ℵ in Numbers

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1 The Muon Chambers

Description: The barrel, the two middle-angle modules and the two end-caps are subdivided into inner and outer chambers. Each chamber consists of two layers of wire counters, made of carbon coated plastic tubes operated in limited streamer mode. Each layer of the counters has two planes of readout strips parallel with and perpendicular to the wires.
Gas: $ArCO_2$ + Isobutane. (12.5% : 56.5% : 30%)

Dimensions:	Length of wires	Barrel:	694.0 cm
		Middle angle:	245.8 to 479.6 cm
		End-cap:	346.0 to 652.8 cm
	Tube cross-section:	$1 \times 1cm^2$	
	Wire diameter:	100μ	

Readout:

Channels:	x-strips	y-strip
Barrel	8578	14098
Middle-angle	2732	4288
End-cap	7104	7104
Total	18414	25490

Performance: Monte Carlo estimates for the typical muon misidentification probability at 5 GeV for 95% efficiency are: 0.7% to mistake a π for a μ and 1.6% to mistake a K for a μ.

2 The Hadron Calorimeter (HCAL)

Description: The iron serves as yoke for the magnetic flux return and for the hadronic calorimetry and as muon filter. There are:

2 x 6	end-cap modules	75 tons each
2 x 12	barrel modules	70 tons each
		$\sum = 2580$ tons

The iron barrel around the coil and the two end-caps are subdivided into 23 layers. The active part of the detector consists of 23 layers of streamer tubes inserted into

the gaps of the iron yoke. The basic element is a wire counter made of a graphite coated plastic tube operated in limited streamer mode. Each tube layer is equipped with pad readout for integrated energy flux measurement and with strips, parallel to each tube for digital reconstruction of the track pattern. The pads of each layer are connected together so as to form towers pointing to the vertex.
Gas: $ArCO_2$ + Isobutane. (12.5% : 56.5% : 30%)

Dimensions:

Iron Yoke:

Barrel radius:	$R_{inner} = 300$ cm, $R_{outer} = 468$ cm
Endcap radius:	$R_{inner} = 45$ cm,$R_{outer} = 435$ cm
Distance from I.P.	$z = 315$ cm
Endcap length	$\Delta z_{pole} = 168$ cm, $\Delta z(R > 2.1m) = 121$ cm
Slab thickness	5 cm (except last layer = 10 cm)
Gap width	2.2 cm
Interaction length	7.16 λ_{int} at $\theta = 90^0$
Total iron thickness	120 cm at $\theta = 90^0$
	199 cm at $\theta = 53^0$

Plastic tubes:

Length:	700 cm (barrel), 40 cm to 450 cm (end-cap)
Cross section	$1 \times 1cm^2$
Wire diameter	100μ
Strip width	0.4 cm
Strip pitch	1 cm

Tower size: $\Delta\phi = 3.7^0$, $\Delta\theta \sim 3.0^0$ ($34^0 < \theta < 90^0$)
$\Delta\phi = 7.5^0$, $\Delta\theta \sim 2.7^0$ ($18^0 < \theta < 34^0$)
$\Delta\phi = 15^0$, $\Delta\theta \sim 2.5^0$ ($6^0 < \theta < 18^0$)

Readout:

Channels	Barrel ($41^0 < \theta < 139^0$)	End-caps ($6^0 < \theta < 41^0$) ($139^0 < \theta < 174^0$)	Total ($6^0 < \theta < 174^0$)
♯ Tubes (=♯ Wires)	48,384	71,040	119,424
♯ Towers	3,456	1,344	4,800
♯ Layers	23	23	

Performance: Energy resolution $\sigma/E = 84\%/\sqrt{E}$

3 The Superconducting Coil

Description: Superconducting solenoid with Helium cooled pipes surrounding the Al conductor.

Conductor	aluminium around NbTi/Cu
Weight Coil+Cryostat	55 tons
Field at 5000A	1.5T
Stored energy	136 MJoule
Refrigeration power	100 W at 4.2 K
	2400 W at 80 K
	30 l/h of liquid He

Dimensions:	Cryostat radius:	$R_{inner} = 248$ cm
		$R_{outer} = 292$ cm
	Cryostat length	7 m
	Absorption length (coil+cryostat)	0.4 λ_{abs}
	Radiation length (coil+cryostat)	1.6 X_0

Performance:	Field homogeneity $\Delta B_z/B_z$	$< 0.2\%$
	Radial field component B_r/B_z	$< 0.4\%$
	Azimuthal field component B_ϕ/B_z	$< 0.04\%$
	Elongation of coil for $\Delta Temp. = 300^0$	2.5cm
	Time to cool down	10 days
	Time of forced cool down	8h
	Time to charge to 5000A	1h

4 The Electromagnetic Calorimeter (ECAL)

Description: A sampling calorimeter, consisting of lead sheets and wire chambers, situated inside the solenoid. The barrel and two end-caps each comprise 12 modules and the longitudinal shower development is sampled in 45 layers grouped in three stacks of 10, 23 and 12 layers. The wire chambers are Al extrusion covered with graphite coated mylar. Signals are taken from cathode pads as well as from the anode wires. In each stack the pads form towers pointing to the interaction vertex. Gas: $XeCO_2$ (80% : 20%).

Dimensions:	Thickness of lead plates	2 mm (stack 1+2), 4 mm (stack 3)
	Diameter of tungsten wire	25 μ
	Wire spacing	5 mm
	Radiation length/stack	Barrel: $3.83X_0$, $8.80X_0$, $8.85X_0$
		Endcaps: $3.46X_0$, $8.86X_0$, $8.91X_0$
	$8.91X_0$	
	Interaction length	1.0 - 1.3 λ_{int} for 5GeV pions

Barrel:		
Radius:	$R_{outer} = 225$ cm	$R_{inner} = 185$ cm
overall length	477 cm	
Weight per module	11 t (12 modules)	
Pad size at inner radius	3 cm $\times$3 cm	
Granularity	$\Delta\theta \times \Delta\phi sin\theta$	
	17 mrad $\times$17 mrad at 90^0	
	12 mrad $\times$12 mrad at 45^0	
Endcaps:		
Radius:	$R_{outer} = 235.0$ cm	$R_{inner} = 54.0$ cm
Radius (active layers)	$R_{outer} = 227.5$ cm	$R_{inner} = 56.8$ cm
Distance from I.P.	250.5 cm	active layer: 255.0 cm
Overall length (each)	56.25 cm	active layers: 41.10 cm
Weight per module	2.6 t (2×12 modules)	
Granularity	$\Delta\theta \times \Delta\phi sin\theta$	
	12 mrad $\times$14 mrad	for $11^0 < \theta < 16^0$
	11 mrad $\times$12 mrad	for $16^0 < \theta < 27^0$
	10 mrad $\times$11 mrad	for $27^0 < \theta < 36^0$
	10 mrad $\times$10 mrad	for $36^0 < \theta < 42^0$

Readout: Channels:
Tower storeys = $12\times3\times4,096$ (barrel) + $2\times12\times3\times1,024$ (endcap) = 221,184 (total)

Performance: Energy resolution $\sigma/E = 0.01 + 0.18/\sqrt{E(GeV)}$
Angular resolution $\sigma_\phi = \sigma_\theta/\sin\theta = .32 + 2.7/\sqrt{E(GeV)}$ mrad

5 The Luminosity Calorimeter (LCAL)

Description: A sampling calorimeter, consisting of lead sheets and wire chambers of 38 layers, grouped in 3 stacks of 9, 20 and 9 layers. Consist of four modules pairwise around the beam pipe. Each module is a half cylinder segmented into 384 towers in projective geometry.
Gas: $XeCO_2$ (80% : 20%).

Dimensions:	Radius:	$R_{inner} = 10$ cm
		$R_{outer} = 52$ cm
	Distance from I.P.	$z = 262.5$ cm
	Length	$\Delta z = 42.5$ cm
	Thickness of Pb plates	2.8 mm (stacks 1+2), 5.6 mm (stack 3)
	Towersize at front face	$2.9 \times 2.9 cm^2$
	Radiation length per stack	$4.77X_0$, $10.60X_0$, $9.35X_0$
	Front face	40 mm Al

Readout: 3 signals/tower $\times$ 384 towers/module $\times$ 4 modules = 4,608 pad signals
1 signal/wire $\times$ 38 wires/module $\times$ 4 modules = 152 wire signals

Performance:	Energy resolution	$\sigma/E = 0.011 + 0.15/\sqrt{E(GeV)}$ (wires)
		$\sigma/E = 0.014 + 0.15/\sqrt{E(GeV)}$ (pads)
	Angular resolution	$\sigma_\theta = 0.16mrad + 2.5mrad/\sqrt{E(GeV)}$

6 The Luminosity Tracking Chamber

(dismantled after 1991)

Description: Nine layers of drift tubes made of brass. The detector is subdivided into four modules. Each module is a half cylinder containing 504 drift cells.
Gas: Ar/CO_2 (90% : 10%)

Dimensions:	Radius:	$R_{inner} = 92$ mm
		$R_{outer} = 300$ mm
	Distance from I.P.:	$z = 2455$ mm
	Length	$\Delta z = 170$ mm
	Cross-section of drift cells:	$9.95 \times 9.95 mm^2$
	Length of drift tubes	from 76.8 mm to 192.7 mm
	Total radiation length	0.68 X_0

Readout Single hit electronics.
2016 wires in total multiplexed to 1152 read-out channels.

Performance: Position resolution of the chamber as a whole: $\sigma = 200\mu$. This corresponds to an angular resolution: $\sigma_\theta = 0.08$ mrad.

7 Very Small Angle Luminosity Monitor (BCAL)

Description: A pair of rectangular calorimeters (one pair on each side of the interaction point) situated on the minor axis of the elliptical beam pipe. Each calorimeter consists of 10 tungsten sheets alternating with sampling layers of plastic scintillator read out in pairs. One plane of silicon strips is located at a depth of 8 radiation lengths.

Dimensions:	Radius:	$R_{inner} = 6.5$ cm (active part)
		$R_{outer} = 8.5$ cm
	Polar angle coverage	
	(including quadrupole effects)	$\theta_{min} \approx 5.1$ mrad
		$\theta_{max} \approx 9.0$ mrad
		Note: only partial ϕ coverage.
	Distance from I.P.	$z = 770.0$ cm
	Thickness	$\Delta z = 14$ cm
	Tungsten sheet thickness	1st layer $= 4X_0$ ($X_0 = 3.8$ mm)
		Other 9 layers $= 2X_0$
		plus $6X_0$ (uninstrumented) at the back
	Scintillator thickness	$\Delta z = 3$ mm
	Silicon plane	40 strips
		Length $= 5$ cm
		Pitch $= 0.5$ mm
		Thickness $= 300$ μm

Readout: 20 scintillator pulse-heights
160 silicon strips read out with Amplex chips

Performance: From GEANT the Bhabha detection efficiency is expected to be about 75% for an energy threshold of 60% of the energy expected for a fully contained shower.

Position resolution expected: $\approx 0.5mm$

8 Solid-State Luminosity Calorimeter (SICAL)

(Sept. 1992)

Description: Cylindrical calorimeter mounted on each side of the interaction region. Each calorimeter is assembled from two half-modules enclosing the new beam pipe, and consists of 12 tungsten sheets alternating with layers of silicon pads. Successive layers of silicon are rotated in phi by one-third of the pad size (3.75^0).

Dimensions:	Radius:	$R_{inner} = 6.0$ cm	
		$R_{outer} = 14.6$ cm	
	Distance from I.P.	$z = 250.23$ cm	
	Thickness	$\Delta z = 12.41$ cm	
	Active region	$R_{inner} = 6.095$ cm	$\theta_{min} = 24.3$ mrad
		$R_{outer} = 14.455$ cm	$\theta_{max} = 57.7$ mrad
	Tungsten sheet thickness	$2.0 X_0$	
	Silicon crystal thickness	$300 \mu m$	
	Pad layout	Radial interval = 16×5.225 mm pads	
		ϕ interval = 11.25^0	

Readout: 12,288 channels (6,144 channels on each side of I.P.)
Read out with 768 Amplex chips, each with 16:1 multiplexing.

Performance: Expected resolutions from EGS studies are:

Energy resolution:	$\sigma/E = 23\%/\sqrt{E} = 3.4\%$ at 45.5 GeV
Phi resolution:	$\sigma_\phi = 0.3^0$ (R_{inner})
	$\sigma_\phi = 0.2^0$ (R_{outer})
Radial resolution on fiducial cut:	$12 \mu m$

9 The Time Projection Chamber (TPC)

Description: Cylindrical drift volume with central electrode and planar wire chambers at the two ends. Electrons from ionization drift to the endplates along the electric field of 11 kV/m. Their charge is recorded by a system of proportional wires which are capacitively coupled to cathode readout pads. Each endcap has 6 inner sectors (type K) and 12 outer sectors (types M and W). Sectors have concentrical rows of pads for 3 dimensional coordinate measurement ($r\phi$ from pad position, z from drift time). Wires across the sectors are used for dE/dx measurements. Each sector is equipped with special trigger padrows.
Gas: $ArCH_4$ (91 % : 9%) at atmospheric pressure.

Dimension:	Radius:	$R_{outer} = 1.8$ m	$R_{inner} = 0.31$ m
	Overall length	4.7 m	
	Drift length	2×2.2 m	
	Weight	3.6 t (with cables)	
	Gas volume	$43 m^3$	
	Radiation length:	inner fieldcage	0.023 X_0
		outer fieldcage	0.048 X_0
		endplate	0.35 X_0

Sectors:	R_{min}	R_{max}	No. padrows	No. trig. padrows	No. wires
Type K	38 cm	91cm	9	8	148
Type W,M	100 cm	170cm	12	11	196

Pad size	$6.2 \times 30mm^2$
Pitch in r-ϕ	6.7 mm
Triggerpad size	6.8 mm $\times 15^0$
Sense wire spacing	4 mm
Sense wire diameter	20 μm
Field wire diameter	127 μm
Diameter of other wires	76 μm
Central electrode thickness	25 μm

Gas Properties:

Drift velocity	5.2cm/μs
Longitudinal diffusion	4mm/$\sqrt{m}$ per single electron.
Transverse diffusion (B=15kG)	0.8mm/$\sqrt{m}$ per single electron.
Specific ionization for min. i. p. (mean)	90 electrons/cm

Electronics:

Sampling rate of digitization	11.4 Mhz
Pulse width of shaped signal (FWHM)	300 ns for 1 m drift

Electronic errors for:

Calibration (channel vs. channel):	gain = 1 %
	time = 6 ns
$r\phi$ - measurement (total)	$\leq 70\mu m$
z - measurement (total)	$\leq 0.5mm(\equiv 10ns)$

Readout:

	pads	wires	total
Channels	2 × 20502	2 × 3168	47340
TPDs	660	108	768
TPPs	36	36	72

Performance:

$r\phi$ spatial resolution	$180\mu m$ at 0^0 pad crossing angle
z spatial resolution	1.2 mm (wires) with "small" z dependence
	0.8 mm (pads) at $\theta = 90^0$
Momentum resolution	$\Delta p/p^2 =$
	TPC only: $1.2 \times 10^{-3}(GeV/c)^{-1}$ at 45 GeV
	ITC + TPC: $0.8 \times 10^{-3}(GeV/c)^{-1}$ at 45 GeV
dE/dx resolution	4.5% for Bhabha electrons

10 The Inner Track Chamber (ITC)

Description: Conventional cylindrical drift chamber with small staggered cells. Eight layers of sense wires. 96 cells on the inner four layers, 144 on the outer four. Hexagonal cell with 4 field wires per sense wire. Each pair of layers separated by a wire mesh. Outer wall of carbon fibre takes the load of wires. Inner wall of polystyrene and aluminium foil until 1990, polystyrene and carbon fiber from 1991. Z-measurement using the time difference for the pulse to reach the two ends of the wire. Provides correlated $r-\phi-z$ information for a fast 3-d track trigger. Gas: $ArCO_2$ (80% : 20%)

Dimensions:

Active length	2 m
R_{inner}	12.8 cm
R_{outer}	28.8 cm
Radiation length:	inner wall $0.0034X_0$
	outer wall $0.01X_0$
W/Au sense wires	960 (30μ diameter)
Al/Au field wires of	3840 (147μ diameter)

Electronics: Single-hit electronics with preamplifier on chamber. Specially constructed AZ board with combined amplifier/constant-fraction discriminator for signal detection and time expansion circuitry for the time difference (z) measurement. 0.5 nsec CAMAC TDC's for drift time measurement until 1992, 0.6 nsec from 1993. FASTBUS readout controlled by ALEPH Event Builder. $R-\phi$ and $r-\phi-z$ fast trigger processors with special bits to indicate the number of tracks, number of hits per layer and back-to-back tracks.

Performance: Track with $-0.97 < cos\theta < 0.97$ will traverse all layers.
$\sigma_{r\phi} = 150\mu$ averaged over the drift cell. (With ArC_2H_6 50%:50% $\sigma_{r\phi} = 130\mu$)
$\sigma_z = 7cm$ averaged over z and all layers
$r-\phi$ trigger decision in 500 nsec.
$r-\phi-z$ trigger decision in 2 μsec.

11 The Minivertex Detector (VDET)

Description VDET I (1991 - Oct.1995): Two concentric layers of silicon wafers, at radii of 6.3 and 10.8 cm are placed around the beam pipe. The silicon wafers have readout strips on both sides: strips oriented parallel to the beam ("$r-\phi$ side") measure the ϕ-coordinate of particle tracks whereas the z-coordinate is measured by strips perpendicular to the beam on the other side ("z side").

The distance between strips, called pitch, is $25\mu m$ on both sides. The readout pitch is $100\mu m$. On the z side, every other strip serves as a "blocking strip", collecting no ionization charges; thus the effective strip pitch on the z side is $50\mu m$. Capacitive charge division is used to interpolate the track impact point between readout strips using a centre-of-gravity method. The CAMEX64 amplifier chips (64 channels each with a pitch of $100\mu m$) are bonded directly to the strips and mounted at the ends of the detector for the readout of the $r-\phi$ side. The amplifier chips for the z- readout are mounted above the silicon detectors.

Dimensions:	Inner layer:	R $\approx$ 6.3 cm	length $\approx$ 20.0 cm
	Outer layer:	R $\approx$ 10.8 cm	length $\approx$ 20.0 cm
	Total thickness:	0.041 X_0 at $\theta = 90^0$	averaged over ϕ
	Silicon detector wafers:	thickness	$\approx 300\mu m$
		size	$5.12cm \times 5.12cm$

Readout: Analogue readout

Each module has 512 strips read out on the rϕ-side and 1024 strips read out on the z-side. Every 256 strips are multiplexed onto 1 "line". This leads to 2 output lines for the z-strips and to four output lines for the rϕ strips per module. In total this gives 6 lines/module $\times$ 9 (15) modules/side $\times$ 2 sides = 108 (180) signal output lines for the inner (outer) layer. Thus the 73728 strips are output with 288 analog lines.

1991 and 1992 Performances: Signal-to-noise ratio: 14:1

Point resolution: $\sigma_{r\phi} \approx 12\ \mu m$, $\sigma_z \approx 10\ \mu m$ for normally incident tracks

Description VDET for LEP II: A new silicon vertex detector (VDET II) was developed during 1994-1995 to replace the former detector for the high energy running periods of LEP after October 1995. The main reason for the upgrade was to increase the discovery potential for the Higgs search by extending the angular coverage of the detector and by reducing the material in the tracking volume. In addition the sensitivity to radiation was reduced to cope with the expected higher radiation level at LEP II. The design and the performance is described in the following in more detail.

The physical strip pitch is the same as for the present detector. The pitch of readout strips is reduced by a factor of two for the $r\phi$ side (now $50\mu m$) and identical to the previous design for the z side. To connect the 1920 readout strips per module on the z-side with the 1024 electronics channels at the end of the detector, the strip-pairs (1,961), (2,962) ...(960,1920) are multiplexed onto the same electronics channel each, using a thin microstrip kapton layer bonded to the z-readout strips. The MX-7RH amplifier chip used is specially processed and can stand a radiation dose of up to 1 Mrad. It has 128 channels, low noise and eight chips are bonded to the readout strips per side.

The new detector improves the performance of Aleph as follows:

- it uses six silicon wafers per face with a length of 6.5 cm each, thus doubling the active length compared to the former detector. This increases the angular acceptance to $-0.95 < cos\theta < 0.95$ for tracks required to hit at least one layer,
- to cope with the higher level of radiation expected at LEP II less radiation sensitive electronics is used (max. dose of 1 Mrad),

- to reduce the amount of passive material the readout electronics previously mounted across the sensitive region above the silicon wafers on the z-side is now mounted at the far end of the detetor. This decreases the tails in the track-impact parameter resolution and improves b-tagging.

The internal allignment is facilitated by larger regions where wafers overlap, thus increasing the statistics of tracks to be used for the allignment.

Dimensions:	Inner layer:	R = $\approx$ 6.3 cm	length $\approx$ 40.0 cm
	Outer layer:	R = $\approx$ 11.0 cm	length $\approx$ 40.0 cm
	Total thickness:	0.015 X_0 at $\theta = 90^0$	averaged over ϕ
	Silicon detector wafers:	thickness	$\approx 300\mu m$
		size	$5.26cm \times 6.54cm$

Readout: Analogue readout
Each module has 1024 strips read out for both the rϕ and the z-side. All 1024 electronic channels per module/side are multiplexed onto one "line". The total of 95088 strips are thus output onto 48 analog lines, further amplified ... and finally digitized in one of the 48 Flash-ADC Fastbus-Modules, which apply zero suppression and fast signal processing in addition to reduce the amount of data to be kept on tape.

Performance as measured during the 161 GeV running in 1996: After modifications in the mechanical support the faces are now stable to better than 5 micron.
Signal-to-noise ratio: $\approx 28:1$ for the $r\phi$ side and $\approx 17:1$ for the z side.
Point resolution achieved: $\sigma_{r\phi} \approx 12\,\mu m$, $\sigma_z \approx 14\,\mu m$ for $\cos(\theta)$ less than 0.4. These values may improve in the future with more data for the allignment and improvements in the reconstruction algorithms.

12 The Beam Pipe (1991 and 1992):

Description: The central part is a cylinder made of Beryllium. Then as one goes out in the z direction, one encounters two carbon fiber pieces and an aluminum piece in 91, only aluminum in 92.

Dimensions:	Central Part: (Beryllium part)	$z = 0$ to $z = 38cm$ $R_{inner} = 5.30cm$ $R_{outer} = 5.41cm$ $0.00312\ X_0$ at $\theta = 90^0$	
	Connecting Part: (1991)	Misc. connecting material	$z = 38$ to $z = 50cm$
		Carbon fiber	$z = 50$ to $z = 153.2cm$
		Misc. connecting material	$z = 153.2$ to $z = 165.2cm$
		Carbon fiber	$z = 165.2$ to $z = 228.5cm$
		Misc. connecting material	$z = 228.5$ to $z = 234.5cm$
		Aluminum	$z = 234.5$ to $z = 269.5cm$
	Connecting Part: (1992)	Misc. connecting material:	$z = 38$ to $z = 50cm$
		Aluminum part:	$z = 50$ to $z = 269.5cm$ $R_{inner} = 5.30cm$ $R_{outer} = 5.45cm$ $0.29\ X_0$ at $\theta = 60mrad$

13 The Trigger

Description: A three-level system sensitive to single particles or single jets. At levels 1 and 2 the trigger consists of specially built hardware to look for signals in coarse segments of the following detector components: HCAL, ECAL, LCAL, ITC, and TPC. The Level 1 decision is based on the following information:

- Track candidates in the ITC
- Energy in a trigger segment
- Total energy in the barrel, in either endcap or in the entire detector

The Level 2 trigger decision is based on track candidates in the TPC, and at Level 3, a software analysis can be performed based on the full readout of the detector.

Timings:

Time between beam crossings:	$23\mu s$
Level 1 decision time:	$5\mu s$
Level 2 decision time:	$\approx 50\mu s$
Maximum allowed rate out of Level 1:	few hundred Hz
Maximum allowed rate out of Level 2:	10 Hz
Maximum allowed rate out of Level 3:	1 Hz

Performance:

Observed rate out of Level 1:	0.5 Hz for luminosity of $10^{30} cm^{-2} sec^{-1}$
Efficiency:	100% for hadronic Z decays
	$\approx$ 100% for leptonic Z decays
	99.7 $\pm$ 0.2% for Bhabha events

14 LEP

Circumference	26.66 km	
Number of dipoles	3280 + 24 injection + 64 weak	
Number of quadrupoles	520 + 288 + 8 superconducting	
Peak magnetic field	0.135 T	
Number of RF cavities	52 Cu + 32 Nb + 208 NbCu	(LEP phase IIIb)
Beam energy	94.8 GeV maximum	(LEP phase IIIb)

Bunch configuration:	"Normal"	Pretzel	Bunch trains
Year:	$\rightarrow$ 1992	1993 – 1994	1995
Number of bunches per beam:	4	8	4×3
Time between crossings:	22 μs	11 μs	22 μs between trains
			247 ns between bunches in a train

1995 performance:

Bunch length	9 – 13 mm	
Beam spot size (σ)	Vertical: $\approx$ 5 μm,	Horizontal: $\approx$ 250 μm
β^*	Vertical: 5 cm,	Horizontal: 2.5 m
Max. beam currents	$\approx$ 4 mA per beam	
Max. peak luminosity	$\approx 2.2 \times 10^{31} \mathrm{cm}^{-2} \mathrm{s}^{-1}$	
Luminosity lifetime	15 – 20 hours	

15 The Offline System

Description: The offline system consists of software and hardware to process the ALEPH data from the raw-data tapes to the result of physics analysis.

Software:

Program	Function	Lines of source	Language
ALEPHLIB	General library	111000	FORTRAN
GALEPH	Simulation program	43000	FORTRAN
TPCSIM	TPC simulation	10000	FORTRAN
JULIA	Reconstruction program	113000	FORTRAN
BOS	Memory manager	14000	FORTRAN
DALI	Graphics program	140000	FORTRAN/C
LOOK	Data browser	3000	FORTRAN
ALPHA	Analysis frame	42000	FORTRAN
SCANBOOK	Data Bookkeeping	30000	FORTRAN
BANKDOC	Bank description	22000	DDL
ALPROD	Production control	8000	REXX
FALCON-SOFT	FALCON software	16000	DCL/FORTRAN
Total		552000	

Processing time: Time per hadronic Z^0

JULIA	35 sec	[CERN units]
GALEPH	290 sec	[CERN units]
ALPHA	1-10 sec	[CERN units]

Data Banks/Data Base:

Number of Banks defined:	1052
Size of database:	3.7 Mbytes

Real Data Number of Cartridges (200 Mbytes each):

Year	1989	1990	1991	1992	1993	1994	Total
Had Z^0	24 k	163 k	295 k	785 k	692 k	1808 k	3767 k
Raw	233	483	980	1546	1406	5668	10316
POT	31	147	335	993	1170	2197	4873
DST	12	65	147	392	391	769	769
MINI		10	15	28	37	100	190
NANO		2	3	7	8		20
Total	276	707	1480	2966	3012	8734	17175

Computer Systems

Name	Op.Sys	Purpose	♯ Nodes	CERN-units	Disks GB
FALCON	VMS	Online reconstruction	4	55	12
ALWS	VMS	Physics analysis	105	336	150
ALOHA	OSF1	Physics analysis	17	397	78
SAGA	OSF1	Physics analysis (batch)	8	120	10
SHIFT	IRIX5	Physics analysis (batch)	8	136	193

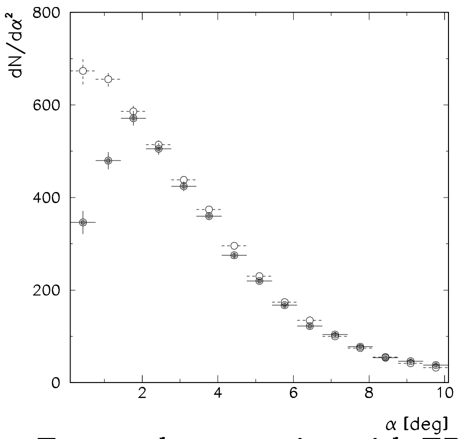
16 Aleph Performances

Luminosity measurements:

Year	$\int Ldt\ (pb^{-1})$ LEP	$\int Ldt\ (pb^{-1})$ used total	$\int Ldt\ (pb^{-1})$ used pk-x/peak/pk+x	exp. error %	theor. error %
1990	8.0	7.5	1.6/3.9/2.0	0.49	0.30
1991	16.9	13.1	2.4/8.3/2.3	0.37	0.28
1992	29.4	25.7		0.37/0.15	0.28
1993	40.2	36.0	9.4/17.1/9.5	0.09	0.16
1994	66.0	59.3		0.12	0.16
1995	38.8	35.9	8.6/18.1/9.2	0.12	0.16

Track reconstruction:

VDET+ITC+TPC:	$\sigma_{r-\phi} = 25\mu m$
Impact param. resol.	$\sigma_z = 30\mu m$
Mom. resol. (at 45 GeV)	$\Delta p/p^2 = 6\,10^{-4}(\mathrm{GeV/c})^{-1}$



Two tracks separation with TPC (open circle: opposite sign, full circle: same sign pairs)

Error on charged multiplicity:
$\sigma(N_{measured}) = 0.5792 \pm 0.06538\ N_{true}$

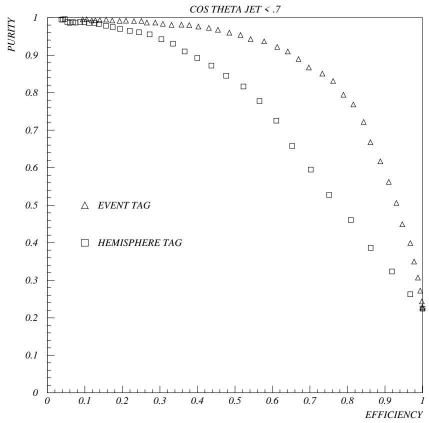
b decay length:	$\sigma_{\parallel} = 300\ \mu m$
	$\sigma_{\perp} = 30\ \mu m$
τ decay length:	$\sigma_{\parallel} = 740\ \mu m$
	$\sigma_{\perp} = 25\ \mu m$
Invariant mass $J/\Psi \to \mu^+\mu^-$	$\Delta m = 25\ MeV$

Efficiencies:

Leptons identification	Efficienty	Mis-ident. probability
electrons	85%	5×10^{-3} (ECAL only)
	75%	1×10^{-3} (ECAL + dE/dx)
muons	88%	1×10^{-3}

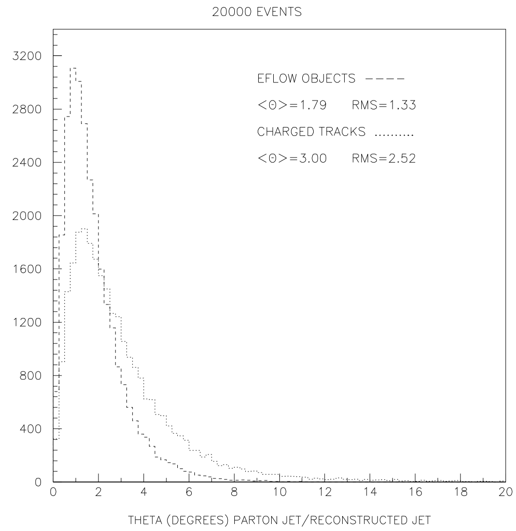
π^0/γ separation: π^0 with energy between 10 and 30 GeV and fully containted are identified with 90 % probability

b tag performances:



b tag with two methods
(QVRSCH routine on 91 monte-carlo)

Energy flow:



Parton angular resolution:
with charged only and
with energy flow objects

Total energy reconstruction:
$\sigma(E_{total}) = 6.4\ GeV$

Parton reconstruction:

jet energy	angular resolution
$10\ GeV$	$40\ mrad$
$40\ GeV$	$25\ mrad$

17 Aleph Results

(as published until October 1996)

Electro-Weak results

	ALEPH publ. 89 to 92	ALEPH prel. 89 to 95	LEP prel. 89 to 95
M_Z (GeV)	91.187 ± 0.009	91.1873 ± 0.0030	91.1863 ± 0.0020
Γ_Z (GeV)	2.501 ± 0.012	2.4950 ± 0.0047	2.4946 ± 0.0027
$\sigma^0_{hadrons}$ (nb)	41.60 ± 0.16	41.576 ± 0.083	41.508 ± 0.056
R_l	20.69 ± 0.09	20.766 ± 0.049	20.778 ± 0.029
$A^{0,l}_{FB}$	0.0171 ± 0.0033	0.0187 ± 0.0017	0.0174 ± 0.0010
$\mathcal{A}_\tau$		0.136 ± 0.015	0.1401 ± 0.00674
$\mathcal{A}_e$		0.129 ± 0.017	0.1382 ± 0.0076
R_b		0.2158 ± 0.0014	0.2179 ± 0.0012
R_c		0.1683 ± 0.0091	0.1715 ± 0.0056
$A^{0,b}_{FB}$		0.0968 ± 0.0037	0.0979 ± 0.0023
$A^{0,c}_{FB}$		0.081 ± 0.013	0.0733 ± 0.0049
$\sin^2\theta^{eff}_W \langle Q_{FB} \rangle$		0.2322 ± 0.0013	0.2320 ± 0.0010
$\sin^2\theta^{eff}_W$	0.2321 ± 0.0012	0.2319 ± 0.0005	0.23209 ± 0.00024
N_ν	2.983 ± 0.034		2.989 ± 0.012
M_{top}(GeV)	$172 \pm^{20}_{22} \pm^{17}_{18}$	$178 \pm 22^{+17}_{-19}$	$171 \pm 8^{+17}_{-19}$
α_s	0.114 ± 0.011	$0.119 \pm 0.005 \pm 0.002$	$0.122 \pm 0.003 \pm 0.002$
+ SLD, $p\bar{p}$ and ν			
M_{top}(GeV)			$177 \pm 7^{+16}_{-19}$
α_s			$0.121 \pm 0.003 \pm 0.002$

QCD results

Event shape with exponentiation method:	$\alpha_S(M_Z^2) = 0.125 \pm 0.005$		
Evidence of non abelian gauge:		measured	SU(3)
	N_F/C_F	$2.24 \pm 0.32 \pm 0.24$	2.25
	T_F/C_F	$0.58 \pm 0.17 \pm 0.23$	0.375
Charged multiplicity:	$< N_{charged} >_{at\ M_Z} = 20.85 \pm 0.24$		
at τ mass:	$\alpha_S(M_\tau^2) = 0.330 \pm 0.046$		
by running to M_Z :	$\alpha_S(M_Z^2) = 0.118 \pm 0.005$		

τ results

τ lifetime: $\tau_\tau = 0.2937 \pm 0.0027 \pm 0.0016$ ps (89 to 92 data)

$\mu - \tau$ universality: $g_\tau/g_\mu = 0.9943 \pm 0.0065$

Inclusive Branching ratios:

BR($\tau \to$ 1 charged)	$= 85.45 \pm 0.97\%$	BR($\tau \to$ 3 h $+\nu_\tau$)	$= 9.5 \pm 0.7\%$
BR($\tau \to$ 3 charged)	$= 14.35 \pm 0.48\%$	BR($\tau \to$ 1 h $+2\pi^0\nu_\tau$)	$= 10.2 \pm 1.1\%$
BR($\tau \to$ 5 charged)	$= 0.10 \pm 0.05\%$		

Leptonic Branching ratios: (91 to 93 data)

$BR_e = 17.79 \pm 0.12 \pm 0.06\%$

$BR_\mu = 17.31 \pm 0.11 \pm 0.05\%$

τ polarisation: (90 to 92 data)

g_V^τ/g_A^τ	$= 0.073 \pm 0.012$	g_V^e/g_A^e	$= 0.060 \pm 0.013$
A_τ	$= 0.136 \pm 0.015$	A_e	$= 0.129 \pm 0.017$
$\sin^2\theta_W^{eff}$	$= 0.2332 \pm 0.0014$		

τ neutrino mass limit < 24 MeV (95% CL)

b physics

b-hadrons lifetime:	$\tau_{b-hadrons}$	$= 1.533 \pm 0.013 \pm 0.022$ ps	(89 to 93 data)
$\bar{B}^0$ and B^- lifetimes:	$\tau_{\bar{B}^0}$	$= 1.55 \pm 0.06 \pm 0.03$ ps	
	τ_{B^-}	$= 1.58 \pm 0.09 \pm 0.03$ ps	
Λ_b lifetime:	τ_{Λ_b}	$= 1.04 \pm 0.13$ ps	(91 to 93 data)
B_s lifetime:	τ_{B_s}	$= 1.54 \pm 0.14$ ps	(91 to 95 data)
Ξ_b lifetime:	τ_{Ξ_b}	$= 1.35^{+0.37+0.15}_{-0.28-0.17}$ ps	(91 to 95 data)

Oscillations: $\Delta m_d = 0.436 \pm 0.033 ps^{-1}$ (91 to 94 data)

$\Delta m_s > 6.6 ps^{-1}$ (91 to 95 data)

Energy fraction for b and c hadrons: $<x>_b = 0.702 \pm 0.004 \pm 0.005$

$<x>_c = 0.508 \pm 0.083 \pm 0.06$

J/Ψ production from b: BR(b$\to J/\Psi X) = 1.21 \pm 0.13 \pm 0.08\%$

gives $\tau_b = 1.35^{+0.19}_{-0.17} \pm 0.05$ ps

Semi-leptonic decays of B_s and Λ_b:

BR($\bar{b} \to B_s$)BR($B_s \to D_s^- l^+ \nu X$)	$= 0.040 \pm 0.011^{+0.010}_{-0.012}$
BR(b$\to \Lambda_b$) BR($\Lambda_b \to \Lambda_c^+ l^+ \bar{\nu} X$)	$= 0.030 \pm 0.007 \pm 0.009$
BR(b$\to \tau^- \bar{\nu}_\tau X$)	$= 0.0408 \pm 0.0076 \pm 0.0062$

$\mid V_{cb} \mid$

F(1) $\mid V_{cb} \mid = (31.4 \pm 2.3 \pm 2.5)10^{-3}$

$\mid V_{cb} \mid = (34.5 \pm 2.5 \pm 2.7)10^{-3}$

Searches

MSM Higgs:	MSSM (h,A) doublet search:
$m_{H^0} \geq 63.9$ GeV (at 95% CL)	$m_h \geq 44$ GeV $m_A \geq 21$ GeV

Compositeness: $m_{e^*} \geq 46.1$ GeV $m_{\mu^*} \geq 46.1$ GeV $m_{\tau^*} \geq 46.0$ GeV

$m_{\nu^*} \geq 47.0$ GeV $m_{q^*} \geq 45.0$ GeV

New weakly interacting particle X^0:
assuming BR(Z$\rightarrow l^+l^-X^0$)/ BR(Z$\rightarrow l^+l^-$) $\geq 2.5\,10^{-3}$,
$m_{X^0} \in [7, 60]$ GeV is excluded at 95 % CL

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