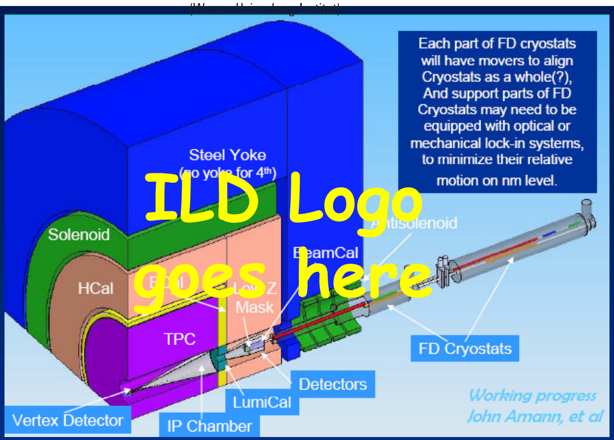
Max-Planck-Institut für Physik

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




# TPC R&D for an LC detector @

# 1. √s < 1 TeV (ILC)

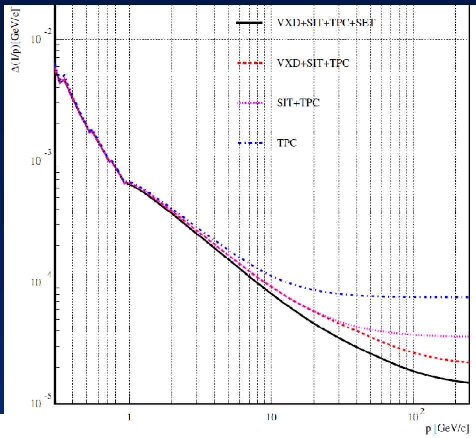
# 2. √s > 1 TeV (CLIC)


# Coherent layout of detector:

-VTX:perf,,min.material

-TRK:perf.,min.material

-CALO:granularity




ILD Detector Performance

## 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, $\theta$, 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.

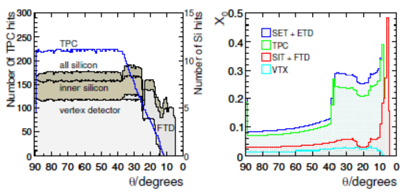
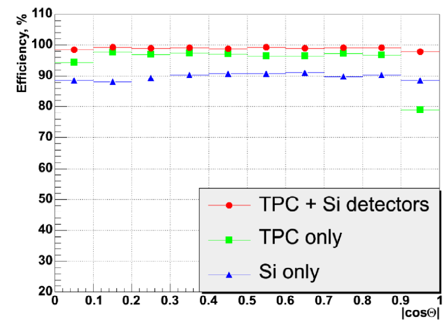



FIGURE 3.2-2. a) Average number of hits for simulated charged particle tracks as a function of polar angle. b) Average total radiation length of the material in the tracking detectors as a function of polar angle.

ILD - Letter of Intent 27

**P_t > 1 GeV/c**




Performance Requirements

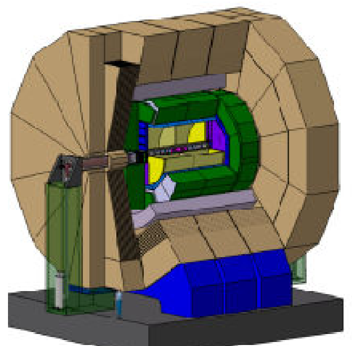


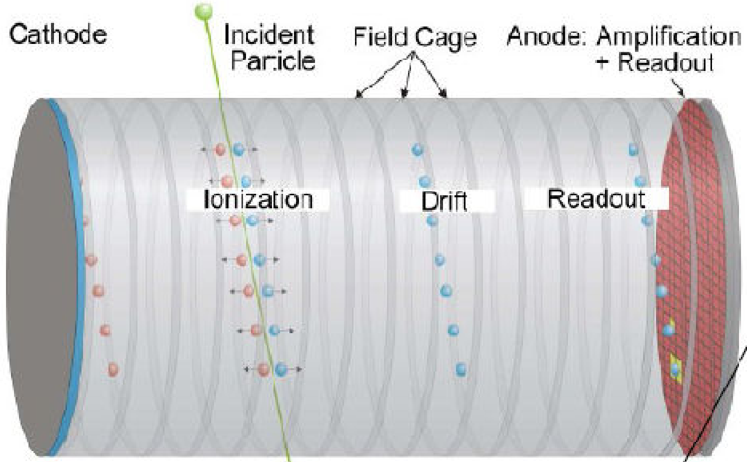
FIGURE 1.2-1. View of the ILD detector concept.

# LC-TPC Motivation/Goals

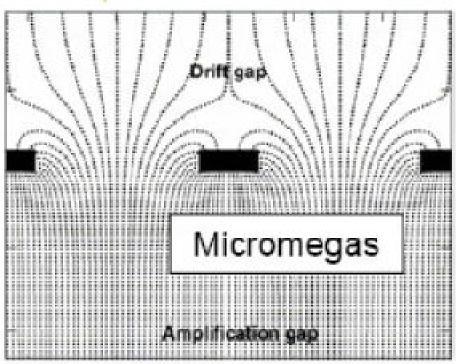
…to be tested@the R&D where possible…

- 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)
- $\sigma_{pt}$ ~ 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

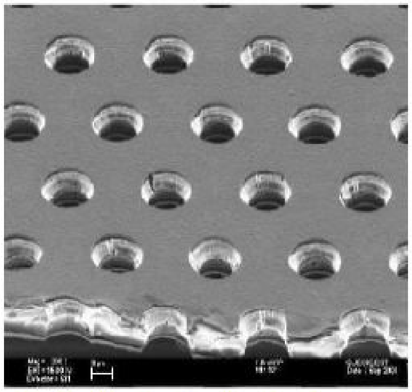
# TPC with MPGD

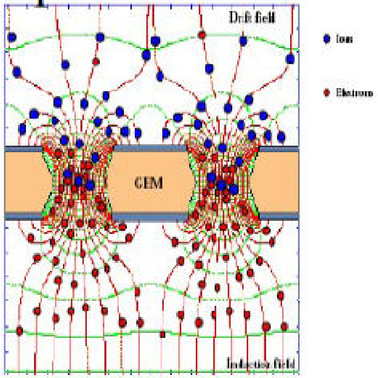



MicroPatternGasDetector
MPGD
not limited by **E** x **B** effects




Gas Electron Multiplier GEM






ALCPG 2009
Sept 30, 2009

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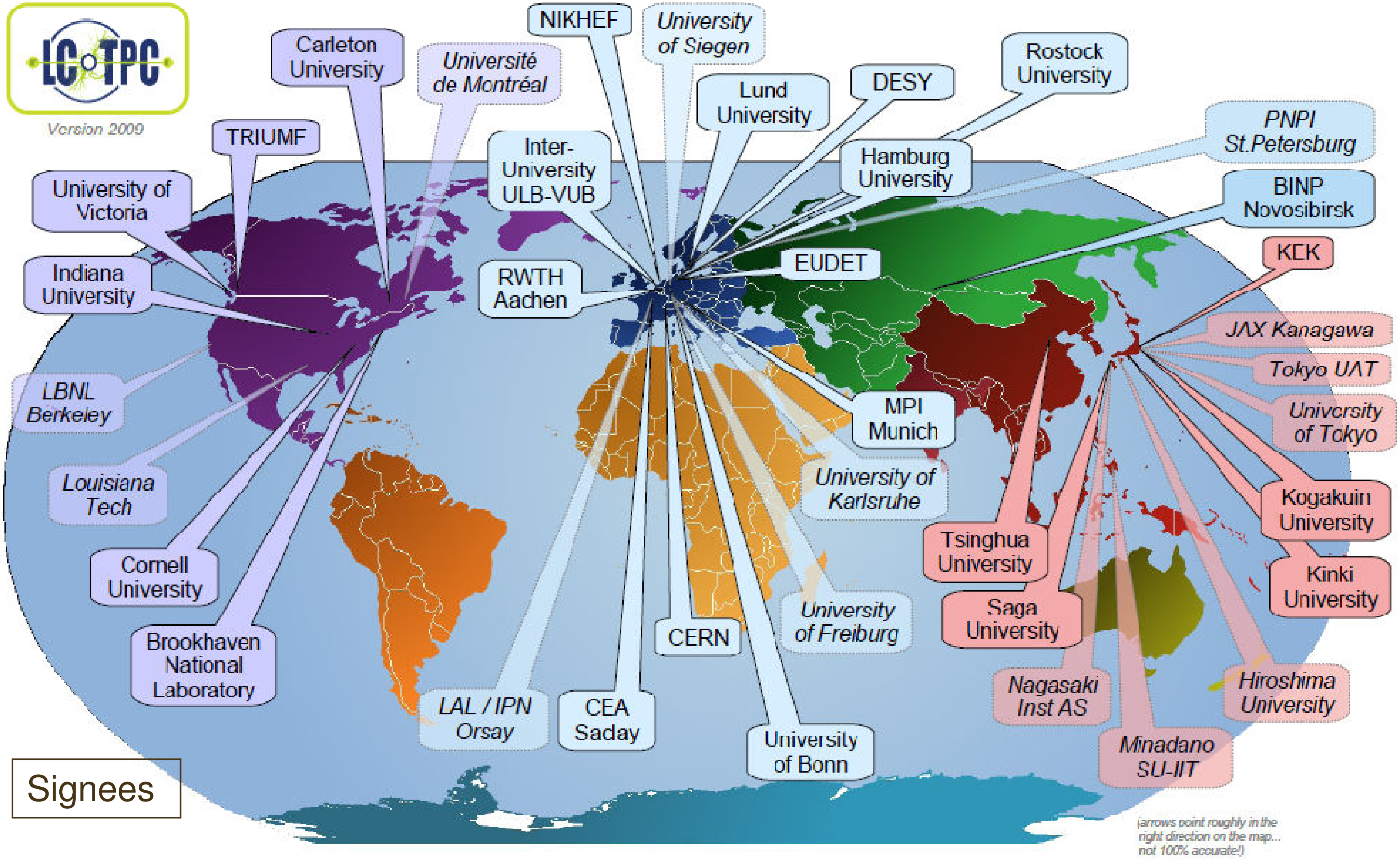
K. Dehmelt

# TPC Collaboration 2009



# TPC R&D Planning

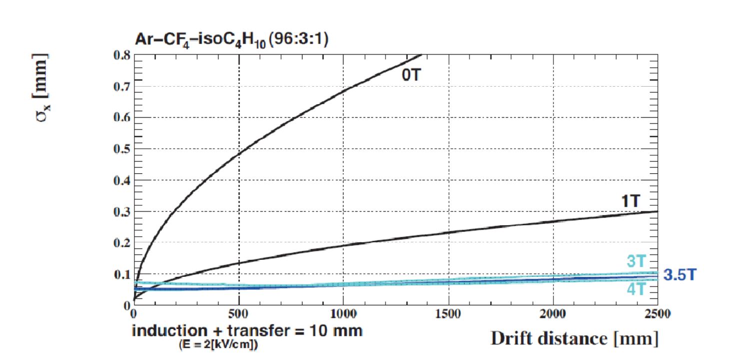
- 1) Demonstration phase
  - Continue work with small prototypes (SP) on mapping out parameter space, understanding resolution, etc, to improve the design of an MPGD TPC.
- 2) Consolidation phase
  - Build and operate the Large Prototype (LP), Ø ~ 90cm, drift ~ 60cm together with SIT prototype, with 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

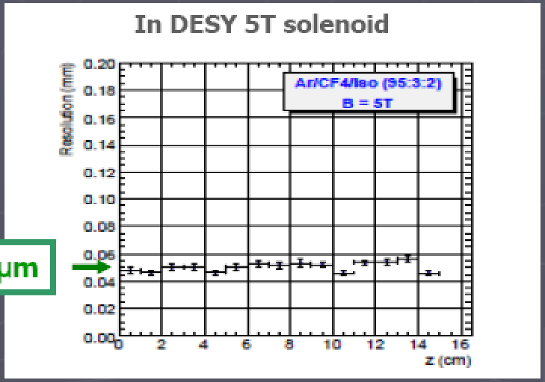
Present goals based on results from small prototypes using cosmics or beams at KEK, DESY, CERN. Three options left →

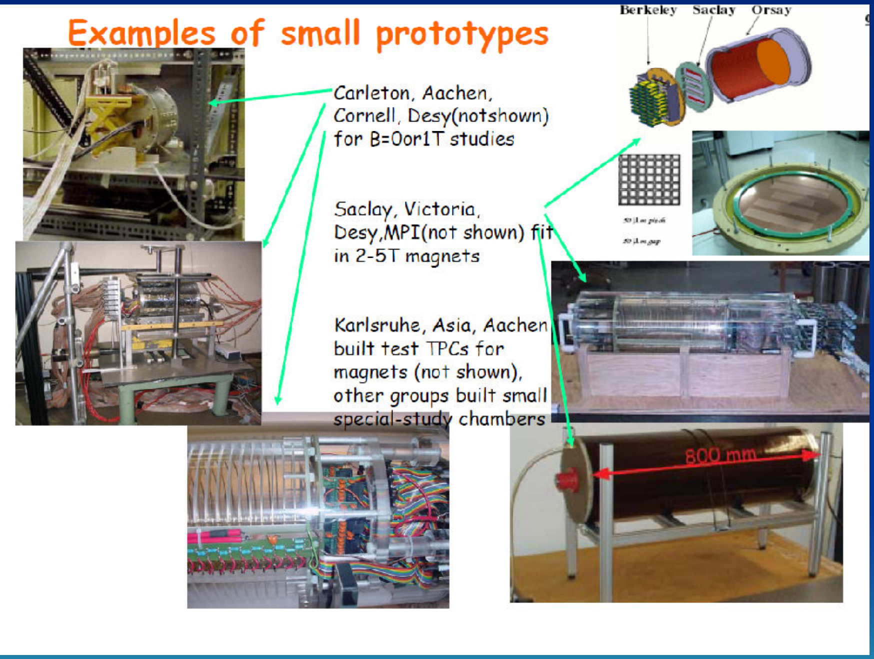
**GEM gas-amplif. for a TPC**



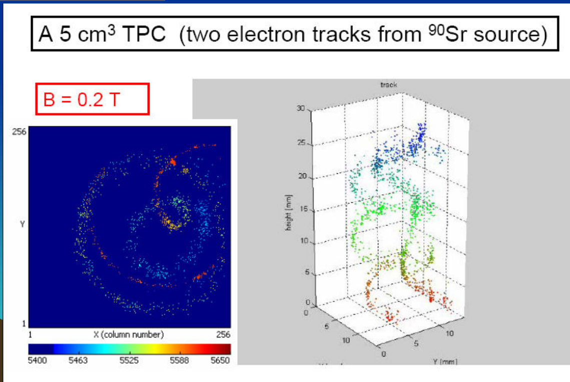

**MicroMEGAS TPC with resistive anode**

**Carleton TPC (M. Dixit et al., 2007)**




**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: see Klaus Dehmelt's talk preceeding this one.

# Road map for test beams



Table 1 for LCTW09.

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 | FL?Cern/Aida?(2011) | 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 | FL?Cern/Aida?(2012) | 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(2007-2010) | Gas tests, gating configurations |
| SP2,SP3 | FL?Cern(2010-2011) | 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 |

# 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

# 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

**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

# 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 $\sigma_{\mathrm{point}}$, 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.

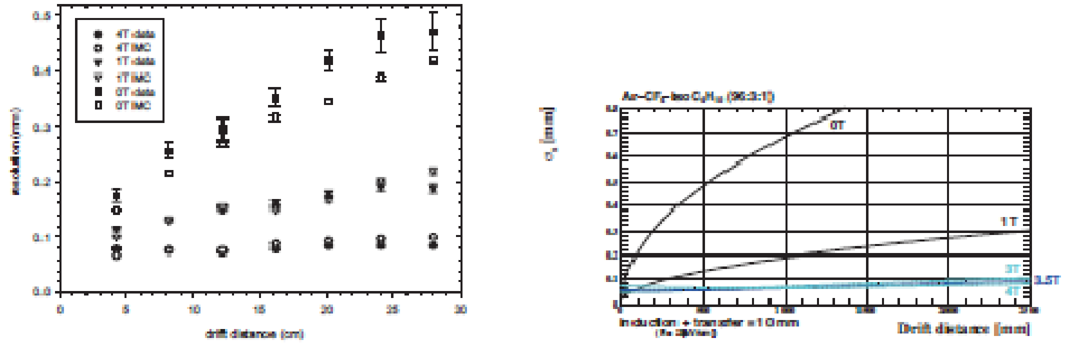



FIGURE 4.3-5. (left): Example of resolution results from a small prototype [92] measurements with TDR gas, $ArCH_4CO_2$ (95-3-2); other candidate gases are e.g. P5 and $ArCF_4$Isobutane. (Right): Theoretical resolution for $ArCF_4$Isobutane (96-3-1) gas (right), based on an algorithm [79] verified during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

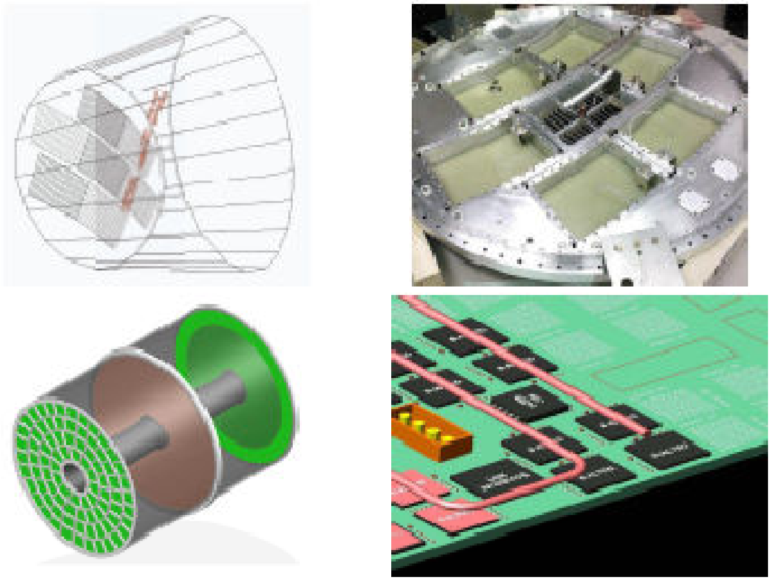


FIGURE 4.3-6. (Top left): Event display from the LP beam tests. (Top right) View of the Endcap subdivision as used for the Large Prototype. (Bottom left)Conceptual design of enplate for LCTPC. (Bottom right) Possible layout of PCB, electronics and cooling for the LCTPC.

**‘After LOI’ bottom line:**

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

# Conclusions:

# WIP

# Backup

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

TPC info mainly from ILDLOI, recent lctpc collaboration meeting, ALCPG09, EUDET09

# Large Prototype TPC

## Performance goals…

# LCTPC Collaboration

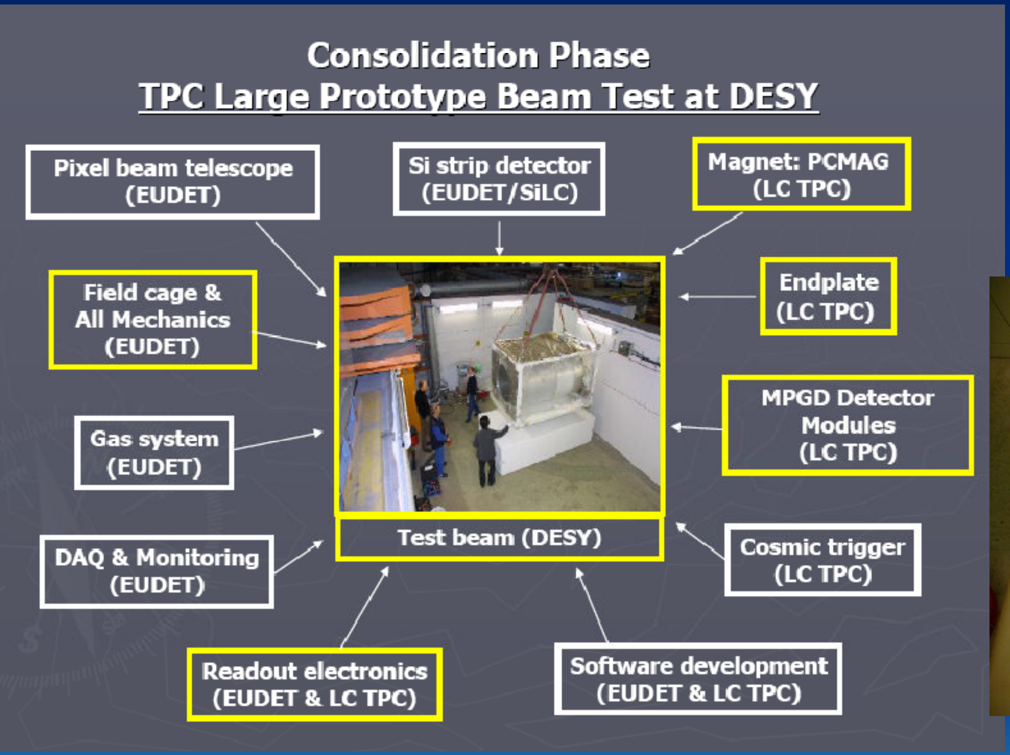
- Performance goals and design parameters for a TPC with standard electronics at the ILC detector

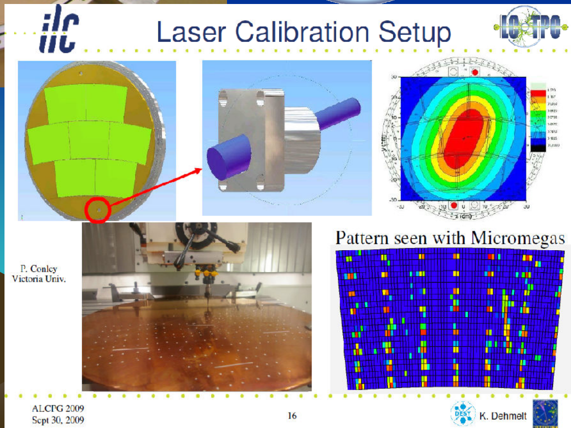
| | |
|---|---|
| Size | $\phi$ = 3.6m, L = 4.3m outside dimensions |
| Momentum resolution (3.5T) | $\delta(1/p_t) \sim 9\times10^{-5}$/GeV/c TPC only ($\times$ 0.4 if IP incl.) |
| Momentum resolution (3.5T) | $\delta(1/p_t) \sim 2\times10^{-5}$/GeV/c (SET+TPC+SIT+VTX) |
| Solid angle coverage | Up 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) |
| $\sigma_{\rm point}$ in $r\phi$ | $<100\mu m$ (average over $L_{sensitive}$, modulo track $\phi$ angle) |
| $\sigma_{\rm point}$ in $rz$ | $\sim$ 0.5 mm (modulo track $\theta$ 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 ($p_t$ > 1GeV/c), and |
| | > 99% all tracking ($p_t$ > 1GeV/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 |

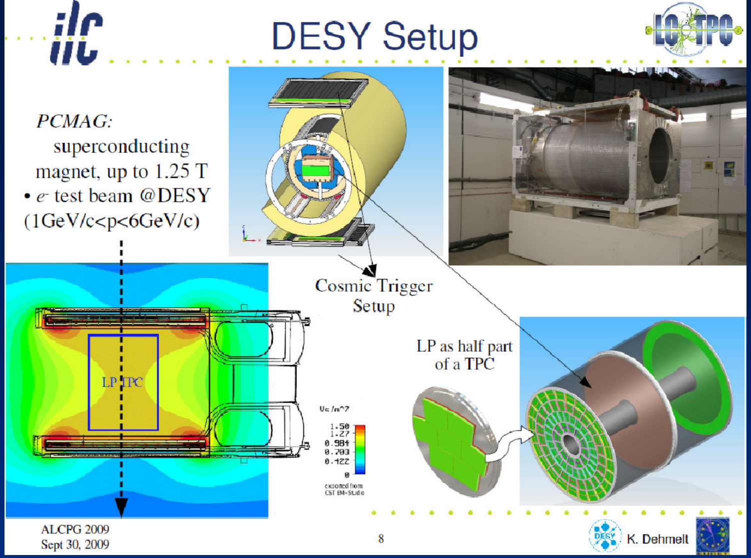
with MPGD

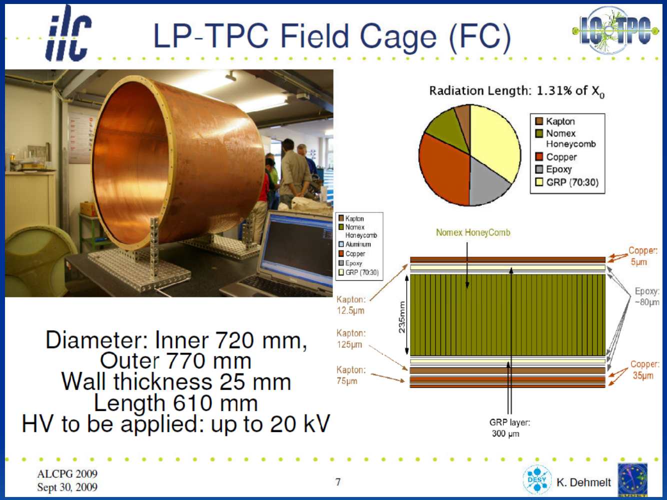
# LCTPC performance goals…

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



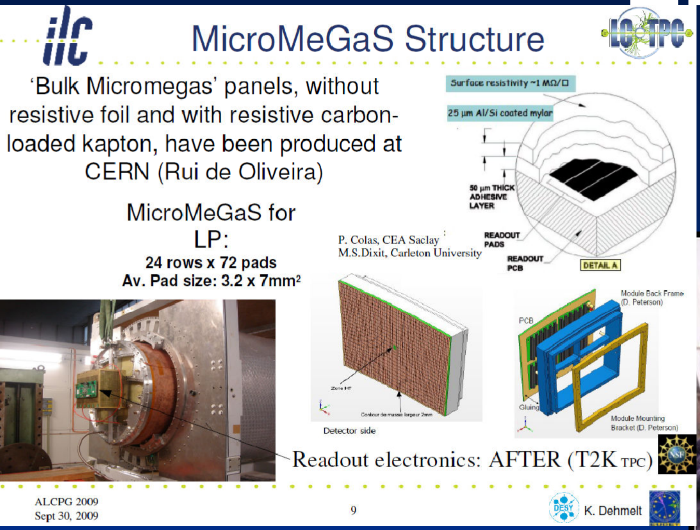



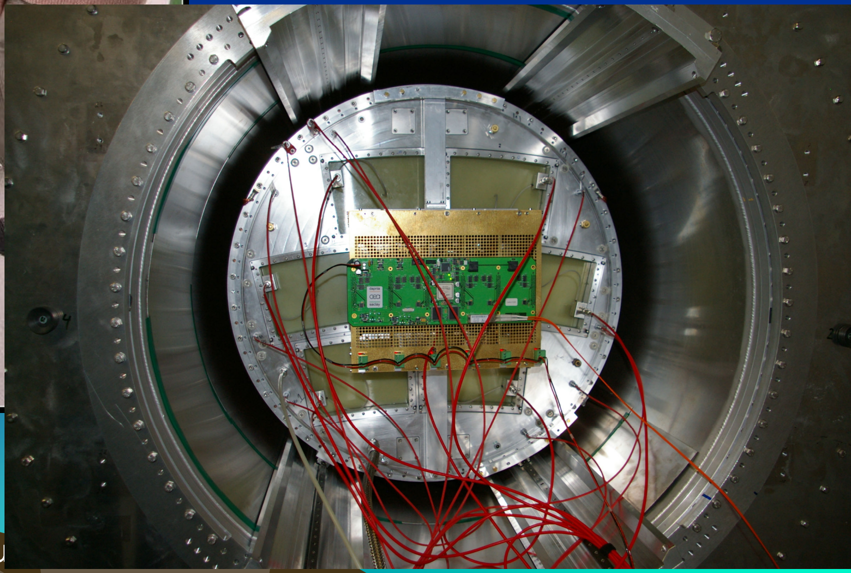



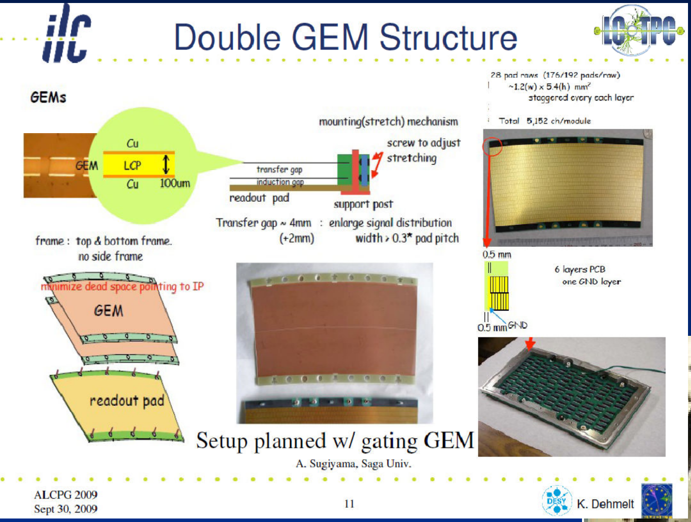

- Software goals: Develop MarlinTPC to reconstruct:
  - Technology's signals (GEM, Micromegas, Pixel)
  - Correct distortions (B,Efields)

# LP - MicroMeGaS



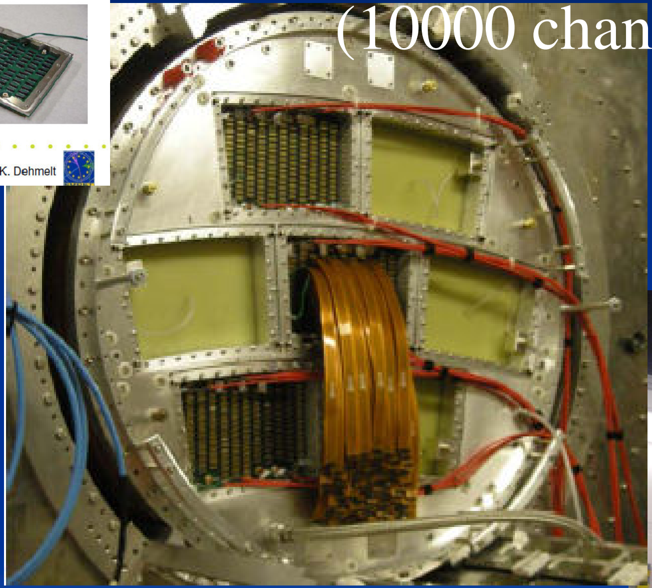



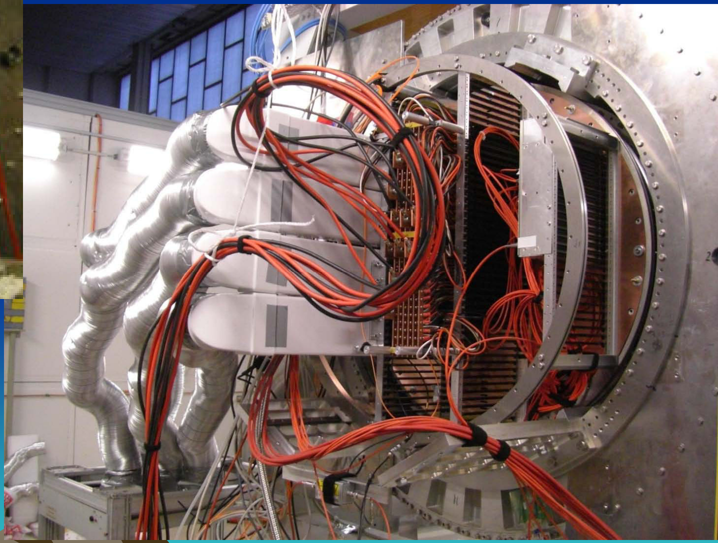
# Double GEM



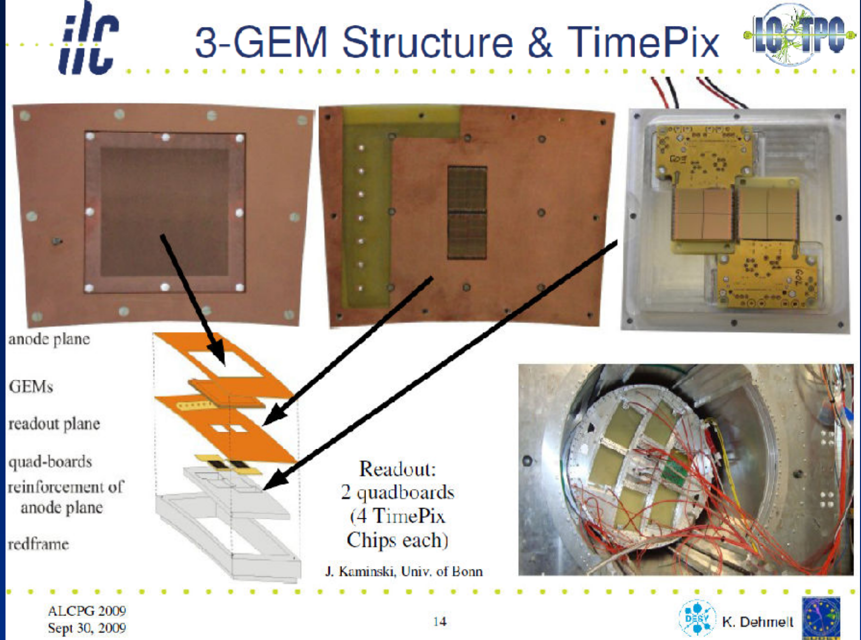

About 3200 channels readout electronics (Altro/Alice) CERN&Lund

(10000 channels later in 2009)





Triple-Gem being prepared by Desy group


ilc
3-GEM Structure & TimePix
LC-TPC
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
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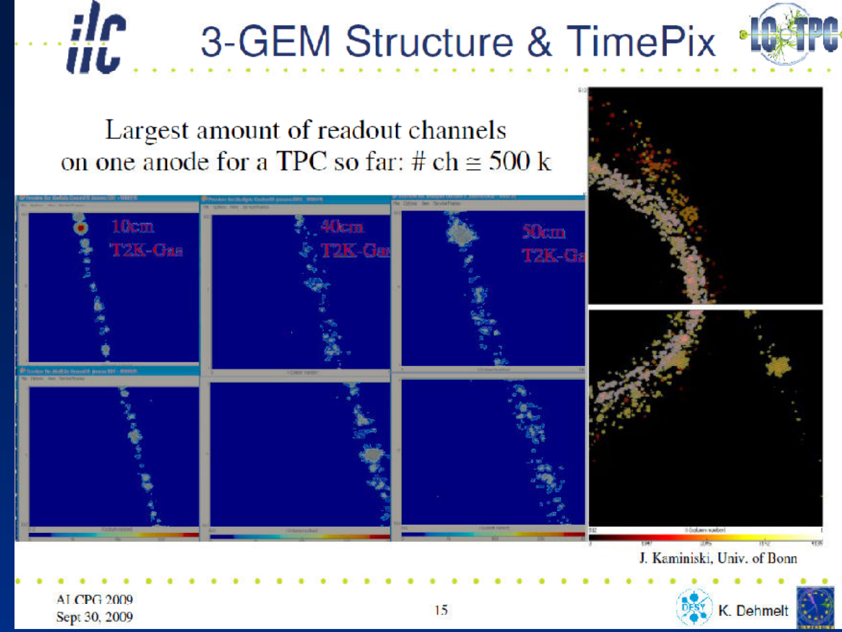
K. Dehmelt


ilc
3-GEM Structure & TimePix
LC-TPC
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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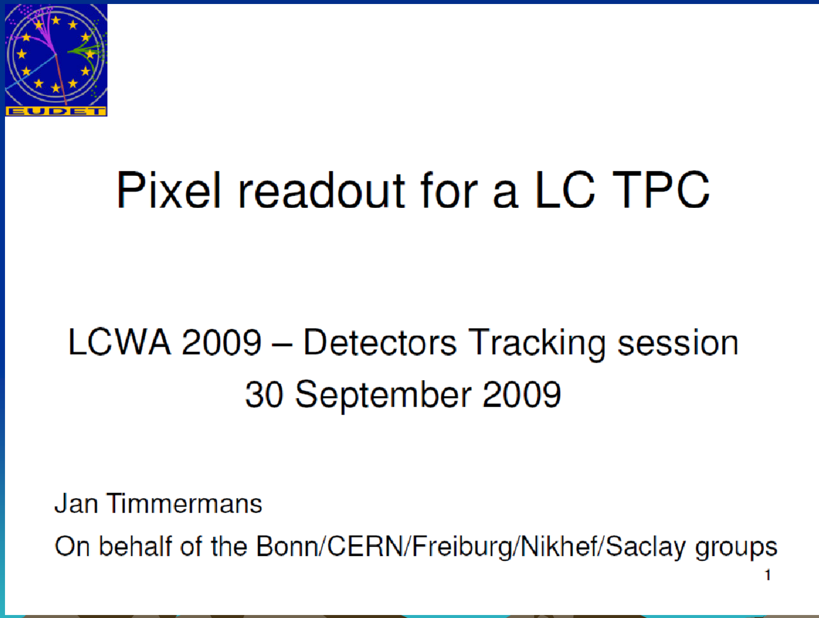
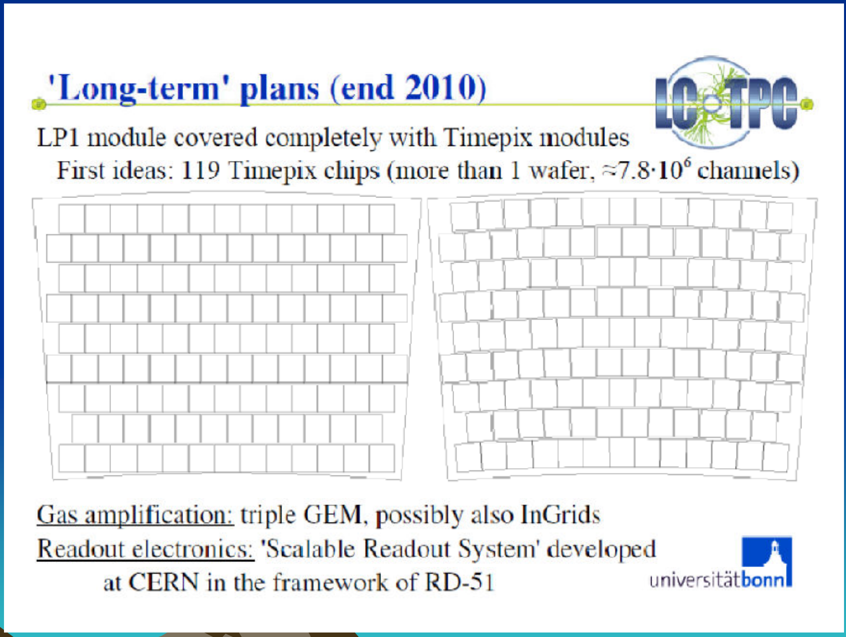
K. Dehmelt


EUDET
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)
LC-TPC
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
universität bonn

**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**

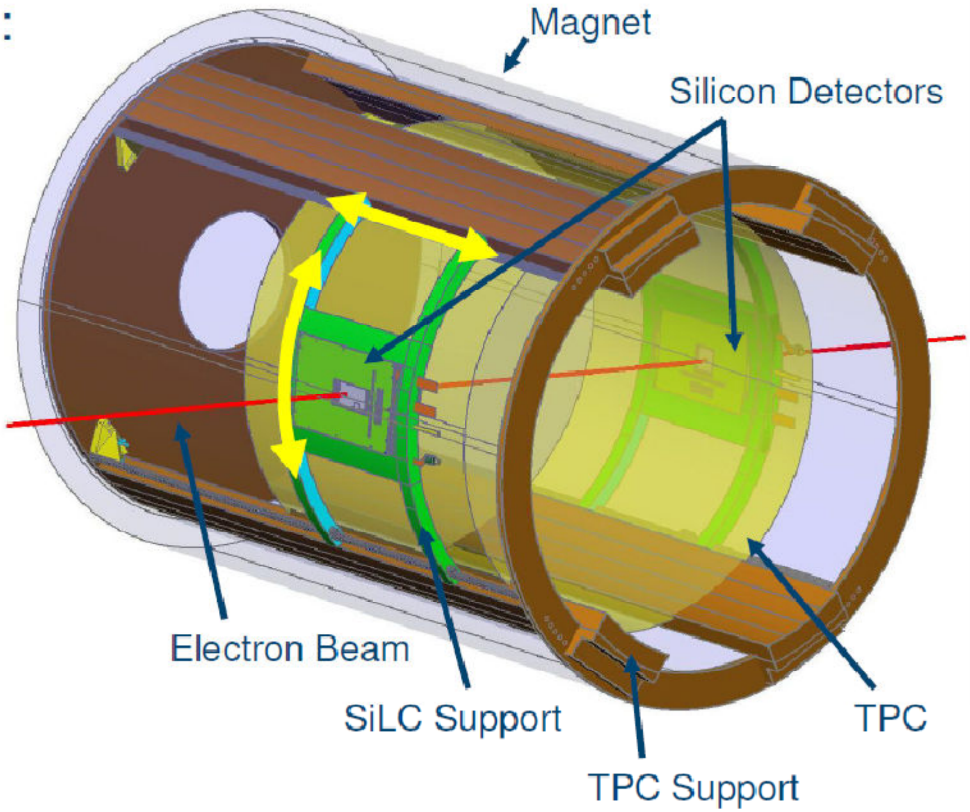
HEPHY+Karlsruhe

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.



# > 1 TeV (CLIC09)

# LCTPC Collaboration

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| $\sigma_{point}$ in $rz$ | ~ 0.5 mm (modulo track $\theta$ angle) |
| 2-hit resolution in $r\phi$ | ~ 2 mm (modulo track angles) |
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| dE/dx resolution | ~ 5 % |
| Performance | > 97% efficiency for TPC only ($p_t$ > 1GeV/c), and<br>> 99% all tracking ($p_t$ > 1GeV/c) |
| Background robustness | Full efficiency with 1% occupancy |
| Background safety factor | Chamber will be prepared for 10 × 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…**

# 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 $\lambda_I$ (ILD = 6 $\lambda_I$)
- ★ Effect on jet energy resolution

| $E_{JET}$ | $\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$ | $\sigma_E/E_j$ |
|---|---|---|
| 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 % |

⇨

| $E_{JET}$ | $\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$ | $\sigma_E/E_j$ |
|---|---|---|
| 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…

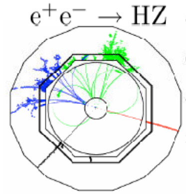
ALCPG Meeting, Albuquerque, 29/9/2009 Mark Thomson 16

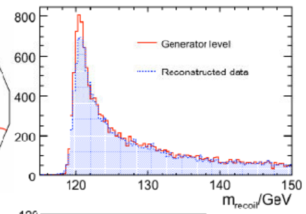
# ILC Detector Requirements

M. Thomson

★ momentum: (1/10 x LEP)
e.g. Muon momentum
Higgs recoil mass

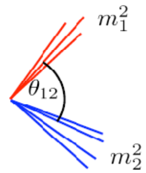
$\sigma_{1/p} < 5 \times 10^{-5}\,\mathrm{GeV}^{-1}$

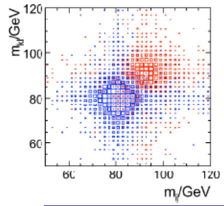



★ jet energy: (1/3 x LEP/ZEUS)
e.g. W/Z di-jet mass separation
EWSB signals

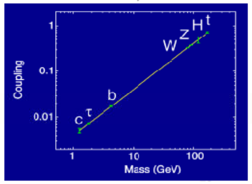
$\frac{\sigma_E}{E} \approx 3-4\%$




★ impact parameter: (1/3 x SLD)
e.g. c/b-tagging Higgs BR

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




★ hermetic: down to θ = 5 mrad
e.g. missing energy signatures in SUSY

Dieter Schlatter - 21.10.09

# From ILC to CLIC Detector Requirements

On assumption that CLIC would be staged: e.g. 500 GeV → 3 TeV
- Must meet all ILC detector goals
- Hence ILD and SiD represent good starting points
- Requirements for 500 GeV are VERY demanding, may still be ok at 3 TeV.

What are the detector requirements at 3 TeV?
- Still want to separate W/Z hadronic decays → good jet energy resolution
- Heavy flavour-tagging still will be important; → good vertex resolution heavy new bosons decay to b quarks, higher boost of b/c-hadrons will help.
- Measure high $p_T$ muons in cascade decays of heavy new particles → good momentum resolution

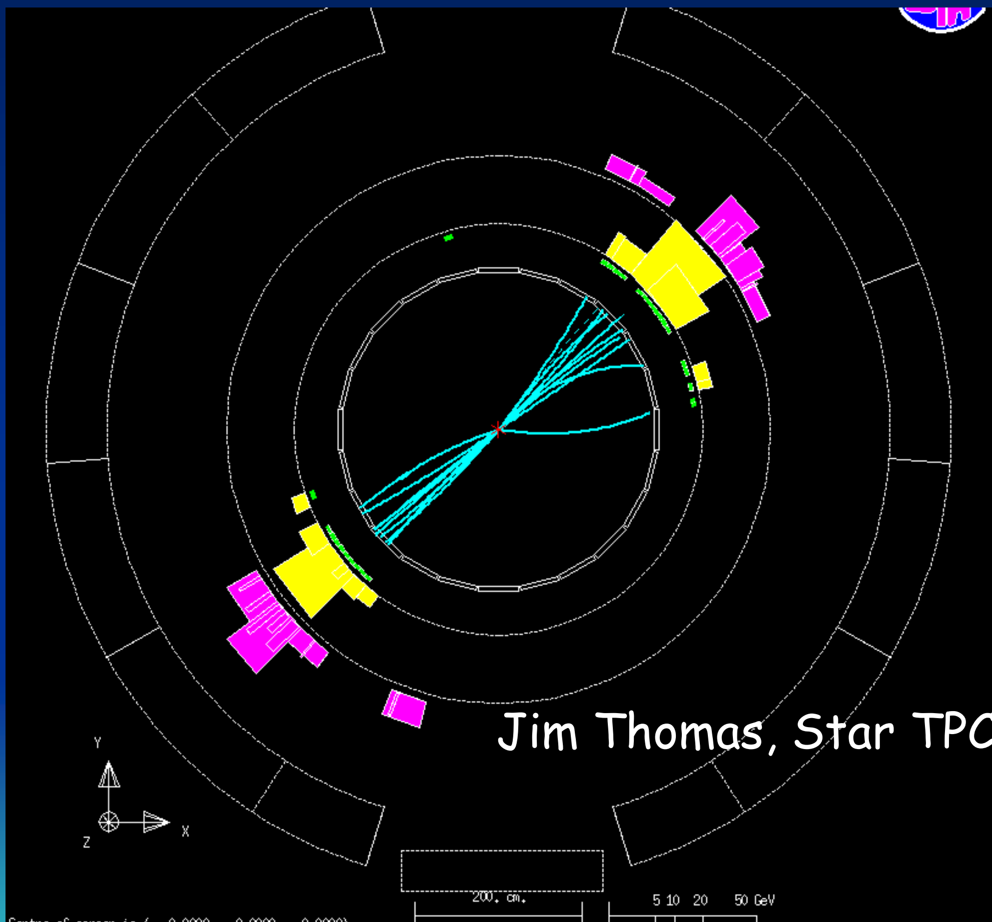
First studies indicate that ILC requirements are sufficient and necessary for physics at 3 TeV

Dieter Schlatter - 21.10.09 14

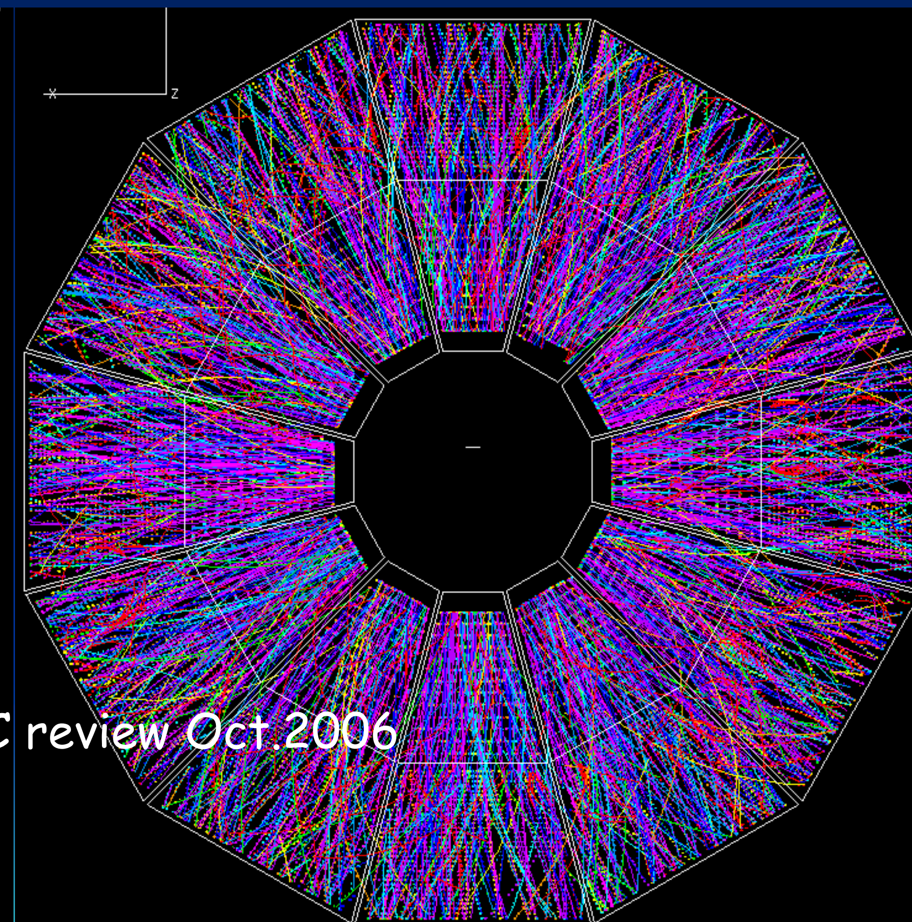
# Backgrounds

# 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 $\phi$ 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 $\sqrt{s} = 500\,\mathrm{GeV}$ 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 interaction 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 $B = 3.0\,\mathrm{T}$, 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 %

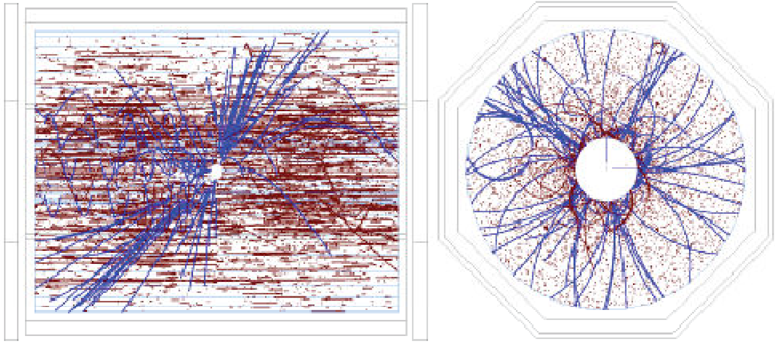


FIGURE 1.2-5. The $rz$ and $r\phi$ views of the TPC hits from a 500 GeV $t\bar{t}$ event (blue) with 150 BXs of beam background (red) overlayed.

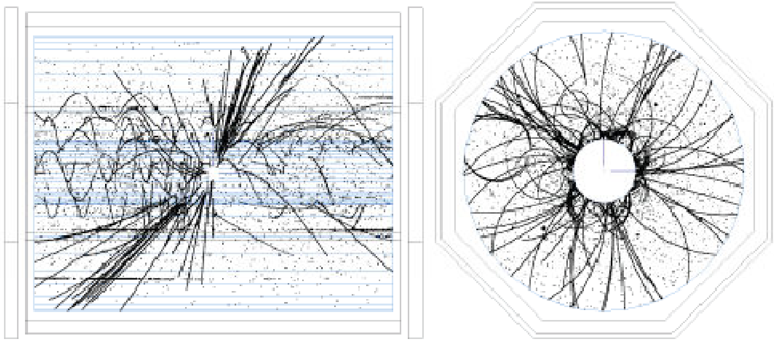


FIGURE 1.2-6. The same event as the previous figure, with the micro-curler removal algorithm applied. This is the input to the TPC track finding algorithm.

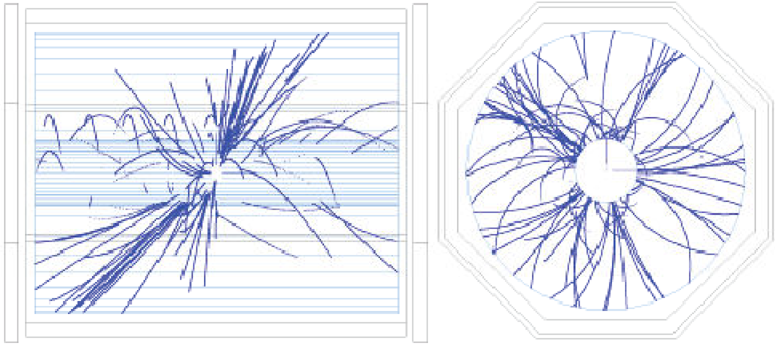


FIGURE 1.2-7. The same event as the previous plot, now showing the reconstructed TPC tracks.

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%

THE ILD SUB-DETECTOR SYSTEMS

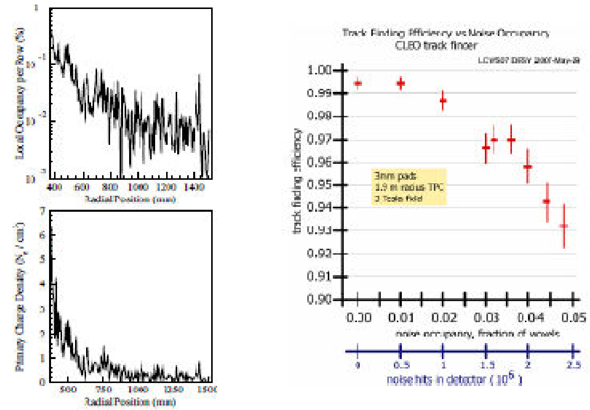



FIGURE 4.3-4. Occupancy for $xyz = 1 \times 5 \times 5\mathrm{mm}^3$ voxels (left, top) and space charge(left, bottom) due to the major beam-beam effects (beamstrahlung photons, electron-positron pairs and neutrons) as simulated in [83]. Study of the tracking efficiency in the presence of backgrounds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

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