ASAHEL

A Simple Apparatus for High Energy Lep

?

Elizabeth Locci
CEA-Saclay/DSM/IRFU/SPP

Based on a document https://archive.org/details/ASAHEL
reviewing the characteristics/performances of LEP/LHC/ILC experiments
drawing conclusions from the comparison, propose a detector philosophy

Elizabeth Locci (elizabeth.locci@cern.ch) Draft : 02/06/2015

ASAHEL
(A Simple Apparatus for High Energy LEP)

Proposal[1]

Authors, Institutes

Abstract

The TLEP Design Study Working Group published "First 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 starting point 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.

Following the ALEPH philosophy of using as few detection techniques as possible, we propose to evaluate the modifications that would be needed for an "ALEPH-like" detector to fulfil the requirements of FCC-ee. We will investigate the use of Micromegas detectors instead of limited-streamer tubes and will adjust the size of the detector and its granularity.

[1] This document is not meant for publication in the present state, but should be considered as a basis for future work to explore the adequacy of an « ALEPH-like » detector with the physics benchmarks of FCC-ee.

PRELIMINARY

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MOTIVATION

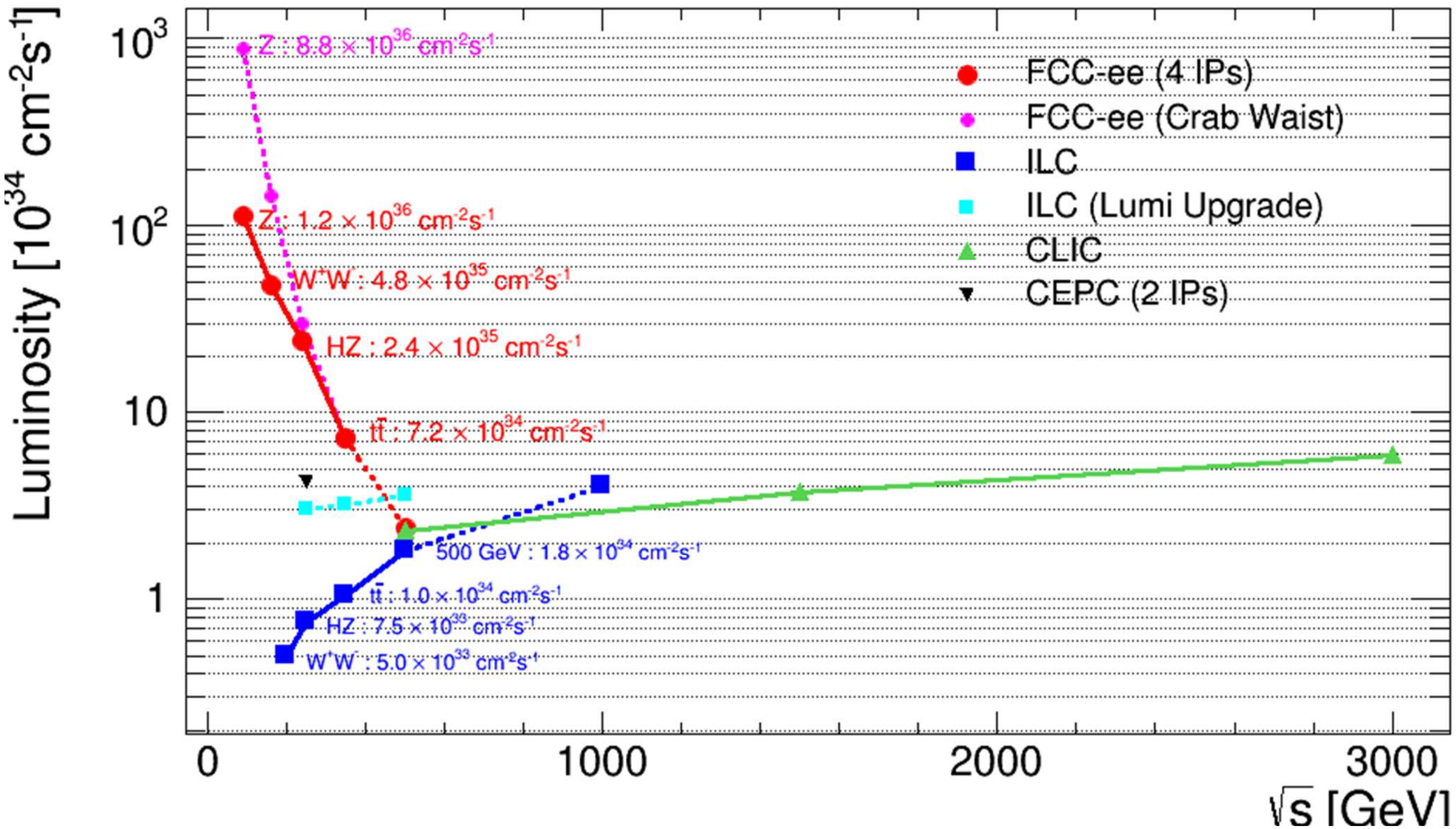
- FCC-ee experimental conditions ≈ LEP
- Physics program ≈ ILC
- At least 2 IPs, hopefully 4

→ Why not considering the 2 “extreme” detector philosophies

- a “sophisticated detector,” using the most performant up-to-date technologies, that might perhaps evolve (partly) towards a FCC-hh detector
- a “simple” detector inspired from LEP + recent developments for ILC, still fulfilling FCC-ee physics requirements

This talk

Physics Goals



Precise measurements & Discovery potential @ High Luminosity

Physics Goals

Asset: -- high luminosity (10^{12} Z decays + 10^8 Wpairs + 10^6 top pairs)

-- exquiste energy calibration up and above WW threshold

target precisions

Quantity	Present precision	Measured from	Statistical uncertainty	Systematic uncertainty
m_Z (keV)	91187500 ± 2100	Z Line shape scan	5 (6) keV	< 100 keV
Γ_Z (keV)	2495200 ± 2300	Z Line shape scan	8 (10) keV	< 100 keV
R_ℓ	20.767 ± 0.025	Z Peak	0.00010 (12)	< 0.001
N_ν	2.984 ± 0.008	Z Peak	0.00008 (10)	< 0.004
N_ν	2.92 ± 0.05	$Z\gamma$, 161 GeV	0.0010 (12)	< 0.001
R_b	0.21629 ± 0.00066	Z Peak	0.000003 (4)	< 0.000060
A_{LR}	0.1514 ± 0.0022	Z peak, polarized	0.000015 (18)	< 0.000015
m_W (MeV)	80385 ± 15	WW threshold scan	0.3 (0.4)MeV	< 0.5 MeV
m_{top} (MeV)	173200 ± 900	$t\bar{t}$ threshold scan	10 (12) MeV	< 10 MeV

Also -- $\Delta \sin^2 \theta_W \approx 10^{-6}$

-- $\Delta\alpha_S$= 0.0001 from W and Z hadronic widths

-- orders of magnitude on FCNCs and rare decays etc. etc.

(A. Blondel, FCC Future Circular Colliders, 4/30/2015)

Physics Goals

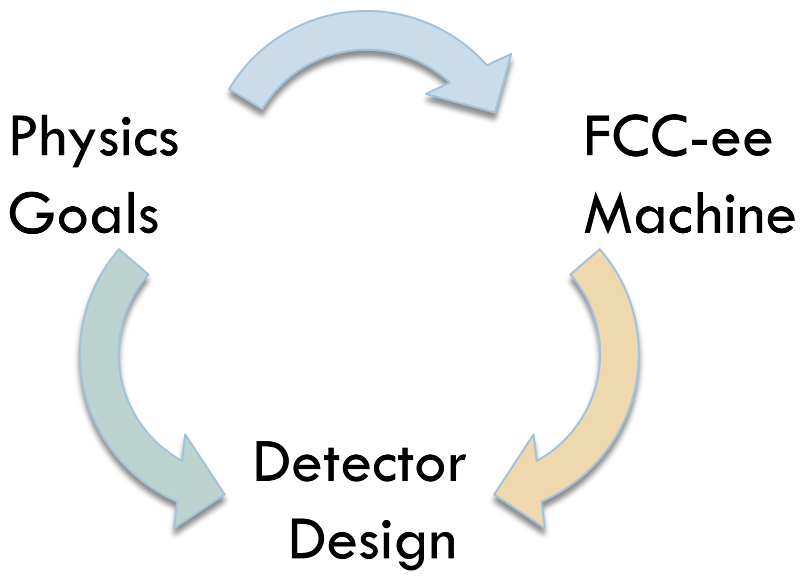
FC-ee : a Z, W, t, H Factory for precision measurements & great potential for direct searches)

→ Benchmarks for defining detector requirements:

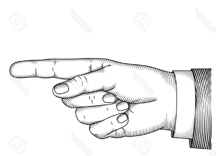
- a vertex detector, performances similar to (better than?) ILC detectors, with lifetime-based flavour-tagging capabilities
- a good tracking capability : $\sigma_{1/p} \approx$ a few (how much?) 10^{-5} Gev^{-1}
- a highly granular (how high?), hermetic calorimetric system.
- a precision device for luminosity measurement

LEP/LHC : well-known detector design & performances

ILC : expected performances from detector designed for physics goals (no in-situ measurements)



Machine differences FCC-ee / ILC impacts :

- Very Forward Calorimetry  extensively discussed by M.Dams Pisa & Washington workshops)
- Central & Forward Detectors
  - Continuous running → no power-pulsing → cooling issues
  - High luminosity at the Z-pole → High physics rates → TPC?

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
- OPAL optimum detector with well-proven technologies
- 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 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

Characteristics of LEP/LHC/ ILC Main Trackers

	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	540	470	111-304
Material (% X_0)	7.1	-	7	4	1.2 10	30	5	10-15
Point resolution ($R\phi$) (μm)	150	250	50	120	17 170	15	60-100	8
TPC only $\sigma(1/p_T)$ (/GeV)	$1.2\text{x}10^{-3}$	$5.0\text{x}10^{-3}$	-	-	-	-	$9\text{x}10^{-5}$	-
Global $\sigma(1/p_T)$ (/GeV)	$6\text{x}10^{-4}$	$6\text{x}10^{-4}$	$2.1\text{x}10^{-2}$	$1.5\text{x}10^{-3}$	$3.5\text{x}10^{-4}$	$1.5\text{x}10^{-4}$	$2\text{x}10^{-5}$	$2\text{-}5\text{x}10^{-5}$

$\sim 10^{-3}$ → $\sim 10^{-4}$

The Calorimeters Granularity / Resolution

Jet energy resolution is crucial

⇨ Particle Flow Algorithms (PFA)

- Most of the jet energy is carried by charged particles
- Charged particle momentum is measured in the tracker with better precision than energy in calorimeters

⇨ separate and reconstruct particles using

- Tracker for charged particles
- Calorimeters for γ (ECAL) & neutral hadrons (ECAL+HCAL)

PFA has already been used with great success in ALEPH & CMS

⇒ Jet-energy resolution 50-60% / $\sqrt{E_J}$

(about a factor 2 better than calorimetric approach)

⇒ Build imaging calorimeters with 3D high granularity

- Requirements on energy resolution for γ & neutral hadrons
- Requirements on granularity to track particles through the calorimeters & match with tracker informations
- Sophisticated algorithms (PANDORA, ARBO)

The Calorimeters Granularity / Resolution

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

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, $\mu\nu$qq, $\tau\nu$qq, lνqq, qqqq channels. The first uncertainty is statistical, the second uncertainty is systematic.

The ASAHEL Detector General concept

Comparison of LEP , LHC, ILC experiments shows

- 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 measurement uncertainties are either comparable to others or better
  A high intrinsic energy resolution does not grant the smallest measurement error.
- High resolution calorimeters (L3) suffer from difficulty of calibration & monitoring, from cracks
- Multiplication of detection techniques (DELPHI) increases the systematic uncertainties and complicates maintenance, analysis, …
- Excellent pattern reconstruction and id is a must

Conclusion : ALEPH philosophy of using as few different detection techniques as possible was rewarding at LEP !

Basically ASAHEL might be :

The Magnet

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

The Vertex Detector

ILC expts target 10 x better point / impact parameter resolution than LEP/LHC expts with 10x10 mm^2 (ILD) to 20x20 mm^2 (SiD) pixels

→ 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 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)

NB: To be studied in FCC-ee conditions. Alternative :Si

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 (HCAL? inside:ILC, outside: ALEPH)

- Hermiticity

→ Suitable calorimeter length for small angle coverage

→ Suitable calorimeter depth for shower containment

→ Minimized cracks

ECAL

- 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

- 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 brass (or stainless 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 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 ASAHEL Detector Proposal: Explore if

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

We can find a configuration: geometry /granularity
detector techniques

That can reach the FCC-ee physics goals/benchmarks

What might be the main obstacles:

- TPC : usable at the Z pole with very high luminosity?
  (currently studied in Saclay)
- Are Micromegas detectors suitable for e.m. calorimetry? (RD51)
- Others???

How could we proceed? (Not exhaustive)

Define precise benchmarks for all designs (common files, analysis…)

Hardware-wise

- TPC : explore the limits (ion backflow, 2 track separation, resolution …)
- ECAL : follow/participate in RD51 tests
- Si remains a possible alternative if this fails

Software-wise

- Start with ALEPH design/simulation & evaluate physics perf.
  (PFA performances can be evaluated separately with tools such as PAPAS)
- Determine which granularity is actually needed
- Determine which momentum resolution is actually needed
- Play with the solenoid dimensions/field
- Study the configurations HCAL inside vs outside the solenoid

- Define "figures-of-merit"

  Example: ECAL radius /ECAL material / B Field BR^2 / R_m^{eff}

ECAL	**ILC**	**ALEPH**	**CMS**
Absorber / Sensor	W / Si	Pb / PWC	PbWO4
Density (g/cm^3)	19.3	11.35	8.28
Radiation length X_0 (cm)	0.3504	0.5612	0.89
Depth (X_0)	26	22 (4+9+9)	26
Layer (absorber + sensor) thickness (cm)	W 20 x 0.25 + 10 x 0.5 Sensor 30 x 0.125	Pb 33 x 0.2 + 12 x 0.4 Sensor 45 x 0.38	23
Absorber Molière radius (cm)	0.9327	1.602	1.959
R_M^{eff} (effective Molière radius, cm)	1.40	4.65	1.959
Interaction Length Λ (cm)	9.946	17.59	20.27
B (T)	3.5 (ILD) / 5 (SiD)	1.5	4
R (cm)	125	185	129
BR^2 ($T.m^2$)	5.5 (ILD) / 7.8 (SiD)	5.1	6.6
BR^2 / R_M^{eff}	391 / 558	110	340
Depth (Λ)	0.7	0.9	1.1

- Optimise physics performances vs cost
- Etc…

Conclusion

- Lessons from LEP & LHC
- Synergy with ILC

→ Retain ALEPH philosophy:

Use as few detection techniques as possible

→ Keep ALEPH basic design as a starting point for ASAHEL

→ Replace all wire chambers with Micromegas chambers

→ Tune longitudinal & transversal granularity (fast simulation)

→ At each step check intrinsic performances, physics performances (benchmarks)

(there is some interest for reviving ALEPH simulation)

Find 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 ?

Interested in WADAPT ?

Talk to me !