOI + more discussion

How to make technical choices in 2012
First ideas in LOI

> 1 TeV

LCTPC Collaboration

- Performance goals and design parameters for a TPC with standard electronics at the ILC detector

Size	$\phi = 3.6$m, L = 4.3m outside dimensions
Momentum resolution (3.5T)	$\delta(1/p_t) \sim 9 \times 10^{-5}$/GeV/c TPC only ($\times$ 0.4 if IP incl.)
Momentum resolution (3.5T)	$\delta(1/p_t) \sim 2 \times 10^{-5}$/GeV/c (SET+TPC+SIT+VTX)
Solid angle coverage	Up to $\cos\theta \simeq 0.98$ (10 pad rows)
TPC material budget	$\sim 0.04X_0$ to outer fieldcage in r $\sim 0.15X_0$ for readout endcaps in z
Number of pads/timebuckets	$\sim 1\times10^6$/1000 per endcap
Pad size/no.padrows	$\sim$ 1mm$\times$4–6mm/$\sim$200 (standard readout)
σ_{point} in $r\phi$	$< 100\mu$m (average over $L_{sensitive}$, modulo track ϕ angle)
σ_{point} in rz	$\sim$ 0.5 mm (modulo track θ angle)
2-hit resolution in $r\phi$	$\sim$ 2 mm (modulo track angles)
2-hit resolution in rz	$\sim$ 6 mm (modulo track angles)
dE/dx resolution	$\sim$ 5 %
Performance	$>$ 97% efficiency for TPC only ($p_t > 1$GeV/c), and $>$ 99% all tracking ($p_t > 1$GeV/c)
Background robustness	Full efficiency with 1% occupancy
Background safety factor	Chamber will be prepared for 10 $\times$ worse backgrounds at the linear collider start-up

with MPGD

NO DIFFERENCE for CLIC, because this is ~ best you can do with standard readout.

What about pixels? Potentially more accurate, see Jan's talk from this morning…

Conclusions:

WIP

Backup

Mark Thomson: ILD size good for Cilc?

PandoraPFA/ILD Jet Energy Resolution

- ★ Is an ILD-sized detector suitable for CLIC ?
- ★ Defined modified ILD⁺ model:
  - B = 4.0 T (ILD = 3.5 T)
  - HCAL = 8 λ_I (ILD = 6 λ_I)
- ★ Effect on jet energy resolution

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	25.2 %	3.7 %
100 GeV	29.2 %	2.9 %
180 GeV	40.3 %	3.0 %
250 GeV	49.3 %	3.1 %
375 GeV	81.4 %	3.6 %
500 GeV	91.6 %	4.1 %

⇨

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	25.2 %	3.7 %
100 GeV	28.7 %	2.9 %
180 GeV	37.5 %	2.8 %
250 GeV	44.7 %	2.8 %
375 GeV	71.7 %	3.2 %
500 GeV	78.0 %	3.5 %

NOTE:

- ★ Meet "LC jet energy resolution goal [3.5%]" for 500 GeV ! jets
- ★ Importantly, PFA is still working for 500 GeV jets
  - ★ Raw calo. energy : 5.2 %
  - ★ PandoraPFA : 3.5 %

Looks promising…

ALCPG Meeting, Albuquerque, 29/9/2009 Mark Thomson 16