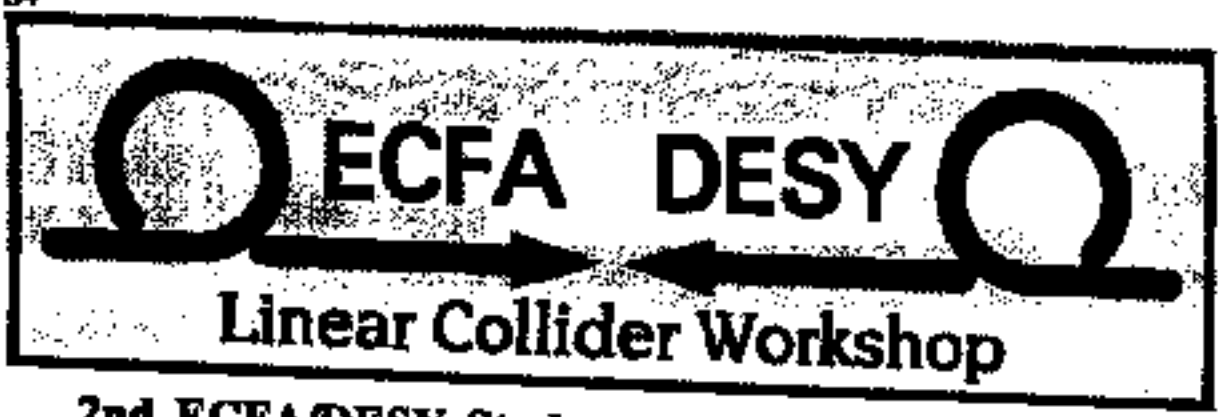
S4



2nd ECFA/DESY Study on Physics and Detectors for a Linear Electron-Positron Collider

LAL - Orsay - France, April 5-7, 1998

Date : April 5, 1998 - 15:25

Speaker : R. Settles

Review of features of the reference detector

Ron Settles/MPI-Munich

Orsay Meeting 5.4.98

REFERENCE DETECTOR

from

1st ECFA/DESY STUDY

- FRAMEWORK
- STEPS LEADING TO CHOICES
- PRESENT DESIGN
- WHAT NEXT?

WORLD WORKSHOPS on e^+e^- BEYOND LEP/SLC

USA	– SLAC STUDY GROUP	1987
	– SNOWMASS	1988, 1990
	– SLAC "TRILOGY OF WORKSHOPS" YALE, WISCONSIN, SANTA CRUZ	1992
	– DPF STUDIES	1994
	– 3 WORKSHOPS → SNOWMASS	1995-1996
JAPAN	– 3 JLC WORKSHOPS	1989, 1990, 1992
	– 22nd SYMP. on PHYSICS with High En. Coll.	1994
	– 4th JLC WORKSHOP	1995
EUROPE	– La Thuile STUDY (CLIC)	1987
	– EE500 WORKSHOPS MUNICH, ANNECY, HAMBURG	1991, 1993
	– RINGBERG WORKSHOPS	1991, '93, '95, '97
	– TELPITZ, SAARISELKÄ, WARSAW	1994
	– LC2000 WORKSHOPS ANNECY, GRAN SASSO, DESY	1995
	– ECFA/DESY STUDY on PHYSICS and DETECTOR FRASCATI, LONDON, MUNICH, HAMBURG	1996
	– 2nd ECFA/DESY STUDY	1998
WORLD	– FINLAND (SAARISELKÄ)	LCWS91
	– HAWAII (WAIMEA)	LCWS93
	– JAPAN (MORIOKA-APPI)	LCWS95
	– SPAIN (BARCELONA/SITGES)	LCWS97

e^+e^- LINEAR COLLIDER MACHINE PROGRESS

YEARLY WORKSHOPS

LC88	SLAC
LC90	KEK
LC91	PROTVINO
LC92	GARMISCH-PARTENKIRCHE
LC93	SLAC
LC96	KEK
LC97	ZUENIGOROD

INTERNATIONAL COLLABORATION,
NOW FORMED TO COORDINATE R&D,
REQUESTED THE REPORT OF A

TECHNICAL REVIEW COMMITTEE

➡ TO DOCUMENT THE STATE OF THE ART AFTER LC96

➡ ALL CHAPTERS UPDATED @ LC97 BASED ON:

- ZEROTH DESIGN REPORT for NLC
- CONCEPTUAL DESIGN REPORT DESY LC500
- JLC DESIGN STUDY

CONCEPTUAL DESIGN REPORT of a 500 GeV e+e- LINEAR COLLIDER with INTEGRATED X-RAY LASER FACILITY

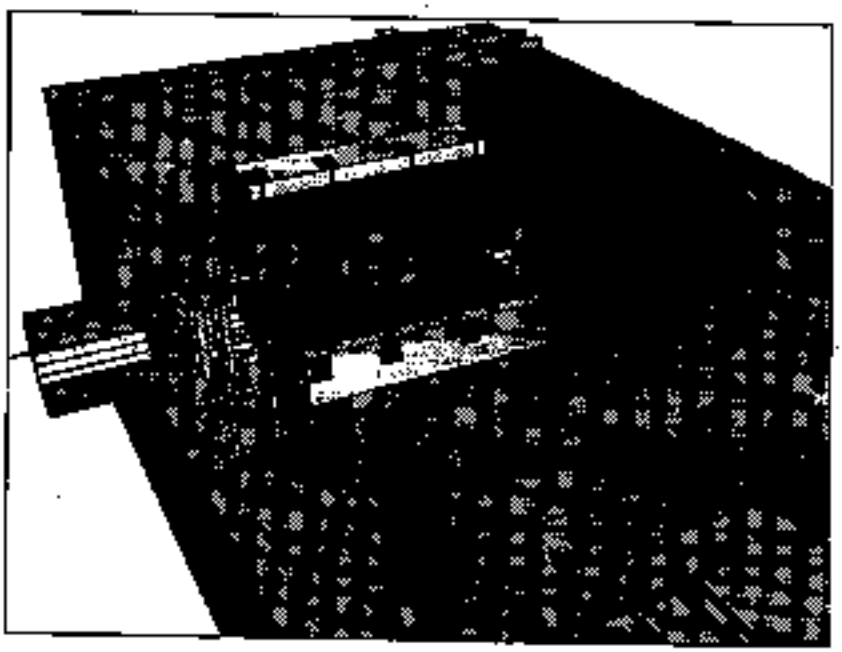
DESY 1997-048
ECFA 1997-182

- CHAPTERS
  - PHYSICS } ECFA/DESY STUDY
  - DETECTOR } (see CDR for list of authors)
  - TESLA LC
  - S-BAND LC
  - FEL
- 1100 PAGES
- FINAL VERSION SENT TO
  - DESY SCIENTIFIC COUNCIL
  - FRG GOVERNMENT
  - PARTICLE PHYSICS COMMUNITY

DESY 97-123E
December 1997

e^+e^- LINEAR COLLIDERS: PHYSICS AND DETECTOR STUDIES

PART E



Contributions to the Workshops – Frascati, London, Munich, Hamburg

February to November 1996

edited by

R. Settles

Organizing Committee

L. Mandelli , INFN Milano (Chairman)
G. Coignet, LAPP Annecy
M. Danilov, ITEP Moscow
E. Fernandez, IFAE Barcelona (Chair of ECFA)
K. Gaemers, NIKHEF Amsterdam,
L. Jönsson, Phys. Inst. Lund
M. Leenen, DESY Hamburg
D.J. Miller, UC London
A. Wagner, DESY Hamburg

Working Groups and Conveners

Physics	*J.-P. Grivaz, T. Sjöstrand, P. Zerwas*
Detector Performance	*M. Martinez, D.J. Miller, M. Piccolo*
Detector Subsystems	*M. Mazzucato, D. Saxon, R. Settles*
Collider-Experiment Interface	*N. Holtkamp, M. Leenen, O. Napoly*

Secretariats for these proceedings: *S. Günther, DESY Hamburg*

JOINT DESY/ECFA STUDY: Workshop Sessions

1. **LNF Frascati**
   February 5–6, 1996
   Organizer: *S. Bertolucci*

2. **University College London**
   July 4–6, 1996
   Organizer: *D.J. Miller*

3. **Max-Planck-Institut für Physik, Munich**
   September 16–18, 1996
   Organizer: *R. Settles*

4. **Deutsches Elektronen-Synchrotron DESY, Hamburg**
   November 20–22, 1996
   Organizers: *M. Leenen, J. Meyer*

STRATEGY FOR DETECTOR

- REVIEW TECHNOLOGIES:
  LEP, SLC, HERA + LHC R&D
- SET PERFORMANCE GOALS
  BASED ON PHYSICS
- CHOOSE TECHNOLOGIES FOR
  CDR REFERENCE DETECTOR

REVIEW

REVIEW

SET / CHOOSE

CHOOSE

Forward

This ECFA/DESY Study followed three series of workshops in 1991, 1992/93 and 1995. In each series were workshops — held at MPI-Munich (91 and 92/93), Annecy(91, 92/93 and 95), Gran Sasso(95) and Hamburg(91, 92/93 and 95) — on the physics with e^+e^- linear colliders in the energy range from 0.2 to 2 TeV. The results are documented in the reports DESY 92-123A&B, DESY 93-123C, and DESY 96-123D, all edited by P.M. Zerwas. Thus the present volume is the fifth in the sequence.

The results of the ECFA/DESY Study appear as the first two chapters of the "*ODR*", the report: *Conceptual Design of a 500 GeV e^+e^- Linear Collider with Integrated X-ray Laser Facility*, eds. R. Brinkmann, G. Materlik, J. Rossbach and A. Wagner, DESY 1997-048/ECFA 1997-182, Vols. I and II. Chapter 1 summarises the physics and Chapter 2 the detector, its performance and the collider-experiment interface. The physics also appears in the publication *Physics with e^+e^- Linear Colliders*, DESY 97-100 (to appear in Physics Reports).

The purpose of this DESY 97-123E volume is to present details that could not be included in the *Conceptual Design Report* due to space limitations. Since the it has not been published elsewhere, the "hardware" parts of the detector chapter are also included, i.e., without the section on physics performance which is covered in DESY 97-100 and by papers in these proceedings, for comparison with the detector studies that follow here and in future.

Ron Settles
Munich, December 1997

CONTENTS, *Part E*

I. PHYSICS

1. TOP QUARK PHYSICS

QCD Potential and $t\bar{t}$ Threshold Cross Section –Status Report– ... 3
M. Jezabek, J.H. Kühn, M. Peter, Y. Sumino and T. Teubner

Top Threshold Studies 19
A. Juste, M. Martinez and D.Schulte

Six Fermion Processes at Future e^+e^- Colliders: Signal and Irreducible Background for Top, WWZ and Higgs Physics in Charged Current Final States 31
E. Accomando, A. Ballestrero and M. Pizzio

Prospects for Top Flavour Violation at a Future Linear Collider ... 49
G.A. Blair

Single Top and Light Higgs at TeV Energy γe Colliders 59
E. Boos, A. Pukhov, M. Sachwitz and H.J. Schreiber

Tests of Possible Non-Standard Properties of the Heavy Quarks and the Higgs Boson 77
G.J. Gounaris, M. Layssac, D.T. Papademou, G. Tsirigoti and F.M. Renard

2. QCD AND TWO–PHOTON PHYSICS

Photon-Photon Total Cross-section 91
A. Corsetti, R.M. Godbole and G. Pancheri

The Hadronic Final States in Deep Inelastic $e\gamma$ Scattering at a Future e^+e^- Linear Collider 105
J.J. Ward

The $\gamma^*\gamma^*$ Total Cross Section and the BFKL Pomeron at the 500 GeV e^+e^- Linear Collider 111
J. Bartels, A. De Roeck, C. Ewerz and H. Lotter

Diffraction in Two-Photon Collisions at TESLA 128
A. De Roeck, R. Engel and A. Rostovtsev

3. ELECTROWEAK GAUGE BOSONS

Approximations for W-Pair Production at Linear-Collider Energies 131
A. Denner and S. Dittmaier

Semi-analytic Preditions for W Pair Production at 500 GeV 139
J. Biebel and T. Riemann

Studying the Trilinear Gauge Couplings in $e^+e^- \to f^-\bar{\nu}_e q\bar{q}'$ at Linear Collider Energies 143
G.J. Gounaris and C.G. Papadopoulos

Study of $e^+e^- \to WW \to \ell\nu q\bar{q}$ at 500 GeV 157
G. Doskeloikis, A. Kyriakis, C. Markou, H. Nowak, I. Riu, E. Simopoulou, R. Shanidze

Six Fermion Processes at Future e^+e^- Colliders: Signal and Irreducible Background for Top, WWZ and Higgs Physics in Charged Current Final States 31
E. Accomando, A. Ballestrero and M. Pizzio

QCD Corrections to Charged-Current Processes at the Next Linear Collider: CC10, CC11 and CC20 at $\mathcal{O}(\alpha_s)$ 171
E. Maina, R. Pittau and M. Pizzio

Model Independent Analysis of the Trilinear Gauge Boson Couplings at LC: Role of Polarised Cross Sections 185
A.A. Pankov and N. Paver

Anomalous Higgs Couplings in Triple Gauge Boson Production at the NLC 195
F. de Campos, S.M. Lietti, S.F. Novaes and R. Rosenfeld

Anomalous Fermionic and Trilinear Gauge Couplings 205
R. Casalbuoni, S. De Curtis and D. Guetta

Scaling of Z' Limits at the Linear Collider 219
A. Leike

Prospects to Detect a Z' with the LC 227
S. Riemann

Identification of Virtual New Physics Effects at a Linear Collider 235
F.M. Renard and C. Verzegnassi

Direct Tests of the Left-Right Electroweak Model at Linear Collider 247
K. Huitu, J. Maalampi, A. Pietilä, K. Puolamäki and M. Raidal

A Strong Electroweak Sector at Future Linear Colliders: Comparison of Models 289
R. Casalbuoni, A. Deandrea, S. De Curtis, D. Dominici and R. Gatto

Strongly Interacting Vector Bosons at TeV e^+e^- Linear Colliders ..303
E. Boos, H.-J. He, W. Kilian, A. Pukhov, C.-P. Yuan and P.M. Zerwas

4. THE HIGGS MECHANISM

SM Higgs Mass Bounds from Theory 343
T. Hambye and K. Riesselmann

The Standard Model Higgs: Discovery Potentials and Branching Fraction Measuretnents at the NLC 349
M. Sachwitz, H.J. Schreiber and S. Shichanin

A Study of the Higgs Hadronic Decay Branching Ratios at the e^+e^- Linear Collider 381
M. Battaglia and R. Vuopionperä

Higgs Boson Production in $e^+e^- \to$ 6 Fermions Processes at NLC ..393
F. Gangemi, G. Montagna, M. Moretti, O. Nicrosini and F. Piccinini

Six Fermion Processes at Future e^+e^- Colliders: Signal and Irreducible Background for Top, WWZ and Higgs Physics in Charged Current Final States 31
E. Accomando, A. Ballestrero and M. Pizzio

Single Top and Light Higgs at TeV Energy γe Colliders 59
E. Boos, A. Pukhov, M. Sachwitz and H.J. Schreiber

Measuring $Z\gamma H$ Vertex Effects at $e\gamma$ Linear Colliders 405
E. Gabrielli, V.A. Ilyin and B. Mele

Tests of Possible Non-Standard Properties of the Heavy Quarks and the Higgs Boson 77
G.J. Gounaris, M. Lagouac, D.T. Papadamou, G. Tsirigoti and F.M. Renard

5. SUPERSYMMETRY

Study of HA Production in e^+e^- Collisions at $\sqrt{s} = 800$ GeV 417
A. Andreazza and C. Troncon

Testing the CP-Violating Higgs-Boson Sector at e^+e^- Colliders 429
B. Grzadkowski and J. Kalinowski

Production of Nonlinear SUSY-SU(5) Higgs Bosons at e^+e^- Colliders 439
H. Franz, B.R. Kim and M. Weber

Higgs Bosons of the Nonlinear SUSY Standard Model and Their Test at e^+e^- Colliders 457
H. Genden, S.W. Ham, B.R. Kim and S.K. Oh

Production and Decay of Stops and Sbottoms and Determination of SUSY Parameters 471
A. Bartl, H. Eberl, T. Gajdosik, S. Kraml, W. Majerotto, W. Porod and A. Sopczak

Production of Neutralinos in Superstring-inspired E_6 Models 479
S. Hesselbach, F. Franke and H. Fraas

6. THE ALTERNATIVE

Leptoquark Pair Production at e^+e^- Linear Colliders: Signals and Background 485
R. Rückl, R. Settles and H. Spiesberger

II. DETECTOR STUDIES

7. DETECTOR FOR THE LINEAR COLLIDER

Baseline Design for the *Conceptual Design Report* 507
S. Aïd, A. Andreazza, P. Bambade, G. Bardin, T. Barklow, W. Bartel, M. Battaglia, R. Bellazzini, S. Bertolucci, G. Blair, R. Brinkmann, I. Brock, R. Brown, J. Bürger, P.J. Bussey, M. Caccia, C. Cavata, P. Checchia, G. Colas, P. Colas, P. Clarke, C. Damerell, G. Daskalakis, M. David, A. De Roeck, S. Dvoshkin, E. Elsen, E. Fernandez, Y. Giomataris, T. Greenshaw, R. Heuer, C. Hessch, N. Holtkamp, P. Hüntemeyer, D. Jackson, P. Jenot, L. Jönsson, J.-P. Jorda, A. Juste, F.P. Juster, B.J. King, F. Kircher, U. Kötz, V. Korbel, Y. Kurihara, A. Kyriakis, P. Le Du, M. Leenen, W. Lohmann, C. Luci, L. Mandelli, C. Markou, M. Martinez, H.U. Martyn, M. Maxmanto, C. Meroni, J. Meyer, D.J. Miller, N. Mokhov, R. Nahnhauer, R. Nania, O. Napoly, H. Novak, R. Orava, M. Piccolo, M. Pohl, D. Reed, F. Richard, I. Riu, A. Rousarie, M. Sachwitz, H.-G. Sander, D. Saxon, U. Schneekloth, H.J. Schreiber, S. Schreiber, D. Schulte, R. Settles, R. Shanidan, C. Shepherd-Themistocleous, S. Shichanin, F. Simonetto, E. Simopoulou, K. Sinram, A. Shilinan, A. Sopczak, P. Steffen, H. Steiner, J. Steuerer, G. Tonelli, M. Tonutti, C. Troncon, C. VanderVelde, G. Vegni, R. Vuopionperä, A. Wagner, N. Walker, M. Weber, W. Wiedenmann, G.W. Wilson, and K. Zapfe-Düren

8. DETECTOR ↔ PHYSICS STUDIES

Vertex Detector Optimisation 607
P. Hüntemeyer and J. Steuerer

Detector Requirements for Top Physics at a 500 GeV Linear Collider 623
C.H. Shepherd-Themistocleous

Charged Higgs Boson Detector Aspects 637
A. Sopczak

9. TRACKING STUDIES

Studies on the Vertex Tracker Design and Backgrounds at the High Energy e^+e^- Linear Collider 641
M. Battaglia, A. Andreazza, M. Caccia and V. Tsulaia

A CCD-Based Vertex Detector for TESLA 659
C.J.S. Damerell and D.J. Jackson

An Inner Tracker of Scintillating Fibers Enclosing a Drift Chamber 667
M. Pohl and R. Nahnhauer

Momentum Resolution Studies for a TPC-Based Central Tracker ..671
B.J. King

An All-Solid-State Central Tracker for the Proposed DESY Electron-Positron Linear Collider 689
B.J. King

Micro Strip Gas Counters for a Tracker at the LC 745
C. Vander Velde, F. Udo and W. Van Doninck

A Method for an Approximate Evaluation of Tracking Errors 757
A. Andreazza

The Studies on Gas Mixtures with Respect to their Application at the LC Detector 771
E. Rulikowska-Zarębska, B. Bednarek, K. Jeleń and T.Z. Kowalski

10. CALORIMETRY STUDIES

Proposal for Monte Carlo Optimization Studies of a Calorimeter at a Future Linear Collider 779
S. Aïd and V. Korbel

Study of a Shashlik Calorimeter at NLC 785
M. Pagnoni, T. Camporesi, F. Terranova, M. Bigi, E. Migliore and V. Obraztsov

Compact Electromagnetic Calorimetry inside a Large Hadronic Calorimeter 795
V. Korbel

Luminosity Monitor Studies for TESLA 809
O. Napoly and D. Schulte

11. MUON SYSTEM STUDIES

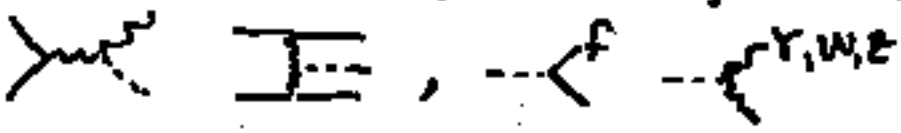
Reconstruction of Forward Muons Produced in an e^+e^- Linear Collider Facility 819
B. Bruni and R. Nania

12. ANALYSIS TOOLS

SMEAR version 3.02, A Detector Simulation Program for e^+e^- Linear Collider Studies 831
R. Settles, H. Spiesberger and W. Wiedenmann

PHYSICS

HIGGS (DISCOVERY &) PRECISION MEAS. of PRODUCTION, DECAY PROPERTIE



→ $100\,fb^{-1}$ @ $\sqrt{s} \sim m_Z + m_H + 25$ GeV

~ 250 GeV acc. to present e.w. →

TOP PRECISION MEAS.

Chirality of decay

Non-standard decays $t \to bH^+, \tilde{b}\tilde{\chi}^0_1, \tilde{b}\tilde{\chi}^+_1$

Mass $\delta m_t \approx \pm 120$ MeV

Z charges $v_t = 1 - \frac{8}{3}\sin^2\theta$, $a_t = +1$

Magn. Moment

El. Dipole Moment

→ $50\,fb^{-1} + 50\,fb^{-1}$ @ $\sqrt{s} \approx 350 + 500$ GeV

WW PRECISION MEAS.

$\mu_{\gamma,Z} = \frac{e}{M_W}[2 + \Delta K_{\gamma,Z} + \lambda_{\gamma,Z}]$ Magn. Dipole Mom.

$Q_{\gamma,Z} = -\frac{e}{M_W^2}[1 + \Delta K_{\gamma,Z} - \lambda_{\gamma,Z}]$ El. Quadr. Mom.

$\delta K, \delta\lambda \sim 10^{-3}$ → $50\,fb^{-1} + 50\,fb^{-1}$ @ $\sqrt{s} \approx 350 + 500$ GeV

SUSY PRECISION MEAS.

→ few $100\,fb^{-1}$ up to highest energy →

DETECTOR

WHAT DO WE NEED?

+ PHYSICS TOOLS?

+ MEASURING PERFORMANCE?

+ WHICH SUB-DETECTORS?

CONCEPT?

+ LARGE DETECTOR, LOW FIELD (2-3T)?

+ COMPACT DETECTOR, HIGH FIELD (4-5T)?

JLC, NLC COLLEAGUES...

"SON OF JADE"
$\phi \sim 16m$
THE TECHNICAL "NEW LAND"

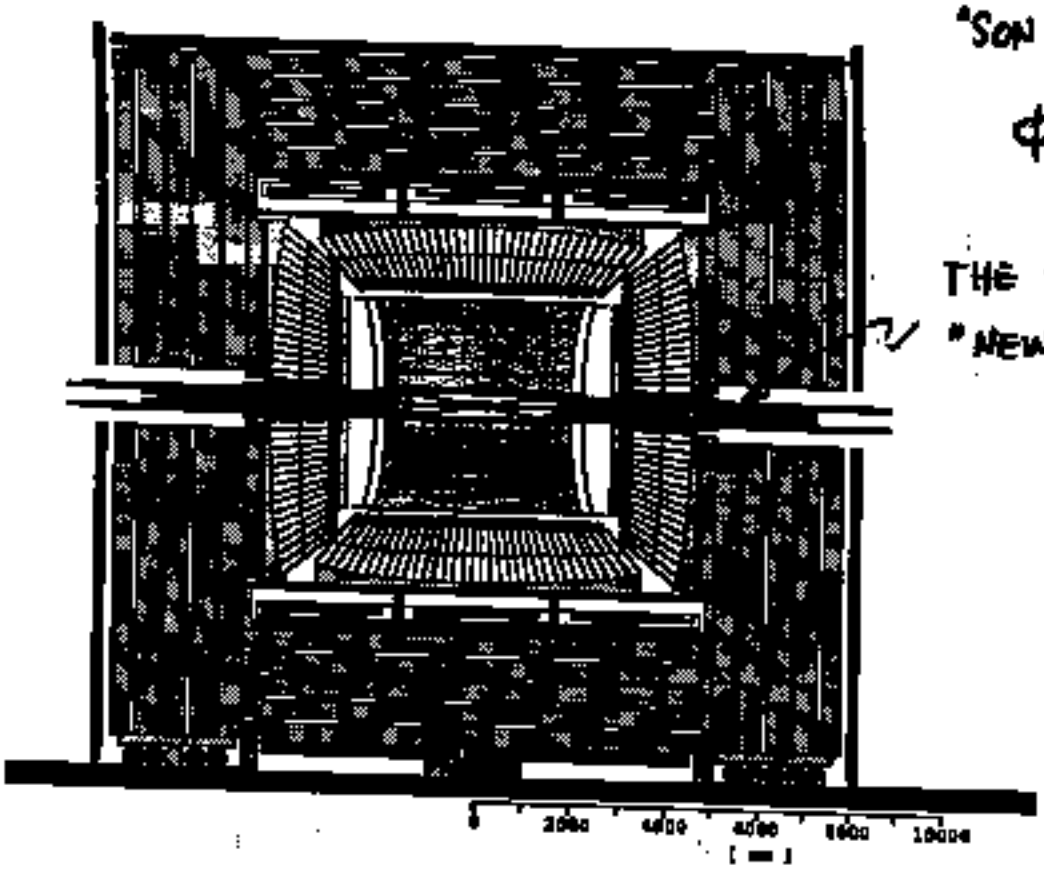
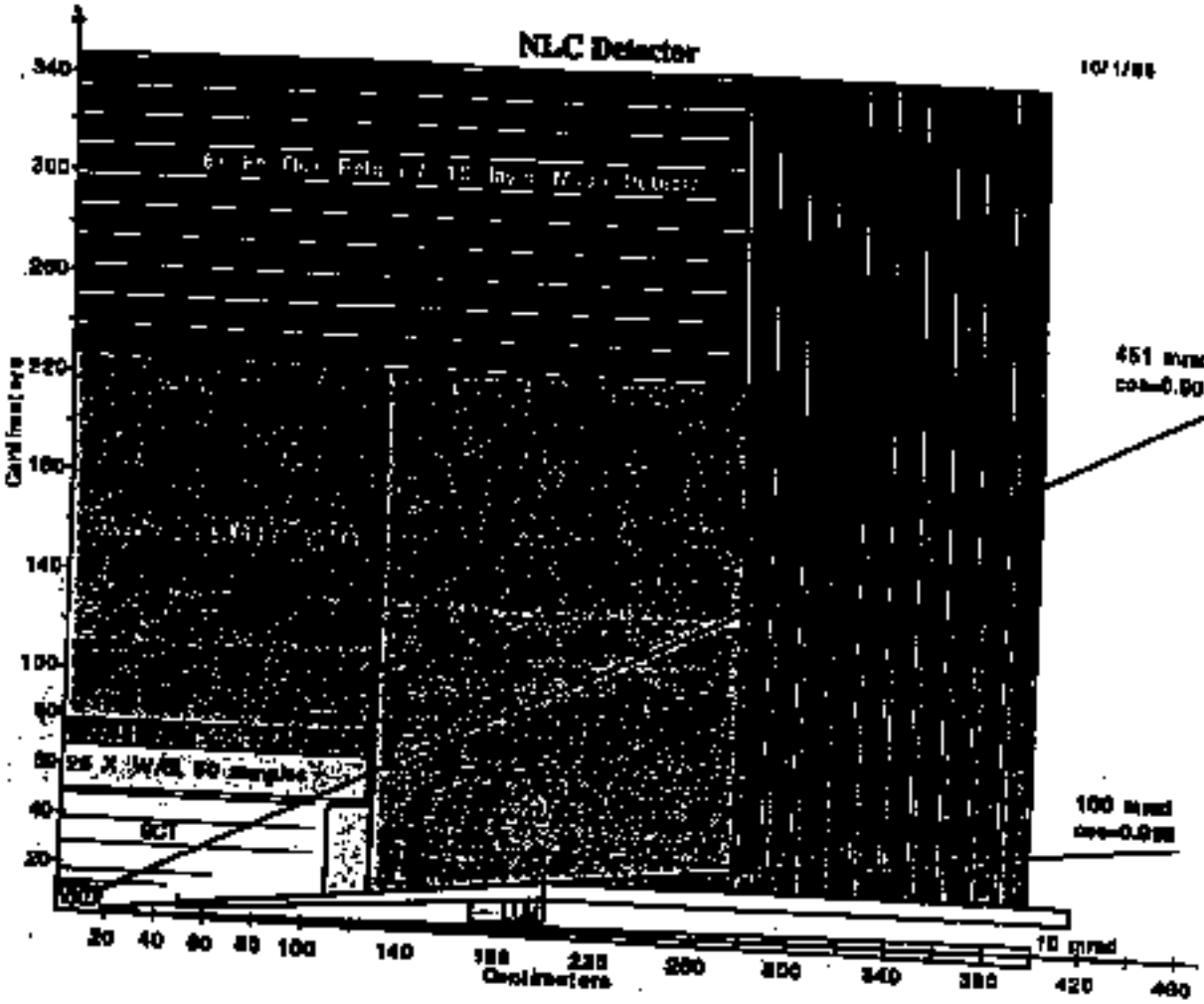


Figure 3.1: Schematical drawing of the JLC detector

DETECTOR	TYPE	CONFIGURATION	PERFORMANCE
VTX (Vertex Detector)	Silicon CCD	Pixel Size : 20 μm Number of Layers : 2 layers Layer Position : r=2.5cm & 7.5cm Thickness : 300 μm / layer $\|\cos\theta\| < 0.95$	Position Resolution : $\sigma = 7.2$ μm Impact Parameter Resolution δ (μm): $\delta^2 = 11.6^2 + (28.8/p)^2 / \sin^3\theta$
CDC (Central Drift Chamber)	Small-cell Jet Chamber	Radius : r = 0.3 - 2.3 m Length : l = 4.6 m Number of Sampling = 100 $\|\cos\theta\| < 0.78$ (full sampling) $\|\cos\theta\| < 0.95$ (20 samplings)	Position Resolution : σ_R = 100 μm (r-ϕ plane wire) σ_z = 2 mm (r-z plane wire) Momentum Resolution : $\sigma_{p_t}/p_t = 1.1\times10^{-4} p_t$ @ 0.1% $\sigma_{p_t}/p_t = 3\times10^{-3} p_t$ @ 0.1% , (with vertex constraint)
CAL	Lead + Plastic Scintillator Sandwich (Compensated)	EM part : thickness = 20 X_0 cell size = 10cm x 10cm HAD part : thickness = 5.6 λ_0 cell size = 20cm x 20cm Si Pad : pad size = 1cm x 1cm $\|\cos\theta\| < 0.99$	Energy Resolution : $\sigma_E/\sqrt{E}$ = 15% / $\sqrt{E}$ @ 1% (e & γ) $\sigma_E/\sqrt{E}$ = 40% / $\sqrt{E}$ @ 2% (hadron) Si Pad Position Resolution : σ = 3 mm Si Pad π^0 Rejection = 1/50
MUON	Single Cell Drift Chamber	Number of Superlayers : 6 $\|\cos\theta\| < 0.99$	Position Resolution : σ = 500 μm P_T > 3.5 GeV (barrel)

* All momentum and energy are expressed in [GeV].

Table 3.1: Parameters and performances of the JLC detector



NLD

$\phi \sim 7$ m

TRACKING Vdet + 5 Layer Si

Ecal W/Si 25 X_0

Coil 4 T

Hcal Fe/Scint. 6 λ

Muon Fe Yoke 10 Layer

... FROM NLC ZDR

LC DETECTOR

EXCELLENT PERFORMANCE ✓

REQUIRED FOR:

	MISSING ENERGY	JET-JET RECONSTR.	LEPTON I.D.	b,c,e VERTEX	FORWARD DIRN.
HIGGS B.R.	✓	✓	✓	✓	✓
TOP THR.	✓	✓		✓	✓
W-COUPL.	✓	✓	✓		✓
$\tilde{\chi}^{\pm}, \tilde{\chi}^{0}, \tilde{\ell}\tilde{q}$...	✓	✓	✓	✓	

➡ DETECTOR MUST BE VERY GOOD

DETECTOR BREAKDOWN

SOME DIFFERENT VIEWPOINTS

MEAS. ACC. ⬅	ANALYSIS PERF. ➡	SUBDETECTORS
HERMETICITY	$\not{E}$ MEAS.	VDET
TRACKING	ENERGY FLOW	INNER TRACKER
CALORIMETRY	JET RECONSTR.	CENTRAL TRACKER
3-D GRANULARITY	J-J. RESOLUTION	ECAL
LEPTON I.D.	LEPTON RECONSTR.	HCAL
VERTEXING	ℓ-ℓ RESOLUTION	COIL
π/K I.D.	b/τ-TAG	MUON
	FORWARD DIRECTION	DAQ/TRIGGER
		RECONSTRUCTION FARM

CORRELATION

Table 8. Correlation between different ways of looking at the detector.

	Detector Performance						
Analysis Performance	Hermeticity	Tracking	Calorimetry	3-Dim. General.	Lepton I.D.	Vertex Tag	pi/K I.D.
Missing-Energy Measurement	x	x	x	x	x		
Energy-Flow Measurement		x	x	x	x		
Jet Reconstruction	x	x	x	x			
Jet-Jet Resolution		x	x	x			
Lepton Reconstruction		x	x	x	x		
b/τ-Tagging		x	x	x	x	x	
Forward-Backward Direction	x	x	x				
Subdetector System							
Vertex Detector		x		x	x	x	
Inner Tracker	x	x		x	x	x	
Central Tracker	x	x		x	x	x	x
Electromagnetic Calorimeter	x		x	x	x		
Hadron Calorimeter	x		x	x	x		
Muon Chambers	x	x	x	x	x		
Luml and End-Cap Devices	x	x	x	x	x		

→ JET-JET RESOLUTION VERY IMPORTANT

... EXPERIENCE AT LEP2

ECFA/DESY STUDY
CERN MEETING 6-7 May 1996

PRELIMINARY

SOME THOUGHTS ABOUT ENERGY-FLOW (*)

Patrick Janot
CERN-PPE

(*) Based on ALEPH's experience

ALEPH :

- Central Tracking : $\Delta\left(\frac{1}{P_T}\right) = 6 \cdot 10^{-4}$ GeV/c^{-1}
  $E_{tracking} \geq 99.8\%$

- Electromagnetic calorimeter
  3cm x 3cm read-out ; $\sigma_E/E \sim 20\%/\sqrt{E}$
  45 planes

- Hadronic calorimeter
  15cm x 15cm read-out ; $\sigma_E/E \sim 85\%/\sqrt{E}$
  23 planes

on Physics and Detectors for the Linear Collider
[illegible] CERN [illegible]

0. INTRODU[illegible]ON

- MOST OF THE FINAL STATES IN HIGH ENERGY PHYSICS CONTAINS HADRONIC JETS

  e.g.
  - $Z \to$ hadrons 70%
  - $W \to$ hadrons 67%
  - $H \to$ hadrons 92%
  - $t \to$ hadrons (wb) 100%

- MANY OF THE NEW PHYSICS PROCESSES L[illegible] TO MISSING ENERGY

  e.g.
  - $H\nu\bar{\nu}$
  - SUSY (χ is $\approx \nu$)
  - ...

- ⇒ TO RECONSTRUCT THE FINAL STAT[illegible] AS PRECISELY AS POSSIBLE, NEED T[illegible] DETERMINE

ENERGY FLOW
1) THE VISIBLE ENERGY (THE MISSING ENERGY)
2) THE JET ENERGIES
3) THE JET DIRECTIONS

THE (IN VA[illegible] MAS[illegible]

I. ENERGY FLOW MEASUREMENT : HOW TO DO IT ?

THREE "PHILOSOPHIES" :

- THE SIMPLEST : USE CHARGED PARTICLES ONLY
  → NEED $\vec{B}$; MISS ALL NEUTRALS (γ, π^0, n, K_L^0)

- THE CALORIMETRIC ENERGY FLOW : USE ONLY THE CALORIMETERS
  → NEED VERY GOOD ENERGY RESOLUTION
  NEED COMPENSATED E-CAL / LOW $\vec{B}$
  MISS MUONS

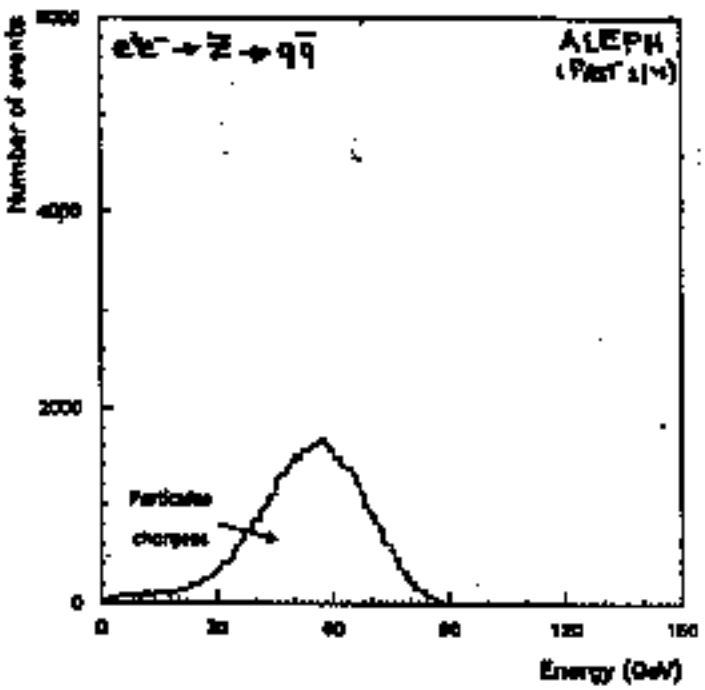
- THE MOST SOPHISTICATED : USE THE PARTICLE-ID FROM ALL SUBDETECTORS ($e, \nu, \mu, \pi^0, K_S^0, \Lambda, \pi^\pm$)
  → NEED HIGH $\vec{B}$
  NEED 3d-GRANULARITY IN ALL SUB-DETECTORS
  NEED MEASUREMENT REDUNDANCY
  MISS ONLY NEUTRINOS

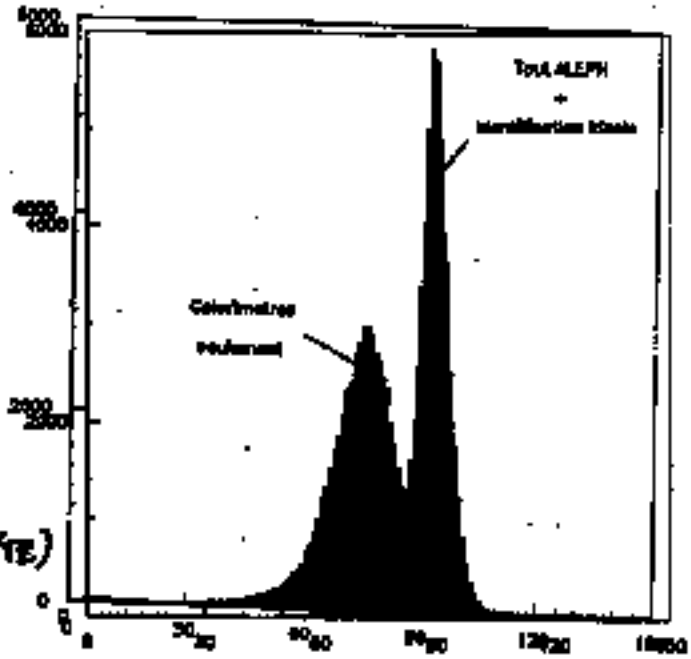
IN ALEPH: $Z^0 \to q\bar{q}$

① CHARGED PARTICLES ONLY

$E_{tot} \sim 53$ GeV

$\Delta E/E \sim 25\%$





1) CALORIMETERS ONLY

$E_{tot} \sim 73$ GeV

$\Delta E/E \sim 12\%$

(ECAL: 20%/√E ; HCAL: 85%/√E)

2) WITH THE WHOLE DETECTOR, ASSUMING AN IDEAL IDENTIFICATION OF γ, e, μ, charged and neutral hadrons

$E_{tot} \sim 90$ GeV ; $\Delta E/E \sim 4\%$

⇒ IDENTIFY AS MANY PARTICLE AS POSSIBLE.

1) CHARGED PARTICLES

- TRACKS IN THE CENTRAL DETECTOR(S)
- LINK TO THE CALORIMETRIC CLUSTERS

2) ELECTRONS, PHOTONS

- IDENTICATION FROM THEIR TYPICAL TRANSVERSE / LONGITUDINAL SHOWER DEVELOPMENT + LINK TO CHARGED PARTICLE
- NEED HIGH ECAL GRANULARITY

3) MUONS

- CHARACTERISTIC PENETRATION PATTERN IN THE HCAL
- NEED HIGH HCAL SAMPLING

4) NEUTRAL HADRONS

- ISOLATED / UN-LINKED SHOWERS IN THE HCAL + ECAL
- NEED HCAL GRANULARITY + COMPACT HADRONIC SHOWER

→ RATHER FOR IN ALEPH

↓

IN CLUSTERS OF CELLS / TRACKS TOPOLOGICALLY MANIFESTED

IDENTIFY NEUTRAL HADRONS IN CHARGED CLUSTERS AS ENERGY EXCESSES ONCE γ, e.g. π^0 ARE REMOVED

AFTER-MUNICH STATUS

DETECTOR CONCEPTS (WG2)

SIMULATE REFERENCE REACTIONS

	$\sqrt{s}$	
$e^+e^- \to t\bar{t}$	350 GeV	K. Kawagoe, A. Juste, D. Schulte, H. Yamamoto, J. Schreiber
$e^+e^- \to ZH$ (120GeV)	350 GeV	
$e^+e^- \to W^+W^-$	500 GeV	H. Nowak, R. Shanidze, E. Simopoulou
$e^+e^- \to \tilde{\chi}^+\tilde{\chi}^-$ (200GeV)	800GeV	
$\tilde{\mu}^+\tilde{\mu}^-$ (300GeV)		M. Ukerlyn

OPTIONAL

$e^+e^- \to hA$	500GeV	Milan group, Attilio Andreazza

FAST SIMULATION PROGRAM

ZELTHEN — J. Schreiber et. al.

MPI-MUNICH — H. Spiesberger et. al.

LAILLE DETECTOR ↔ SMALL DETECTOR

JET RESOLUTION ⇒ ENERGY FLOW

⇒ PARTICLE I.D.

⇒ GRANULARITY/HERMETICITY

⇒ ECAL/HCAL INSIDE COIL

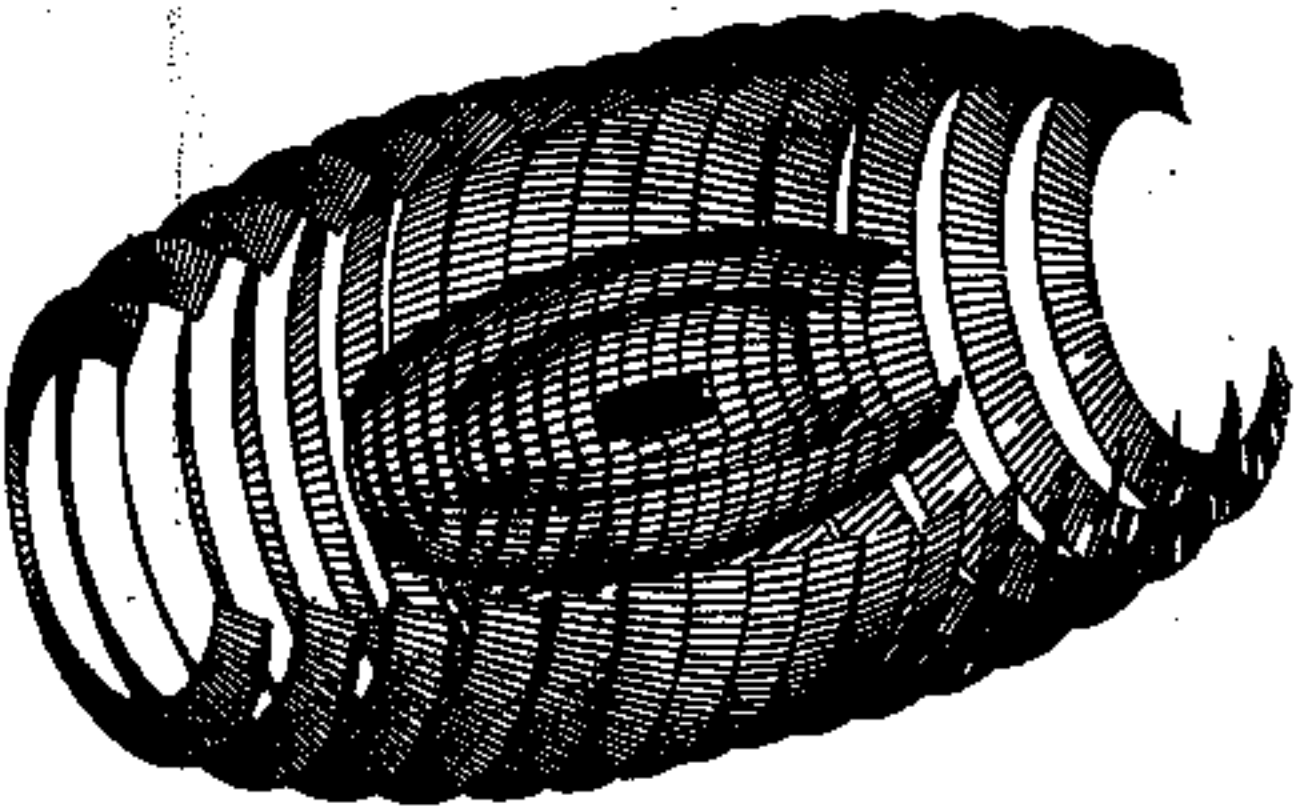
⇒ DETECTOR TYPE ?

LC DETECTOR

"TYPE 5"

An All-Solid State Central Tracker for Collider Experiments

Bruce King
CERN
DESY
BNL



LC DETECTOR

"TYPE L" = "SON OF ALEPH/HA"

$\phi \sim 13$ m

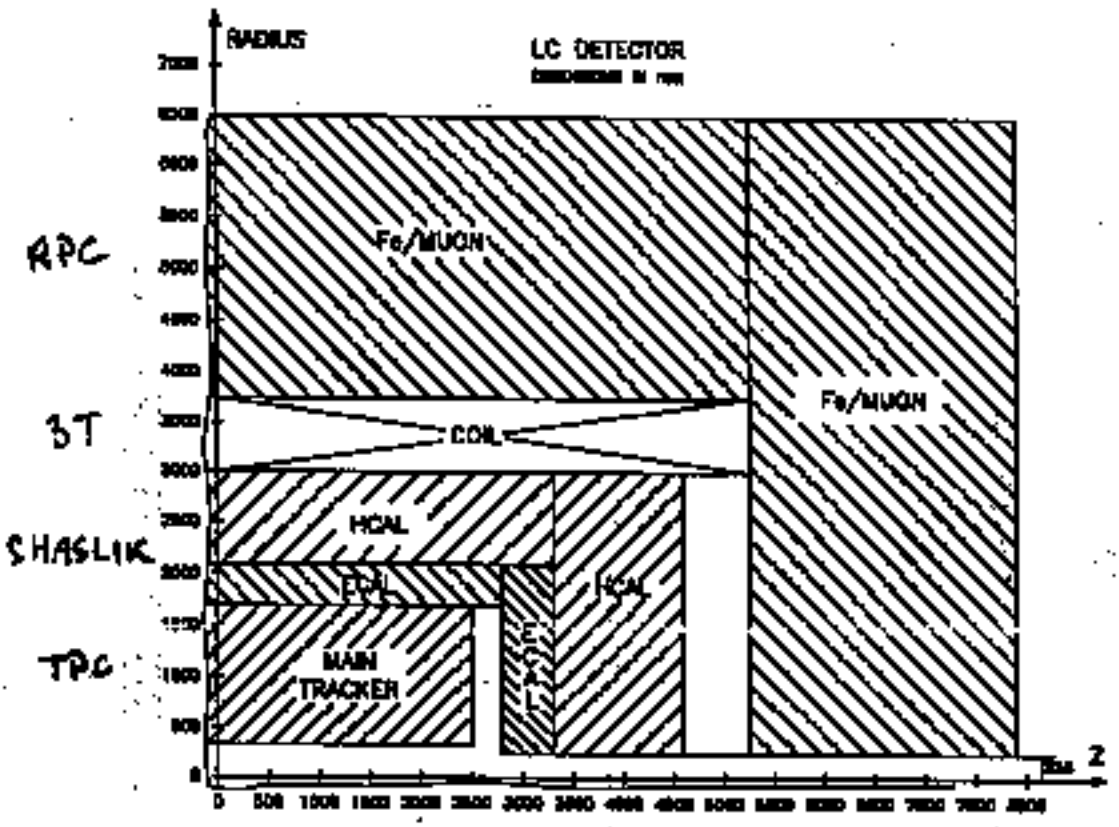
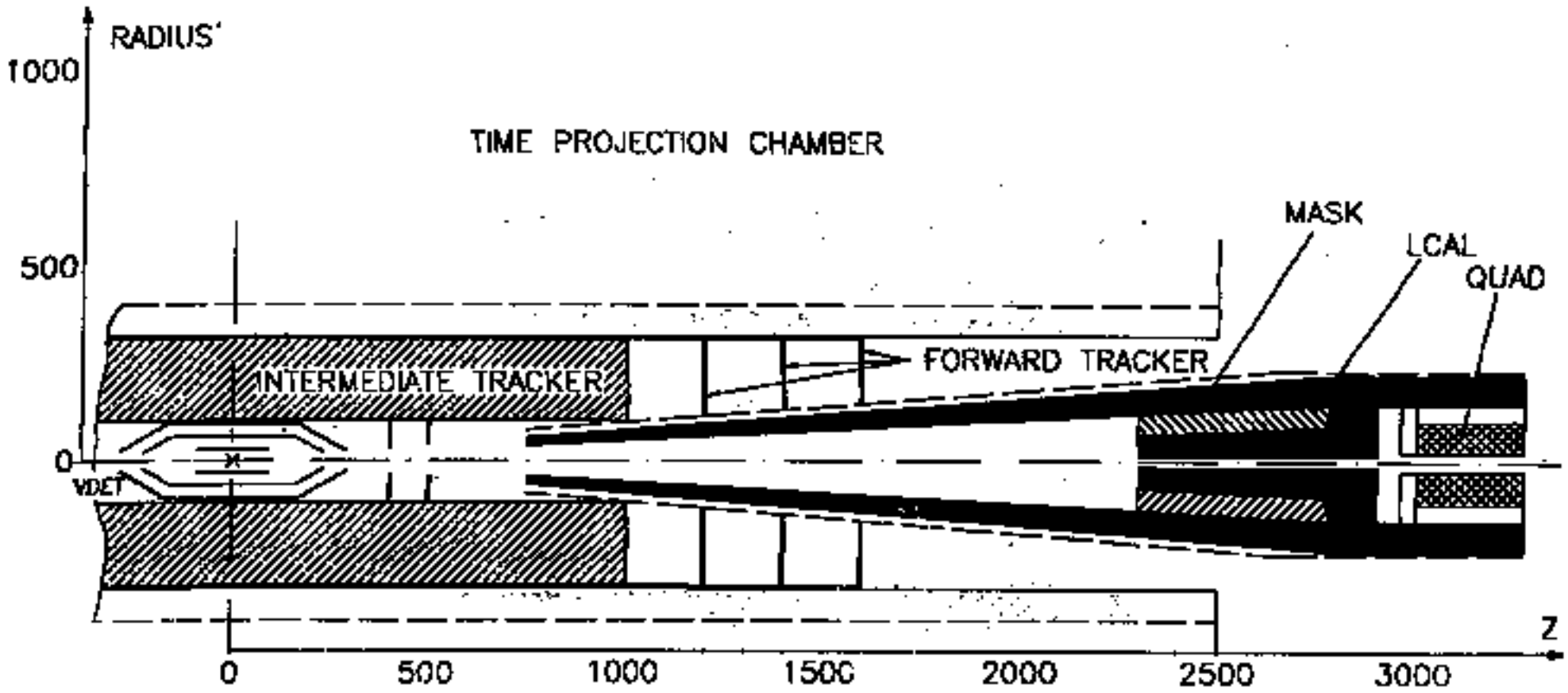
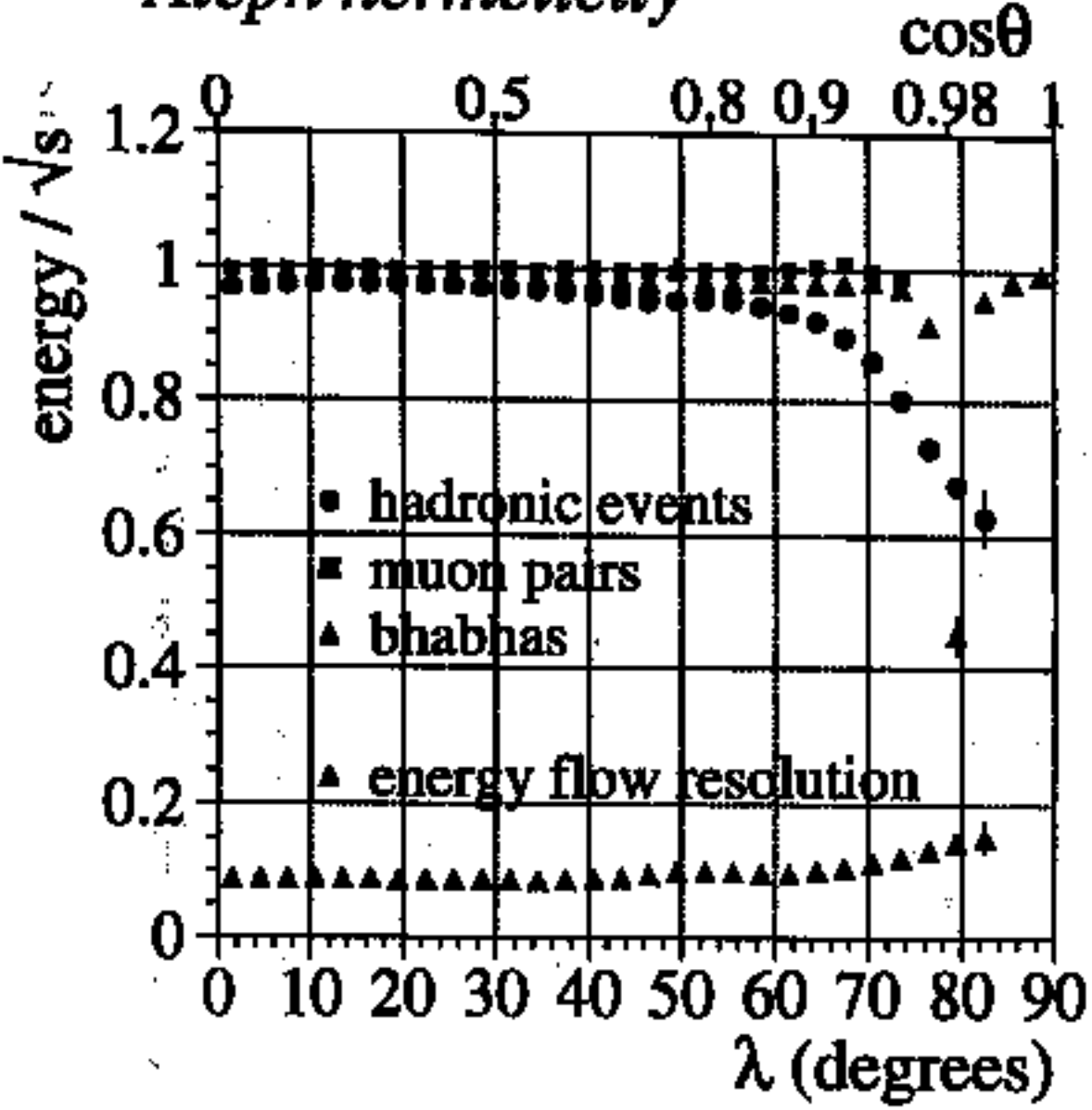


Figure 2.1.1: *Schematical layout of one quadrant of the LC Detector*

INNER DETECTORS



Aleph hermeticity



PERFORMANCE GOALS

Table 2.1.2: *Detector performance goals*

Vertexing	$\delta(IP_{r\phi}) \leq 10\mu m \oplus \frac{3\mu m GeV/c}{p\,\sin^{3/2}\theta}$ $\delta(IP_z) \leq 20\mu m \oplus \frac{3\mu m GeV/c}{p\,\sin^{3/2}\theta}$
Forward Tracking	$\frac{\delta p}{p} < 20\%$, $\delta_\theta < 200$ *µrad* for 100–250 GeV particles down to lowest polar angle θ.
Tracking	$\frac{\delta_{p_T}}{p_T} \leq 1 \times 10^{-4}(\frac{GeV}{c})^{-1}$ Good particle identification.
Electromagnetic Calorimeter	$\frac{\Delta E}{E} \leq 0.10\frac{1}{\sqrt{E}} \oplus 0.01$ (E in *GeV*) Granularity $0.7^\circ \times 0.7^\circ$, at least 3 samples in depth.
Hadronic Calorimeter	$\frac{\Delta E}{E} \leq 0.50\frac{1}{\sqrt{E}} \oplus 0.04$ (E in *GeV*) Granularity $1.5^\circ \times 1.5^\circ$, at least 3 samples in depth.
Muon Detector	Fe yoke instrumented as tail catcher and muon tracker. Toroid momentum analysis for forward muons ($\theta < 15^\circ$), $\frac{\delta p}{p} < 20\%$.
Energy Flow	$\frac{\Delta E}{E} \simeq 0.3\frac{1}{\sqrt{E}}$ (E in *GeV*)
Hermetic Coverage	$\lvert\cos\theta\rvert < 0.99$

CHOICES

Table 2.1.3: *Techniques chosen for the LC detector*

Subdetector	Technique chosen (Radiation Length)	Alternative techniques
Barrel		
Beam pipe	(0.3% X_0)	
Vertex detector	CCD or APS (1.6% to 2.4% X_0)	Silicon strip
Intermediate tracker	Honeycomb straw tubes (0.28% X_0)	Scintillating fibres with drift chamber; Silicon strip
Intermediate layer	Double-sided silicon strip (1% X_0)	
Main tracker	Time projection chamber (5% X_0 to outer field cage)	MSGC; Silicon strip
(Total thickness to outermost tracking radius = 11%(CCD) or 13%(APS) X_0)		
Preshower	Scintillating fibres	
E-M calorimeter	Pb-scintillator sandwich; cal.	Spaghetti calorimeter; Crystals
Hadron Calorimeter	Cu-scintillator sandwich	
Tailcatcher, muon identifier	Resistive plate chambers	Limited streamer
Forward		
Luminosity calorimeter	Scintillating fibres in Pb	Spaghetti calorimeter Silicon-tungsten Sandwich
Instrumented mask	Quartz fibres in W	
Forward tracker	Silicon strip and/or pixels	
Forward muon tracker	Toroids with honeycomb tubes	

DETAILS IN CDR

DETAILS IN DESY 97-123E

RESUMÉ OF SOME CRUCIAL POINTS

- 100 - 400 1 MeV γ's / bunch IN BARREL

  ⇒ MINIMISE MATERIAL

- EXCELLENT VERTEXING

  (MULT. SCATT. TERM)

- A.G.A.P. ENERGY FLOW

  ⇒ HIGH GRANULARITY, REDUNDANCY IN TRACKING, CALORIMETRY: PARTICLE I.D.

- GOOD ECAL

  ⇒ SOFTWARE COMPENSATION

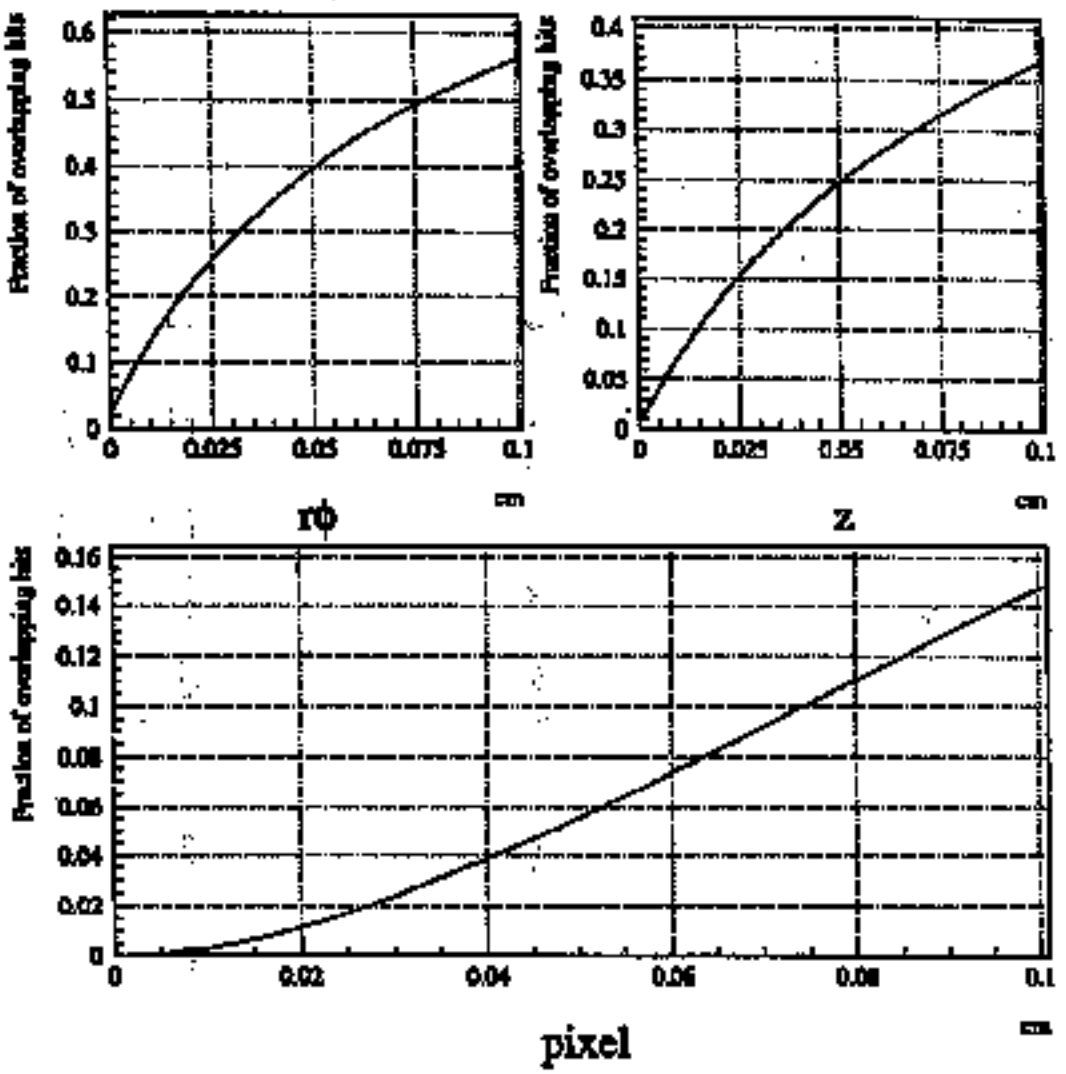
- GOOD HCAL

  ⇒ HOW MUCH INSIDE COIL? (SIZE OF MAGNET)

- FORWARD DIRN. IMPORTANT

  ⇒ - TRACKING INSIDE
  - TOROIDS OUTSIDE

UDET



STRIPS ☹

PIXELS 😐

Figure 2.2.1: *Fraction of overlapping hits for the inner layer at 8.5 cm radius, as a function of the two-track resolution for rφ strips and z strips (upper plots) and for pixels (lower plot). The generated events were $t\bar{t}$ final states at $\sqrt{s} = 500$ GeV. For the upper plots, the rφ strips are 10 cm long in z, and the z strips are 2 cm long in rφ.*

VDET

35

APS ⟷ CCD Technology

2cm ⟷ 1cm $r_{beampipe}$

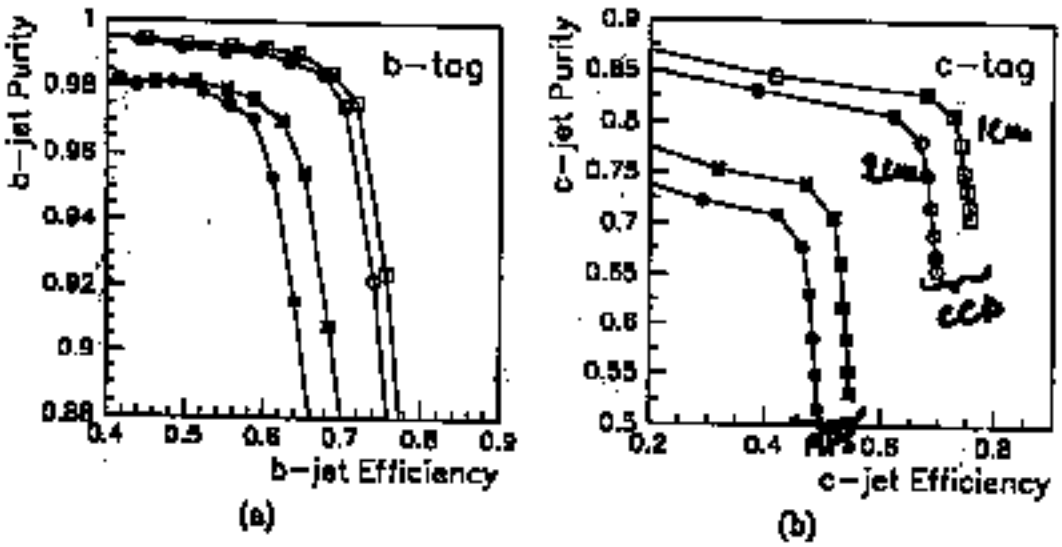
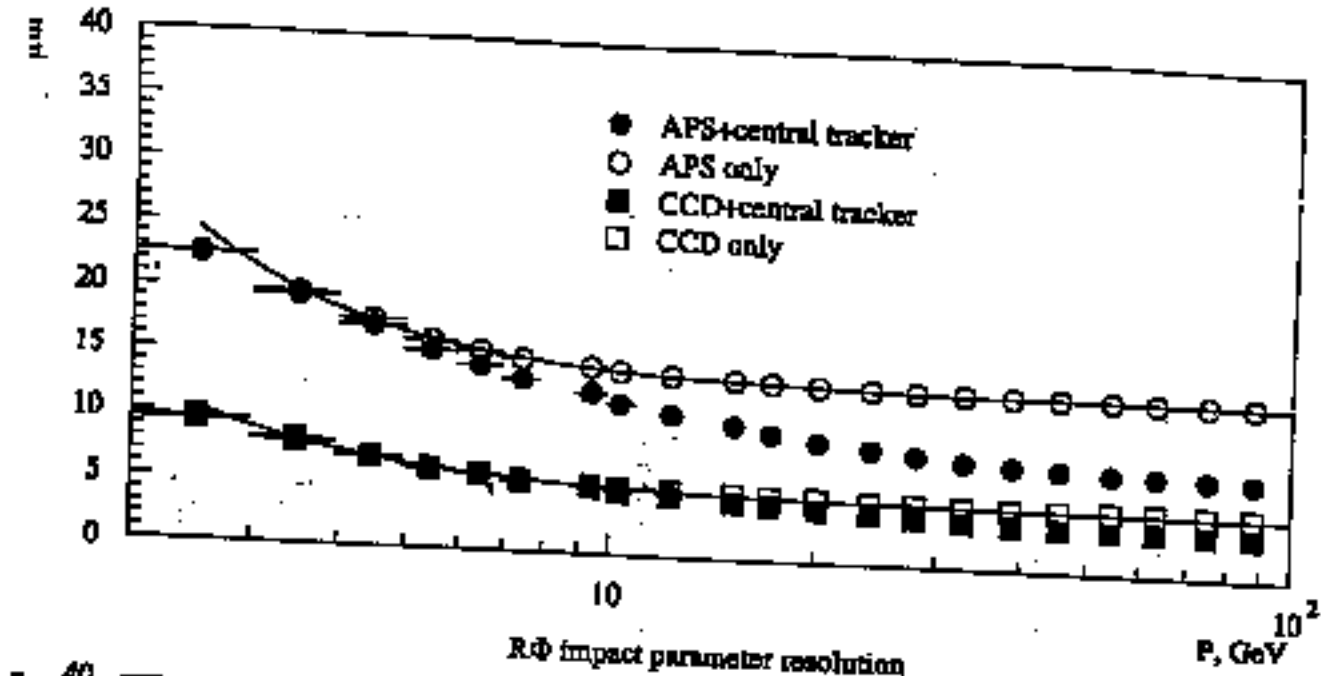
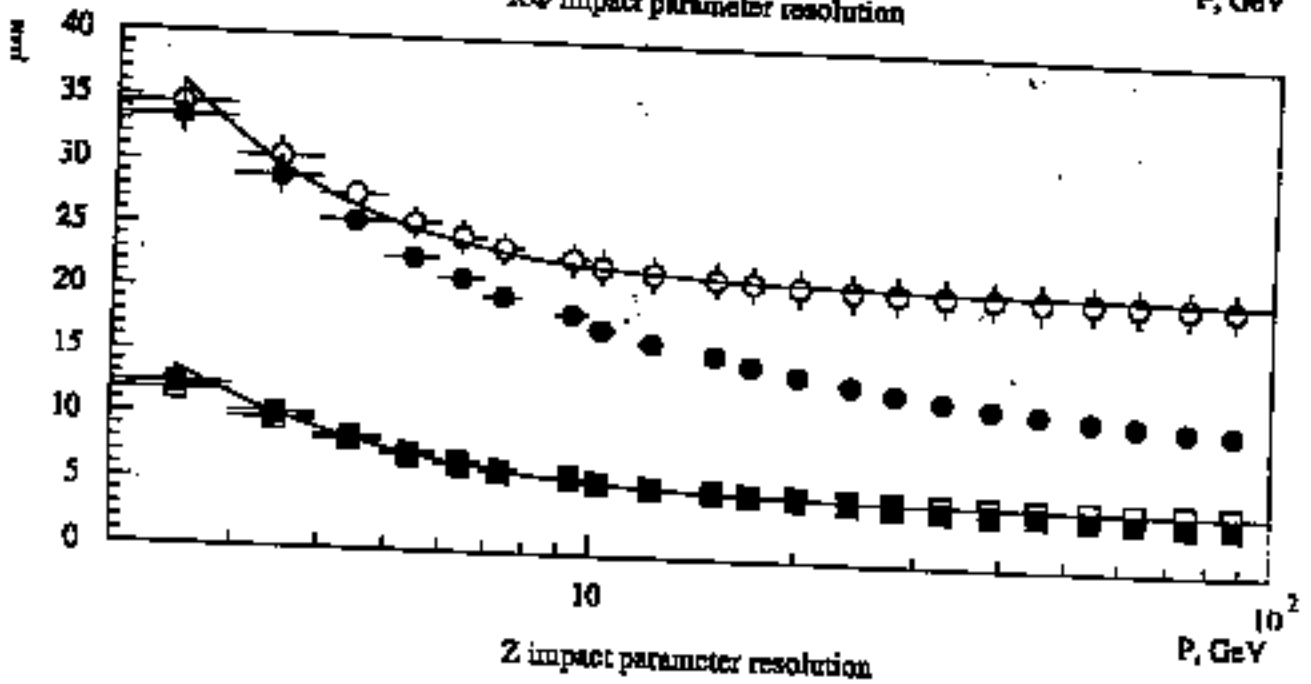


Figure 2.2.2: *Purity vs efficiency for (a) beauty and (b) charm identification in 50 GeV jets. Open squares and circles refer to the CCD option, with respectively* $r_{beampipe}$ = *10 and 22 mm. The filled squares and circles refer to the APS option for the same* $r_{beampipe}$ *values.*



RΦ impact parameter resolution



Z impact parameter resolution

INTERMEDIATE TRACKER

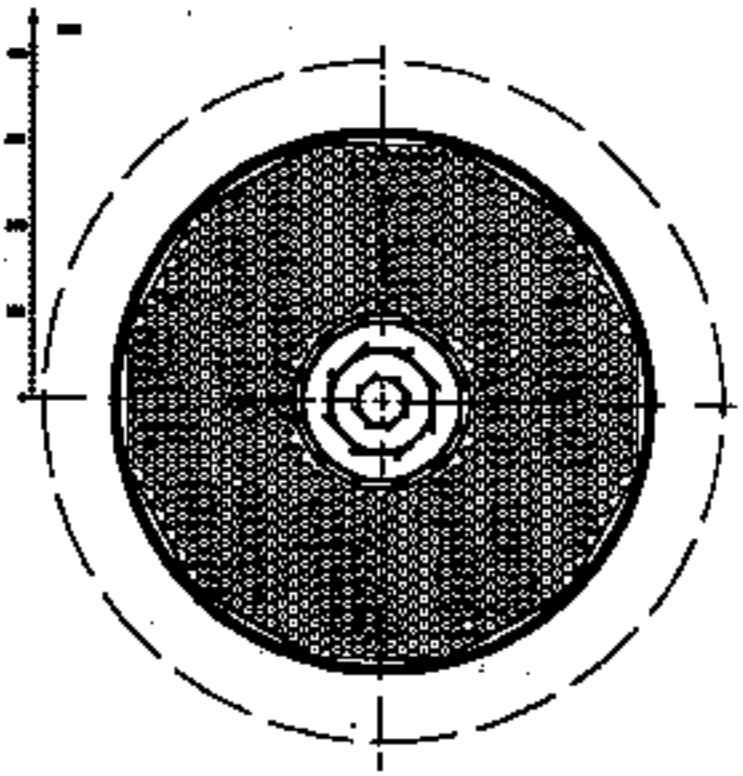


Figure 2.2.3: $r\phi$ view of the honeycomb chamber and the vertex detector.

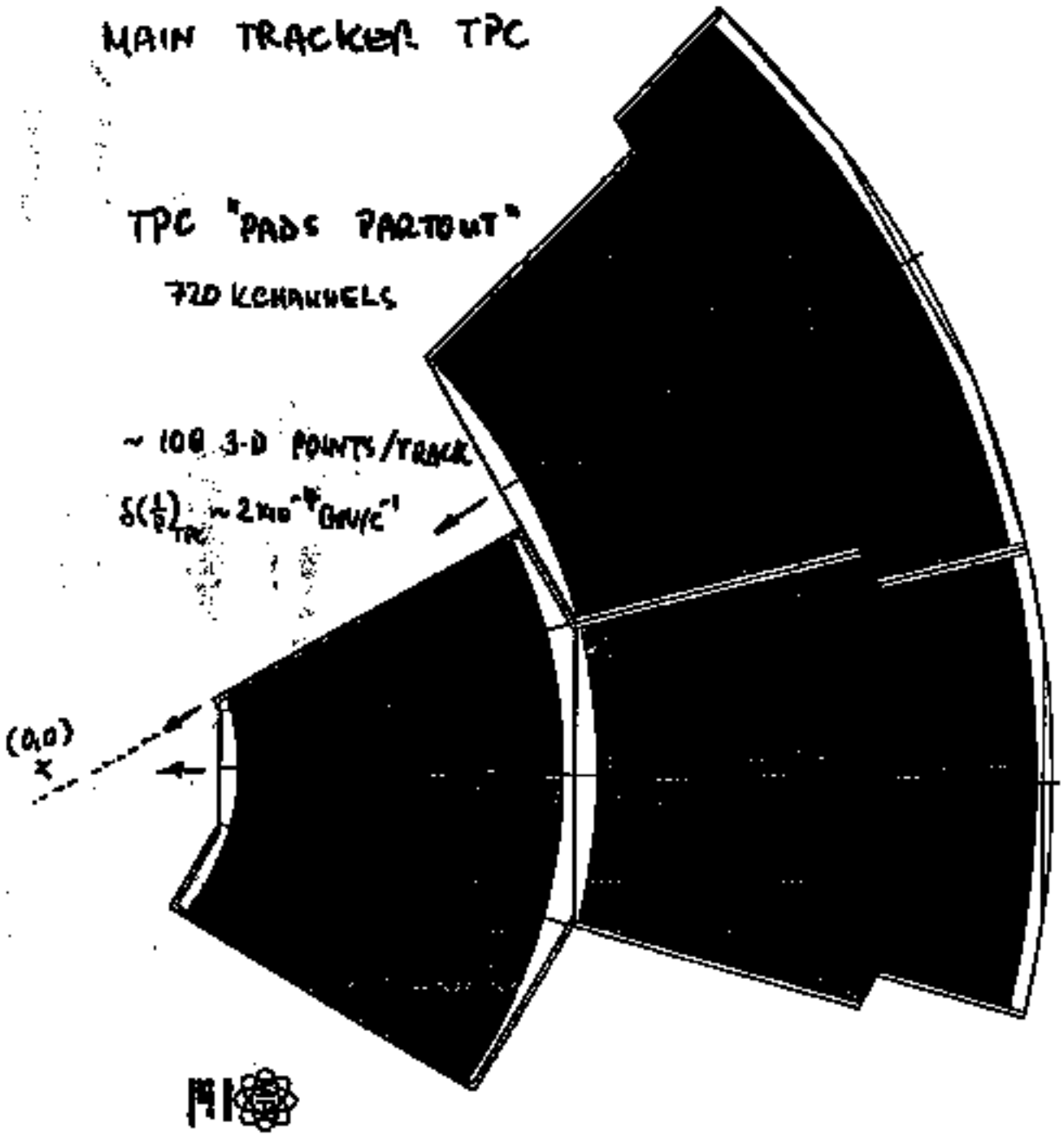


Figure 2.2.5: *TPC sectors with pad structure. The inner sector boundaries do not point to the origin.*

TRACKING

BACKGROUNDS

1? CURRENTS?

2? OCCUPANCY?

SOURCES

	a) PHOTONS	b) CHG PTCLS
1) BRAM-BEAM	✓	✓
2) NEUTRONS	✓	
3) SYNCH. R. FINAL QUADS	0	0
4) DEBRIS	?	?

ASSUME

TRIGGER RATE = 5 Hz

GATE OPEN 50 μs, CLOSE

⇒ "SEE" 70 BUNCHES TESLA

333 BUNCHES S-Band

BACKGROUND CURRENTS

	TESLA		S-BAND	
	a) PHOTONS	b) CHGD	a)	b)
1) BDAH-BEAM	0.09μA	0.06μA	0.09μA	0.04μA
2) NEUTRONS	0.43μA		0.55μA	

ACEPII @ LEP: 0.5 - 5μA TYPICAL
~3μA MAX

LAB TESTS ⇒ ≥ 100μA SHOULD BE POSSIBLE
(HV TRIP AT LEP SET AT 1μA/SECTOR × 36 SECTORS)

BACKGROUND OCCUPANCY (ONE TRIGGER)

	TESLA		S-BAND	
	a) %	b) CHGD	a)	b)
1) BDAH-BEAM	.012%	1%	.9%	8%
2) NEUTRONS	.6%		.4%	

ALICE: 10%/EVENT → 6K
(HEAVY ION @ LHC) 60000 TRACKS

TRACKING OVERALL

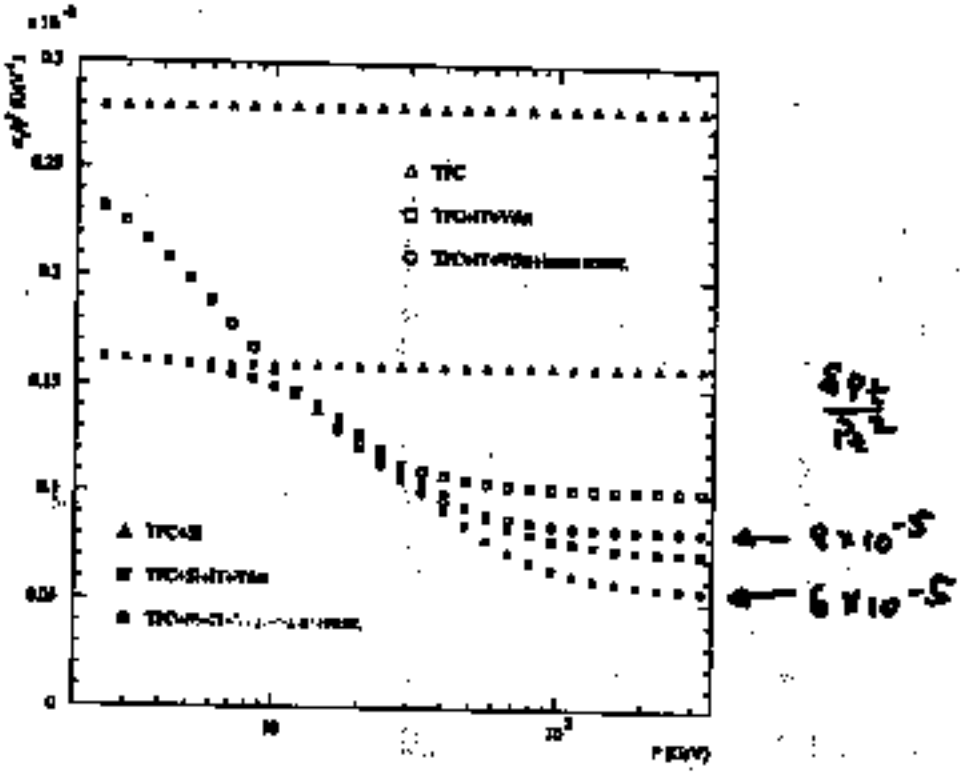


Figure 2.2.6: Resolution of $1/p_t$ for 90° tracks assuming an APS vertex detector. Symbols: Vdet = vertex detector, IT = intermediate tracker, Si = intermediate silicon layer.

< 10 μm systematic error ?!!

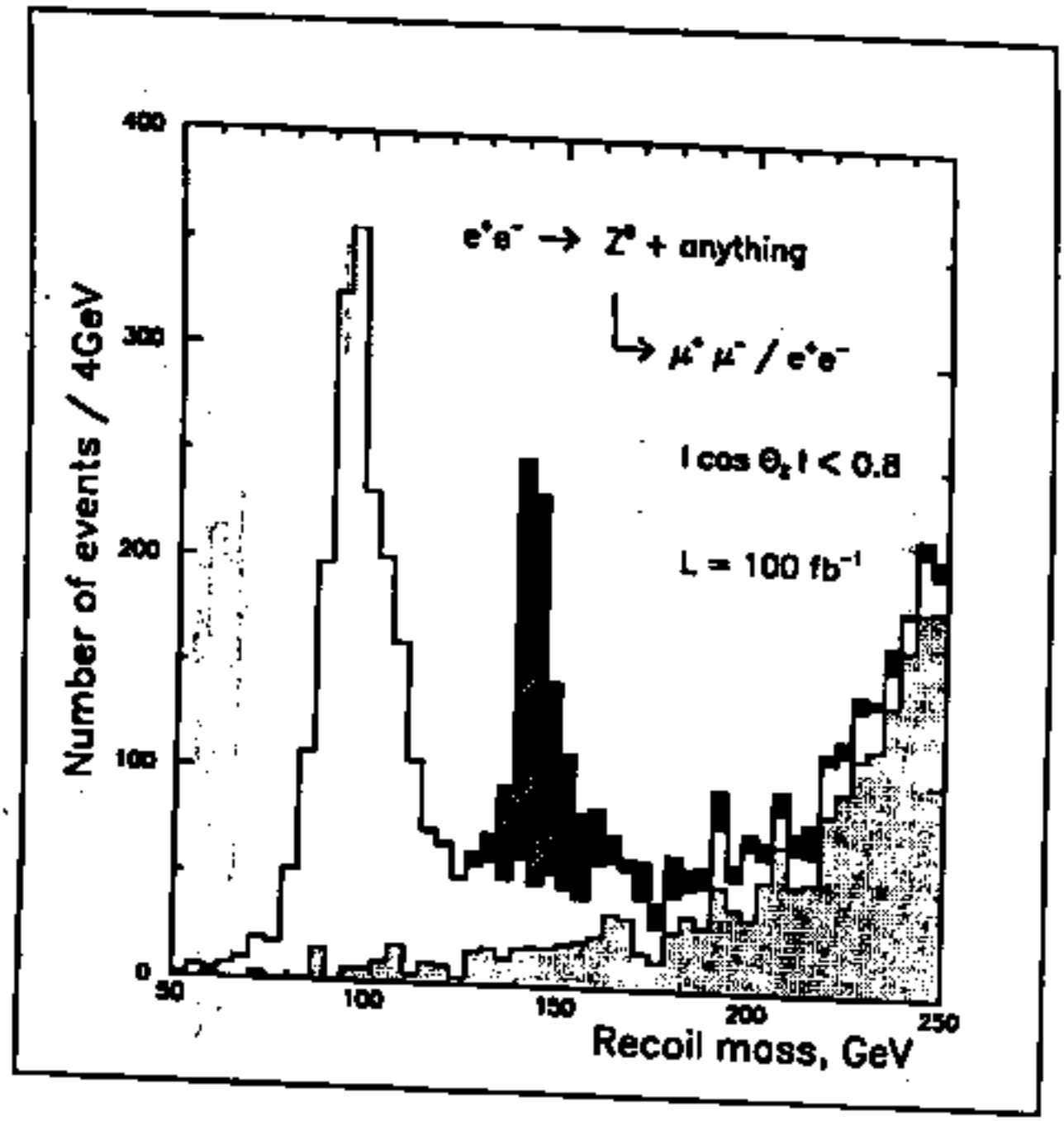


Figure 7: *Inclusive recoil mass distribution in the process $e^+e^- \longrightarrow Z^0 (\longrightarrow \mu^+\mu^- / e^+e^-) +$ anything for an integrated luminosity of 100 fb^{-1} and $|\cos\theta_Z| < 0.8$. The shaded histogram represents the reducible background expected, whereas the Higgs contribution is shown cross-*

TRACKING $\frac{\delta p_t}{p_t^2} \sim 7 \times 10^{-5} (\text{GeV}/c)^{-1}$

COIL

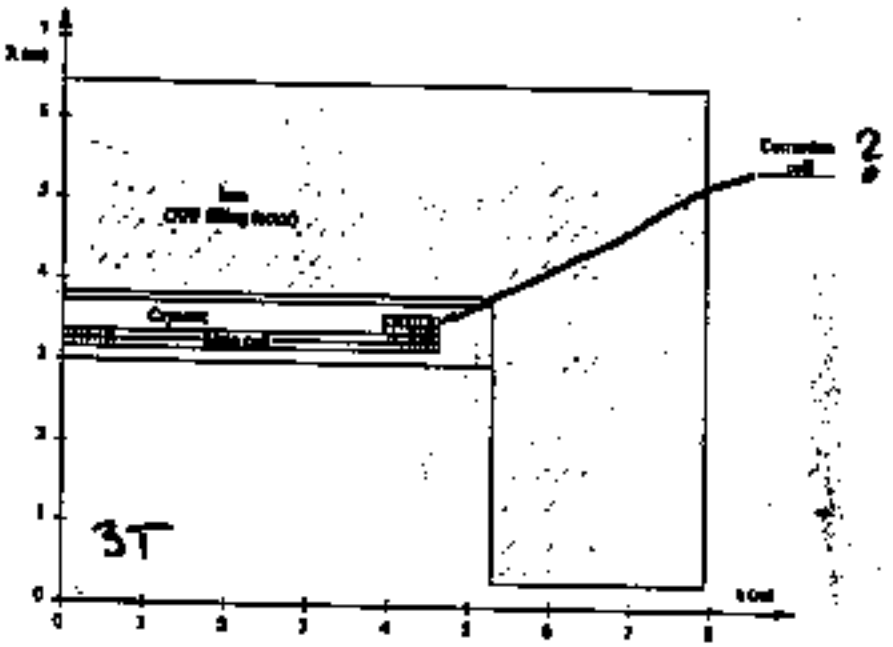


Figure 2.1.3: *Cross section through the magnet.*

3T "CONSERVATIVE"

Table 2.1.5: *Main characteristics of the superconducting solenoid.*

Dimensions	
Cryostat inner radius (m)	3
Main coil inner radius (m)	3.15
Main coil outer radius (m)	5.35
Correction coil inner radius (m)	3.35
Correction coil outer radius (m)	3.55
Cryostat outer radius (m)	3.75
Iron inner radius (m)	4.8
Iron outer radius (m)	6.4
Iron filling factor (%)	70
Main coil length (m)	9.2
Cryostat overall length (m)	10.6
Magnetic field	
Central field (T)	3
Maximum field at conductor (T)	3.8
Stored energy (MJ)	1 380
Nominal current (A)	15 000
Ampere turns main coil	$21.9\ 10^6$
Ampere turns correction coil	$1.8\ 10^6$
Conductor	
Type	NbTi cable in high purity Al plus mechanical reinforcement
Strand diameter (mm)	1.1
Cu to Sc ratio	1.9
No. of strands in cable	32
Overall dimensions (mm^2)	100 x 12
Critical current at 4.2 K and 4 T (A)	35 500

ECAL, HCAL

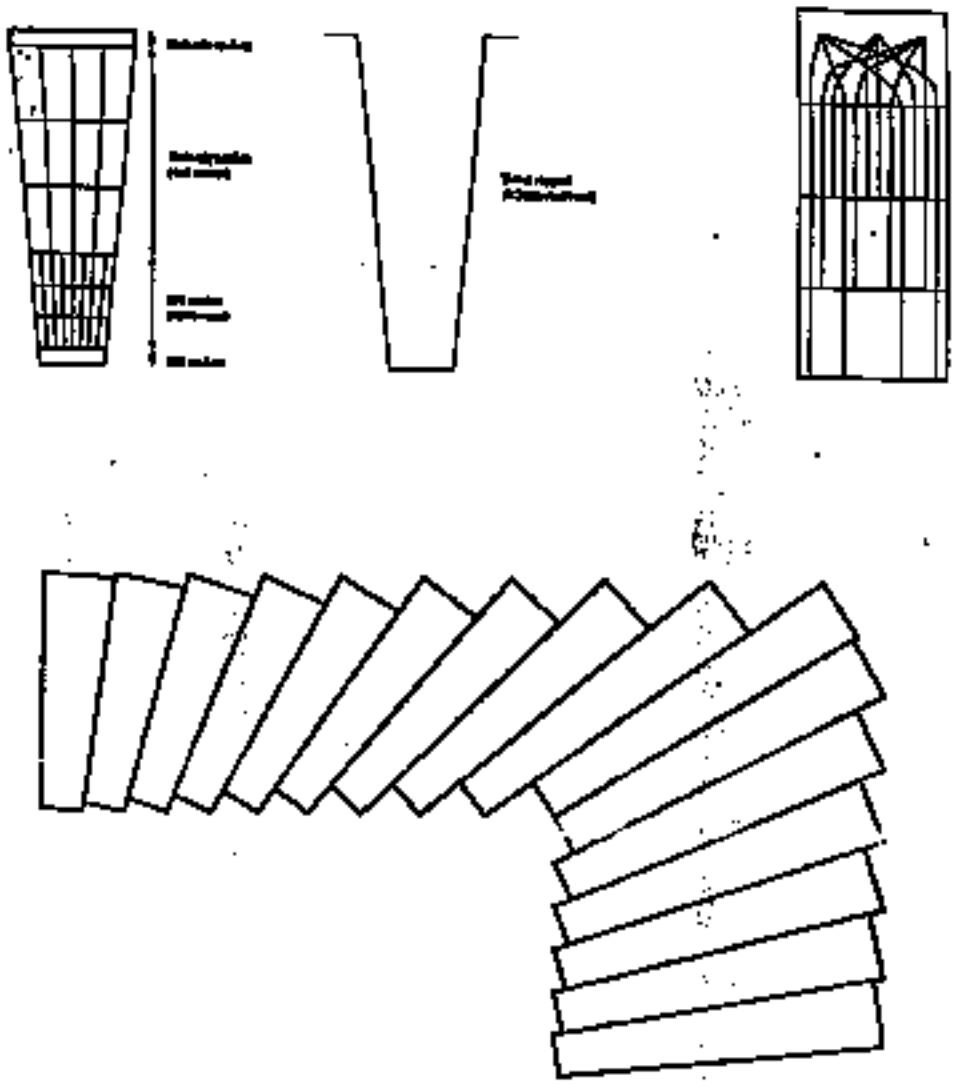


Figure 2.2.8: *Schematic drawings of a Shashlik supertower (top left), of the steel band support (top center), of the WLS readout fibres (top right) and of the arrangement of the rings of supertowers(bottom).*

ECAL, HCAL

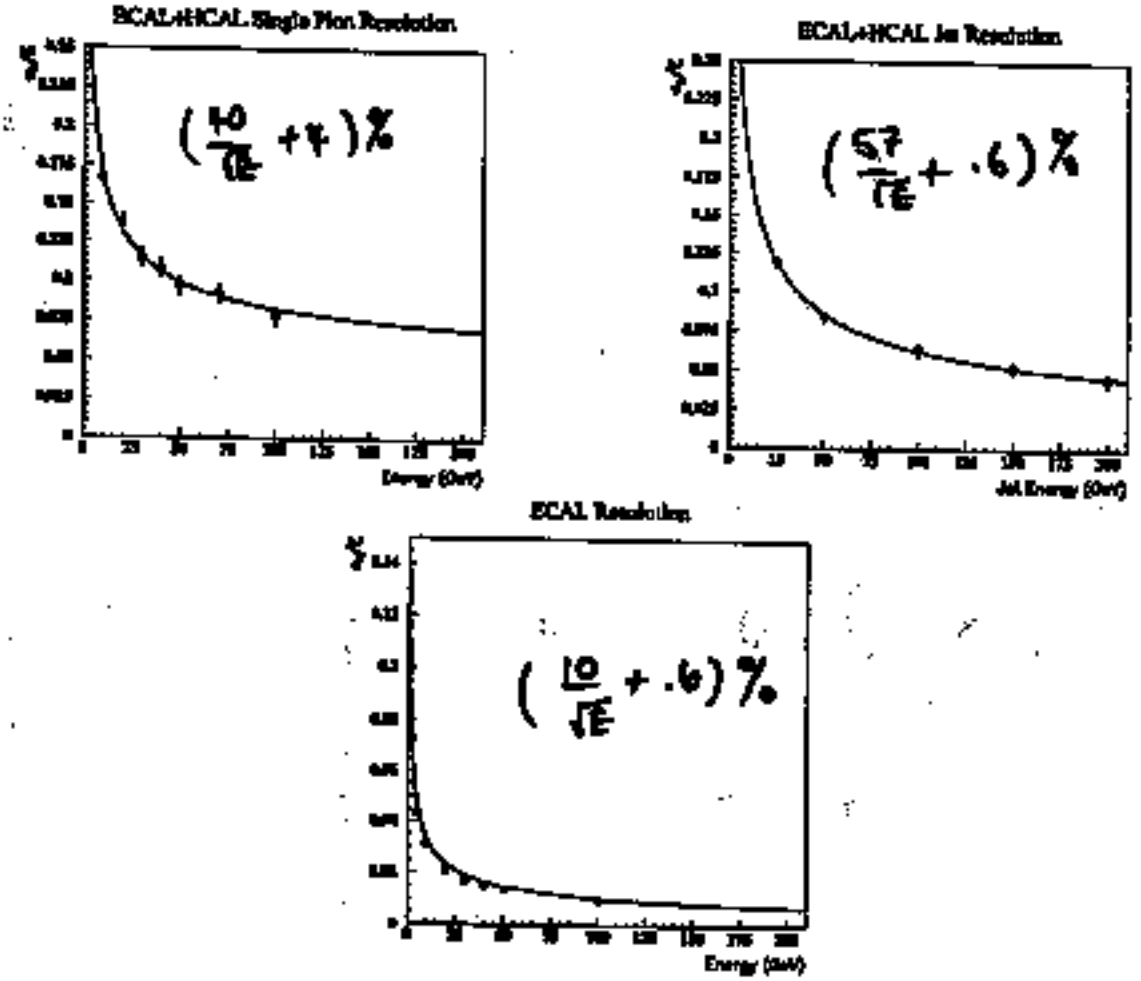
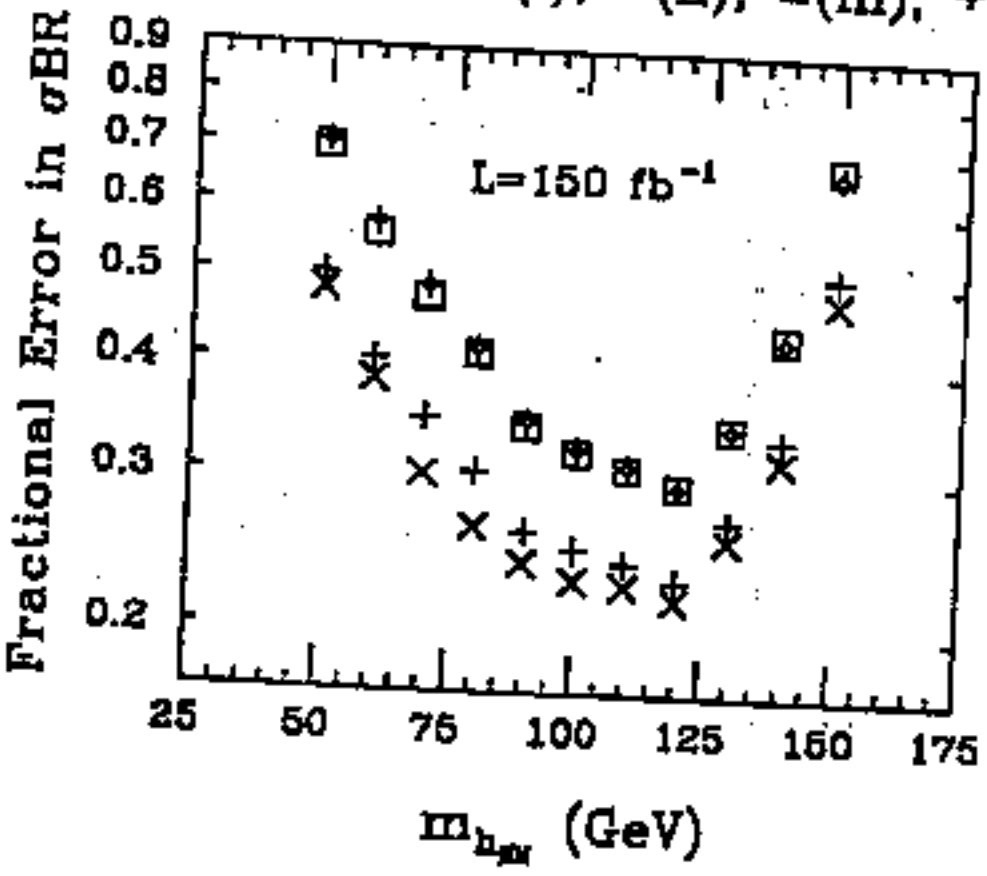


Figure 2.2.11: *Single-pion energy resolution (top left), jet energy resolution(top right) and electromagnetic energy resolution (bottom).*

SLAC ±DR

$e^+e^- \to Z^* \to Z h_{SM} \to Z\gamma\gamma$

Resolutions: ×(I); +(II); □(III); ✛(IV)



ECAL $\frac{\delta E}{E} \sim \frac{2\%}{\sqrt{E}}$ (I) $\longrightarrow$ $\frac{12\%}{\sqrt{E}}$ (IV):

i.e., × $\frac{2\%}{\sqrt{E}} \oplus 0.5\% \oplus \frac{0.2\%}{E}$

\+ $\frac{5\%}{\sqrt{E}} \oplus 0.5\%$

□ $\frac{10\%}{\sqrt{E}} \oplus 1\%$

✛ $\frac{12\%}{\sqrt{E}} \oplus 0.5\%$

HOW MUCH NCAL INSIDE COIL?

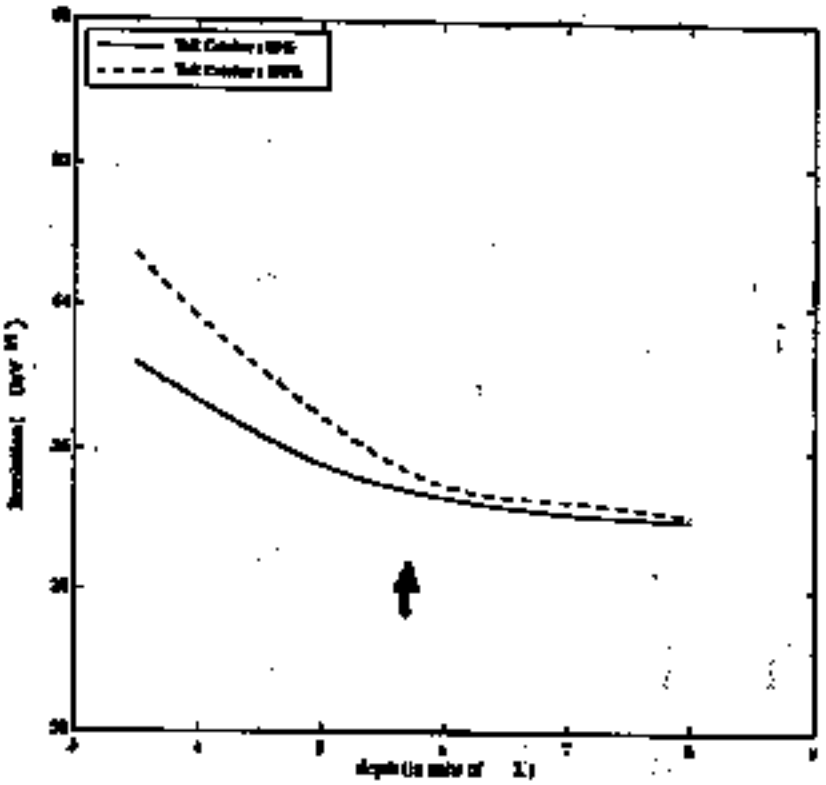


Figure 2.2.9: *Dependence of the intrinsic energy resolution* $(\sigma/E)\sqrt{E}$ *as a function of the depth (in units of interaction length) of the calorimeter inside the coil volume for two different tail-catcher resolutions.*

INSTRUMENTED IRON

53

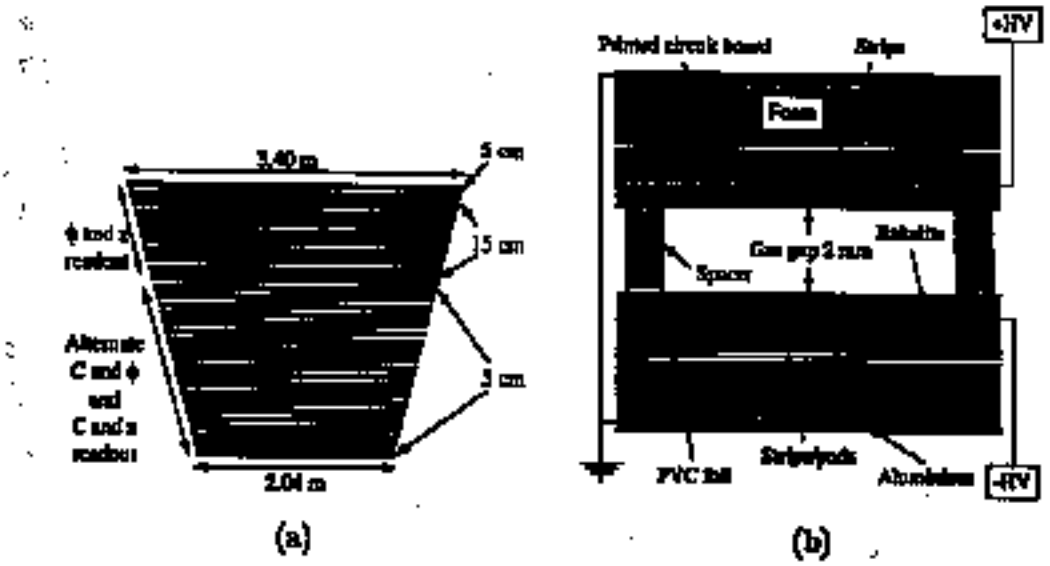


Figure 2.2.13: *(a) Cross section through one of the twelve symmetrical segments of the barrel of the iron return yoke showing the slits into which the resistive plate chambers are inserted; these are instrumented with calorimetric (C), φ and z readout as indicated. (b) Cross section through a resistive plate chamber.*

READOUT, TRIGGER

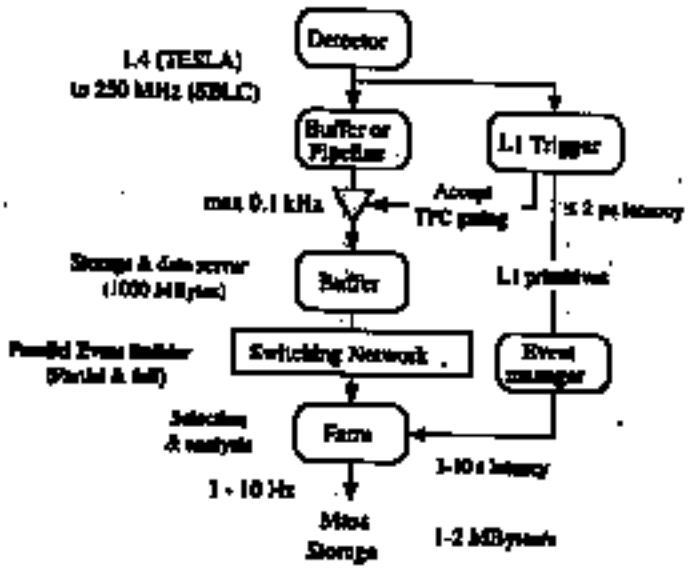


Figure 2.1.4: *Trigger and readout scheme.*

STRAIGHT FORWARD

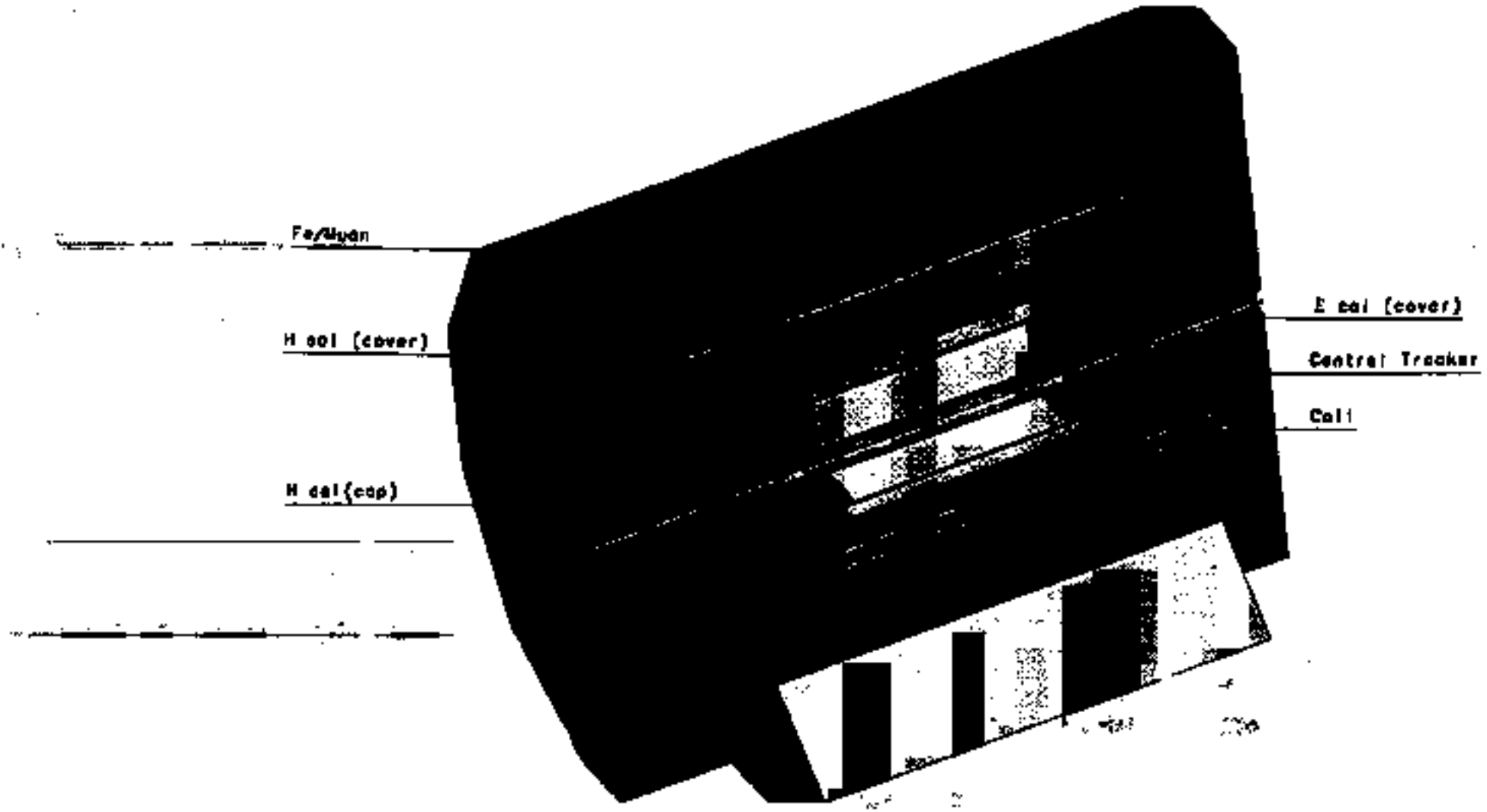
RATES

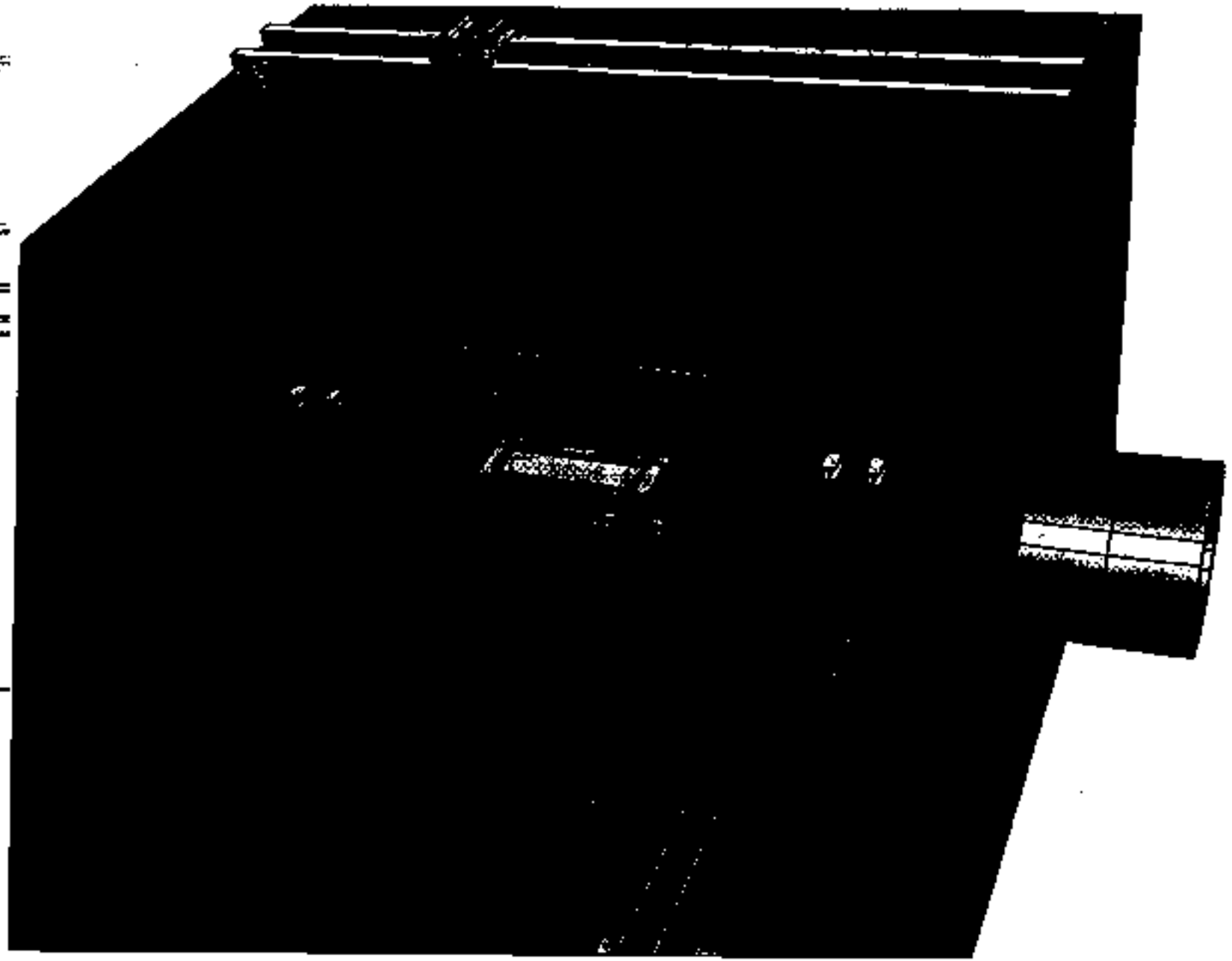
Table 2.1.7: *Table of some machine properties and related backgrounds.*

	TESLA	SBLC	TESLA	SBLC
Units in brackets	0.5 TeV		0.8 TeV	
Beam properties				
Trains/sec	5	50	3	50
Bunches/train	1130	330	3130	125
Interbunch spacing	708ns	8ns	666ns	4ns
$N_{e^\pm}$ per bunch[10^{10}]	3.6	1.1	3.6	1.2
$N_{\text{gamma's}}$ per $e^\pm$	2.0	1.4	2.4	1.8
$\langle E_{\text{gamma's}} \rangle$[GeV]	3.0	4.7	6.7	11.1
Backgrounds/bunch				
$N_{\text{gamma's}}$/bunch crossing θ>150mrad, p_t>20MeV/c	31	7	47	17
Hadr.ev./bunch $E_{\gamma\gamma\to\text{had's}}$ >5GeV	.13	.04	.45	.17
Minijet ev./bunch[10^{-3}] p_T^{min}= 2.2 GeV/c	.30	.10	1.6	.68
Backgrounds/100ns				
$N_{\text{gamma's}}$/100ns θ>150mrad, p_t>20MeV/c	31	118	47	425
Minijet ev./100ns, p_T^{min}=3.2GeV/c	.003	.017	.016	.15
Physics events per hour				
Bhabha	3200	3000	900	1000
W^+W^-	140	138	34	36
$q\bar{q}$	63	60	19	20
$t\bar{t}$	15	14	5	5
$\nu\nu H_{SM}(M_{H_{SM}}$=140 GeV)	1.4	1.4	2.9	3.0
ZH_{SM}	1.2	1.2	0.4	0.4

← PROB. UNDESIRABLE EVENT PER 100ns TT

← PHYSICS EVENTS


Fe/Kyan
H cal (cover)
H cal (cap)
E cal (cover)
Central Tracker
Coil



FURTHER STUDIES, R&D (RANDOM THOUGHTS)

- ANOTHER ITERATION ON DETECTOR DIMENSIONS
- BACKGROUND STUDIES γ's, n's, ...
  EFFECT ON ALL SUBDETECTORS
- VDET
  - APS or CCD ?
  - 1 cm BEAMPIPE ← MACHINE?
- INT. TRACKER
  - HOW TO GET σ GRANULARITY?
- INT. Si LAYER
  - CAN WE ALIGN?
- TPC
  - OTHER R.O. CHAMBERS
  - OTHER GAS ?
  - FIELD HOMOGENITY
- TRACKING
  - SYST. ERROR $< 10\mu m$ ⇒ CHALLENGE
- ECAL
  - IMPROVE $\frac{\delta E}{E}$, KEEPING SOFTWARE COMPENS.
  - GEANT EM.FLOW STUDIES
- HCAL
  - GEANT INSIDE/OUTSIDE STUDIES
- Fe
  - ANALOG R.O. OF RPC?