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

BILCW07

TPC R&D for an ILC Detector
Beijing Tracking Review

Ron Settles MPI-Munich/Desy

OUTLINE of TALK

1. Overview LCTPC
2. LCTPC Design Issues
   - Performance
   - Endplate
   - Electronics
   - Fieldcage
   - Chamber gas
   - Space charge
   - Non-uniform fields
   - Calibration
   - Backgrounds
3. R&D effort: introduction
   - R&D topics: Dan Peterson
Madhu Dixit
Jan Timmermans
   - Next R&D steps: Takeshi Matsuda
4. LCTPC Collaboration

HISTORY

1992: *First discussions on detectors in Garmisch-Partenkirschen (LC92). Silicon? Gas?*
1996-1997: *TESLA Conceptual Design Report. Large wire TPC, 0.7Mchan.*
1/2001: *TESLA Technical Design Report. Micropattern (GEM, Micromegas) as a baseline, 1.5Mchan.*
5/2001: *Kick-off of Detector R&D*
11/2001: *DESY PRC proposal. for TPC R&D (European & North American teams)*
2002: *UCLC/LCRD proposals*
2004: *After ITRP,*
WWS R&D panel

Europe
Chris Damerell (Rutherford Lab. UK)
Jean-Claude Brient (Ecole Polytechnique, France)
Wolfgang Lohmann (DESY-Zeuthen, Germany)

Asia
HongJoo Kim (Korean National U.)
Tohru Takeshita (Shinsu U., Japan)
Yasuhiro Sugimoto (KEK, Japan)

North America
Dean Karlen (U Victoria, CAN)
Ray Frey (U. of Oregon, USA)
Harry Weerts (Fermilab, USA)

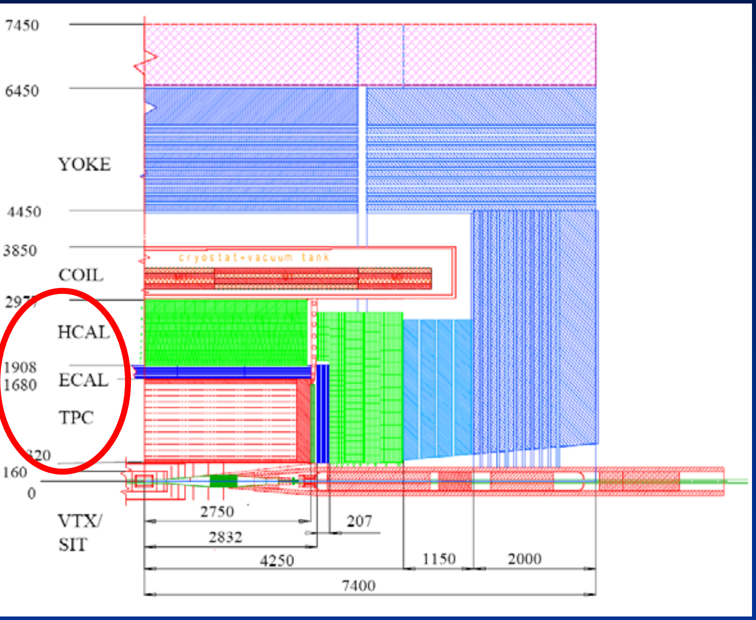
GOAL

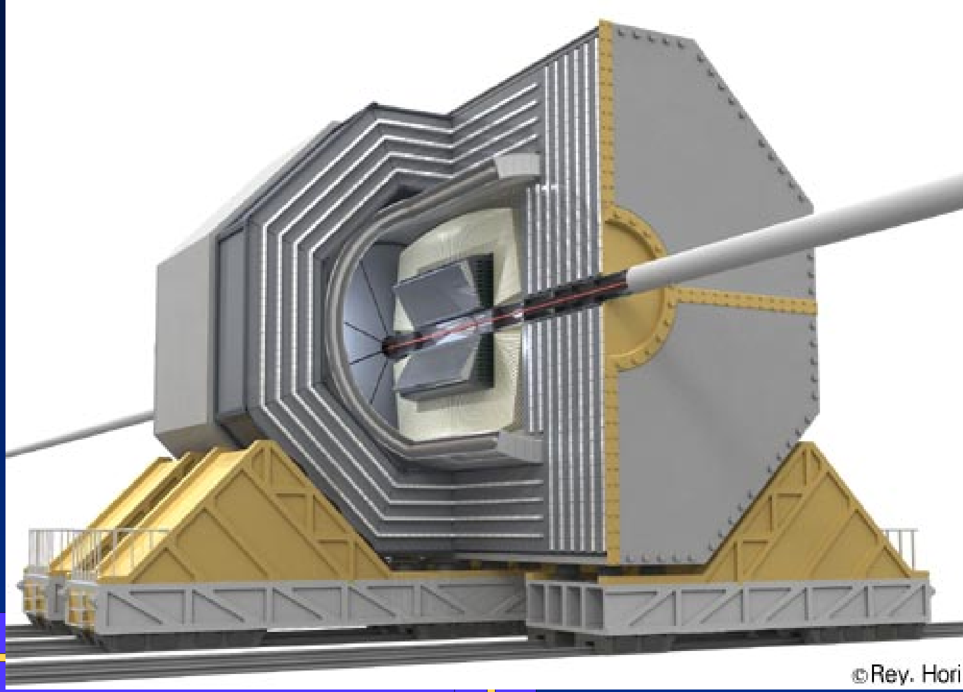
To design and build an ultra-high performance

Time Projection Chamber

...as central tracker for the ILC detector, where excellent vertex, momentum and jet-energy precision are required

LDC (old)

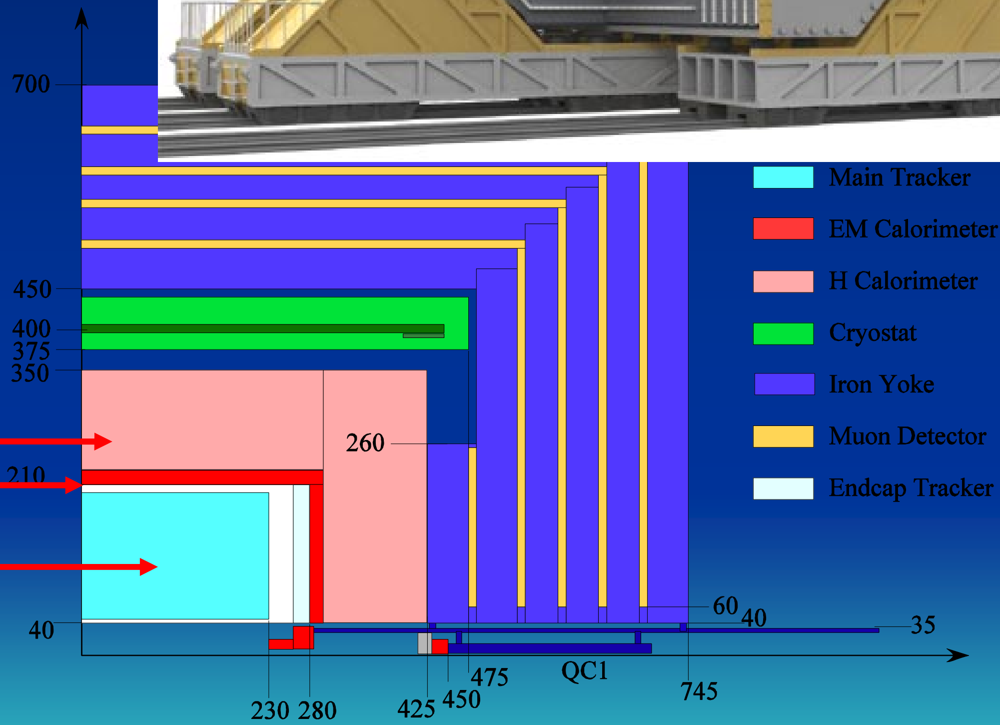




HCal

ECal

TPC



GLD

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
- time stamping to 2 ns together with inner silicon
- minimum of X_0 inside Ecal (<3% barrel, <30% 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

LCTPC/LP Groups (03Dec06)

Americas

Carleton
Montreal
Victoria
Cornell
Indiana
LBNL
Louisiana Tech
Purdue (observer)

Asia

Tsinghua
CDC:
Hiroshima
KEK
Kinki U
Saga
Kogakuin
Tokyo UA&T
U Tokyo
U Tsukuba
Minadano SU-IIT

Europe

LAL Orsay
IPN Orsay
CEA Saclay
Aachen
Bonn
DESY
U Hamburg
Freiburg
MPI-Munich
TU Munich (observer)
Rostock
Siegen
NIKHEF
Novosibirsk
Lund
CERN

Other groups

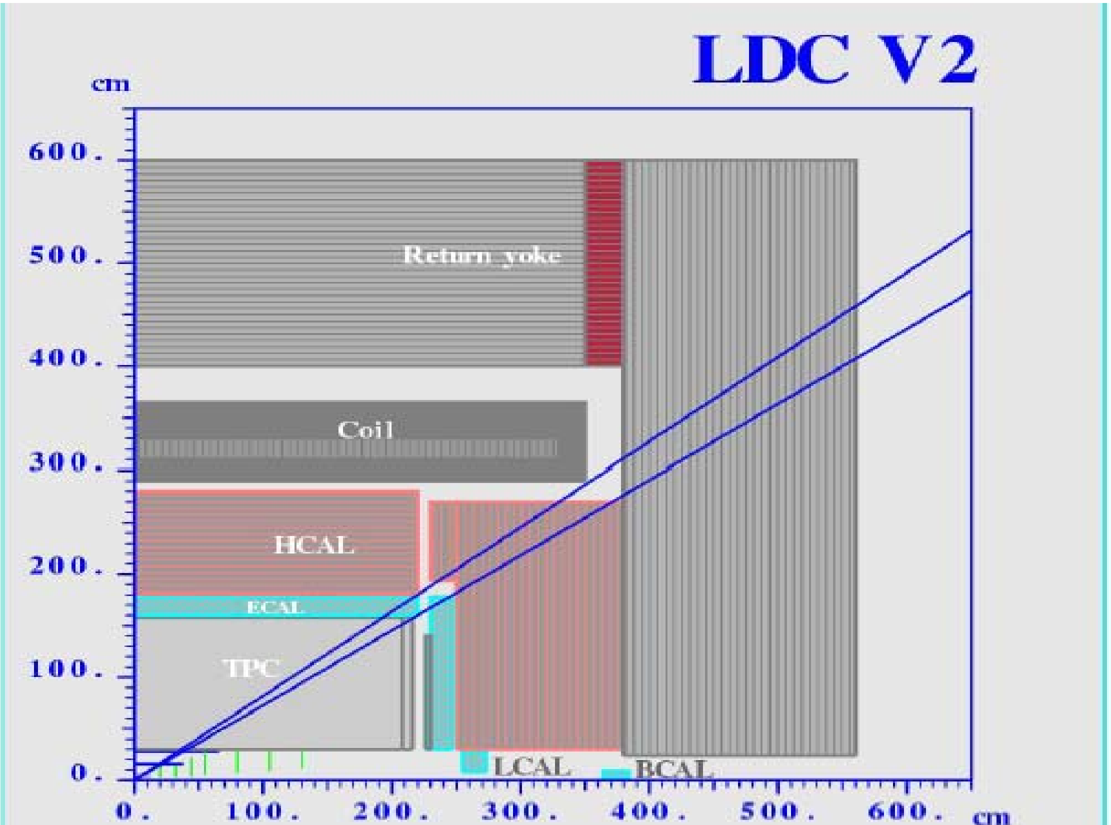
MIT
MIT (LCRD)
Temple/Wayne State (UCLC)
Yale
Karlsruhe
UMM Krakow
Bucharest

Large Detector Concept example

- Flavor tag $\delta(\mathrm{IP}) \sim 5\mu m \oplus \frac{10\mu m\ \mathrm{GeV/c}}{p \sin^{3/2}\theta}$
- Track momentum $\delta(1/p_t) \sim 3\mathrm{x}10^{-5}\ \mathrm{GeV/c}^{-1}$
- **Particle Flow** $\delta E/E \sim .30\ /\sqrt{E}$

Particle flow

- granularity
- hermeticity
- min. material inside calos
- calos inside 4 T coil



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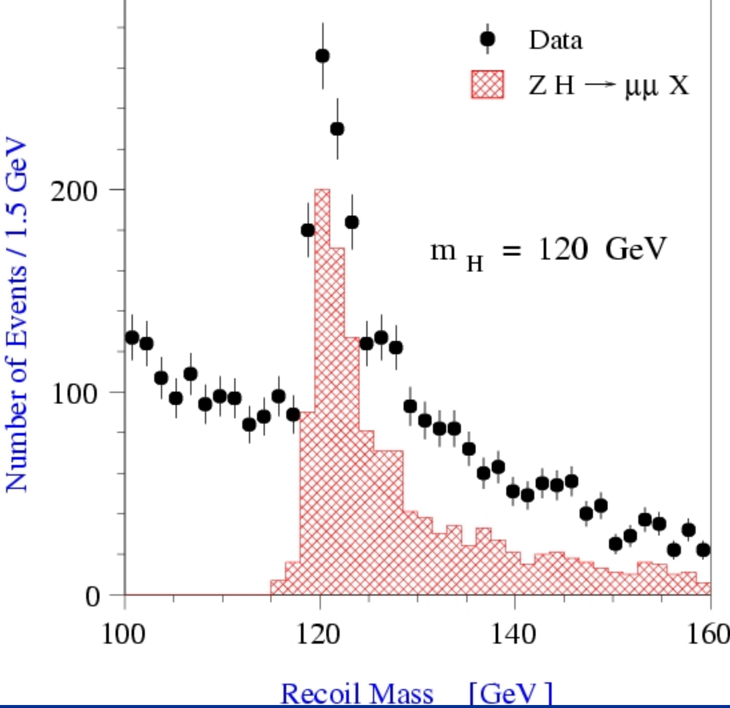
Physics determines detector design

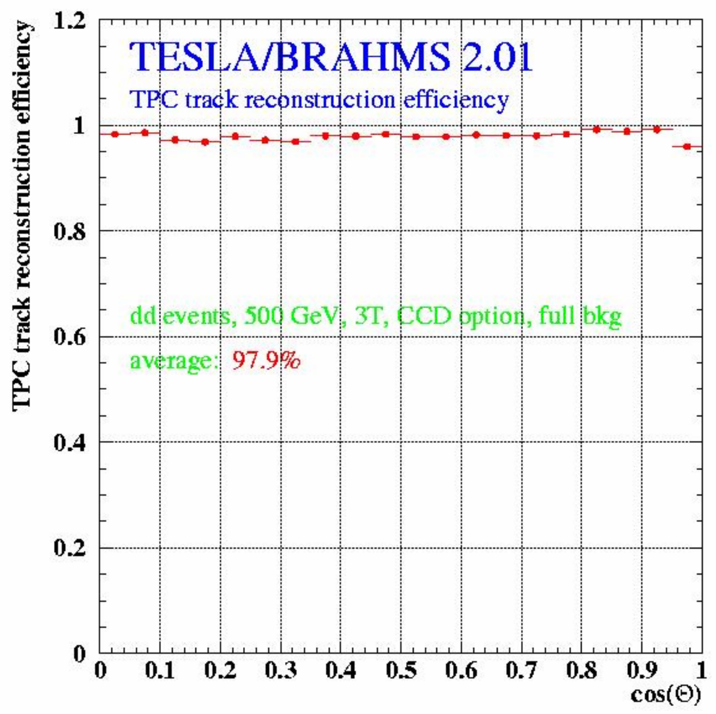
★ **momentum: d(1/p) ~ 10^{-4}/GeV(TPC only)**
~ 0.4×10^{-4}/GeV(w/vertex)
(1/10xLEP)

$e^+e^- \to ZH \to ll\ X$ → $\delta\sigma_H$ dominated by beam-beam, effects, backgrounds. Better momentum resolution not needed?

★ **tracking efficiency: ~99% (overall)**

excellent and robust tracking efficiency by combining vertex detector and TPC, each with excellent tracking efficiency





Step through the design issues described in the written report

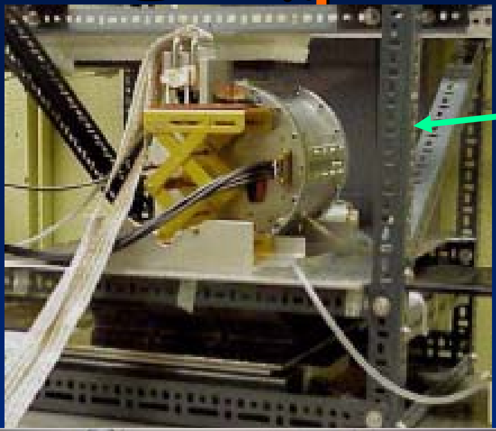
Performance, Resolution

Table 1: Performance goals and design parameters for a TPC with standard electronics at the ILC detector.

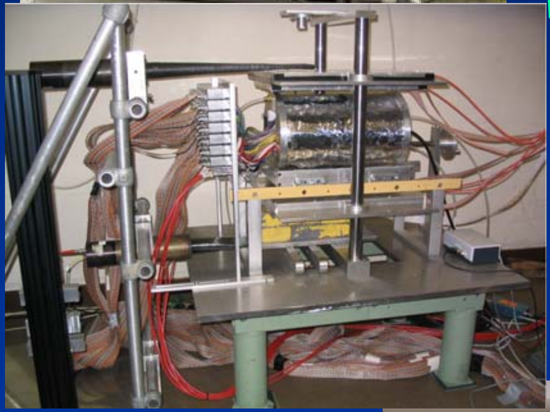
Size (LDC–GLD average)	$\phi = 3.6$m, L = 4.3m outside dimensions
Momentum resolution (B=4T)	$\delta(1/p_t) \sim 10 \times 10^{-5}$/GeV/c TPC only; $\times$ 0.4 incl. IP
Momentum resolution (B=4T)	$\delta(1/p_t) \sim 3 \times 10^{-5}$/GeV/c (TPC+IT+VTX+IP).
Solid angle coverage	Up to at least $\cos\theta \sim 0.98$
TPC material budget	$< 0.03X_0$ to outer fieldcage in r
	$< 0.30X_0$ for readout endcaps in z
Number of pads	$> 1\times10^6$ per endcap
Pad size/no.padrows	$\sim$ 1mm$\times$4–6mm/$\sim$200 (standard readout)
$\sigma_{\mathrm{singlepoint}}$ in $r\phi$	$\sim 100\mu$m (for radial tracks, averaged over driftlength)
$\sigma_{\mathrm{singlepoint}}$ in rz	$\sim$ 0.5 mm
2-hit resolution in $r\phi$	$<$ 2 mm
2-hit resolution in rz	$<$ 5 mm
dE/dx resolution	$<$ 5 %
Performance robustness	$>$ 95% tracking efficiency for all tracks–TPC only)
(for comparison)	($>$ 95% tracking efficiency for all tracks–VTX only)
	$>$ 99% all tracking[13]
Background robustness	Full precision/efficiency in backgrounds of 1% occupancy
	(simulations estimate $<$ 0.5% for nominal backgrounds)
Background safety factor	Chamber will be prepared for 10 $\times$ worse backgrounds
	at the ILC start-up.

w/ MPGD!

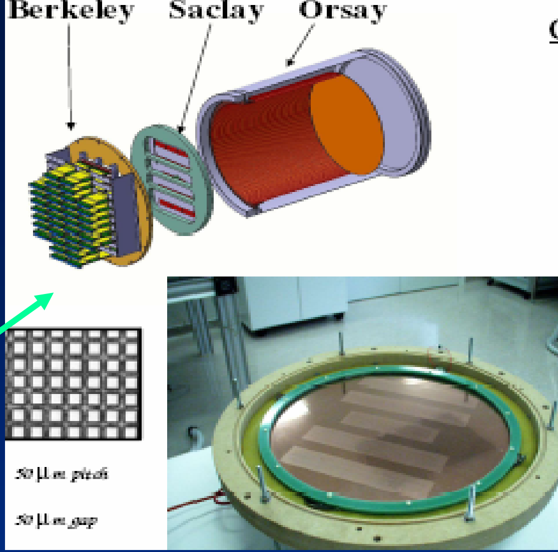
Examples of Prototype TPCs



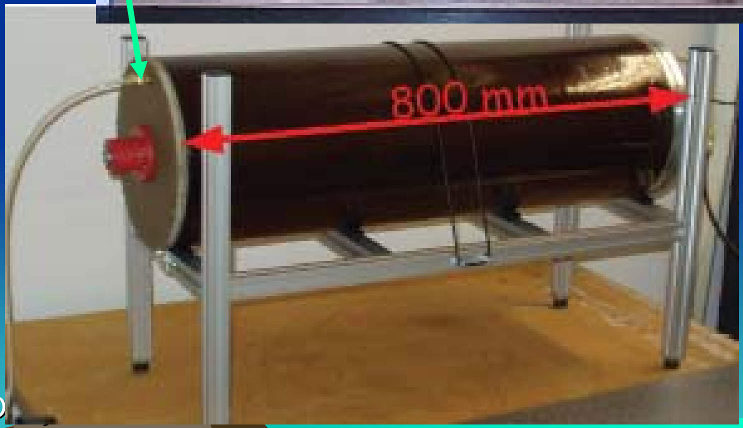
Carleton, Aachen, Cornell/Purdue,Desy(n.s.) for B=0or1T studies



Saclay, Victoria, Desy (fit in 2-5T magnets)



Karlsruhe, MPI/Asia, Aachen built test TPCs for magnets (not shown), other groups built small special-study chambers



Electronics

(a) Standard readout:

While an earlier proposed size was 2mm×6 mm[4]), smaller pads, 1mm×4–6 mm, have been found to provide improved resolution in our R&D work (Sec. 5). Studies have started to establish the realistic density of pads that can be achieved. A preliminary look at the FADC approach (à la Alice[14]) using 130 nm technology (Sec. 5.3) indicates that even smaller sizes might be feasible. An alternative to the FADC-type is the TDC approach (see [5][15]) in which time of arrival and charge per pulse by charge to time conversion are measured[16]. If it turns out that the material budget requires larger pads, then the charge-dispersion readout technique[17] is being systematically studied and is an option to maintain the good point resolution.

Thus, depending on the achievable electronics density, there will be between 1 and 10 million pads per endcap to be read out.

(b) CMOS pixel readout:

A new concept for the combined gas amplification and readout is under development [5]. In this concept the "standard" MPGD is produced in wafer post-processing technology[18] on top of a CMOS pixel readout chip[39], thus forming a thin integrated device of an amplifying grid and a very high granularity endplate with all necessary readout electronics incorporated. For a readout chip with $\sim 50\mu m$ pixel size, this would result in $\sim 2 \cdot 10^9$ pads ($\sim 4 \cdot 10^4$ chips) per endcap. This concept offers the possibility of pad sizes small enough to observe the individual primary electrons formed in the gas and count the number of ionisation clusters per unit track length, instead of measuring the integrated charge collected. If this concept turns out to be realistic, better momentum resolution, dE/dx resolution (through primary ionisation cluster counting) and 2-track separation seem possible.

Fieldcage, Chamber gas

ionization cluster counting) and 2-track separation seem possible.

3.4 Fieldcage

The design of the fieldcage involves the geometry of the potential rings, the resistor chains, the central HV-membrane, the gas container and a laser system. These will have to be laid out for sustaining at least 100kV at the HV-membrane and with a minimum of material. For alignment purposes (Secs. 3.7 and 3.8) a laser system is foreseen and may be integrated into the fieldcage[20][14] or not[21] (this decision is pending further investigation).

3.5 Chamber gas

The choice of the gas for a TPC is crucial decision for efficient and stable operation at the ILC[9]. The $\sigma_{\mathrm{singlepoint}}$ resolution achievable in $r\phi$ is dominated by the transverse diffusion, which should be as small as possible. This means that $\omega\tau$ for the gas should be large so that the transverse diffusion is compressed by the B-field. Large $\omega\tau$ will have the added advantage of making the chamber less sensitive to space-charge effects (Sec. 3.6) and other sources of electric field non-uniformities (Sec. 3.7). Simultaneously a sufficient number of primary electrons should be created for the position and dE/dx measurements. The drift velocity

at a drift field of at most a few times 100 V/cm should be 5–10 cm/μs to limit the central cathode voltage and the event overlap. The choice of operating voltage must also take into account the stability of the drift velocity due to fluctuations in temperature and atmospheric pressure. Finally while hydrocarbons have traditionally been used as quenchers in TPC gases, the concentration of hydrogen should be chosen to limit the number of background hits due to neutron-proton scattering.

Ion build-up

Three sources of space charge are (a) ion build-up at the readout plane, (b) ion build-up in the drift volume and (c) ion backdrift, when ions created in the gas amplification drift back into the TPC volume.

(a) Ion Build-up at the readout plane.

At the surface of the gas-amplification plane during the bunch train of about 3000 bunch crossings spanning 1 ms, there will be few-mm thick layer of positive ions built up due to the incoming charge, subsequent gas amplification and ion backflow. An important property of MPGDs is that they suppress naturally the backflow of ions produced in the amplification stage. Steps to minimize this backflow are described in Sec. 5.6, where a suppression to 0.25% is shown to be achievable. Thus this layer of ions will reach a density of a few tens of fC/cm^3, depending on gas gain and the background conditions during operation. Its effect will be simulated, but intuitively it should affect coordinate measurement only by a small amount since the drifting electrons incoming to the anode experience this environment during only the last few mm of drift. The TPC must plan to run with the lowest possible gas gain, meaning $\sim 1\text{–}2 \times 10^3$, in order to minimize this effect.

(b) Ion build-up in the drift volume.

In the drift volume, an irreducible positive-ion density due to the primary ionization will be collected during about 1s (the time it takes for an ion to drift the full length of the TPC). The positive-ion density will be higher near the cathode and will be a few fC/cm^3 at the estimated occupancy of $\sim$ 0.5%. The effect of the charge density will be established by our R&D program, but the experience of the STAR TPC[20] indicates that 200 fC/cm^3 is tolerable (Sec. 3.7(b)) and a few fC/cm^3 is well below this limit.

(c) Ion backdrift and gating.

Ion backdrift, gating

tolerable (Sec. 3.7(b)) and a few fC/cm^3 is well below this limit.

(c) Ion backdrift and gating.

The operational conditions at the linear collider – long bunch trains, high physics rate – require an open-gate operation without the possibility of intra-train gating between bunch-crossings should the delivered luminosity be optimally utilized. As already mentioned, MPGDs lend themselves naturally to the intra-train un-gated operation at the ILC since they can operate with a significant suppression of the back-drifting ions. In order to minimize the impact of ion drifting back into the drift volume, a required backdrift suppression of about 1/gasgain has been used as a rule-of-thumb, since then the total charge introduced into the drift volume is about the same as the charge produced in the primary ionization.

Not only have these levels of backdrift suppression not been achieved during our R&D (Sec. 5.6), but also this rule-of-thumb is misleading. Lower backdrift levels will be needed since these ions would drift as few-mm thick sheets through the sensitive region during subsequent bunch trains. The charge density in the sheets would be much higher than a few fC/cm^3 (Sec. 3.6(b)) since the volume in the sheets is $\sim$ 100 times smaller than that of the drift volume. How these sheets would affect the track reconstruction will be simulated to understand their influence, but since this backdrift into the drift volume can in principle be completely eliminated by a gating plane, a gate should be foreseen, to guarantee a stable and robust chamber operation. The added amount of material for a gating plane will be small (e.g., it was $< 0.5\% X_0$ average thickness for the Aleph TPC). The gate will be closed between bunch trains and remain open throughout one full train. This will eliminate the need to

Field non-uniformity

(a) Magnetic field.

Non-uniformity of the magnetic field of the solenoid will be by design within the tolerance of $\int_{\ell_{\mathrm{drift}}} \frac{B_r}{B_z} dz < 2\mathrm{mm}$ 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 the IRs with 14 mrad crossing-angle (as has been decided for the ILC). This issue was studied intensively at the 2005 Snowmass workshop[22][23], where it was concluded that the TPC performance will not be degraded if the B-field is mapped to 10^{-4} relative accuracy and the calibration procedures outlined in the next point (Sec. 3.8) are followed. These procedures will lead to an overall accuracy of 2×10^{-5} which has been shown to be sufficient[23] and was already achieved by the Aleph TPC[22]. Based on past experience, the field-mapping gear and methods should be able to accomplish the goal of 10^{-4} for the B-field. The B-field should also be monitored during running since the DID or other corrector windings may differ from the configurations mapped; for this purpose the option of a matrix of Hallplates and NMR probes mounted on the outer surface of the fieldcage is being studied.

Field non-uniformity

(b) Electric field.

Non-unformity of the electric field can arise from the fieldcage (Sec. 3.4) and from the processes explained in Sec. 3.6: ion build-up at the gas-amplification plane and due to primary ionization in the drift volume. The other source in Sec. 3.6, ion-sheets drifting back through the chamber can be eliminated via a gating plane, as explained there.

–For the first, the field cage design, the non-uniformities can be minimized using the experience gained in past TPCs.

–The effect due to the second, ion build-up at the readout plane can be minimized by running at the lowest possible gain.

–The effect due to the third, the primary ions, is due to backgrounds and is irreducible as already mentioned. The maximum allowable electrostatic charge density remains to be specified, but studies by the STAR experiment[20] for their high-luminosity running in future, and taking into account that the LCTPC will use a gas with high $\omega\tau$ (Sec. 3.5), indicate that about 0.2 pC/cm^3 at the center of the TPC will give a ~10 mm displacement, which is of the same order as due to that of the anti-DID and is correctable. At the nominal occupancy due to backgrounds of $\sim 0.5\%$, the space charge is estimated to be of order 1 fC/cm^3. This will be revisited by simulation within the R&D program (Sec. 6).

Calibration

The tools for solving this issue are Z-peak running, the laser system, the B-field map, a matrix of Hallplates/NMR probes outside the TPC and Si-layers inside the inner fieldcage and outside the outer fieldcage. In general[24] about 10/pb of data at the Z peak will be sufficient during commissioning for the alignment of the different subdetectors, and typically 1/pb during the year may be needed depending on the backgound and operation of the ILC machine (e.g., beam loss). A laser calibration system will is foreseen (see e.g., [21][20][14]) which can be used to understand both magnetic and electrostatic effects, while a matrix of Hallplates/NMR probes may supplement the B-field map. The z coordinates determined by the Si-layers inside the inner fieldcage of the TPC were used in Aleph[25] for drift velocity and alignment measurements, were found to be extremely effective and will thus be included in the LCTPC planning. The overall tolerance is that (Sec. 3.7) systematics have to be corrected to about 2×10^{-5} throughout the chamber volume[22][23], and this level was already achieved by the Aleph TPC[22][25].

Robustness

The issues are the space-charge (Sec. 3.6) and the track-finding efficiency in the presence of backgrounds; the latter 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 2-gamma interactions and beam-halo muons being deposited in the TPC at each bunch crossing[26]. Preliminary simulations of these under nominal conditions[4][27] indicate an occupancy of the TPC of less than about 0.5%.

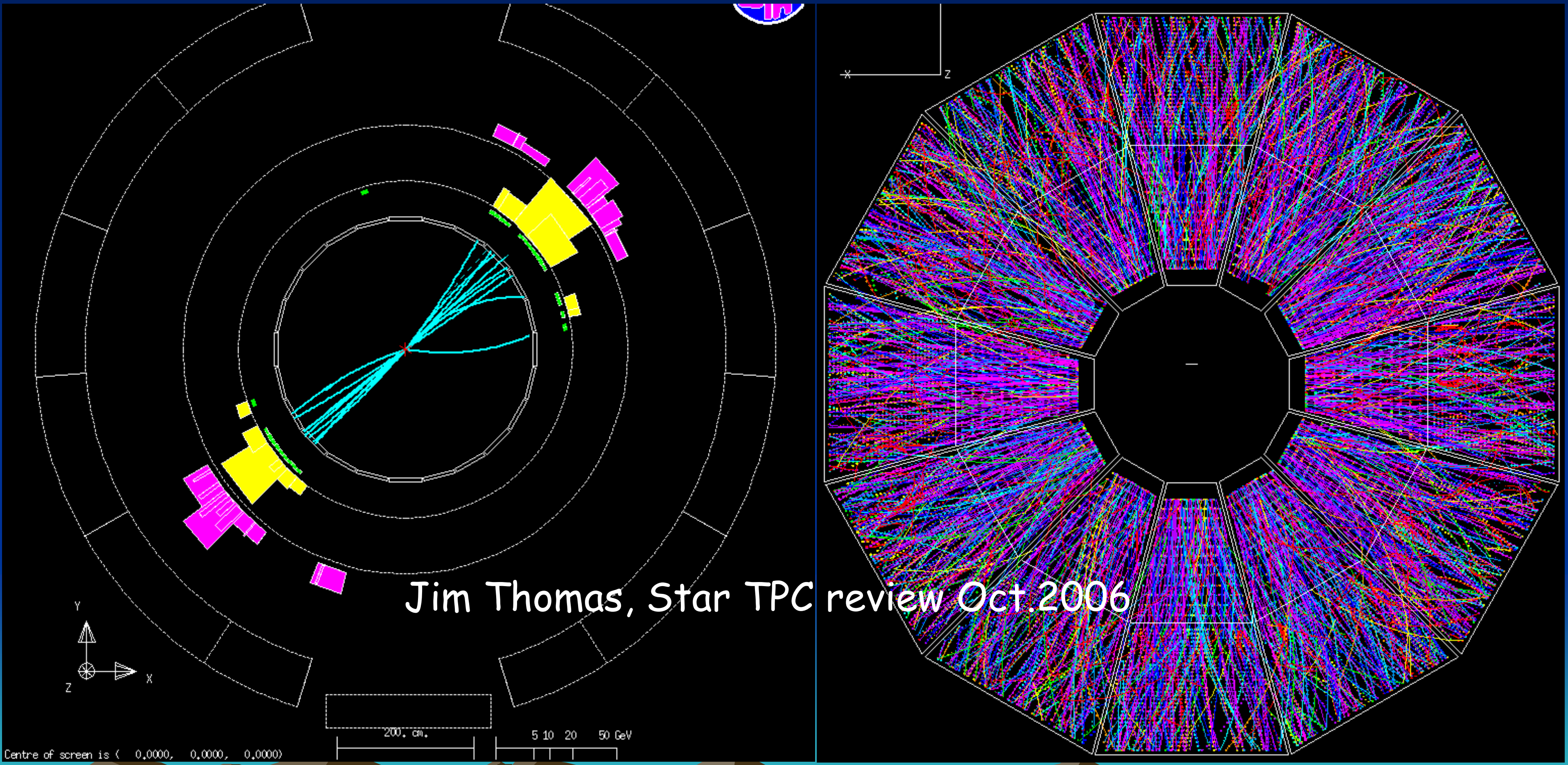
This level will be of no consequence for the LCTPC performance. Caution is in order here: the experience at LEP was that the backgrounds were much higher at the beginning of the running (years 1989-90). Then, after the simulation programs and understanding of the collider improved, the backgrounds were much reduced, even negligible at the end (year 2000).

Since such simulations have to be tuned to the collider once it is commissioned, the ILC backgrounds at the beginning could be much larger and the LCTPC should be prepared for higher occupancy, $\sim$10% or more.

What would be the tracking efficiency in this case? For comparison, heavy-ion TPCs[20] can run with 50–5% occupancy (inside–outside radius) and still have a track recognition efficiency of $\sim$ 90% at the outside. Of course, the heavy-ion event topologies are very different from e^+e^- events (they are more like the LC background), and heavy-ion physics is less sensitive to tracking efficiency. Nevertheless this statement is of technical interest: it shows how much a TPC can be loaded with hits and still function well. The TPC track finding at these occupancy levels remains good due to its continuous, high 3D-granularity tracking which is still inherently simple, robust and very efficient with the unoccupied remainder of the chamber. Results of tracking-efficiency simulation for the LCTPC in the presence of backgrounds are shown in Sec. 5.9.

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

R&D efforts

- gain experience with MPGD-TPCs, compare with wires
- study charge transfer properties, minimize ion feedback
- measure performance with different B fields and gases
- find ways to achieve the desired precision
- investigate Si-readout techniques
- start electronics design for > 1 million pads
- study design of thin field cage
- study design thin endplate: mechanics, electronics, cooling
- devise methods for robust performance in high backgrounds
- pursue software and simulation developments

R&D Planning

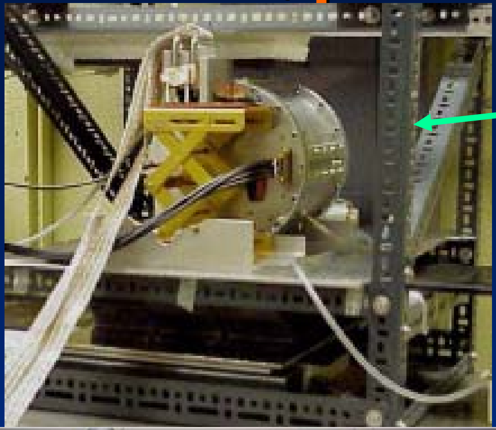
- 1) Demonstration phase
  - Continue work with small prototypes on mapping out parameter space, understanding resolution, etc, to prove feasibility of an MPGD TPC. For CMOS-based pixel TPC ideas this will include proof-of-principle tests.
- 2) Consolidation phase
  - Build and operate the Large Prototype (LP), Ø ~ 90cm, drift ~ 60cm, with EUDET infrastructure as basis, to test manufacturing techniques for MPGD endplates, fieldcage and electronics. LP design is starting → building and testing will take another ~ 3-4 years.
- 3) Design phase
  - During phase 2, the decision as to which endplate technology to use for the LC TPC would be taken and final design started.

What have we been doing in Phase 1 ?

Talks by

- Dan Peterson – MWPC, GEM, software
- Madhu Dixit – Micromegas, charge-dispersion anode foil, standard electronics
- Jan Timmermans – CMOS pixel work

Examples of Prototype TPCs



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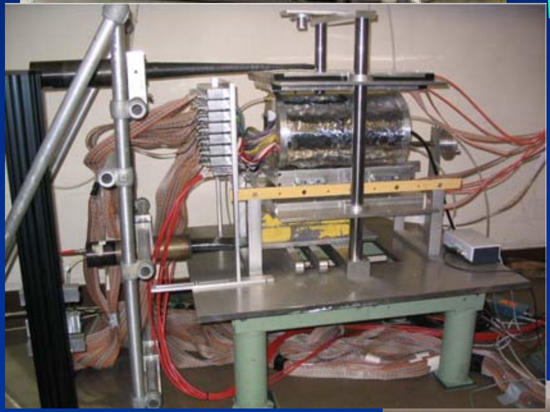

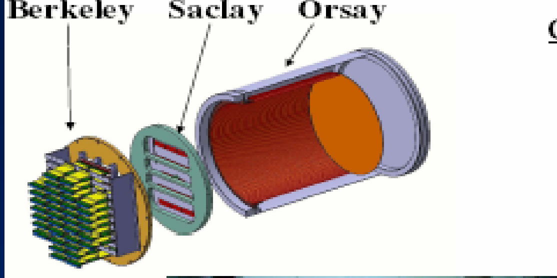

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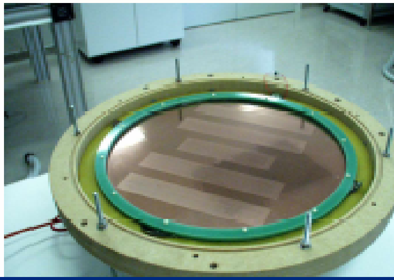

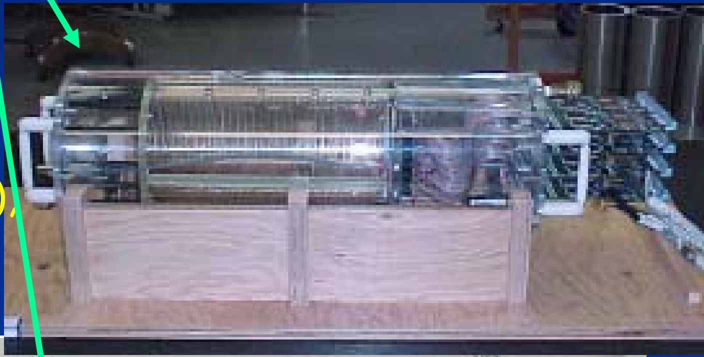

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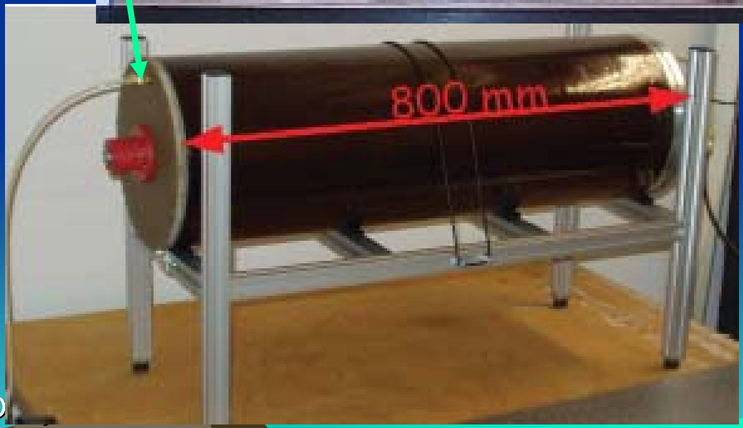
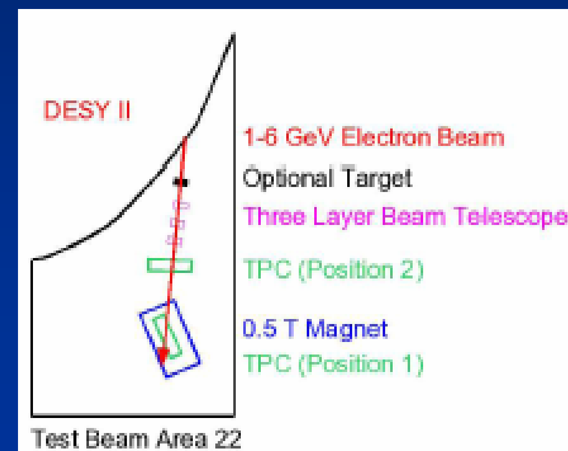
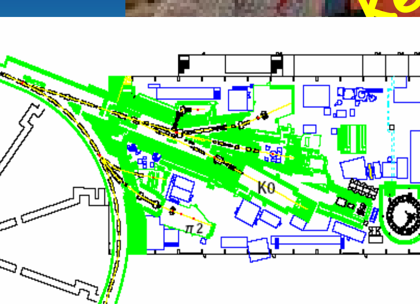


Facilities

Cern test-beam (not shown)



EUDET



TPC R&D summary to date

- Now > 4 years of MPGD experience gathered
- Gas properties rather well understood
- Limit of resolution understood
- Resistive foil charge-spreading demonstrated
- CMOS RO demonstrated
- Work starting for the Large Prototype

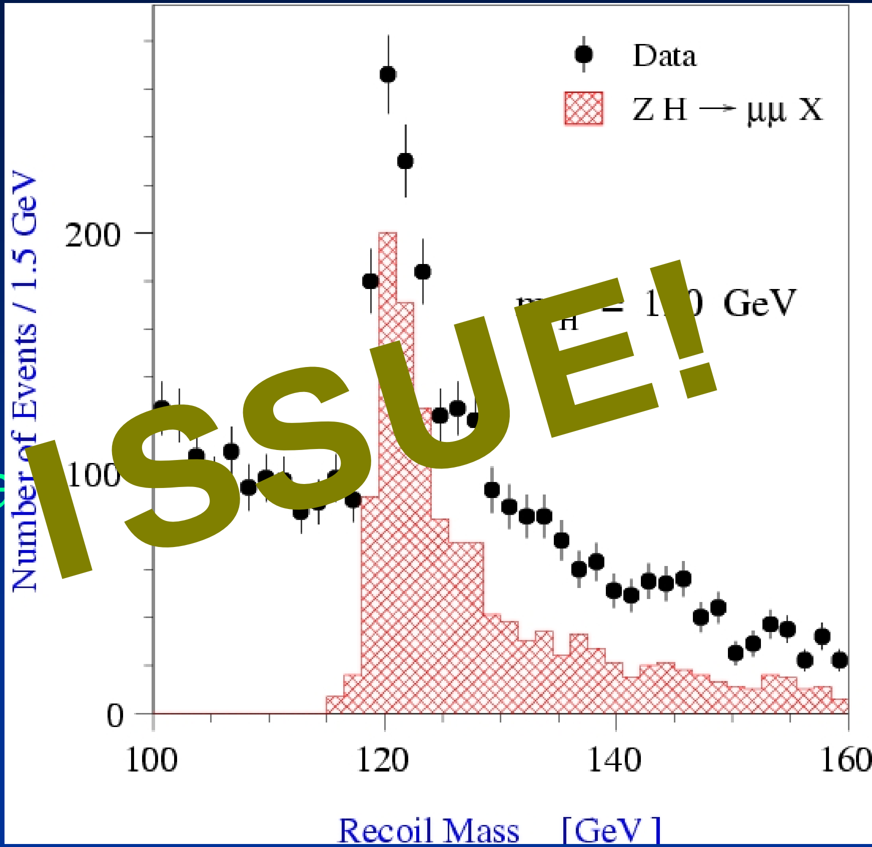
Performance

- •Momentum precision needed for overall tracking?
- Momentum precision needed for the TPC?
- •dE/dx resolution, V° detection goals
- Requirements for
  - 2-track resolution (in rφ and z)?
  - track-gamma separation (in rφ and z)?
- Tolerance on the maximum endplate thickness?
- Tracking configuration
  - Calorimeter diameter
  - TPC
  - Other tracking detectors
- TPC OD/ID/length

Physics determines detector design

★ **Overall momentum resolution:**
d(1/p) ~ ?????

$e^+e^- \rightarrow ZH \rightarrow ll\ X \rightarrow$ couplings. What else?

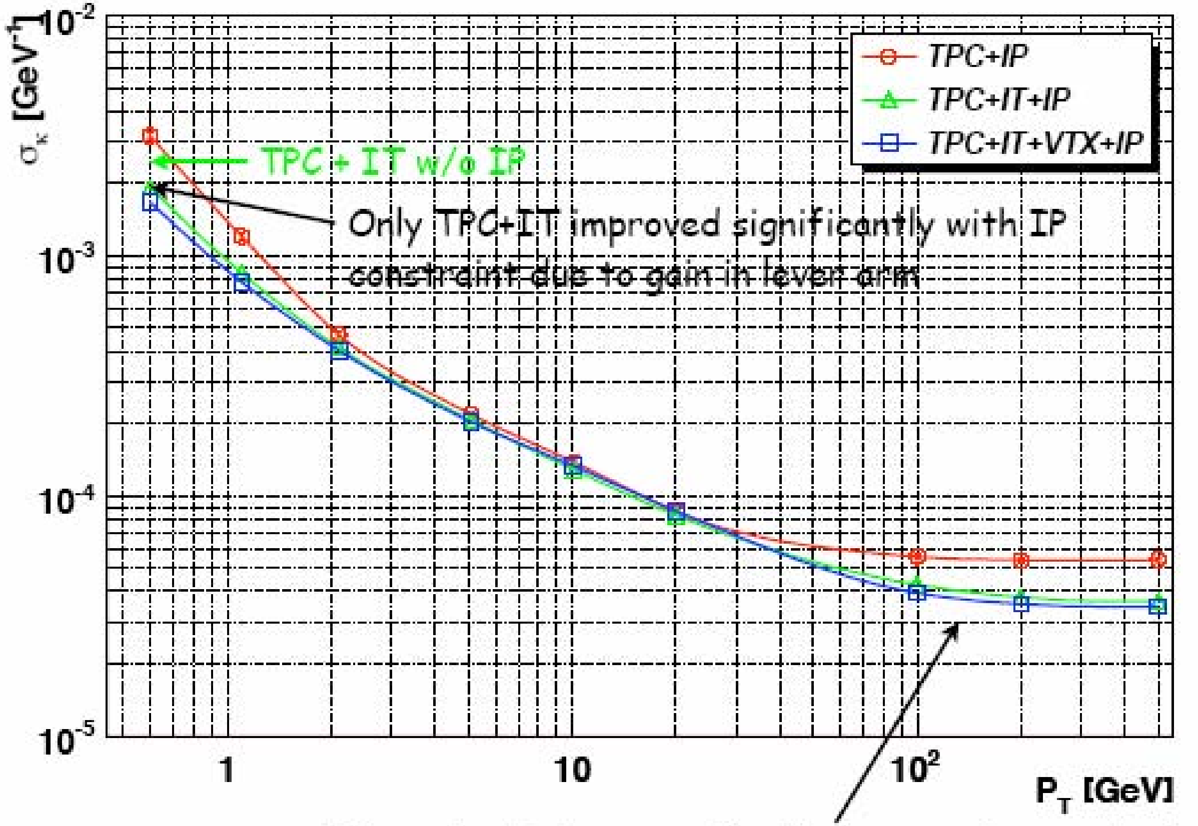


STILL an ISSUE!

★ **Concepts redoing study at √s = 230 GeV (for 120 GeV Higgs)…**

Astushi Yamaguchi, Keisuke Fujii @ ACFA 8 (Jupiter framework)

Momentum resolution vs transverse momentum with IP constraint



IP constraint improves the high momentum region in particular for the TPC-only and TPC+IT cases.

B=3T,

σ~120μm

Performance

- Momentum precision for the TPC
  → What is the best we can do?
  → next talks

- dE/dx? A (very) few examples…

Use of particle identification by measurement of the specific energy loss dE/dx in physics analysis at OPAL

M. Hauschild
CERN

1 b-Tagging via Semi-Leptonic Decays

1.1 $\Gamma_{b\bar{b}}$

Paper: PR076, CERN-PPE/93-46 (9-March-1993)
submitted to Phys. Lett. B
Title: Measurement of $\Gamma(Z^0 \to b\bar{b})/\Gamma(Z^0 \to \text{hadrons})$ using Leptons
dE/dx: Rejection of hadronic background for Muons:
dE/dx-norm for Muons $\geq -2.0\sigma$ for $N_{dE/dx} \geq 20$
Electron identification:
dE/dx-norm for Electrons $\geq -2.0\sigma$ for $N_{dE/dx} > 40$

Paper: PR056, CERN-PPE/92-38 (6-March-1992)
Zeitschrift für Physik C55 (1992) 191-207
Title: A Measurement of Electron Production in Hadronic Z^0 Decays and a Determination of $\Gamma(Z^0 \to b\bar{b})$
dE/dx: Electron identification:
dE/dx-norm for electrons $\geq -2.0\sigma$ for $N_{dE/dx} > 40$

1.2 b-Lifetime

Paper: PR048, CERN-PPE/91-201 (15-November-1991)
Phys. Lett. B274 (1992) 513-525
Title: Measurement of the Average B hadron Lifetime in Z^0 Decays
dE/dx: Electron identification:
dE/dx-norm for electrons $\geq -2.0\sigma$ for $N_{dE/dx} > 40$

1.3 B^0-$\bar{B}^0$ Mixing

Paper: PR049, CERN-PPE/91-212 (2-December-1991)
Phys. Lett. B276 (1992) 379-392
Title: Measurement of B^0-$\bar{B}^0$ Mixing in Hadronic Z^0 Decays
dE/dx: Rejection of hadronic background for muons:
Muon probability > 1 % IF $N_{dE/dx} \geq 60$
Electron identification:
dE/dx-norm for electrons $\geq -2.0\sigma$ for $N_{dE/dx} > 40$

2 τ Branching Ratios

2.1 Topological Branching Ratios

Paper: PR058, CERN-PPE/92-66 (29-April-1992)
Phys. Lett. B288 (1992) 373-385
Title: Measurement of the τ Topological Branching Ratios at LEP
dE/dx: Electron identification:
dE/dx-norm(pion) > -2.5 σ for $N_{dE/dx} > 20$
Rejection of photon conversions:
Pairs of oppositely charged tracks with both dE/dx-norm(electron) > -2.0 σ

2.2 Exclusive Branching Ratios

Paper: PR041, CERN-PPE/91-103 (25-June-1991)
Phys. Lett. B266 (1991) 201-217
Title: Measurement of Branching Ratios and τ Polarization from $\tau \to e\nu\bar{\nu}$, $\tau \to \mu\nu\bar{\nu}$ and $\tau \to \pi(K)\nu$ Decays at LEP
dE/dx: Cross-check of electron selection efficiency in $\tau \to e\nu$ using dE/dx-distribution of low-momentum electron tracks ($x_e = 0.05 - 0.10$).

3 Exclusive b- and c-Decays

3.1 B^0_s

Paper: PR064, CERN-PPE/92-144 (3-September-1992)
Phys. Lett. B295 (1992) 357-370
Title: Evidence for the Existence of the Strange b-flavoured Meson B^0_s in Z^0 Decays
dE/dx: Kaon selection and Pion rejection in D_s decays:
dE/dx within $\pm 2\sigma$ of expected Kaon dE/dx AND
below -1σ of expected Pion dE/dx
Electron identification:
dE/dx-norm for electrons $\geq -2.0\sigma$ for $N_{dE/dx} > 40$
Rejection of hadronic background for muons:
Muon probability > 1 % IF $N_{dE/dx} \geq 60$

3.2 b-Baryons, Λ_b

Paper: PR055, CERN-PPE/92-34 (28-February-1992)
Phys. Lett. B281 (1992) 394-404
Title: Evidence for b-flavored Baryon Production in Z^0 Decays at LEP
dE/dx: Proton selection in Λ-Decays $\Lambda \to p\pi$:
dE/dx of larger momentum track compatible with proton
Rejection of hadronic background for muons:
Muon probability > 1 % IF $N_{dE/dx} \geq 60$
Electron identification:
dE/dx-norm for electrons $\geq -2.0\sigma$ for $N_{dE/dx} > 40$

3.3 $J/\psi \to l^+l^-$

Paper: PR039, CERN-PPE/91-92 (12-June-1991)
Phys. Lett. B266 (1991) 485-496
Title: Observation of J/ψ Production in Multihadronic Z^0 Decays
dE/dx: Rejection of hadronic background in $J/\psi \to \mu^+\mu^-$:
Muon probability > 1 % IF $N_{dE/dx} \geq 60$
Electron identification in $J/\psi \to e^+e^-$:

4 c-tagging via $D^{*\pm}$

4.1 c Fragmentation Function

Paper: PR034, CERN-PPE/91-63 (8-April-1991)
Phys. Lett. B262 (1991) 341-350
Title: A Study of $D^{*\pm}$ – Production in Z^0 Decays
dE/dx: Kaon selection in $D^{*\pm} \to K\pi\pi$:
Kaon probability > 10 % for $x_D^* < 0.5$

5 QCD

5.1 Baryon Correlations

Paper: PR072, CERN-PPE/93-26 (8-February-1993)
Submitted to Phys. Lett. B
Title: Evidence for Chain-Like Production of Strange Baryon Pairs in Jets
dE/dx: Proton selection: ???

Aleph ~ similar list…
also: π/e separation for Ecal jet i.d. was extremely important

This dE/dx tool used effectively for S/N ehancement in >hundred papers for all of Lep1/Lep2 running for Opal and Aleph…

10 examples, year 1992

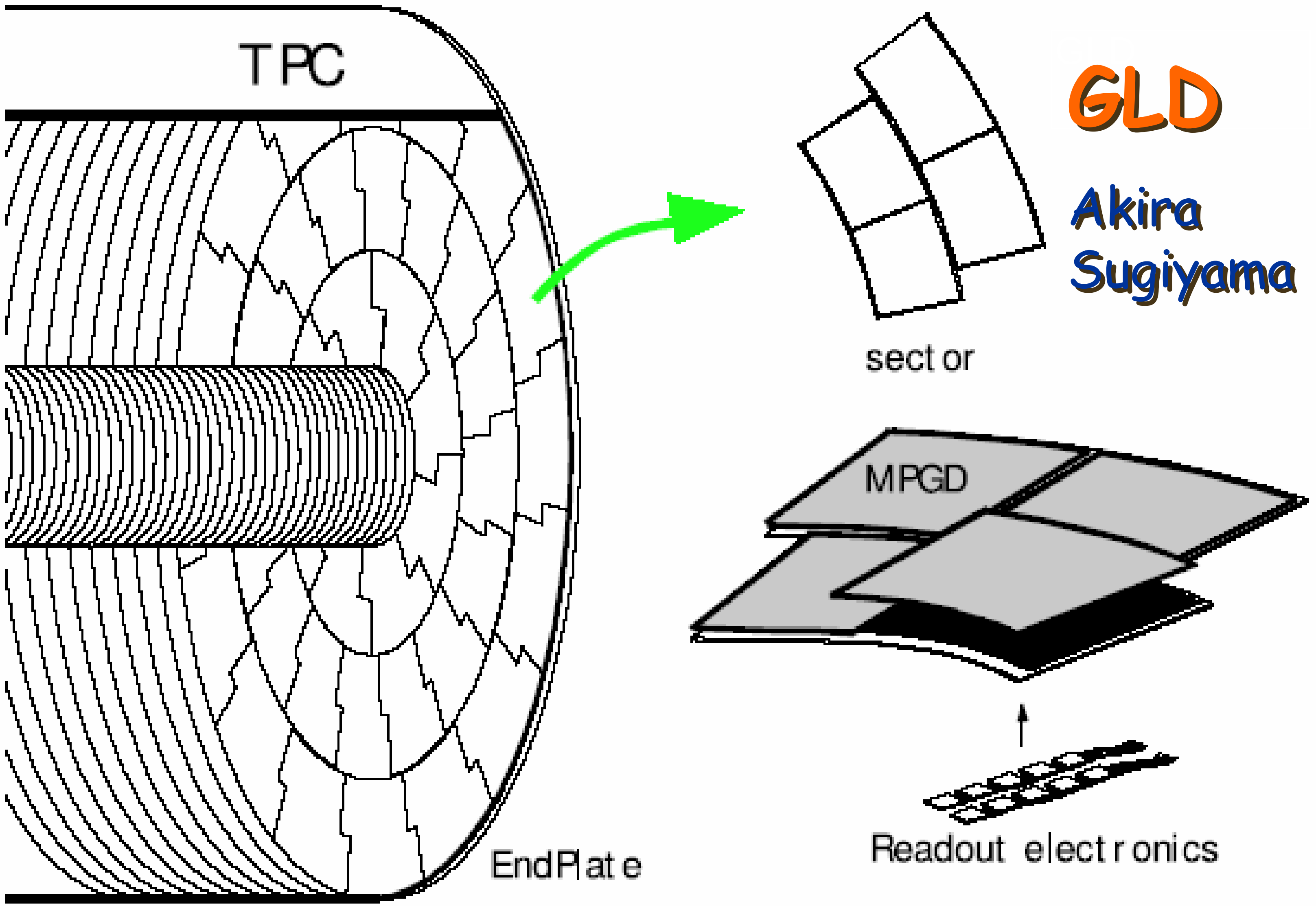
What will we be doing in Phase 2 ?

Talk by

- Takeshi Matsuda – LP, SP, simulation

Design

- Gas-amplification technology → input from R&D projects
- Chamber gas candidates: crucial decision!
- Electronics design: LP WP
  - Standard-RO design
  - Is there an optimum pad size for momentum, dE/dx resolution and electronics packaging?
  - Silicon RO: proof-of-principle
- Endplate design LP WP
  - Mechanics
  - Minimize thickness
  - Cooling
- Field cage design LP WP



GLD

Akira Sugiyama

Backgrounds/alignment/distortion-correction

- Revisit expected backgrounds
- Maximum positive-ion buildup tolerable
- Maximum occupancy tolerable
- Effect of positive-ion backdrift: gating plane
- Tools for correcting inhomogeneous B-field or space charge effects in heavy backgrounds

LCTPC Collaboration

8 APPENDIX–Formation of the LCTPC Collaboration

Several meetings of the TPC groups were held between May and October 2006 where the ground rules were discussed. The following structue was decided on:

- THE COLLABORATION WILL REMAIN OPEN TO NEW GROUPS
- GENERAL STRUCTURE

  1)There will be three coordinators, one for each region, for a period of two years. These three regional coordinators (RC) will choose a chairperson who will be the LCTPC Spokesperson.

  The RCs will work with the following two boards:

  2)The technical board (TB), consisting of the existing workpackage (WP) conveners (Sec. 6.1). The TB will ensure the technical integrity of their WP and compatibility with other WPs while maintaining close contact with the collaboration.

  3)The collaboration board (CB), consisting of one representative from each group or set of groups (the group leader, principle investigator or other chosen member). Each CB member looks after the resources for its group(s) (money and people).

LCTPC Collaboration

- STATUS

1)The RCs, after selection of candidates by search committees in each region which were voted on by the CB members of the respective region, are
–Americas: Dean Karlen
–Asia: Takeshi Matsuda
–Europe: Ron Settles (who only wants to continue the job for at most one year) followed by Jan Timmermans.

2)The TB members are listed in Sec. 6.1. ⟵ **see Takeshi's talk**

3)The CB members are:

```
--Americas--
Carleton:             Madhu Dixit
Montreal:             Jean-Pierre Martin
Victoria:             Dean Karlen
Cornell:              Dan Peterson
Indiana:              Rick Van Kooten
LBNL:                 Dave Nygren
Louisiana Tech:       Lee Sawyer
--Asia----------
Tsinghua:             Yuanning Gao
For the CDC groups:   Akira Sugiyama
Hiroshima
KEK
Kinki
Saga
Kogakuin

Tokyo U A & T
U Tokyo
Tsukuba
Mindanao
--Europe-----------
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LCTPC Collaboration

Europe

LAL Orsay/IPN Orsay:	Vincent Lepeltier
CEA Sacly:	Paul Colas
Aachen:	Stefan Roth
Bonn:	Klaus Desch
DESY/UHamburg:	Ties Behnke
EUDET:	Joachim Mnich
Freiburg:	Andreas Bamberger
MPI-Munich:	Ariane Frey
Rostock:	Henning Schroeder (deputy: Alexander Kaukher)
Siegen:	Ivor Fleck
Nikhef:	Jan Timmermans
Novosibirsk:	Alexei Buzulutskov
St.Peterburg:	Anatoliy Krivchitch
Lund:	Leif Jonsson
CERN:	Michael Hauschild (deputy: Lucie Linsen)

--Groups with Observer status do not have CB members--

TU Munich:	Bernhard Ketzer
Purdue:	Ian Shipsey
Iowa State	
MIT	
Yale	
Karlsruhe	
Krakow	
Bucharest	

LCTPC Collaboration

- SPOKESPERSON SELECTION

  The RCs decided not to have a predetermined rotation of RCs as Chairman/Spokesperson; the Chairman will be chosen by the RCs once per year, and the reasoning for the choice will be explained to the collaboration.

  For the first year, Ron Settles was chosen to be Chairperson/Spokesperson.

- TO-DO LIST:

  –Set up important subcommittees:
  steering,
  editorial,
  speakers,
  among others.

  –Draft a collaboration document.

  –Draft an MOA for the LP work.

TPC milestones

2006-2010	Continue LCTPC R&D via small-prototypes and LP tests
2010	Decide on all parameters
2011	Final design of the LCTPC
2016	Four years construction
2017	Commission/Install TPC in the LC Detector

No conclusions…

Keisuke Fujii