ASAHEL

A Simple Apparatus for High Energy Lep

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Based on a document

review of characteristics/performances of LEP/LHC/ILC experiments

drawing conclusions from the comparison, propose a detector

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PRELIMINARY

ASAHEL
(A Simple Apparatus for High Energy LEP)

Proposal

Authors, Institutes

Abstract

The TLEP Design Study Working Group published "Fist Look at the TLEP Physics Case" in December 2013. TLEP, a 90-400 GeV high-luminosity, high precision, e^+e^- machine, is now part of the Future Circular Collider (FCC) design study, as a possible first step (named FCC-ee) towards a high-energy proton-proton collider (named FCC-hh).

The above paper presents an initial assessment of some of the relevant features of the FCC-ee potential, to serve as a baseline for the more extensive design study that is now carried out.

FCC-ee will provide the opportunity to make the most sensitive tests of the Standard Model of electroweak interactions. The first requirement of the detector must therefore be to ensure it has the capability to make these precise tests. The detector must have excellent vertexing and tracking performances and a highly granular, homogeneous calorimetric system covering as great a solid angle as possible. We make the choice to use as few different detection techniques as possible for meeting these requirements.

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INTRODUCTION

FCC-ee experimental conditions ≈ LEP

- With bonus of stable beam conditions 
- But increased beam divergence → effect on luminosity detector acceptance
- But large synchrotron radiation → require shielding
- But more beamstrahlung → more e.m. background at the IP
  << linear colliders 
- But higher repetition rate

As for ILC, a detector for FCC-ee needs:

- Excellent vertexing & tracking capabilities
- Highly granular & hermetic calorimetric system for optimal use of Particle-Flow Algorithms
- High precision luminosity detectors (measurement of Bhabha scattering)

General concept

Inspired from LEP detectors

mitigated with recent developments for LHC, ILC

(references from LOIs, TDRs, …)

General philosophy of LEP detectors

- ALEPH as few detection techniques as possible
- DELPHI multiplied detection techniques
- LEP3 concentrated effort on high resolution for γ, e, μ

The Magnet

$$\Delta p / p = p\, \Delta s / [0.0375\, B\, (R_{outer} - R_{inner})^2]$$

- All LEP, LHC, ILC experiments
  have chosen a central solenoid (surrounded by a toroid in ATLAS)
- Field LEP 0.435 T (OPAL), 0.5 T (L3), 1.2 T (DELPHI), 1.5 T (ALEPH)
  LHC 2 T (ATLAS), 4 T (CMS)
  ILC 3.5 T (ILD), 5 T (SiD)

The Vertex Detector for good pattern recognition, excellent impact param. resol.

- All experiments have chosen silicon based sensor layers of strips or pixels
- Typical impact point resolution

LEP & LHC	100 –150 μm @	1 GeV
	20 – 30 μm @	20 GeV
ILC	10 μm @	1 GeV
	2 μm @	20 GeV

The Main Tracker Large volume, high B, precise space-point measurement

2 main options: Drift Chambers TPC (time proj. chamb.) ALEPH, DELPHI, ILD

TEC (time expansion chamb.) L3

JC (jet chamb.) OPAL

Silicon strips ATLAS, CMS, SiD

	ALEPH	**DELPHI**	**L3**	**OPAL**	**ATLAS**	**CMS**	**ILD**	**SiD**
Type	TPC	TPC	TEC	JC	Si strips Straws	Si strips	Si strips TPC Si strips	Si strips
Layers	-	-	-	-	4 x2 (Si) 36 (st.)	10	-	5
Rin(cm)	31	29	17	25	30 (Si) 56 (st.)	20	33	22
Rout(cm)	180	122	94	183	52 (Si) 107 (st.)	116	181	122
Length (cm)	470	260	126	400	150	240	470	111-304
Material (% X_0)	7.1	-	7	4	1.2 10	30	5	10-15
Point resolution ($R\varphi$) (μm)	150	250	50	120	17 170	15	60-100	8
$\sigma(1/p_T)$ (/GeV)	1.2×10^{-3}	1.3×10^{-3}	2.1×10^{-2}	1.5×10^{-3}	5×10^{-4}	1.5×10^{-4}	10^{-4}	$2\text{-}5\times10^{-5}$

Table 3: Characteristics of main trackers

$\sim10^{-3}$ → $\sim10^{-4}$

The Calorimeters Granularity / Resolution

PFA (particle-flow algorithms) applied since LEP era (ALEPH,CDF, ZEUS, CMS)
→ significant improvement whilst none was optimized for PFA

E
C
A
L

	ALEPH	DELPHI	L3	OPAL	ATLAS	CMS	ILD	SiD
Absorber	Pb	Pb	BGO	Lead glass	Pb	PbWO4	W	W
Detector	Wire chamber	HPC	BGO	Lead glass	Liq.Ar	PbWO4	Si or Sc.	Si
X_0	22 (4,9,9)	18 (9 samp)	22	24.6	25 (6,16,3)	25	24	26
Granul.	0.8^0	0.5^0	2.3^0	2.3^0	1.2^0	1^0	0.25^0	0.2^0
σE/E a	0.18	0.32	0.02	0.15	0.10	0.03	0.17	0.17
σE/E b	-	-	-	-	-	0.25	-	-
σE/E c	0.009	0.043	0.005	0.002	0.02	0.006	0.01	0.01
σE/E (%) @50 GeV	2.7	6.2	0.6	2.1	2.5	0.9	2.6	2.6
σE/E (%) @150 GeV	1.7	5.0	0.5	1.2	2.2	0.7	1.7	1.7
σE/E (%) @500 GeV	1.2	4.5	0.5	0.7	2.1	0.6	1.3	1.3

Table 4: Characteristics of ECAL calorimeters

The Calorimeters Granularity / Resolution

PFA (particle-flow algorithms) applied since LEP era (ALEPH,CDF, ZEUS, CMS)
→ significant improvement whilst none was optimized for PFA

H
C
A
L

	ALEPH	DELPHI	L3	OPAL	ATLAS	CMS	ILD	SiD
Absorber	Fe	Fe	U	Fe	Fe	Brass	Steel	Steel
Detector	Stream tubes	Stream tubes	PWC	Stream tubes	Sc.	Sc.	Sc. or RPC	RPC
Λ	7.16	6.6	3.36	4.8	7.2	5.8	5.5	4.5
Granul.	3.7^{0}	3.0^{0} x 3.7^{0}	2.5^{0}	7.5^{0}	5^{0}	4^{0}	$1\text{-}2^{0}$	0.5^{0}
σE/E a	0.85	1.12	0.55	1.2	0.52	1.	0.5	0.6
σE/E b	-	-	-	-	1.6	-	-	-
σE/E c	-	0.21	0.05	-	0.03	0.05	-	0.08
σE/E (%) @50 GeV	12	26	9	17	9	11	7	12
σE/E (%) @150 GeV	7	23	7	10	5	10	4	9
σE/E (%) @500 GeV	4	22	6	5	4	7	2	8

Table 5: Characteristics of HCAL calorimeters

The Muon Detector In the iron yoke / around / inside the coil (L3)

Large areas & cost

→ Gaseous detectors : streamer tubes, drift chambers, RPCs
(also scintillators option at ILC)

Benchmark Physics Processes A few examples @ LEP, @ LHC

LEP experiments m_W, Γ_W

	ALEPH	DELPHI	L3	OPAL
m_W^{eq}(GeV)	80.536±0.087±0.027	80.388±0.133±0.036	80.225±0.099±0.024	-
$m_W^{\mu q}$(GeV)	80.353±0.082±0.025	80.294±0.098±0.028	80.152±0.119±0.024	-
$m_W^{\tau q}$(GeV)	80.394±0.121±0.031	80.387±0.144±0.033	80.195±0.175±0.060	-
m_W^{lq}GeV)	80.429±0.054±0.025	80.339±0.069±0.029	80.196±0.070±0.026	80.449±0.056±0.028
m_W^{qq}(GeV)	80.475±0.070±0.028 ±0.028 (FSI)	80.311±0.059±0.032 ±0.119 (FSI)	80.298±0.064±0.049 (FSI incl.)	80.353±0.060±0.058 (FSI incl.)
Γ_W^{eq}(GeV)	1.84±0.20±0.08	-	-	-
$\Gamma_W^{\mu q}$(GeV)	2.17±0.20±0.06	-	-	-
$\Gamma_W^{\tau q}$(GeV)	2.01±0.32±0.06	-	-	-
Γ_W^{lq}(GeV)	2.01±0.13±0.06	2.452±0.184±0.073	-	1.927±0.135±0.091
Γ_W^{qq}(GeV)	2.31±0.12±0.04 ±0.11 (FSI)	2.237±0.137±0.139 ±0.0248 (FSI)	1.97±0.11±0.09	2.125±0.112±0.177

Table 7: Results on m_W and Γ_W in the eνqq, μνqq, τνqq, lνqq, qqqq channels. The first uncertainty is statistical, the second uncertainty is systematic.

Benchmark Physics Processes A few examples @ LEP, @ LHC

LHC experiments m_t, m_H

	ATLAS	CMS
m_t^{ll}(GeV)	173.09 ± 0.64 ± 1.50	172.50 ± 0.43 ± 1.46
m_t^{lj}(GeV)	172.31 ± 0.23 ± 1.35 ± 0.72 (JES)	173.49 ± 0.27 ± 0.98 ± 0.33 (JES)
m_t^{jj}(GeV)	174.9 ± 2.1 ± 3.8	173.49 ± 0.69 ± 1.23
$m_H^{\gamma\gamma}$(GeV)	126.8 ± 0.2 ± 0.7 (125.98 ± 0.42 ± 0.28)	125.4 ± 0.5 ± 0 .6
m_H^{4l}(GeV)	124.3 ± 0.5 ± 0.5 (124.51 ± 0.52 ± 0.06)	125.8 ± 0.5 ± 0.2 (125.6 ± 0.4 ± 0.2)

Table 10: Results on m_H[2] in the γγ and four-lepton channels, and m_t in the dilepton, l+jets, all jets channels. The first uncertainty is statistical, the second uncertainty is systematic.

m_t(GeV)	ATLAS	CMS
j En. scale	0.88 / 1.07 / 2.1	0.97 / 0.42 / 0.97
b-jet En. scale	0.71 / 0.08 / 1.4	0.76 / 0.61 / 0.49
j En. resol.	0.21 / 0.22 / 0.3	0.14 / 0.23 / 0.15
j reco eff.	- / 0.05 / 0.2	-
Method	0.07 / 0.13 / 1.0	0.40 / 0.06 / 0.13
MC gen	0.20 / 0.19 / 0.5	0.04 / 0.02 / 0.19
ISR / FSR	0.37 / 0.45 / 1.7	0.58 / 0.30 / 0.32
PDF	0.12 / 0.17 / 0.6	0.09 / 0.07 / 0.06
Backgd model.	0.14 / 0.10 / 1.9	0.05 / 0.13 / 0.13

Table 11: Systematic uncertainty contributions on the measurement of m_t. The three numbers in each cell correspond to the dilepton, l+jets, all jets channels.

The ASAHEL Detector

General concept

Comparison of LEP , LHC, ILC experiments show

- Silicon-based vertex detectors are a must
- TPC (ALEPH, DELPHI) is still considered for ILC experiments
  where wire chambers are replaced by MPGDs (GEM, Micromegas)
  immersed in a stronger field (3.5 – 5 T vs 1.5 T)
- The energy resolution of the ALEPH ECAL ≈ ILC

  The energy resolution of the ALEPH HCAL ≈ CMS, SiD
- The granularity of the ALEPH ECAL < CMS (but 4 X SiD)

  The granularity of the ALEPH HCAL < CMS (but 4 X SiD)
- Muon detector large areas & cost drive the choice of gaseous detectors

The ASAHEL Detector

General concept

Comparison of LEP , LHC, ILC experiments show

- ALEPH systematic uncertainties are either comparable to others or better
- High resolution calorimeters (L3) suffer from difficulty of calibration & monitoring, from cracks
- Multiplication of detection techniques (DELPHI) increases the systematic uncertainty and complicates maintenance, analysis, …
- Excellent pattern reconstruction and id is a must

Conclusion : ALEPH philosophy of using as few different detection techniques as possible is rewarding !

Adopted for ASAHEL.

The ASAHEL Detector

Follows ALEPH philosophy :

based on ALEPH design
adapted to FCC-ee conditions
using techniques developed for LHC, ILC

The Magnet

ALEPH and SiD have very similar dimensions (L, R), but B(SiD) = 5 T
However B may be to high for TPC (ref. B(ILD) = 3.5 T)

→ Tune B, L, R for maximizing momentum resolution & minimizing cost

The ASAHEL Detector

The Vertex Detector

ILC experiments target a factor 10 better point / impact parameter resolution

than LEP / LHC experiments with 10x10 mm^2 (ILD) to 20x20 mm^2 (SiD) pixels

However TLEP physics case used CMS detector (100x150)

→ What is the actual size needed for required performances ?

Larger pixels possible if use of charge sharing

Beware heat dissipation (no power pulsing at FCC-ee !)

→ SiD basic design with tuned pixel size

The ASAHEL Detector

The Central Tracker

TPC unique pattern recognition capability + particle id (dE/dx)

Complemented by Si envelope (SiD)

- provides precise space points before/after the TPC
- helps linking vertex detector to TPC, extrapolating from TPC to calorimeters

→ Eases calibration of the overall tracking system

→ Improves overall momentum resolution

Long experience with TPCs & LCTPC collaboration pursues R&D to develop TPC for linear colliders

Gas amplification & readout: MPGDs (GEM, Micromegas) instead of wire chambers (ALEPH)

The ASAHEL Detector

- A TPC for FCC-ee would benefit from studies for ILC
- A group actively working at IRFU on ILC TPC, joined by a group of FCC-ee that investigates different machine conditions (luminosity, repetition rates) affecting TPC operation

  e.g. how electric field distortions caused by positively charged ions would affect the position resolution at the highest luminosity envisaged at FCC-ee (10^{36} $cm^{-2}s^{-1}$).

Ion backflow can be reduced by

- playing with TPC volume, B
- using gating devices in front of amplification devices
- Increasing EA/ED (Micromegas natural backflow suppression)

The ASAHEL Detector

The Calorimeters

Requirements:

- Enhanced separation electrons / charged hadron tracks

→ minimize e.m. shower lateral size → Minimize ECAL Molière radius

- Optimal assignment of energy cluster deposits to charged or neutral particles

→ Fine ECAL/HCAL transverse/longitudinal segmentation

- Optimal track to cluster association

→ ECAL inside the solenoid (what about HCAL? inside:ILC, outside: ALEPH)

- Hermiticity

→ Suitable calorimeter length for small angle coverage

→ Suitable calorimeter depth for shower containment

→ Minimized cracks

ECAL

- The energy resolution of the ALEPH ECAL ≈ ILC
- The granularity of the ALEPH ECAL < CMS (but 4 X SiD)

→ ALEPH ECAL baseline for ASAHEL

- Sampling calorimeter: 45 layers (lead + wire chambers) in 3 stacks (22 X_0)

→ Increase depth for containment of high-energy showers 26 X_0 (+2.5 cm Lead)

→ Lead vs Tunsten (smaller X_0 & Molière radius: ILC)

→ Replace wire chambers with Micromegas chambers

(thin chambers needed as effective R_M also depends on gap between absorber plates)

- Projective towers (~ 0.8°x0.8°); 49152 in the barrel, 24576 in endcaps.

→ Optimize longitudinal / transversal granularity

for maximal performance

for minimal number of readout channels

HCAL

- The energy resolution of the ALEPH HCAL ≈ ILC
- The granularity of the ALEPH HCAL < CMS (but 2 X ILD)

→ ALEPH HCAL baseline for ASAHEL

- ALEPH magnet iron instrumented with 23 layers of limited-streamer tubes separated by 5 cm iron sheets
- ALEPH HCAL outside the coil / ILC HCAL inside the coil

→ Quantify advantage of HCAL outside/inside the coil

→ If HCAL inside the coil, need to use steel

→ Replace streamer tubes with Micromegas chambers (SiD possible option)

- Projective towers (~ 3.7°x3.7°); 4788 towers

→ Optimize granularity

for maximal performance

for minimal number of readout channels

The ASAHEL Detector

The Muon Detector

- Behind the last layer of ALEPH HCAL, 2 double layers of streamer tubes
- Digital signals from streamer tubes in HCAL used for muon id (background from penetrating hadronic showers removed by pattern recognition)

→ Replace streamer tubes with Micromegas chambers (ATLAS upgrade)

The Luminosity Detectors

- ALEPH luminosity detector : SiCAL (W/Si) covering 24-58 mrad angular interval

→ Size, position, angular coverage very dependent on machine parameters

Conclusion

- Lessons from LEP & LHC
- Synergy with ILC

→ Retain ALEPH philosophy:

Use as few detection techniques as possible

→ Keep ALEPH basic design as a baseline for ASAHEL

→ Replace all wire chambers with Micromegas chambers

→ Tune longitudinal & transversal granularity (fast simulation)

→ Redo TLEP benchmark physics cases with ASAHEL full simulation
(there is some interest for reviving ALEPH simulation)

Optimal balance of simplicity, expertise concentration, synergy with ILC/LHC, accuracy, low cost

Associated project

Wireless data & power transfer

A proposal by a proto-colaboration (12 physicists/engineers from 7 institutes)

Work has already started

e.g. ATLAS vertex detector upgrade with wireless readout

But a wider, longer-term R & D project

Interested in ASAHEL ?

Talk to me !