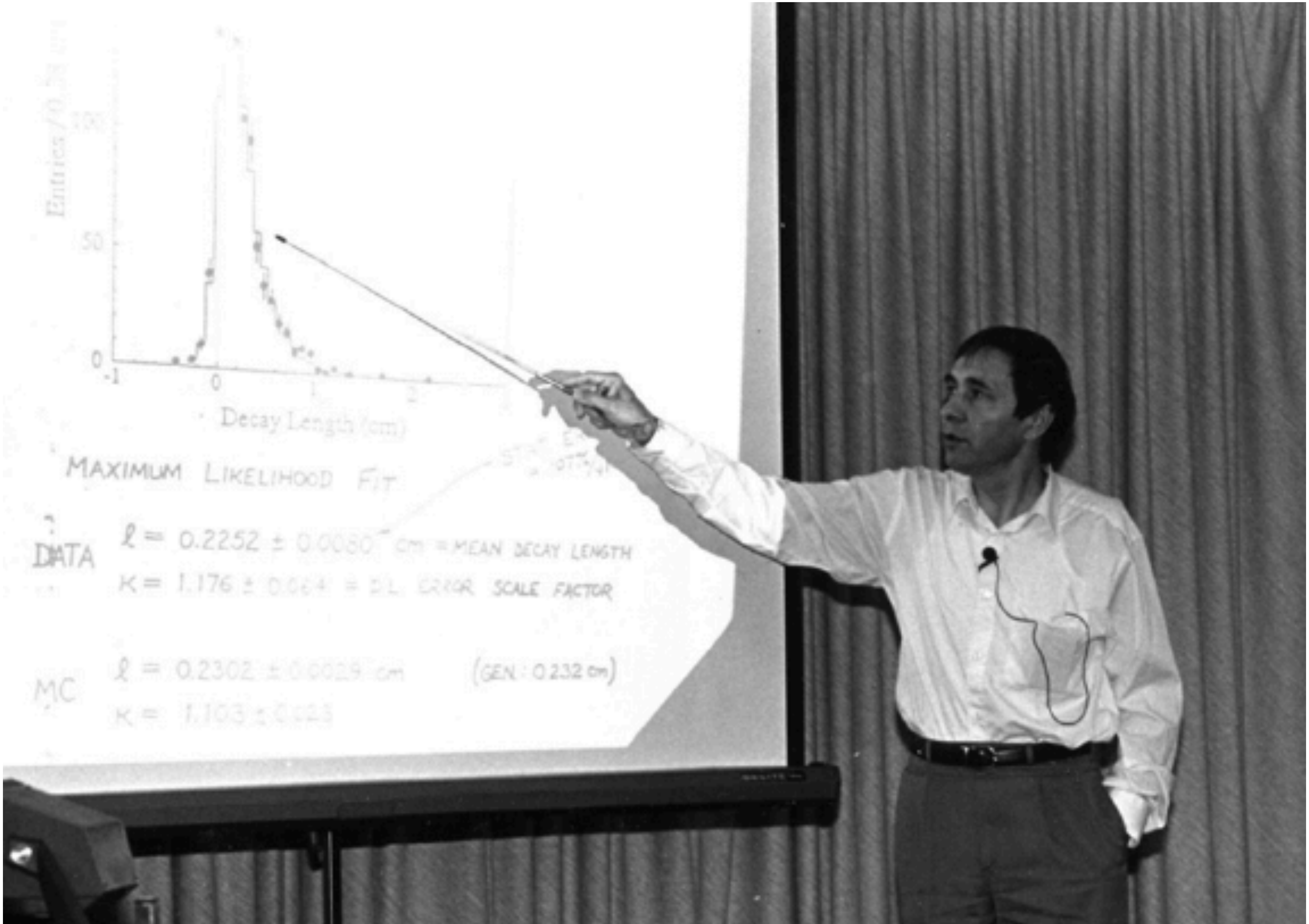
The art of precision physics at ALEPH and BABAR



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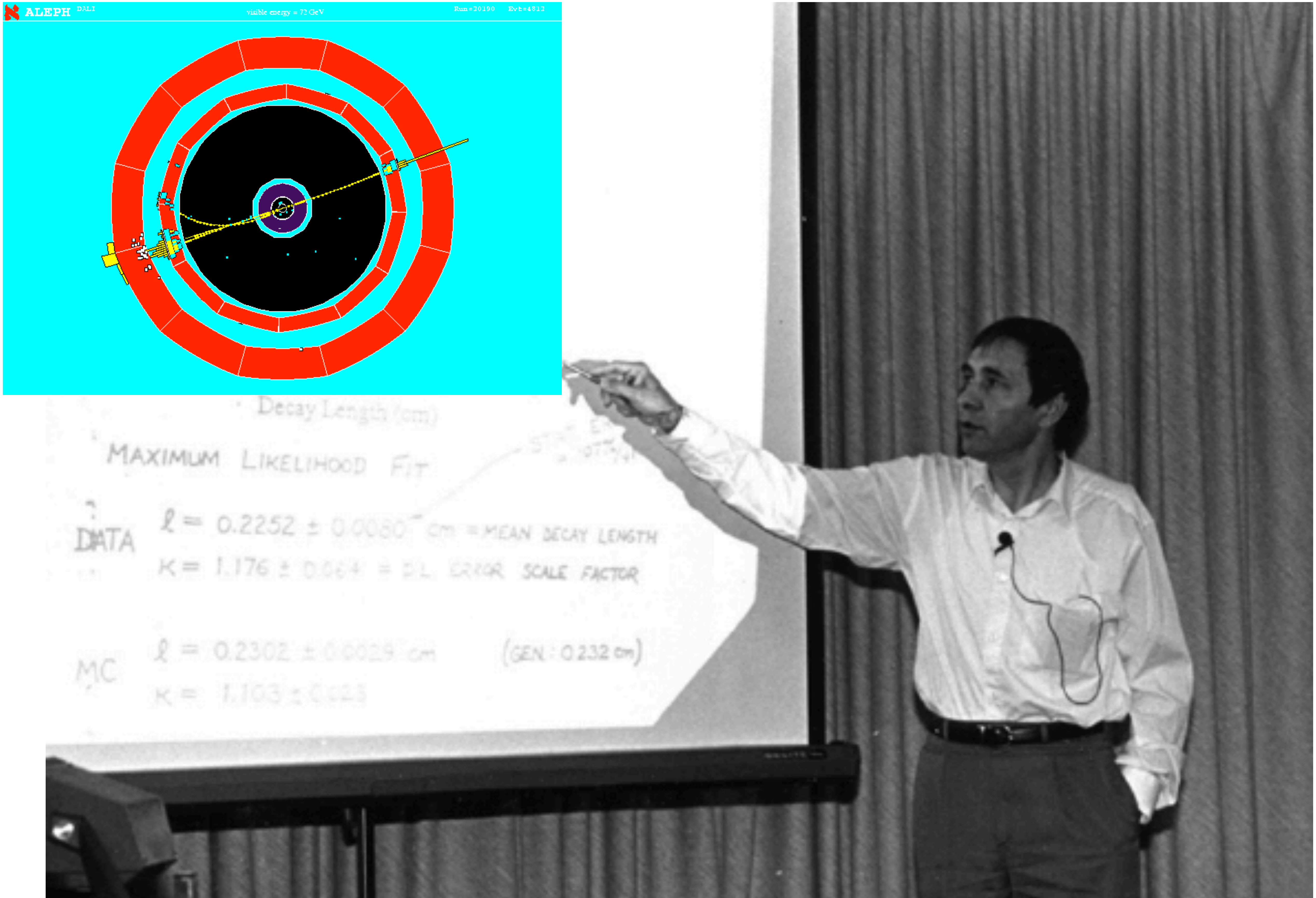

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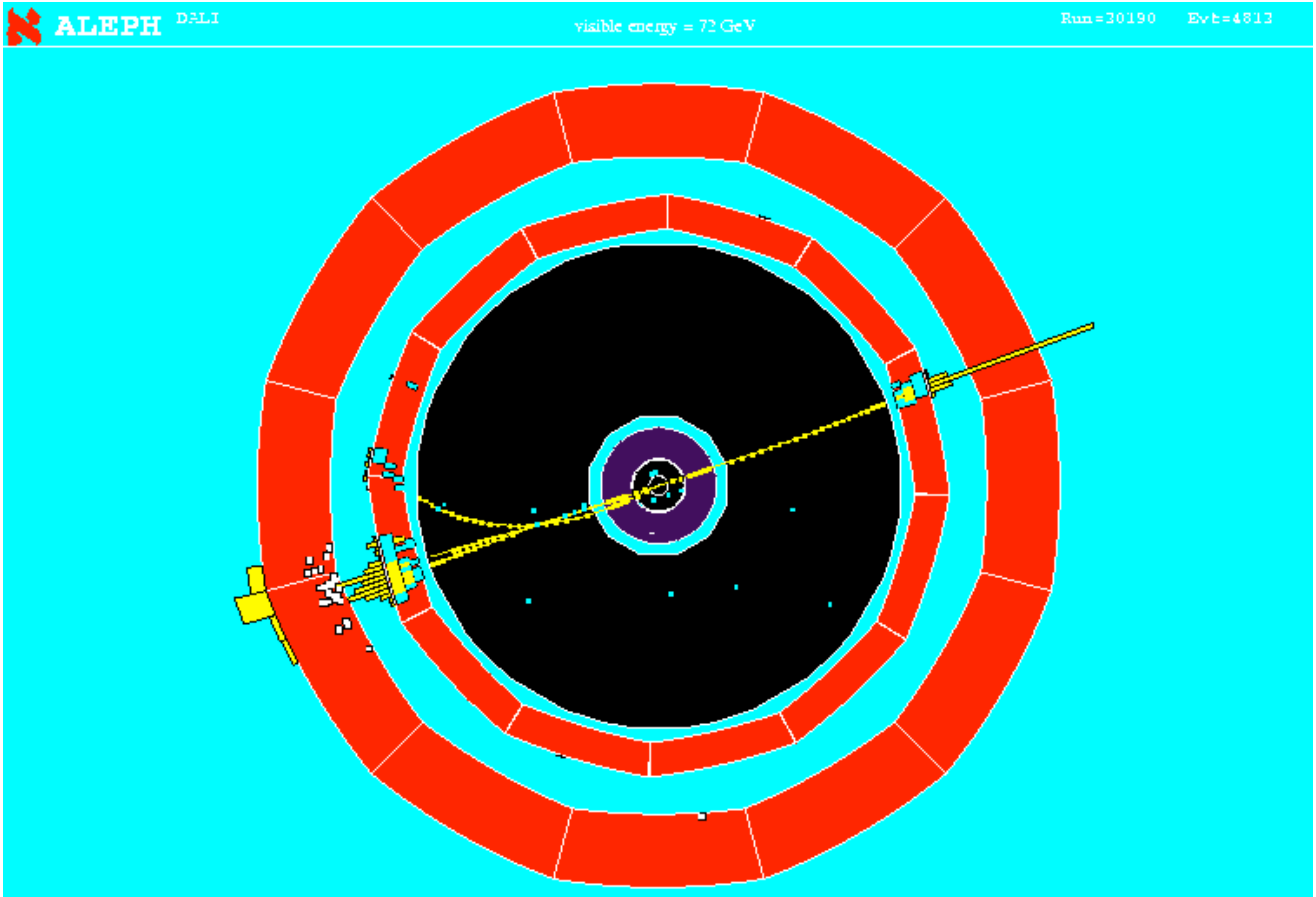

Why was tau physics at ALEPH (LEP) so precise ?

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Michel: the amazing tale of the tau

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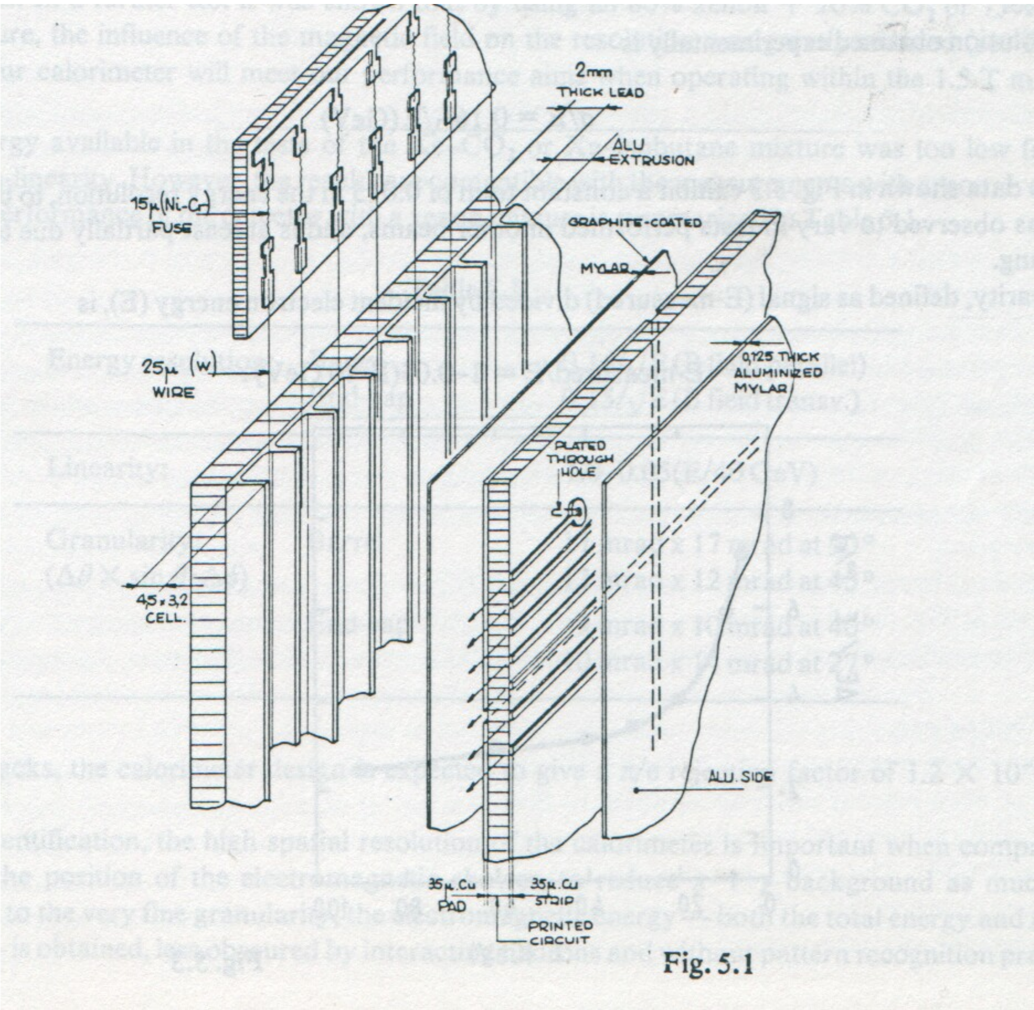


Fig. 5.1

Three ingredients :

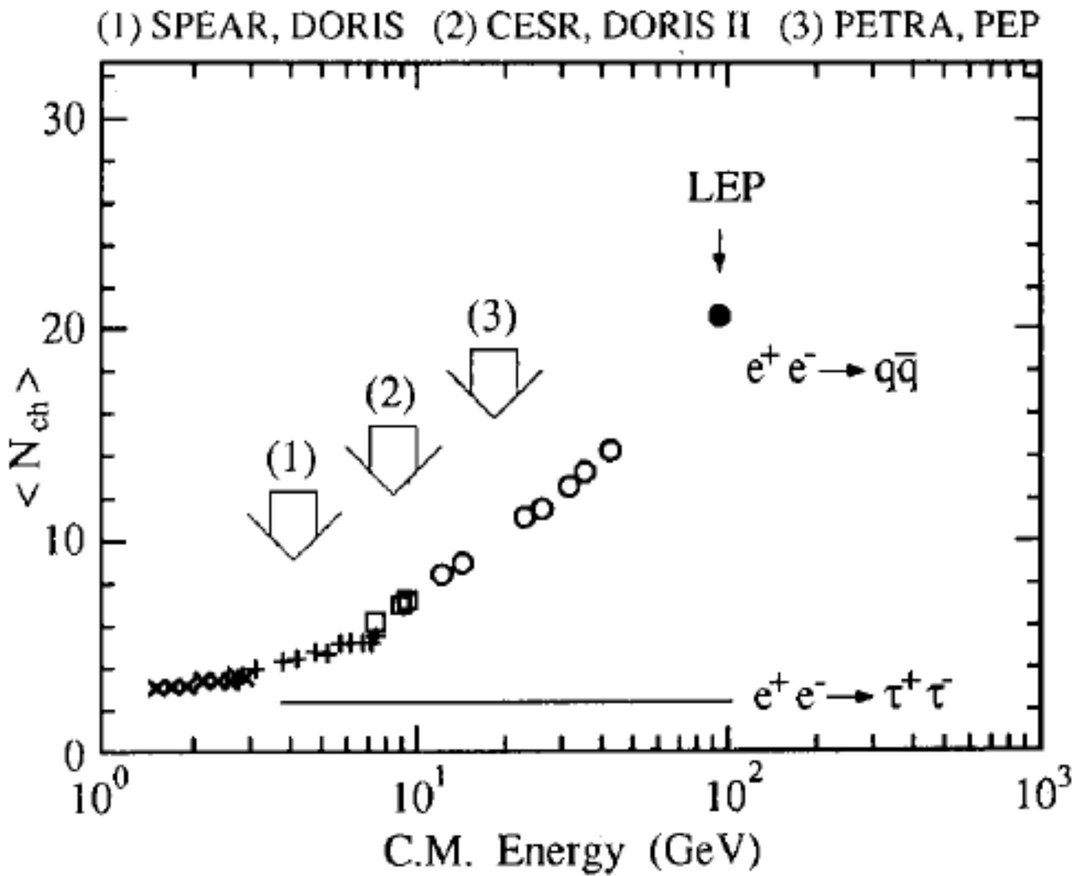
First Ingredient

First, and most importantly, the Aleph detector was beautifully designed to study τ production and decay

.....Various criteria can be used to choose between different designs for an electromagnetic calorimeter. We have decided to emphasize granularity….it simplifies the identification of electrons in hadronic jets and facilitates the separation of photon energy from the background produced by interacting hadrons…..

Second Ingredient

At LEP energies, τ pairs led to two collimated back-to-back particle jets due to the large Lorentz boost in each τ decay. This provided for a very clear signature resulting in a large selection efficiency and a small background.



Michel, Columbus

Fig. 7 : Charged particle multiplicity for the process $e^+e^- \to$ hadrons and $e^+e^- \to \tau^+\tau^-$ as a function of centre-of-mass energy.[8]

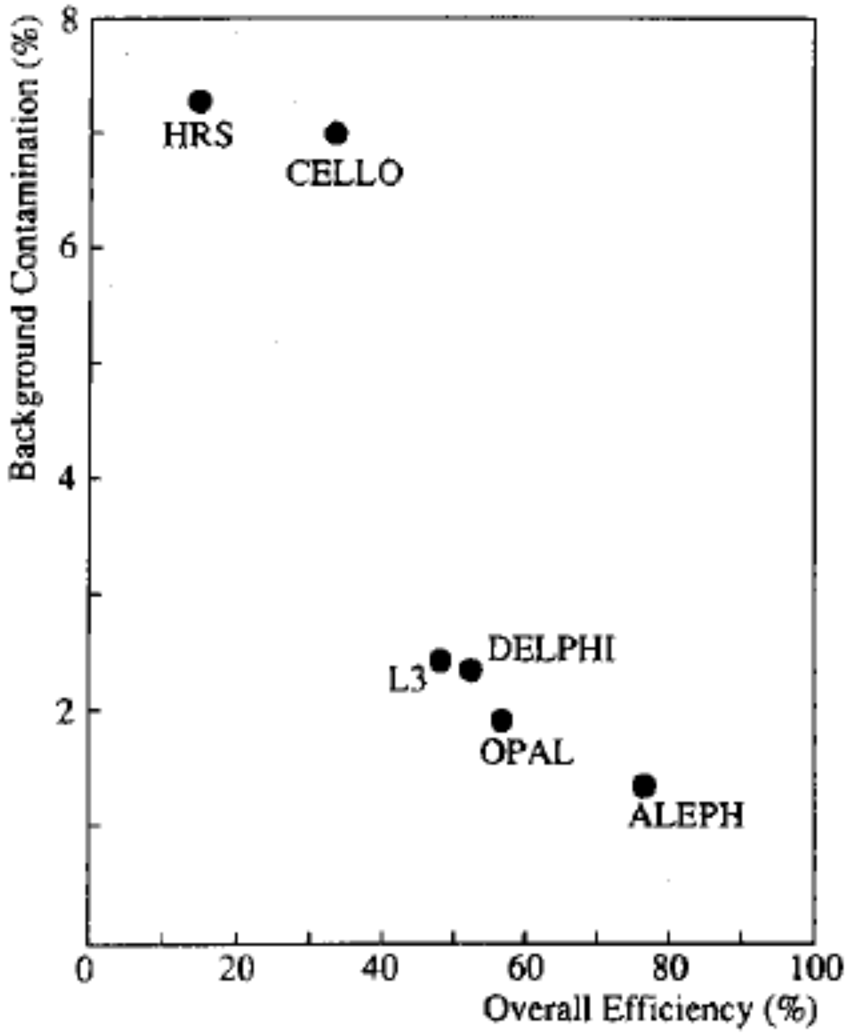


Fig. 8 : Overall selection efficiency for $e^+e^- \to \tau^+\tau^-$ and the corresponding non-τ background achieved by experiments performing analyses on a global ττ sample.

ALEPH papers with Taus

- 19 Papers on EWK precision measurement
- 13 τ branching fractions and spectral functions
- 6 τ charged-current couplings and τ neutrino,
- 5 τ spin and polarization
- 5 τ lifetime.

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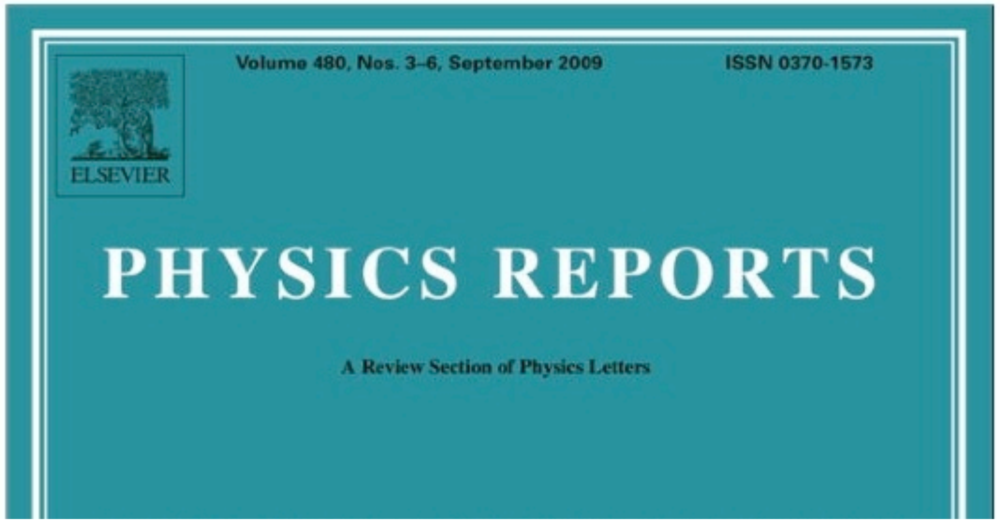

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Branching ratios and spectral functions of τ decays:
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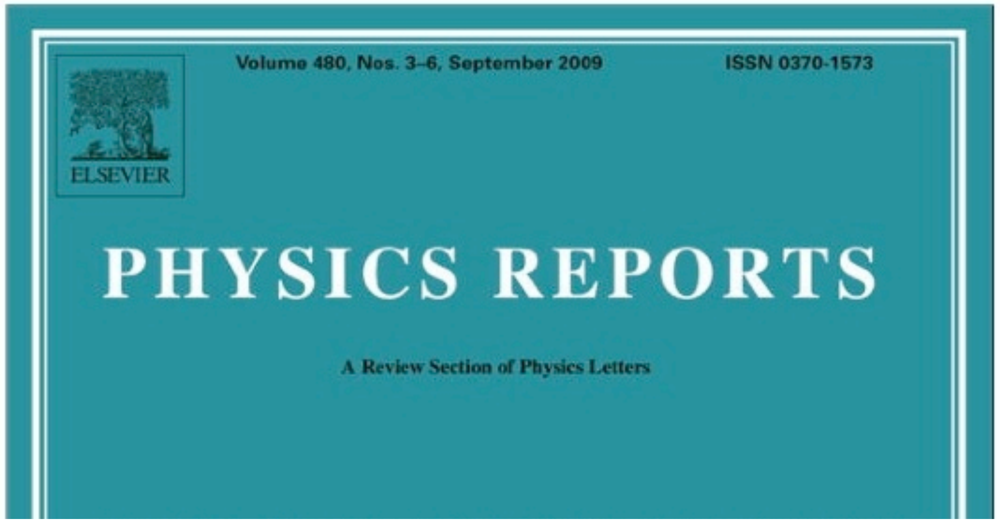

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Branching ratios and spectral functions of τ decays:
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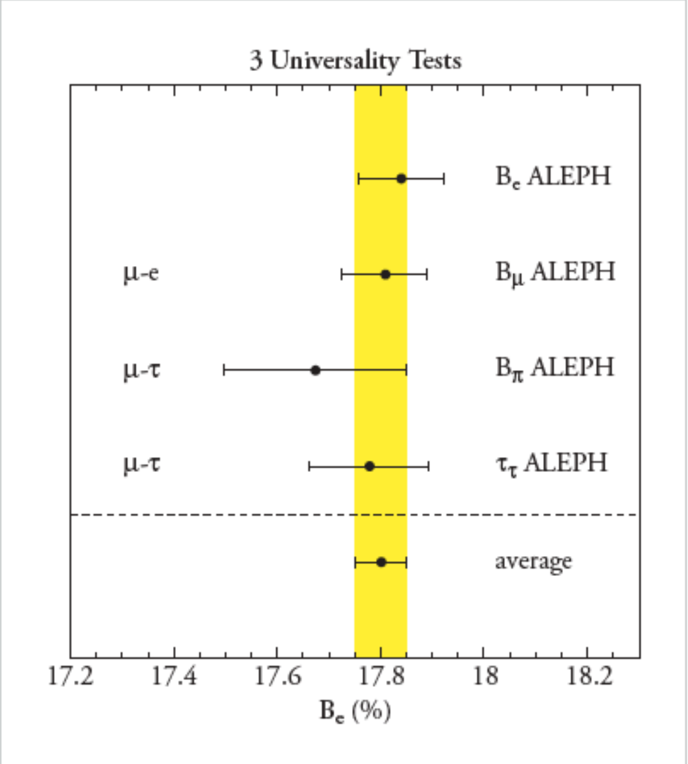
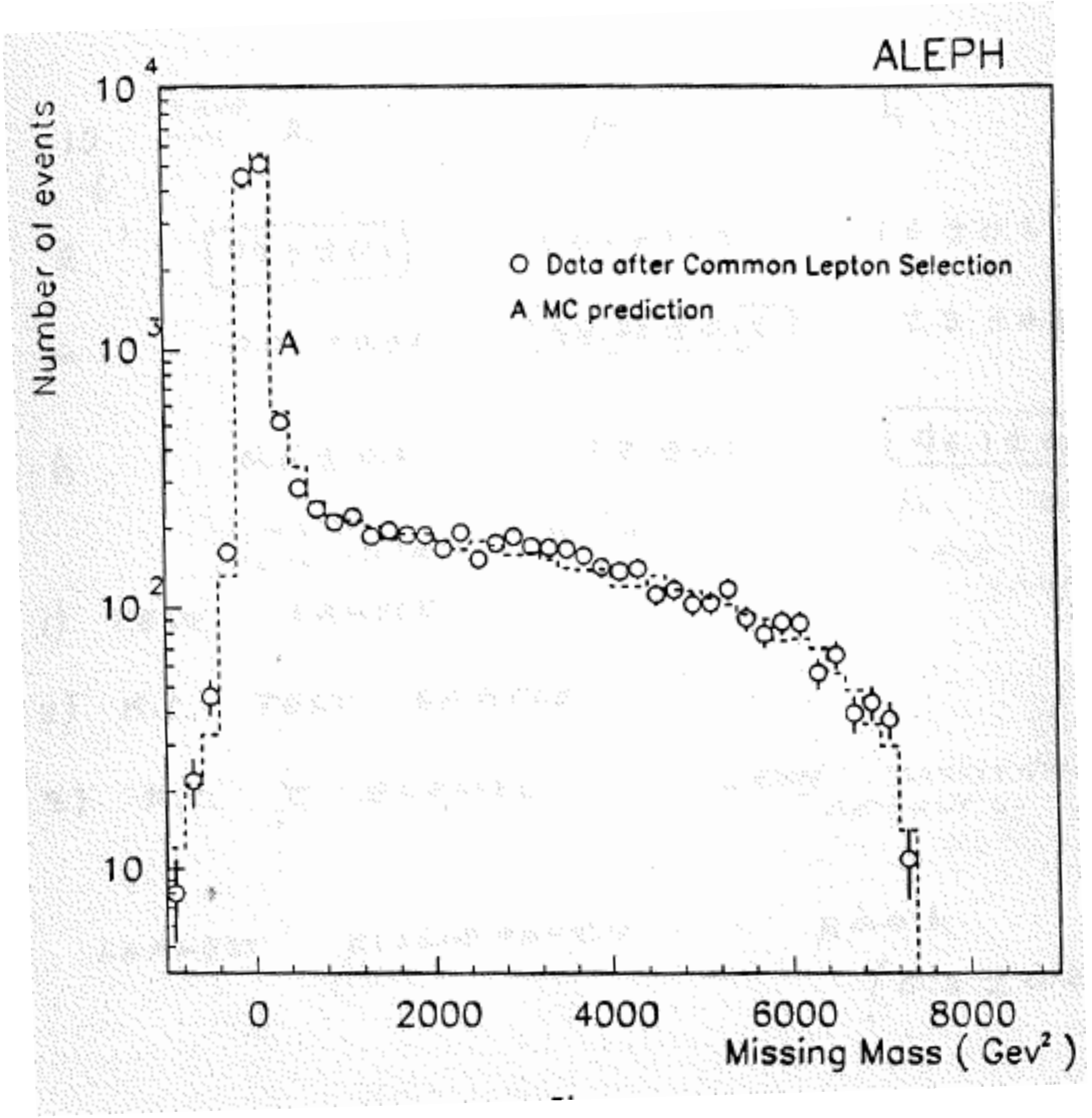
The ALEPH Collaboration

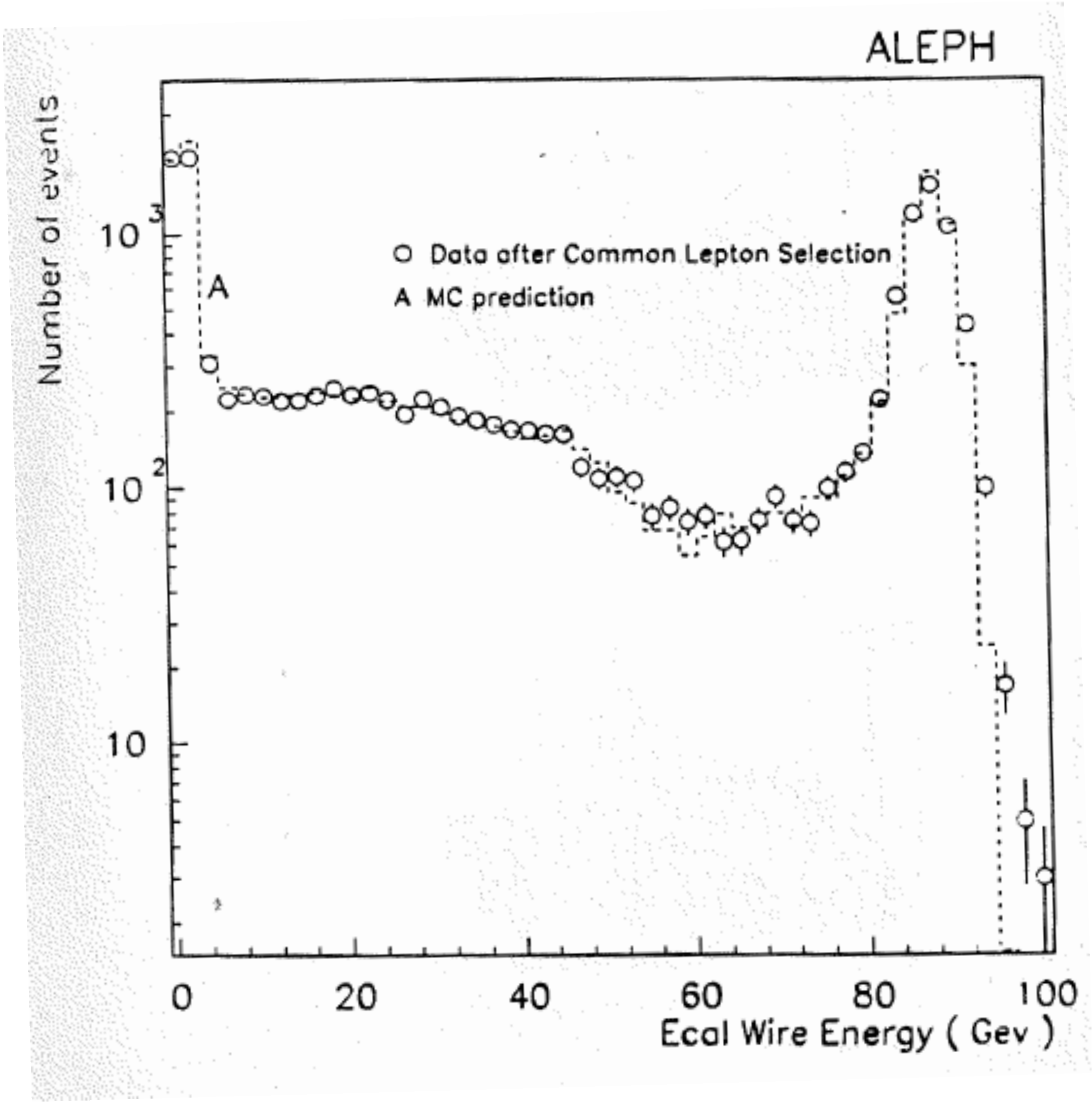
….. Certainly the overall description of τ decays obtained by Aleph had a profound impact. All previously reported problems (one-prong, also three-prong) have vanished and the τ lepton appears standard with leptonic couplings displaying universality with a precision of 3×10^{-3}…..



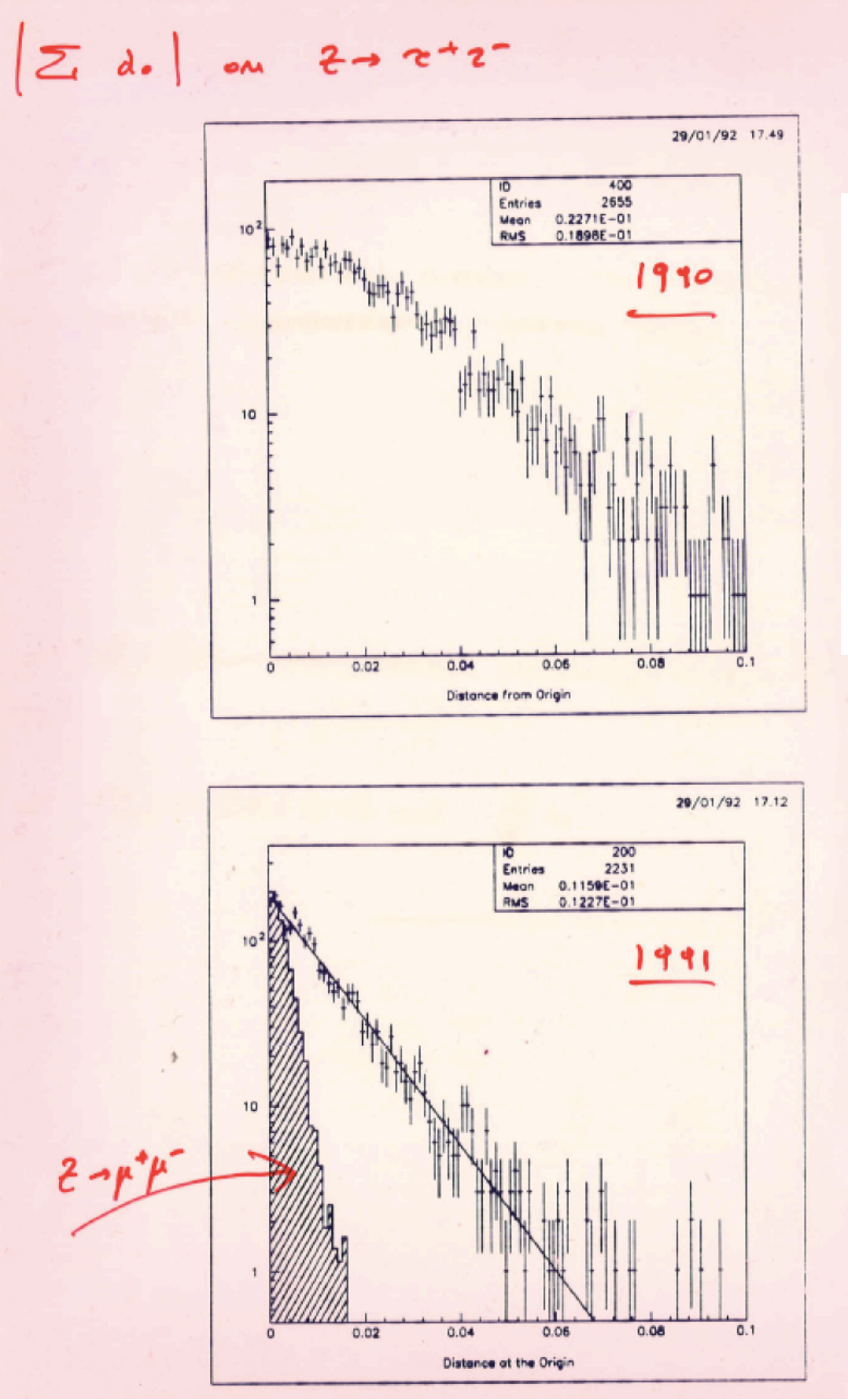
Tau selection

……. using the energy flow tool from Patrick Janot, a very efficient selector TAUSEL was designed by Laurent Duflot and Gerry Ganis………

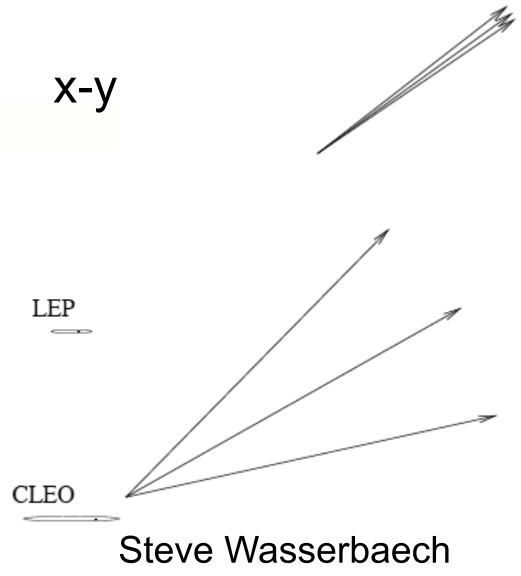


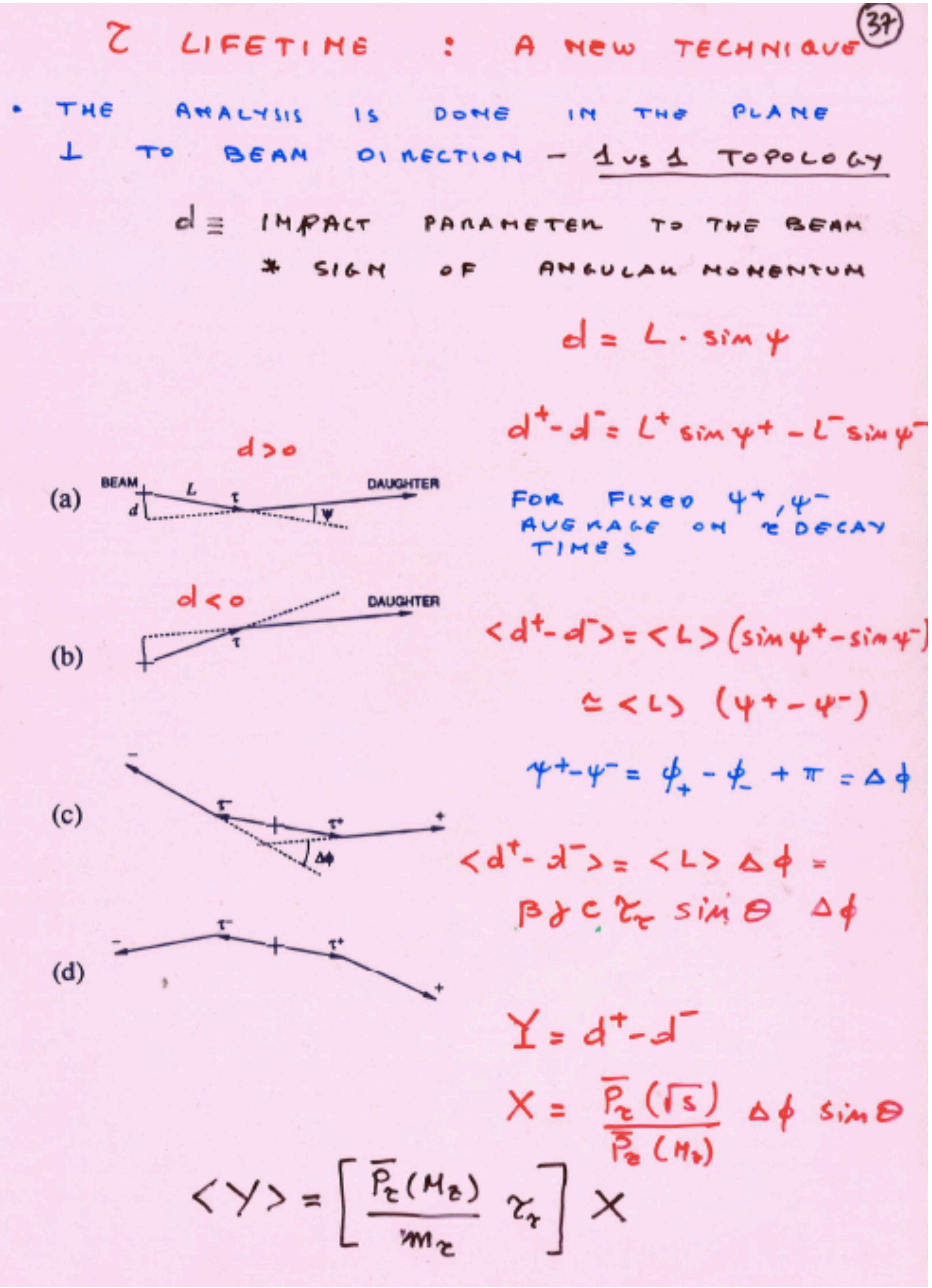


.... the τ lifetime. At Z energies, the produced τ's travel on average 3 mm in the LEP beam pipe before decaying, so measuring accurately their decay path is a real challenge. It was beautifully met thanks to the precise vertex detector..........



$|\Sigma\, d_\circ|$ on $Z \to \tau^+\tau^-$





τ LIFETIME : A NEW TECHNIQUE ㊲

- THE ANALYSIS IS DONE IN THE PLANE ⊥ TO BEAN DIRECTION – 1 vs 1 TOPOLOGY

d ≡ IMPACT PARAMETER TO THE BEAM
* SIGN OF ANGULAR MOMENTUM

$$d = L \cdot \sin\psi$$

$$d^+ - d^- = L^+ \sin\psi^+ - L^- \sin\psi^-$$

FOR FIXED ψ^+, ψ^- AVERAGE ON τ DECAY TIMES

$$\langle d^+ - d^- \rangle = \langle L \rangle (\sin\psi^+ - \sin\psi^-)$$

$$\simeq \langle L \rangle \; (\psi^+ - \psi^-)$$

$$\psi^+ - \psi^- = \phi_+ - \phi_- + \pi = \Delta\phi$$

$$\langle d^+ - d^- \rangle = \langle L \rangle \, \Delta\phi =$$

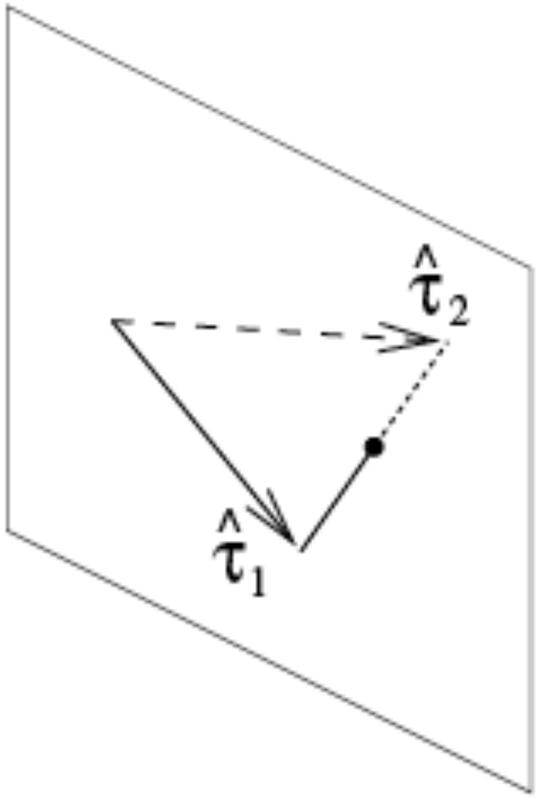
$$\beta\gamma c\, \tau_\tau \sin\theta \;\; \Delta\phi$$

$$Y = d^+ - d^-$$

$$X = \frac{\bar{P}_\tau(\sqrt{s})}{\bar{P}_\tau(M_z)} \, \Delta\phi \, \sin\theta$$

$$\langle Y \rangle = \left[\frac{\bar{P}_\tau(M_z)}{m_\tau} \, \tau_\tau \right] X$$

......breakthrough came from Inkyu Park and Anne-Marie Lutz who developed the completely new and most powerful 3D impact-parameter method.



In events where both tau decay to hadrons , the common direction of the τ+ and τ- can be measured up to a two fold ambiguity.

The event is projected along the direction given by difference between these two directions

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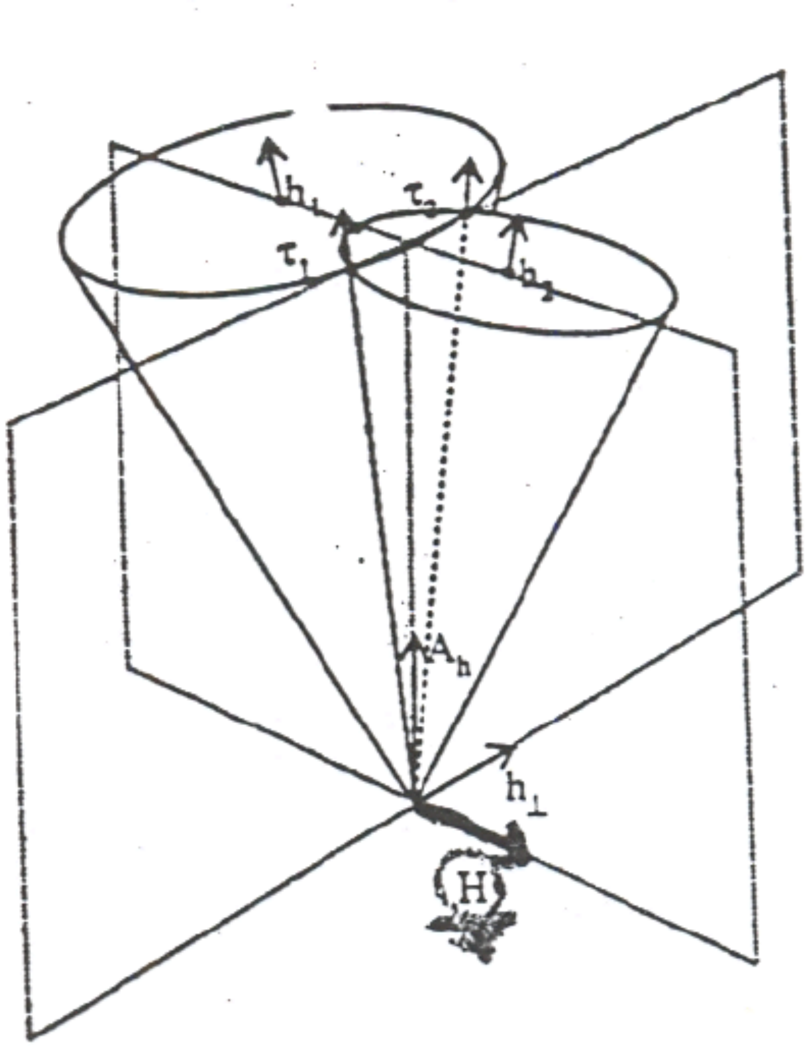

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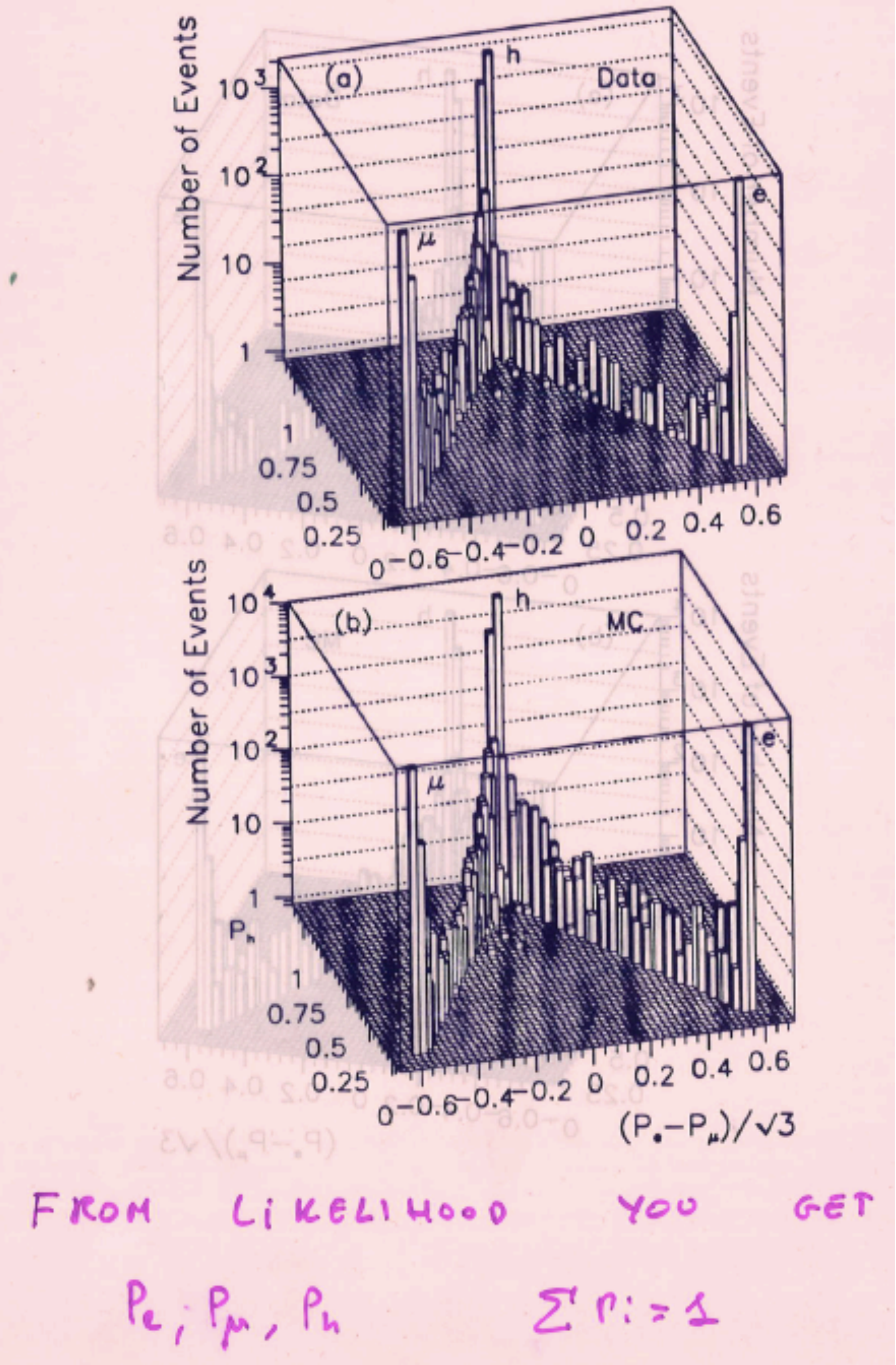
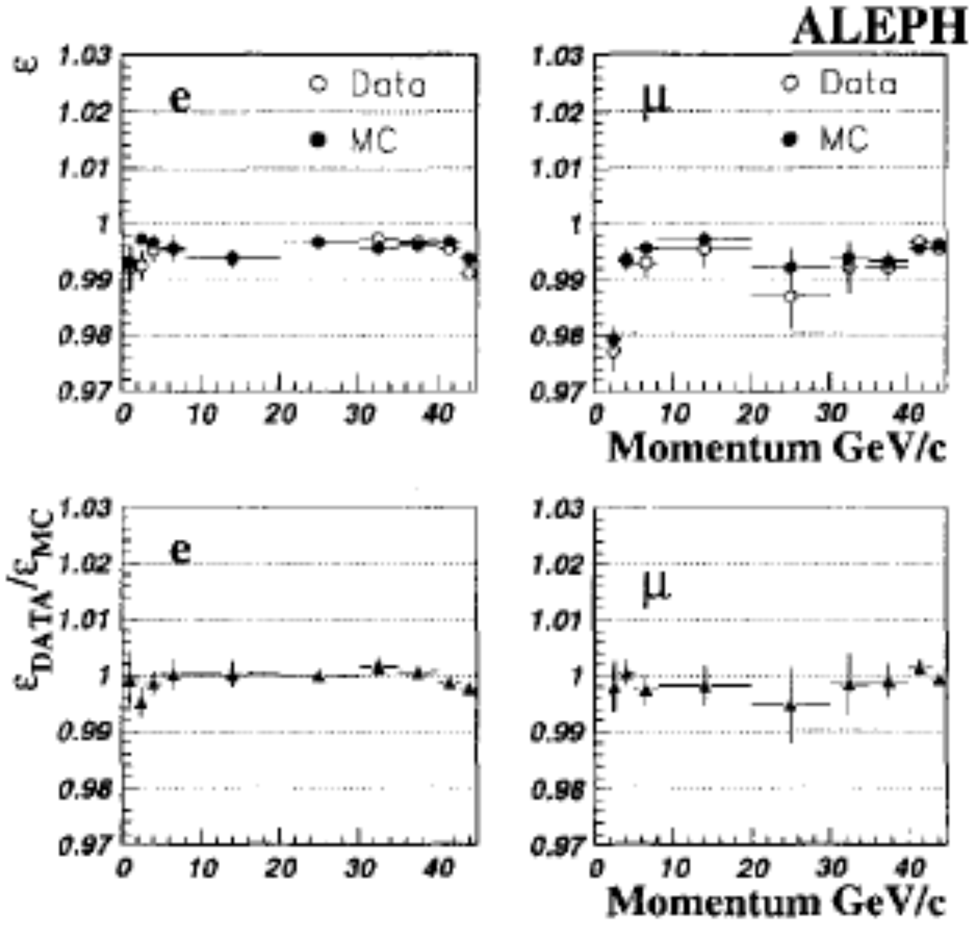
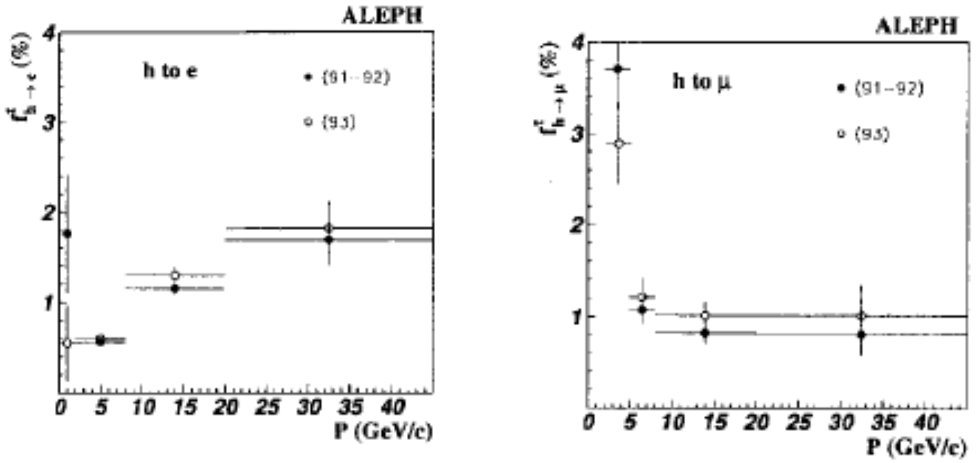
….. Particle identification was crucial for the understanding of τ decays in order to separate electrons, muons and hadrons. At the beginning, most people were using cuts, but a likelihood method TAUPID was soon developed by Zhiqing Zhang and Michel which proved so superior that everyone adopted the method……..



FROM LIKELIHOOD YOU GET

P_e, P_μ, P_h $\Sigma P_i = 1$

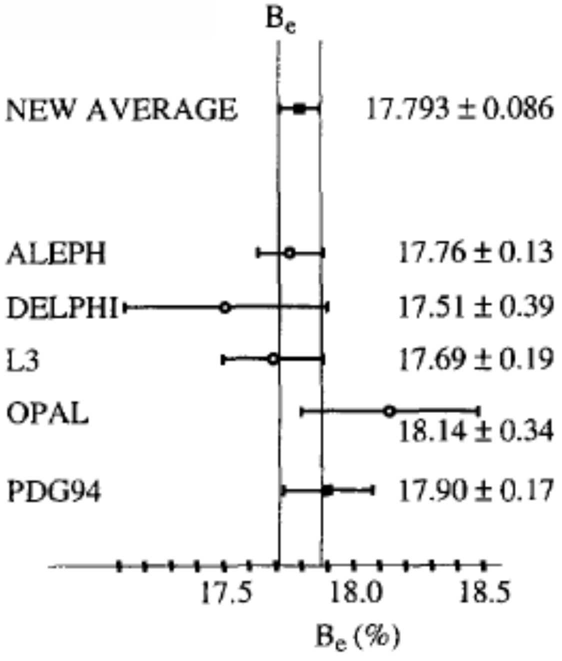


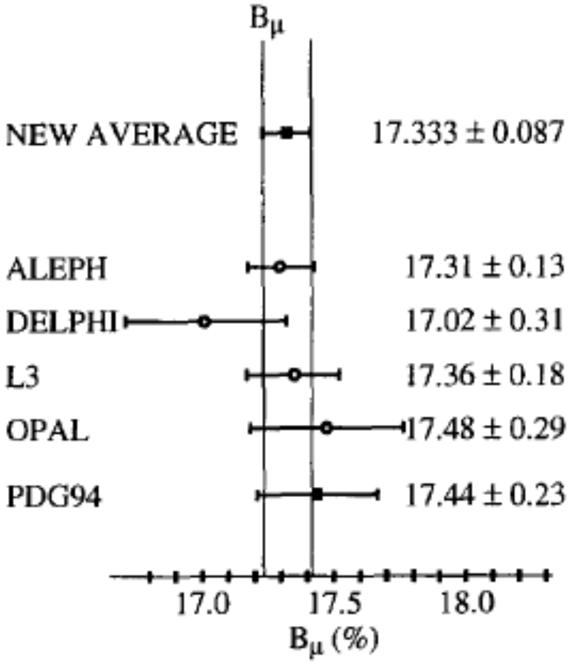


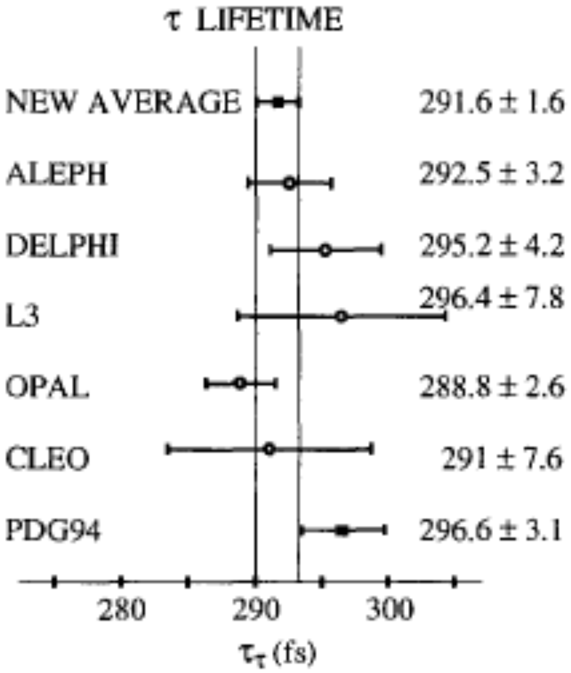
Michel, Montreux

Lepton Universality of the charged current

Michel, Montreux







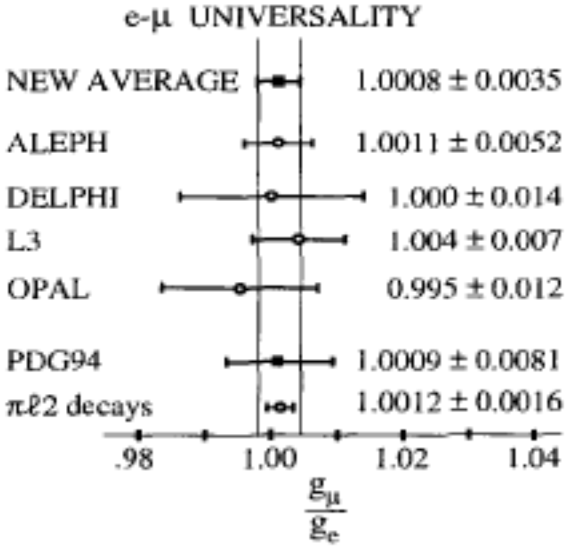


Figure 11. Test of $e - \mu$ universality in leptonic τ decays.

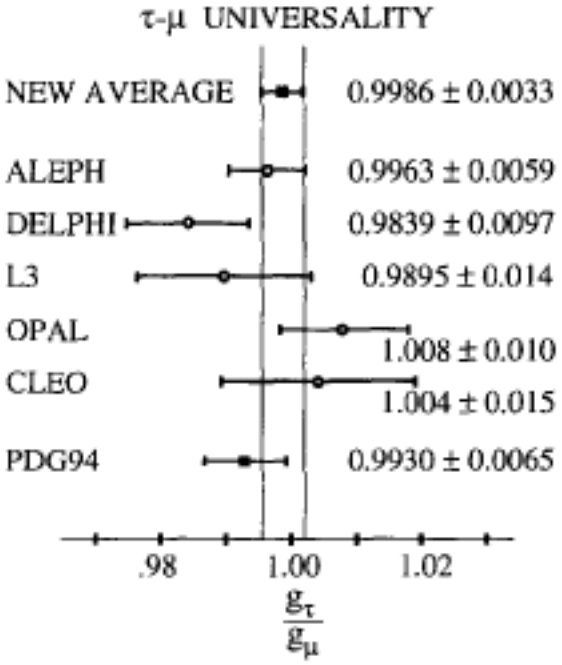
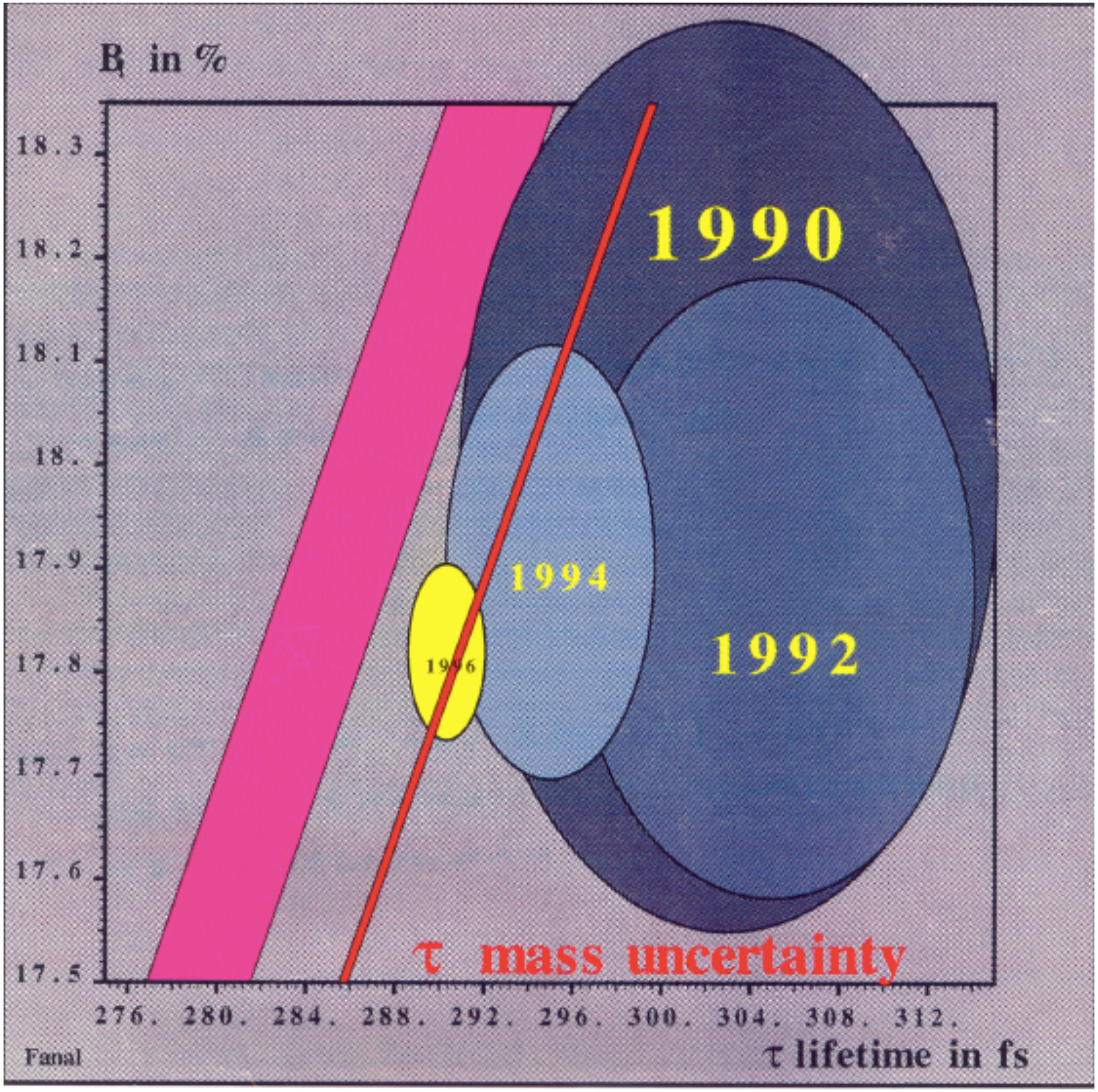
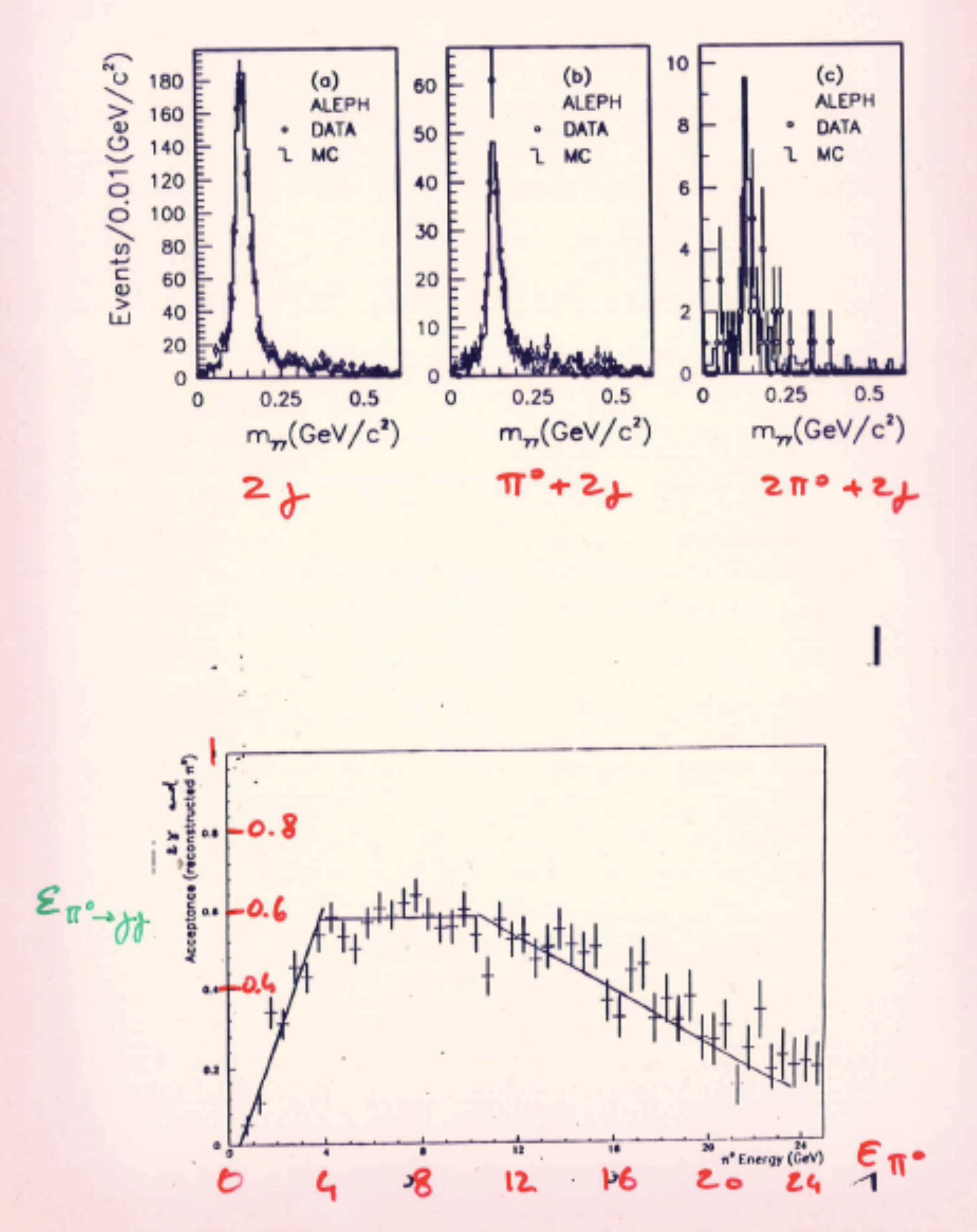


Figure 12. Test of $\mu - \tau$ universality with τ lifetime and leptonic branching ratios.

Universality

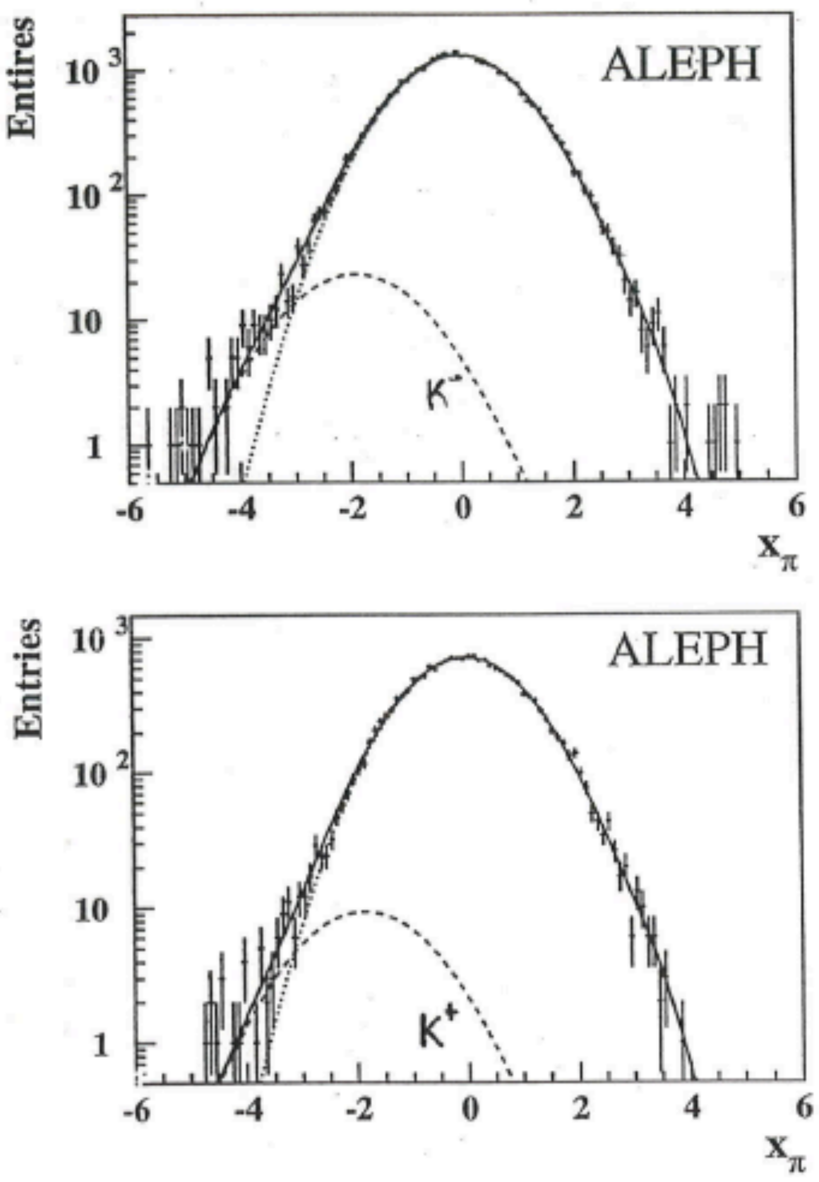


The exploitation of the excellent properties of the detector was made possible by a first-class software environment........... the next most important piece was photon and $\pi0$ reconstruction in the situation where clusters overlap in ECAL, which was beautifully handled with the GAMPEC package, written by André Rougé, Jean-Claude Brient and Marc Verderi...........



.... Other useful developments occurred for pion/kaon separation using dE/dx in the TPC and K0L reconstruction in the ECAL-HCAL (Hyongjong Park and Michel)........

$\rho = \rho(x_\pi)$



$3h^-$

SAME SIGN "K"

$3h^-$

OPPOSITE SIGN "K"

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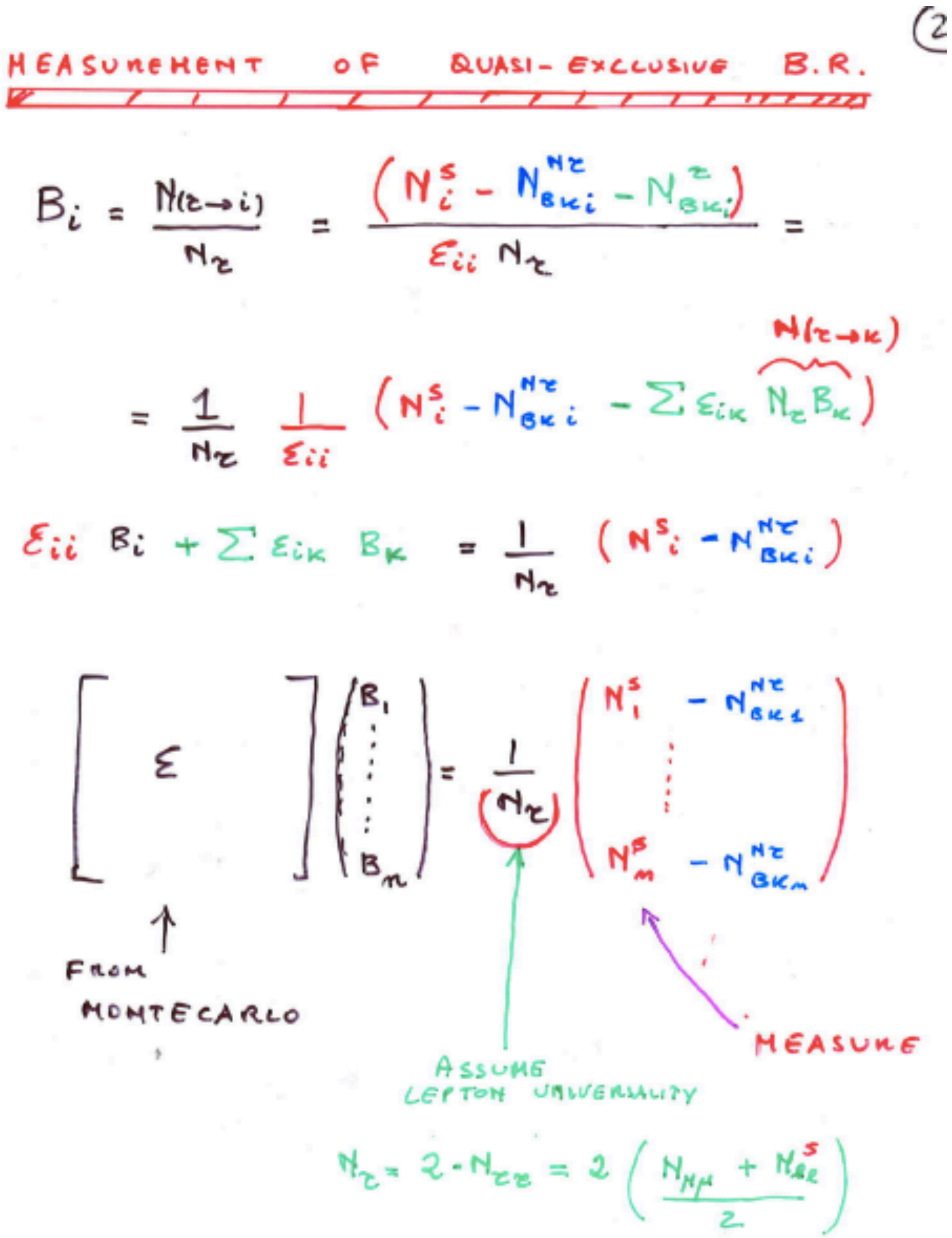


(2

MEASUREMENT OF QUASI-EXCLUSIVE B.R.

$$B_i = \frac{N(\tau \to i)}{N_\tau} = \frac{\left(N_i^S - N_{BKi}^{N\tau} - N_{BKi}^{\tau}\right)}{\varepsilon_{ii} N_\tau} =$$

$$= \frac{1}{N_\tau} \frac{1}{\varepsilon_{ii}} \left(N_i^S - N_{BKi}^{N\tau} - \sum \varepsilon_{iK} \overbrace{N_\tau B_K}^{N(\tau \to K)}\right)$$

$$\varepsilon_{ii} B_i + \sum \varepsilon_{iK} B_K = \frac{1}{N_\tau} \left(N_i^S - N_{BKi}^{N\tau}\right)$$

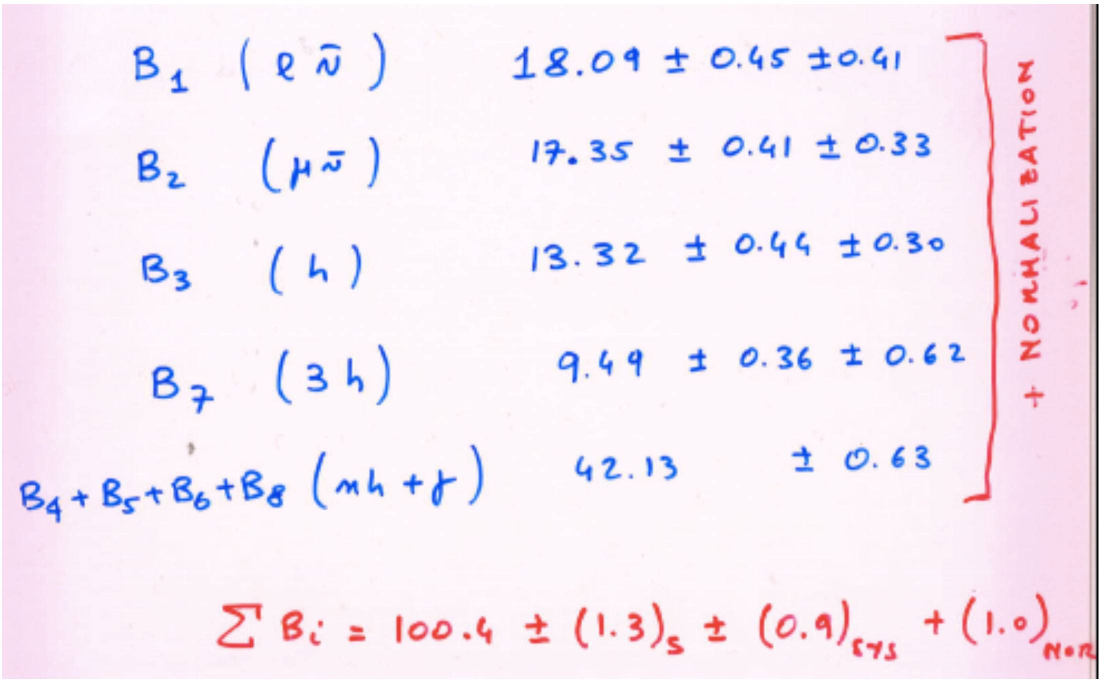
$$\Big[\quad \varepsilon \quad \Big] \begin{pmatrix} B_1 \\ \vdots \\ B_n \end{pmatrix} = \frac{1}{N_\tau} \begin{pmatrix} N_1^S - N_{BK1}^{N\tau} \\ \vdots \\ N_m^S - N_{BKm}^{N\tau} \end{pmatrix}$$

FROM MONTECARLO

ASSUME LEPTON UNIVERSALITY

MEASURE

$$N_\tau = 2 \cdot N_{\tau\tau} = 2 \left(\frac{N_{\mu\mu} + N_{ee}^S}{2}\right)$$



B_1 $(e\bar{\nu})$	$18.09 \pm 0.45 \pm 0.41$
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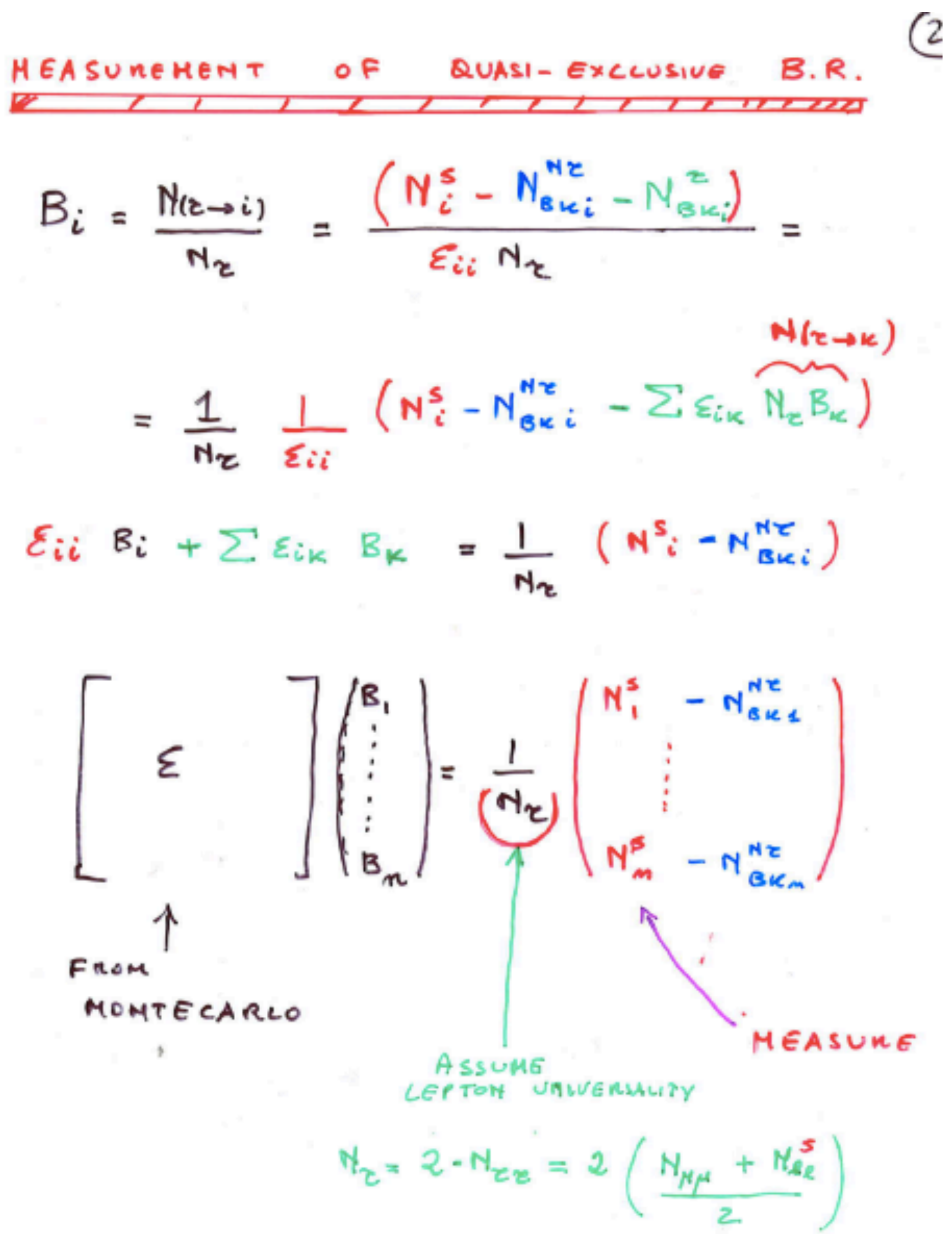
B_3 (h)	$13.32 \pm 0.44 \pm 0.30$
B_7 $(3h)$	$9.49 \pm 0.36 \pm 0.62$
$B_4+B_5+B_6+B_8$ $(nh+\gamma)$	42.13 ± 0.63

+ NORMALISATION

$$\sum B_i = 100.4 \pm (1.3)_S \pm (0.9)_{SYS} + (1.0)_{NOR}$$

…… We developed a global method to measure all the decay channels simultaneously, profiting from our pure and unbiased τ sample........



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↑ FROM MONTECARLO

ASSUME LEPTON UNIVERSALITY

MEASURE

$$N_\tau = 2\cdot N_{\tau\tau} = 2\left(\frac{N_{\mu\mu} + N_{ee}^S}{2}\right)$$

SCHAEL 2005C (PRPLC,421,191)

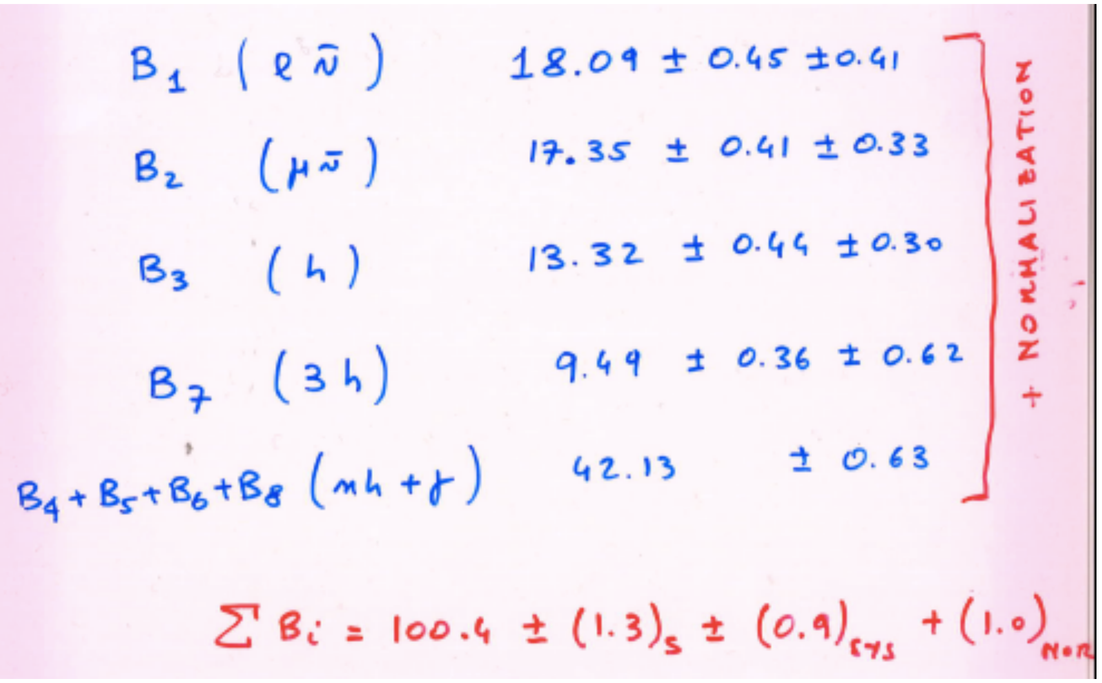
Physics Reports (Physics Letters C) **421** (2005) 191

SCHAEL 2005C **Branching Ratios and Spectral Functions of τ Decays: Final ALEPH Measurements and Physics Implications**

S. Schael ... **ALEPH Collab.**

	Measurement		(Unit)	Particle (Section)	Observable	
used	17.319 ± 0.070 ± 0.032	f&a	(%)	τ	$\Gamma(\mu^- \bar{\nu}_\mu \nu_\tau)/\Gamma_{total}$	1
used	17.837 ± 0.072 ± 0.036		(%)	τ	$\Gamma(e^- \bar{\nu}_e \nu_\tau)/\Gamma_{total}$	2
used	10.828 ± 0.070 ± 0.078	f&a	(%)	τ	$\Gamma(\pi^- \nu_\tau)/\Gamma_{total}$	3
used	25.471 ± 0.097 ± 0.085	f&a	(%)	τ	$\Gamma(\pi^- \pi^0 \nu_\tau)/\Gamma_{total}$	4
used	9.239 ± 0.086 ± 0.090	f&a	(%)	τ	$\Gamma(\pi^- 2\pi^0 \nu_\tau (\text{ex.}K^0))/\Gamma_{total}$	5
used	0.977 ± 0.069 ± 0.058		(%)	τ	$\Gamma(\pi^- 3\pi^0 \nu_\tau (\text{ex.}K^0))/\Gamma_{total}$	6
used	0.112 ± 0.037 ± 0.035		(%)	τ	$\Gamma(h^- 4\pi^0 \nu_\tau (\text{ex.}K^0,\eta))/\Gamma_{total}$	7
used	14.652 ± 0.067 ± 0.086	avg	(%)	τ	$\Gamma(h^- h^- h^+ \geq 0$ neutrals ν_τ (ex. $K_S^0 \to \pi^+ \pi^-$) (``3-prong") $)/\Gamma_{total}$	
used	9.041 ± 0.060 ± 0.076		(%)	τ	$\Gamma(\pi^- \pi^+ \pi^- \nu_\tau (\text{ex.}K^0,\omega))/\Gamma_{total}$	8
used	4.598 ± 0.057 ± 0.064		(%)	τ	$\Gamma(\pi^- \pi^+ \pi^- \pi^0 \nu_\tau (\text{ex.}K^0))/\Gamma_{total}$	9
used	0.435 ± 0.030 ± 0.035		(%)	τ	$\Gamma(h^- h^- h^+ 2\pi^0 \nu_\tau (\text{ex.}K^0))/\Gamma_{total}$	10
not used	< 4.9		(10^{-4})	τ	$\Gamma(h^- h^- h^+ 3\pi^0 \nu_\tau)/\Gamma_{total}$	
used	0.093 ± 0.009 ± 0.012	avg	(%)	τ	$\Gamma(3h^- 2h^+ \geq 0$ neutrals ν_τ (ex. $K_S^0 \to \pi^- \pi^+$) (``5-prong") $)/\Gamma_{total}$	
used	7.2 ± 0.9 ± 1.2		(10^{-4})	τ	$\Gamma(3h^- 2h^+ \nu_\tau (\text{ex.}K^0))/\Gamma_{total}$	11
used	2.1 ± 0.7 ± 0.9		(10^{-4})	τ	$\Gamma(3h^- 2h^+ \pi^0 \nu_\tau (\text{ex.}K^0))/\Gamma_{total}$	12
used	775.5 ± 0.7		(MeV)	ρ(770)	CHARGED ONLY, τ DECAYS and $e^+ e^-$	13,12
used	− 2.4 ± 0.8		(MeV)	ρ(770)	$m_{\rho(770)^0} - m_{\rho(770)^\pm}$	14
used	149.0 ± 1.2		(MeV)	ρ(770)	CHARGED ONLY, τ DECAYS and $e^+ e^-$	15,14
used	− 0.2 ± 1.0			ρ(770)	$\Gamma_{\rho(770)^0} - \Gamma_{\rho(770)^\pm}$	16
not used	1328 ± 15		(MeV)	ρ(1450)	$\pi\pi$ MODE	17
not used	468 ± 41		(MeV)	ρ(1450)	$\pi\pi$ MODE	18

Aleph measurements dominate the world averages for all channels with branching ratios above 10^{-3}.



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$$\sum B_i = 100.4 \pm (1.3)_s \pm (0.9)_{sys} + (1.0)_{NOR}$$

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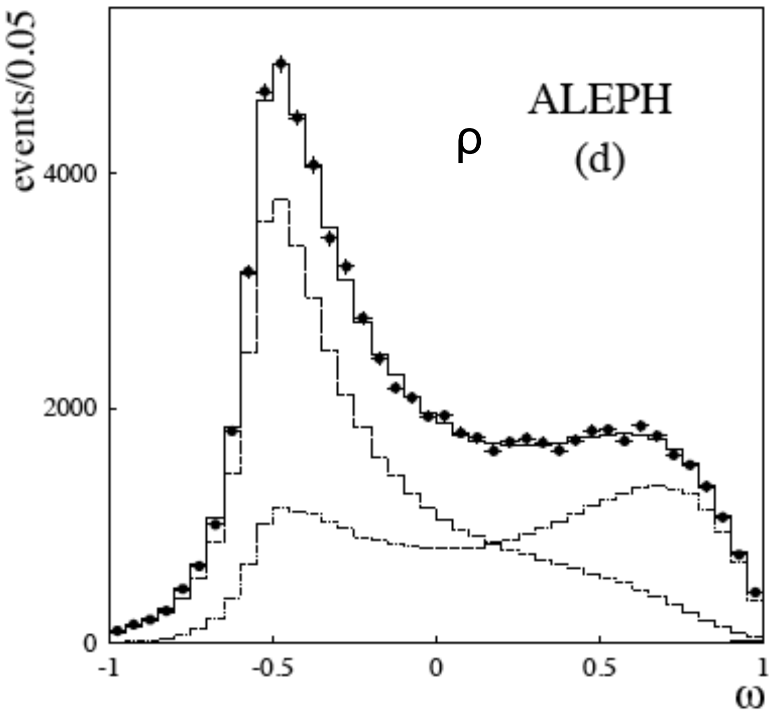

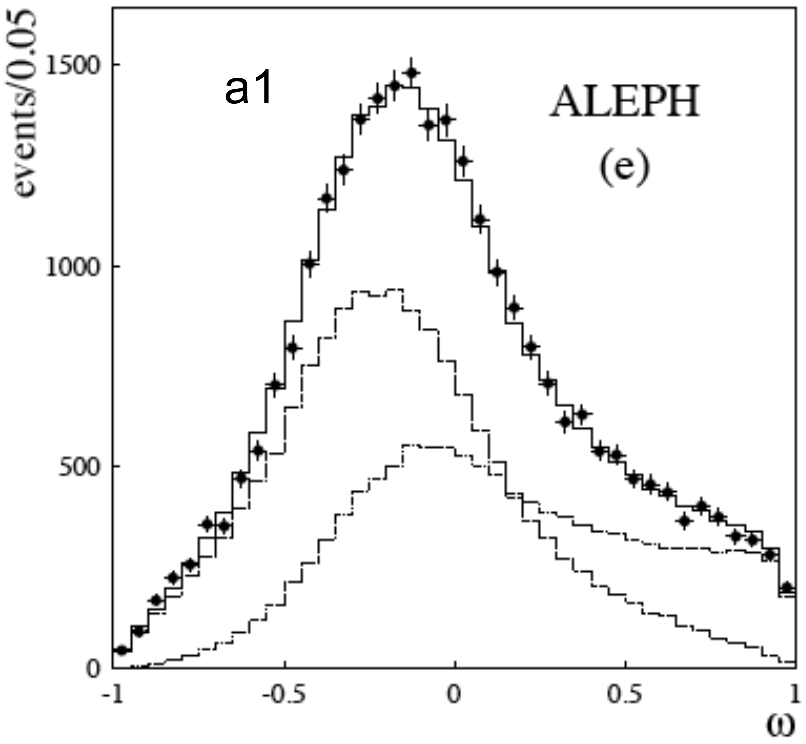

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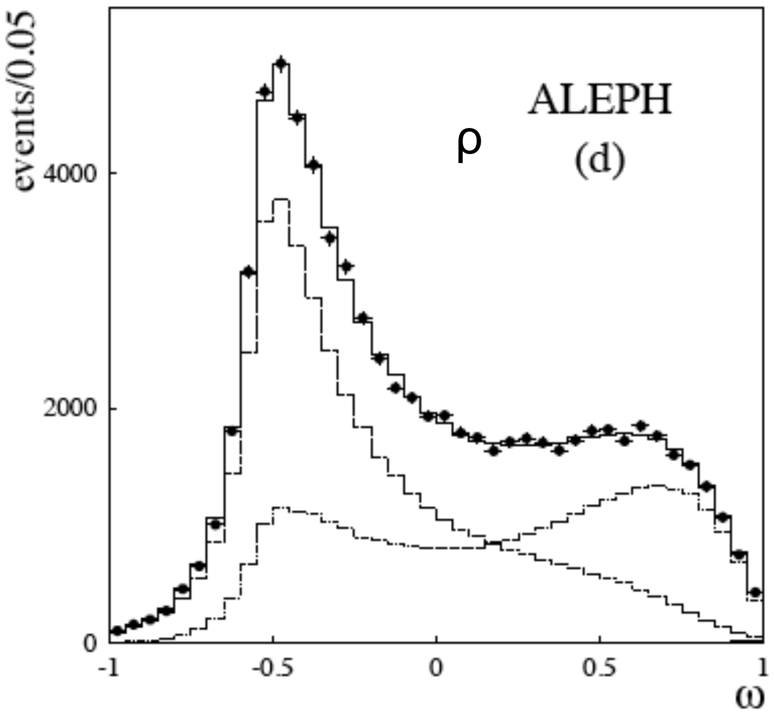
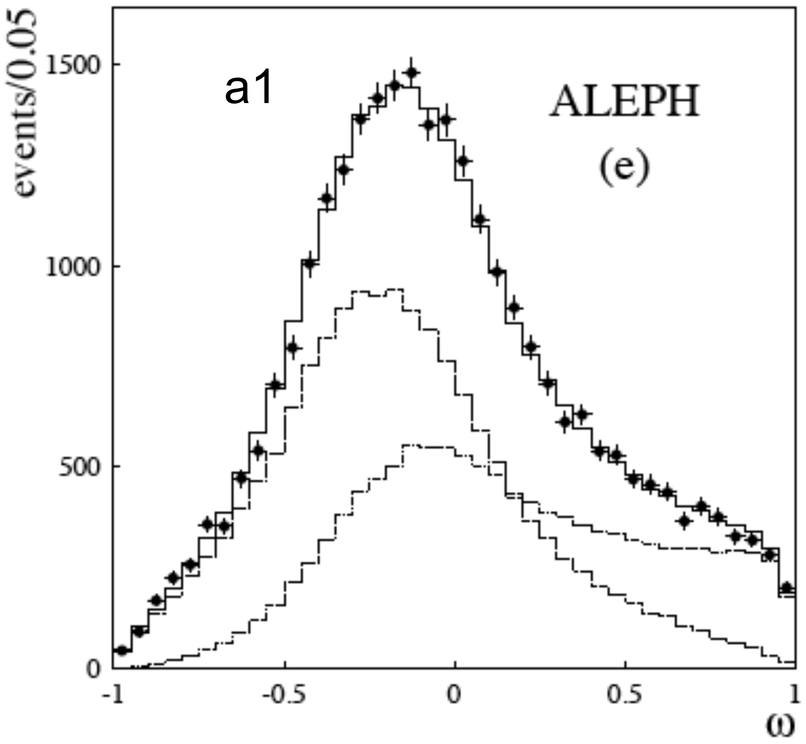
..... The final analysis with the full LEP1 data was done independently at Ecole Polytechnique by Jean- Claude Brient, André Rougé and Henri Videau, and at Orsay by Ricard Alemany, Irena Nikolic and Michel........It was not easy to converge.......

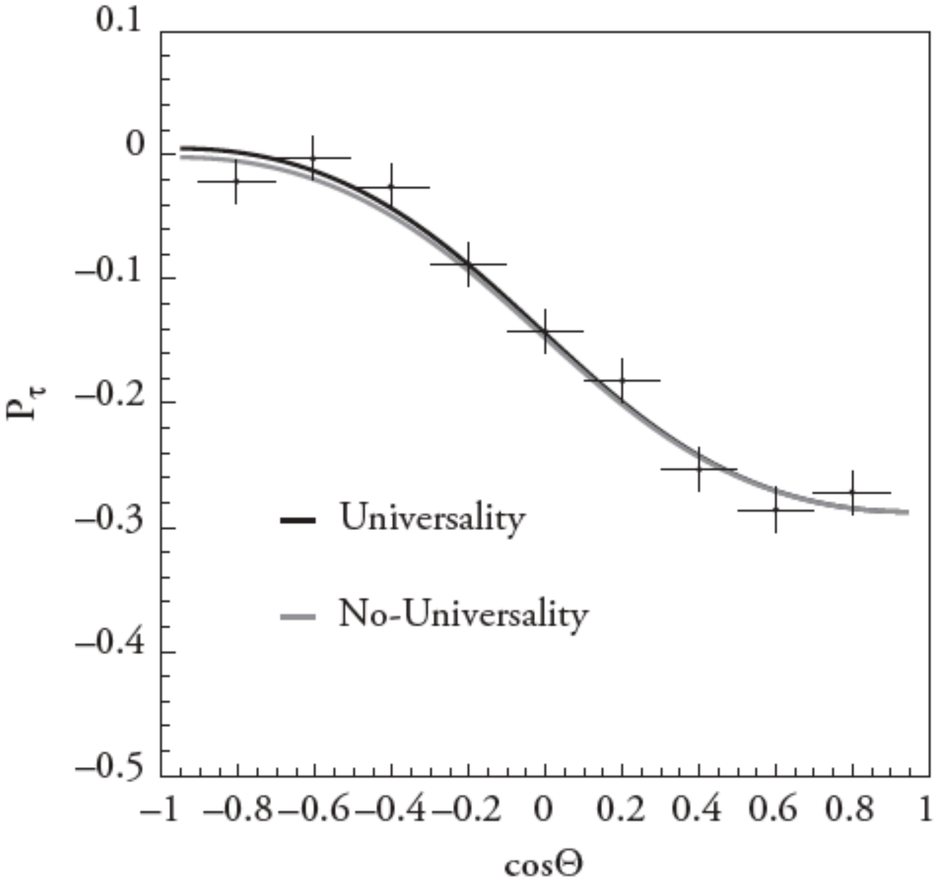


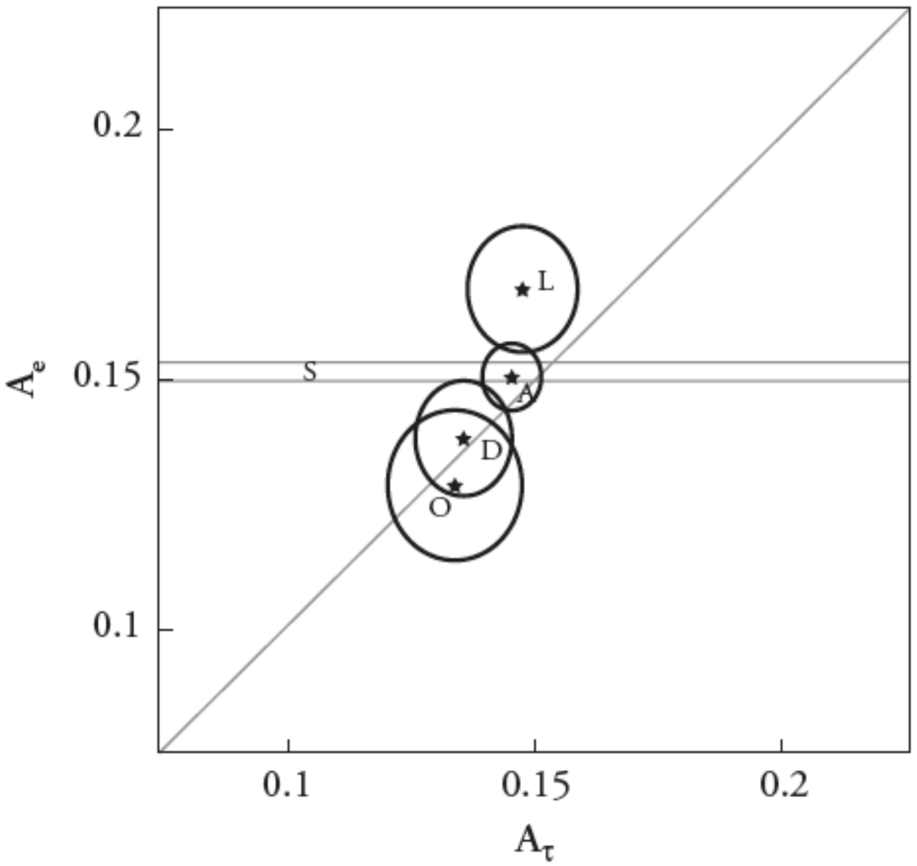


.... The fact that each produced τ rapidly decays through the parity-violating charged current allows one to measure its polarization. This is a unique measurement at LEP, analogous to the famous left– right asymmetry using polarized electrons at SLC......

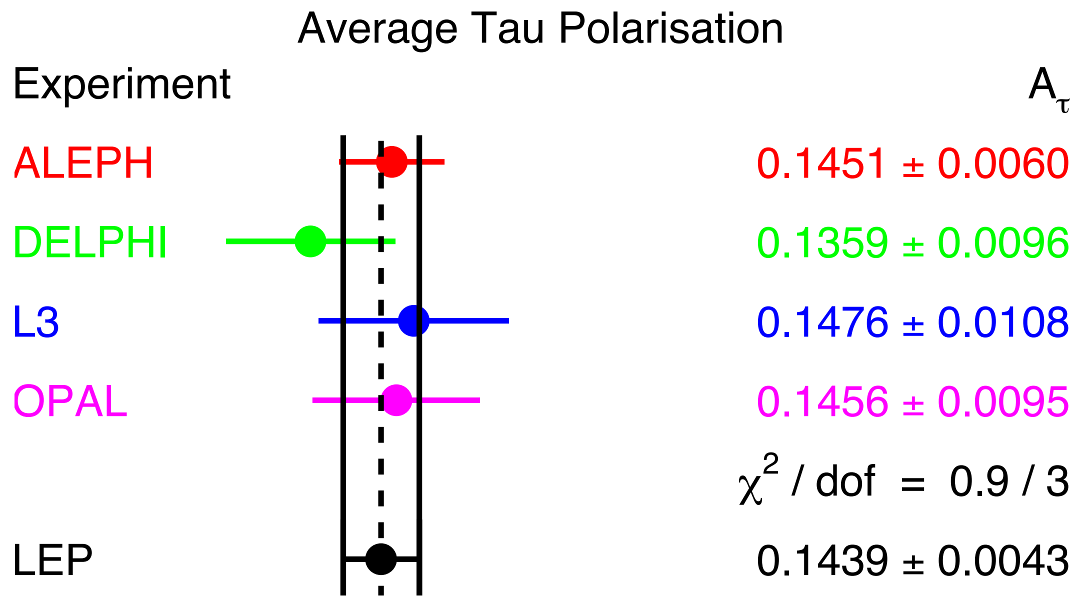
.........A real breakthrough occurred in summer 1992 in a quite unexpected way. At Orsay, we were looking for a more optimized way to handle the hadronic channels and François Le Diberder came up with a brilliant idea.....
André Rougé had got exactly the same idea and also came to the meeting with a physics note.........

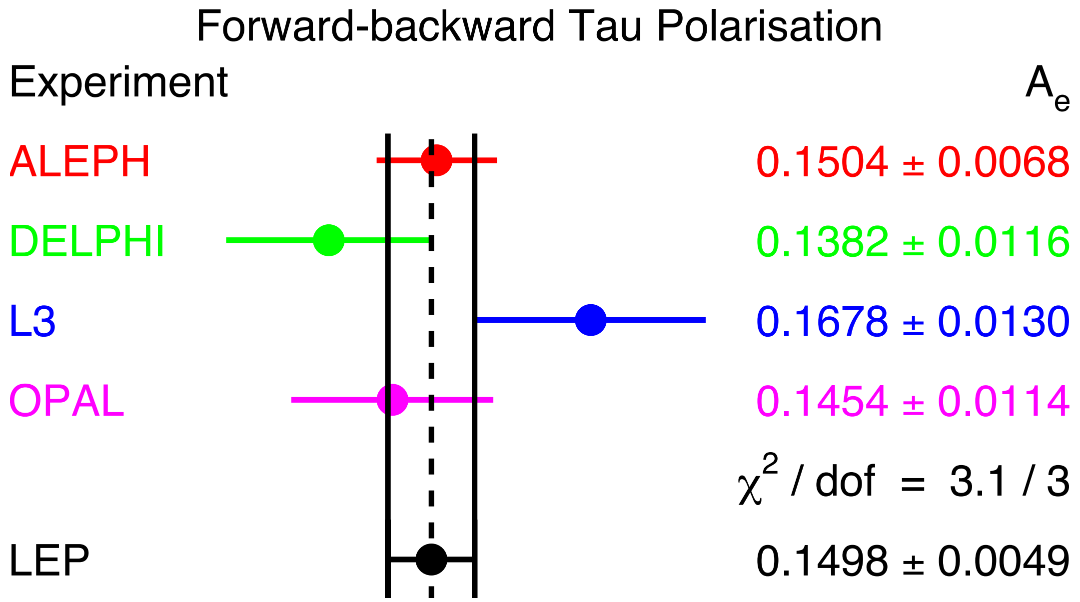
..... The final analysis with the full LEP1 data was done independently at Ecole Polytechnique by Jean- Claude Brient, André Rougé and Henri Videau, and at Orsay by Ricard Alemany, Irena Nikolic and Michel........It was not easy to converge.......

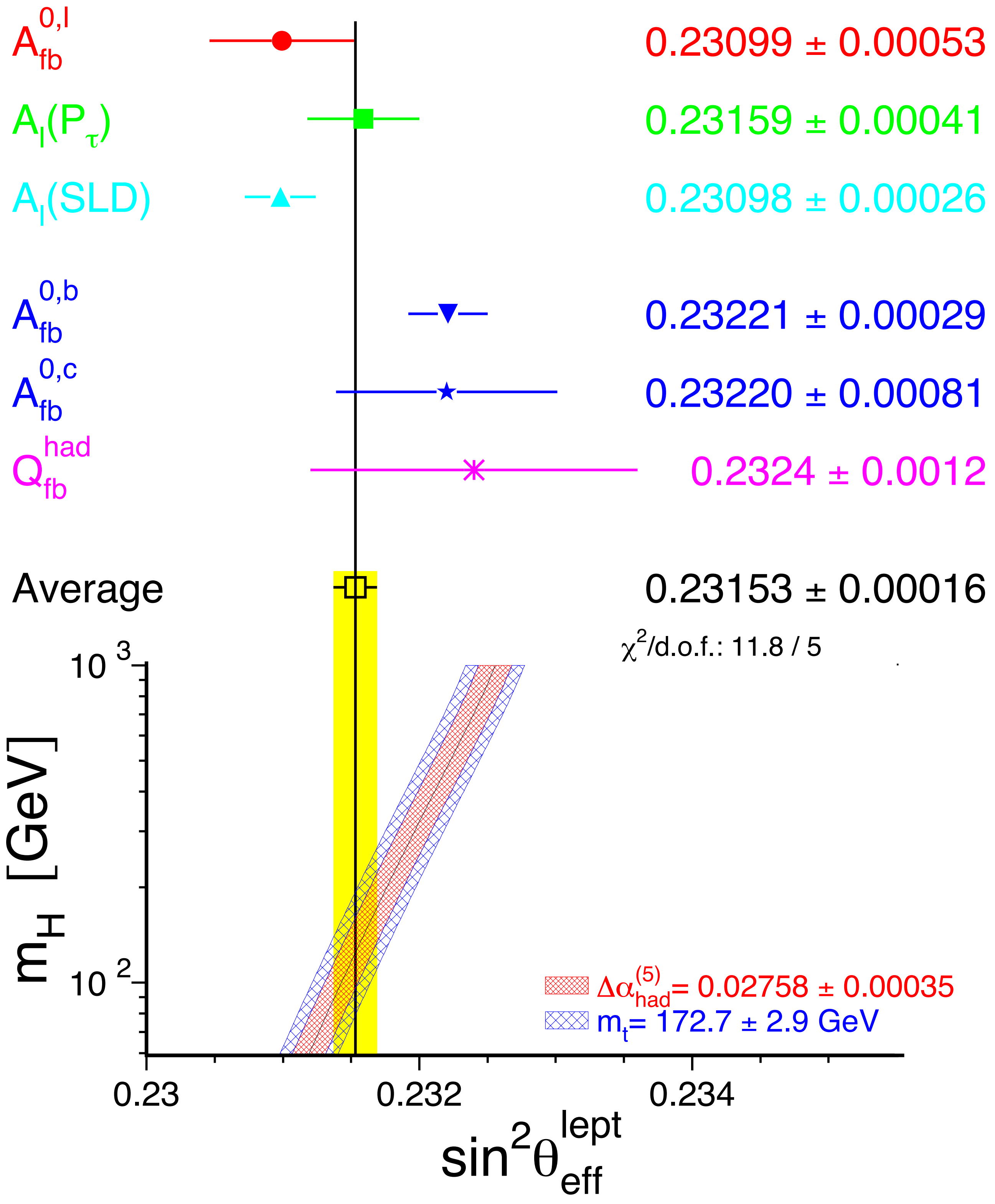




LEP Legacy


Average Tau Polarisation
Experiment
A_τ
ALEPH
0.1451 ± 0.0060
DELPHI
0.1359 ± 0.0096
L3
0.1476 ± 0.0108
OPAL
0.1456 ± 0.0095
χ^2 / dof = 0.9 / 3
LEP
0.1439 ± 0.0043


Forward-backward Tau Polarisation
Experiment
A_e
ALEPH
0.1504 ± 0.0068
DELPHI
0.1382 ± 0.0116
L3
0.1678 ± 0.0130
OPAL
0.1454 ± 0.0114
χ^2 / dof = 3.1 / 3
LEP
0.1498 ± 0.0049

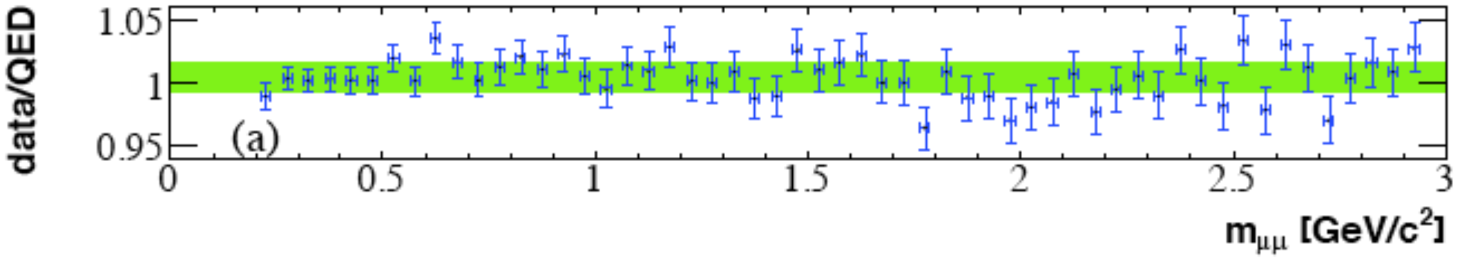

$A_{fb}^{0,l}$
0.23099 ± 0.00053
$A_l(P_\tau)$
0.23159 ± 0.00041
A_l(SLD)
0.23098 ± 0.00026
$A_{fb}^{0,b}$
0.23221 ± 0.00029
$A_{fb}^{0,c}$
0.23220 ± 0.00081
Q_{fb}^{had}
0.2324 ± 0.0012
Average
0.23153 ± 0.00016
χ^2/d.o.f.: 11.8 / 5
10^3
10^2
m_H [GeV]
$\Delta\alpha_{had}^{(5)}$= 0.02758 ± 0.00035
m_t= 172.7 ± 2.9 GeV
0.23
0.232
0.234
$\sin^2\theta_{eff}^{lept}$

Precise Measurement of the e+e- --> π+π- (γ) Cross Section with the Initial State Radiation Method at BABAR

Two measurements : e+e- --> π+π- (γ)
e+e- --> μ+μ- (γ)

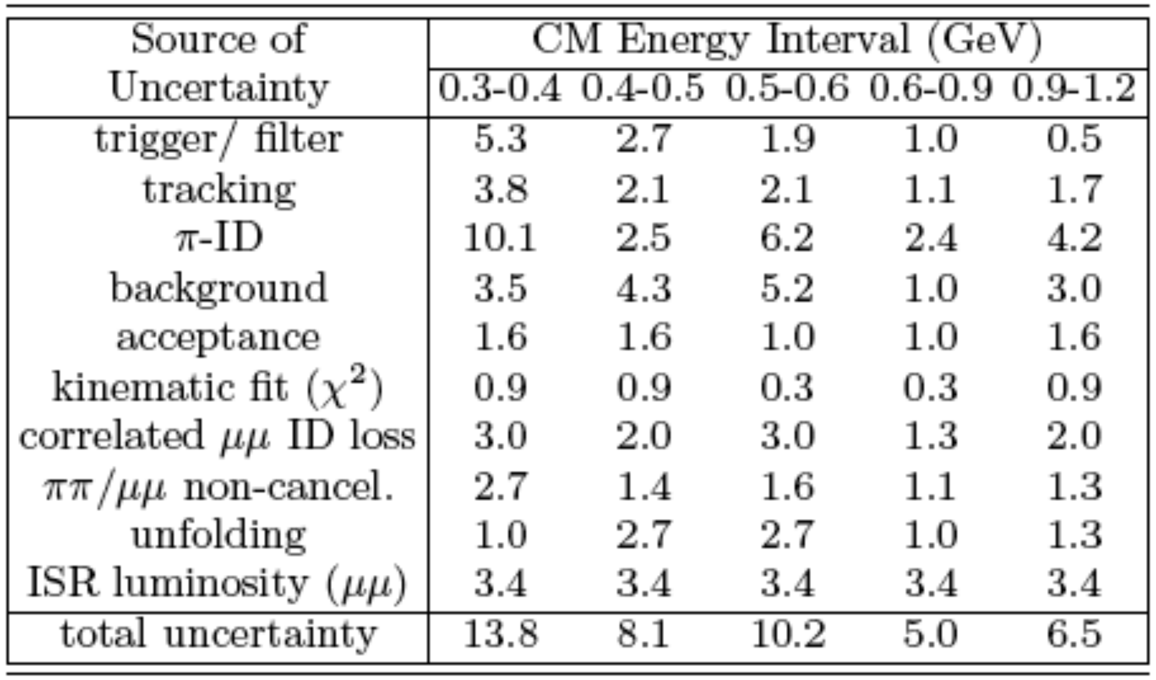
as a function of the c.o.m. energy after ISR √s'

$$\frac{\sigma^{data}_{\mu\mu\gamma(\gamma)}}{\sigma^{NLO\ QED}_{\mu\mu\gamma(\gamma)}} - 1 = (40 \pm 20 \pm 55 \pm 94) \times 10^{-4}$$

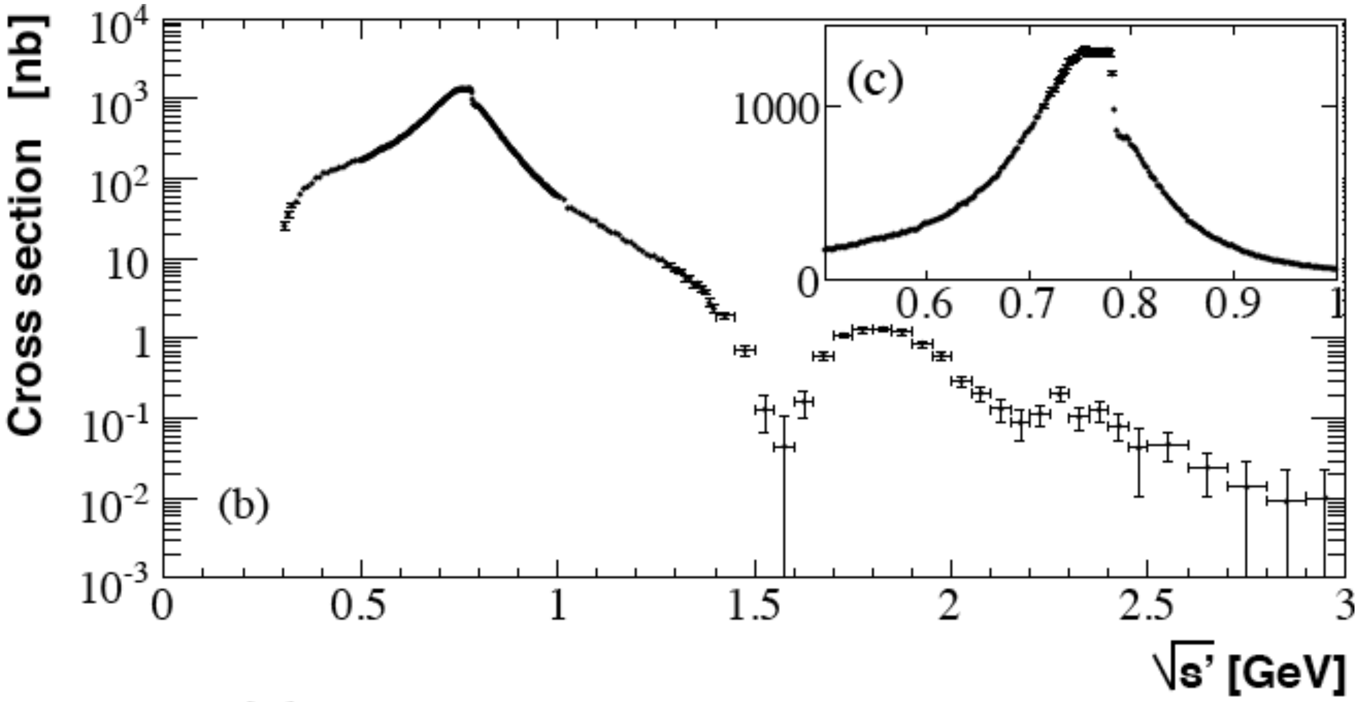


using the ratio of the two processes

x 10^{-3}



Source of Uncertainty	CM Energy Interval (GeV)				
	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.9	0.9-1.2
trigger/ filter	5.3	2.7	1.9	1.0	0.5
tracking	3.8	2.1	2.1	1.1	1.7
π-ID	10.1	2.5	6.2	2.4	4.2
background	3.5	4.3	5.2	1.0	3.0
acceptance	1.6	1.6	1.0	1.0	1.6
kinematic fit (χ^2)	0.9	0.9	0.3	0.3	0.9
correlated $\mu\mu$ ID loss	3.0	2.0	3.0	1.3	2.0
$\pi\pi/\mu\mu$ non-cancel.	2.7	1.4	1.6	1.1	1.3
unfolding	1.0	2.7	2.7	1.0	1.3
ISR luminosity ($\mu\mu$)	3.4	3.4	3.4	3.4	3.4
total uncertainty	13.8	8.1	10.2	5.0	6.5



$a_\mu^{\pi\pi(\gamma),LO}$ = 514.1±2.2±3.1

503.5±3.5	Previous e+e- data
515.2±3.4	value from tau decays

Why was tau physics at ALEPH (LEP) so precise ?

Third Ingredient

Finally, and not the least, many talented colleagues, postdocs and students joined in this effort over a period of ten years, bringing original physics ideas and powerful analysis methods.

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Fourth Ingredient

The motivation, the physics knowledge, the talent, the example and the quest for precision of Michel Davier

Thank You Michel !