Measurement of the Tau Lifetime and Leptonic Branching Ratios in L3

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(L3 Collaboration)

- Motivation
- Lifetime
- Leptonic branching ratios
- Conclusions

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Motivation

The lifetime is an intrinsic property of the tau

Decay rate:

$$\Gamma(\tau \to \ell\bar{\nu}_\ell\nu_\tau) \equiv \frac{\mathcal{B}(\tau \to \ell\bar{\nu}_\ell\nu_\tau)}{\tau_\tau} = \frac{g_\tau^2 g_\ell^2}{m_{\mathrm{W}}^4} \frac{m_\tau^5}{96(4\pi)^3}(1+\epsilon)$$

$\mathcal{B}(\tau \to \mathrm{e}\bar{\nu}_\mathrm{e}\nu_\tau)$ and $\mathcal{B}(\tau \to \mu\bar{\nu}_\mu\nu_\tau)$ provide a measurement of g_μ/g_e

From τ_τ and $\mathcal{B}(\tau \to \ell\bar{\nu}_\ell\nu_\tau)$, using also τ_μ, we can determine g_τ/g_e and g_τ/g_μ

TEST LEPTON UNIVERSALITY OF THE CHARGED CURRENTS

Assuming lepton universality:

τ_τ and $\mathcal{B}(\tau \to \ell\bar{\nu}_\ell\nu_\tau)$ provide a measurement of G_F

Two *independent* measurements of R_τ and $\alpha_s(m_\tau)$:

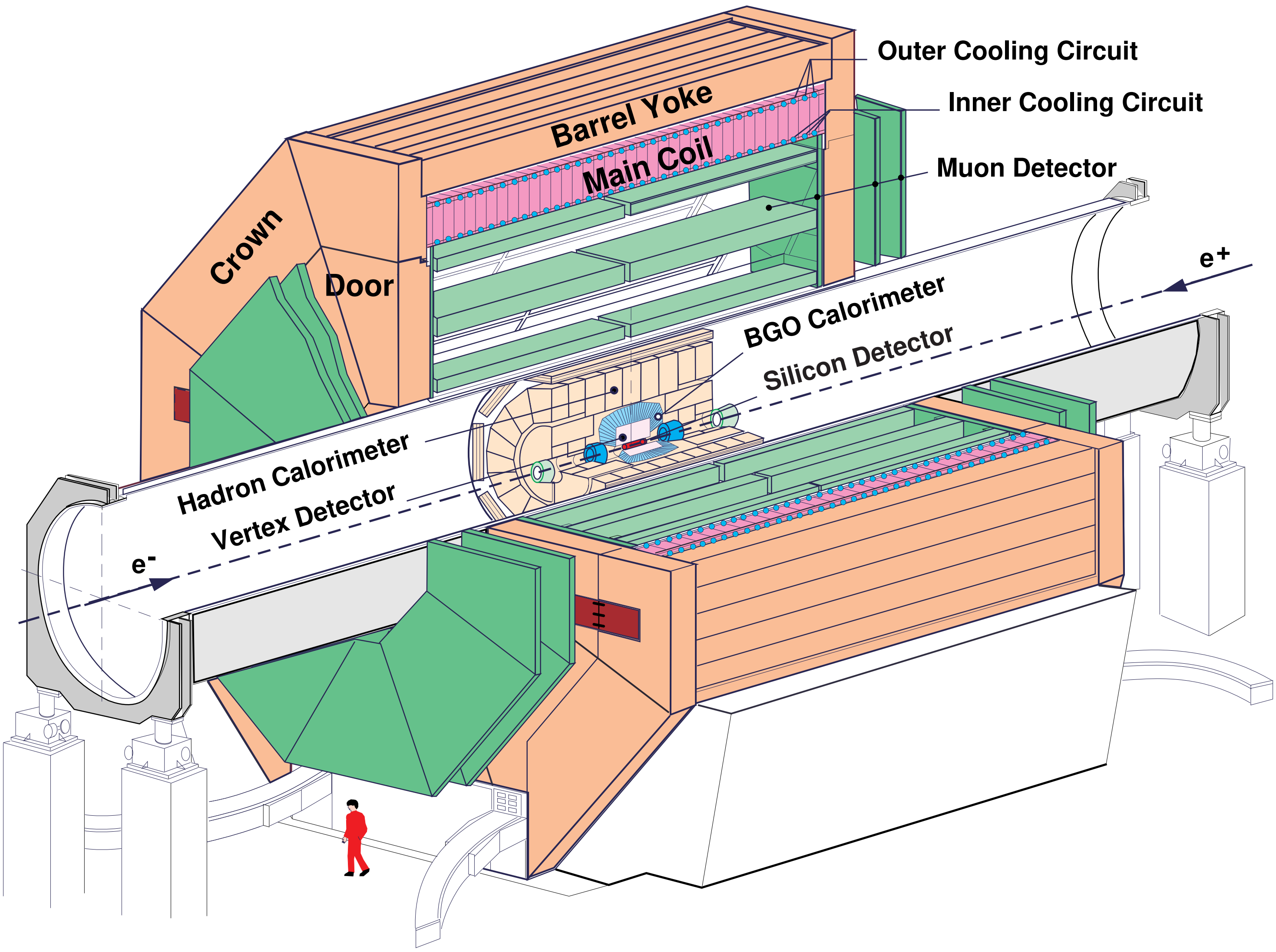
- from $\mathcal{B}(\tau \to \ell\bar{\nu}_\ell\nu_\tau)$
- from τ_τ and m_μ, m_τ, τ_μ

The Experiment

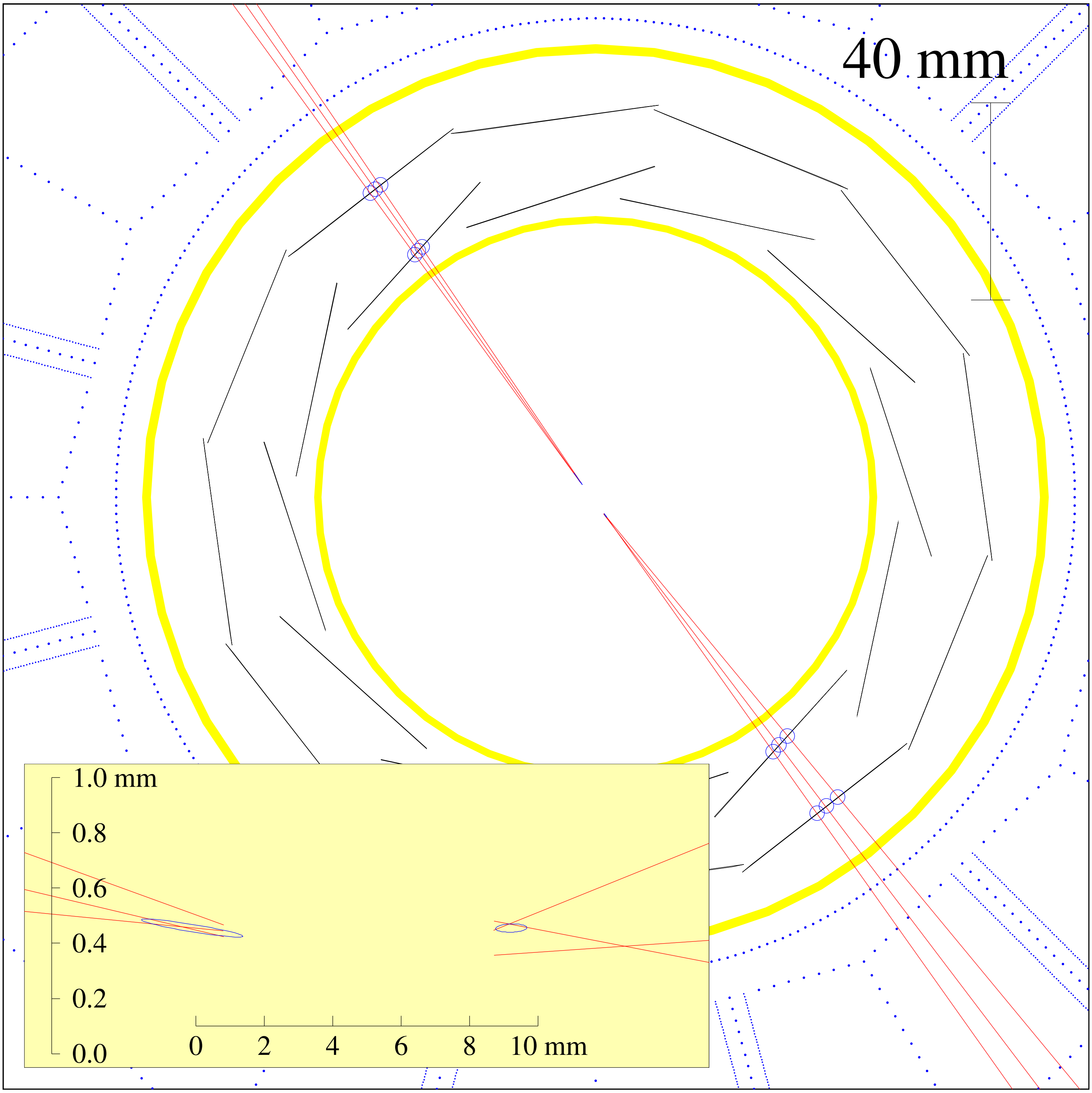
LEP: $e^+e^- \rightarrow \tau^+\tau^-(\gamma)$; $\sqrt{s} \simeq M_Z$

1990-95: $\mathcal{L} = 150\ \mathrm{pb}^{-1} \Longrightarrow N_{\tau\tau} \simeq 180 \times 10^3$

The L3 detector

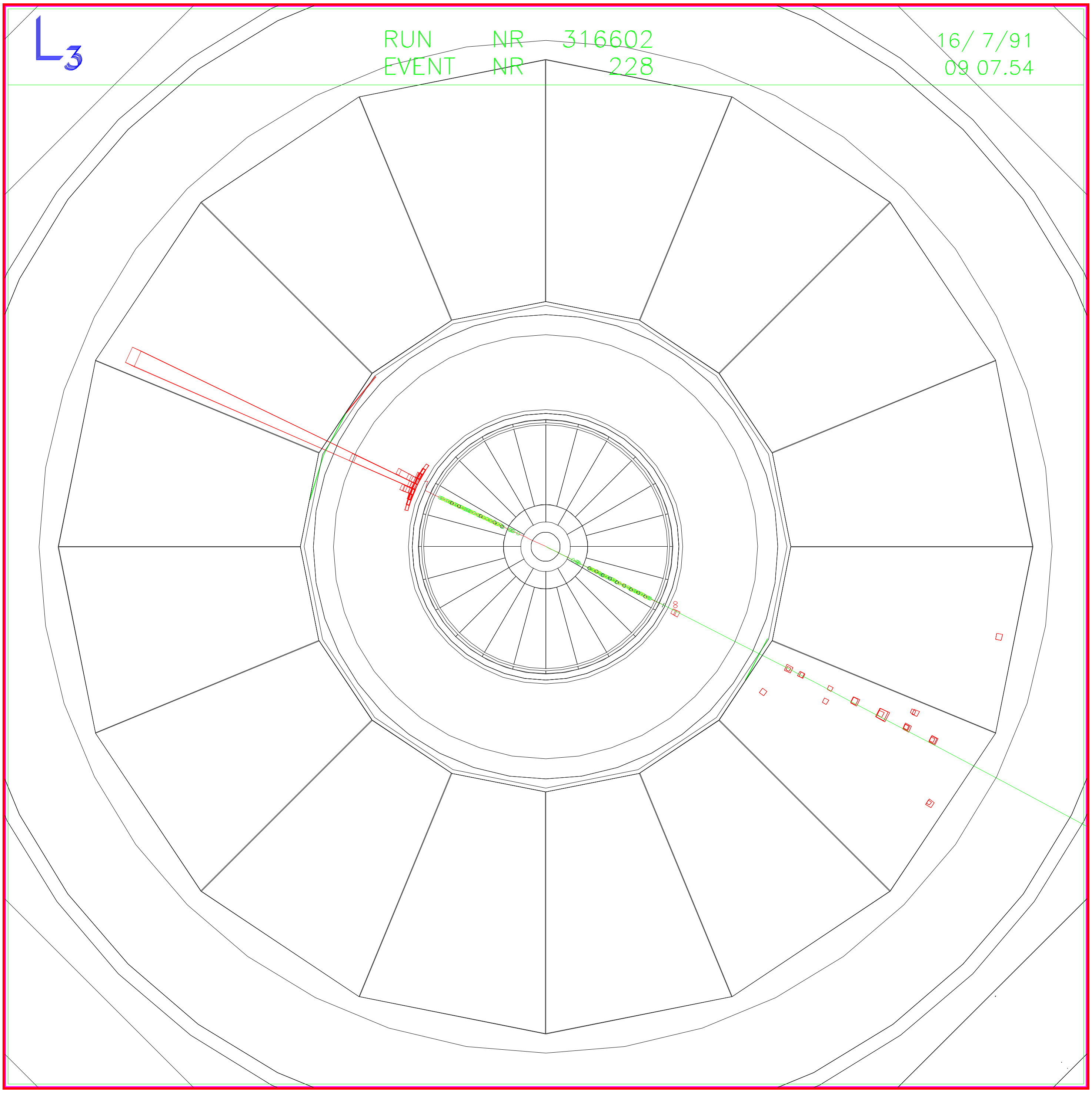


Tracking is essential for the τ lifetime measurement



Electron ID: electromagnetic calorimeter

Muon ID: muon chambers and hadron calorimeter



Tau lifetime

Selection of $\tau^+\tau^-$ events:

Events accepted in the barrel region only

Low track multiplicity per event hemisphere

Inconsistency with $e^+e^-(\gamma)$, $\mu^+\mu^-(\gamma)$ and $\gamma\gamma$

Efficiency $\sim 76\%$; Purity $\sim 98\%$

Two methods:

Impact parameter: 1-prong decays

Decay length: 3-prong decays

New analysis: 1994 + 1995 data combined with older results from 1990–93

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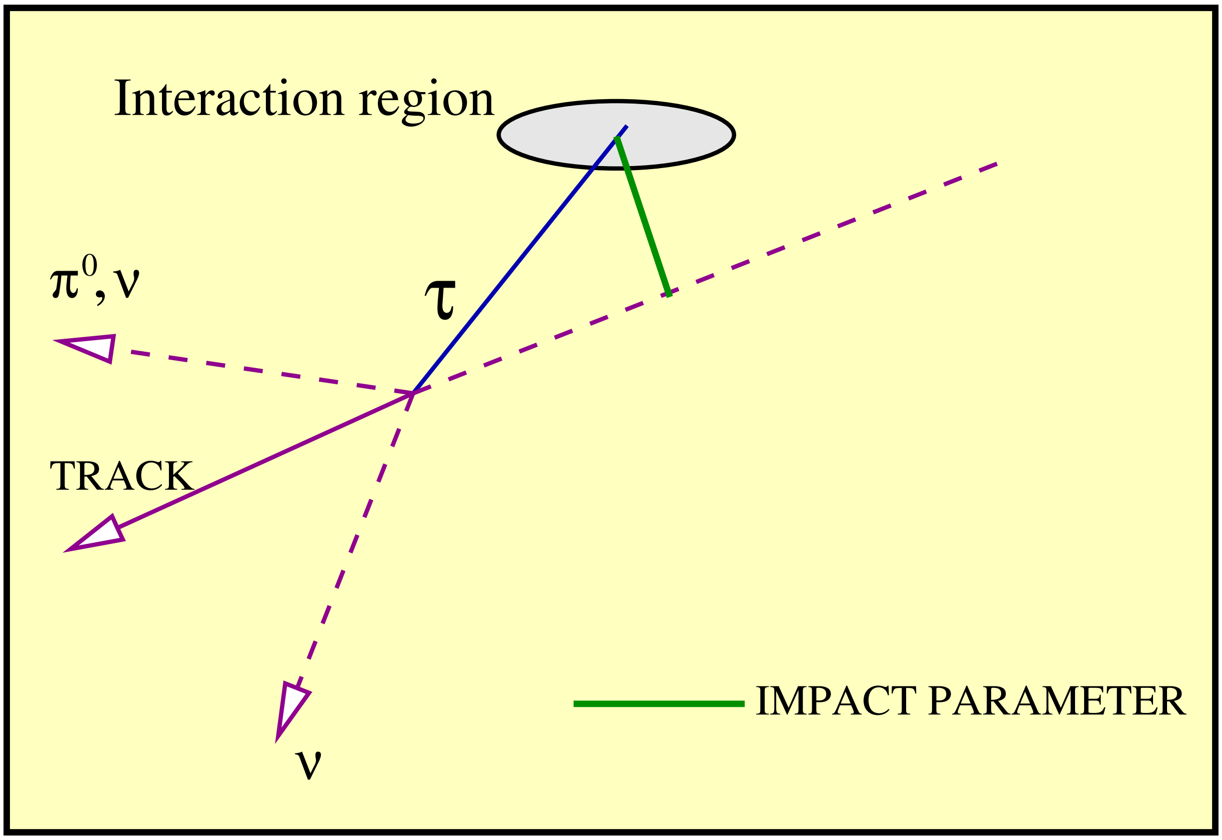
Impact parameter method



Use 1-prong tau decays

Error on the impact parameter:

$$\sigma_{IP}^2 = \sigma_{int}^2 + \sigma_{bspot}^2 + \sigma_{ms}^2$$

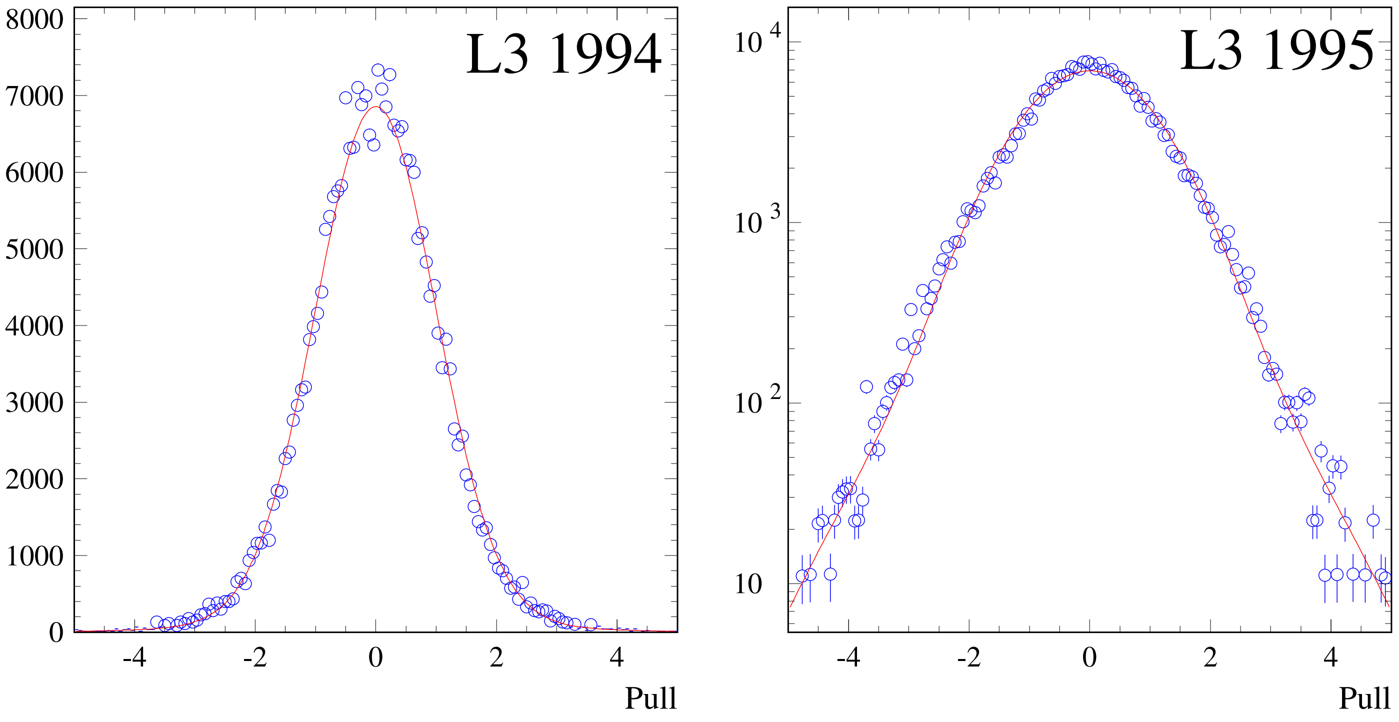
Detector intrinsic:	σ_{int}	$=$	$20 - 40\ \mu\mathrm{m}$
Beam spot region size:	σ_{bspot}	$=$	$15 - 150\ \mu\mathrm{m}$
Multiple scattering:	σ_{ms}	$=$	$120\ \mu\mathrm{m}/p_t \sin\theta$

Impact parameter resolution

Description of resolution important for this analysis

Look at pull distribution for Bhabha and dimuon events:

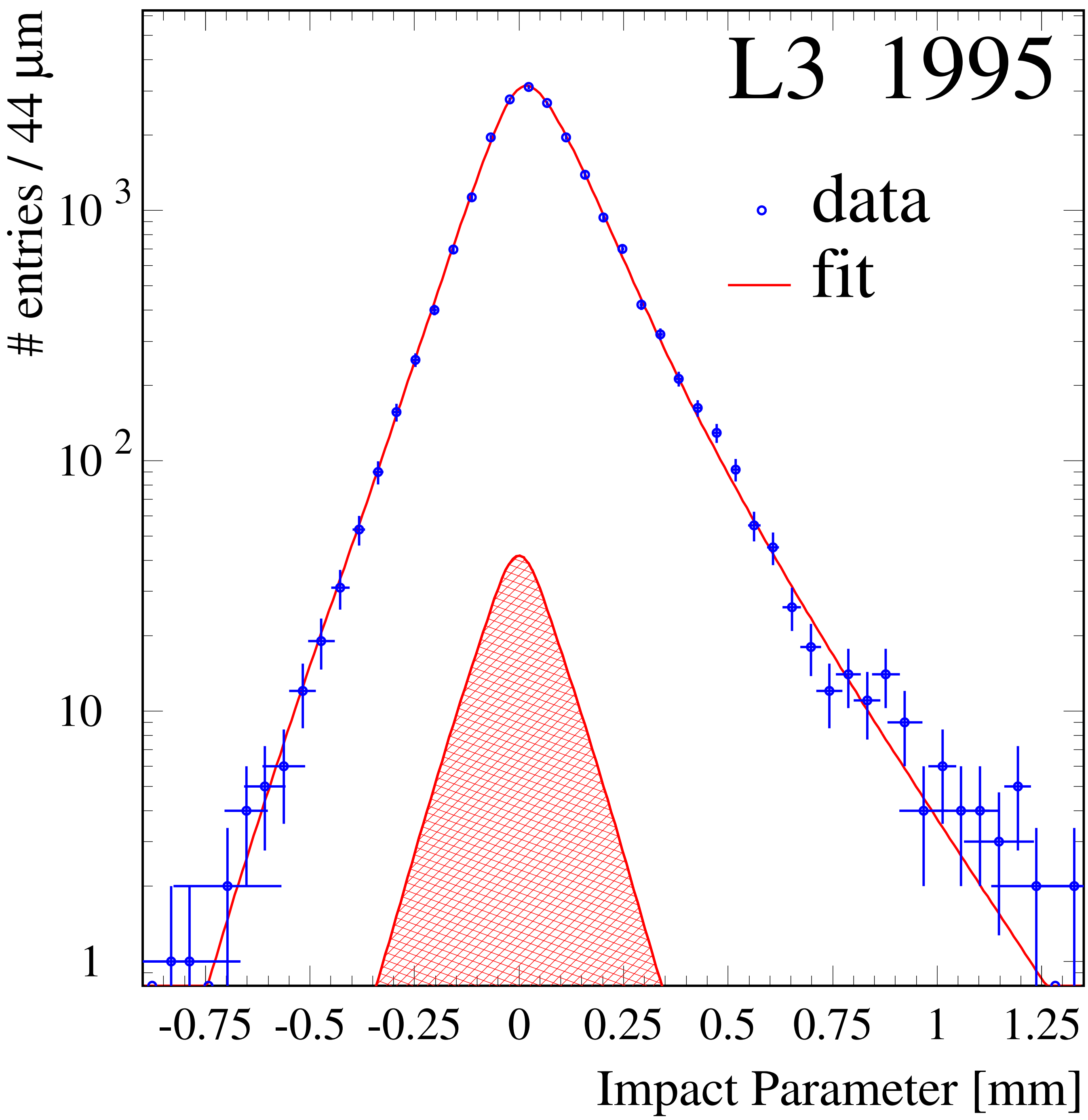
$$\mathbf{Pull} = \frac{\mathbf{IP}}{\sigma_{IP}}$$



Resolution function well described in terms of a double Gaussian

About 95% of the events in the Gaussian with $\sigma = 1$

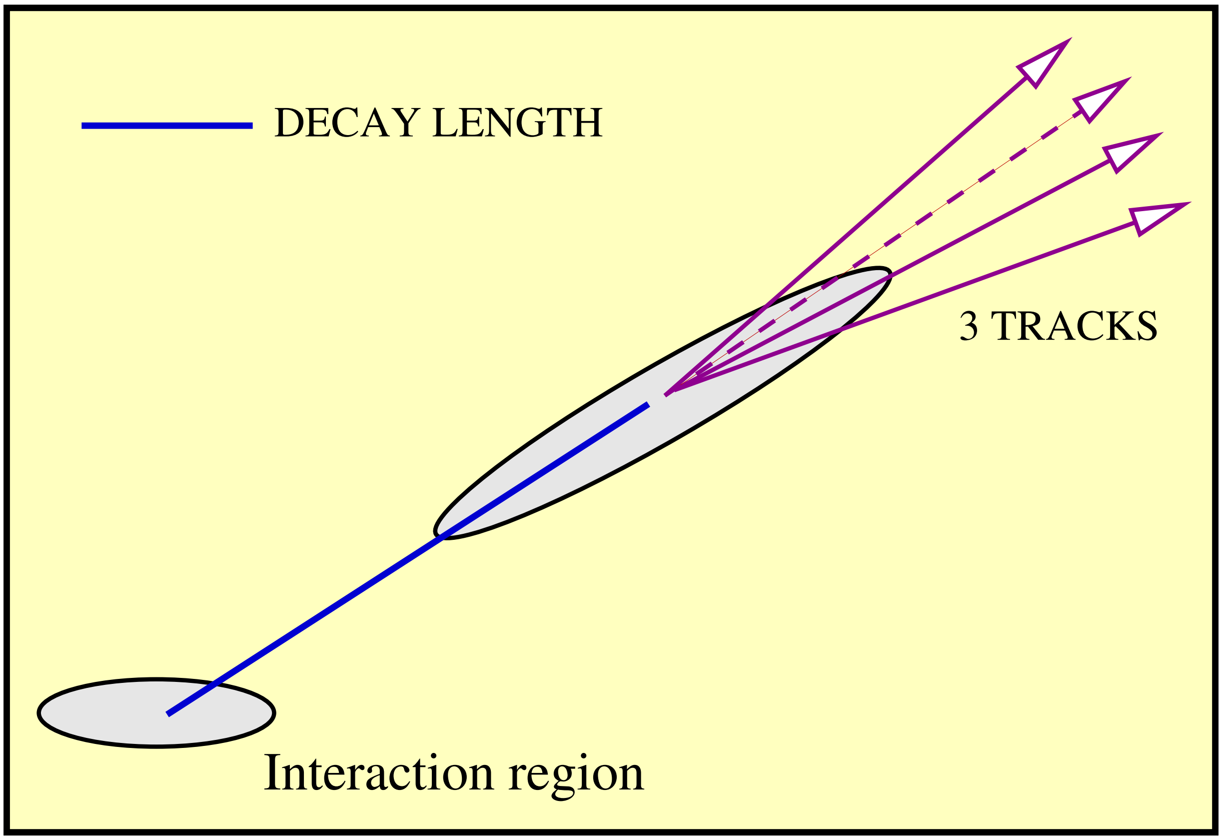
Result from 1994 and 1995 data: $N_\tau \; = \; 58\,656$



From 1-prong:

$$\tau_\tau = \mathbf{292.8 \pm 2.7\,(stat) \pm 2.0\,(syst)\;fs}$$

Decay length method



Use 3-prong tau decays

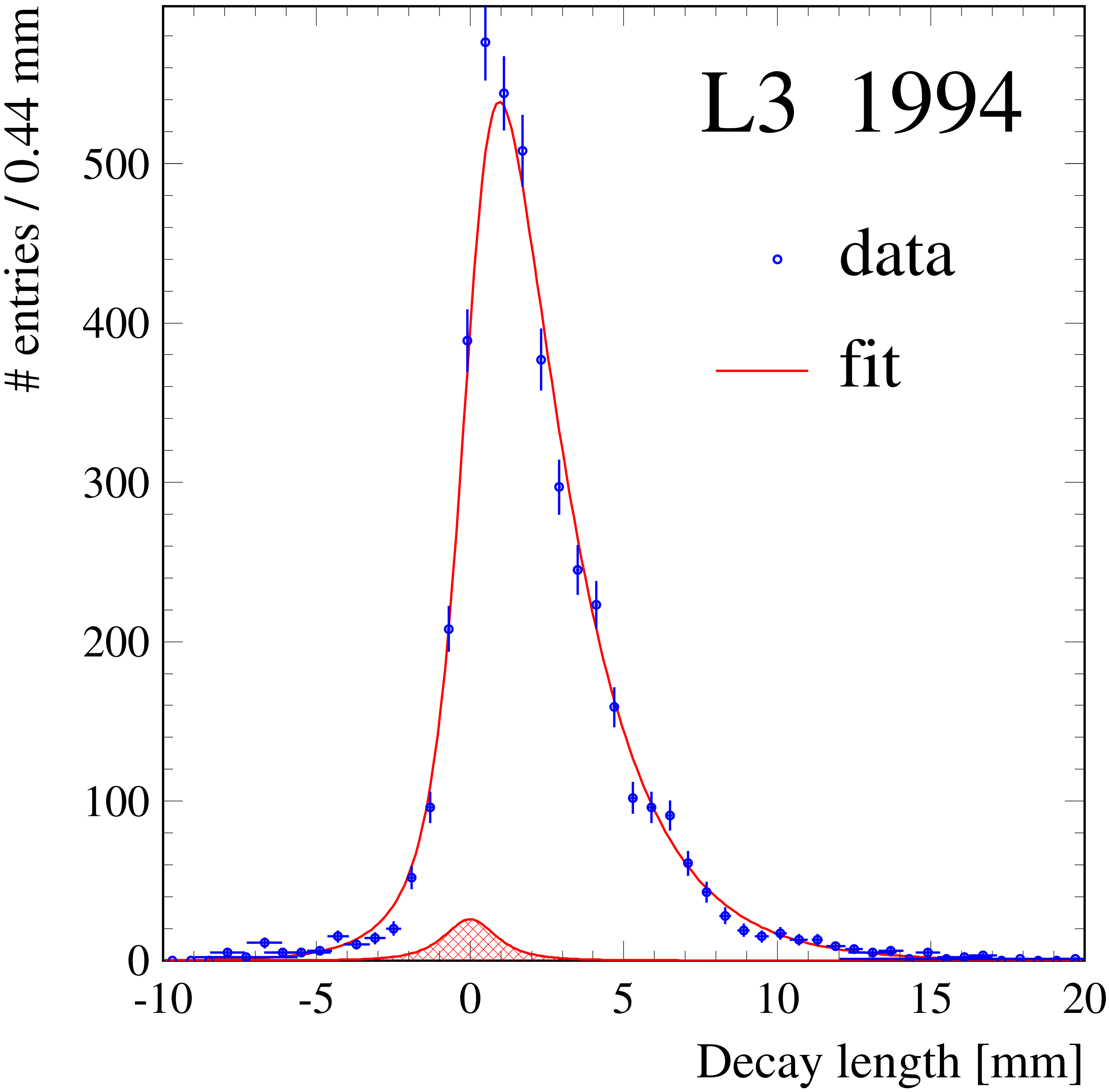
Secondary vertex from χ^2 minimisation:

$$\chi^2 = \sum_{i=1}^{3} \left(\frac{d_i}{\sigma_{d_i}} \right)^2 \quad \Longrightarrow \quad \tau_\tau = \frac{\langle L \rangle}{\beta\gamma c}$$

On average, decay length $\approx 2 \pm 1$ mm

Gaussian resolution from vertex fit

Result from 1994 and 1995 data: $N_\tau = 6620$



From 3-prong:

$$\tau_\tau = 292.9 \pm 3.9\,(\mathrm{stat}) \pm 1.9\,(\mathrm{syst})\ \mathrm{fs}$$

Tau lifetime

Combination of results from 1990 to 1995 data:

$$\tau_\tau = 293.2 \pm 2.0\,(\mathrm{stat}) \pm 1.5\,(\mathrm{syst})\ \mathrm{fs}$$

Systematic Errors

Source	Error (fs)	
	IP	DL
Method	0.2	0.5
Resolution function	1.1	1.5
SMD radius	0.7	0.7
Background estimate	0.5	0.8
Fit Range	0.5	1.0
Beam spot size	0.5	–
Underlying function	1.3	–
Systematic error	2.0	1.9
Statistical error	2.7	3.9

Leptonic branching ratios

Method (naively):

$$\mathcal{B}(\tau \to \ell \bar{\nu}_\ell \nu_\tau) = \frac{\tilde{N}_\ell}{\tilde{N}_\tau} \qquad \begin{array}{l} \longleftarrow \text{ produced leptons} \\ \longleftarrow \text{ produced taus} \end{array}$$

In reality:

Not all the $\tau\tau$ events are selected: $\varepsilon^{sel}_{\tau\tau}$

Not all the $\tau \to \ell \bar{\nu}_\ell \nu_\tau$ decays are selected/identified: ε^{sel}_ℓ, ε^{ID}_ℓ

The $\tau \to \ell \bar{\nu}_\ell \nu_\tau$ sample contains background from non $\tau\tau$ events (f^{bg}, f^{bg}_ℓ) and from other tau decays ($f_{\tau \nrightarrow \ell}$)

$$\mathcal{B}(\tau \to \ell \bar{\nu}_\ell \nu_\tau) = \frac{N_\ell (1 - f^{bg}_\ell - f_{\tau \nrightarrow \ell})}{N_\tau (1 - f^{bg})} \frac{1}{\varepsilon^{ID}_\ell} \frac{\varepsilon^{sel}_{\tau\tau}}{\varepsilon^{sel}_\ell}$$

Unbiased selection of $\tau \to \ell \bar{\nu}_\ell \nu_\tau$ decays: $\boxed{\dfrac{\varepsilon^{sel}_{\tau\tau}}{\varepsilon^{sel}_\ell} = 1}$

Event selection

Selection of $e^+e^- \longrightarrow \ell^+\ell^-(\gamma)$ events:

Events accepted in the barrel region only

Low track multiplicity

High acollinearity

Event divided in two hemispheres:

Tagging of $\tau^+\tau^-(\gamma)$ events in one hemisphere

Lepton identification in the other hemisphere

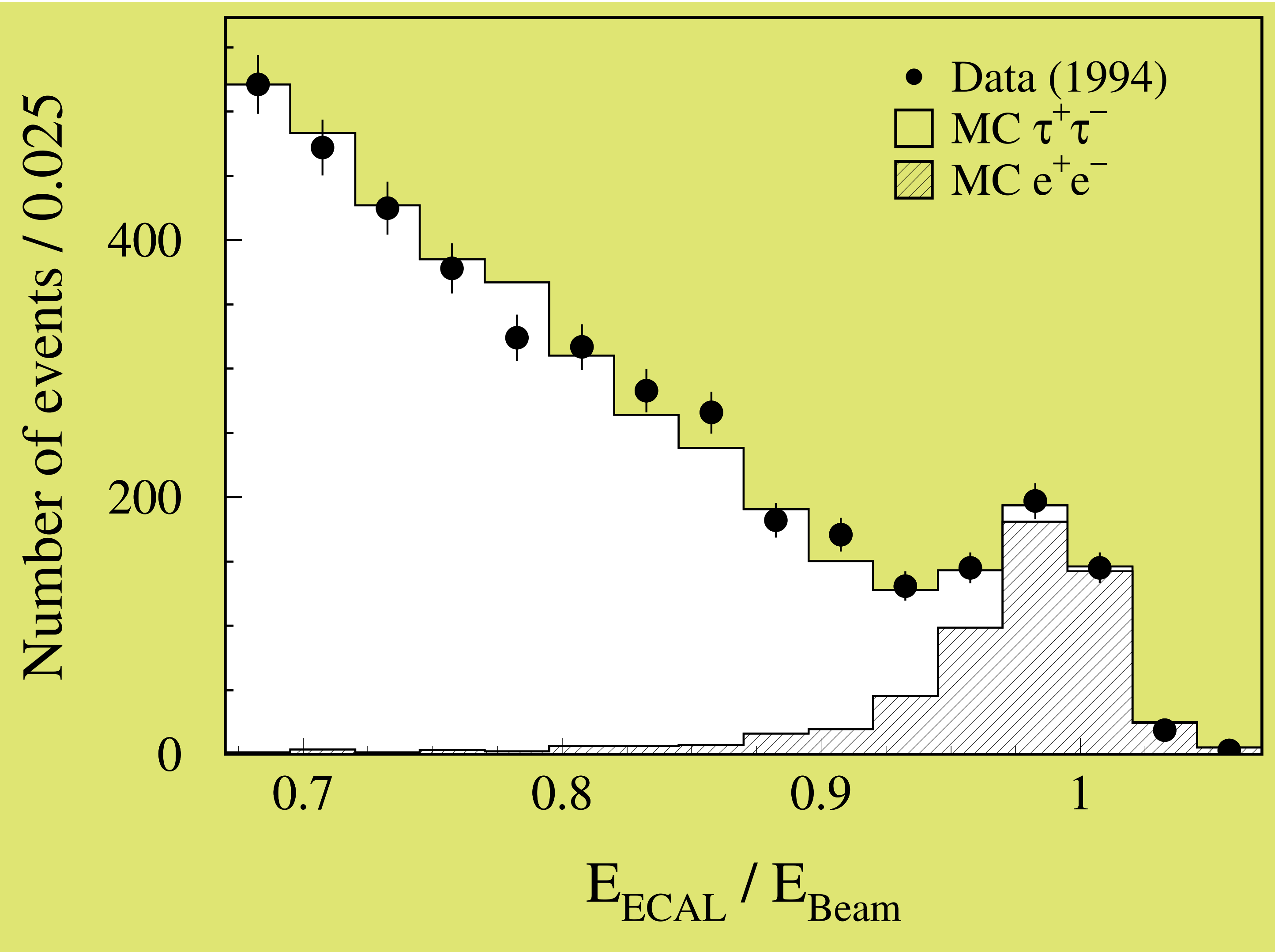
Efficiency $\sim 76\%$

This selection keeps $\dfrac{N_\ell}{N_\tau}$ unchanged

in the hemisphere under consideration

Background from non $\tau^+\tau^-$ events

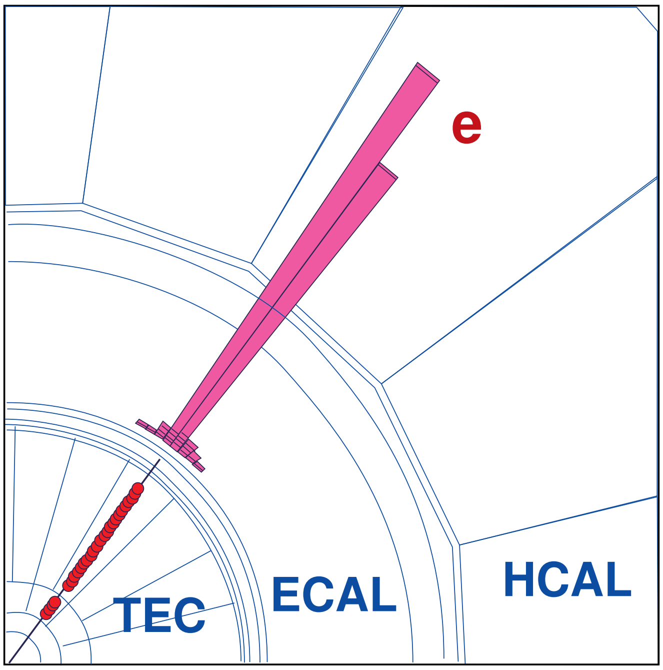
$e^+e^- \longrightarrow e^+e^-(\gamma)$



Background normalisation from data

Background shape from MC and a control data sample

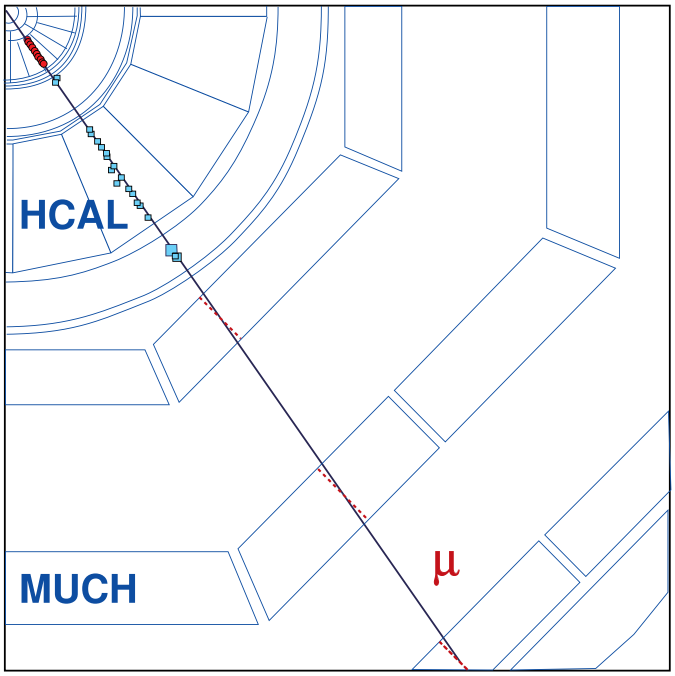
Lepton identification



electron:

- Energy and angular maching
  TEC and ECAL
- highly colimated shower

$$\varepsilon_e^{ID} \approx 90\%$$



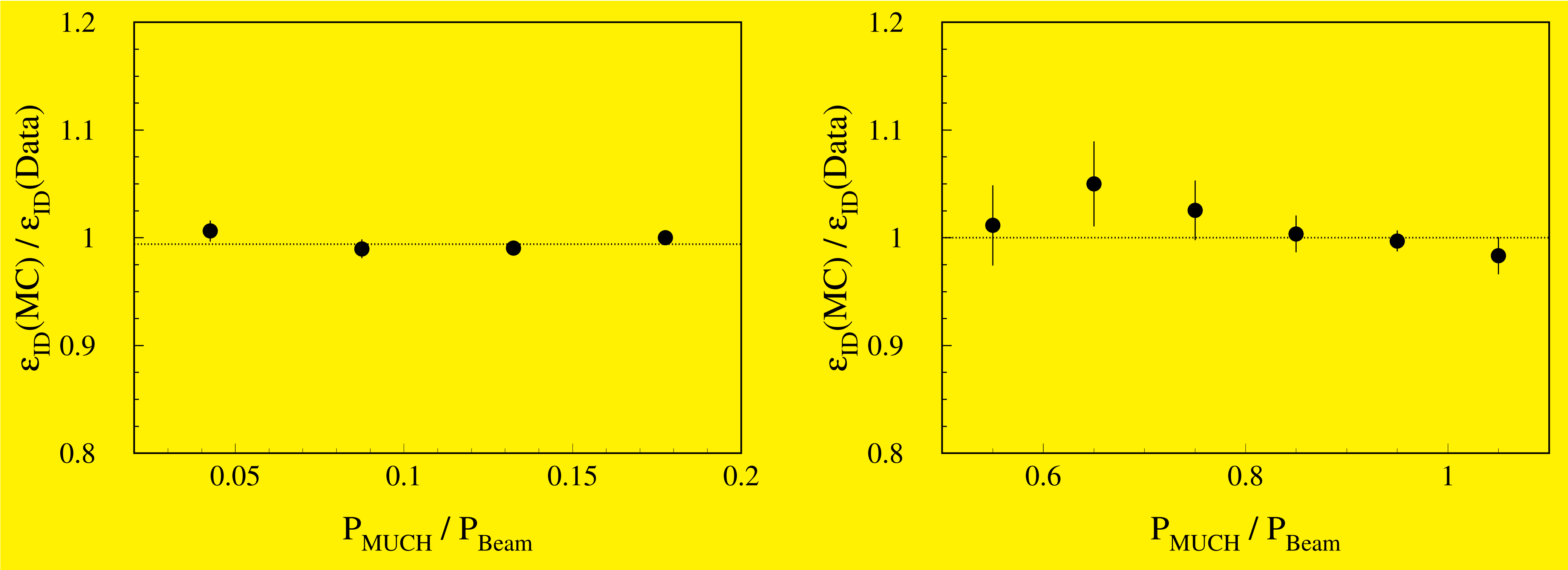
muon:

- Track in μ-chambers
- Angular matching
  TEC and μ-chambers
- MIP in calorimeters

$$\varepsilon_\mu^{ID} = 75\%$$

Identification efficiency

$e^+e^- \to e^+e^-\mu^+\mu^-$ $\qquad\qquad$ $e^+e^- \to \mu^+\mu^-(\gamma)$



A correction ($\simeq 1$) is applied to $\varepsilon_{\rm ID}(\rm MC)$

Data sample: $\tau \longrightarrow \ell\bar{\nu}_\ell\nu_\tau$

Analysis is done for each year separately

Example, numbers for 1994 analysis:

Selected τ decays: $N_\tau = 65\,392$

Background: $f^{bg} = 2.7 \pm 0.1\ (\%)$

N_e	9754
ε_e^{ID}	$83.86 \pm 0.17\ (\%)$
f_e^{bg}	$1.32 \pm 0.19\ (\%)$
$f_{\tau \not\rightarrow e}$	$1.70 \pm 0.10\ (\%)$

N_μ	8554
ε_μ^{ID}	$75.10 \pm 0.17\ (\%)$
f_μ^{bg}	$1.11 \pm 0.09\ (\%)$
$f_{\tau \not\rightarrow \mu}$	$1.44 \pm 0.09\ (\%)$

Results

$$\mathcal{B}(\tau \longrightarrow \mathrm{e}\bar{\nu}_{\mathrm{e}}\nu_\tau) = (17.806 \pm 0.104\,(\mathrm{stat}) \pm 0.076\,(\mathrm{syst}))\ \%$$

$$\mathcal{B}(\tau \longrightarrow \mu\bar{\nu}_{\mu}\nu_\tau) = (17.342 \pm 0.110\,(\mathrm{stat}) \pm 0.067\,(\mathrm{syst}))\ \%$$

Systematic Errors

Evaluated for each year separately. The numbers for 1994 are:

Source	$\mathcal{B}(\tau \longrightarrow e\bar{\nu}_e\nu_\tau)$	$\mathcal{B}(\tau \longrightarrow \mu\bar{\nu}_\mu\nu_\tau)$
Preselection	0.040	0.031
Selection of $e^+e^- \longrightarrow \tau\tau(\gamma)$	0.026	0.029
Background	0.031	0.021
Identification Eff. correction	0.041	0.048
Lepton energy range	0.054	0.028
Monte Carlo statistics	0.053	0.057
Total uncertainty	0.103	0.093

Lepton universality

From $\mathcal{B}(\tau \longrightarrow e\bar{\nu}_e\nu_\tau)$ and $\mathcal{B}(\tau \longrightarrow \mu\bar{\nu}_\mu\nu_\tau)$:

$$\frac{g_\mu}{g_e} = 1.0007 \pm 0.0051$$

supporting e–μ universality. Under this assumption we get:

$$\mathcal{B}(\tau \longrightarrow \ell\bar{\nu}_\ell\nu_\tau) = (17.818 \pm 0.094)\ \%$$

taking into account the correlations.

From $\mathcal{B}(\tau \longrightarrow e\bar{\nu}_e\nu_\tau)$, $\mathcal{B}(\tau \longrightarrow \mu\bar{\nu}_\mu\nu_\tau)$, τ_τ and τ_μ we obtain:

$$g_\tau/g_e = 0.996 \pm 0.006 \qquad ; \qquad g_\tau/g_\mu = 0.996 \pm 0.006$$

supporting τ–e and τ–μ universality.

Determination of α_s

Two *independent* measurements of R_τ and $\alpha_s(m_\tau)$

From the τ lifetime:

$$R_\tau = \left(\frac{m_\mu}{m_\tau}\right)^5 \frac{\tau_\mu}{\tau_\tau} - C$$

$$R_\tau = 3.595 \pm 0.048$$

$$\alpha_s(m_\tau^2) = 0.319 \pm 0.015\,(\mathrm{exp}) \pm 0.014\,(\mathrm{theory})$$

From the leptonic branching ratios:

$$R_\tau = \frac{1}{\mathcal{B}(\tau \to \ell\bar{\nu}_\ell\nu_\tau)} - C$$

$$R_\tau = 3.640 \pm 0.030$$

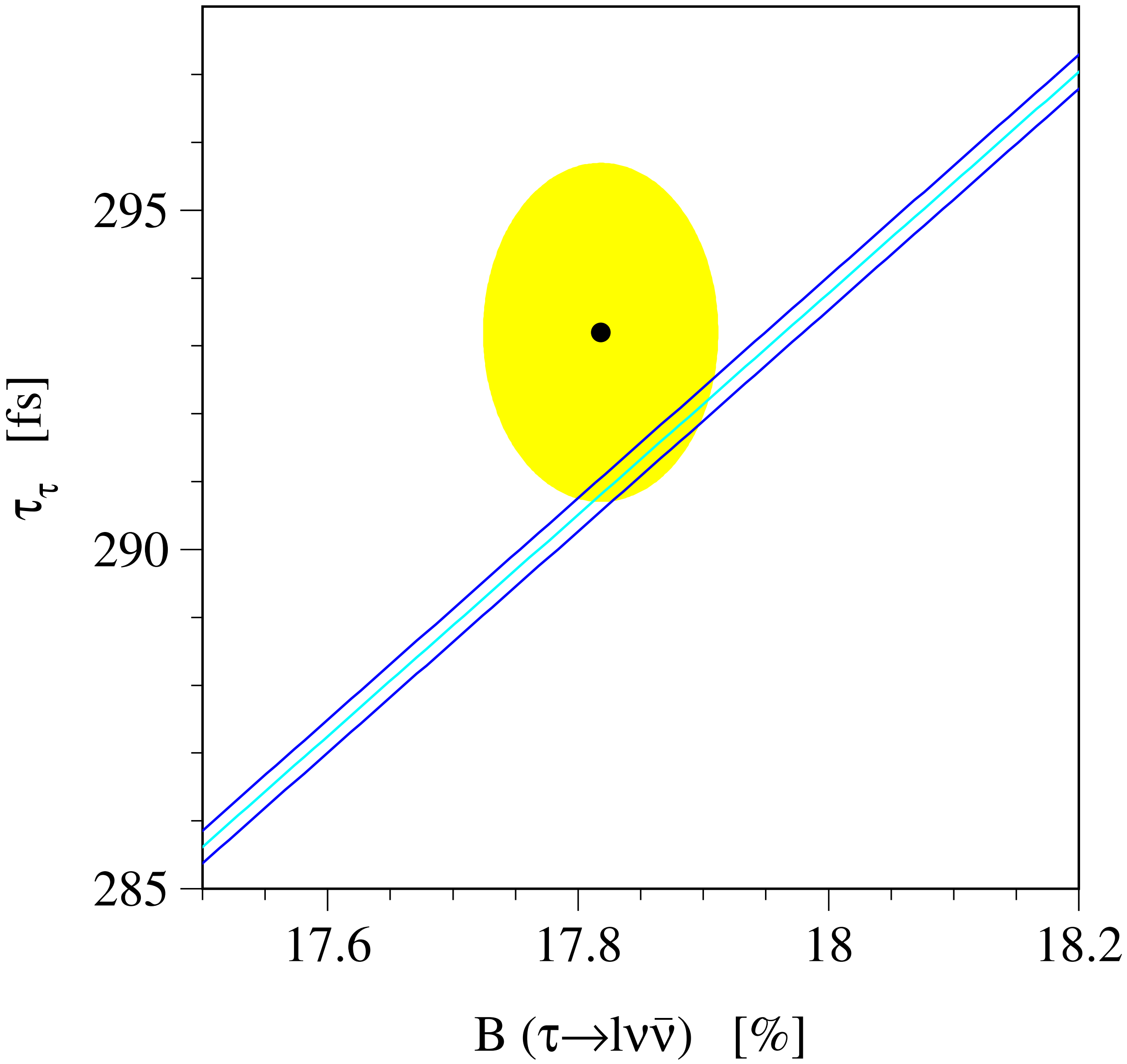
$$\alpha_s(m_\tau) = 0.332 \pm 0.009\,(\mathrm{exp}) \pm 0.015\,(\mathrm{theory})$$

Both values of $\alpha_s(m_\tau)$ give almost the same value of $\alpha_s(m_Z)$:

$$\boxed{\alpha_s(m_Z) = 0.119 \pm 0.002}$$

From hadrons: $\alpha_s(m_Z) = 0.1207 \pm 0.0016 \pm 0.0066$

Determination of G_F



τ_τ **and** $\mathcal{B}(\tau \to \ell \bar{\nu}_\ell \nu_\tau)$ **provide a measurement of** G_F**:**

$$G_F = (1.1615 \pm 0.0046) \times 10^{-5}\ \mathrm{GeV}^{-2}$$

in agreement with G_F **from** τ_μ**.**