Measurement of the Tau Lepton Lifetime with the L3 Detector

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- Introduction
- The L3 detector
- Selection of $Z \to \tau^+\tau^-$ Decays
- Tracking performance
- Lifetime measurements
- Summary

Introduction

LEP1, running at the Z, provides very favourable conditions for measurement of the τ lifetime - one of the shortest accessible directly in particle physics.

The event sample is characterised by

- high efficiency and purity
- large boost of the τ $\Rightarrow$ average decay length of ~ 2.2 mm

Basic test of lepton universality for the charged current:

- put alongside τ and μ decays
- compare the coupling strength of the muon and the τ lepton to the W boson

$$(\frac{g_\tau}{g_\mu})^2 = (\frac{\tau_\mu}{\tau_\tau}) Br(\tau^- \to e^-\bar{\nu}_e\nu_\tau)(\frac{m_\mu}{m_\tau})^5 \Delta_\gamma \Delta_W$$

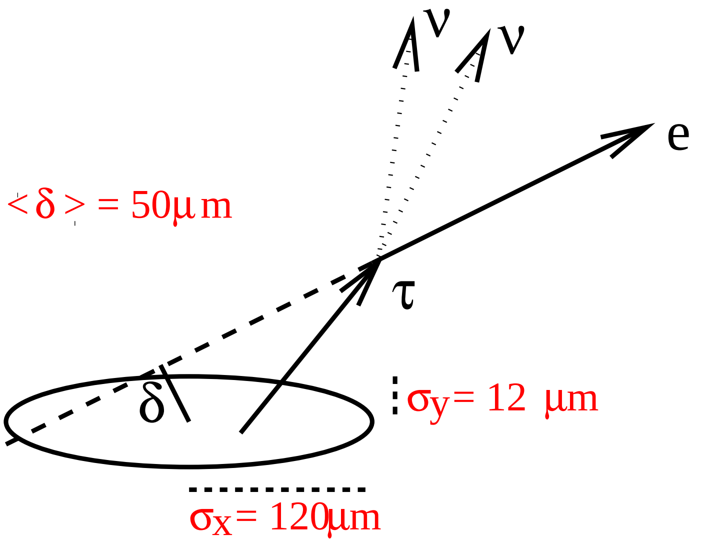
Δ_γ, Δ_W - QED and weak corrections

Needs a precise measurement of τ_τ and $Br(\tau^- \to e^-\bar{\nu}_e\nu_\tau)$ together with m_τ.

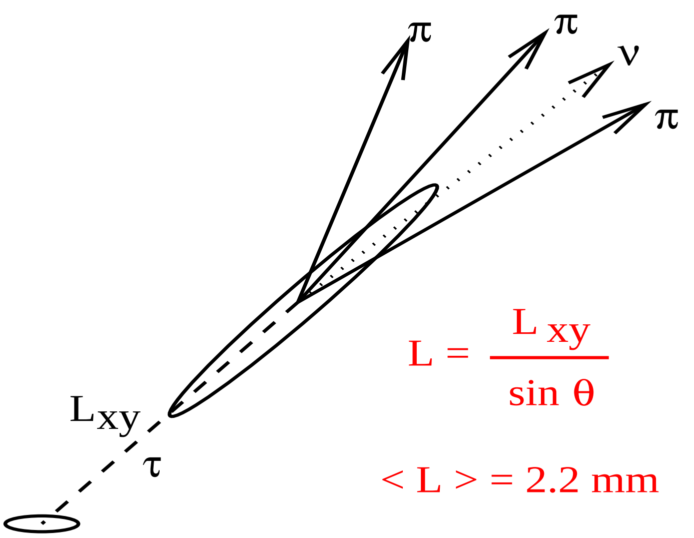
Introduction - Methods

Impact Parameter (IP) - One Prong Decays

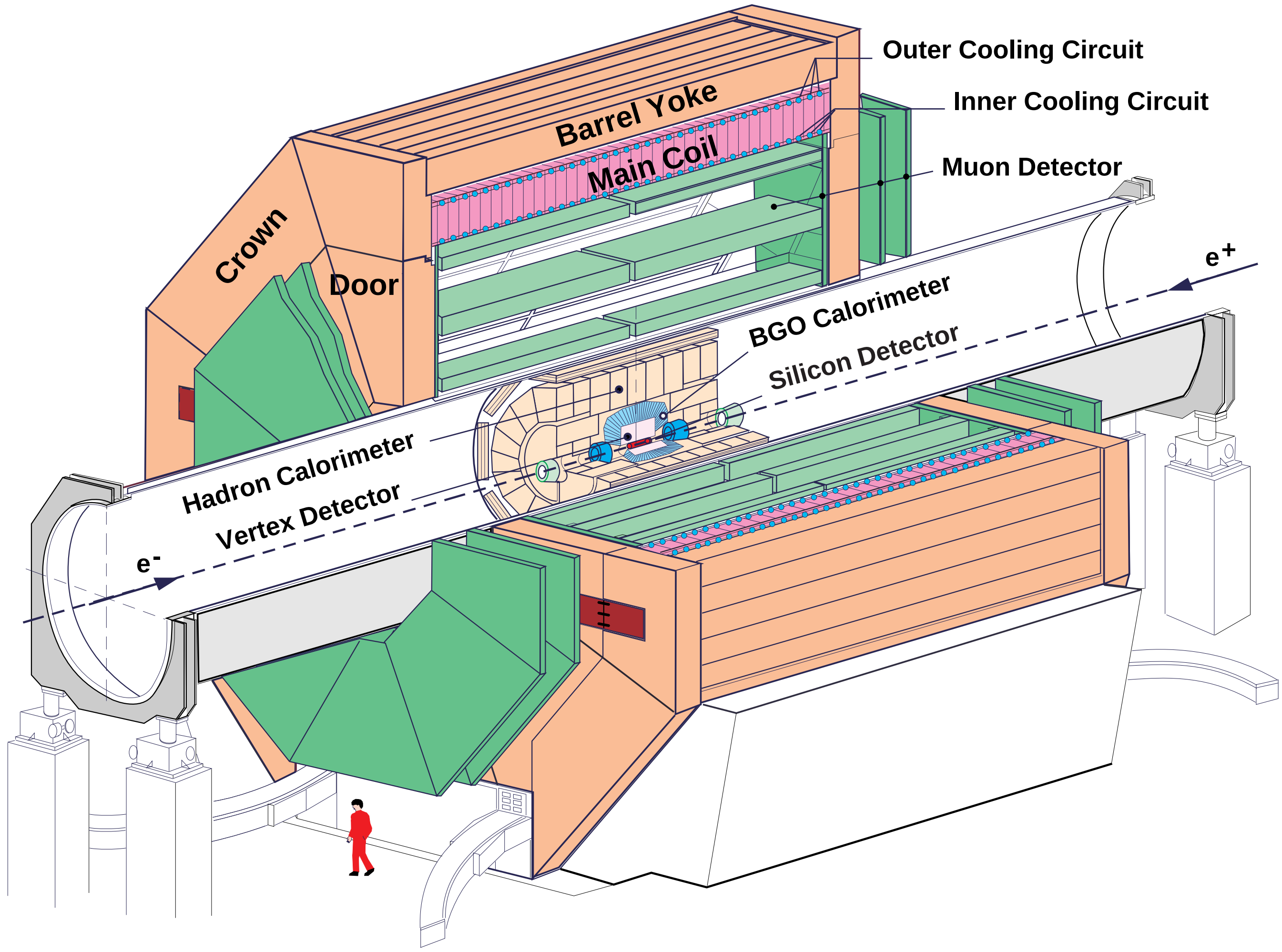
Distance of closest approach with Lifetime sign.



Decay Length (DL) - Three Prong Decays



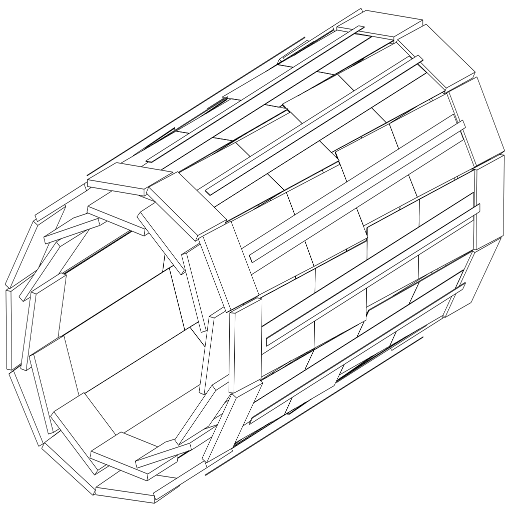
The τ flight direction is approximated by the thrust axis.

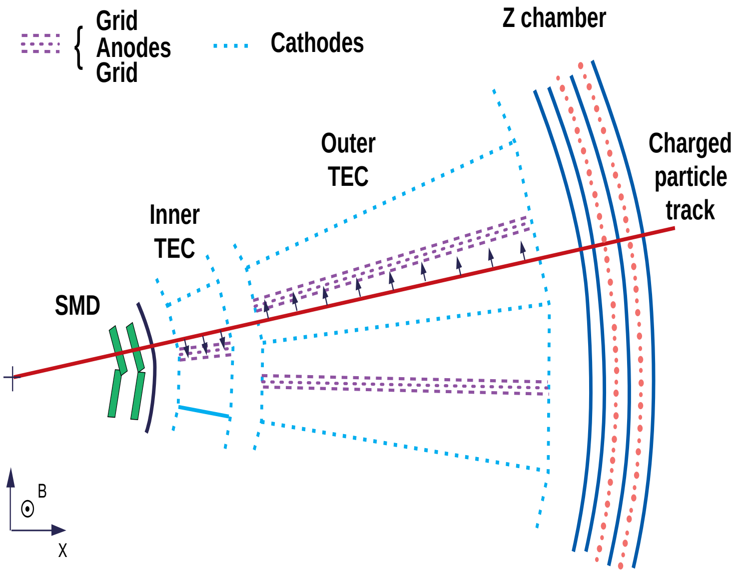


- Inner Tracker
- EM calorimeter
- Hadron Calorimeter
- Muon Spectrometer

0.5 Tesla magnetic field parallel to beam axis

- Magnetic field 0.5 Tesla
- Silicon Microstrip Detector (SMD)
  2-layers of 2-sided silicon ($r\varphi$ and Z info)
- Time Expansion Chamber (TEC)
  low speed (5.9 μm/ns) drift chamber; 62 wires





Detector	Intrinsic $r-\varphi$ Resolution	R_{in}	R_{out}
TEC	$36-80\ \mu m$	10.98 cm	42.72 cm
SMD	$8\ \mu m$	$\approx$ 6 cm	$\approx$ 8 cm

Selection of $Z \to \tau^+\tau^-$ Decays

Barrel region - $|\cos\theta_t| < 0.72$, θ_t - thrust axis

Suppression of the background:

- hadronic Z decays : select low track multiplicity ($N \leq 3$) highly collimated pairs of jets
- $e^+e^-(\gamma)$ and $\mu^+\mu^-(\gamma)$: require missing energy (e.m. energy < 75 % or μ momentum < 70 %)
- cosmic ray and two-photon - negligible

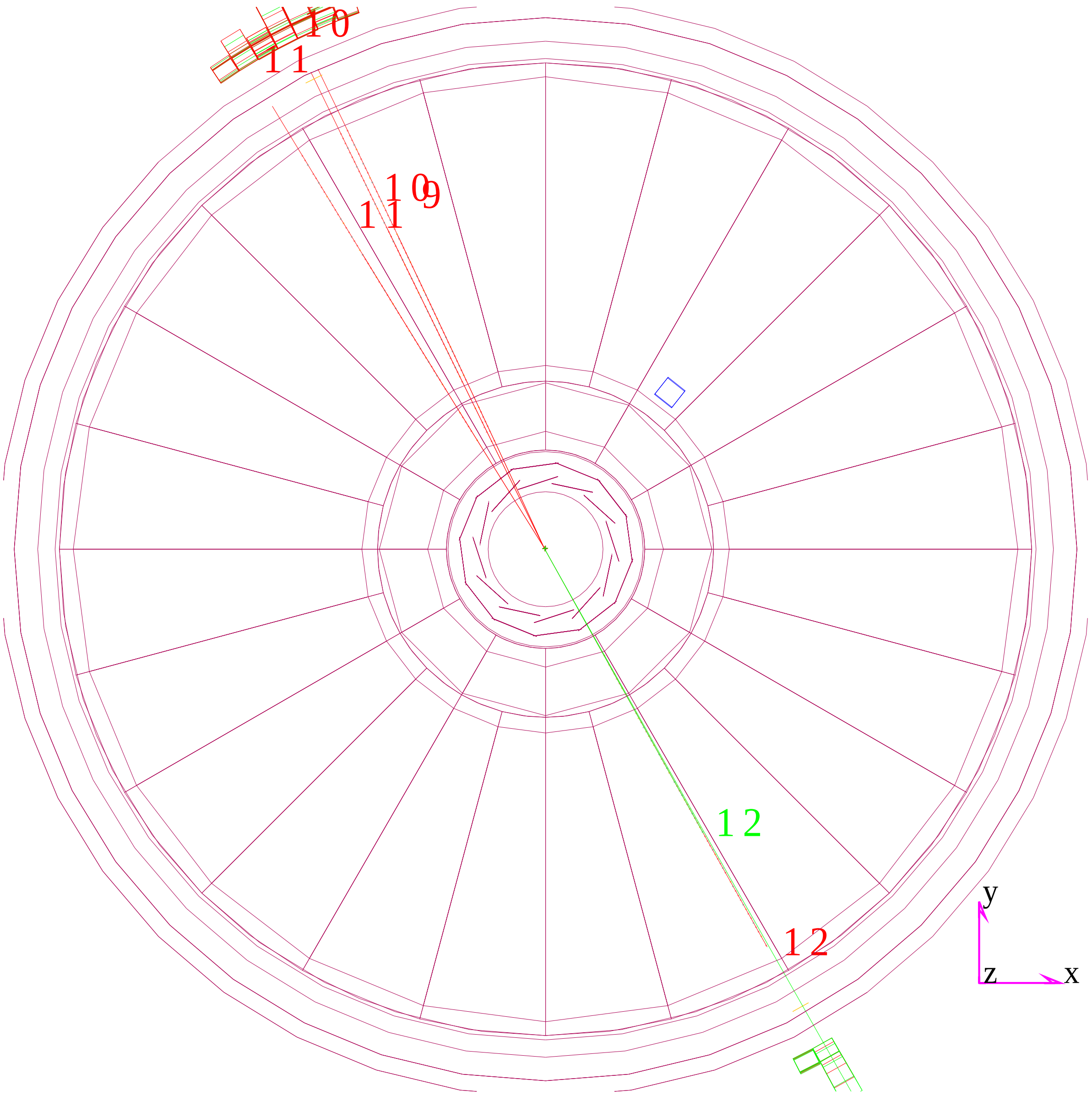
Selection efficiency from Monte Carlo - $77.7 \pm 0.1\%$.

Backgrounds: 0.5% (e^+e^-), 0.6% ($\mu^+\mu^-$), 0.2% ($q\bar{q}$)

Cuts on the track quality:

- transverse momentum $p_t > 0.5\ GeV/c$
- at least 40 TEC hits out of 62 maximum
- at least one hit from the SMD inner $r\varphi$ layer (for 3-prong decays at least 2 tracks with SMD hits)

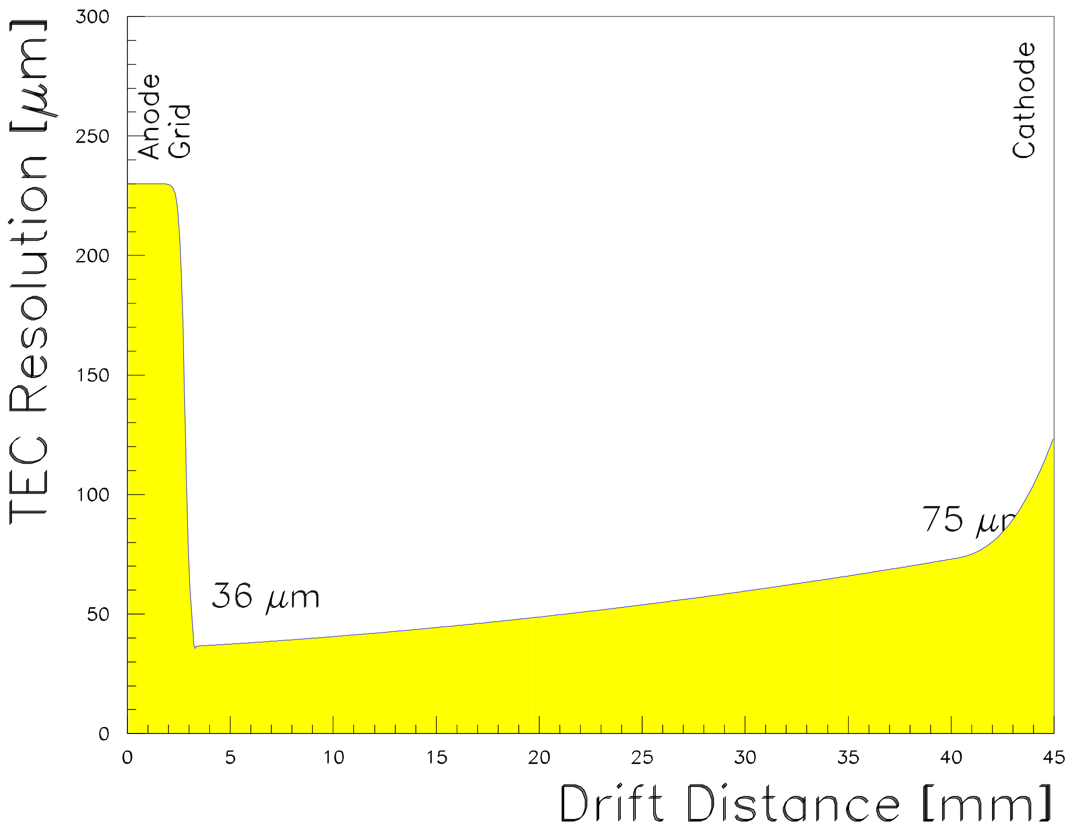
A typical 1-prong versus 3-prong $\tau^+\tau^-$ event, as seen in the central tracker.



A new method to calibrate the TEC - define a precise independent trajectory through the central chamber using back-to-back e^+e^- or $\mu^+\mu^-$ events:

- SMD hits on both tracks
- fixed curvature (from e.m. calorimeter or μ-chambers or beam constraint)

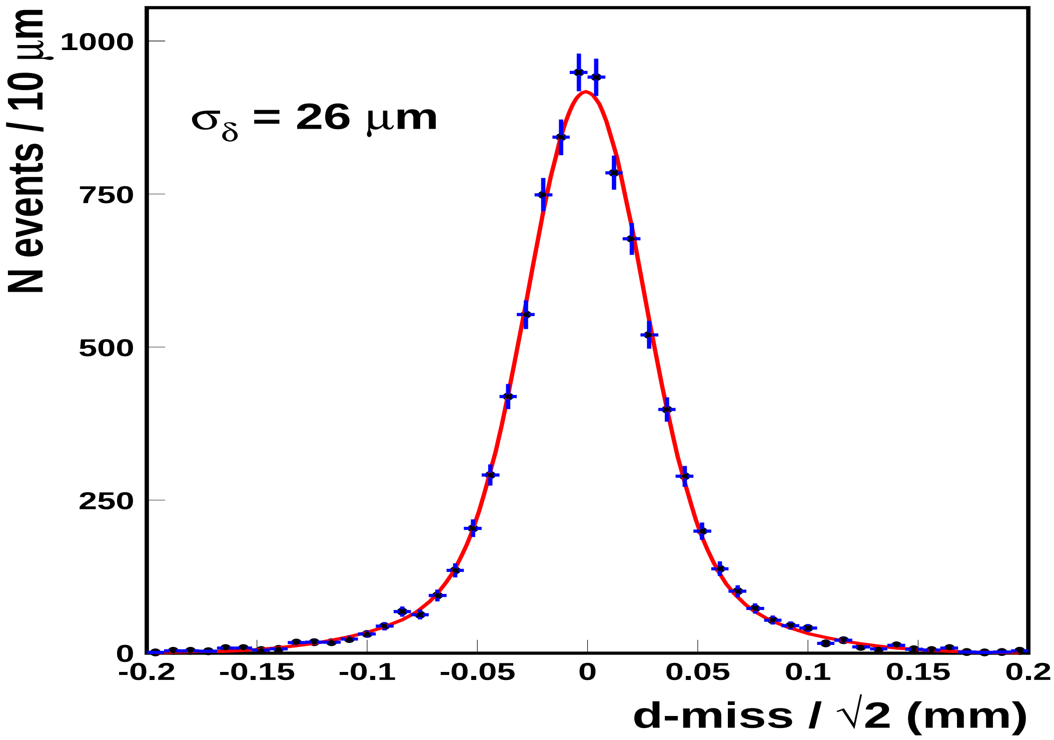
Fit directly the drift distance to time relation for each wire.



Tracking Performance

- Iterative procedure of TEC calibration - SMD alignment
- Corrections for residual local biases ($< 20\ \mu$m)

Final DCA (Distance of Closest Approach) resolution estimated from the miss distance of $Z \rightarrow e^+e^-, \mu^+\mu^-$ events - $26\ \mu m$ for 72 % of the tracks.



Lifetime extraction:

- experimental distribution (δ_i, σ_i) of DL or IP
- unbinned maximum-likelihood fit

Likelihood function - a convolution between

- Physics function P
- Double Gaussian resolution function R (correction factors for the calculated errors σ_i and the relative fraction of the 2 Gaussians are obtained from the fit to the data)

$$\log L = \sum_{i=1}^{N} \log \left\{ (1 - f_B) P(\tau_\tau, \delta') \otimes R(\delta', \delta_i, \sigma_i) + f_B B(\delta_i, \sigma_i) \right\}$$

f_b gives the background fraction

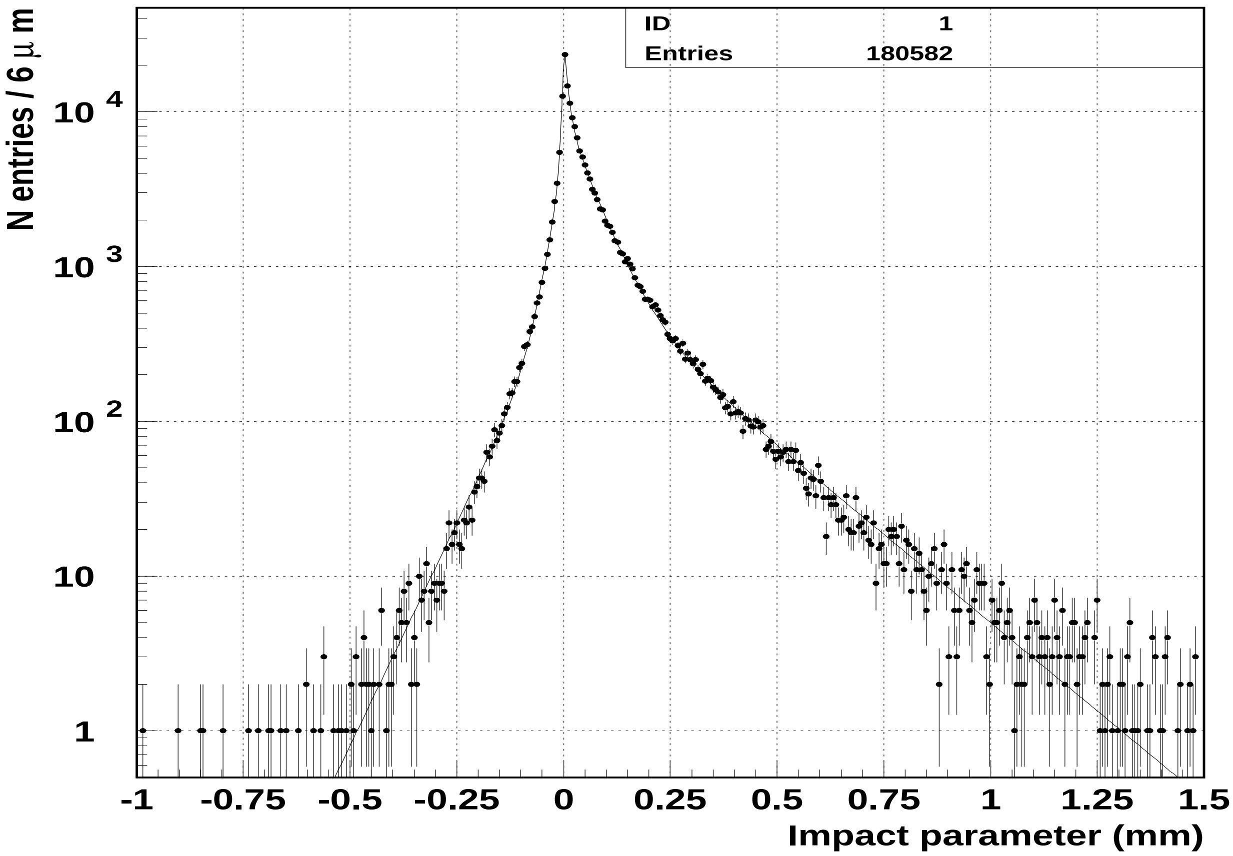
Impact Parameter resolution: $\sigma_\delta^2 = \sigma_{int}^2 + \sigma_{bspot}^2 + \sigma_{ms}^2$

1. σ_{int} : intrinsic resolution
2. σ_{bspot} : size of interaction region
3. σ_{ms} : multiple scattering

Decay Length resolution: depends on the single track resolution, weakly dependent on the beam spot position and size

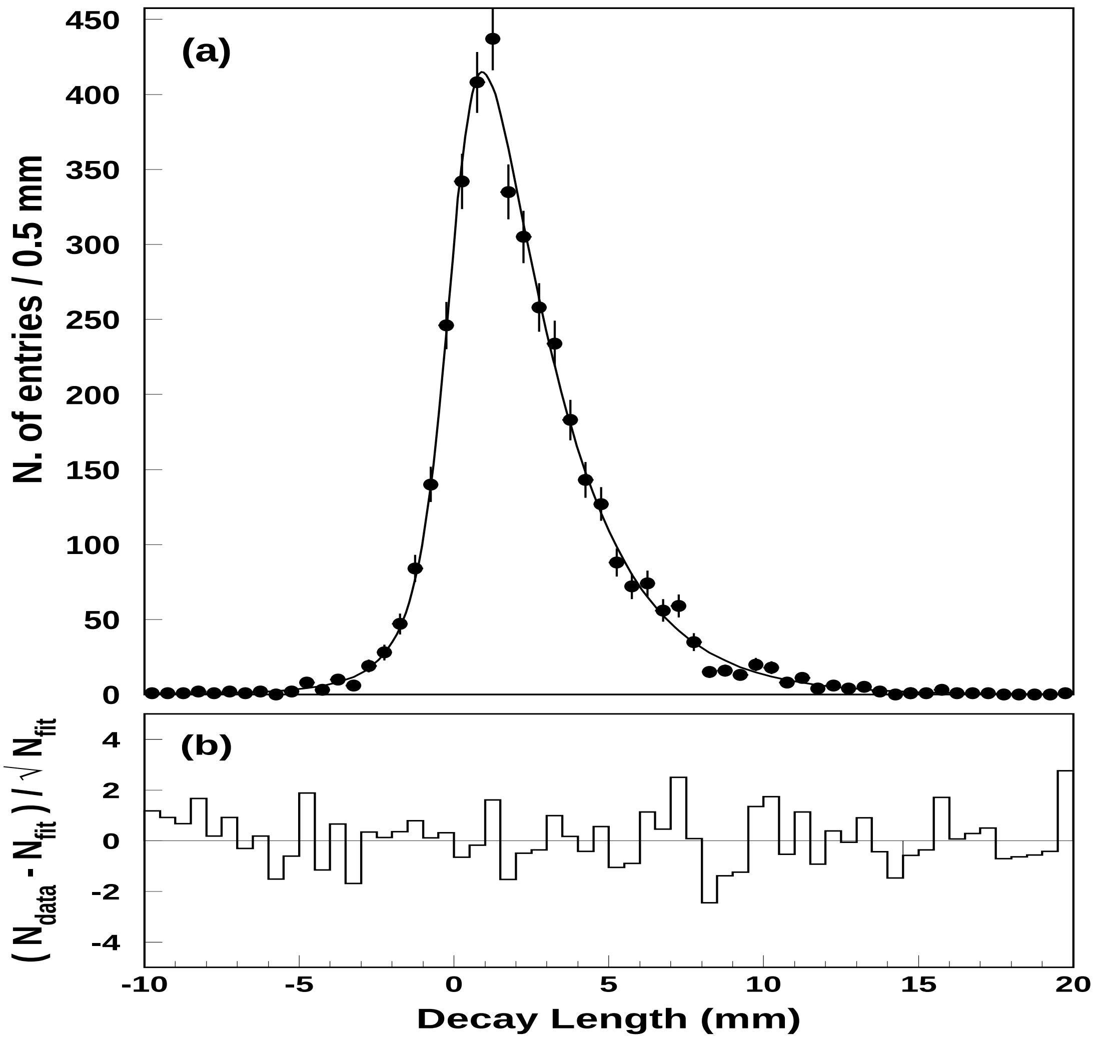
DL method: P - exponential function related to the average decay length

IP method: P - sum of 3 exponential functions for positive and 3 for negative IP: $\sum exp(-\delta/\lambda_i) \rightarrow \tau_\tau \propto \lambda_i$;
determined at generator level, including the possibility of wrong sign assignment due to the uncertainty in the τ flight direction



Lifetime meas. - DL Method

- Number of 3-prong τ decays collected during 1994: 3891
- Decay lengths in the range [-10, 20] mm
- Calculated DL error < 3 mm (most probable $\sigma = 0.9\ mm$)
- Purity of $\sim 99\ \%$

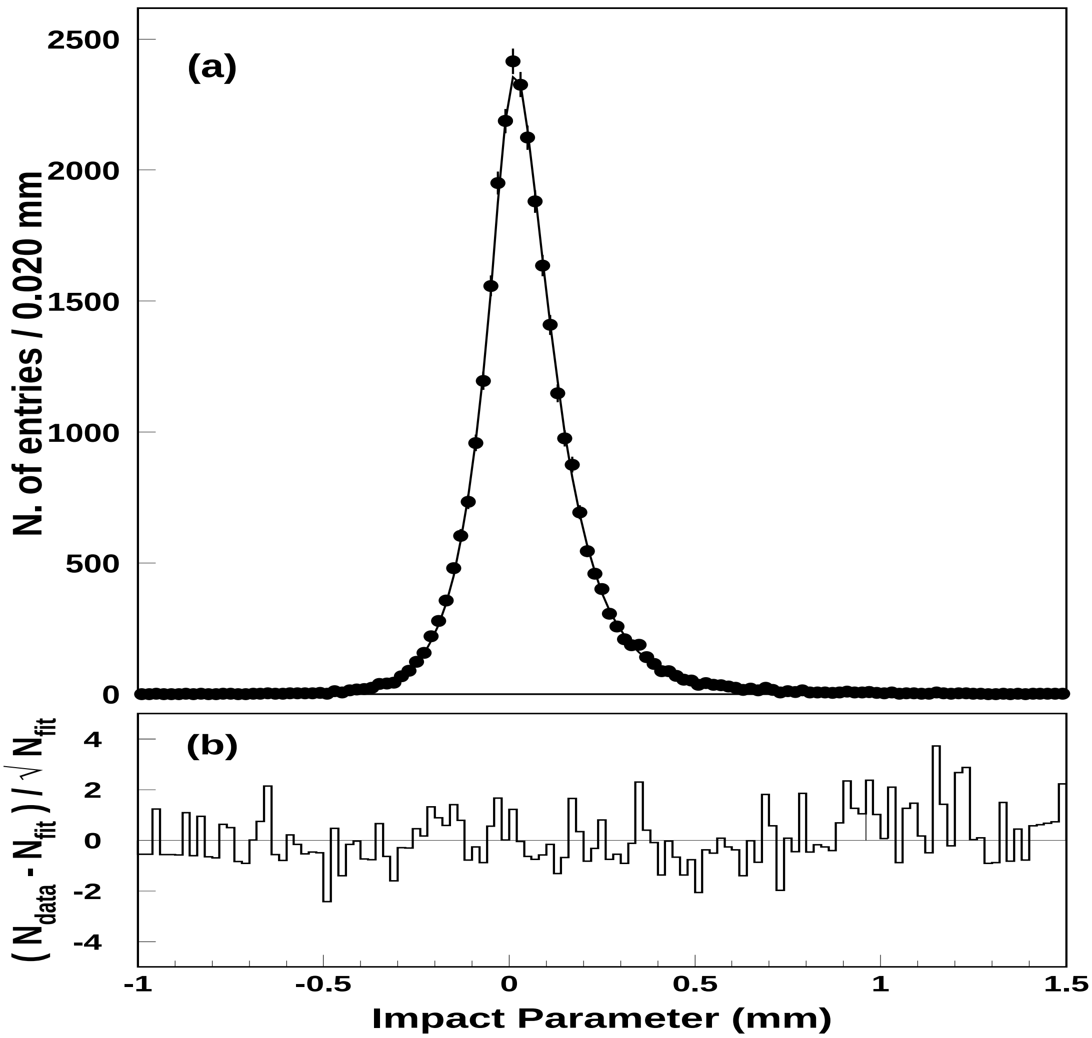


Result:

$$\tau_\tau = 293.0 \pm 5.3(stat.) \pm 2.5(syst.)\ fs$$

Lifetime meas. - IP Method

- Number of 1-prong τ decays collected during 1994: 30322
- Impact parameters in the range [-1.0, 1.5] mm
- Calculated IP error $< 150\ \mu m$ ($<\sigma>= 88\ \mu m$)
- Purity of $\sim 99\ \%$



Result:

$$\tau_\tau = 287.5 \pm 3.8(stat.) \pm 3.9(syst.)\ fs$$

Systematic errors from:

- Uncertainties in the selection and in the background fraction
- Knowledge of the physics function P
- Knowledge of the resolution function R
- Possible biases and variations in the fit procedure

Source of error	DL Method	IP Method
Selection:		
secondary vertex cut	0.5	-
Background uncertainty	0.5	1.0
Physics function	-	2.2
Resolution function	1.5	2.6
Beam spot size	-	0.5
Fit: possible bias	1.5	1.5
Variation of fit range	1.2	0.5
Total	2.5	3.9

Systematic errors in the lifetime measurement in [fs]

τ lepton lifetime measured with 1994 L3 data using:

- Signed impact parameter method
- Decay length method

The two results are independent as they are obtained from different sets of τ decays. By combining them we get

$$\tau_\tau = 290.1 \pm 4.0 \text{ fs.}$$

Adding earlier L3 results for the 1991-94 data sample we obtain

$$\tau_\tau = 291.6 \pm 3.4 \text{ fs}$$

which is in agreement with the PDG 1996 value.