Studies of the Radiative $\tau^{\pm}$ decays $\tau^{\pm} \to \ell^{\pm}\nu\bar{\nu}\gamma$ with the *BaBar* detector

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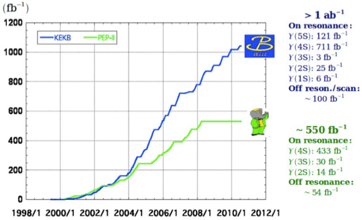
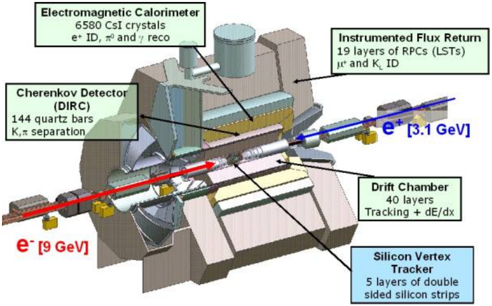
BABAR and PEP-II

More than just a B factory

Accumulated total $0.5ab^{-1}$ of data over $\sim$ 10 years
B mesons primary goal - but also produce charm and τ
($\sigma_{\tau^+\tau^-} = 0.92, \sigma_{B\overline{B}} = 1.05, \sigma_{c\overline{c}} = 1.35nb$)
Accumulated $\approx 400M\tau^+\tau^-$ pairs
Long series of *BABAR* τ publications.





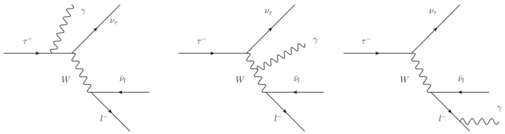
Detector features

- CsI(TI) crystal ECAL $\rightarrow$ EM energy resolution:
  γ energy well measured
  Good π^0 reconstruction
  Clean e identification
- Superb K/π separation
- Vertexing

Radiative tau decays

Taken from our recent Phys. Rev. D. rapid communication **PRD-RC 91**, 051103 (2015) and Ben Oberhof's PhD Thesis, University of Pisa (2015)

Take tau decay diagram to electron or muon (and two neutrinos) and add a photon



Need cutoff: naïve calculation diverges as $E_\gamma \to 0$, as all charges radiate at some level. Consider only events with photons of energy $\omega \geq 10$ MeV (in tau rest frame) as 'signal'.

Monte Carlos used:

- `KK2F` for tau pair production
- `Tauola` for tau decays
- `Photos` for radiative corrections in these decays (except electrons)

Used (among other things) to find number of $\tau \to \ell\gamma\nu\overline{\nu}$ events with $2 < \omega < 10$ MeV accepted as signal: very few events, classed as background.

Selection

Use full 431 fb^{-1} sample of e^+e^- collisions at $\Upsilon(4S)$ energy

2 opposite charge tracks

Transverse momentum

$$p_T > 0.3 GeV/c$$

Polar Angle (Ecal acceptance)

$$-0.075 < cos\theta < 0.95$$

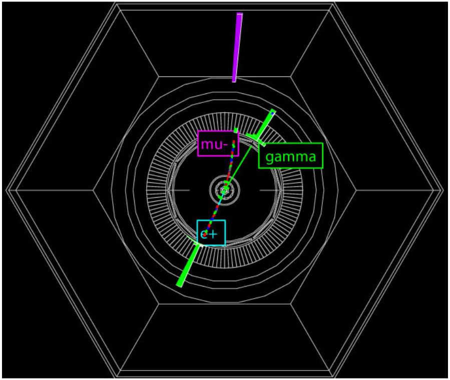
$0.900 < Thrust < 0.995$

$Thrust = max \frac{\sum |\vec{p}_i . \hat{t}|}{\sum p_i}$

Thrust axis $\hat{t}$ divides into hemispheres: 'signal' and 'tag'

signal: 1 track identified as μ or e and one neutral cluster

tag: 1 identified track, not same nature as signal track. Possible additional π^0 photon pairs

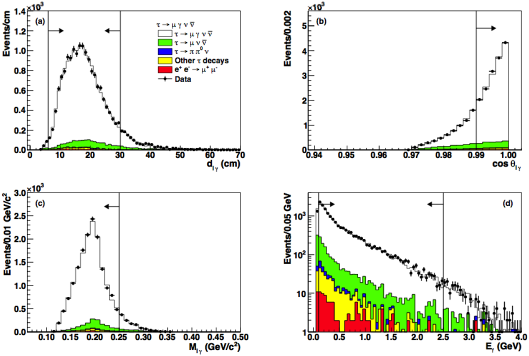


$E_{vis} < 9 GeV$ $\qquad P_T^{miss} > 0.5 GeV/c$

Muon channel

Identification using BDT (Bagged decision tree) with IFR hits, Ecal deposit, $\frac{dE}{dx}$...
Muon ID efficiency 62 %, pion misidentification probability approx 1%
Background for μ channel mostly ISR.

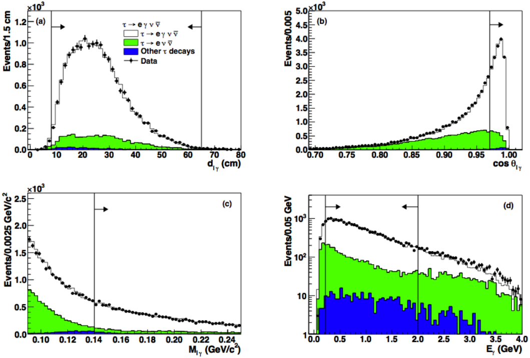
Tune cuts on variables:
$d_{\mu\gamma}$ in ECAL
$cos\theta^*_{\mu\gamma}$ muon-photon angle in CMS
$M_{\mu\gamma}$ invariant mass
E_γ in CMS
Get $15,688 \pm 125$ events (Background 1,596)



Electron channel

Identification using ECOC (Error Correcting Output Code), from BDT based on $E_{EMC}/p_{tracking}$, $\frac{dE}{dx}$, shower shape...
Electron ID efficiency 91 %, pion misidentification probability < 0.1 %
Background mostly bremsstrahlung from $\tau \to e\nu\overline{\nu}$

Tune cuts on same 4 variables:
$d_{e\gamma}$ in ECAL
$cos\theta^*_{e\gamma}$
$M_{e\gamma}$
E_γ
Obtain $18,149 \pm 135$ signal events
(Background 2,823)



Optimisation

How were the cuts tuned? What do we optimise on?
Measuring $BR = \frac{N-B}{2\epsilon\sigma\mathcal{L}}$
Adjust cut(s) to minimise B and maximise ϵ.
Usual route: Minimising Statistical errors $\rightarrow$ Maximise $\frac{S}{\sqrt{S+B}}$

Here statistical errors are very small and systematic errors are important. Including systematic errors on background B and efficiency ϵ, due to Monte Carlo statistics
$\rightarrow$ maximise $\frac{S}{\sqrt{S+B+\alpha^2B^2+\beta^2}}$

where $\sigma_B = \alpha B, \sigma_S = \beta S$

Use of this method favours harsher cuts, with lower backgrounds, giving smaller total errors. Standard optimisation would give 50,517 μ and 531,765 e decays, with backgrounds of 25,264 and 993,417 respectively.

Systematics

	μ channel uncertainty (%)	e channel uncertainty (%)	method
Photon efficiency	1.8	1.8	$\mu^+\mu^-\gamma$ and π^0 effcy from $\tau \to \pi\nu/\tau \to \rho\nu$ ratio
Particle ID	1.5	1.5	$\mu\mu\gamma$ and $ee(\gamma)$ for effcy
Background	0.9	0.7	$\tau^\pm \to \pi^\pm\pi^+\pi^-\nu$
BF	0.7	0.7	PDG
L and cross section	0.6	0.6	standard value
MC statistics	0.5	0.6	
Selection criteria	0.5	0.5	comparisons
trigger selection	0.5	0.6	comparisons
Track reconstr.	0.3	0.3	standard value
Total	2.8	2.8	Sum above in quadrature

Results

	$B(\tau \to \mu\gamma\nu\overline{\nu})$	$B(\tau \to e\gamma\nu\overline{\nu})$
OPAL	$(3.0 \pm 0.4 \pm 0.5) \times 10^{-3}$	
CLEO	$(3.61 \pm 0.16 \pm 0.35) \times 10^{-3}$	$(1.75 \pm 0.06 \pm 0.17) \times 10^{-2}$
BABAR	$(3.69 \pm 0.03 \pm 0.10) \times 10^{-3}$	$(1.847 \pm 0.015 \pm 0.052) \times 10^{-2}$
SM - LO	3.67×10^{-3}	1.84×10^{-2}
SM - NLO	$(3.572 \pm 0.003 \pm 0.006) \times 10^{-3}$	$(1.645 \pm 0.019 \pm 0.003) \times 10^{-2}$

Note: OPAL used ω of 20 MeV rather than 10 MeV so not directly comparable.

SM - NLO have just been done (Fael et al, arXiv 1506.03416). Errors shown are split into theory uncertainty from NNLO etc and uncertainty due to τ lifetime
3.5 σ disagreement with Fael et al for electrons (though good agreement for muons). May be due to their 'exclusive' requirement that only one photon exceeds 10 MeV threshold. 'Inclusive' value is higher (1.728×10^{-2}) . Experimental situation probably intermediate.

Conclusions

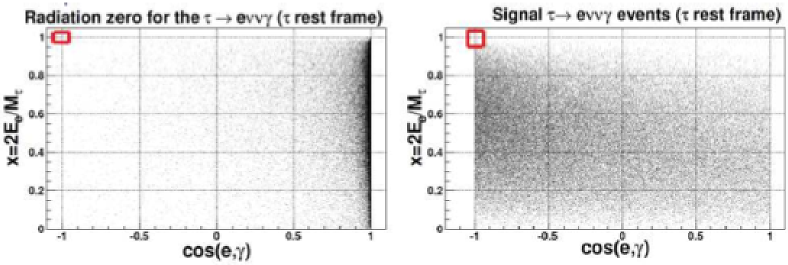
We have measured
$BF(\tau^{\pm} \to \mu^{\pm}\gamma\nu\overline{\nu}) = (3.69 \pm 0.03 \pm 0.10) \times 10^{-3}$
$BF(\tau^{\pm} \to e^{\pm}\gamma\nu\overline{\nu}) = (1.847 \pm 0.015 \pm 0.052) \times 10^{-2}$
Much more precise than previous measurements
Interesting test of electroweak calculations

Backup slides

Any questions?

What can we say about the anomalous magnetic moment of the tau?

Motivation for adding $\tilde{a}_\tau$ and $\tilde{d}_\tau$
Contribute to phase space region where ℓ and γ are back to back (in τ rest frame)
Unfortunately this region is removed by our cuts, being background-dominated.



(Figure from M. Passera, Tau2012, Nagoya)