L3 Measurement of the Tau Lifetime
Tau Lepton Workshop 1998

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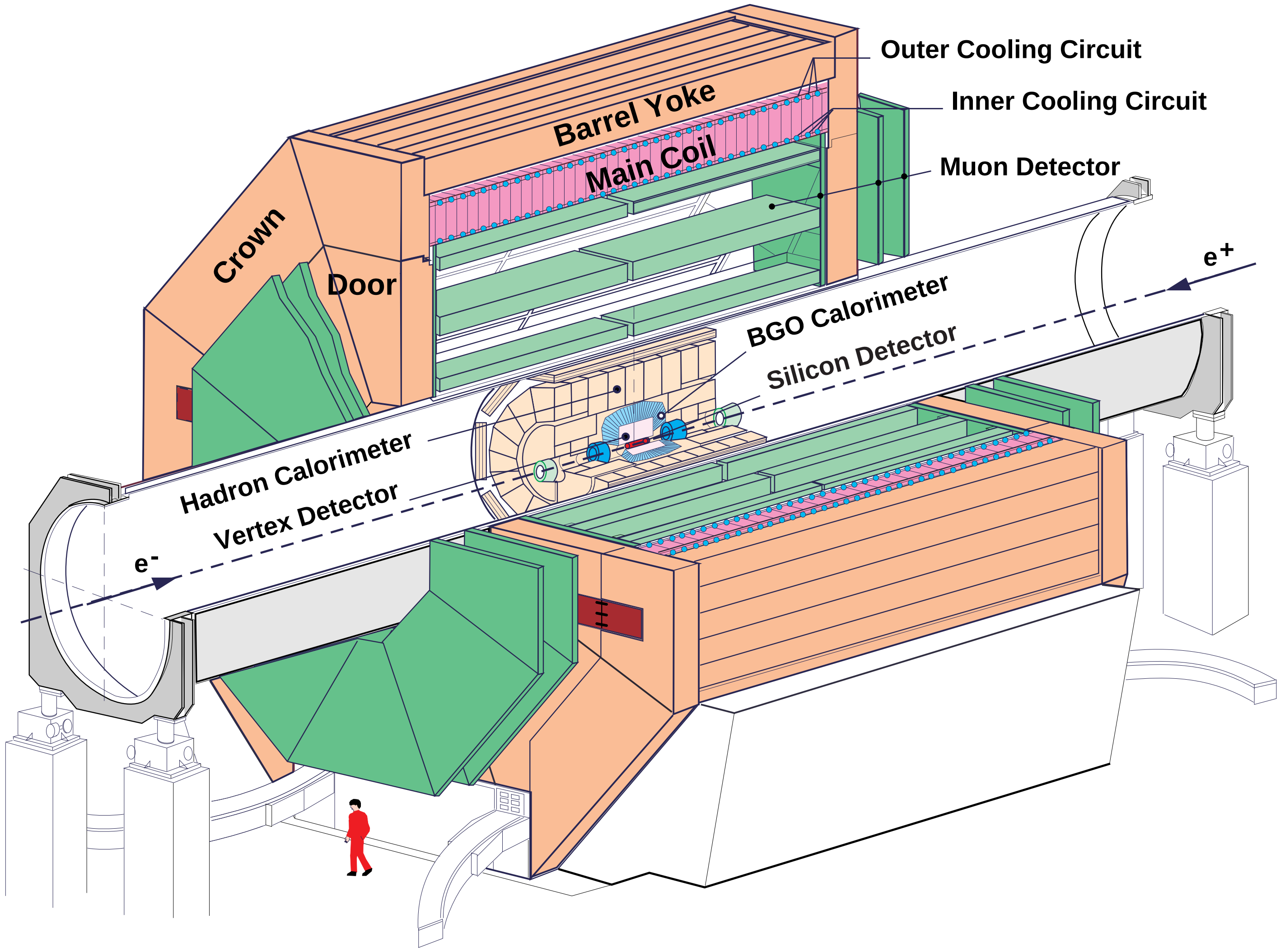
NIKHEF

OUTLINE

- Detector + Performance
- Tau selection
- Impact Parameter
- Decay Length
- 2 Decay Length

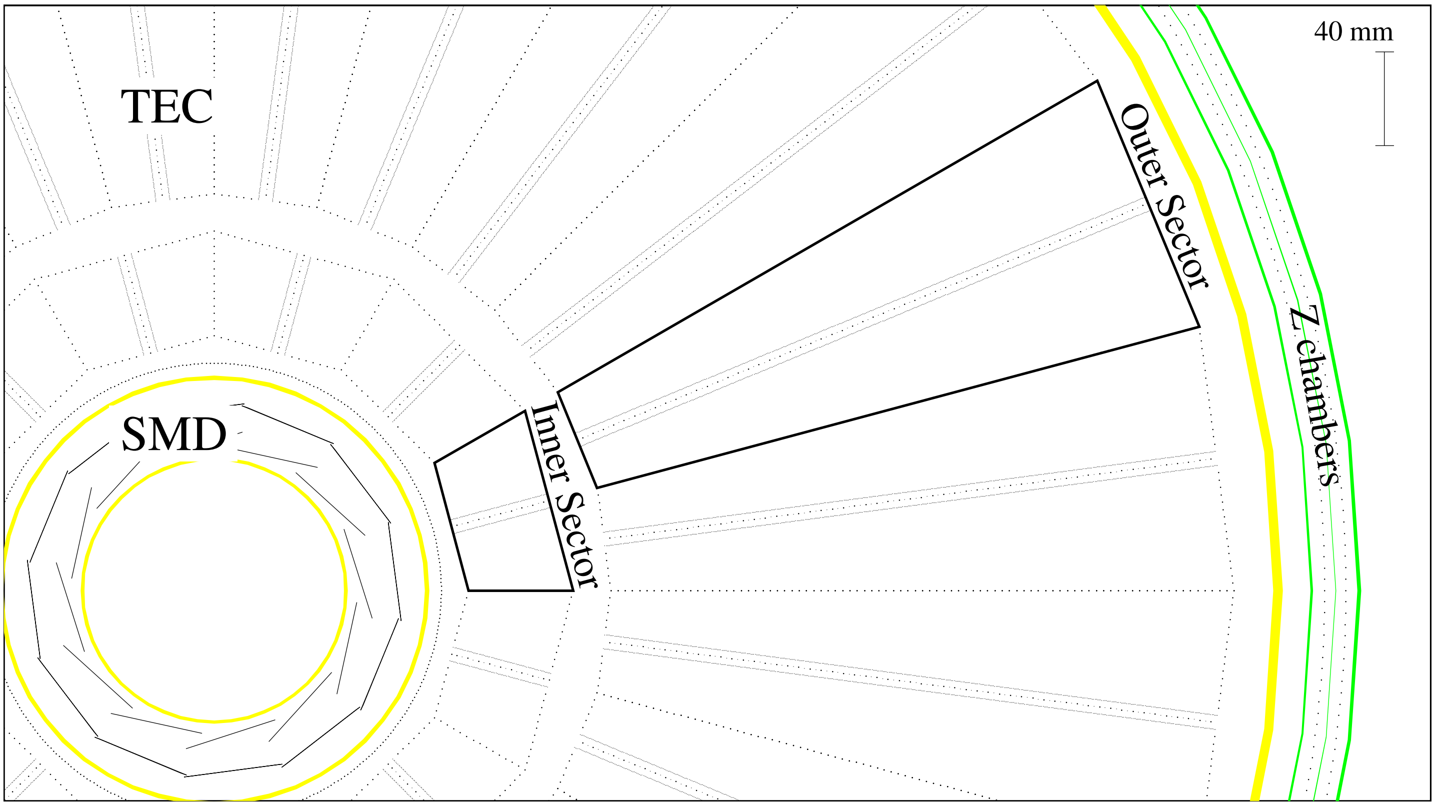
L3 detector



- Inner Tracker (SMD + TEC)
- EM calorimeter
- Hadron Calorimeter
- Muon Spectrometer

0.5 Tesla magnetic field parallel to beam axis

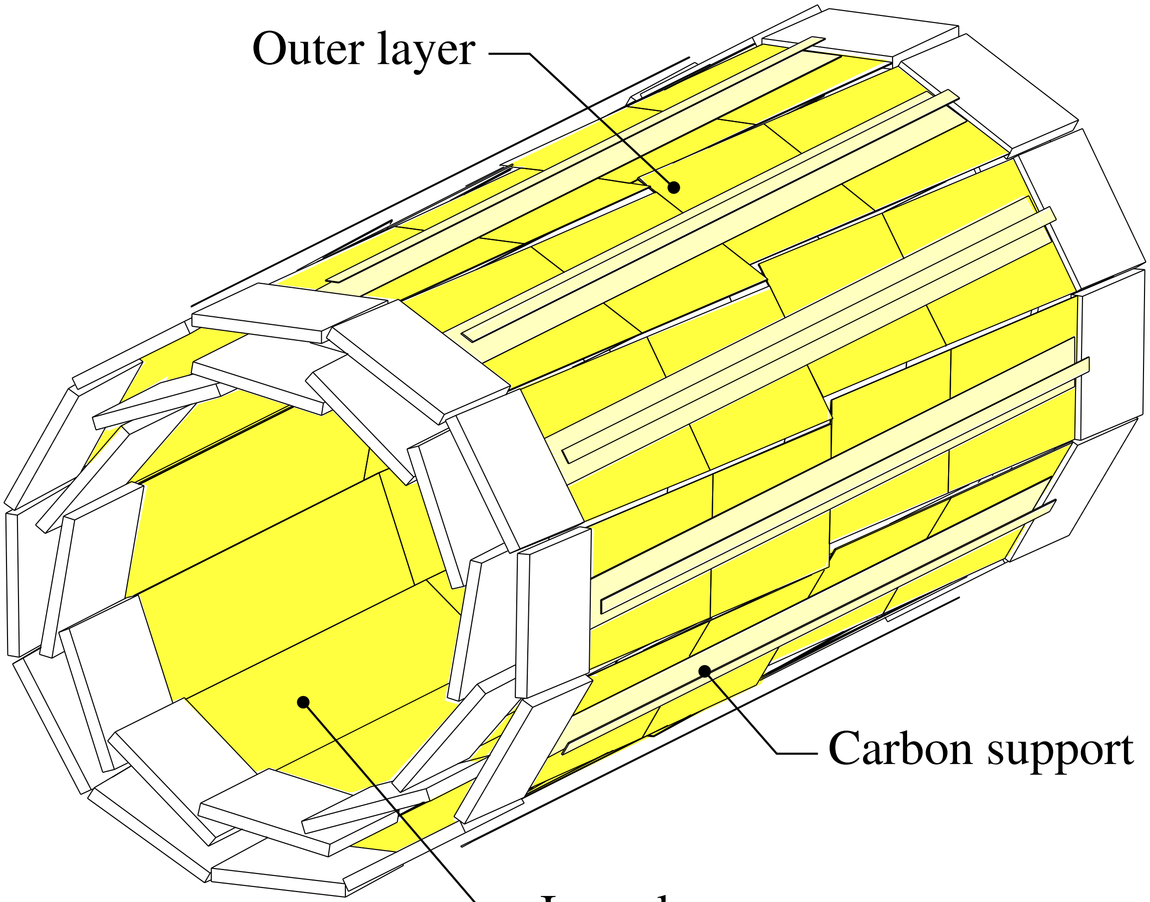
Inner Detector - TEC



Time Expansion Chamber:

- 62 sense wires
- 12 Inner sectors + 24 Outer sectors
- single wire resolution $50 - 100\,\mu$m
- double track resolution $500\,\mu$m
- maximum span 32 cm
- calibration on Bhabha and dimuon events

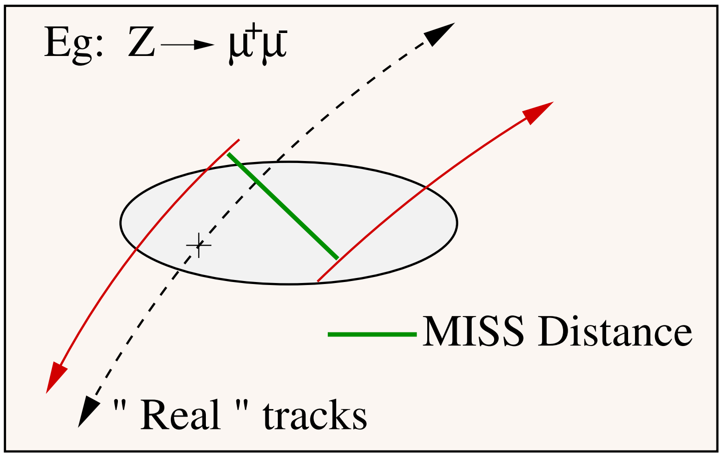
Inner Detector - SMD



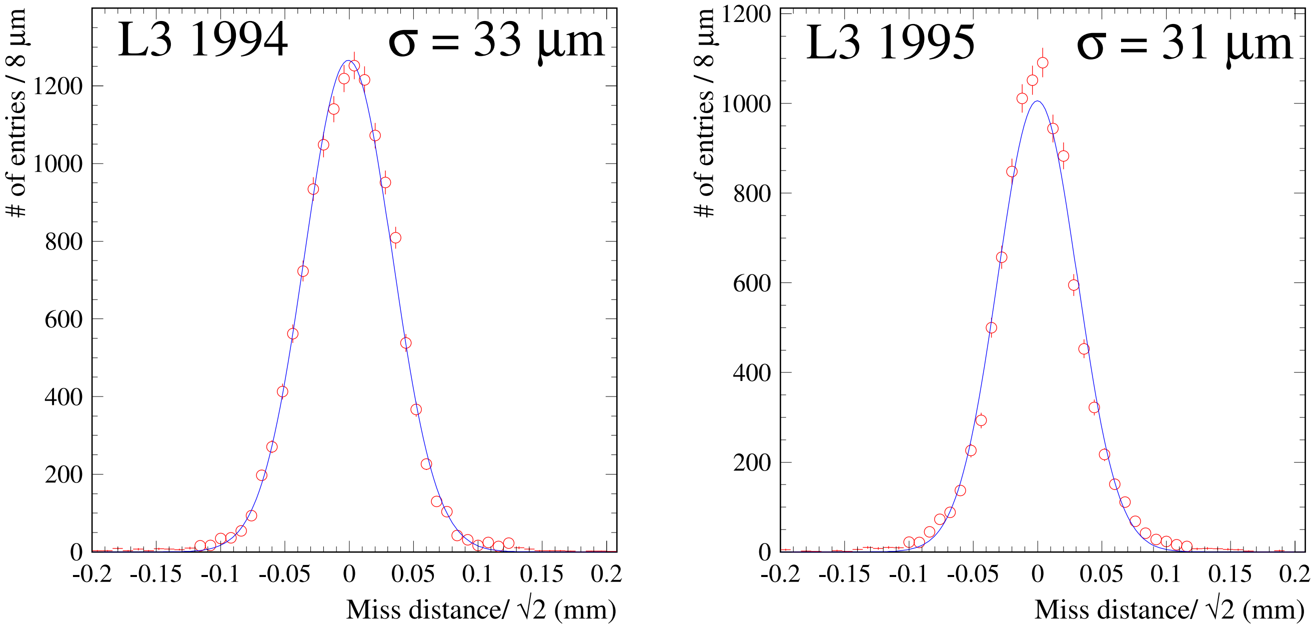
Silicon Microvertex Detector:

- 2 layers of double sided silicon
- 2-3 points to track close to vertex (6-8 cm)
- resolution of $7.5\ \mu$m in plane $\perp$ beam

Resolution



Distance between tracks close to vertex in Bhabha or dimuon events should be zero, since the tracks come from the same point. So width of miss distance measures detector resolution.



Tau pair selection

Find the two highly collimated, back-to-back jets with missing energy.

ACCEPT:

- Events with 2 (or 3) jets
- Fiducial volume $|\cos\theta| \leq 0.72$
- N hits in SMD ≥ 1

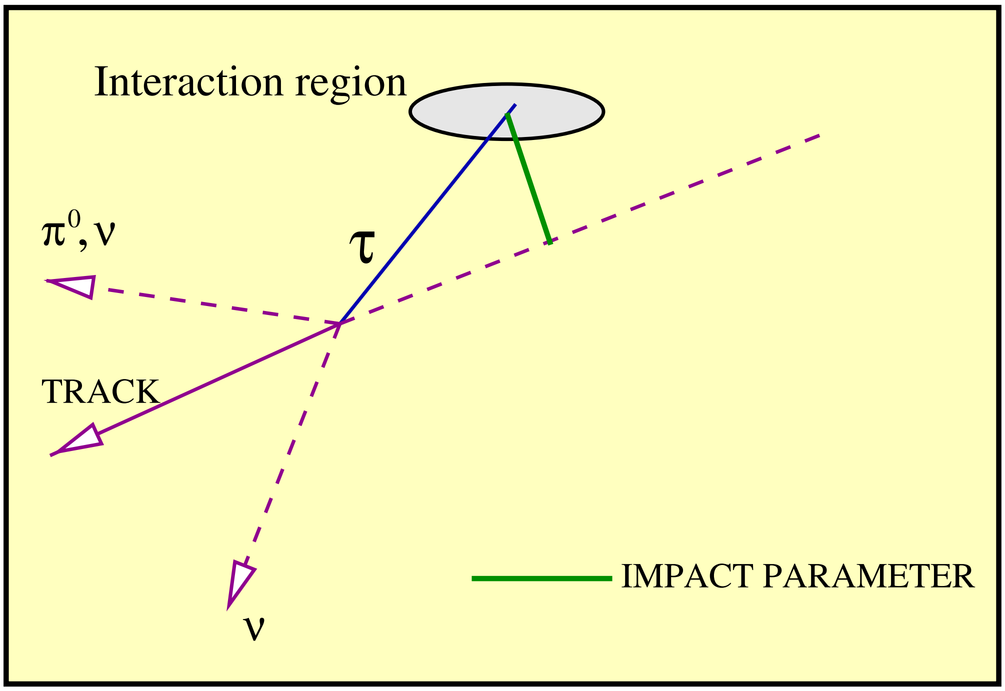
REJECT:

Background	Signature
• $Z \to e^+e^-$	Energy deposit in EM calorimeter
• $Z \to \mu^+\mu^-$	Energy measured in muon chambers
• $Z \to q\overline{q}$	Multiplicity
• Cosmic rays	Out of time with bunch crossing

In the fiducial volume efficiency 77% .
purity $\approx 97\%$.

$$N_{\tau\tau}(94) = 29k \qquad N_{\tau\tau}(95) = 13k$$

Impact Parameter



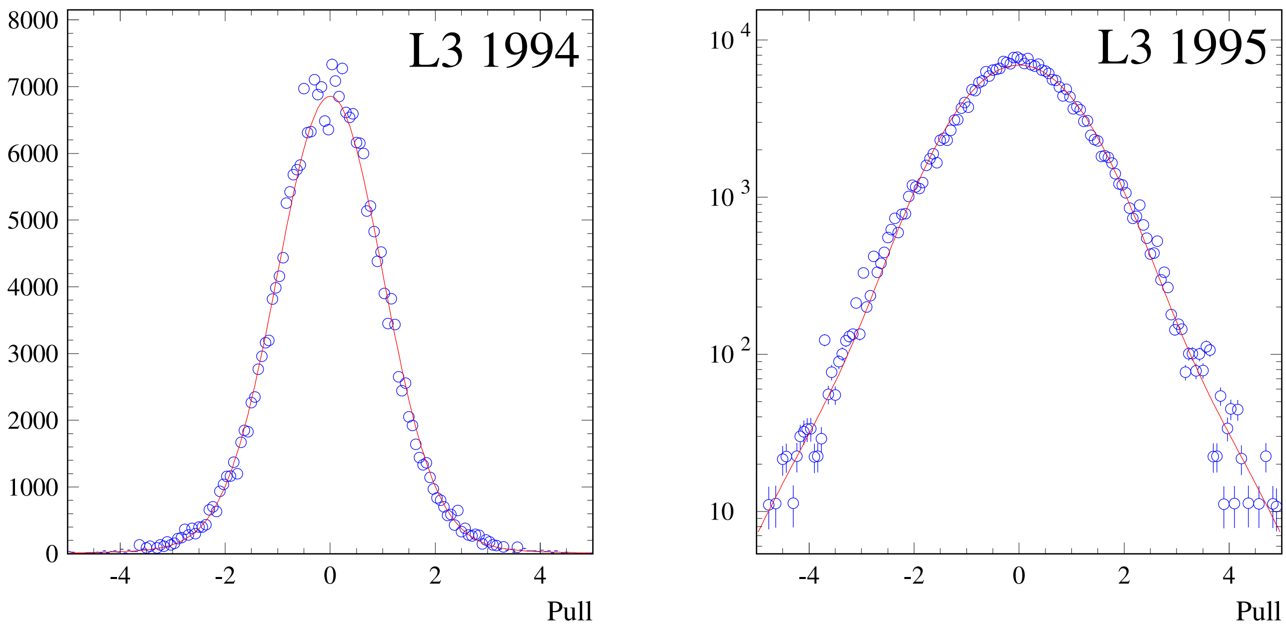
- Use 1-prong tau decays
- On average IP $\approx 50\ \mu$m
- Impact parameter error: $\sigma^2_{IP} = \sigma^2_{int} + \sigma^2_{bspot} + \sigma^2_{ms}$

σ_{int}	- detector intrinsic	20-40 μm
σ_{bspot}	- beam spot region size	15-150 μm
σ_{ms}	- multiple scattering	$\frac{120\ \mu\mathrm{m}}{p_t \sin\theta}$

IP - Resolution Function

- For Impact Parameter analysis description of resolution important
- Look at pull distribution for Bhabha and dimuon events.

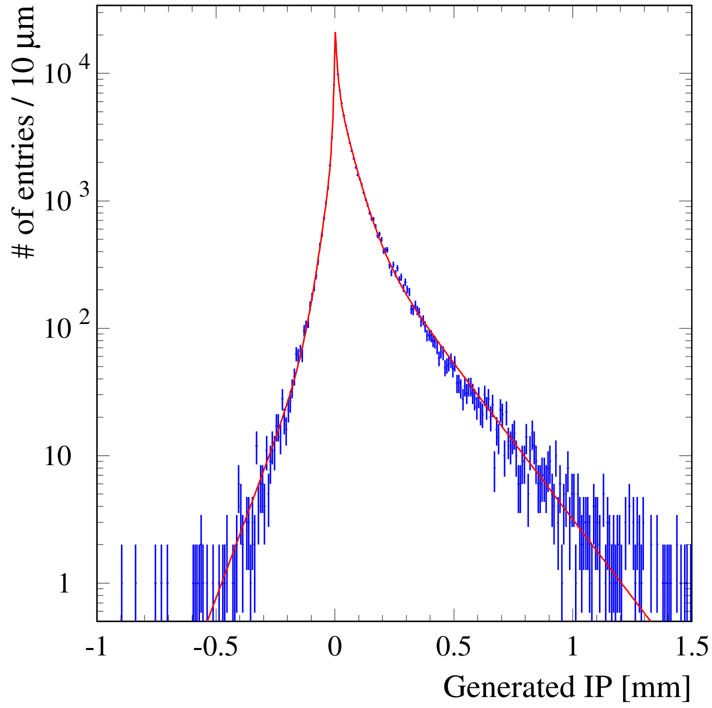
$$\text{Pull} = \frac{\text{IP}}{\sigma_{IP}}$$



- Resolution function well described in terms of a double Gaussian function.
- % in Gaussian with $\sigma = 1$:

$$f(1994) = 0.95$$
$$f(1995) = 0.91$$

IP - Physics Function

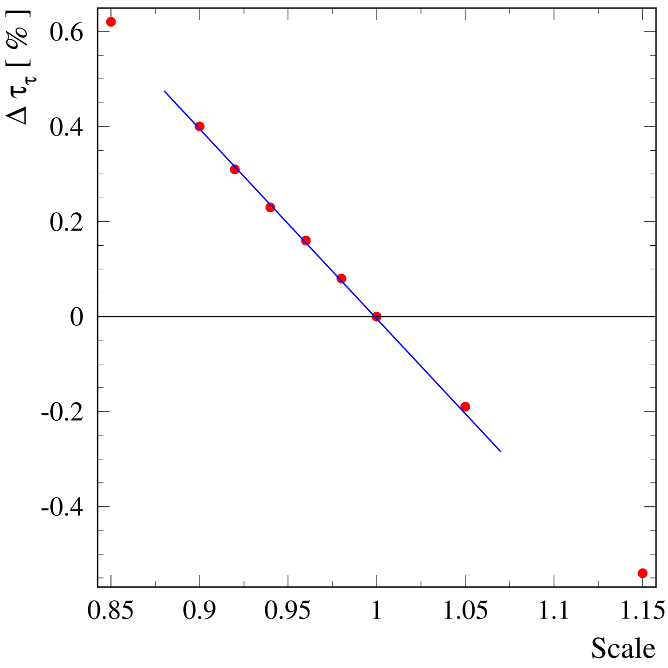


Physics Function

"MC-Generator" IP distribution

Slopes of exponentials, $\lambda_i^{\pm}$, in $U(\mathrm{IP})$ scale with tau lifetime.

$$U(\mathrm{IP}) = (1-W)\,\Sigma_{i=1}^{3} \frac{f_i^+}{S\lambda_i^+} e^{-\frac{\mathrm{IP}}{S\lambda_i^+}} + W\,\Sigma_{i=1}^{3} \frac{f_i^-}{S\lambda_i^-} e^{\frac{\mathrm{IP}}{S\lambda_i^-}}$$

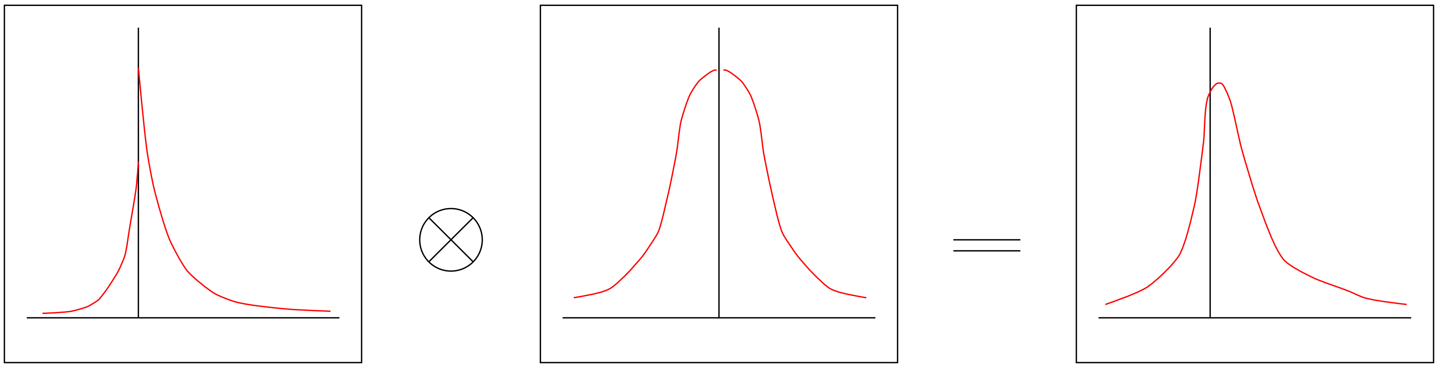


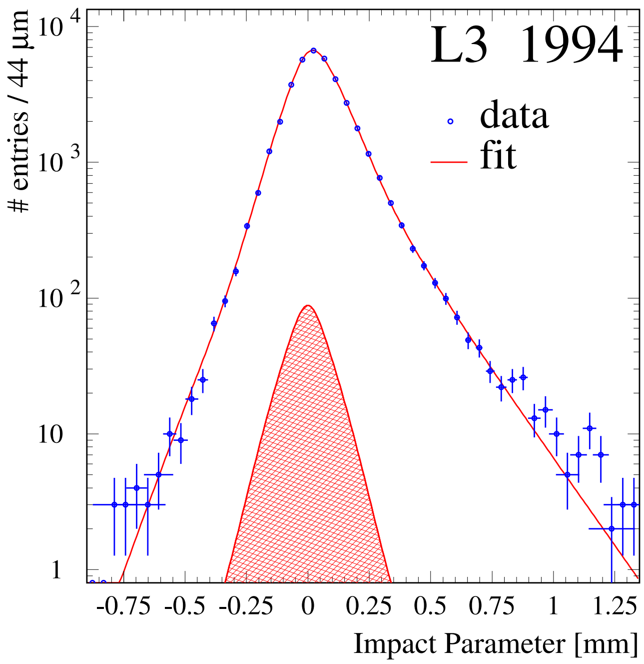
Linearity

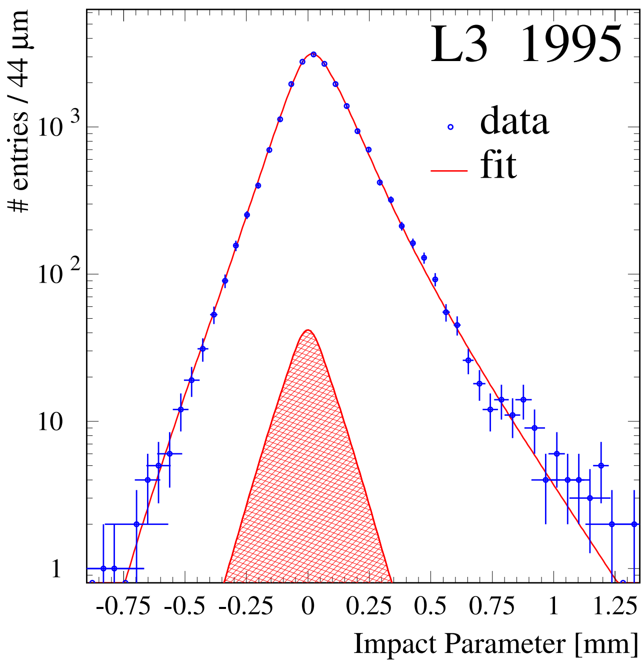
Scaling assumption is checked.

Impact Parameter

Physics Function | Resolution Function | IP distribution







$$\tau_\tau(IP94) = 289.6 \pm 3.3 \text{ fs}$$
$$N_{IP94} = 38\,751$$

$$\tau_\tau(IP95) = 292.6 \pm 4.9 \text{ fs}$$
$$N_{IP95} = 19\,905$$

Systematic Errors for the Impact Parameter method:

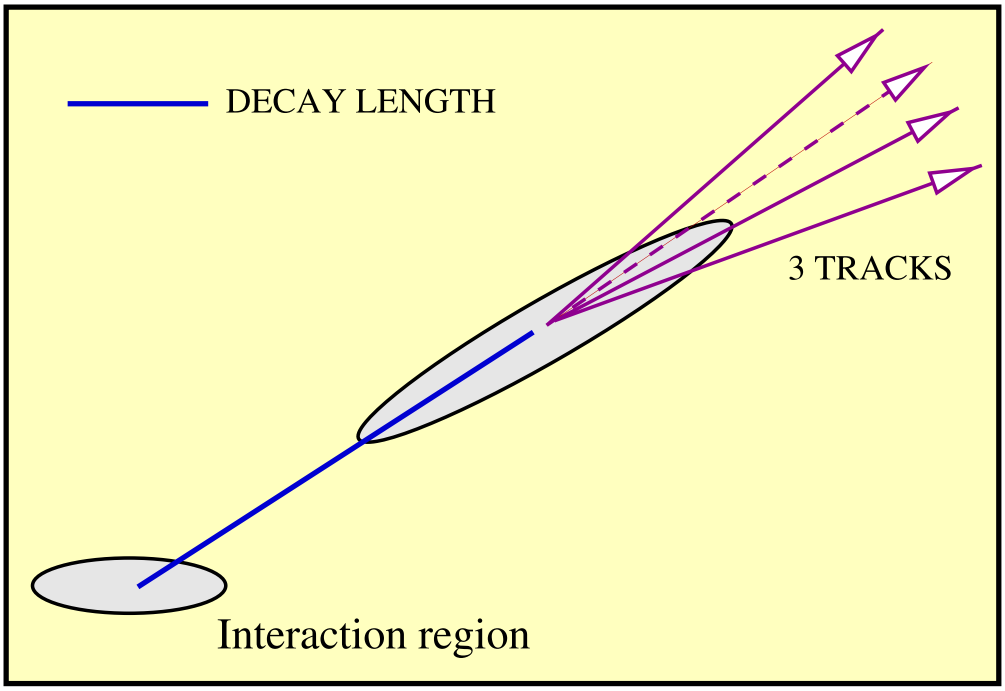
Source	Error (fs)	
Resolution description	2.1 (94)	3.1 (95)
Physics Function	1.8	
Linearity	0.6	
Monte Carlo bias	0.7	
Background uncertainty	0.5	
Size of interaction region	0.5	
Fit Range	0.5	

Result on 1994+1995 Z sample (Silicon era):

$$\tau_\tau(IP) = 290.5 \pm 2.7 \text{ stat} \pm 2.9 \text{ syst fs}$$

$$N_{IP} = 58\,656$$

Decay Length



- Use 3-prong tau decays
- 2D secondary vertex from χ^2 minimisation:

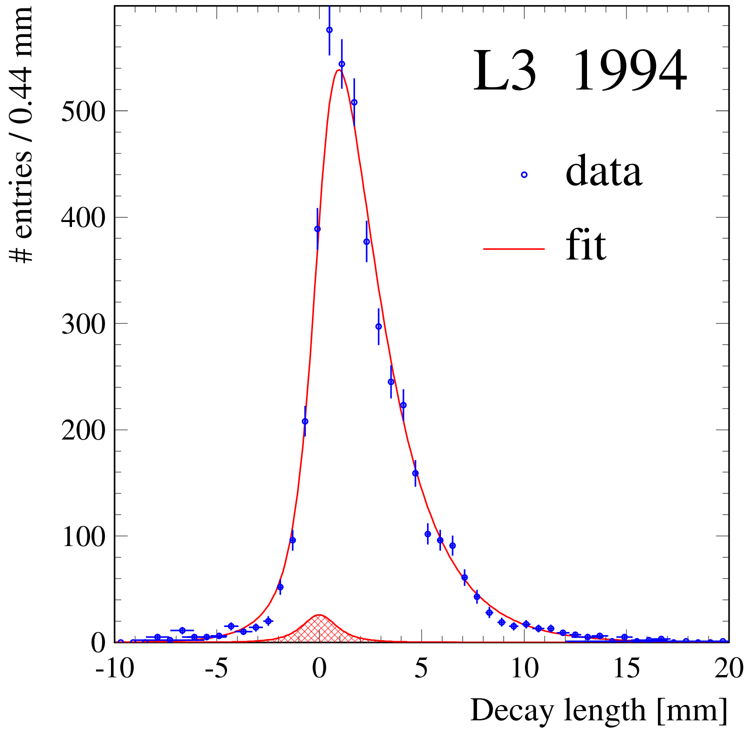
$$\chi^2 = \sum_{i=1}^{3} \left(\frac{d_i}{\sigma_{d_i}} \right)^2$$

- 2D to 3D with θ of the thrust axis
- Typical distance to primary vertex ≈ 2 mm . Error ≈ 1 mm .
- Direct relation between decay length and lifetime:

$$T_i = \frac{L_i}{\beta\gamma c}$$

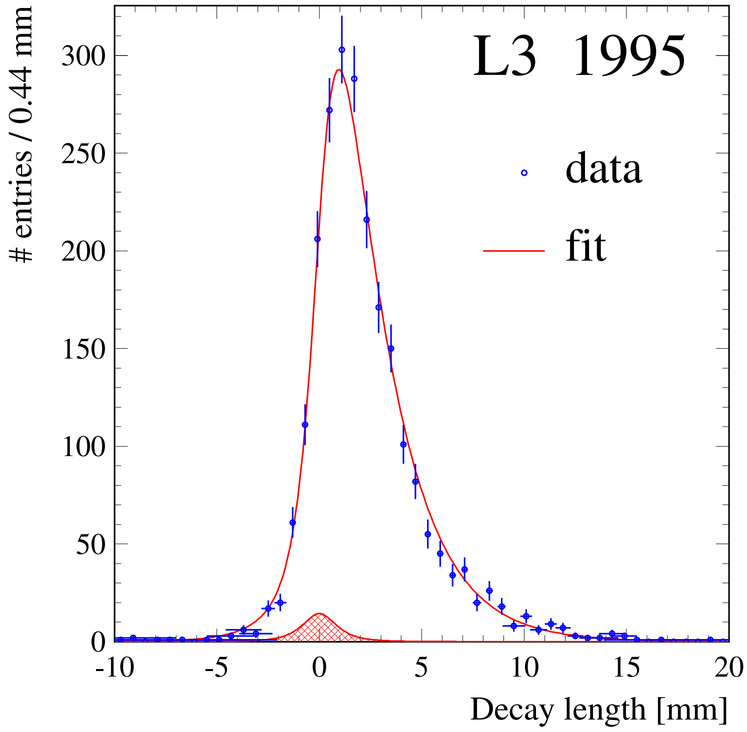
- Physics function a simple exponential.

Decay Length



$$< l >= 2.245 \pm 0.037\text{mm}$$

$$\tau_\tau(DL94) = 290.4 \pm 4.9 \text{ fs}$$
$$N_{DL94} = 4\,306$$



$$< l >= 2.265 \pm 0.051\text{mm}$$

$$\tau_\tau(DL95) = 293.1 \pm 6.6 \text{ fs}$$
$$N_{DL95} = 2\,314$$

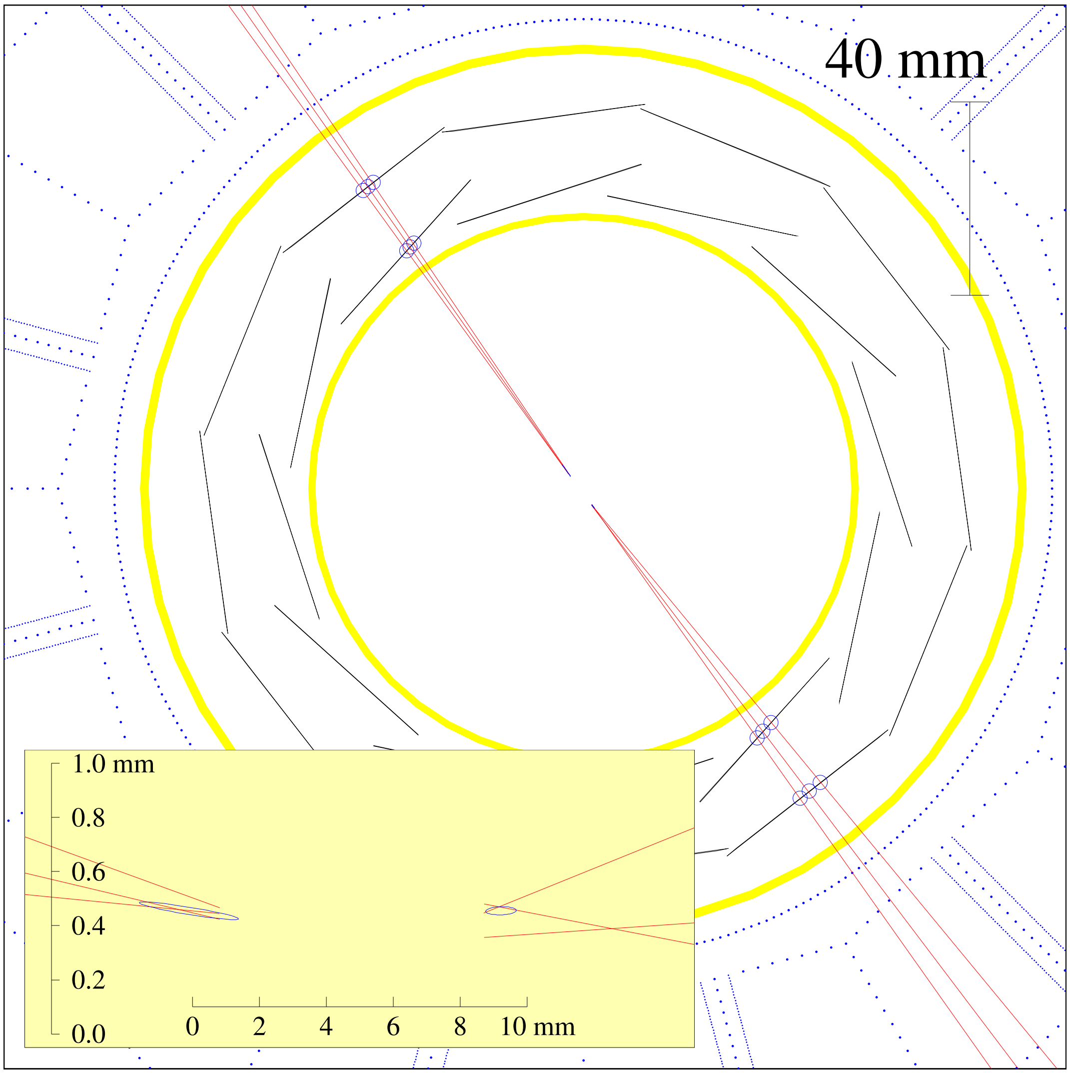
Systematic Errors for the Decay Length method:

Source	Error (fs)	
Resolution description	1.5 (94)	2.0 (95)
Monte Carlo Bias	1.0	
Background uncertainty	0.7	
Fit range	1.0	

Result on 1994+1995 Z sample (Silicon era):

$$\tau_\tau(DL) = 291.4 \pm 3.9 \text{ stat} \pm 2.0 \text{ syst fs}$$
$$N_{IP} = 6\,620$$

Double Decay Length



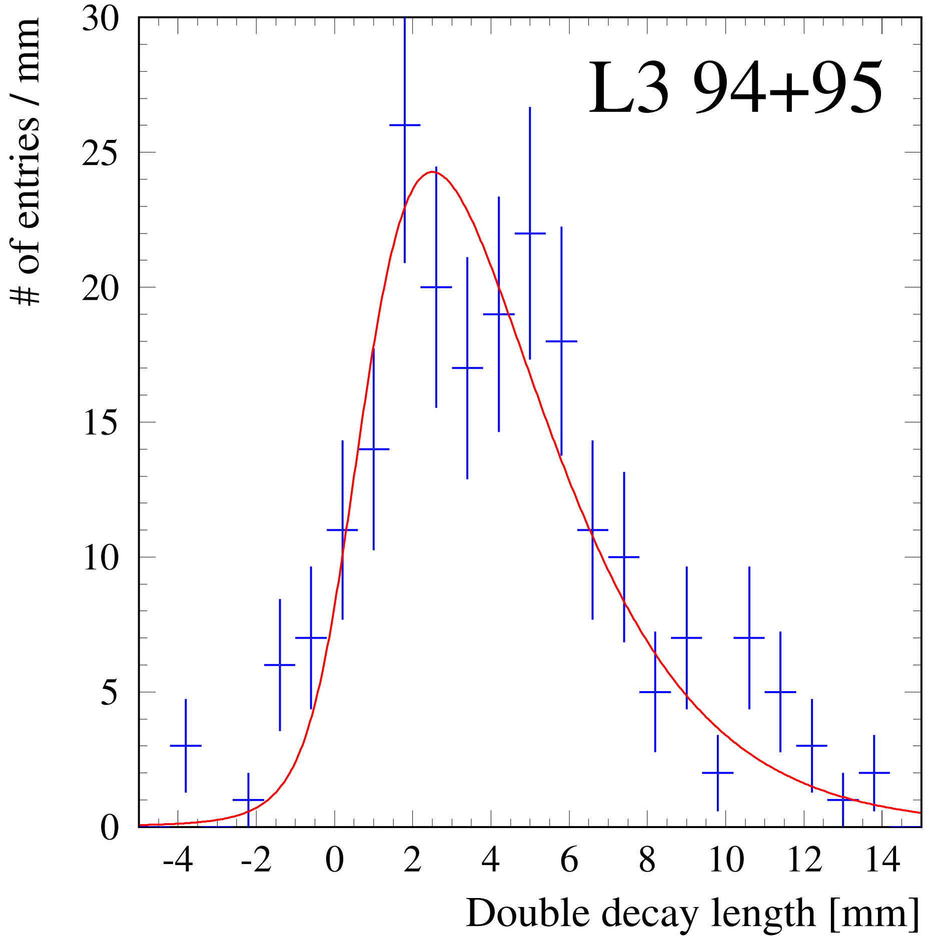
Double Decay Length:

- Expected distribution:

$$P(L;<l>) = \int dl_1 dl_2 P(l_1)\cdot P(l_2)\delta(l_1+l_2-L)$$
$$= \frac{L}{<l>^2} e^{-\frac{L}{<l>}} \qquad L>0$$

- Independent of beam position

Double Decay Length



$$\tau_\tau(LL) = 271 \pm 14 \text{ fs}$$
$$N_{LL} = 217(!)$$

Combination with previous results:

$$\begin{aligned} \tau_\tau(91) &= (293 \pm 9 \text{ stat} \pm 12 \text{ syst}) \text{ fs} \\ \tau_\tau(92-93) &= (296.4 \pm 6.4 \text{ stat} \pm 3.5 \text{ syst}) \text{ fs} \\ \tau_\tau(IP94-95) &= (290.5 \pm 2.7 \text{ stat} \pm 2.9 \text{ syst}) \text{ fs} \\ \tau_\tau(DL94-95) &= (291.4 \pm 3.9 \text{ stat} \pm 2.0 \text{ syst}) \text{ fs} \end{aligned}$$

$$\Downarrow$$

$$\tau_\tau = (291.7 \pm 2.0 \textbf{ stat} \pm 1.8 \textbf{ syst}) \textbf{ fs}$$

$$\Downarrow$$

Compact detector. Great measurement!