Minireview on lepton flavor violation at e^+e^- colliders

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31st International Conference on High Energy Physics

Amsterdam, July 24 – 31, 2002

Outline

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$\sqrt{s}$ =189-209 GeV at OPAL

5. Summary

1. Introduction

-In the SM of electroweak theory, the lepton flavor symmetries are conserved

-In many extensions of the SM, such as SUSY,GUT, left-right symmetric models ,lepton flavor symmetries speculated to be violated

-Some theorists predicted LFV decay branching-ratio of vector bosons(ϕ,J/Ψ,Υ, Z^0) in recent years

-Super-Kamiokande and SNO experimental results indicates strongly $m_\nu \neq 0$, and mix with each others.

Experimental status

-Experimentally, no evidence for direct LFV has been reported so far.

-Upper bounds for muon decays are BR($\mu^- \rightarrow e^- \gamma$)< 1.2x$10^{-11}$ and BR($\mu^+ \rightarrow e^+e^+e^-$)<$10^{-12}$

-Searches for neutrinoless τ decays such as $\tau^+ \rightarrow e^+e^+e^-$ and $\tau^+ \rightarrow \mu^+\mu^+\mu^-$ yield upper limit BR($Z \rightarrow e\,\tau$)<5.4x$10^{-5}$and BR($Z \rightarrow \mu\,\tau$) <7.1x10^{-5}(90% CL)

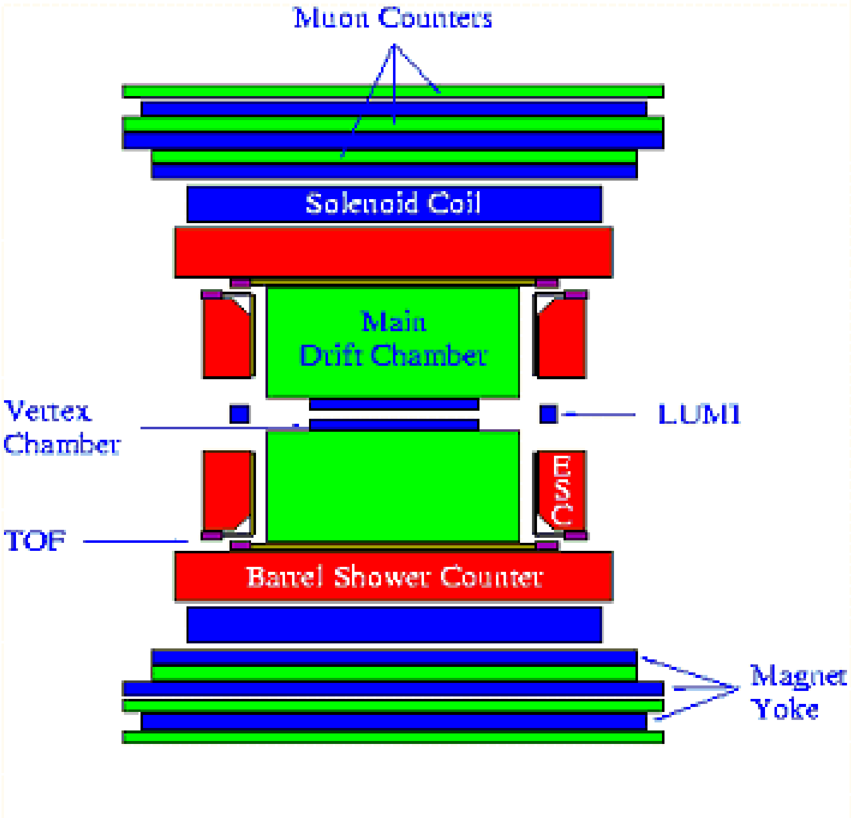
-Direct searches at the Z peak performed by the LEP experiments yielded 95% CL limits BR($Z \rightarrow e\,\mu, \mu\,\tau, e\,\tau$)<O(1)x$10^{-5}$

-No results reported yet about searching for J/Ψ and $\Upsilon \rightarrow e\,\mu, \mu\,\tau, e\,\tau$.

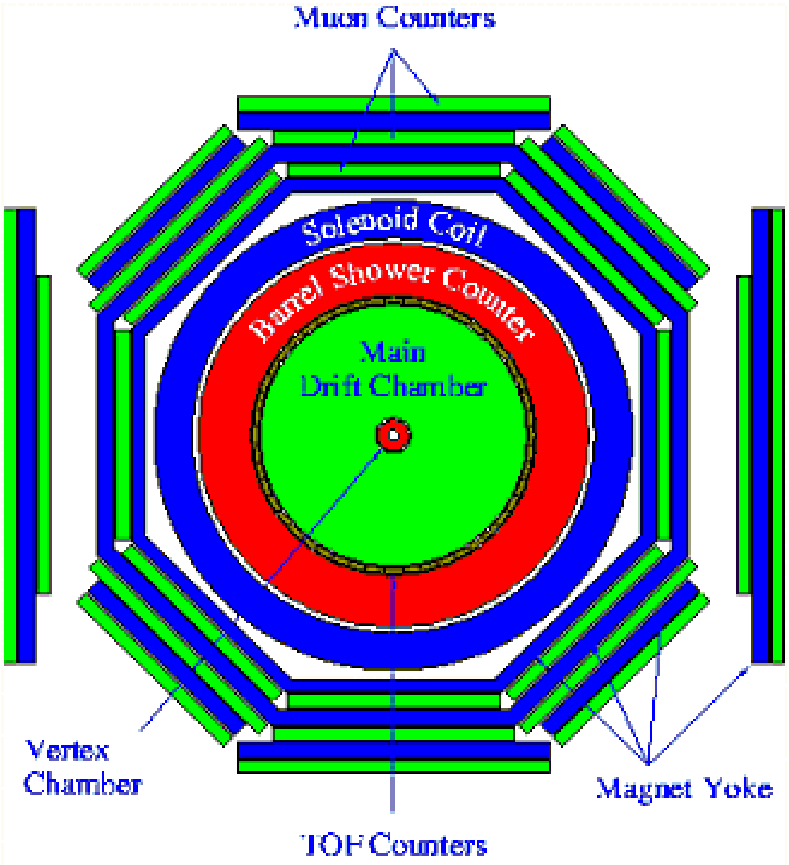
Table 1. Theoretical limits and predictions on BR

Boson	Mode	Theoretical limits (Peccei, Nussinov and Zhang, PRD63 ,016003 ,2001)	Theoretical Predictions (Leptoquark model, SUSY model, Huo, Feng, Yue and Zhang
J/Ψ(1S)	$\mu\,\tau$	< 6x10^{-7}	3x10^{-8}
	$e\,\tau$	<6x10^{-7}	3x10^{-8}
	$e\,\mu$	<4x10^{-13}	1.1x10^{-12}
Υ(1S)	$\mu\,\tau$	< 10^{-2}	1.3x10^{-7}
	$e\,\tau$	<10^{-2}	1.3x10^{-7}
	$e\,\mu$	<2x10^{-9}	4.1x10^{-12}

BESII Detector (upgraded during 1995-1997)



Side view of the BES detector



End view of the BES detector

VC: $\sigma_{xy} = 100\ \mu m$
MDC: $\sigma_{xy} = 200\ \mu m$
$\sigma_{dE/dx} = 8.4\ \%$
$\Delta p/p = 1.8\sqrt{(1+p^2)}$

TOF: $\sigma_T = 180$ ps
BSC: $\Delta E/\sqrt{E} = 22\ \%$
$\sigma_\phi = 7.9$ mr
$\sigma_z = 2.3$ cm

μ counter: $\sigma_{r\phi} = 3$ cm
$\sigma_z = 5.5$ cm
B field: 0.4 T
Dead time/event: 10 ms

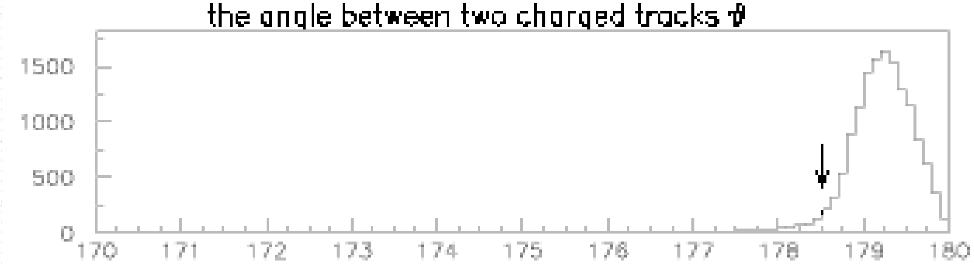
2.Search for LFV in J/Ψ —> eμ at BES

We have had the largest sample(5.8×10^7) of J/Ψ in the world (BESII), so we trust we can obtain more accurate conclusion about LFV in the J/Ψ decay.

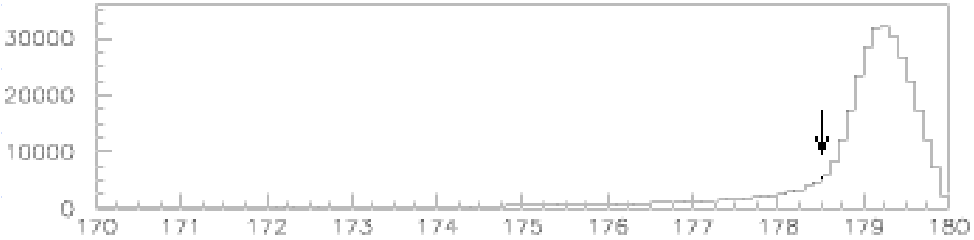
2.1 Event selection

1. $N_{chrg} = 2, \sum Q = 0, N_{neu} \leq 4$
2. For charged tracks:
   - mfit=2 or –19
   - polar angle: $|\cos\theta| \leq 0.8$
   - vertex: $|x| \leq 1.5cm, |y| \leq 1.5cm, |z| \leq 15cm$
   - the angle between two charged tracks, $\theta_{12} > 178.5^\circ$ (see Fig.1)
3. to reject cosmic ray, $|T_1 - T_2| \prec 1.2\ ns$

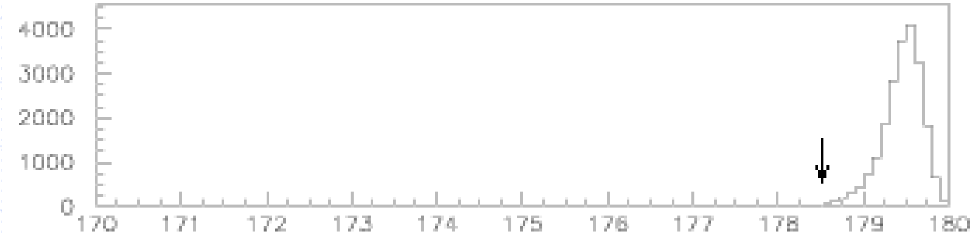
the angle between two charged tracks ϑ



J/ψ → μμ(data)



J/ψ → ee(data)



J/ψ → eμ(MC)

Figure 1: the angle between two charged tracks θ_{12}

4. the invariant mass of two charged tracks

$2.95 < M_{e\mu} < 3.25\ GeV/c^2$

(see Fig.2)

5. the momentum of charge tracks,

1.45<P<1.65GeV/c (see Fig.2)

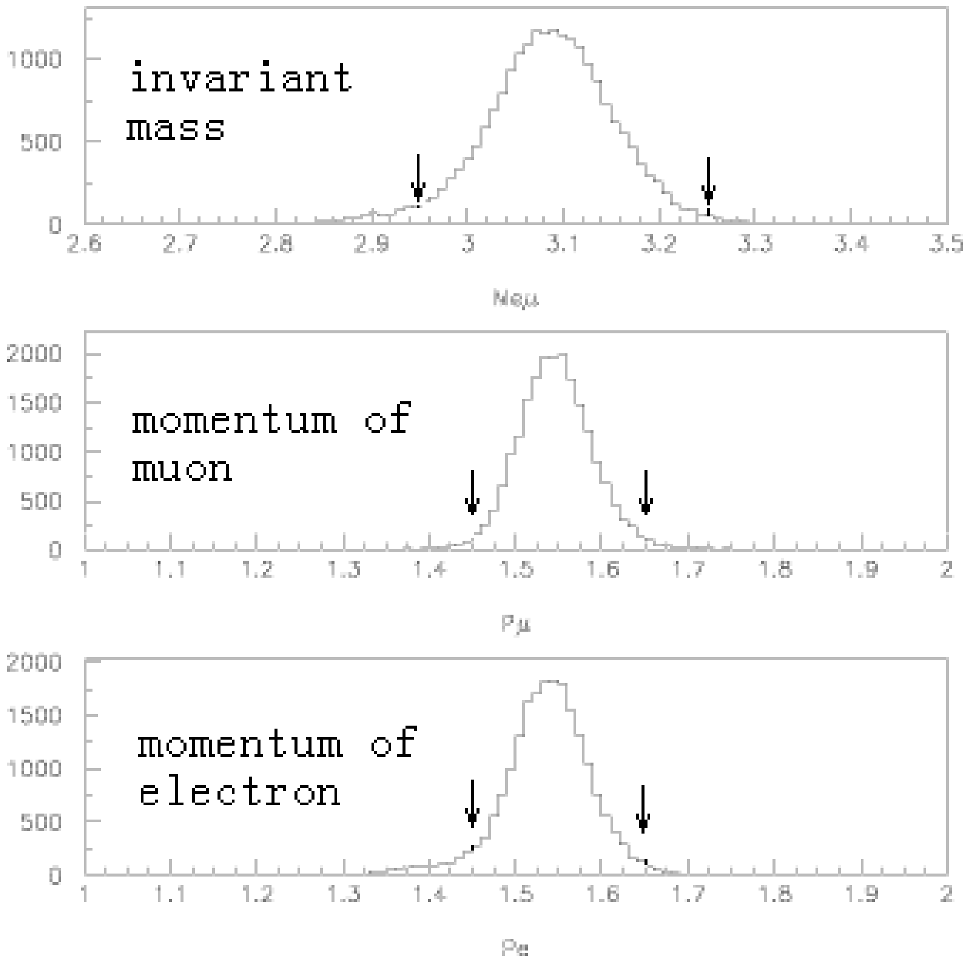


Figure2 : the invariant mass of electron and muon and the momenta of electron and muon. MC

6 • particle identification

- identify e: E/P>0.7(see Fig.3),μ_{hit}=0
- identify μ: E/P<0.3(see Fig.3), μ_{hit} must pass P_{xy} and δ cuts

P_{xy} (GeV/c)	μ_{hit}
$P_{xy}<0.75$	$\mu_{hit} \geq 1$
$0.75<P_{xy}<0.95$	$\mu_{hit} \geq 2$
$P_{xy}>0.95$	$\mu_{hit} = 3$

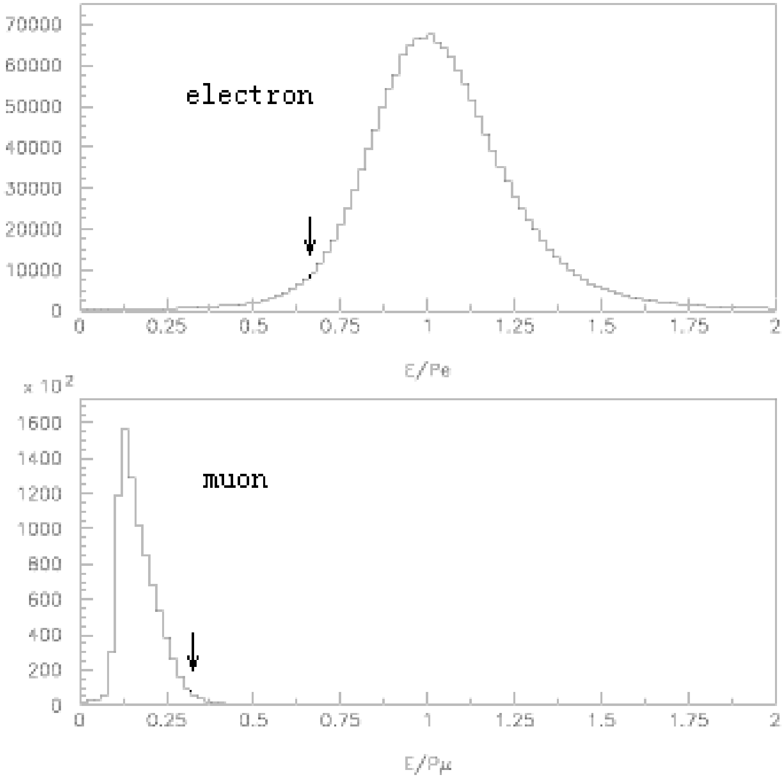


Figure 3: E/P of electron and muon

7.For neutral track,cuts for isolated photon are

- $E_{sc} \geq 50\ MeV$
- $\theta_{\gamma c} > 15^\circ$
- $\alpha < 18^\circ$

we need no isolated photon.

The list of main cuts(about 58M J/Ψ events)

cuts	**Surviving events**
$N_{chrg} = 2$	38045098
Vertical cuts and M_fit=2 or -19	16119944
$\Sigma Q_i = 0$	15878836
$1.45 < P < 1.65$GeV/c	4114702
$\lvert\cos\theta\rvert < 0.8$	3963145
$\theta_{12} > 178.5^0$	1947195
Reject cosmic ray	1843853
$N_{iso} = 0$	1799597
One of two track is identified as μ	152820
The other is identified as e	4
$2.95 < M_{e\mu} < 3.25$GeV/c^2	4

2.2 Background Analysis

Since the information of e, μ, π and K in BSC and μ counter could not be simulated with MC well, it is necessary to select sample of e, μ, π and K to study their performance in the sub-detectors:

- e sample was selected from $J/\Psi \to ee(\gamma)$ and $ee \to ee(\gamma)$ with $\mu_{hit} = 0, E/P > 0.7$
- μ sample was selected from $J/\Psi \to \mu\mu$ with $E/P < 0.3$, μ_{hit} must pass P_{xy} and δ cuts.
- π sample was selected from $J/\Psi \to \rho^{\pm}\pi^{\mp}$
- K sample was selected from $J/\Psi \to K^{*\pm}K^{\mp}$

Then we obtained the detection efficiency and misidentification for each other,they are listed in the following table.

The detection/misidentification

	Identified as e	Identified as μ
e sample	95.3%	$6.29\text{X}10^{-7}$
μ sample	0	19.0%
π sample	3.6%	0.46%
K sample	3.11%	0.38%

The selection efficiency of J/Ψ→eμ:

J/Ψ→eμ:

$\varepsilon_{e\mu} = \varepsilon_{\mu\to\mu} \times \varepsilon_{e\to e} \times \varepsilon_{e\mu\to MC} = 11.0\%$

The mixing with background channel:

J/Ψ→ee:

$\varepsilon_{ee} = \varepsilon_{e\to e} \times \varepsilon_{e\to\mu} \times \varepsilon_{ee\to MC} \times 2 = 7.37 \times 10^{-7}$

J/Ψ→μμ:

$\varepsilon_{\mu\mu} = \varepsilon_{\mu\to\mu} \times \varepsilon_{\mu\to e} \times \varepsilon_{\mu\mu\to MC} \times 2 = 0$

J/Ψ→ππ:

$\varepsilon_{\pi\pi} = \varepsilon_{\pi\to\mu} \times \varepsilon_{\pi\to e} \times \varepsilon_{\pi\pi\to MC} \times 2 = 1.51 \times 10^{-4}$

J/Ψ→KK:

$\varepsilon_{KK} = \varepsilon_{K\to\mu} \times \varepsilon_{K\to e} \times \varepsilon_{KK\to MC} \times 2 = 1.75 \times 10^{-5}$

ee→eeγ:

$\varepsilon_{ee\gamma} = \varepsilon_{e\to e} \times \varepsilon_{e\to\mu} \times \varepsilon_{ee\gamma\to MC} \times 2 = 3.90 \times 10^{-7}$

* $\varepsilon_{e\mu}$ is the selected efficiency of J/Ψ→eμ.

•ε_{ee}, $\varepsilon_{\mu\mu}$, $\varepsilon_{\pi\pi}$, ε_{KK} and $\varepsilon_{ee\gamma}$ is the rate of background channel misidentified as J/Ψ→eμ respectively.

$\varepsilon_{e\mu\to MC}$ is the selection efficiency of J/Ψ→eμ with MC(but BSC and μ counter),and other $\varepsilon_{bg.\to MC}$ are the mixing from background channels with MC(but BSC and μ counter)

2.3 Result

- The upper limit of BR($J/\Psi \to e\mu$) with 58 M J/Ψ sample at BES could be got: $Br < \lambda(N_{OB})/[N_T \varepsilon_{J/\Psi \to e\mu}]$
- Now the analysis of $J/\Psi \to \mu\,\tau$, $e\,\tau$ is going on

	Background, candidates and Upper limit
$J/\psi \to ee$	2.55
$J/\psi \to \mu\mu$	0
$J/\psi \to \pi\pi$	1.29
$J/\psi \to KK$	0.24
$e^+e^- \to e^+e^-\gamma$	1.15
Total number of backgrounds	**5.23**
$J/\psi \to e\mu$	**4**
The upper limit (conservatively calculated with 0 background)	**$1.35\mathrm{X}10^{-6}$(90% C.L)**

3.New results on rare leptonic B decays and $\tau \to \mu\gamma$ at BaBar

3.1 Analysis Strategy for $B^- \to K^- \nu\bar{\nu}$

- Tag one B, $B^+ \to \overline{D}^0 l^+ \nu(X)$

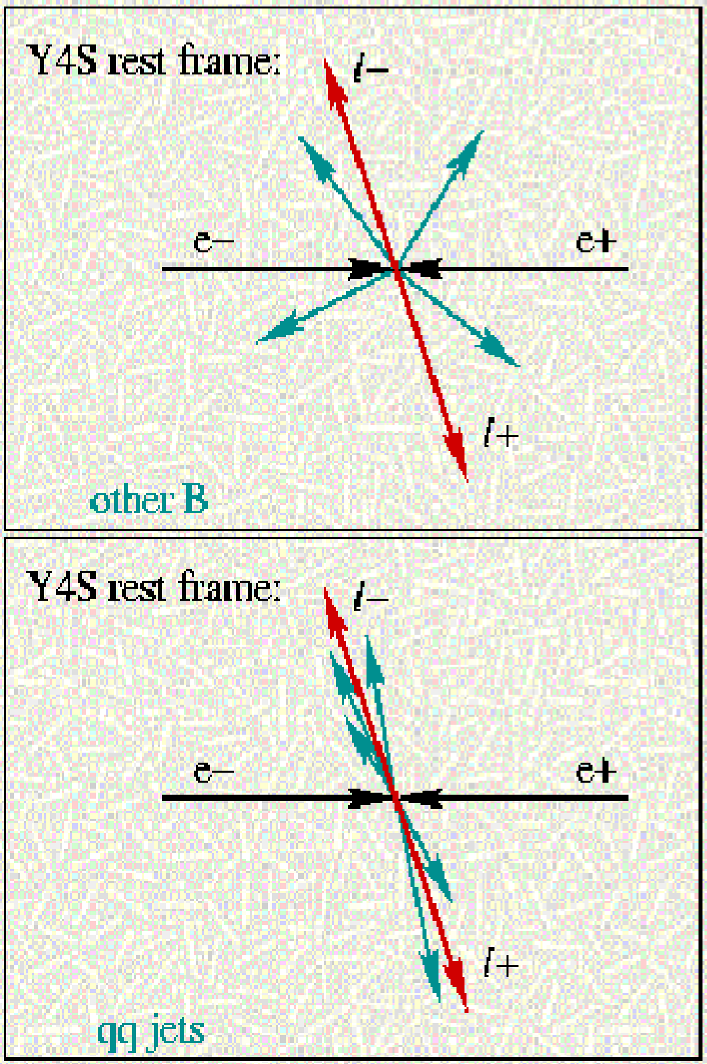
$\overline{D}^0$ modes	D^* modes
$\overline{D}^0 \to K^+\pi^-$	$\overline{D}^{*0} \to \overline{D}^0\gamma$
$\overline{D}^0 \to K^+\pi^-\pi^-\pi^+$	$\overline{D}^{*0} \to \overline{D}^0\pi^0$
$\overline{D}^0 \to K^+\pi^-\pi^0$	$D^{*-} \to \overline{D}^0\pi^-$

- Remove the daughters of the tagged B from the event
- Veto events with more than one charged track
- Attributed the remaining particles with the signature expected from $B^- \to K^- \nu\bar{\nu}$
- No background subtraction applied for UL

This method yield 0.5% of B^+ decays reconstructed as tags
The tagging efficiency was corrected using a double tags sample.

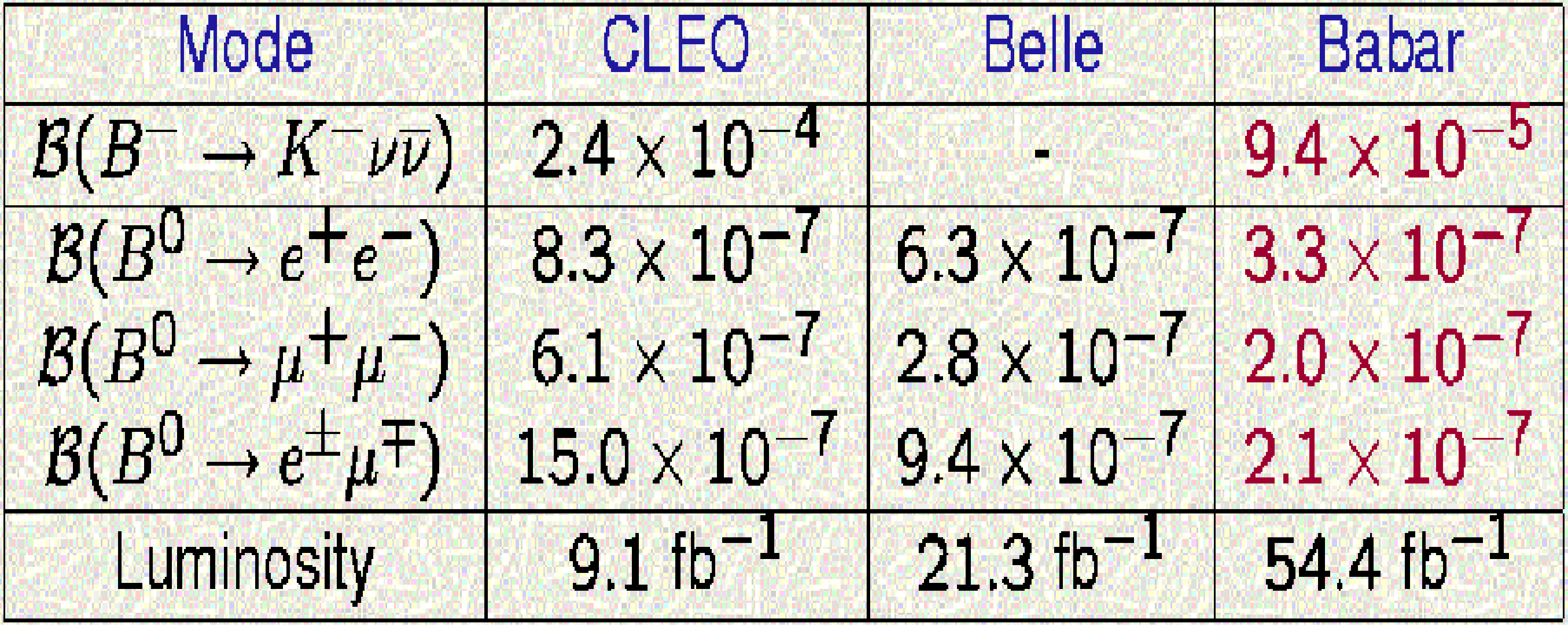
3.2 Analysis Strategy $B^0 \to l^+l^-$

- Reconstruct the signal B with two high momentum leptons
- Apply cuts to suppress the background
- Estimate the background in signal box
  - Fit the data in the sidebands
  - Normalization from data
- No background subtraction applied for Upper limit



3.3 BaBar Results for the Rare B Decays

- The Upper Limits values for the BR of $B^0 \to l^+ l^-$ and $B^- \to K^- \nu \bar{\nu}$ at 90% CL are:



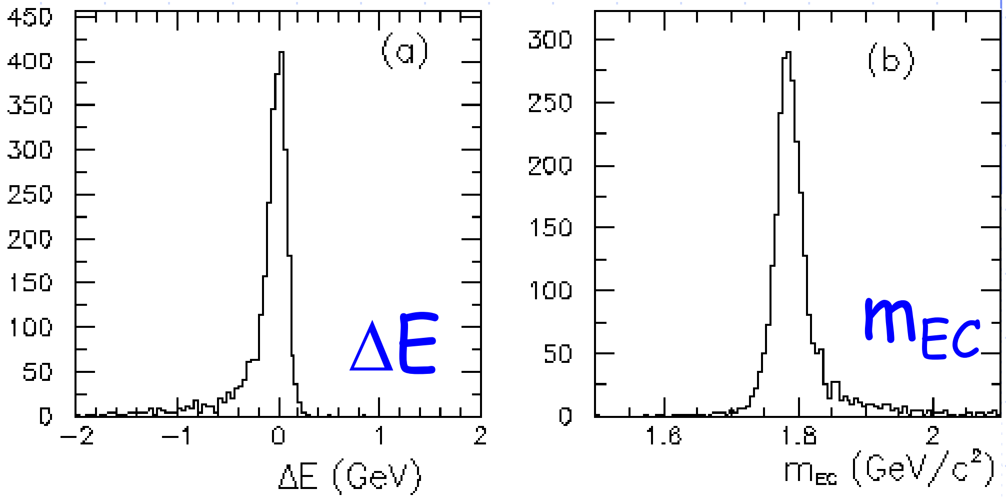
Mode	CLEO	Belle	Babar
$\mathcal{B}(B^- \to K^- \nu \bar{\nu})$	2.4×10^{-4}	-	9.4×10^{-5}
$\mathcal{B}(B^0 \to e^+ e^-)$	8.3×10^{-7}	6.3×10^{-7}	3.3×10^{-7}
$\mathcal{B}(B^0 \to \mu^+ \mu^-)$	6.1×10^{-7}	2.8×10^{-7}	2.0×10^{-7}
$\mathcal{B}(B^0 \to e^\pm \mu^\mp)$	15.0×10^{-7}	9.4×10^{-7}	2.1×10^{-7}
Luminosity	$9.1\ \mathrm{fb}^{-1}$	$21.3\ \mathrm{fb}^{-1}$	$54.4\ \mathrm{fb}^{-1}$

3.4 Search for $\tau \rightarrow \mu\gamma$ at *BABAR* *(Roney,PA Session HQ-4)*

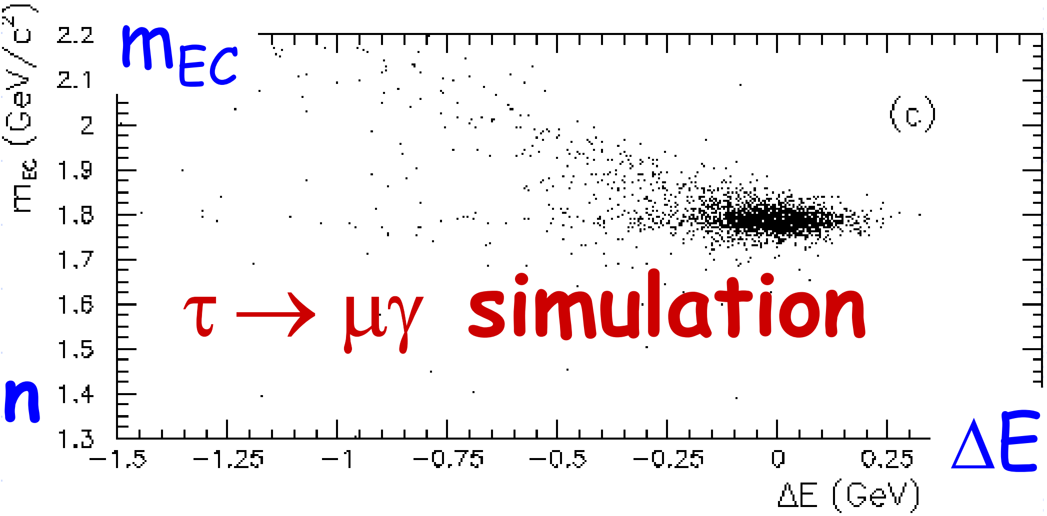
Signature of $\mu\gamma$ signal:

mass of τ

energy ~ beam energy



beam-energy constrained mass: m_{EC}



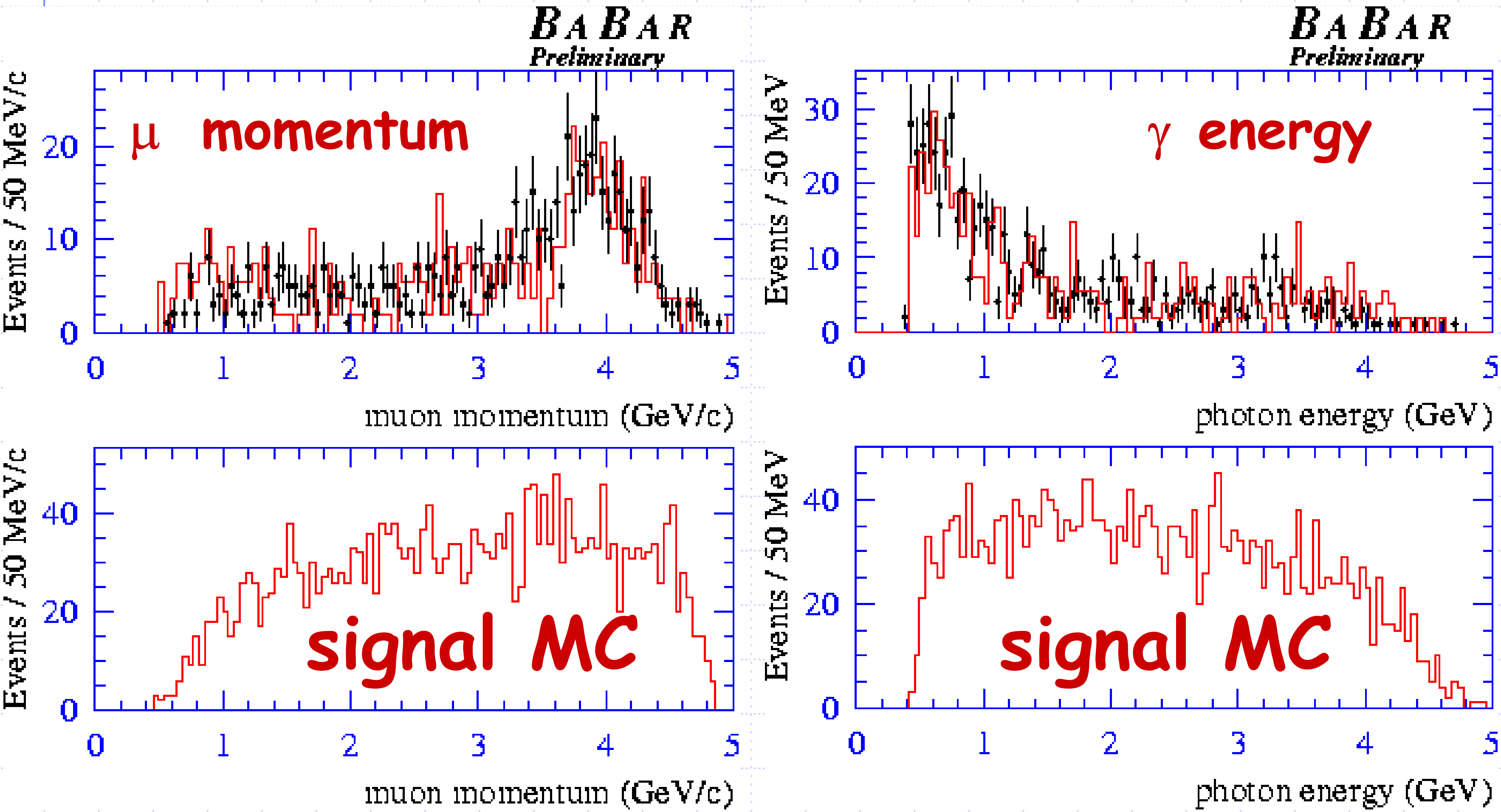
$\tau \rightarrow \mu\gamma$ **simulation**

$\Delta E = E_{\mu\gamma} - E_{beam} \sim 0$

in absence of radiation

Signal Selection:

Efficiency using signal simulation with corrections from data control samples. Also, Grand Side Band events have nearly identical signature as signal →obs./expected=1.022±0.069±0.025



Limit

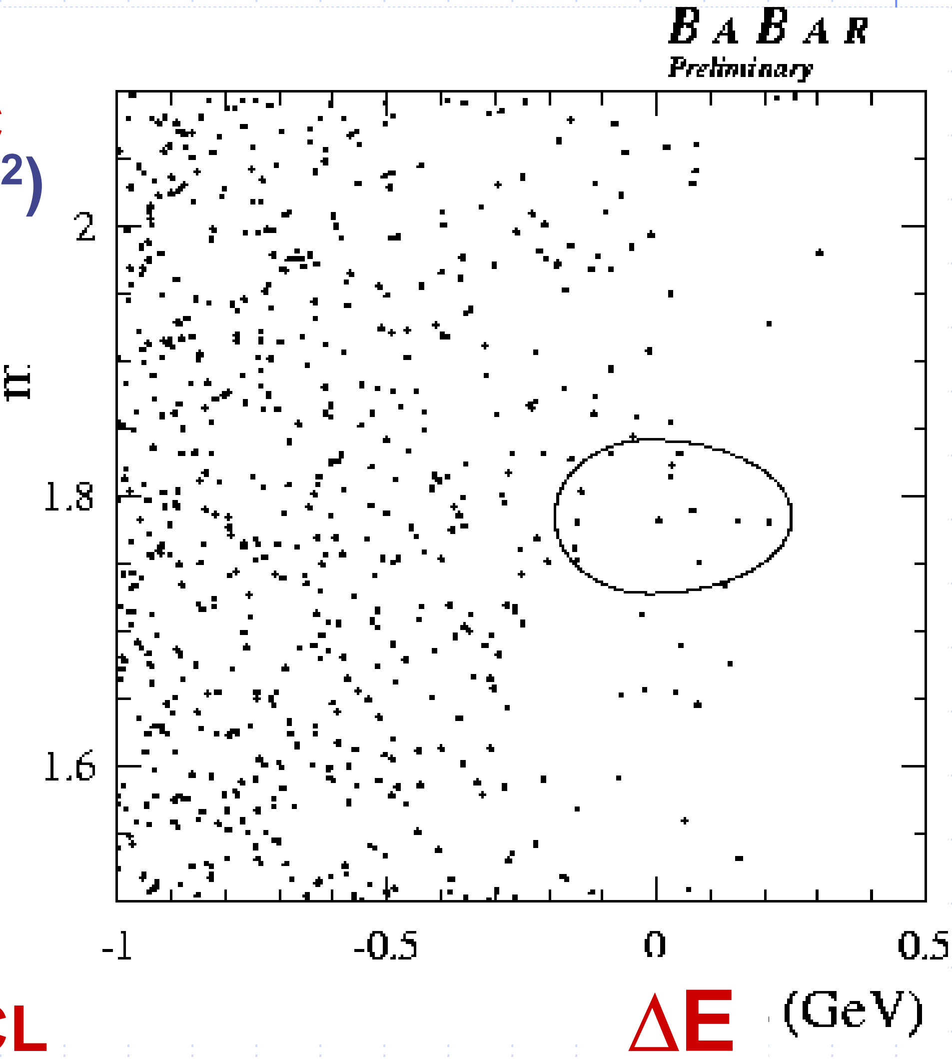
- 13 observed
- 7.8±1.4 events expected

Prob. of 7.8±1.4 events fluctuating to 13 or more in absence of signal is 7.6%.

efficiency = 5.2 ± 0.1 ± 0.5%

$N_{\tau\tau}$=56million

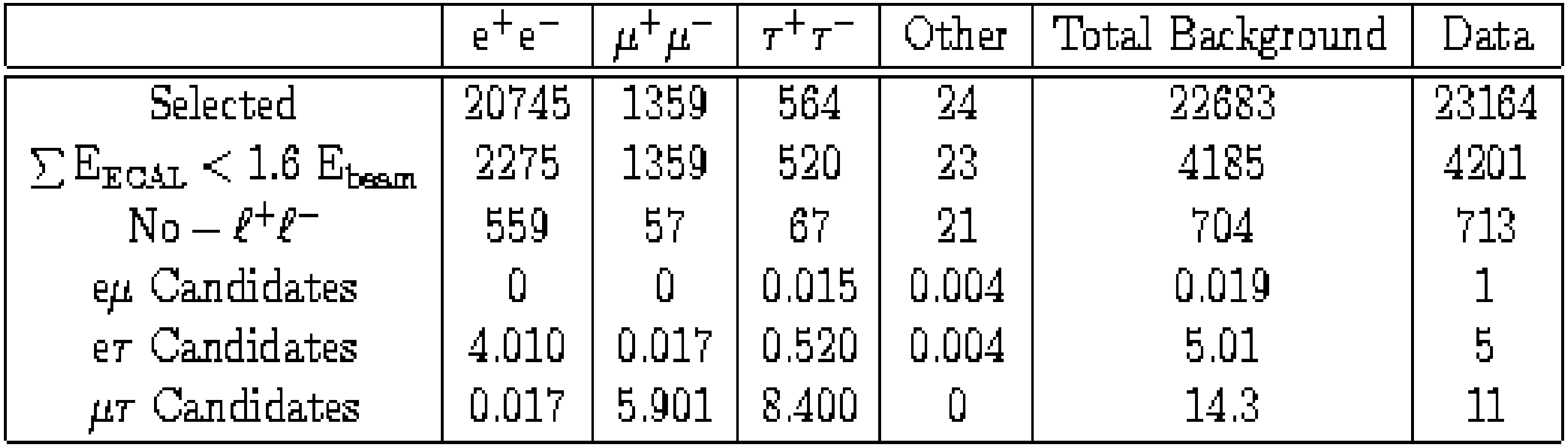
$BR(\tau \to \mu\gamma) < 2.0\times 10^{-6}$ @90%CL



4.Search for LFV in e+e-collisions at $\sqrt{s}$=189-209 GeV at OPAL

In this search, a single $e\mu$ candidate has been found at $\sqrt{s}$ =189GeV, the effects of the selection criteria are summarised in Table 2 .

Table2: Selected data events versus SM expectations. " No $-\ell^+\ell^-$" stands for the cut against events having a pair of electron (e^+e^-) or a pair of muon ($\mu^+\mu^-$) candidates in the final state.



	e^+e^-	$\mu^+\mu^-$	$\tau^+\tau^-$	Other	Total Background	Data
Selected	20745	1359	564	24	22683	23164
$\sum E_{ECAL} < 1.6\ E_{beam}$	2275	1359	520	23	4185	4201
No $-\ \ell^+\ell^-$	559	57	67	21	704	713
$e\mu$ Candidates	0	0	0.015	0.004	0.019	1
$e\tau$ Candidates	4.010	0.017	0.520	0.004	5.01	5
$\mu\tau$ Candidates	0.017	5.901	8.400	0	14.3	11

- The single $e\mu$ candidate is displayed in Fig. 4 for the $r-\phi$ view and in Fig.5 for the $r-\theta$ view.

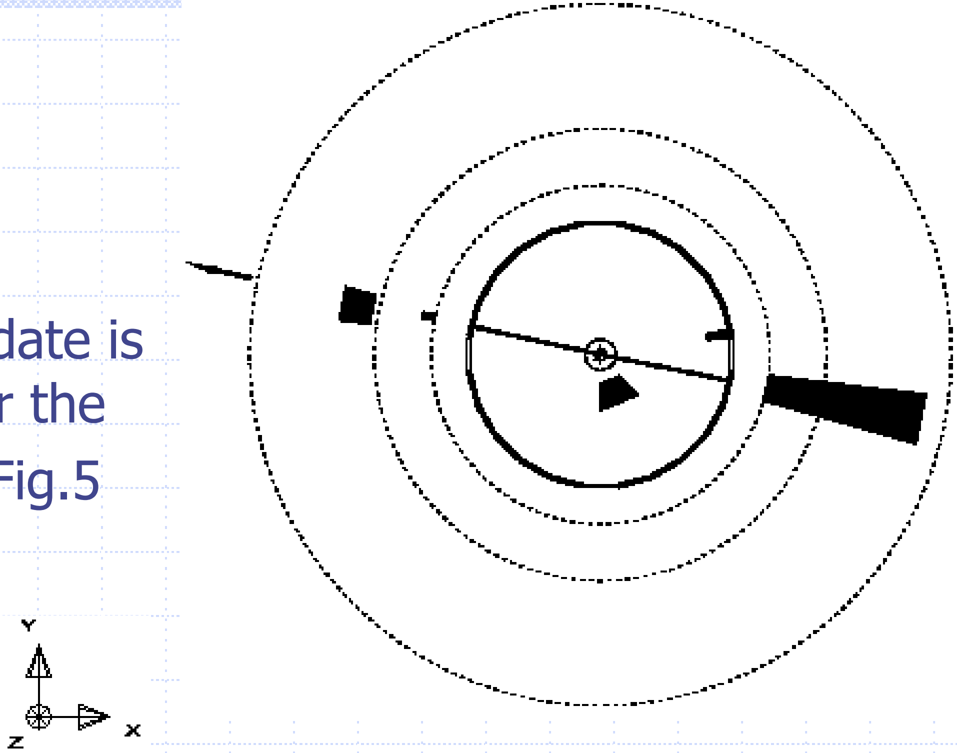


Figure 4 : An $r-\phi$ view of the $e\mu$ candidate at 189 GeV. Two well measured tracks can be seen in the trackers(inner thick circle).The track in the right side deposited all its energy in the electromagnetic calorimeter(black trapezoid),and is the electron candidate. The track in the left side has a small electromagnetic energy deposit and has matching muon hits in muon chambers (the arrow), and is the muon candidate.

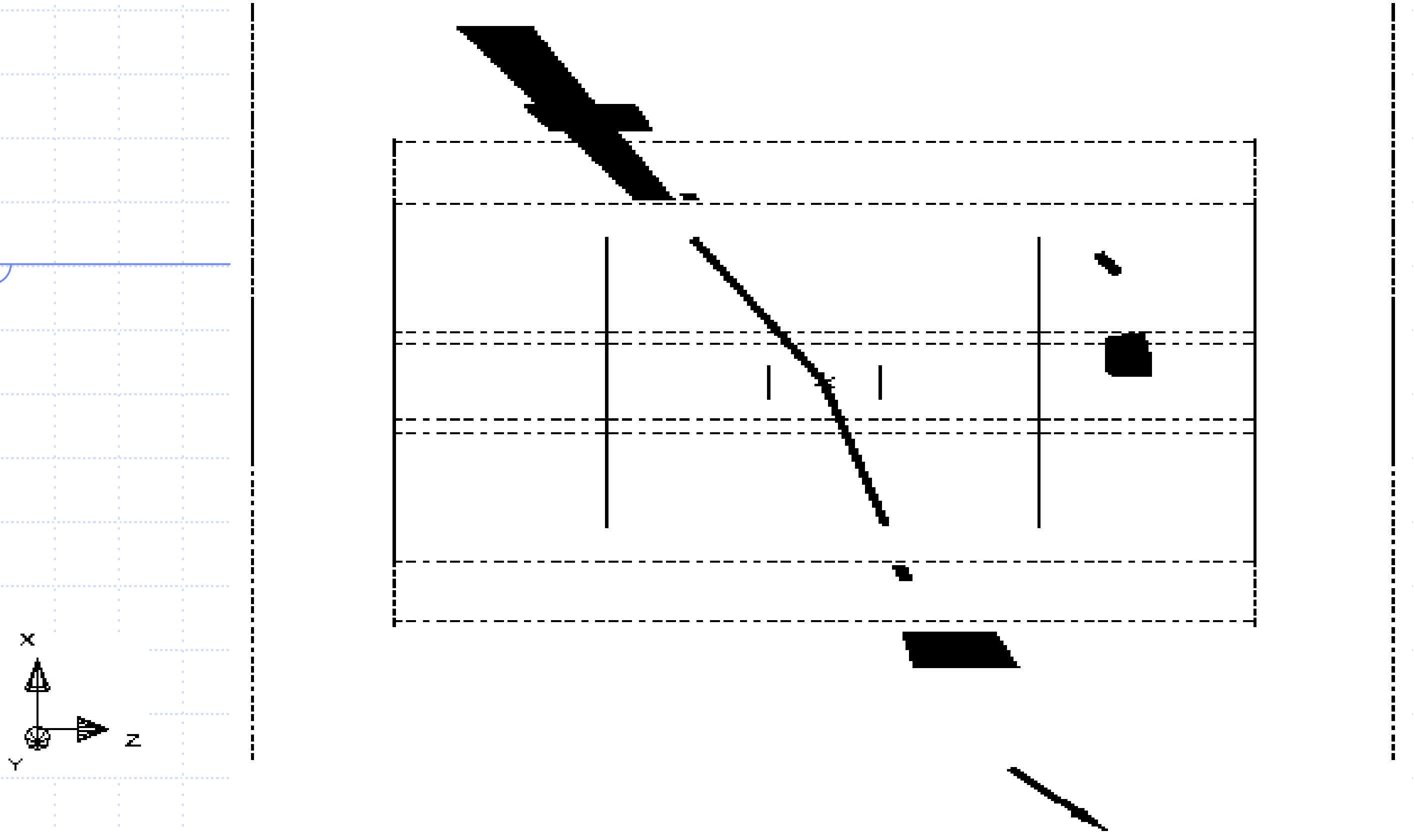


Figure 5 :An $r - \theta$ view of the $e\mu$ candidate at 189 GeV. The beam direction is a horizontal line passing trough the intersection of the two tracks.The tracks are not back-to-back, and the missing momentum is compatible with the observed cluster in the forward detector which is the dark block close to the beam axis (right side).

possible interpretation

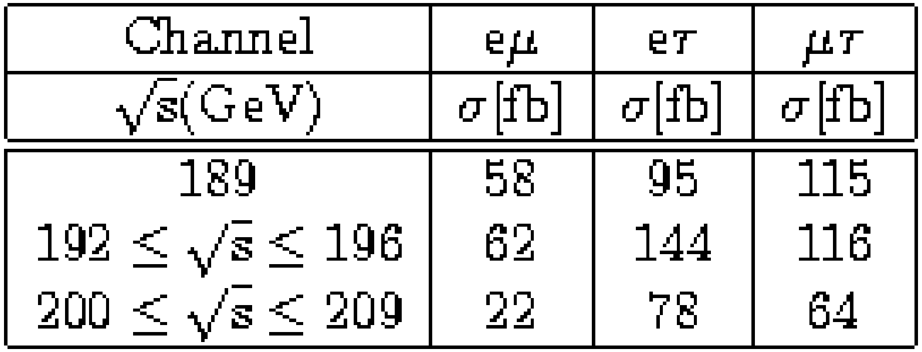
The most likely SM interpretation is $e^+e^- \rightarrow \tau^+\tau^- \gamma$,

where at least one of the leptons from the tau gives rise to a fake electron or muon. There is also a cluster in the forward detector,which is probably from the gamma produced in initial state radiation.

Upper limits

95% confidence level upper limits on $\sigma(e^+e^- \rightarrow e\mu, e\tau, \mu\tau)$

as a funtion of $\sqrt{s}$.



Channel	$e\mu$	$e\tau$	$\mu\tau$
$\sqrt{s}$(GeV)	σ [fb]	σ [fb]	σ [fb]
189	58	95	115
$192 \leq \sqrt{s} \leq 196$	62	144	116
$200 \leq \sqrt{s} \leq 209$	22	78	64

5.Summary

- The first upper limit of BR(J/Ψ→eμ) at BES is **1.35×10^{-6}(90%C.L),** now the analysis of J/Ψ→μ τ, e τ is going on.
- The upper limit of BR($B^- \to K^- \nu \bar{\nu}$, $B^0 \to e^+e^-, \mu^+\mu^-, e^\pm\mu^\mp$, $\tau \to \mu\gamma$) at BaBar is **9.4×10^{-5}, 3.3×10^{-7}, 2.0×10^{-7}, 2.1×10^{-7}, 2.0×10^{-6} (90%C.L),** respectively.
- The first upper limits for $\sigma(e^+e^- \to e\mu, e\tau, \mu\tau)$ as a function of $\sqrt{s}$ at LEP2 energy have been obtained at OPAL.
- No evidence for direct LFV has been found in these searches.