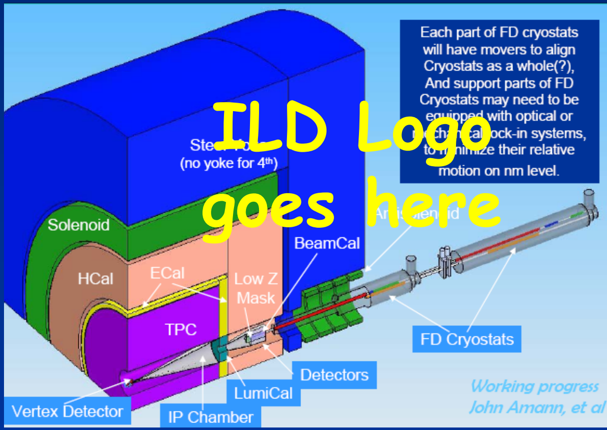
LCTPC issues for ILC/CLIC (="CILC"?)



ILD Logo goes here

Here is some space for another logo…

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

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Ron Settles MPI-Munich

Outline

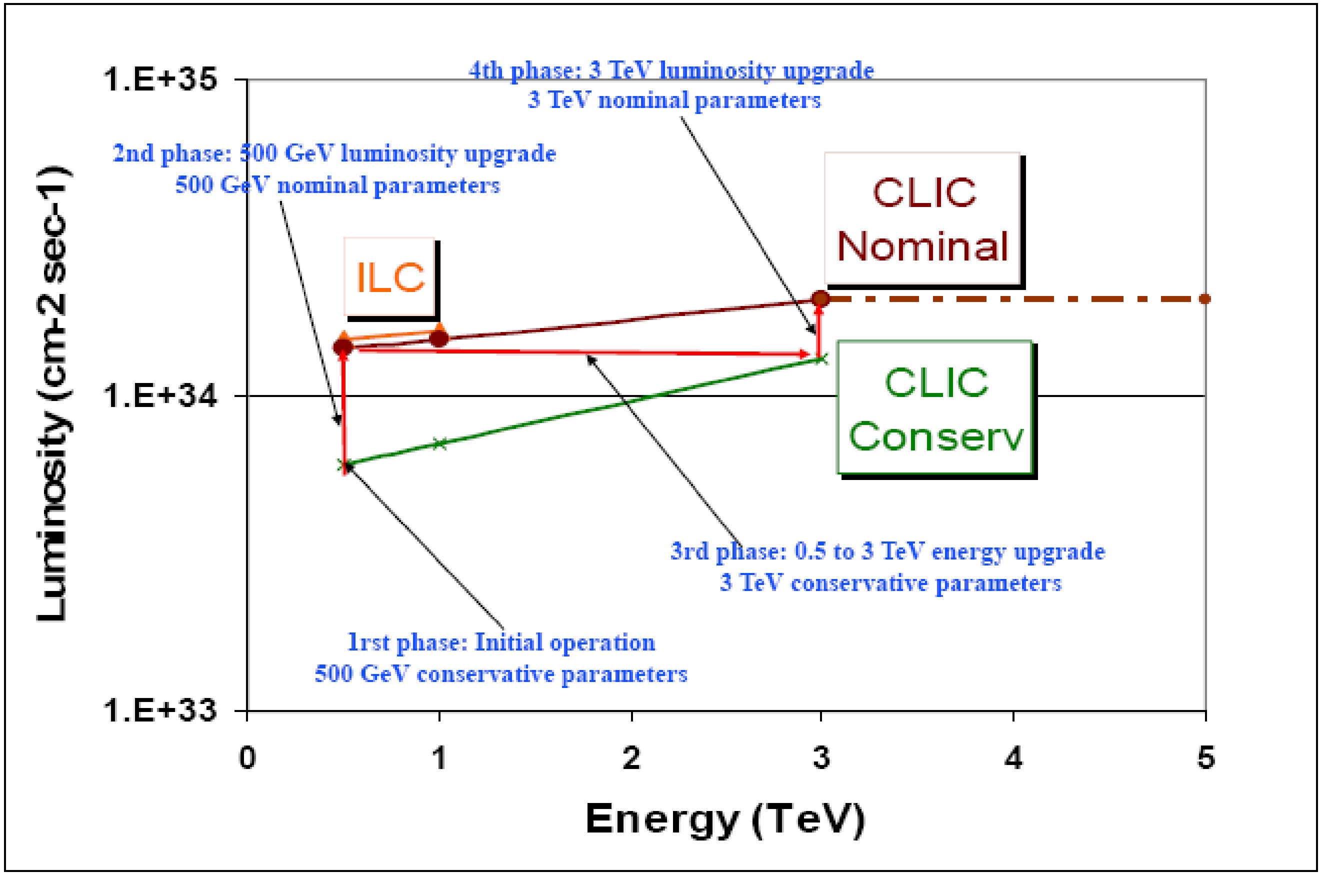
- General remarks about physics at the linear collider
- Summary of LCTPC status for ILD
- Differences between cold and warm machines for the TPC

General remarks about physics at the linear collider

- In 2010-2012, after the LHC/Tevatron/LEP results are combined, there will be a decision as to which LC machine technology (cold or warm) will be built next.
- If this decision is for CLIC, the machine will start at low energy and work up (as will ILC if chosen). This was clearly said by Jean-Pierre at Tuesday's opening meeting and by Daniel this morning.

CLIC Parameters and upgrade scenario

http://cdsweb.cern.ch/record/1132079/files/CERN-OPEN-2008-021.pdf



General remarks…

- Therefore the detector can be designed for low energy at the start and be laid out to evolve along with the machine to higher energies over the years.

- Since ultimately 3 TeV will be attained, the detector should be large to start with.

General remarks…

- From our study for Snowmass 2001:

Detector Requirements at a multi-TeV Linear Collider

Ron Settles*
Max-Planck-Institut für Physik, Munich Germany
(Dated: February 13, 2002)

Early thinking towards a detector for a multi-TeV e^+e^- linear collider is reviewed. Several ideas presented here have been generated within the framework of the CLIC studies. The detector must perform well in the e^+e^- range $\sqrt{s} \sim 1-5$ TeV, which will be demanding on the measuring precision and robustness towards backgrounds.

Acknowledgments

Thanks go to several colleagues who have attended our recent CLIC-detector brainstroming sessions: Ralph Assmann, Helmut Burkhardt, Marco Battaglia, Helmut Burkhardt, Ariane Frey, Marcello Piccolo, Alert De Roeck, Daniel Schulte, Graham Wilson and Frank Zimmermann (apologies if someone forgotten).

I. INTRODUCTION

Many reflections for a detector at a future e^+e^- linear collider are strongly influenced by the experience gained at LEP/SLC covering $\sqrt{s}$ up to 0.2 TeV cms energy. The extrapolation for a detector up to 1 TeV, a factor five more than at LEP, is well advanced within the TESLA/JLC/NLC studies (see e.g. [1][2]). TESLA will be used for comparison here. In a nutshell the detector goals are for vertexing $\delta(IP_{r\phi,z}) \leq 5\,\mu\text{m} \oplus \frac{10\,\mu\text{m GeV/c}}{p \sin^{3/2}\theta}$, for tracking $\delta(\frac{1}{p_t}) \leq 5 \times 10^{-5}(\text{GeV/c})^{-1}$ with systematics $\leq 10\,\mu$m, for energy flow $\frac{\delta E}{E} \simeq 0.35 \frac{1}{\sqrt{E(\text{GeV})}}$ meaning both electromagnetic and hadron calorimetry must be inside the coil and for hermeticity excellent forward coverage and beam pipe as only (10 mrad) hole in the 4π coverage. To be robust against backgrounds, finest granularity in all subdetectors, minimal material inside the Ecal and a 4T $\vec{B}$-field are envisaged.

CLIC pushes the energy range up by another factor of five relative to TESLA, and the detector question is, "can we still extrapolate from what we learned at LEP/SLC?" We have started thinking towards a detector for CLIC, and an attempt will be made to summarize the issues.

General remarks…

- A scenario (my opinion) was:

V. A POSSIBLE LAYOUT

As a result, the layout might look as tabulated below. To repeat, this is the opinion of the present author. Another example using discrete Si tracking can be found in [11].

Radius (cm)	Subdetector	comment
3–15	Vdet	δ(IP)$\sim$10μm
15–80	Silicon/fwd disks	covering$\sim$10m^3
80–230	TPC	covering$\sim$100m^3
240–280	ECAL	30 X_0
280–400	HCAL	6λ
400–450	Coil	4T
450–800	Fe/muon	

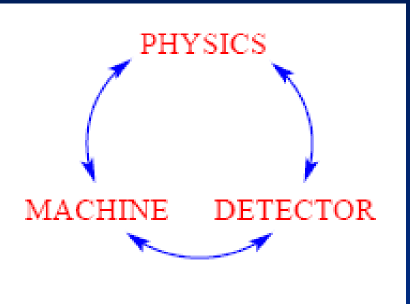
[1] World Studies on Physics and Detectors for a Linear Collider, http://hepwww.physics.yale.edu/lc/
[2] TESLA Technical Design Report, DESY 2001-011, ECFA 2001-209, March 2001.
[3] M. Battaglia, "Physics Signatures at CLIC", CLIC Note 474, LC-PHSM-072-CLIC.
[4] D. Schulte, "Backgrounds at Future Linear Colliders", CLIC Note 424, CERN/PS 99-069.
[5] M. Ronan and R. Settles, "LC-TPC Design Requirements", these proceedings.
[6] R. Settles, Proceedings of LC93 at SLAC.
[7] R. Assmann et al, "Stability Considerations for Final Focus Systems of Future Linear Colliders, CERN/SL 2000-059.
[8] G. White, "IP Feedback Simulation", talk at the Ecfa/Desy Workshop at Cracow 14-18 Sept. 2001 can be found at the website http://fatcat.ifj.edu.pl/ecfadesy-krakow.
[9] T. Markiewicz, T. Maruyama, Proc. 1999 LCWS and http://physics.web.cern.ch/Physics/LCWS99/talks.html
[10] T. Markiewicz, these proceedings.
[11] A. Frey, Proceedings of LCWS2000 at Fermilab.

General remarks…

- The design of the ILD detector emphasizes vertex-, track- and jet-measurement as well as hermeticity, and the same approach will hold for CLIC physics.

- The philosophy involves a coherent interplay between subdetectors to achieve the best performance for these measurements.

E.g., from talk at Nanobeam08:



Physics → Detector Goals

- vertexing — $\delta(\mathrm{IP}_{\phi,z}) \lesssim 5\mu\mathrm{m} \oplus \frac{10\mu\mathrm{m\,GeV}/c}{\mathrm{p}\sin^{3/2}\theta}$
  e.g. $t\bar{t}$
- tracking — $\delta(1/\mathrm{p_t}) \lesssim$ **Now 2-3x10-5/(GeV/c)**
  e.g. Higgs
- fwd. dirn — $\delta(1/\mathrm{p_t}) \lesssim 3 \times 10^4 \mathrm{GeV/c}^{-1}$,
  e.g. lumi, t–ch.phys. — $\delta(\theta) \lesssim 2 \times 10^{-5}, \cos\theta \lesssim 0.99$
- jet energy — $\delta(\mathrm{E/E}) \lesssim$ **Now 0.25/√E (Zpeak)**
  from **Particle Flow**
- hermeticity — $\sim$ 5 – 10 mrad for beampipe,
  for $\not{E}$ meas. — only hole
- backgrounds — min. material inside Ecal,
  robustness — $\vec{\mathrm{B}} \gtrsim$ 3T, granularity

R & D, prototyping to shoot for these goals

Last remark, I like to look at it this way

- An old paradigm for each subdetector said "measure with the best possible accuracy".
- Our new paradigm (motivated by energy flow/PFA) says "measure as well as possible but with high 3-D granularity and with the highest possible detection efficiency".
- Because if you miss energy, your PFA resolution gets worse (as Mark Thomson put it, "measure as completely as possible all details of an event").
- My back-of-the-envelope guesstimate says PFA resolution gets worse by ~3%/√E per GeV of lost energy, lost either in cracks or by "confusion". It would be nice to see what the factor really is from simulation at some point (later when we have more time).

Summary of LCTPC work for the ILD LOI

- From Cambridge ILD workshop 11 Sept 08

Additional Questions from IDAG (Draft)

June 22, 2008

IDAG wishes the proponents of the 3 LOI's to address the following points in their LOI document:

(1) Sensitivity of different detector components to machine background as characterized in the MDI panel.
(2) Calibration and alignment schemes.
(3) Status of an engineering model describing the support structures and the dead zones in the detector simulation.
(4) Plans for getting the necessary R&D results to transform the design concept into a well-defined detector proposal.
(5) Push-pull ability with respect to technical aspects (assembly areas needed, detector transport and connections) and maintaining the detector performance for a stable and time-efficient operation.
(6) A short statement about the energy coverage, identifying the deterioration of the performances when going to energies higher than 500 GeV and the considered possible detector upgrades.
(7) How was the detector optimized: for example the identification of the major parameters which drive the total detector cost and its sensitivity to variations of these parameters.

IDAG

1. All sub-detectors
   - overall sizes, especially outer and inner diameters and total length
   - total weight
   - support method/mechanism
   - total cross section of cables and pipes (gas and cooling material) and the maximum diameter among them in order to determine gaps between sub-detectors for them
   - location of front-end electronics
   - route of cable and pipe extraction, i.e. where and how are they extracted ?
   - total electric power consumption
   - alignment method, e.g. laser system- how to inject a laser beam, where the laser system is installed, etc.

3. TPC
   - How much is the field uniformity ?
     - a LCTPC note is available at http://www.mppmu.mpg.de/~settles/tpcbfieldlcnote31.pdf .
       - field reproducibility during push pull
       - anti-DID field is not constant, i.e. it will be varied during experiments
       - requires precise field measurement and calibration at Z-pole

ILD MDI

We are planning to have a TPC talk in the subdetector technology session.

The purpose is

a. to summarize the R&D status and present plans for LOI and toward the real detector,
b. to present alignment and calibration schemes, and
c. to present basic engineering design (including supports).

It is important that this is NOT intended to present summary of all the specific and existing R&Ds.

For the presentation in Cambridge we hope that you can summarise the state of the subdetector you are representing with a clear focus on the letter of intent. Things which probably should be covered are
- which resolutions can be realistically achieved
- which big risks exist - as far as we are currently aware - for this particular technology / system
- are there obvious options which we should consider within ILD - that is, do we have a clear techological candidate, or are there more than one competing technologies.
- which parameters are from a subdetector point of view most relevant in an optimization process
- how well is the costing of the system understood
- are there major constraints from the subsystem on the detector integration etc (for this see also the questionare which was sent to you by the MDI group some time ago).

ILD agenda panel

Many questions to answer for the LOI. An attempt to synthesize them into one list is →

List of questions for this talk:

LCTPC issues for the ILD LOI

1. Performance goals
   - R&D plans/options/risks
   - How was the subdetector optimized? (e.g., using resolution, costing?)
2. Sensitivity to backgrounds
3. Calibration and alignment schemes
4. Engineering model for LOI and simulation
   - Size, weight, support, dead areas
   - Endplate, electronics, power
   - Fieldcage, chamber gas
5. Push-pull ability
6. $\sqrt{s}$ coverage

1. LCTPC performance goals

- continuous 3-D tracking, easy pattern recognition throughout large volume
- ~98-99% tracking efficiency in presence of backgrounds
- time stamping to 2 ns together with inner silicon layer
- minimum of X_0 inside Ecal (~3% barrel, ~15% endcaps)
- $\sigma_{pt} \sim 50 \oplus \mathrm{diff}\,\mu m$ ($r\varphi$) and ~ 500μm (rz) @ 4T
- 2-track resolution <2mm ($r\varphi$) and <5mm (rz)
- dE/dx resolution <5% -> e/pi separation, e.g.
- design for full precision/efficiency at 10 x estimated backgrounds

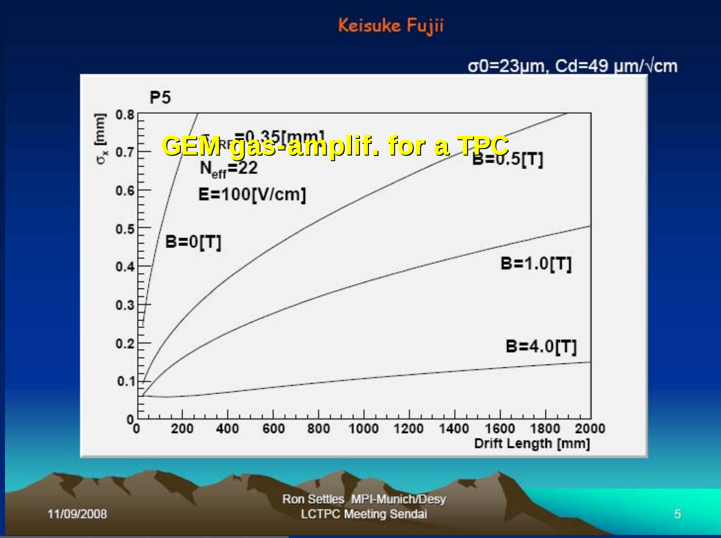
} modulo angles:

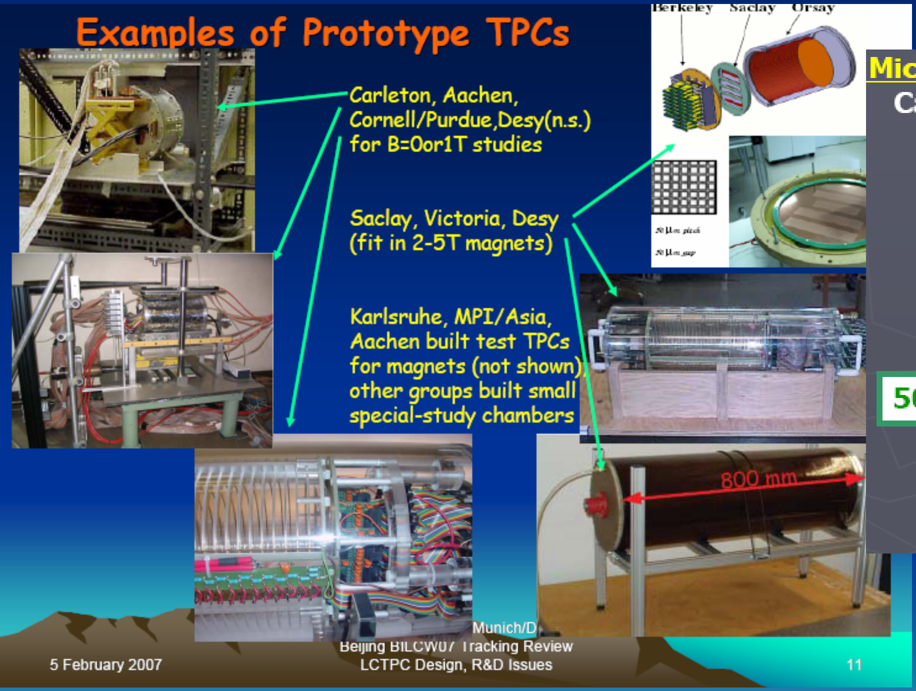
```
1) As a function of drift-distance L_{drift}, the expression for the
r\phi point resolution is, as you know,

sigma_{point}^2 = sigma_0^2 + Cd^2/N_{eff} * L_{drift}

Proposal 1) on point resolution:
--------------------------------
=>sigma_0^2 = (50micron)^2 + (900micron*sin(phi))^2
(where phi is the local azimuthal angle of track wrt the padrow)

=>Cd^2/N_{eff}=25^2/(22/sin(theta)*h/6mm)=(5.3micron/sqrt(cm))^2*(6mm/h)*sin(theta)
(this is for B=4T which we favor, h is the pad height=pad-row pitch in mm,
theta is the polar angle)

=>sigma_z(z)= sqrt{400micron**2 + z(cm) x (80micron/sgrt{cm})**2}
```

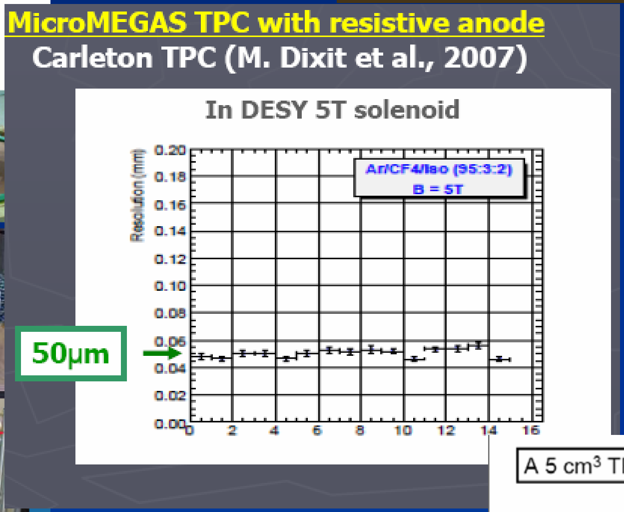
1. LCTPC performance goals

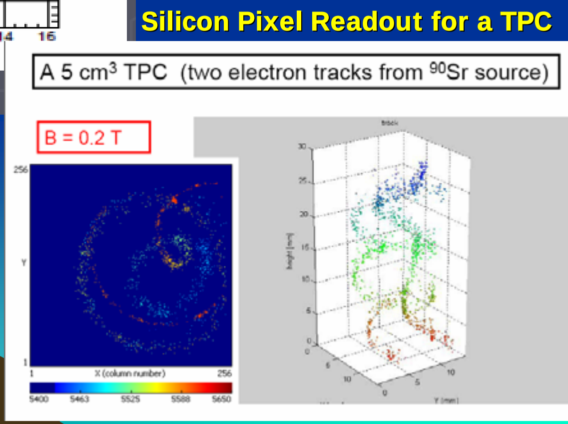
- R&D plans/options

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





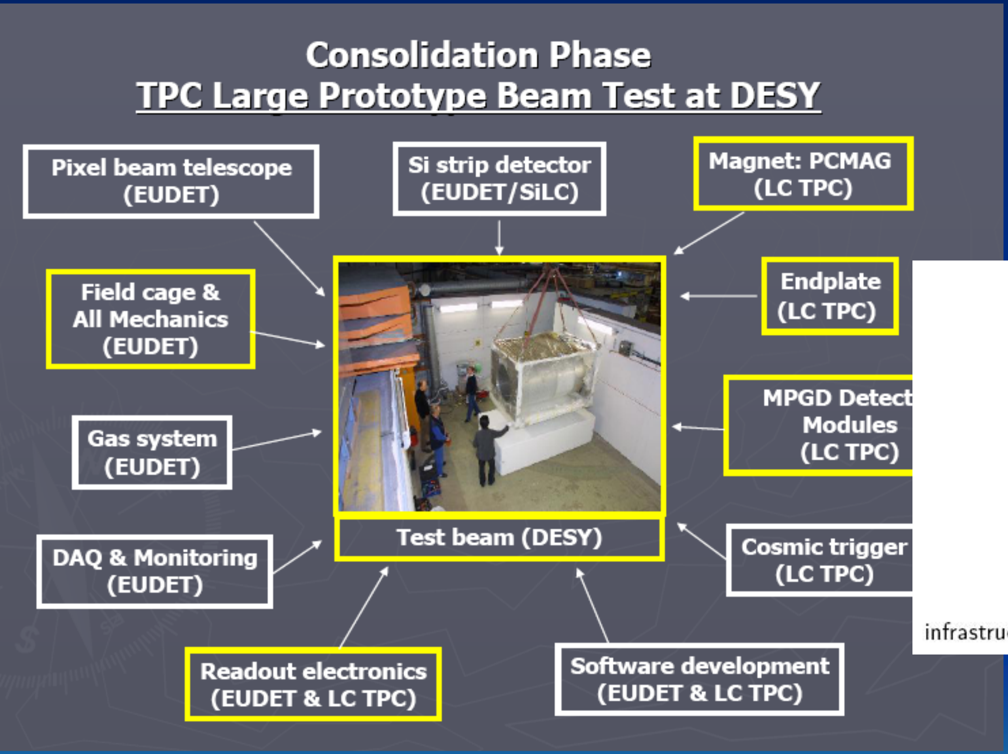


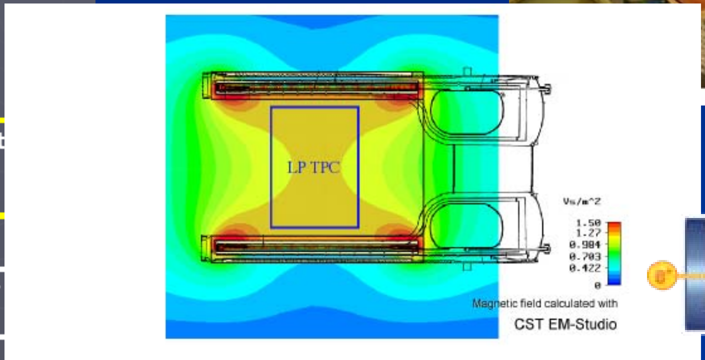


1. LCTPC performance goals

- R&D plans/risks

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





infrastructure for TPC R&D, available for many researcher groups

LCTPC MOA to R&D/design a TPC: Status August2008

Americas
- BNL √
- Carleton√
- Montreal req
- Victoria √
- Triumf√
- Cornell √
- Indiana√
- LBNL prom
- Louisiana Tech req

Observer groups
- Iowa State
- MIT
- Purdue
- Yale
- TU Munich
- UMM Krakow
- Bucharest

Asia
- Tsinghua√
- CDC:
- Hiroshima req
- KEK √
- JAX Kanagawa req
- Kinki U√
- Nagasaki InstAS req
- Saga √
- Kogakuin √
- Tokyo UA&T req
- U Tokyo req
- Minadano SU-IIT req

Signatures 24

Promised 3

Requested 11

New groups welcome

Europe
- Brussels√
- LAL Orsay req
- IPN Orsay req
- CEA Saclay √
- Aachen √
- Bonn√
- DESY √
- EUDET√
- U Hamburg √
- Freiburg req
- Karlsruhe req
- MPI-Munich√
- Rostock√
- Siegen prom
- NIKHEF√
- Novosibirsk√
- St. Petersburg prom
- Lund√
- CERN√

1. LCTPC performance goals

• R&D plans/risks (cont'd)

•From the LCTPC MOA:

Workpackage (0) TPC R&D Program
Workpackage (1) Mechanics
a) LP endplate structure with panels
b) Fieldcage
c) GEM panels
d) Micromegas panels
e) Pixel panels
f) Panels with charge-dispersion-anode
Workpackage (2) Electronics
a) Standard RO/DAQ sytem for LP
b) CMOS RO electronics
c) Electronics for LCTPC
Workpackage (3) Software
a) LP software +simul./reconstr.framework
b) LCTPC simulation/perf./backgrounds
c) Full detector simulation/performance
Workpackage (4) Calibration
a) Field map for the LP
b) Alignment
c) Distortion correction
d) Radiation hardness of materials
e) Gas/HV/Infrastructure for the LP

The LP tests will enable us to choose the best technology for constructing a real detector…

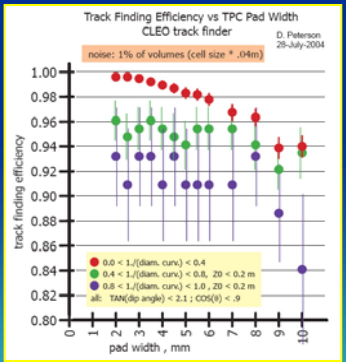
• Our basic approach for the ILD LOI has been to use optimistic assumptions as goals for TPC resolution, materal, etc. These goals are based on various R&D results (small-prototypes), continuing efforts (large-prototype/electronics/software developments) by LCTPC groups. So the only risk is that some goals turn out to be too aggressive.

1. TPC Performance goals

- How was the subdetector optimized?

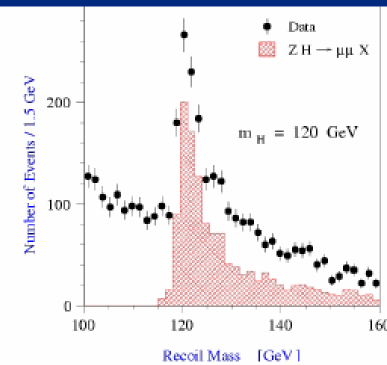
- ILD subdetectors must be optimized coherently by present optimization studies, ∴ for the TPC, this means:

σ_pt ~ 50⊕diffμm (rφ)

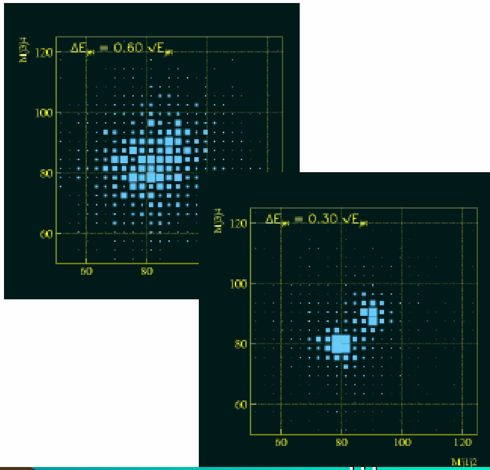


Physics determines detector design

★ Momentum d(1/p) ~ 3 x 10^{-5}/GeV all tracking
10 x 10^{-5}/GeV TPC

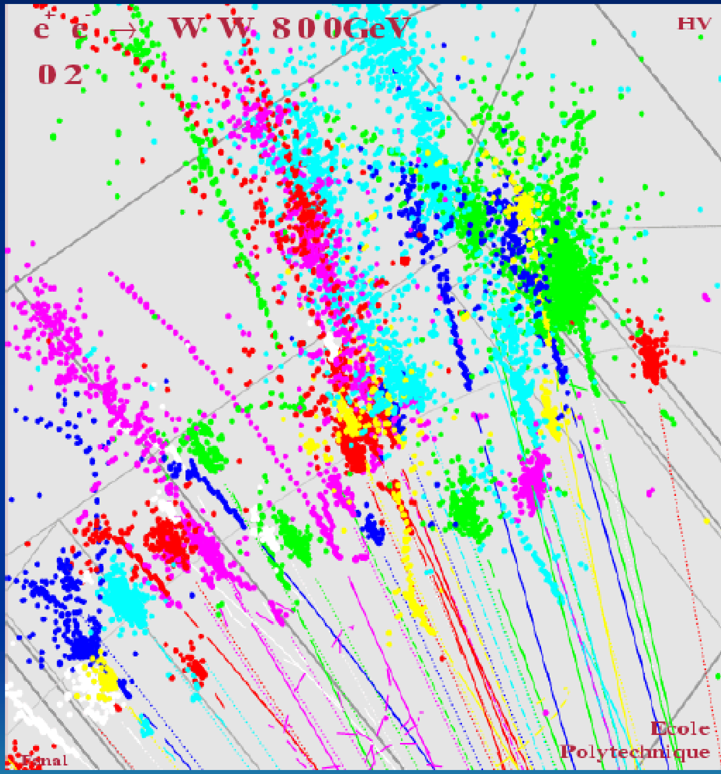


★ Tracking efficiency ~ 99% to help PFA reach dE/E ~ 0.25/√E



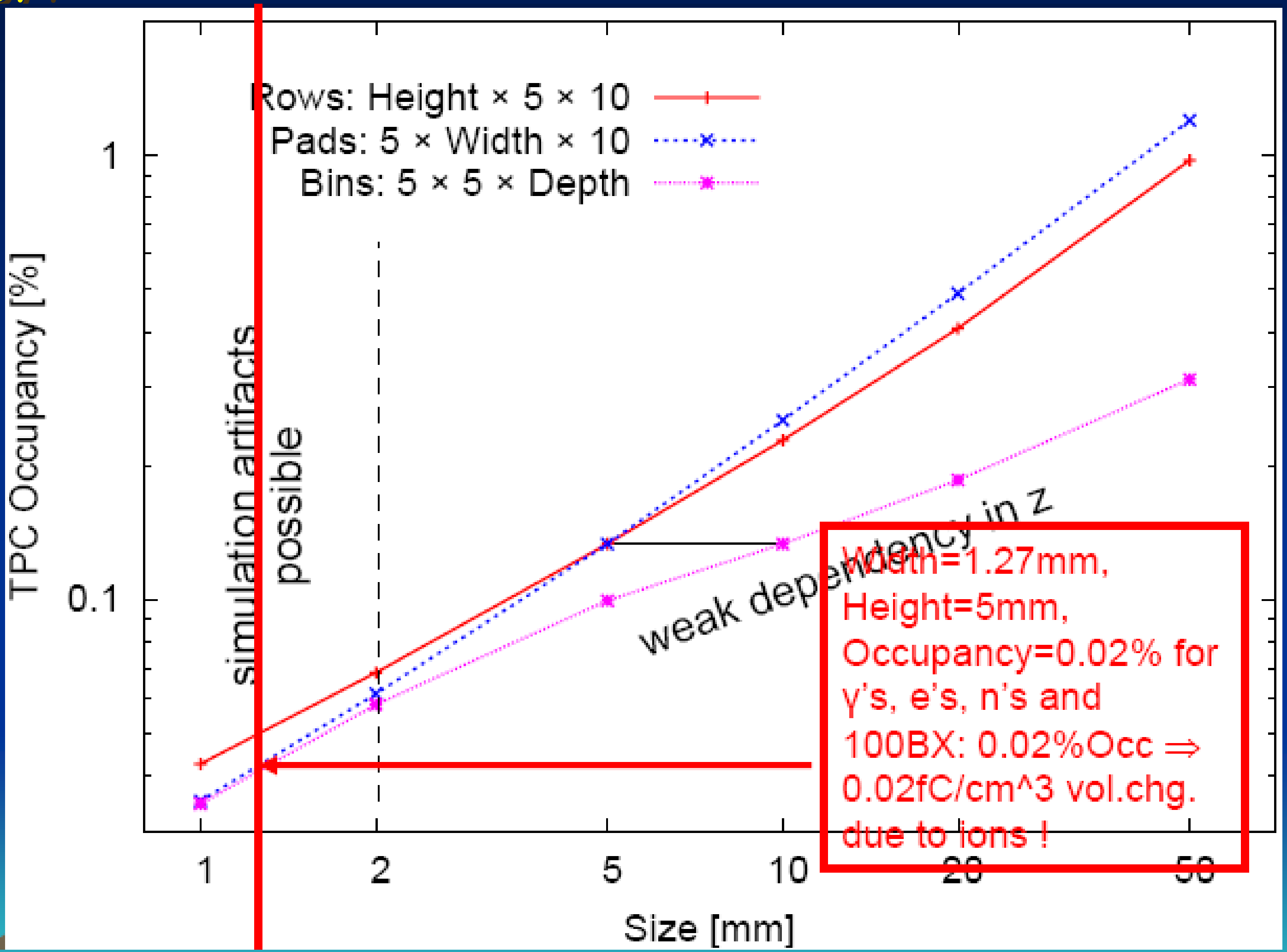
1. TPC Performance goals
   - How was the subdetector optimized? (e.g., using resolution, costing?)

- Resolution: previous slide.
- Costing: The TPC cost is nearly independent of the size for the different ILD models. Previous TPC estimates at ~25 M€ can only become reliable after the design decisions. For earlier ILD-detector estimates at ~ 500 M€, cost drivers are the magnet and the calorimeters, so the TPC cost is not an issue for the optimization.



2. LCTPC sensitivity to backgrounds

See talk#3 in opening session today by Dr. Adrian Vogel. Status at LCWS07:



3. LCTPC calibration and alignment schemes

TPC issues:

- Space charge due to ion "backflow"
  - In TPC volume due to positive ions: see previous slide.
  - At gas-amplification plane: eliminate ion sheets w/ gating plane .
- B-field: no requirement on homogeneity, only on accuracy of field map. See LC Note that Werner Wiedenmann and I finally finished:

LC-DET-2008-002
at http://www-flc.desy.de/lcnotes
ILC-NOTE-2008-048
at http://ilcdoc.linearcollider.org/

**The Linear Collider TPC:
Revised Magnetic-field Requirements[1]**

R. Settles[2]
Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 Munich, Germany

W. Wiedenmann[3]
c/o Physics Department, University of Wisconsin at Madison, CERN PH Divison, CH-1211 Geneva, Switzerland

August 2008

Aleph field map was good enough but can be improved on to increase B-map accuracy for the LCTPC.

3. Calibration and alignment schemes (cont'd)

Calibration tools for all tracking subdetectors:

- Z-peak running, 10/pb beginnin of year, 1/pb during (after push-pull e.g.). Internal alignment of each tracking subdetector, then between detectors. (See http://wisconsin.cern.ch/~wiedenma/TPC/Distortions/Cern_LC.pdf for examples of calibrating the Aleph TPC.)
- Physics data at $\sqrt{s}$ also powerful (e.g. $e^+e^- \to \mu^+\mu^-$, radiative-returns to the Z)
- B-field map (see LC Note, preceeding slide)
- Hall/NMR probes on magnet and field cage
- Laser calibration system
- TPC: time-stamping using silicon layers

4. LCTPC engineering model for LOI and simulation

- Size, weight, support, dead areas

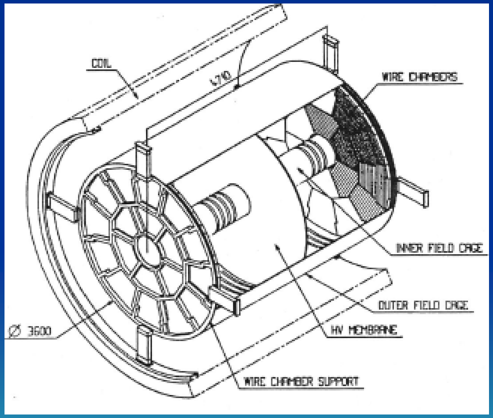
- Size to be decided at this optimization meeting.

  Ø_outer ~ 3.6m, Ø_innerILD2 ~ 0.61m, Ø_innerILD1 ~ 0.75m
  L_outer ~ 4.7m, tracking volume ~ 40 m^3

- Weight ~ 4 t

- Support from Ecal, not from coil

as in Aleph...



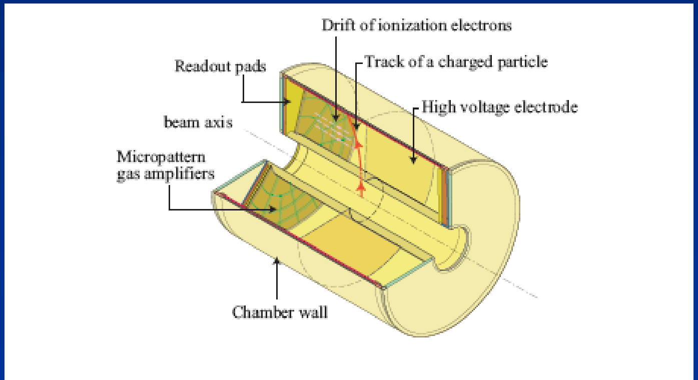


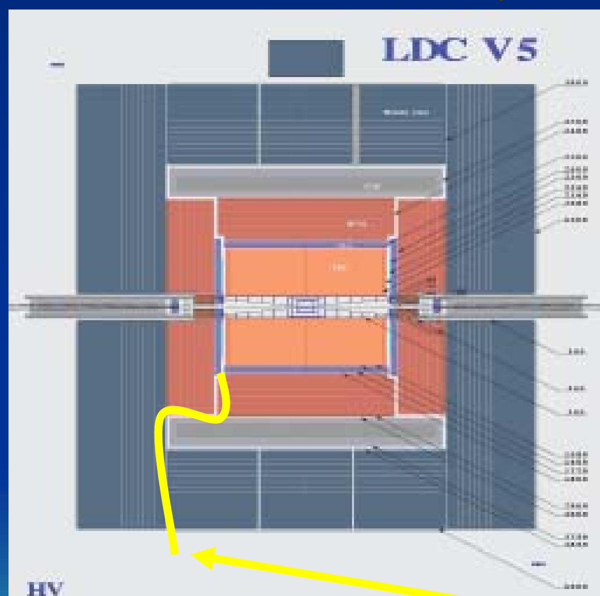
FIGURE 5.5. Schematic layout of the TPC

...MDI designing LCTPC support

4. LCTPC engineering model for LOI

- Size, weight, support, dead areas (cont'd)

- Dead areas:
  - 10 cm in z at each endcap for "standard" electronics/cables (may be increased later)



2) Endplate thickness:

Proposal 2) on Endplate thickness:

=>X_{tpcendplate}/X_0 = 0.15

New Mokka list (** mark changes wrt old list):

dz (mm)	material	% X_0	
0.003	copper	0.02	gating
0.03	kapton	0.01	
0.003	copper	0.02	
1.964	TPC_gas	0.002	
0.003	copper	0.02	mpgd
0.03	kapton	0.01	
0.003	copper	0.02	
1.964	TPC_gas	0.002	
0.003	copper	0.02	mpgd
0.03	kapton	0.01	
0.003	copper	0.02	
3.964	TPC_gas	0.004	
0.05	copper	0.35	pads
2	g10	1.03	
0.5	silicon_2.33gccm	0.53	ROelectr
2	epoxy,etc	1.932	
1	kapton	0.35	
**2	aluminium	2.24	cooling
1	kapton	0.35	
**3	carbonfibre	1.59	stiffness
80.45	Air(0.85)+G10(0.15)	0.02 +6.22	air+ g10 space/ROboards
summa (new model)			
100mm		14.77 %X_0	

- Space needed for cables here
  ~10^3 cables/side thru 5cm rings ~ 1 m^2/side

4. LCTPC engineering model for LOI and simulation

- Endplate, electronics, power

- This is about "standard" electronics (CMOS pixel-electronics require a separate study). [May be ready in time for CLIC].
- Endplate material-estimate on preceeding slide.
- "Advanced endplate" meetings ongoing to understand the electronic density that will allow building a coolable, stiff, thin endplate.
- The present exercise assumes ~ 10^6 channels per endcap.
- With 0.5mW/channel with power pulsing, estimated by a EUDET development of a generalize TPC RO chip based on a further development of the Alice Pasa/Altro ⇒ 0.5kW/endcap
- Cooling (liquid or gas) still has to be studied. (Aleph had 1.5kW/endcap cooled with a combination of liquid and gas.)

4. LCTPC engineering model for LOI and simulation

- Fieldcage, chamber gas

- Based on experience (Aleph, Star, Alice) and recent fieldcage for the LP:

we estimate ~ 3-4% X_0 total for the inner and outer fieldcages.

- Gas properties have been rather well understood by our many small-prototype R&D tests. The choice for the LCTPC will be a BIG issue which would require a long discussion for which there is no time here. This has no effect on the simualtion. For the engineering, the boundary condition is that we must use a non-flammable gas.

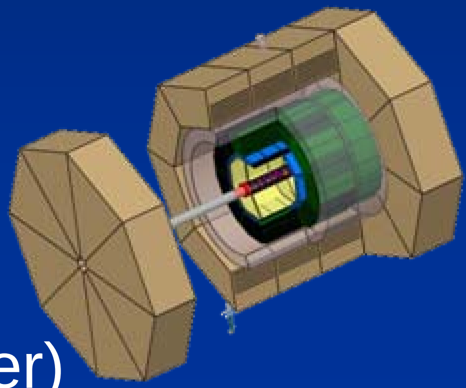
5. Push-pull ability

- At start, guess need 1/pb Z-peak calibration after each push-pull.
- This can probably be relaxed as experience is gained.
- Preliminary hardware discussion at IRENG07, SLAC Sept. 07:

Services **Detector ←→ Trailer**

TPC :

- **500 W per end plate**
- HV/service/data cables: ~ 10^3 per side
- Gas/cooling supply
- Alignment laser
- 50-200kW racks in the counting house (trailer)



6. $\sqrt{s}$ coverage

- Present optimization studies should confirm a good ILD performance up to 1 TeV.
- The highest possible momentum of a single particle is 0.5 TeV/c which will be measured to dp/p ~ 1.5% by combined tracking and ~ 5% by the TPC alone.
- The peak of the momentum distribution of all produced particles (zero to a few 10s of GeV) remains unchanged as $\sqrt{s}$ increases while the tail to high momenta grows. Therefore the vast majority of the particles, the ILD tracking performance will be more than adequate as the c.m.s. energy goes up to and beyond 1 TeV.
- Since the multi-jet numbers grows with logarithmically with $\sqrt{s}$, the average jet energy increases slowly. $\therefore$ PFA should also be good up to 1 TeV and beyond. This statement was written for the Cambridge meeting, and Mark Thomson's talk yesterday verified that it is true .

Differences between warm and cold machines for the TPC at CLIC 500 GeV (starting energy studied a lot in TESLA/NLC days)

Issue/ Property	Warm: 50Hz of 300BX in 150ns	Cold: 5 Hz of 3000BX in 1000000ns
2ns time stamp	$\int$ 4 BX	$\int$ 1 BX
Primary vertex	Few µm evt reconstr.	Few µm evt reconstr.
Pair background	$\int$ 300 BX ~ 0.06% occ.	$\int$ 100 BX ~ 0.02% occ.
Ion background from primary ionization	$\int$ 1 s	$\int$ 1 s
Power pulsing		
10µs turn-on	5 x 10 ^ - 4 better	5 x 10 ^ - 3
100µs turn-on	5 x 10 ^ - 3 same	5 x 10 ^ - 3 same
1000µs turn-on	5 x 10 ^ - 2	1 x 10 ^ - 2 better
Gating/trigger	~ same	~ same