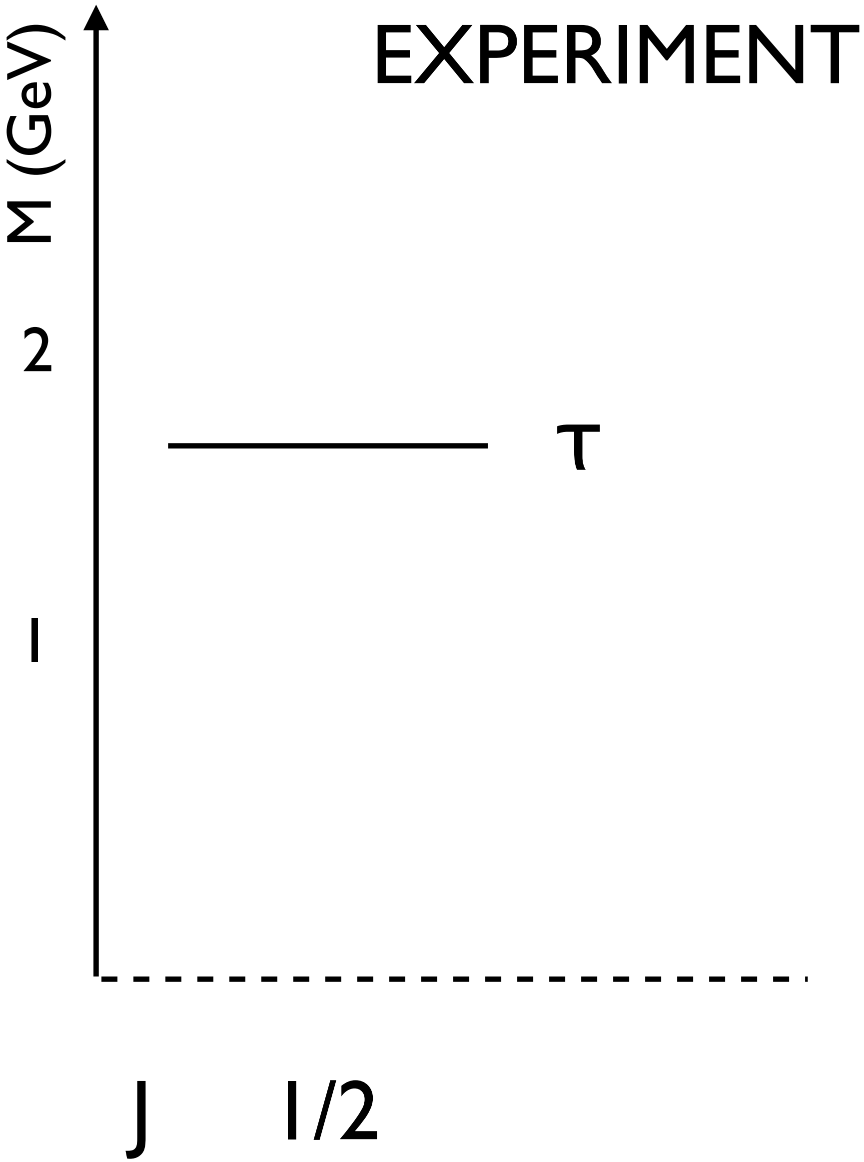
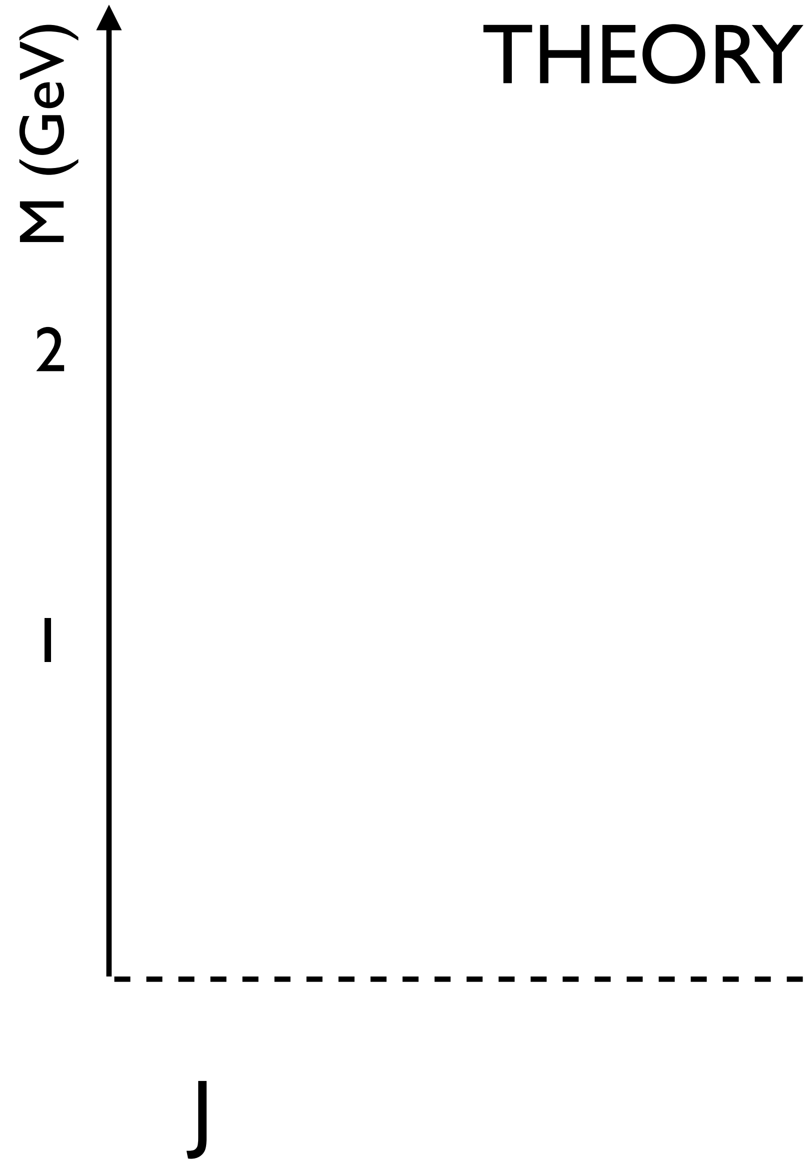
J.E. Duboscq Jan 2004 Beijing

Opportunities for τ Physics

- Overview of Tau's at low energy
- Tau Threshold Measurements
  - Tau Mass
  - Massive Neutrino in $\tau \rightarrow \ \nu\nu$
  - Exotic Decays: $\tau \rightarrow eX$
  - Radiative Leptonic Decays
  - Tau Atoms
- High Statistics Measurements
  - Precision Branching Fractions
  - Hadronic structure
  - Rho Line Shape
  - CP Violation
  - Lorentz Structure
  - Neutrino Mass

Spectroscopy Is Everything



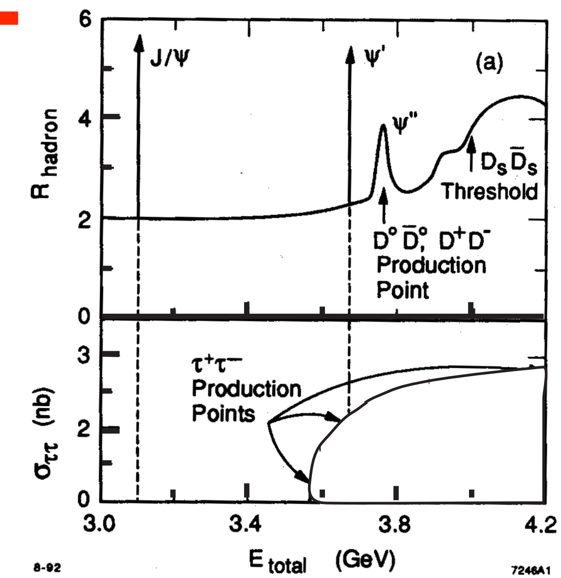


Overview of τ's at low energy

Lowest Order Production Cross section

$$\sigma^{(0)}_{\tau\tau} = \frac{4\pi\alpha^2}{3s}\,\frac{(3\beta-\beta^3)}{2}$$

$\oplus$ Radiative Effect $\oplus$ Beam Energy Width



CLEO-c Running Idea - no guarantee

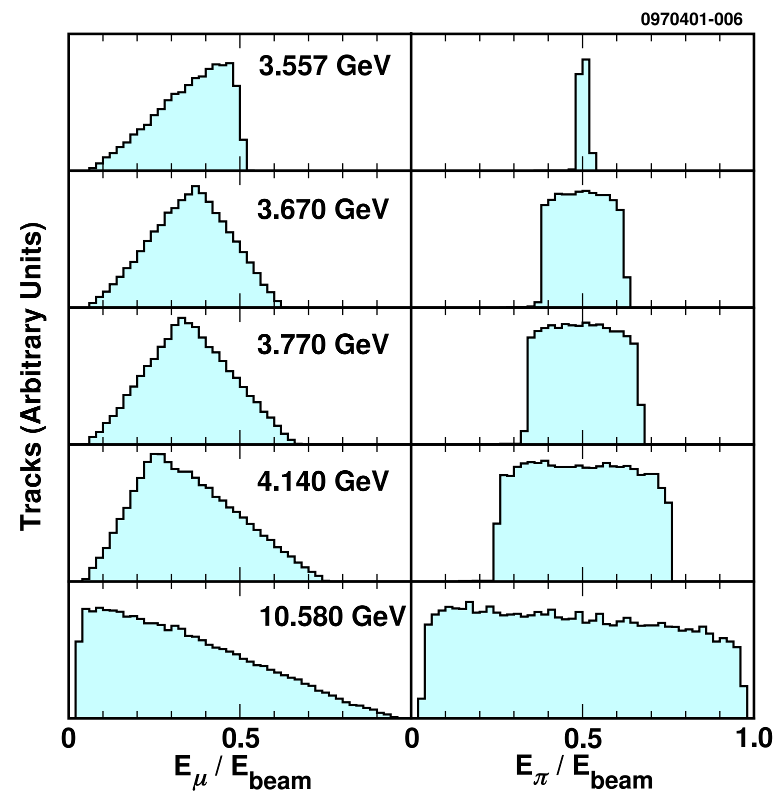
Ecm (GeV)	Lumi /fb	N(ττ)	σ (nb)	pτ (GeV)	βτ
3.557	0.25	100K	0.42	0.07	0.04
3.770 - ψ''	3.0	9 M	2.95	0.63	0.33
4.14 - Ds	3.0	11M	3.56	1.06	0.51

Small Sample near Threshold
Larger sample with Charm background

Compare: CLEO2+3 = 15 M ττ, Belle, Babar > 100 M+ ττ

Event Kinematics

- τ's are always produced in pairs and always have >0 ν's
- τ's are slow – decay products are less smeared than B Factory
- Two Body τ→[X]ν – momentum of [X] is sharp for narrow [X]
- τ→π/ρν are convenient tags in addition to τ→e/ νν tags
- Bhabha/ bgd not a problem
- No ISR/FSR at threshold
- BUT: τ decay not jet-like



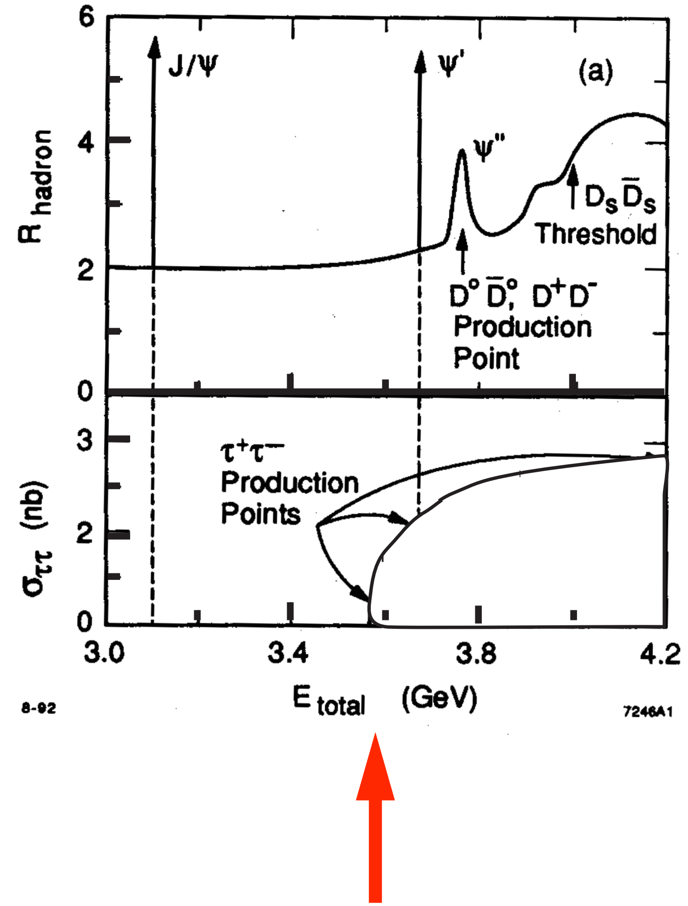
Lab Spectrum for τ→ νν, τ→πν

τ Backgrounds

- Bhabha/ (γ) not a problem
- Below charm: uds background
  - Use missing E,P cuts
  - Use 1 prong tags
  - Use sample below τ threshold to get MC right
- Charm:
  - D semileptonic, K_L^0 decay bgd
  - Use missing E,P cuts
  - Use 1 prong tags
  - Use tagged charm sample to get charm MC right
  - Use (uds) sample to get (uds) MC right
- τ Feed across: need to get MC right

Tau Threshold Measurements

- Tau Mass
- Massive Neutrino in $\tau \rightarrow \pi\nu$
- Exotic Decays: $\tau \rightarrow eX$
- Radiative Leptonic Decays
- Tau Atoms



Tau Mass

This is a fundamental number in the Standard Model

Important in precision work - eg BR($\tau \rightarrow l\nu\nu$) vs τ_τ

Current best tau mass is from BES:

$$m_\tau = 1776.96^{+0.18+0.25}_{-0.21-0.17}\ MeV$$

Obtained by scanning near rapidly varying threshold

5 pb^{-1}, 2 months, narrow σ(Ebeam)

CLEO-c/BESIII can get sample > x50 greater in same time

Most of BES error was from Energy Scale from ψ, ψ' , not spread
σ(Ebeam) is 2x as large in default config compare to BESII can be made comparable at lower lumi

Look for anomalous production effects too

BESIII, CLEO-c could get $\sigma \approx$ 0.1 MeV

No one else can do this this well

Very Massive Neutrinos?

Current bias: neutrinos have eV scale masses

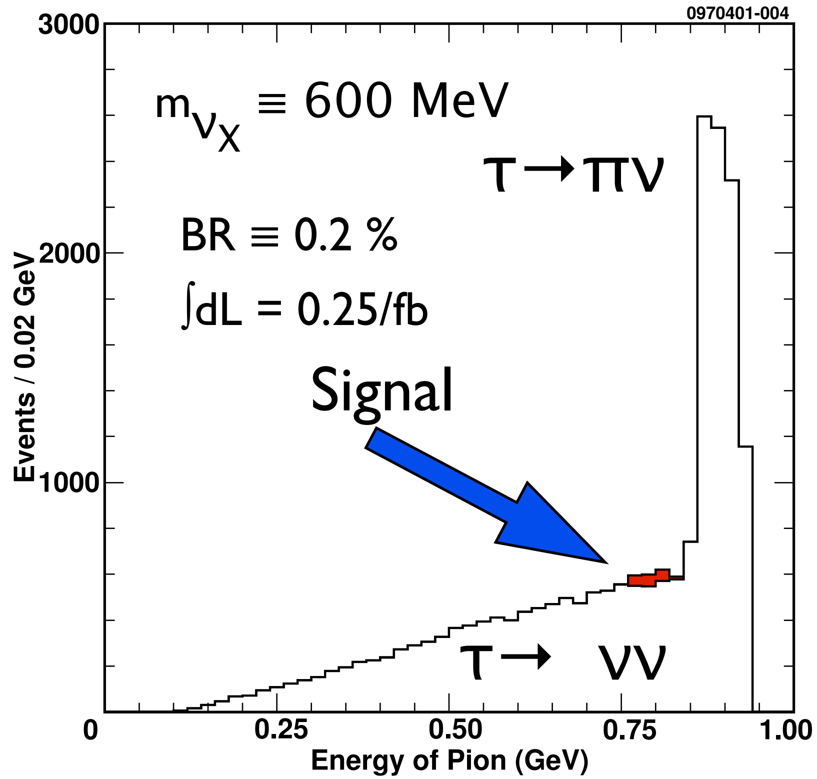
But we have NOT looked everywhere...

$\tau \rightarrow \pi \, \nu_X$

2 body decay –

well defined $p\pi$ near threshold

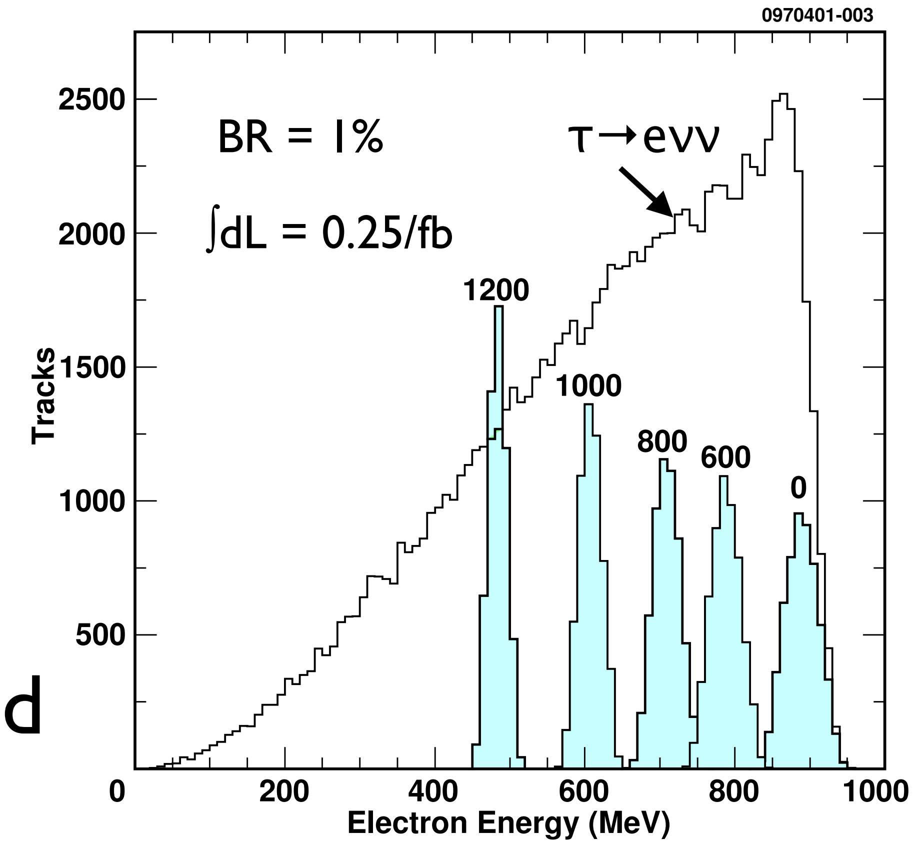
Look for e, ,π tag vs π



This is best near threshold at BESIII and CLEO-c

Exotic Decays: $\tau \to e^- X$

Unique Opportunity to look for exotic bosons, eg *familon*

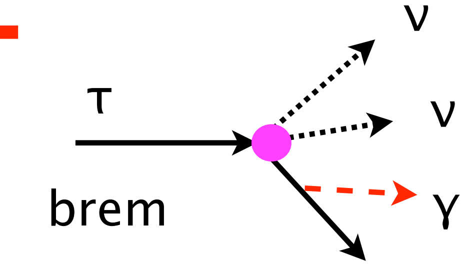


Electron signature is smeared out at higher energies - Michel Parameter measurements could miss this

PDG: BR($\tau \to eX$) < 0.2% (ARGUS)

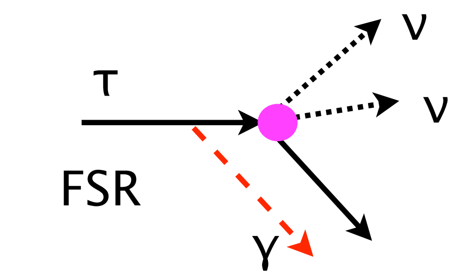
Radiative Leptonic Decays

$\tau \to l\nu\nu\gamma$ is "easy" – measured to 10%

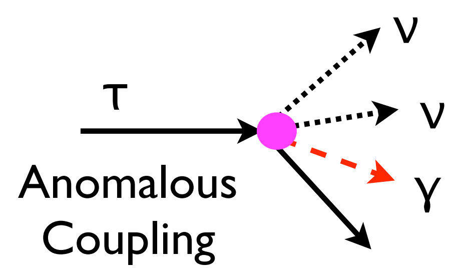


Any deviation from expectations is very significant

No ISR/FSR at threshold



Less boost at threshold:
Greater lepton γ separation
Access to back to back lepton γ



.25 /fb at threshold should allow a 1% measurement of BR and access to "hard" kinematic regime

Tau Atoms

M. Perl Tau92 Proceedings

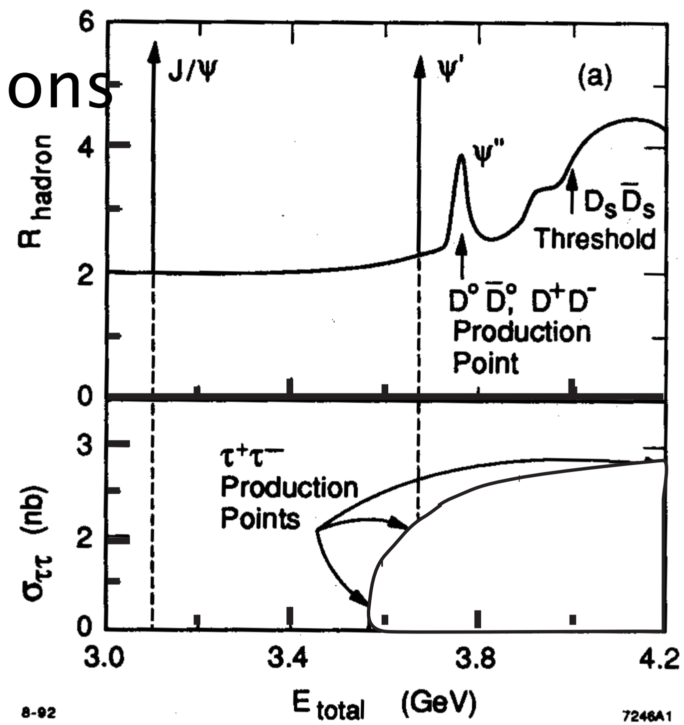
- $\tau^+\tau^-$ should form $^3S_1$ bound states in e^+e^- collisions
  - Bohr radius 0.0003 Angstrom $\approx a_0(H)/1000$!
  - Binding energy = -23.7 keV/n^2
- Tau atom decay via:
  - τ weak decay $\Gamma \approx 10^{-3}$ eV
  - $\tau\tau$ annihilation – S states: ee , , hadrons (10^{-3} eV), 3γ (10^{-5} eV) – 2γ is not from $^3s_1$ states
- Peak production cross section huge = 1 millibarn
- Very narrow width = 0.006 eV
- □E beam 1 MeV □ □$_{effective}$($ee \rightarrow \tau\tau$ atom) = 0.1 nb
- If $L=10^{33}$ cm^{-2}s^{-1} , 1 tau atom every 2 minutes

Tau Atoms 2

- Binding Energy on the order of keV – no hope of seeing EM transition γ between levels
- Best hope is to look for annihilation signal into vs ee:
  - Signal sits on top of large pair and larger Bhabha background
  - Run at threshold and compare N( )/N(ee) to off threshold running
  - L=0.25 fb-1 suffices to see signal
  - Investigate 3γ annihilation – might get lucky
- Only CLEO-c and BESIII can hope to see tau
- Is there any real physics here? Could be...

High Stats Measurements

- Neutrinoless decays
- Precision Branching Fractions
- Lorentz Structure
- Hadronic structure
- Rho mass
- CP Violation
- Neutrino Mass



Neutrinoless Decays

- Current limits on neutrinoless decays are at the BR < 10^{-6} – 10^{-5} level
- In some models $\tau \rightarrow$ γ is more sensitive to new physics that $\rightarrow e\gamma$ due to τ mass
- It is likely B factory limits will not decrease fast
- Two body neutrinoless decays should be trivial at CLEO-c and BESIII
- Sensitive to e/ /π/K discrimination near 1 GeV
- CLEO-c limits conceivable at 10^{-6}
- BESIII limits conceivable at 10^{-7}

Precision Branching Fractions

- BR(τ→lνν) has applications to lepton universality and R_τ measurements

$$R_{\tau} = \frac{1 - B(\tau \to e\nu\nu) - B(\tau \to \mu\nu\nu)}{B}$$

- Absolute BR(τ→lνν, hν) currently known to σ≈1%, mostly lumi, τ cross section systematics limited

- With 10^7 tau pairs, BESIII could match this in a global 2 track + missing energy fit

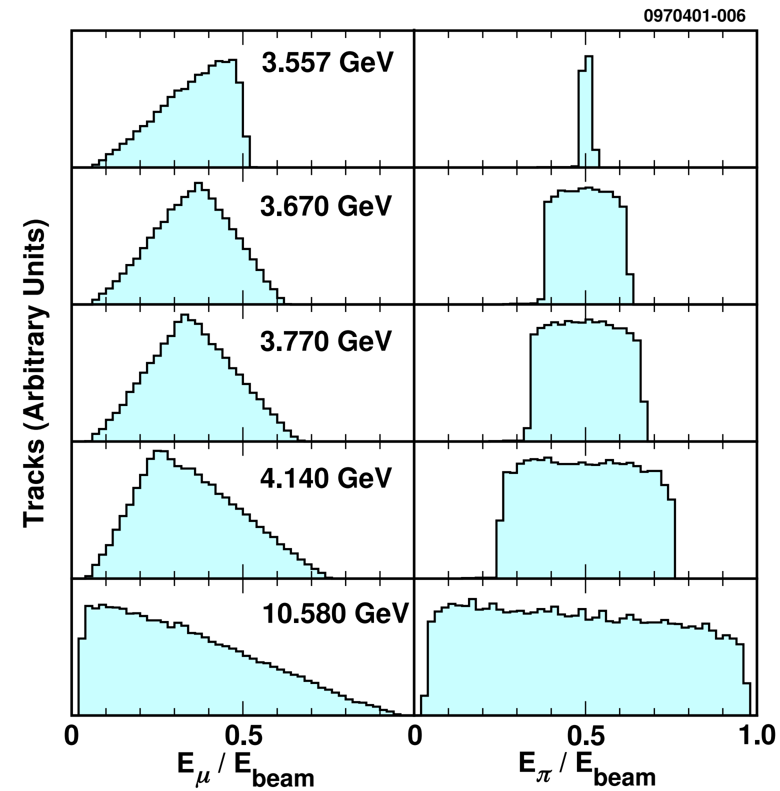
  - Use threshold τ→lνν, hν to verify trigger knowledge

mode	eνν	νν	πν	ρν	Kν	K*ν
BR %	18	17	11	25	.7	.5
σ/BR %	.3	.4	1	.6	4	7

Precision BR 2

The 1 vs 1 sample has great promise for **relative** Branching Ratios

- Look for 1 vs 1, with both tracks E< 0.65 Ebeam
- Even with NO e or id, the almost monochromatic π/K will stick out
- Use electron id to suppress (uds) backgrounds
- π^0 reconstruction should easily show a ρ
- 5/fb at ψ'' => errors much less than 1% for hν, $h\pi^0\nu$ relative to lνν
- With some K/π id + kinematic constraints, this should leverage into better known πν,ρν,Kν, K*ν



Lab Spectrum for τ→ νν, τ→πν

Lorentz Structure

The Lorentz Structure is studied via the Michel Parameters ρ, η, ξ, δ in τ→e/ νν

$$\frac{d\square}{dxdcos\square} \quad x^2 \left[h_0 + \square h_\square + \square \frac{m_l}{m_\square} + P_\square \square cos \square (h_\square + \square h_\square) \right]$$

η multiplies lepton mass ratio

where $h_\eta = h_\eta(x)$, and $x = E_l/E_{max}$

	SM value	→eνν	τ→lνν
ρ	3/4	±.0026	±.01
η	0	±.013	±.097( )
ξ	1	±.008	±.04
δ	3/4	±.004	±.02

Lorentz Structure 2

- CLEO2 dominates Michel Parameter measurements:
  - Used $\tau \to \rho\nu$ vs $\tau \to l\nu\nu$ – ρ decay as a spin analyzer
  - Dominant errors are stat => B factories will do much better
- τ pair spin correlations are different at lower energy => chance for an interesting confrontation
- ISR/FSR dilutes spin correlations – interesting possibilities for threshold running

Lorentz Structure 3

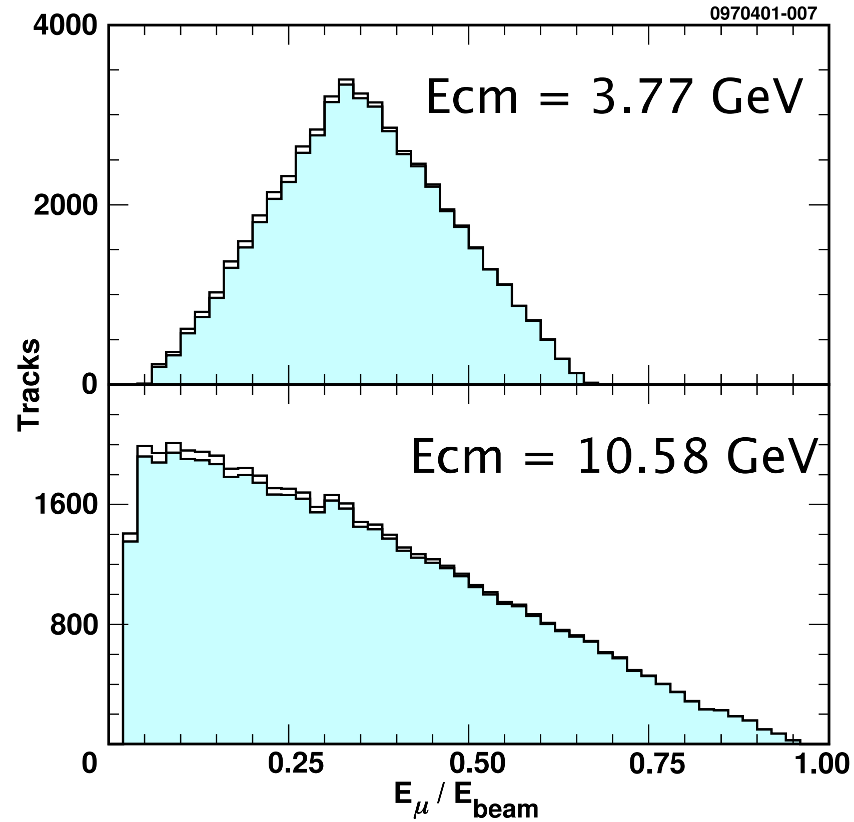
η is of particular interest at CLEO-c and BES: effect is largest for slowest 's

Look for 1 vs (monochromatic) π

CLEO-c sensitive to $\eta \approx 0.05$

(currently $\sigma_\eta \approx 0.1$)

BESIII will be even more sensitive

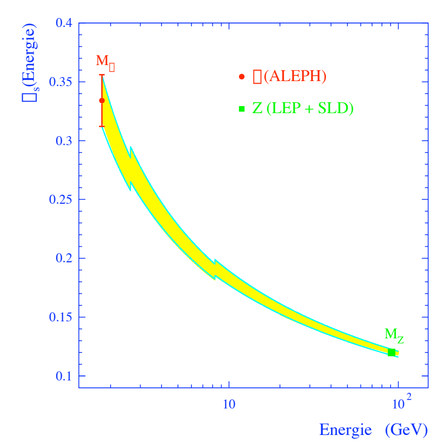


1 M τ pairs

η=0 vs η=0.2

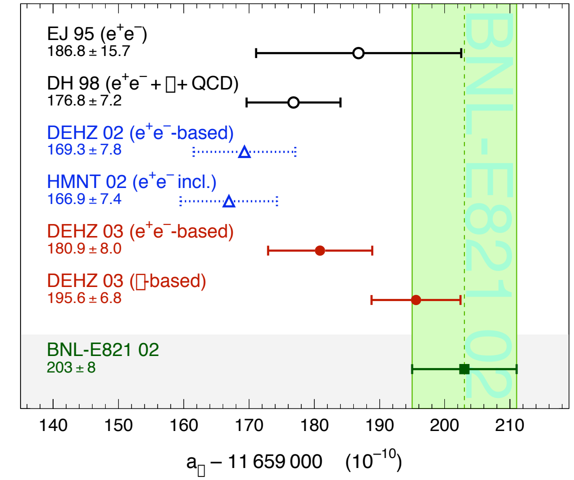
Hadronic structure

- For exclusive channels, BESIII/CLEO-c offer a large sample with statistics comparable to LEP/CLEO but smaller than BaBar/Belle
- Kinematic separation with monochromaticity for narrow resonances could be an important factor
- However good π/K separation is key to sorting out wider resonance/interference structure
- PID also key to using the τ as a QCD laboratory for inclusive hadronic studies
  - QCD coupling α_S derived from τ is more precise (and consistent) with that from the Z
  - $\tau \rightarrow [X]_{S=1}\nu$ key to getting strange quark mass



M. Davier hep-ex/0312064

Rho Mass



- The ρ is where e^+e^- confronts the τ – see g–2 value
- Both the BR and line shape are problematic

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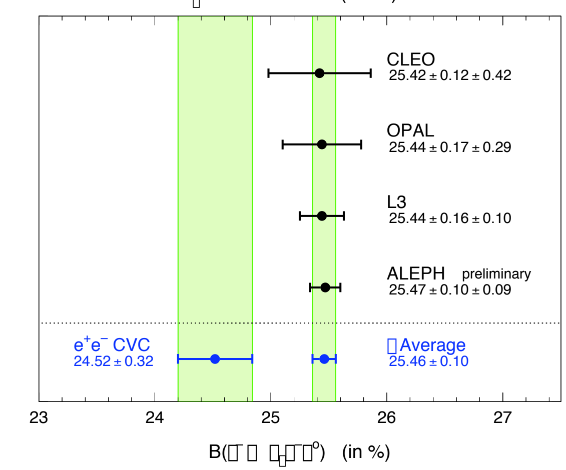
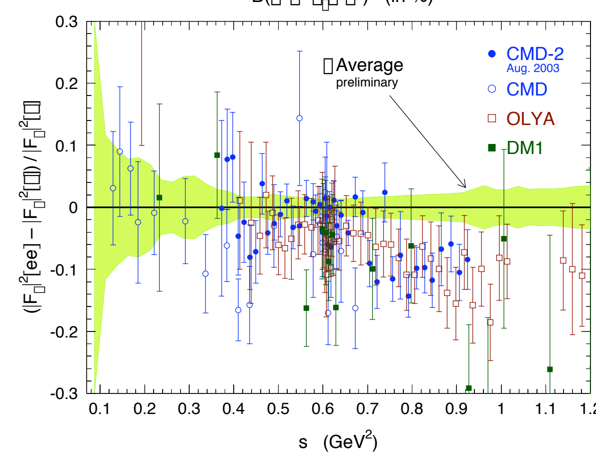


- LEP: high purity, not so good at high $\pi\pi^0$ mass
- CLEO: very good at high $\pi\pi^0$ mass
- BESIII/CLEO-c: chance for low background and very good line shape
- 10^7 τ will easily surpass LEP/CLEO sample sizes and bring important input to g–2

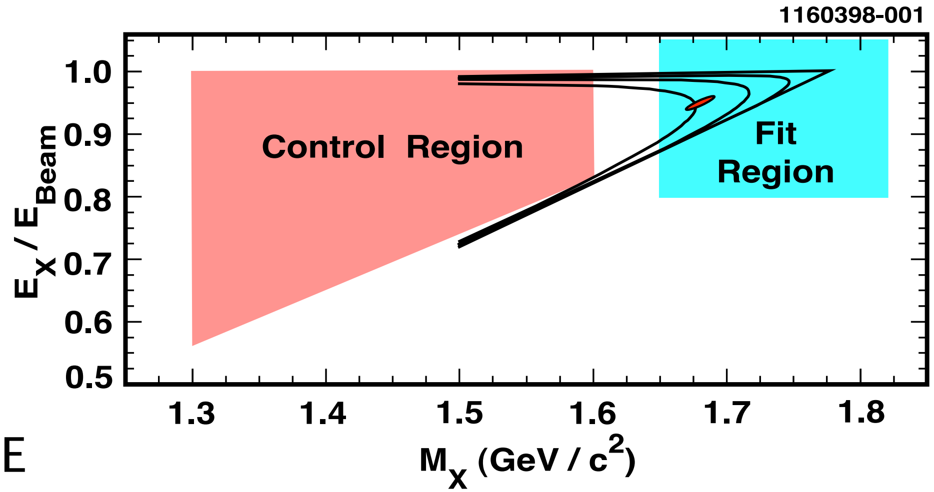


CP Violation

- Triple product (P_{beam}, P_{l_1},P_{l_2}) in $\tau \to l_1 \nu\nu$ vs $\tau \to l_2 \nu\nu$ probes CP in τ **production** - B Factories will do this very well
- CP in τ **decay** best probed by spin correlations in hadronic decays
  - High energy: longitudinal correlations
  - Low energy: transverse spin correlations
- CP searches at CLEO-c/BESIII probe different mechanisms than at B Factories

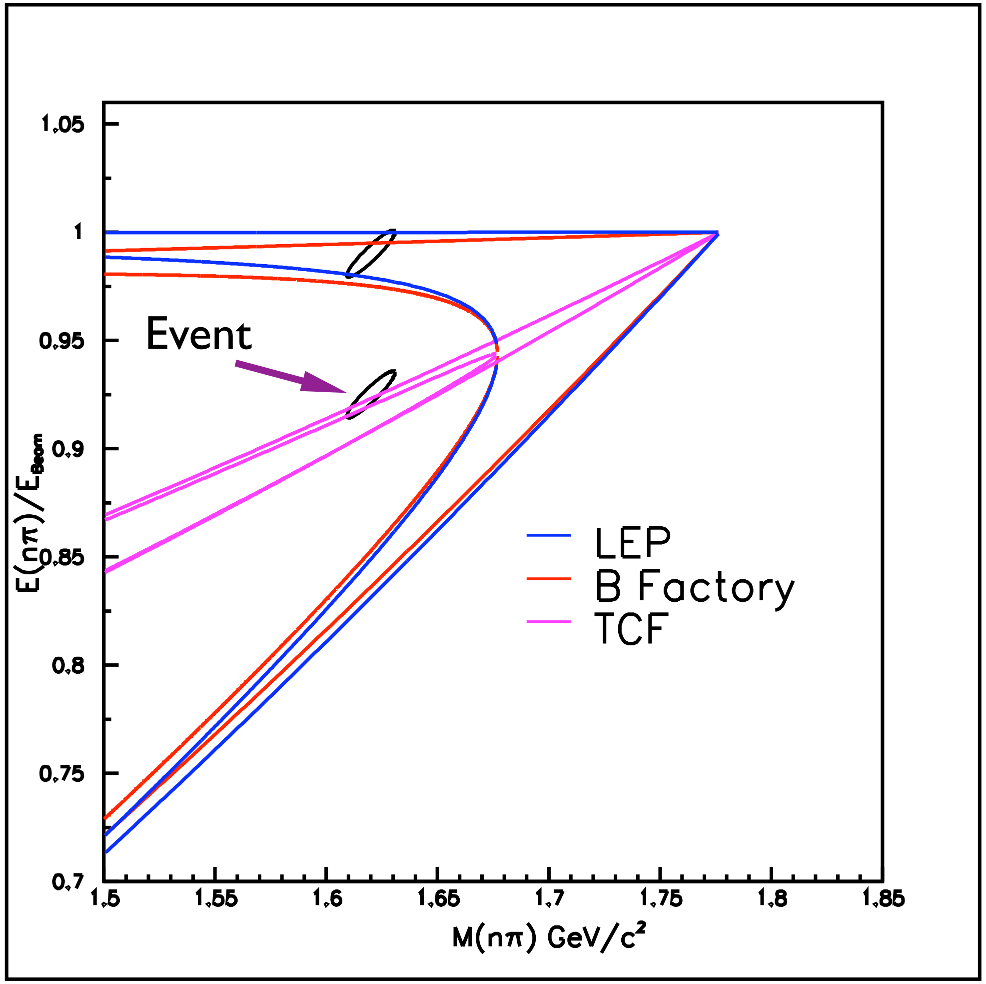
Neutrino Mass

- Neu mass limits come from Energy vs Mass fits to $\tau \to 5\pi\nu$, $4\pi\nu$
- Current limit ≈18 MeV
- Technique requires understanding MeV Scale systematics:
  - 2D correlated detector resolution (E vs M error)
  - Mass scale
  - underlying hadronic physics ("Spectral Function")
- ISR/FSR washes out usefulness of 1/2 of events



Neutrino Mass 2

- The 2D technique does not appear to be nicely behaved as a statistical estimator – it is more a probe of lucky events near the kinematically allowed edges – these are sensitive to detector modeling
- At low energies, the allowed region sharpens from a triangle to a line ⇒ loose the supposed gain of the 2d method – this might be a good thing.
- At threshold – No ISR/FSR to wash out weight of events – effective factor of 2 gain in lumi
- B Factory error ellipses are same scale as 18 MeV and 0 MeV contour differences – diminishing returns?



Allowed regions for 0, 100 MeV nu

Neutrino Mass 3

Very rough comparison of samples between CLEO98 (30 MeV limit) and 0.25/fb at CLEO-c tau threshold

mode	BR	CLEO 98	<CLEO-c>
$3\pi 2\pi^0$	0.5%	200 events	100 events
5π	.1%	250 events	50 events
$KK\pi$	.2%	Not used	65 events

The above assumes e/mu/pi/rho tags at CLEO-c + no charm background + perfect PID

PID

High energy colliders cut very hard to get pure samples

Even a small threshold run can give a data sample comparable to current world's largest samples

Again - an important opportunity for unique work at CLEO-c and especially BESIII

Neutrino Mass 4

- At BESIII/CLEO–c, expect smaller error ellipses – more discrimination near endpoint
- Running at 3.67 GeV (above τ threshold, below charm), with $\approx$10/fb could possibly give U.L. in the MeV region
- This likely represents the limit of this technique

Conclusions

- BESIII/CLEO-c will play an important role in τ physics - no matter what BaBar/Belle do
- There are unique opportunities near threshold using the lack of ISR/FSR, and unique τ decay kinematics
- CLEO-c is not guaranteed to do any tau only running - BESIII should not miss this opportunity.

Recipe for BESIII Tau Success

1. Get a sufficient sample below tau threshold to get (uds) MC right
2. A 50 /pb scan near threshold to get the tau mass – a larger sample will allow a detailed inspection of the turn-on curve
3. 0.25 /fb at tau threshold for the threshold measurements, plus 0.25/fb 3 MeV below to get normalization for tau atom search
4. Several /fb at 3.67 GeV to for high stats measurements – use to make sure you know what you are doing above charm
5. > 10 /fb at 3.67 GeV for neutrino mass
6. All the data you can get above charm threshold
7. Goto step 1